Linear Collider Calorimetry

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CALICE
Calorimeter for ILC

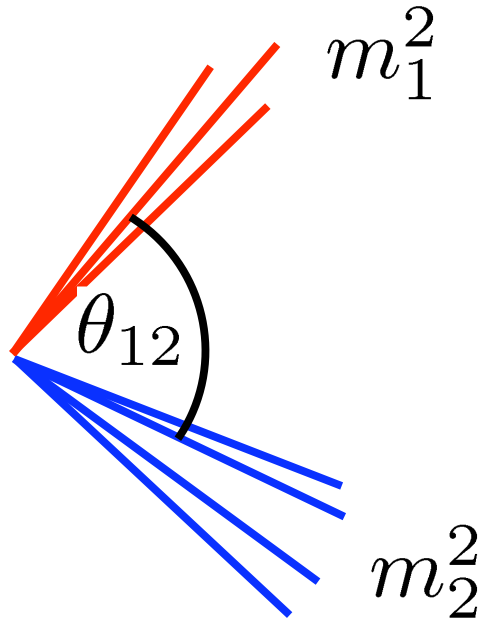
TUM
LMU
Excellence Cluster
Universe

Overview

- Motivation: Requirements for Jet Energy Reconstruction at a LC
- Particle Flow & Imaging Calorimeters
- The CALICE Test Beam Program, Results
- Selected Activities within the Alliance
- The Next Generation

Jets at a Linear Collider: Requirements

- Di-jet mass resolution is guaranteed to be important at a future collider

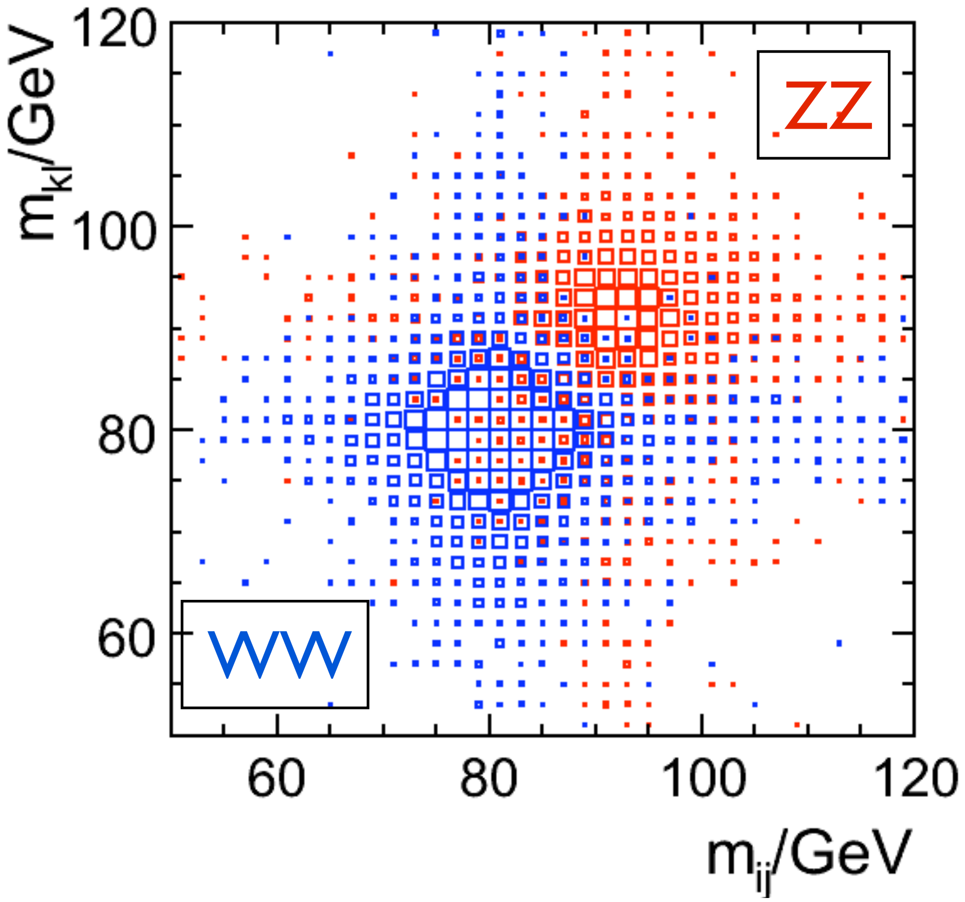


Typical case:
A narrow resonance decaying into quark pairs

Significance: $\propto \frac{S}{\sqrt{B}} \propto \frac{1}{\sqrt{\sigma(M)}}$

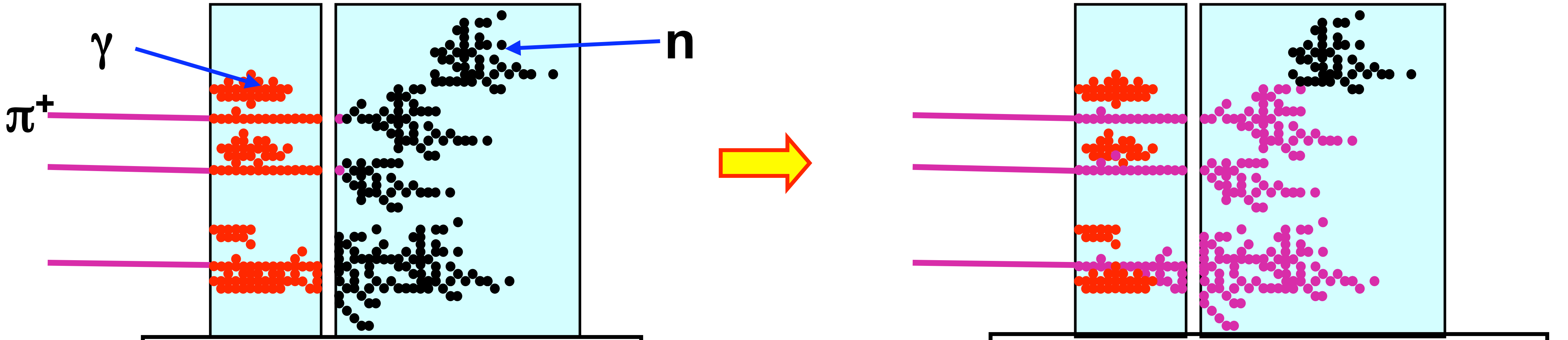
Minimum requirement:
Separate gauge bosons (W and Z)

➩ Jet energy resolution of 3.5% or better
(x2 better than ATLAS, x3 better than LEP)



Particle Flow: Unprecedented Jet Energy Resolution

- A simple idea: Measure each particle in a jet with the best possible precision



$E_{JET} = E_{ECAL} + E_{HCAL}$

$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

Particle Flow: Unprecedented Jet Energy Resolution

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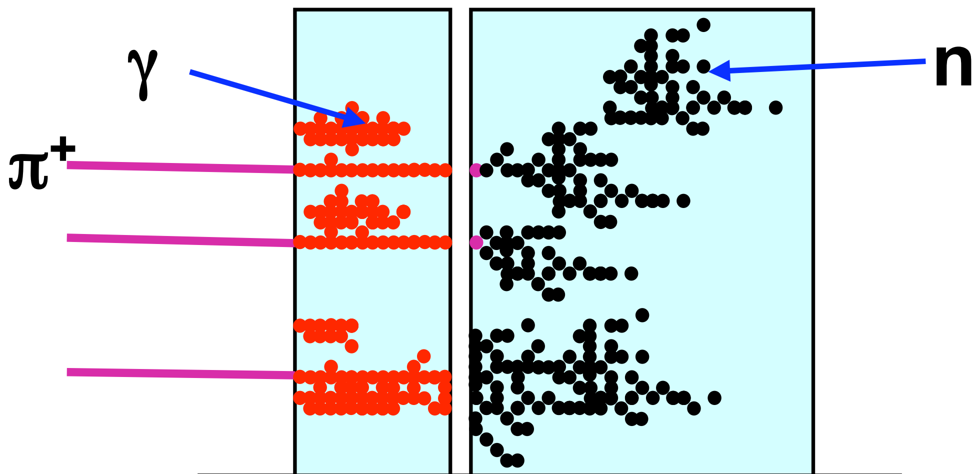

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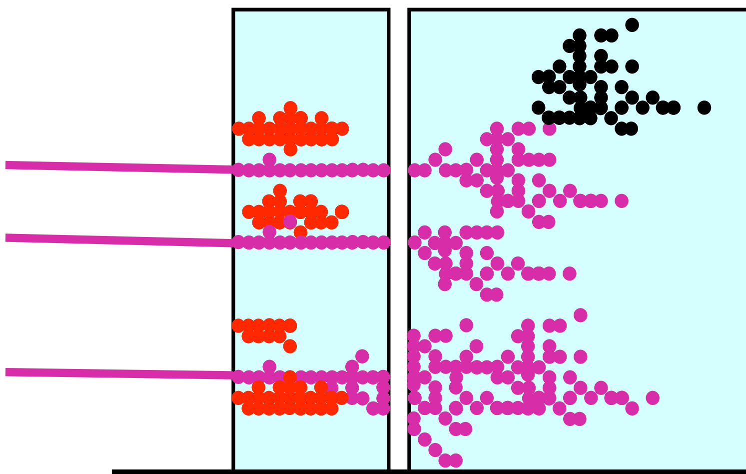
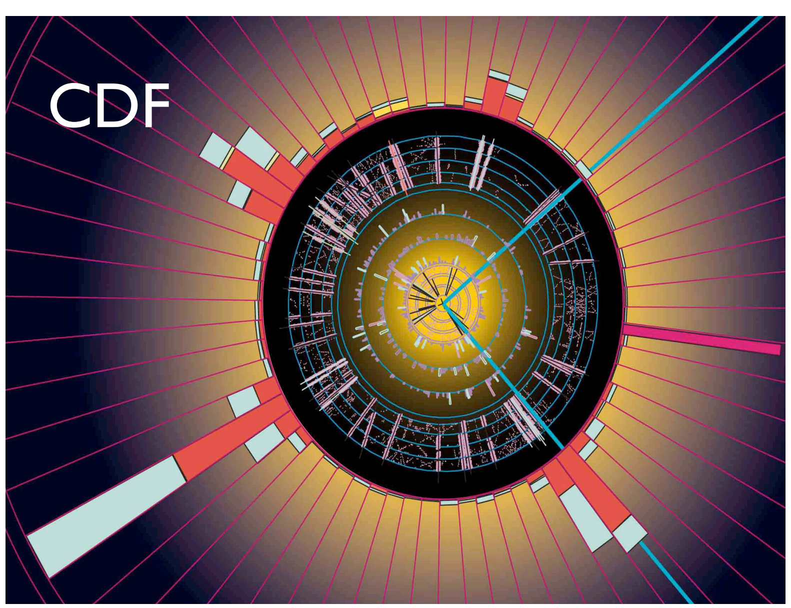


$$E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$$

- A challenging concept: Requires separation of particle showers in the calorimeters



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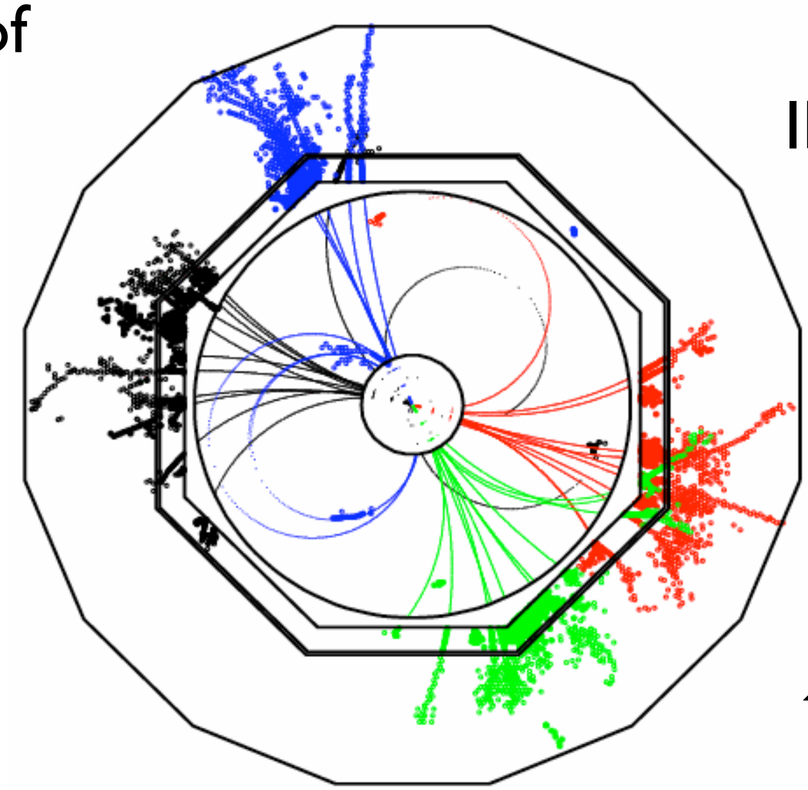

ILD

to this!

Imaging Calorimeters: A Requirement of PFA

- Extreme granularity needed in the calorimeters
  - ECAL: Cell size < Moliere Radius, longitudinally < 1 X_0
  - HCAL: Cell size ~ Moliere Radius, longitudinally ~ 1 X_0
- Explosion of the channel count:
  - ~ 100 M channels for a full ECAL
  - ~ 10 M channels for a full HCAL

Factor 1000 more than typical LHC calorimeters!

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Factor 1000 more than typical LHC calorimeters!

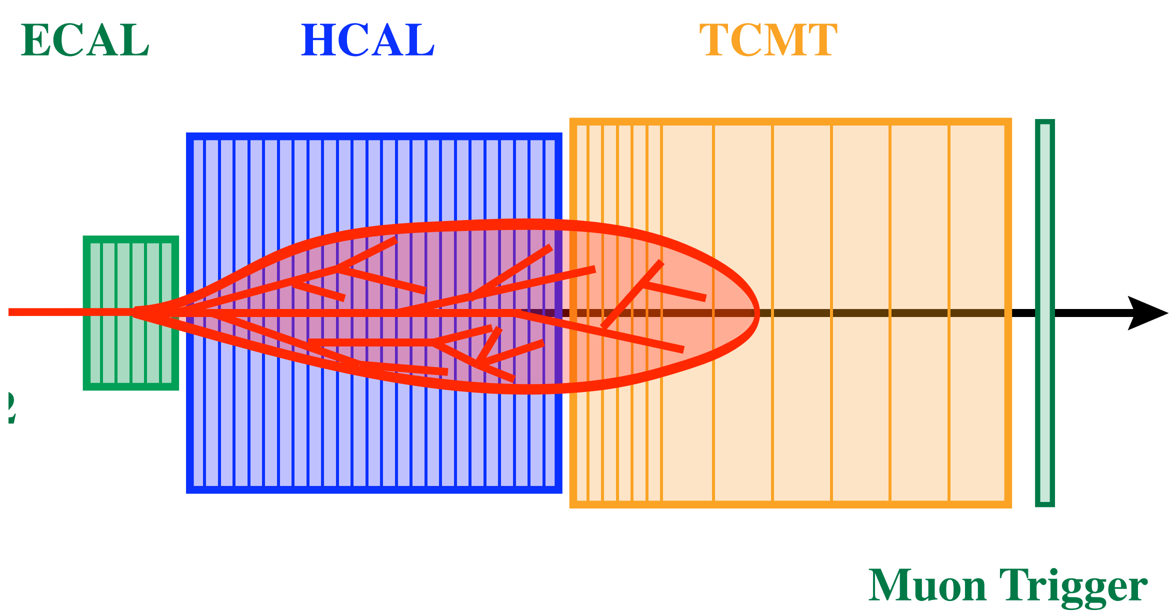
Needs a proof of principle!

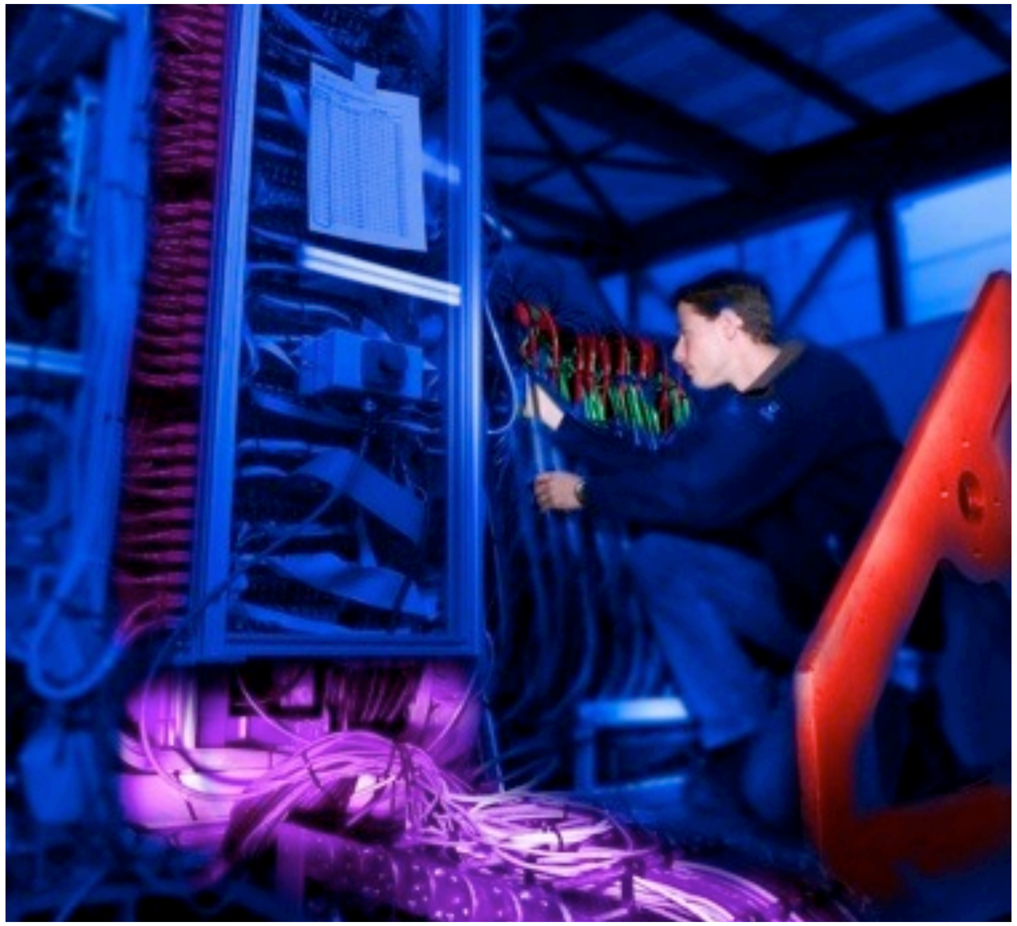
Crucial questions:

- Can such detectors be built, do they perform as expected?
- Can we trust the simulations (crucial for the evaluation of PFA)?
- What reconstruction techniques are possible (software compensation, particle ID,...)?
- Can such detectors be calibrated and operated in a stable mode?
- What are the relative merits of different readout technologies?

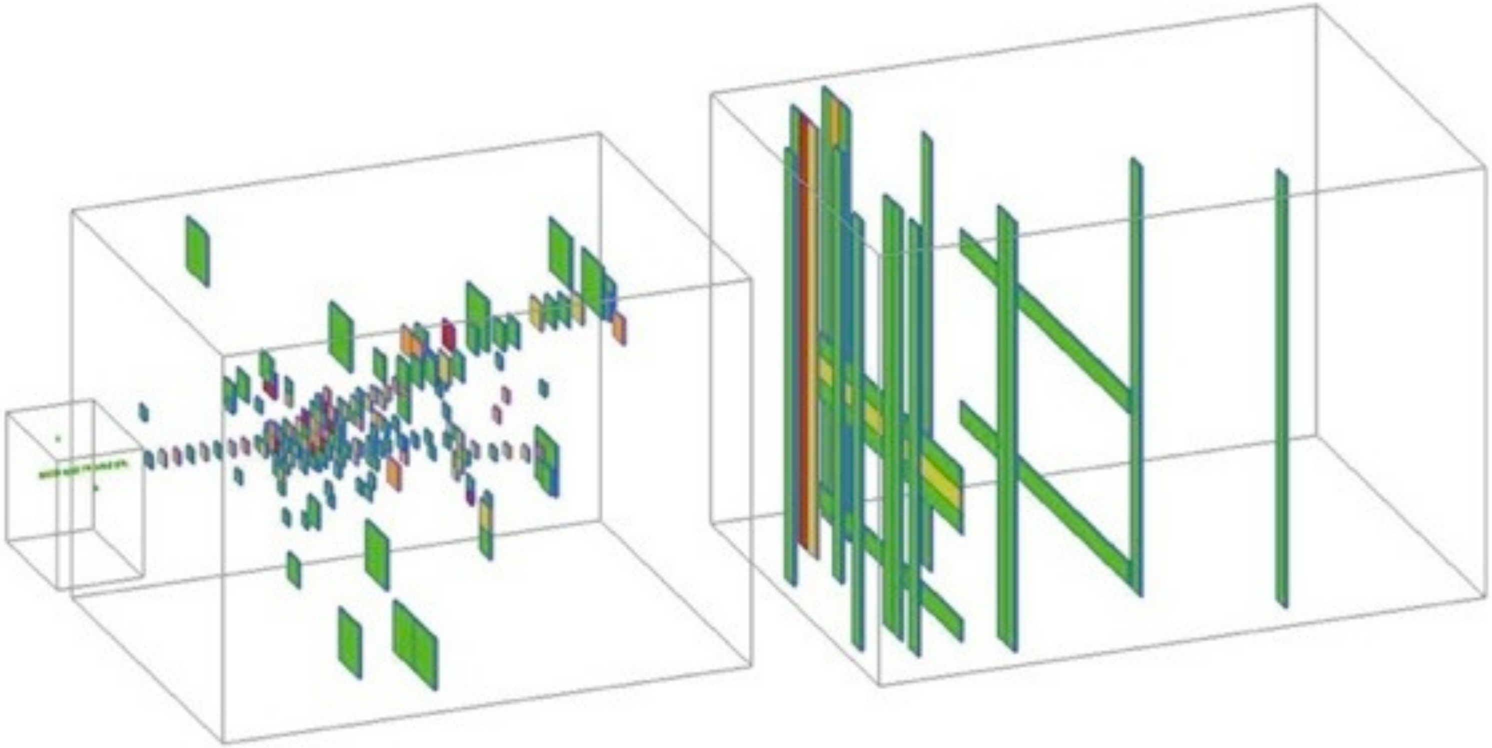
Answers provided by an extensive test beam program!

CALICE: Testing Imaging Calorimeters



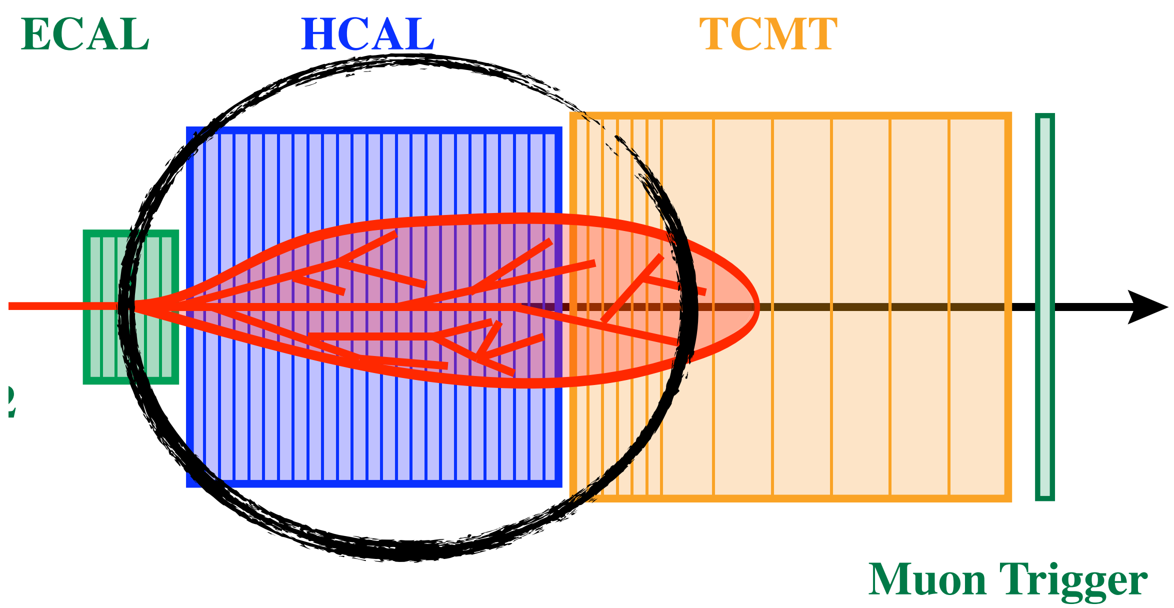


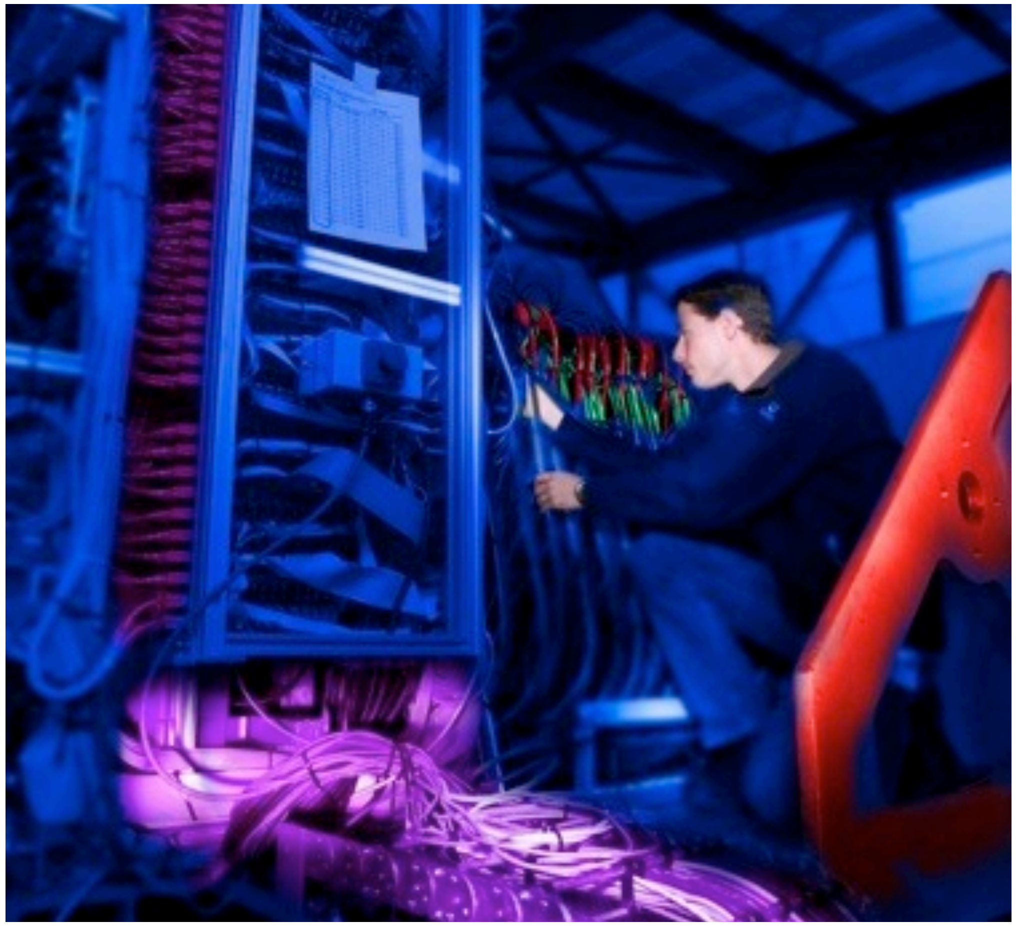
Extensive program:
2006 DESY, 2006/7 CERN, 2008/9 FNAL
Coming up: Tests at FNAL and at CERN



CALICE: Testing Imaging Calorimeters

PHYSICS AT THE TERA SCALE
Helmholtz Alliance





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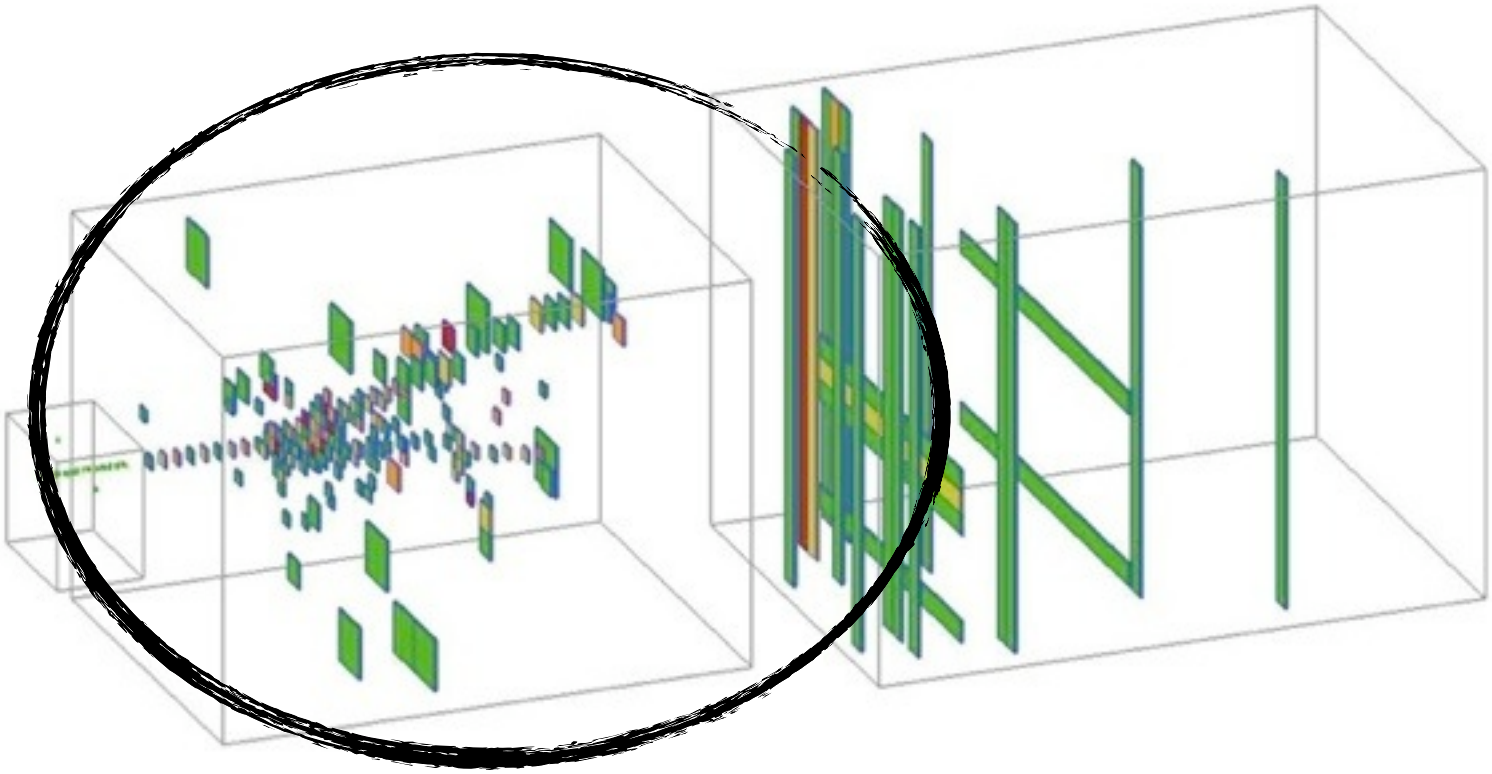
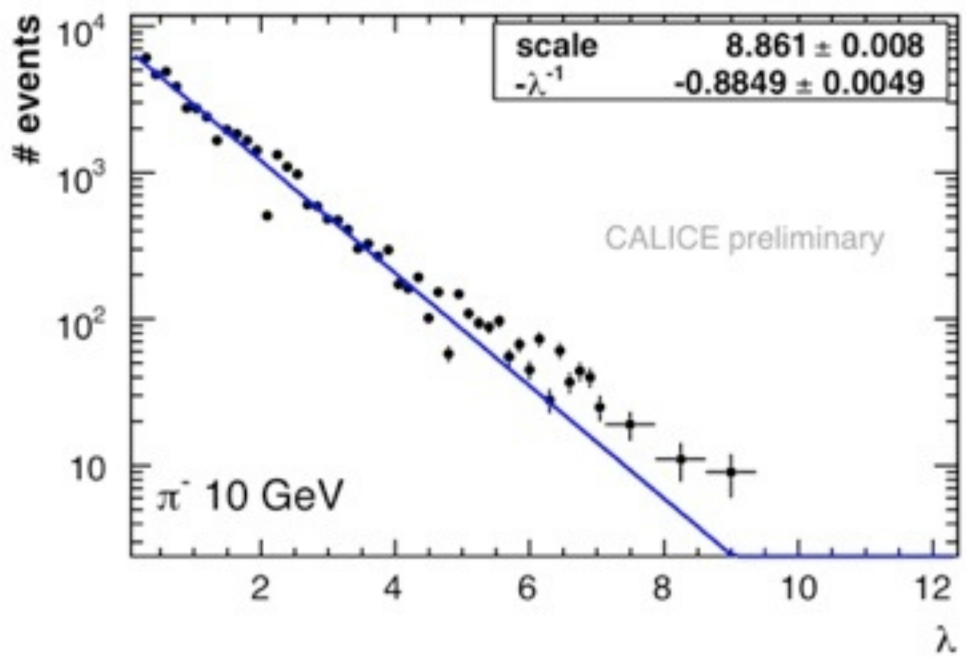
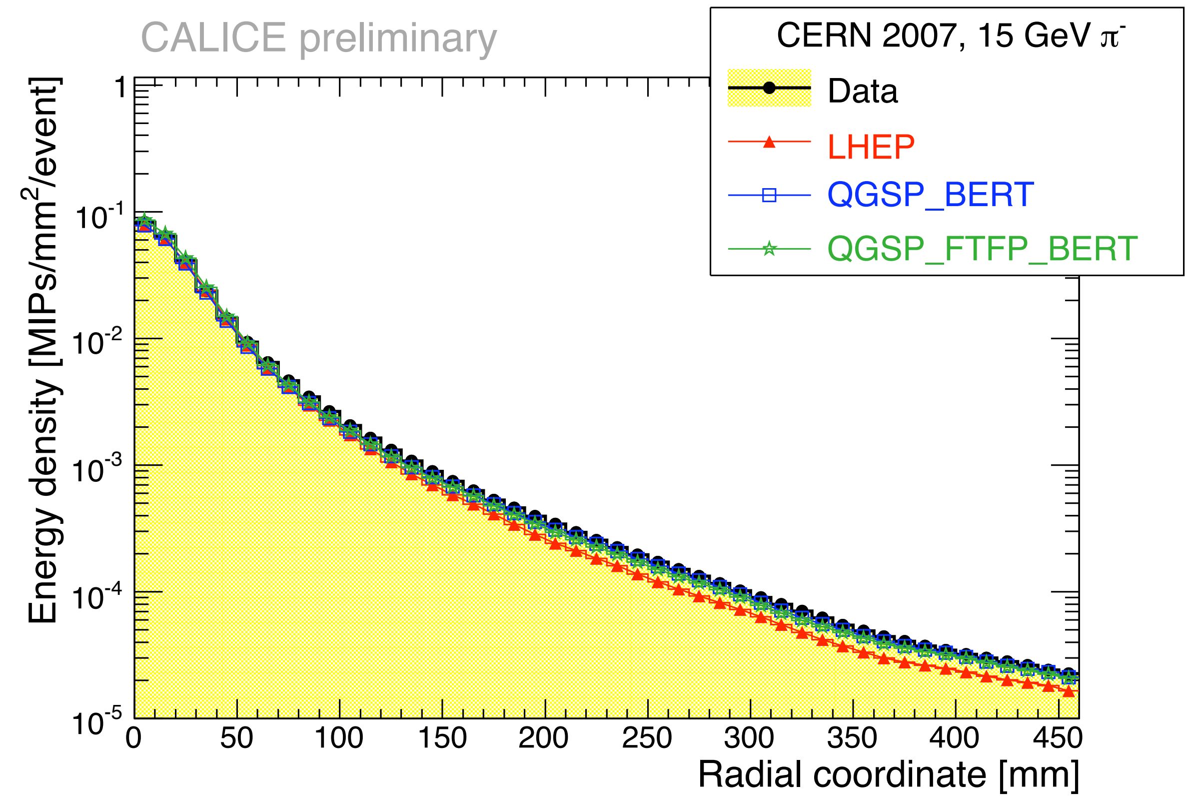


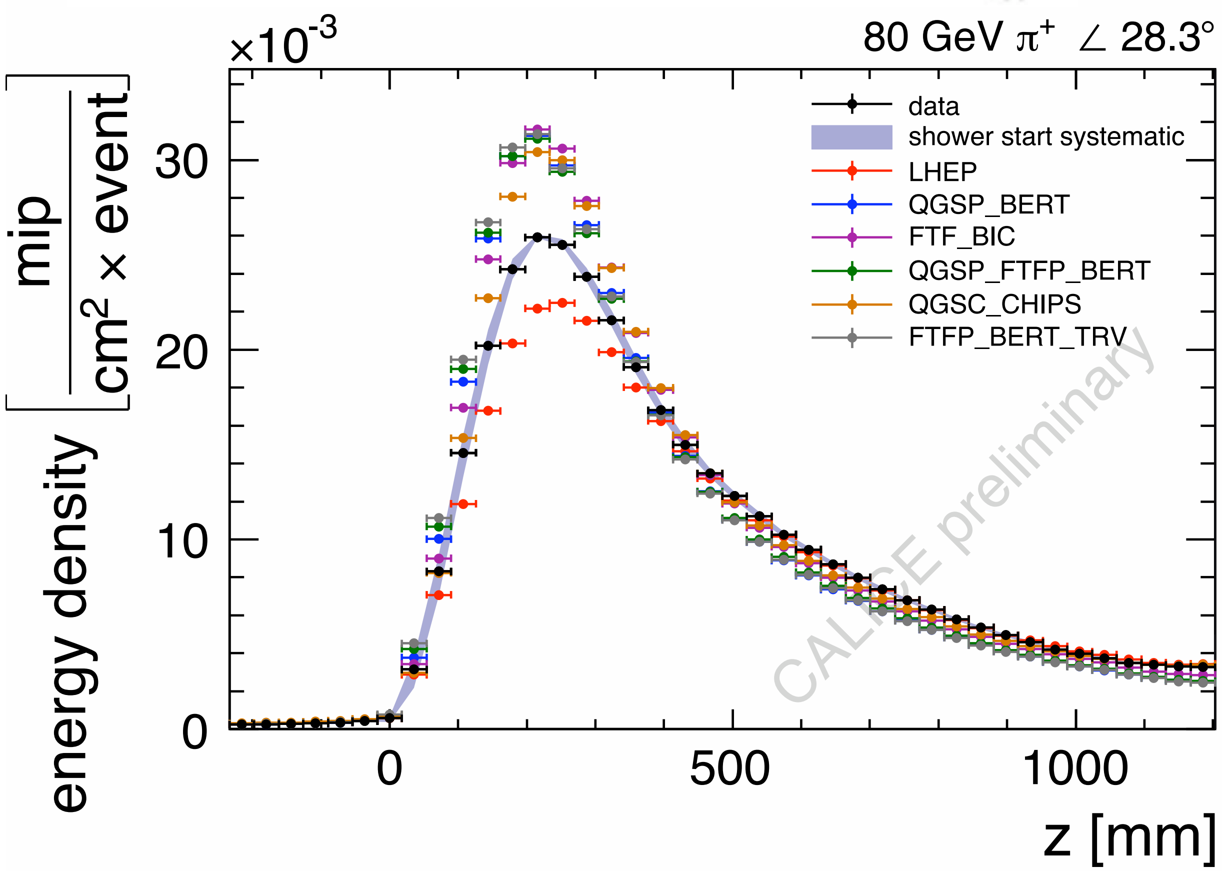
Focus in Germany:
Analog Hadron Calorimeter:
3 x 3 cm^2 scintillator tiles read out by silicon photomultipliers,
all groups involved in various aspects of data analysis

Test Beam Results: Detailed Shower Profiles

identify the starting point of each shower







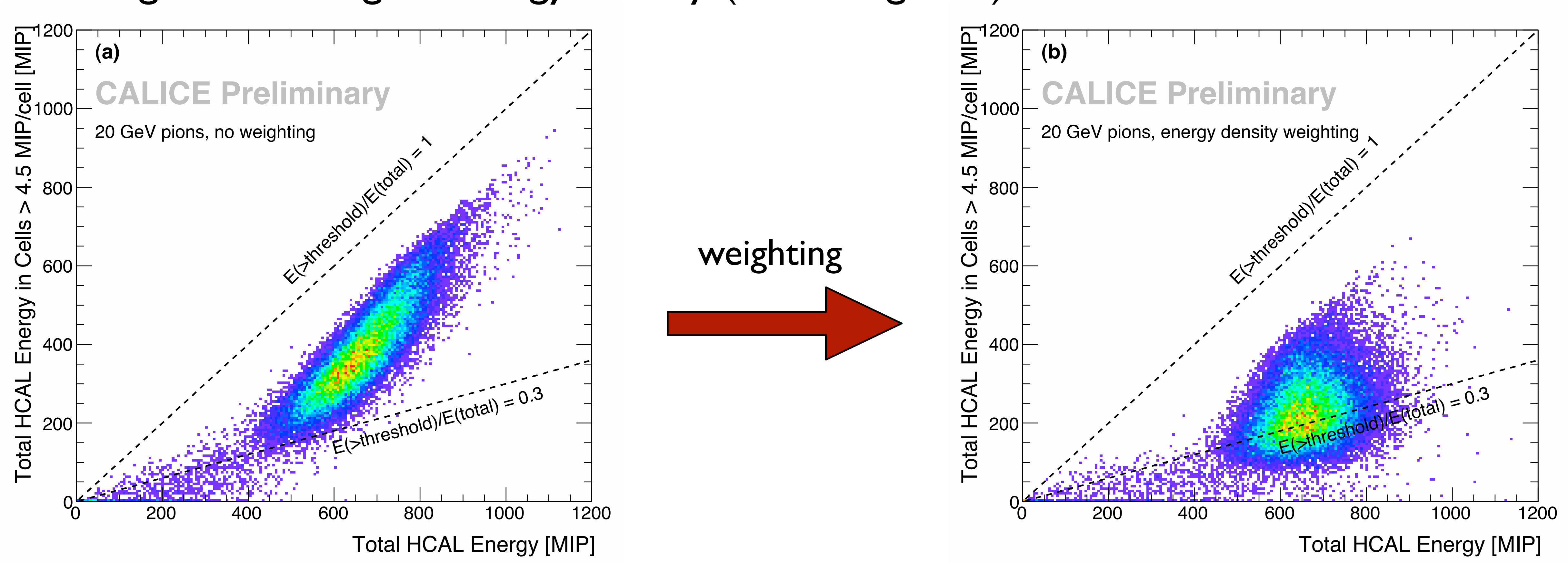
radial profile for pion shower in the AHCAL

longitudinal profile for pion shower in the AHCAL, relative to shower start

- Validate simulations, provide input for physics list developers

Test Beam Results: Software Compensation

- Improved energy resolution helps, also with PFA
  - Use granularity to identify electromagnetic and hadronic shower components
  - Weight according to energy density (local or global)



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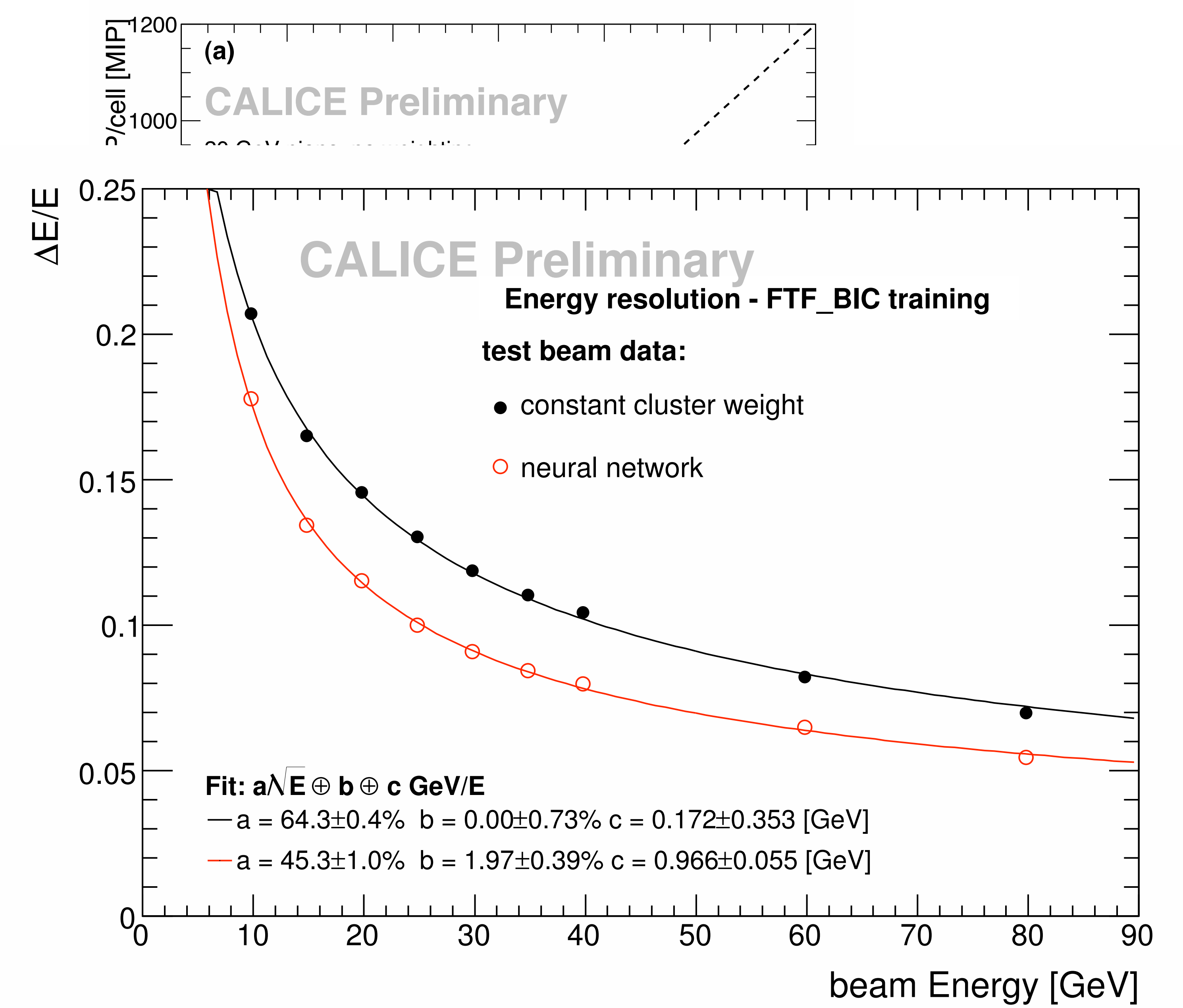
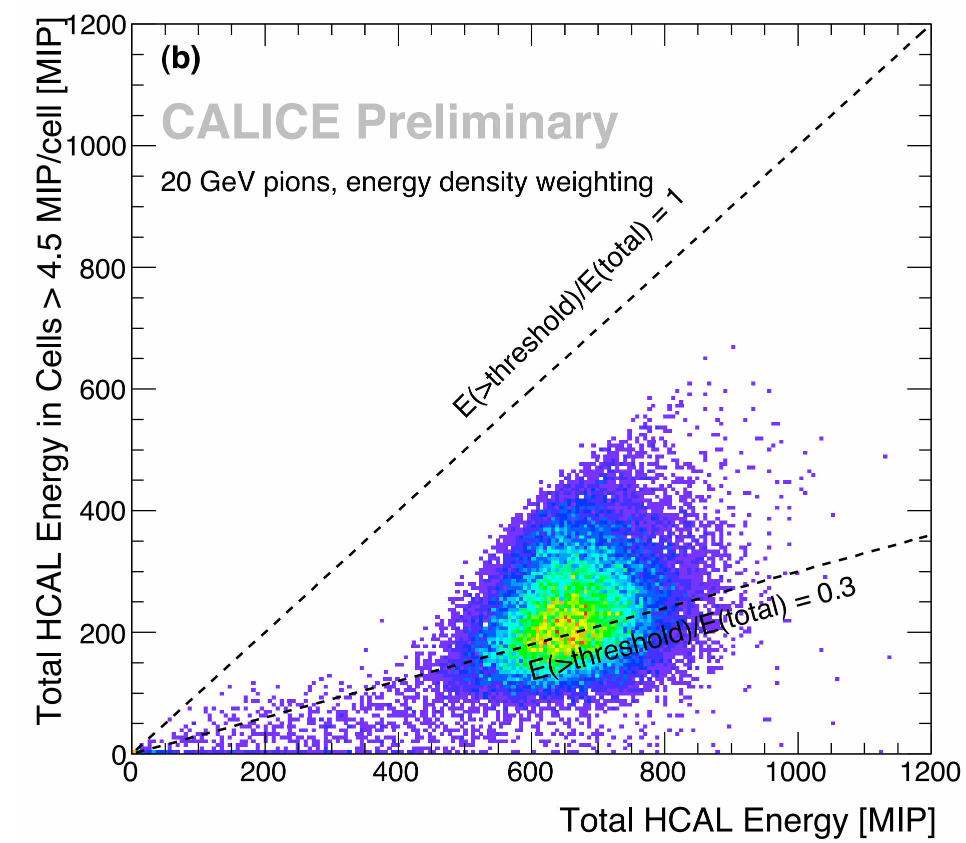
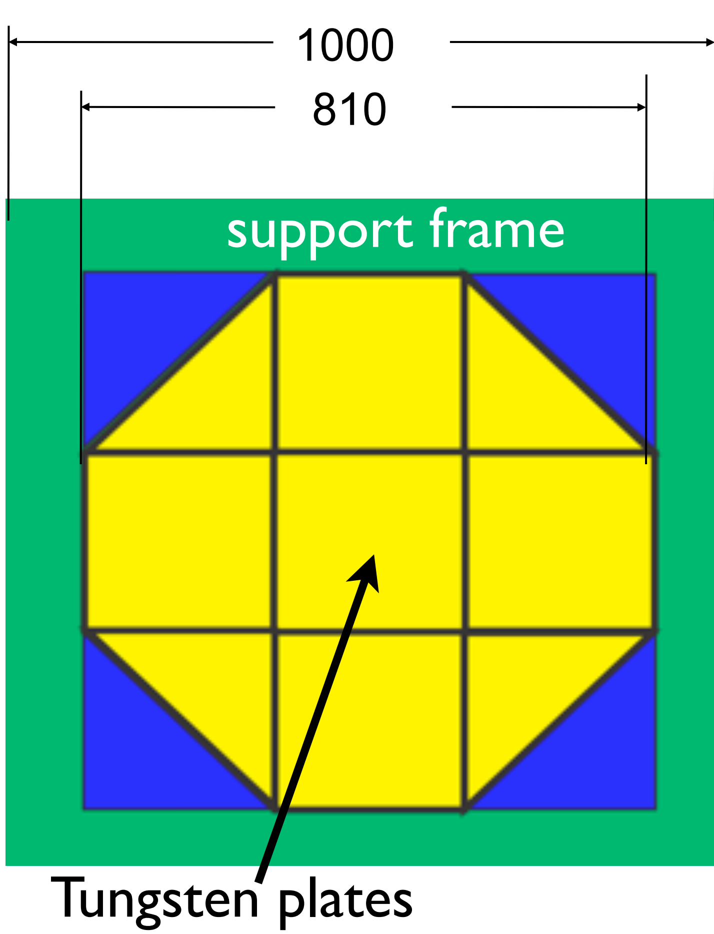




25% improved resolution with a global method using a neural net trained on simulations: Also a validation of the simulations!

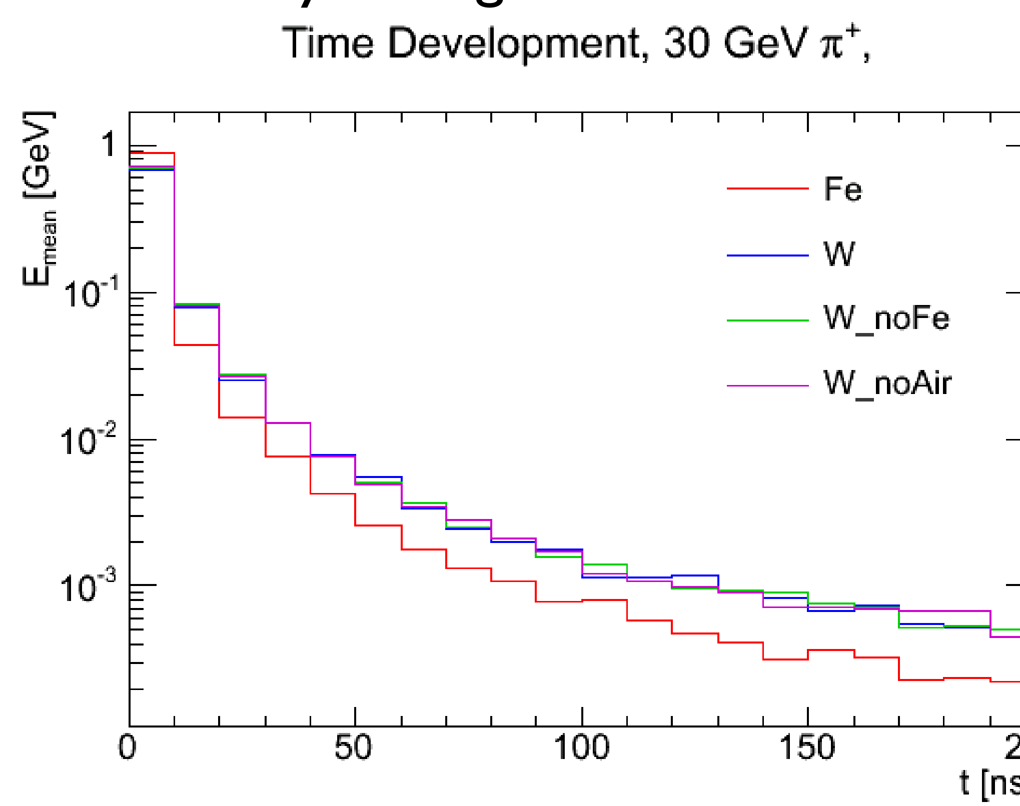
Upcoming Test Beams

- Fermilab, October 2010
  - Alternative technologies: Digital HCAL with RPC readout, Steel absorber from AHCAL physics prototype
- CERN, November 2010
  - Analog HCAL with tungsten absorber plates: Motivated by requirements for a deeper HCAL at CLIC: High energy jets require more material for containment



active layers from physics prototype

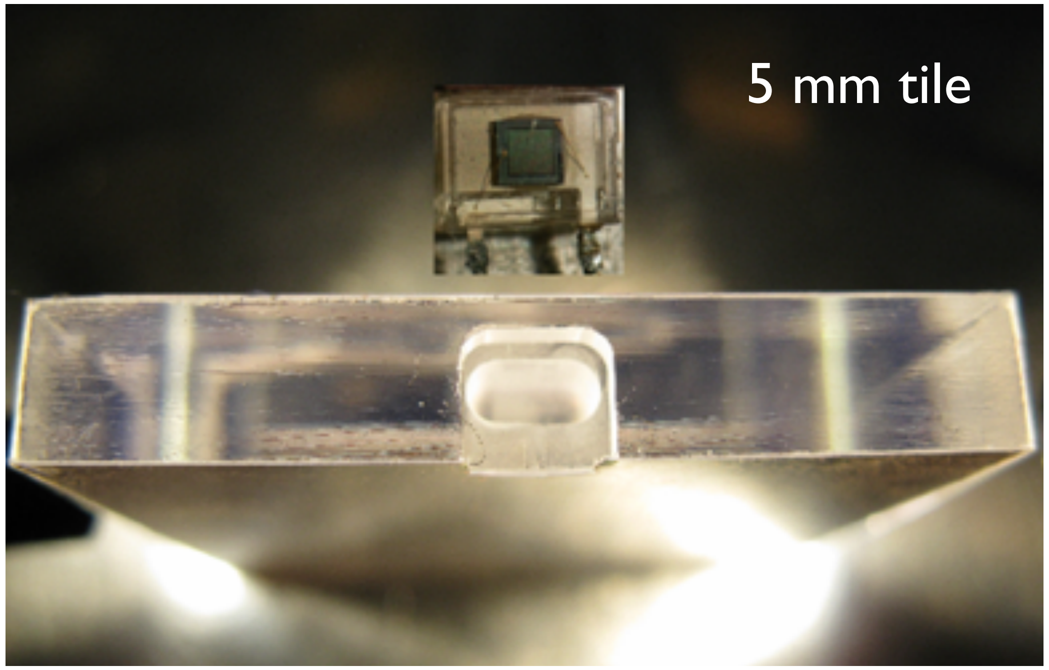
Different time structure: more late energy deposits ➯ Study timing!

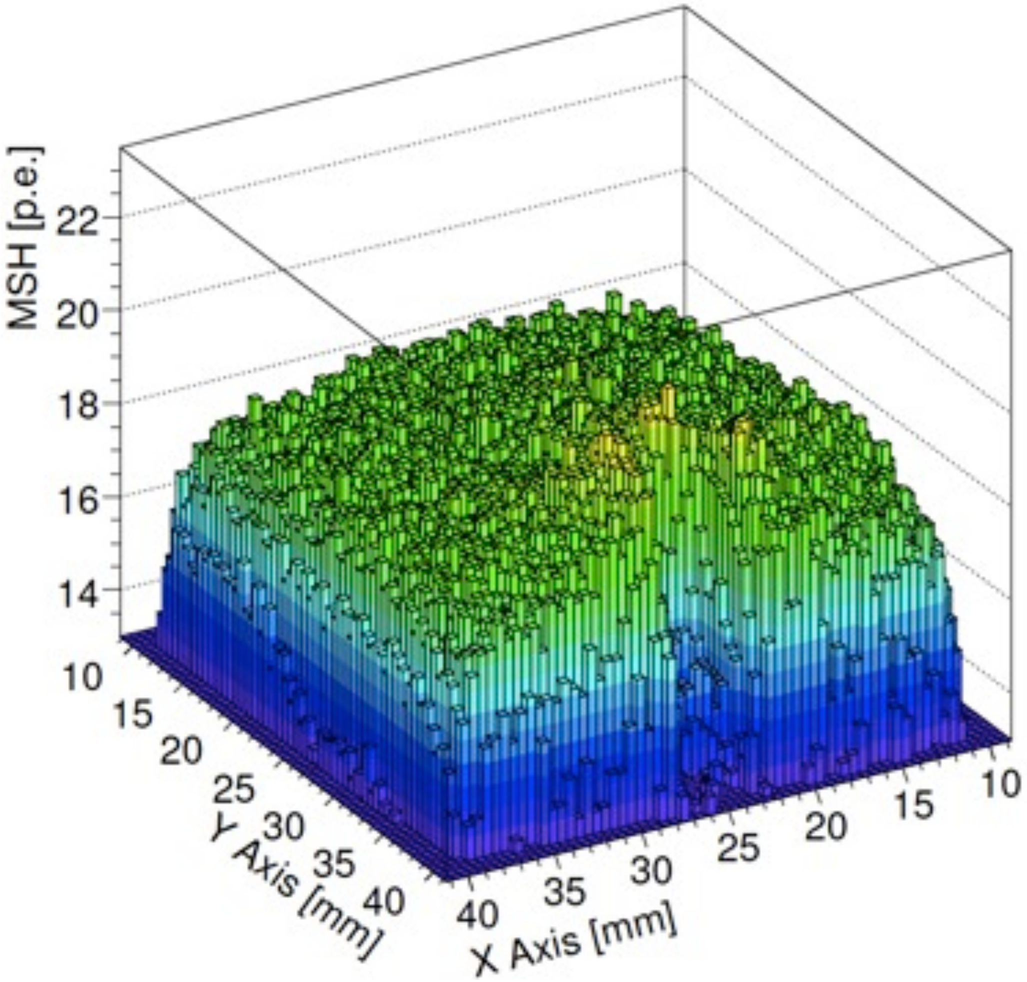


Direct Coupling for Scintillator Tiles [MPI]

- Blue scintillation light can be directly detected with new generation SiPMs
  - No WLS fiber necessary: Simplified mechanics, faster response
  - The challenge: Uniform response over the tile, WLS serves also as "light collector"

Uniform response achieved with special shaping of tile near SiPM coupling position

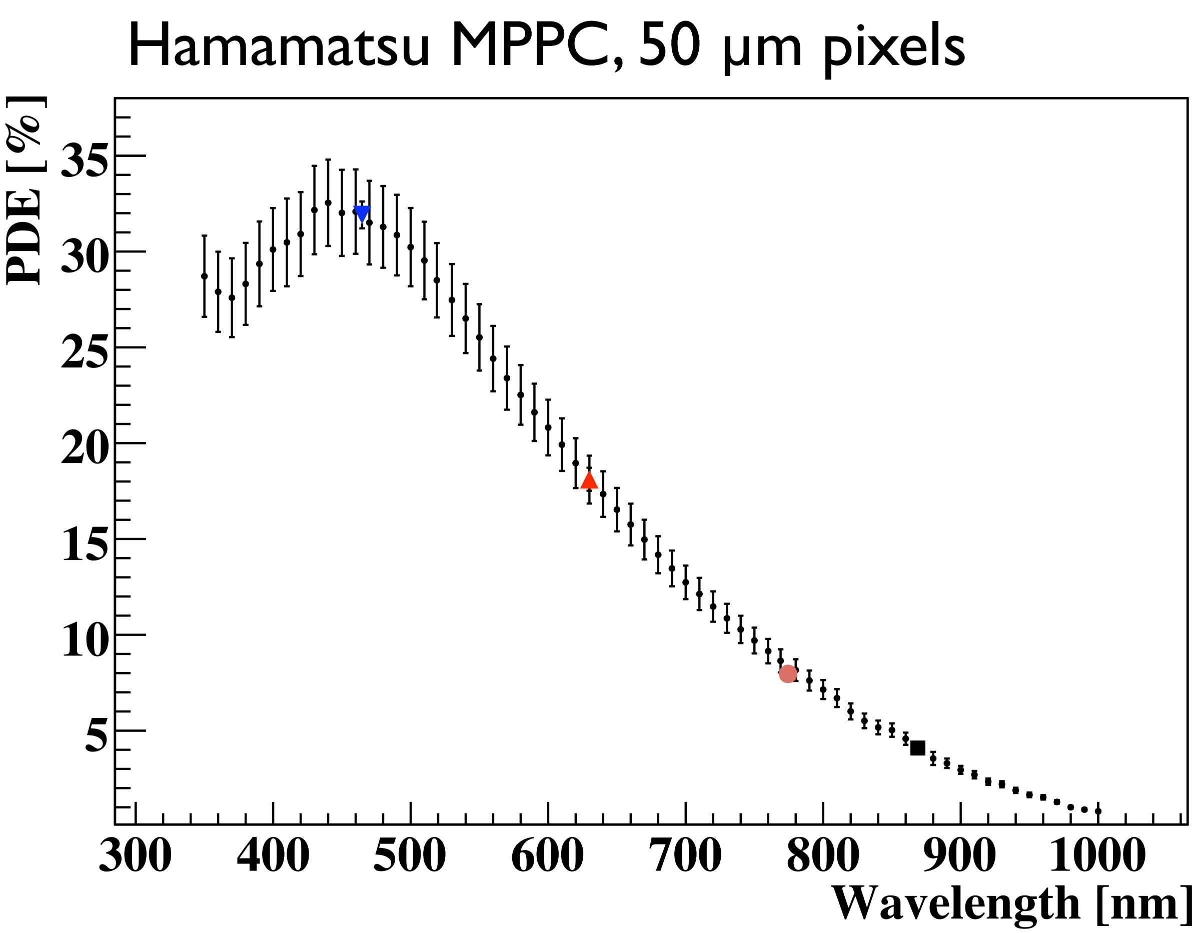


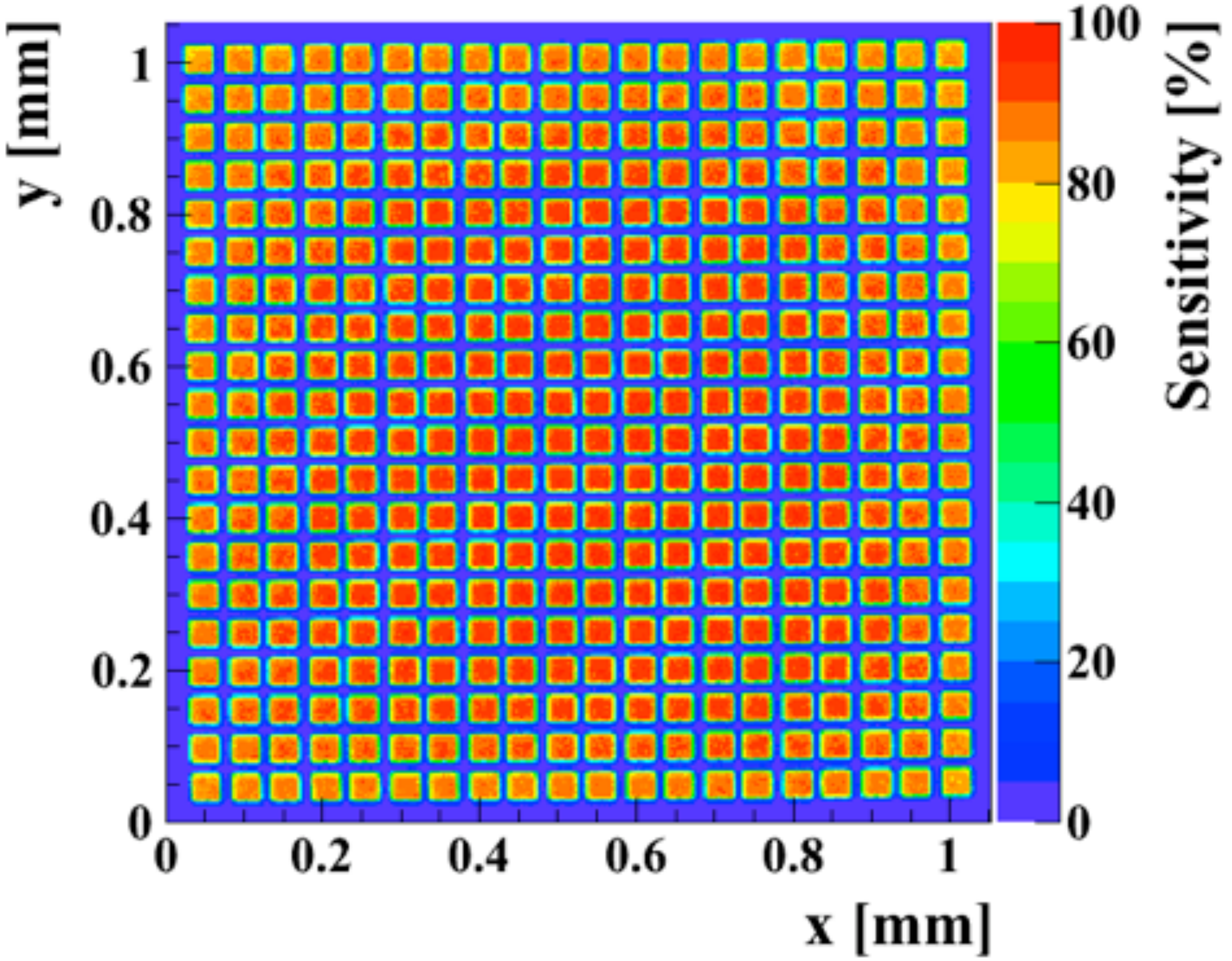


Faster response: Will be used for a first investigation of the time structure of hadronic showers in a Tungsten calorimeter in the November test beam at CERN

SiPM Studies [HD]

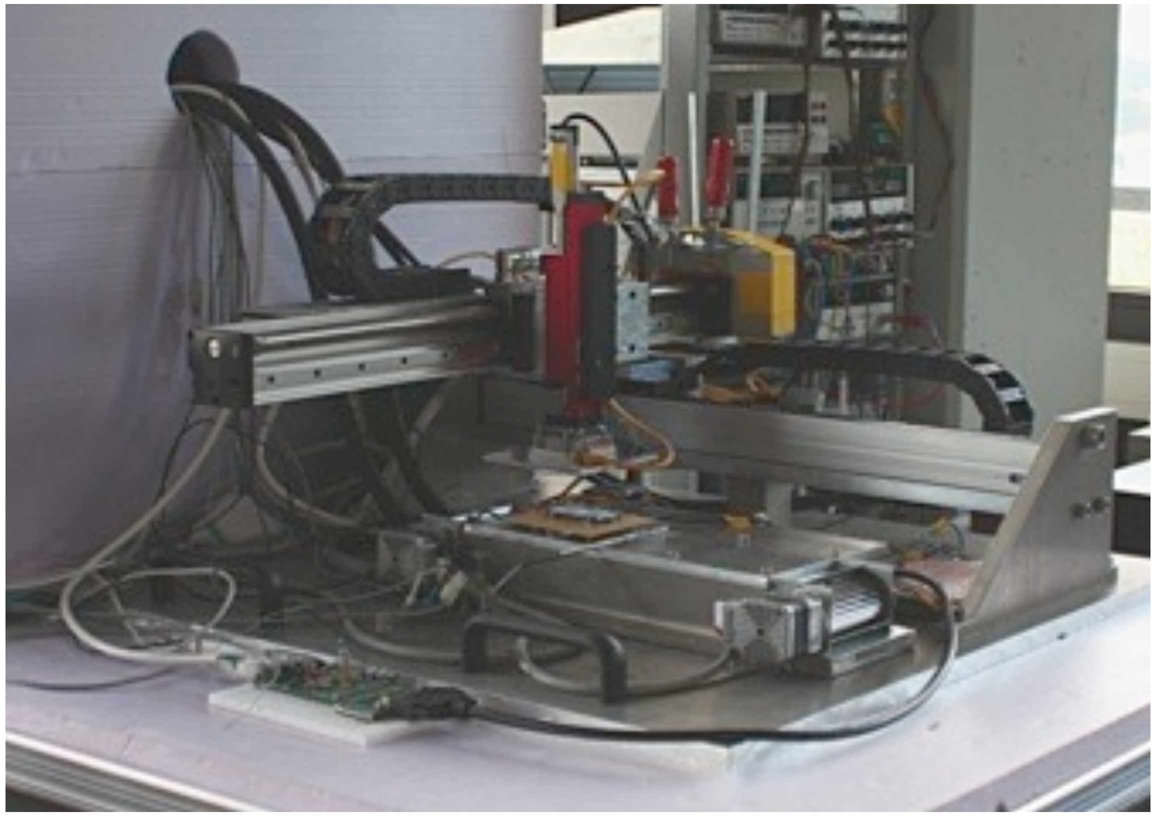
- Detailed studies of SiPM properties: noise, gain, temperature dependence, ...
  - Photon detection efficiency over a broad wavelength range with Xe lamp and filters
    - Selected wavelengths for calibration with LED
  - Scan over the SiPM surface with focused LED light: Response map



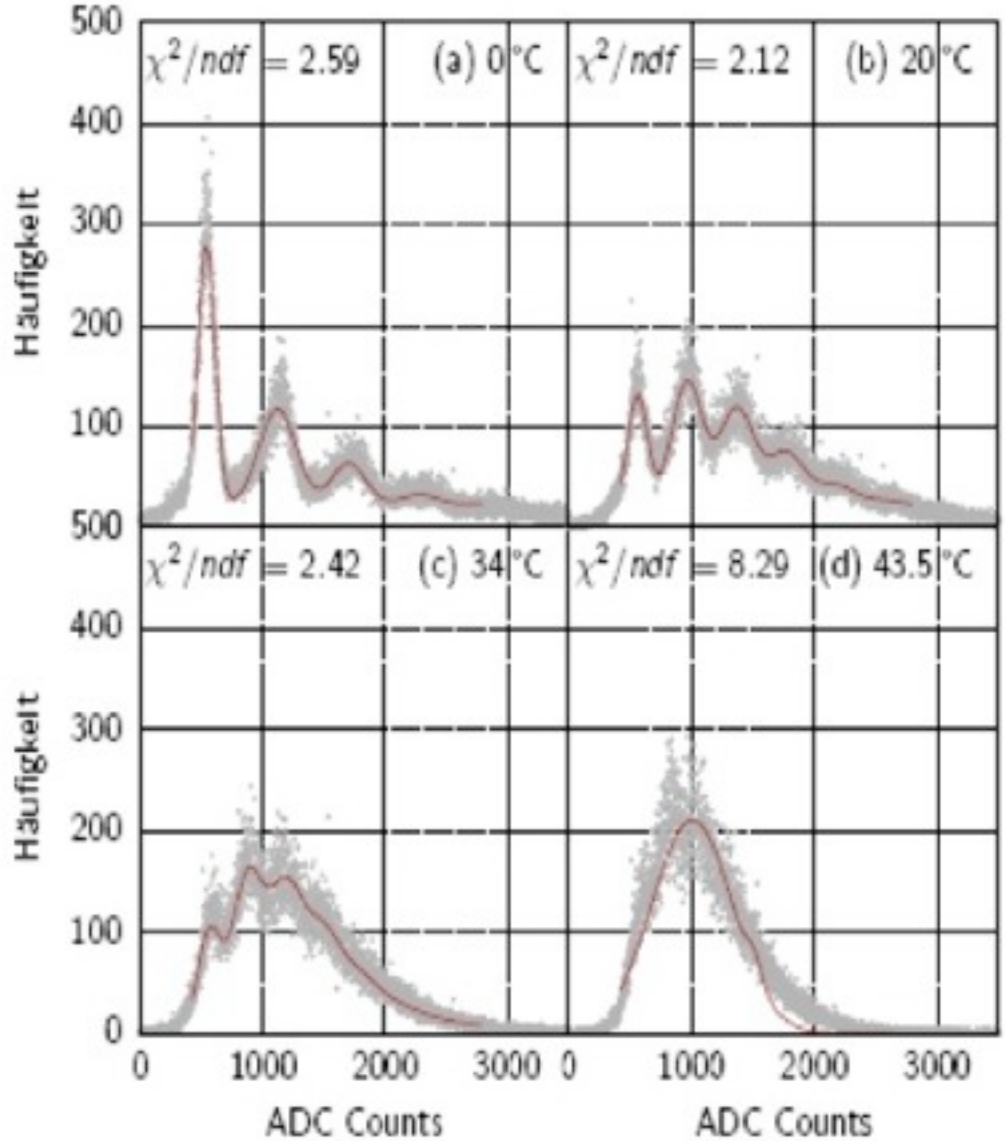


The goal: Find the best SiPMs for the calorimeter, establish QA procedures

Calibration Tools [W]



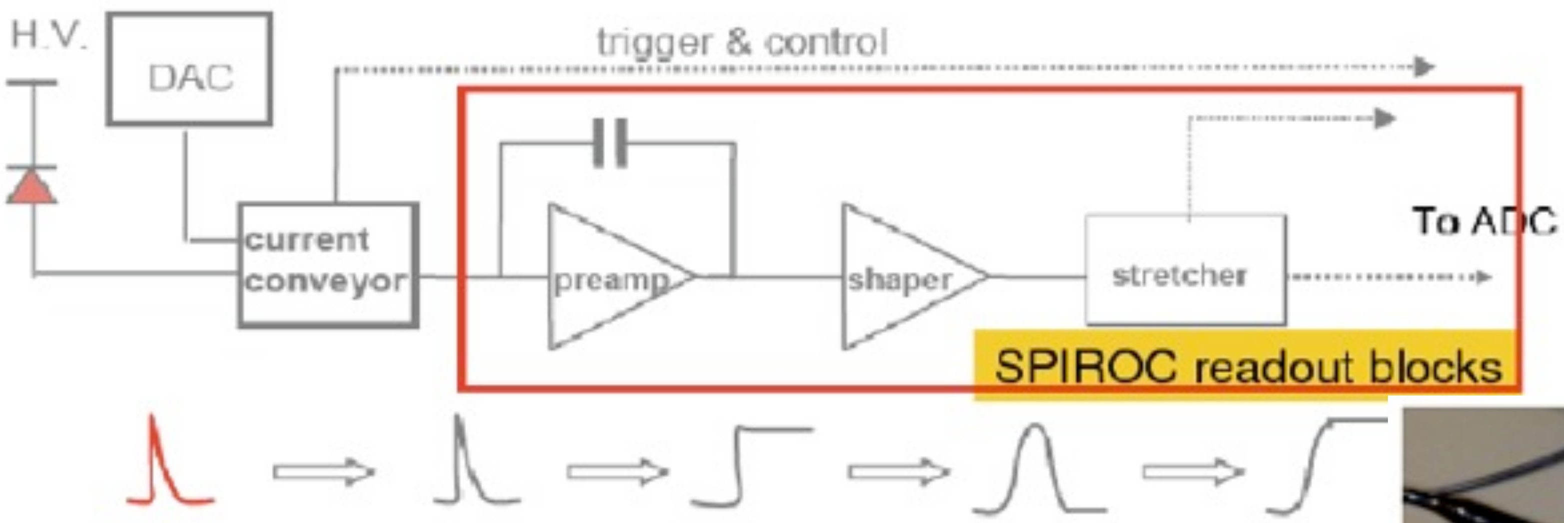
- Gain of SiPMs varies considerably from device to device: Intercalibration necessary
- Use LED light coupled into each scintillator tile (one embedded LED per tile), calibrate SiPM gain from peak to peak distance
  ➩ scalable calibration system



- Test setup: XYZ table to position LED on top of scintillator tiles determine:
  - best LED
  - optimal positioning
- Automatized fit extracts gain from spectra of reasonable quality

Virtual SiPM Laboratory [DESY, HD, MPI, W]

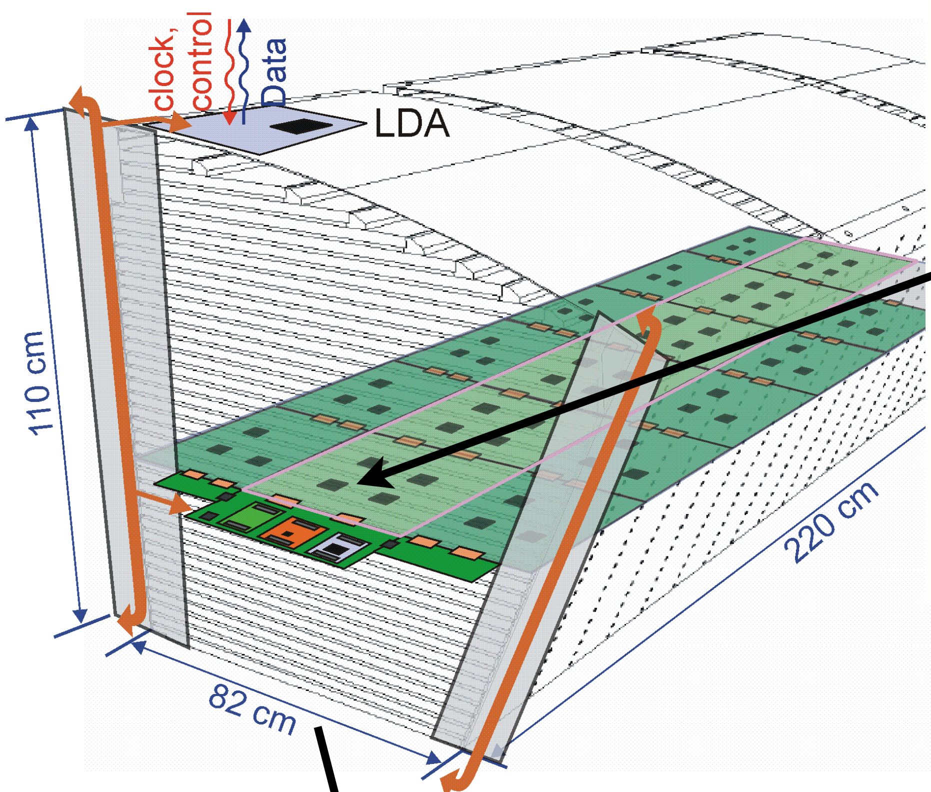
- Collaboration within the Terascale Alliance to establish infrastructure for SiPM testing and evaluation, needed for calorimetry development and other projects
  - Portable SiPM test stand, specialized SiPM readout ASIC

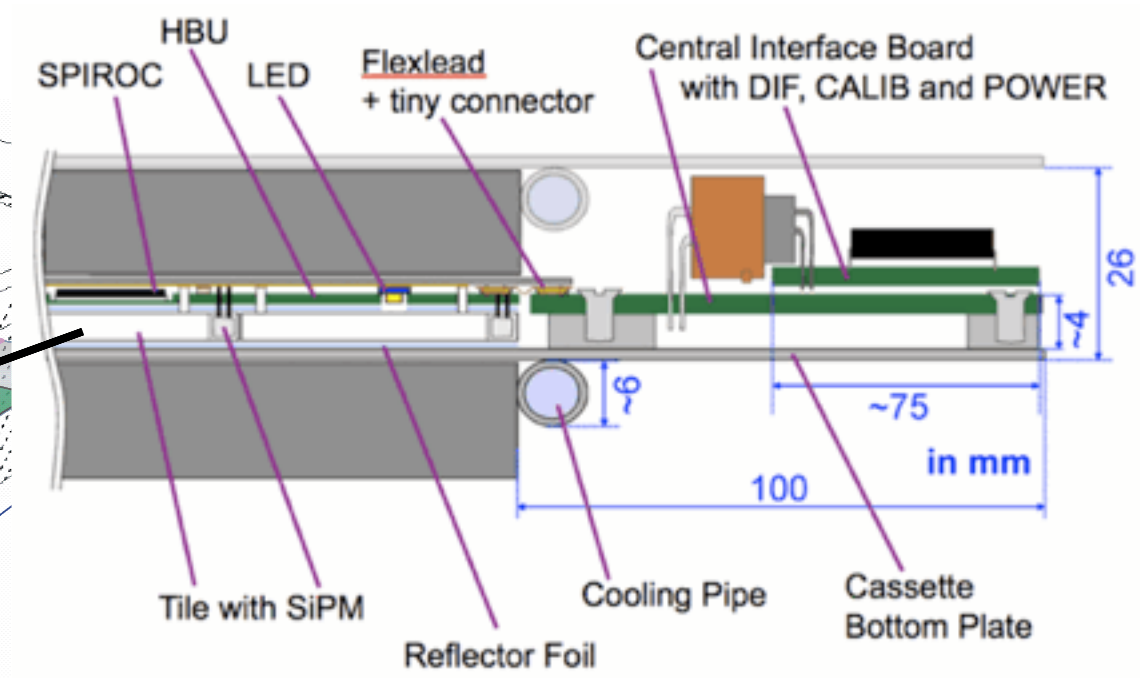


readout ASIC KLauS: 4 channels first prototypes undergoing testing

based on SPIROC readout blocks (chip for 2nd generation AHCAL)

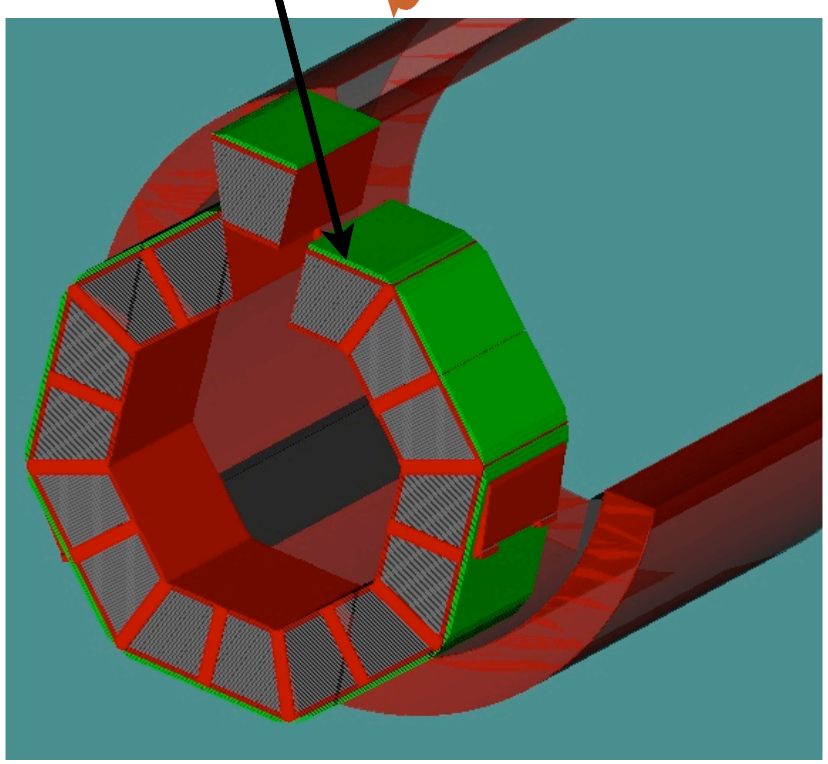
Next Generation Prototype [DESY]





Analog HCAL

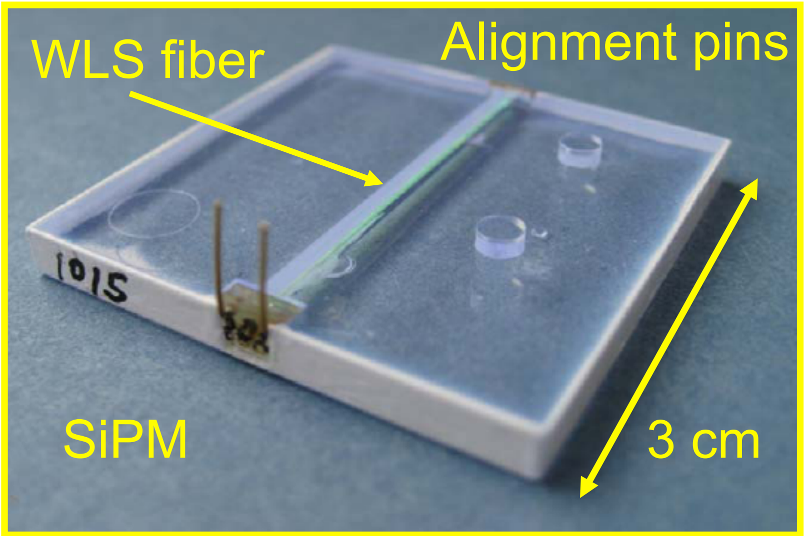
compact layers:
3 mm thick tiles +
electronics in a cassette



mechanical prototype:
steel structure,
tolerances for module
insertion met

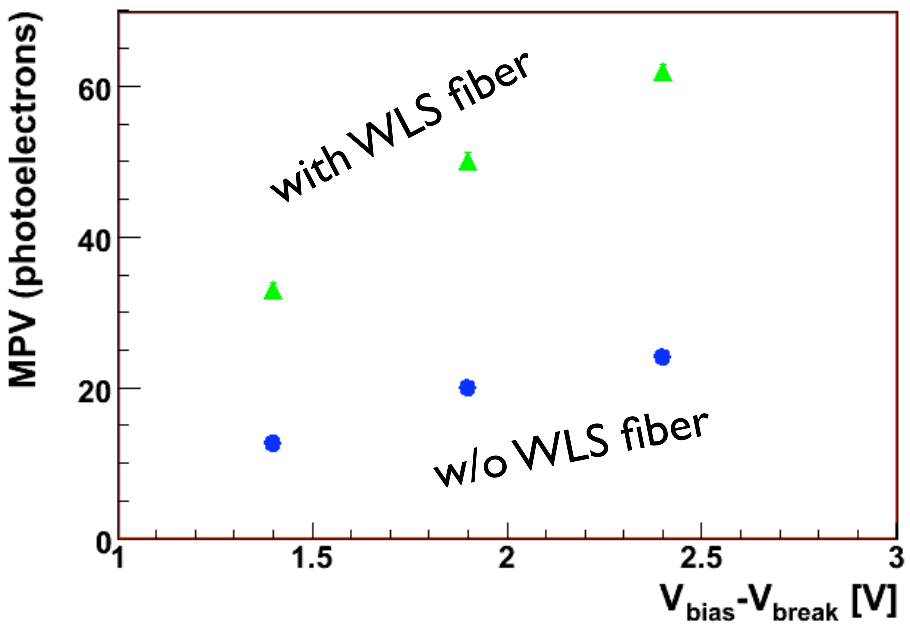
Next Generation Prototype: Electronics [DESY]

- Fully integrated electronics: time stamping capabilities
- New SiPMs, thin tiles with WLS

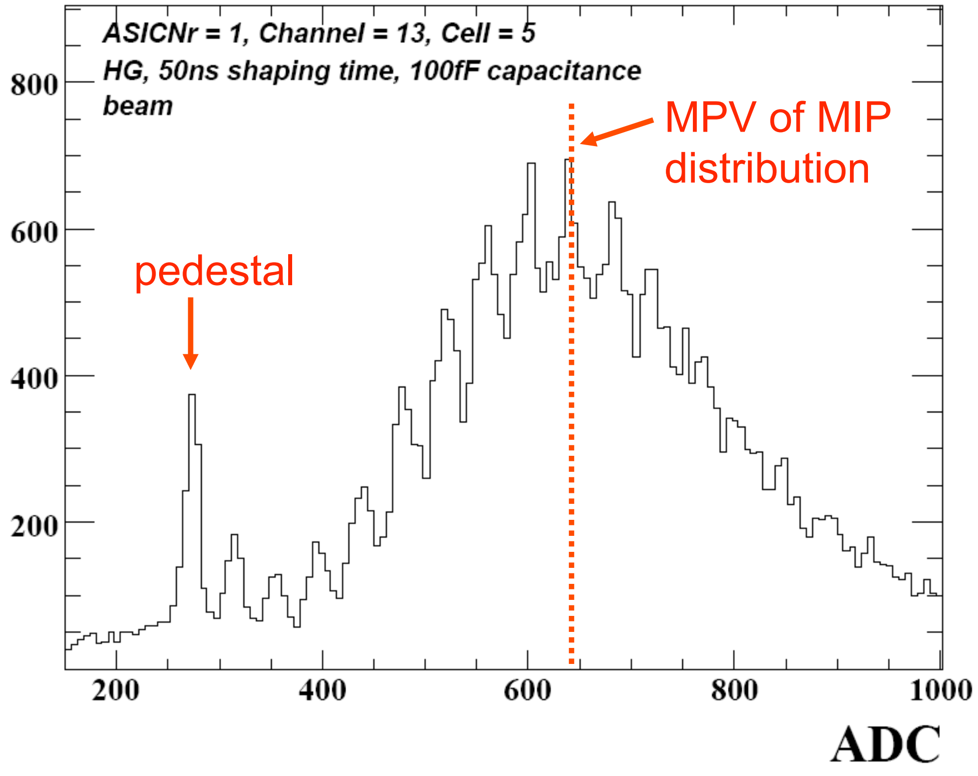


evaluation of scintillator tiles with MPPC 50

3 mm tile, read out with (1.3 mm)^2 MPPC 50



- First test beam results with a single module in e beam



⇨ Towards 4D images of hadronic showers!

Summary

- Calorimetry is a key component of a Linear Collider Detector
  - Particle Flow Algorithms rely on imaging capabilities: Shower separation in the calorimeters drives jet energy resolution
- CALICE develops PFA Calorimeters, extensive test beam program to evaluate different technologies
  - Data provide valuable input for the validation of shower simulations and the development of reconstruction algorithms
- Strong participation of members of the Alliance in the Analog HCAL
  - Development and evaluation of electronics, read-out techniques, photon sensors, calibration systems
  - Preparations for future test beams and next generation prototypes