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A new approach to EAS investigations in energy region 10^{15} - 10^{19} eV

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Contents

Introduction

- In EAS data interpretation, primary spectrum, composition, and interaction characteristics are unknown.
- To solve the problem involving several unknown functions, measurements of different EAS observables are necessary.
- In this talk, phenomenology and recent data on a new EAS observable – local muon density distributions in a wide range of zenith angles – are considered.

Local muon density phenomenology - 1

For inclined EAS, dimensions of muon LDF exceed hundreds meters. The detector with sizes of tens meters may be considered as a point-like probe. In a muon bundle event, the local muon density D (in a random point of the shower) is estimated:

$$D = (\text{number of muons}) / (\text{detector area});\quad [D] = \text{particles} / \text{m}^2.$$

Without considering fluctuations, spectrum of events in local density may be written as

$$F\left(\geq D\right) = \int N\left(\geq E\left(\mathbf{r}, D\right)\right) dS,$$

where $N\,(\geq E)$ - primary spectrum, E is defined by the equation:

$$\rho(E, \mathbf{r}) = D.$$

Dimension: $[F\,(\geq D)\,] = \text{events} / (\text{s sr}).$

Local muon density phenomenology - 2

For a nearly scaling LDF around some energy E_0

$$\rho(E,\mathbf{r}) = (E/E_0)^{\kappa} \times \rho(E_0,\mathbf{r}),\ \ \kappa \approx 0.9$$

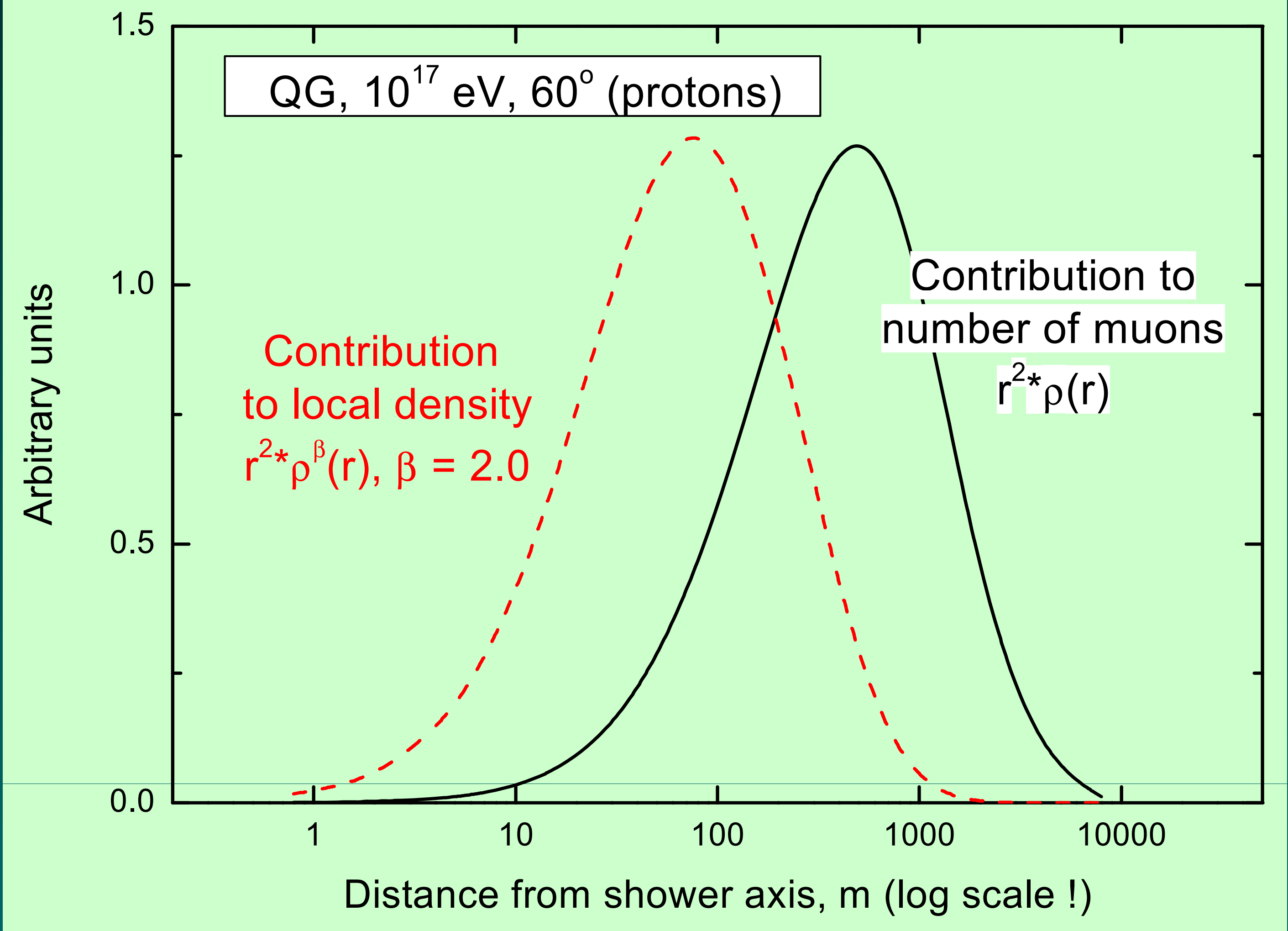
and power type primary spectrum $N(\geq E) = A(E/E_0)^{-\gamma}$,

$$F(\geq D) = AD^{-\beta} \int \left[\rho(E_0,\mathbf{r})\right]^{\beta} dS$$

1) Power type spectrum of local density, a bit steeper than the primary one $(\beta = \gamma / \kappa)$.

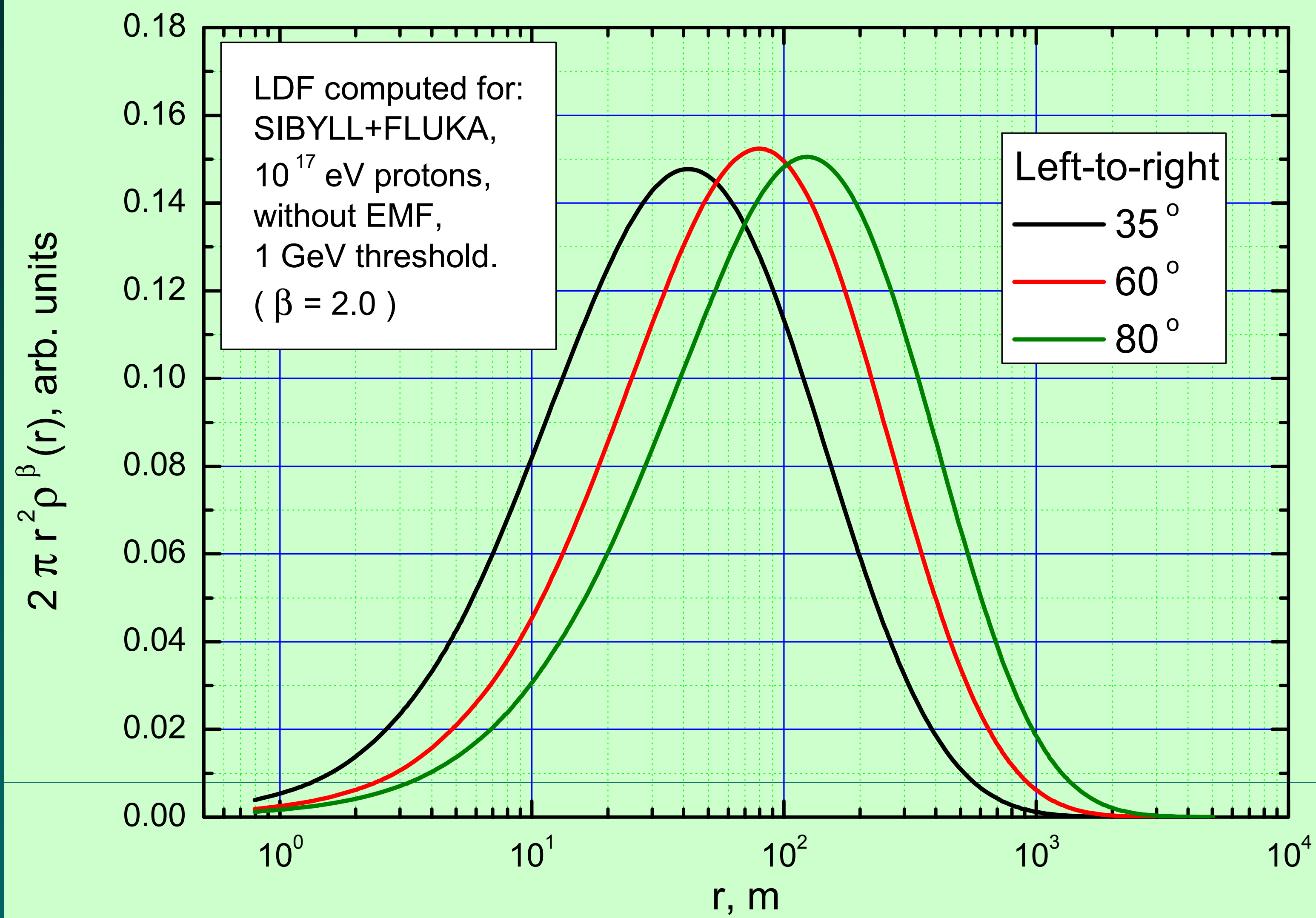
2) Enhanced sensitivity to the central part of the shower $(\beta \approx 2)$.

Contribution of different distances to total number of muons in EAS and to local muon density spectrum



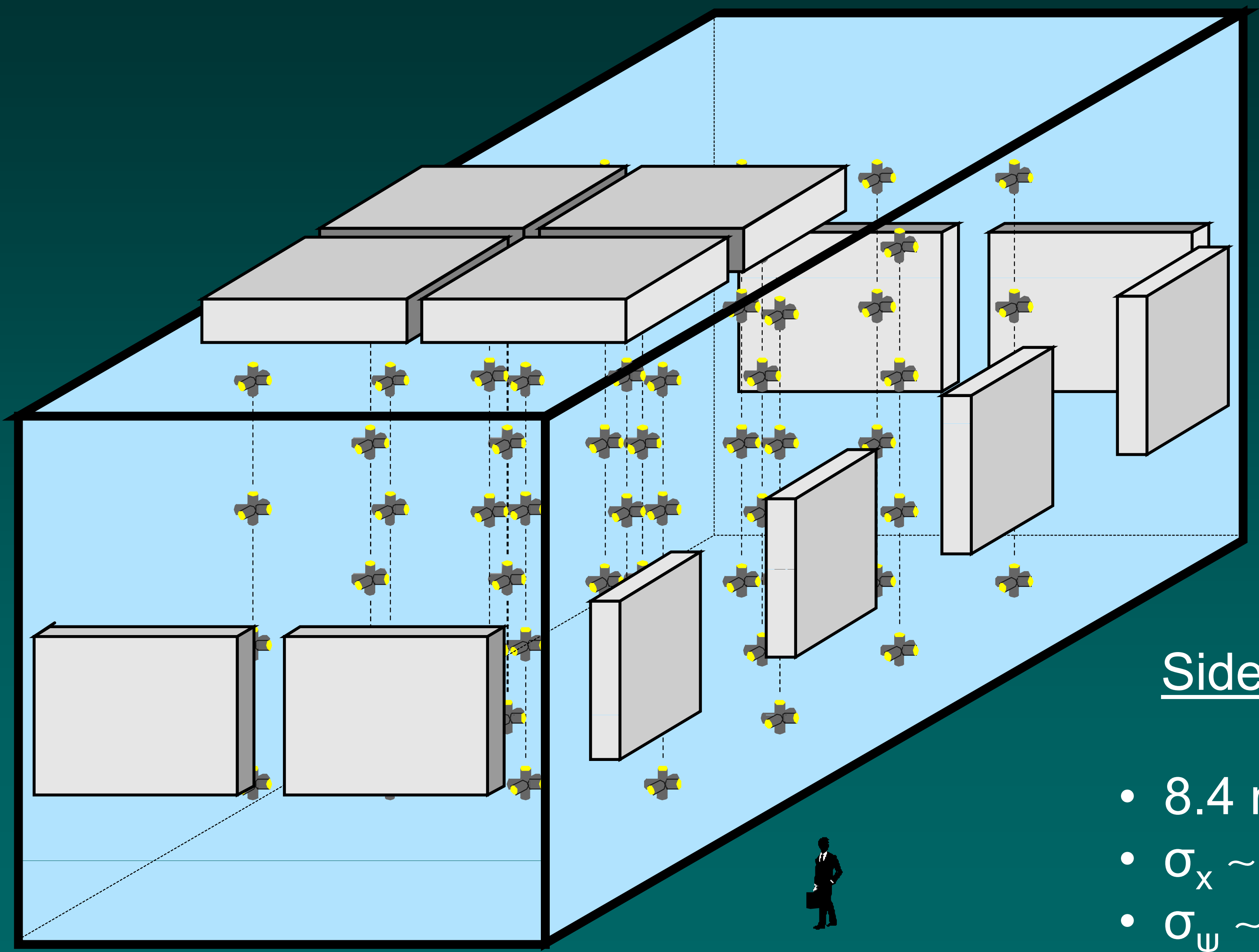
Enhanced sensitivity to the central part of the shower (forward interaction region) !

Contribution of distances, different zenith angles



- Collection area increases with zenith angle.
- The effect is enhanced by the EMF influence.

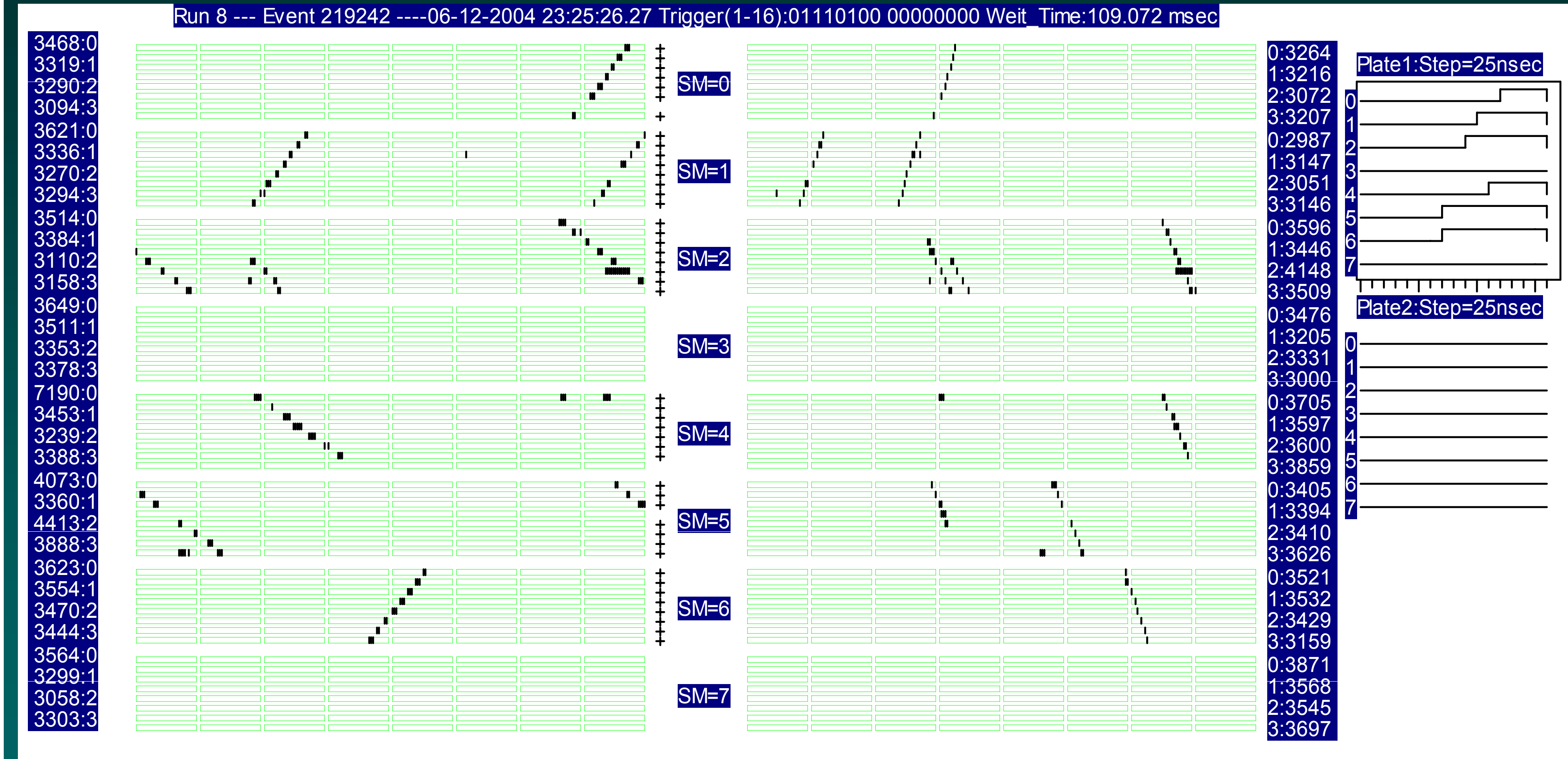
General view of NEVOD-DECOR complex



Side SM:

- 8.4 m^2 each;
- $\sigma_x \sim 1$ cm;
- $\sigma_\psi \sim 1°$.

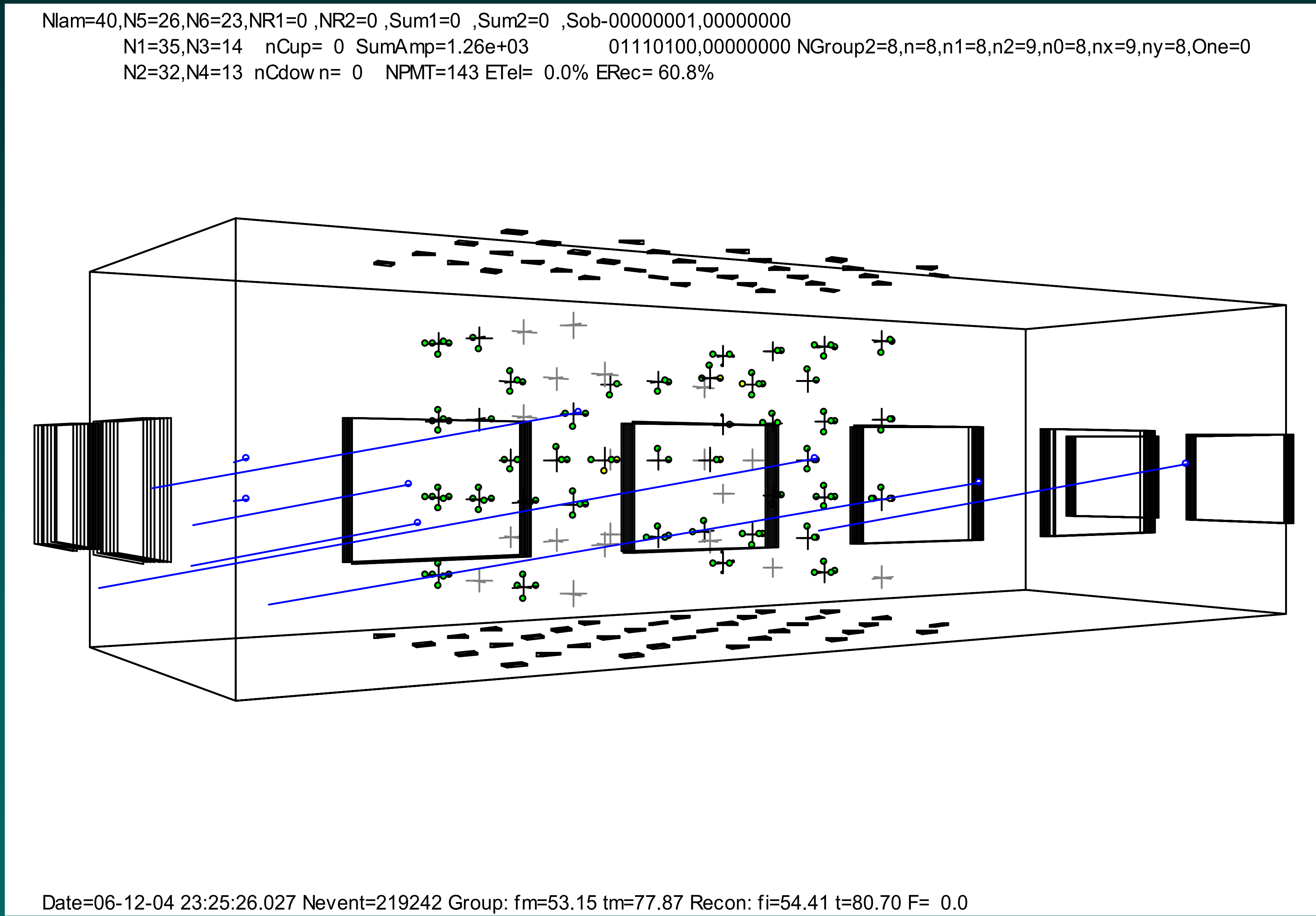
A typical muon bundle event in Side DECOR
(9 muons, 78 degrees)



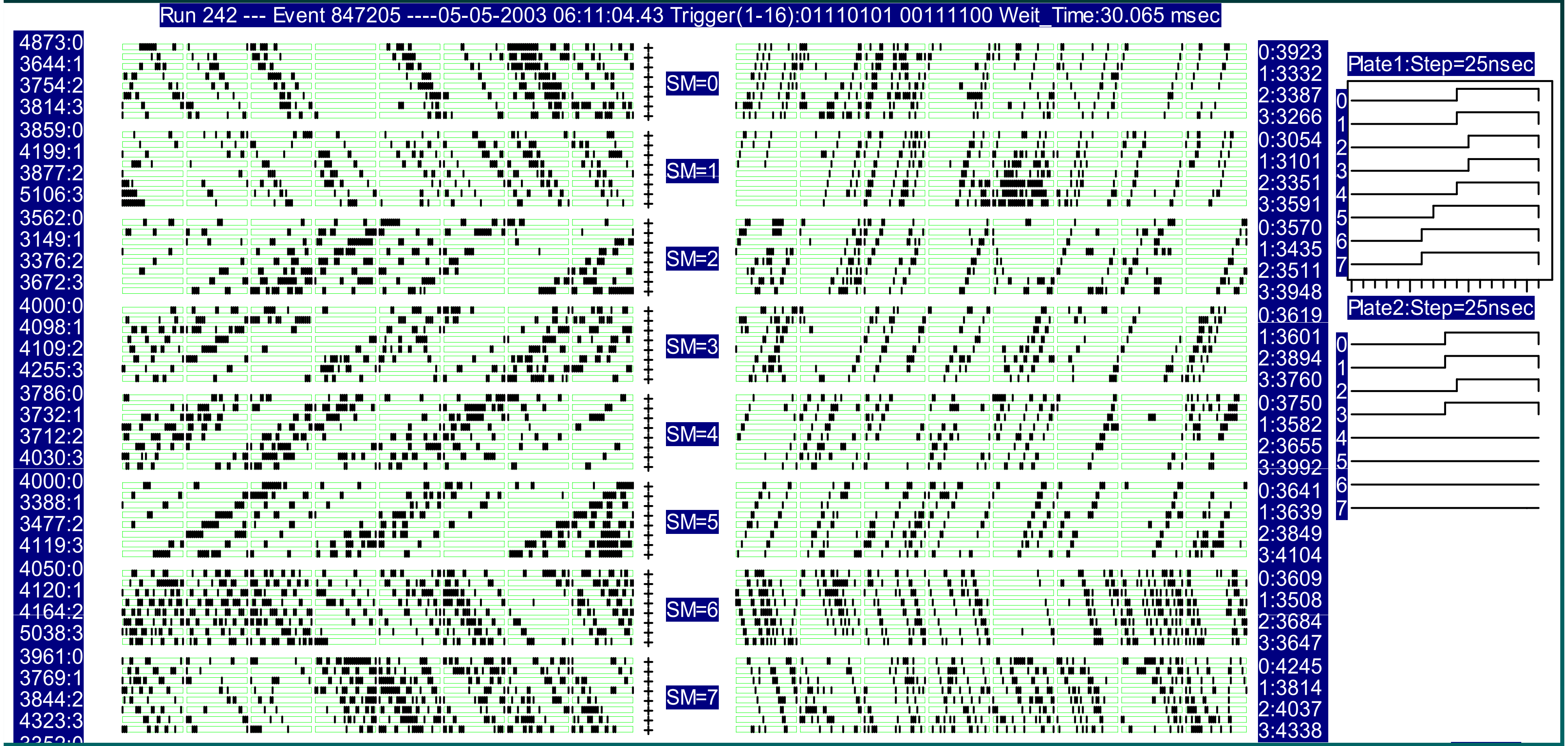
Y-projection

X-projection

Muon bundle event (geometry reconstruction)



A “record” muon bundle event (~ 160 muons, θ = 80°)



Y-projection

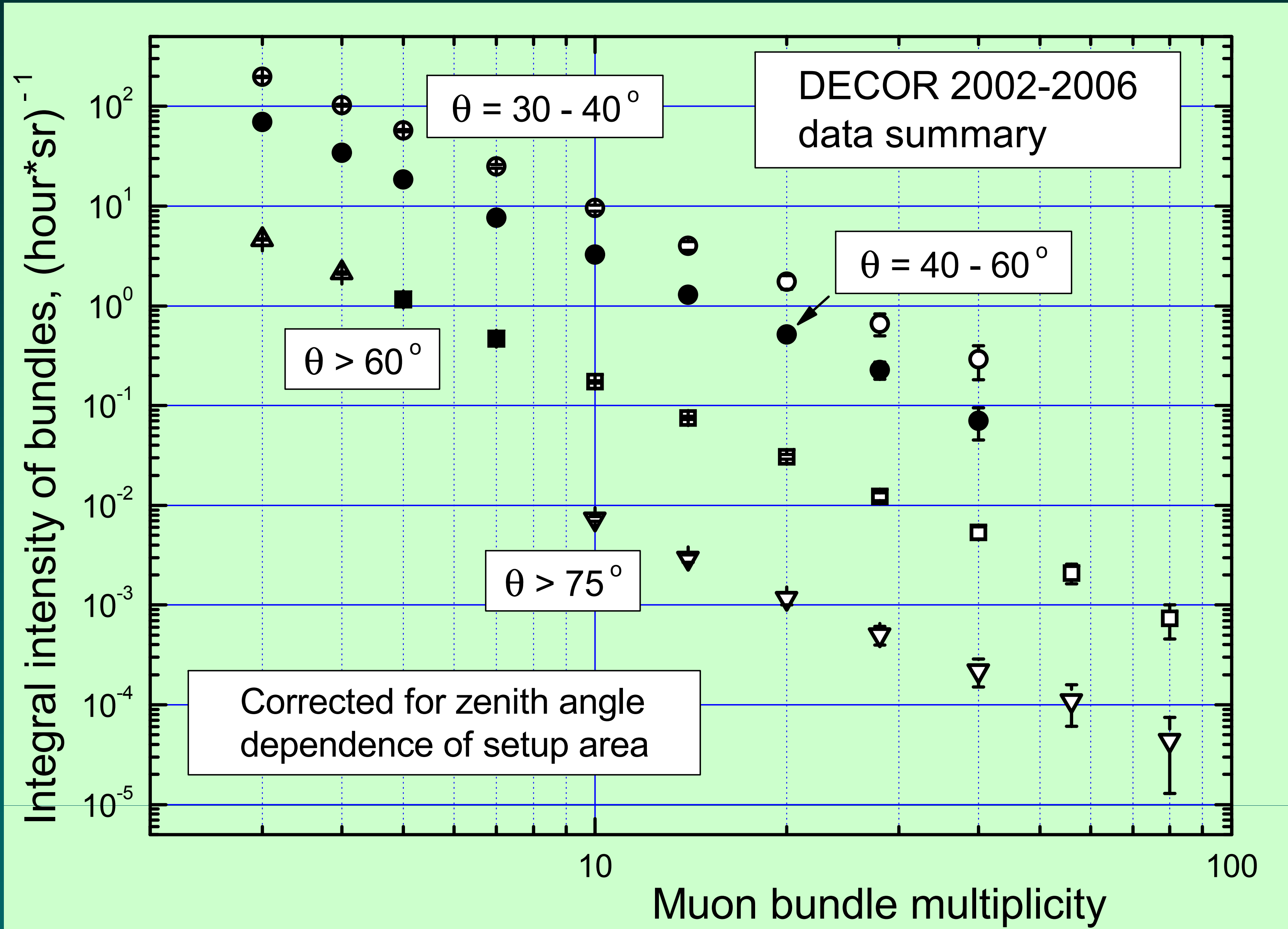
X-projection

DECOR data summary - 1.
Muon bundle statistics

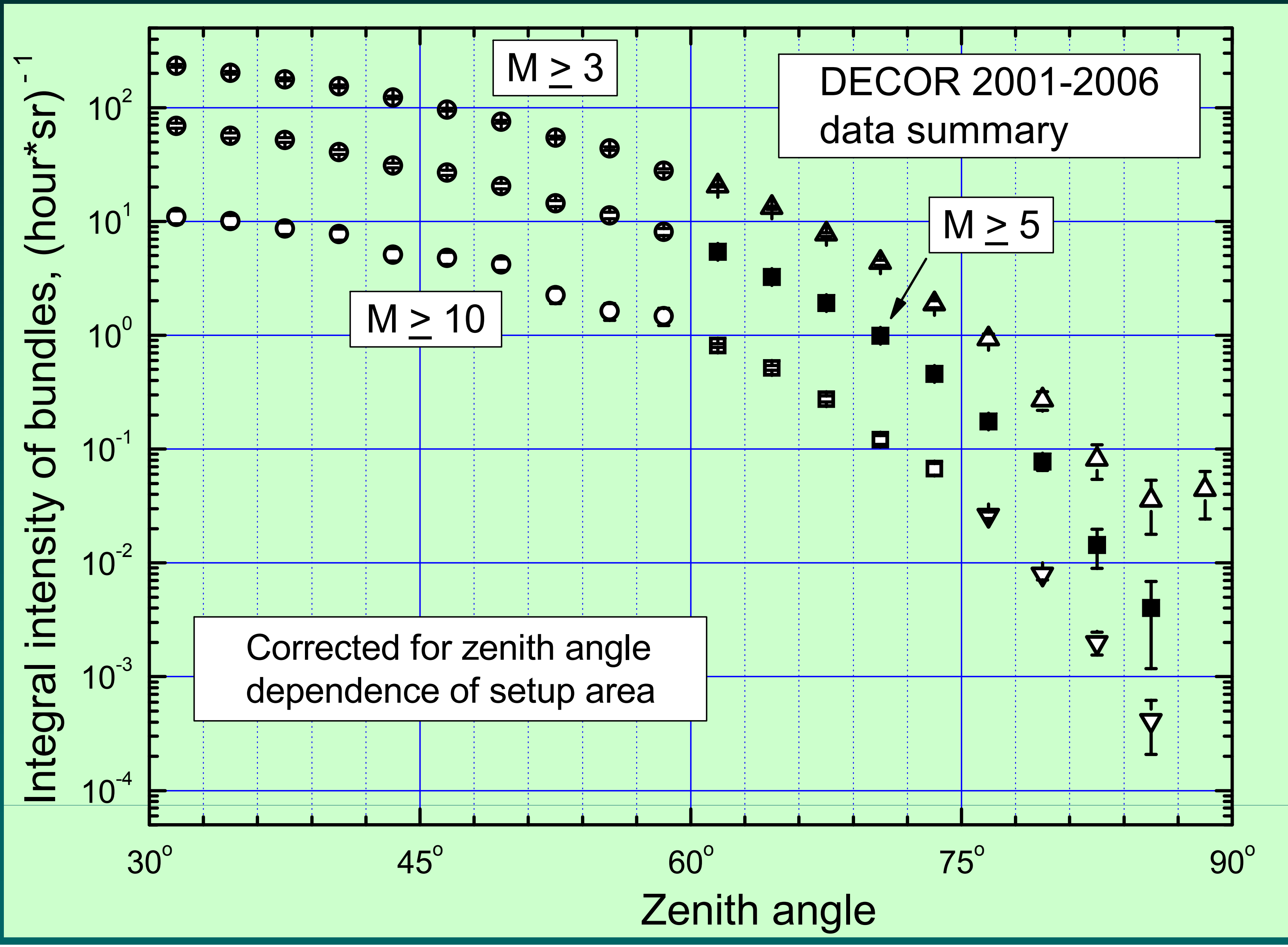
Muon multiplicity	Zenith angle range (*)	Live time, (hours)	Number of events
≥ 3	30 – 40°	524.7	4754
≥ 3	40 – 60°	524.7	7945
≥ 3	≥ 60°	1552	4114
≥ 5	≥ 60°	6848	4531
≥ 10	≥ 60°	16668	1651
≥ 10	≥ 75°	16668	332

(*) For zenith angles < 75°, only events in limited intervals of azimuth angle (with DECOR shielded by the water tank) are selected.

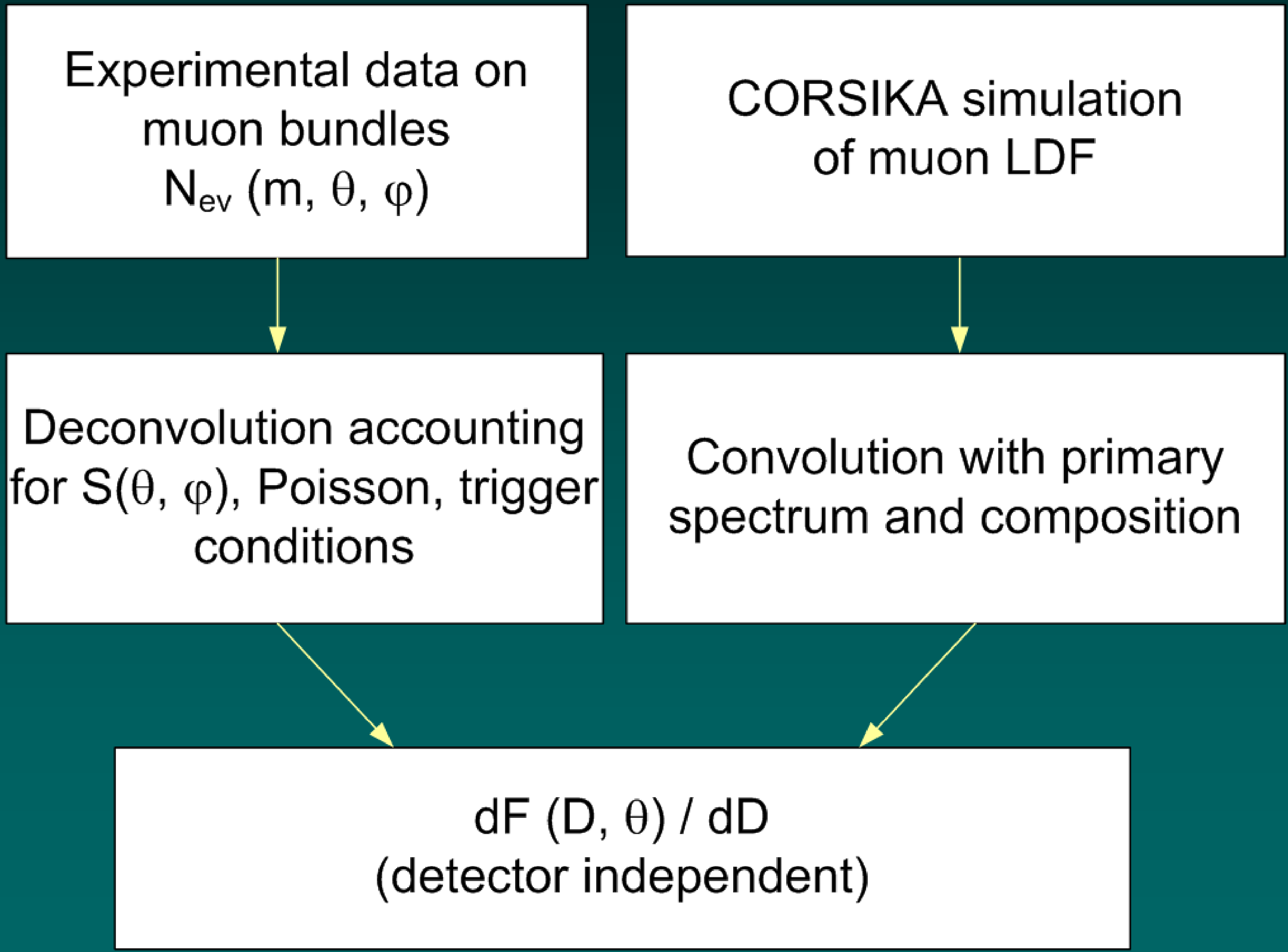
DECOR data summary - 2.
Distribution in multiplicity



DECOR data summary - 3.
Distribution in zenith angle



Procedure of the analysis



Calculation details

Reference primary "all-particle" spectrum:

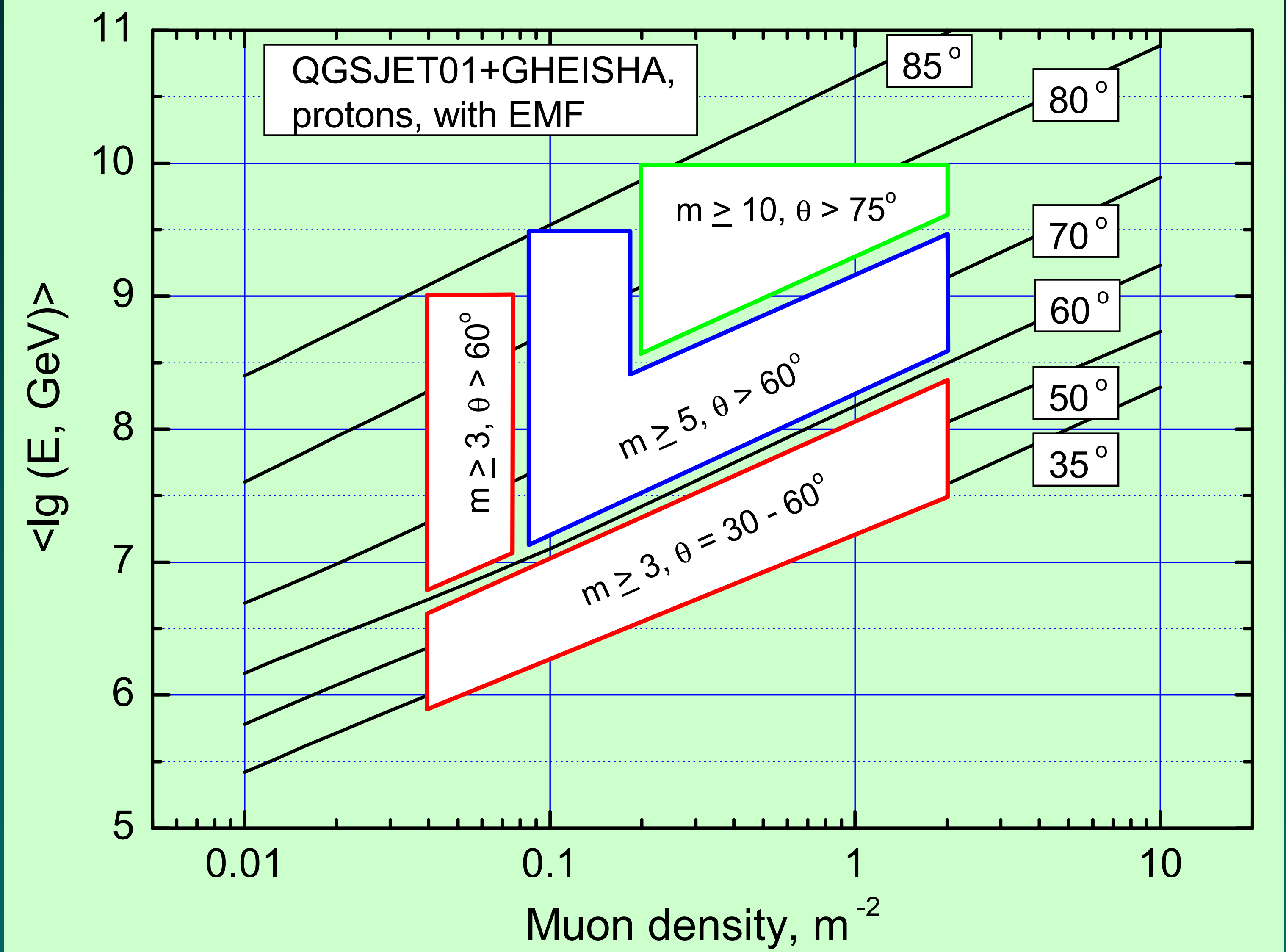
Power type spectrum with the knee at 4 PeV.
Below the knee, $dN / dE = 5.0 \, (E, \text{GeV})^{-2.7}$ $\text{cm}^{-2} \, \text{s}^{-1} \, \text{sr}^{-1} \, \text{GeV}^{-1}$;
steepening to $(\gamma + 1) = 3.1$ after the knee.

Close to MSU "all-particle" spectrum as given by PDG (T. Gaisser, T. Stanev); not much different from most of other data around the knee; close to Fly's Eye "stereo" at 10^{18} eV.

CORSIKA simulation of 2D muon LDF:

CORSIKA 6.502; two combinations of interaction models QGSJET01c + GHEISHA2002, SIBYLL2.1 + FLUKA2003.1.b.
Set of fixed zenith angles and of primary energies.
Primary protons and Fe nuclei; with and without EMF.

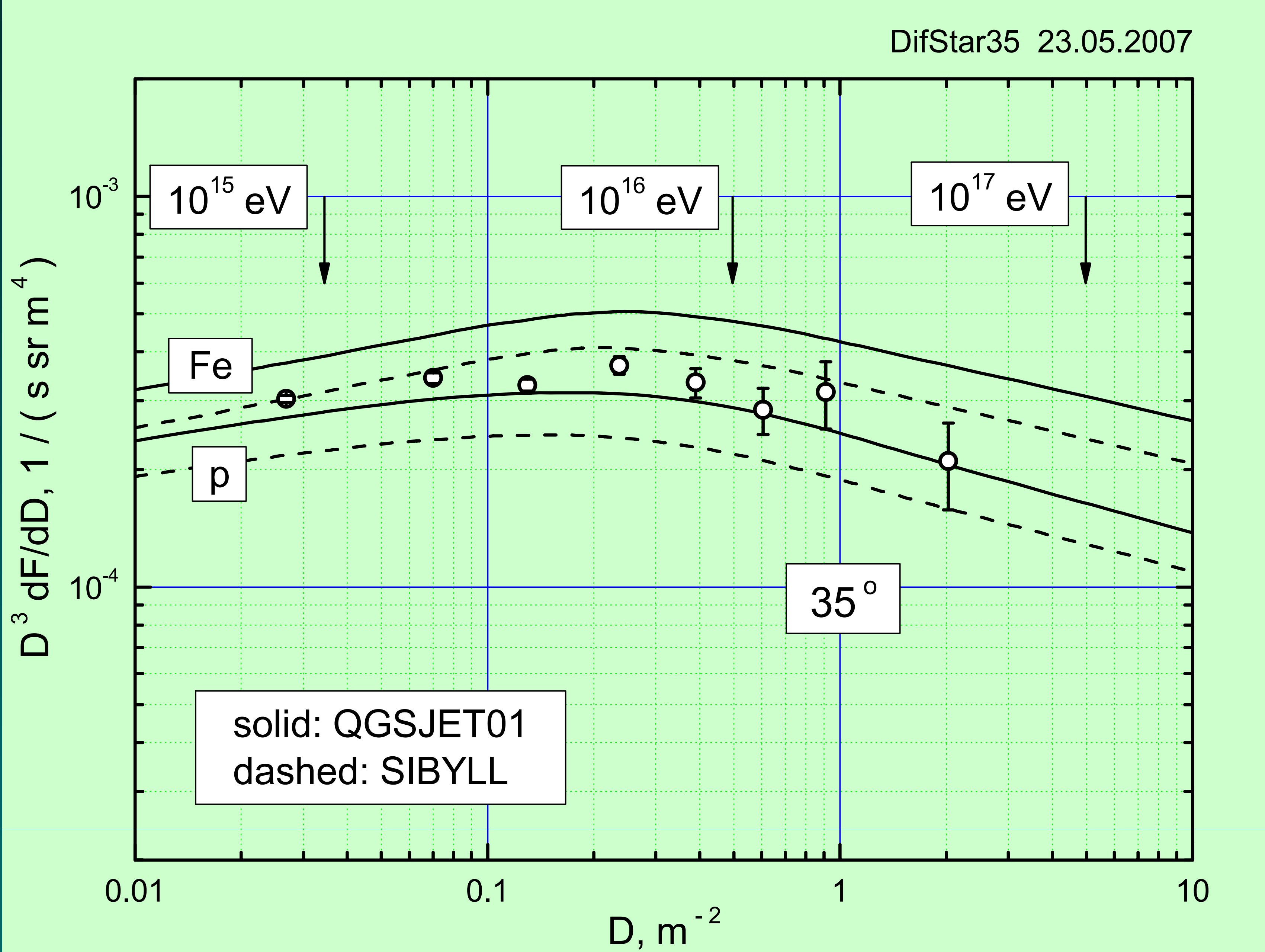
Effective primary energy range



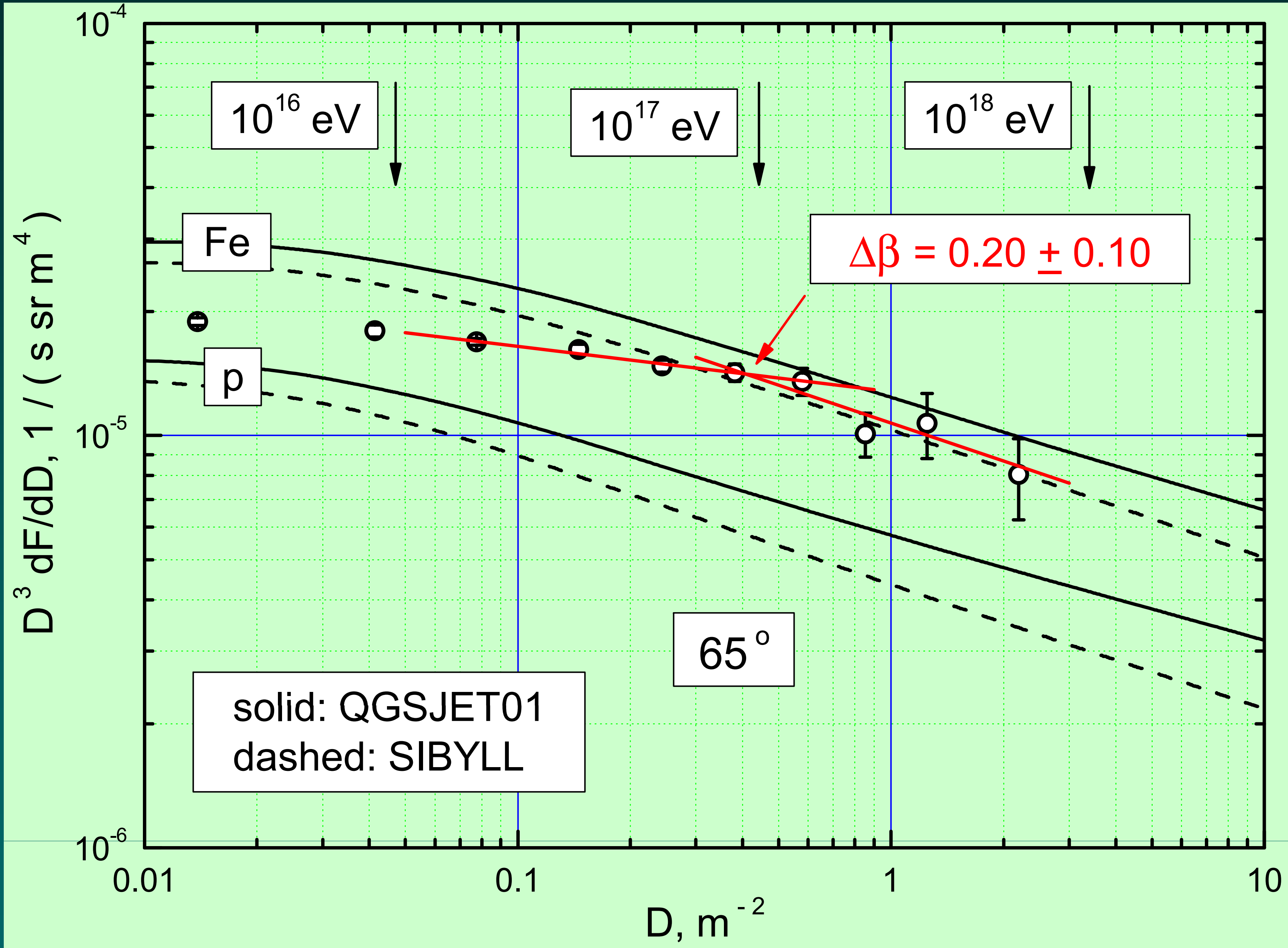
Lower limit ~ 10^{15} eV (limited by DECOR area).

Upper limit ~ 10^{19} eV (limited by statistics).

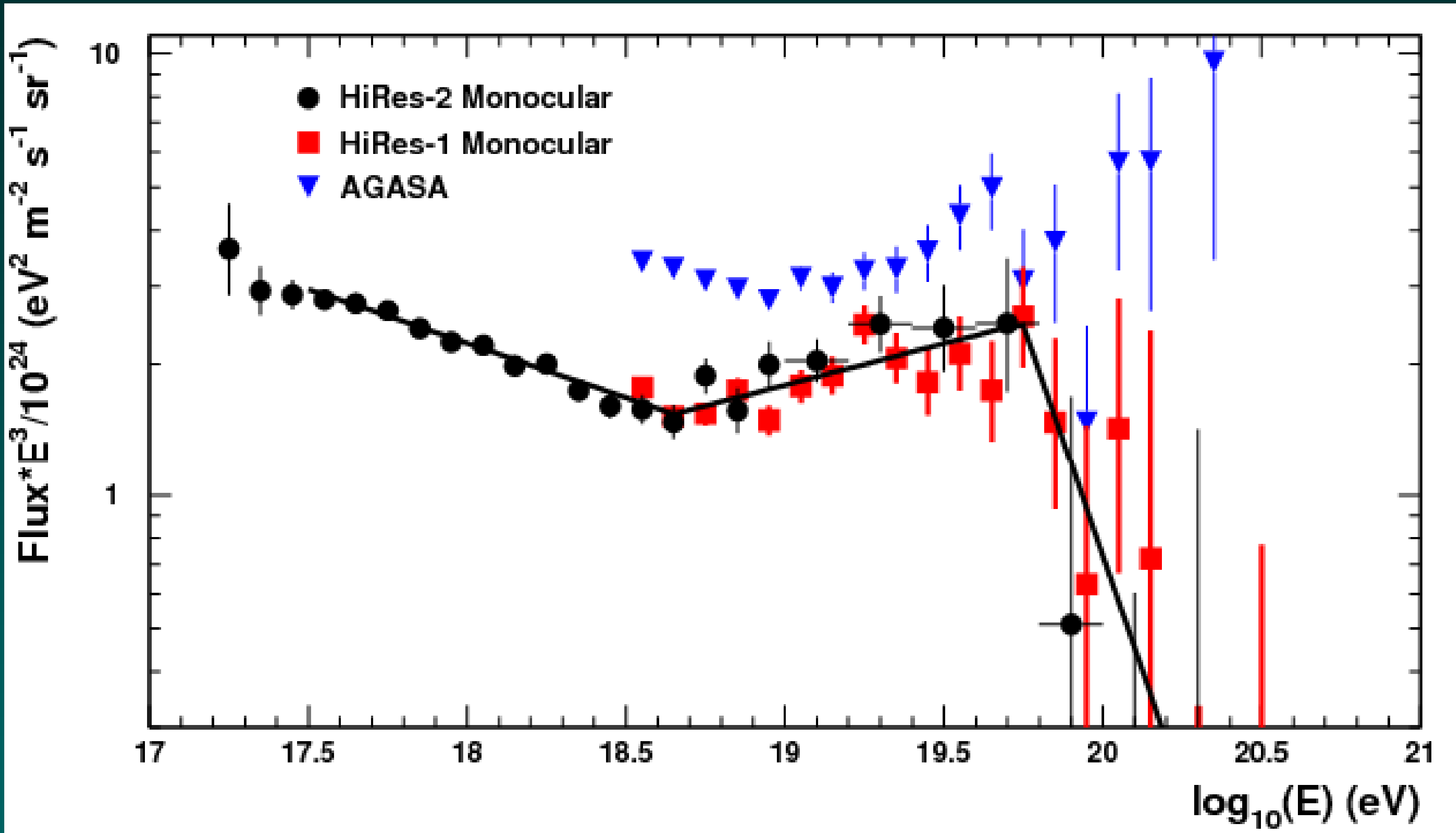
Differential local muon density spectrum - 35°



Differential local muon density spectrum - 65°

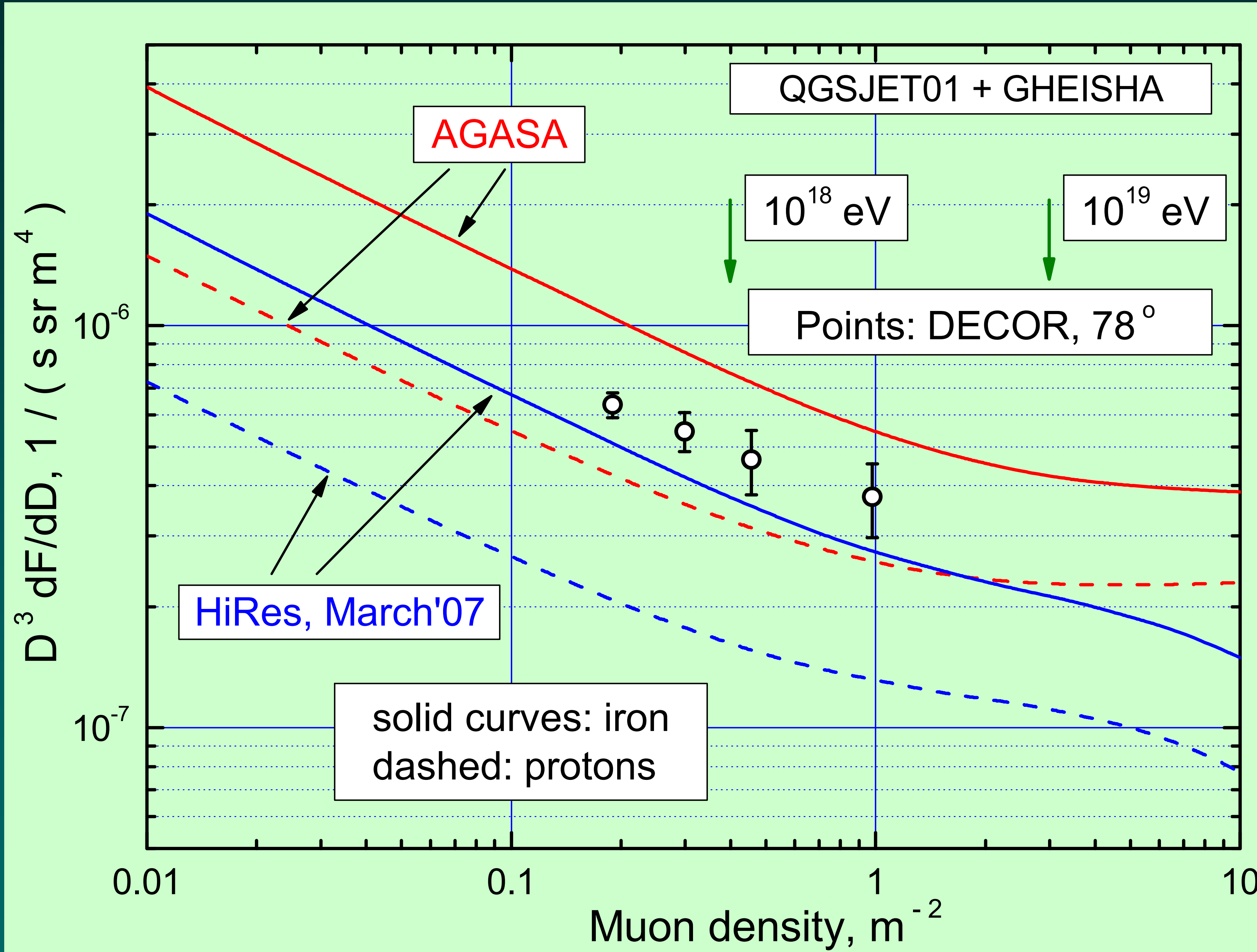


PCR intensity around 10^{18} eV: two models



HiRes Collaboration: astro-ph/0703099v1 (March 2007)

PCR intensity around 10^{18} eV: two models



Conclusions - 1

1. Local muon density spectra are sensitive to primary spectrum and composition, and have an enhanced sensitivity to forward region of hadronic interactions.
2. A new approach based on local muon density spectrum phenomenology provides possibility to study PCR in a very wide energy range (from 10^{15} to 10^{19} eV) by means of a single, relatively small-size detector.
3. Analysis of local muon density spectra together with data of experiments on other EAS observables will allow putting new constraints on combinations of spectrum, composition and interaction models.

Conclusions - 2

1. DECOR data at moderate zenith angles are in a reasonable agreement with simulations based on a usual picture of PCR spectrum and interaction around the knee.
2. Within the frame of the considered spectrum model (with $\gamma \sim 2.1$ after the knee), DECOR data favor an increase of the effective primary mass up to energies 10^{17} eV.
3. There is an indication (at 2σ-level) for an increase of local muon density spectrum slope at effective primary energy around 10^{17} eV.
4. Within the considered interaction models, DECOR data at large zenith angles ($E_0 \sim 10^{18}$ eV) are not compatible in absolute intensity with spectrum model based on HiRes data, and are in agreement with AGASA-based intensity.

Thank you !