A hadron calorimeter for future ILC optimized for particle flow

Sebastian Laurien

Overview

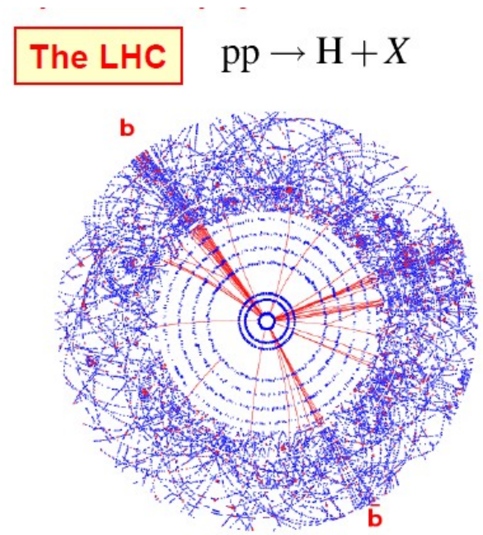
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

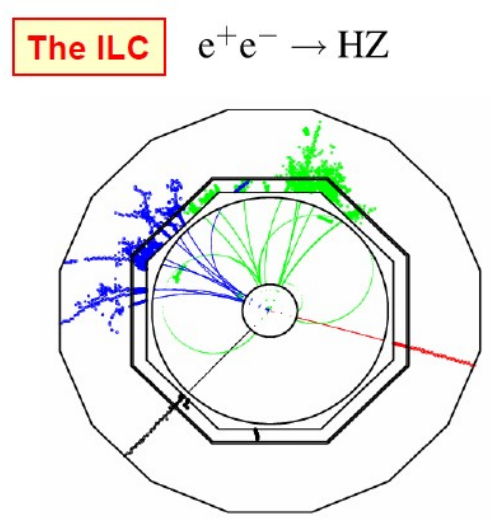
- ILC
- Hadron calorimetry and particle flow
- AHCAL: analogue hadron calorimeter
- Test beam at CERN with the technological prototype

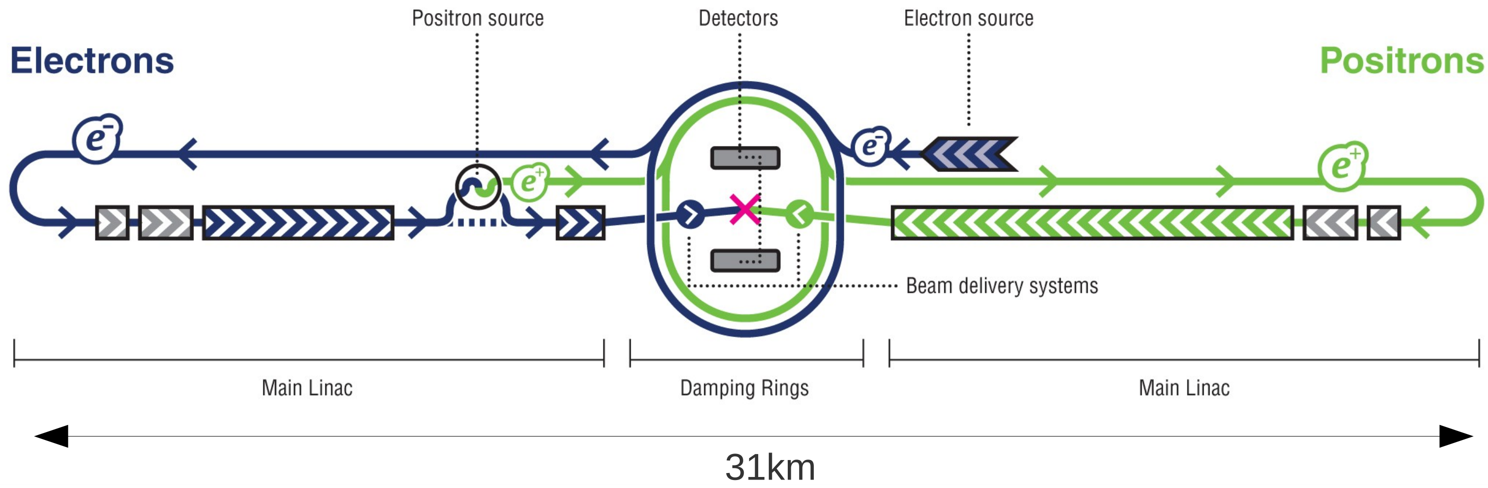
Next Collider - ILC

ILC:

- next generation lepton collider
- clean environment
- 500GeV / 1TeV
- high luminosity
- precision studies/ measurement





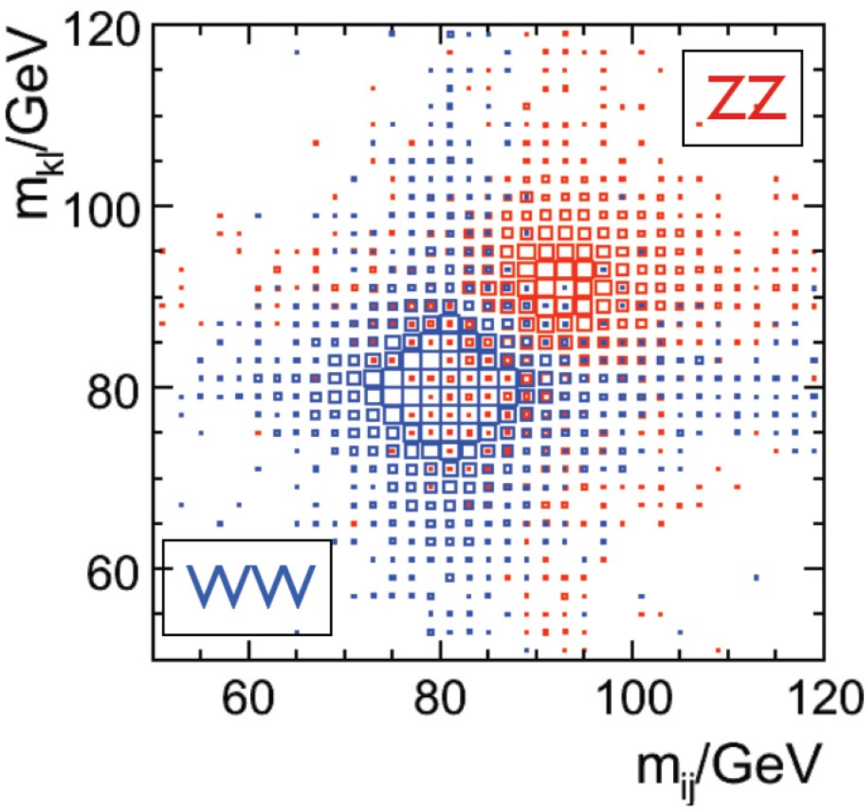


ILC hadron calorimetry

ILC physics: separation of hadronic W, Z decays

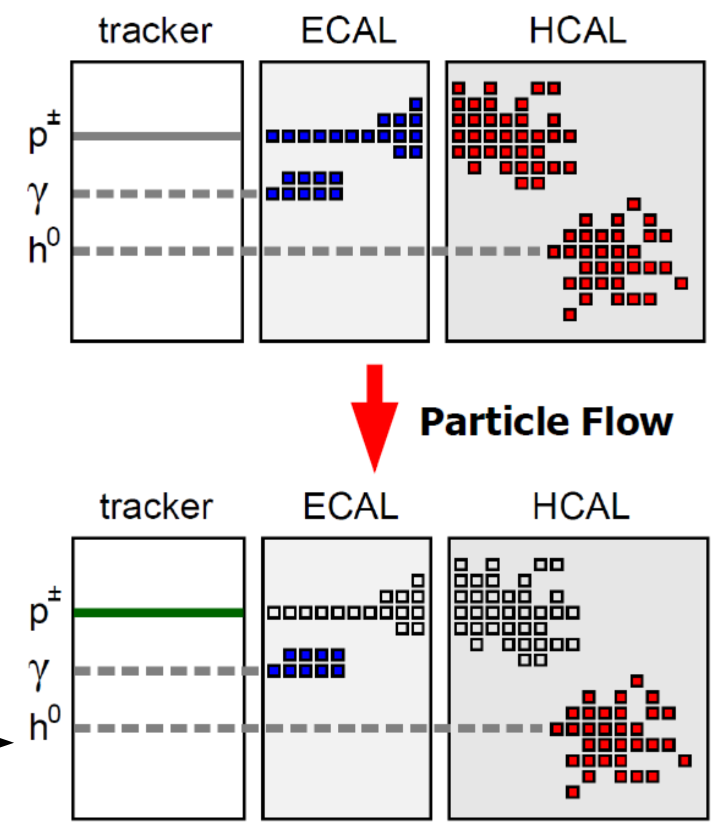
→ need high jet energy resolution : $\frac{\delta E_{jet}}{E_{jet}} = \frac{30\%}{\sqrt{E}}$

→ particle flow : choose detector best suited for particular particle type



Typical jet energy composition:
60% charged hadrons
30% photons
10% neutral hadrons

$$\sigma_{jet} \approx f_{\pm} \cdot \sigma_{tracker} \oplus f_{\gamma} \cdot \sigma_{ECAL} \oplus f_{0} \cdot \sigma_{HCAL} \oplus \sigma_{confusion}$$



measured by HCAL

→ Build the best possible calorimeter in order not to use it.

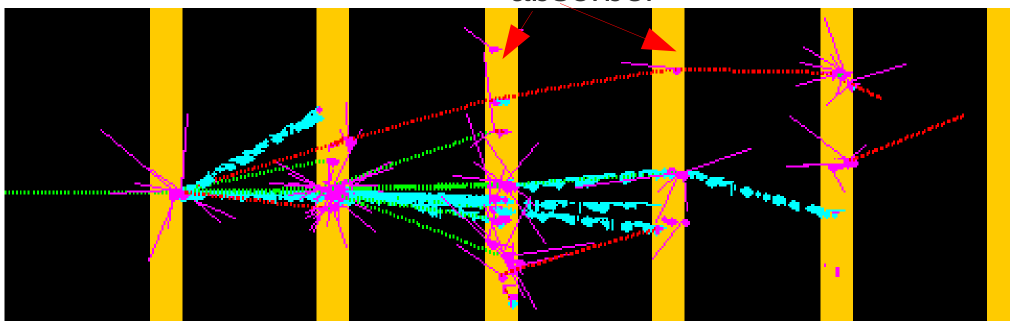
Hadron Sampling Calorimeter

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

- measures the energy of a neutral hadron → need to stop particles: very dense absorber (Steel)
- only fraction of the calorimeter is sensitive volume (detectors)

absorber

incoming particles



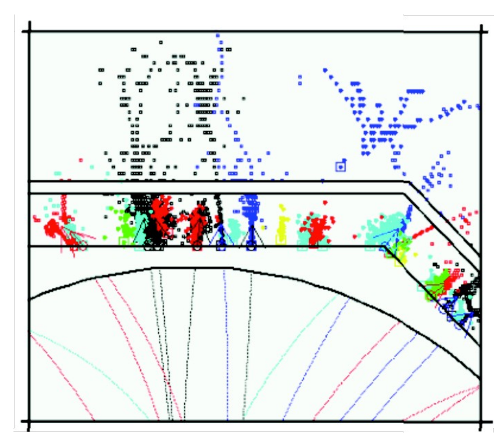
sensitive layers read out with scintillators and light detectors.

(www.harfesoft.de)

detectors (scintillators)

HCAL for ILC:

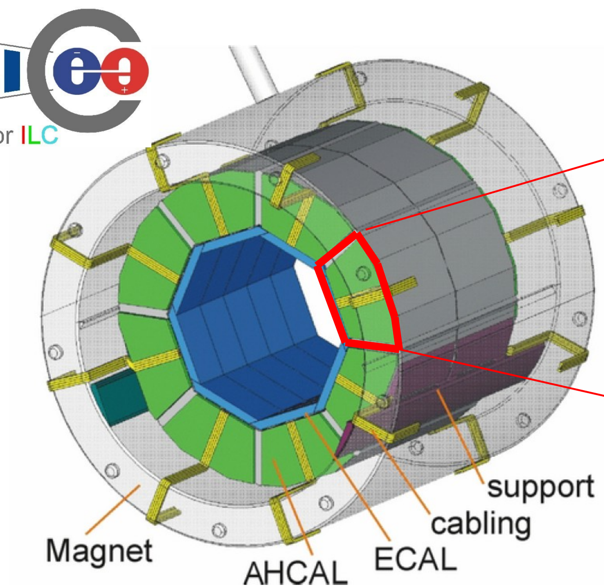
- highly segmented for particle flow (separate energy deposits in calorimeter)
- 48 layers (~6λ)
- ~10^6 channels
- integrated readout
- low power consumption (avoid active cooling)
- time information
- HCAL inside magnetic field



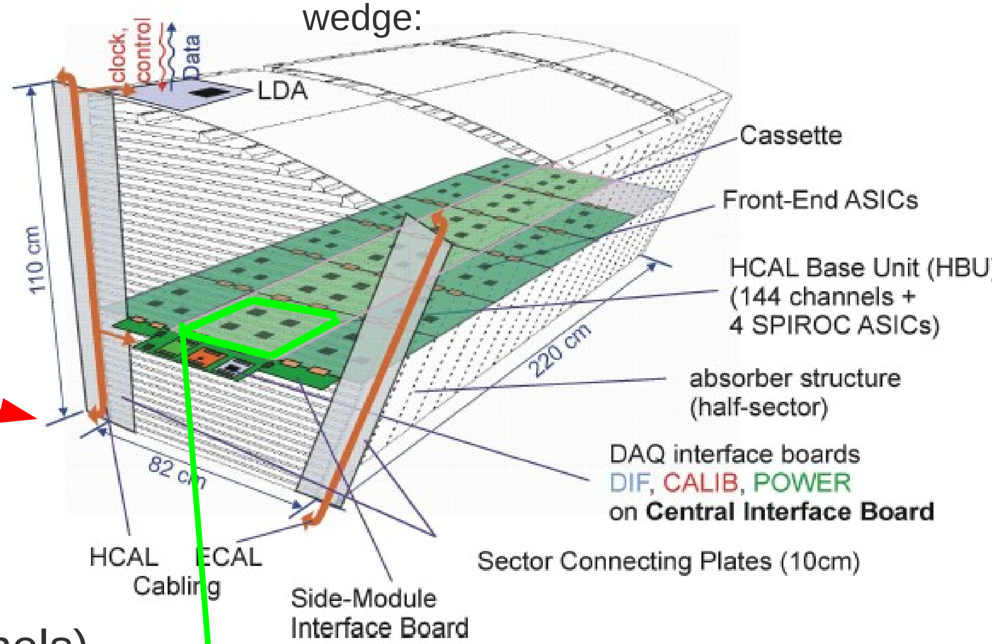
The AHCAL (analogue hadron calorimeter)

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

CALICE – Calorimeter for ILC

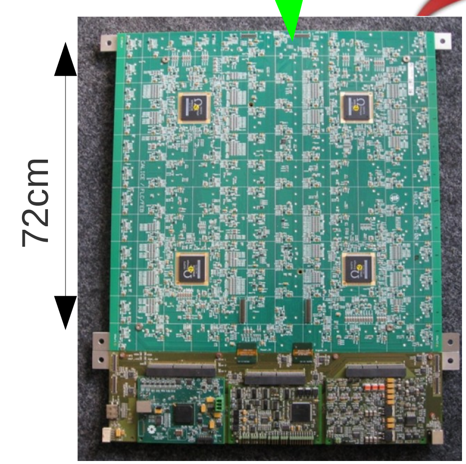


wedge:



The analogue hadron calorimeter:
- modular, smallest hcal base unit (144 channels)
- 48 cassettes in one wedge
- 3x3x0.3 cm³ plastic scintillator
- fully integrated readout and ASICs
- power pulsing (25 µW/ channel)
  (not needed electronics switched
  off in parts of a cycle)

HBU with ASICS

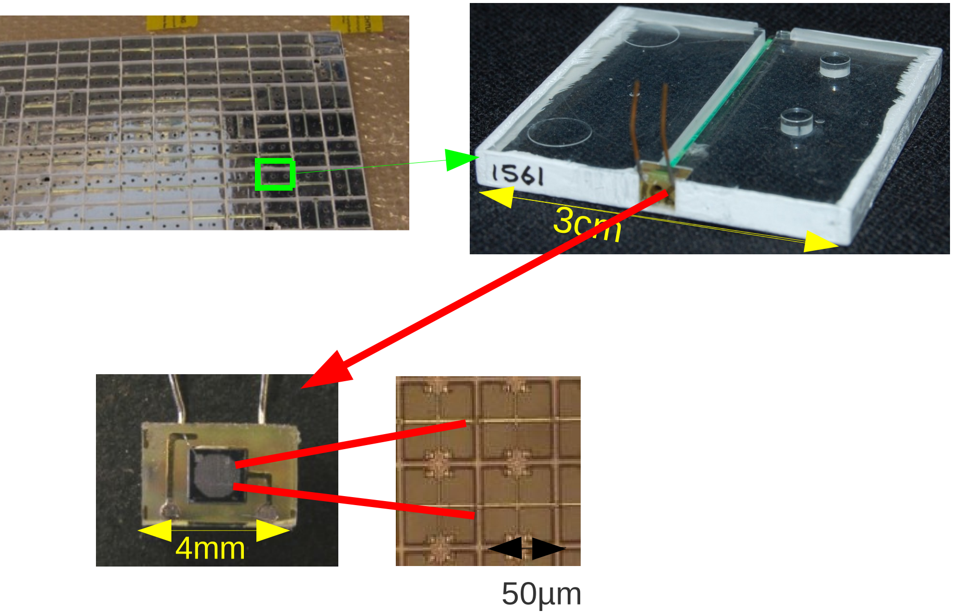


scintillating tiles mounted on the other side

AHCAL – single channel

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

plastic scintillator tile



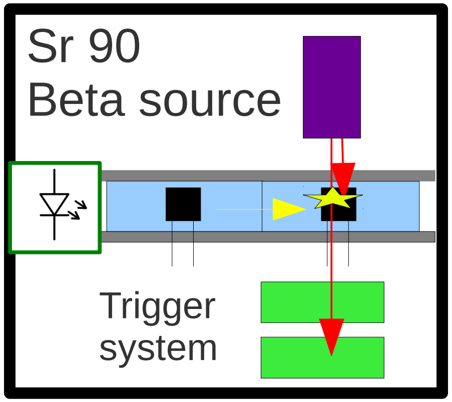
Readout of tiles with silicon photo multipliers (SiPM) mounted directly on HBU

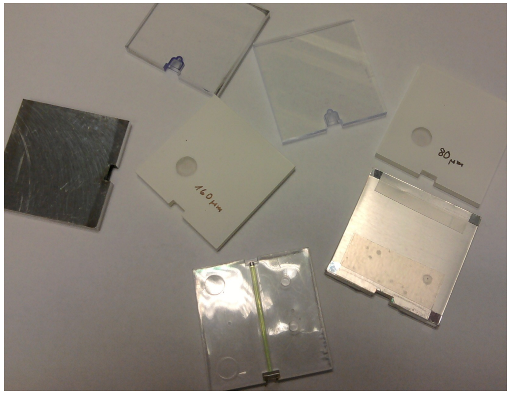
SiPM:
- insensitive to magnetic fields
- array of ~1000 APD pixels in Geiger mode
- every fired pixel gives a fixed charge
- analogue signal: sum of all pixels
- single photon sensitivity

Up and running setup for scintillator tile and SiPM characterization:

- response to minimal ionizing particles (MIP)
- temperature and voltage dependencies
- investigation of different SiPMs and tile coating / wrapping

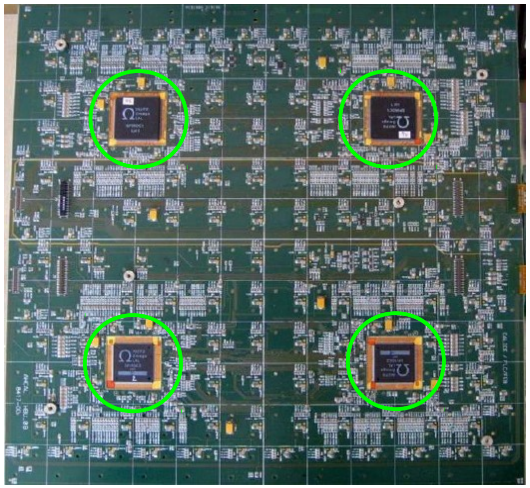
clima box





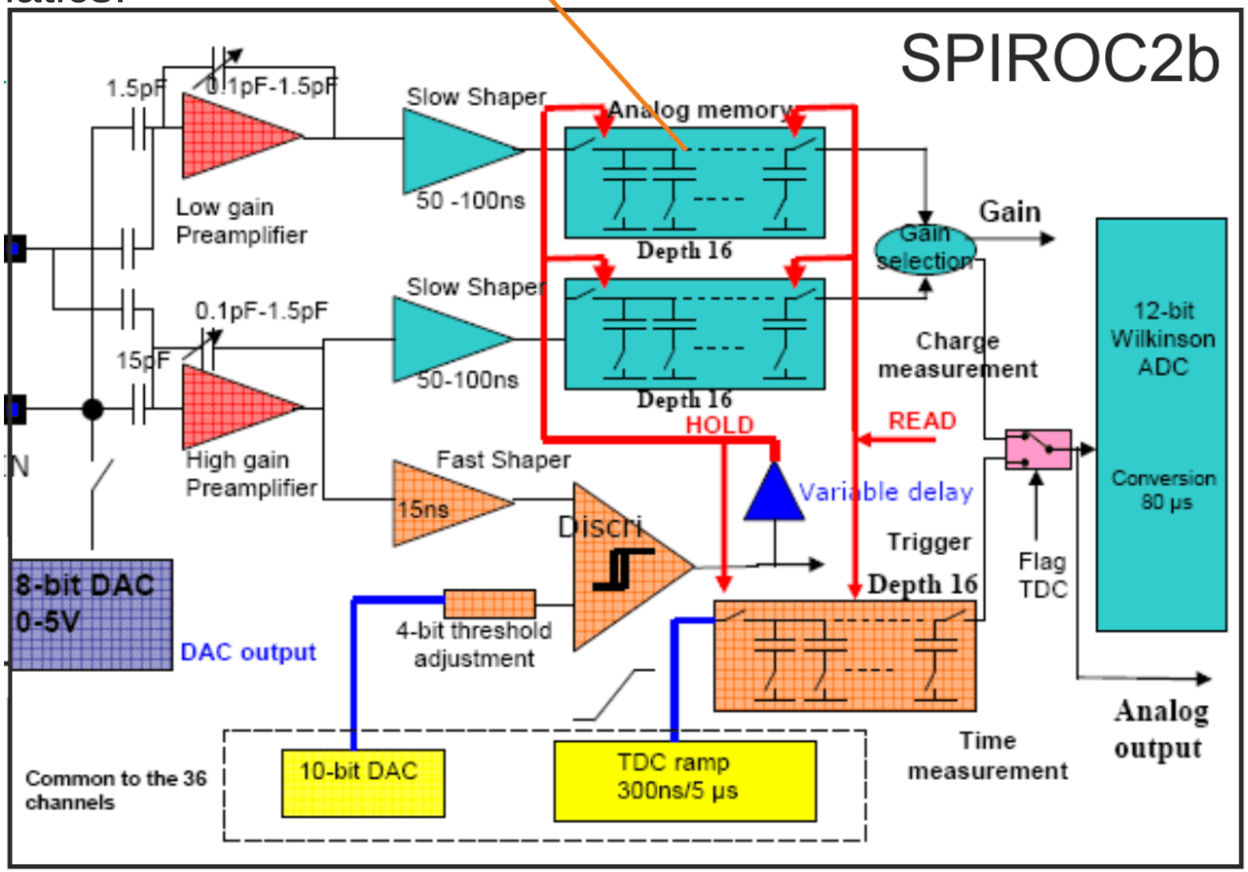
The readout chip

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG



single channel schematics:

16-stage analogue memory

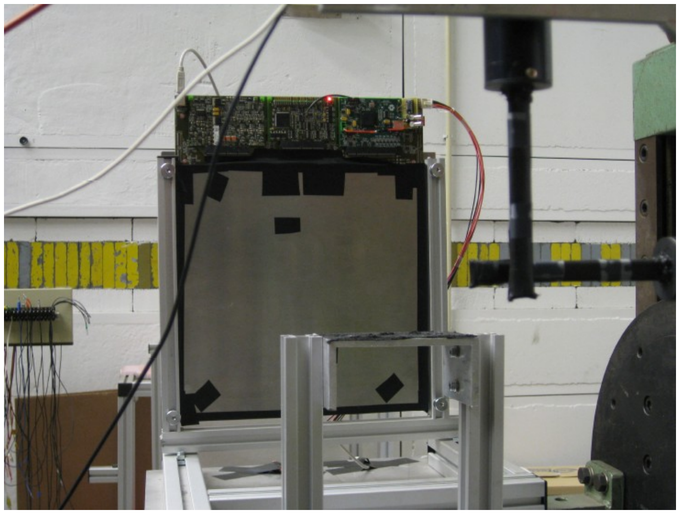


4 ASICs on one base unit:
- optimized for ILC operation
- 36 channels
- low power consumption (25µW/ch)
- dual gain ADC (adjustable)
- auto trigger with adjustable threshold
- timing measurement (resolution ILC mode 100ps)

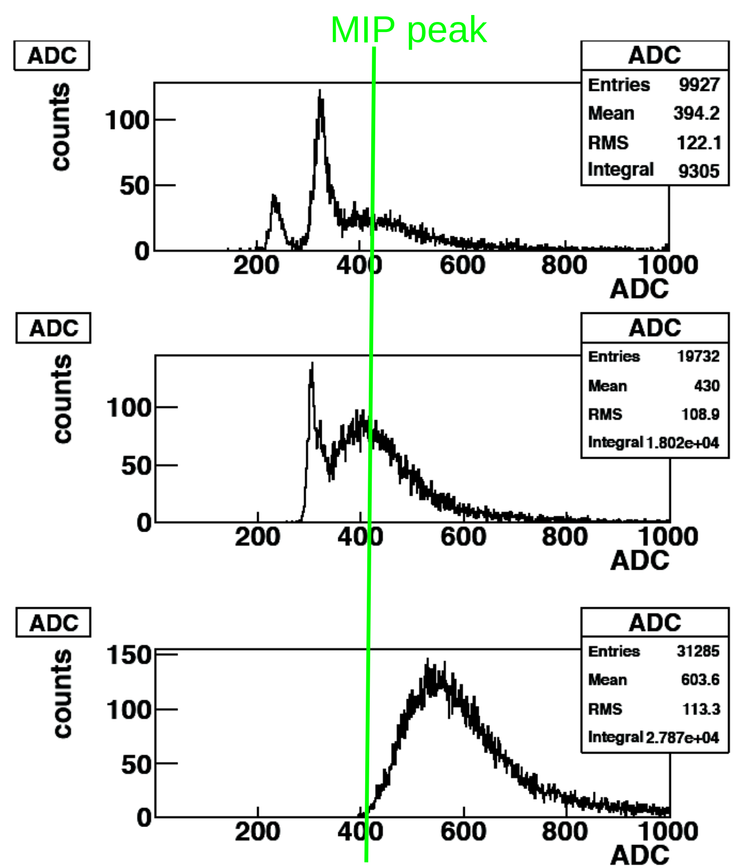
DESY electron test beam

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

base unit in DESY test beam:



Minimal ionizing particles (MIP) in DESY test beam for calibration of auto trigger threshold

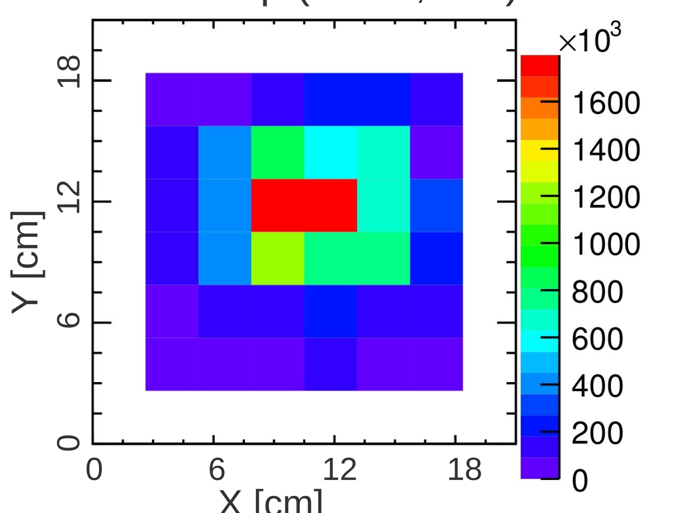


too low threshold

good threshold

too high threshold

Shower in one chip (3GeV, $2X_0$)



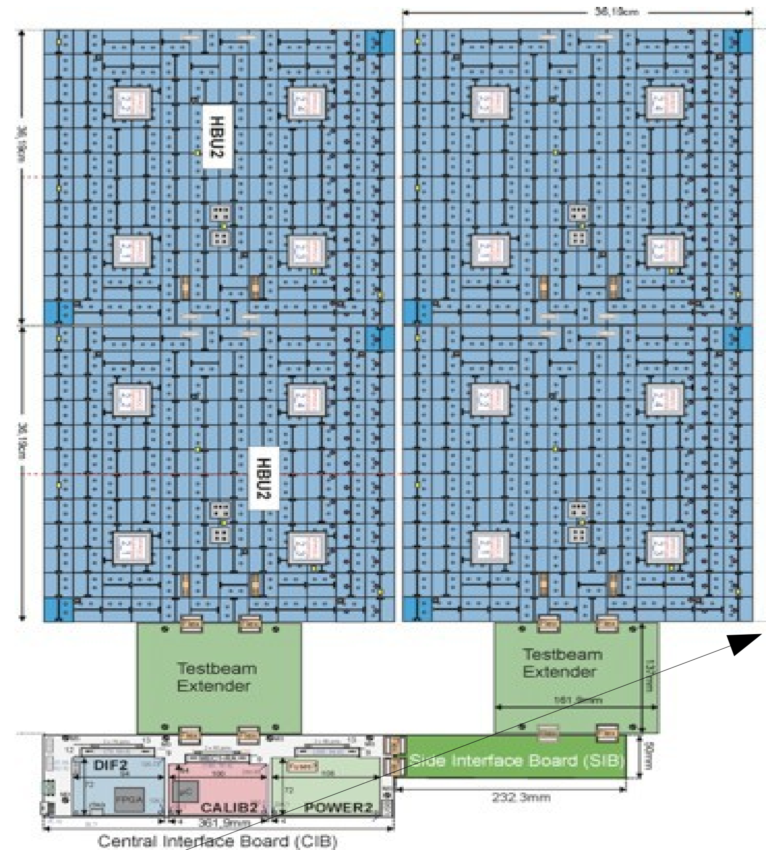
The AHCAL – CERN test beam

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

The technological prototype: one layer with 4 HBU:

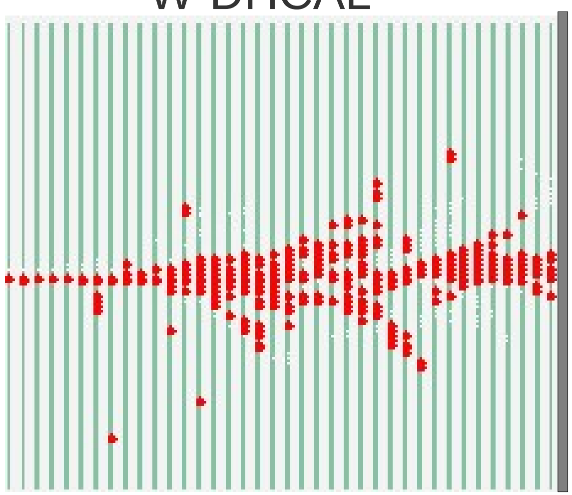
- 576 channels
- same electronics and readout as for ILC
  → 16 independently auto triggered chips

AHCAL technological prototype will go in test beam :
- SPS at CERN (pions) in November
- downstream the tungsten digital HCAL (W-DHCAL) after 4λ
- time resolution 1ns (test beam mode)



W-DHCAL

SPS



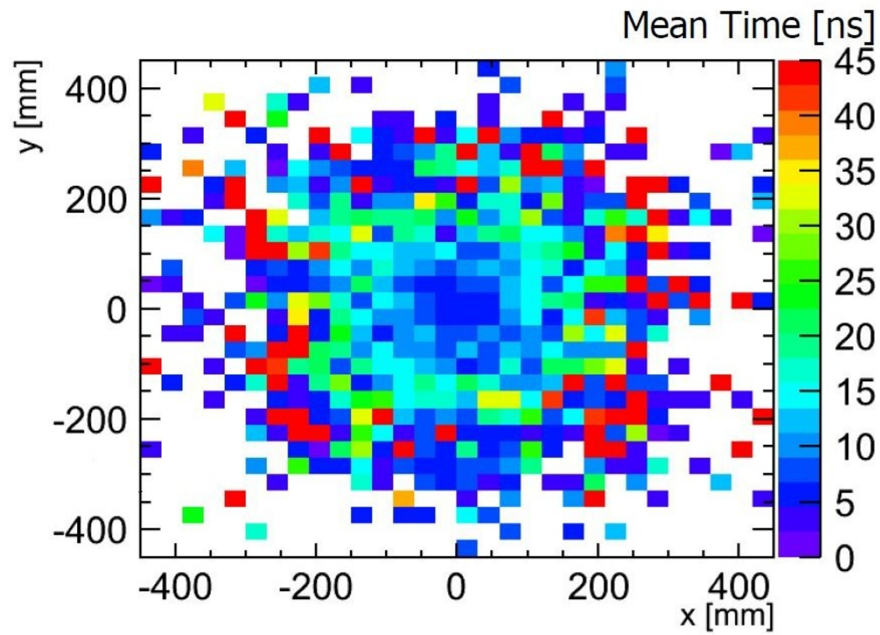
Hadron test beam goals

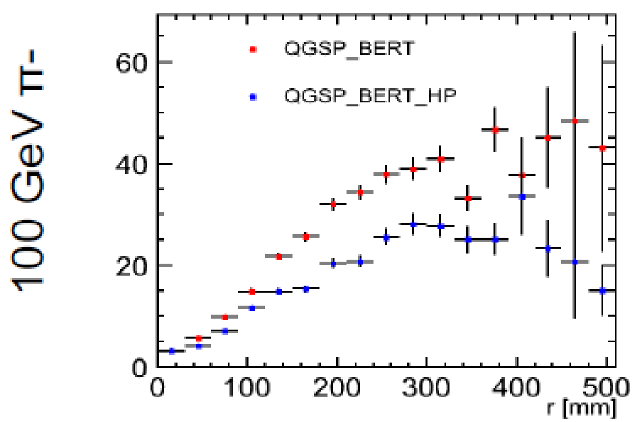
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

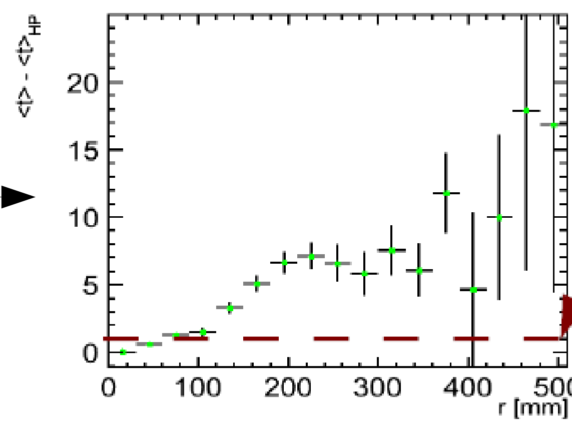
Main goal:
establish electronics and readout in a realistic detector scenario

Physics goal:
- detailed measurements of Hadronic showers
- test and validation of different physics simulations
- resolution **1ns**

→ e.g. radial distribution of mean time of hit in the last layer







Time resolution of prototype

Summary and Outlook

- CALICE collaboration is developing particle flow calorimeters for linear colliders

- AHCAL technological protoype:
  - One layer with 4 AHCAL base units (HBU) in hadronic test beam Nov.2012
    - test of the integrated readout electronics
    - investigation of hadronic shower time development

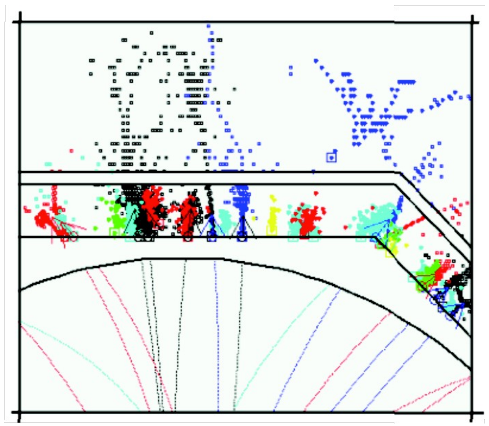
Thank You!

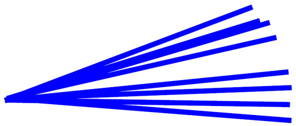
For your attention

Calorimetry – Particle Flow

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

ILC detectors need to be optimized for precision measurements in difficult multi-jet environment

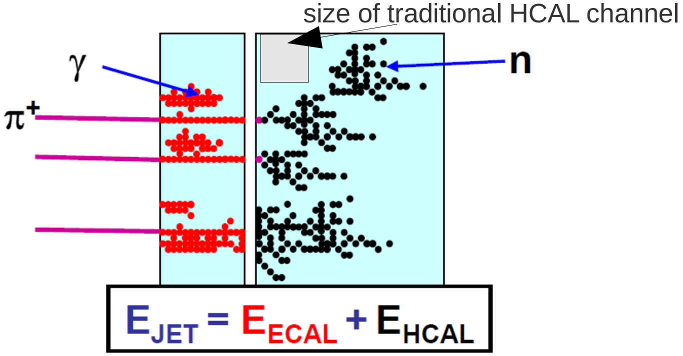




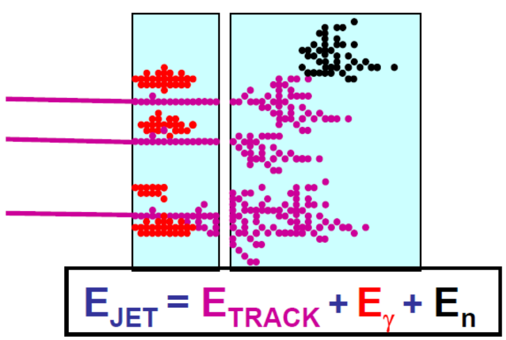
Typical jet energy:
60% charged hadrons
30% photons
10% neutral hadrons

Traditional approach
- energy measured by ECAL + HCAL
→ poor HCAL resolution limits jet resolution

Particle Flow (PF) approach
- measure every particle in the device with best resolution
- need to assign energy deposit in calorimeter to single particles (tracks)
→ only neutral hadrons measured in HCAL (only 10% of jet energy)



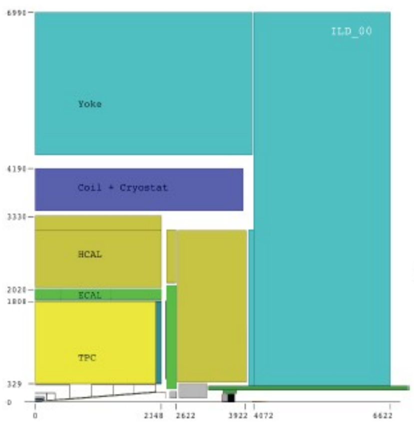
Traditionell approach

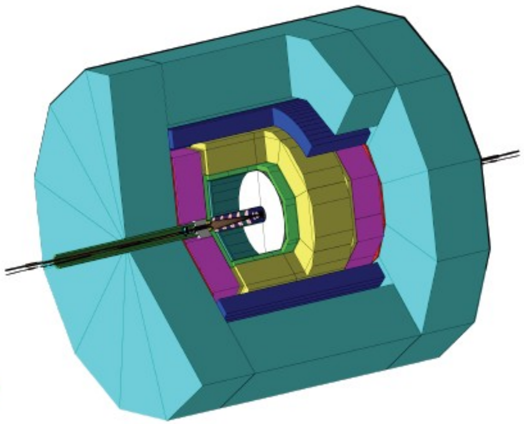


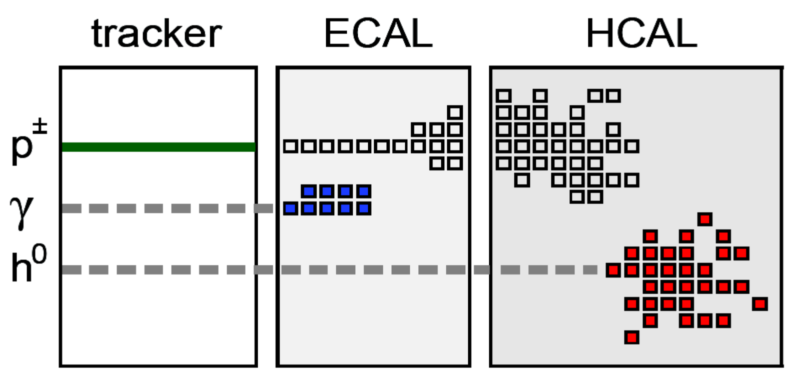
PF approach

PF HCAL: Build the best possible calorimeter in order not to use it.

The Energy resolution of the ILD







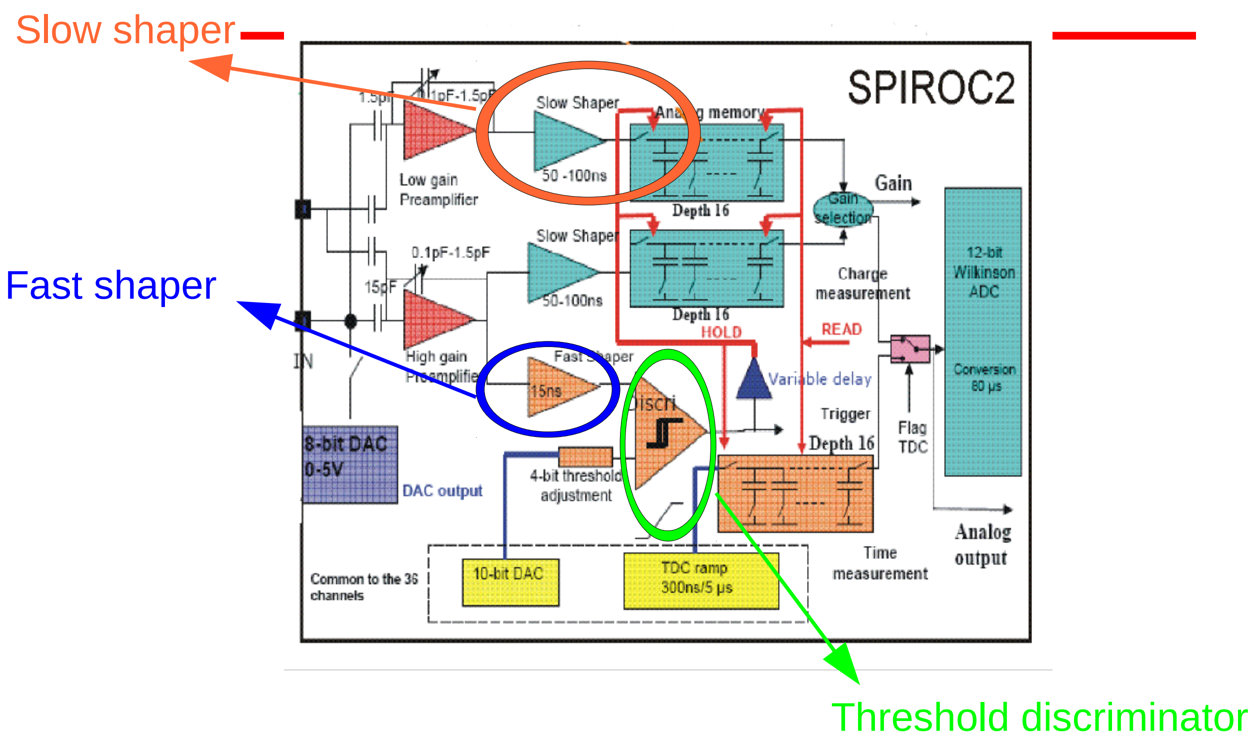
Archive better Energy resolution through the Particle Flow Algorithm (PFA) approach:

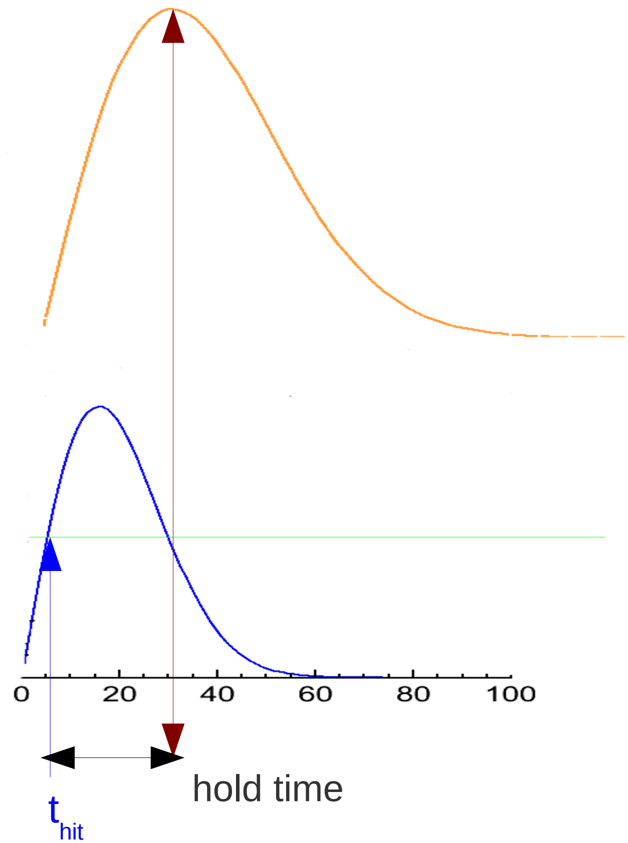
- Energy of charged particles measured by tracking detectors
- Energy of photons measured by Electromagnetic Calorimeter (ECAL)
- Neutral particles energy measured by the Hadronic Calorimeter (HCAL)

$$\sigma_{jet} \approx f_{\pm} \cdot \sigma_{tracker} \oplus f_{\gamma} \cdot \sigma_{ECAL} \oplus f_{0} \cdot \sigma_{HCAL} \oplus \sigma_{confusion}$$

To reduce the confusion term of Energy resolution, an high granularity calorimeter is needed to precisely reconstruct the final states of the jet

Time stamping: the ASIC





Hit signal splitted:

- A fast shaper (~ 25 ns shaping time) feeds a threshold discriminator;
- A slow shaper (~ 50 ns) feeds the analog memory;

Whenever fast signal amplitude passes the threshold:

- Time information is stored (of threshold passing);
- Amplitude of slow signal at hold time is stored;

Time stamping: digitization

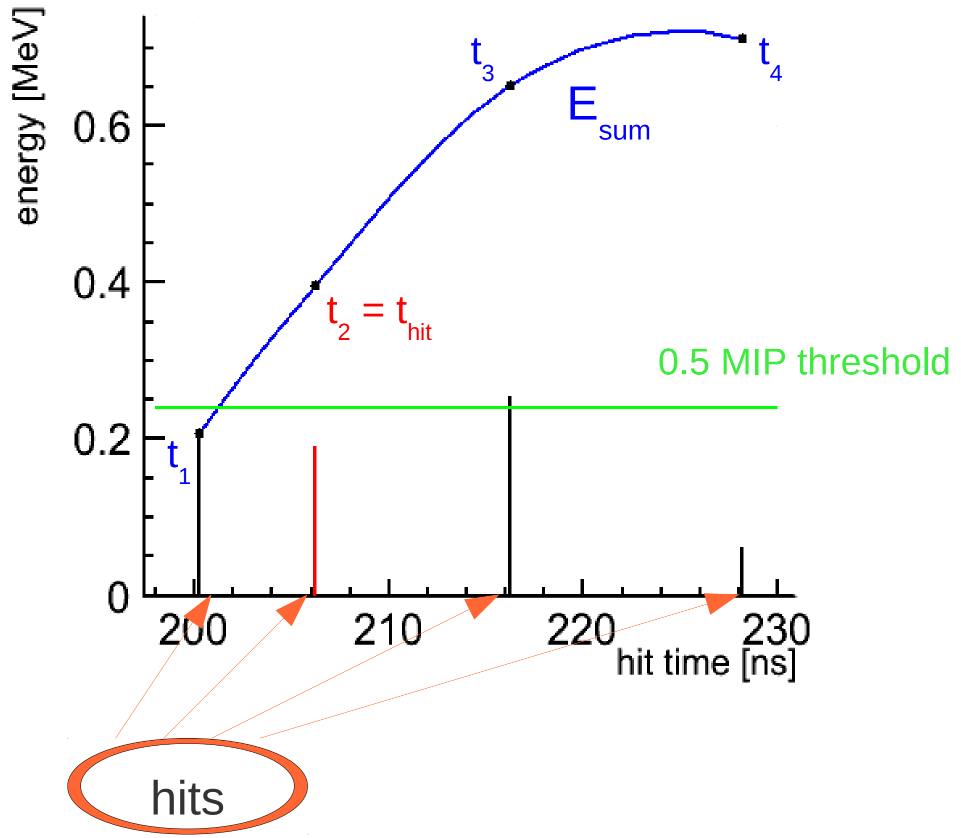
Universität Hamburg
BILDUNG

For each cell several hits characterized by:
•A time value
•A deposited energy value

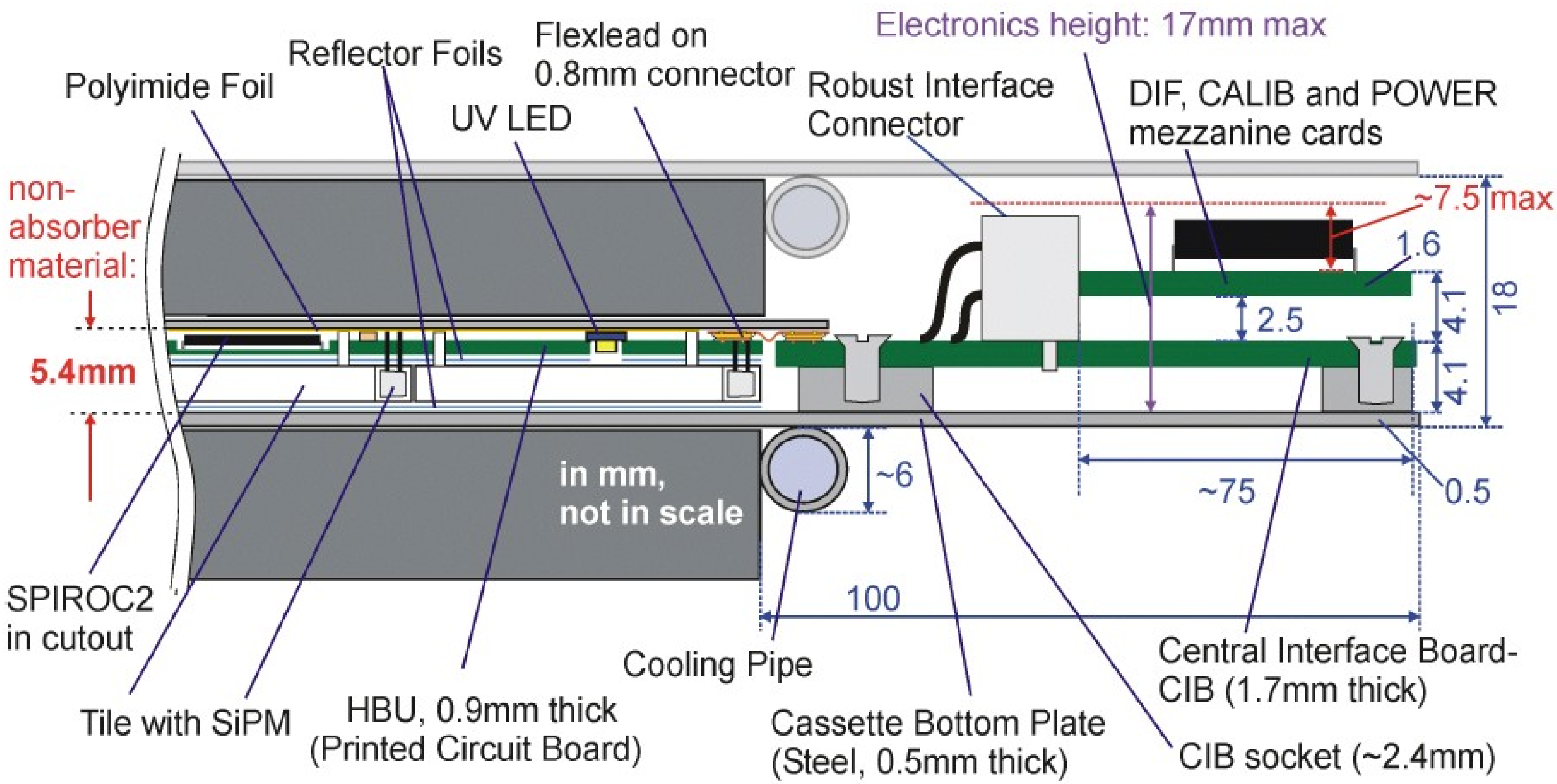
To simulate ASIC behavior, for each Cell:

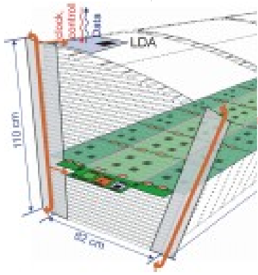
1a) hits are temporally ordered
1b) hit energy is added until $t_i = t_1 + 25$ ns
1c) $t_{hit} = t_i$ first hit passing threshold

2) E_{sum} = sum of E_i until $t < t_{hit} + t_{hold}$ $t_{hold} \sim 50$ ns



No ASIC noise or time jitter had been considered yet ...





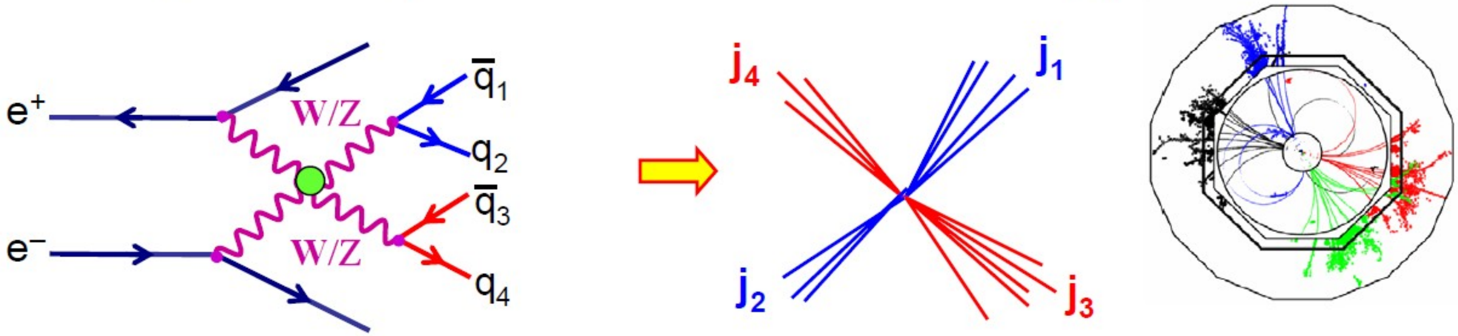
Abbr.	Name
DIF	Detector Interface Board
CALIB	Steering for LED calibration
CIB	Central Interface Board
HBU	Front-end board

- Compliant with steel and tungsten options
- Redesign and production of components almost finished

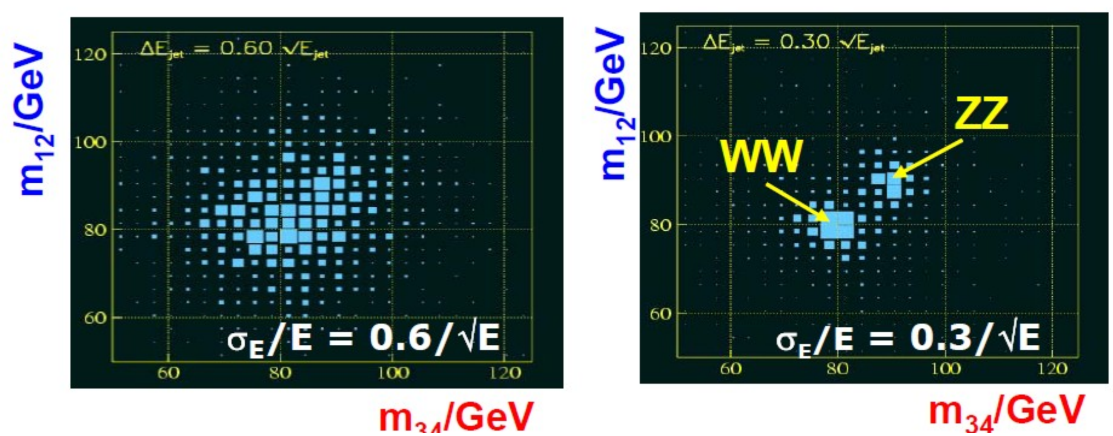
Linear Collider Calorimetry

★ **Any future collider experiment geared towards precise measurements requires very good jet energy resolution to maximise physics reach:**

Often-quoted example at ILC: $e^+e^- \rightarrow \nu\overline{\nu}W^+W^-$ **vs.** $e^+e^- \rightarrow \nu\overline{\nu}ZZ$



Reconstruction of two di-jet masses discriminates between WW and ZZ final states



AHCAL – Beyond R&D for ILC

First generation physical prototype of the AHCAL:
→ proof of principle for particle flow

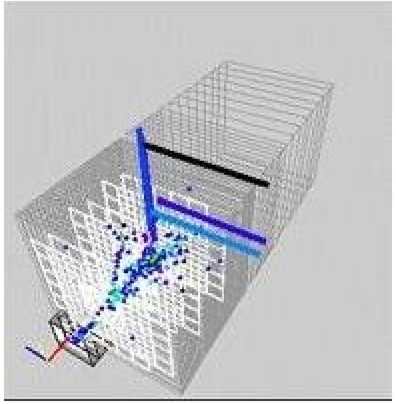
but also:
→ test and tune
of particle physics simulations (Geant4)

Detailed data from test beam makes it possible to distinguish between different physics simulations

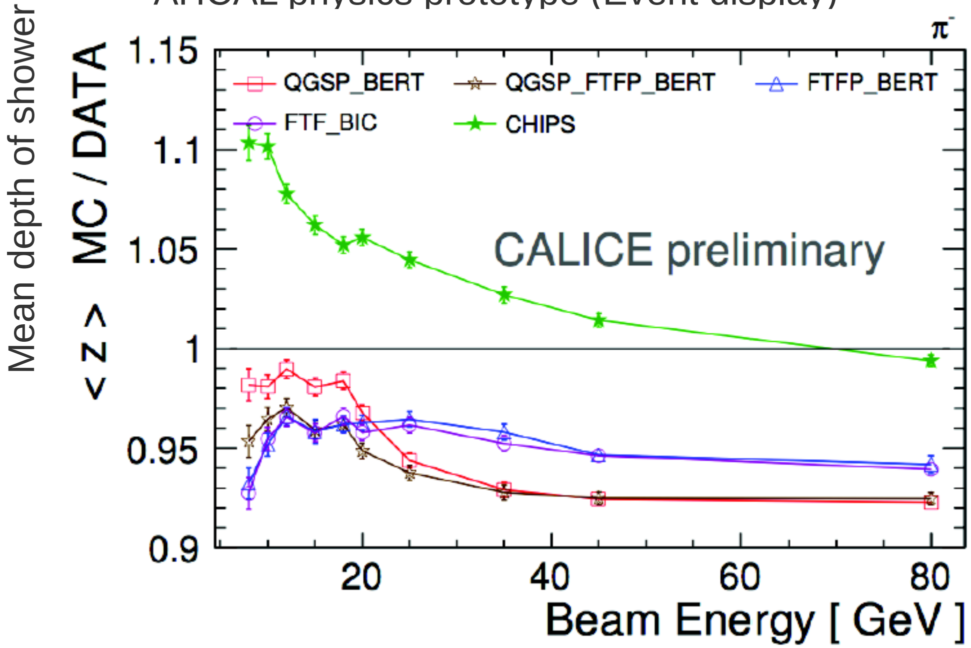
- longitudinal and lateral shower shapes
- shower starting point
- visible

Second generation technical prototype:

- adding time information
→ timing of hadronic shower development



AHCAL physics prototype (Event display)

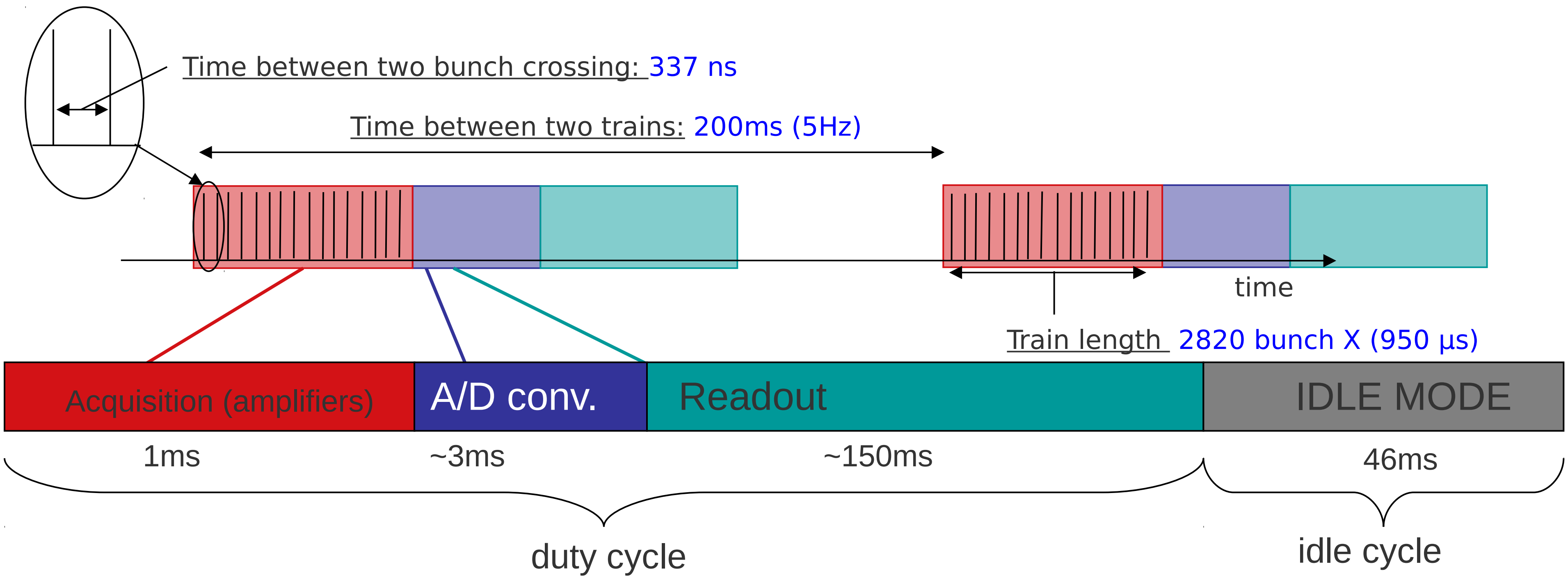


arXiv:1109.1982 [physics.ins-det]

Technical Prototype TDC

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

ILC Bunch structure:



AHCAL ASICs are designed for ILC cycle:

- measure timing only in a fraction of the duty cycle
- Analogue TDC measurement of voltage ramp in sync with ILC bunch train
- resolution of ~100ps in ILC mode

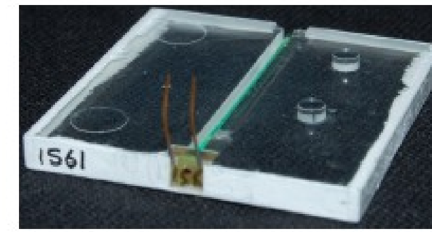
→ **Power pulsing on the TDC**

Mayor modification for CERN:
provide zero time on a “fake” channel
with fast signal from upstream scintillator
and small time jitter on one chip

The setup has been optimized with an ITEP tile (delivered at DESY in November 2011)

ITEP Standard tile:

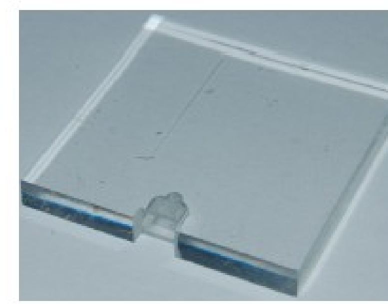
SiPM	Tile	border	surface	LY (Pixel)
CPTA	ITEP 1235	Acid polish	3M	15,4±0,4



a first tile had been modeled from **Bicron BC-400**
dimple for **direct coupling** to SiPM designed by MPI Munich
coupled to **Hamamatsu MPPC S10362-11-50P**

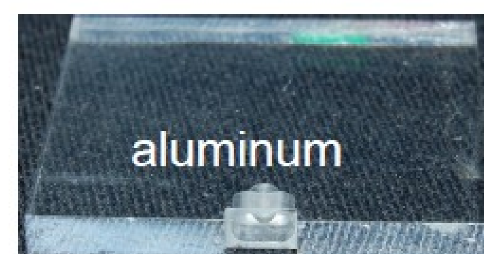
} reference for comparison

a second tile had borders coated with aluminum evaporation



Reference tile+SiPM:

SiPM	Tile	border	surface	LY (Pixel)
MPPC	BC-400	air	3M	10,4±0,4
MPPC	BC-400	Al	3M	9,3±0,4



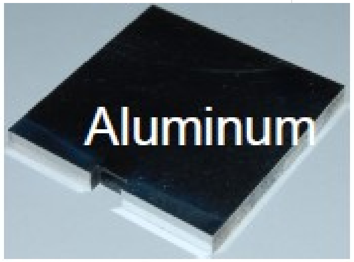
direct aluminum deposition shows less average LY value!

Several complete tile coatings have been studied:

Direct deposition on tile surface:

(from C.Soldner)

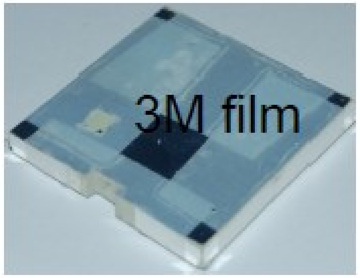
SiPM	tile	borders	surface	LY (Pixel)
MPPC	BC-400	Al	Al	~5
MPPC	BC-400	TiO2	TiO2	8,7



wrapping:

Reference:

SiPM	tile	borders	surface	LY (Pixel)
MPPC	BC-400	air	3M	10,4±0,4
MPPC	BC-400	3M	3M	28,8±0,4
MPPC	BC-400	paper	paper	19,7±0,4



With a different SiPM:

SiPM	tile	borders	surface	LY (Pixel)
Ketek II	BC-400	3M	3M	33,7±0,4

~15 % higher LY value due to better Ketek PDE

Wrapped tiles show promising results:
consistent with previous CALICE studies on coatings (e.g. Shinshu 2008 ScECAL studies, MPI Munich 2011 studies)

Next step: uniformity scan at MPI Munich
Though it has extensively demonstrated that tile non-uniformity have small impact on energy reconstruction of hadronic showers (see for example F.Simon talk on AHCAL meeting @ DESY, 13 December 2011)