SiW ECAL for future e^+e^- collider

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on behalf of SiW ECAL ILD / CALICE collaboration

Outline:

(1) High granularity silicon calorimeters

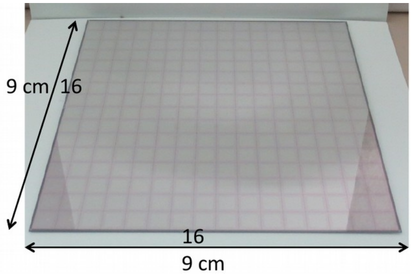
(2) R&D and optimization of ILD detector

(3) SiW ECAL technological prototype and SPS beam test results

Conclusions

Supported by:

Silicon calorimeters



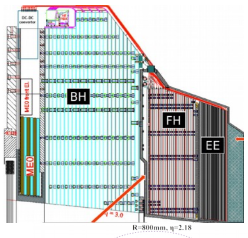
- easily segmentable,
- stable linear response (7000 e-holes /100 um/MIP), easy calibration,
- independent to environmental changes, stable in time
- radiation hard
- excellent timing (σ_t~20-50 psec)

Ideal for PFA: lowest systematics, best granularity, but:

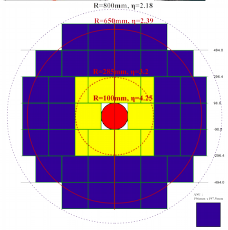
- high cost, ~ 2.5 EUR / cm^2 for mass production (offer from Hamamatsu in 2014)
- moderate sampling ECAL intrinsic resolution, though $\sigma_E \leq 20\% \cdot \sqrt{E}$ is sufficient for PFA
- low-noise electronics required

Detectors:

(1) ECAL in future e^+e^- high-energy colider: **ILD, SiD, CEPC, FCC, CLIC**



(2) Approved for **CMS HGCAL phase II project:**
radiation hard 40 silicon layers in endcaps, 20 psec timing to reduce ≤ 200 pile-up



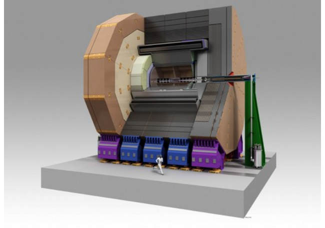
(3) Proposed for **ATLAS High Granularity Timing Detector (HGTD = preshower):**
4 Si layers with low gain, fast to reduce pile-up

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LArHGTDPublicPlots

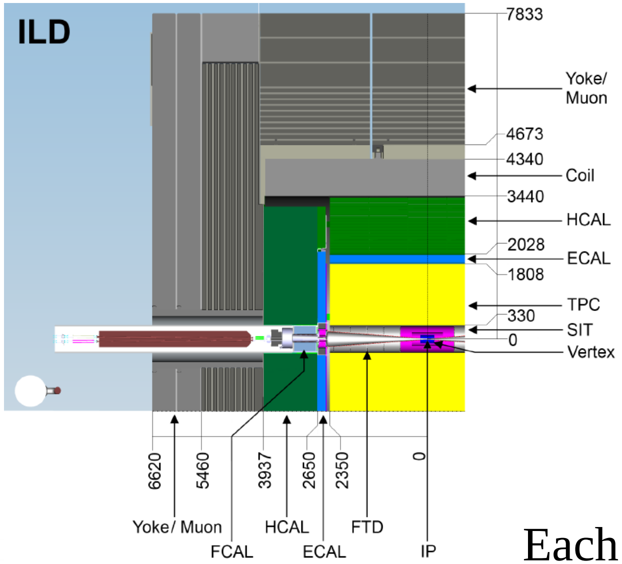
(4) Proposed for **LHCb phase II ECAL upgrade,**
eg. 3 silicon layers, high granularity to measure angle btw pi0 photons, fast to reduce pile-up

LHCB-LHCB-EOI-2017-001-002

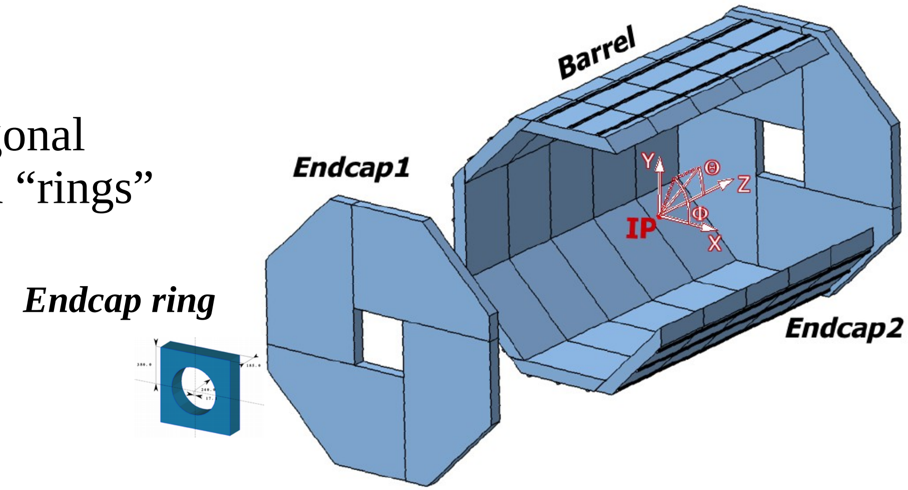
Silicon sensors expand from trackers to calorimeters



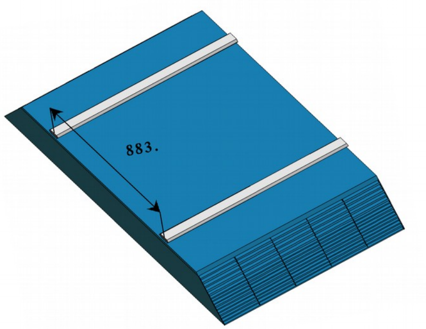
International Large Detector (ILD)

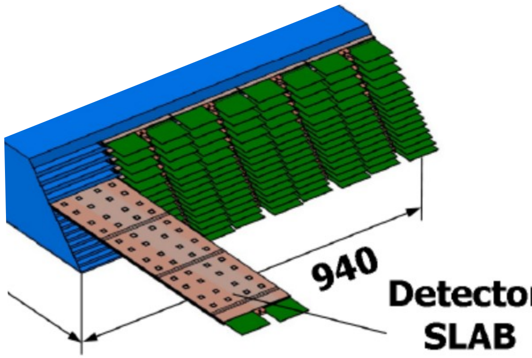


ECAL = modular octagonal barrel + 2 endcaps with "rings"



Each module = carbon-fiber + W structure with alveoli where detector elements (slabs) slide in. Slab = Si sensor glued to PCB with electronics on both sides of W wrapped into carbon fiber.





To avoid radial cracks:

(1) trapezoidal shape is "inverted" (Videau structure"),
(2) odd # barrel modules
(3) minimal clearance between modules

1/8 of barrel

ECAL options: 2012 ILD TDR baseline with 30 layers, 22 layers, 23% smaller radius

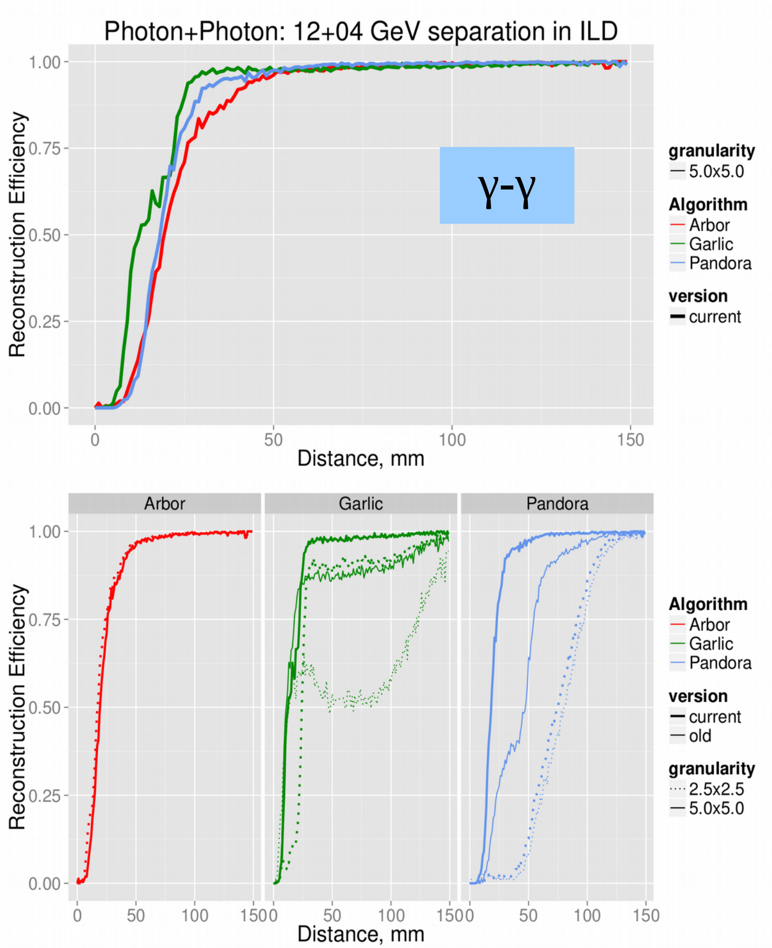
Separation of two close showers in ILD

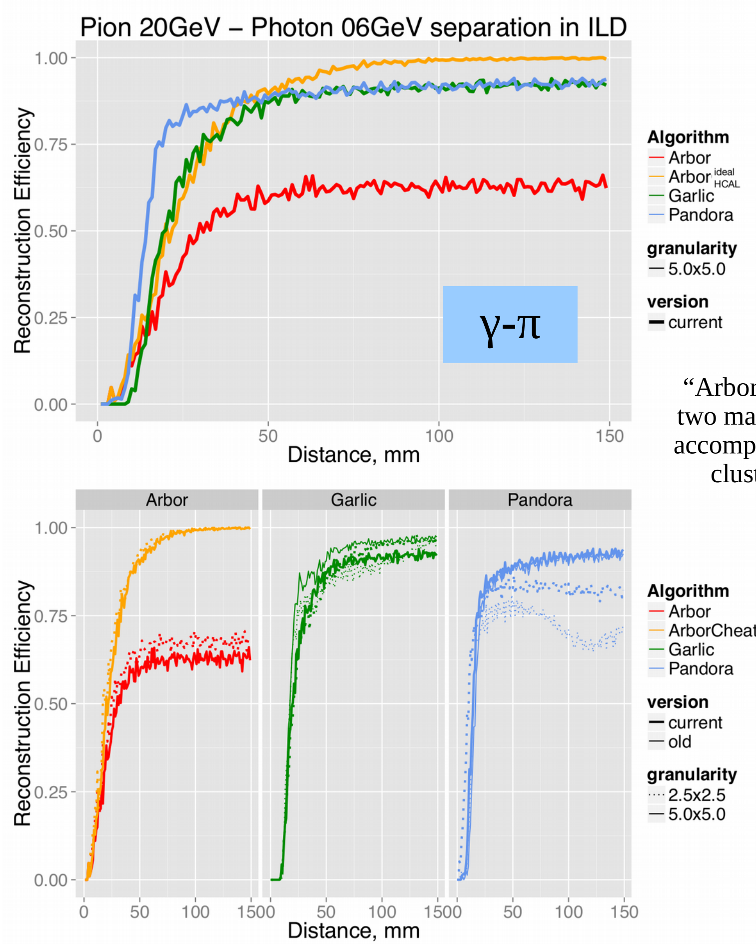
… determines PFA confusion for P(jet)>100 GeV.

π-π JINST 6, P07005 (2011)

$\tau^{\pm} \rightarrow N\gamma$ Eur. Phys. J. C (2016) 76: 468.

Recent results on γ - γ (π) separation efficiency VS distance in ILD for PFA Garlic (only ECAL), Pandora and Arbor (both for jets). Both γ (π) should be reconstructed with E, position within ±20%, ±5 mm.





"Arbor Cheat" (yellow): two main clusters may be accompanied by (small E) clusters in AHCAL

Garlic and Pandora: 2.5x2.5 mm² pixel is worse than default 5x5 mm² (!), artefact of optimization.
Comparison with CALICE physical prototype data will be available soon (note under review).

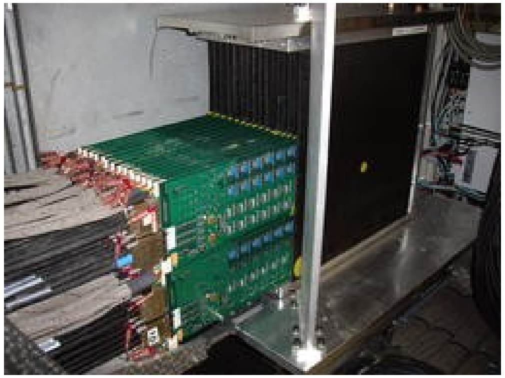
CALICE / ILD SiW ECAL

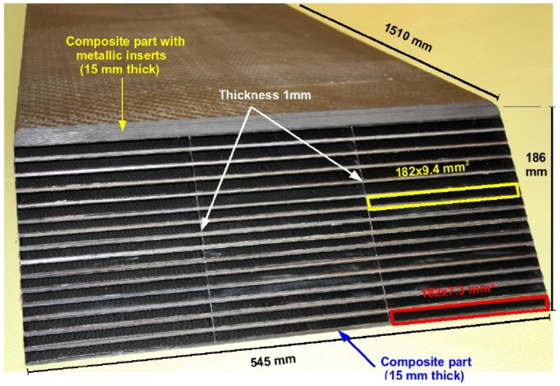
SiW ECAL “physical” prototype (2005 – 2011), 18x18x20 cm^3

σ(E)/E = (16.6 ± 0.1)% / √E ☺ (1.1 ± 0.1)%   (MC: 17.3 / √E ☺ 0.5%)
linearity within 1%

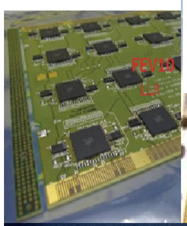
but not embedded electronics, big power consumption

NIM A608 (2009) 372

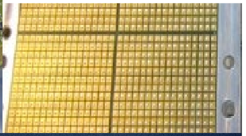


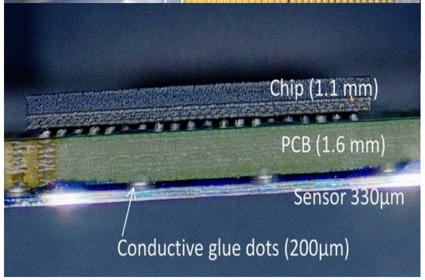


Carbon fiber – tungsten mechanical structure manufactured: 3/5 ILD module (5 years of R&D), max deviation from planarity 0.65 mm.



Glue dots on PCB





2d generation technological ECAL with embedded electronics (2011 – now):

(1) 18x18 cm^2 layer: ILD design channel density, 1024 pixels, 16 SKIROC chips, 4 sensors glued to PCB with 20 um precision; 10 layers produced

(2) Power pulsed: readout switched OFF between “ILC trains” (~100 less power)

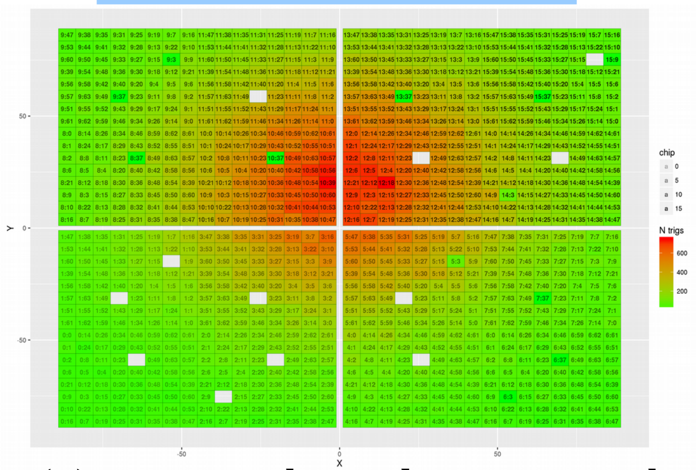
(3) DAQ R&D ongoing, last beam test suffered from high noises, not finalized

(4) Optimization of Si sensors, laser tests

(5) Irradiation tests (50 ILC years Ok for Si)

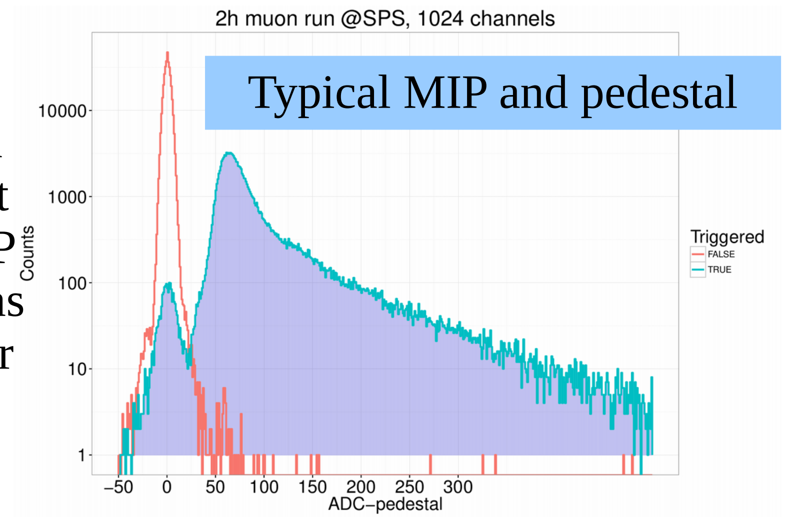
Test beam with 3 layers (SPS, Nov'15)

Typical beam spot

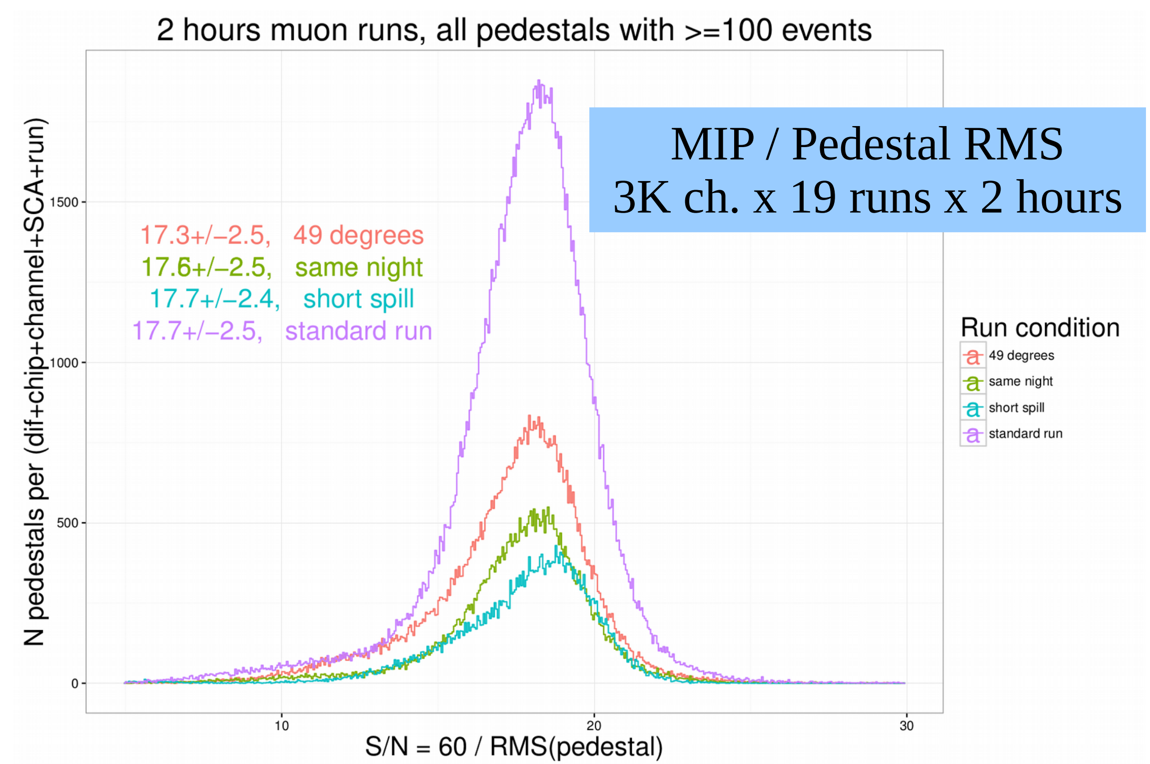


(1) In 3072 channels: 2.2% masked.
All layers power pulsed.
Bunch crossing (BX) = 400 nsec.

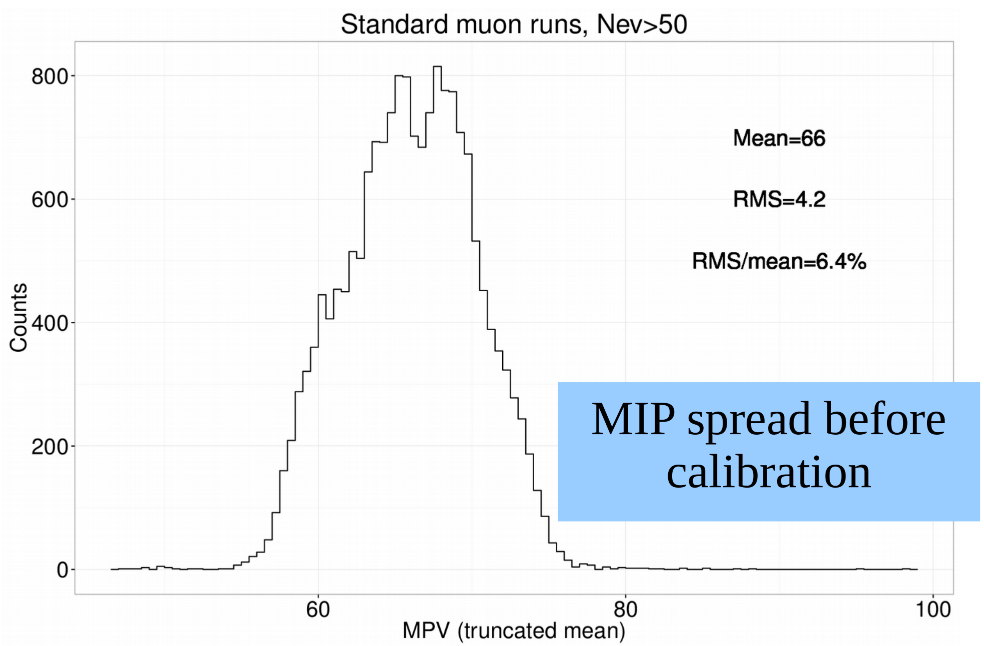
(2) Pedestal stable within ±1% ·MIP during 5 test days, except 2-3% ·MIP correction in one layer as f(stabilization time after power ON)

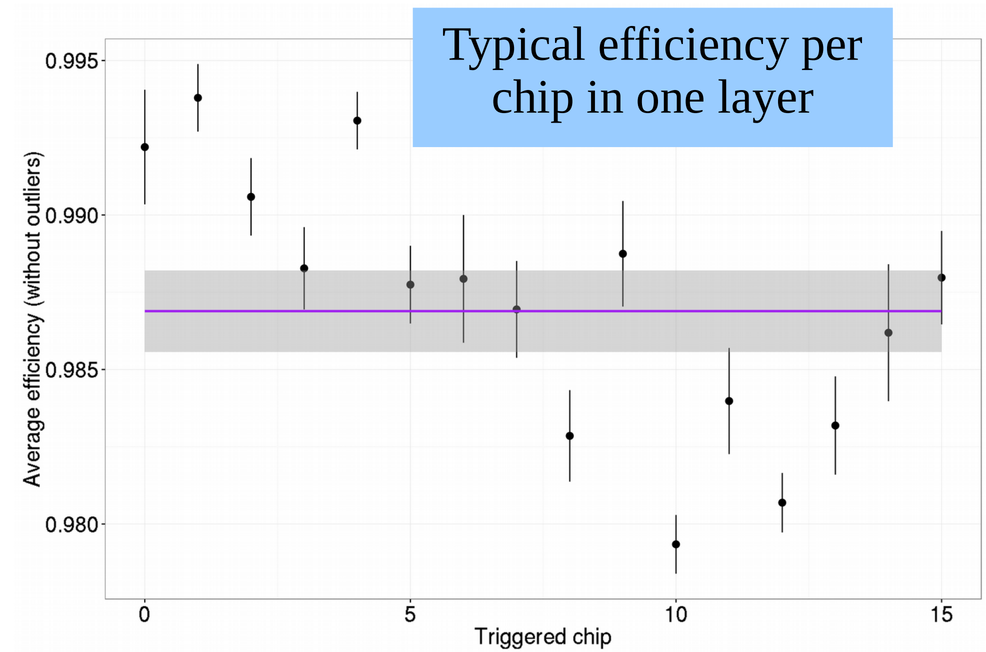


(3) Excellent MIP / Noise = 18
for optimal SKIROC settings
(twice less for ILC)



Test beam with 3 layers (SPS Nov'15)





Raw data: ±6.4% spread between MIPs in channels with sufficient $\mu^{\pm}$ statistics (83% out of ~3000)

Efficiency = 98 – 99% ,
except 2.9% of channels
(dominated by 1 chip out of 48)

Problems:

(1) noise due to re-triggers = 1 usec "macro" event when almost every channel triggers once,
(2) synchronization: signals in 2 layers may differ by one BX,
(3) in shower, under high load chip trigger is delayed by one BX.

Conclusions

(1) Silicon sensors for highly granular calorimetry, though expensive, are baseline option for many proposed detectors:

- **ECAL for ILD, SiD, CEPC, FCC, CLIC,**
- **CMS HGCAL** phase-2 upgrade of ECAL+HCAL endcaps for HL LHC (approved),
- **ATLAS HGTD fast preshower,**
- A few layers of LHCb ECAL in phase-II upgrade.

Silicon sensors expand from trackers to calorimeters (if budget allows)

(2) Analysis of PFA "confusion" in ILD:

- $\pi - \pi$ separation
- separation of tau-decay photons
- recent results: γ - γ and $\gamma - \pi$ separation efficiency drops below ~3 cm distance, comparison with physical prototype data should appear soon as a CALICE note

JINST 6, P07005 (2011)

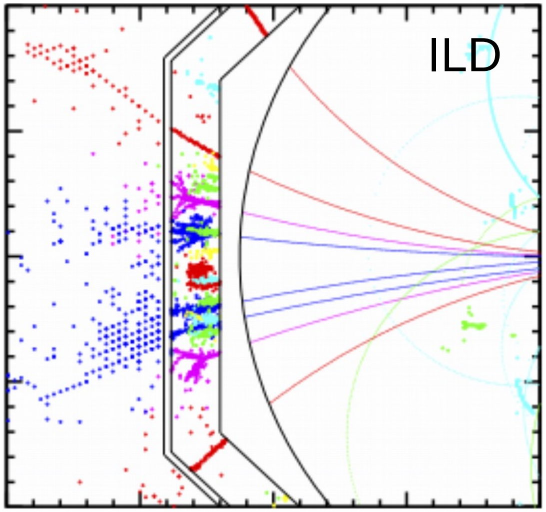
Eur. Phys. J. C (2016) 76: 468.

(3) After successful "physical" prototype, **CALICE / ILD SiW ECAL** group develops 2nd generation **"technological" prototype:**

- ILD design channel density is reached
- power pulsing successfully tested
- excellent MIP/Noise = 18, spread btw. pixel responses to MIPs *before calibration* = 6.4%
- efficiency = 98-99%
- still, much more work ahead.

Backup slides

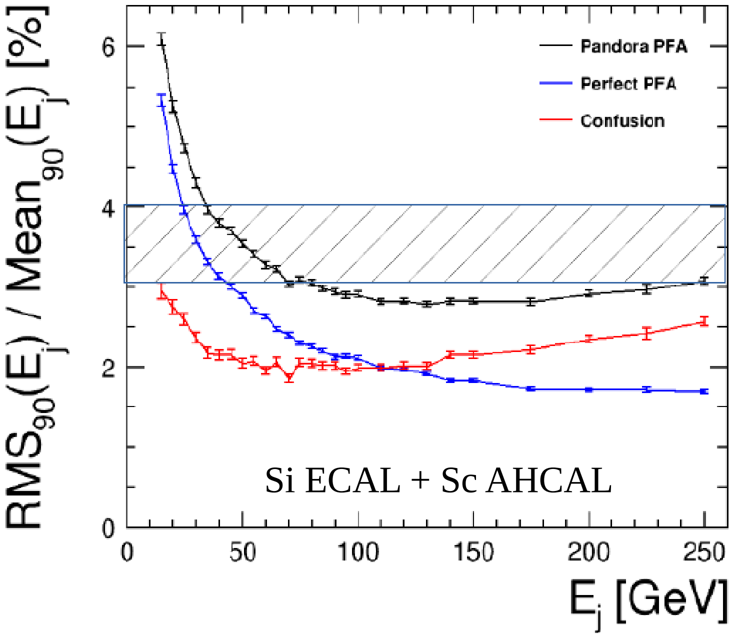
Particle Flow Algorithms (PFA)



E(jet) measurement:

- charged tracks (65%) in tracker,
- photons (25%) in ECAL,
- neutral h (10%) in HCAL

$\sigma(E)/E$ = 3-4% for 35-500 GeV jets (~50% of traditional calo)
eg. $\sigma(M_{W,Z}) \sim \Gamma_{W,Z}$, sufficient to distinguish W,Z statistically



S.Green plot cited by D.Jeans at https://agenda.linearcollider.org/event/7014/contributions/34651/attachments/30224/45180/ild-caloOpt-talk.pdf