CALICE Calorimeter Resolutions

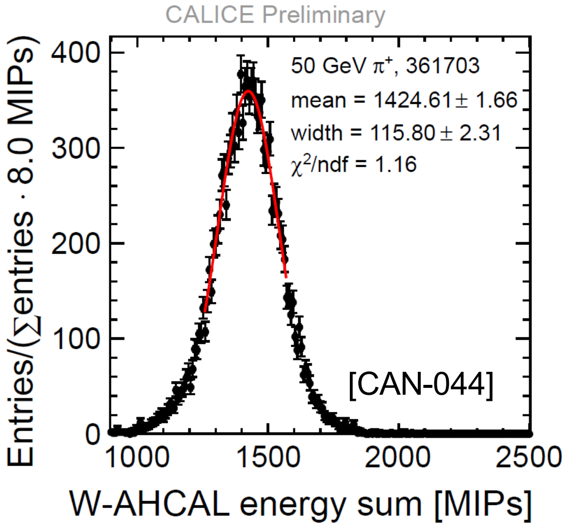
Prototypes in Testbeams from 2006-2012

Oskar Hartbrich
8th Annual Workshop
"Physics at the Terascale"
02.12.2014

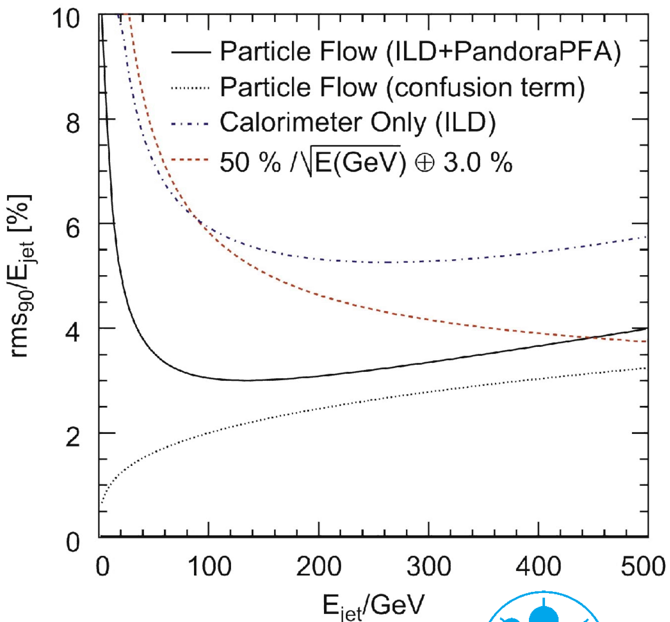
Energy Resolution in Calorimetry

- Calorimetric energy resolution depends on particle energy:

$$\frac{\sigma(E)}{E} = \underbrace{\frac{a}{\sqrt{E[\mathrm{GeV}]}}}_{\text{stochastic term}} \oplus \underbrace{b}_{\text{constant term}} \oplus \underbrace{\frac{c}{E[\mathrm{GeV}]}}_{\text{noise term}}$$

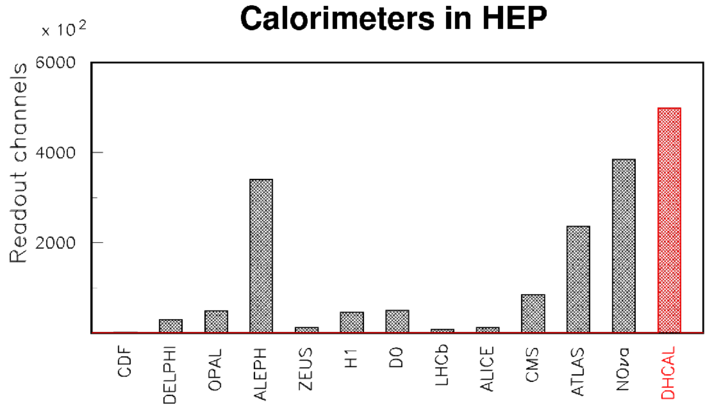


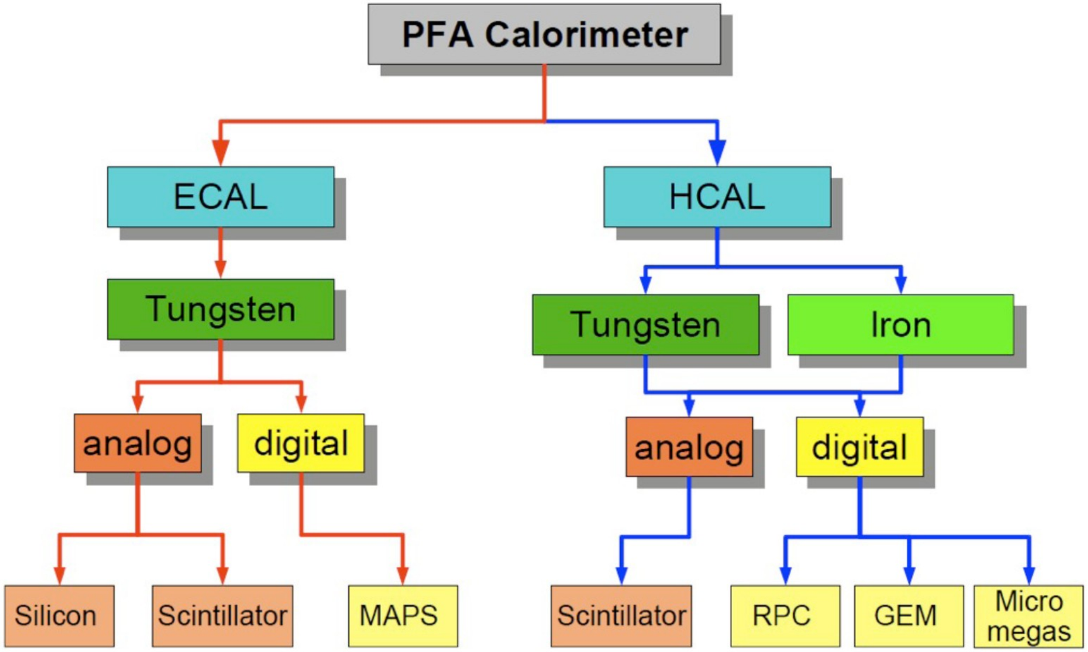
- Particle flow improves jet energy resolution
  - Typical jet: ~60% $(h/l)^+$, ~30% γ, ~10% h^0
  - Use best resolution detector for each particle in jet
  - Needs high granularity to discern energy depositions from neutral and charged particles
  - Always improves resolution above classic calorimetry
- Need unprecedented spatial resolution while maintaining competitive energy resolution



CALICE Collaboration

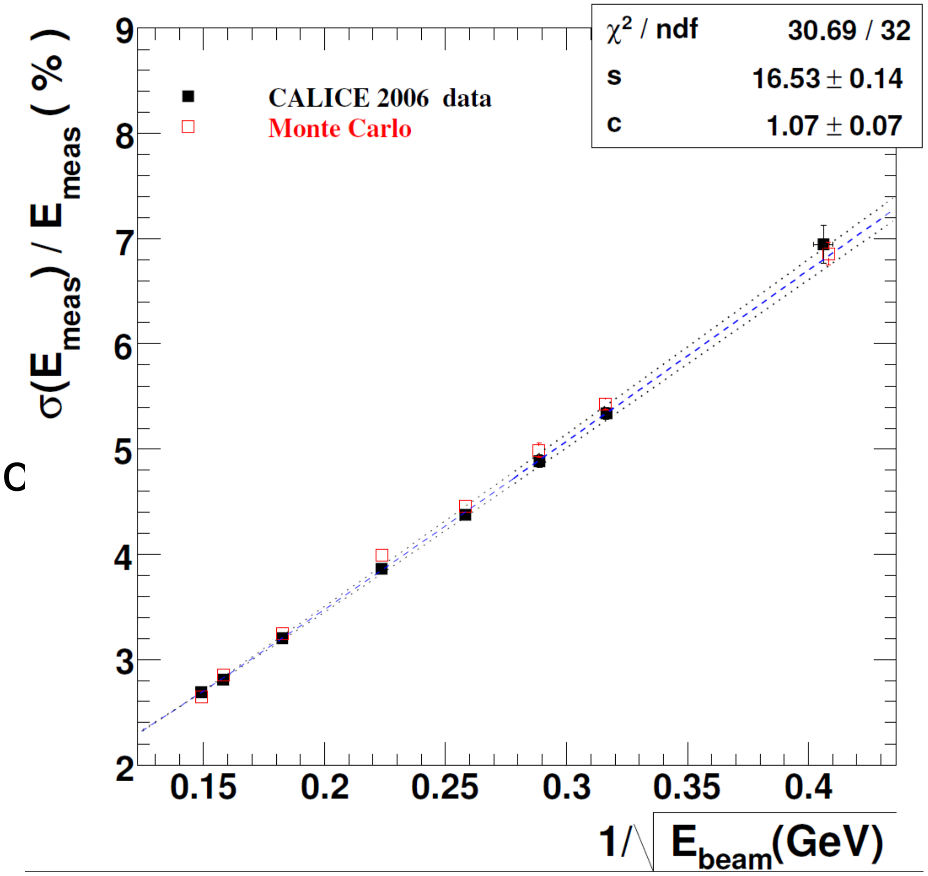
- R&D of Particle Flow calorimeters for future linear collider experiments
  - 60 groups/institutes, ~350 people
- Different absorber and detection materials under investigation
  - Sandwich calorimeter, very high granularity in X/Y/Z
  - Multiple large scale prototypes built and tested at CERN, DESY and FNAL testbeam facilities





Silicon ECAL (SiECAL)

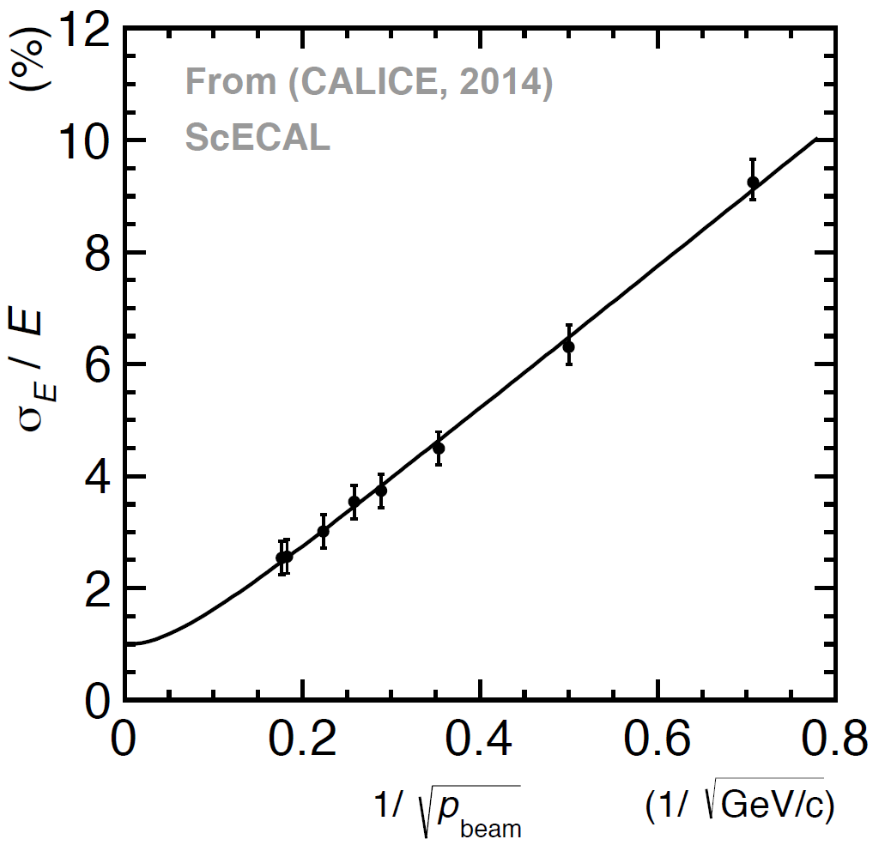
- Tungsten absorber
  - 30 layers ($0.4X_0$, $0.8X_0$, $1.2X_0$)
- Silicon PIN diode array
  - $1*1cm^2$ cells
  - 9720 channels in total
- Linearity deviations <1%
- Acceptable electron energy resolutic
  - 16.5% stochastic, 1.1% constant
  - Significantly worse than e.g. crystals
  - High spatial granularity enables PFA



[NIM A608, 372-383]

Scintillator Strip ECAL (ScECAL)

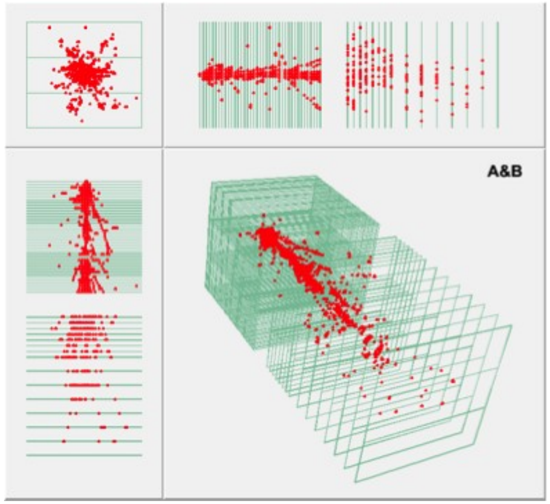
- Tungsten absorber
  - 30 layers, constant thickness
- Scintillator-SiPM readout
  - $10*45mm^2$ scintillators, staggered by layer
  - 30 layers, 72 strips per layer → 2160 cells
  - 16bit hit digitisation
- Linearity deviations <2%
- Good electron energy resolution
  - 12.8% stochastic, 1.0% constant
  - Strip geometry requires separate reconstruction of hit positions for PFA

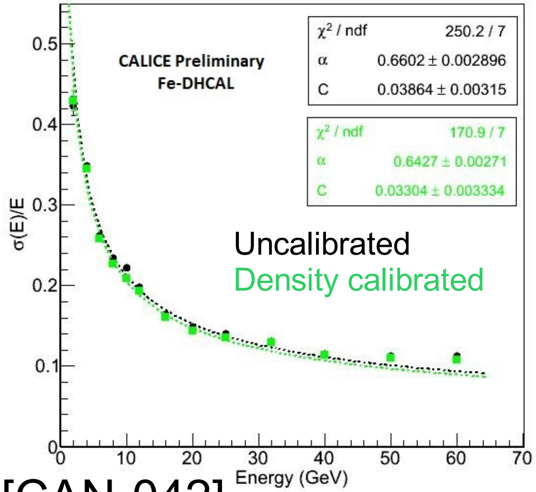


Published in:
CAN-016c

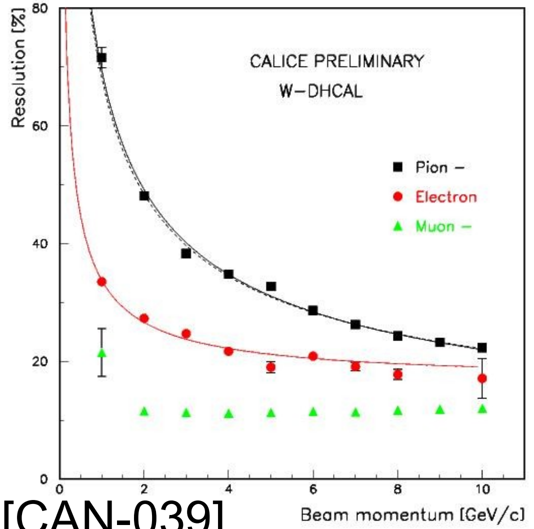
Digital HCAL (DHCAL)

- Steel/Tungsten absorber
  - Up to 54 instrumented layers (incl. TCMT)
- RPC readout, single-threshold (digital)
  - 1*1cm^2 readout pads →500k channels!
- Pion energy resolution
  - Fe absorber: ~65% stochastic term <30GeV
    constant ~12% >30GeV
  - W absorber: clearly worse resolution, denser showers
- Most detailed hadron shower imaging yet





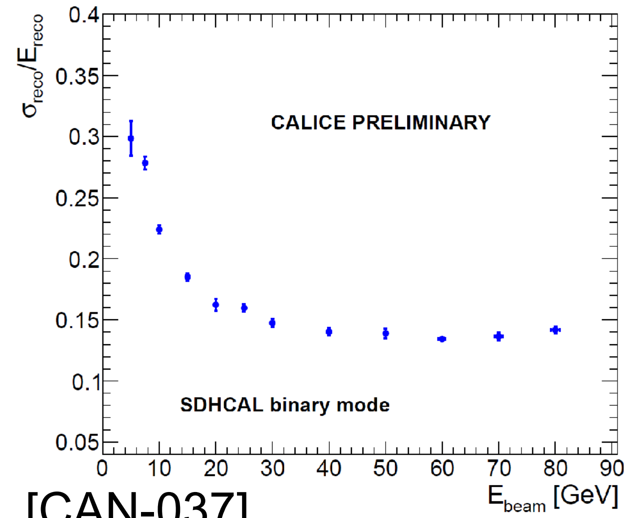
[CAN-042]



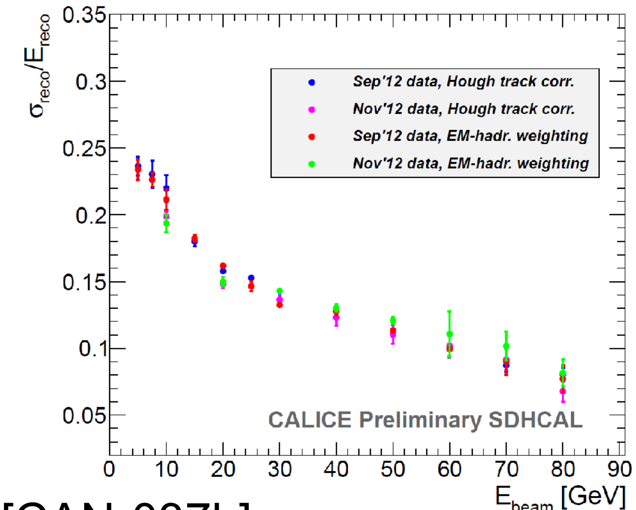
[CAN-039]

Semi-Digital HCAL (SDHCAL)

- Steel absorber
  - 48 layers instrumented
- RPC readout, multi-threshold (2bit)
  - Readout ASIC already designed for ILC timings, power budget etc.
- Binary mode resolution similar to DHCAL
  - Similar flattening of resolution >30GeV
  - Details and contributions to binary energy resolution to be clarified in simulations
- Multi-threshold mode significantly improves resolutions
  - Critically depends on exact threshold positions and monitoring
  - Complex threshold weighting of hits



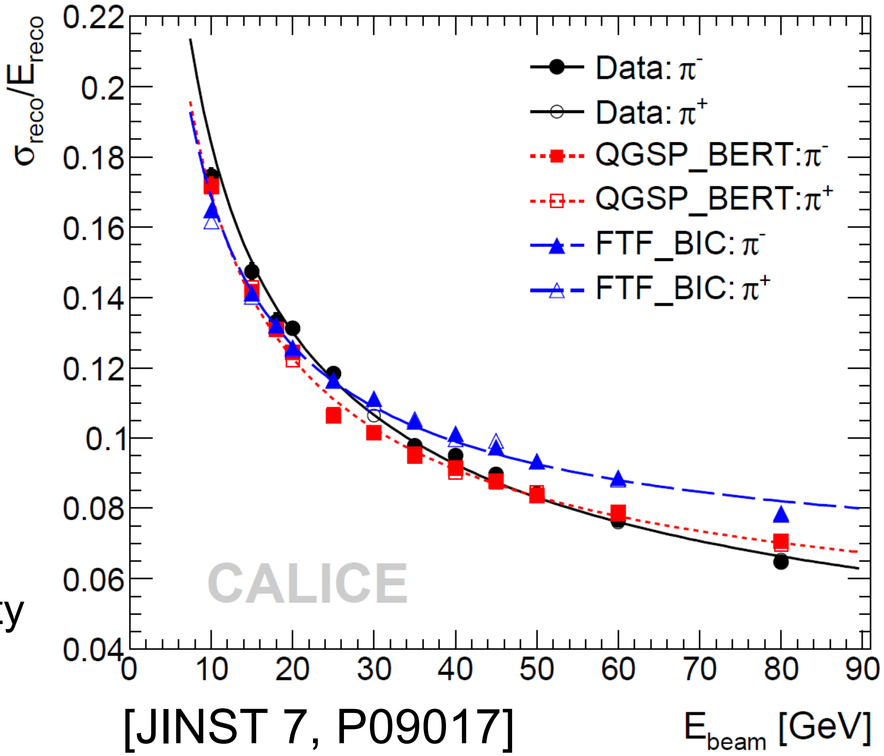
[CAN-037]



[CAN-037b]

Analog HCAL, Steel Absorber (Fe-AHCAL)

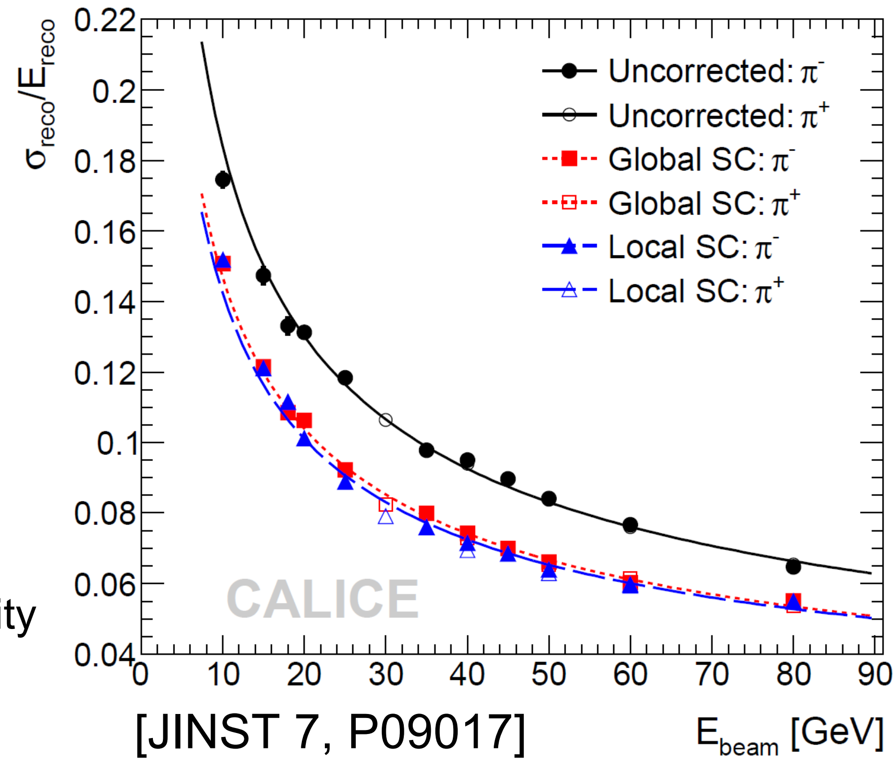
- Steel absorber
  - Up to 38 layers instrumented
- Scintillator-SiPM readout
  - 30*30mm^2-120*120mm^2 scintillator tiles
  - 7608 tiles total
- Good agreement with MC
  - 57.6% stochastic, 1.6% constant term
- Software compensation greatly improves resolution
  - Identify EM subshowers using high granularity
  - ~45% stochastic, <2% constant term
  - Proves cell size is correct to identify hadron shower substructure



[JINST 7, P09017]

Analog HCAL, Steel Absorber (Fe-AHCAL)

- Steel absorber
  - Up to 38 layers instrumented
- Scintillator-SiPM readout
  - 30*30mm^2-120*120mm^2 scintillator tiles
  - 7608 tiles total
- Good agreement with MC
  - 57.6% stochastic, 1.6% constant term
- Software compensation greatly improves resolution
  - Identify EM subshowers using high granularity
  - ~45% stochastic, <2% constant term
  - Proves cell size is correct to identify hadron shower substructure

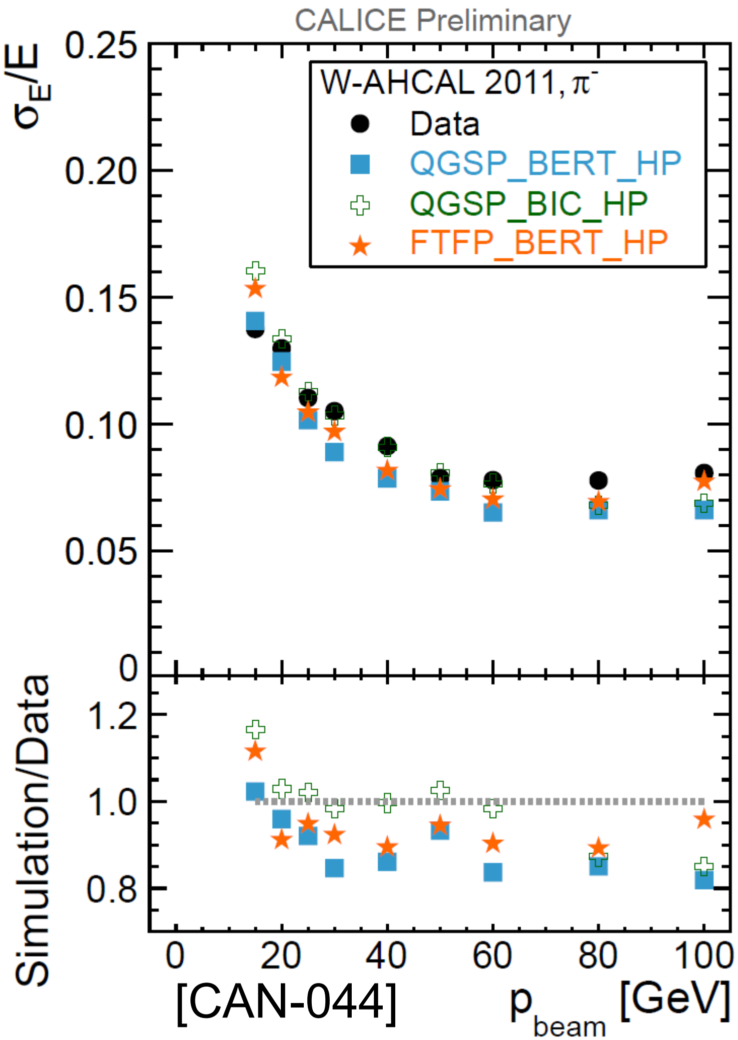


[JINST 7, P09017]

Analog HCAL, Tungsten Absorber (W-AHCAL)

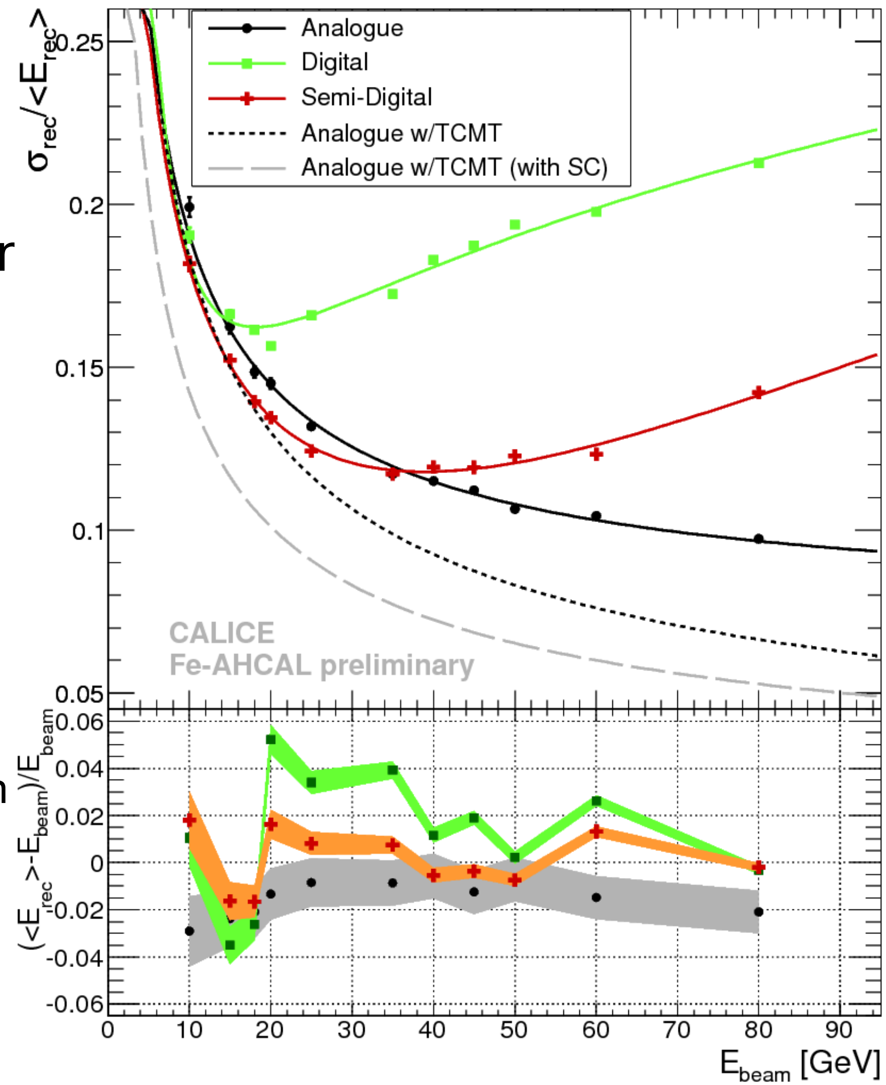
- Tungsten absorber
  - Longitudinal sampling in λ_h ≈ Fe
  - Longitudinal sampling in X_0 ≈ 3*Fe
  - Accidentally compensating calorimeter for energies >3GeV
- Resolution agrees well with MC prediction
  - ...when using _HP versions of physics list
  - ~63% stochastic term, slightly worse than Fe
  - TCMT not included in analysis

    → leakage, resoution levels off >50GeV
  - EM resolution significantly worse than Fe absorber, smaller Moliere radius, longitudinal sampling



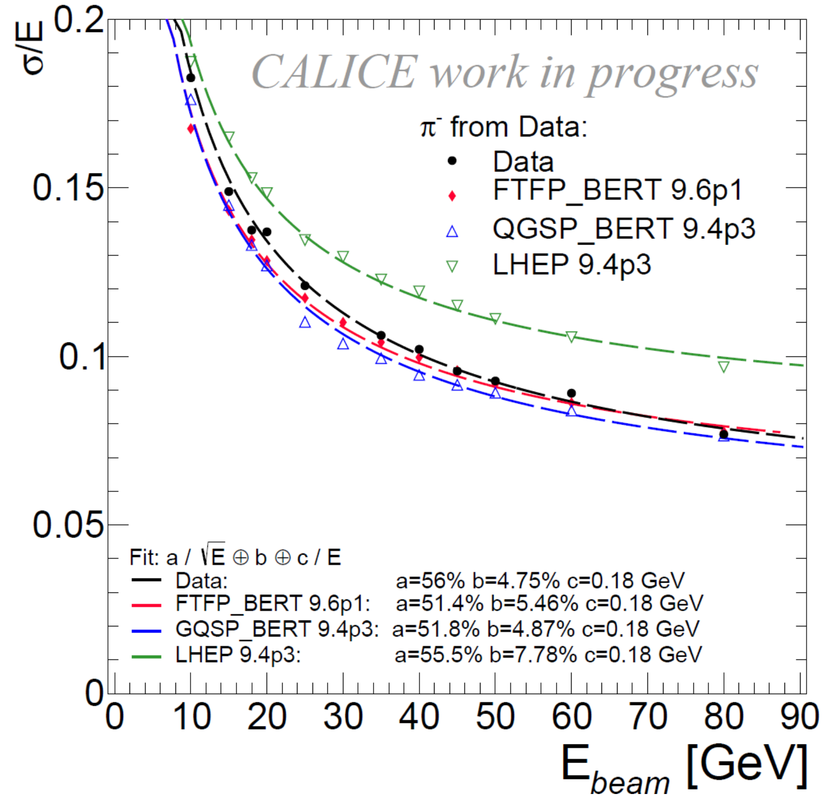
Analog HCAL, (Semi-)Digital Reconstruction

- Full amplitude information in AHCAL
  - Can emulate single and multi-threshold energy reconstruction
- Digital (single threshold) reconstruction
  - Expectedly worse resolution than (S)DHCAL (cell size)
  - In good agreement with MC
- Multi-threshold reconstruction
  - Hit energy dependent weighting
  - Better than analog for energies <30GeV
  - Worse than SC using full analog information



SiECAL + AHCAL + TCMT Calorimeter System

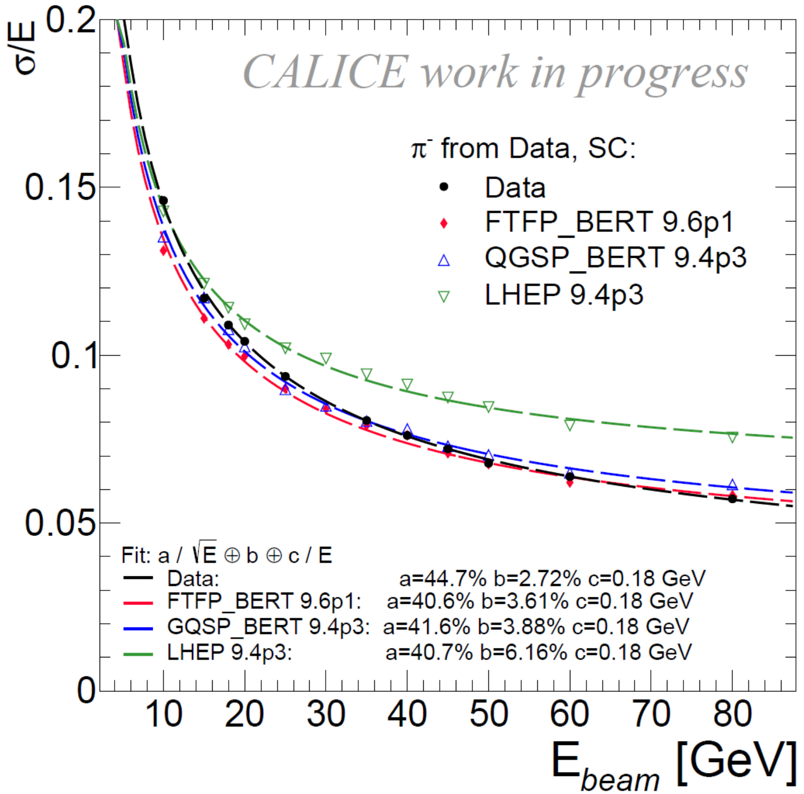
- Full Calorimeter system
  - SiECAL, AHCAL, Scitillator TCMT
  - Pion resolution
- Different weighting methods:
- Constant weights
  - Optimise weights once from data or MC
  - 56% stochastic, 4.8% constant term
- Energy dependent weights
  - Complex iterative weighting procedure
  - Factor dependencies from data or MC
  - Effectively global software compensation
  - 45% stochastic, 2.8% constant
- Any case: Pion resolution not degraded by ECAL



[M. Gabriel, MPI Munich 2014]

SiECAL + AHCAL + TCMT Calorimeter System

- Full Calorimeter system
  - SiECAL, AHCAL, Scitillator TCMT
  - Pion resolution
- Different weighting methods:
- Constant weights
  - Optimise weights once from data or MC
  - 56% stochastic, 4.8% constant term
- Energy dependent weights
  - Complex iterative weighting procedure
  - Factor dependencies from data or MC
  - Effectively global software compensation
  - 45% stochastic, 2.8% constant
- Any case: Pion resolution not degraded by ECAL



[M. Gabriel, MPI Munich 2014]

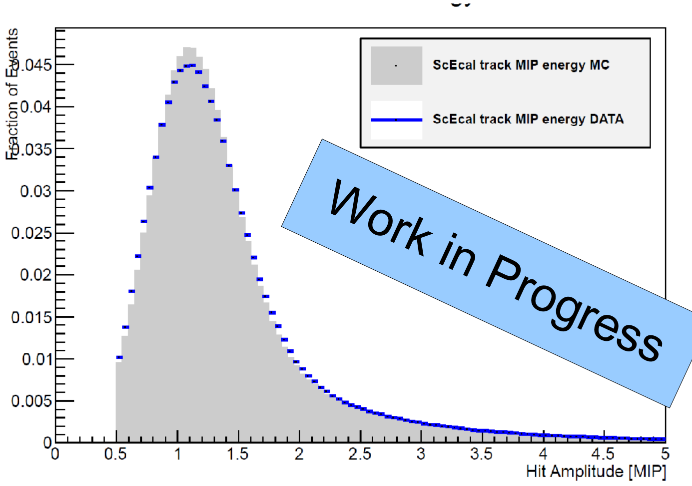
Summary and Outlook

Summary

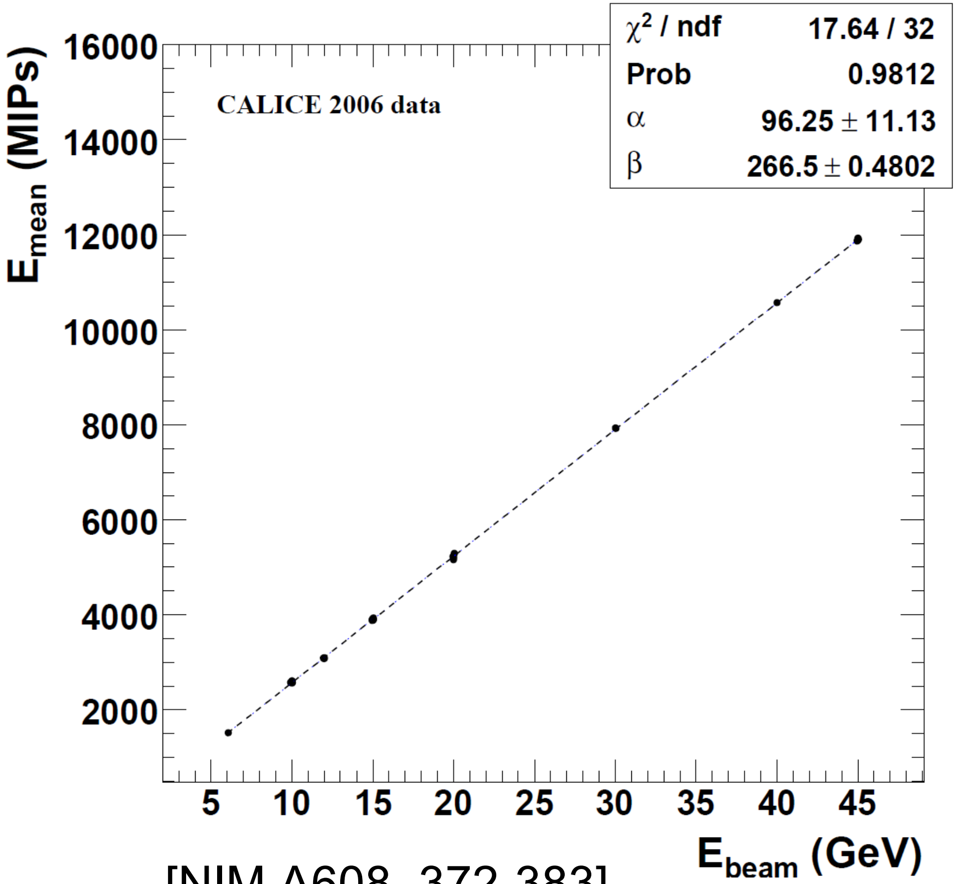
- CALICE has developed and built multiple large scale highly granular calorimeter prototypes
- Prototypes have been tested at numerous testbeams around the world
- Resolution analyses and publication well progressed
- Performance is close to expectations and simulations

Outlook

- Scintillator calorimeter system performance under investigation
- Technical prototype development and testing well underway

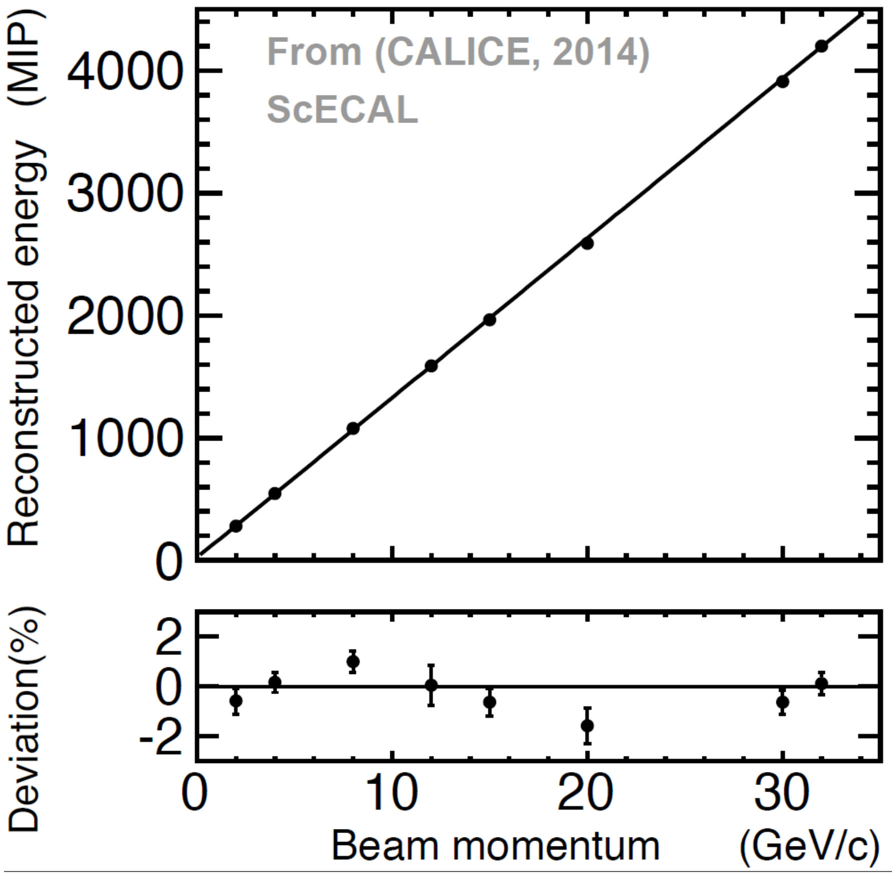


SiECAL Linearity



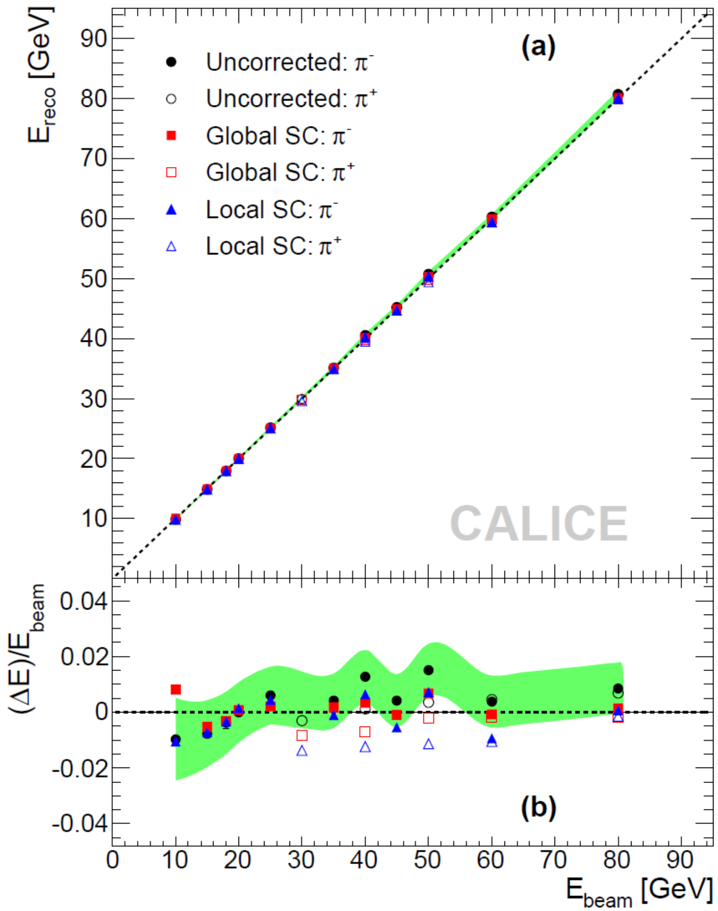
[NIM A608, 372-383]

ScECAL Linearity

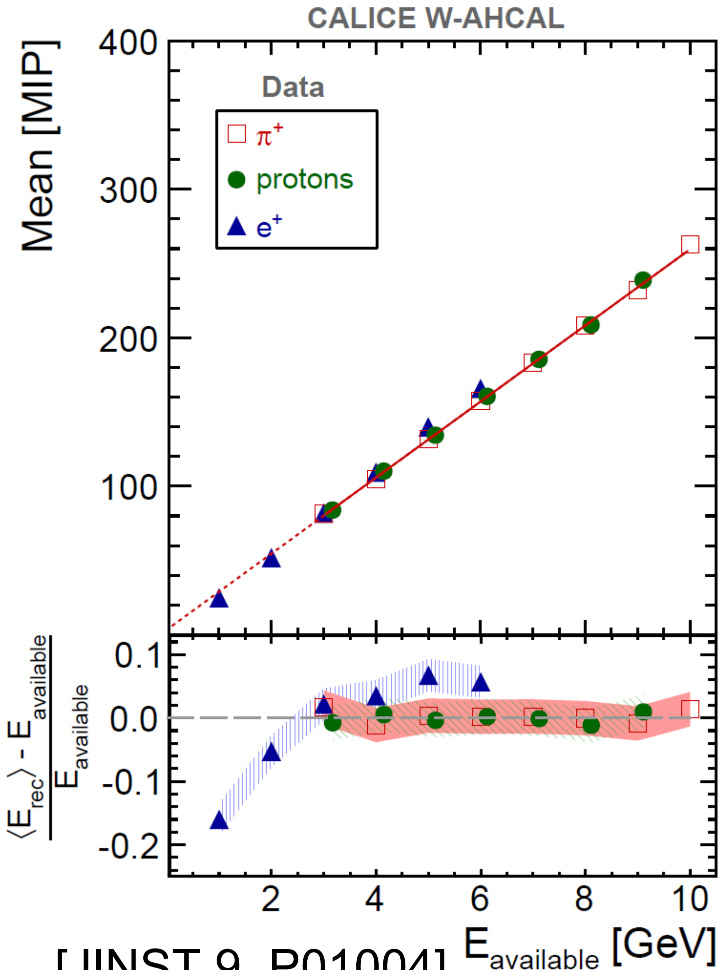


[CAN-016c]

AHCAL Linearity

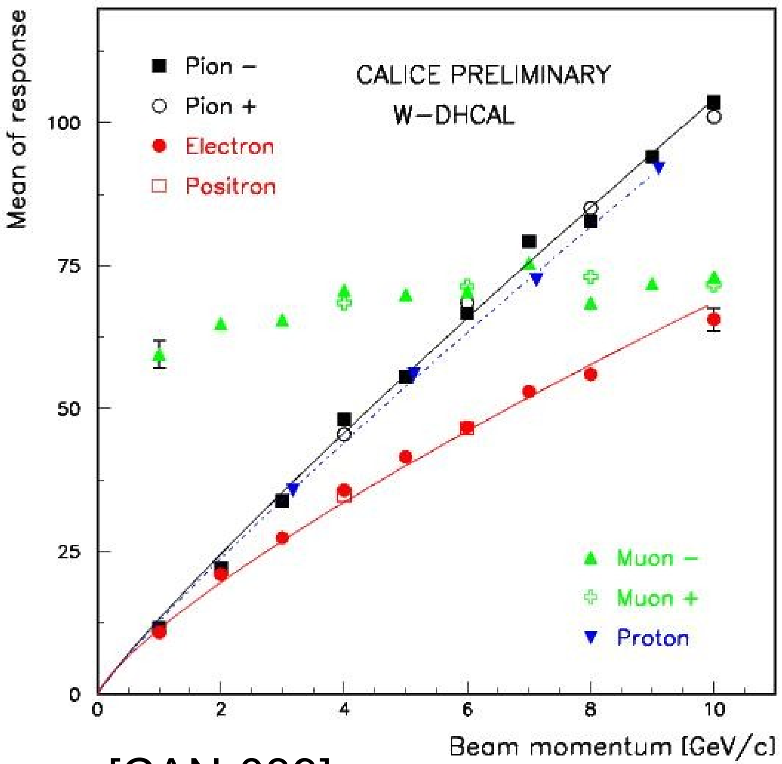


[JINST 7, P09017]

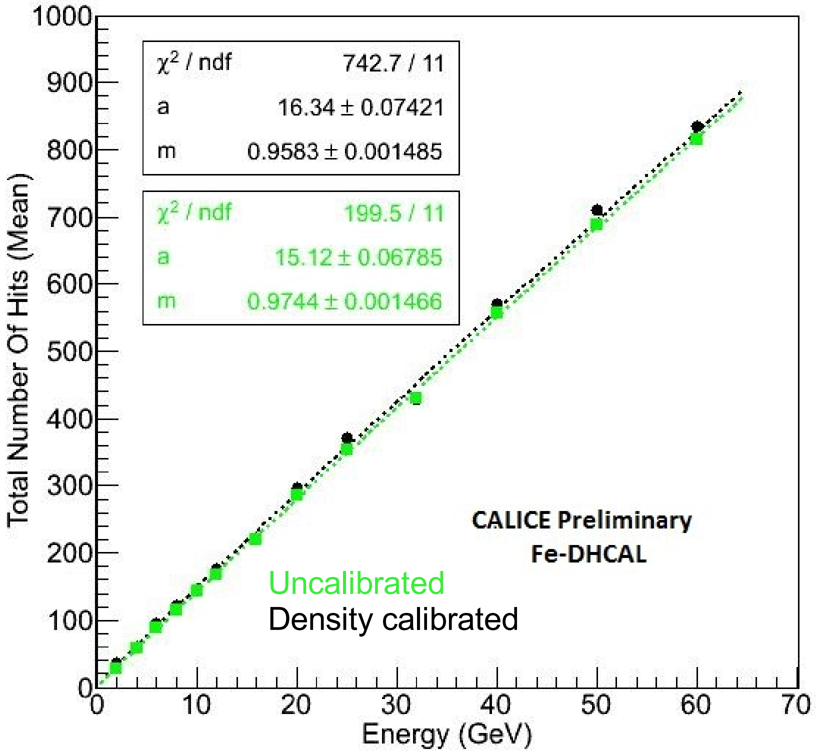


[JINST 9, P01004]

DHCAL Linearity

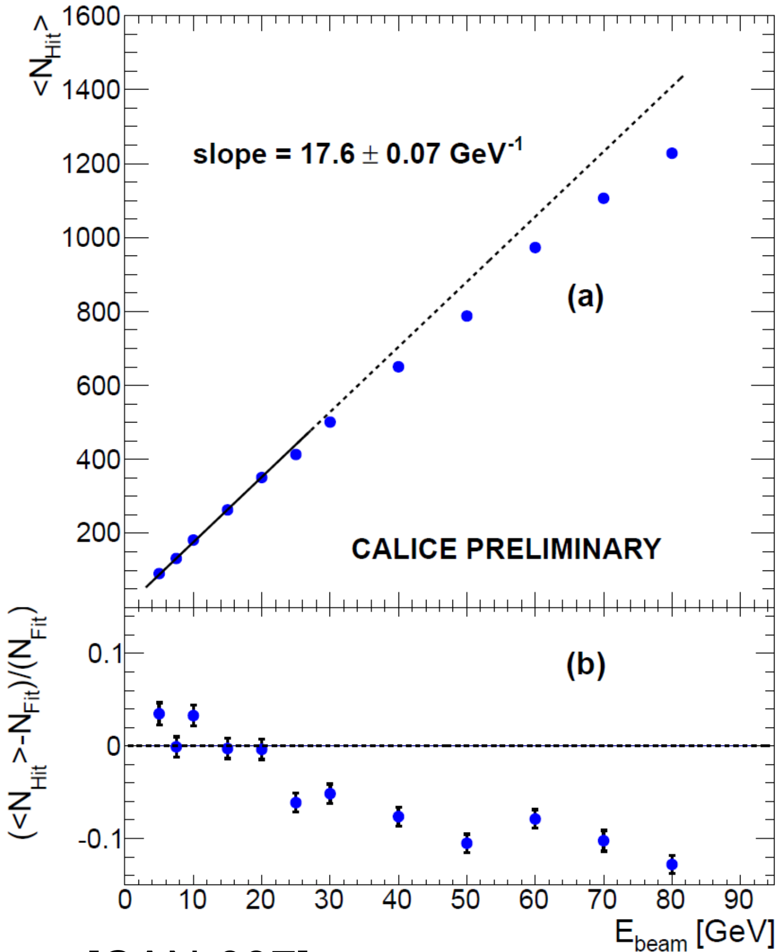


[CAN-039]

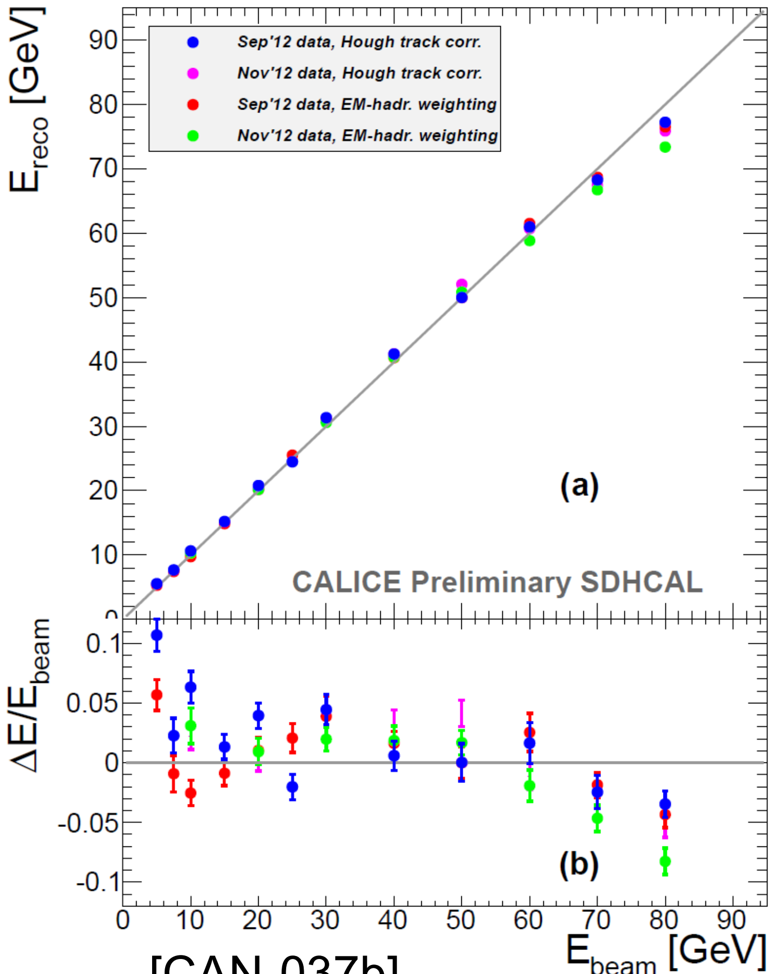


[CAN-042]

SDHCAL Linearity



[CAN-037]



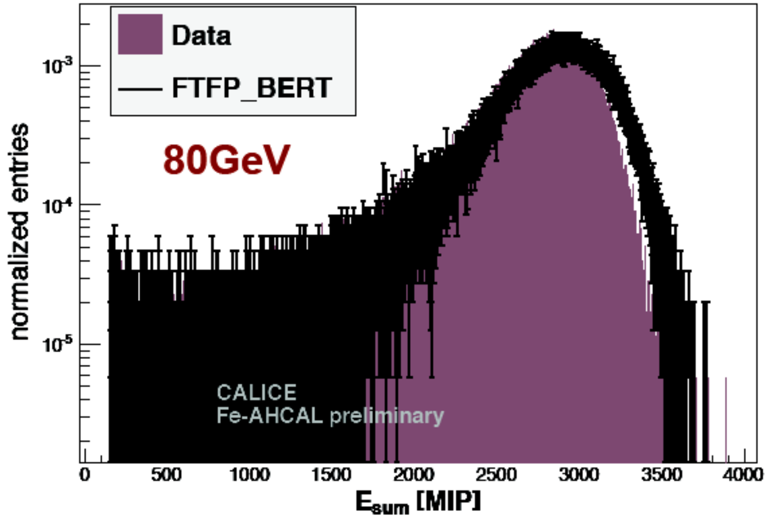
[CAN-037b]

Response Fit Procedure

Analogue (12bit readout)

E_{Sum}

> Deposited Energy



"Standardised" mean extraction procedure:

1. Gaussian pre-fit
2. Novosibirsk fit within $\mu \pm 3\sigma$ of Gaussian (χ^2<3)
3. Novosibirsk parameters for filling histogram randomly from 0 to 3σ
4. Mean & RMS of histogram