Towards an RPWELL-based DHCAL

RD-51 mini-week – 17.02.2021

Dan Shaked Renous

Weizmann Institute of Science

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Future Lepton Collider Experiments Require E_{Jet} Resolution of $\frac{\sigma}{E} \leq \frac{30\%}{\sqrt{E}}$

Jet energy resolution is limited by high dependence on the HCAL

- 70% of the jet energy is carried by hadrons

Intrinsic limitation of hadronic calorimeters (HCAL)

- Large fluctuations in the fraction of the EM and Hadronic component
  - Non-compensation: different response to EM and hadronic components
- Large jet-by-jet energy deposition fluctuations
- Large fluctuations in the fraction of the ‘invisible energy’ - deposited energy not contributing to the measured signal

Two possible solutions:

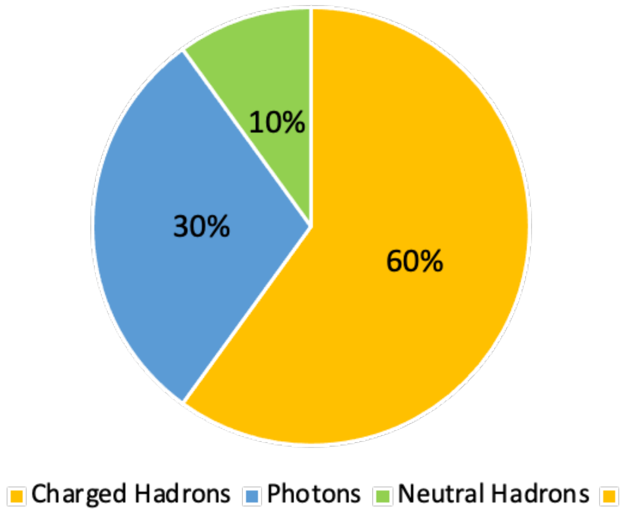
- Build compensating calorimeters ⇒ Dual readout
- **Reduce the dependency on the HCal ⇒ Particle flow calorimeters**

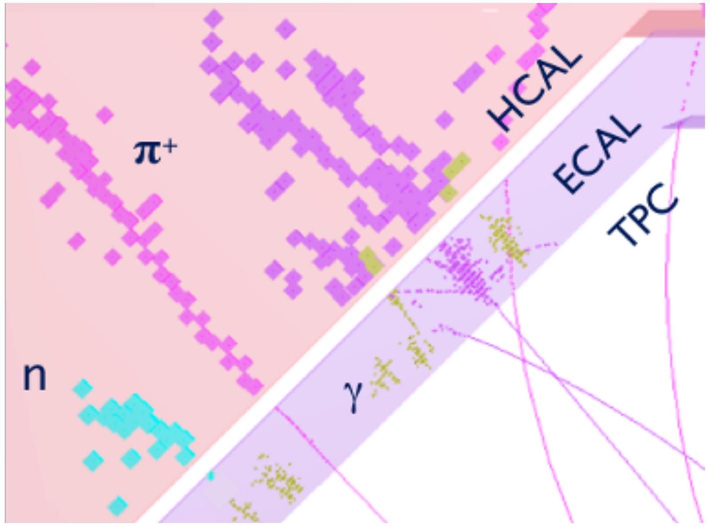
Particle Flow Calorimetry

- **Traditionally: Jet-energy is measured as a whole**
  - Measured in ECAL/HCAL
  - ~70% of the energy is measured in HCAL with $\frac{\sigma}{E} \approx \frac{60\%}{\sqrt{E[GeV]}}$
- **High granularity Particle Flow: Reconstruct individual particles**
  - Charged particle momentum is measured precisely in tracking system
  - Neutral hadrons (10%) energy is measured in HCAL

Perfect PFA can yield $\sim \frac{19\%}{\sqrt{E[GeV]}}$

using HCAL with $\frac{55\%}{\sqrt{E[GeV]}}$ energy resolution





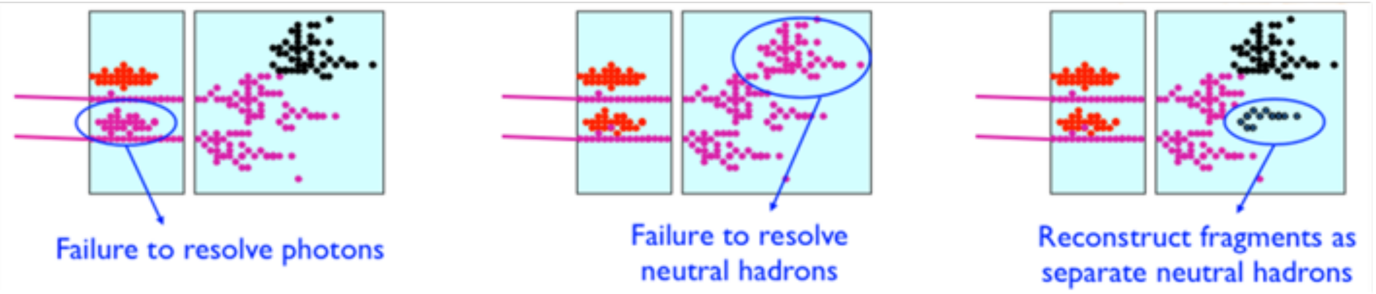
Marshall et. al. arXiv: 1308.4537

The Largest contributions to Jet Energy Resolution

Neutral hadron energy resolution (HCAL)

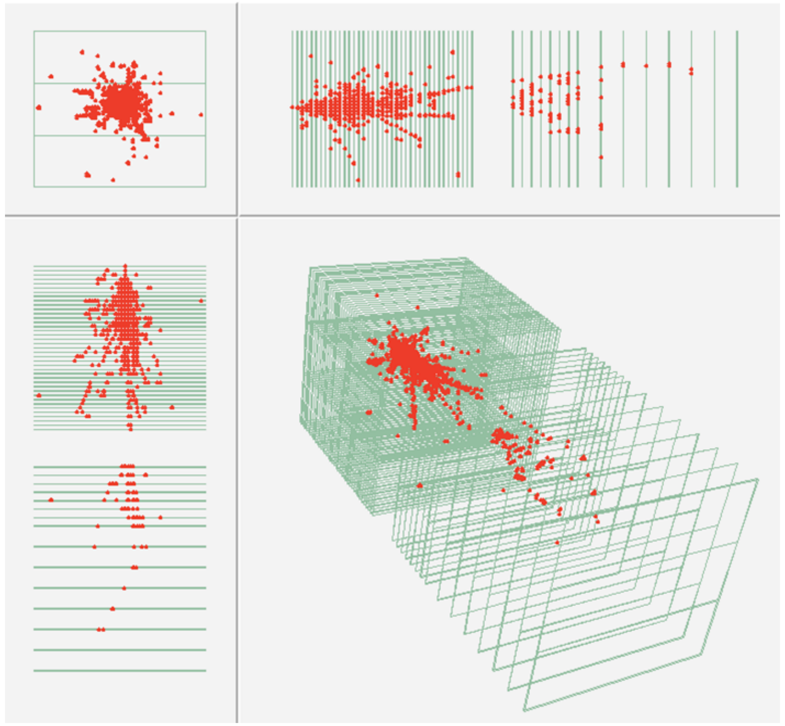
Confusion term – deposited energy can be assigned to more than particle.

Marshall et. al. arXiv: 1308.4537



(S)DHCAL: Requirements

- (Semi) Digital readout
- 1 cm^2 granularity
- 40-50 layers of sampling element with absorbers in between
- As thin as possible
  - minimizing cost of the magnet system
- High detection efficiency
- Low pad multiplicity - one pad fire per track
- For SDHCAL: Proportional response

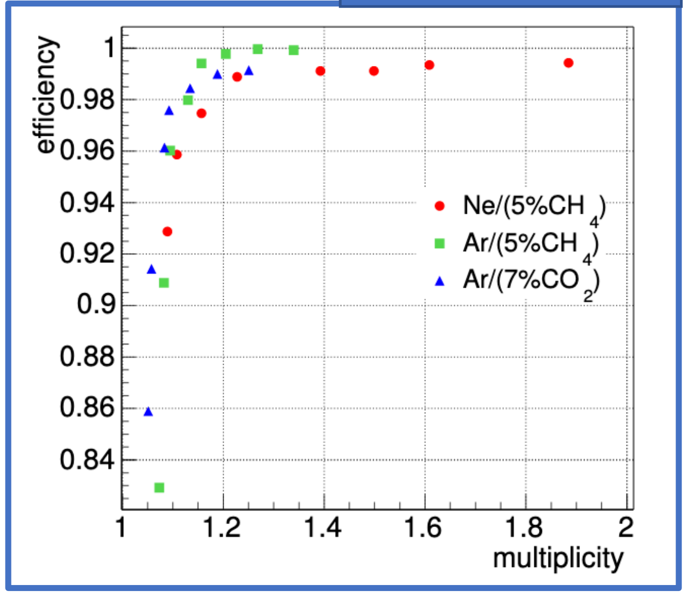


W-DHCAL (CLIC)

MPGD - a Possible Technology for SDHCAL

- High granularity:
  - 1x1 cm^2 semi-digital readout pads
  - 1.4-cm-thick sampling elements
- Excellent response of single sampling element
  - ~98% efficiency
  - 1.3 average pad-multiplicity

L. Moleri, 2016



Milestones

Scale-up RPWELL: 50x50 cm2

Analog readout (TB: Jul. ‘17, Apr. and Aug ‘18)

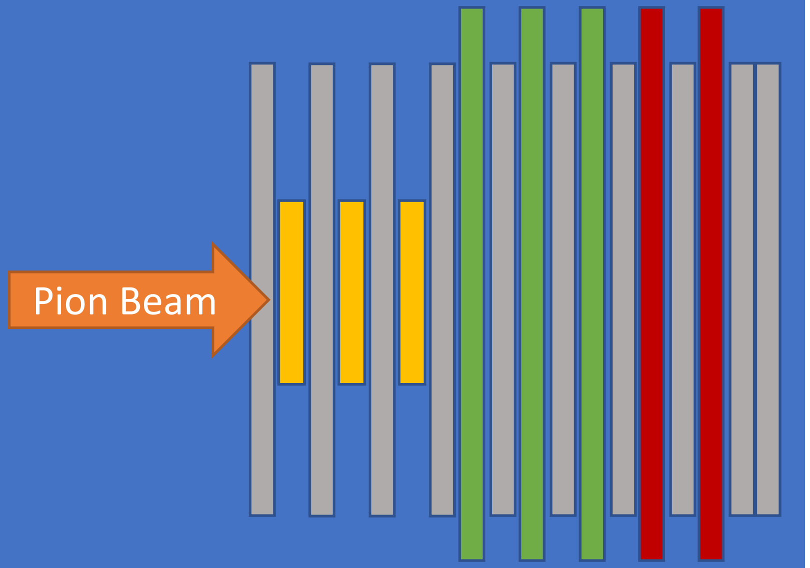
Semi-digital readout (TB: Aug. and Nov. ‘18)

Operate mini-DHCAL of 8 MPGD layers (TB Nov. ‘18)

Current Work

Extract	Input parameters for MC: detection **efficiency** per pad and **pad-multiplicity**
Validate	MC using MIP events
Simulate	50-layer RPWELL-based Prototype
Calculate	Pion energy resolution

Experimental Setup



Source pion-beam (2-6 GeV/c)

Single DAQ system – based on MICROROC chip

8 layers

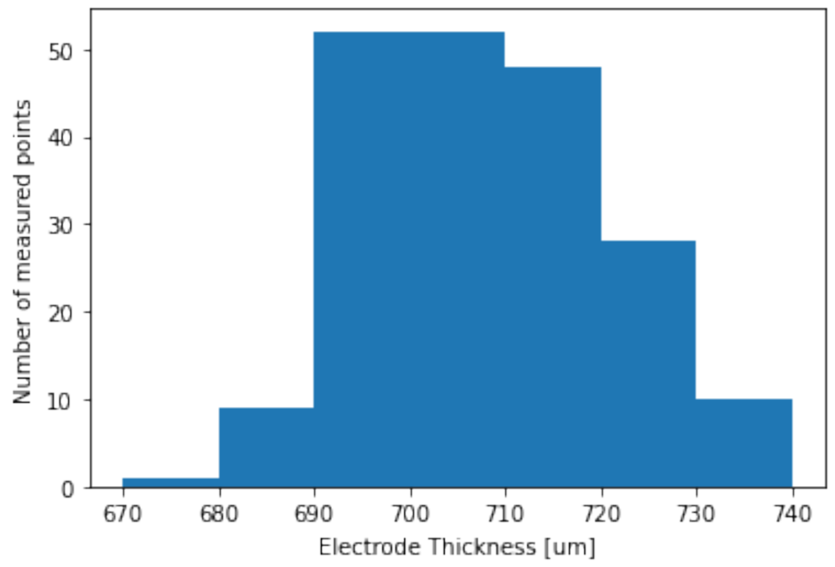
- 2 cm Steel absorbers between layers
- λ_{int} = 20 cm: 45% chance of shower inside our setup
- X_0 = 1.8 cm: 99.9% chance of EM shower inside our setup

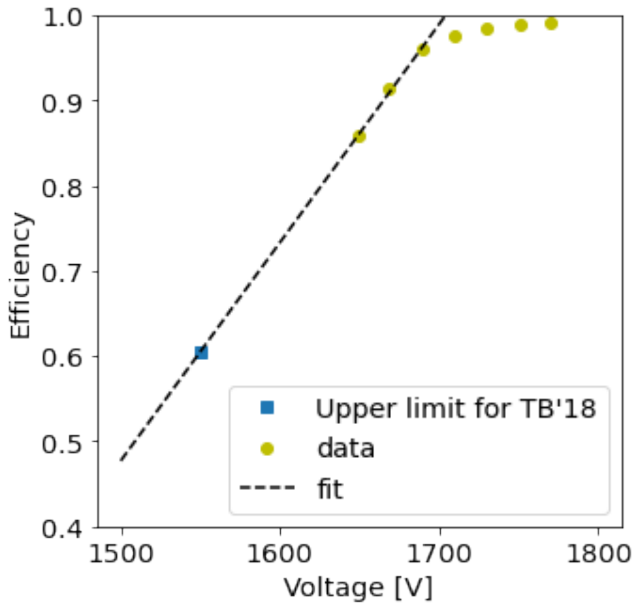
Sampling elements:

- 2+1 16x16 cm^2 bulk + resistive bulk µM
- 3 48x48 cm^2 resistive bulk µM
- 2 48x48 cm^2 RPWELL

Suboptimal Operation Conditions

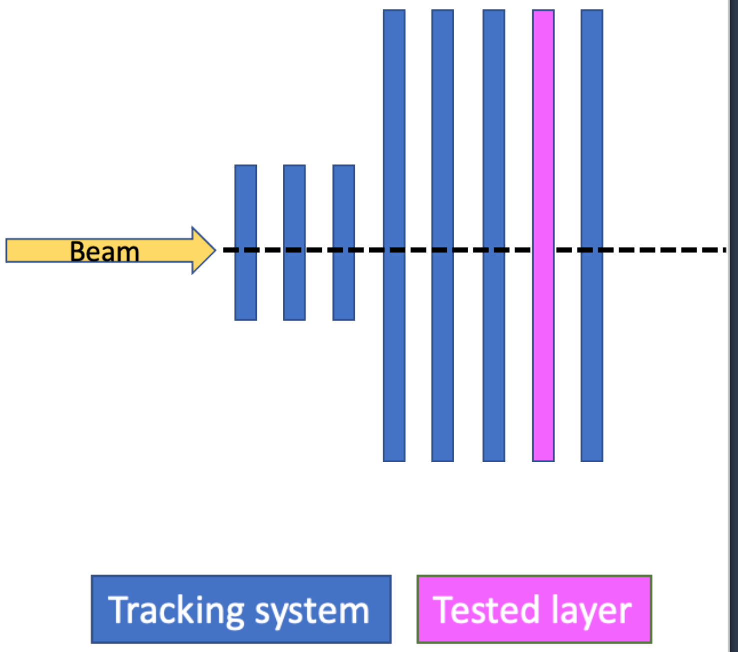
- Large thickness non-uniformity
- Operated at lower voltage (1550 V)
  - Far below efficiency plateau





Extracting Detection Efficiency and Pad Multiplicity from Data

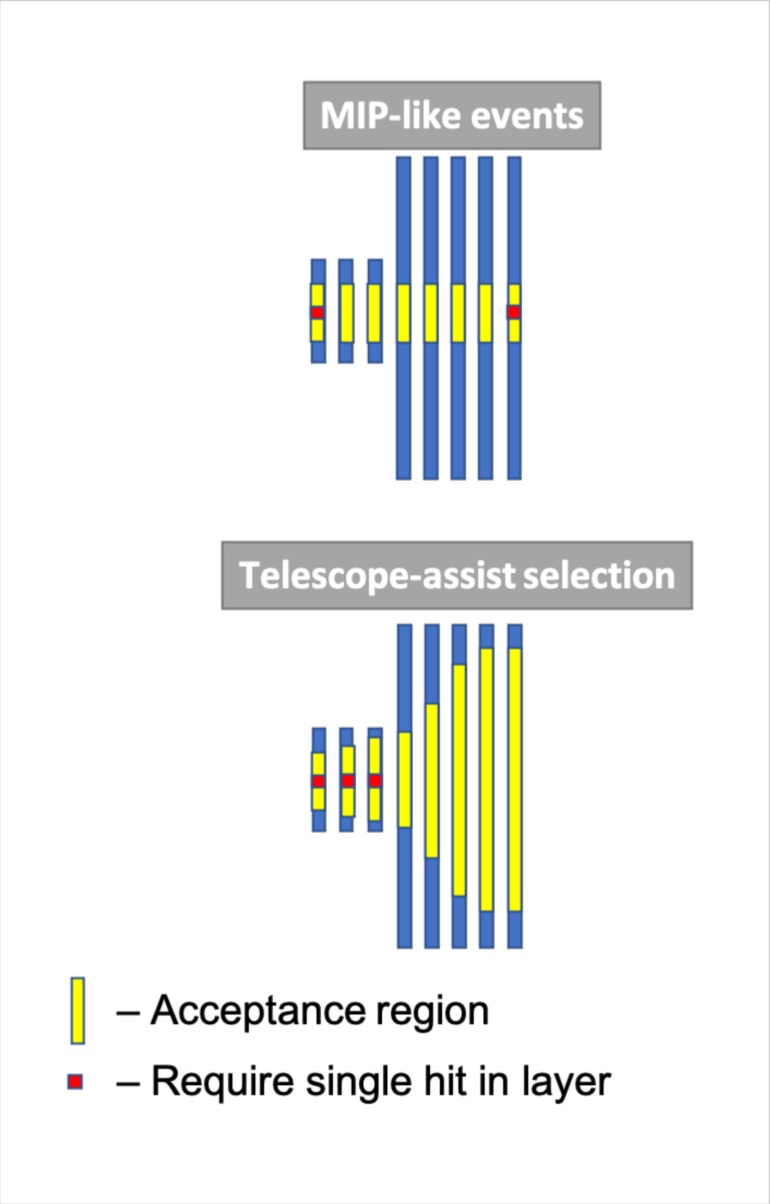
- Select only MIP-like events
  - **Reconstruct** tracks using Hough transform
  - **Identify** hit-clusters along track
  - Demand 7 out of 8 layers to have **up to two hits** in a cluster.
- Testing detection efficiency with respect to all other layers
- *Pad-multiplicity* distribution filled by size of cluster in the **tested layer**



MC Validation Process

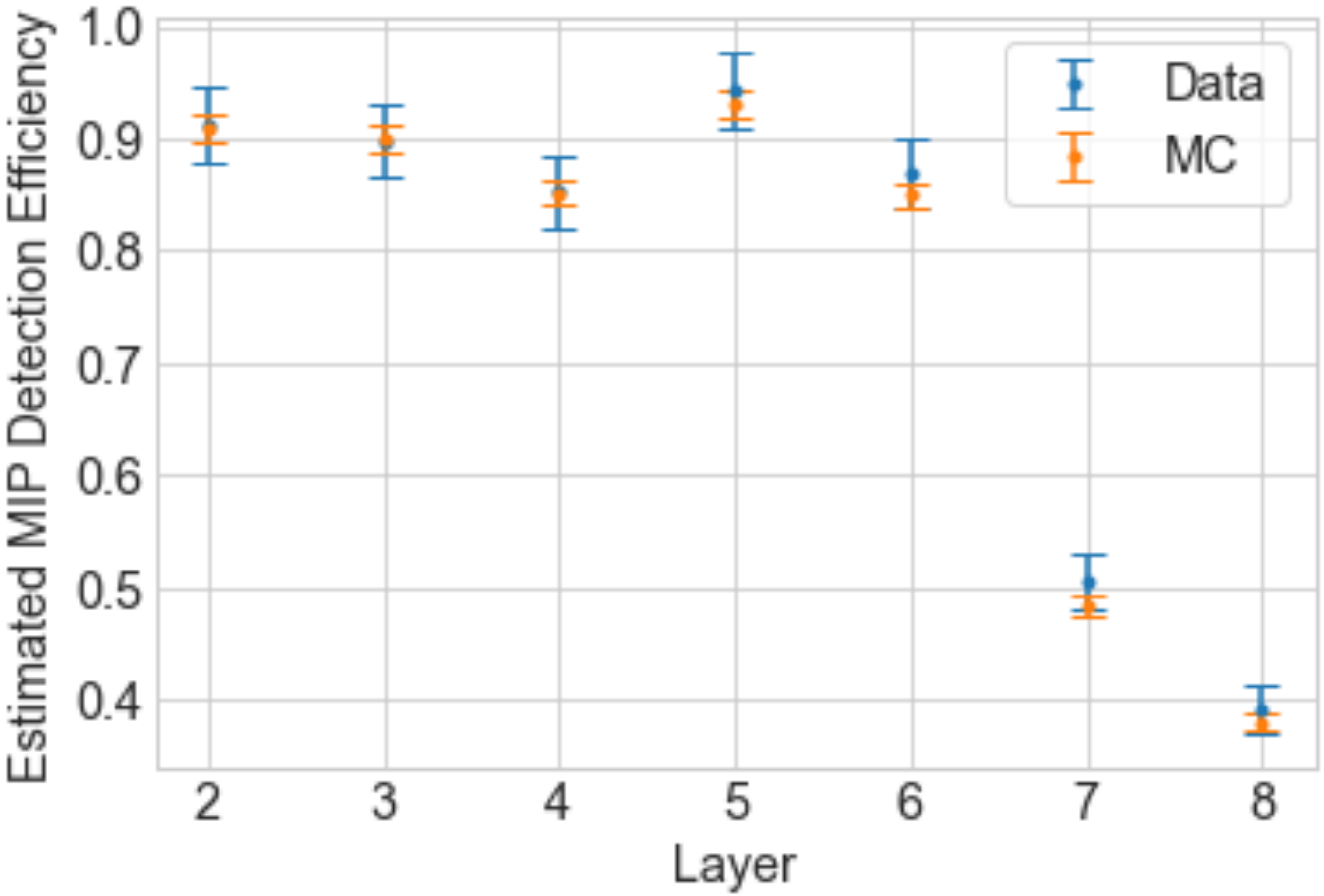
Comparing the following outputs:

- Estimated MIP detection efficiency
  - Using same method on data and MC.
- Number of hits per event for different cuts of events:
  - **MIP-like events**: events with single hit in the first and last chamber and up to 3 hits per chamber
  - **Telescope-assist selection**: a widening acceptance region while requiring a single hit in each of the first chambers

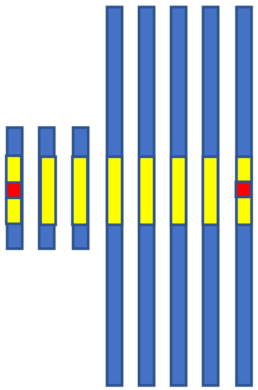


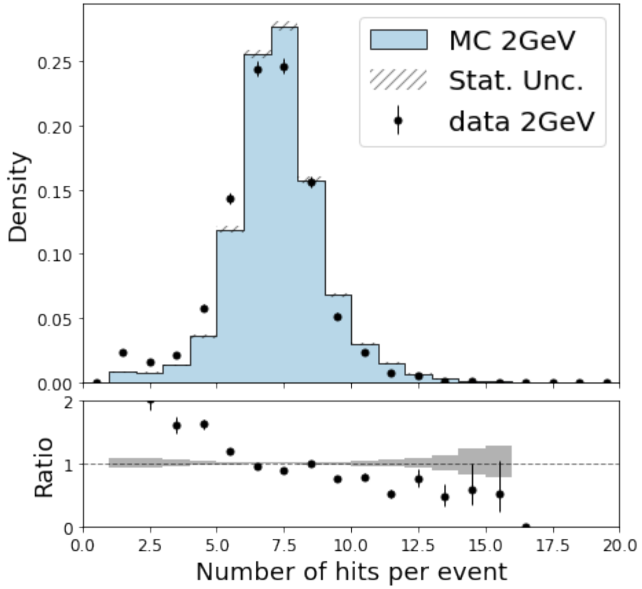
Efficiency Estimation

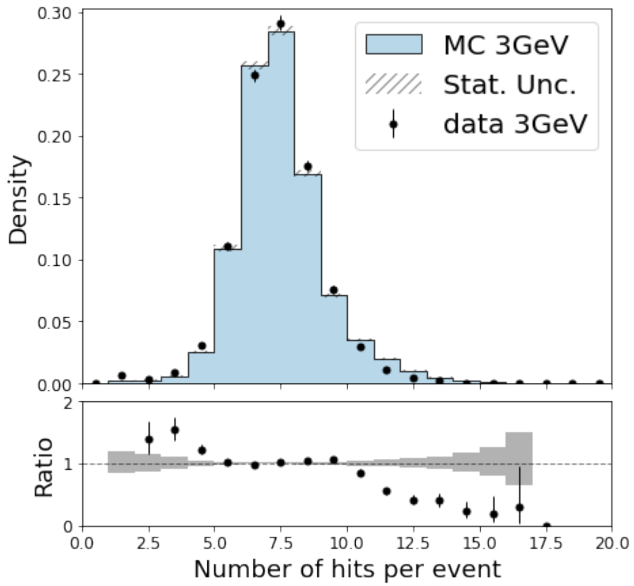
- Data suffers from high statistical uncertainties
- Agreement between data and MC

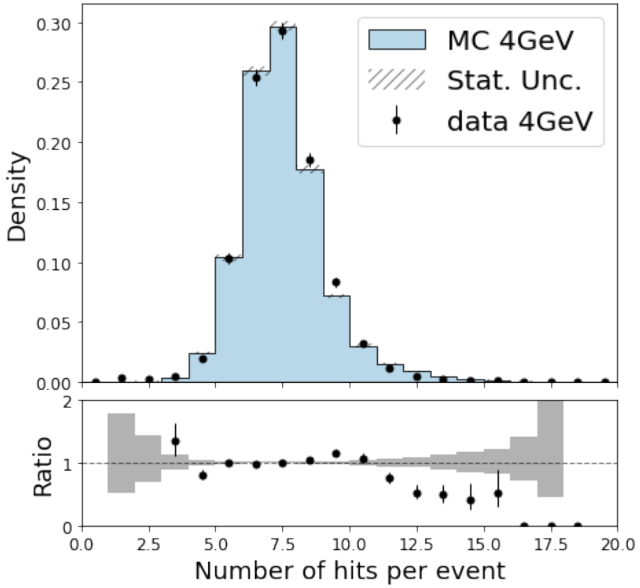


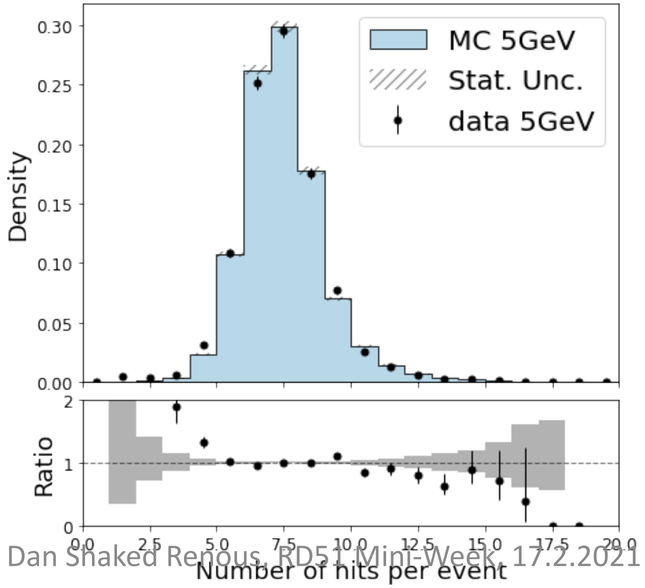
MIP-like Events

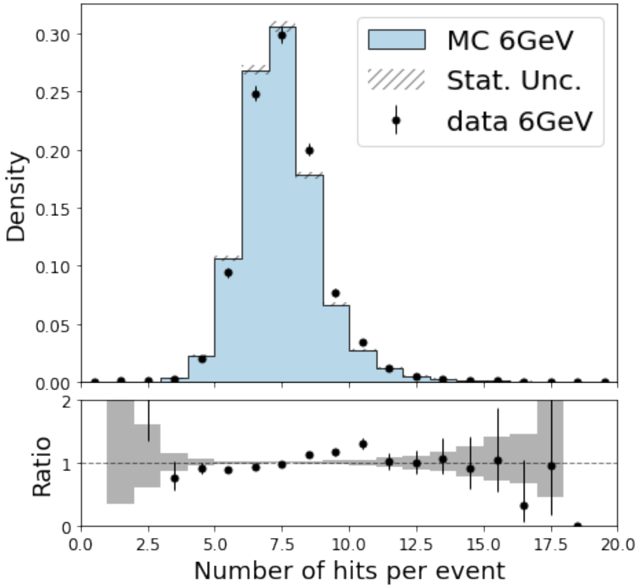




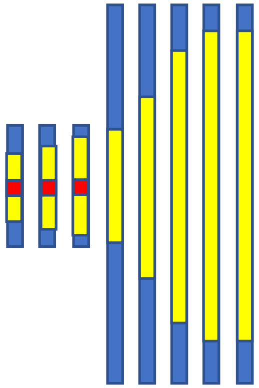


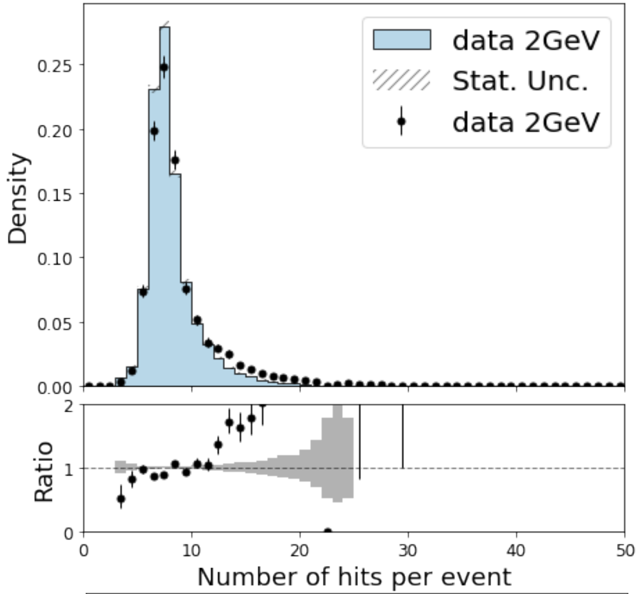


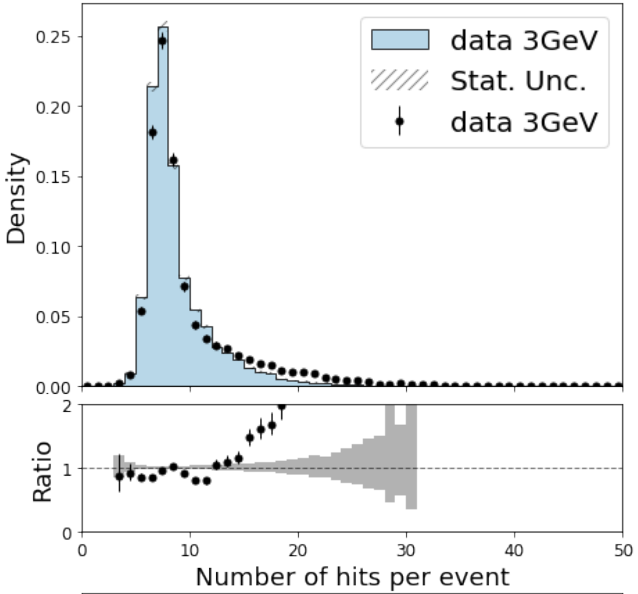


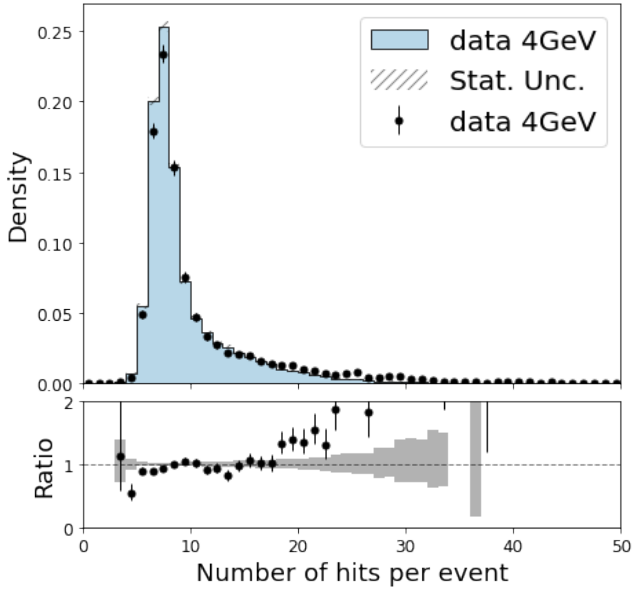


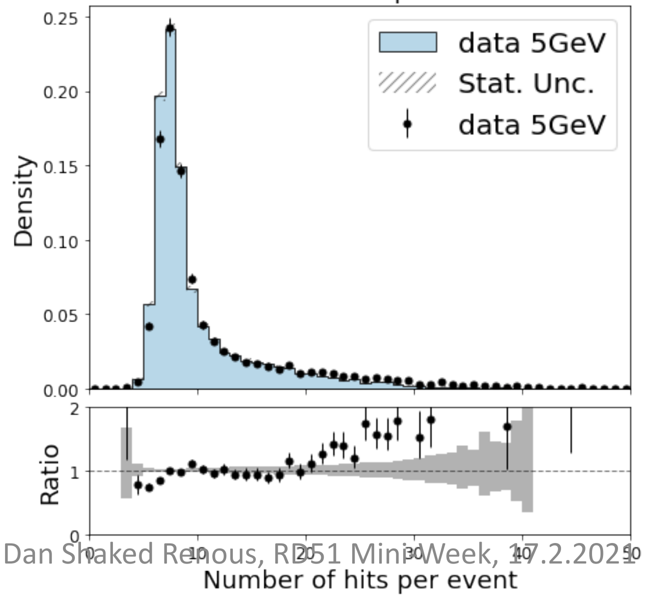
Telescope-assist Selection

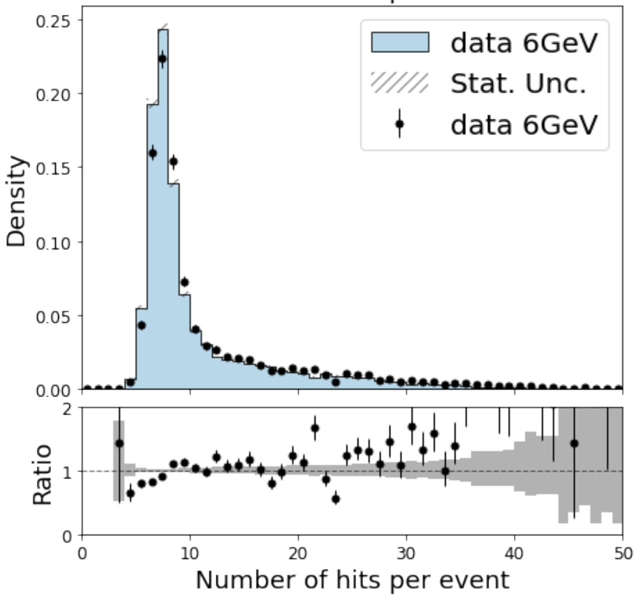








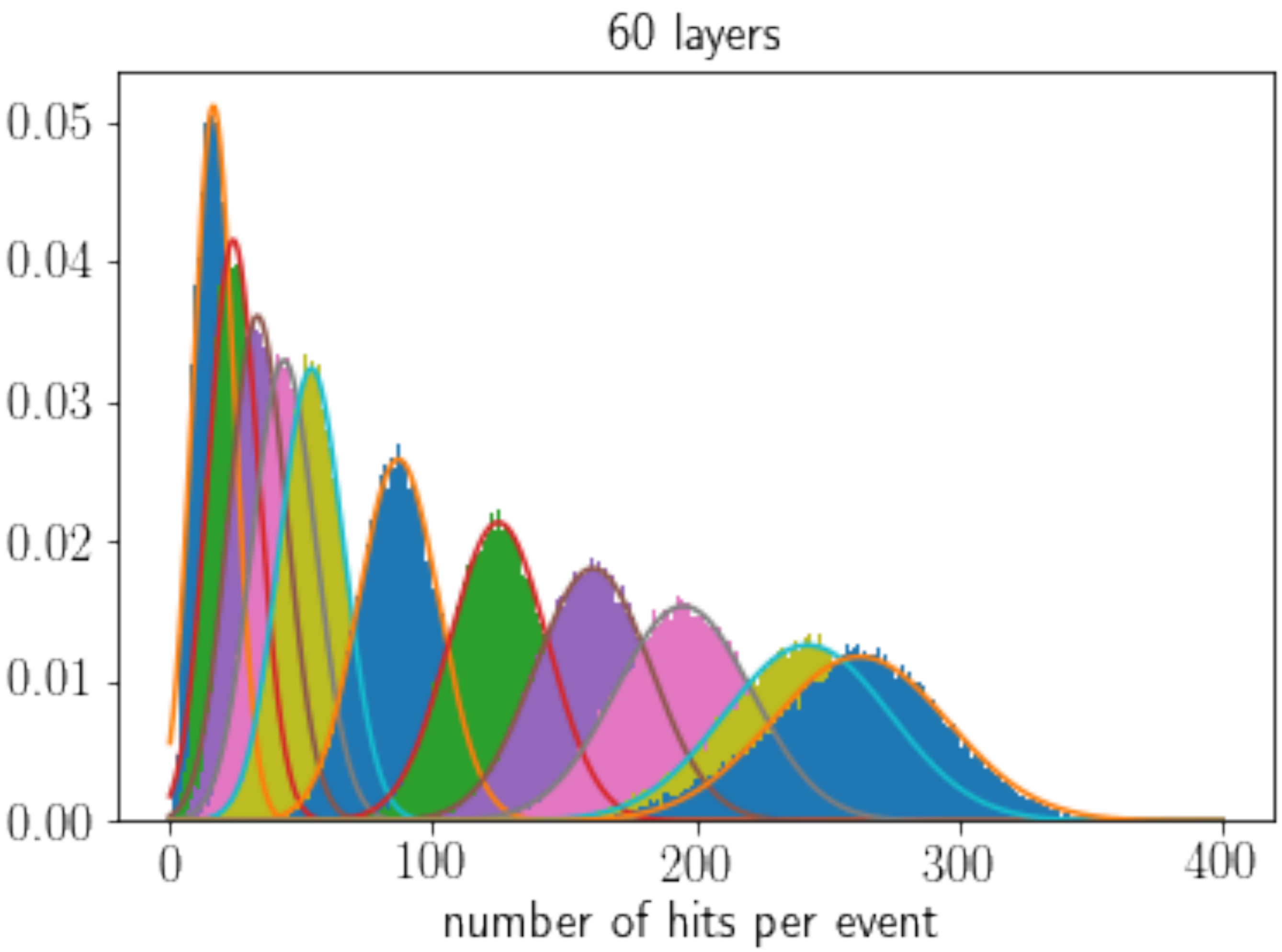




Simulation: RPWELL-based DHCAL with 50-layers

50 Layers

- Pions beam energy values: 2, 3, 4, 5, 6, 10, 15, 20, 25, 30, 32, and 36 GeV
- Best RPWELL (TB Jul. ’15)
    - 98% MIP detection efficiency
    - 1.37 average pad multiplicity



Energy resolution: Estimation

- Extract calorimeter's response:

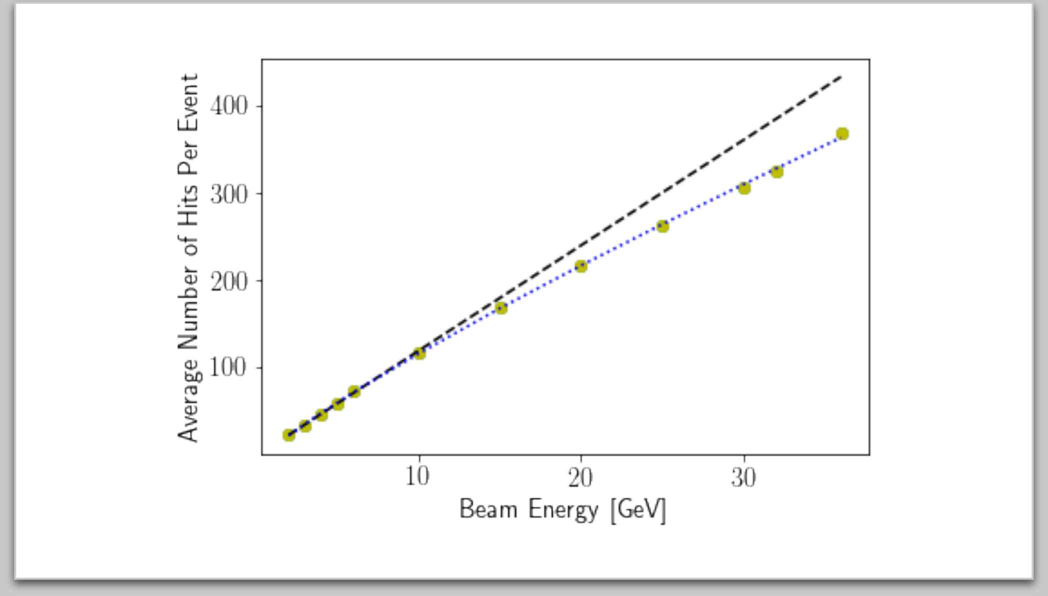
$$\langle N_{hits} \rangle = a \cdot E_{beam}^{b} - c$$

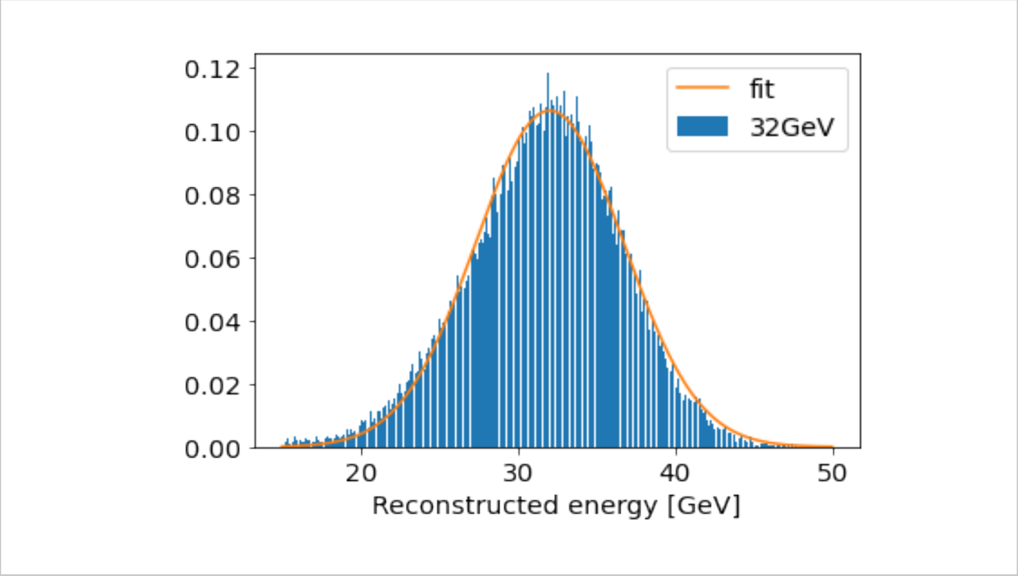
- Reconstructed energy using the inverse response function:

$$E_{rec} = \sqrt[b]{\frac{N_{hits} + c}{a}}$$

- Fit $\frac{\sigma_{rec}}{\langle E_{rec} \rangle}$ as a function of E_{beam}:

$$\frac{\sigma}{E} = \frac{S}{\sqrt{E}} \oplus C$$





π Energy Resolution

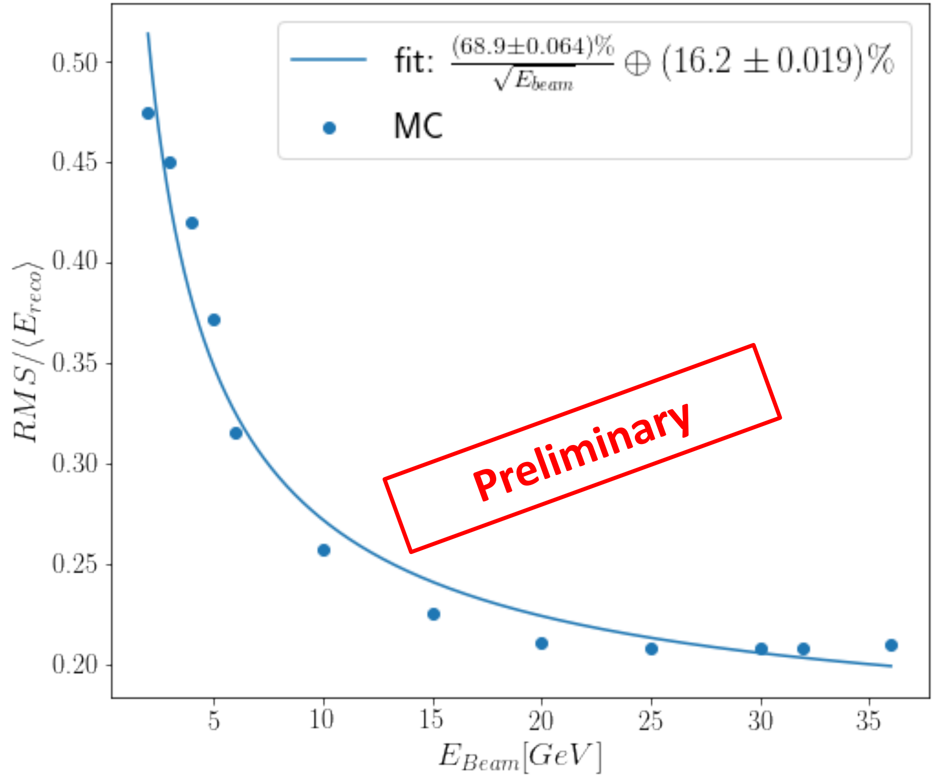
$$\frac{\sigma}{E} = \frac{68.9\ \%}{\sqrt{E_{beam}}} \oplus 16.2\%$$

Reference results: CALICE Fe-DHCAL

$$\frac{(51.5 \pm 1.5)\%}{\sqrt{E_{beam}}} \oplus (10.6 \pm 10.5)\%$$

Difference could be due to:

- Software compensation based on energy-density



The next steps:

- Build new prototypes
  - New electrodes with uniformity <5% are available
  - Improved construction techniques
- Hadron energy reconstruction using ML-tools
- Reduce confusion in energy deposits assignment to hadrons

Thank you!

Questions?

Back up slides

Energy Resolution: Parametrization

- Stochastic term
  - Poisson-like statistics
  - Intrinsic particle fluctuations, sampling, quantum fluctuations
- Noise term
  - Internal (e.g. electronics) and external (e.g. pile-up) noise
- Constant term
  - Leakage
  - Imperfections in construction, non-uniformity

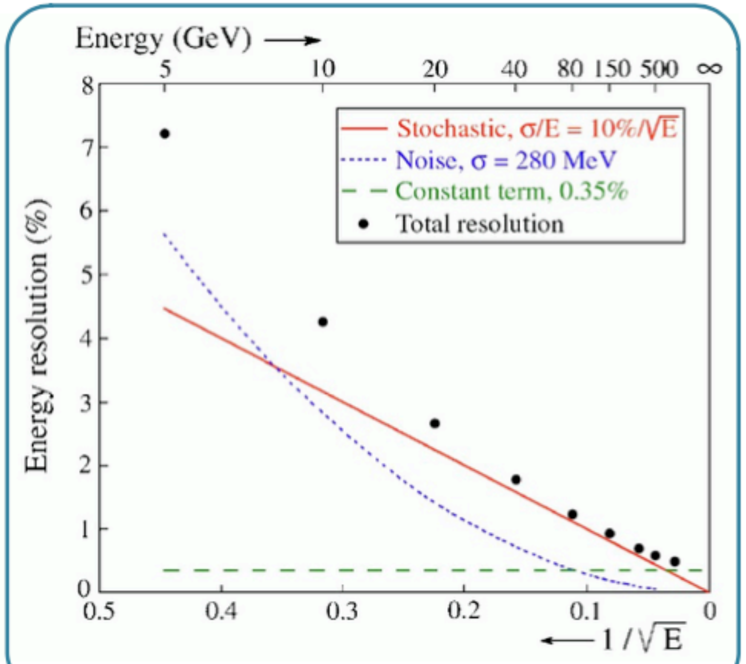
Stochastic   Constant

$$\frac{\sigma(E)}{E} = \frac{S}{\sqrt{E}} \oplus \frac{N}{E} \oplus C$$

Noise

$\oplus$ = quadratic sum

Energy resolution in EM ATLAS barrel calorimeter



Taken from a lecture by J. B. Sauvan

Essential Input Of Simulation