Review of the ADC reconstruction with the Underground Muon Detector

Marina Scornavacche[1,2] **Supervisors:** R. Engel[2], J. Figueira[1]

1 Instituto de Tecnologías en Detección y Astropartículas (ITeDA), CNEA-UNSAM.
2 Institut für Astroteilchenphysik (IAP), Karlsruher Institut für Technologie.

UMD: Binary vs ADC

- **64 SiPMs independently, Nμ sequences of "1"s**
- Low particle density (far from shower core)
- Pile up and corner clipping corrections

- **64 SiPMs summed**
- High particle density (close to shower core)
- **Number of muons in the ADC** →

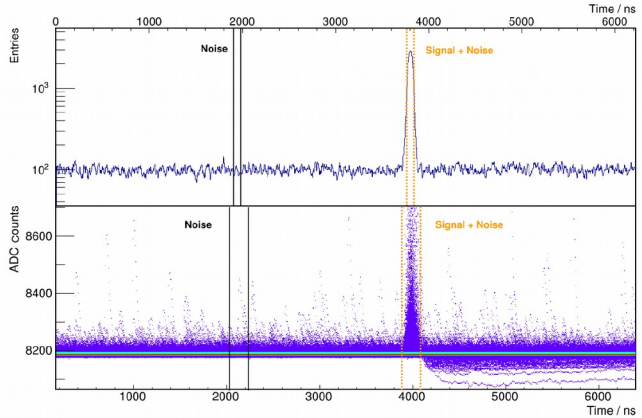
$$N_\mu = \frac{q_{\text{meas}} \cdot \cos(\theta)}{< q_{1\mu}(\theta = 0°) >} = \frac{q_{\text{vert}}}{< q_{1\mu}(\theta = 0°) >}$$

- Calibration: $< q_{1\mu}(\theta = 0°) >$

Before PhD:

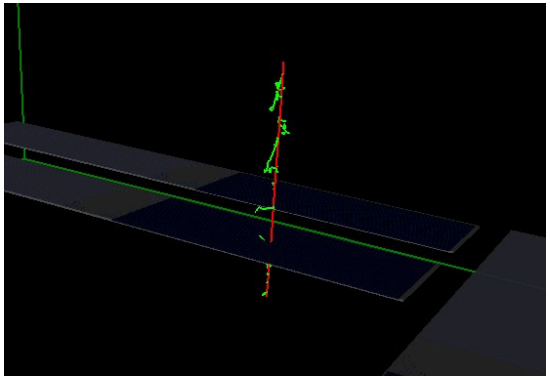
- ADC module in Offline for simulations

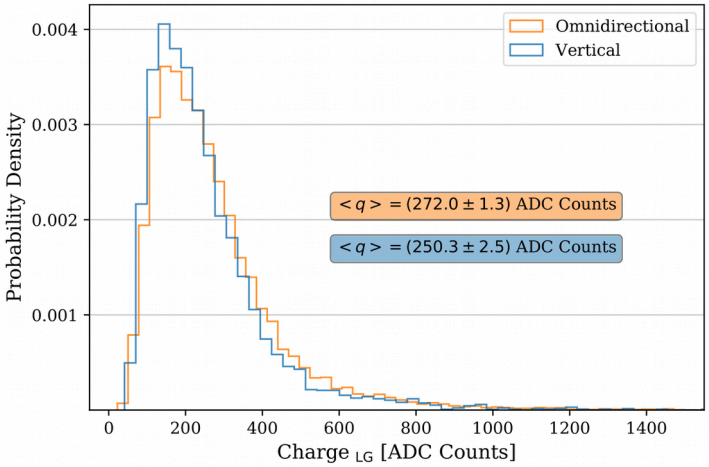
- ADCT1 files to calibrate the ADC with atmospheric muons: search for a muon pattern after a T1 trigger from the WCD in two different windows [*Calibration of the underground muon detector of the Pierre Auger Observatory.* The Pierre Auger Collaboration, JINST 048P 1220]

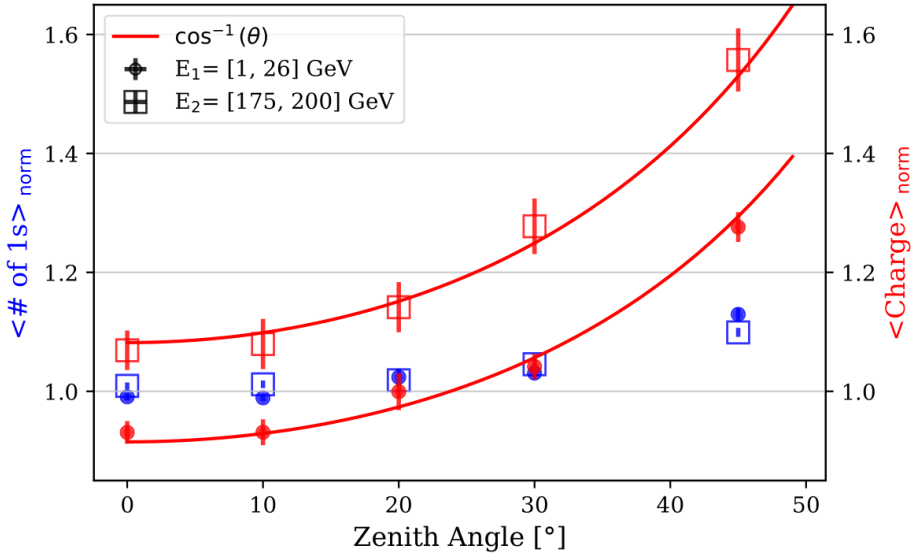


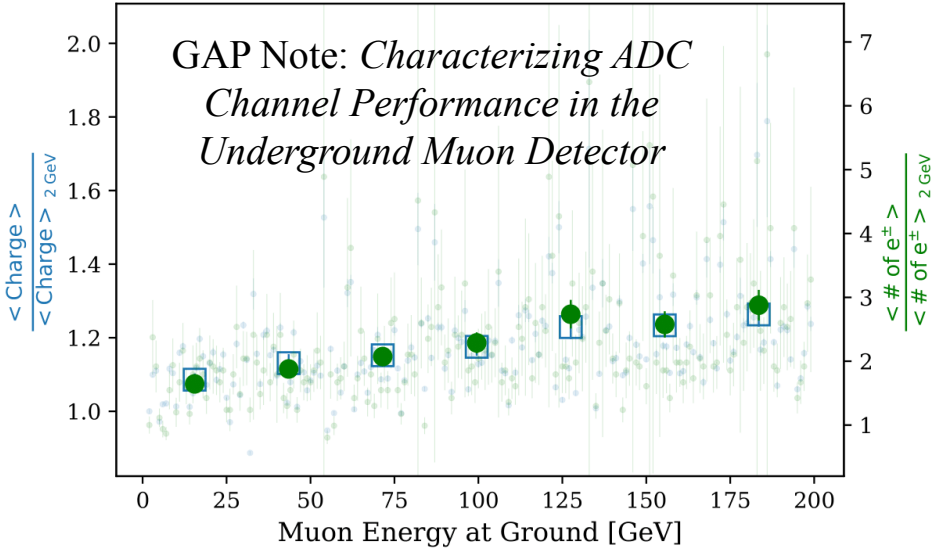
Single muon simulations

- Injected one muon directly
- ADC reconstruction is also sensitive to the energy of the muons



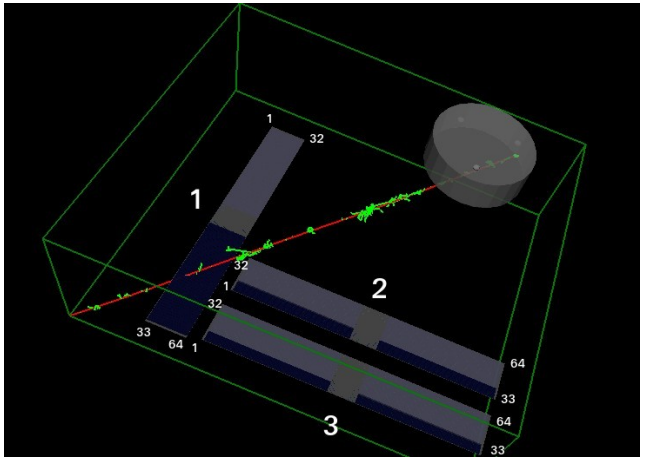


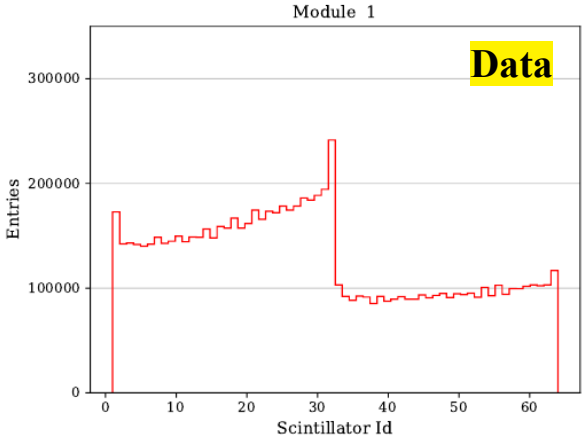




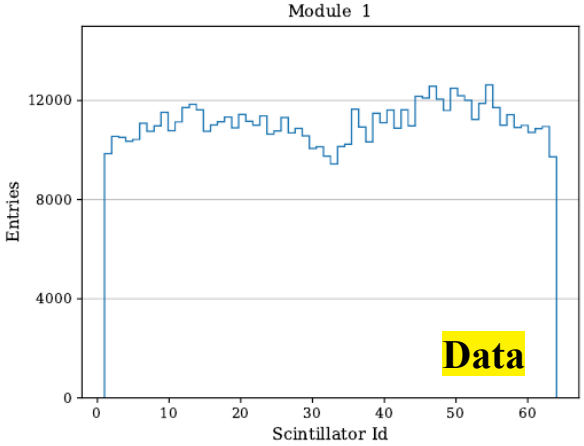
ADCT1 files

- Monitoring: found problems with the installation of the new electronics
- Asymmetries found between halves of the modules, discrepancies in charge values with simulations and lab data
- Simulated muons in coincidence (2.3 M!!!)

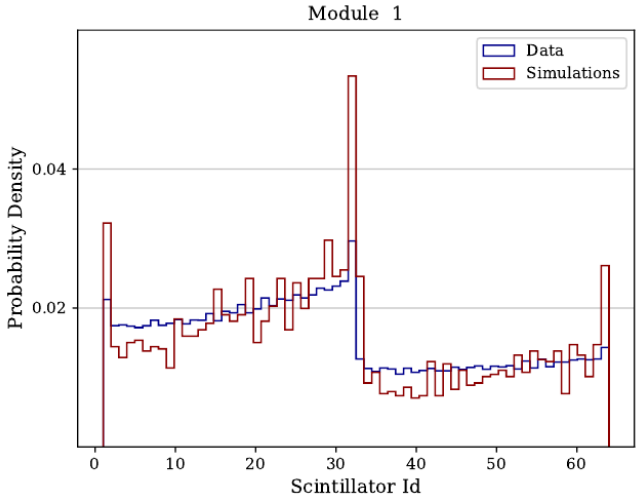




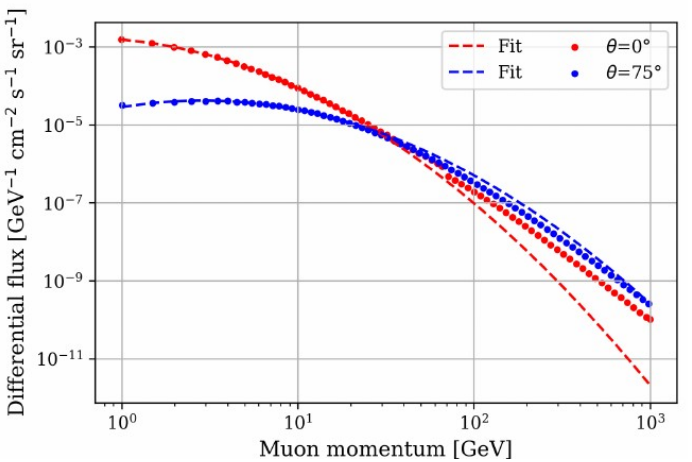
(a) "Signal + Noise" window



(b) "Noise" window



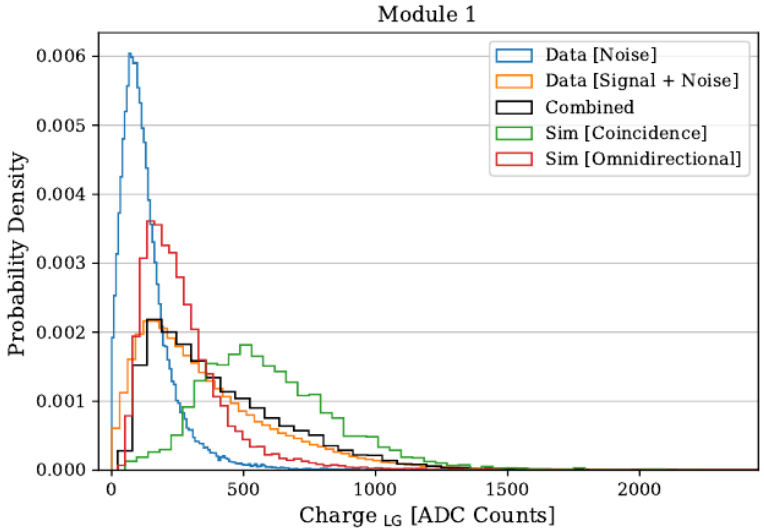
ADCT1 files



$$j(E) = \frac{dN}{dt\, dA\, d\Omega\, dE} \quad \rightarrow \quad \frac{dN}{dt\, dA\, d\Omega} = \int_{E_0}^{E_{\max}} j(E) dE$$

$$Rate_{\text{vert after WCD}} = Rate_{\text{vert}} \,.\, Rate_{\text{T1 WCD}} \,.\, \tau$$

- $Rate_{\text{vert after WCD}}$ not enouth to explain data rate
- The combination of various distributions arriving at the UMD detector is influenced by the trigger dependence with the WCD and the geometry of the detectors



GAP Note: *Online calibration of the ADC channel in the UMD* [being corrected by supervisor]

Low level reconstruction

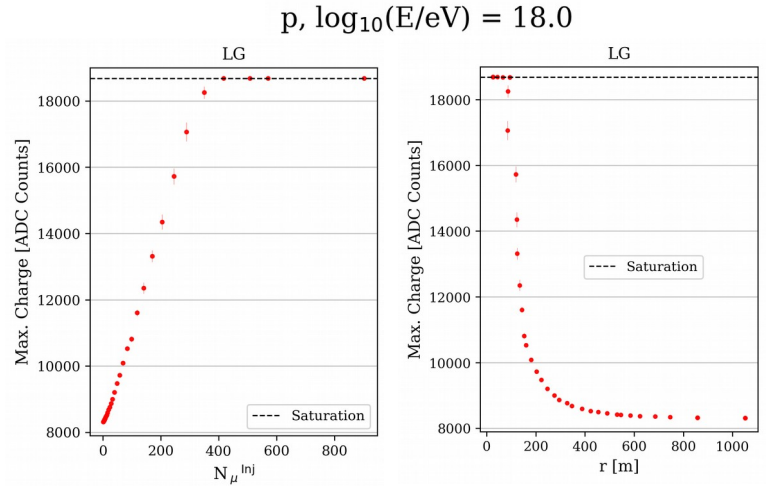
Created 2 modules in Offline to reconstruct data:

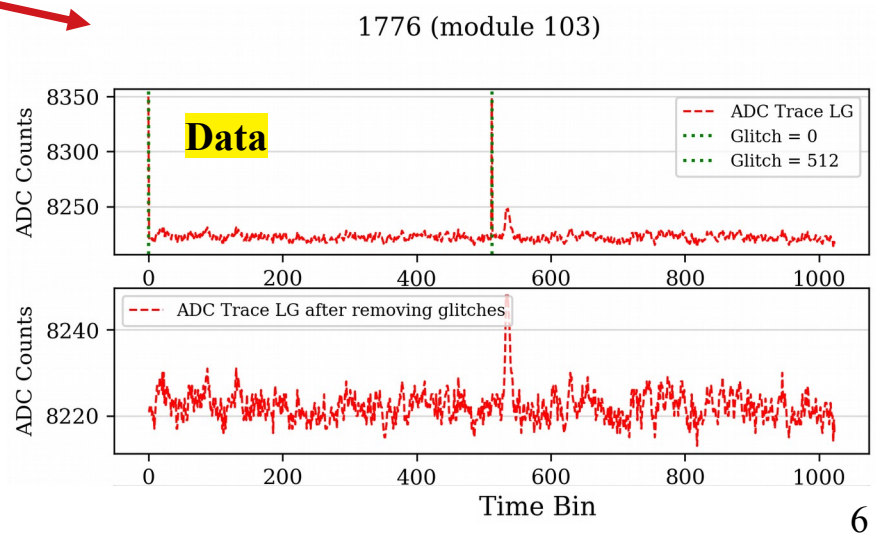
- Added saturation
- Removed glitches
- Improved reconstruction technique (use binary for low densities to find integration windows)

Cleaned 3 years of UMD data:

- Problem found with deployment of modules (CDAS)

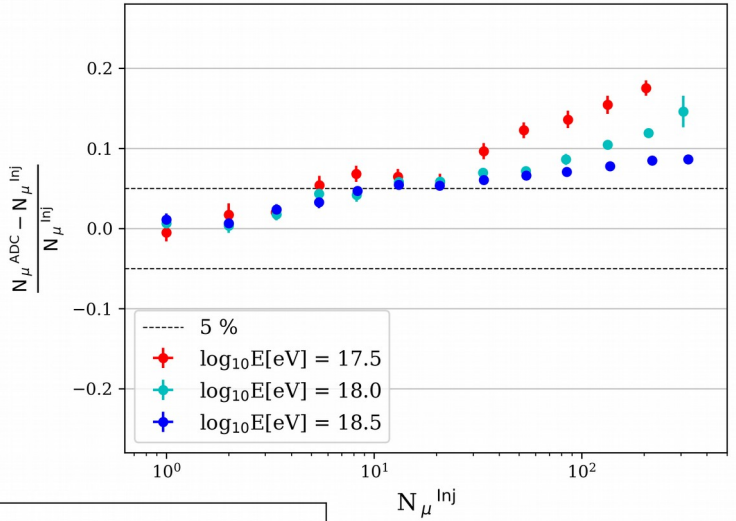
GAP Note: *Low level reconstruction of the ADC channel in the UMD* [~ 50 % written]

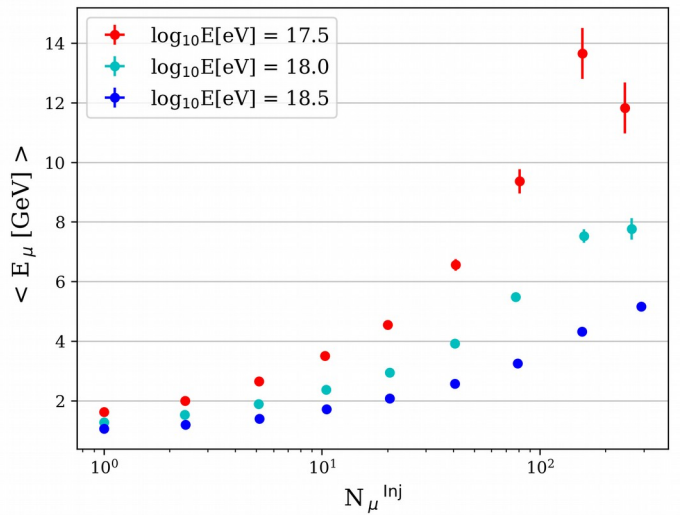


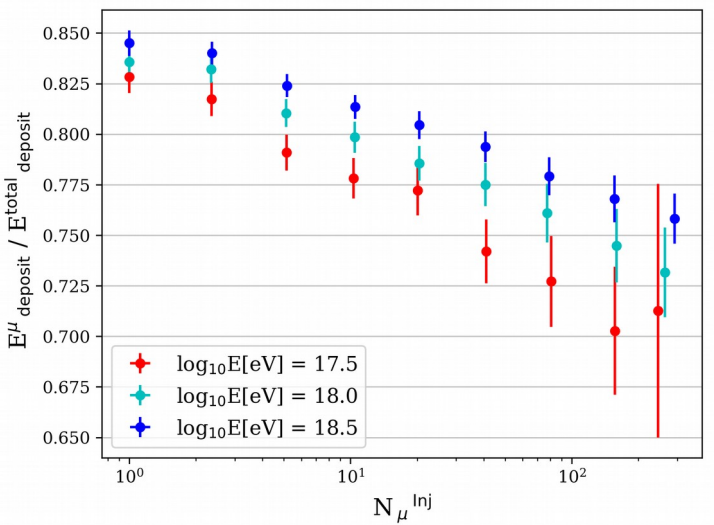


Number of muons ADC

- Data set: 1800 **proton** showers (EPOS-LHC), $10^{17,5}$, 10^{18}, $10^{18.5}$ eV, θ= [0, 12, 22, 32, 38]°
- Histogram of charge from single vertical muon simulations (slide 3)
- The fraction of energy deposited by other particles is higher for more energetic muons

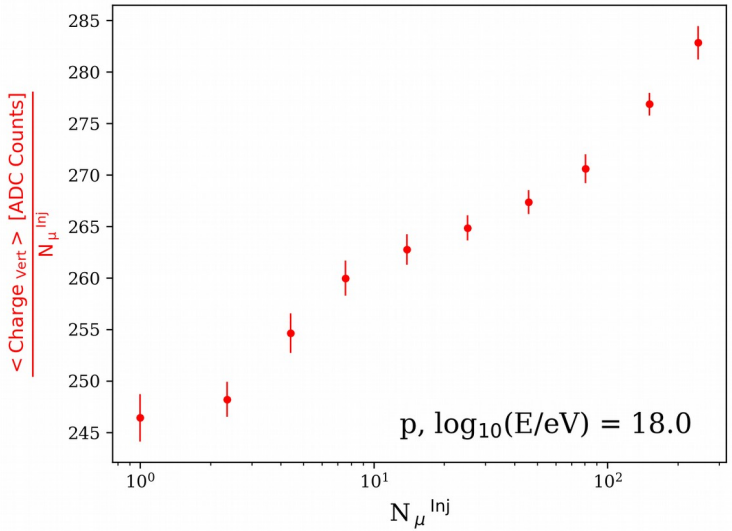


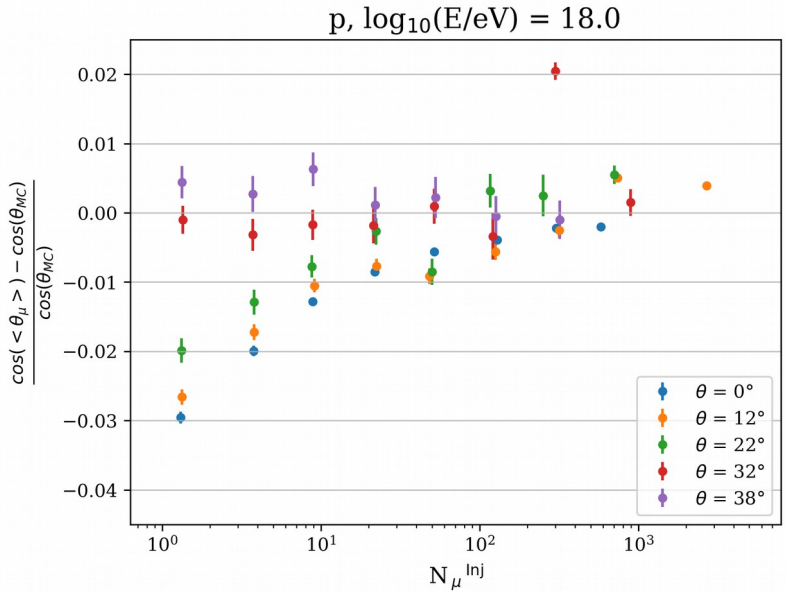




Number of muons ADC

- The approximation $< \theta_\mu > \sim \theta_{MC}$ is quite efficent
- Bias in ADC reconstruction comes from E_μ: Close to the shower core **more energetic muons** produced **more knock on electrons from the soil**
- $\frac{q_{vert}}{N_\mu^{Inj}}$ is not constant and it increases with N_μ

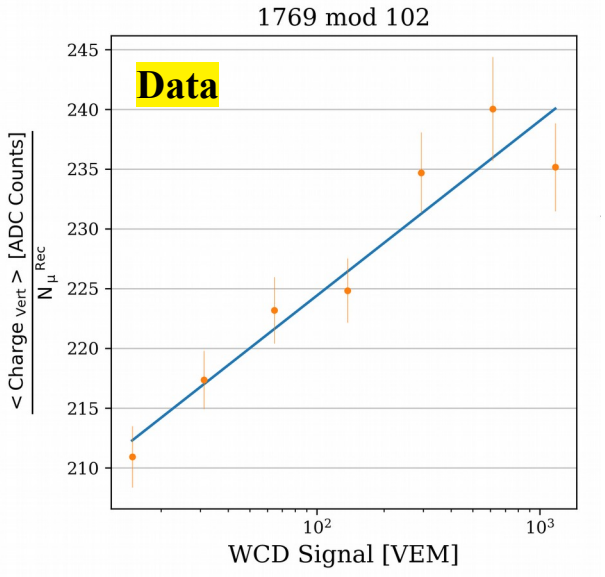


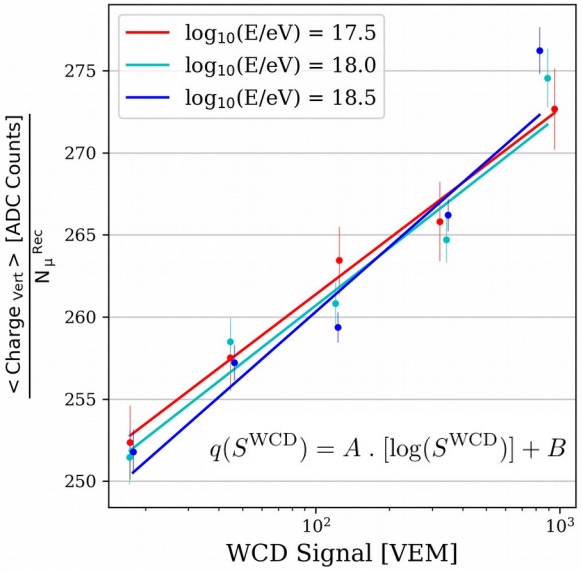


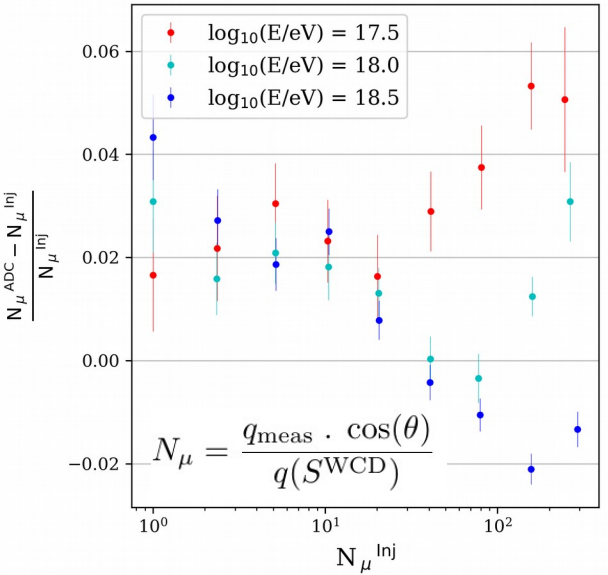
GAP Note: *Parametrization of the ADC calibration in the Underground Muon Detector* [~ 50 % written]

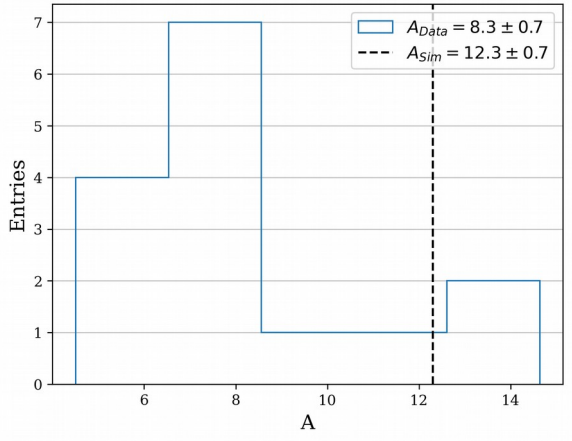
Parametrization with S^{WCD}

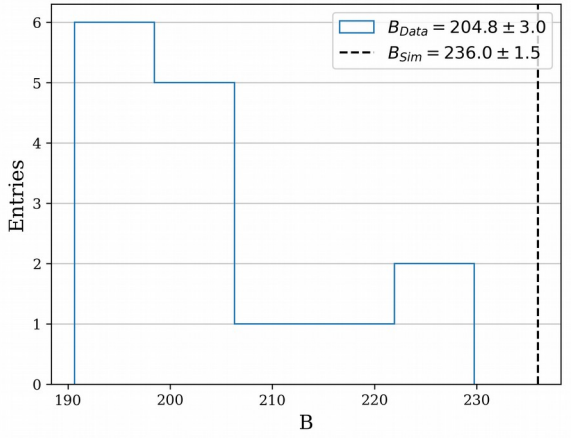
- Measure ADC charge and use binary reconstruction up to $N_\mu = 100$
- Data set: 15 modules, 3 years
- Coefficients in data similar to simulations







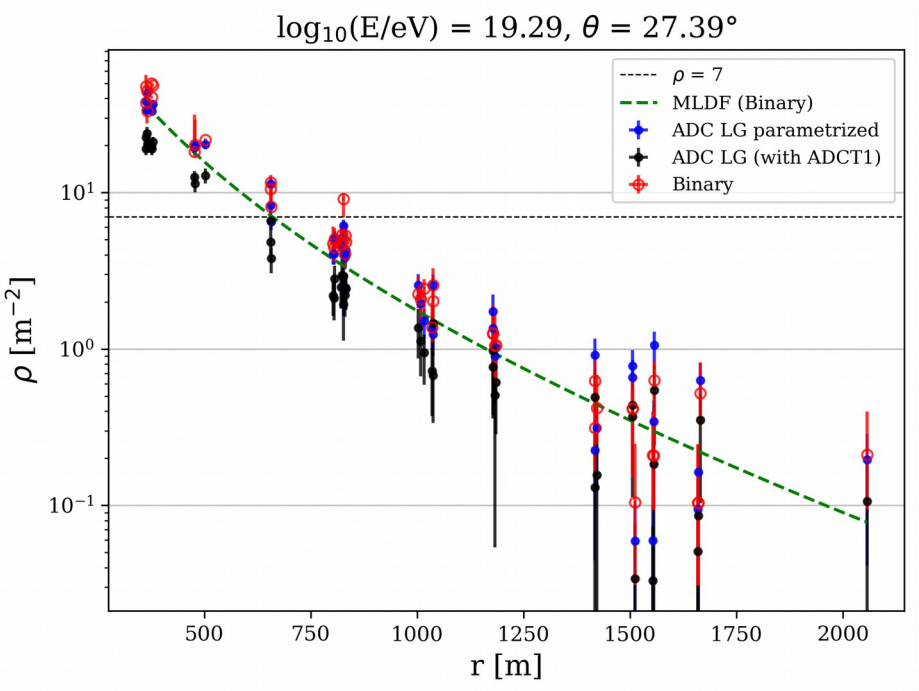


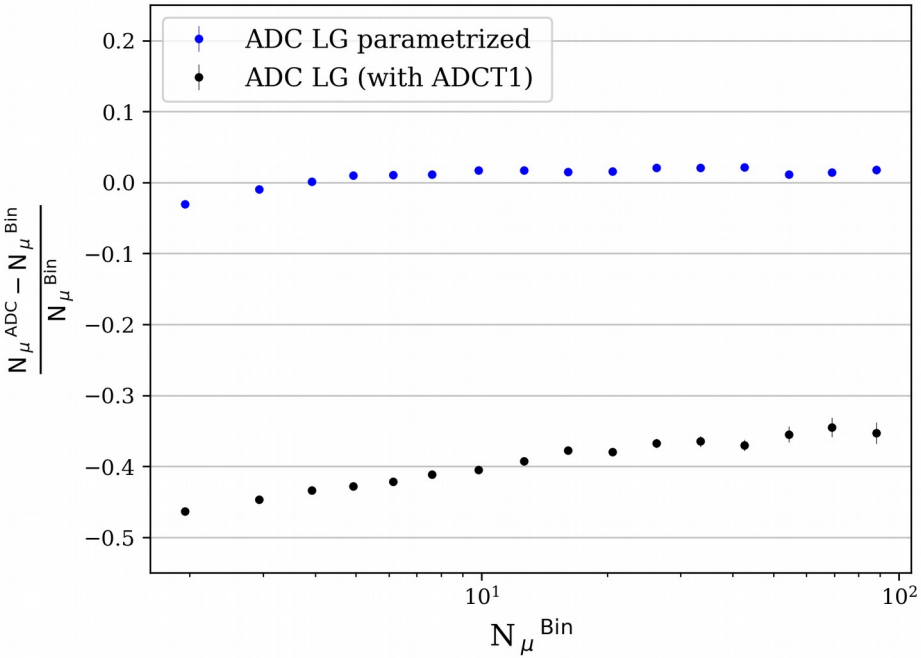


Parametrization with S^{WCD}

Data

- Data set: 6 months
- ADC parametrized and Binary in data are in agreement for intermediate densities (as expected)
- ADCT1 files still useful for long performance and monitoring

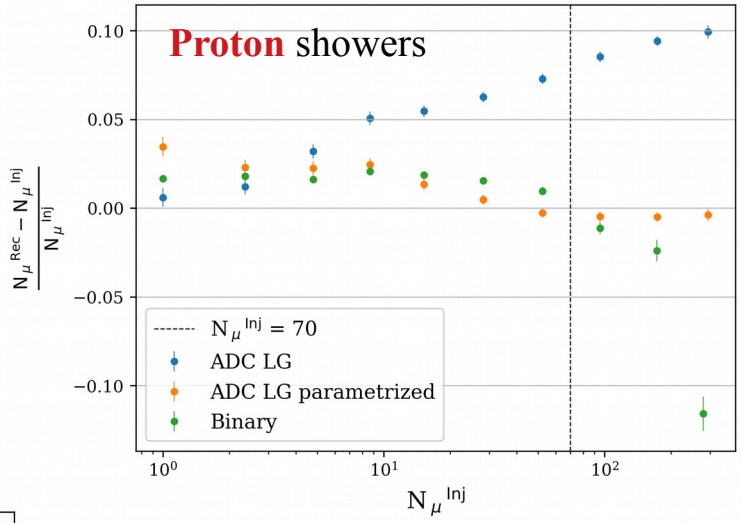


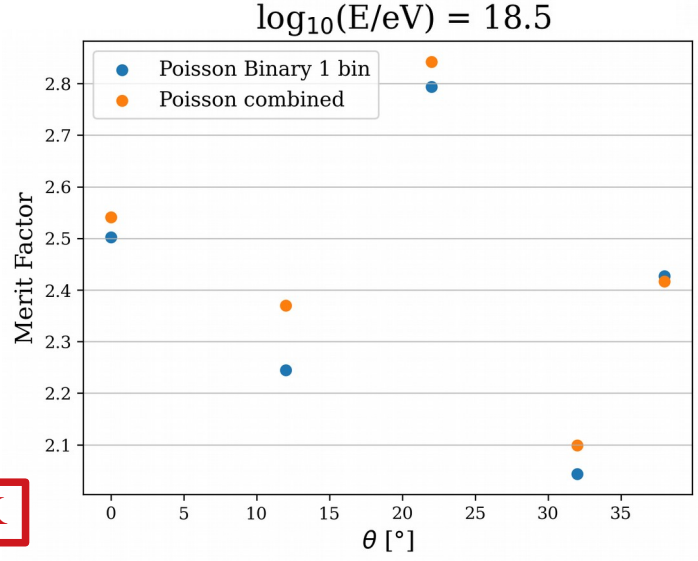


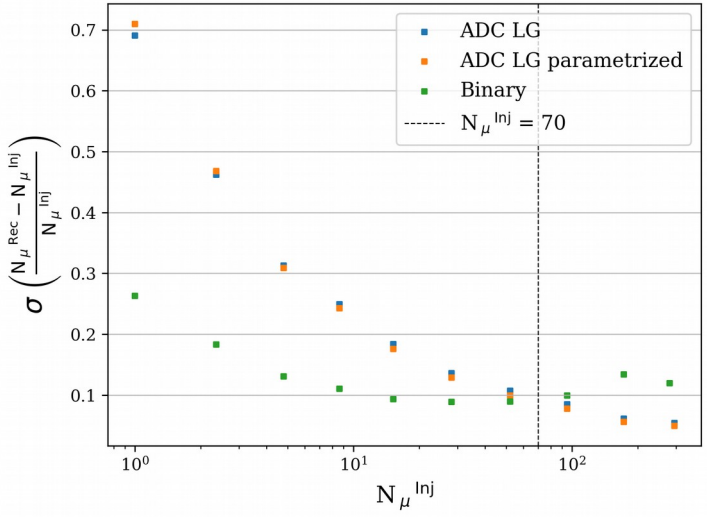
Combined strategy

- The bias of the **ADC** reconstruction improves with the **parametrization**
- Poisson likelihood:
  - → Binary for $N_\mu <= 70$
  - → ADC parametrized for $N_\mu > 70$
- Merit factor for proton – iron discrimination:

$$MF = \frac{\left|\overline{\rho^{i}_{450}} - \overline{\rho^{p}_{450}}\right|}{\sqrt{\sigma^2_{\rho^{i}_{450}} + \sigma^2_{\rho^{p}_{450}}}}$$







PRELIMINARY WORK

Summary

- Improved the low level reconstruction of ADC for data
- Cleaned and monitored UMD data, developed code for Offline (made contributions to 5 UMD modules)
- Found **bias in the ADC reconstruction** produced by the **knock on electrons from the soil**
- Developed **new strategy to calibrate**, applied strategy to data
- Data: ADC parametrized is in agreement with binary for intermediate densities
- **Future work:** Reconstruct data with combined strategy Likelihood

Writing

- GAP Note: *Characterizing ADC Channel Performance in the Underground Muon Detector*
- GAP Note: *Online calibration of the ADC channel in the UMD* [being corrected by supervisor]
- GAP Note: *Low level reconstruction of the ADC channel in the UMD* [~ 50 % written]
- GAP Note: *Parametrization of the ADC calibration in the Underground Muon Detector* [~ 50 % written]