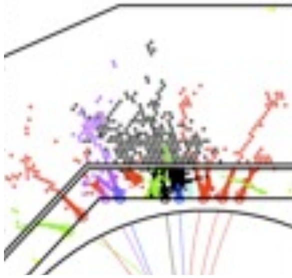
The Scintillator Analogue HCAL for ILD - status and goals

Felix Sefkow

ILD Meeting, Oshu-shi, 6.-9. September 2014

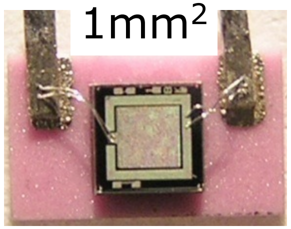
Outline

- The AHCAL experience
- The AHCAL in ILD
- AHCAL R&D
- Towards a technology selection

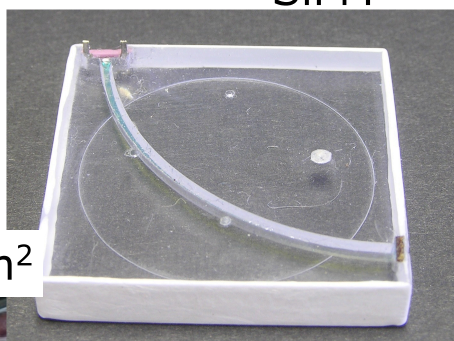


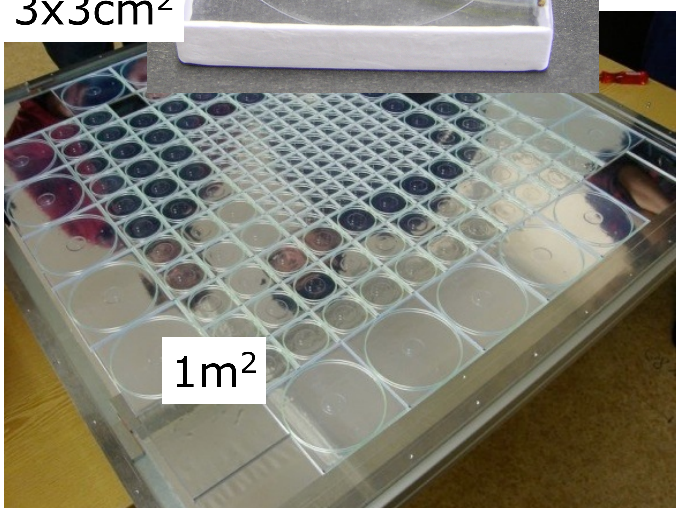
AHCAL physics prototype

7608 channels
38 layers
Fe & W



SiPM





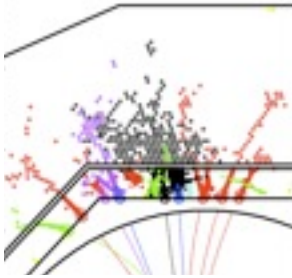
- Constructed in 2005-06: first device using SiPMs at large scale
- Now many followers: T2K, Belle2, CMS, medical applications,...

- 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

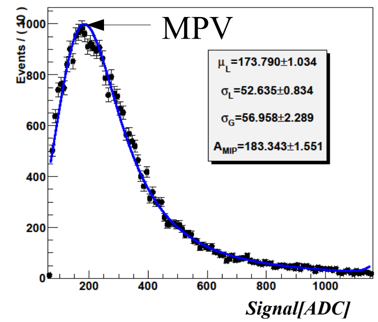
... and the SiPMs survived without problems!

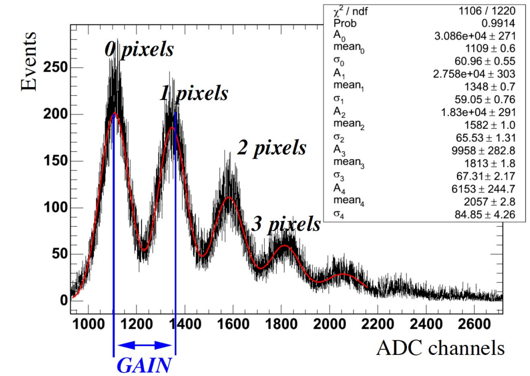


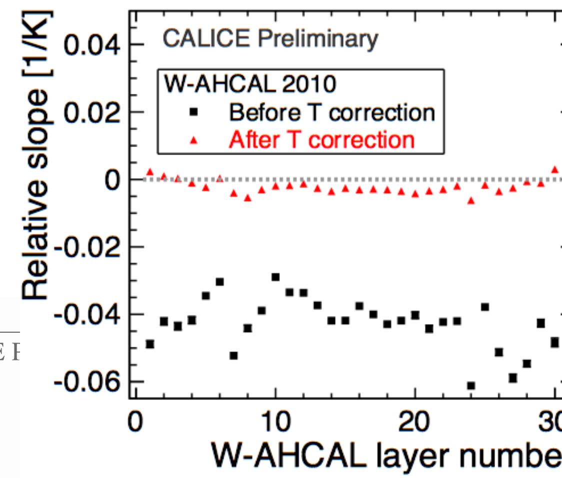
Calibration

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

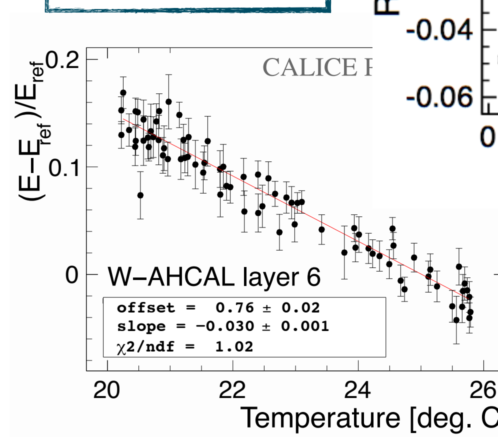
- Needed time to find right procedures
  - some limitations from test bench data
  - large spread of SiPM parameters
- Guidance for future developments
  - e.g. gain stabilisation



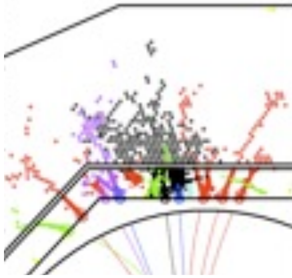




no climate control

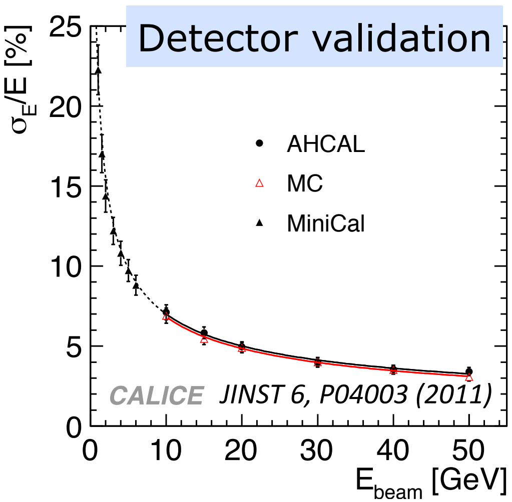


After layer-wise correction stable to better than 0.2%/K

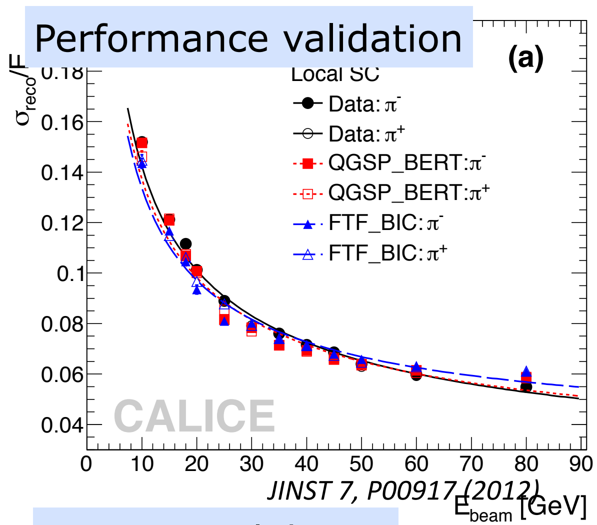


Validation of Simulation

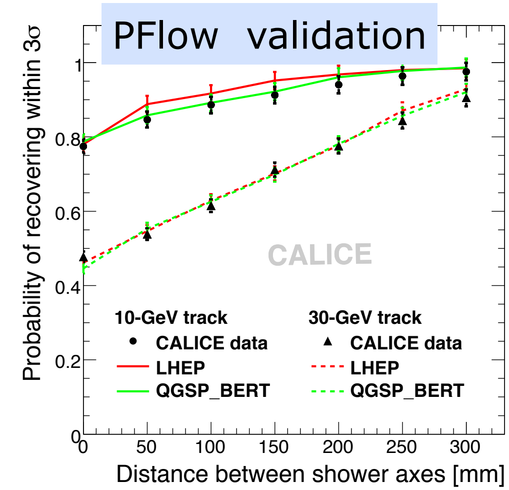
- Validation with first generation prototype
- Published 8 papers



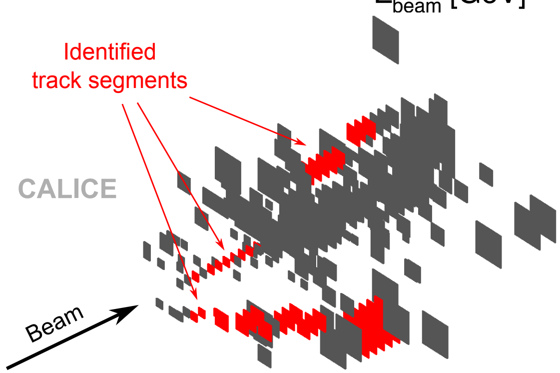
JINST 6, P04003 (2011)



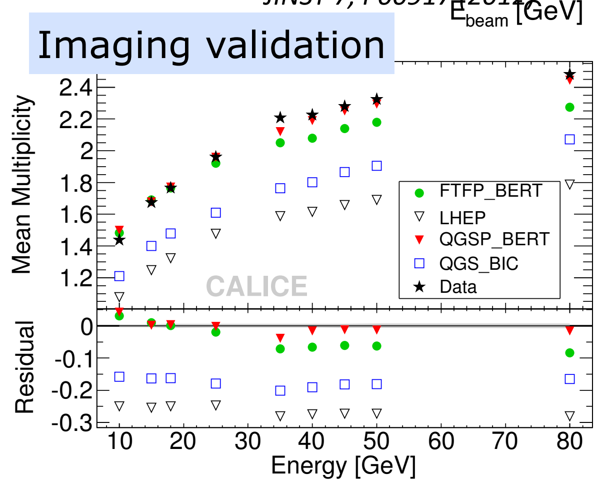
JINST 7, P00917 (2012)

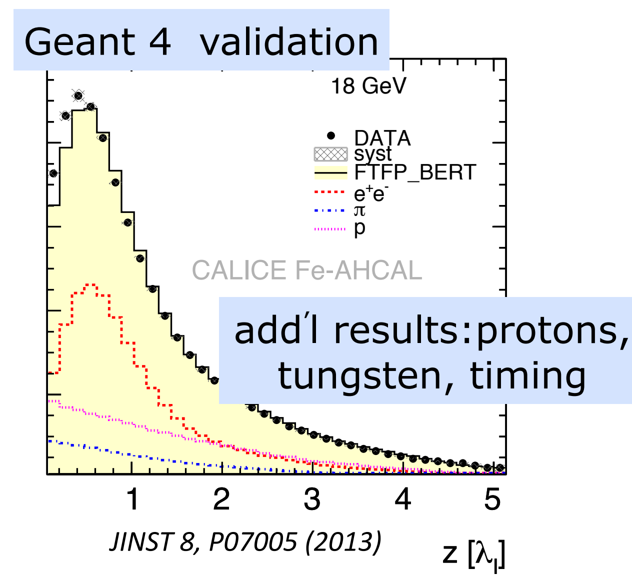


JINST 6, P07005 (2011)



JINST 8, P09001 (2013)





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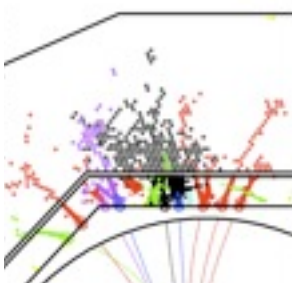
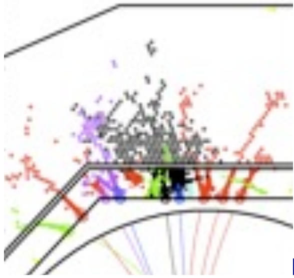


Coming:

- Combined ECAL HCAL resolution
  - preliminary for Si ECAL
  - on-going for Sci ECAL

Proof of principle: done.

Towards a real detector:

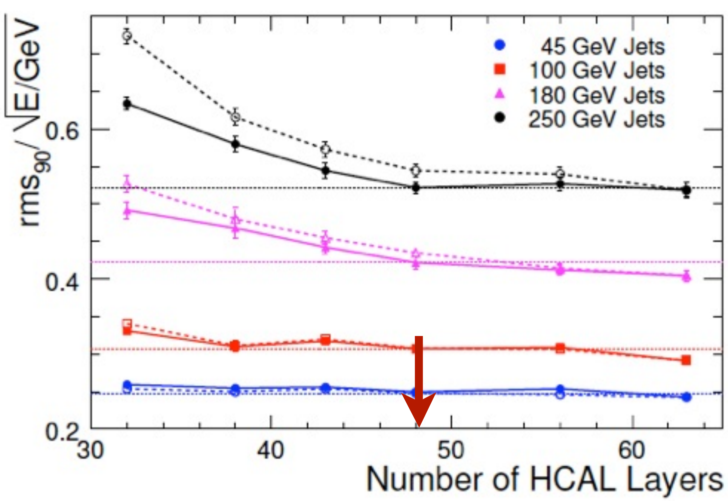


ILD optimisation

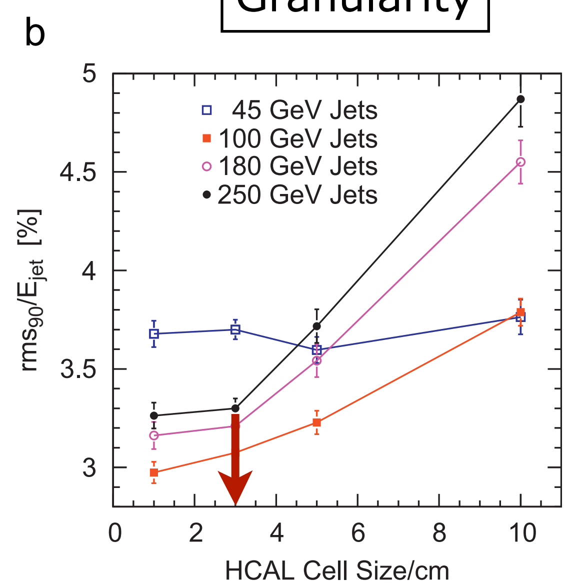
- Based on Pandora PFA
- Extensive studies done for the LOI
- AHCAL design parameters in plateau region

- Cost optimisation postponed

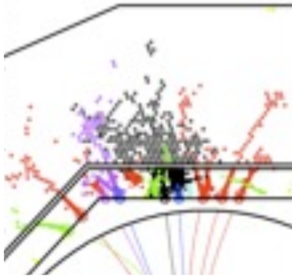
Depth



Granularity

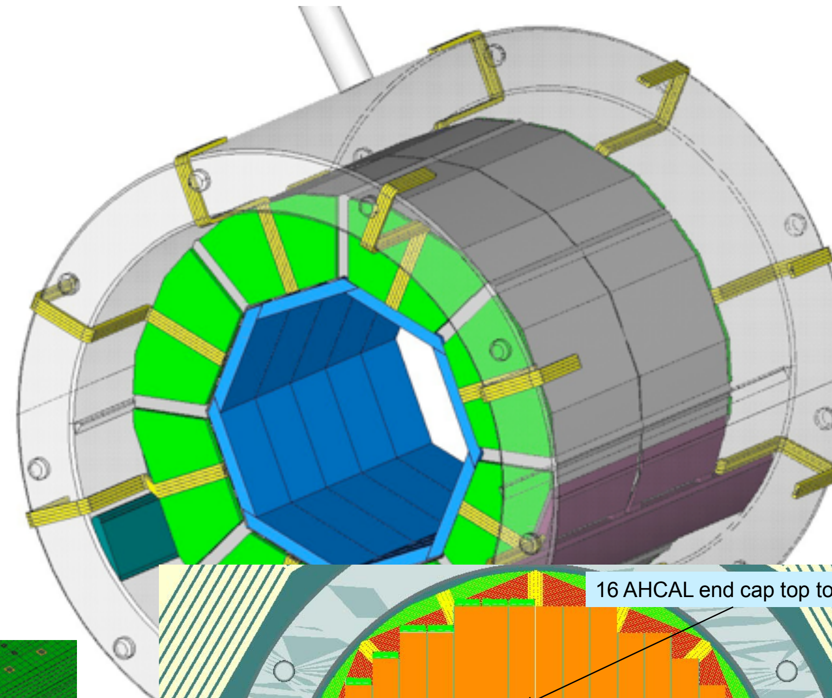


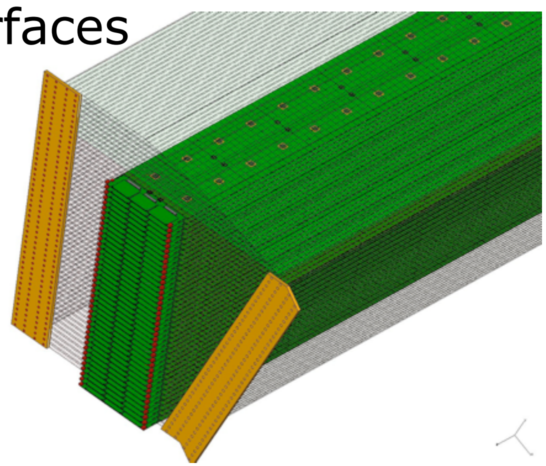
reflects shower feature size rather than particle separation

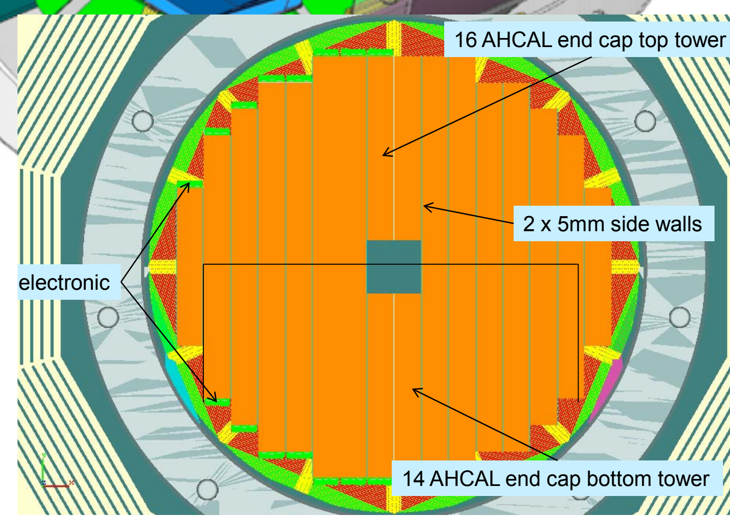


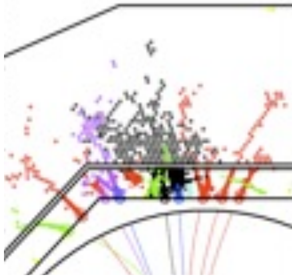
AHCAL implementation

- 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

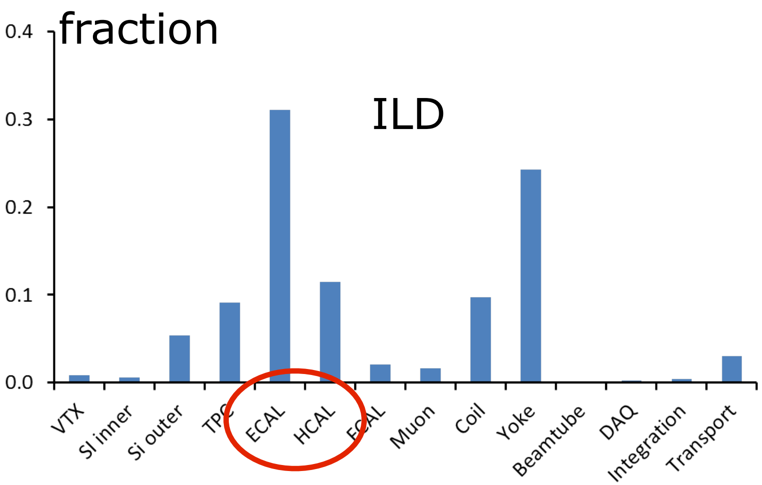








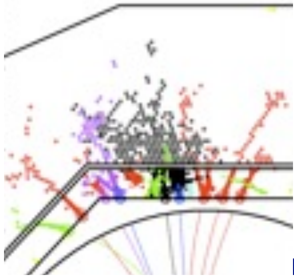
AHCAL cost drivers and scaling



- DBD costing is far from final, but much better than anything before
- Yet, many lessons learnt from 2nd generation prototypes
- What are the real cost drivers at present?
- What are the scaling laws?

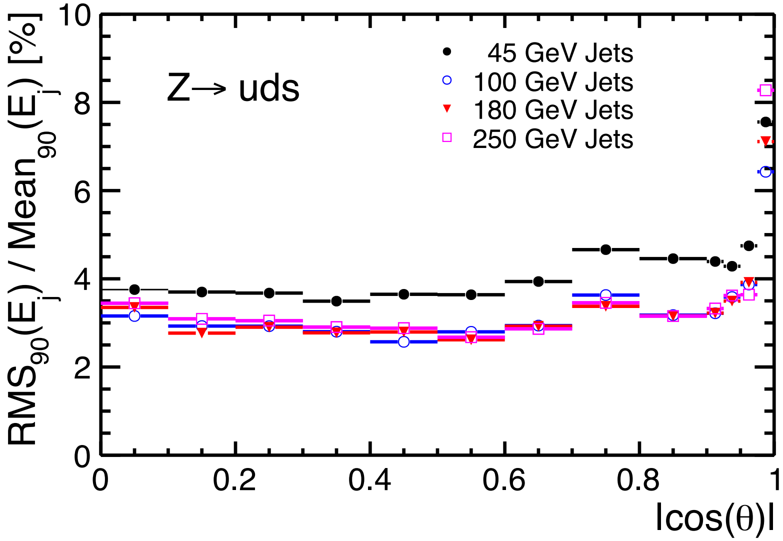
- ILD scint HCAL total: 45M
- 10M fix, rest ~ volume
- 10M absorber, rest ~ area (n_{Layer})
- 16M PCB, scint, rest ~ channels
- 10M SiPMs and ASICs

- Not cost drivers:
- Scintillator 1.5M
- ASICs 1.8M
- Interfaces 1.4M
- ...



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 (n_{layers})
  - varying granularities

For scintillator, optimise energy and space resolution independently

- Further improvement possible!
- Implement software compensation
  - most efficient and most relevant at low energies
  - but could also help in re-clustering stage to reduce confusion

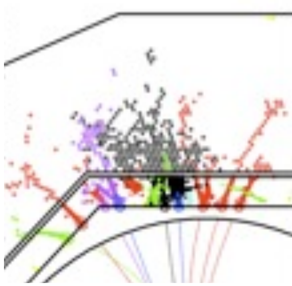
Beyond jet energy resolution

- ILD and its calorimeters have been optimised for jet energy resolution using particle flow
- **Particle ID** is under-exposed

- Indirect impact on PFLOW performance
- Direct impact on other physics analyses
  - isolated leptons vs hadronic background
  - leptons from heavy quark decays,
    - e.g. for calibration of vertex based b,c tag efficiencies

No picture

- Combined detector studies:
- **Electron pion separation** : ECAL and HCAL
- **Muon pion separation** : (ECAL,) HCAL and tail catcher

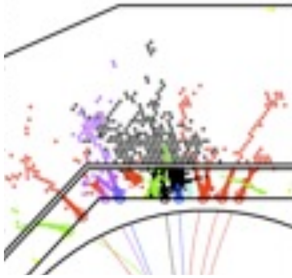


Coming:

- Re-optimisation of sampling in 3D
- Lepton ID studies with ECAL and TCMT
- Study of digitisation effects

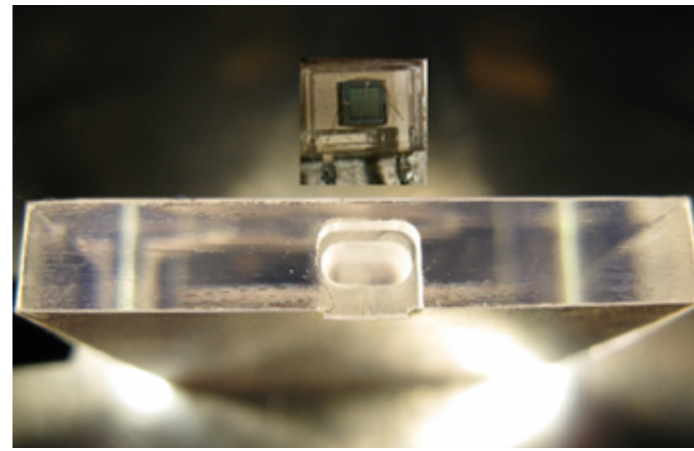
- Earthquake stability studies
- Cooling system for interfaces

Conceptual design: done.
Steps towards realisation:



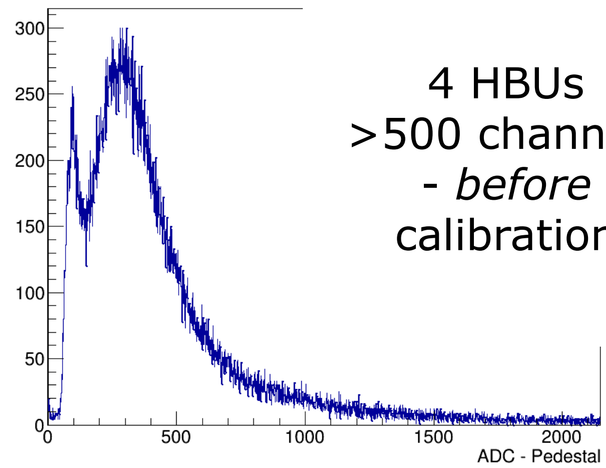
SiPM improvements

- Dynamic field, driven by medical applications (PET)
  - commercial use requires uniform devices, too, and moves to larger channel counts
  - SensL quotes 0.25V bias spread for several 100,000 devices
- 1€ per piece not unrealistic
  - Hamamatsu, SensL
- Improved performance in today's prototypes
  - today's sensors (Russian, German, Irish, Japanese) have 100x less noise than in physics prototype

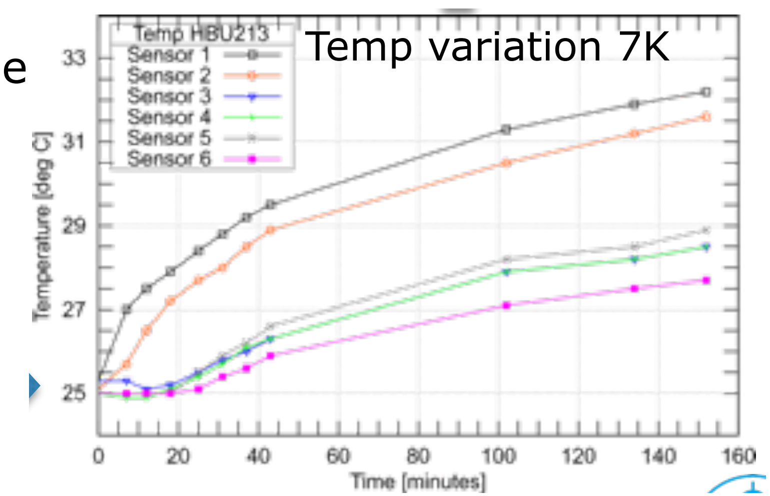


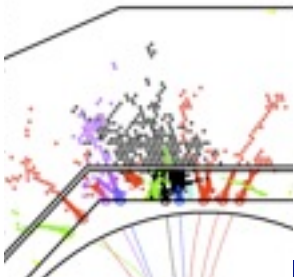
Benefits

- Device uniformity: dramatic simplification of commissioning procedures
- Many degrees of freedom become obsolete
  - no need anymore for bias adjustment to equalise light yield
  - no need anymore for pre-amp compensation of SiPM gain variation
  - no need anymore for channel-wise trigger thresholds
- Low noise: auto-trigger works
- Higher over-voltage possible - reduce temperature dependence



4 HBUs
>500 channels
- *before*
calibration





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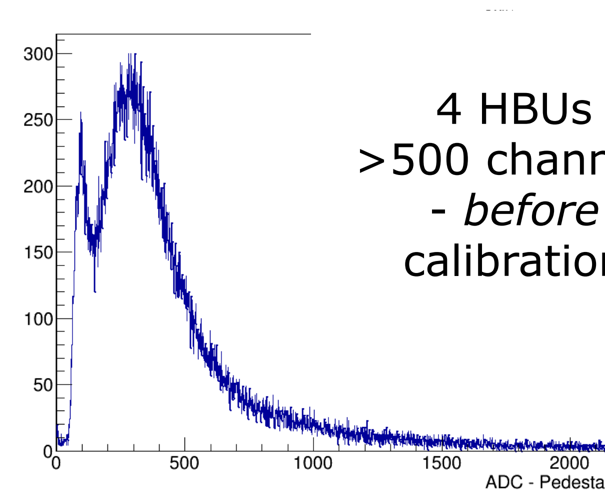

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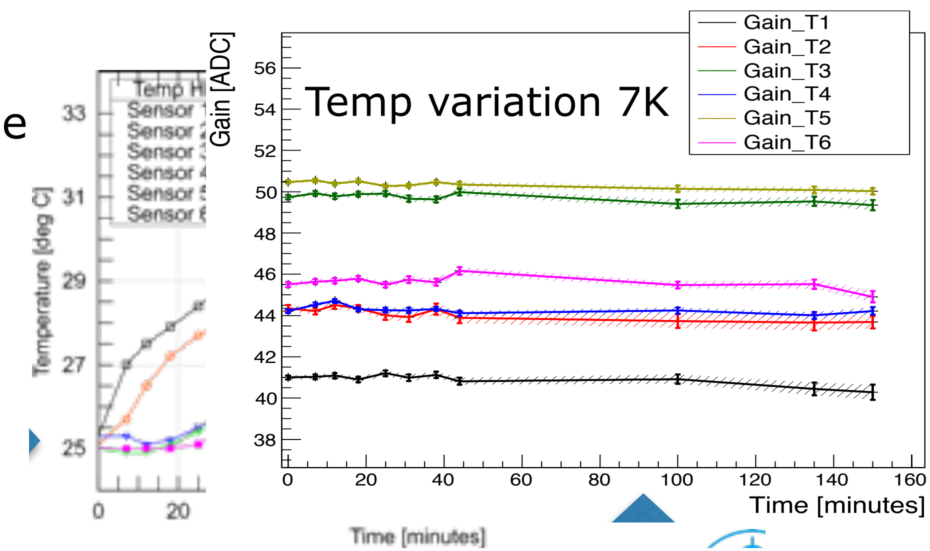
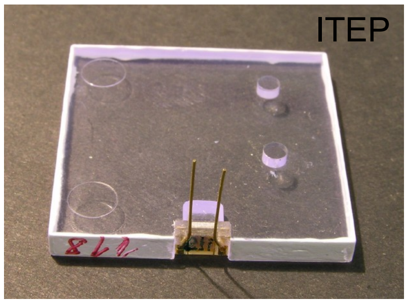
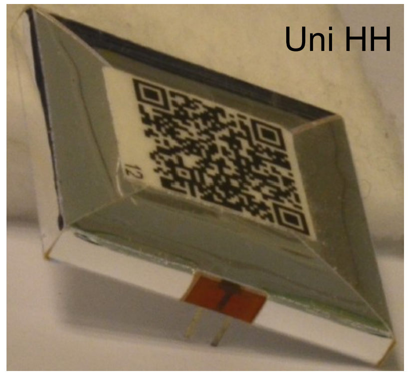


Scintillator tile options

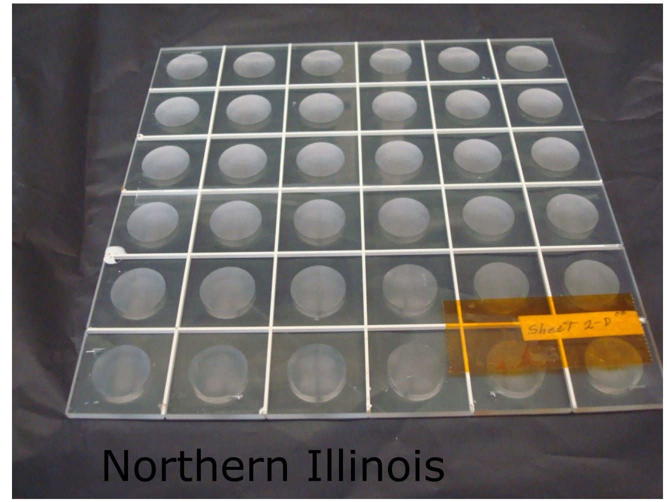


CPTA, KETEK or Hamamatsu sensors

no WLS fibre

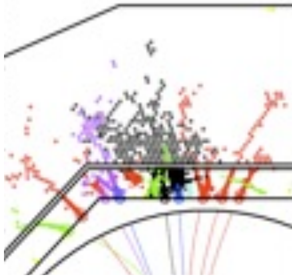


individually wrapped; KETEK sensors



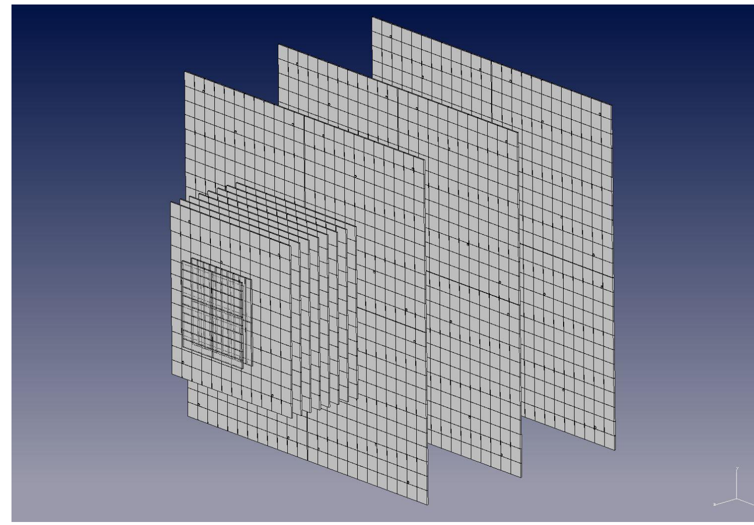
Hamamatsu sensors, on PCB surface

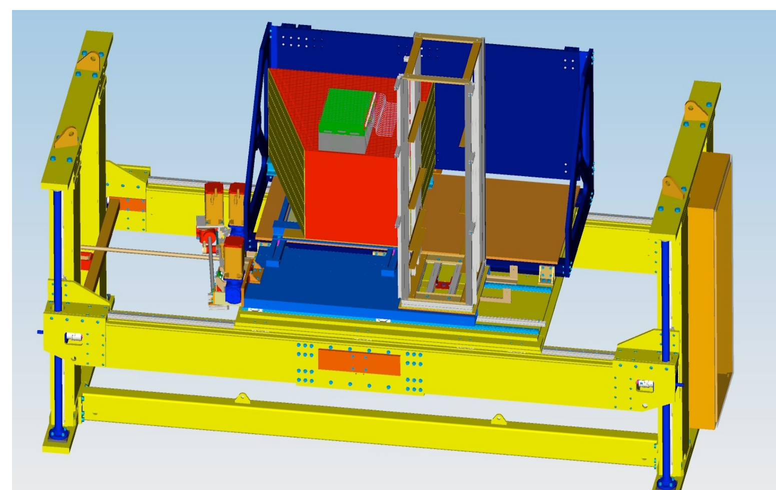
- Simplification, industrialisation
- Blue-sensitive sensors: eliminated WLS fibre and reflector
  - Developed direct coupling - from side or from top
- Megatiles interesting alternative for mass assembly
  - need to optimise design and production together

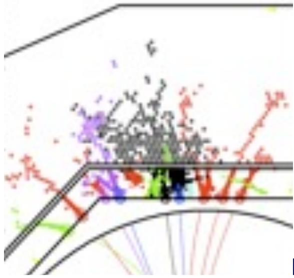


Flexible test beam roadmap

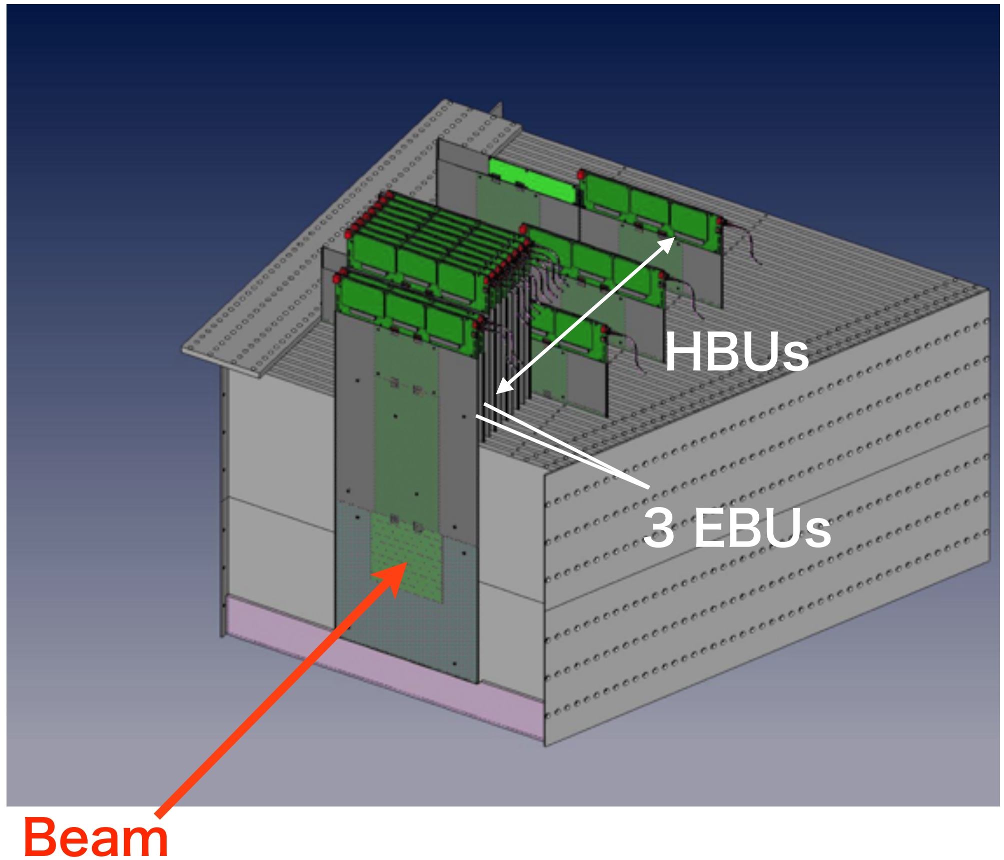
- 2013-14:
  - e.m. stack, 10-15 layers, ~2000 ch
- 2015-16:
  - hadron stack w/ shower start finder
  - 20-30 ECAL and HCAL units, ~ 4000 ch
- 2017-18:
  - hadron prototype, 20-40 layers, 10-20,000 ch
- Gradual SiPM and tile technology down-select
- Exercise mass production and QC procedures



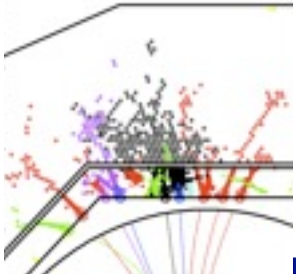




Getting real



- Test beam at CERN PS in Oct and Nov/Dec 2014



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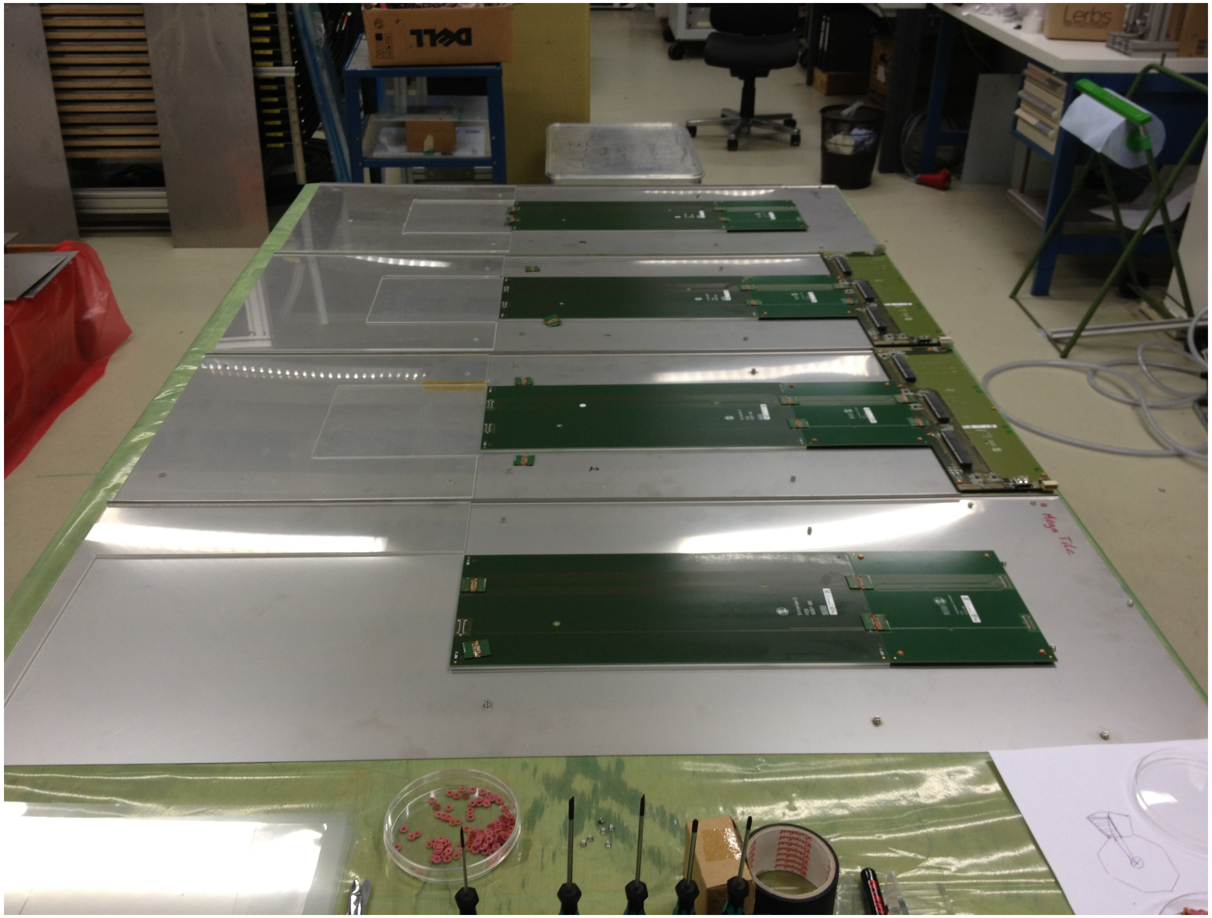

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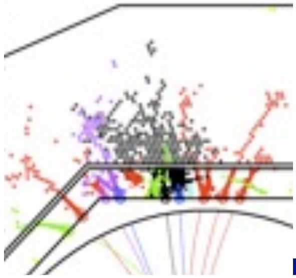

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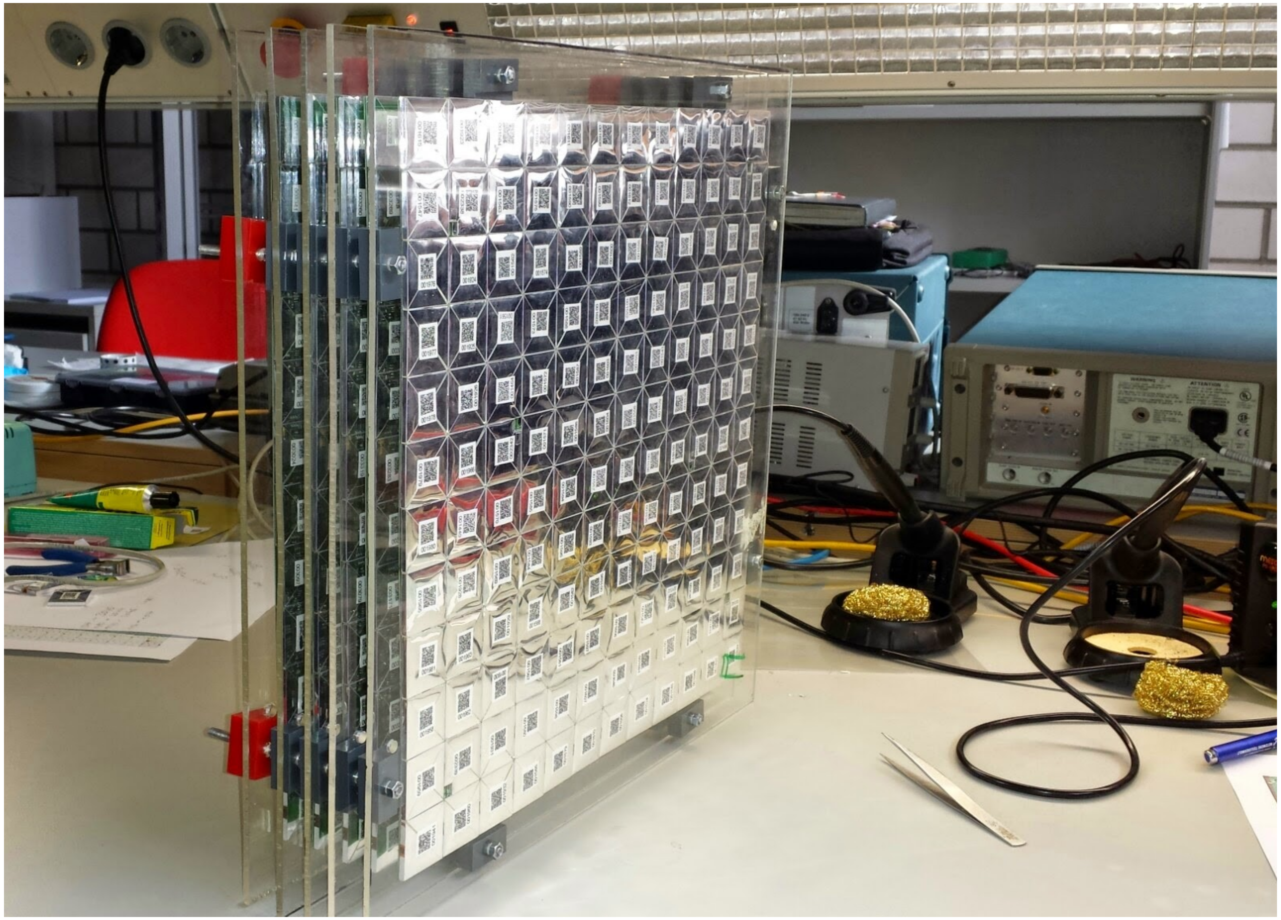

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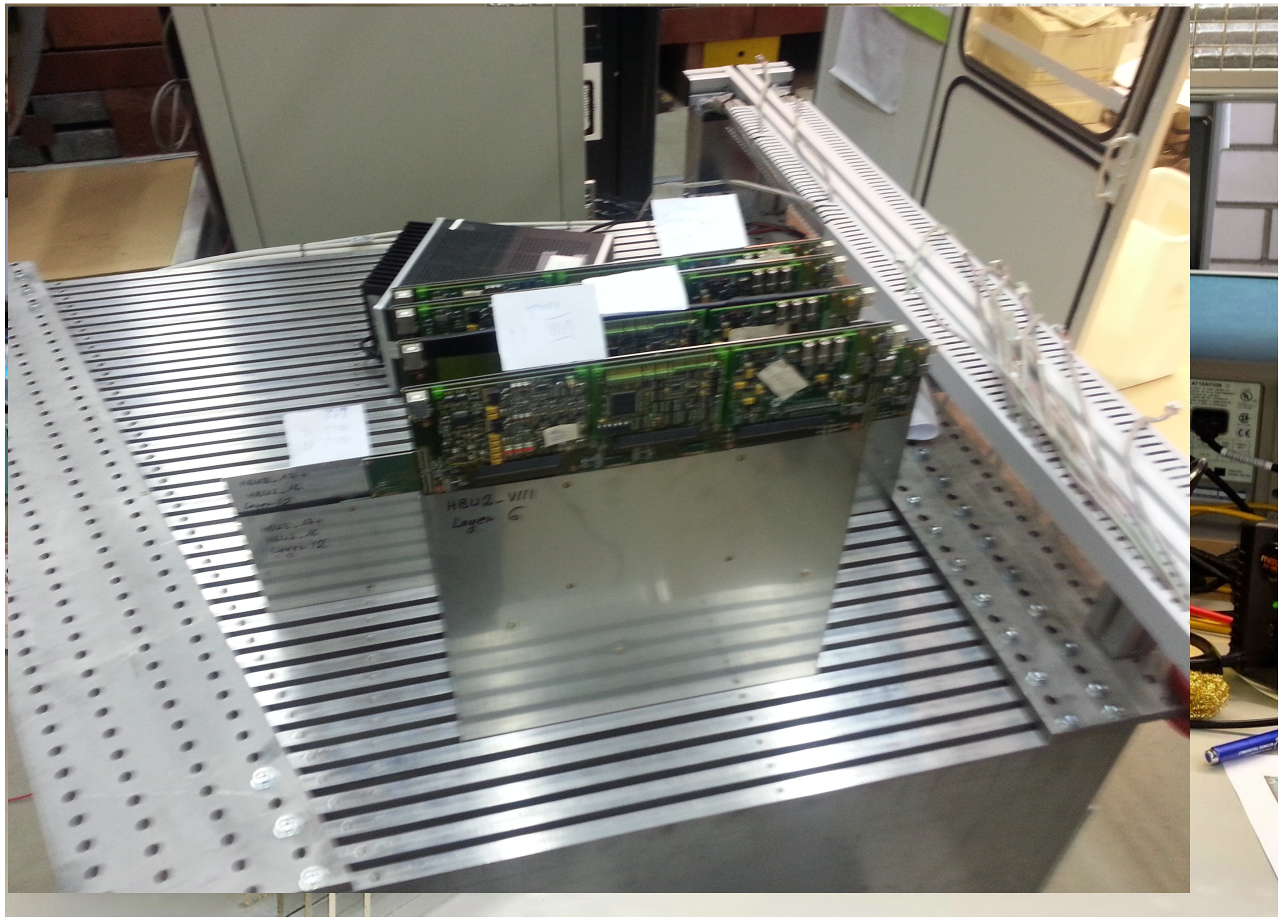

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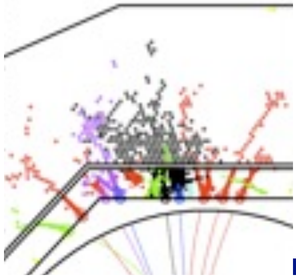

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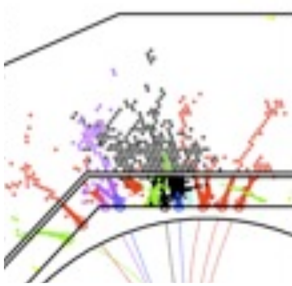


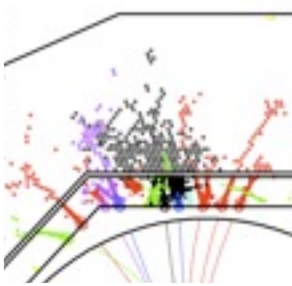
Coming:

- Establish technological prototype test beam performance
  - detector only
  - do not repeat full Geant 4 study
- Mass production concept

- Optional, but attractive:
- Megatiles option
- Strip HCAL option
- SiPM active temperature compensation

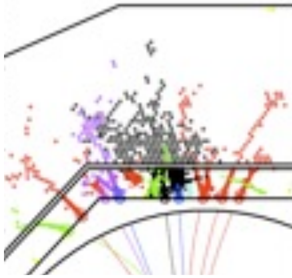
R&D converging.
Towards technology selection:

R&D converging.
Towards technology selection:



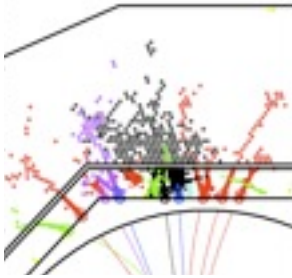
Procedure

- First establish catalogue of criteria for validation
  - difficult to specify "thresholds"
  - but information must be there
  - role for R&D groups and external reviewers
- Second do comparisons to select among validated options
  - physics performance
  - operational aspects
  - both will be important
  - cost: only if large differences appear



Validation criteria

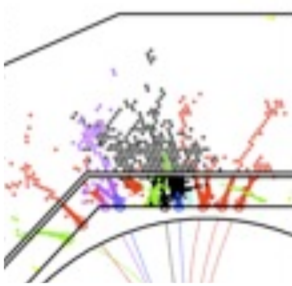
- Formulated by CALICE for DBD
  - **Established performance:** energy resolution, linearity, uniformity, two particle separation
  - **Validated simulation:** longitudinal and transverse shower profiles, response, linearity and resolution, for e trons and hadrons
  - **Operational experience:** dead channels, noise, stability, monitoring and calibration
  - **Scalable technology solutions:** power and heat reduction, low volume interfaces, data reduction, mechan structures, dead spaces, services and supplies
  - **Open R&D issues:** analysis and R&D to be completed before a first pre/production prototype can be built, reduction and industrialization issues
- Add for concepts: combined performance
- Both AHCAL and SDHAL not ready today
- Request continued “support” by ILD to fulfil our ambition



Selection criteria

- Physics: clear
- Jet energy resolution, of course
- Single hadron resolution (combined) important, too
- Lepton ID

- Operation: less clear
- Stability, reliability
- Calibration scenarios
- Redundance
- ….



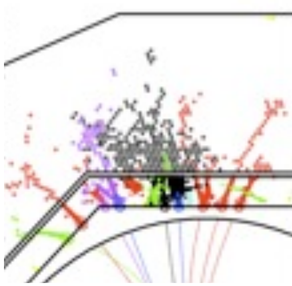
Separate the issues:

- Used to look at “AHCAL vs SDHCAL”

- Actually, there are 3 largely independent choices:

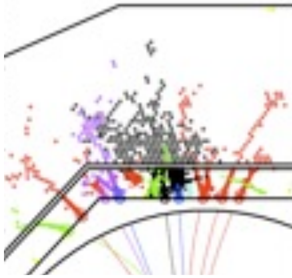
1. The absorber structure: “TESLA vs Videau”
2. The active medium: “scintillator vs gas”
3. The readout scheme: “analogue vs semi-digital”

- Should have answers individually for barrel and endcap



Personal remarks

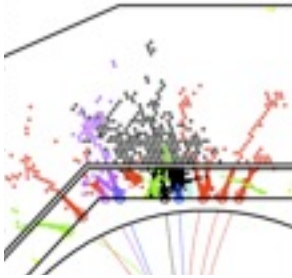
- Even if ILD resists the pressure to select early, may end up with incomplete information on each side.
- Even if everything available, likely to end up in a situation where:
  - no large difference in performance or physics impact
  - debate in operational aspects
  - little documentation on the latter



Proposal:

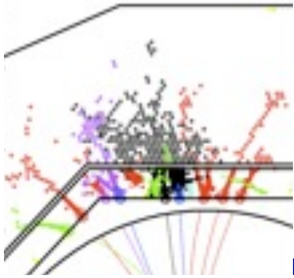
- Both AHCAL and SDHCAL concepts have attracted motivated and competent groups
- Not unlikely that, given we have so much more time than we like, both solve the issues
- Next period should not just be another round in the arms race spiral
- Build confidence
- We invite SDHCAL leadership to give "critic's review" talks at AHCAL meetings
- And the SDHCAL group to participate in AHCAL test beam campaigns and analysis

Back-up



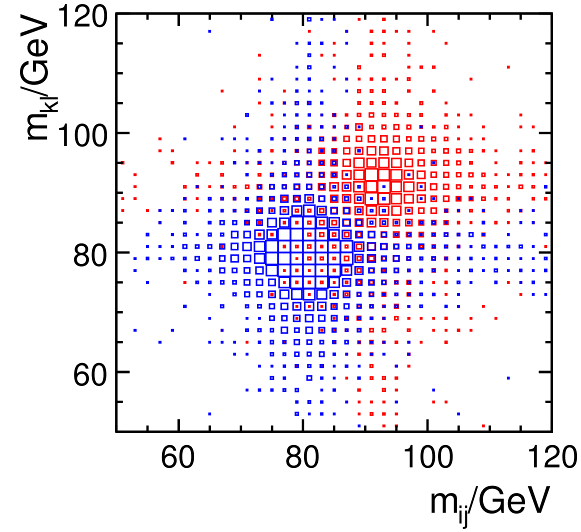
AHCAL groups in CALICE

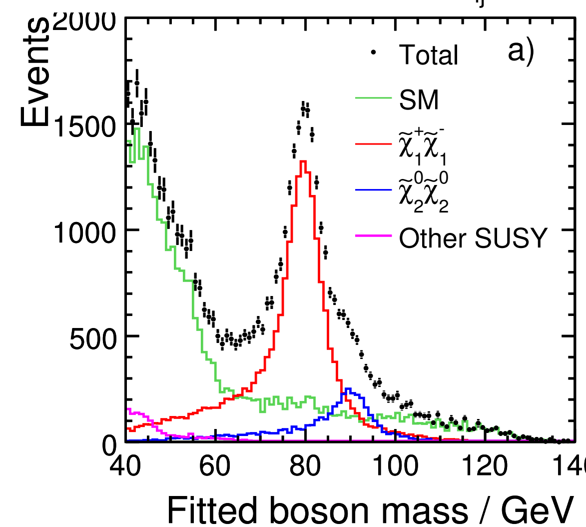
thanks, Katja!

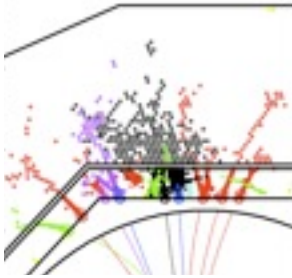


Jet energy resolution

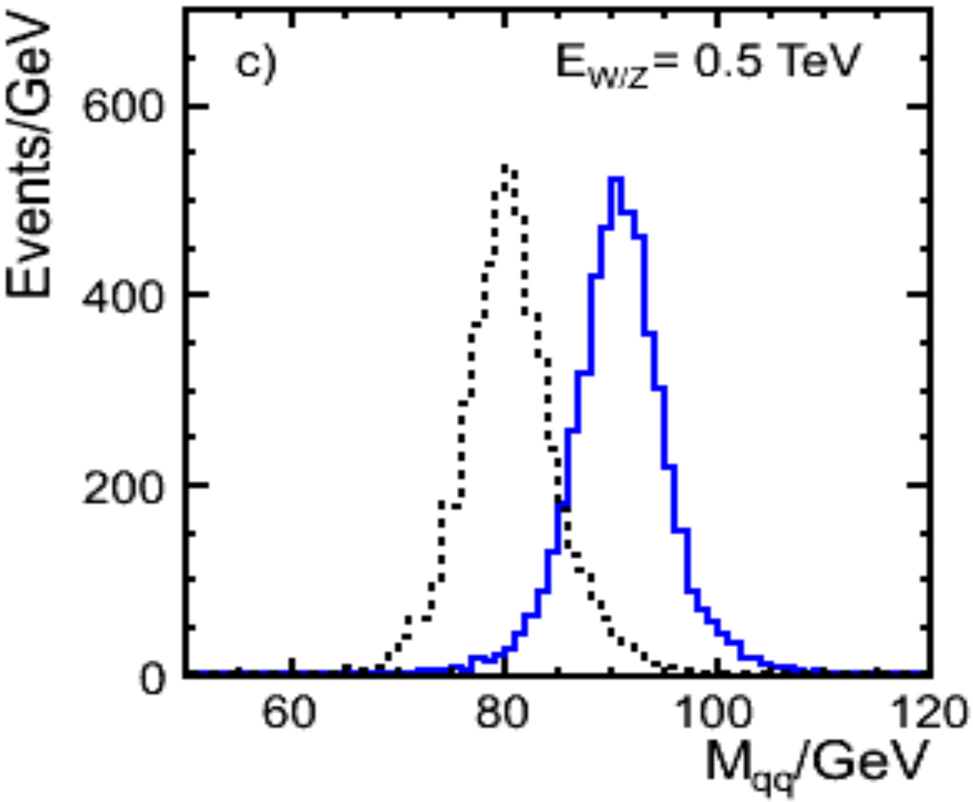
- At the ILC, must separate hadronic W and Z line D+ and Ds at Belle
- Famous “blue plot”: study strong electro-weak symmetry breaking at 1 TeV
  - WWvv, ZZvv production
  - but this is not the only one
- H → WW*, ZZ* (total width)
- H → cc, Z → vv
- Chargino neutralino separation
- In contrast, multi-jet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

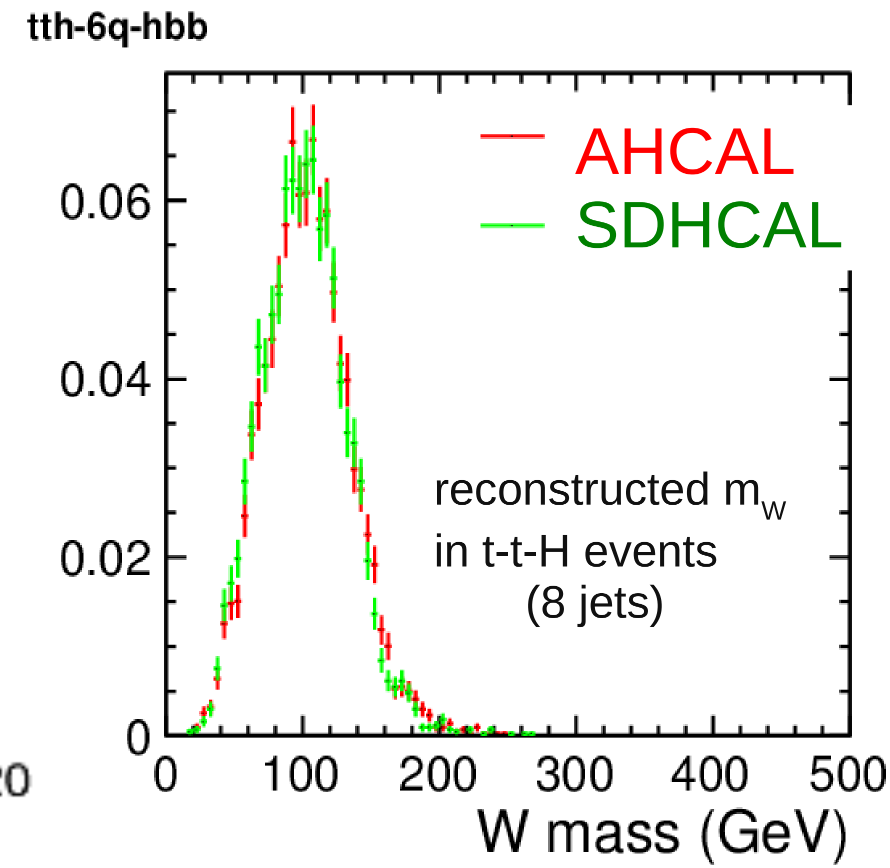


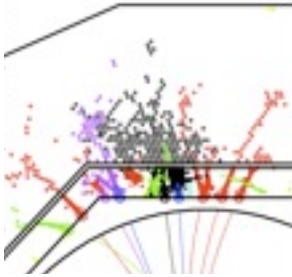




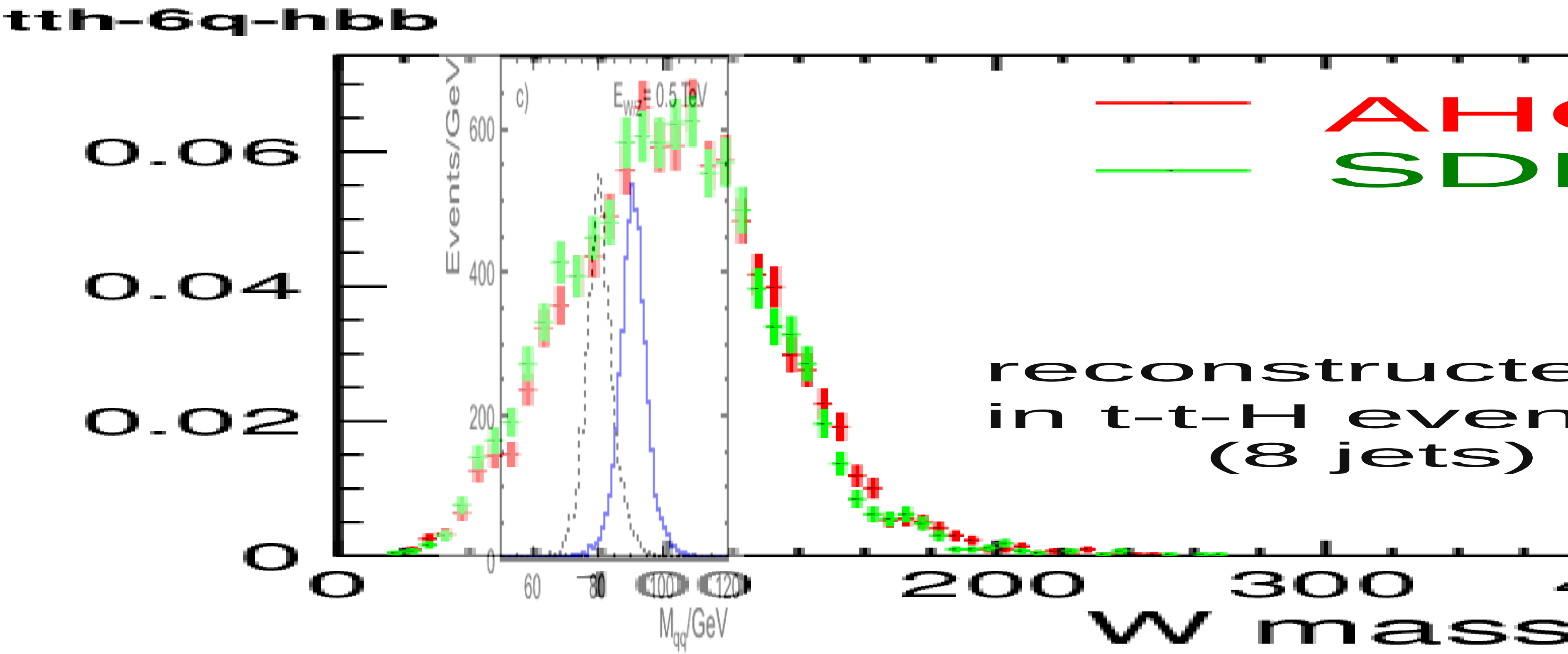
W Z separation

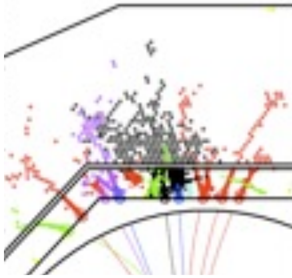






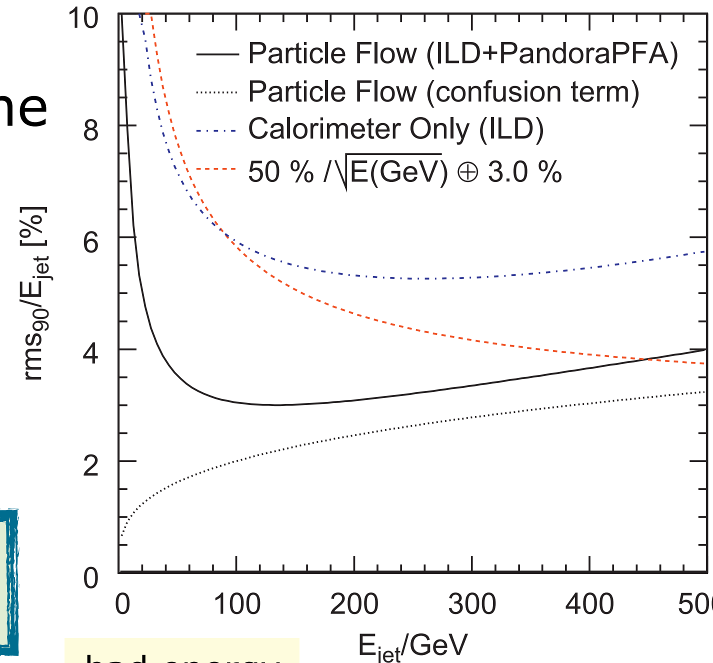
W Z separation

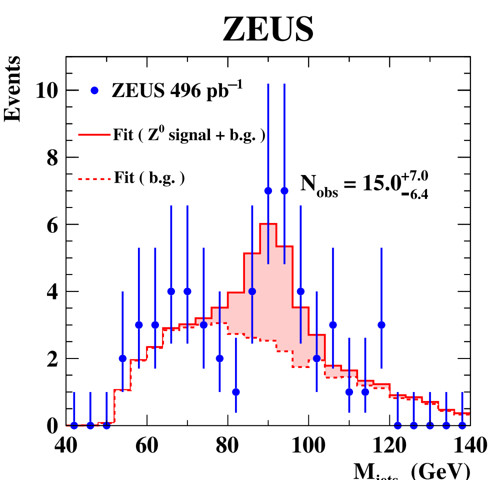




Particle flow

- 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





For scintillator, optimize independently

had energy resolution

energy and topology

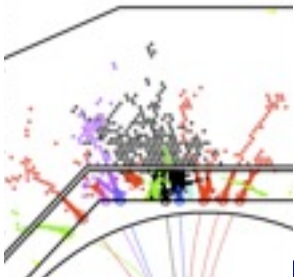
containment, constant term

$35\%\sqrt{E}$ for pions, 6 GeV for Z

$$\frac{rms_{90}}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E$$

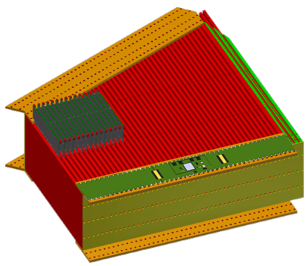
$$\oplus\ 2.1\left(\frac{R}{1825}\right)^{-1.0}\left(\frac{B}{3.5}\right)^{-0.3}\left(\frac{E}{100}\right)^{0.3}\%$$

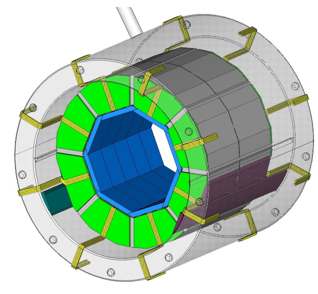
calo intrinsic, tracking, leakage, confusion

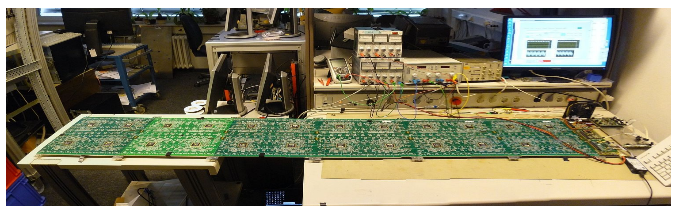


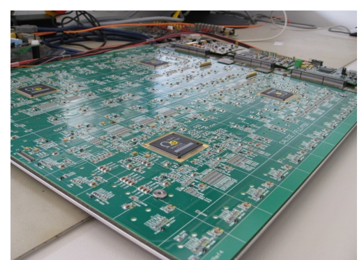
Industrialisation: Numbers!

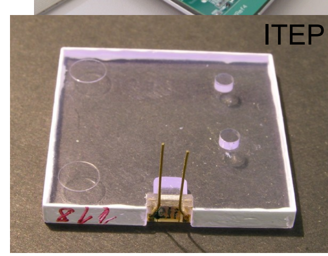
- The AHCAL
- 60 sub-modules
- 3000 layers
- 10,000 slabs
- 60,000 HBUs
- 200’000 ASICs
- 8,000,000 tiles and



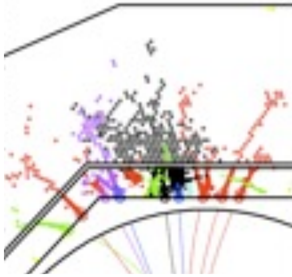








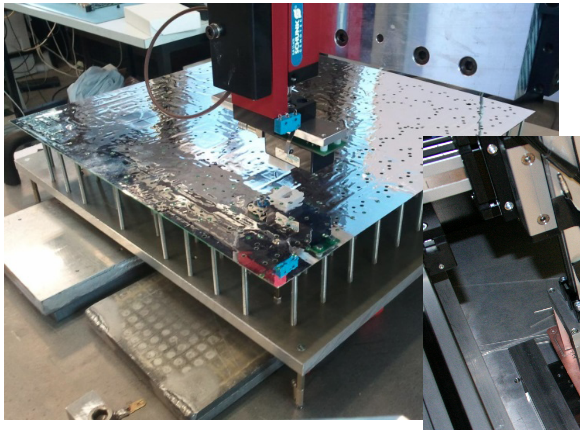
- One year
- 46 weeks
- 230 days
- 2000 hours
- 100,000 minutes
- 7,000,000 seconds

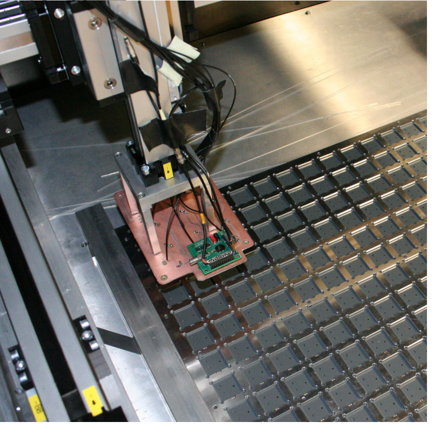


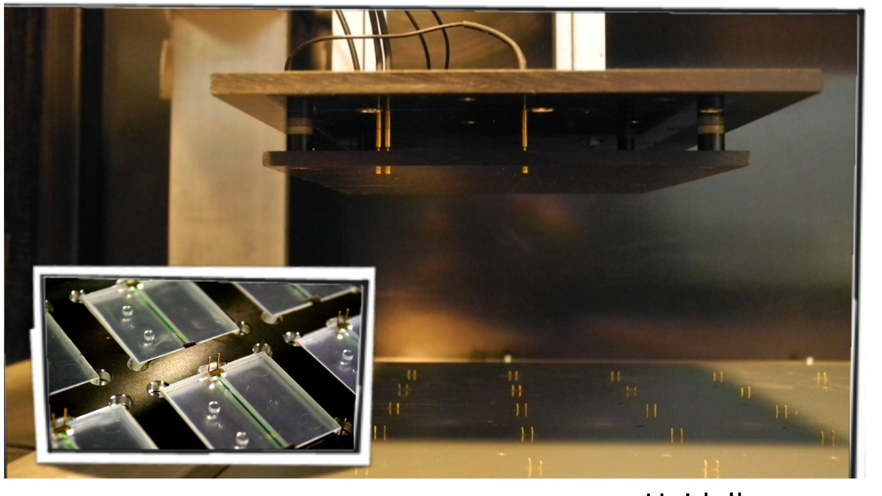
Quality control and production

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

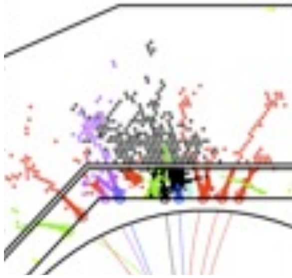
- SiPM and tile QC and characterisation
  - with UV light and beta source
  - fully automatised, fast parallel readout
- LED ad ASIC tests
- HBU assembly
  - place tiles, solder SiPMs
  - close relation to tile design and SiPM coupling
  - impact on QC chain



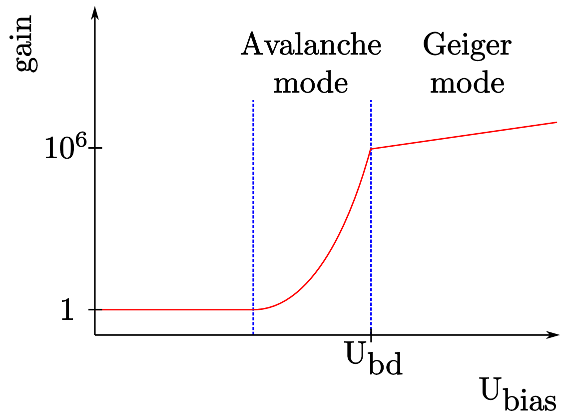


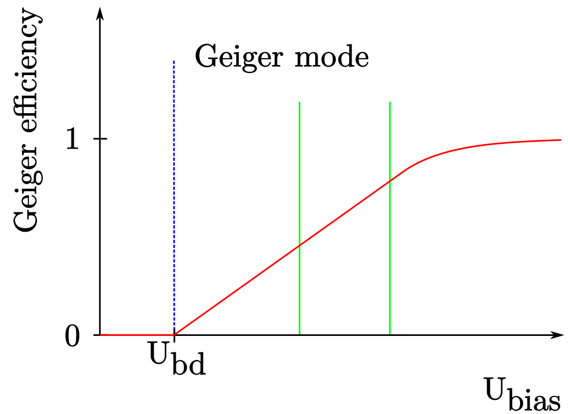


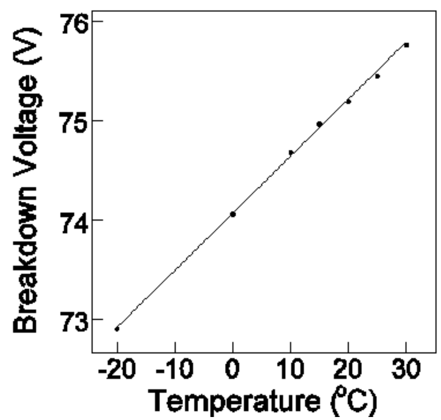
Heidelberg

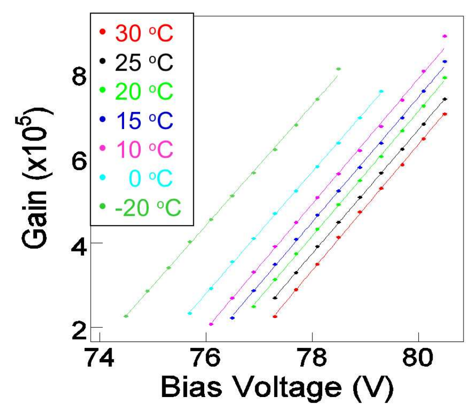


SiPM response

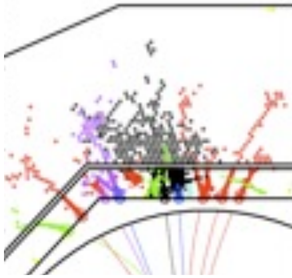








- $X = X(\Delta V)$, $\Delta V(T) = V_{bias} - V_{breakdown}(T)$

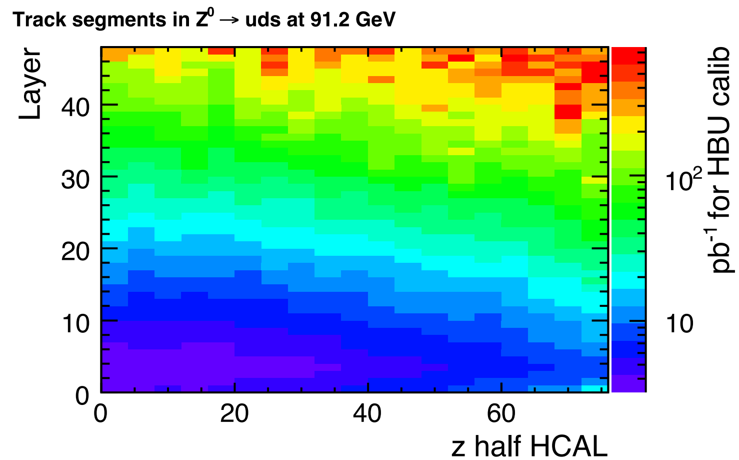


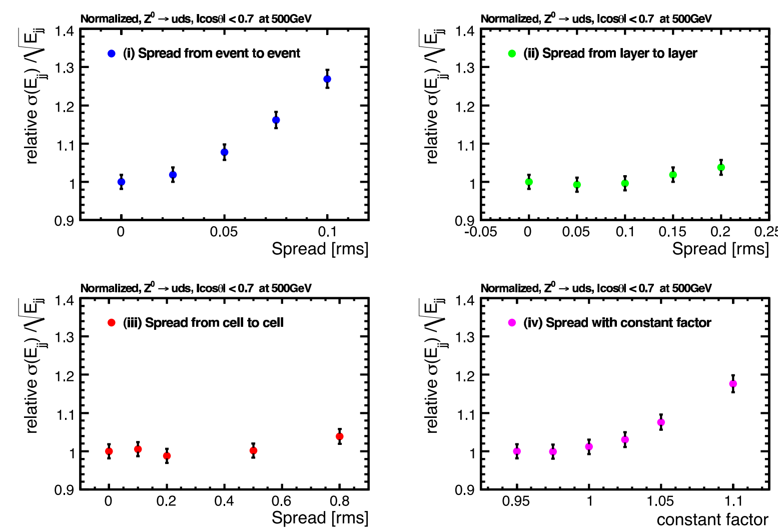
Calibration: look at full chain

- LOI validation: IDAG triggered study of required precision and luminosity for calibration
- Using track segment finding established in test beam showers

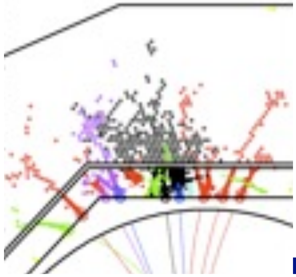
- Studied also impact of systematics due to calibration uncertainties on single particle and jet resolution
- Very insensitive to single channel effects
- For averages, statistics is not an issue

- Test benches: "Precision" = measurement accuracy or device-to-device non-uniformity





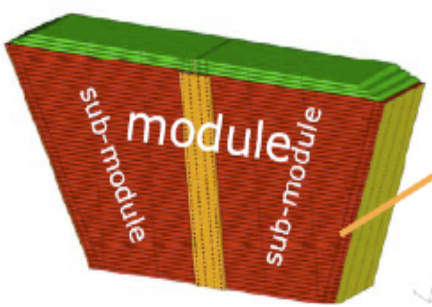
Calice Analysis note 18 and ILD note

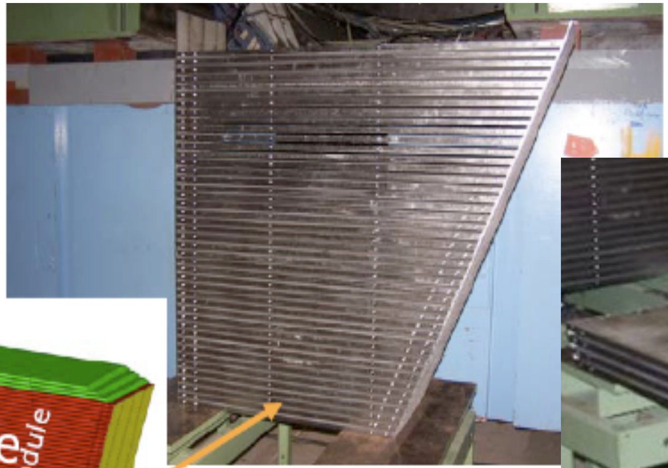


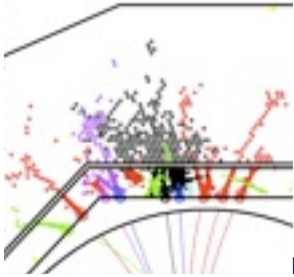
Mechanical prototypes

- 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

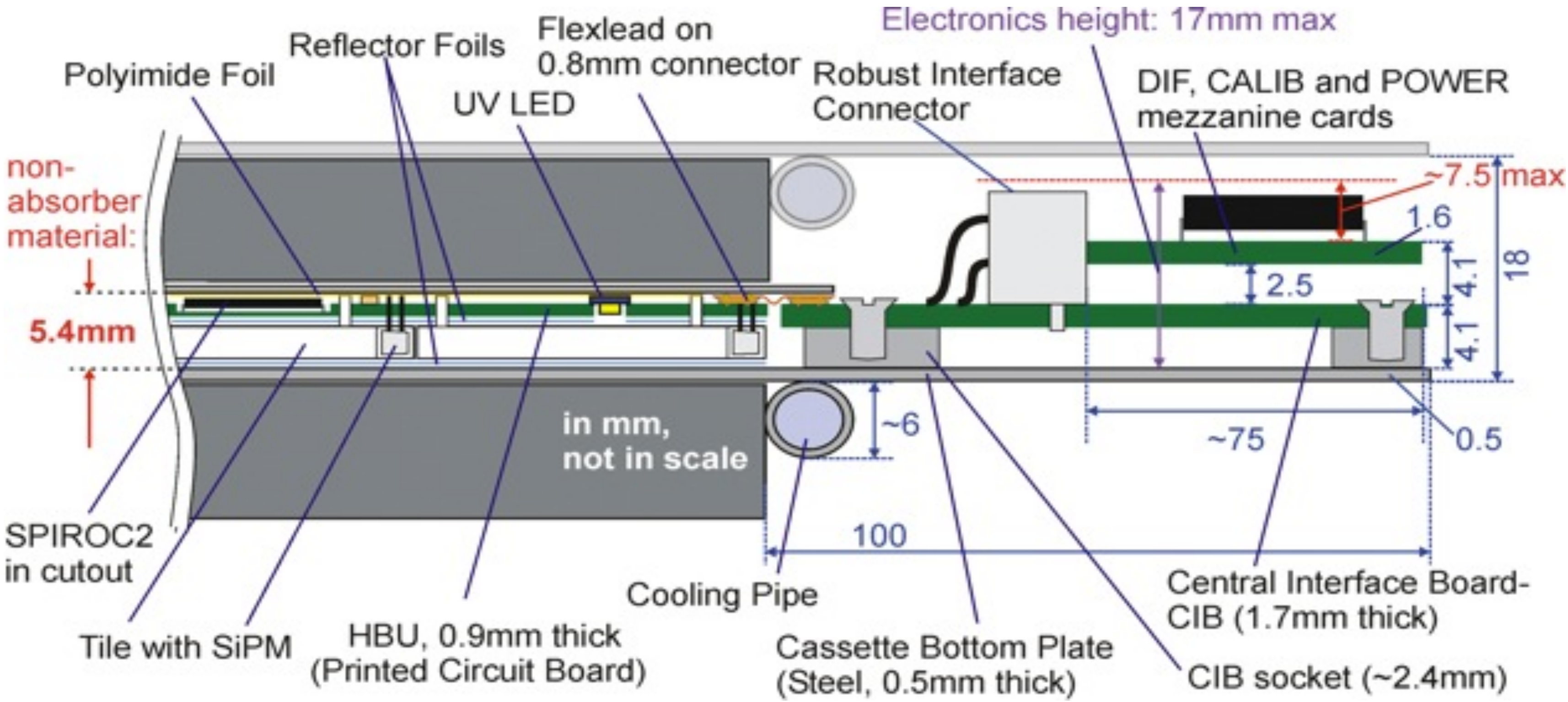
started dynamic simulations of ILD structure

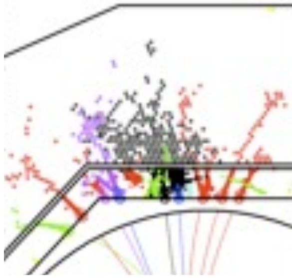






Layer cross section





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