Multimessenger astronomy

High-energy photons, cosmic rays, and neutrinos

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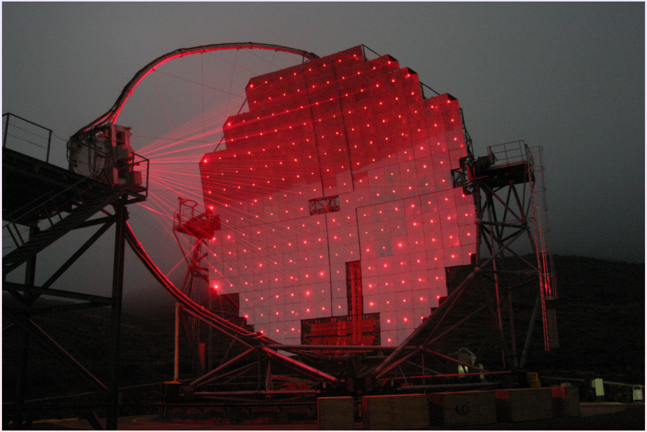
NTNU, Trondheim

Third annual ILIAS-N6 ENTApP meeting

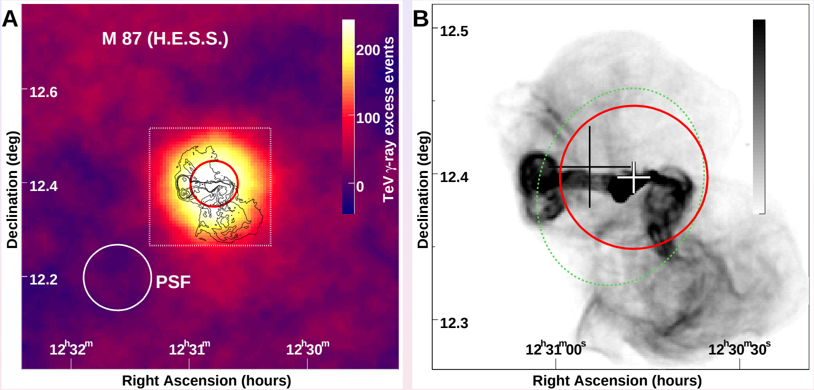
Three options for HE astronomy:

- High-energy photons:
  - new ACT's (HESS, MAGIC, ...) extremly succesful



  - new sources, extragal. backgounds, evidence for hadronic accelerators, M87, ...

HESS observations of M87:



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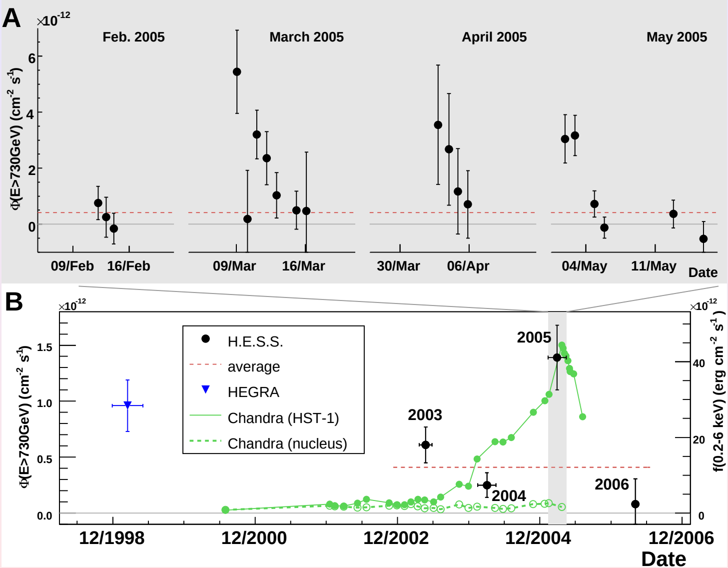

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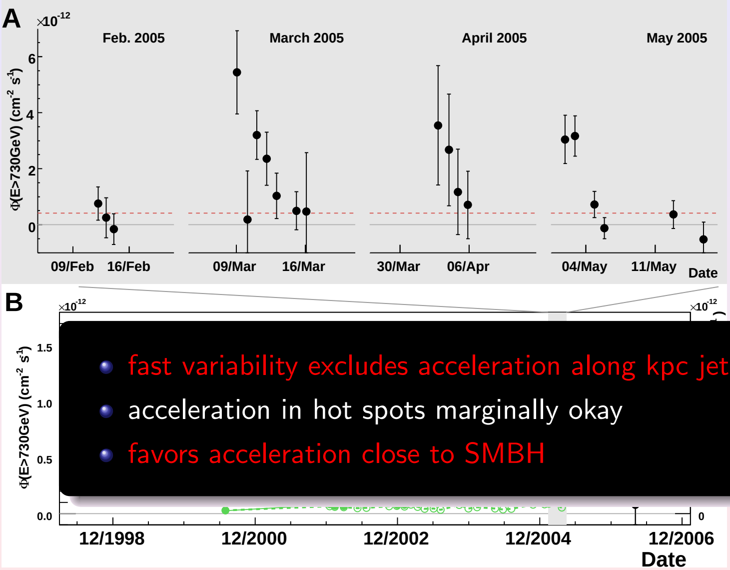

- fast variability excludes acceleration along kpc jet
- acceleration in hot spots marginally okay
- favors acceleration close to SMBH

Three options for HE astronomy:

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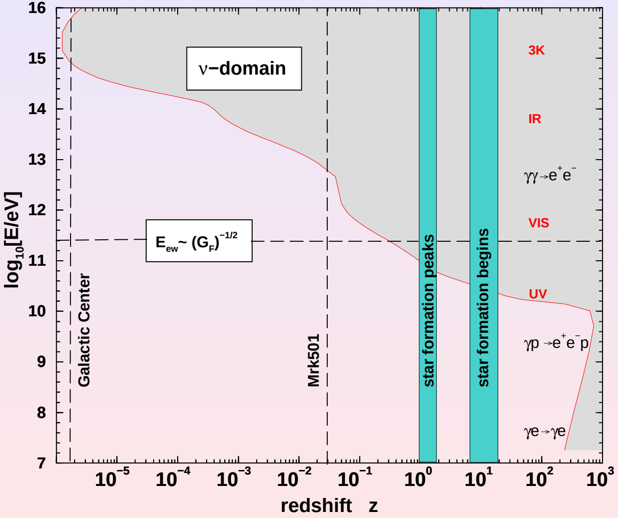
  but: astronomy with HE photons restricted to few Mpc



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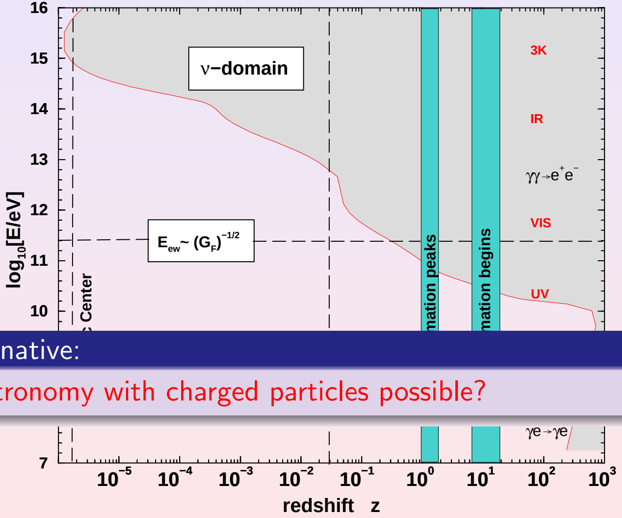
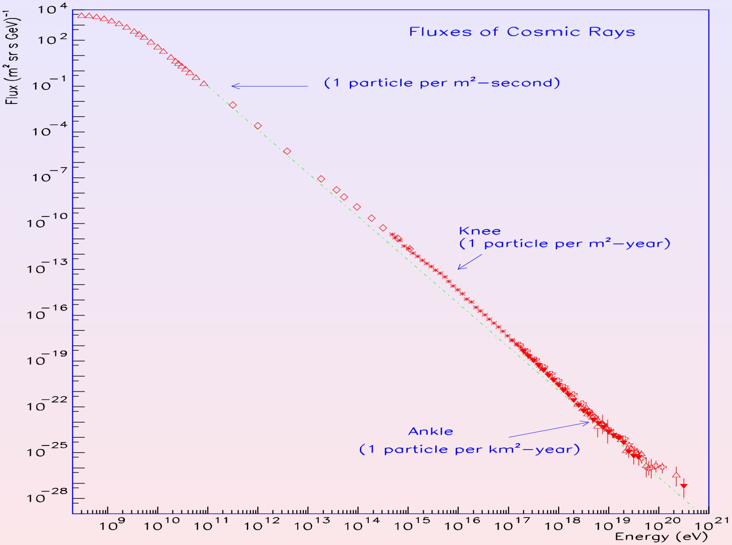


Alternative:

is astronomy with charged particles possible?

Second option for HE astronomy: UHECRs



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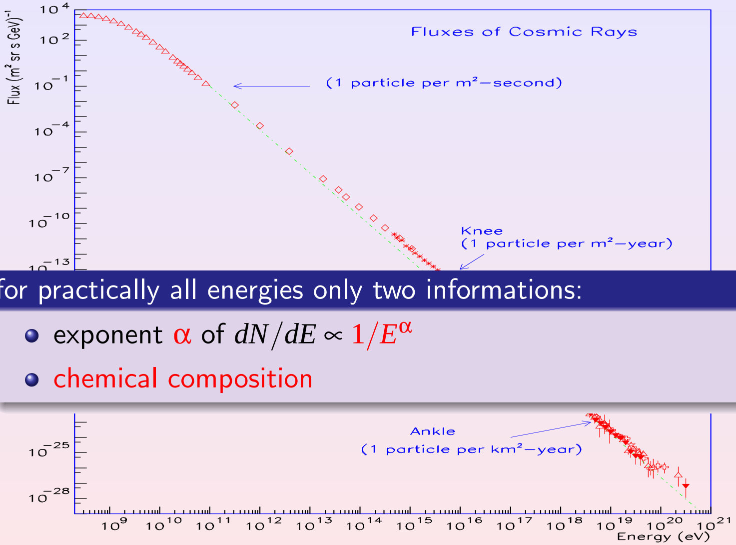
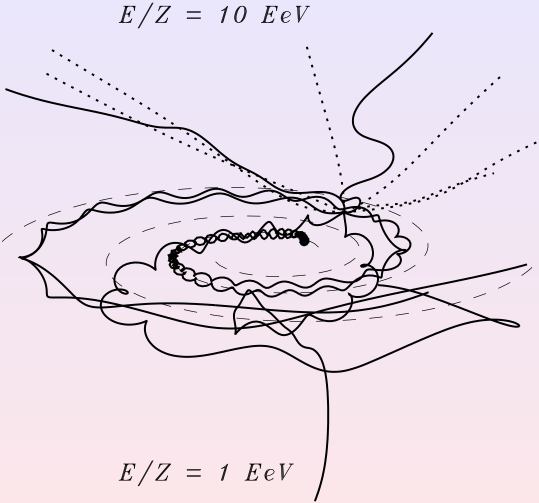


for practically all energies only two informations:

- exponent α of $dN/dE \propto 1/E^{\alpha}$
- chemical composition

Deflection of protons in galactic B-field:



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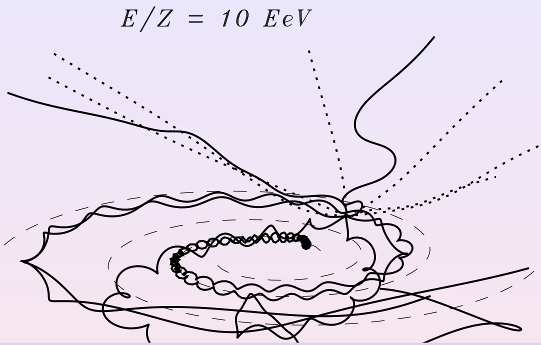
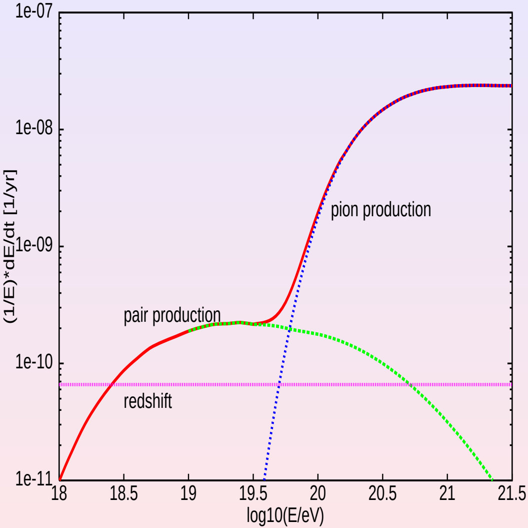


- additionally deflections in extrag-gal. B-field
- deflections are dangerous for UHE protons, deadly for nuclei?
- what are hints for chemical composition?

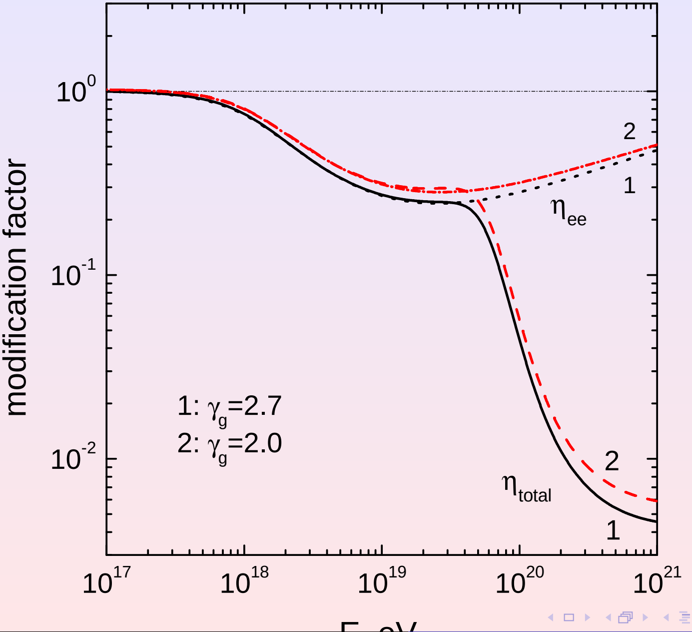
Energy losses, the dip and the GZK cutoff



- at $E \sim 4 \times 10^{19}$ eV: $N + \gamma_{3K} \to \Delta \to N + \pi$ starts and reduces free mean path to ~ 20 Mpc
- pair production leeds to a dip at $\sim 10^{19}$ eV

The (first) dip

[*Berezinsky, Gazizov, Grigorieva '03*]



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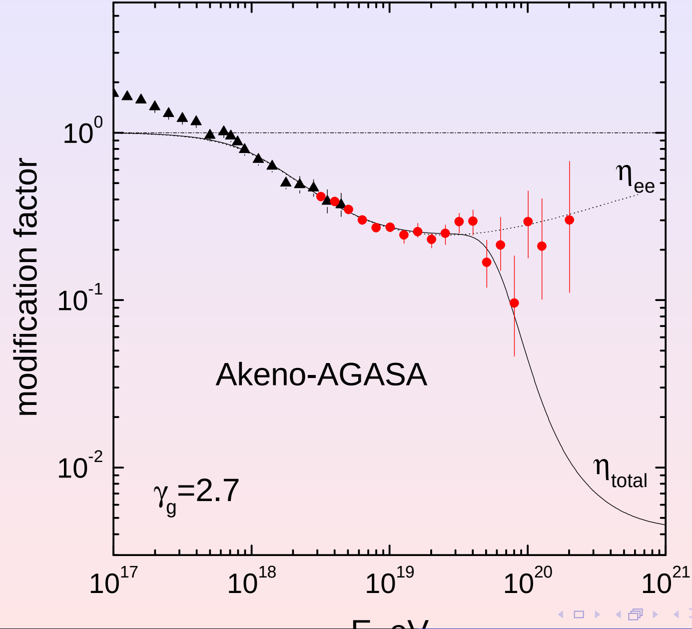

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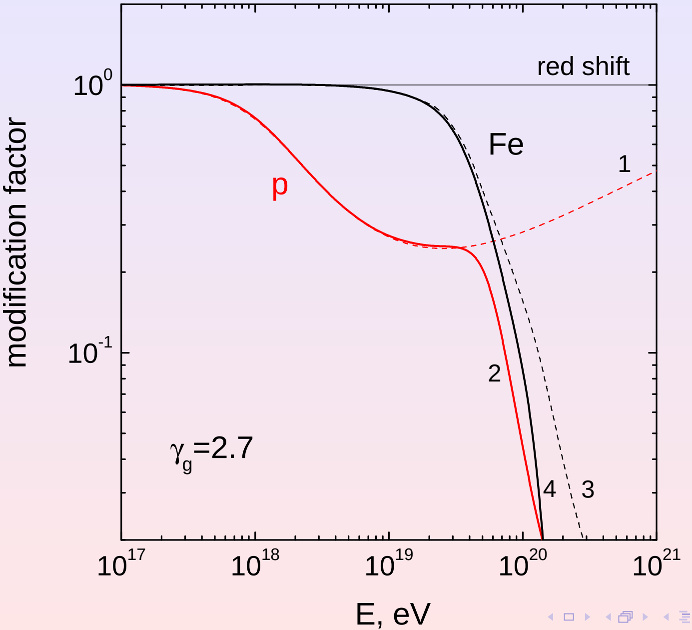
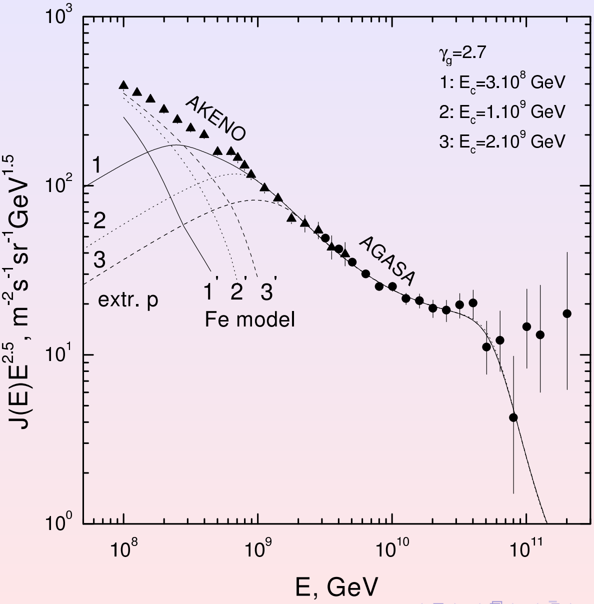


Transition to extragalactic protons

[Berezinsky, Grigorieva, Hnatyk '04]



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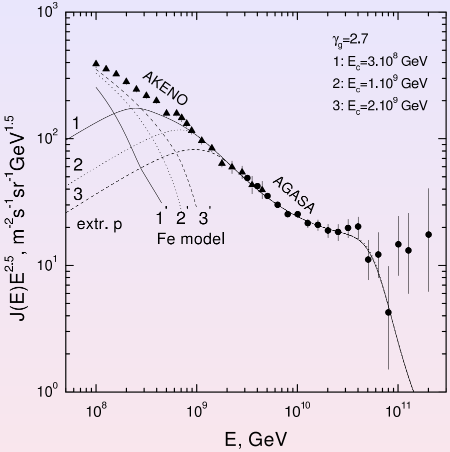
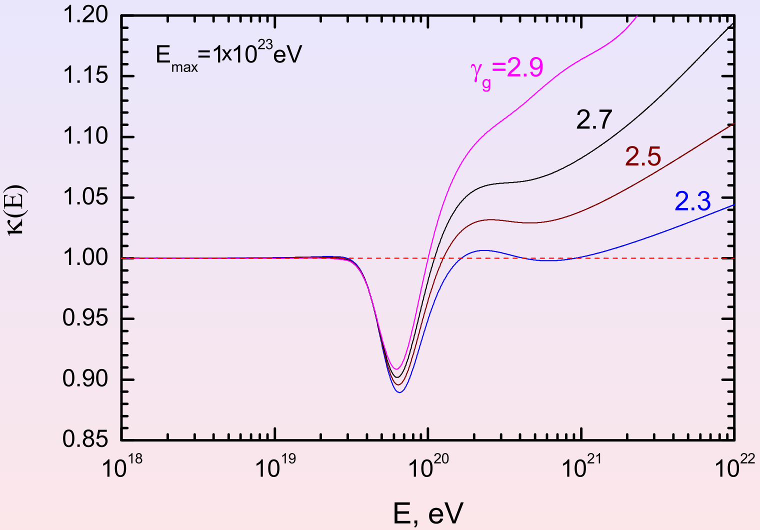


- hint for protons
- transition at $E \lesssim 10^{18}$ eV

The second dip

[*Berezinsky, Gazizov, MK '06*]



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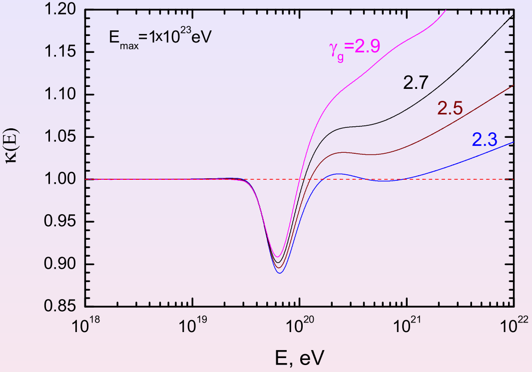

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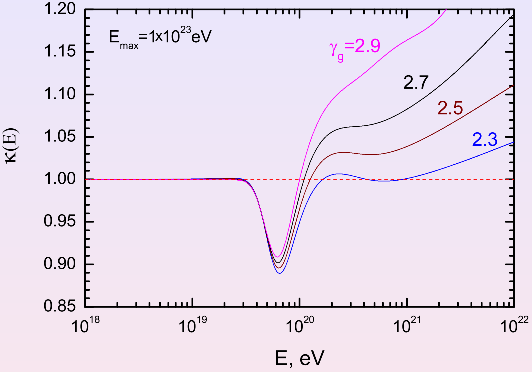

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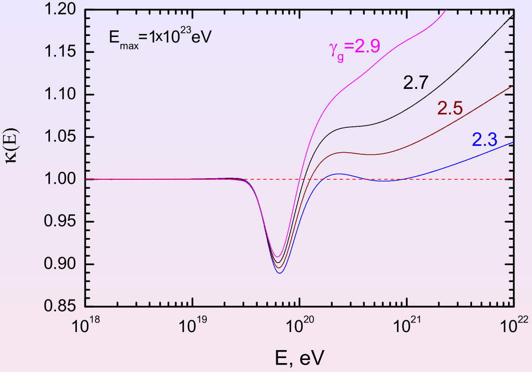

- at $E_{\rm eq2}$ where $dE/dt|_{\rm pion} = E/dt|_{\rm e^+e^-}$:
- 2.nd sip shows up in $\kappa = J_{\rm obs}/J_{\rm CEL}$
- cleanest signature for CMB interactions of protons

Possible anisotropies of extragalactic CRs:

1. Dipole anisotropy – cosmolog. Compton-Getting effect
   - induced by motion of Sun relative to cosmological rest frame
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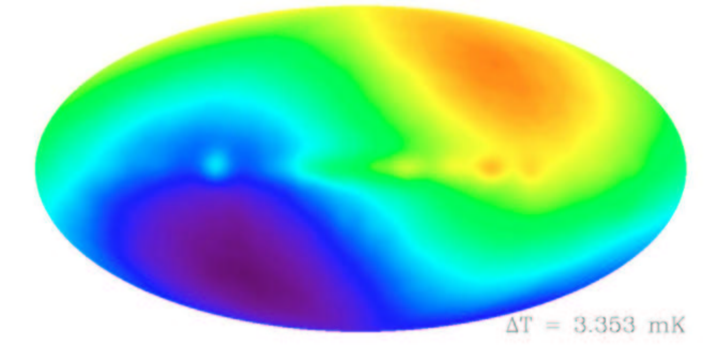
3. Small-scale clustering
   - Small-scale $\sim$ angular resolution of experiments

   $\Rightarrow$ CR from the same point sources
   - requires small qB/E and small n_s

Cosmological Compton-Getting effect:

[MK, Serpico '06]

- Solar System is moving with $v \approx 368$ km/s relative to CMB



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- lower on transition energy $E_{\rm tr}$ to galactic CRs

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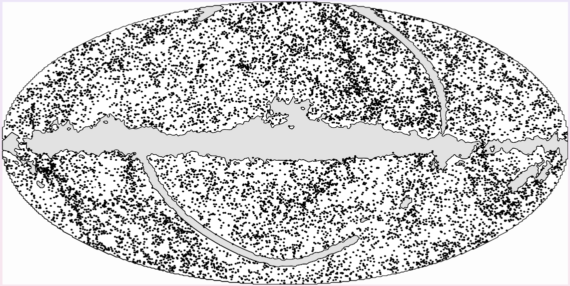

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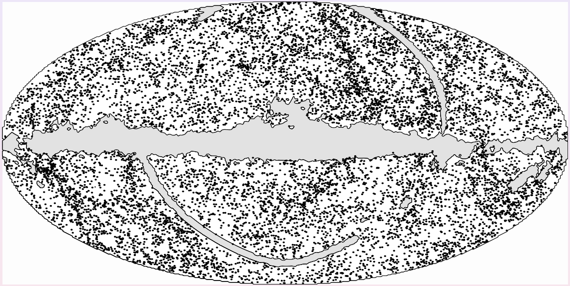

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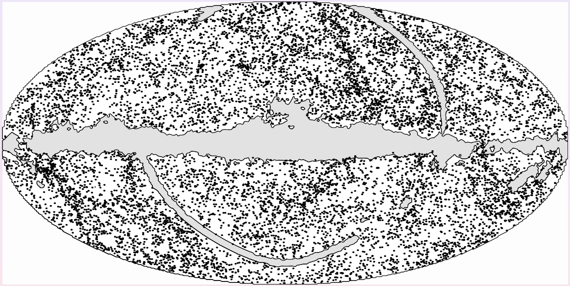

- $O(100)$ events needed to detect effect, energy range around $\gtrsim 4 \times 10^{19}$ eV [A. Cuoco et al. '05, '06]
- increasing E even further, single sources become visible

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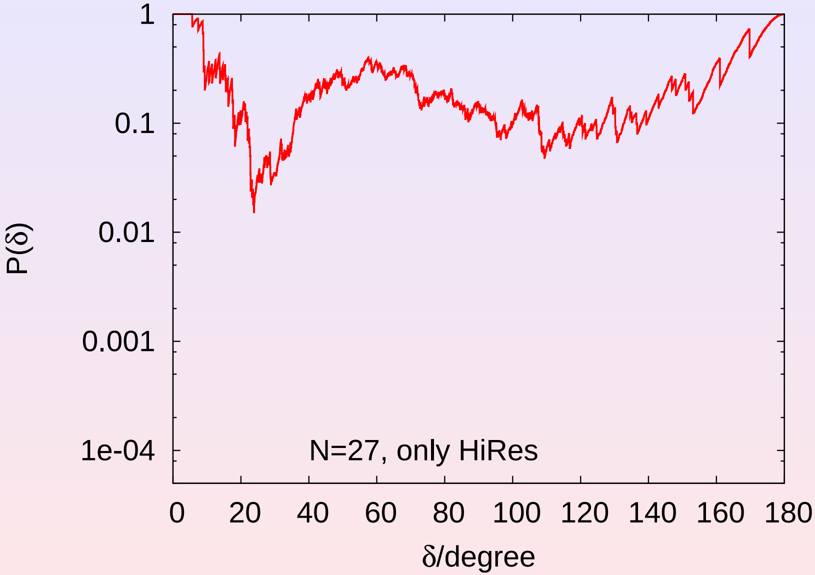
[*MK, D. Semikoz '05*]



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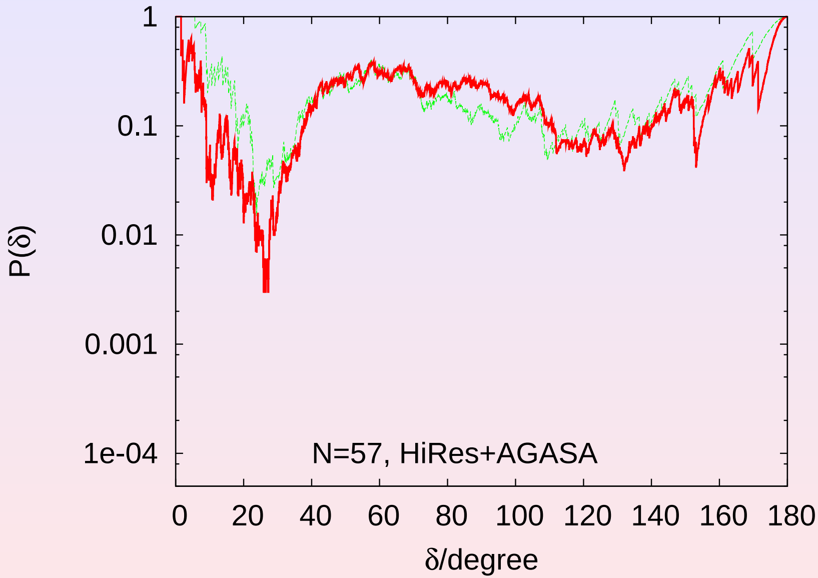

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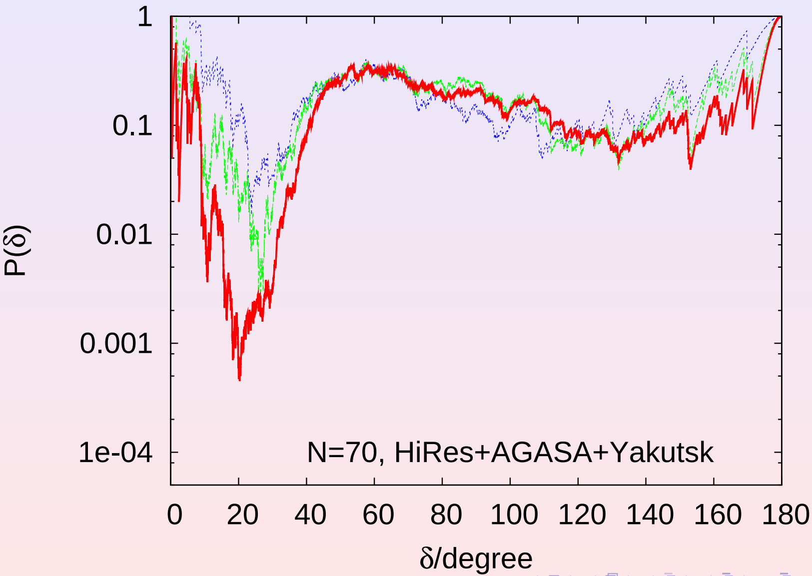

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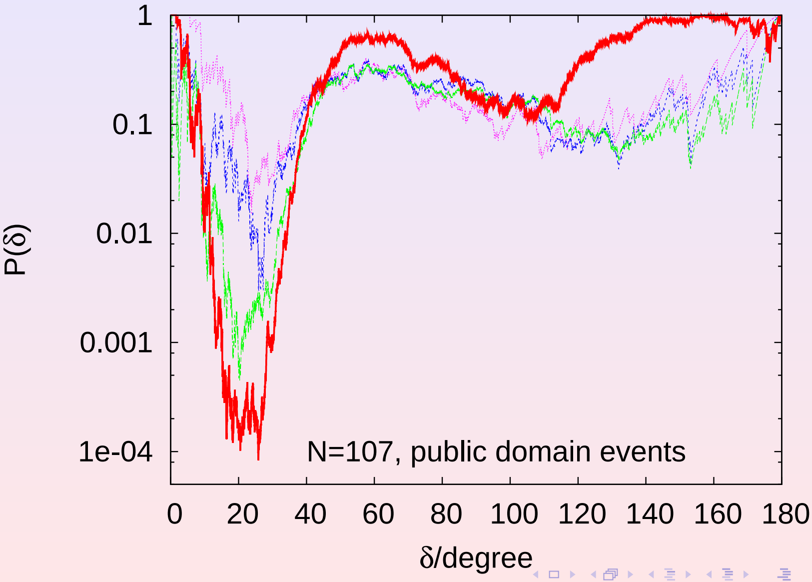

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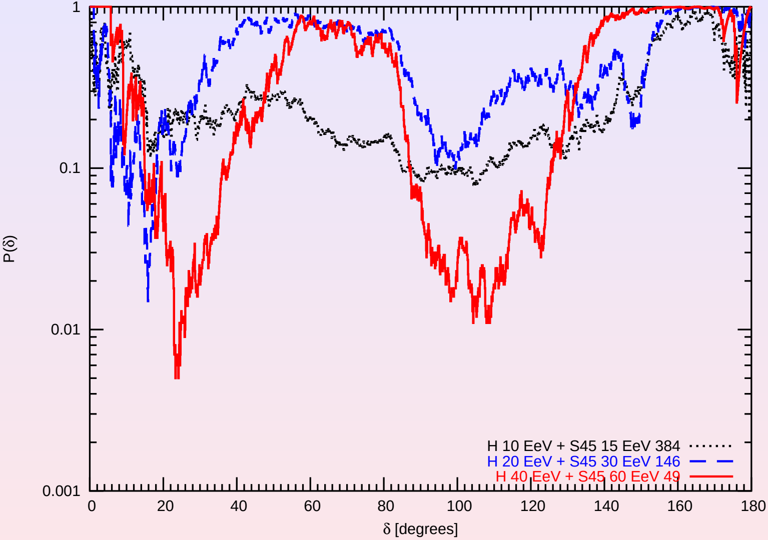

P(δ)
1
0.1
0.01
0.001
0
20
40
60
80
100
120
140
160
180
δ [degrees]
H 10 EeV + S45 15 EeV 384
H 20 EeV + S45 30 EeV 146
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- penalty factor for scan over angles: ~ 6–30

Summary of charged particle astronomy

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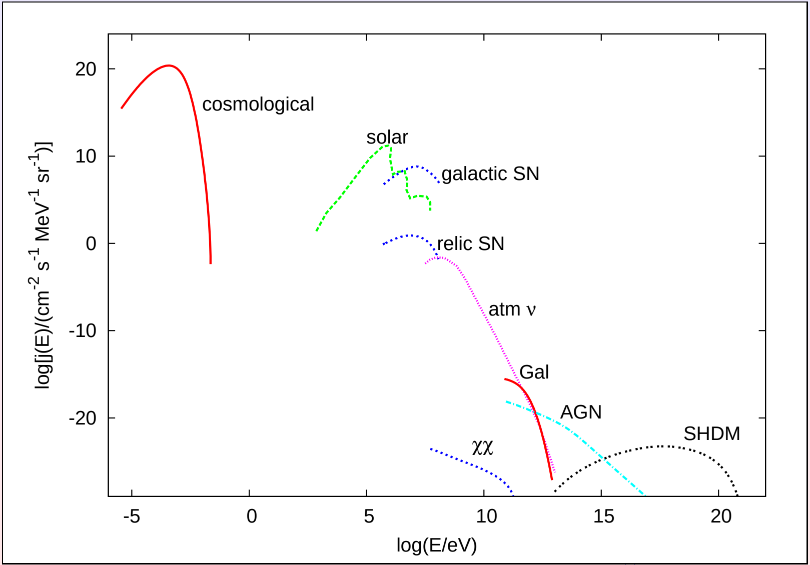
Correlations with sources

- various claims
- no news in the last 2 years

Neutrino opportunities:



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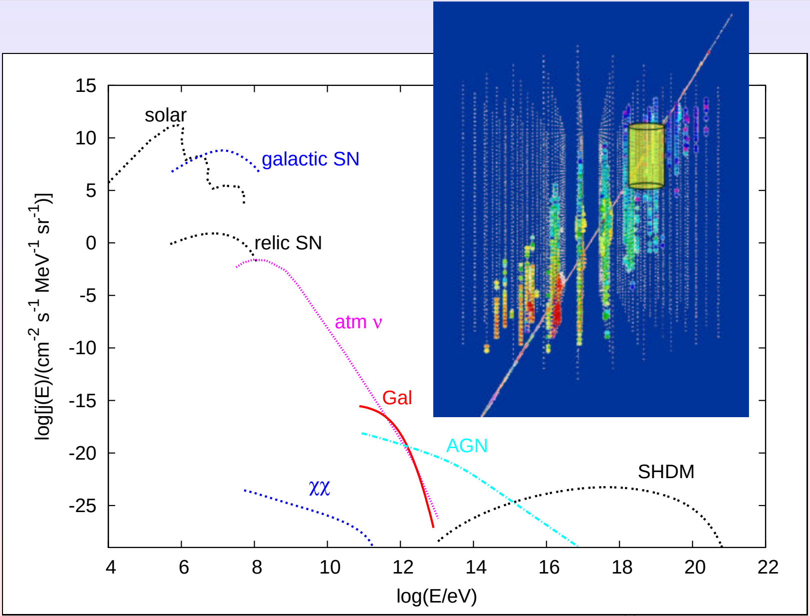

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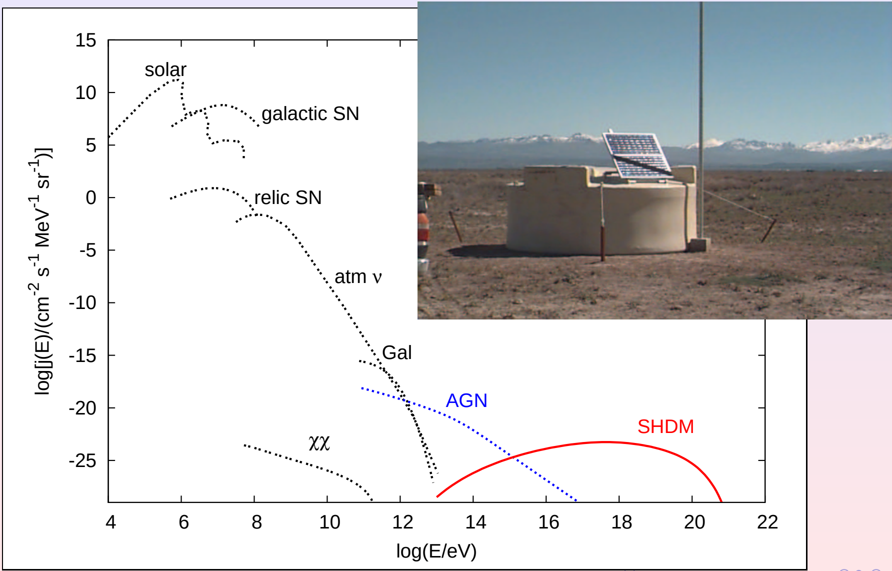

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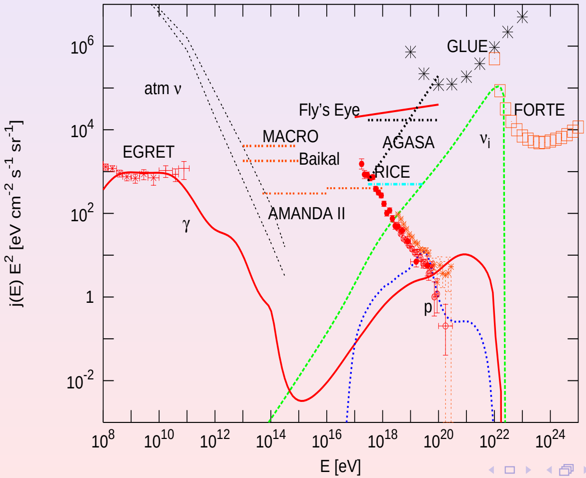

[Semikoz, Sigl '03]

Standard picture:

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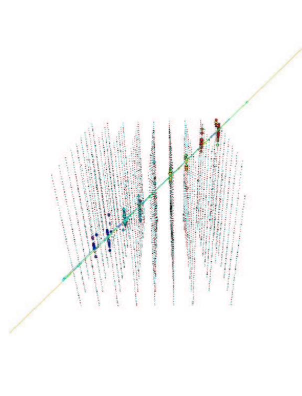
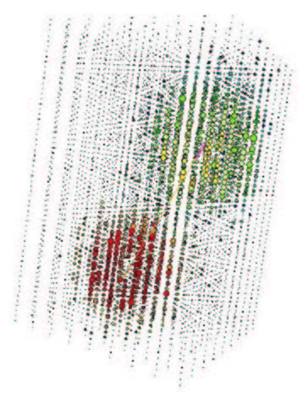
- basis for CR bounds (WB, MPR)

Neutrino telescopes and neutrino mixing

- neutrino telescopes can distinguish muon neutrinos from electron and tau neutrino events:





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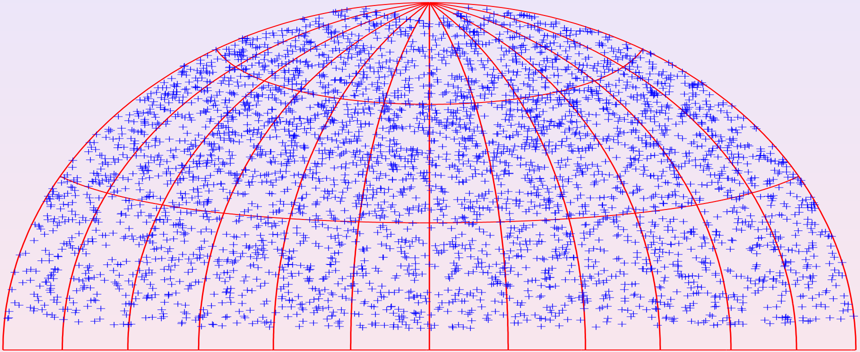
- but maximal mu-tau mixing washes-out flavor information for $l \gg l_{\rm osc}$:

$$\varphi_e : \varphi_\mu : \varphi_\tau = 1 : 2 : 0 \quad \Rightarrow \quad \varphi_e : \varphi_\mu : \varphi_\tau = 1 : 1 : 1$$

AMANDA neutrino results:



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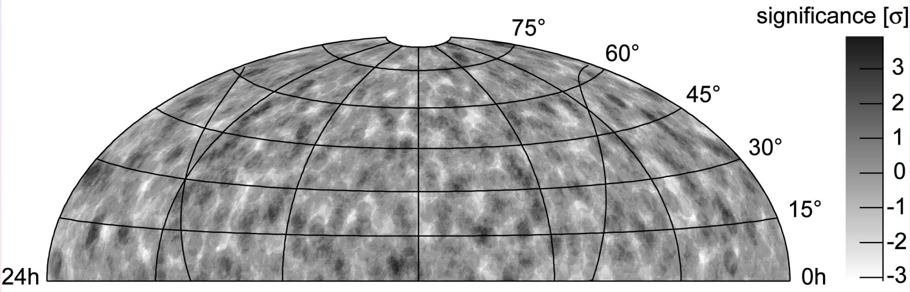

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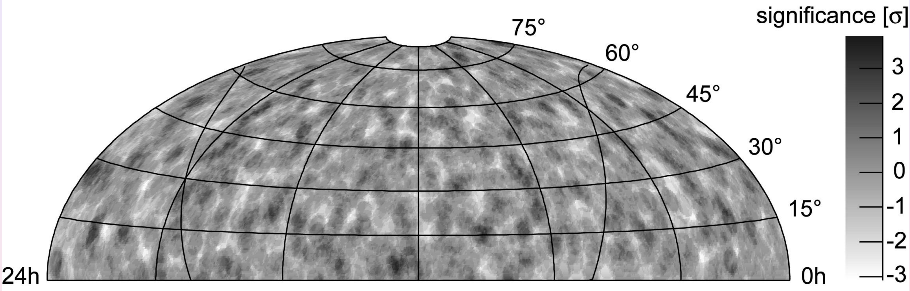

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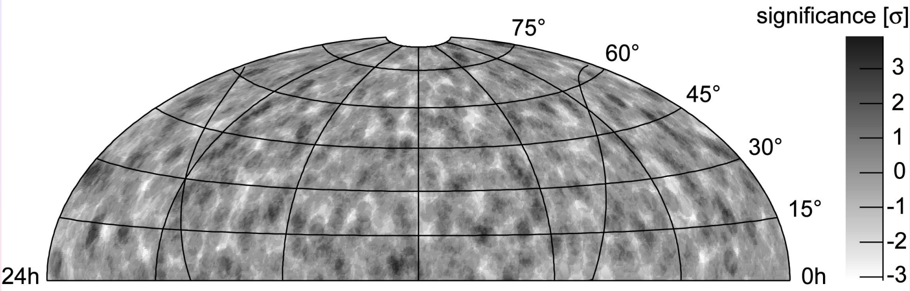

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- main result is flux limit for ν point sources

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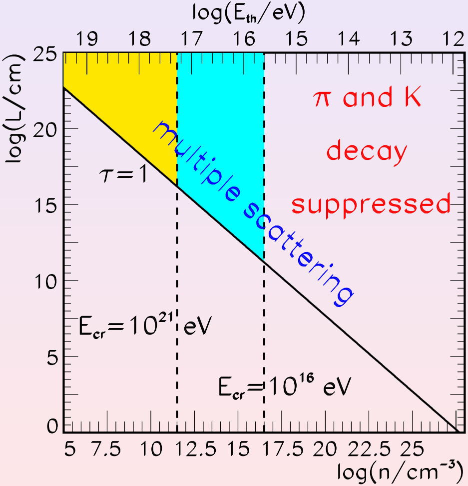
- competition decay vs scattering $\Rightarrow$ suppression of UHE flux



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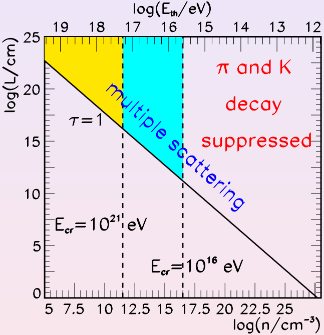
- WB or MPR limits apply only to transparent sources – what about hidden sources ($\tau \gg 1$)?
- competition decay vs scattering $\Rightarrow$ suppression of UHE flux



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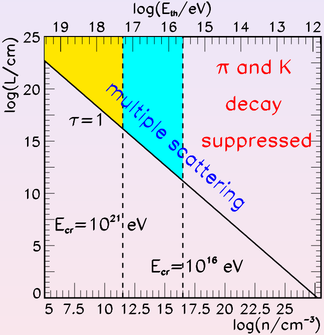
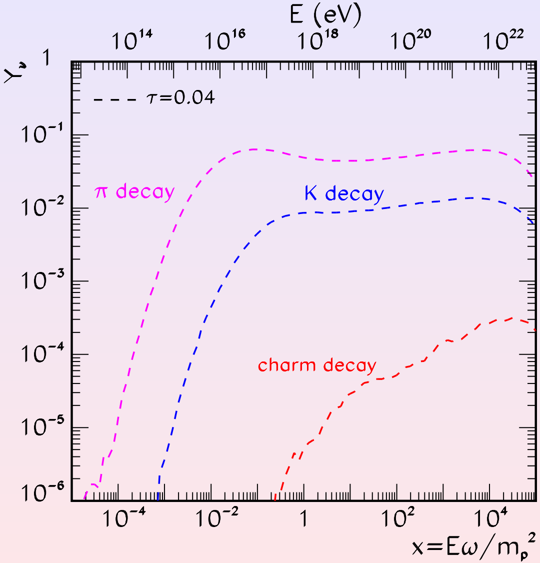


- multiple scattering
  - $\Rightarrow$ distortion of energy spectrum
  - $\Rightarrow$ non-trivial flavor composition

Neutrino yields $Y_\nu = J_\nu/(\tau J_p)$ from hidden sources: [MK, R. Tomàs '06]



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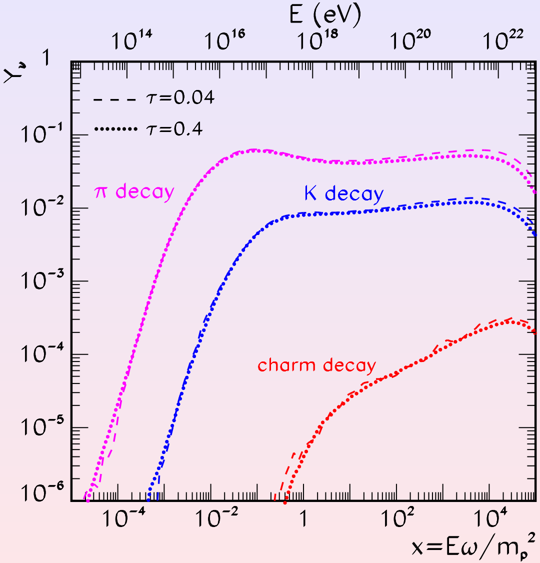

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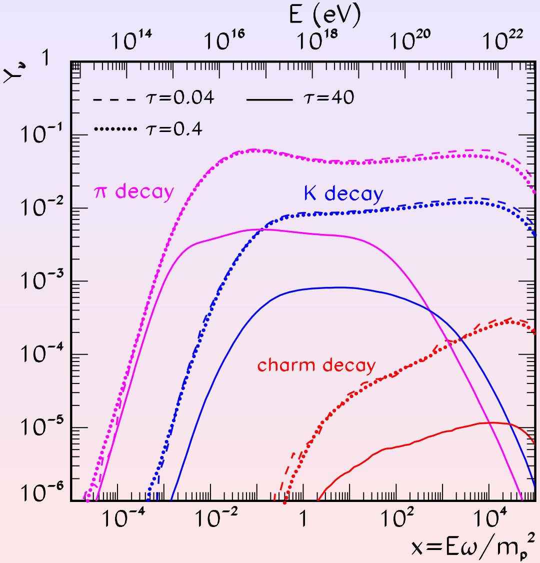
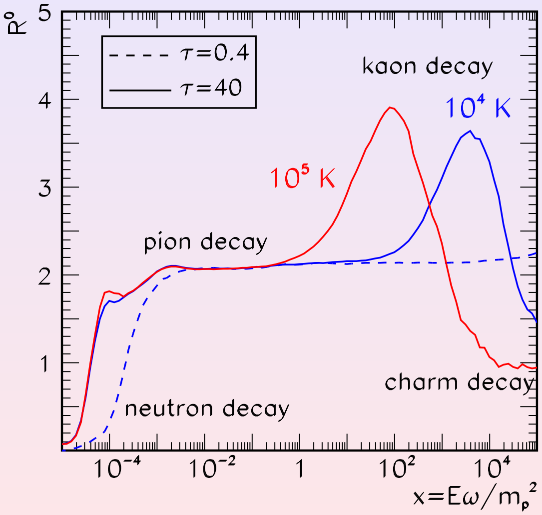
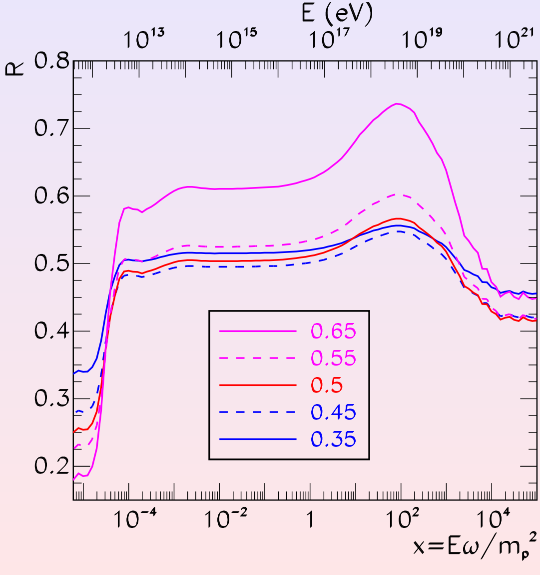


Flavor ratio $R^0 = \varphi_{\nu_\mu}/(\varphi_{\nu_e} + \varphi_{\nu_\tau})$ at source



Flavor ratio $R = \varphi_{\nu_\mu}/(\varphi_{\nu_e} + \varphi_{\nu_\tau})$ at Earth

$\varphi^D_{\nu_\alpha} = \sum_\beta P_{\alpha\beta}\varphi_{\nu_\beta}$ $\Rightarrow$ R depends on the ν mixing, mainly on ϑ_{23}



Neutrino yields from transparent, magnetized sources:

- particles diffuse below $R_L(E_0) \lesssim R_s$ or

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- phenomenology of transparent sources is even richer than the one of hidden sources

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   - new techniques (radio) are coming (and are needed)