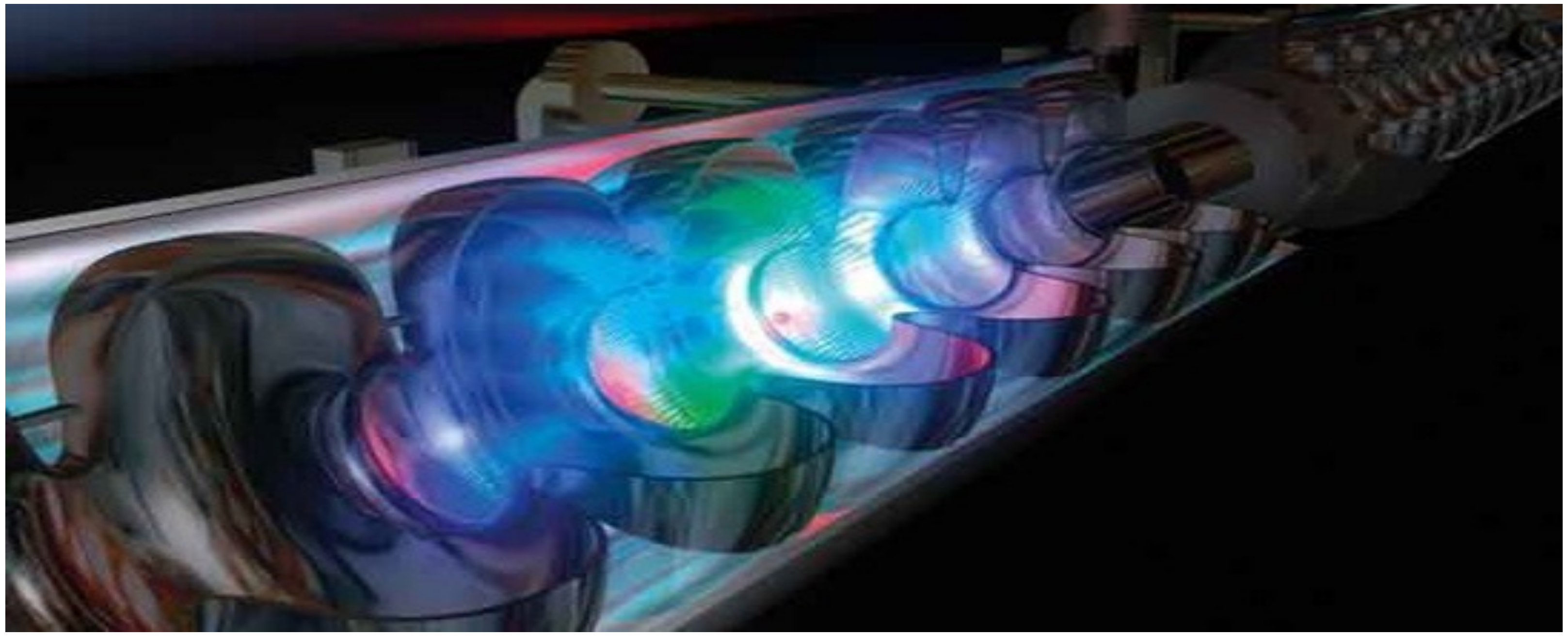


International Linear Collider

Huong Lan Tran

82^{th} Physics Research Committee

DESY, October 20, 2016

DESY activities at ILC

- DESY Linear Collider group plays a key role in the worldwide ILC effort

Accelerator:

- Positron source (Zeuthen)
- SCRF
- and more

ILD integration:

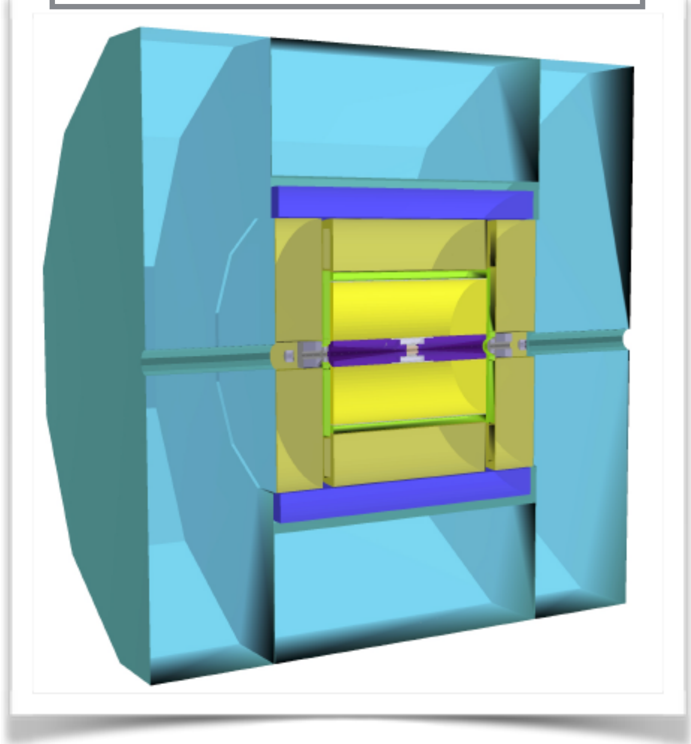
- MDI, EDMS, testbeam

SiD management

Software:

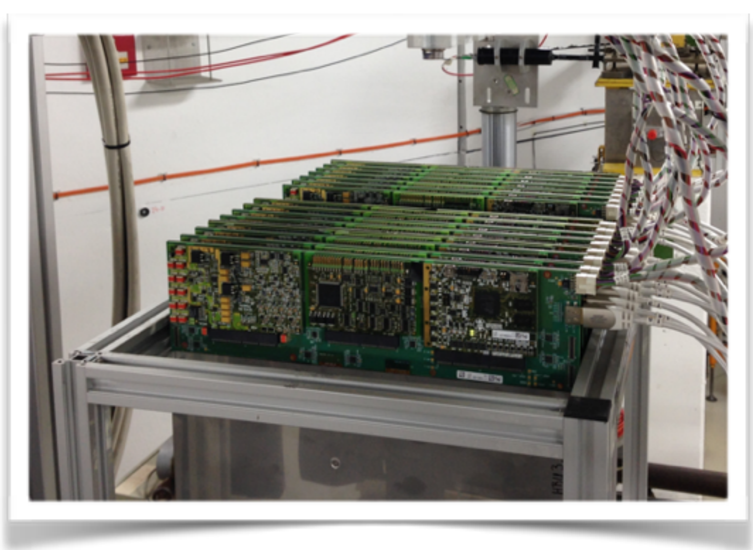
- Core software
- Tracking, PFlow
- DD4hep

International Large Detector (ILD)



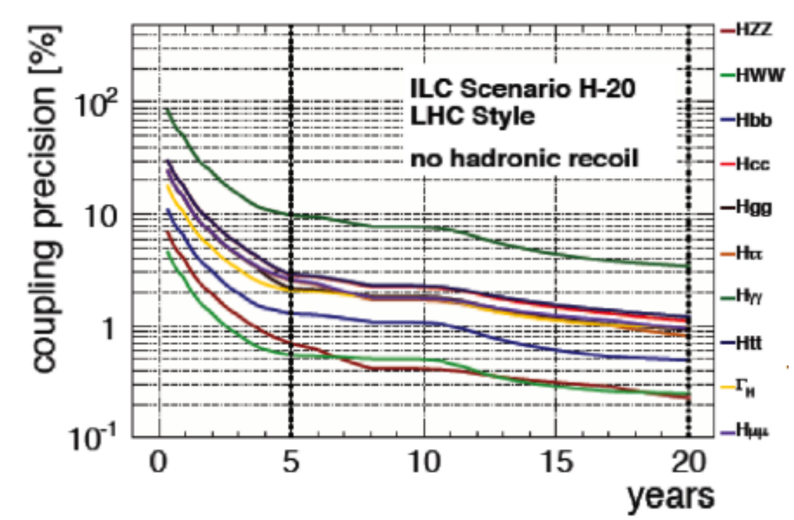
Detector R&D:

- Polarimetry
- Time Projection Chamber (TPC)
- Forward Calorimeter (FCAL)
- Analog Hadronic Calorimeter (AHCAL)



Physics:

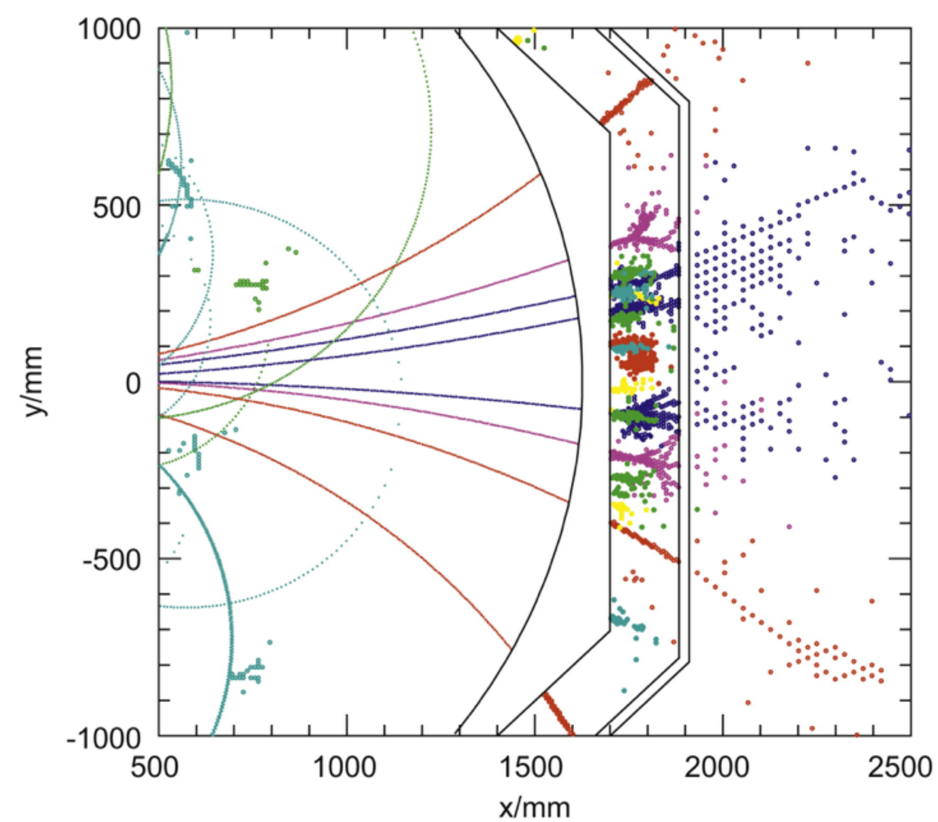
- Higgs physics, BSM

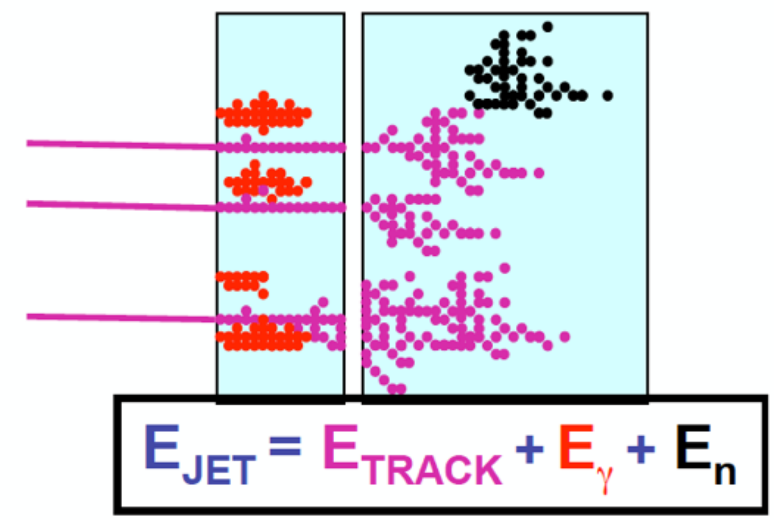


Particle Flow reconstruction & Hadronic calorimeter resolution

- AHCAL: highly granular hadronic calorimeter for Particle Flow reconstruction
- In a typical jet:
  - 60% energy in charged hadrons
  - 30% in photons
  - 10% in neutral hadrons
- Particle Flow reconstruction: trace individual particles with ***high granularity calorimeters***
  - Measure charged particle energy through track momentum
  - Photon energies measured in ECAL
  - Neutral hadron energies measured in HCAL
- ***Hadron calorimeter resolution plays substantial role:***
  - Neutral hadron energy resolution (intrinsic energy resolution)
  - Track-calorimeter cluster energy comparison (confusion term)

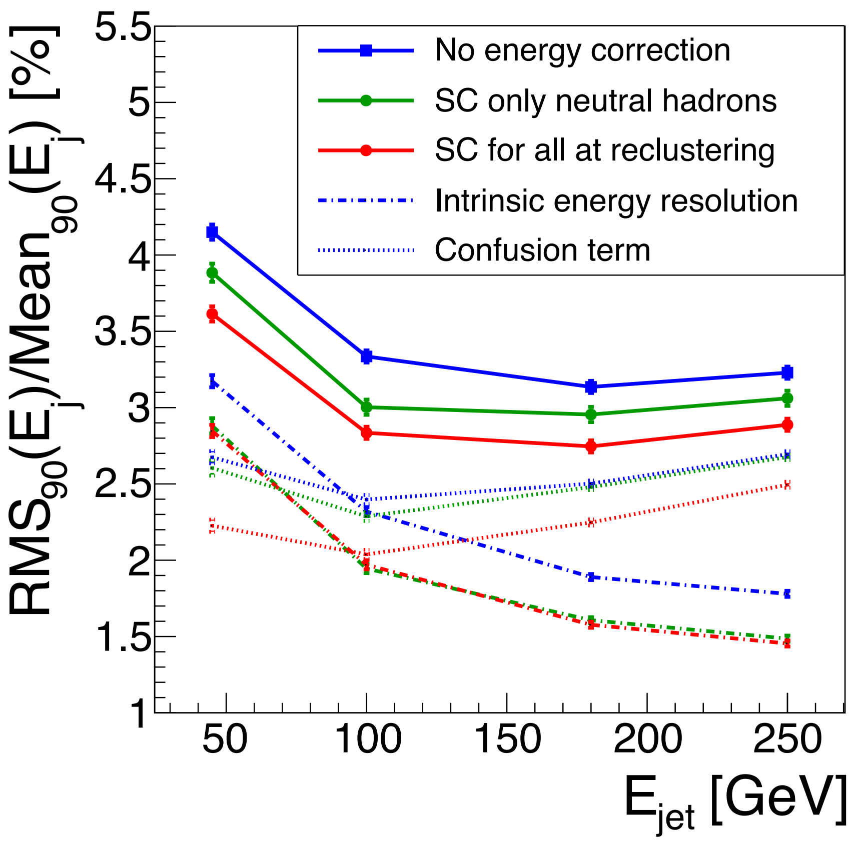
ILD jet events simulation

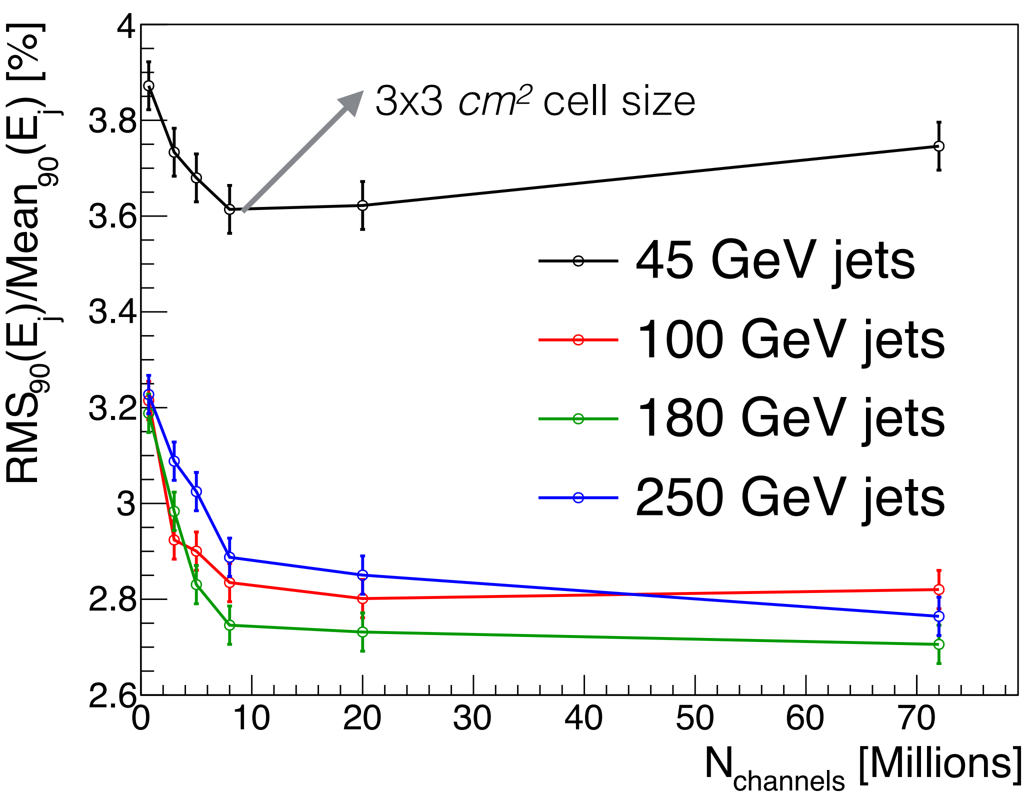




Particle Flow reconstruction & Hadronic calorimeter resolution

- Software compensation has shown significant improvement on intrinsic single hadron energy resolution with testbeam data
- Expect strong impact on overall jet energy resolution (JER)
- Implementation of software compensation into PandoraPFA: gives significant improvement in JER
  - JER vs $N_{channels}$ shows that 3x3 cm^2 tile size is a preferable choice
  - Effort in **collaboration with the Cambridge University group** (author of PandoraPFA)





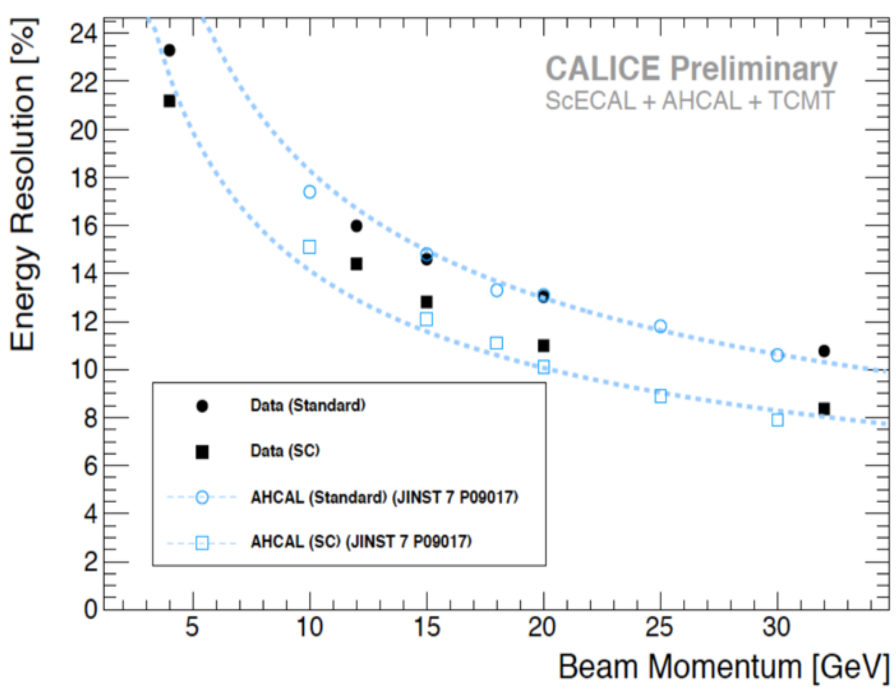
Fruitful collaboration
First time software compensation implemented in PFlow reconstruction and gave significant improvement on JER

Calorimeter optimisation study done in close collaboration with CLIC

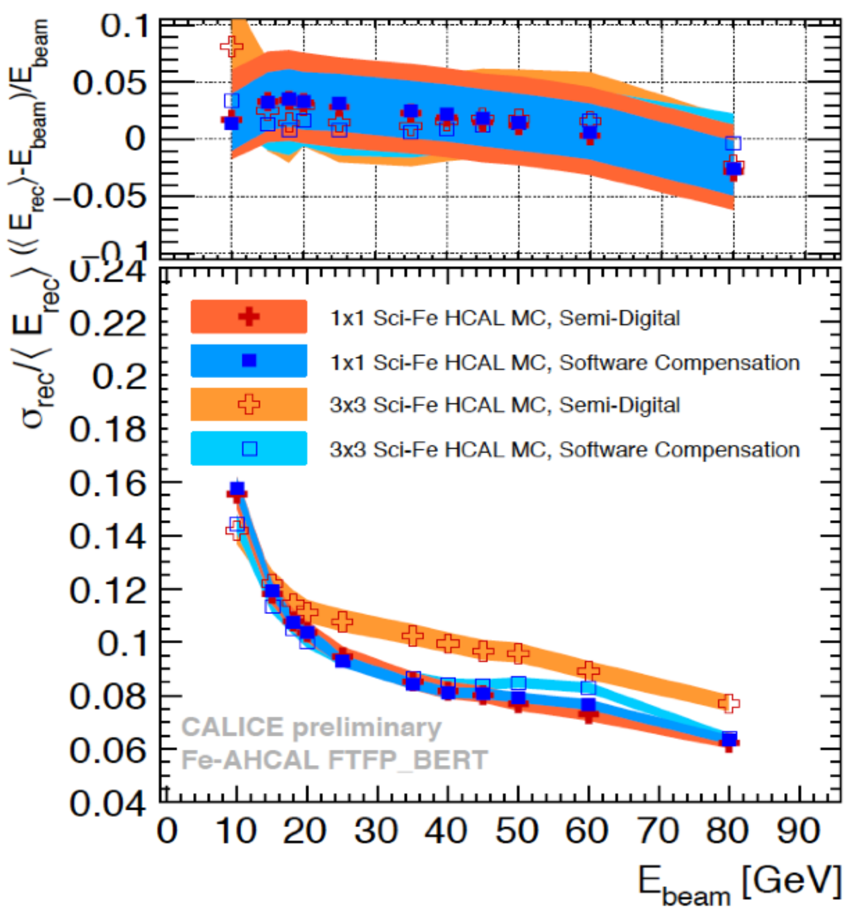
AHCAL physics prototype

- Demonstrated capability to deliver desired physics
- Different testbeam 2006-2011, analysis of data complete
  - 11 papers in refereed journals
    - Stable detector operation, excellent performance, established detailed detector modelling and shower simulation, verified particle flow algorithm on data
    - Fully propagated into simulation-based performance studies for large collider detectors
  - 2 new results

- Scintillator ECAL+AHCAL combined system consistent with AHCAL alone



Work in collaboration with Tokyo & Shinshu Uni

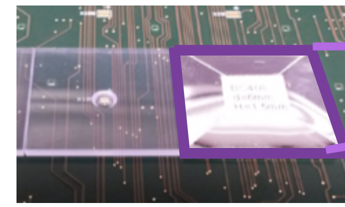


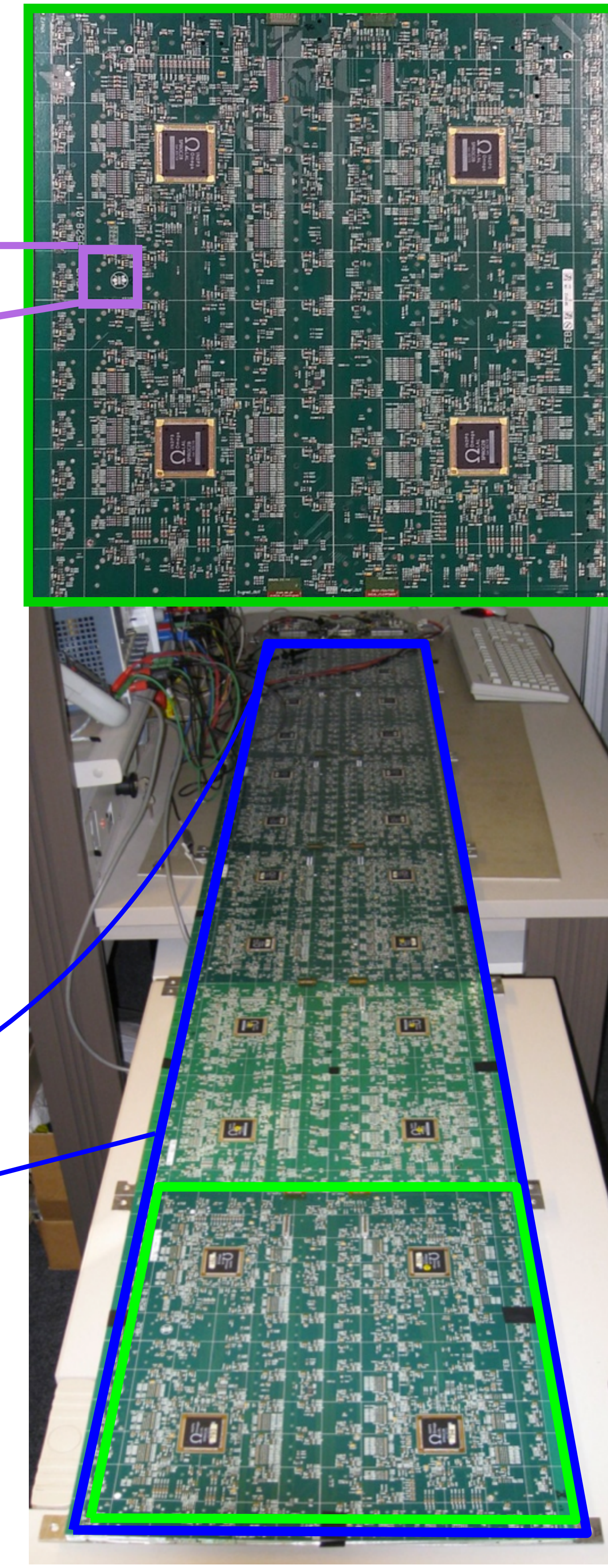
Work in collaboration with Argonne Lab

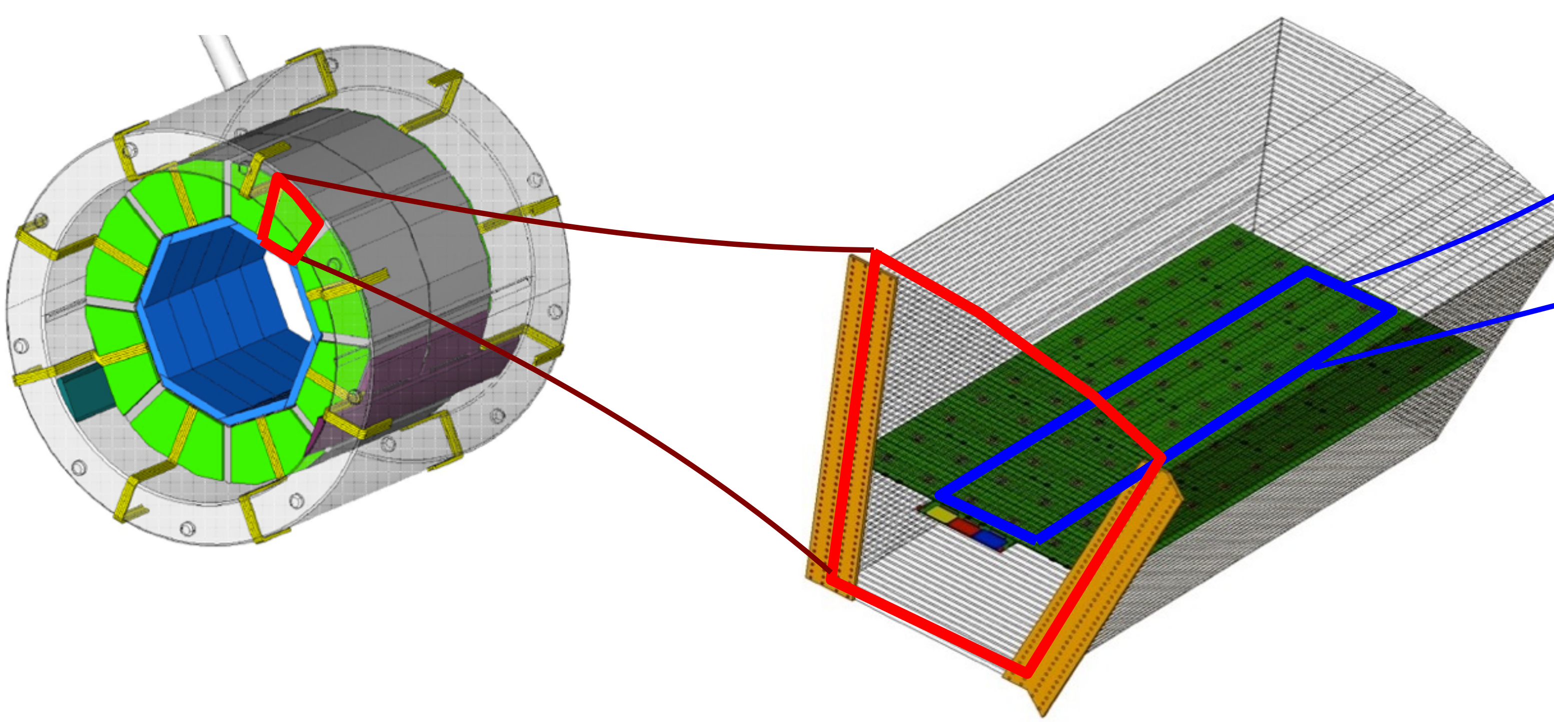
- For AHCAL technology, 3x3 cm^2 tile size is sufficient (right), consistent with ILD performance study result
  - For analog readout scheme, 1x1 cm^2 tile size brings no further improvement in performance

Analog Hadronic Calorimeter

- Sandwich calorimeter based on scintillator tiles (3x3cm^2) readout using Silicon Photomultipliers (SiPM)
- HCAL Base Unit (HBU): 36x36cm^2
  - 144 channels readout by 4 ASIC chips
  - Fully integrated electronics
- In total 8M channels, challenge on data concentration
- ***Technological prototype***: demonstrate scalability to full detector
  - Improvement in all aspects compared to physics prototype





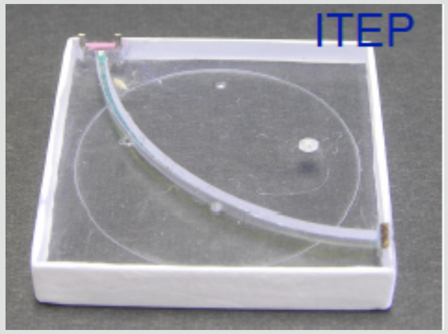


SiPMs & Tiles developments

- SiPMs sensitive to blue light → no need for Wave Length Shifting fibers

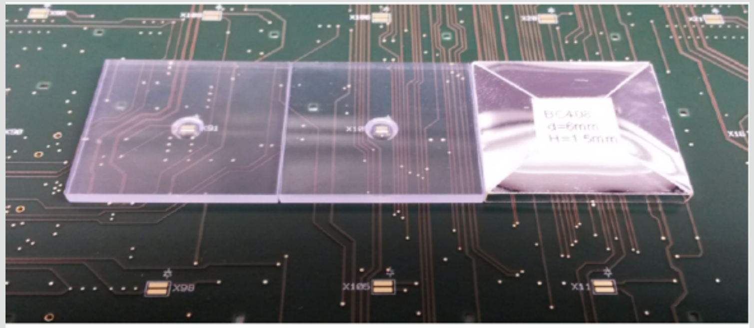
Physics prototype

2006 - 2011



Old ITEP tiles with WLS fibre
1200 px SiPMs

Technological prototype



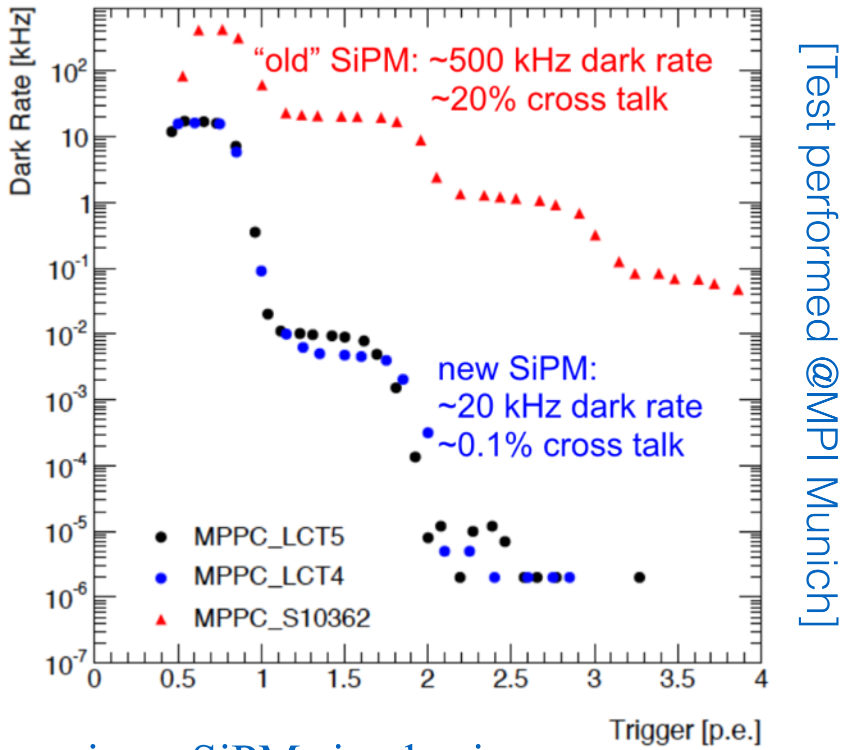
Surface mounted SiPMs & tiles

- with *MPPC* SiPMs **2700** px

Suitable for automated mass assembly

New generation of industrial SiPMs: drastically improved over the past years

- Dramatically reduced dark rate and increased photon detection efficiency
  - Better signal-to-noise ratio, allows simpler tile design
- After-pulses and inter-pixel cross-talk largely reduced
  - Noise rate decreases quickly with threshold, much more stable operation
- Excellent uniformity (operating voltage, gain)
  - Simplified calibration
- High over-voltage operation
  - Reduced temperature sensitivity

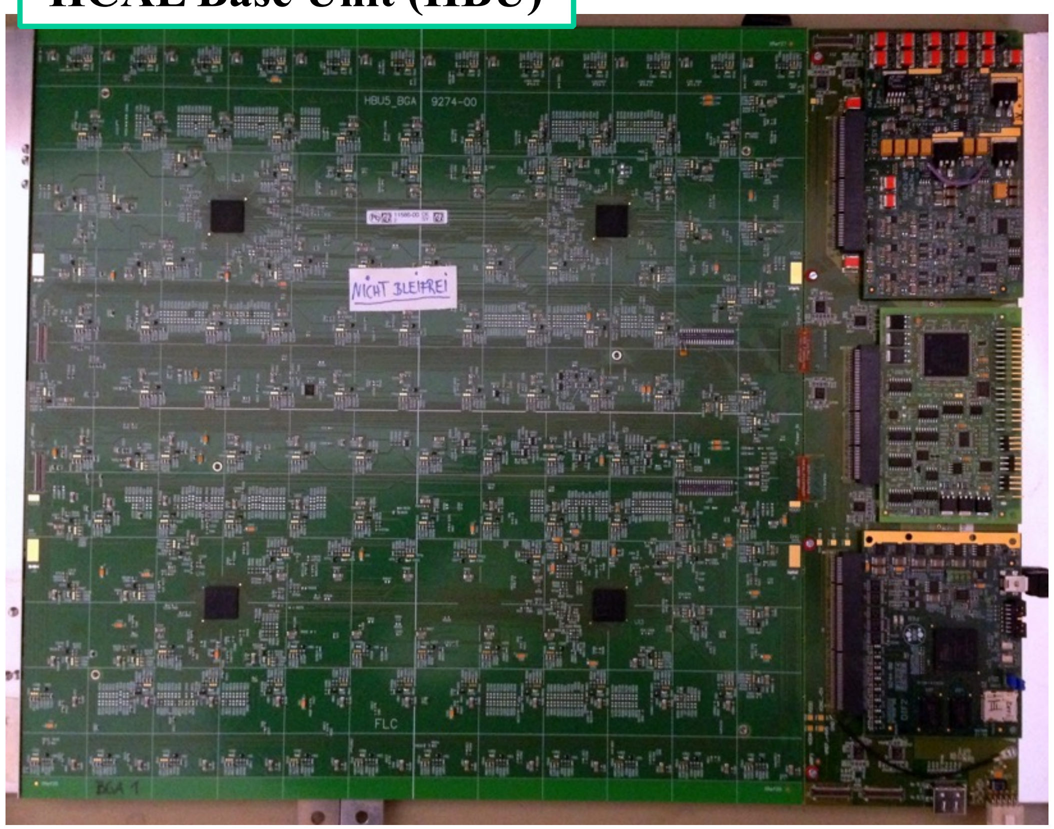


For comparison: SiPMs in physics prototype 2 MHz dark rate, 30% cross talk

Electronics

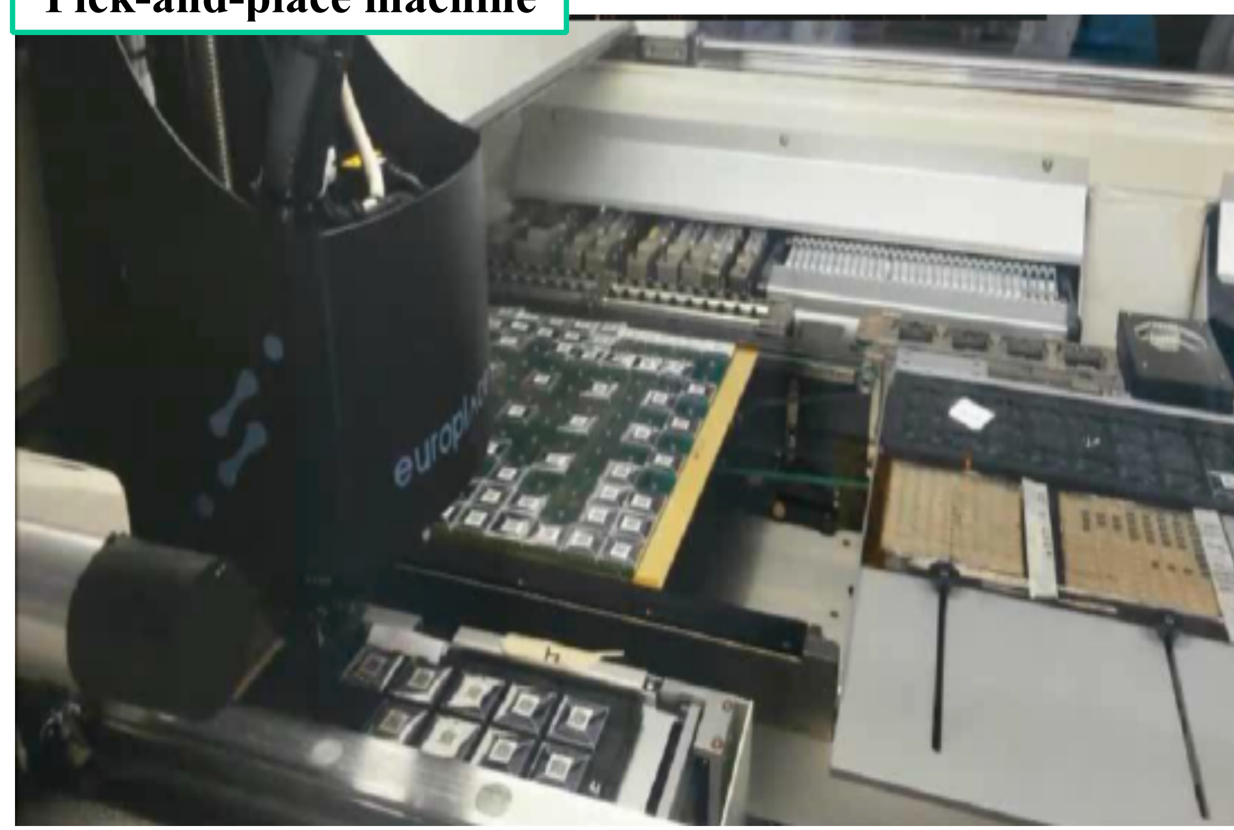
- Fully integrated electronics for mass production & reduced power consumption
  - LED driver circuit improved channel uniformity: minimise time for test and calibration runs
  - Auto-trigger & external trigger mode
  - HBU4 designed for surface mounted SiPMs & suitable for *automated tile assembly*
  - HBU5 designed for SPIROC2E chip in production
    - SPIROC2E with power consumption reduced, so far successfully tested

HCAL Base Unit (HBU)



Tested this week in beam. Works perfectly!

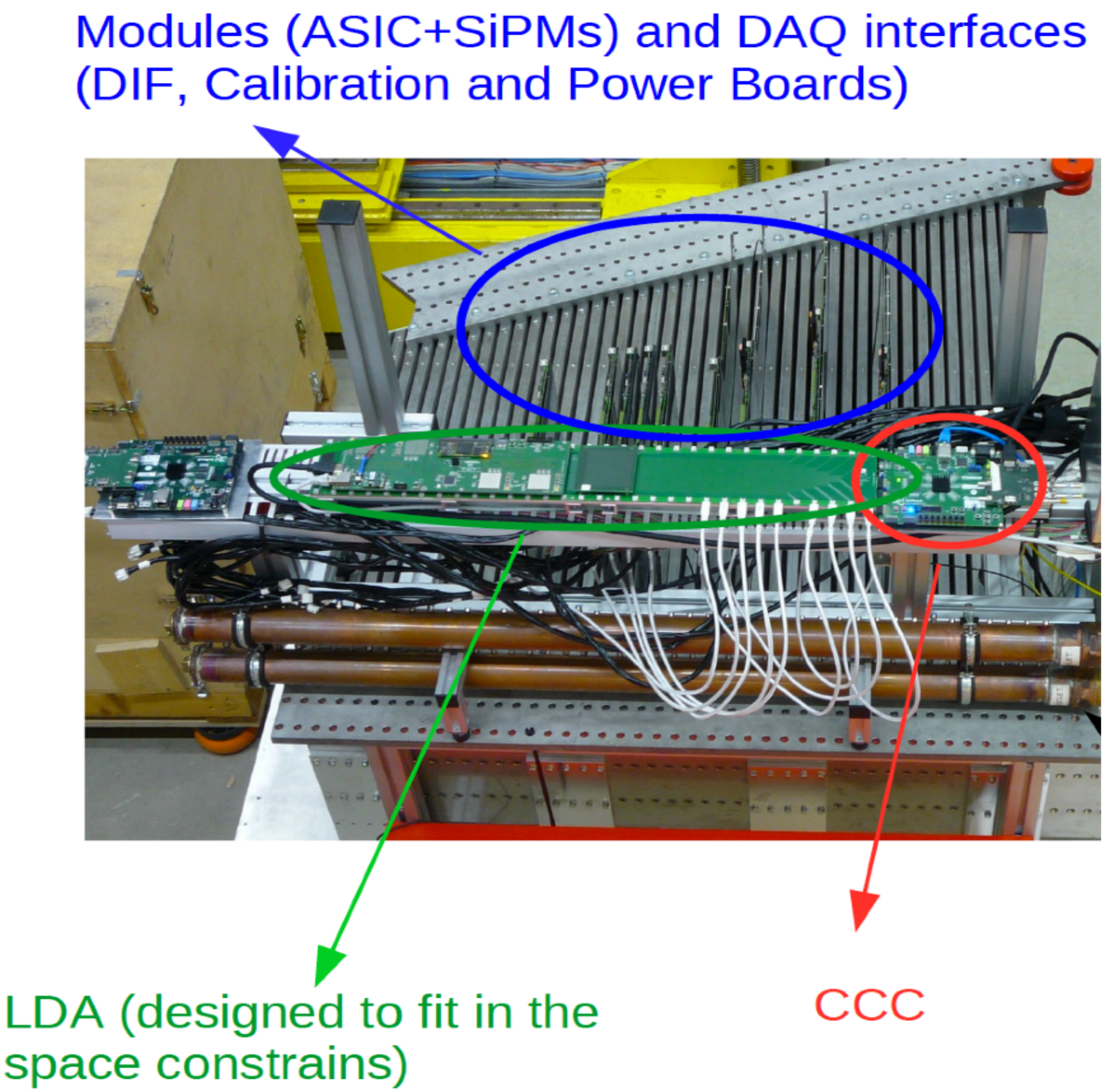
Pick-and-place machine



Now used routinely

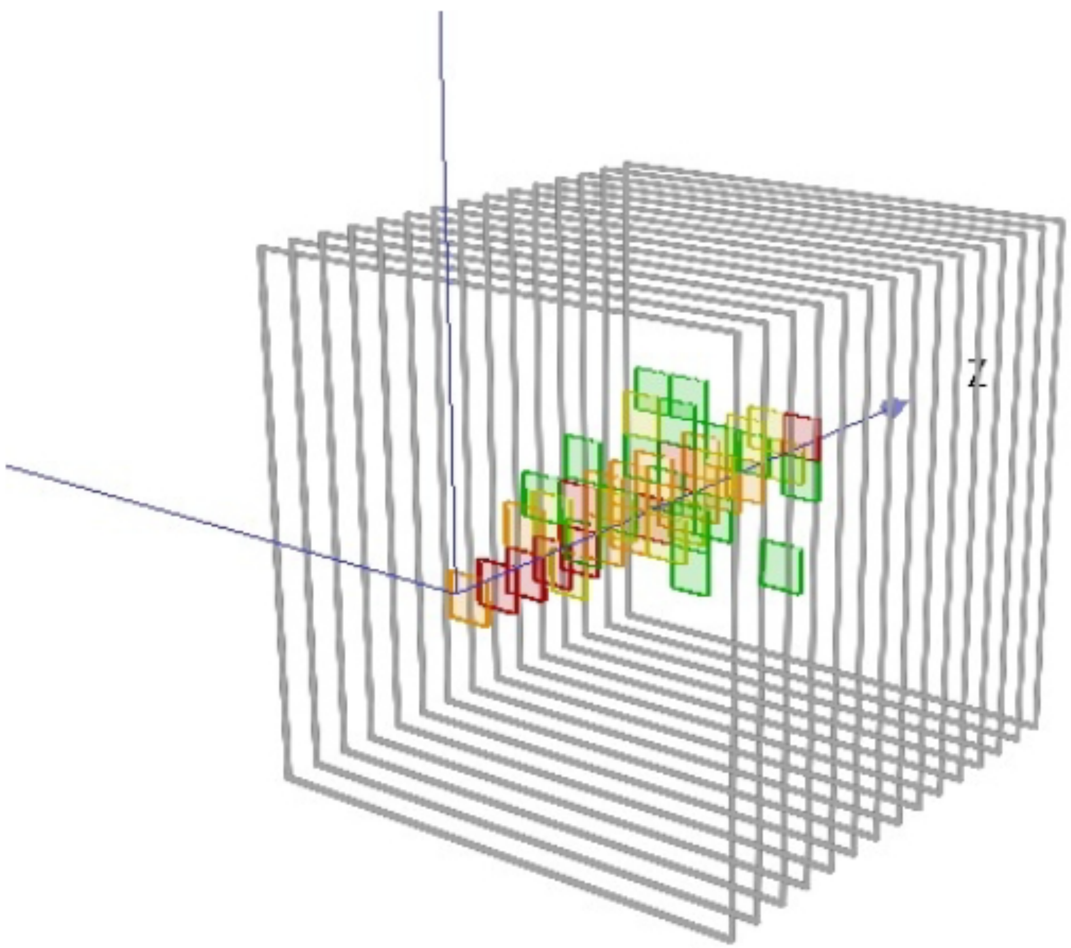
Data read-out

- **Interfaces and data concentration:** 3 interface boards (POWER, DIF, CALIB) handle on full layer of large detector
  - POWER board equipped with capacitor bank for ***power pulsing***, temperature compensation possible
  - DIF board uses more advanced FPGA to communicate with the ASICs
- **System integration:**
  - Wing-LDA designed for ILD-AHCAL successfully operated
  - Thanks to power pulsing mode, only water-cooling for interface boards needed
- **Data acquisition:**
  - Integrated into EUDAQ system (chosen by LC community and actively supported by AIDA-2020): successful operation

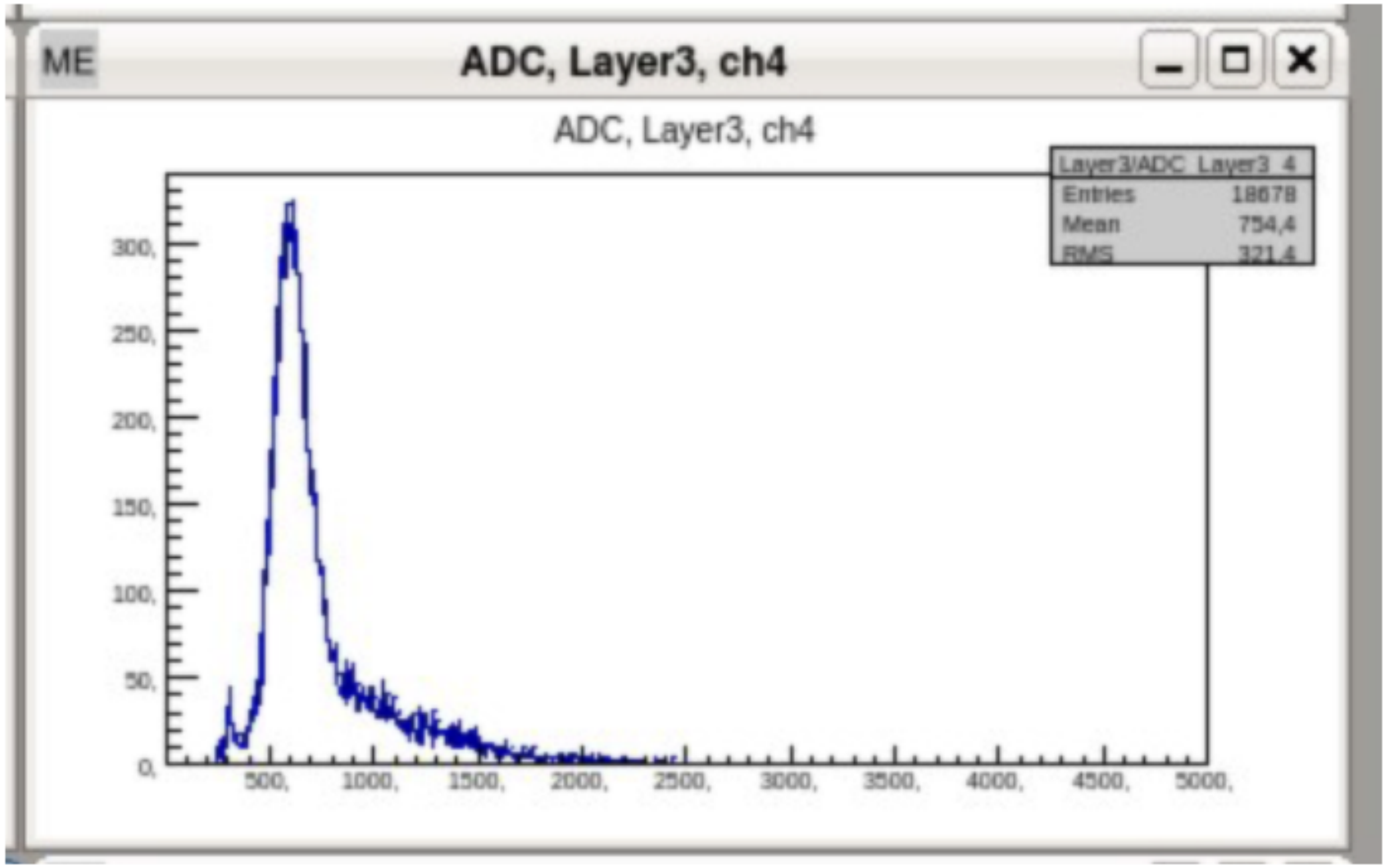


Testbeam software & monitoring

- Testbeam software developed in ILCsoft framework
  - Simulation done in Mokka, recently in DD4hep (in validation)
  - Online & semi-online monitoring with full event reconstruction (~ few minutes)
    - Online monitoring: effort within CALICE collaboration (developed by Lyon and Gent, newly implemented by Sussex Uni in AHCAL)



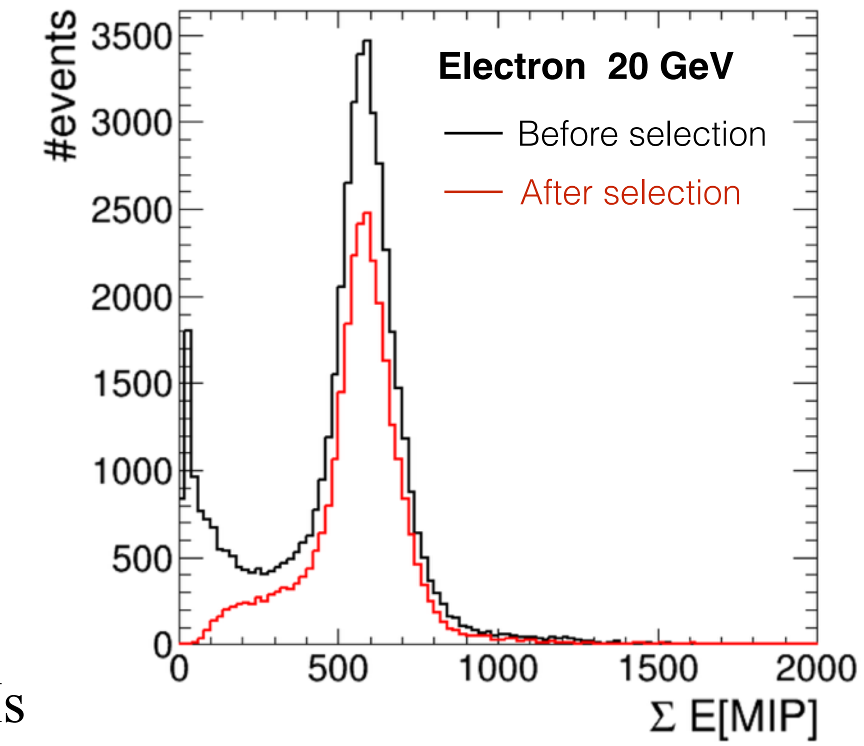
Event display of an electromagnetic shower

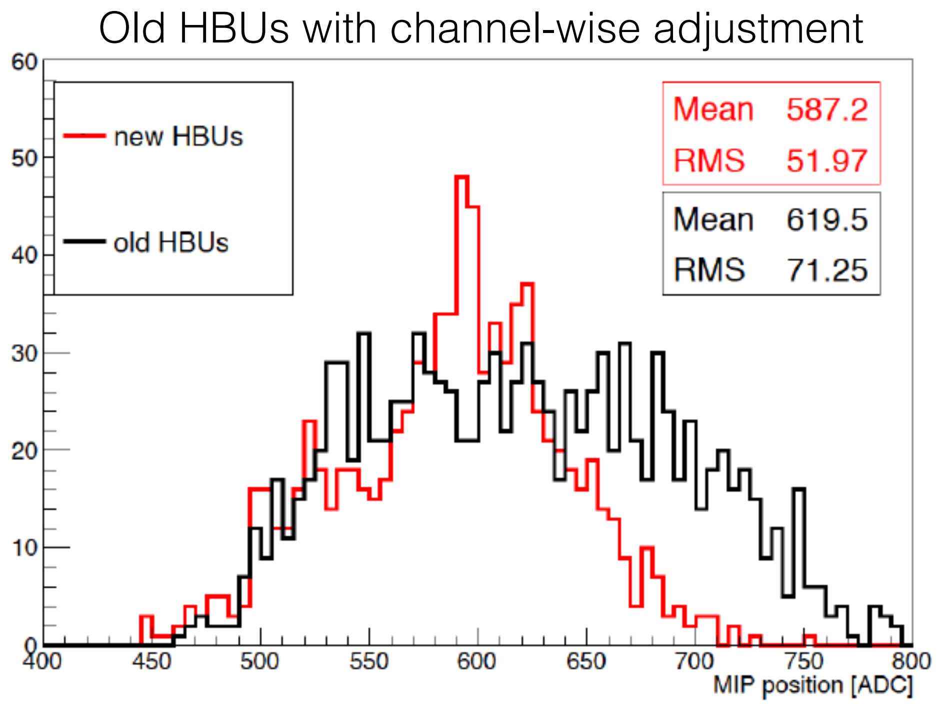


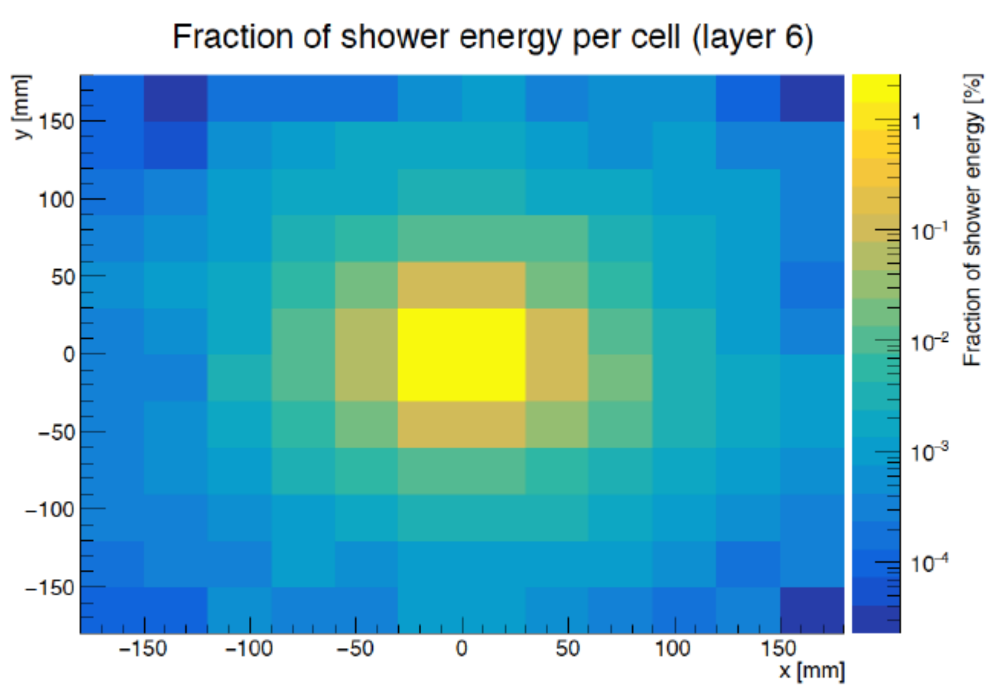
Hit size spectrum for a MIP

Testbeam analysis

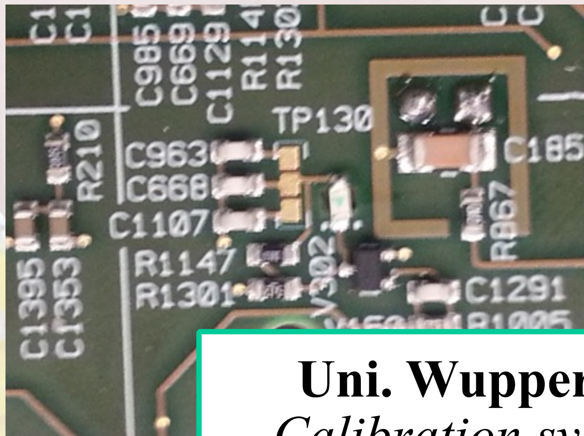
- **Meaningful physics program accessible with technological prototype**
- ***2015 CERN SPS data:***
  - Electromagnetic shower analysis: Validation of calibration and simulation with electron data
  - Hadronic shower analysis: Shower profile, hit time correlations in different parts of hadron showers first time possible with this prototype
- ***2016 DESY data:***
  - 6 additional HBUs with new tile design and newest generation SiPMs (all 864 work, all but one perfectly)
  - Performance for measurement of electron shower energies







AHCAL technological prototype



Uni. Wuppertal
Calibration system
ASIC tests

Strong contribution from different international & German institutes

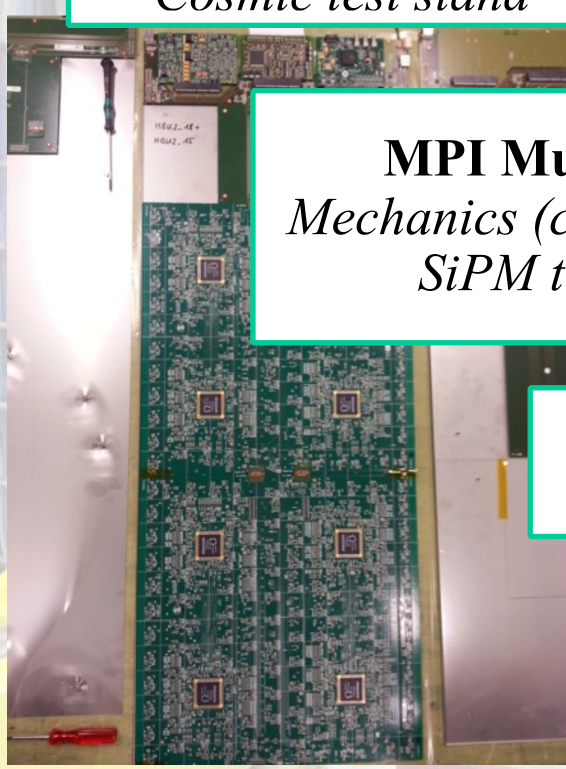
Uni. Hamburg
Tile & SiPM tests

Uni. Heidelberg
Tile & SiPM tests

Uni. Mainz
DAQ, assembly
Cosmic test stand

DESY in leading role
Electronics & mechanics design
Commissioning
Testbeam software
Testbeam coordination

Uni. Sussex
Monitoring



MPI Munich
Mechanics (cassettes),
SiPM tests

All institutes
Analysis of data

Lebedev I
Tile production

Omega (IN2P3)
ASICs

Prague
DAQ

R&D contribution from additional partners

Shinshu Uni, Tokyo Uni (Japan)
JINR, Dubna, MEPHI (Moscow)
UT Arlington, Northern Illinois Uni (USA)

CERN
Tungsten structure,
test beam, logistics

Strategy

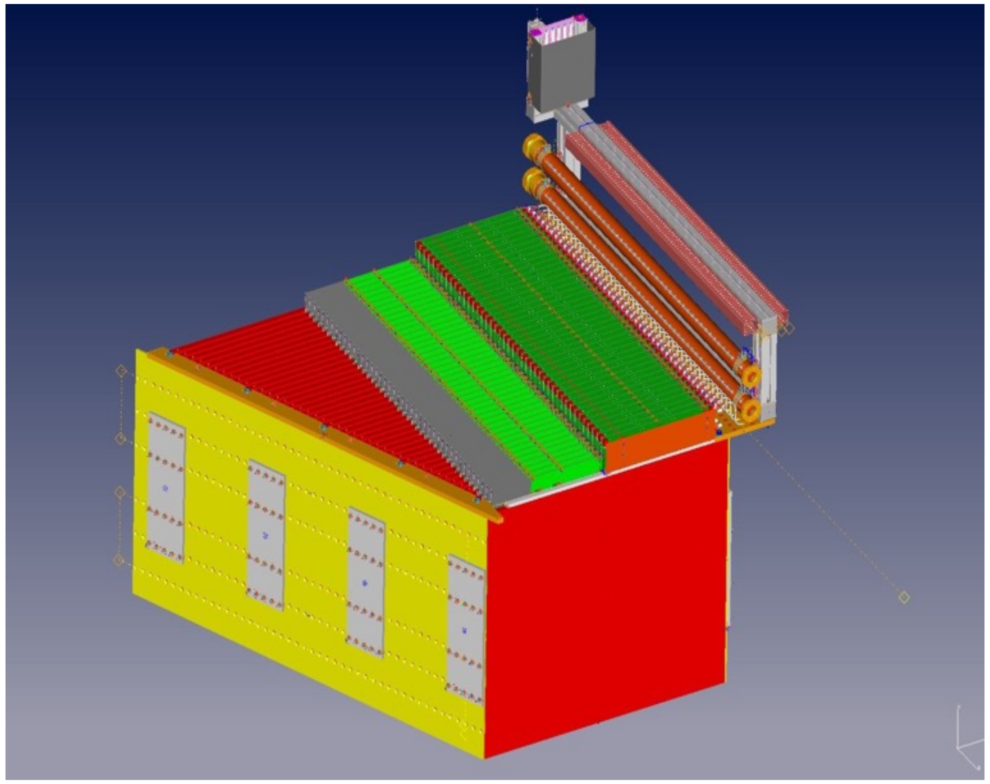
- From one single HBU to full AHCAL stack

- Component test
- Assembly procedure
- Commissioning

15 layers of 1 HBU
electrons

- System integration
- Cooling, power consumption
- Data quality monitoring
- Feedback to:
    - hardware component
    - calibration, temperature compensation
    - performance

40 (or 48) layers of 2x2 HBUs
hadrons



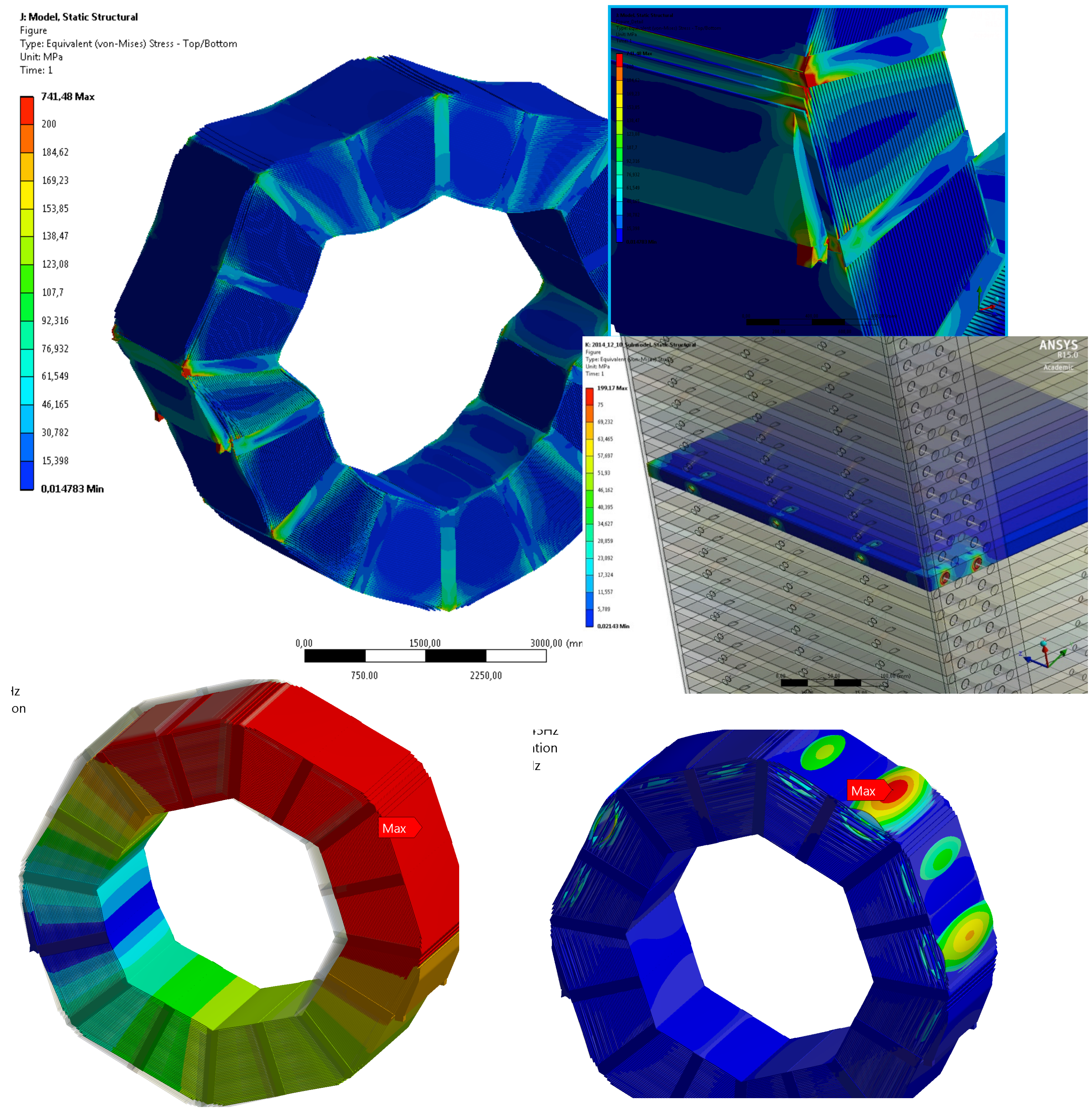
- System test
    - Large-scale electronics assembly
    - Scalability to full detector
- Rich physics program
    - Hadron performance

Timeline

Task	2016	2017	2018	2019
Tests with small stack	DESY			
Component production and commissioning				
Tests with partly equipped hadronic stack			CERN	
Tests with fully equipped hadronic stack				CERN

Mechanics

- HCAL structures for particle flow: roof-top size, furniture-type tolerances
    - Challenge for FEM calculations
- Validation of static stability done
- Dynamic simulation of earthquake scenarios on the way
- Worst case w.r.t. smaller or coarser structure



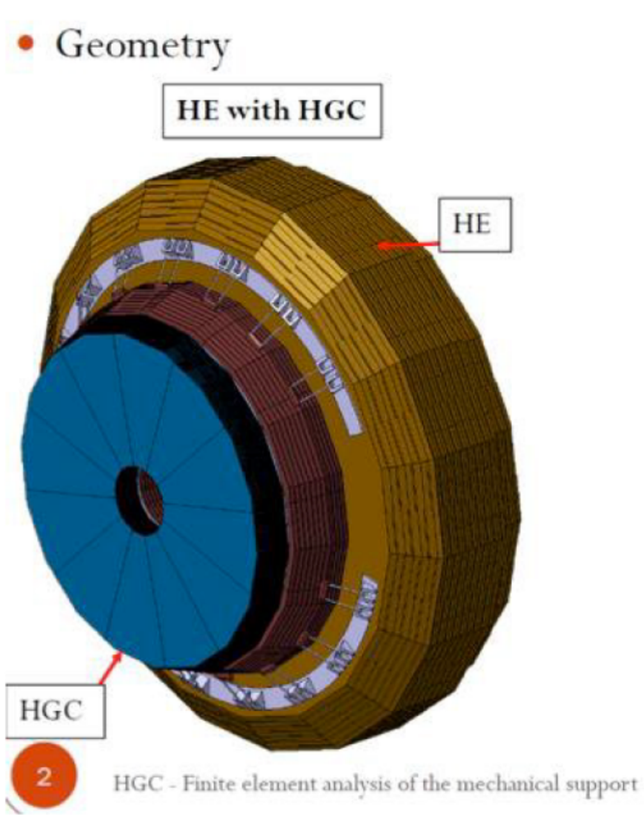
Applications in the CMS HGCAL upgrade

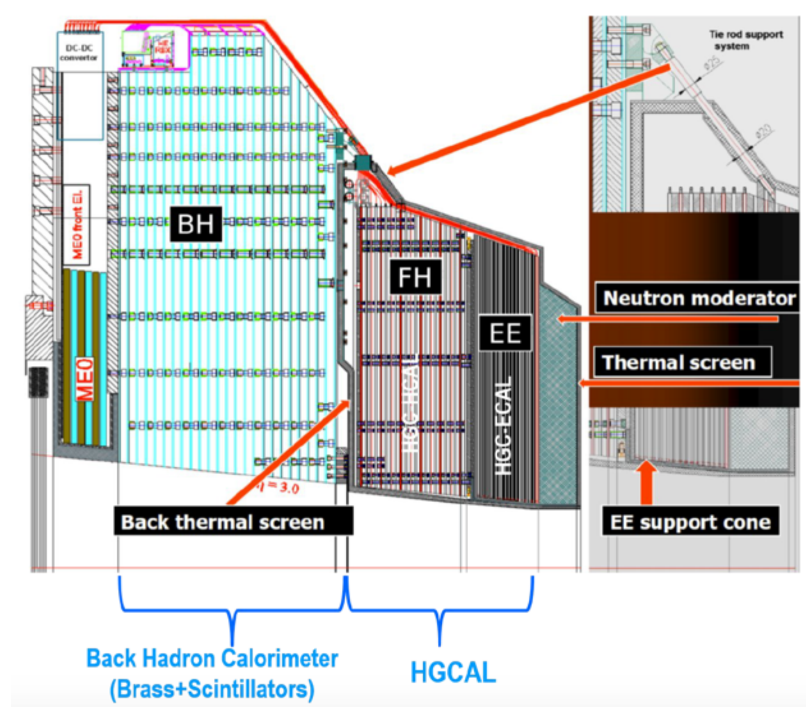
- Success of CALICE highly granular calorimeters inspired CMS phase II upgrade project
- Phase II upgrades of LHC experiments face many challenges (high pile-up, irradiation,…)
  - ➢ Need good spatial resolution ➢ highly granular detectors
  - ➢ Timing separation between vertices can improve detector performance ➢ detectors with good timing resolution

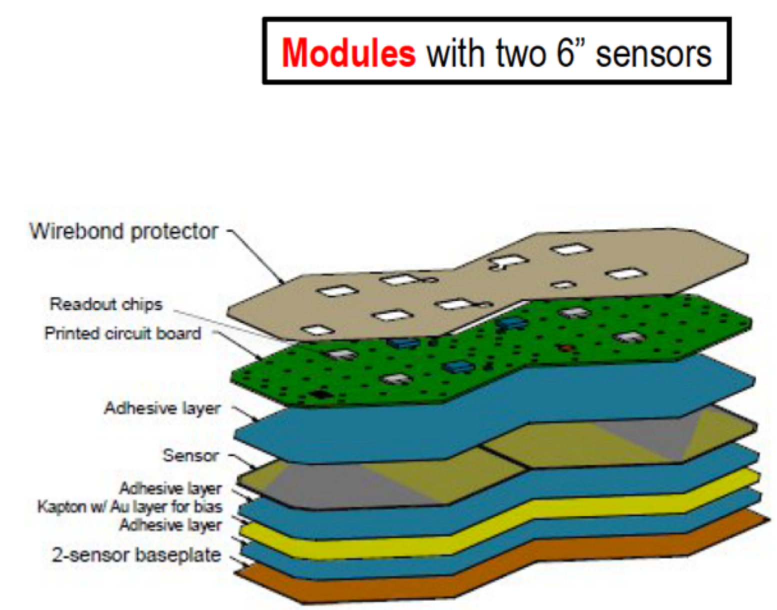
CMS: High Granular Calorimeter (CMS-HGCAL)

Phase II upgrades of CMS detector involves CALICE-developed technologies

- EE, FH: silicon wafer; **BH: scintillator-SiPM technology**
- **New readout chip (SKIROC2-CMS)** being prepared by Omega+LLR







Summary & Outlook

- DESY Linear Collider group plays key role in the worldwide ILC effort
  - AHCAL is strong pillar in the DESY effort
- Scintillator-based HCAL with SiPM read-out for a future LC collider made significant progress in the past years, both in technological components and system integration
- We are capable of building and operating a new prototype
  - Built in 2017, put in beam in 2018
- AHCAL effort is the largest ILD activity in Germany
  - DESY group maintains its leading role as coordinator and integration centre
  - Development of technological prototype as well as integration scheme of AHCAL into ILD

Back-up slides

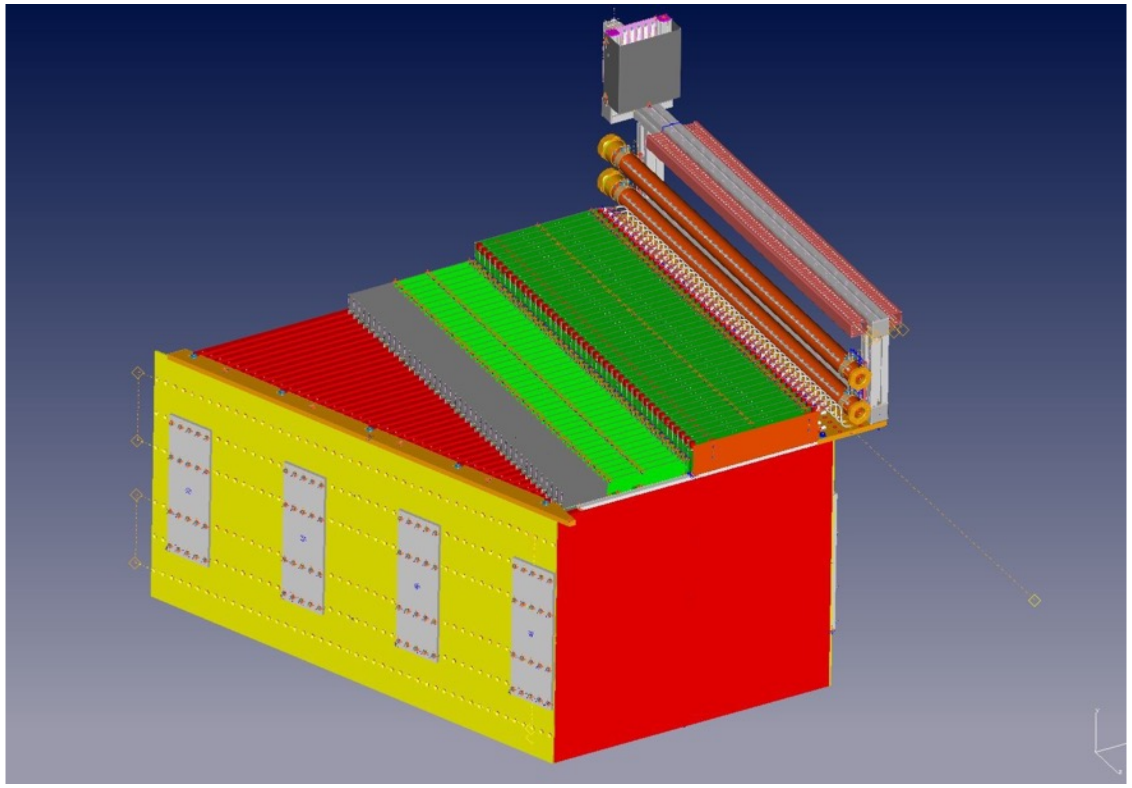
AHCAL technological prototype

Strategy: improvement in components and assembly procedures

- ***Development of components*** with fully integrated design
  - Front-end electronics, readout
  - Voltage supply, LED system for calibration
  - No cooling within active layers
  - *Improvement in assembly procedure*: mass production
    - SiPM sensitive to blue light → no need for Wave Length Shifting fiber
    - Surface mounted SiPM (with corresponding tile design) to ease pick&place procedure
  - Commissioning procedure appropriate for full detector (8M channels)
  - Mechanically scalable: EUDET absorber structure designed for ILD
- ***Provide fast feedback during data taking***: sufficient monitoring and data acquisition system
- ***Physics analyses in parallel***:
  - Maintain/improve performance previously obtained with physics prototype
  - Important input to ILD performance study

Second generation technological prototype timeline

- **Small stack:** so far 15 layers, 2160 channels, all read out by recent SiPMs with good performance, 50% in latest surface mounted design
  - Re-establish performance of the technology under power-cycled operation, online zero suppression and temperature compensation
- **HCAL stack** will be instrumented in 2 steps, dictated by funding constraints
  - As minimum: 20 additional layers (12000 channels) necessary, with existing modules achieve more than 50% of instrumentation capability
  - For competitive performance: fully equipped stack with at least 40 (better 48) layers



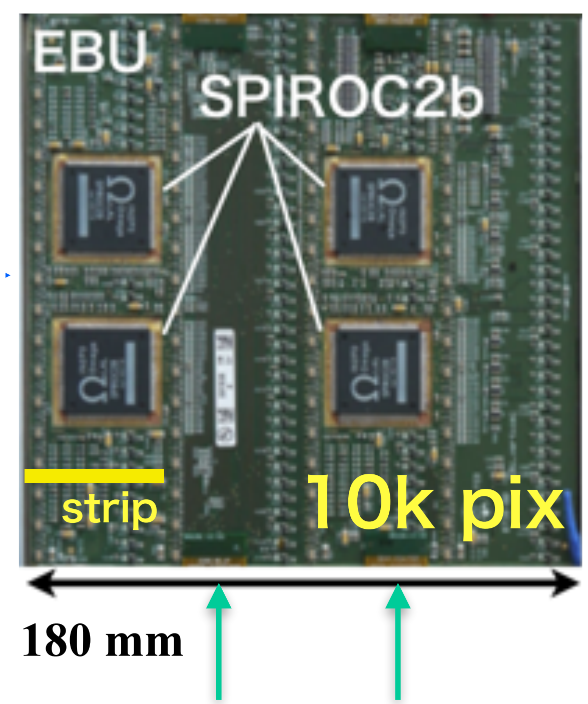
EBUs

- Two readout geometries:

New design

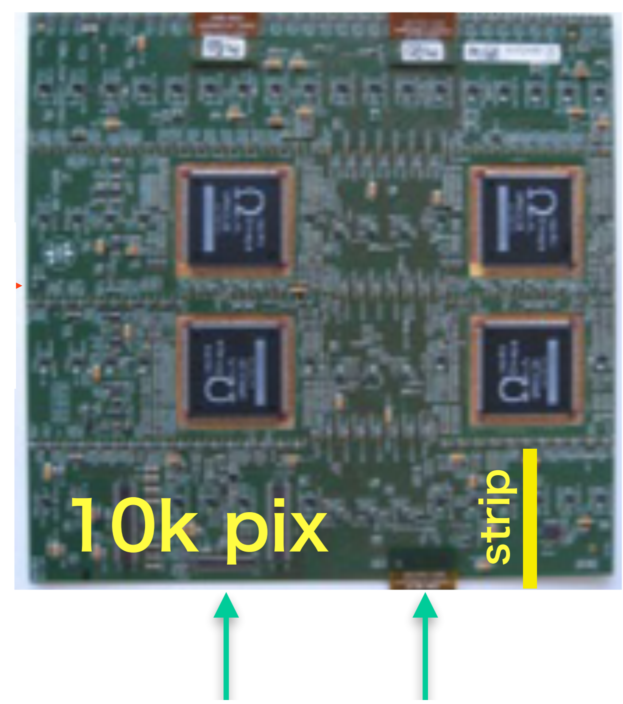
Baseline design

Bottom readout
Transverse EBU



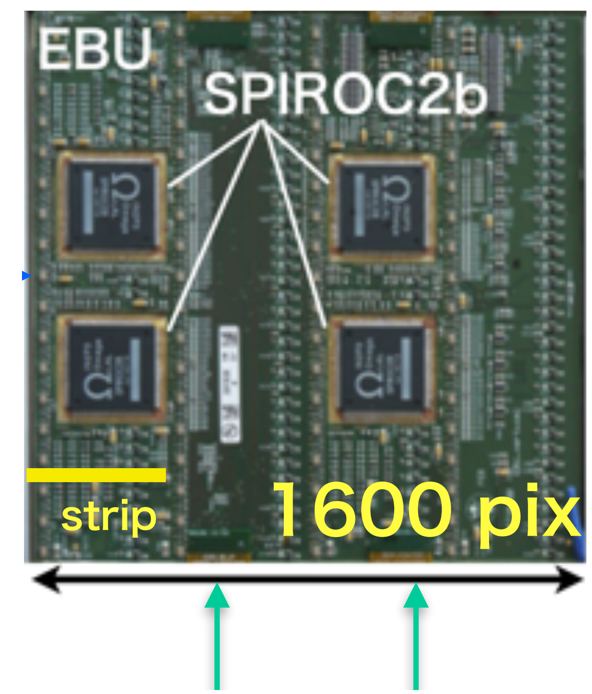
Flex-leads

Baseline readout
Parallel EBU



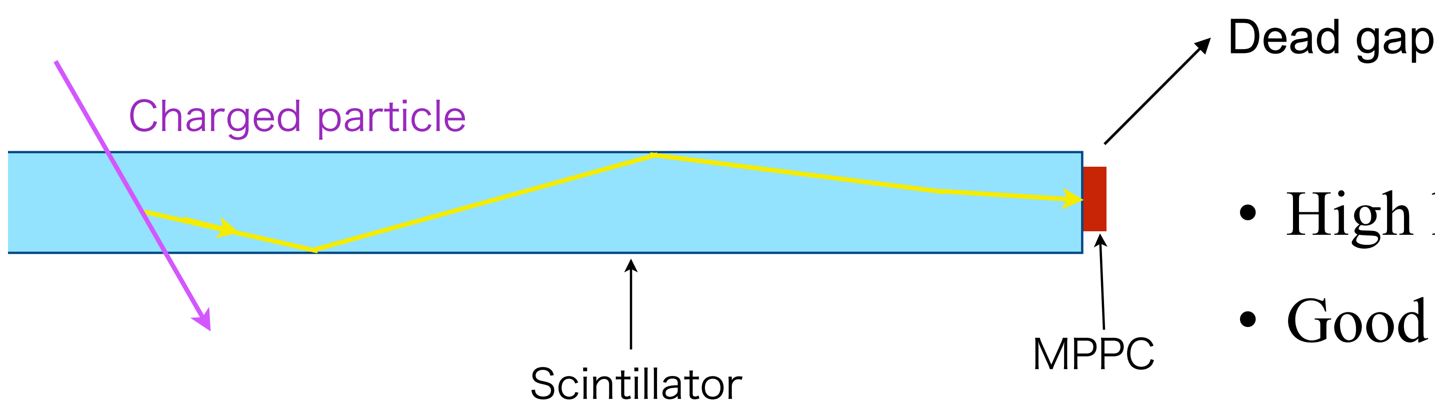
Flex-leads

Baseline readout
Transverse EBU



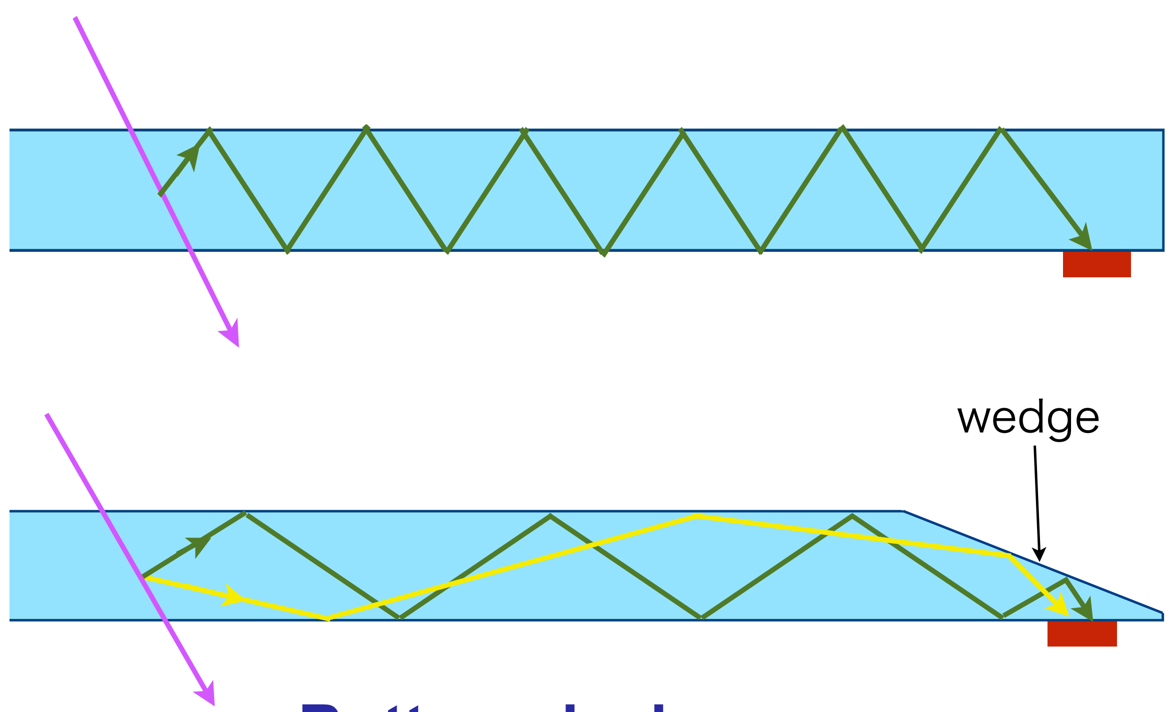
Flex-leads

EBUs



Baseline design

- High light yield (less number of reflections)
- Good uniformity
- Issues due to MPPC installation

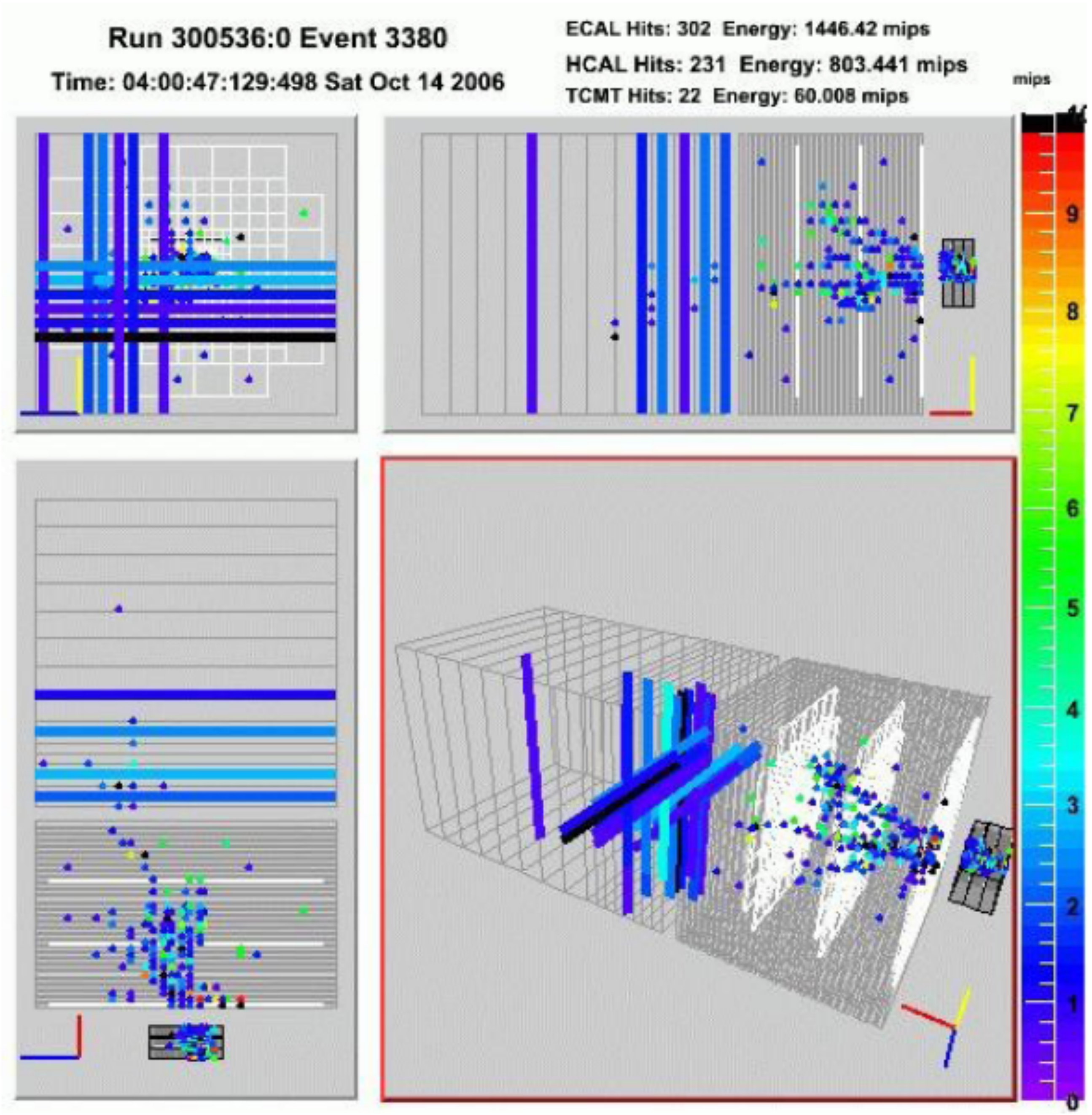


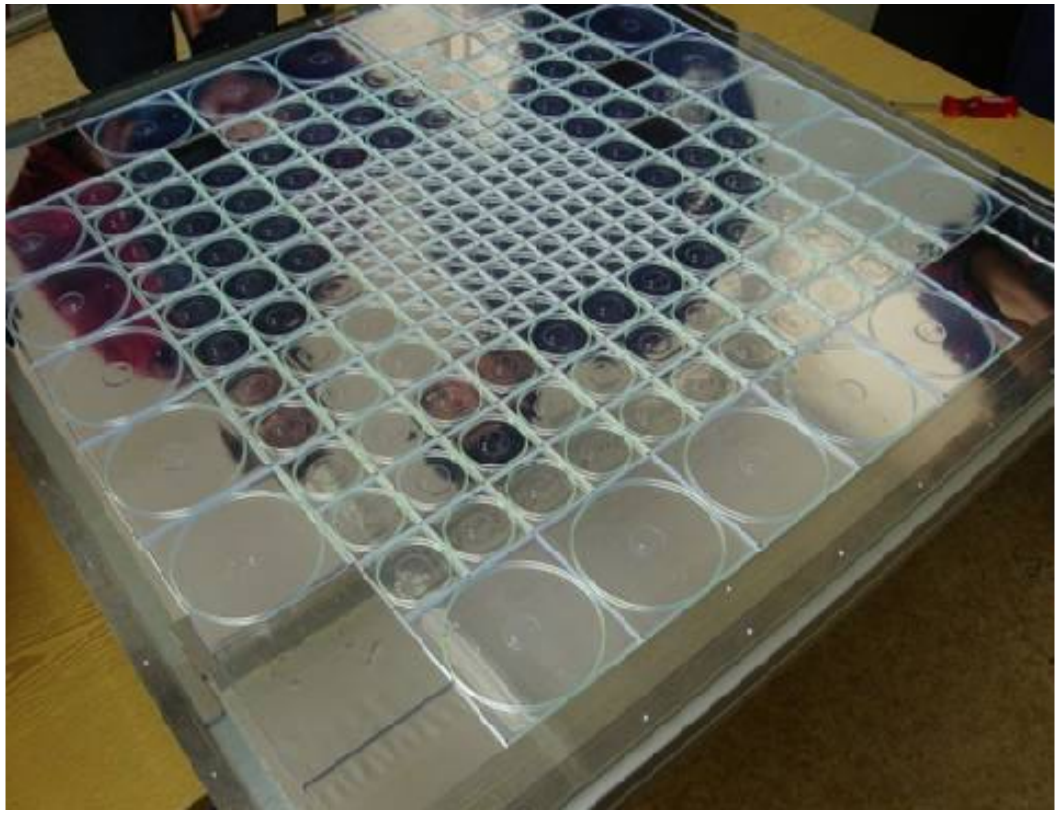
Bottom design

- Gapless layout possible
- Wedge shape: prism to guide light to SiPM helps recover light yield
- Shorter path length for particle going through part near MPPC ➢ recover uniformity

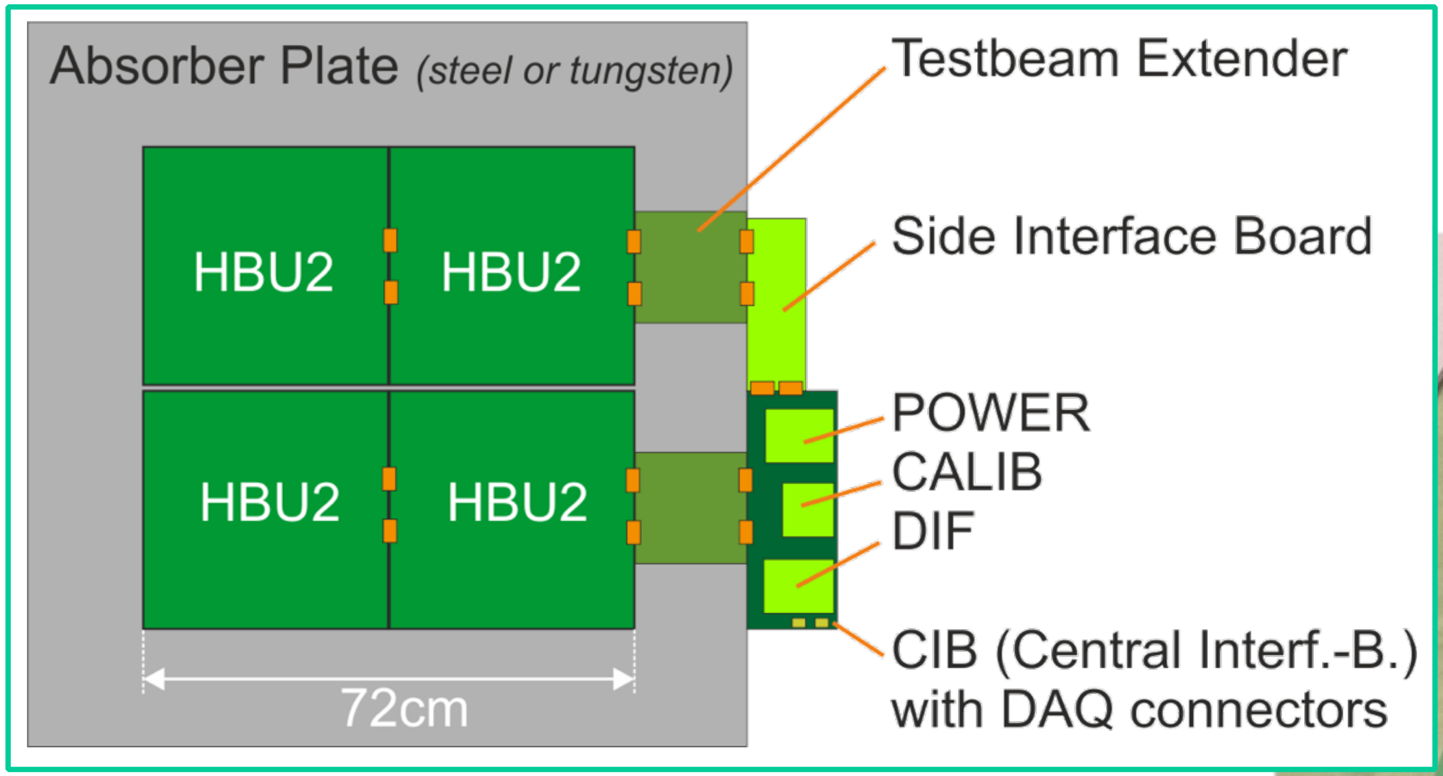
AHCAL physics prototype

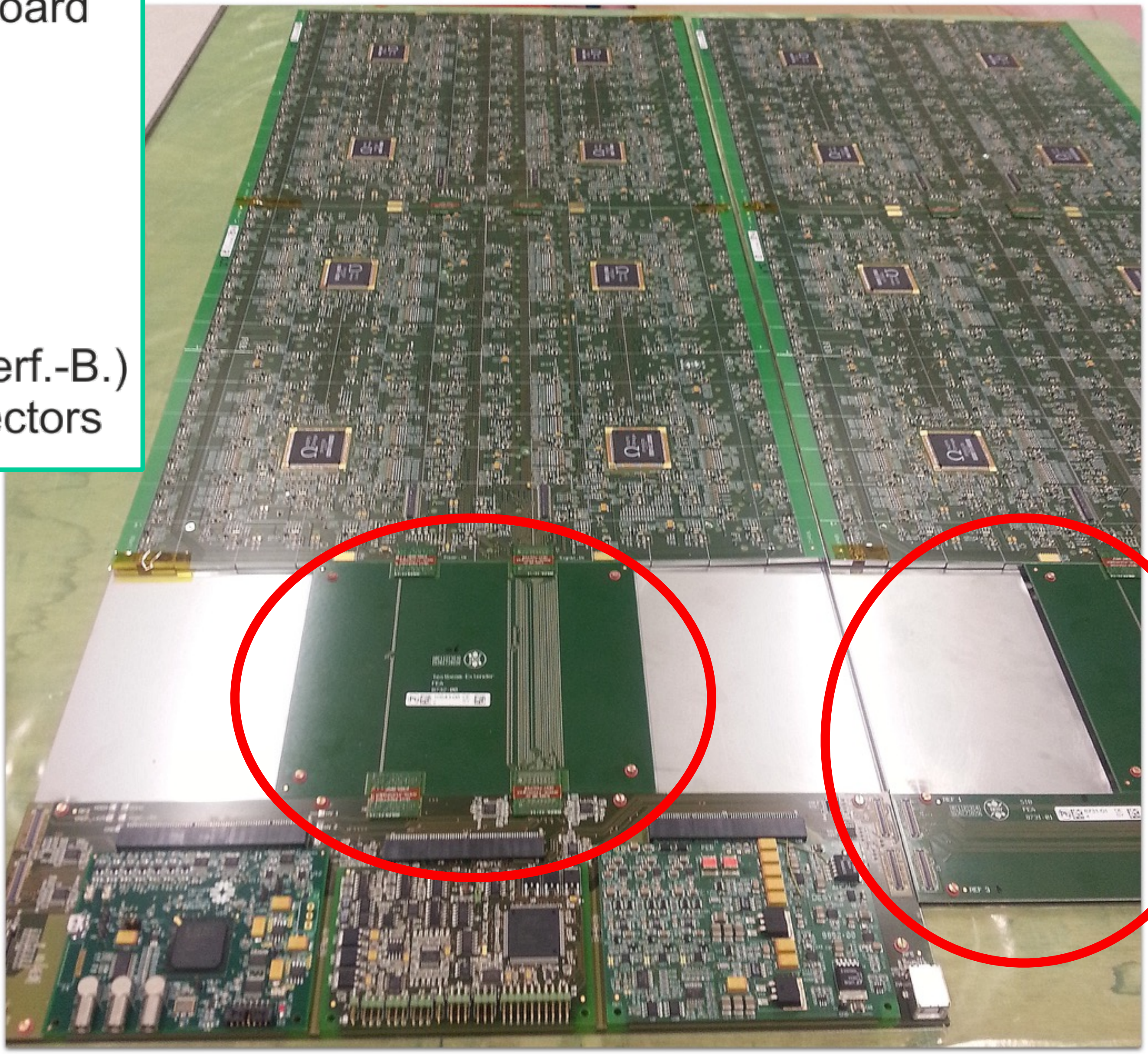
- ✓ 1m^3 physics prototype used in different testbeams 2006-2012





AHCAL technological prototype - Extender boards





- Specifically for next testbeam
  - Extender boards for EBUs
  - Extender boards for HBUs
- Side Interface Board (SIB)
  (for ILD as well)