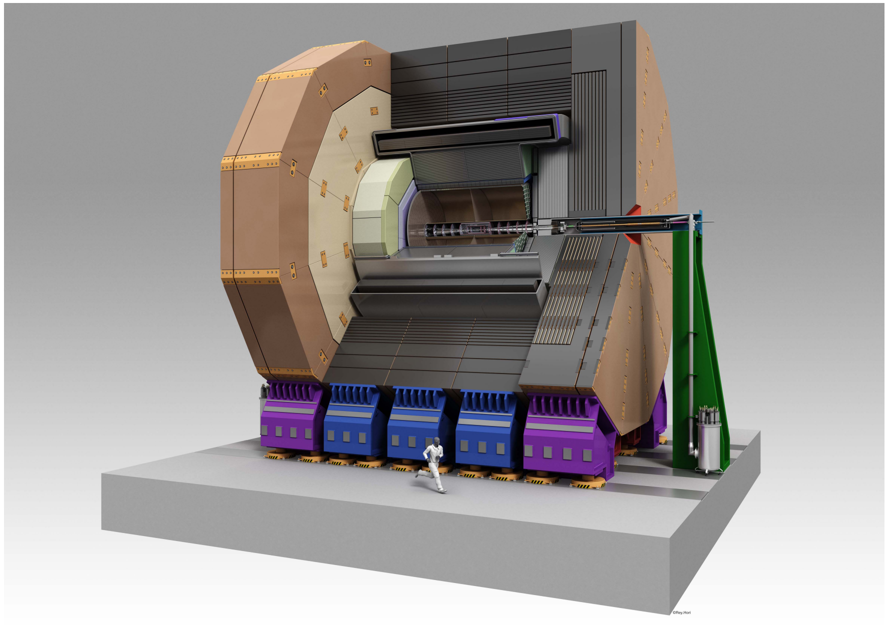
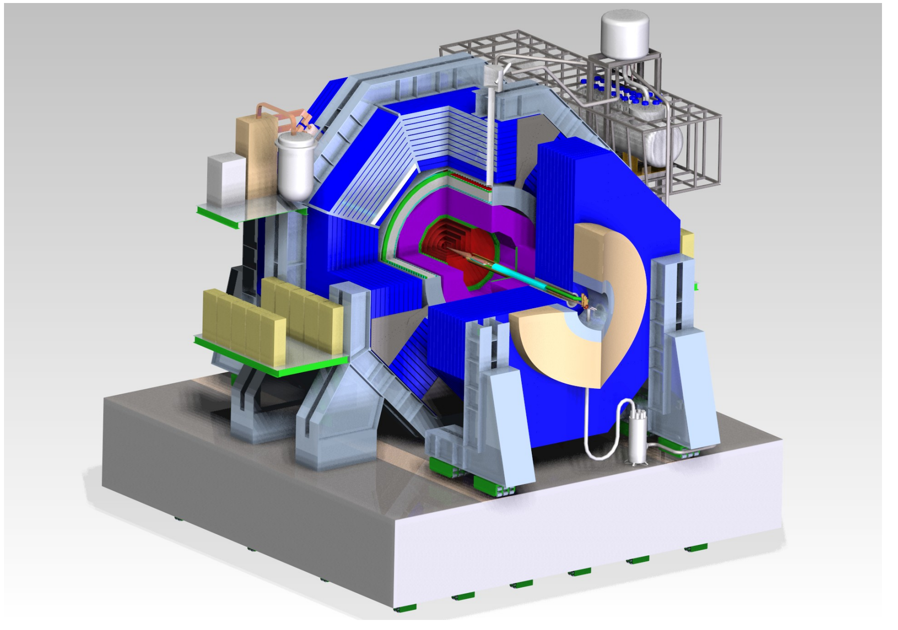
A Scintillator Analogue HCAL for ILD and SiD

Felix Sefkow

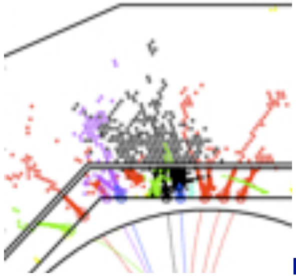




SiD Meeting, SLAC, 14-16. October 2013

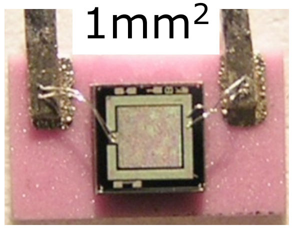
Outline

- The AHCAL experience
- The AHCAL in ILD
- AHCAL R&D
- The AHCAL in SiD

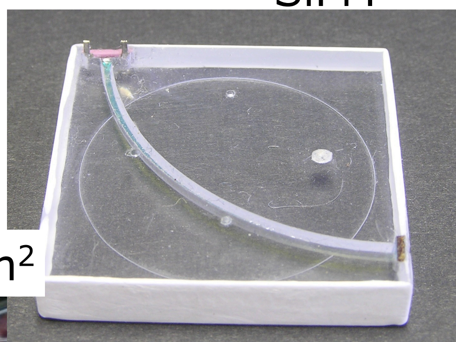


AHCAL physics prototype

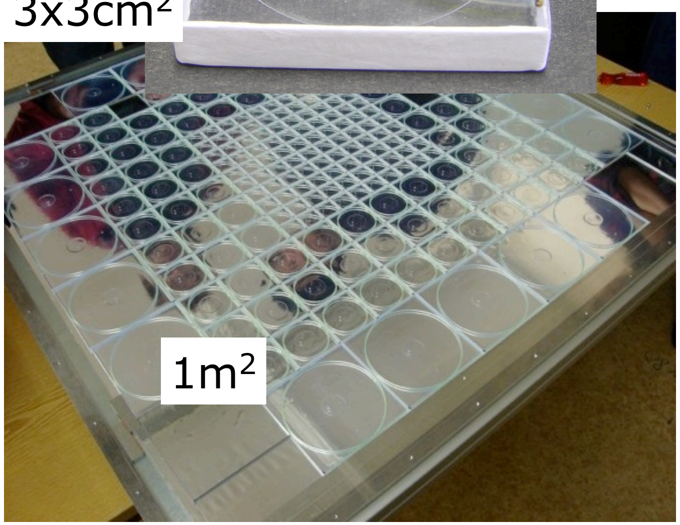
7608 channels
38 layers
Fe & W



SiPM



3x3cm²



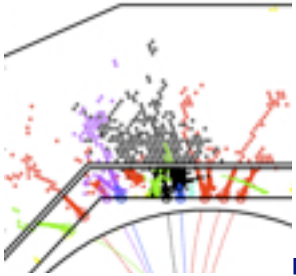
- Constructed in 2005-06: first device using SiPMs at large scale
- Now many followers: T2K, Belle2, CMS, medical applications,...

- Extremely robust: 6 years of data taking
  - 2006-7 CERN: Fe with SiW ECAL
  - 2008-9 FNAL: Fe with Si/Sci ECAL
  - 2010-11 CERN: Tungsten

Many trips with disassembly & reassembly of the calorimeter:

DESY - CERN - DESY - FNAL - DESY - CERN PS - CERN SPS

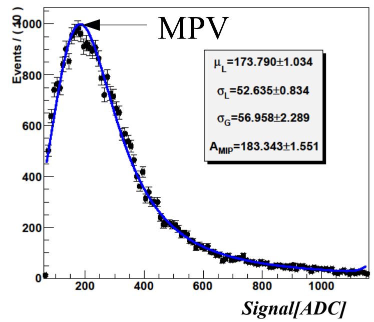
... and the SiPMs survived without problems!

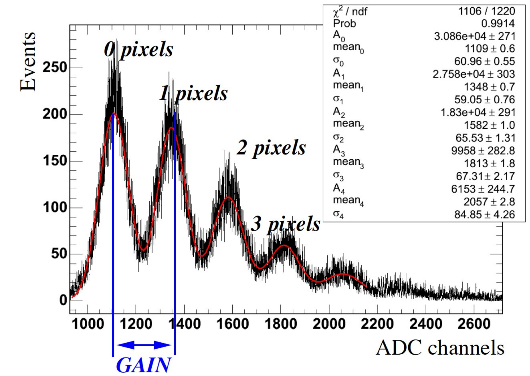


Calibration

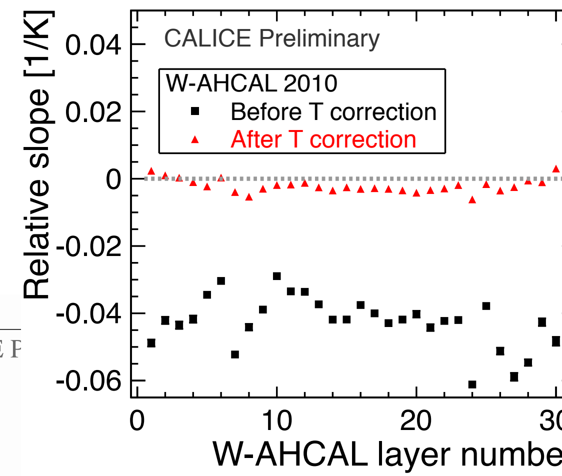
- Cell-wise equalisation: MIP
- Saturation correction: gain
- All SiPM properties depend on one parameter
  - $\Delta V = V - V_{\text{break-down}}(T)$

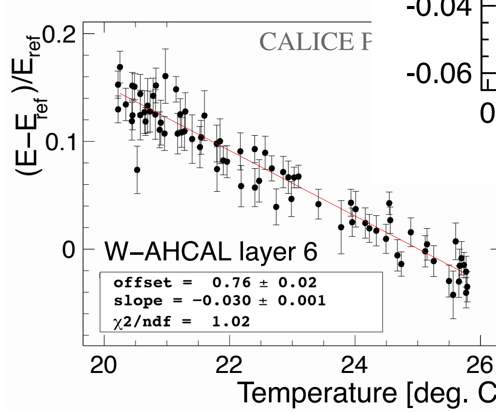
- Needed time to find right procedures
  - some limitations from test bench data
  - large spread of SiPM parameters
- Guidance for future developments
  - e.g. gain stabilisation



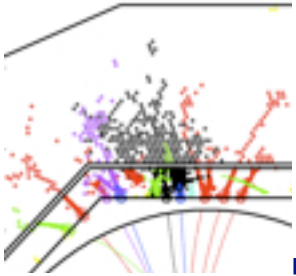


no climate control



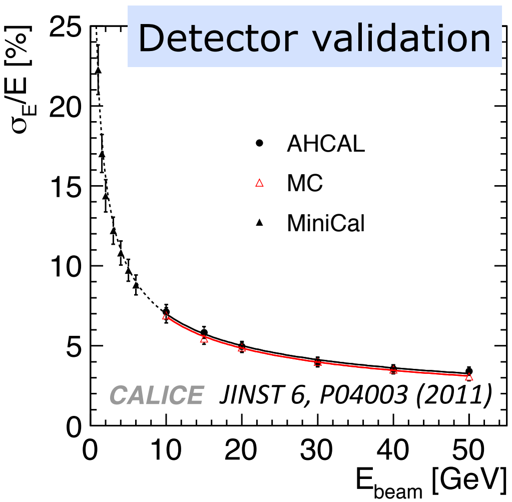


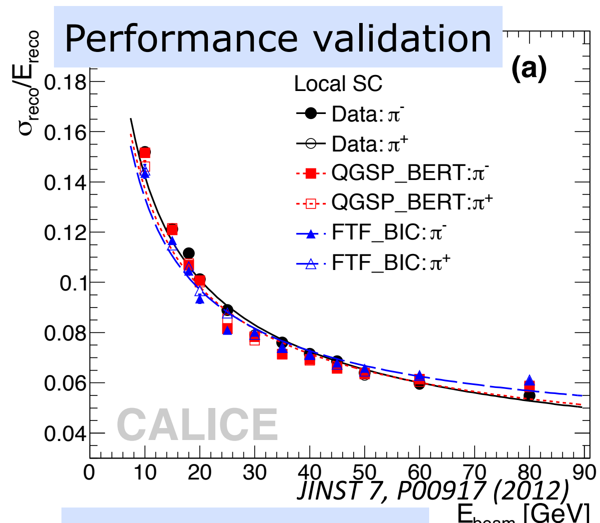
After layer-wise correction stable to better than 0.2%/K

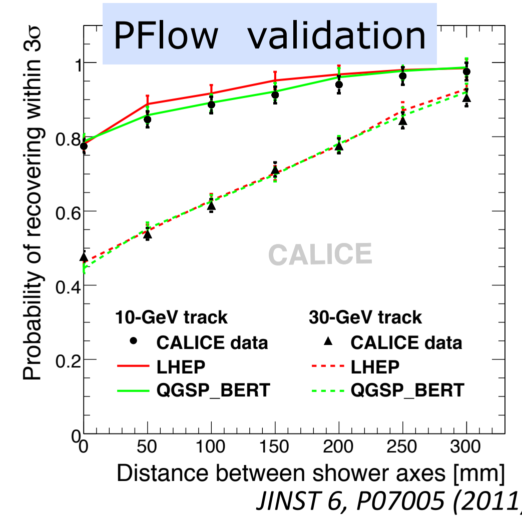


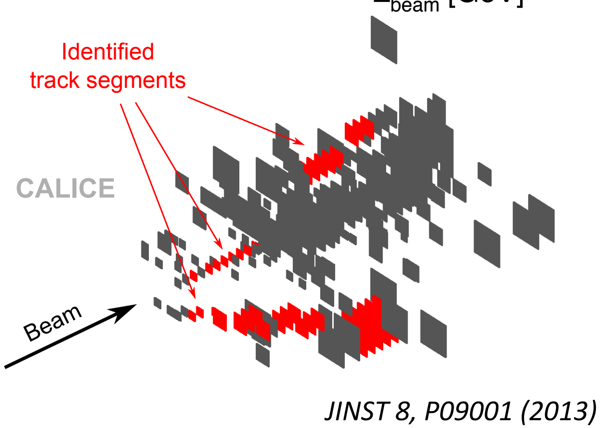
Validation of Simulation

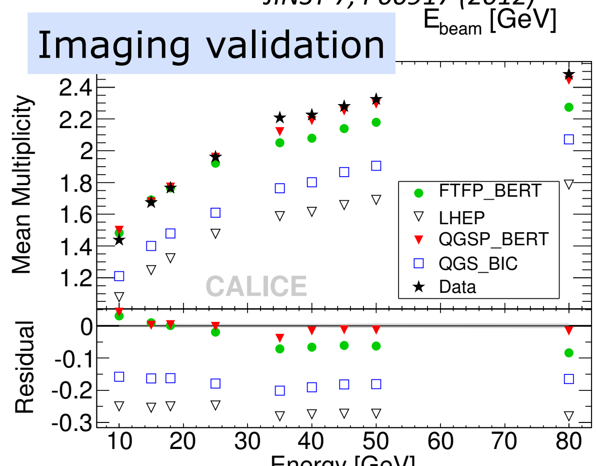
- Validation with first generation prototype
- Published

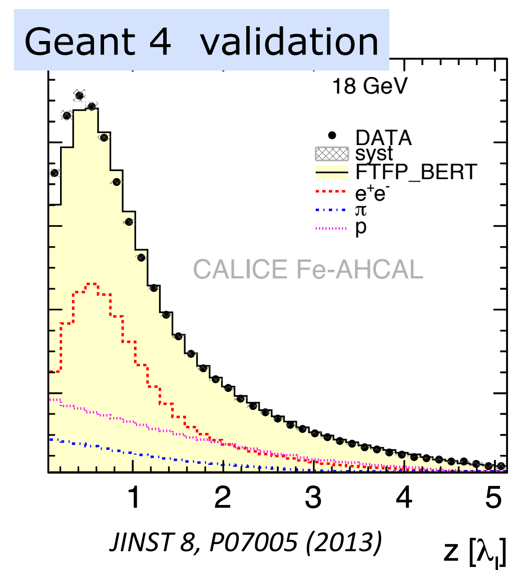






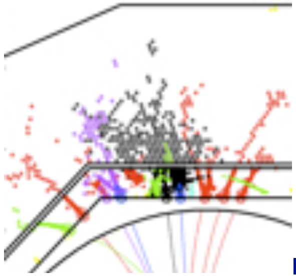






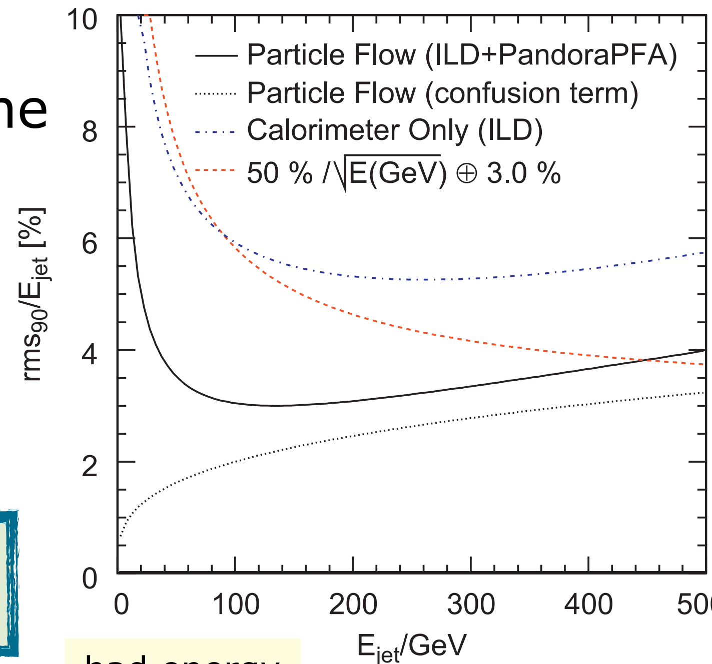
Proof of principle: done.

Towards a real detector:

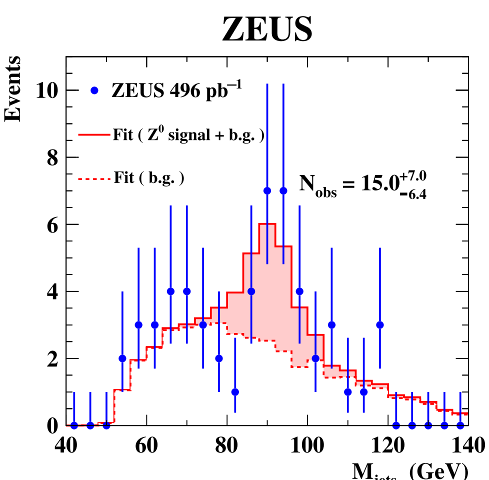


Particle flow

- For the reconstruction of invariant masses, it is not sufficient to have the best calorimeter
- But energy resolution does matter
  - dominant for jets below 100 GeV
  - helps in track cluster matching



had energy resolution



35%√E
for pions,
6 GeV for Z

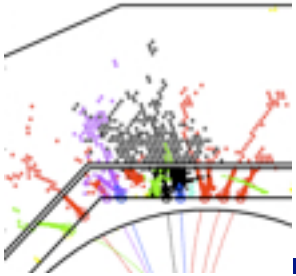
For scintillator, optimize independently

energy and topology

containment, constant term

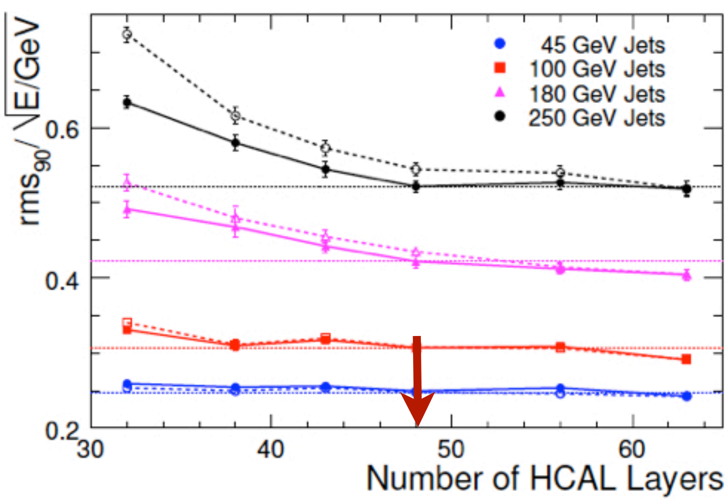
$$\frac{\mathrm{rms}_{90}}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E \oplus 2.1\left(\frac{R}{1825}\right)^{-1.0}\left(\frac{B}{3.5}\right)^{-0.3}\left(\frac{E}{100}\right)^{0.3}\%$$

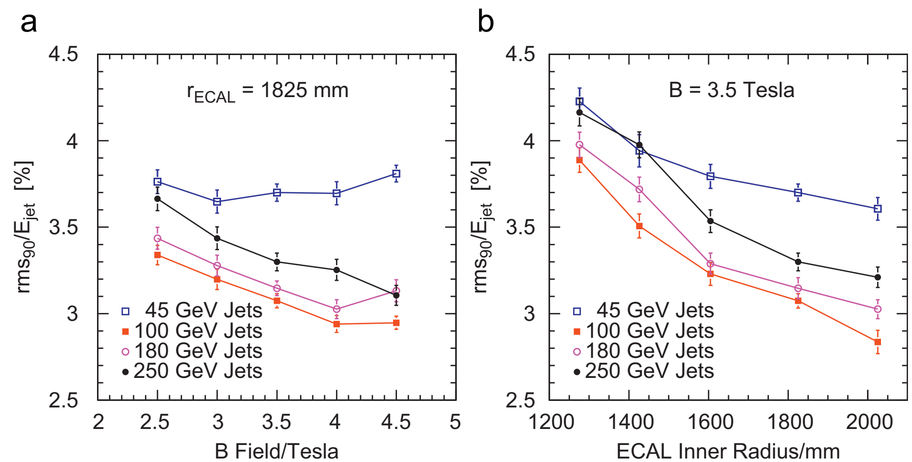
calo intrinsic, tracking, leakage, confusion

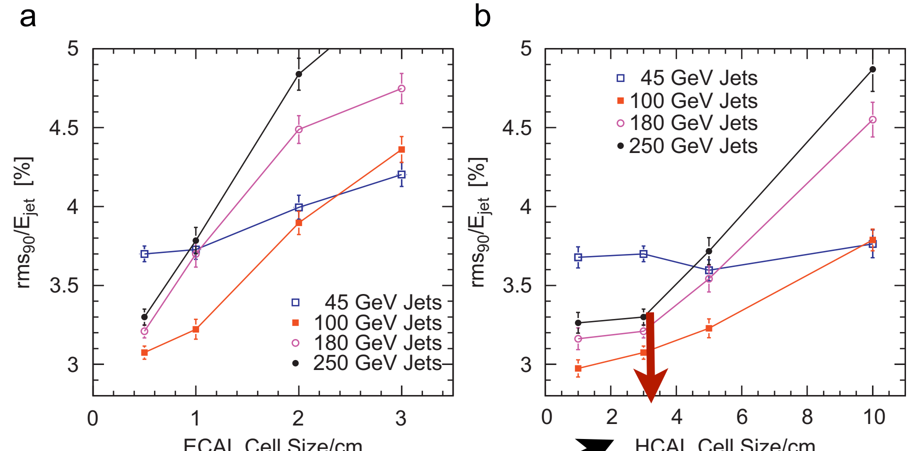


ILD optimisation

- Based of Pandora PFA
- Extensive studies done for the LOI
- Cost optimisation postponed





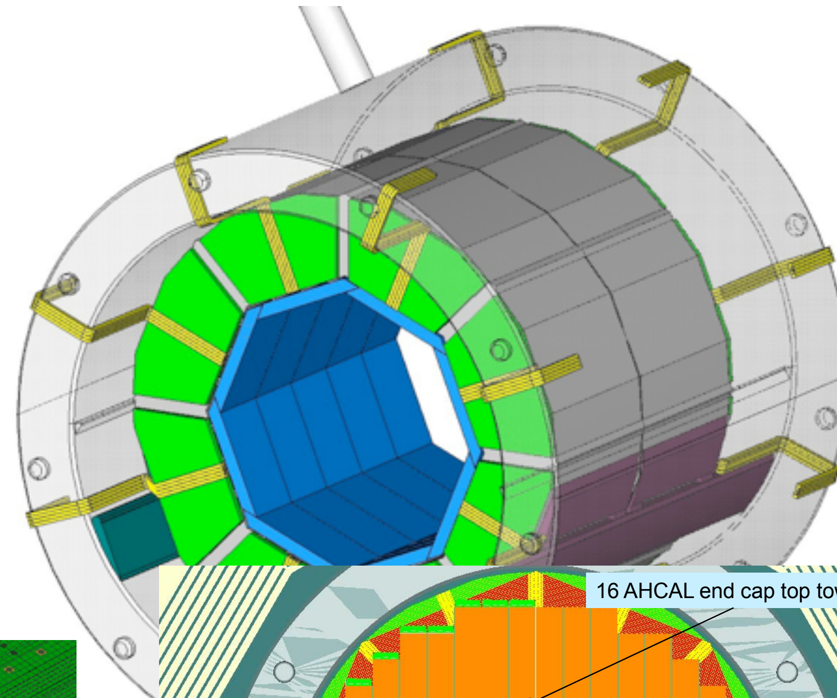


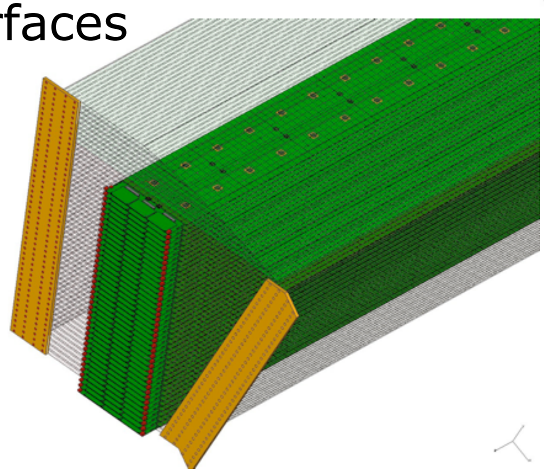
reflects shower feature size rather than particle separation

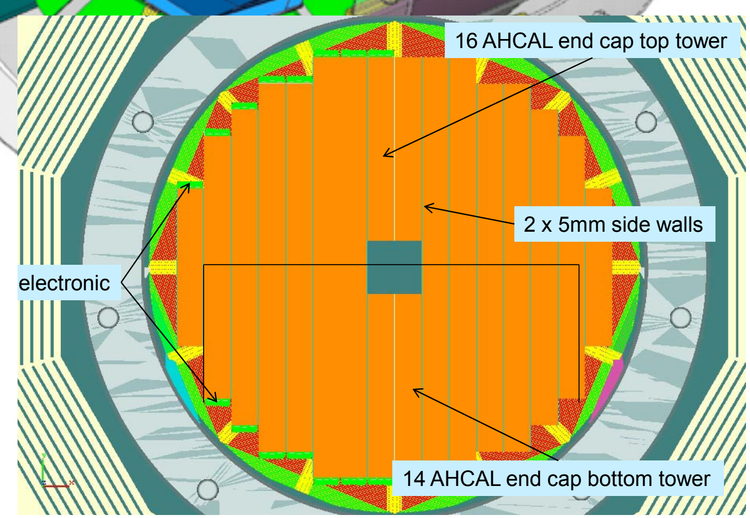
Scintillator HCAL

AHCAL implementation

- Short barrel (2x 2350 mm)
  - big endcap R = 3190 mm
- 8-fold symmetry
  - 16 sub-modules
- 6 λ deep, 48 layers x 2 mm
  - R = 2058-3410 mm
  - 8000m^2
- Cracks filled with steel
- Embedded front end electronics
- Accessible interfaces

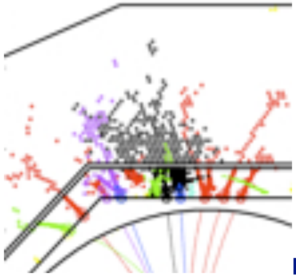




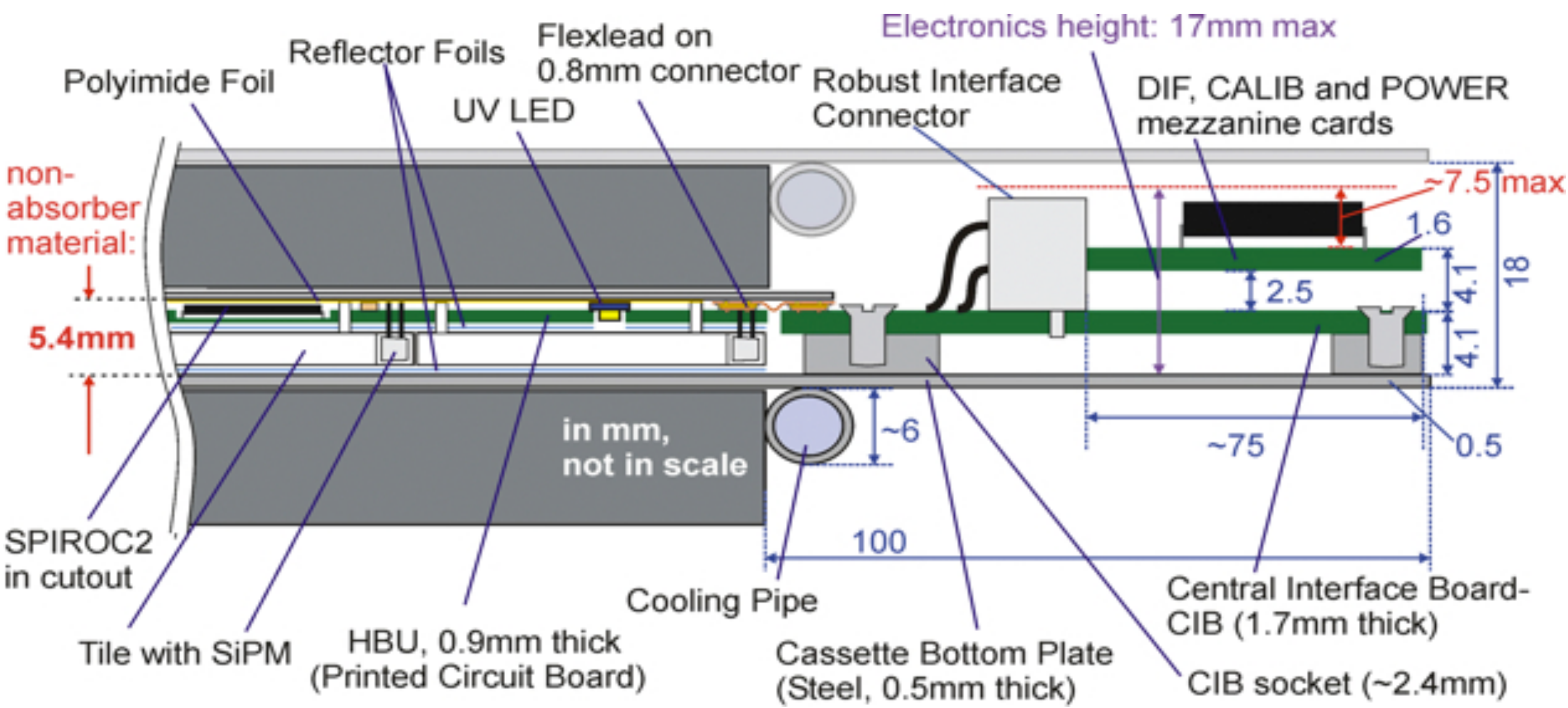


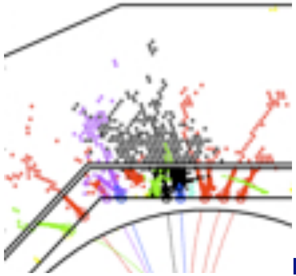
Mechanical prototypes

- Horizontal and vertical test structures built
  - used cost-effective roller leveling - no machining
- Tolerances verified: 1mm flatness over full area
- To be used for integration studies, test beams
  - and earthquake stability tests



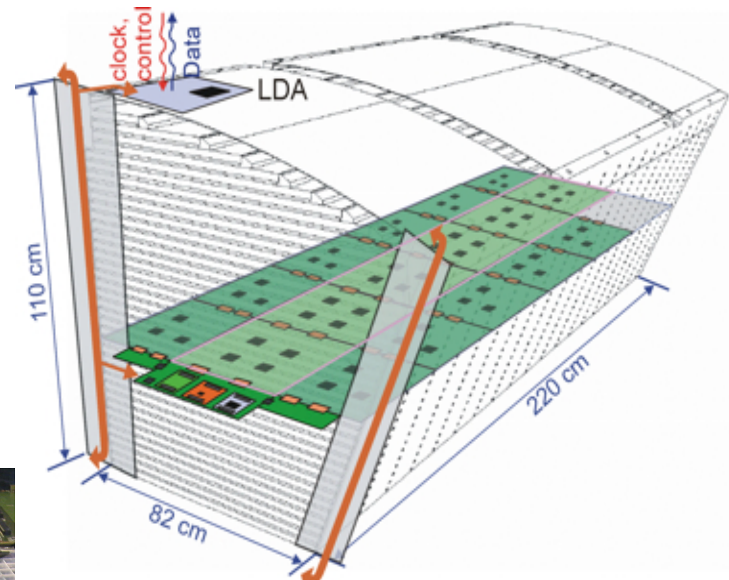
Layer cross section

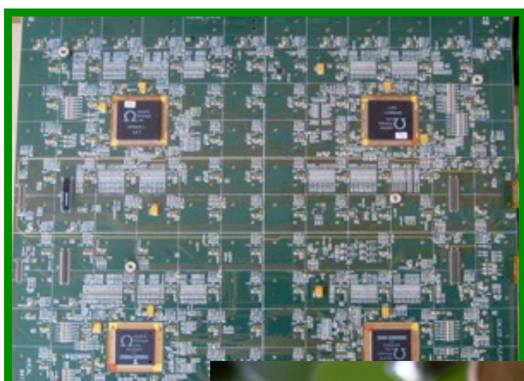


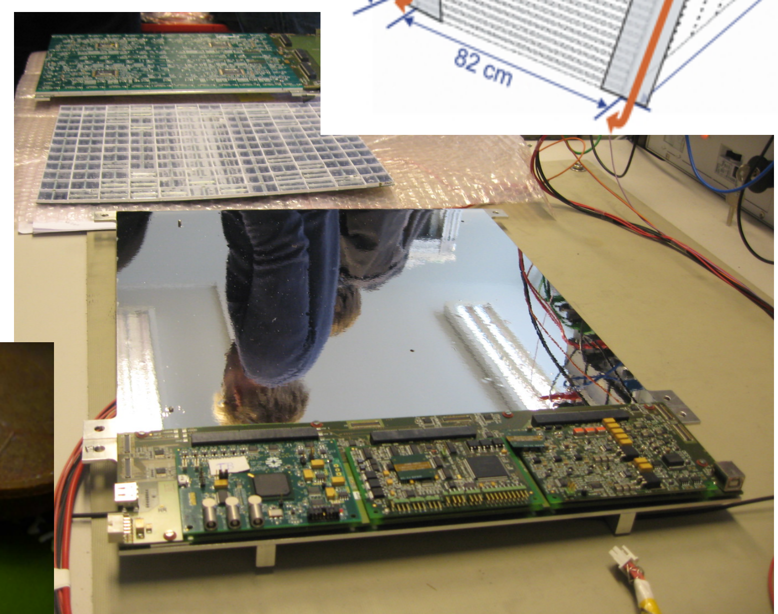


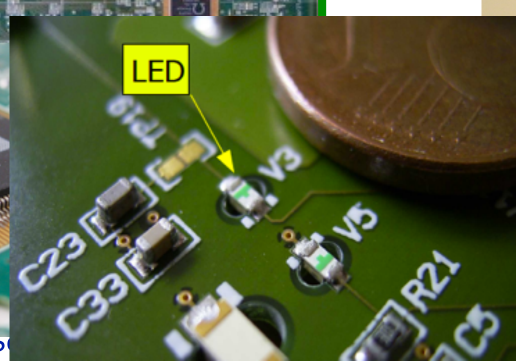
Electronics integration

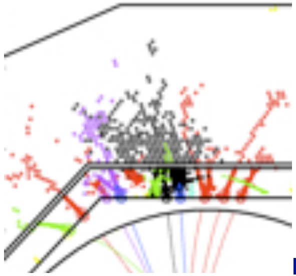
- Basic unit: 144 tiles, 36x36cm^2
- 36 ch. ASICs, power pulsed
  - self-trigger, 16x memory, ADC
- embedded LED system
- compact design
  - 5.4mm incl 3mm scintillator



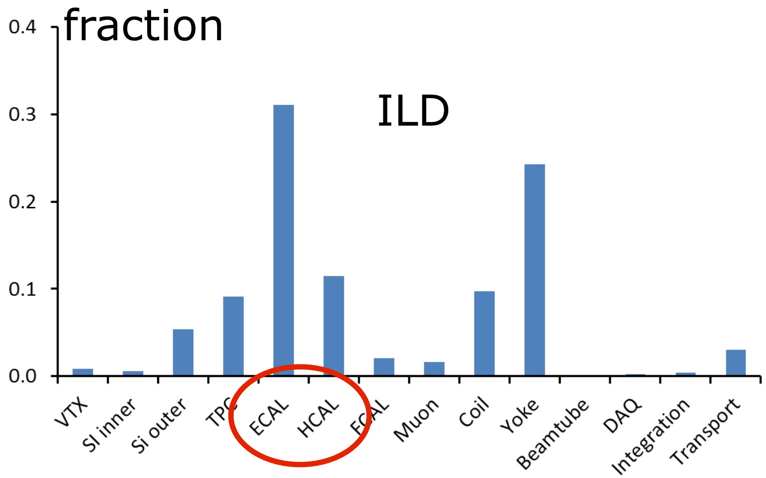








AHCAL cost drivers and scaling



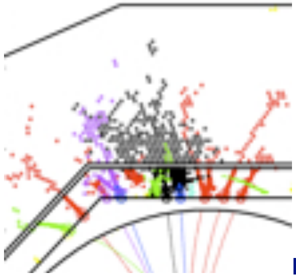
- DBD costing is far from final, but much better than anything we had before, largely based on 2nd gen. prototyping
- Many lessons to be learnt
- What are the real cost drivers at present?
- What are the scaling laws?

- Absorber 10M ~ volume
- SiPM 8M ~ channel
- PCBs 22M ~ area

- and not

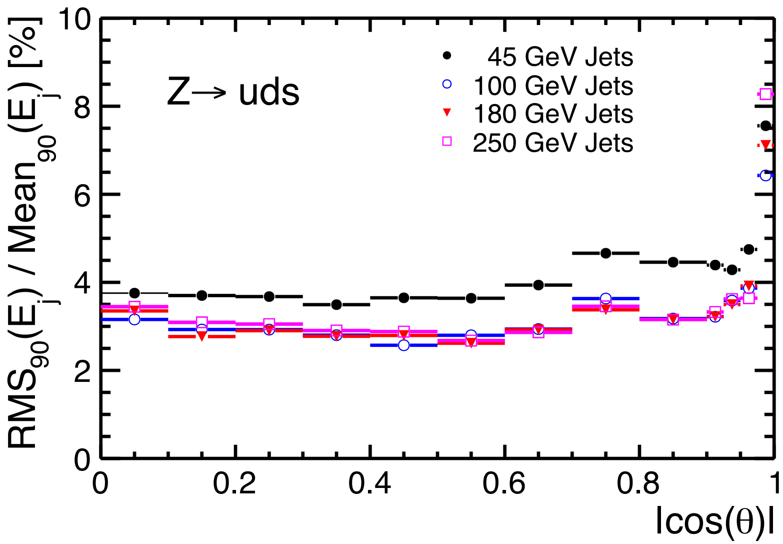
- Scintillator 1.5M
- ASICs 1.8M
- Interfaces 1.4M
- ...

- total 50M



Performance

- Essentially all ILD DBD analyses were done with the AHCAL
- Dead regions, interfaces, services included in simulation



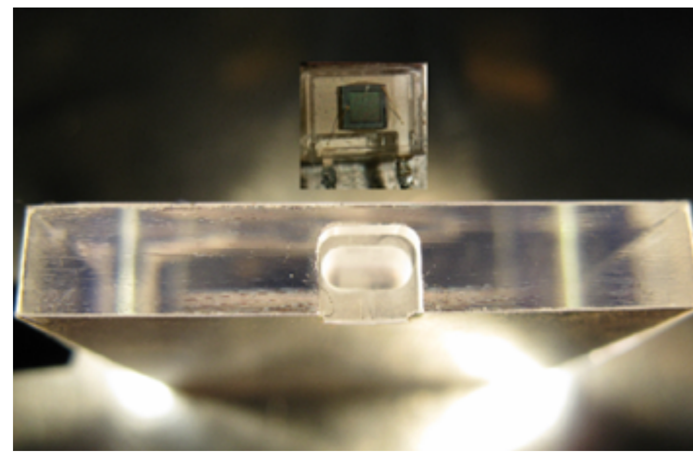
- Further optimisation possible
- Dependencies are smooth
- Fold in cost scaling
- New degrees of freedom
  - sampling
  - two granularities

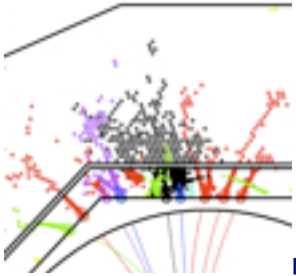
For scintillator, optimize independently

Conceptual design: done.
Steps towards realisation:

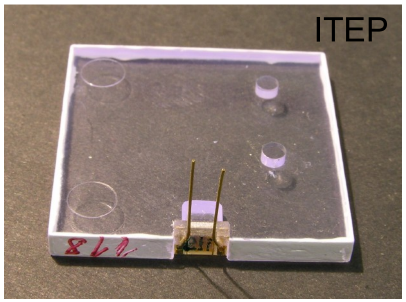
SiPM improvements

- Dynamic field, driven by medical applications (PET)
  - commercial use requires uniform devices
- 1€ per piece not unrealistic
  - Hamamatsu, SensL
- Improved performance in today's prototypes
  - e.g. Russian sensors have 100x less noise than in physics prototype



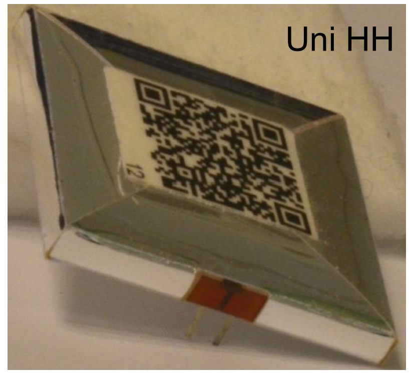


Scintillator tile options

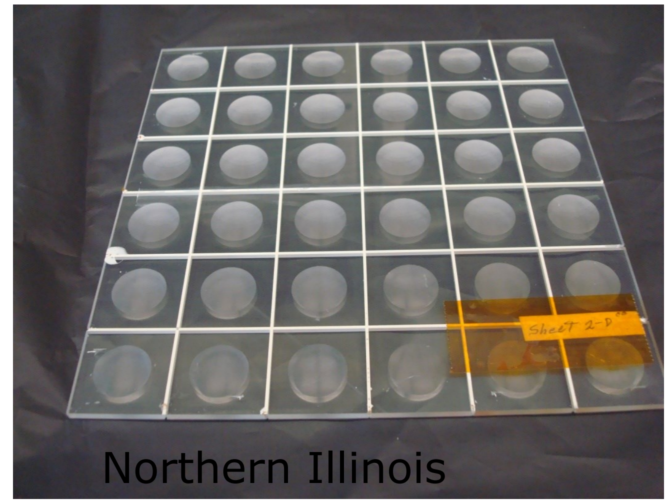


CPTA, KETEK or Hamamatsu sensors

no WLS fibre

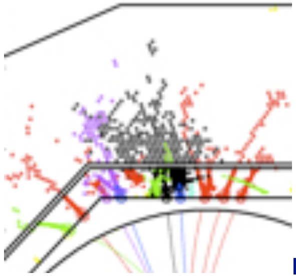


individually wrapped; KETEK sensors



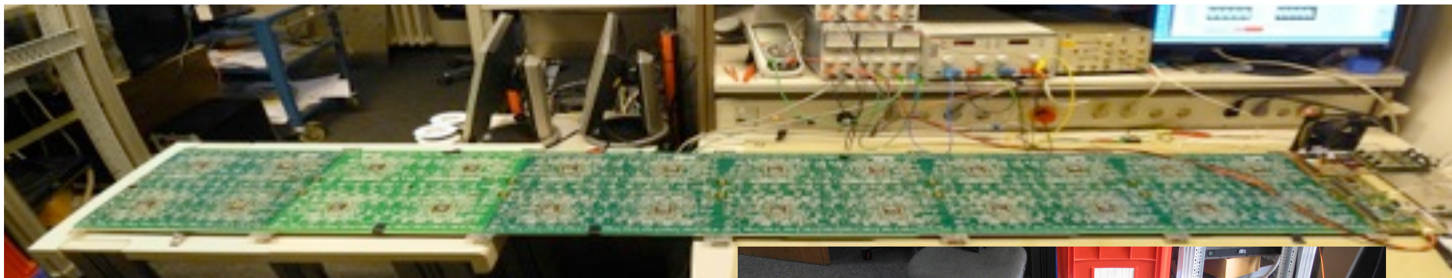
Hamamatsu sensors, on PCB surface

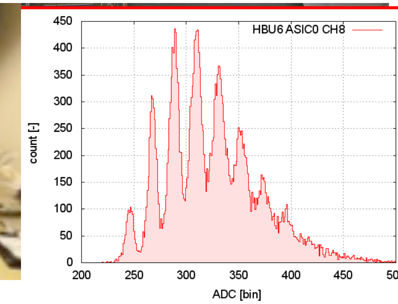
- Megatiles interesting alternative
  - need to understnd limitations and impact of optical cross talk
- need to optimise design and production together
- implication for QC chain: scintillator SiPM system independent of final electronics - or not



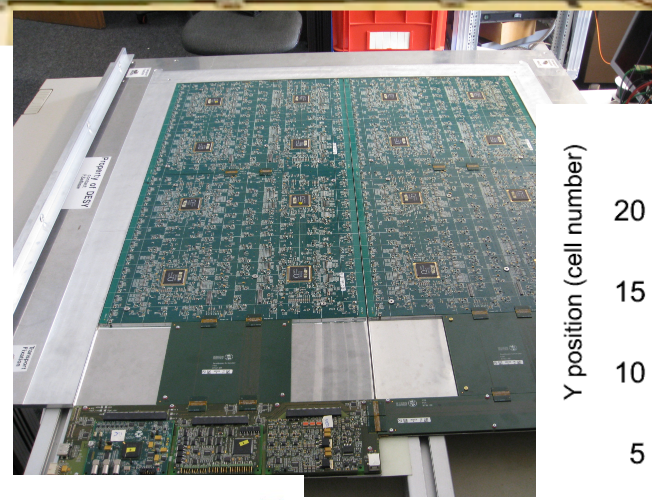
2nd generation prototype

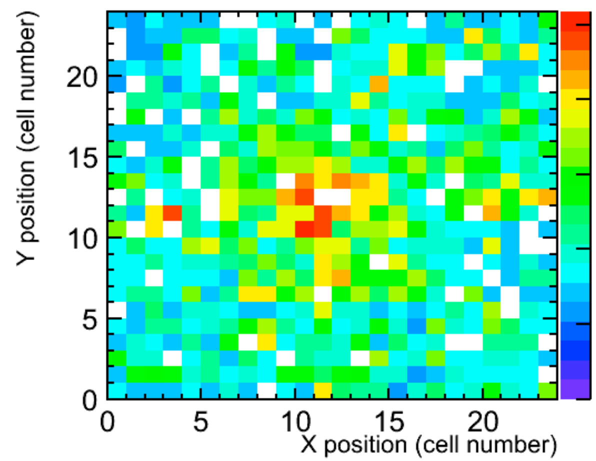
- Full slab: signal integrity



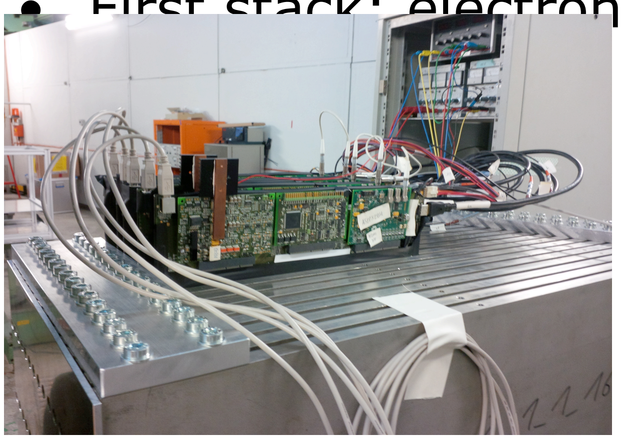


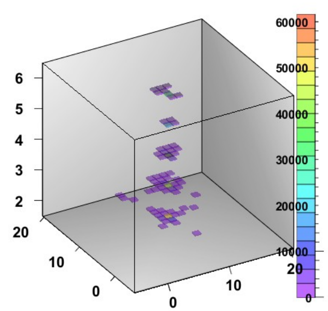
- Full layer: hadrons

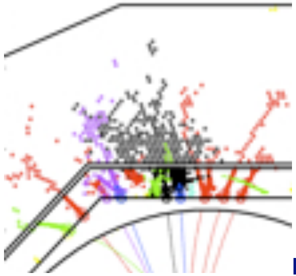




- First stack: electrons

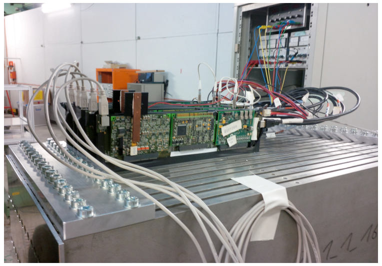


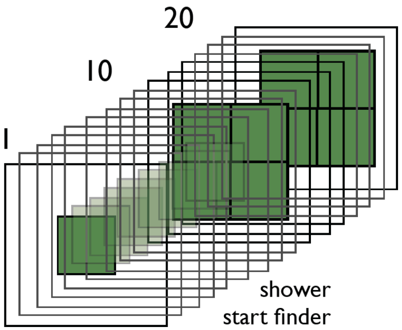




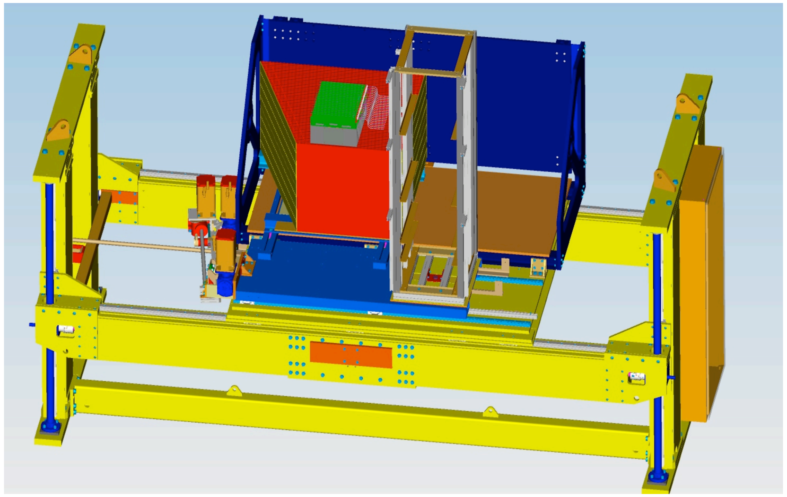
Flexible test beam roadmap

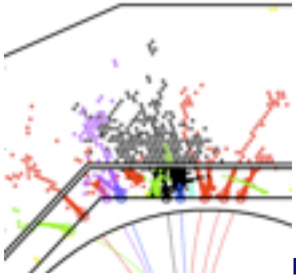
- 2013-14:
  - e.m. stack, 10-15 layers, ~200 ch
- 2015-16:
  - hadron stack with shower start finder, 20-30 HBUs, ~ 4000 ch
- 2017-18:
  - hadron prototype, 20-40 layers, 10-20,000 ch
- Gradual SiPM and tile technology down-select
- Exercise mass production and QC procedures





Fe and W





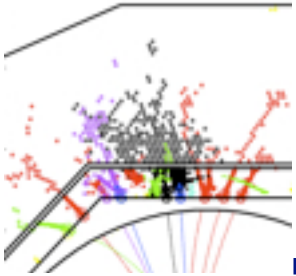
AHCAL groups in CALICE

thanks, Katja!

Realisation: on the way.
AHCAL for SiD:

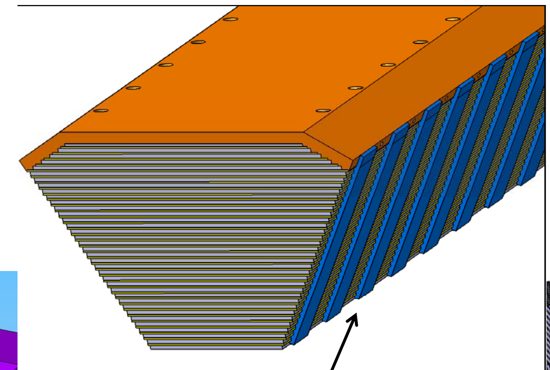
Realisation: on the way.
AHCAL for SiD:

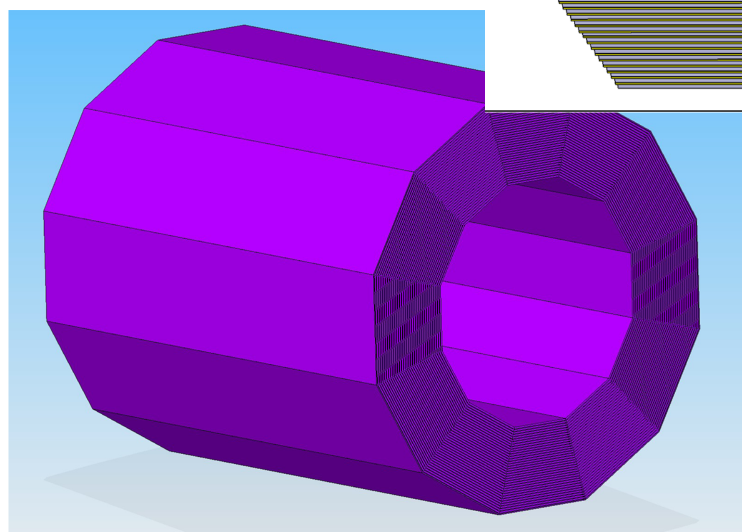
Stanitzki, options!

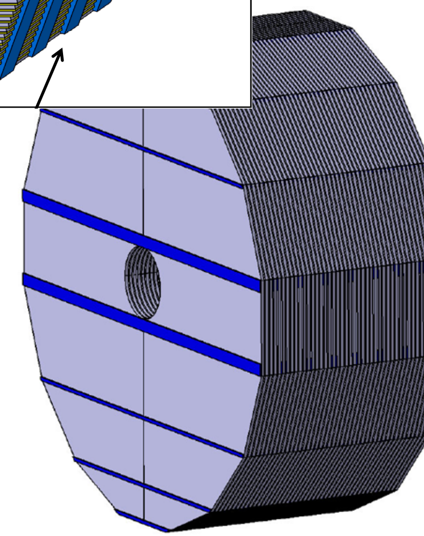


SiD HCAL

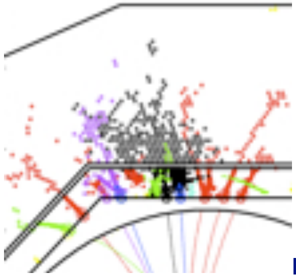
- Similar architecture
  - accessible electronics
- Barrel: smaller but longer
  - not a problem
- Same sampling





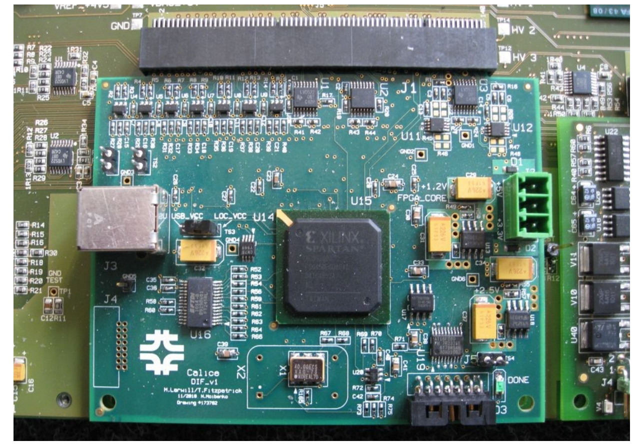


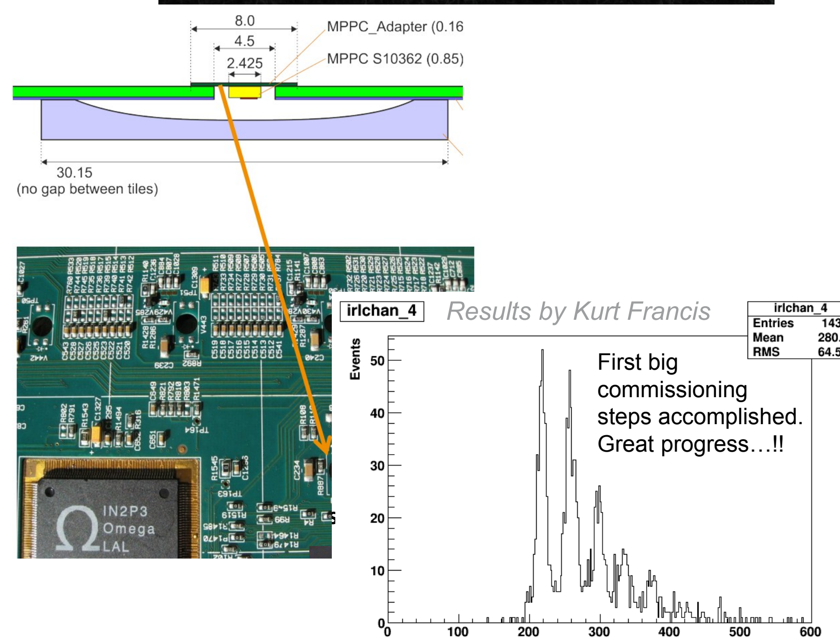
- To be done:
- Optimise granularity
  - expect no changes
- Implement active layers in mechanical design
  - HBUs are 8,9, 10, 12 tiles wide, smaller is easy
  - space for interfaces and services

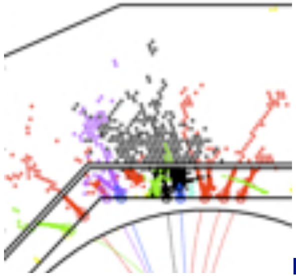


Electronics

- Cooperation DESY, NIU (+FNAL)
  - DIF: DAQ interface
    - design: DESY
    - prod: NIU (+FNAL)
  - IRL: HBU with NIU coupling concept
    - design: DESY and NIU
    - prod: DESY
- To be done:
  - evaluate combined operation with kPix
  - SPIROC and kPix both have time-stamping, memory, digitisation and readout between trains
  - common beam test at SLAC?



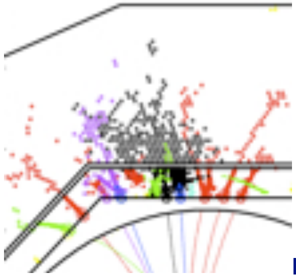




Summary

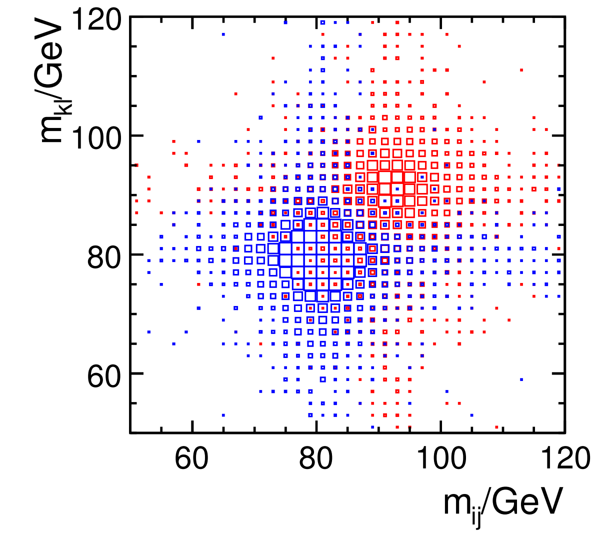
- Scintillator optimises energy resolution and imaging capability
- SiPM technology is established, understood and holding further potential
- Nothing on the AHCAL is particularly closely related to detector size or tracking technology
- There is relatively little required to arrive at a fully qualified option for SiD

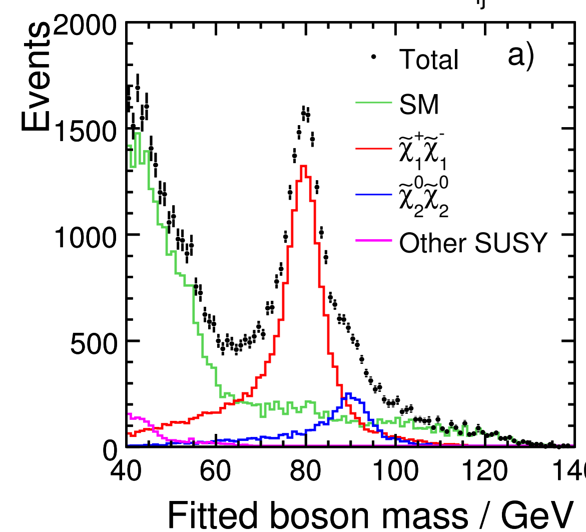
Back-up

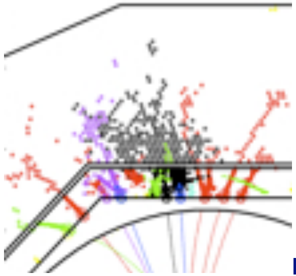


Jet energy resolution

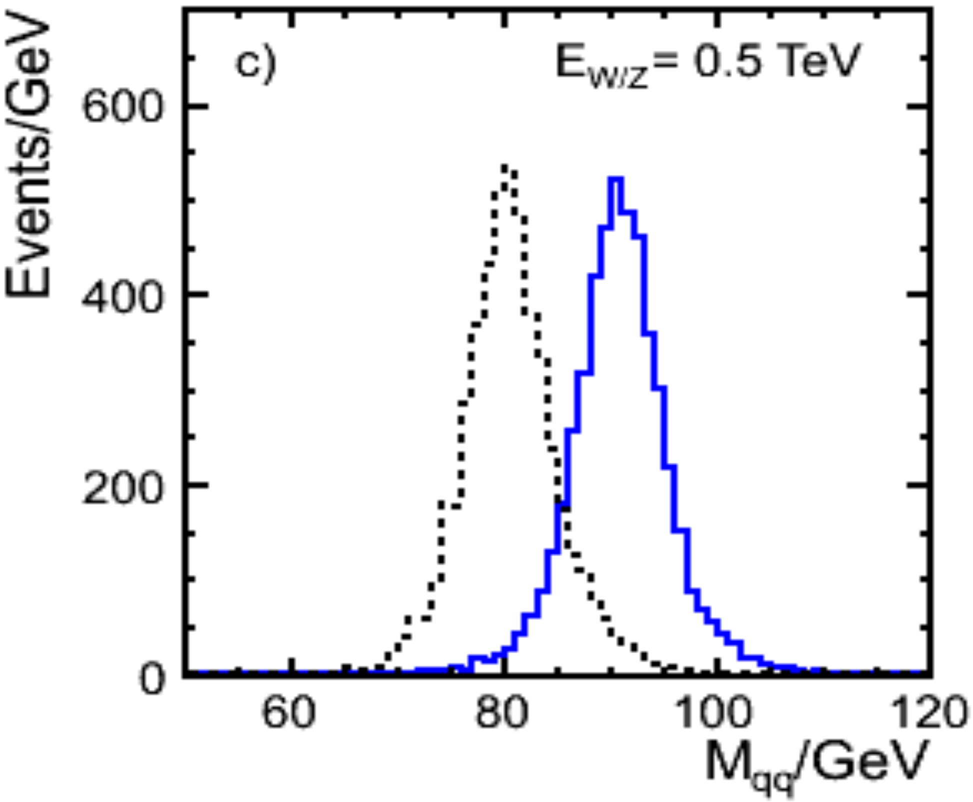
- At the ILC, must separate hadronic W and Z line D+ and Ds at Belle
- Famous "blue plot": study strong electro-weak symmetry breaking at 1 TeV
  - WWvv, ZZvv production
  - but this is not the only one
- H → WW*, ZZ* (total width)
- H → cc, Z → vv
- Chargino neutralino separation
- In contrast, multi-jet final states like ttH are rather insensitive
  - jet finding dominates



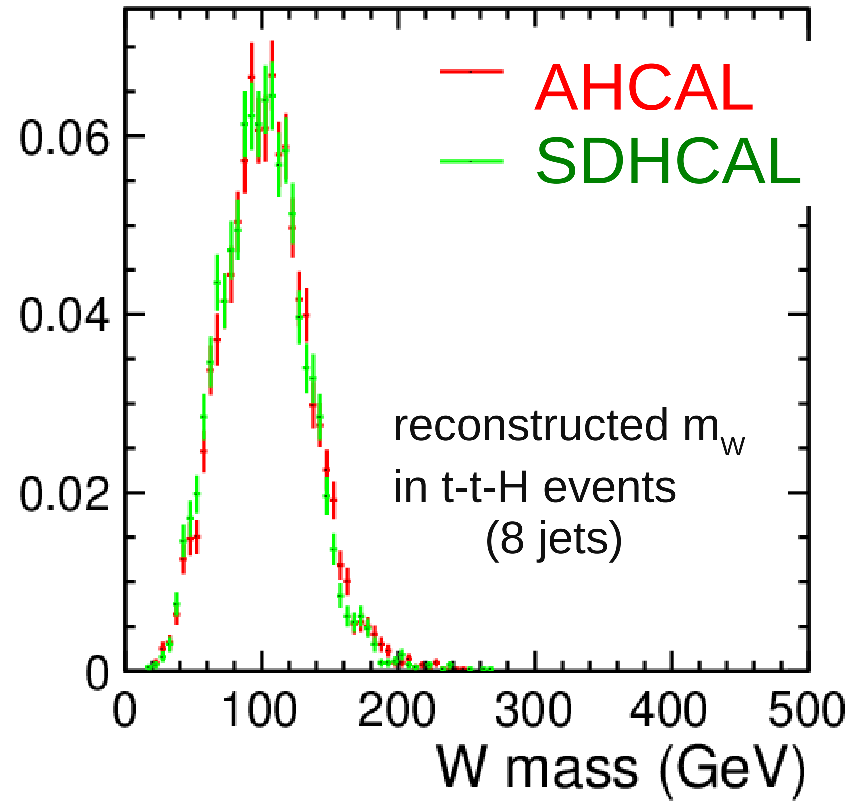


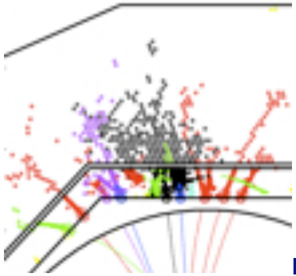


W Z separation

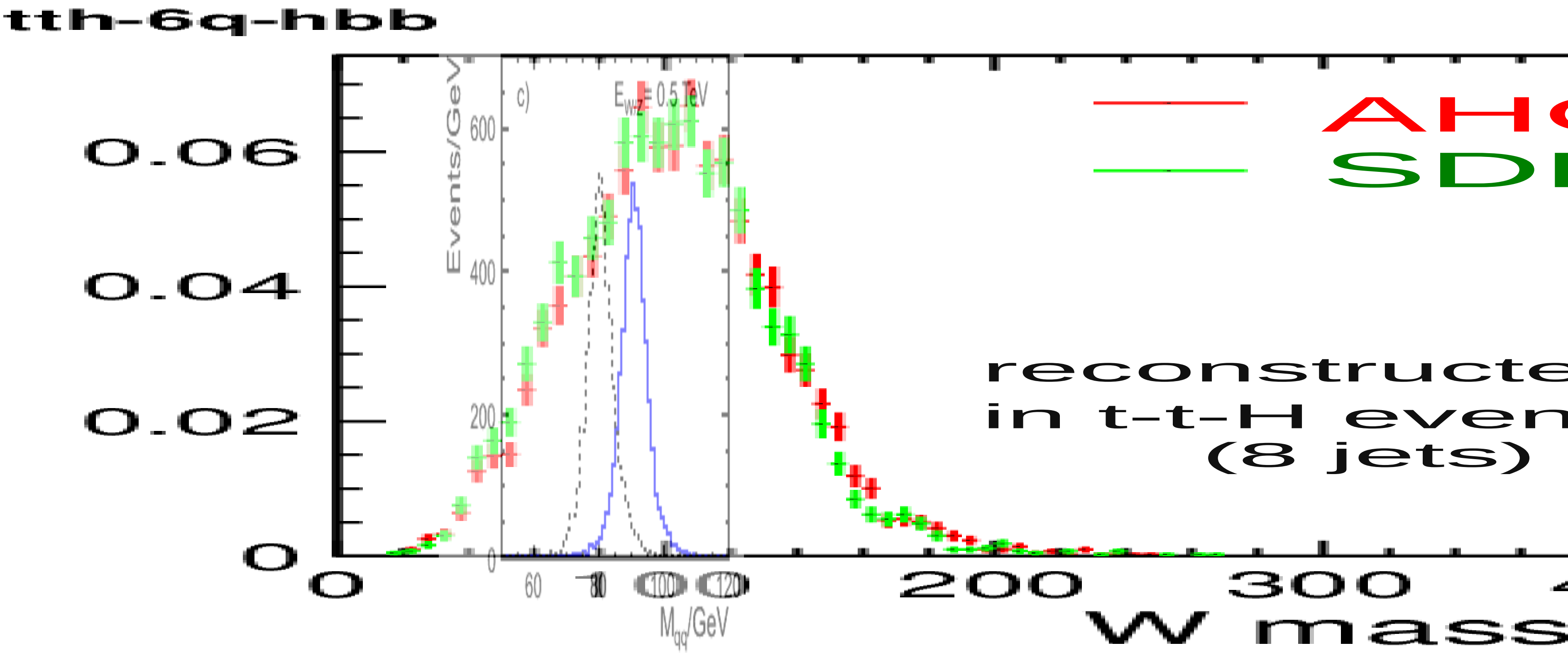


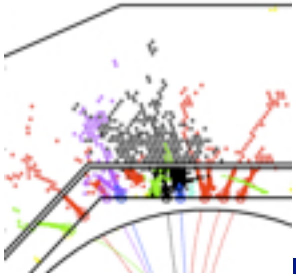
tth-6q-hbb



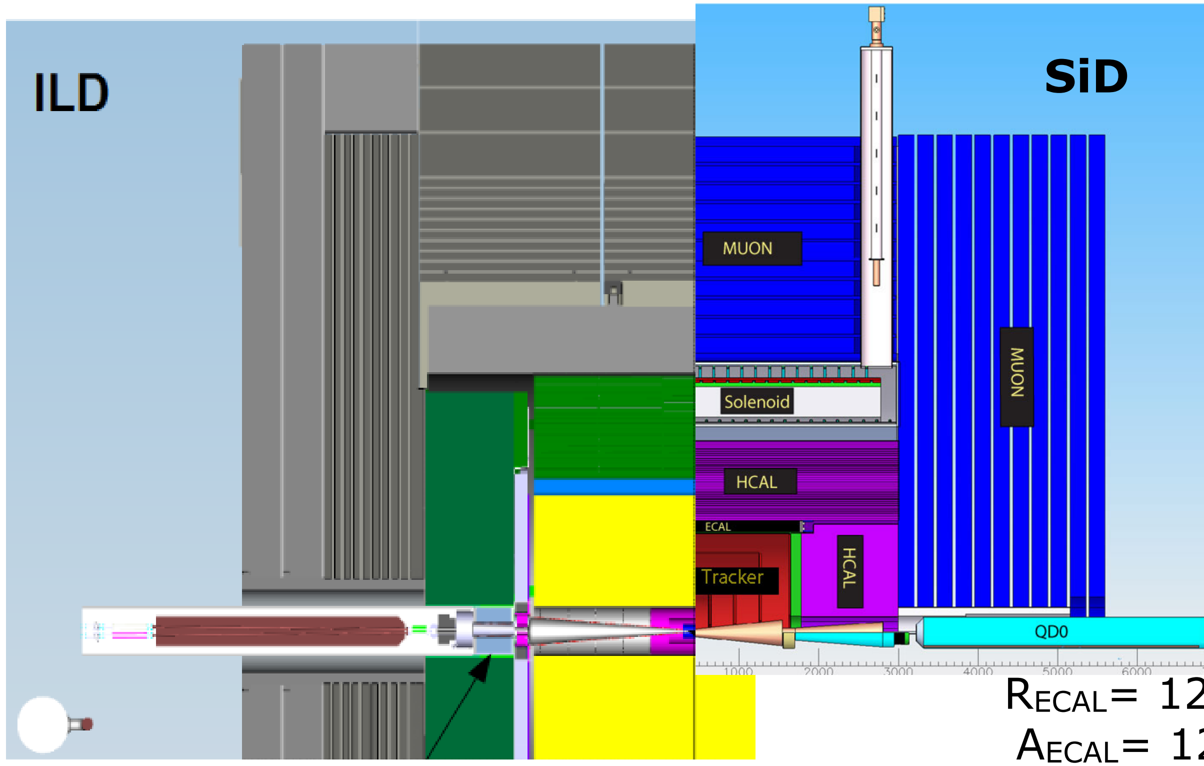


W Z separation





Design parameters



R_{ECAL} = 1843 mm
A_{ECAL} = 2500 m^2

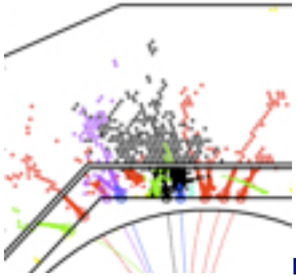
R_{COIL} = 3440 mm
R_{TOT} = 7555 mm

B = 3.5 T
M_{YOKE} = 13.4 kt

R_{ECAL} = 1265 mm
A_{ECAL} = 1200 m^2

R_{COIL} = 2591 mm
R_{TOT} = 6042 mm

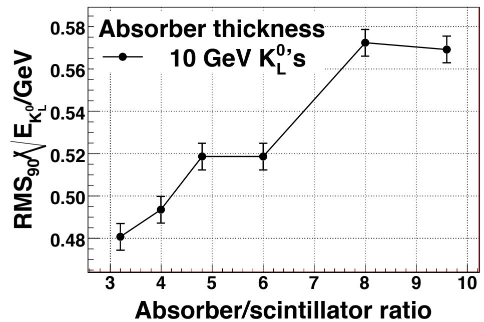
B = 5 T
M_{YOKE} = 8 kt

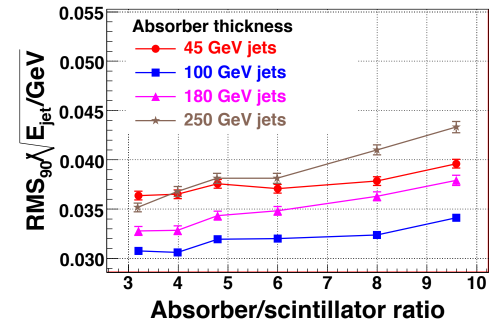


Parameter optimisation

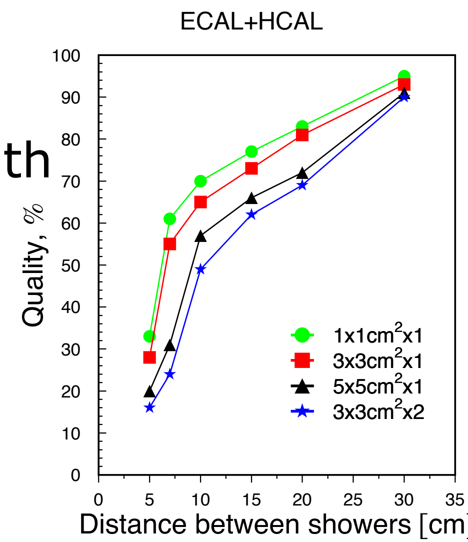
- Was done for the LOI
  - see Angela Lucaci's talk at ILD meeting in Cambridge, 2008
  - tile size
  - tile thickness
  - absorber material
  - absorber plate thickness
  - total thickness
  - dead zones
- Revise main cost drivers with new Pandora
  - absorber plate thickness d
  - tile size g; varying?
  - total thickness T
- Strip option: need SSA

single hadrons and jets:

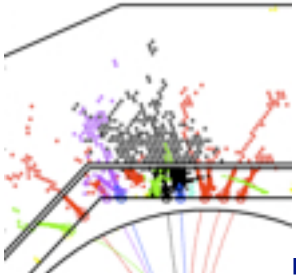




note zero suppression

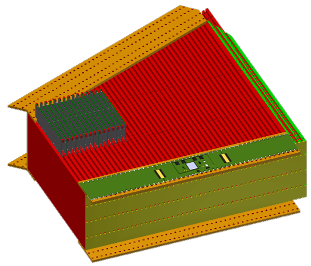


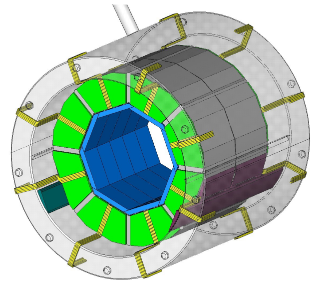
Raspereza 2004: transverse *and* longitudinal sampling important for shower separation

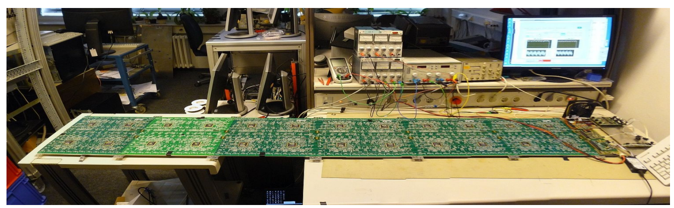


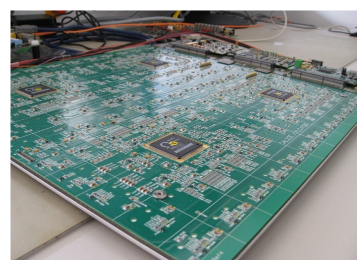
Industrialisation: Numbers!

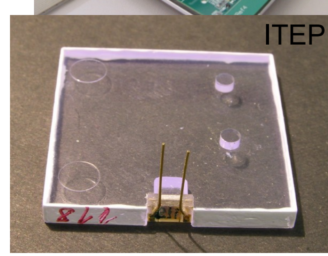
- The AHCAL
- 60 sub-modules
- 3000 layers
- 10,000 slabs
- 60,000 HBUs
- 200’000 ASICs
- 8,000,000 tiles and



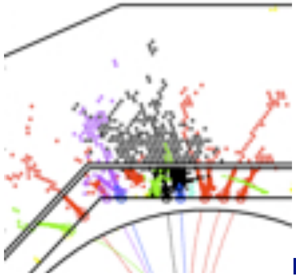






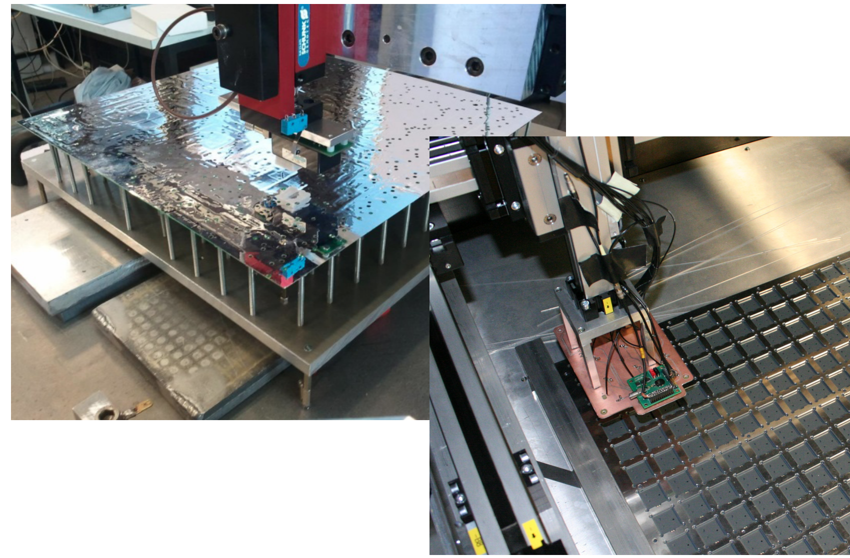


- One year
- 46 weeks
- 230 days
- 2000 hours
- 100,000 minutes
- 7,000,000 seconds

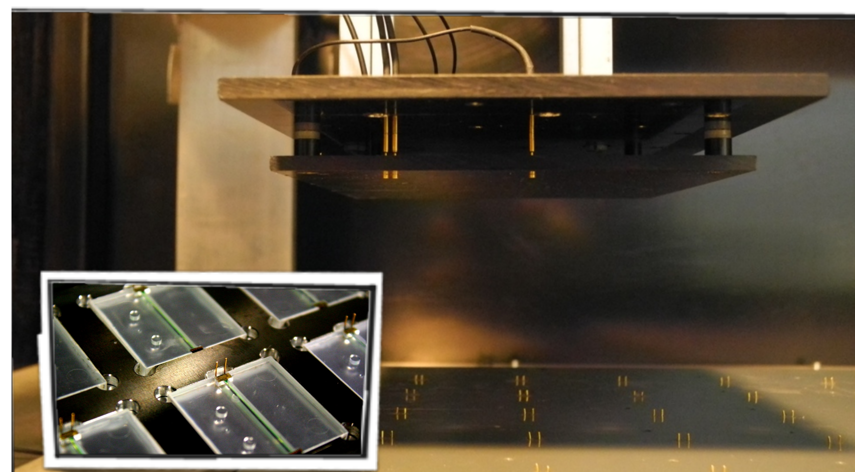


Quality control and production

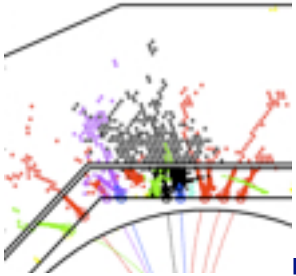
- Can be done: our engineers are looking forward to it
- There are interesting problems to solve
- Some efforts started:



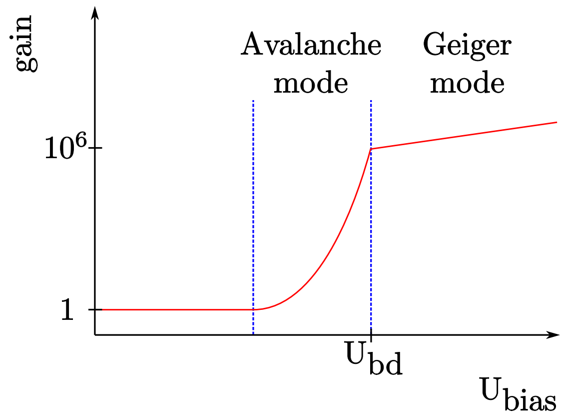
- SiPM and tile QC and characterisation
  - with UV light and beta source
  - fully automatised, fast parallel readout
- LED ad ASIC tests
- HBU assembly
  - place tiles, solder SiPMs
  - close relation to tile design and SiPM coupling
  - impact on QC chain

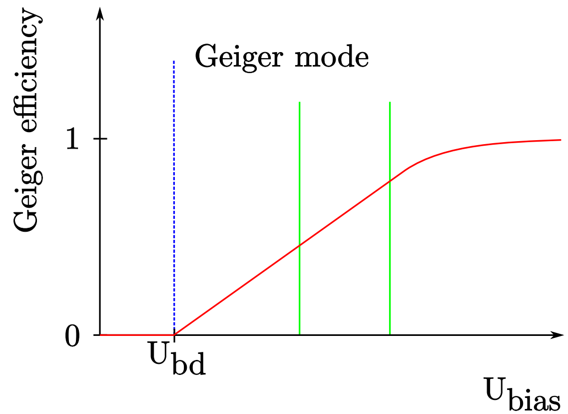


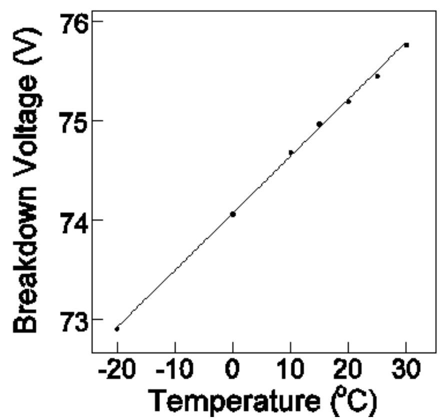
Heidelberg

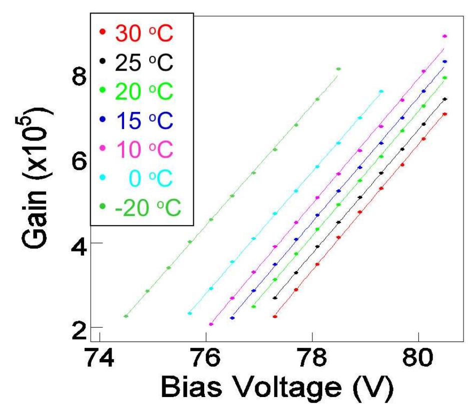


SiPM response

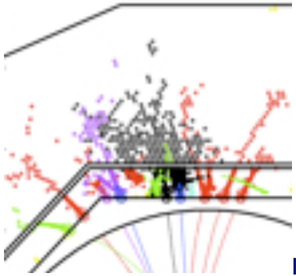






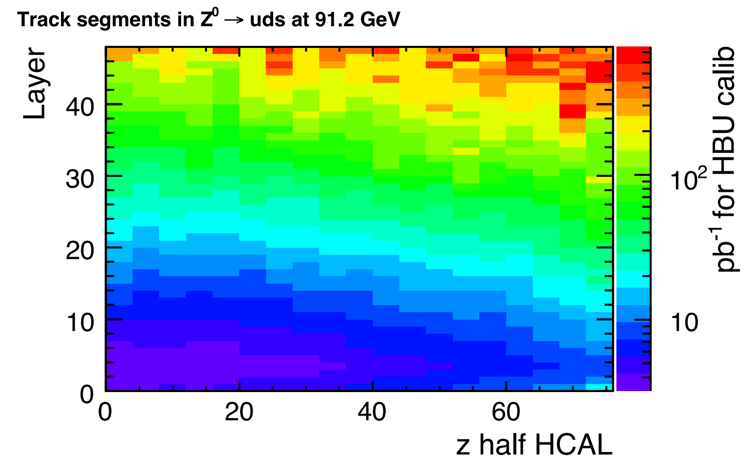


- $X = X(\Delta V)$, $\Delta V(T) = V_{bias} - V_{breakdown}(T)$

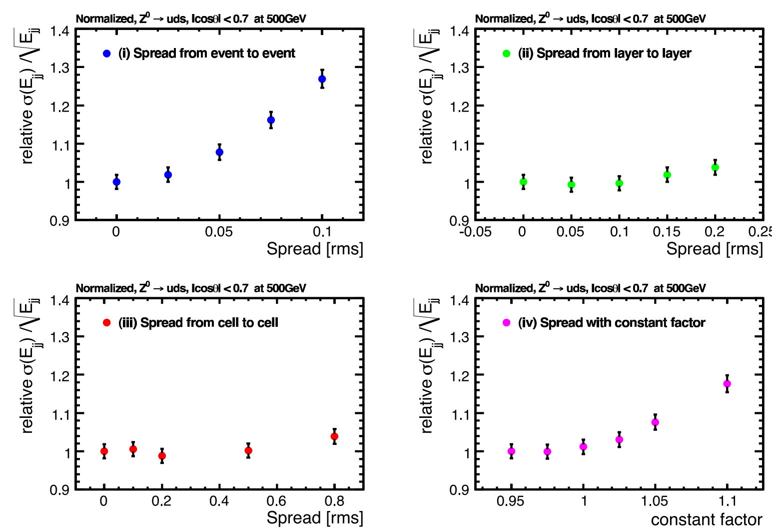


Calibration: look at full chain

- LOI validation: IDAG triggered study of required precision and luminosity for calibration
- MIP (= cell energy) scale well understood

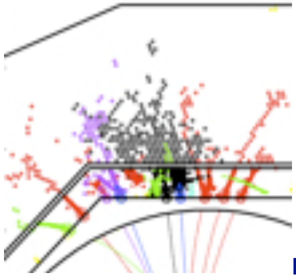


- LEDs for gain monitoring: issue is not cost, but time, and bandwidth
- need to optimize strategy, possible feedback on design and specs



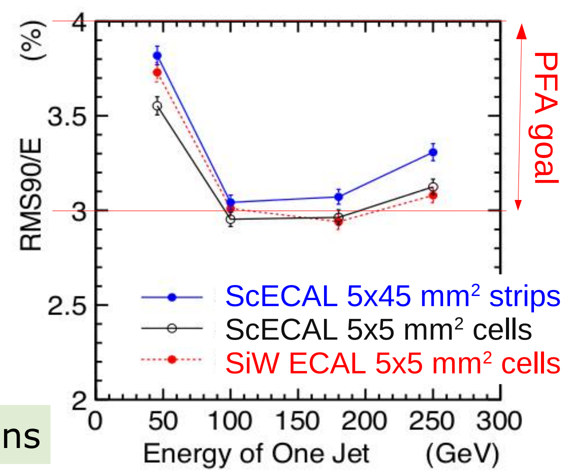
- Test bench is part of calibration - study required precisions vs. time needed for procedures
- "Precision" = measurement accuracy or device-to-device non-uniformity

Calice Analysis note 18 and ILD note

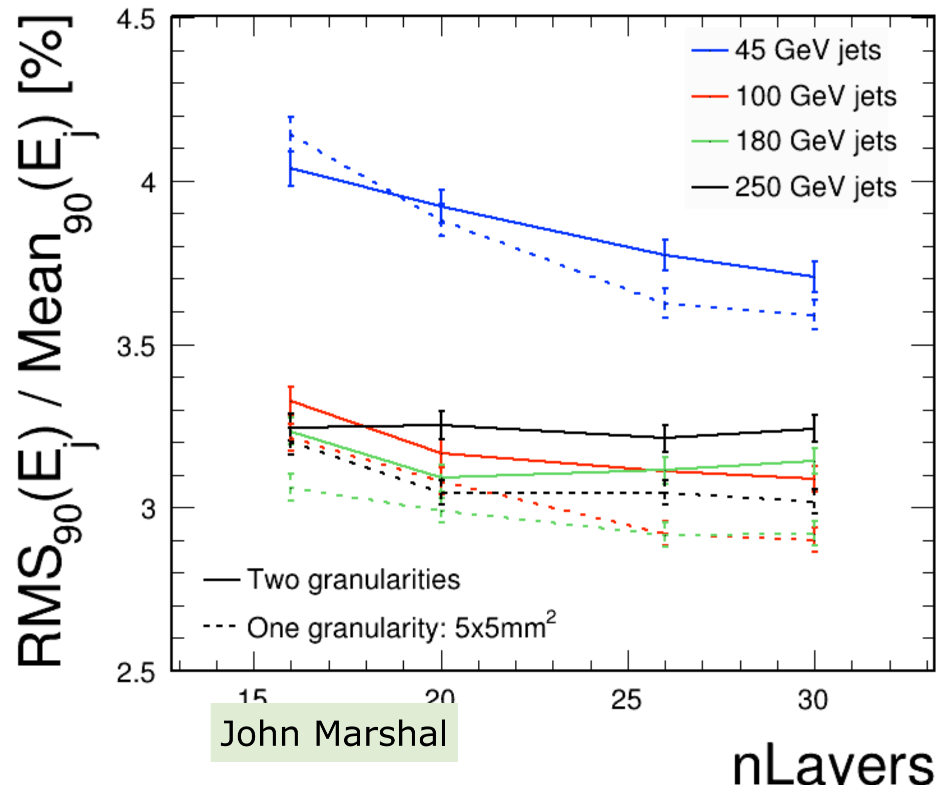


ILD ECAL

- 2500 m² sensor area: main cost driver
- work with industry on unit cost
- re-visit optimisation with new degrees of freedom
  - hybrid scintillator silicon transition
  - variable transverse segmentation
  - vary sampling (no of layers)
  - account for inter-calibration
- strip alternative



Daniel Jeans



John Marshal

Sampling counts at low energy (resolution)
Granularity counts at high energy (confusion)
Mostly in first 1/3 of layers (photon-hadron separation)