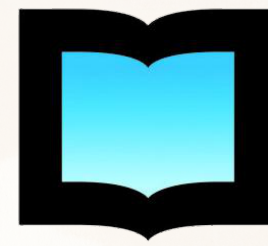





CONICET



UNSAM

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SAN MARTÍN

Estimation of the muon density and the muon lateral distribution function in AMIGA

 HIRSAP meeting, 2-3 November 2021

Flavia Gesualdi

Director: Dr. Daniel Supanitsky

Co-director: Prof. Dr. Ralph Engel

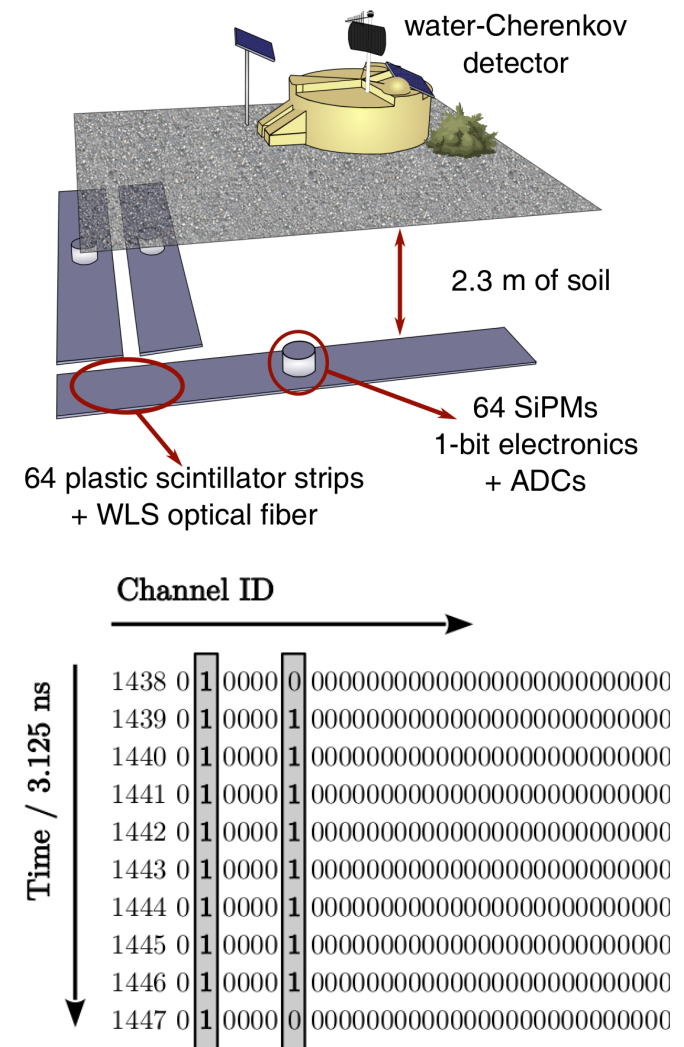
Supervisor: Dr. Markus Roth

Double Doctoral degree in
Astrophysics
DDAp 

 **KIT**
Karlsruher Institut für Technologie

Introduction

- The **U**nderground **M**uon **D**etector is designed to measure the muon content of air showers
- Two types of outputs:
 - Integrated signals (integrator)
 - Binary traces (counter)



Images from GAP2020 003

Introduction

Offline MD Data Reconstruction

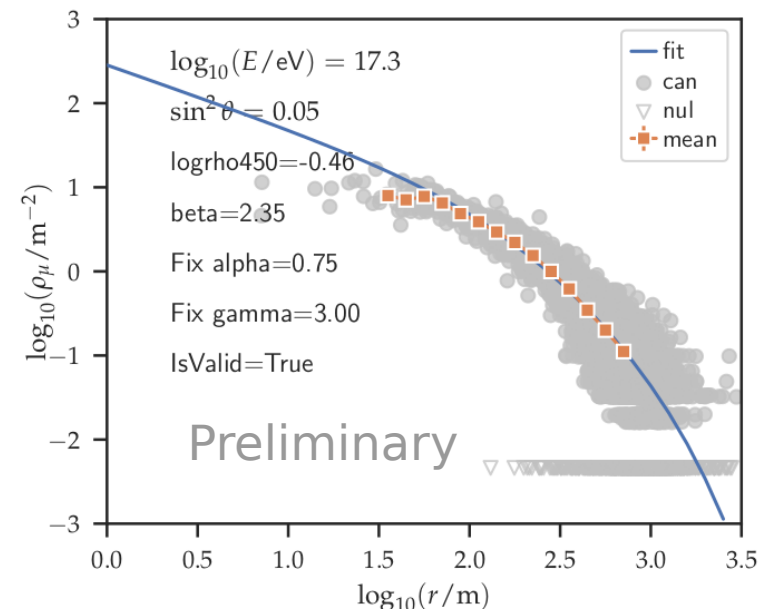
Input: 64 Binary Traces/Module

1. Identify muon **patterns**
“1111xxxxxxxx”
2. Correct for **pile up**
(>1 muon detected as 1)
3. Correct for **clipping corners**
(~ 1 muon detected as 2)

Output: 1 Muon density/Module

Almost every AMIGA data analysis uses this reconstruction

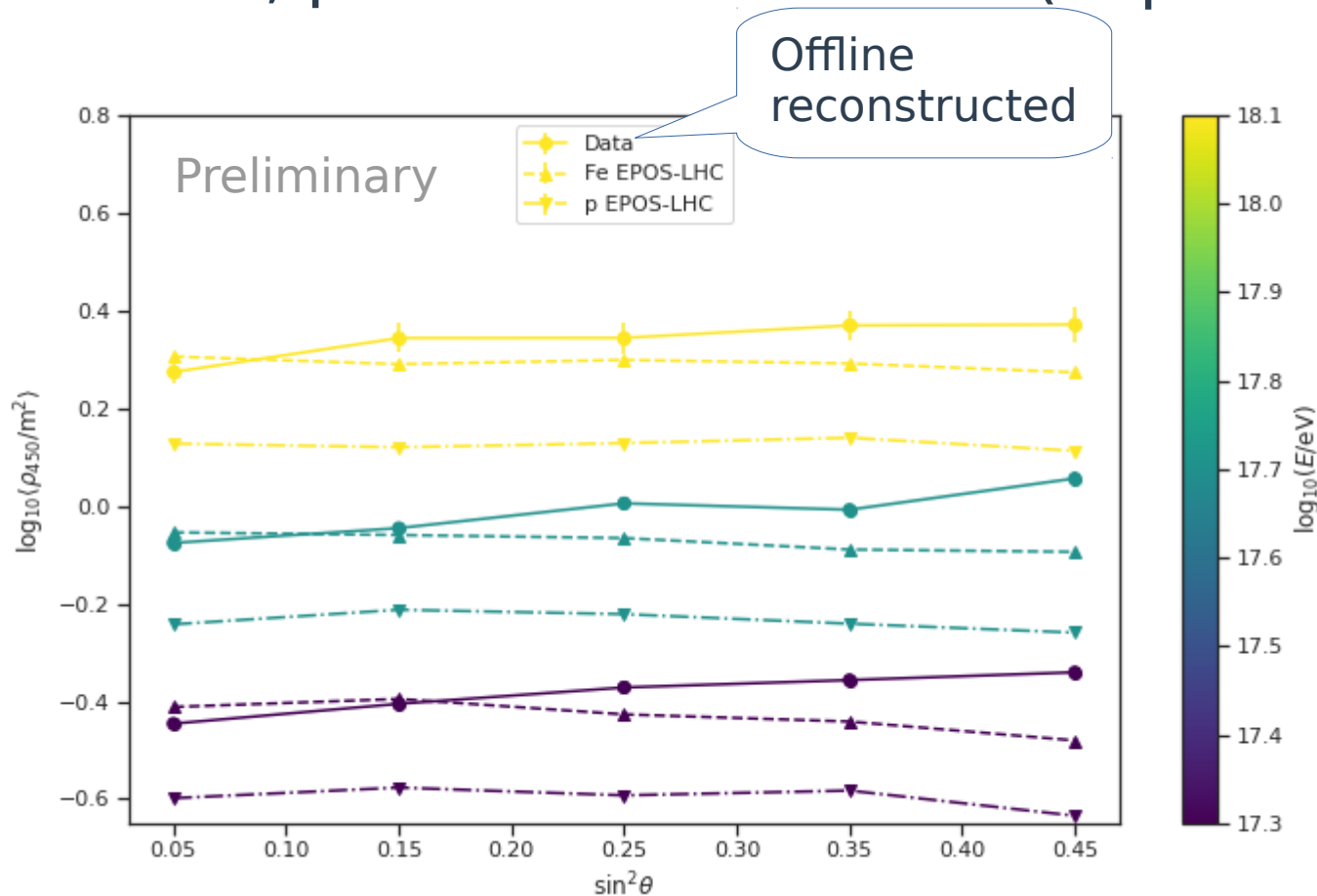
In our work, we use AMIGA data to study the muon lateral distribution function



Motivation

In data, ρ_{450} increases with θ

In sim., ρ_{450} decreases with θ (expected from attenuation)



We found no bugs
in our analysis
code.

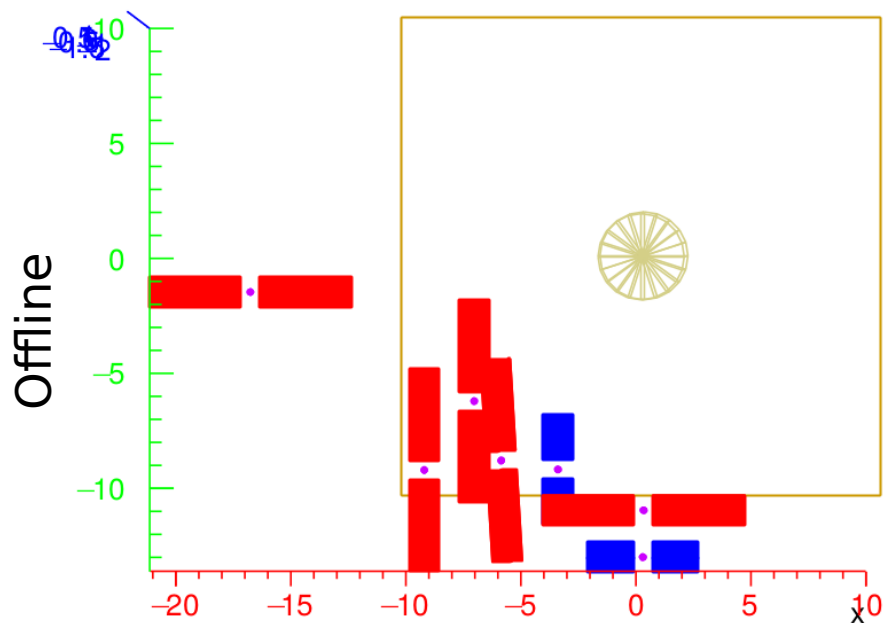
Is it a problem of
in the MD Data
Reconstruction of
Offline?

→ **Inspect code**

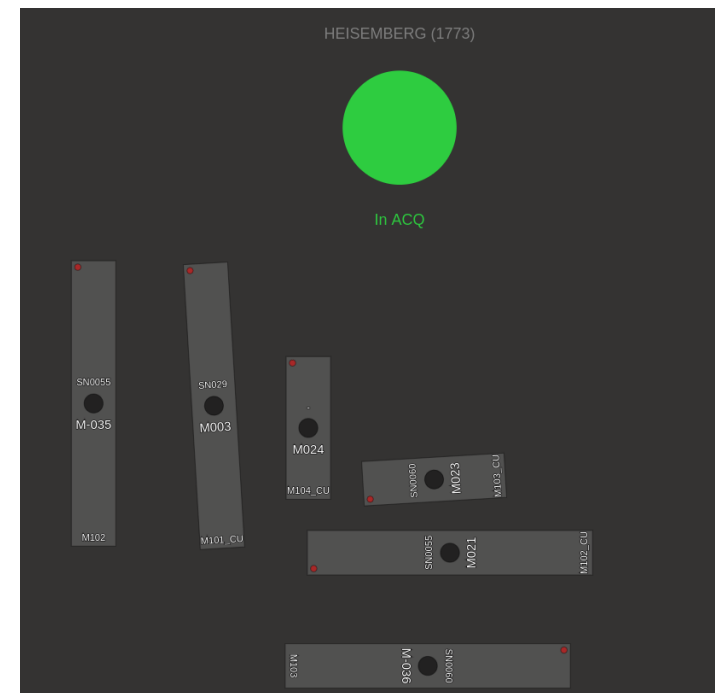
1) Correct Offline MD Framework

Positions and azimuths of the modules in Offline did not match deployment maps.

E.g.: Heisenberg 1773



Deployment map



1) Correct Offline MD Framework

We **compared** the values in the **MD Framework** to those of the **deployment maps**

In the Unitary Cell we found:

- **8/40** modules with **$\sim 90^\circ$ differences in ϕ** .
- 37/40 modules with $\sim 1\text{m}$ (avg) differences in the (X,Y) coords.

Effect: Up to **20% bias** in the corrected muon densities (90° differences in ϕ).

This is corrected as of r34282*.

* Measurements of (X,Y, ϕ) for Phill Collins are on the way, and will be updated in Offline when available.

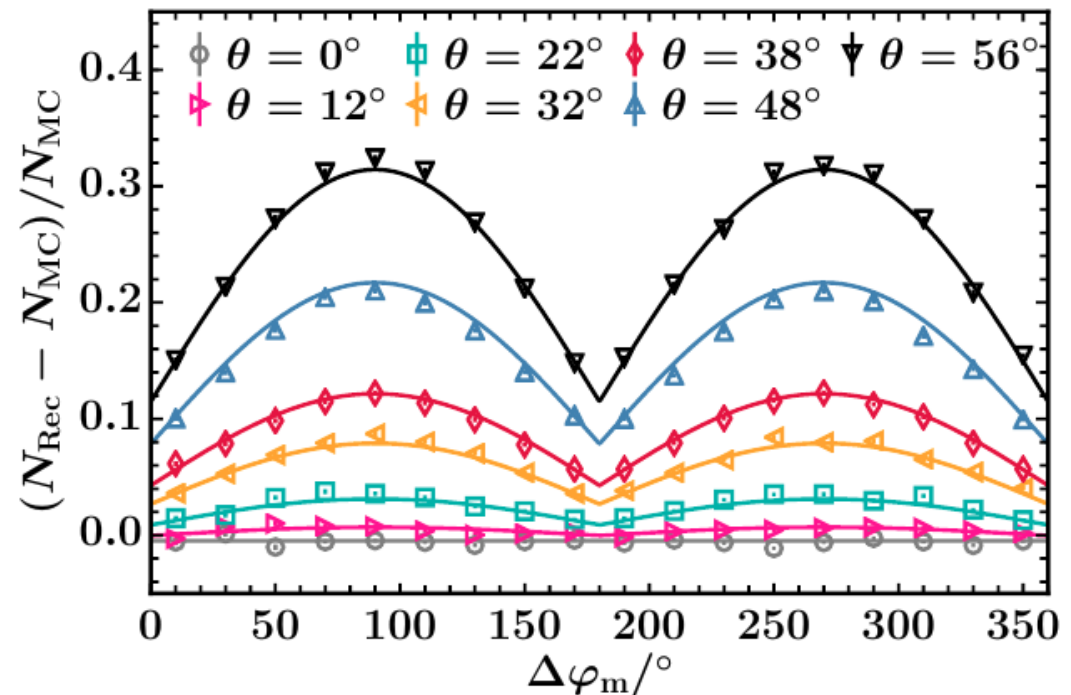
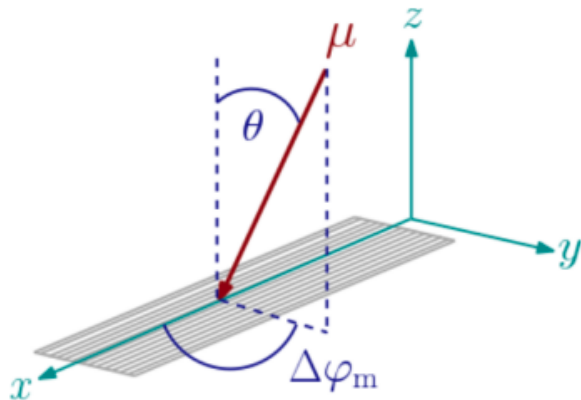
* 180° differences in ϕ can exist in modules from the older deployment.

2) Correct the implementation of the clipping corner correction

The clipping corner correction is parameterized as a function of $\Delta\varphi_m = \varphi_{\text{shower}} - \varphi_{\text{module}}$

$$f_{\text{clip}}(\theta, \Delta\varphi_m) = a(\theta) + b(\theta) \cdot |\sin \Delta\varphi_m|$$

$$N_{\text{Rec}}^{\text{corr}}(\theta, \Delta\varphi_m) = \frac{N_{\text{Rec}}}{1 + f_{\text{clip}}(\theta, \Delta\varphi_m)}$$



Images from S. Müller, GAP2019 029

2) Correct the implementation of the clipping corner correction

However it was implemented as a function of $\phi_{\text{shower}} + \phi_{\text{module}}$

```
// Apply correction to numberOfMuons and errors
mevt::ModuleRecData& mRecData = module.GetRecData();
const double numberOfMuons = mRecData.GetNumberOfEstimatedMuons();
const double corrfac = CorrectionFactor(phi+phi0, theta);
const double numberOfMuonsCor = numberOfMuons*corrfac;
mRecData.SetNumberOfEstimatedMuons(numberOfMuonsCor);
//currently no error estimate for bias corrected number of muons
mRecData.SetNumberOfMuonsErrorHigh(0);
mRecData.SetNumberOfMuonsErrorLow(0);
```

The bug and its correction were verified against data
Effect: Up to **10% bias** in the corrected muon density

This is corrected as of r34282.

Clipping Corner parametrization from data

Idea

$$\rho_{\mu,\text{corr}}(r, \theta) = \frac{\rho_{\mu}(r, \theta, \Delta\phi)}{1 + \boxed{a(\theta) + b(\theta)} |\sin \Delta\phi|}$$

The one at each module

What do we use as a reference?

Functions we want to find

Idea: - At $\theta = 0^\circ$ the effect is negligible
- We can parameterize $\rho_{\mu}(r, \theta = 0^\circ)$ from data

$$\rho_{\mu,\text{ref}}(r, \theta) = \frac{\rho_{\mu}(r, \theta = 0^\circ) f_{\text{att}}(\theta)}{f_{\text{att}}(\theta = 0^\circ)}$$

- $f_{\text{att}}(\theta)$ from previous data & sim AMIGA analysis*

*Eur. Phys. J. C (2020) 80:751

Clipping Corner parametrization from data

Then:

The one at each module

$$\rho_{\mu,\text{corr}}(r, \theta) = \rho_{\mu,\text{ref}}(r, \theta)$$

The one parameterized from our data

$$\frac{\rho_{\mu}(r, \theta, \Delta\phi)}{1 + a(\theta) + b(\theta) |\sin \Delta\phi|} = \frac{\rho_{\mu}(r, \theta=0^\circ) f_{\text{att}}(\theta)}{f_{\text{att}}(\theta=0^\circ)}$$

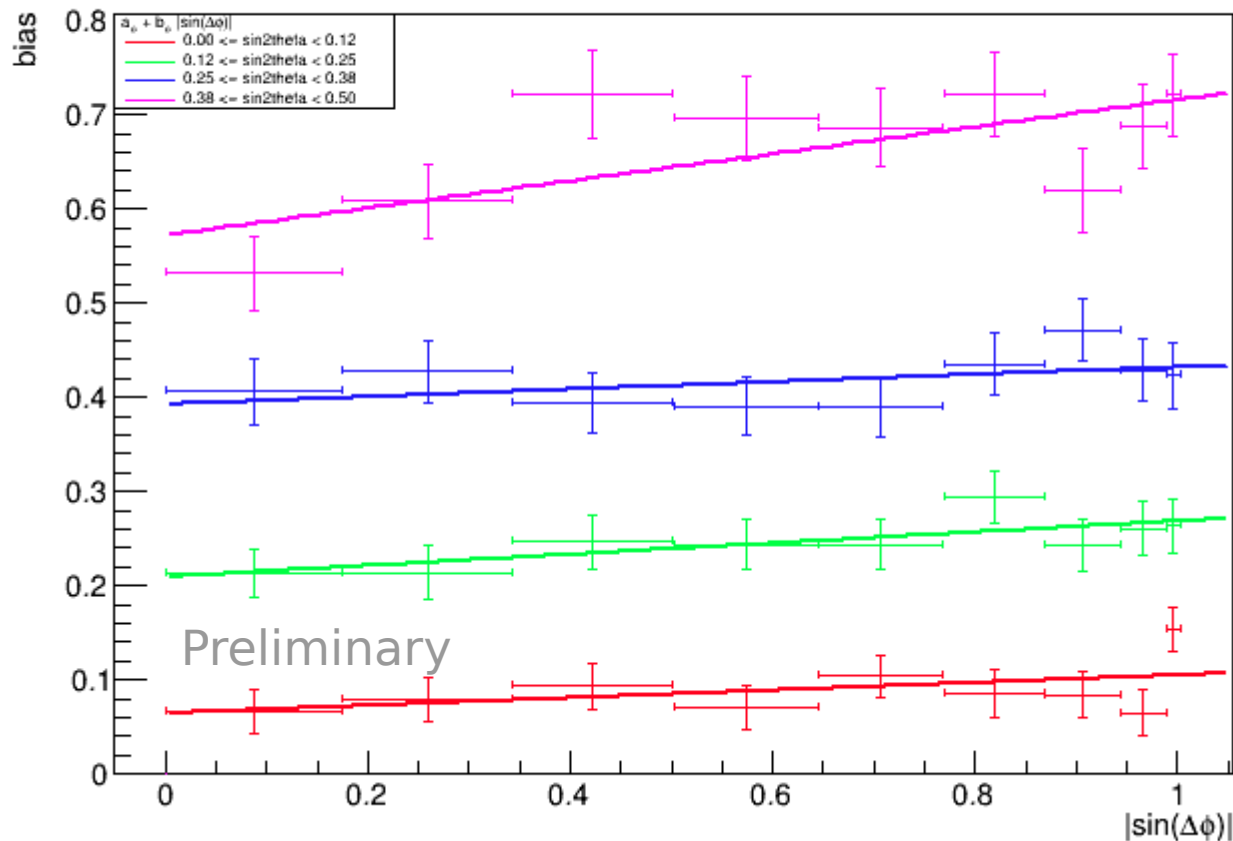
$$\rho_{\mu}(r, \theta, \Delta\phi) = \frac{\rho_{\mu}(r, \theta=0^\circ) f_{\text{att}}(\theta)}{f_{\text{att}}(\theta=0^\circ)} \times [1 + a(\theta) + b(\theta) |\sin \Delta\phi|]$$

Knowns

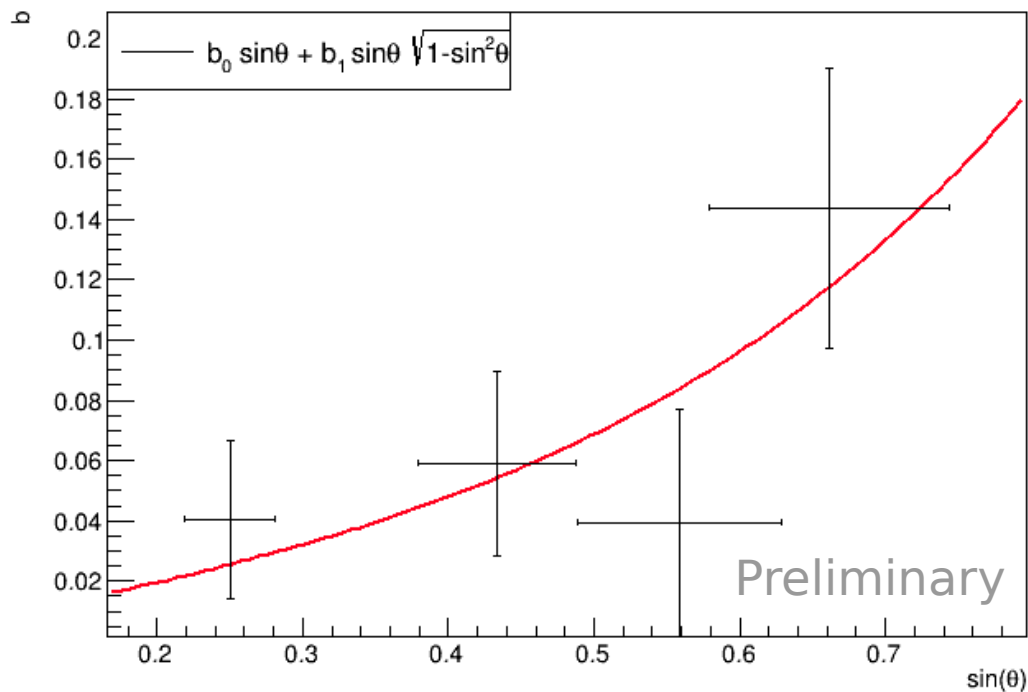
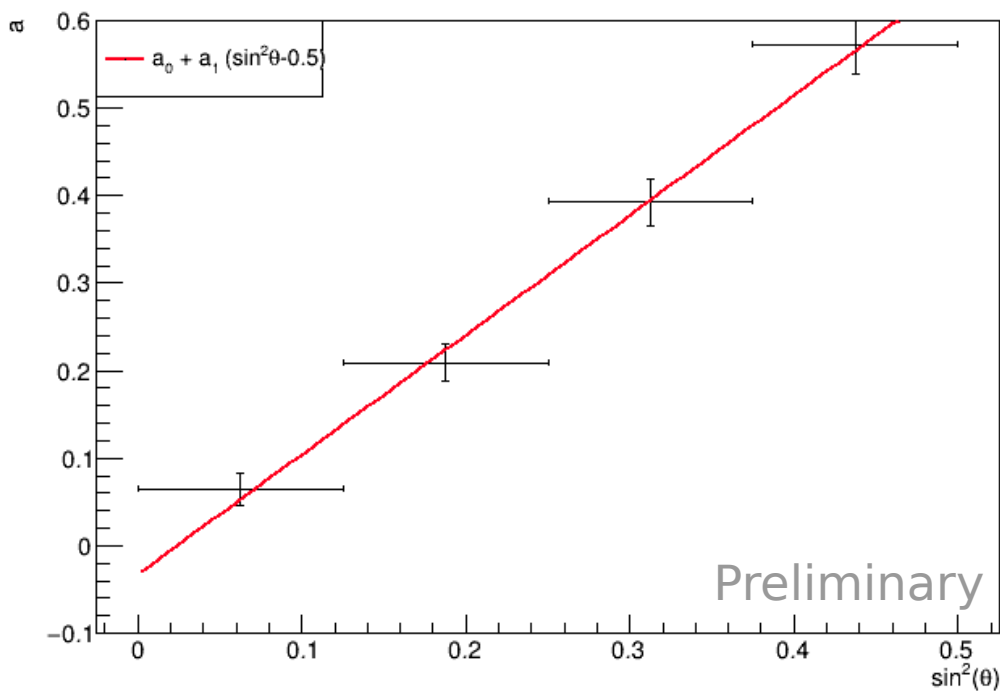
Unknowns

Clipping Corner parametrization from data

$$\text{bias} = \frac{\rho_{\mu}(r, \theta, \Delta\phi)}{\rho_{\mu}(r, \theta=0^{\circ}) f_{\text{att}}(\theta) / f_{\text{att}}(\theta=0^{\circ})} - 1 = a(\theta) + b(\theta) |\sin \Delta\phi|$$



Clipping Corner parametrization from data

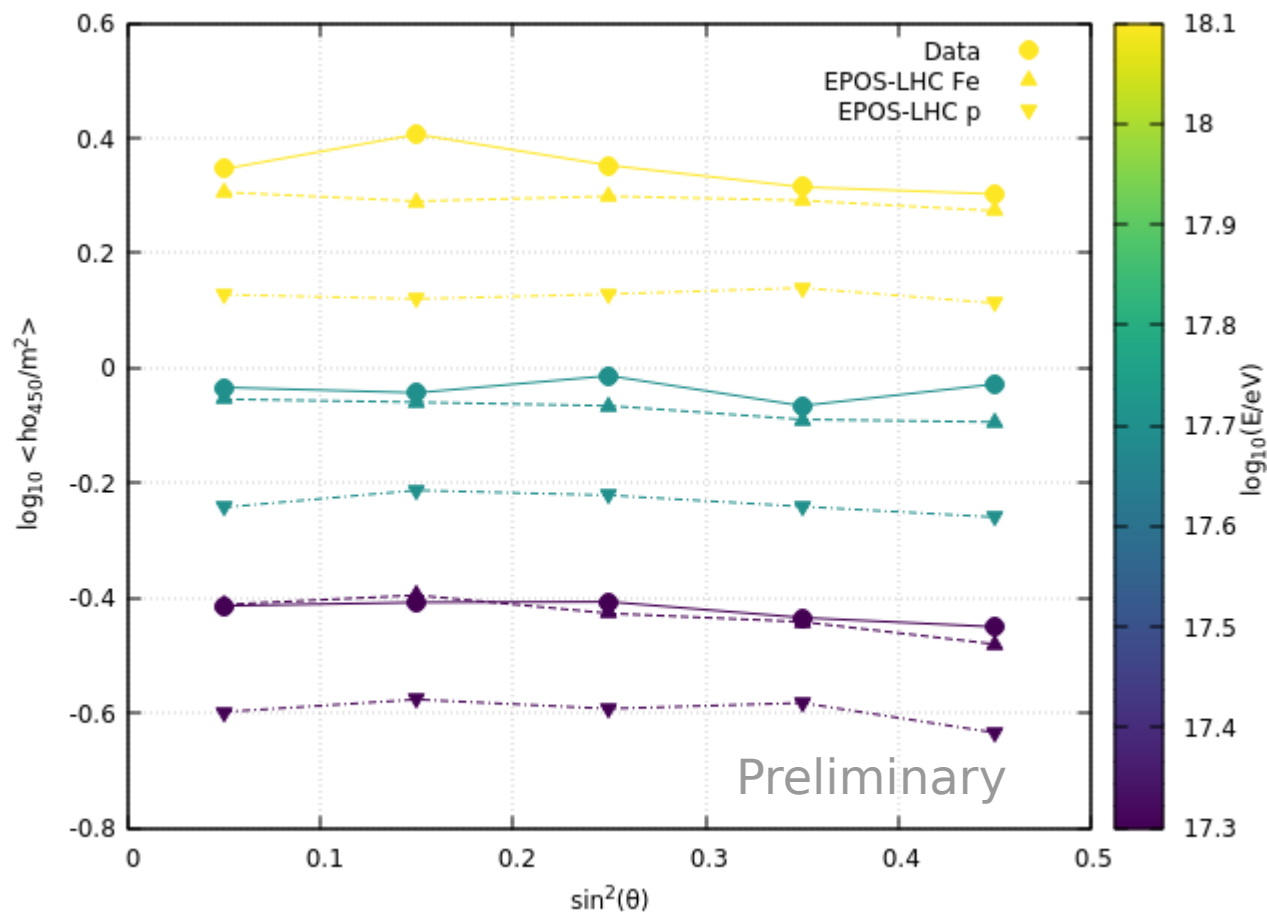


We implemented this parametrization in Offline

Clipping Corner parametrization from data

Problem solved!

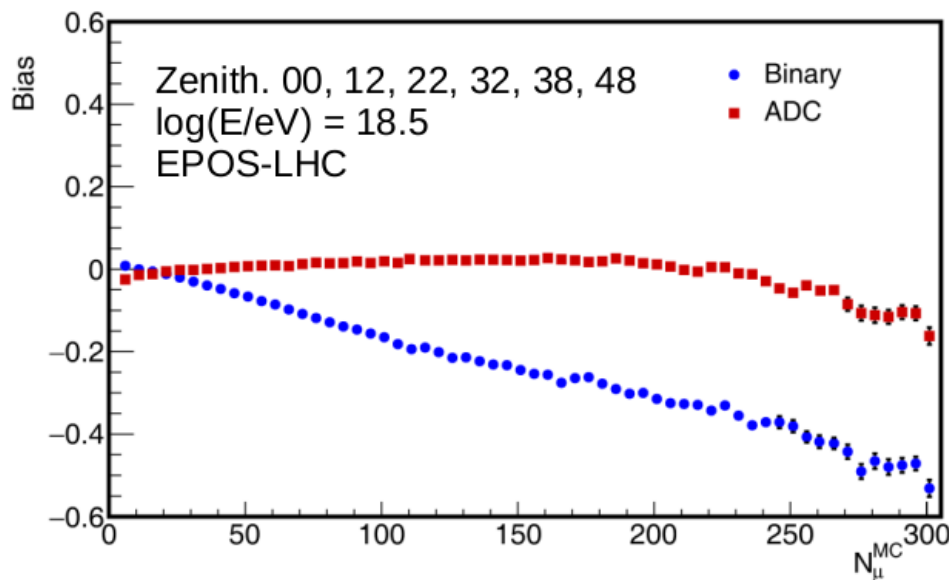
With the new CC parametrization p_{450} decreases with θ also in data



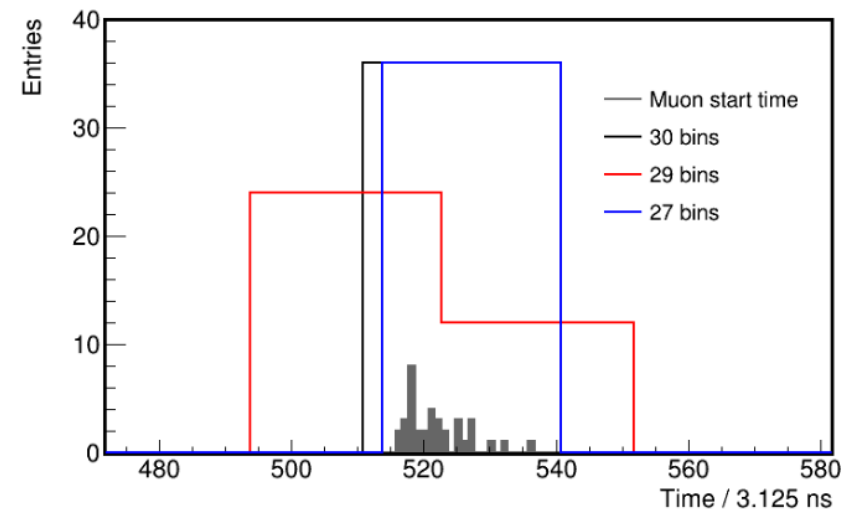
Work in progress: Pile up correction

A. Botti had reported a **bias** in the pile up correction
(**up to ~60%!)**

It is **not corrected** for the data reconstruction



Injected muons: 49
Rec Number of muons w/27 bins: 51.67
Rec Number of muons w/29 bins: 43.16
Rec Number of muons w/30 bins: 51.67



Images from A. Botti, OCM talk from 22.05.2020

Summary and outlook

- **Offline (r34282)**

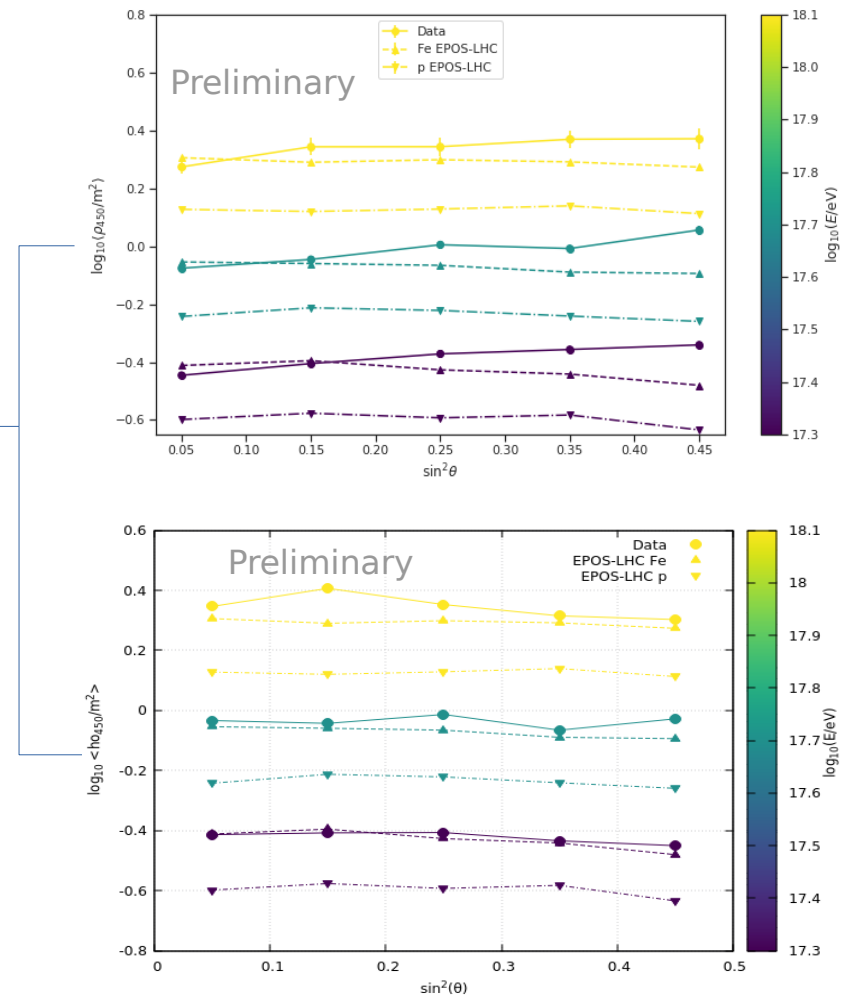
- We corrected (X, Y, ϕ) for all modules (caused up to 20% bias in $\rho_{\mu\text{corr}}$)
- We corrected a sign in the CC correction (caused up to 10% bias in $\rho_{\mu\text{corr}}$)

- **CC parameterization from data**

- We designed & implemented it successfully
- Result: Now ρ_{450} decreases with θ as expected

- **Future steps**

- Fix the bias in pile up correction
- Report final parametrizations of the muon lateral distribution function
- Compare them to simulations



BACKUP

Structure

- **Introduction and motivation**
- **Offline corrections**
 - Positions and azimuths of the MD modules
 - Implementation of the clipping corner correction
- **Clipping corner parametrization from data**
- **Work in progress: Pile up correction**
- **Summary and Outlook**