Charm: KM3NeT MC results

MANTs meeting 2016

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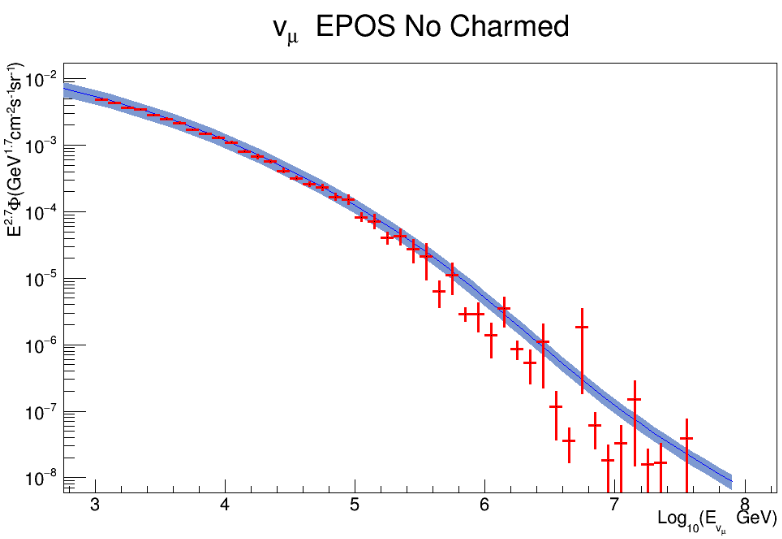
Motivation

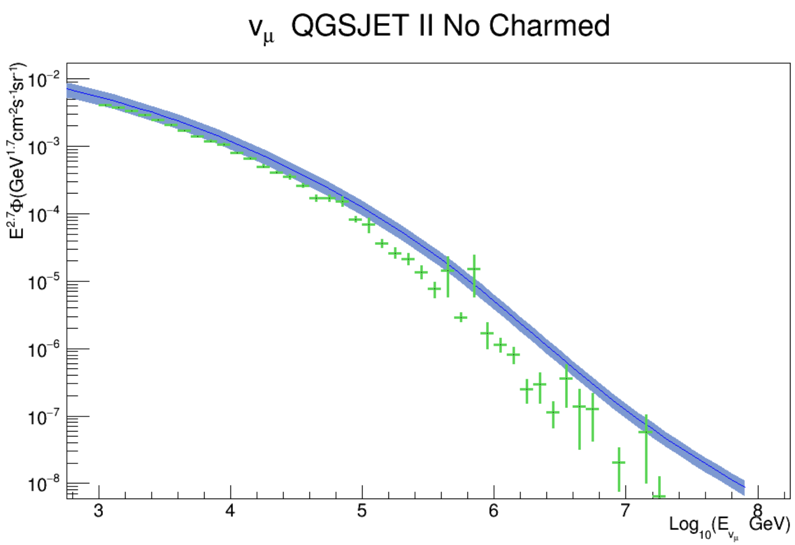
- The aim is to create a production of atmospheric showers with CORSIKA to study the atmospheric background.
  - Compare CORSIKA flux to those adopted.
  - Study muon bundles
  - Study neutrinos accompanied by muon bundles.
  - Study the prompt component.
- As a first step 5 productions were made (each 1 % of the final size) in order to determine the best parameters to be used
  - High energy interaction models.
  - The contribution of prompt component.
  - Models of the atmosphere.
  - Energy cuts.
- In parallel to this CORSIKA production, another production is being made in the framework of ASTERICS (Astronomy ESFRI and Research Infrastructure Cluster)

Productions, High Energy Interaction Models

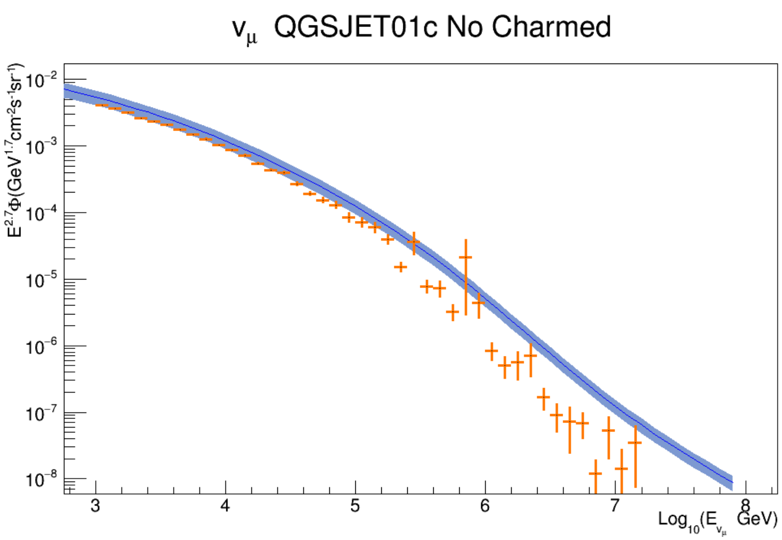
- QGSJET 01c , QGSJET II, EPOS LHC with CORSIKA version 74005
- SIBYLL 2.3 with CORSIKA version 75000
- QGSJET II and EPOS LHC are not compatible with CHARM.
- QGSJET 01c and SIBYLL are compatible with CHARM.
- 5 productions:
  1) QGSJET 01c with CHARM
  2) SIBYLL 2.3 with CHARM
  3) QGSJET 01c without CHARM
  4) QGSJET II without CHARM
  5) EPOS LHC without CHARM
- Primaries' Nuclei: p, He, C, N, O, Mg and Fe.
- Cosmic Ray model: Primary model used H3a. Also H4a is used for comparison
- The model of the atmosphere used is customized to ARCA location.

ν_μ Conventional flux / No CHARM





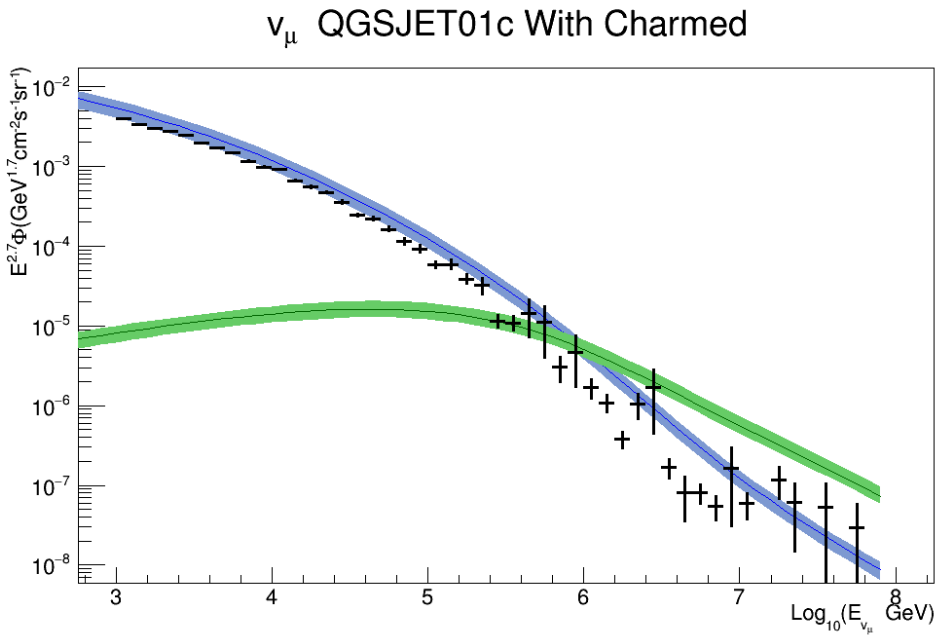
Honda flux ± 25%

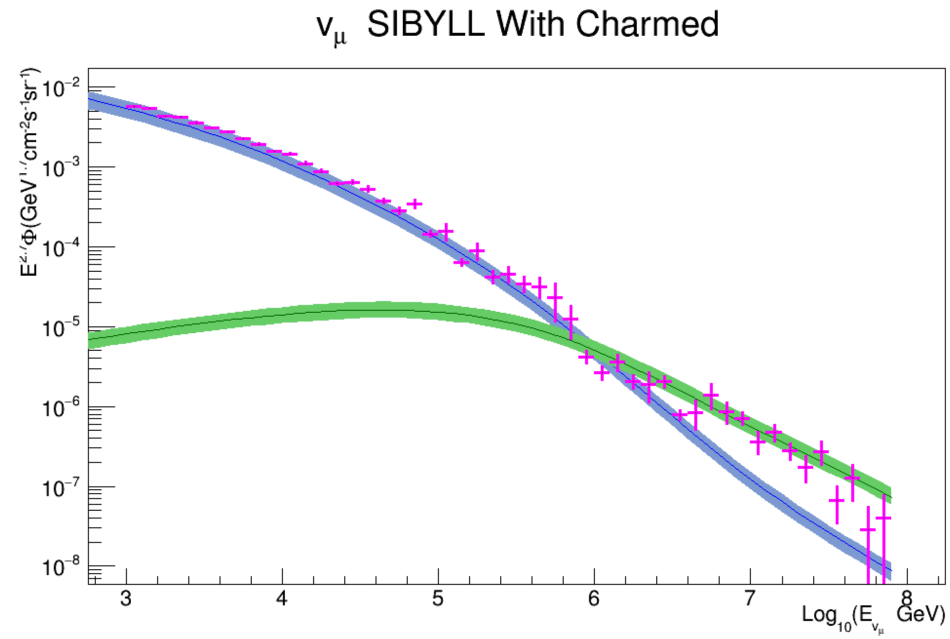


Honda flux:
Phys. Rev. D 75 043006 (2007)

arXiv:astro-ph/0611418

ν_μ flux / With CHARM





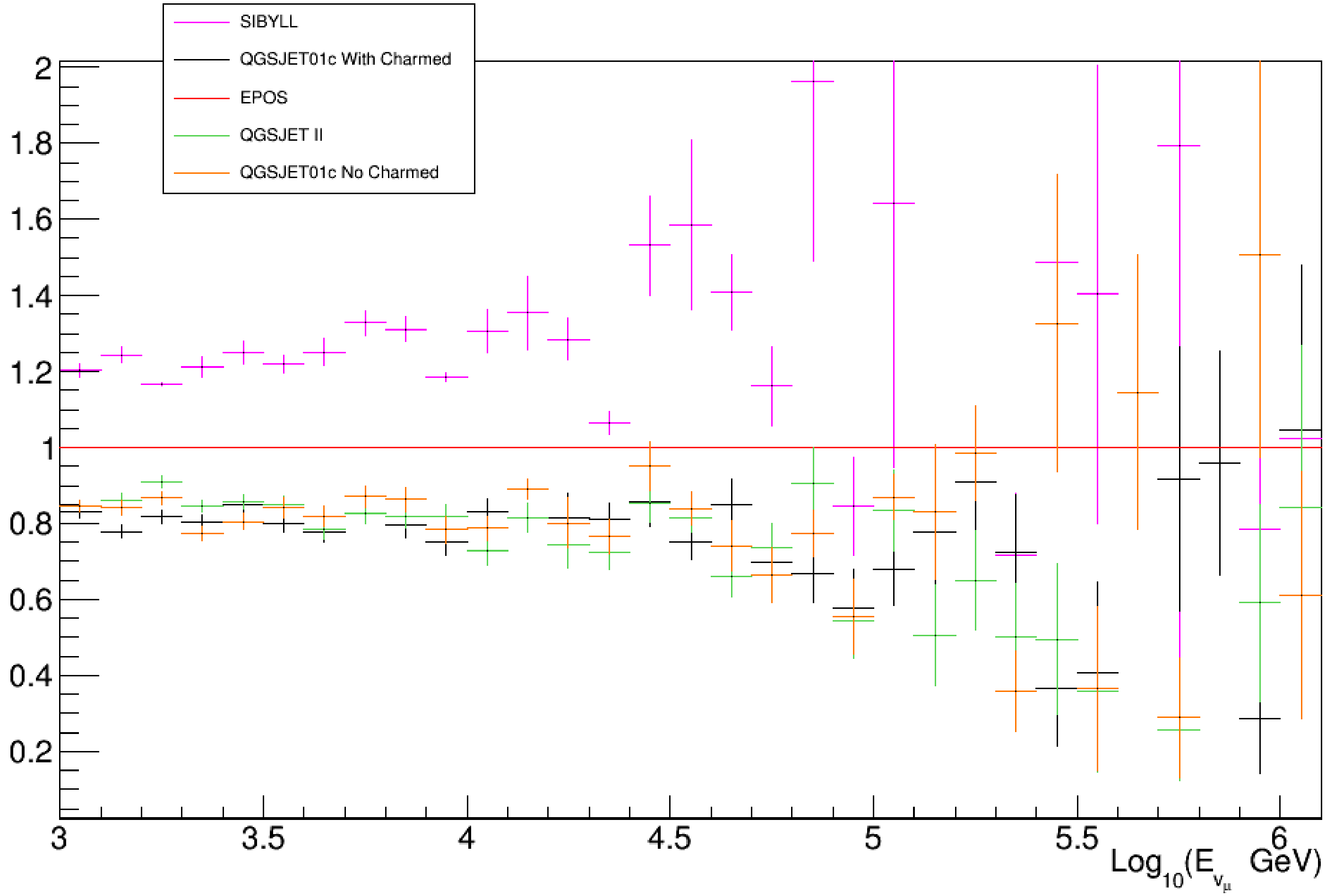
Honda
flux ± 25%

Enberg
flux and
uncertainty
band

Enberg flux:
Phys. Rev. D 78
043005 (2008)

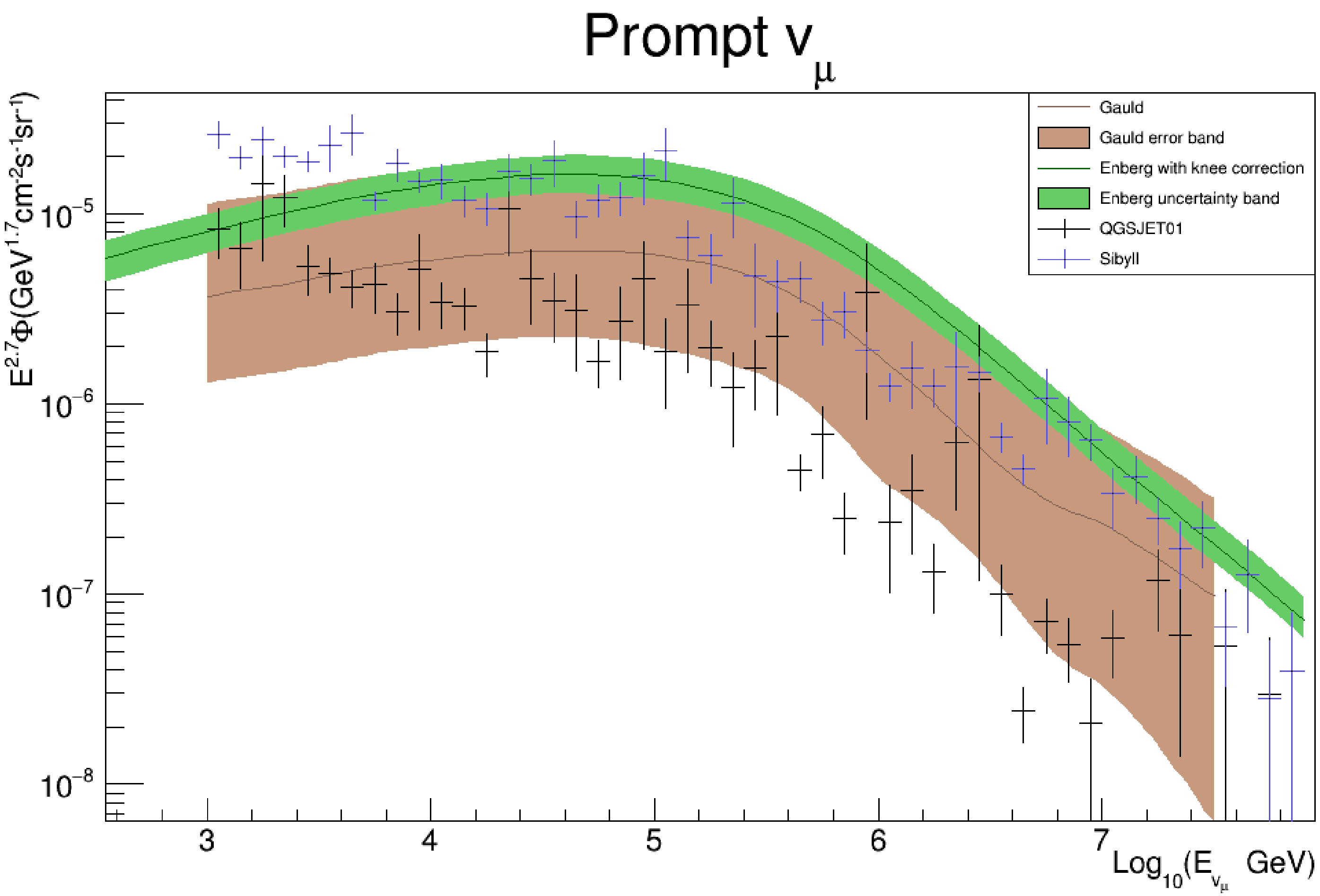
arXiv:0806.0418

ν_μ Conventional flux, all models



The conventional flux of all models normalized to EPOS LHC

ν_μ Prompt flux



Enberg flux and uncertainty band

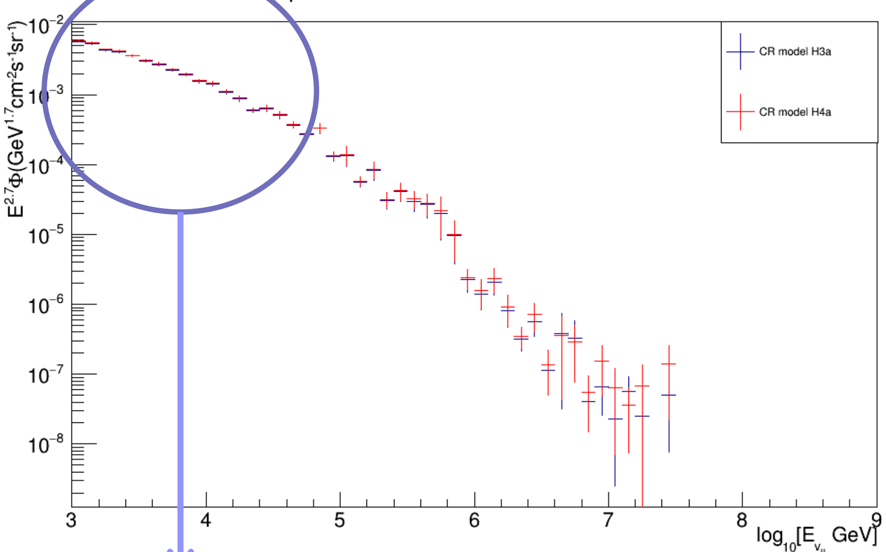
Prompt flux as calculated by Gauld at al. (2016)

JHEP 02 (2016) 130, arXiv:1511.06346

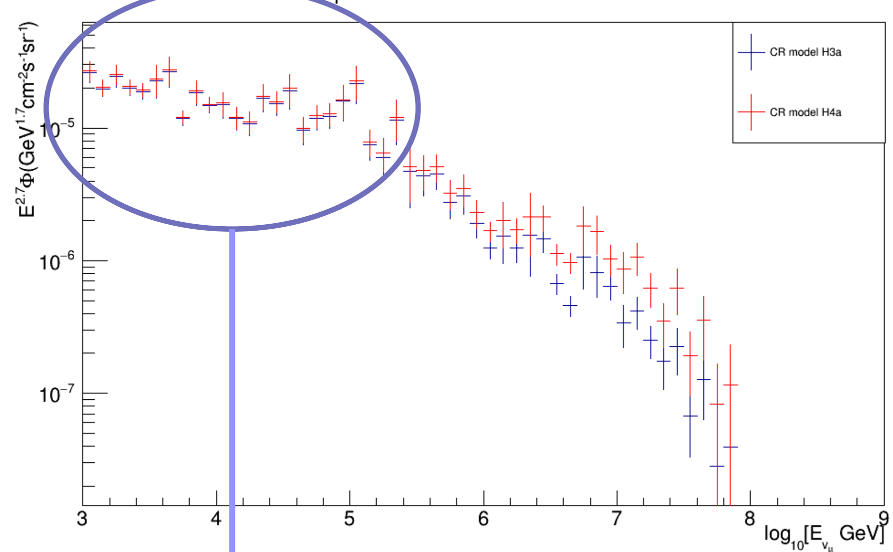
QGSJET0.1c was used in Gauld et al. calculations so a better agreement between the two is expected

Comparison of the ν_μ fluxes by H3a and H4a

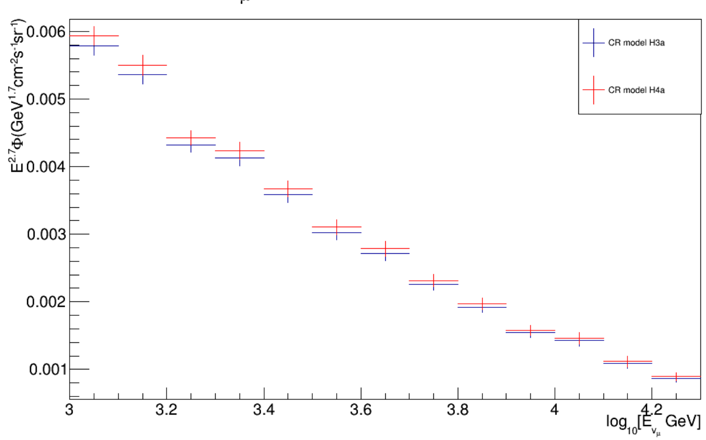
ν_μ conventional flux SIBYLL



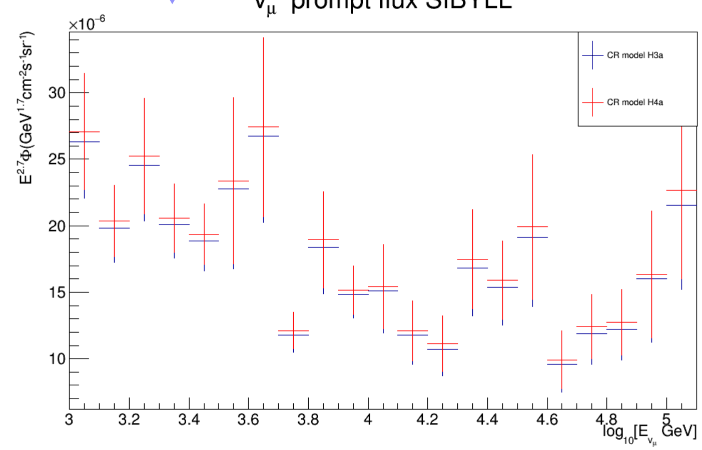
ν_μ prompt flux SIBYLL



ν_μ conventional flux SIBYLL



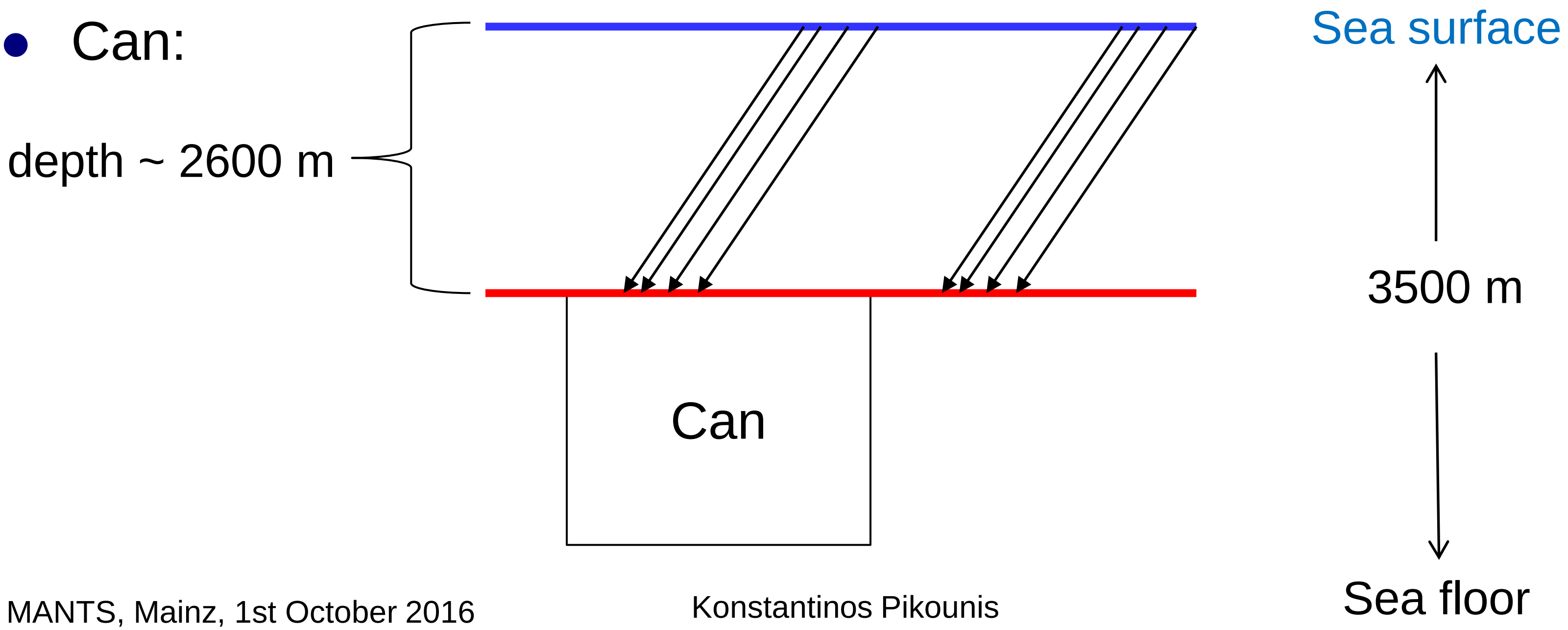
ν_μ prompt flux SIBYLL



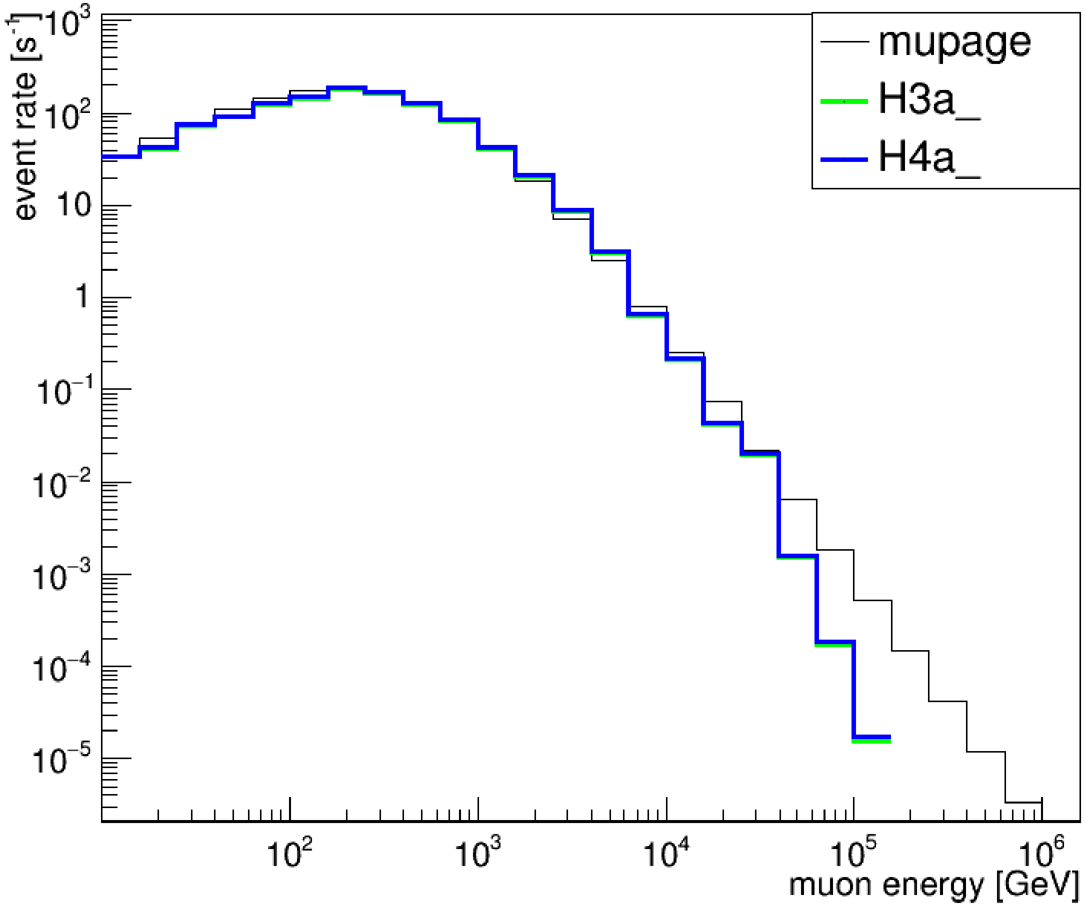
Atmospheric muons

- Mupage (MUon GEnerator from PArametric formulas) is the generator code used. Generates atmospheric muon bundles at the can.
  - Incomparable faster than a full CORSIKA simulation to the can.
  - Based on HEMAS and data from MACRO.
  - Prompt component is not included.
  - [arXiv:0802.0562v2]

- Can:



Muons at the Can: Energy Spectra

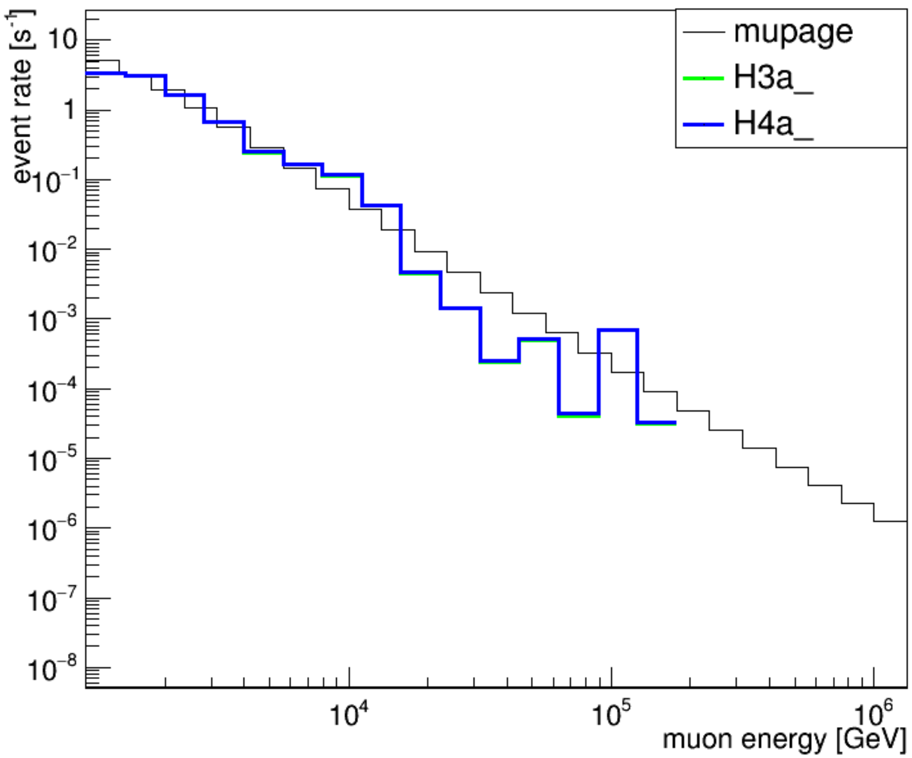


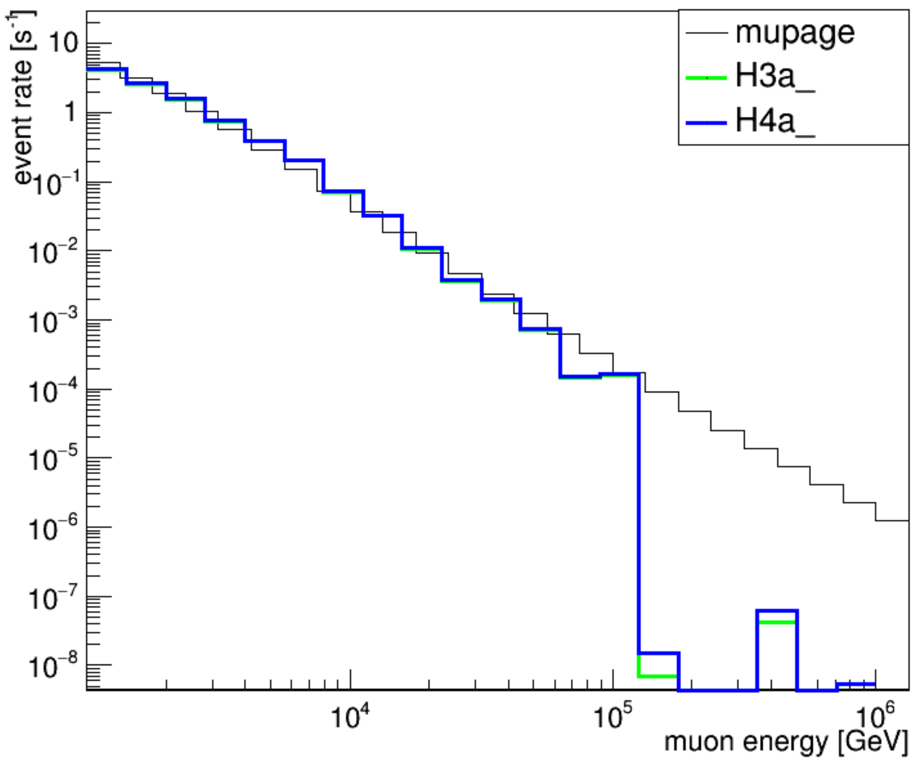
Energy spectrum of atmospheric muon bundles consisting only of **1 muon**

High energy interaction model: **SIBYLL**

Muons at the Can: Energy Spectra

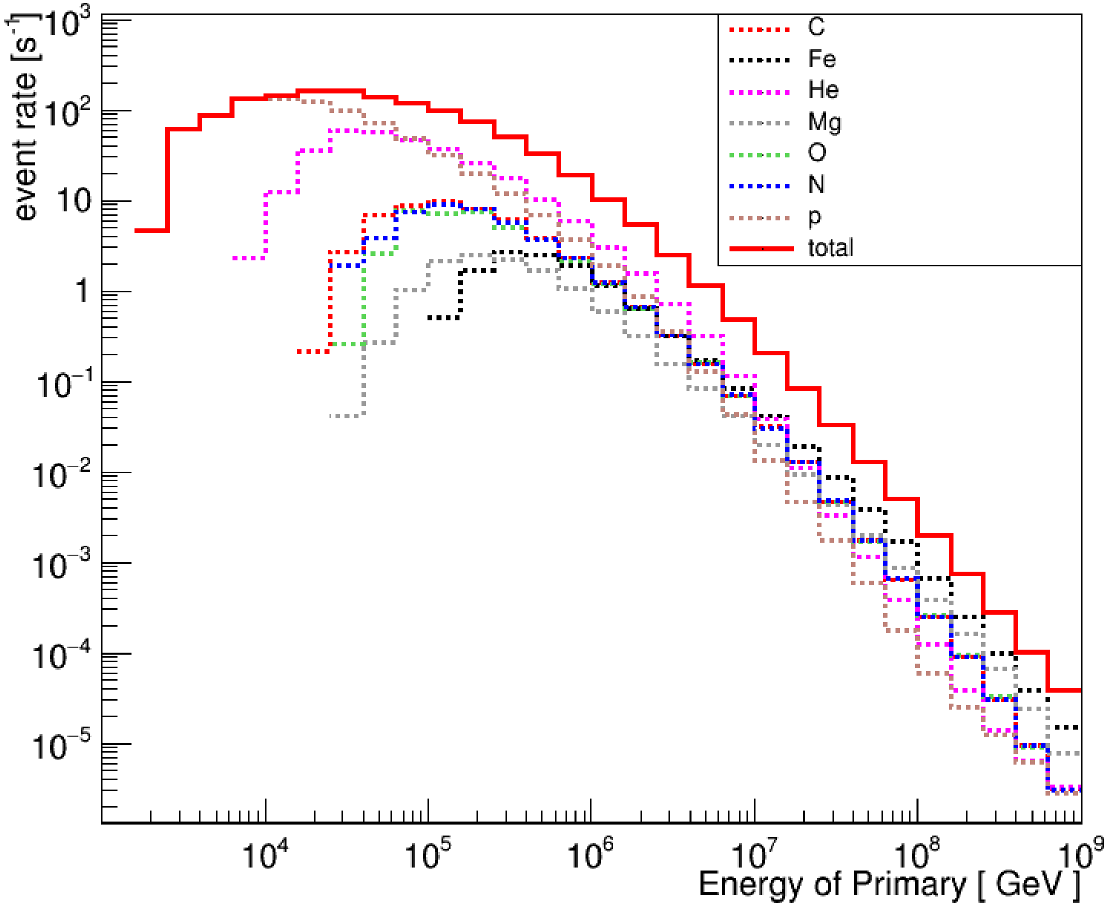
Energy spectrum of atmospheric muon bundles consisting only of **2 muons**





High Energy interaction models: **EPOS LHC** **SIBYLL**

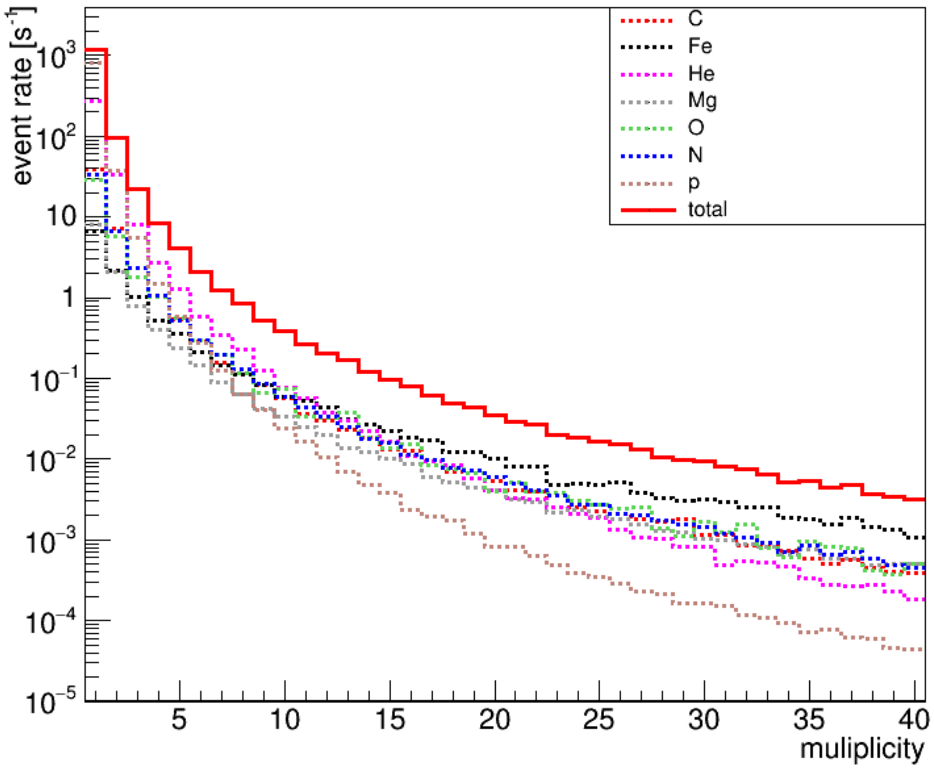
Muons at the Can

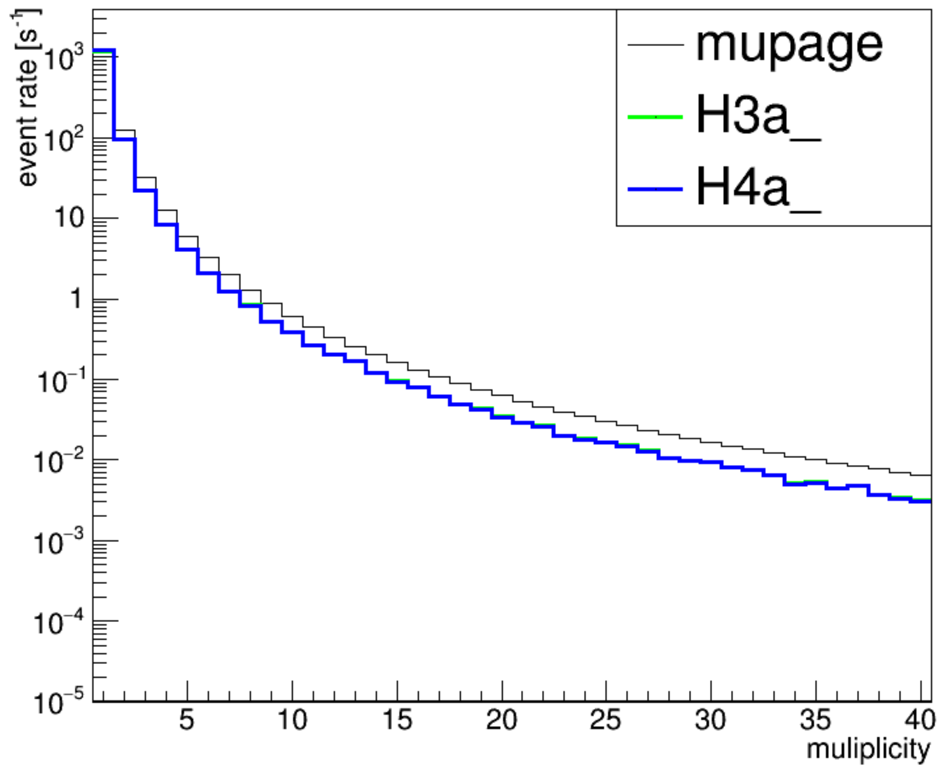


Energy spectrum of primaries that give muons reaching the can.

High Energy interaction model: **SIBYLL**

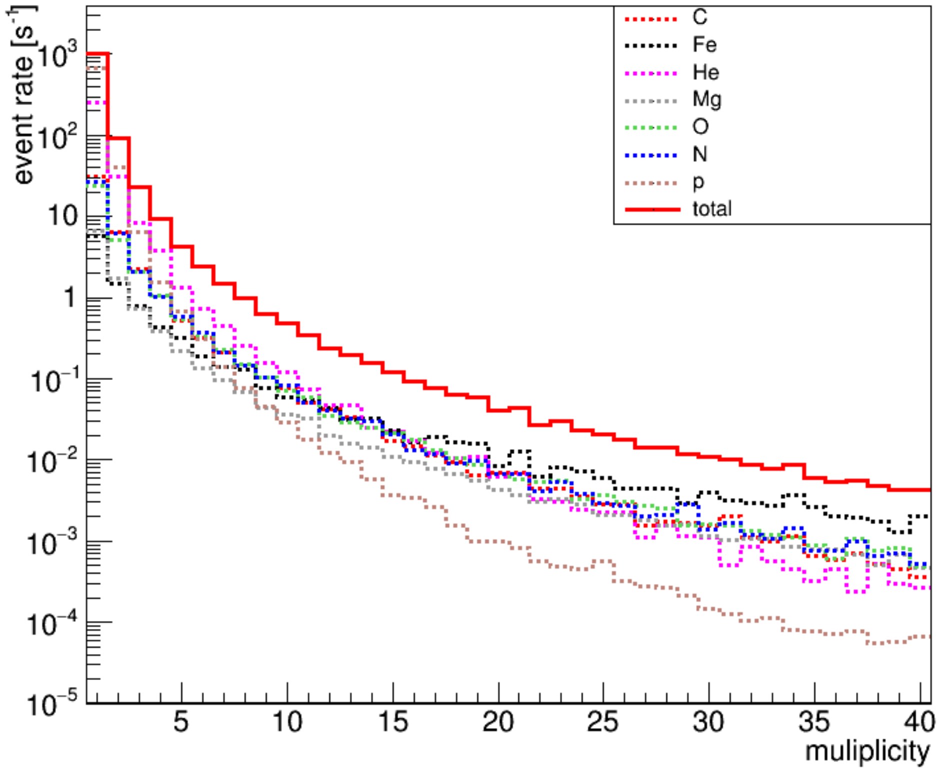
Muons at the Can: Multiplicity

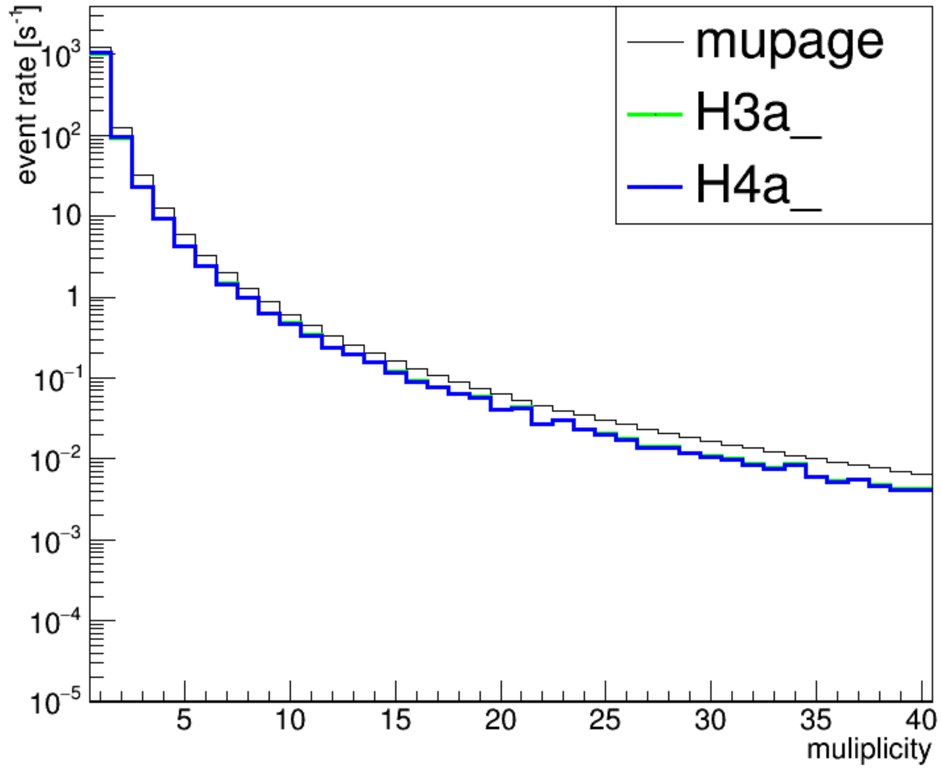




High energy interaction model: **SIBYLL**

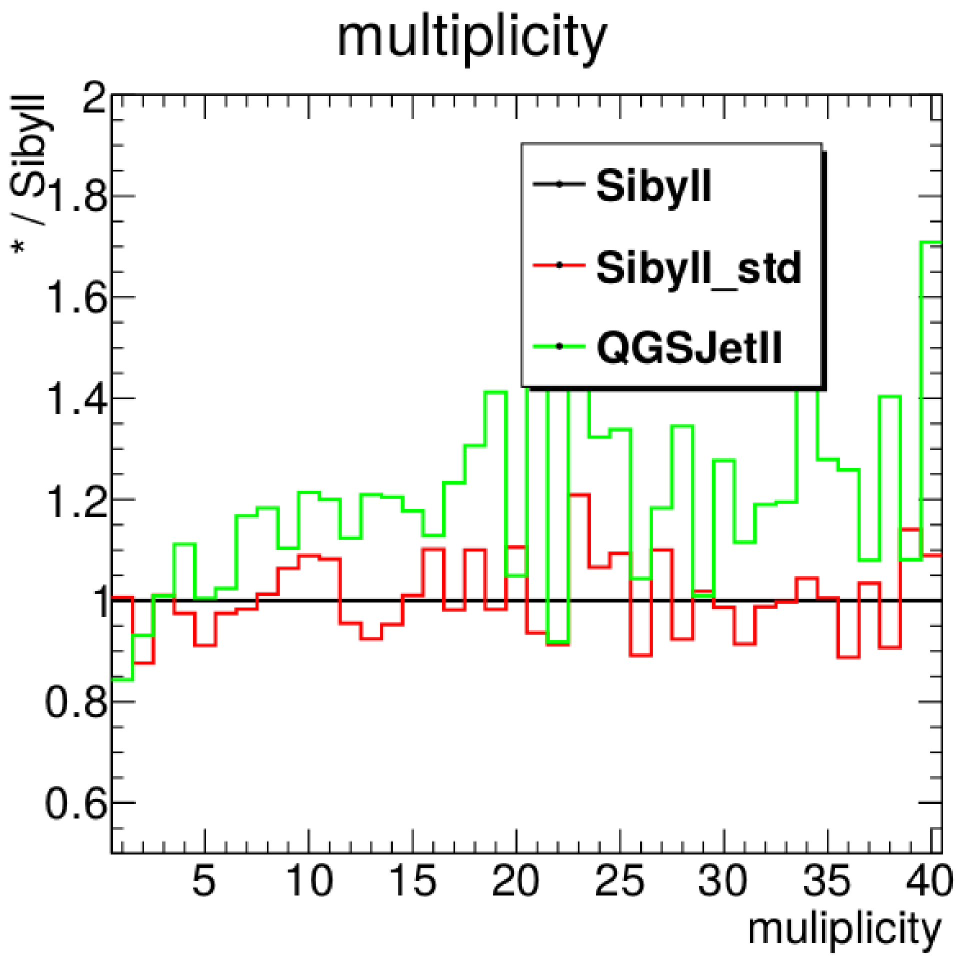
Muons at the Can: Multiplicity





High energy interaction model: **QGSJETII**

Muons at the Can: Different models of atmosphere

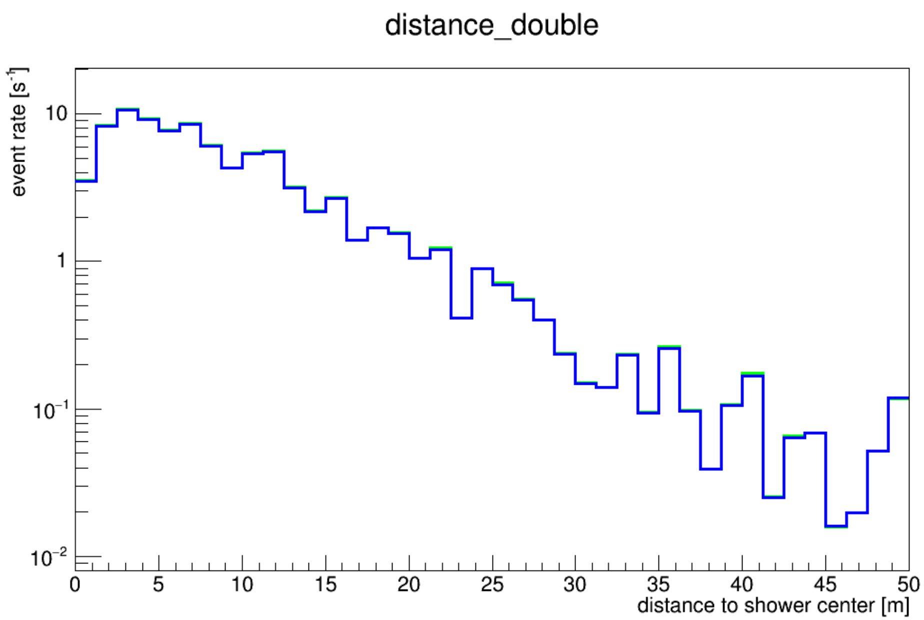


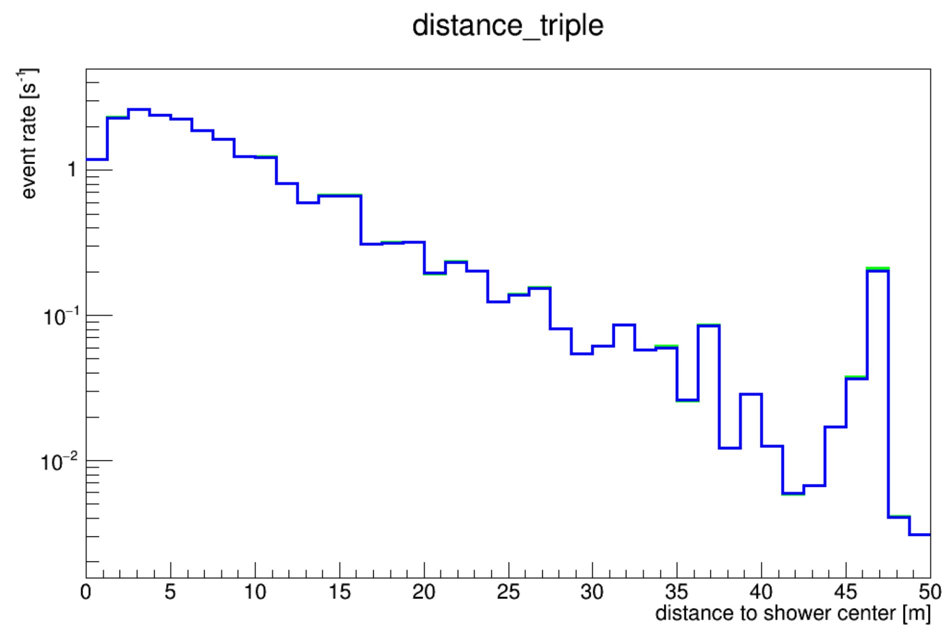
Comparison of different high energy models:
Sybill with model of the atmosphere customed to ARCA position.
Sybill with standard model of the atmosphere (U.S. Atmosphere parametrized by Linsley)
QGSJetII with model of the atmosphere customed to ARCA position.

All models normalized to **Sybill** model with atmospheric model customed to ARCA position.

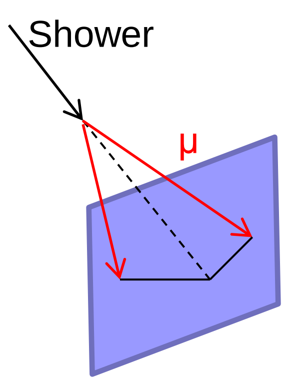
The differences induced by the different of atmospheric models is in the range of 20%

Muons at the Can: Lateral distance





High energy interaction model: **EPOS LHC**

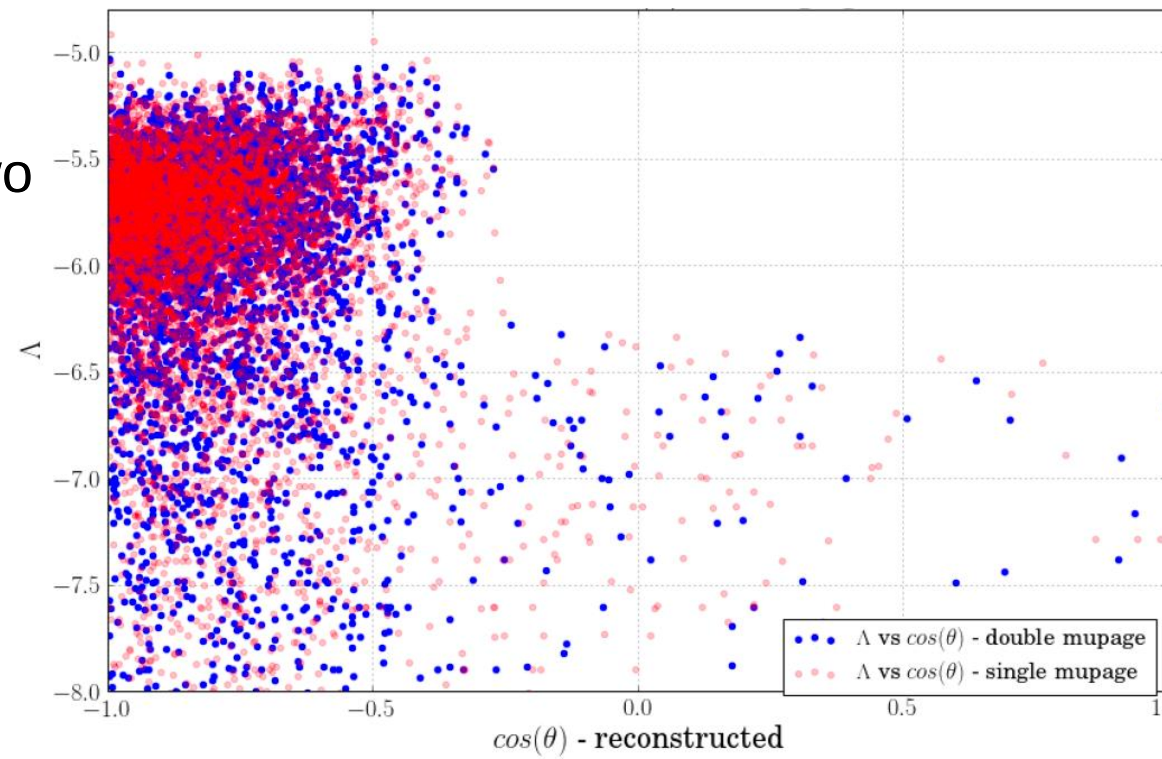


Plots by T.Heid

Reconstructing events with 2 muon bundles

- One atmospheric muon bundle per event.
- Events containing two different muon bundles randomly combined in a 10 μs window [2.9 yr livetime].

- No differences in the two distributions.
- After standard quality cuts (cuts in Λ), no misreconstructed “double” events left!



Plot by C.James

Asterics / Obelics

OBELICS (OBservatory E-environments LInked by common ChallengeS).

- Working package of the Astronomy ESFRI and Research Infrastructure Cluster (ASTERICS) funded by the European Commission's Horizon 2020 framework.
- In this framework 4 CORSIKA (1%) productions with different High energy interaction models were created.
  - Production done in Grid (as part of KM3NeT production)
  - Ready to deploy a full production (with the addition of Cherenkov).
- CORELib a C++ library for reading the CORSIKA outputs.
- Planed activities. ROAST(Root extensions for ASTronomy) Libraries :
  - containing coordinates of astrophysical objects.
  - for astrophysical coordinates transformations
  - containing parameterization of fluxes.

Coclusions / Outlook

- Five 1% productions were created. Comparisons of these productions to theoretical models and to existing simulations were performed.
- Before starting a full production these five 1% productions need to be studied more.
  - Differences in the atmospheric neutrino fluxes seem to depend more on the high energy hadronic interaction model than on the CR model.
  - Found less muon bundles with high multiplicity compared to mupage.
  - The energy and lateral distributions' shapes are similar compared to the ones produced by mupage. Further investigation of the lateral distributions is needed.
  - No conclusion can be drawn on the impact of the prompt component of muons at the can level due to insufficient statistics in high energies. Waiting for the full production.

- An additional CORSIKA production will be also created by Asterics. Also a lot of useful tools are being developed in the framework of Asterics.

Thank you!

Questions?

Back up

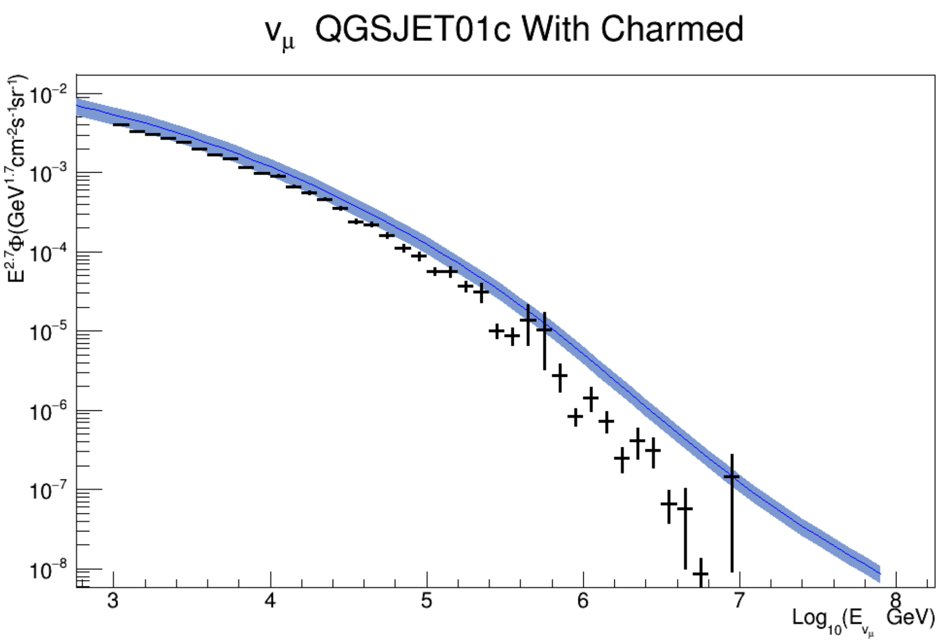
Chain of simulation

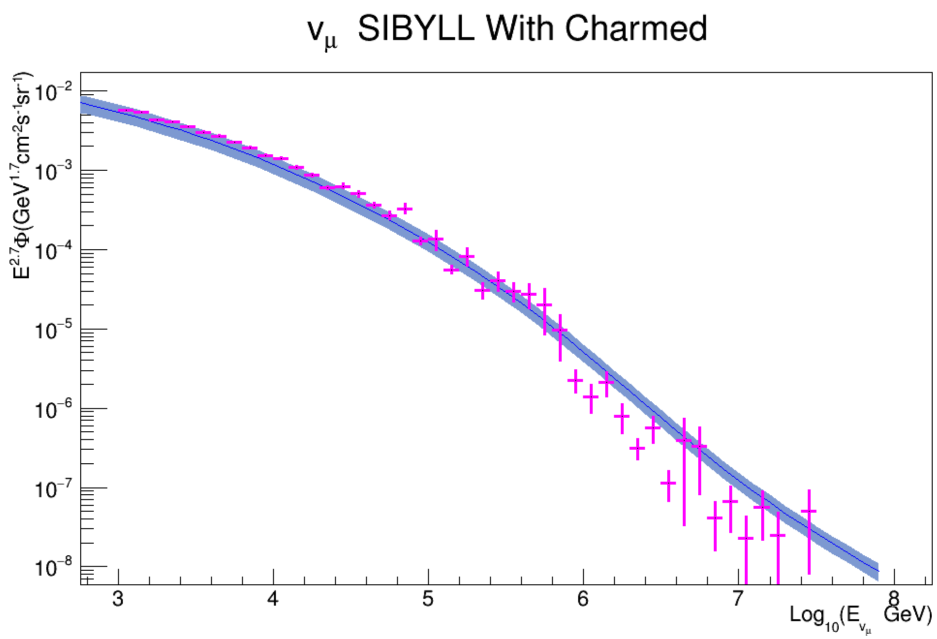
1) CORSIKA → neutrinos and muons at sea level
   - Evaluate fluxes at sea level by reading CORSIKA files.
2) PROPAgating muons to the can while evaluating energy losses with MUSIC. For neutrinos just a geometrical propagation.
   - Evaluate the muon fluxes at can level.
   - Compare the results by CORSIKA to productions of atmospheric muon bundles already in use.
3) Forcing one neutrino to interact from each shower. For each shower repeat this process for a few neutrinos selected appropriately. Creating the appropriate weights.
4) Simulate the response of the detector.

ν_μ Conventional flux / With CHARM

The conventional ν_μ flux as found by high energy models QGSJet01c and Sibyll with CHARM.

In the following plots the conventional neutrino fluxes are found by ν_μ that their mother particle is NOT a charmed particle

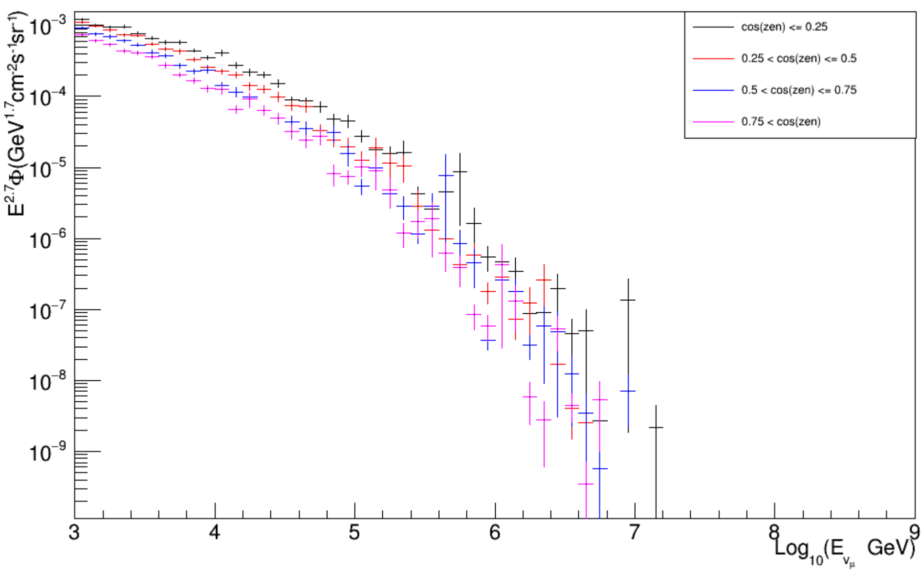




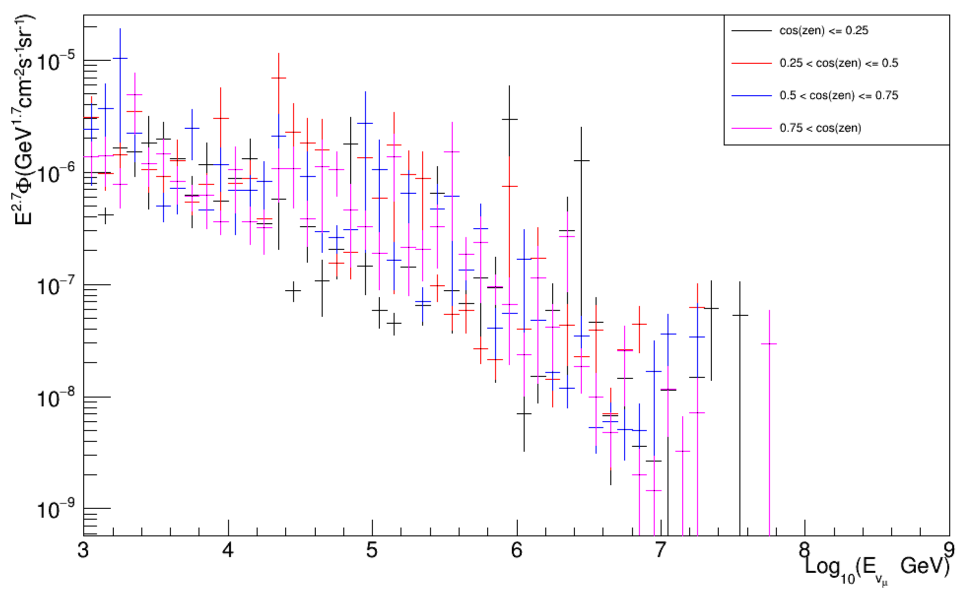
Honda flux ± 25%

ν_μ Zenith dependence

ν_μ QGSJET01c With Charmed Conventional



ν_μ QGSJET01c With Charmed Prompt

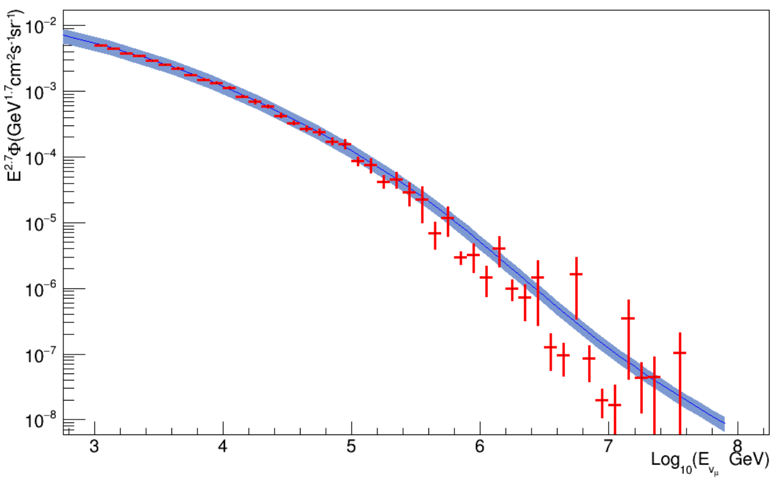


As expected lower conventional flux in higher zenith angles and no zenith dependence for the Prompt flux

CR model H4a

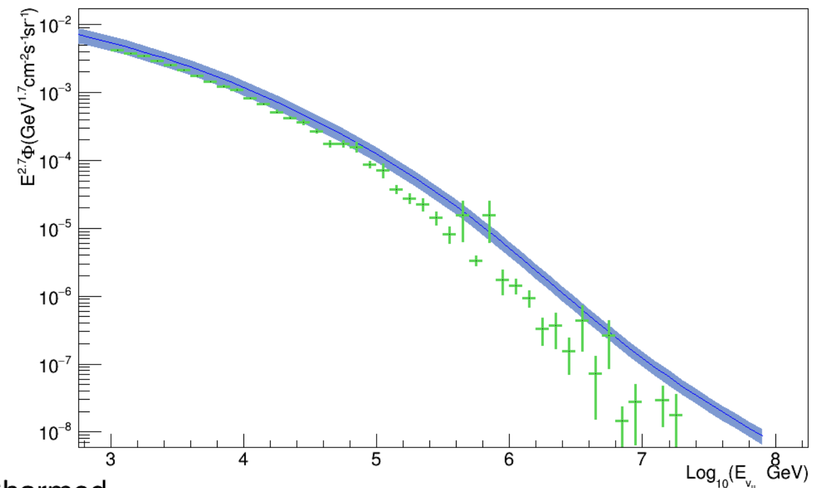
ν_μ Conventional flux / No CHARM

ν_μ EPOS No Charmed

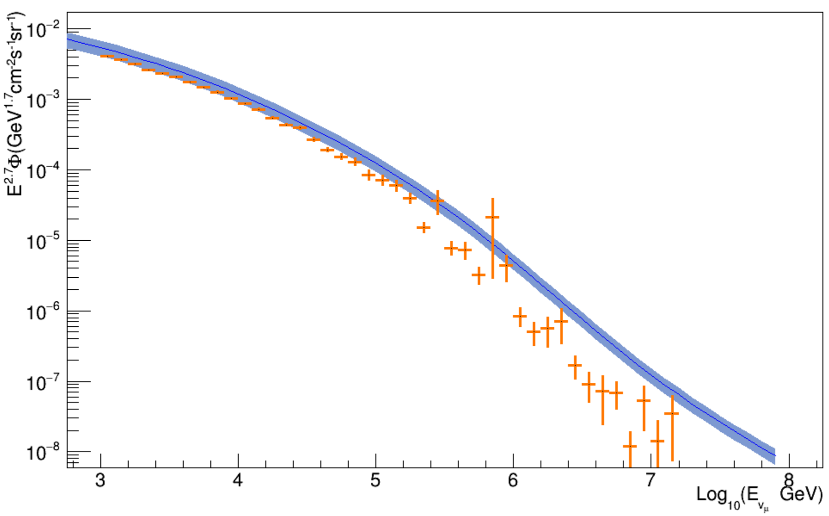


Honda
flux ± 25%

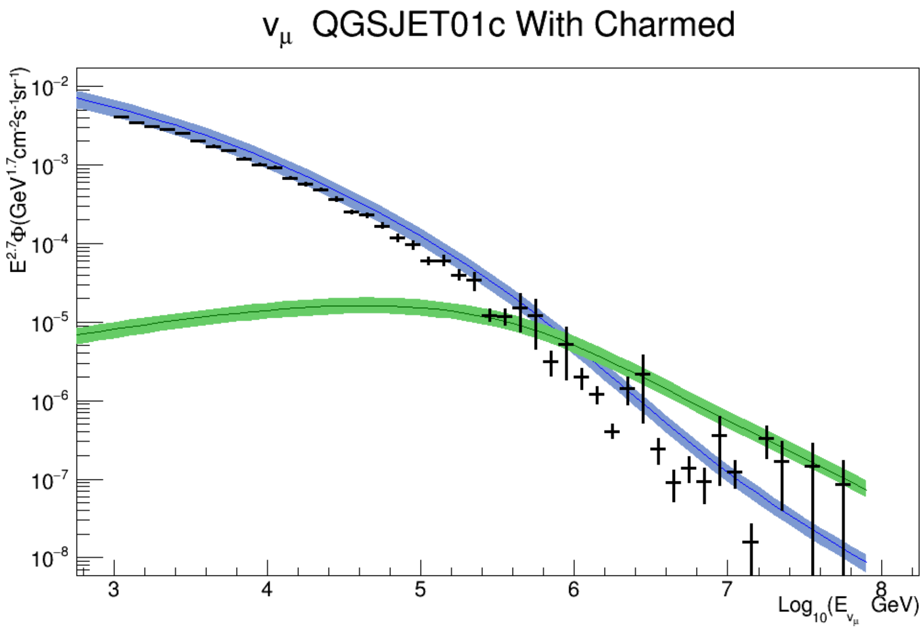
ν_μ QGSJET II No Charmed

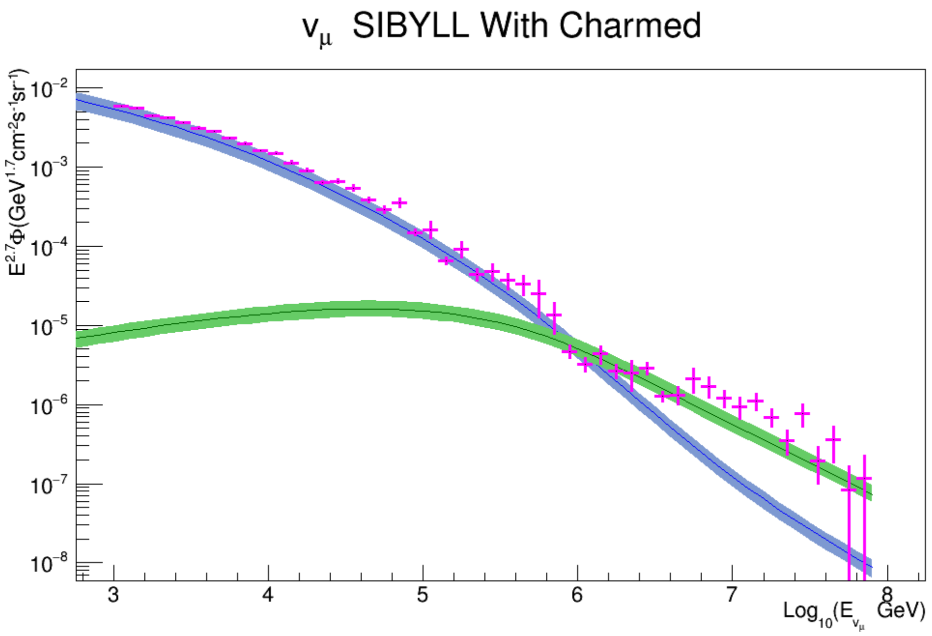


ν_μ QGSJET01c No Charmed



CR model H4a
ν_μ flux / With CHARM

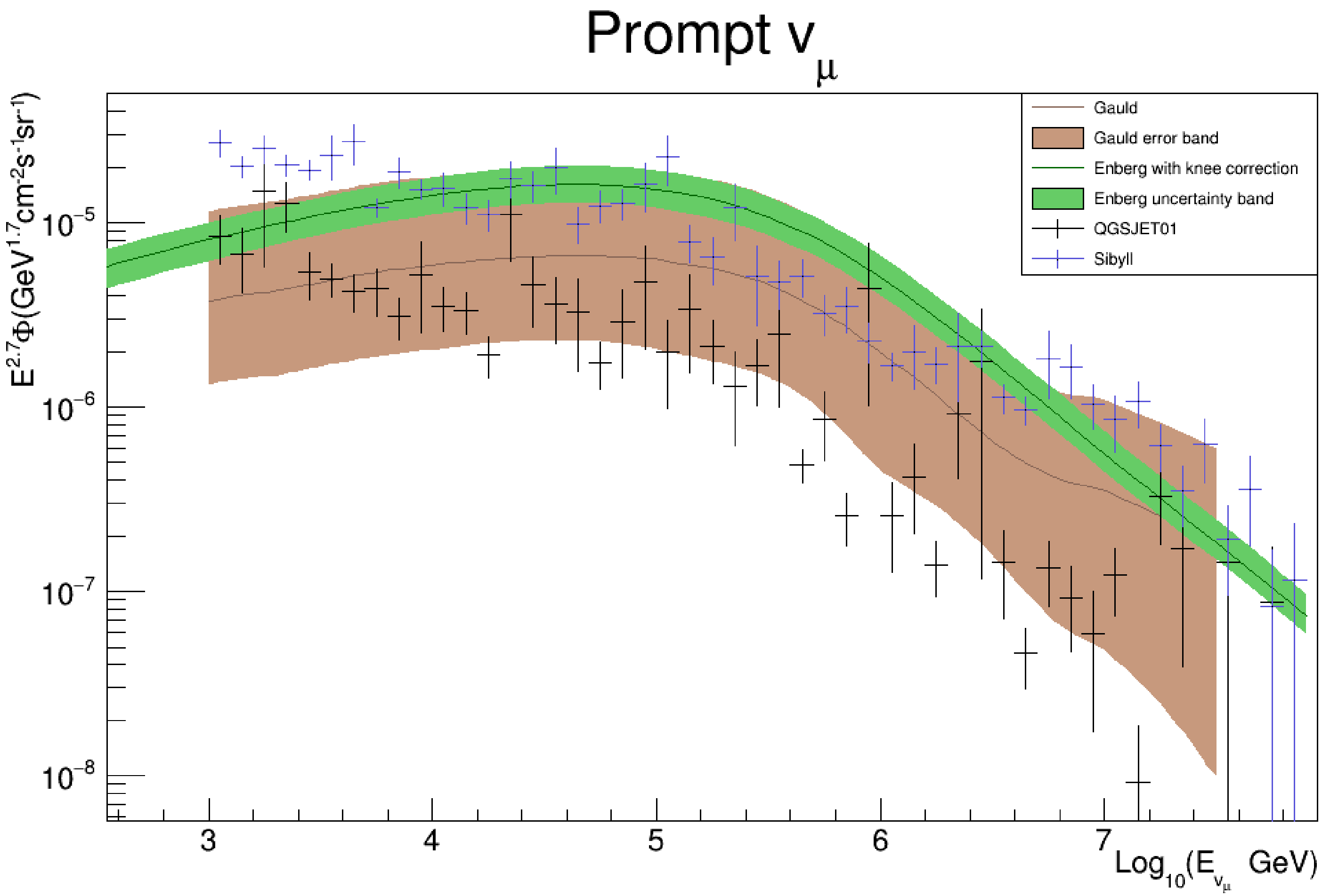




Honda
flux ± 25%

Enberg
flux ± 25%

CR model H4a ν_μ Prompt flux

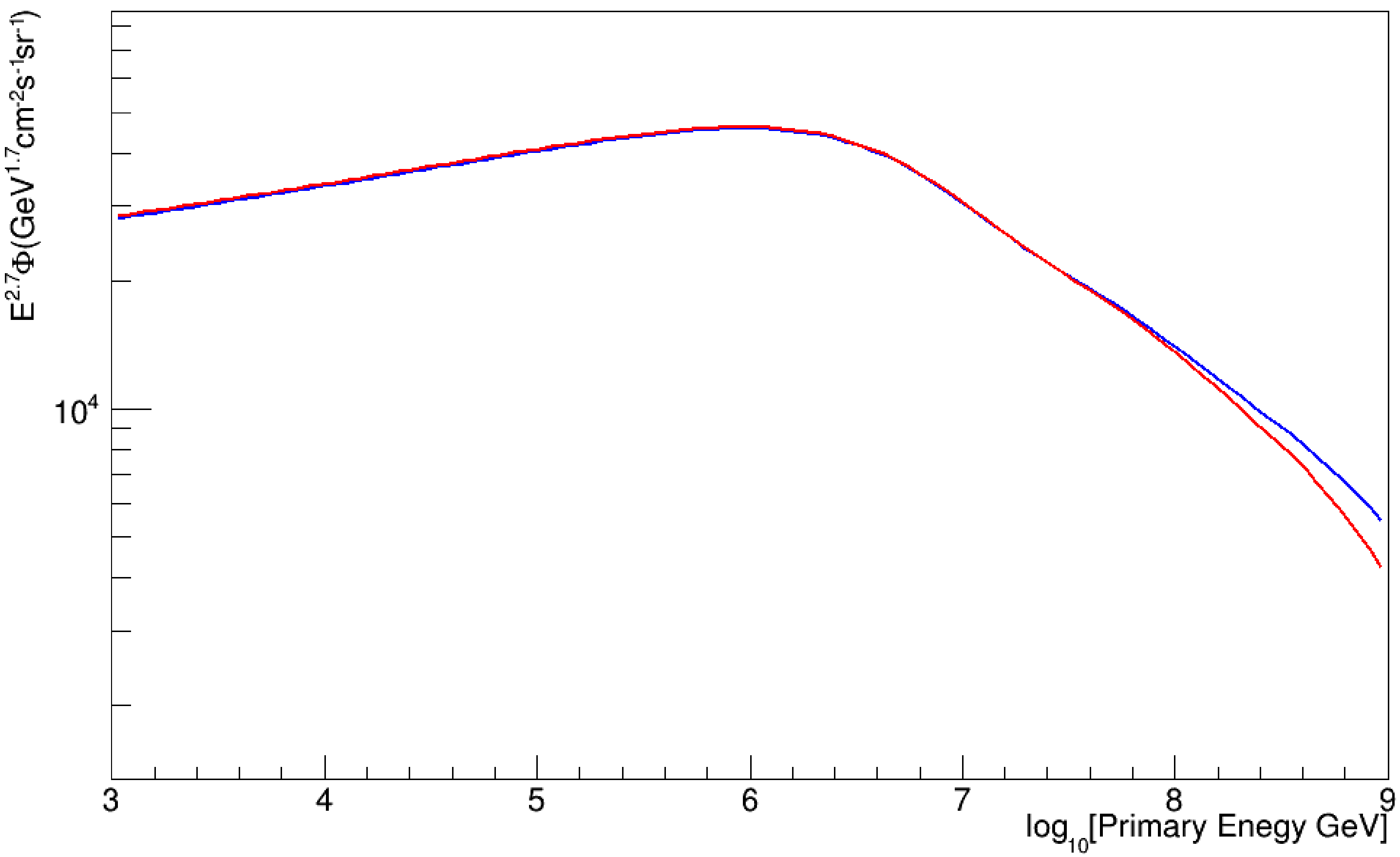


Enberg flux ± 25%

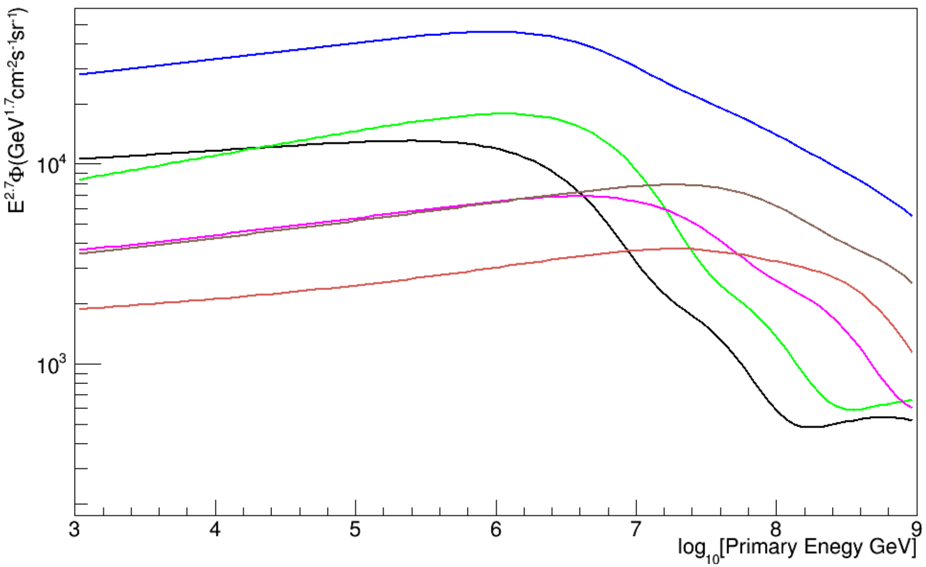
Prompt flux as calculated by Gauld at al. (2016)

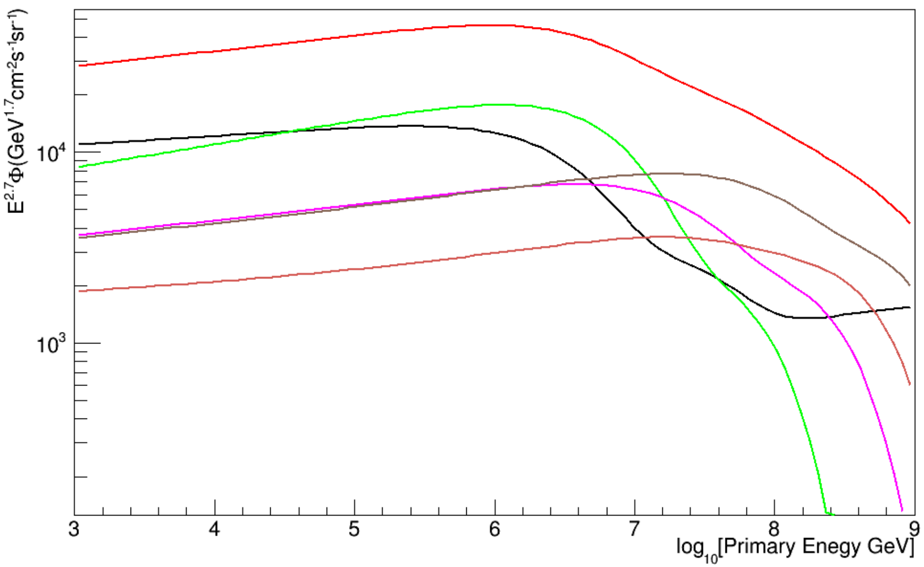
QGSJET0.1c was used in Gauld et al. calculations so a better agreement between the two is expected

Comparison of fluxes H3a and H4a



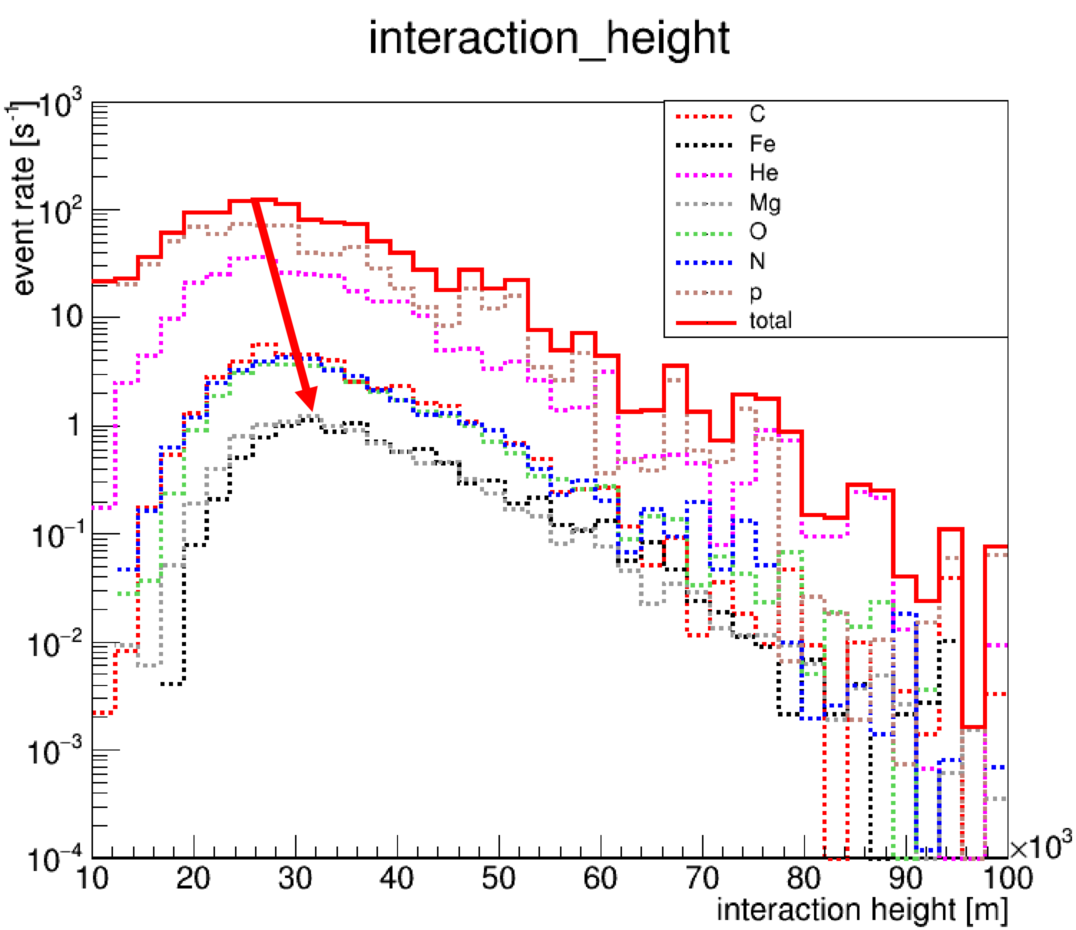
Comparison of fluxes H3a and H4a





Primaries: p, He, CNO, Mg, Fe

Interaction Height of Primaries

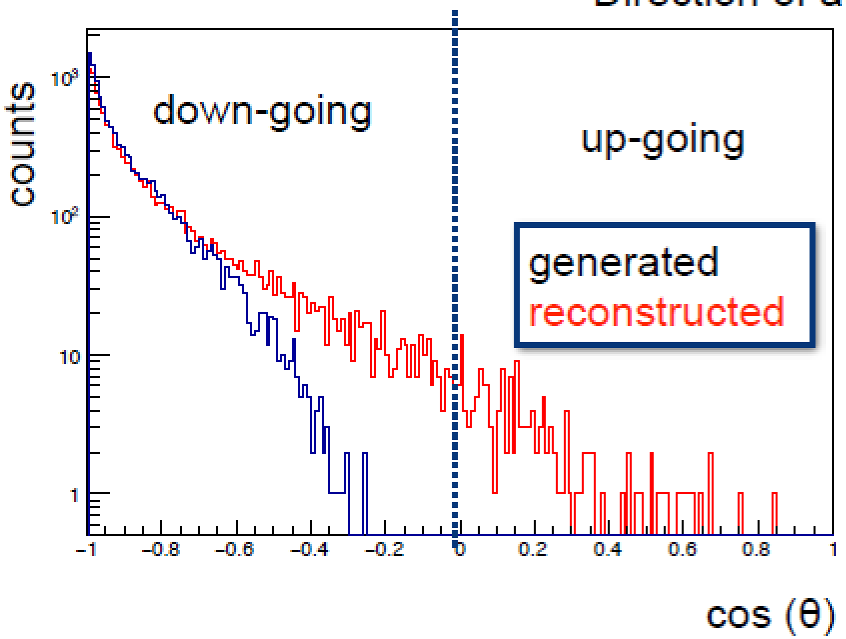


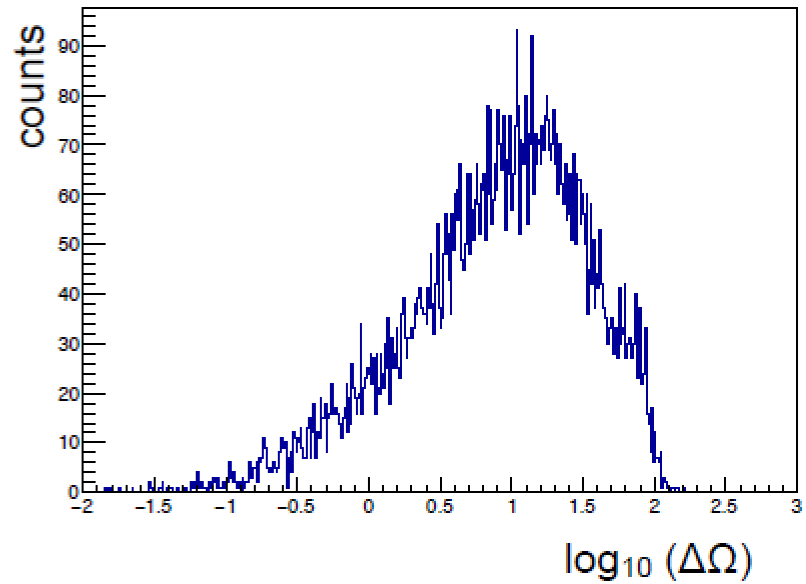
High energy interaction model: **QGSJETII**

Heavier the nuclei seem to interact higher in the atmosphere

ARCA 2 strings Reconstruction performance

Direction of atmospheric muons



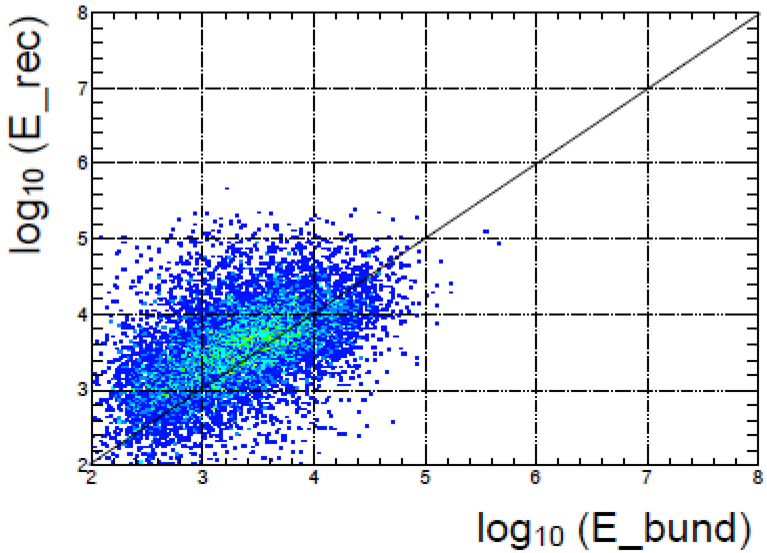


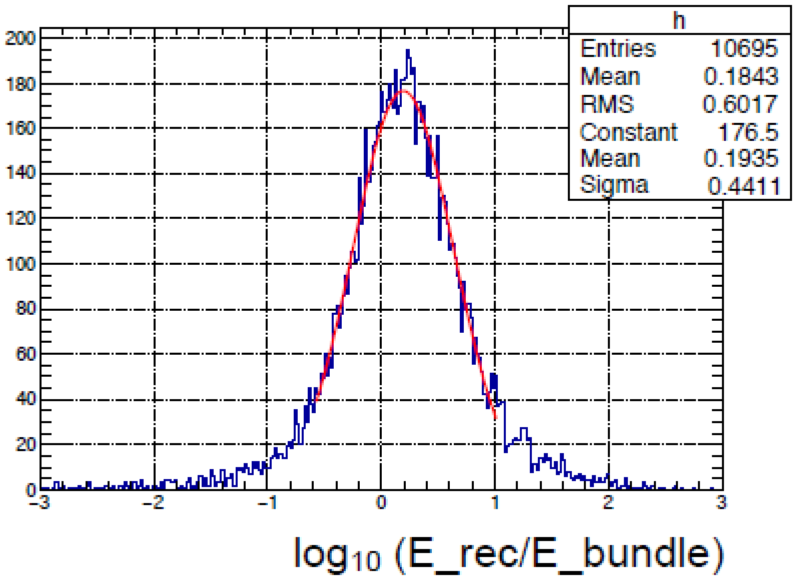
ΔΩ is the angle between the reconstructed track and the direction of the muon bundle

Resolution about 10° (no cut applied)

ARCA 2 strings
Reconstruction performance

Energy of atmospheric muons





Energy resolution 44% (cut not applied)