Upgrade Phase II & HGCAL:

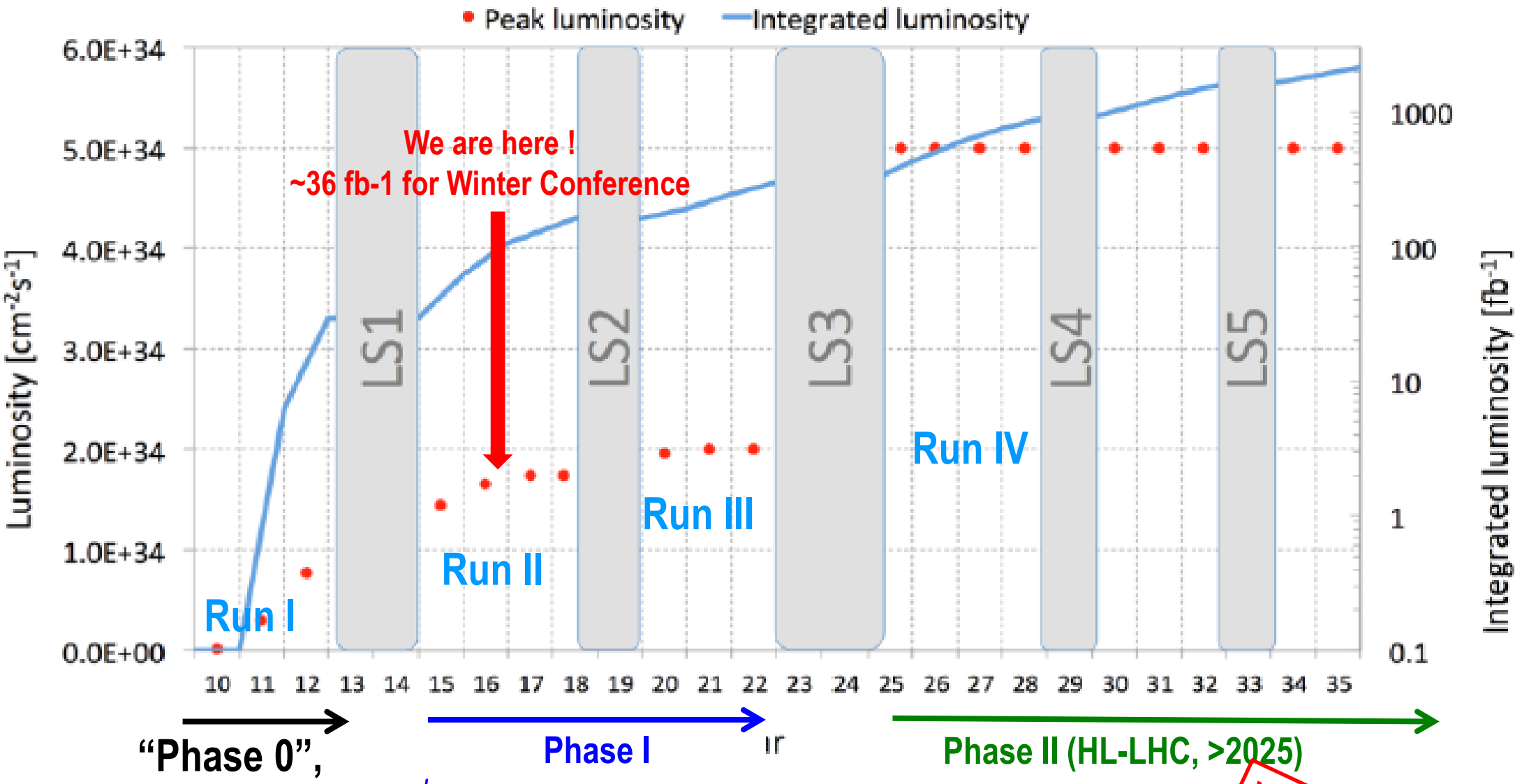
Christophe Ochando
(LLR/Ecole Polytechnique/CNRS)

On behalf of the LLR-CMS Group

November 21th 2016,
Conseil Scientifique LLR

Upgrade Phase II: Timeline, Funding

LHC: from Run I to HL-LHC



√s = 7-8 TeV
∫ L dt = 25 fb^{-1}
Higgs boson discovery !

√s = 13 TeV
Lumi inst. : up to 2.5x10^{34} cm^{-2}s^{-1},
∫ L dt = 300-500 fb^{-1}
<PU> : from ~25 to 60
X(750) ? SUSY ? ☺

√s = 13-14 TeV
Lumi inst. : >= 5x10^{34} cm^{-2}s^{-1},
∫ L dt : 3000 fb^{-1}
<PU> : ~140-200

Well beyond design !

CMS Upgrade Phase II & France

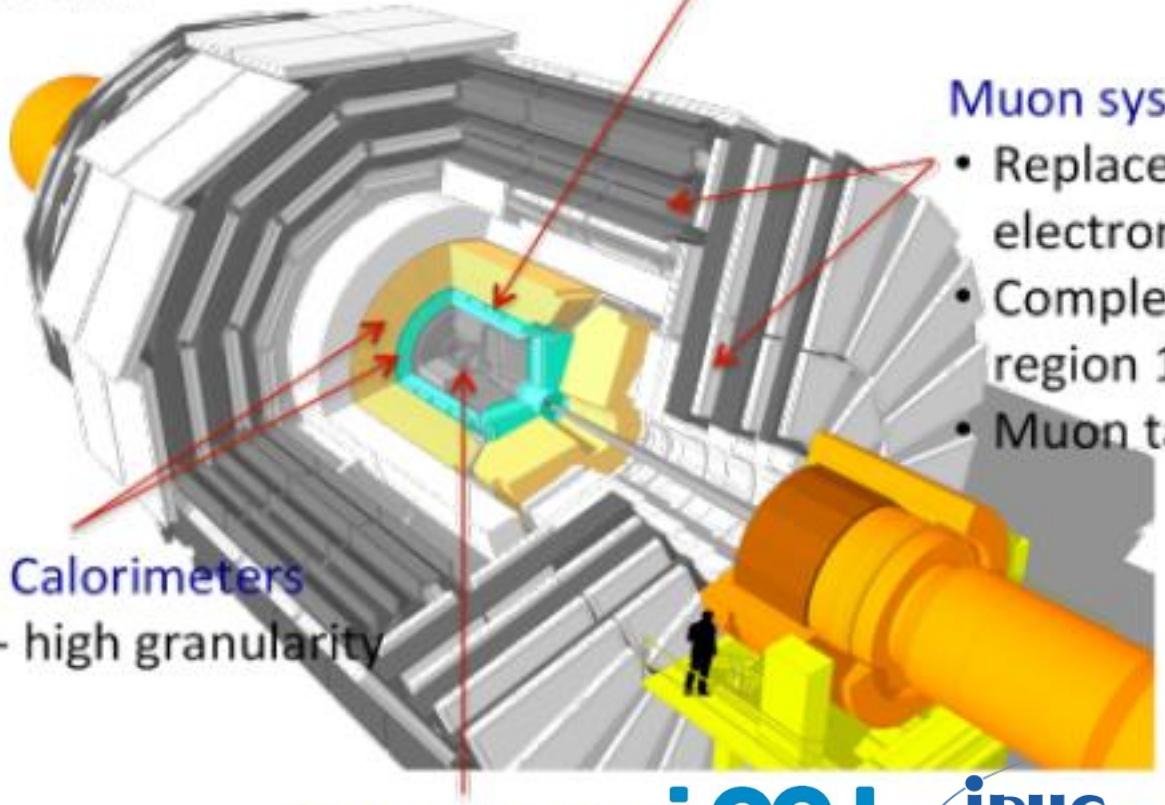
Major Upgrade: About half the CMS initial cost

Trigger/HLT/DAQ

- Track information at L1-Trigger
- L1-Trigger: 12.5 µs latency - output 750 kHz
- HLT output ≈7.5 kHz

Barrel EM calorimeter

- Replace FE/BE electronics
- Lower operating temperature (8◦)



Muon systems

- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region $1.5 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$

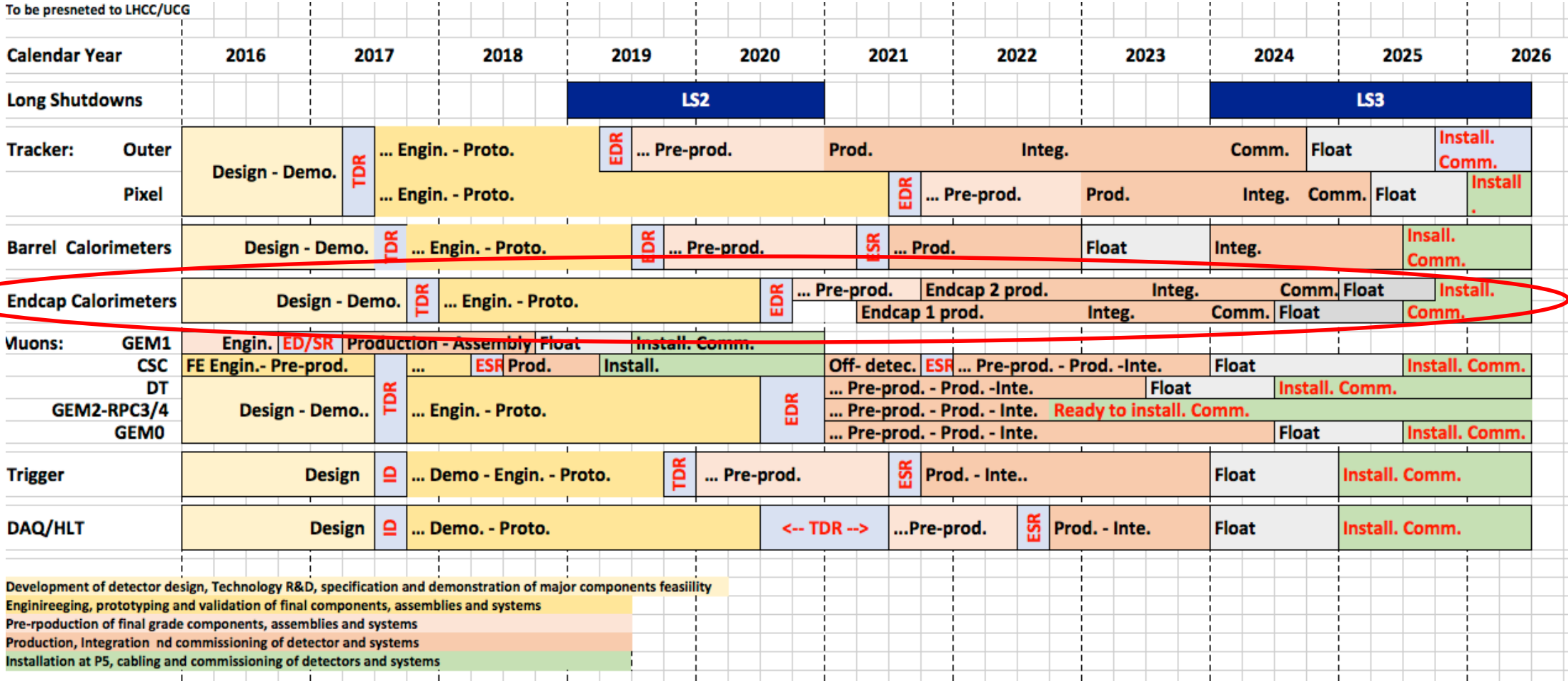
Replace Endcap Calorimeters

- Rad. tolerant - high granularity
- 3D capability

Replace Tracker

- Rad. tolerant - high granularity - significantly less material
- 40 MHz selective readout (Pt≥2 GeV) in Outer Tracker for L1-Trigger
- Extend coverage to $\eta = 3.8$

Upgrade Phase II Timeline (2016 – 2026)



- **4 major TDR's in 2017-2018:**
  - Tracker,
  - Muons,
  - Barrel Calorimetry
  - **Endcap Calorimetry (last one)**

- **HGCAL Schedule:**
  - -> 2020 : Prototyping
  - 2020 – 2014 : Pre-production et Production
  - 2024 – 2026 : Installation

Calendrier de la Revue du HC-TGIR

- **28 Juin 2016 – Saisine du HC-TGIR par le Ministère**

  5 Septembre: réunion de préparation IN2P3-CEA

- **12 Septembre 2016 – Présentation au HC-TGIR**

  Participation restreinte : direction IN2P3/CEA + HC-TGIR

  Présentation par P. Verdier / G. Hamel de Monchenault:
  https://dl.dropboxusercontent.com/u/43400808/HCTGIR_HLLHC-VerdierGHdM_Reunion_160912-final.pdf

- **26 Septembre 2016 – Réunion du comité HC-TGIR + Experts**

  Présentation du 26/09/2016 par Ph. Schwemling:
  https://dl.dropboxusercontent.com/u/43400808/HCTGIR_HLLHC_Physics_160926_v3_Final.pdf

  Document de synthèse IN2P3+IRFU présenté au HC-TGIR:
  https://dl.dropboxusercontent.com/u/43400808/HCTGIR-HLLHC-Document_160926-final.pdf

- **30 Novembre 2016 – Rapport du HC-TGIR Disponible**

- **Janvier 2017 – Réunion plénière du HC-TGIR**

Rapport scientifique seulement.
Echos très favorable en provenance du TGIR

Demandes en ressources spécifiques Phase II

- **Besoin en Recherche et Développement (2014 – 2018) :**
  - ~1.5 M€.
    - **Environ 50% pour HGCAL (FE+trigger+meca)**
    - Environ 1/3 déjà dépensé (principalement FE via Omega)

- **Besoin pour phase de construction et mise en route (2018 – 2027) :**
  - Hors R&D, hors fonctionnement normal, hors ressources humaines
  - Total CMS-IN2P3 : **13 900 k€**
    - Dont 10 500 k€ “CORE” construction de CMS
      3 400 k€ non-CORE pour les laboratoires de l’IN2P3

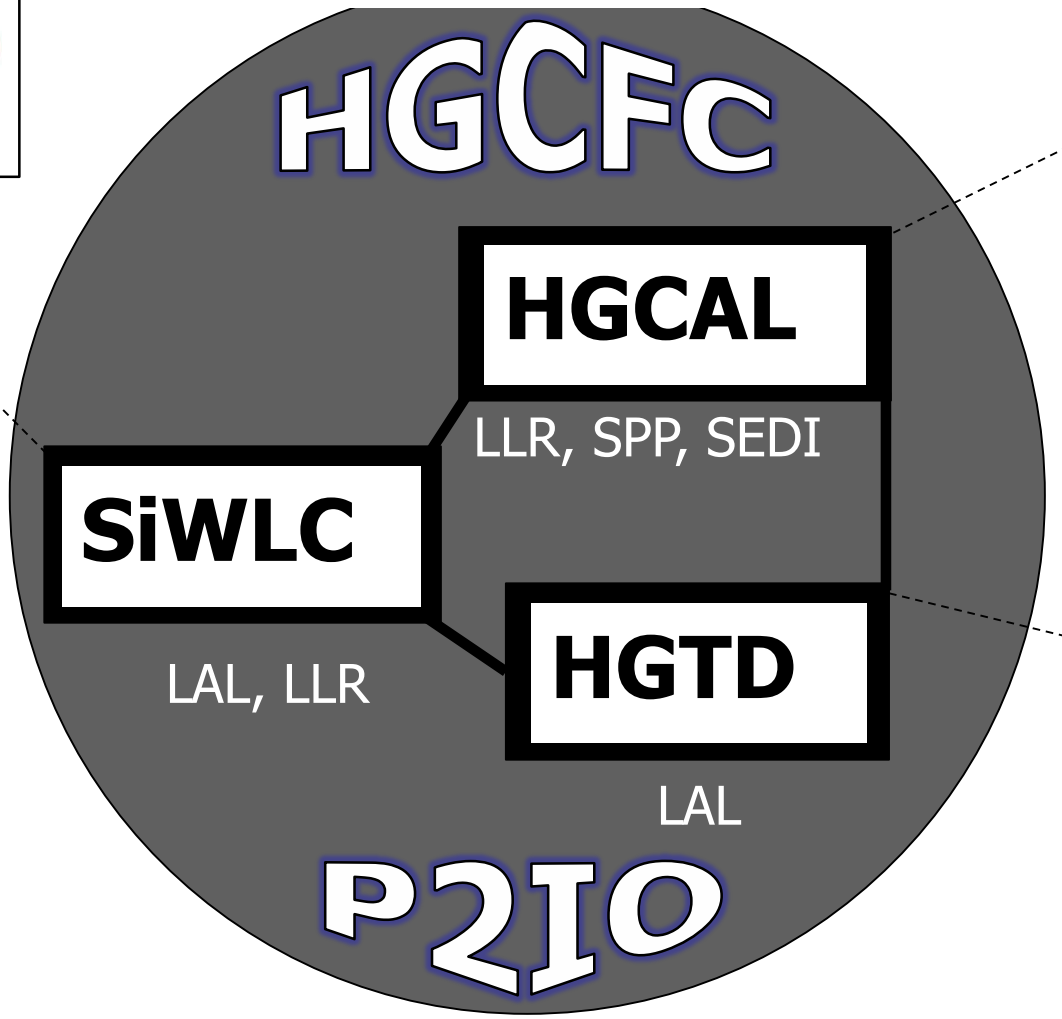
~40% pour HGCAL. Fort soutien de l’IN2P3.

+ besoins spécifiques Phase II en ressources humaines

P2IO : Projet Emblématique

From Y. Sirois (presentation at P2IO)

High Granularity Calorimetry for Future Colliders



CALICE Calorimeter for ILC

ILC

Palaiseau
Orsay
Saclay

CMS

LHC

LHC

ATLAS

Omega

Objectif:

développement d'une nouvelle calorimétrie haute granularité « 5D » avec des capacités de mesure de flux de particules et de temps

P2IO : Rappel des objectifs & moyens

From Y. Sirois (presentation at P2IO)

- Collaboration forte entre 3 laboratoires majeurs de P2IO impliqués dans 3 grandes expériences de hautes énergies (ILD, ATLAS, CMS)
- Objectifs de réalisations de calorimétrie haute granularité pour des applications auprès de collisionneurs e^+e^- ou hadroniques
- Mise en valeur et mutualisation de l'expertise P2IO dans les techniques de « flux de particules » (PFlow) et de calorimétrie Haute Granularité

- The LAL+LLR **SiWLC** groups will construct, and validate in test beams, a first complete ECAL prototype that meets the requirements for a future e^+e^- collider experiment

- The LLR, SPP, and SEDI **HGCAL** groups will perform essential R&D on mechanics, trigger, and timing for the forward calorimetry to be deployed at High-Luminosity LHC

~200 k€ (sur 4 ans)
pour HGCAL-LLR
+ missions

Fort soutien de P2IO

- The LAL **HGTD** group project will perform essential R&D for the timing capabilities of a forward detector proposed for HL-LHC

P2IO : Rappel des objectifs & moyens

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- Collaboration forte entre 3 laboratoires majeurs de P2IO impliqués dans 3 grandes expériences de hautes énergies (ILD, ATLAS, CMS)
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Arrivée au LLR (post-doc) au 1er Décembre : Artur Lobanov

- PhD CMS à DESY (2016)
- Expertises:
  - Analyse (SUSY searches)
  - CMS HCAL upgrade
  - Si-W calorimetry (NUCLEON experiment)

Travaillera sur test beams, physics performance

~200 k€ (sur 4 ans)
pour HGCAL-LLR
+ missions
+ post-doc 2 ans

Fort soutien de P2IO + X/IN2P3

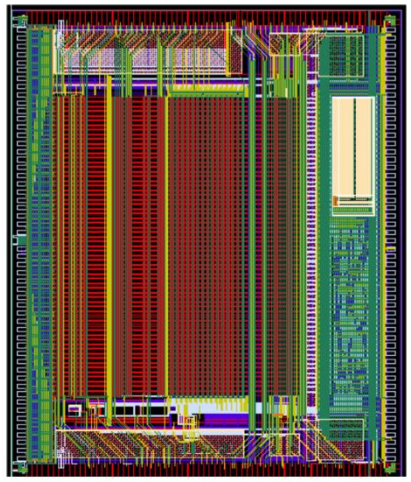
- The LAL **HGTD** group project will perform essential R&D for the timing capabilities of a forward detector proposed for HL-LHC

HGCAL Status

Physicien(ne)s du groupe impliqué à ce jour du projet HGCAL pour HL-LHC:
S. Baffioni, P. Busson, C Charlot, C. Ochando,
G. Ortona, R. Salerno, JB Sauvan, Y. Sirois

Front-End Electronics

- **SKIROC2-CMS:** Modify existing CALICE chip (SKIROC2) to include most of the required functionalities
  - 0.35 mm AMS (non radhard)
  - cross calibration sampling ADC@ 40 MHz, depth of 300ns,
  - Fast shaper (25 ns instead of 200ns)
  - ToT, TDC for ToA, 20 ps binning, 50 ps jitter
  - Destined for use in test beams 2017
    - ***Received* late June**



2) Submit Test Vehicles (TV) in 130 nm

TV1 *received* mid-September: analogue architecture, baseline + variants

(good preliminary results –see following slides)

TV2 to be submitted before end 2016: 8 channels, full analogue channel (ADC+ToT+ Trigger sums)

3) New CERN-PCB design under fabrication

4) Working day on preliminary architecture took place on 21st October

(https://indico.cern.ch/event/575804/)

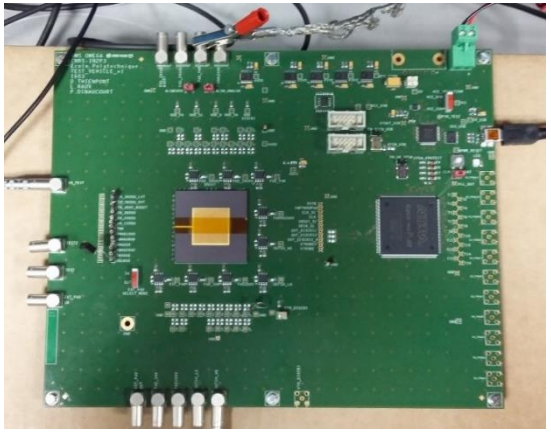
5) Submit first "complete" ASIC June 2017

(some digital functionalities may still be incomplete)

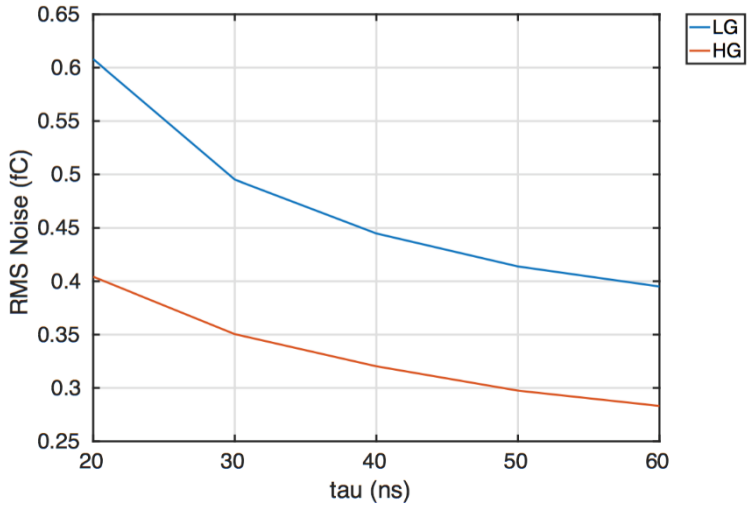
Front-End Electronics

➢ **SKIROC2-CMS:** Modify existing CALICE chip (SKIROC2) to include most of the required functionalities

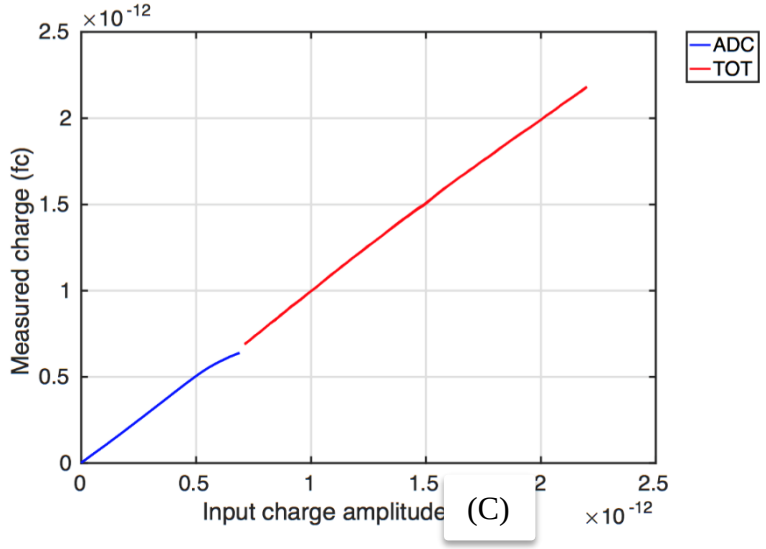
- **Under test (Imperial College, Split)**
- **Good preliminary results**
  - All channels functional
  - Noise measurements according to simulations
  - Noise density : E_n ~0.5 nV/√Hz
  - Good linearity



Noise after adding extra decoupling



TOT transfer characteristics, LG



(C)

- FE tests: Support from LLR (set-up similar to ILC).
- Will profit from it (from January to March) to acquire expertise (Artur et al.) in view of the test beams
- **We would like the support from Yannick from January to July (including test beam at CERN)**

Electronics & Trigger @LLR+Friends

Arrivées: Octobre -> Mars

"Distinguished Visiting Professor" @ X: Ivica Puljak ,
Professor at FESB Split

Arrivée au 1er Décembre :

Jean-Baptiste Sauvan (CR2)

Toni Sculac (PhD)
[co-tutelle Split/UPsay]

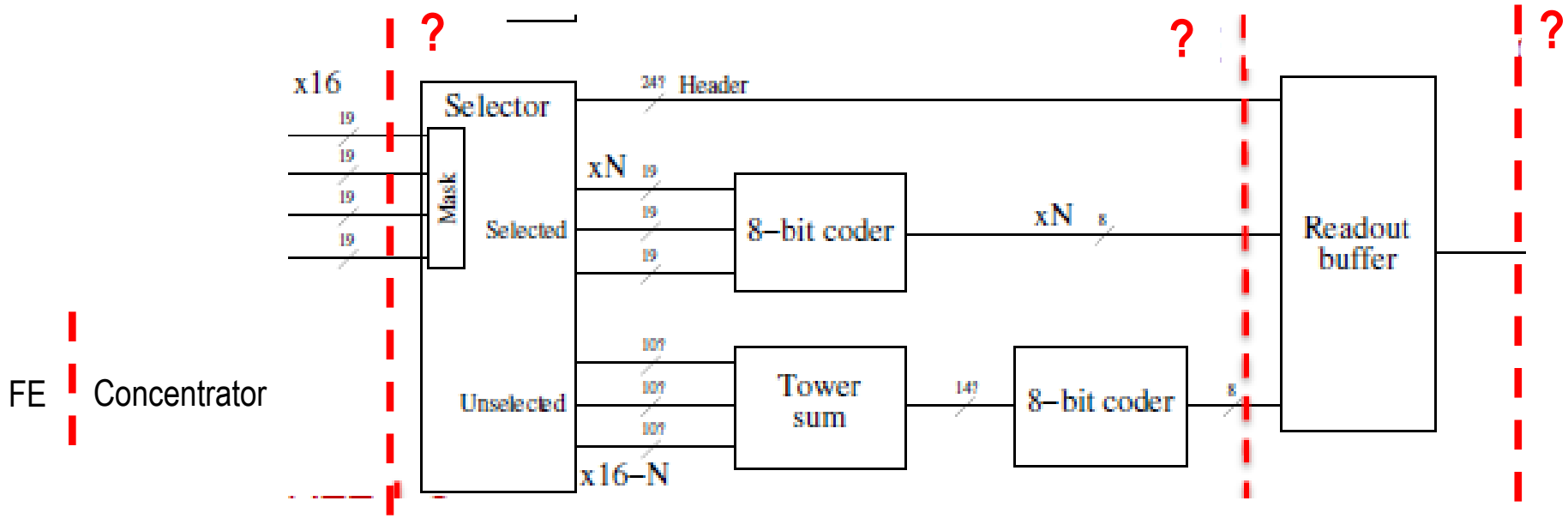
Marina Prvan
(PhD Split)

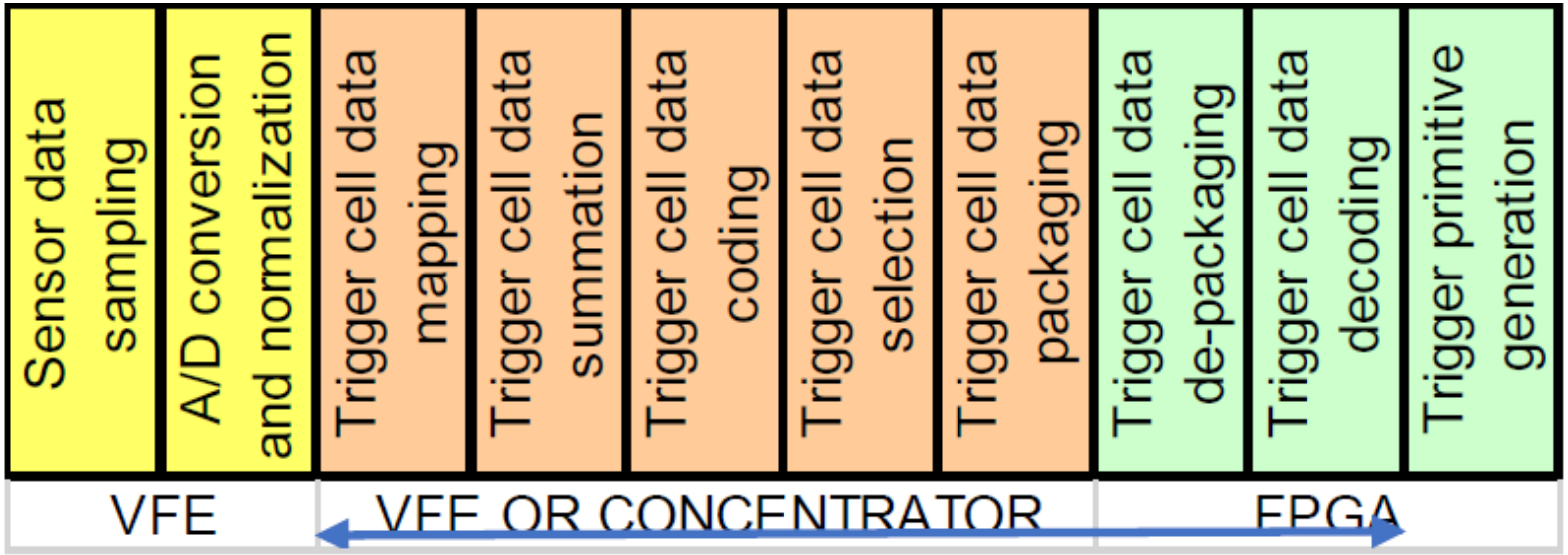
After some delay, now have assemble a strong team
with new arrivals
& present manpower
(SB, CC, PB, YG, TR + colleagues from Split)

+ reinforcement from G. Ortona (Marie Curie + grant to spend 5 months in Split)
+ M2 student internship next year with JBS/PB

Electronics & Trigger @LLR+Friends: (some of the) Activities

- Working on Architecture:
  - What is part of the FE ? What is part of the Concentrator (if any) ?
    Mapping sensors cells/trigger cells, Trigger cell sum ? … ?

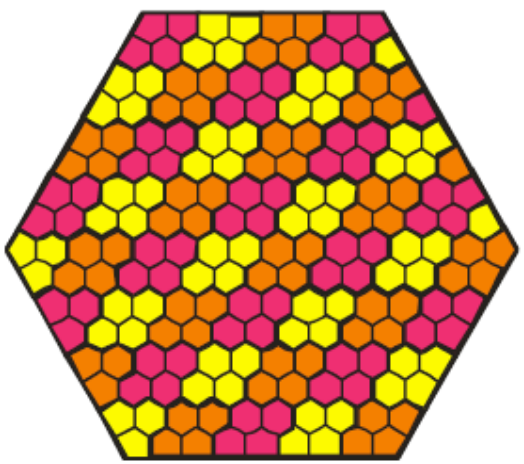


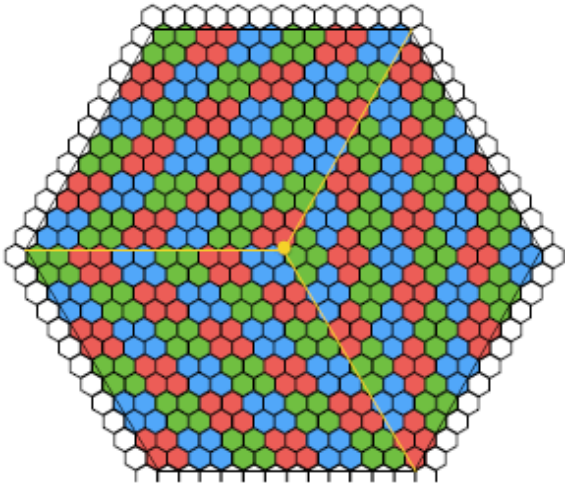


Electroncs & Trigger @LLR+Friends: (some of the) Activities

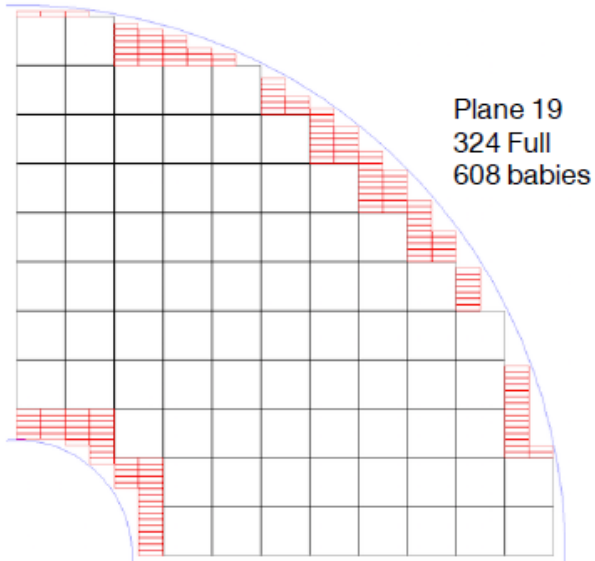
- Testing various options, various cell geometry / size, estimating data rates, developing simulation, …

Asymmetric or symmetric module





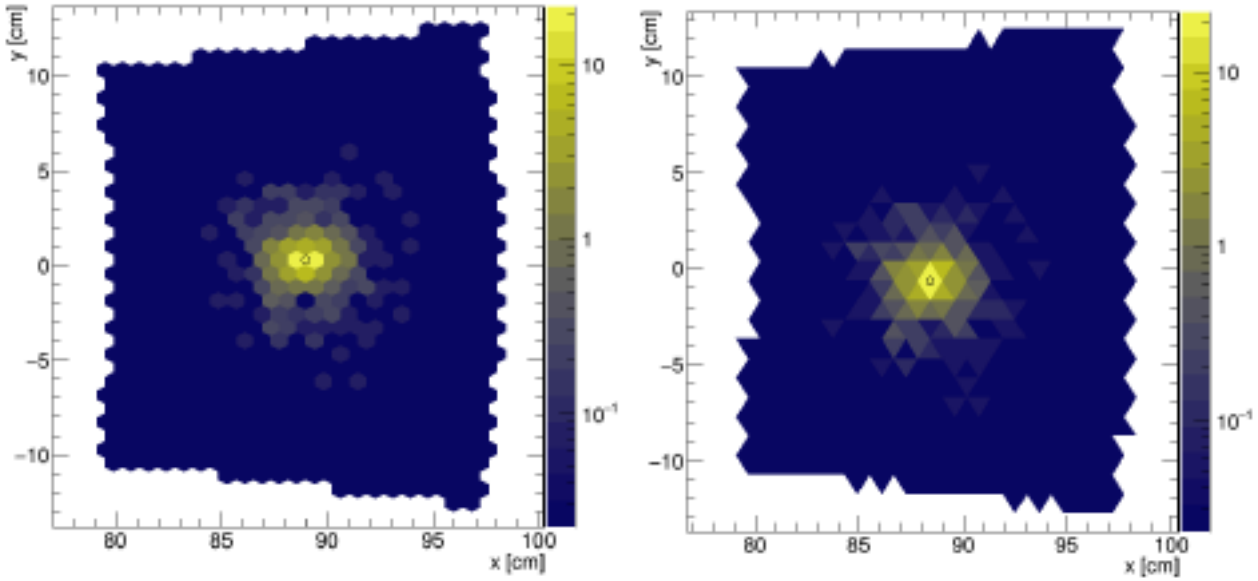
Square modules are back in the game…

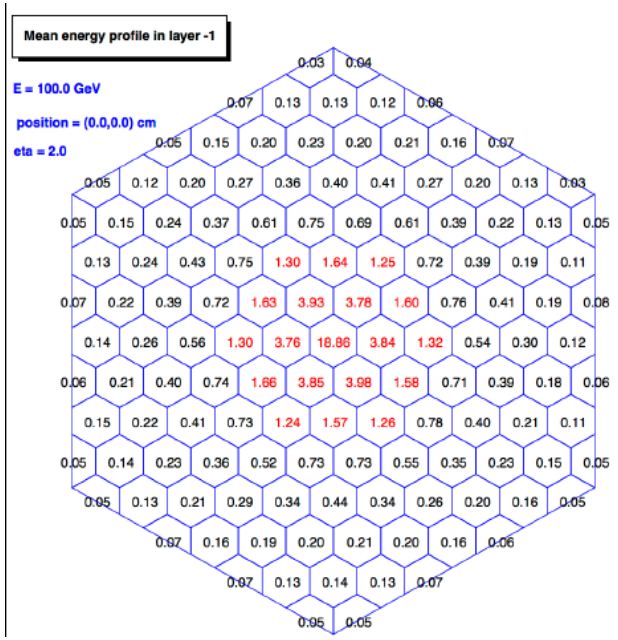


From P. Bloch's presentation @ HGC TC meeting 9-11-2016

Hexagons vs triangles cells

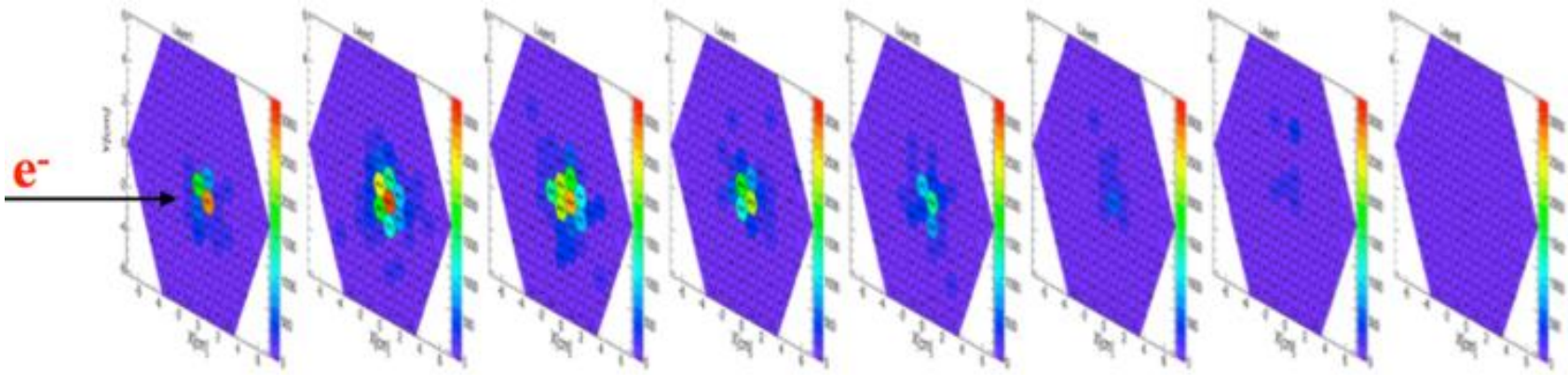
Development of Fast shower simulation





HGCAL Test beams plans (2017) @ CERN

CERN, 250 GeV e- passing through 8 layers (25 X0)

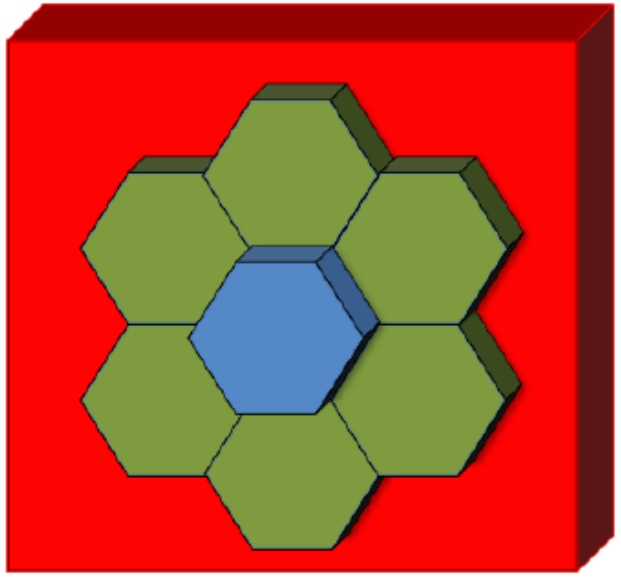


2017 Test beams (preliminary) schedule:

With SKIROC2_CMS

@CERN

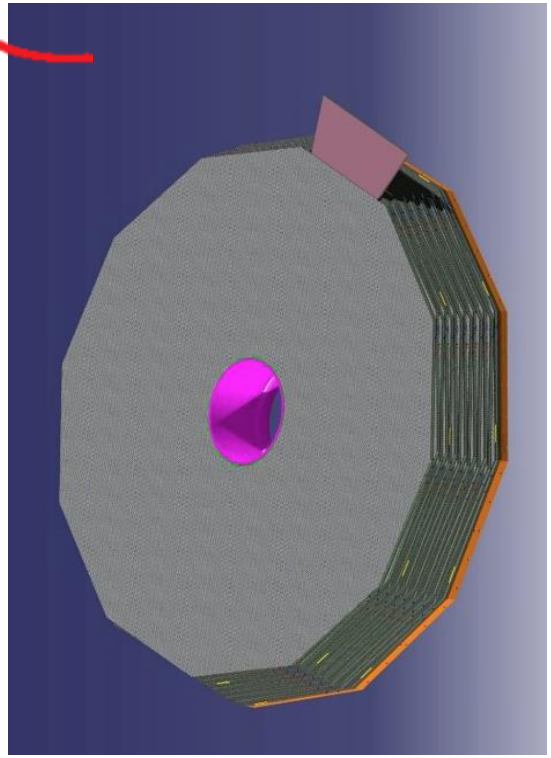
- March/April: Commissioning of new modules/DAQ @FNAL
- Mid-May: 28 **EE** Layers (26 X0, ~1 λ)
- Mid-June: 28 **EE** Layers (26 X0, ~1 λ) + 12 **FH** Layers (4 λ)
- Mid-July: 28 **EE** Layers (26 X0, ~1 λ) + 12 **FH** Layers (4 λ) + **CALICE Analogue HCAL** (~5 λ)

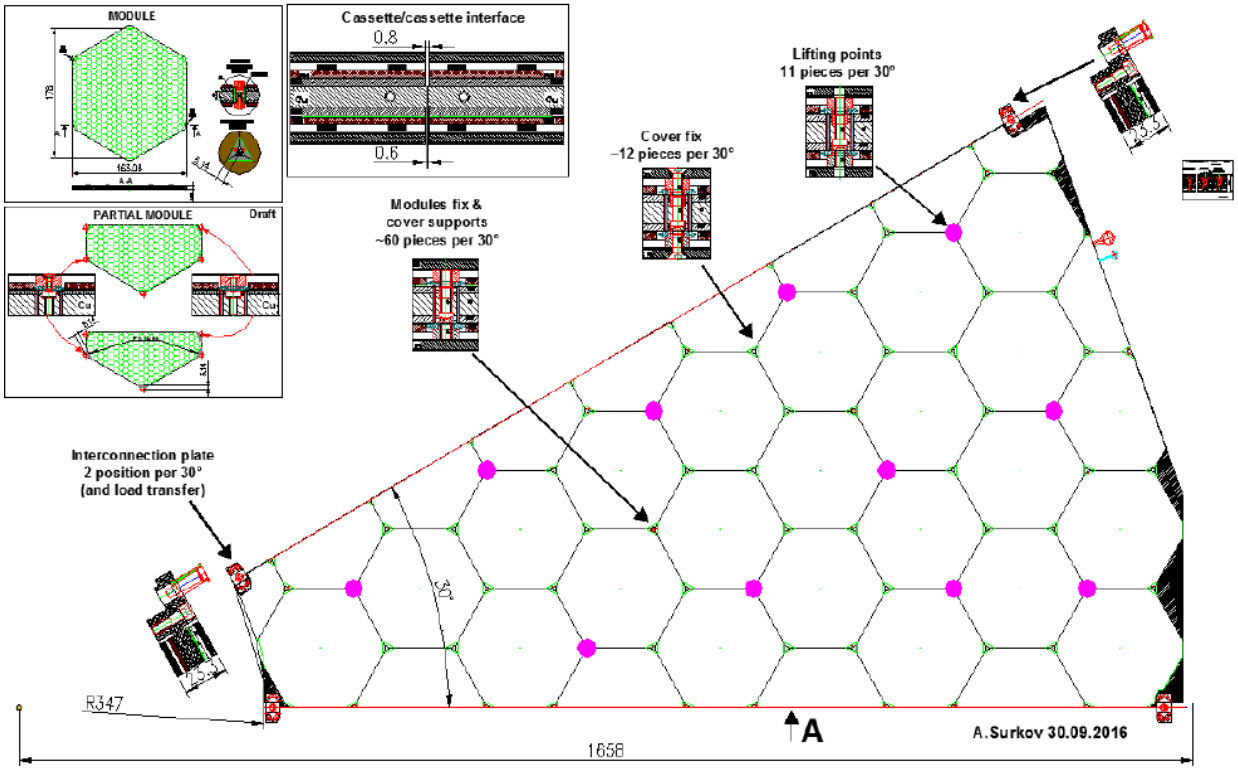


LLR will participate in >= 2017 tests (with Artur et al.)

HGCAL Mechanics

2 designs/concepts of the HGCAL-ECAL mechanical structure studied since 1-2 years:





Alveolar Disks design

- *Carbon Fiber structure with embedded W plates and slots ("alveoli") to insert 30° cassettes containing active elements.*
- *Made from disks of alveoli*
- *Inner cone to support load*

Disk & Spacer design:

- *Non-insertable 30 ° Cassettes inter-connected to form disks*
- *Disks stacked in horizontal position, supported by spacers*
- *Cone + Front/back plate to support load*

Evaluation

From Jim Virdee

Both design approaches are sound, and it is clear that the EE could be successfully built using either one.

3. Physics capabilities enabled by the two approaches are equivalent
4. Mechanical behaviour: the structural designs are both considered sound

Excellent work from the LLR (Thomas Pierre-Emile et al.) !

Design meets the requirements

In total 27 Achievement Awards 2016

Achievement texts will be attached to the CB111 indico page

- Zhenbin Wu (L1 Trigger, Chicago)
- Thomas Strebler (L1 Trigger, LLR)
- Dominick Olivito (Trigger (TSG), UCSD)
- Nadir Daci (Trigger (TSG), Brussels)
- Fabio Ravera (CT-PPS, Torino)
- Finn Rebassoo (CT-PPS, LLNL)
- Douglas Berry (Tracker, Chicago)
- Francesco Fiori (Tracker, Taipei)
- Mario Galanti (Run, Rochester)
- Dinyar Rabady (Run, HEPHY)
- Marco Peruzzi (ECAL, CERN)
- Pierre Depasse (ECAL, Lyon)
- Erica Brondolin (Upgrade, Lyon)
- Andrey Marinov (Upgrade, Brussels)
- Louise Skinnari (Upgrade, Cornell)
- Danila Tlisov (Upgrade, Moscow)
- Marco Musich (PPD, Louvain)
- Matti Kortelainen (PPD, CERN)
- Rajdeep Chatterjee (HGC/EC, Minnesota)
- Thomas Pierre-Emile (HGC/EC, LLR)
- Jared Sturdy (Muons, Wayne State)
- Nicolo Magini (Computing/Offline, FNAL)
- Paul Lujan (BRIL, Canterbury)
- Arkady Lokhovitskiy (BRIL, Canterbury)

"For his outstanding contributions to the engineering work developing the design, performing comprehensive and rigorous engineering analysis, and the material tests and prototyping for the EE structure for the Endcap Calorimeter"

Congratulations to all awardees !

HGCAL Choice

However, there are areas where the two designs could be distinguished, among which:

1) Cost:

- D&S enable the usage of Pb/SS as absorber
  - W plates cost ~2MCHF vs 0.5 for Pb/SS as estimated from ATLAS cost book.
- No external structure needed in D&S => may result in lower cost as well.
  - (molds, … ~1 MCHF in the Technical Proposal for the Alveolar design)

D&S allows some cost saving

- important as HGCAL under-funded now
- Several other components (electronics, …) will have cost increase…

2) Flexibility

- D&S places **fewer constraints on the geometry of the cassettes** (30°, 60°, 90°…) and adapt to optimize layout and connection of modules, electronics, cooling circuits.
- D&S could use W or Pb as absorber
- Would **be easier to introduce modifications "down-the-line"** if needed or proven to be beneficial

Disk & Spacer design recommended for the HGCAL-ECAL Structure.
Recommendation has to be fully endorsed by the HGCAL IB by December.

What's next ?

- **CMS-LLR plays a leading role in mechanics since 2 years**
  - **No selection of HGCAL over Shashlik and Dual-Readout without LLR**
  - First design described in Technical Proposal (June 2015)
    - shown in many international conference (*)
  - **Expertise recognized and appreciated**
    - **HGCAL-CMS would like LLR to continue the effort.**

- **Project is being re-organized**
  - Tiziano Camporesi (ex-CMS spokesperson) is becoming CMS-CERN Group Leader
    - wants to create an HGCAL CERN group on mechanics.
  - Newcomers will join

Discussions between us (LLR) on our future contributions <=> discussion with Tiziano et al.
(meeting at LLR on Nov 29th already planned)
Suggest to meet again after these discussions.

- **P2IO:**
  - The HGCAL decision may lead to re-shuffle the funds dedicated to mechanics studied.
    - Some fraction could go to HGC-Trigger (LLR) or HGC-Timing (IRFU) depending on our next contributions to mechanics.

(*) ex: C. Ochando in CALOR 2016

Summary / Conclusion

- **HL-LHC is a major program in HEP over the next decades**

- **HGCAL is a very challenging and exciting project**
  - **CMS-LLR: pivotal role** in the acceptance of the proposal by CMS
  - Strong team (LLR / Split) in Trigger studies assembled (with Jean-Baptiste, Ivica et al.)
  - CMS-LLR took the lead in mechanics, with support from LLR
    - Discussion on future contributions after CMS decision about ECAL Design.
  - CMS-LLR will contribute to the important test-beams next year.

  - **Strong support from IN2P3, X and P2IO**
    - HGCFC flagship P2IO project will help CMS-LLR group to continue playing a leading role in the HGCAL project in 2017-2019

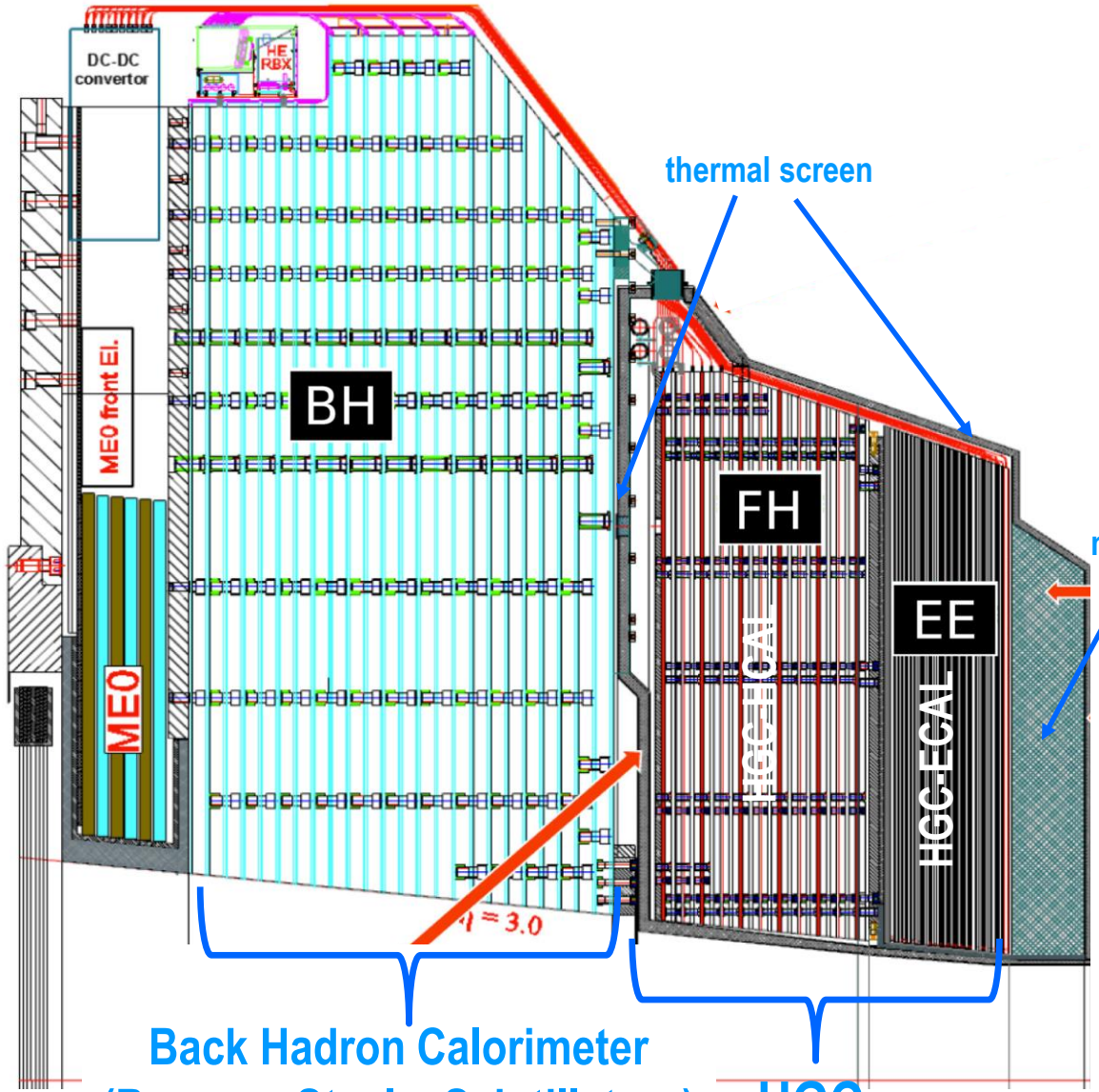
- **2017 will be an interesting and busy year**
  - Test beam, first iteration of FE, TDR, …
  - **CMS-LLR fully committed to make this project a success !**

BACK UP SLIDES

HGCAL: General Layout

CMS choice: **High Granular Sampling Si-based Calorimeter [*]**
with 4D measurement of showers (energy, position)
(possibly 5D with timing) [**]

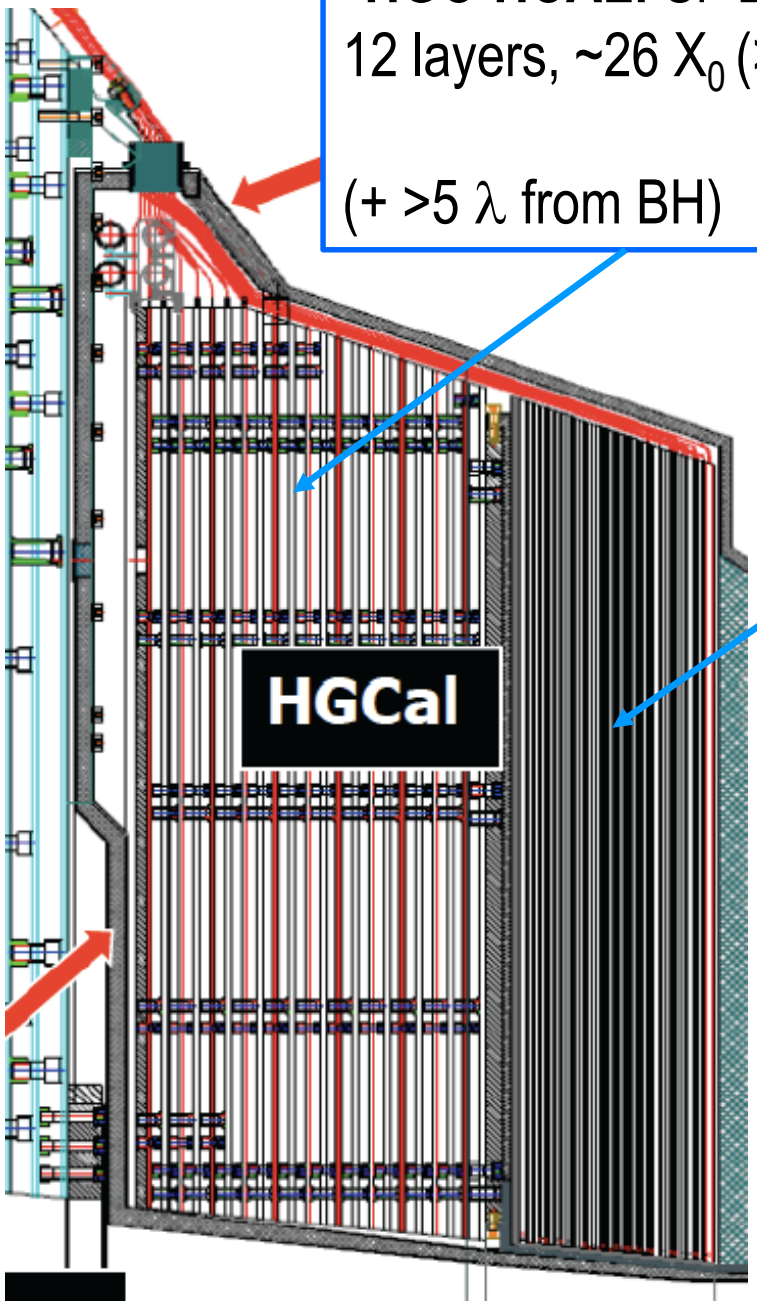
HGC+BH: covers η range up to 3



Technical Proposal
CERN-LHCC-2015-010
(Juin 2015)

[*] thanks to CALICE developments, progress on Si & data transmission

HGC Parameters



HGC-HCAL: Si+Brass or Steal
12 layers, ~26 X_0 (>3.5 λ)

(+ >5 λ from BH)

HGC-ECAL: Si+W/Cu
28 layers, ~26 X_0 (1.5 λ)
10 x 0.65 X_0 +
10 x 0.88 X_0 +
8 x 1.26 X_0

Operation at -30°C via CO_2 Cooling
(to mitigate Si leakage current)

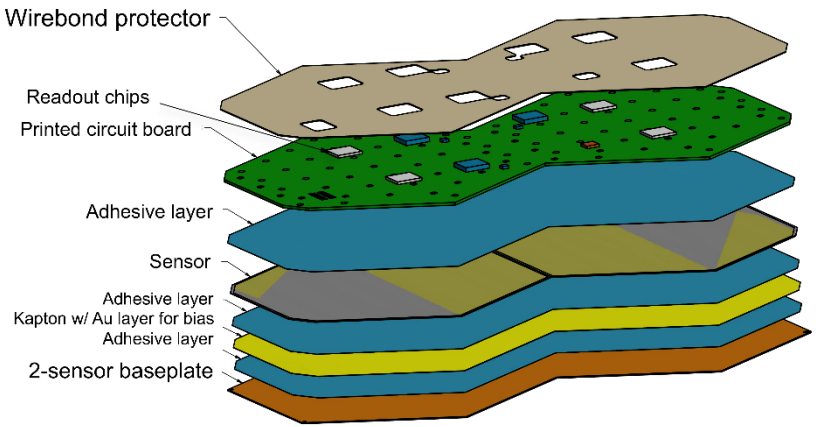
Table 3.2: Parameters of the EE and FH.

	EE	FH	Total
Area of silicon (m^2)	380	209	589(*)
Channels	4.3M	1.8M	6.1M
Detector modules	13.9k	7.6k	21.5k
Weight (one endcap) (tonnes)	16.2	36.5	52.7(**)
Number of Si planes	28	12	40

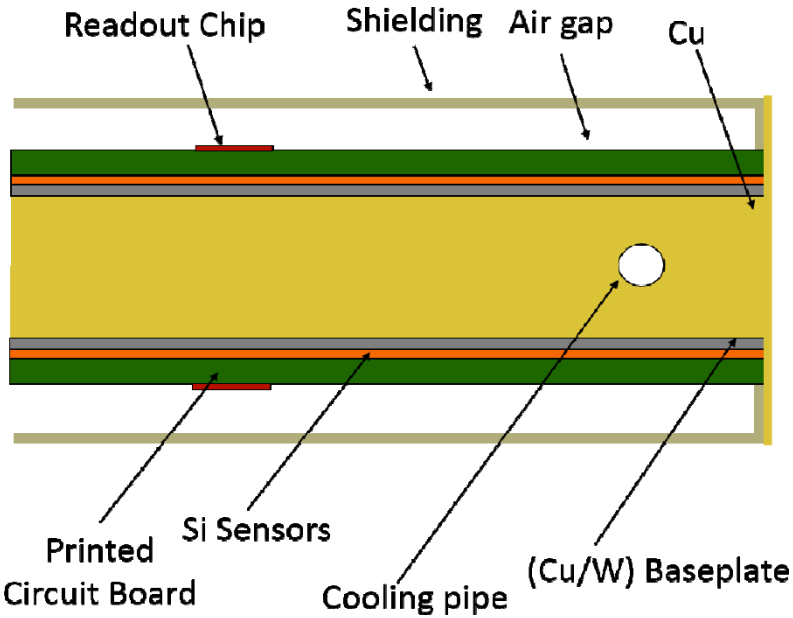
(*) 3x CMS tracker ! (**) one HGC+BH endcap: ~230 tonnes

Modules, Cassettes & Mechanics (Technical Proposal)

Modules
with 2x6 or 8" Hexagonal Si sensors,
PCB, FE chip, on W/Cu baseplate



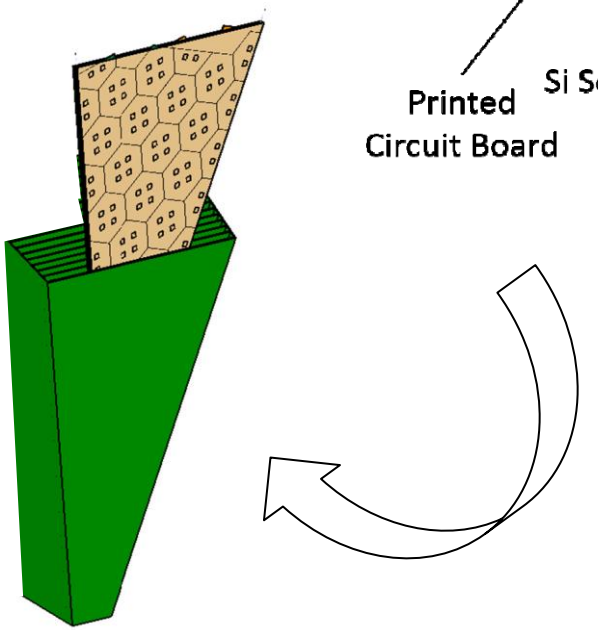
Modules mounted on
Cu Cooling plate with embedded pipes
== **Cassettes**



To cope the irradiation / PU:

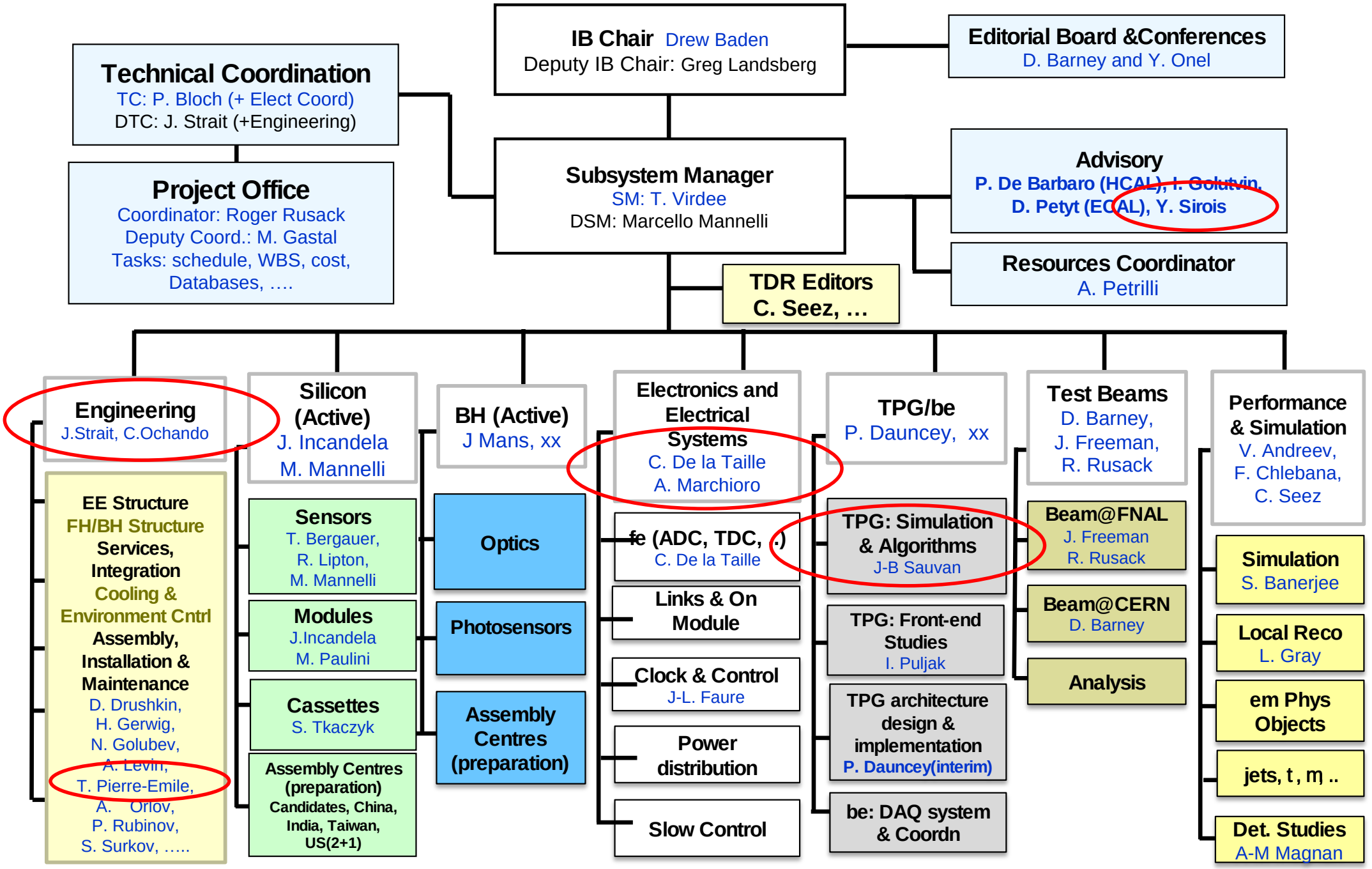
- η-dependent depletion of Si (100, 200 or 300μm)
- η-dependent cell size (0.5 cm² or 1 cm²)

Cassettes
inserted in **mechanical structure**
(containing absorber)



W/C-fiber EE alveolar structure

Endcap Calorimeter Project
Structure to Q1-17 (making Technical Choices, ..)



Hardware HGCAL pour CMS à l'X

Chapeau:
Ecole Polytechnique/IN2P3
HGCAL Finance Board and Institution Board: **Y. S.**

Economie du ticket d'entrée CMS pour le laboratoire Oméga; ∀ accès via CMS-LLR

Laboratoire **OMEGA**
X / **IN2P3**

Laboratoire **LLR**
X / **IN2P3**

FE chip
Ch de la Taille et al.

Back-End Electronics
J.B. Sauvan et al.

Mechanics
C. Ochando et al.

Omega (Fr.),
Timing: IC London (UK) ?
SPP Saclay (Fr.) ?

HGCAL FE chip
SKIROC-CMS
Test Vehicules

LLR (Fr.), CERN, FESB Split (Cr.),
SPP Saclay (Fr.), IC London (UK),
Minnesota (USA)

Trigger
J.B. Sauvan et al.
Architecture,
Trigger primitive generation***
Simulation & algorithms

LLR (Fr.), CERN, RDMS

ECAL
Design & structures
Simulations

*** TPG FE studies: JB Sauvan (CERN), I. Puljak (FESB)

- **Mechanics:** C.O, Th. Pierre-Emile, Y.S., (M. Frotin)
- **Trigger:** P.Busson, S. Baffioni, T. Romanteau
+ JB. Sauvan (CERN)
- **Perf.:** C. Charlot, R. Salerno, Y.S.
- *Tests pour FE/TPG*: Y. Gerebaert, JB. Sauvan (CERN), I. Puljak (FESB)

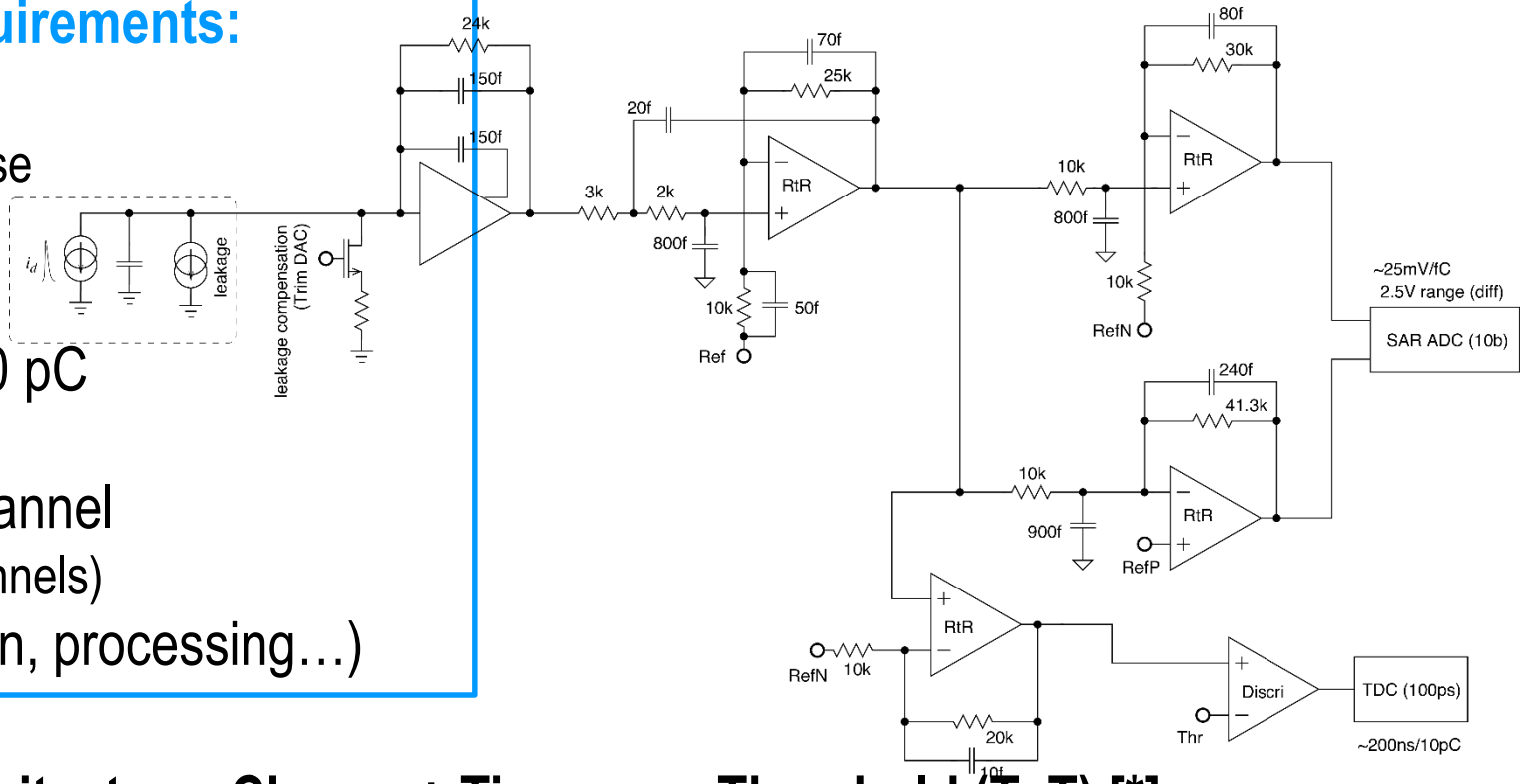
Front-End Electronics (1)

One of the most challenging aspect of the project !

Need to have large dynamic range @ low power + low noise

➢ (stringent) Requirements:

- **Low Noise**: ~ 2000 e-
  - including sensor I_{leak} noise
- Shaping Time: 10-20 ns
  - Pulse Shape is 1-2 ns
- Dynamic Range: up to ~10 pC
  - ~3000 MIP in 300µm Si
- **Low Power**: ~10 mW / channel
  - (Σ = 100 kW for 6M channels)
- System on chip (digitization, processing…)



➢ Baseline architecture: Charge + Time-over-Threshold (ToT) [*]

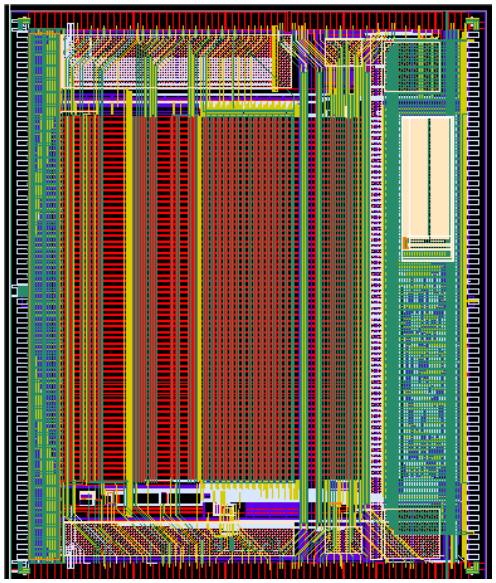
- Switch from charged readout to ToT at ~100 fC
- ADC (10 bits) and TDC (12 bits) with existing designs
- Potential for 50 ps timing per cell

[*] alternative: more classical readout (bi-gain) or switched feedback

Front-End Electronics (2)

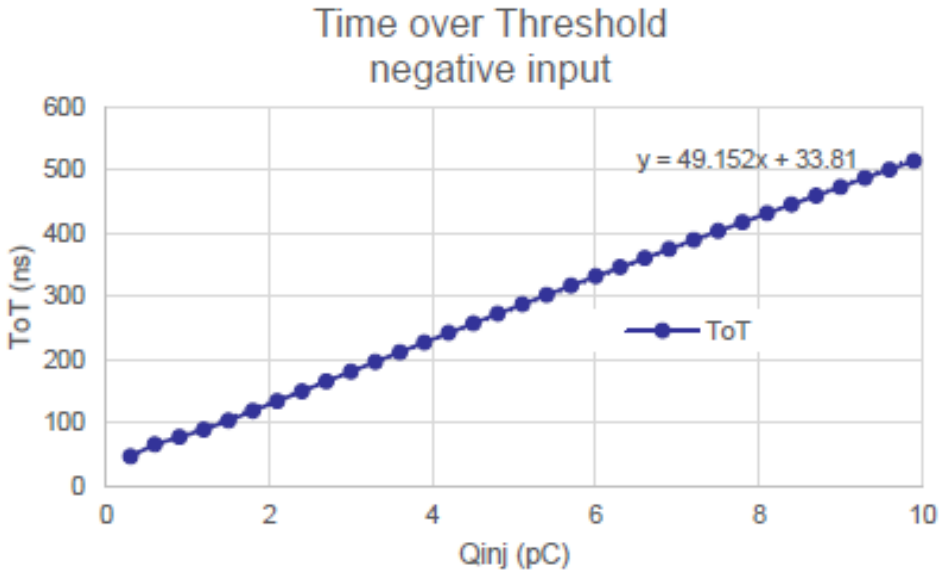
One of the most challenging aspect of the project !

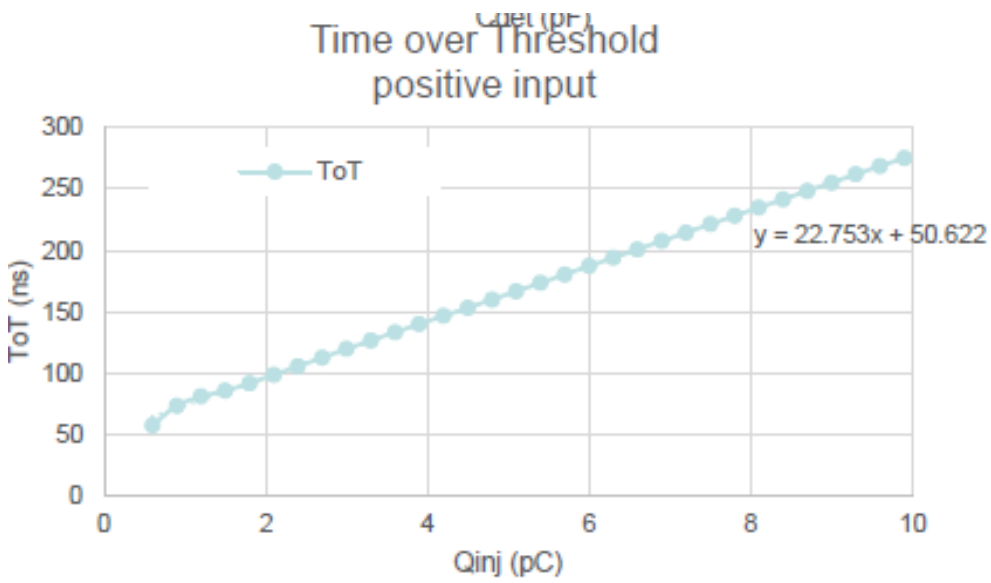
Need to have large dynamic range @ low power + low noise



➢ **SKIROC2_CMS** (not the final chip)**:**

- Includes some of the HGC features:
  - ~20ns shaping time and 40MHz sampling
  - ADC + TOA (~50ps) + TOT
  - P-on-N and N-on-P read-out options
- **Production launched in January, Received mid-June**
- **First tests on-going** (noise, stability, linearity, crosstalk, …)

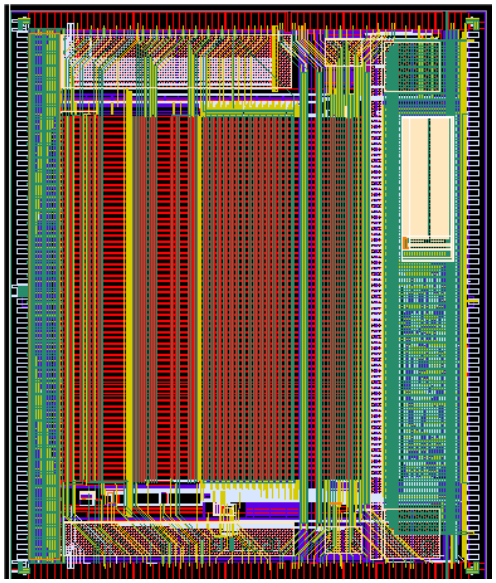




Front-End Electronics (3)

One of the most challenging aspect of the project !

Need to have large dynamic range @ low power + low noise



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  - ~20ns shaping time and 40MHz sampling
  - ADC + TOA (~50ps) + TOT
  - P-on-N and N-on-P read-out options
- **Production launched in January, Received mid-June**
- **First tests on-going** (noise, stability, linearity, crosstalk, …)
- Plan to use it for CERN test beams (Fall)

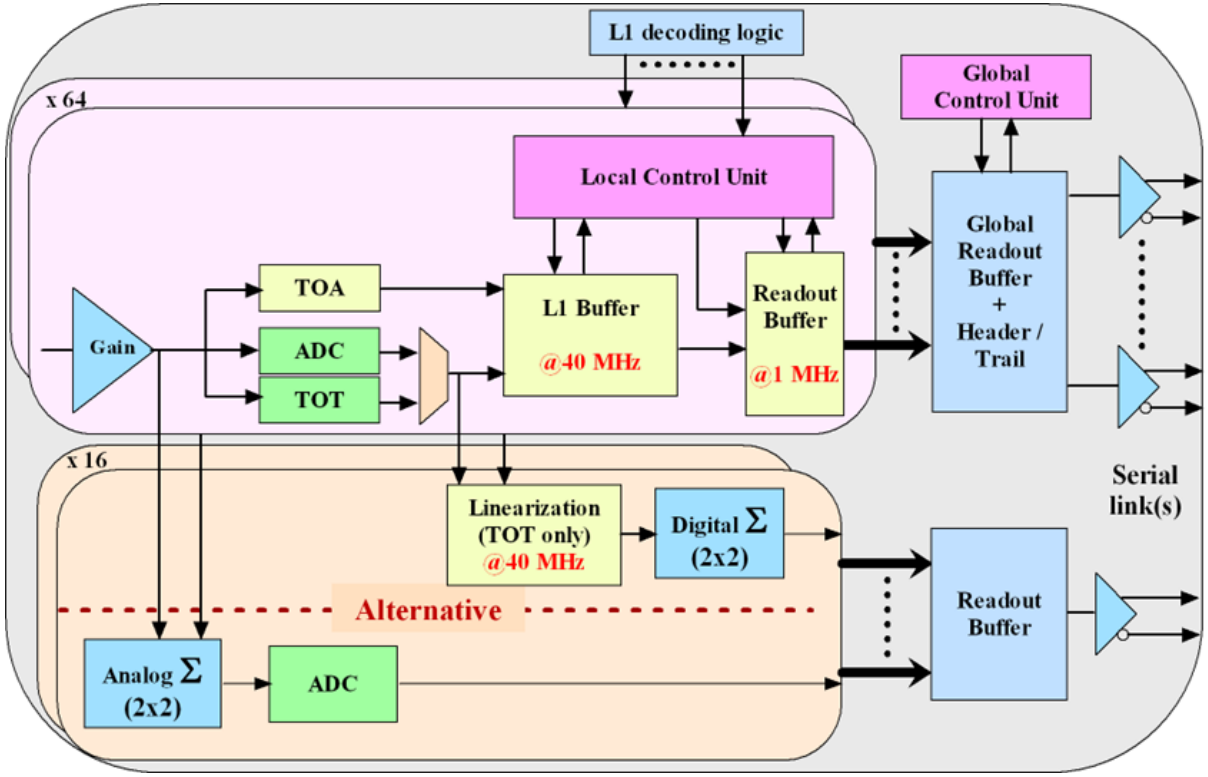
- Also: test vehicles on blocks launched
  - (TSMC 130nm, various preamps flavors, shapers, discriminators)
  - Second TV in September with one full channel (various flavors)
- **First iteration of full chip expected by Spring 2017.**
  - with feedback from test vehicles & SKIROC2_CMS

Highlights: Front End electronics

Ch. De La Taille et al., (Omega)
Test FE pour TPG: Y. Geerebaert

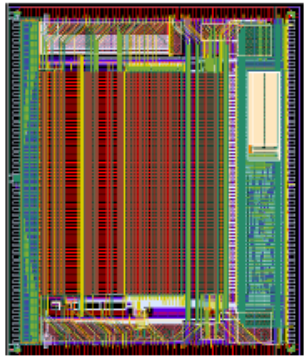
Stringent requirements for FE Electronics:

- Low power (few mW), low noise (<2000 e-)
- High radiation (200 Mrad, $10^{E}16$ N)
- System on chip (digitization, processing…)
- High speed readout (5-10 Gb/s)
- Timing information to 50ps accuracy



SKIROC_CMS:

- **Includes some of the HGC features:**
  - ~20ns shaping time and 40MHz sampling
  - ADC + TOA (~50ps) + TOT
  - P-on-N and N-on-P read-out options
- On going tests (IC, CERN, Split)
  - **Will equip test beams modules in 2017**



More on slides by YS or CdlT

In the mean time, **test vehicles** on blocks (various pre-amps, shapers,…) [May 2016], full analog 8-channel, digital sum for trigger path, common services [Dec 2016]

Submission of HGCROC_v1 in June 2017 on track

(major) Changes wrt TP

The TP chose schemes that could be built using currently available technologies.
Now studying many options that may lead to cost or performance benefits.

Absorber for FH and BH: non-magnetic stainless steel

Under consideration: enclosing the whole endcap calorimeter in the cold volume

EE and FH: tiling the full face of the disks with hexagons or keeping the phi-wedges.
A module comprises one 8" sensor or two 6" sensors.

We can use FEC5 protocol LpGBT links that can transmit 9.0 Gb/s instead of the assumed 6.4 Gb/s

The numbers of links "10 Gb/s" optical links has increased: Data 3761 -> 5415 and Trigger 6428 -> 7572.

The trigger scheme and granularity is being reassessed

Hexagonal cells have been introduced in the simulation geometry

The milestones are being updated

HGCAL at LLR: L1 Trigger

P. Busson, S. Baffioni, *T. Romanteau*, J-B. Sauvan

➢ **LLR among the main drivers of the HGCAL L1 Trigger project**

- **Now in strong collaboration with Split & CERN**

Architecture

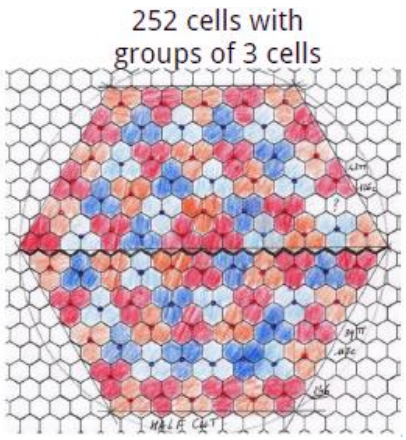
- Define baseline architecture for TP

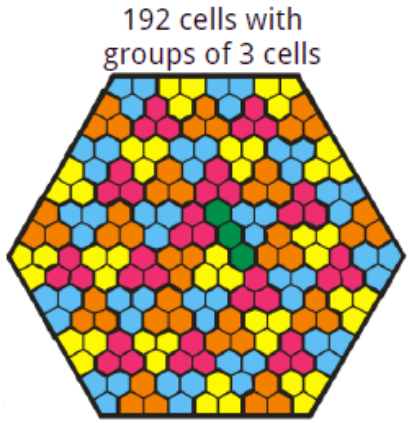
Front-End Studies

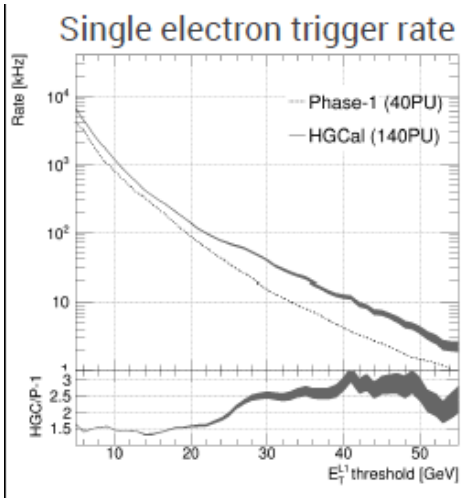
- Work on trigger "raw data" (Data reduction, trigger cell geometry, …)

Simulation & Algorithms

- Development of emulator, + standalone tools (digitization, ..)







Besoin urgent d'un Test Bench SKIROC-CMS au LLR pour rester dans le jeu côté interface trigger avec le chip de FE

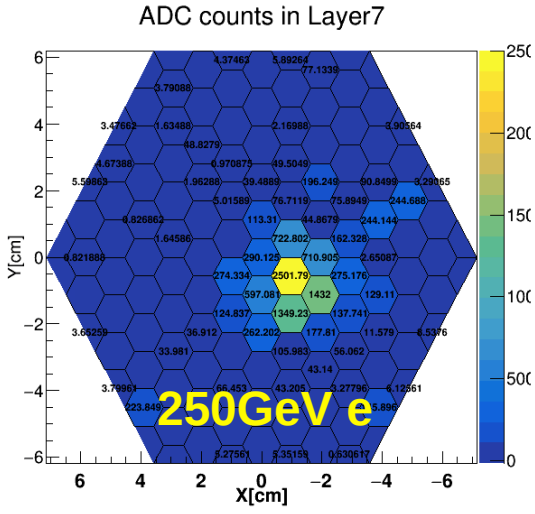
Highlights: Test beams

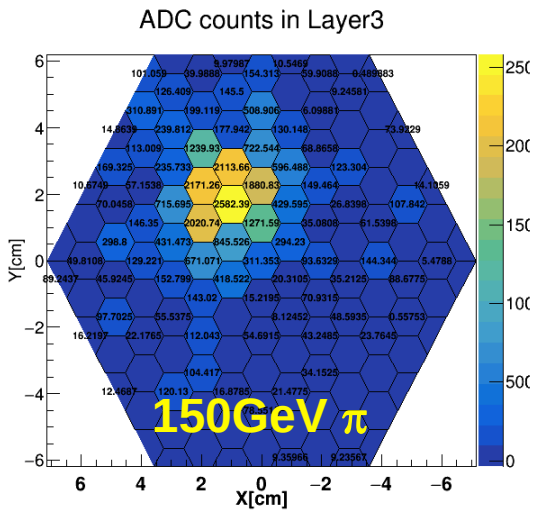
➢ Goals:

- Performance studies: S/N, timing, energy and positions resolutions
- Comparison with simulation

➢ Several test beams campaign (FNAL, CERN)

- FNAL: 120 GeV protons, 4-32 GeV electrons/pions
- CERN: 125 GeV pions, 20-250 GeV electrons





Laboratory	Layers	X_0	Date
FNAL	1	6	March 2016
FNAL	4	12	May 2016
FNAL	16	15	July 2016
CERN	8	27	Aug 2016

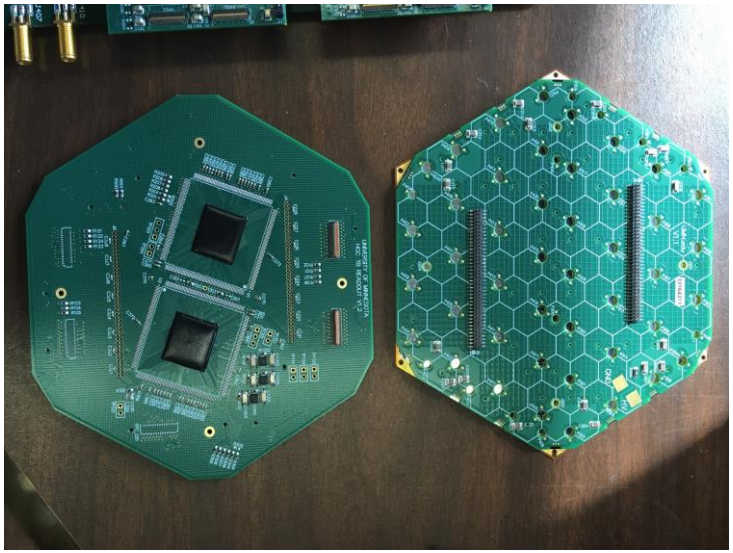
+ various timing tests
(next in November at CERN?)

➢ Common DAQ, Modules:

- 6” Si wafers, 200um, p-on-n,
- 1.1 cm² cells,
- 2-layers PCB, SKIROC2 chip

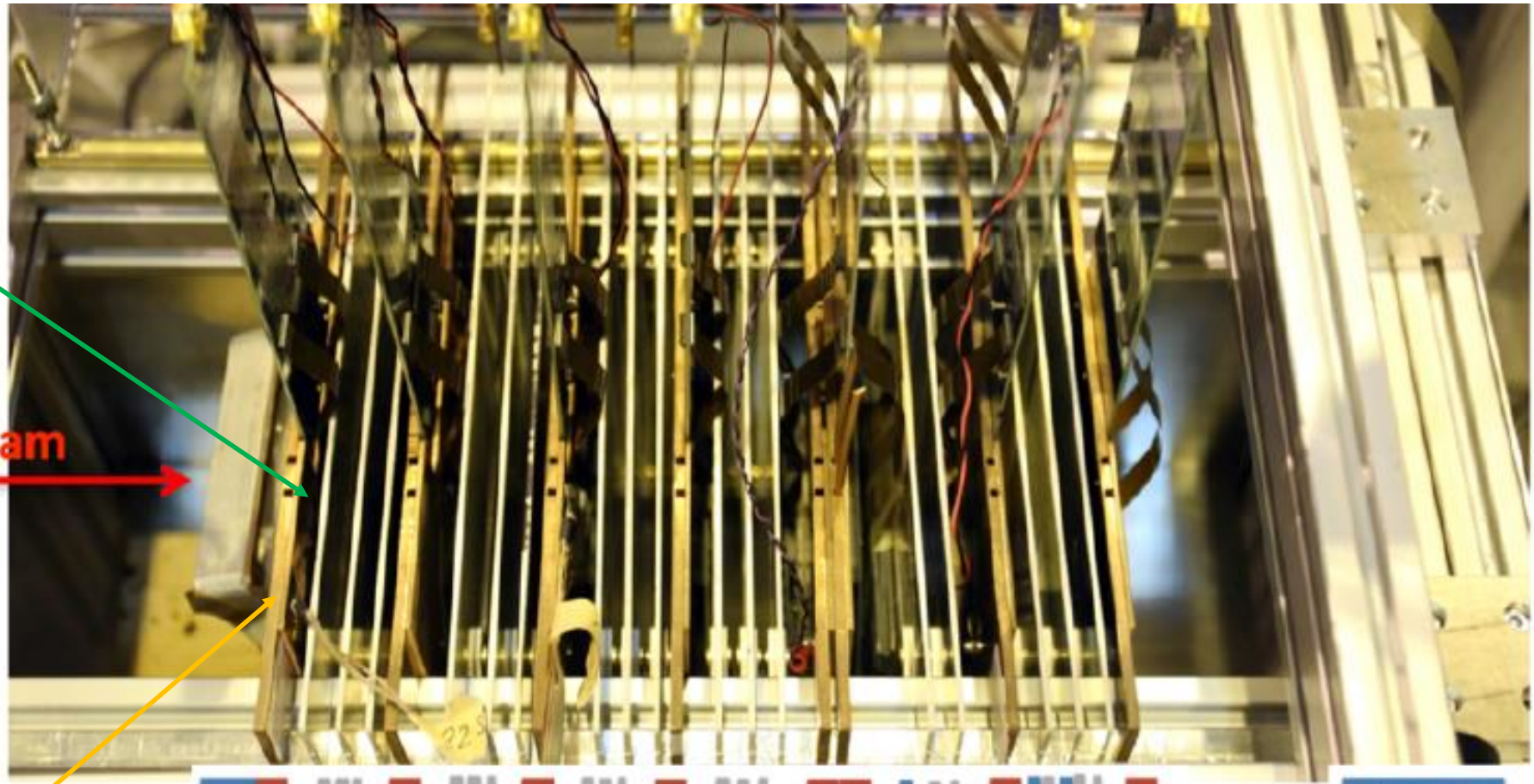
(single PCB version still at work…)

All done in US
(UCSB, FNAL, …)



Test Beams: set up

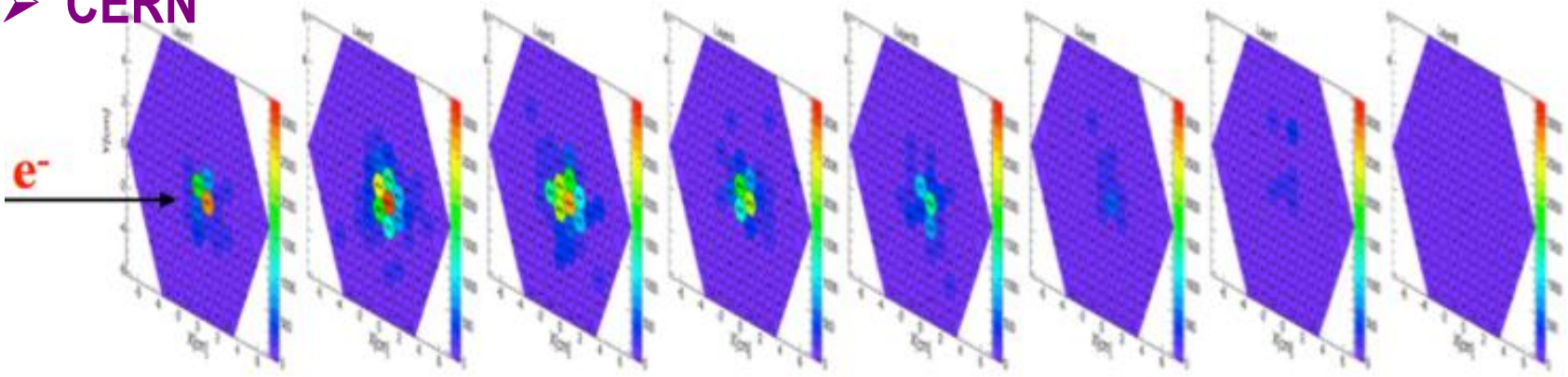
CERN (Similar at FNAL)

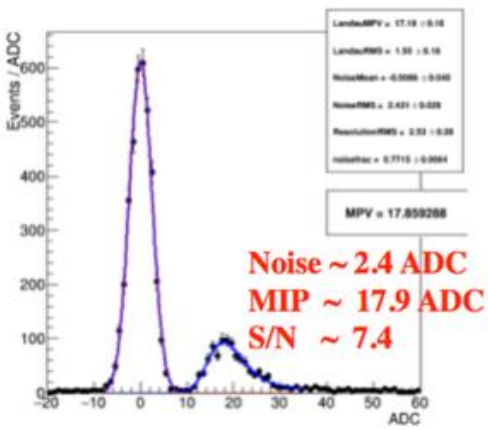


Mechanical design allows flexible insertion of modules and absorbers plates

Test Beams: (some) results

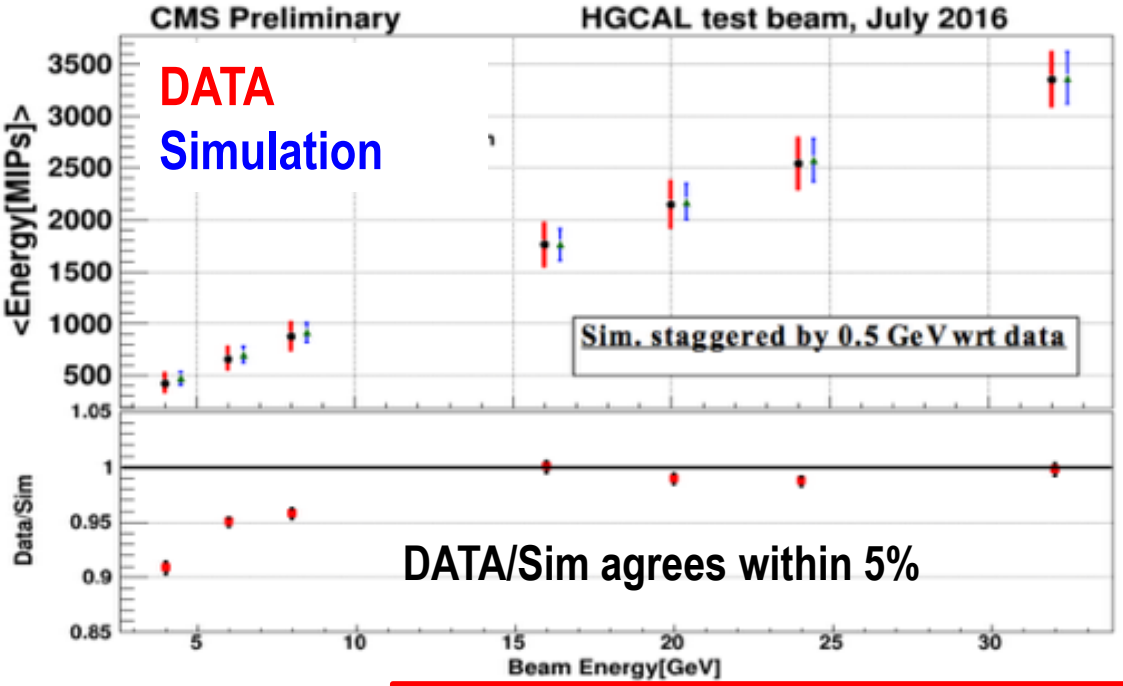
➢ CERN





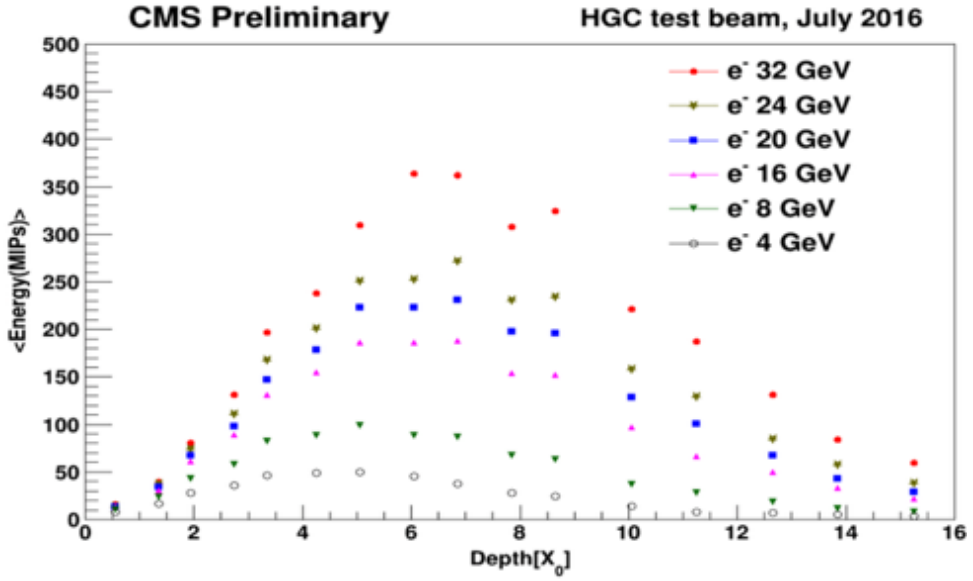
➢ FNAL

Total energy deposited in all layers vs e- beam energy



Energy deposited in each layer

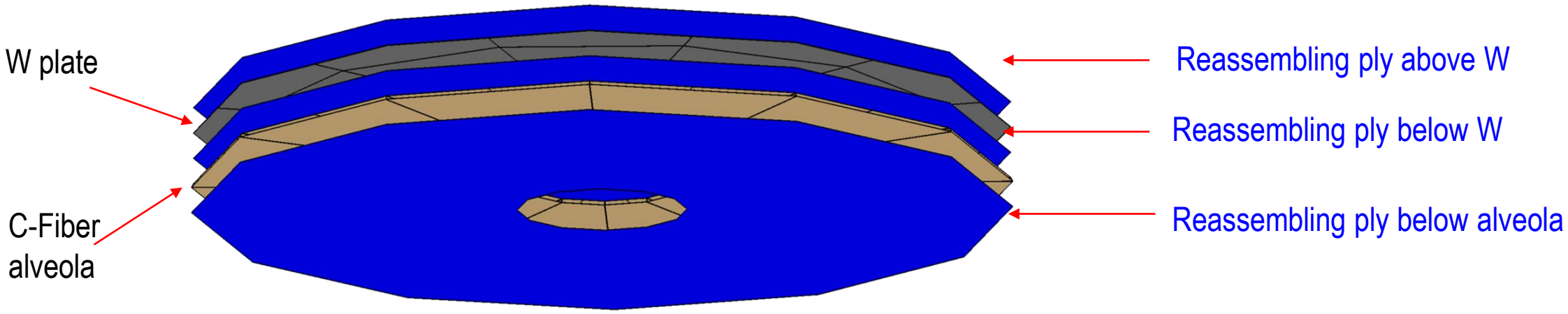
Shower max moves to higher depth as expected



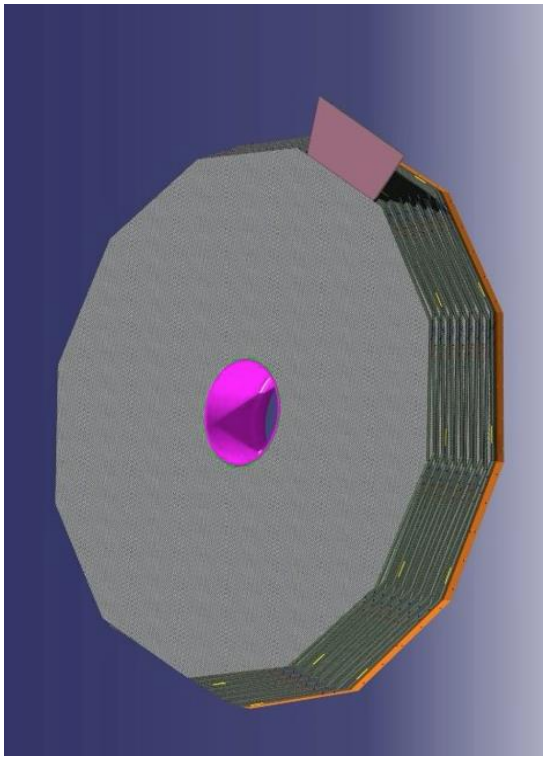
LLR will participate in >= 2017 tests (with help of P2IO project)

Alveolar Structure: Disk design

M. Anduze, C. Ochando,
T. Pierre-Emile, Y. Sirois

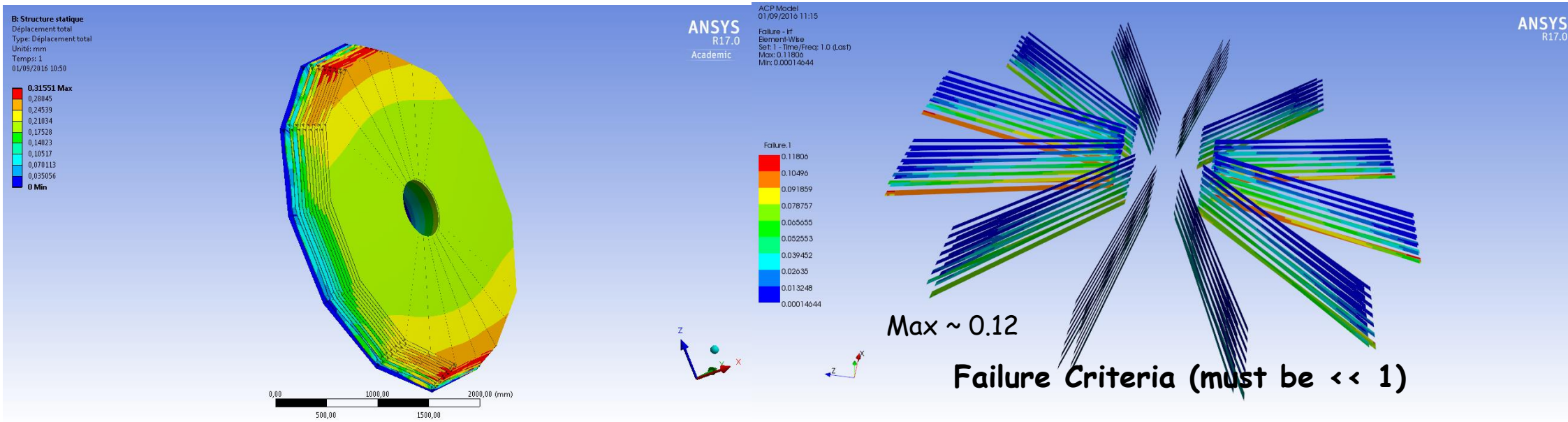


- C-fiber alveolar disks, with W plates embedded inside.
- W absorber plates not aligned with cassette gaps (“walls” of alveoli)
- **Freedom to rotate each disk wrt each others.**
- Inner cone to take load, can attach cassettes on it.
- Last disk attached on back plate for attachment on FH.



Alveolar Structure: FEA simulations

M. Anduze, C. Ochando,
T. Pierre-Emile, Y. Sirois



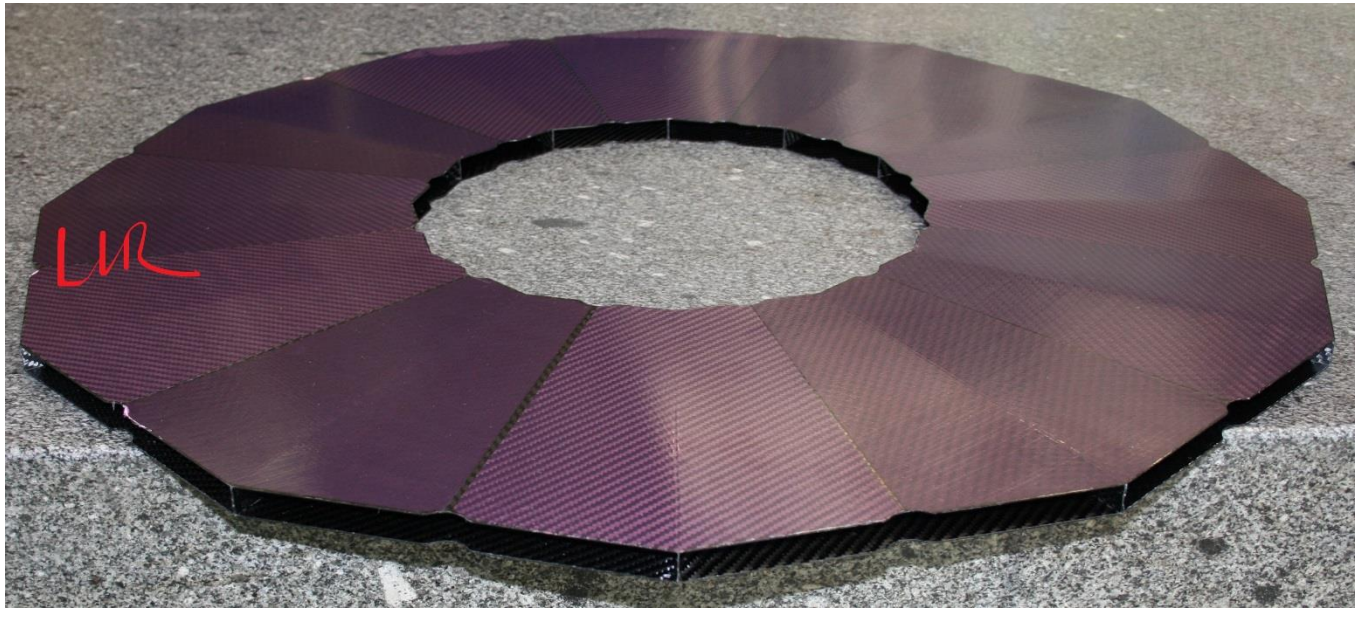
Several rounds of FEA performed:
(horizontal, vertical positions, various designs, varying C-fiber layers, cone thickness…)

- In vertical position
  - **FEA simulation with shell elements shows that the structure holds.**
  - **Maximum absolute deformation ~0.4 mm. Margin of Safety ~200%.**

- Part of the load is taken by an Al inner cone (15mm in these calculations).

Alveolar Structure: prototyping

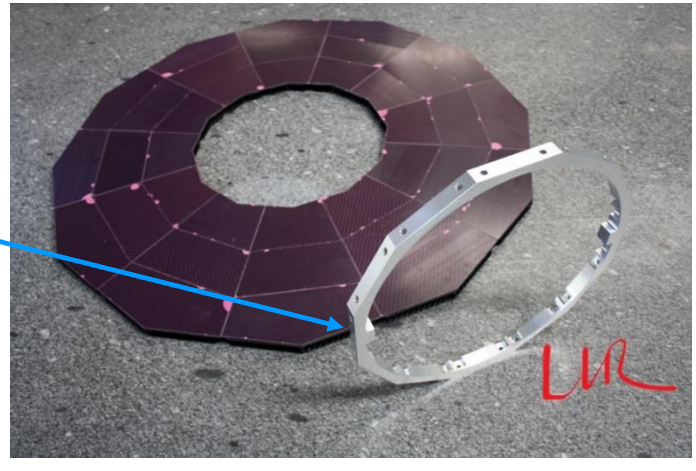
M. Anduze, C. Ochando,
T. Pierre-Emile, Y. Sirois



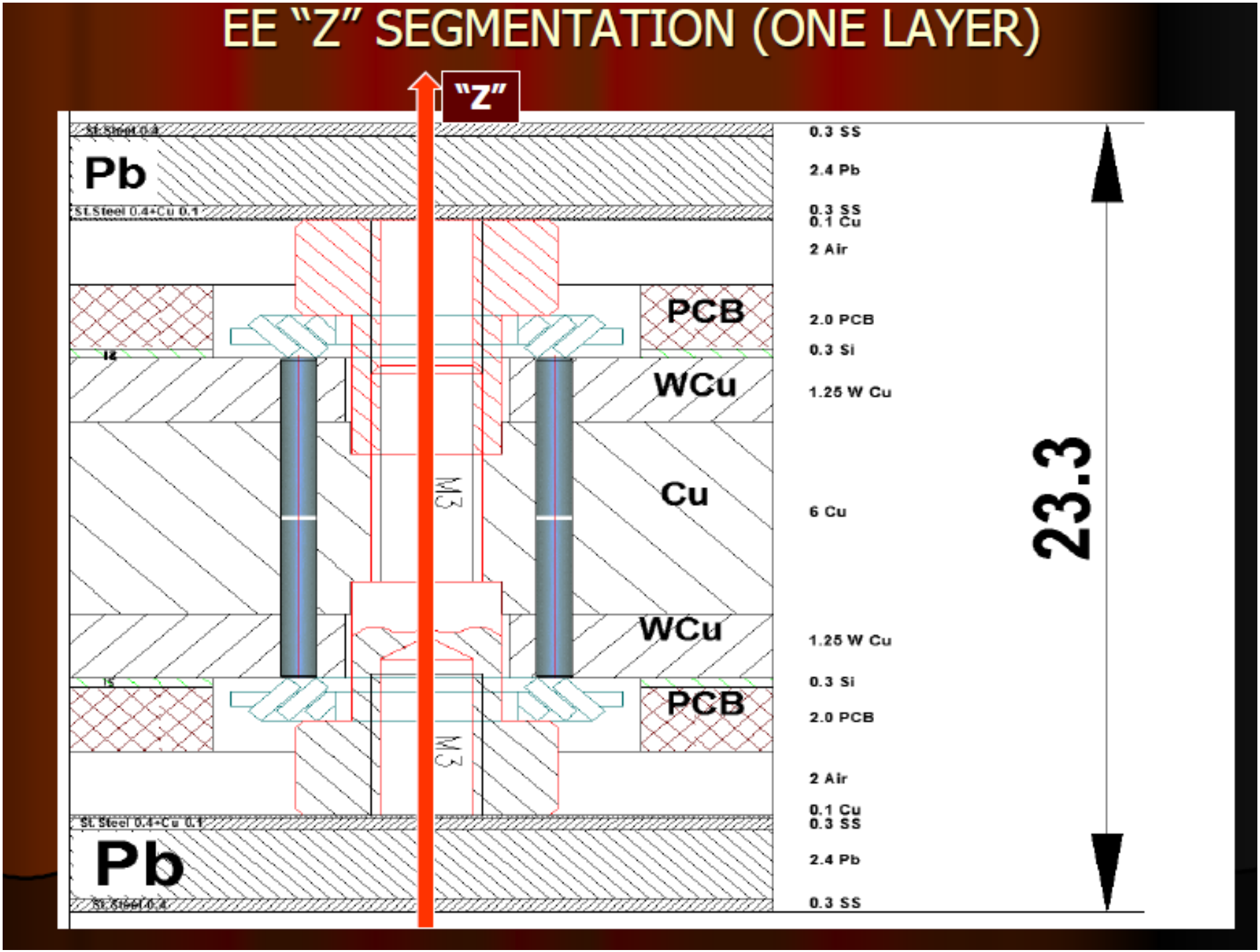
Dimensions	Outer diameter	803mm	2 carbon plies per alveola
	Inner diameter	325mm	1 reassembling ply on each side of the alveola
	Alveola thickness	15mm	No tungsten

➢ **Next steps :**

- Equip one disk with indexing ring
  (control of positioning of disks wrt each other)
- Add carbon plates to simulate tungsten
  before adding real tungsten
- Build a second disk and test gluing process of 2 disks



Disk & Spacer cassette



Disk & Spacer design

Modules attachment elements & spacers (Scale 1:1) EE layer N14

DRAFT

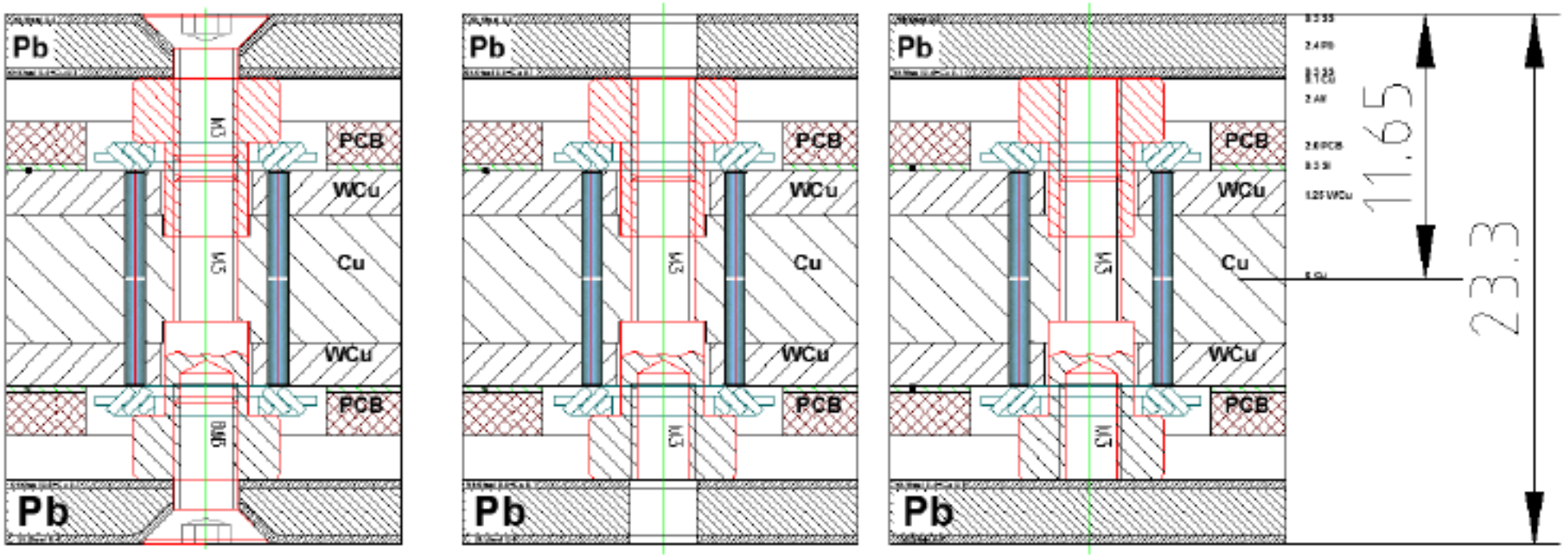
Cassettes cover fix ~12 pieces per 30°

Lifting points 11 pieces per 30°

Modules fix & cover supports ~60 pieces per 30°

EE 14 layers:

23.3x14=326.2mm



A.Surkov 30.09.2016