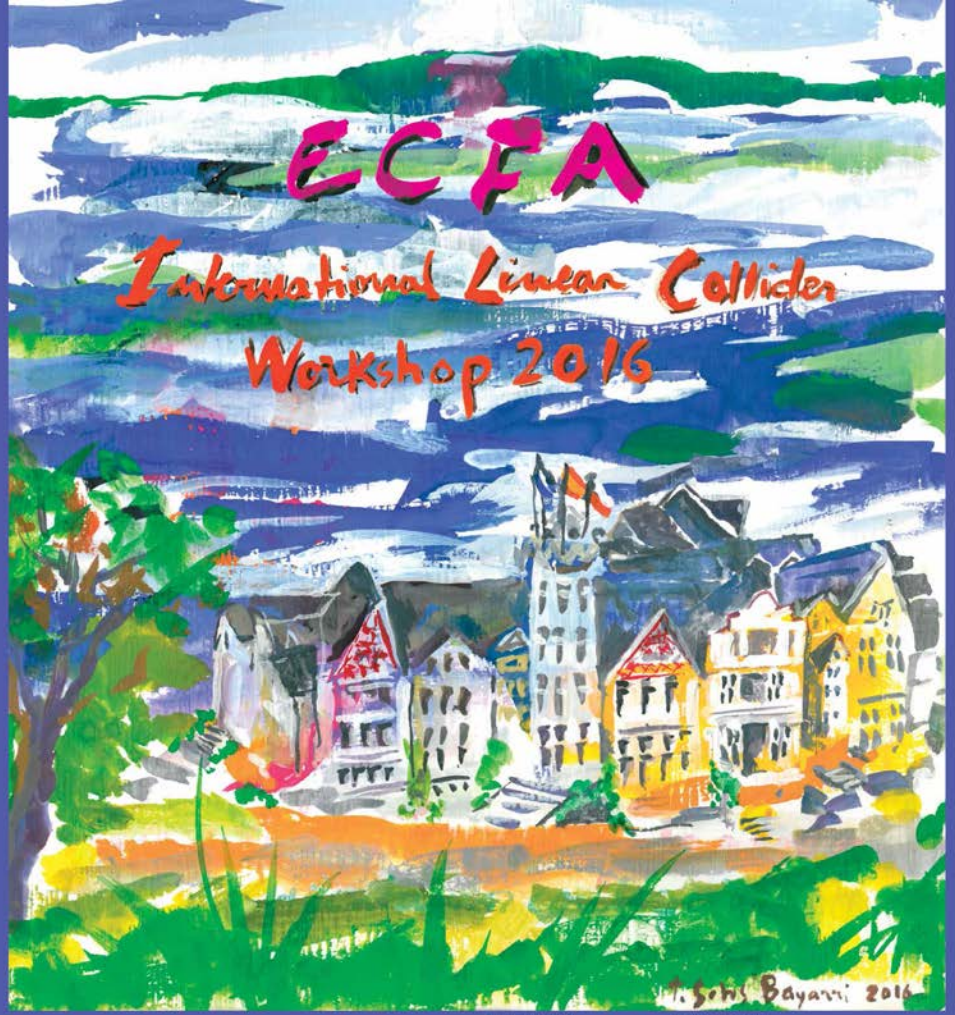

ECFA
International Linear Collider
Workshop 2016

30 May — 5 June · Santander, Spain

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Designing the world's next great particle accelerator

ILC Detector R&D: Report from Liaisons

ILC Accelerator and Detector Spin-Offs (some remarks)

LCCPDeb
Detector R&D Liaisons:

Jan Strube (PNNL)
Maxim Titov (CEA Saclay)

ILC Spin-Offs:

Marc Winter (IPHC Strasbourg)

ECFA Linear Collider Workshop, Santander, Spain, June 2, 2016

RPC DHCAL

Scintillator ECAL

SPiDeR

Collaborations

FCAL

CLICPix

DEPFET

LCTPC

SOI

ChronoPixel

SDHCAL

TPAC

RPC Muon

GEM DHCAL

KPIX

Silicon ECAL (SiD)

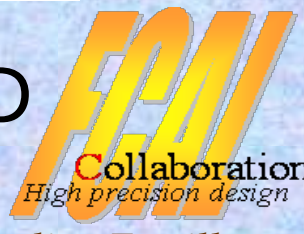
VIP

Silicon ECAL (ILD)

Dual Readout

CMOS MAPS

FPCCD



Scintillator HCAL

Many forms of Detector R&D relevant to LC:

- Large collaborations such as CALICE,LCTPC,FCAL
- Collection of many efforts such as the vertex R&Ds
- Individual group R&D activities
- Efforts currently not directly included in the concept groups (ILD, SiD, CLIC), which may become important for LC in future

NB: incomplete list. For illustration purposes only.

Detector R&D Liaison Report

Working group - Detector R&D liaison

Detector R&D liaison (http://www.linearcollider.org/P-D/Working-groups/Detector-R-D-liaison)

The detector R&D liaison ensures productive communication between the LCC Phy… Detectors Executive Board and detector R&D groups. The liaison is a mem… Board and communicates relevant information from the Executiv… groups and vice versa. The liaison is in contact with all detector … linear colliders to keep track of the overall detector R&D efforts … linear colliders and to periodically compile summaries of th…

- Jan Strube (deputy liai…
- Maksym Titov …

Talks are available at the LCC Webpage

Pres… …s

- *Report from the Detector R&D Liaisons (http://agenda.linearcollider.org/event/6301/session/13/contribution/24/material/slides/1.pdf)*, J. Strube, M. Titov
  2014 Americas Workshop on Linear Colliders (AWLC14), Fermilab, USA (May 12-16)
- *Status Report of the LCC Detector R&D task force (https://agenda.linearcollider.org/event/6440/contribution/18/material/slides/1.pdf)*, J. Strube, M. Titov
  2014 SiD Meeting, University of Tokyo, Japan (Sep. 2-3)
- *Status Report of the LCC Detector R&D task force (https://agenda.linearcollider.org/event/6360/session/7/contribution/28/material/slides/1.pdf)*, J. Strube, M. Titov
  2014 ILD Meeting, Oshu City, Iwate, Japan (Sep. 5-9)
- *LC Detector R&D: Report from Liaisons (https://agenda.linearcollider.org/event/6389/session/17/contribution/19/material/slides/1.pdf)*, J. Strube, M. Titov
  2014 International Workshop on Future Linear Colliders (LCWS14), Belgrade, Serbia (Oct. 6-10)
- *ILC Detector R&D: Report from R&D Liaisons and French contributions (https://indico.in2p3.fr/event/12649/session/7/contribution/8/material/slides/0.pdf)*, J. Strube, M. Titov
  2016 - 4th French Linear Collider Days, Paris, France (March 23-24)

https://www.linearcollider.org/P-D/Working-groups/Detector-R-D-liaison

Detector R&D Liaison Report: get an overview over LC Detector R&D Efforts

- Update of the R&D developments since ILC DBD and CLIC CDR
- "Publicize" the technology. Summarize contributions of individual R&D efforts.
  → Make areas of overlap obvious without pointing out (not an attempt to control R&D)
- Provide a "showcase" for the technology. Manpower and financial resources are explicitly not mentioned in the report.
- Provide an entry point for new groups → help them to learn the current landscape of the LC R&D efforts and the areas where they can contribute

EFFORT STARTED 1.5 YEARS AGO → WE ARE LATE, BUT FINALLY ON A FINAL TRACK → REQUIRED A LOT OF EXTRA EDITING, NOT FORESEEN …

Detector R&D Liaison Report

- > ~ 50 individuals R&D groups contacted
- List of responses was rather variable → from pointers to past publications to 100+ page documents; from text in the mail to bullet points and to 18+ dedicated pages
- Today: Detector R&D Liaison Report is being written in LaTeX.
  → Currently 150 pages + > 10 pages references.
- Separate Chapter - ILC Detector R&D Spin-Offs (not comprehensive one)

Detector R&D Report

Editors
Jan Strube jan.strube@pnnl.gov
Maxim Titov maxim.titov@cea.fr

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ILC Detector R&D Liaison report structure:

- Motivation and Constraints of the sub-detector in a Linear Collider (by R&D Liaisons)
- Write-up for each technology
- Summary table
- Executive Summary (by R&D Liaisons)

Detector R&D Liaison Report: Summary

- Following discussions at the Whistler'2015 LCWS Meeting, it was agreed:

  - Publication:
    Report to be available on the LCC Website
    Not to be published on arXiv or in a Journal
    Live document, updated periodically, much like online documentation

  - Authorship: 2 editors (Liaison, Deputy)
    One contact person per technology

- Report includes:
  R&D activities which are part of Calice, ILCTPC and FCAL and separate R&D efforts, which are not part of ILC and SiD concepts (e.g. some vertex technologies, dual-readout calorimetry)

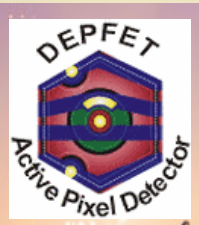
  - Should not be considered as the summary to select between technologies → general overview of the landscape of the LC R&D activities

  - Available to general public and all newcomers interested in ILC R&D

ILC Detector Challenges: R&D Collaborations and Group Efforts

Individual R&D Efforts
(e.g. vertex detectors):

MAPS
CMOS



FPCCD Chronopixel

SOI 3D

"Horizontal R&D"
Collaborations:

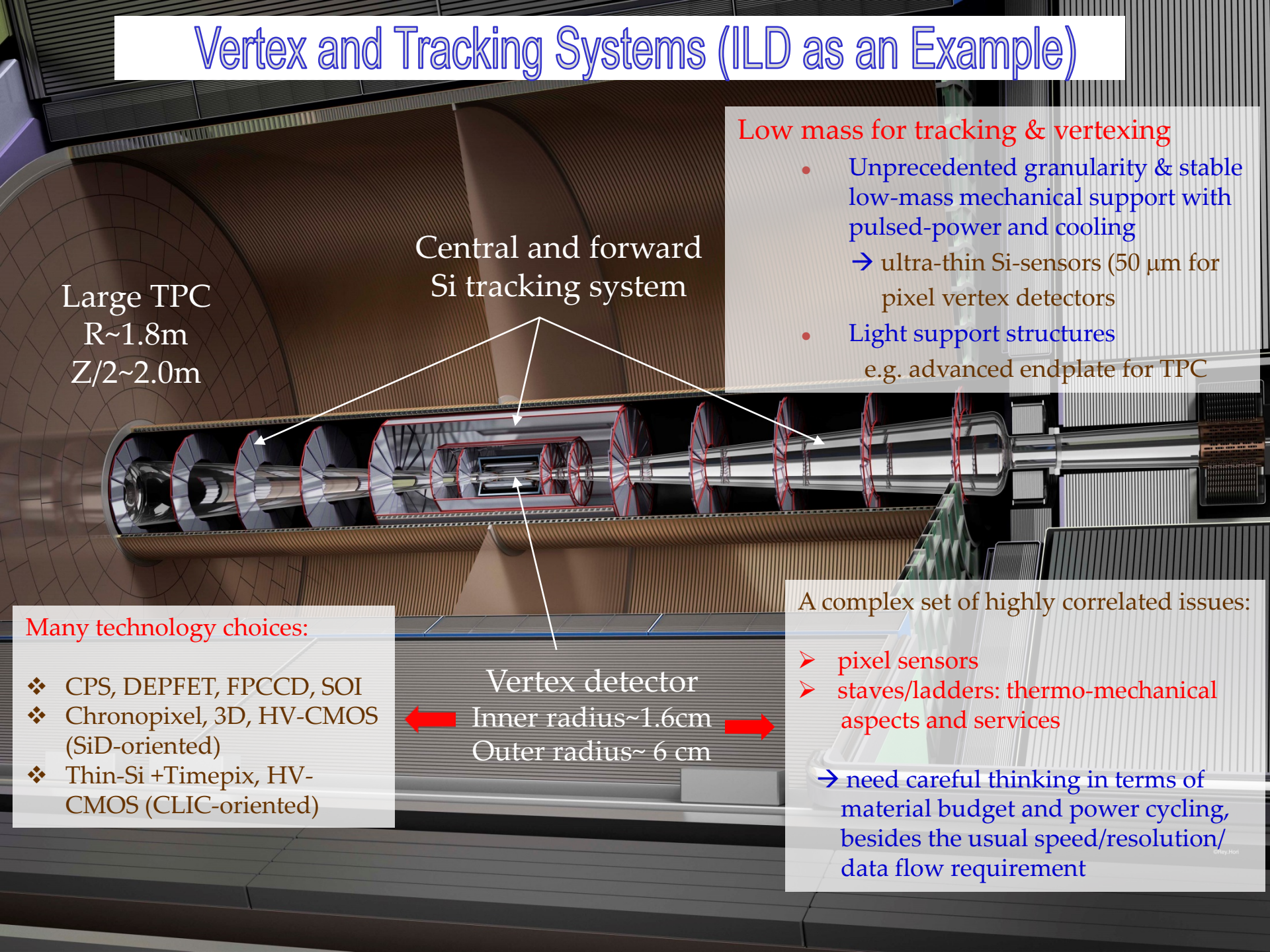
Time Projection Chamber for Linear Collider

Forward calorimeters for Linear Collider

Highly granular calorimeters for Linear Collider

- A lot of R&Ds is being carried out both within the ILD/SiD and through the "horizontal R&D collaborations"

Vertex and Tracking Systems (ILD as an Example)



Low mass for tracking & vertexing

- Unprecedented granularity & stable low-mass mechanical support with pulsed-power and cooling
  → ultra-thin Si-sensors (50 μm for pixel vertex detectors
- Light support structures
  e.g. advanced endplate for TPC

Many technology choices:

- CPS, DEPFET, FPCCD, SOI
- Chronopixel, 3D, HV-CMOS (SiD-oriented)
- Thin-Si +Timepix, HV-CMOS (CLIC-oriented)

A complex set of highly correlated issues:

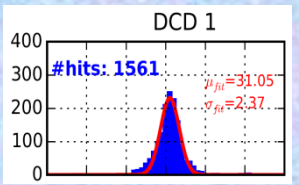
- pixel sensors
- staves/ladders: thermo-mechanical aspects and services

→ need careful thinking in terms of material budget and power cycling, besides the usual speed/resolution/ data flow requirement

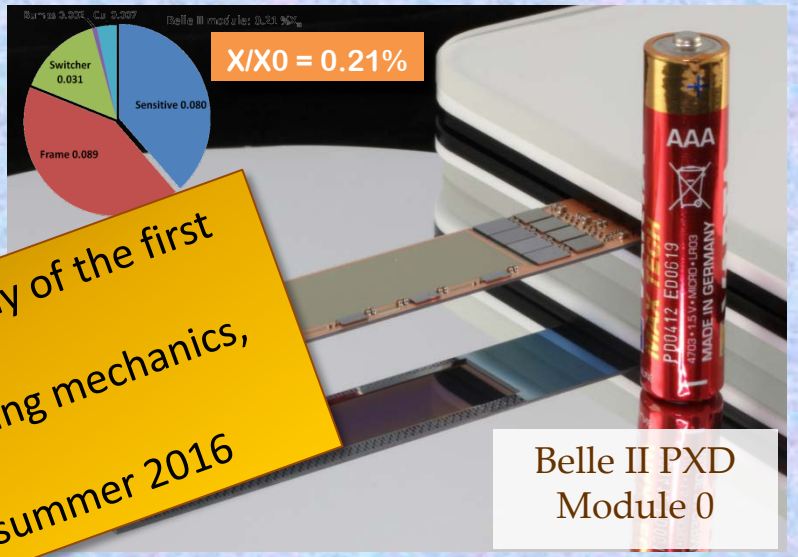
DEPFET R&D for ILC Vertex Detector

M. Vos
L. Andricek

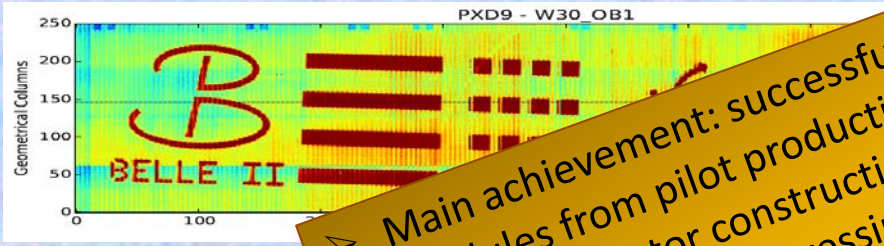
- DEPFET R&D for ILC vertex detector in the frame work of Belle II PXD construction
  - Pixel sensor design and auxiliary ASICs
  - Integration to low-mass modules



- Latest achievement
  - Module 0 assembled
  - Final sensor production started

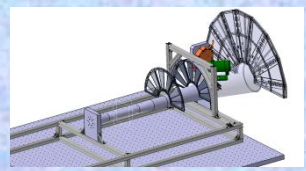


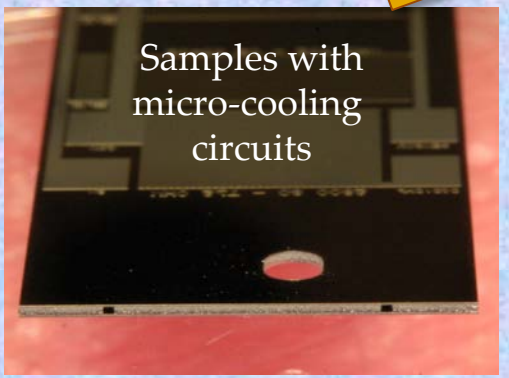
Belle II PXD Module 0

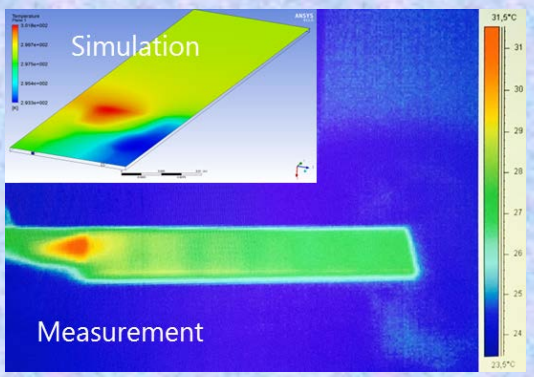


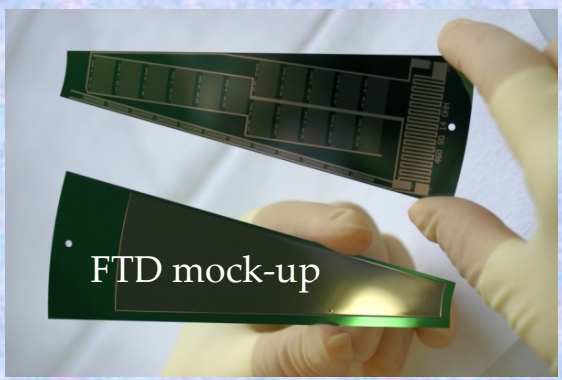
- Main achievement: successful assembly of the first modules from pilot production
- Overall detector construction including mechanics, cooling, DAQ, is progressing.
- Start series module production in summer 2016

- Purely LC rela
  - Silicon-int channels (AIDA 2020)
  - Extension module concept to the vertex forward region









Chronopixel R&D and Status

J. Brau / N. Sinev

- Chronopixel design provides for single bunch-crossing time stamping (when signal exceeds threshold, time stamp provided by 14 bit bus)

- Prototype 1 (50x50 μm2 pixels, 180nm TSMC)

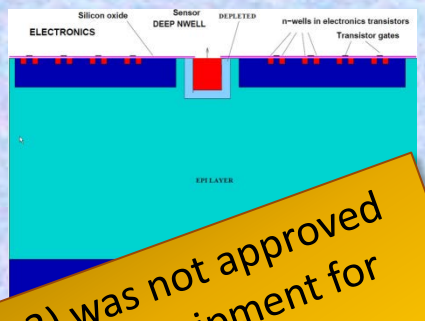
- Prototype 2 (25x25 μm2 pixels, 90nm TS
  → Sensor capacitance larger than
  (because of design rule

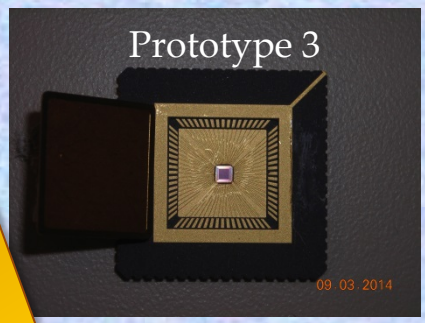
- Prototype 3 (25x25 μ
  → Six different sensor
  shallow nwells and
  on design

  → Main problem of large sensor capacitance due to 90 nm design rules has been solved

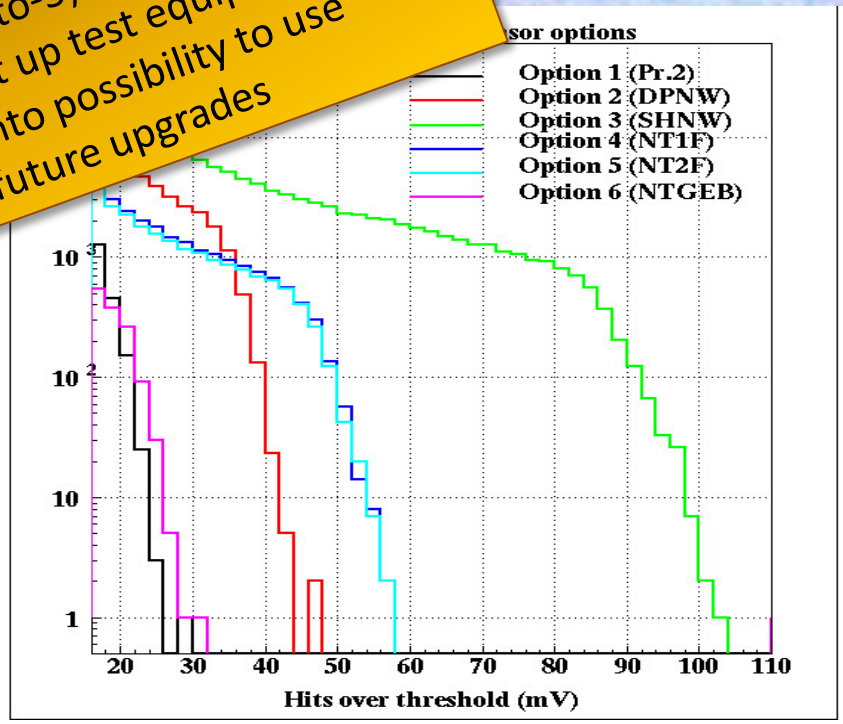
  → 4 out of the 6 options are acceptable for ILC applications (1 – 9.04 fF, 2 – 6.2 fF, 3 – 2.73 fF, 4/5 - 4.9 fF, 6 – 8.9 fF; opt. 1,6 are not accept.)

- More tests are under way to optimize the design based on minimum ionizing track efficiency.





- Future funding (beyond proto-3) was not approved
- Yale University trying to set up test equipment for proto 3 chips → looking into possibility to use Chronopixel for the LHC future upgrades



^{55}Fe results for 6 sensor options:
1 – the same design as prototype 2;
2 & 3 – violate TSMC design rules – granted waiver;
4 & 5 – "natural transistors", allowed by design rules, with gate connected to source and drain;
6 – same, as 5, but gate connected to external bias.

3D Vertical Integrated Circuits (VIP Chip)

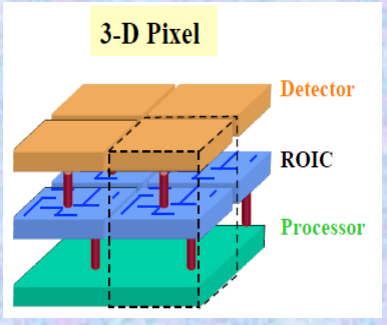
R. Lipton

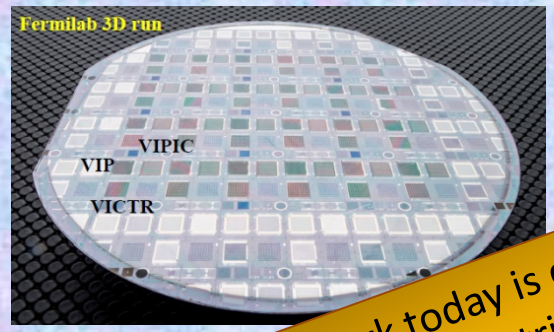
- An alternative to achieving ultra-low material budget is 3D integrated circuits:

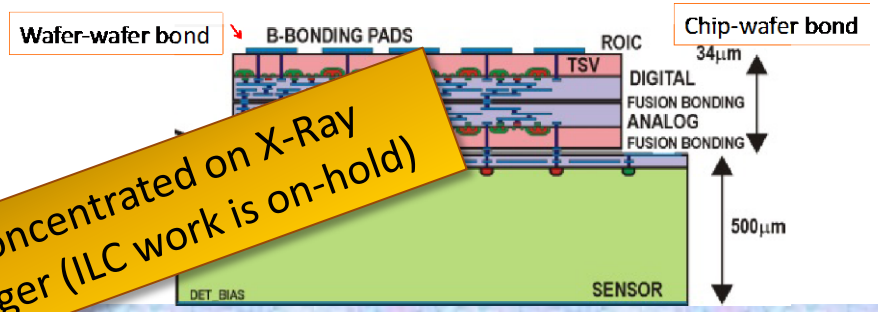
- Fermilab 3D-IC MPW Run for HEP (2010): 3 chips VICTR(CMS),VIP(ILC),VIPIC(x-ray)

Vertical Integrated pixel (VIP) chip for ILC:
- single pixel time stamping
- 24 x 24 μm² pixels, 192x192 array

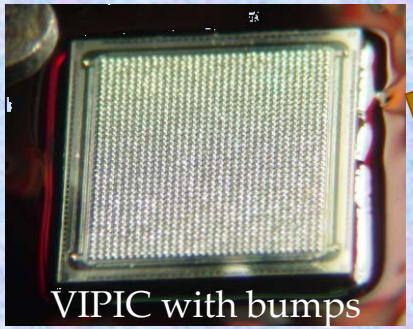
- Two layer 3D ASIC bonded to silicon wafer
- ASIC is thinned to TSV for metal contact to the sensor on other layer of the ASIC
- ASIC is 34 μm thick

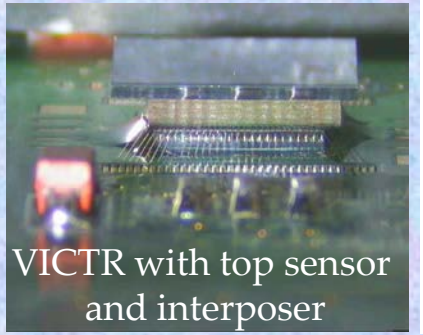


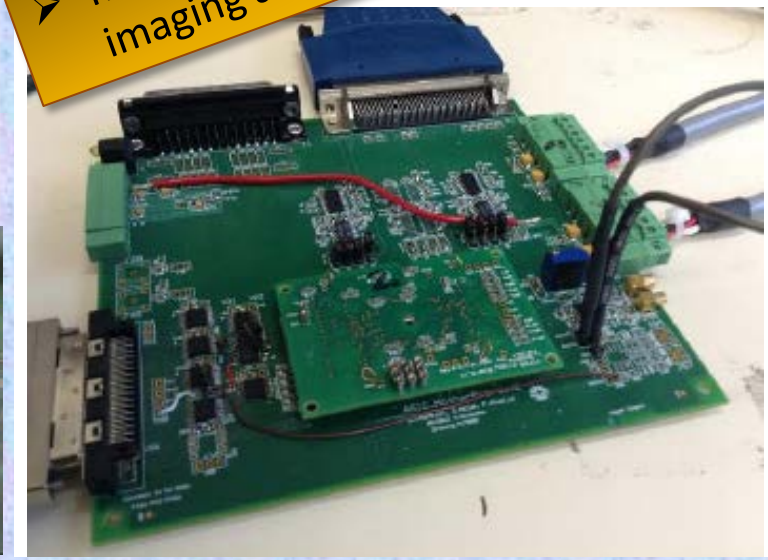


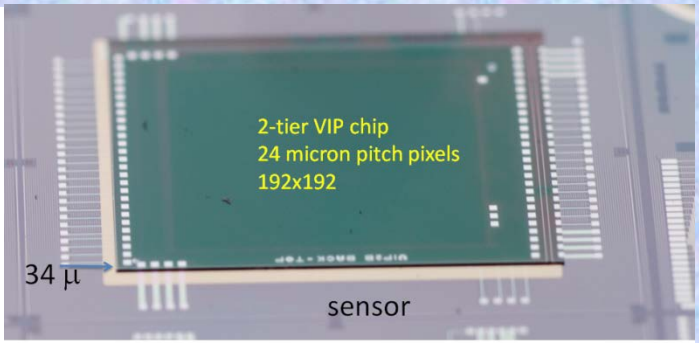


Most of the work today is concentrated on X-Ray imaging and CMS track trigger (ILC work is on-hold)









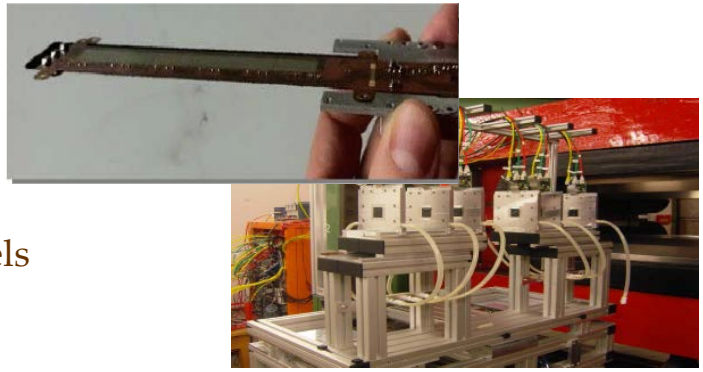
- Successfully read out all 192x192 = 36,864 pixels
- Token passes though at 189ps/pixel
- Sees source
- Issues with test pulse masking,
- odd row test pulse
- Beam test winter 2014

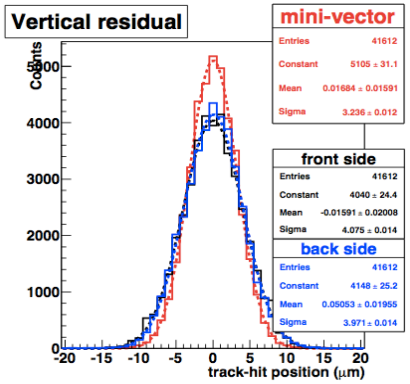
R&D on CMOS Pixel Sensors Adapted to an ILC Vertex Detector

MIMOSA sensors equipping EUDET BT : M. Winter ~ 3µm track resolution achieved:

→ 0.35 µm process with high-resistivity epitaxial layer (coll. with IRFU/Saclay)

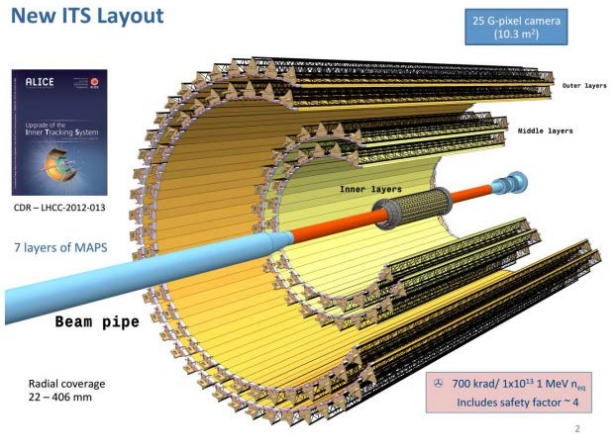
→ binary charge encoding
→ active area: 1152 columns of 576 pixels (21.2×10.6 mm2)
→ pitch: 18.4 µm 0.7 million pixels





STAR-PXL PHYSICS RUN OF SPRING '14
→ CPS validated for vertex detectors

→ sensor architectures developed in 0.35 µm CMOS process for ILD-VXD comply with DBD requirements



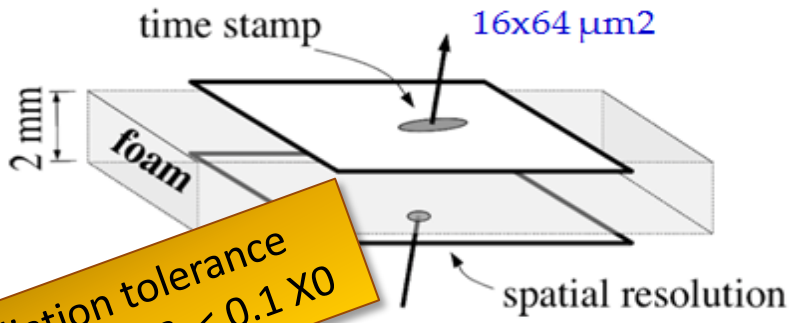
ALICE-ITS = NEW DRIVING APPLICATION OF CPS
based on a better suited (180 nm) CMOS process
(TDR approved by LHCC in March '14)
1st real scale sensor prototype adapted to 10 m² fabricated

→ 1st test results validate architecture in 180 nm technology
→ 2-4 times faster read-out w.r.t. 0.35 µm technology, with up to 60 % power reduction
→ Prototyping to be completed in 2016
→ New detector expected to be installed in LHC-LS2

R&D on CMOS Pixel Sensors Adapted to an ILC Vertex Detector

DOUBLE-SIDED LADDER DEVELOPMENT:

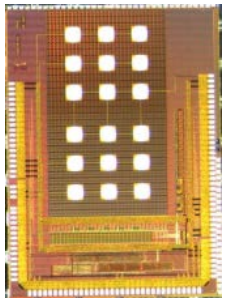
- Develop concept of 2-sided ladder using 50 µm thin CPS
- Develop concept of mini-vectors providing high spatial resolution & time stamping
- Address the issue of high precision alignment & power cycling in high magnetic field (IL C)



How to improve speed, radiation tolerance while preserving ~ 3-5 um precision & < 0.1 X0

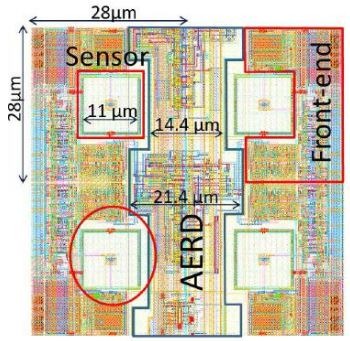
M. Winter

ITS Pixel Sensors: Two arch
Synchronous rea



Asynchronous readout:

ALPIDE (Alice Pixel detector):



Main goals of the coming years are :

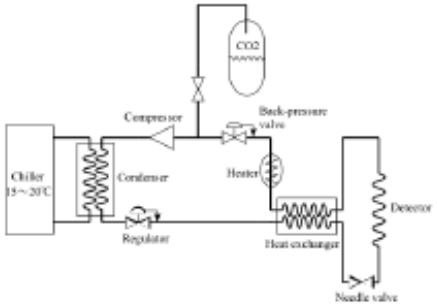
- improved read-out speed (single ILC bunch tagging) via new read-out architecture and enhanced sensitive volume depletion
- introduce NN in CPS to mitigate data flow from beam-related background
- realization of double-sided ladders (PLUME) equipped with two complementary types of CPS (high resolution, but rather slow and fast but less accurate); next test power cycling in mag field with impact of Lorentz forces

Detector R&D Liaison Report: Vertex and Tracking R&D

Fine Pixel CCD (FPCCD) Detector R&D:

FPCCD thinned to 50 um

2-phase CO2 cooling

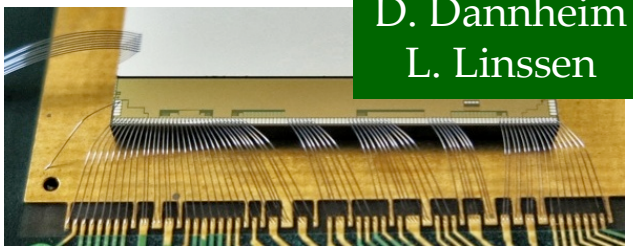


Y. Sugimoto

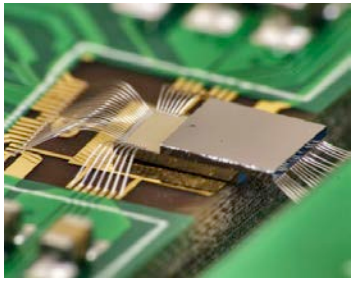
CLIC Vertex Detector R&D:

D. Dannheim
L. Linssen

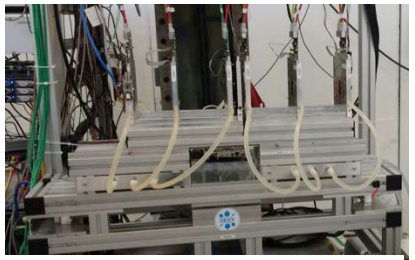
Ultra-thin sensors 50 um



Test beams with new readout ASICs



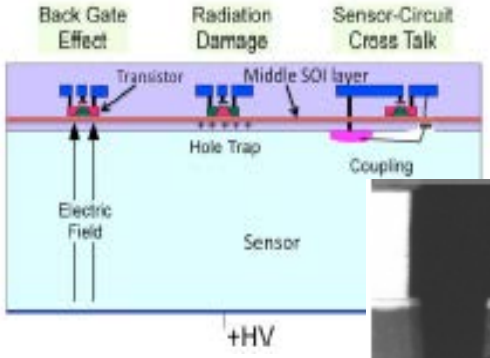
CCPDv3+CLICpix



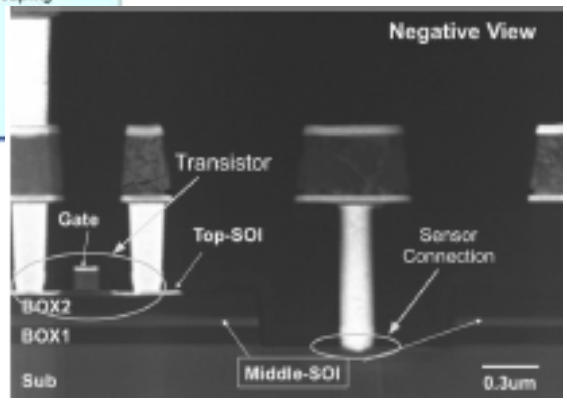
Timepix3 in AIDA telescope (CERN PS-T9)

- Capacitively-coupled active CMOS sensors
- Through-Silicon Vias (TSV)

Silicon-on-Insulator (SoI) Pixel Det. R&D:



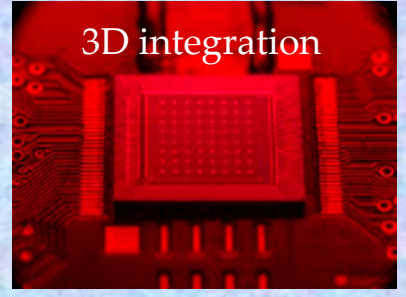
Y. Arai

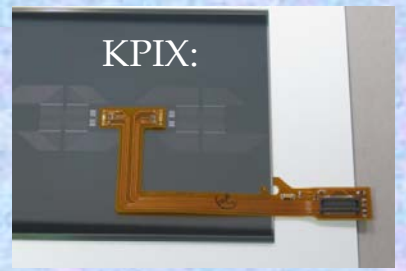


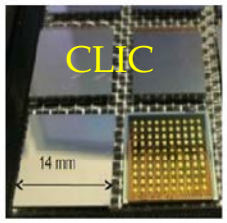
Cross section of double SOI chip after processing

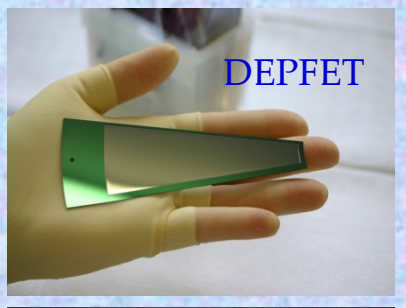
R&D on Si-Tracking Detectors:

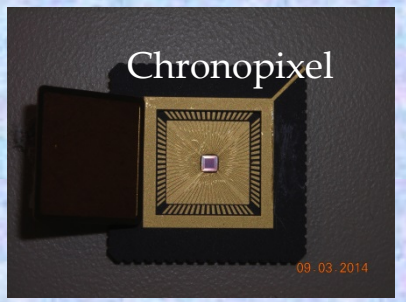
- Silicon Ladders and Charge Division Tracking R&D (B. Schumm)
- KPIX (M. Breidenbach)
- Resistive charge-division on thinned μ-strips sensors with low sig. amp. (I. Vila)









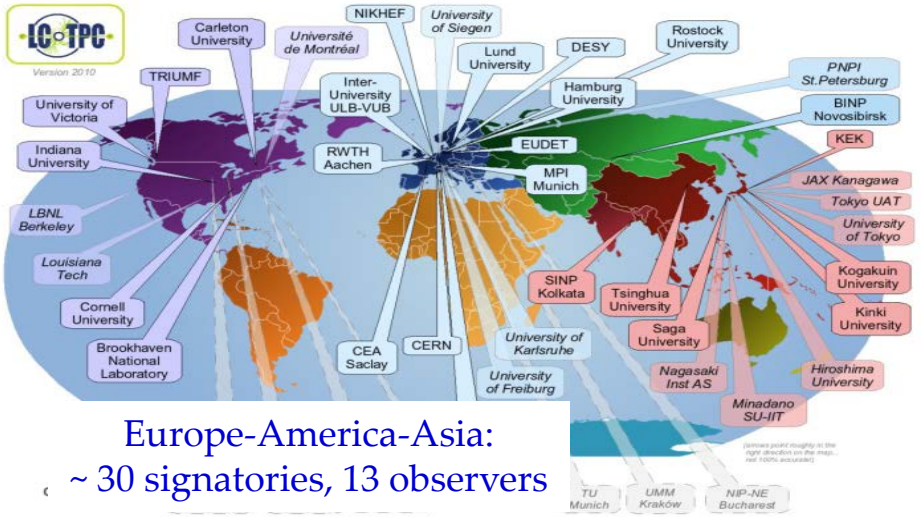


Detector R&D Liaison Report: Vertex R&D Summary Table

Vertex and Tracking Detector R&D Chapter: ~ 30 pages length

R&D Technology	Participating Institutes	Description / Concept	Milestones	Future Activities
ChronoPix	University of Oregon Yale University Sarnoff Corporation	ChronoPix is a monolithic CMOS pixelated sensor with the ability to record up to two time stamps per pixel during the bunch train. Hits are read out in the time between bunches.	April 2014: Device tests of prototype 2 inform the design of prototype 3 to be submitted to foundry	Prototype 3 was manufactured in September 2014. Tests have shown that problems revealed in prototype 2 were solved.
CMOS MAPS	IPHC Strasbourg DESY, Hamburg University of Bristol University of Frankfurt	The CMOS pixel sensor uses as a sensitive volume the 10–20 µm thin high-resistivity epitaxial Si-layer deposited on low resistivity substrate of commercial CMOS processed chips. The generated charge is kept in a thin epi-layer atop the low resistivity silicon bulk by potential wells that develop at the boundary and reaches an n-well collection diode by thermal diffusion.	2016 : production of CPS for the ALICE-ITS upgrade 2018/19 : production of CPS for the micro-vertex detector of the CBM experiment at FAIR/GSI 2018/19 : validation of light double-sided ladder concept combining highly granular sensors on one side with timestamping sensors on the other side < 2020 : validation of power pulsing of double-sdied ladders inside a high magnetic field 2022/23 : finalisation of the R&D on various CPS adapted to the different layers of a very high performance vertex detector at the ILC	Until 2018-2019: Development and production of CPS for the ALICE-ITS and CBM-MVD Development of various CPS optimised for the different layers of a vertex detector at the ILC, with emphasis on bunch tagging Development of low material double-sided ladders
DEPFET	University of Barcelona, Spain University of Bonn, Germany Heidelberg University, Germany Giessen University, Germany University of Göttingen KIT Karlsruhe, Germany IFJ PAN, Krakow, Poland MPI Munich MPG HLL Munich, Germany Charles University, Prague, Czech Republic IFIC, CSIC-UVEG, Valencia, Spain DESY, Hamburg, Germany IFCA, CSIC-UC, Santander, Spain	The DEPFET technology implements a single active element within the active pixel by integrating a p-MOS transistor in each pixel on the fully depleted, detector-grade bulk silicon. Additional n-implants near the transistor act as a trap for charge carriers created in the substrate (internal gate), so that they are collected beneath the transistor gate.	2014: Full-scale 75 µm thin Belle II ladder in beam test at DESY	Development of die-attach technology Full-scale test of all ASICs on ladder Integration of read-out and steering ASICs on pixel sensor using flip-chip technique and microscopic solder ball bump-bonding Production of Belle II vertex detector modules Tests of the last version of the DHP chips Engineering design for all-silicon module with petal geometry required for ILC Detailed characterization of device response Design of ancillary ASICs, taking full responsibility for future design cycles of the FE read-out chip, called Drain Current Digitizer
FPCCD	KEK Shinshu University Tohoku University JAXA, Japan Aerospace Exploration Agency	Fine Pixel CCD sensors have pixel sizes of 5 µm and a fully depleted epitaxial layer with a thickness of 15 µm	Fabrication of real size (12.3 mm × 62.4 mm) sensors with 50 µm total thickness Neutron irradiation of a small (6 mm× 6 mm) FPCCD sensor Construction of a prototype cooling system and demonstration of cooling between −40°C and +15°C	Characterization of FPCCD sensors including beam tests and radiation damage studies Development of FPCCD sensors with a pixel size of 5 µm Construction of prototype ladders for the inner layers of a vertex detector Development of readout electronics downstream of ASICs Development of larger FPCCD sensors and prototype ladders for outer layers Development of readout electronics with a small footprint Construction of a real size engineering prototype and cooling test
3D Pixels	Brown University Cornell University Fermilab Northern Illinois University SLAC University of Illinois Chicago	3D technology allows very fine pitch (4 µm) integration of sensors with multiple layers of electronics, allows interconnection oto both the top and bottom of devices, and provides techniques for low mass, thinned devices.	Completed multi-year effort to demonstrate commercial 3D technology, consisting of 0.13 CMOS interconnected with Direct Oxide bonding technology and access using TSV. Received readout wafers with thickness of 25 µm, processed with TSV and DBI to connect to 3D electronics Currently working on active edge demonstrator devices	Complete the 3D active edge project Apply concepts to x-ray imaging devices Re-start ILC developments pending renewed funding
SOI	KEK University of Tsukuba Tohoku University Osaka University	In the Silicon-On-Insulator (SOI) technology the sensing and processing functionalities are separated in different layers; the sensing is provided by a high-resistive substrate connected through an insulating layer with the processing layer.		Sep 2014: Complete architecture study for the ILC pixel detector Mar 2015: Design and fabrication of first test chip for the ILC Dec 2015: Beam test of the chip
CLICPix	Cambridge University CERN University of Geneva Karlsruhe Institute of Technology (KIT) University of Liverpool SLAC Institute of Space Science Bucharest Spanish Network for Linear Colliders	Hybrid pixel-detector technology comprising fast, low-power and small-pitch readout. ASICs implemented in 65 nm CMOS technology (CLICpix) coupled to ultra-thin planar or active HV-CMOS sensors via low-mass interconnects.	Beam tests of prototype assemblies with ultra-thin sensors (50–300 µm) CLICpix demonstrator ASIC in 65 nm technology Beam tests of assemblies with capacitive coupling between CCPDv3 HV-CMOS active sensors and CLICpix ASICs Power-pulsing demonstrator with dummy loads Prototypes of carbon-fibre ladder supports Full-scale thermal mockup of the CLIC vertex-detector region	Demonstration modules for all major components in time for the next update of the European Strategy for Particle Physics in 2018/19

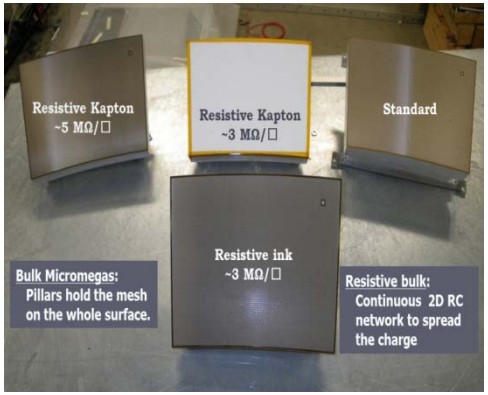
Time Projection Chamber R&D: LCTPC Collaboration



Europe-America-Asia:
~ 30 signatories, 13 observers

TPC with MPGD-Readout (endcap size~10m^2):
→ spatial resolution < 100 μm @ 4T

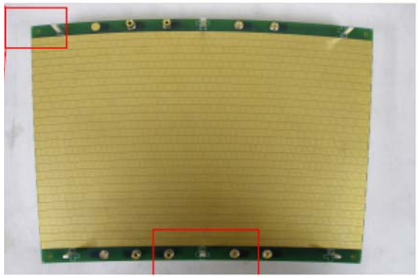
- Wet-etched triple GEMs
- Laser-etched double-GEMs 100μm thick ("Asian")
- Resistive MM with dispersive anode
- InGrid (integrated Micromegas grid with pixel readout); GEM + pixel readout

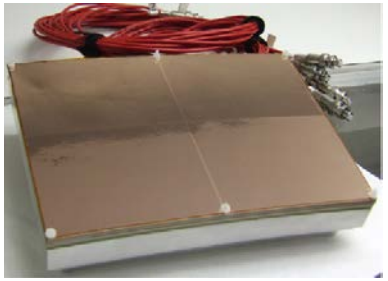


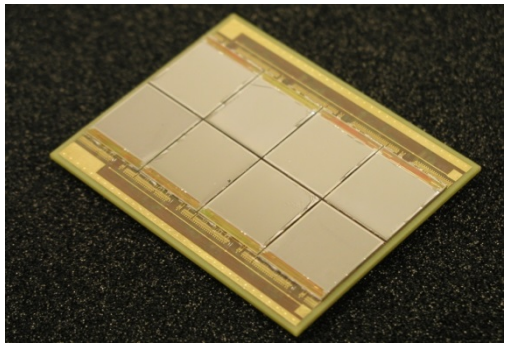
Resistive MM:
CEA Saclay (P. Colas)
Carleton (A. Bellerive)

Laser- etched GEMs "Asian Module":
KEK (K. Fujii); Univ. Saga (A. Sugiyama)

Wet-etched GEM "DESY Module":
DESY (T. Behnke)







InGrid: Bonn (K. Desch), Saclay, NIKHEF, Kyiv Univ.

GEM-pixel: Bonn; Siegen

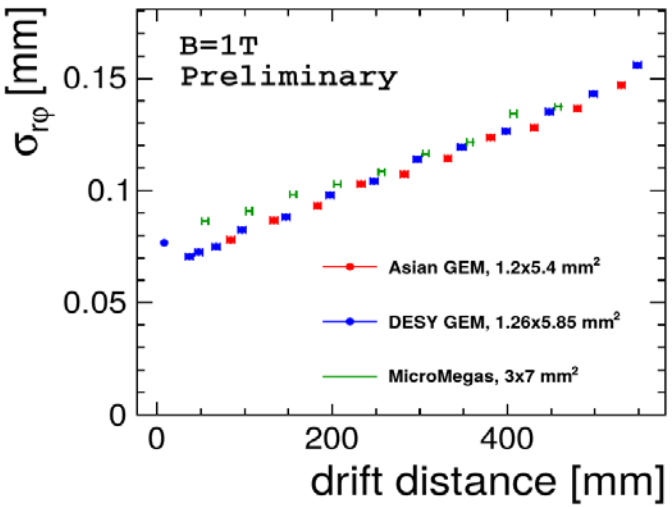
Ion Backflow & Gating – Univ. Saga (A. Sugiyama)
Mechanics & Calibration – DESY (T. Behnke); Electronics, DAQ, Cooling – Lund (L. Jonsson)

LCTPC R&D: Ongoing Activities

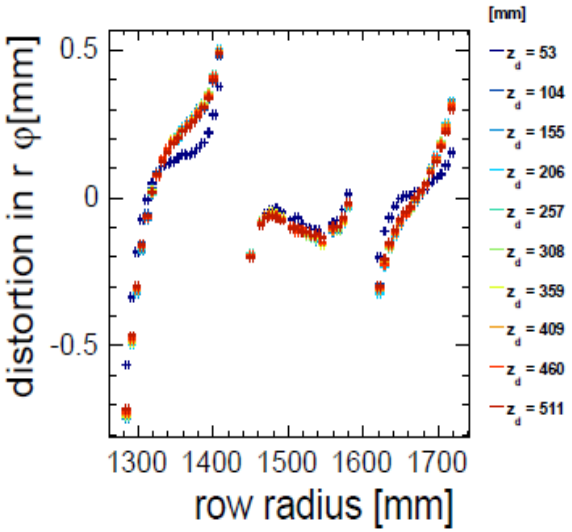
J. Kaminski

- Efforts to improve the module designs for all technologies → several test-beam campaigns
- Unify the reconstruction and analysis software: (e.g. correction of inter-module field distortions.

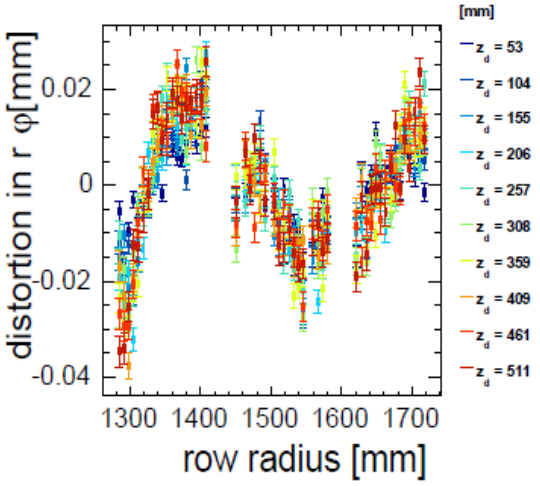
Goal for final TPC can be reached:
GEM / MM performance similar



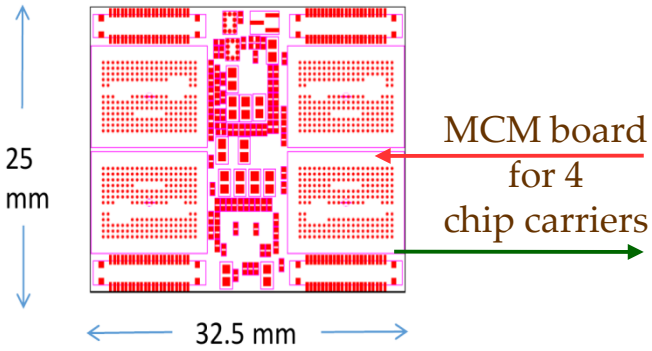
MM: Before correction



MM: After correction
(note – different scale)



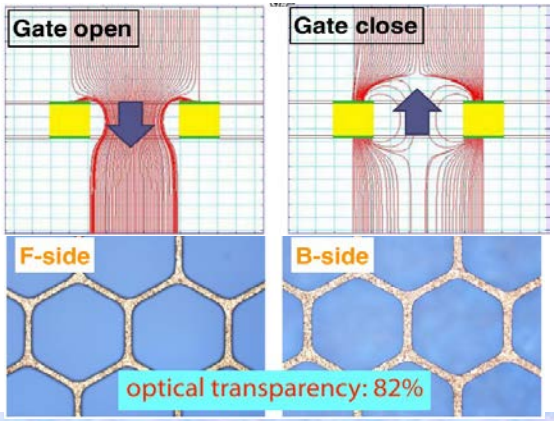
New set of electronics based on the SALTRO-16 (pad readout)



Machine-induced bkg. and ions from gas amplification → track distortions 60 μm

Gating is needed:

- Wire-gating
- GEM-gating

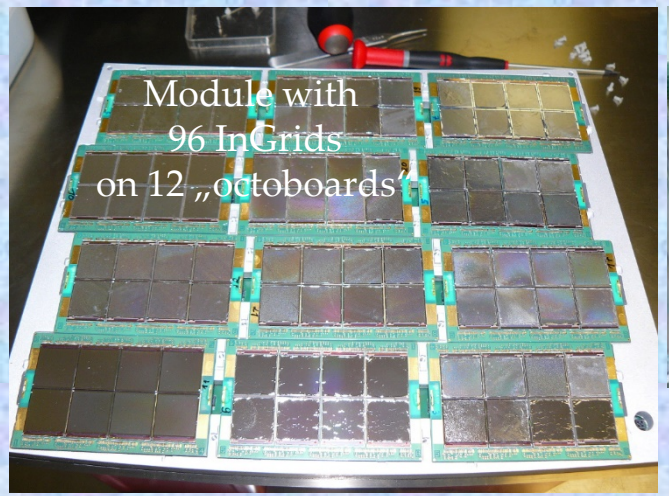


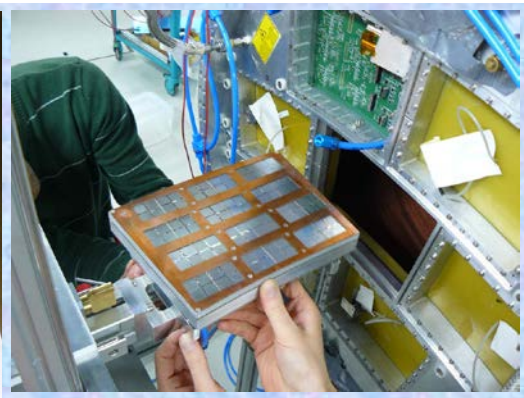
ILC Time Projection Chamber (TPC): Pixel-Based Readout

BREAKTHROUGH: feasibility shown in test-beam with 160 InGrids detectors

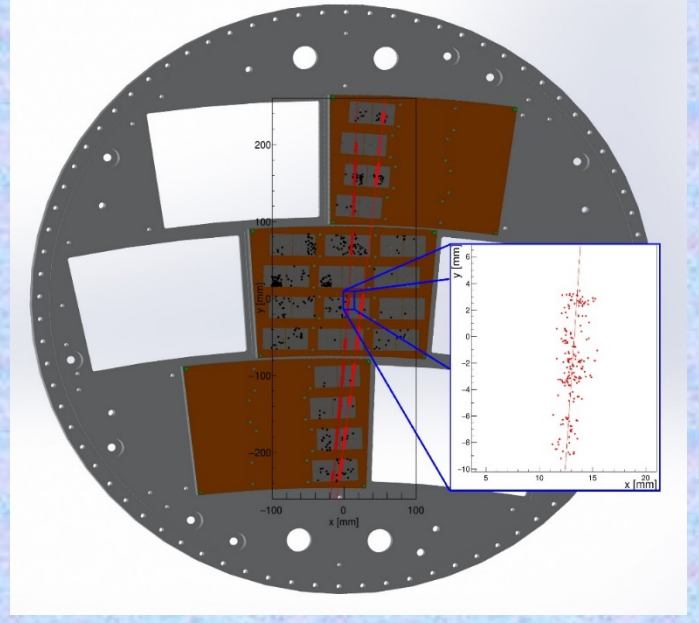
3 modules for LCTPC large prototype : 1 x 96 InGrid, 2 x 24 InGrids
320 cm² active area, 10,5 mio. channels, new readout system-
Readout 5 SRS FECs

By design:
- Single electron detection
- Time-of-arrival measurement
- High granularity; Uniform gas gain



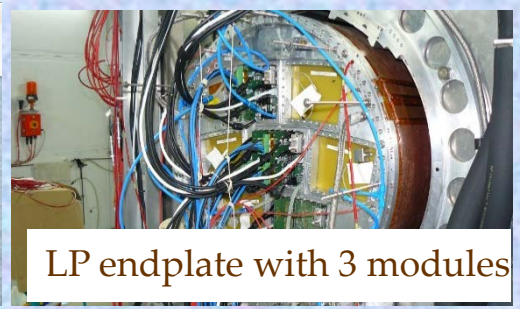


M. Lupberger



50 cm track length with about 3000 hits
→ each representing an electron from the primary ionisation.
→ demanding for track reconstruction, especially in case of curved tracks

24 InGrid installation in LP



LP endplate with 3 modules

- Physics properties of the TPC
→ field distortions; reliability
→ dE/dx resolution;delta identification
→ single point resolution
→ momentum measurement
→ Track angular effect

LCTPC Collaboration: TPC R&D Next Steps

GEM modules:

→ triple CERN GEMs: new set of modules with improved production techniques for higher GEM flatness and more reproducible module properties

→ 2 thicker GEMs: new module construction with gating grid included, decrease number of micro-discharges

J. Kaminski

Micromegas modules:

→ test different mesh sizes and different resistive materials;

→ large module with cooling and high channel density

GridPix modules:

→ Prepare GridPixes based on Timepix3 ASICs; test-beam studies

Electronics:

→ Produce a significant amount of the S-ALTRO-16 ASIC for pad-based modules

Gating grid:

→ Expected electron transparency has been demonstrated, ion absorption is to be demonstrated

Large Prototype Setup:

→ A new field cage and an external tracking telescope are under construction guaranteeing a better field homogeneity and independent knowledge of track position

Detector R&D Liaison Report: Gaseous Tracking R&D Summary Table

Gaseous Tracking Detector R&D Chapter: ~ 30 pages length

R&D Technology	Participating Institutes	Description / Concept	Milestones	Future Activities
Asian GEM	Saga, KEK, Hiroshima, Kindai, Kogakuin, Iwate, Nagasaki IAS, Tsinghua	Design of an endcap readout module with a stack of two thicker laser etched polymer-based GEMs and pads	2010-2013: Several test beam campaigns were performed with three readout modules.	During test beam activities the stability of the HV was not as good as in lab tests. The origin of the discharges is being investigated. A modified module with a gating device will be designed and constructed in the next step, and pad plane adapted for the SALTRO is also planned. (2016/17)
GEM	DESY, Hamburg Bonn Siegen	Design of an endcap readout module with a stack of three standard CERN GEMs and pads	2009-2013: Several test beam campaigns were performed with three readout modules.	Though no problems occurred during the test beam, the HV-stability is still being investigated. A new module with gating device, reduced local field distortions and pad plane adapted for the SALTRO is planned. (2016/17)
Resistive Micromegas	CEA Saclay, Carleton	Design of an endcap readout module with a Micromegas gas amplification stage, a resistive layer for charge dispersion and integrated readout. Construction of 11 modules.	2010-2015: Several test beam campaigns were performed with up to seven readout modules, covering the complete LP-endplate.	New materials as resistive layer are being investigated. A module with lower local field distortions is planned.
GridPix ConceptGEM + pixel readout	Bonn, NIKHEF, CEA Saclay Bonn, Siegen	Design of an endcap readout module with a highly pixelized readout with GridPixes. These devices consist of a Micromegas mesh built by postprocessing technology on a pixel ASIC. Alternatively a GEM-stack is used as a gas amplification stage.	2009-2015: Several test beam campaigns with up to three modules were performed. The three modules featured a total of 160 GridPixes and this test beam was performed in March/April 2015. This demonstrated that a large area could be covered with GridPixes and about 100 GridPixes per module could be operated.	2017: The successor chip Timepix3 will be implemented in the readout chain and a test beam with several Timepix-3 chips is planned. This new chips fulfills basic requirements for an operation in an ILD environment.
Field cage	DESY	Design and construction of a TPC field cage	2009: A first prototype has been built and is used as a test device at DESY	A new field cage with improved geometrical precision is under construction at DESY. (2017)
Electronics	Lund, CERN, CEA Saclay	Design of a readout electronics fit for test beam operation at T24/1 at DESY and for investigation the requirements of the ILD-TPC electronics.	2009: Sofar, readout systems based on the AFTER and the ALTRO chip have been used with 10,000 channels each.	A new system based on the SALTRO-16 chip is being prepared (2017). Simulations on the impact of key electronics parameters on the TPC-performance are planned.
DAQ	Lund, ULB-VUB, Hubei	Design of a data acquisition system fit for test beam operation at T24/1 at DESY.	Sofar, DAQ systems for both readout systems (AFTER and ALTRO) have been set up.	A new DAQ system for the SALTRO-16 based readout electronics is being prepared and will be available soon.
Endcap	Cornell	Study of different endplate designs for an ILD-TPC with CAD programs and production of smaller endplates fit for operation at test setup at T24/1 at DESY.	A detailed model of the endplate was implemented in a CAD program and in 2009 a first endcap for the test beam setup has been produced several years ago. A new version also fulfills the requirements of the material budget and will be used from 2015 onwards.	Simulations optimizing the module size are planned.
	CEA Saclay, DESY	Mechanical studies for ILD-TPC regarding the effect of pressure, weight, hanging/support schemes on the mechanical deformation of the endplate and field cage.	First studies have been done.	More detailed studies are planned
Calibration	BNL, CERN, Indiana, Kolkata	Laser calibration system, Alignment/calibration of the TPC, Integration with other tracking systems		
Study of systematic effects	Victoria, Kolkata	Field distortions are a major source uncertainties in track reconstruction. The sources of these distortions are studied and minimized.		
Analysis software	DESY, Carleton, CEA Saclay, KEK, Saga, Siegen, Tsinghua	Development of a software package MarlinTPC, which serves all groups for reconstructing and analyzing the test beam data and for simulation, reconstruction and analysis of ILD events.	MarlinTPC is well developed and the key analysis tool for all analyses.	Further improvements are continually made.
Ion backflow/Gating	Japanese Univers., KEK, Tsinghua, Kolkata, DESY	The ion back flow from gas amplification stages is a major source for time dependent field distortions and has to be suppressed as much as possible. With simulations and experimental setups the minimization of ion production and the reduction of the back flow by a gating device are under study. Field distortions are a major source uncertainties in track reconstruction. The sources of these distortions are studied and minimized.	Simulations have shown, that all gas amplification stages release too many ions into the drift volume and a gating device is necessary. 2014: A first MPGD-based device, a Gating-GEM, has been produced and is being compared to a standard wire gate.	2016: module sized GEM-gates will be available. Then the impact of the gate on the TPC-performance will be studied by using a UV-laser facility at KEK, and in test beams.
Cooling	KEK, Saga, NIKHEF, Saclay, Kolkata	Cooling is important to divert the heat produced by the readout electronics at the endplate. The temperature influences the gas gain and drift properties in the gas and has to be kept as stable as possible to achieve a reliable measurement.	2014: A CO_2 cooling plant has been purchased and setup at the test beam site. First results show a significantly reduced temperature gradient due to heating at the endplate.	Cooling of the SALTRO-16 based module will be studied with a mockup which emulates heat and mechanical conditions of the module. Then, the SALTRO-16 based module will be built with the CO_2 cooling pipes.

GEM-Based readout: arXiv:1604.00935; MM-Based readout (under preparation)

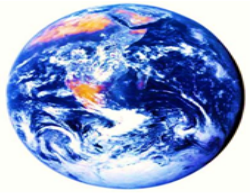
Calorimeter R&D: CALICE Collaboration

- Development and study of finely segmented/imaging calorimeters

- Initially focused on the ILC
- Now widening to include the developments of all imaging calorimeter

Kyushu, September 2015

2nd largest R&D collaboration in HEP



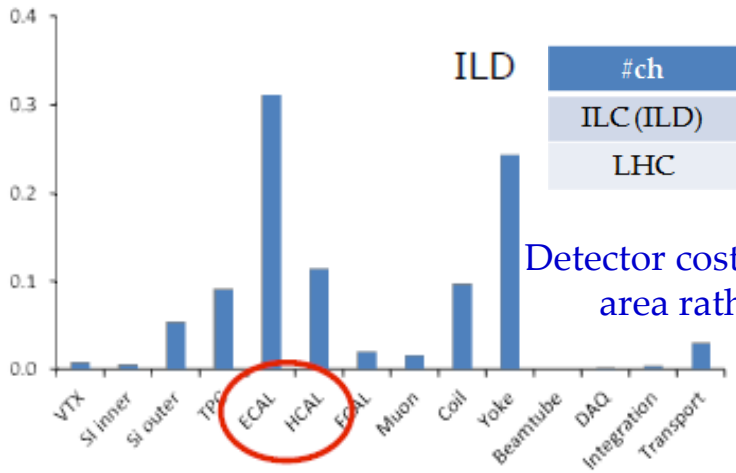
4 continents

19 countries

59 institutes

361 physicists/ engineers

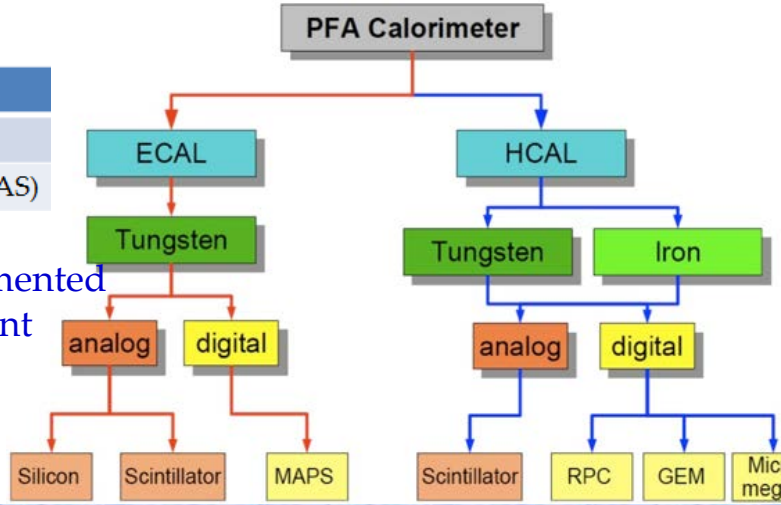
- 1st generation prototypes built/tested (SiW ECAL, Sc-W ECAl, Sc-Fe/HCAL,RPC-Fe/W HCAL (mostly without embedded electronics, integrated HV / LV, power pulsing)
- 2nd generation prototypes meant to address all remaining technical issues (scalable to the size needed for a 4π detector; not necessarily fully instrumented)



ILD

#ch	ECAL	HCAL
ILC (ILD)	100M	10M
LHC	76K(CMS)	10K(ATLAS)

Detector cost is driven by instrumented area rather than channel count

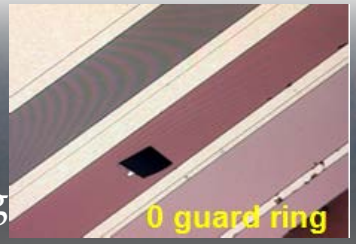


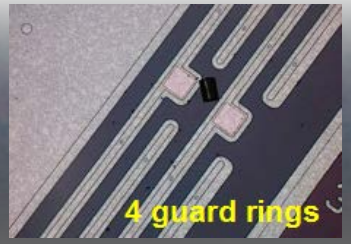
CALICE R&D: Further R&D on Active Elements

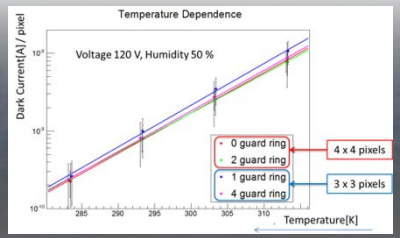
J. Repond

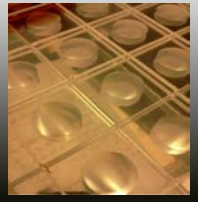
Silicon sensors

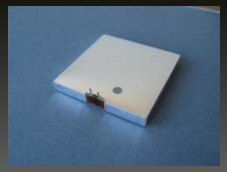
Guard ring design studies
→ segmented or no guard ring

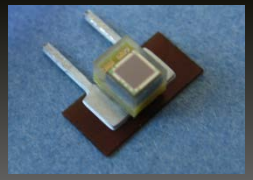












Scintillator pads / strips

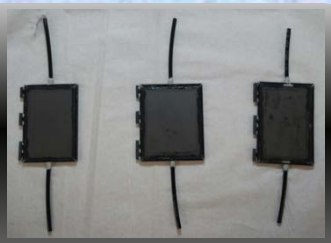
- Tiles with dimples → easier assembly, uniformity
- Wedged tip of strips → more uniform response

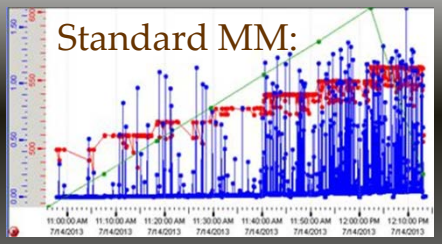
MPPC developments

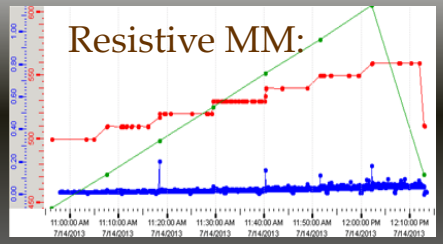
- Improved linearity, Si-purity; increased # of pixels
- Implement. of barrier (noise rate), trench (cross-talk)

Resistive Plate Chambers (RPCs)

1-glass design → beam tests (successful!)
Development of semi-conductive glass → higher rates



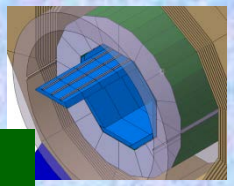




GEM / Thick GEMs / Micromegas

MM: implementation of resistive layer
→ reduced spark rate

Silicon-Tungsten (SiW) ILD ECAL



Kyushu, Tokyo Univ., LLR, LAL, LPNHE, LPSC, Omega, SKKU Korea

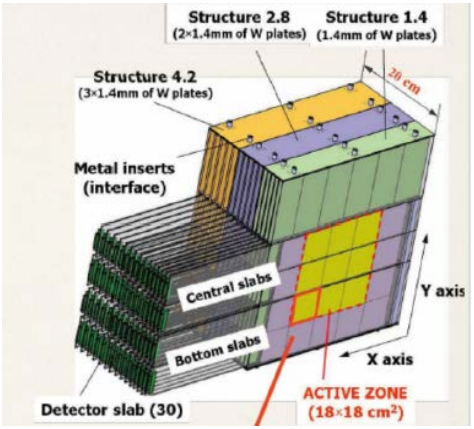
SiW ECAL: Low systematics → Perfect linearity, simple calibration, stable in time, robust
Cost reduction → 10% of bad pixels is affordable (not tracker device)

1st Physical Prototype (2005-2011):

Conceptual proof of PFA, verification of MC

10x10 mm2, 30 layers
Electronics outside

σE/E = 16.6%/√E ⊕ 1.1%, linearity within 1%.



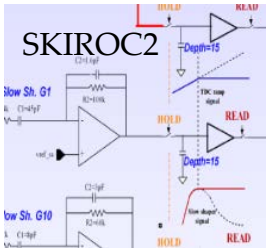
BROADENING THE SCOPE:

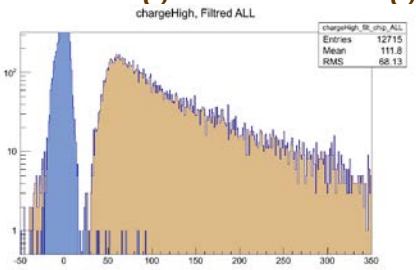
Recent interest to SiW(Pb) technology:

- CMS EC Phase 2 Upgrade (HGCAL)
- ATLAS high-granularity timing det.
- Future circular colliders (TLEP/CEPC)

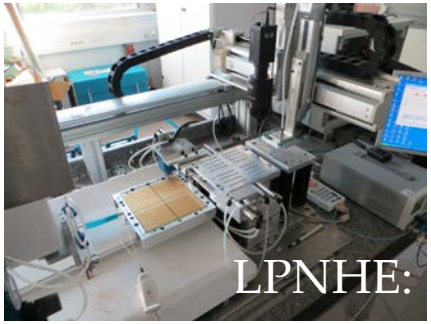
2nd Technological Prototype (2012-present)

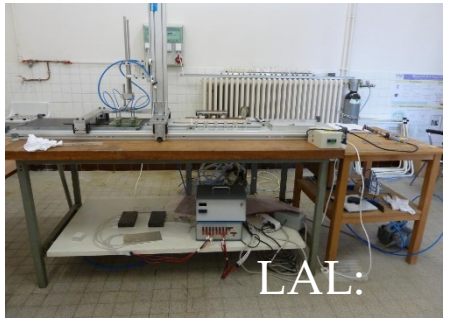
- DAQ Electronics: FE Integration of SKIROC2 in Power-Pulsing & auto-trig.





- Detector Assembly: gluing and positioning robots: automated system developed in the framework of the Calice R&D





Silicon-Tungsten (SiW) ILD ECAL

J.-C. Brient

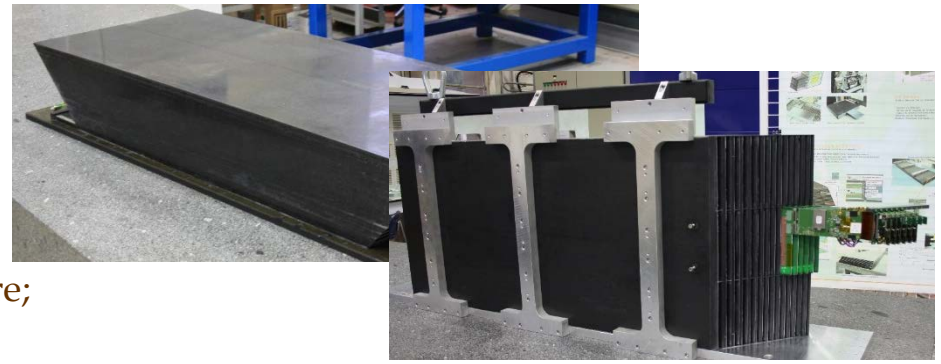
Prototype with all the key techniques needed for a large ILC detector :
Sensors, Readout, Thermal & Mechanical constraints with industrial feasibility
(2600m² of sensors, 26 MCh, 25k detection units, 3500 cassettes, 40+16 modules)

Mechanical Structure: Carbon-Fibre–Tungsten prototype: 60% model of barrel module:

→ 3/5 x ILD barrel module (600 kg, 5 years R&D)
Self-standing, minimal dead zone structure for Casette hosting

→ Mechanical simulation of large composite structure;

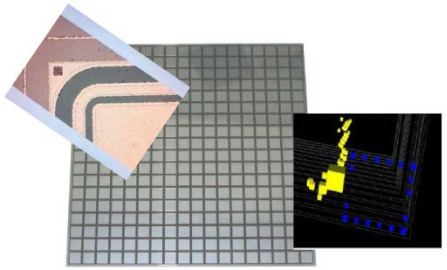
Unique object at the size of ILD detector

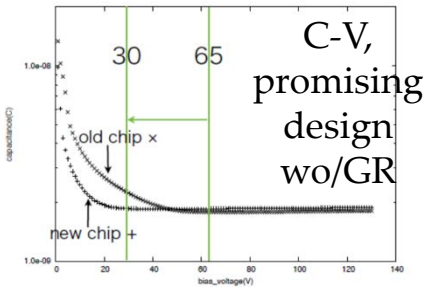


Silicon sensors

❖ Highly Resistive Si-pin diode: Guard Rings design

❖ Industrial contact for production and characterisation for cost/perf optimisation
R&D in Hamamatsu HPK (CNRS, Kyushu)
→2.5 EUR/cm2; know-how design :"no guard ring"
LFoundry (Europe) with CNRS
→Larger (8') and thicker (700 um) sensors.





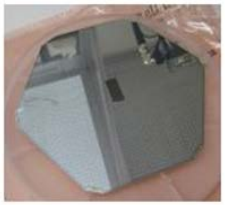
❖ Highly integrated cassette design with minimal thickness (for reduced R_M):
- Production of a long cassette with cooling capacity

Detector R&D Liaison Report: Other ECAL R&D Efforts

SiD

Silicon pads

W

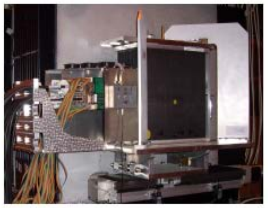


CALICE

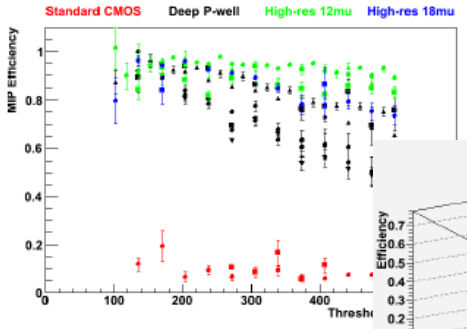
Calorimeter for ILC

Silicon pads | Scintillator tiles | MAPS

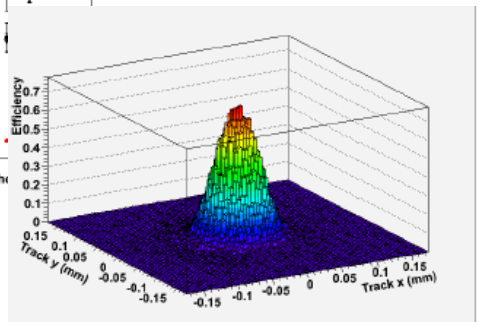
W | W | W



Digital ECAL with INMAPS R&D:

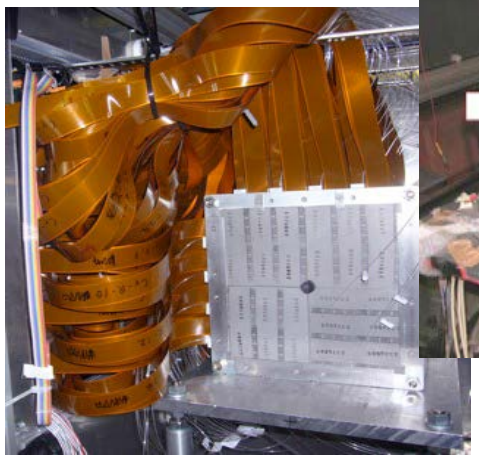


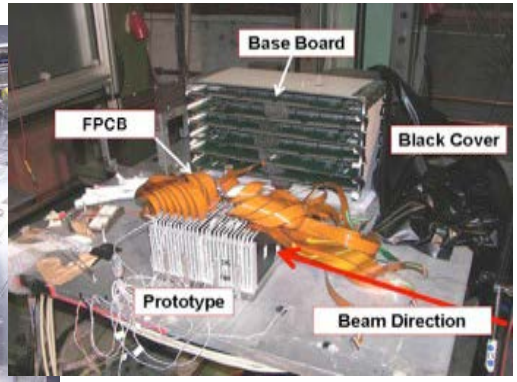
2009 CERN test-beam:



Scintillator- Tungsten ECAL R&D:

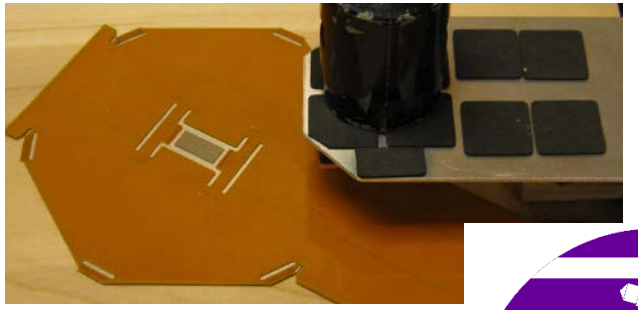
Scintillator strips with MCCPs (10 x 45 mm^2)
Wedge shaped, same absorber as for SiW





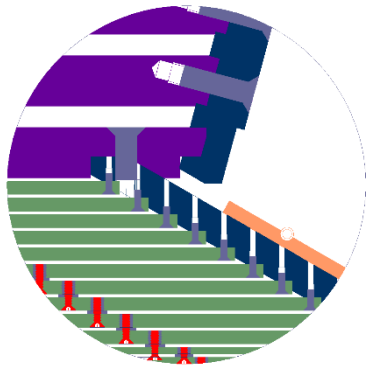
T. Takeshita

Silicon- Tungsten SiD ECAL R&D:



Si-sensors+ KPIX readout

Progress towards a mechanical design

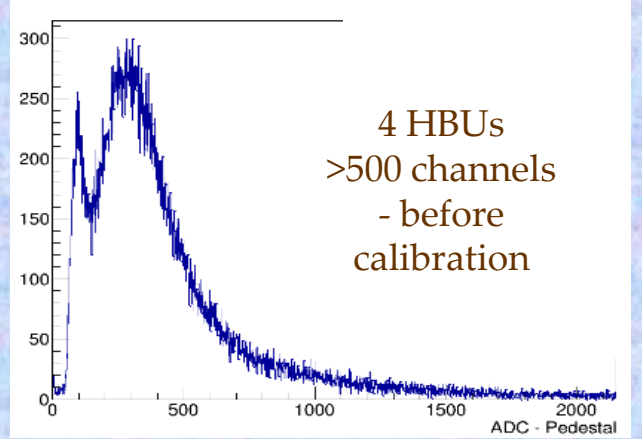


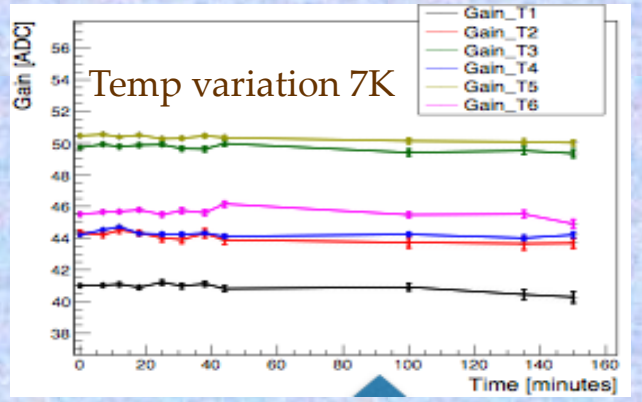
M. Breidenbach
J. Brau

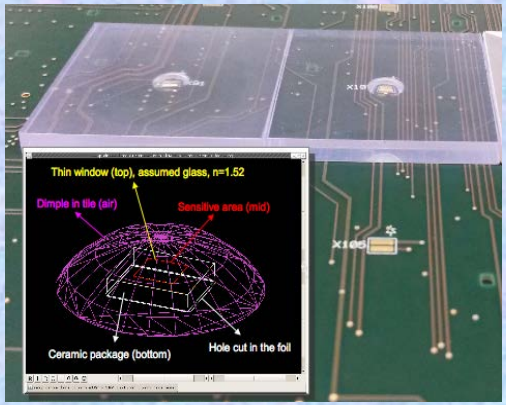
AHCAL R&D: The Scintillator Analogue HCAL

F. Sefkow

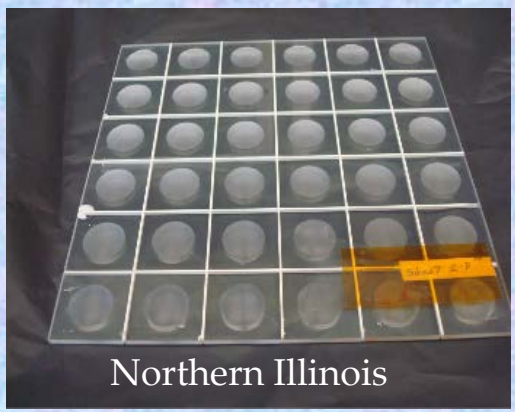
- SiPM trends: driven by industry, medical applications: benefits in present prototype
  - uniformity → simplification: no need anymore for light yield, gain and threshold equalisation
  - lower noise → higher over-voltage → better T stability
- Scintillator trends: optical coupling concepts amenable to mass production - under test in present prototype
  - No WLS fibre (blue-sensitive sensors), SiPM on board, mega-tiles



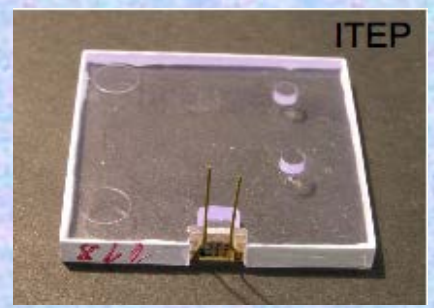




Mainz, with DESY und Uni HH



Hamamatsu sensors, on or in PCB surface



CPTA, KETEK or Hamamatsu sensors no WLS fibre

individually wrapped; KETEK sensors

AHCAL R&D: The Scintillator Analogue HCAL

F. Sefkow

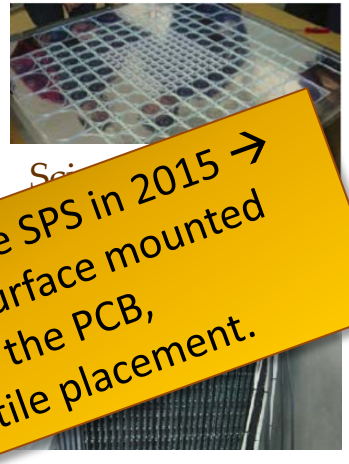
Flexible Test-Beam Roadmap towards 2nd generation prototype (synergy with ScECAL):

- General approach: proceed with system integration whilst remaining open on sensor technology side
  → possible thanks to versatile electronics

- 2014 - 2015 → 3 ECAL + 24 HCAL + shower start finder + 4 big l
  (~ 4000 channels); Fe

Very successful test beam run at the SPS in 2015 → operation of a layer in the new surface mounted design with the SiPM on the PCB, assembled with automated tile placement.

Large Scale Prototypes:

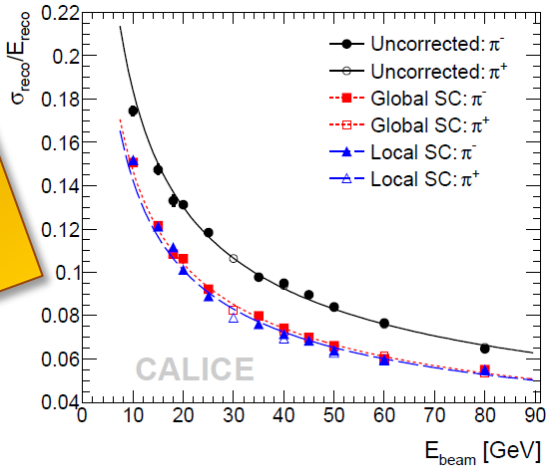


Sci

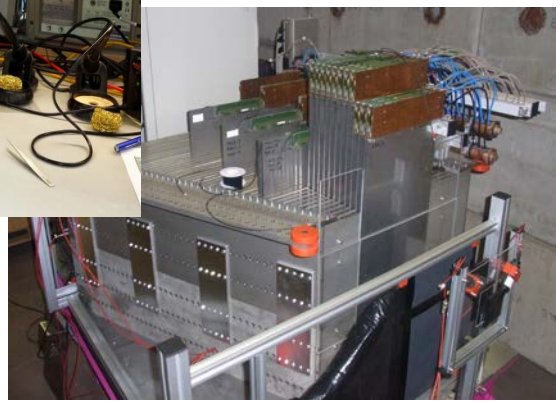
1m³ abs.: steel or W

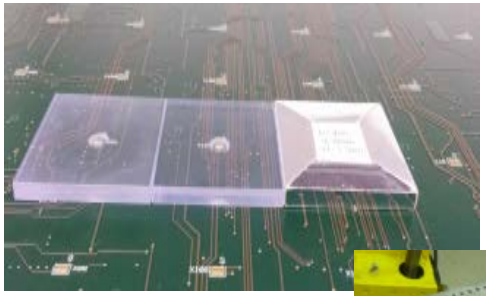
Earlier AHCAL test-beam:

Excellent hadronic energy resolution by software compensation



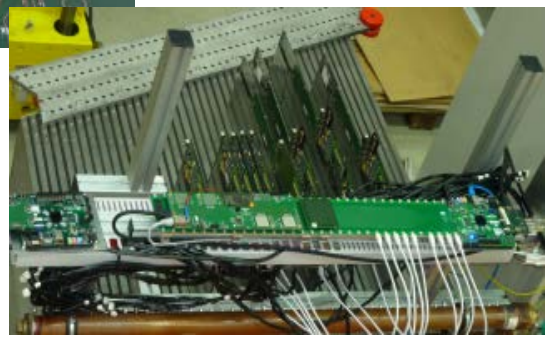
Test beam at CERN PS





AHCAL readout board with SiPM and tiles

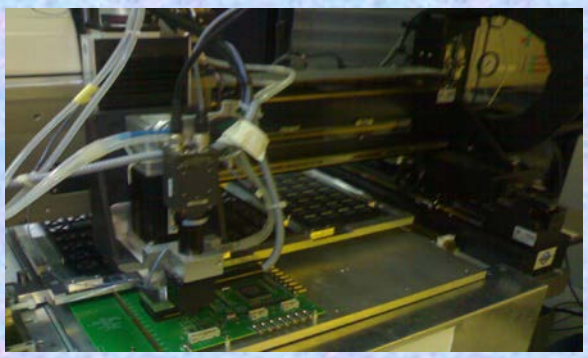
AHCAL stack with integrated read-out electronics

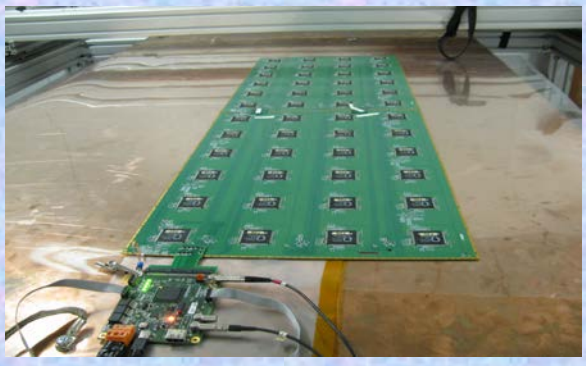


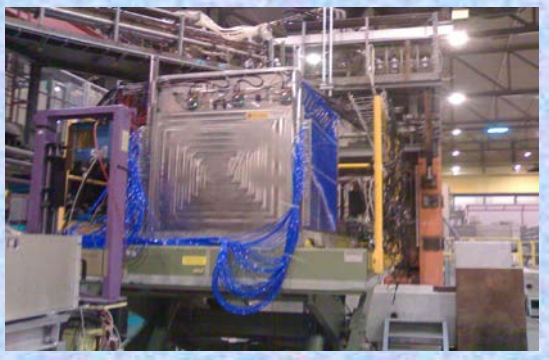
SDHCAL R&D: RPC for HCAL

I. Laktineh

Concept, construction and commissioning of the first technological prototype of ILC: the SDHCAL



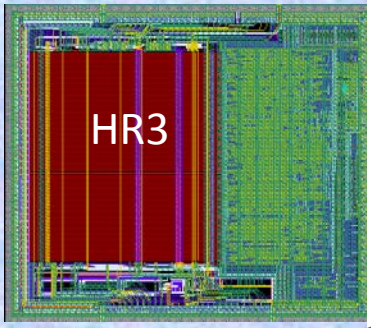


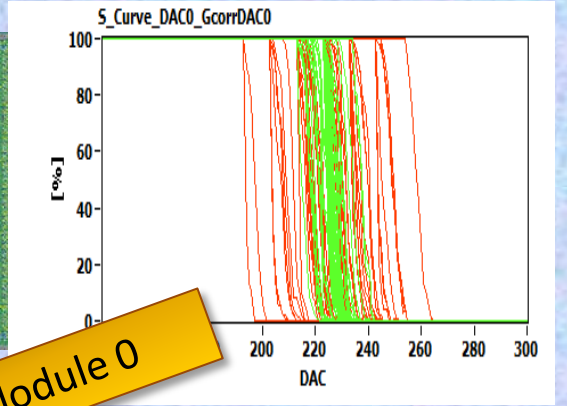


2011: 50 m^2 GRPC detector conceived and built, 10500 ASIC tested, 50 large electronic boards assembled and 50 cassettes completed (power-pulsing, self-supporting, compact)

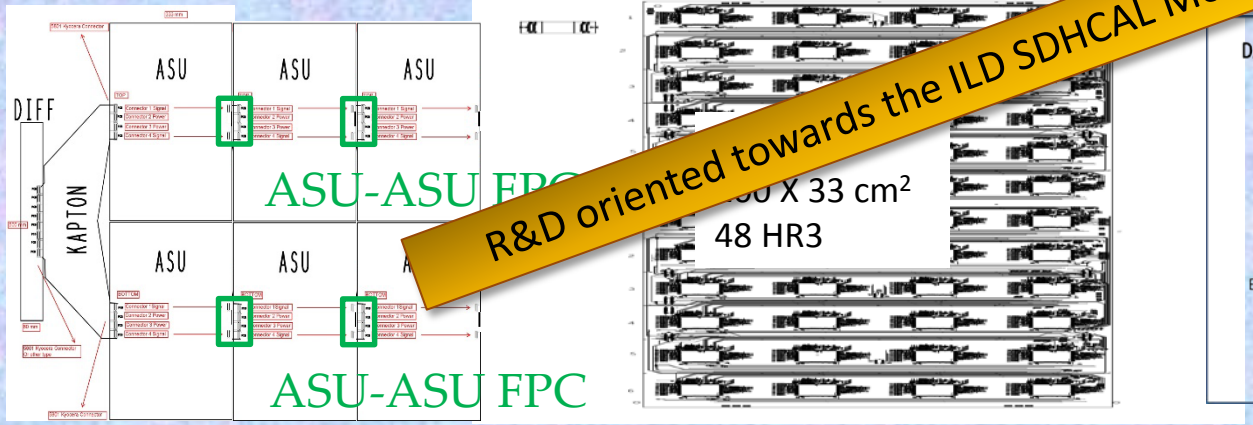
Towards the ILD SDHCAL Module 0: LP with 3rd generation of readout electronics

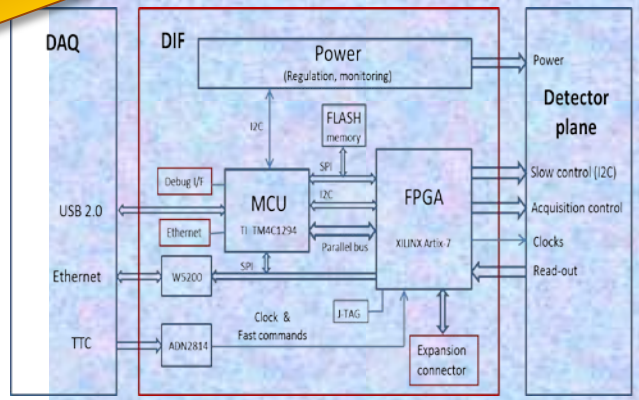
- → 7500 HR3 (zero-suppres., I2C,…) are produced and tested.
- → New ASUs to cover large detectors (> 2m²) are designed and to be produced shortly
- → New acquisition boards are designed and
- → New schemes for large detectors are being tested
- → New mechanical welding process (EBW) are tested

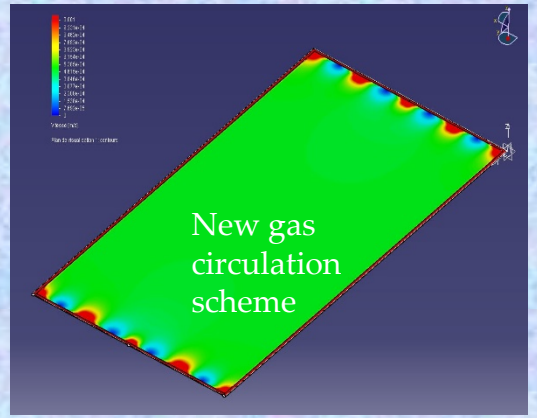


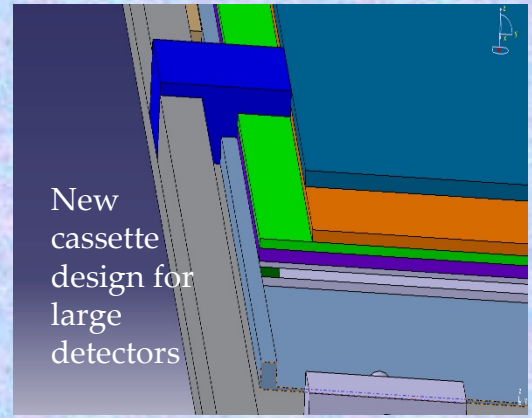


R&D oriented towards the ILD SDHCAL Module 0



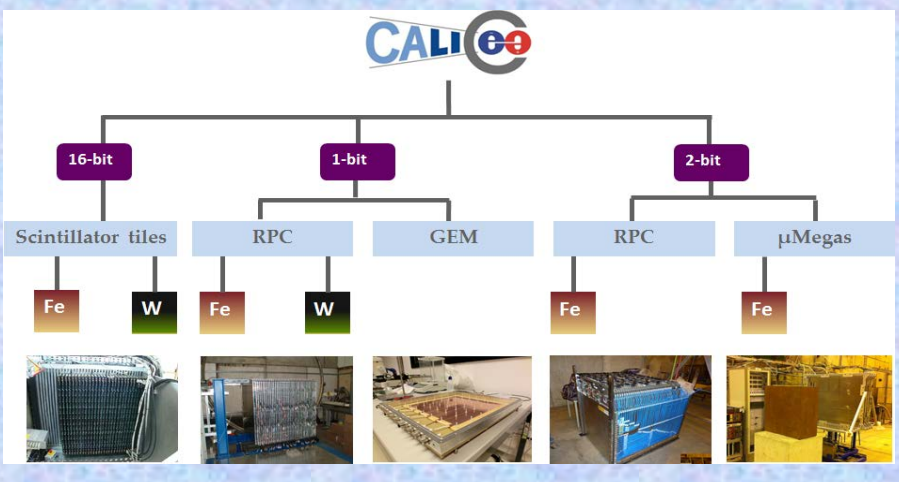






I. Laktineh

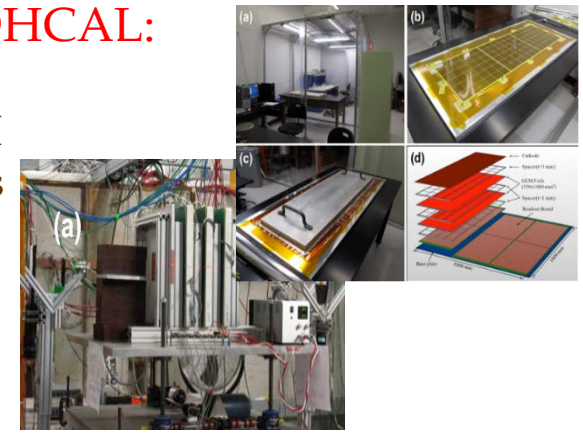
Detector R&D Liaison Report: Other HCAL R&D Efforts



GEM R&D for DHCAL:

Large scale 2GEM (1m x 33cm) layers were constructed

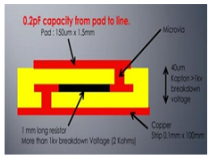
A. White



Micromegas R&D for SDHCAL:

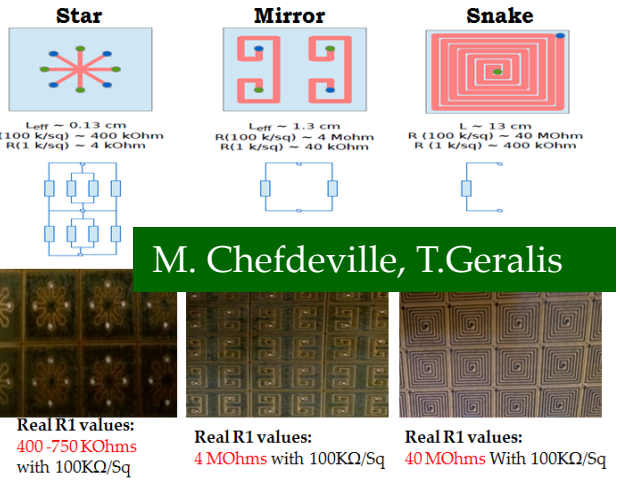
Optimisation:
→ reduce resistivity and evacuation time but still suppress sparking

– "Vertical" evacuation of charge using buried resistors, proposed by Rui de Oliveira



– Ongoing program:
Vary the RC, measure the linearity (rate & dE/dx scans), check sparking

PCB with pads & resistive pattern

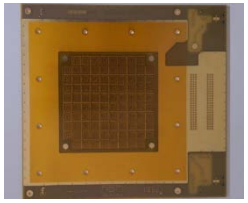


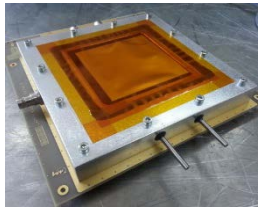
M. Chefdeville, T.Geralis

Real R1 values: 400 -750 KOhms with 100KΩ/Sq

Real R1 values: 4 MOhms with 100KΩ/Sq

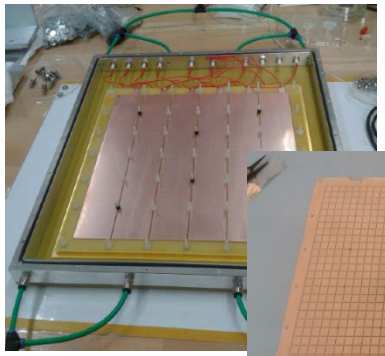
Real R1 values: 40 MOhms With 100KΩ/Sq

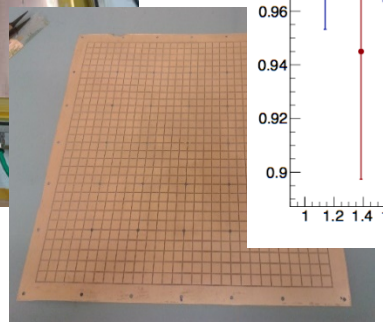


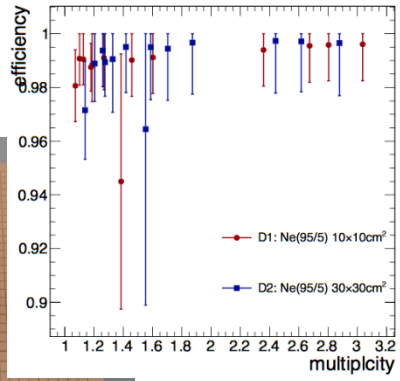


THGEM & RPWELL R&D for DHCAL:

Small (10x10 cm^2) & medium (30x30cm^2) proto:



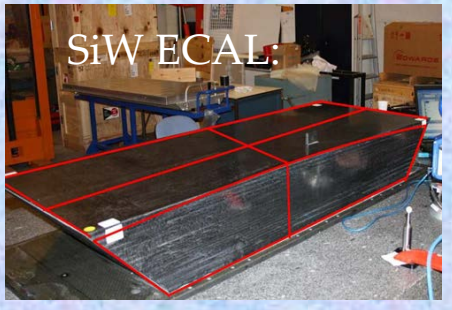


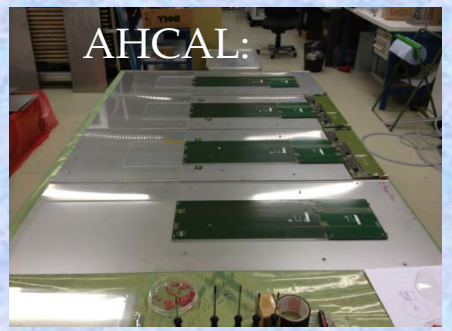


S. Bressler

- RPC R&D for DHCAL (J. Repond)
- Dual-Readout R&D (J. Hauptmann)

Detector R&D Liaison Report: Calorimetry R&D Summary Table

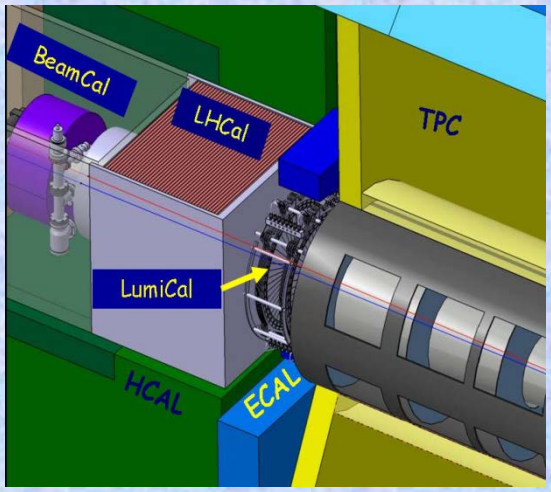


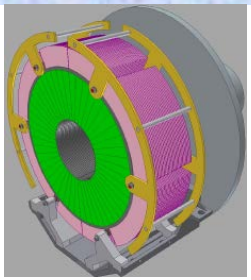


ECAL and HCAL Detector R&D Chapter: ~ 45 pages length

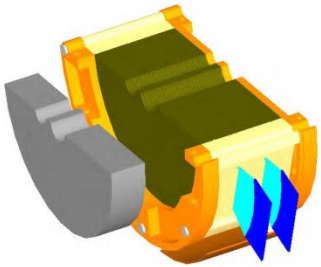
R&D Technology	Participating Institutes	Description / Concept	Milestones	Future Activities
Scintillator ECAL	Nihon Dental University Shinshu University Tokyo University, ICEPP Tsukuba University			
SiliconECAL ILD	LLR / Palaiseau LAL / Orsay LPNHE / Paris University of Tokyo Kyushu University SKKU / Suwon, Korea LPSC / Grenoble OMEGA / Palaiseau	High granularity ECAL ($\approx$ 4000 channels/dm^3). Active sensor: square matrix of about $5 \times 5 [mm^2]$ PIN diode pixels produced from one high resistivity Si wafer. 4 sensors are glued to PCB holding fully integrated readout electronics and passive cooling. Absorber: self-supporting modular tungsten in carbon-fiber structure.	2013–: tests of several layers of technological prototype with one sensor per PCB. 2014–2015: Design, production and first tests of prototypes with 4 sensor PCBs. Sensors are glued to PCB by a robot. Design of a distributed, quality controlled assembly chain of detector elements.	2015– SPS beam tests of a new several layer prototype. Each layer has one PCB with 4 sensors (1024 pixels of 5.5×5.5 mm^2). Documentation of prototype production steps for future industrial mass production. Tests of sensors of various designs / manufacturers. Optimization of DAQ electronics. Design, production and tests of ILD-like detector element with several PCBs connected consecutively and readout from one end.
SiliconECAL SiD				
AHCAL	DESY Hamburg Heidelberg MPI Munich Wuppertal Mainz Omega CERN ITEP MEPHI Dubna Prague NIU Tokyo University, ICEPP Bergen Shinshu	The analog hadron calorimeter is based on small plastic scintillator tiles read out with SiPM. It uses fully integrated electronics with power pulsing, auto-trigger and time-stamping capability.	2014 - multi-layer test beam campaign at CERN with technical prototype electronics, including large-size layers (4 HBUs) 2015 - First beam tests of full HBU with SMD SiPMs fabricated with automated assembly procedure	2015 Test beams at DESY and SPS with >15 HBUs 2016/17 Test beam at SLAC with 15 layer EM stack, powerpulsing & ILC time structure, tests in magnetic field-Further develop SMD SiPM HBUs, explore "mega-tile" options Hadronic beam tests with a prototype with 1 m^3 fully instrumented volume (depends on pending funding request)
DECAL	University of Birmingham (inactive) University of Bristol (inactive) Imperial College London (inactive) Queen Mary, University of London (inactive) Rutherford Appleton Laboratory (inactive)	The digital electronic calorimeter (DECAL) proposes to use monolithic active pixel sensors (MAPS) for the readout of the silicon-tungsten ECAL. The pixels are small enough to count the number of secondary particles of the particle shower, hence the digital calorimeter.	Four TPAC 1.2 sensors were tested at CERN (2009) and DESY (2010). The tests validated the INMAPS process and demonstrated that sensors with a high-resistivity epitaxial layer can meet the required MIP efficiency.	DECAL efforts are currently dormant. The Arachnid collaboration continues some of the work on MAPS chips.
DHCAL (RPC)	Argonne National Laboratory Boston University COE College (Iowa) University of Iowa Shanghai Jiao Tong University – SJTU (in discussion) University of Science and Technology of China – USTC (in discussion)			
SDHCAL (RPC)				
SDHCAL(micromegas)	CALICE (LAPP) CEA Saclay Institute of Nuclear and Particle Physics, Demokritos Weizman	Micromegas is a thin steel micromesh that separates the gas volume in a region of charge conversion and a region of charge multiplication. It is interesting for EM and H calorimetry because its signal is proportional to the the energy deposit in the gas. To avoid discharge upon very large energy deposits, it now incorporates resistive elements on the readout electrodes.	• Study of different resistive configurations to suppress sparking (ANR SPLAM) • Test in e-beam of 3 prototypes with integrated ASIC, show charge-up effect and spark suppression • Systematic study of a resistive configuration for spark suppression and high rate capability • Vary the RC-constant with 6 small prototypes with external electronics • Rate capability and in-beam spark study to determine the optimal RC	• Implement the best resistive configuration on an ASU (with integrated ASIC) • Build several layers, number depending on funding • If sufficient number of layers, build and operate a small calorimeter prototype equipped with resistive Micromegas and possibly also THGEM-based elements. • Full characterization in-beam of Micromegas calorimetry: response, resolution, profiles, multi-threshold compensation, MC validation.
GEM DHCAL	University of Texas, Arlington			
Thick Gems	Weizmann Institute, Rehovot Coimbra University Aveiro University	Cost-effective sampling element based on the a novel concept derived from the Thick gaseous electron multiplier	2014: 10×10 cm^2 discharge free (Ne/CH_4) single stage RPWELL 2015: 30×30 cm^2 discharge free (Ar-based gas mixture)	Early 2016: new design of 30×30 cm^2 detector 2016: 1×1 m^2 prototype 2017- testing RPWELL layer in a fully equipped (S)DHCAL
Dual Readout RD52	Texas Tech University Iowa State University INFN (Pavia, Pisa, Cagliari, Rome, Cosenza, Lecce) LIP Lisbon CERN Tufts University	Measure scintillation and Cerenkov light independently in optical fibers and measure neutron content event-by-event. Current small modules are dominated by lateral leakage.	Twenty-nine papers published in NIM on all aspects of dual readout calorimetry, including crystal dual readout. GEANT (FTFP HP) simulations of a large copper module yield an energy resolution approximately represented by $\sigma/E \approx 30\%/\sqrt{E}$ for pion-induced showers.	Measure the difference between pion-induced and proton-induced hadronic showers; measure the time history of light at 5 GHz. Build a large module 4 ton for final test of hadronic performance.

Forward Calorimetry R&D: FCAL Collaboration





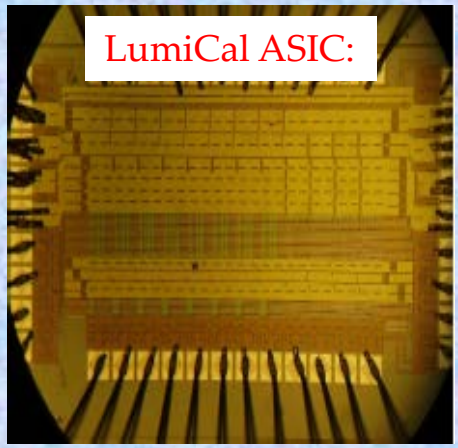
LumiCal:
→ precise luminosity measurement
10^{-3} - 500 GeV @ ILC
10^{-2} - 3 TeV @ CLIC

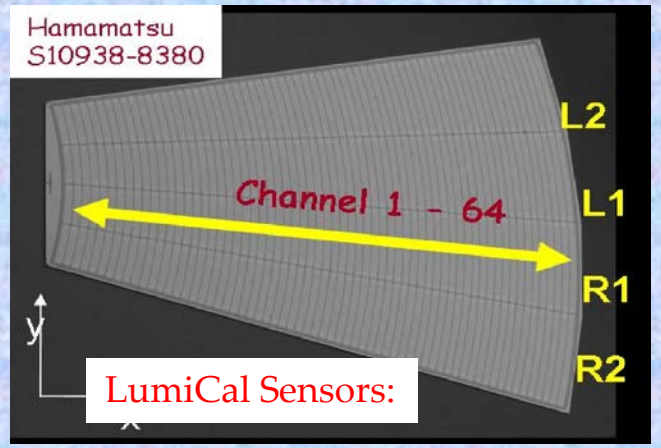


BeamCal:
→ inst. lumi measurement / beam tuning, beam diagnostics

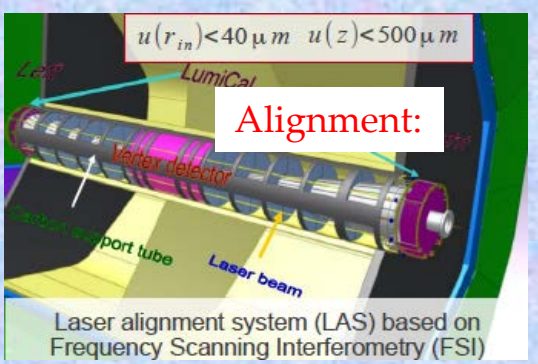
LumiCal: Two Si-W sandwich EM calo at a ~ 2.5 m from the IP (both sides)
30 / 40 (ILC/CLIC) tungsten disks of 3.5 mm thickness
BeamCal: very high radiation load (up to 1MGy/ year) → similar W-absorber, but radiation hard sensors (GaAs, CVD diamond)

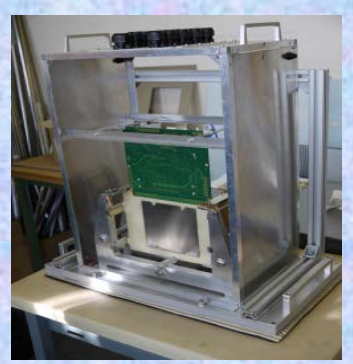
BeamCal Sensors





- Unique contributions to the ILC DBD, the CLIC CDR, and to the detector concepts ILD and SiD
- Successful prototyping and test of major components in the beam → final preparation of a 'large testbeam paper' (2010 - 2012 results) → the performance of fully assembled sensor planes matches the requirements



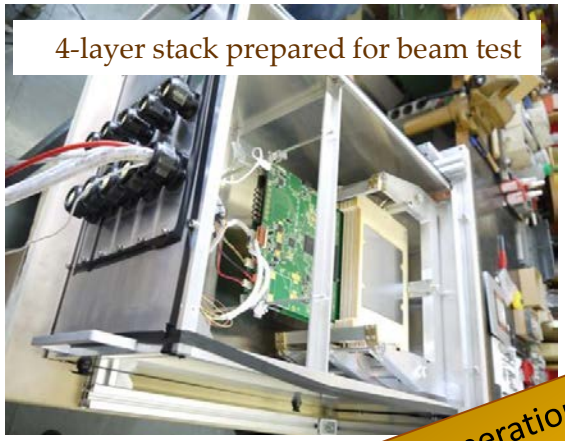


FCAL R&D: Ongoing Activities

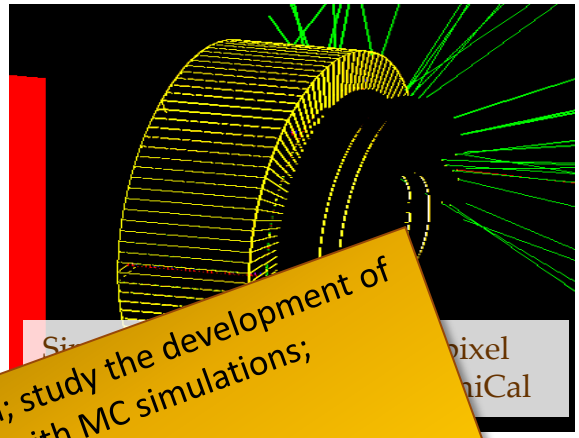
W. Lohmann

Test-beam (October 2014) at CERN:

- Four sensor layers assembled with ASICs in a 10 GeV mixed beam
- Acquire expertise to operate a multi-layer structure
- Data-MC comparison



4-layer stack prepared for beam test



Si… …ixel …iCal

- 2014: Demonstrated multi-plane operation; study the development of the electromagnetic shower and compare with MC simulations;
- Response to different tagged particles investigated
- Test-beam results published: arXiv: 1604.00276

Radiation hardness test bench at SLAC

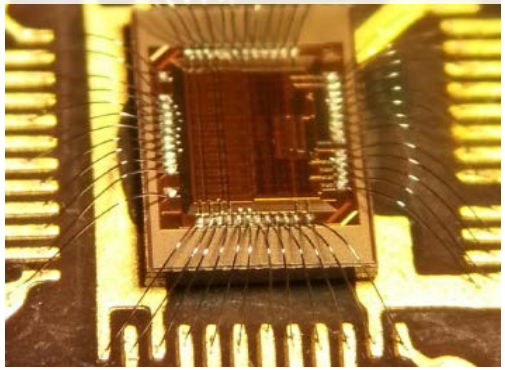
Sensor R&D:

- … position
- …duce dead areas)
- …tudies in a 'realistic' environment (T506 at SLAC)
- …GaAs sensors

ASIC development (130 nm CMOS):

- 8 channel FE ASIC, dual gain, low power consumption; 8 channel SAR ADC
- Prototypes of both ASICs are tested and match the specification
- Power pulsing implemented
- Next step will be to enhance the number of channels per chip, integrate in a readout board

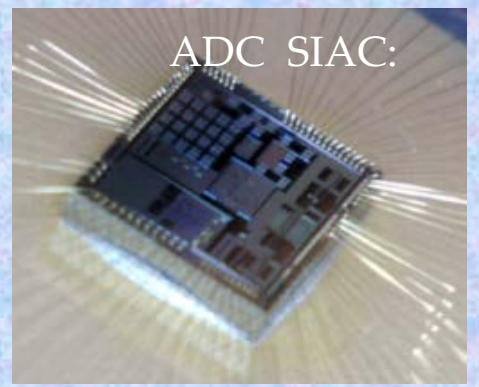
8 channel FE ASIC in the test bench

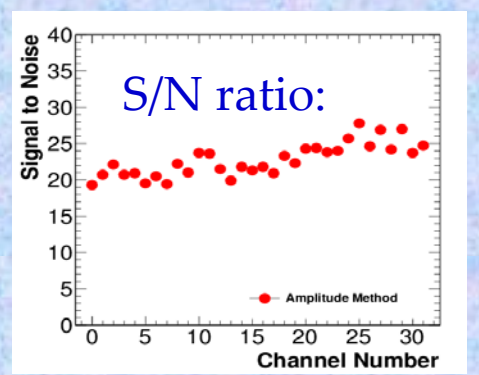


Detector R&D Liaison Report: FCAL R&D Summary Table

FCAL Detector R&D Chapter: ~ 15 pages length

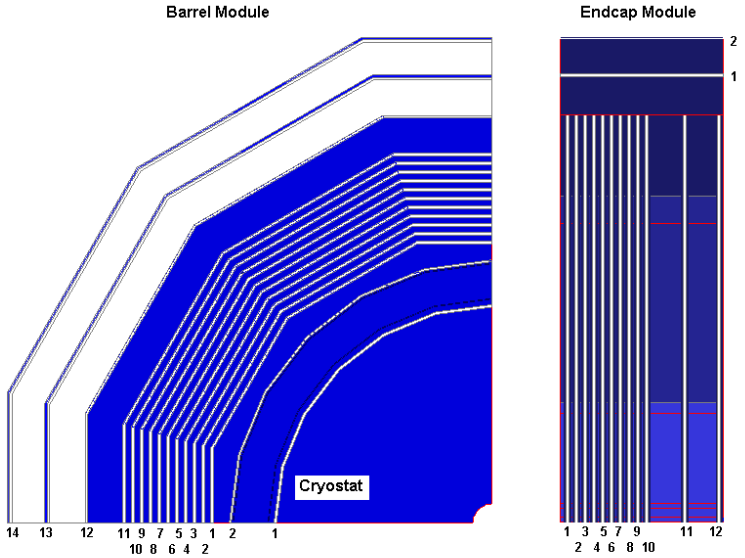
R&D Technology	Participating Institutes	Description / Concept	Milestones	Future Activities
LumiCal SiW Sandwich EM calorimetry	AGH-University of Science and Technology, Cracow, Poland	FE and ADC ASIC development in 130 nm CMOS technology, integration and data analysis	submission December 2015	Performance measurements, test-beam preparation
	CERN, Geneva, Switzerland	Mechanics frame, simulations for design optimization	test-beam infrastructure	
	DESY, Zeuthen, Germany	sensor qualification, connectivity scheme, integration, test-beam infrastucture, simulations	prototype of a thin fan-out 2016	conceptual design studies
	IFIN-HH, Bukharest, Romania	Data analysis and simulation		
BeamCal GaAs on CVD diamond tungsten calorimeter	IFJPAN, Cracow, Poland	laser based position monitoring, physics performance studies		FPGA programming for DAQ system, semi-transparent sensor studies
	ISS Bukharest, Romania	Data handling and analysis		
	JINR Dubna, Russia	GaAs sensor production and qualification, absorber plate production and qualification	delivery of absorber plate prototypes 2016	
	NCPHEP Minsk, Belarus	test-beam preparation, diamond sensor studies		
	Pontificia Universidad Catolica de Chile, Santiago, Chile	FE and ADC ASIC development in 180 nm TSMC technology	prototype performance results 2017	
	Tel Aviv University, Tel Aviv, Israel	sensor qualification, assembly of detector planes, data analysis and simulations	sensor plane prototype end 2015	
	Tohoku University Sendai, Japan	pixel sensor in SoI technology	prototype 2017	
	University of Colorado Boulder, USA	simulations		
	University of California Santa Cruz, USA	radiation hardness studies for silicon and GaAs sensors		
	VINCA Institute of Nuclear Science & University of Belgrade, Belgrade, Serbia	data analysis, simulations, physics performance studies		Test-beam measurements and data analysis





ILD Muon System / Tail Catcher System

V. Saveliev



Main Tasks:

- Efficient Identification of Muons
- Measurement of the Energy Leakage from Hadron Calorimeter (especially if HCAl inside the magnet)

Historical aspects:

- 2000: Muon System R&D started since TESLA proposal CALICE HCAL groups involved in Muon system R&D; some test-beams are common
- 2006: more active R&D, US groups joined; development of special facility (Fermilab) for the scintillator strip with embedded WLS production

Instrumentation of ILD Muon/Tail Catcher System

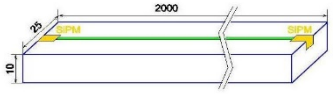
Main option – Scintillation strips with WLS and SiPM readout

Barrel: 11stereo Layer, absorber 10 cm (Tail Catcher Function) + 3 stereo Layers, absorber 60 cm

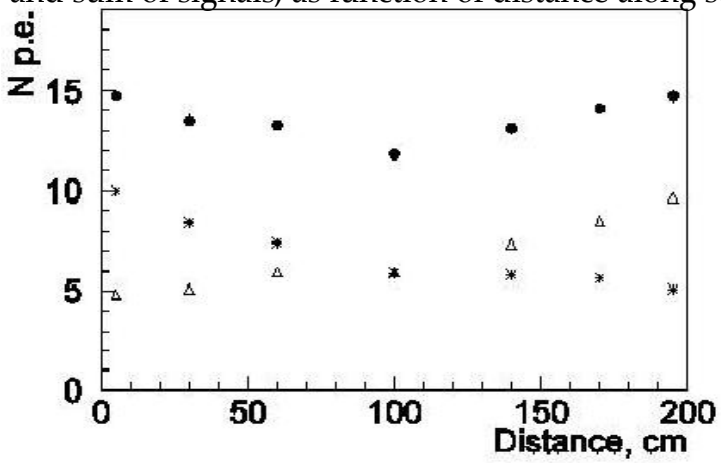
Endcap: 10 stereo Layers, absorber 10 cm,
+ 2 stereo Layers, absorber 60 cm

Detection Element :

Scintillation Strip with WLS and SiPMs on both side

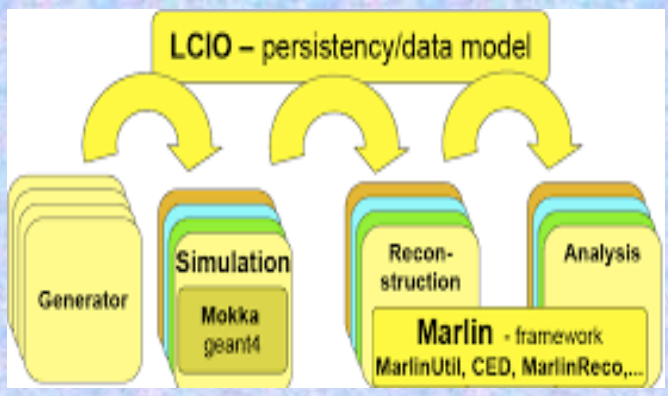


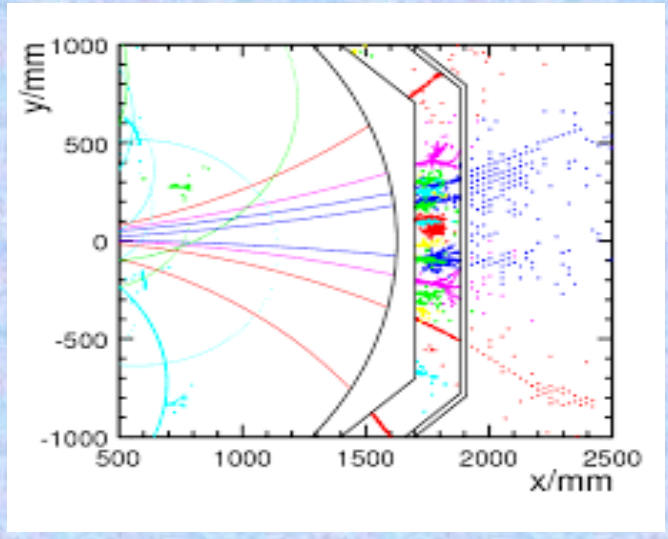
Number of photons detected from both side by SiPMs and sum of signals, as function of distance along strip

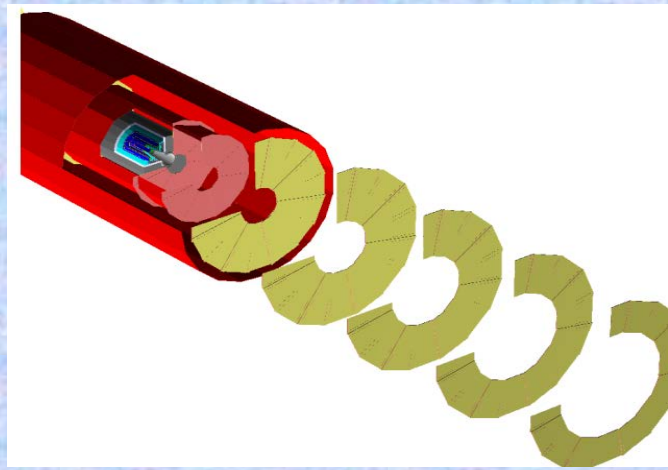


Common Linear Collider Software

- LCIO: Common event data model,
  → allows easy exchange of tools
- LCSIM: provides a toolkit to study multiple detector designs for ILC
- DD4HEP: Comprehensive suite of simulation and reconstruction tools
  → Replaces Mokka
- Mokka: Framework for all ILD and CLIC-dp detector versions, since 1999





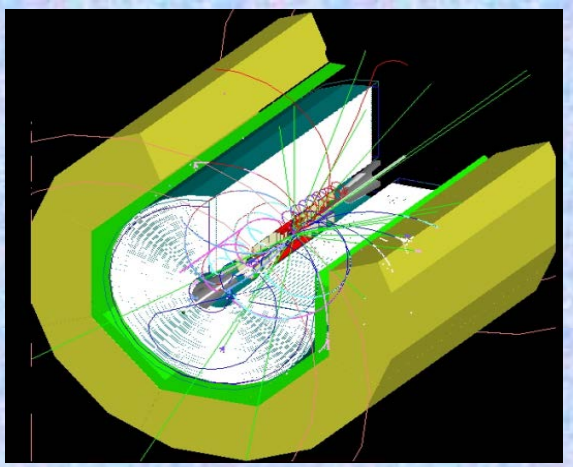


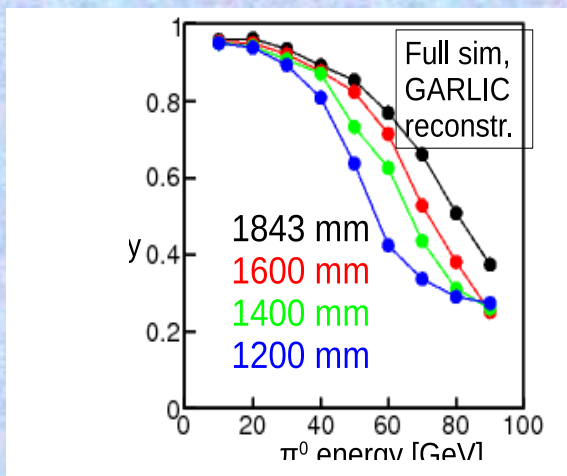
Common Linear Collider Software

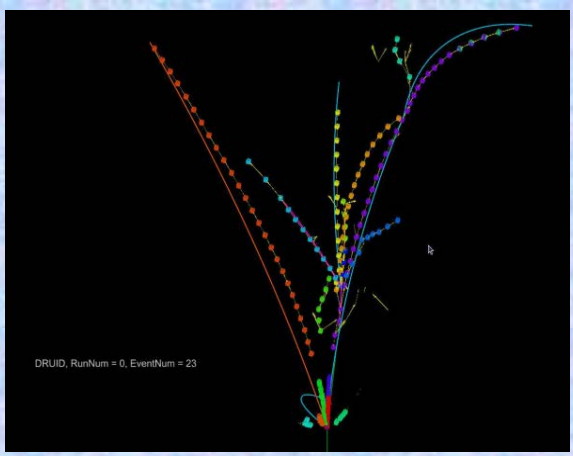
- MARLIN: C++ application framework for processing LCIO data files

Advanced Reconstruction Algorithms for Highly Granular Calorimeters:

- PandoraPFA (Cambridge, CERN): PFA event reconstruction
- GARLIC: Dedicated reconstruction for photons
- Arbor: Particle Flow reconstruction based on branching structure of particle showers
- LCFIPlus: vertex reconstruction / flavor tagging





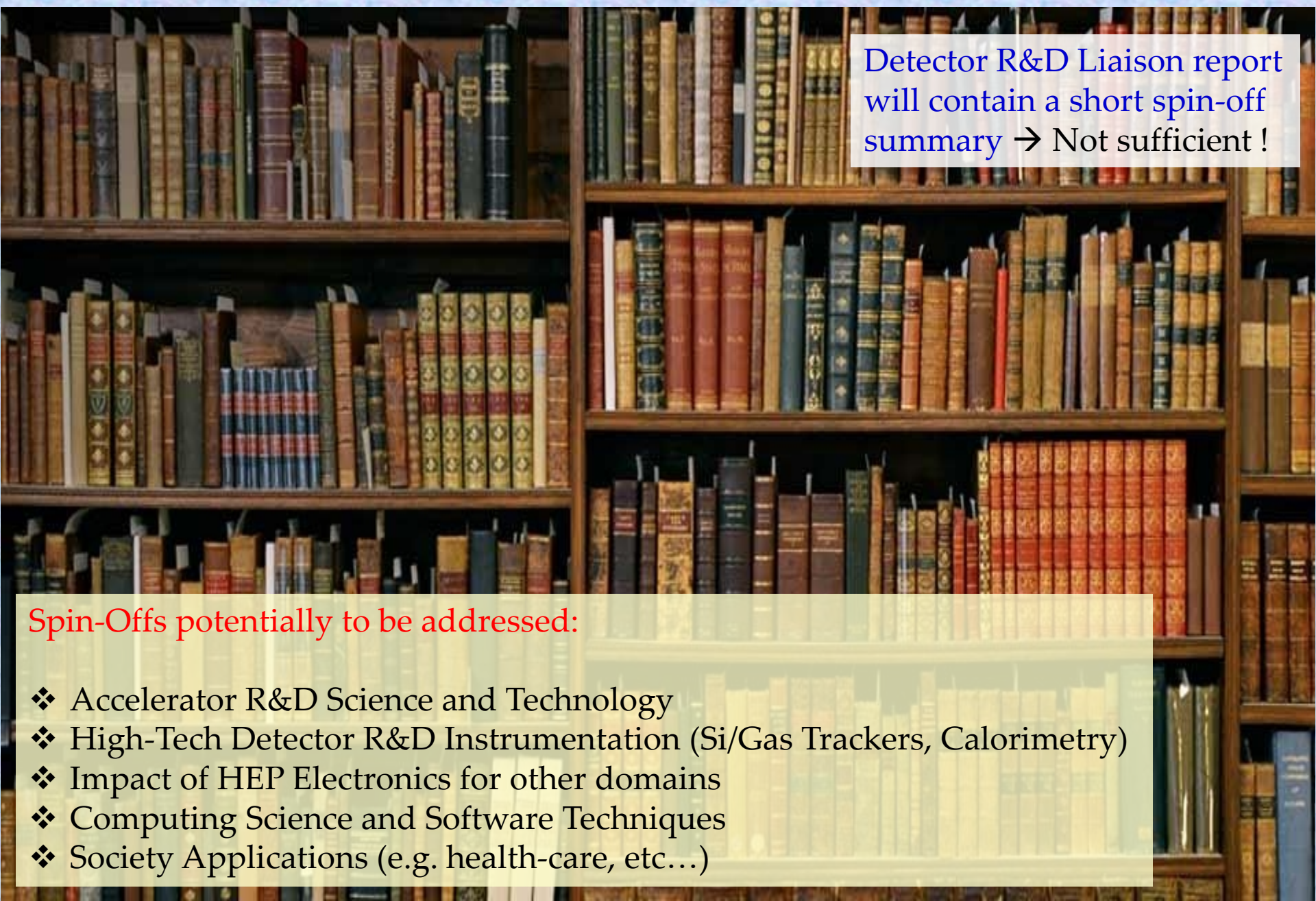


Detector R&D Liaison Report: Software Summary Table

Common Linear Collider Software Chapter: ~ 10 pages length

Technology	Institutes	Description / Concept	Milestones	Future Activities
LCIO	SLAC DESY	Event data model (EDM) and persistency format		
LCSim	SLAC	Physics and detector response simulation and event reconstruction toolkit		
DD4HEP	CERN	Detector description, including geometry, materials, visualization, readout, alignment and calibration.		
Marlin	DESY	C++ application framework for processing LCIO event data files.		Parallelization and adaptation to multi-core hardware
PandoraPFA	Cambridge	Particle Flow reconstruction package, consisting of a software development kit and reconstruction libraries		- improvement of π^0 reconstruction - improve the ability to identify and separate neutral hadrons from nearby charged hadrons.
LCFIPlus	Kyushu Tokyo PNNL	Vertex reconstruction, jet clustering, and flavor tagging toolkit	Development of a vertex-aware jet finder Efficient flavor tagging in 6-jet events	Improvements to vertex reconstruction Addition of particle ID to flavor tagging Better integration with geometry description
Arbor Garlic ILCDIRAC Mokka				

Some thoughts about ILC Spin-Offs: How it could be seen by the Community



Detector R&D Liaison report will contain a short spin-off summary → Not sufficient !

Spin-Offs potentially to be addressed:

- Accelerator R&D Science and Technology
- High-Tech Detector R&D Instrumentation (Si/Gas Trackers, Calorimetry)
- Impact of HEP Electronics for other domains
- Computing Science and Software Techniques
- Society Applications (e.g. health-care, etc…)

ILC Detector R&D Spin-Offs: Its Impact

ILC Detector R&D: Its Impact

2011:

September 2011

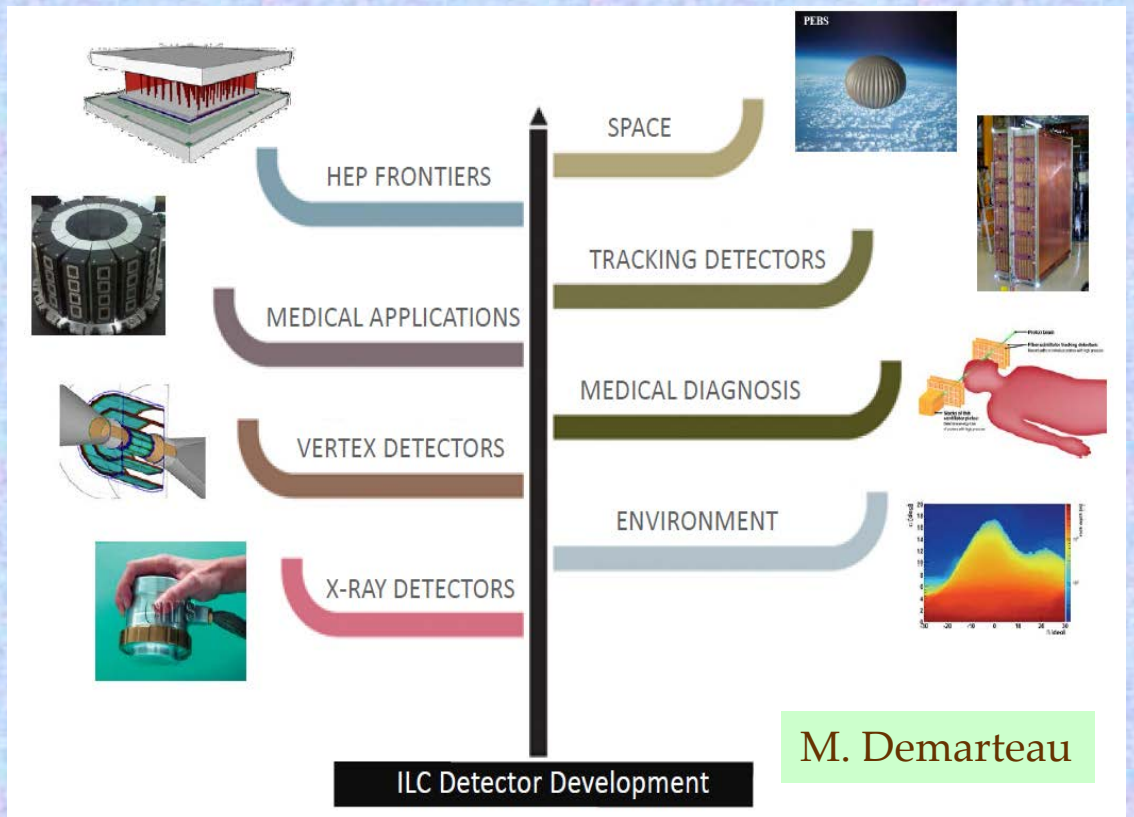
ILC Research Directorate

Director: Sakue Yamada

Prepared by the Common Task Group for Detector R&D

Dhiman Chakraborty, Marcel Demarteau (convenor), John Hauptman, Ron Lipton, Wolfgang Lohmann, Tim Nelson, Aurore Savoy-Navarro, Felix Sefkow, Burkhard Schmidt, Tohru Takeshita, Jan Timmermans, Andy White, Marc Winter

Most of ILC Detector R&D Spin-Offs is in HEP Domain:

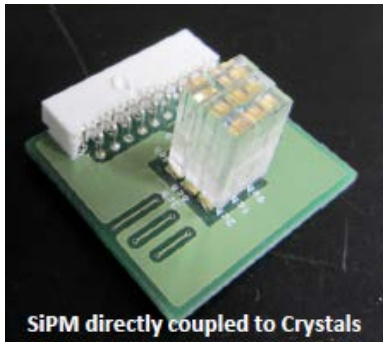


M. Demarteau

… Outside High Energy Physics:

Prototype for PET Applications:

3x3 array of LYSO crystals with SiPMs (300 ps time resolution):



TRECAM (Tumor Resection CAMera): miniaturized gamma-camera for breast cancer surgery

49 x 49 mm^2 field of view $LaBr_3$:Ce crystal optically coupled to a multi-anode photomultiplier tube

Linear Collider Event at the 2012 IEEE NSS/MIC:

Institute of Electrical and Electronics Engineers

2012 IEEE NSS/MIC/RTSD Anaheim, California

27 October - 3 November 2012

Special Linear Collider Event
29-30 October 2012

As part of the NSS Symposium, a special Linear Collider (LC) event is organized, which will include presentations on:

- > International Linear Collider (ILC) and the Compact Linear Collider (CLIC) accelerator
- > Detector concepts
- > Impact of LC technologies for industrial applications
- > Forum discussion about LC perspectives

James Brau, University of Oregon, USA
Juan Fuster, IFIC Valencia, Spain
Michael Harrison, BNL, USA
Steinar Stapnes, CERN, Switzerland
Hitoshi Yamamoto, Tohoku University, Japan
Maxim Titov, IRFU/CEA Saclay, France (ex officio)
Ingrid-Maria Gregor, DESY Hamburg, Germany (ex officio)

More information: www.nss-mic.org/2012
Contact: nss2012@desy.de

clic ilc IEEE NUCLEAR & PLASMA SCIENCES SOCIETY

- AAA talk (Mr. Matsuoka)
- Forum discussion with participation of CERN, DESY, FNAL, KEK directors

ILC Detector R&D Spin-Offs:

LC3-5 (09:30, invited): Summary of the Spin-off Document "ILC Detector R&D: its Impact"
M. Demarteau, *Argonne National Laboratory, Argonne, USA*
Although the actual construction date of the ILC accelerator and its detectors is uncerta… deep impact of … tector community on the particle physics community and beyond will be discussed.

LC4: ILC/CLIC Detector Spin-offs and ILC/CLIC Accelerator Instrumentation

Tuesday, Oct. 30, 10:30-12:30, Grand Ballroom South AB

LC4-1 (10:30 … ILC Imaging Calorimeter to a PET Detect…

…CLIC Accelerator Technologies for …L Applications I

…14:00-16:05, Grand Ballroom South AB

…invited): Opportunities for Applications of LC …ology (Institutional Perspective)
M. C. Ross, *SLAC National Accelerator Laboratory, Palo Alto, CA, USA*
Particle accelerators are widely perceived as tools for mankind in the service of science. The next generation will see applications of accelerators broadly expanded and adapted for use in service to society. This transition has been enabled by an era of work to extend the frontiers of technology in terms of per… has… the… ma… tec… ger… in … high energy physics community to develop the International Linear Collider an unprecedented degree of global focus and participation allowed this investment in, for example, superconducting RF technology and precision beam control. As we now move forward to realize the linear collider, it is time to consider the ROI, especially toward industrial applications. In this talk we will review this remarkable era and consider the next steps to be taken toward applying what has been learned.

…overview i… research.

LC4-2 (11:00, inv…
C. De La Taille, *Il…*
Detectors designe… feature unpreceden… the "image" of sho…

LC Accelerator Technologies for Industrial, Medical, Energy and Security Applications

LC5-2 (14:25, invited): Overview of Industrial, Medical, Energy and Security Related Accelerator Use (Industry Perspective)
N. Holtkamp, *SLAC National Accelerator Laboratory, USA*

Next Generation of Particle Accelerators

Development of high intensity particle beams:

- Ordinary: electrons, protons, X-Ray
- Specific: positrons, neutrons, ions, ...
- Energy sector, power-savings issues

Develop new generation acceleration technics:

- klystrons = energy sources
- Super-conducting accelerating cavities
- Higher accelerating gradients (plasma)

Particle Accelerators

Develop particle transport systems:

- vacuum systems
- magnetic elements: dipoles, sextupoles, ...

Develop particle beam focusing systems:

- SC quadruples
- Damping ring
- nm -cale beams

Develop beam control systems:

- non-destructive beam diagnosis
- fast high-precision feedback / correction

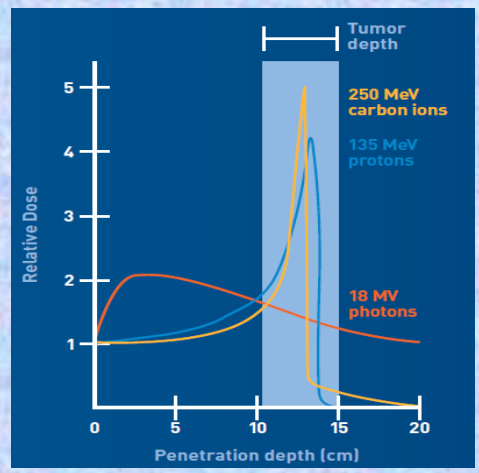
Accelerators are Essential Tools for Medical Treatment and Diagnosis

Radioisotope production

→ New high power accelerators benefit dramatically from SRF technology

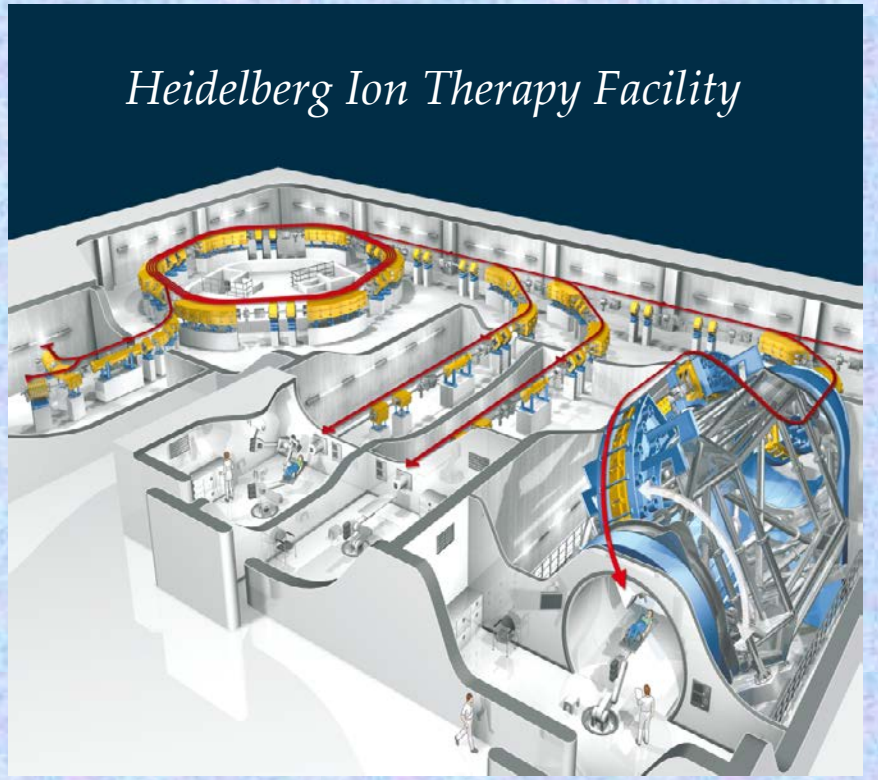
Beam (proton/light ion) therapy

→ Higher biological dose effectiveness
→ Superior dose distributions



Proton and Hadron therapy:

Future Directions & Current Trends



Modern particle-beam facilities incorporate very sophisticated delivery systems to carefully tailor the beam distribution by scanning, depth modulation, and gantry systems

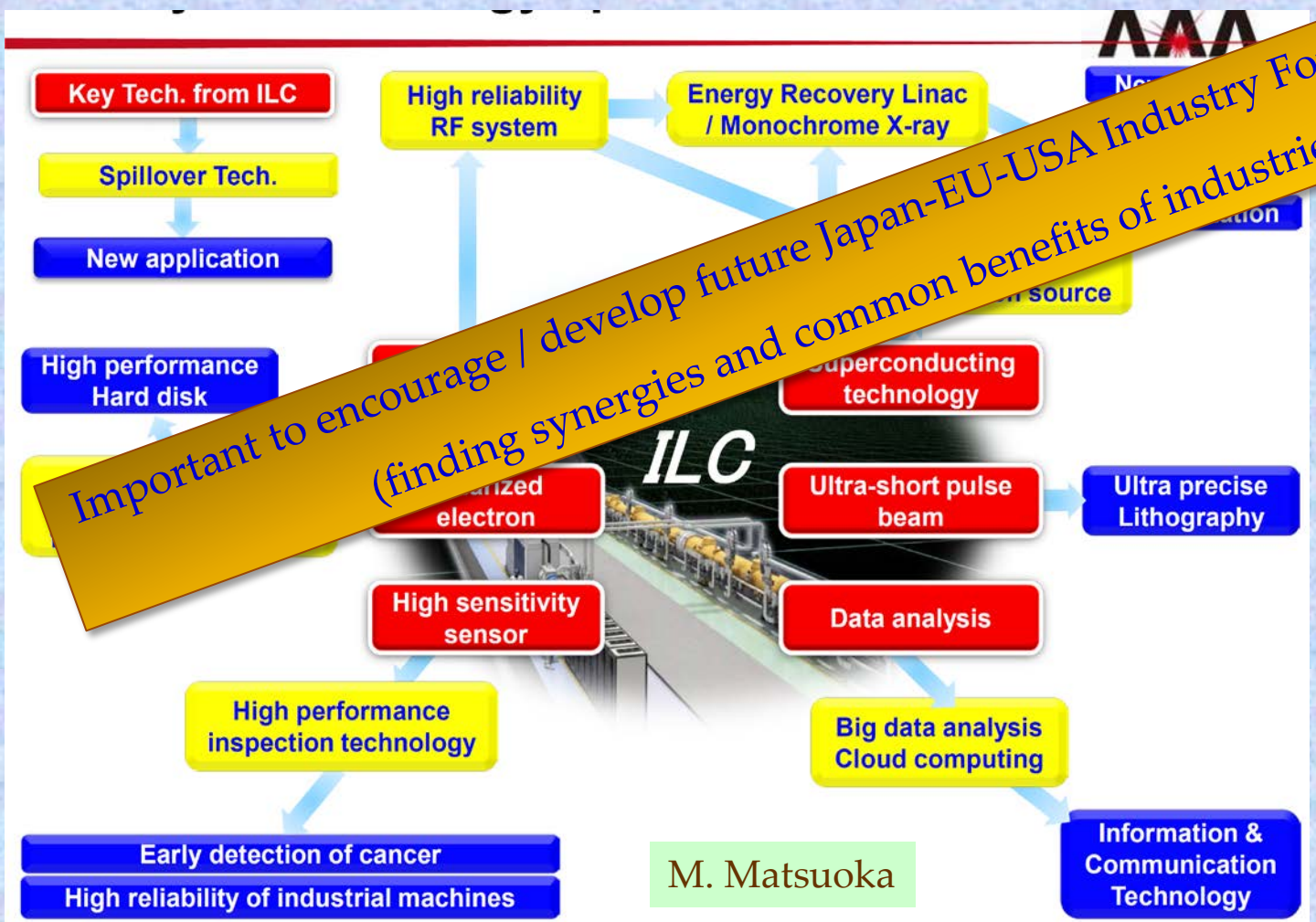
→ e.g. in-beam PET for quality assurance of hadron therapy treatments (tumor control)

→ Imaging calorimeters for proton CT (range uncertainty, tumor shrinkage)

This field will benefit from R&D into compact accelerator systems

Study of Technology Spill-Over Effect of the ILC:

Since 2008: The Advanced Accelerator Association Promoting Science & Technology (AAA) in Japan → originally 76 companies/institutes, nowadays - 14



Important to encourage / develop future Japan-EU-USA Industry Forums on ILC

(finding synergies and common benefits of industries)

- Technology Study Group
- ➢ Outreach Group
- ➢ Civil Group
- ➢ Large Project Study Group

to facilitate Industry – Government – Academia Cooperation

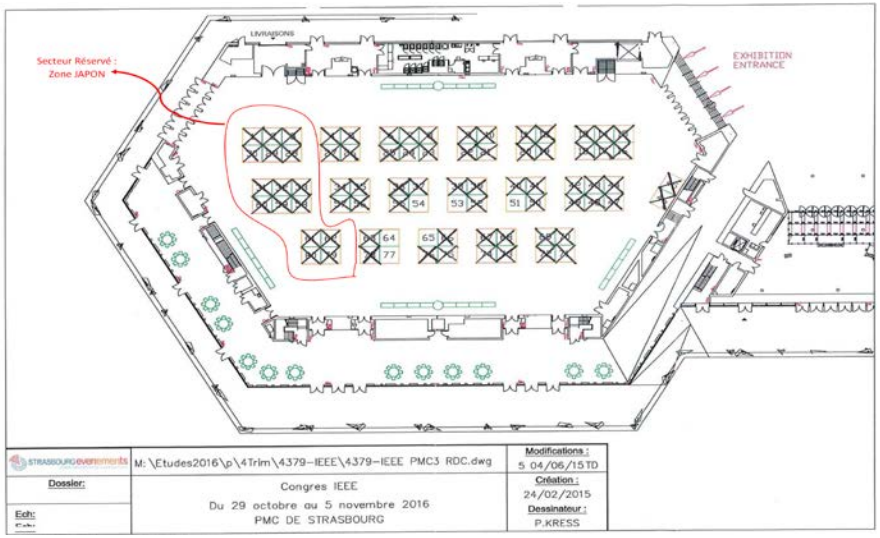
As part of ECFA2016 on June 1, 2016: Japanese-Spanish Industrial Forum on Accelerator Technologies and Advanced Detector Instrumentation

The 2016 IEEE NSS/MIC Symposium in Strasbourg: Industrial Exhibition

Accelerator R&D Domain* ← Technology Spin-offs → Detector R&D domain

* Not MAJOR TOPIC for IEEE NSS/ MIC/RTSD

AAA participation in the IEEE Exhibition:



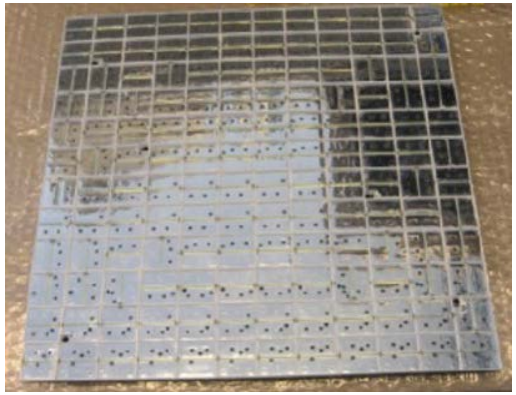
- Accelerator-based technologies for medical physics and hadron therapy
- Energy-related issues for large infrastructures (e.g. power savings, …)

- Nuclear Medical imaging; beam diagnostics/treatment (position/doses)
- Advanced safety/control systems for large infrastructures and equipment (e.g. nuclear plants, FEL, etc. …)

From SiPM-based ILC Imaging Calorimeter to Advanced PET Systems

2006: CALICE-AHCAL(8k ch.):

First large experience with SiPM operation (2006):



Today's PET imaging platforms using SiPMs:

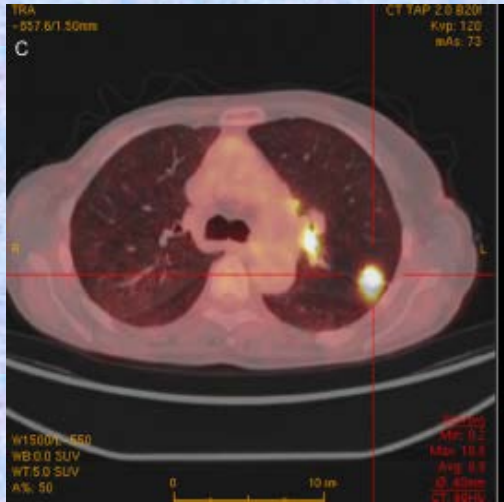
- GE clinical PET/MR uses analog SiPM
- VEREOS Philips PET/CT uses digital SiPM

Multi-channels arrays of crystals + SIPM:

- minimum dead material between crystals
- SiPM packaging is crucial →up to 50% sensitivity improvement
- Monolithic arrays/high density of chan.

SiPMs represent today the future of Nuclear Medical Imaging → the only slowing down factor at the moment being the high associated cost.

A muli-modality approach (PET/CT,PET/MR) will be more and more requested in the clinical practice.



ILC CMOS-based Sensors for Science and Industry

CMOS sensors expected to provide an attractive trade-off between granularity, material budget, radiation tolerance, speed and power dissipation

Sub-atomic Physics:

- BT (EUDET, AIDA),
- Vertex det. (STAR, ALICE)

- X-Ray imaging lights sources equipment (SOLEIL)
- Industrial quality control (soldering, micro-cracks)

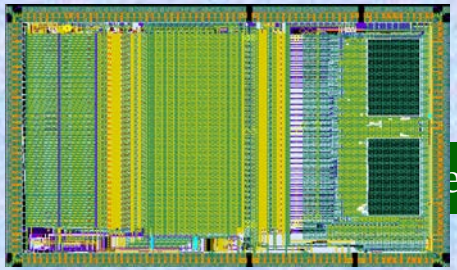
- β-Ray imagers: molecular biology, nano-science
- Mass Spectroscopy (PIMMS)

Art: C. Monet, Nymphéas et Pont Japonais

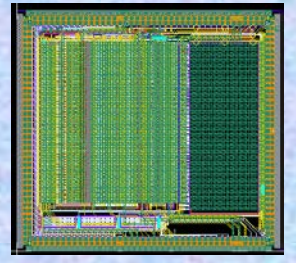
Impact of Electronics (e.g. OMEGA Chips) for Other Domains

Production Runs in 2010 - 2016

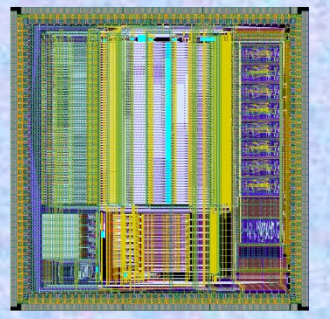
SPIROC2
AHCAL SiPM
36 ch 30 mm²



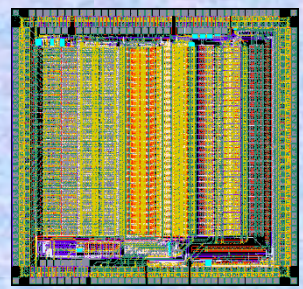
HARDROC2
SDHCAL RPC
64 ch 16 mm²



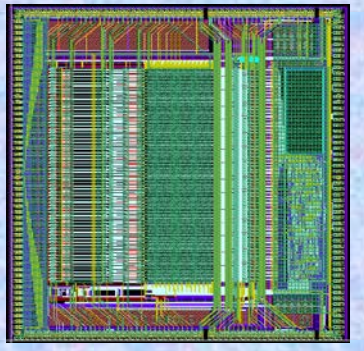
SPACIROC
PMT readout
JEM-EUSO



EASIROC
SiPM readout
PEBS, HN,

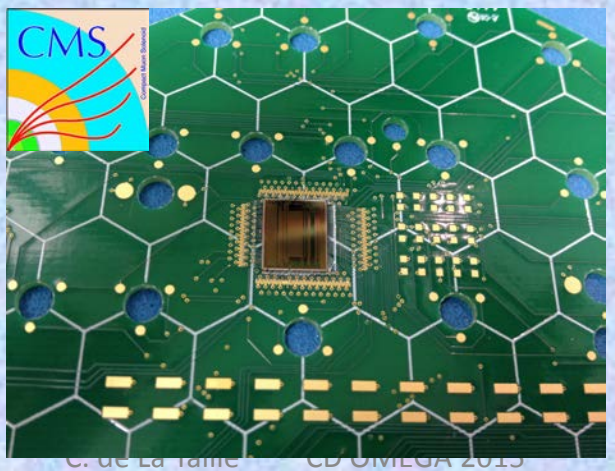


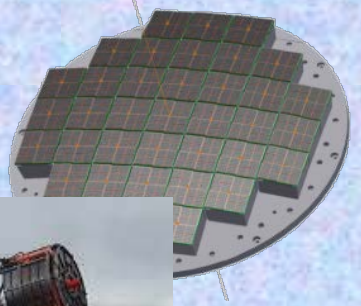
SKIROC2
ECAL Si
64 ch. 70 mm²

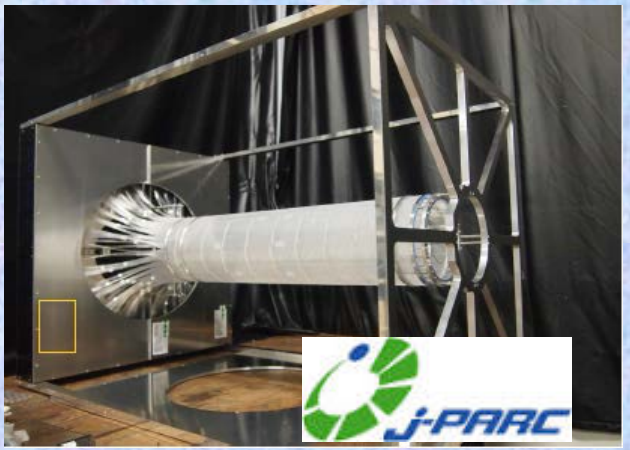


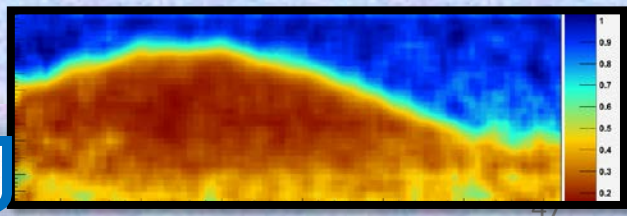
Re-used by many experiments outside ILC : (partly in collaboration with SIEMENS)

EASIROC → muon tomography and nuclear physics
CITIROC → CTA small telescopes
HARDROC → Medical Application (TRECAM)









Summary and Outlook

- Linear Collider R&D remains a very active field
  → synergies exists with other projects HL-LHC, STAR, ALICE, Belle2, …
  → important to keep an eye on new technologies, since the existing designs were started a long time ago

- All contributions to the Detector R&D Liaison Report received → editing is nearly completed → to be sent to the different R&Ds groups

- The Impact of the ILC Accelerator and Detector R&D Program is continuously increasing and impacting society in-depth:

  → might be useful to have an update of Spin-Off Document in the future
  → communicate between groups on specific ILC Spin-Offs applications