ILD: a Detector for the International Linear Collider

A. Irles* on behalf of the ILD concept group

TIPP2021 - 25th May 2021

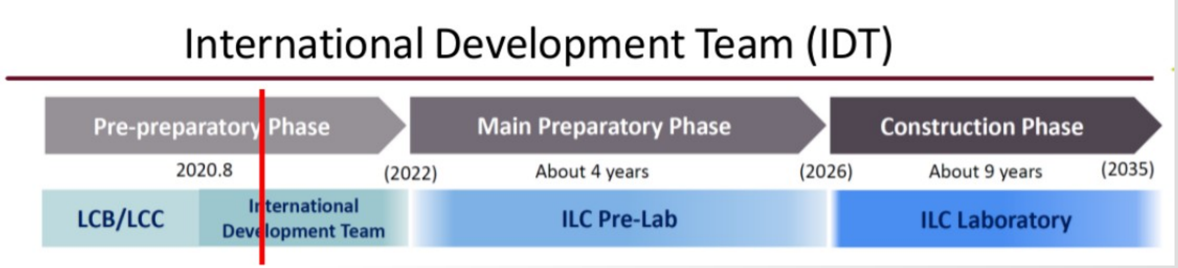
** AITANA group at IFIC - CSIC/UV*

The International Linear Collider

© Rey Hori

- Energy: Z-mass - 1 TeV
- **Electron and positron polarisation**
- TDR in 2013
  - + DBD for detectors
- Initial Energy 250 GeV – *Footprint ~20km*

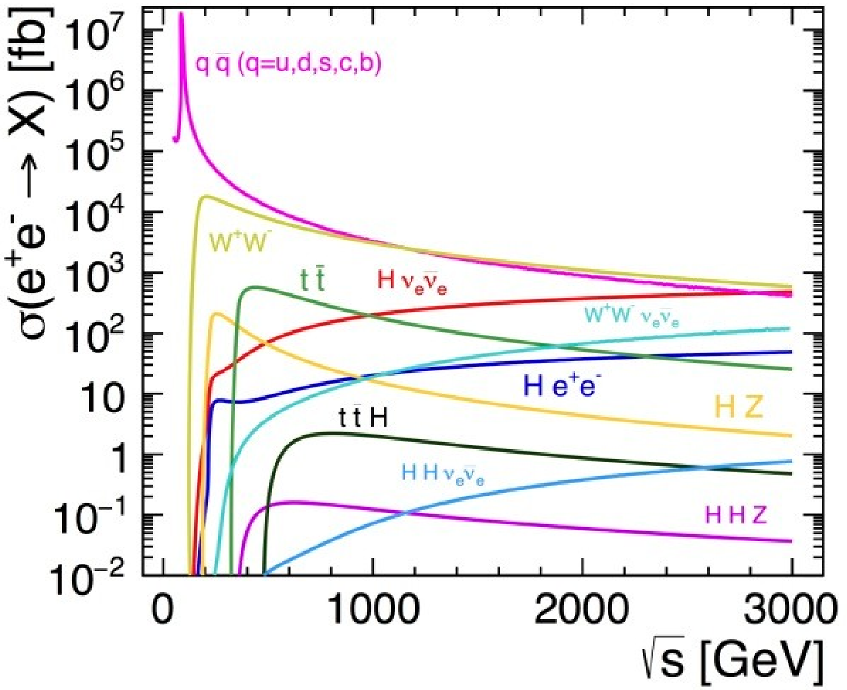
Under discussion in Japanese Government and international community



Higgs factory (and EW, and top-quark and…)

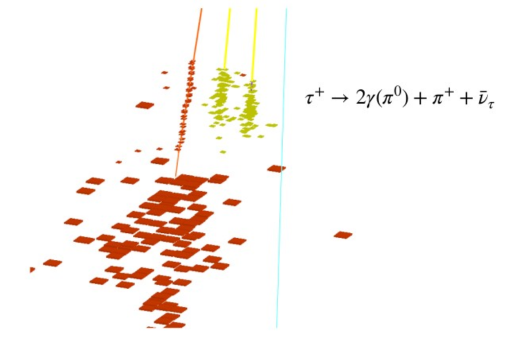
- ▶ **All Standard Model particles within reach of the ILC project**
- ▶ High precision tests of Standard Model over wide range to detect onset of New Physics
  - **Machine settings can be "tailored" for specific processes → straightforward at the ILC**
  - **Centre-of-Mass energy**
  - **Beams polarisation** (±80% e^-, ±30%e^+)

- ▶ Higgs factories but also...
  - **"light" qq factory**
    (and Z-factory at Z-pole)
  - **WW factory**
  - **Top-quark factory**
  - **ttH factory**
  - **…**

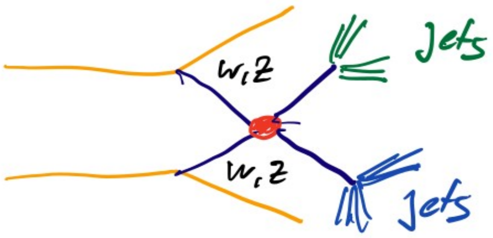


Detector Requirements

- A comprehensive test of the SM and BSM (specially in the Higgs sector) requires unprecedented performance of the detector and reconstruction techniques
- Excellent tracking + flavour tagging + Particle Identificatin
- Single particle separation
- Excellent energy resolution of ~3%



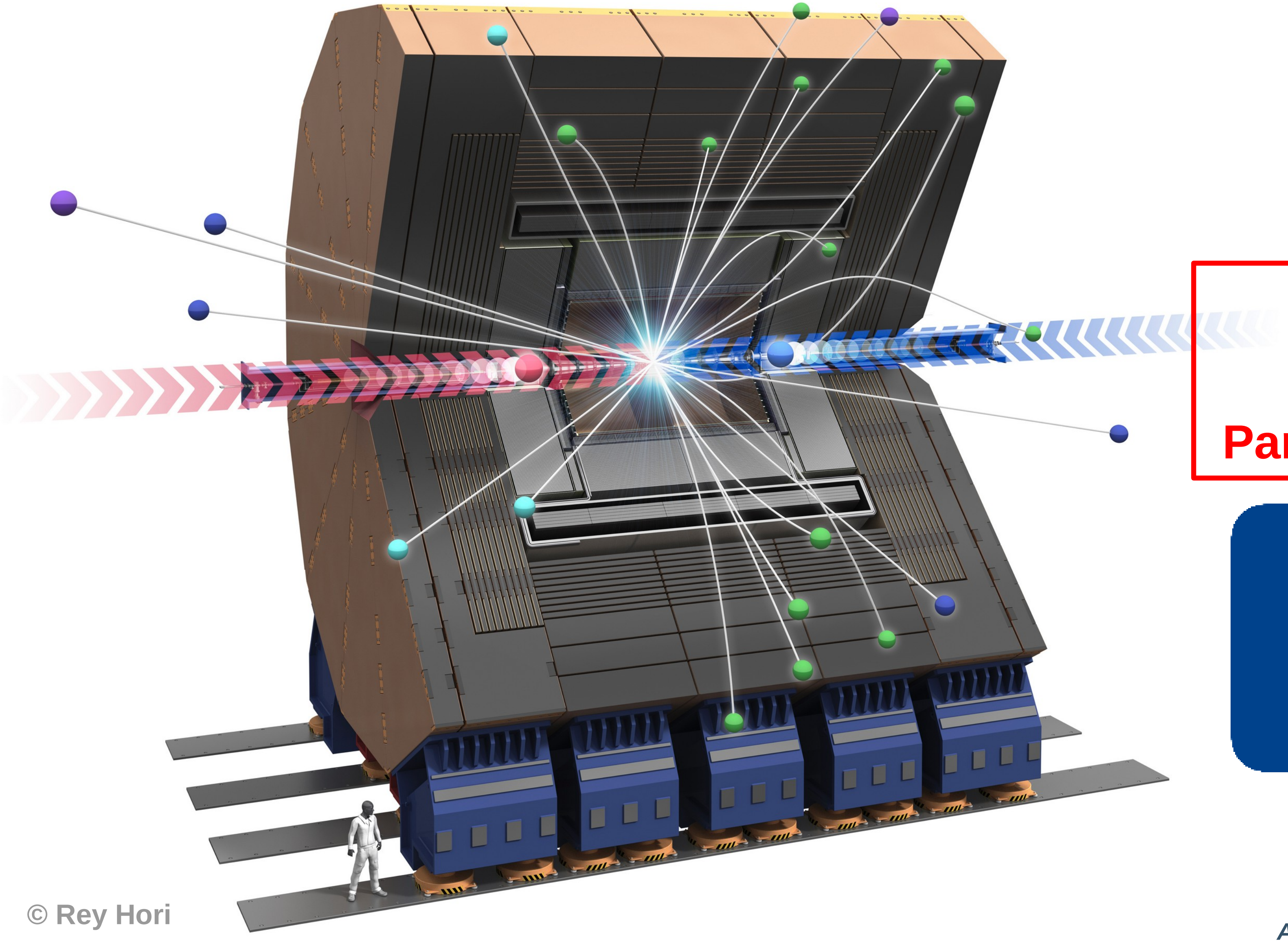
- Results in close-by / overlapping electromagnetic and hadronic showers



How ?

By designing a

Particle Flow Detector



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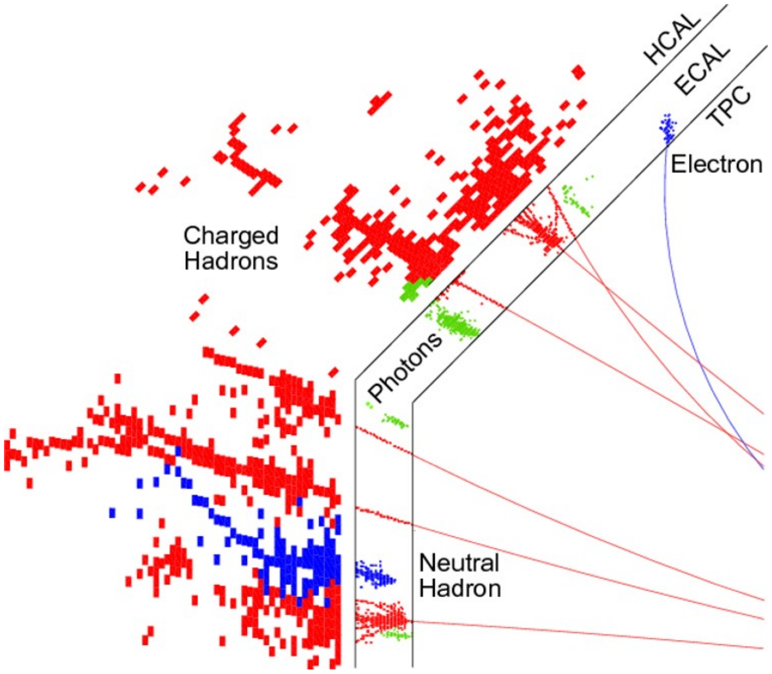
How ?

By designing a

Particle Flow Detector

Particle Flow Concept



Concept

- ▶ Base the measurement on the subsystem with best resolution for a given particle type (and energy)
- ▶ Separation of signals by charge and neutral particles in the calorimeters
- ▶ **Single particle separation**

Technological Challenges

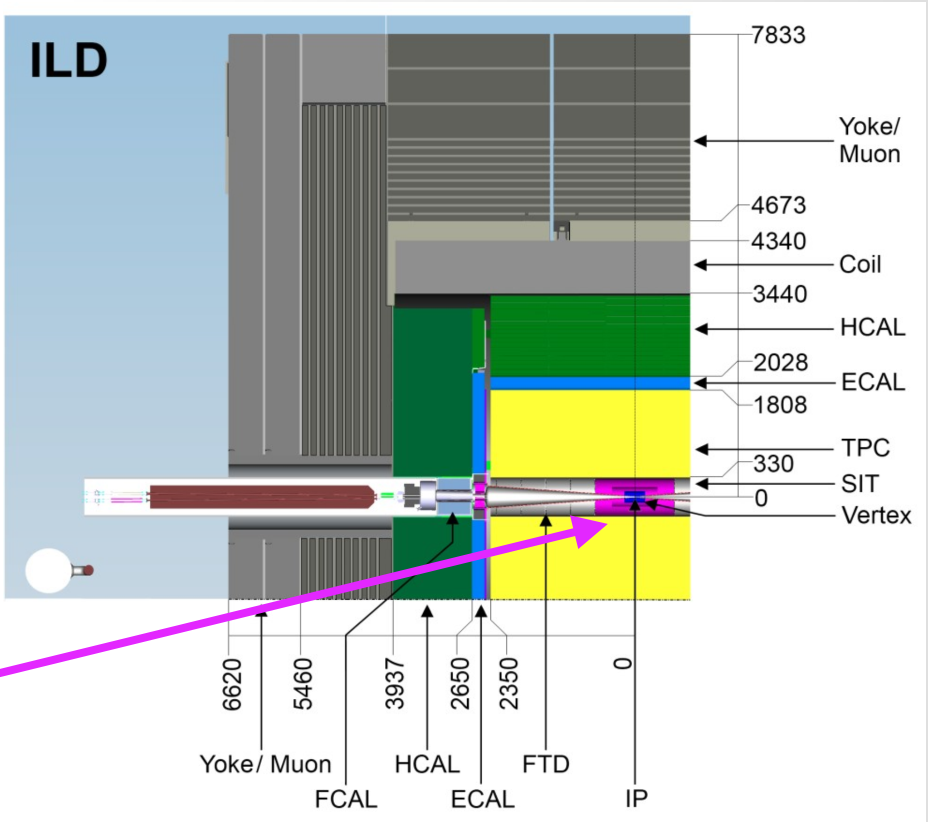
- ▶ Need **extremely granular calorimeters** (100 of millions of cells…!)
- ▶ Require **very low material budget** in front of the calorimeters and **excellent tracking systems**

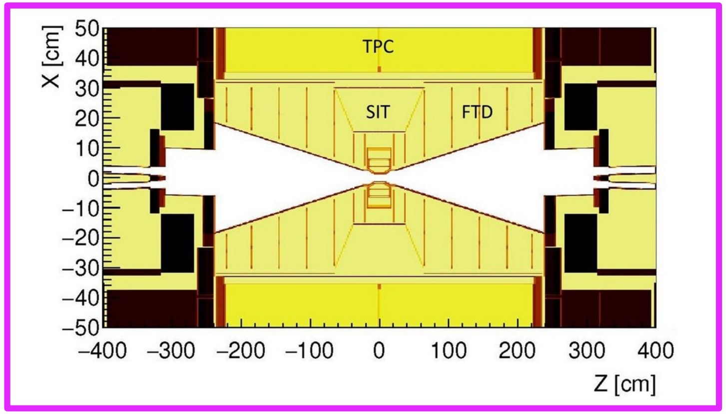
Limitations

- ▶ Complicated topology by (hadronic) showers
- ▶ Overlap between showers compromises correct assignment of calorimeter hits **–> Confusion term**
  - Need to minimize this term as much as possible

Main features of the ILD

- Particle **flow as the key design driver**
- **Excellent vertexing very close to the IP**
- **Hybrid tracking system** optimized for excellent resolution at high energies and ultimate efficiency over a broad momentum range
- **High granular calorimetry**
- Up to and including the HCAL, **all inside solenoidal coil of 3-4 T**





Optimized layout Particle Flow Detector

From key requirements from physics:

- **p_t resolution** (total ZH x-section)

  $\sigma(1/p_t) = 2 \times 10^{-5}\ \mathrm{GeV}^{-1} \oplus 1 \times 10^{-3} / (p_t \sin^{1/2}\theta)$

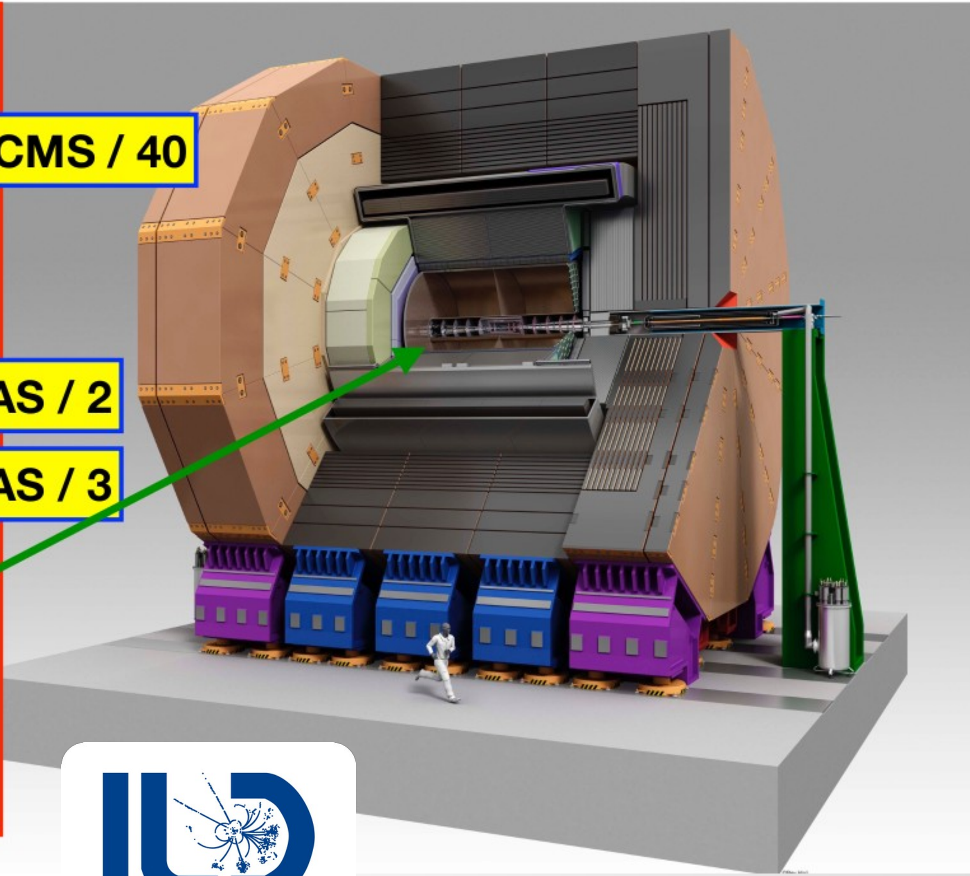
- **vertexing** ($H \rightarrow bb/cc/\tau\tau$)

  $\sigma(d_0) < 5 \oplus 10 / (p[\mathrm{GeV}] \sin^{3/2}\theta)\ \mu m$

- **jet energy resolution** ($H \rightarrow$ invisible) 3-4%
- **hermeticity** ($H \rightarrow$ invis, BSM) $\theta_{min} = 5$ mrad

To key features of the detector:

- **low mass tracker:**
  - main device: **Time Projection Chamber** (dE/dx !)
  - add. silicon: eg VTX: 0.15% rad. length / layer)
- **high granularity calorimeters**
  optimised for particle flow



~x1000 more ro cells than LHC exps.
~x10-100 more than HL-LHC exps.

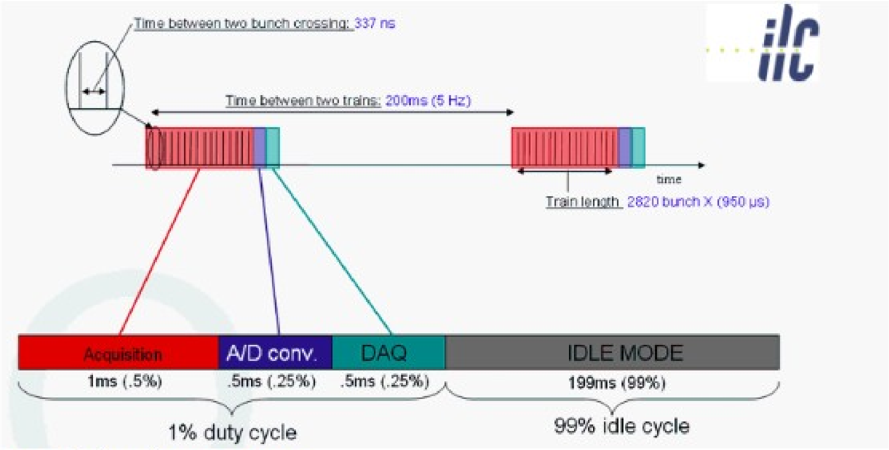
ILC offers a favorable experimental framework

Linear Lepton Colliders favor fully optimized PFA detectors

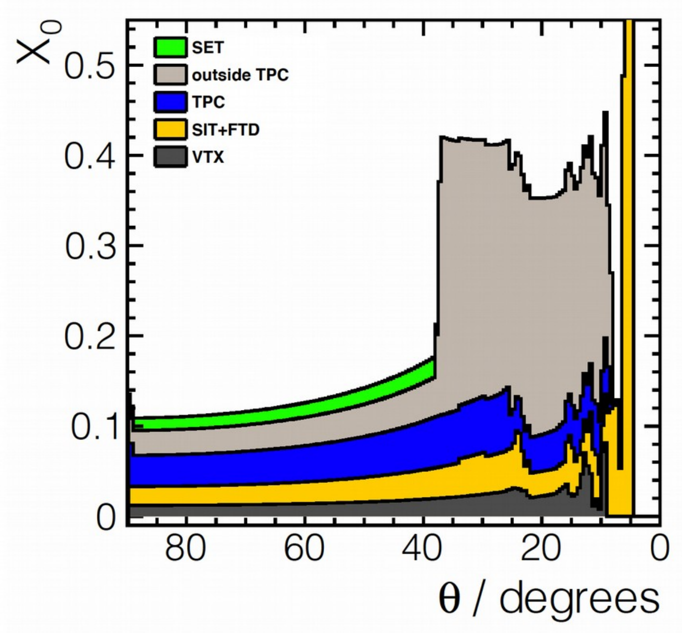
▶ Possible since experimental environment at ILC very different from LHC/LEP:

- much smaller beam spot and beam pipe (first tracking layer at ~1cm of the IP)
- much lower backgrounds
- much less radiation
- **Pulsed beam structure**

Power pulsed electronics → low material budget !
triggerless operation ! –> ALL events are recorded



N.B. Final numbers may vary

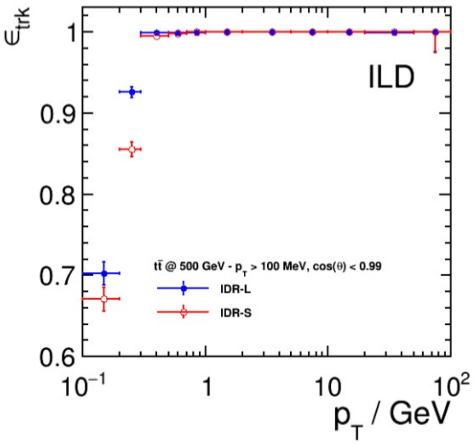


The ILD performance

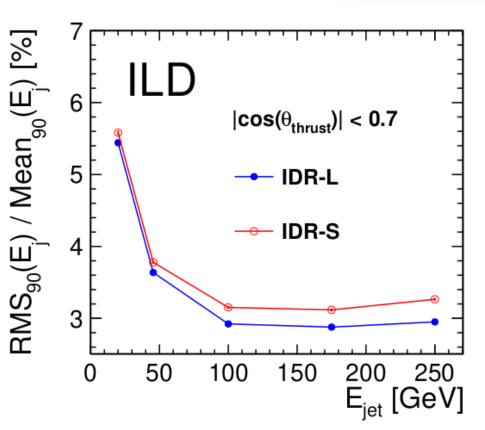
Different ILD models have been optimized to maximize the performance:

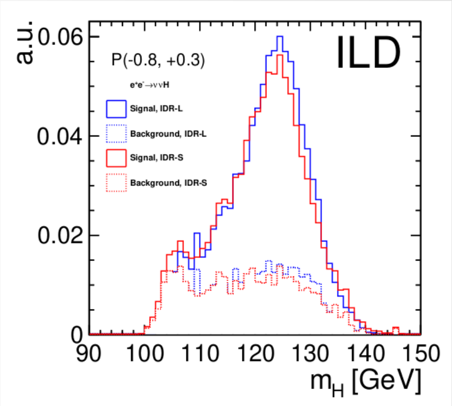
Full simulation & realistic reconstruction

Tracking efficiency

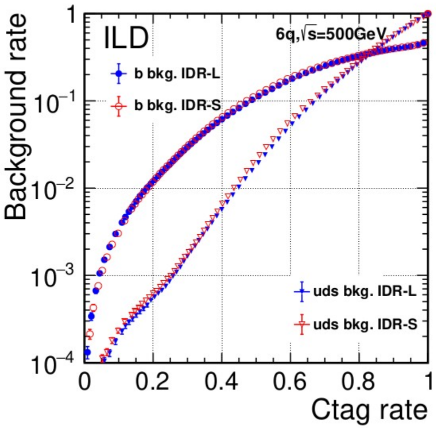


Jet Energy resolution



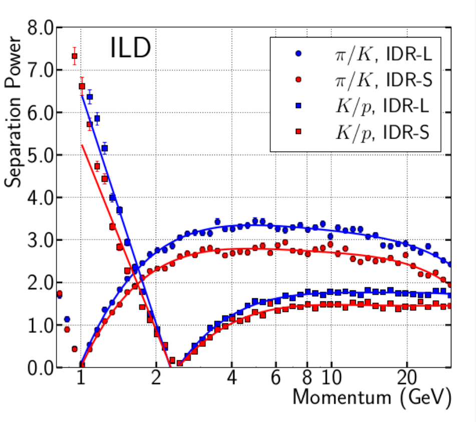


Flavour Tagging

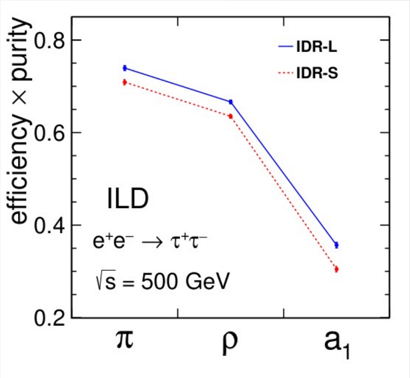


Particle ID

jet charge measurement



Tau Decay ID

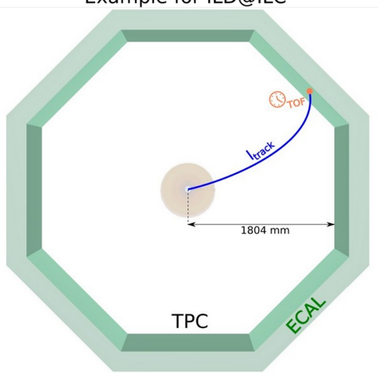


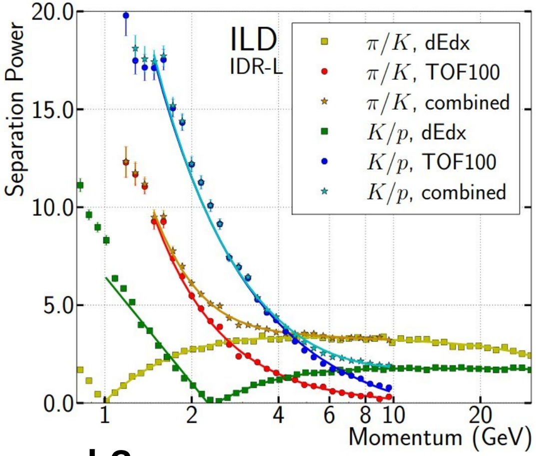
The ILD performance: timing ?

TOF in the ECAL – Particle ID

- ▶ "Standard" silicon sensors could reach O(100-300ps)
- ▶ LGAD sensors could get us to O(10ps) Drawback: high power consumption.

Example for ILD@ILC



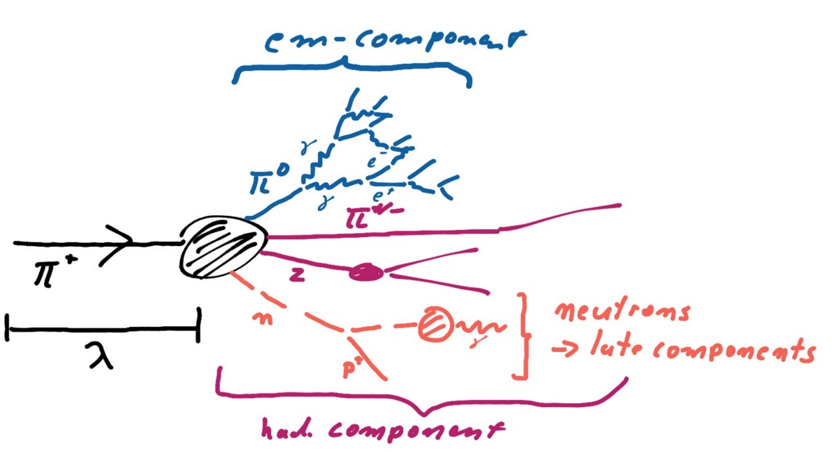


Impact in the physics reach?

- ▶ Could be a game changer for s-quark measurements
  - Z/γ/Z' → $s\bar{s}$ or **H → $s\bar{s}$**

Timing measurements for shower developments

- ▶ Neutral and slow components
  - Require ~ns precision
  - Reachable today with "standard" silicon, scintillators calorimeters
- ▶ ~0.1 ns scale: near the corner
- ▶ An even lower with GRPC (20ps)



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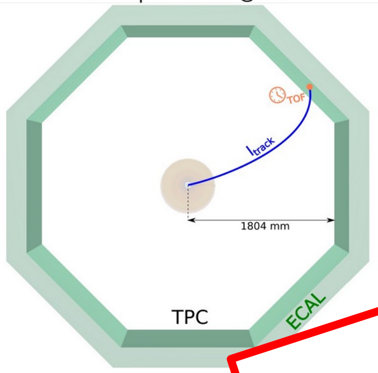

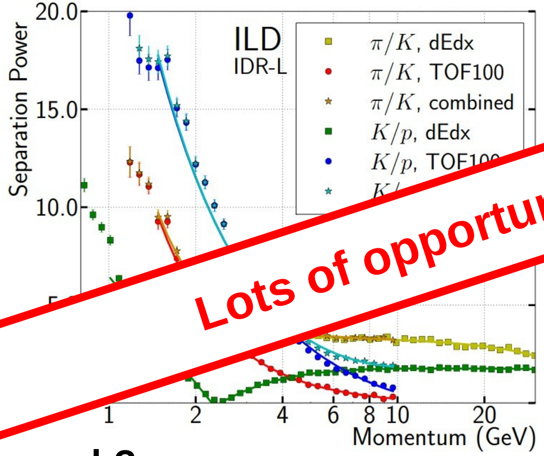

Lots of opportunities in this field

Impact in the physics reach?

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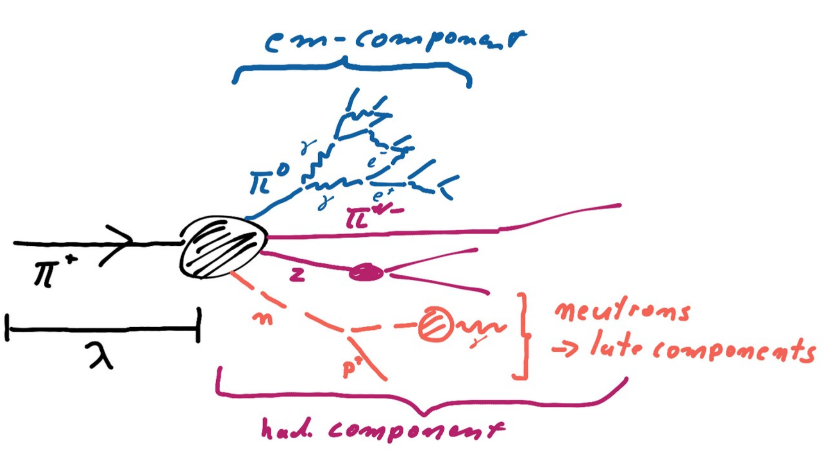


Status of the R&D

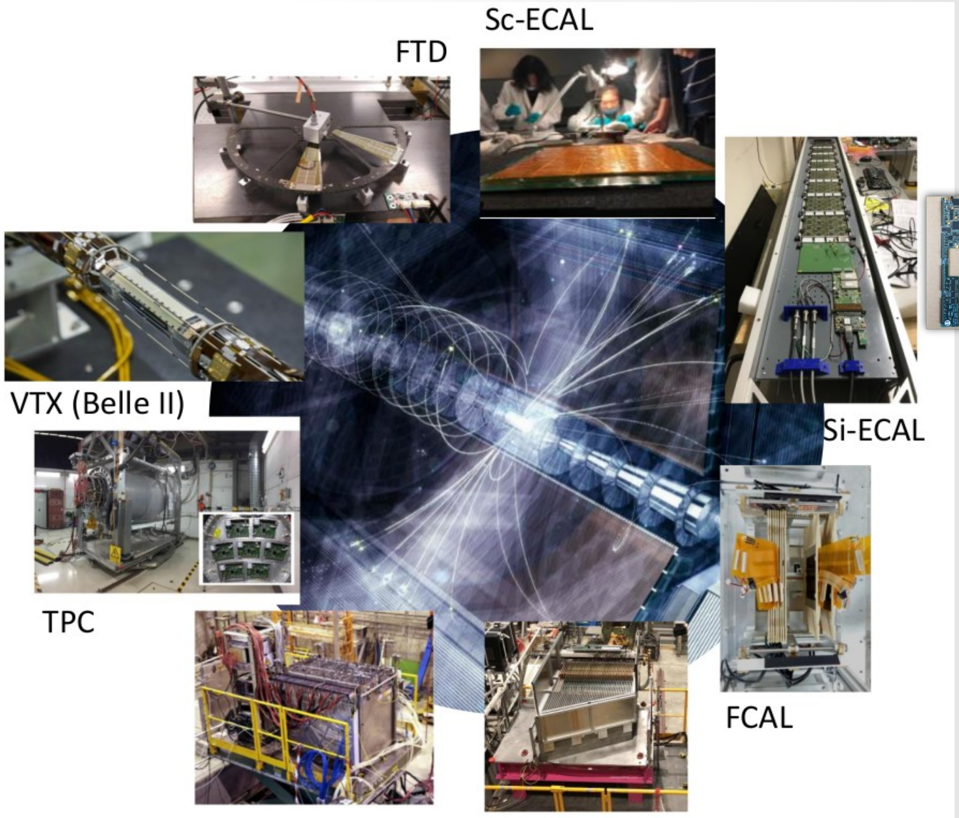
R&D status

- ILD has a concept of the detector,
  - well defined
  - with technological options where sensible

- The main components of ILD
  - have been validated and beam-tested.

- A coherent System design has been developed.

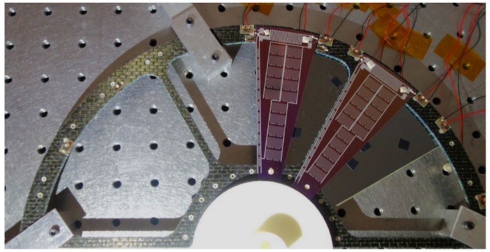
Application of our technologies: CMS Calo upgrade, Belle VTX, T2K TPC, ALICE TPC

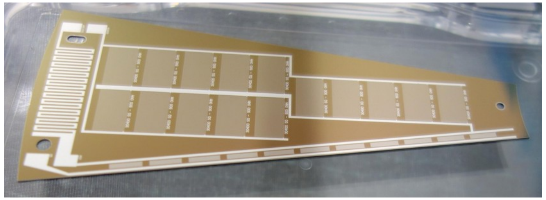


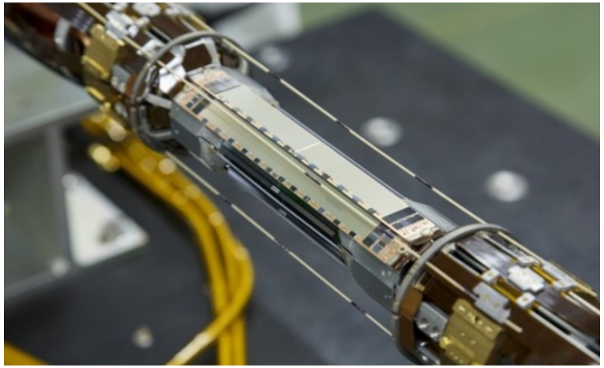
Slide borrowed from T. Benhke (ILD spokeperson)

Silicon Tracking Systems: R&D status

Forward Tracking
Petal Thermomechanical mock-up

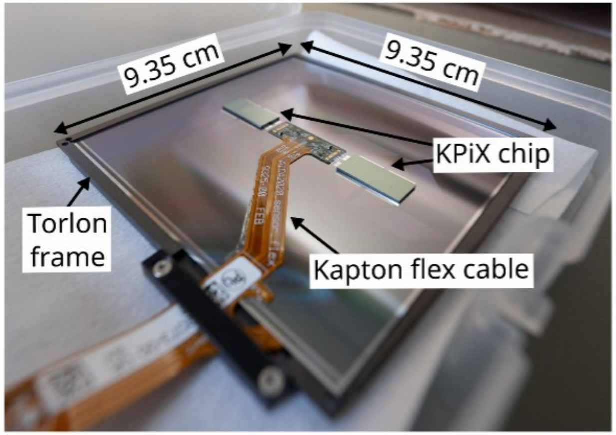






DEPFET VXD @ Belle2

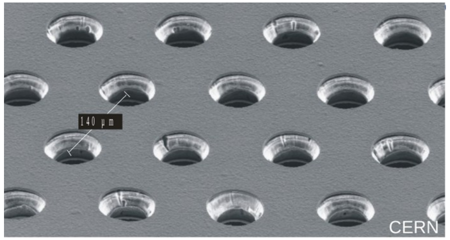
- **Silicon tracking conceptual studies**
  - VTX extensive technology studies
- **Several technology options remain open**
  - CMOS / FPCCD / DEPFET / 3D-integrated / SOI

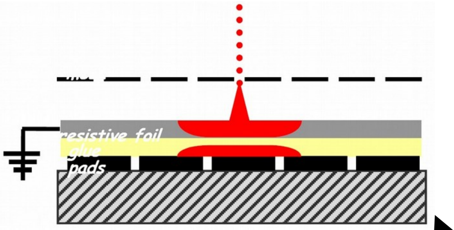


microstrip sensor

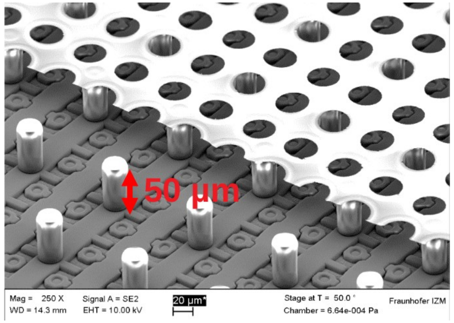
TPC Tracking System: R&D status

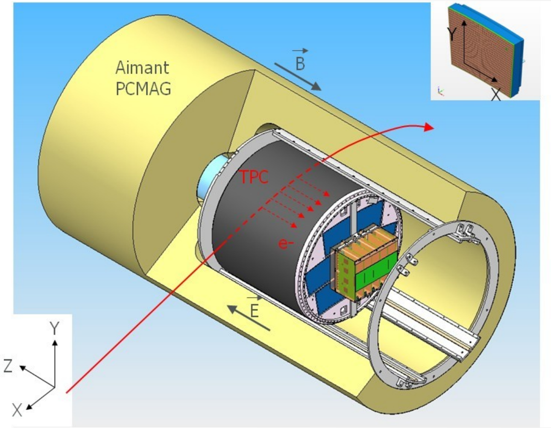
- **Three baseline technologies**
- **GEMs**: copper-insulator- copper sandwich, with holes

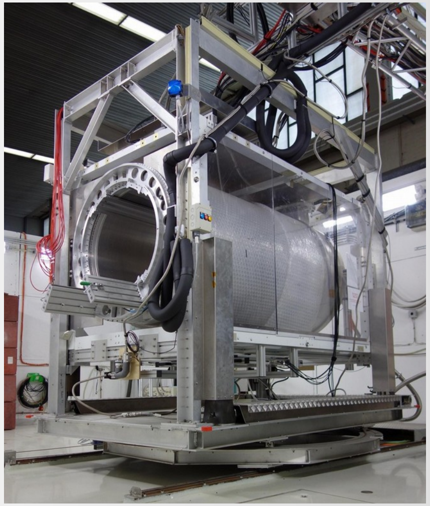


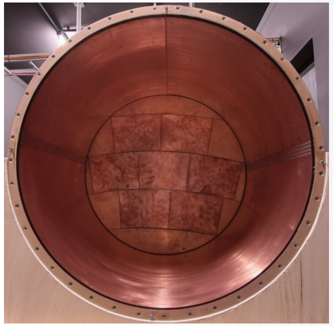


- Resistive Micromegas:
- GridPix







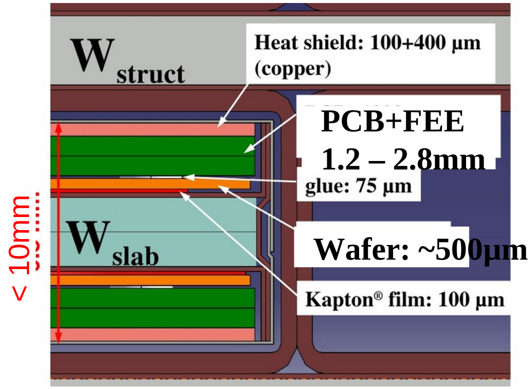


PCMAG: B < 1.2 T,
bore diameter: 85 cm
Electron test beam: E = 1- 6 GeV

Large Prototype has been built to compare different detector readouts under identical conditions and to address integration issues

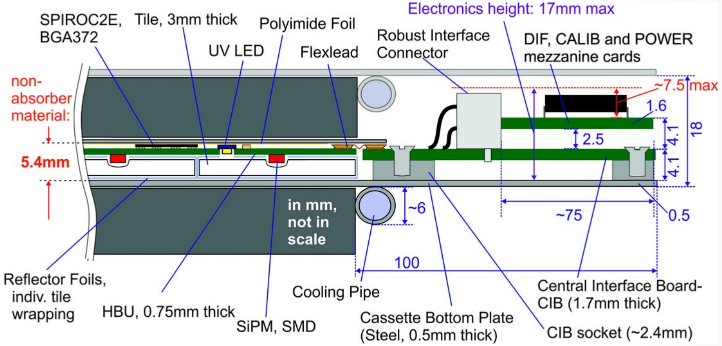
HG Calorimetry: Technological solutions I

SiW Ecal



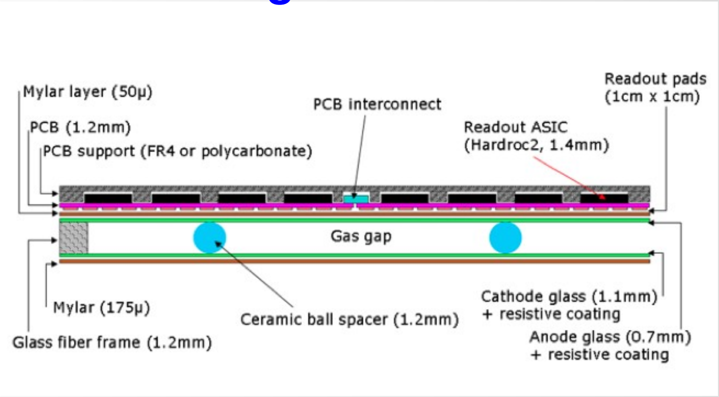
Semi-conductor readout
Typical segmentation: 0.5x0.5 cm^2

Analogue Scintillator HCAL and ECAL



Optical readout
Typical segmentation: 3x3cm^2

Semi Digital HCAL



Gaseous readout
Typical segmentation: 1x1cm^2

Integrated front end electronics

No drawback for precision measurements ***NIM A 654 (2011) 97***

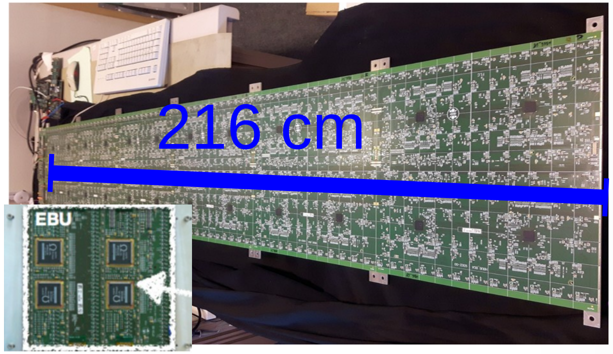
Calorimeter for ILC

HG Calorimetry: Technological solutions II

SiW Ecal

Semi-conductor readout

Analogue Hcal and Scintillator Ecal



Optical readout

Semi-digital Hcal

- **Realistic detector dimensions**
  - **Structures of up to 3m in length (more than 10000 cells)**
  - With compact external components
- Challenge for the power pulsing techniques (for the power consumption management)

CALICE Calorimeter for ILC

HG Calorimetry: Technological solutions II

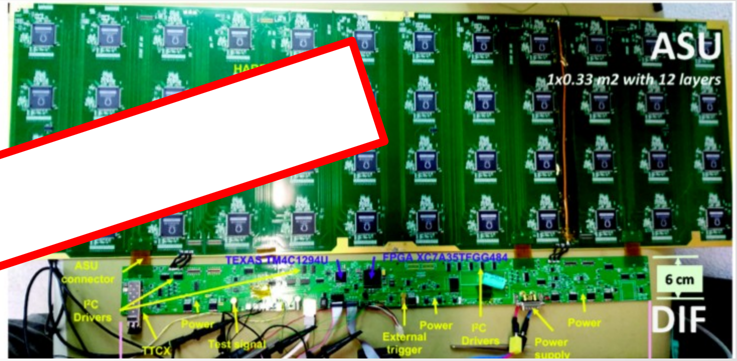
SiW Ecal

Semi-conductor reado

Analogue Hcal and Scintillator Ecal

ptical readout

Semi-digital Hcal



VERY LONG DETECTORS

istic detector dimensions

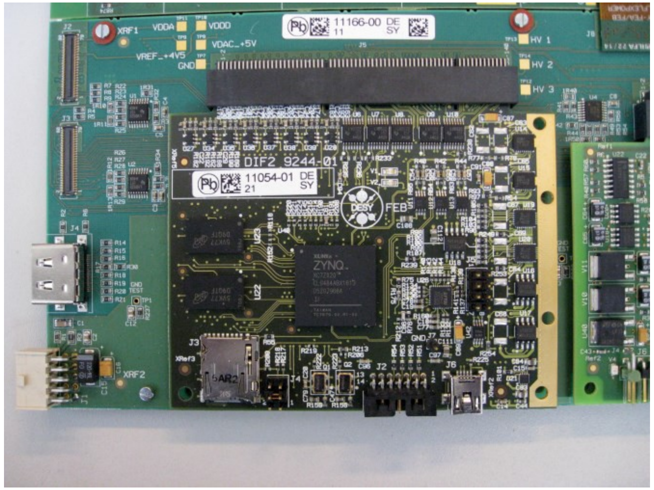
- Structures of up to 3m in length (more than 10000 cells)
- With compact external components

- Challenge for the power pulsing techniques (for the power consumption management)

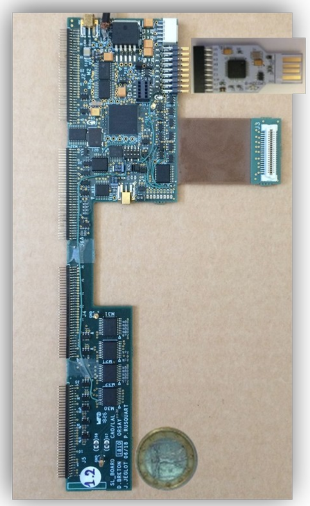
Calorimeter for ILC

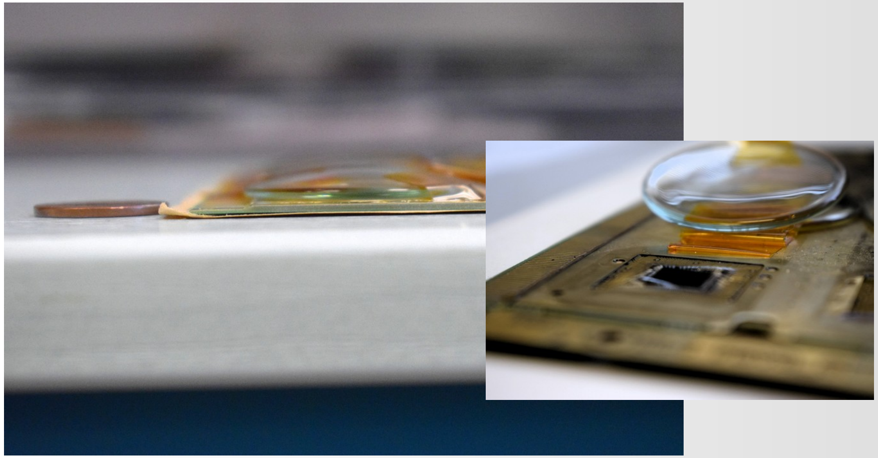
HG Calorimetry: Technological solutions III

Current detector interface card - AHCAL



Current detector interface card and thin detection unit – SiW Ecal





Current detector interface card - SDHCAL

- “dead space free” granular calorimeters put **tight demands on compactness**
- Current developments within **CALICE meet these requirements**

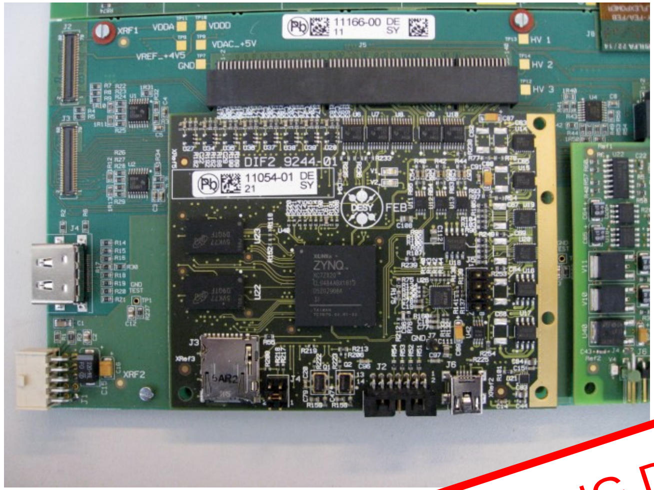
Unique successes in worldwide detector R&D

- Can be applied/adapted wherever compactness is mandatory
- Components will/**did already go through scrutiny** phase in beam test

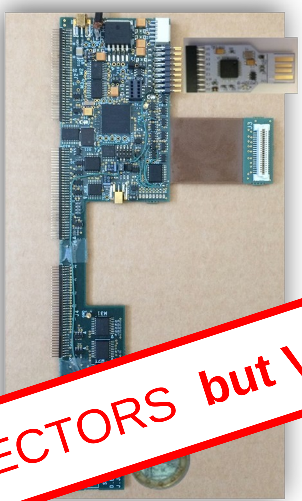
Calorimeter for ILC

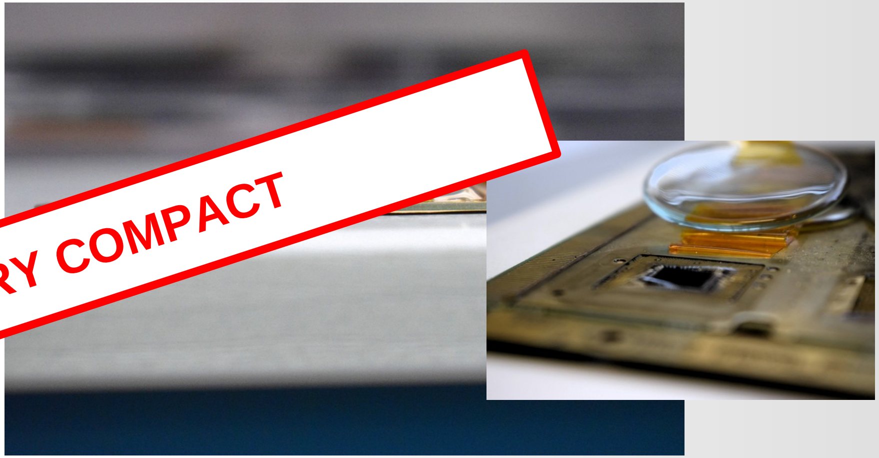
HG Calorimetry: Technological solutions III

Current detector interface card - AHCAL



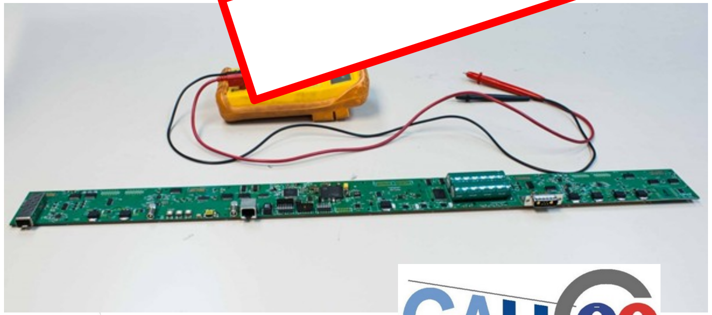
Current detector interface card and thin detection unit – SiW Ecal





LONG DETECTORS but VERY COMPACT

Current detector i... HCAL



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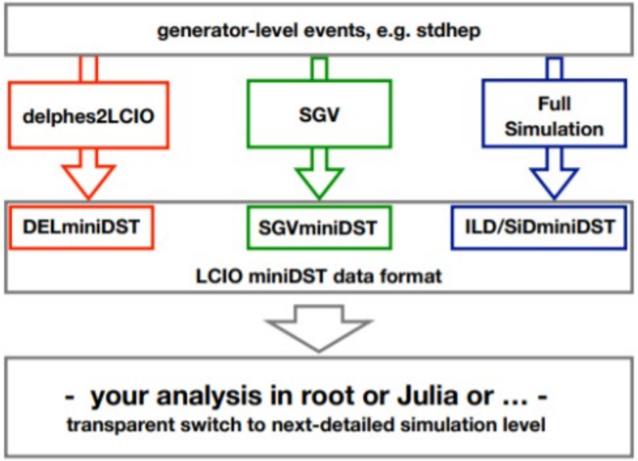
CALICE Calorimeter for ILC

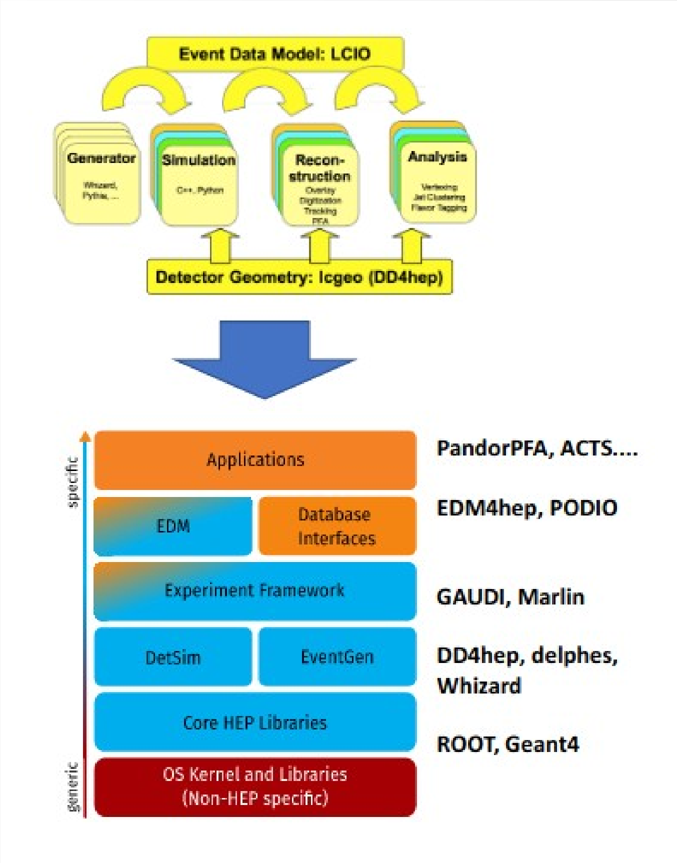
Software

ILD has done a lot on the software and reconstruction side:

- ▶ We are a central player in pushing community wide software solutions in particular with iLCSoft (LCIO, DD4hep, etc) developed over 15 years
- ▶ We are collaborating with other communities (linear, circular, FCC-hh) to modernize our software stack: **key4hep** (DD4hep, EDM4hep,…)

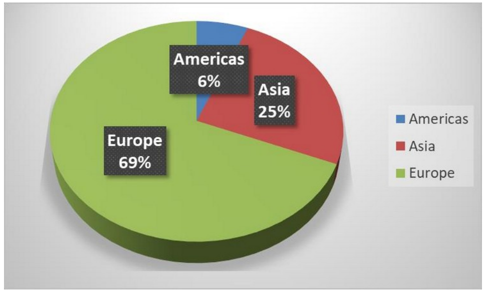
Accessing ILD simulated data





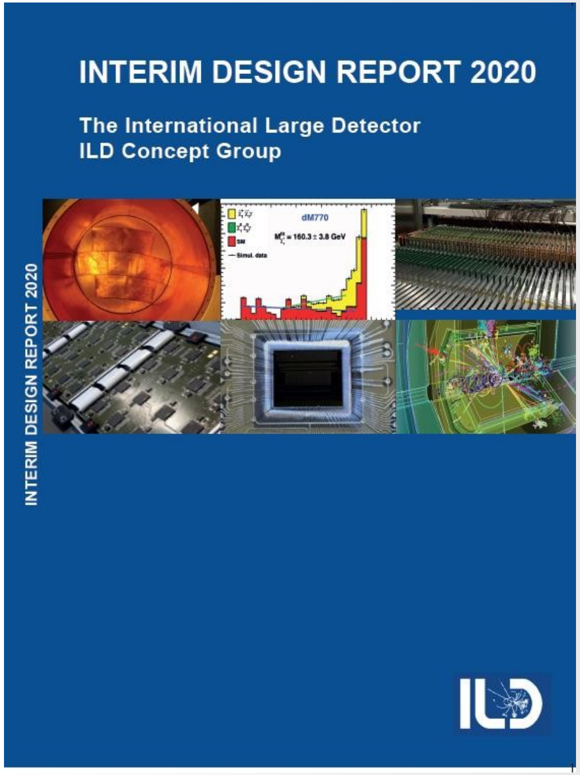
The ILD status: Interim Design Report

The work of ILD over the last years
has been documented in the IDR
and published this year.
Signed by 302 authors from 62 institutes



What promising direction of R&D do we see to further improve ILD

- Timing
- Forward
- ..
- Technology scouting



https://arxiv.org/abs/2003.01116

The ILD concept group

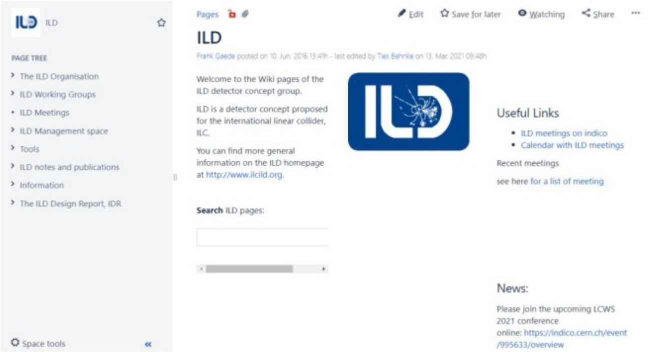
Very exciting moment to join ILD

Joining ILD

We welcome new members

- No resource commitments needed
- Key contributions are possible in many areas
- Full participation in the shaping of the ILD program and future

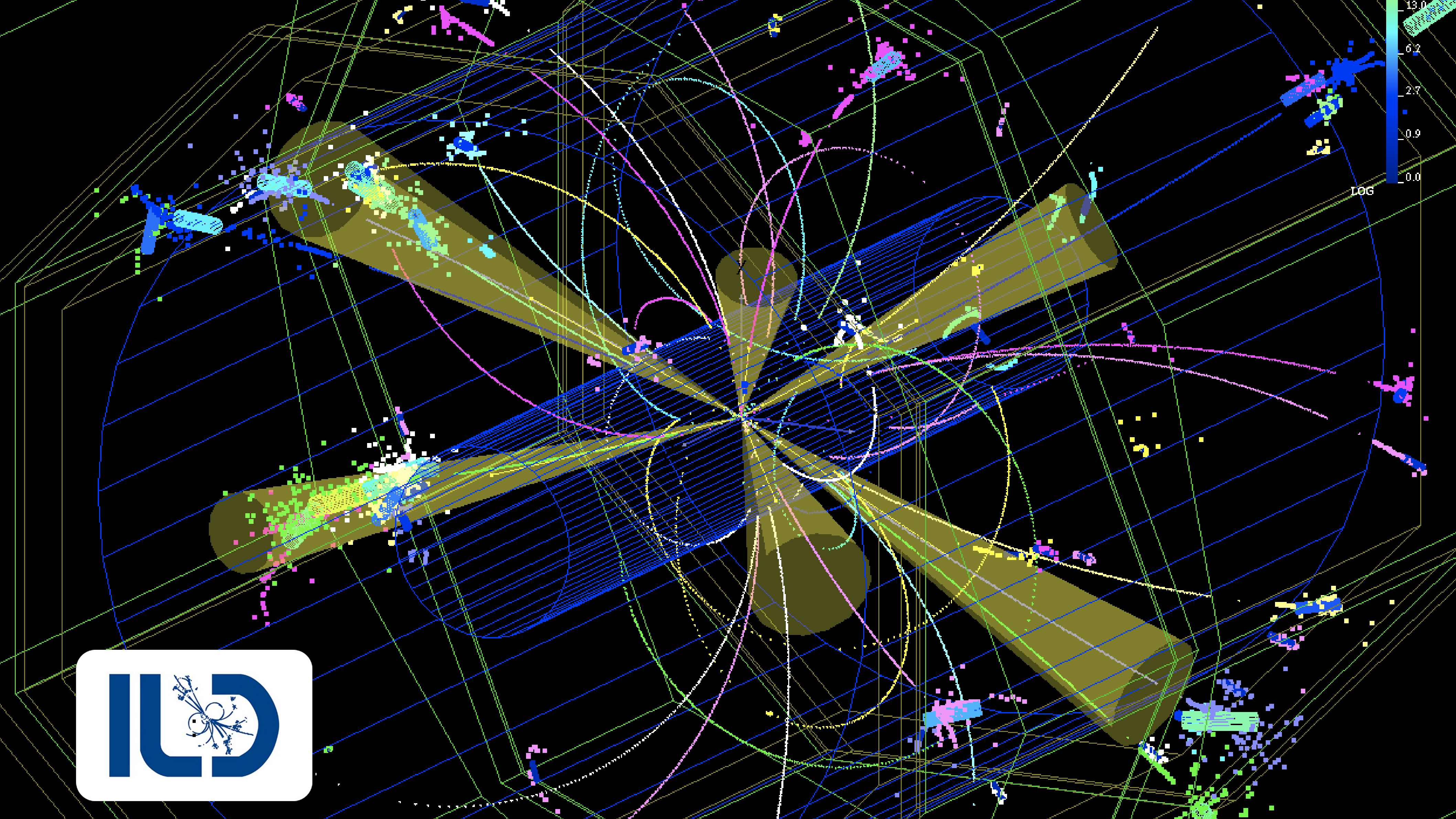
Guest membership
- Very simple access mechanism
- Access to ILD simulated data and tools
- Great to do a study or a feasibility study in the ILD context
- Limited duration



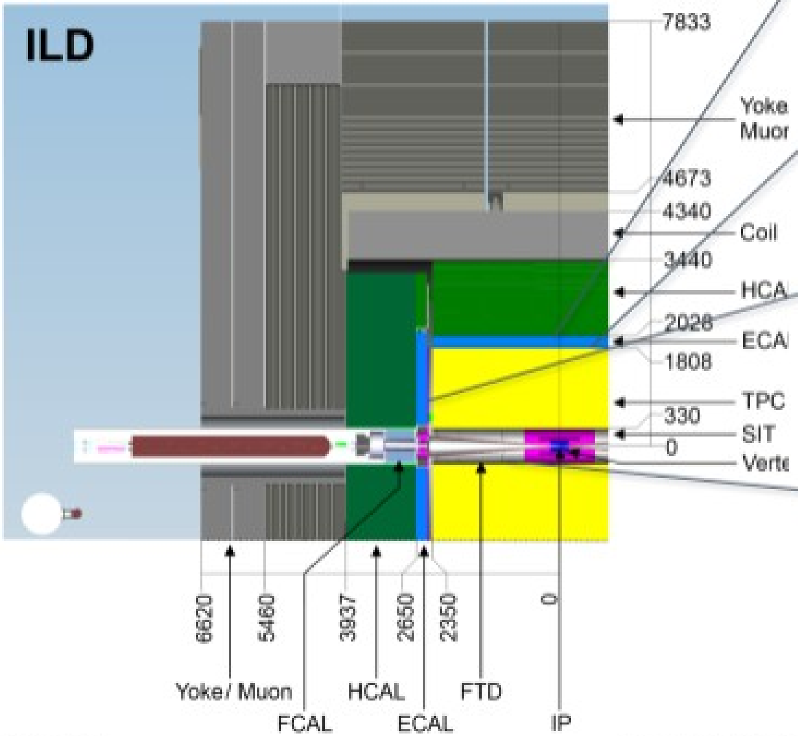
https://confluence.desy.de/display/ILD/ILD

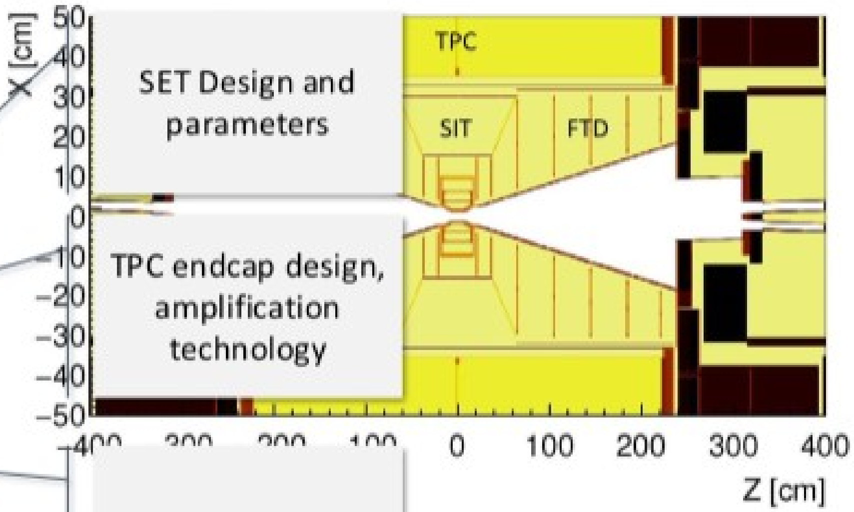
http://www.ilcild.org

Slide borrowed from T. Benhke (ILD spokeperson)


13.0
6.2
2.7
0.9
0.0
LOG
ILD

Opportunities in ILD





Timing in the ECAL

SET Design and parameters

TPC endcap design, amplification technology

Forward design

Slide borrowed from T. Benhke (ILD spokeperson)

ILD as an organisation

ILD executive team (2021-2023)

Ties Behnke

Kiyotomo Kawagoe

Technical working group

Mary-Cruz Fouz, Karsten Buesser

Software working group

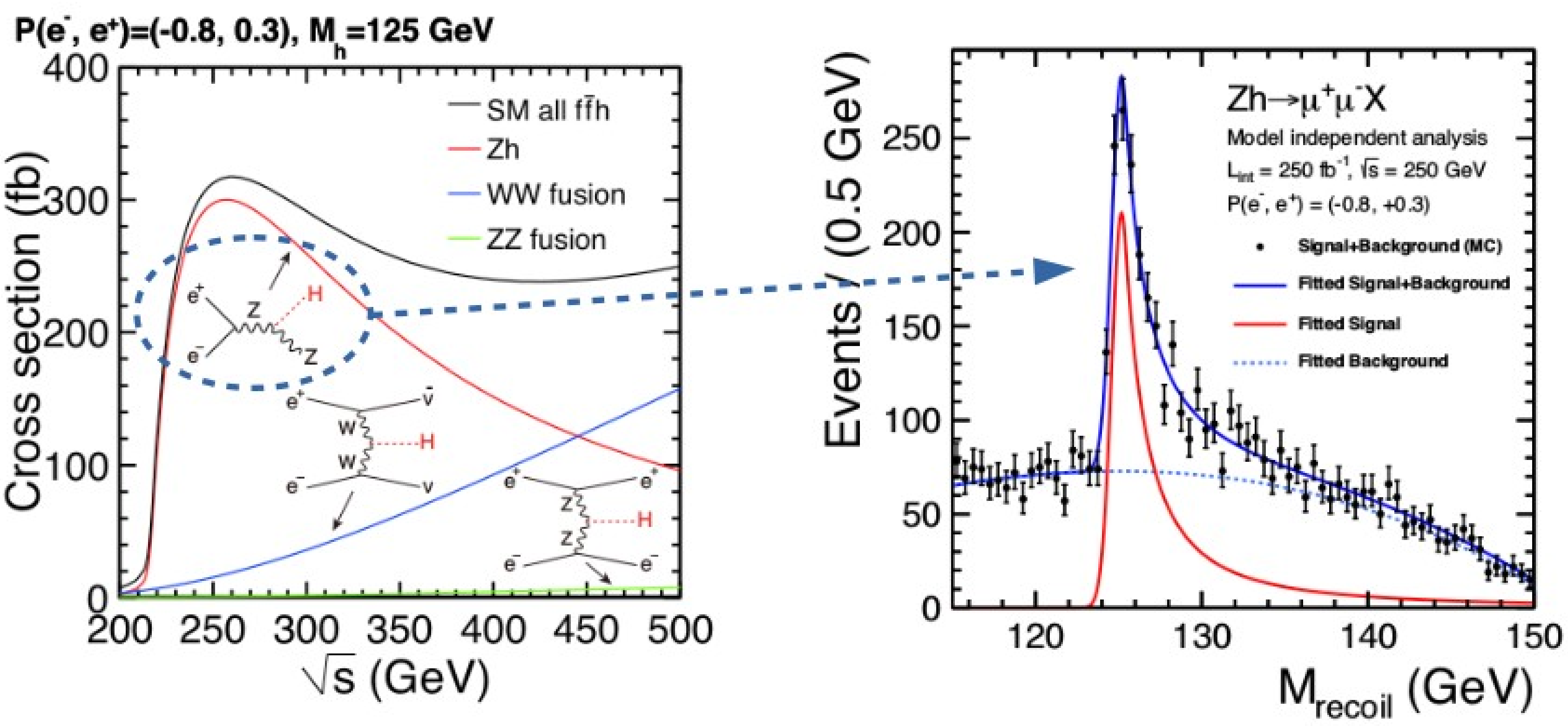
Frank Gaede, Daniel Jeans

Physics working group

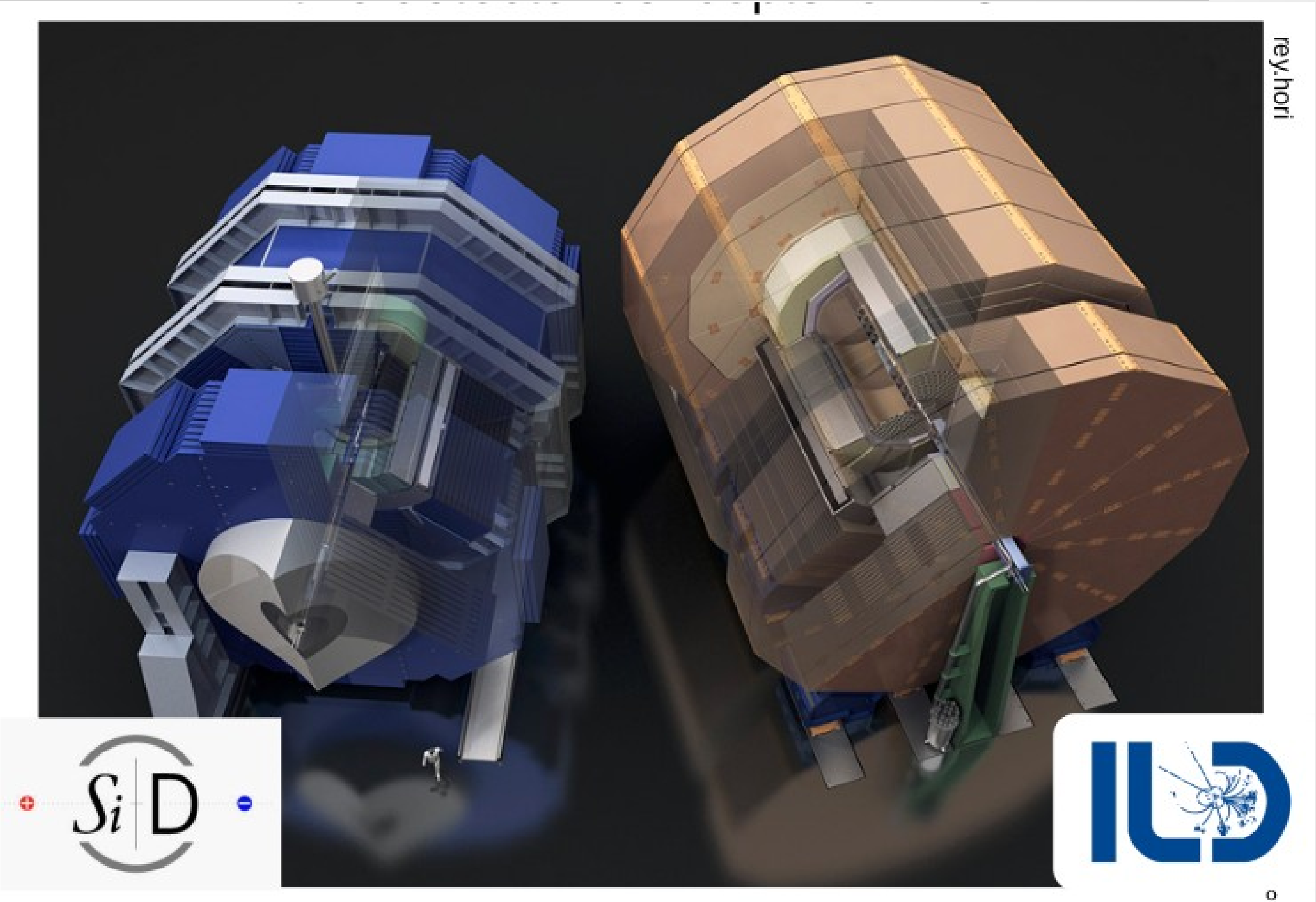
Keisuke Fujii, Filip Zarnecki

+ four elected members from the ILD community. Elections for these positions are in progress.

Slide borrowed from T. Benhke (ILD spokeperson)

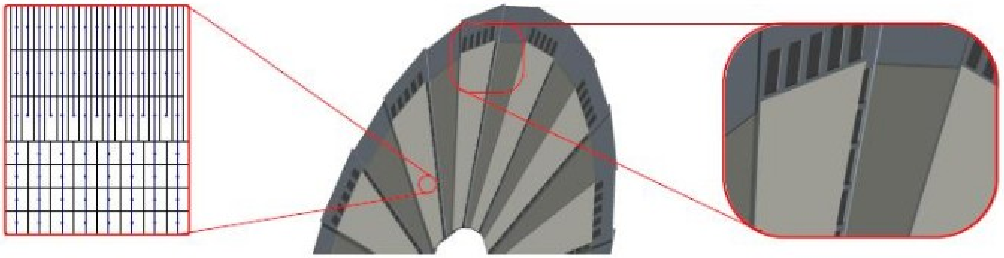


P(e-, e+)=(-0.8, 0.3), Mh=125 GeV
Cross section (fb)
√s (GeV)
SM all ff̄h
Zh
WW fusion
ZZ fusion
Zh→μ+μ-X
Model independent analysis
Lint = 250 fb-1, √s = 250 GeV
P(e-, e+) = (-0.8, +0.3)
Signal+Background (MC)
Fitted Signal+Background
Fitted Signal
Fitted Background
Events / (0.5 GeV)
Mrecoil (GeV)



single Interaction Point, shared by 2 detectors: “push-pull”

Technologies for pixelated FTD 1 & 2



-All technology options remain open
- CMOS
- FPCCD
- DEPFET
- 3D-integrated
- SOI
- ...

-Conceptual adaption of barrel design to disk geometry for some technologies, but no fully engineered design

-This talk: develop a realistic prototype (mock-up) and simulation

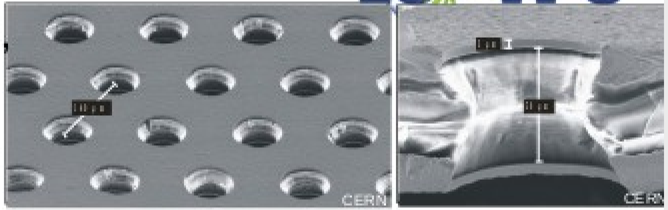
-Assess thermo-mechanical performance

Most studies for inner disks FTD 1&2 were inspired by DEPFET vertex detector developments for ILC and Belle II

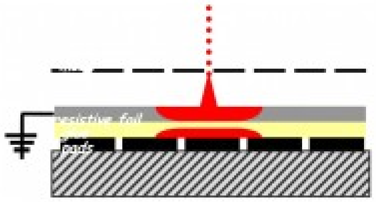
Incorporate new developments:
- IFIC activity in CMOS for Belle II PXD upgrade
- advent of LGAD sensors

Three Baseline Technologies

GEMs: copper-insulator- copper sandwich, with holes
2 configurations are being tested:
- triple GEMs with 'standard CERN GEMs'
- double GEMs with 100µm LCP insulator



Resistive Micromegas: Bulk-Micromegas with 128 µm gap size between mesh and resistive layer



NIM A581(2007) 254

GridPix: Micromegas with 1 µm Al-grid over Pixel readout ASIC
- 55µm pitch of readout pixels
- resistive layer needed for protection of ASIC