Hadronic interactions and EAS muon multiplicity investigated with the new Tibet hybrid experimental muon data

Liuming Zhai for **The Tibet ASγ Collaboration**

National Astronomical Observatories， Chinese Academy of Sciences

zhailiuming@nao.cas.cn

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M. Amenomori,[1] Y.-W. Bao,[2] X. J. Bi,[3] D. Chen,[4] T. L. Chen,[5] W. Y. Chen,[3] Xu Chen,[3] Y. Chen,[2] Cirennima,[5] S. W. Cui,[7] Danzengluobu,[5] L. K. Ding,[3] J. H. Fang,[3,6] K. Fang,[3] C. F. Feng,[8] Zhaoyang Feng,[3] Z. Y. Feng,[9] Qi Gao,[5] Q. B. Gou,[3] Y. Y. Guo,[3] Y. Q. Guo,[3] H. H. He,[3] Z. T. He,[7] K. Hibino,[10] N. Hotta,[11] Haibing Hu,[5] H. B. Hu,[3] J. Huang,[3] H. Y. Jia,[9] L.Jiang,[3] H.-B. Jin,[4] F. Kajino,[12] K. Kasahara,[13] Y. Katayose,[14] C. Kato,[15] S. Kato,[16] K. Kawata,[16] W. Kihara,[15] Y. Ko,[15] M. Kozai,[17] Labaciren,[5] G. M. Le,[18] A. F. Li,[19,8,3] H. J. Li,[5] W. J. Li,[3,9] Y.-H. Lin,[3,6] B. Liu,[2] C. Liu,[3] J. S. Liu,[3] M. Y. Liu,[5] W. Liu,[3] Y.-Q. Lou,[20] H.Lu,[3] X. R. Meng,[5] H. Mitsui,[14] K. Munakata,[15] H. Nakada,[14] Y. Nakamura,[3] H. Nanjo,[1] M. Nishizawa,[21] M. Ohnishi,[16] T. Ohura,[14] S. Ozawa,[22] X. L. Qian,[23] X. B. Qu,[24] T. Saito,[25] M. Sakata,[12] T. K. Sako,[16] Y. Sengoku,[14] J. Shao,[3,8] M. Shibata,[14] A. Shiomi,[26] H. Sugimoto,[27] W. Takano,[10] M. Takita,[16] Y. H. Tan,[3] N. Tateyama,[10] S. Torii,[28] H. Tsuchiya,[29] S. Udo,[10] H. Wang,[3] H. R. Wu,[3] L. Xue,[8] K. Yagisawa,[14] Y. Yamamoto,[12] Z. Yang,[3] Y. Yokoe,[16] A. F. Yuan,[5] L. M. Zhai*,[4] H. M. Zhang,[3] J. L. Zhang,[3] X. Zhang,[2] X. Y. Zhang,[8] Y. Zhang,[3] Yi Zhang,[3] Ying Zhang,[3] S. P. Zhao [3] Zhaxisangzhu,[5] and X. X. Zhou[9]

(The Tibet ASγ Collaboration)

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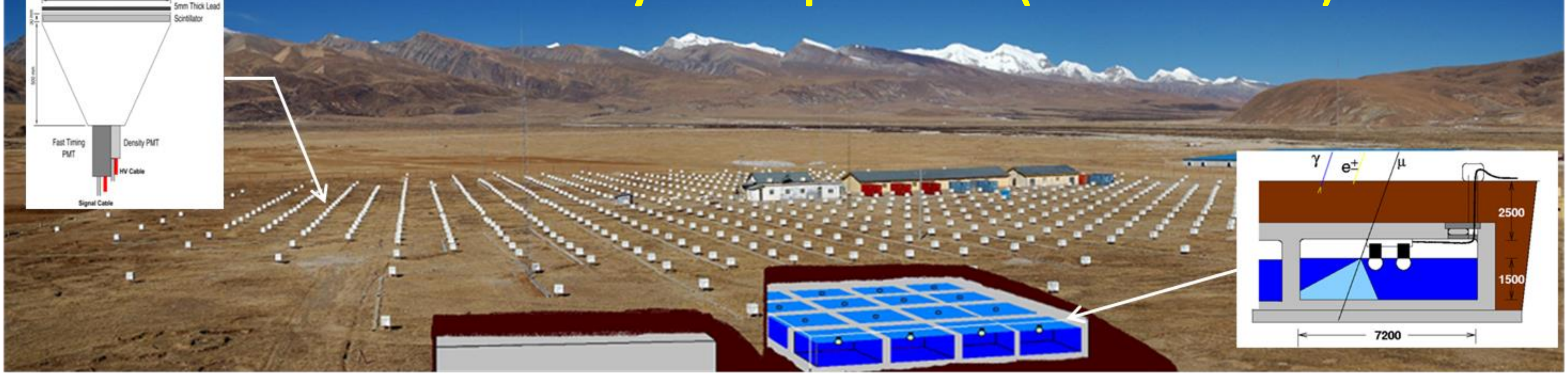
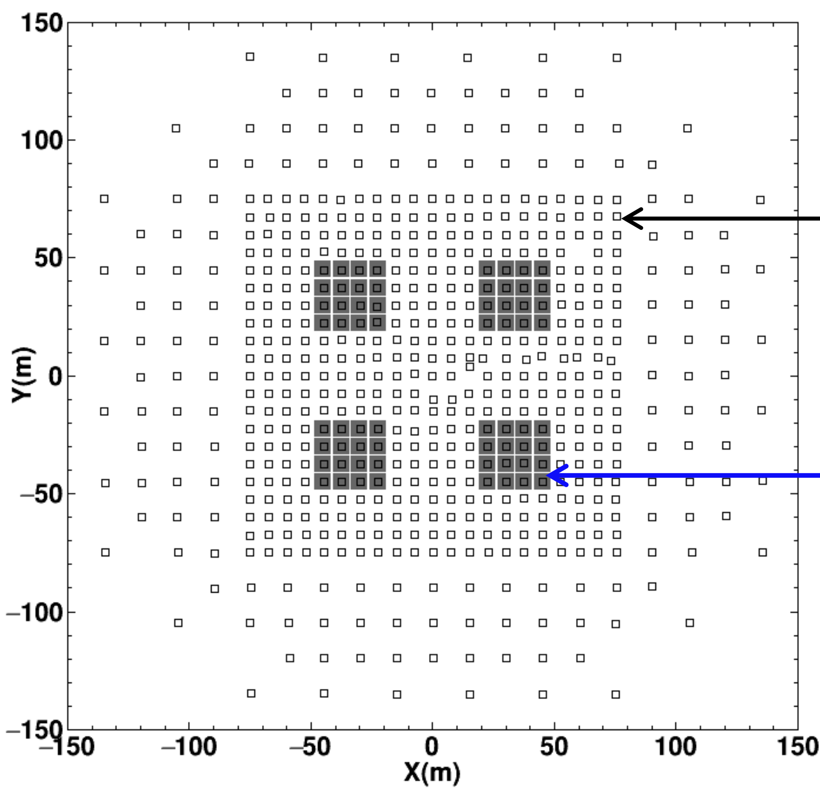
The new Tibet hybrid experiment (Tibet-AS+MD)





The new Tibet ASγ experiment

☐ Tibet-AS array:

597 plastic scintillation detectors

65700 m² (Cover area)

☐ Tibet-MD array:

64 water-Cherenkov-type detectors

2.4 m underground

3400 m² (Effective area)

Monte Carlo simulation

□ Air Shower Simulation CORSIKA

- ✓ *Hadronic interaction model :* **QGSJET01c, SIBYLL2.1** *and* **EPOS-LHC**
- ✓ *Low-Energy hadronic Interaction model:* ***GHEISHA***
- ✓ *Primary composition model :* **He-poor** *and* **He-rich**
- ✓ *Primary CRs energy :* $\mathbf{E_0 \geq 50\ TeV}$
- ✓ *Zenith angle (θ):* $\mathbf{0 \sim 60^0}$
- ✓ *Energy of secondary particles trace :* $\boldsymbol{E_i \geq 1\ \mathrm{MeV}}$
- ✓ *Observation Site :* **Yangbajing (606 g/cm^2)**

□ Detector Simulation Geant4

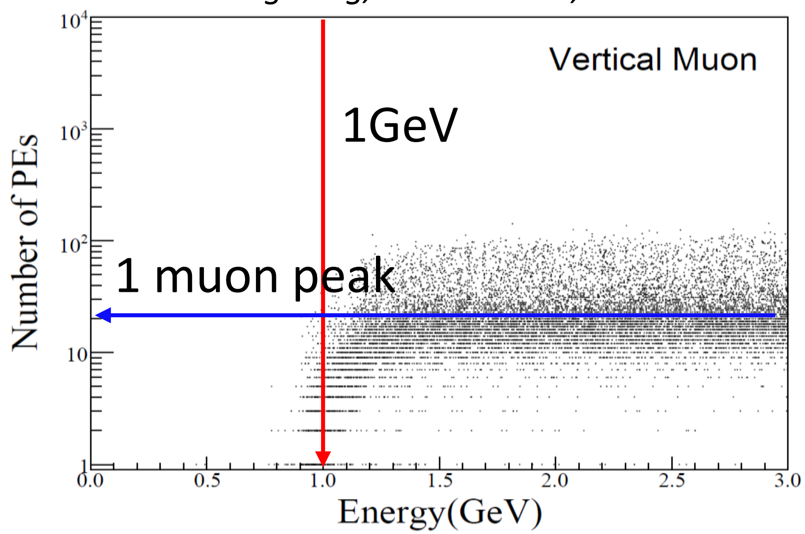
- ✓ *Dropping Area :*

  200 m ×200 m, 100 m away from the Tibet-AS array center

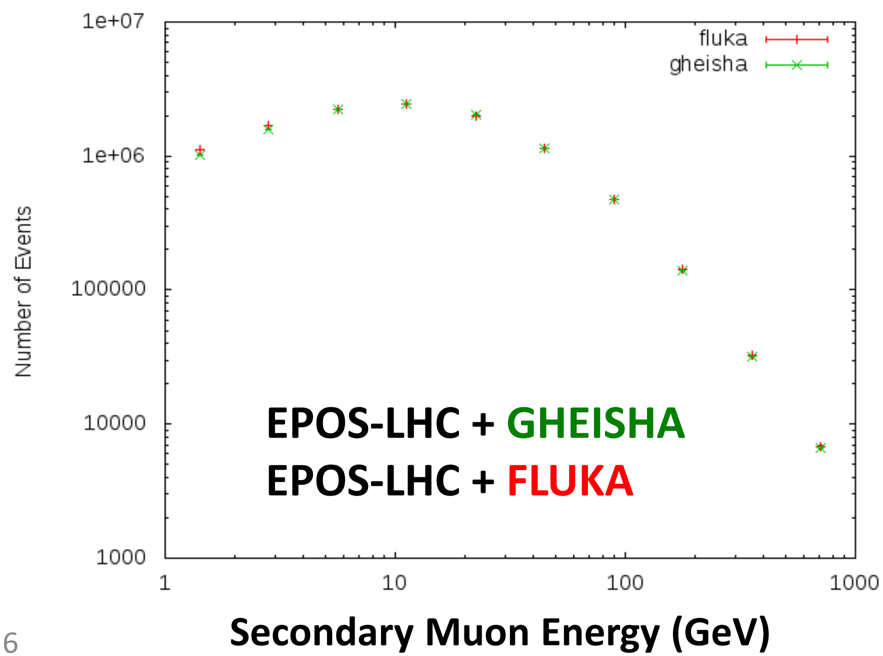
The detector performance, the trigger efficiency of detectors and the effective area are adequately taken into account based on the experimental conditions.

Comparison of Number of muon between GHEISHA and FLUKA for the Tibet-AS+MD array

ZhaoYang Feng, Ph.D. Theses, 2010.



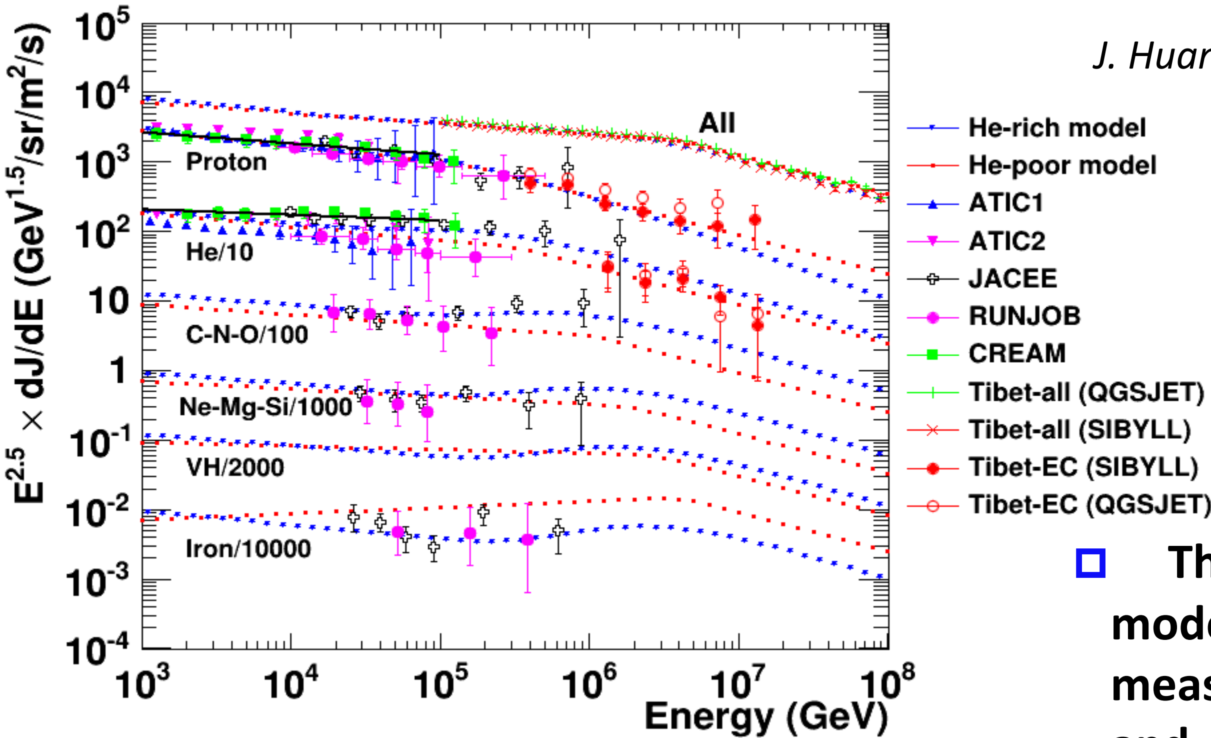
The Tibet-MD array is located at **2.4 m underground** beneath the Tibet-AS array, the mass thickness of the soil is equivalent to 19 radiation lengths, and the **energy threshold for muons** to penetrate the soil is approximately **1 GeV**.



The Comparison of Number of secondary Muon in CORSIKA output with use of the low-energy hadronic interaction models GHEISHA and FLUKA as shown in the left figure, the shapes of the N_μ are almost the same, there are less than ~5% differences between them.

The results in this work are based on the GHEISHA model for low-energy hadronic interaction model in the CORSIKA.

The Primary Cosmic-ray Composition models



J. Huang et al. Astropart. Phy. 66 (2015) 18.

He-poor model

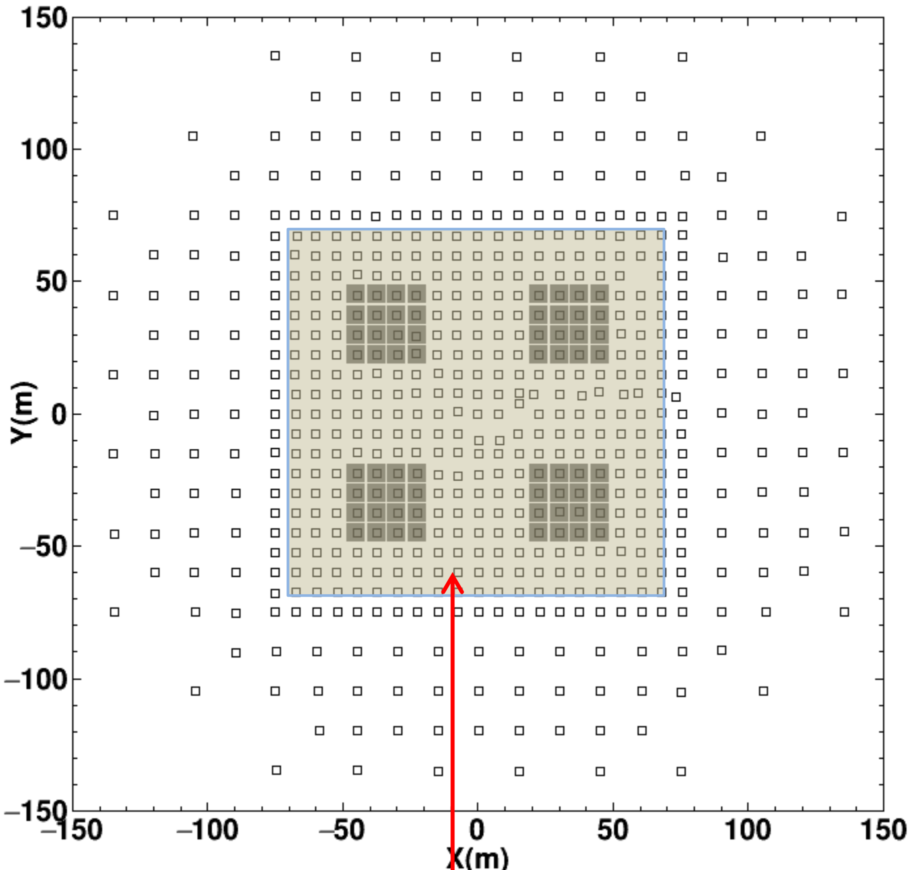
He-rich model

The fractions of the components in the models.

Component	$10^{13}-10^{14}$ eV (%)	$10^{14}-10^{15}$ eV (%)	$10^{15}-10^{16}$ eV (%)
He-poor model			
P	31.5	22.7	9.6
He	22.4	18.8	9.7
M	26.6	26.6	26.1
Fe	19.5	31.9	54.6
He-rich model			
P	31.1	26.3	10.0
He	25.1	28.7	17.5
M	32.4	34.4	50.3
Fe	11.3	10.6	22.2

- The proton spectrum of two models is fitted to the direct measurement at the low energy and consistent with the spectrum obtained from the Tibet-EC experiment at the high energy.
- The Helium spectrum of He-poor model coincides with the results from RUNJOB and ATIC1, while the He spectrum of He-rich model coincides with the results from JACEE, ATIC2 and CREAM3.

The Data-select Condition



The cores distribution of events selected as shown in the *grey area* in the Up figure.

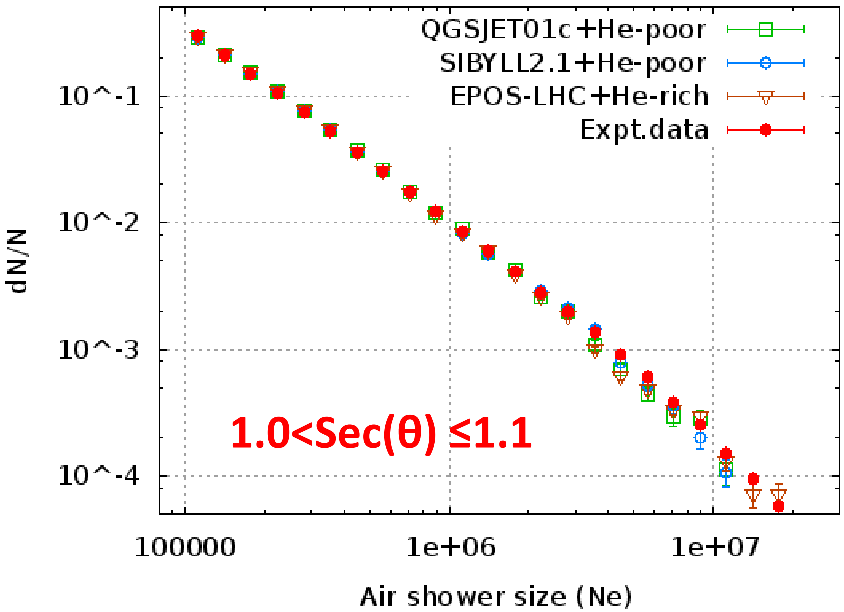
Data selection

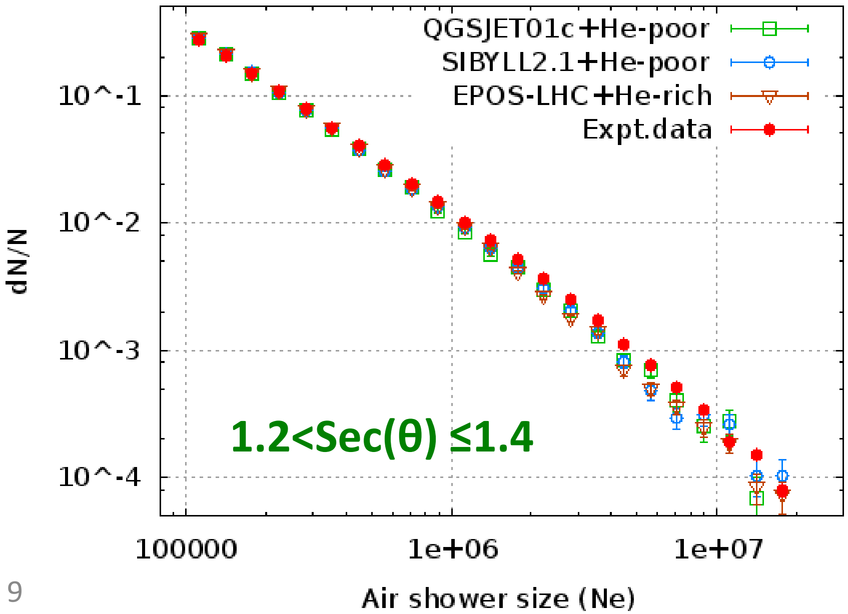
- Number of the AS detectors hit ≥ 10
- Number of particles per AS detector ≥ 1.6
- Air shower Size (Ne) ≥ 10^5
- The core position should be inside the inner most 135 m × 135 m of area

Statistics of the MC and Expt. Data.

MC Expt.data	Number of Events selected
QGSJET01c+He-poor	360574
SIBYLL2.1+He-poor	461655
EPOS-LHC+He-rich	786738
Expt.data	6287316

Comparison of Air Shower Size between MC and Expt. data





The Air Shower Size (N_e)

The distribution of air shower size (N_e) as shown in left figure, under the different zenith angles.

The shapes of the N_e are almost the same between the Expt. data and MC data.

Parameters used for Hadronic interactions and muon multiplicity investigated

The hadronic interactions and EAS muon multiplicity are investigated by comparing the following parameters reconstructed with the new Tibet ASγ hybrid experiment (Tibet-AS +MD):

- **Mean energy-flow spread (Tibet-AS array)**

  The mean energy-flow spread, <R_{AS}> =$\sum N_i \cdot r_i / \sum N_i$

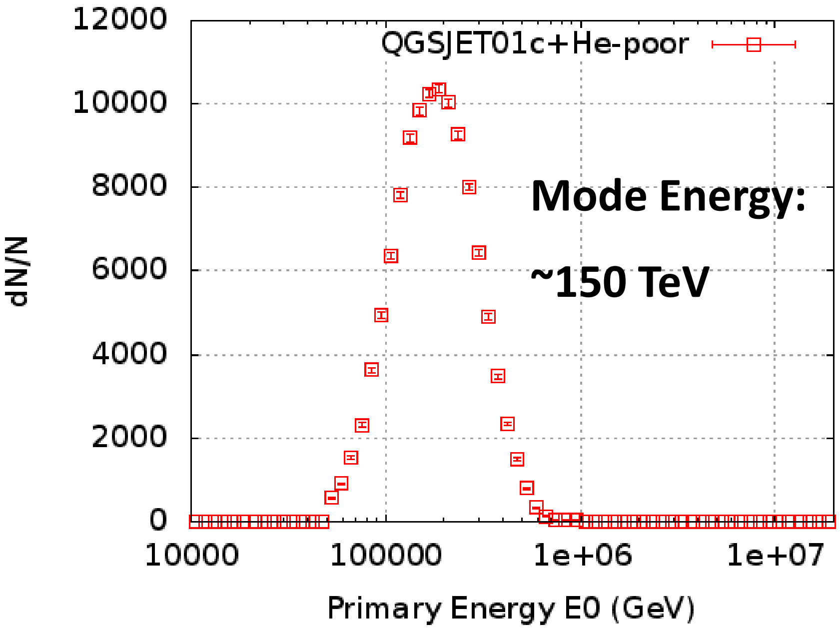
- $\sum N_\mu$ **(Tibet-MD array)**

  The Number of **total** muon of all fired **MD** detector units

- **Mean Lateral spread (Tibet-MD array)**

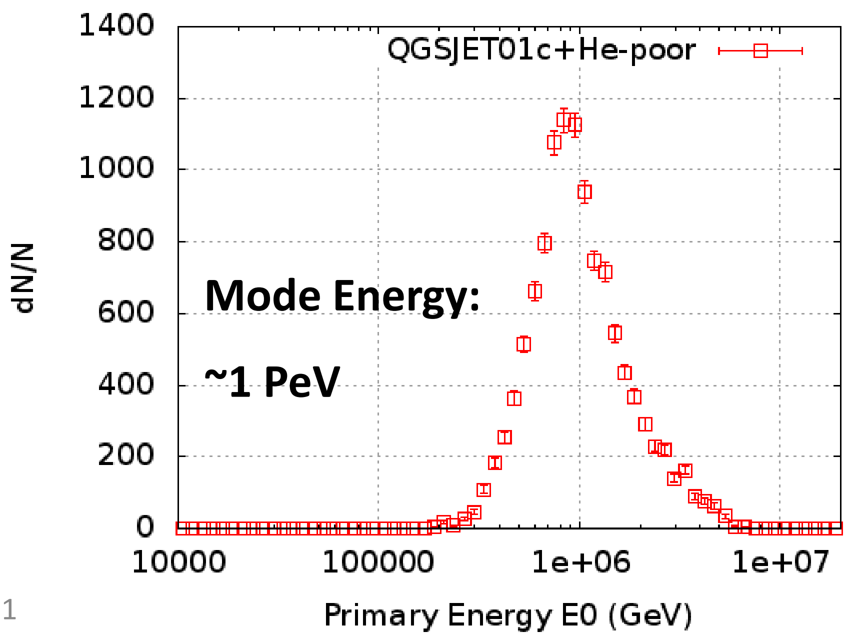
  The mean lateral spread, <R_{MD}> = $\sum r_i / N_{hit}$

Two data sets for Hadronic interactions and EAS muon multiplicity investigated



Data-set-I (150 TeV)

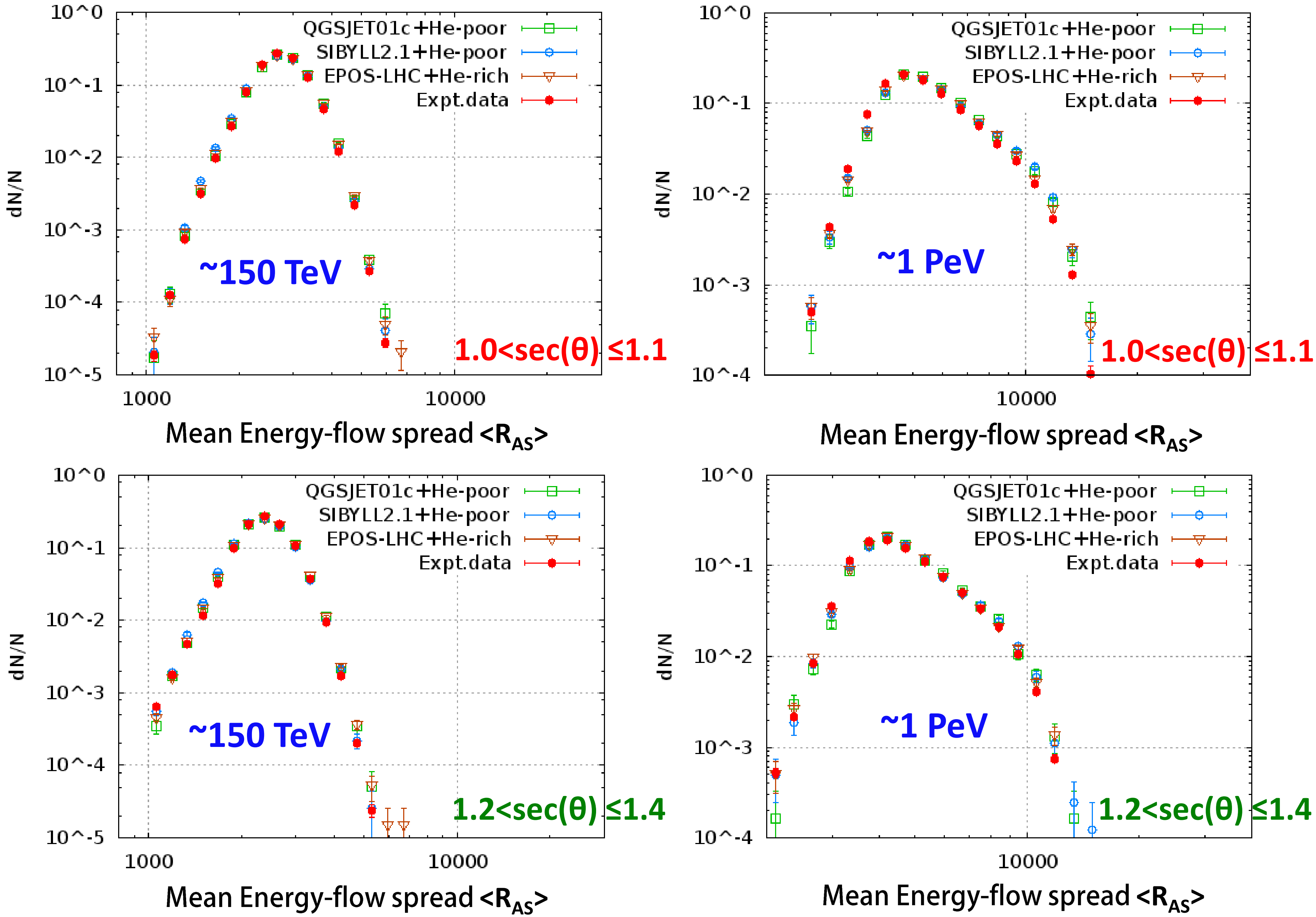
	1.0<sec(θ) ≤1.1	1.2<sec(θ) ≤1.4
	(P+He)/All (%)	(P+He)/All (%)
QGSJET01c+ He-poor	62.5±0.5	68.0±0.7
SIBYLL2.1+ He-poor	62.0±0.4	67.6±0.6
EPOS-LHC+ He-rich	76.6±0.3	79.2±0.4



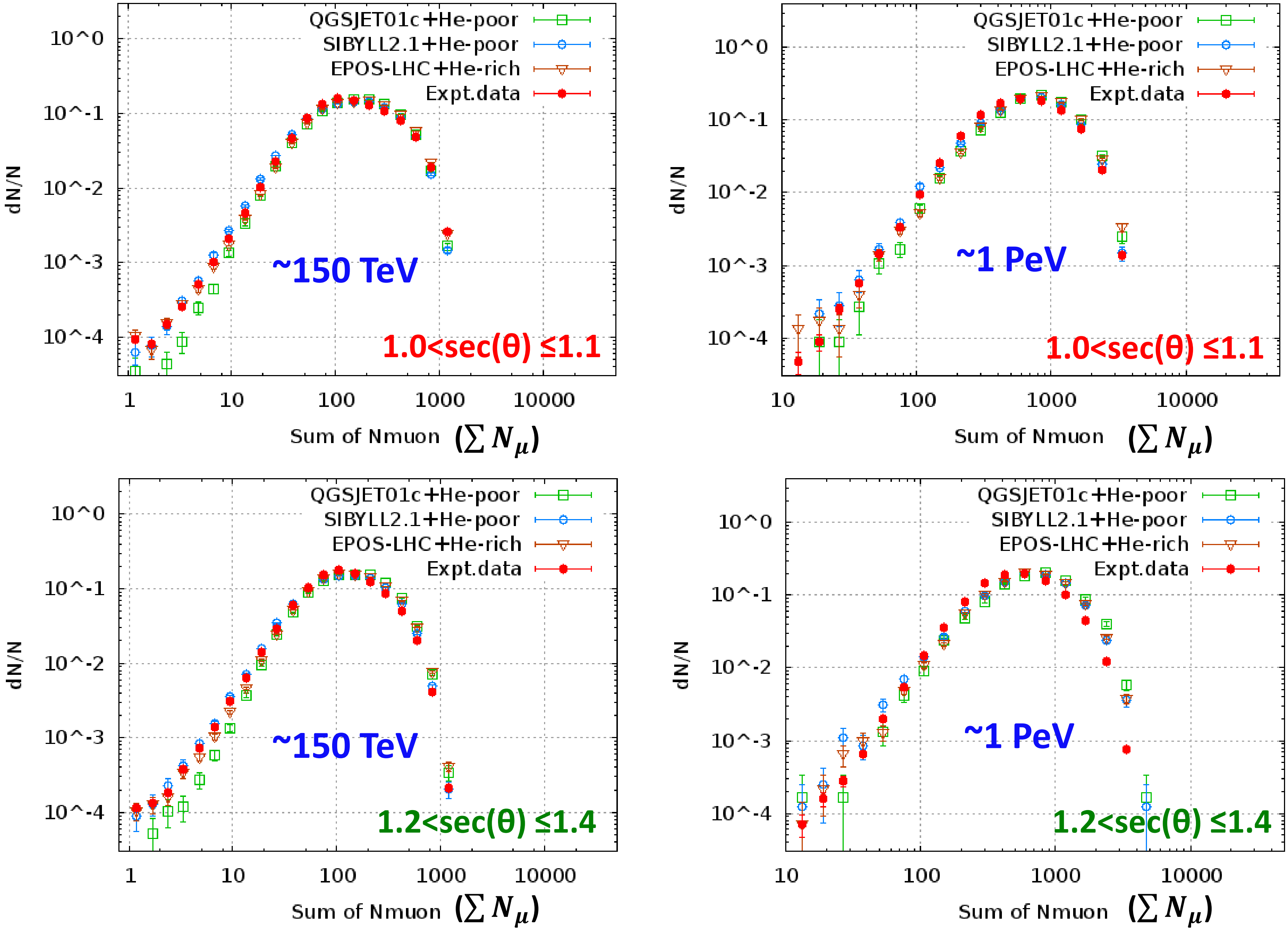
Data-set-II (1 PeV)

	1.0<sec(θ) ≤1.1	1.2<sec(θ) ≤1.4
	(P+He)/All (%)	(P+He)/All (%)
QGSJET01c+ He-poor	39.2±1.8	42.5±2.4
SIBYLL2.1+ He-poor	39.4±1.6	42.1±2.0
EPOS-LHC+ He-rich	51.7±1.1	54.9±1.4

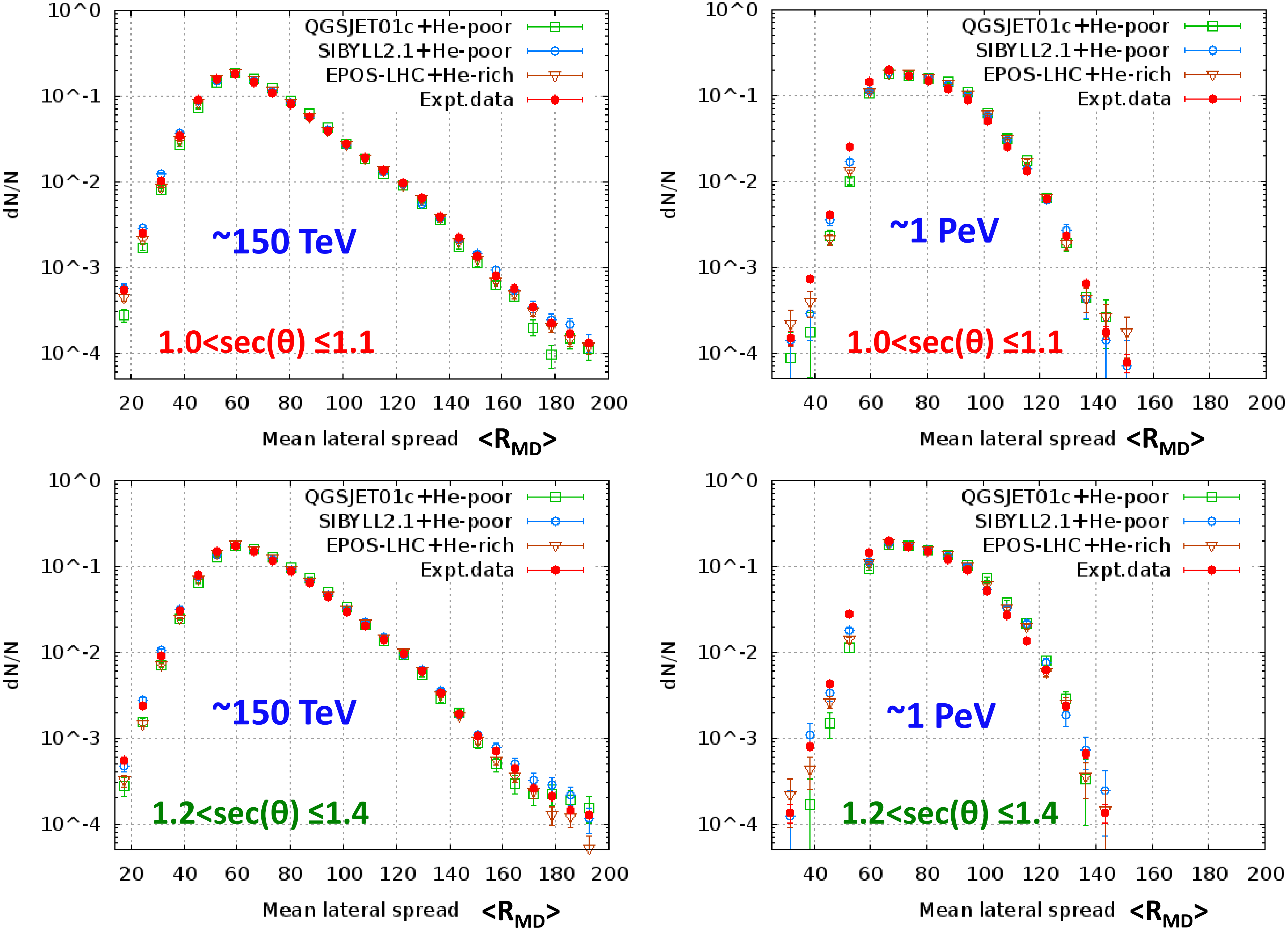
Comparison of Mean energy-flow spread obtained by Tibet-AS



Comparison of $\sum N_\mu$ obtained by Tibet-MD



Comparison of Mean Lateral spread obtained by Tibet-MD



Summary

1. We check three hadronic interaction models (QGSJETI01c, SIBYLL2.1 and EPOS-LHC) and investigate the Number of total muon with use of the data of (Tibet-AS+MD) array, by comparing the distribution of some parameters (Ne, Nμ, mean lateral spread, etc.) between MC and Expt. data in different zenith angles and different energy regions, and we found that the SIBYLL2.1 and EPOS-LHC models could reproduce the Expt. data well, while there are some differences in the distribution of $\sum N_{\mu}$ between the QGSJET01c model and Expt. data.

2. The checking of hadronic interaction models and muon multiplicity mentioned in this work are under the all-particle data-sets, which are the mix components, the more detailed work will be discussed in the near future.