Silicon-Tunsgten ECAL R&D

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Si-W ECAL for ILD

Work of many groups:
LLR (Palaiseau), LAL (Orsay), LPNHE (Paris), LPC (Clermont), LPSC (Grenoble), Tokyo, Kyushu

Adaptation for CEPC

"Small ILD" model: simulation & mechanical model

1st Cooling Studies

an ECAL optiminsed for the PFA

Requiments:

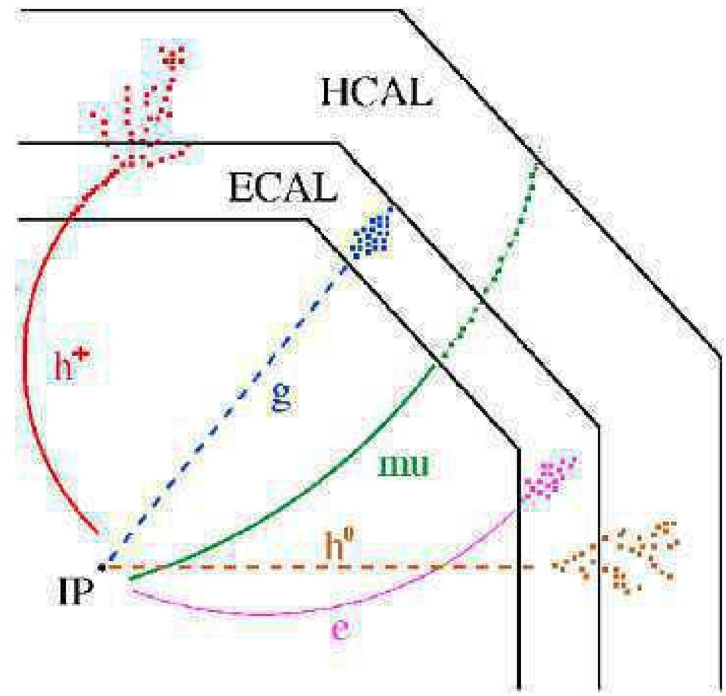
- Measure the photons
- Identifiy the electrons deposits (to be removed) ↔ tracks
- Follow the tracks
  - to a eventual hadronic interaction
- measure the non-charged hadrons (1/3 interact in the ECAL)

IN HIGH E JETS

⇒ Excellent Imaging capacities, separation

- Compact showers: Si-W ECAL

⇒ Good resolution for γ, h^0

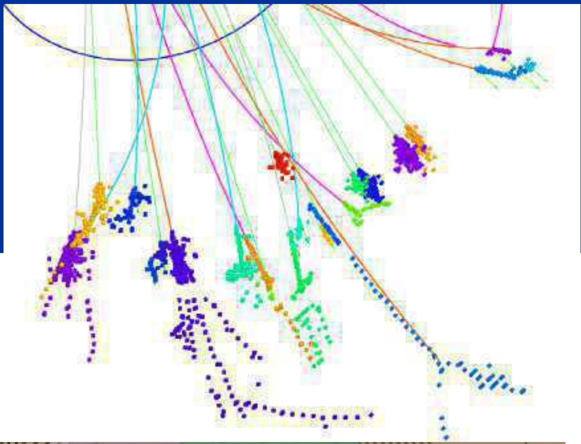


Particle Flow Algorithms :

- Jets = 65% charged + 25% γ + 10% h^0
  Tracks ECAL CALO's
- TPC $\delta p/p \sim 5 \cdot 10^{-5}$; VTX $\sigma_{x,y,z} \sim 10$ µm

H. Videau and J. C. Brient, "Calorimetry optimised for jets," in Proc. 10th International Conference on Calorimetry in High Energy Physics (CALOR 2002), Pasadena, California. March, 2002.

Imaging Calorimetry

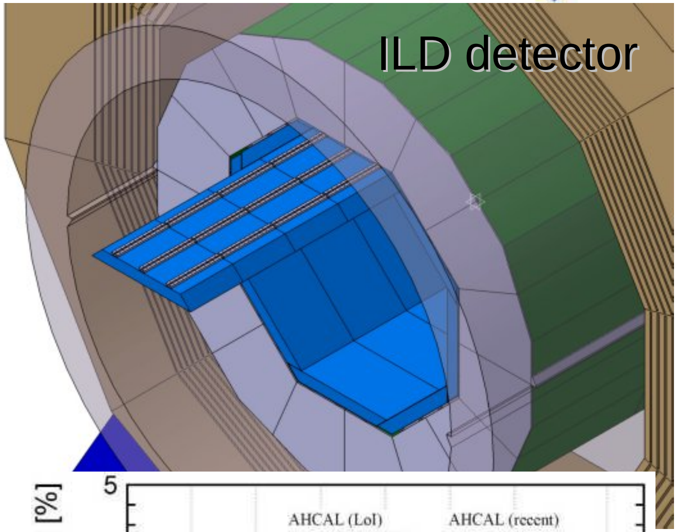


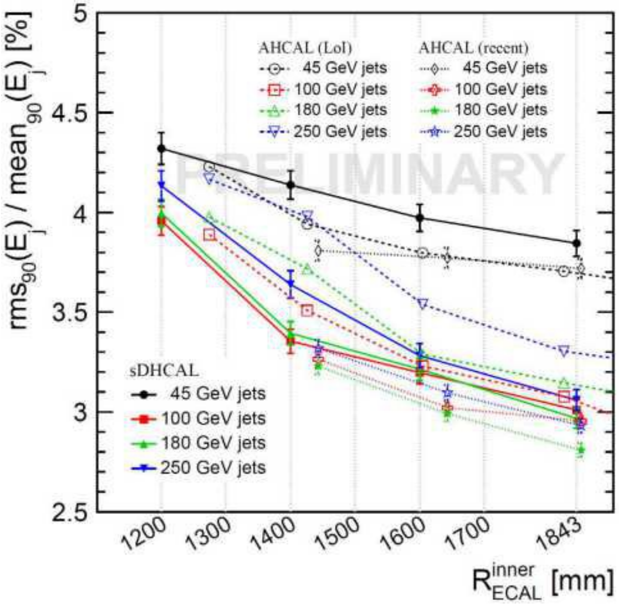
Imaging Calorimeters 1000× current granularity

- wrt LHC: data rate ↘↘ but embedded electronics
- Pattern recognition

Needed R&D:

- Dimensioning, Mechanics (uniformity), Sensors, Electronics, VFE, Power Consumption, Thermal dissipation & uniformity
- Iterative construction & test of Prototypes
- Detector & Integration
  - Optimisation : Physics vs cost, services (PP, cooling)





Dedicated SW tools for PFA:

Difficulty : perf in JER = HW ⊗ SW

SiW ECAL: Physics & Technological prototype

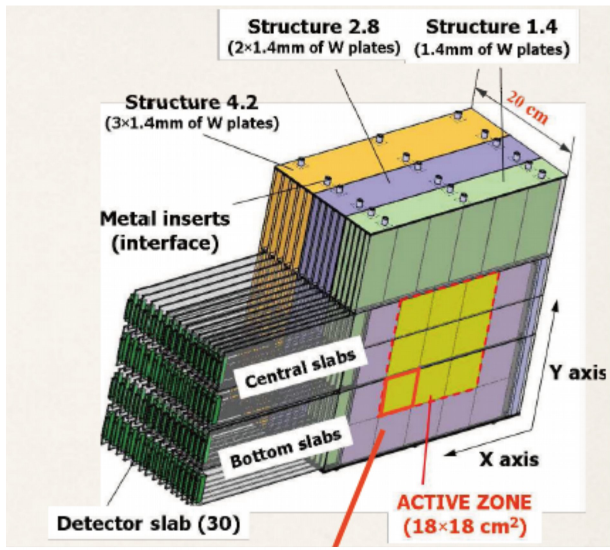
Physics prototype: 2005-2011

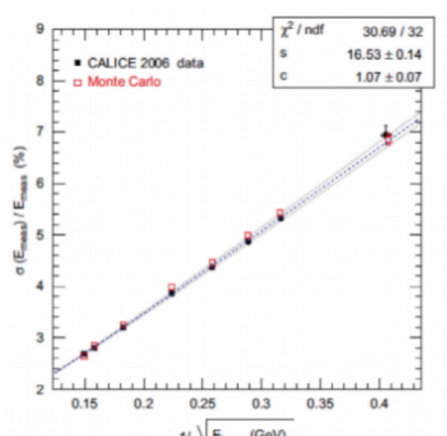
PFA proof of concept with comparison to MC (PandoraPFA etc.)

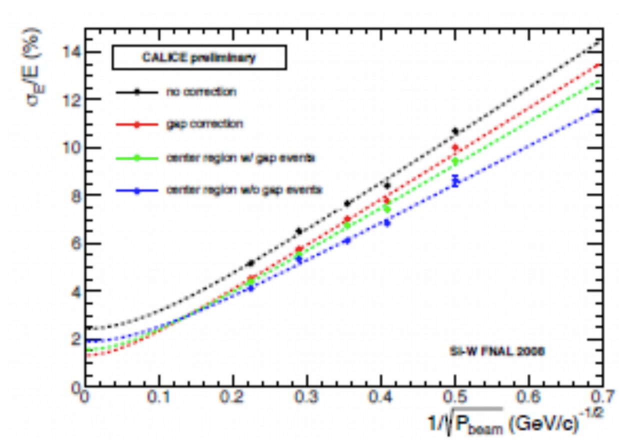
Electronics outside

- 1cm x 1cm pixels
- full 30 layers

(used for PAMELA sat.)

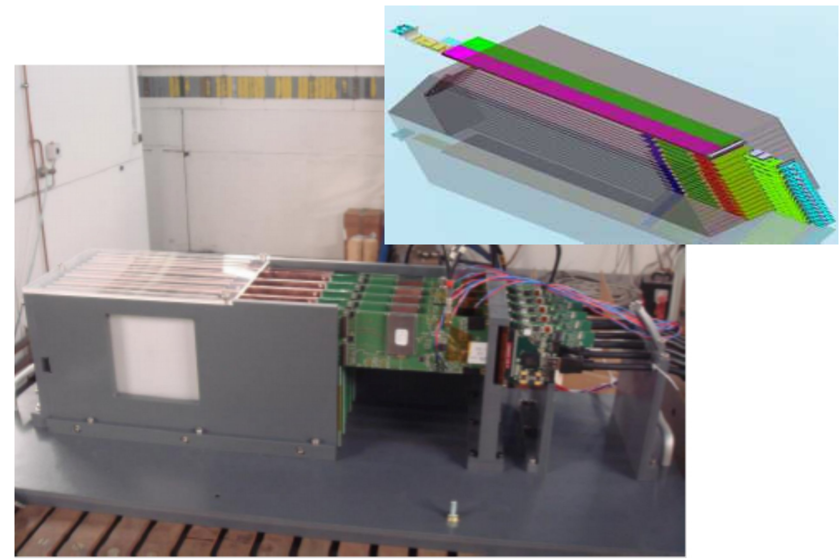






16.5%(stochastic) 1–2% (constant) obtained with 1–45 GeV e⁻/e⁺ at 2006/2008 BT

Technological prototype



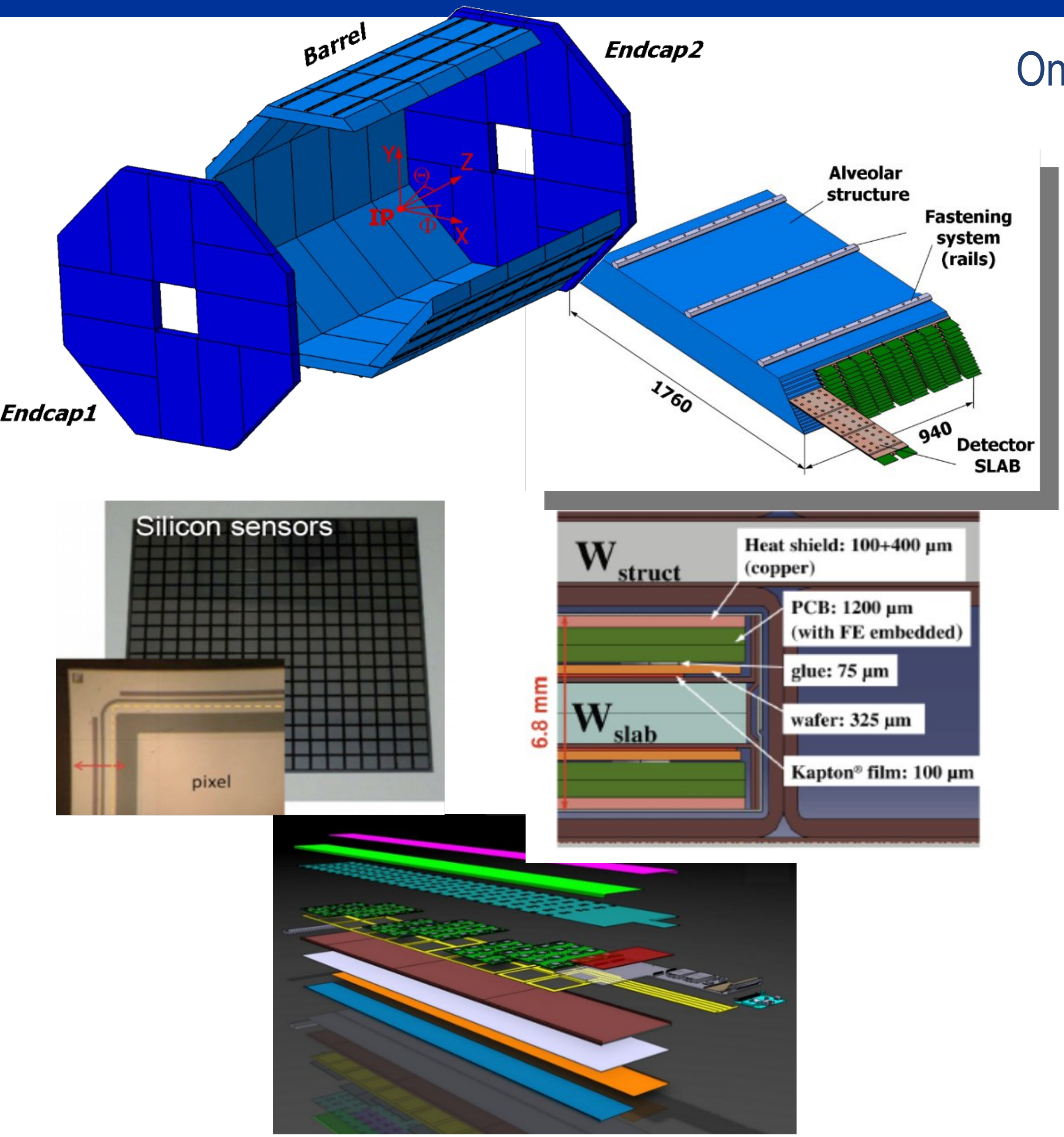
Embedded electronics

- SKIROC2 analog/digital ASICs
  - auto-triggered, zero suppr., PP
- pixels 5×5mm²

Assess the feasibility

Establish procedures and develop test benches for mass production

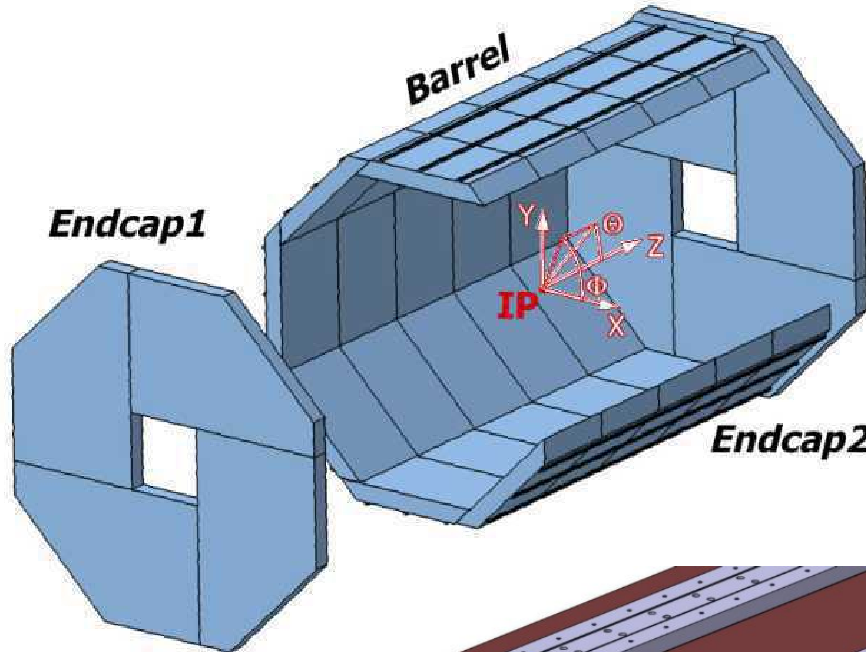
The SiW-ECAL of ILD



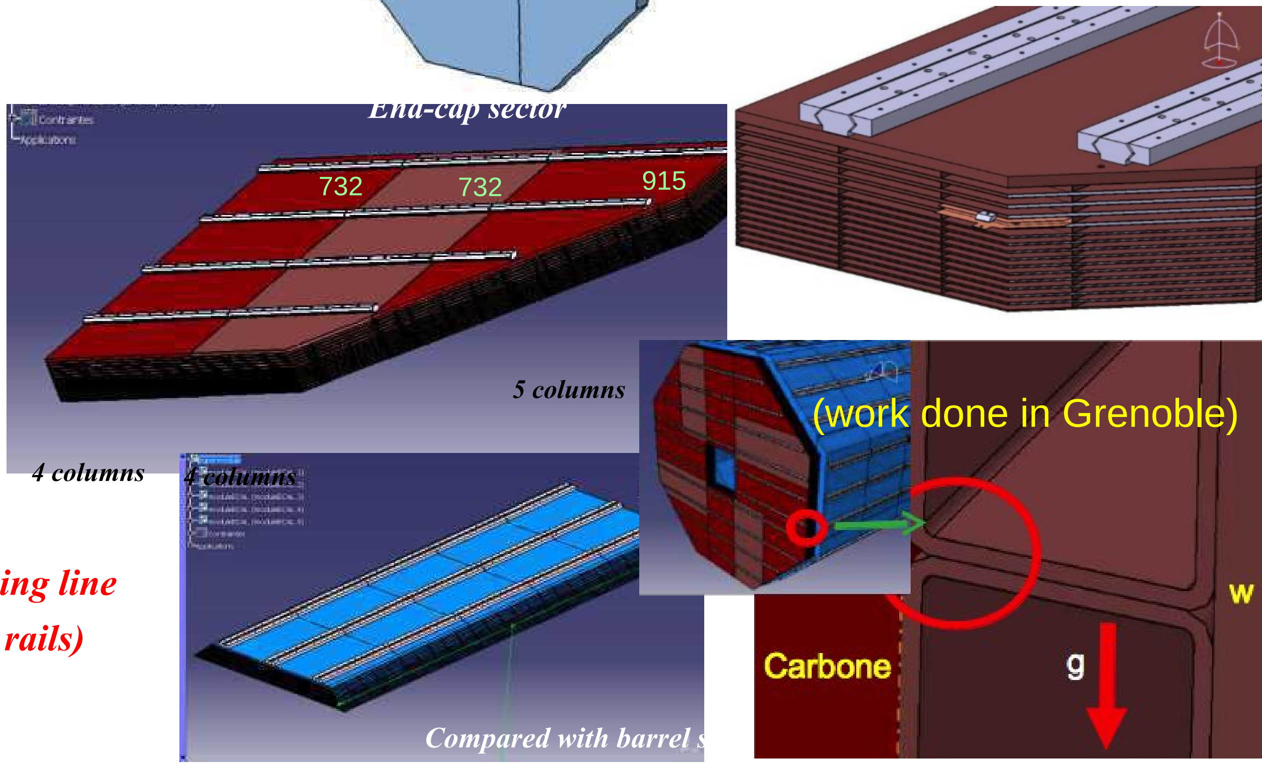
On going R&D

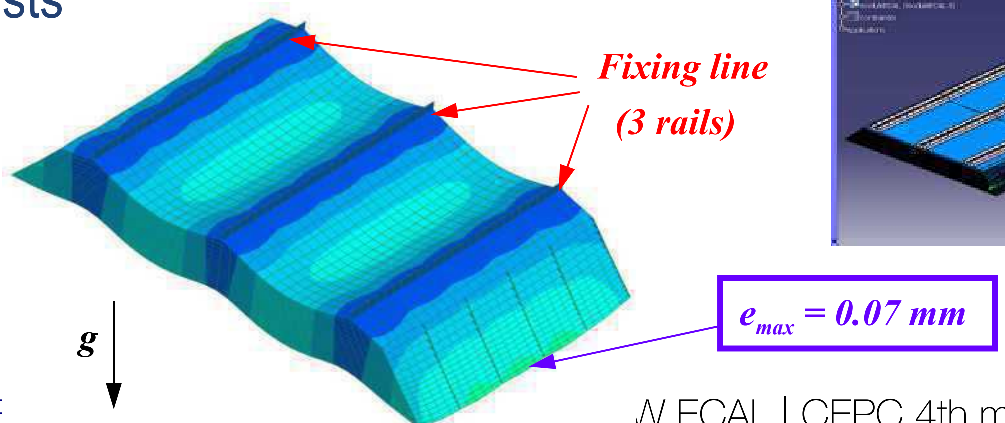
- Thermic & Mechanical studies
  - Production, Characterisation & Monitoring
  - Thermic simulation & cooling
    - Also for the CMS-HGCAL
- Assembly: Quality tests & preparation of large production for ILD
  - VFE, PCB's, ASU's
  - TB, Cosmics, Charge injection
- Wafers:
  - Guard Ring Studies
  - Characterisation
    - Charge injection by Laser
- Optimisation: Cost → reduction of radius
  - for ILD, CEPC (Dan Yu).

ECAL structure

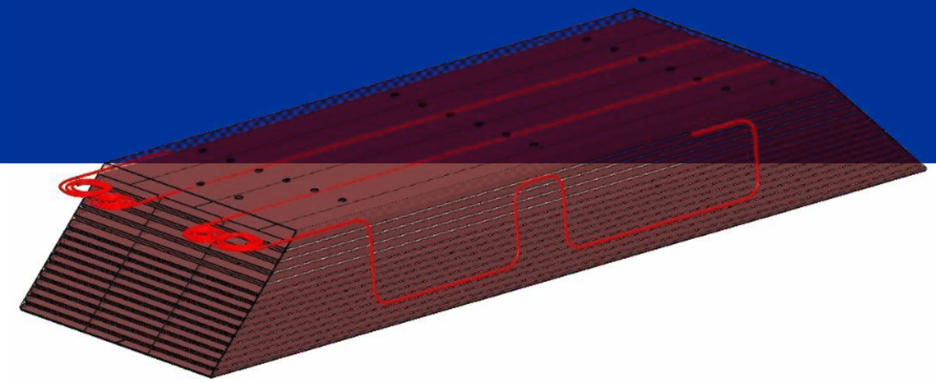


- Barrel: 5 octagonal wheels
  - R_{min} = 1808 mm; R_{max} = 2020
  - Width = 940mm
- End-caps: 4 quarters
  - $\varnothing_{min}$ = 800 mm
- Carbone / Tunsgten structure
  - filled with Si or scintillators (option MAPS/DECAL)
- Extensive mechanical simulation & tests





ECAL : Composite Structure (barrel)



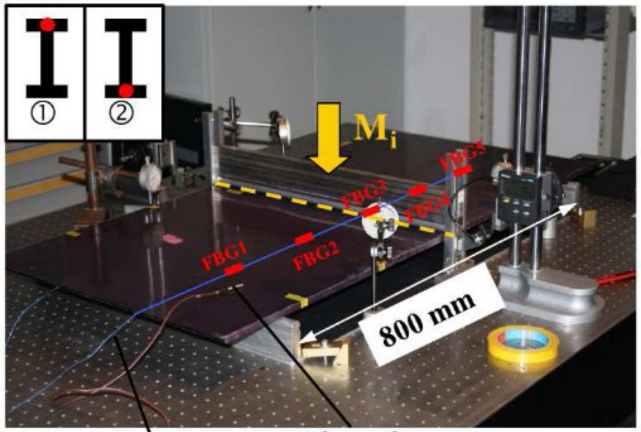
Carbon Fiber + Tunsgten

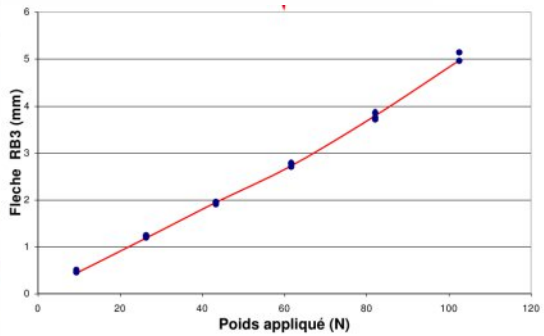
- Prod : dec 2011 (5 yrs of R&D)
- 600kg, 15 layers

15 alveoli produced, 1 faulty

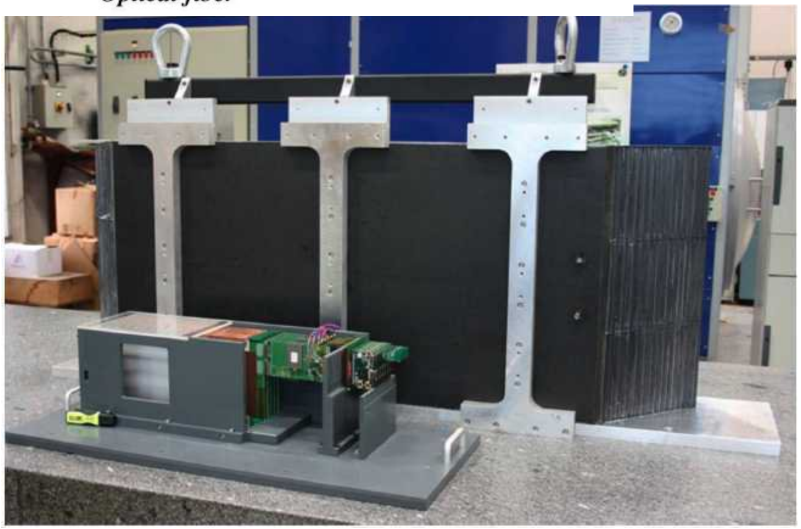
1 equipped with Fiber Bragg-Gratted (FBG)

⇒ Comparison calculation and measurement





Vérification des paramètres du modèle en comparant la flèche FBG3 mesurée et simulée



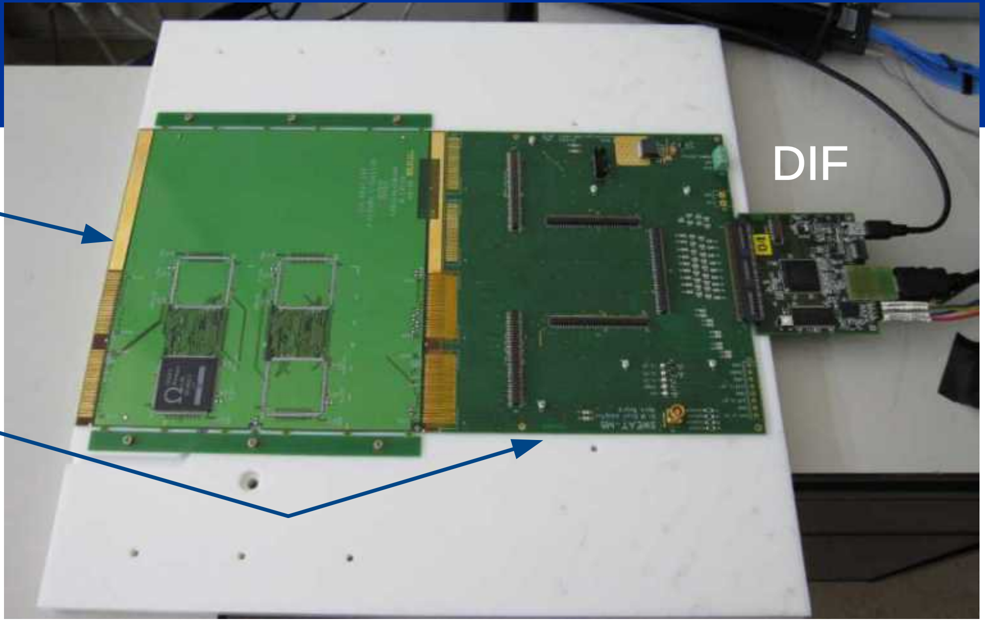
Assembling mould

- Cooking in autoclave

Metrology

- Minor on-side deformation

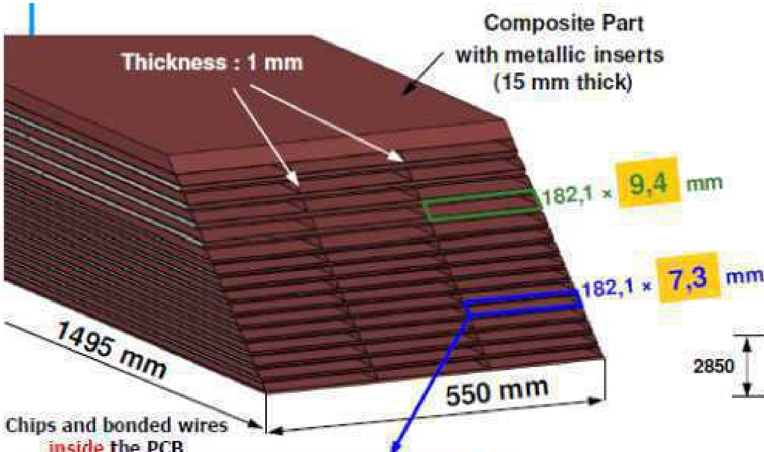
ECAL : FE Boards

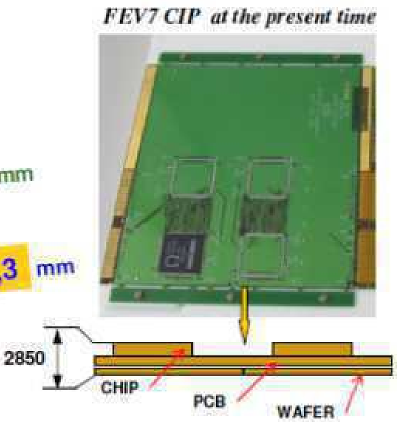


Tests of (early) FEV7 CIP et COB PCB (now FEV11 in prodcution)

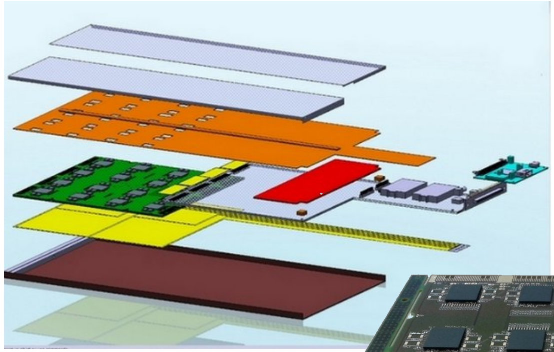
“Adaptator” board

- Interface to cooling
- Buffer for power pulsing
  - with super-capacitors (super-C)
- Connexions tested in strong B field → DESY (02/2013): no effect

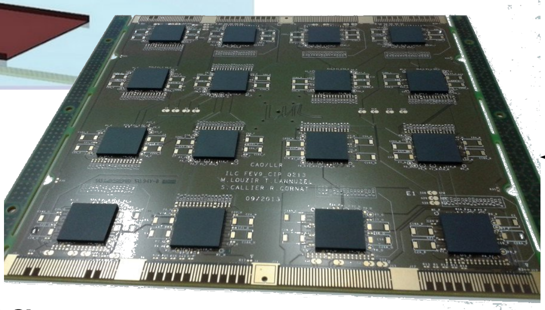




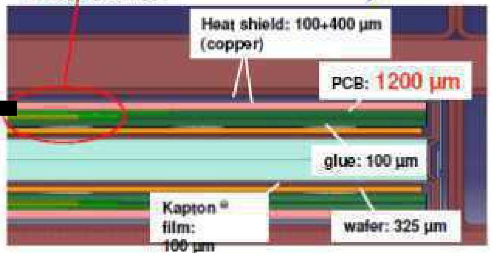
CIP



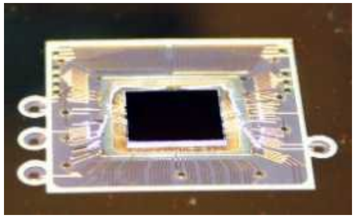
FEV9



BGA packaging



COB



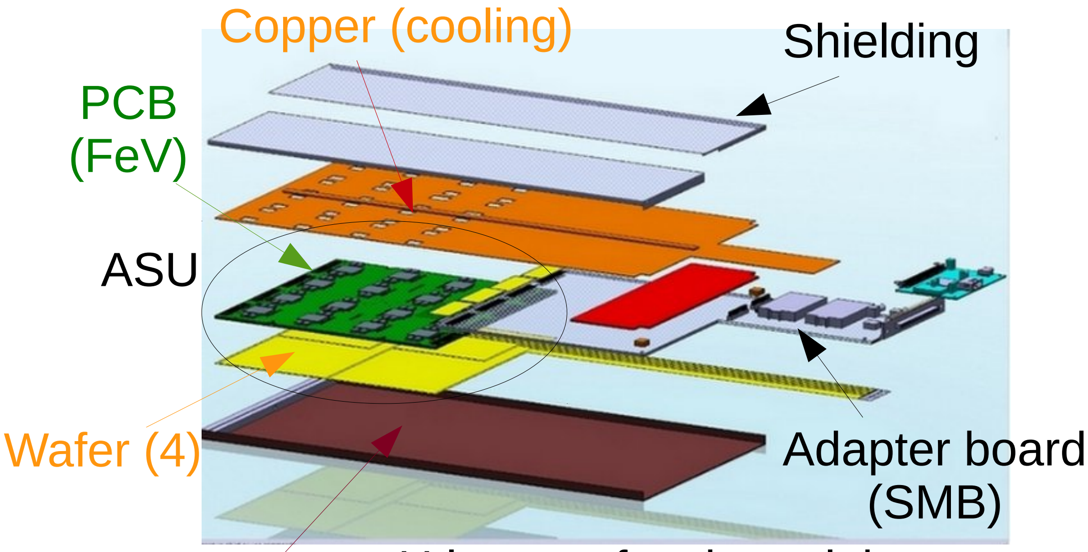
SLAB Assembly: full chain

R&D for "mass production" and QA

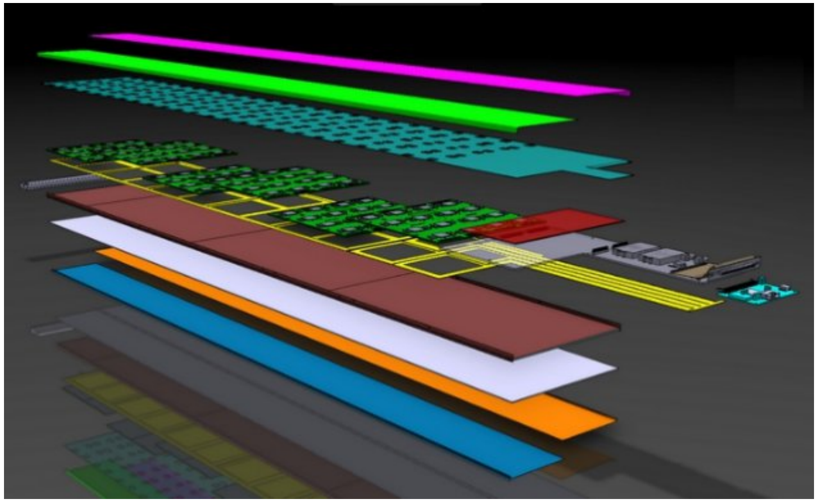
- Quality tests & preparation of large production
- Modularity → ASU & SLABs
  - Choice of square wafers (≠ from hex: SiD, CMS HGCAL)

Numbers (R_{ECAL} = 1,8 m, $|Z_{Endcaps}|$=2,35m) (likely to be reduced by 30–40%)

- Barrel modules: 40 (as of today all identical)
- Endcap Modules: 24 (3 types)
- Slabs = 6000 (B) + 3600 (EC) = 9600
  - many ≠ lengths
- ASUs = ~75,000
  - Wafers ~ 300,000 (2500 m²)
  - VFE chips ~ 1,200,000
  - Channels: 77Mch



U layout of a short slab


U layout of a long slab

Wafers:

Key elements of detector

- Basic unit for the size of the detector
- (Most expensive part too)

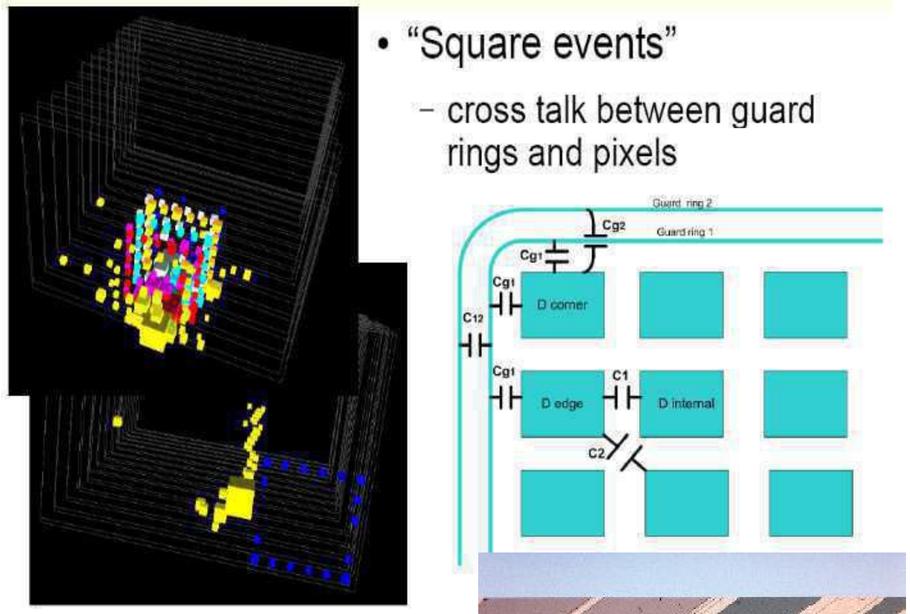
Guard Rings

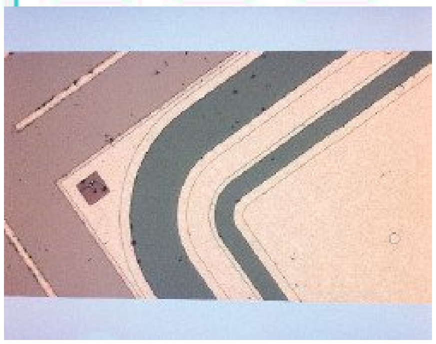
- Alternative designs
  - segmented, “edgeless”
- Complete characterisation of sensors ⇒ link to & test variety of producers
- Work in CALIIMAX-HEP French ANR in relation with Kyushu/Hamamatsu

Test of Silicon sensors

- Test different HPK designs: C-V, I-V.
- Laser tests: xtalk via GR.

From physics prototype test beams





Plans:

- **Irradiation tests (γ,n)**
- **Validation of GR design in HE electron beam.**

Si-W ECAL for the CEPC

Same mechanical structure as ILD but...

- Rates of machine ≠ ⇒ worst case: ~continuous
- no power-pulsing ⇒ **VFE power ↗↗↗**
  - 27 μW/ch ⟶ **~5mW/ch** (for 25 ns BX)
    - μ-power pulsing for slower modes ?

Adaptations:

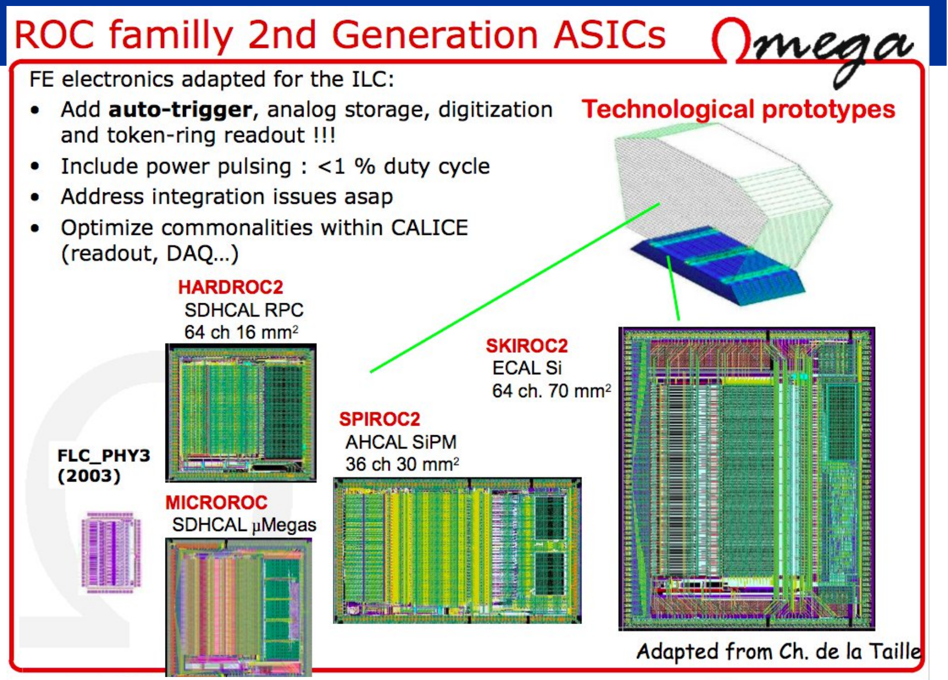
- Reduced number of layers
  - 30 ⟶ 20 ?
- Less electronics channels
  - 0.5 ×0.5 cm² ⟶ 1×1 cm² ?

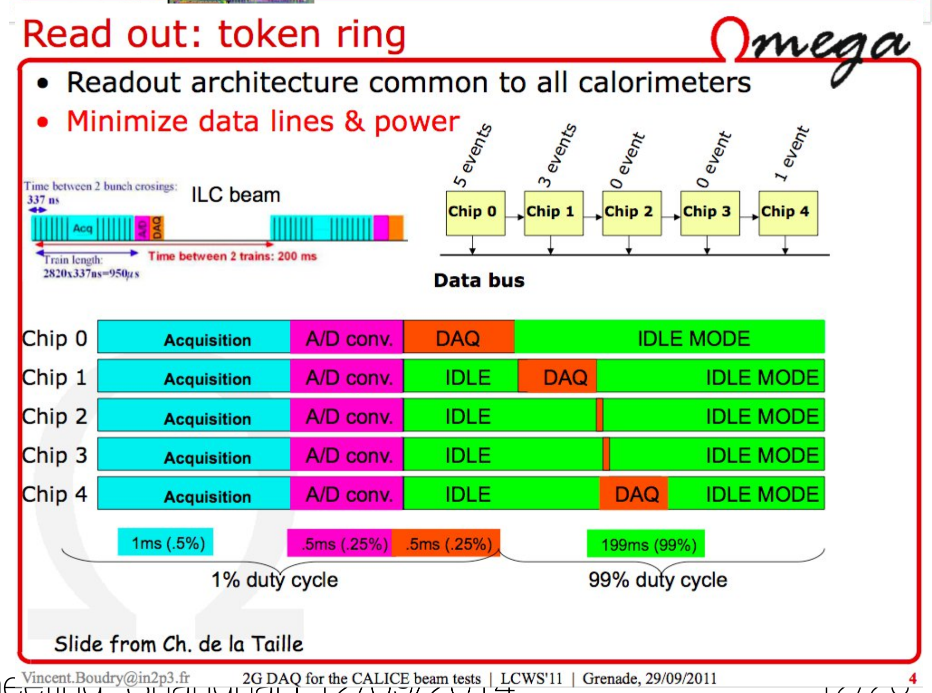
Radiations ? ⟶ leakage current ↗

- cooling at -20°C for CMS-HGCAL ?

Performances to be evaluated

- Occupancy!!! ⟶ power consumption
- (Simulation on Small ILD version).





Exemple of design with cooling

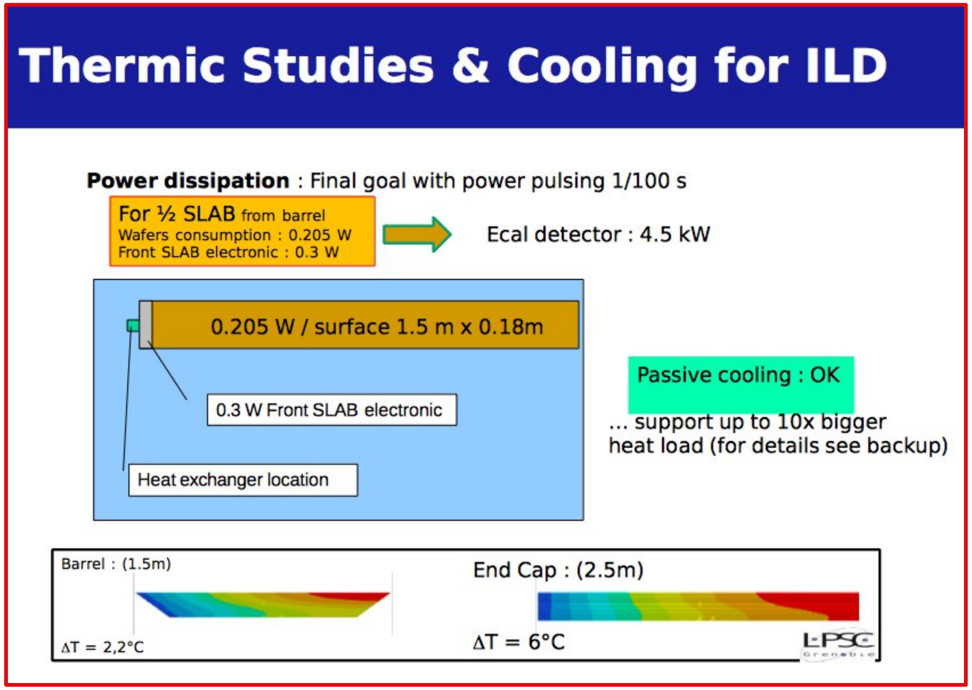
Passive cooling

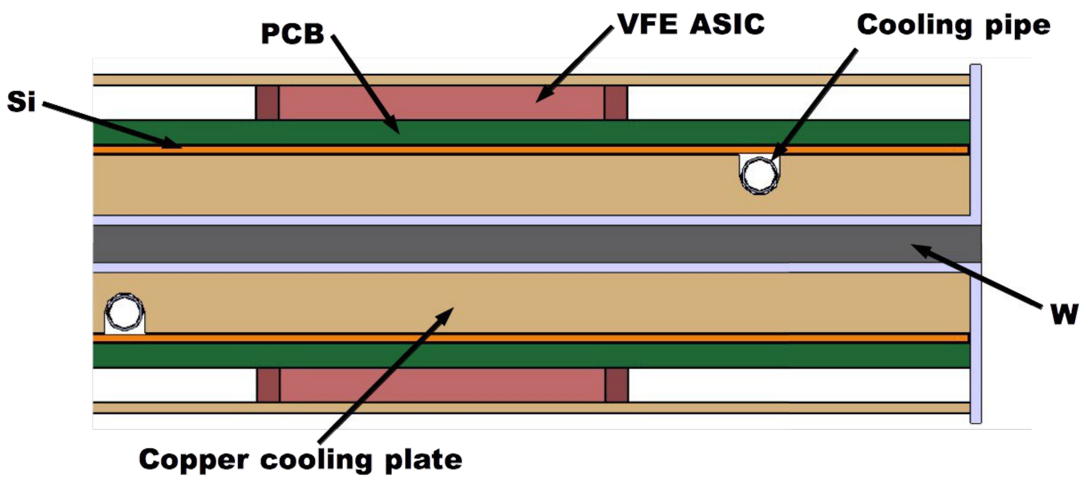
- too much gradient in Si...

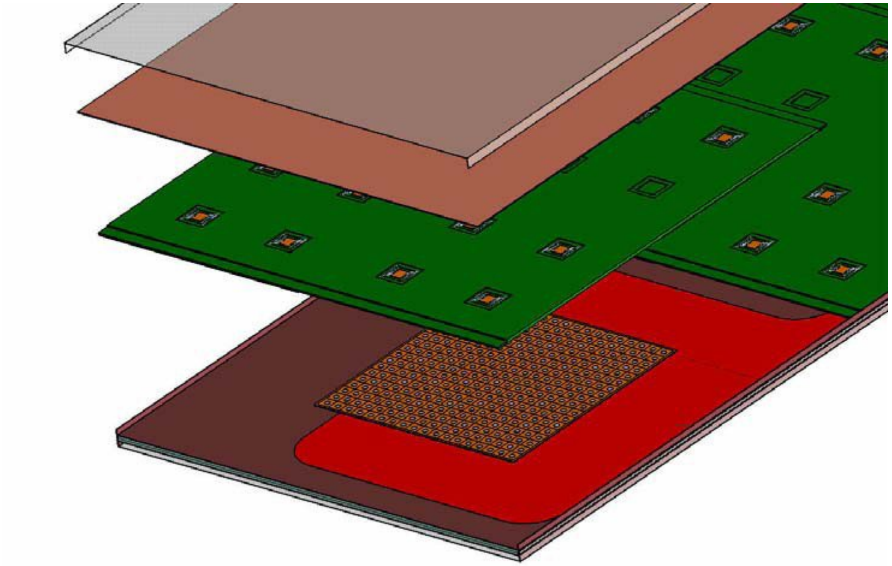
Active cooling

- Evaporative CO_2 cooling in thin pipes embbeded in Copper exchange plate
  - for CMS-HGCAL : 33mW/cm²
    - down to 0.6×0.6cm² OK (safety margin of 2)

→ To be modelled for Mokka simulation







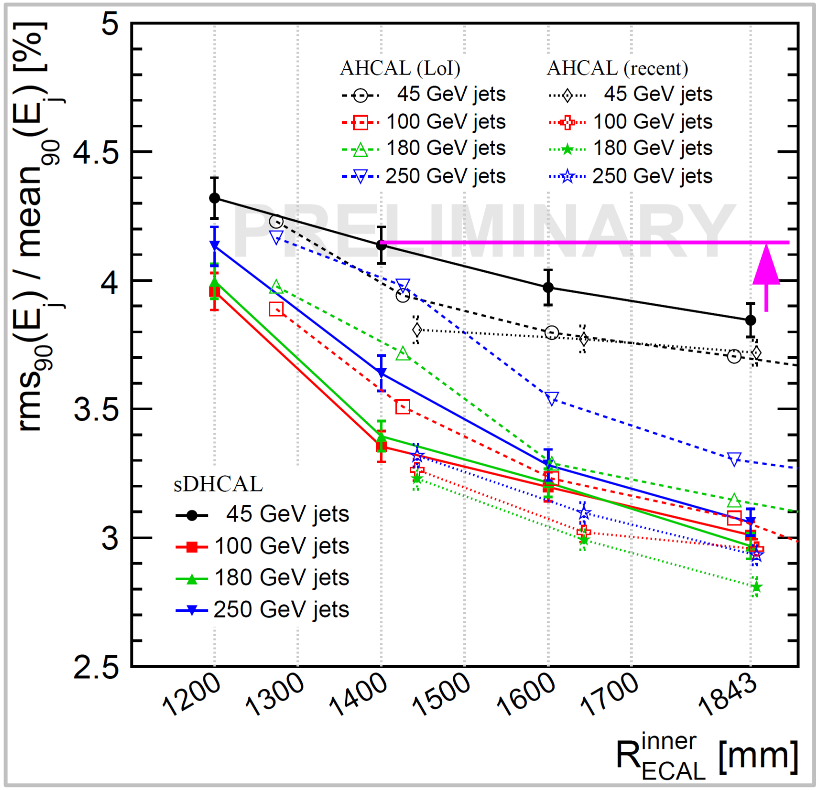
Simulation studies

Shown @ LCWS'13 (work by Trong Hieu Tran)
https://agenda.linearcollider.org/getFile.py/access?contribId=67&sessionId=35&resId=0&materialId=slides&confId=6000

- Evaluation of the JER vs R_{INNER} ($\leftrightarrow R_{TPC}$, @ fixed R/L ratio).
- Using PandoraPFAnew v0.12 and full calibration procedure
  - μ, γ, K^0_L samples ⇒ ECAL/HCAL intercalib + E2H/H2H + angular corr.
- ILD_o1/2_v05(SEcal04, AHCAL/SDHCAL)
  - SiW ECAL: 5×5 mm², AHCAL: 3×3 cm², sDHCAL: 1×1 cm²

Results

- ≤10% for RI_{NNER}=1800⟶1400mm



Variation of N_{Layers}

PhD student in co-tutelle LLR / IHEP on ILC / CEPC ECAL

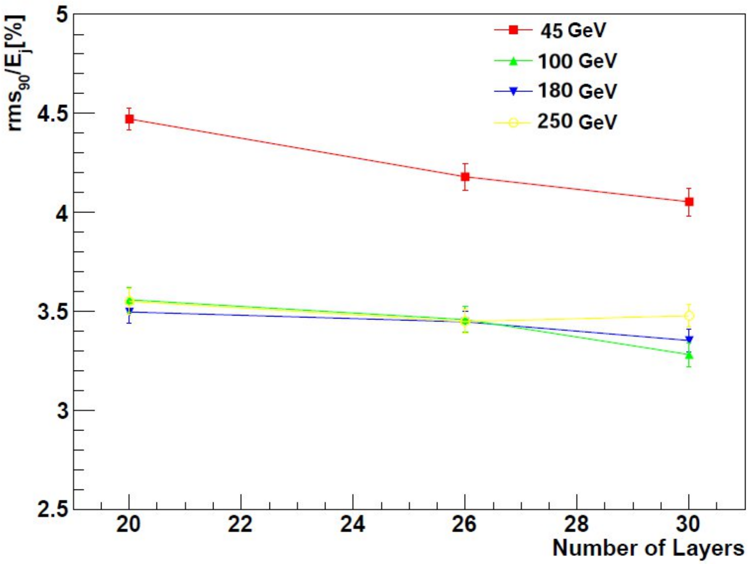
Shown @ 6th ILD Optim meeting (16/07/2014) [Internship work of **Dan Yu (LLR)**]
https://agenda.linearcollider.org/getFile.py/access?contribId=2&resId=0&materialId=slides&confId=6435

- Variation of ECAL's N_{Layers} for R=1450mm, HZ_{Barrel}=1848mm on ILD_o2_v05
- Exact Same procedure as previous study
  - Non-Linearity ≤ 1%
- For |cosθ| ≤ 0.7

number of Si layers	W layers (1st section)	Thickness (mm)	W layers (2nd section)	Thickness (mm)
20	13	3.15	6	6.3
26	17	2.4	8	4.8
30	20	2.1	9	4.2

Results

- JER + ≤6% @45 GeV



Simulation to be improved in endcaps

Realistic parameters for small ILD

From preliminary mechanical model ⇒ in simulation & cost

Reduced radius $\mathbf{R_{INNER}}$**=1400mm**.

Base unit = Wafer size

- Largers Wafers: 6” ⟶ **8”** (OK from HPK, LFoundry); smaller wafers (4”) in 2nd part ?
- Wafer side: ~90 ⟶ **126** mm; Alveola ~200mm⟶ 253,8 mm;

Barrel: **5 modules of 3 alveola**

- L_{Barrel} = 3829mm (Z_{endcap} = 3929mm).

Endcaps: **Quadrants of 2 modules of 2 and 3 alveola**

- with R(ECAL Ring) = 40cm + Integer number of Wafers + ½ Wafers

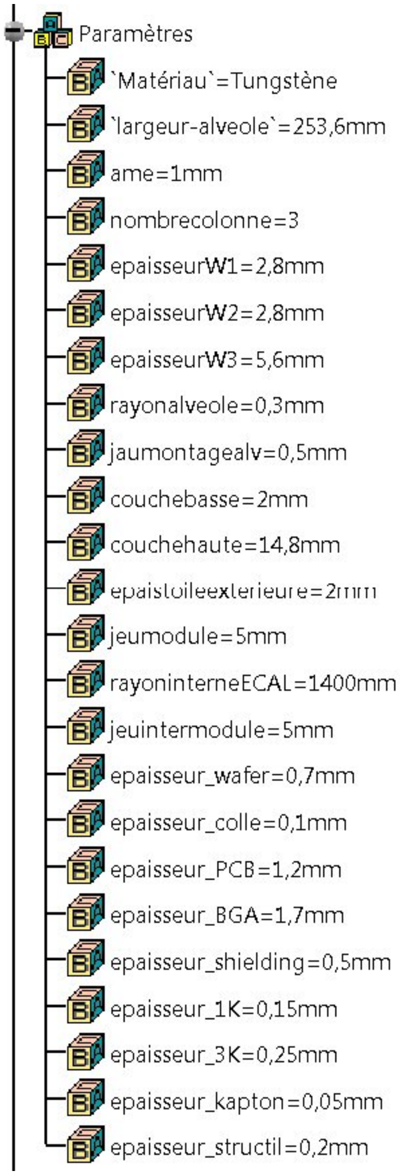
  ⇒ R_{Endcap} = 1676mm

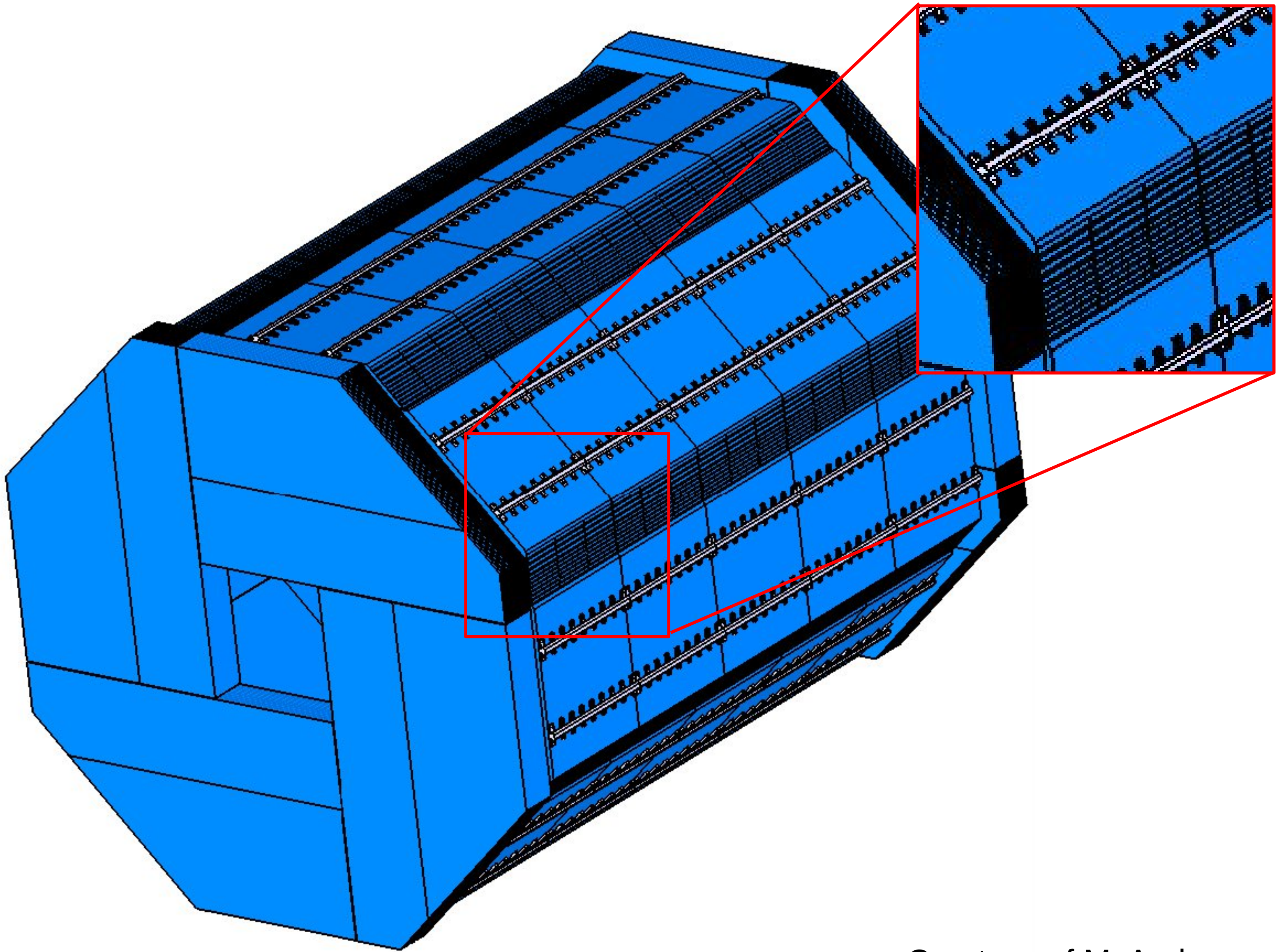
N_{layers} = 22 = **14 + 8** (single and double W thickness)

Wafer thickness 500⟶ **~725µm**

- Improved $\sigma(E\gamma) \propto \sqrt[5]{t}$ ⇒ ~recovery of N_{layers} effect. ⇒ compensation of N_{Layer} loss.
- ECAL thickness = 223,85 mm

Mechanical model





Courtesy of M. Anduze

Small ILD ECAL Cost

Complete re-evaluation for the ressource survey in July (PRELIMINARY)

- Number of elements
  - Wafers, ASICs, PCB's, SLABs, structures,
  - moulds, processes, test benches
  - transportation boxes
- Man•Years
  - Reception, Tests, Mounting, Installation

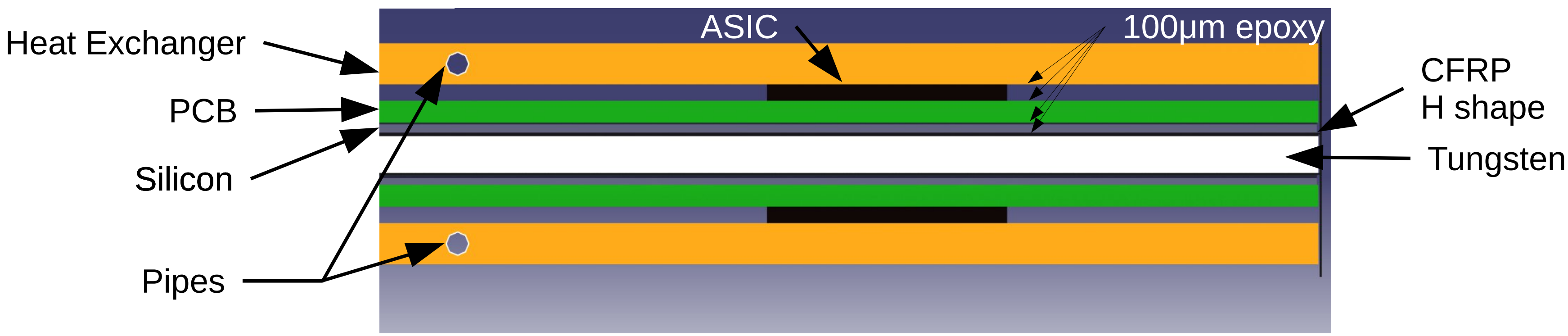
Outcome:

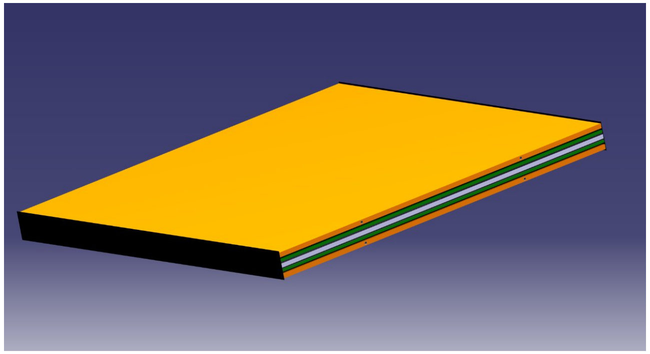
- Cost ratio 1.4m/1.8m of **47,5%**

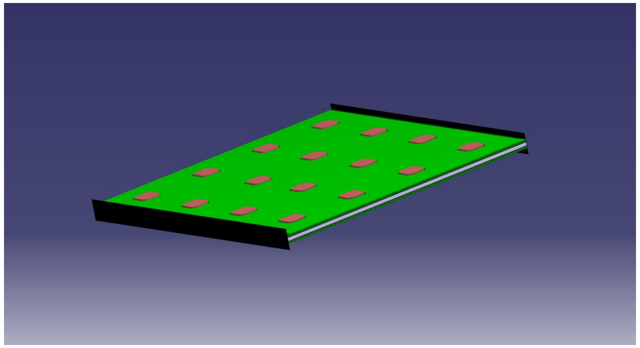
Cooling studies (preliminary)

Based on CALICE and CMS-HGCAL schemes

- cooling with di-phasic CO_2 pipes with extra Copper for heat transfert:







- 3 mm of Cu, 2.8mm of W, Silicon Wafers of 725 µm, pipes of $\varnothing_{int/ext}$ = 1.6/1.8mm
- Working point of CO_2 : 20°C, Chips power of 10mW/ch × 64 = 0.64W

ANSYS thermal simulation

Fully transversally isolated system,
with ASICs a sole heat source, and pipes @ 20°C as heat sink

- purely diffusive model (no convection), at equilibrium,
- ideal heat interfaces, chips packaging, cooling pipes
- 2 side longitudinal modules simulated

Heat conductivity are “best guess” only:

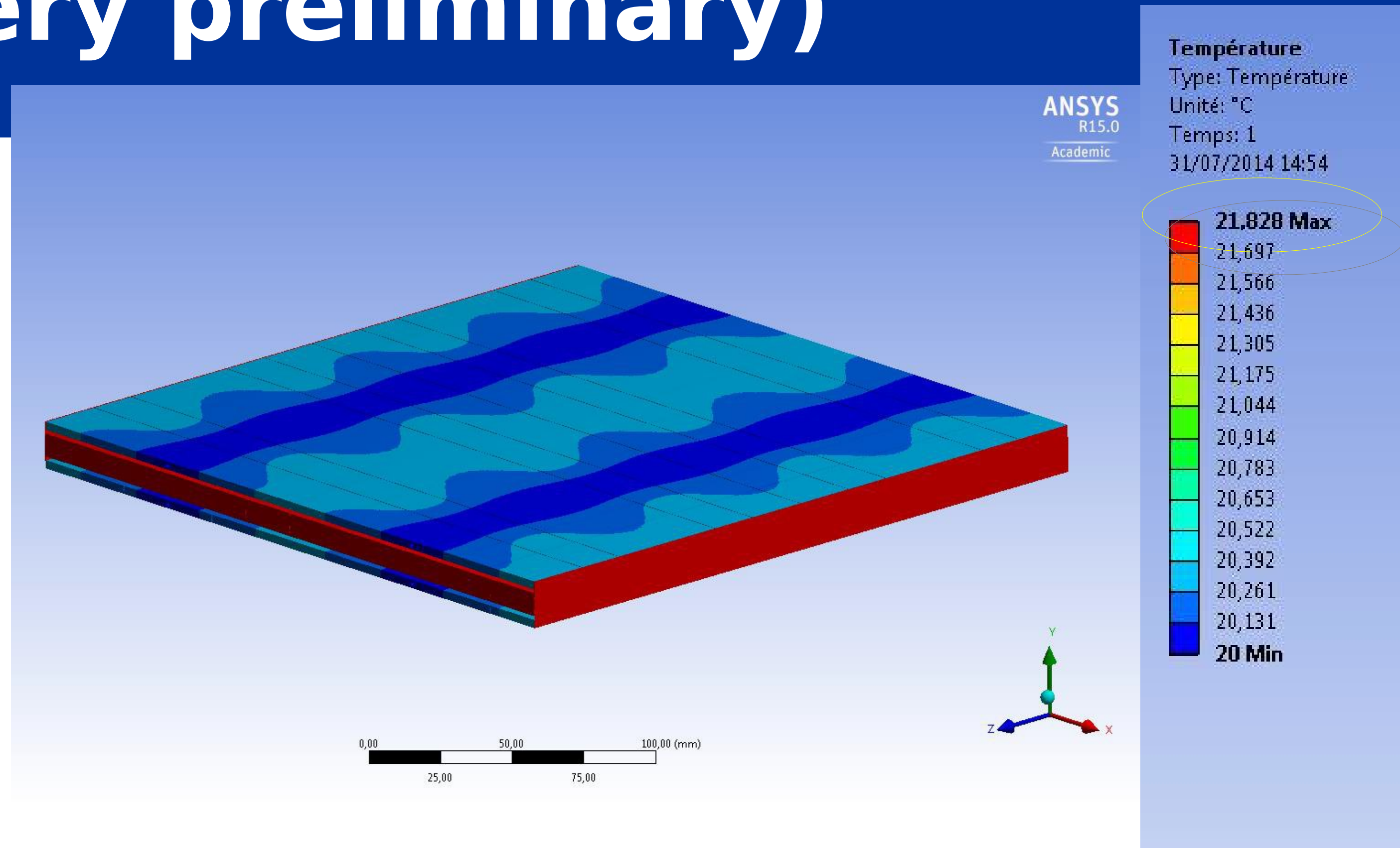
- Epoxy ~ 0.795 W/m•K
- Composite highly anisotropic (high along fibres)
- PCB are laminated of 3% of Cu (385W/m.K) + 97% of FR4 (0.3W/m.K)
- ASICs package choosen as 1 W/m.K

First results, to be re-evaluated...

Results (very preliminary)

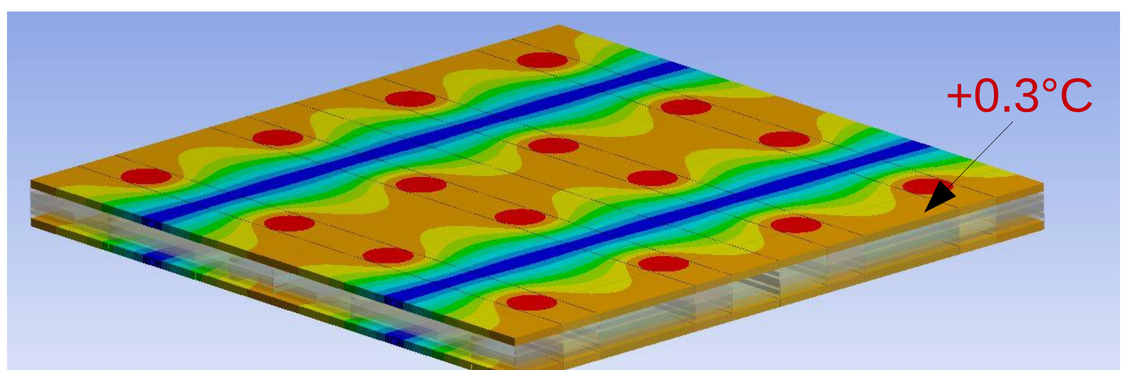
Over complete module:

- ΔT ≤ ~2°C
- Mostly in ASICs
- PCB, CFRP & W harmonize the temp.
- Max temp at the center



Over the exchanger:

- ΔT ~ 0.3°C



Conclusion: the tool and the expertise exists...
… results will arrive.

Perspectives

Many years of R&D on ECAL (esp. at LLR) for ILC “easily” adaptable to CEPC case

Work on design modell has started

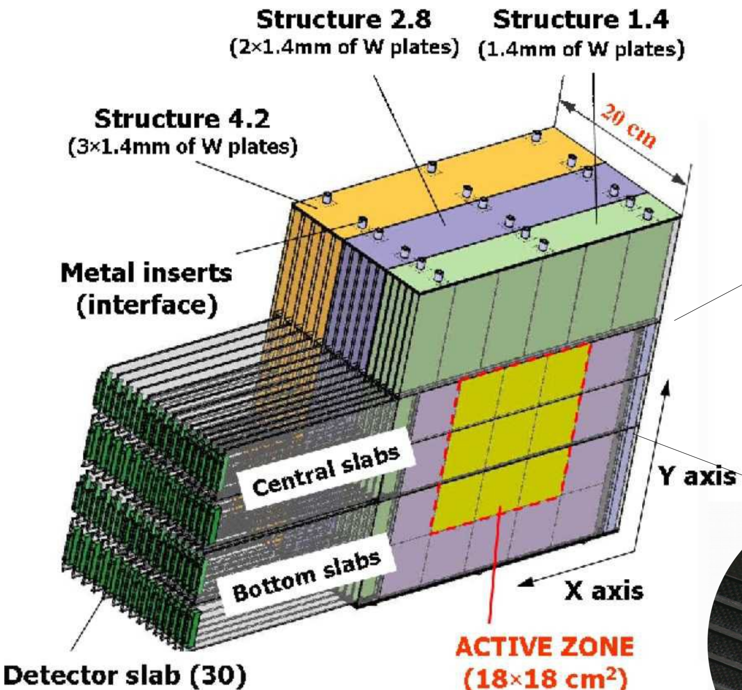
- benefit from CMS-HGCAL studies
- expertise on cooling and thermal simulation building-up

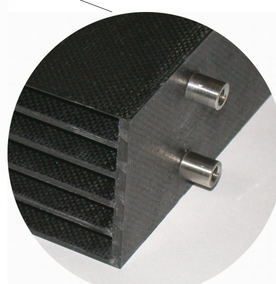
Most urgent to assess the performances and the needed granularity:

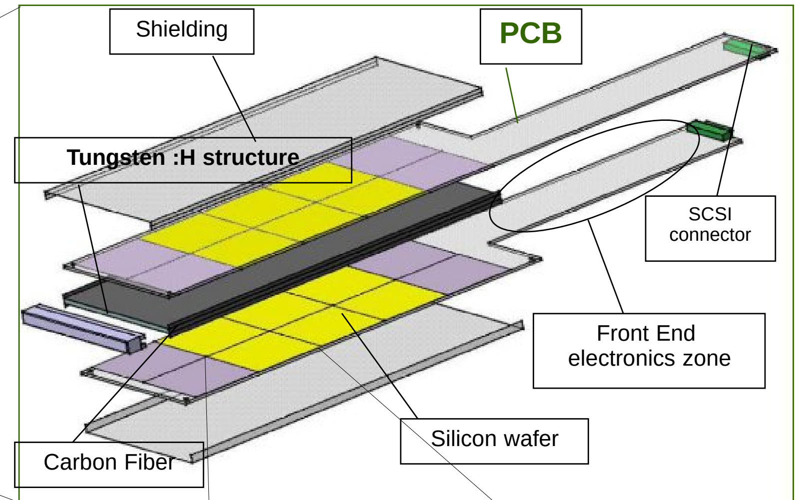
- Bunch structure of the machine will determine the granularity and performance of the ECAL
  - ⇒ Occupancy studies mandatory to fine tune the electric comsumption
    - Specific R&D needed on VFE ASICs
- Updated GEANT4/Mokka models needed (support from LLR)
- 1 PhD student (Dan Yu) will work both on ILD and CEPC performances

Extras

Physical prototype



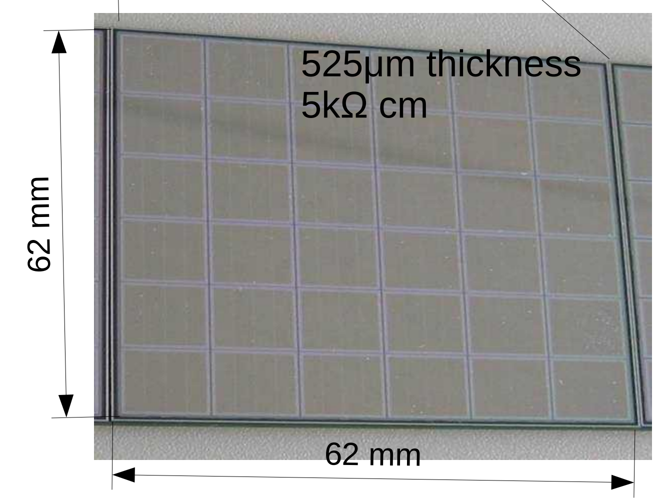




Structure

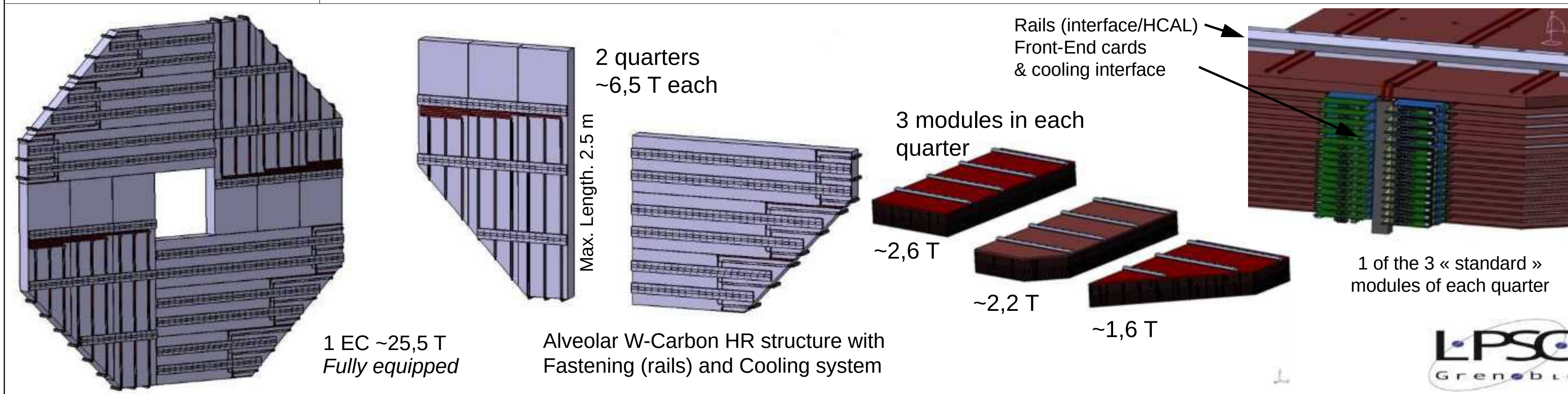
- 30 layers of Carbon Fiber /Tungsten
  $10 \times 0.4\ X_0 + 10 \times 0.8\ X_0 + 10 \times 1.2\ X_0 = 24\ X_0$
- Self supporting Structure
- Sensor Units with external analog readout chips

High resistivity Si PIN Diode divided in $10 \times 10\ mm^2$ cells

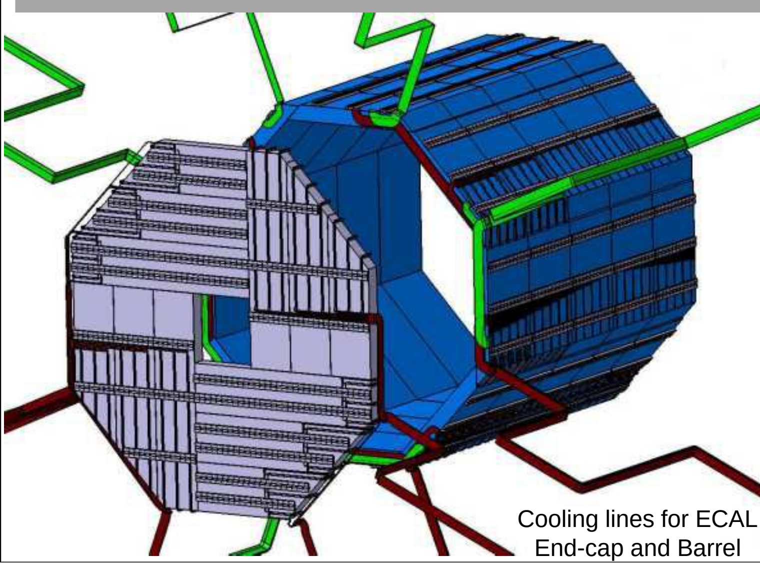


Current structure of end caps

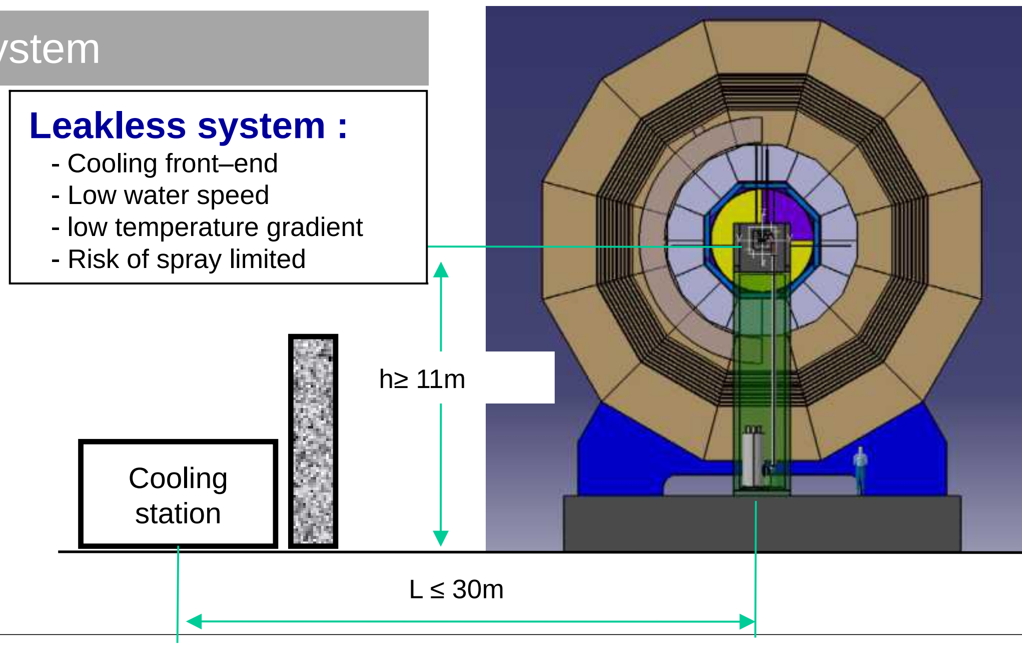
Modular structure	2 End-Caps Total of 2x12 modules = 2 x [4 quarters each]



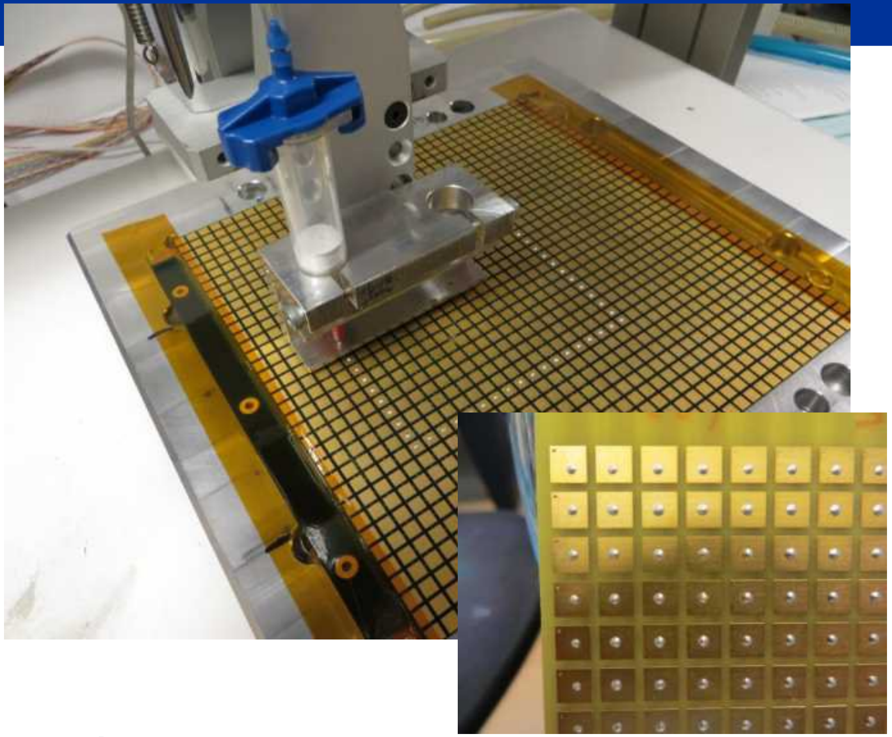
ECAL Cooling Integration - Leakless system



Cooling lines for ECAL End-cap and Barrel



Assembly 1: Gluing



Toward semi-automatic gluing of 4 wafers on every PCB:

- Constraints on the PCB geometry have been identified:
  - Flatness
  - Parallelism of the edges
  - Uniform height of the ASIC soldered on the board

9 sensors has been glued with the robot: used at 2012–13 beam tests

The leakage currents measured before and after the gluing process are similar.

Recent improvements

- Use of specific pumps for dry and clean vacuum
- Careful cleaning of PCB
- New positioning of the glue dots for the external pads, to avoid short-circuits.