R&D for LC detector

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LLR

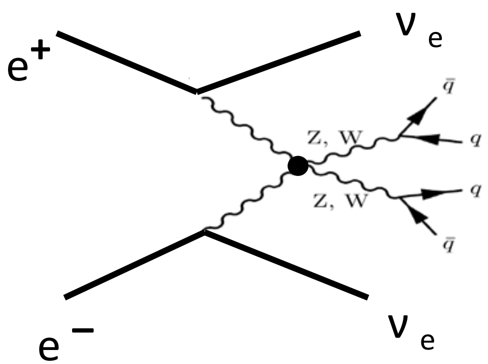
OUTLINE

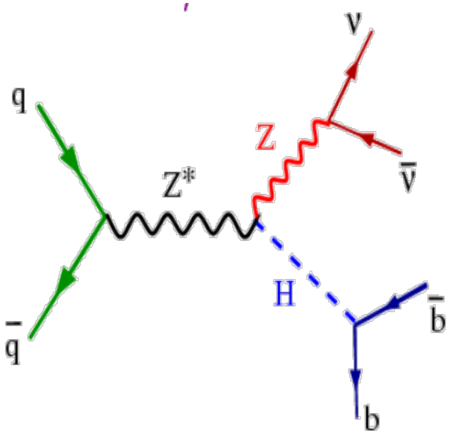
1. Starting from physics
2. PFA in one word
3. Which devices for a “PFA” detector
4. R&D and concepts
5. Tagging vertex
6. Tracks reconstruction
7. Neutrals reconstruction
8. Luminosity measurement
9. conclusion

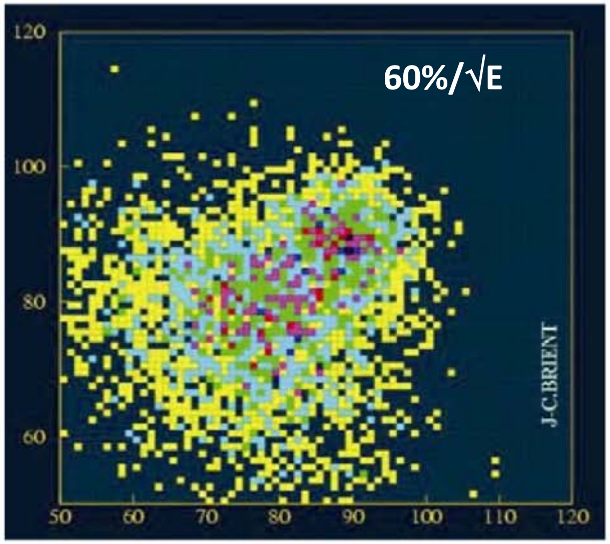
Final states in e+e- interaction up to 1 TeV c.m.s

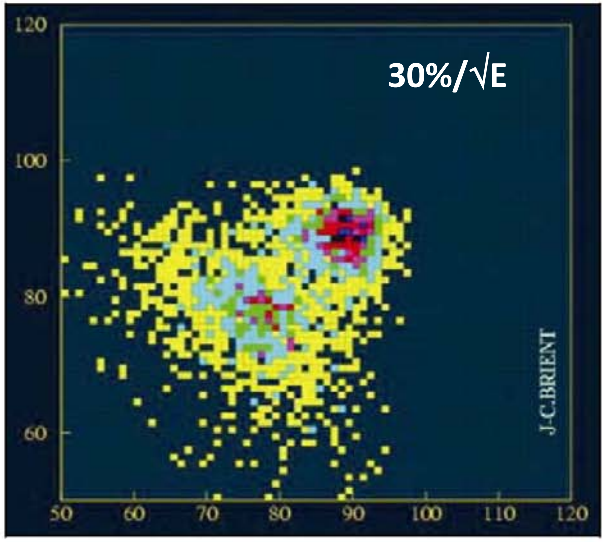
Multi bosons	Multifermions + Boson(s)
ZH	e^+e^- H , e+e− Z
WW	νν H , νν Z
ZZ	ttH
ZHH	e ν W
ZZZ	νν WW, νν ZZ
ZWW	ttbar

Examples of no kin . fit









Disentangle Z,W,H in jets

Detector concepts and tracker R&D

Recommended by IDAG

	ILD	SID
LC-TPC	X	
SILC	X	X
VDET	X	X

PFA based design

Detector Concepts and Calorimeter R&D

Recommended by IDAG	ILD	SiD	4th concept
CALICE Calorimeter for ILC	X	X	
DREAM (**SLAC, UoOregon**, ...)			X
SiD Ecal Group		X	

PFA based design

PFA ??

PFA : « Particle Flow » Algorithm

In our detectors, the charged tracks are better measured than photon(s) which are themselves better measured than neutral hadron(s)

Resolution on the charged track(s)	$\Delta p/p$	$\sim$ qq 10^{-5}
Resolution on the photon(s)	$\Delta E/E$	$\sim 12\%$
Resolution on the h°	$\Delta E/E$	$\sim 45\%$

$$E_{jet} = E_{\text{charged tracks}} + E_{\gamma} + E_{h^0}$$

fraction: 65% (charged tracks), 26% (γ), 9% (h^0)

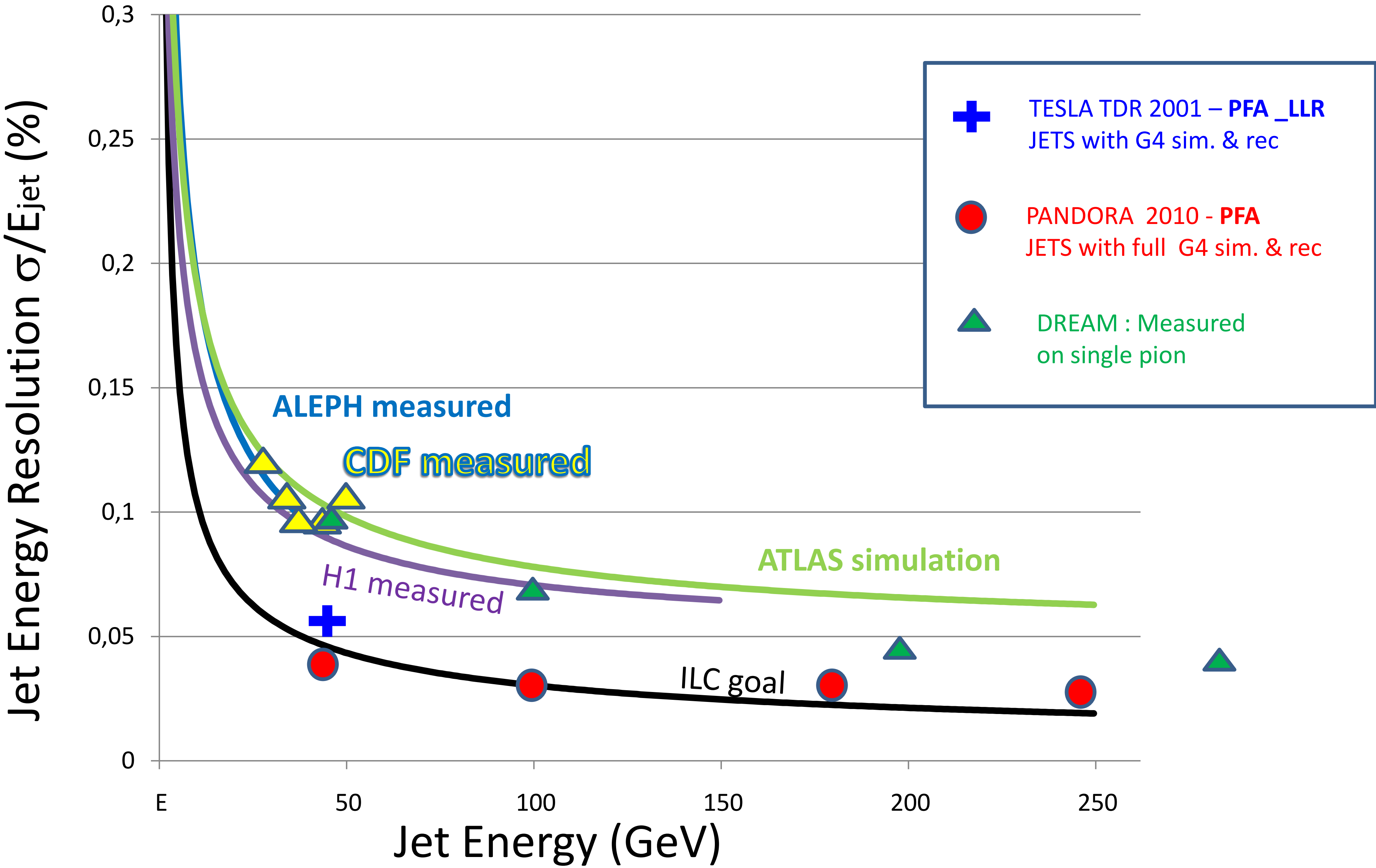
With a perfect detector, no confusion between species and individual reconstruction

$$\sigma^2\,\text{jet} = \sigma^2\text{ch.} + \sigma^2\,\gamma + \sigma^2\,h^0 \quad \text{gives about} \quad (0.14)^2\,E_{jet}$$

Real life and real detector $\Rightarrow$

- σ^2threshold → Energy threshold to be rec. (depends on species)
- σ^2efficiency → loss of particles (not reconstructed)
- σ^2confusion → Mixing between particles in the calorimeter

Jet energy resolution



Events rec. and PFA recommendations are the following:

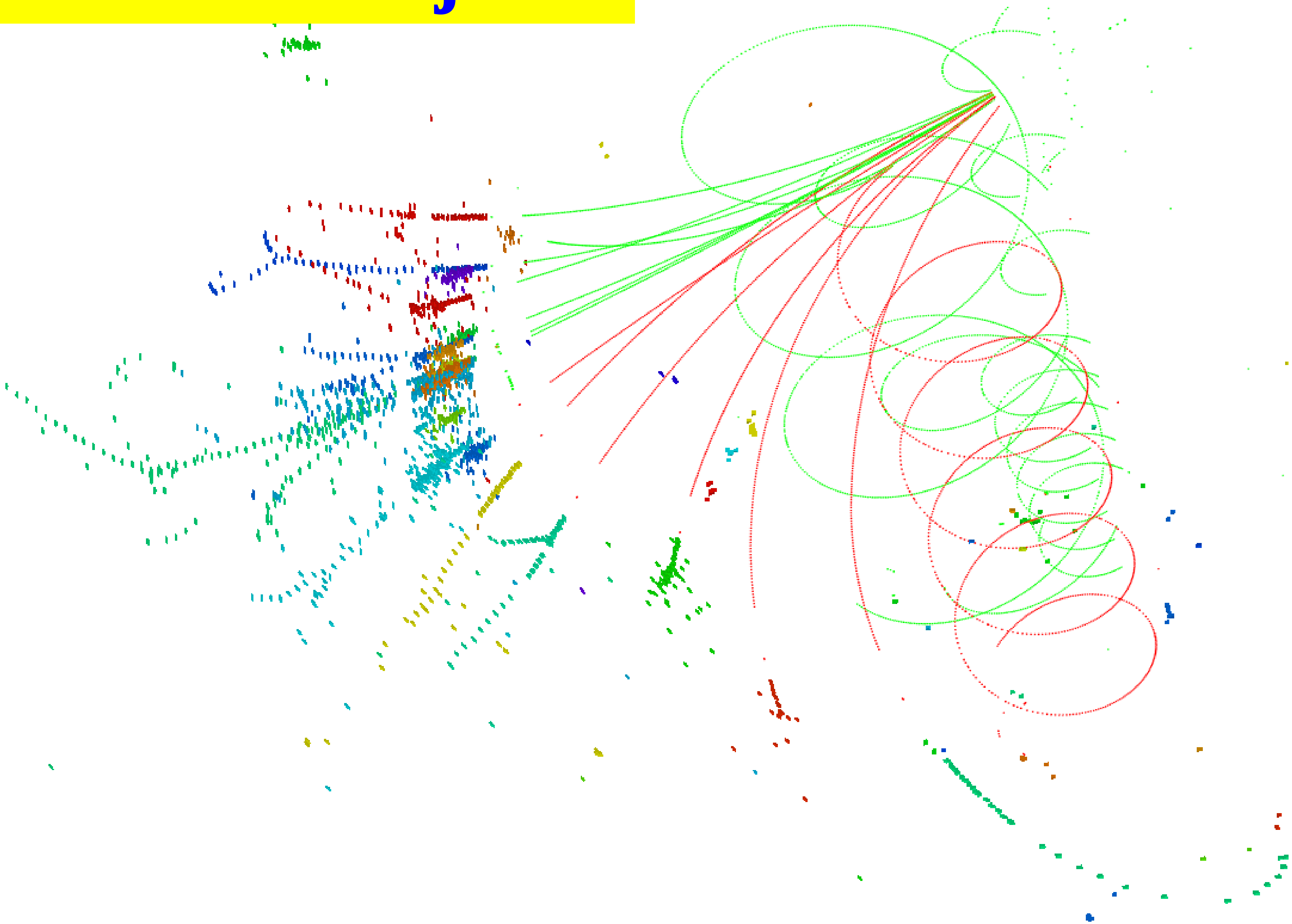
VDET (the priority is the b/c/tau tagging **AND** the low Pt efficiency & transparency for charged hadrons)
- The VDET must have excellent tagging of b/c/τ type of vertex (time structure & machine background)
- It must be as transparent as possible to pion (the major enemy of PFA is the nuclear interaction of hadrons in the inner part of the detector)
- It has to be efficient in reconstructing low Pt tracks

TRACKER (the priority is the efficiency of tracks rec. in dense environment…like HE jets)
Beside the fact that the main tracker must be precise on reconstructing large Pt tracks
- It has to be efficient in dense environment (HE Jets)
- It has to be efficient on VO (Ks and Λ and converted photon in the inner part of the detector)
- it has to be as transparent as possible for photon and pion

CALORIMETER (the priority is showers separation & neutral rec. efficiency)
The first job of the calorimeter is to
- disentangle the showers coming from neutrals from the ones from charged
- disentangle neutral hadron from photon (τ decays and energy compensation)
- to be efficient at low energy (down to 100 MeV particle)

Low ANGLE Devices
- Cover the low angle region to close the fiducial volume for PFA
- Give some help in the muon/pion/photon/electron separation
- As usual , measure the luminosity with Bhabha events

Simulation of a jet ?



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Some consequences

VDET
> Precision on the IP and vertexing capability (as close as possible to IP→ radiation resistance & readout speed)
> The material budget is also essential !! (if possible, no cooling, no passive support, etc...)

TRACKERS
> Gas detector is interesting for transparency (low X0 budget) and good pattern recognition (imaging capability)
> Silicon is an option (point precision) as long as the material budget is manageable (Strong R&D) (V0 rec ?)

CALO
> Ultragranular device (large segmentation and small pixel size) for better pattern rec. of showers
> Dense in order to separate close showers
> Better far away from IP , to use the bending to separate the charged from the neutrals

Imaging calorimetry

VDET

The figure of merit

$$\sigma_{ip} = a \oplus b/p \cdot \sin^{3/2}\theta$$

a governs high momentum **(<5 µm for LC)**
b governs low momentum i.e. < 1 GeV/c **(<10 µm.GeV for LC)**

R&D on devices with high granularity and thin pixel sensors: (3 main streams)

> SLD-VTX based on CCDs (a=8, b=33, $t_{r.o.}$ = 200 ms) leading to CPCCD, FPCCD, ISIS

> X-Ray imager leading to DEPFET

> industrial CMOS pixel imagers ……… MIMOSA, APSEL, CAPS, Chronopix, ...

Main difficulties:

> Suppressed material budget (m.s., Nγ, **Nuclear interaction**)
⇒ constrains pixel technology & services
⇒ vigorous upstream R&D

> Be as close as possible to the I.P. (short lever arm)
⇒ Readout speed (occupancy !) & radiation tolerance (beam & physics related)

Marc Winter@ICHEP 2010 - Paris

- **ILC drives (since $\sim$ 1 decade) an R&D prog. on novel, highly granular and thin, pixelated devices introducing a new performance standard for vertex detectors:**
  - ⋇ new pixel technologies: CMOS pixel sensors, DEPFETs, CCD variants, ..., 3DIT
  - ⋇ new ladder concepts: double-sided, unsupported, monolithic

    $\hookrightarrow$ to be assessed in FP-7 project AIDA

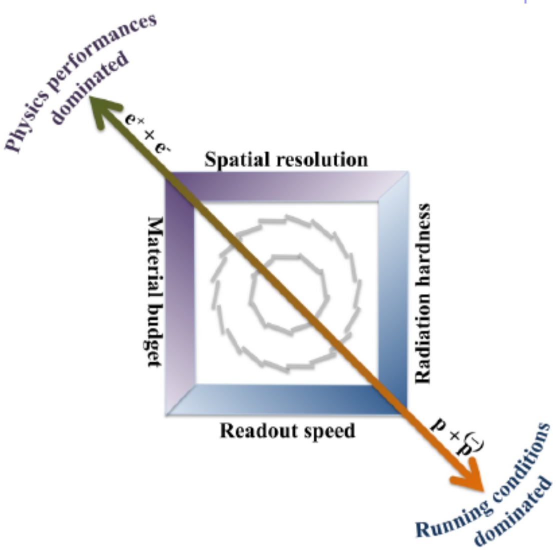
- **2 pixel techno. being prepared for vertex detectors of less demanding expts than those at ILC:**
  - ⋇ CMOS sensors: numerous BT, STAR ('12/13), CBM ('16), perspectives at CLIC, LHC, etc.
  - ⋇ DEPFETs: BELLE-2 ('14)

- **CMOS pixel sensors undergo a fast transition in radiation tolerance & speed:**
  - ⋇ 1st step: high res. epitaxy $\Rrightarrow$ SNR $\sim$ 40, rad. tol. $\longrightarrow \gtrsim O(10^{14}) n_{eq}/cm^2$
  - ⋇ important goal: combine thin HR sensitive tier with 2nd step:

    CAIRN $\equiv$ 3D sensors combining high-res epitaxy with fast FEE $\longrightarrow\ \lesssim$ 10 ns

    $\hookrightarrow$ the vertex detector quadrature may be achievable ...

    $\hookrightarrow$ horizon opens up for CLIC & HL-LHC



Marcel Vos

R&D effort	technology	Main selling point	demonstrated	Envisaged use other than ILC/CLIC VXD
MIMOSA, Strasbourg	CMOS MAP	Maturity, transparency	TB, EUDET telescope	STAR VXD (2011)
DEPFET collaboration	MPI process	All-Si solution	TB	Belle-II (2014)
				X-ray imagers
TimePix	Hybrid	time-stamping	Medical imaging	LHCb VELO upgrade,TPC
APSEL, INFN	CMOS MAP	Read-out speed	TB	SuperB
Spider, STFC	CMOS MAP	speed	TB	calorimetry
ISIS(2), STFC	CCD	power	TB	
SOI MAPs, LBL	SOI	Depleted sensor	TB	
ChronoPix		speed	Bench test	
Avalanche devices, Obninsk, Barcelona	CMOS APD	Ultra-fast signal	proof-of-principle	photo-sensors
VIP, FNAL	Vertical Interconnect	combine speed and precision	proof-of-principle	

- Dedicated effort to non-sensor issues: support concepts (PLUME/SERWIETTE), stitching, buttable sensors (several, notably STFC), air cooling (STAR, DEPFET)

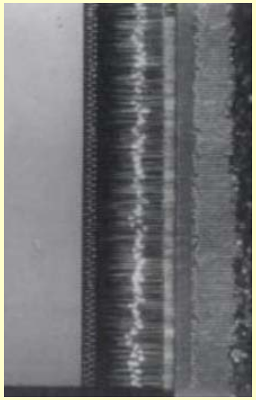
- Several European groups (INFN, Strasbourg) **access 3D** MPW runs at Tezzaron through FNAL

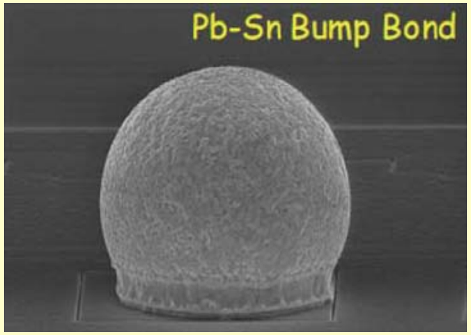
- **AIDA** to serve as a platform to provide access to vertical interconnects in Europe

DEPFET development for ILC …. Now for BELLE-2 at KEK superB

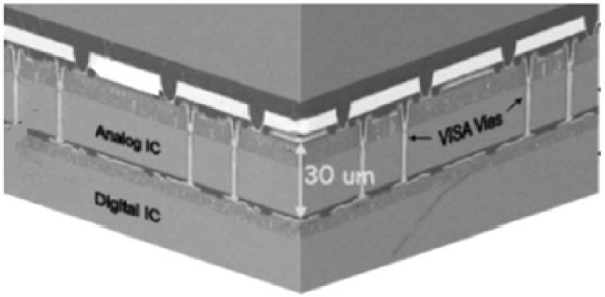
Integration - pixels

From 1D to 2D…

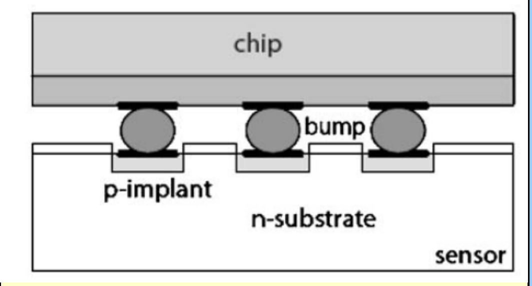




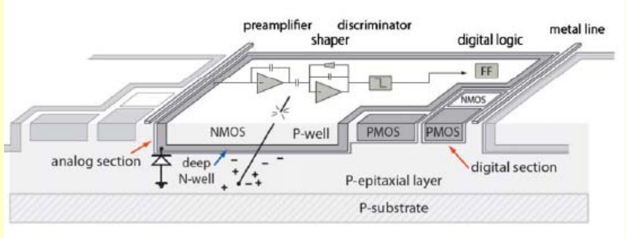
Coarse, bumps diameter is 10s of ❍m



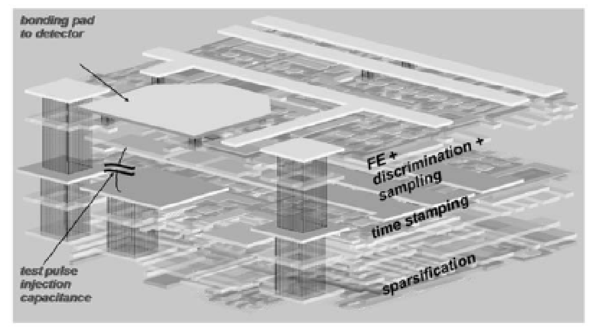
… to 3D



Specialized sensor material and FE coarsely integrated



Put FE in sensor (DEPFET) or sensor in FE (MAPs)



Integrated specialized sensor and FE

1rst prototype submitted to industry spring 2009 …. Still waiting for …..

TRACKING

From **Takeshi MATSUDA**
IWLC 2009

Demonstration Phase

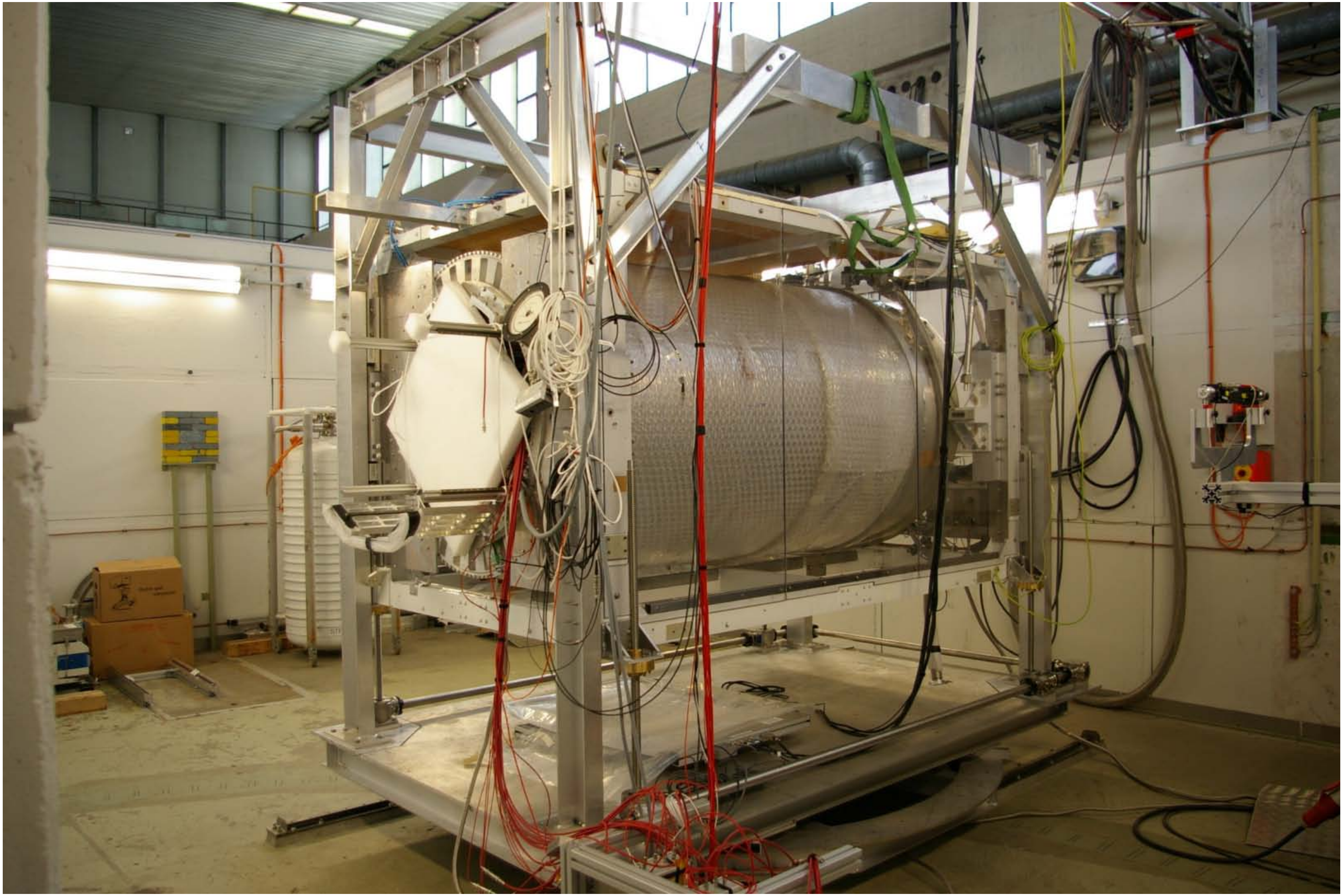
From wire TPC to MPGD TPC:

1. Comparison of wire TPC and MPGD TPC: This stage we knew that the wire TPC has poor resolution due to ExB in high B → but cosmic ray test in 1,5T magnetic field and beam tests in 1T were dispensable.
2. Beam tests and the cosmic ray tests with many small TPCs prototypes to study stable operation and point resolution of MPGD TPC: learned a lot about the basic structure of MOGD TPC → GEM: signal spread in the induction gap, Micromegas: bulk structure, resistive anode readout etc.
3. A full analytic formula of the point resolution of MPGD TPC "born from a beam test" giving a guidline for the point resolution of ILC TPC.

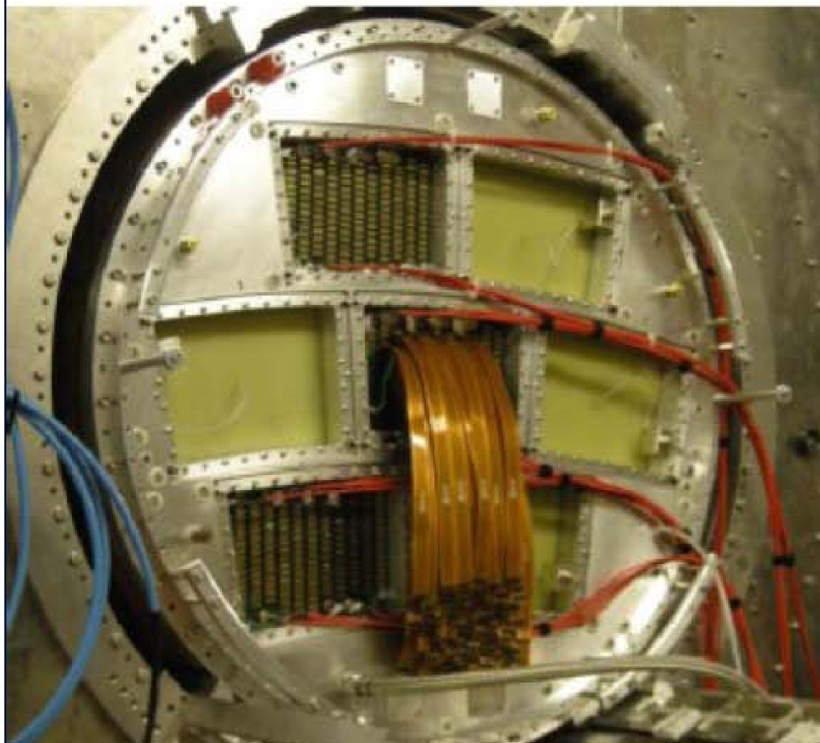
Some other issues

4. Search for the best gas for LC TPC
5. Ion feedback and gating- a simulation and (beam) tests.

TPC Large Prototype Test Beam

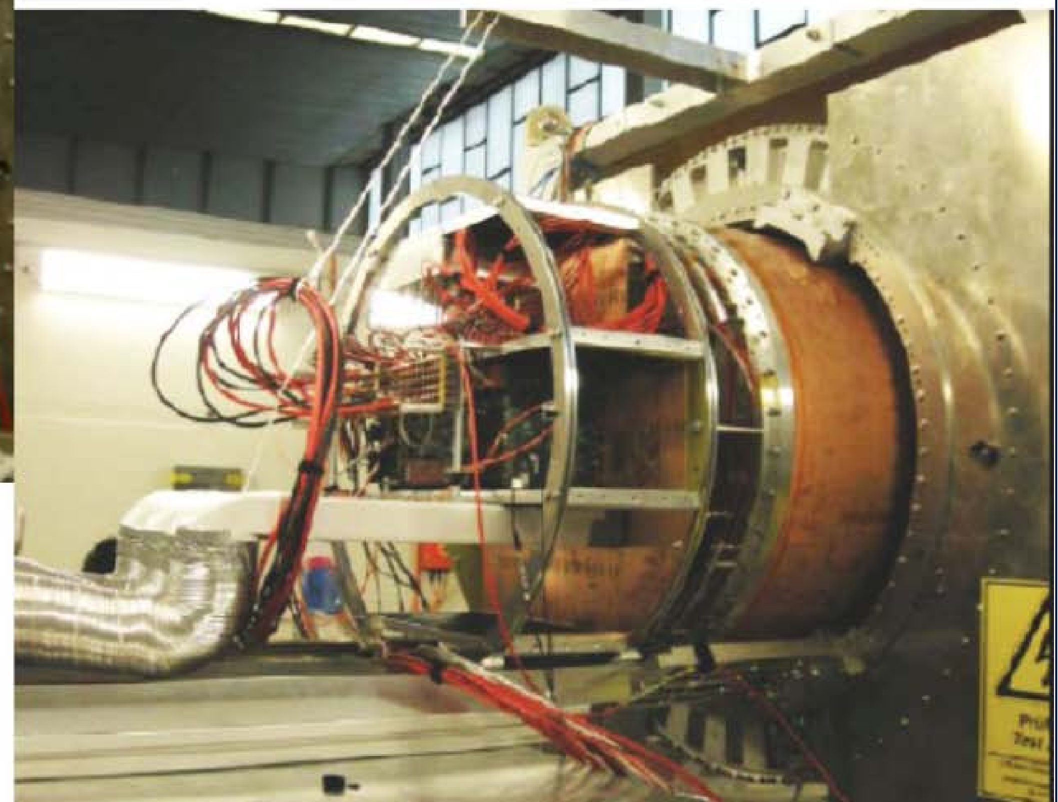


And then there was Beam



Testbeam with 2-GEM

About 3200 channels readout electronics



Readout electronics:
Based on ALTRO (ALICE TPC)
L. Joensson, LUND University

Sept. 30, 2010 | Klaus Dehmelt | 21 | EUDET Annual Meeting 2010

- Gas-/HV-infrastructure ready
- Infrastructure for LP present and being used
- Infrastructure for SiLC envelope installed
- LP assembled, commissioned and being tested
- LP with three different amplification technologies operated
- First SiLC run performed
- ~22 weeks of test beam with LP operation so far
- >10M events recorded → ~2TB data on GRID → more to come

Items not yet completed:

- Alignment system for LP within PCMAG to be tested/installed
- Slow control to be (further) developed
- Automation of processes
- DESY GEM module

Further test beam campaigns for this/next year:

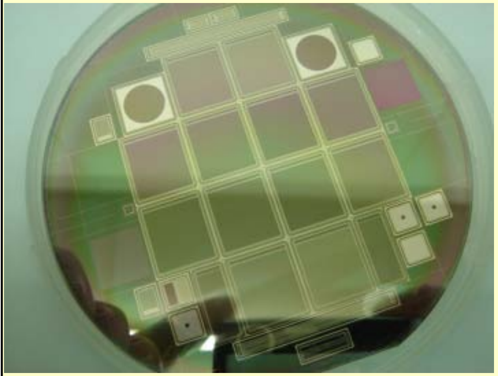
- Backplane integrated 7,500 channels readout system, based on ALTRO electronics just completed
- Seven Micromegas modules with AFTER electronics attached to the modules (in 2011)
- DESY-GEM module with ALTRO electronics (end 2010?)

PCMAG modifications in 2011 (modification of the cooling)

S-ALTRO16 to be prototyped (AIDA ?)

Si μ-strip R&D

IFCA/CNM: IR transparent sensor provides no-added-material alignment system a la AMS

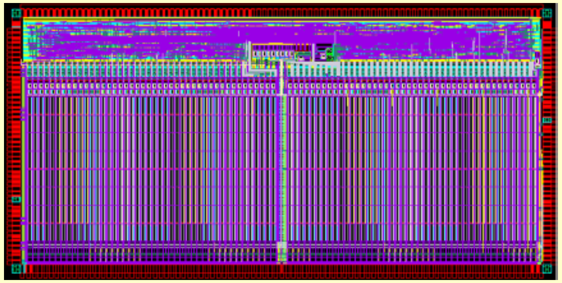


T= 55%

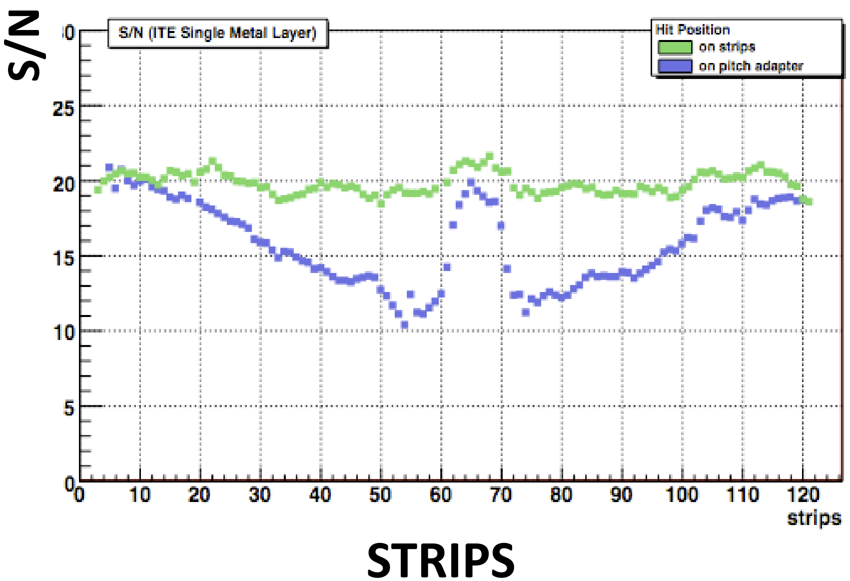
See EUDET Annual MEMO

Next step: Bragg Fibers monitoring?

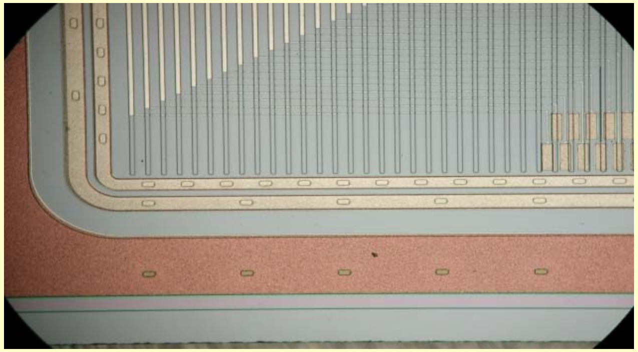
SiTra FE,
ILC read-out,
500 mW/channel
EUDET-MEMO-2009-15



Both SiD and SiLC pursue **hybrid-less modules**: direct integration of FE on sensitive material. Additional metal layer incorporates pitch adapter

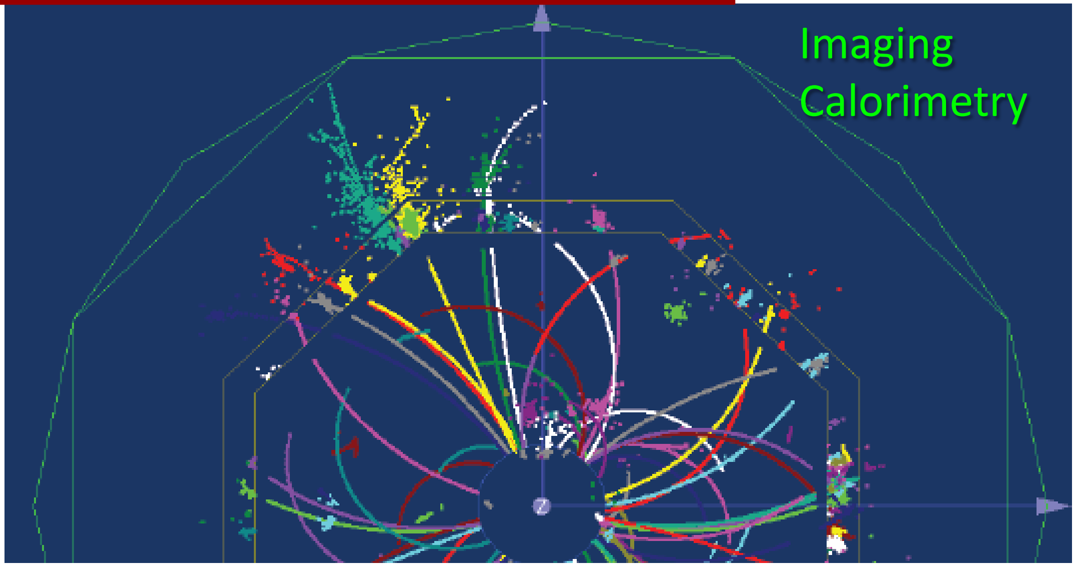


Signal loss observed for particles incident on PA, compared to other areas of the sensor



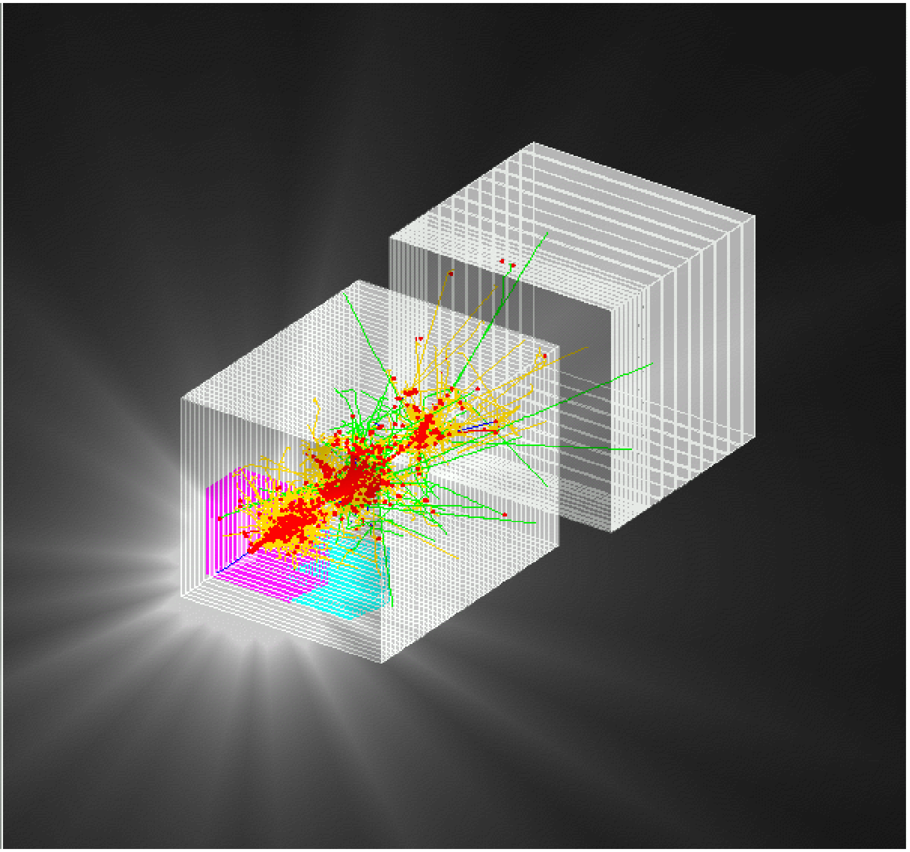
CALORIMETER

Imaging calorimeter



Final goal:

A highly granular calorimeter optimised for the Particle Flow measurement of multi-jets final state at the International Linear Collider



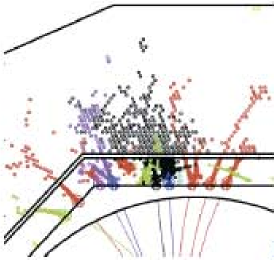
Intermediate task:

Build prototype calorimeters to

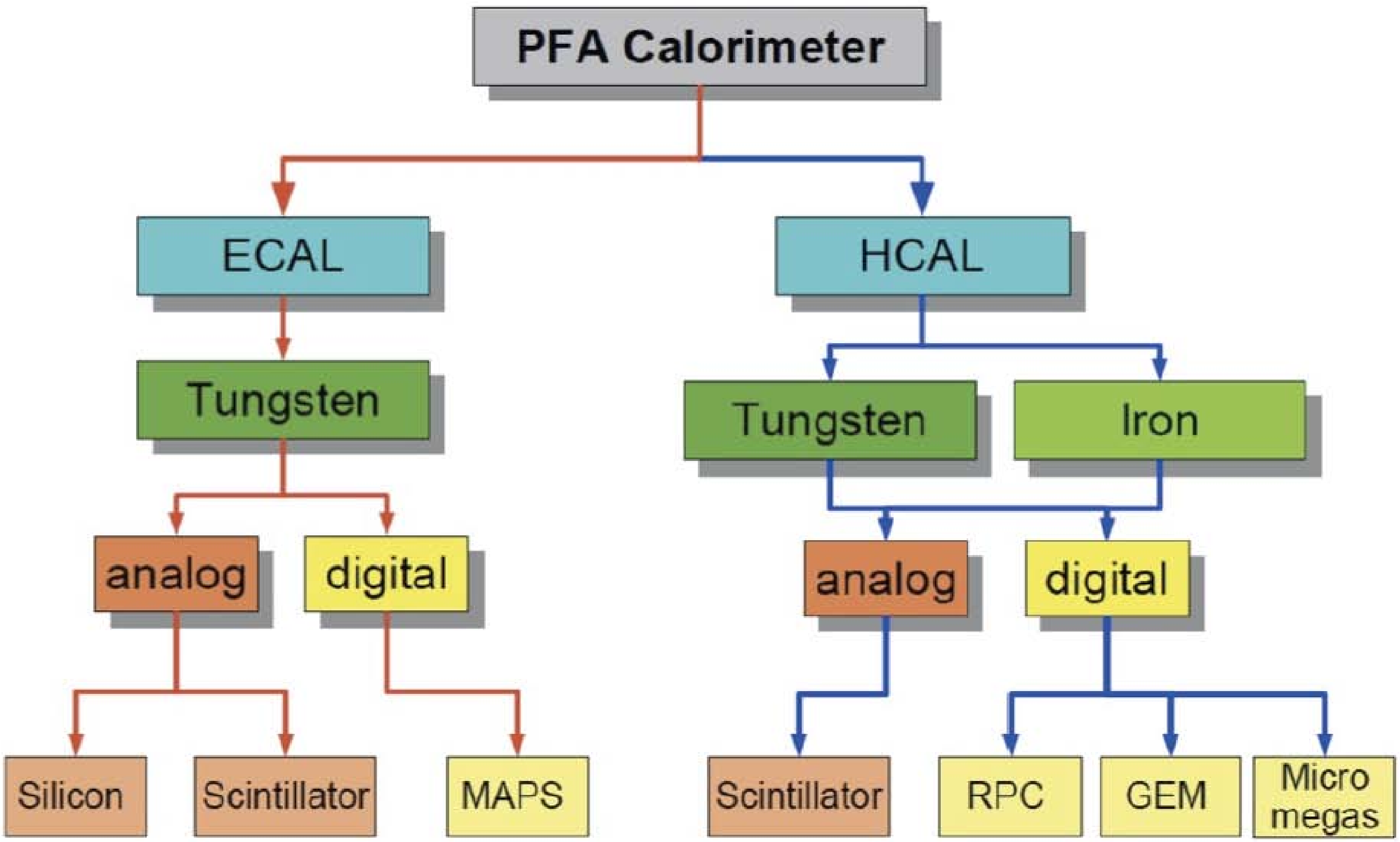
- Establish the technology
- Collect hadronic showers data with unprecedented granularity to

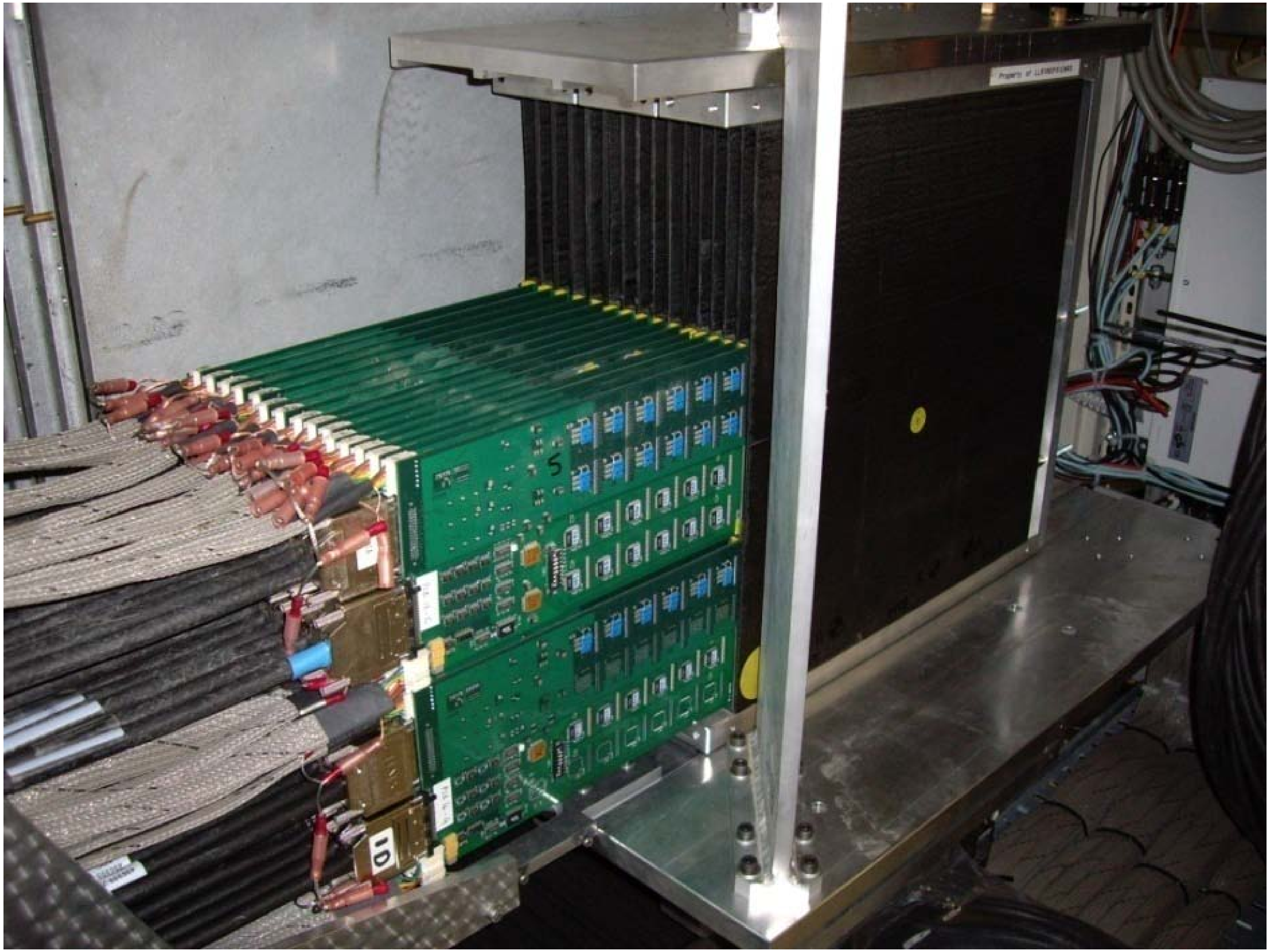
  - tune clustering algorithms
  - validate existing MC models

CALORIMETER



Technology tree





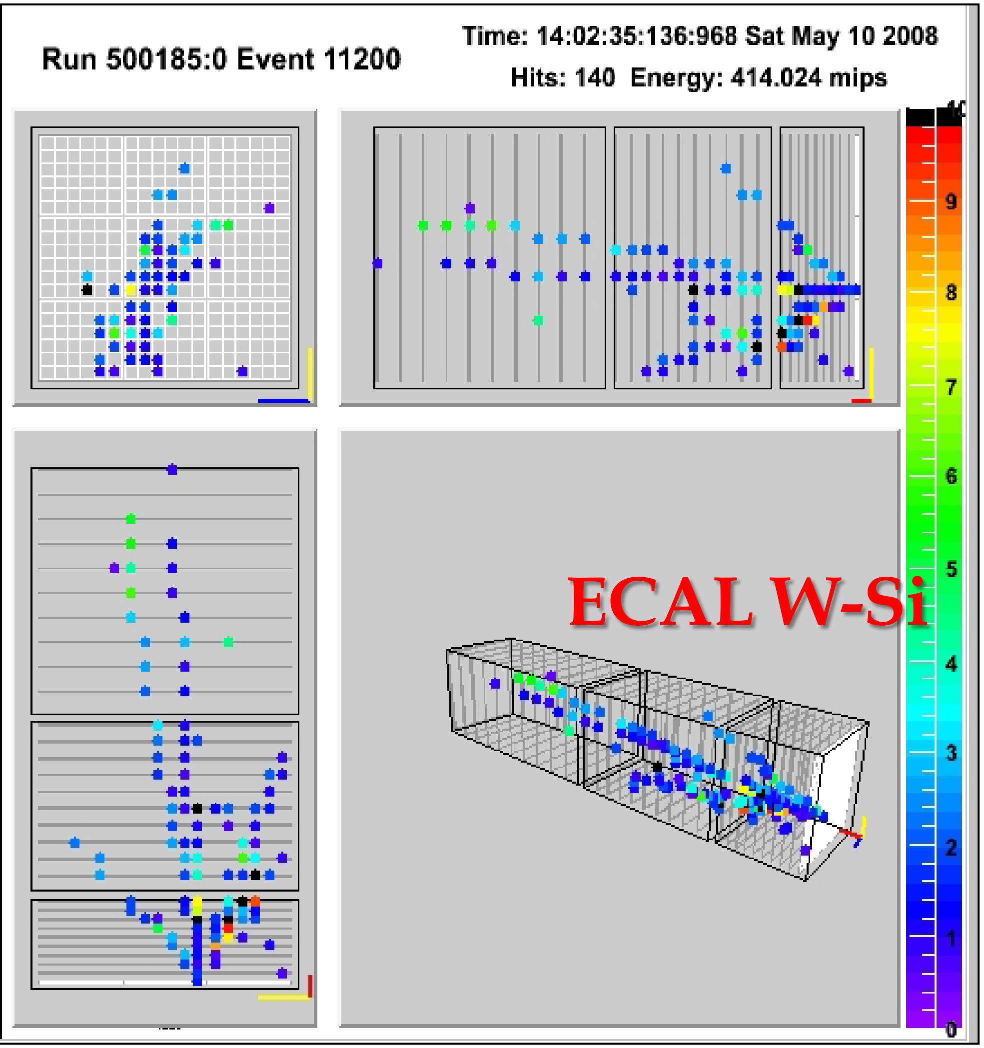
Calorimeter for ILC

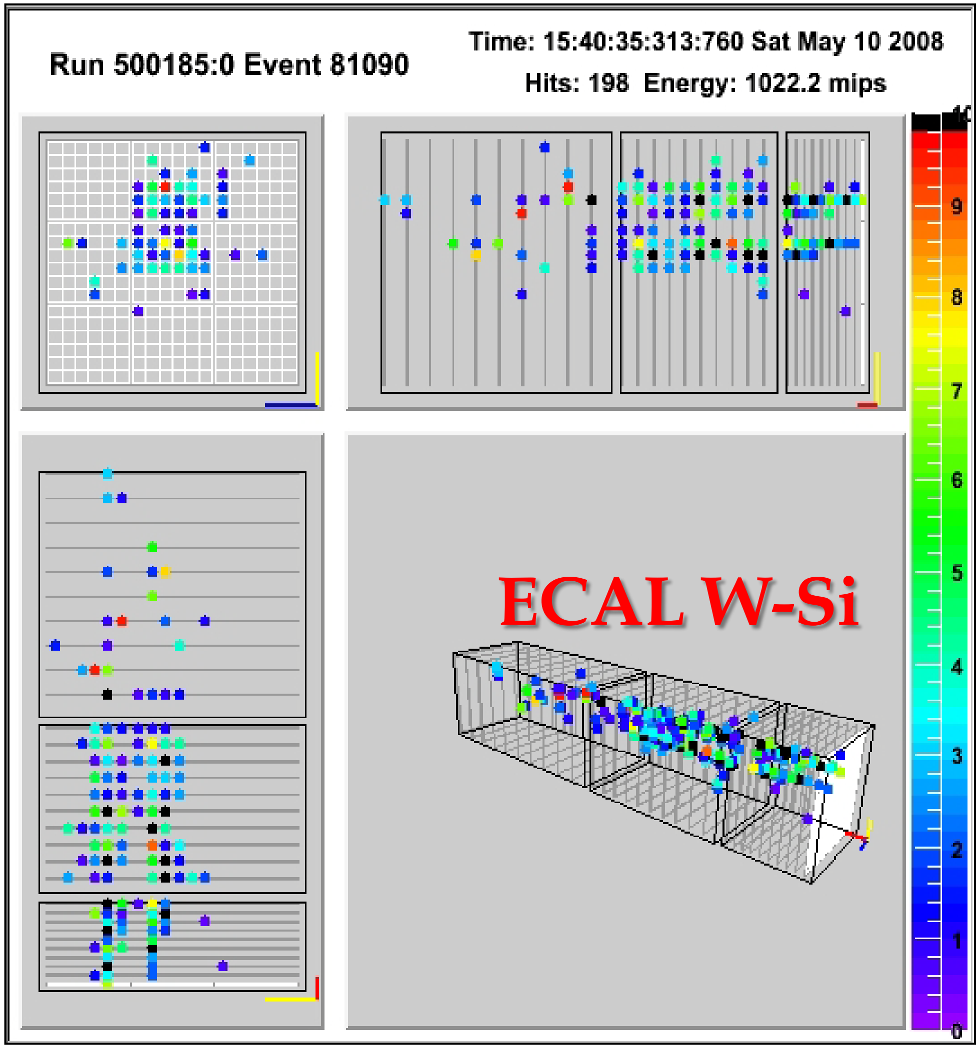
Number of ECAL readout channels

1/8 of CMS in a cube of 18 cm side

Imaging calorimeter

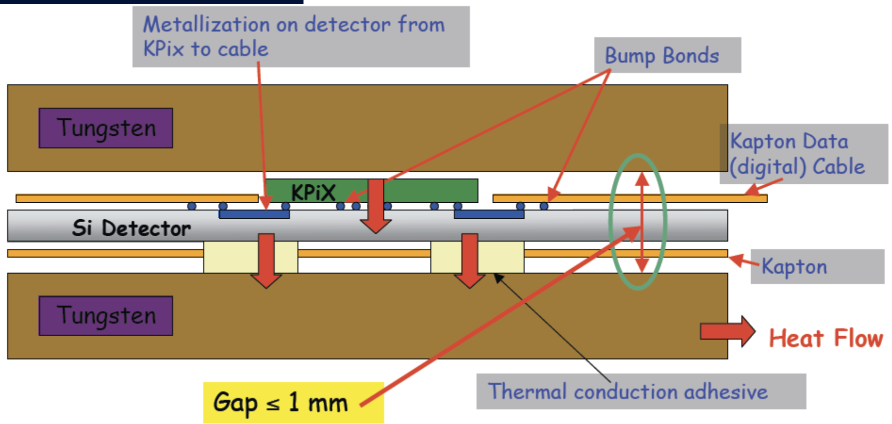
8 GeV pion beam
@ Fermi National Laboratory





ECAL in **SID** is following the other bank of the pathway to detector design:

ECAL



"Start from the most advanced technology "

- Very large hexagonal wafers – VFE bump-bonded on wafer
- KPIX -1024 channels for the readout VFE

> KPIX-9 with 512 channels is under test and measurement

> R&D on flex cable interconnects

R&D agenda for 2011-2012

- Make technology choices for sensor to KPiX and sensor to flex-cable attachments.
- Commission 32-channel probe card for testing KPiX.
- Fabricate flex-cables for version 2 sensors.
- Evaluate 1024 channel KPiX (KPiX-1024) for noise under load.
- Complete first fully loaded sensor assembly (with KPiX-1024 and flex-cable.attached using chosen interconnect technologies).
- Bench test of first assemblies.

- Development of KPiX series of chips is nearing completion. 1024 channel chip has been laid out and is awaiting a green light from the testing of the 512 channel chip.
- Interconnect developments are converging on solder bumping as a viable option for both KPiX and flex cable attachment.
- Sensors are in hand and mechanical design is proceeding.
- Integration/assembly being planned.

Milestones for Aug 15, 2012

- Construct 30+ loaded sensor assemblies (i.e. 30+ readout layers).
- Develop data buss for 30 assemblies.
- Construct a 30-layer sensor-tungsten stack.
- Beam test.

ECAL

CALICE Calorimeter for ILC

-Successful R&D for a highly granular electromagnetic calorimeter

Physics Prototype (2005-2009):
- Energy resolution ~17%/√E
- Signal to Noise Ratio ~8/1
- Stable calibration

Technological Prototype (2010-...):
- Mechanical concept validated with demonstrator
- Silicon Wafer technology at hand
- Front End Electronics will be challenging
  Embedded into calorimeter layers, power pulsing

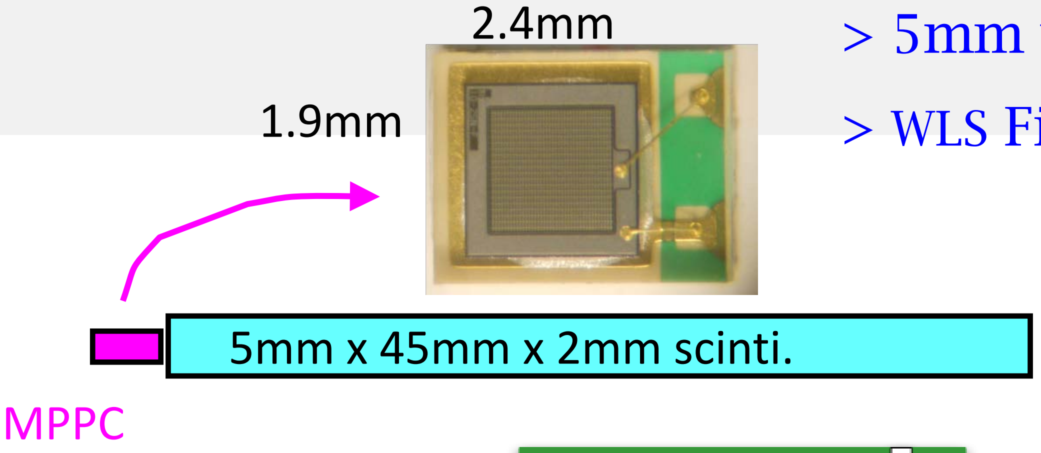
- Capacity of separating particles impressively demonstrated by test beam analysis

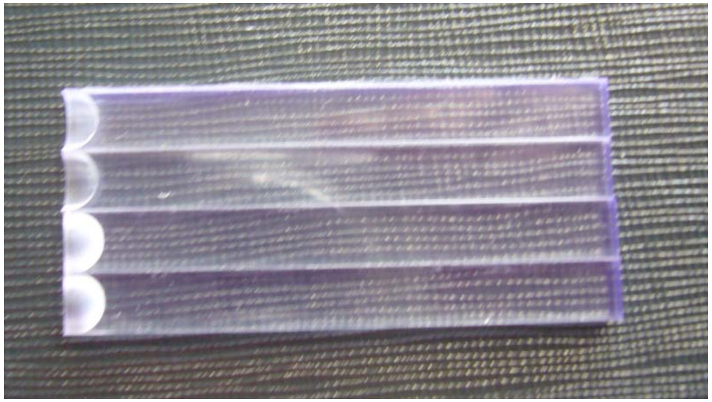
-Unprecedented realistic views into hadronic showers thanks to high granularity
'Modern bubble chamber'

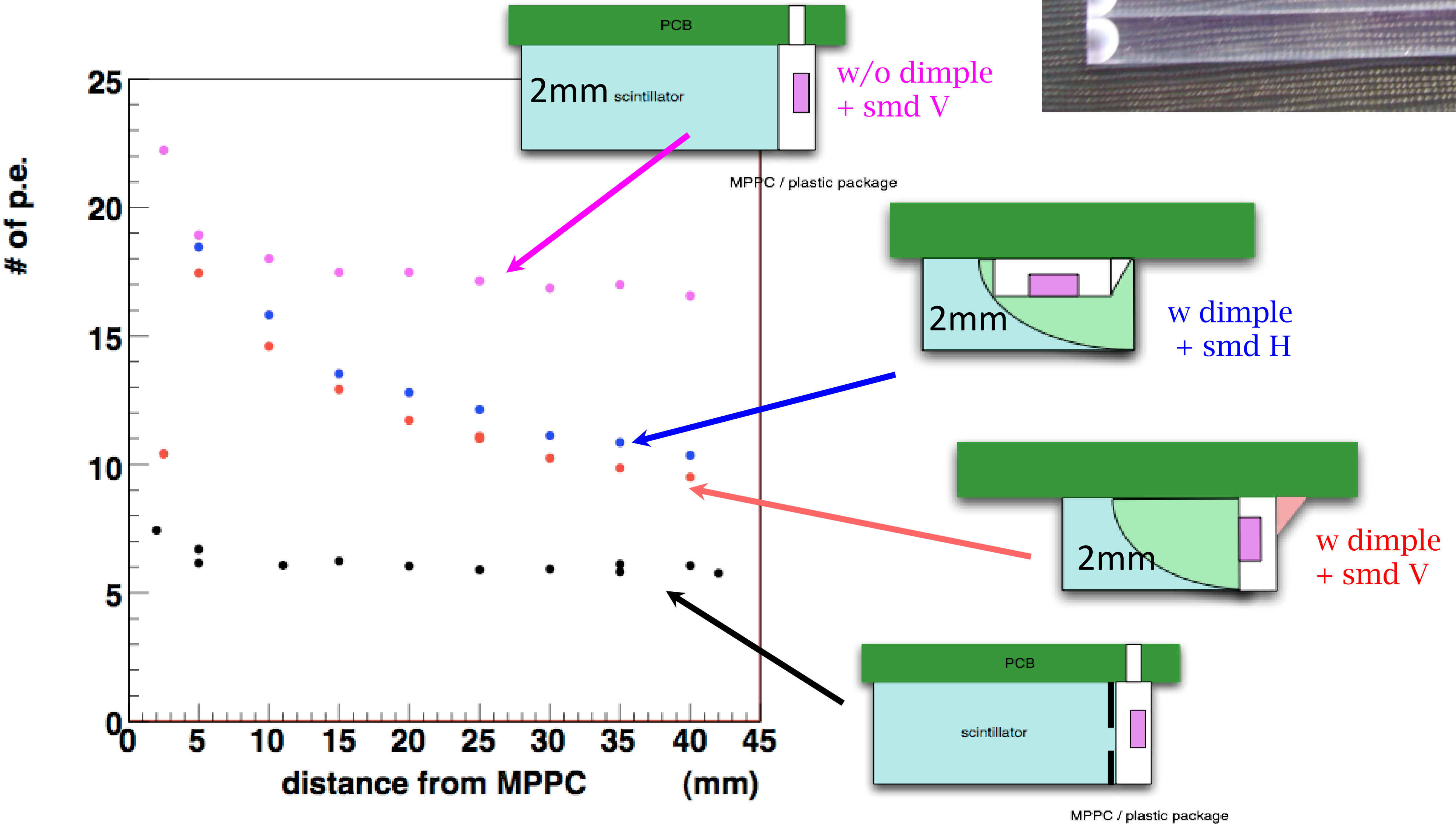
OPTIMISATION studies began
Cost/performance trade off between silicon pin diodes and scintillator strips read by MPPC .... Industrial aspect of the projects

> 5mm wide scintillator strip

> WLS Fiber not necessary (PDE)



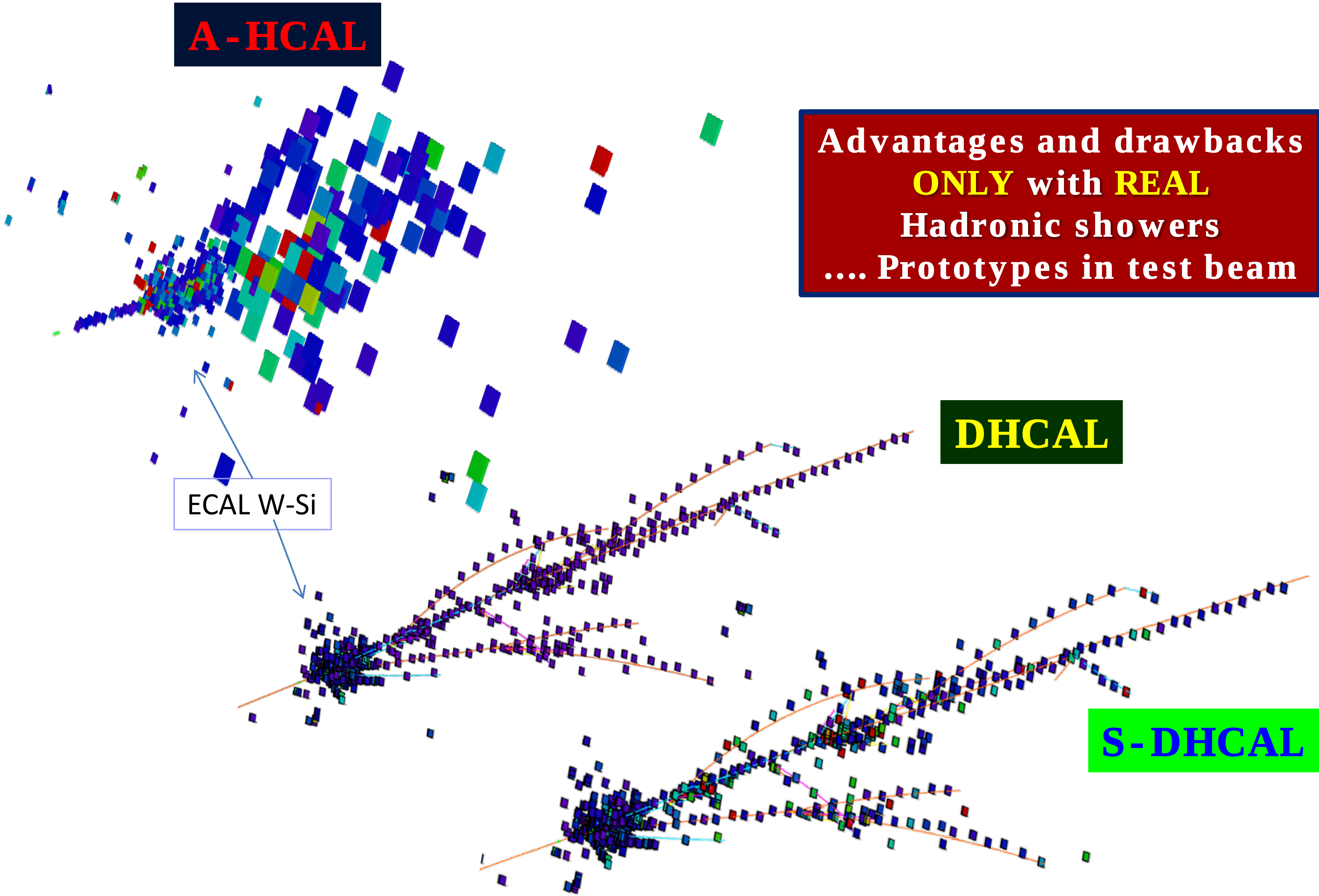




40 GeV pion interaction
in different type of HCAL

Which type of HCAL for LC ?

Advantages and drawbacks
ONLY with REAL
Hadronic showers
…. Prototypes in test beam



HCAL - analog readout

-Successful R&D for a 3x3cm² tile calorimeter (readout by SiPM)

Physics Prototype (2007-2009):
- mass production of SiPM (first in the world)
- running with monitoring of the calibration in-situ
- Compensation software gives impressive improvement on energy resolution
- First “tight” constraint on G4 hadronic model

Technological Prototype (2010-...):
- R&D on uniformity response in a tile
- Embedded into calorimeter layers, power pulsing

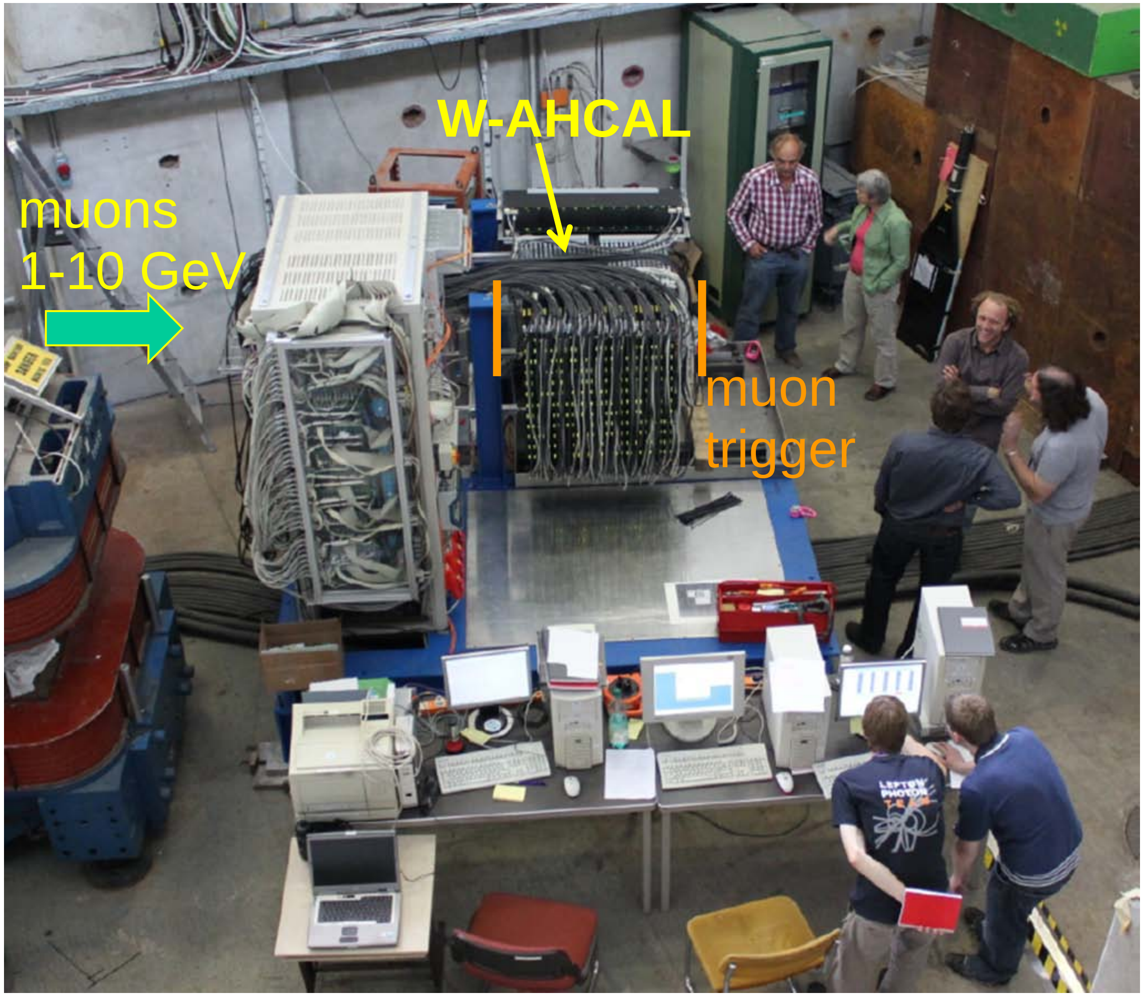
And NOW

-Test with tungsten radiator instead of stainless steel (CLIC)

-T3B (part of CALICE) to measure the time structure in hadronic showers (essential for CLIC)

TB for W-HCAL (CLIC HCAL)

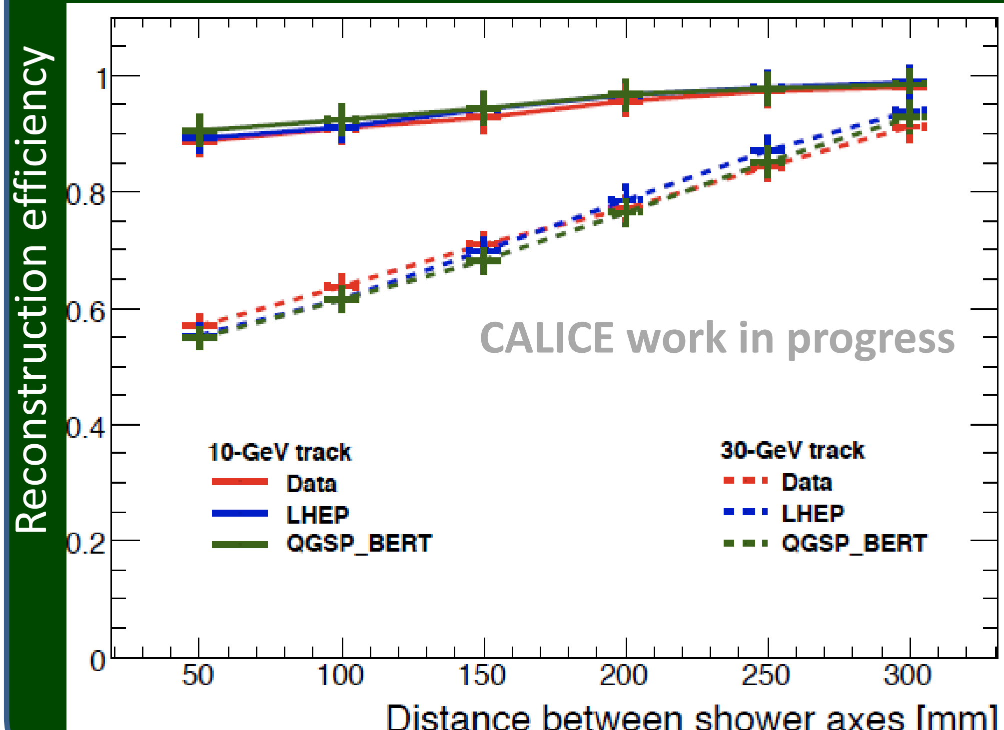
here the test with the tile HCAL



Installation of T3B

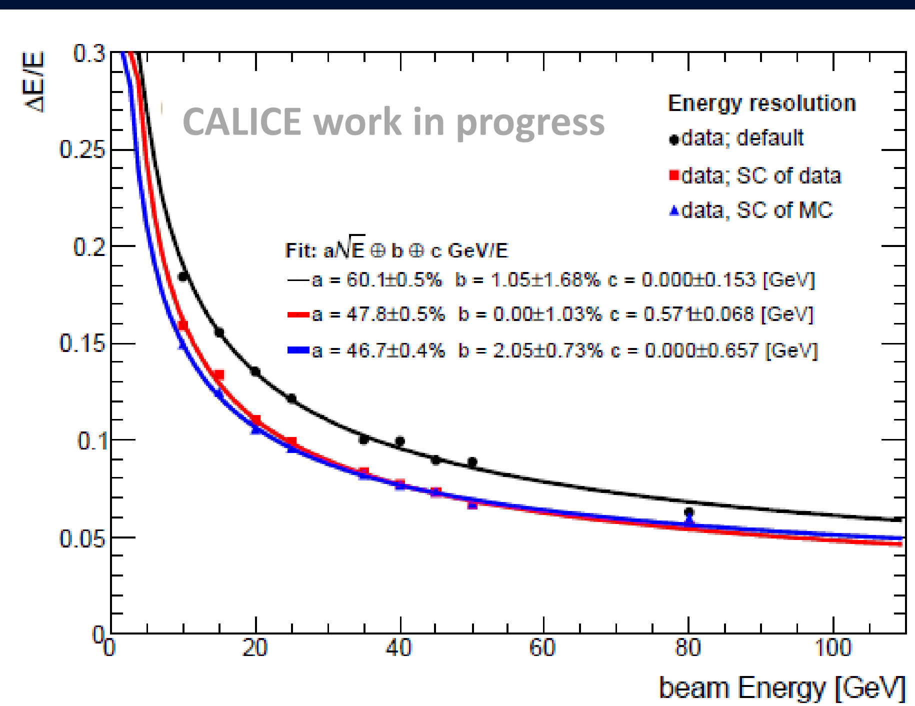
Work for CLIC detector has started …

PANDORA on overlaid TB events



Important results obtained with TB of the AHCAL

Software Compensation on TB



HCAL - gas device with (semi)digital readout

Digital HCAL (proof of principle)

After 6 years waiting for funding, it arrives this year

- A 1m^3 prototype now in construction …. Surface made of 3 chambers of 30x90 cm^2
- TB @ FNAL alone , beginning of 2011
- TB @ FNAL with ECAL silicon-W in front , mid 2011
- **GOAL** : Validate the concept of DHCAL (eff./tracks, resol. energy, noise, etc…)

Semi Digital HCAL (proof of readiness for use @collider)

Test of all aspects related to use in ILC condition (power pulsing, VFE embedded in detector, Large area RPC, etc…)

- A 1m^3 prototype now in construction …. Large GRPC (1 m^2 Glass RPC)
- One layer of 1 m^2 already tested at CERN (see later first results)
- TB @ CERN 2011 ?

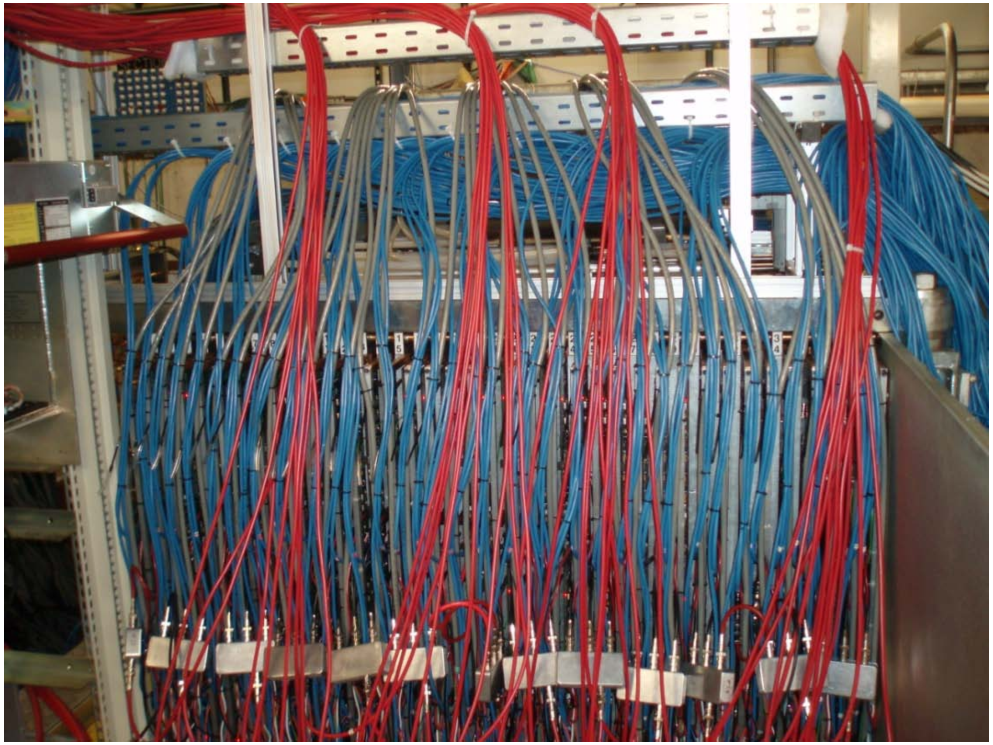
- **GOAL** : Validate the concept in experimental condition for use at LC collider

In both case, for TB data, some layer(s) will equipped by different active device, micromegas(LAPP) and GEM(UTA)

Digital HCAL

Prototype ~1 m^3 .... 350 000 channels
Pixel 1x1 cm^2 on 40 layers

Installation at **MTBF-FNAL** last week

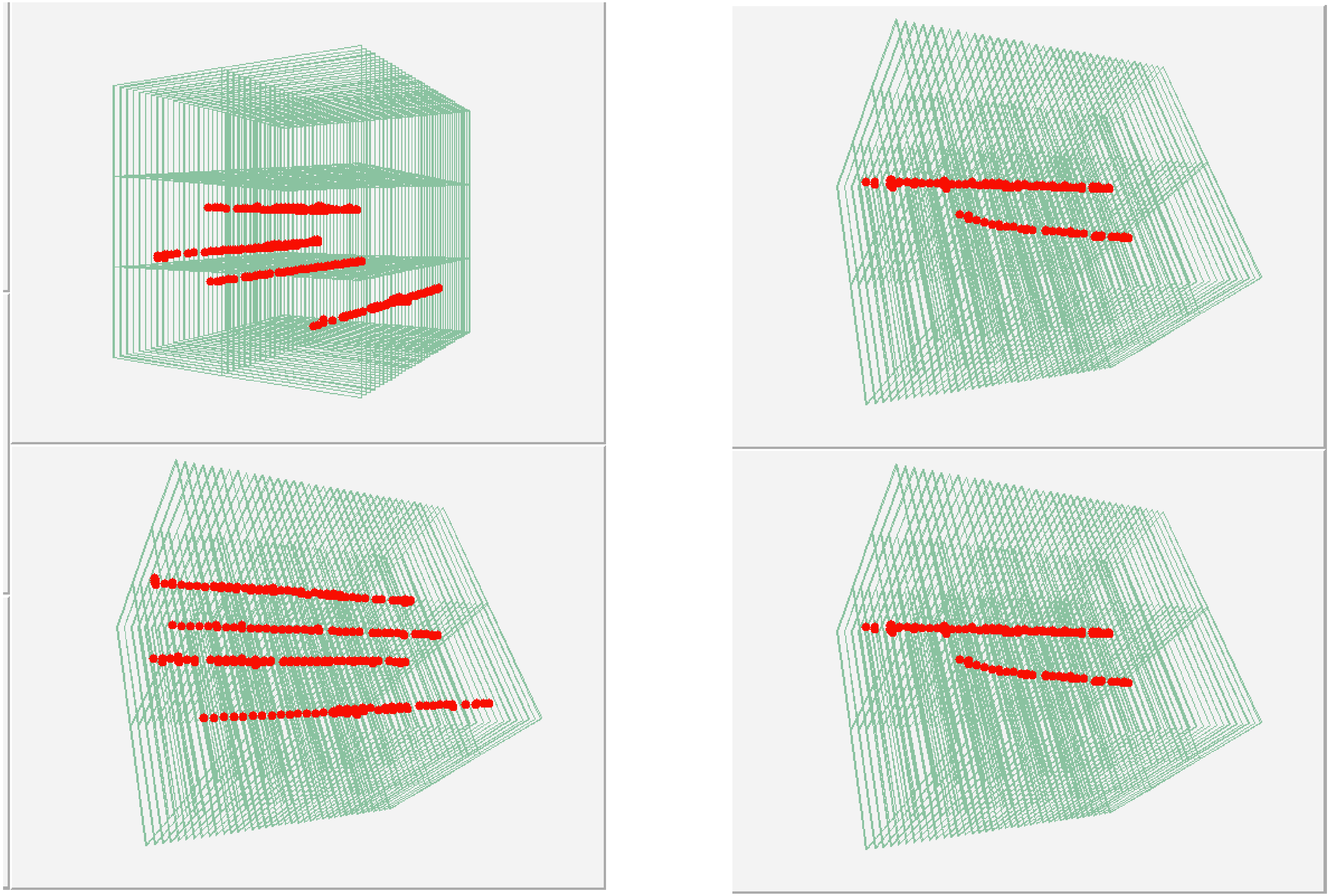


Test Beam in 2010 - 2011
Information ready on the proof of principle for the DBD 2012

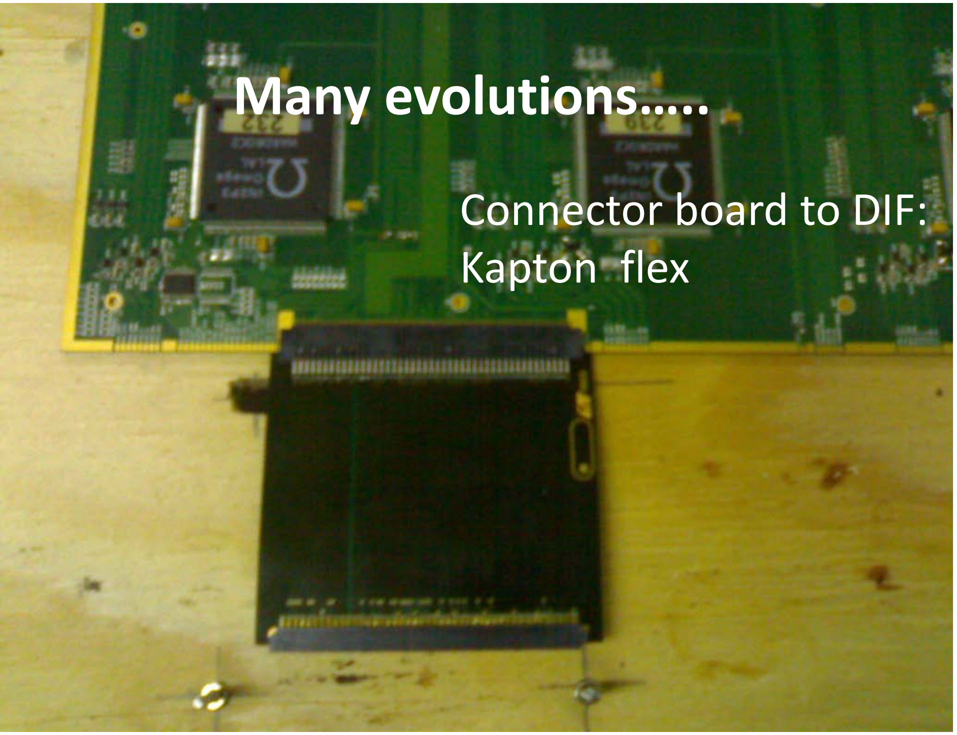
Digital HCAL

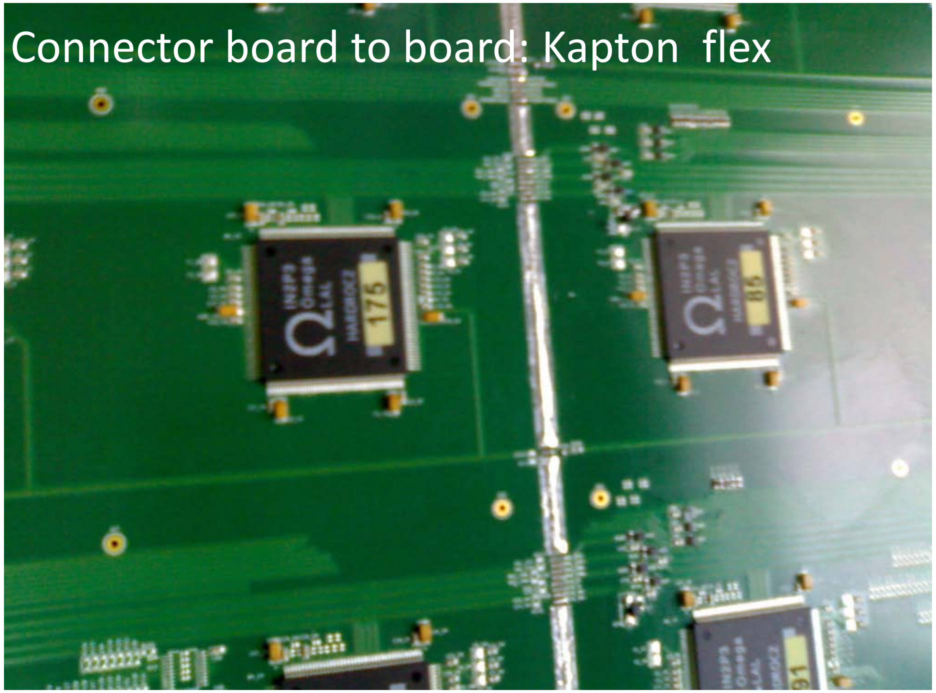
3 DAYS AGO !!

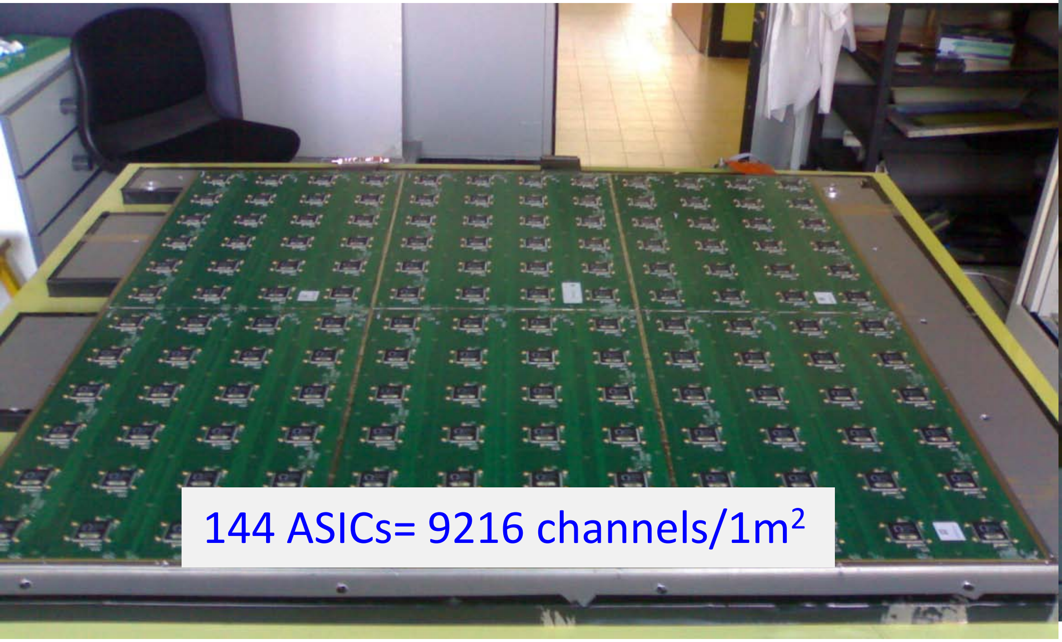
Muons runs - FNAL – TB   16th October 2010

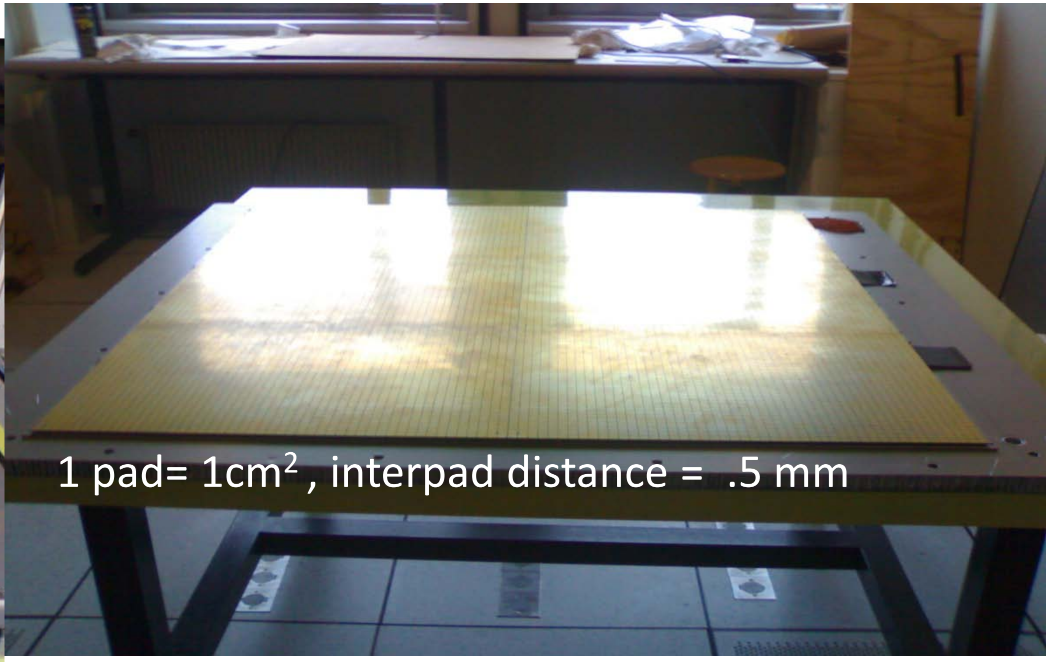


S-Digital HCAL





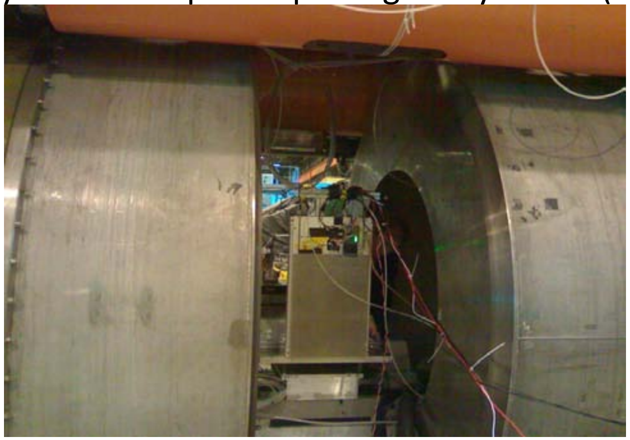


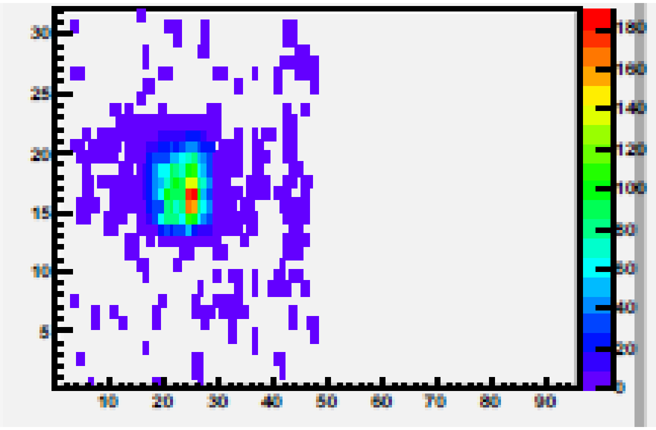


S-Digital HCAL

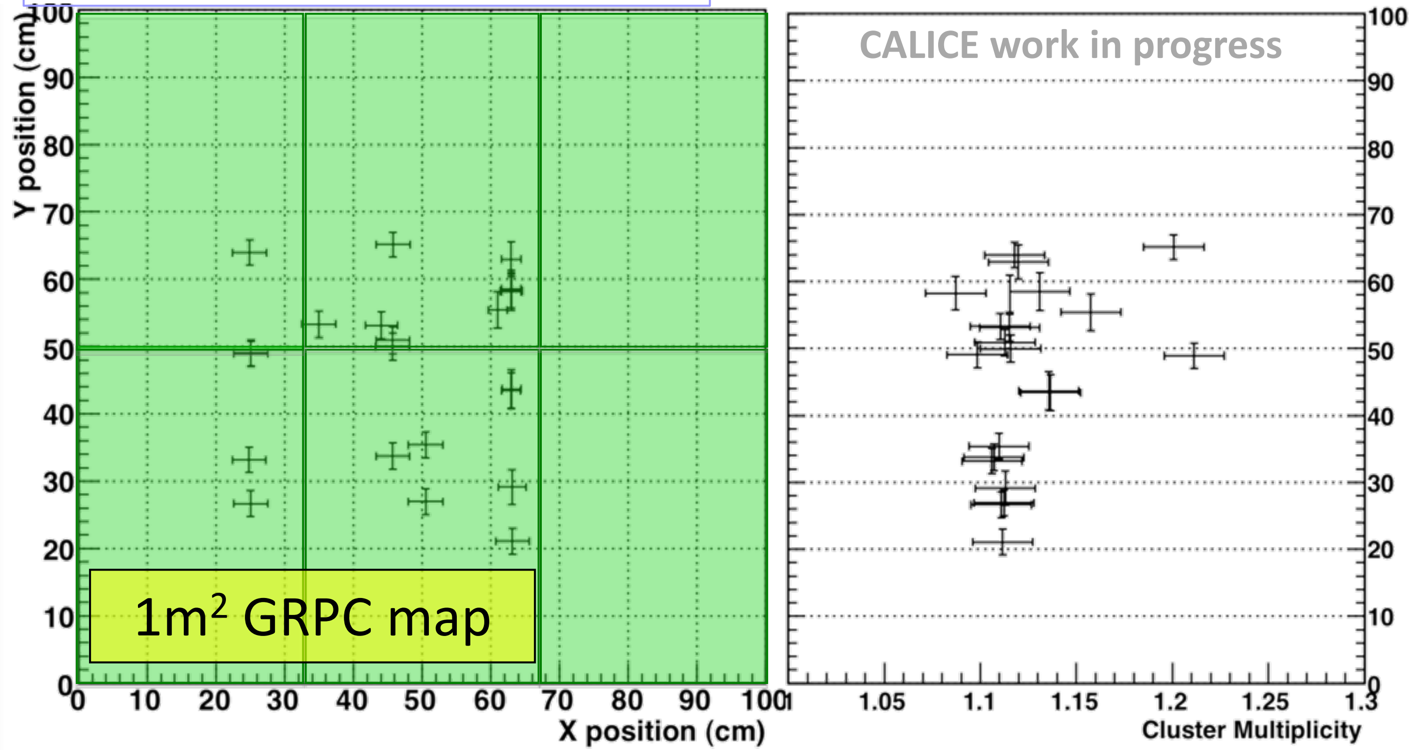
First test of power pulsing in 3T field

Cycle of 2 ms power pulsing every 10 ms (100 Hz rather than cool 5 Hz ILC duty cycle)





Preliminary test of homogeneity



Electronic readout are strongly correlated to the beam structure (CLIC is not ILC)

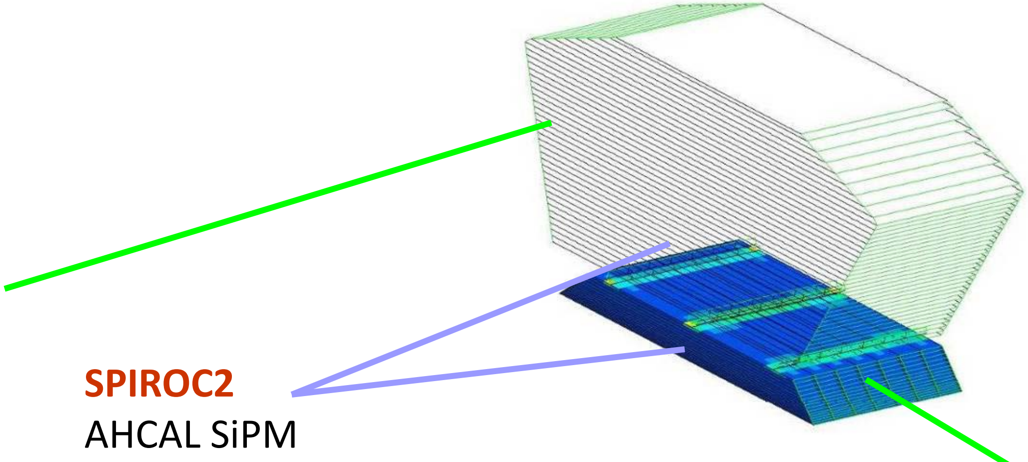
R&D on the concept of readout for CLIC detector is starting

Already done

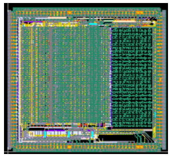
- Embedded electronics with 2nd generation DAQ
- First power pulsing operation at system level
- FCAL : new sensors and readout electronics
- Thousands of readout chips
- 2nd generation DAQ infrastructure

To do list

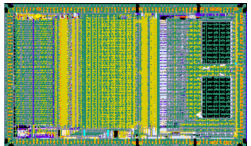
- Lots of important tests ahead : Power pulsing, coherent noise, power dissipation, timing, system aspects, DAQ…
- Small Testbeam program starting



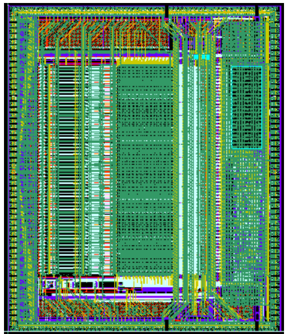
HARDROC2
SDHCAL RPC
64 ch 16 mm^2



SPIROC2
AHCAL SiPM
36 ch 30 mm^2

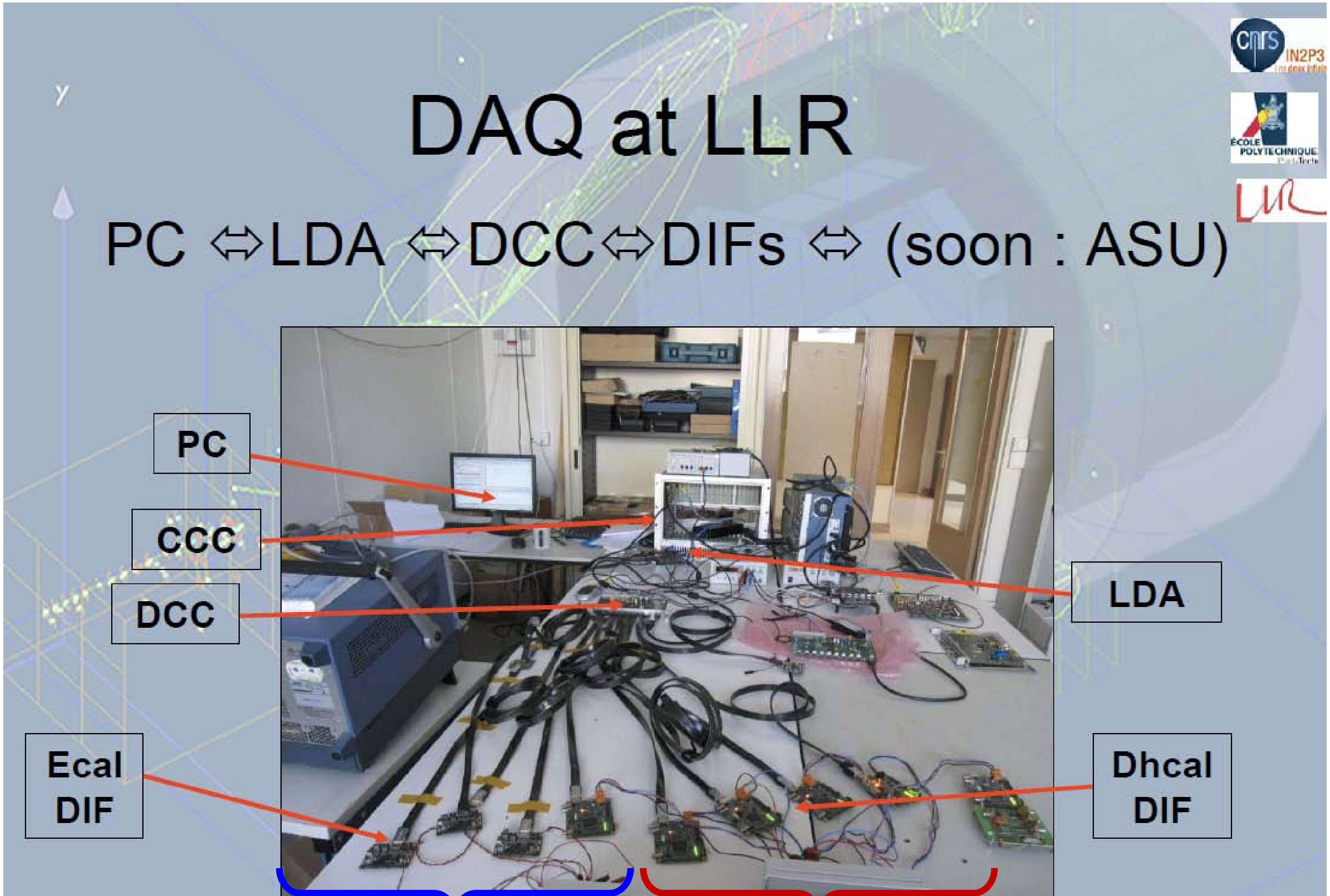


SKIROC2
ECAL Si
64 ch. 70 mm^2



The development of a new generation DAQ is well advanced.
Able to work on ANY type of device @500 Mbits/s (limitation not conceptual)
Adapted to a VERY large number of channels

The new generation DAQ (R&D in AIDA) would reach few Gbit/s



46 000 channels of ECAL
(16 bits dynamics)

120 000 channels of DHCAL
(3 bits)

Exemple of IDAG questions :

1. The **vertex detector** is sensitive to machine backgrounds.

>> Can you assess what “headroom” there is if backgrounds are higher than planned? For example, what is the flavor tagging behavior – purity vs. efficiency - in the presence of added background.

>> In addition, the tagging is evaluated at the Z pole. What is the response at higher energies?

>> What is the impact of misalignments of the several hundred million independent channels on the tagging behavior?

>> How long will an alignment take – both initially and after each push-pull cycle?

2. For the **Trackers (TPC, Silicon)**

>> what would be the impact of increased machine background?

>> What is the tracking alignment plan and how long does it take?

>> Once aligned how are field distortions and temperature/pressure variations monitored?

>> Is the speed of monitoring sufficient to track machine transients?

>> What is the impact of a range of machine noise and misalignment of the TPC on the physics performance?

3 . **The calorimeter** has ~ 100 million channels.

>> How will manufacturing uniformity be maintained?

>> Is there sufficient industrial capacity to supply the silicon?

>> How will the calibration be first made and then maintained?

>> Why is there no “constant term” in the resolution due to cracks, supports, cables, and other non-uniformities in the medium or errors in calibration?

>> When will there be a test of power pulsing with B field? For example CDF have had difficulties with wire bonds.

>> Is power pulsing required or is there an alternative?

IDAG questions :

3 . **The calorimeter** has ~ 100 million channels.

\>> *How will manufacturing uniformity be maintained?*

The uniformity would be at the level of few % (producers information) . The absence of geometrical CORRELATION will be essential

\>> *Is there sufficient industrial capacity to supply the silicon?*

At least, some producers are able to do it in few years

\>> *How will the calibration be first made and then maintained?*

TB of the ECAL from 2005 to 2010 will be a first answer

\>> *Why is there no "constant term" in the resolution due to cracks, supports, cables, and other non-uniformities in the medium or errors in calibration?*

Cracks are in simulation, but calibration errors as well as most of the other effects are NOT in the simulation …. Need input from R&D and TB

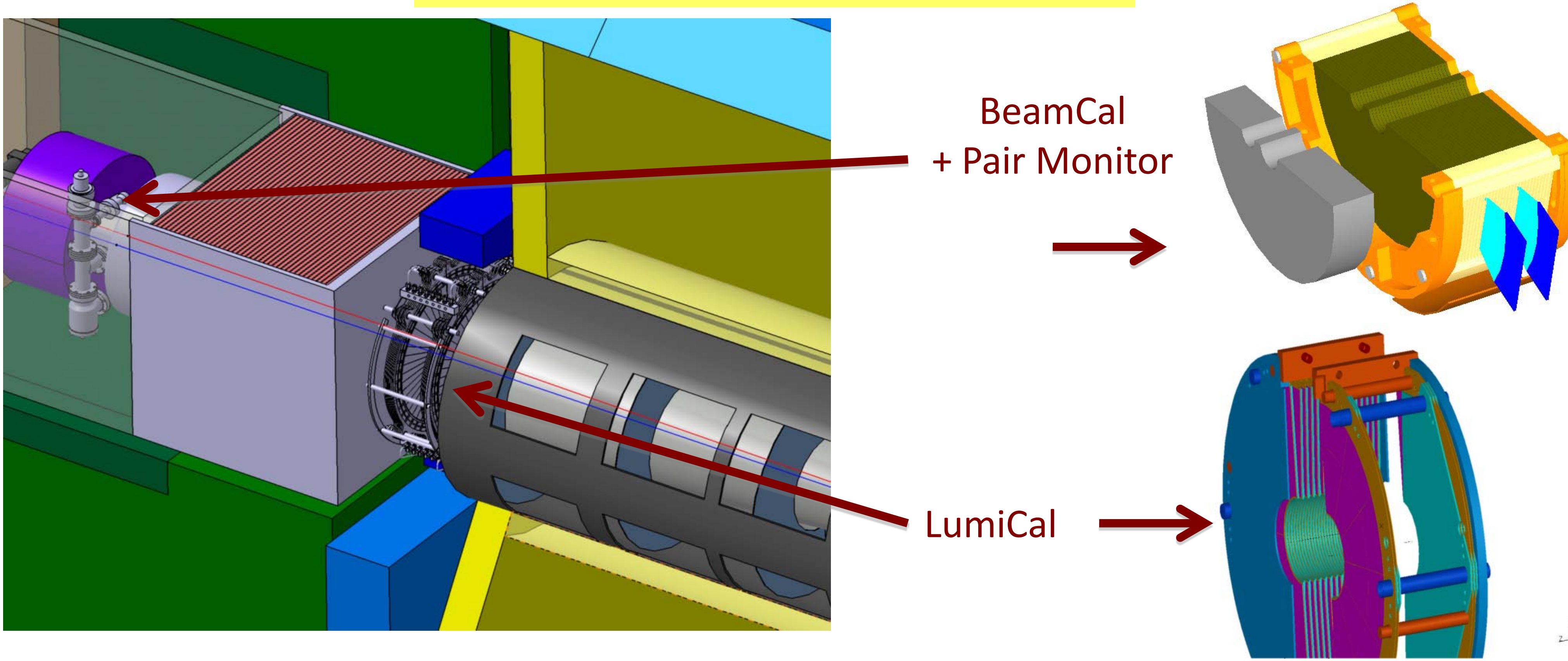
\>> *When will there be a test of power pulsing with B field? For example CDF have had difficulties with wire bonds.*

Test Beam in 3T field has been done this year. No effect on PCB or glue. On Wire bonding ???

\>> *Is power pulsing required or is there an alternative?*

The alternative will be an active cooling inside the detector. (Modify the overall geometry)

Very Forward Instrumentation- Example ILD



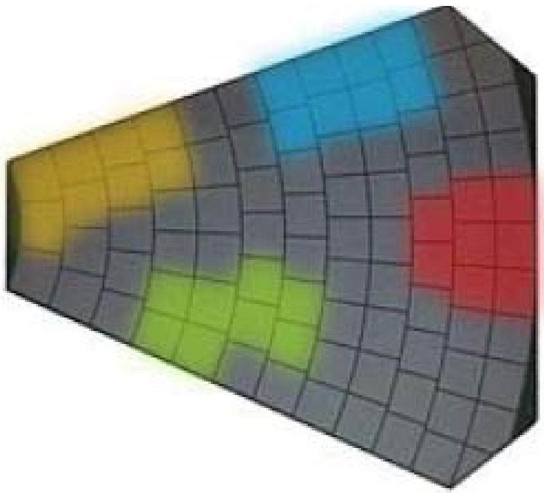
- Ongoing simulations to optimize detector design for
  - precise luminosity measurement,
  - hermeticity (electron detection at low polar angles),
  - assisting beam tuning (fast feedback of BeamCal data to machine)

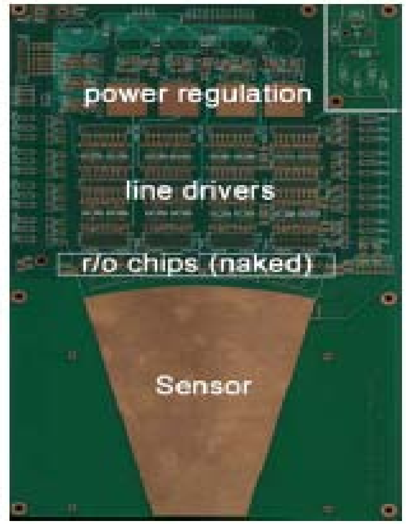
- Challenges: radiation hardness (BeamCal), high precision (LumiCal) and fast readout (both)

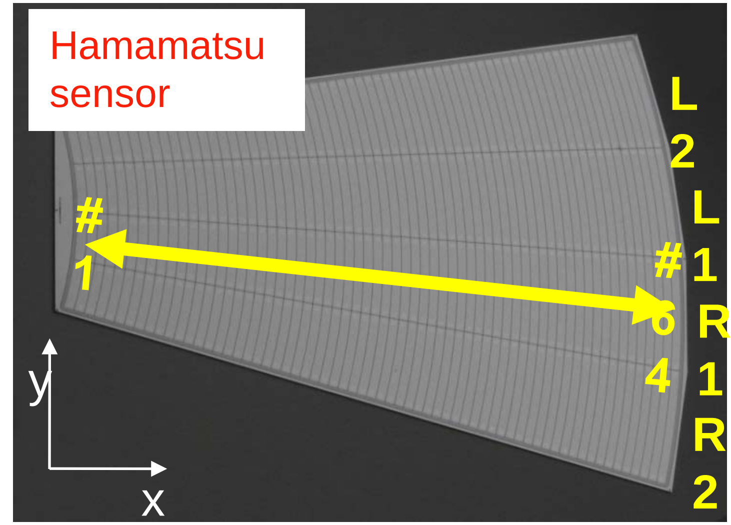
Similar or harder challenges are expected at CLIC

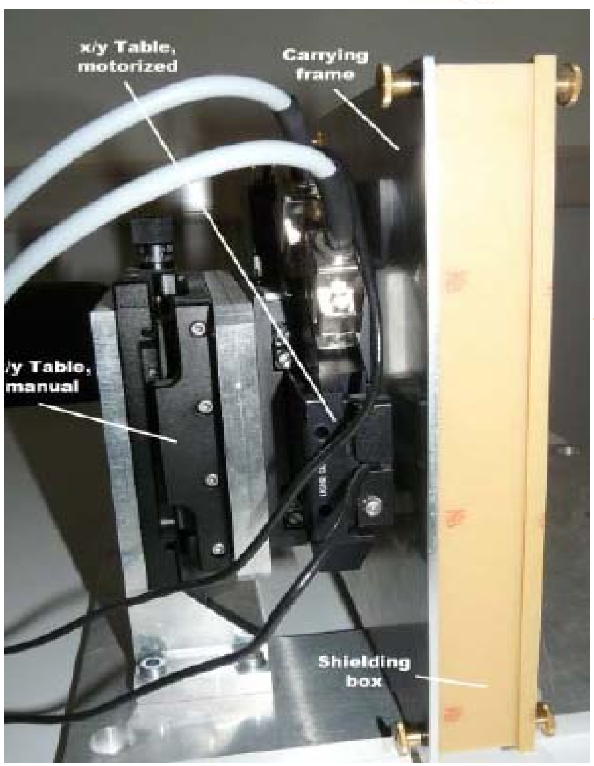
Succesfull test-beam venture in August

Beam 22 at DESY, 4 GeV electrons, sensors equipped with FE electronics from UST Cracow









Stand-by box Device under test

To conclude

Many nice results came and continue to come from R&D and test beam analysis.
Sorry for the results I don't speak here … question of time and my own bias

Yes, we can

.
.
be ready for DBD 2012 to propose AT LEAST one technology which fulfils the requirements

But the times are difficult for the point of view of the resources (funding and manpower)…. whatever the devices concerned by the R&D. The DBD could reflect it …

"L'avenir se construit sur la passion"
Future is built out of passion

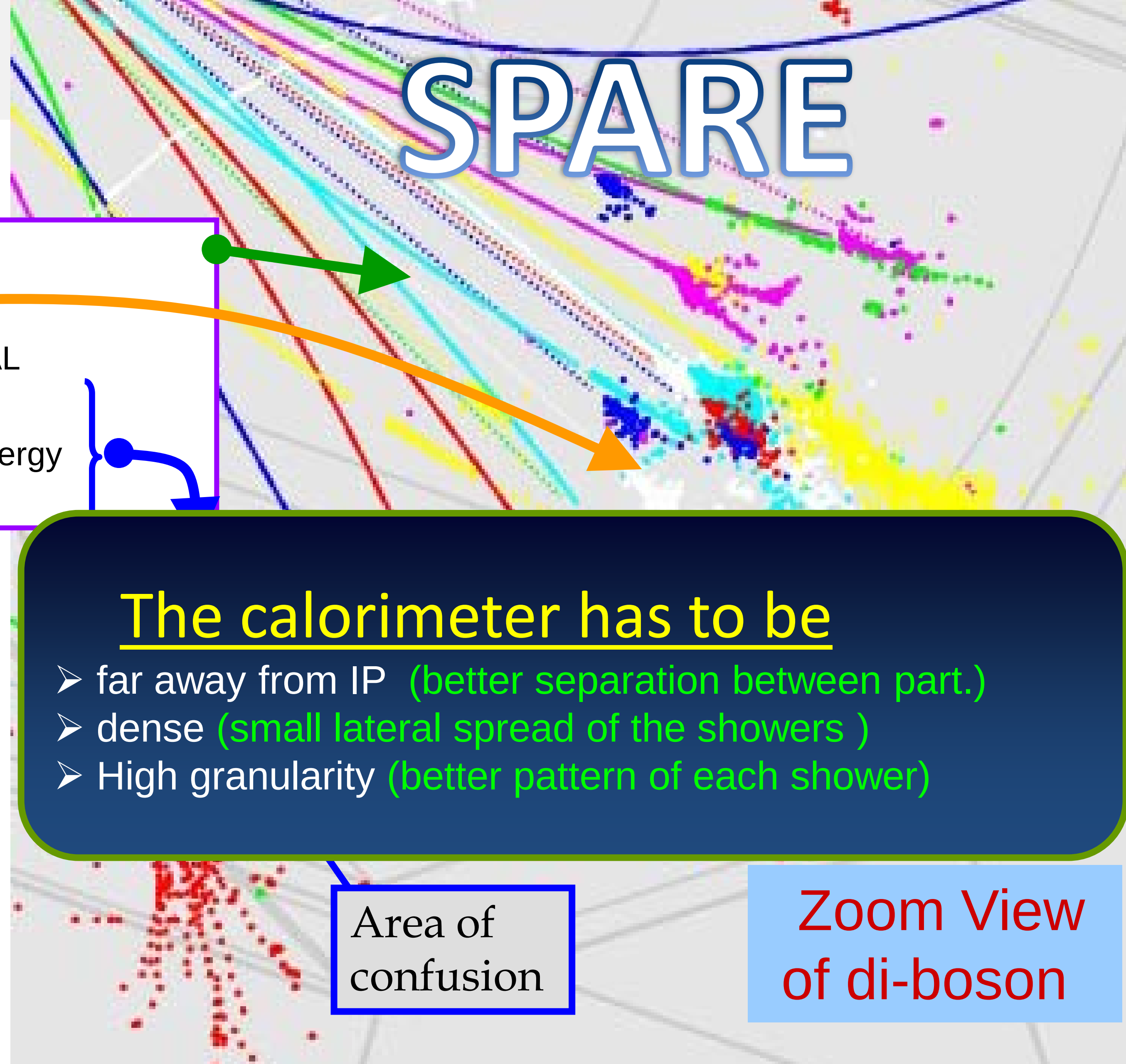
Thanks to
Ties Behnke, Daniel Jeans, Wolfgang Lohman, Roman Poeschl, Jose Repond, Felix Sefkow, Ron Settles, Tohru Takeshita, Henri Videau, Marcel Voss, Marc Winter and of course to all people working on these R&D …

HOW

SPARE

❶ find the charged particles in the tracker
❷ the photon(s) in the ECAL
❸ the neutral hadron(s) in the ECAL, HCAL

Process ❷ and ❸ are possible only if there is no mixing between deposited energy from different particles



The calorimeter has to be

- far away from IP (better separation between part.)
- dense (small lateral spread of the showers)
- High granularity (better pattern of each shower)

Associate the deposited energy With the depositing particle

Quality of the «photo»

- Detector readout in 3D
- Small pixel size
- ECAL AND HCAL inside the coil

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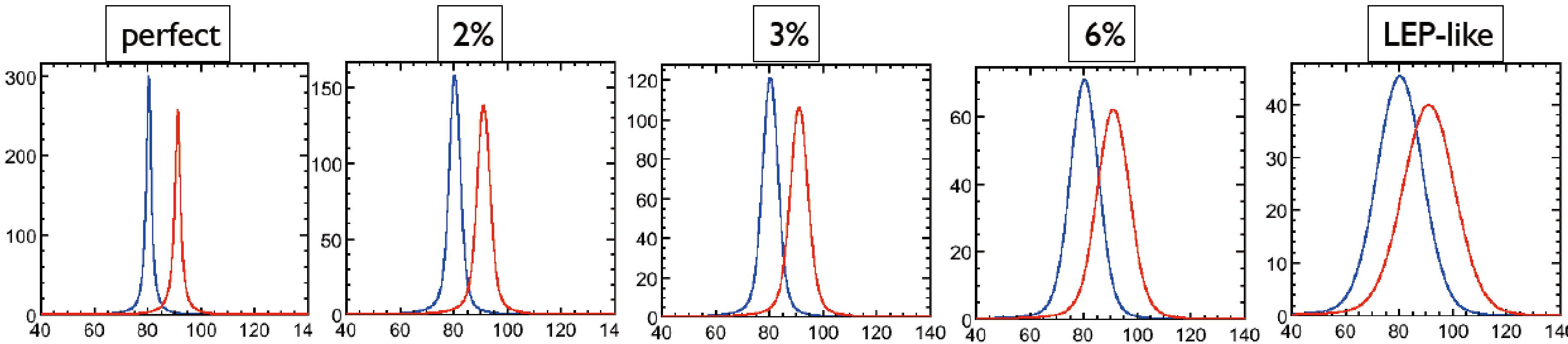
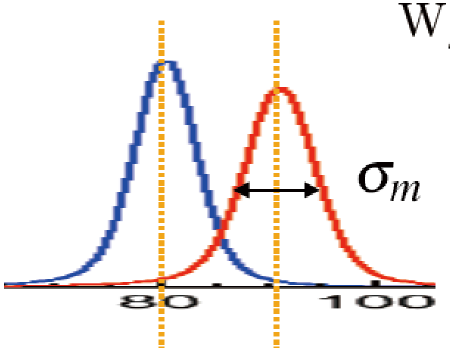
Franck Simon – KEK seminar

Mass Resolution: Requirements for separation

- Width of gauge bosons sets a natural scale for the required resolution



Jet E res.	W/Z sep
perfect	3.1 σ
2%	2.9 σ
3%	2.6 σ
4%	2.3 σ
5%	2.0 σ
10%	1.1 σ



$$\text{W/Z separation} = (m_Z - m_W)/\sigma_m$$

effective gaussian equivalent mass resolution

Efficiency homogeneity studies

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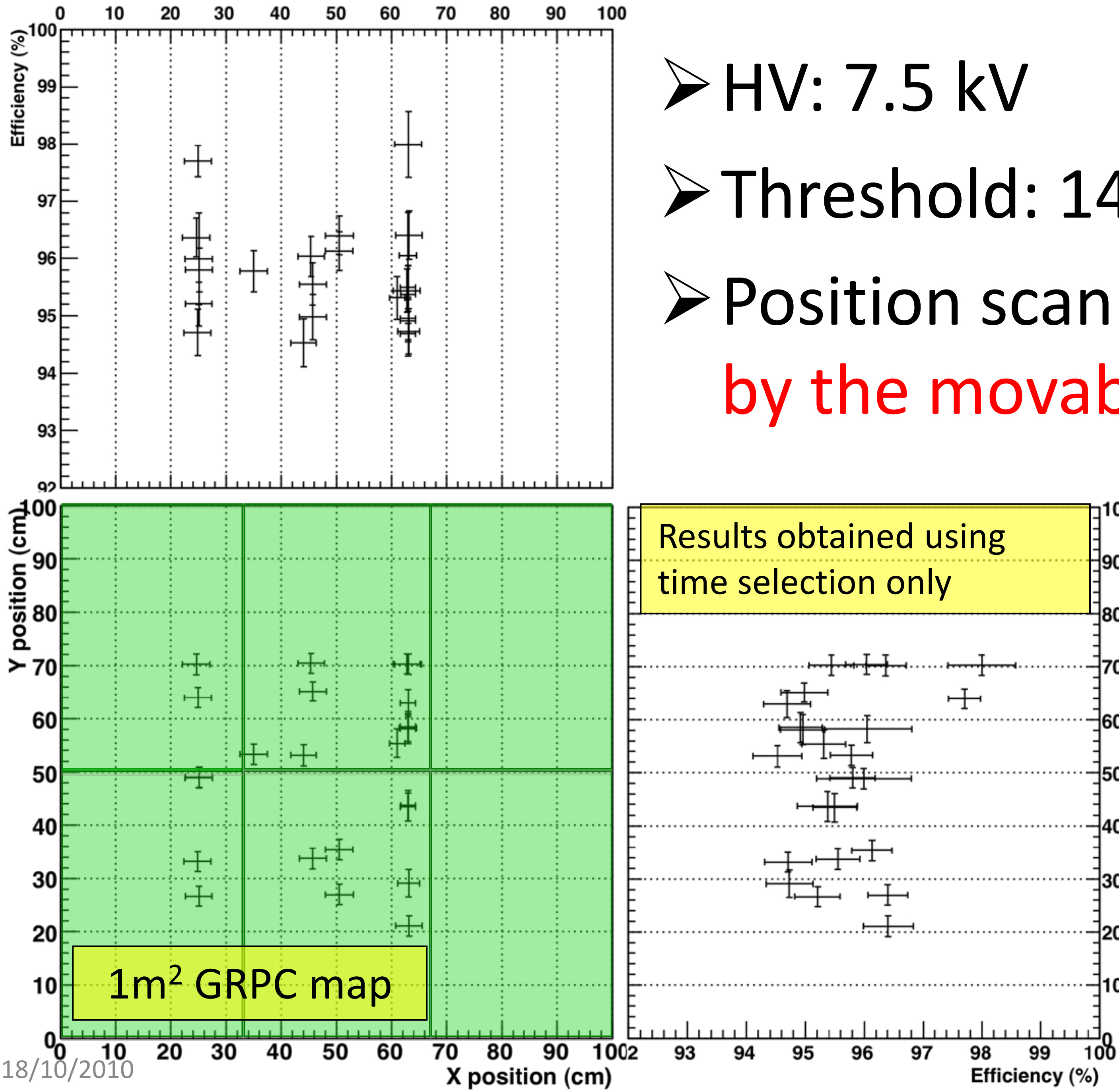
- HV: 7.5 kV
- Threshold: 144 DAC
- Position scan area limited by the movable table.



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EUDET

AIDA

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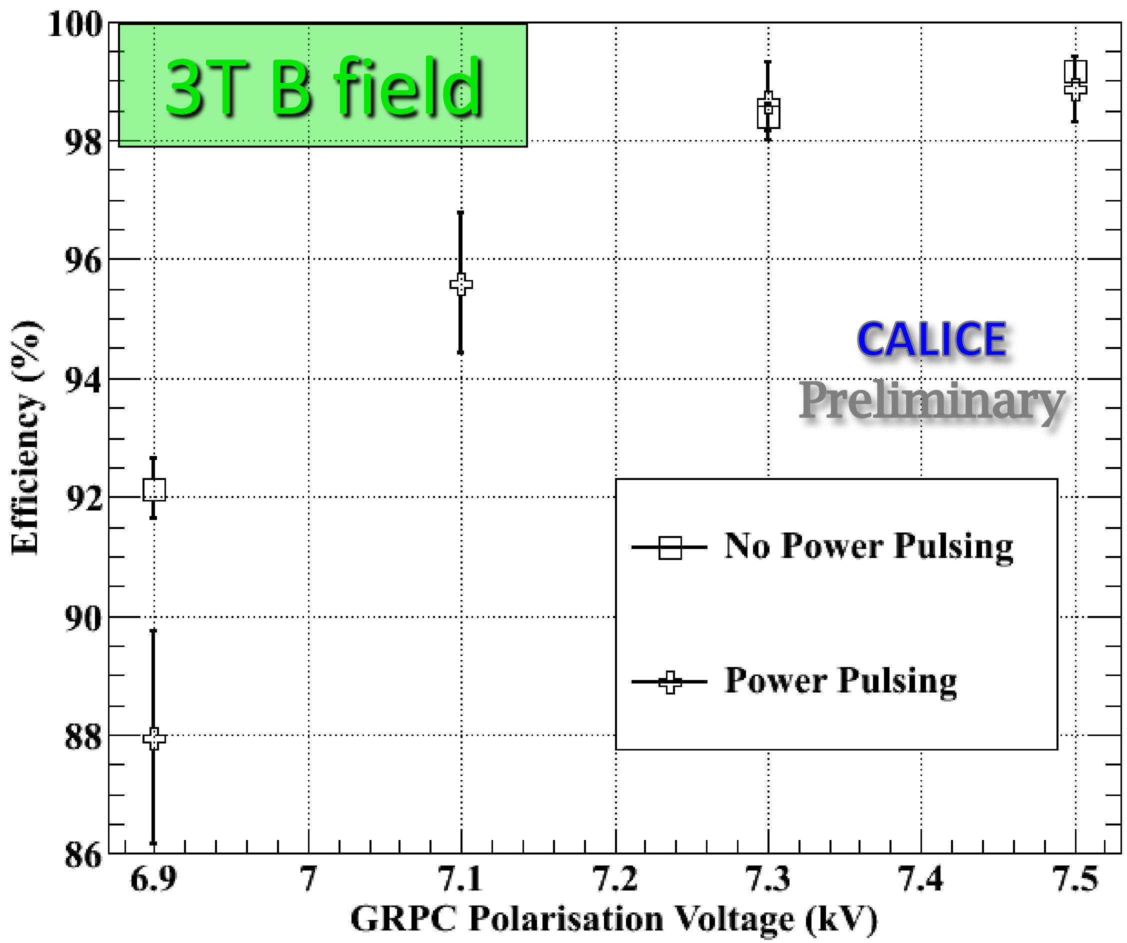

3T B field
CALICE
Preliminary
No Power Pulsing
Power Pulsing
Efficiency (%)
100
98
96
94
92
90
88
86
6.9
7
7.1
7.2
7.3
7.4
7.5
GRPC Polarisation Voltage (kV)

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e+e- ... evt

Is it ...

Selecting the di-boson ?

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Use the masses of the di-jet

Mw ≈ 80 GeV

Mz ≈ 91 GeV

MH > 115 GeV

The selection performance depends on the mass resolution

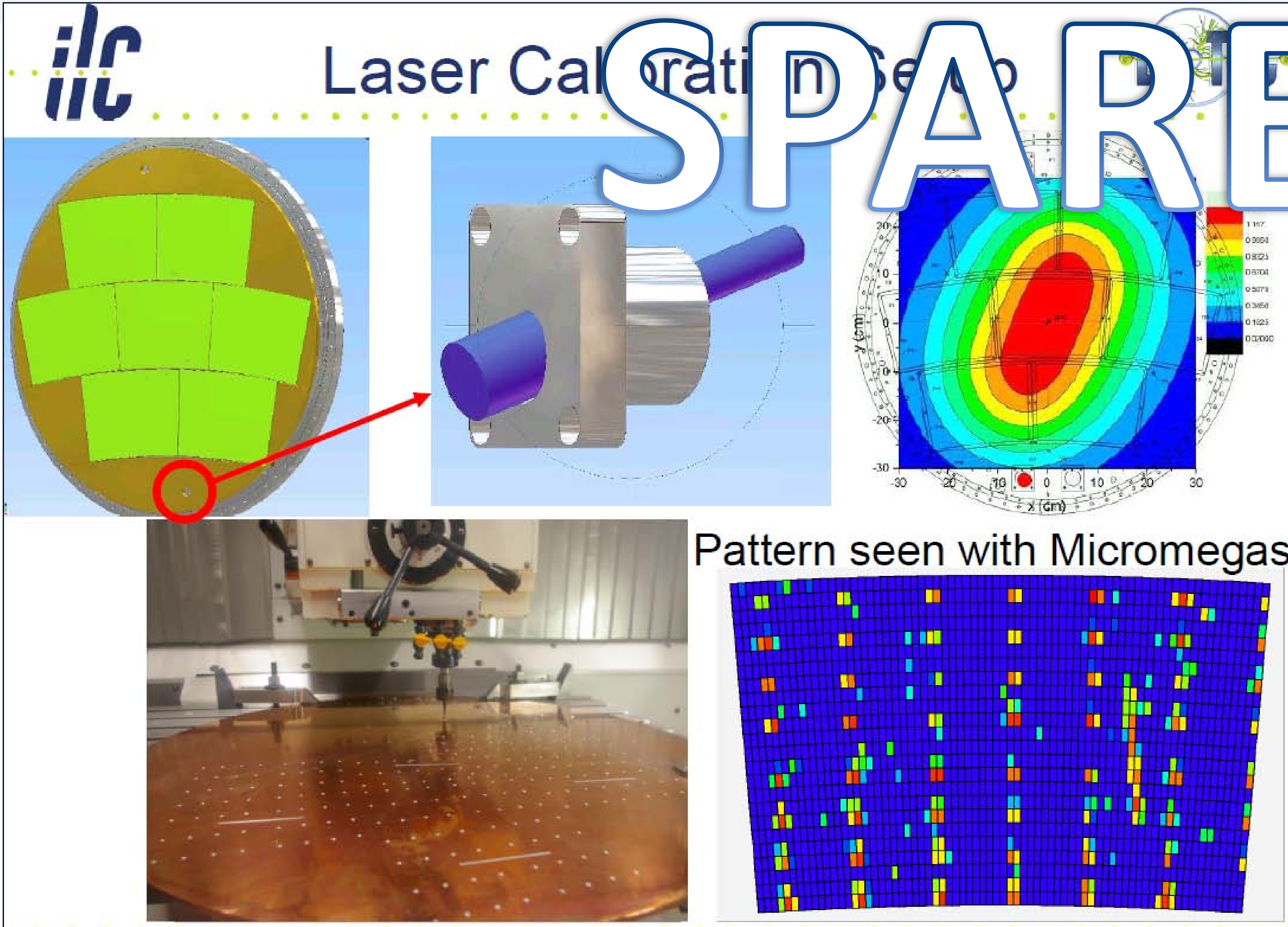
di-jet

The best method is PFA

that is to reconstruct individually

ALL the final state particles

Sort of modern bubble chamber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Pattern seen with Micromegas
x (cm)
y (cm)

End of the TPC