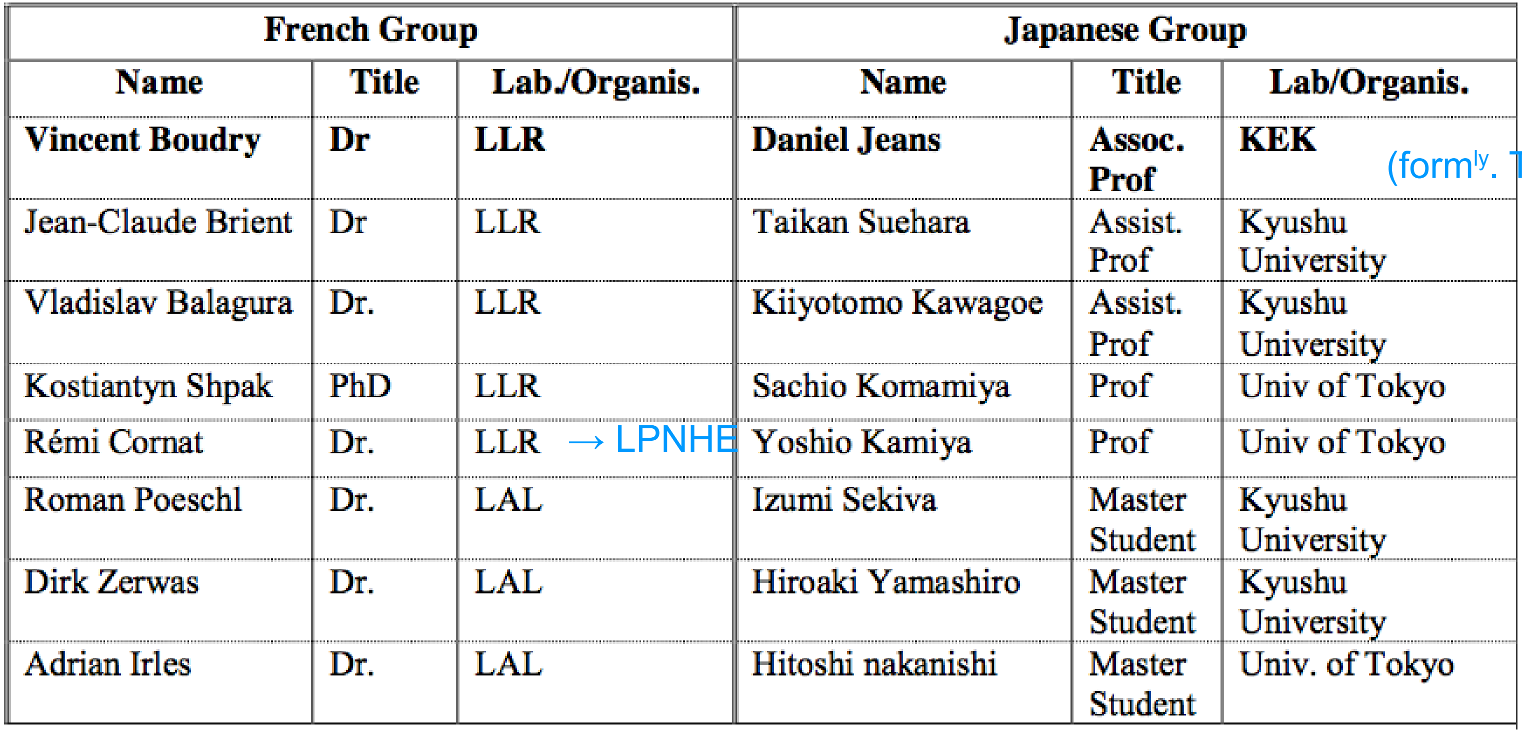
A highly granular Silicon-Tunsgten ECAL for the ILC

Vincent Boudry
École polytechnique, Palaiseau
for SiW-ECAL groups

FJPPL 2017
IHPC, Strasburg
11/05/2017

TNA support + WP14

Involved persons & institutions

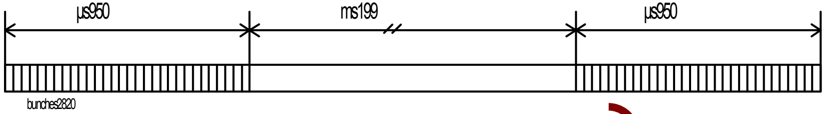


French Group			Japanese Group		
Name	**Title**	**Lab./Organis.**	**Name**	**Title**	**Lab./Organis.**
Vincent Boudry	**Dr**	**LLR**	**Daniel Jeans**	**Assoc. Prof**	**KEK** (form^{ly}. Tokyo)
Jean-Claude Brient	Dr	LLR	Taikan Suehara	Assist. Prof	Kyushu University
Vladislav Balagura	Dr.	LLR	Kiiyotomo Kawagoe	Assist. Prof	Kyushu University
Kostiantyn Shpak	PhD	LLR	Sachio Komamiya	Prof	Univ of Tokyo
Rémi Cornat	Dr.	LLR → LPNHE	Yoshio Kamiya	Prof	Univ of Tokyo
Roman Poeschl	Dr.	LAL	Izumi Sekiva	Master Student	Kyushu University
Dirk Zerwas	Dr.	LAL	Hiroaki Yamashiro	Master Student	Kyushu University
Adrian Irles	Dr.	LAL	Hitoshi nakanishi	Master Student	Univ. of Tokyo

2 “new” institutions

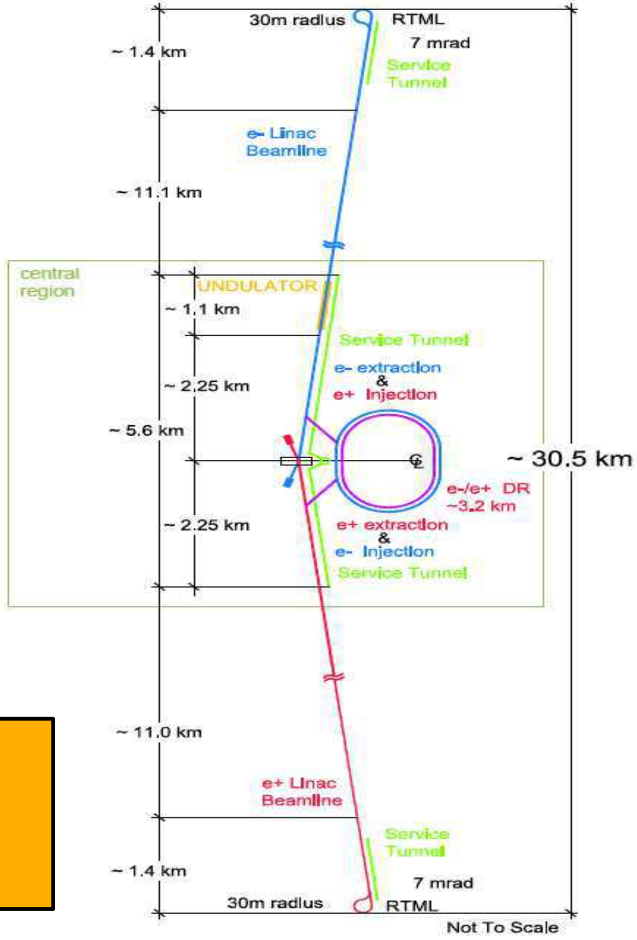
ILC parameters

Max. Center-of-mass energy	**250**–1000 (90)	GeV
Peak Luminosity	0,8–3x10^{34}	1/cm^{2}s
Beam Current	5.8	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.95	ms
Total Site Length	31	km
Total AC Power Consumption	120-300	MW



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

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



Constrains 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 ~ $(\text{resol})^{-1/2}$
  60%/√E ⟶ 30%/√E ⇔ +~40% L

Large TPC

- Precision and low X_0 budget
- Pattern recognition

High precision on Si trackers

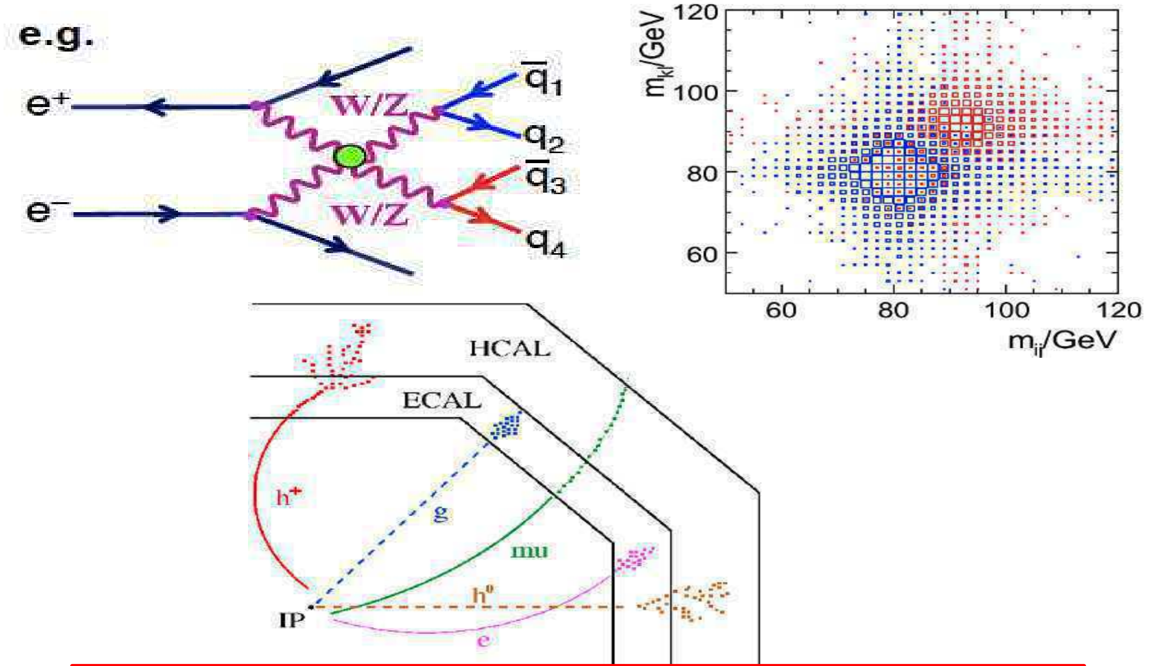
- Tagging of beauty and charm

Large acceptance

Fwd Calorimetry:

- lumi, veto, beam monitoring

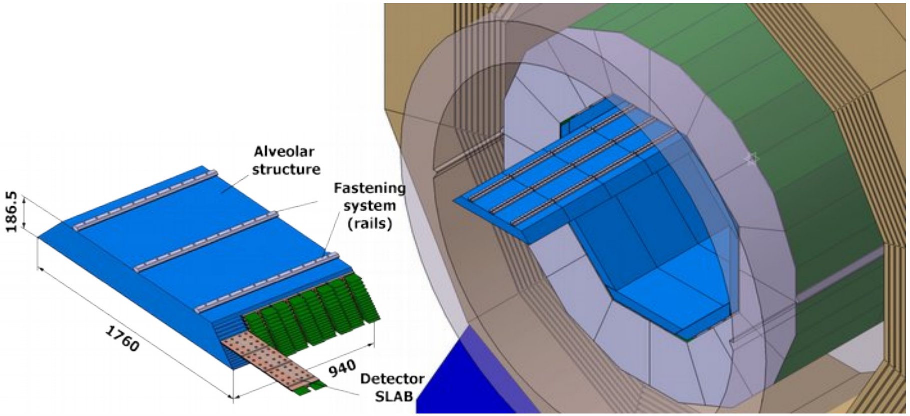
Imaging Calorimetry



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

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

An Ultra-Granular SiW-ECAL for experiments



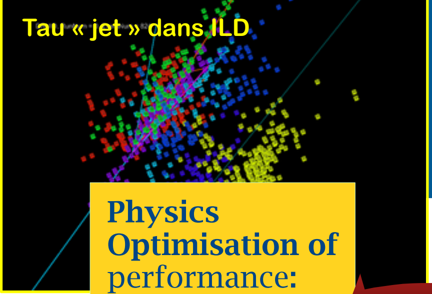
Particle Flow optimised calorimetry

- Standard requirements
  - Uniformity, Hermeticity, Stability, (E, x , t) Resolution
- PFlow requirements:
  - Extremely high granularity
  - Compacity (density)

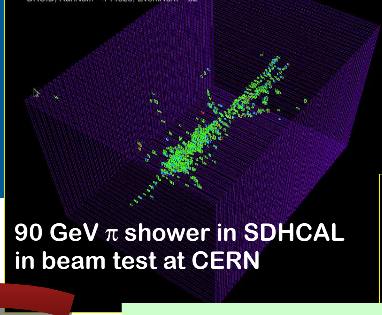
SiW+C baseline choice for future Lepton Colliders

Basic Choices:

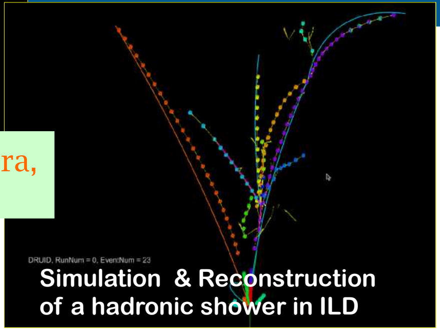
- Tungsten as absorber material
  - $X_0 = 3.5$ mm, $R_M = 9$ mm, $\lambda_I = 96$ mm
  - **Narrow showers**
  - **Assures compact design**
- Silicon as active material
  - **Support compact design**
  - **Allows for ~any pixelisation**
  - **Robust technology**
  - **Excellent signal/noise ratio: ≥10**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



Physics Optimisation of performance:
- **Z-jets, Tau's**
- **ILC, CEPC**



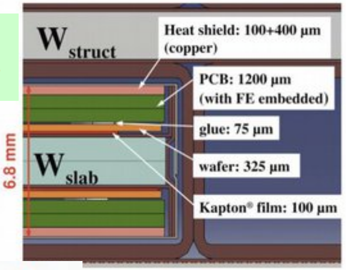
PFA tools Pandora, ARBOR, GARLIC



ILD

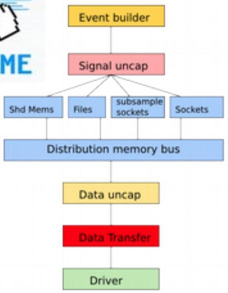
CALICE
Calorimeter for ILC

Simulation:
Mokka / DD4HEP

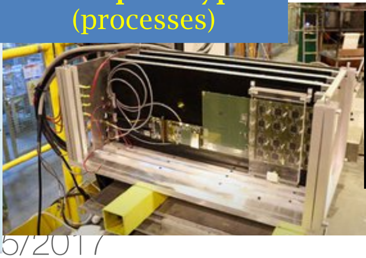


R&D **DAQ**
generic
HW, FW et SW

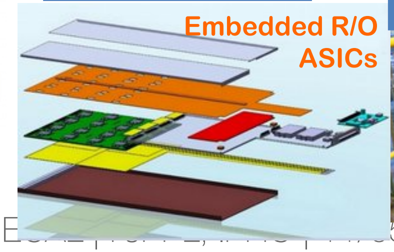
PYRAME

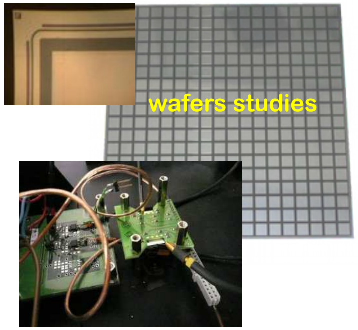


Building &
Test of **prototypes**
(processes)

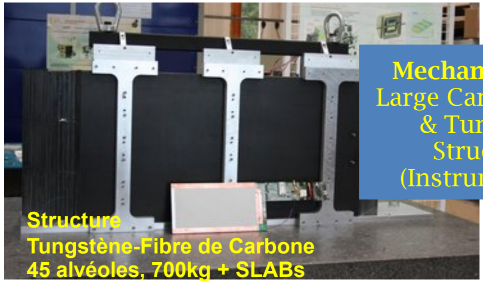


R&D Instrum.:
Design, Test &
industrialisation
Silicon Wafers

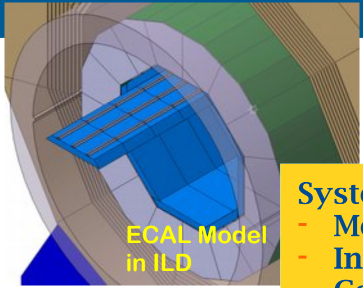


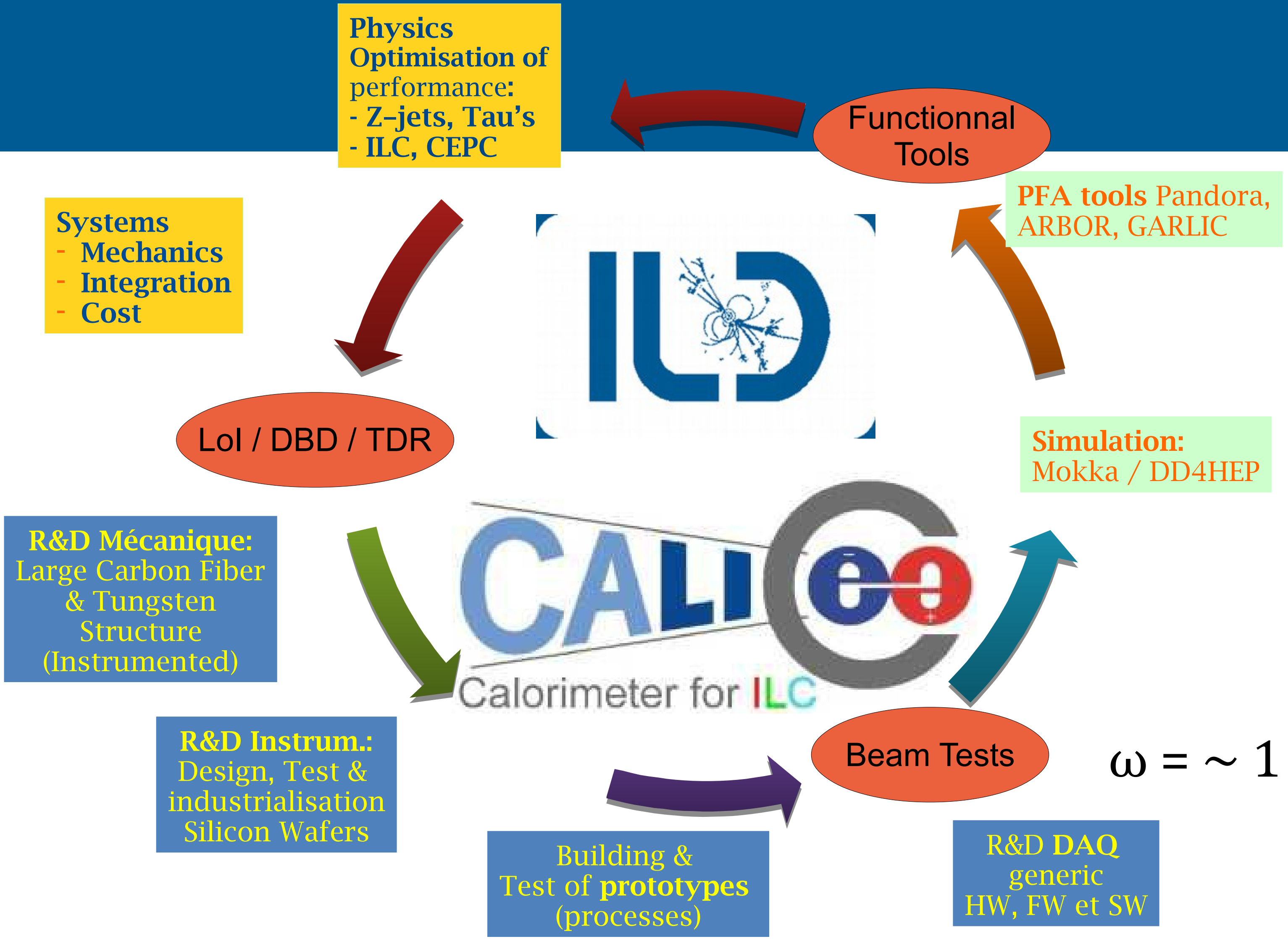


Mechanics R&D
Large Carbon Fiber
& Tungsten
Structure
(Instrumented)



Systems
- **Mechanics**
- **Integration**
- **Cost**





Physics
Optimisation of performance**:**
- **Z–jets, Tau's**
- **ILC, CEPC**

Systems
- **Mechanics**
- **Integration**
- **Cost**

LoI / DBD / TDR

R&D Mécanique:
Large Carbon Fiber
& Tungsten
Structure
(Instrumented)

R&D Instrum.:
Design, Test &
industrialisation
Silicon Wafers

Building &
Test of **prototypes**
(processes)

Beam Tests

R&D **DAQ**
generic
HW, FW et SW

Simulation:
Mokka / DD4HEP

PFA tools Pandora,
ARBOR, GARLIC

Functionnal
Tools

ω = ~ 1 / 5 years

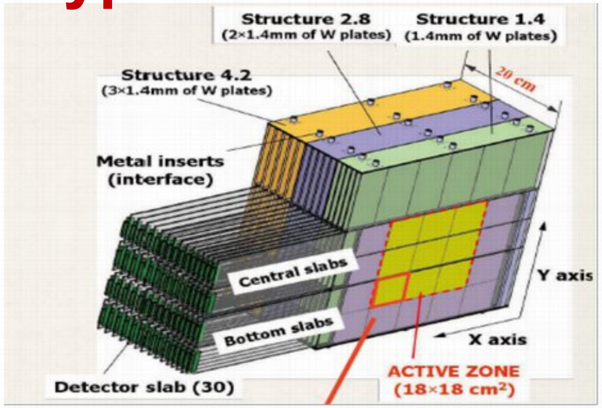
SiW ECAL: Physics & Technological prototype

Physics prototype: 2005–2011

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

- 1cm x 1cm pixels
- full 30 layers

(used for PAMELA sat.)



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

Assess the feasibility:
Establish procedures and develop
test benches for mass production : ***AIDA-2020, pre-prod test benches.***

- 10 000 SLAB's ⊃ ~75 000 ASU to be produced for ILD

Technological prototype

Embedded electronics

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

ILD Building blocks: SLAB’s & ASU’s

R&D for “mass production” and QA

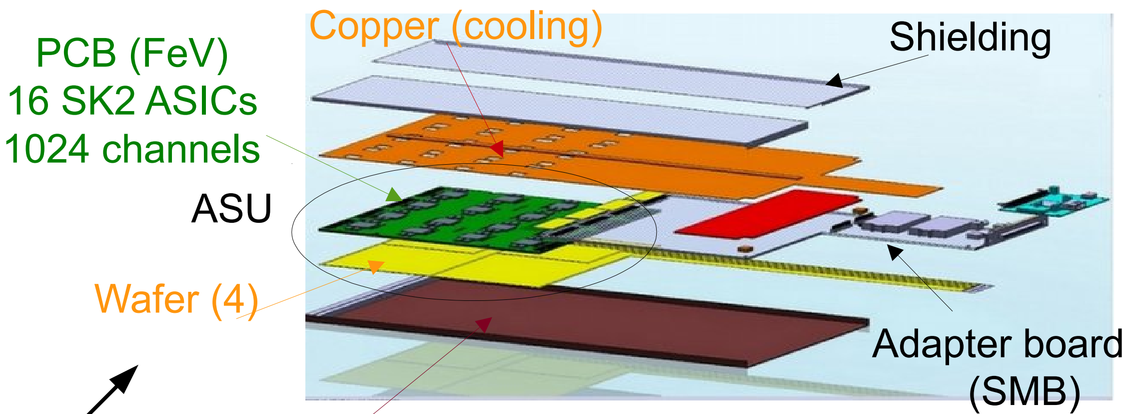
- Quality tests & preparation of large production
- Modularity → ASU & SLABs
- Choice of square wafers
  - (≠ from hex: SiD, CMS HGCAL)

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

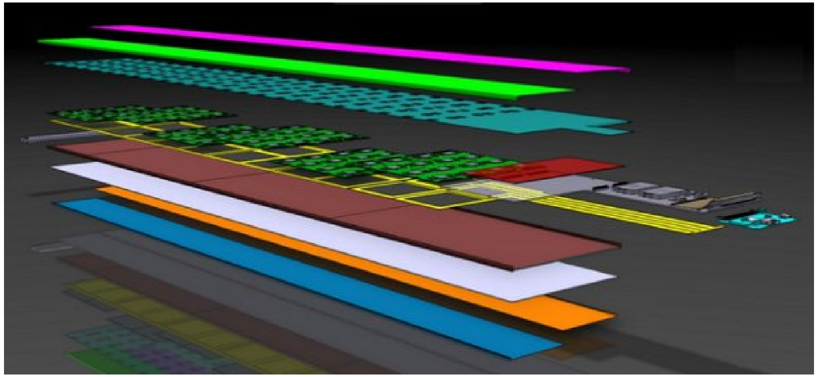
- Barrel modules: 40 (as of today all identical)
- Endcap Modules: 24 (3 types)
- ASUs = ~75,000
  - Wafers ~ 300,000 (2500 m^2)
  - VFE chips ~ 1,200,000
  - Channels: 77Mch
- Slabs = 6000 (B) + 3600 (EC) = 9600
  - ≠ lengths and endings

Tests of producibility

Tests of feasability



U layout of a **short slab**

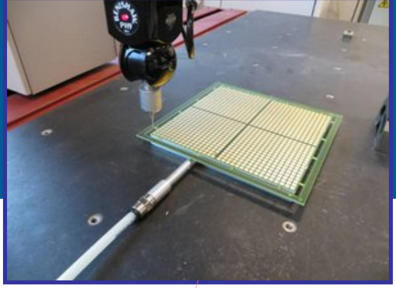


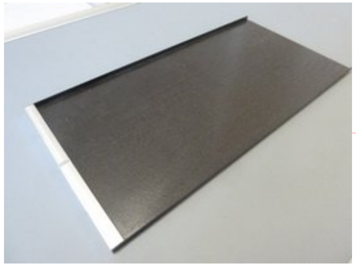
U layout of a **long slab**

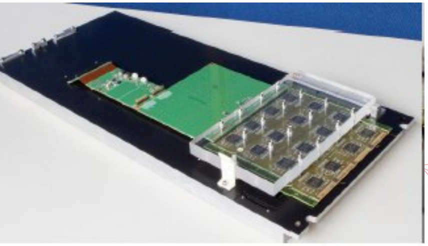
Full assembly chain

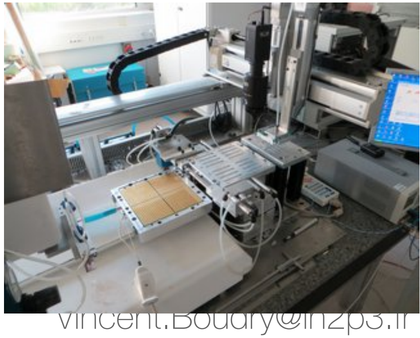
resp: R. Cornat

LLR, LPNHE, LAL

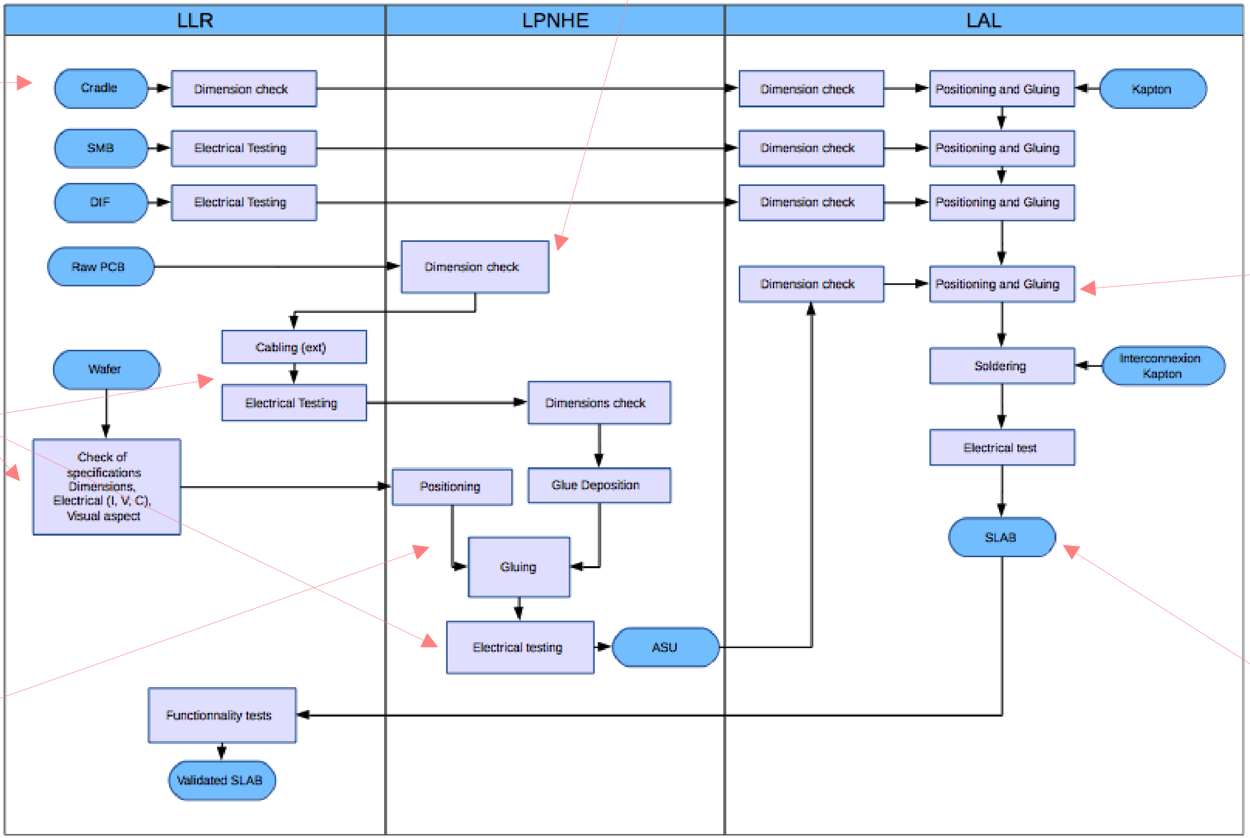


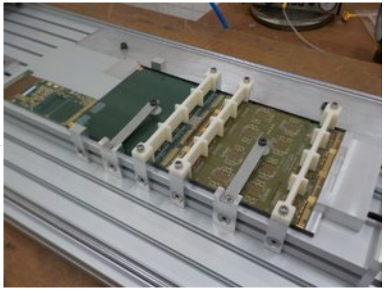


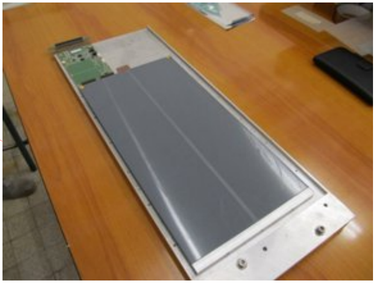




‘Simplified view’



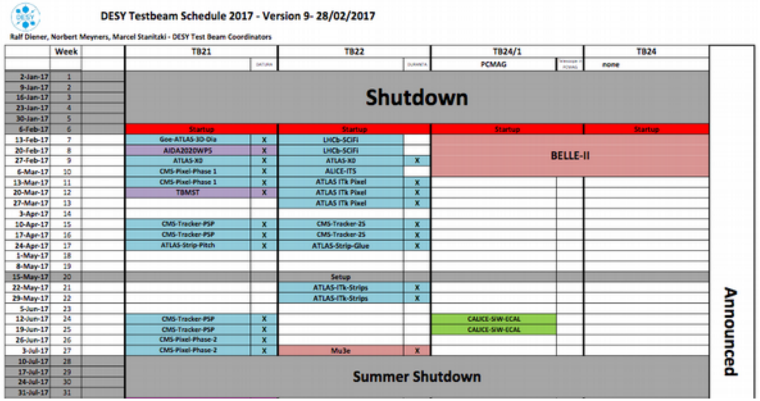




Beam test 2017: Prototype

with 10 first^{t} SLAB's

- noise handling
  - Scans.
  - Time dependance ?
  - PS dependance ?
- Cosmic data taking
  - ⚠ hasher running conditions…
    (longer integration time)



DESY Testbeam Schedule 2017 - Version 9- 28/02/2017

Ralf Diener, Norbert Meyners, Marcel Stanitzki - DESY Test Beam Coordinators

	Week		TB21		TB22		TB24/1		TB24
				DATURA		DURANTA	PCMAG	[illegible]	none
2-Jan-17	1		Shutdown						
9-Jan-17	2								
16-Jan-17	3								
23-Jan-17	4								
30-Jan-17	5								
6-Feb-17	6		Startup		Startup		Startup		Startup
13-Feb-17	7		Goe-ATLAS-3D-Dia	X	LHCb-SCIFI		BELLE-II		
20-Feb-17	8		AIDA2020WP5	X	LHCb-SCIFI				
27-Feb-17	9		ATLAS-X0	X	ATLAS-X0	X			
6-Mar-17	10		CMS-Pixel-Phase 1	X	ALICE-ITS				
13-Mar-17	11		CMS-Pixel-Phase 1	X	ATLAS ITk Pixel	X			
20-Mar-17	12		TBMST	X	ATLAS ITk Pixel	X			
27-Mar-17	13				ATLAS ITk Pixel	X			
3-Apr-17	14								
10-Apr-17	15		CMS-Tracker-PSP	X	CMS-Tracker-2S	X			
17-Apr-17	16		CMS-Tracker-PSP	X	CMS-Tracker-2S	X			
24-Apr-17	17		ATLAS-Strip-Pitch	X	ATLAS-Strip-Glue	X			
1-May-17	18								
8-May-17	19								
15-May-17	20				Setup				
22-May-17	21				ATLAS-ITk-Strips	X			
29-May-17	22				ATLAS-ITk-Strips	X			
5-Jun-17	23								
12-Jun-17	24		CMS-Tracker-PSP	X			CALICE-SiW-ECAL		
19-Jun-17	25		CMS-Tracker-PSP	X			CALICE-SiW-ECAL		
26-Jun-17	26		CMS-Pixel-Phase-2	X					
3-Jul-17	27		CMS-Pixel-Phase-2	X	Mu3e	X			
10-Jul-17	28		Summer Shutdown						
17-Jul-17	29								
24-Jul-17	30								
31-Jul-17	31								

Announced

⇒ Test of 15–20 SLABs early in 2018

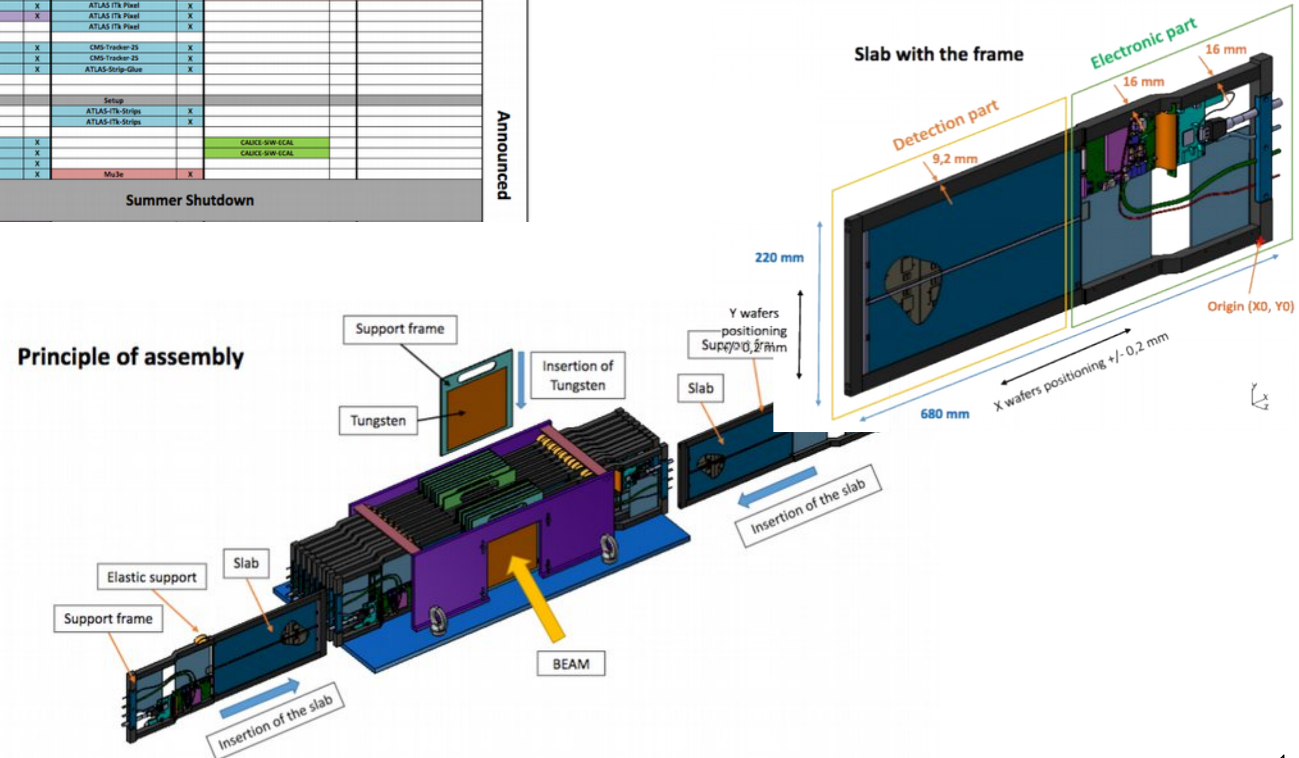
- with new structure [Guillaume]

Beam test in 12–24 June @ DESY

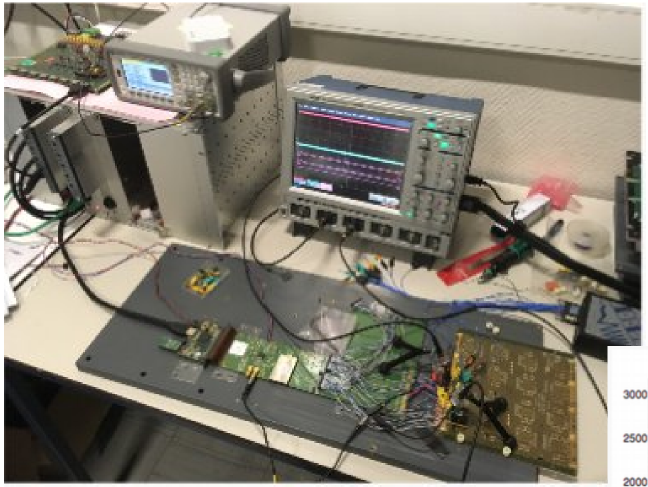
- Readiness review mi-April

Analysis + of nov 15 data.

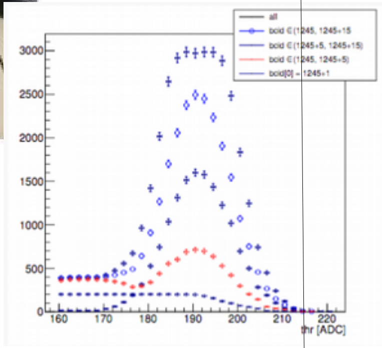
- ⇒ Start of assembly for second batch …

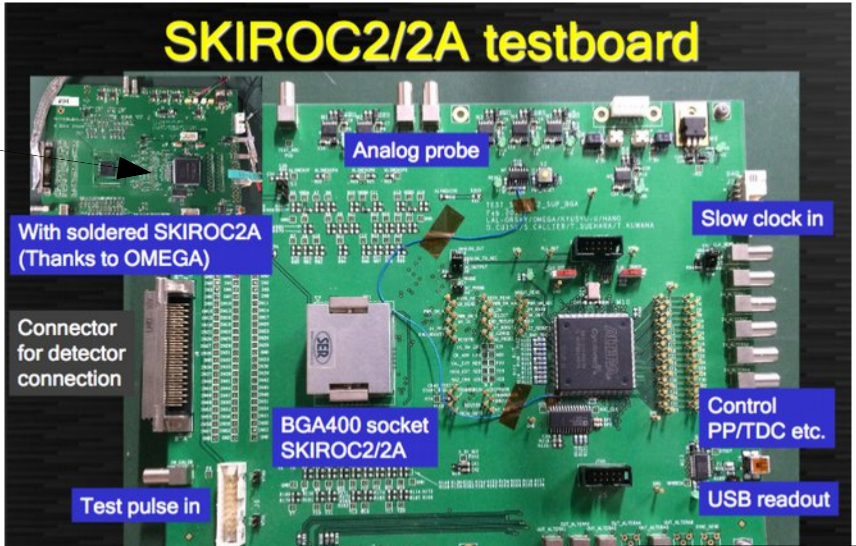


VFE ASIC [LLR, Kyushu]
Omega Skiroc2 vs Skiroc2a



Same with SK2**CMS**



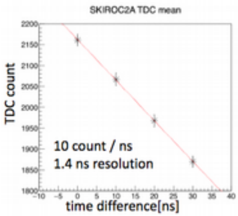


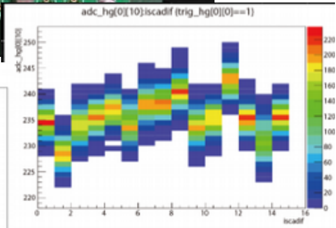
Socket test of ASICs on ASU

- Noise & functional checks
  - trigger (over)efficiency, tagging, ADC, TDC, …
- Running modes for Beam Tests
  - ↔ Full SLABS

V. Boudry, S. Chaitanya, A. Lobanov (LLR)

Dedicated Test board





- for optimal use of ASIC (all protections)
  - Systematic test of protections (on-going)

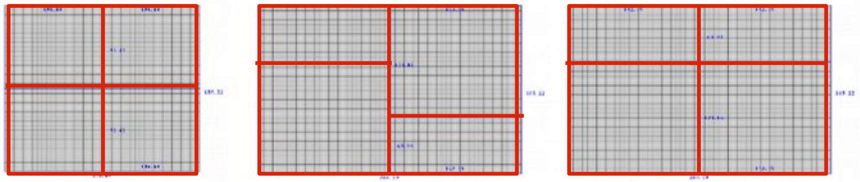
I. Sekiya, T. Suehara(Kyushu University)

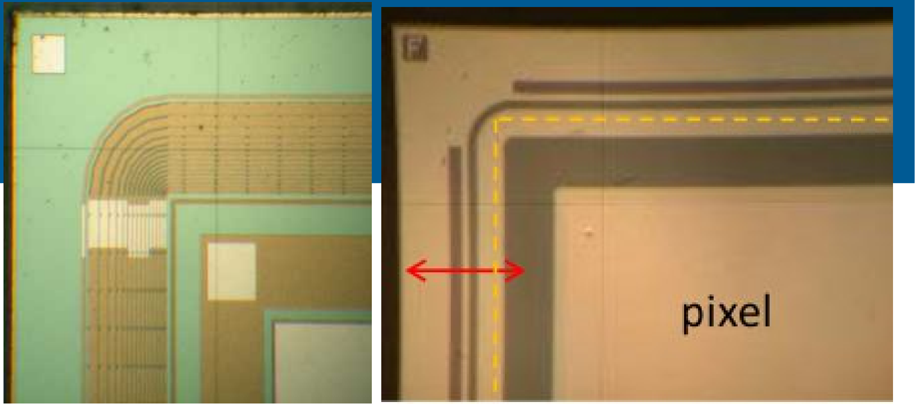
Silicon Sensors

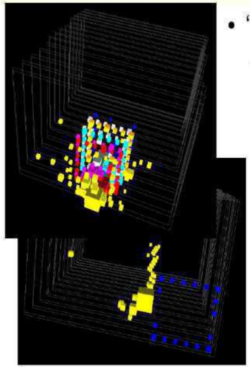
Cost driven

- ~30% of the total cost of the SiW-ECAL
  - ⇒ Units Cost reduction(CALIIMAX program)
- Decoupling of Guard Ring (Square Events).
- new design of ILD detector

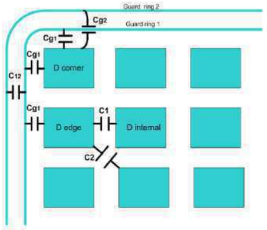
Command Sensors @ Hamamatsu

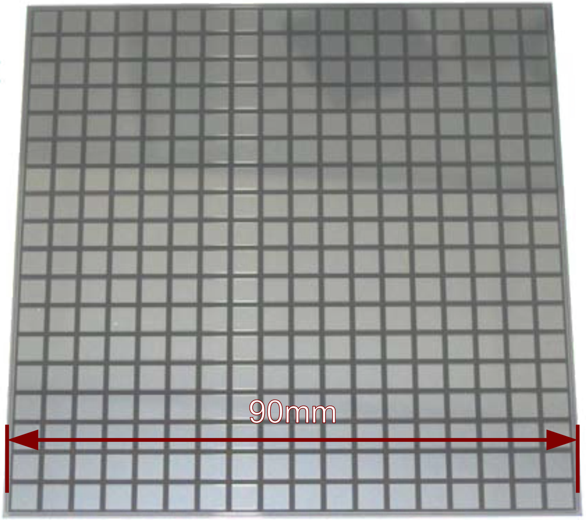
- ⚠ Minimal cost of Command ≥ 20k€
- direct contact with HPK engineers
  - (last @ LCWS'2016)
- Possibility of design for 8'' in 186mm alveola
- 





- "Square events"
  - cross talk between guard rings and pixels





'quantum unit' of ILD dimensions (here 4'' wafer)

Wafers [LLR, Kyushu]

"Edgeless wafers"integrated in 2 of the 10 SLABs (2016)

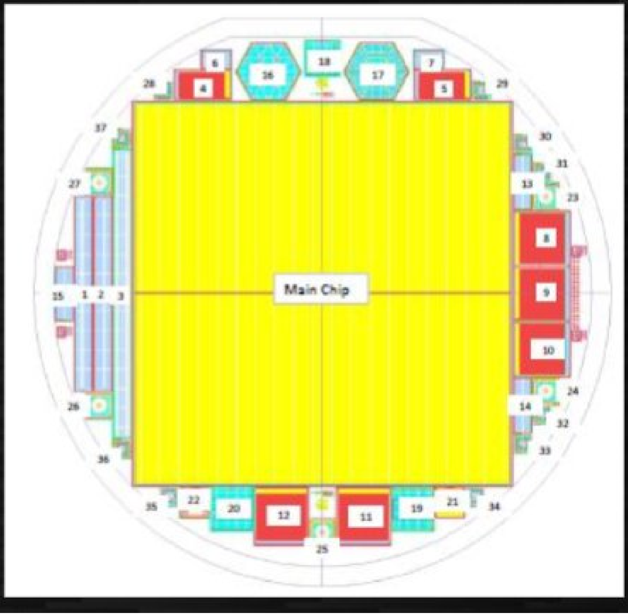
- needs BT data (with muon beam → edge scan)
  - Beam Tests June 2017 @ DESY

Baby sensors

- HPK change or resistivity in 2013
- Parasitic production

Position Sensitive Detector

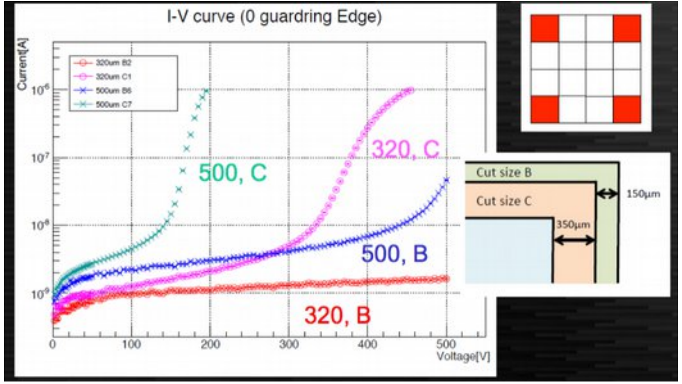
- Laser scan
  - reconstruction.



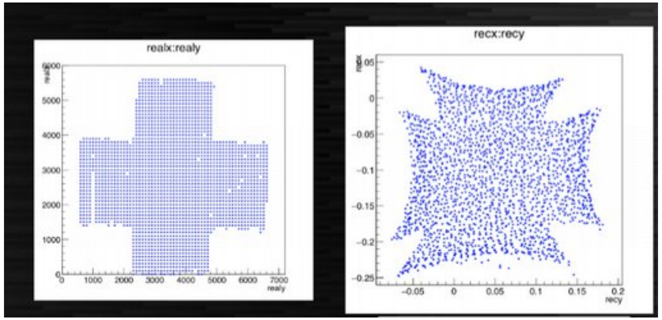
320 µm thickness
lower resistivity

16,17: Hexagon
(hexagonal cells,
triangular cells)
19,20: 4x4 (small pix)
(0 GR, 2 GR, 2.5 mm)
21,22: PSD (7 mm)
(meshed, non-meshed)

Each > 40 sensors

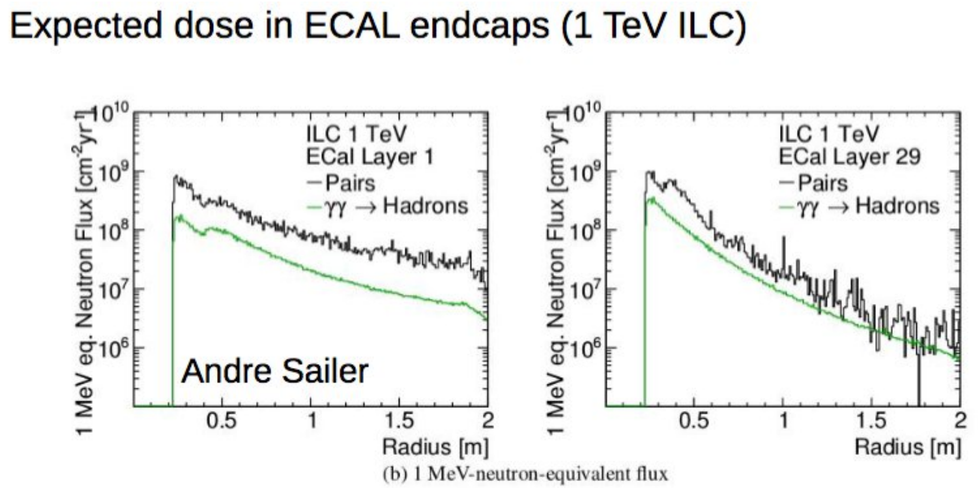


Prelim PSD reconstruction



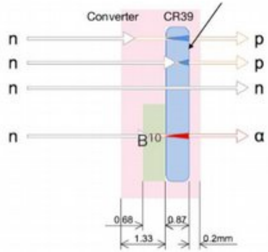
Irradiation tests [Tokyo]

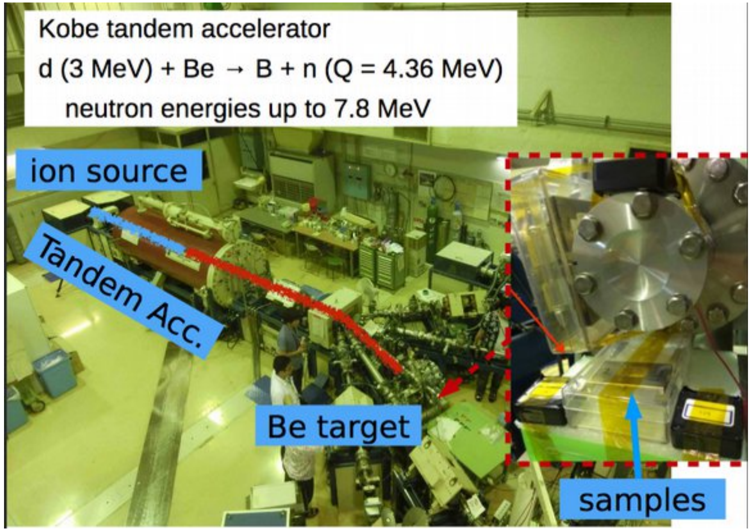
H. Nakanishi, C. Kozakai, Y. Kamiya, D. Jeans, S. Komamiya



(b) 1 MeV-neutron-equivalent flux

Flux meas. using CR30





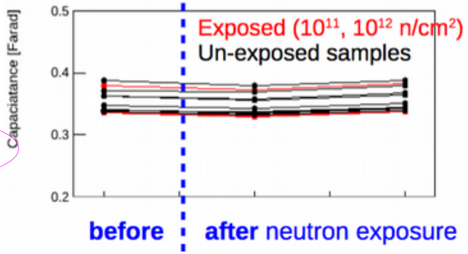
Expected dose in ECAL endcaps (1 TeV ILC) [ext^{ed} from CLIC studies]

- inner part of ECAL endcap: up to 10^9 1MeV eq. neutrons / cm² / year

Test of

- super-capacitor (AVX BestCap, 400mF)
- conductive glue: EPOTEK
- sensor HPK baby ECAL sensor (3x3 pixels) [standard guard ring design]

- Capacitance ✔
- Resistance ?
  - OK but puzzling
- I to V curve ✔
  - lim. to ASIC
  - for 50 years of ILC

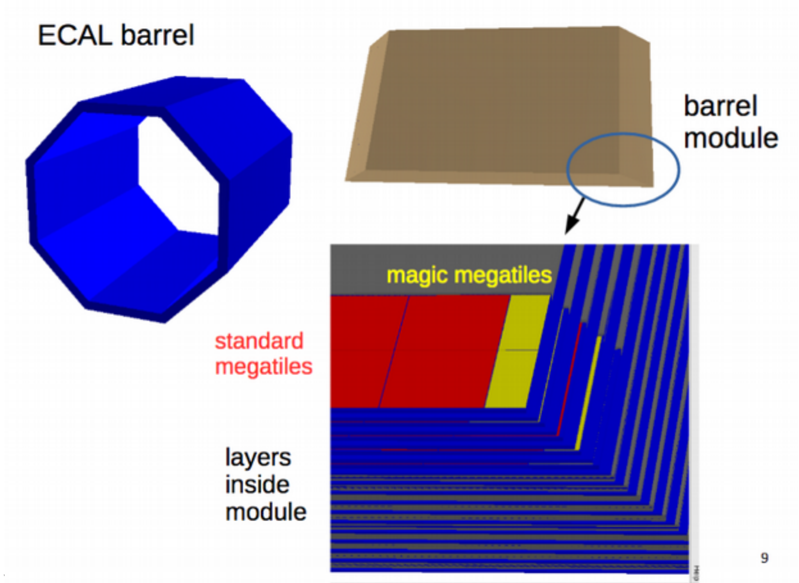


No sign of damage

New Simulation [D. Jeans]

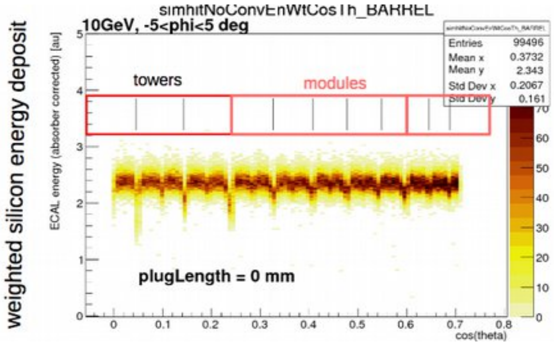
ECAL driver used in ILD models has been largely re-written (Mokka ⟶ DD4HEP)

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

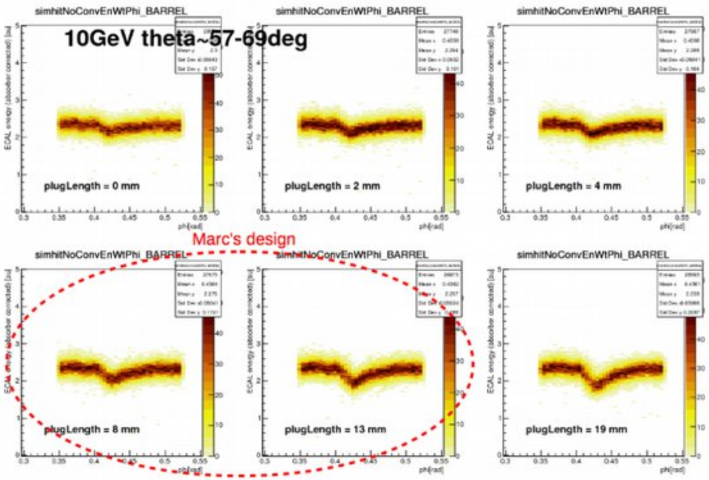


Effect of cracks [RAW= no correction at all!!]

- Drop ~ 15%



Effect of plug (missing in previous simulations)



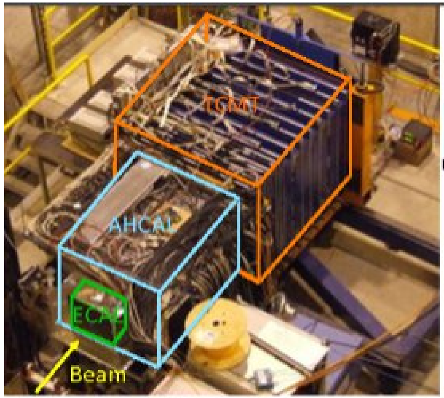
Performances: photon reconstruction confusion studies [K. Shpak]

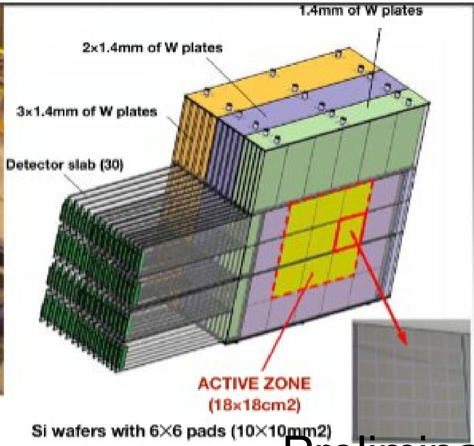
“raw performances”

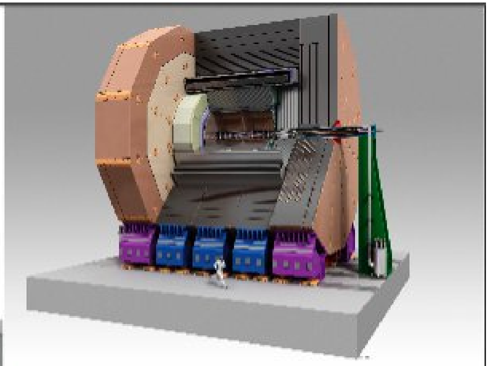
- Efficiency vs separation distance
- EM vs EM (e / γ)
- EM vs π

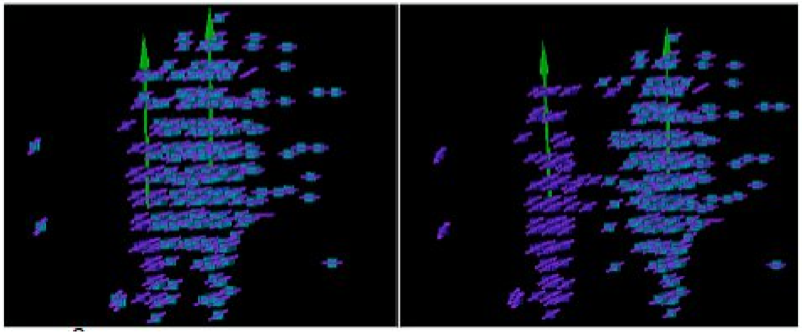
Using Particle Flow Algorithms

- PandoraPFA, Arbor (IHEP/LLR)
- **GARLIC** (LLR, Tokyo)

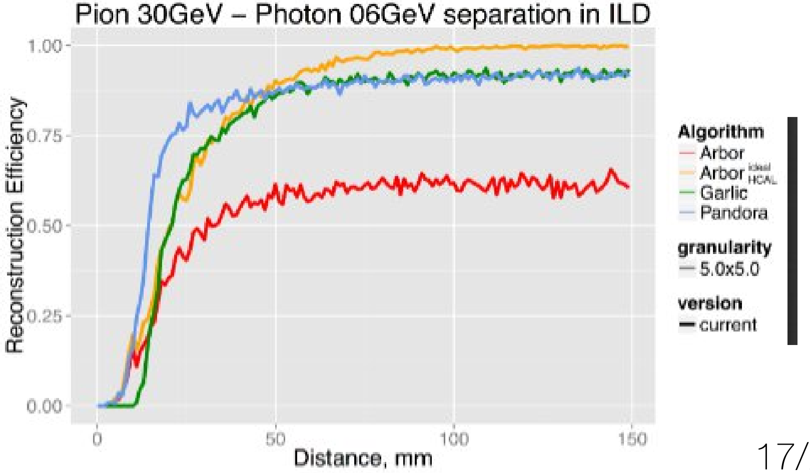








Preliminary



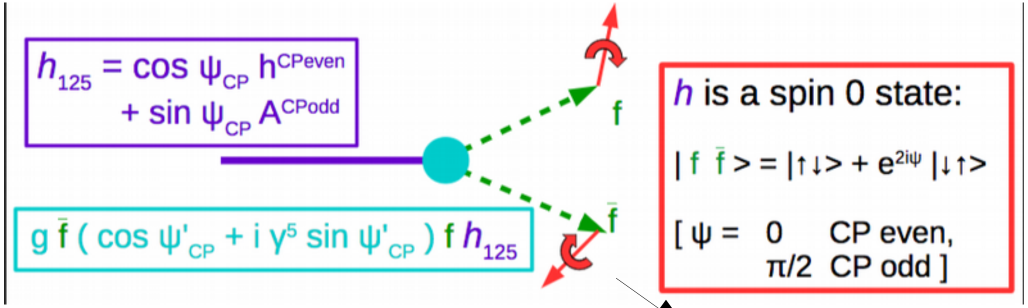
Performances: tau reconstruction [D. Jeans]
CP State analysis in H→ττ

T. Hieu et al, “Tau decay identification in ILD” arXiv:1510.05224

Using GARLIC

Higgs CP state and CP conservation in coupling

CP of H ⟶ $f f$ through polarisation of f



$h_{125} = \cos\psi_{CP}\, h^{CPeven} + \sin\psi_{CP}\, A^{CPodd}$

$g\,\bar{f}\,(\cos\psi'_{CP} + i\,\gamma^5 \sin\psi'_{CP})\,f\,h_{125}$

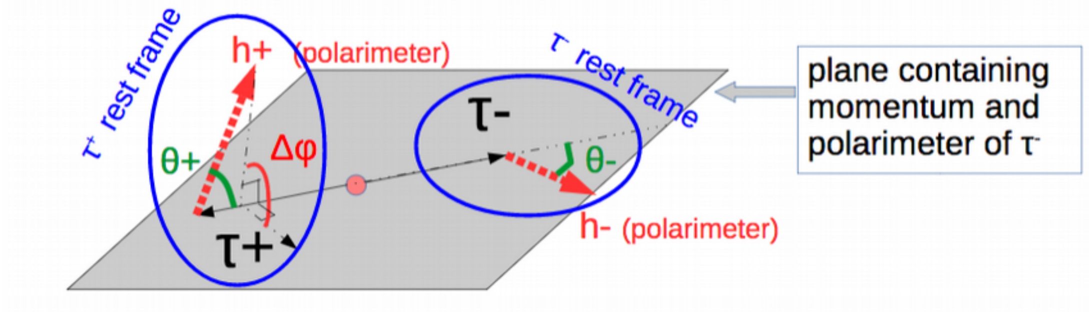
h is a spin 0 state:

$|f\,\bar{f}> = |\uparrow\downarrow> + e^{2i\psi}\,|\downarrow\uparrow>$

[ψ = 0 CP even,
π/2 CP odd]

Through decay

CP from polarimeters : taus from spin 0 parent



plane containing momentum and polarimeter of τ⁻

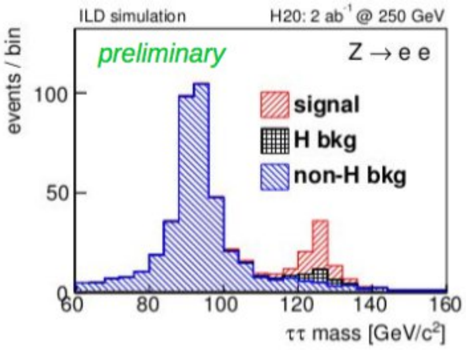
Best for τ in ee→ZH, Z→ee, qq
H→ττ

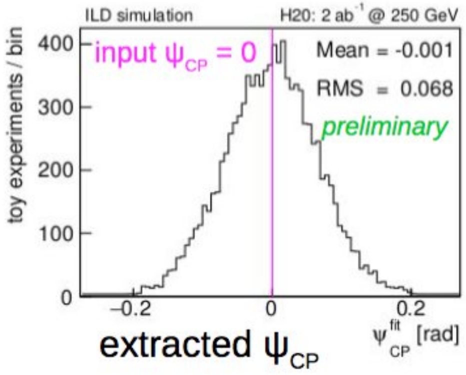
NIM A810 (2016) 51
arXiv:1507.01700

– Needs full τ reconstruction

- in hadronic tau decays (# neutrino = 1), if we know
  the tau **production vertex**,
  the **impact parameters** of charged tau decay products,
  the p_T of the tau-tau system,

  then the neutrino momenta can be reconstructed





Prospects

Very active collaboration between

- LLR, LAL, (LPNHE)$_{2017}$ + *Omega*
- Tokyo, Kyushu + KEK$_{2017}$

Pure R&D (CALICE):

- test of ASIC (test benchs, material, experience)
- test of wafers (contact with Hamamatsu)
- beam test and irradiation tests

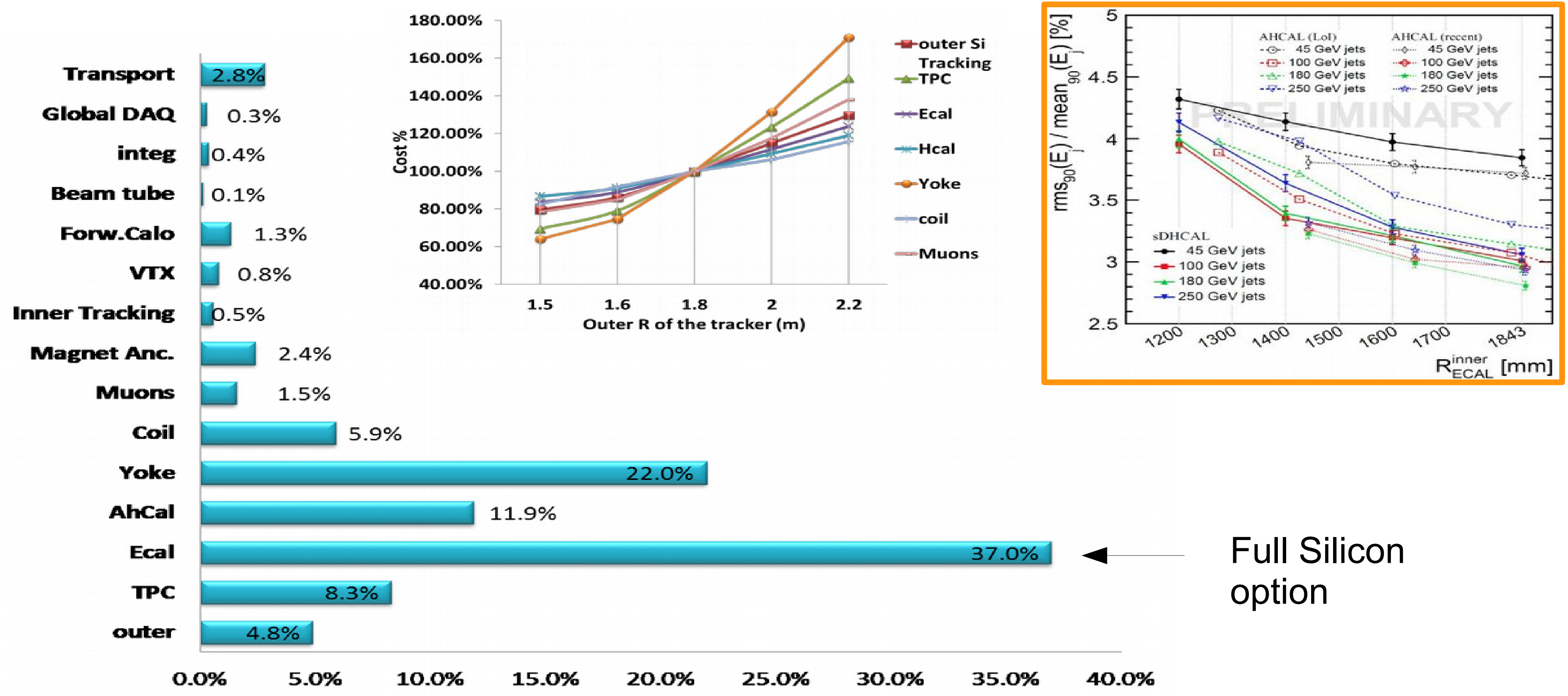
Toward ILD detector re-design

- Consolidated baseline & small radius
- Simulation
- Mechanical design
- Performance studies
- Physics & Detector analysis

Vincent.Boudry@in2p3.fr

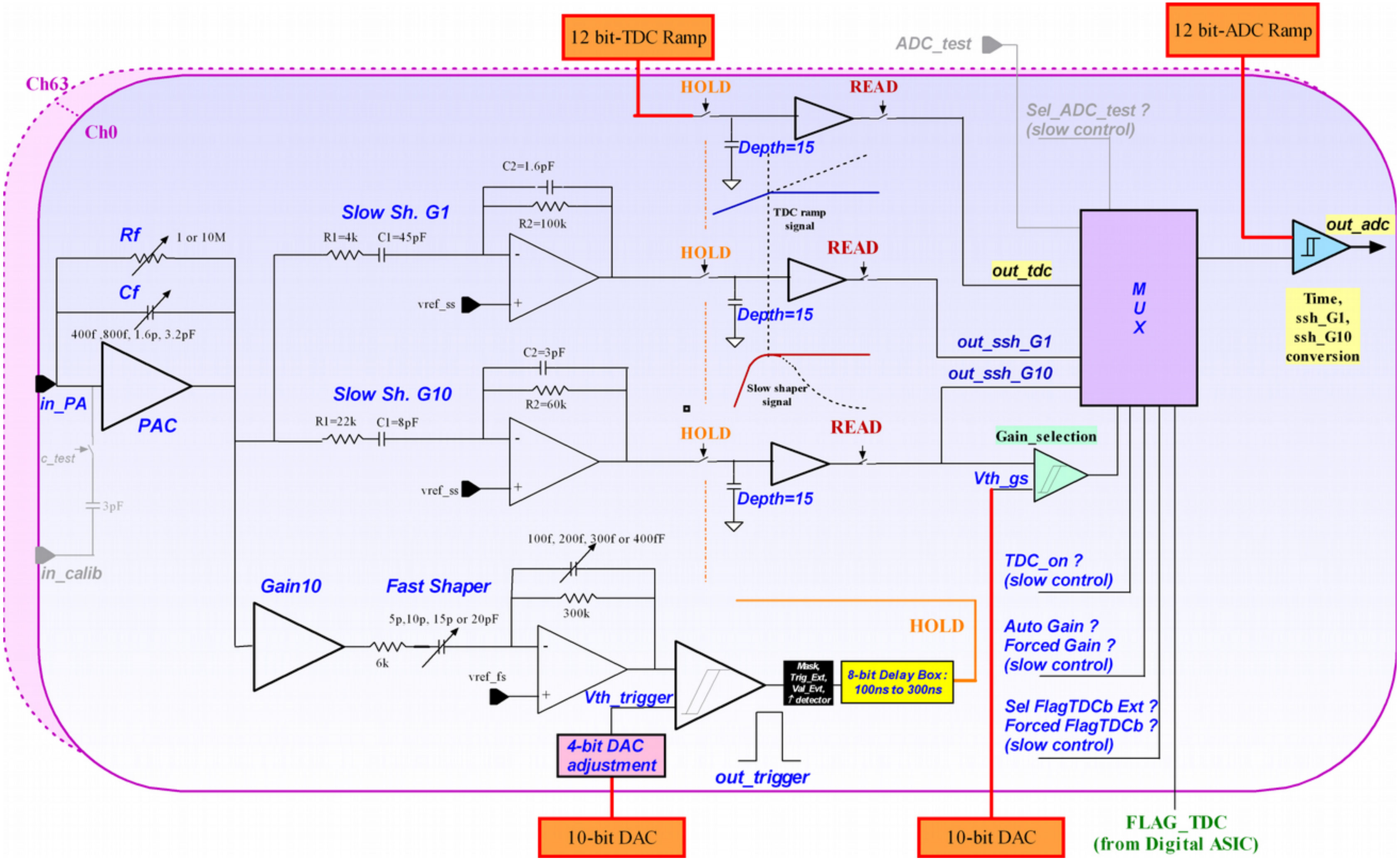
Extras

Structure de coût d’ILD

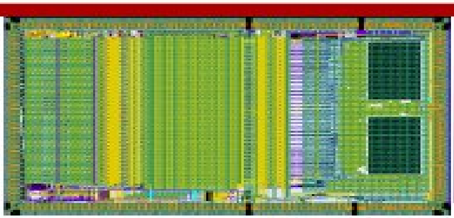


Full Silicon option

SKIROC2 / 2A Analogue core



ROC chips for ILC prototypes



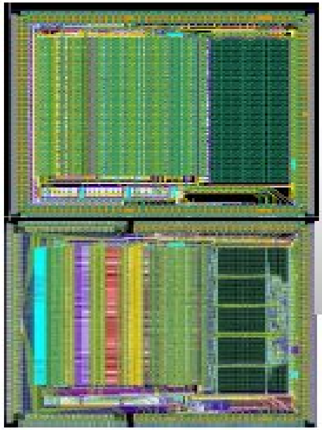
SPIROC2

Analog HCAL (AHCAL)

(SiPM)

36 ch. $32mm^2$

June 07, June 08, March 10, Sept 11



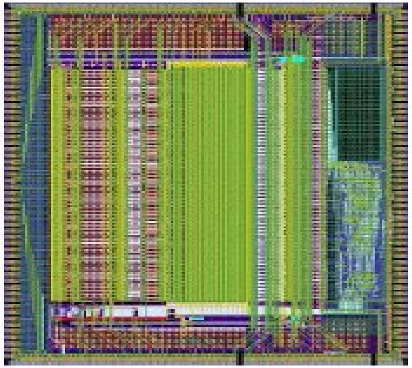
HARDROC2 and MICROROC

Semi Digital HCAL (sDHCAL)

(RPC, µmegas or GEMs)

64 ch. $16mm^2$

Sept 06, June 08, March 10



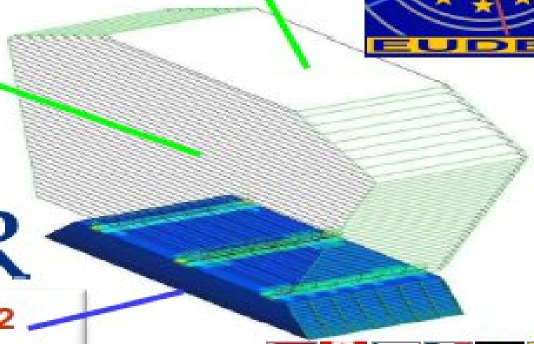
SKIROC2

ECAL

(Si PIN diode)

64 ch. $70mm^2$

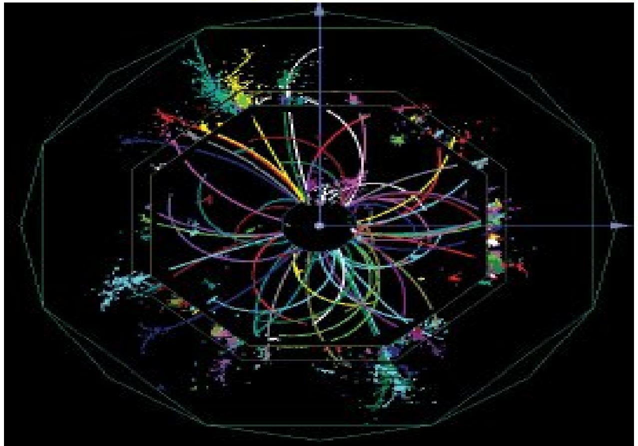
March 10



ROC chips for **technological prototypes**: to study the feasibility of large scale, industrializable modules (Eudet/Aida funded)

Requirements for electronics

- Large dynamic range (15 bits)
- Auto-trigger on ½ MIP
- On chip zero suppress
- **10^8 channels**
- Front-end embedded in detector
- **Ultra-low power : 25µW/ch**



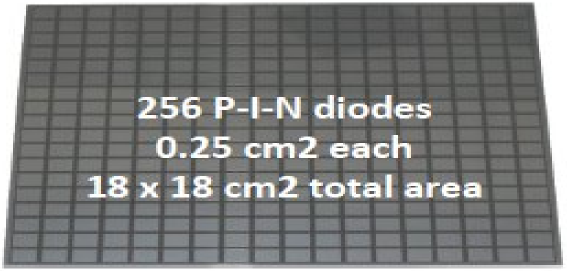
http://omega.in2p3.fr

callier@omega.in2p3.fr

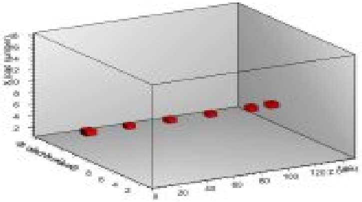
SKIROC2A

by S. Callier, C. de la Taille

- BUG CORRECTIONS
  - Some « Zero events » during digitization : **DONE** (added delays, cf. SP2C)
  - Substrate Shielding, Inputs Shielding : **IMPROVED** (added connections)
  - Test mode for naked dies (voltage drop off & missing pads) : **CORRECTED**
  - Trig Ext path no more thru delay cells to store the analog data : **DONE**
- IMPROVEMENTS
  - 4-bit DAC for trigger level adjustment : **OPTIMIZED**
  - Bandgap : **CHANGED** (from HR3)
  - Delay Cell : **Slightly IMPROVED**
  - AutoGain Selection : **CHANGED** (from SP2C)



256 P-I-N diodes
0.25 cm2 each
18 x 18 cm2 total area



Production possible through CMS-HGCAL collaboration

Prototyping : who is doing what

© R. Cornat