DESY Theory Workshop

Sept, 28th – Oct, 1st 2004

Cosmic Rays and Fundamental Physics

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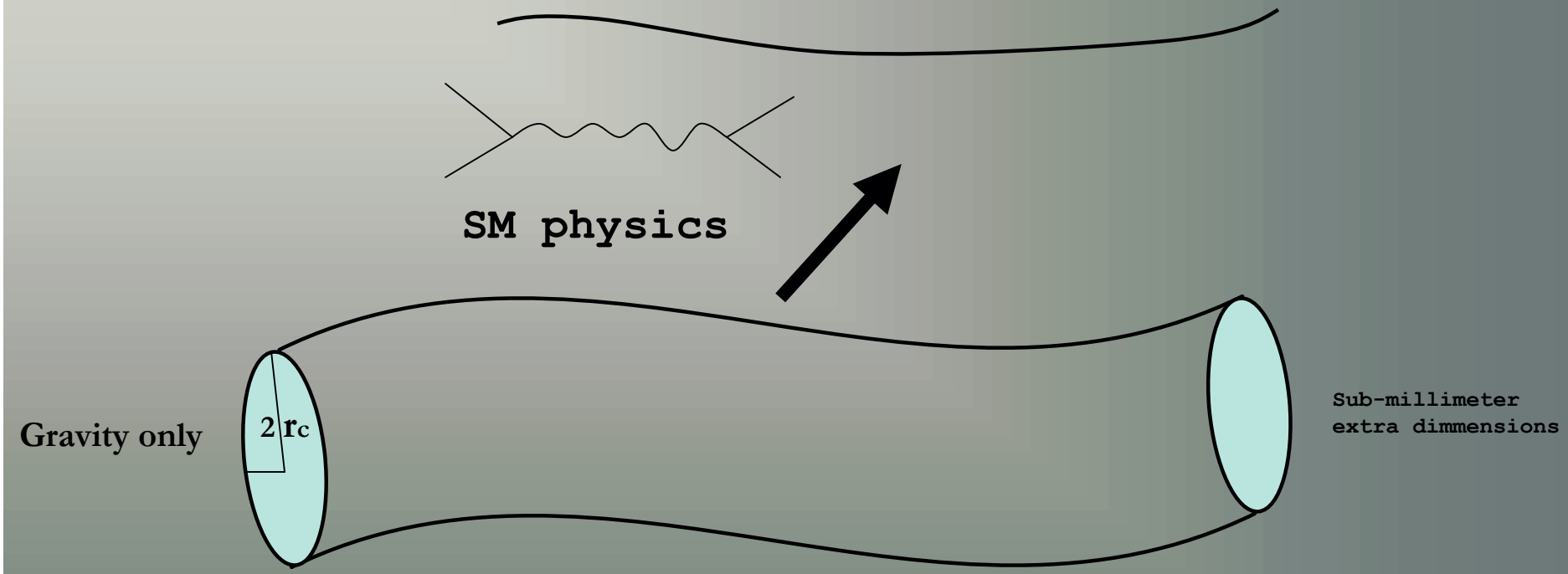
TESTBED OF NEW PHYSICS

OUTLINE

- Neutrino interactions as probes of TeV-scale gravity
- Neutrinos as messengers of high energy astrophysical processes
- Neutron β-decay as a test of local Lorentz invariance
- Probing SUSY with cosmic rays
  - » observing neutralinos from space-based detectors
  - » gluino air showers as a signal of split SUSY

Hypothesis: Universe has D= 4 + n dimensions



- SM lives in 4 dimensions
- Gravity spills into internal dimensions

Gravitational Strength: $8\pi M_D^{2+n} r_c^n \approx (10^{19}\ \mathrm{GeV})^2$

Gravity is weak because:

- D = 4 and $M_D \approx 10^{19}$ GeV
- D > 4 and $M_D \approx 10^{3}$ GeV but r_c large in Planck units

Arkani Hamed-Dimopoulos-Dvali PLB429 (1998) 263

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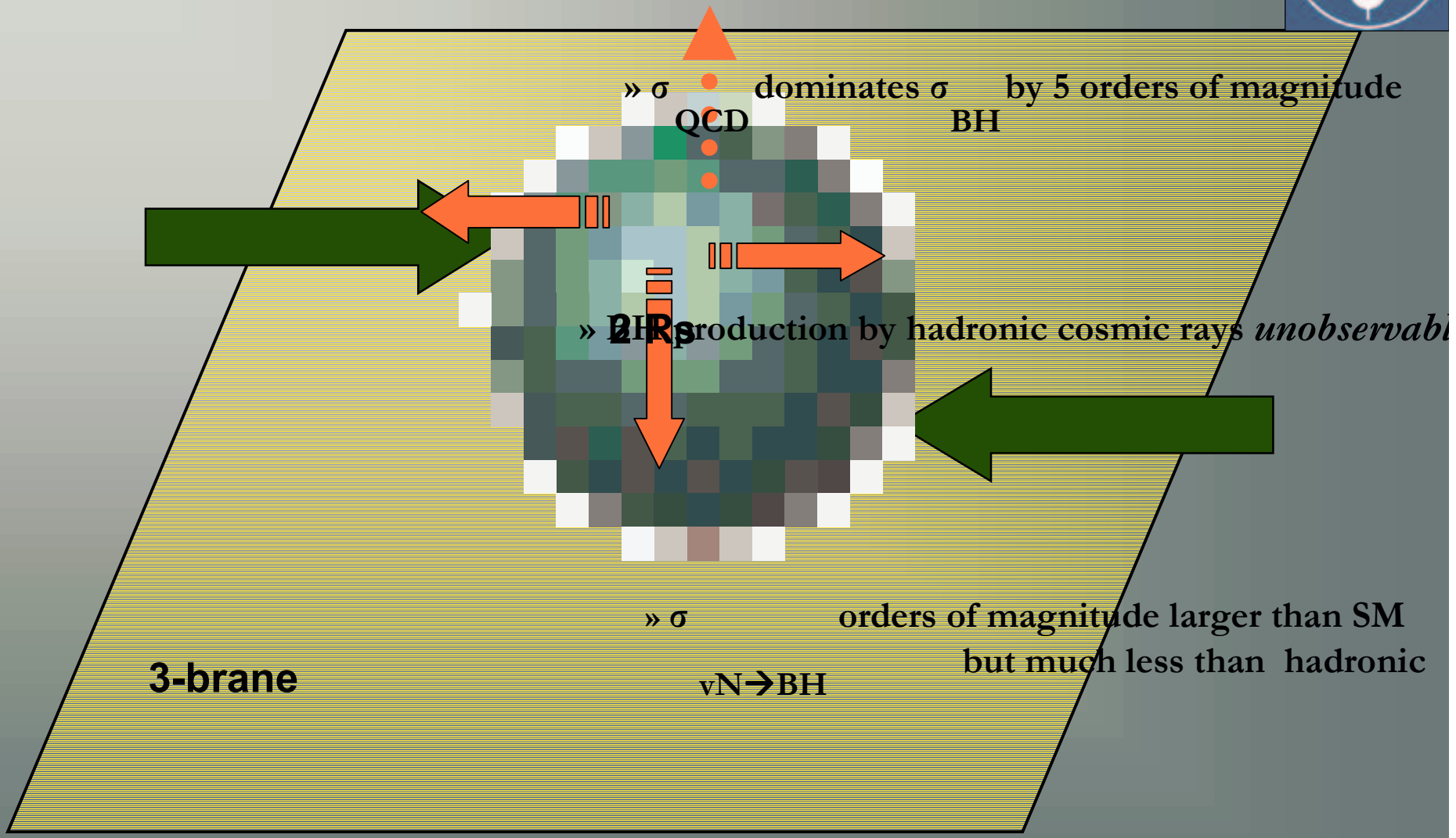
BH PRODUCTION IN PARTICLE COLLISION

HAWKING RADIATION

PAO



Dimopoulos – Landsberg PRL 87 (2001) 161602

Guiddings- Thomas PRD 65 (2002) 056010

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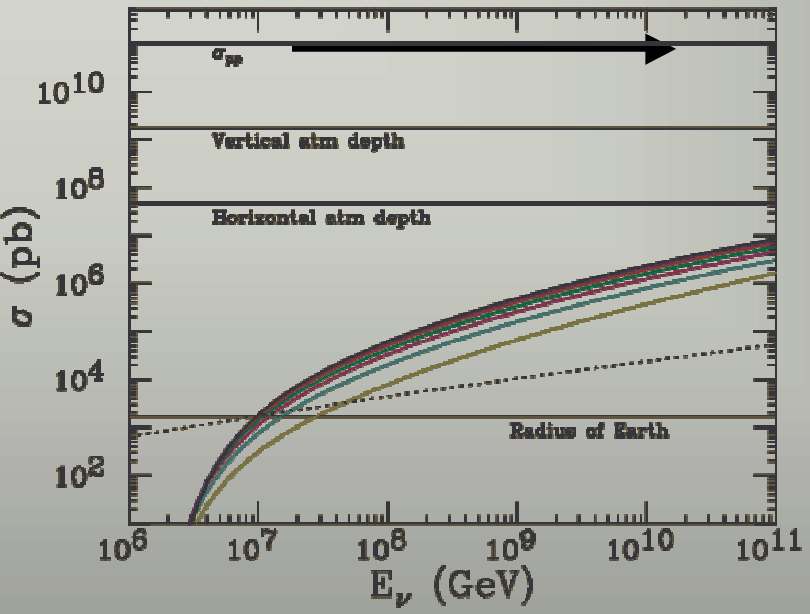
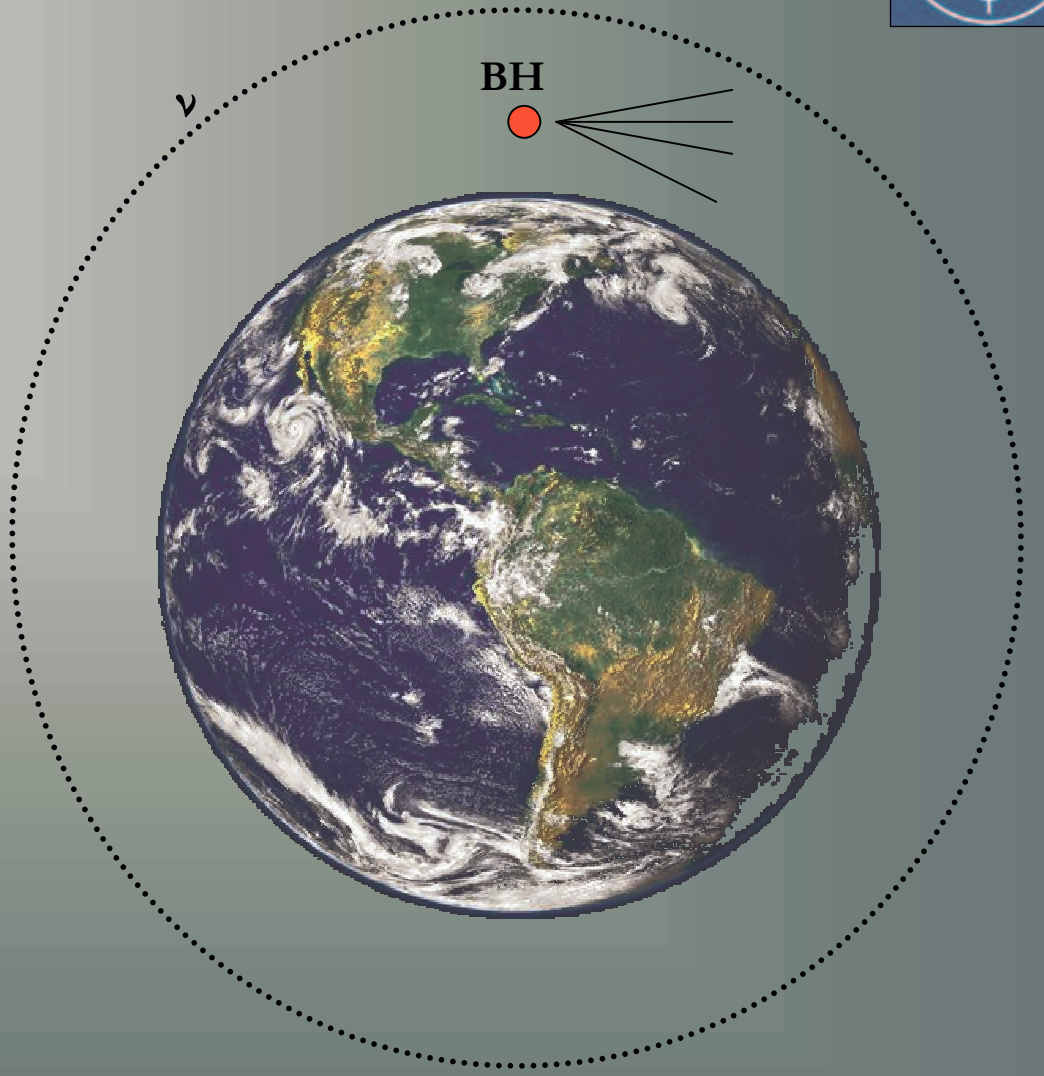
BLACK HOLES FROM COSMIC RAYS





- Nearly horizontal showers are especially interesting
  - Baryonic background largely filtered by atmosphere

Feng-Shapere PRL 88 (2002) 021303

SENSITIVITY OF PAO FOR BH DISCOVERY

For Quasi-Horizontal neutrinos

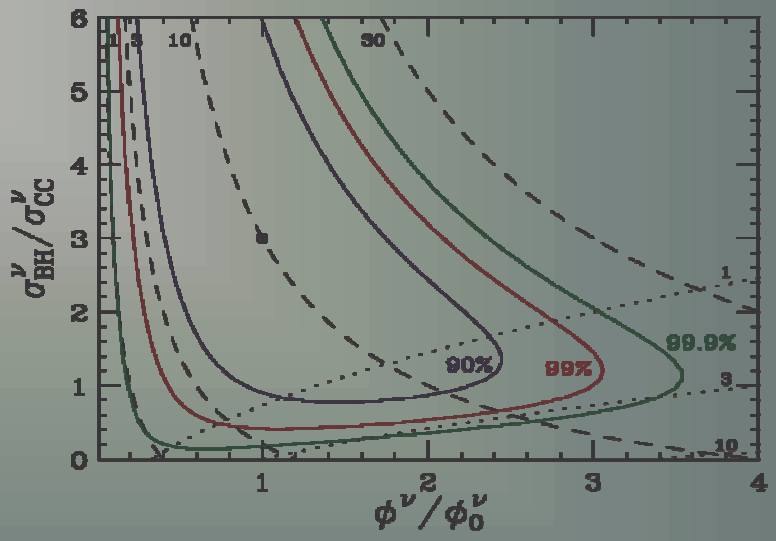
- $\sigma_{BH} \Rightarrow$ increases event rates
- $\Phi > \Phi_{cosmogenic} \Rightarrow$ increases event rates

For Earth-skimmers

- $\Phi > \Phi_{cosmogenic} \Rightarrow$ increases event rates
- $\sigma_{BH} \Rightarrow$ rate suppressed

$$N_{QH} \propto \phi^{\nu}(\sigma^{\nu}_{CC} + \sigma_{BH})$$

$$N_{ES} \propto \phi^{\nu} \frac{\sigma^{\nu\,2}_{CC}}{(\sigma^{\nu}_{CC}+\sigma_{BH})^2}$$



PAO 5 years

QH showers dashed

ES dotted

LAA-Feng-Goldberg-Shapere PRD 65 (2002)124027

NON OBSERVATION OF DEEPLY PENETRATING SHOWERS

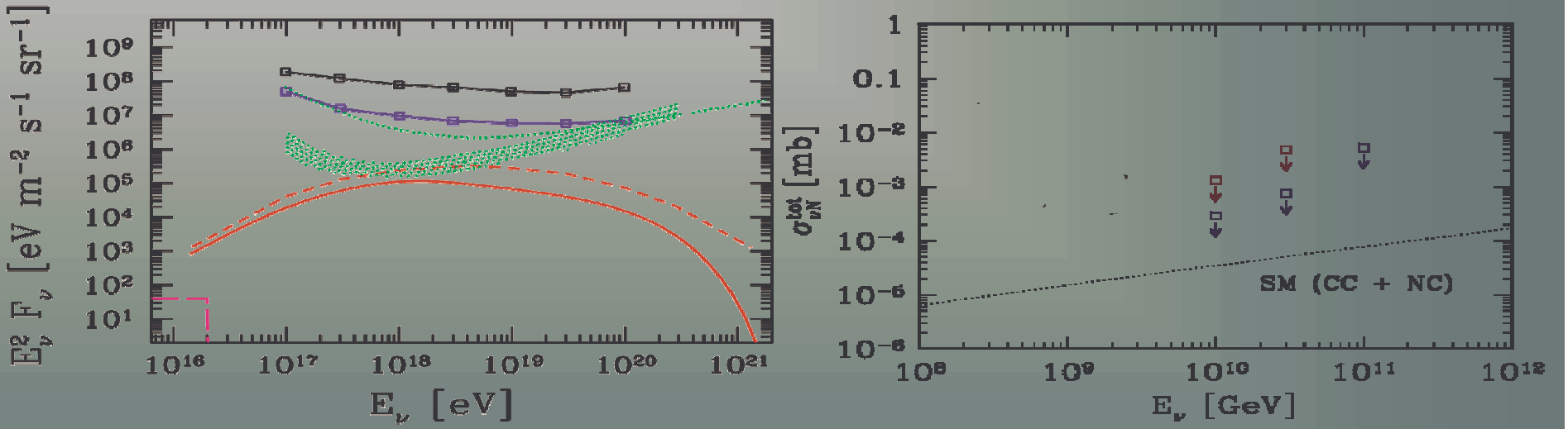
+

ASSUMPTION ON NEUTRINO FLUX

BOUNDS ON NEUTRINO- NUCLEON CROSS SECTION

UHECR interactions with CMB

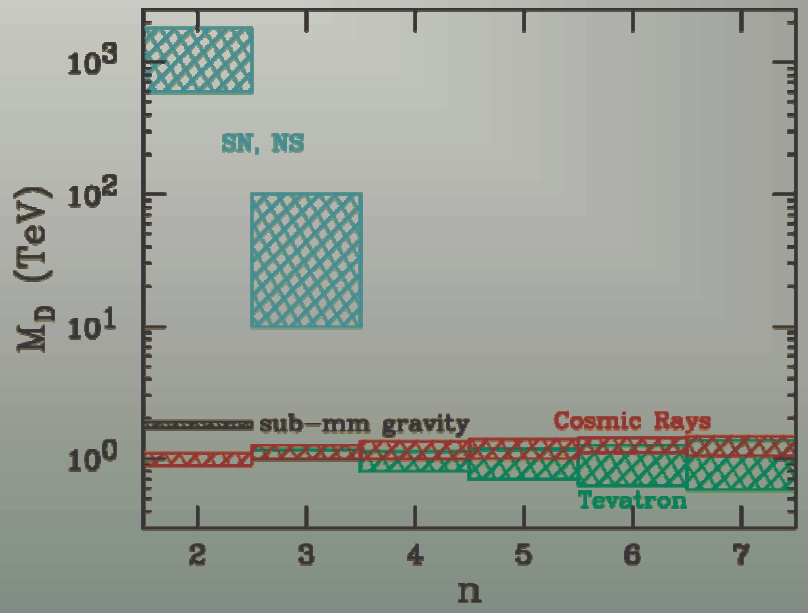
cosmogenic neutrinos



LAA-Fodor-Katz-Ringwald-Tu (*work in progress*)

LIMITS ON EXTRA DIMENSIONS

$$\sigma_{BH} \sim M_D^{-2}$$



Hannestad-Raffelt PRL 88 (2002) 071301

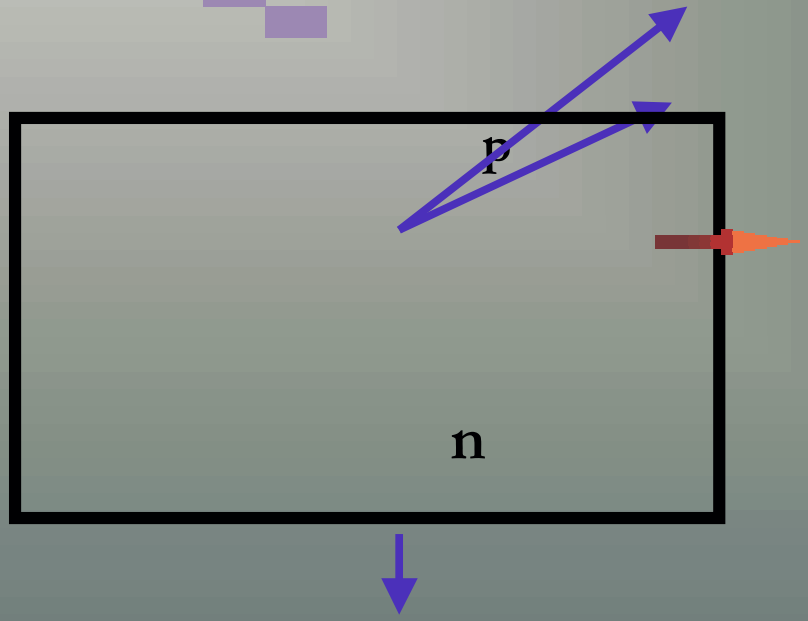
LAA-Feng-Goldberg-Shapere PRD 68 (2003) 104025

D0 Collaboration PRL 86 (2001) 1156

UHECR PRODUCTION IN ASTROPHYSICAL SOURCES

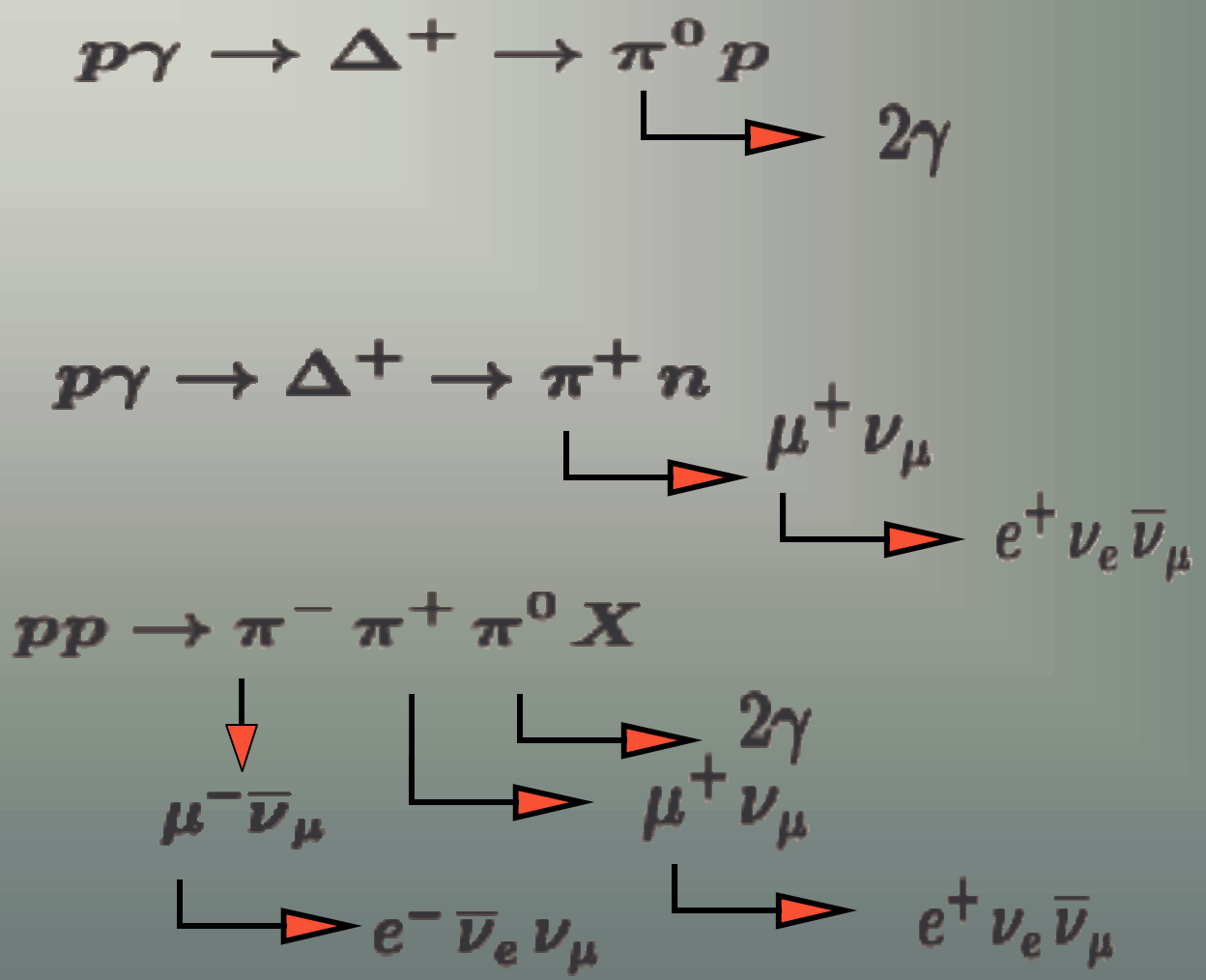
$\pi^{\pm} \rightarrow \nu$

$\pi^{o} \rightarrow \gamma$



H_{II} or γ

cosmic ray


$p\gamma \to \Delta^+ \to \pi^0 p$
2γ
$p\gamma \to \Delta^+ \to \pi^+ n$
$\mu^+ \nu_\mu$
$e^+ \nu_e \bar{\nu}_\mu$
$pp \to \pi^- \pi^+ \pi^0 X$
$\mu^- \bar{\nu}_\mu$
2γ
$\mu^+ \nu_\mu$
$e^- \bar{\nu}_e \nu_\mu$
$e^+ \nu_e \bar{\nu}_\mu$

Isotopically neutral mix of pions create on decay

neutrino population in the ratio

$$N_{\nu_\mu} = N_{\bar{\nu}_\mu} = 2N_{\nu_e} = 2N_{\bar{\nu}_e}$$

Neutrino oscillations

- Maximal $\nu_\mu \leftrightarrow \nu_\tau$ mixing
- $|(\nu_e|\nu_3)|^2$ « 1
- $\nu_3 \simeq (\nu_\mu + \nu_\tau)/\sqrt{2}$

$$N_{\bar{\nu}_e}^{\text{Earth}} = \frac{1}{6} N_{\nu+\bar{\nu}}^{\text{total}}$$

Photopion production ➡ **isotopically asymetric process**

$$N_{\nu_\mu} = N_{\bar{\nu}_\mu} = N_{\nu_e} \gg N_{\bar{\nu}_e}$$

Neutrino oscillations

$$N_{\bar{\nu}_e}^{\text{Earth}} = N_{\bar{\nu}_\mu} P(\bar{\nu}_\mu \to \bar{\nu}_e) = \frac{1}{3} \sin^2\theta_\odot \cos^2\theta_\odot \, N_{\nu+\bar{\nu}}^{\text{total}}$$

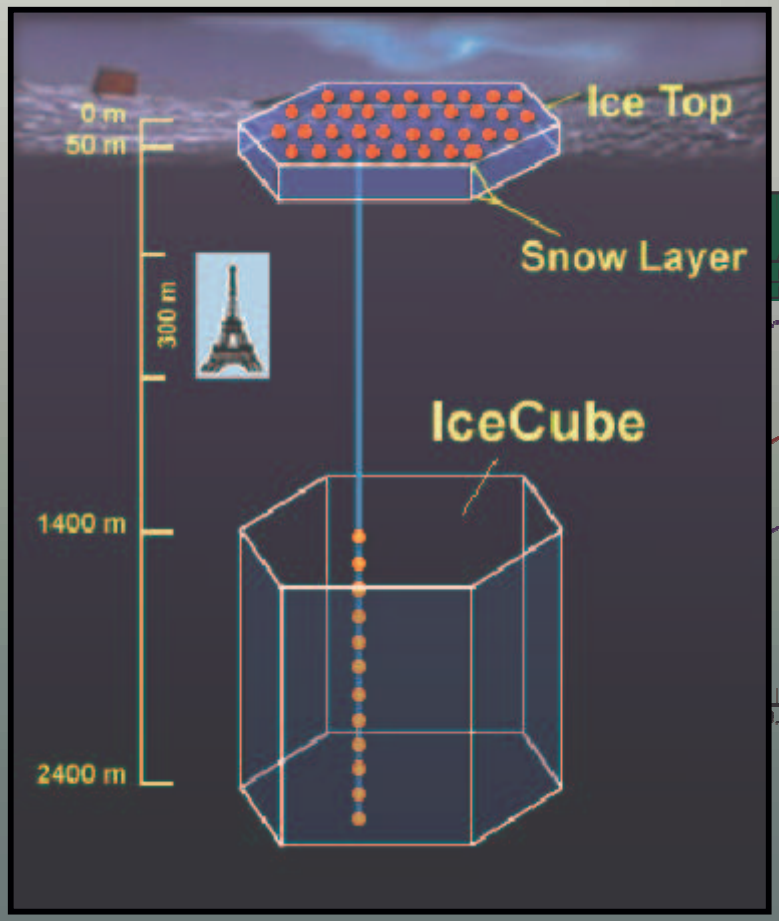
SNO $\theta_\odot \simeq 32.5°$

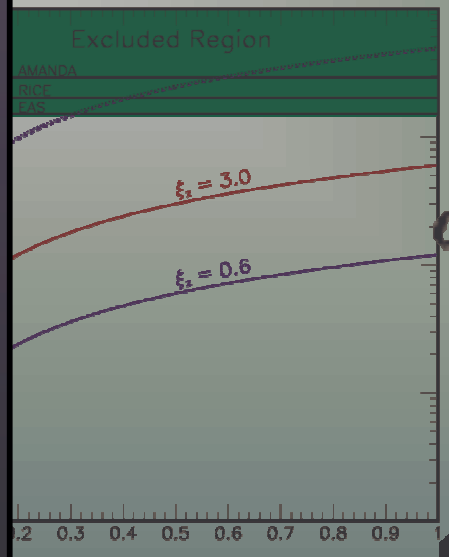
$$N_{\bar{\nu}_e}^{\text{Earth}} = \frac{1}{15} N_{\nu+\bar{\nu}}^{\text{total}}$$

THE GLASHOW SIGNAL

Resonant scattering

$$\bar{\nu}_e e^- \rightarrow W^- \rightarrow \text{anything}$$





Signal

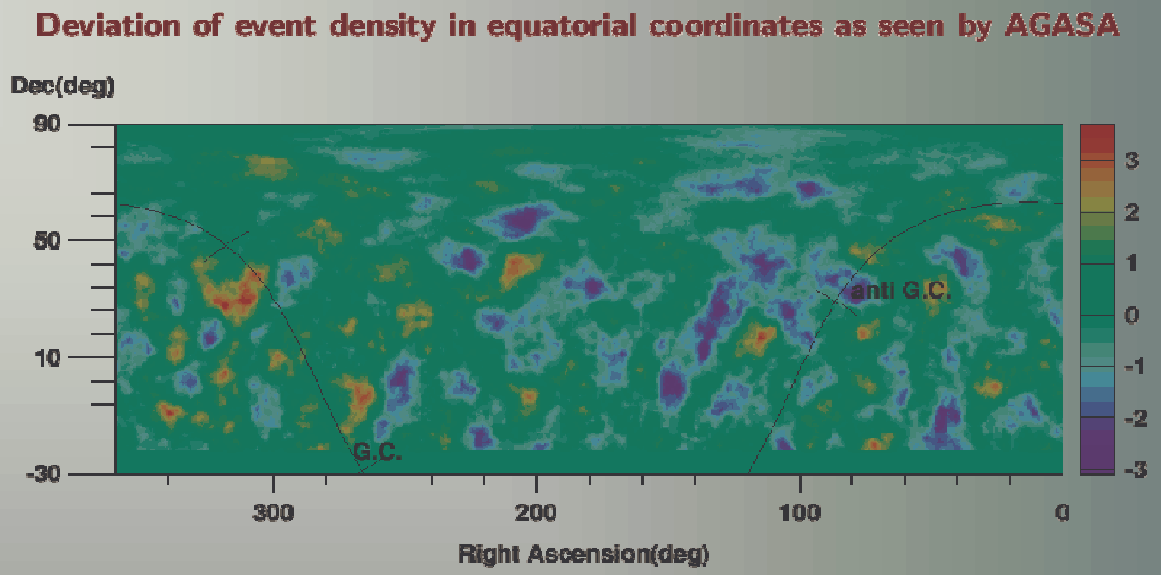
$$dN/dt = 3.2\ \mathrm{yr}^{-1}$$

Background

$$dN/dt = 0.8\ \mathrm{yr}^{-1}$$

LAA-Goldberg-Halzen-Weiler (*work in progress*)

COSMIC RAY ANISOTROPY



AGASA Collaboration, ICRC2001

AGASA

Largest deviation observed at coordinates $\alpha \approx 313°$ $\sigma \approx 32°$

4 σ deviation ➡ 4 % of total flux

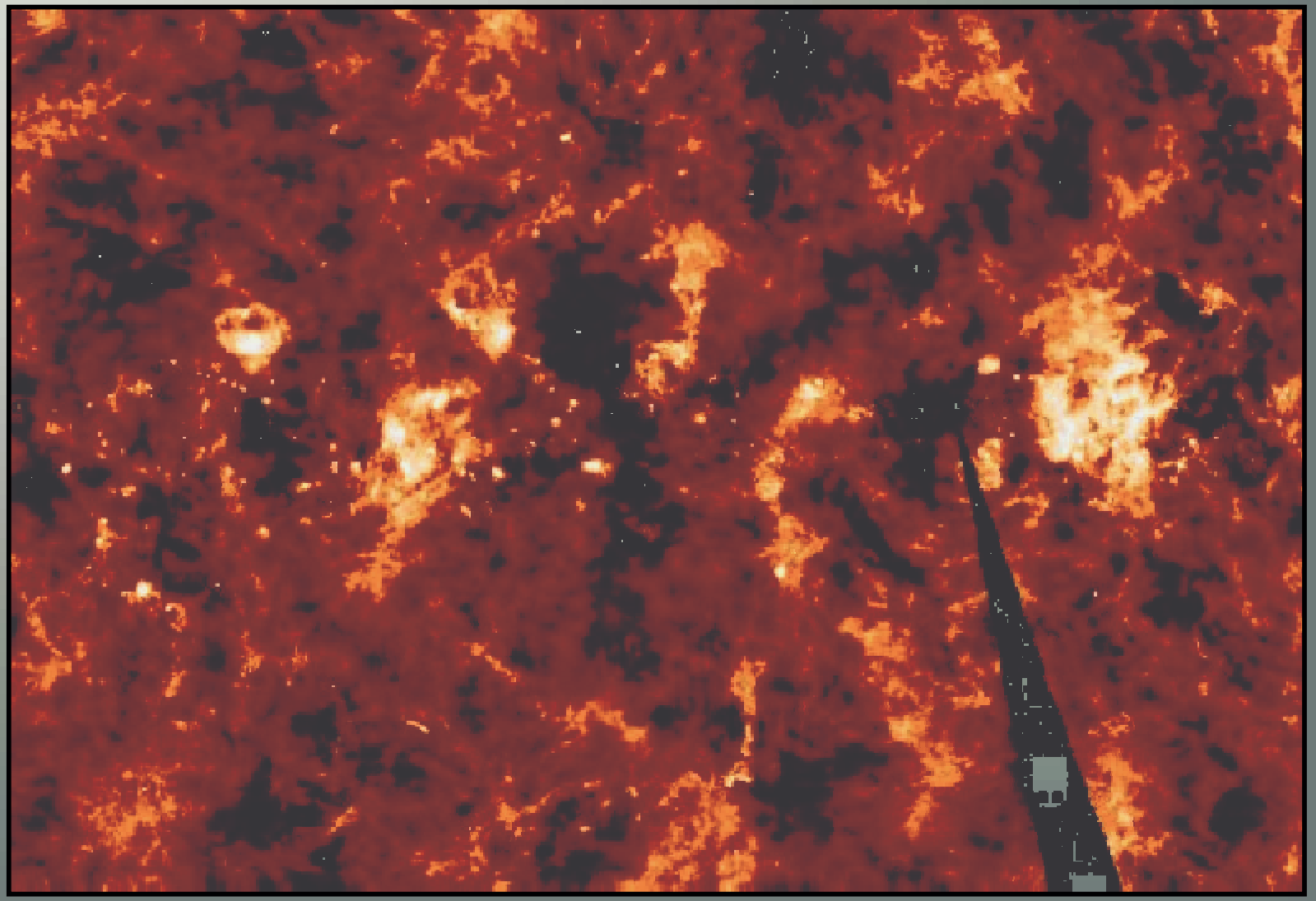
Fly's Eye [astro-ph/9806096]

Galactic Plane enhancement $\Rightarrow$ 3.2 σ ➡ same *E* region

SUGAR [astro-ph/0009039]

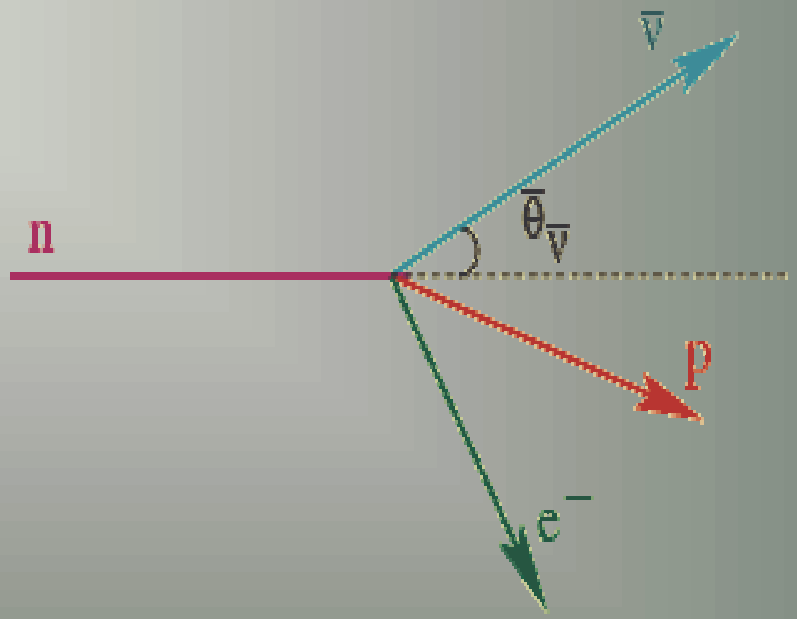
Galactic Center anisotropy $\Rightarrow$ 3σ ➡ same *E* region

THE CYGNUS ACCELERATOR



http://antwrp.gsfc.nasa.gov/apod/ap 970424.html

$n\,DK \rightarrow \bar{\nu}$



- **Probe of Local Lorentz Invariance**
  - ☛ **Shape of lower cutoff in observed anisotropy (if taken as neutrons) ⇒ validity of time dilation formula up to $\gamma \sim 10^9$**
  - ☛ **$\bar{\nu}$–flux "smoking ice" of n–hypothesis**

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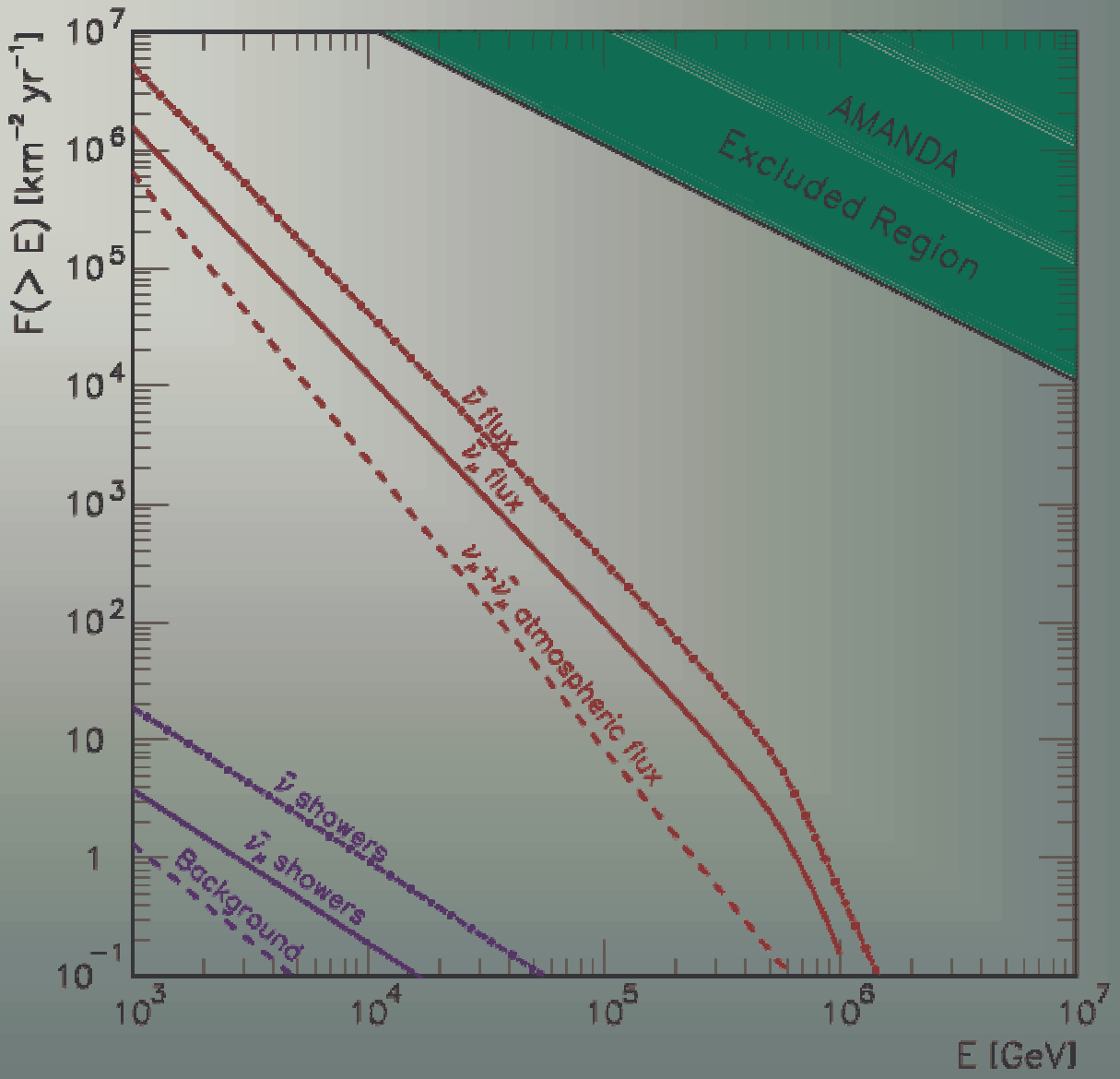
THE CYGNUS SIGNAL



LAA- Goldberg- Halzen- Weiler PLB 593 (2004) 42

SUSY

SM particles have partners with $\Delta J = ½$

broken symmetry $\rightarrow \Lambda_{SUSY}$

MSSM

R – parity ⇒ stable dark matter candidate

⇓

the neutralino

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SUSY IN THE SKY

with rising energy

2003) 132

LAA-Goldberg-Nath PRD 70 (2004) 025014

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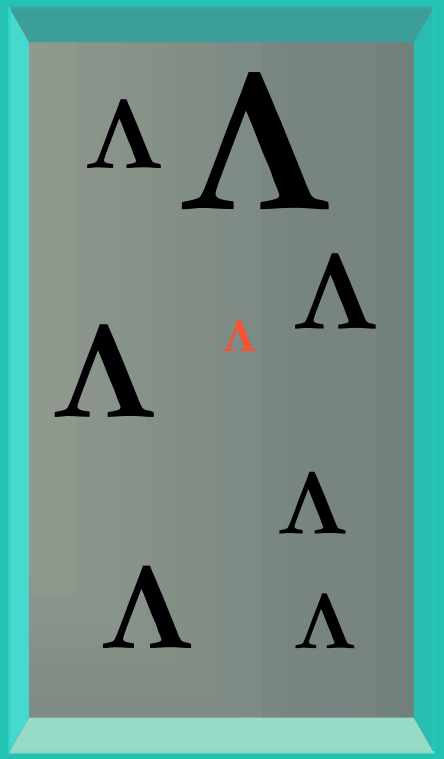
TRHOUGH THE LOOKING GLASS
THE COSMOLOGICAL CONSTANT PROBLEM
INTO THE LANDSCAPE

DIVINE INTERVENTION

STATISTICS



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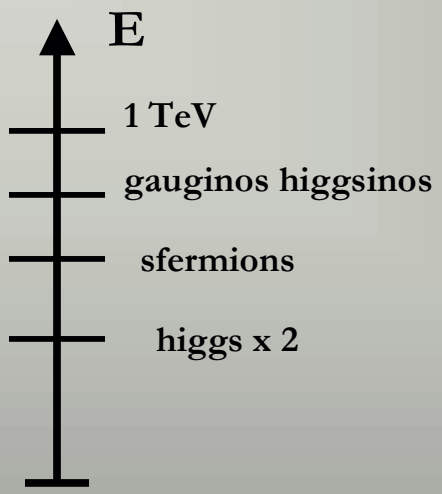
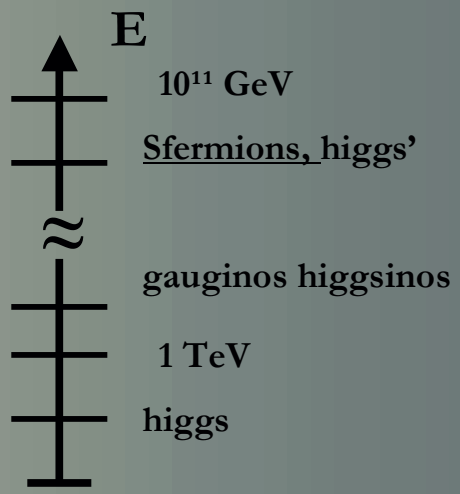
SPLIT SUSY



MSSM

The mass of the higgs is natural

Unified running



SPLIT SUSY

The mass of the higgs is fine tuned

Unification works (better)

Arkani Hamed – Dimopoulos hep-th/0405159

Giudice- Romanino hep-ph/ 0406088

PROBING SPLIT SUSY WITH COSMIC RAYS

- Because of the large mass of the sfermions → metastable gluinos

$$\tau_{\tilde{g}} \propto m_{\tilde{q}}^{4}$$

- Very strong limits on heavy isotope abundance

↓

Upper limit on Λ_{SUSY}

- Observation of cosmological gluinos

↓

Lower limit on Λ_{SUSY}

$$10^{11}\ \text{GeV} < \Lambda_{SUSY} < 10^{13}\ \text{GeV}$$

LAA-Goldberg-Nuñez hep –ph/0408284

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SUMMARY

- Future Cosmic Ray data will not only provide clues to cosmic ray origin,but could enhance our understanding of fundamental particle physics
- The puzzle of ultrahigh energy cosmic rays may even have something to say about issues as fundamental as local Lorentz inavariance
- Contrasting the observed quasi-horizontal neutrino flux with the expected neutrino flux can help to improve existing limits on the fundamental Planck scale
- An optimist might even imagine the discovery of microscopic black holes, the telltale signature of the universe's unseen dimensions
- Λ_{SUSY} written in the sky ?
- We are entering this new High Energy Physics era with PAO + Ice Cube

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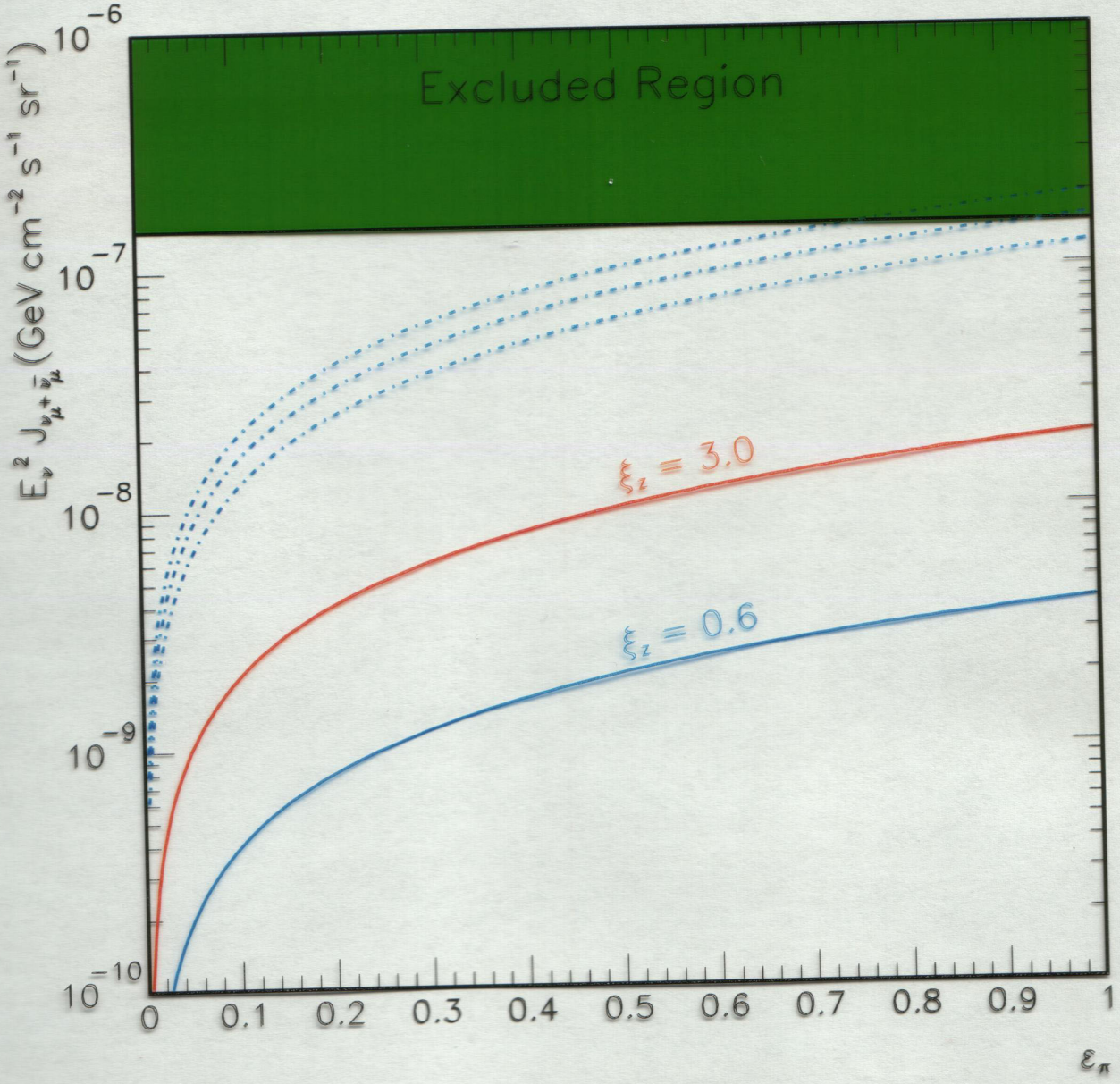
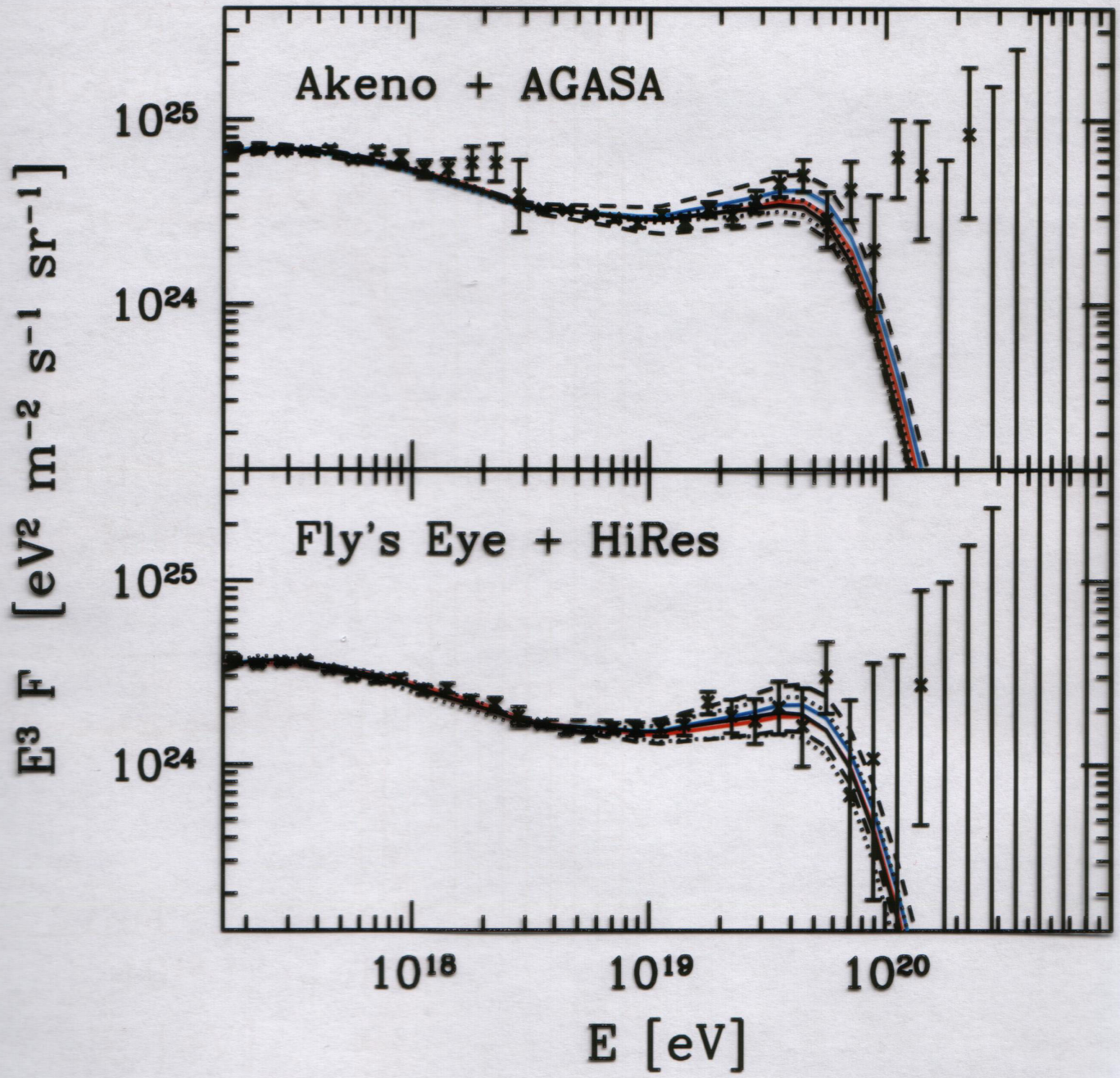
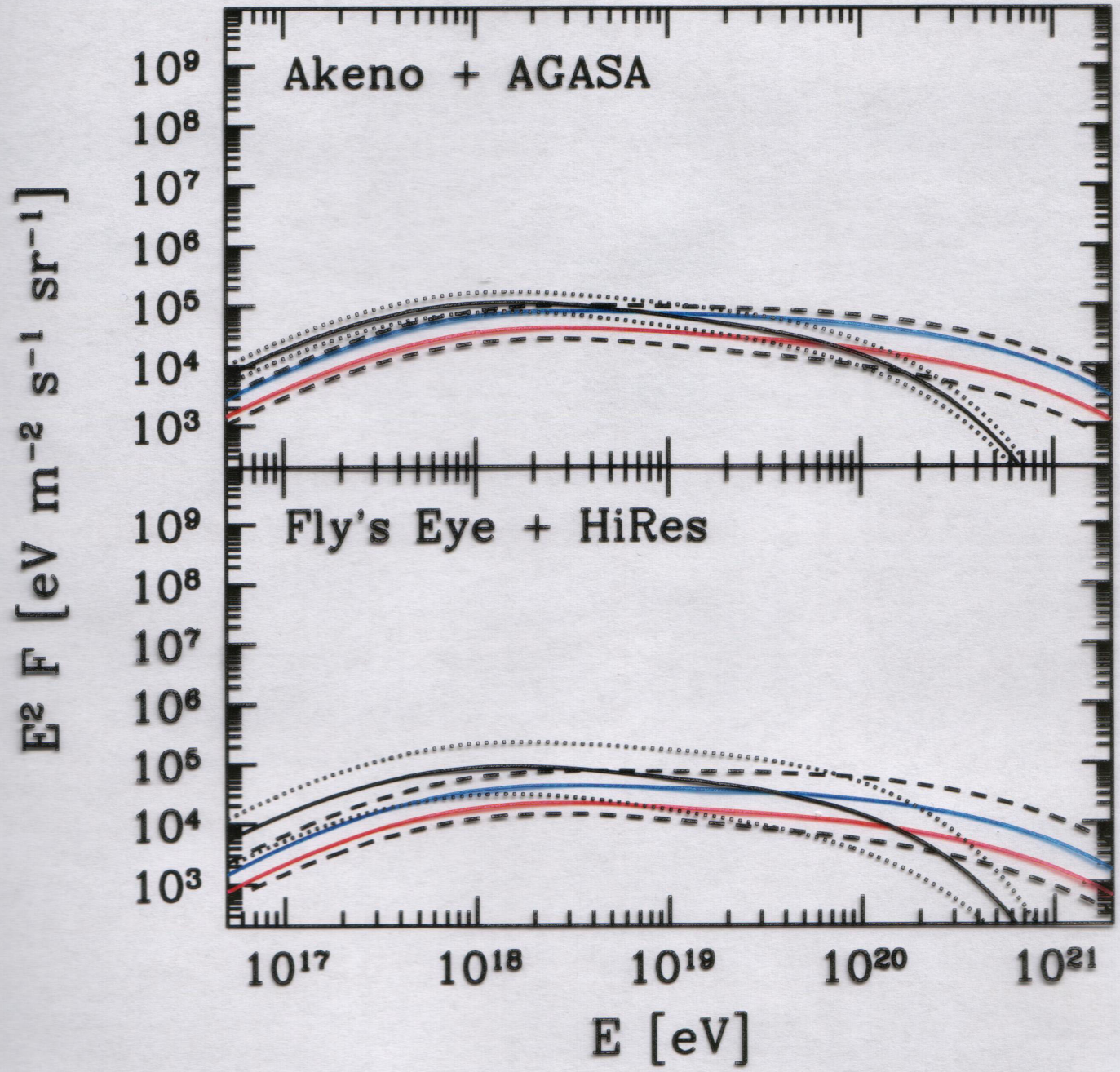
THANKS

&

QUESTIONS


Excluded Region
$\xi_z = 3.0$
$\xi_z = 0.6$
$E_\nu^2 J_{\nu_\mu + \bar{\nu}_\mu}$ (GeV cm^{-2} s^{-1} sr^{-1})
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
ε_π


Akeno + AGASA
Fly's Eye + HiRes
10^{25}
10^{24}
10^{25}
10^{24}
E^3 F [eV^2 m^{-2} s^{-1} sr^{-1}]
10^{18}
10^{19}
10^{20}
E [eV]


Akeno + AGASA
Fly's Eye + HiRes
E^2 F [eV m^{-2} s^{-1} sr^{-1}]
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
E [eV]