Collisionneurs e^+e^-
CALICE/ILD
2013–18 and beyond

V. Boudry, F. Magniette

Conseil Scientifique du LLR
11/02/2019

e^+e^- Physics, Machines and Detectors

Team

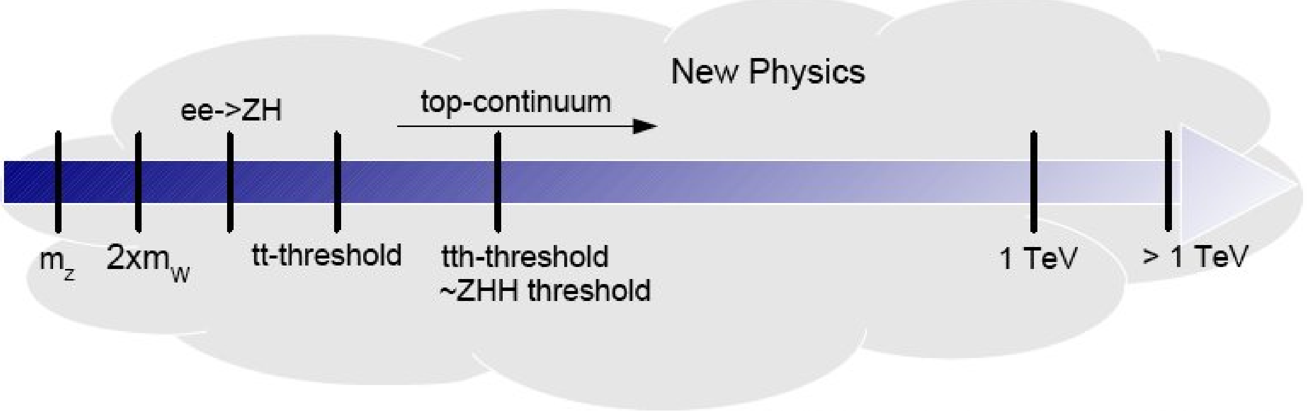
5 years of R&D

ILD design & optimisation

Prospects

e+e– physics
&
colliders

e^+e^- physics 90–1000 GeV



Continuous spectrum

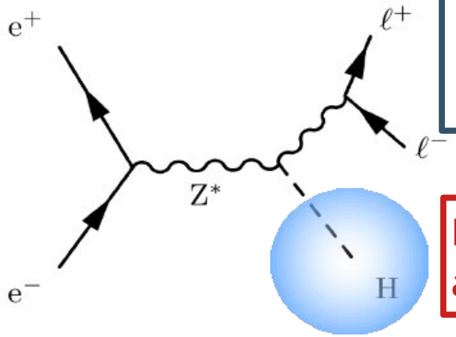
⇒ all particles available

Known initial states

- Energy (~ beam, bremsstrahlung)
  - ⇒ Energy scans (thr. WW, tt, HH, ...
- Polarisation
  - ⇒ BSM search «Background free», contact interactions

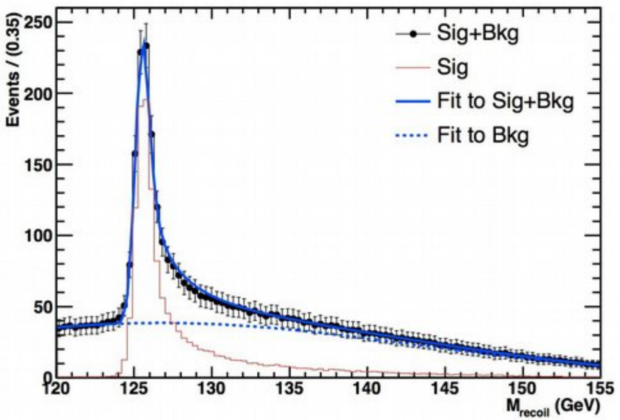
Clean final states

- low amount of data
- low corrections
- missing (E,**P**)



Well measured final states: ee, μμ

No assumption made access to H → invisible

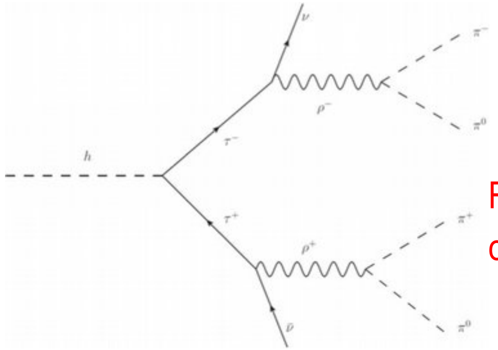


M_H from Z→μμ

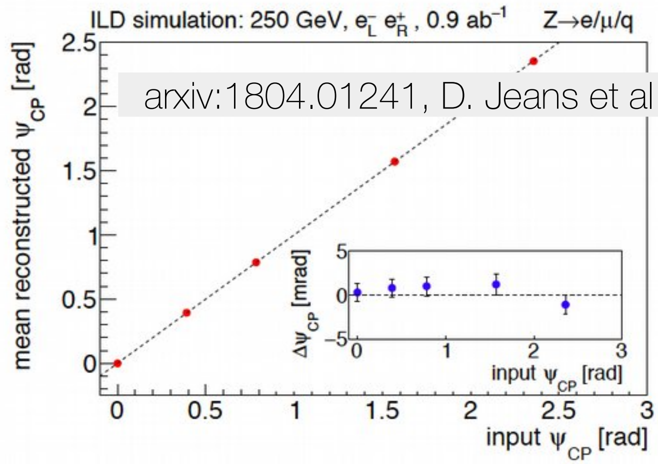
(tracker only)

Polarised physics

Higgs CP state



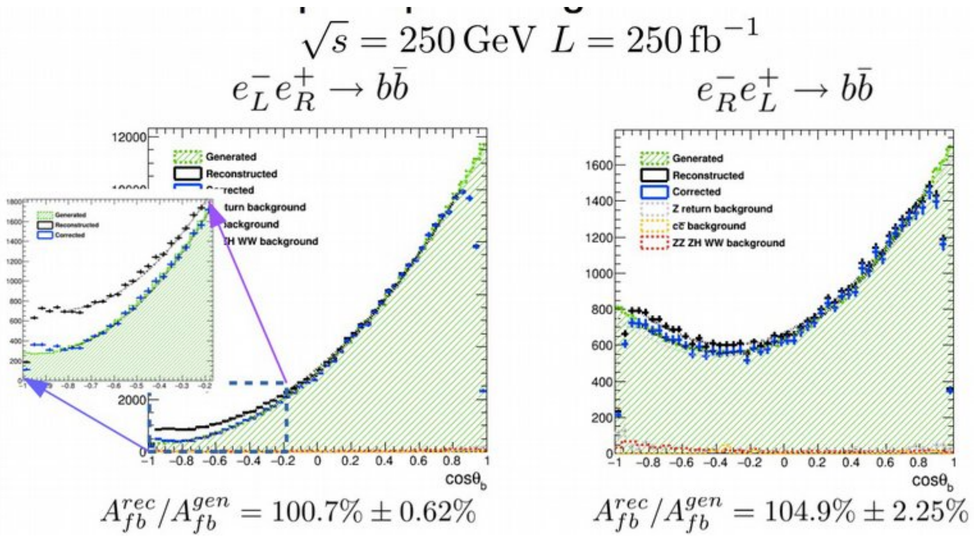
Rel. τ spin direction $\delta\varphi$ of τ's In had. τ decays



arxiv:1804.01241, D. Jeans et al.

Precise reconstruction of the CP phase ψ

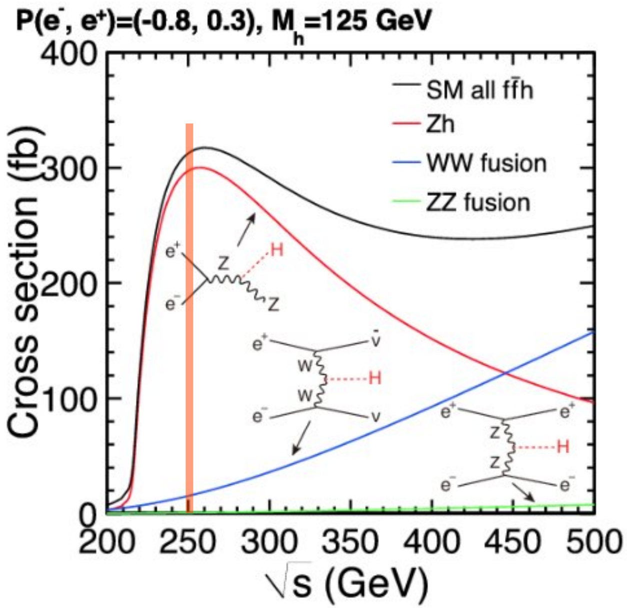
$A_{FB}(b) \to$ EW coupling to b



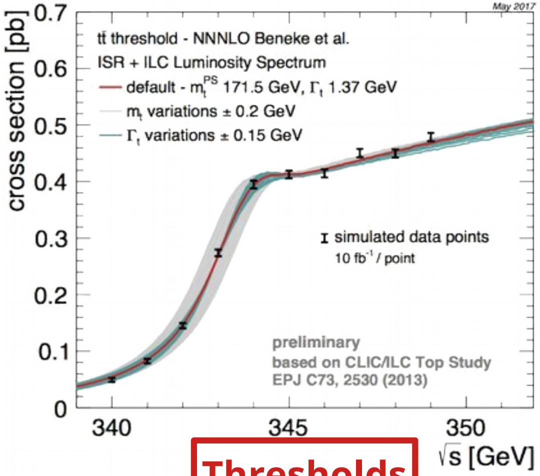
arxiv:1709.04289 S, Bilokin (LAL)

Experimental challenge: Measurement of b's charge on event-by-event basis

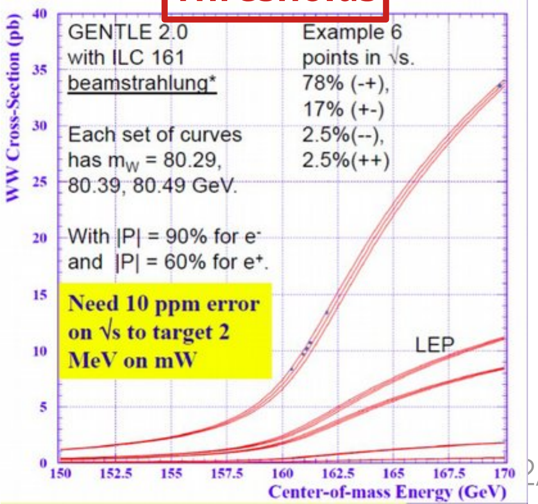
Productions

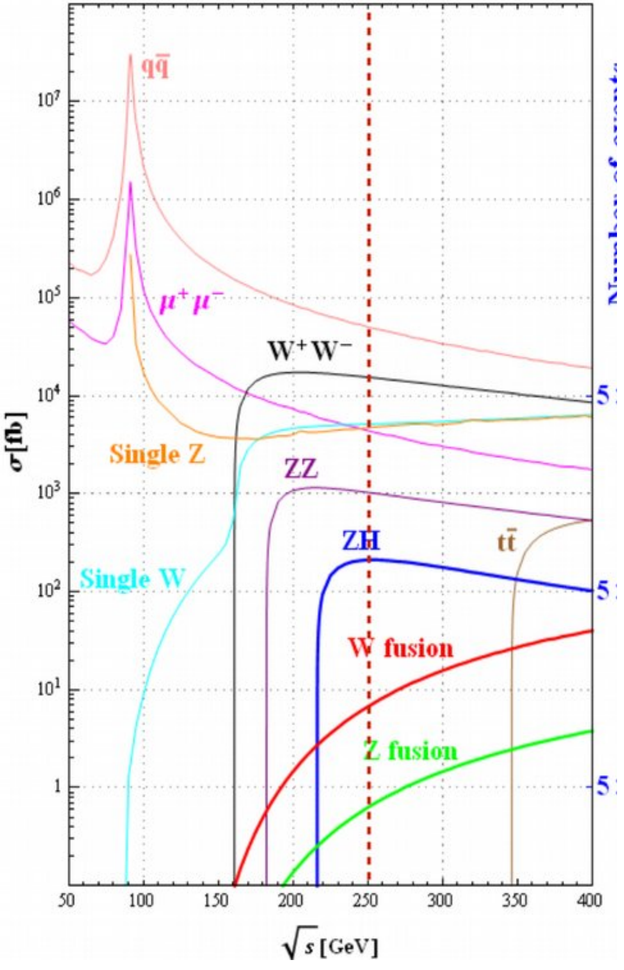


Z production



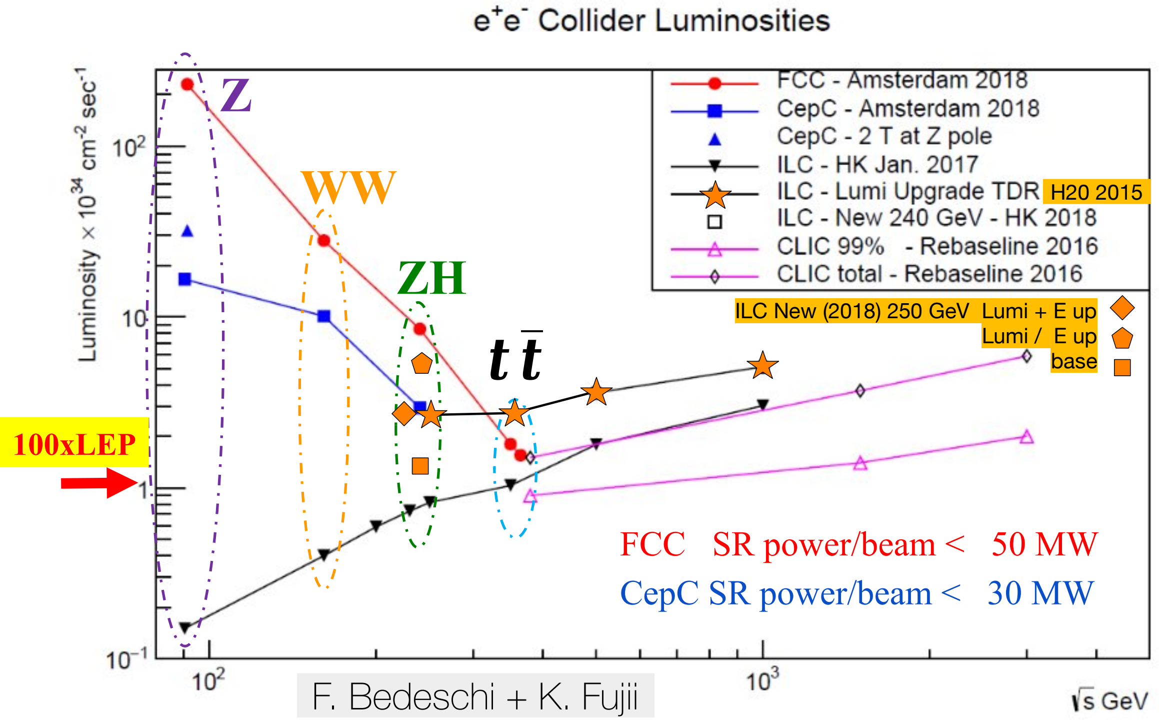
Thresholds



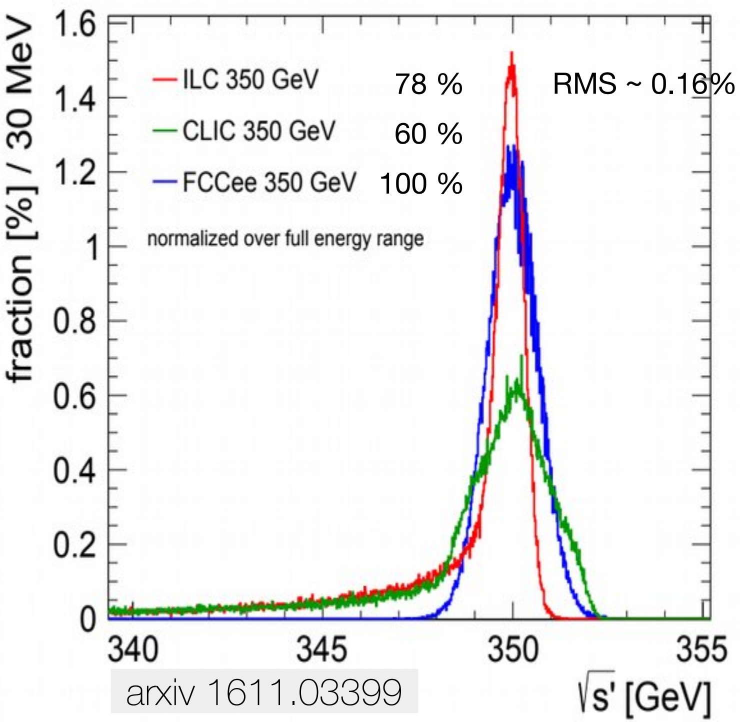


N/S ~ 10^{2-3}

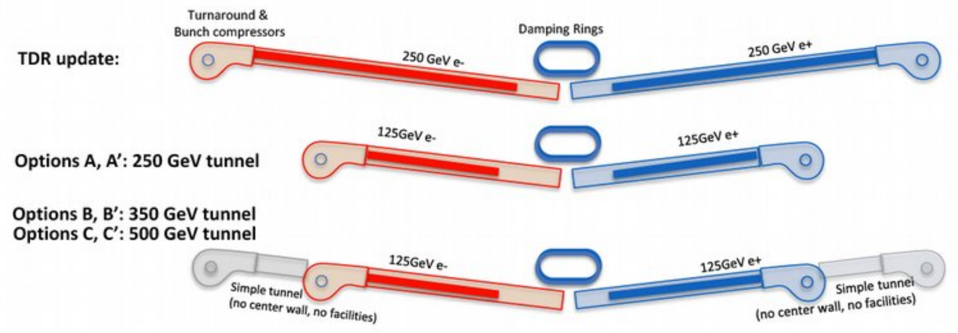
Machines e^+e^- : ILC, CepC, FCC-ee, CLIC

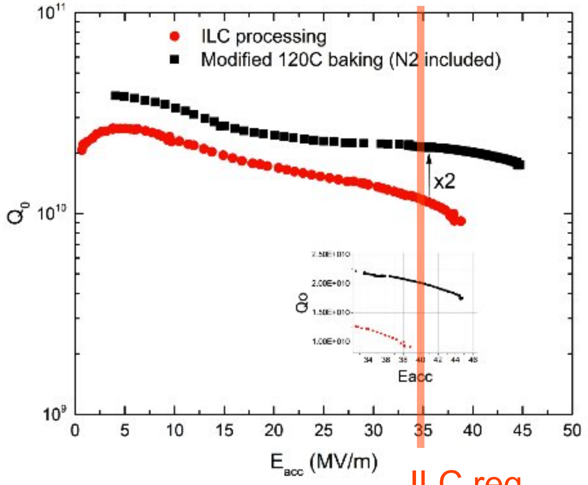


Fraction of luminosity with 99% of nom. E.



ILC Staging and options





2018/10/21

Design Luminosity

Lumi-Up = # bunches x 2

E-Up = E-Up to 500 GeV

	Base Line 1312 bunches (5 Hz)	Lumi-Up 2625 bunches (5 Hz)	(Lumi+E-Up) 2625 bunches (High Rep)
250 GeV (H20)	0.82×10^{34} (5 Hz)	1.64×10^{34} (5 Hz)	3.28×10^{34} (10 Hz)
350 GeV (H20)	1.0×10^{34} (5 Hz)	2.0×10^{34} (5 Hz)	2.8×10^{34} (7 Hz)
500 GeV (H20)	1.8×10^{34} (5 Hz)	3.6×10^{34} (5 Hz)	–
250 GeV (New)	1.35×10^{34} (5 Hz)	2.7×10^{34} (5 Hz)	5.4×10^{34} (10 Hz)

H20 numbers from arXiv: 1506.07830 with revision according to Change Request 5 (approved by Change Control Board in 2015)

250 GeV (New) numbers based on arXiv: 1711.00568

K. Fujii

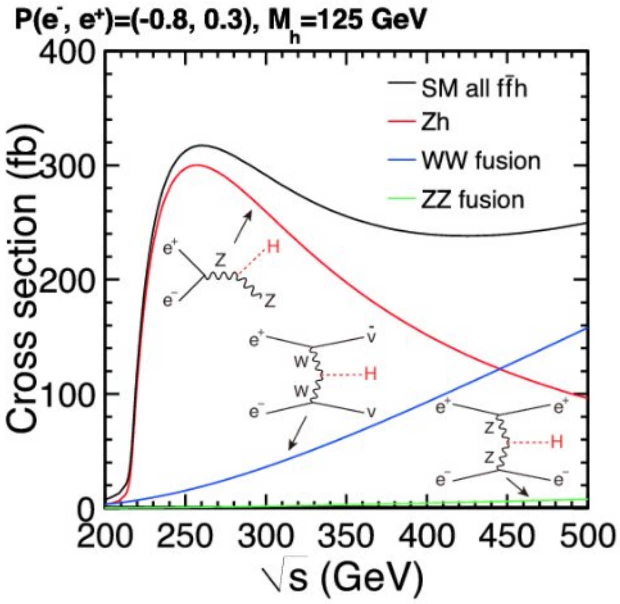
Staging scenario

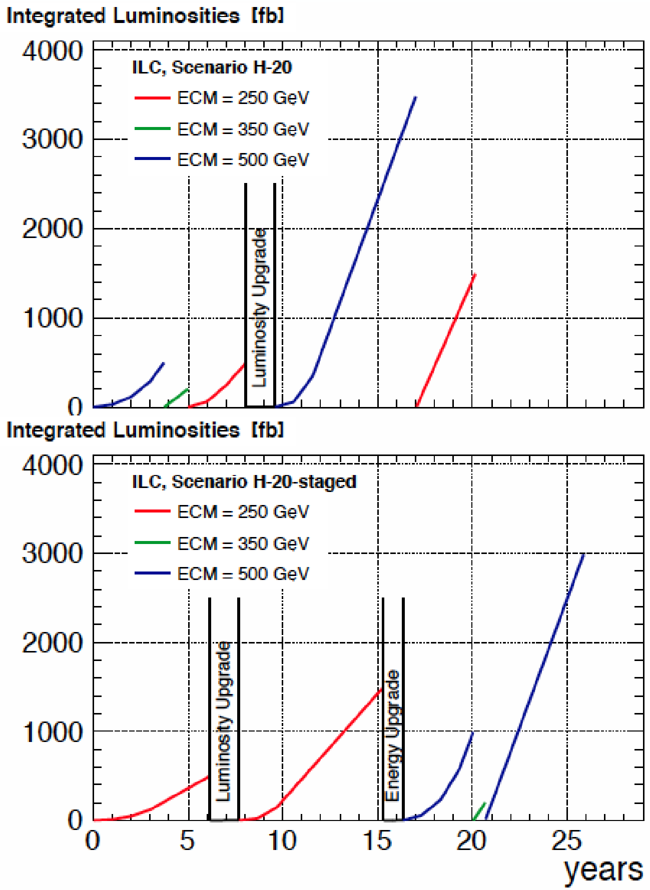
Starts at √s = 250 GeV

- no new physics @ LHC run2

opt: Higher luminosity (×1.6) by reduced $\varepsilon_{x,n}$

Polarisation : e-(80%) e+(30%)





Example of scenario change

ILC500
H20

ILC250
H20 staged

top physics starts after > 16y
in total ~ 6y longer

Performances: Higgs coupling precision

Latest results from SFITTER group

- Assuming HL-LHC ~ completed before e+e starts

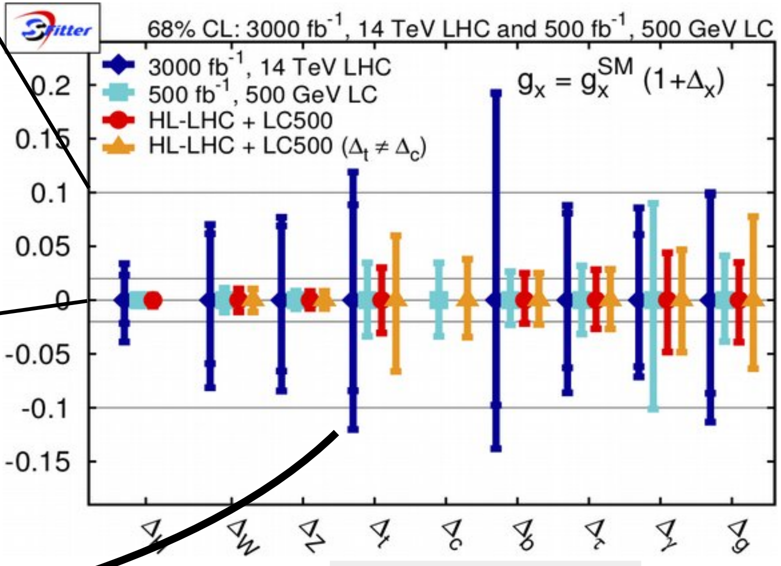
Relative precisions on Higgs couplings

G. Hamel de Monchenault @ SFP 2018-11-22

	HL-LHC	ILC		CLIC	FCC-ee		CEPC
$\sqrt{s}$ (GeV)	14000	250	+500	380	90-240	+365	90-250
L (ab^{-1})	3	2	+4	0.5	5	+1.5	5
Years	13	15	+10	7	3	+6	7
ZZ (%)	3.5	0.38	0.30	0.80	0.25	0.22	0.25
WW (%)	3.5	1.8	0.4	1.3	1.3	0.46	1.2
ττ (%)	6.5	1.9	0.8	4.2	1.4	0.8	1.4
tt (%)	4.2	–	–	–	–	3.3(*)	–
bb (%)	8.2	1.8	0.6	1.3	1.4	0.7	1.3
cc (%)	–	2.4	1.2	1.8	1.8	1.2	1.8
gg (%)	–	2.2	1.0	1.4	1.7	0.9	1.4
γγ (%)	3.6	1.1(*)	1.0(*)	4.7	4.7	1.3(*)	4.7
Γ_H (%)	50	3.9	1.7	6.3	2.8	1.5	2.6
exo (%)	–	<1.6	<1.3	<1.2	<1.2	<1.0	<1.2

Recent HL-LHC re-estimation : prec × 2 (syst ~ stat)

Relative precisions on Higgs couplings
ILC + HL-LHC

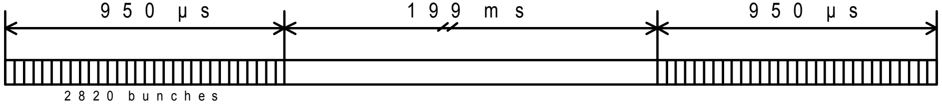


arXiv:1301.1322

ILC parameters

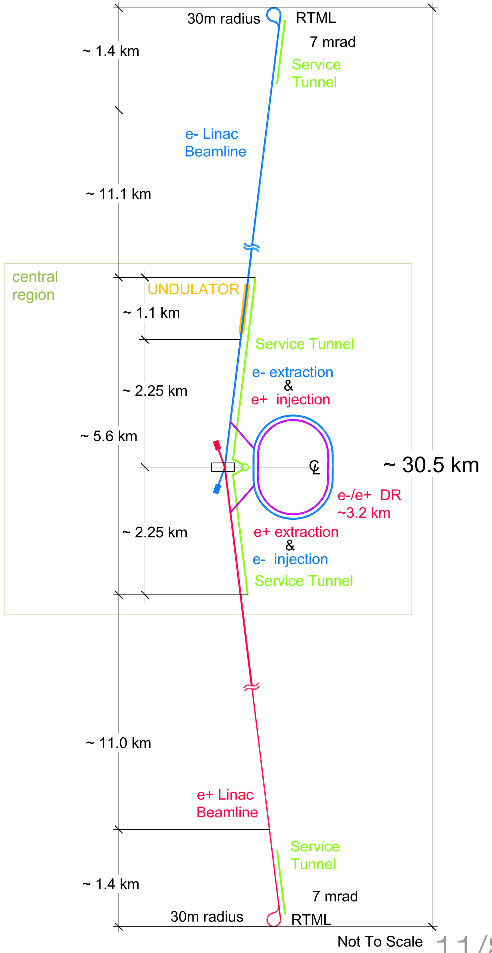
arXiv:1711.00568

Max. Center-of-mass energy	**250**–500 (1000)	GeV
Peak Luminosity	1.35×10^{34}	$1/cm^2s$
Beam Current	5.8	mA
Repetition rate	5 (–10)	Hz
Average accelerating gradient	31.5 – 35.0	MV/m
Beam pulse length	0.95	ms
Bunches per train	1312–2625	
Total Site Length	20–31	km
Total AC Power Consumption	125–164	MW



- Time between collisions : 350–700 ns
- Trains of 1300–2700 Bunches
- Low detector occupancy
- Low bgd : $e^+e^- \to qq \sim 0.1$ / BC
  $\to \gamma\gamma \to X \sim 200$ / BX

- High B field
- Trigger-less
- Power Pulsing (≤1-2%)
- Differed readout



LC @250^{+} GeV : Constraints on detectors:

Basis: sep of H → WW/ZZ → 4j

- $\sigma_Z/M_Z \sim= \sigma_W/M_W \sim= 2.7\% \oplus 2.75\ \sigma_{sep}$
  - **⇒ σ_E/E (jets) < 3.8%**

Sign ~ S/√B ~ (resol)$^{-1/2}$
60%/√E → 30%/√E ⇔ + 40% ℒ

Large TPC

- Precision and low X_0 budget
- Pattern recognition

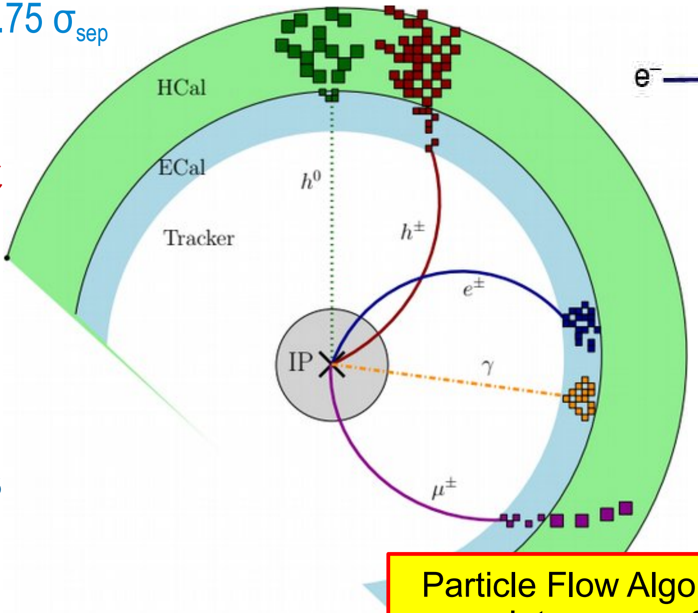
High precision on Si trackers

- Tagging of beauty and charm

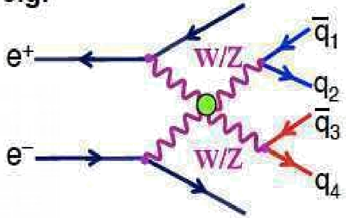
Large acceptance

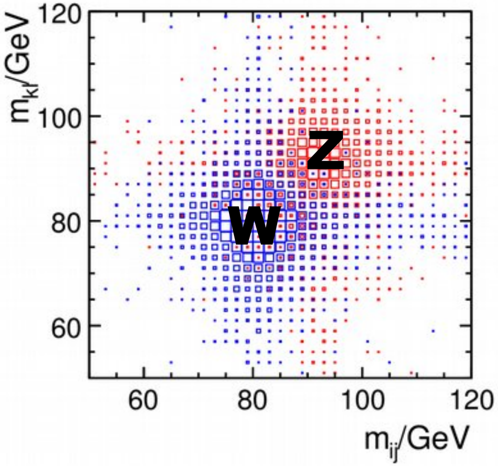
Fwd Calorimetry (lumi, veto, beam monitoring)

Imaging Calorimetry



e.g.





Photons in jets

Tau physics (γ vs π_0)

1/3 of Hadr. IA in ECAL

Particle Flow Algorithms :

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

+ timing ?

H. Videau and J. C. Brient, “Calorimetry optimised for jets,” in Proc. of CALOR 2002, Pasadena, California. March, 2002.

ILD performances

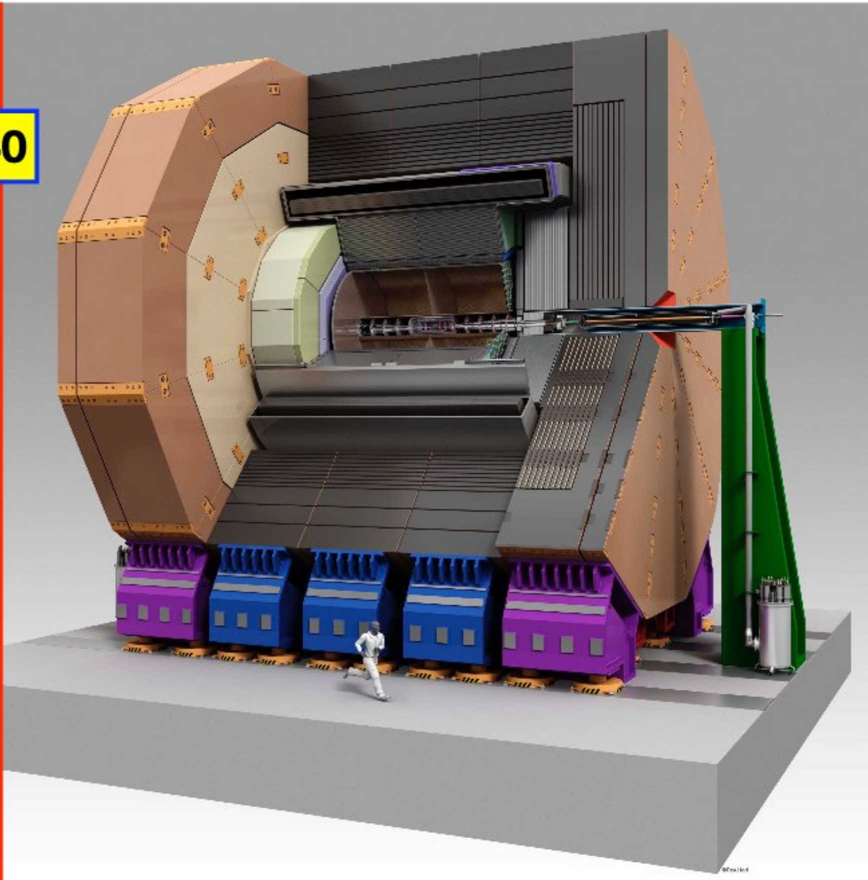
From key requirements from physics:

- **p_t resolution** (total ZH x-section)
  $\sigma(1/p_t) = 2 \times 10^{-5}\ \mathrm{GeV}^{-1} \oplus 1 \times 10^{-3} / (p_t \sin^{1/2}\theta)$
  ≈ CMS / 40
- **vertexing** ($H \rightarrow bb/cc/\tau\tau$)
  $\sigma(d_0) < 5 \oplus 10 / (p[\mathrm{GeV}] \sin^{3/2}\theta)\ \mu m$
  ≈ CMS / 4
- **jet energy resolution** 3-4%
  ($H \rightarrow$ invisible)
  ≈ ATLAS / 2
- **hermeticity** θ_{min} = 5 mrad
  ($H \rightarrow$ invis, BSM)
  ≈ ATLAS / 3

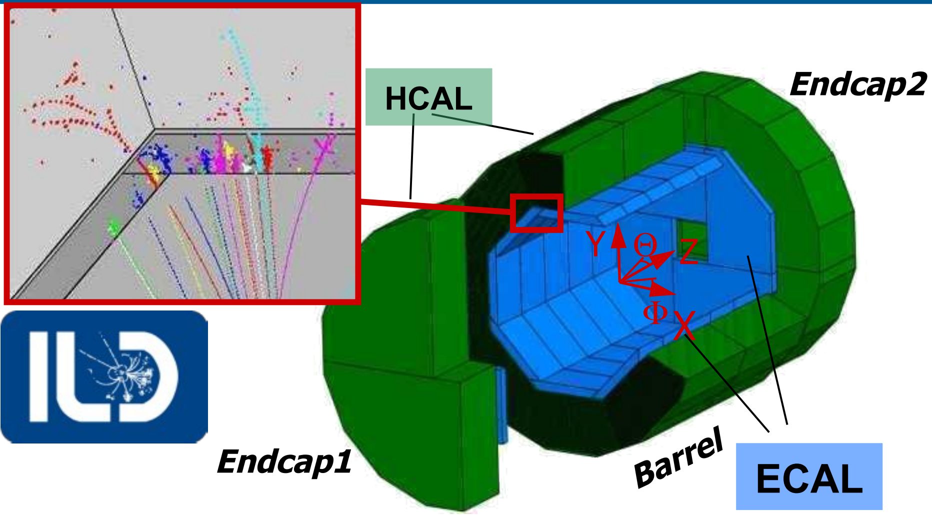
To key features of the **detector**:

- **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

J. List @ LWCS'18



An Ultra-Granular SiW-ECAL for experiments



Particle Flow optimised calorimetry

- Standard requirements
  - Hermeticity, Resolution, Uniformity & Stability (E, (θ,φ), t)
- PF requirements:
  - **High Granularity** for individual shower shapes
  - **Compactness (density)** for compacts showers

SiW+CFRC baseline choice for future Lepton Colliders:

- Tungsten as absorber material
  - $X_0 = 3.5$ mm, $R_M = 9$ mm, $\lambda_I = 96$ mm
  - Narrow showers
  - Assures compact design
- Silicon as active material
  - **Support compact design: Sensor+RO≤2mm** ←
  - Allows for ~any pixelisation
  - Robust technology
  - **Excellent signal/noise ratio: ≥10** ←
  - **Intrinsic stability (vs environment, aging)** ←
  - **Albeit expensive…**
- Tungsten–Carbon alveolar structure
  - **Minimal structural dead-spaces** ←
  - **Scalability** ←

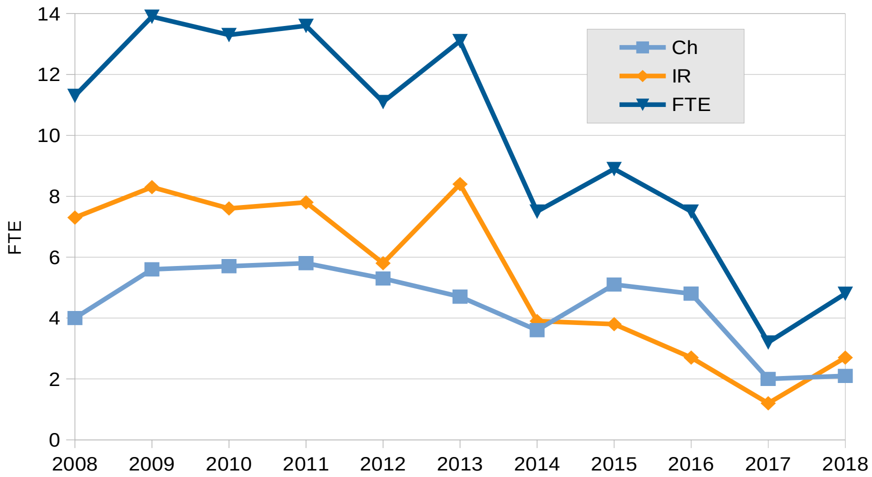
To be assessed by prototypes

+ general services: DAQ, cooling

CALICE & ILD Team

Composition actuelle du groupe

Total	**10**	**4.7 ETP**
Physiciens	**5**	**2.0 ETP**
V. Boudry	**EQUIPE***+ CALICE + **PFA**	80% Perm.
J-C. Brient	ILD + PFA	10% Perm.
H. Videau	ILD + PFA	50% Perm.
V. Balagura	ILD	50% Perm.
A. Lobanov	CALICE	10% CDD
ITA	**5**	**2.7 ETP**
Électronique	***3***	***1.6 ETP***
J. Nanni	CALICE + ILD	80% I.R.
M. Louzir	CALICE	20% A.I.
R. Guillaumat	CALICE	60% A.I.
Mécanique	***1***	***0.3 ETP***
M. Anduze	**CT ILD**	10% I.R.
E. Edy	CALICE + ILD	20% T.R.
Informatique	***1***	***0.8 ETP***
F. Magniette	**CT PROTO +** DAQ	80% I.R.
Étude Système	***0***	***0.0 ETP***

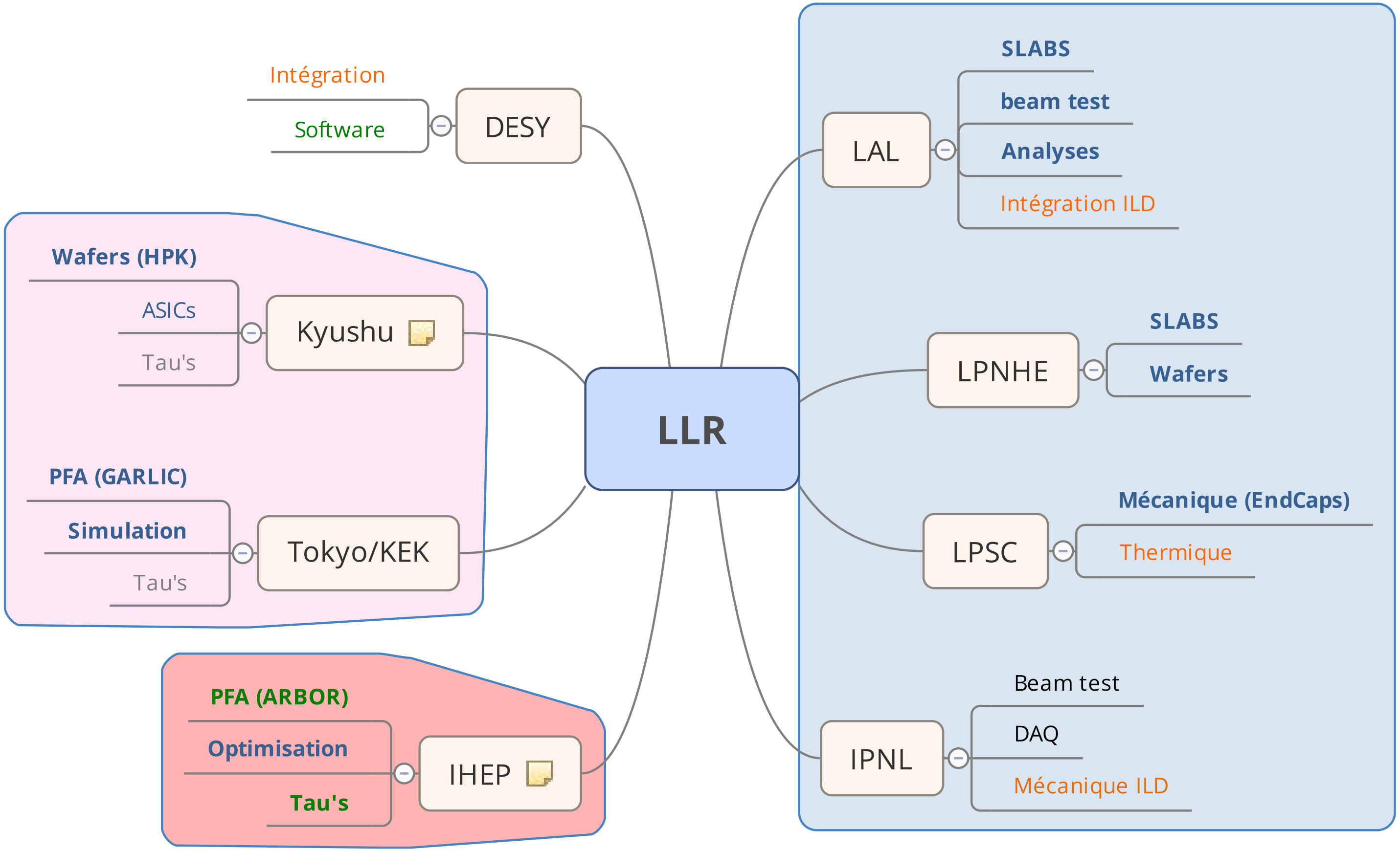


Activités actuelles à l'étiage

Transfers (5 dern années):

- SDHCAL (Méca, Analyse) ⟶ IPNL
- Simulation ⟶ IHEP (Mokka) et KEK (ECAL)
- PFA : Arbor ⟶ IHEP, Garlic ⟶ KEK
- Higgs CP ⟶ KEK
- ILD model & interfaces ⟶ LAL

Collaborations



Évolutions récentes

Permanents :

- Pas de modification ≡ aucun recrutement depuis 2012 (V. Balagura), mais V. Balagura à 50% LHCb depuis 2016

CDD:

- M. Ruan (nov 08 – jan 13)
- E. Guliyev (juil 11 – juin 13)
- T.H. Tran (Oct. 11 – Fev 14,
  6m @ CERN [HGCAL]
  Oct. 14–Oct 15)
- N. van Der Kolk (30 % LLR) : (Sept 13 – Sept 15)
- B. Li, (jan 16 – juin 17)
- A. Lobanov (sept 16 – mai 19, ~25% CALICE)

Thèses:

- Yacine Haddad (2011–2014) [dir. V. Boudry]
- Jean-Baptiste Cizel (2014–2017) [dir. R. Cornat]
- Dan Yu (2014–2018) [cotutelle LLR-IHEP, dir V. Boudry & M. Ruan)
- Konstantyn Shpak (2014–2018) [dir V. Balagura]
- Pas de thèse en 2018

Étudiants:

- ⟨2–3 étudiants/an⟩
  - L3–M2 ⊗ X : Prog internat'l, PRL, PSC, ...

Organisation & Responsabilités

Contrats : EUDET, ANR DHCAL, P2I, FJPPL, FCPPL, (ANR CALIIMAX), AIDA, AIDA-2020, P2IO HiGHTEC

- **V. Boudry**
  - Admin : budget, contrats, rapports, …
  - 'Contact' CALICE SiW-ECAL (⊃ Editorial board)
  - Analyse CALICE, outils PFA
- **F. Magniette (rempl. R. Cornat)**
  - Tech Coord. CALICE SiW-ECAL
- **J.C Brient**

  Coord. ILD SiW-ECAL
- **M. Anduze**

  Tech Coord. ILD SiW-ECAL
- **V. Balagura**

  Contact ILD ; analyse CALICE
- **H. Videau**

  ILD Exec Team (Elected) / Optim. design / **Costing**

F. Magniette →
- J. Nanni
- E. Edy
- F. Gastaldi
- M. Louzir
- R. Guillaumat

H. Videau →
- M. Anduze
- F. Magniette
- T. Pierre-Émile

Visibilité et rayonnement

Conférences, Workshops et Séminaires (Perm, CDD et doct., IR):

- 2013: CHEF'2013 (D. Jeans*, M. Ruan*, Y. Haddad*,H, Videau*), MPGD'13 (Y. Haddad), LCWS'13 (Y. Haddad, T.H. Tran, V. Balagura), TWEPP'13 (F. Magniette)
- 2014: TIPP'14 (V. Boudry, F. Gastaldi), TWEPP'14 (J.B. Cizel), LCWS'14 (V. Balagura), CEPC WS'14 (V. Boudry)
- 2015: EPS-HEP'15 (R. Cornat, V. Balagura), CHEP'15 (F. Magniette)
- 2016: ICHEP'16 (T.H. Tran, K. Shpak), CHEP'2016 (M. Rubio-Roy), 7e Coll. Interdisc. Instru (M. Anduze), LCWS'16 (T.H. Tran)
- 2017: CHEF'2017 (V. Balagura*, T. Pierre-Emile*, K. Shpak*, J.C. Brient, F. Magniette), INSTR'17 (V. Balagura), LCWS'17 (A. Lobanov), CEPC WS (J.C. Brient)
  Sem japon : U. Kyushu + U. Tokyo + KEK (J.C. Brient, J. Nanni)
- 2018: CEPC EU WS (V. Boudry), LCWS'18(V. Boudry), CEPC Int. WS'18 (J.C. Brient)
- 2019 : VCI (F. Magniette)

* Présentations plénières

Highlights récents:

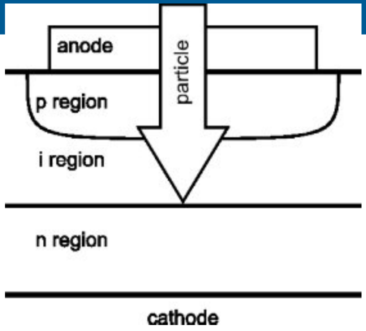
- Dec 2017, J.C. Brient, « Advanced Technology For ILC Calorimeters», KEK & Kyoto
- Jan. 2018, V. Boudry, « Silicon Tungsten Calorimetry », IAS HKUST, HEP'2018

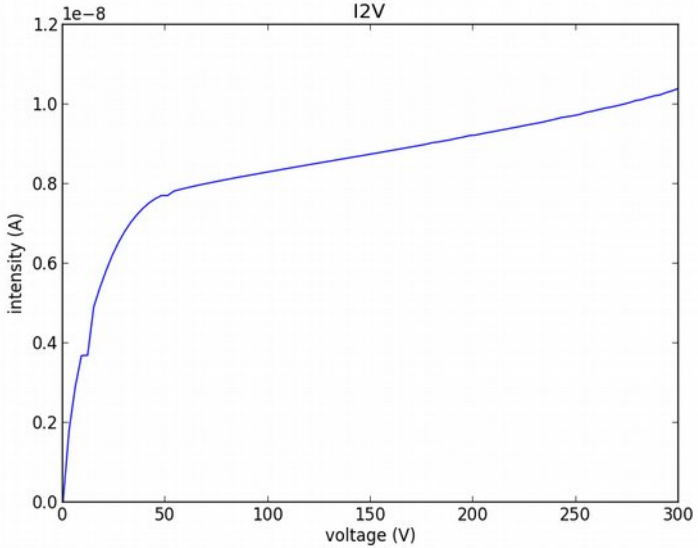
Accueil de la réunion annuelle de la Collaboration CALICE 2017: sur le campus, 3 jours, 70 pers.

5 dernières années de R&D

Silicon Detector

- Sampling Calorimeter
- Based on silicon PIN diode (pixelated wafer)
- Inverse polarisation voltage
- Leakage ~0.5nA
- Depletion zone: trade-off
- 1 MIP = 25000 e- (for 320µm)
- Target : 750µm
- 6 inch vs 8 inch

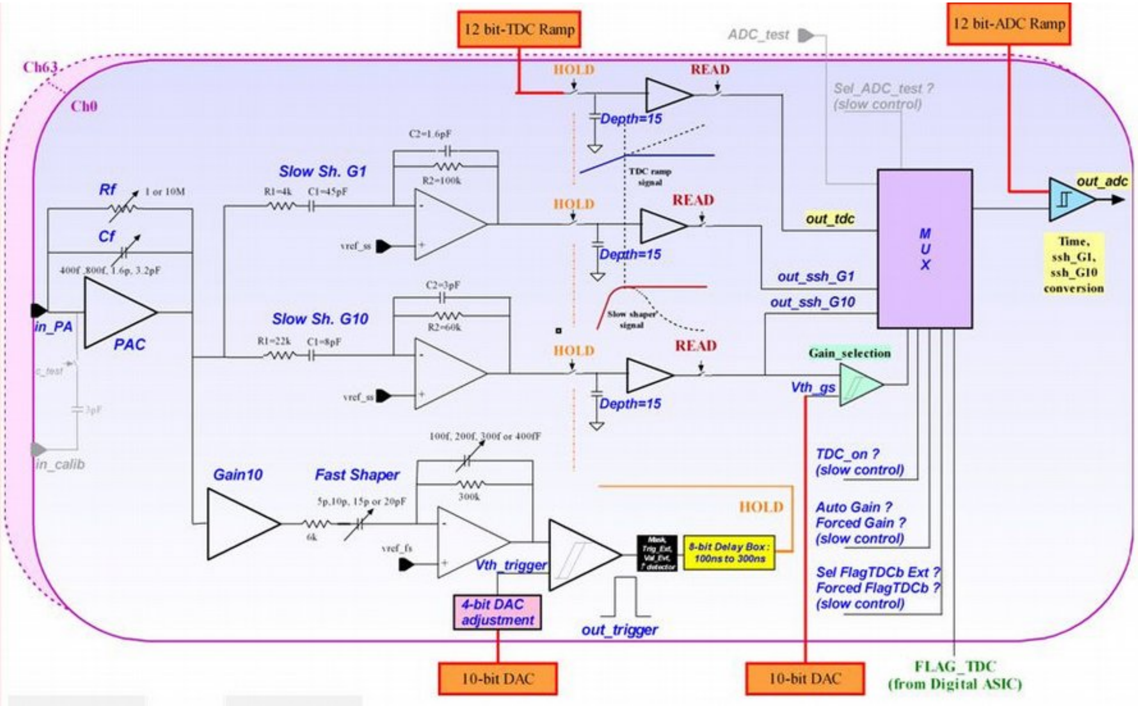




Produced by Hamamatsu Photonics

Skiroc 2 (a) ASIC

- 64 channels - Internal trigger – 15 memories
- Packaged in BGA for thickness
- Power-pulsed
- AMS 0.35

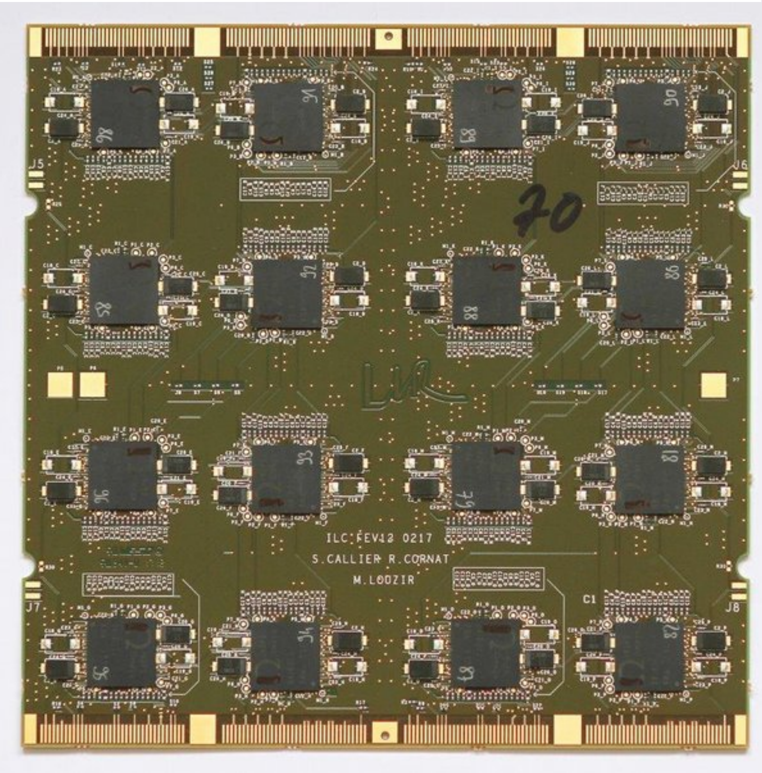


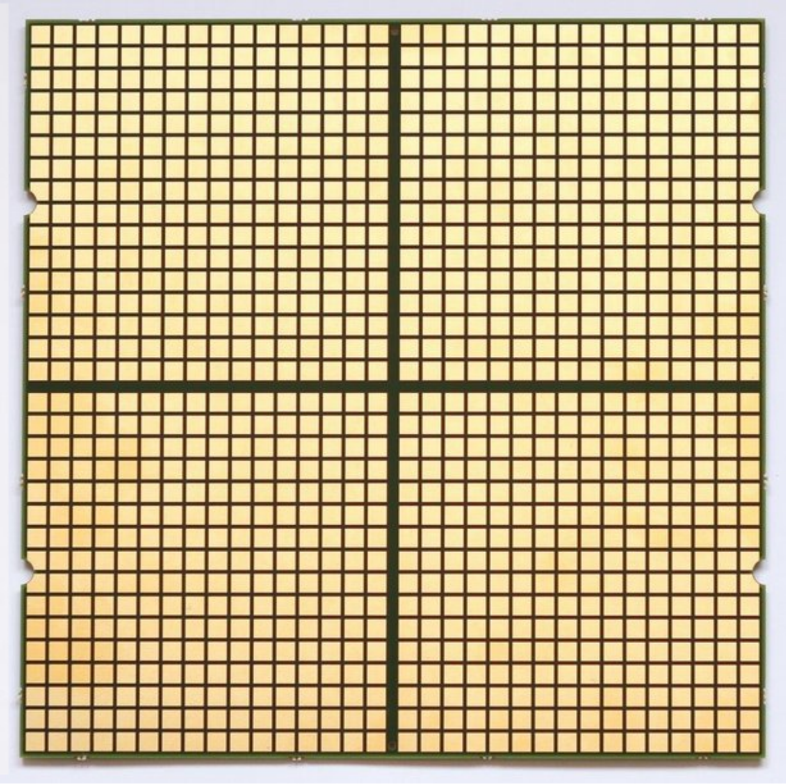
Designed by S. Callier @ OMEGA

ASU version 11

- Electronic card handling the reading ASICs and the wafer
- Version 11 2014-2015
- Nominal integration level
- 16 skirocs 1024 channels in 180x180 mm²
- Mechanical precision 20µm
- Interconnections for daisy chaining

Designed by R. Cornat, M. Louzir and S. Callier

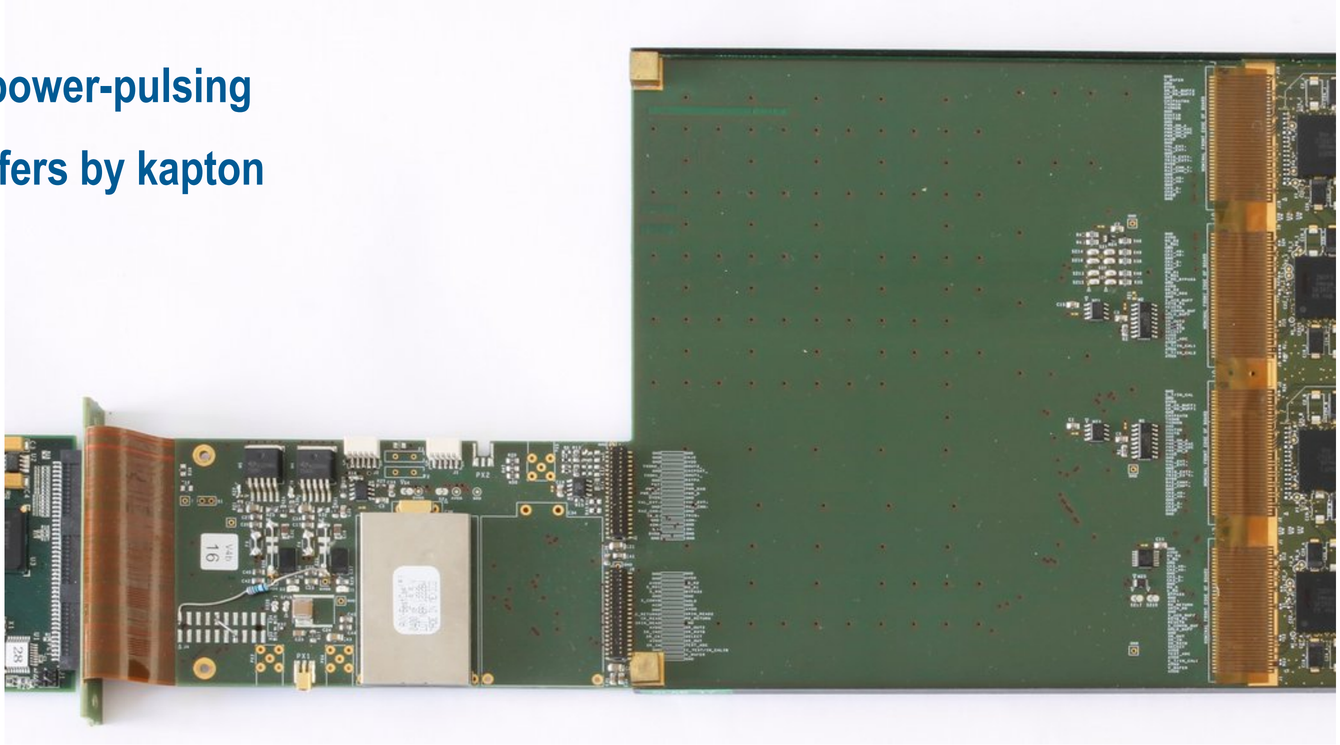




SMB : adaptating card

- Provides power supply to ASUs
- Drive the data to DAQ
- Handle the capacitance for power-pulsing
- Connect High-voltage to Wafers by kapton

Designed by
R. Cornat & M. Louzir



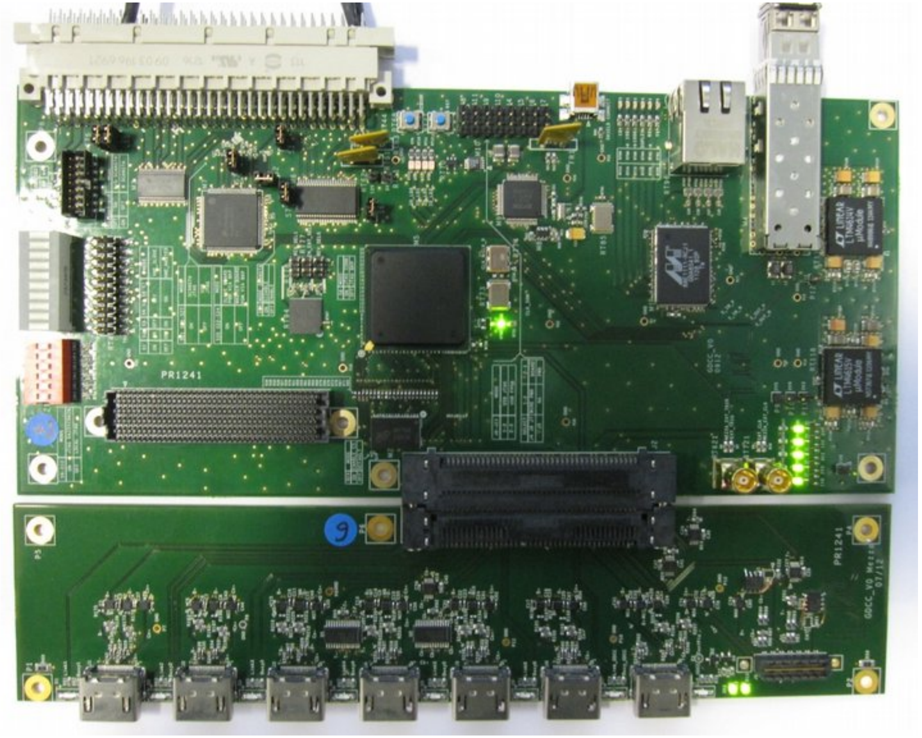
Detector interface DIF

- Dispatch configuration to Skiroc ASICs
- Gather data from ASICs
- Multi-ASIC
- Credit card size
- Old card : need refactoring
- First design by University of Cambridge,
- Adapted for Wagasci

Firmware by R. Cornat, J. Nanni & Y. Geerebaert

Gigabit Data Concentrator Card (GDCC)

- Aggregate data from DIFs (up to 9)
- Send data to gigabit ethernet network (Copper or Fiber)
- Fan-out the clocks and control signals from CCC
- Fully developped at LLR
- Possibility to add an intermediate level of aggregation (DCC)
- Used on Wagasci



Designed by F. Gastaldi

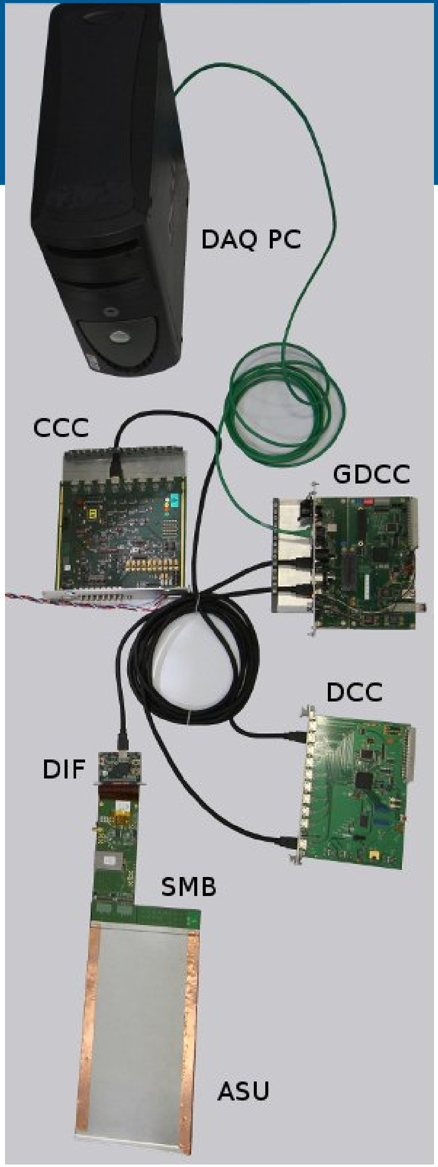
CCC

- Clock and Control Card
- Generate and fan-out commands for all detector
- Generate the clocks (FPGA internal clocks + machine emulation)
- Old card, will be replaced by a z-board
- Designed by UCL University
- Adapted for common Testbeam with SDHCal

Full DAQ

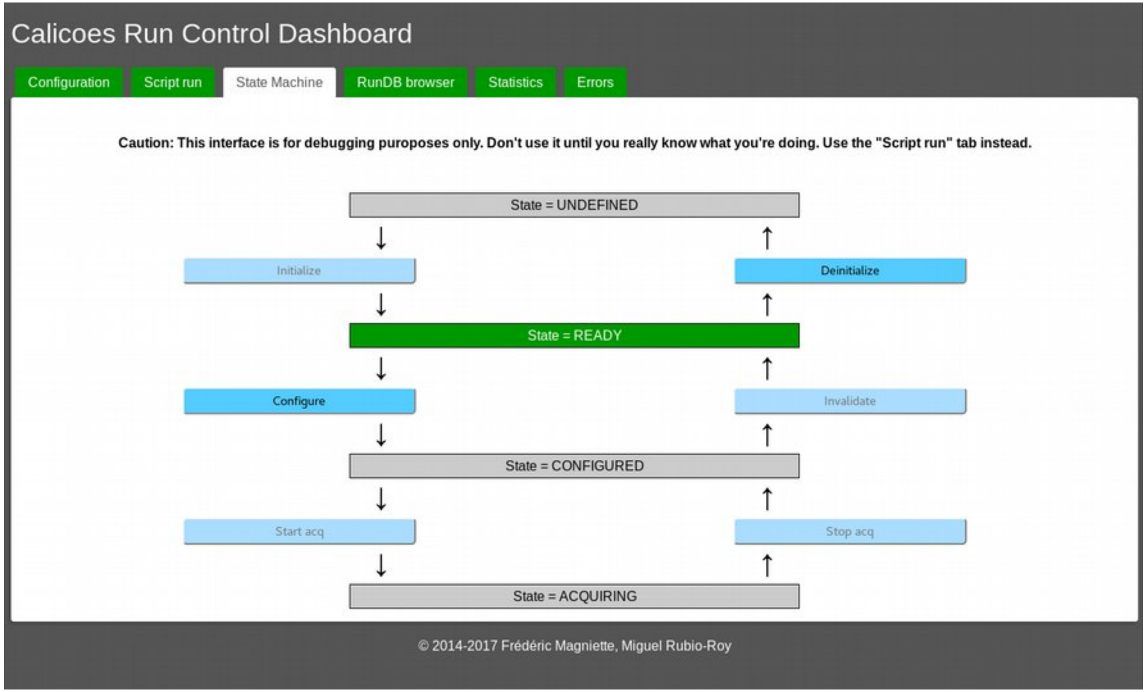
- **Slab = ASU + SMB + DIF + Hood**
- **Low speed DAQ : adapted to ILC timing**
  - 5 or 10 Hz trains
  - 1 ms for 2700 bunch crossings
  - Bad timing for testbeams
- **Cables**
  - HDMI from DIF to GDCC
  - Ethernet from GDCC to PC

Published in TWEPP'13 & TIPP'14



Calicoes software

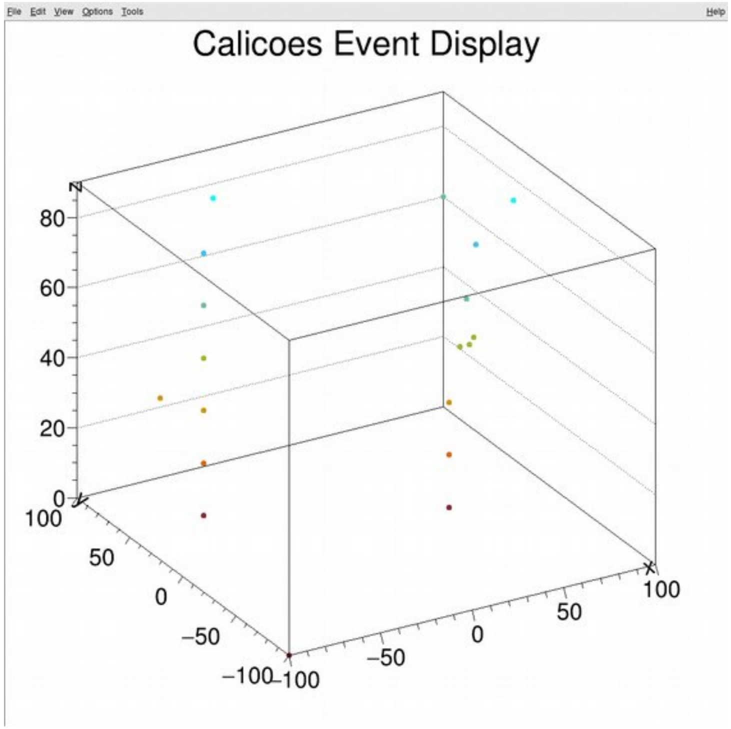
- Based on Pyrame framework
- Allows to configure and run the detector
- Collect and store data
- online stats & monitoring
- Web interface
- Used by Wagasci, HGRoc benches, Pepites

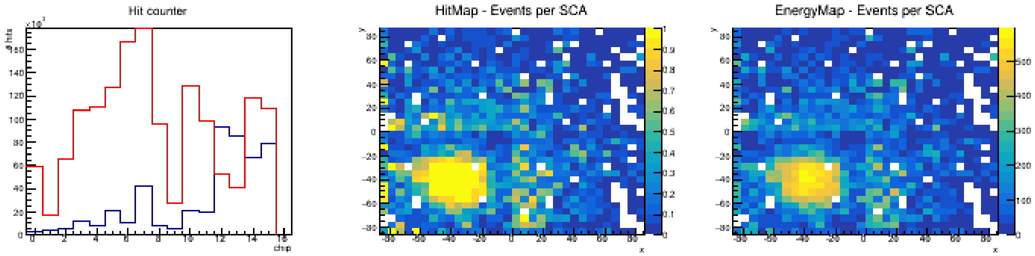


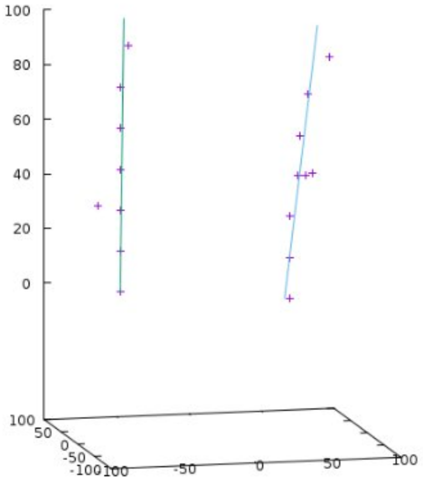
Designed by
F. Magniette & M. Rubio-Roy

Online monitoring

- **Decode and plot data in real-time**
- **Automatic and self-adjusting sub-sampling**



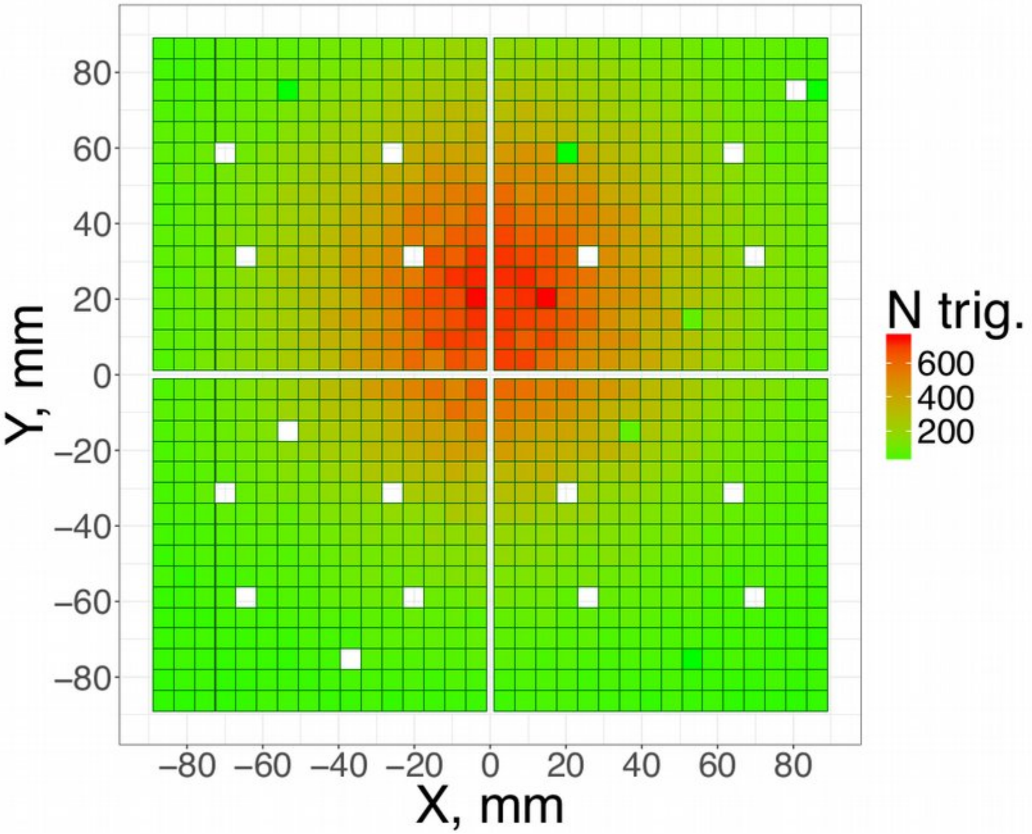




Designed by A. Irles & F. Magniette
Published in CHEF'17

Online / Offline graphical analysis tool

- **RAW data conversion**
- **Automatic pedestal suppression**
- **Graphical interface**
- **R-analysis module**
- **Multiple display available**
- **Can be extended by root analysis**



Designed by V. Balagura

Short slabs stack prototype

- **Up to 10 short slabs (1 ASU)**
- **Mechanical structure with tungsten plate slots (24 X_0)**
- **Patch-panel for Power-supplies**

Designed by M. Frotin, R. Cornat & J. Nanni

Testbeams

- **12/2012 : ASU 8 @ DESY :** New DAQ system, first full slab testbeam
- **07/2013 : ASU 8 @ DESY :** New configuration system, Full scans
- **11/2015 : ASU 11 @ CERN :** first test of ASU11 on plateau
- **06/2016 : ASU 11 slabs @ CERN :** first test with ASU11 slabs, common with SDHCal
- **06/2017 : ASU 11 @ DESY :** first test with 7 layers with ASU11, scans and calibrations
- **07/2018 : ASU 11+13 + long slab @ DESY :** first test with ASU13 layers, first test with long slab
- **09/2018 : ASU 11+13 @ CERN :** high intensity for ASU11/13 stack, common with SDHCal

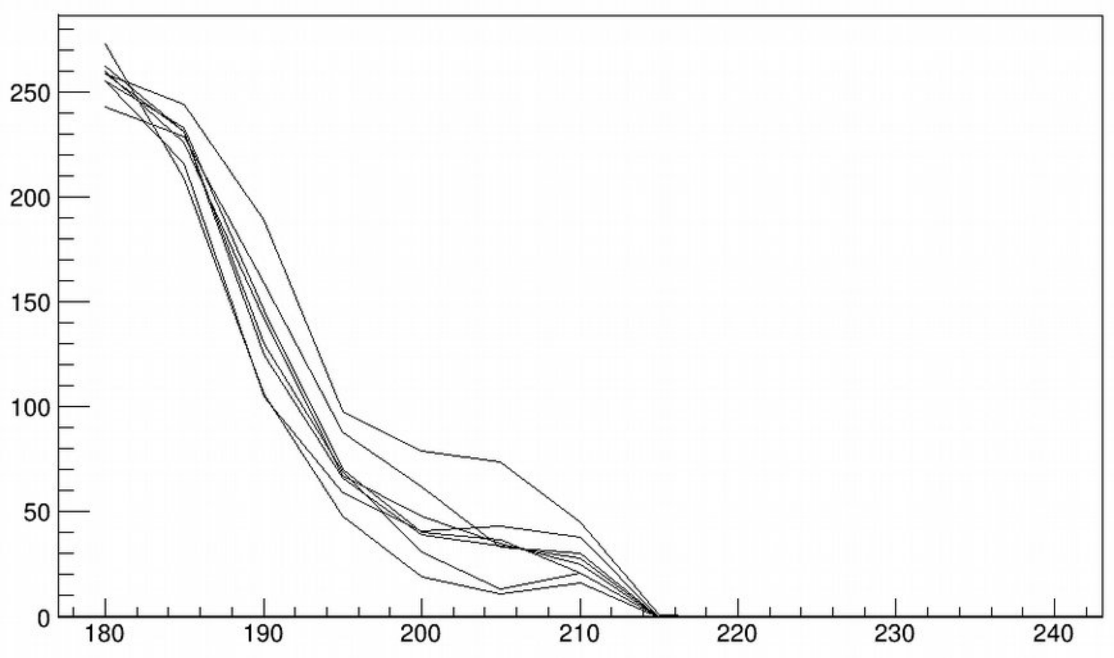
TB 2017 @ DESY

- **First fully operational version of stack with nominal integration level**
- **Program**
  - Configuration
  - Pedestal uniformity test
  - MIP calibration
  - Energy scan with 3 W configuration
  - MIP calibration at 45°
  - Tests in B field

Submitted to NIM

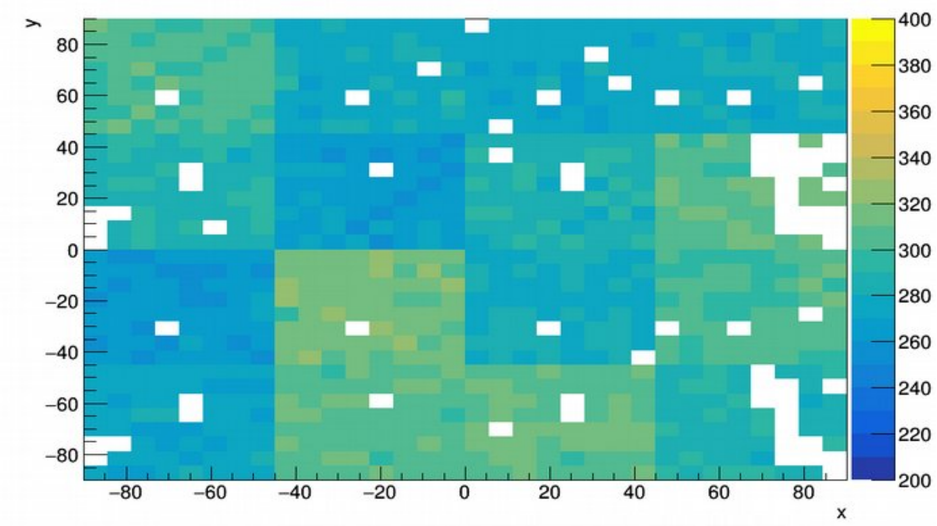
Configuration

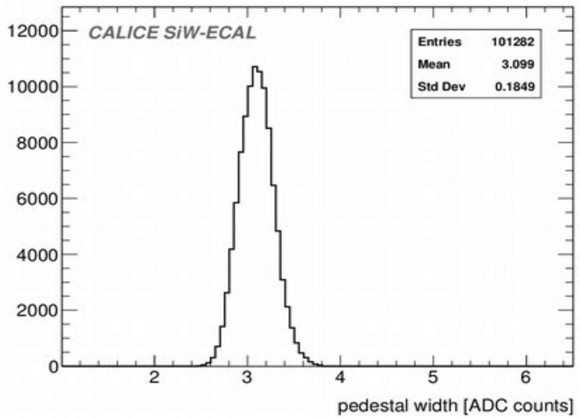
- Removal of noisy channels
- Adjustment of trigger threshold (by chip) by S-curves
- Quality passport for each slab
- Producing a configuration file for the whole TB
- Very stable in time (years)
- 8% of masked channels



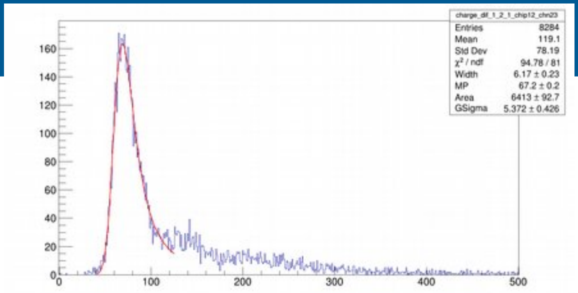
Pedestal uniformity and dead channels

- Spread in pedestal uniformity
- Little dispersion
- Chip effect
- No geometrical effect
- Pedestal shift along memories
- 8% of dead channels
- Systematics in dead channels
- Channel 37



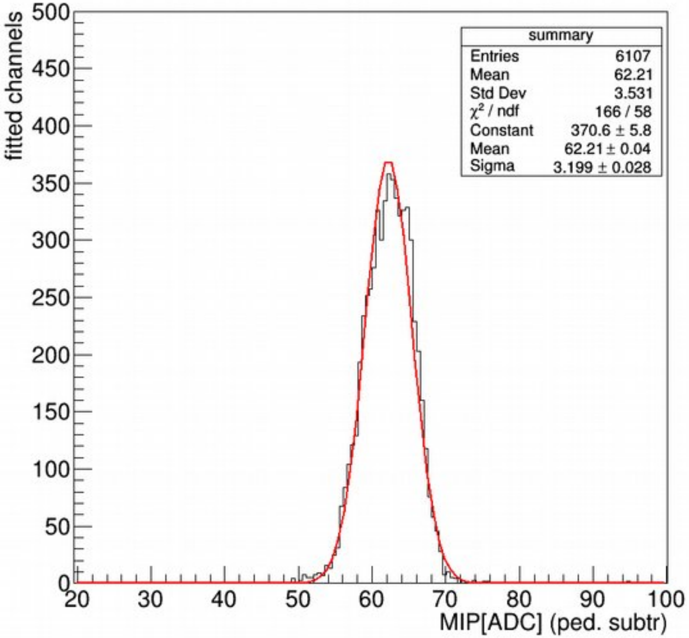


MIP calibration



- **Fit energy histogram with a Landau distribution convoluted with Gaussian (after pedestal substraction)**
- **All MIP estimations are summarized on histogram (Gaussian distribution)**
- **MIP around 62.2 sigma 3.5 (~5.6%)**
- **Signal over noise ratio**
  - Around 20 in high gain branch
  - Around 12 in trigger branch

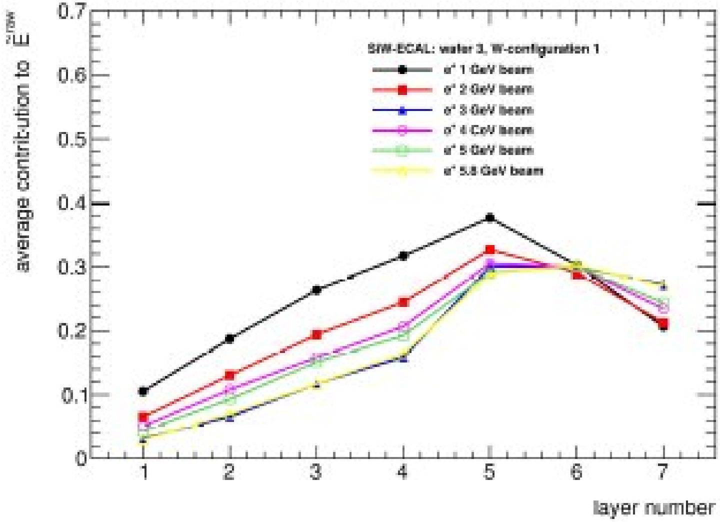
MIP summary (all slabs)

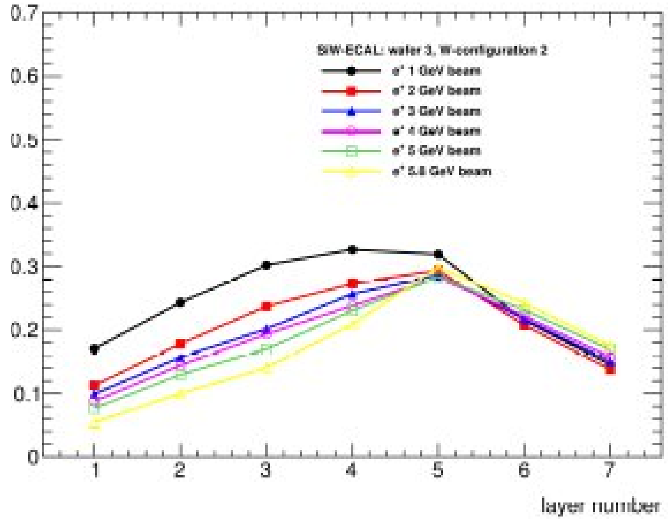


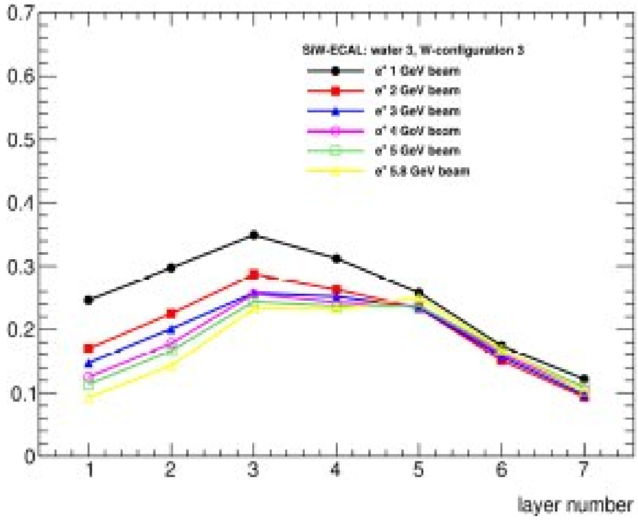
Analysis by A. Irles

Energy Scan with W

- **Shifting the shower by adapting the W configuration**
- **No bad surprise**
- **Need high intensity analysis for non-linearity (on CERN@2018 data)**

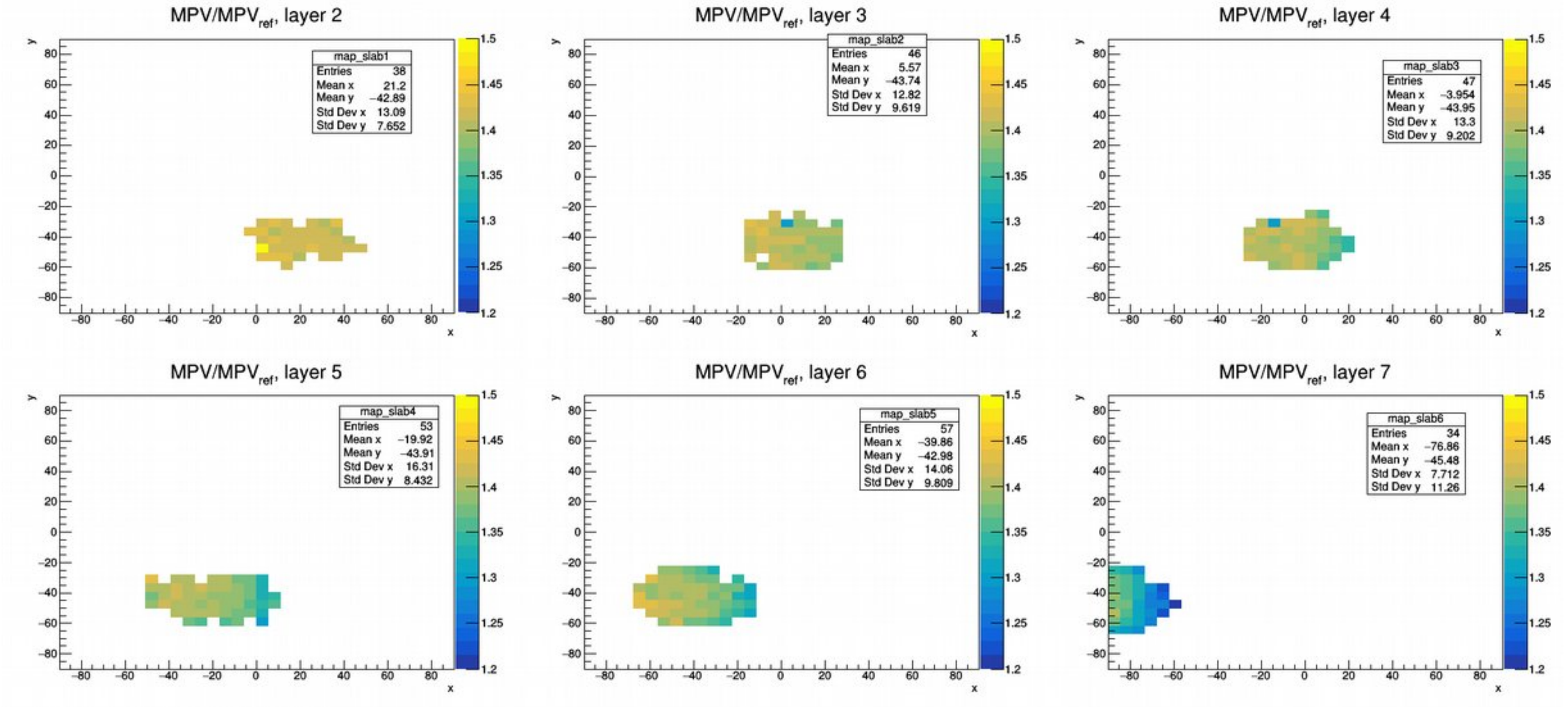






MIP Calibration at 45°

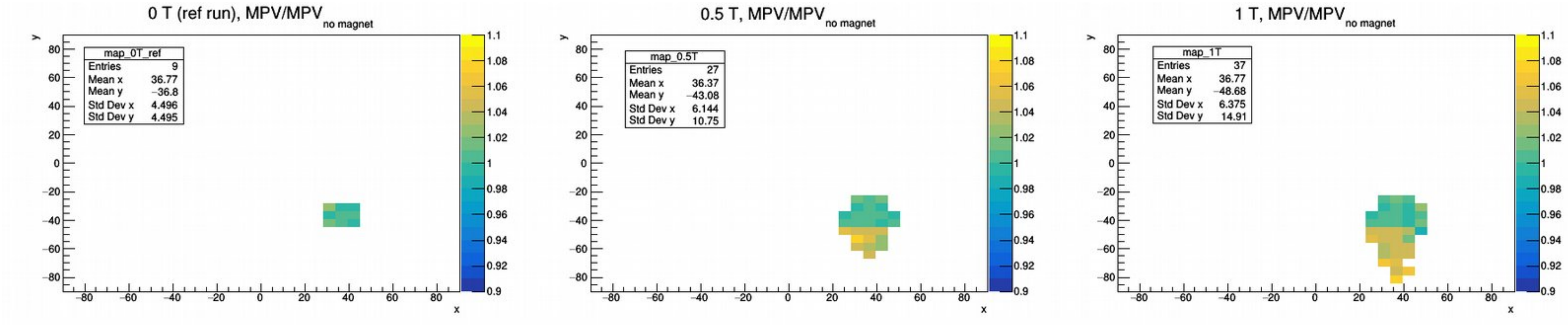
- **Orienting the detector with 45° from beam line**
- **MIP Fit obtained around 86 while expecting 62.2/cos(43.6)=85.9 → good agreement**



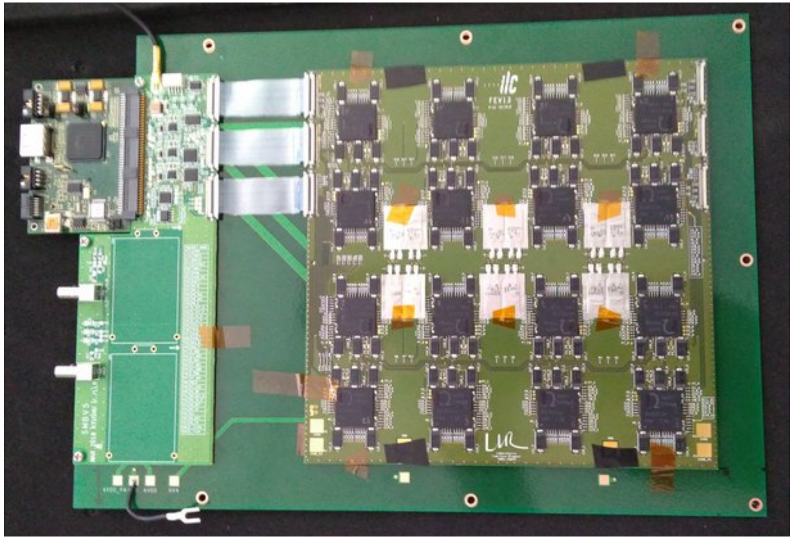
Tests in 1T B field

- **Two components : photons and electrons**
- **Electrons are shifted by the B field**
- **Mechanical constraints on pulsed electronics**

Designed by G. Fayolle



New slab 2017-2018



Goals

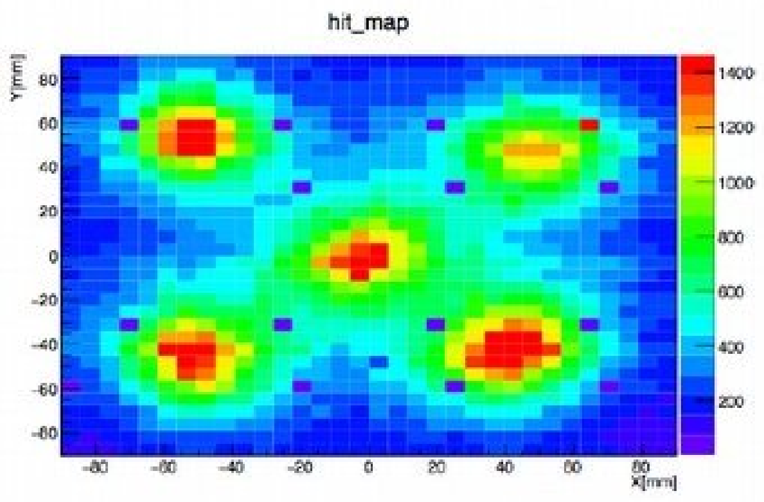
- Reduce dead channels + reduce noise → split analog power supply + DIF refactoring
- Reduce self-triggers → Upgrade to Skiroc 2a
- Adapt data path to long slab → U shape of data path
- Unique identification of slabs
- Geometrical adaptation for ILD : SMB + DIF in 40x70 mm² → moving power pulsing capacitance on ASU

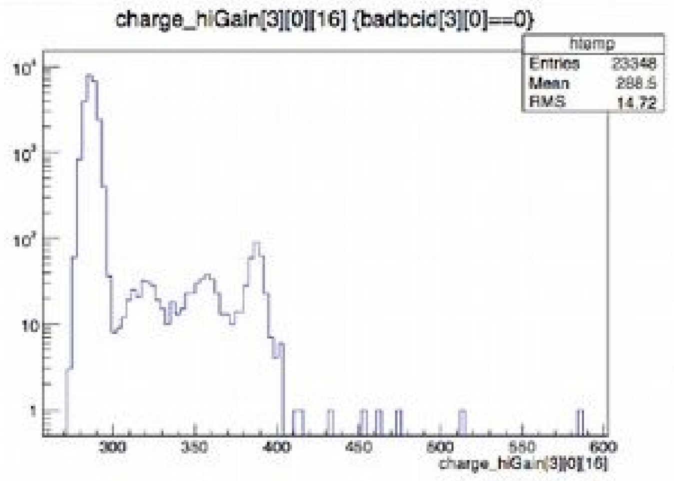
New prototype developed in collaboration with Kyushu U.

- Omega : new Skiroc2a ASIC — Designed by S. Callier (Omega)
- LLR : ASU13 + SMBv5 schematics — Designed by J. Nanni, R. Guillaumat, M. Louzir, F. Magniette
- Kyushu : SMBv5 routing & prod and assembly of 5 new slabs — Designed by Taikan Suehara, Yu Miura

Testing the new slab

- **Less dead channels : only 37 remaining, still retriggering**
- **S/N=40!**
- **Power-pulsing with ILD geometry with flat capacitance**
- **Test with Co57 and testbeam @ DESY 2018**



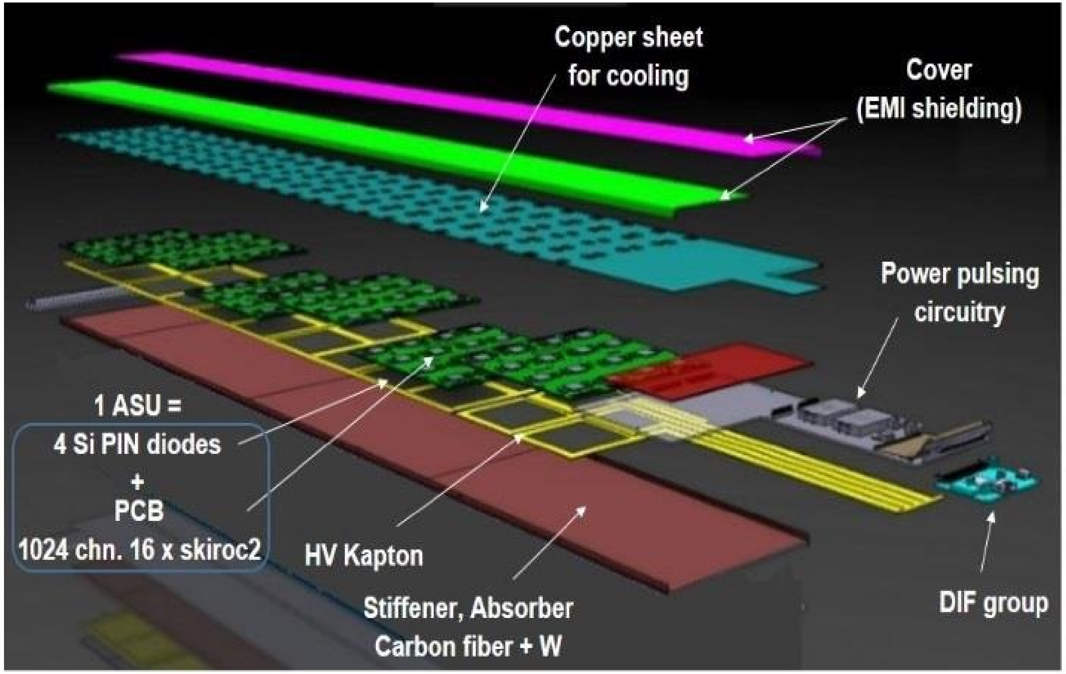


Published in IEEE 2018 NSS

Long slab

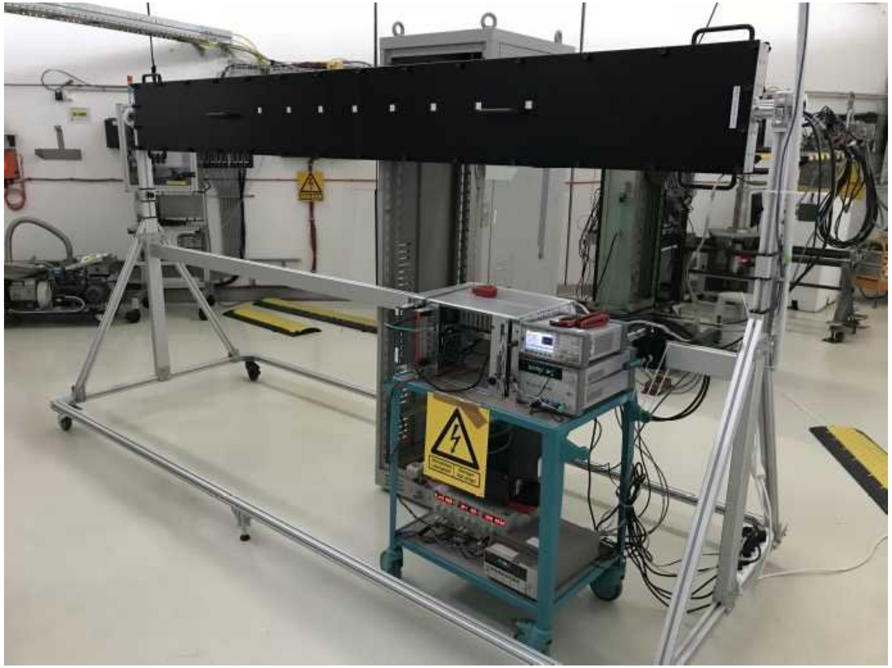
- Electrical prototype of the future ILD slab : 8 ASUs long (1440x180 mm² of detecting surface)
- No mechanical constraint

Designed by J.Nanni & F. Magniette

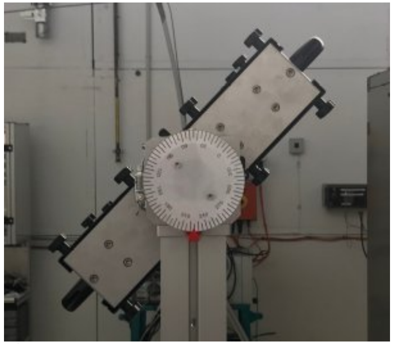


Mechanical structure

- **Porting structure with rotation system**
- **Shielding from EM perturbation**

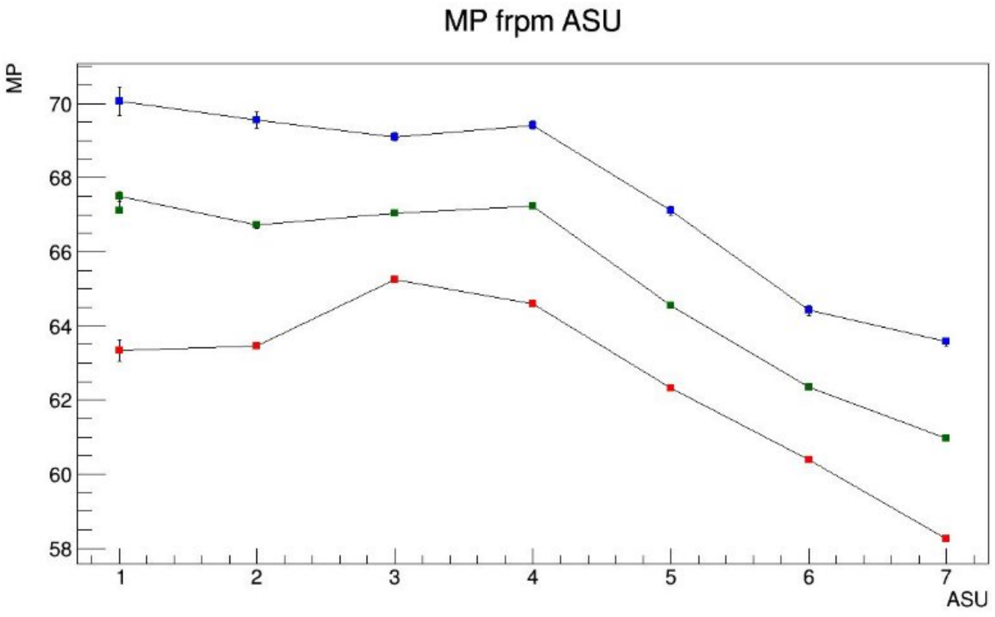


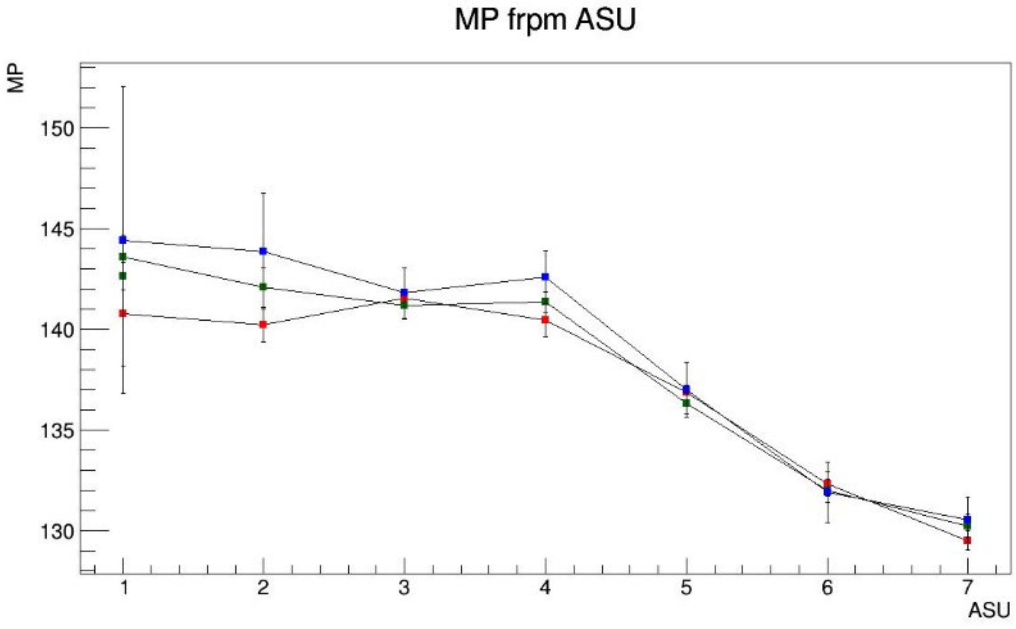
Designed by M. Anduze & E. Edy



Long slab MIP calibration

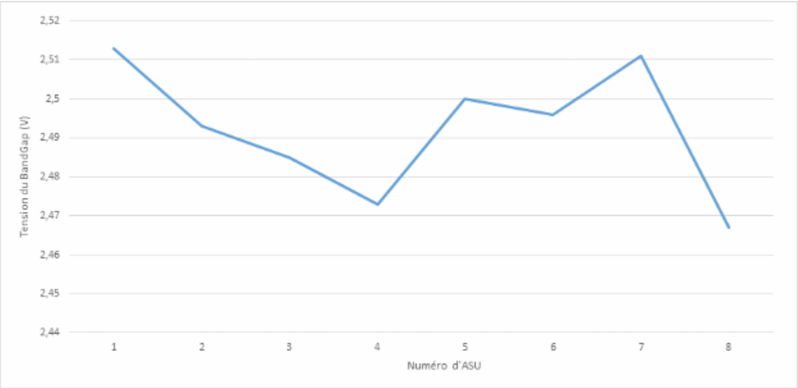
- MIP calibration at 3 angles 0°, 45° and 60°
- MIP shifted accordingly 1/cos(a)

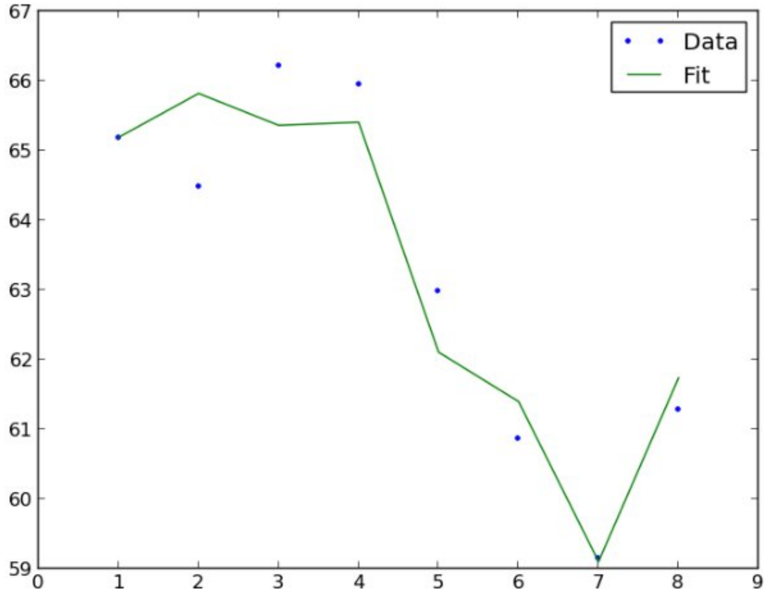




Hints for next version

- **Inflexion is a sum of two effects**
  - power supply weakening along line
  - Bandgap dispersion (uniform random)
- **Need for octopus power-supply (same line length for all ASU)**
- **Need for better bandgap or software compensation**





y=a*ASU+b+c*BG(ASU)

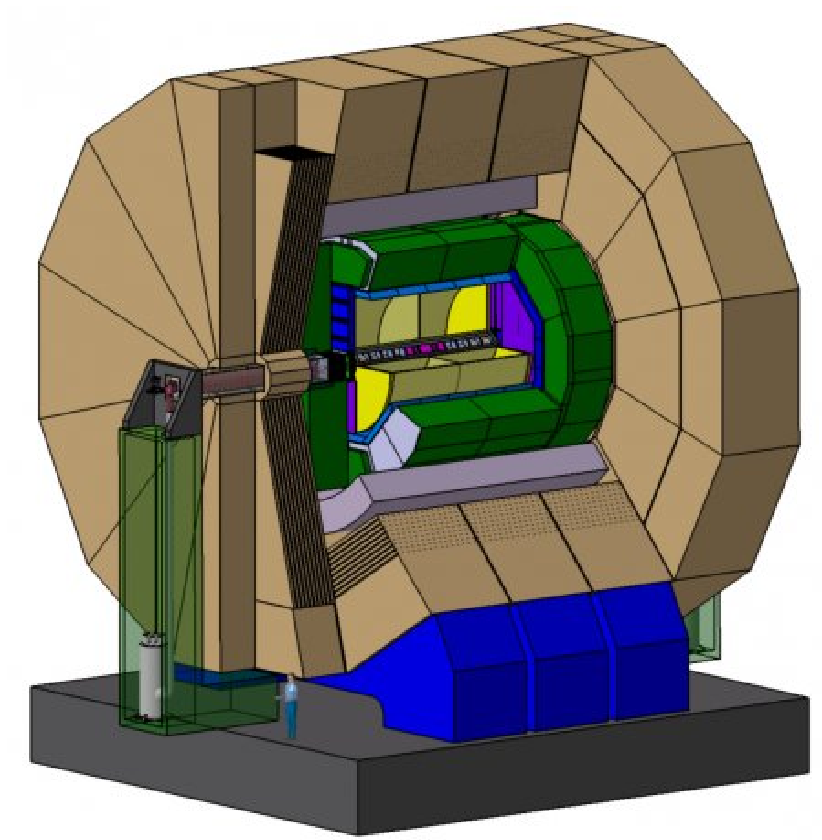
Technical conclusions

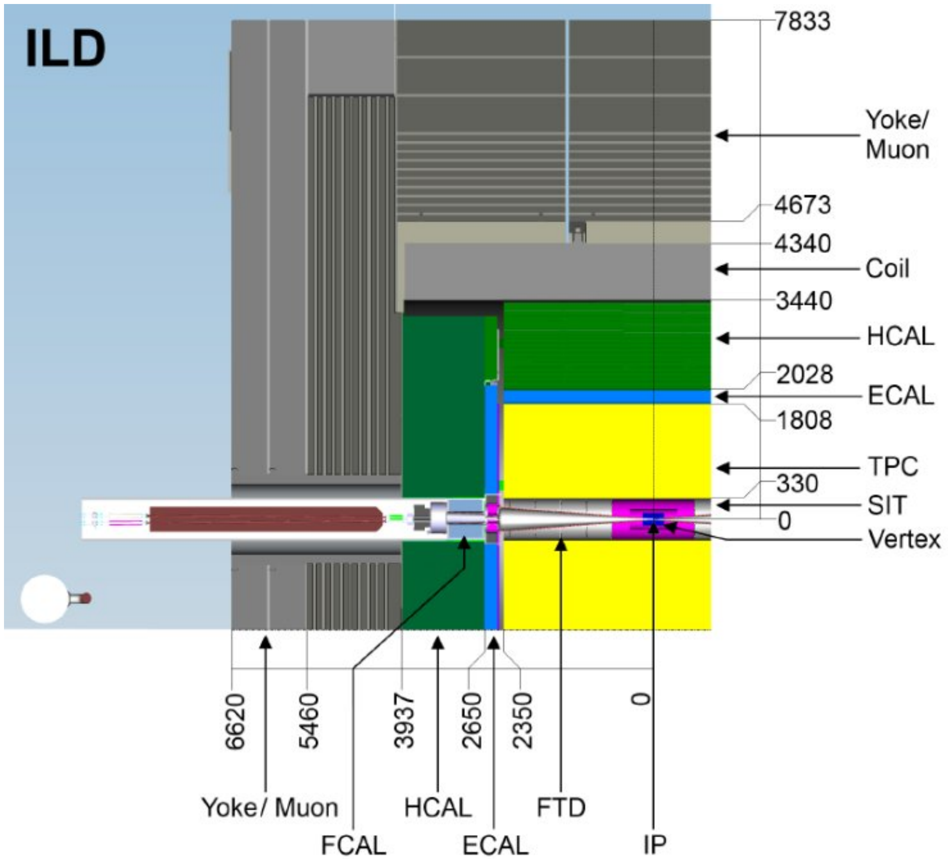
- **Single ASUs fully functional with very good S/N ratio**
  - High energy response to be validated
- **Necessary improvements for daisy chaining**
- **Need a new version of ASIC**
  - with new technology (TCMC?)
  - with channel 37 and retriggering problem solved
  - Zero-suppression (and pedestal runs)
- **Need a new version of SMB/DIF compatible with ILD geometry**
- **Be prepared to 8 inch (compatible ASU)**
- **Unique expertise on design and integration**

→ toward a finalised DIF/SMB/ASU/ASIC development to cope with ILD requirements

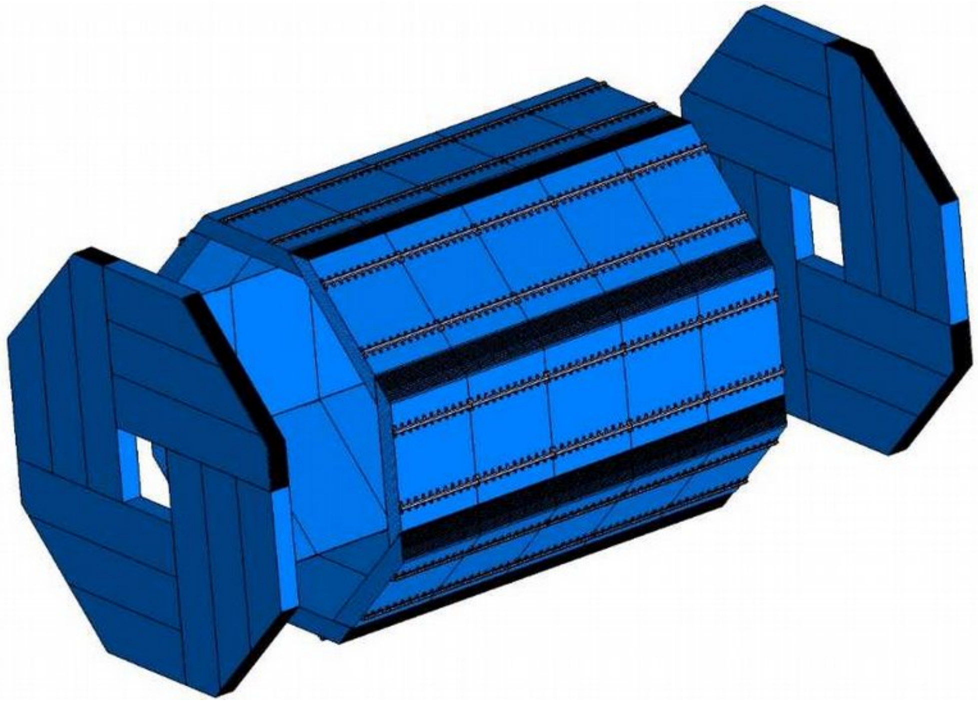
ILD conception

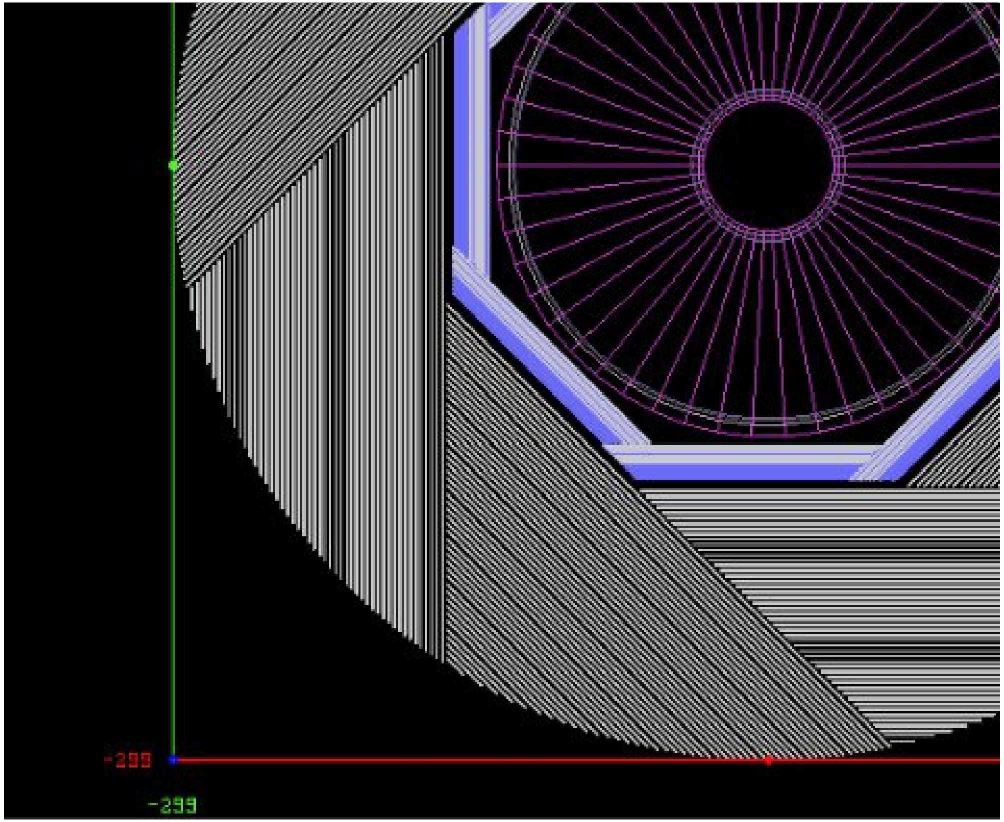
ILD geometry



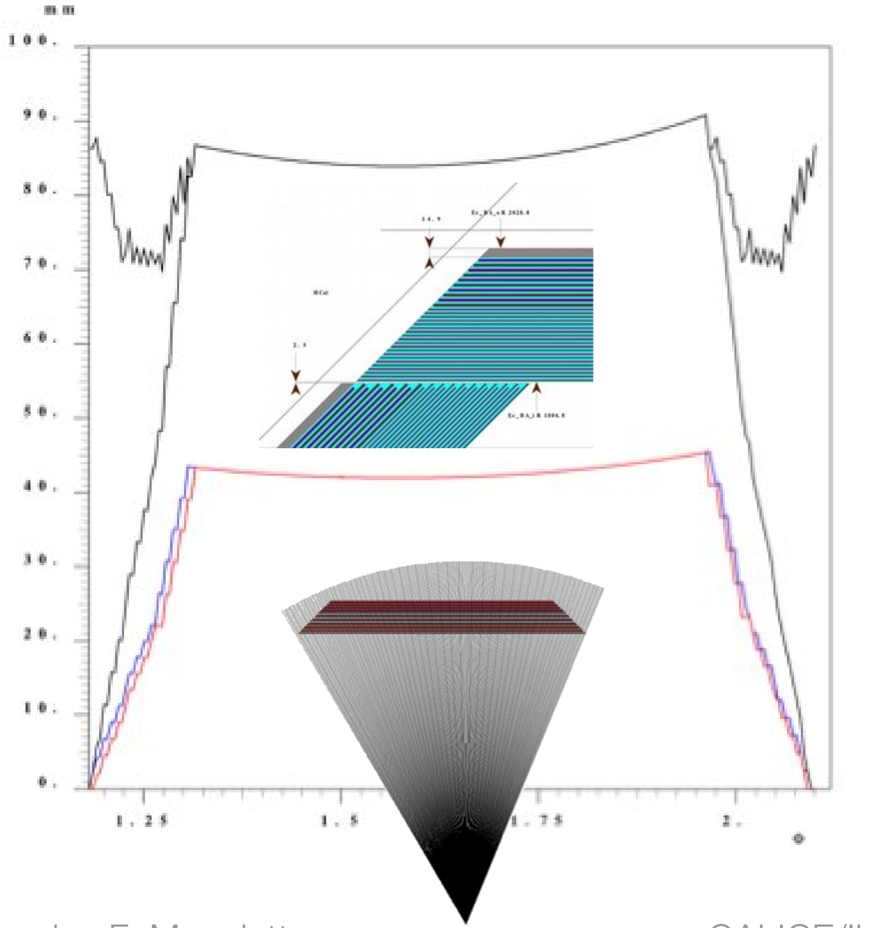


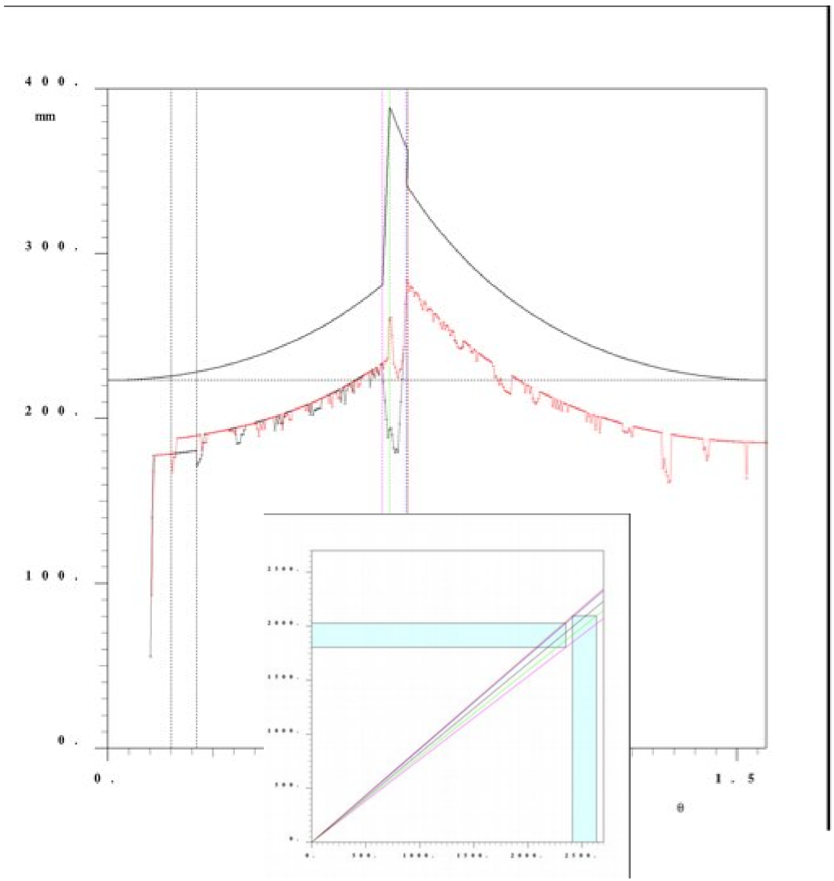
A crack-less ECAL geometry



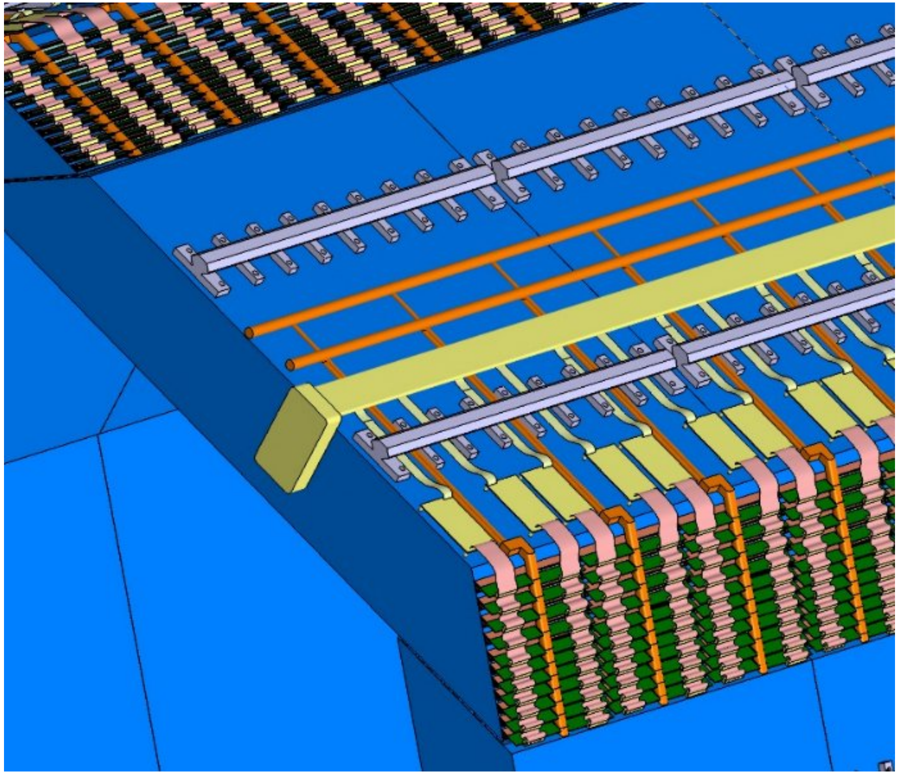


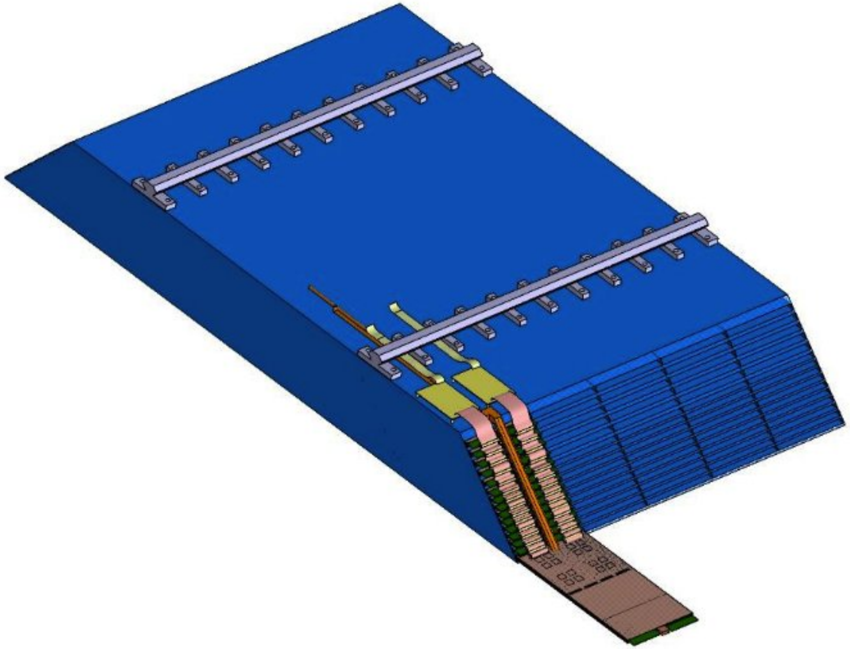
ILD ECAL Uniformity



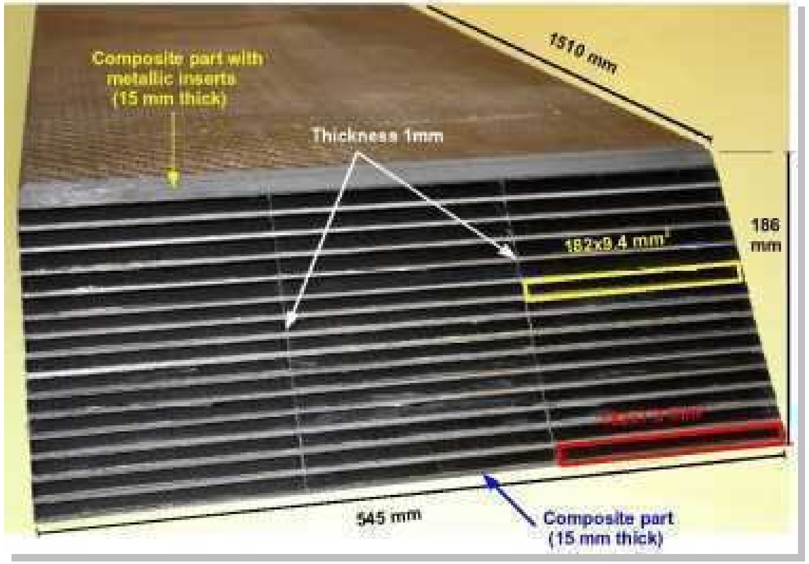


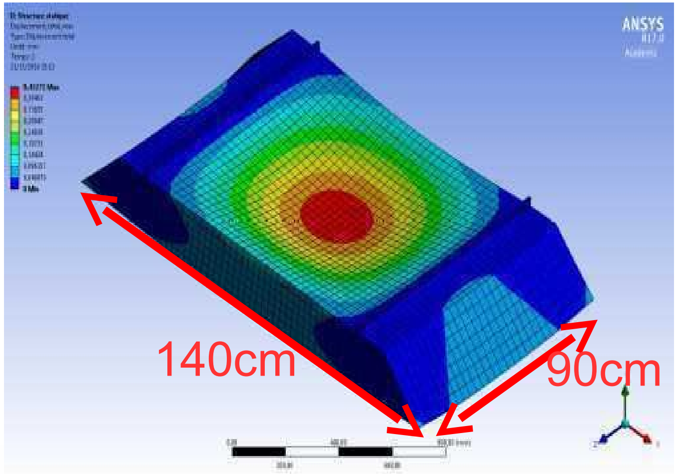
Modules





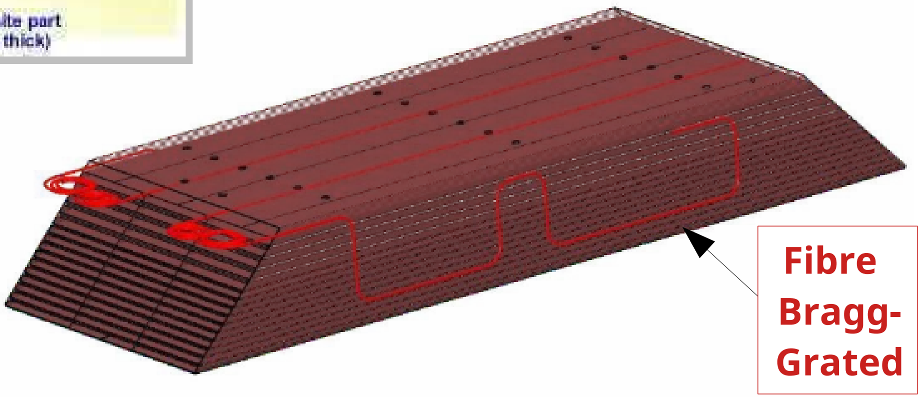
CFRC+W Structures
ILD Design



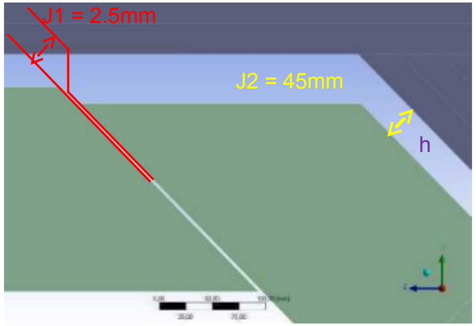


Study by M. Anduze

Measurements
with FBG
still to be done...



Static and Dynamic Simulations



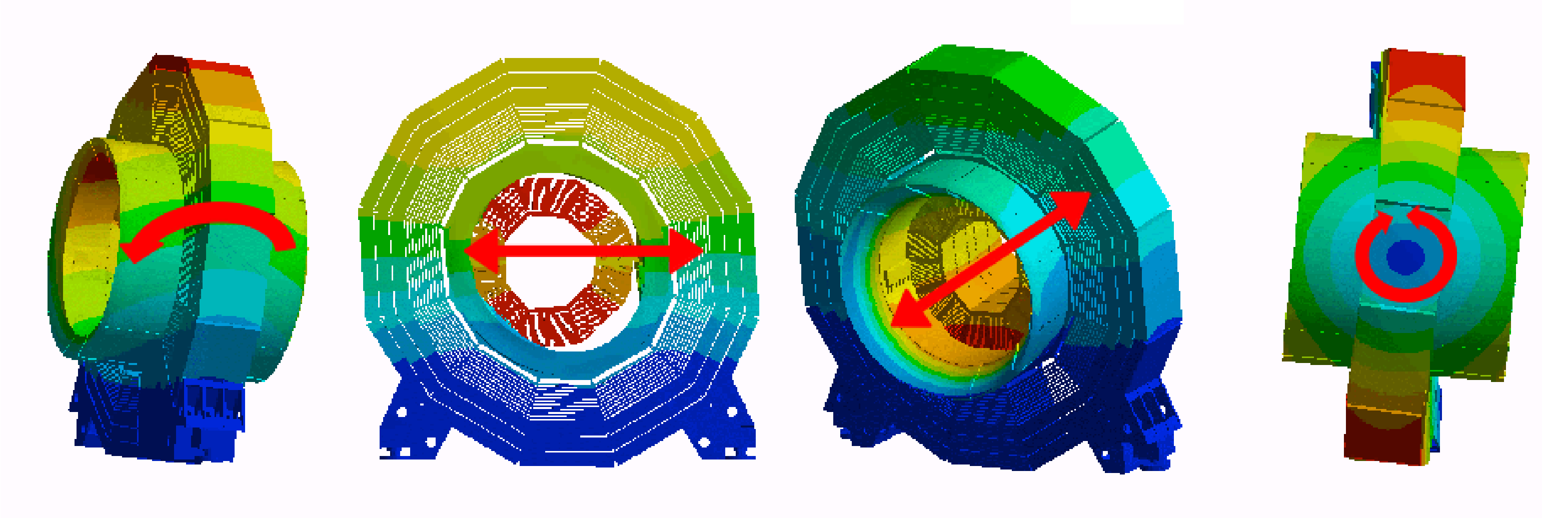
Study by T. Pierre-Émile

Mode 1 @ 2,3Hz

Mode 2 @ 3,05Hz

Mode 3 @ 3,8Hz

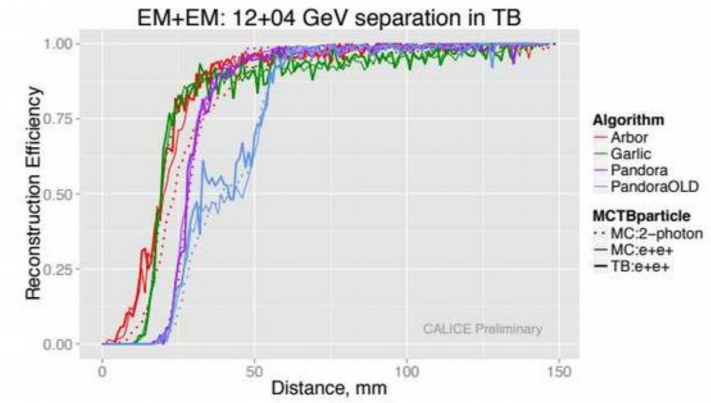
Mode 6 @ 7Hz



Particle Flow Studies

Algorithm Comparison on test beam data

- Photon-Photon
- Pions vs Photons

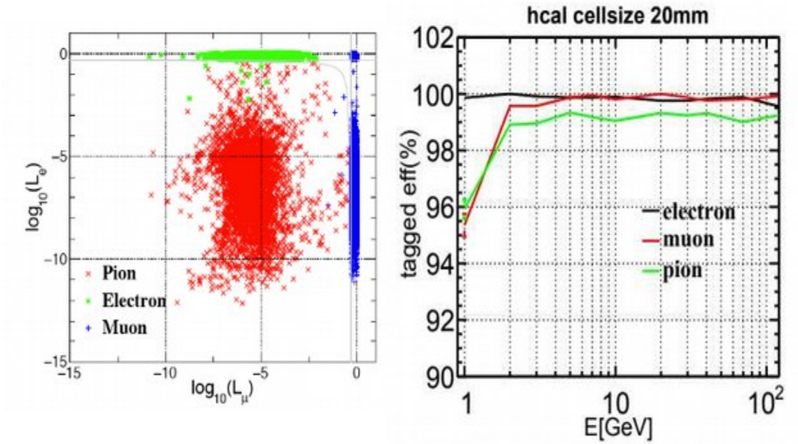


K. Shpak & VBa., CALICE CAN-057

Fractal dimension of Showers

M. Ruan, DJ, VBo, JCB, HV,
Phys. Rev. Lett. 112 (Jan, 2014) 012001,
arXiv:1312.7662 [physics.ins-det].

Particle ID with highly granular calorimeters

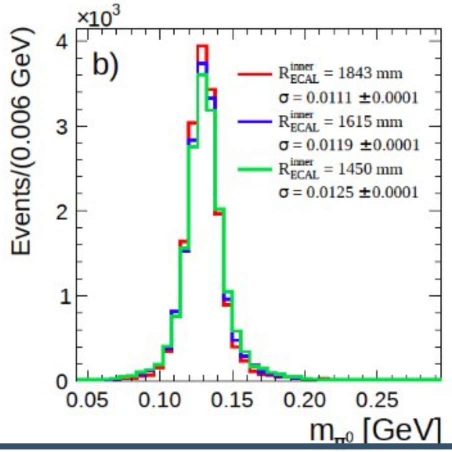


BDT method using 4 classes of 24 input discrination variables

D. Yu, M. Ruan, VBo, HV
Eur. Phys. J. C77 no. 9, (2017) 591,
arXiv:1701.07542

Optimisation studies

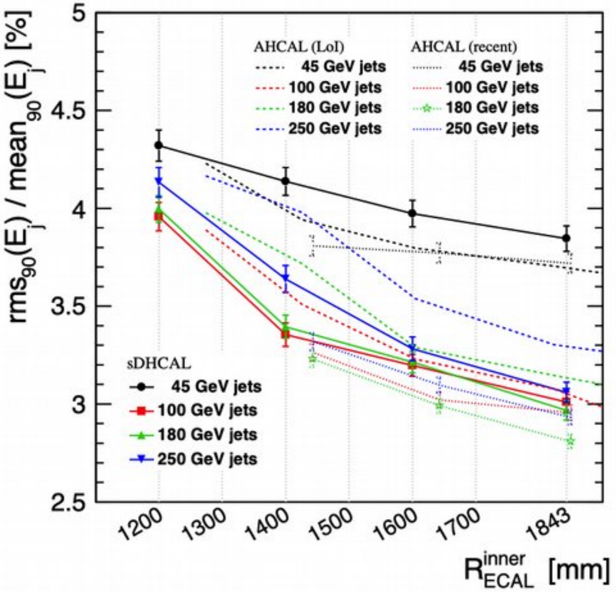
Tau reconstruction



π0-mass spectrum for different detector models

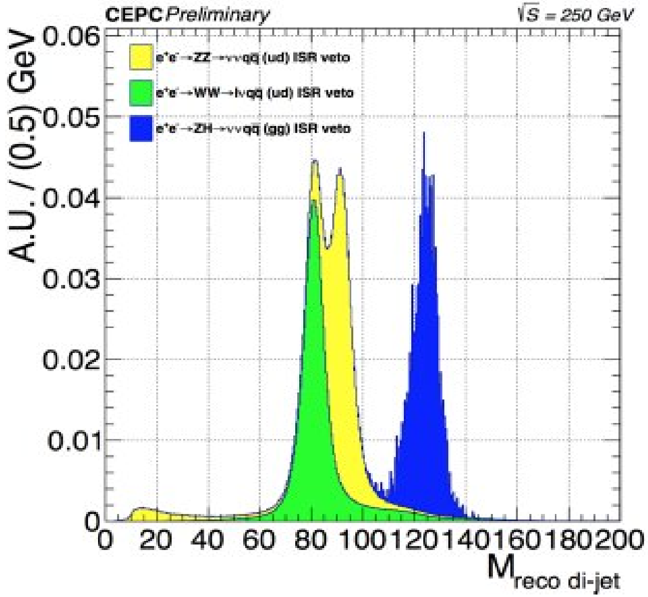
H.T. Tran, VBa, VBo, JCB, HV, Eur.Phys.J.C76 (2016) no.8, 468

Jet Energy resolution



H.T. Tran, arXiv:1404.3173 [physics.ins-det]

Boson di-jet reconstruction



CEPC CDR vol 2. Det & Physics arXiv:1811.10545 [hep-ex].

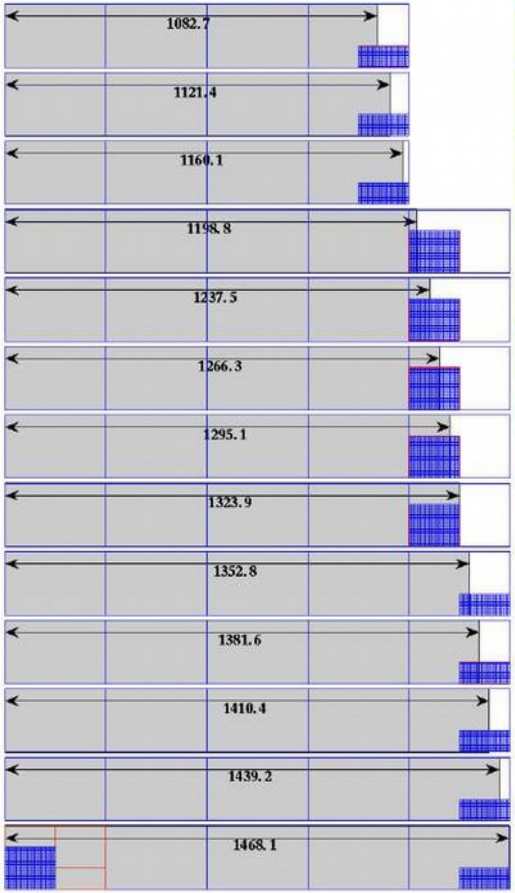
Redefinition of dimensions

- **Full costing (hardware and man-power) and integration planning done by Henri Videau**
- **3 designs looked at**

    under work version of **ECal Technical Design Document** (TDD, ~100 pages)
    by Henri Videau (LLR), Marc Anduze (LLR) and Denis Grondin (LPSC)

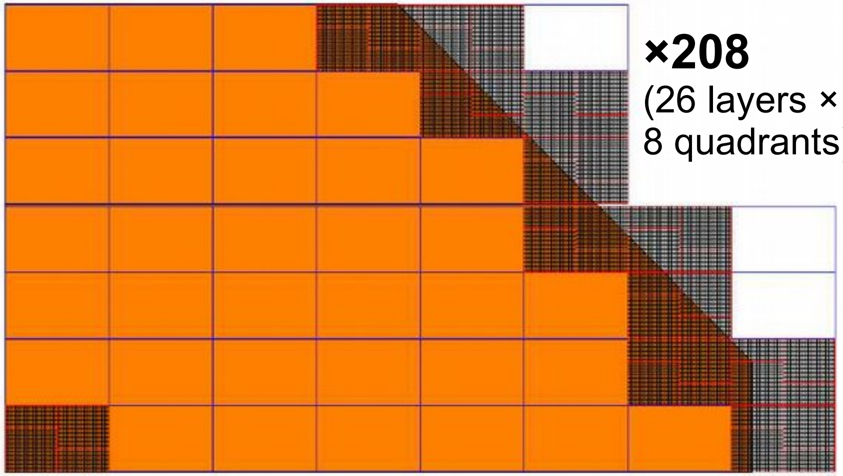
    - a “baseline” (or “large”) with inner ECal radius at RECal =1804mm, (model close to the DBD) with 30 layers
    - a “small ILD” model RECal ~1500 mm (all related quantities adapted ↔ $R_{outer}^{Endcaps}$)
    - a model with slightly reduced number of layers = 26 layers
- **725µm thickness with 200mm (8”) wafers ; 5.08 → 6mm cell size**
    - ~ identical photon resolution expected
    - 13% gain cost on Silicon surface, PCB, and 40% on electronics (and power consumption) wrt DBD
    - Improved S/N ratio & timing, less channeling @ 90°

Tiling



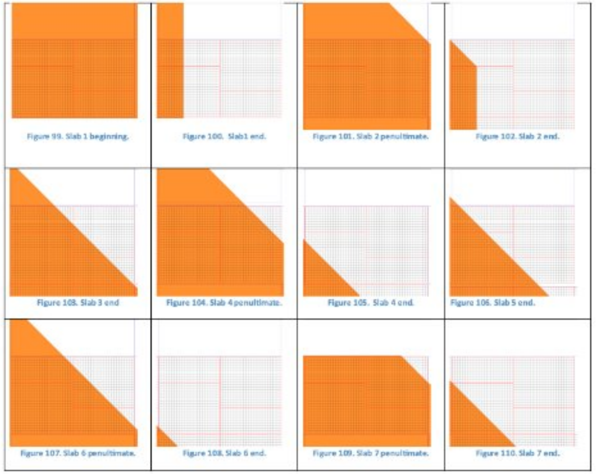
×400

(2 sides × 5 columns ×40 modules)



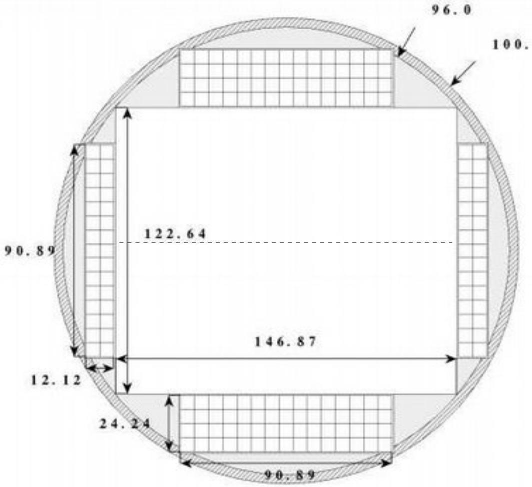
×208

(26 layers × 8 quadrants)



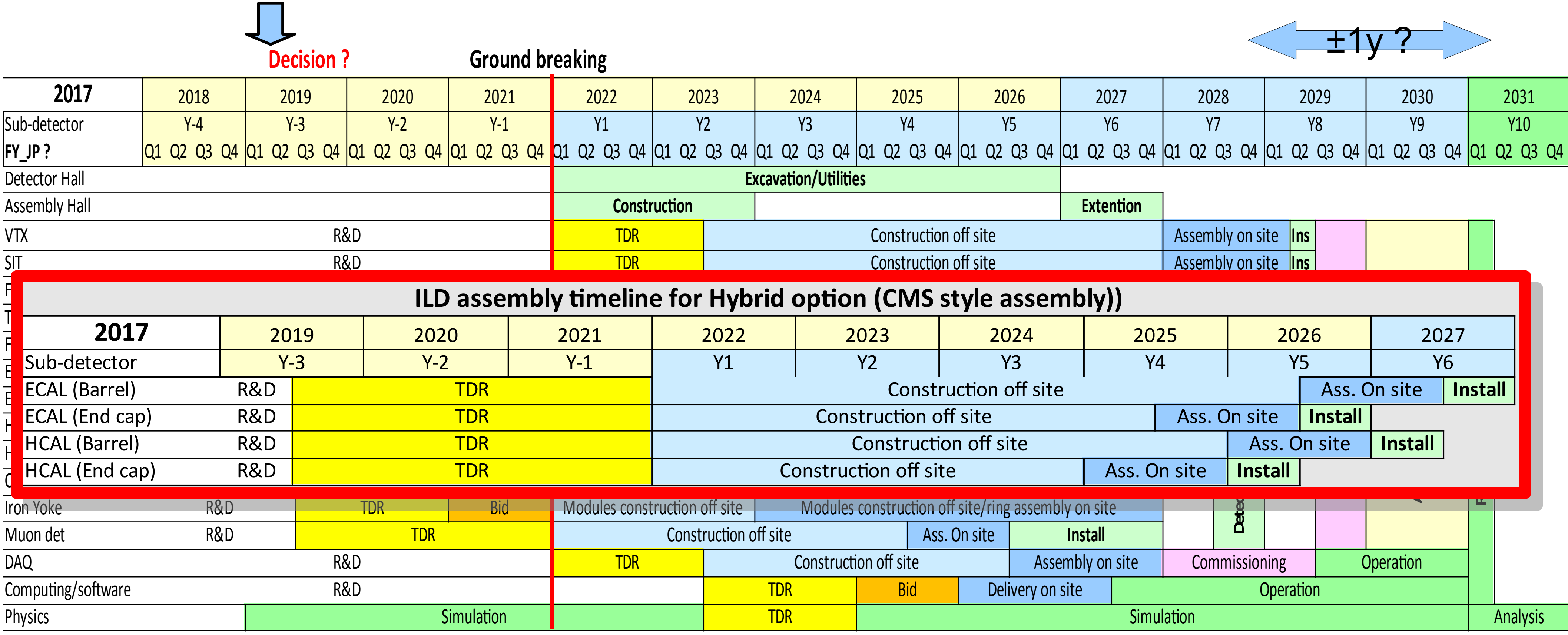
Matching of large and small rectangles, triangles and diamonds to be detailed for optimal use

add'l small rectangles:
87 % use of surface
(83 % for an hexagonal shape)



Prospects

ILC Construction (putative planning)



adapted from 2014 ressource survey

Strategy

Future work in case of ● ILC

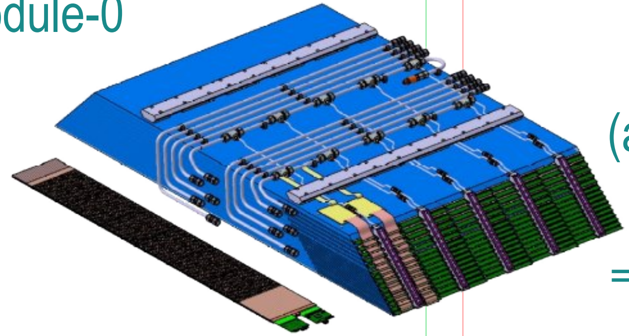
Keep expertise on design & techniques

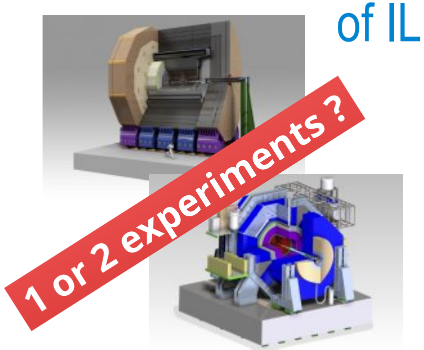
Design of the final detector (2 years)

… build infrastructure & module-0

… build a SIW-ECAL

… with LLR in charge of ILD-ECAL





In any case:

Publish results and designs

CALICE /ILD detectors and prototypes are reference for

CEPC, CLICdp, FCC-ee

(asked for)

⇒ adaption for machine conditions required (Pulsing, Cooling, Granularity)

Questions ?

XFEL tunnel

SUPPORTS

Now and next 2–4 years

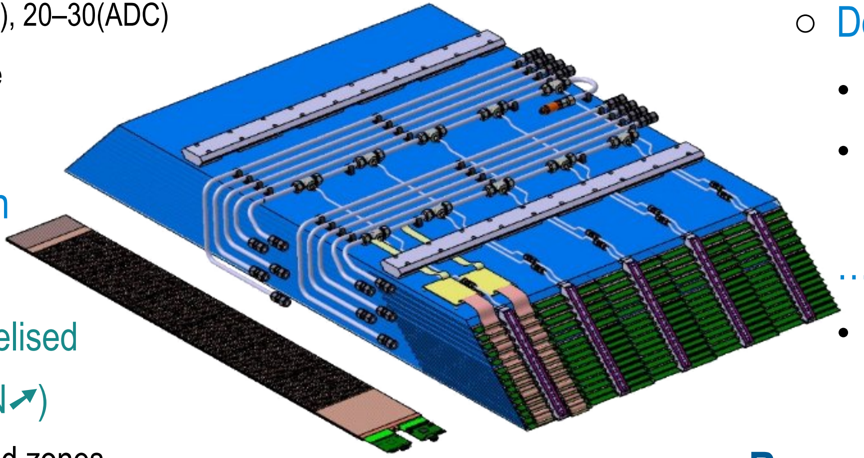
Technical Milestones:

At hand on CALICE prototype:

- Workable, scalable design
- ASU with 1024 channel
  - » Signal/Noise > 10 (trigger), 20–30(ADC)
  - » on-going: HE e⁻ response
- Reduced GR event rates

On-going on ILD-like design

- Connection over 8 ASU's
- Mechanics & Cooling modelised
- Thicker & larger wafer (S/N↗)
  - – red. number of layers, dead zones
- Compact DAQ



Next steps

- ○ Final chips (SK3-like): full 0-suppr …
  - • machine dependant (duty cycle, timing)
- ○ Industrial aspects (components, aging, …)
- ○ Double Layered Long Slab Prototype
  - • Design with larger wafers
  - • Demonstrator for industry

    Estimated cost ~160k€ / piece

… Build a module-0 …

- ~13 DL-Long Slabs × 3–5

… build a SIW-ECAL.

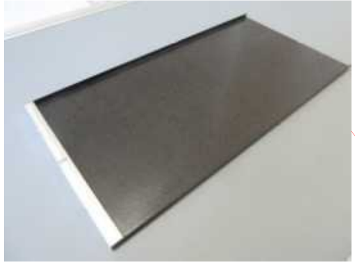
Resources

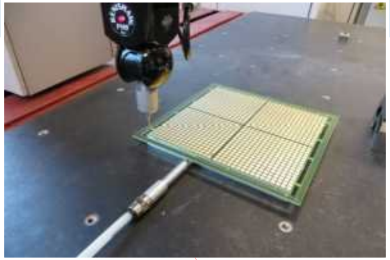
… political dependant …

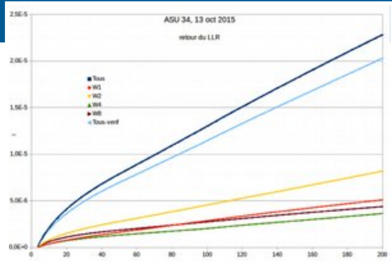
Assembly chain IdF

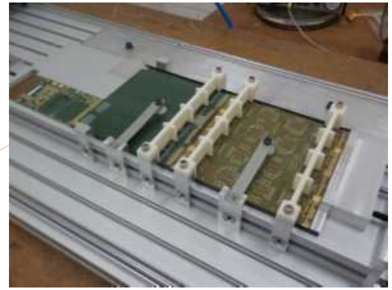
R. Cornat (resp), J. Nanni, M. Louzir, M. Frotin,
J. Bonis, P. Cornebise, J. David, D. Lacour,
S. Pavy, P. Ghislain, A. Irles

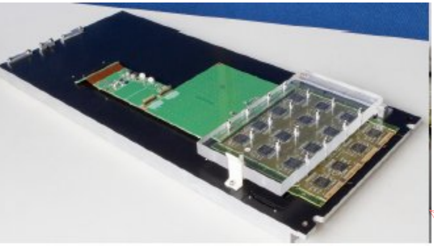
'Simplified view'

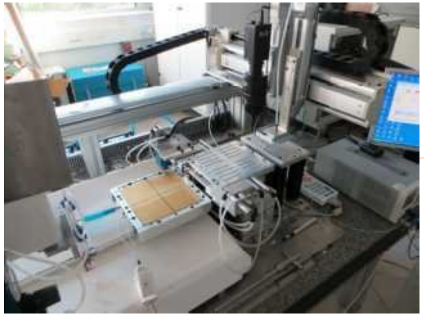


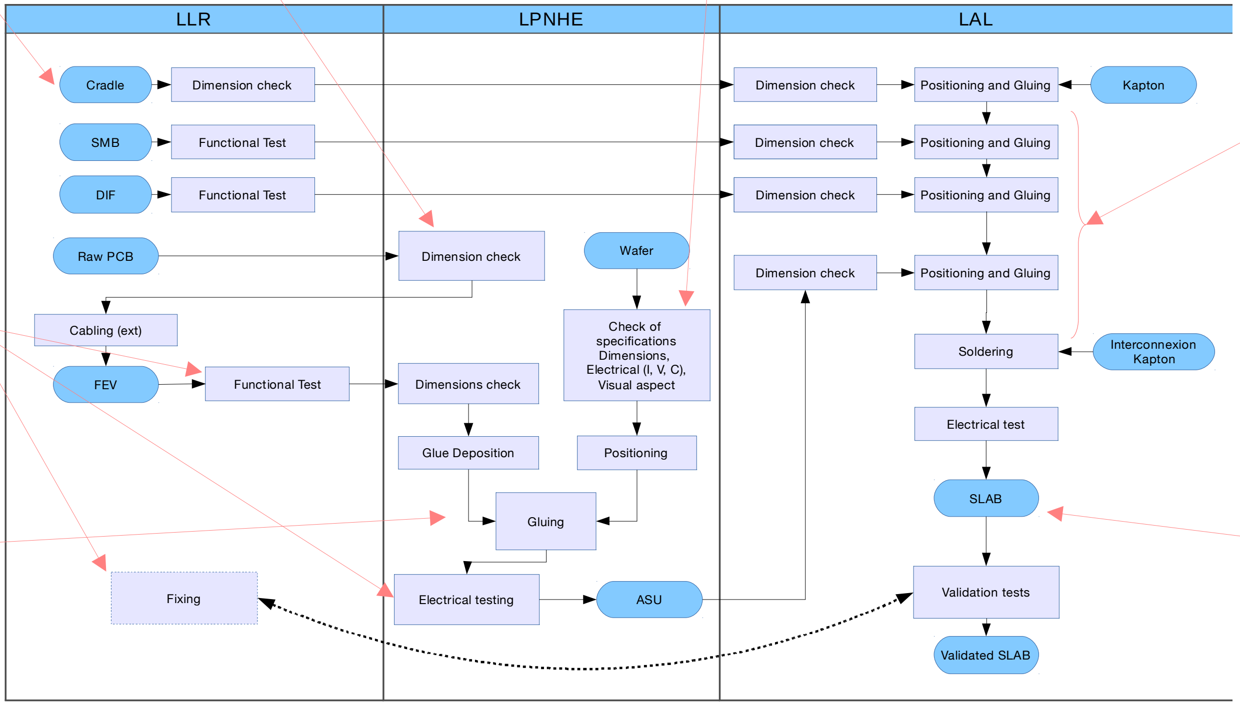












ILD Building blocks: SLAB’s & ASU’s

R&D for “mass production” and QA

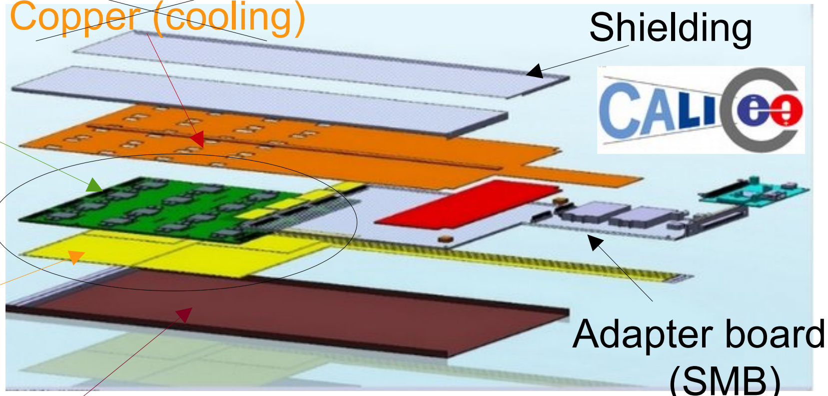
- Quality tests & preparation of large production
- Modularity → ASU & SLABs
- Choice of square wafers
  - (≠ from hex: SiD, CMS HGCAL)

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

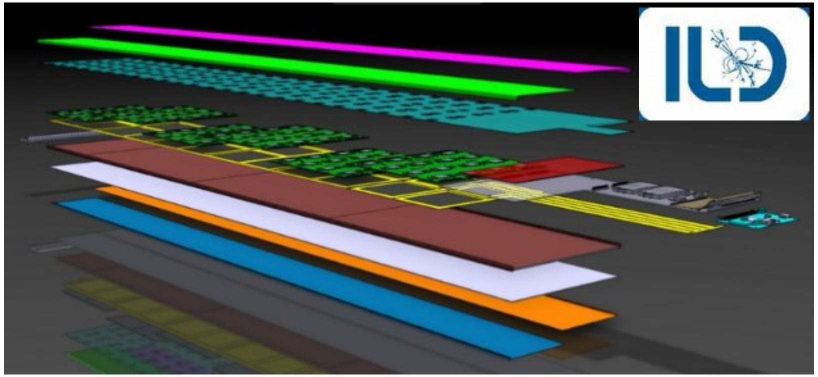
- Barrel modules: 40 (as of today all identical)
- Endcap Modules: 24 (3 types)
- ASUs = ~75,000
  - Wafers ~ 300,000 (2500 m²)
  - VFE chips ~ 1,200,000
  - Channels: 77Mch
- Slabs = 6000 (B) + 3600 (EC) = 9600
  - ≠ lengths and endings

Tests of producibility

Tests of feasability



U layout of a **short slab**



U layout of a **long slab**

Sketch for a Historical Picture of the Progress of the ILD Silicon ECAL

Milestone	Date	Object	Details	REM
1st ASIC proto	2007	SK1 on FEV4	36 ch, 5 SCA	proto, lim @ 2000 mips
1st ASIC	2009	SK2	64ch, 15 SCA	3000 mips
1st prototype of a PCB	2010	FEV7	8 SK2	COB
1st working PCB	2011	FEV8	16 SK2 (1024 ch)	CIP (QGFP)
1st working ASU in BT	2012	FEV8	4 SK2 readout (256ch)	best S/N ~ 14 (HG), no PP retriggers 50–75%
1st run in PP	2013	FEV8-CIP		BGA, PP
1st full ASU	2015	FEV10	4 units on test board 1024 channel	S/N ~ 17–18 (High Gain) retrigger ~ 50%
1st SLABs	2016	FEV10 & 11	7 units	
pre-calo	2017	FEV10 & 11	7 units	S/N ~ 20, 6–8 % masked
1st technological ECAL ?	2018	SLABvFEV10 & 11 & 13 SK2a+ COB + Compact stack	SK2 & SK2a (ↄtiming)	Improved S/N Timing...

Synergies HGCAL-CALICE

- **Ideas**: Start of HGCAL: Common brainstorming on solutions: mechanics, electronics, design, view on Particle Flow Algorithms. Later: Realization of the potential of timing for ILC (and CEPC) experiments: ToF complementary of dE/dx for PID, help for PFA, … still being explored.
- **Technical** help and exchange: SK2 chips for HGCAL, support for SK2a chips prod & packaging for CALICE; 2 weeks of “offered” HGCAL beam-test at CERN in nov. 2015 to CALICE; participation of CMS to the data-taking & simulation (with premium support!); Common development on the RO elec and DAQ (SK2 as 1st ROC for CMS); test bench mounting and FW common development (clock change, code cleaning)
- **Formation**: shared Post-Doc Artur Lobanov (25% CALICE, 75% CMS) on RO electronics, beam-test and data analysis was formed on CALICE, exp. immediately applicable to CMS HGCAL.
- **Mechanics**: Proposal of “ILD” like solution for the HGCAL mechanics: CFRC-W structure with cassettes (not kept for many reasons, main: tight planning requiring flexibility until the final mounting)

Conclusion: The synergy allowed for an estimated critical gain of 2–3 year of R&D for HGCAL and boosted CALICE actvities (beam test, SK2a, FW). It has strengthened the on-going reshaping of the electronics group toward more shared developments (DAQ and Electronics).

Production Scientifique
- Analyses de Physique -

Analyses

Premiers résultats du prototype de 1m³ du Semi-Digital Hadronic CALorimeter (SDHCAL) ;
thèse de Y. Haddad ; arXiv:1306.6329 [physics.ins-det] (CHEF'2013),

Optimisation des dimensions d'ILD pour l'option ultra-granulaire (SiW-ECAL+SDHCAL),
arXiv:1404.3173 [physics.ins-det]

Évaluation des performances d'ILD pour la reconstruction des Tau's,
Eur. Phys. J. C76 no. 8, (2016) 468, arXiv:1510.05224 [physics.ins-det].

Optimisation du ECAL à 250 GeV (pour le CepC);
thèse de D. Yu ; arXiv:1712.09625 [physics.ins-det]

Outils (PFA)

ARBOR, a new approach to Particle Flow ; arXiv:1403.4784 [physics.ins-det], Eur. Phys. J. C78 no. 5, (2018) 426.

GARLIC GAmma Reconstruction at a LInear Collider experiment, JINST 7 (2012) P06003, arXiv:1203.0774 [physics.ins-det].

Analyse de la dimension fractale des gerbes, Phys. Rev. Lett. 112 (Jan, 2014)

Nouvelles méthodes d'identification de particules à l'aide de calorimètres ultra-granulaire ;
thèse de D. Yu ; Eur. Phys. J. C77 no. 9, (2017) 591, arXiv:1701.07542 [physics.ins-det].

Évaluation des algorithmes PFA sur les données CALICE ; thèse de K. Shpak arXiv:1711.08529 [physics.ins-det]

Production Scientifique
- Contributions techniques -

Détecteurs

Publication du Detector Baseline Document de l'ILD en 4e partie du TDR ILC arXiv:1306.6329 [physics.ins-det].

CEPC-SppC Preliminary Conceptual Design Report; IHEP-CEPC-DR-2015-01 (CDR en cours de finalisation)

Analyse mécanique de la stabilité statique et dynamique du SiW-ECAL ; JINST 13 no. 03, (2018) C03011

2013–2018 : Réalisation d'une DAQ pour la lecture de détecteurs ultra-granulaire :
(EPS-HEP 2015), vol. 9, p. C01030. 2014, TIPP2014, p. 032009. 2017.
et extension en une DAQ générique (PYRAME) ; J. Phys. Conf. Ser. 898 no. 3, (2017) 032009 ; JINST 13 no. 03, (2018) C03009.

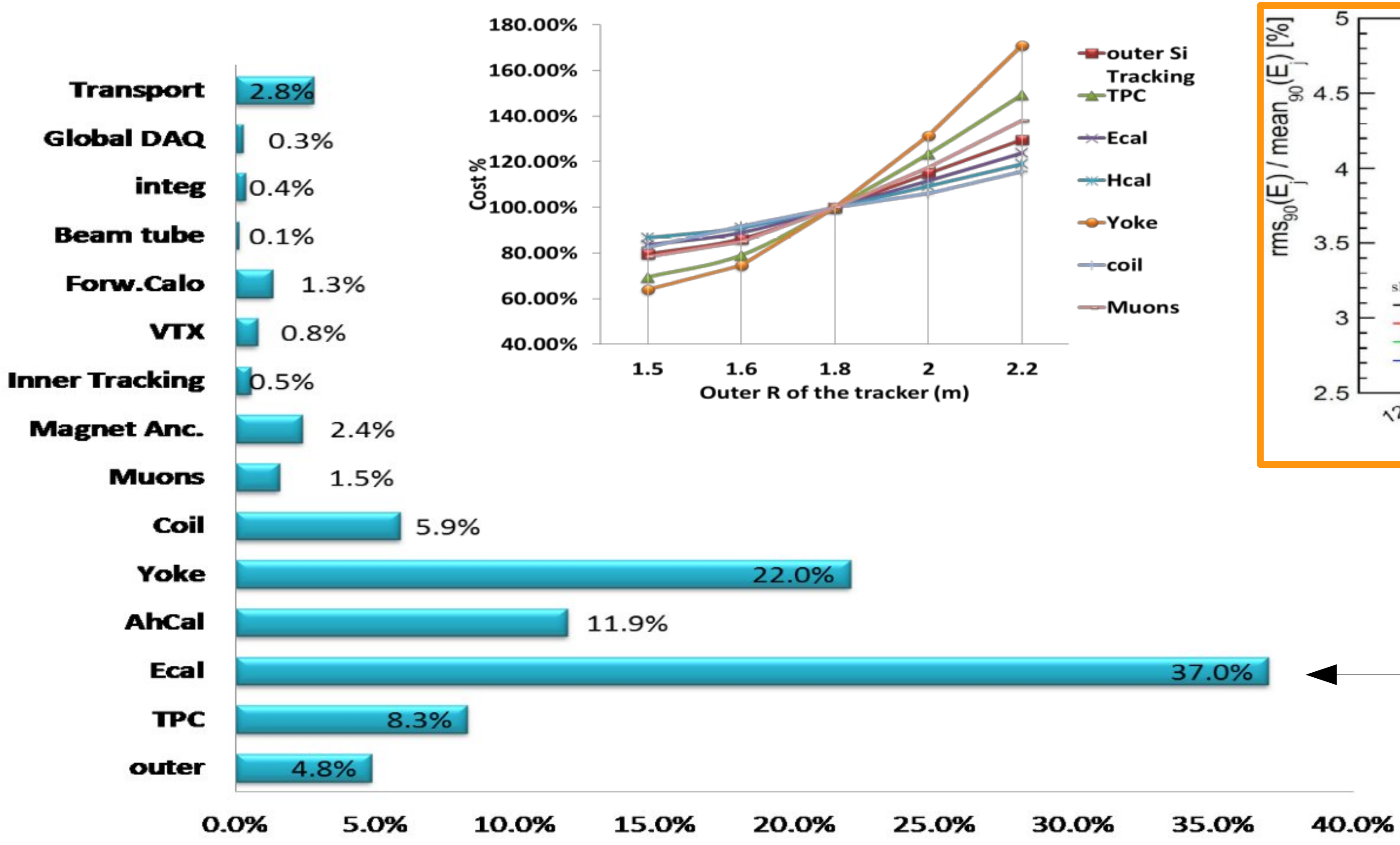
Réalisation progressive & tests en faisceau du prototype technologique du SiW-ECAL, jusqu'à 8 couches instrumentées de 1024 voies en 18×18 cm² ;
DESY-2012, CERN-2015, CERN-2016, DESY-2017, DESY-2018 (CERN-2018) : Nucl. Instrum. Meth. A778 (2014) ; arXiv:1802.08806 [physics.ins-det].
JINST 12 no. 05-06, (2017) ; arXiv:1705.10838 [physics.ins-det].

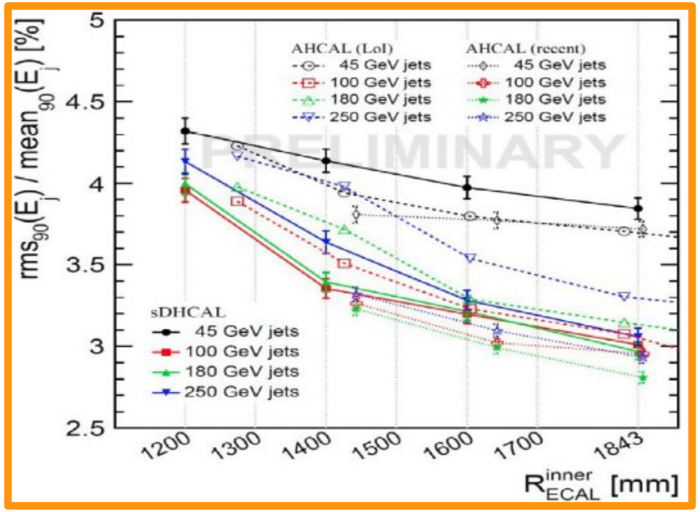
Réalisation d'une couche longue (8 cartes) et test en faisceau : DESY-2018, analyses en cours

Études de design des ASICs en C-FAB SOI 180 nm ; thèse JB. Cizel, JINST 10 no. 02, (2015) C02007

Utilisation de réseaux de Bragg pour la mesure des déformées d'une structure alvéolaire,
7e Colloque Interdisciplinaire en Instrumentation

Cost Structure of ILD





Full Silicon option

Reduced number of Layers

Going from 30 to 22 layers

- Reduction of cost; (small) reduction of R_M ; increase of Energy resolution
  - "better separation at the expanse of the intrinsic resolution"

Increasing the Si thickness to 725µm, if really feasible (next slide)

Energy resolution σ(E)/E:

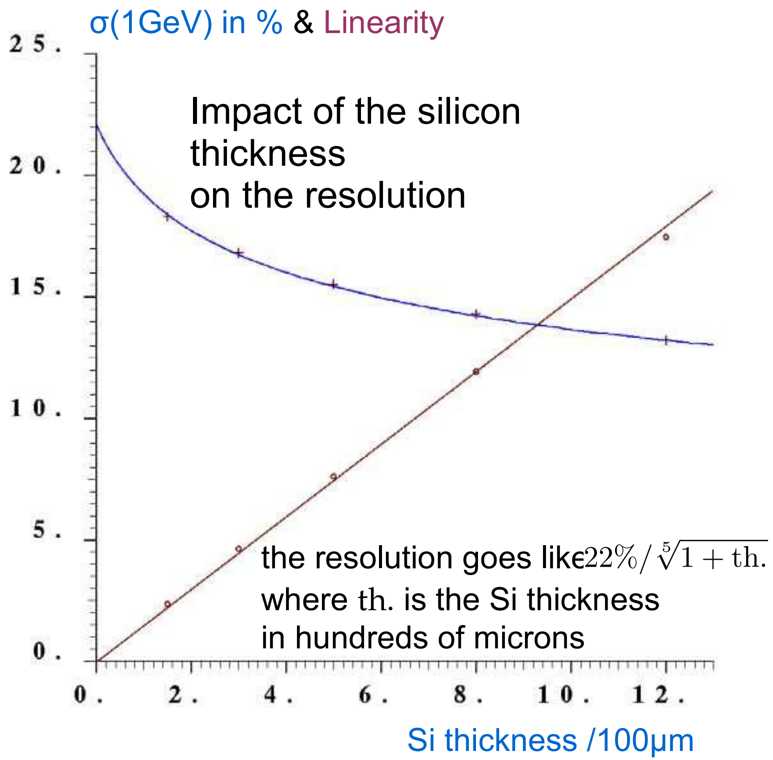
- for 22 layers w.r.t. 30: +16.8%
- with 725µm w.r.t 500µm : –6.1%

ECal thickness = 190.1 mm (close to 185 mm of DBD).

- 22 layers = 14 layers with 2.8mm thickness
  + 8 layers with 5.6mm shared between structure and slabs.

Study needed on separation, resolution and efficiency performances at low energy.

- JER : $\sigma(E_J)/E_J$ +10% for 20 layers (500 µm).



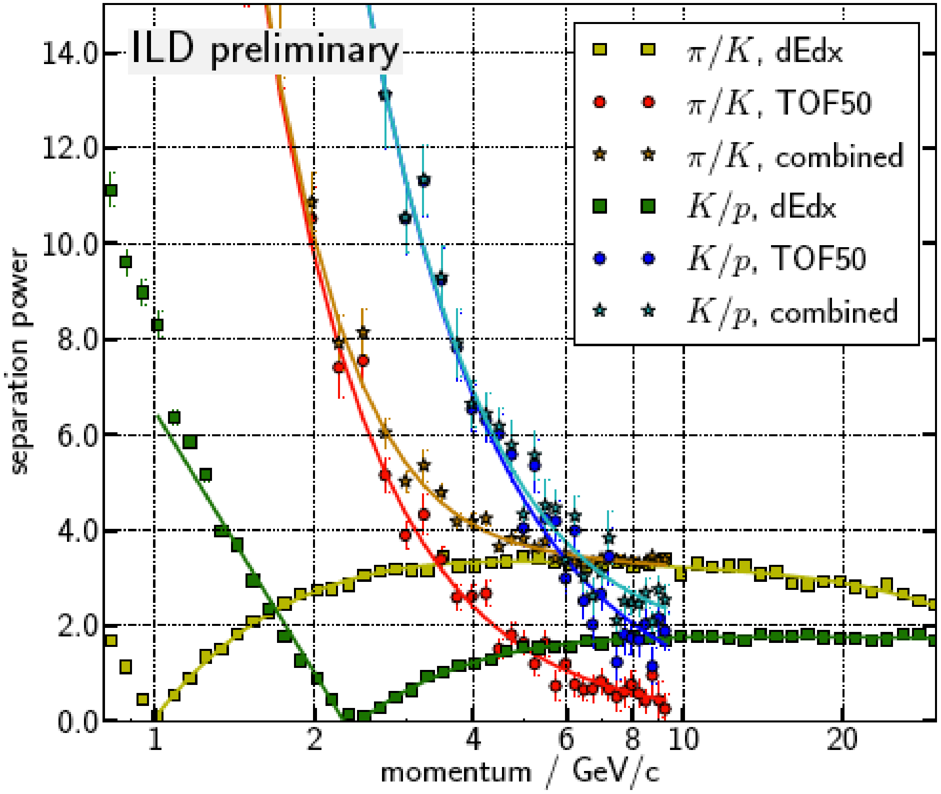
Timing

Particle ID:

- ToF ⊕ dE/dx

Partcle Flow:

- Fast core of showere for early clustering
- Suppression of slow & diffuse neutrons
- Identification of backscattered particles



Test of SK2A → Timing ?

Adding 5th dimension:

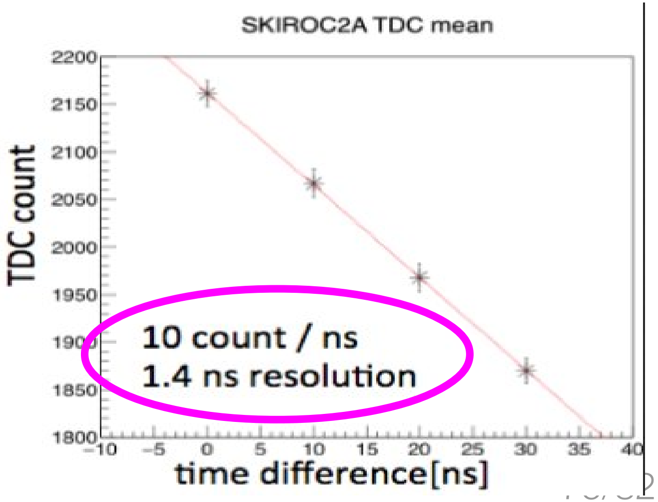
- Can:
  - Improve Particle Flow SW ***with ~ns mip precision***
    - Tracking of particles
    - Removal of late neutrons
    - Identification of back scattered
  - Allow Particle identification by ToF ***with sub-ns precision***

- *Clean Clock distribution*
  - *Shower timing ~ 1/√E*

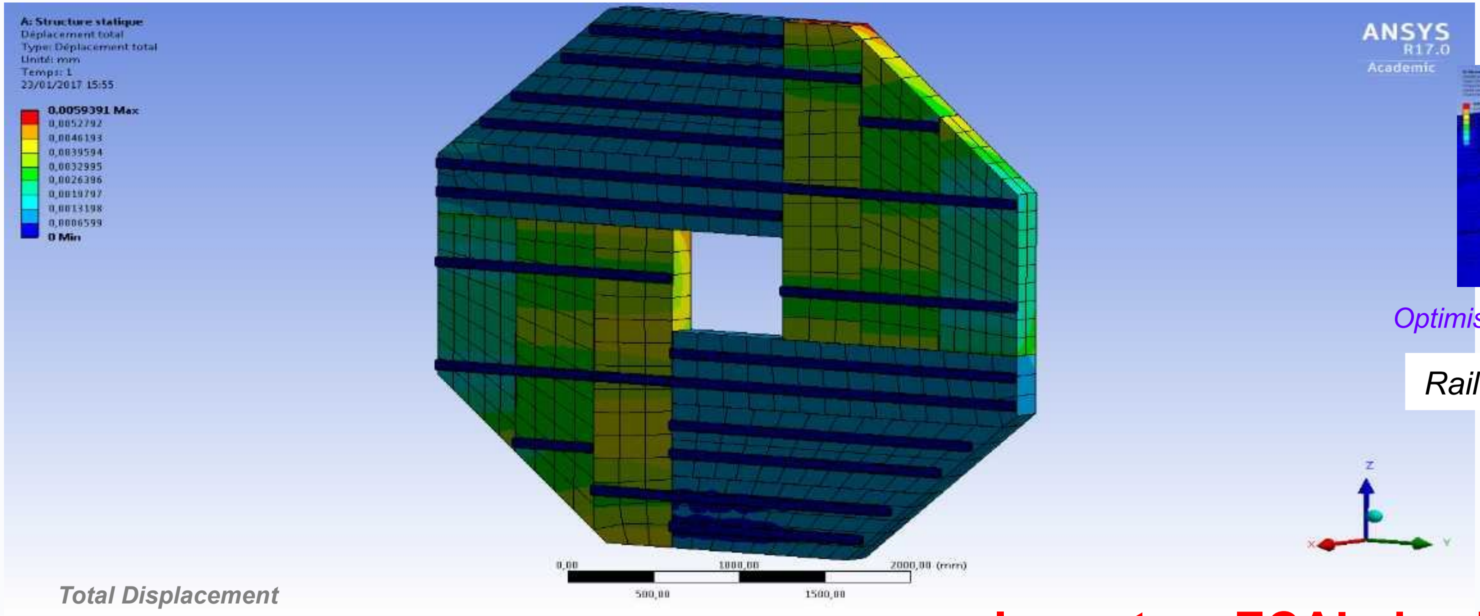
- *@ LHC See presentation on HGCAL*

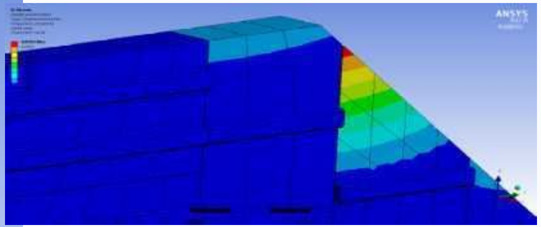
Checked SK2A on Test Board

- Thorough checks on 1–2 mip injected signal
  - All seems OK
  - No difference in Analog part
- Trigger:
  - large channel-by-channel adjustment ✔
  - TDC: OK



Structure composite & séisme



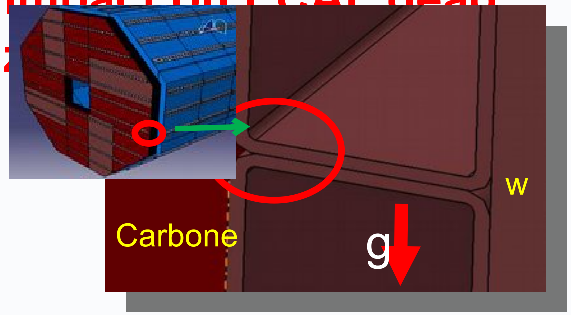


Optimisation on going / rails localisation/ on going

Rails fixed

Mode	Fréquence [Hz]
1,	203,56
2,	204,24
3,	206,17
4,	208,13
5,	211,64
6,	212,02

Impact on ECAL dead



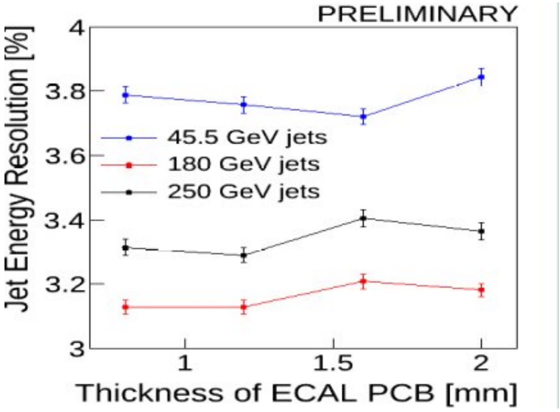
Problem of bending stress of alveoli skins: influence / evolution of thickness of outer plies

Safety coefficient

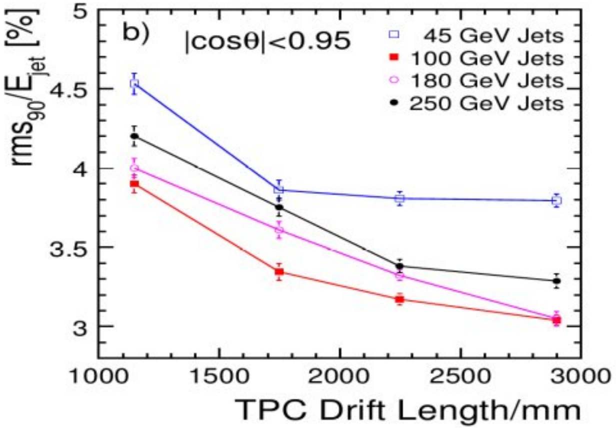
- Static: Sufficient / to the stress induced by weight of modules
- just sufficient / seism (s =3.2 for Japan?)
  / risks during integration and transport

-> increase nb of ext. plies... Impact on ECAL dead zone=0,5mm= 1 extra external ply on modules

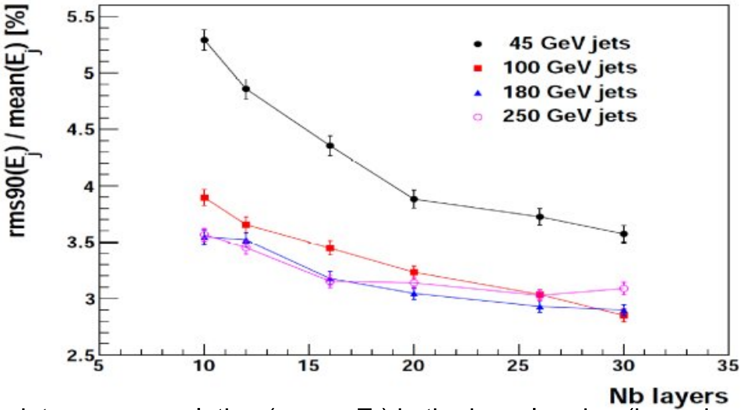
Some optimisation studies



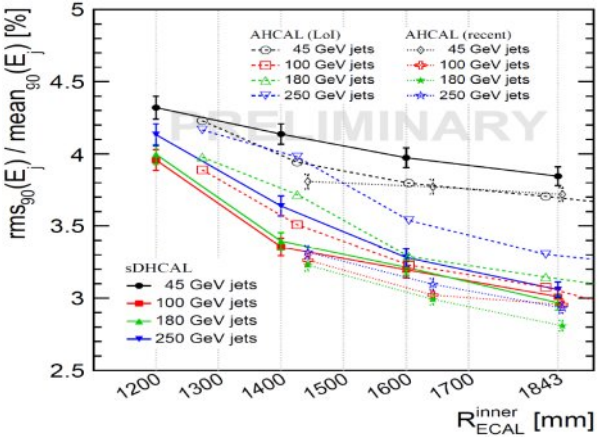
Single jet energy resolution as a function of the thickness of PCB with embedded electronics.



Single photon energy resolution as a function of the number of silicon layers for four photon energies.

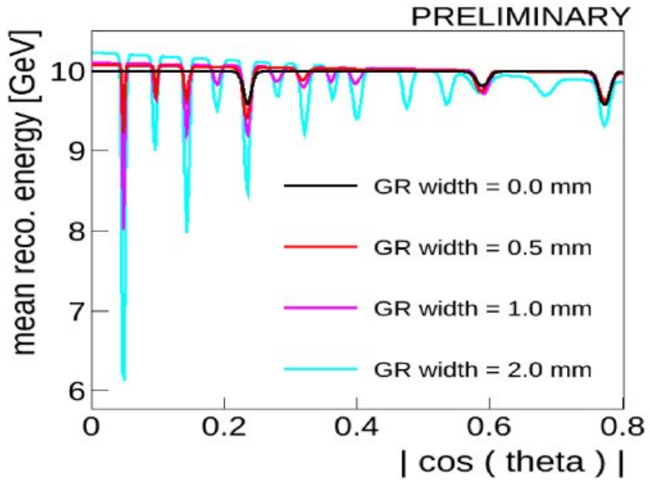


Single jet energy resolution (rms90=E) in the barrel region (j cos j < 0: 7) as a function of the number of ECAL silicon layers in events e+e-→ ZX → usd

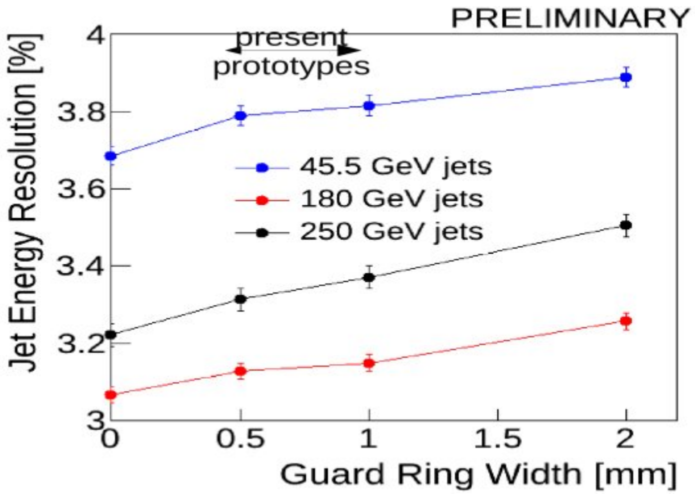


ILD jet energy resolution in the barrel region j cos j < 0: 7 as a function of its radius.

Some optimisation studies



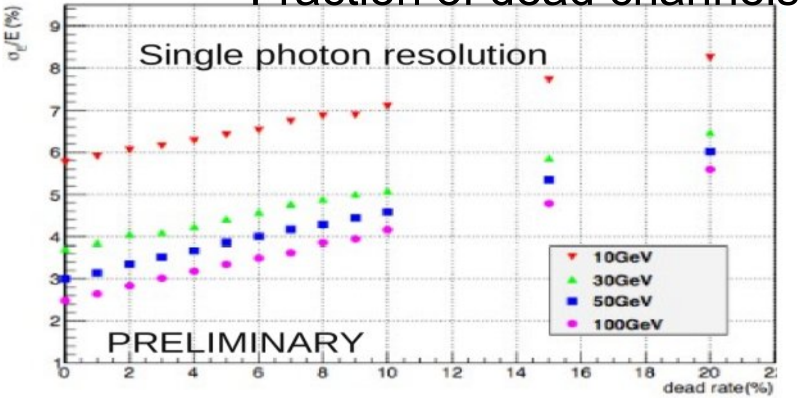
An ECAL average signal versus azimuthal angle. The loss in inter-sensor dead areas is visible (between barrel modules, barrel and endcap and between the sensors, the latter depends on the guard ring).

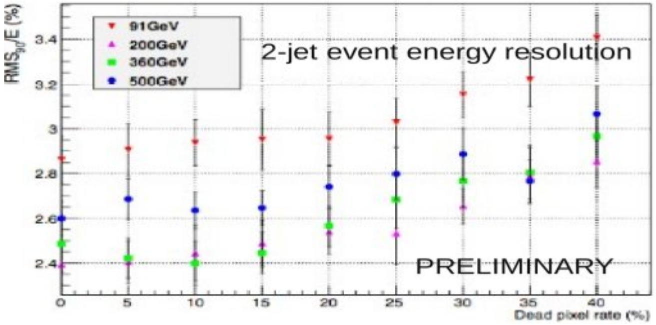


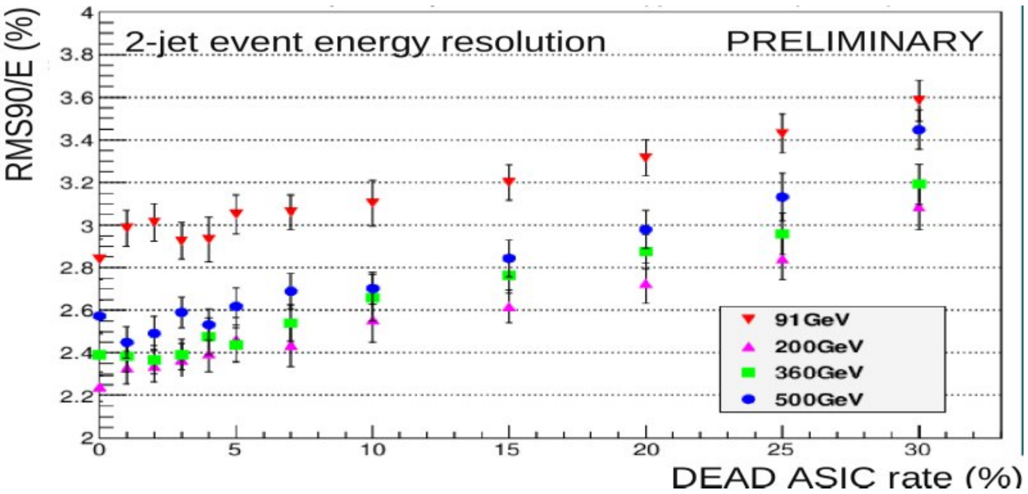
the single jet energy resolution after a simple dependent correction as a function of the guard ring thickness.

Resilience studies

Fraction of dead channels

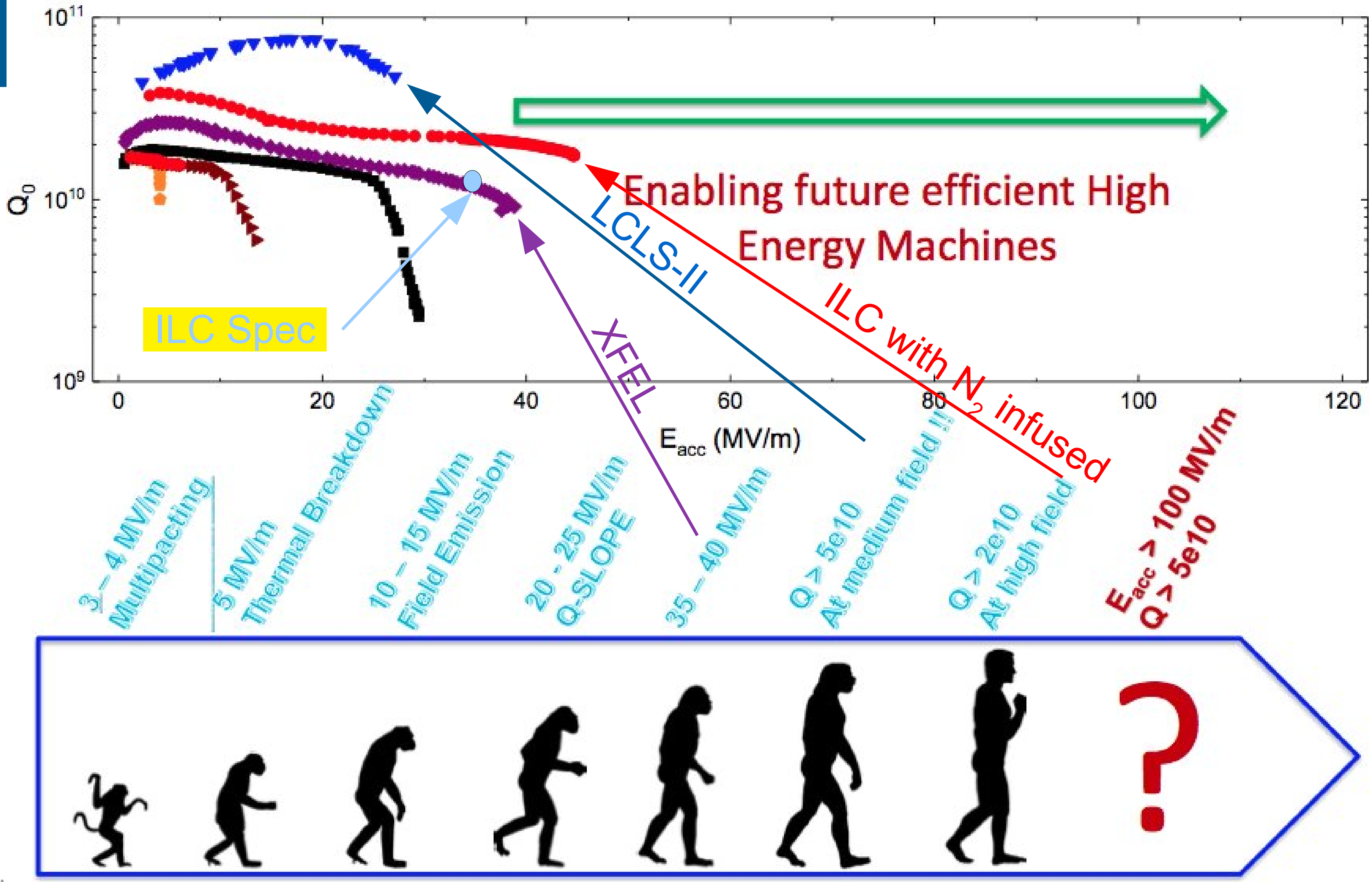


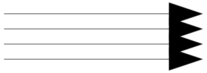




SRF Performance Evolution

Courtesy A. Grassellino

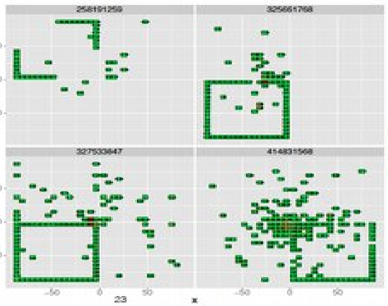


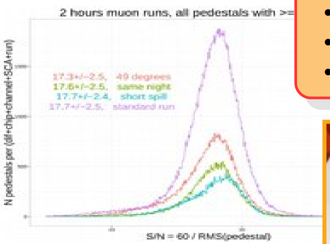


Beam-test 2015–2018

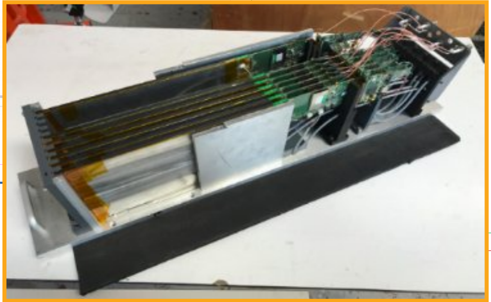
CERN 2015

"Naked FEV11"





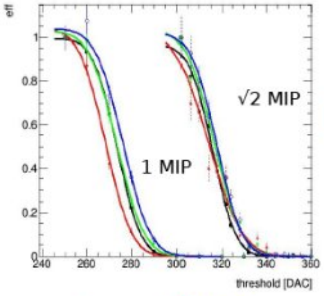
S/N_{ADC} = 16–17
(MIP – ped) / σ_{ped}
Defaults cataract :
- Negative signals
- re-triggers
- ~ high thr.
- sq events / 10



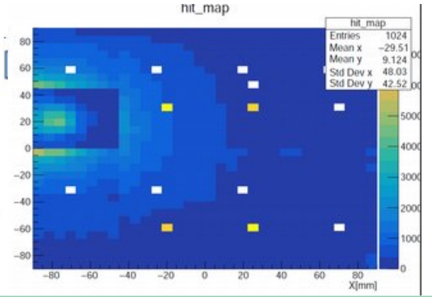
DESY 2018

7 FEV11 + 1 FEV13(650µm)

S/N_{Trig} ~ 11.6.±0.7
Trigger → ~1/3 mip (est.)
First comm. of FEV13

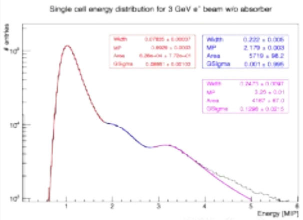


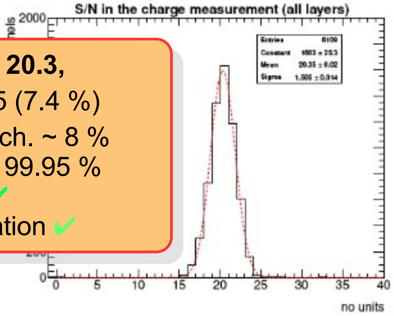
Slab **17**, **18**, **19**, **20**
S/N = 11.6 ± 0.7

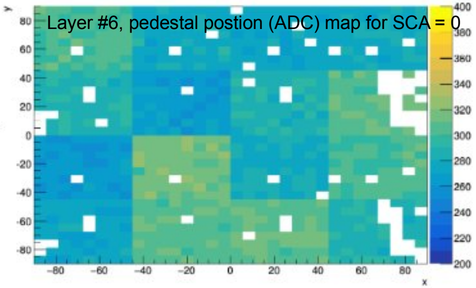


DESY 2017

7 FEV11





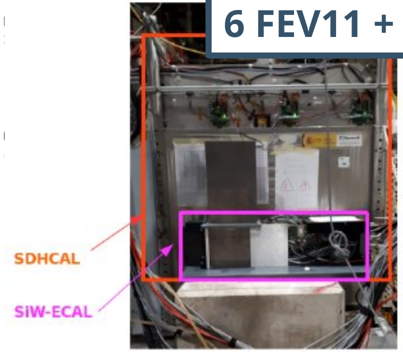


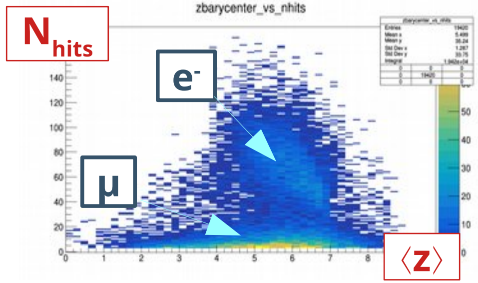
S/N_{ADC} = 20.3,
$\sigma_{S/N}$ = 1.5 (7.4 %)
masked ch. ~ 8 %
Hit eff. ~ 99.95 %
0°, 45° ✔
1T operation ✔

CERN 2018

Masked ch (FEV11) ~ 4 %

6 FEV11 + 4 FEV13(320 & 650µm) + 24X_0 W

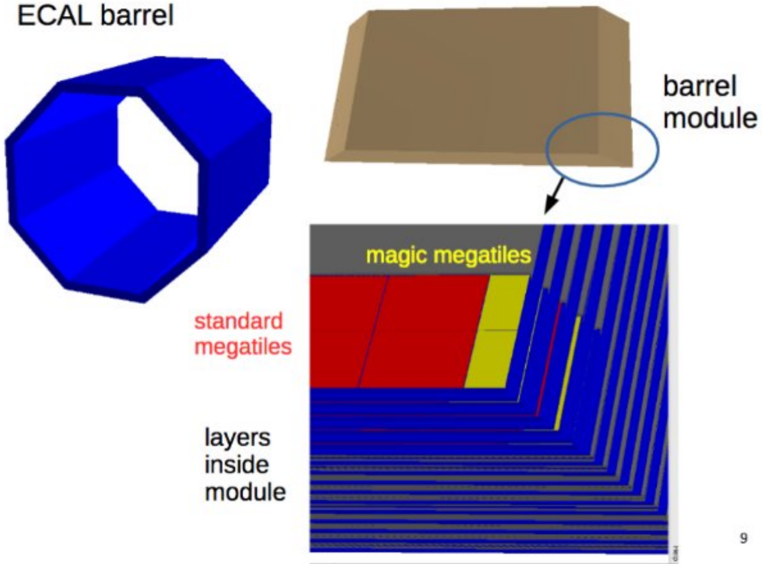




Simulation

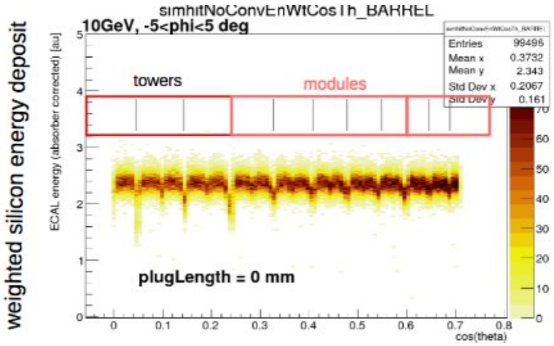
ECAL driver used in ILD models has been largely re-written (Mokka → DD4HEP)

- more modular code:
- less duplication Barrel & Endcap
- more configurable…



Effect of cracks [RAW= no correction at all!!]

- Drop ~ 15%



Effect of plug (missing in previous simulations)