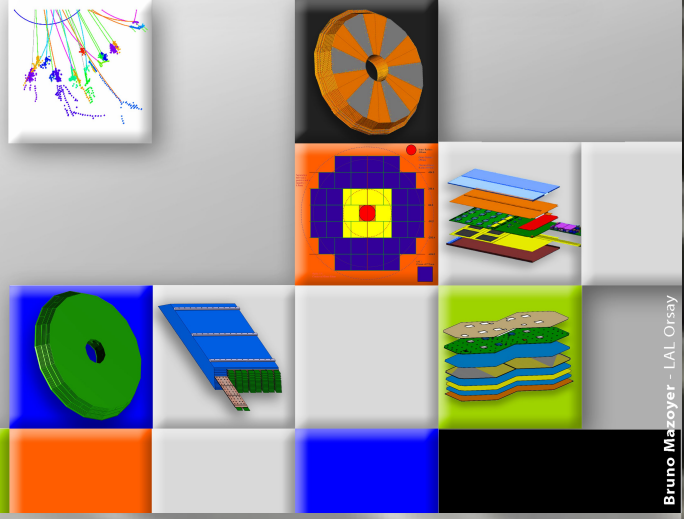
HIGHTEC

HIgh Granularity Hybrid Timing and Energy Calorimetry

a P2IO project by LLR, LAL and IRFU



Bruno Mazoyer - LAL Orsay

Rapport # 2

R. Pöschl,
On behalf of HIGHTEC colleagues from

LAL-CNRS Orsay
LLR-CNRS Palaiseau
DPhP-CEA Saclay
DEDIP-CEA Saclay

Annual meeting of P2IO Flagship Projects

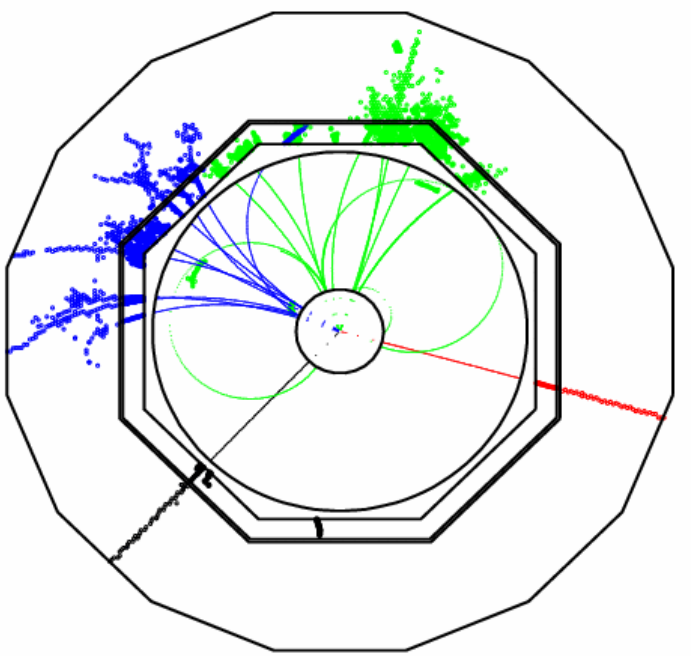
15. November 2017

Open Questions

Experimental Tool – Particle Flow at Colliders

ILC

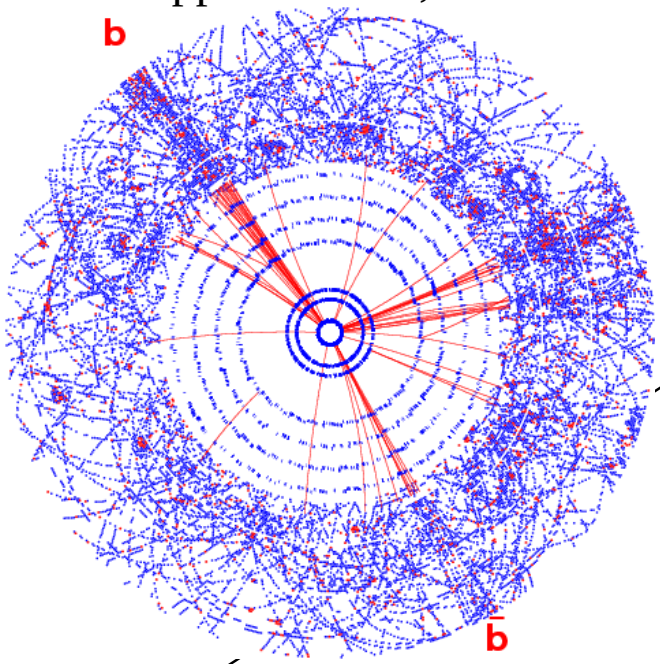
e+e- 2> H + Z; H 2> bb; Z -> μμ



- Clean, low repetition rates
- Pulsed electronics
- No trigger / data reduction
- Reconstruct full particle patterns

LHC

pp 2> H + X; H 2> bb

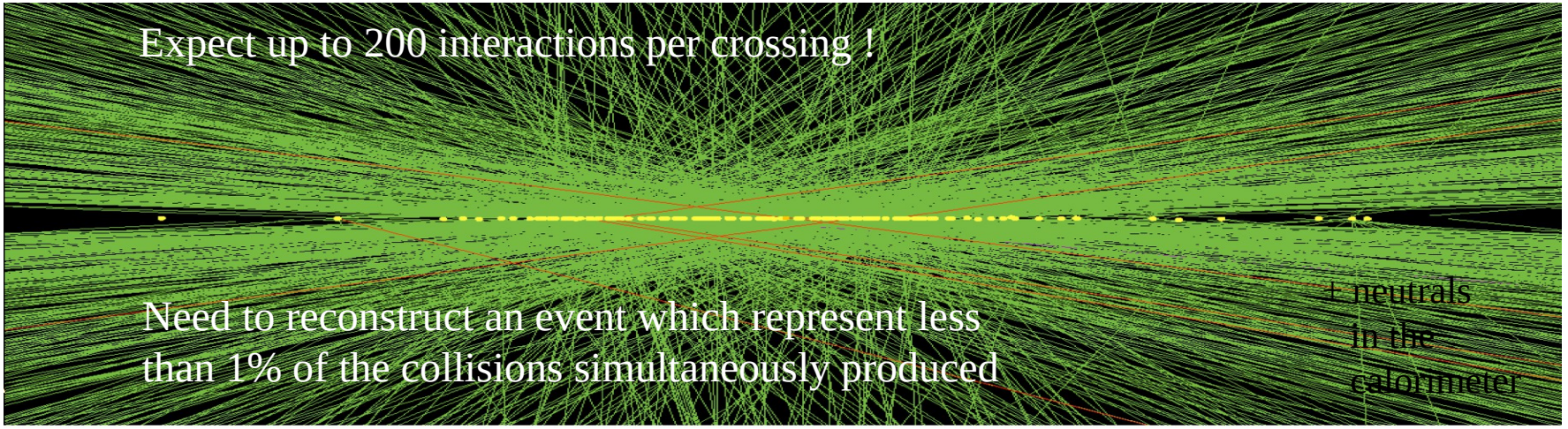


- Messy, High rates (40 Mhz)
- Continuous readout
- Data reduction/trigger challenge
- Reconstruct constrained patterns

Particle Flow Technique does require highly granular calorimeters

P2IO Groups of LLR/LAL do pioneer this technology
Founding members of CALICE Collaboration, first prototypes ~10 years ago

Experimental Tools – ... with timing



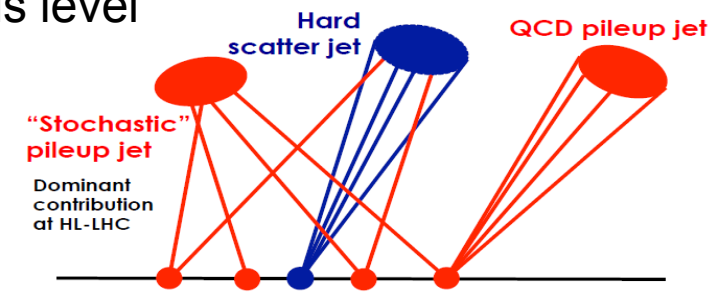
Spatial separation: Mean z-spacing of vertices down to ~ 500 μm

For a Poisson distributed probability per unit length for a beam interaction
- → spatial separation of two neighbouring vertices is exponentially falling
- → **significant overlap probability in vertex reconstruction**
- → PF algorithms start to fail in end cap region for <PU> ~200

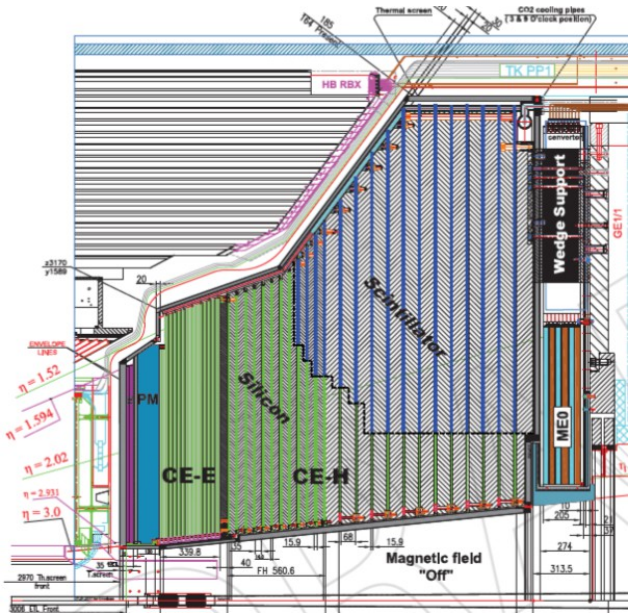
Timing separation The RMS spread of vertices is ~ 150 ps

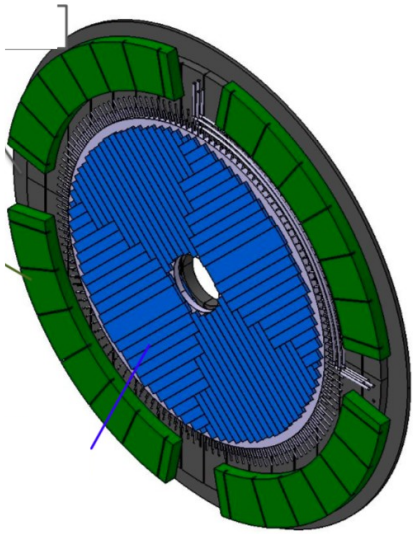
Goal: maintain or improve the performance of the forward detector at HL-LHC with <PU> ~ 200 at trigger or analysis level

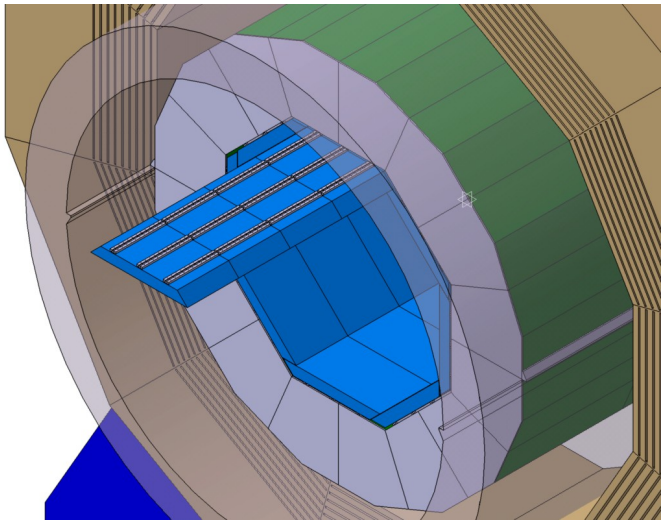
Benchmark processes:
- Primary vertex for H -> γγ
- VBF production with X 2> invis. against Z + jet & fake forward jets



Calorimeter projects of HIGHTEC Groups







CMS-HGCAL=EE+FH

Coverage
$1.5 < |\eta| < 3$
28+24 layers
0.5-1,2cm^2 cell size
6M channels

ATLAS-HGTD:

Coverage
$2.4 < |\eta| < 4$
Up to 4 layers
1.3x1,3mm^2 cell size
1.5M channels

LC Calorimeter:

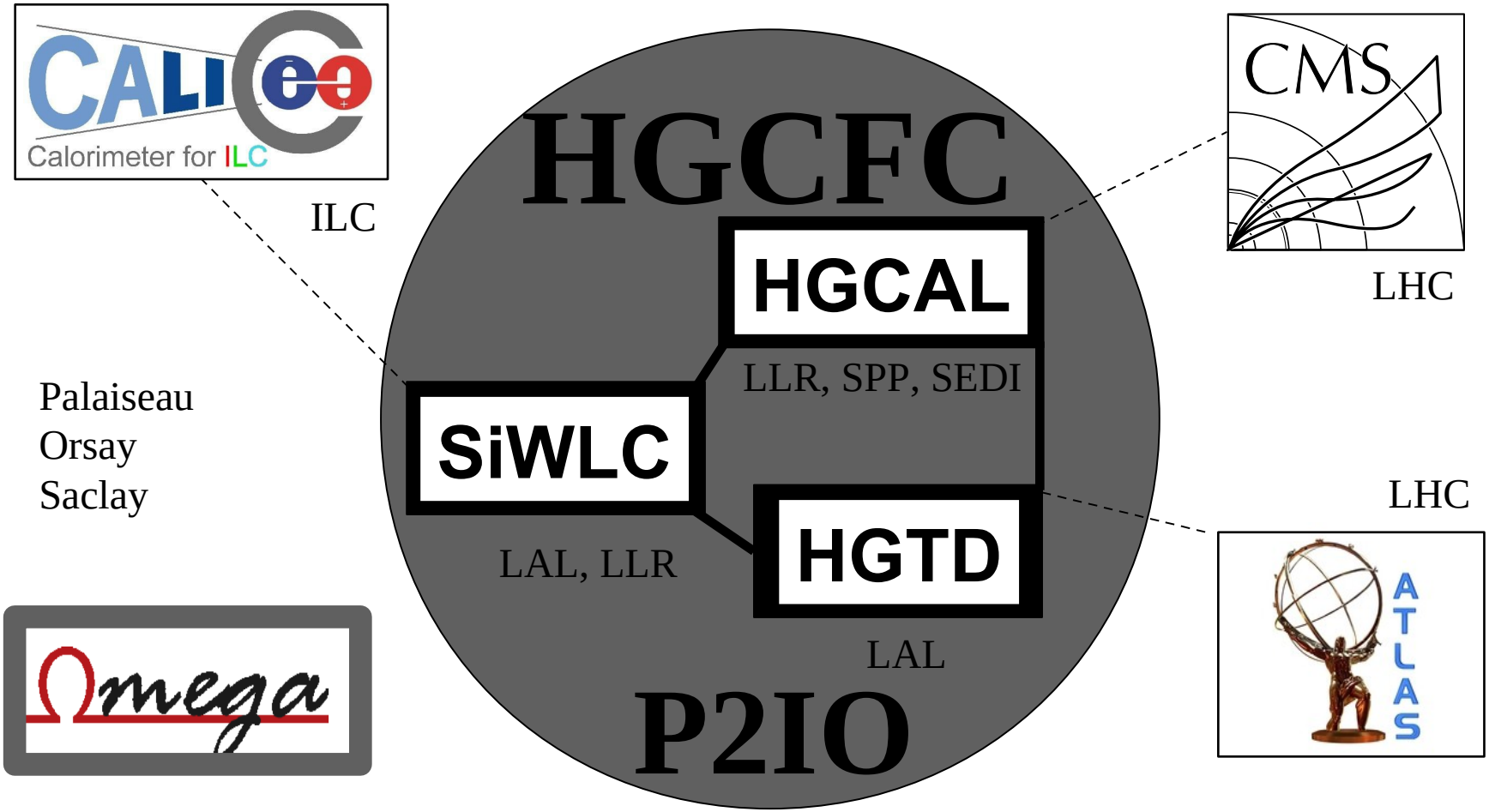
Coverage
$6^o < \theta < 174^o$
30 layers
5x5mm^2 cells
10^8 channels

- All calorimeter projects are organised in international collaborations

- P2IO enables HIGHTEC Groups to assume leading roles in project committees and to contribute to design documents

High **G**ranularity **H**ybrid **T**ime-**E**nergy **C**alorimetry©

HIGHTEC



Objectif:

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

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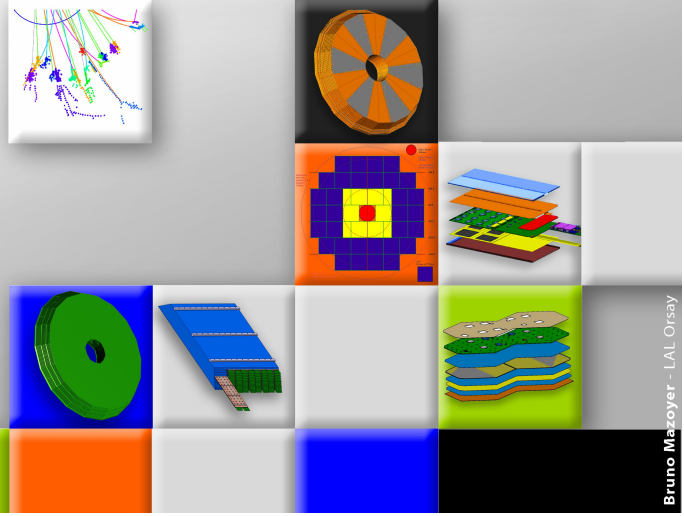
HIgh Granularity
Hybrid Timing
and Energy Calorimetry

a P2IO project by LLR, LAL and IRFU



Bruno Mazoyer - LAL Orsay

Status des

Projets HIGHTEC

HGCAL-Timing, Mechanics, and B.E. Electronics; SiWLC; HGTD

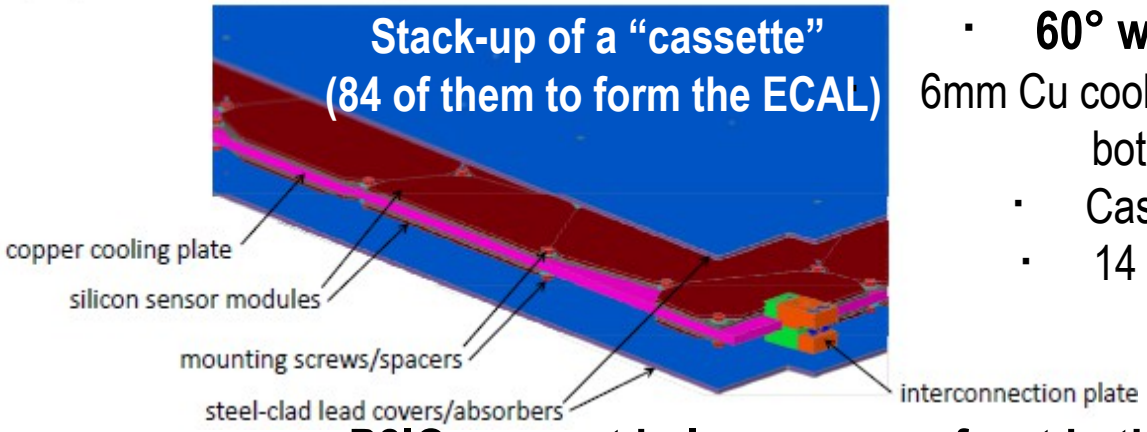
Two project meetings in 2017:

11/4/17: https://indico.in2p3.fr/event/14484/
9/11/17: https://indico.in2p3.fr/event/16684/

For a complete bibliography of talks and publications see backup slides

HIGHTEC HGCAL Mechanics - LLR (1/2)

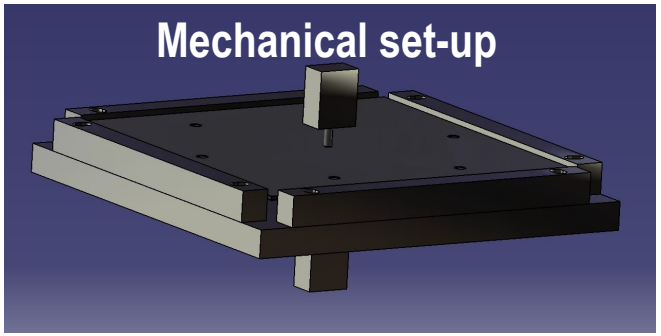
LLR co-responsible (with CERN) of the HGCAL-ECAL mechanical structure design

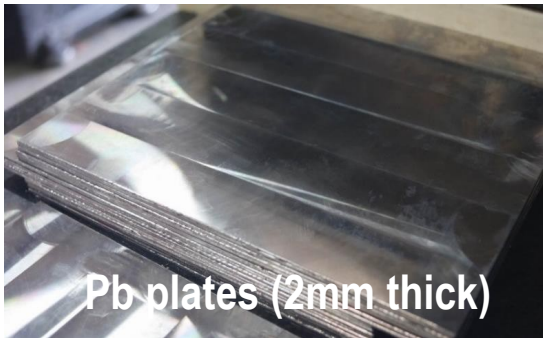


- **60° wide wedge-shaped cassettes:**
  6mm Cu cooling plate with Silicon sensors modules on both sides + Pb/SS absorber cover
- Cassettes assembled to form disks.
- 14 disks stacked-up to form ECAL.

P2IO support helps on many front in the R&D and prototyping:

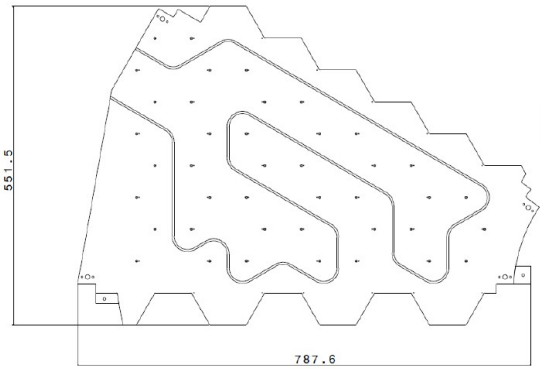
Mechanical tests:
Tests of mechanical behavior of Pb/SS sandwich





Cooling plate tests:

- Achievable precision, machining process
- Integration of cooling pipes
  (SS 4mm Outer Diameter tubes)
- Mechanical strength, etc…



Also: spacer design, Calculations…

Final design to be delivered by the end of 2019 (well in line with the P2IO project)

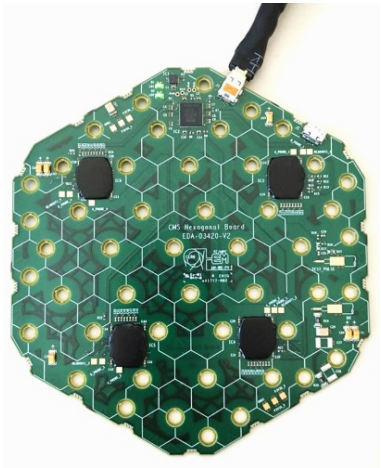
HIGHTEC HGCAL Front End Electronics

Detector modules have to very thin (<6mm) and f t the full front-end electronics, supply and communication lines

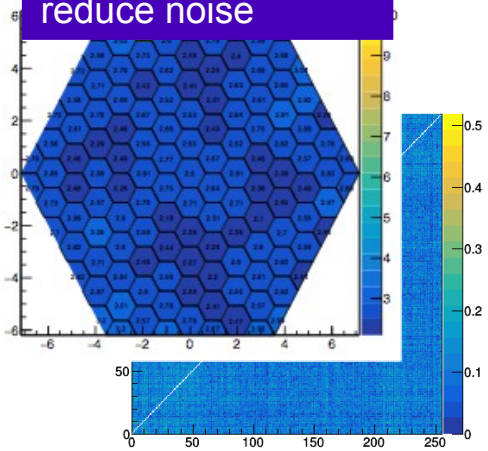
– 2 PCB modules:

1. PCB: 8” hexaboard
Wire-bonds to Si-sensor and very-FE ASICs

2. PCB: Motherboard for powering, data concentration, trigger generation And bi-directional communication



6” hexaboard PCB For Test Beam: Several versions to optimise design and reduce noise



Very Front-end ASIC: HGCROC

Multi-channel readout chip for Si sensors

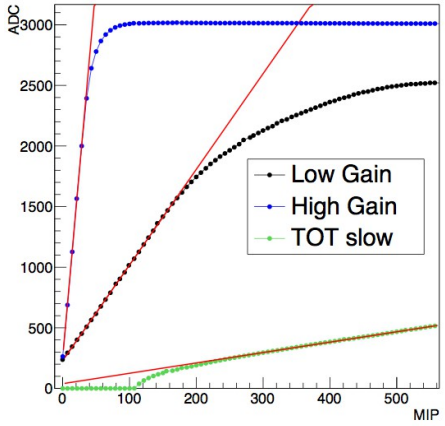
Charge measurement with traditional gain for 1-100 MIP signals and Time-over-Threshold (TOT) for 100-3000 MIPs

Time-of-Arrival (TOA) measurement with 50ps precision (20ps for cluster of cells)

HGCROCv1 received in October, lab tests starting soon

Proof or principle for TOT and TOA in beam tests using simpler ASIC: SKIROC2cms based on SiWECAL ASIC

Transfer characteristics for high/low gain and TOT of SKRIOC2cms using charge injection

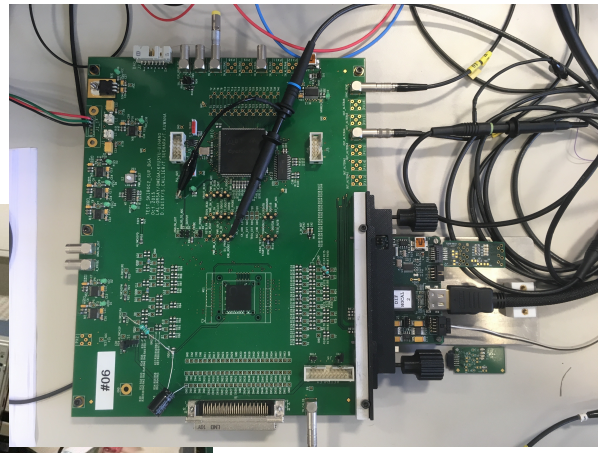


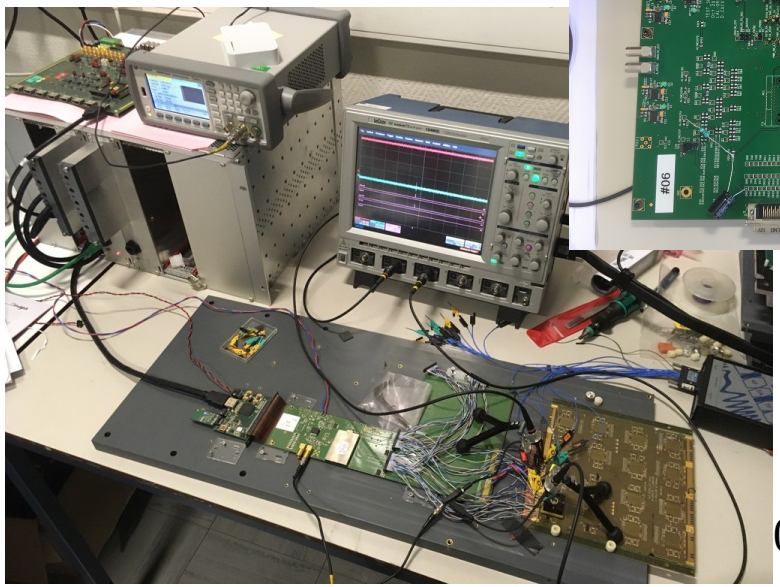
A. Lobanov et al.

HGCAL – SiW LC ECAL – Common Test bench

- Common test bench for ASIC characterisation of LC SiW-ECAL and CMS HGCAL
  - ASICs by Omega: SKIROC2 and SKIROC2cms
  - DAQ hard- and software developed at LLR
  - Common measurement and analysis tools
  - Exchange of knowledge and tools

Great example of synergy between P2IO projects!

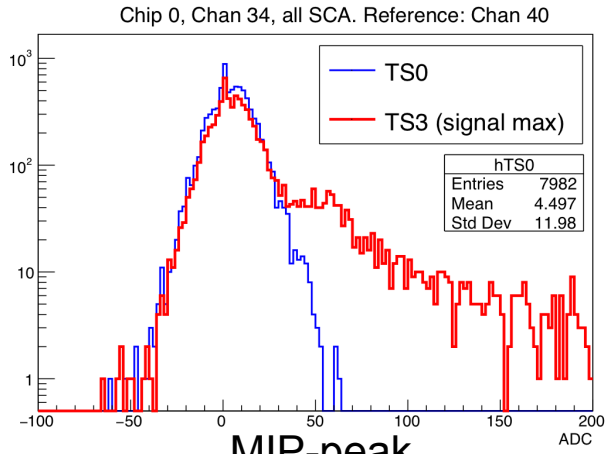




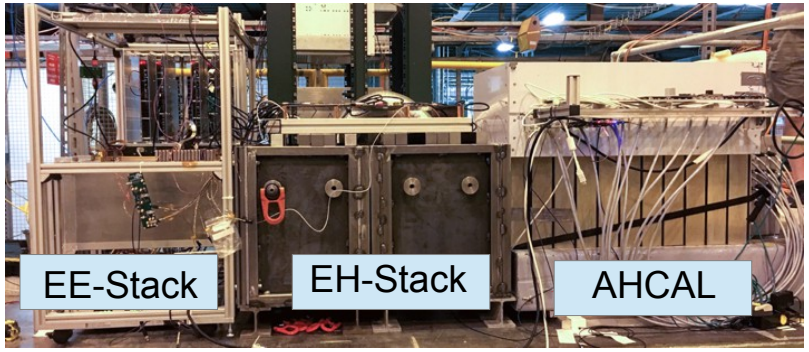
HIGHTEC HGCAL Beam Test

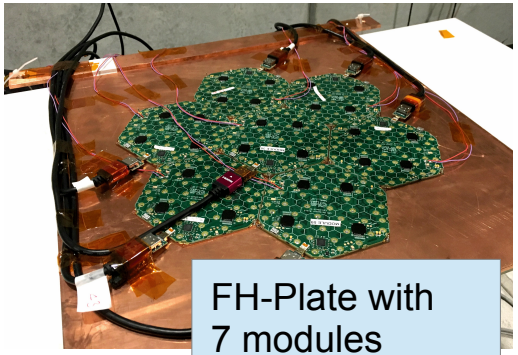
A. Lobanov et al.

- Several test beam periods at CERN in 2017 to test a full stack of EE+FH+AHCAL (CALICE)
- Studied different configurations in the EE/FH with electron, pion and muon beams (for calibration)
- Overall satisfactory performance of electronics and detector:
  - MIP calibration performed, preliminary energy response linear, shower shapes agree with MC simulation — very promising

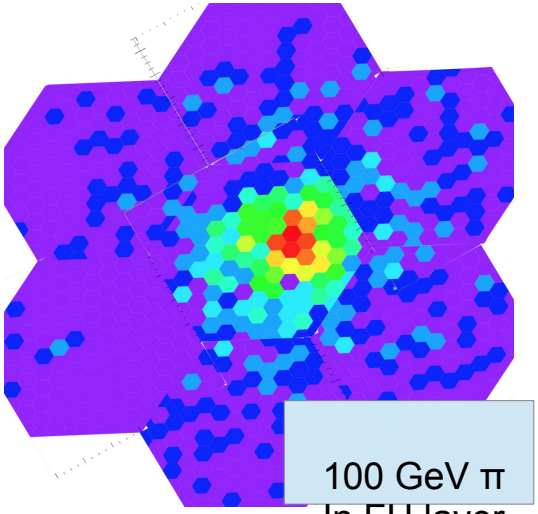


MIP-peak
Data ~ test pulse





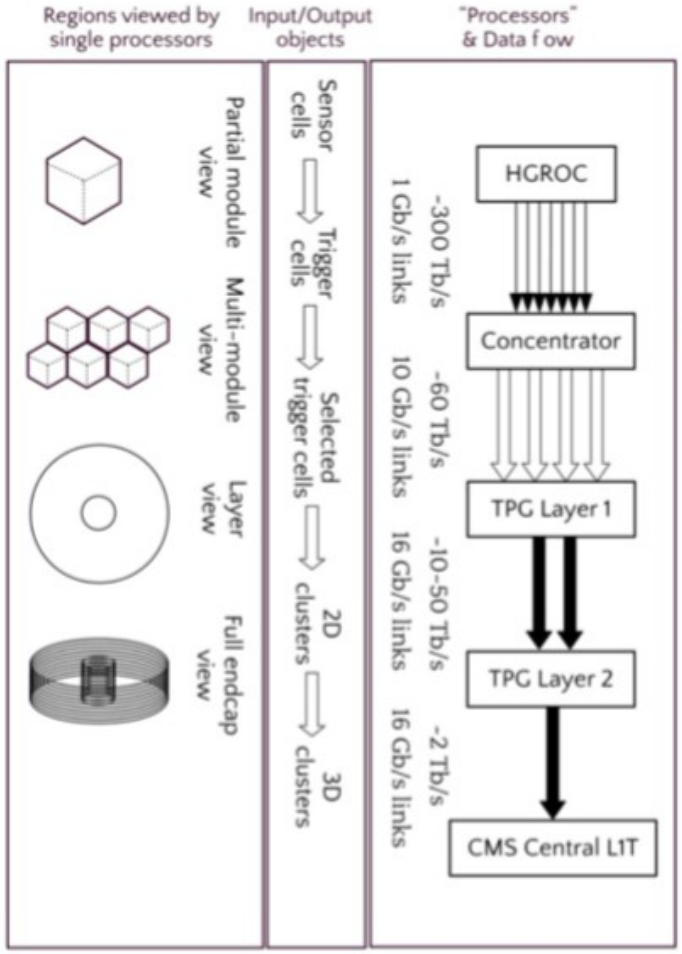
FH-Plate with 7 modules



100 GeV π
In FH layer

Note: Common running of CMS Ecal and CALICE AHCAL paves way for common running of HIGHTEC Prototypes

HIGHTEC HGCAL Trigger



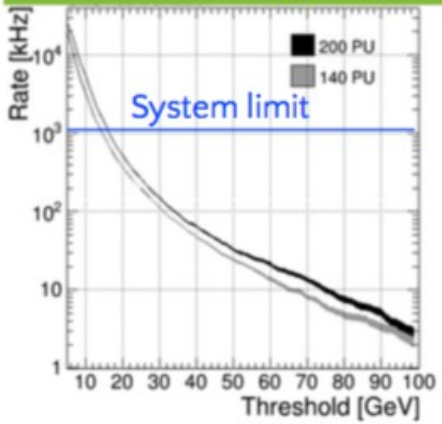
- Work on the frontend and backend
- Algorithms, simulation and firmware developments
- TDR results and longer term studies

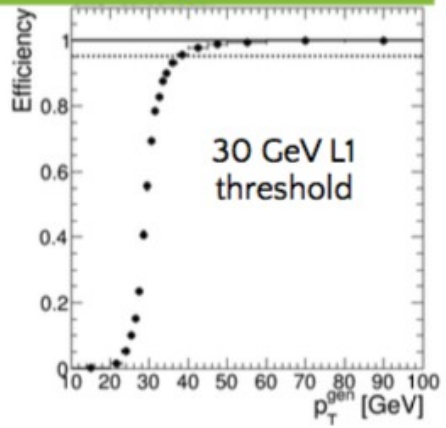
Study of trigger cell selection algorithms

Firmware implementation

Development of clustering algorithms

Single e/g rate and efficiency



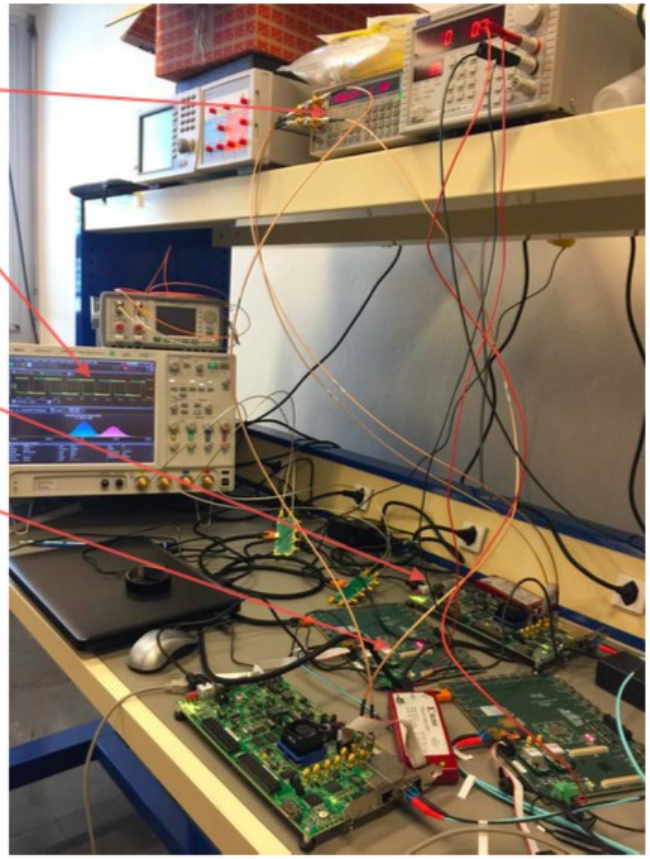


HIGHTEC HGCAL Timing - DPhP

CEA – Saclay

Test bench designed to perform various tests and measurements of the clock distribution system at backend (BE) and frontend (FE) level

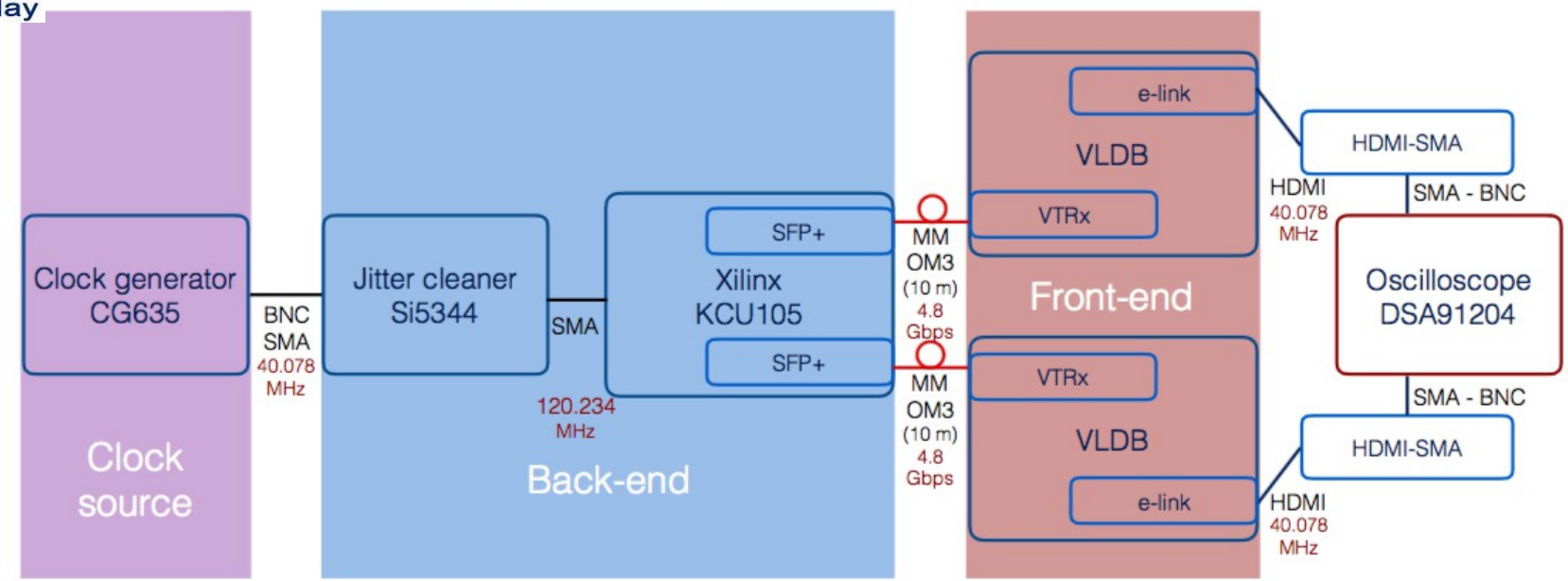
- Stanford CG635 clock generator
- Keysight DSA91204 oscil. (12 GHz)
- Keysight SSA-E5052B spectrum analyzer
- 2 x Xilinx KCU105 evaluation board
- 2 x VLDB (GBTx) and MM VTRx
- Finisar SM SFP+, Avago MM SFP+
- Keysight optical reference receiver
- High quality shielded cables, converters.



Setup at CEA realised during 2017

Ö. Sahin et al.

HIGHTEC HGCAL Timing - SPP



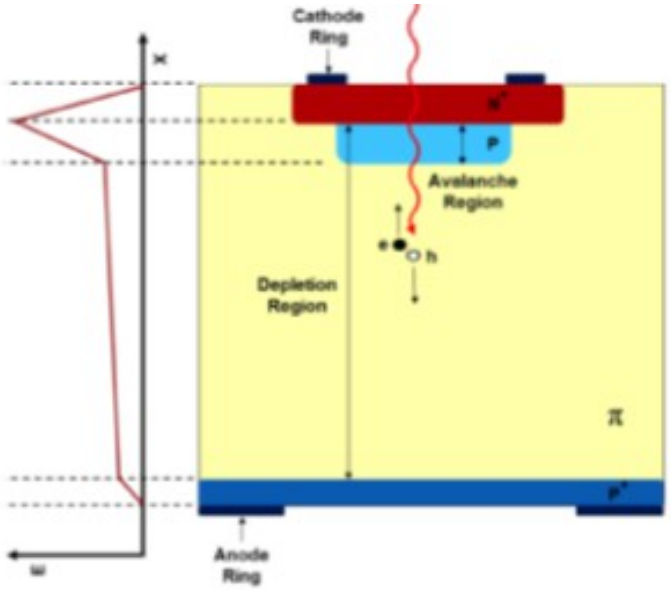
Measurement	RJ [ps]	σ [ps]	DJ [ps]	σ [ps]
Single channel - two e-links	7.8	$\pm$ 0.1	5.6	$\pm$ 4.3
Two channels - single BE	8.7	$\pm$ 0.1	24.2	$\pm$ 2.1
Two channels - two BEs	13.7	$\pm$ 0.1	12.7	$\pm$ 1.4
Two channels - two BEs - Si5344 PLL	8.2	$\pm$ 0.1	18.6	$\pm$ 2.3

Moving on to use microTCA and ATCA crates and study temperature effects

RJ = Random Jitter
DJ = Deterministic Jitter

HIGHTEC HGTD – Sensor technology and tests

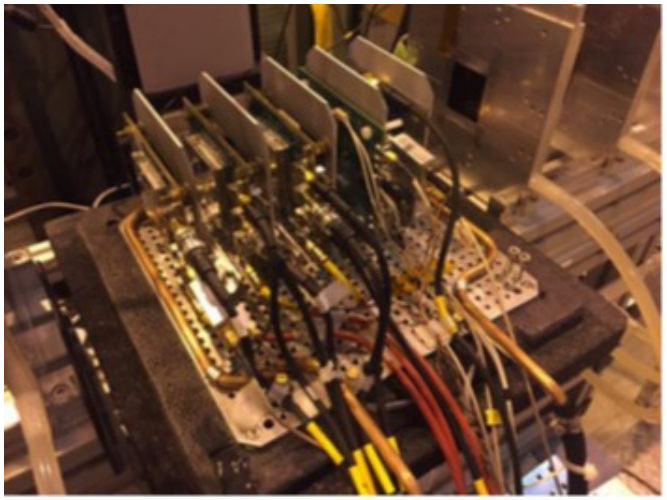
LGAD: n-on-p Si detector with
Extra doped layer -> x20 internal ampl.

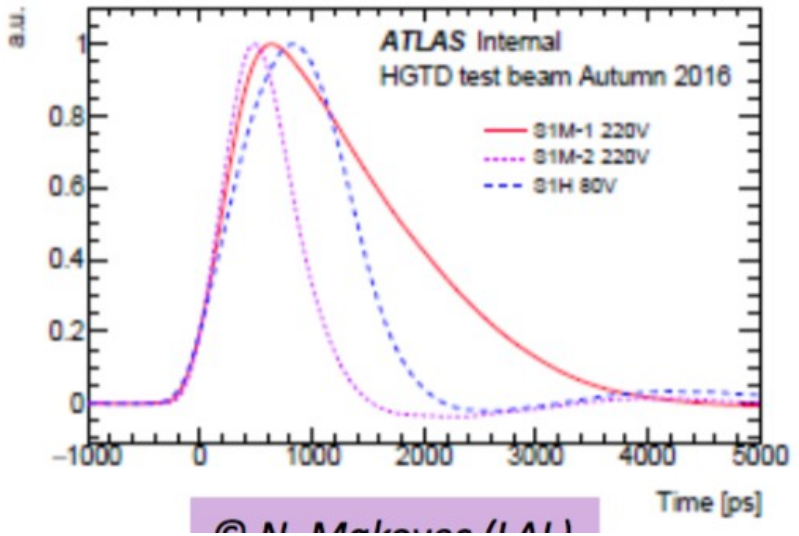


$$\sigma^2_{det} = \sigma^2_{Landau} + \sigma^2_{Elec}$$

Thin sensor: higher slew rate and minimal Landau fluctuation
Small area => Small C_{det} => Small Noise

Testbeam setup in H6 = 120 GeV p

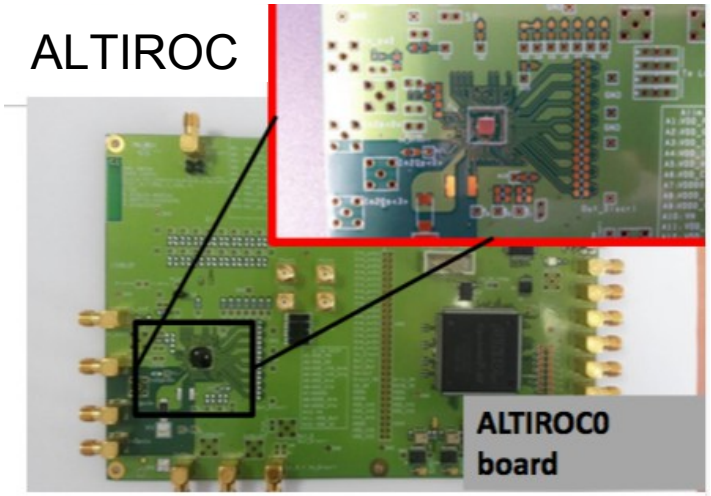


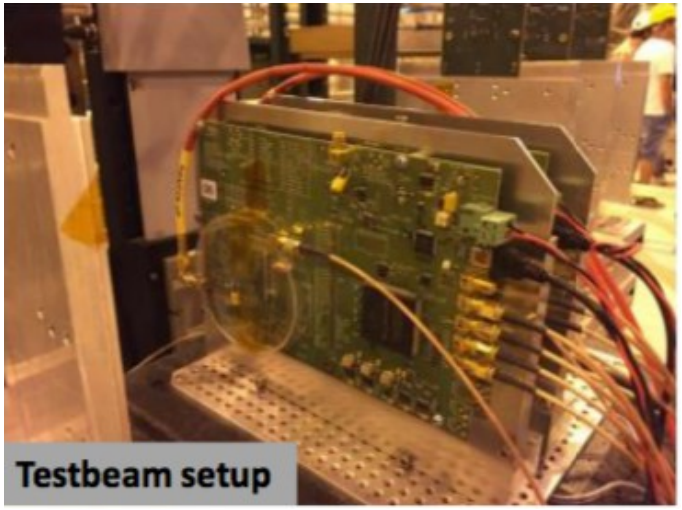


HIGHTEC HGTD – ALTIROC

Brother/Sister of SKIROC and SKIROCcms/HGROC

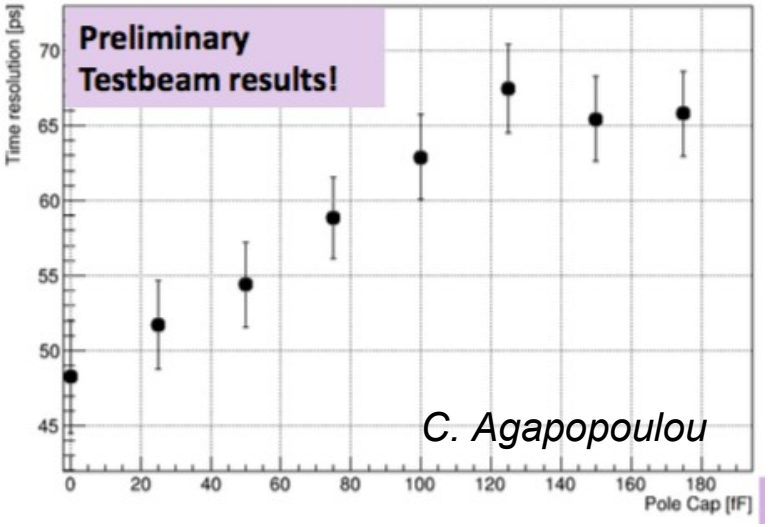
ALTIROC





- Time measurement for HGTD sensors
- 225 Channels

Testbeam setup with 2x2 sensor array

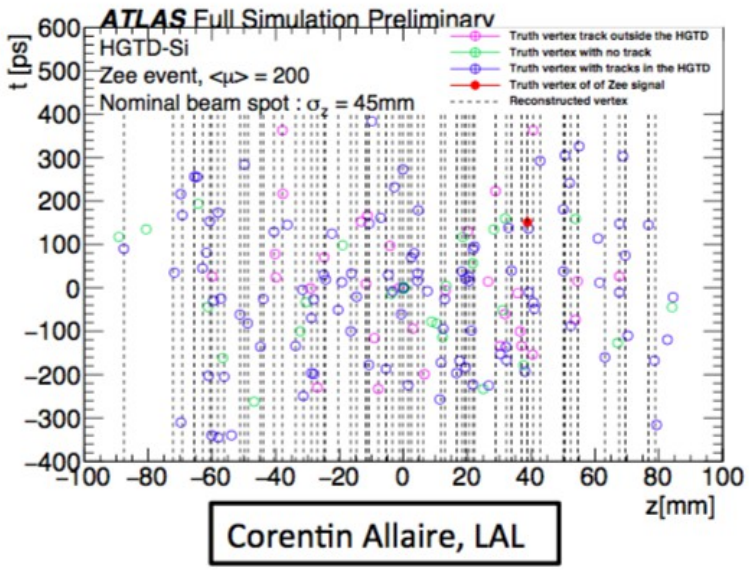


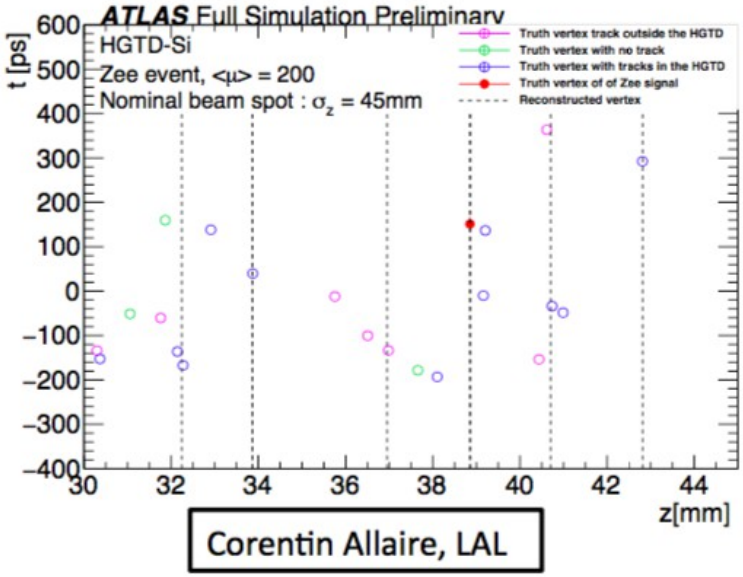
- Time resolution 48ps for C_p = 48ps
- Important step for further debugging
  e.g. Pre-amplifier noise and detector noise

First experience with real ASIC for timing measurements

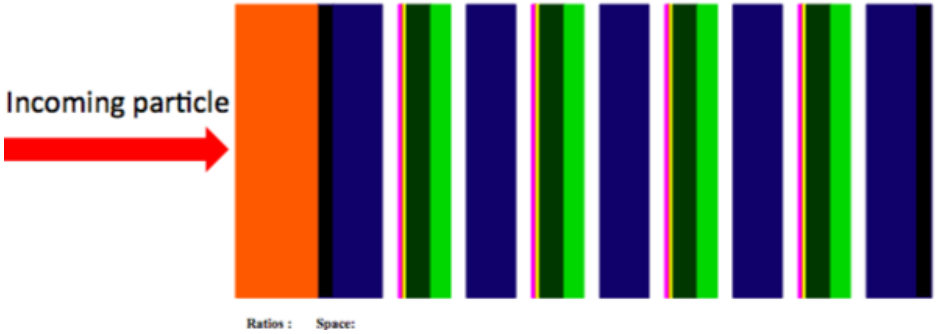
HIGHTEC HGTD – Simulation studies

Z->ee: Timing allows for filtering the correct vertex

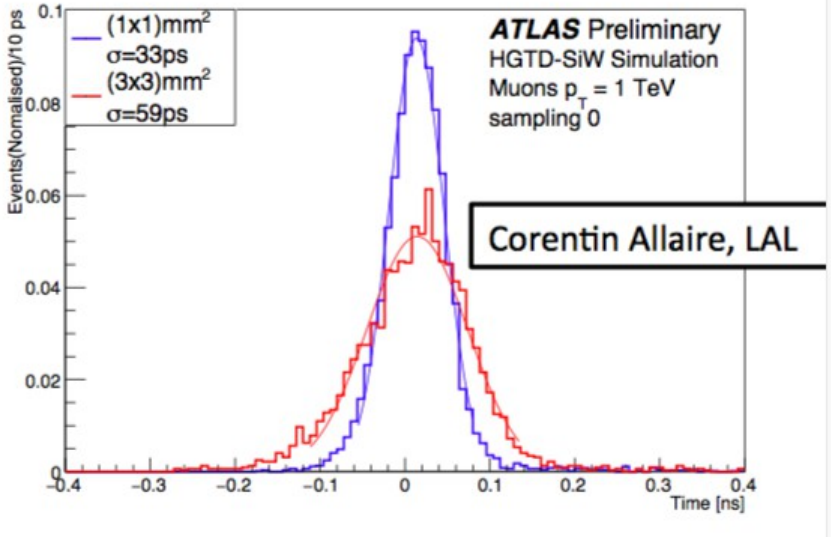




Optimal cell size?



- HGTD Si: 43 mm, 4 Si sensors
- Timing simulation based on beam test results



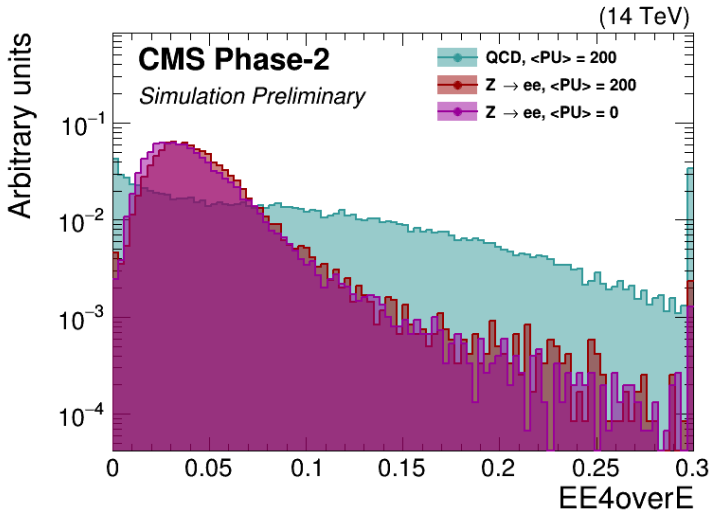
Electron reconstruction with highly granular calorimeters

High granularity and very high Pile-Up (PU~200): challenges for the reconstruction

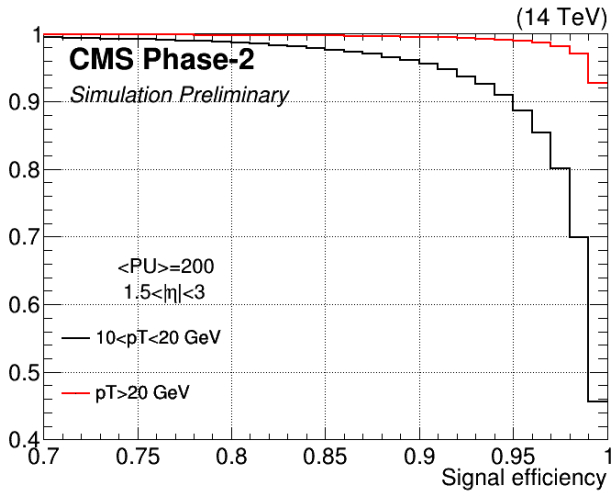
- HGCAL: "5D information" (x,y,z,t,E), ideally suited for PFlow reconstruction
- Focus on electrons, important for channels such as H2>ZZ2>4e, SUSY with soft leptons, …

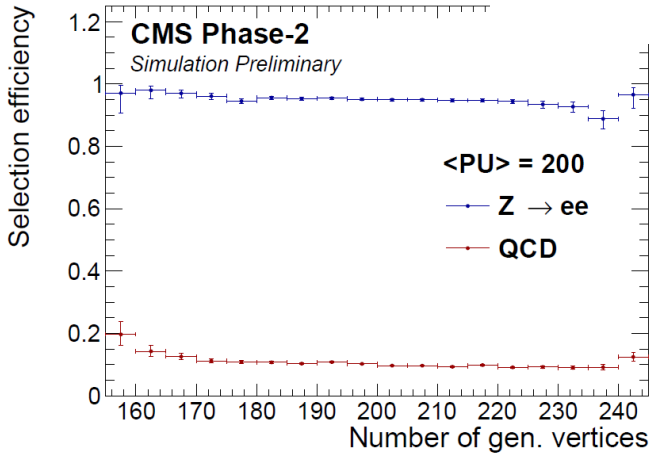
- 3D reconstruction of th showers,
- Combination with the tracker
- Exploits 3D fine granularity

Energy (the first 4 layers) / E(total)



Electron ID performance, with a BDT





Very good preliminary performance:

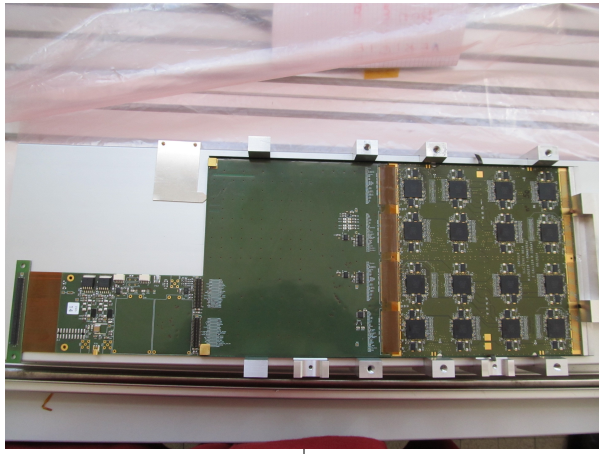
- High efficiency (95%)

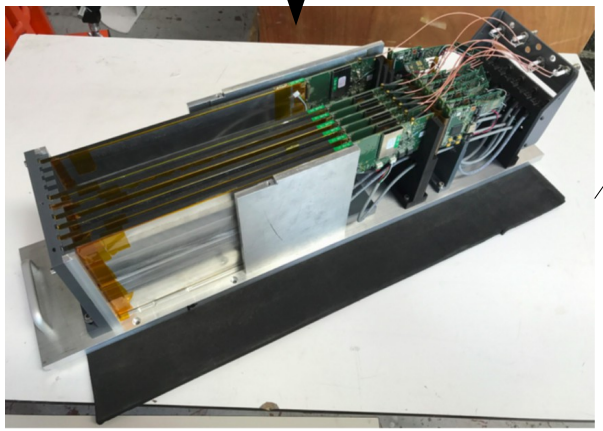
for very high background rejection (>99%) at high momentum.

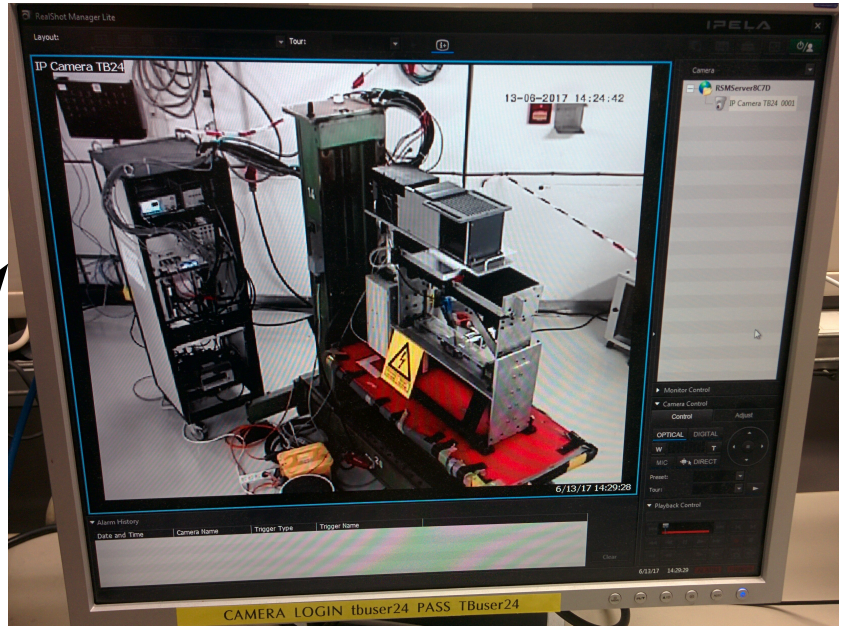
- **very stable with the number of PU interactions !**

All studies/plots related to electrons performances in the HGCAL TDR from LLR, **thanks to P2IO**

HIGHTEC SiW LC Ecal



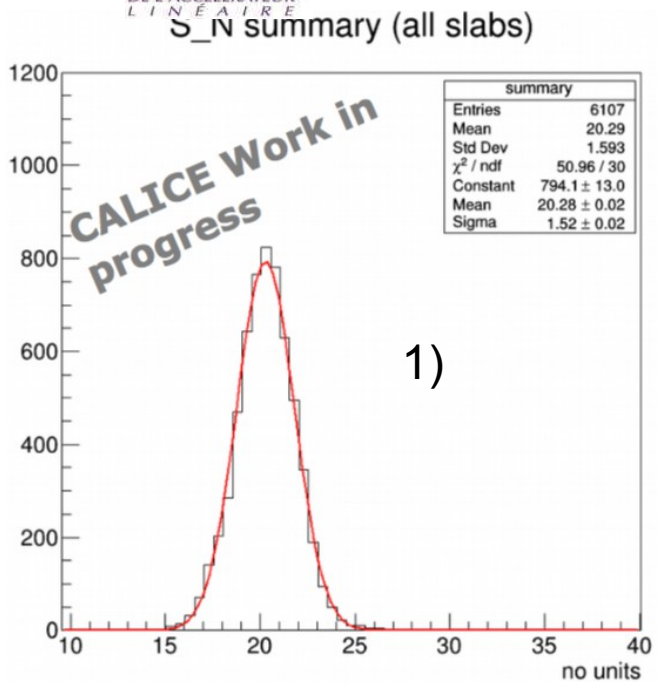


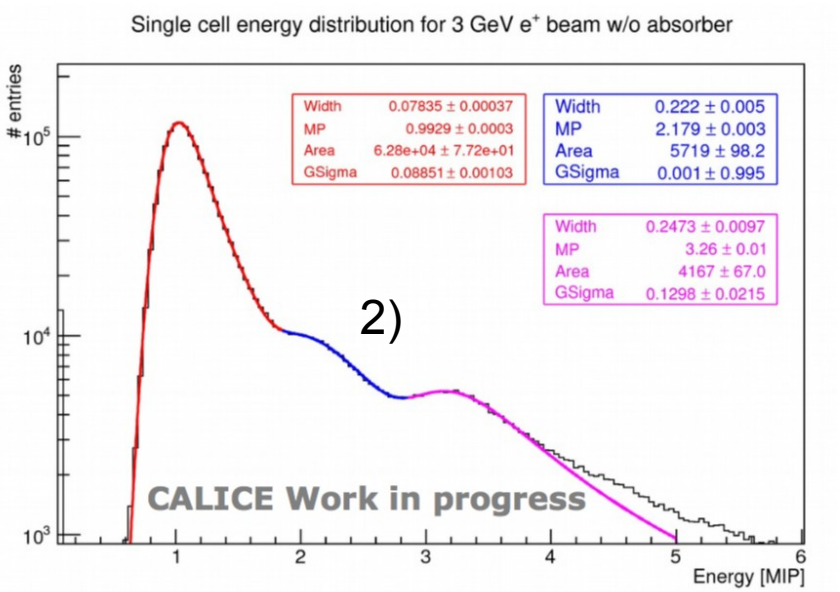


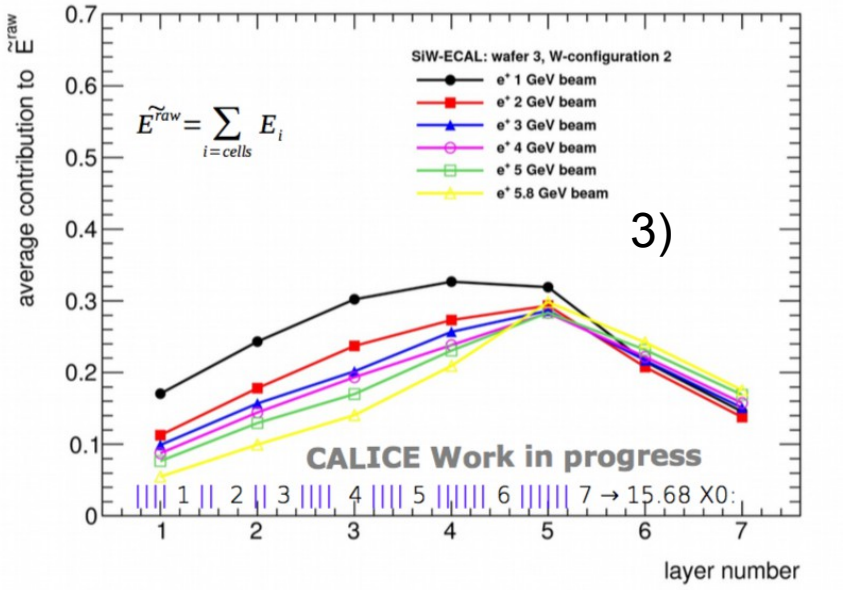
- **CNRS: LLR, LAL,** LPNHE, **Kyushu, SKKU**
- June 2017 at DESY, HIGHTEC Funding + AIDA-2020 TA
- Positrons 1-6 GeV
- Detector and energy scans, tests in magnetic field (PCMAG)

- Commissioning and conduction (A. Irles + LLR Engineers)
- Analysis (mainly) A. Irles, A Lobanov

HIGHTEC SiW LC Ecal – Beam test results







1) Signal-over-Noise: ~20
   Compare with 10 as target value

2) MIP Spectrum
   Clear single MIP peak and
   Signals from multiparticle events

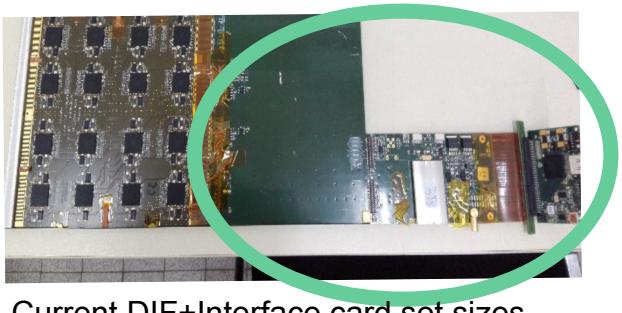
3) Shower profiles compatible with expectation

=> Excellent results

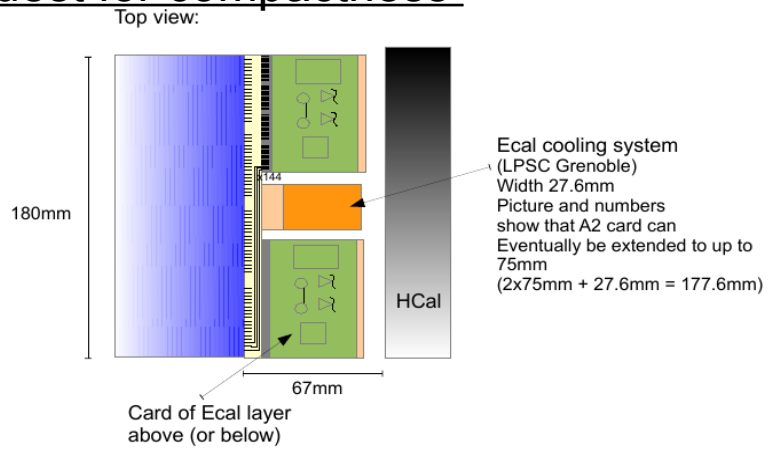
Beam test allow for further
system improvement and progress to next major step

HIGHTEC SiW LC Ecal – System Integration and R&D

Digital readout – Quest for compactness



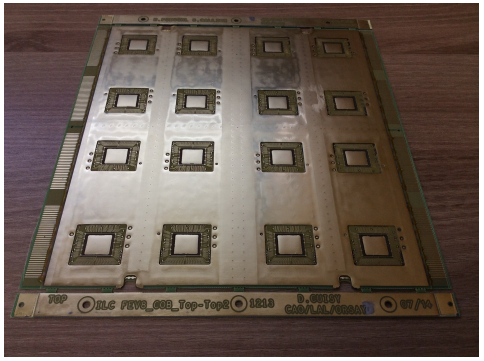
Current DIF+Interface card set sizes
~ 1 ASU (18x18cm)
→ **to be reduced to credit card size (7×4 cm²)**



Wafer R&D

- Cost Driver
- Key questions: 6” or 8”, thickness, guard ring

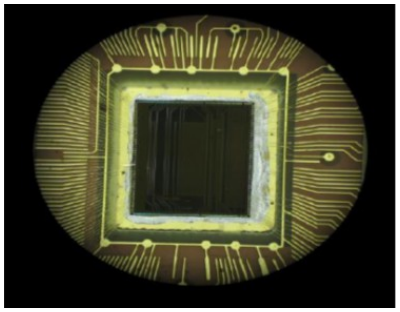
Thin PCB



1.2 mm

Flatness < 0.5 mm

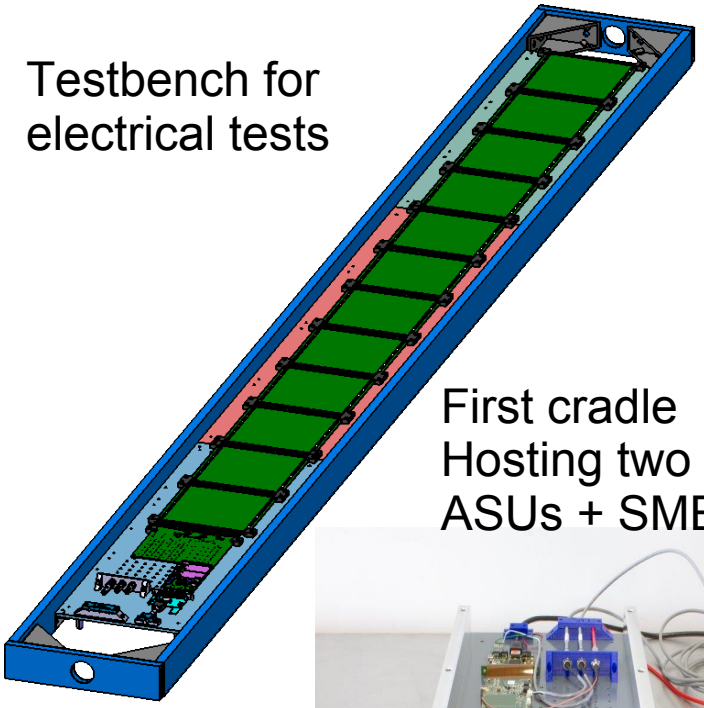
Bonding with



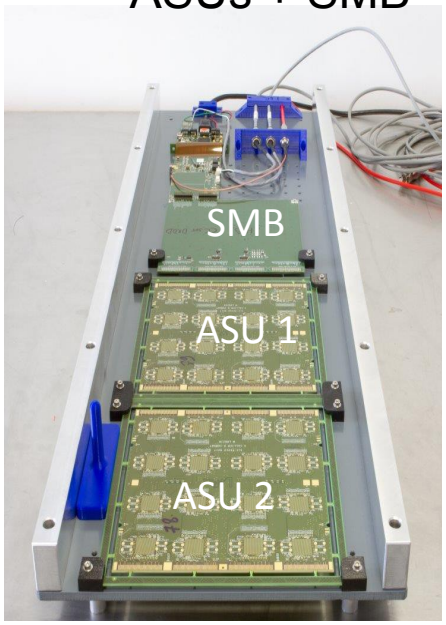
CAPTINNOV

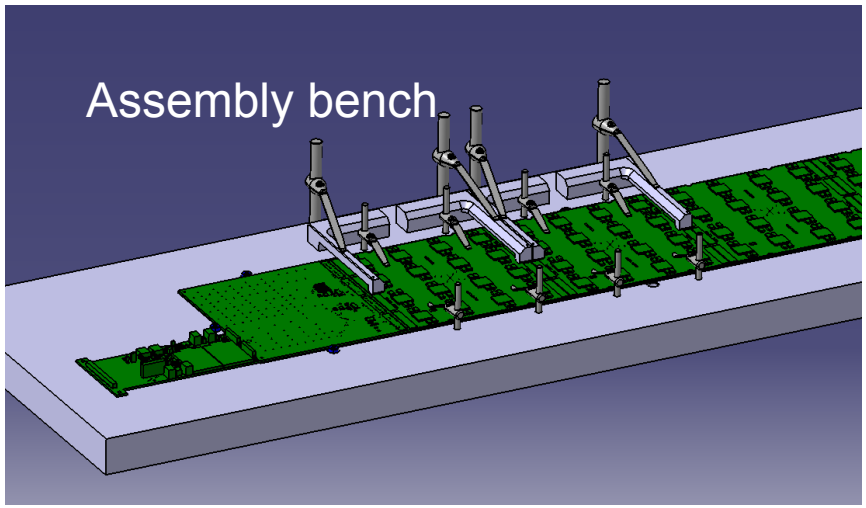
HIGHTEC SiW LC Ecal – Long layer

Testbench for electrical tests



First cradle Hosting two ASUs + SMB

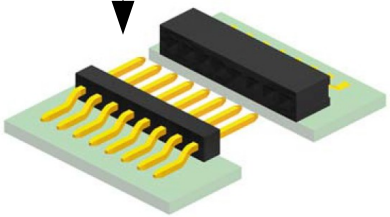




Critical item Interconnection

Flat Kapton (so far)

(Mobile phone) connectors



Will become “objet emblematique” of HIGHTEC project

Essential work for upcoming ILD Detector Document – Impossible w/o P2IO

Summary and Conclusions

- In 2017 HIGHTEC has ramped up and is now running at full speed
- All subprojects deliver first results and are on track towards deliverables
  - Several test benches are up and running
  - Validation in beam tests
  - Engineering studies beyond prototyping
  - Influence on detector design(s)
  - Algorithms (online and offline) exploiting high granularity and timing
- All three HIGHTEC PostDocs plaz leading roles in experimental program!!!
  - A. Irles selected as PRESTIGE/MSCA Fellow
- Regular communication among partners has created synergies among different branches
  - e.g. “common” front-end electronics architecture
- Beyond the actual projects the P2IO funding boosts the formation of a

  Center of excellence

  around calorimeter technology that will dominate future detectors

HIGHTEC Talks

A. Irles: “Latest R&D news and beam test performance of the highly granular SiW-ECAL technological prototype for the ILC”, Talk CHEF2017*

A. Irles: “Latest developmens on the highly granular Silicon Tungsten Electromagnetic Calorimeter”, Poster IEEE 2017*

A. Lobanov: “R&D News and beam test SiW Ecal”, Talk LCWS2017*

J-B. Sauvan: “The CMS High Granularity Calorimeter for the High Luminosity LHC », Talk CHEF2017”*

A. Lobanov: “Electronics and Triggering Challenges for the CMS High Granularity Calorimeter”, Talk CHEF2017*

N Makovec: Talk at CHEF2017*

C. Agapopoulou: Talk at IEEE 2017*

C. Allaire: Poster for HGST Symposium in Okinawa*

**Will be followed by proceedings*

HIGHTEC Publications

- The Phase-2 Upgrade of the CMS endcap calorimeter",
  CMS Technical Design Report, CMS-TDR-17-007, to be published.

- HGTD IDR in September 2017

- Paper of HGTD beam test results in preparation

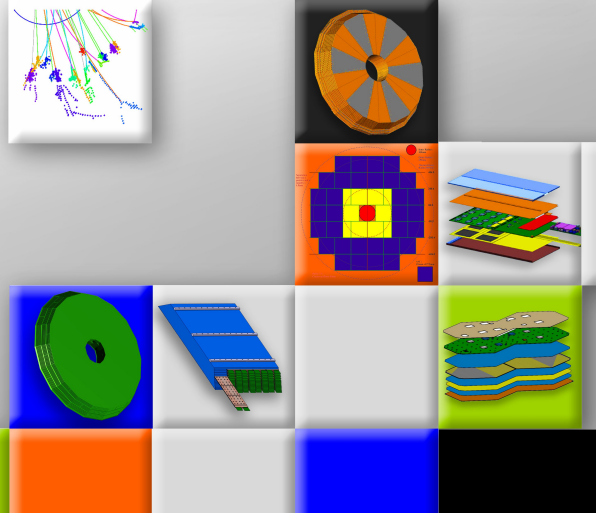
- HGTD EOI paper for LHCC end of november

- SIWLC Ecal paper on beam test results in preparation

HIGHTEC

HIgh Granularity Hybrid Timing and Energy Calorimetry

a P2IO project by LLR, LAL and IRFU



Bruno Mazoyer - LAL Orsay

Status des

Ressources Financières

Prof l de dépenses de 2016 à 2019

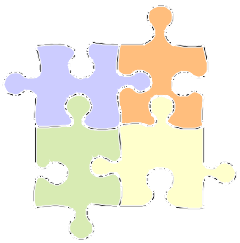
	2016	2017	2018	2019
Total Equipement:	**63.0 k€**	**0.0 k€**	**0.0 k€**	**-**
Total Fonctionnement	**66.0 k€**	**134.0 k€**	**114.0 k€**	**-**
Total Missions	**8.5 k€**	**20.5 k€**	**20.5 k€**	**13.5 k€**
Total Post-doc + ½ Thèse P2IO	**37.5 k€**	**116.7 k€**	**58.33**	**12.5 k€**
Total Post-doc X+IN2P3	**25.0 k€**	**50.0 k€**	**25.0 k€**	
LAL				
HIGHTEC SiWLC (R. Pöschl) **:**				
2- Fonctionnement	22.0 k€	50.0 k€	13.0 k€	
3- Missions	2.5 k€	5.0 k€	5.0 k€	2.5 k€
4- Post-doc	16.67 k€	50k€	33.33 k€	
HIGHTEC HGTD (D. Zerwas) **:**				
3- Missions	1.0 k€	3.0 k€	3.0 k€	1.0 k€
4- Demi-Thèse	4.16 k€	16.67 k€	16.67 k€	12.5 k€
LLR				
HIGHTEC SiWLC (V. Boudry) **:**				
2- Fonctionnement	22.0 k€	37.0 k€	25.0 k€	
3- Missions	2.5 k€	5.0 k€	5.0 k€	2.5 k€
HIGHTEC HGCAL (C. Ochando) **:**				
1- Equipement (LLR)	63.0 k€			
2- Fonctionnement	22.0 k€	47.0 k€	76.0 k€	
3- Missions	1.5 k€	4.0 k€	4.0 k€	4.0 k€
HIGHTEC SiWLC + HGCAL (V.B/C.O.)				
4- Post-doc	25.0 k€	50.0 k€	25.0 k€	
SPP				
HIGHTEC HGCAL TIMING (M. Besançon) **:**				
3 - Missions	1.0 k€	3.5 k€	3.5 k€	3.5 k€
4 - Post-doc	16.67 k€	50k€	8.33 k€	

Δ= 766 k€


Backup
Réserve

Science Drivers

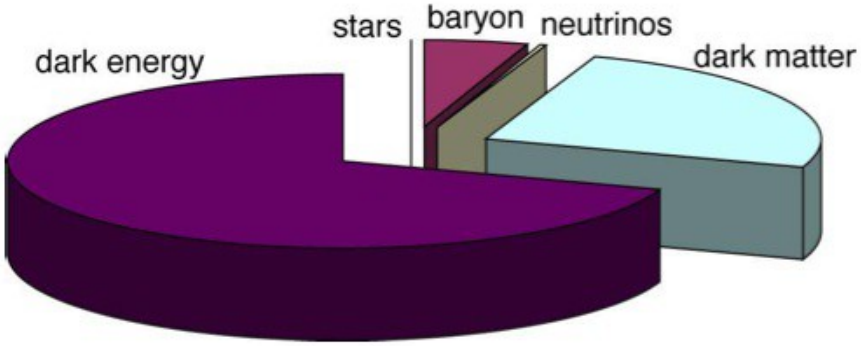
Study of the Higgs Boson



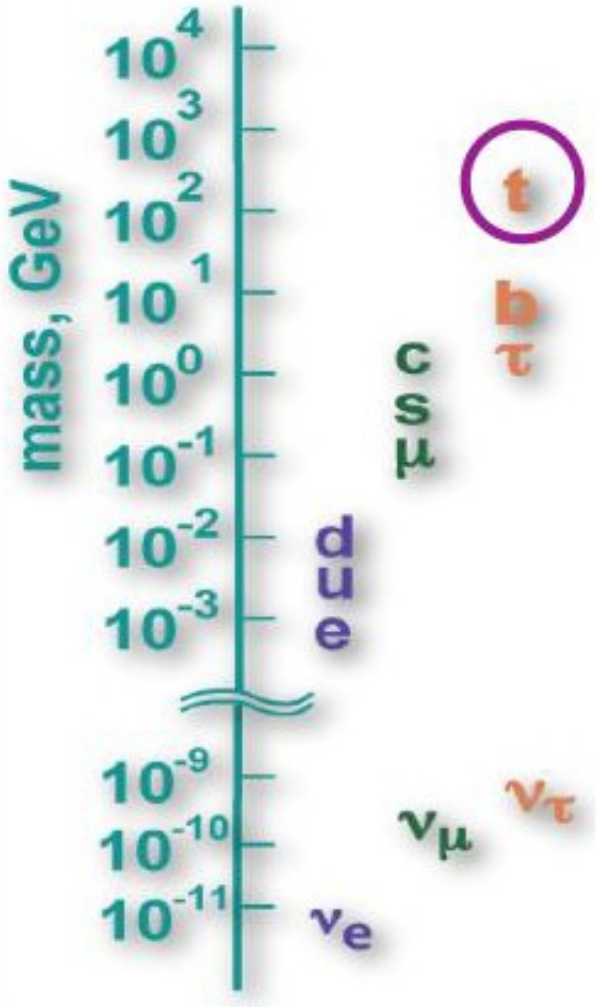
Elementary Scalar?

Composite object?

Search for new particles



Study of the flavor hierarchy



Questions to be addressed at HL-LHC and future e+e- colliders, e.g. ILC

Budget « HIGHTEC » (HGCFC) alloué le 13/04/2016 = 666 k€

+ f inancement de 2 ans de post-doc: 1 an HGCAL/HGCFC (X) et 1 an HGCFC (IN2P3)

Δ= 766 k€

Profil de dépenses de 2016 à 2019!

	2016	2017	2018	2019
Total Hardware:	**66.5 k€**	**197.5 k€**	**114 k€**	**-**
Total Missions	**8.5 k€**	**20.5 k€**	**20.5 k€**	**13.5 k€**
Total Post-doc + ½ Thèse P2IO	**37.5 k€**	**116.7 k€**	**58.33**	**12.5 k€**
Total Post-doc X+IN2P3	**25.0 k€**	**50.0 k€**	**25.0 k€**	

Projet HIGHTEC @ 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

Pour une revue complète du projet, voir:
https://dl.dropboxusercontent.com/u/43400808/P2IO_HIGHTEC_YS_160607.pptx

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

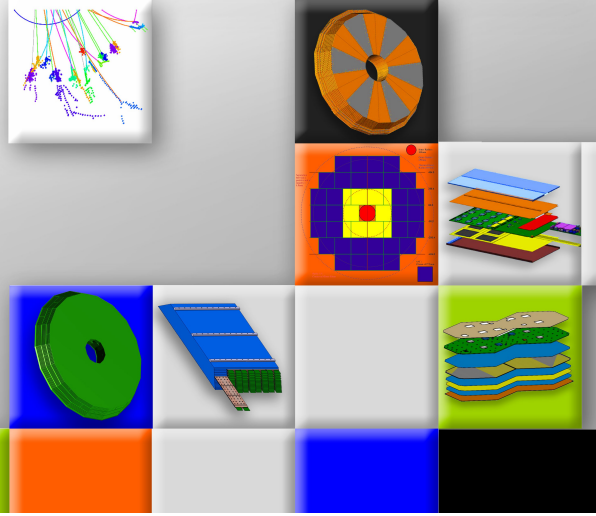
The LAL **HGTD** group project will perform essential R&D for the timing capabilities of a forward detector proposed for HL-LHC

7 June 2016

HIGHTEC

HIgh Granularity Hybrid Timing and Energy Calorimetry

a P2IO project by LLR, LAL and IRFU



Bruno Mazoyer - LAL Orsay

Nouvelles

RESSOURCES HUMAINES

Support prévu par le projet pour une ½ thèse et trois post-docs

Post-doc: HIGHTEC Test Beams SiWLC/CMS LLR

ARTUR LOBANOV

2013 – 2016: PhD in Particle Physics, *University of Hamburg*, Hamburg, Germany.
Search for gluino production in final states with an isolated lepton and b-tagged jets using 13 TeV collisions at CMS

- Research Assistant at Deutsches Elektronen-Synchrotron (DESY)
- Member of the PIER Helmholtz Graduate School

2007–2013 Specialist degree in Physics (equivalent of MSc),
Moscow State University, Moscow, Russia, *Degree with Honours*.

- **Search for supersymmetry at the LHC** (**PhD Thesis**)
  - Study of prospects of a future search for non-simplified SUSY models at 14 TeV
  - Developed a framework for a SUSY search in the single lepton final state
  - Data-driven background estimation for a multi-bin counting experiment
  - Trigger development and measurement
- **Upgrade and commissioning of the HCAL Outer (HO) detector of CMS** (**Phd Thesis**)
  - **Key participant** in the installation of the new readout electronics of the HO
  - Performance measurements and cosmic muon calibration of the SiPMs
  - Commissioning of the new HO hardware within CMS
- **Nucleon experiment ECAL** (**Diploma Thesis**)
  - Development of electron/hadron separation algorithm
  - readout electronics performance studies (test-stand, beam test, development of DAQ and DQM systems,…)

Post-doc: HIGHTEC HGCAL-Timing IRFU/SPP

MEHMET ÖZGÜR ŞAHİN

2012 - 2016: DESY Hamburg/GERMANY
Ph.D., Physics, Magna Cum Laude, Joachim Herz Fellow,
University of Hamburg, and PIER Helmholtz Graduate School

2005 - 2012: Middle East Technical University (METU) Ankara/TURKEY
MSc, BSc Physics (Special Undergraduate Program - Advanced Physics)

- **2016 - Present (CERN/DESY)**
  Upgrade of the CMS Outer Hadronic Calorimeter (HO) and Muon System trigger link

  - re-design of detector readout system of the upgraded HO to handle higher data transfer rates with improved reliability

  - FPGA design of the readout system to establish a trigger link for the first time between the muon system and HO

- **2012 - Present (DESY)**
  Design of the next generation Front-End Controller (ngFEC) of the CMS Had.Calorimeter (Ph.D.)

  - development of a new front-end readout control system for the CMS HCAL detector, using high speed (4.8Gbps) duplex links with RS error correction, redundant paths for slow controls and monitoring

  - lead designer for a new firmware for the Kintex-7 FPGA of the ngFEC motherboard (FC7 board)

- **2012 - Present (DESY)**
  Search for Pair Production of Supersymmetric Top-Quark Partners in Events with a Single Lepton using Support Vector Machines at CMS (Ph.D.)

Marc Besançon, IRFU-SPP

Post-doc : HIGHTEC SiWLC LAL

ADRIAN IRLES QUILES

2010-12/2014: PhD in particle physics by the University of Valencia.
Thesis title: "Top-quark mass measurement in the ATLAS detector at the LHC using jet rates"
http://inspirehep.net/record/1339742?ln=es

2009 Master en Fi sica Avanzada
Especialidad Fi sica Nuclear y de Parti culas. Universidad de Valencia.
Thesis title: "Estudio introductorio a la topologi a de sucesos tt+g en el Gran Colisionador Hadro nico (LHC)".

- PhD
- The theoretical proposal, study and development of a new method to measure the top-quark pole mass with high in an unambiguously def ned mass scheme.

Refs:: http://inspirehep.net/record/1225522/ and http://inspirehep.net/record/1381766

- DESY Fellow at DESY Hamburg (1/2015 – 10/2016)
- Commissioning of a power-cycled operation mode for the CALICE analogue hadron calorimeter (AHCAL) read-out electronics, and the integration of its data acquisition (DAQ) into the higher level EUDAQ framework with the goal to enable the combination of different detector types in a common test beam set-up.

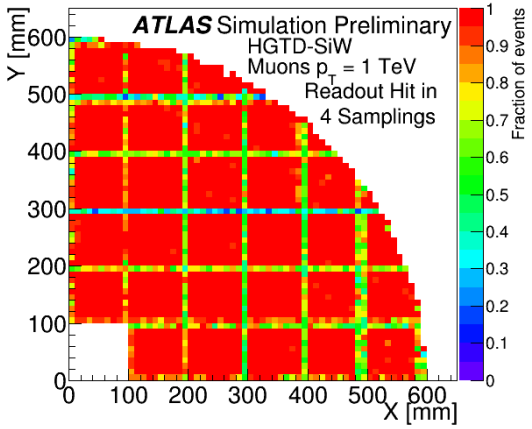
Workpackage leader on *« Common Data Acquisition and Common Testbeams »* of AIDA-2020 WP5

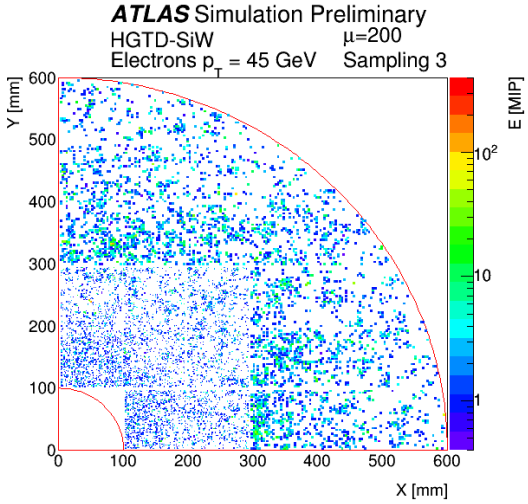
PhD Student: HIGHTEC HGTD/ATLAS LAL

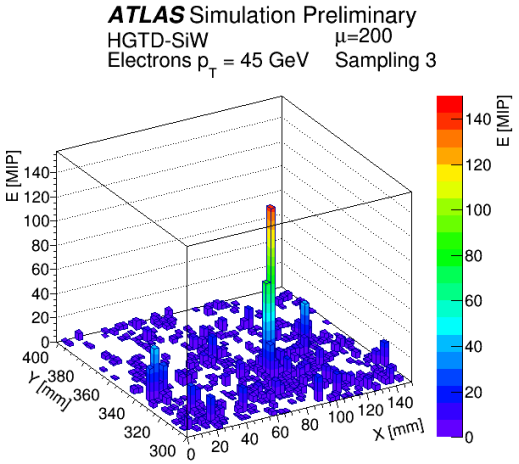
CORENTIN ALLAIRE

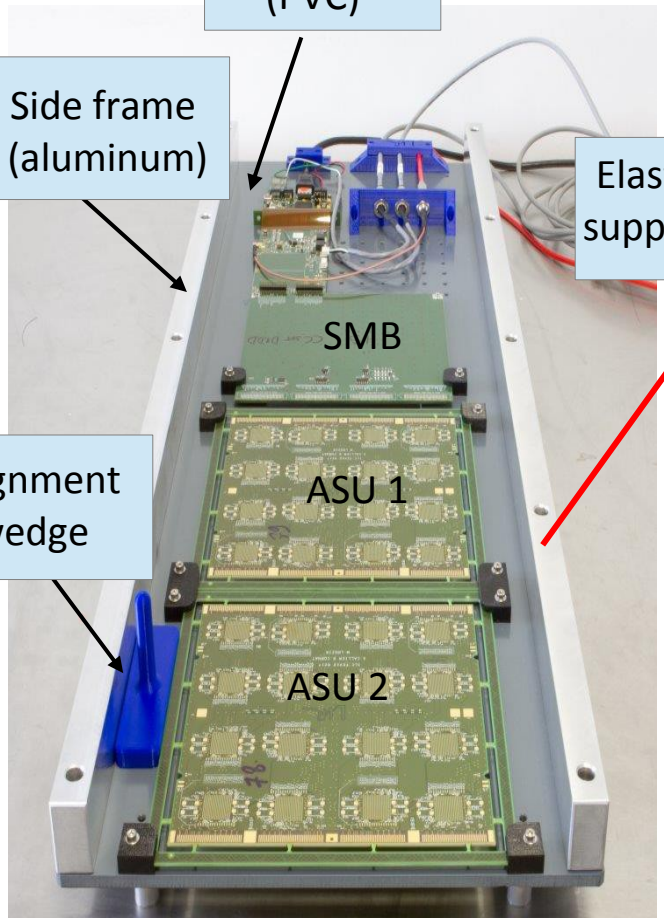
Master (NPAC):

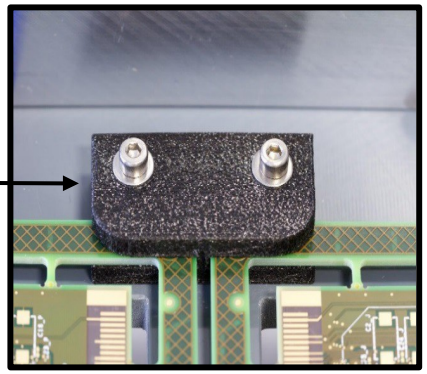
- Study of muons in simulation:
  uninstrumented zones lead to only 1% inefficiency
- Electron properties in HGTD:
  separate electron cluster from pile-up
- Testbeam analysis and simulation of timing performance
  ECFA workshop HL-LHC (Oct 2016):
  27 Simulation figures made public (20 provided by LAL)
  13 figures provided by Corentin

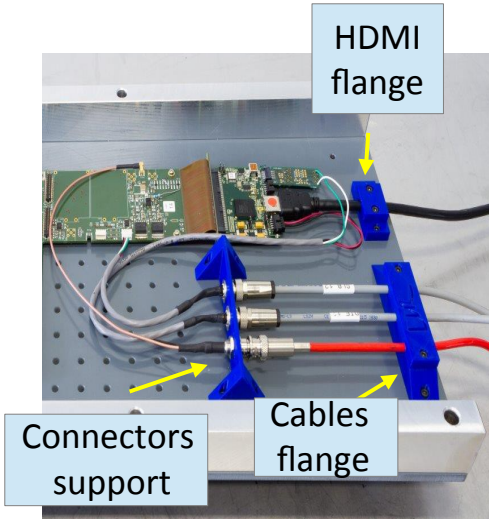


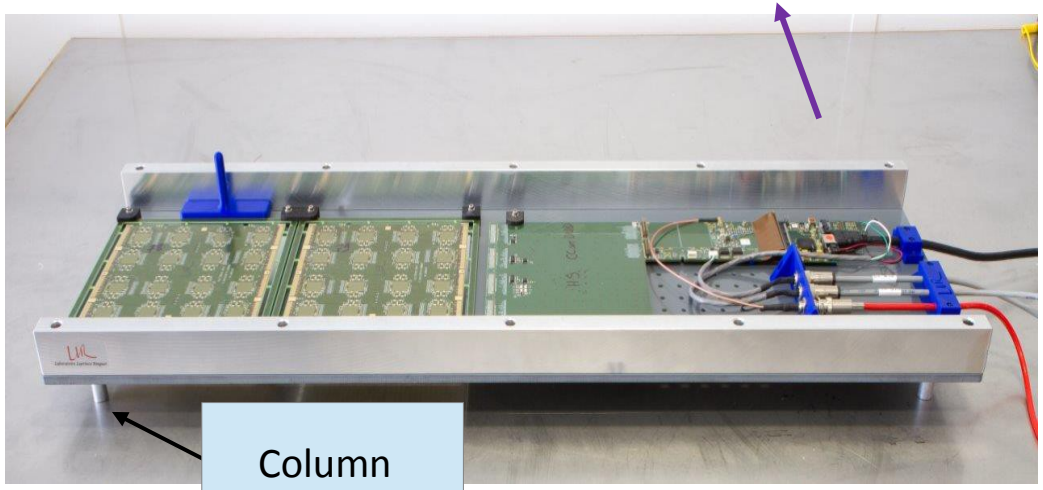





Base plate
(PVC)
Side frame
(aluminum)
SMB
ASU 1
ASU 2
Alignment
wedge


Elastic
support


HDMI
flange
Connectors
support
Cables
flange


Column
(aluminum)