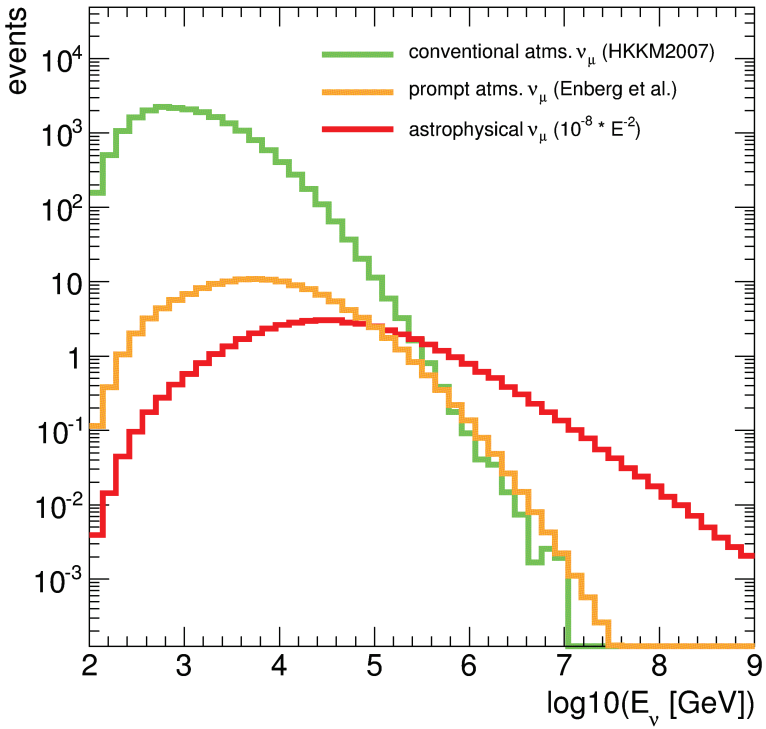
The 2 Icecube PeV events

[*A. Schuhkraft@NOW2012*]

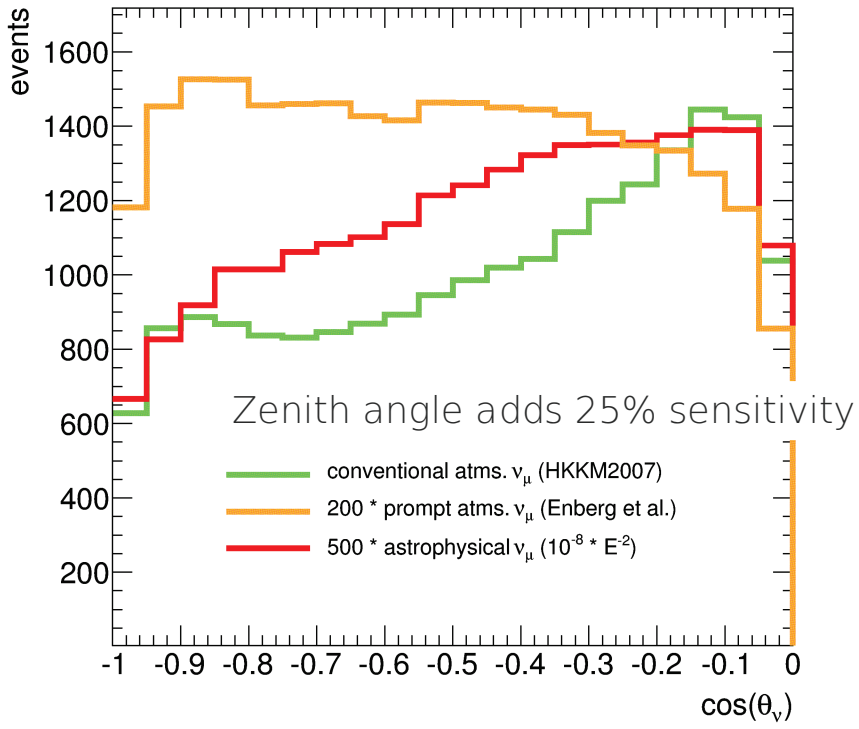
Energy distribution

The three neutrino components have different spectral slopes



Zenith angle distribution

Additional sensitivity through characteristic angular distributions



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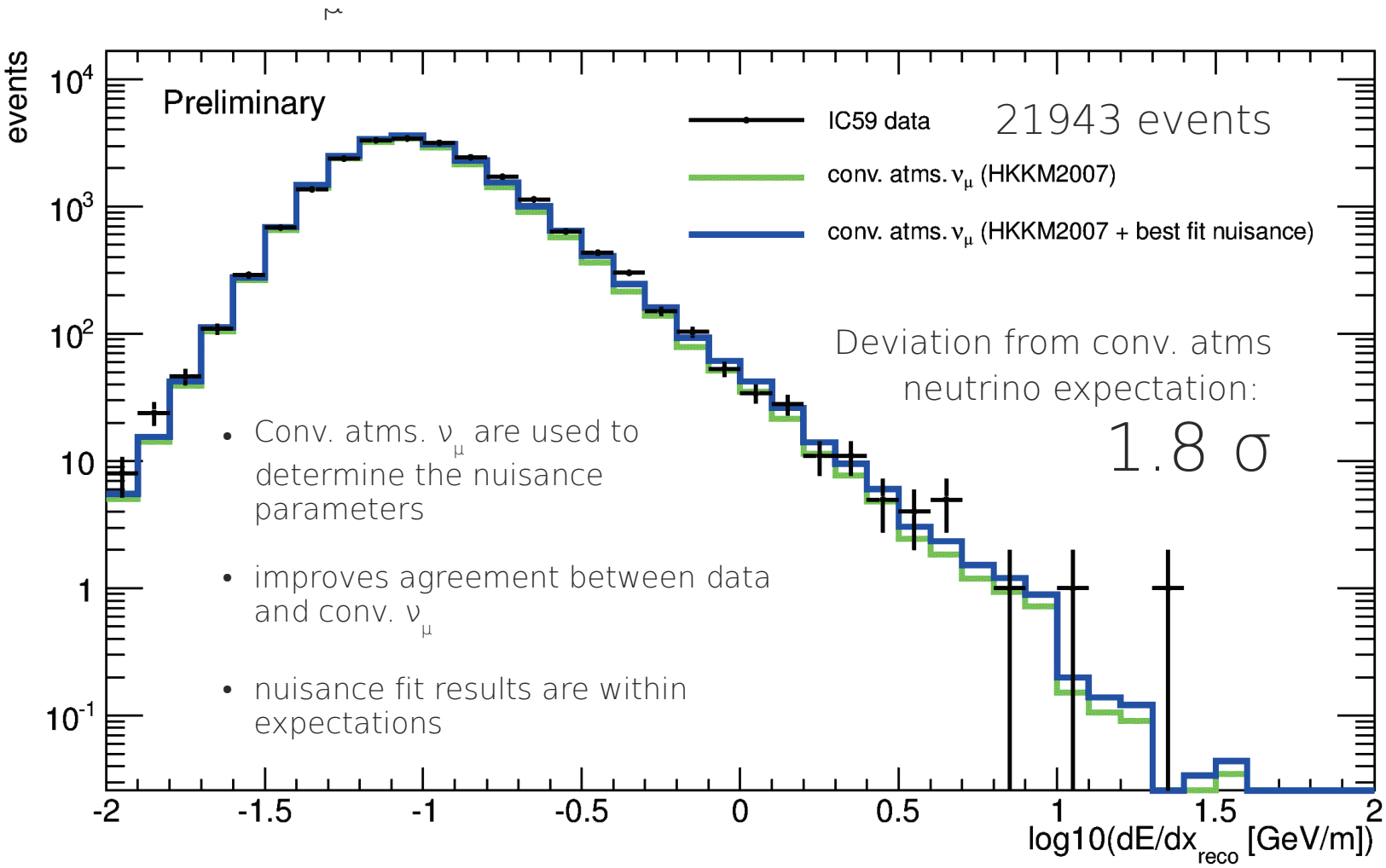

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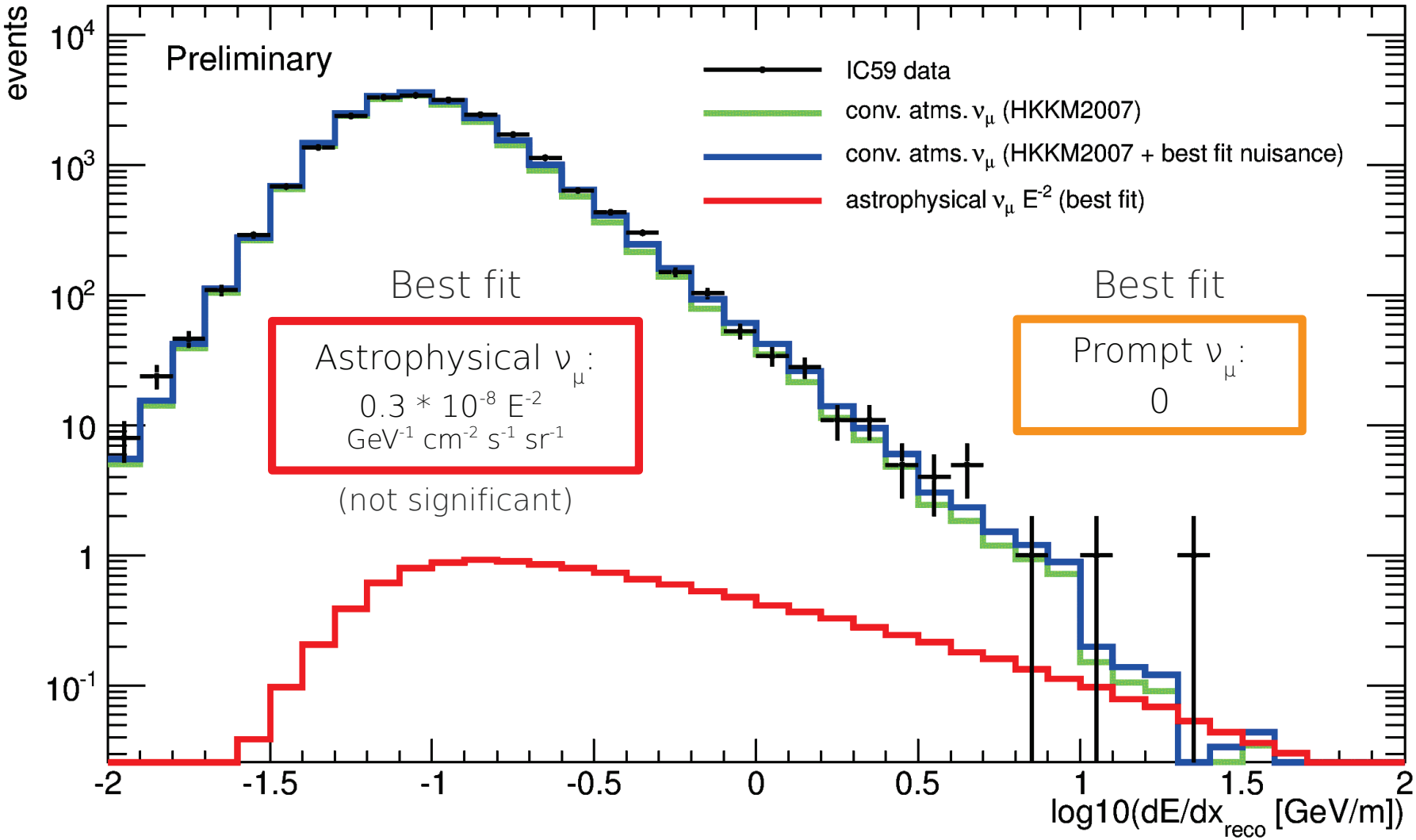

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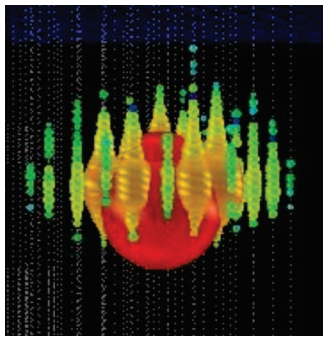

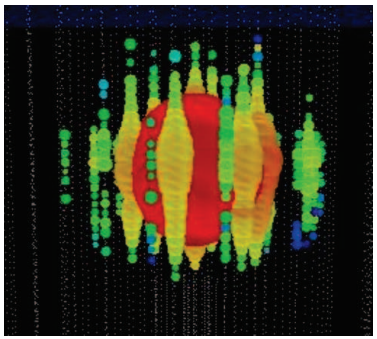

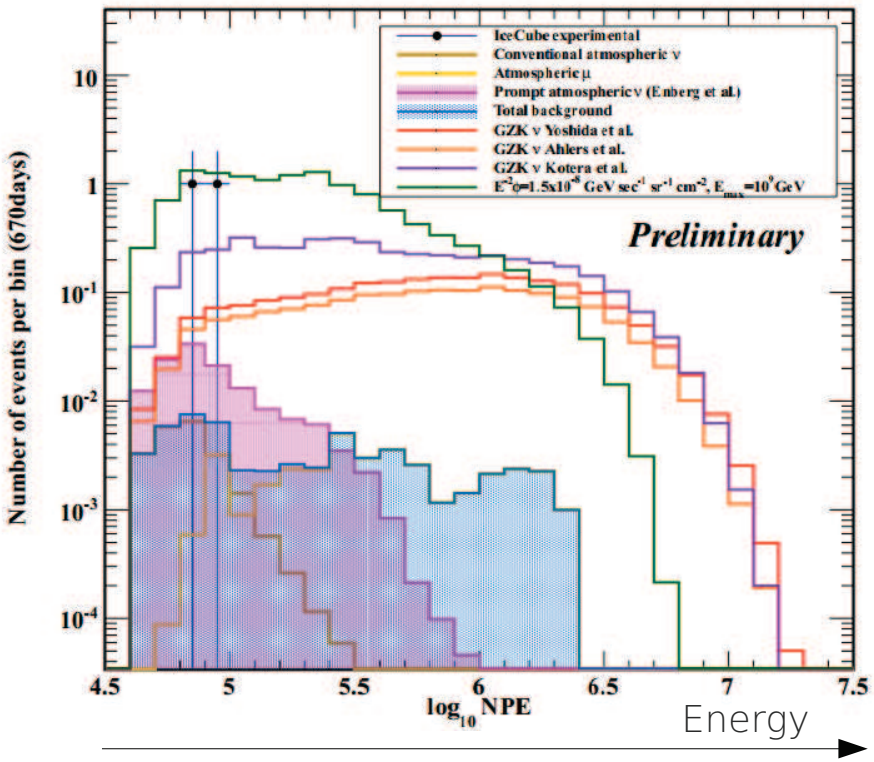

Expected event numbers

Atms. Background (conv. ν + μ)	0.06
Prompt atms. ν (Enberg et al. + knee)	0.13
Prompt (IC59 limit)	0.30
Astrophysical (IC59 best fit) 0.3×10^{-8} GeV cm^{-2} s^{-1} sr^{-1}	1.7
Astrophysical (IC59 limit) 1.4×10^{-8} GeV cm^{-2} s^{-1} sr^{-1}	9.1
GZK (various models)	0 – 4
Data	2

First PeV-events detected at the low-energy threshold of the IC86 EHE analysis!

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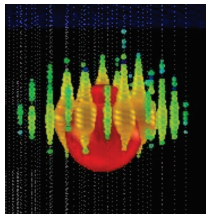

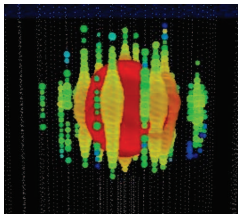

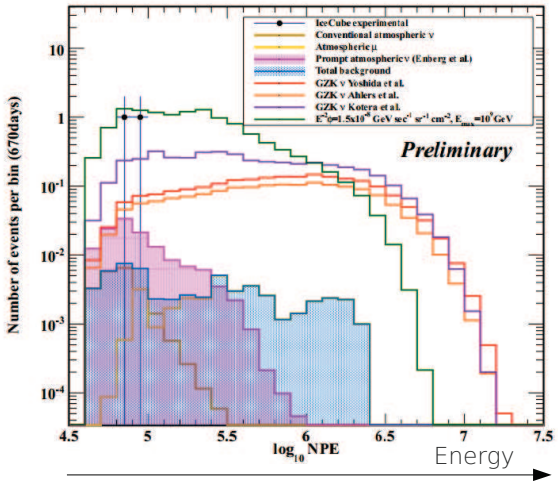

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Comments:

- event rate of cosmogenic neutrinos in PeV range is ~ 0
- event rate due to Glashow resonance is ~ 0
- energies 1.1 PeV and 1.3 PeV below Glashow resonance

$\Rightarrow$ unlikely cosmogenic, rather diffuse extragalactic flux

Acceleration in a Monte Carlo framework

- Bell's microscopic picture:
  - random walk + advection flow

$$\boldsymbol{x}(t+\Delta t) = \boldsymbol{x}(t) + \boldsymbol{l}_0 + v_2\,\Delta t\,\vartheta(r_{\rm sh}-r)\,\boldsymbol{e}_r$$

  - Bohm diffusion: step size $l_0 = R_L$
  - energy gain, if shock is crossed

$$\xi = \frac{4}{3c}(v_2 - v_1) = v_{\rm sh}/c$$

  - stop, if $t > t_{\rm max}$ or $r > r_{\rm esc}$

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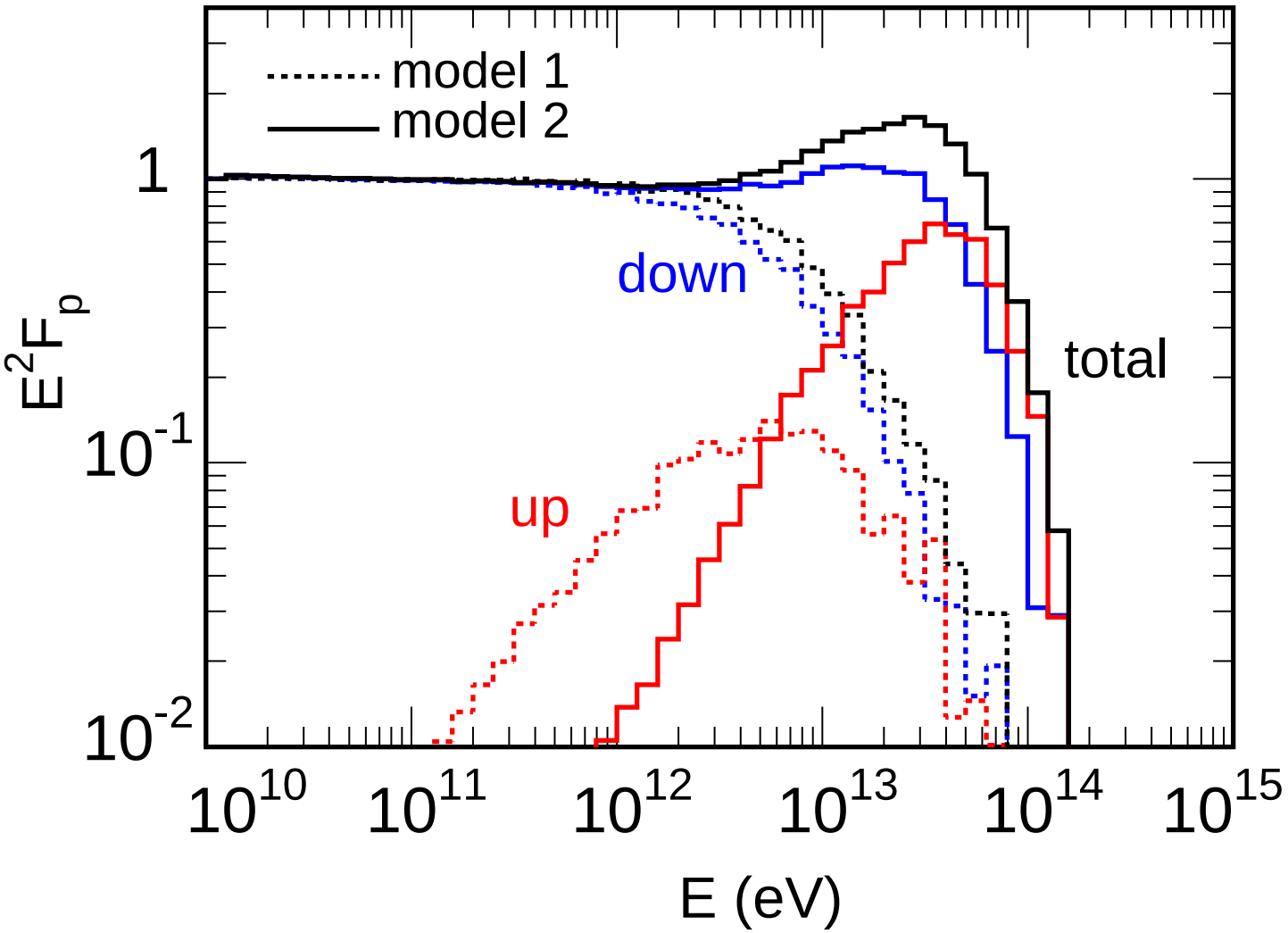
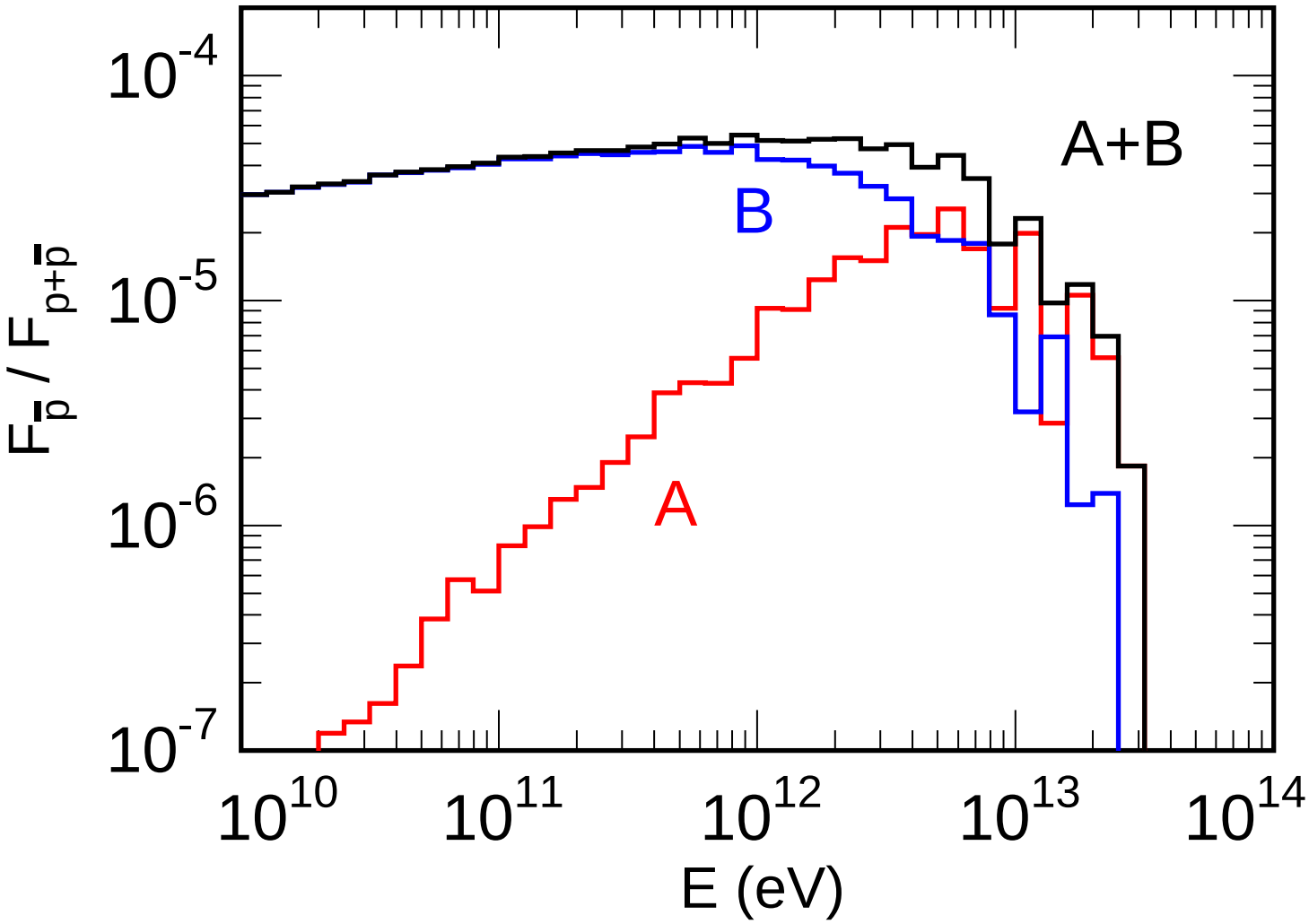
- easy to include:
  - time-dependence of $v_{\rm sh}, B, \ldots$
  - interactions: production of multi-particle states using e.g. QGSJET

Time-dependent framework: Proton flux [MK, Ostapchenko, Tomàs '10,'11]



Time-dependent framework: Antiproton ratio



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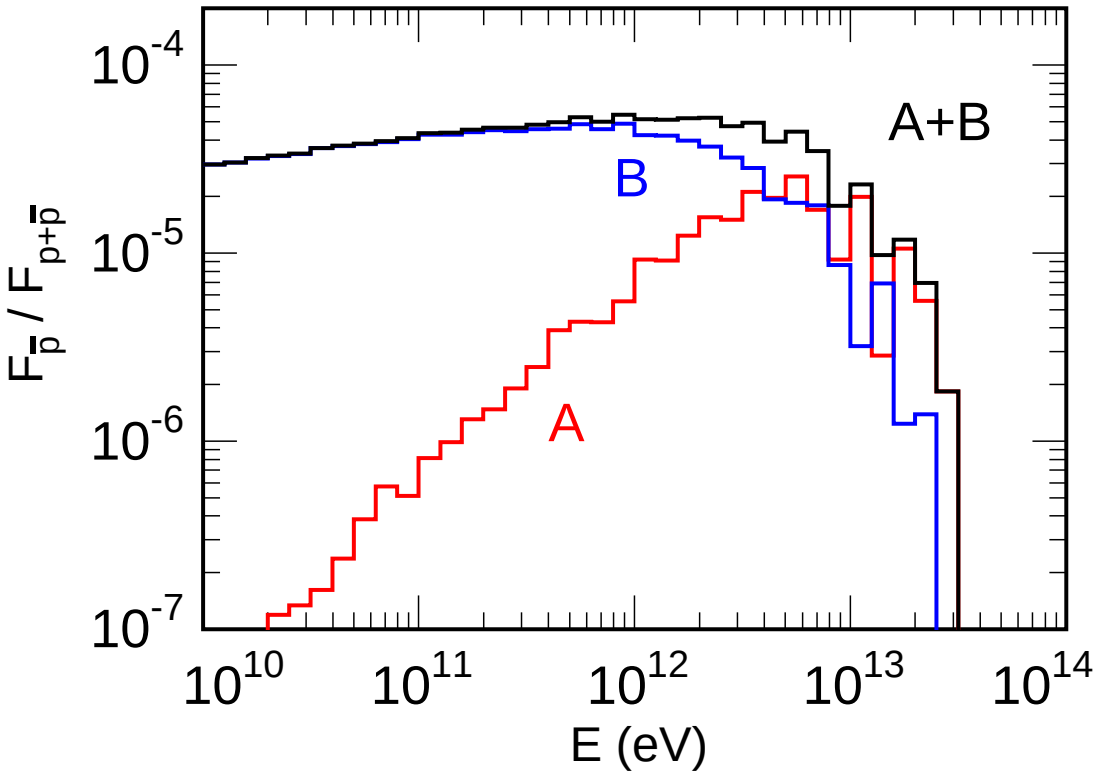

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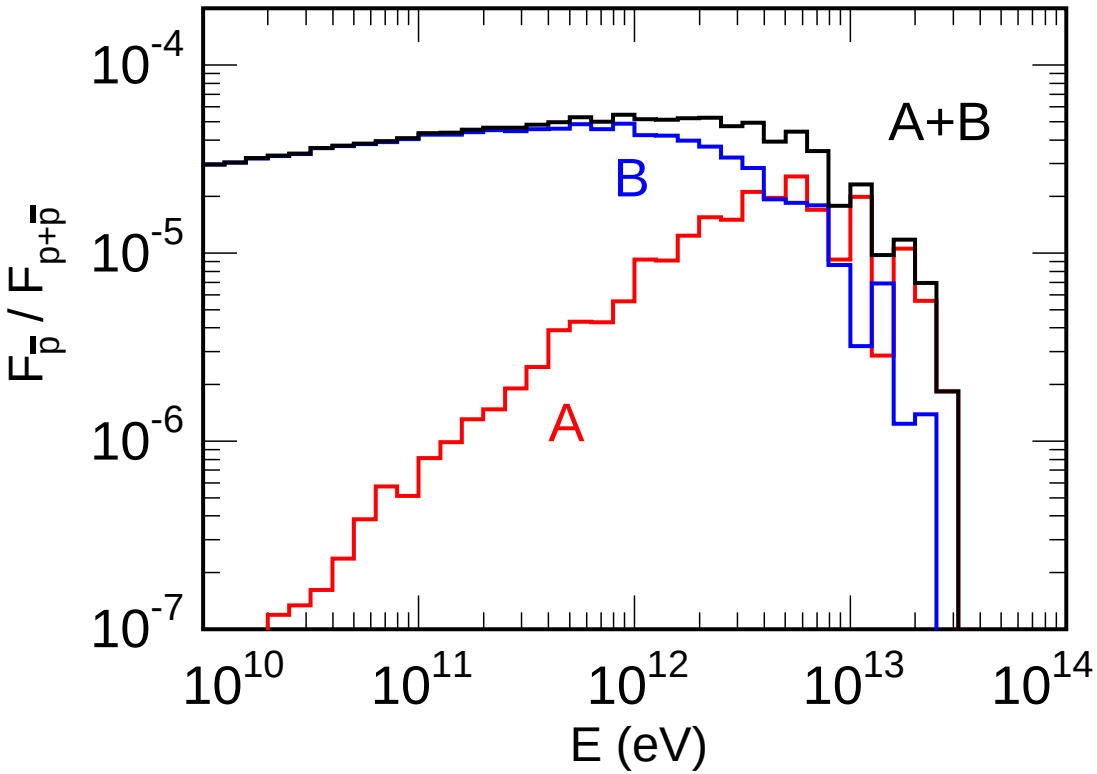
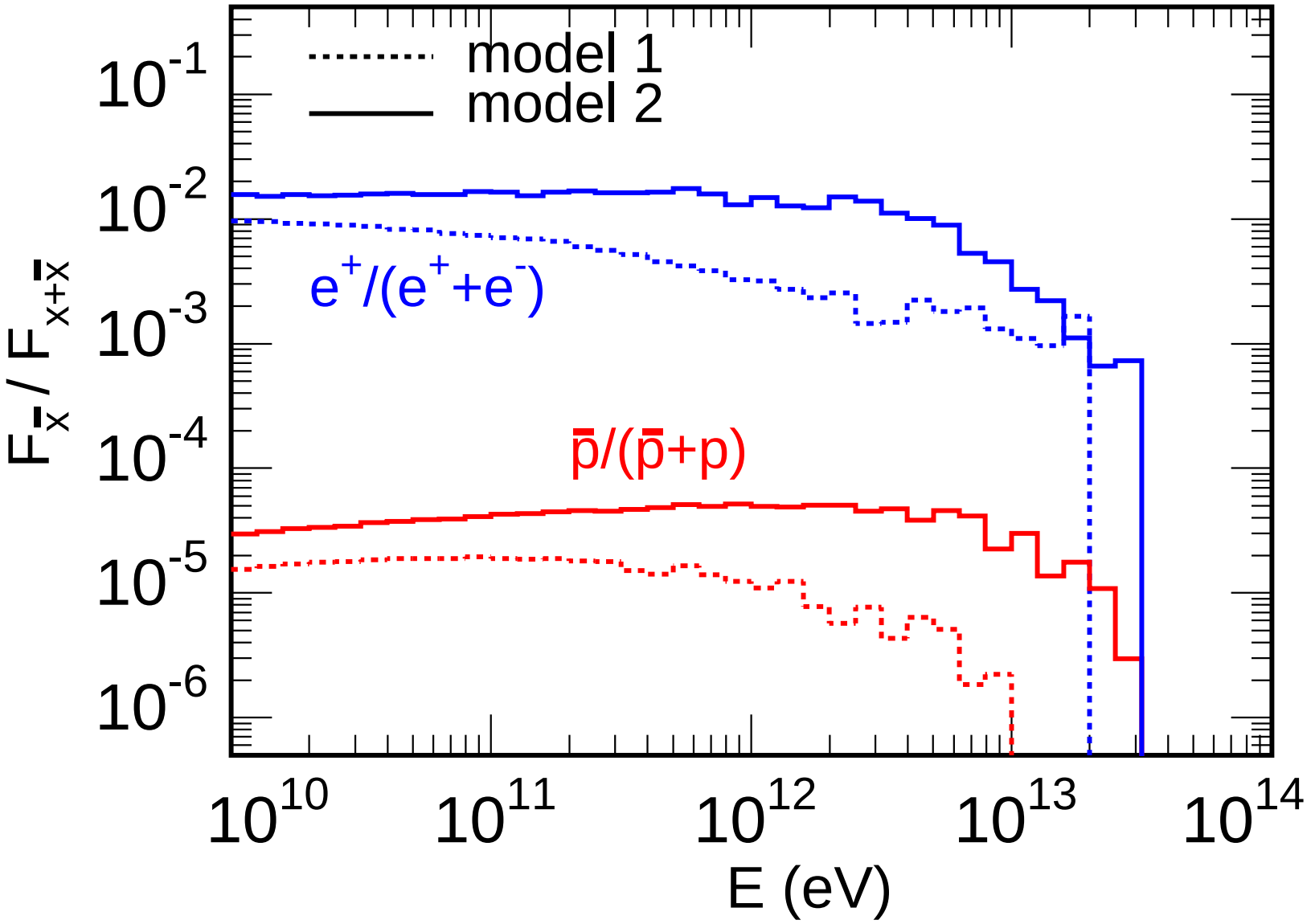


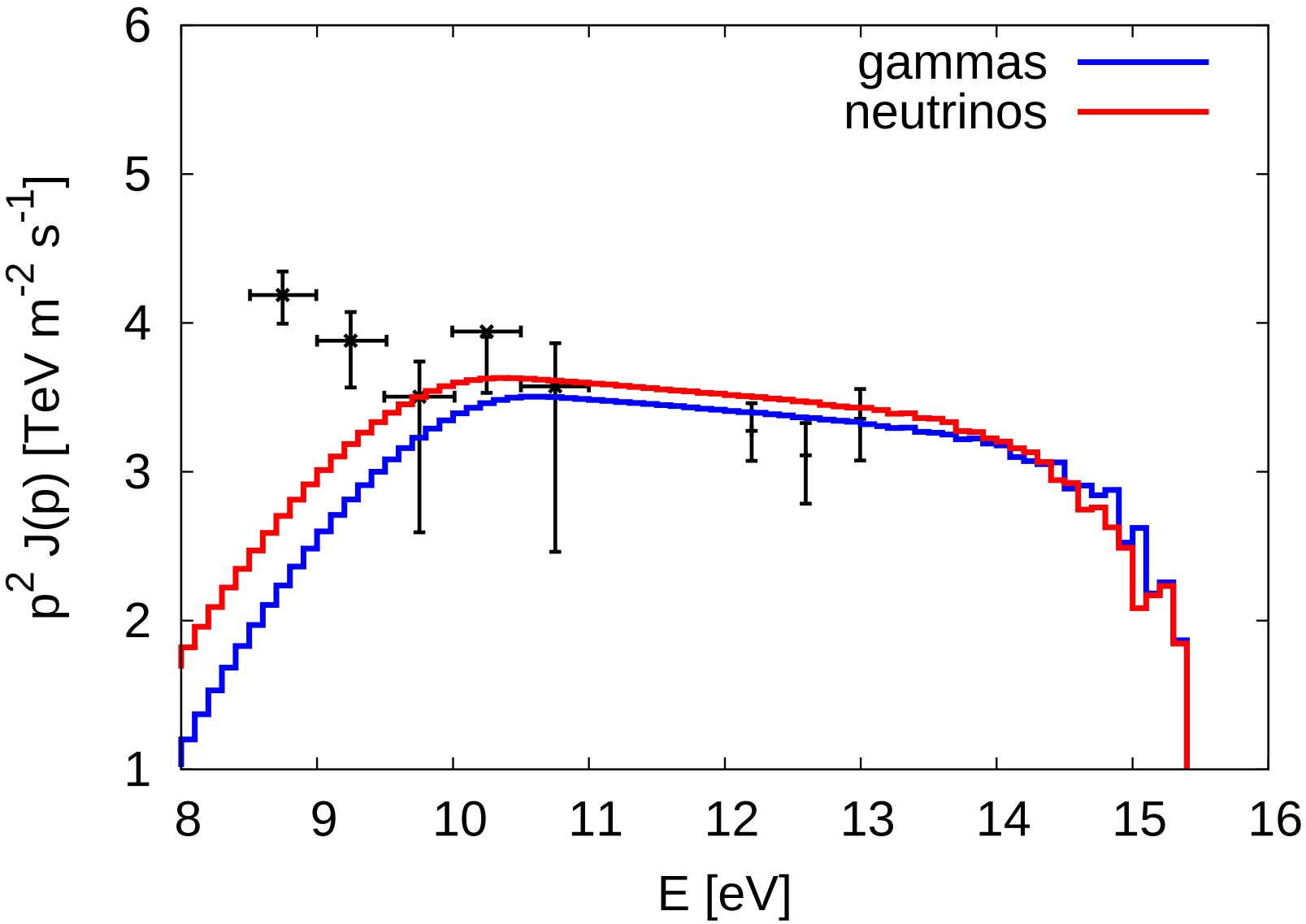
- component A: $\bar{p}$ produced in acceleration zone;
- component B: $\bar{p}$ produced downstream
- A is flatter: $dN/dE(A) \sim E^{-1}$
- but $dN/dE(A+B) \sim E^{-2}$

Antimatter ratios from SNRs

[MK, Ostapchenko, Tomàs '10,'11]



(Hadronic) Photons and neutrinos from Tycho:



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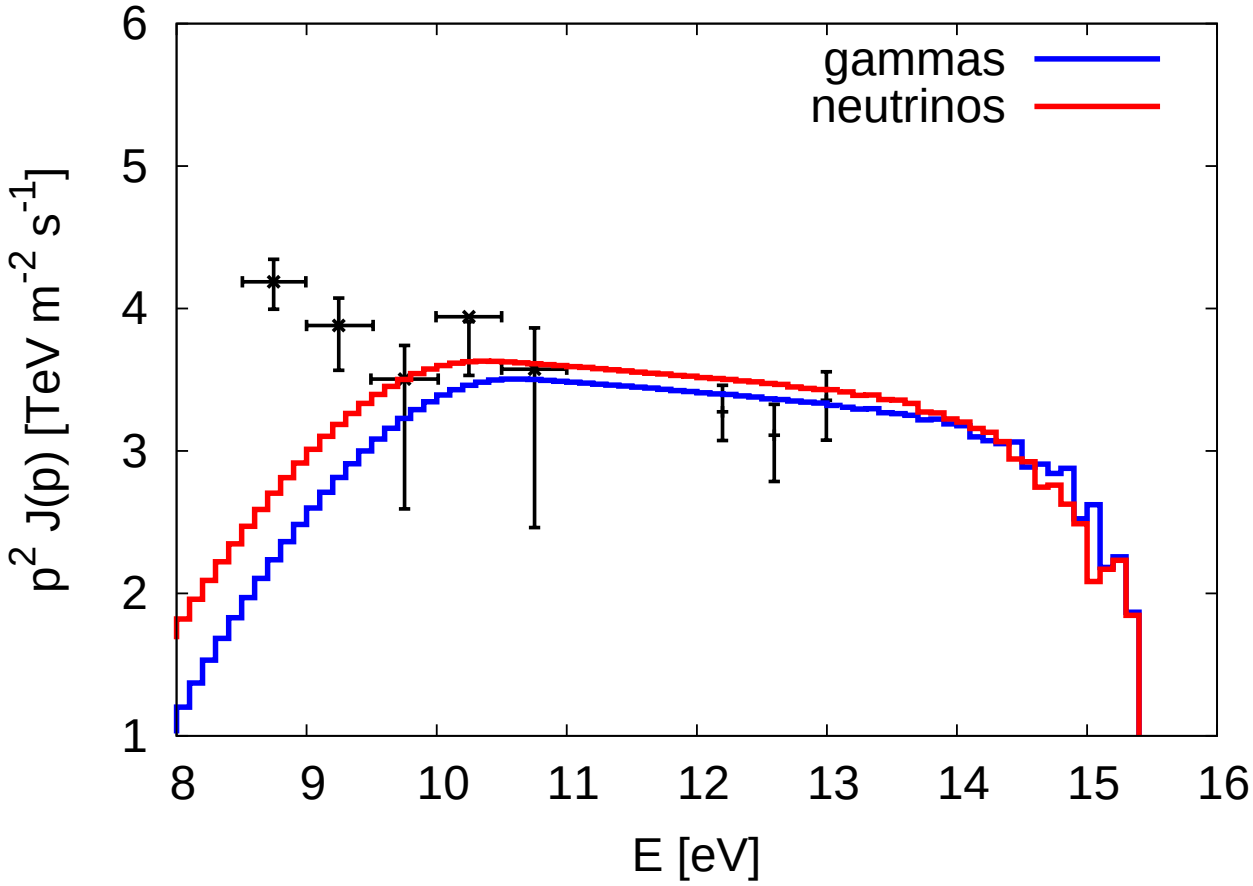
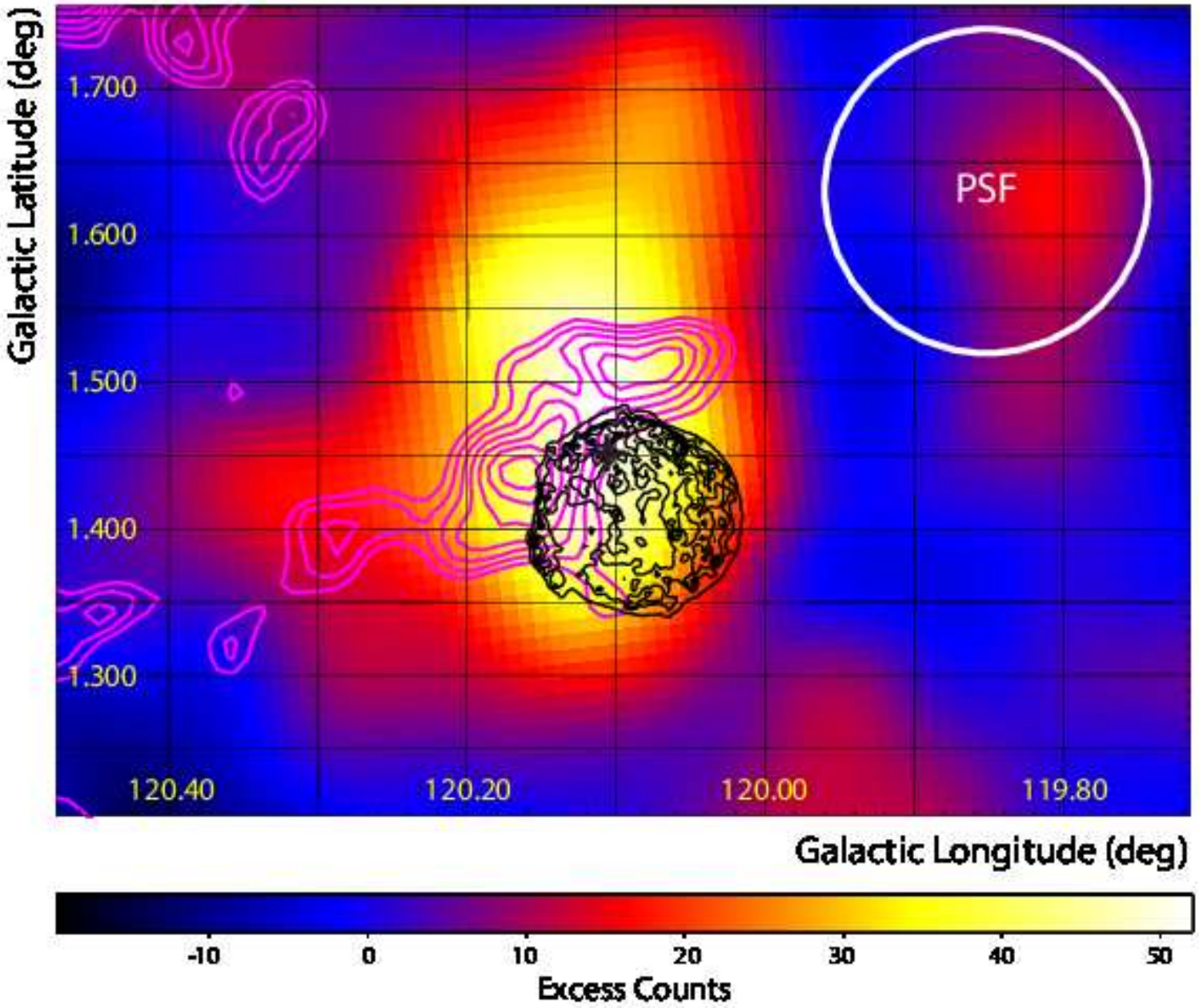
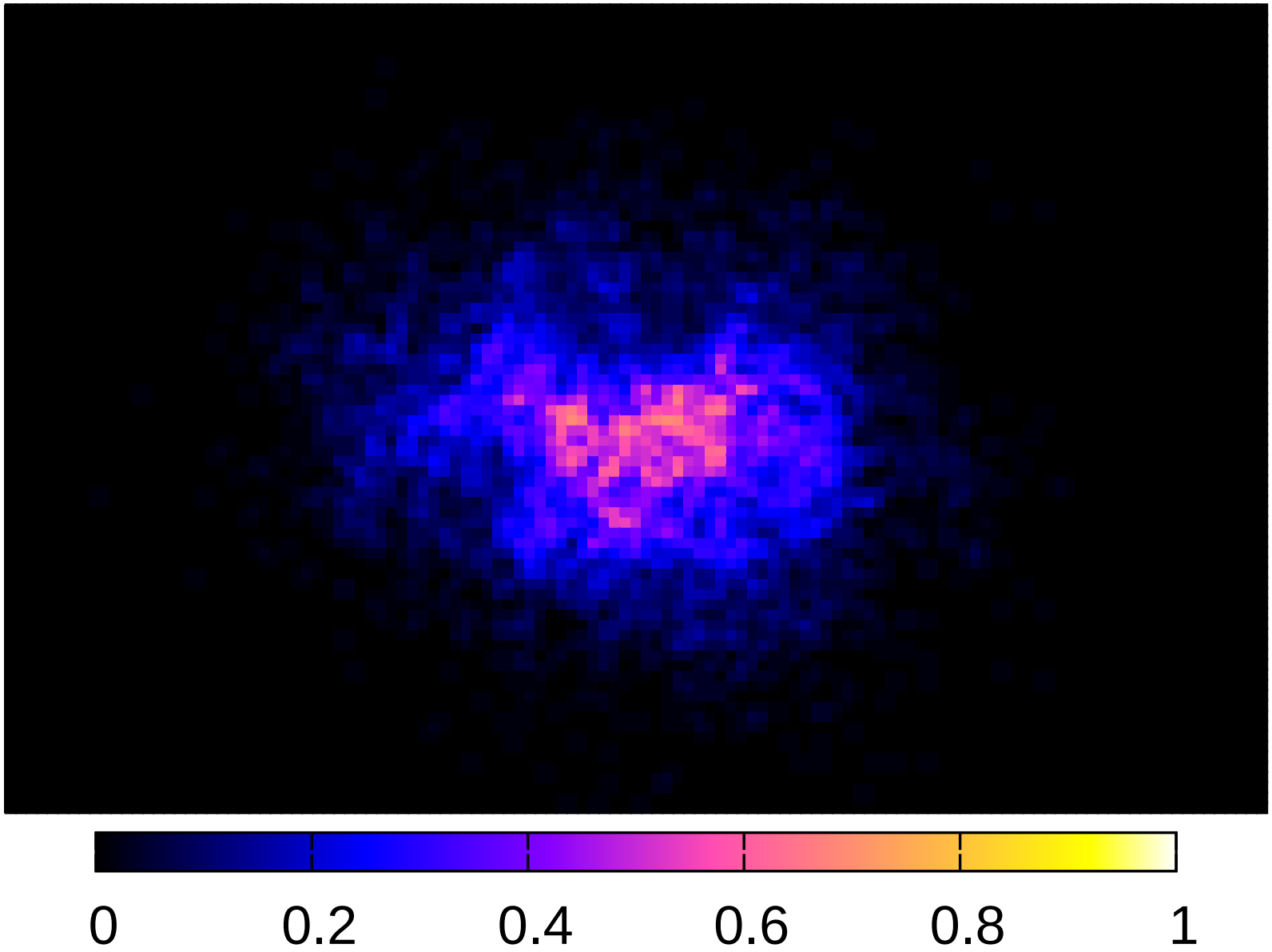


- SNR produce neutrinos with energies up to PeV
- $I_\gamma(E) \sim I_\nu(E)$

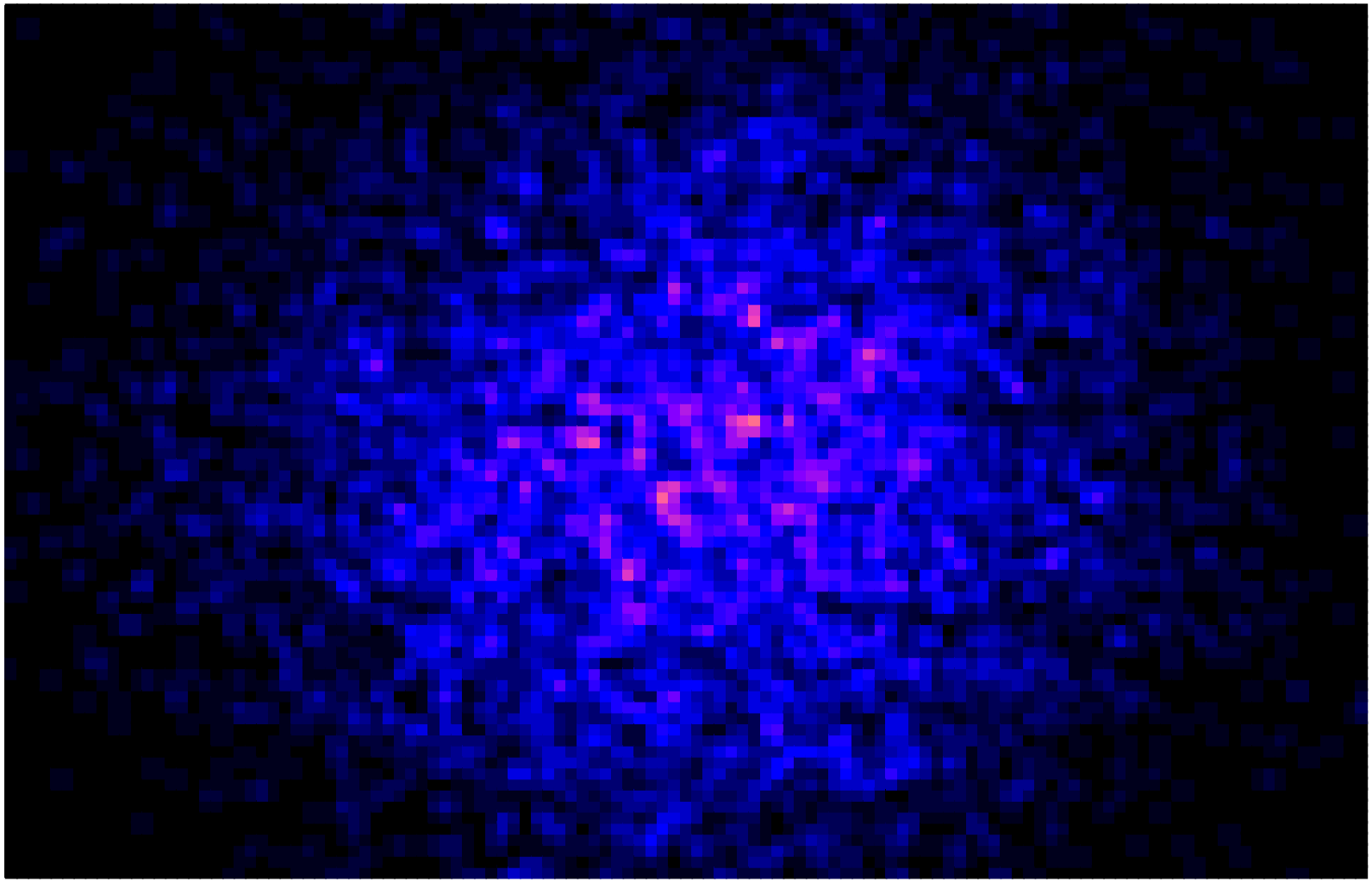
Tycho observations by VERITAS



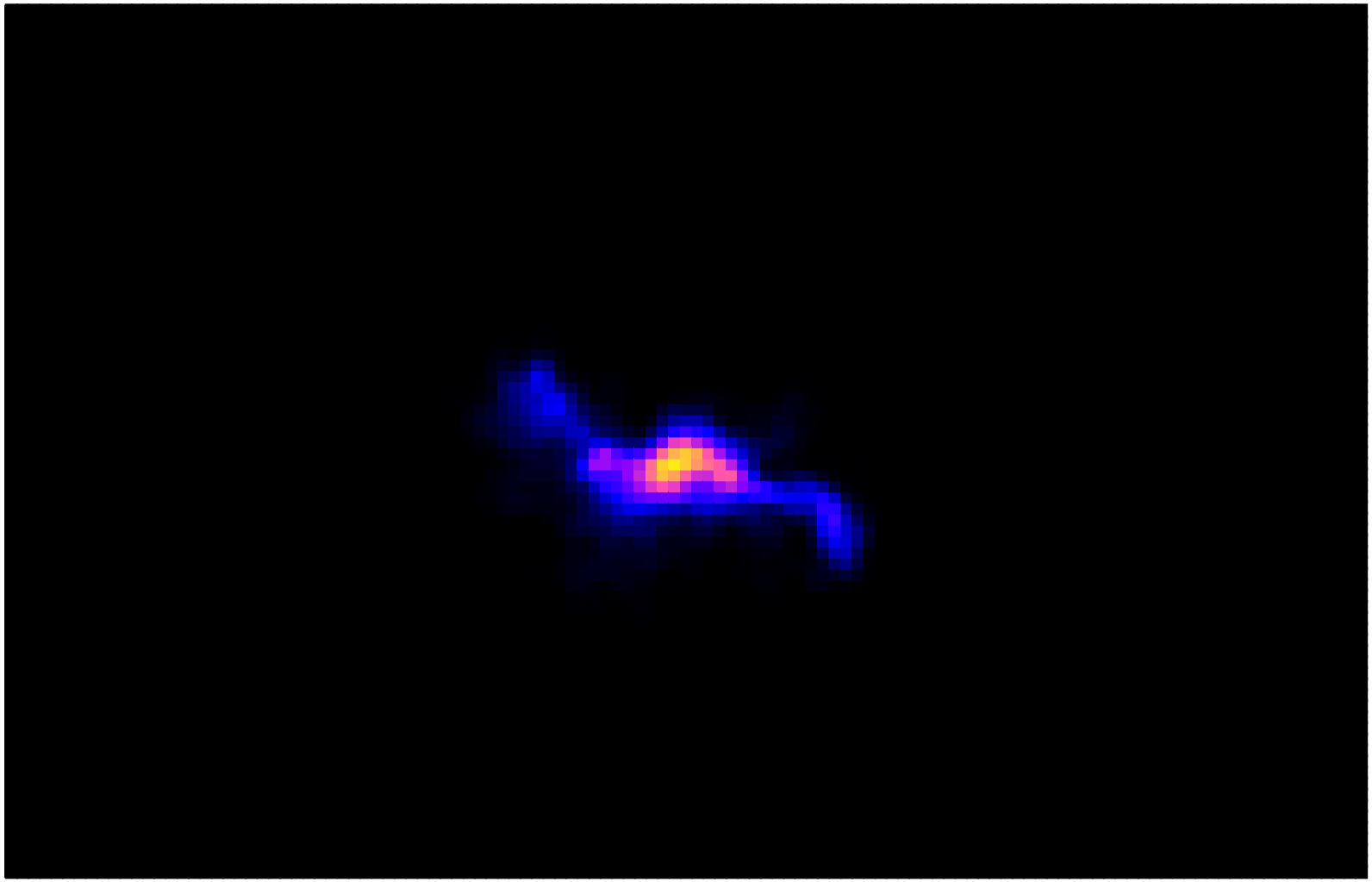
CR diffusion close to source, $E = 10\,\mathrm{PeV}$, $t = 2000\,\mathrm{yr}$



CR diffusion close to source, $E = 10\,\mathrm{PeV}$, $t = 7000\,\mathrm{yr}$



CR diffusion close to source, $E = 10\,\mathrm{PeV}$, $t = 500\,\mathrm{yr}$



Filamentary CR diffusion close to source: [Giacinti, MK, Semikoz '12]

Explanation:

- CRs scatter on modes with $kR_L \sim 1$
- fast modes with $kR_L \gg 1$: irrelevant
- slow modes with $kR_L \ll 1$: act as regular, uniform field B_0
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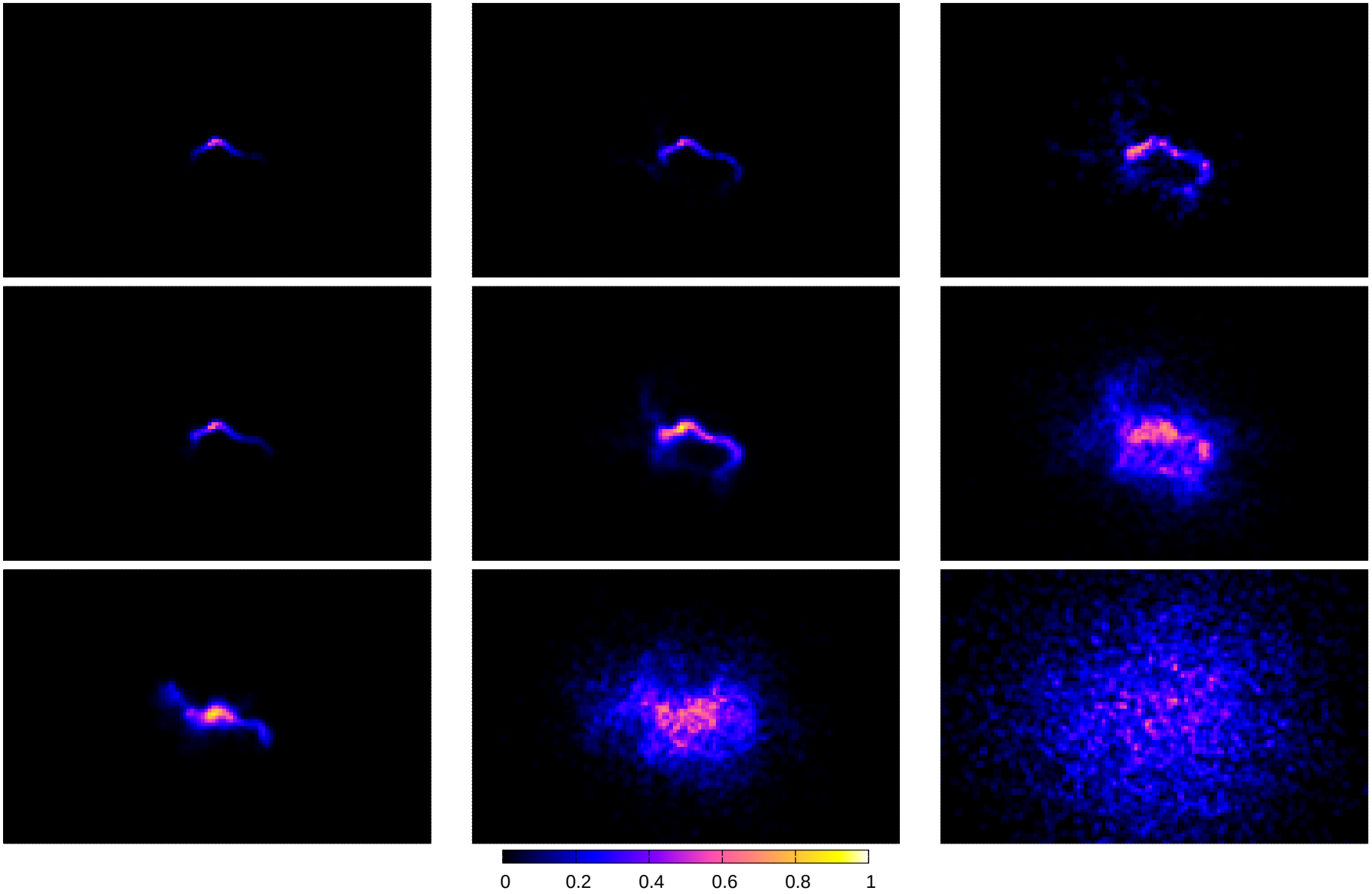
Why not seen earlier in simulations?

- too large scales, $l \gg l_{\rm max}$, considered
- anisotropy vanishes averaging over field realizations
- anisotropy vanishes for random start positions

$E = 100\,\mathrm{TeV} \rightarrow 1\,\mathrm{PeV} \rightarrow 10\,\mathrm{PeV}$ $t = 500\,\mathrm{yr} \downarrow 2000\,\mathrm{yr} \downarrow 7000\,\mathrm{yr}$



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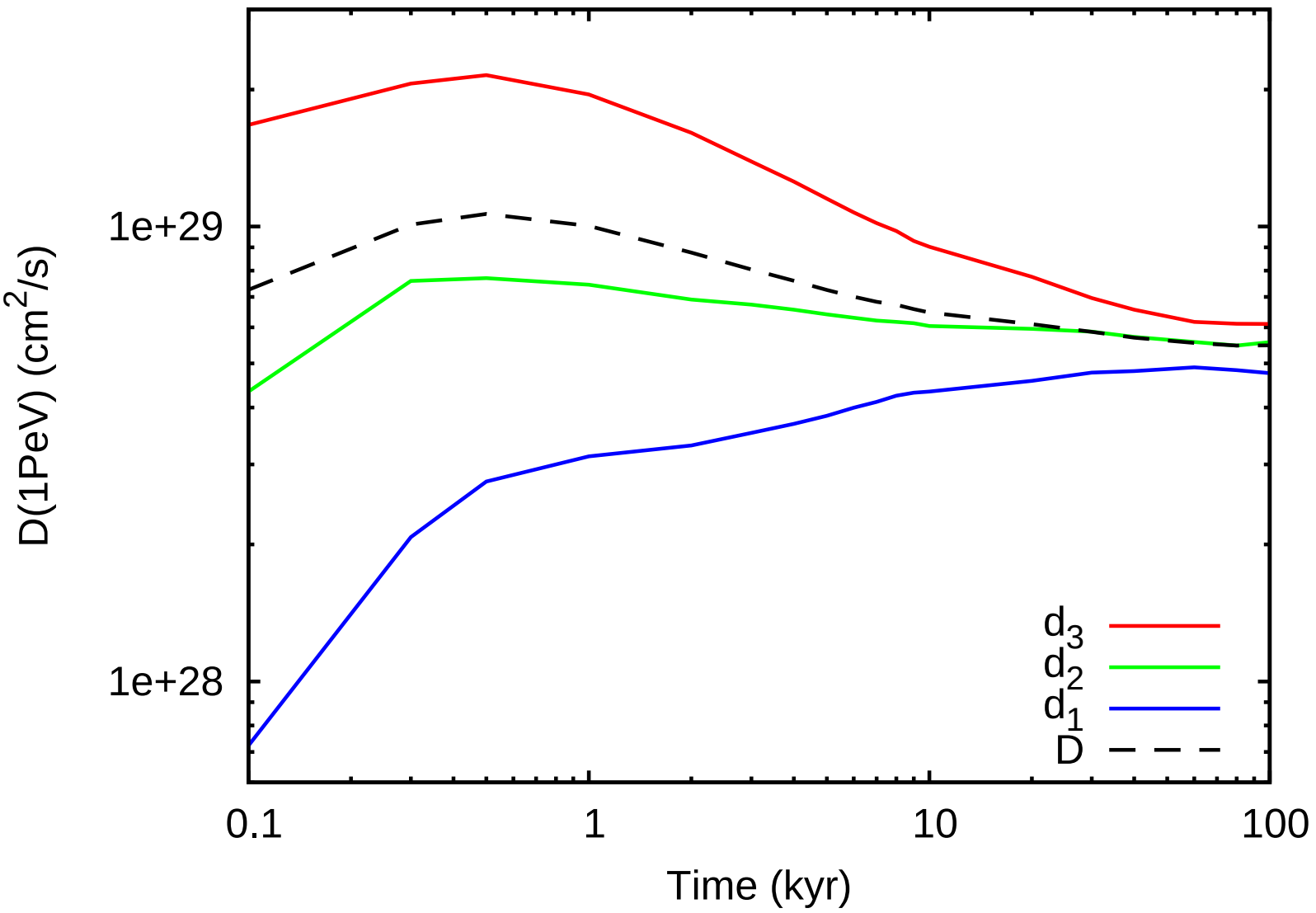
- diagonalizes $D_{ij}^{(b)}$, determine eigenvalues $d_i^{(b)}$
- average the ordered eigenvalues, $d_1^{(b)} < d_2^{(b)} < d_3^{(b)}$, over the M realizations,

$$d_i = \frac{1}{M} \sum_{b=1}^{M} d_i^{(b)}$$

Eigenvalues of $D_{ij} = \langle x_i x_j \rangle / (2t)$ for $E = 10^{15}$ eV



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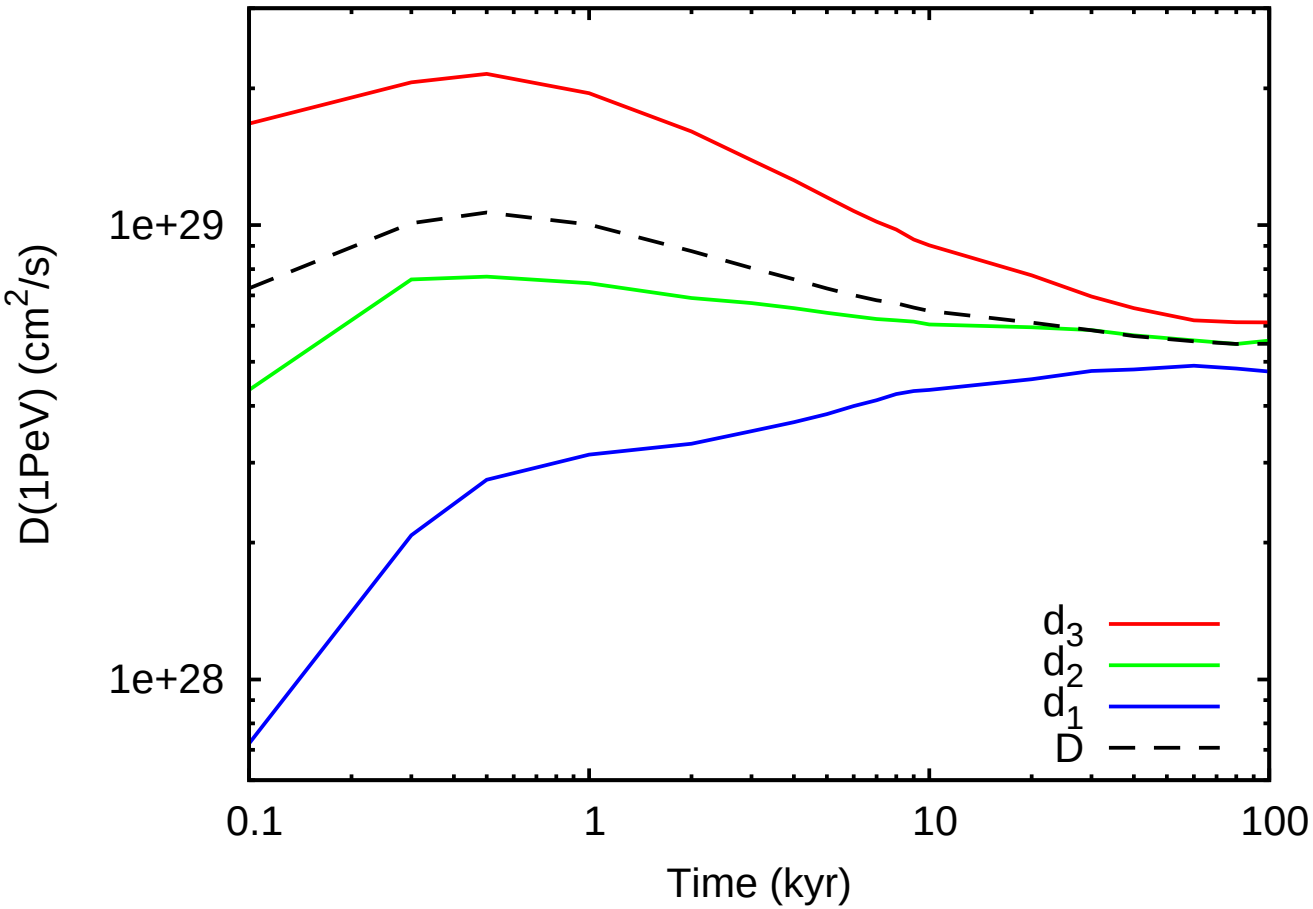
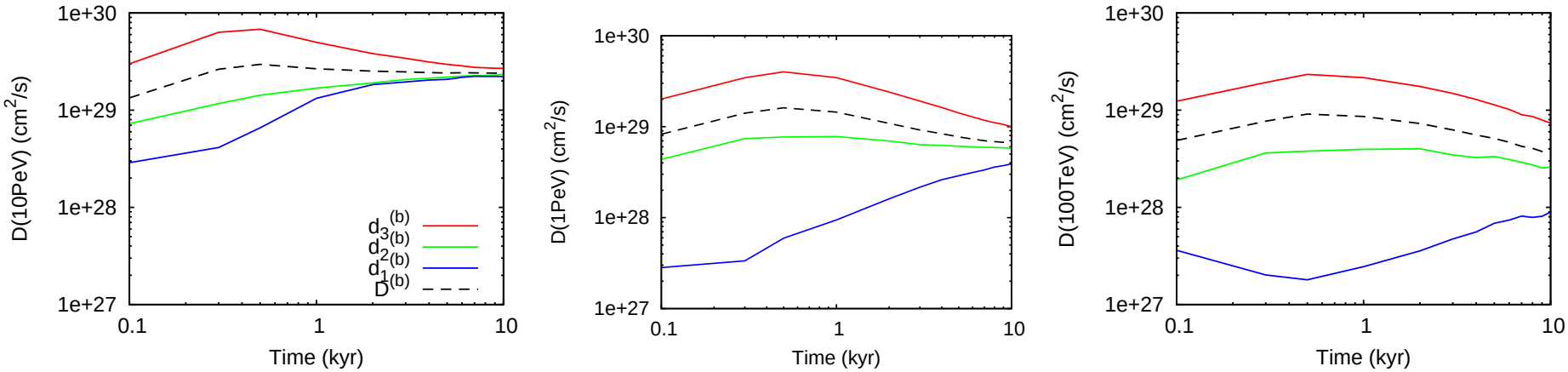


- asymptotic value is ~ 4 smaller than "Galprop value"

Transition time to standard diffusion:

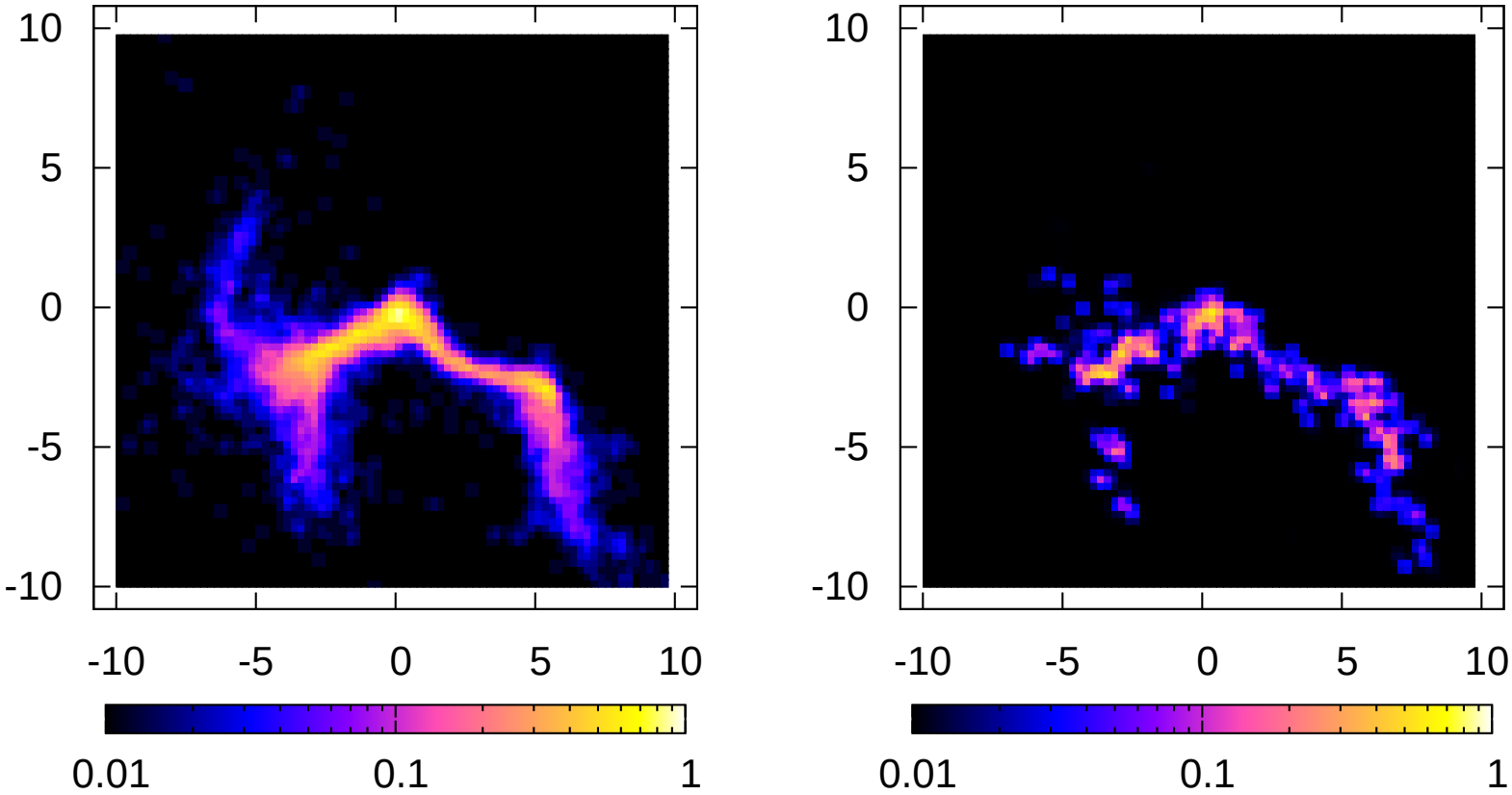


$$t_* \sim 10^4\,\mathrm{yrs}\ (l_{\max}/150\,\mathrm{pc})^{\beta}\,(E/1\,\mathrm{PeV})^{-\gamma}$$

with $\beta \simeq 2$ and $\gamma = 0.25$–0.5

for Kolmogorov turbulence and $B_{\mathrm{rms}} = 4\,\mu$G.

Comparison CR density vs. photon flux



$\Rightarrow$ irregular gamma-ray halos as tracker of CR density

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- ill-posed problem, fit instead physically motivated trial functions
- (broken) power-laws

Neronov, Semikoz and Taylor 2012:

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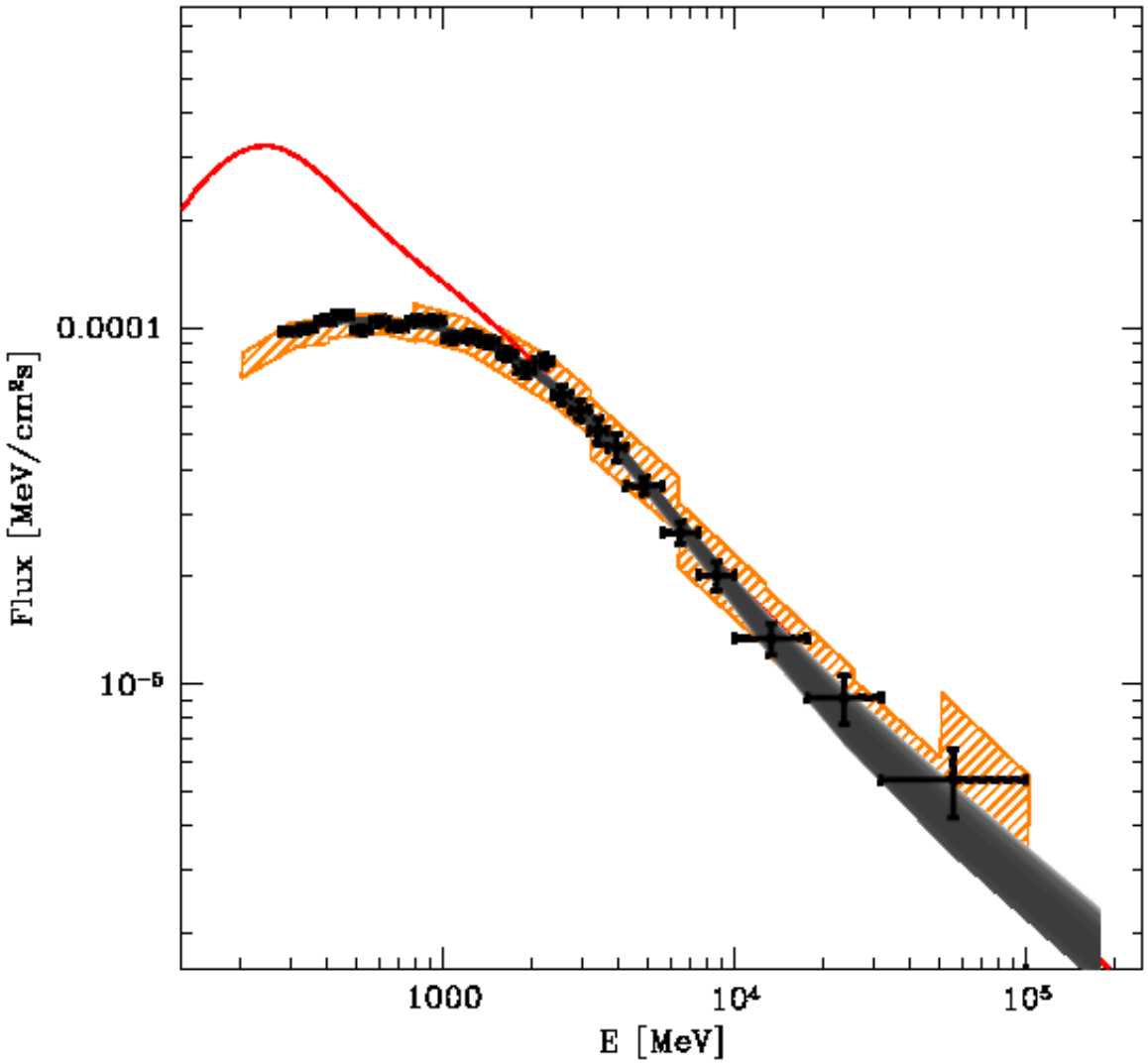

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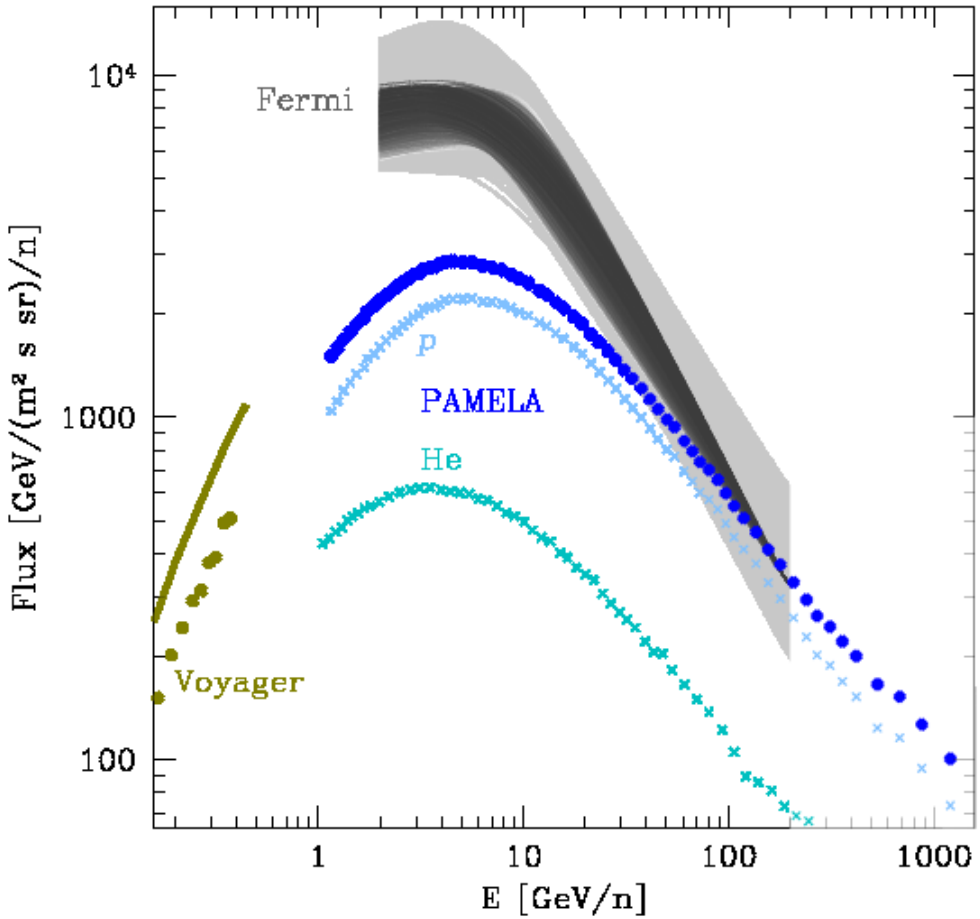

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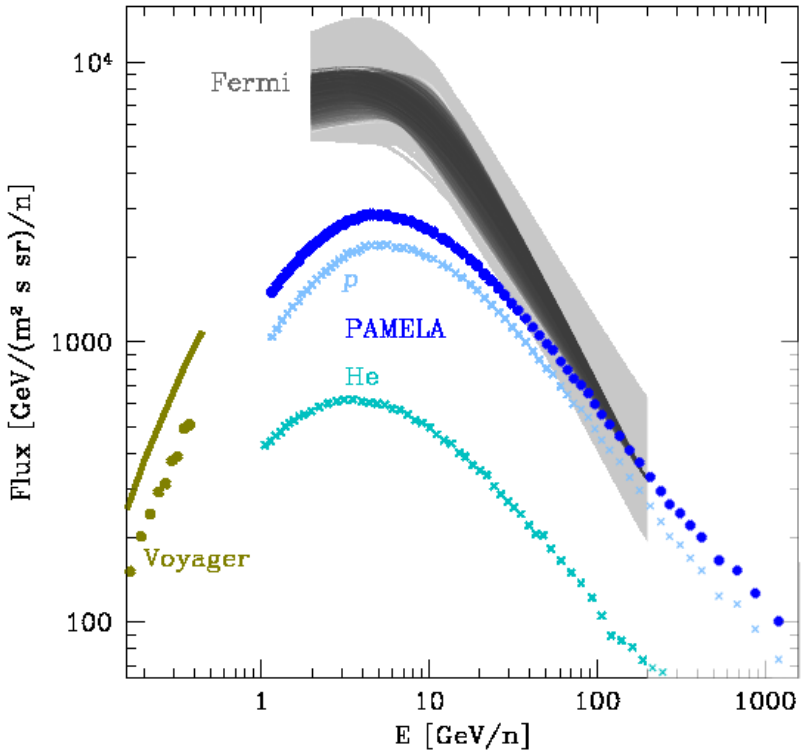
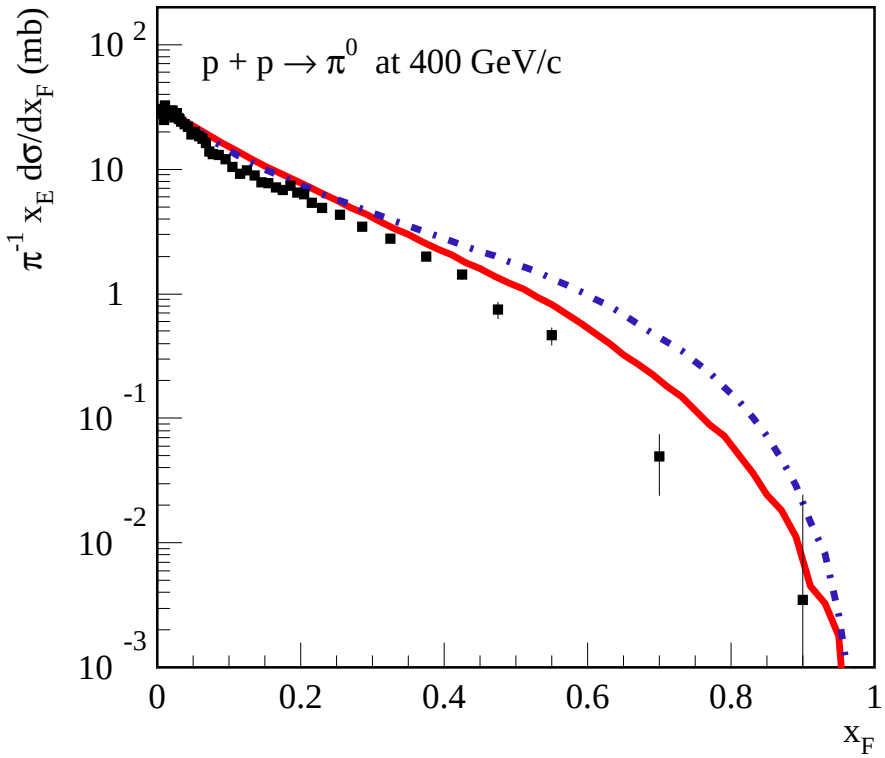
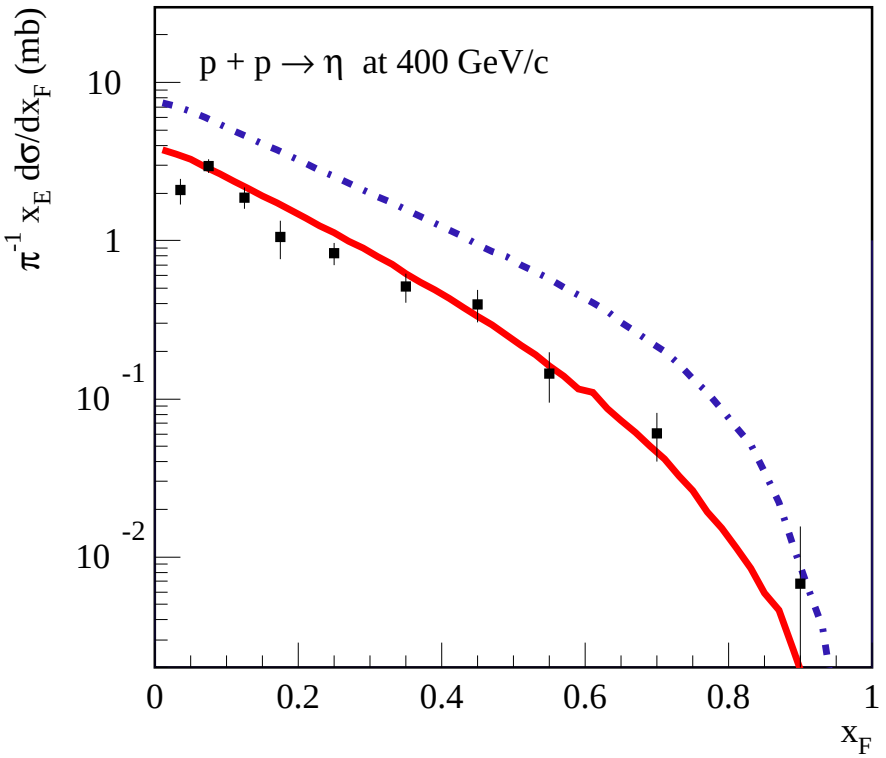


- physical explanation?
  - 200 GeV: end of solar modulation
  - 10 GeV: change in $D(E)$

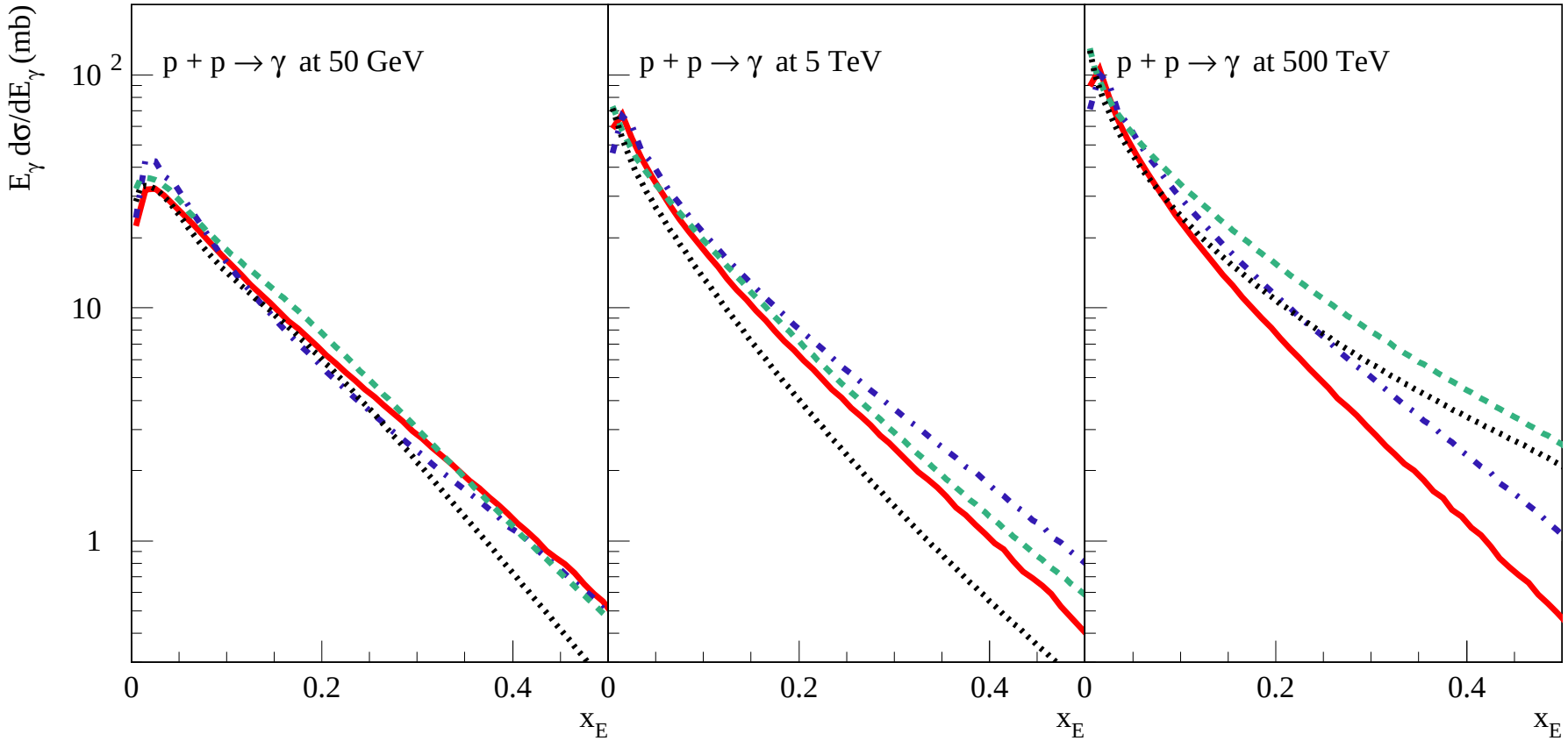
[*Blasi, Amato, Serpico '12*]

How good are photon FF? QGSJET vs. SIBYLL [*MK, Ostapchenko '12*]





How good are photon FF? QGSJET, SIBYLL, Kamae



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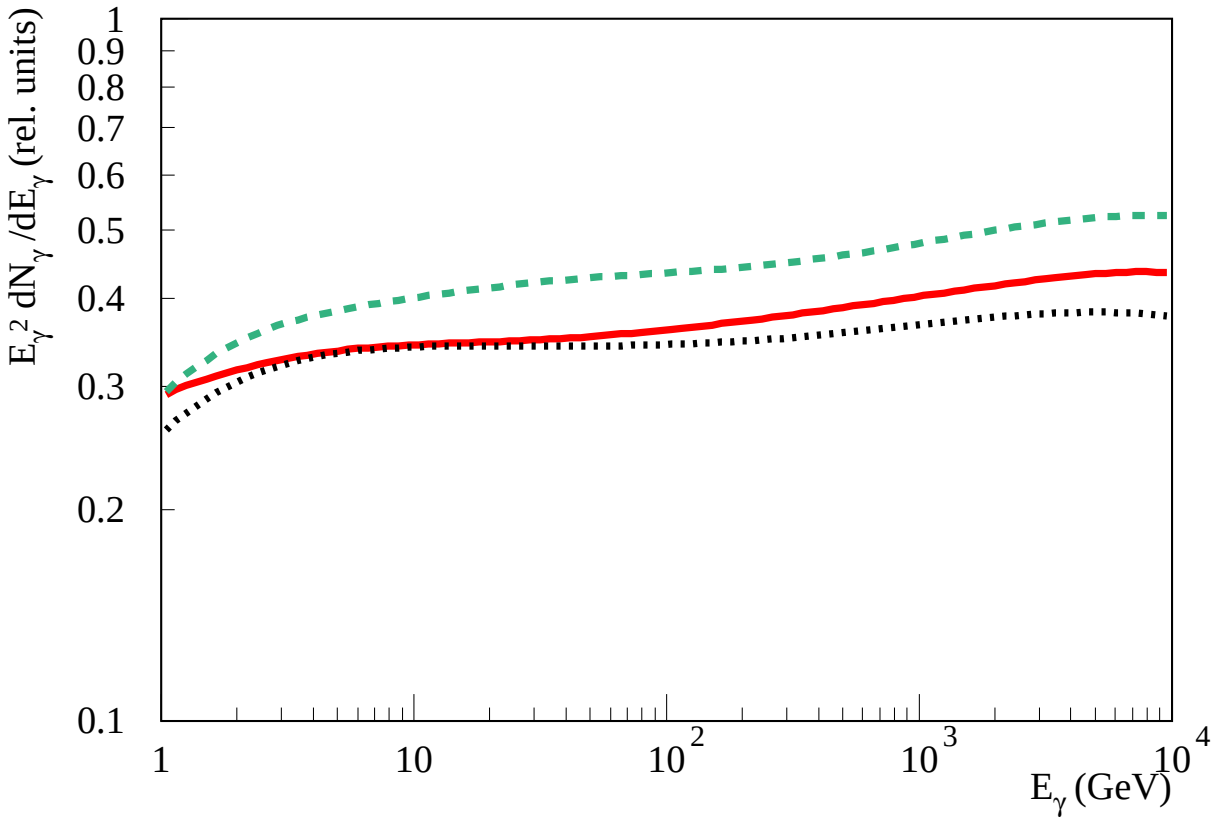

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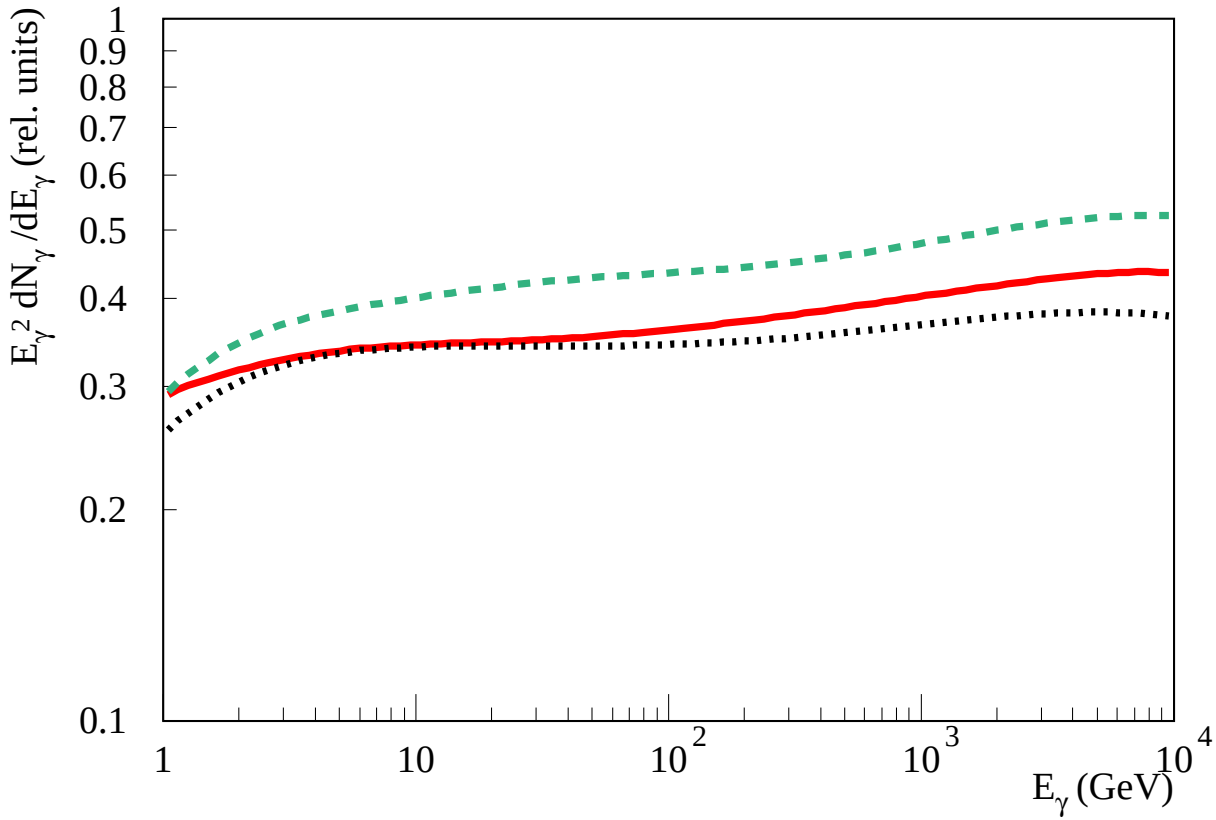
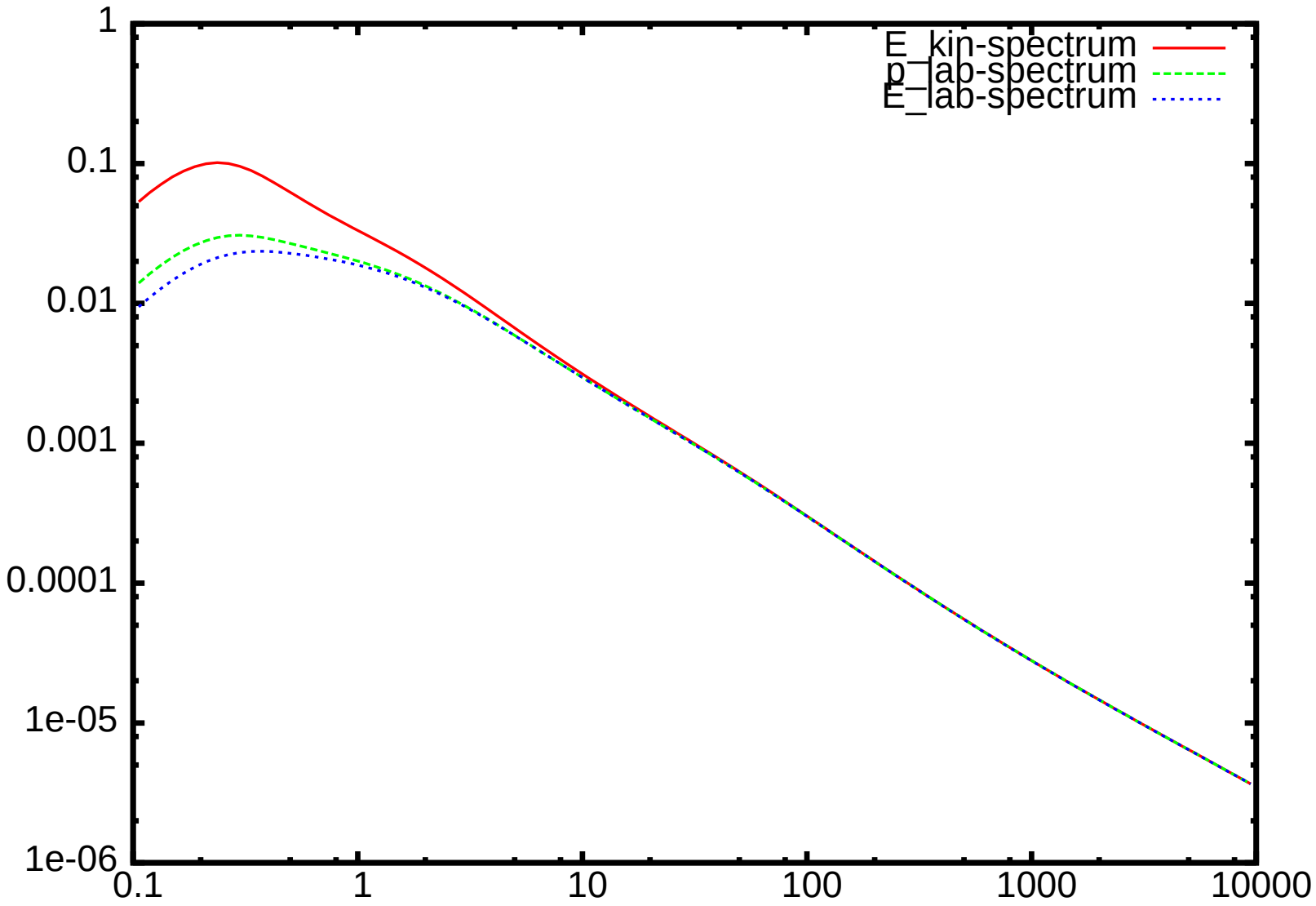


$\Rightarrow$ Kamae FF not reason for bump

Gammas from CR power-laws in T vs. p



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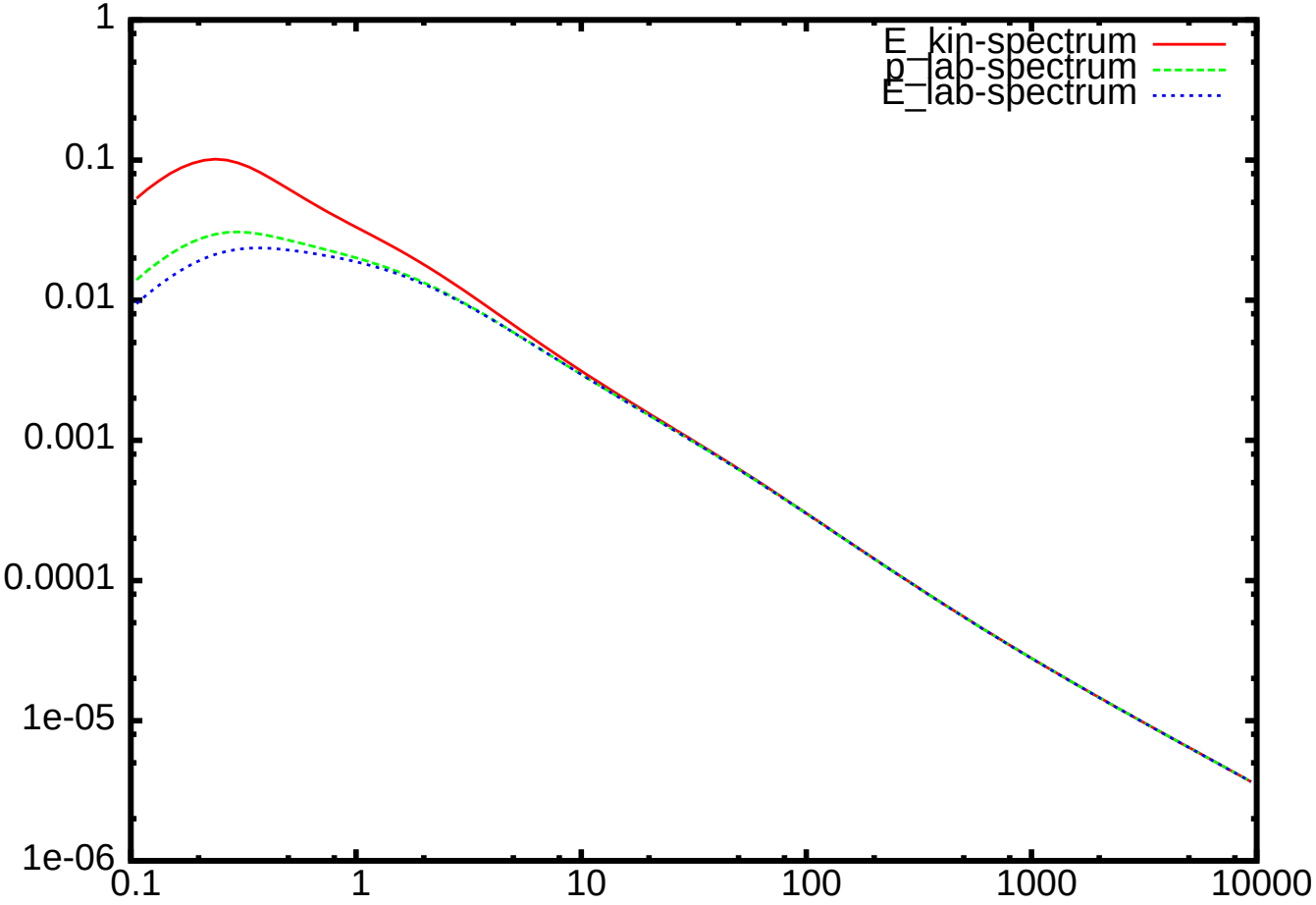
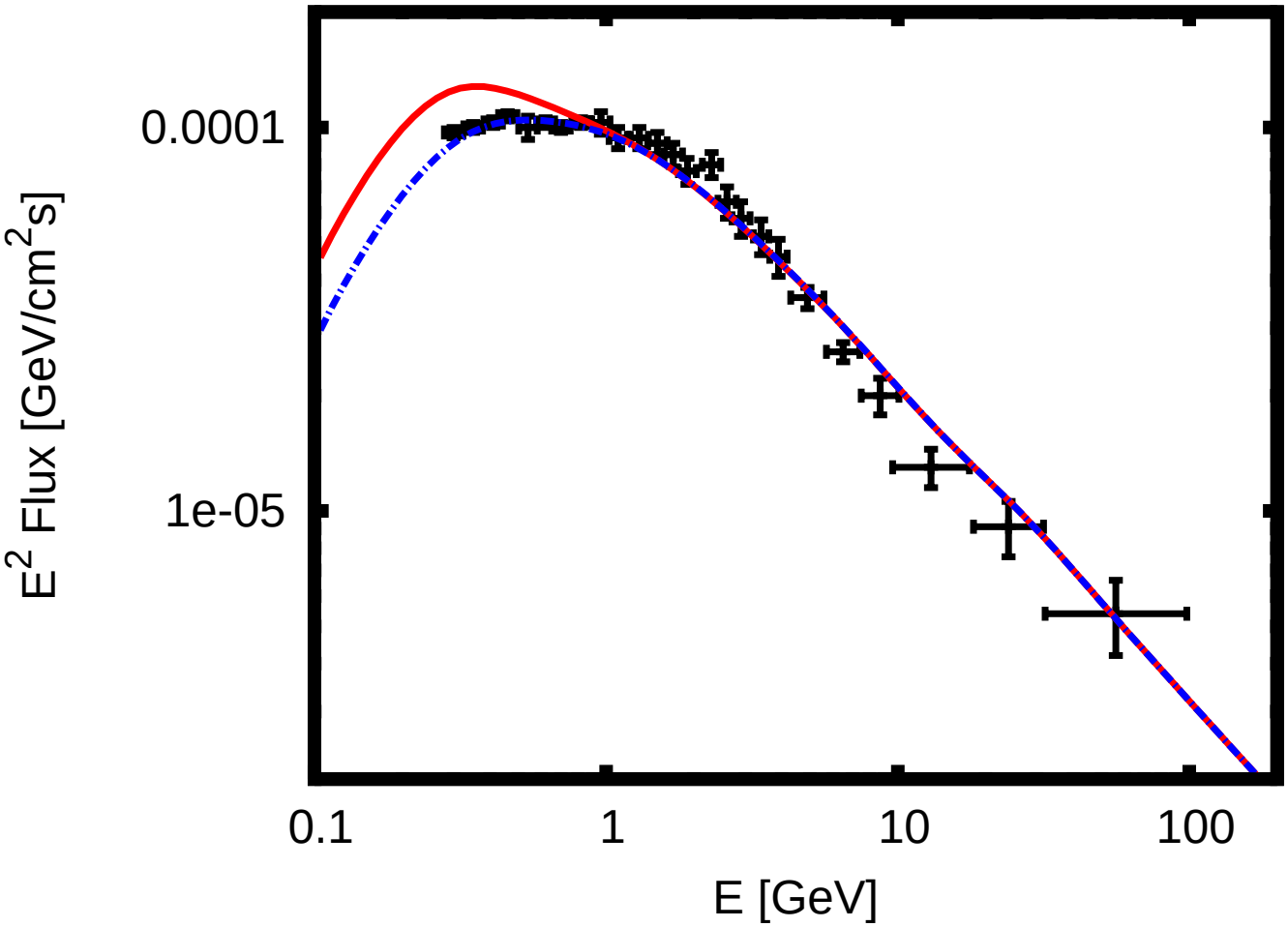


- most of the bump comes from power-law in T
- DSA predicts power-law in p

[*Bell '77*]

Gammas from CR power-laws in T vs. p



- red: $I \propto p^{-2.85}$ (our FF)
- blue: $I \propto p^{-2.85}$, break to $I \propto p^{1}$ at 3 GeV (our FF)

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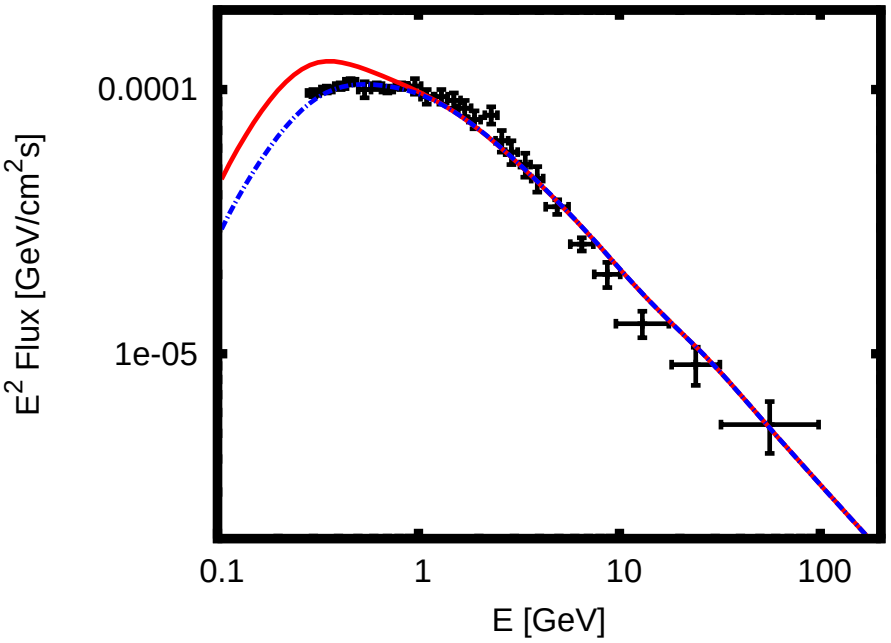

- red: $I \propto p^{-2.85}$ (our FF)
- blue: $I \propto p^{-2.85}$, break to $I \propto p^{1}$ at 3 GeV (our FF)
- explanation:
  - break in $D(E)$ around 3 GeV as suggested by radio data
  - caused by CR damping
  - standard solar modulation

Summary

- Intensity $I(p)$ of sea CRs important for CR physics, DM searches.
  - determination via GMC requires additional input

  $\Rightarrow$ controversial solutions
  minimal: power-law in $I(p)$ supports DSA, consistent with standard solar modulations, break $\sim 3\,\mathrm{GeV}$
- Anisotropic diffusion on scales $l \lesssim l_{\mathrm{max}}$ leads to irregular CR and gamma halos
- Icecube events:
  - consistency between diffuse ν_μ and cosmogenic analysis
  - unlikely cosmogenic, rather diffuse extragalactic flux;
  - galactic possible?

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