Reconstruction of All-Particle Energy Spectrum for ICETOP

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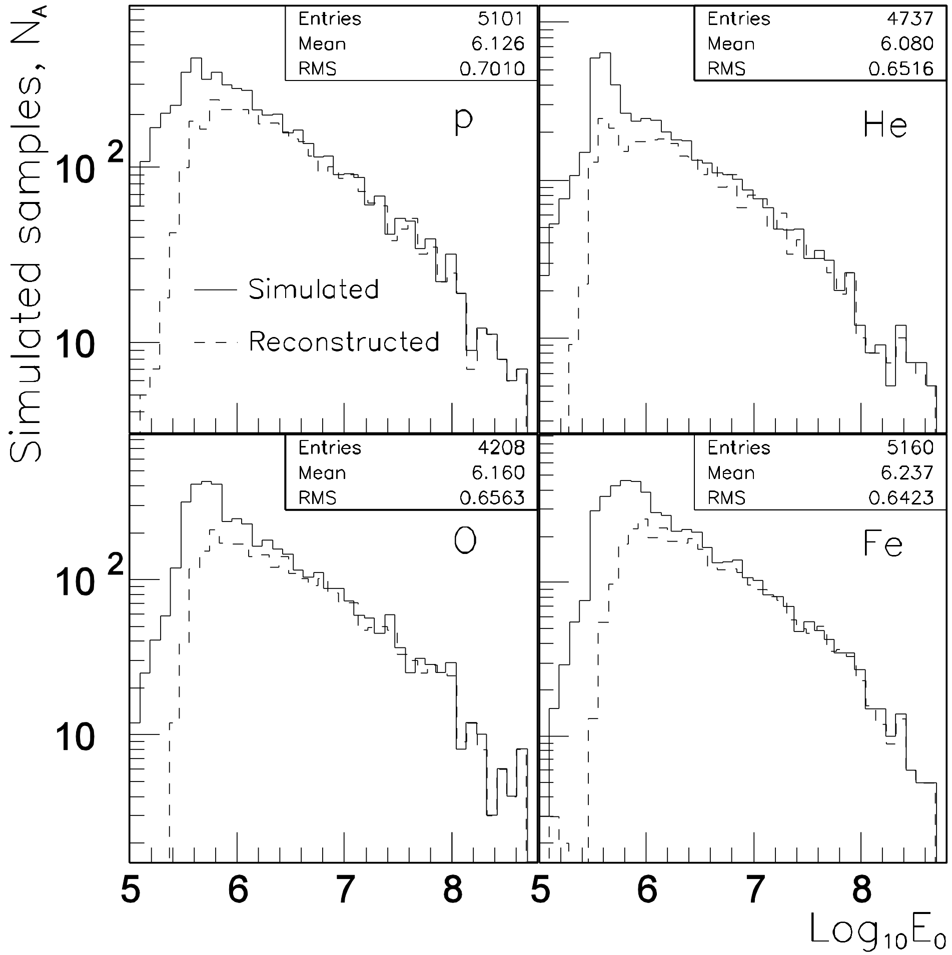
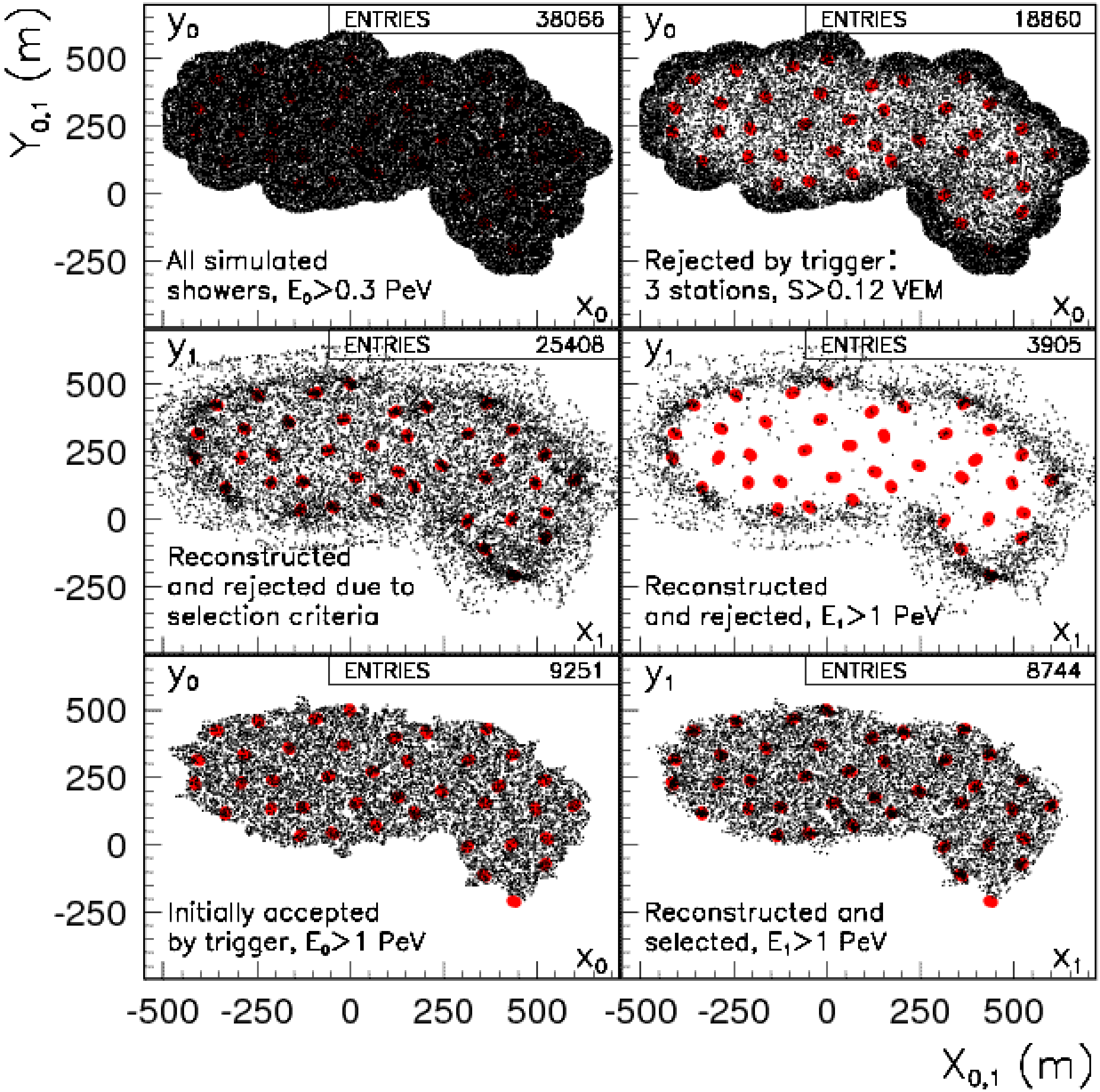
CORSIKA simulated EAS database for 80 tanks configuration

Simulated:
$0.1 < E_0 < 500$ PeV
$\theta < 40^0$
p, He, O, Fe
$R_{nearest1} < 120$m

Reconstructed:
$S_{min} = 20$pe
At least 3 stations within R<150m



Shower core coordinate distributions



Multi-parametric energy estimator for ICETOP Array

Energy estimator: $$E_1 = a_1 + \frac{a_2}{\cos\theta} + S_{125}\left(a_3 + \frac{a_4\cos\theta}{\beta} + (a_5\beta)^{a6}\right)$$

$\min\{\chi^2(a_1, a_2, \ldots a_6, \sigma(E_i) \mid E_{0,i})\}$

$$\chi^2 = \sum_A \sum_i \frac{(\ln E_{0,A,i} - \ln E_{1,i})^2}{\sigma^2(E_0)}$$

$\chi^2/n_{df} = 1.05$

$i=1,\ldots 2000$

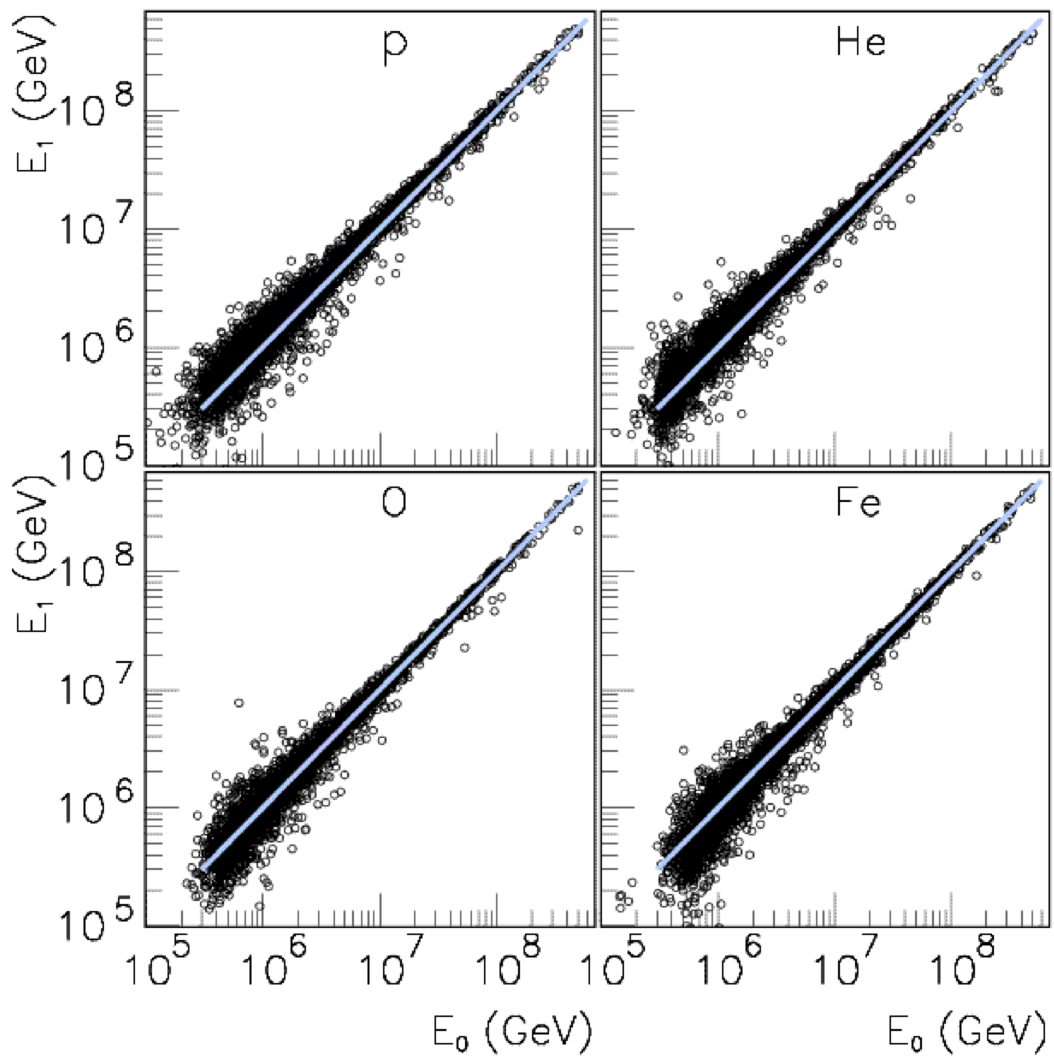
$A \equiv H, He, O, Fe$

$E_0 > 1$ PeV

$\sigma = 0.35 - 0.055 Ln(E/PeV) \pm 0.07$

a1	11.21 ±	0.05
a2	2.336 ±	0.042
a3	0.558 ±	0.015
a4	1.200 ±	0.034
a5	0.241 ±	0.004
a6	7.29 ±	0.52

E_0 - E_1 scatter plots



Inverse problem

Energy estimator: $E_0 \approx E_1 \begin{cases} (N_{e+\gamma}, N_\mu, s, cos\theta) \\ (N_e, N_\mu, \theta)? \\ \rightarrow \{E_0, S_{125}, \theta\}^{-1} \\ (S_{125}, \beta, \cos\theta) \end{cases}$

[GAMMA_09]
[KASCADE-GRANDE]
[ICETOP_09]
This work

$$f(E_1) = \int F(E_0) W(E_0, E_1, A) dE_0$$

is ill-posed problem for $F(E_0)$ due to $A \equiv H, He, \ldots Fe$

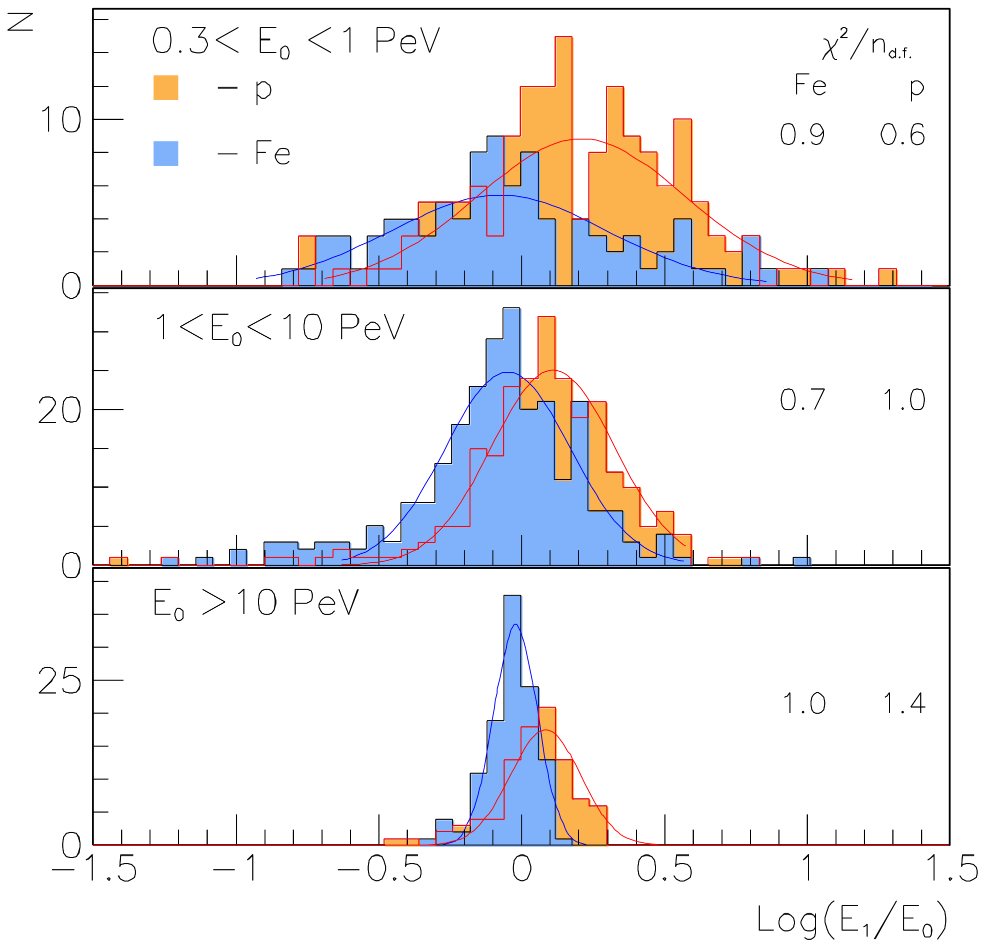
Redefinition of inverse problem:

- *a priori*: $F(E_0) \sim E_0^{-\gamma}$,
- Let $W(E_1, E_0, A) \cong \mathrm{N}(\delta, \sigma \,|\, Ln(E_1))$

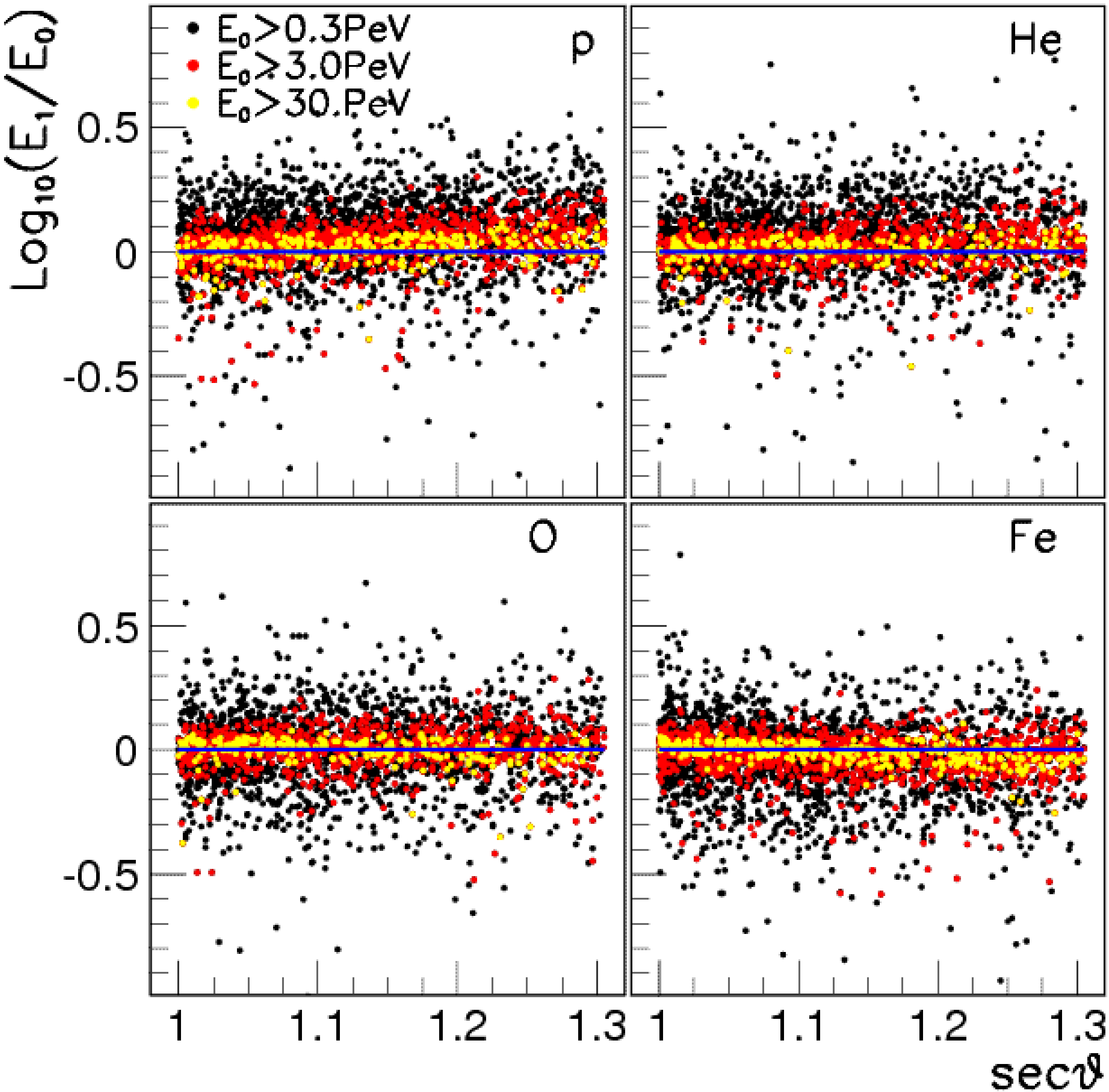
Solution: $$f(E) \cong F(E) \cdot \delta^{\gamma-1} \cdot \exp\left(\frac{\sigma^2(\gamma-1)^2}{2}\right)$$

~1960

Distribution of energy errors (~ Gaussian)



Energy bias versus shower zenith angle



Inverse problem for ICETOP: $f(E_1) = \int F(E_0)P(E_0)W(E_0,E_1)dE_0$

- $F(E_0) \sim E_0^{-\gamma \pm \Delta\gamma}$ for γ=2.9 and $\Delta\gamma$=0.25
- $\delta = \langle E_1 / E_0 \rangle \cong 1 \pm \Delta\delta(E_0)$, $\sigma(E_0) \cong a \cdot Ln(E_0) + b \pm \Delta\sigma$
- $P(E_0) = 1 - \alpha \cdot \exp(-E_0/E_{th})$, uncertainties: $\pm\Delta\alpha$, $\pm\Delta E_{th}$

Fit of solution:

$$f(E) \cong F(E) \cdot P(E'') \cdot \exp\left(\frac{\sigma^2(E') \cdot (\gamma - 1)^2}{2} \right)$$

where $E' = E/3.35$ and $E'' = E \cdot \exp[(-b^2 + 0.88a) \cdot (\gamma - 1)]$

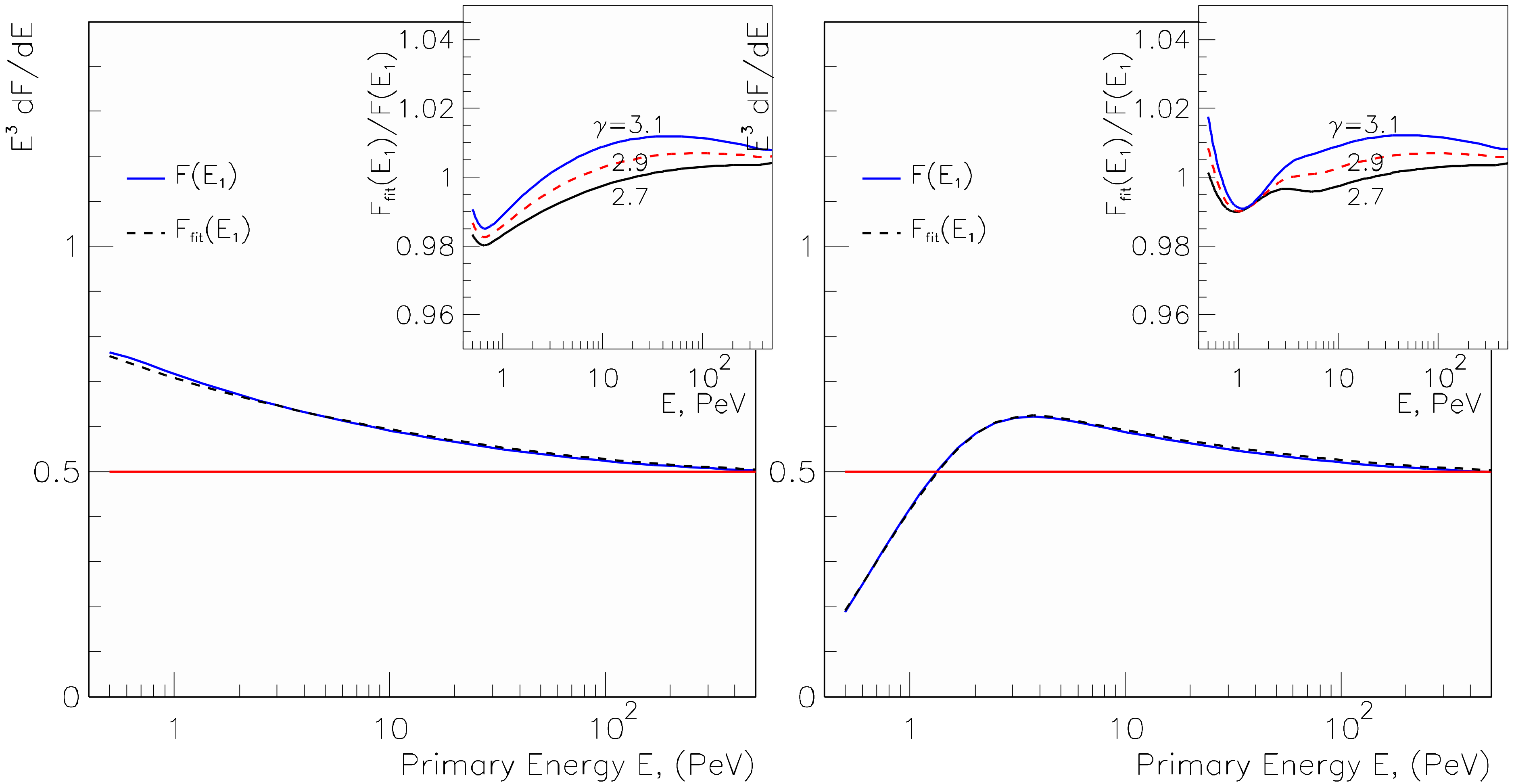
Total systematic spectral errors:

$$\left(\frac{\Delta\tilde{F}}{\tilde{F}} \right)^2 \cong \Delta\delta^2(\gamma-1)^2 + \left[\sigma^2(\gamma-1)^2 \left(\frac{\Delta\sigma}{\sigma} + \frac{\Delta\gamma}{\gamma-1} \right) \right]^2 + \left(\frac{\Delta E_{th}}{E_{th}} \right)^2 \left(e^{E/E_{th}} - 1 \right)^{-2}$$

ICETOP: a=-0.055; b=0.35; $\Delta\sigma$=0.07; α=1.35; $\Delta\alpha$=0.1; E_{th}=0.6; ΔE_{th}=0.15

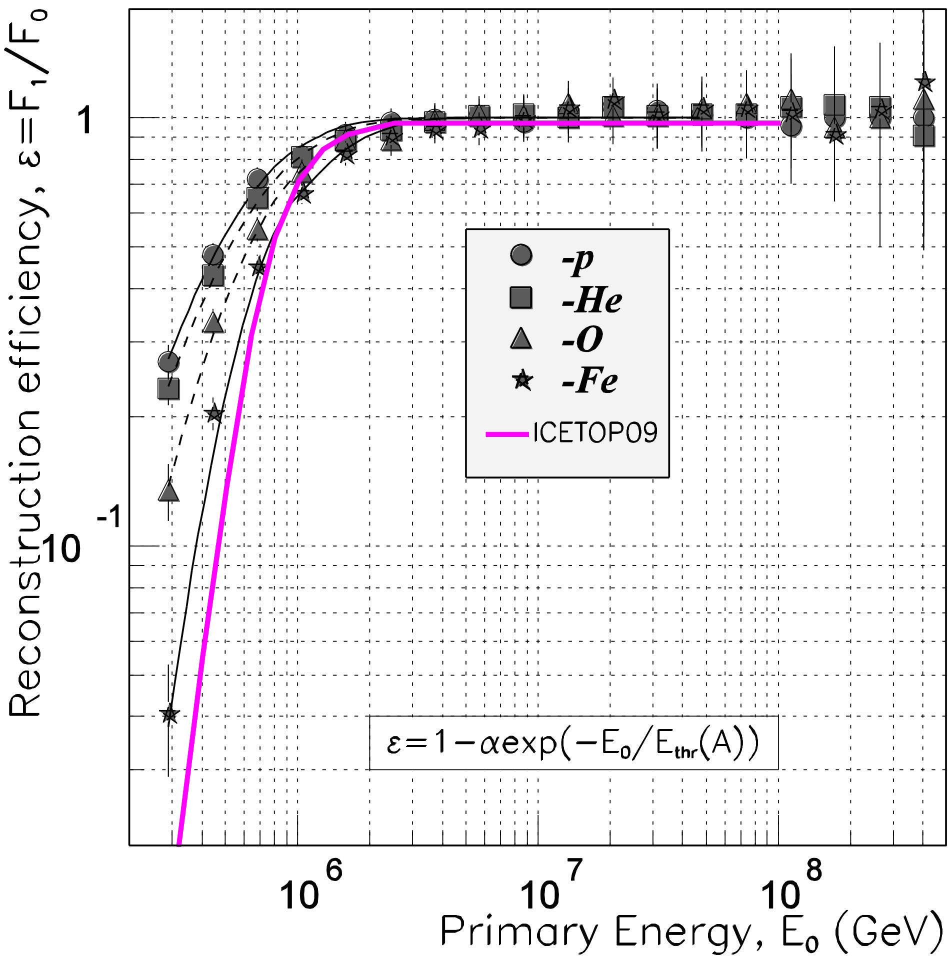
Accuracy of fit of solution (≤ 2%)

Taking into account the threshold



$0.02<a<0.09$; $0.2< b <0.5$; $0.45< E_{th}<$ 0.75 PeV; $0.5<E_0<$700 PeV

Efficiency

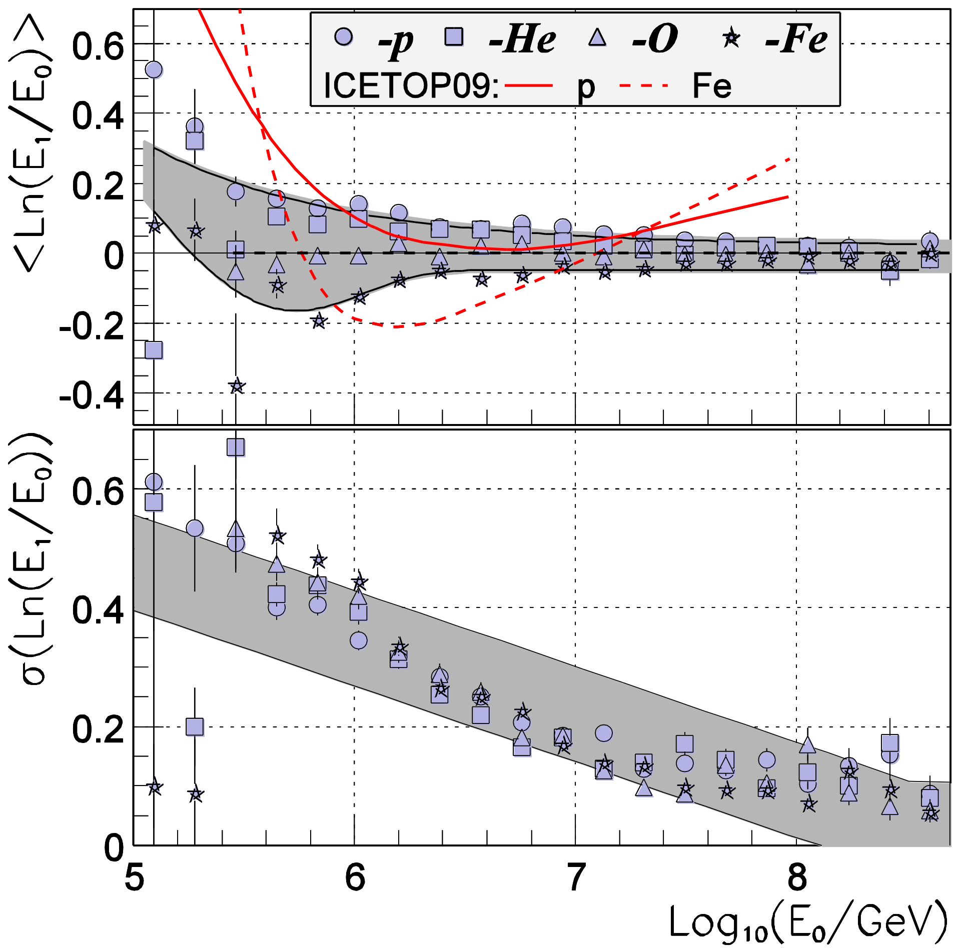


Reconstruction efficiency, ε=F₁/F₀
1
10⁻¹
10⁶
10⁷
10⁸
Primary Energy, E₀ (GeV)
-p
-He
-O
-Fe
ICETOP09
ε=1−αexp(−E₀/E_thr(A))

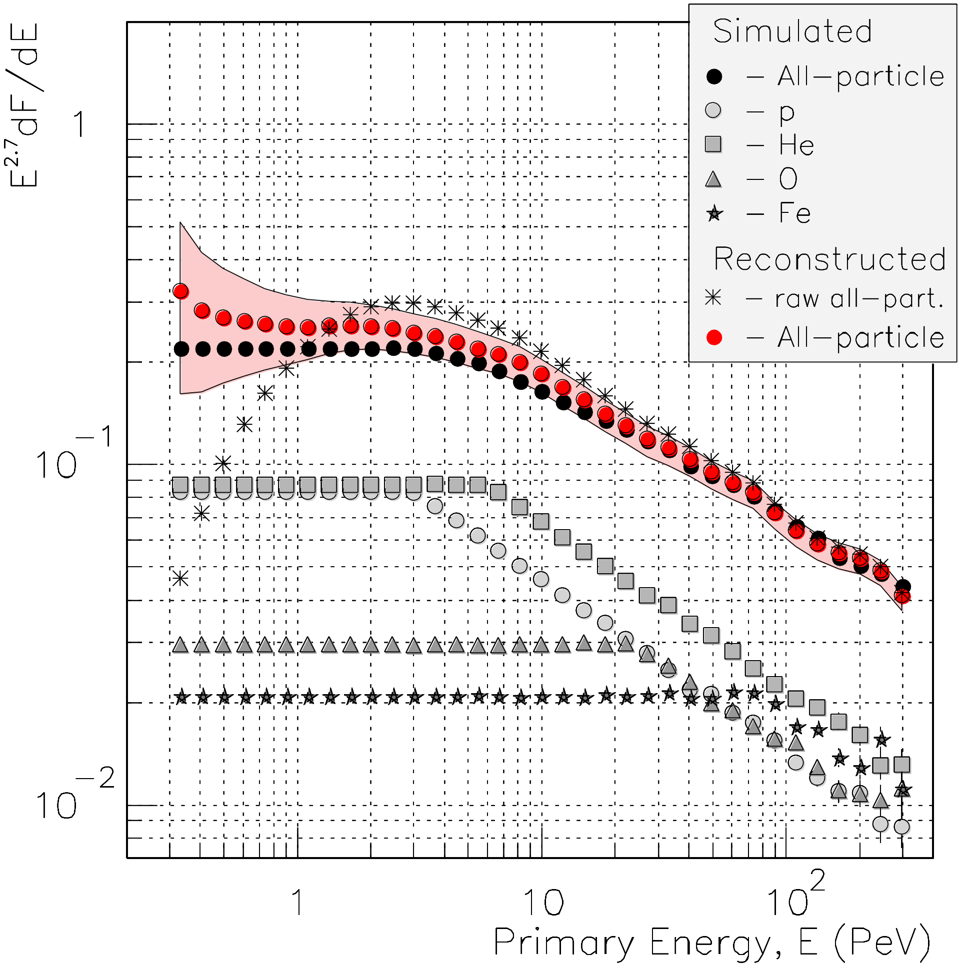
Expected biases and uncertainties of primary energy

if

then



All-particle energy spectrum reconstruction



CONCLUSION

- The results are based on 4x5000 simulated shower events for ICETOP 80 tanks configuration and primary nuclei A $\equiv$ p, He, O and Fe respectively.
- The fluctuation of tank signal and shower reconstruction uncertainties were taken into account.
- 6-parametric primary energy estimator provides 10-15% accuracy for $E \cong$1 PeV and 5-10% for E >10 PeV regardless of primary nuclei kind.
- On the basis of inverse problem approach the reconstruction method for the all-particle primary energy spectrum was developed for ICETOP array.
- The reconstruction method was tested using 4-component rigidity dependent primary energy spectra.

The corresponding all-particle energy spectrum for ICETOP array was derived taking into account the energy threshold and energy reconstruction biases and uncertainties in the energy range 0.5-500 PeV.