Water-Cherenkov detector response to atmospheric muons using a RPC hodoscope

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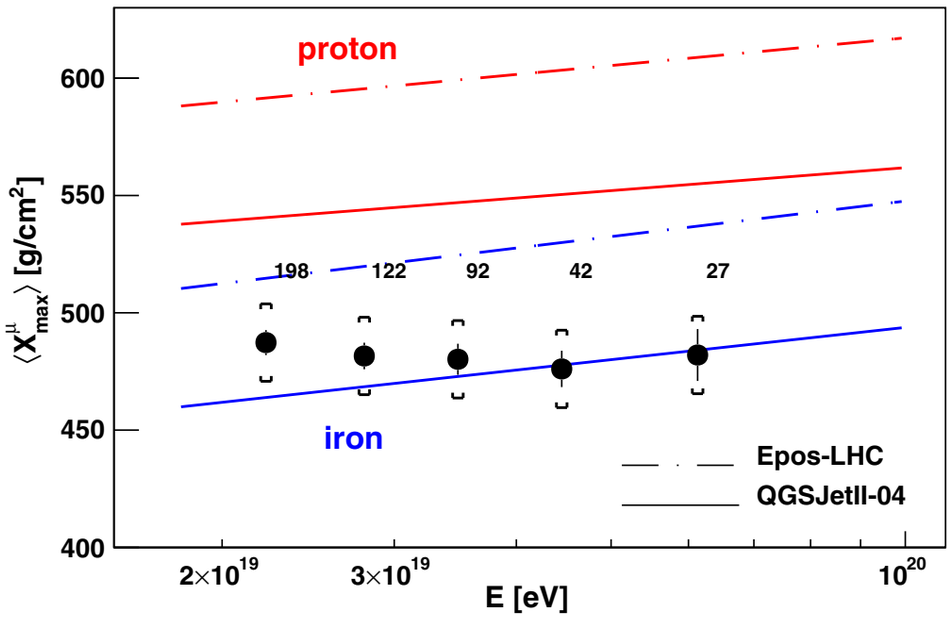
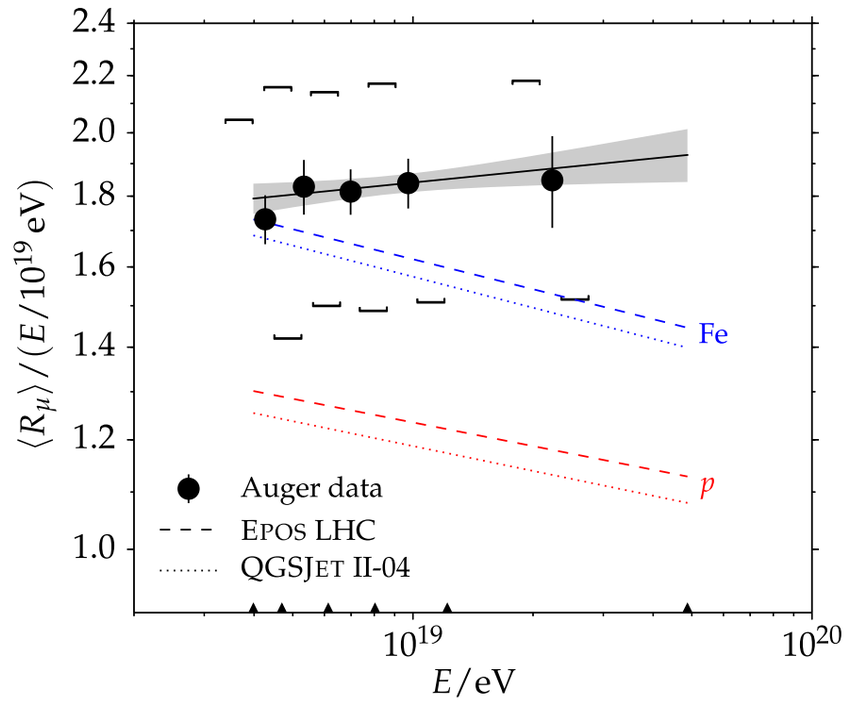
1st Joint workshop IGFAE/LIP, Braga, May 4th 2018

The muon excess in the Pierre Auger Observatory

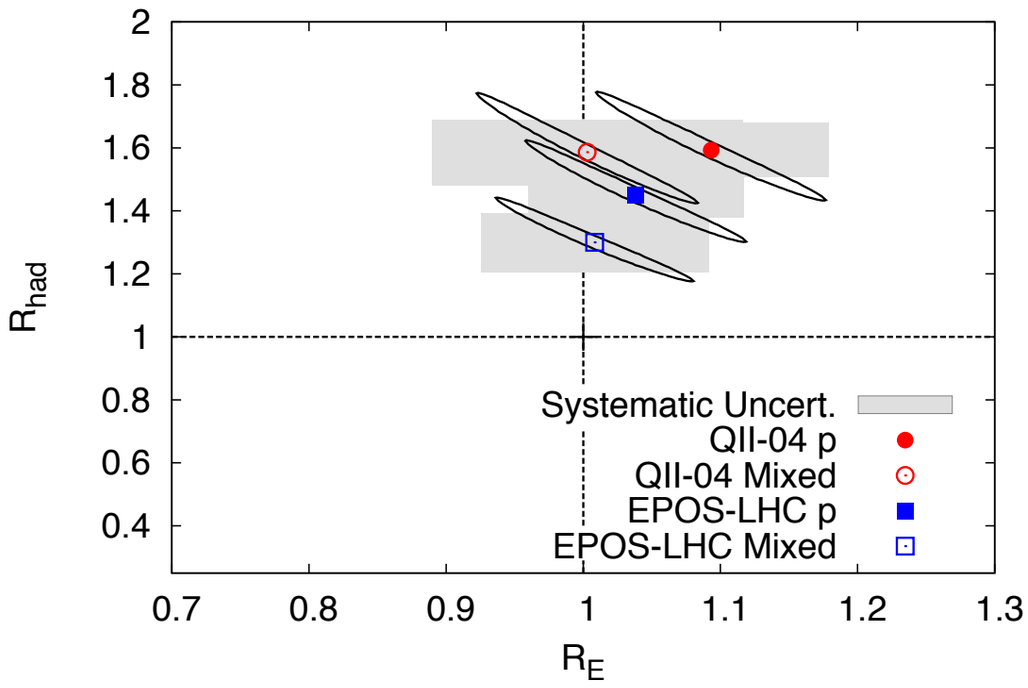
Phys. Rev. D 90, 012012 (2014)
Muon Production Depth

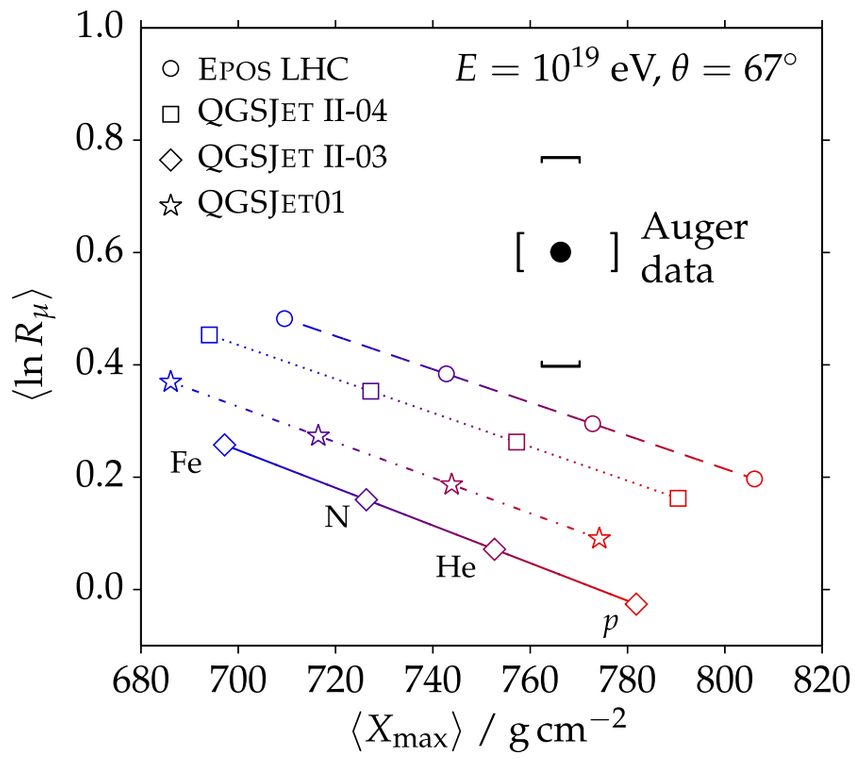


Phys. Rev. D 91, 032003 (2015)
Inclined Showers



Phys. Rev. Lett. 117, 192001 (2016)
Hadronic content in not so inclined showers...





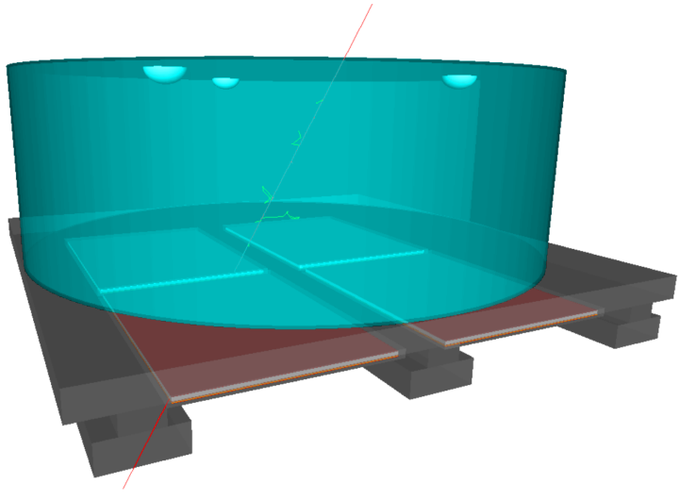
Several complementary approaches to the problem

AugerPrime

Large-scale experimental efforts
arxiv:1708.06592

MARTA

Smaller-scale experiments
arxiv:1712.07685 (accepted for publication in EPJ-C)

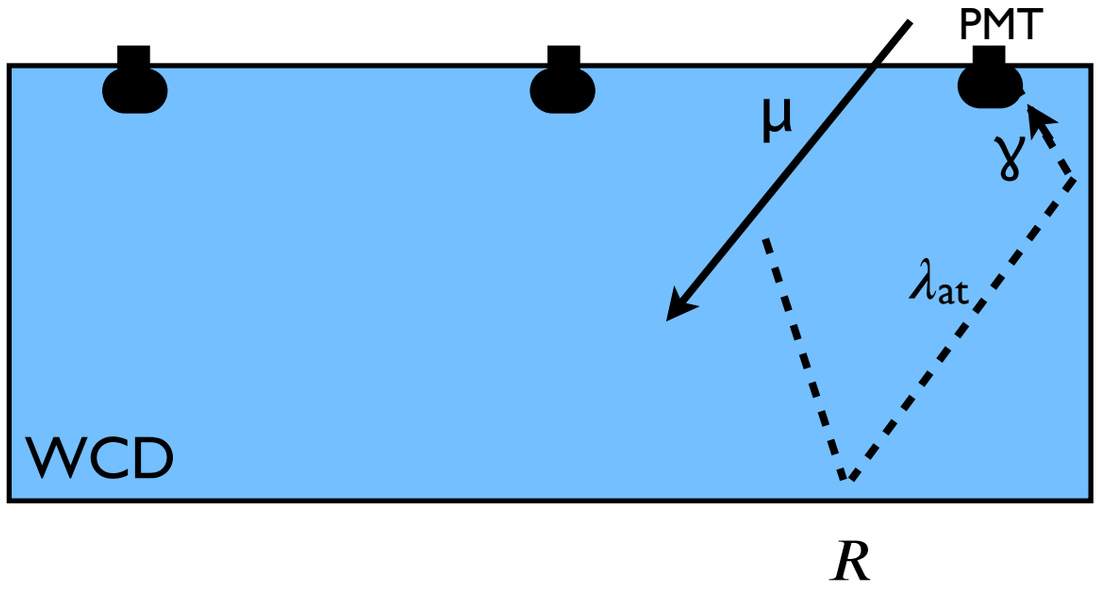


Air-shower phenomenology

- Simulation-based studies to understand which physics parameters correlate with the muon number

Detailed WCD studies

Understanding the water-Cherenkov detector

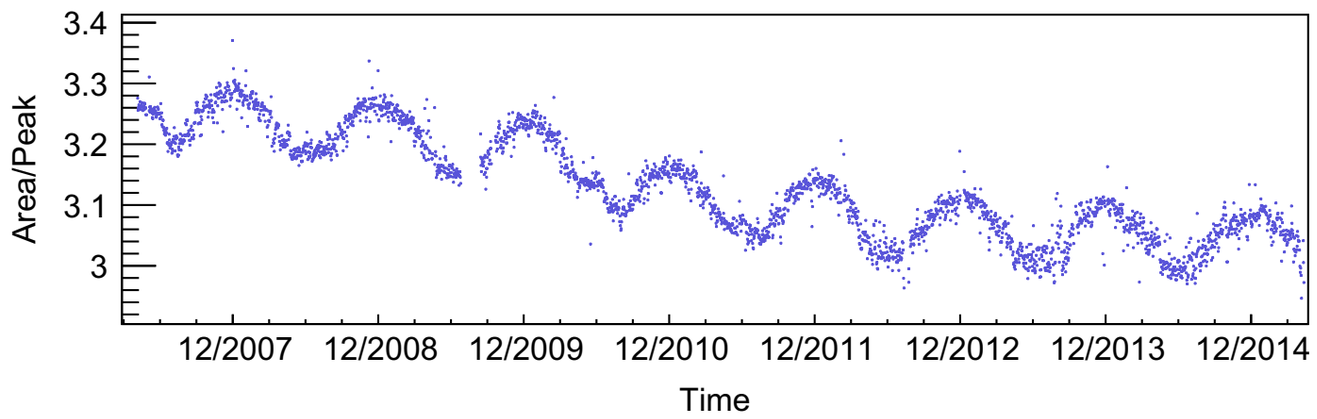


- Light generation: Cherenkov yield
- Light propagation: attenuation length in water
- Light reflection: tyvek reflectivity
- Light collection: PMT geometry, QE

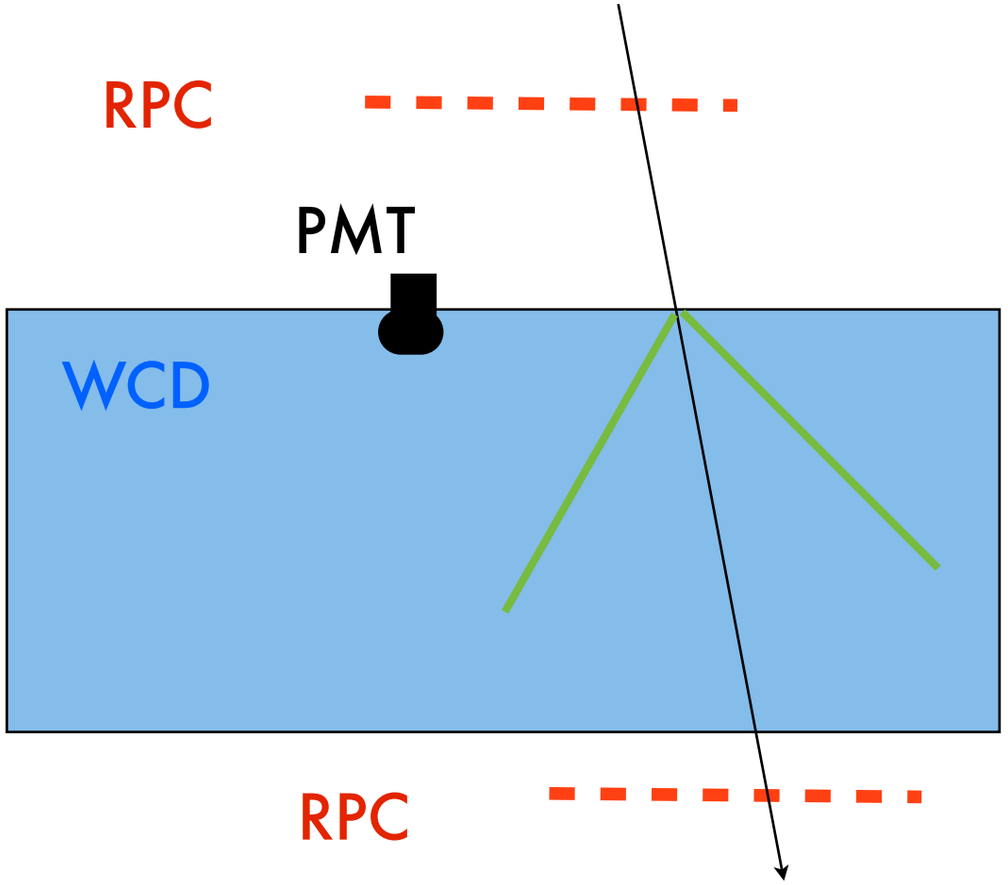
- Other effects (water-air transition, ice formation)

- Ageing factors?

NIM A 798, 172 (2015)



The RPC hodoscope experiment in an Auger test-WCD



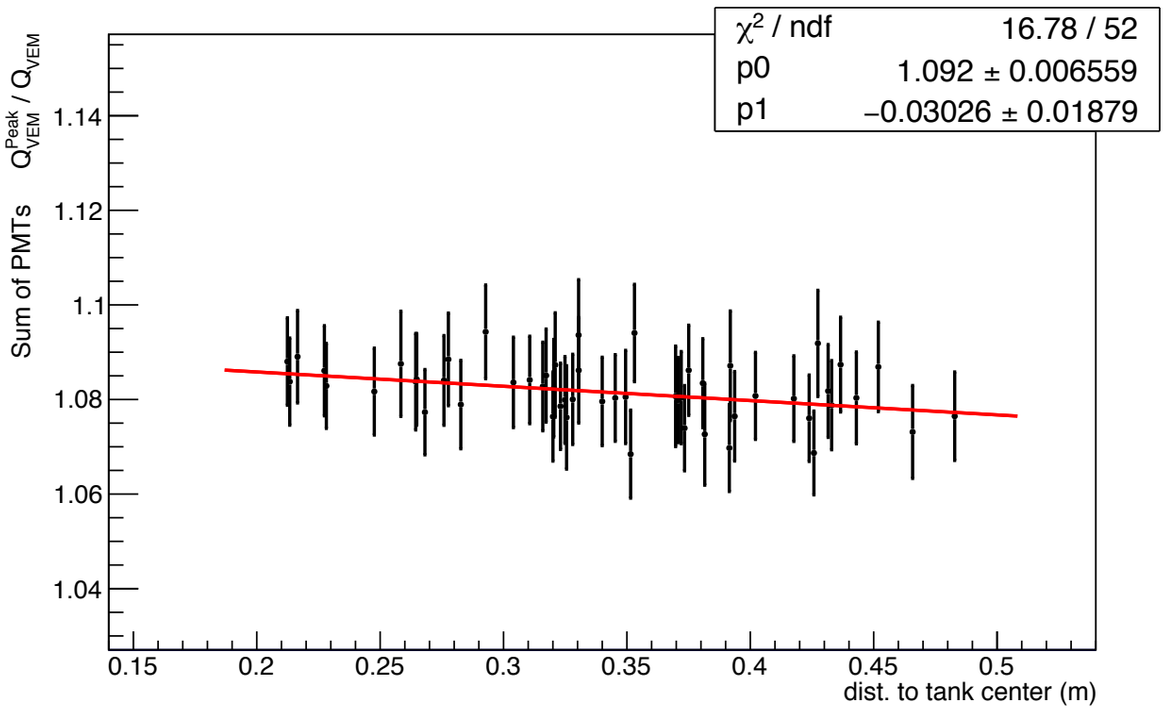
- Resistive Plate Chambers (RPC): position-sensitive detectors
- Trigger on atmospheric muons and study the WCD response for selected trajectories

Results on the WCD: VEM calibration

• Shower size in Auger in **VEM units** - the reference is light output from vertical centered through-going muons

• But: measured at the beginning of Auger operation - what is continuously monitored is the light yield from omnidirectional muons

• After > 10 years - is there **ageing** in the ratio omnidirectional/vertical ? ⟶ No!

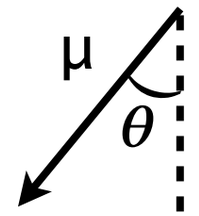


extrapolation to the tank center

Conversion factor	PMT average	PMT sum
Q^{peak}_{VEM}/Q_{VEM}	1.00 ± 0.02	1.09 ± 0.01
I^{peak}_{VEM}/I_{VEM}	0.92 ± 0.03	

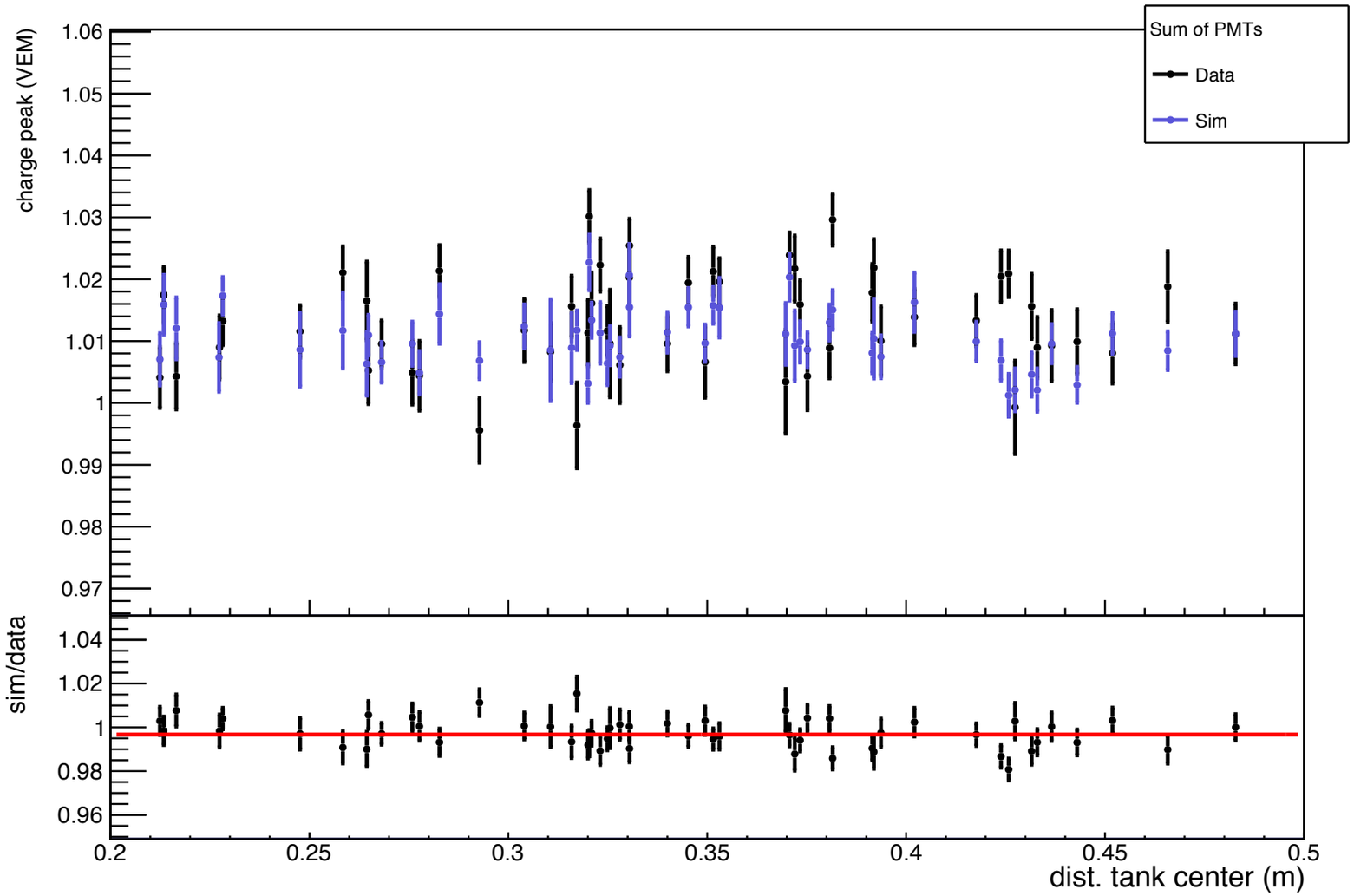
Compatible with the initial measurements

Results on the WCD: vertical muons (θ<10°)



• Are the simulations accurately describing the VEM signal from **vertical muons** ?

Yes!

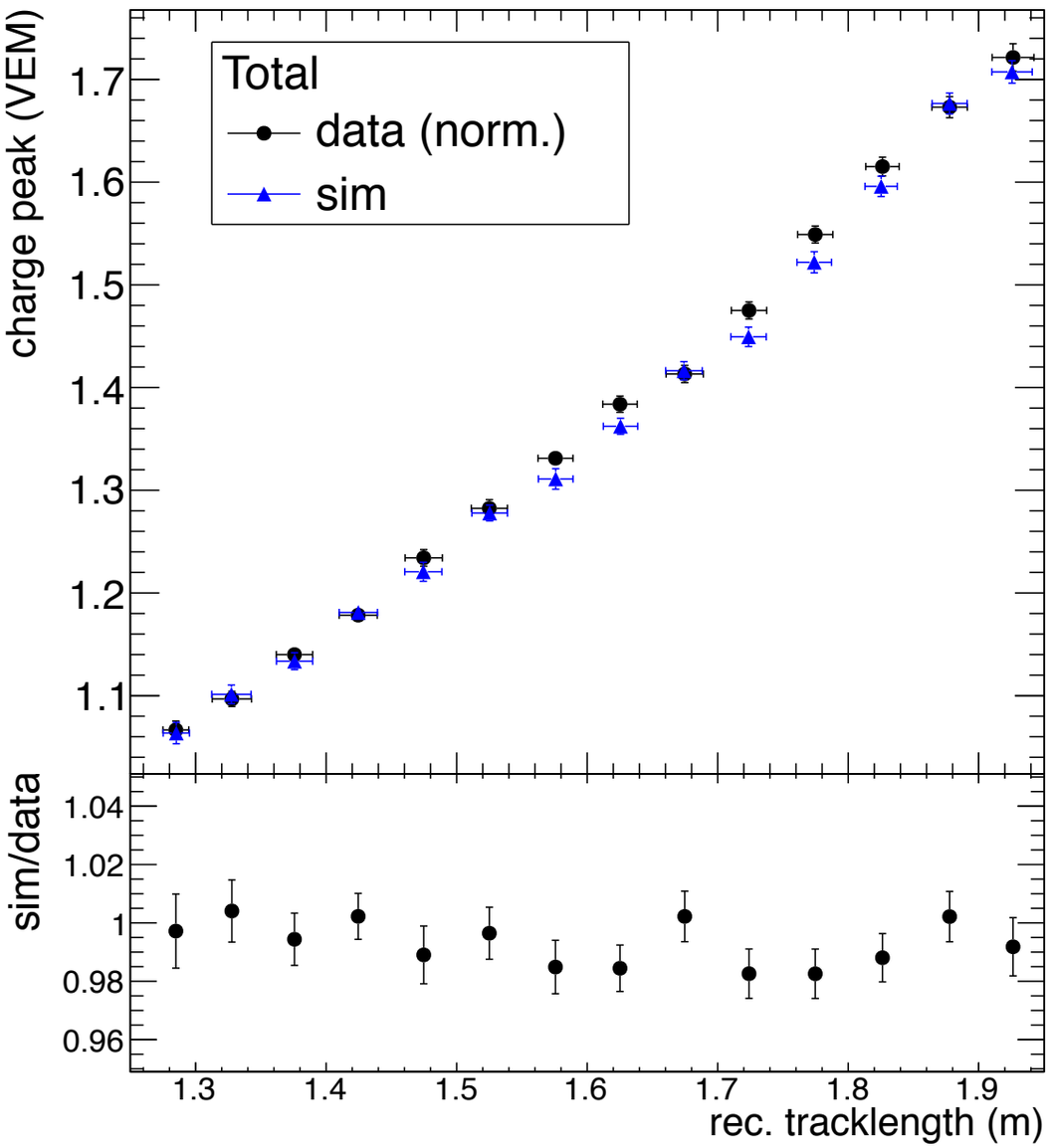


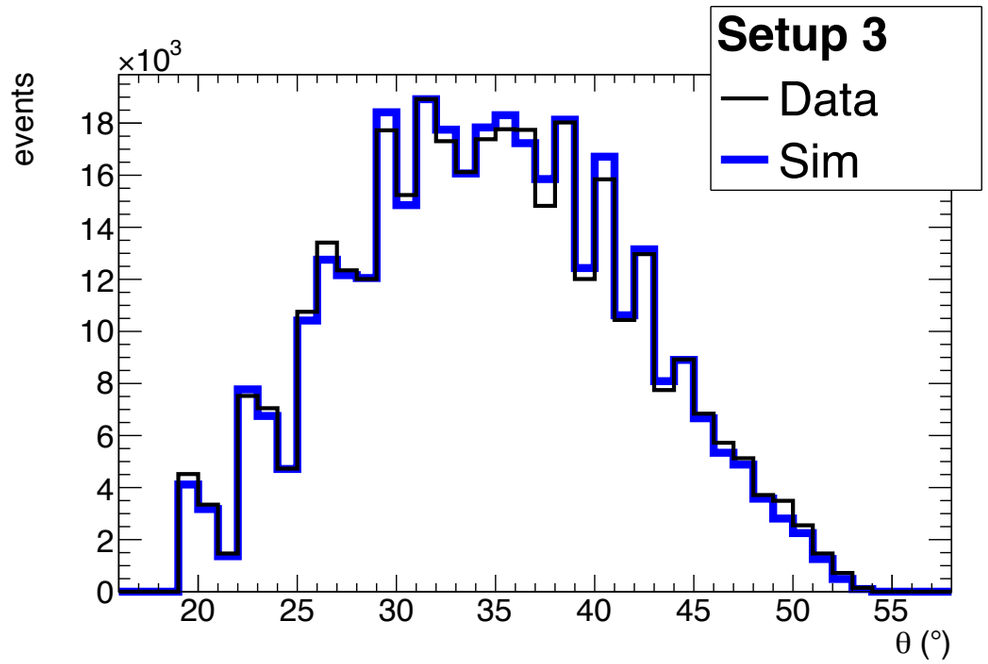
• Setup allows for individual muon trajectory features to be probed:
  - track length
  - distance to tank center
  - distance to PMT

• Simulation and data agree at the percent level

Results on the WCD: muons at 20°<θ<50°

- Are the simulations accurately describing the VEM signal from muons with **intermediate zenith angles** ?





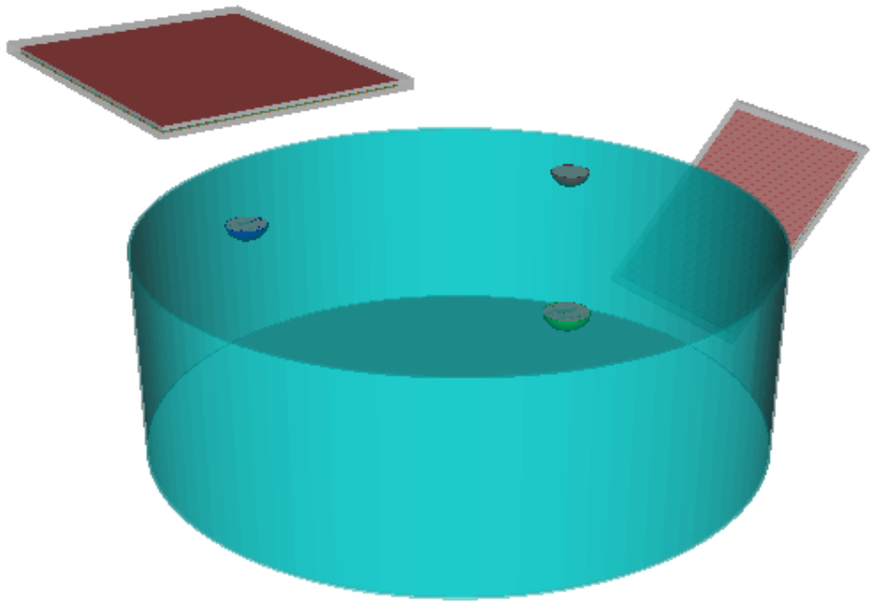
→ Yes!

- Atmospheric muons zenith-angle distribution well described - RPC hodoscope OK

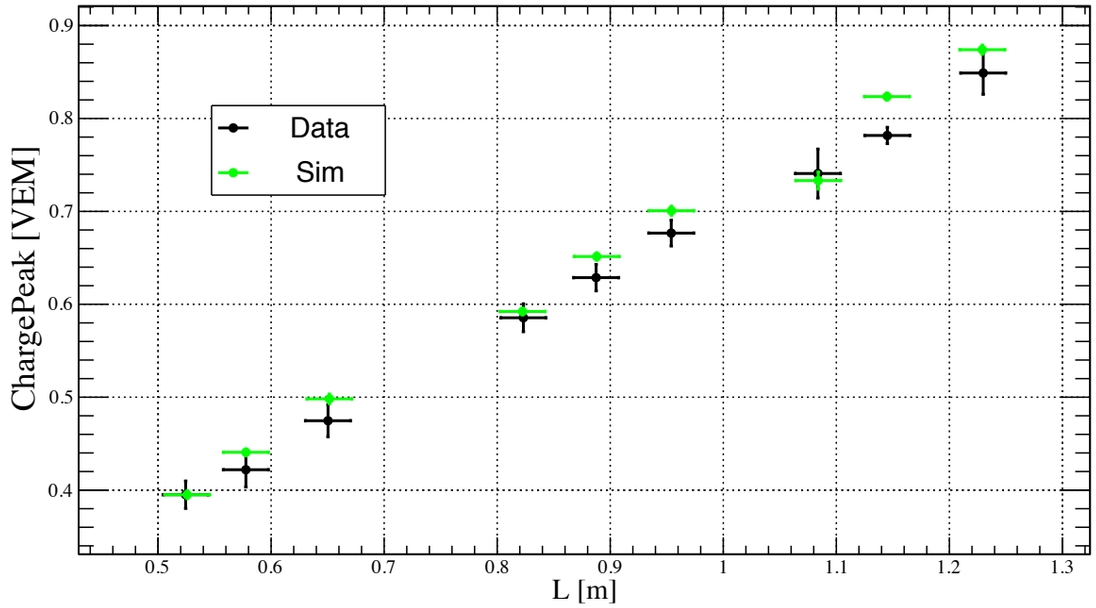
- VEM signal dependence on muon tracklength well described - WCD simulations OK

Results on the WCD: inclined muons (60°<θ<70°)

- **Inclined**: going back to where it all began...



P. Ferreira's Master Thesis, University of Minho, 2017



More challenging...

- Both RPCs unshielded: high background rate
- Inclined muons: low trigger rate
- Clipping muons: high sensitivity to the trajectory

Signal evolution with track length OK but normalization still to be understood

Conclusions and outlook

- Precision measurements on a WCD - the Auger surface detector unit - are complement efforts to tackle the muon excess problem

- All measurements indicate that we do understand its details - the simulation accurately describes all features in data

- We have a mounted setup that, though very remotely operated, can provide useful measurements for multi-purpose analyses

Thank you for the attention!

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