Corsika data analysis

Date: 05-09-2018
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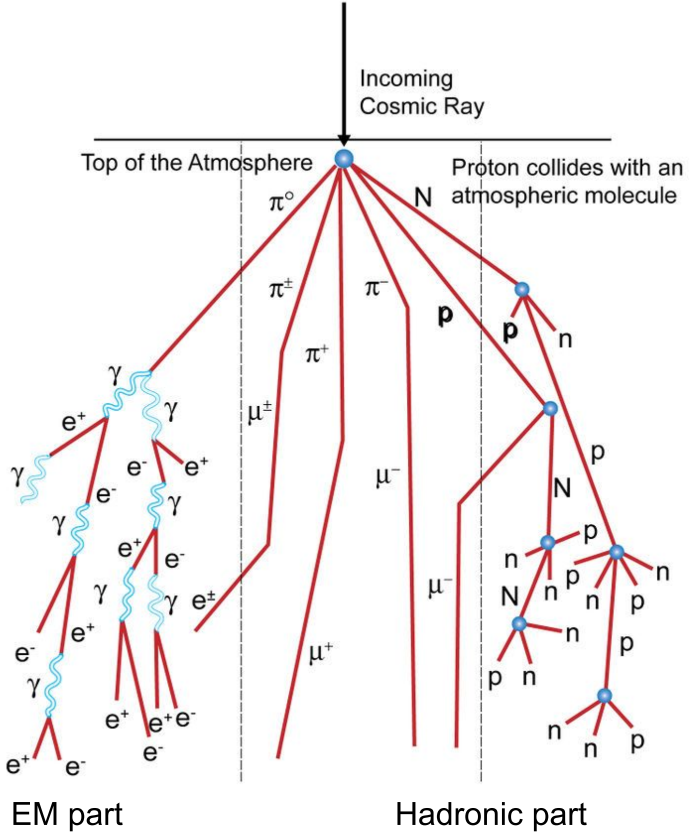
Goal:

Investigate the sensitivity of the KM3NeT detector to determine the cosmic ray **primary composition** and to constrain the **hadronic interaction models**.

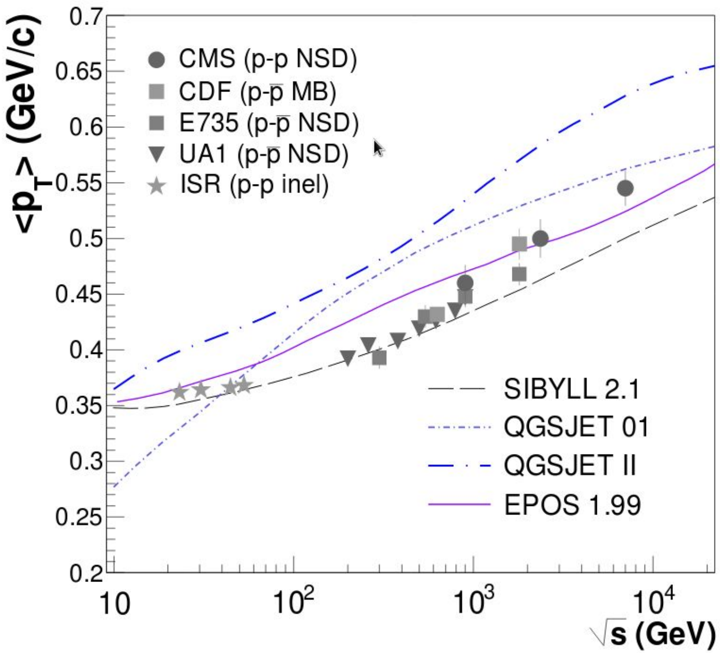
Motivation:

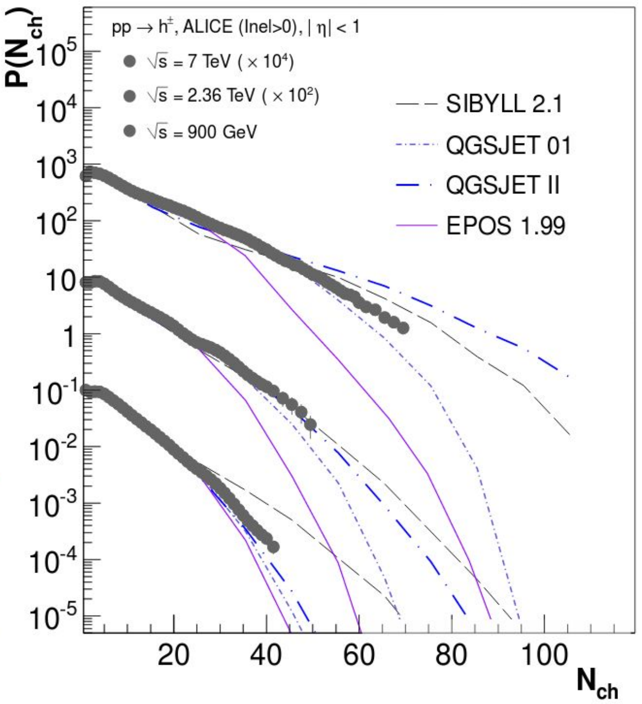
- Origin and acceleration mechanism of cosmic rays are not known.
  → Primary composition can reveal this information
- Large ground based experiments measure the composition, but all have large systematic error due to the uncertainty in the predictions of the hadronic interaction models.



Motivation:

Paper of LHC:
"Constraints from the first LHC data on hadronic event generators for ultra-high energy cosmic-ray physics"
by D. d'Enterria, R. Engel, T. Pierog, S. Ostapchenko and K. Werner. (2011)





Motivation:

- Man made colliders cannot reach the energies of high energy cosmic rays

Why KM3NeT?

- Unique position: 3 km under sea level.
  → only the high energetic muons of the CR shower reach the detector.
- Is able to observe high energy CR events.

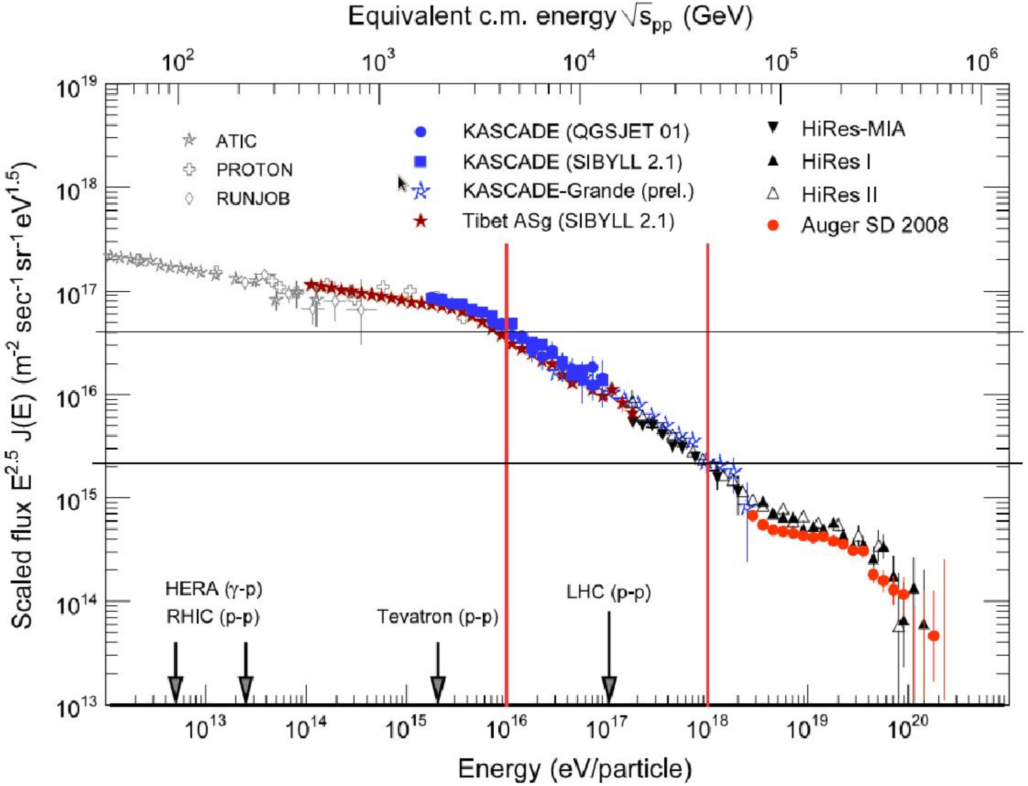


Figure from: “*Cosmic Rays from the Knee to the Highest Energies*” by J. Blümer, R. Engel & J.R Hörandel (2009)

KM3NeT

Reminder:

- The all particle spectrum is the sum of each individual element spectrum

- Following the superposition model, man expect a higher multiplicity for an heavier primary with the same primary energy.

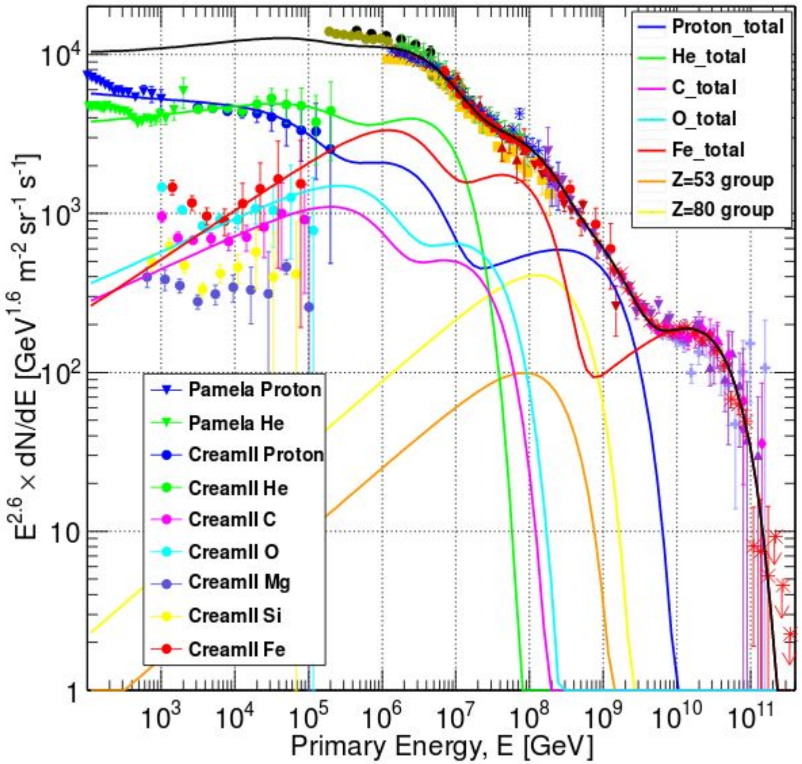


Figure from “*Cosmic ray energy spectrum from measurements of air showers*” by *T.K. Gaisser, T. Stanev & S. Tilav (2013)*

KM3NeT

Corsika data:

Available Corsika data for SIBYLL, EPOS and QGSJET II is taken and can be found at:

https://wiki.km3net.de/mediawiki/index.php/Simulations/CORSIKA

- We only look at the muonic part of the simulations (propa files).
- All the muons are propagated till the can.

KM3NeT

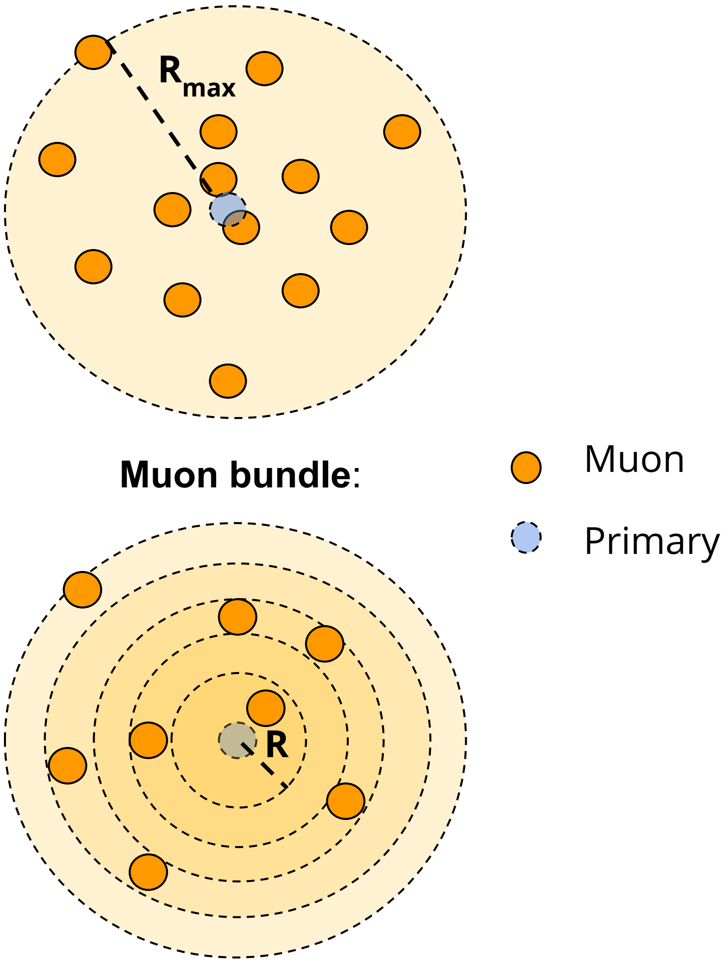
Observables:

With KM3NeT:

- Muon multiplicity: N_{muons}
- Zenith angle: θ
- Radius: R
- Maximum radius R_{max}

Needed:

- Primary energy: E_p

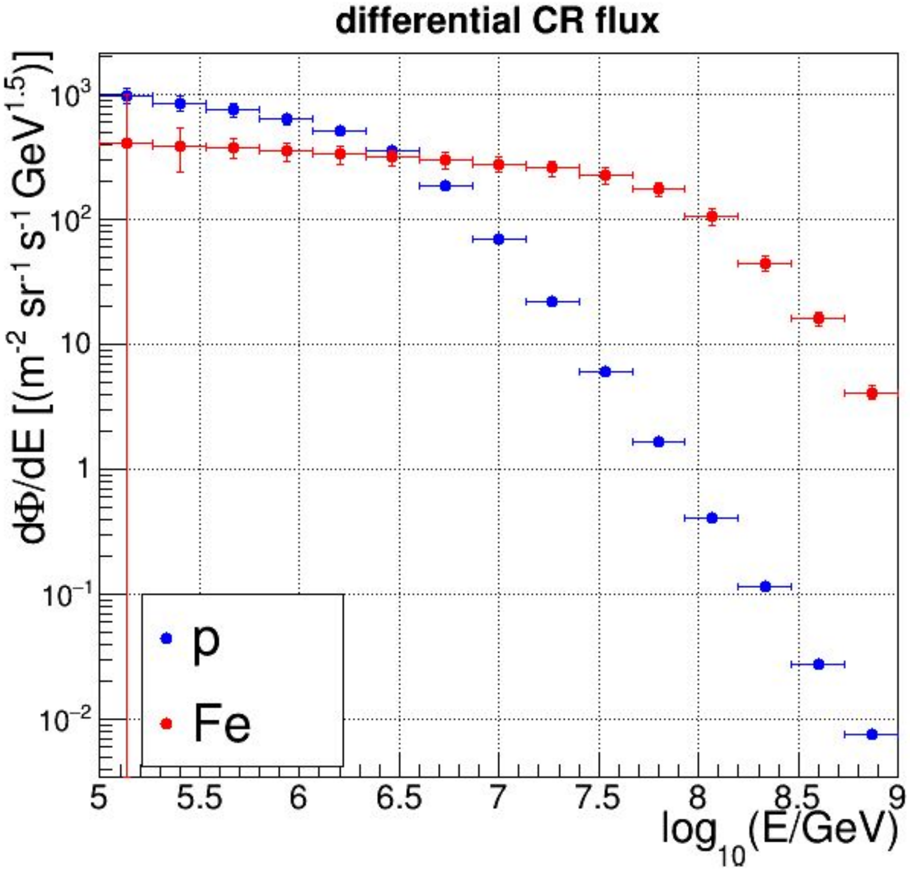


Cosmic ray flux model

1. The CR Flux at sea level is calculated for each primary using the flux formula and the rigidity dependent ansatz as described in:
   "On the knee in the energy spectrum of cosmic rays" by J. R. Hörandel. (2002)

2. The flux is multiplied with the weight (w2) of the event and divided by the norma of files times the number of files used:

   N_{events} = (flux*w2)/(norma*N_{files})



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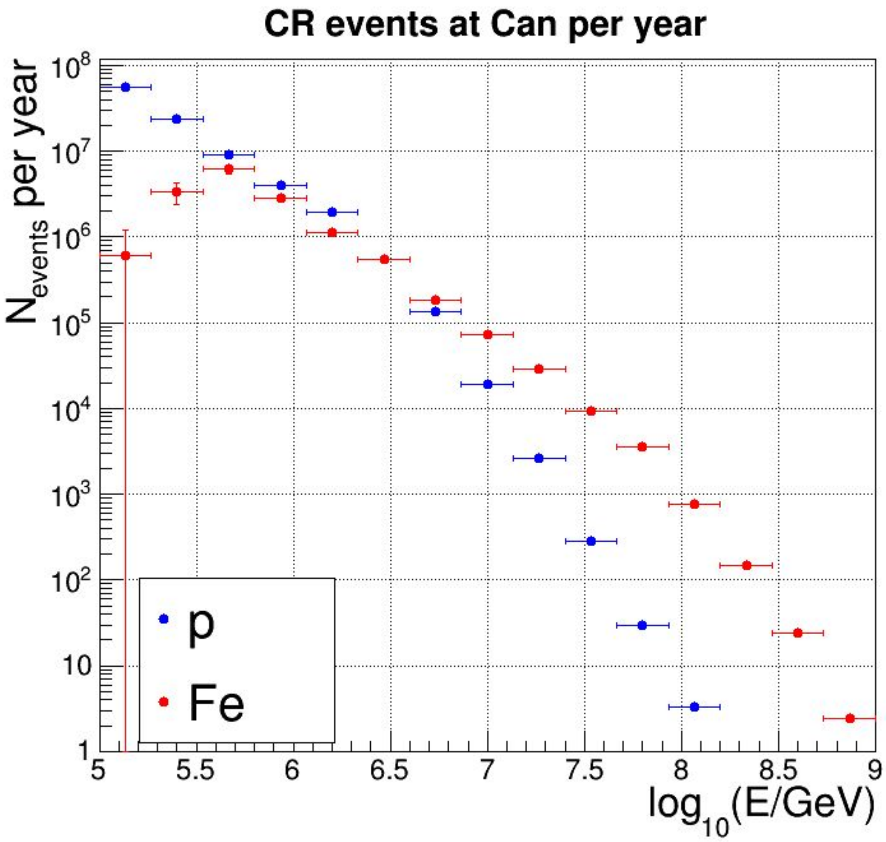
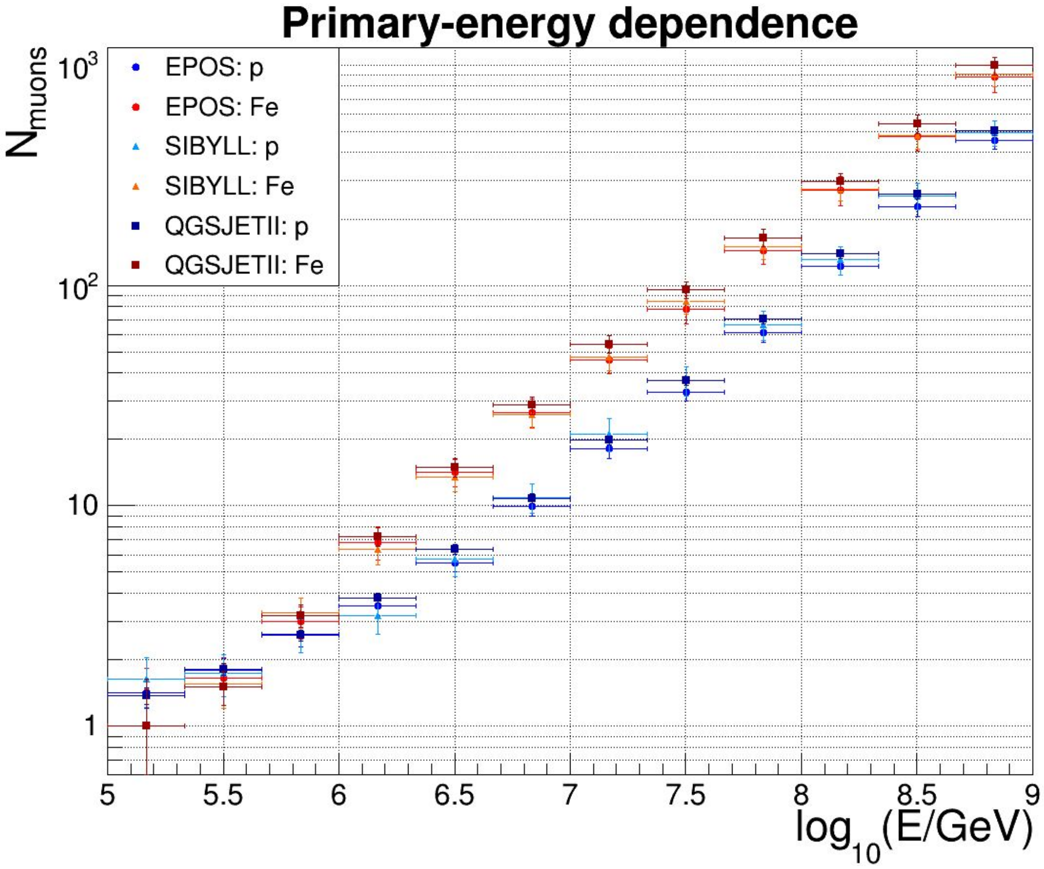


Results: Average muon multiplicity

Features:

- Multiplicity increases with primary energy.
- Higher mass composition causes higher muon multiplicity.
- Differences between hadronic interaction models.



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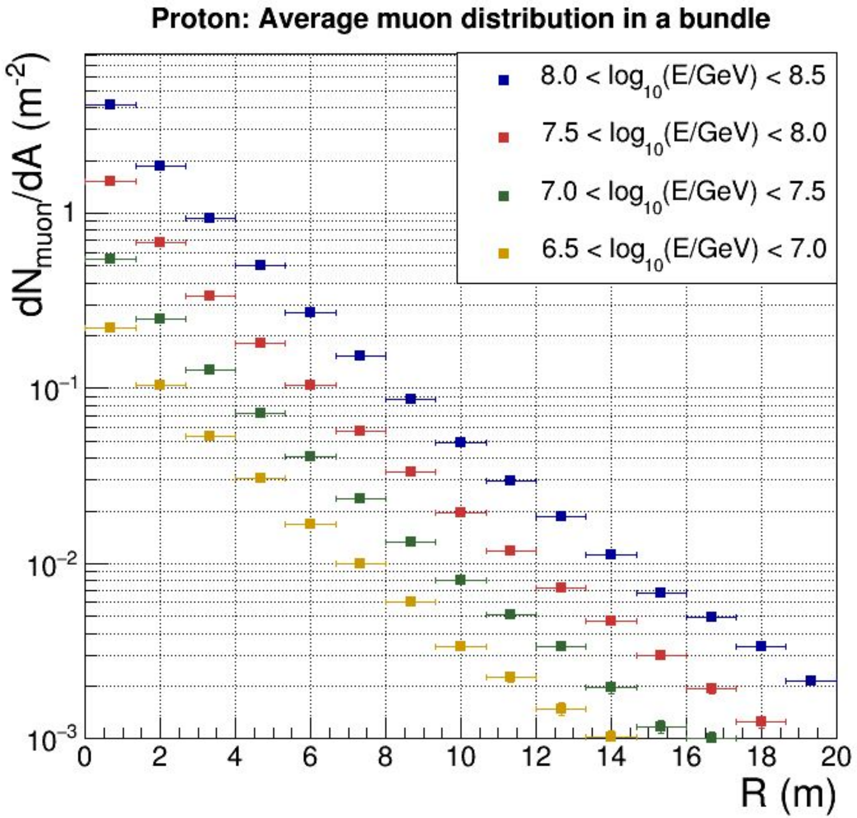
Results: Density distribution in a muon bundle

Features:

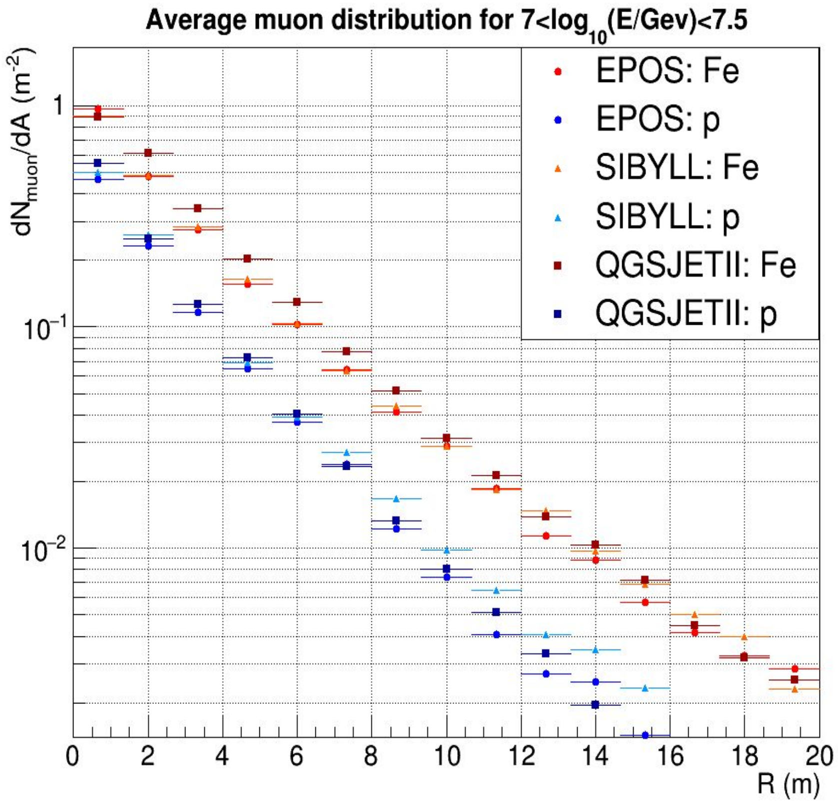
- The density distribution is the same for different primary energies, only the amount changes.



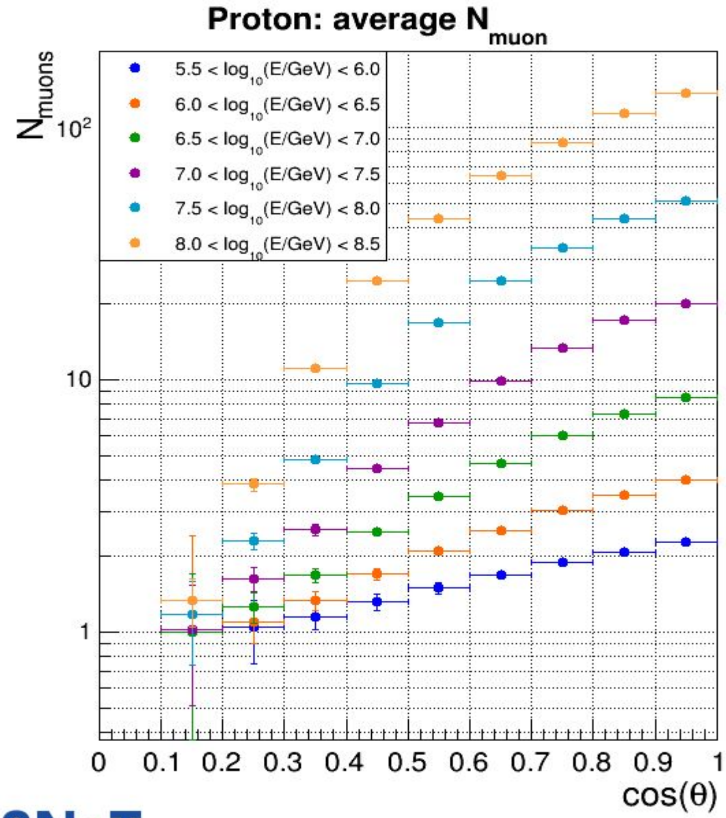
Results: Density distribution in a muon bundle

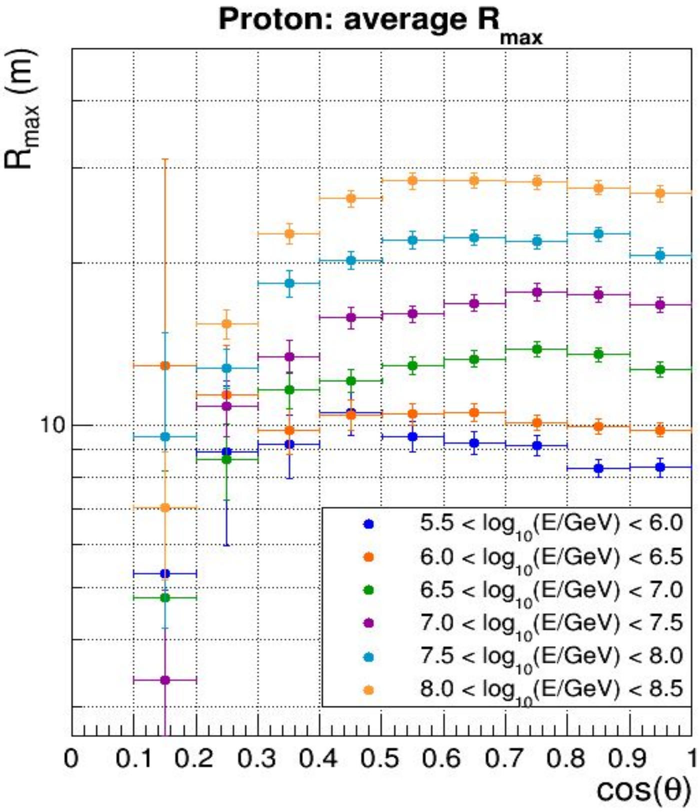
Features:

- Density distribution changes for a different primary composition.
- Difference between predictions of different hadronic interaction models.



Results: Zenith angle dependence





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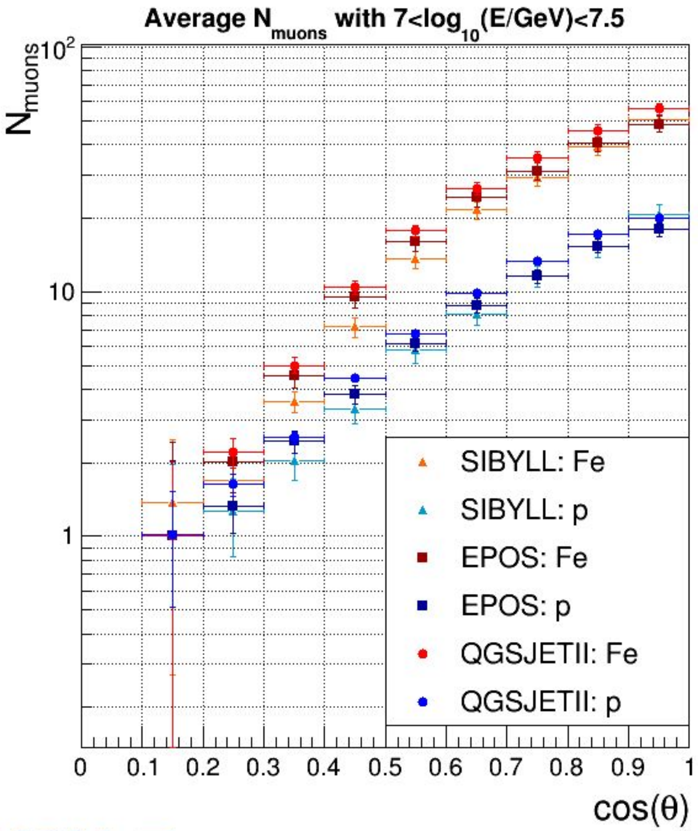
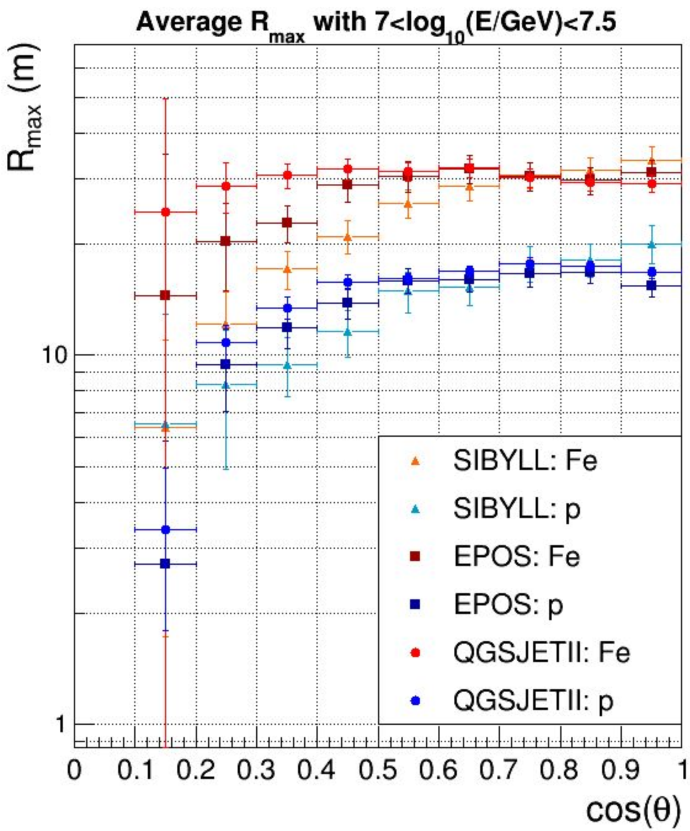
Results: Zenith angle dependence





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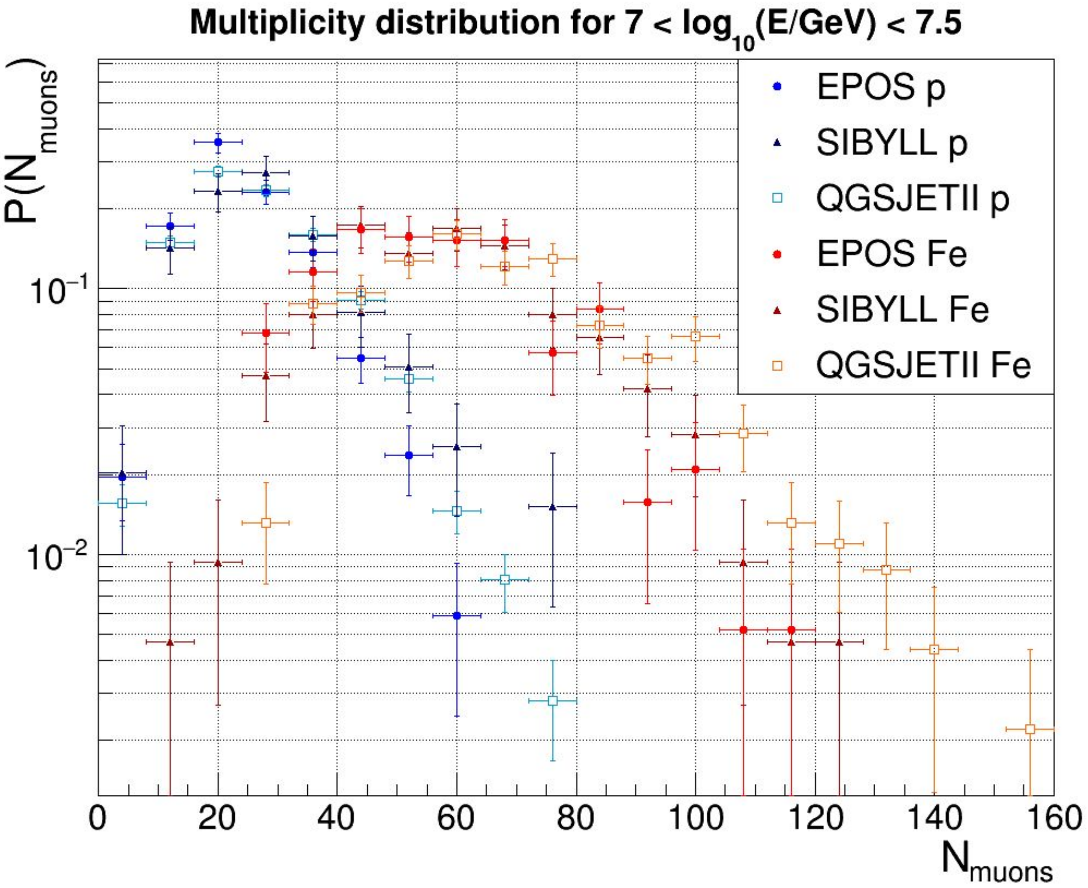
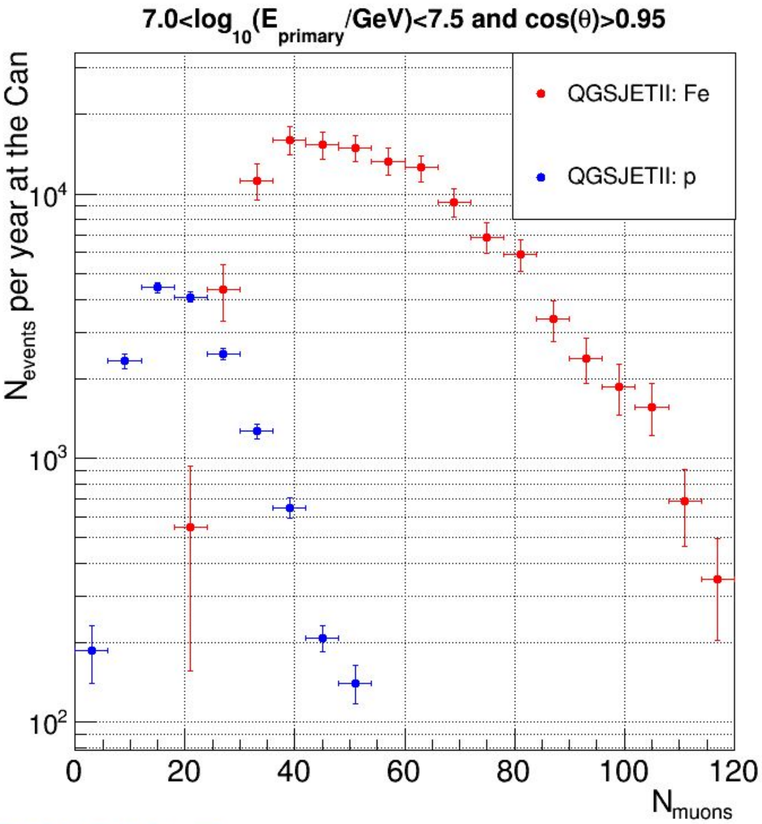
Results: Multiplicity distribution

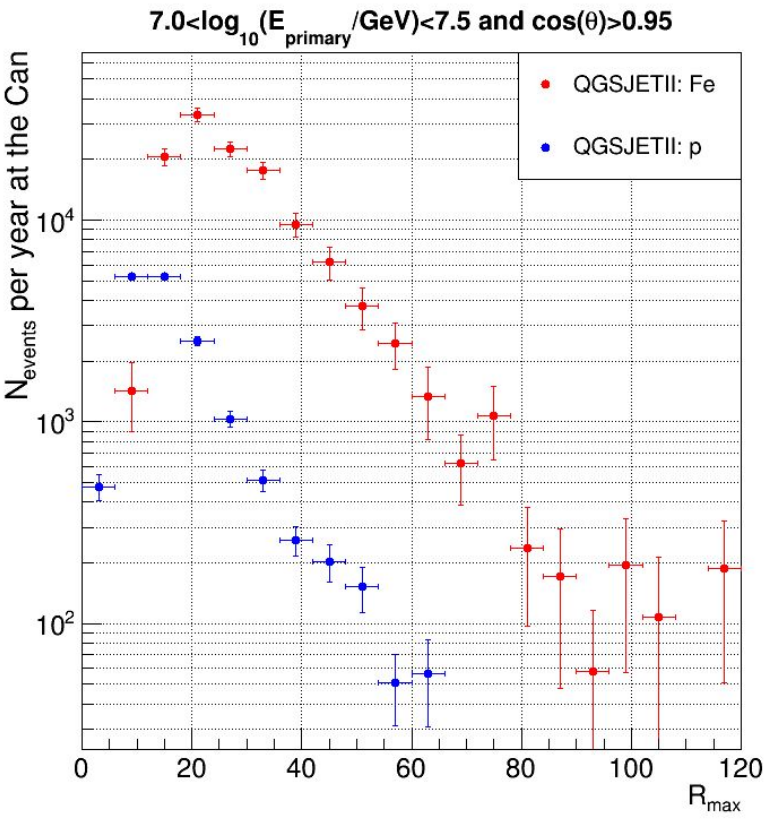
Features:

- Clear difference between hadronic interaction models
- Primary composition visible in multiplicity distribution



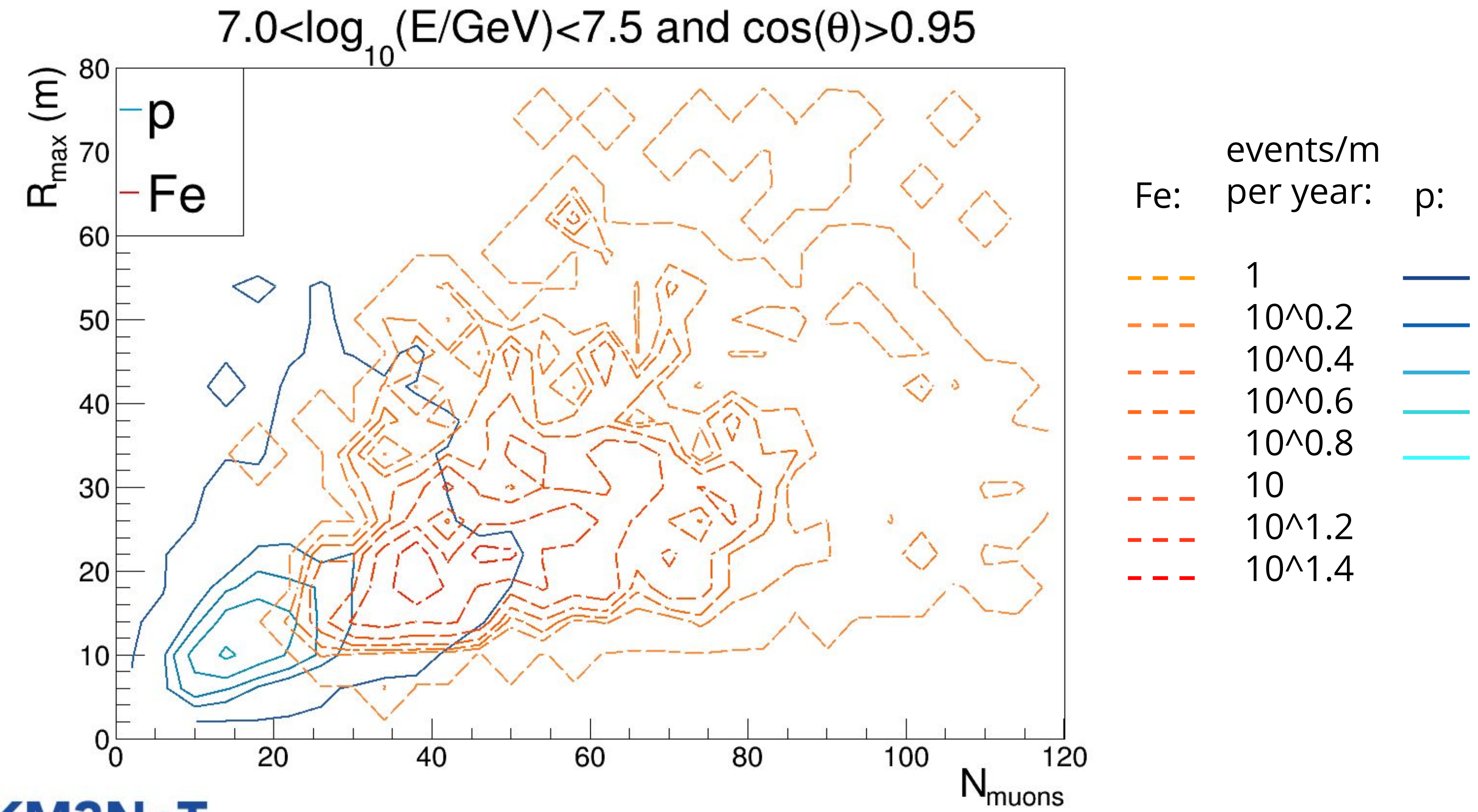
Results: Distinguish between primaries (1D)





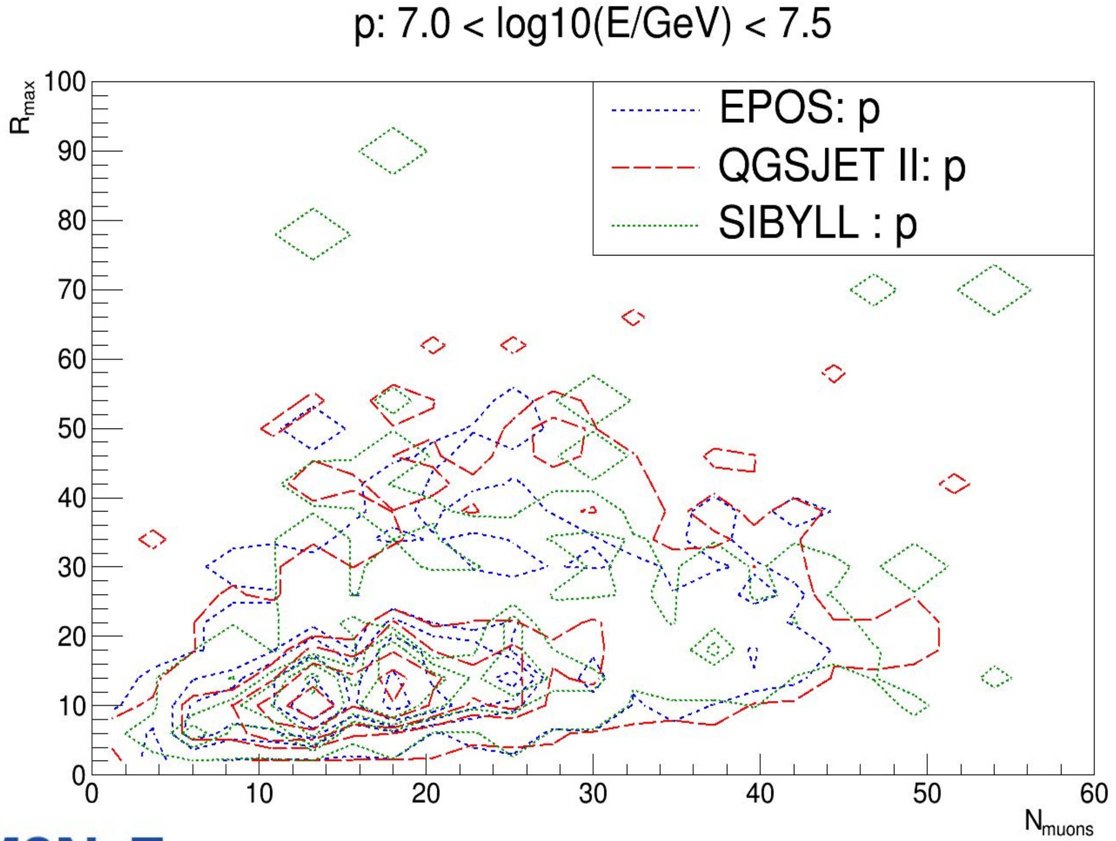
KM3NeT

Results: Distinguish between primaries (2D)



KM3NeT

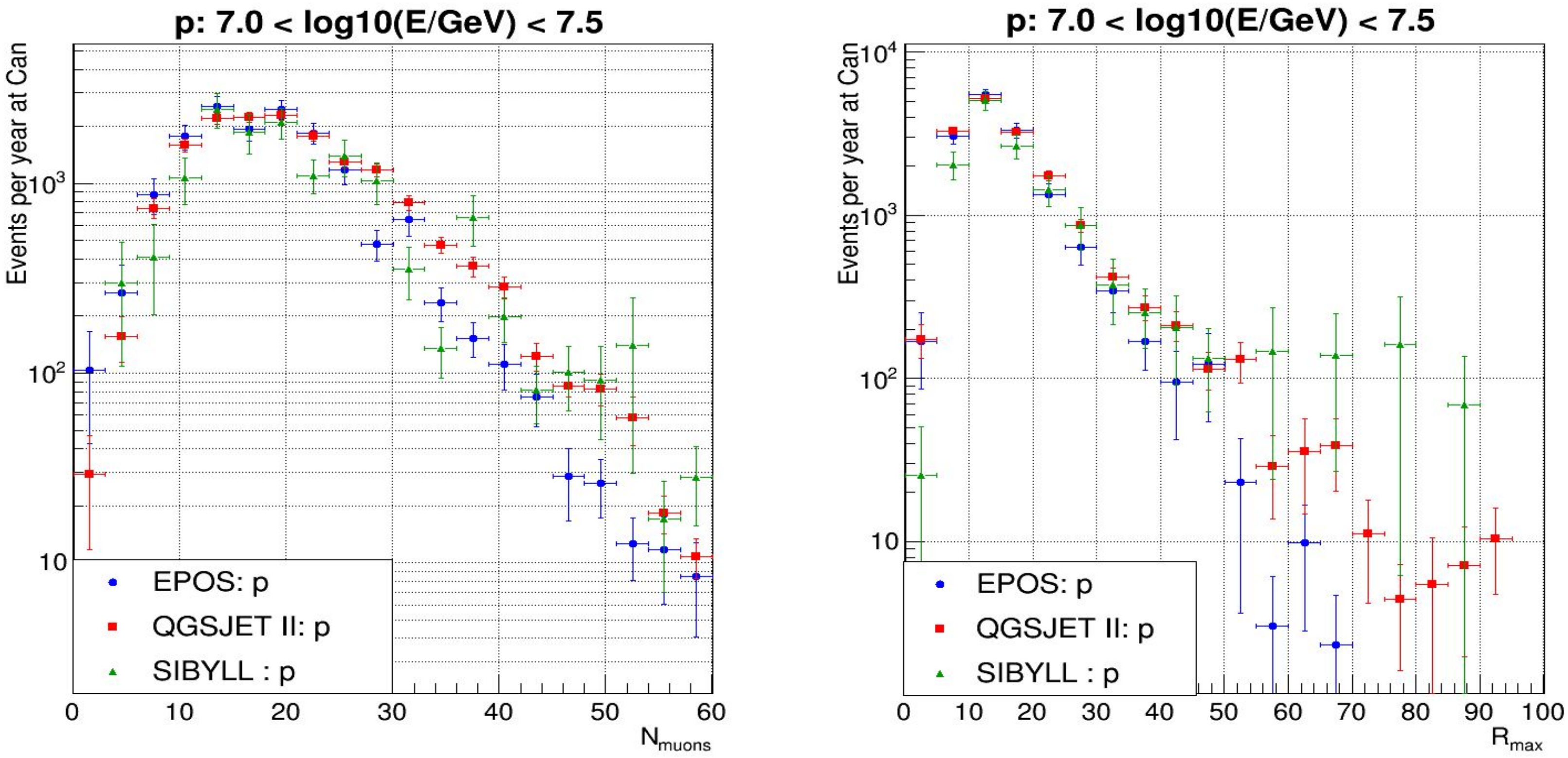
Results: Distinguish between models (2D)



events/m per year:

1
10^0.2
10^0.4
10^0.6
10^0.8

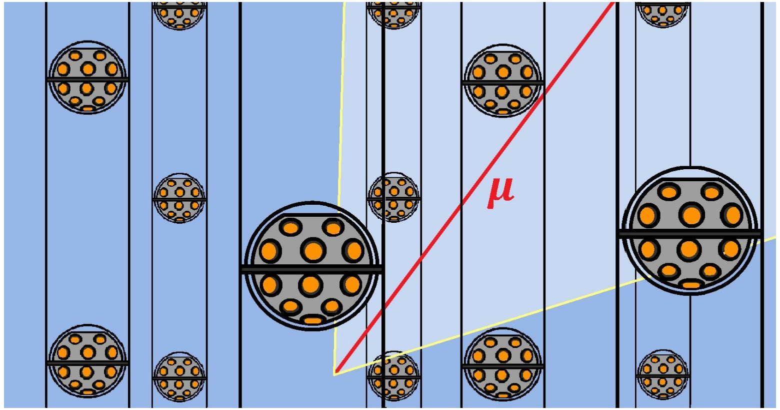
Results: Distinguish between models (1D)



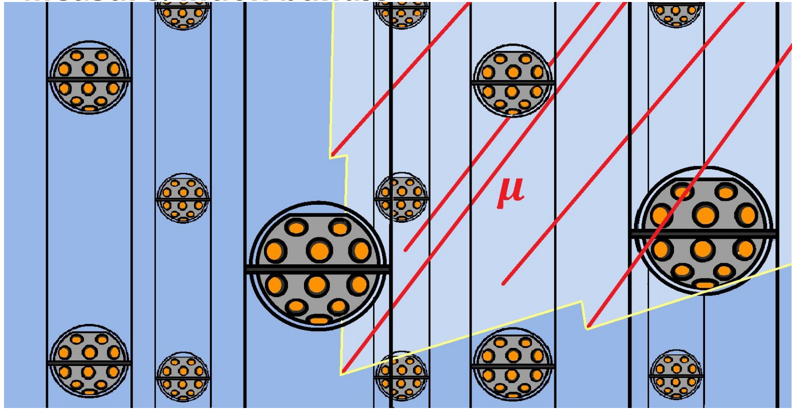
How to measure the observables with KM3NeT?

- **Muon multiplicity:** **N_{muons}**
- Zenith angle: θ
- Radius: R
- Maximum radius R_{max}

Simulate: Middle of muon bundle



Measure: Muon bundle



KM3NeT

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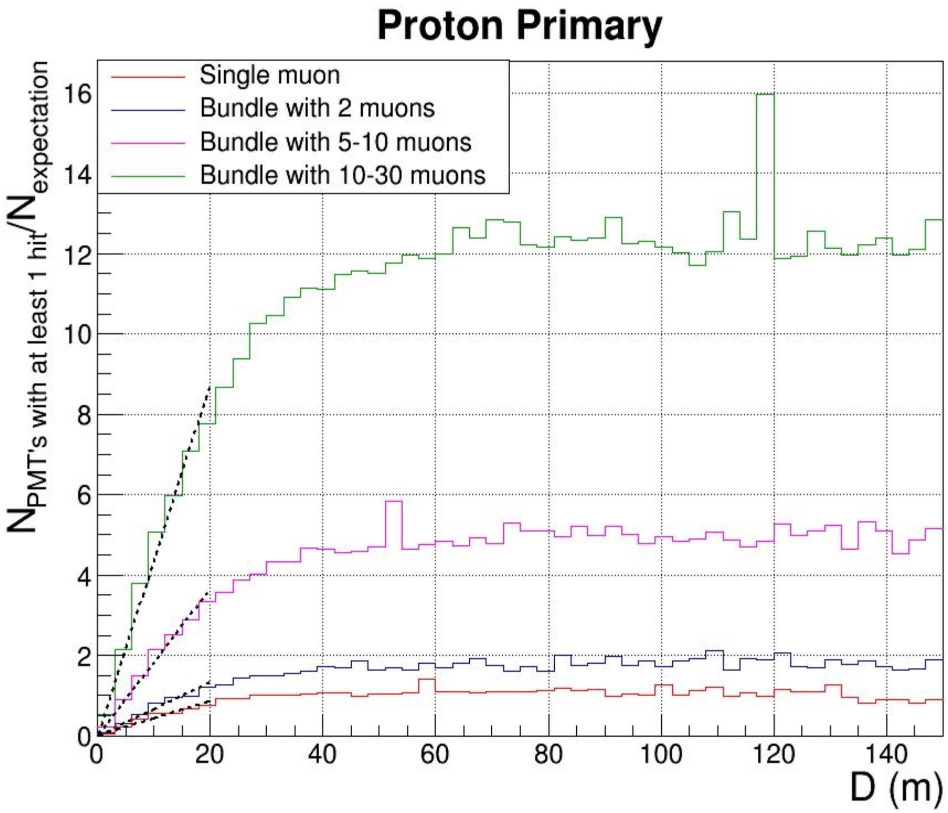


KM3NeT

How to measure the observables with KM3NeT?

- Muon multiplicity: N_{muons}
- **Zenith angle: θ**
- Radius: R
- Maximum radius R_{max}

Reconstruction of the arrival direction of the muon bundle.

KM3NeT

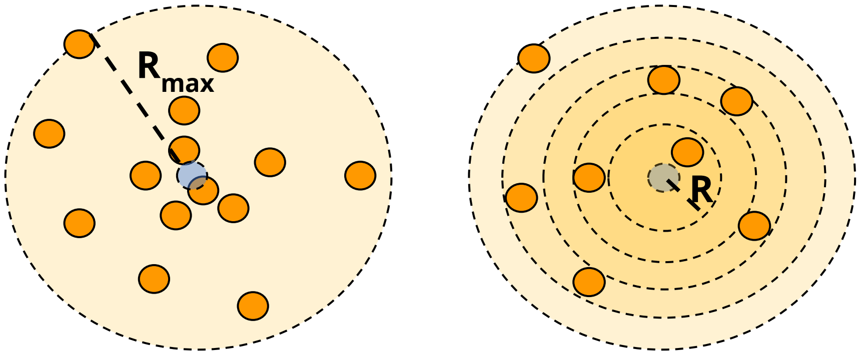
How to measure the observables with KM3NeT?

- Muon multiplicity: N_{muons}
- Zenith angle: θ
- **Radius:** $\mathbf{R}$
- **Maximum radius** $\mathbf{R_{max}}$

Instead of using the primary position at the can (this cannot be measured):

Reconstruct the position of the muons. Use the center of mass method to determine the middle of the bundle.

Muon bundles:



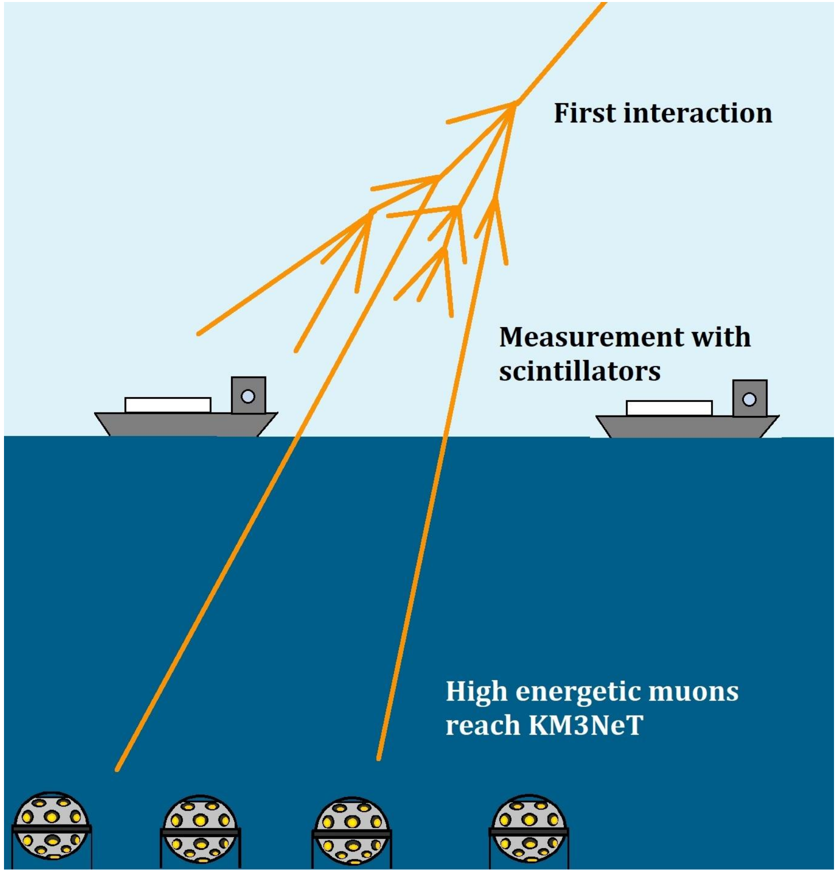
Muon

Primary

How to measure the primary energy?

- Suggestion of Ronald Bruijn:
  Use scintillators at sea level to determine the primary energy
  → For example KASCADE has an energy resolution of 22%

- Use R_{max} to estimate the primary energy. Unfortunate the primary composition is needed for this method.



KM3NeT

Conclusion:

Using the observables, KM3NeT is sensitive to measure the **primary composition** and to differences between **hadronic interaction models**!

But the primary energy is a **key ingredient** for this research, which cannot be easily observed with KM3NeT.

Further research:

- More elements need to be included in the primary composition to get a realistic study.
- Differences in predictions between flux models can be investigated.
- Research in how to obtain the primary energy.