Potential measurement of the primary cosmic-ray proton spectrum between 40 TeV and a few hundred TeV with the Tibet hybrid experiment (Tibet-III + MD)

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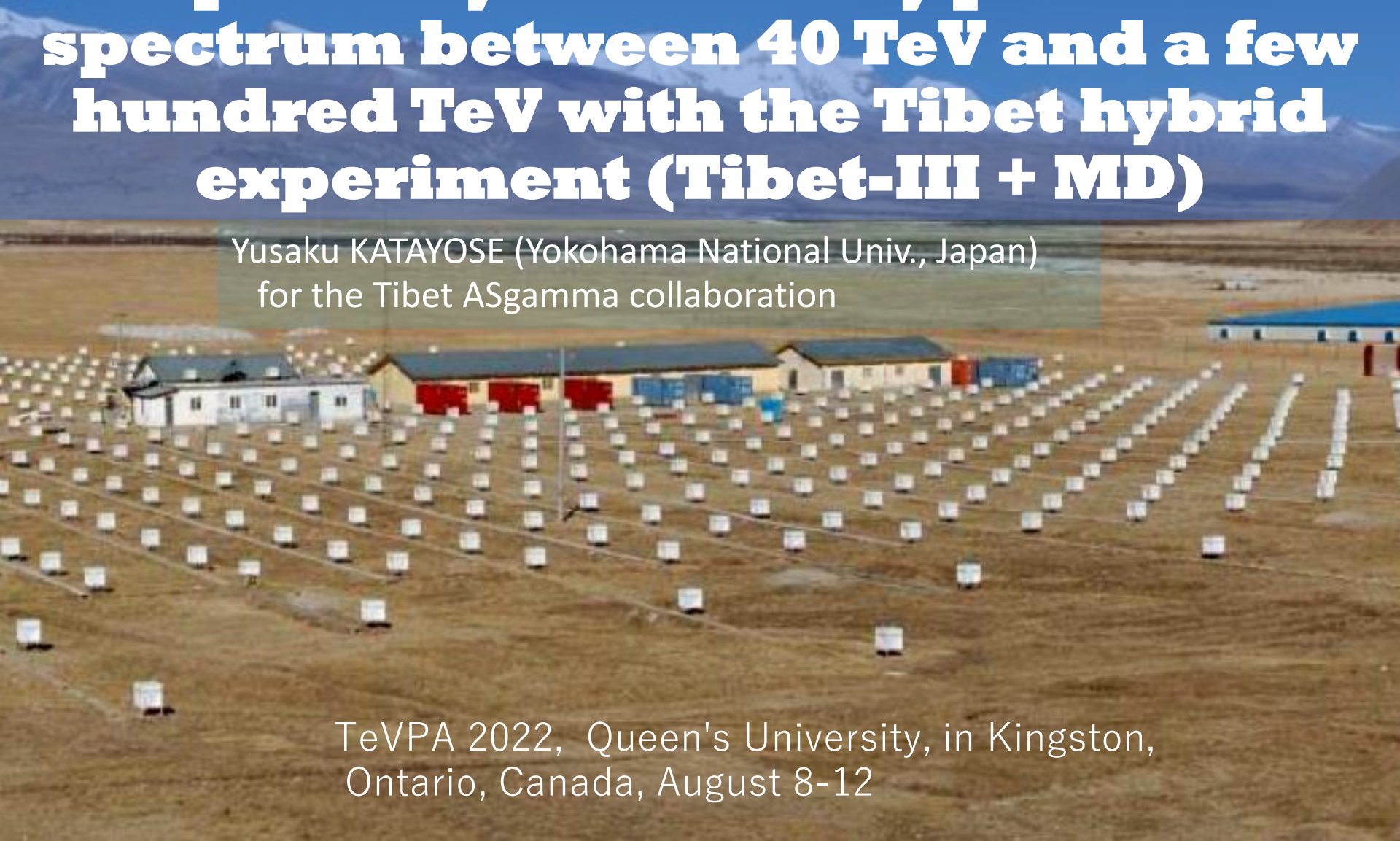
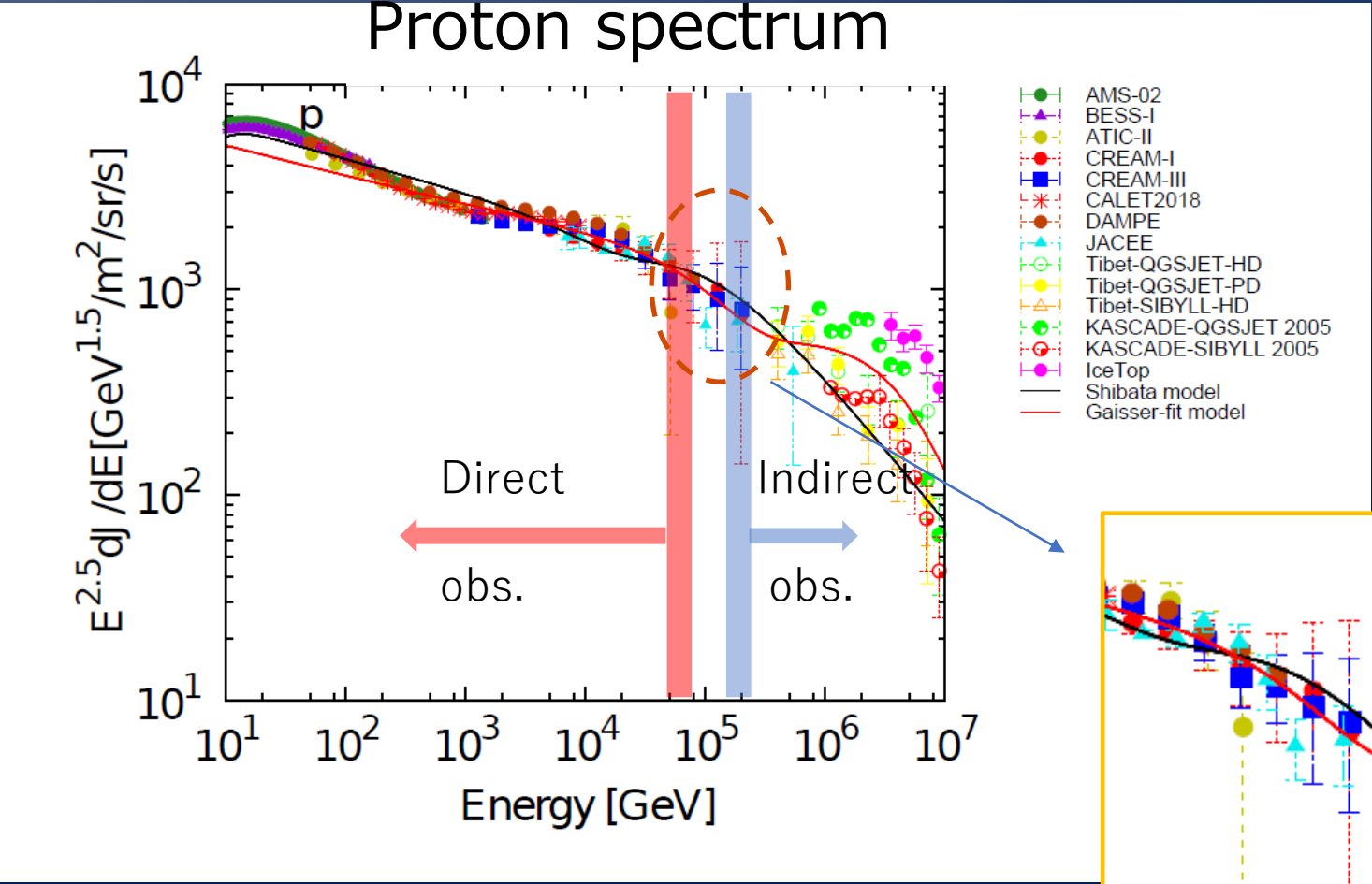
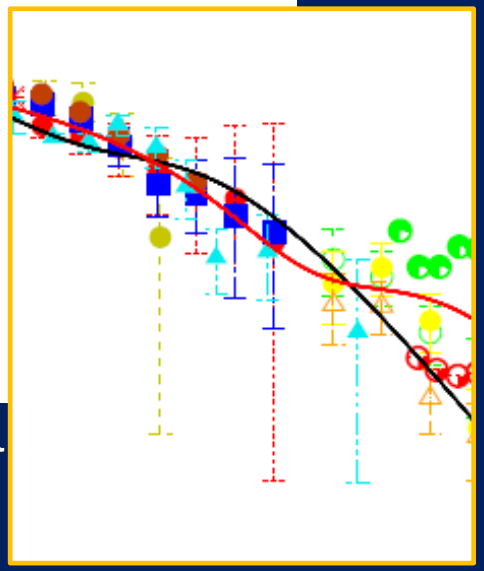
for the Tibet ASgamma collaboration



TeVPA 2022, Queen's University, in Kingston, Ontario, Canada, August 8-12

Introduction





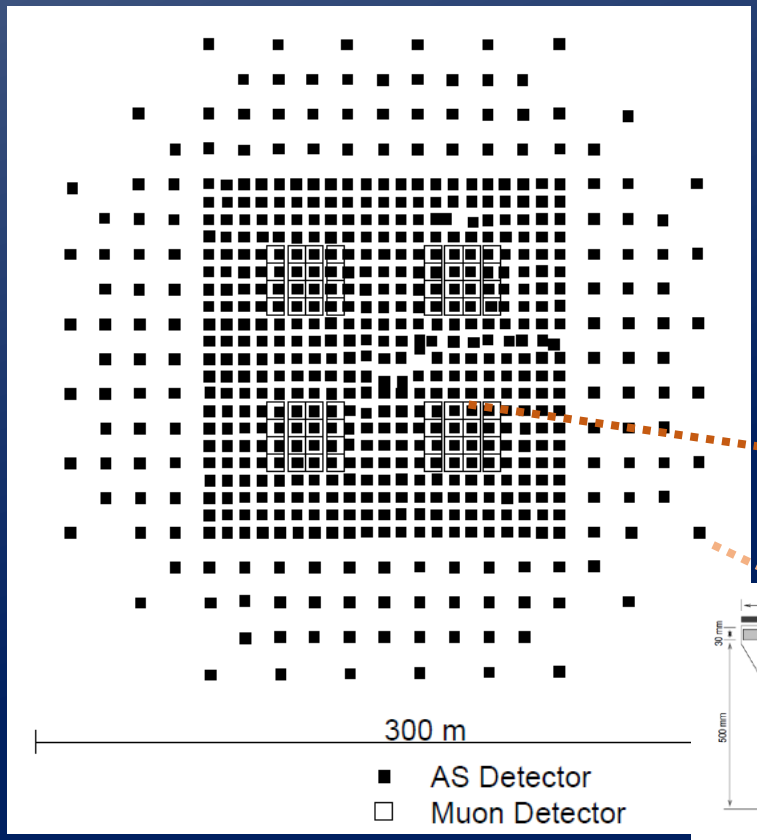
→ Proton measurement with large detection area using Tibet-III and MD

Content of this talk:

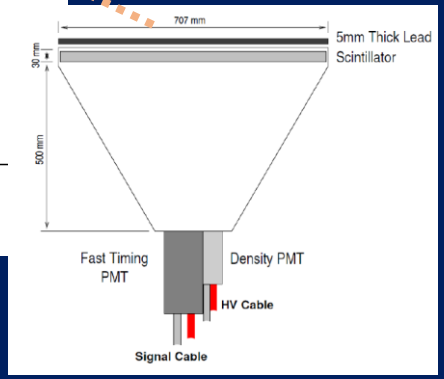
Method of proton spectrum measurement and its performance

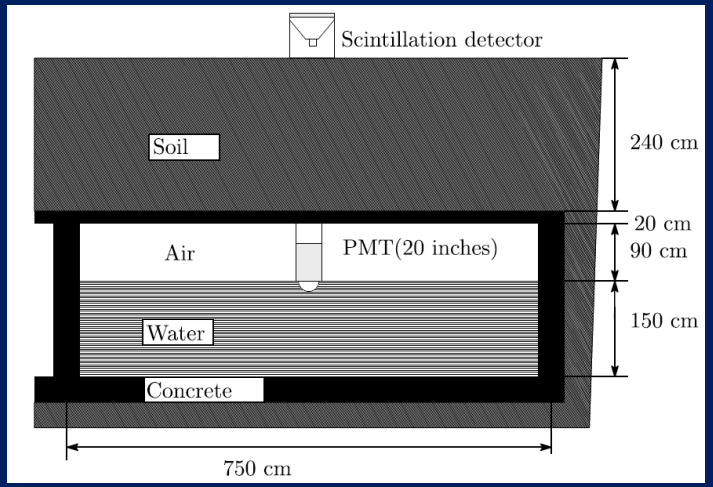
Tibet-III and MD

Tibet-III(Surface detector array)
: Energy, direction of AS



MD(64 water Cherenkov pools, 3,400 ㎡)
: Number of muons in a AS
→ proton selection





MC simulation of air shower and detector response

1. Air shower generation

CORSIKA Ver. 7.6400

Three Interaction models
- SIBYLL 2.3c +FLUKA 2011.2x
- QGSJETII-04 +FLUKA 2011.2x
- EPOS LHC v3400 +FLUKA 2011.2x

Two Cosmic-ray composition models

6 combinations

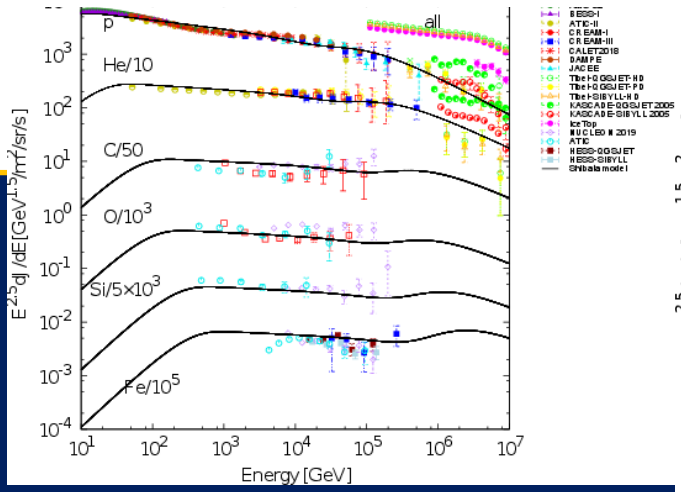
2. Detector response

Geant4.10.02

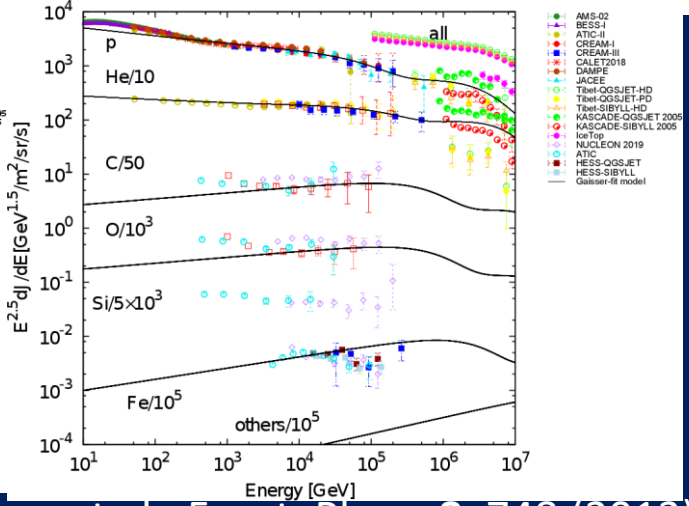
Tibet-III:
- Charged particle number density
- Hit timing

MD: Number of muons

Shibata model
(Heavy dominant)



Gaisser-fit model
(He dominant)



M. Shibata et al., ApJ, **716**, 1076 (2010). T.K. Gaisser et al., Front. Phys., **8**, 748 (2013).

MC data analysis with Tibet-III

Selection of criteria for reconstructed shower events

(1) Any 4 detectors < 600 ns

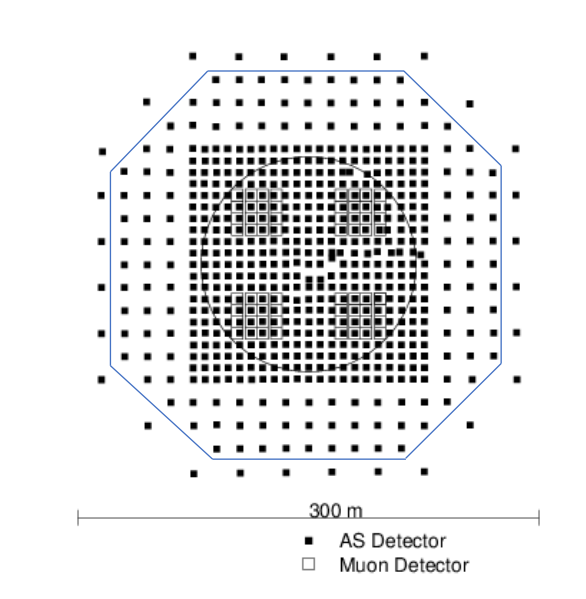
(2) At least 4 detectors with $\rho \geq 3.5$ /m^2

(3) 5 or more of the top 6 detectors with the highest number of detected particles are contained in the inner detectors.

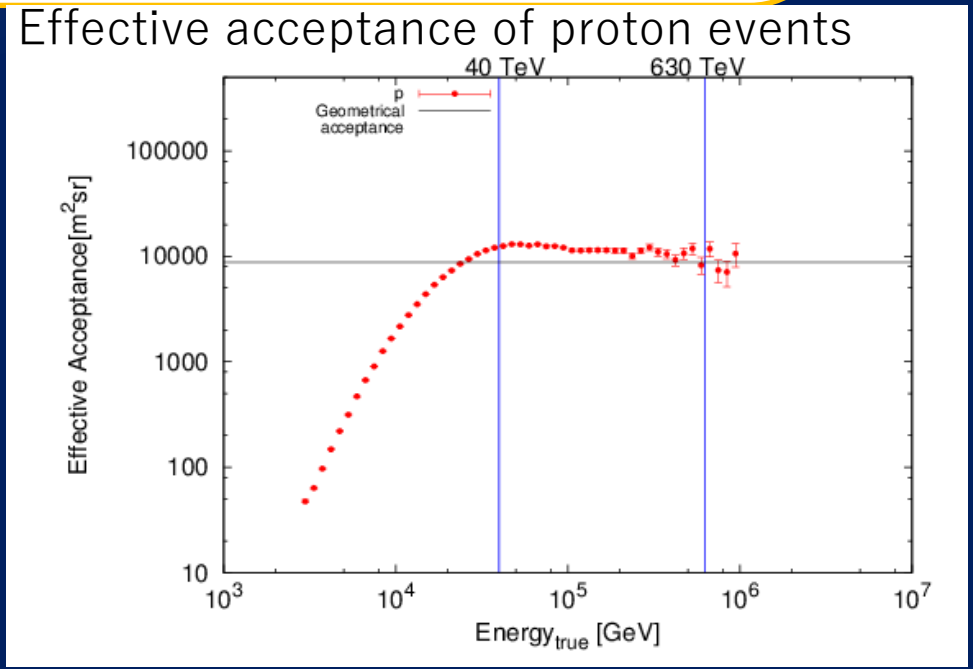
(4) The location of the air-shower core < 70 m from the array center

(5) The residual error from the air shower front < 1.0 m.

(6) The zenith angle : sec θ < 1.1.

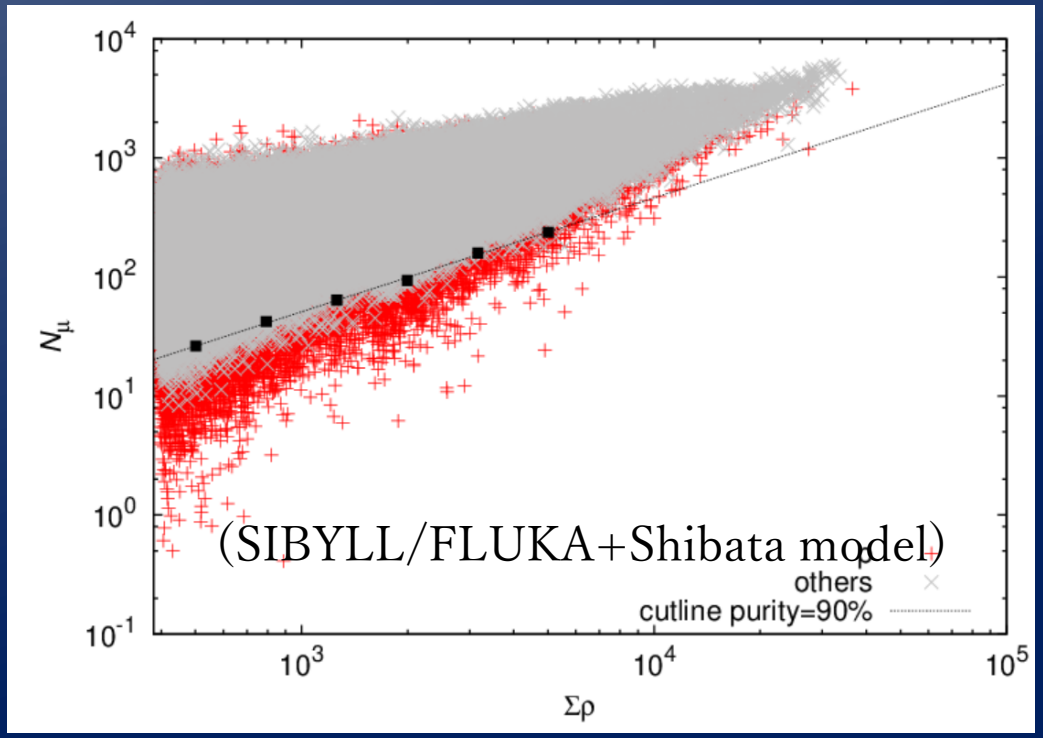


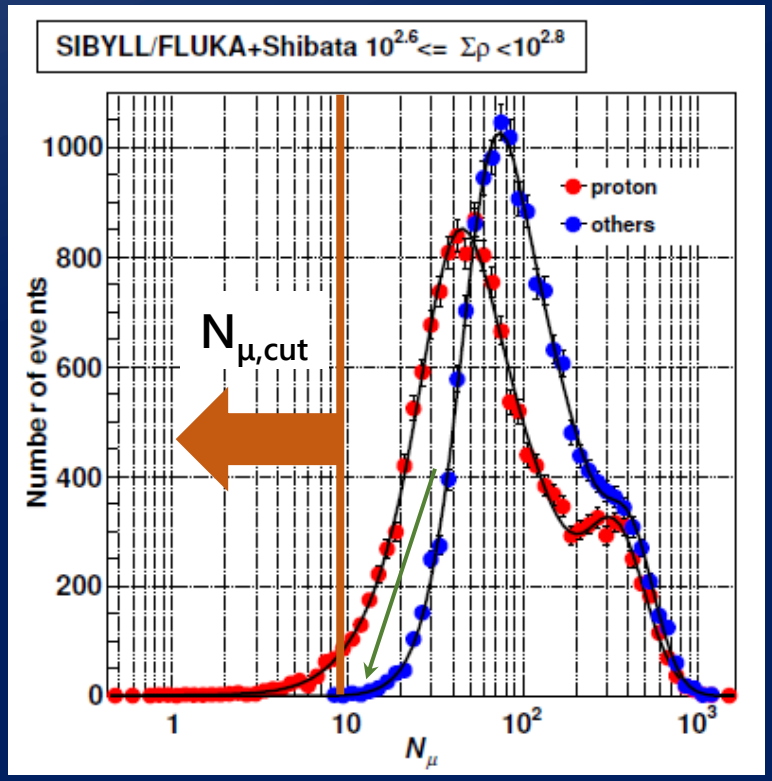
Effective acceptance of proton events



Proton selection with MD

Sum of charged particle number density($\sum \rho$)
vs
Number of muons(N_μ)



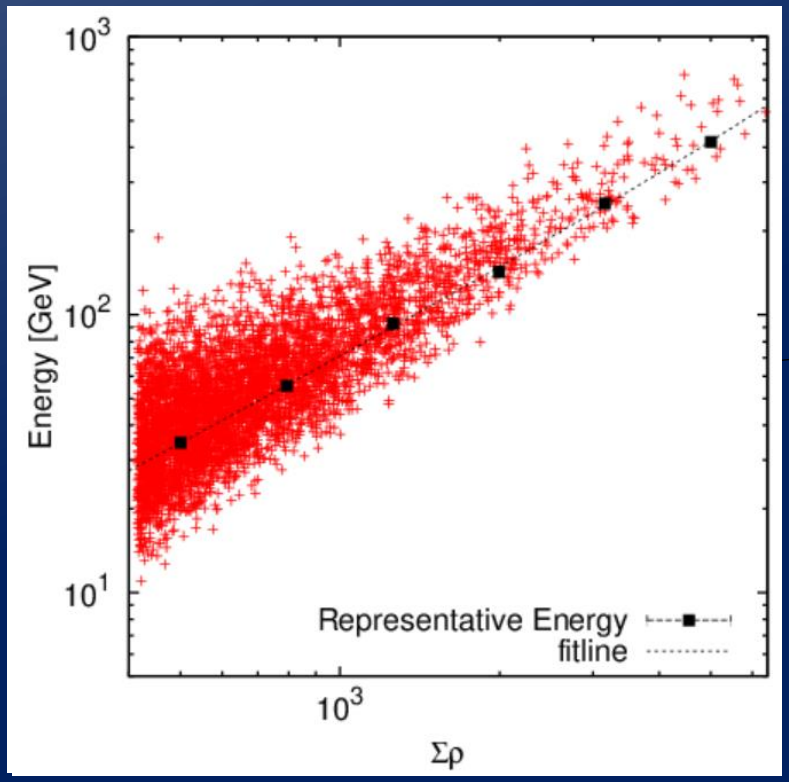


Muon-number-cut condition

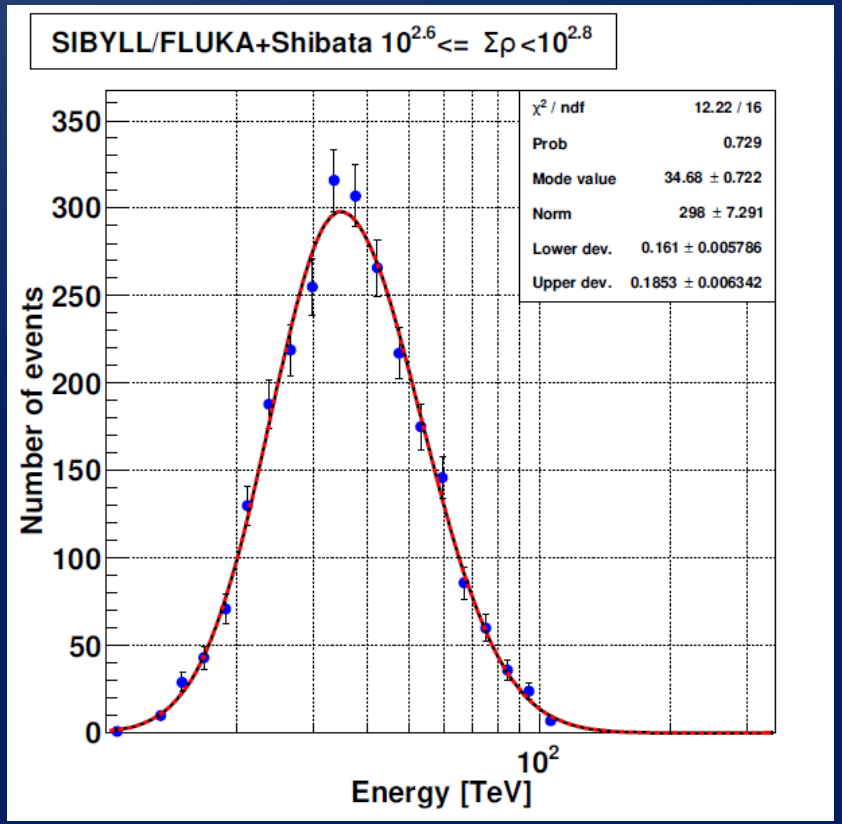
-> proton selection with a purity of 90%

Results:
Energy determination and resolution

Energy distribution
of the proton-like events



(SIBYLL/FLUKA+Shibata model)



$E_{rep} = 34.7$ TeV

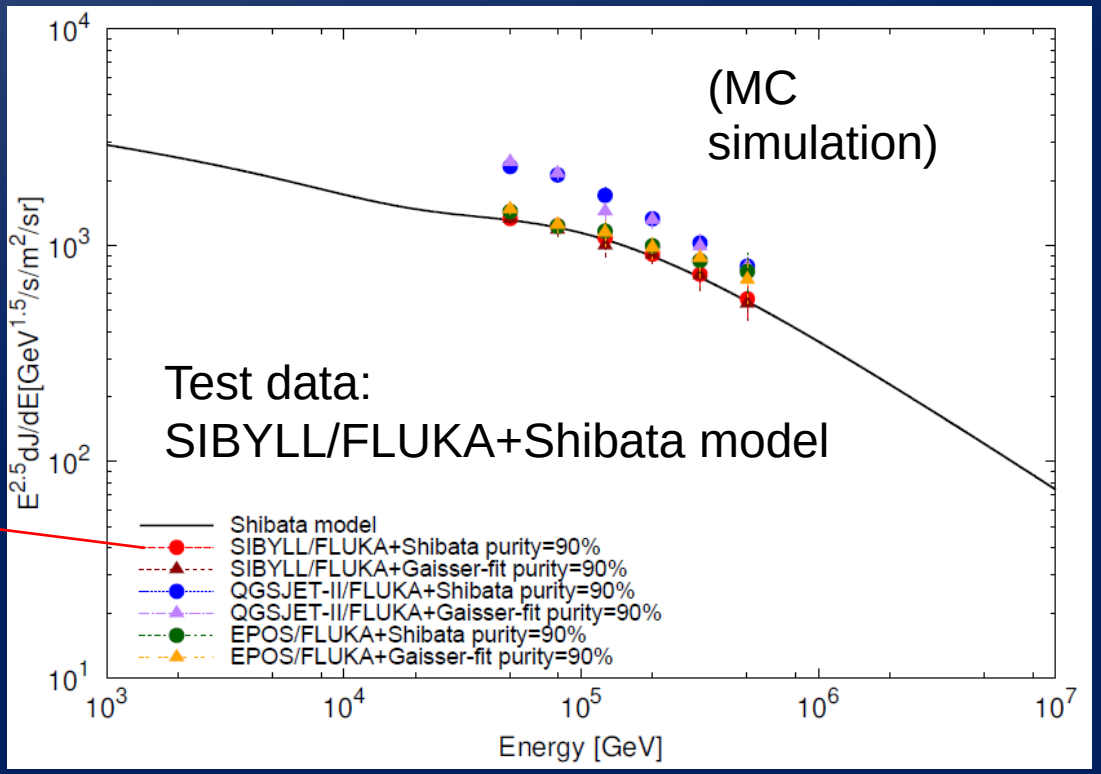
$E_{res}^{upper} = 53\%$

$E_{res}^{lower} = 30\%$

Results: Reconstructed energy spectrum of protons (MC simulation)

Comparison of 6 combinations of 2 CR composition models and 3 interaction models

Statistics:
Leftmost bin:
1413 events
$\rightarrow T_{exp} = 8.4\ hours$
Rightmost bin:
58 events
$\rightarrow T_{exp} = 28.4\ hours$



Systematic uncertainty of proton flux
due to CR composition model dependence < 10 %
due to interaction model dependence ± 37 % @ 50 TeV

Summary

We developed a method for measuring
the proton spectrum using data obtained
by a hybrid experiment of Tibet-III and MD.

- Proton spectrum can be measured
  in the Energy range of 40–630 TeV
  by selecting proton-like events with 90 % purity.
- Systematic error: ± 37 % @ **50 TeV**

- The experiment has been accumulating data
  since 2015

Experimental data analysis is currently underway.