Time development of hadronic showers in a Highly Granular Analog Calorimeter.

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DESY
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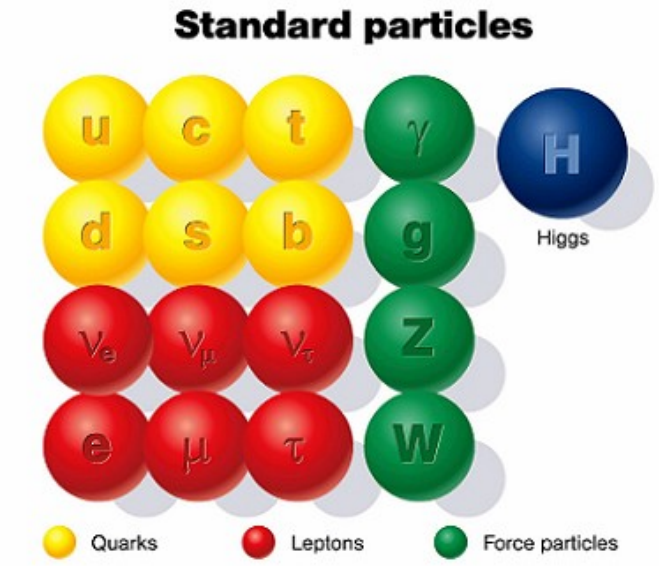
The Standard Model of Particle Physics.

The best description of our Universe so far



The Higgs Boson.

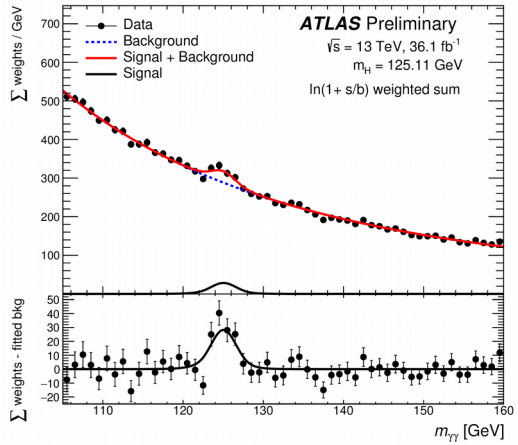
The cornerstone of the SM

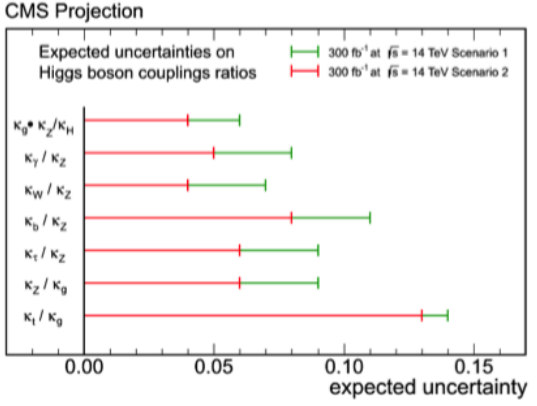
Discovered at the LHC in 2012

- First evidence of the Higgs mechanism predicted by Higgs-Englert-Brout
- Compatible with the SM predictions
- Potential to reveal new physics beyond the Standard Model
- *Deviation of couplings to the SM in the percent level*

Properties of the Higgs

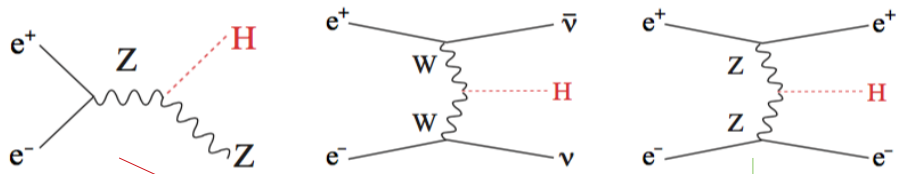
- Important free parameter of the SM
- Higgs boson mass: 125.09 ± 0.21(stat.) ± 0.11(syst.) GeV (CMS+ATLAS combined)
- Projected uncertainty on couplings between 5-20% (300 fb^{-1})
- More precise measurement is needed





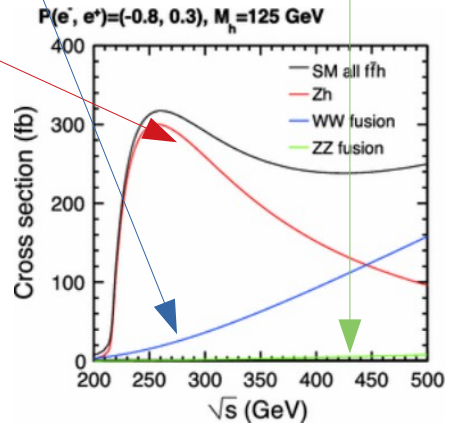
Precision Measurements.

Beyond the LHC - The case for a lepton collider



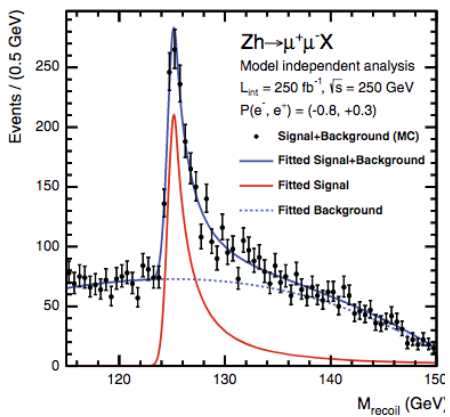
Higgs boson mass:

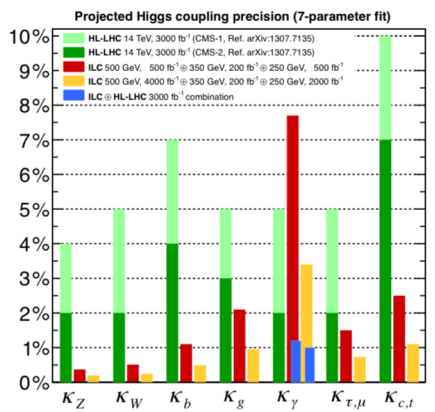
- Recoil technique $m^2_{recoil} = (\sqrt{s} - (E_{l+} + E_{l-}))^2 - |\mathbf{p}_{l+} + \mathbf{p}_{l-}|^2$
- Model-independent measurement (no assumption on the Higgs decay)
- Precision of 32 MeV on the Higgs mass with 250 fb^{-1} at 250 GeV



Couplings to the Higgs

- Precision below few percents for most couplings
- Highest decay BR(H → b$\bar{b}$) (~ 58%)
- Relies on jet energy measurement → minimize the uncertainty



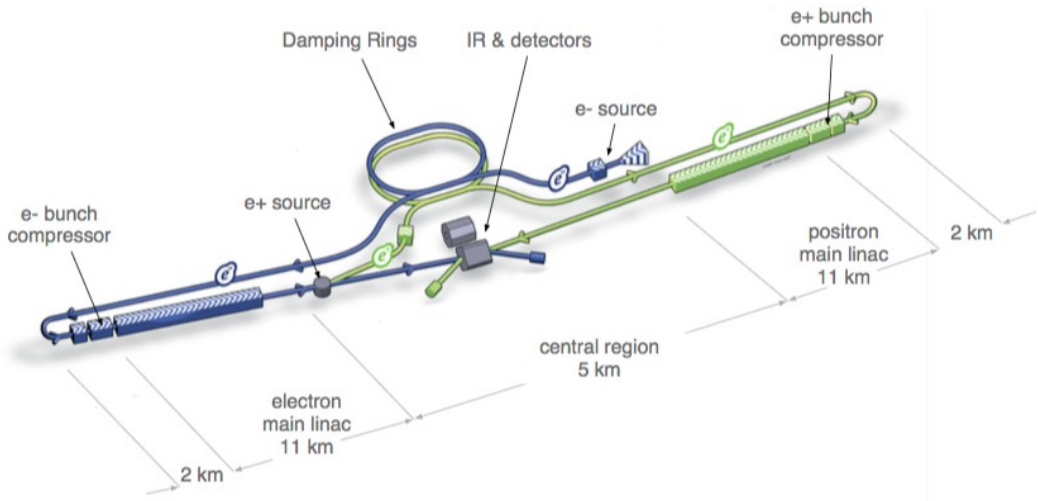


The International Linear Collider.

A future lepton collider

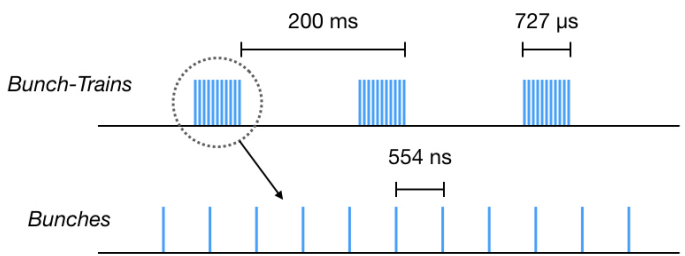
Reaching the best precision

- Linear lepton collider at $\sqrt{s}$ = 250 GeV
- Upgradable to 500 GeV – 1 TeV
- High luminosity: 2 x 10^{34} $cm^{-2}.s^{-2}$
- Low background/High statistics
- Well defined initial state



Machine operating in a 5 Hz scheme:

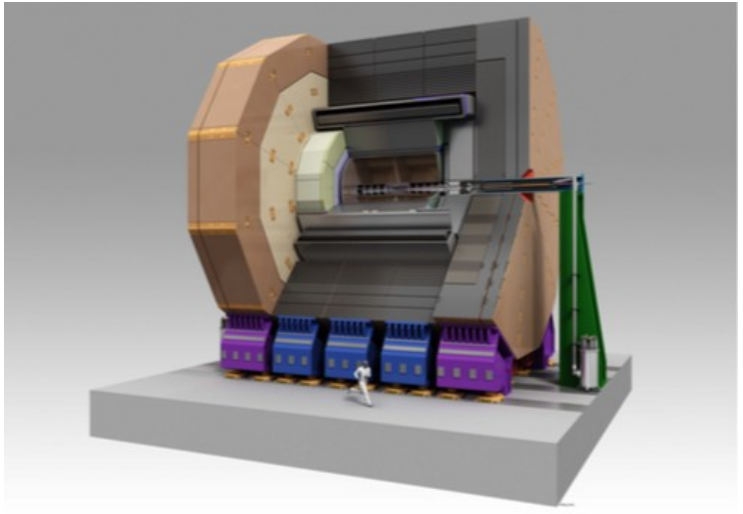
- Bunch-Trains spaced by 200 ms
- Bunches separated by 554 ns



The International Large Detector.

A particle flow driven detector

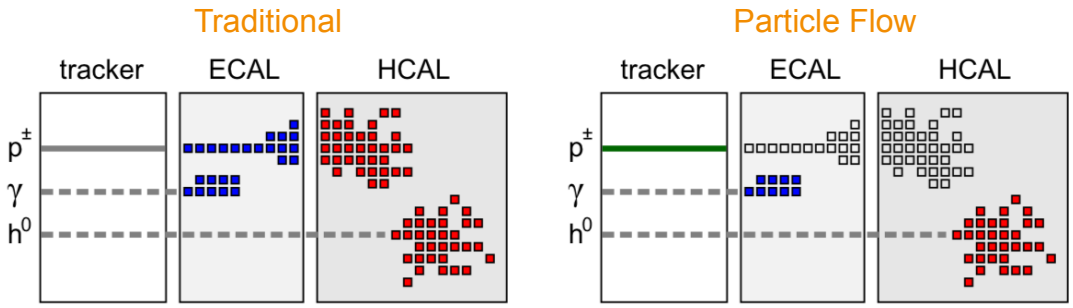
- General purpose detector
- Excellent tracking:
  - Momentum resolution $\sigma_{1/p_T} = 2 \times 10^{-5} GeV^{-1}$
  - Impact parameter resolution $\sigma_{r\phi} = 5\,\mu m \oplus \frac{10}{p\,sin^{3/2}\theta}\,\mu m$
  - 3.5 T magnetic field
- Highly granular calorimeters (millions of channels)
  - ECAL Energy Resolution ~ 10%/√E
  - HCAL Energy Resolution < 60%/√E
- Optimized for Particle Flow
  - Low material budget in front of the calorimeter (< 0.5 X_0)
  - Calorimeters inside the solenoid magnet

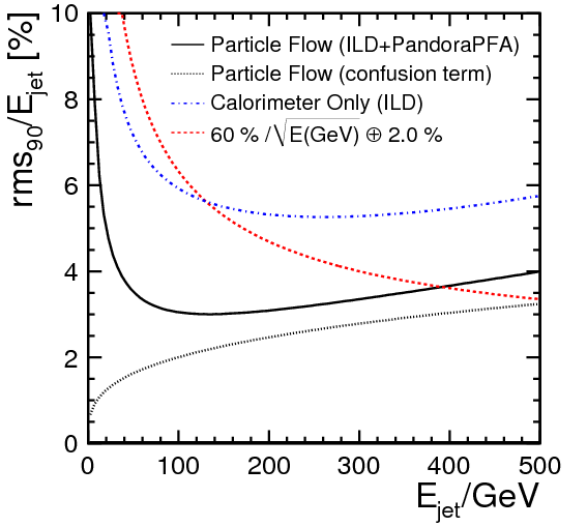


Particle Flow Calorimetry.

More than traditional calorimetry

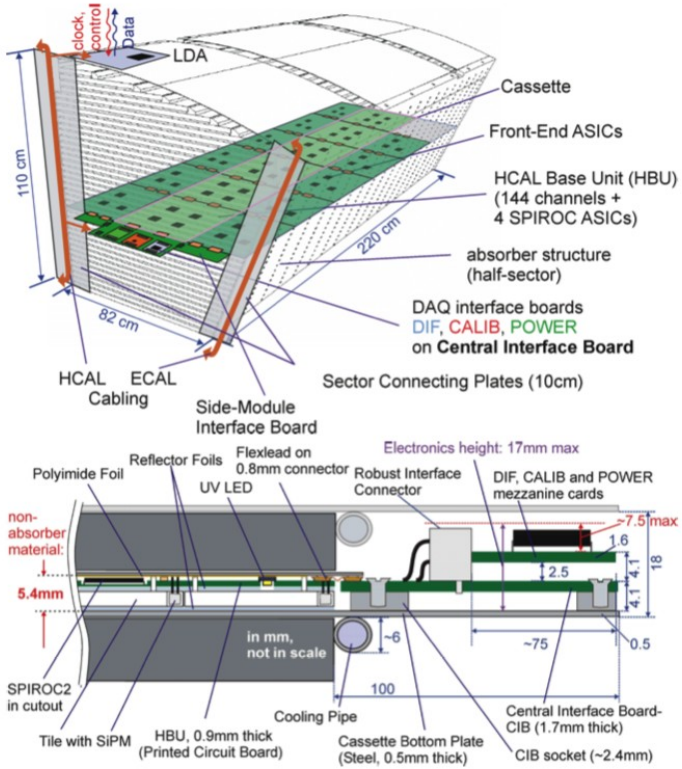
- Jet energy carried by 60% charged hadrons, 30% photons and 10% neutral hadrons
- Traditional approach:
  - Sum up all deposited energy in the calorimeter
  - 30% measured in the ECAL
  - 70% measured in the HCAL → poor energy resolution (~ 60%/√E)
- Particle Flow approach:
  - Each individual particle is measured
  - Best measurement used → charged (tracker)
  - Only 10% measured in the HCAL → reduction of the HCAL poor energy measurement
  - Around 3-4% jet energy resolution in the range of 45 to 250 GeV achieved (~ 30%/√E at 100 GeV)





The CALICE Analog Hadron Calorimeter Concept.

A highly granular calorimeter



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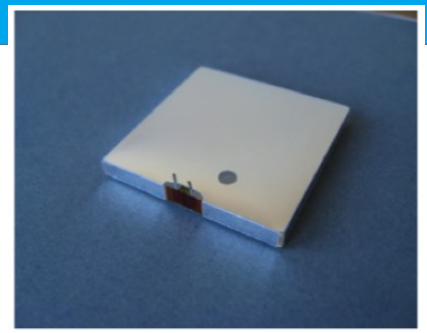
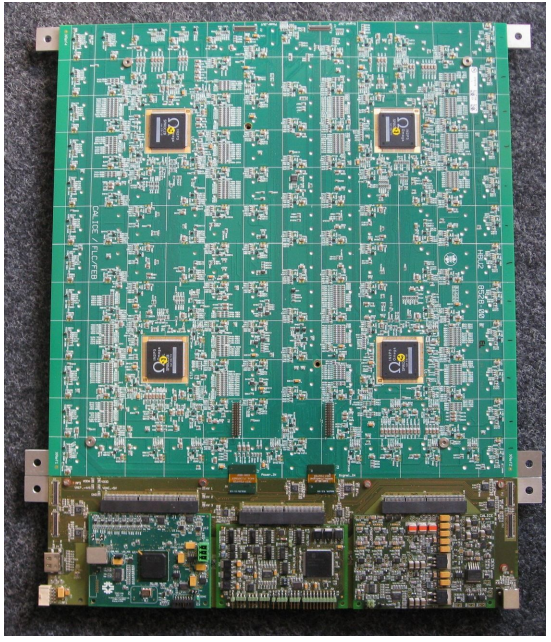
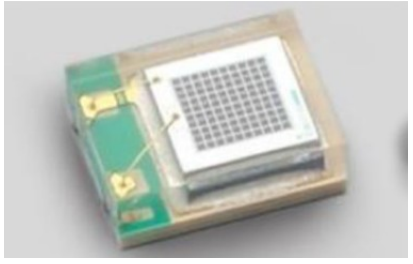
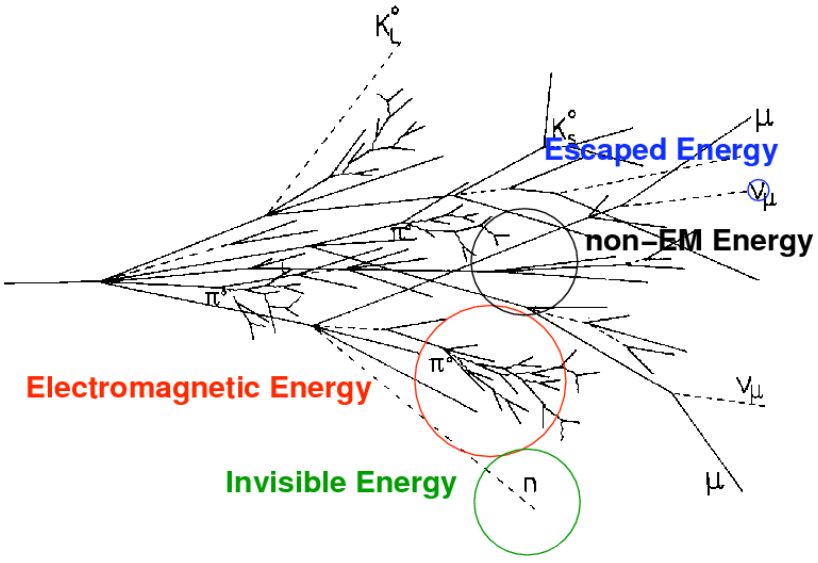






Hadronic showers.

Focus on the time development

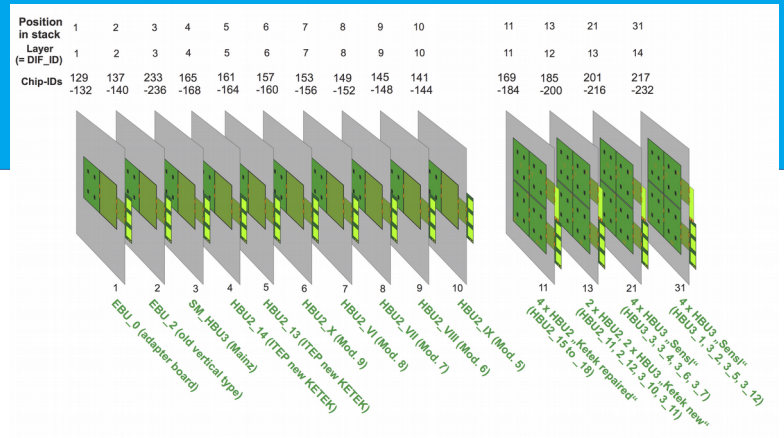


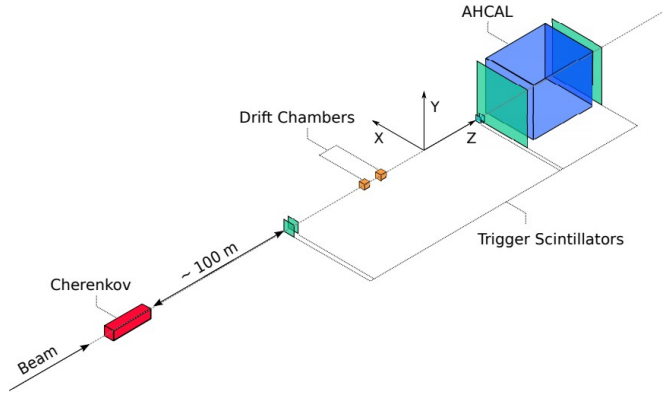
Hadronic showers.

Focus on the time development

The CERN 2015 Testbeam.

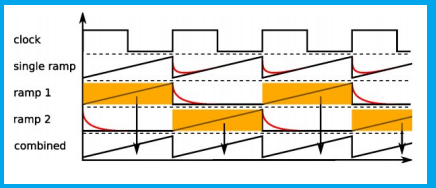
The detector and testbeam setup

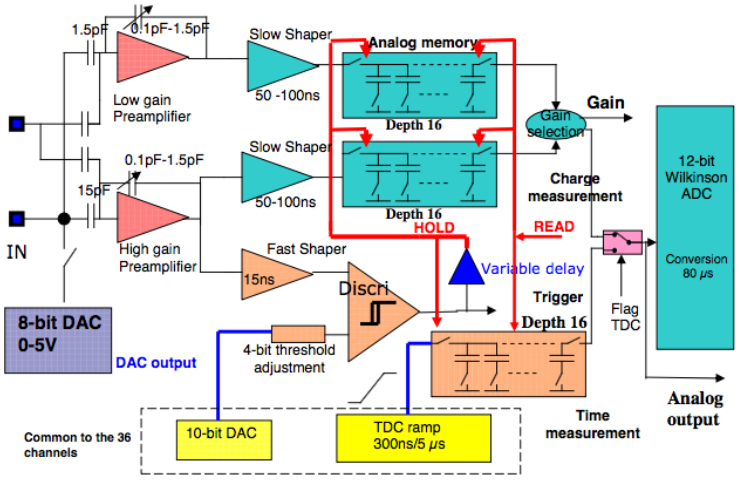


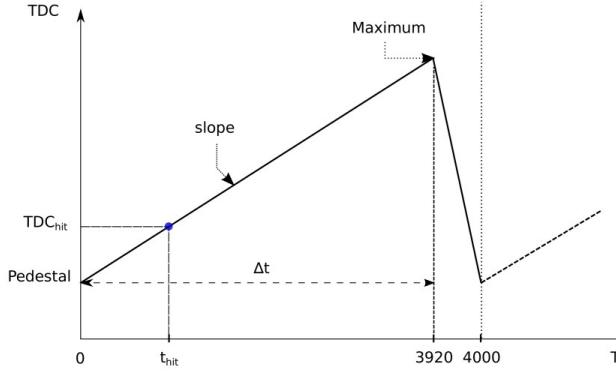


Time measurement in the SPIROC2b.

How to measure time in practical

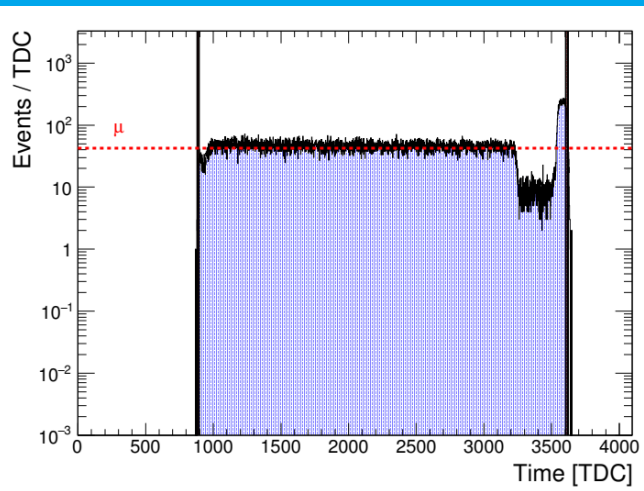


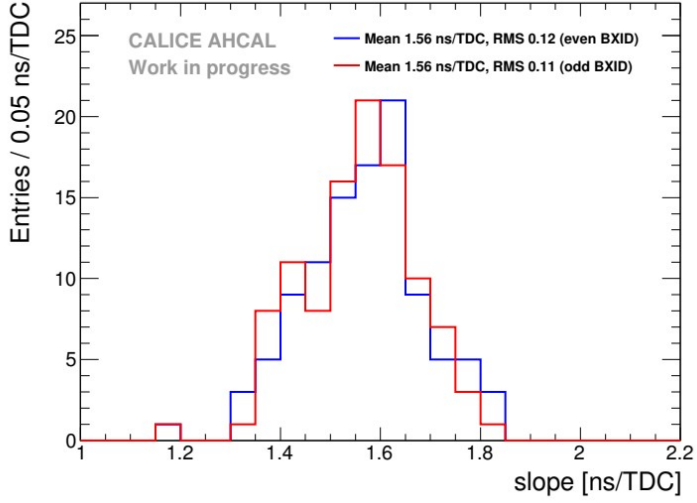




The AHCAL time calibration.

A tedious calibration procedure





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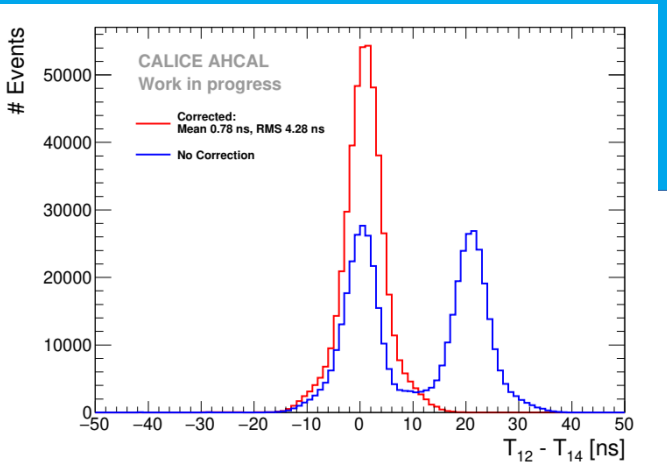

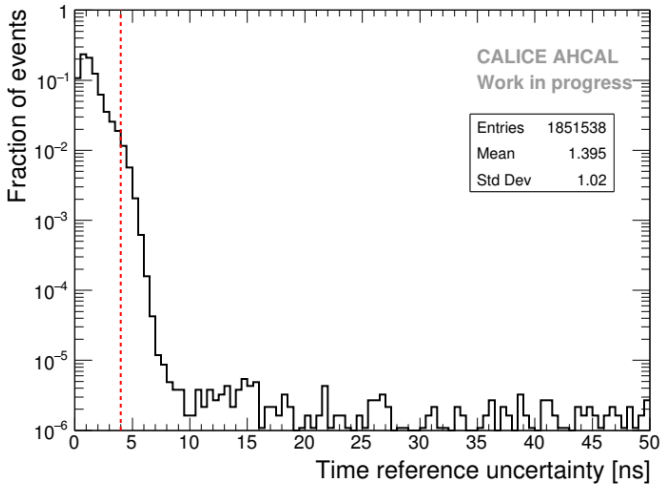

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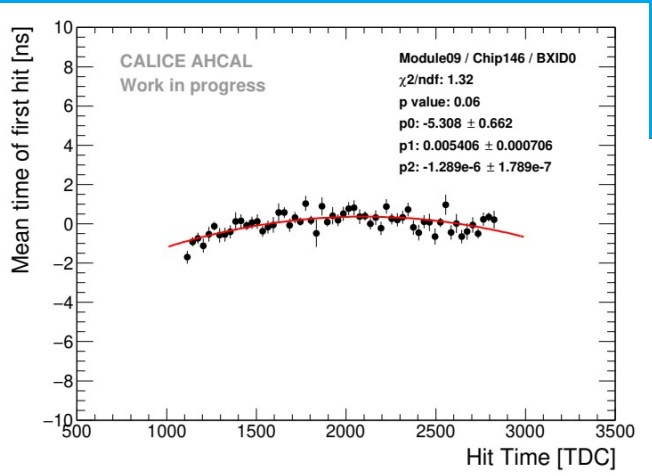

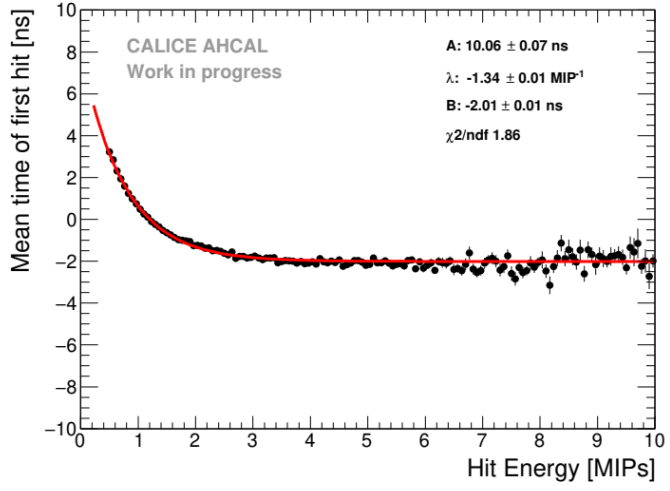

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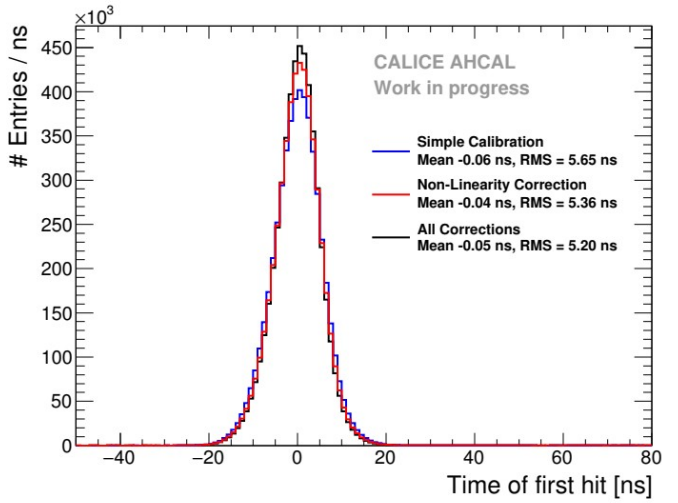

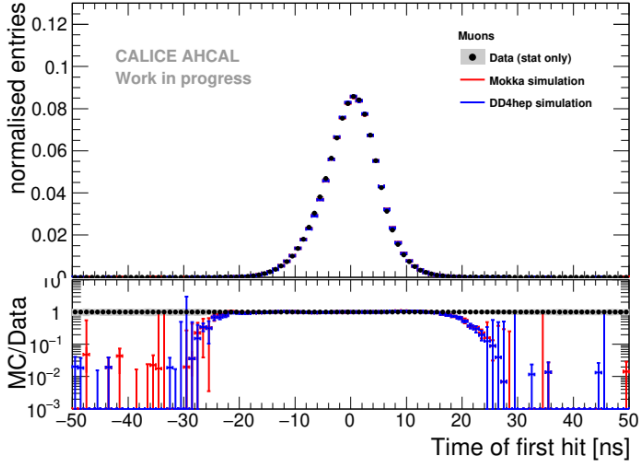

Cross-checking the time calibration.

Using electrons

Time development of pion showers.

Testbeam results

Possible applications of time measurement.

A whole new area to look

The influence of timing cuts on hadron showers in the ILD detector.

Conclusion.

Backup Slides.

Direct observation of the Higgs coupling to the top quark.

One of the latest LHC discovery