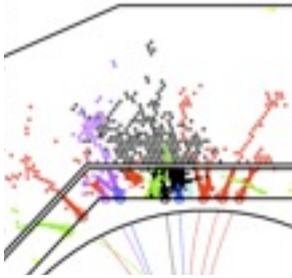
Status of the Scintillator HCAL technological prototype

Felix Sefkow

LCWS 2014, Belgrade, October 6-10, 2014

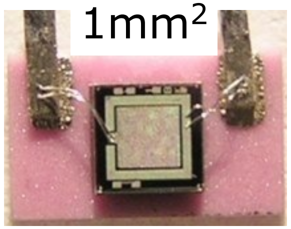
Outline

- Goals and strategy
- Sensor technology progress
- System integration
- Test beam

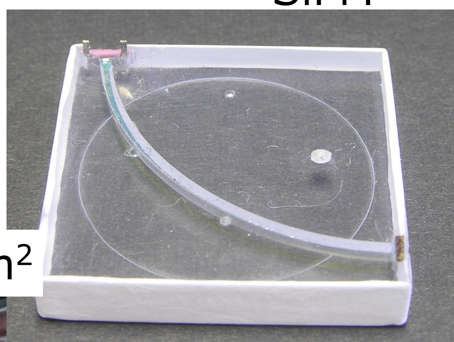


AHCAL physics prototype

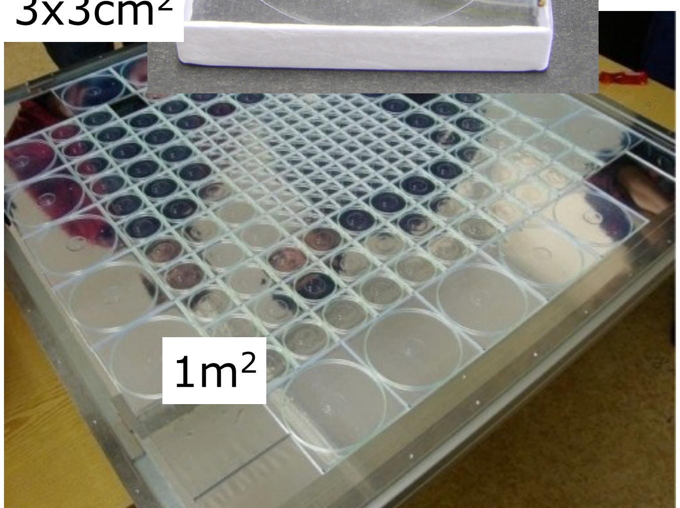
7608 channels
38 layers
Fe & W



SiPM



3x3cm^2

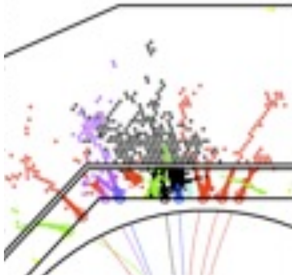


- Constructed in 2005-06: first device using SiPMs at large scale
- Now many followers: T2K, Belle2, CMS, medical applications,...
- Extremely robust: 6 years of data taking
  - 2006-7 CERN: Fe with SiW ECAL
  - 2008-9 FNAL: Fe with Si/Sci ECAL
  - 2010-11 CERN: Tungsten

Many trips with disassembly & reassembly of the calorimeter:

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

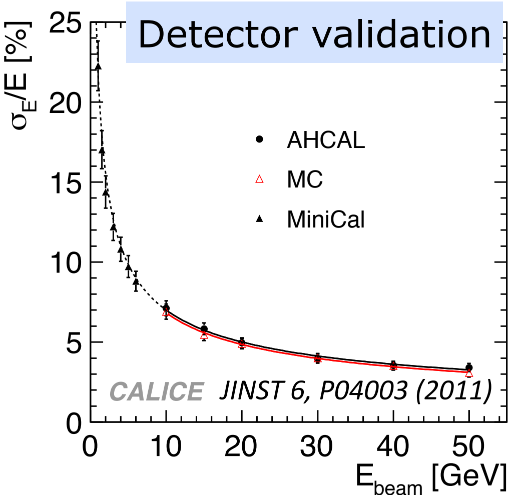
... and the SiPMs survived without problems!



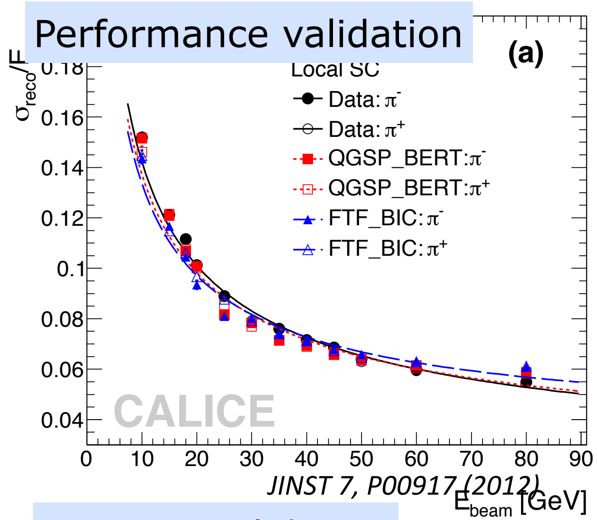
Validation of Simulation

- Validation with first generation prototype
- Published 8 papers

Detector validation

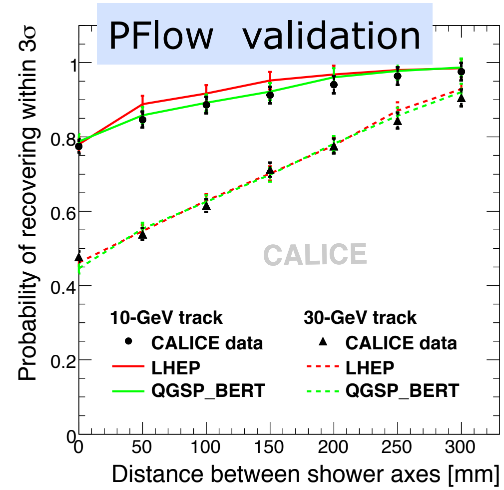


Performance validation



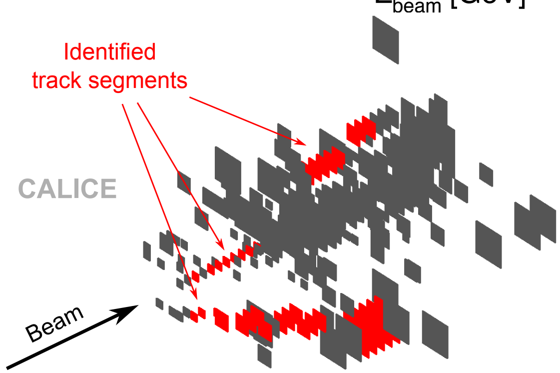
JINST 7, P00917 (2012)

PFlow validation

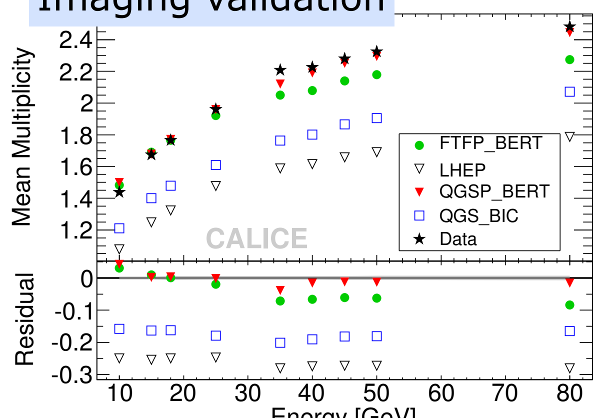


JINST 6, P07005 (2011)

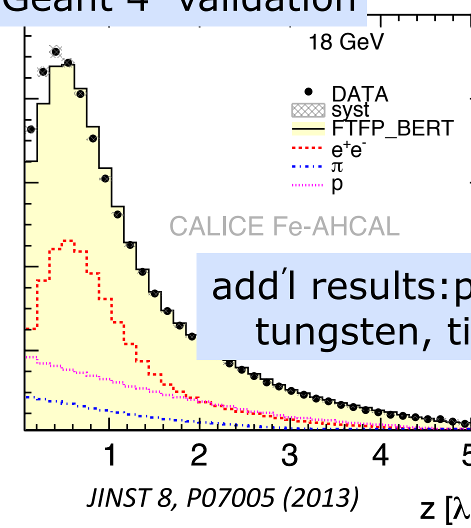
Imaging validation



JINST 8, P09001 (2013)

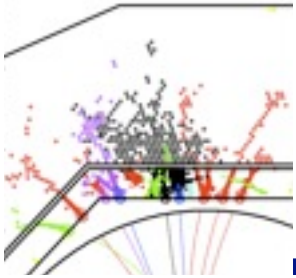


Geant 4 validation



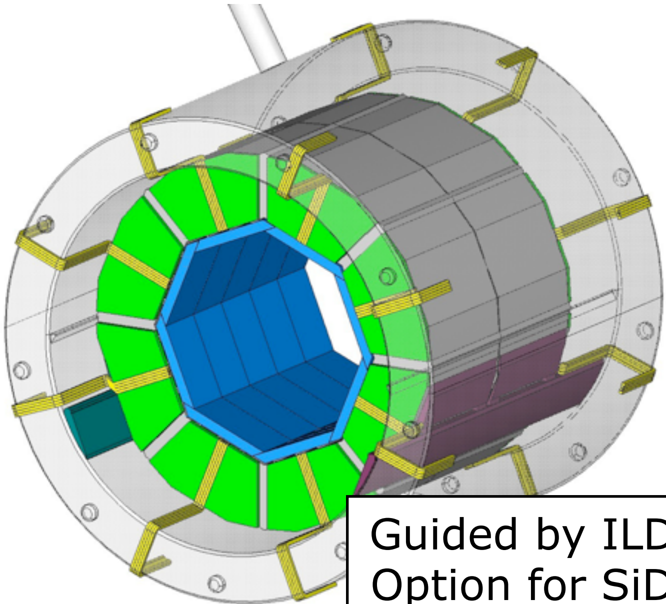
add'l results: protons, tungsten, timing

JINST 8, P07005 (2013)

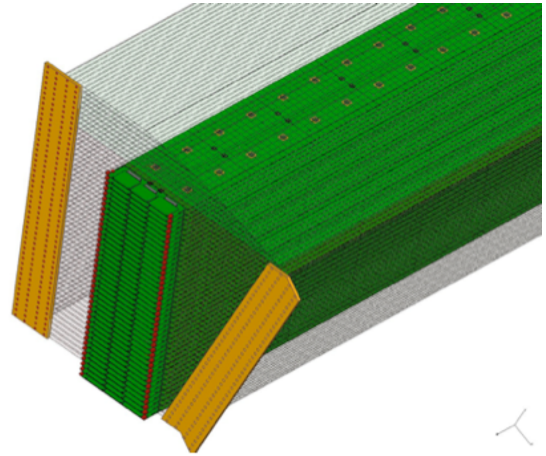


Goals of next stage

- Demonstrate the scalability
  - mechanical structure, tolerances and cost
  - FE electronics integration, power pulsing
  - optical monitoring system integration
  - Auto-trigger, zero-suppression and DAQ
  - Integration of services and cooling
  - Mass production and quality assurance



Guided by ILD
Option for SiD



- Capitalise on progress from 10 years of SiPM development
  - design, production, operation, performance
- Additional hadron shower physics studies
  - time evolution of showers in Fe and W
  - but do not (need to) repeat physics prototype proof-of-principle

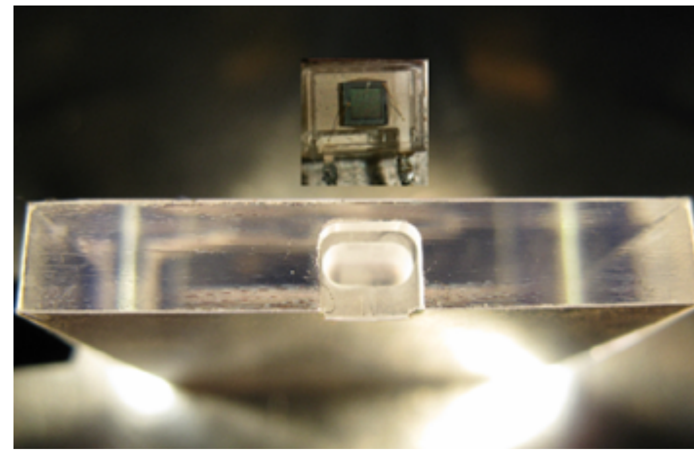
AHCAL groups in CALICE

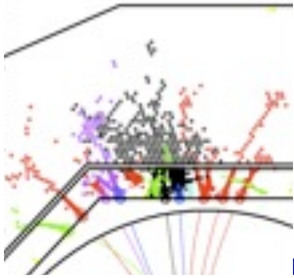
thanks, Katja!

Scintillators and SiPMs

SiPM improvements

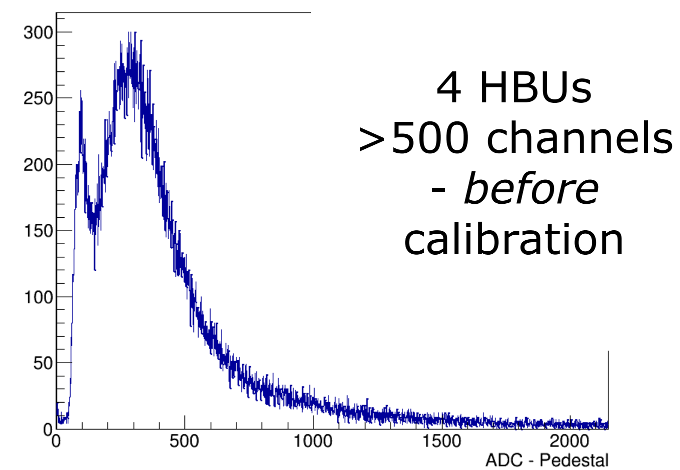
- Dynamic field, driven by medical applications (PET)
  - commercial use requires uniform devices, too, and moves to larger channel counts
  - SensL quotes 0.25V bias spread for several 100,000 devices
- 1€ per piece not unrealistic
  - Hamamatsu, SensL
- Improved performance in today's prototypes
 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



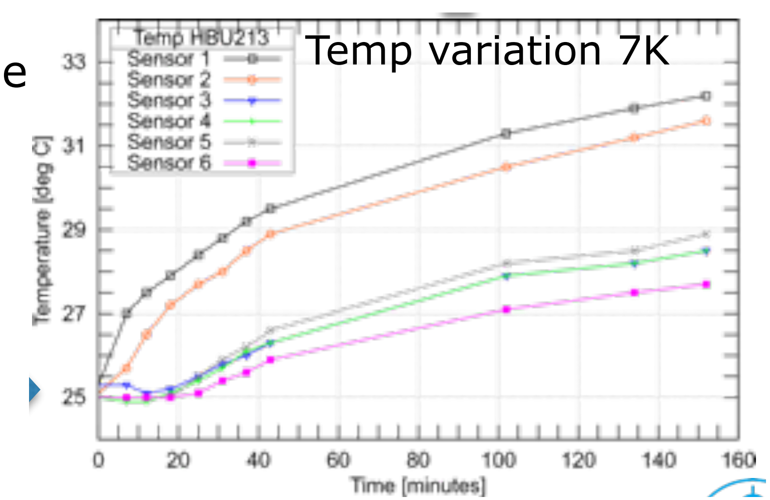


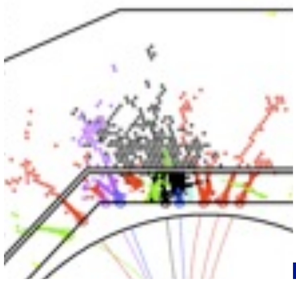
Benefits

- 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





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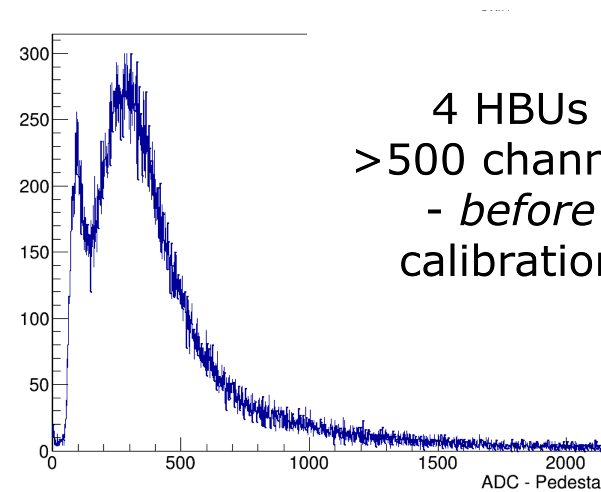
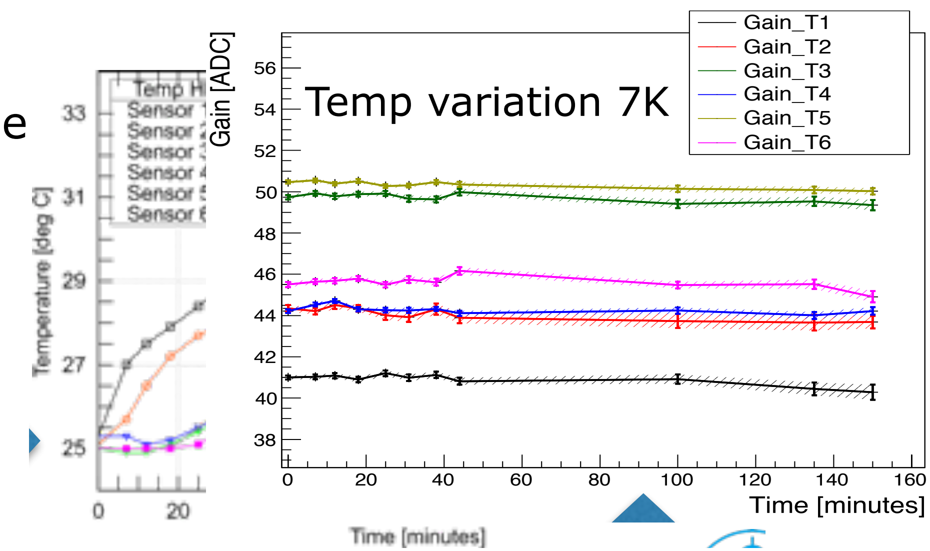
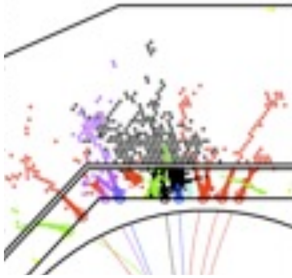
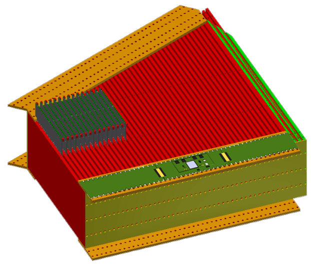


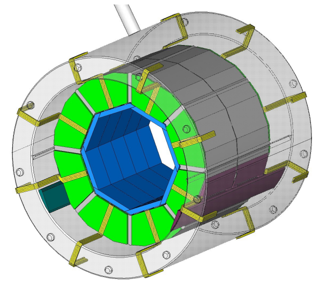


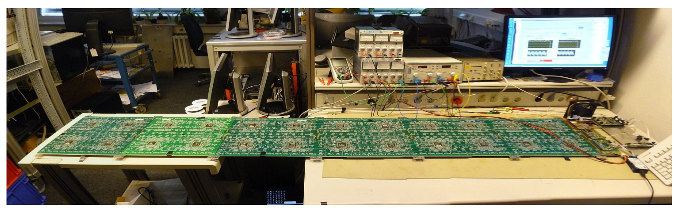


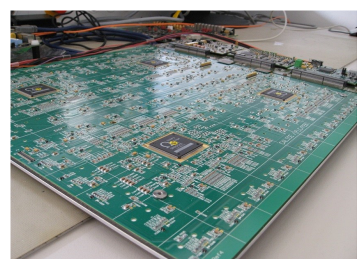
Industrialisation: Numbers!

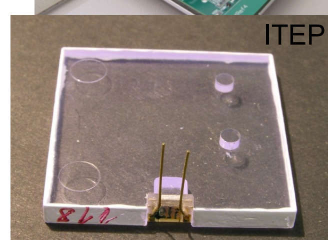
- The AHCAL
- 60 sub-modules
- 3000 layers
- 10,000 slabs
- 60,000 HBUs
- 200’000 ASICs
- 8,000,000 tiles and



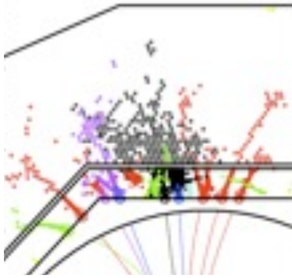




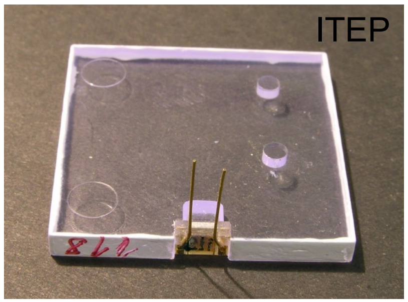




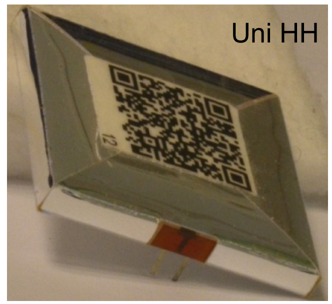
- One year
- 46 weeks
- 230 days
- 2000 hours
- 100,000 minutes
- 7,000,000 seconds



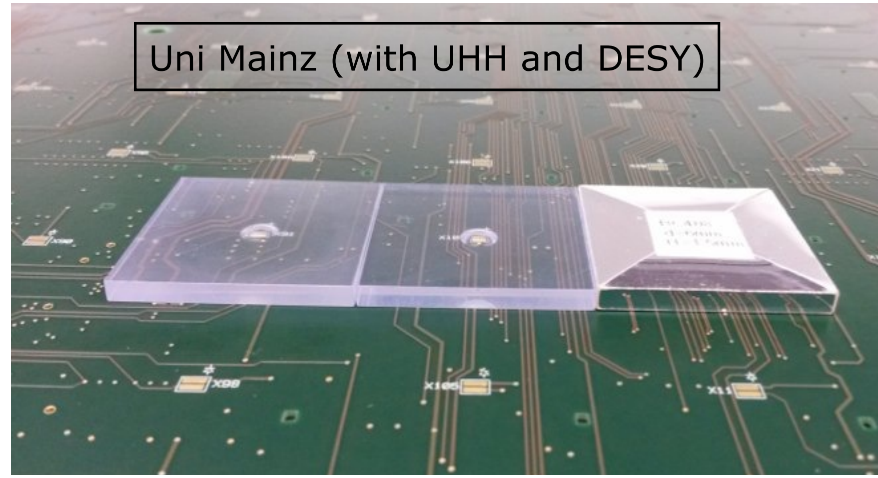
Scintillator tile options



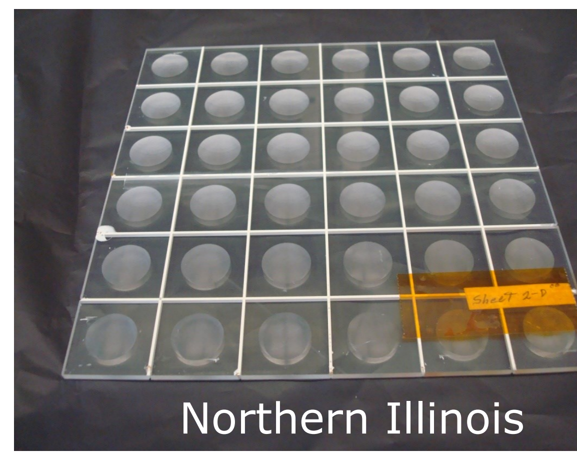
no WLS fibre
CPTA, KETEK or Hamamatsu sensors



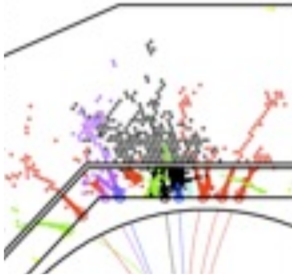
individually wrapped;
KETEK sensors



- Simplification, industrialisation
- Blue-sensitive sensors: eliminated WLS fibre and reflector
  - Direct coupling - from side or from top
- Integration of sensors into PCB
- Megatiles interesting alternative for mass assembly

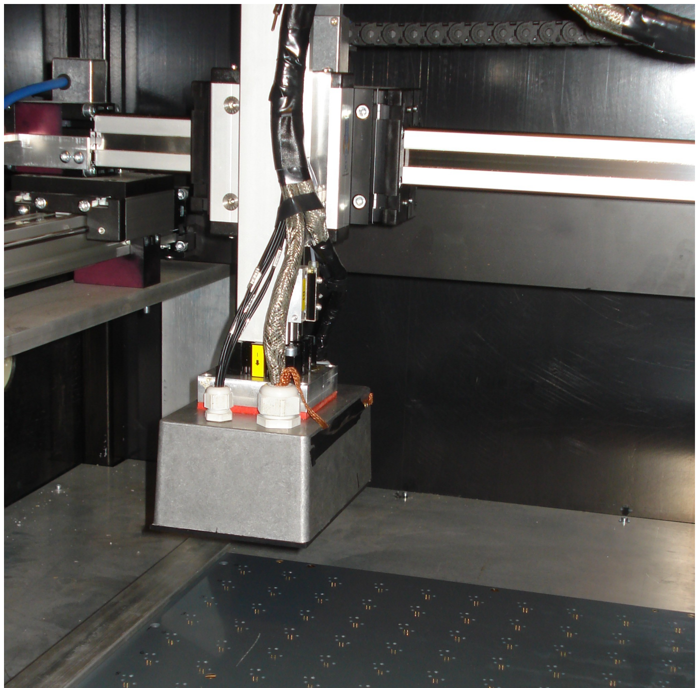


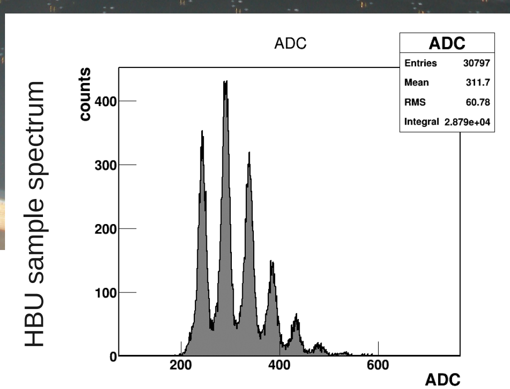
Hamamatsu sensors, on PCB surface

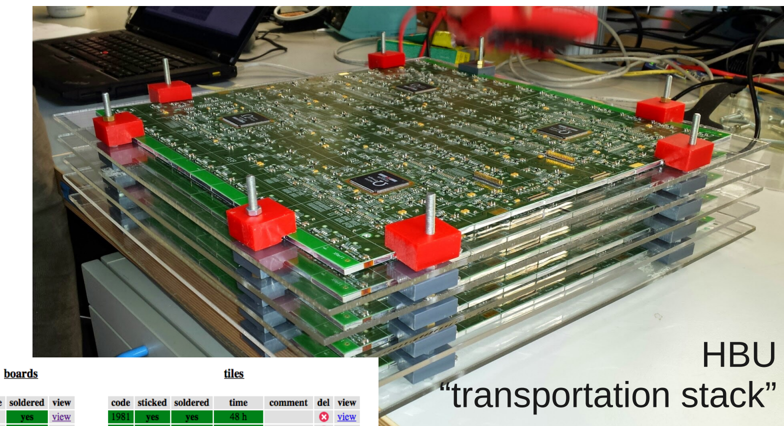


SiPM and tile characterisation

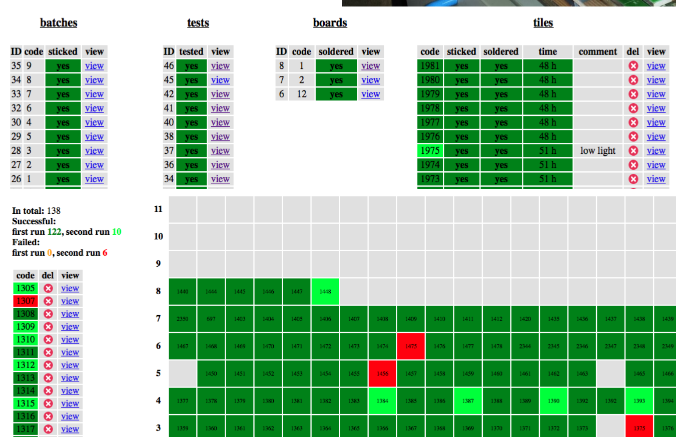
- Automatic set-up for up to 212 tiles
- 12 ch. parallel UV light an read-out
- 40 min / HBU







HBU
“transportation stack”



view of production db.

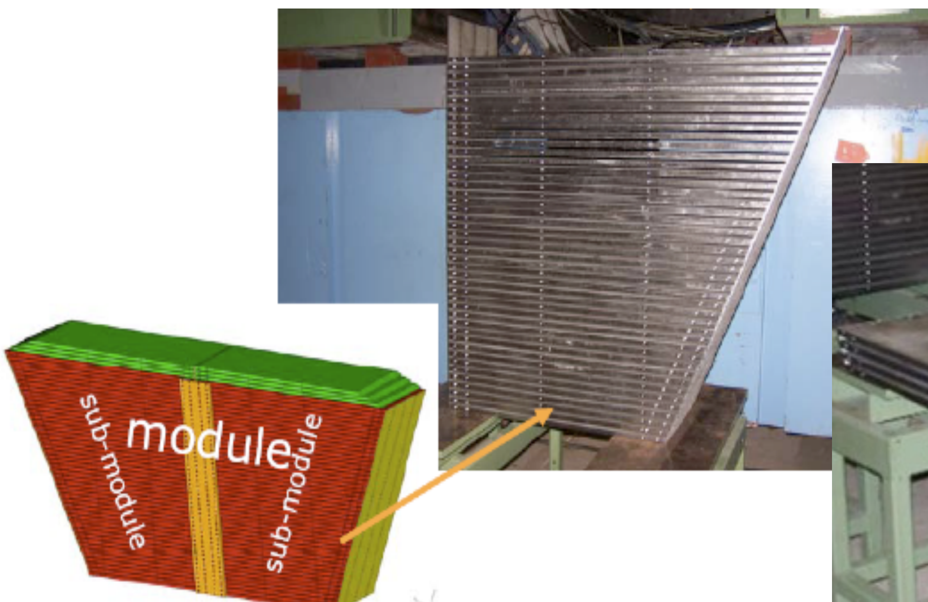
Heidelberg

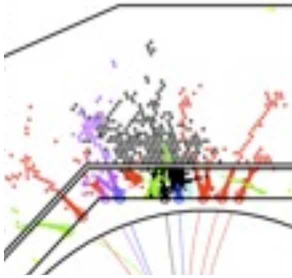
System integration

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

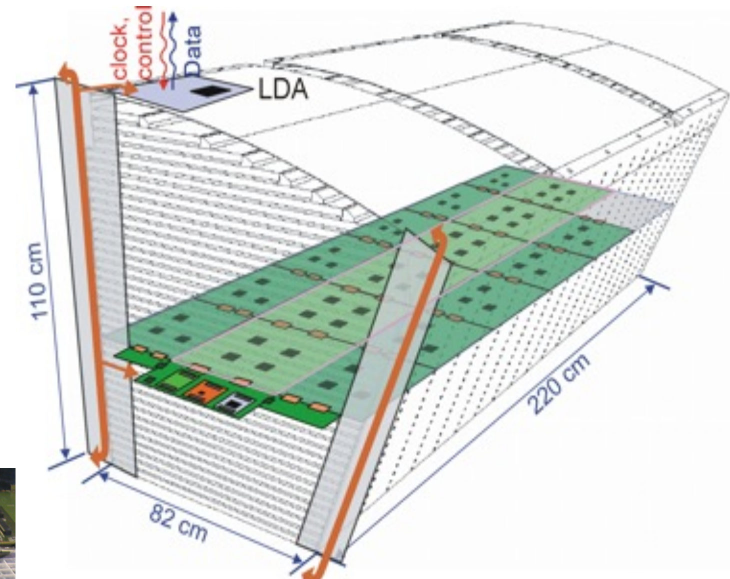
started dynamic simulations of full detector structure

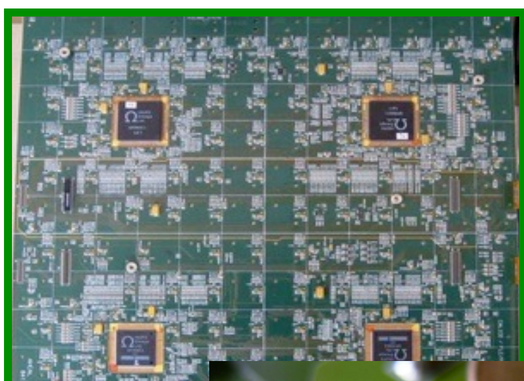


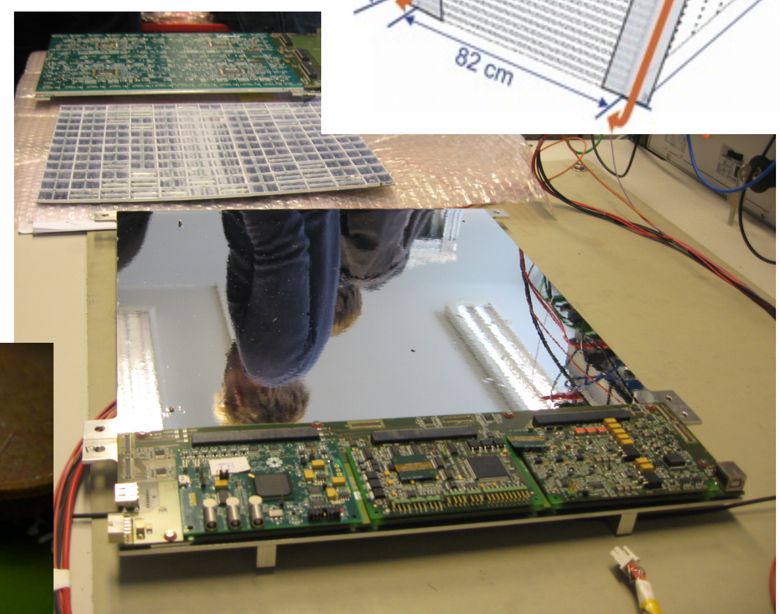


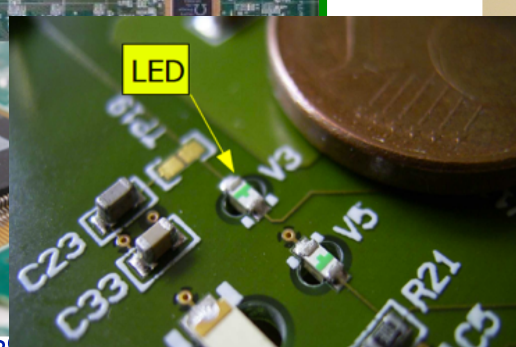
Electronics integration

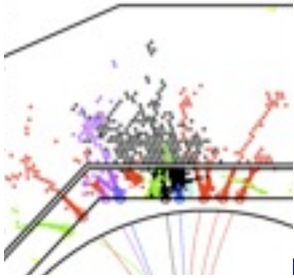
- Basic unit: 144 tiles, $36x36cm^2$
- 36 ch. SPIROC2B ASICs, power pulsed
  - self-trigger, 16x memory, ADC
- embedded LED system
- compact design
  - 5.4mm incl 3mm scintillator





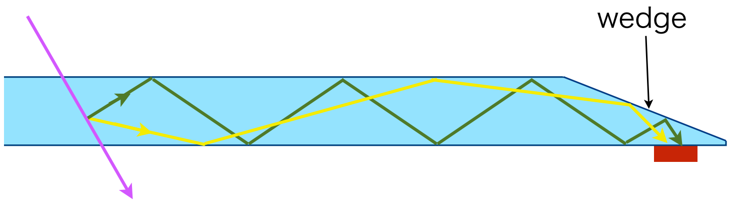


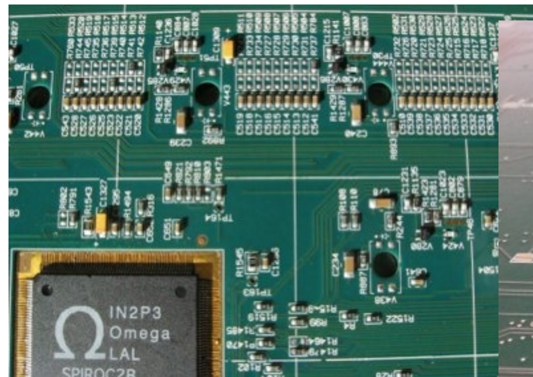


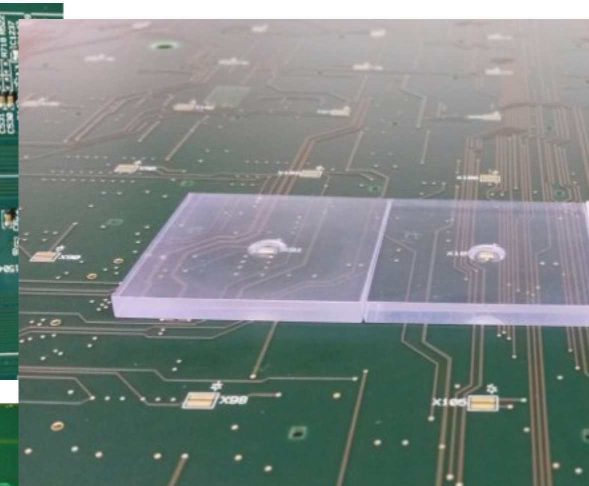


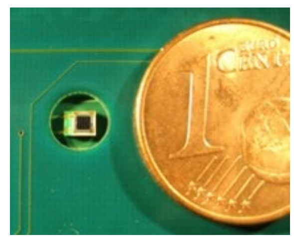
EBU and HBU types

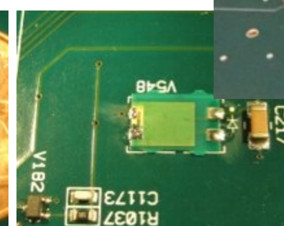
- HCAL base units:
  - improved LED drivers
  - 2 versions for surface-mounted SiPMs
- ECAL base units
  - fully exploit synergies with HCAL
  - also 144 ch, 4x smaller
  - different versions for parallel or transvers trip orientation
  - surface-mount versi with adapter board

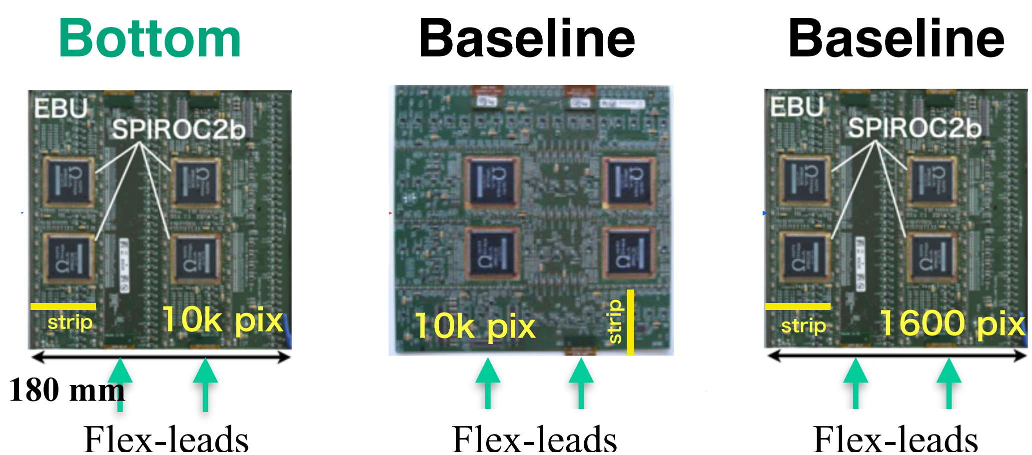


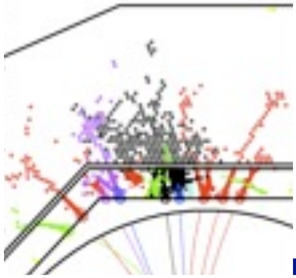






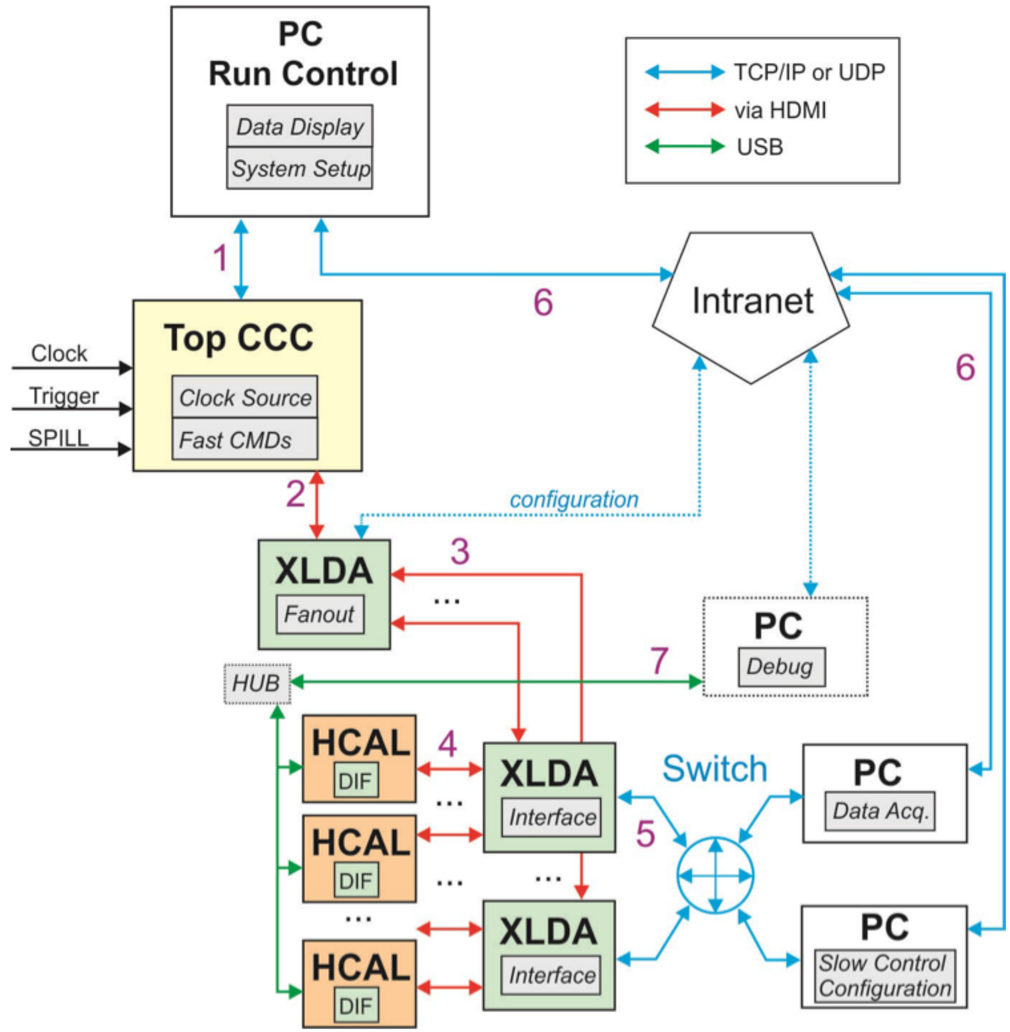


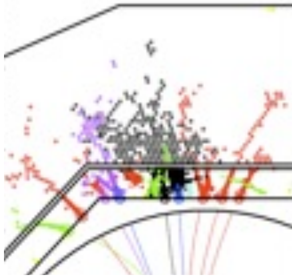




Data acquisition

- Based on EUDET-supported CALICE DAQ2
- Data transfer via Ethernet and HDMI
  - USB as back-up and for debugging
- Distribute time stamps and control signals for auto-triggered front end
- Collect and decode zero-suppressed data

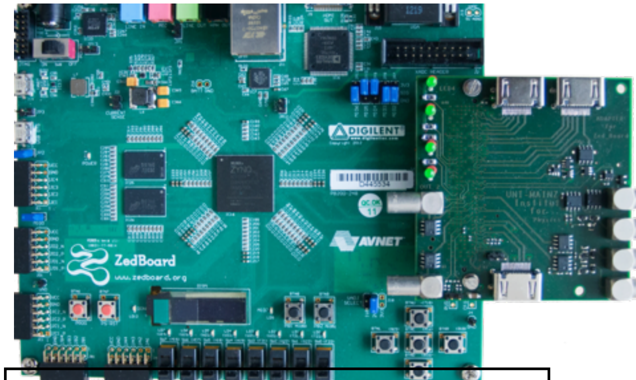




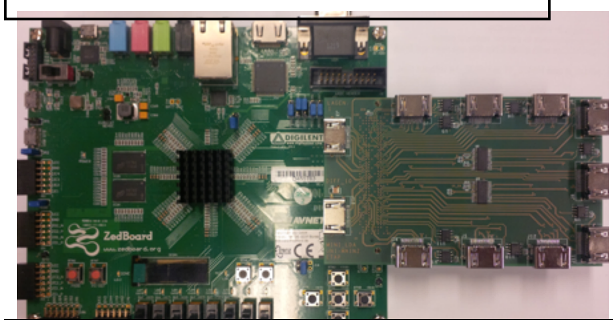
DAQ hardware

- CCC: Clock and Control Card
- New version by Mainz, also used by Si ECAL

- LDA: Link data aggregator
- 2 types:
  - Mini LDA: generic
  - Wing LDA: adapted to HCAL geometry

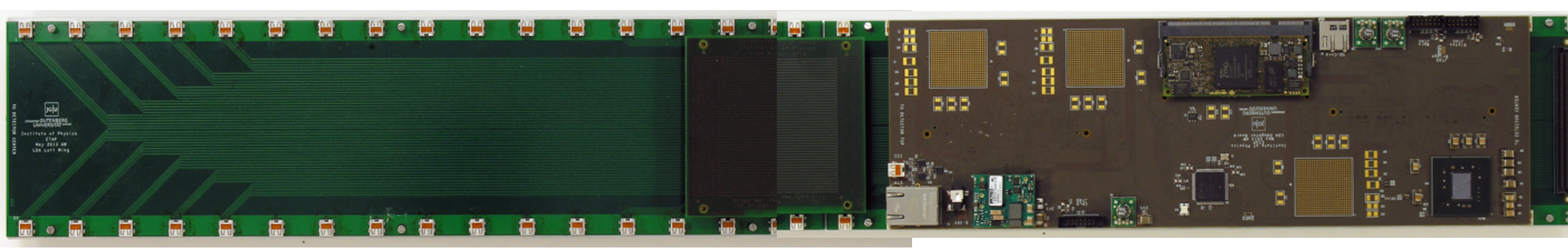


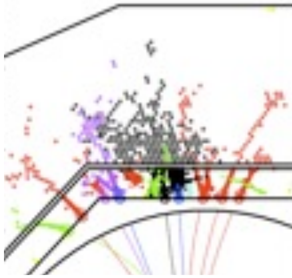
Zedboard with CCC Mezzanine



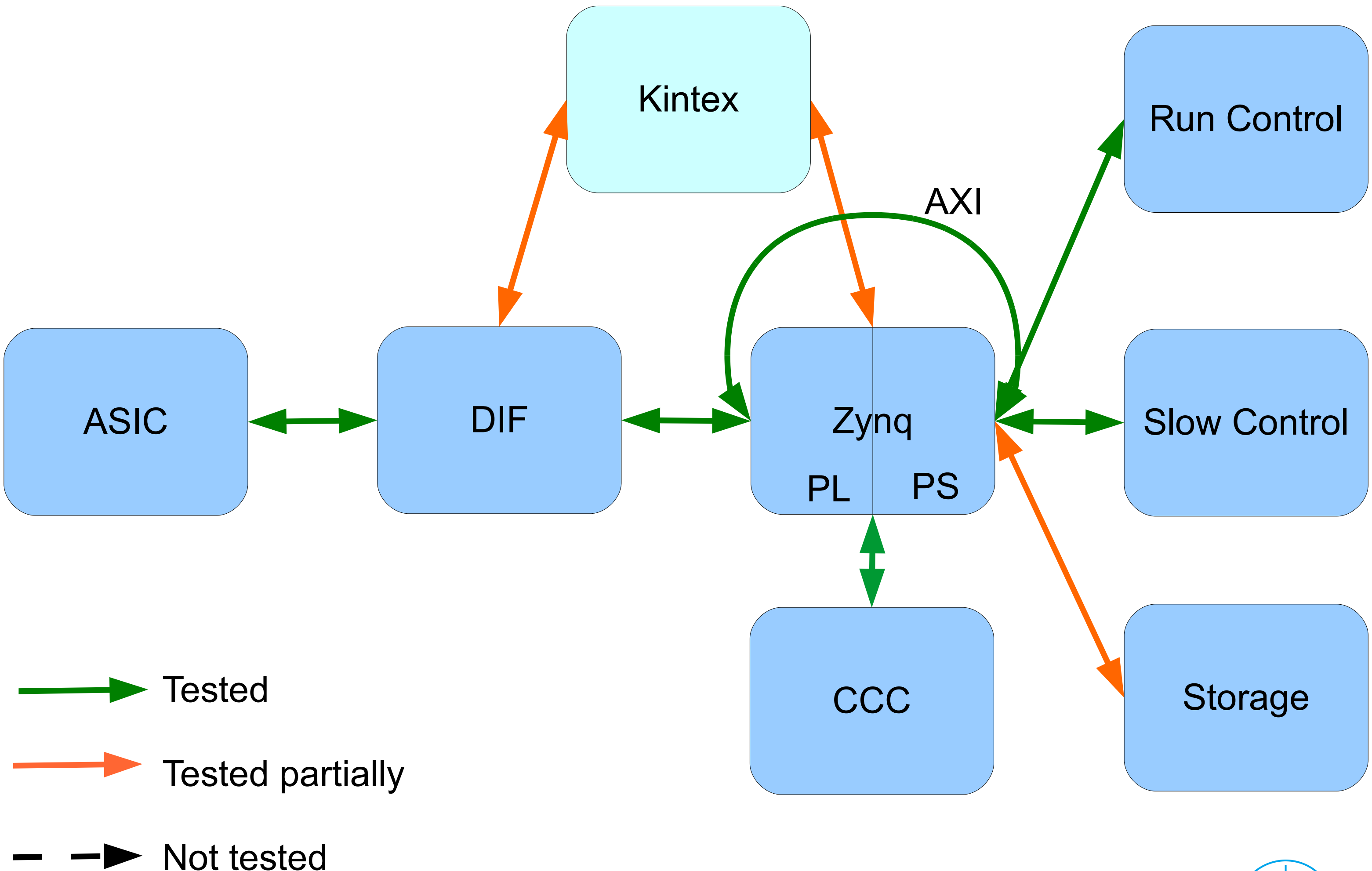
Zedboard with Mini-LDA Mezzanine

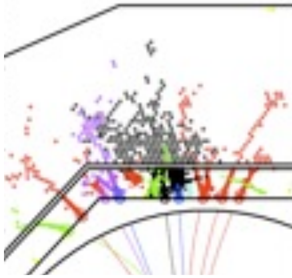
Wing LDA: central piece + 1 wing





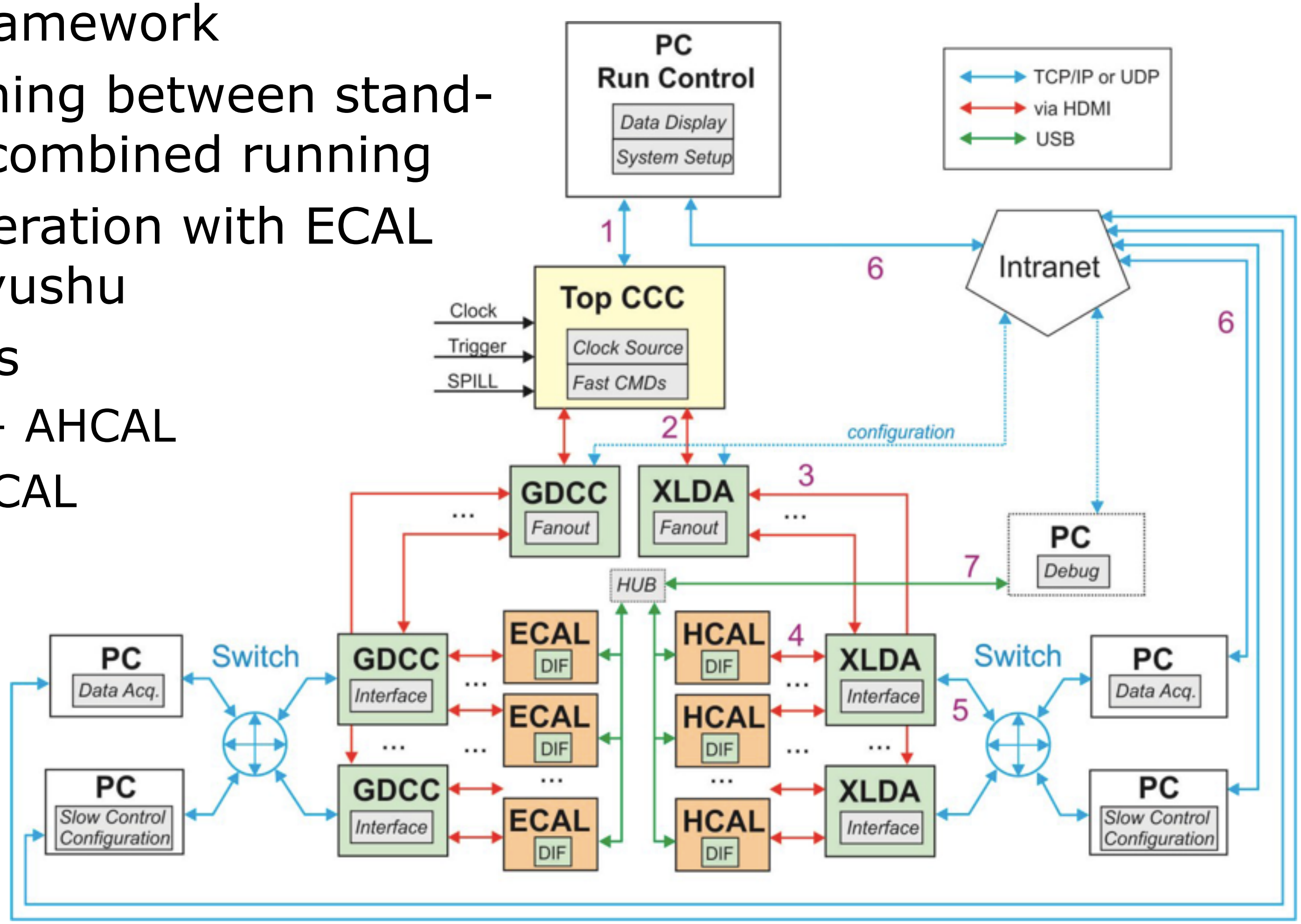
DAQ commissioning



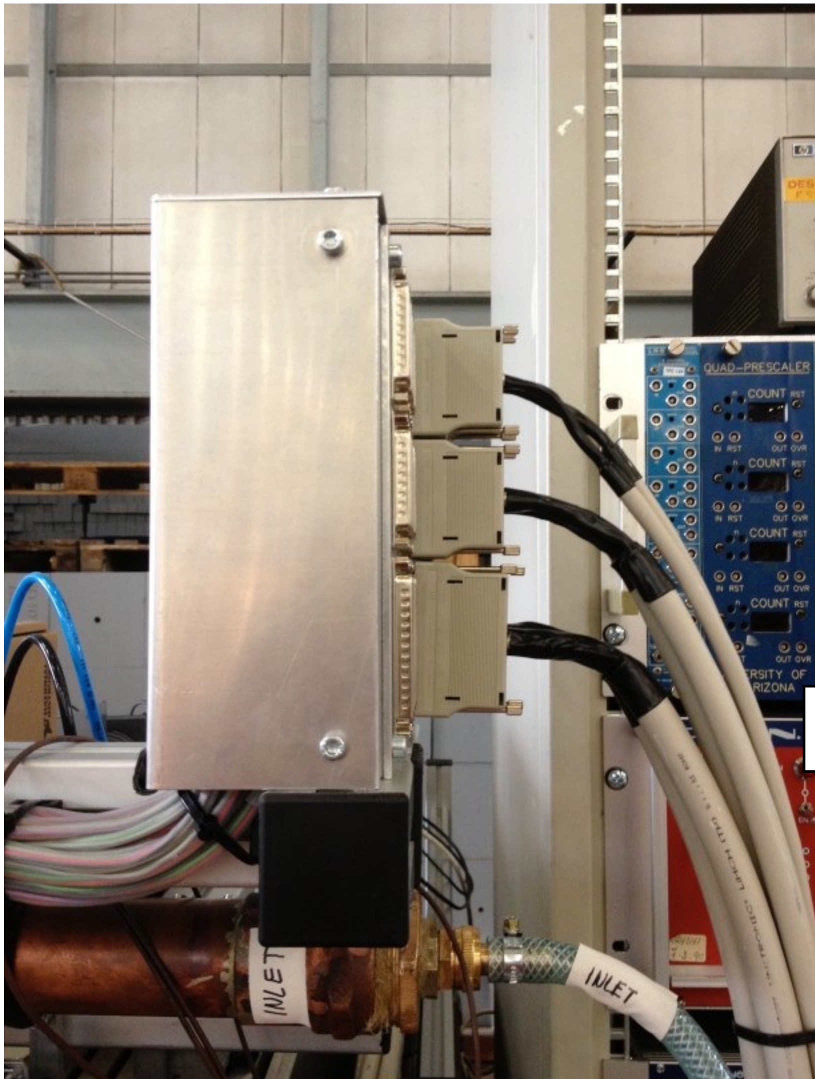


DAQ integration

- Foreseen for integration into common framework
- Easy switching between stand-alone and combined running
- Close cooperation with ECAL group in Kyushu
- Applications
  - SiECAL + AHCAL
  - Hybrid ECAL



Power supply and distribution



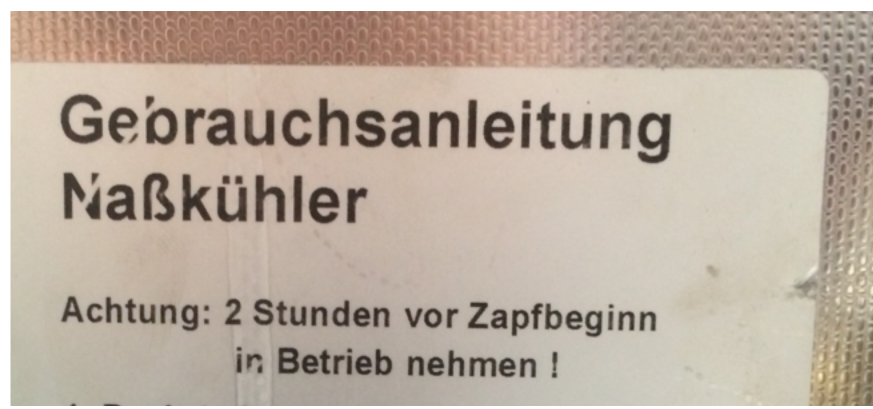
- 3 voltages: FE, LED, SiPM
- Distribution box for full sector
- More compact supply units under development (JINR)

scalable

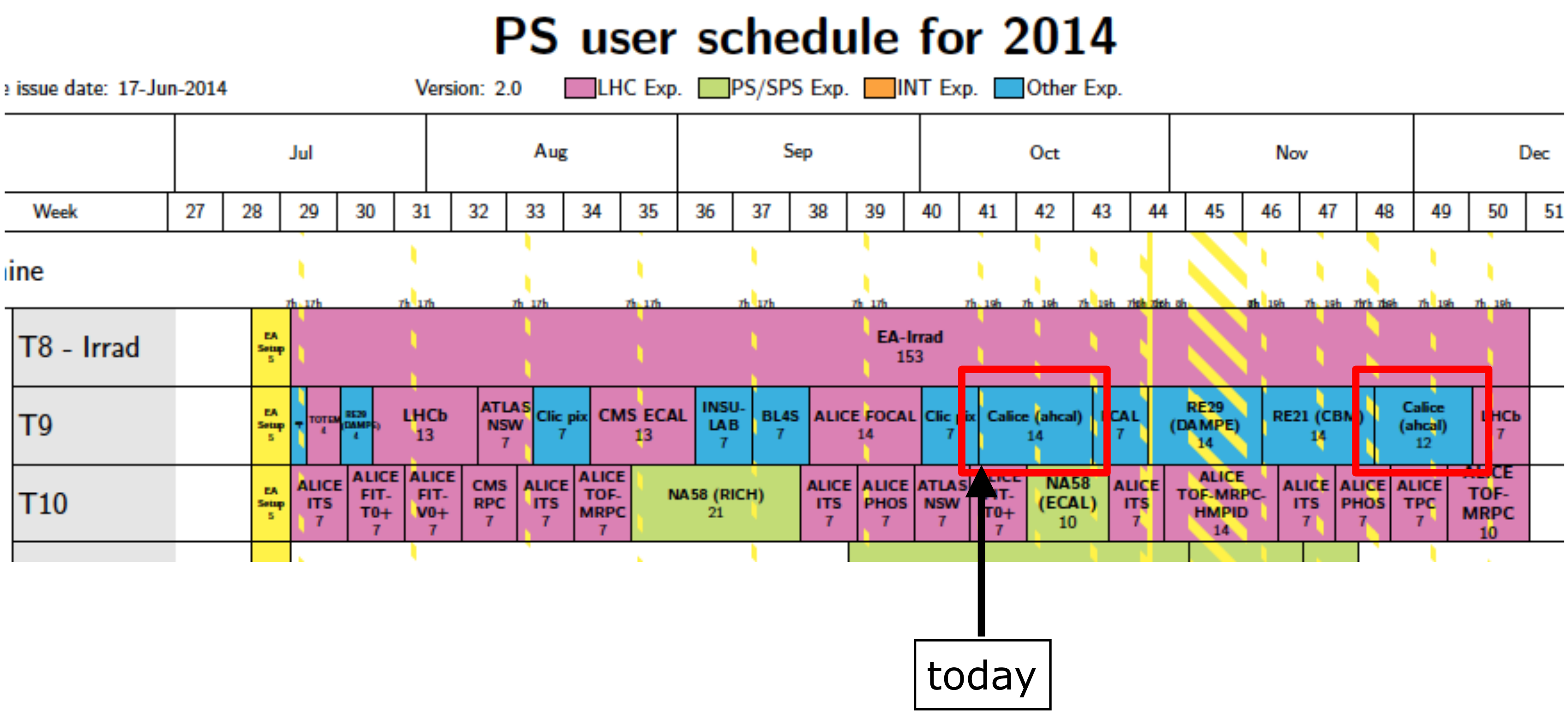
Cooling of the interfaces

- With power pulsing, very little heat produced in the stack
- Interfaces need cooling, though
  - power regulators
  - FPGAs on DIF
- First version for full sector test beam
- More compact and leakless system planned (AIDA-2020)

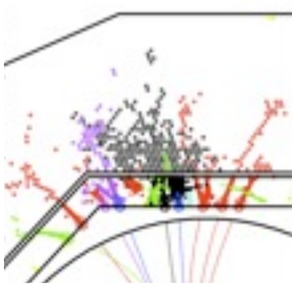
scalable



Test beam

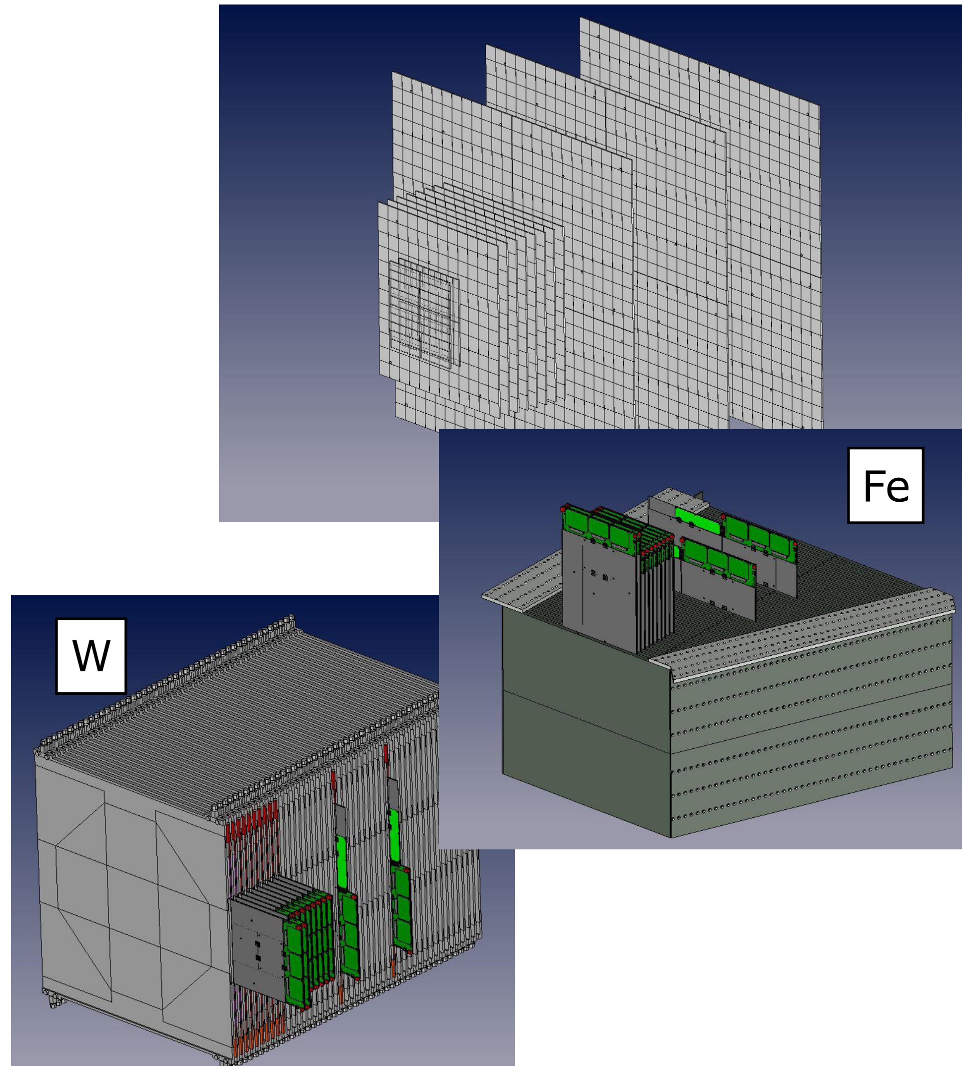


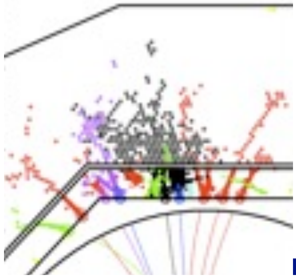
PS user schedule for 2014
issue date: 17-Jun-2014
Version: 2.0
LHC Exp.
PS/SPS Exp.
INT Exp.
Other Exp.
Jul
Aug
Sep
Oct
Nov
Dec
Week 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
T8 - Irrad
T9
T10
EA-Irrad 153
LHCb 13
ATLAS NSW 7
Clic pix 7
CMS ECAL 13
INSU-LAB 7
BL4S 7
ALICE FOCAL 14
Calice (ahcal) 14
RE29 (DAMPE) 14
Calice (ahcal) 12
ALICE ITS 7
ALICE FIT-T0+ 7
ALICE FIT-V0+ 7
CMS RPC 7
ALICE TOF-MRPC 7
NA58 (RICH) 21
ALICE PHOS 7
ATLAS NSW 7
NA58 (ECAL) 10
ALICE TOF-MRPC-HMPID 14
ALICE TPC 7
TOF-MRPC 10
today



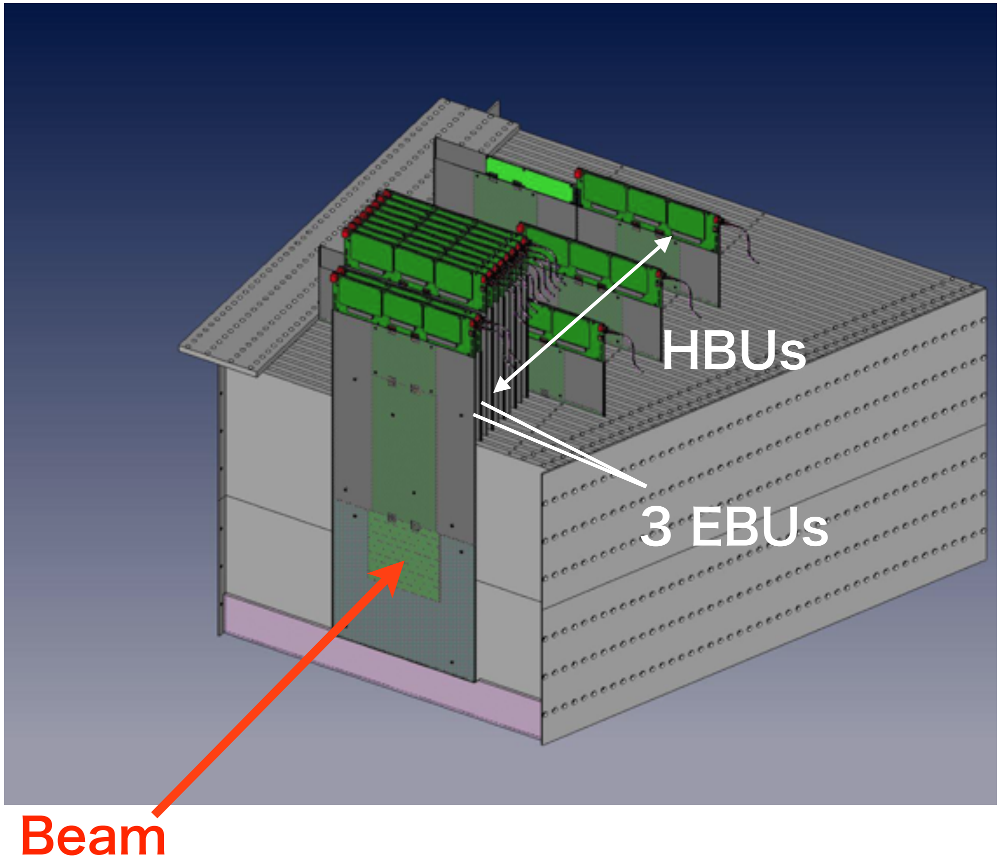
Flexible test beam roadmap

- 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



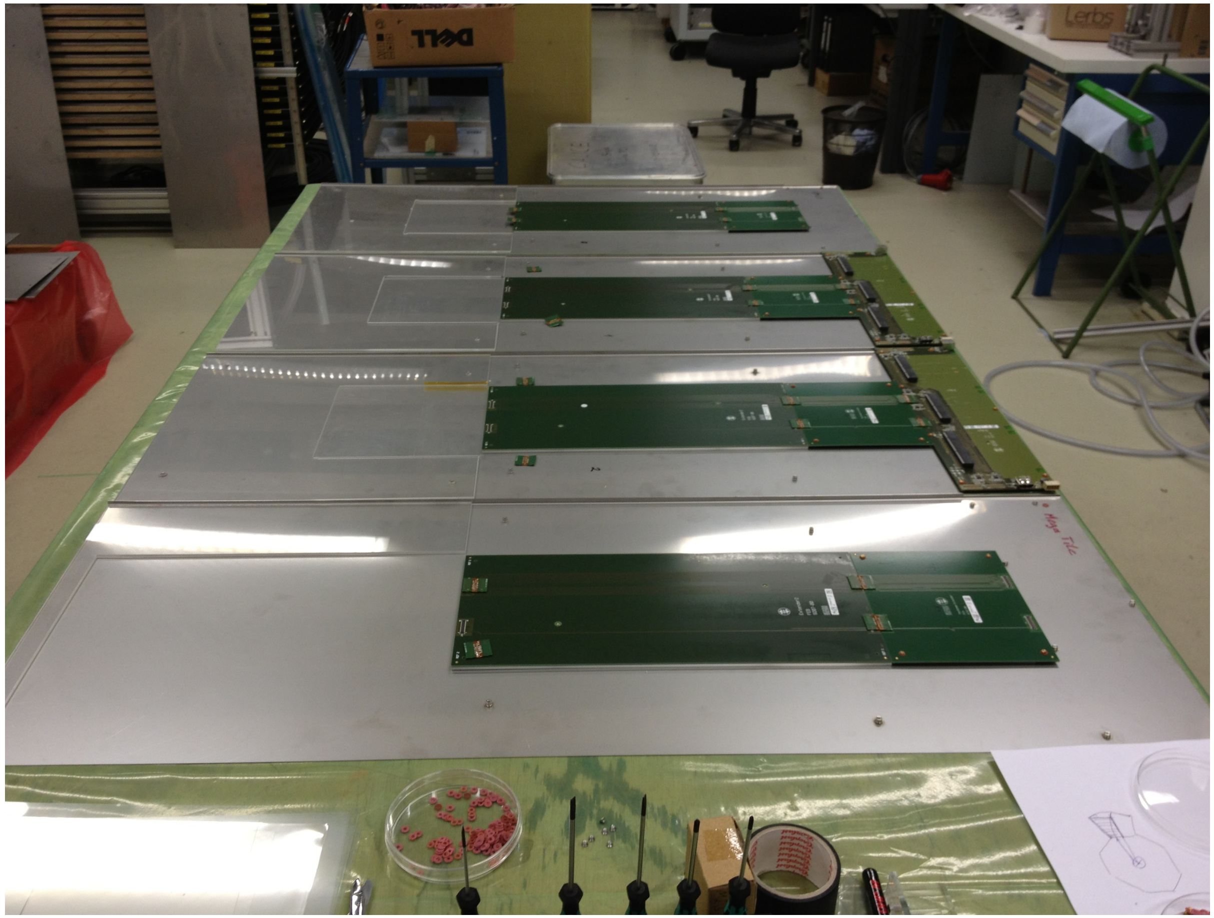


Getting real



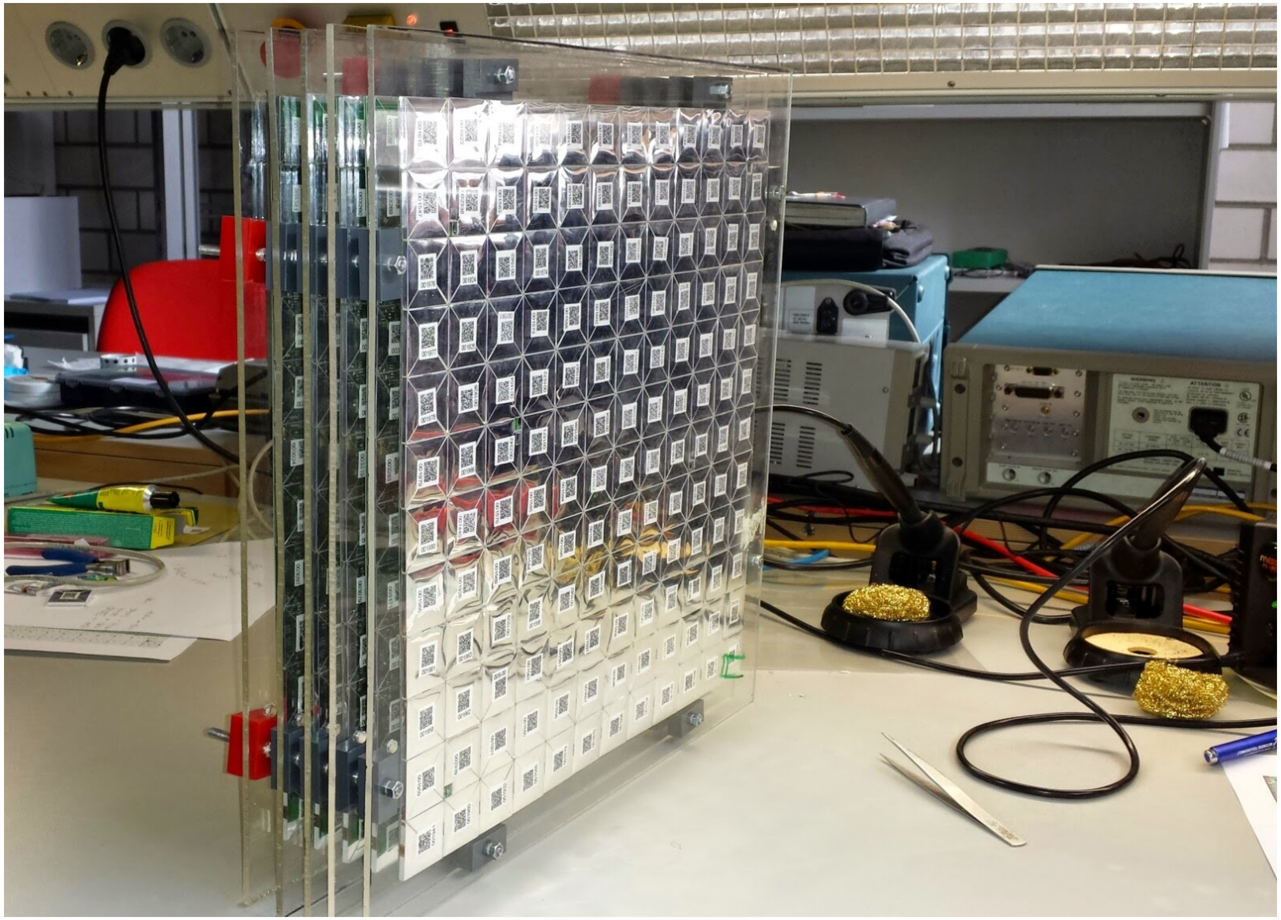
- Test beam at CERN PS in Oct and Nov/Dec 2014

Getting real



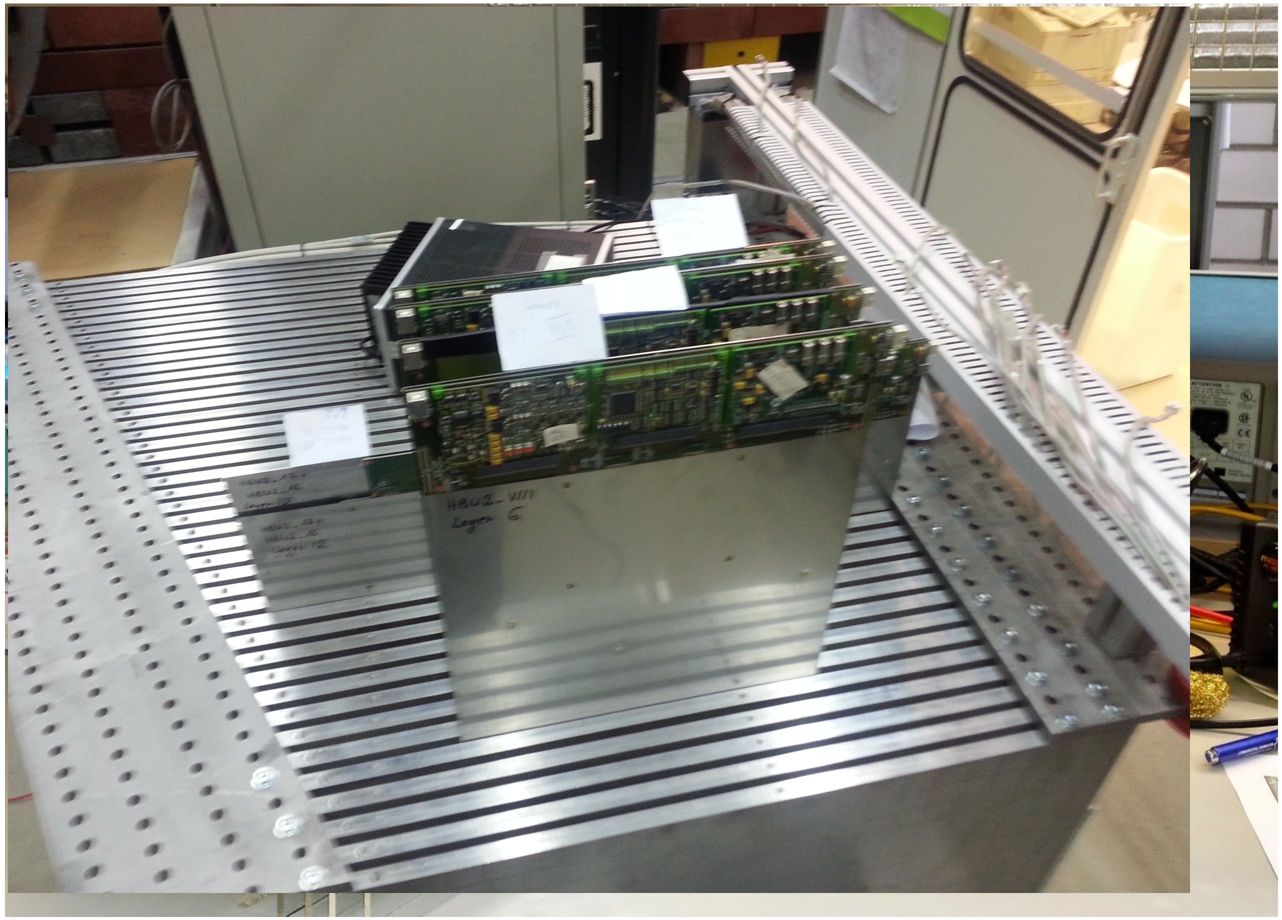
- Test beam at CERN PS in Oct and Nov/Dec 2014

Getting real



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

Getting real



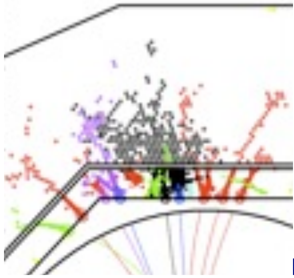
- Test beam at CERN PS in Oct and Nov/Dec 2014

Getting real

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

Commissioning at CERN PS

- All layers work
- DAQ being debugged while running on USB fall-back
- Ready for take-off

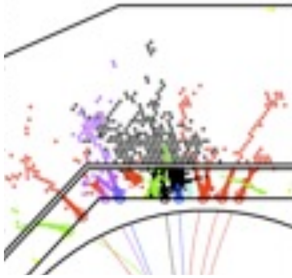


Summary

- Recent progress in SiPM development
  - simplify design, construction, commissioning, operation
  - improve stability
- New prototype to address system integration
  - mechanics and tolerances
  - FE electronics, tiles and SiPMs
  - auto-trigger and DAQ
  - power distribution and cooling

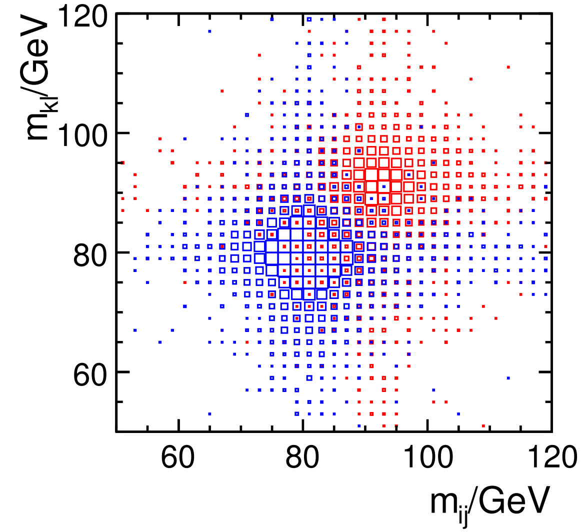
- Start test beam data taking with 10+4 layers now
- Remain open to integrate further improvements

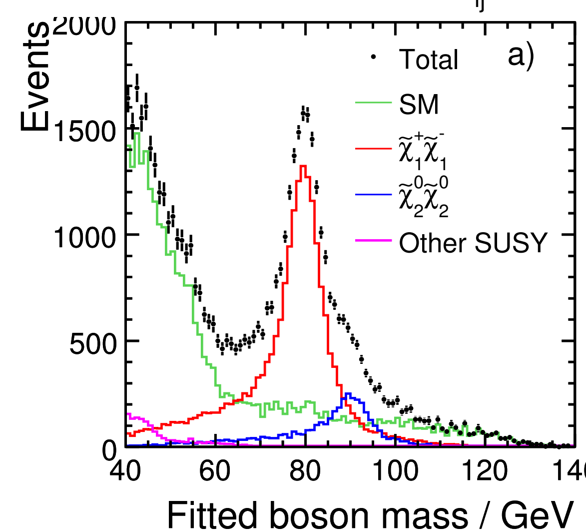
Back-up

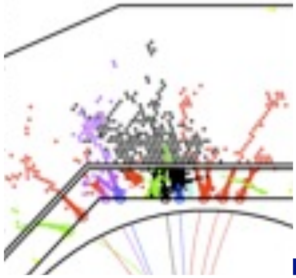


Jet energy resolution

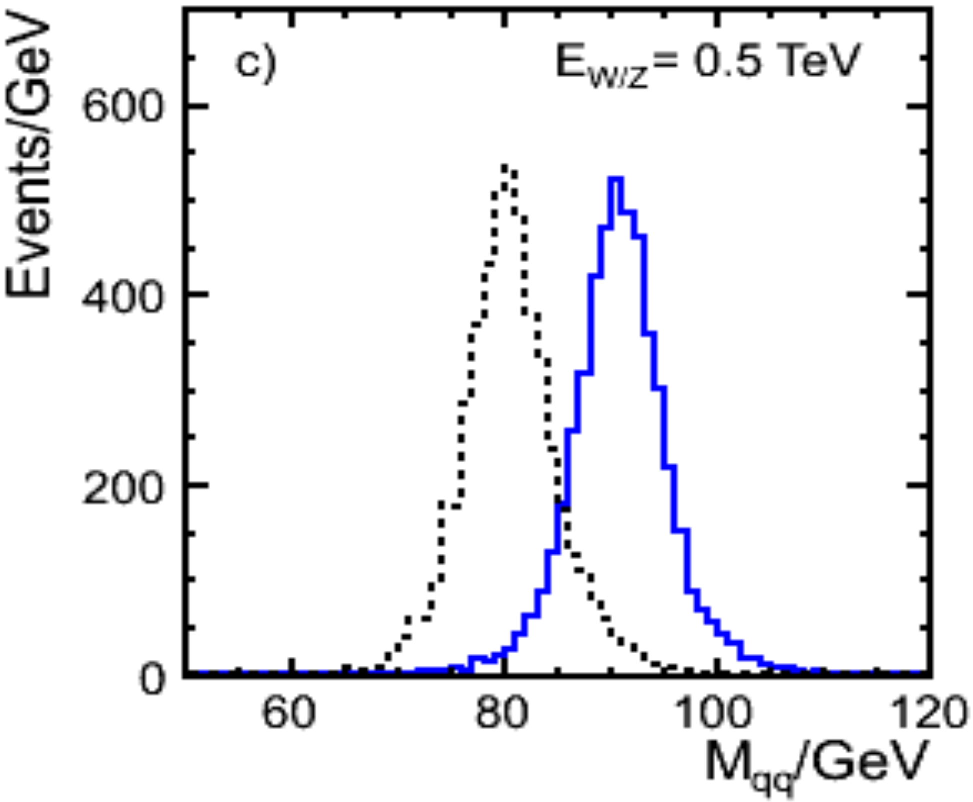
- At the ILC, must separate hadronic W and Z line D+ and Ds at Belle
- Famous “blue plot”: study strong electro-weak symmetry breaking at 1 TeV
  - WWvv, ZZvv production
  - but this is not the only one
- H → WW*, ZZ* (total width)
- H → cc, Z → vv
- Chargino neutralino separation
- In contrast, multi-jet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

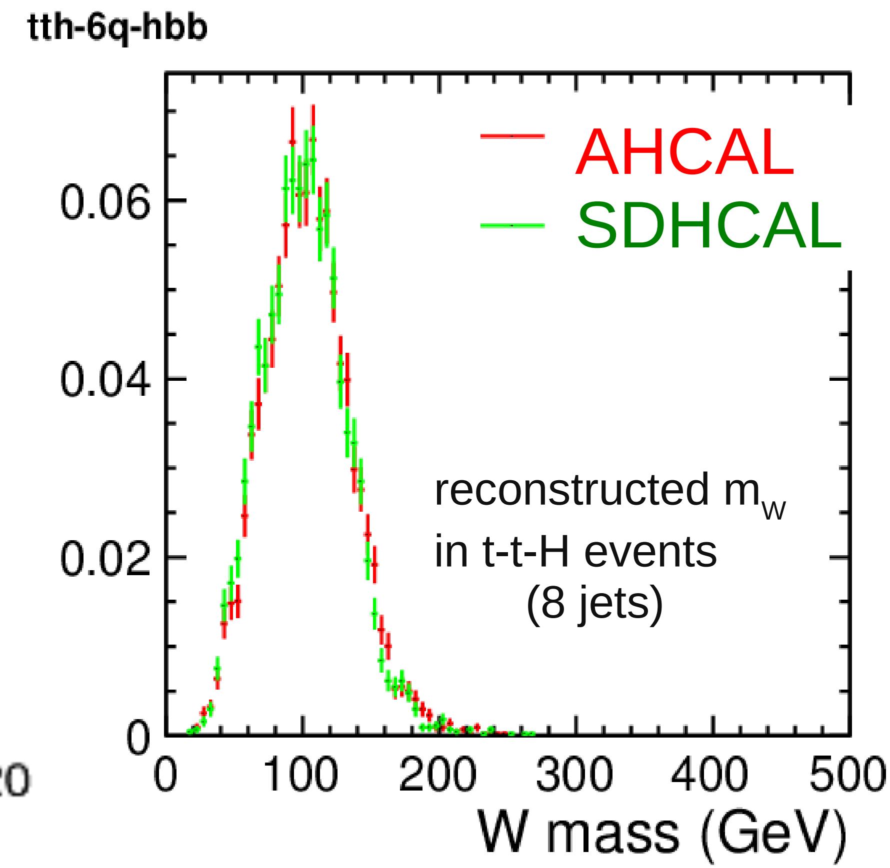




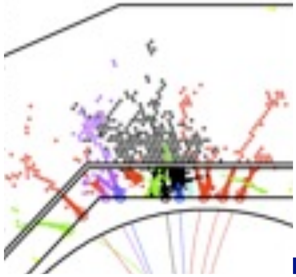


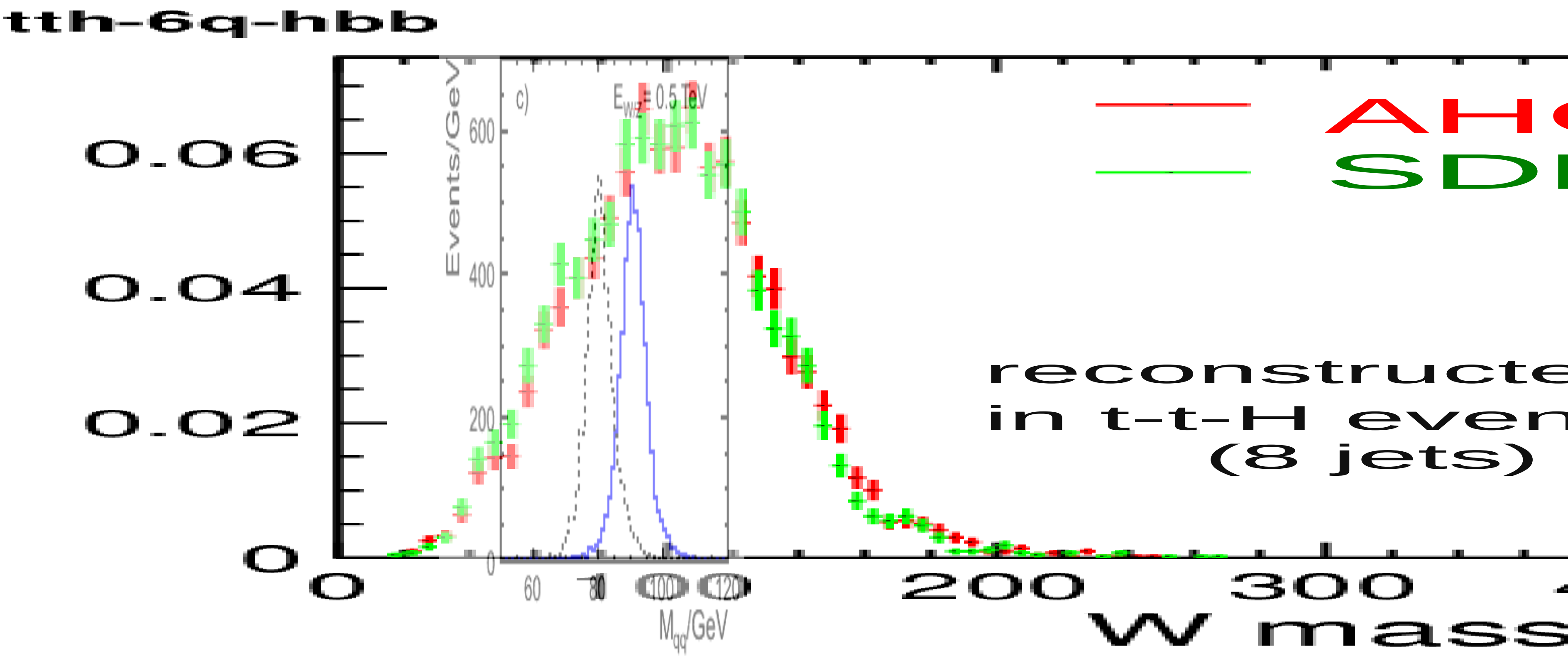
W Z separation

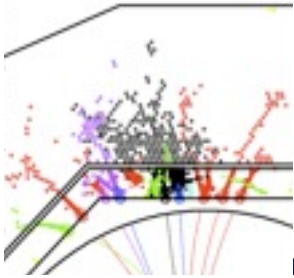




W Z separation

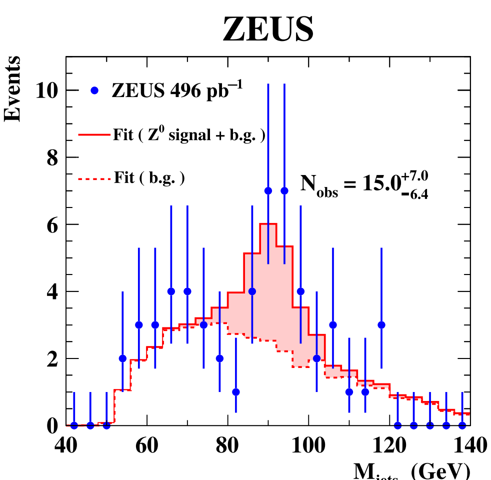






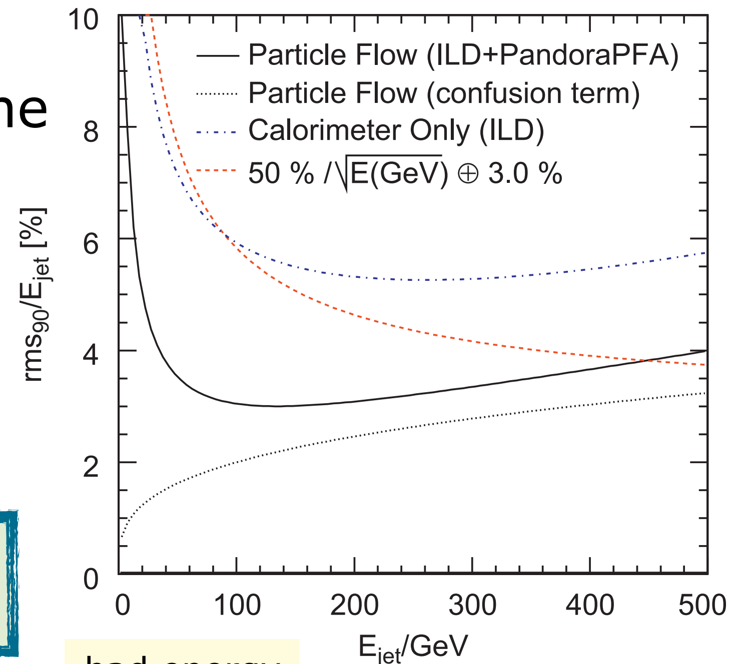
Particle flow

- 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



35%√E for pions, 6 GeV for Z

For scintillator, optimize independently



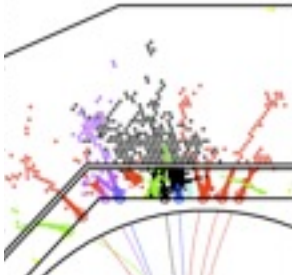
had energy resolution

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

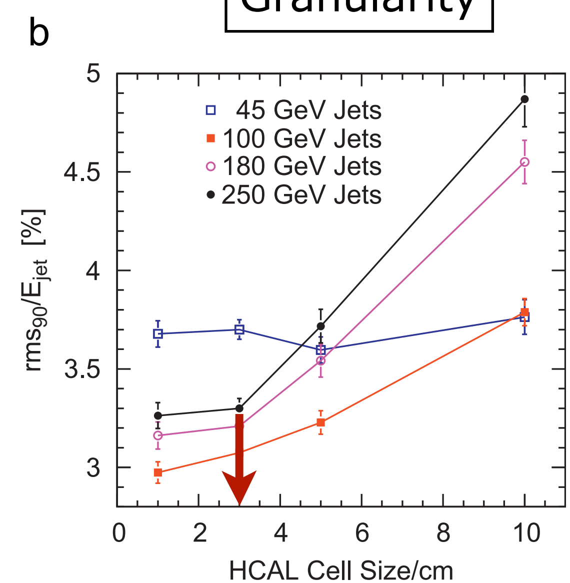


ILD optimisation

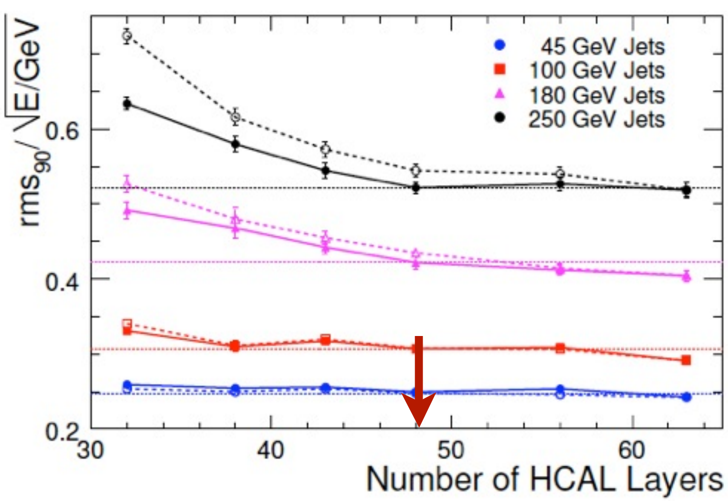
- Based on Pandora PFA
- Extensive studies done for the LOI
- AHCAL design parameters in plateau region

- Cost optimisation postponed

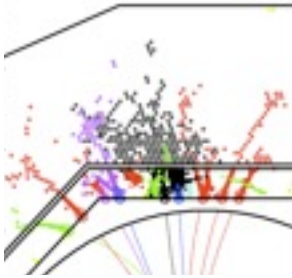
Granularity



Depth

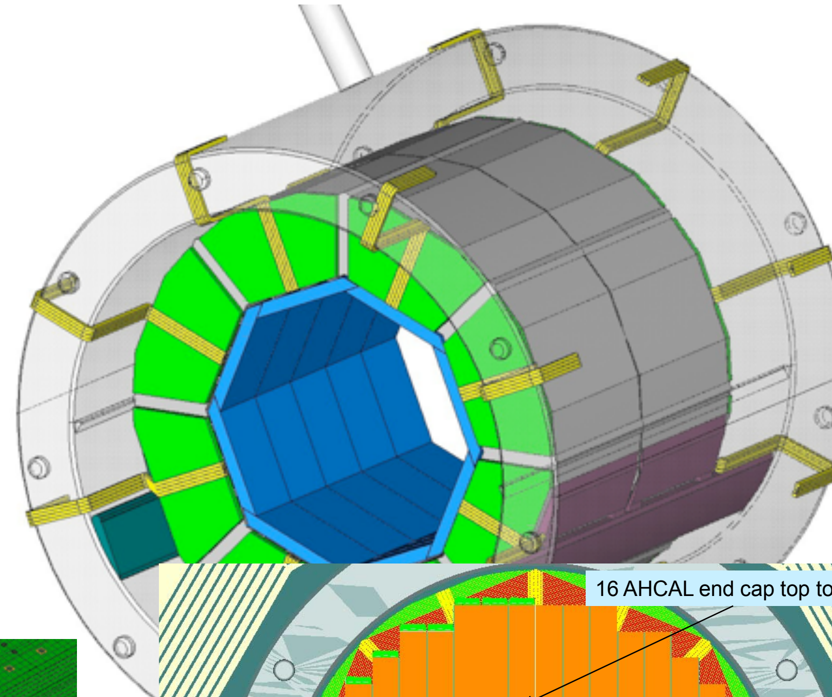


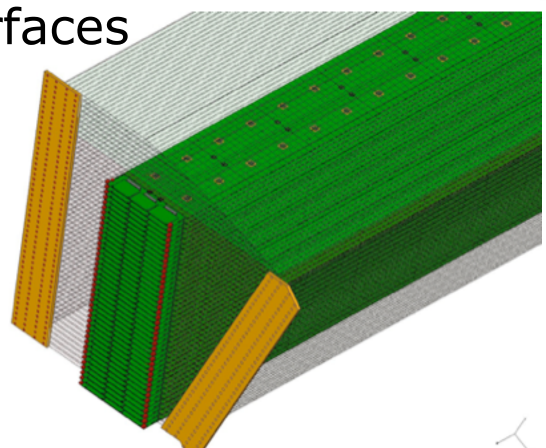
reflects shower feature size rather than particle separation

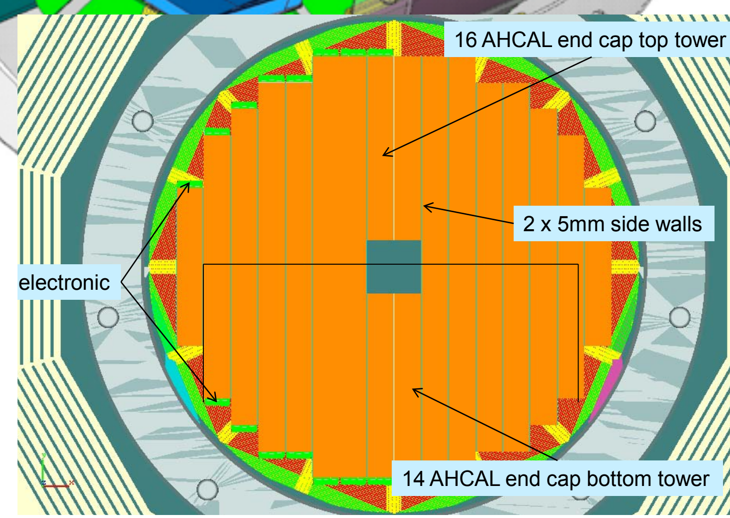


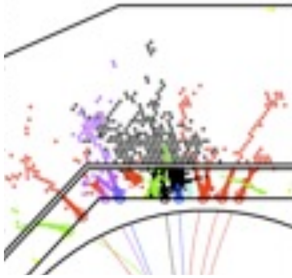
AHCAL implementation

- 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
  - $8000 m^2$
- Cracks filled with steel
- Embedded front end electronics
- Accessible interfaces

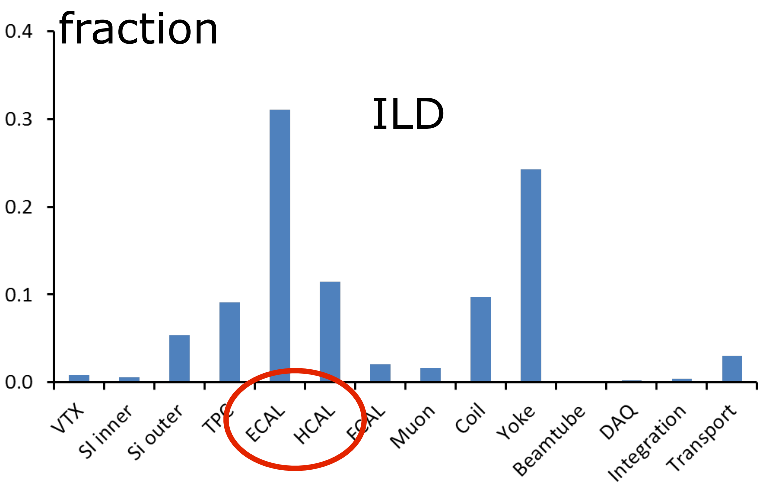








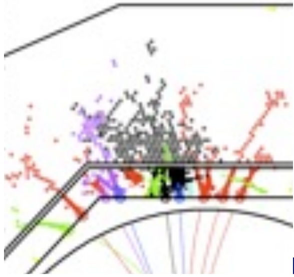
AHCAL cost drivers and scaling



- 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?

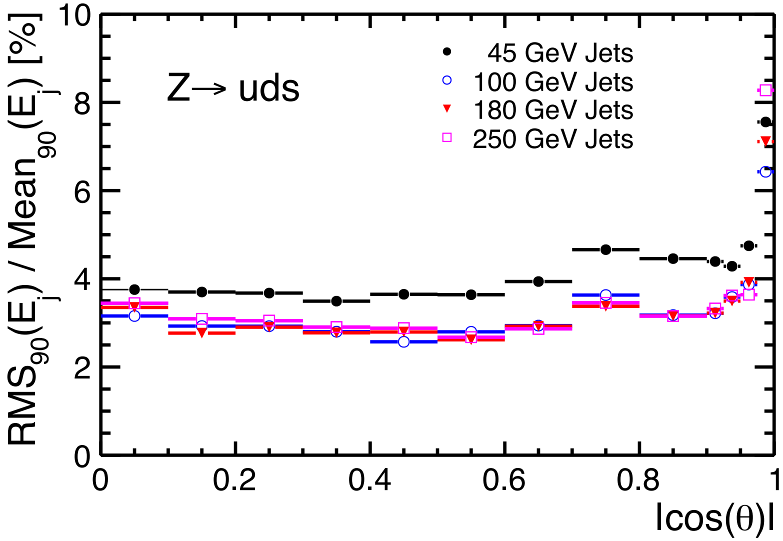
- ILD scint HCAL total: 45M
- 10M fix, rest ~ volume
- 10M absorber, rest ~ area (n_{Layer})
- 16M PCB, scint, rest ~ channels
- 10M SiPMs and ASICs

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



Performance

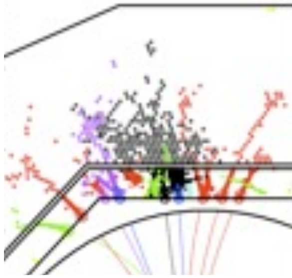
- Essentially all ILD DBD analyses were done with the AHCAL
- Dead regions, interfaces, services included in simulation



- 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



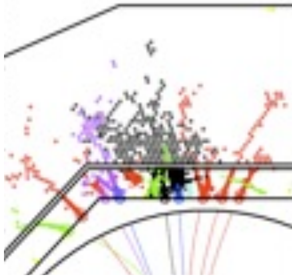
Beyond jet energy resolution

- 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

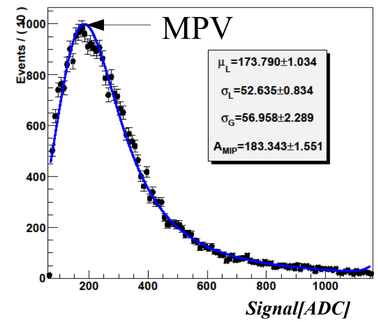
- Combined detector studies:
- **Electron pion separation** : ECAL and HCAL
- **Muon pion separation** : (ECAL,) HCAL and tail catcher

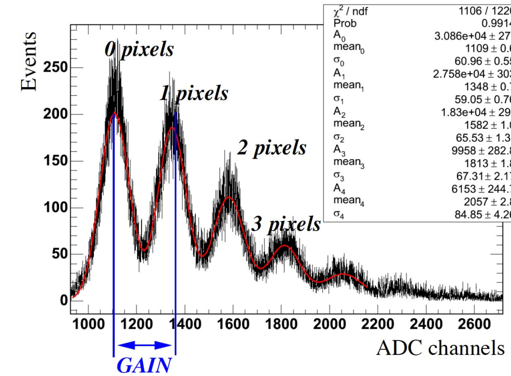


Calibration

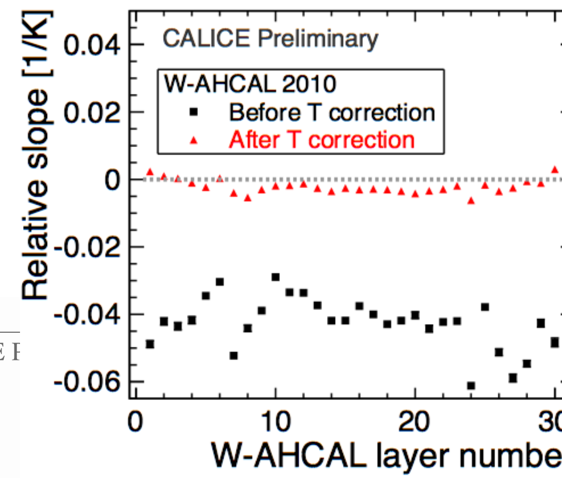
- Cell-wise equalisation: MIP
- Saturation correction: gain
- All SiPM properties depend on one parameter
  - $\Delta V = V - V_{break\text{-}down}(T)$

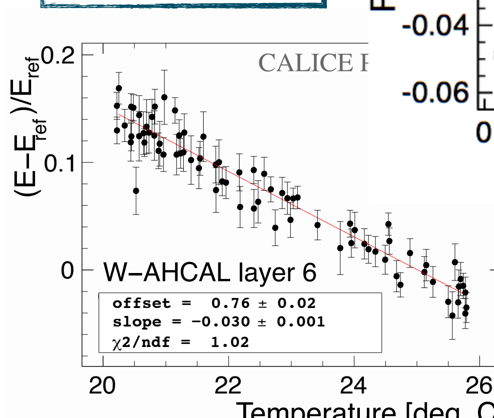
- Needed time to find right procedures
  - some limitations from test bench data
  - large spread of SiPM parameters
- Guidance for future developments
  - e.g. gain stabilisation



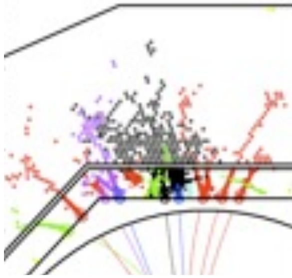


no climate control

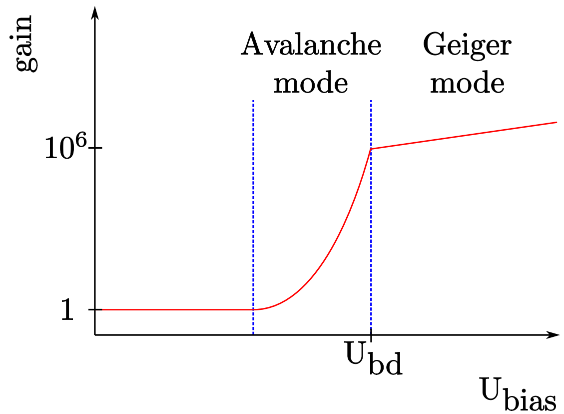


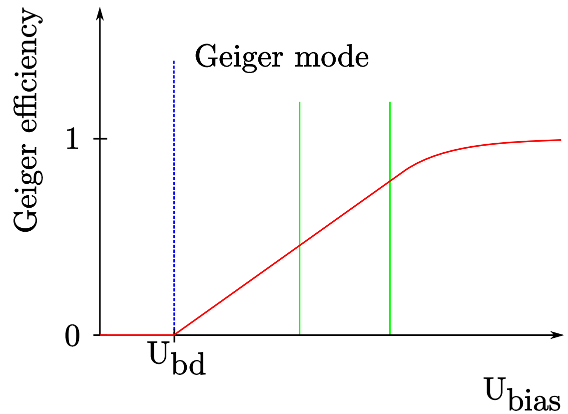


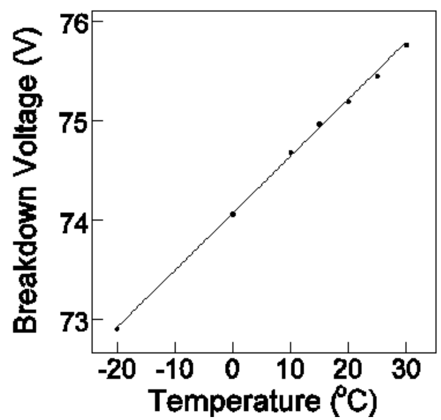
After layer-wise correction stable to better than 0.2%/K

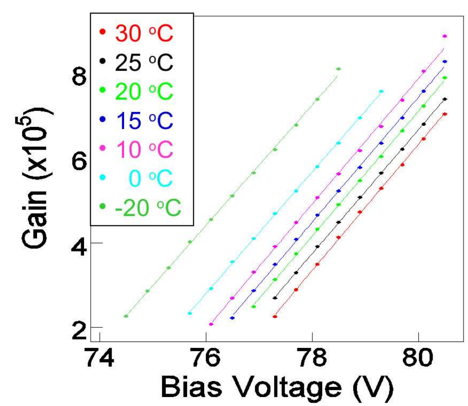


SiPM response

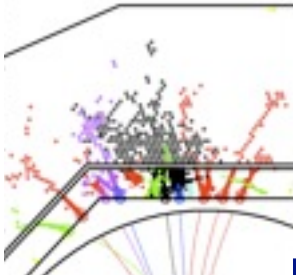






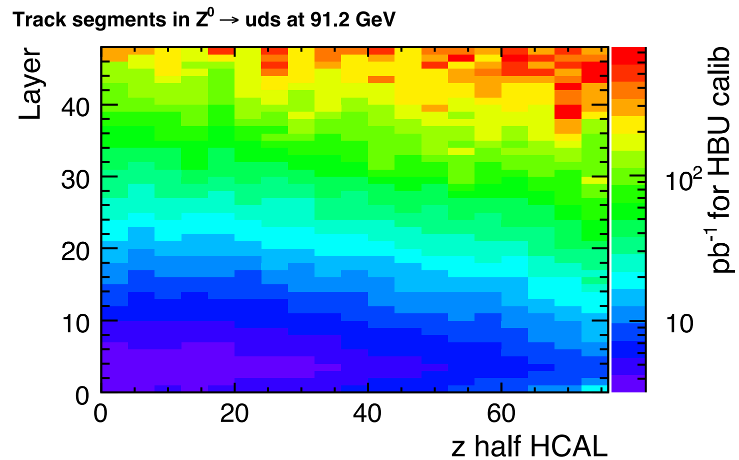


- $X = X(\Delta V)$, $\Delta V(T) = V_{bias} - V_{breakdown}(T)$

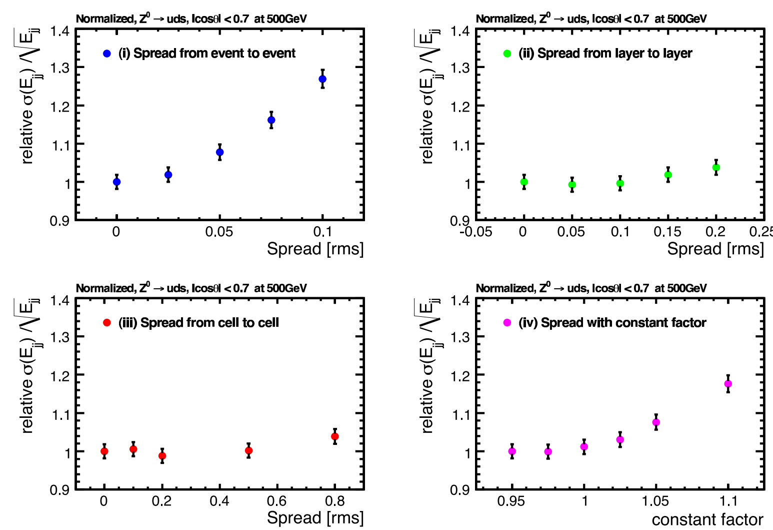


Calibration: look at full chain

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

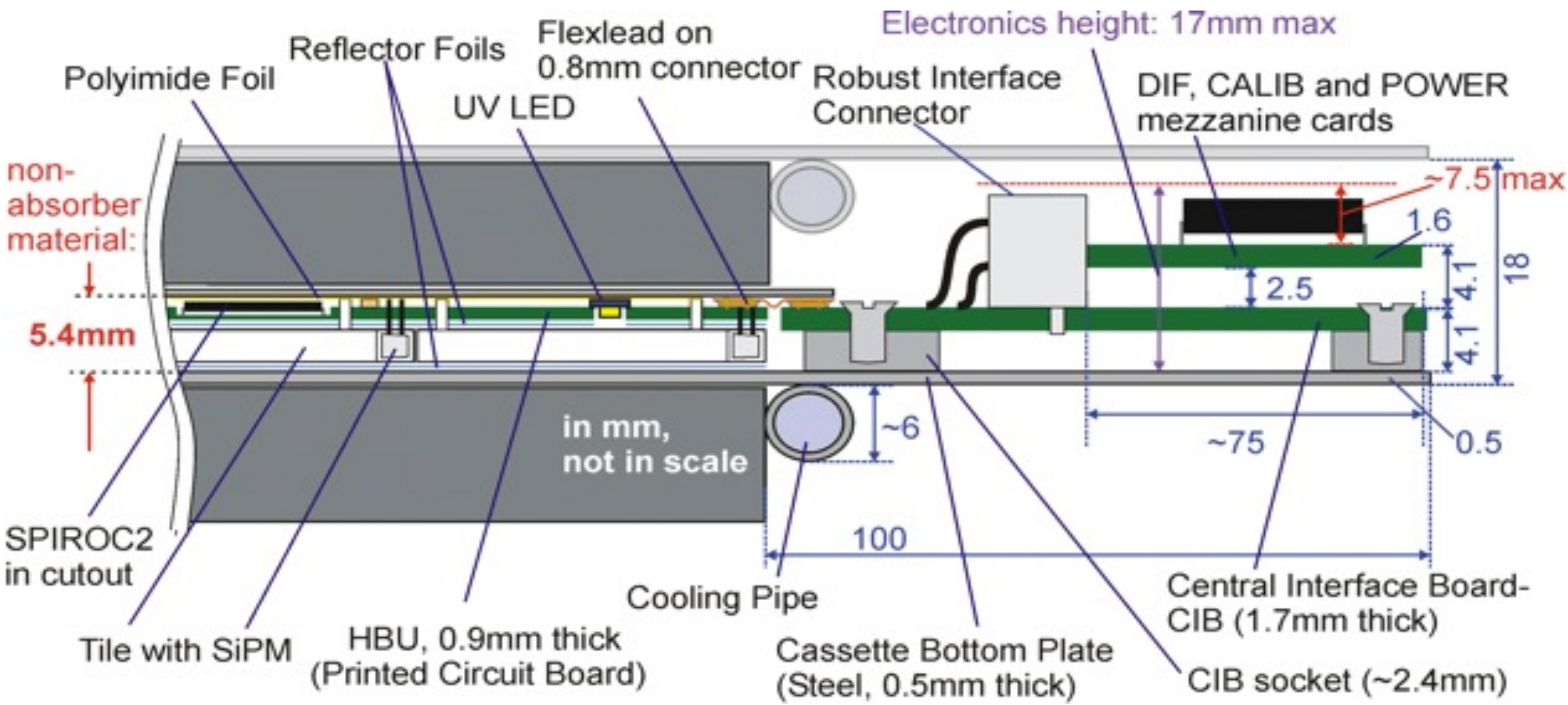


- Studied also impact of systematics due to calibration uncertainties on single particle and jet resolution
- Very insensitive to single channel effects
- For averages, statistics is not an issue
- Test benches: "Precision" = measurement accuracy or device-to-device non-uniformity



Calice Analysis note 18 and ILD note

Layer cross section



What we plan to measure

First testbeam period	Second testbeam period
EUDET steel stack Muon calibration data for central tiles	**Tungsten stack** Cross-check muon calibration

- EM showers: verification of energy calibration
- HAD showers: correlation of hit times

➢ Comparison of hit timing in iron and tungsten

➢ **Configuration:**

- First 11 layers including 3 EBUs (shower start finder)
- 4 full layers (2x2 HBUs) (hadronic shower measurement)

Position in stack	0	1	2	3	4	5	6	7	8	9	10	11	12	21	31
Layer (= DIF_ID)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Chip-IDs	129 -132	133 -136	137 -140	125 -128	141 -144	145 -148	149 -152	153 -156	157 -160	161 -164	165 -168	169 -184	185 -200	201 -216	217 -232