Particle Flow Calorimetry: Experimental Status and Technical Developments

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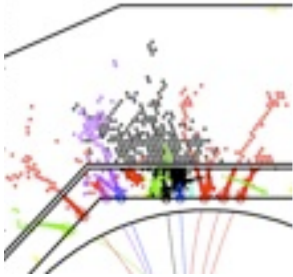
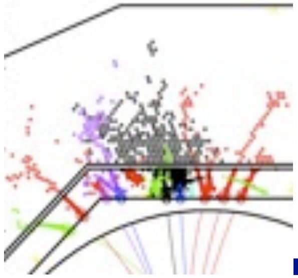


What we learnt from CALICE:

- Introduction:
  - testing PFLOW calorimetry

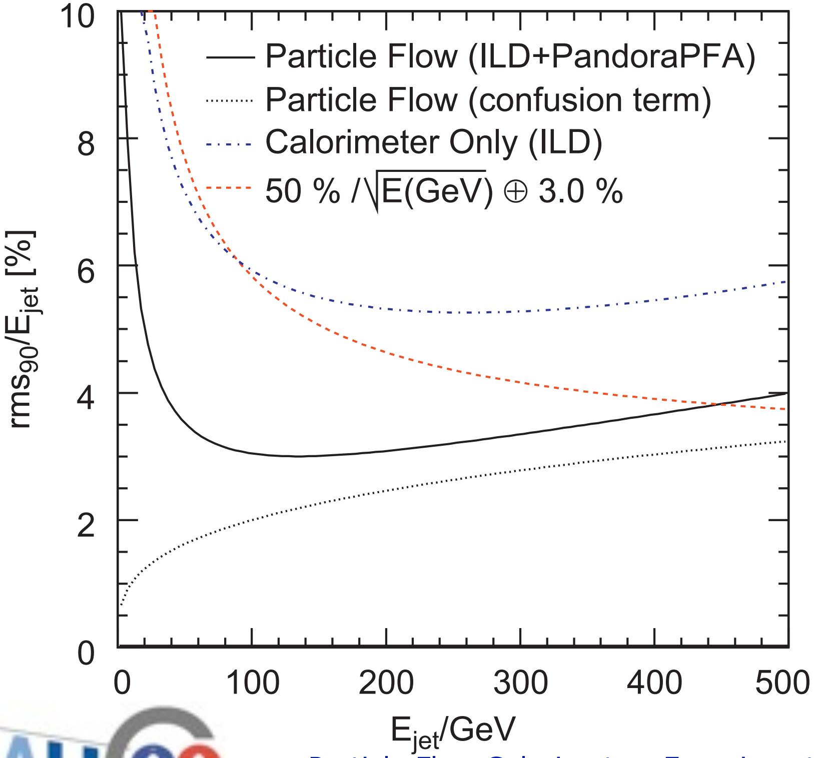
- In real terms:
  - Validate simulation
  - test algorithms
  - test technologies and establish feasibility

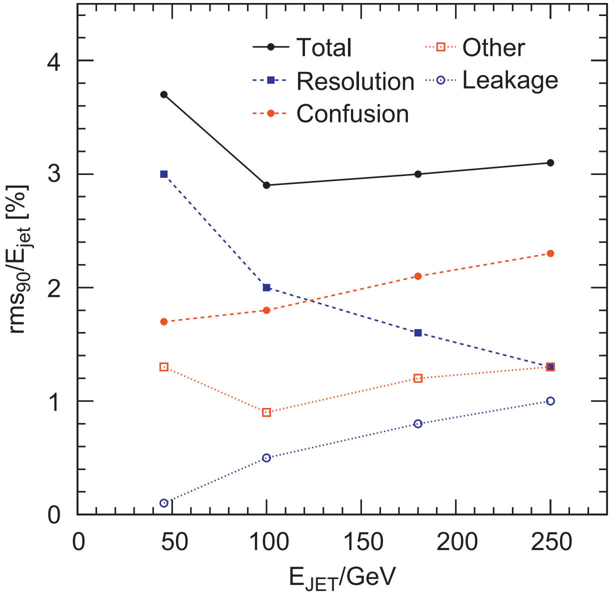


Understand particle flow performance

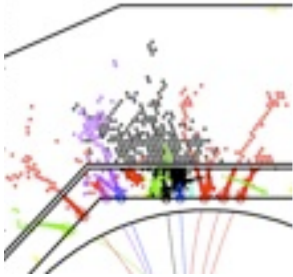
$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E \oplus 2.1 \left(\frac{E}{100}\right)^{+0.3} \%$$

Resolution Tracking Leakage Confusion



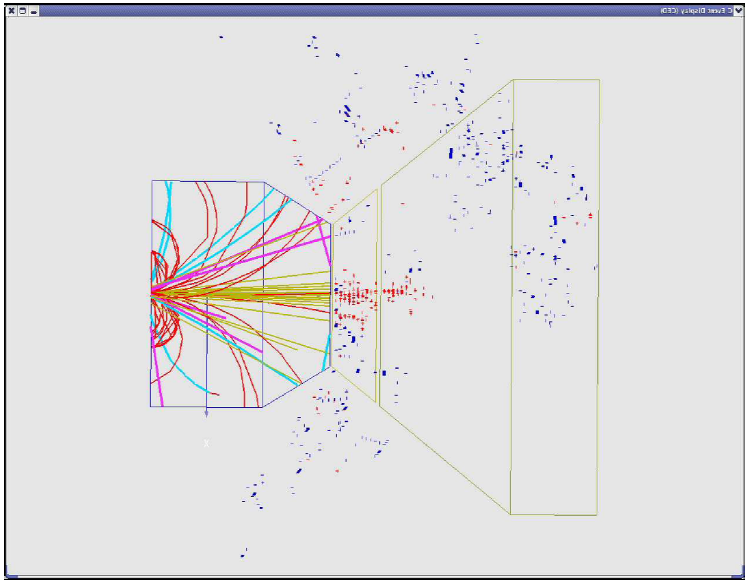


- Particle flow is always better
  - even at high jet energies
- HCAL resolution does matter
  - also for confusion term
- Leakage plays a role, too



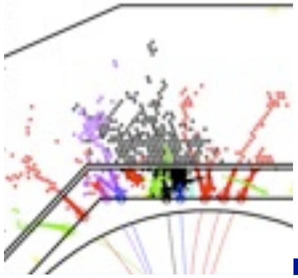
How to test it experimentally?

- “Jets” from thin targets?
  - Would require magnet spectroscopy and large acceptance ECAL + HCAL
    - Simulation study
  - Multi-million $ experiment
  - and still inconclusive
    - need to control target losses and acceptance losses at 1-2% level
    - model dependence



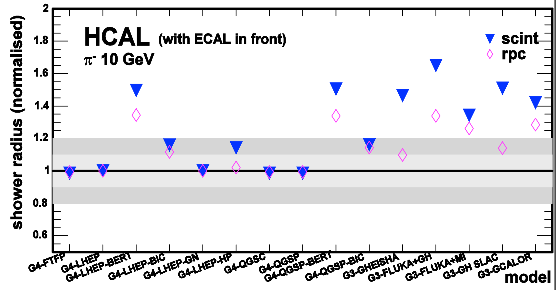
20 GeV pion, 0.8 T

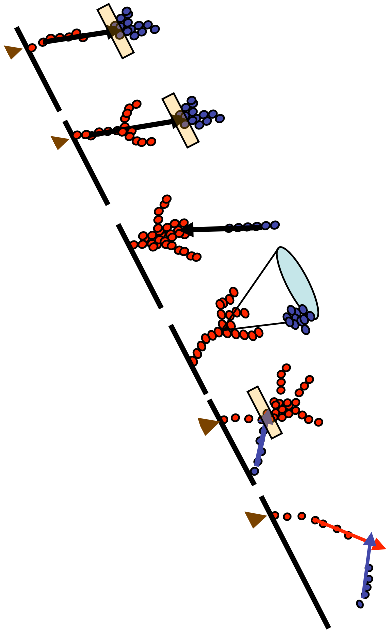
- Factorize the problem: check the ingredients
  - simulation
  - algorithms
  - technical performance

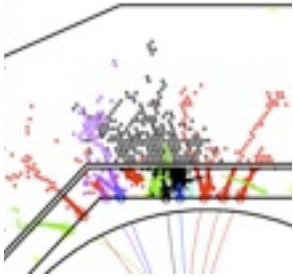


Critical questions

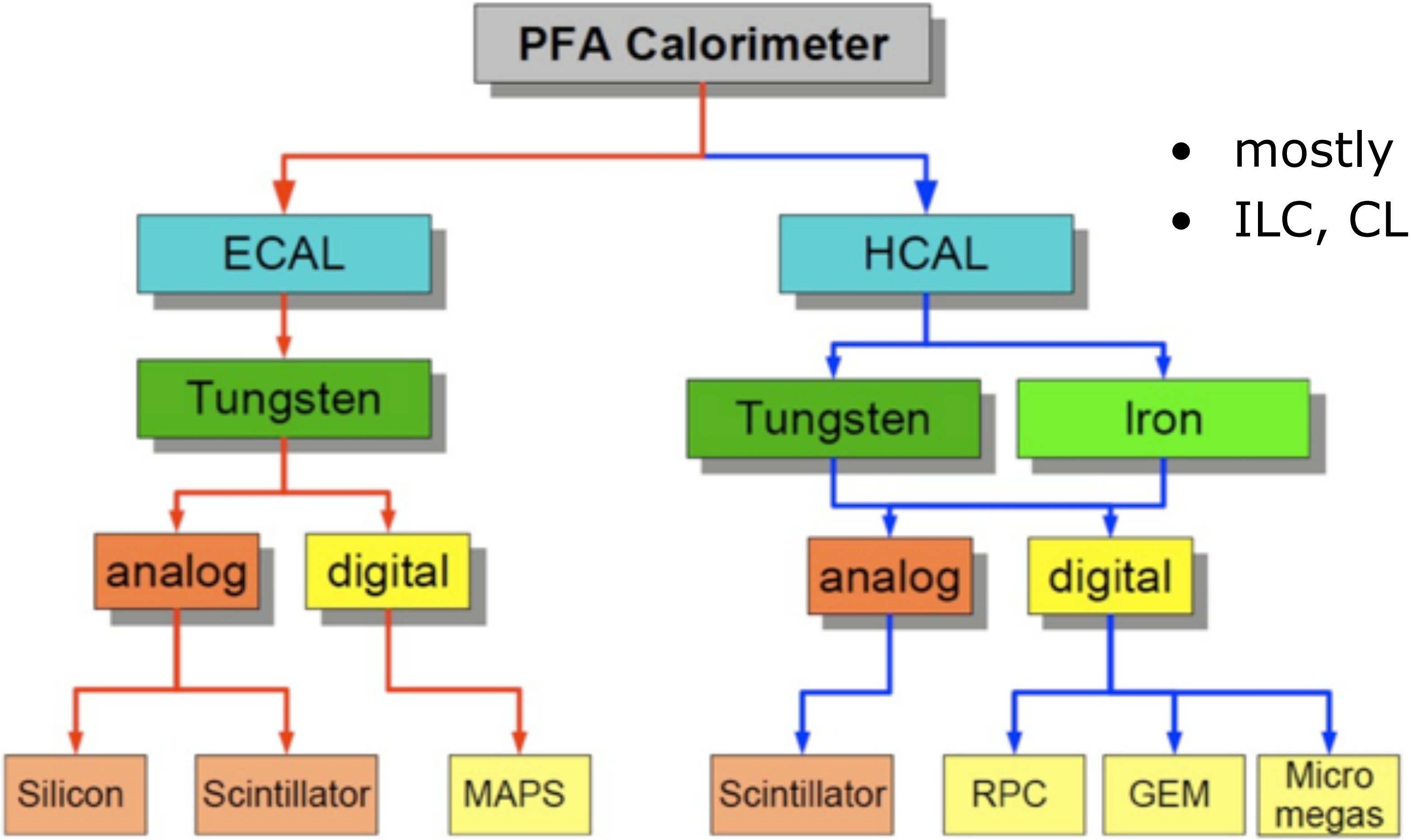
- Are the basic detector **performance** predictions confirmed?
- Are the **shower parameters** well enough simulated to predict PFLOW?
- Is the **substructure** actually there and well modeled
- Can one realize the potential of **software compensation** for gain and linearity?
- Can we verify the "**double track resolution**" of a tracking calorimeter?
- Are **detector effects** under control?
- Can we **calibrate** millions of cells and control stability?
- Can we build the detector without spoiling it by **dead material** everywhere?
- What are the relative merits of **different technologies** for PFLOW?







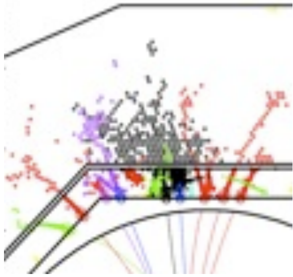
Technology tree



PFA Calorimeter

- ECAL
  - Tungsten
    - analog
      - Silicon
      - Scintillator
    - digital
      - MAPS
- HCAL
  - Tungsten
  - Iron
    - analog
      - Scintillator
    - digital
      - RPC
      - GEM
      - Micro megas

- mostly ILD, SiD
- ILC, CLIC



Overall status

- Major test beam campaigns at DESY, CERN and Fermilab
- 1st generation "physics" prototypes
- Mostly combined set-ups ECAL-HCAL

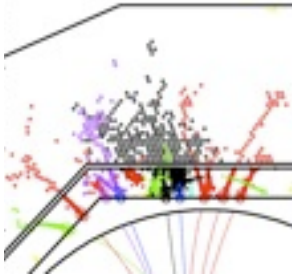
- Si W ECAL 2005-08
- Scint W ECAL 2007-09
- Scint Fe HCAL 2006-09
- RPC Fe HCAL to start end 2010

- 2nd generation "technical" prototypes: construction and commissioning ongoing, single or few layers
- Complete detectors to start with RPC-Fe HCAL 2011
- ECAL, Scint Fe HCAL later

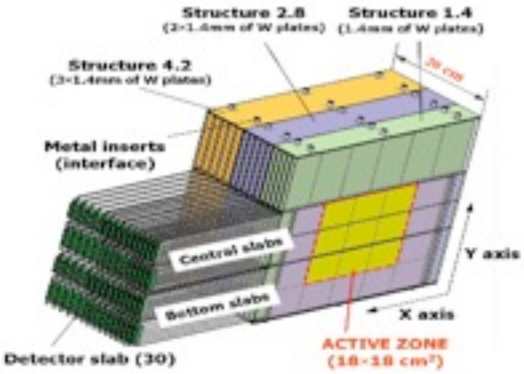
Validation of the simulations

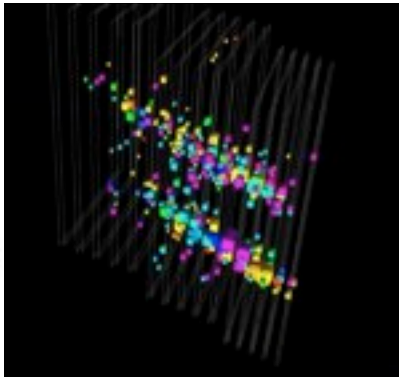
detector performance

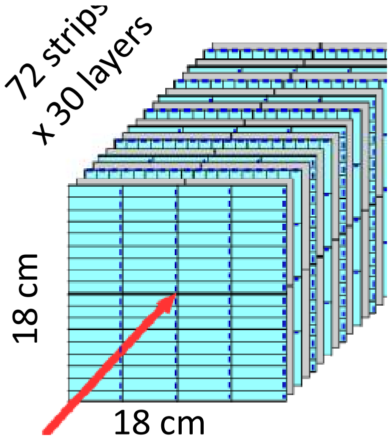
shower models

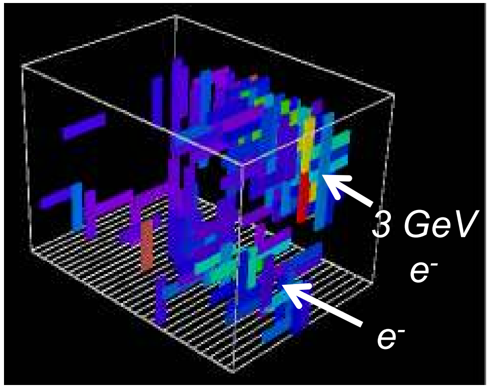


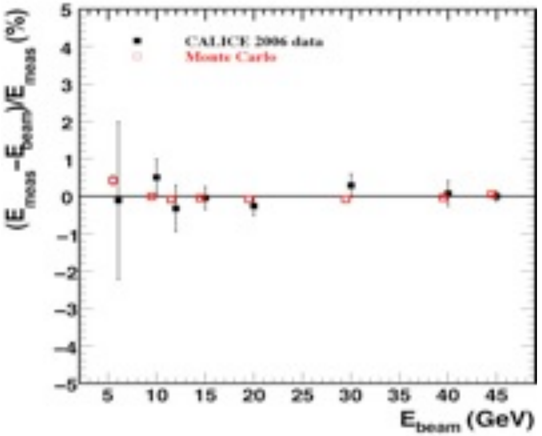
ECAL options

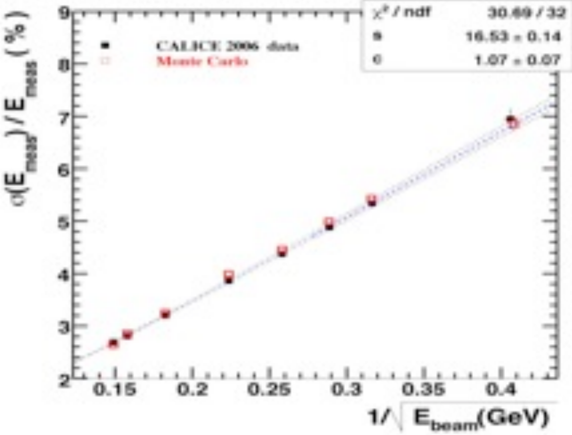


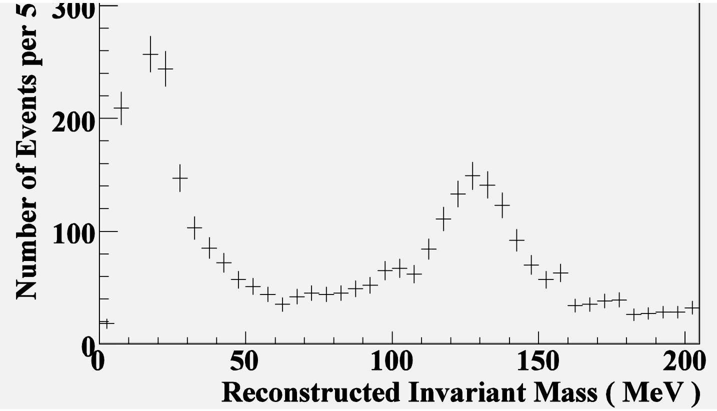




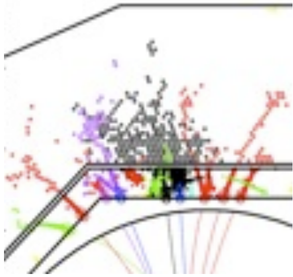






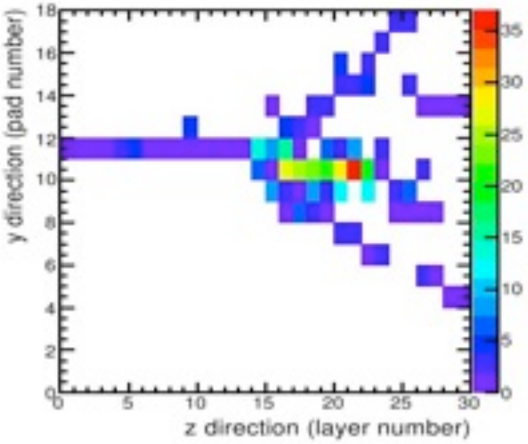


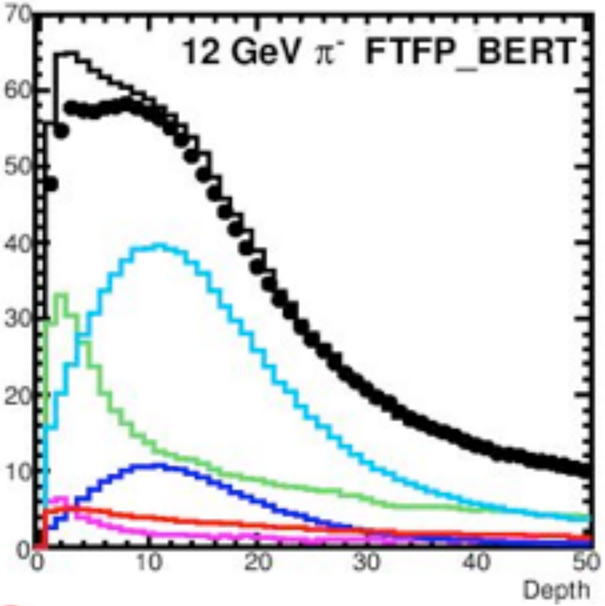
- W Si or Sci: common mechanics, similar electronics



Pions in the SiW ECAL

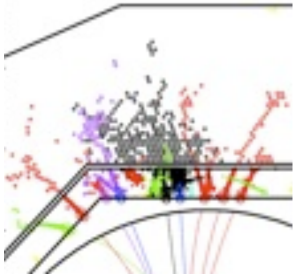
- test Geant 4 predictions with 1 cm^2 granularity
- sensitive to shower decomposition
- favor recent G4 physics lists
- certainly not perfect - certainly not bad either!



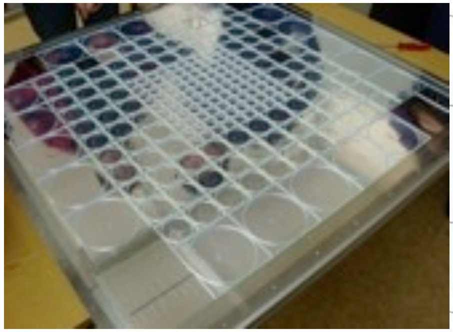


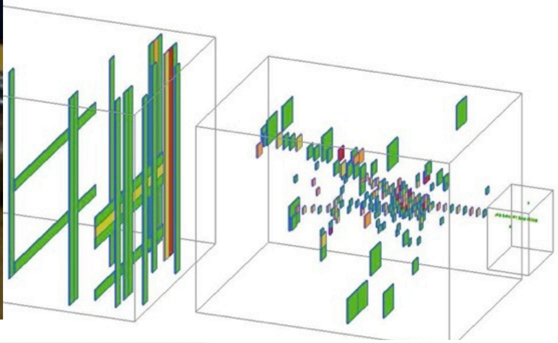
Shower Components:

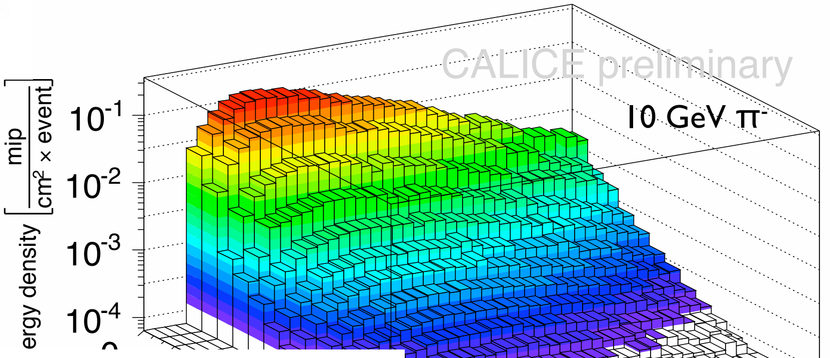
- electrons/positrons
  knock-on, ionisation, etc.
- protons
  from nuclear fragmentation
- mesons
- others
- sum



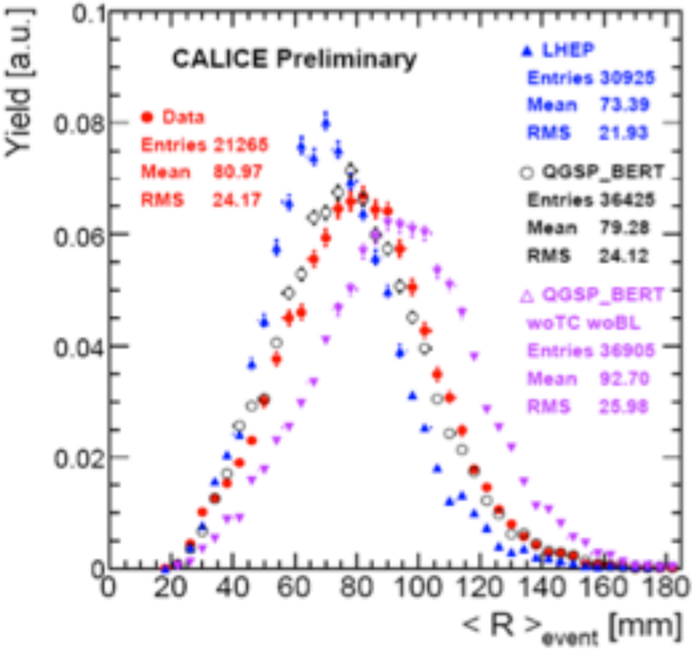
Fe Scint tile HCAL

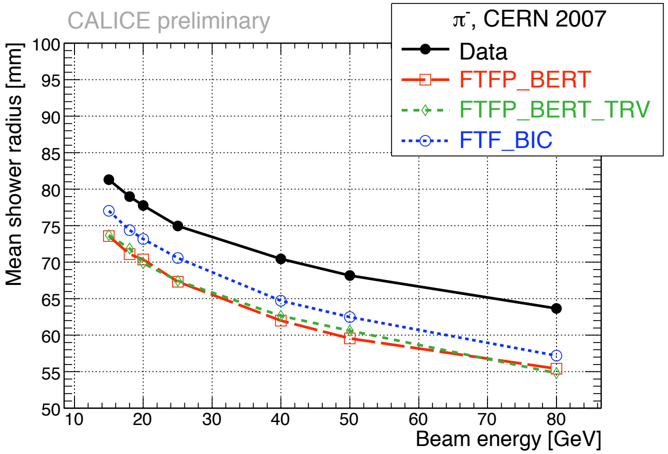




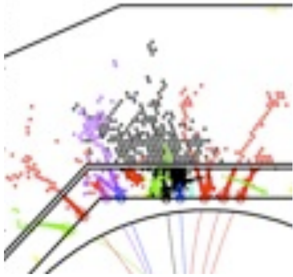


2D profile from starting point

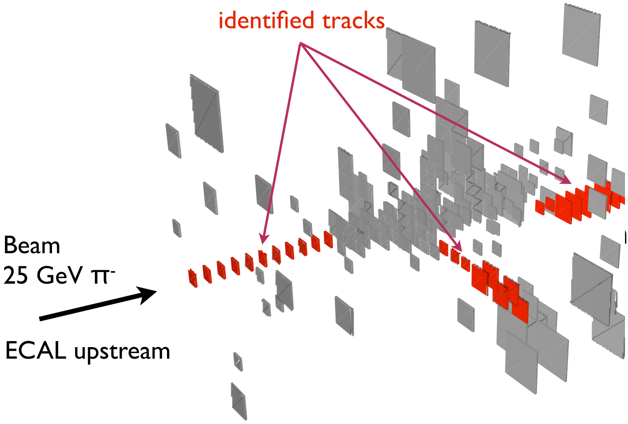


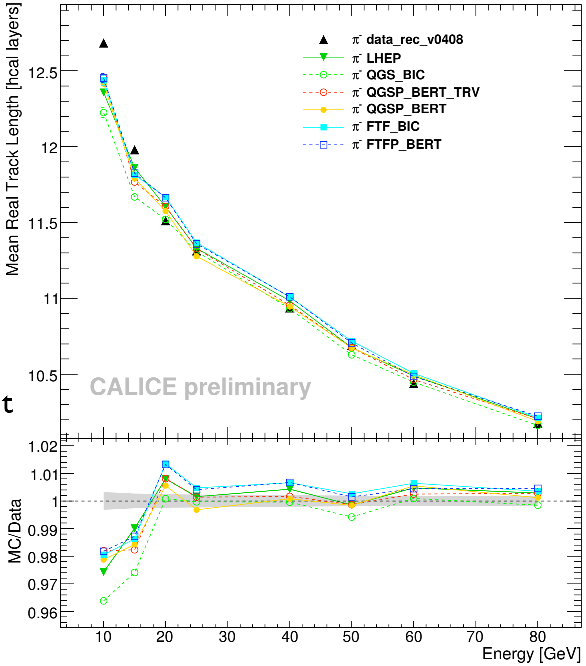


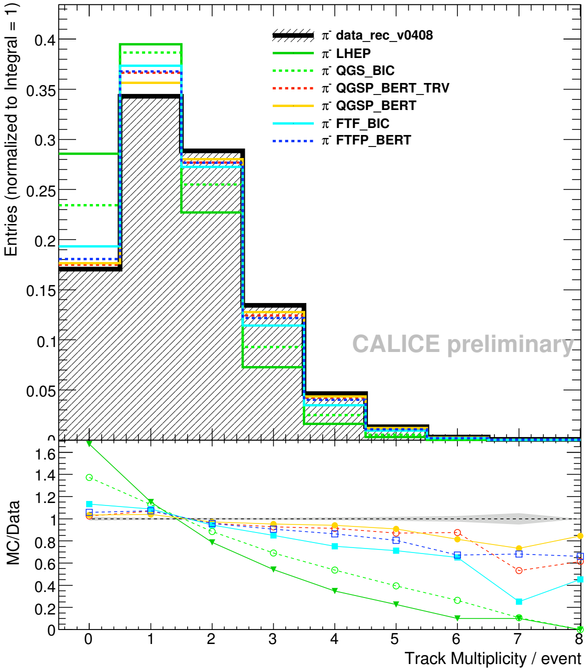
- Present-day simulation quality requires good detector understanding to discriminate
- Fluctuations also well reproduced



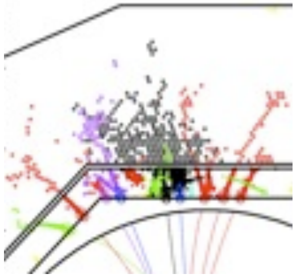
Shower fine structure







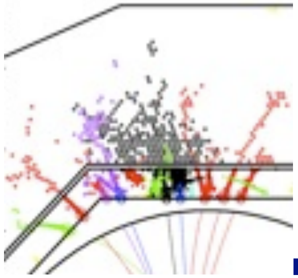
- Could have the same global parameters with “clouds” or “trees”
- Powerful tool to check models
- Surprisingly good agreement already



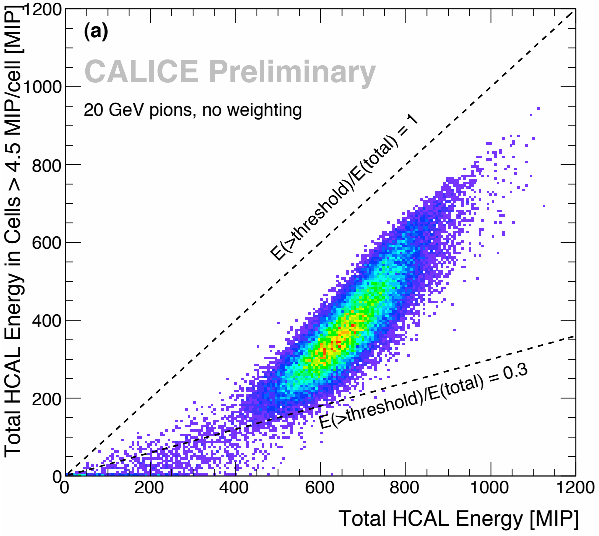
Summary on validation:

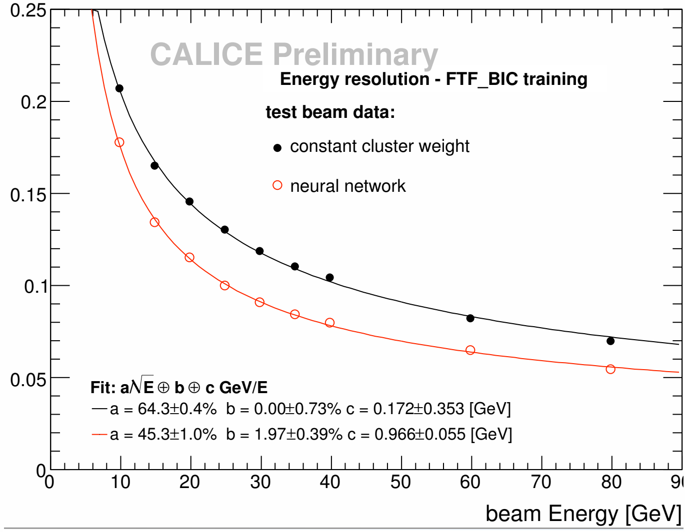
- The particle flow detectors perform as expected
  - support predictions for full-scale detector
- Geant 4 simulations not perfect, but also not as far off as feared a few years ago
  - fruitful close cooperation with model builders ongoing
- Predicted shower sub-structure is seen
  - detailed checks possible, benefits for all calorimeters

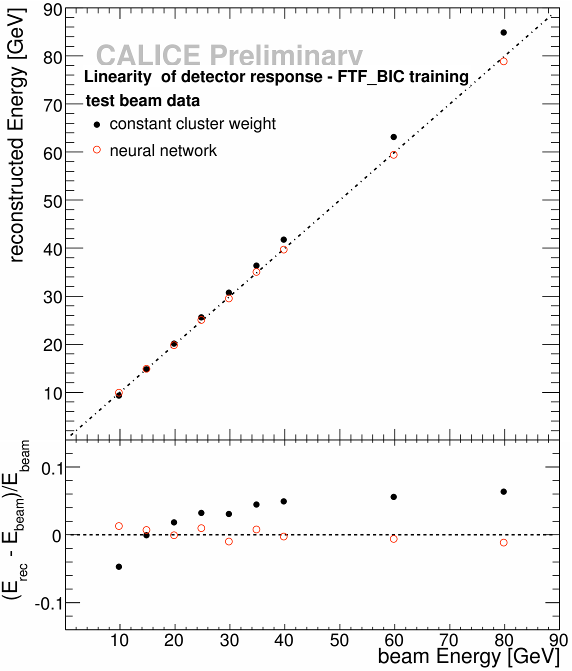
Test the algorithms with real data



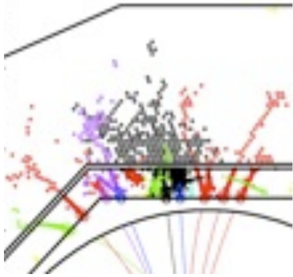
Software compensation



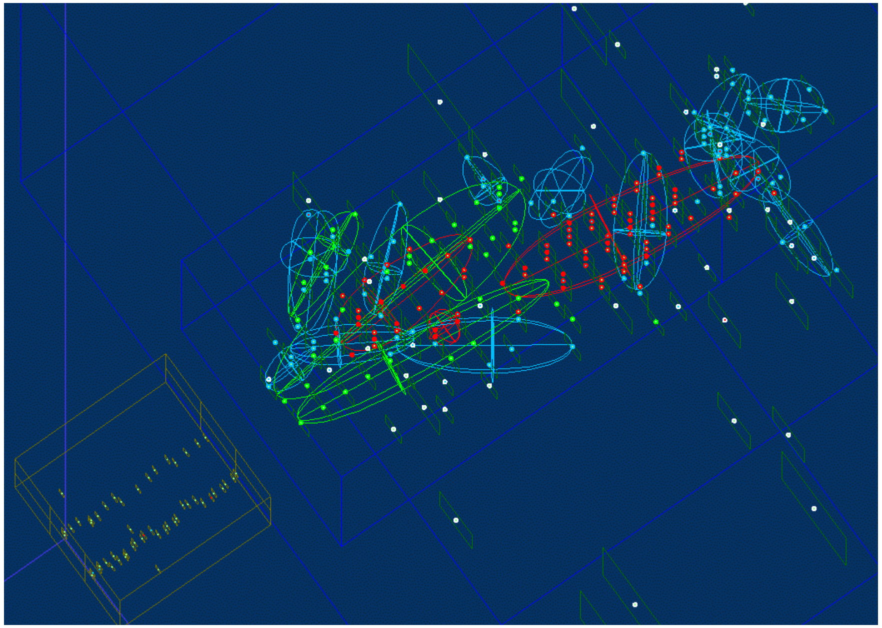


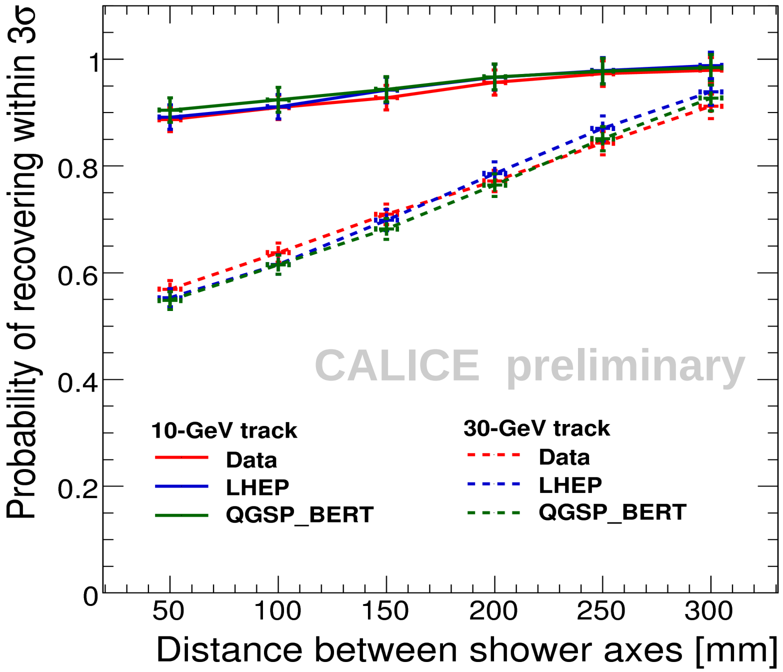


- Poor man’s dream
- Significantly improved resolution AND linearity
- High granularity - many possibilities



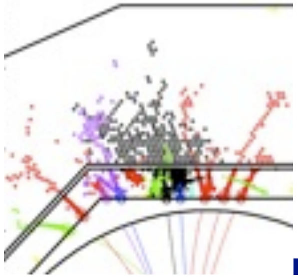
Two-particle separation



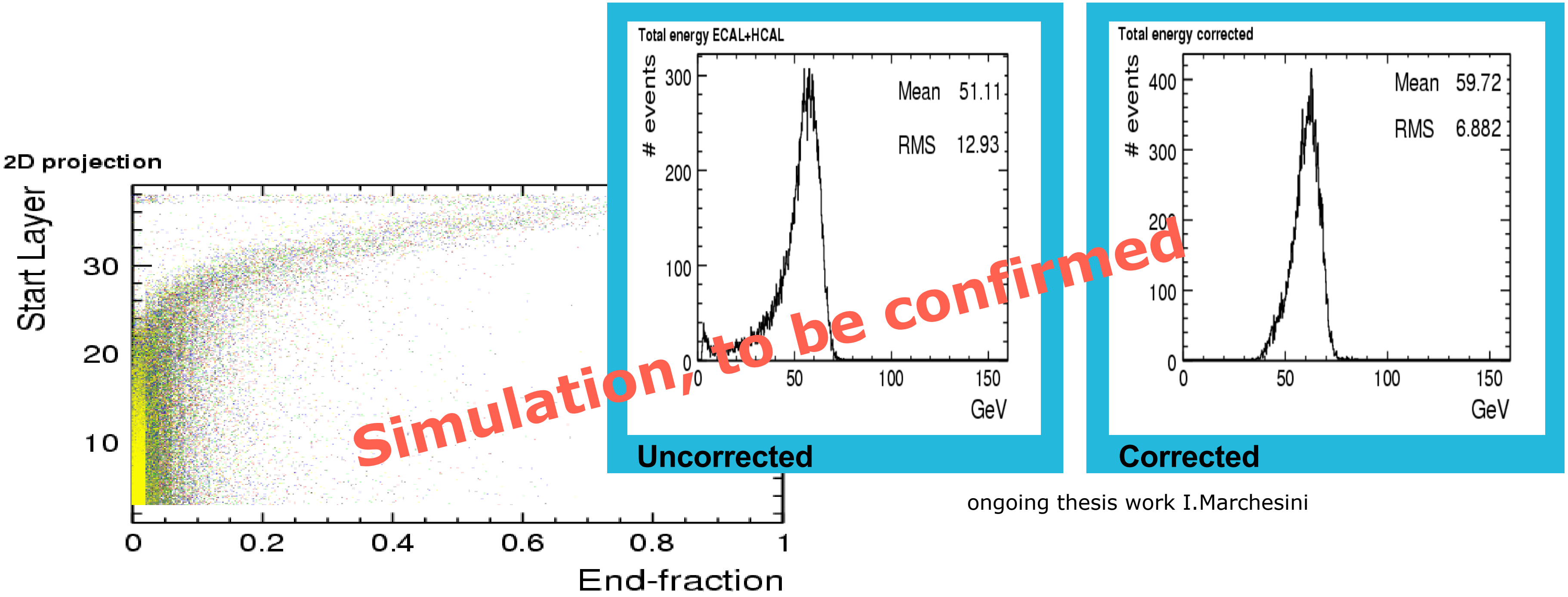


- The “double-track resolution” of an imaging calorimeter
- Small occupancy: use of event mixing technique possible
- Important: agreement data - simulation
  - sharing the same limitations

to be done with photons, too

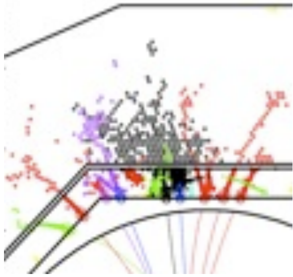


Leakage estimation



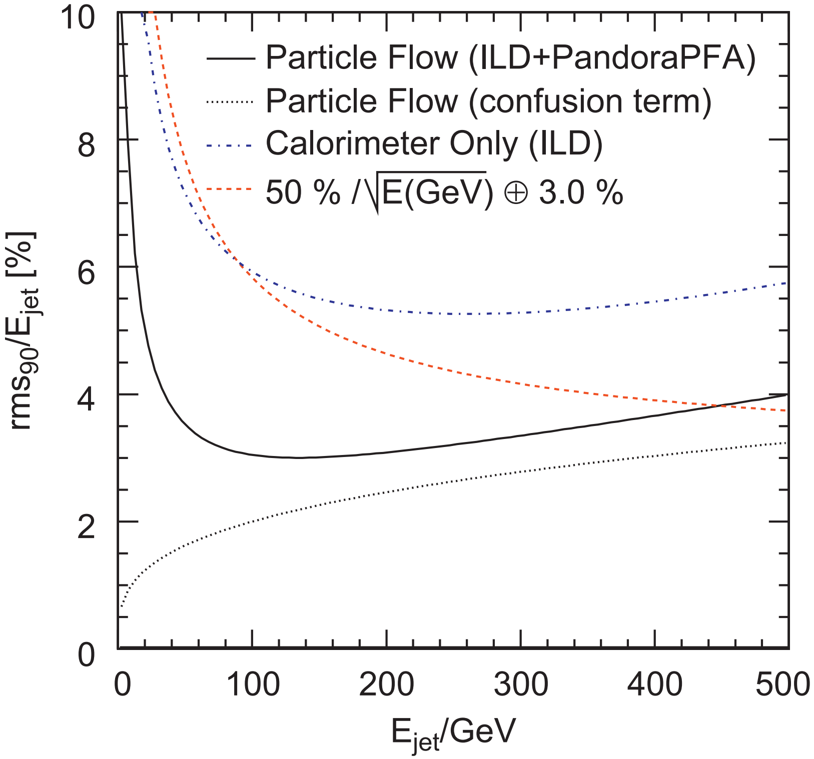
ongoing thesis work I.Marchesini

- Infer leakage from seen part of shower topology and energy
- multivariate techniqes; striking potential
- implications for detector optimization: implement in Pandora

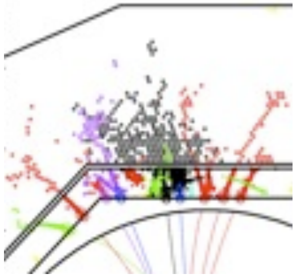


Summary on algorithms

- Granularity is extremely powerful
- Energy resolution and imaging capabilities verified with data at sub-structure level
  - the main drivers of PFLOW performance
- Leakage estimation and software compensation not yet implemented in present Pandora



Test the technologies and establish feasibility

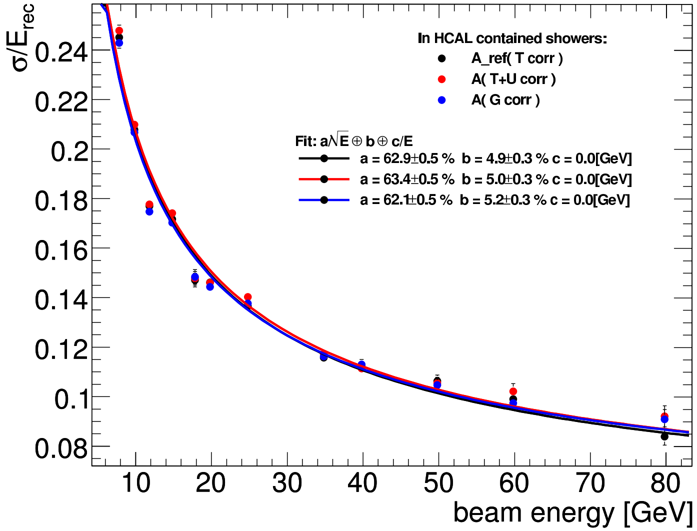


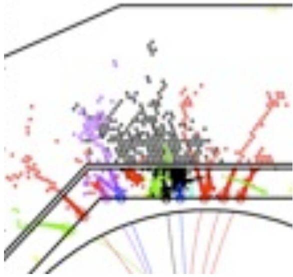
Calibration

- Study triggered by review of LC detector LOI
- Can you calibrate millions of channels and maintain stability?
  - not really a worry for Si, but could be an issue for scintillator

- 1. Simulate impact of statistic (uncorrelated) and systematic (correlated) calibration errors, find ∫*L* for in-situ calibration
  - PFLOW performance VERY robust w.r.t. channel-to-channel variations; coherent effects easy to control

- 2. Exercise in-situ methods (SiPM auto-calib, track segments) with test beam data from CERN and FNAL
  - transport calibration across the ocean and restore performance



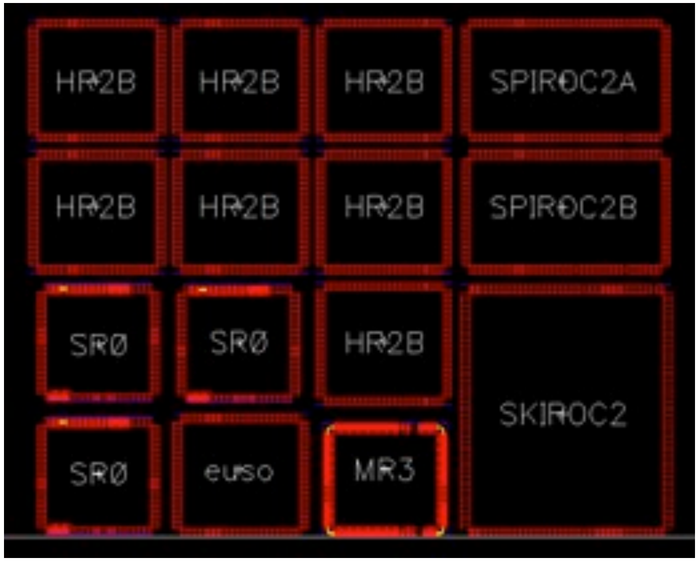


Integration

- Sensor technology, precision mechanics
- Next: system engineering

- Industrialized ASIC development using common building blocks

- New operational challenges
  - power pulsing
  - on-detector zero suppression
  - real-time threshold monitoring
  - time measurement

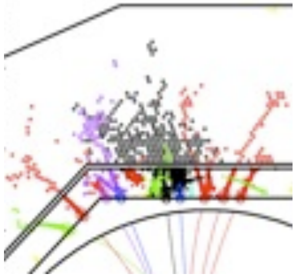


SDHCAL

Scint E/HCAL

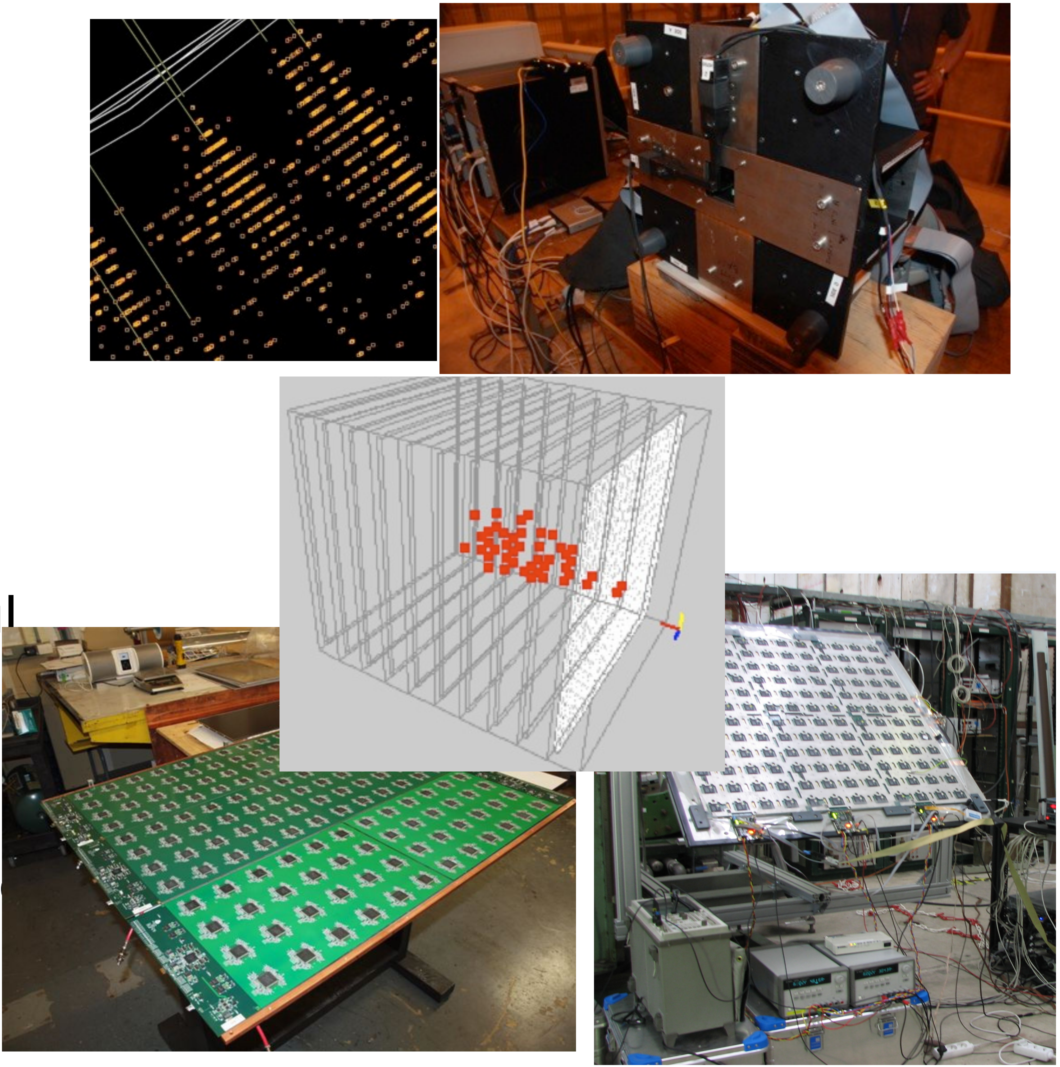
spin-off

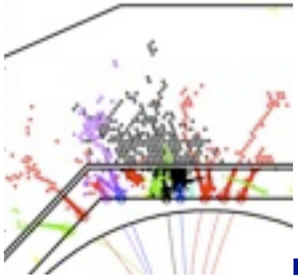
Si ECAL



Digital calorimetry

- MAPS DECAL: Tera-pixel
  - 1st sensor tests in e showers
- Digital and semi-digital hadron calorimeter
  - even higher granularity
  - suppress dE/dx fluct.
  - reduced n sensitivity
  - limited at high E?
- Small RPC proto successful
- Full-size RPC based prototypes underway
- Promising tests of GEM an MicroMEGAS based read-out modules



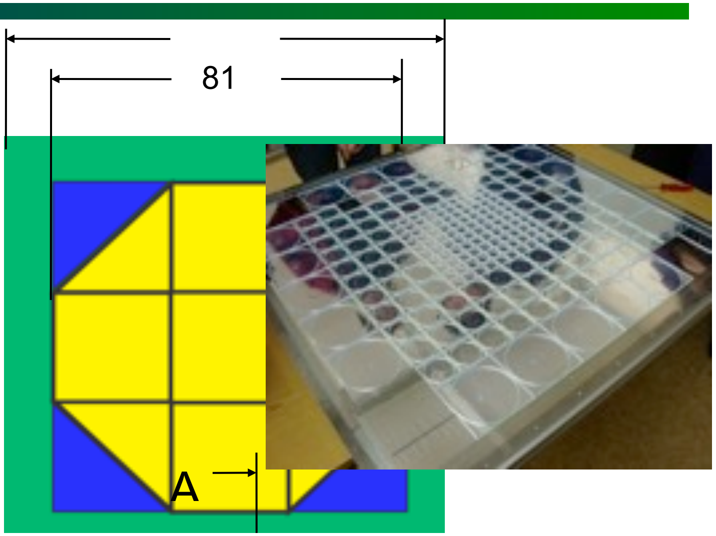


High energy

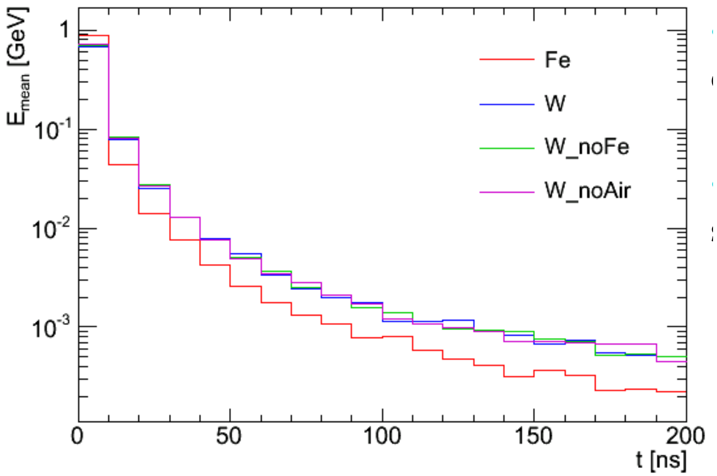
- Particle flow also a promising option for CLIC energies
- Leakage expected to limit PFLOW performance
  - need 1 λ ECAL + 7 λ HCAL
- Tungsten absorber cost-competitive with larger coil - and less risky

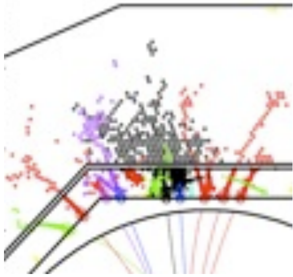
- Test beam validation with scintillator and gas detetctors

- More neutrons:
  - different model systematics
  - timing measurements



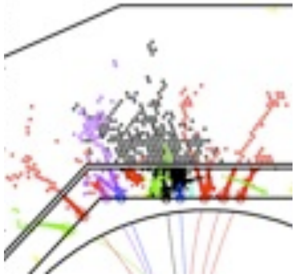
Time Development, 30 GeV π^+,





Summary on technologies

- a leap in several orders of magnitude in channel count
- new sensor technologies, new integration concepts
  - the latter is part of the feasibility demonstration
- progress towards realism:
  - realistic designs
  - realistic simulations
  - realistic cost
  - realistic proposal
- Digital calorimetry ready for exploration



Conclusion

- Particle flow calorimetry does not solve the inherent problems of hadron calorimeters
- But it holds the promise of providing a highly performant work-around

$$\boxed{\frac{\sigma_E}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E \oplus 2.1\left(\frac{E}{100}\right)^{+0.3} \%}$$

- Substantiated by test beam data
- Can be built