The ILD detector concept - Spanish contributions

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AITANA group at IFIC – CSIC/UV

Financiado por la Unión Europea NextGenerationEU

Plan de Recuperación, Transformación y Resiliencia

Outline

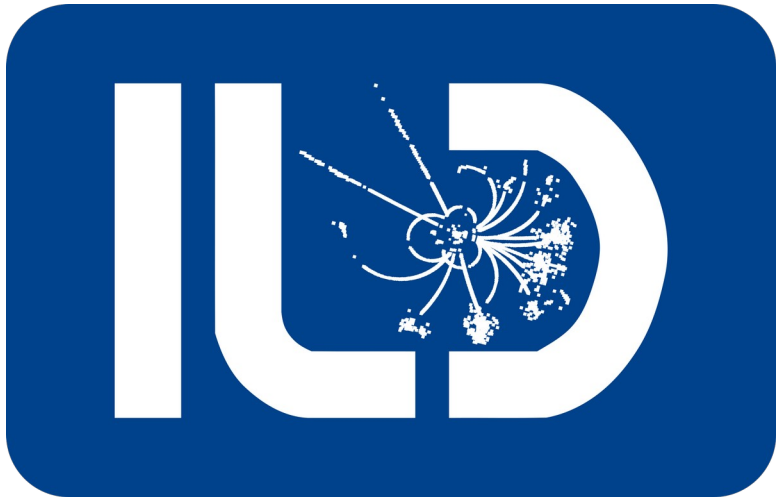
- ILD concept grup short description
- Involvement of spanish groups in
  - Detector R&D
  - Detector and reconstruction tools optimizations: physics benchmarks
  - Based on last 4 years of slides in this forum + CNID + LCWS contributions
  - Omissions are unintended and my full responsibility.
- ILD involvement in the ECFA-Higgs/Top/EW factories workshop

ILD Concept Group – spanish institutes

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

- **6 institutes, 33 members**

- **CIEMAT – 5 members**
  - Contact: MC. Fouz
- **IFCA – 7 members**
  - Contact A. Ruiz
- **IFIC – 9 members**
  - Contact: J. Fuster
- **IMB-CNM – 2 members**
  - Contact G. Pellegrini
- **ITA – 6 members**
  - Contact F. Arteche
- **UB – 4 members**
  - Contact A. Diequez



ILD Concept Group

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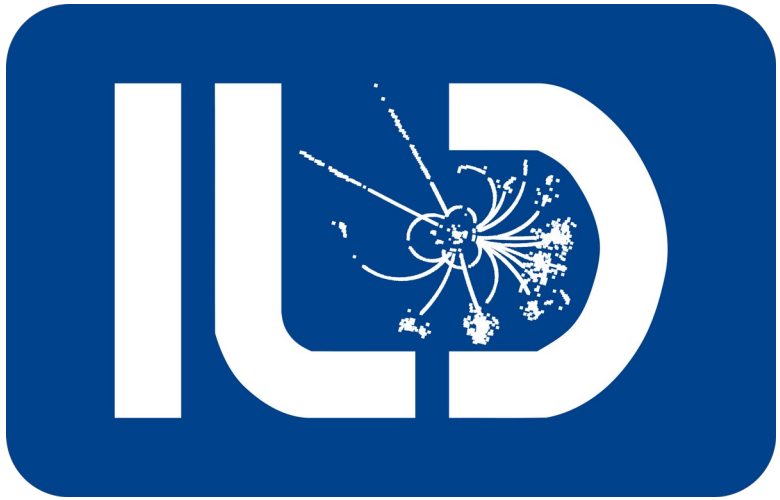
- **68 Institutes Worldwide are members of ILD**
- ILD Executive Team (ILD-ET)
  - Spokesperson: T. Behnke
  - Deputy spokesperson: K. Kawagoe
  - **Marcel Vos, Mary Cruz Fouz** + others



The ILD group participates in the ILC International Development Team (IDT), largely in Working Group 3 (physics and detectors).

ILD Concept Group

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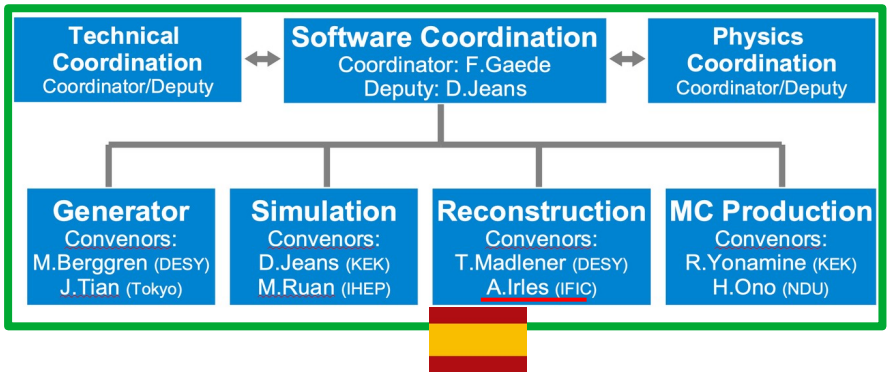
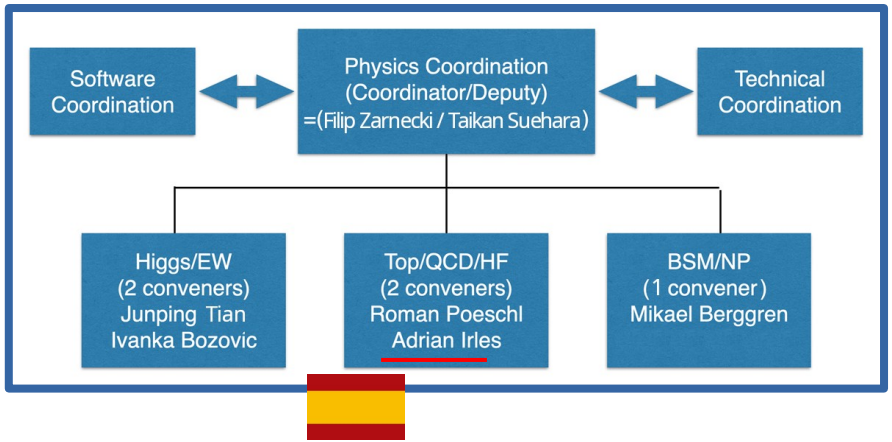
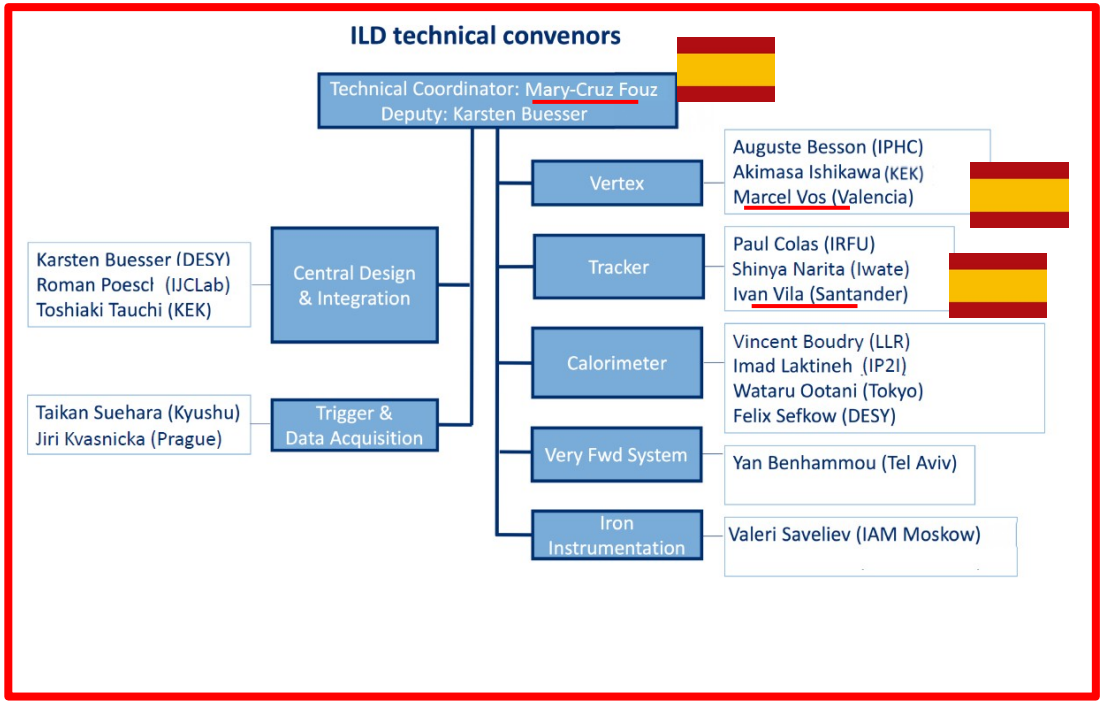
- 68 Institutes Worldwide are members of ILD







The ILD: Interim Design Report 2020 (IDR)

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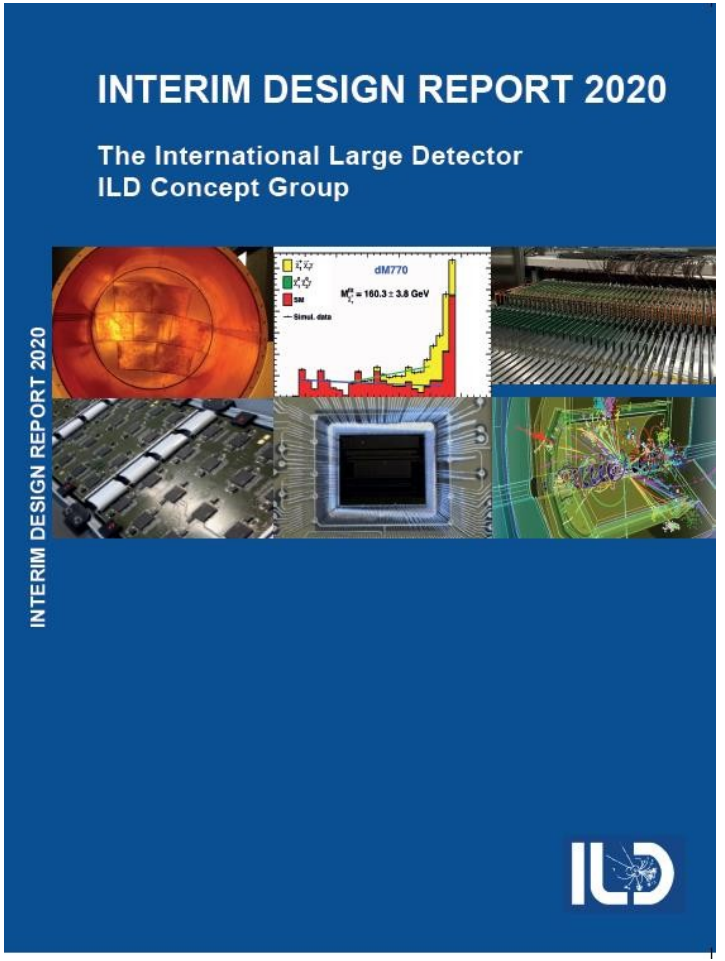
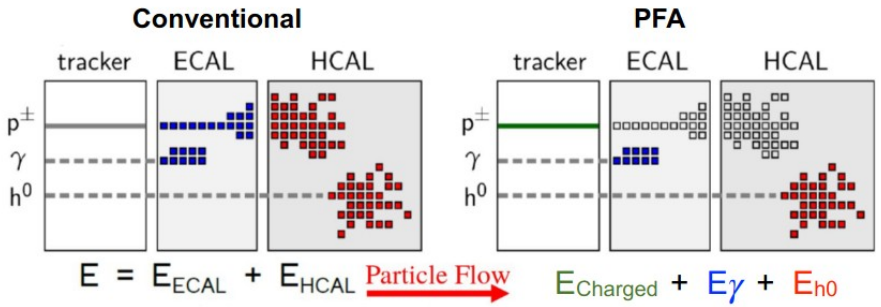
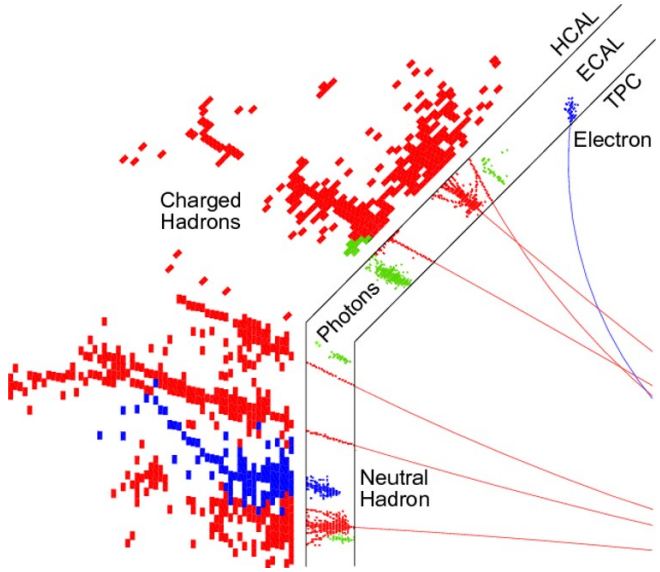
- Recent review of ILD potential and R&D status
  - Full - simulations
  - Dedicated revision and creation of software tools for realistic reconstruction
  - Dedicated full simulation studies on detector performance
  - Dedicated full simulation studies on physics benchmarks
  - Cost studies
  - Planned future actions

arxiv:2003.01116



Particle Flow detector





Aim: perform single particle reconstruction and use the best information in our detector estimate the energy

Example: jet created by a proton
"traditional" detector : $(\Delta E)^2 \sim (\Delta E_{ECAL})^2 + (\Delta E_{HCAL})^2$
Particle Flow detector: $\Delta E \sim \Delta E_{track}$

Full detector design oriented to Particle Flow

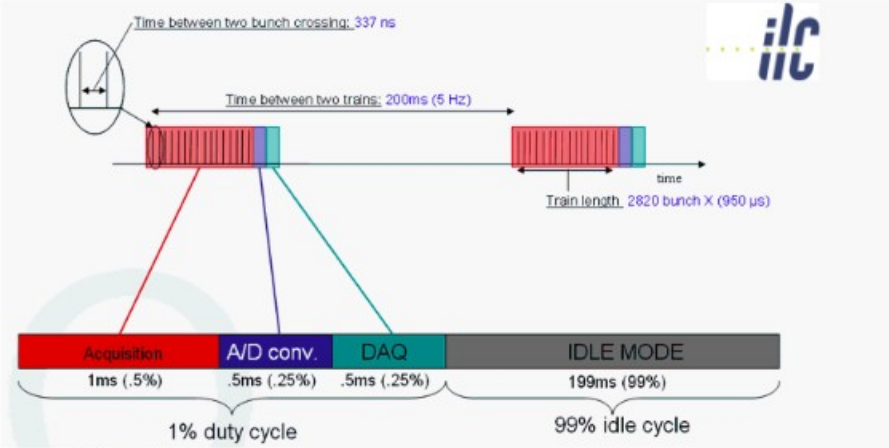
- **Low material budget and power consumption**
  - Power pulsing electronics
- **Fully embedded electronics**
- **Highly granular and ultra-compact calorimeters**
  - Located inside the coil

ILC offers a favorable experimental framework

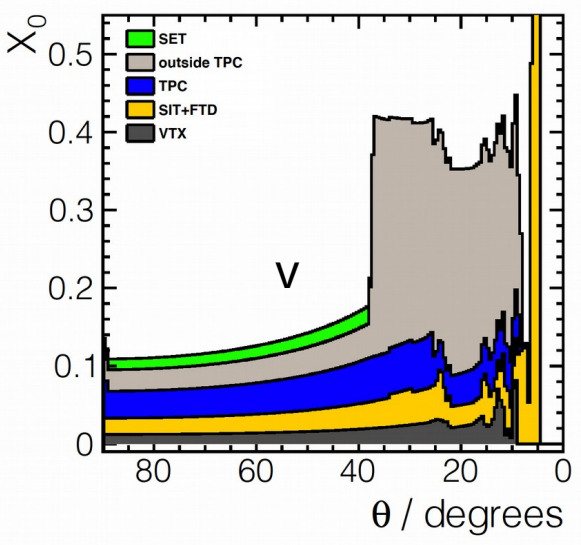
Linear Lepton Colliders favor fully optimized Particle Flow detectors

- Possible since experimental environment at ILC very different from LHC/LEP:
  - much smaller beam spot and beam pipe (first tracking layer at ~1.6cm 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

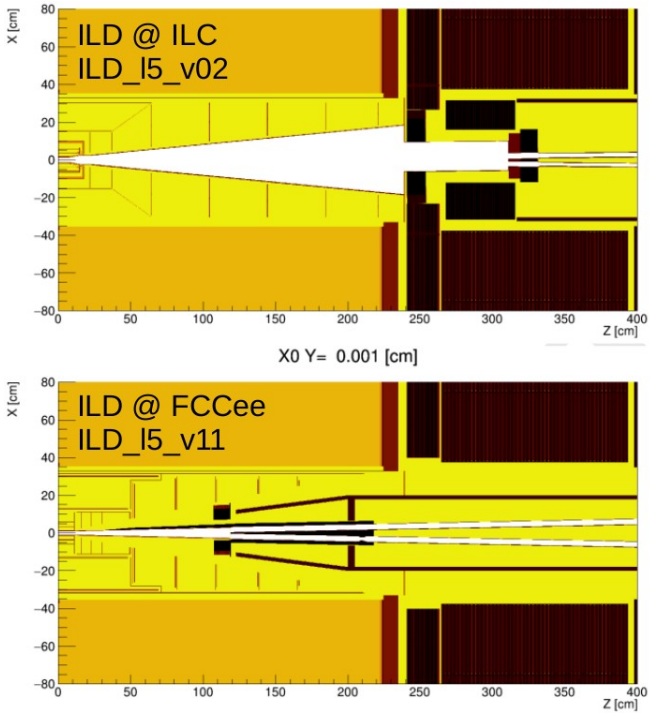


ILD for circular colliders ?

ILD is currently designed and optimized for PF in linear colliders.

Particle Flow detectors are also candidates for FCCee → CLD for example (an adaptation of CLICd)

- **ILD concept group is working towards an adaptation of its design to understand its capabilites in FCCee**
  - will be part of the Input to next european strategy
- Main challenges:
  - Inner region → the beam delivery and focus system at FCC takes more space in the inner region
  - TPC – will it cope with the high rates at TeraZ ? (not a problem at FCCee-HZ)
  - Embedded electronics and power consumption → active cooling will be needed → how will this impact the PF ? → not possible to have a fully hermetic detector anymore…
  - Triggers ? Data management ?



Detector R&D

Status of the R&D

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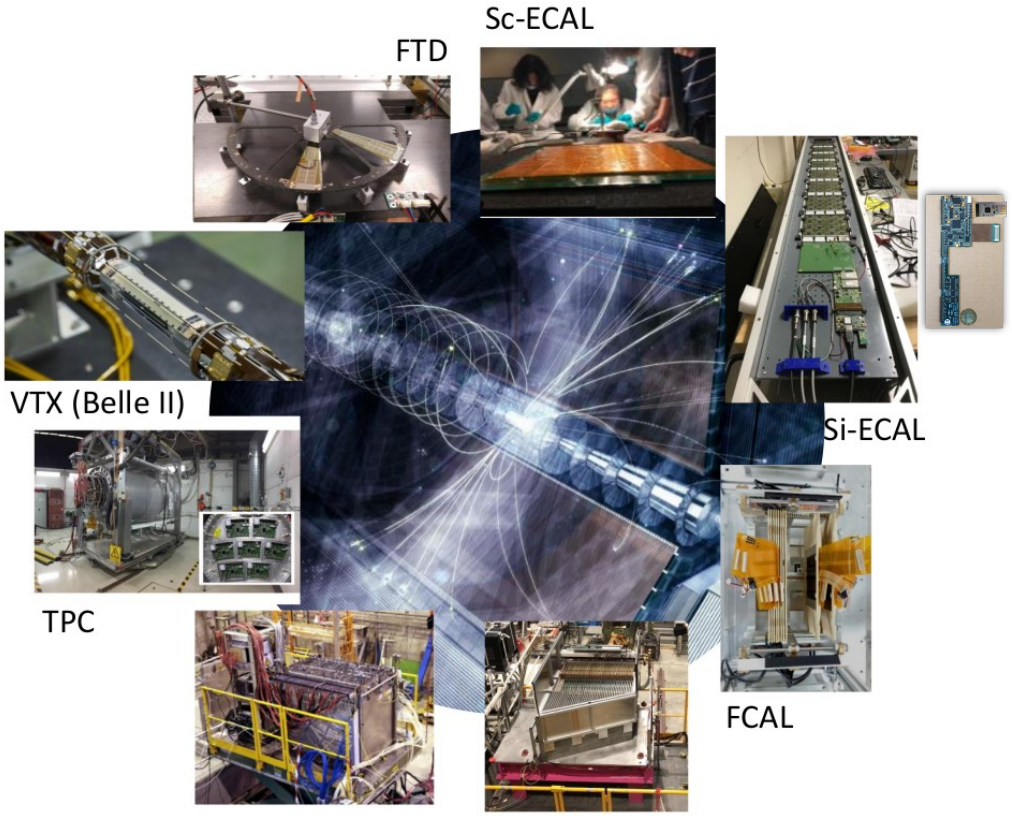
R&D status

- 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.

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

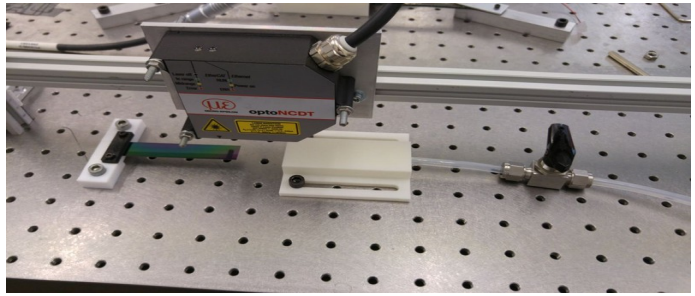
- Still not closed decision in technology choices
- Openness to new ideas and technologies



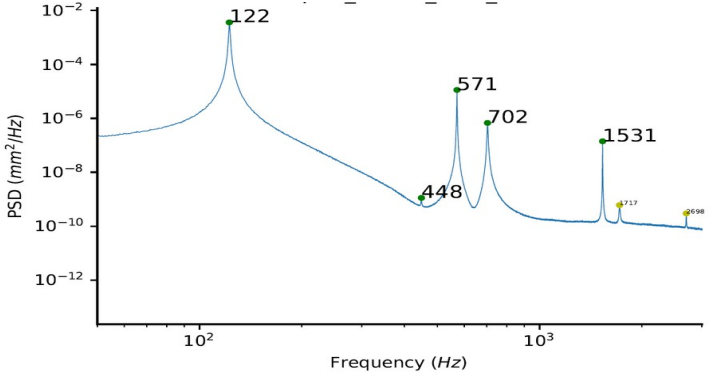
Picture borrowed from T. Benhke (ILD spokeperson)

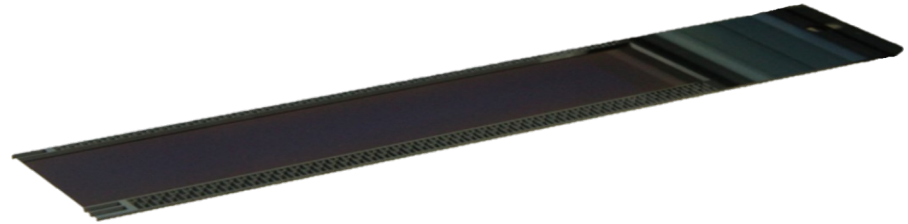
Forward Tracking:
advanced mechanics (AIDA2020-AIDAInnova)

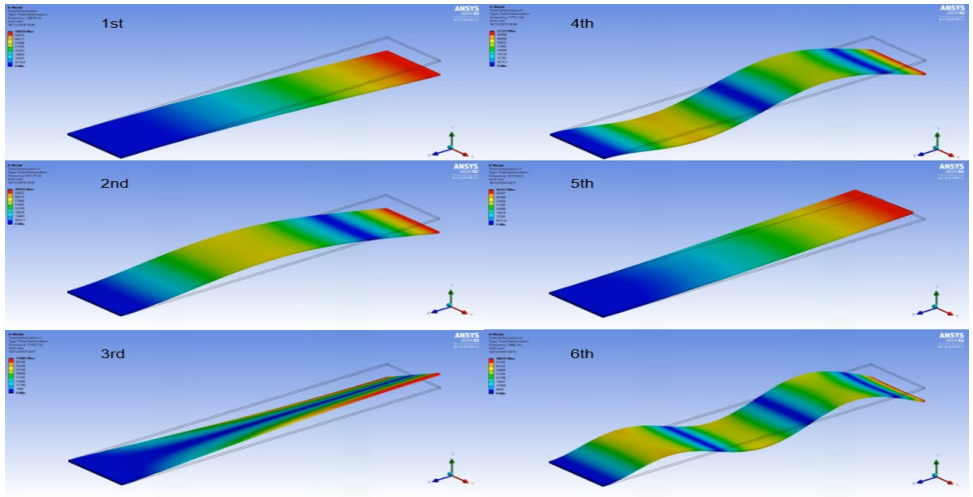
Multiple silicon structures measured in Oxford and Valencia



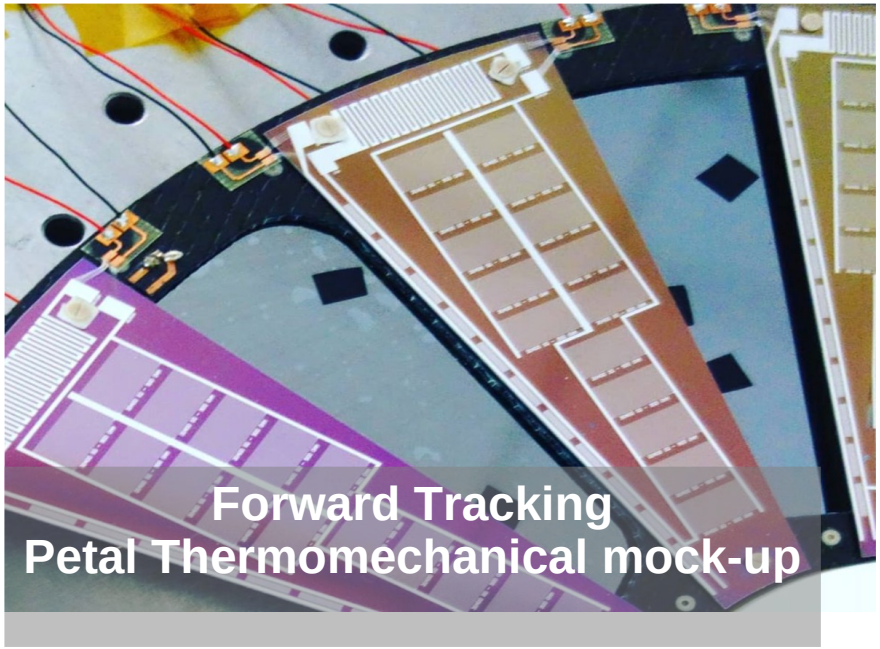
Vibration Setup – IFIC Valencia







Vibration analysis:
advanced mechanics (AIDA2020-AIDAInnova)



Master's thesis Yamal Naser Requena

Analytical expressions

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ANSYS FEA

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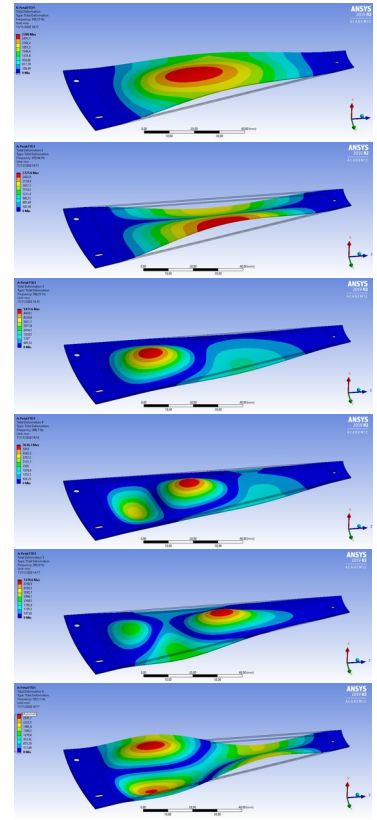
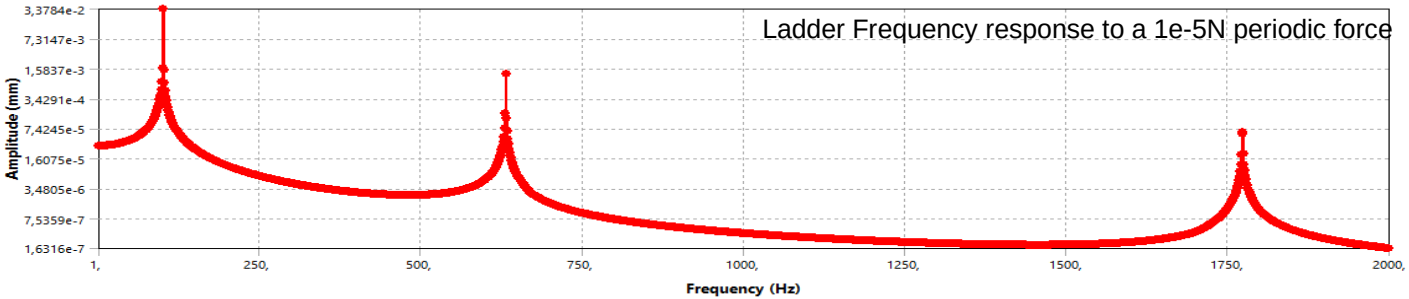
Measurements

Extend to more realistic vibration loads (air flow, cavern floor, earthquake)





CMOS & LGADs R&D – in Spain

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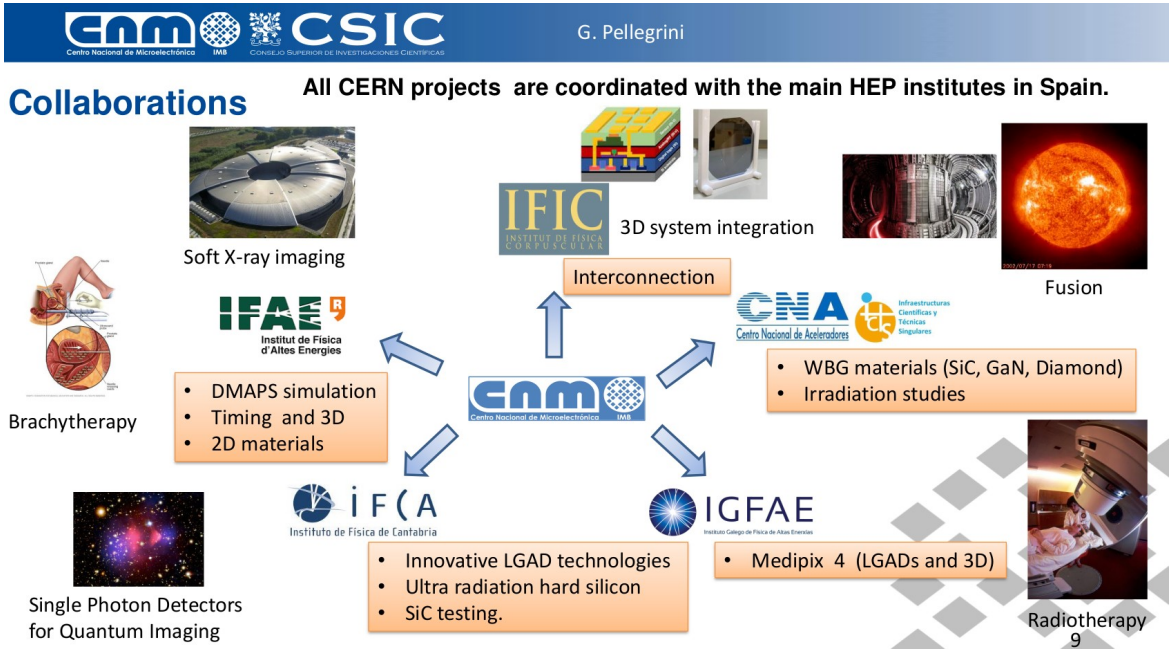
- **CMOS (MAPS) are specially suited for applications requiring low mass and excellent position resolution**
  - Continuous readout: speed ? (trade off consumption vs speed)
  - ILD for ILC has no strict requirements on radiation hardness (but on power consumption and material budget)
  - Industrial technology
  - **Production capabilities not in Spain**
- **LGADs:**
  - High precision timing using thin sensors iLGAD and similar.
  - **Leadership at production in Spain**



DRD3/7 – Spain - ILD

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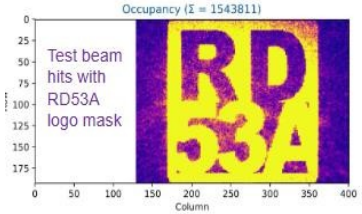
- DRD3(silicon sensors), 7 (electronics)
- Transversal activities (common interests with ILD).
- Many activities ongoing and different expertise, transversal to several DRD and interesting for future projects
  - R&D on, Single Photon Sensors, ASIC development
  - R&D on power transmission, DC/DC, power pulsing,...
- Spanish groups are in leadership positions
  - G. Pelegrini – Collaboration Board Chair DRD3

- **IFIC, IFAE, INB-CNM, IFCA, IGFAE/USC, ITAINNOVA, GIE-ETSI, ICCUB.**

- **Coordinated activities within Europe R&D program on silicon sensors for tracking**



RD50

AIDA innova

Technological premises

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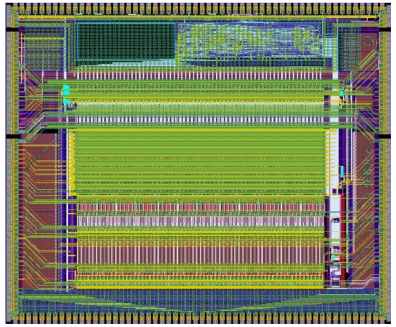
Highly integrated (very) front end electronics

e.g. SKIROC (for SiW Ecal)

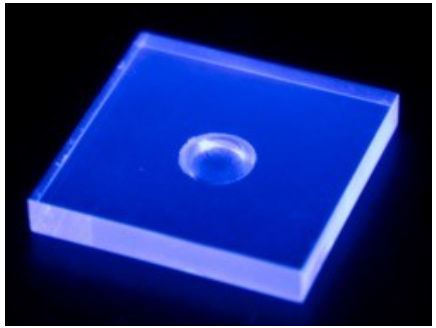


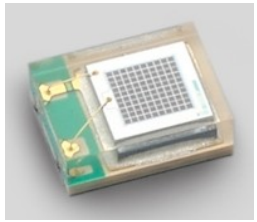
Size 7.5 mm x 8.7 mm, 64 channels

- **Analogue measurement**
- **On-chip self-triggering**
- **Data buffering**
- **Digitisation**
  ... all within one ASIC

- **Common developments on different CALICE projects**

Miniaturisation of r/o devices





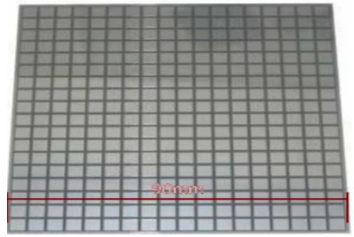
- Small scinitllating tiles
- (Low noise) SiPMs

Power pulsed electronics
to reduce power consumption…
Compactness –> no space left for active cooling systems

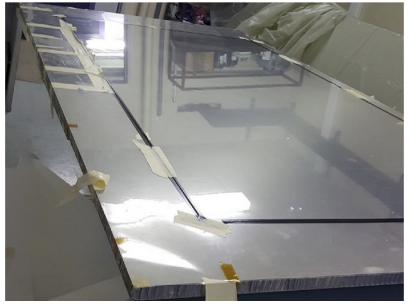
Self trigger of individual cells below MIP level

Large surface detectors

Si Wafer



RPC layers



Many things that look familiar to you today were/are pioneered/driven by CALICE/FCAL

Technological premises

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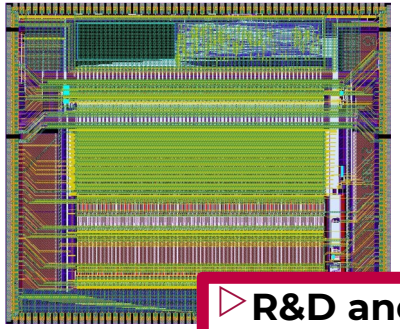
Highly integrated (very) front end electronics

e.g. SKIROC (for SiW Ecal)



Size 7.5 mm x 8.7

- **Analogue meas**
- **On-chip self-trig**
- **Data buffering**
- **Digitisation**

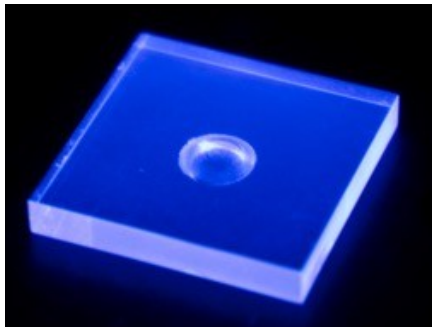
... all within one

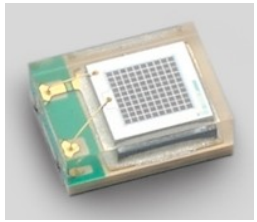
- **Common develo**

on different CA

Many t **L**

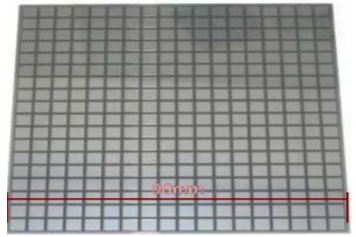
Miniaturisation of r/o devices



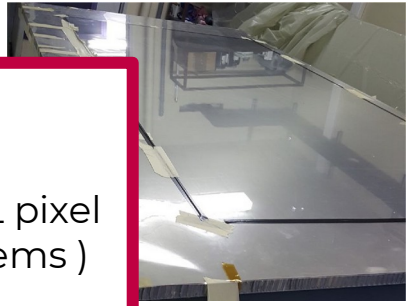


Large surface detectors

Si Wafer



RPC layers



- **R&D and proof of concept driven by the CALICE and FCAL collaborations**
- **Exported to HL-LHC** Upgrade of existing detectors (ALICE FoCAL pixel calorimeter, HGCAL with high granular Si and SC calorimeter systems)
- **Adapted by lower energy** experiments
  - Strong-Field QED experiments (LUXE) LUXE
  - Dark Photon, ALPs Experiments (LUXE-NPOD, EBES -KEK, Lohengrin - Bonn,...)

Prototyping + intensive TB phase

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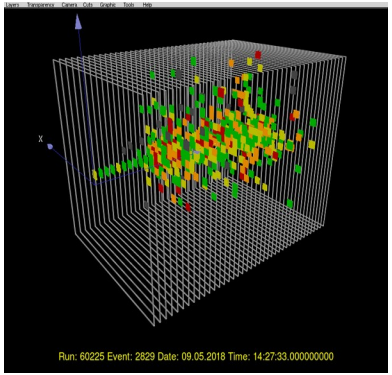
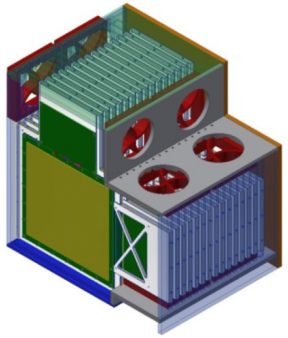
AHCAL

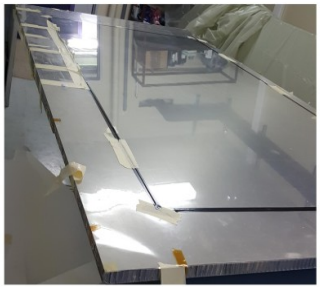


Sc-ECAL

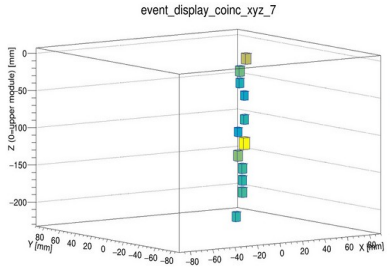


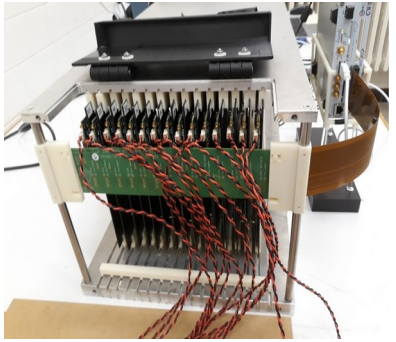
SDHCAL

2 m^2 RPC assembled

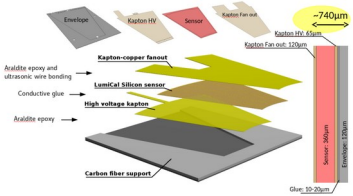


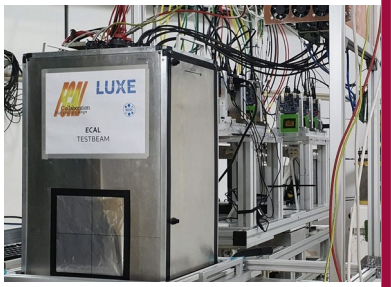
SiW-ECAL





Lumi-CAL





All calorimeter options built large size prototypes → linear and/or circular colliders
Tested at DESY/CERN in common beam tests including telescope synchron.

SDHCAL. Recent developments at CIEMAT

Validation of SDHCAL technology for full size detectors in future experiments as ILD

High precision mechanics

Assembly using electron beam welding (EBW)

DONE

Deformations ~500 microns

Informe Técnico CIEMAT
ISSN: 1135-9420

Present R&D

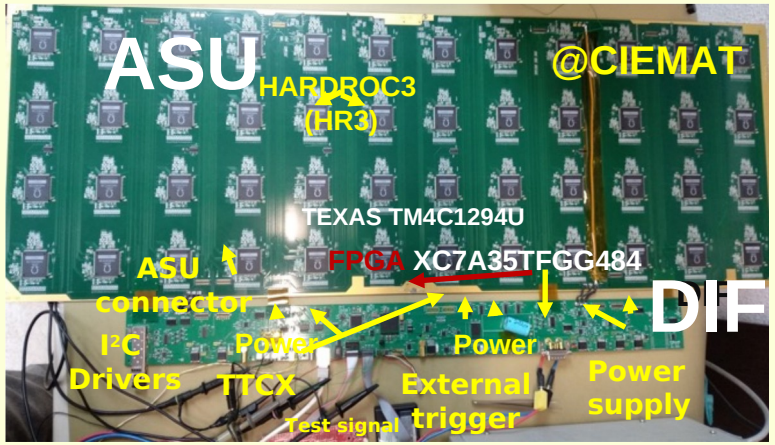
How to extend it to a full calorimeter module (40 plates)

Two steps:

"Small" sub-modules assembly using EBW

Full module made of sub-modules using Laser Welding

Readout electronics



New Detector InterFace (DIF) board able to manage the 30000 channels of a single RPC 3x1m²

Pending to check in a test beam with RPC & DAQ

R&D Next steps. Towards a 5D Calorimeter for linear and circular Higgs Factories: t-SDHCAL

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General t-SDHCAL goal

Extending the Semi-Digital Hadronic CALorimeter (SDHCAL) to include timing information (100 -200ps resolution) for a 5D-calorimetry (space, amplitude & timing)

Implementation

Build multi-gap RPC (MRPC) equipped with a new version of electronics with timing capabilities to prove the final performance

Planned activities with CIEMAT participation/responsibilities in next years

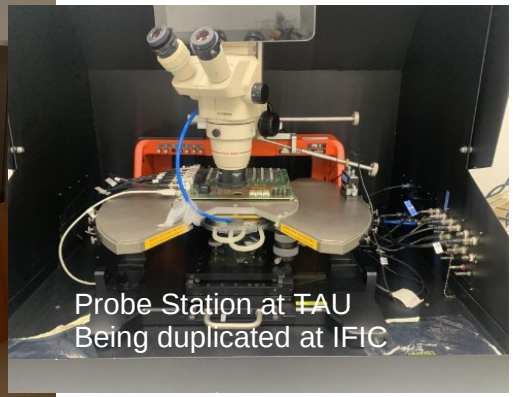
Activities under DRD1 and DRD6

- New electronics with timing implementation
- Detector mechanics for new Multigap GRPCs
  and also continuing in parallel the R&D for the assembling of large absorber calorimeter structures
- Tests of new multigap GRPC prototypes with new electronics
  Single chambers and the 1m^3 calorimeter substituting few planes with the new chamber and electronics
- Monte Carlo simulation studies and software developments to evaluate the impact of timing on shower reconstruction.
  At single calorimeter level and some Physics benchmark channel using the framework of the ILD concept
  Considering also starting implementation of IA for reconstruction.

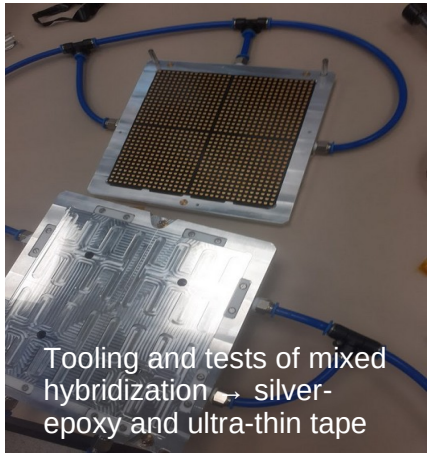
IFIC-Lab for ECAL hybridization

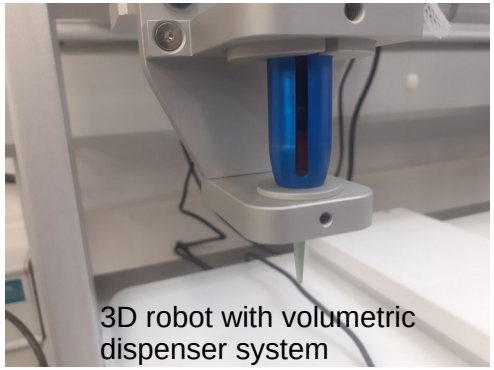
- **New facility and capabilities at IFIC**
- **Funding: CIDEGENT/ASFAE/CNS** → In line with ECFA – R&D roadmap, DRD6, Future Colliders
- **IFIC will become** the hub for module hybridization R&D / production / commissioning for DRD6 Si-ECALs and for the LUXE experiment

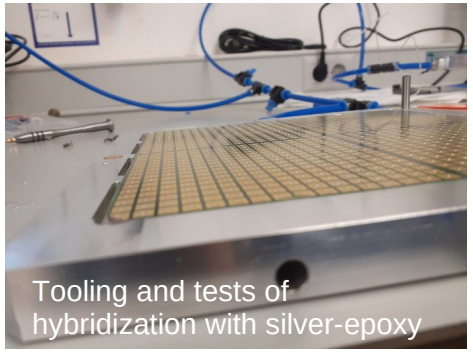

New installation at IFIC
(to be finished in ~~March/Abril~~ May/June 2024)


Probe Station at ~~TAU~~
Being duplicated at IFIC

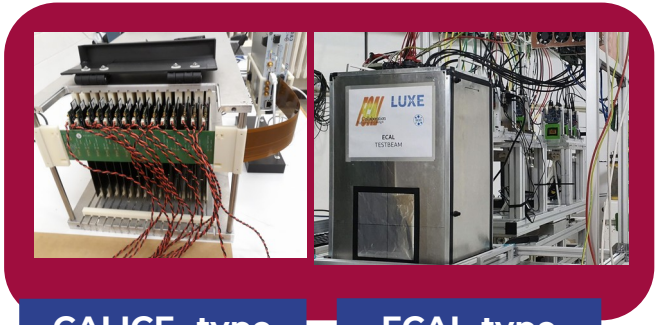

Dry cabinet,
curing oven


Tooling and tests of mixed hybridization ↔ silver-epoxy and ultra-thin tape


3D robot with volumetric dispenser system


Tooling and tests of hybridization with silver-epoxy

ILD – DRD6 – high granular silicon ECALs



CALICE -type calorimeter

FCAL-type calorimeter

DRD6

ILD LUXE

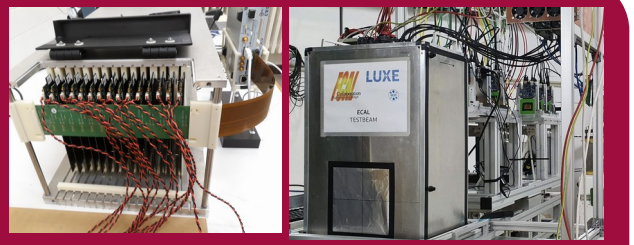
- SiW-ECAL DRD 6 topics (few)
  - Power pulsing (ILC) & continuous mode+cooling (FCC TeraZ)
  - Timing
  - Long modules
  - Full stack production & TestBeam

- FCAL DRD 6 topics (few)
  - Wireless DAQ
  - Sensor development (integrated traces, GaAs, Si, ...)
  - Full stack production & TestBeam

Common R&D: module hybridization

Assembly lab being set-up at IFIC

ILD – DRD6 – high granular silicon ECALs



CALICE -type calorimeter

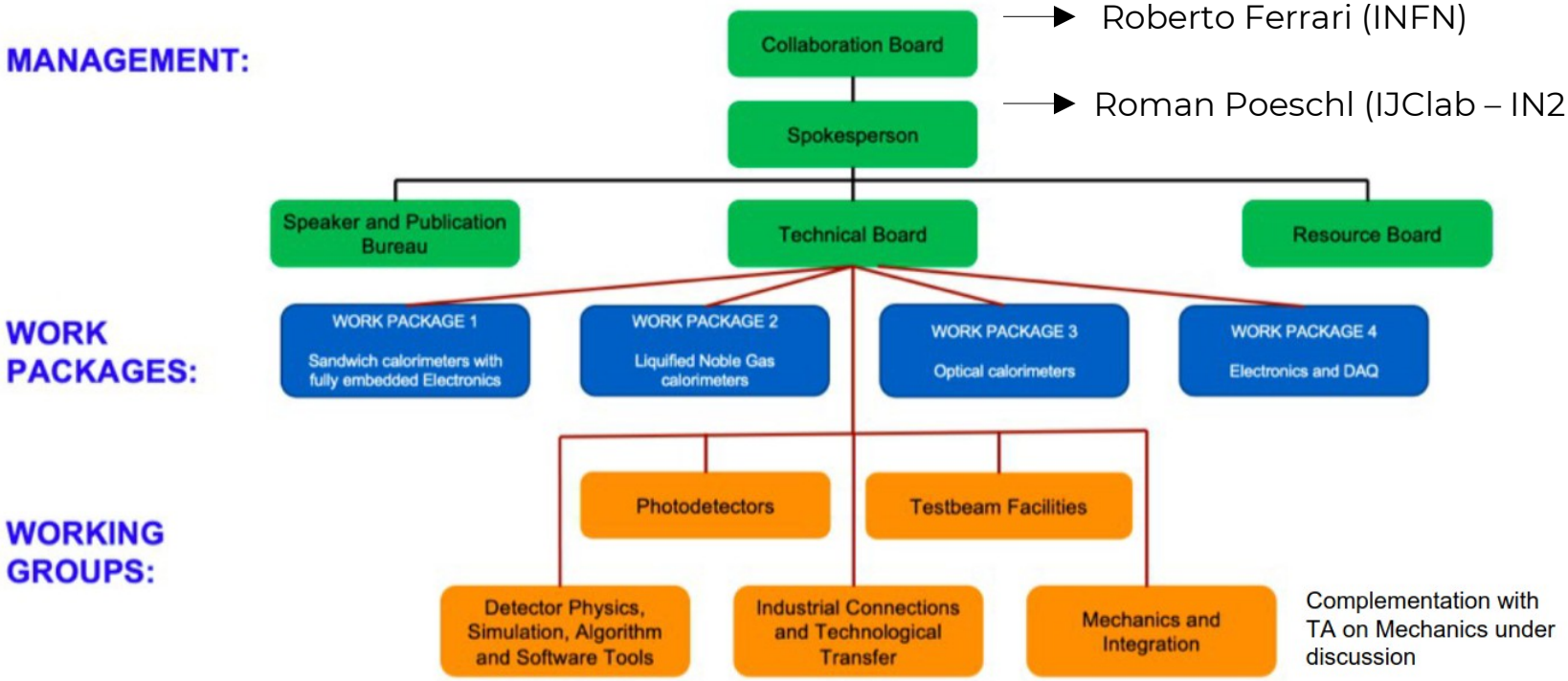
FCAL-type calorimeter

DRD6 ILD LUXE

Common R&D: module hybridization

Assembly lab being set-up at IFIC

DRD6 Calo



Approved by CERN DRC

- First Collaboration Meeting 9th - 11th April
- Transition to real collaboration been handled by the “Proposal Team” that drove the full process
  - Spanish participation (MC fouz, A. Irles, WP1)

DRD6 Spain

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DRD6 spanish groups

- **CIEMAT** - Mary Cruz – SDHCAL and TSDHCAL
- **IFIC**:
  - AI: CALICE SiWECAL and FCAL ECAL
  - L. Fiorini, A. Valero – TileCal (WP3 – Talk by A. Valero in Electronics session)
  - J. Mazorra -SpaCAL (WP3 – Talk by J. Mazorra in this session)
- **DIPC Donostia**
  - Roberto Soleti - CRILIN
- **UB-ICCUB:**
  - Eduardo Picatoste - SpaCAL
- **UCO** (Córdoba)
  - José Berenguer T-SDHCAL
- **UVO** (Oviedo)
  - Pietro Vischia - Software

In blue, the Particle Flow (WP1) oriented groups

Physics Performance – ILD studies

ILD recent studies

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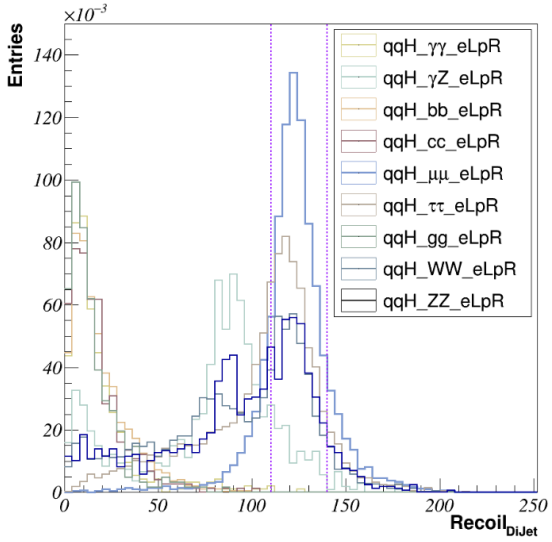
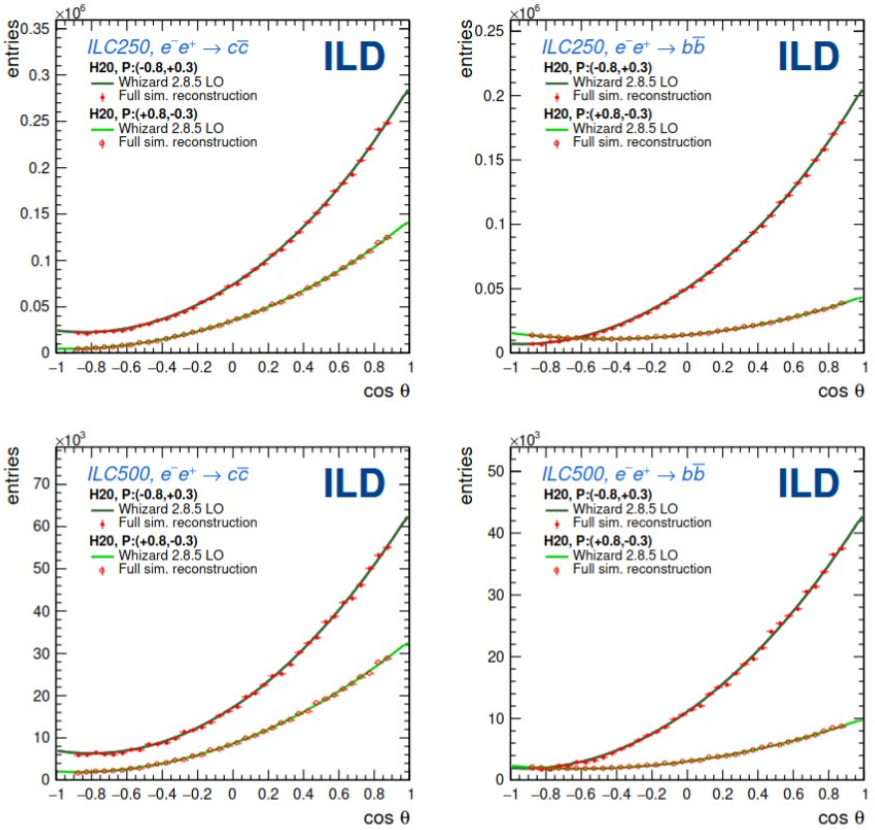
- **Physics studies for future colliders at ILD for ILC**
  - Prospect of the ZH hadronic channel
  - SDHCAL beam test analysis
  - Part of H. García Cabrera PhD thesis. **Supervisor M.C Fouz**



Ongoing:

- SiW-ECAL pion/electron identification studies using ML
  - Ongoing work (PhD of J. P. Márquez – A. Irles)
- Indirect BSM searches studting two particle angular correlations (hidden Valley)
  - https://arxiv.org/abs/2312.06526 (Musumeci, Irles, Corredoira, Mitsou, Sanchis, et al)
  - Based on fast simulation - SGV

b/c Forward-backward asymmetries above Z-pole



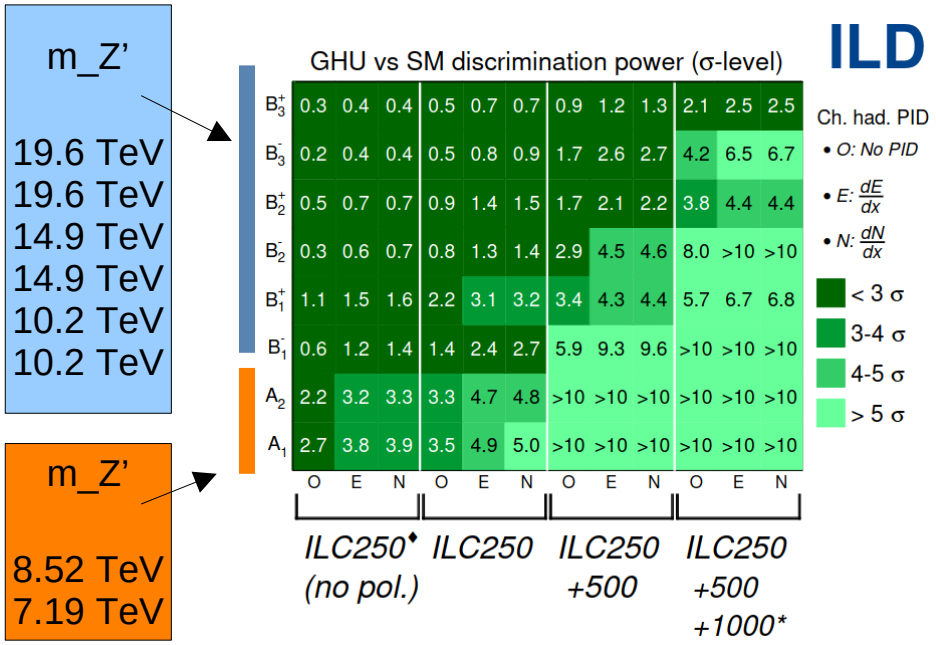
- **AFB measured in the continuum (not Z in rest frame)**
  - Sensitivity to Z, gamma, Z`
- At least 4 observables for AFB at ILC250 per energy point
  - 2 quarks and 2 polarisations (eLpR, eRpL)

- **Per mil level statistical uncertainties reachable for the nominal ILC250-500 program**
  - **Smaller exp syst. Uncertainties**
  - **Fragmentation, angular correlations → minimized** thanks to **double tagging** techniques and Data Driven measurement of efficiencies **à la LEP and SLC**

Eur.Phys.J.C 84 (2024) 5, 537
ILD-PHYS-PUB-2023-001
ILD-PHYS-PROC-2023-013
Irles, Marquez, Poeschl, Richard, Yamamoto, Namatsu, Saibel

NEW 2024!

b/c Forward-backward asymmetries above Z-pole



Eur.Phys.J.C 84 (2024) 5, 537
ILD-PHYS-PUB-2023-001
ILD-PHYS-PROC-2023-013

NEW 2024!

- Recent publication: **phenomenology + experimental of a long standing effort (ICHEP2020-ICHEP2024)**
  - IFIC (Irles, Márquez, Saibel)
  - IJCLab, Tohoku U., Kyoto U.
- **Forward-backward asymmetry for b and c-quark** pairs.
- Study comparing **scenarios** (energy reach, beam polarisation) and **GHU** models.
- This plots "hides" years of **involvement** in **detector and reconstruction optimization**:
  - Study of **forward tracking and calo** region
  - **Flavour tagging** optimization → including dEdx or novel detector solutions (pixel TPC for cluster counting)
  - **Quark-Charge measurement** algorithms.
  - Study of **timing** capabilities for hadron identification

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ILD @ ECFA Higgs/Top/EW Workshop

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- WG3 – Detector R&D -->Mary Cruz Fouz
- WG1 – Physics potential
  - Global interpretations (WG1-GLOB) → M. Vos
  - Precision (WG1-PREC) → A. Irles
  - Higgs/Top/EW (WG1-HTE):
  - Flavour (WG1-FLAV):
  - Searches (WG1-SRCH)

In red, the ILD memebers involved

In the ECFA -HTE

FOCUS Topics document https://arxiv.org/abs/2401.07564

- ttbar-threshold topic
  - M. Vos (coordinator), A.Irles, A. Saibel, D. Melini members of expert team
- W-mass, Luminosity measurements, fragmentation uncertainties
  - 3 topics with A.Irles as co-coordinator (PREC) convener
- Two Fermion Final states
  - A.Irles as coordinator and member of expert team
- Contributions to BSM searches
  - Hidden Valley searches (V. Mitsou, A. Irles as contact persons).

Summary

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- **ILD is an established detector concept** group
  - Based on state of the art technology → driver of different efforts → ILD as a hub for detector R&D technology
  - Coordinated efforts with different projects, collaborations and concepts (AIDAInnova, DRDs, CLIC, FCCee, CEPC CLD, SiD, CLICd…)
  - and other experiments → LUXE

- **With strong spanish contribution.**

back-up

Optimized ILD design

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**:

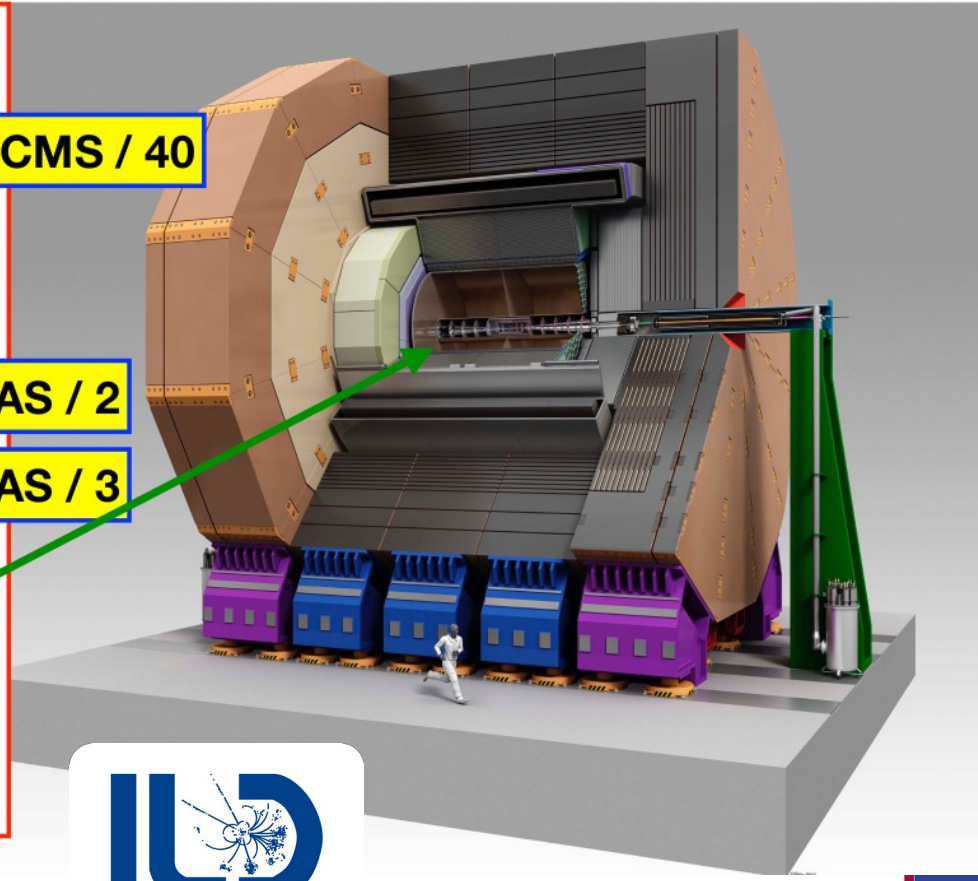
- **low mass tracker:**
  - main device: **Time Projection Chamber** (dE/dx !)
  - add. silicon: eg VTX: 0.15% rad. length / layer)
- **high granularity calorimeters**
  optimised for particle flow

≈ CMS / 40

≈ CMS / 4

≈ ATLAS / 2

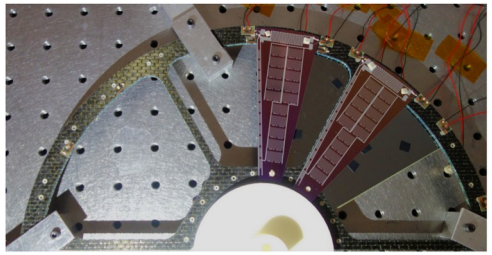
≈ ATLAS / 3

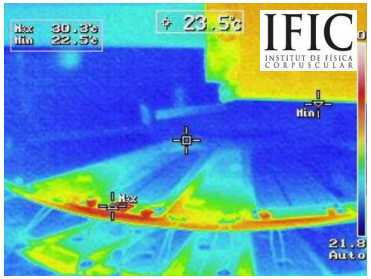


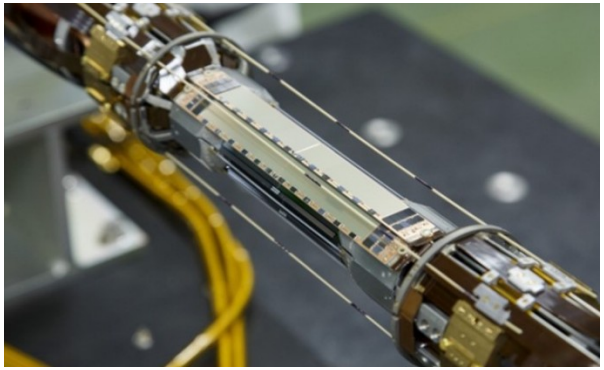
Borrowed from J. List

Silicon Tracking Systems R&D

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

CMOS & LGADs R&D news

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CMOS (MAPS) are specially suited for applications requiring low mass and excellent position resolution

- Continuous readout: speed ? (trade off consumption vs speed)
- Industrial technology

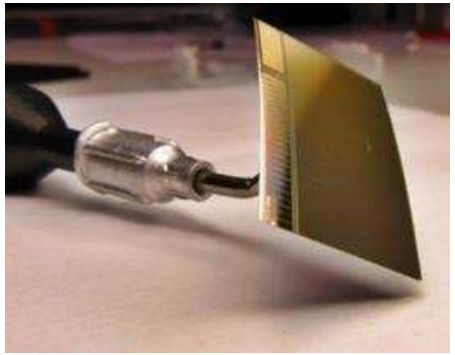
180 nm technology: VALIDATED

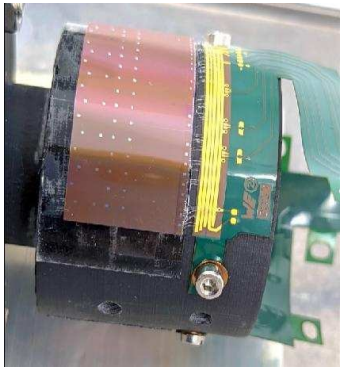
- ALPIDE@ ALICE ITS-3, MIMOSIS @ CBM-MVD)
- ILD doable in 180nm tech: 4um / 4us resolution, <100mW/cm^2
- MIMOSIS-1 → unique in terms of hit density treatment and readout speed (design adaptable to <1us). Testbeams and data analysis in progress.

65 nm technology:

- being explored in order to validate it for charged particle detection → test beams in progress
- smaller pixels, more in-pixel functionalities, less power consumption, faster readout
- driven by CERN EP R&D WP 1.2 and ALICE ITS-3 upgrade with other labs.

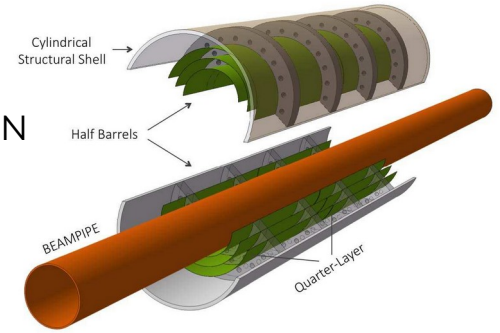
MIMOSIS-1 and bent ALPIDE (at IPHC-Strasbourg)





Bending thin Si-Layers

- ALPIDE sensors bent by CERN and IPHC-Strasbourg for ALICE-ITS3
- *suportless*
- New geometries allowed



Stitching

- Using several reticles from the same wafer
- Possible with both 180nm and 65nm

TPC Tracking System R&D

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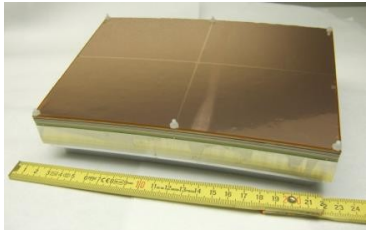
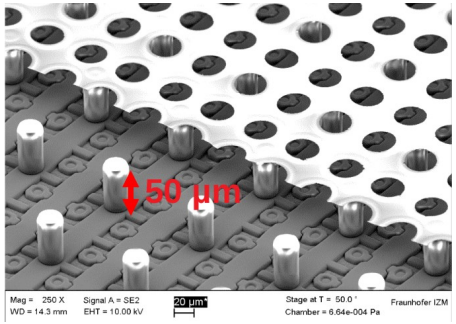
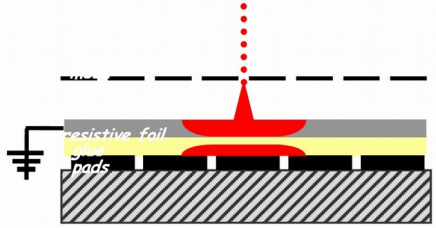
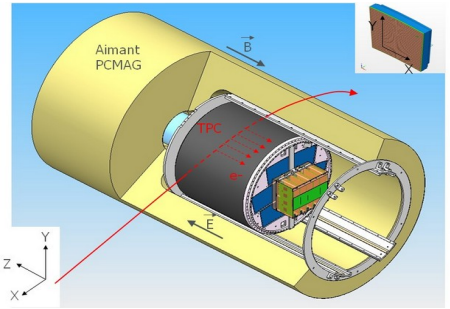
- **GEMs**: double thick – Asia – or triple standard GEMS – DESY
  - Minimize dead area -> no frame at modules sides but a 1 mm grid to hold GEM

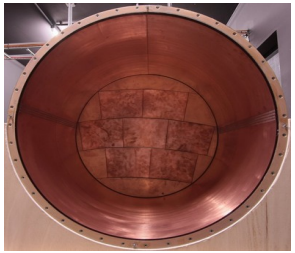


- **Resistive Micromegas** (Saclay)









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

- **GridPix (Nikhef Bonn)**
  - Timepix3 readout + micromegas as gas amplification → smaller pads/pixels

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

No spanish groups involved

LCTPC planning a new generation of modules with comparable design (for better comparisons)

HG Calorimetry: Technological solutions I

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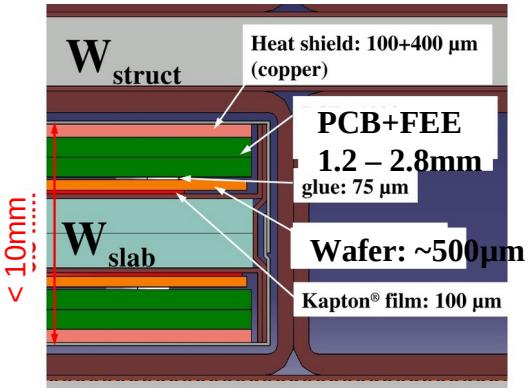
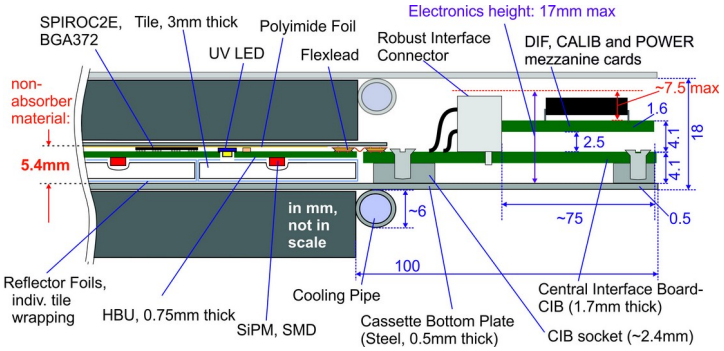
SiW Ecal



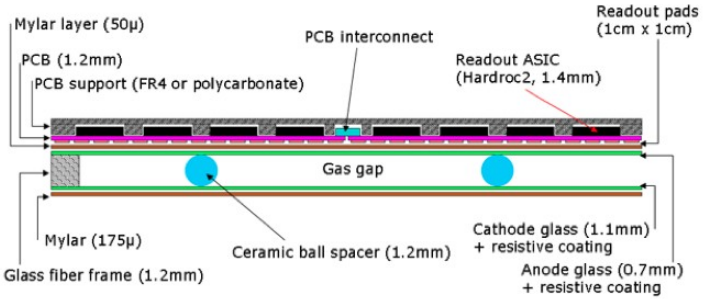
Semi-conductor readout
Typical segmentation: 0.5x0.5 cm^2

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*

CALICE Collaboration High precision design

CALICE Calorimeter for ILC →

HG Calorimetry: Technological solutions II

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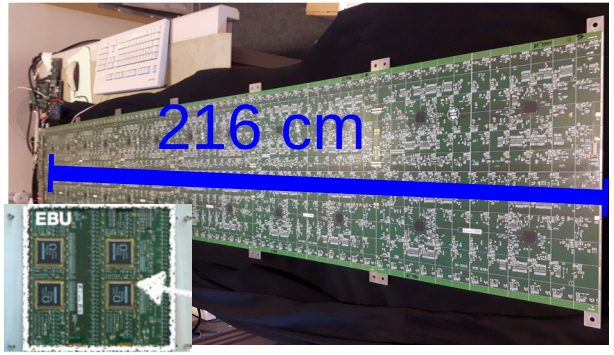
SiW Ecal

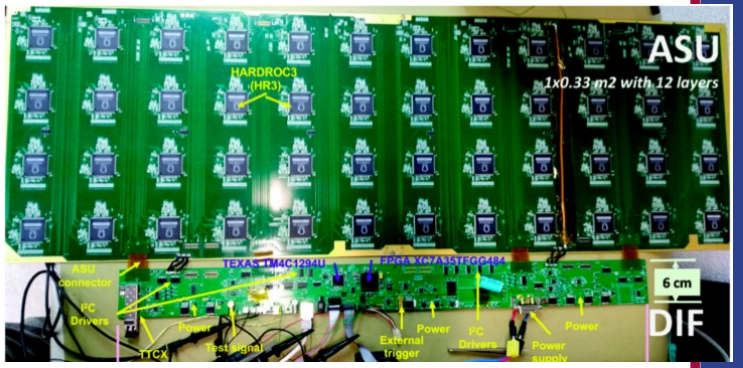
Semi-conductor readout

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 III

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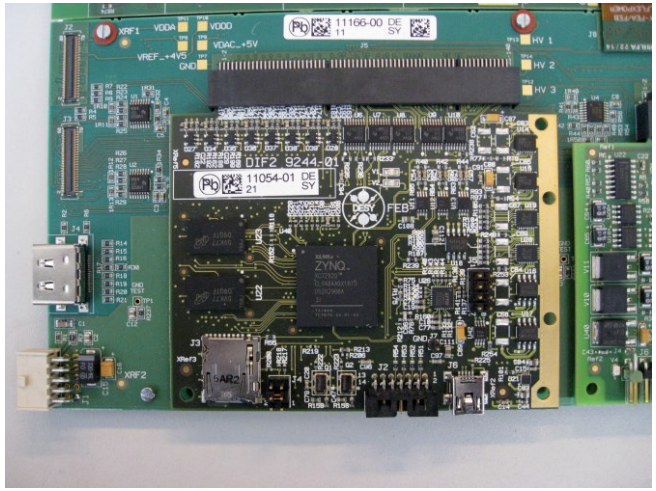
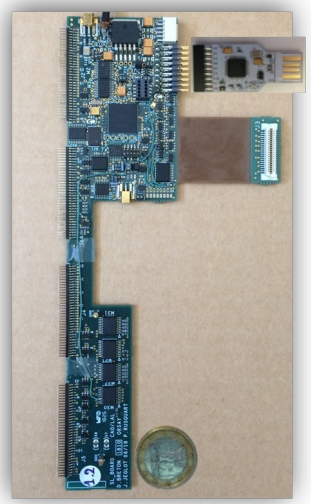
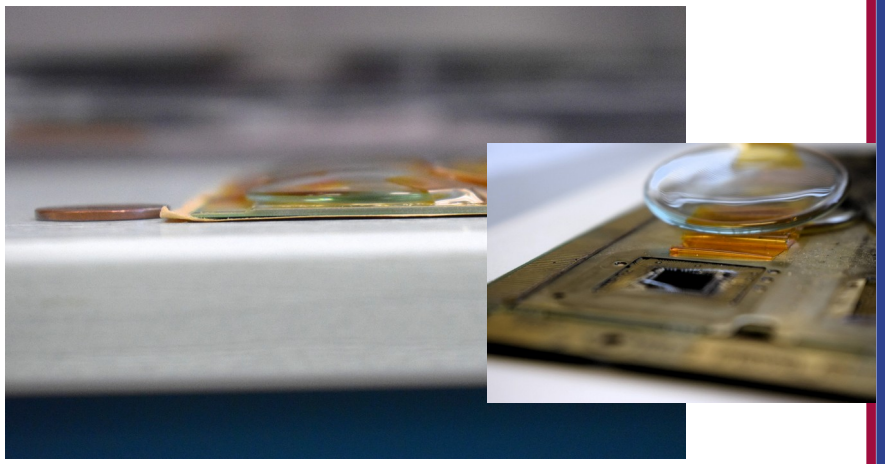
Current detector interface card - AHCAL



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

ILD-Software

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▶ ILD soft and simulated data are accessible

▷ **ILD soft group is** a central player in pushing community wide software solutions in particular with **iLCSoft (LCIO, DD4hep, etc)** developed over 15 years

- have developed **realistic and detailed ILD simulation** models and sophisticated **full (high level) reconstruction algorithms** in this framework

▷ We are very actively **collaborating** with **other communities (linear, circular, FCC-hh)** to modernize our software stack in the **Key4hep** project

▷ ILD software groups highly involved in common efforts with other collider concepts

- AIDA2020, AIDAInnova,...
- ECFA Higgs/Top/EW Higgs factories.