Studies of muon data and simulation with the CALICE AHCAL 2018 Technological Prototype

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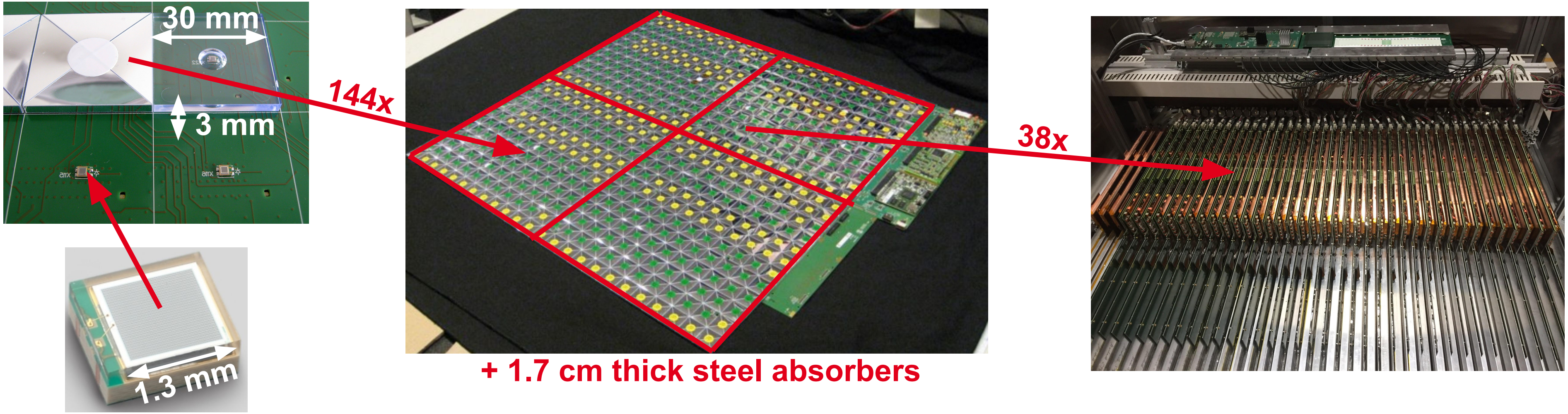
AHCAL 2018 Technological Prototype

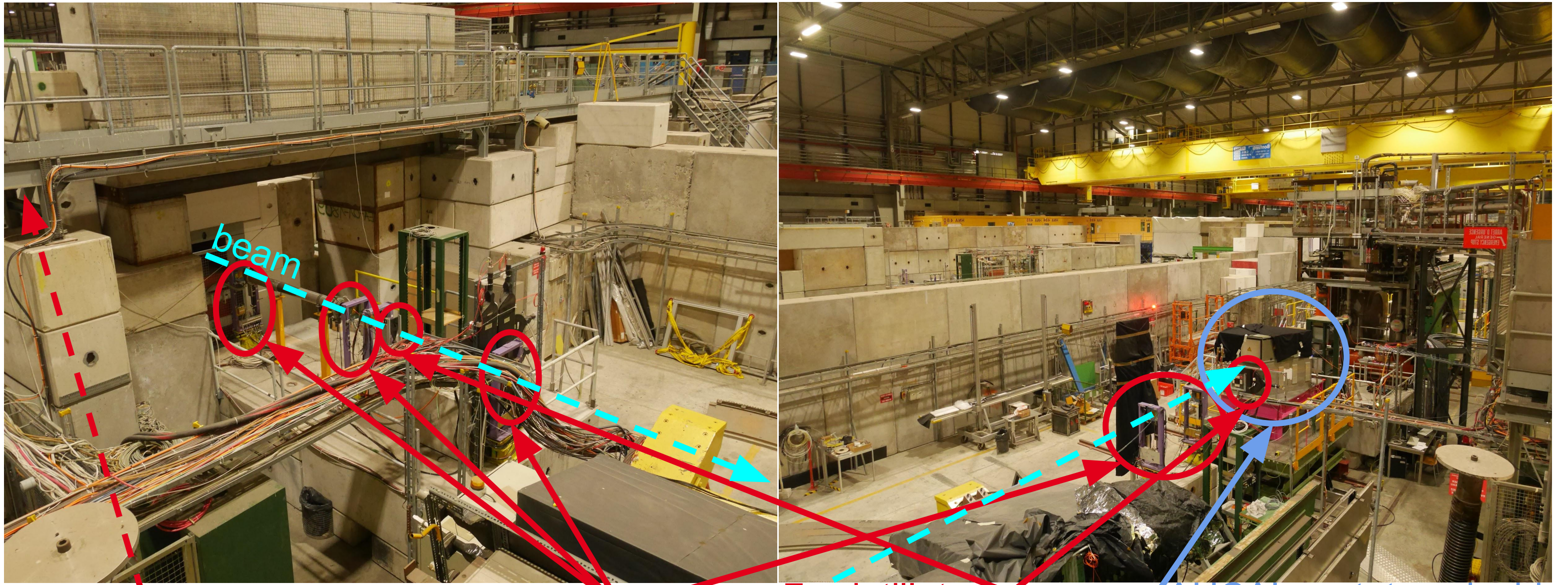
- Analog Hadron Calorimeter (AHCAL): highly granular HCAL for Particle Flow
- 2018 Technological Prototype to test performance of the AHCAL design
- size of ~ 1 m^3, 38 layers ≈ 4 λ_{int}
- ~ 22,000 single channels of plastic scintillator tile + SiPM



+ 1.7 cm thick steel absorbers

Test beam at CERN SPS

- Test beams in May & June 2018 at CERN SPS North Area, beam line H2
- For May: only AHCAL prototype
- For June: additional pre-shower, 60x60 mm^2 tiles layer, tail catcher



Cherenkov detector

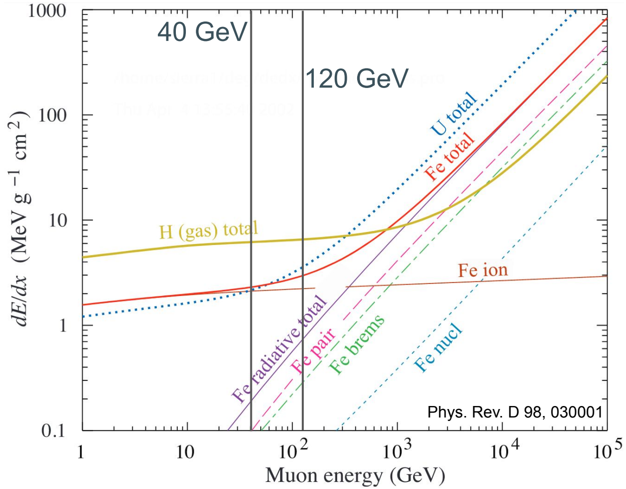
6 wire chambers

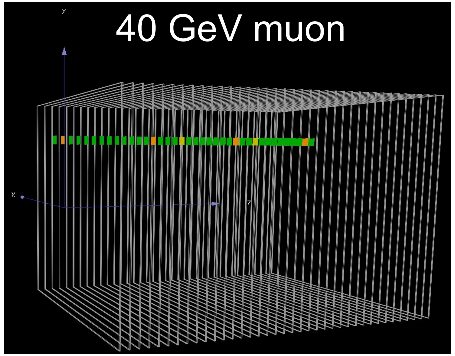
7 scintillator triggers

AHCAL prototype inside light-tight box on movable stage

Muon simulation studies

- Muons used for calibration
  - Definition of 1 MIP = MPV of muon hit energy distribution
  - Many parameters best tuned with muons
- Geant4 10.03 simulation
  - QGSP_BERT_HP physics list
  - Digitisation
  - No simulation of noise
  - Same reconstruction chain as for data including cut of hits with energies < 0.5 MIP
- 40 GeV muons May data
  - Cross-checked with 120 GeV muons
  - Very similar results for June

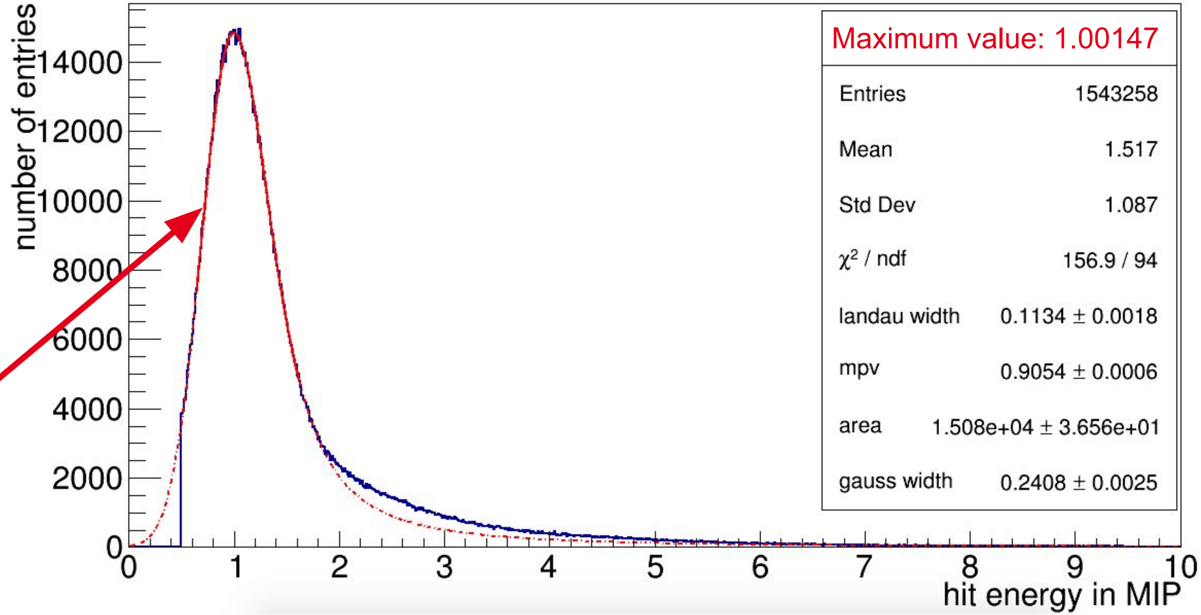




Consistency of the MPV calibration

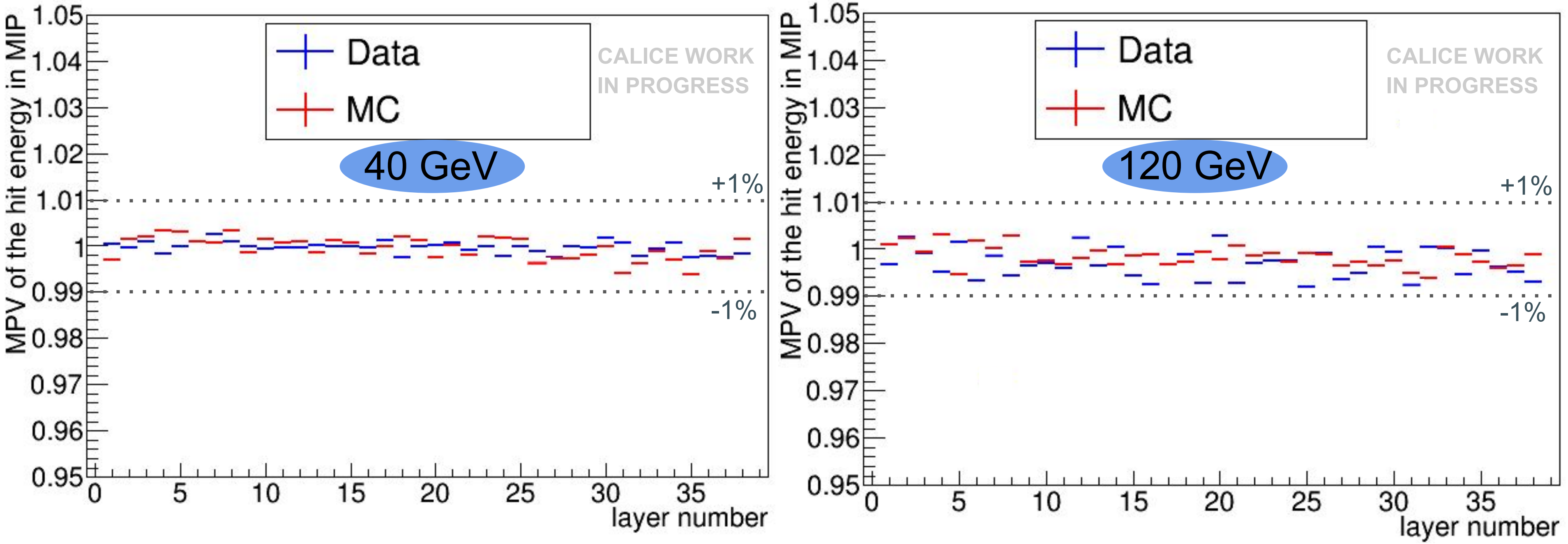
- MPV = maximum of Landau-Gaussian fit to the hit energy distribution
- Calibration of each channel to have MPV = 1 MIP using 40 GeV muons
- Also used to adapt the GeV to MIP conversion factor in the digitisation

Landau-Gauss convolution fit



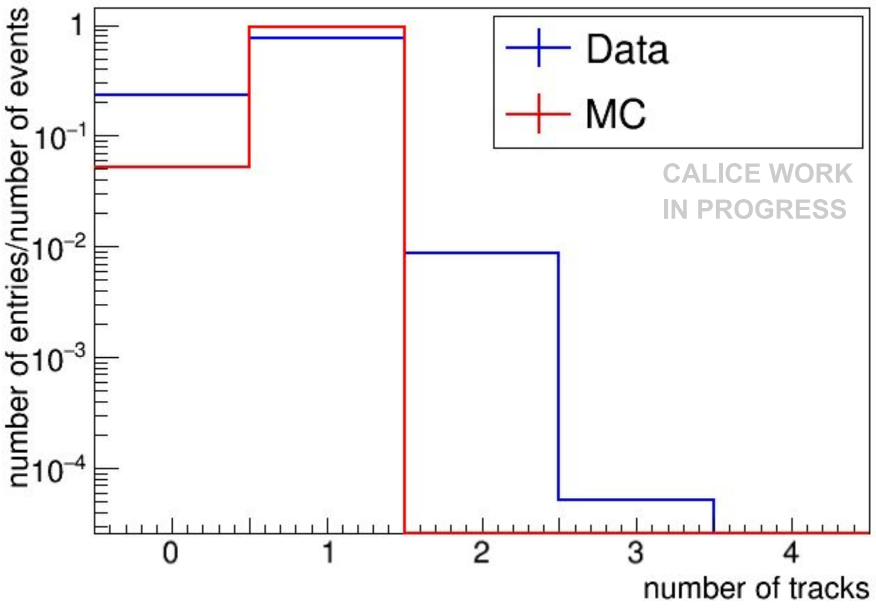
Consistency of the MPV calibration

- MPV = maximum of Landau-Gaussian fit to the hit energy distribution
- MPV consistently at 1 over calorimeter depth and at both energies



Muon track finding

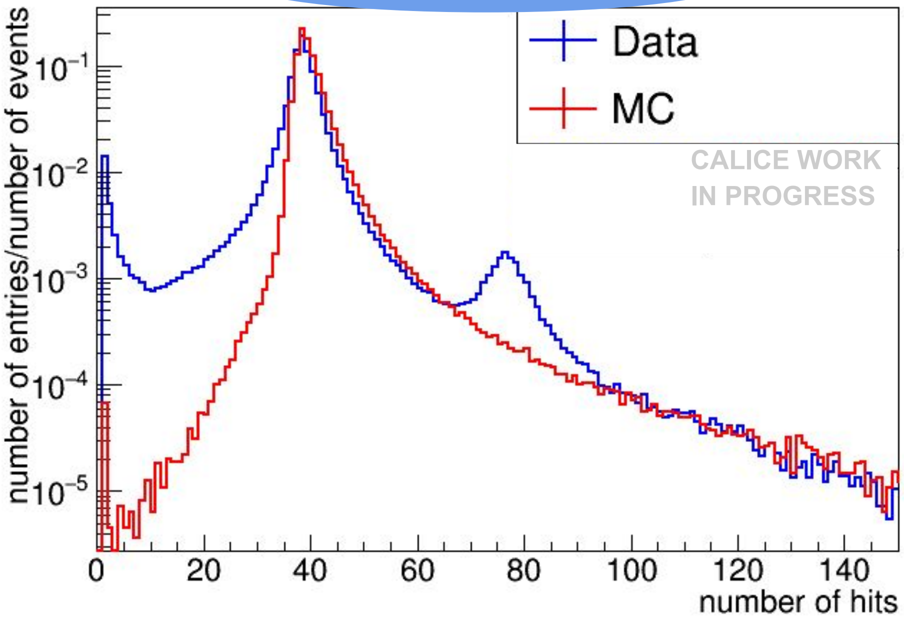
- Definition of a muon track:
  - >= 30 hits in the same tower
  - <= 2 skips in between hits
- Only events with exactly 1 track used
  - 95% of MC events (1.1 million)
  - 76% of data events (1.3 million)



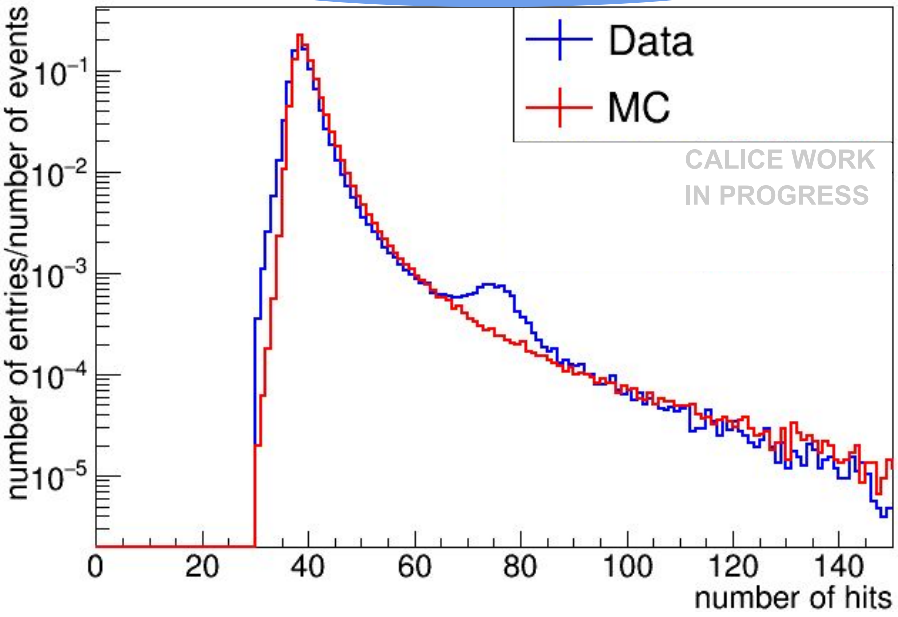
Comparing data and simulation

- **Number of hits per event** overall a bit higher for simulation
- Double muon peak not entirely removed after track selection

no track selection

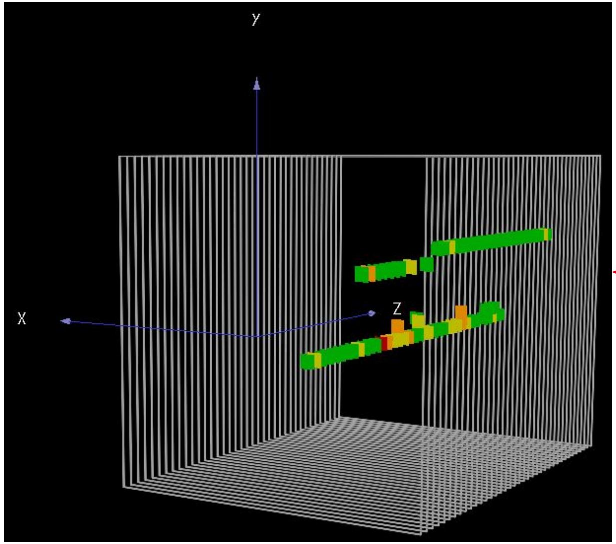


number of tracks = 1

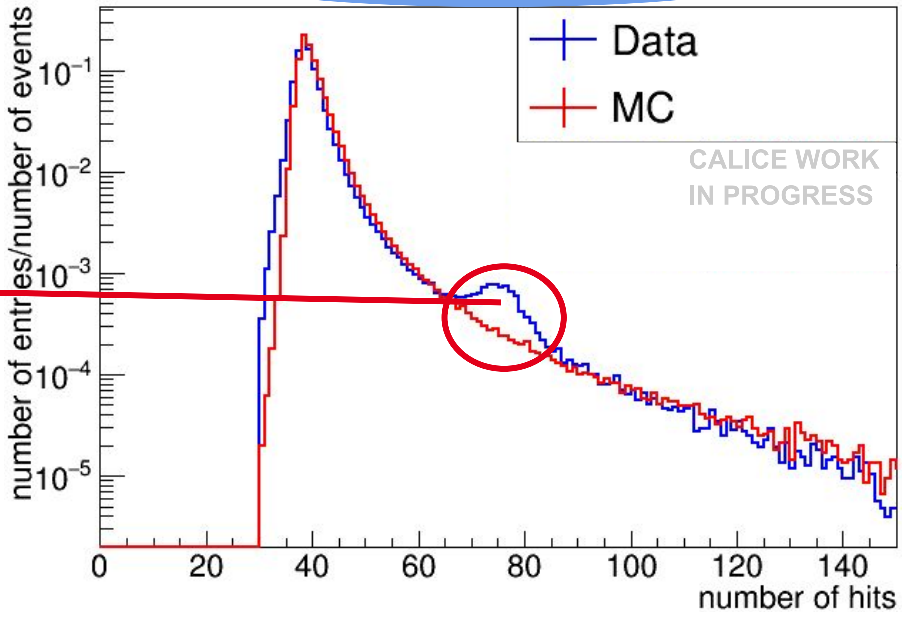


Comparing data and simulation

- **Number of hits per event** overall a bit higher for simulation
- Double muon peak not entirely removed after track selection due to tower-changing tracks



number of tracks = 1



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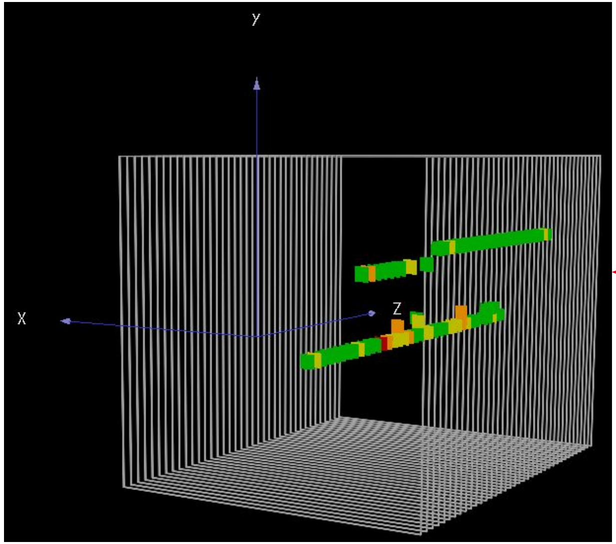
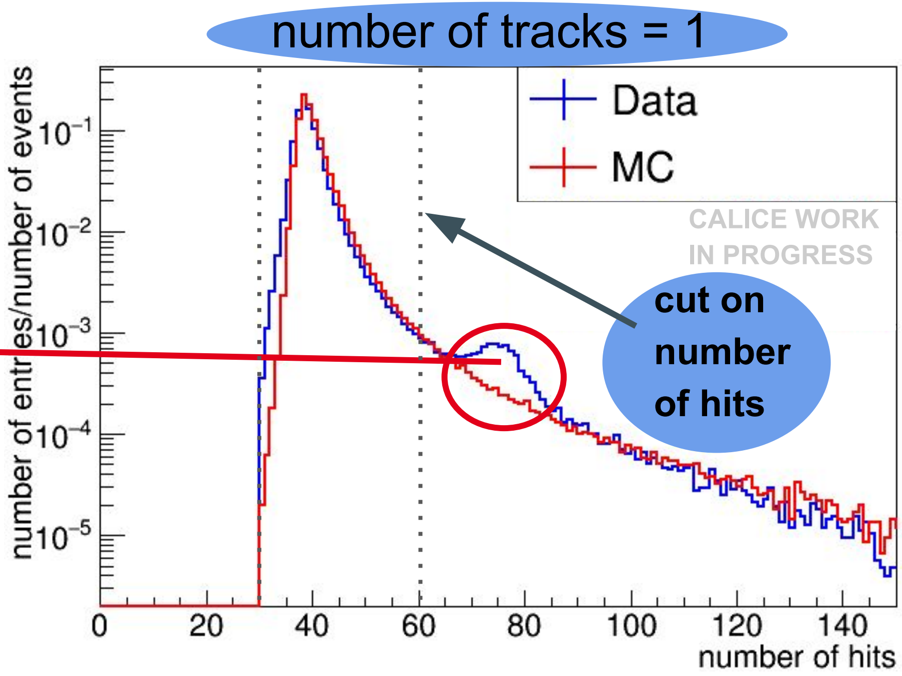
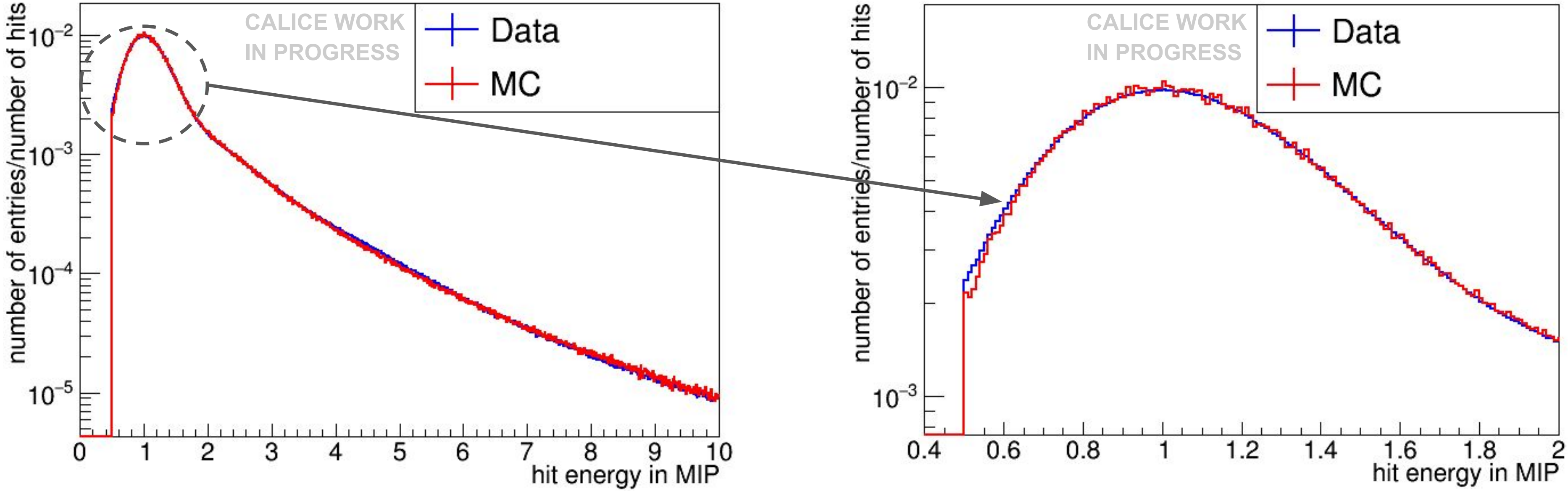




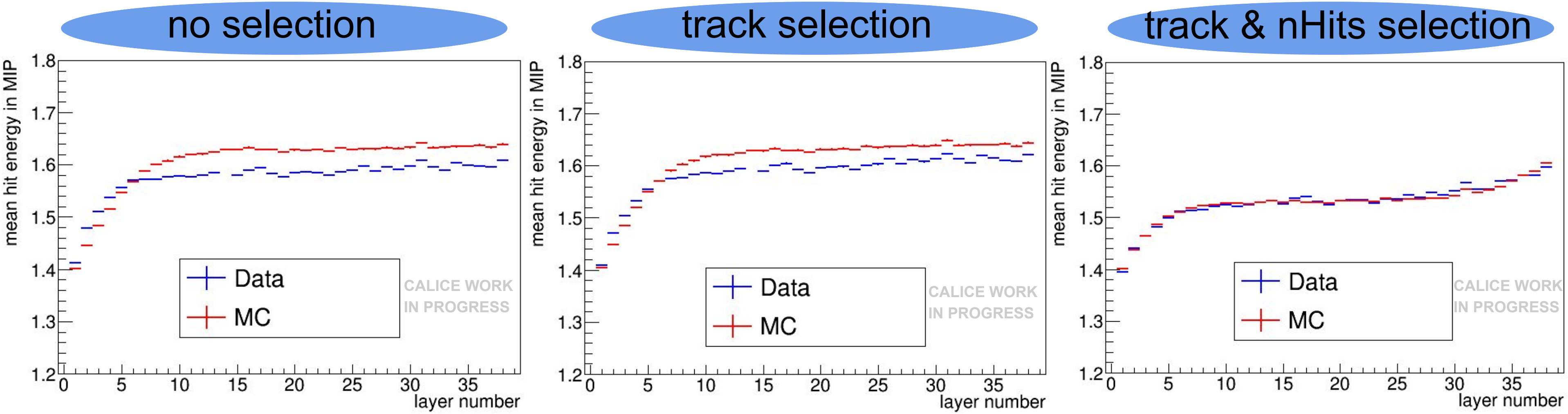
Comparing data and simulation

- **Hit energy distribution** very similar for data and simulation
- Slight excess in high energy tail for simulation
- Slight excess in low energy area for data



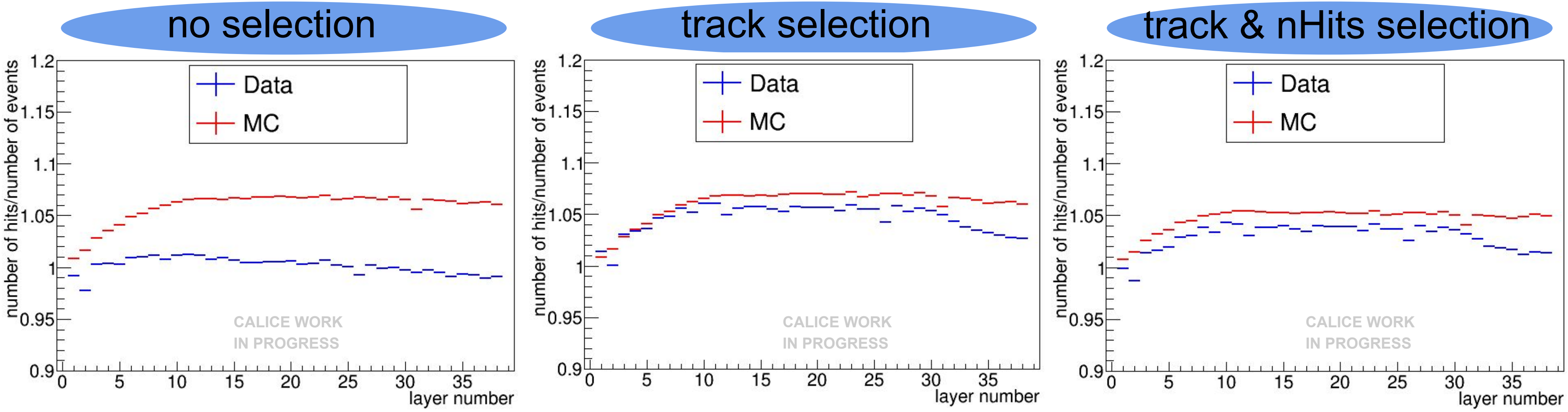
Comparing data and simulation

- Agreement of **mean hit energy per layer** very good after event selection
  - Slightly improved by track selection
  - Greatly improved by nHits selection



Comparing data and simulation

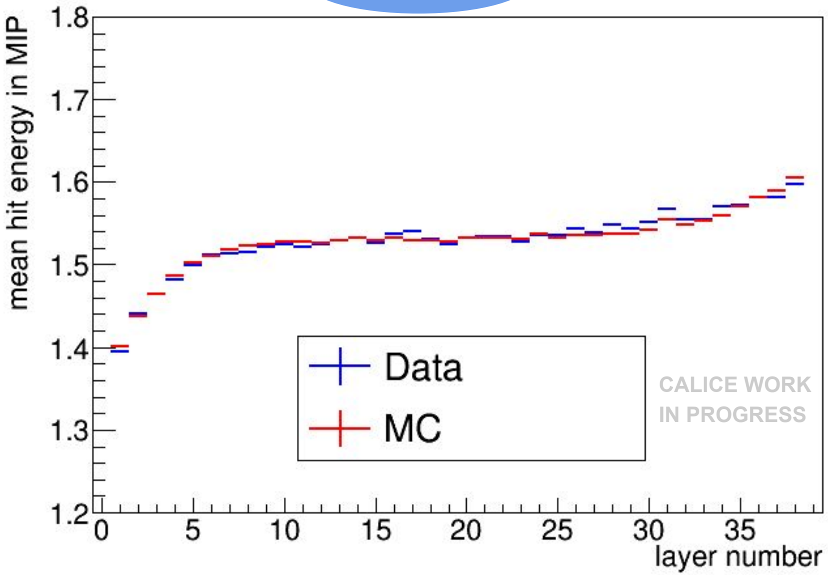
- Agreement of **mean number of hits per layer** improved by event selection
- Rise in number of hits with depth for data only after track selection: contamination?
- Lower number of hits in outer layers due to tower-changing tracks



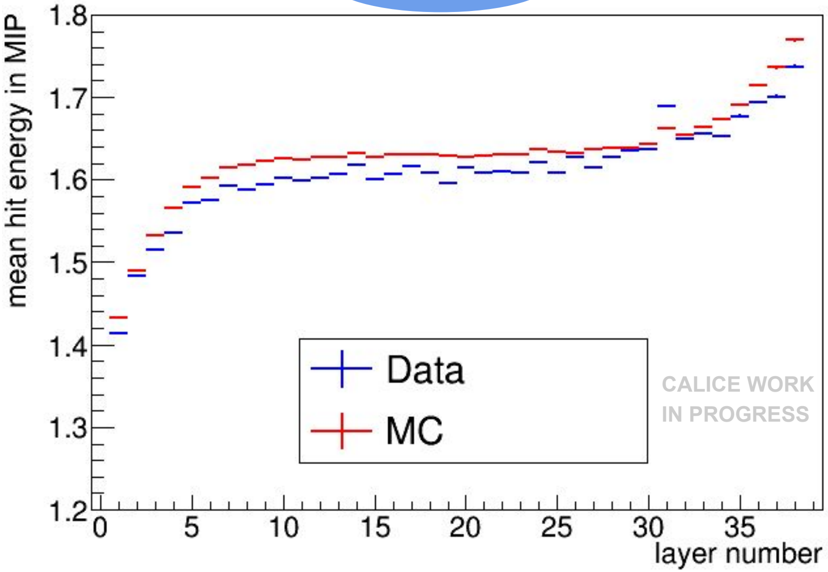
40 and 120 GeV

- Stronger increase of **mean hit energy per layer** with depth at 120 GeV
- Agreement of mean hit energy per layer better at 40 GeV
- Increased influence of radiative effects at 120 GeV

40 GeV

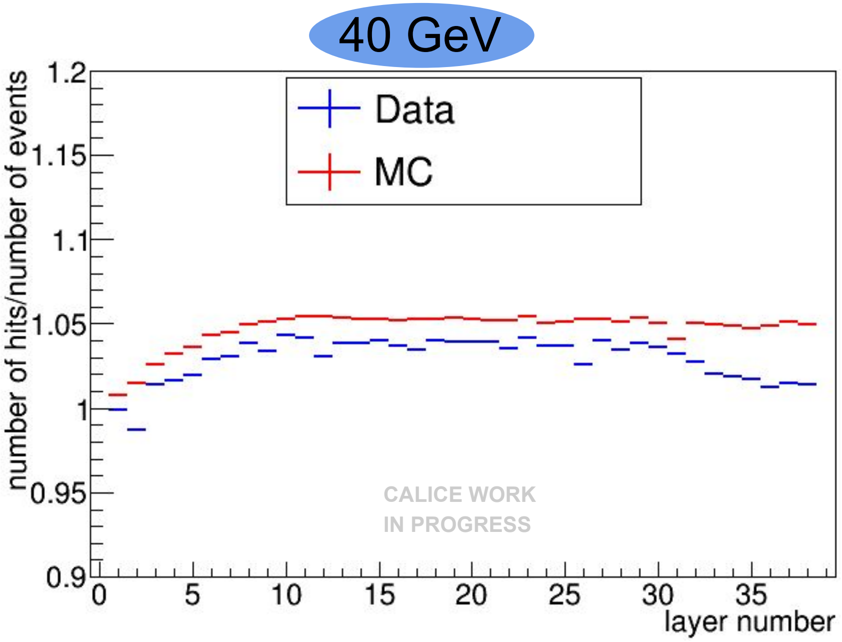


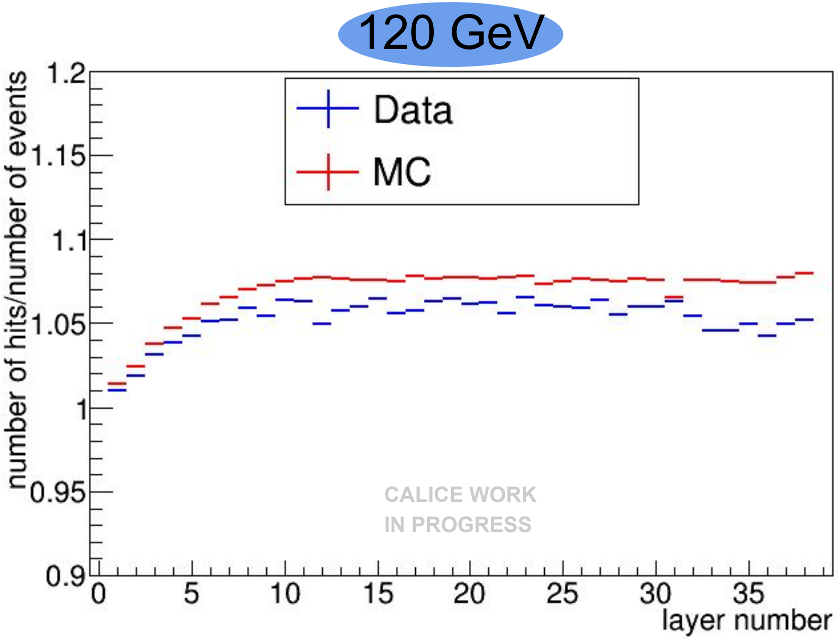
120 GeV



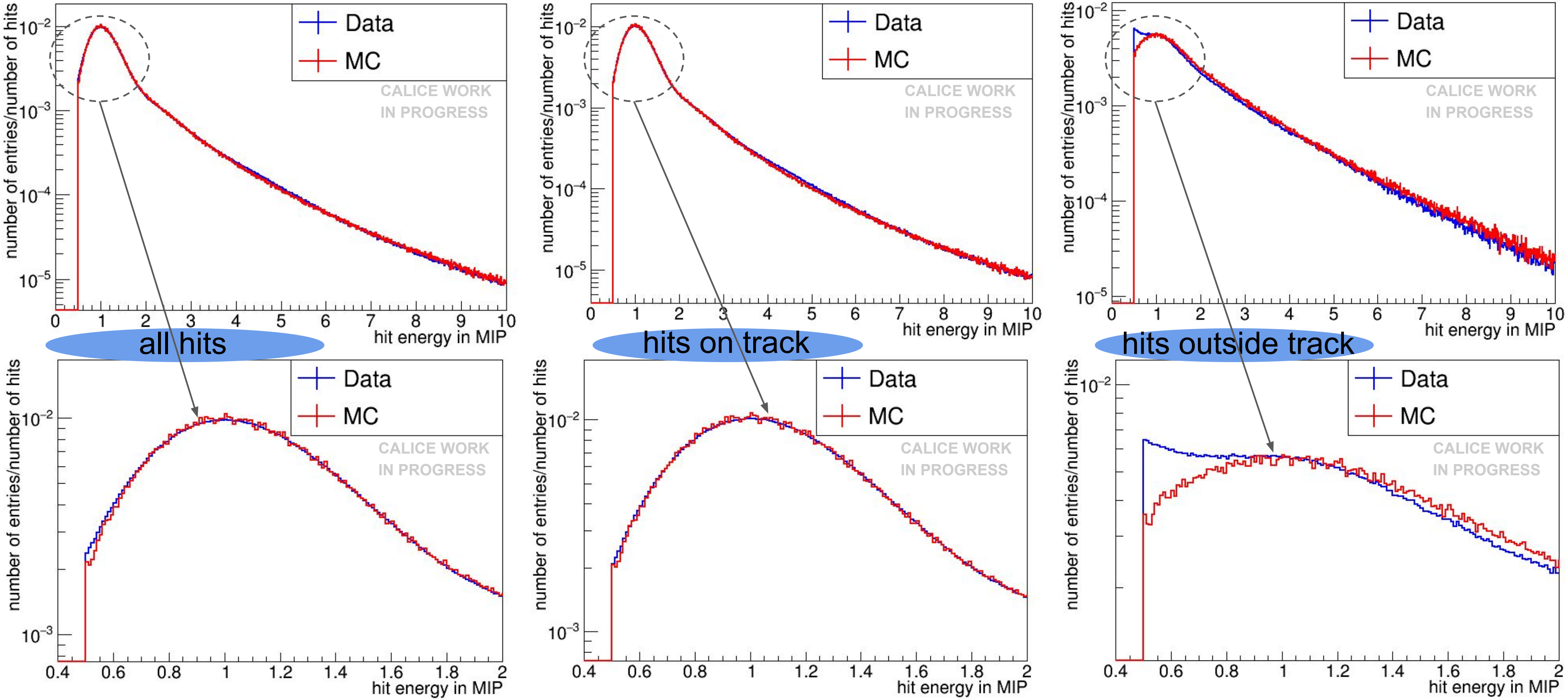
40 and 120 GeV

- Stronger increase of **mean number of hits per layer** with depth at 120 GeV
- Increased influence of radiative effects at 120 GeV





Hits on track and outside track



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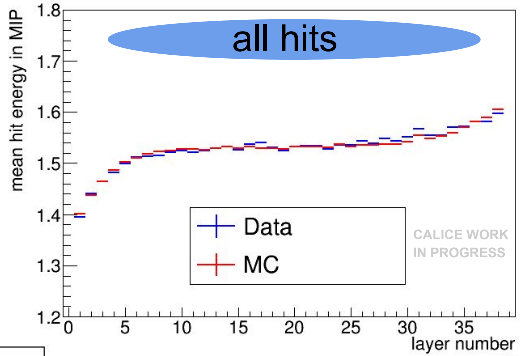
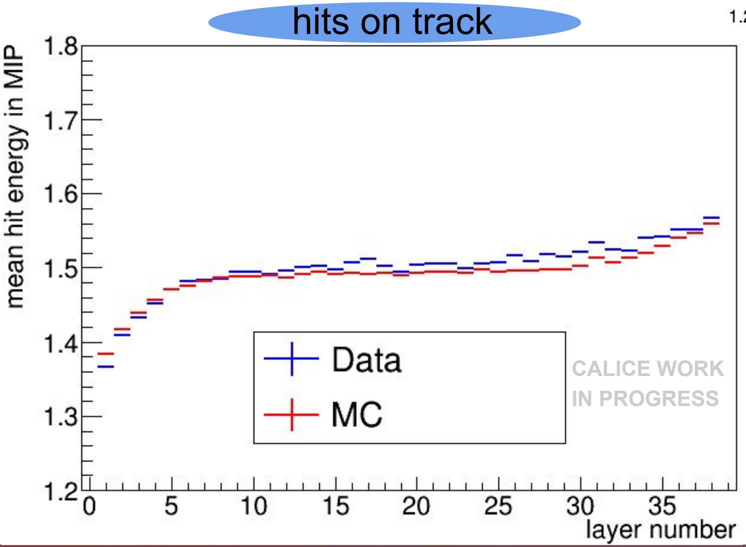
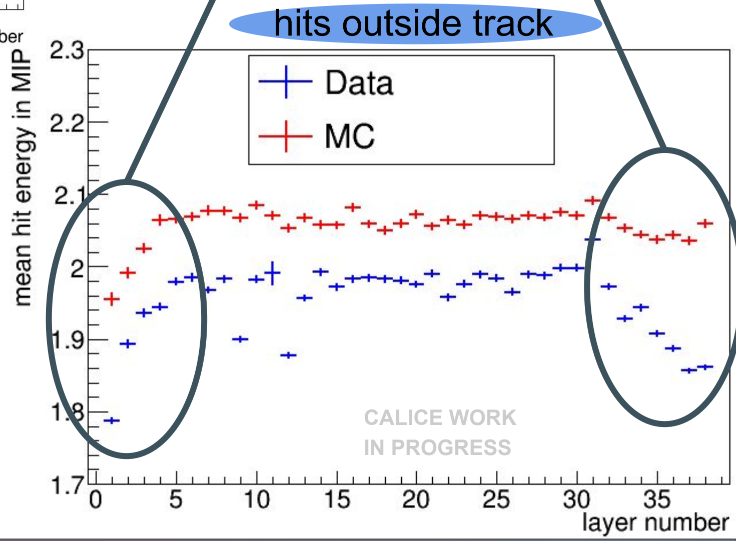
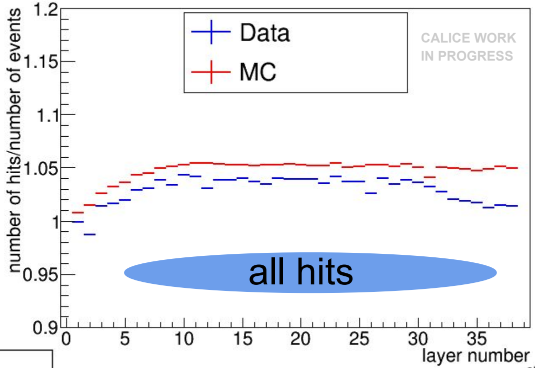


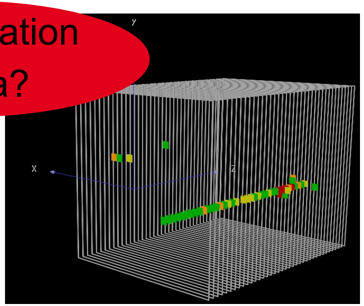


tower-changing tracks



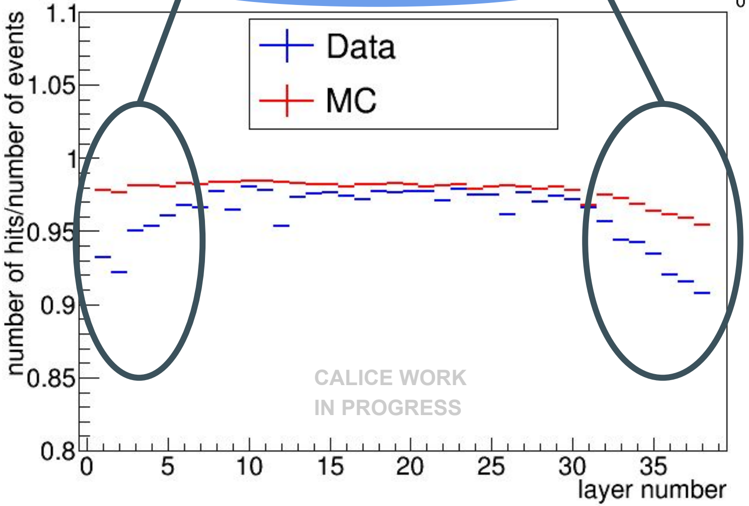
Hits on track and outside track



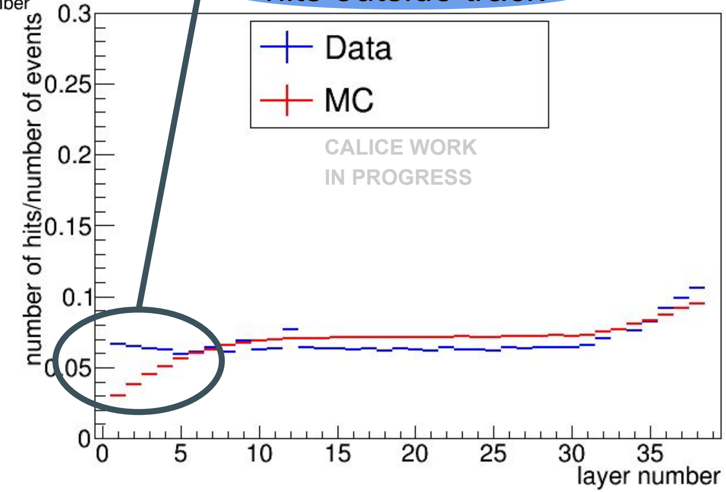


tower-changing tracks

hits on track

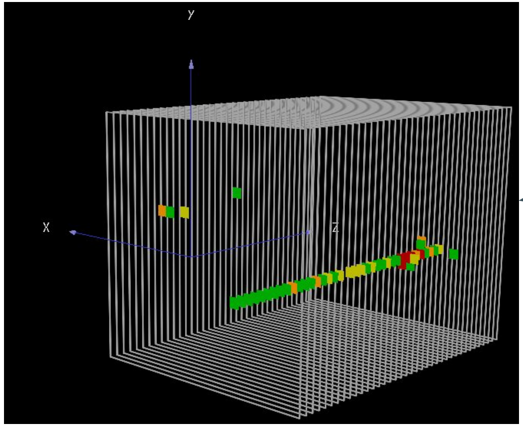


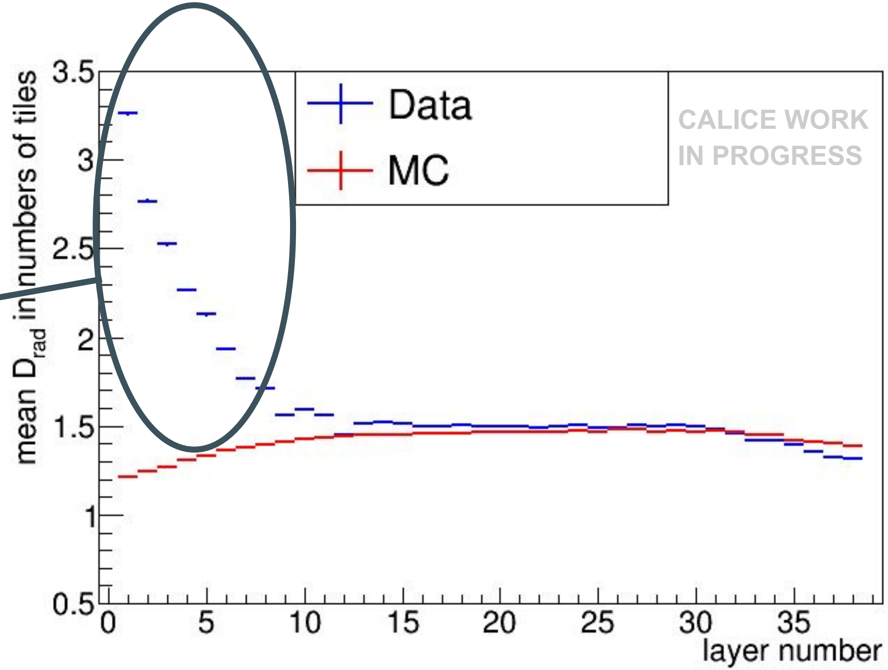
hits outside track



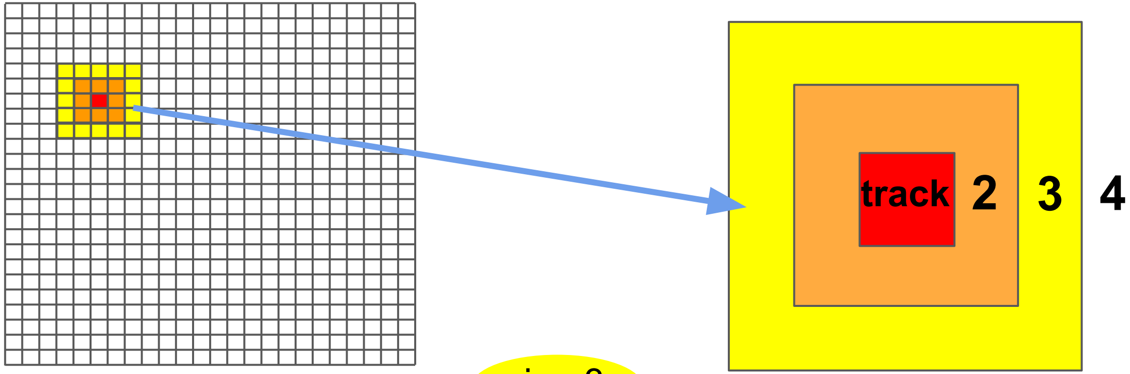
Mean radial distance to track

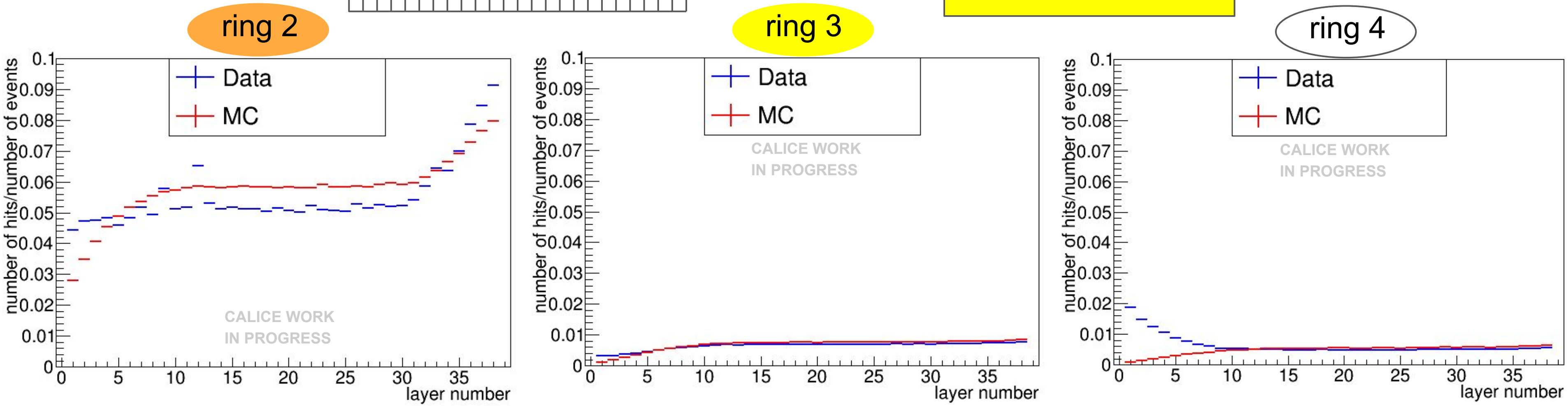
- Very large **mean radial distance to track** in first layers for data: contamination?





Lateral development: hit numbers





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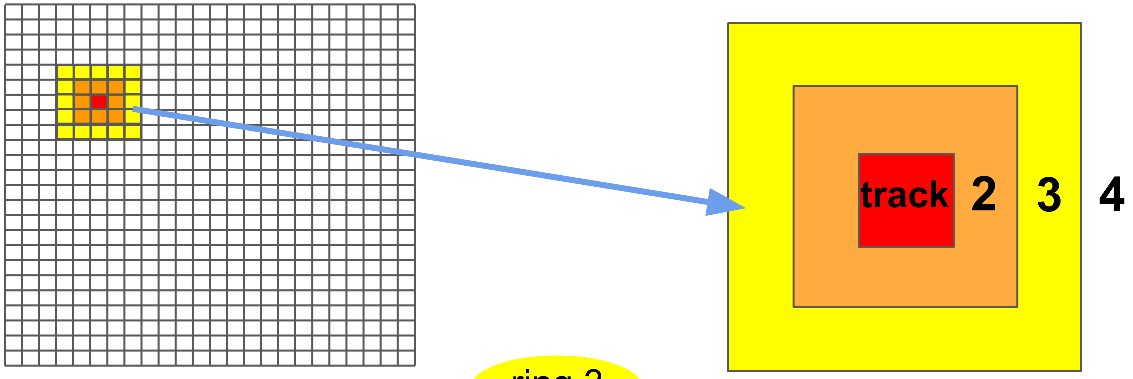
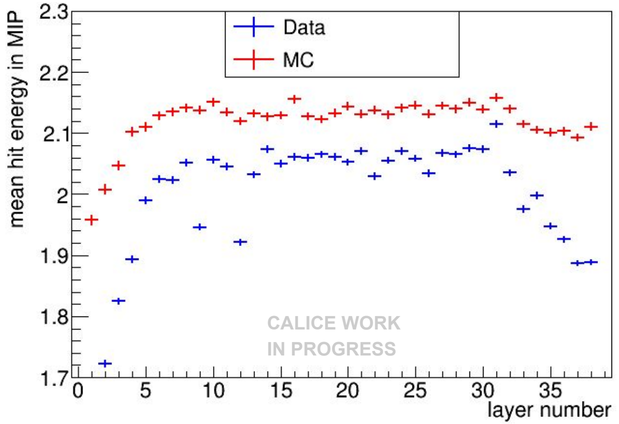
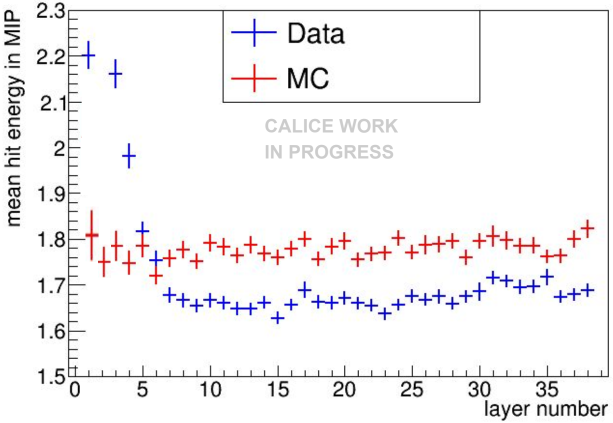


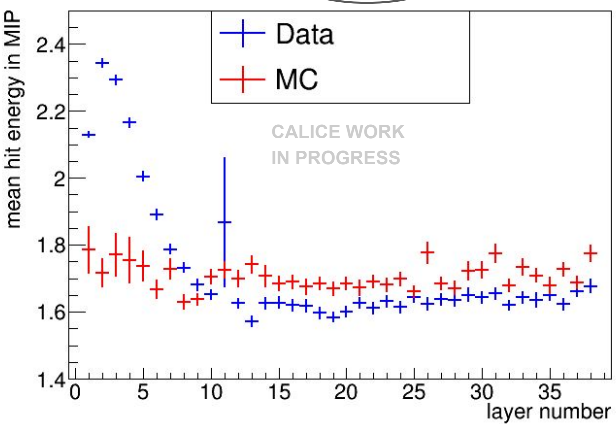
ring 2



ring 3



ring 4

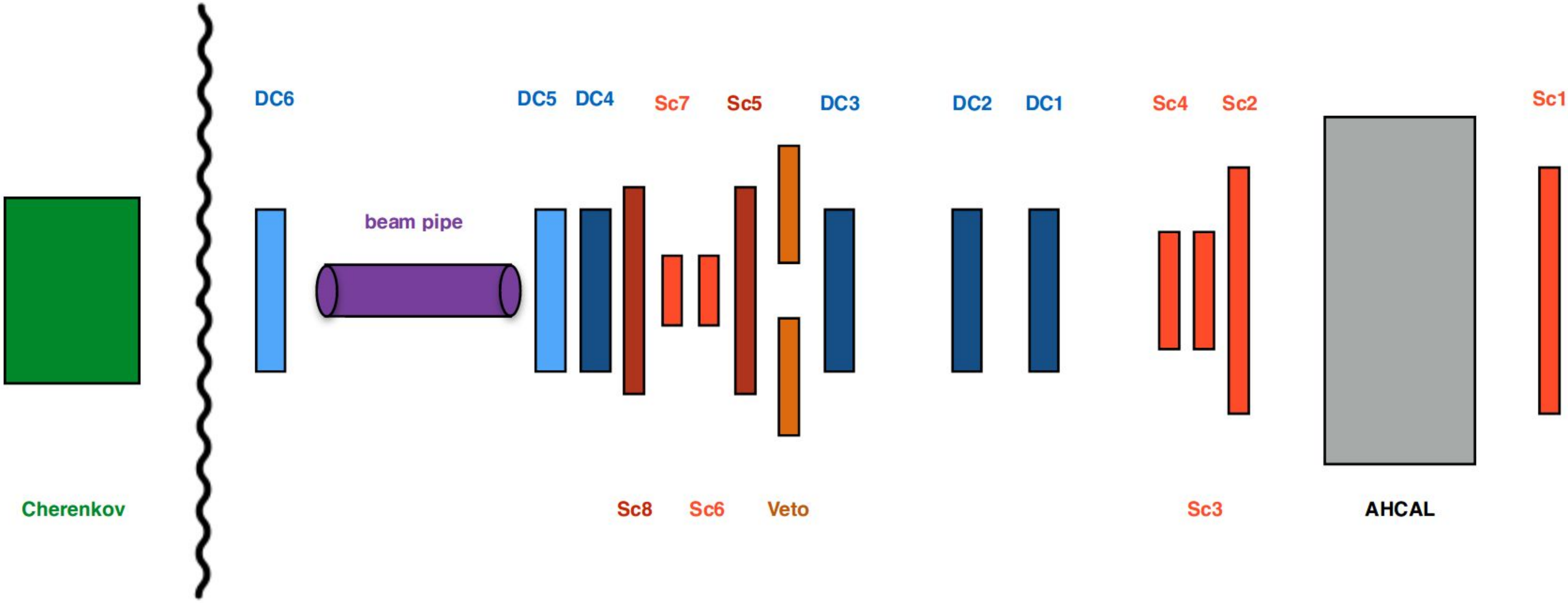


Conclusion

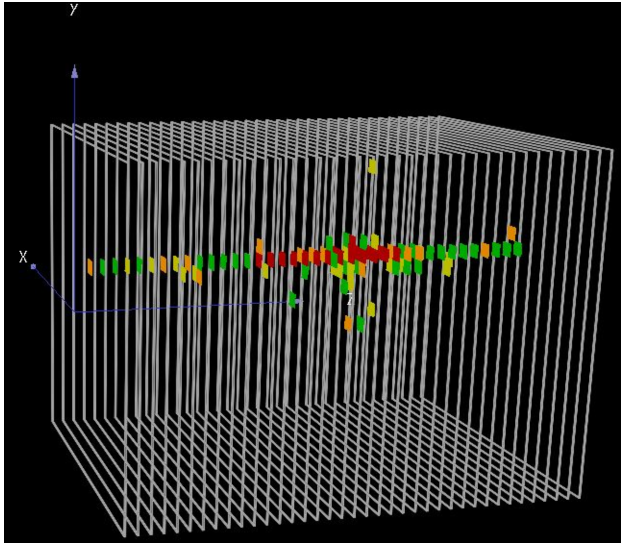
- Muons are an important tool for the calibration of highly granular calorimeters
- MPV is a useful calibration variable
  - Independent of depth
  - Independent of different energies
- Good agreement between muon data and simulation after event selection
- Next steps: understanding the differences outside the tracks
  - Improvement of track finding
  - Finding the sources of the differences
    - Contamination in data
    - Imperfections in the detector description in simulation
    - Treatment of radiative effects in simulation
  - Implementation of the wire chamber information

BACKUP

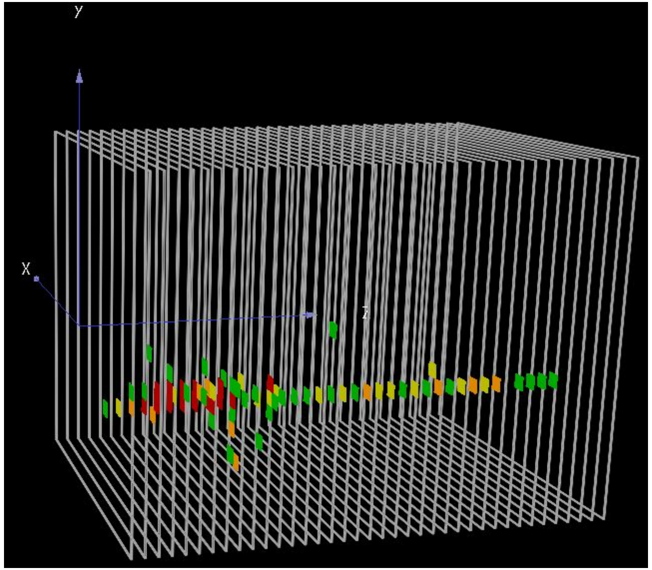
May 2018 test beam setup

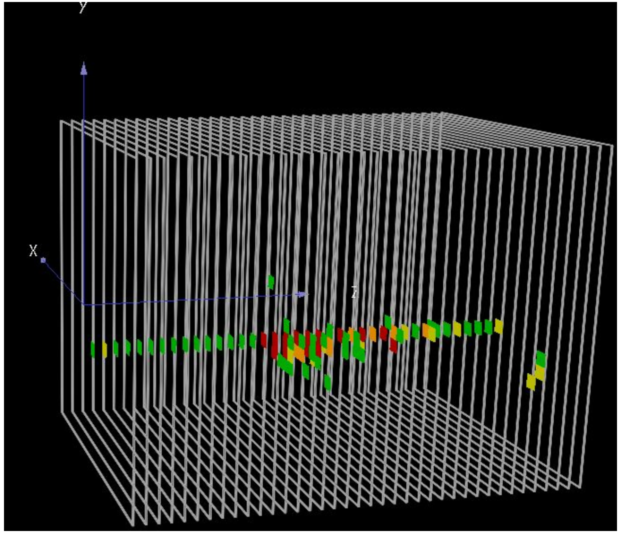


Simulation events

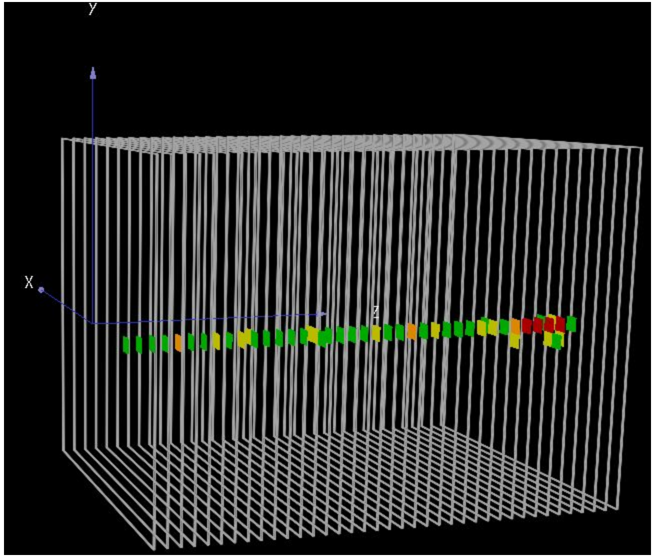


rejected
after
nHits cut

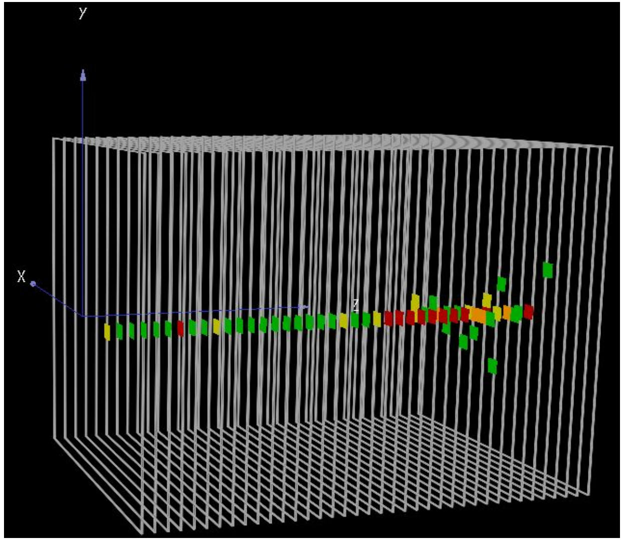


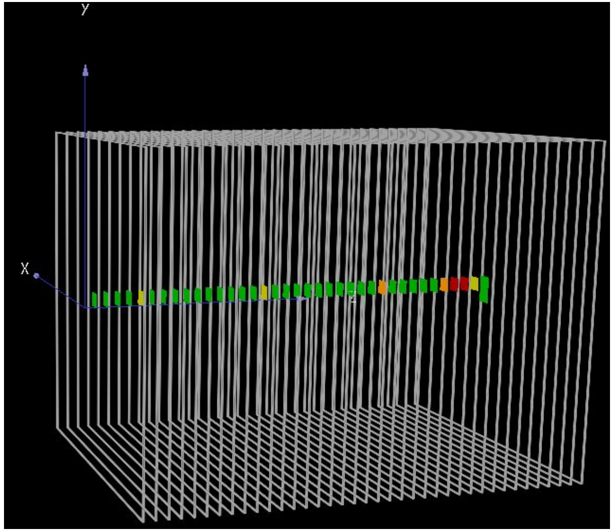


Simulation events

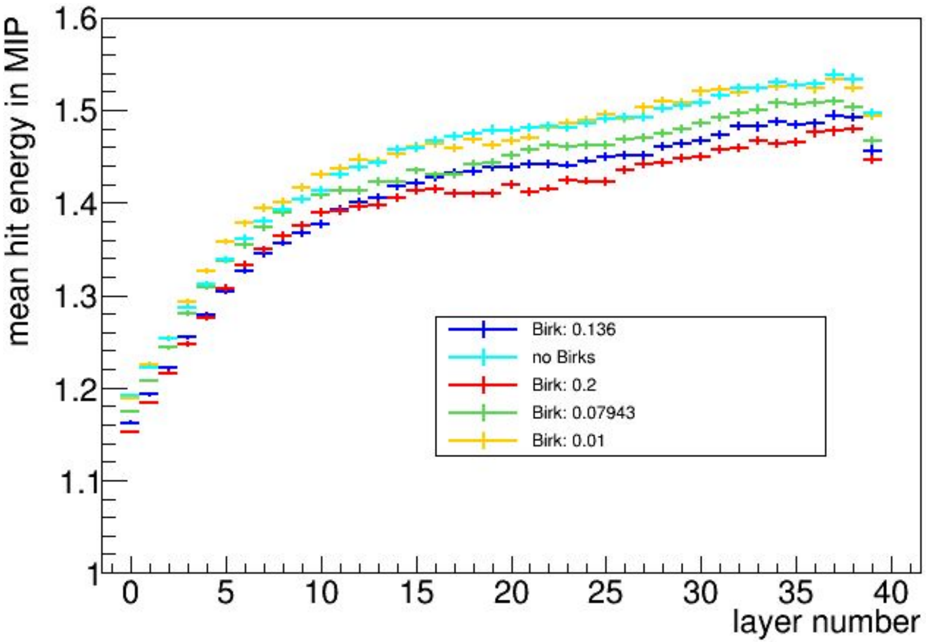


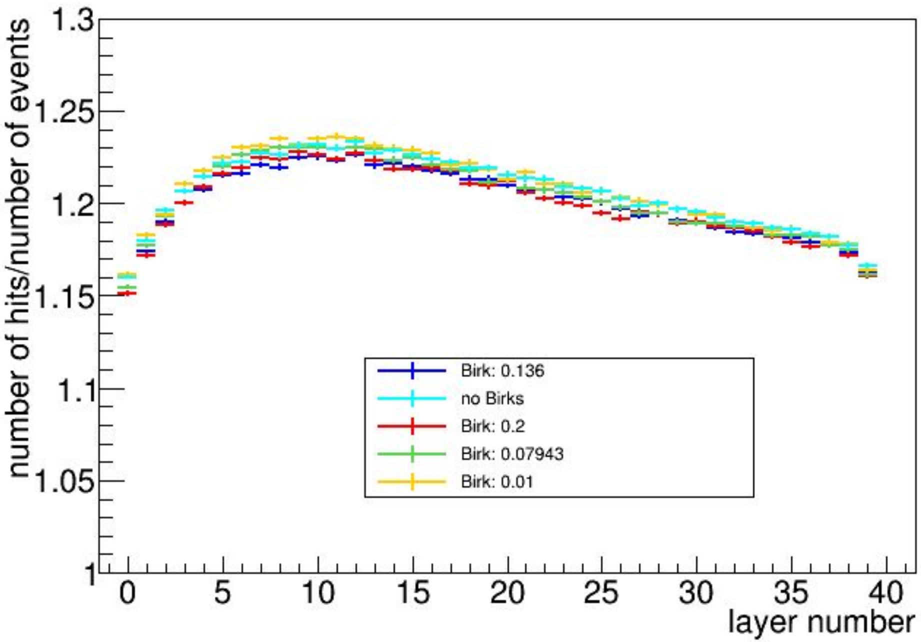
accepted
after
nHits cut



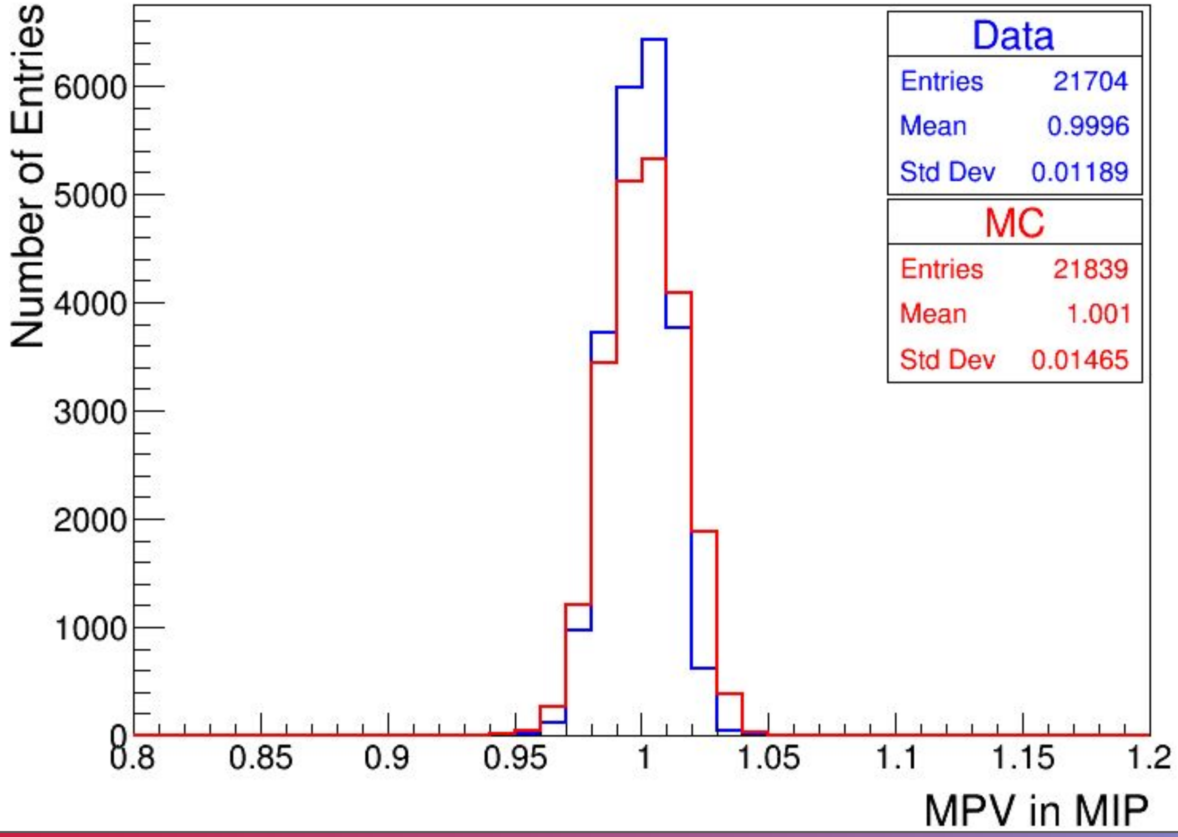


Birk's constant

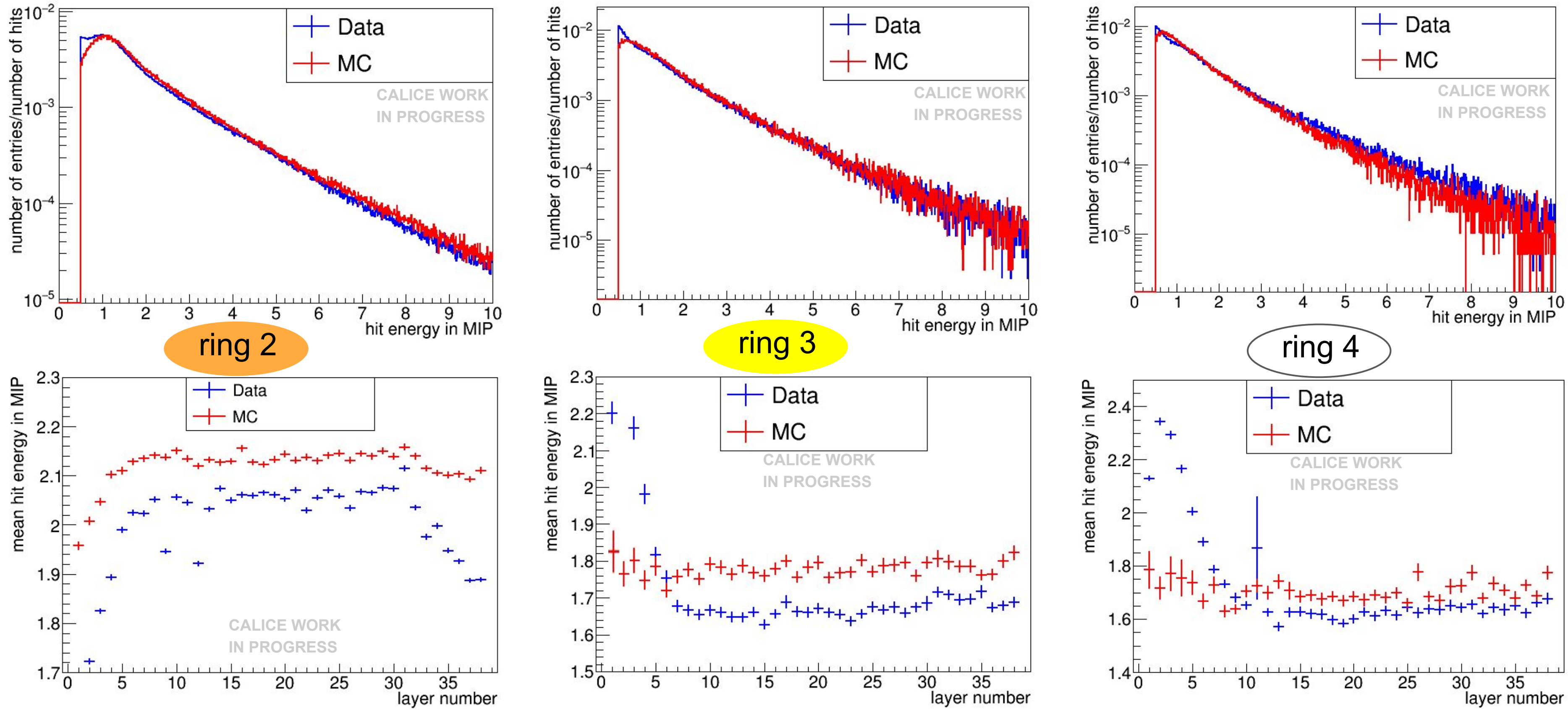




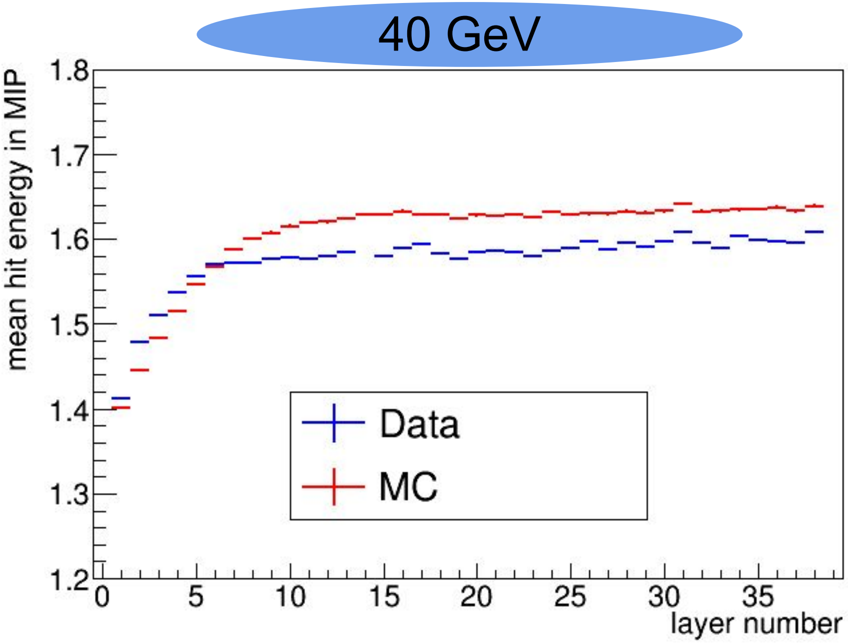
MPV in single channels

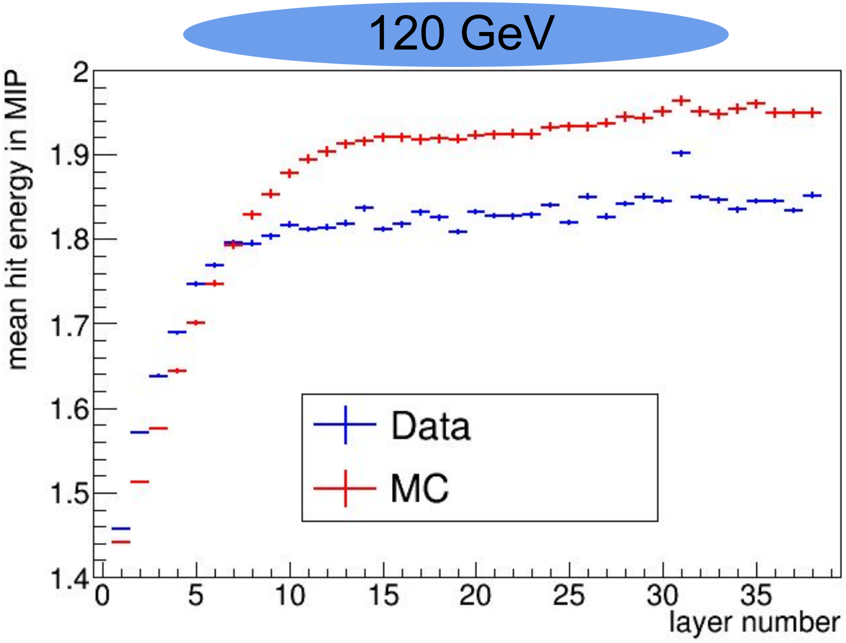


Lateral development: hit energy



40 GeV vs. 120 GeV





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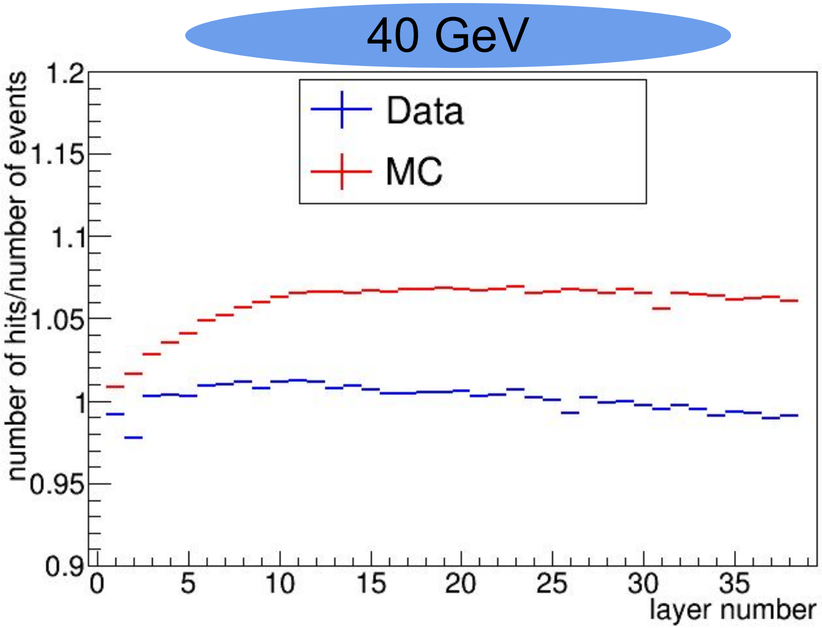
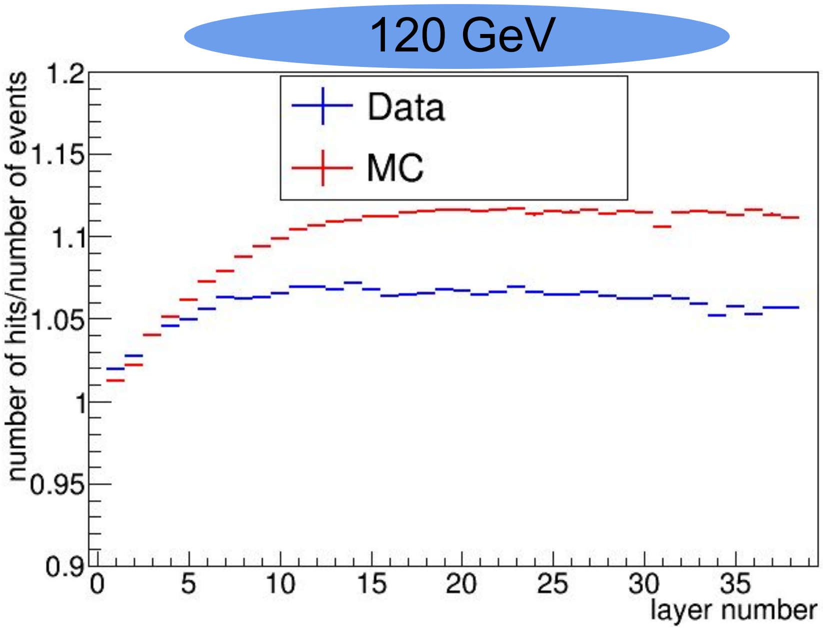
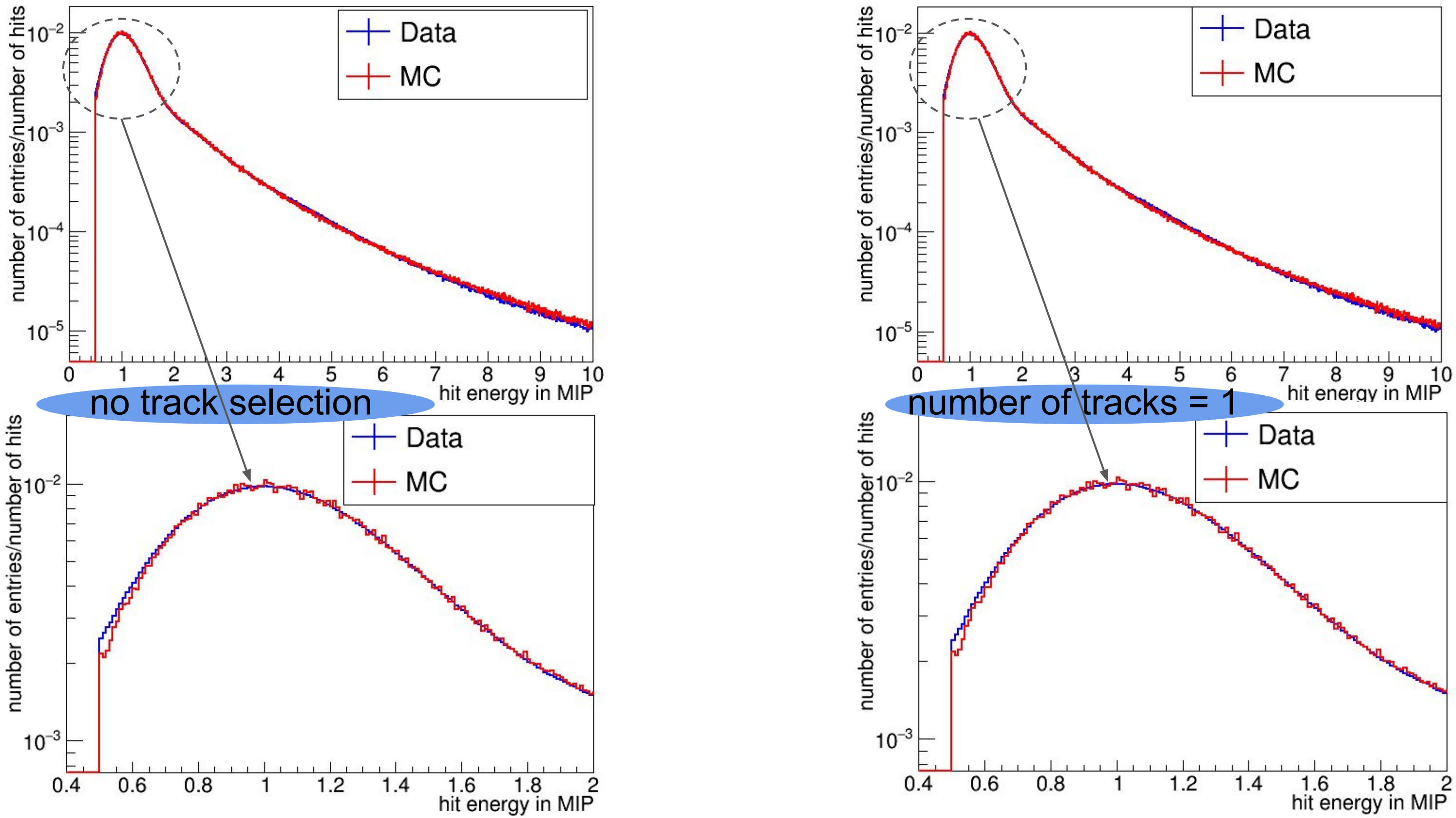
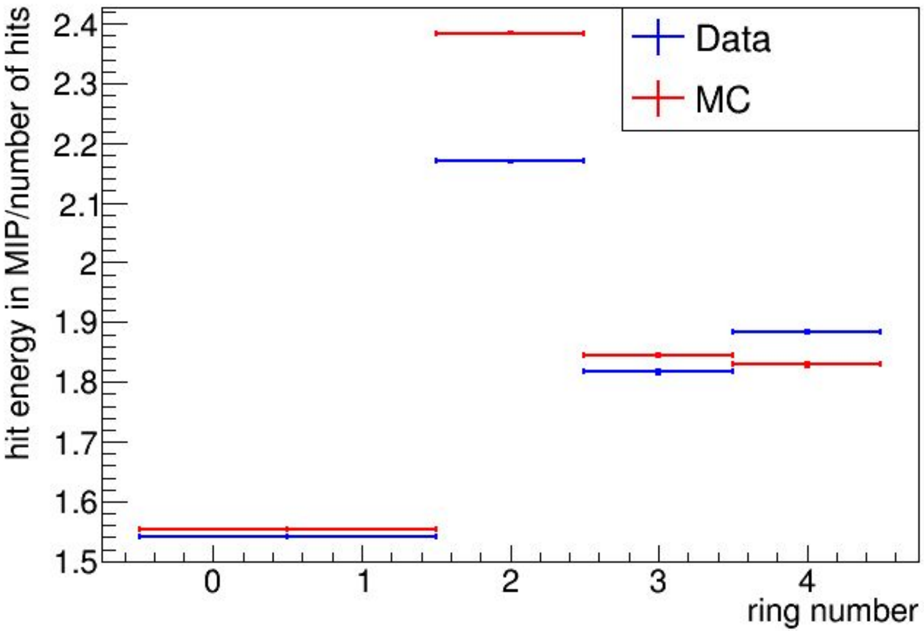


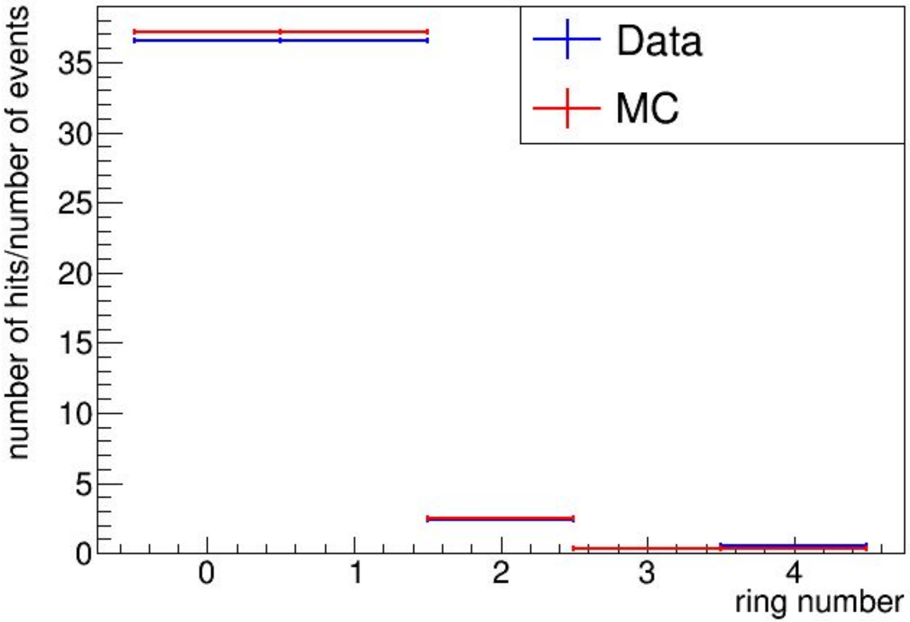


Comparing data and simulation



Lateral profiles





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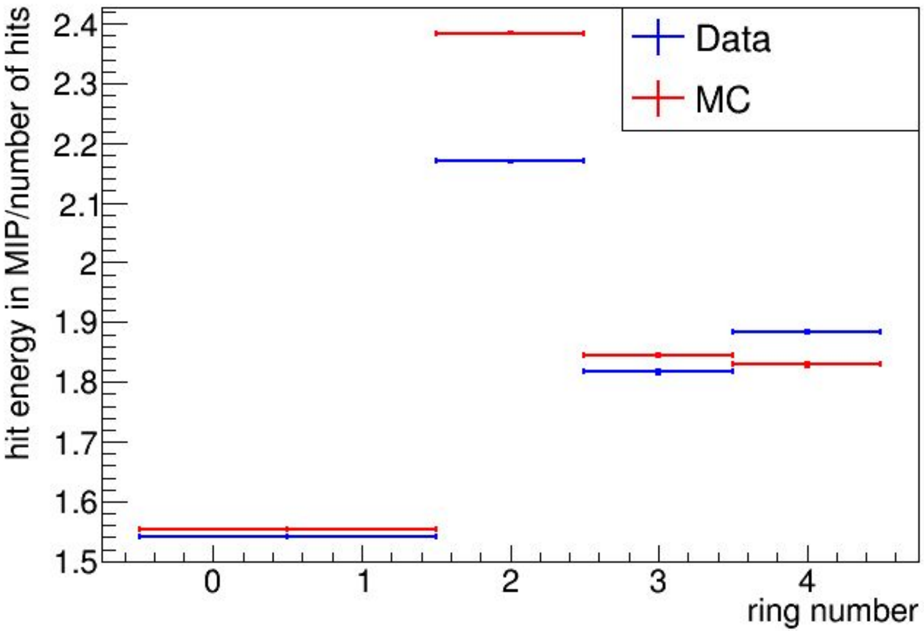
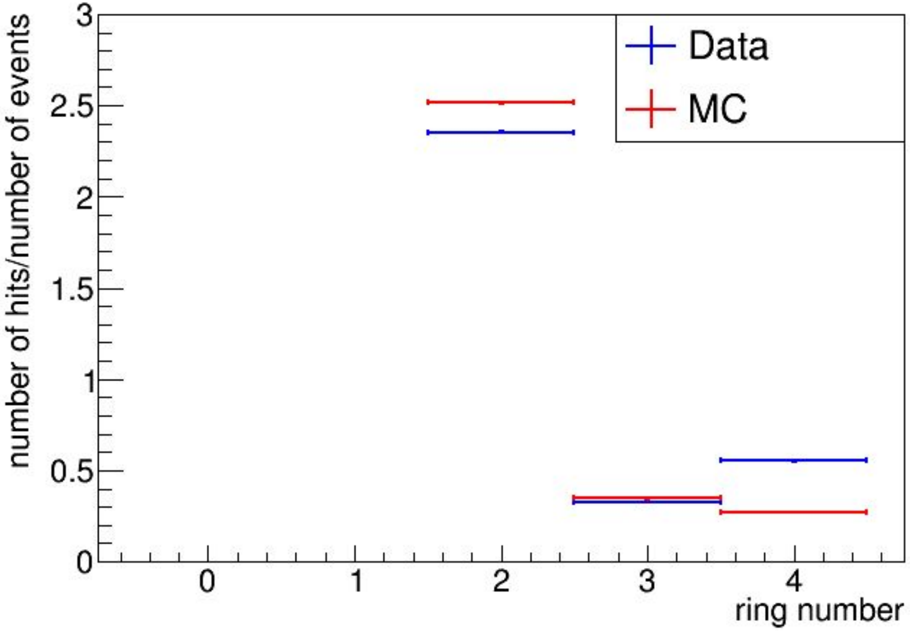


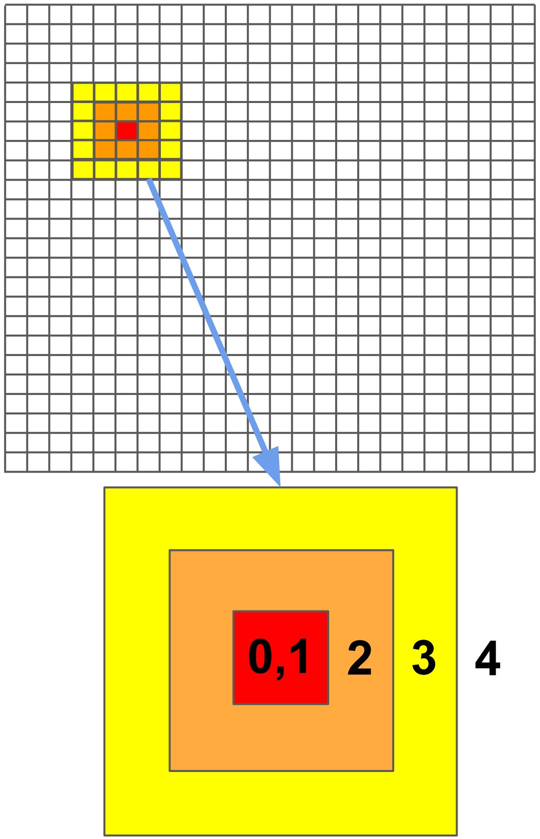


“Rings” around the track

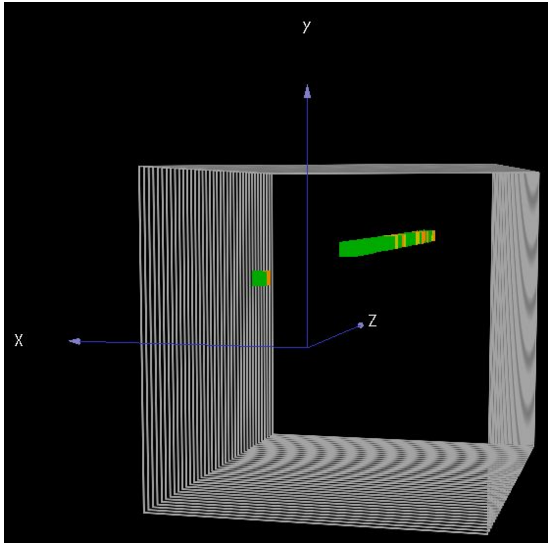
- Radial distance D_{radial} in numbers of tiles

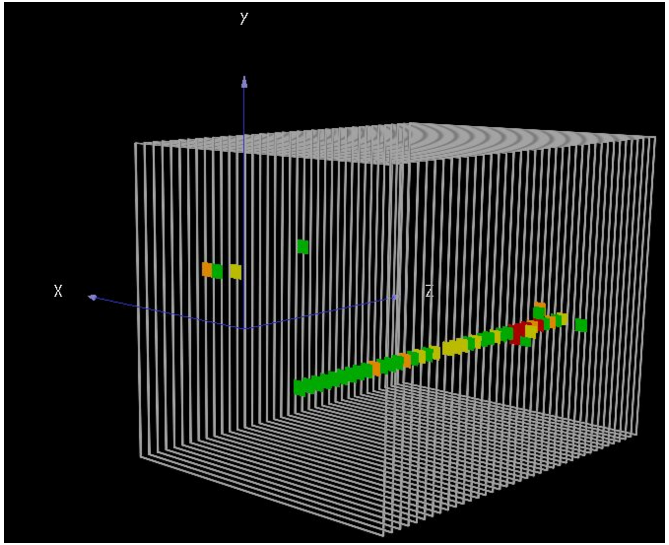
$$\sqrt{(X_{hit} - X_{track})^2 + (Y_{hit} - Y_{track})^2}$$

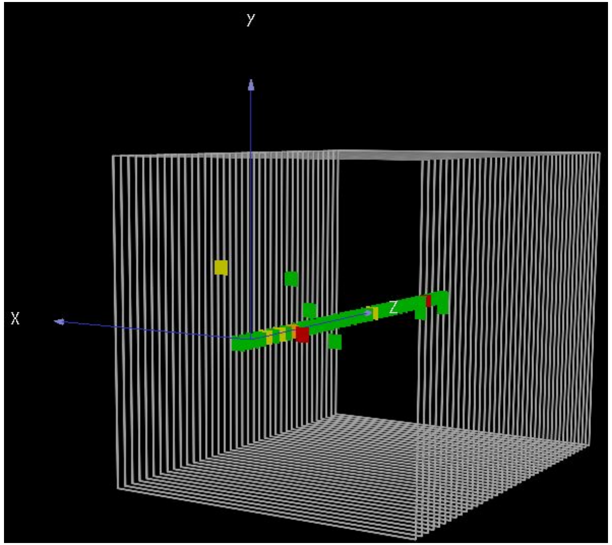
- Ring 0: on track
- Ring 1: in same tower as track
- Ring 2: $D_{radial} > 0$ && $D_{radial} < 2$
- Ring 3: $D_{radial} >= 2$ && $D_{radial} < 3$
- Ring 4: $D_{radial} >= 3$



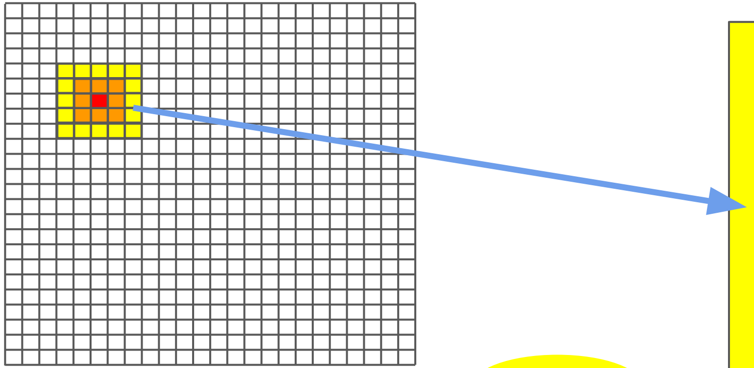
Contamination in data?

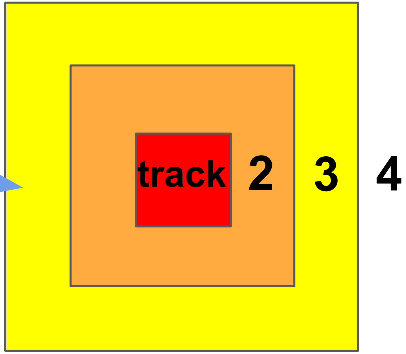




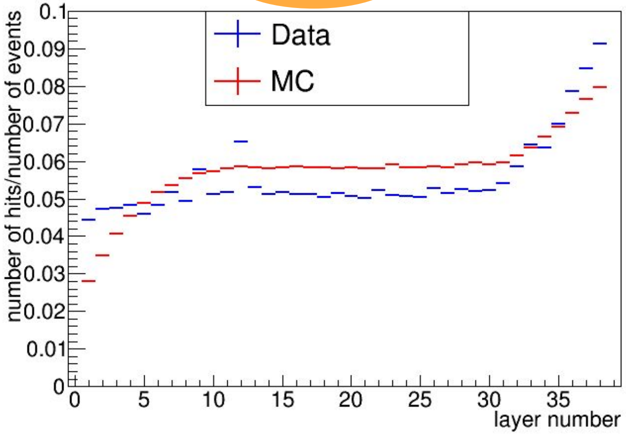


Lateral development: hit numbers

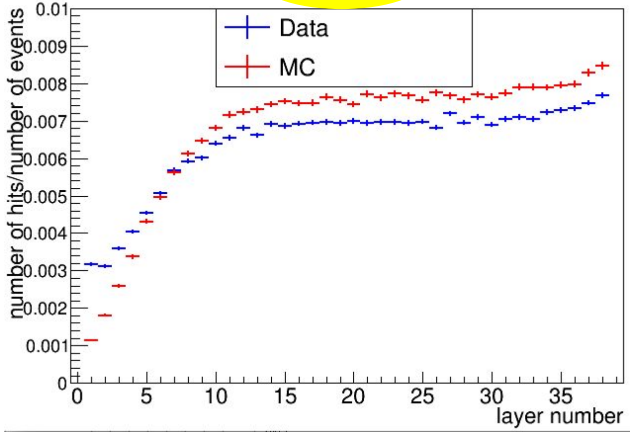




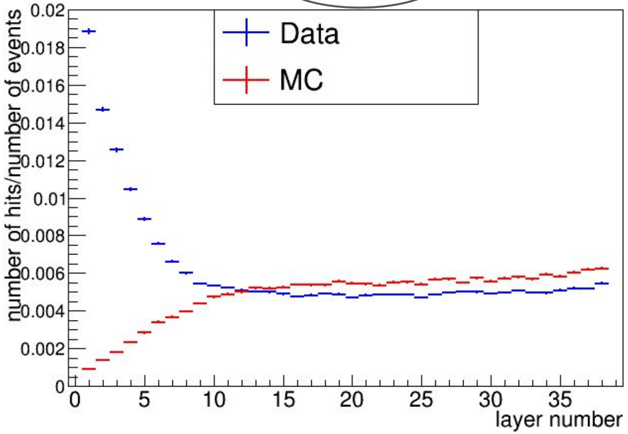
ring 2



ring 3

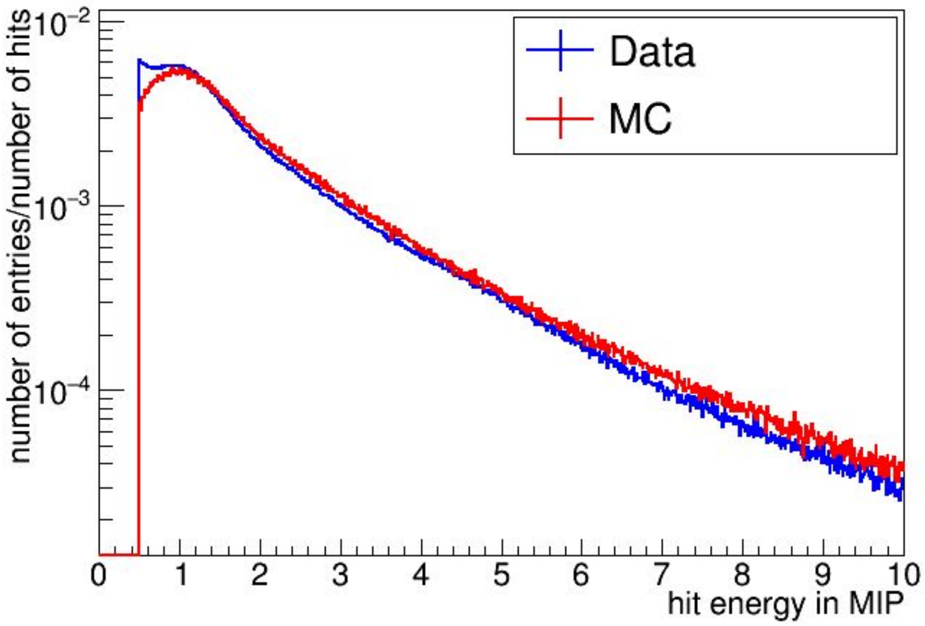


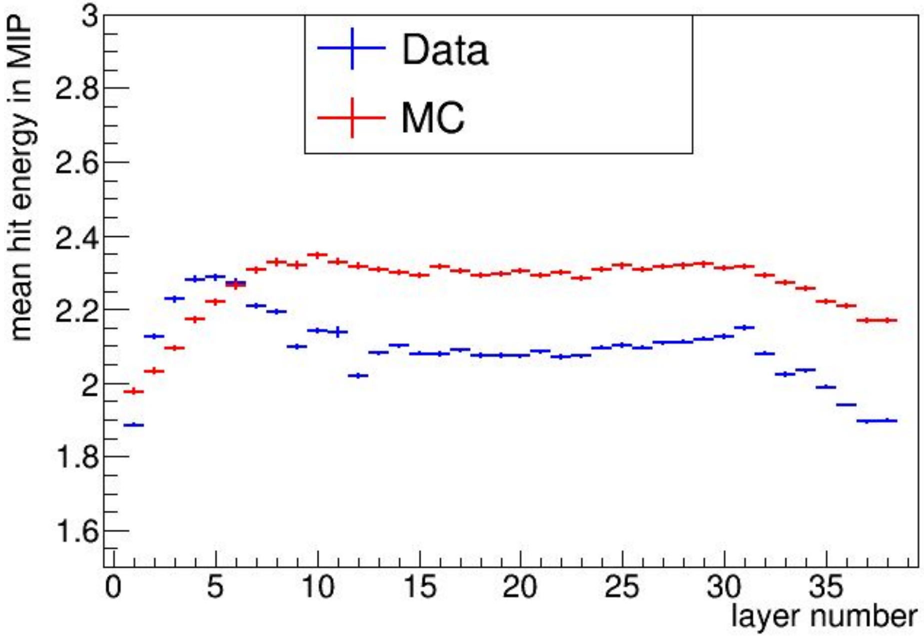
ring 4



Large deviations outside track

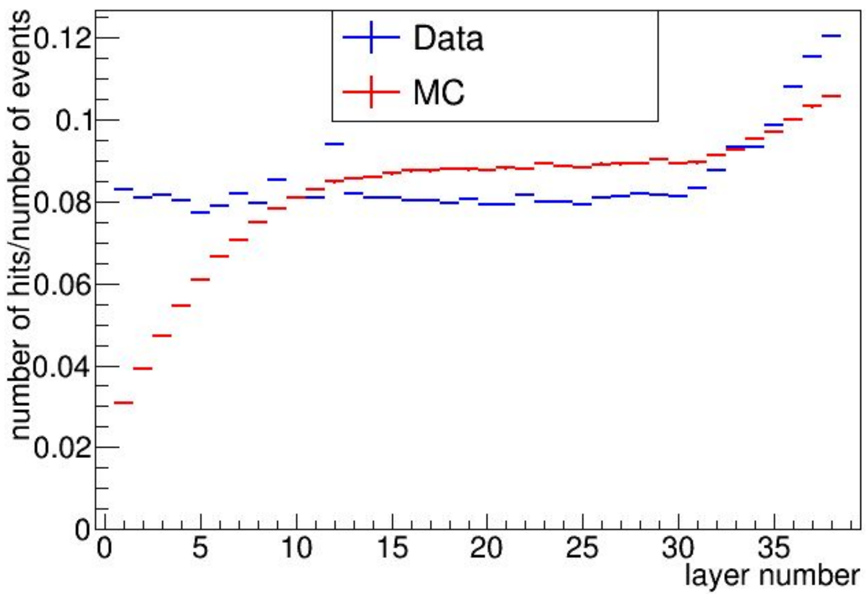
- Peak to low hit energies for data: noise?
- Larger high hit energy tail for simulation: radiation?
- Hit energies higher in first layers for data: contamination?

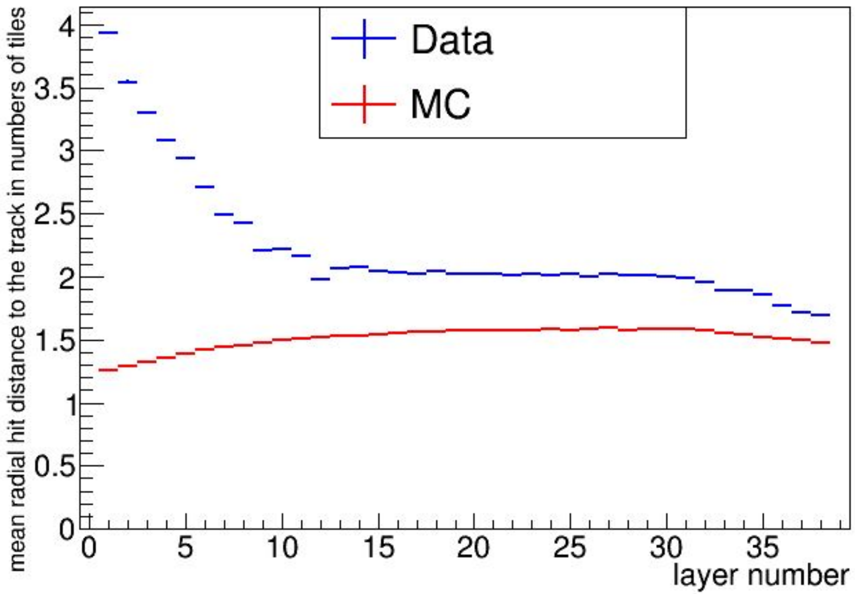




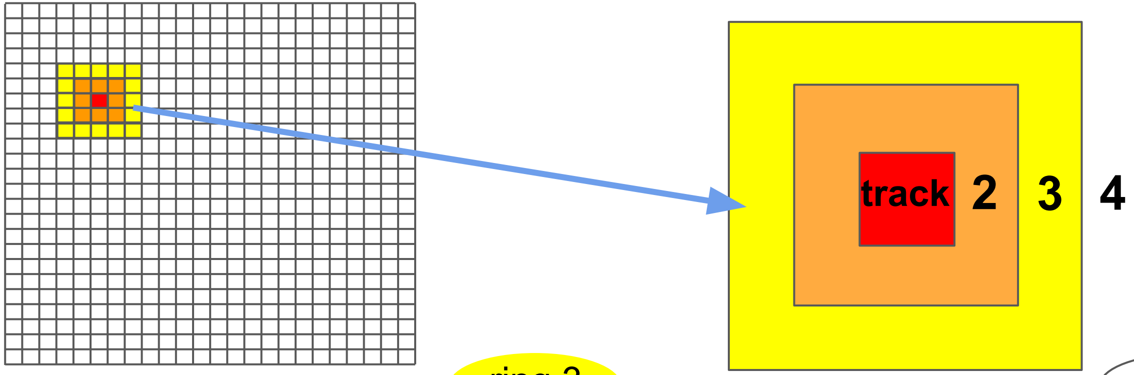
Large deviations outside track

- No rise in number of hits per event over first layers for data: contamination?
- Very large mean radial distance to track in first layers for data: contamination?

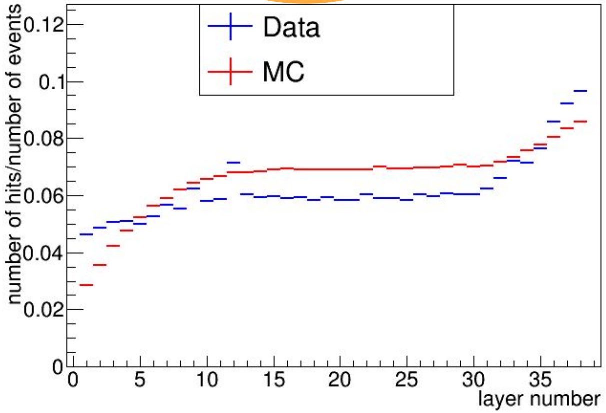




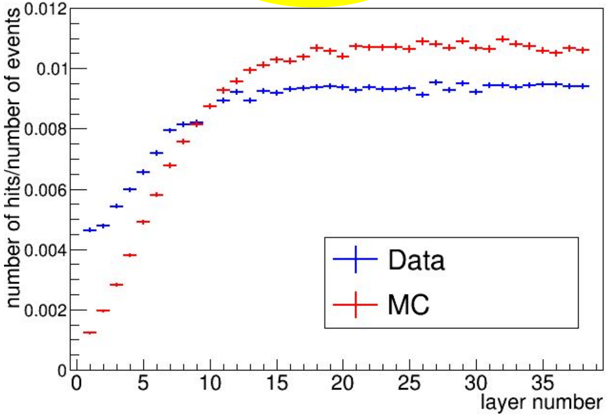
Lateral development: hit numbers



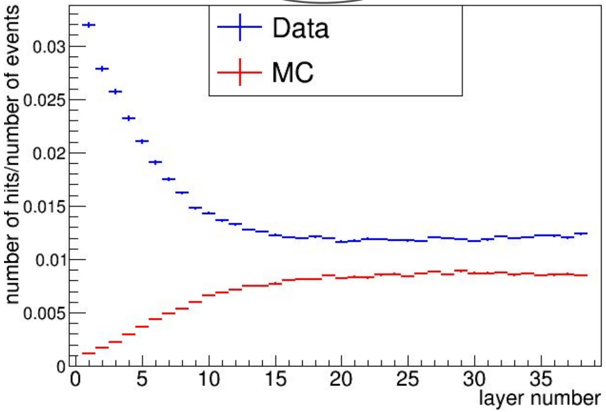
ring 2



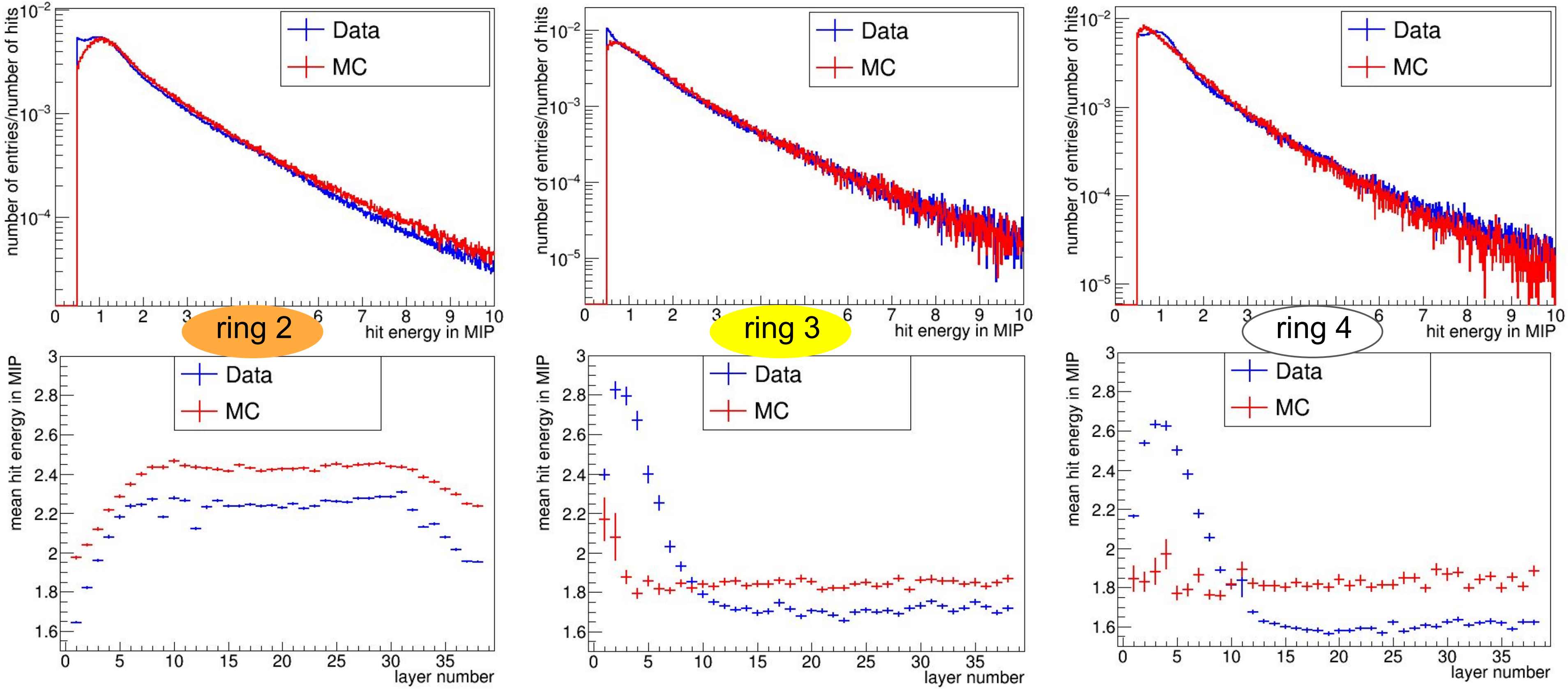
ring 3



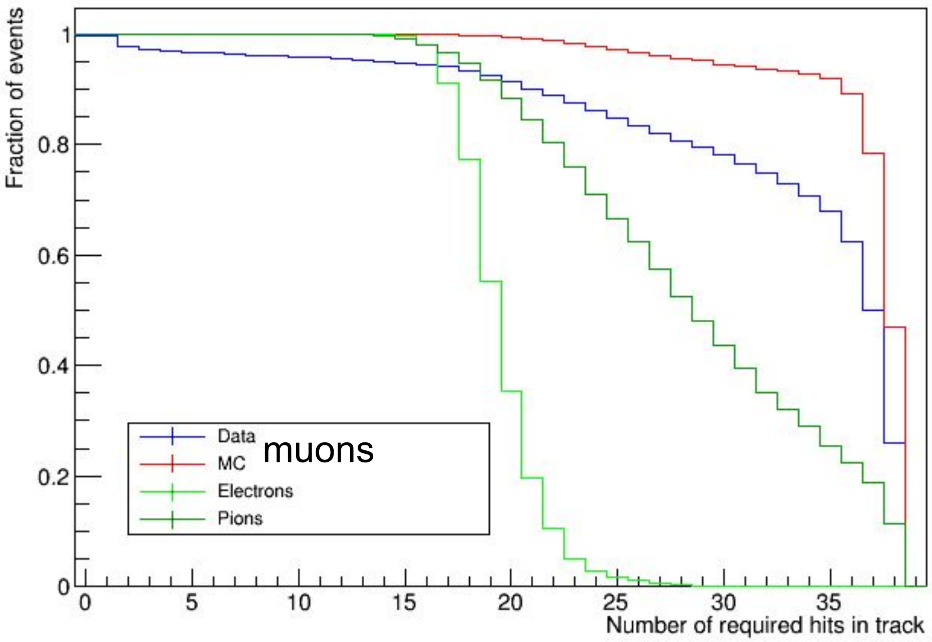
ring 4



Lateral development: hit energy



MIPTrackFinder



Consistency of the MPV calibration

- MPV = maximum of Landau-Gaussian fit to the hit energy distribution
- Calibration of each channel to have MPV = 1 MIP using 40 GeV muons
- Also used to adapt the GeV to MIP conversion factor in the digitisation