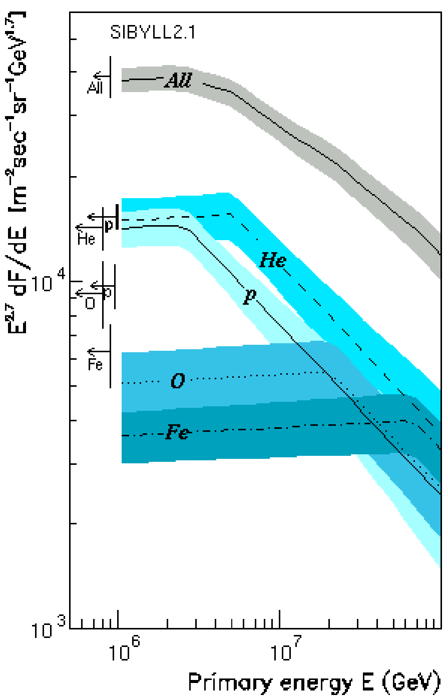
Primary energy spectra in the 1-100 PeV energy range: GAMMA Experiment



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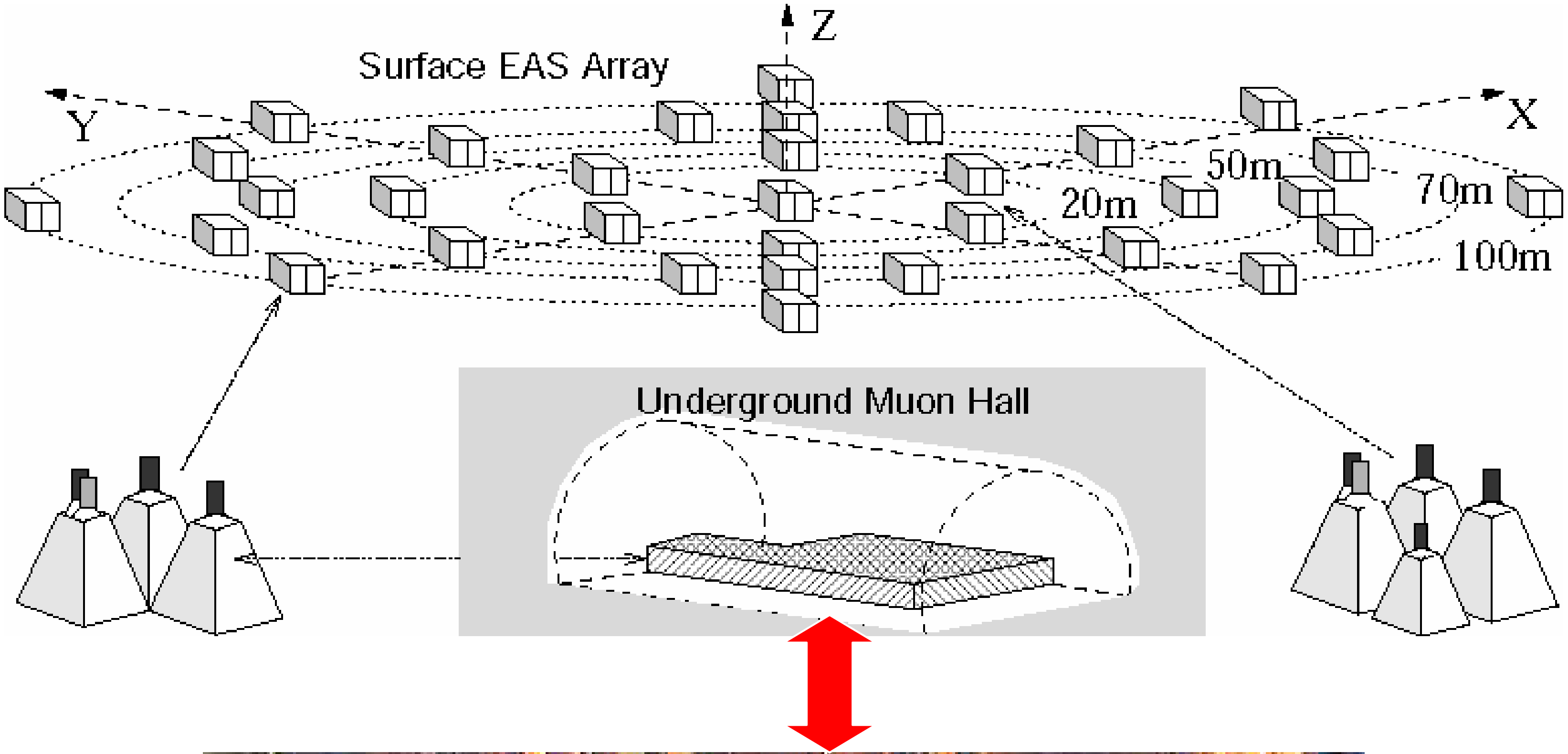
GAMMA facility



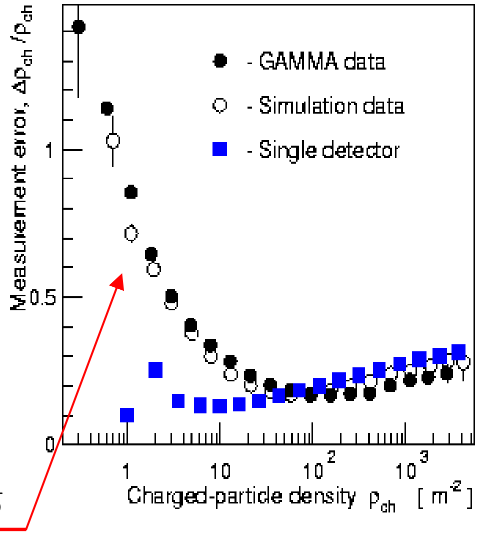
- **Location:**
  Armenia, Mt.Aragats
  3200 m a.s.l.
- **EAS array:**
  33x3 $(1x1x0.05)m^3$+
  +9$(0.3x0.3x0.05)$ m^3
- **Muon hall:**
  2500 g/cm^2 of rock
  150 $(1x1x0.05)m^3$

- **EAS data:**
  $N_{ch} > 5 \cdot 10^5$ (100%)
  R < 25 m (50 m)
  $\theta < 30^0$
  $N_\mu(R_\mu<50m) > 10^3$
  $E_\mu > 5$ GeV
  T = $6.2 \cdot 10^7$ sec

Measurement errors:

$$\frac{\Delta N_{ch}}{N_{ch}} \approx 0.1,\ \Delta s \approx 0.05,\ \Delta x, \Delta y \approx 0.5 \div 1\text{m},\ \Delta\vartheta \approx 1.5^0$$

$$\frac{\Delta N_{\mu}}{N_{\mu}} \approx 0.35 \div 0.2 \quad \text{at} \quad N_{\mu}(R_{\mu} < 50\text{m}) \approx 10^3 \div 10^5$$



EAS simulations:

CORSIKA6.031(EGS, NKG)

A	SIBYLL2.1	QGSJET01	E_{min} [PeV]
P	$1.0\cdot10^5$	$1.0\cdot10^5$	0.5
He	$7.1\cdot10^4$	$6.0\cdot10^4$	0.7
O	$4.6\cdot10^4$	$4.4\cdot10^4$	1.0
Fe	$4.8\cdot10^4$	$4.0\cdot10^4$	1.2

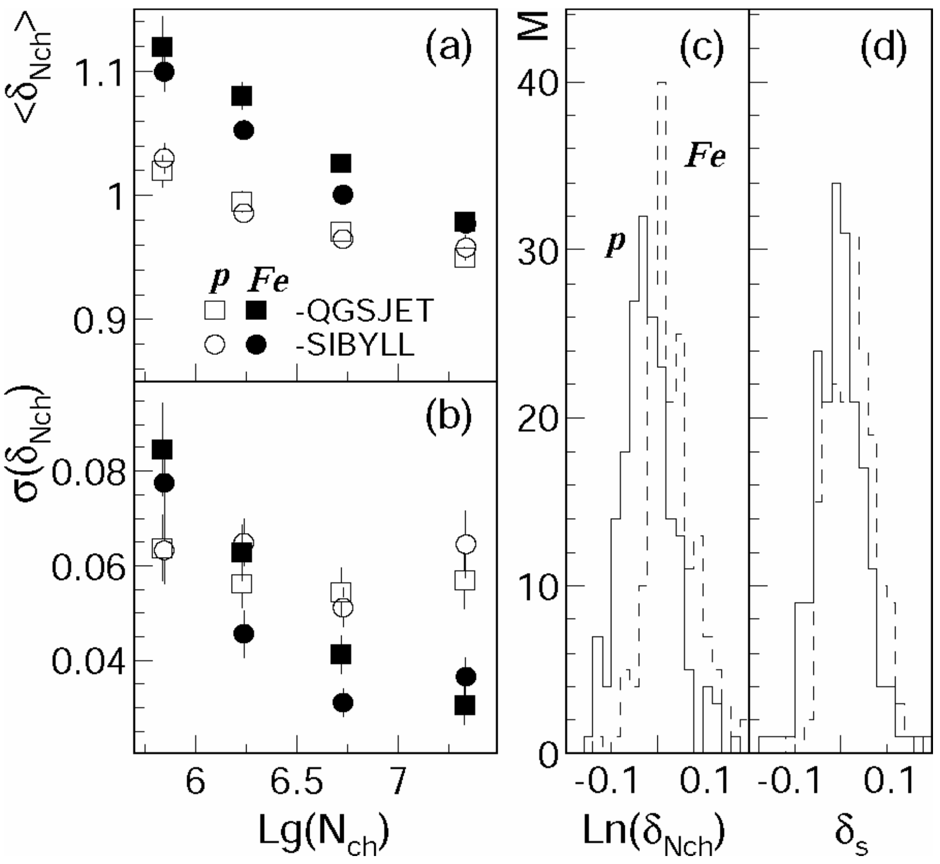
$E_{max} = 5\cdot10^3$ PeV
$\theta < 30^0$
$\gamma = -1.5$
$E_{e,\gamma} > 1$ MeV
$E_{\mu} > 150$ MeV
$\underline{E}_{\mu} > 4$ GeV ($e^{\pm}$)

Detector response

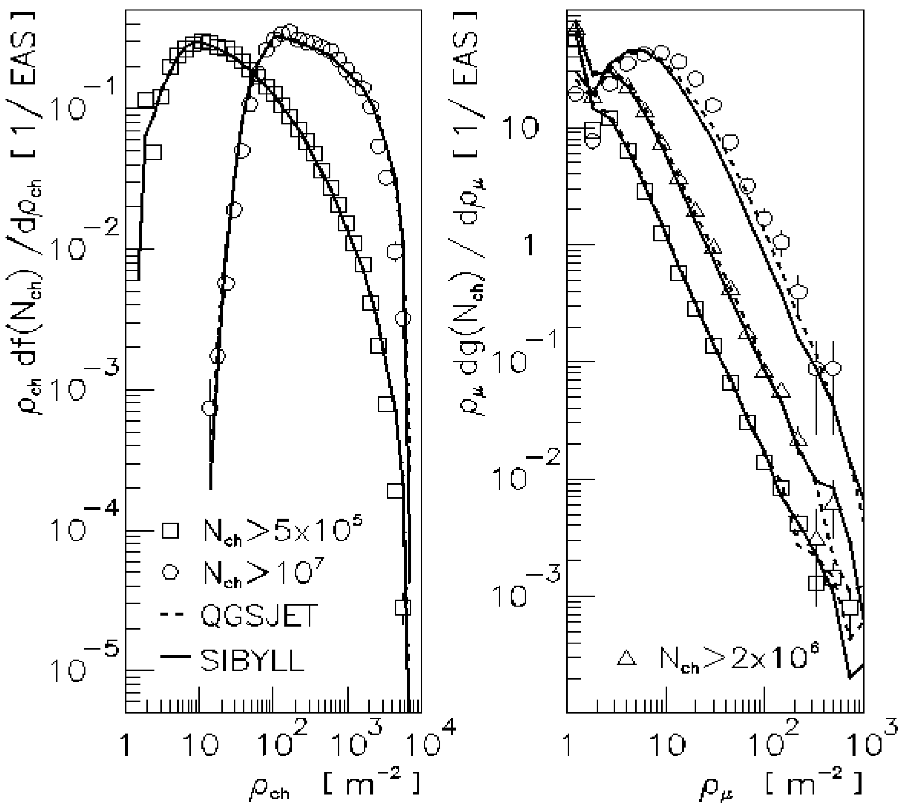
$$\delta_{N_{ch}}(A, N_{ch}) \equiv \frac{N_{ch}(E_e = 1MeV, \text{NKG})}{N_{ch}(E_d, \gamma, \text{EGS})}$$

$$\delta_s(A) \equiv s(E_e = 1MeV, \text{NKG}) - s(E_d, \gamma, \text{EGS})$$

- $s(7\text{m} < r_i < 90\text{m})$

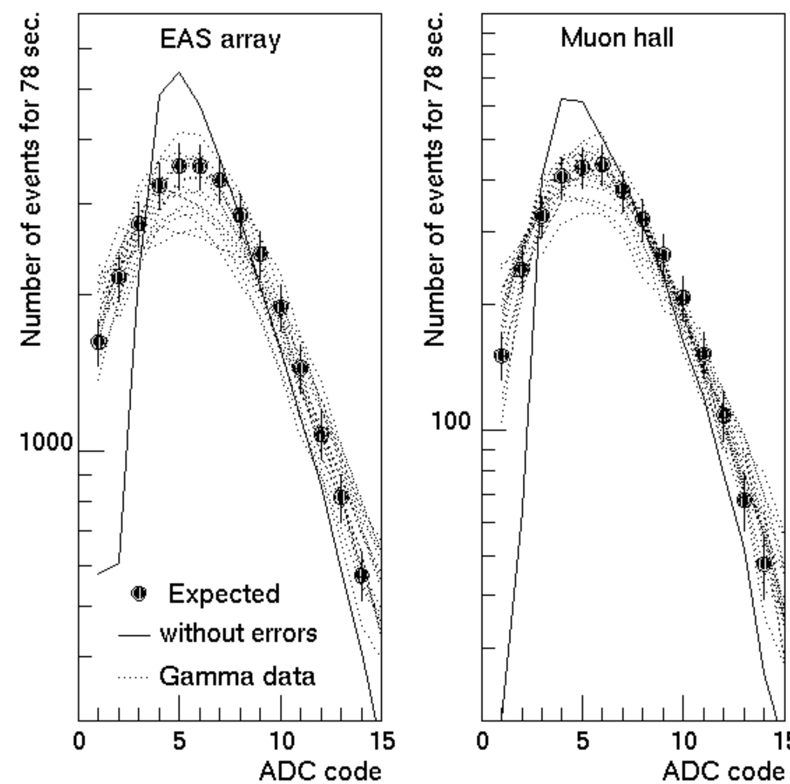


Particle density spectra



$R_i < 50m$

Single particle spectra



15 detectors

EAS Inverse Problem: $$F(X) = \sum_A \int W_A(E,X) f_A(E) dE$$

$$f_Z(E) = \Phi_Z \cdot E_k^{-\gamma_1} \cdot (E/E_k)^{-\gamma}$$

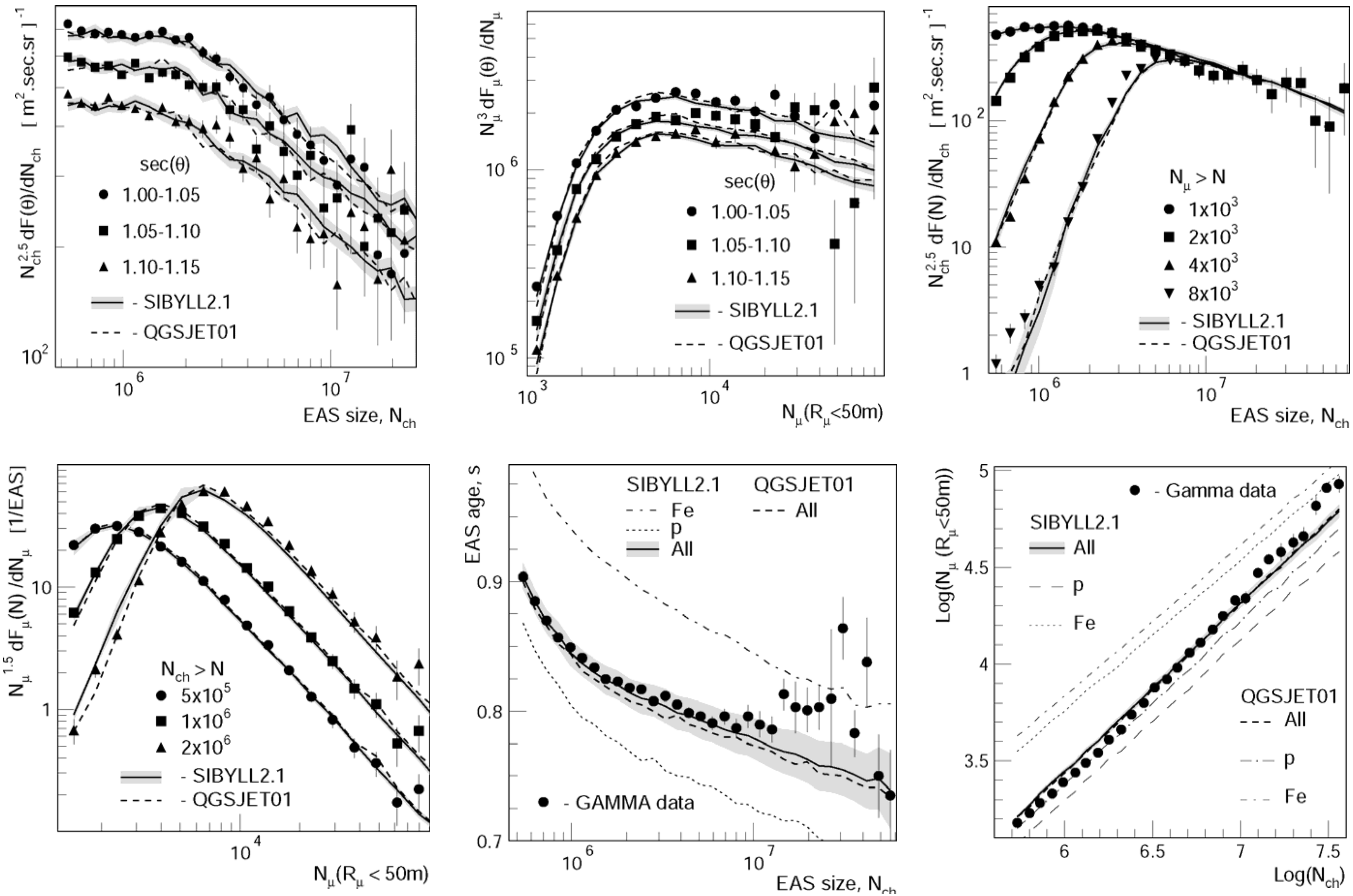
$$\chi^2 = \sum_i [(F_i - \tilde{F}_i)/(\sigma_{F,i} + \sigma_{\tilde{F},i})]^2$$

1) **1-2D** Combined Analysis, $n_{d.f.} = 350$

2) **2D**-Analysis, $\boldsymbol{F(X)} \equiv d^2\boldsymbol{F}/d\boldsymbol{N_e}d\boldsymbol{N_\mu}$, $n_{d.f.} = 240$

3) **4D**-Analysis, $\boldsymbol{F(X)} \equiv d^4\boldsymbol{F}/d\boldsymbol{N_e}d\boldsymbol{N_\mu}d\boldsymbol{s}\, d\boldsymbol{cos}\theta$, $n_{d.f.} = 1640$

GAMMA EAS data and predictions



$$T = 6.19 \cdot 10^7 \ sec, \quad N_{EAS} \approx 2 \cdot 10^5$$

Primary energy spectra

$$f_Z(E) = \Phi_Z E_k^{-\gamma_1} \left(\frac{E}{E_k} \right)^{-\gamma}$$

$$E_k = Z \cdot E_R$$

$$E < E_k \Rightarrow \gamma = \gamma_1 \cong 2.68 \pm 0.02$$

$$E > E_k \Rightarrow \gamma = \gamma_2 \cong 3.19 \pm 0.03$$

Results of 1-2D Combined Analysis

$\Phi_1 = 0.095 \pm 0.008$ [$m^{-2} \cdot s^{-1} \cdot sr^{-1} \cdot TeV^{-1}$]

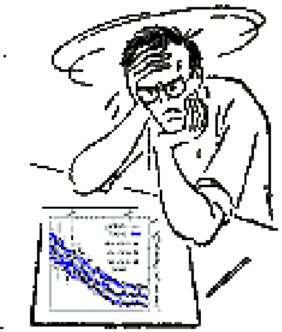
$\Phi_2 = 0.10 \pm 0.012$

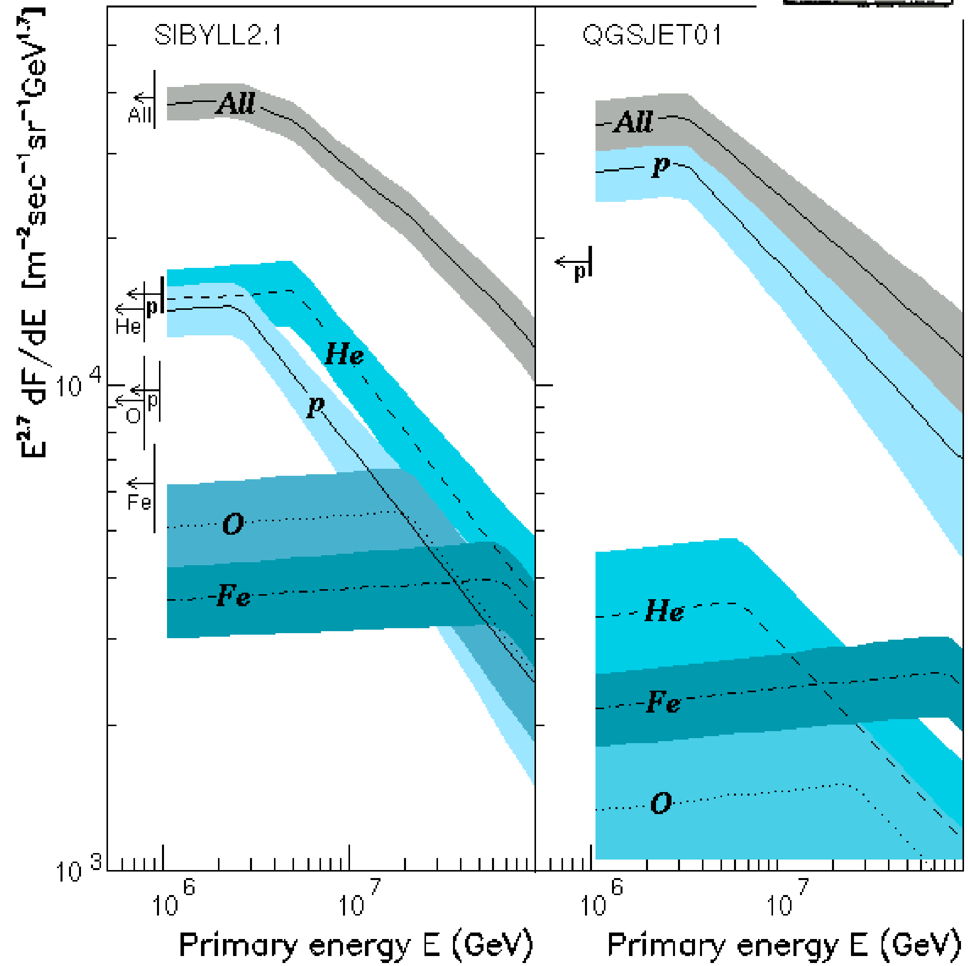
$\Phi_{3\text{-}16} = 0.043 \pm 0.007$ (*O - like*)

$\Phi_{17\text{-}26} = 0.024 \pm 0.004$ (*Fe - like*)

$\boldsymbol{E_R} = 2500 \pm 200$ TV

$\chi^2/n_{d.f.} \approx 2.0$

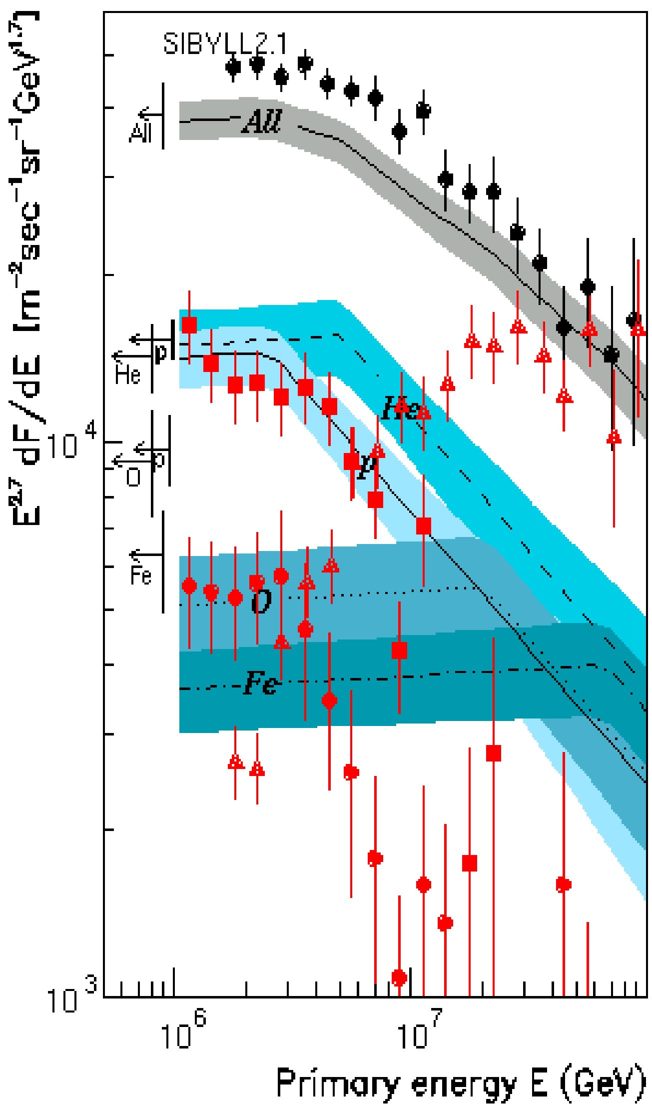




B.Wiebel & P.Biermann, 24th ICRC (1995)

A.Lagutin et al., 29th ICRC (2005)

GAMMA and KASCADE

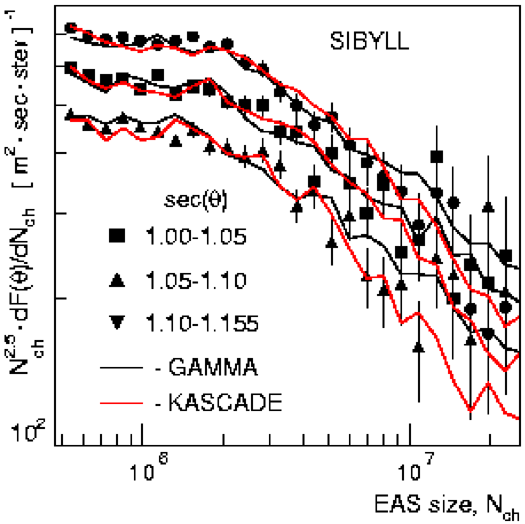


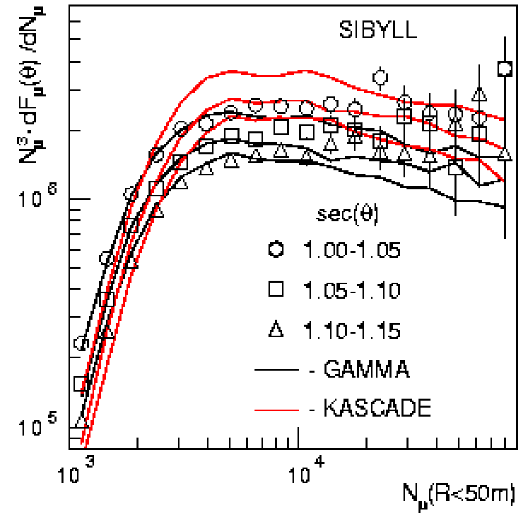
Verification

Test of
KASCADE primary energy spectra
by GAMMA EAS data

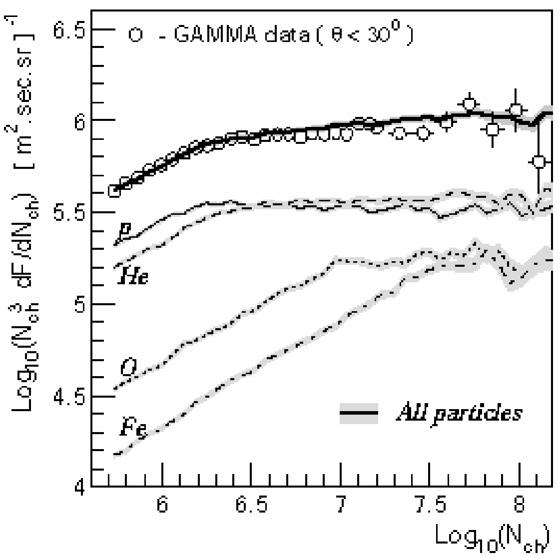
$$\sum_{Z}\int W_Z(E,\boldsymbol{X})\, f_Z(E)\, \mathrm{d}E = F(\boldsymbol{X})$$

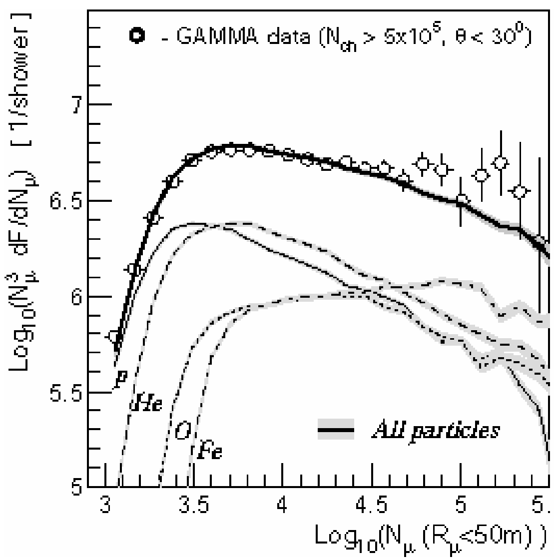
- f_p, f_{He}, $f_O = f_C + f_{Si}$, f_{Fe}



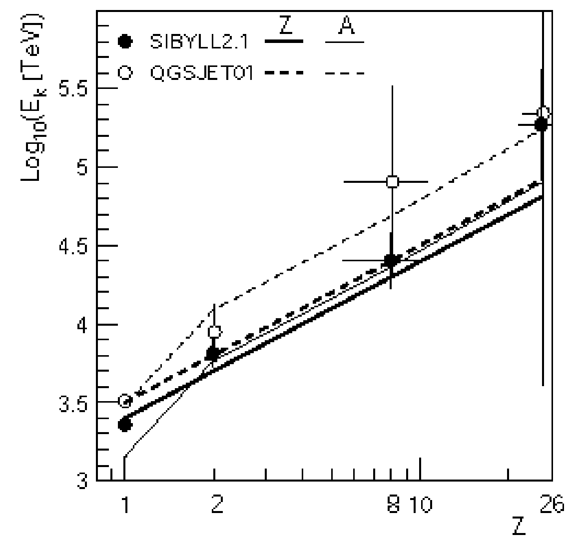


Enlarged EAS data (R<50m)



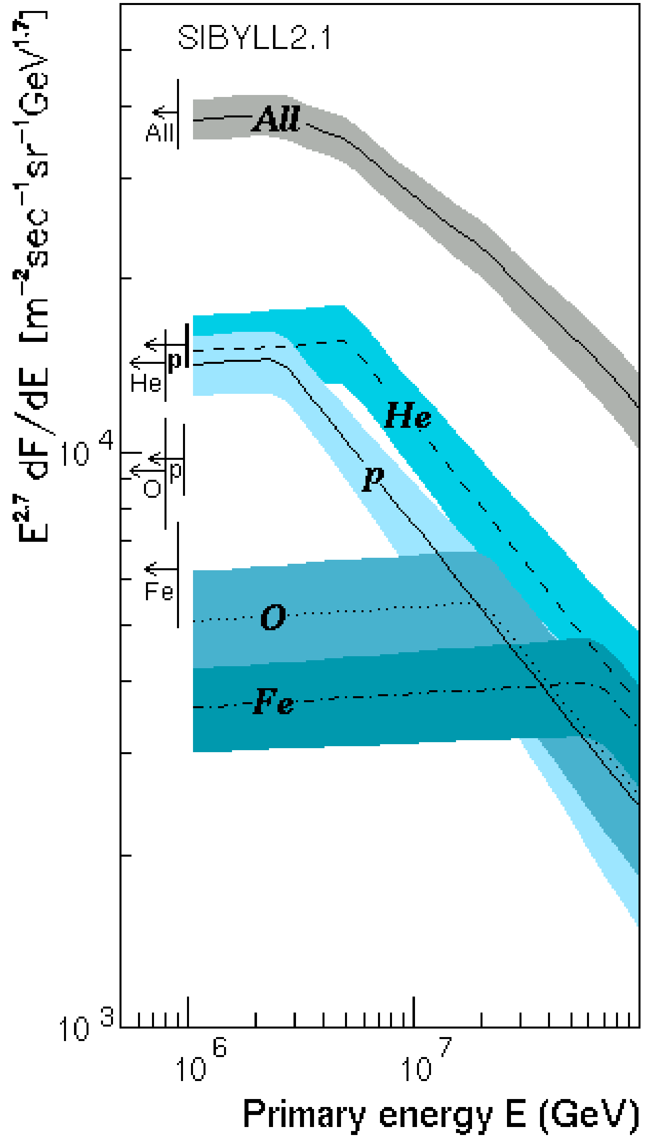


Knee positions



Conclusion

- The obtained primary energy spectra strongly depend on interaction model.
- The SIBYLL interaction model is more preferable.
- Rigidity-dependent spectra describe the EAS data at least up to E~100 PeV.
- All-particle primary energy spectra slightly depend on interaction model.



✓ The energy spectra of primary nuclei disagree with the same KASCADE data in 1-100 PeV energy range, however, the discrepancies of the all-particle energy spectra obtained by the GAMMA and KASCADE are sufficiently small (~20%).