Misura dei parametri di mixing neutrinici con i ν-telescopes

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in collaborazione con M. Kachelrieß

Overview of the Talk

- ν-telescopes and ν-mixing: a (brief) overview
- An interesting Galactic Anisotropy in CR: neutron source(s)?
- A promising point-like target for ν-telescopes
- A chance for galactic β-beams
- Discussion & Conclusions

ν-telescopes and ν-mixing: a (brief) overview

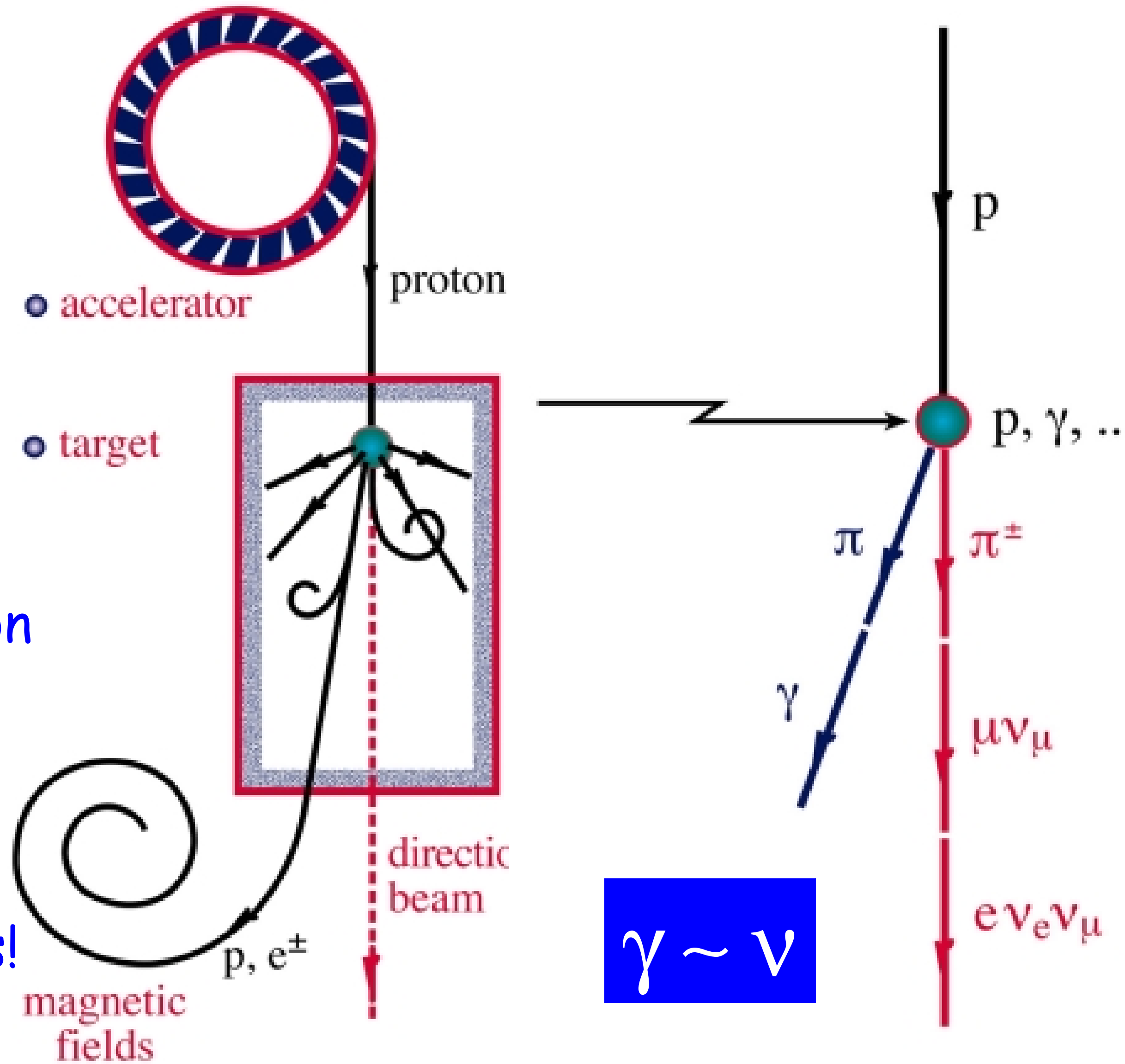
Neutrino Beams: Heaven & Earth

Big Advantages
For ν astronomy:

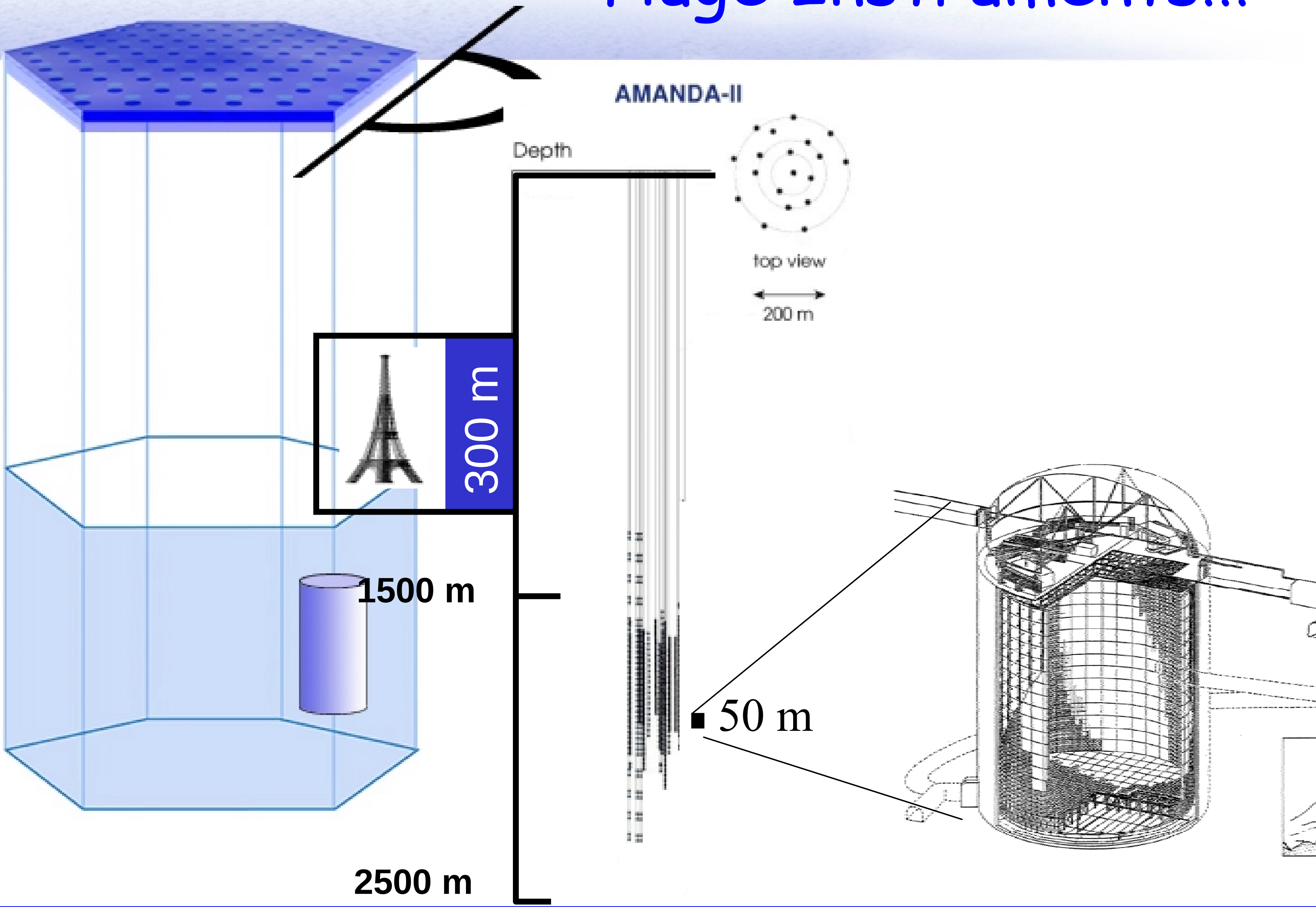
+)Directionality of the signal (differently from Cosmic Rays)

+)Negligible absorption (differently from γ)

"Largest" problem
-)Small cross sections!

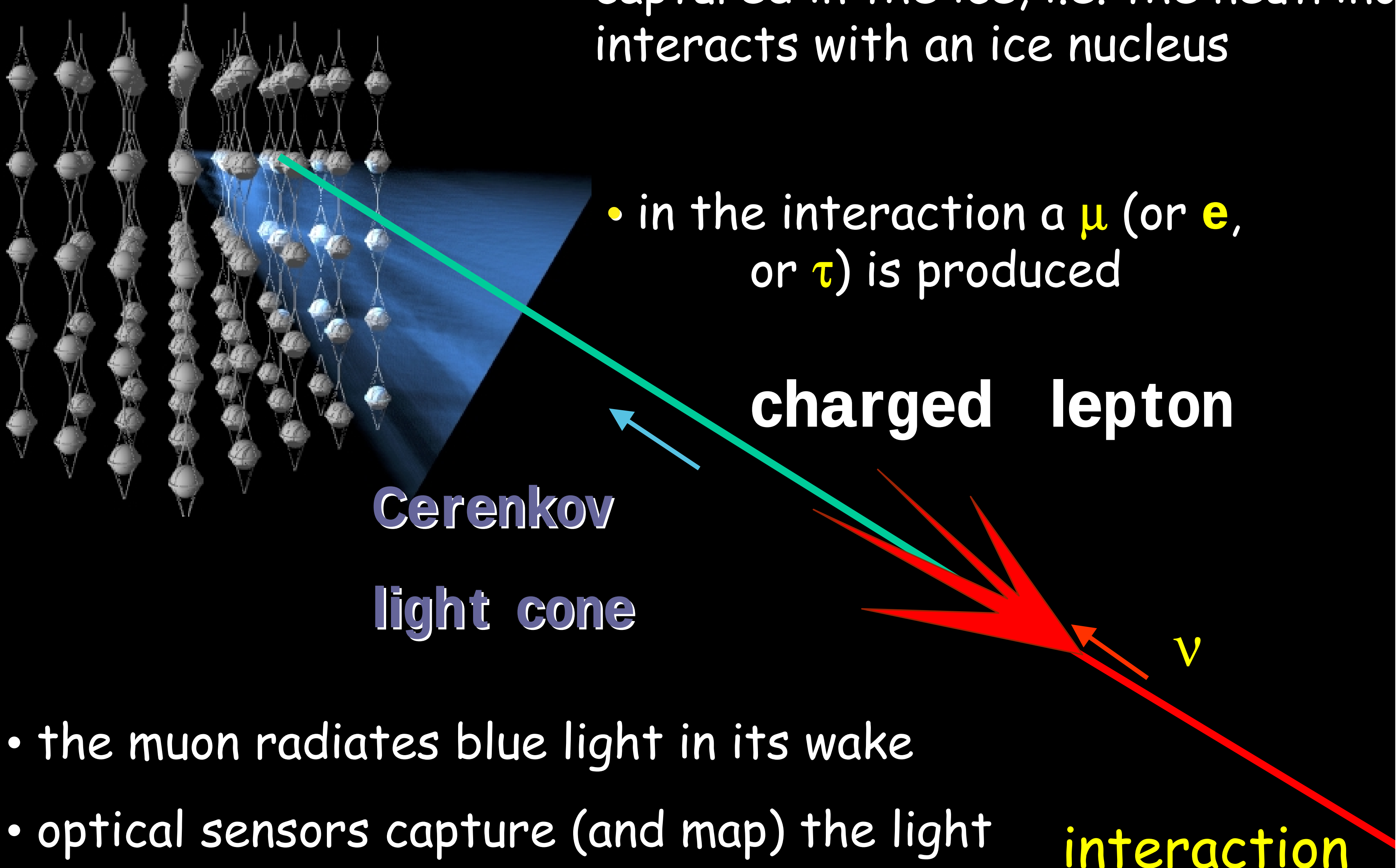


Huge Instruments!!!



detector

- infrequently, a cosmic neutrino is captured in the ice, i.e. the neutrino interacts with an ice nucleus
- in the interaction a μ (or **e**, or τ) is produced



- the muon radiates blue light in its wake
- optical sensors capture (and map) the light

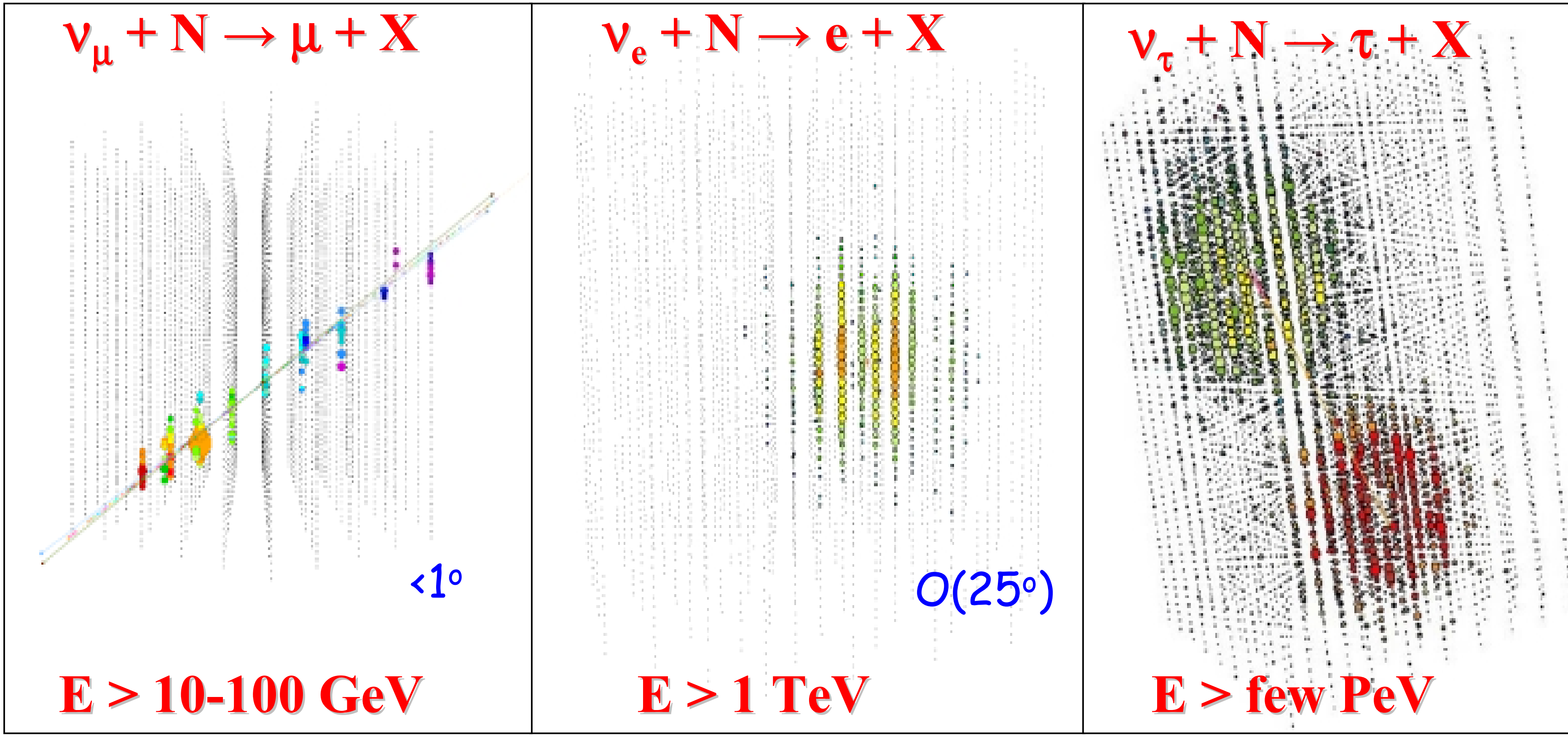
ν-telescopes and ν-mixing

1. The signature and efficiency of these detectors depend on the flavour!
   In particular, oscillations may "rescue" signals

2. In some cases, ν-mixing angles might be studied at ν-telescopes

Only standard physics considered here, otherwise many other interesting possibilities would open!

Flavour Discrimination

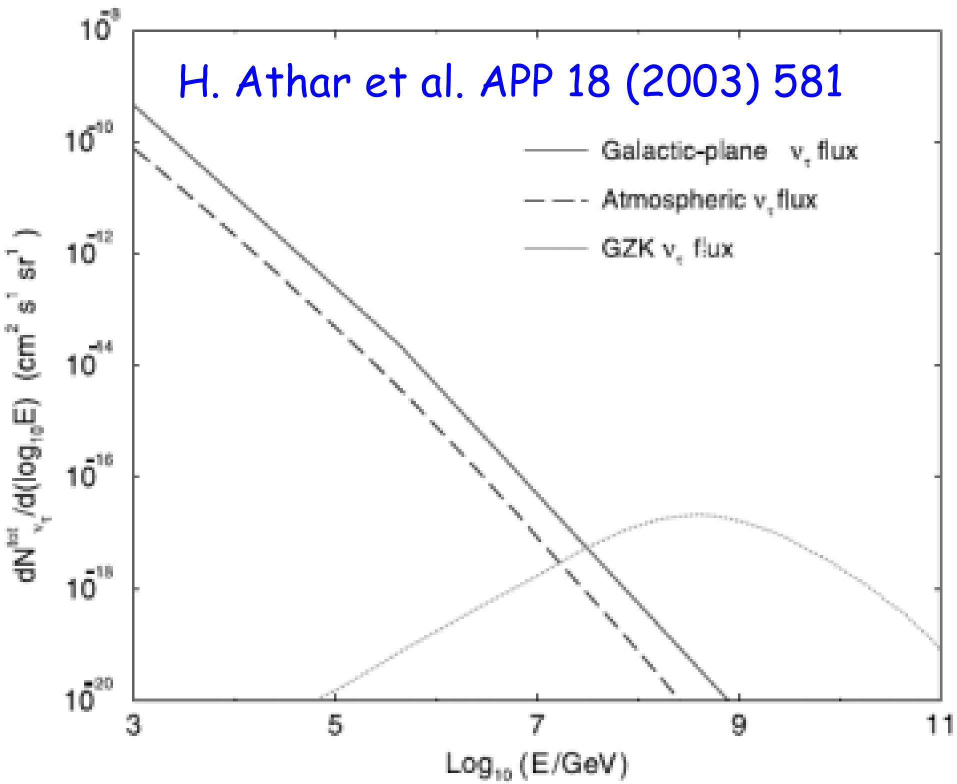


Simplified picture! Subleading flavour-independent effects (NC showers), "fake signals" (e.g. μ events tracks in $\tau \rightarrow \mu$ events)

A "rescued" signal: the Galactic diffuse ν_τ

The pp ν-flux from CR hitting Galactic diffuse matter develops a large oscillated τ-component.

Atmospheric ν background is softer due to relevant energy losses of mesons. Moreover, it is ν_τ-suppressed: at E≈TeV-PeV the oscillation length is too large (mainly prompt ν_τ!)



Event rate of $O(1\ \mathrm{yr}^{-1}\ \mathrm{sr}^{-1})$ for two separable and contained showers with E ≈ PeV in a Km^3 ν-telescope

Independent confirmation of the (large) mixing in the μ–τ sector.

ν-telescopes, the Glashow resonance and θ_{12}

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

"Glashow Resonance"

Unique to $\bar{\nu}_e$, and σ enhanced at E ≈ 6.3 PeV

Standard astrophysical sources produce ν and $\bar{\nu}$ via $pp \rightarrow \pi X$, $p\gamma \rightarrow \pi X$. Both give flavour ratios at production $\phi_e:\phi_\mu:\phi_\tau \approx 1/3:2/3:0$, but $p\gamma$ mainly gives ν_e (via π^+), while pp almost equally ν_e and $\bar{\nu}_e$.

The measurable ratio $R^{GR} \equiv \bar{\nu}_e^{GR}/(\nu_\mu+\nu_{\bar{\mu}})^{CC}$ is thus sensitive to mixing angles (mainly to θ_{12}) as well as to the nature of the astrophysical source (% of pp "contamination" $\equiv \kappa$). For $\theta_{13}=0^\circ$ and $\theta_{23}=45^\circ$ Bhattacharjee & Gupta [astro-ph/0501191] get

$$R^{GR} \approx 15[\mathrm{Sin}^2\, 2\theta_{12} + \kappa(1-0.5\ \mathrm{Sin}^2\, 2\theta_{12})]$$

ν-telescopes, the Glashow resonance and θ_{12} -II

———— θ_{23}=40°

——— θ_{23}=45°

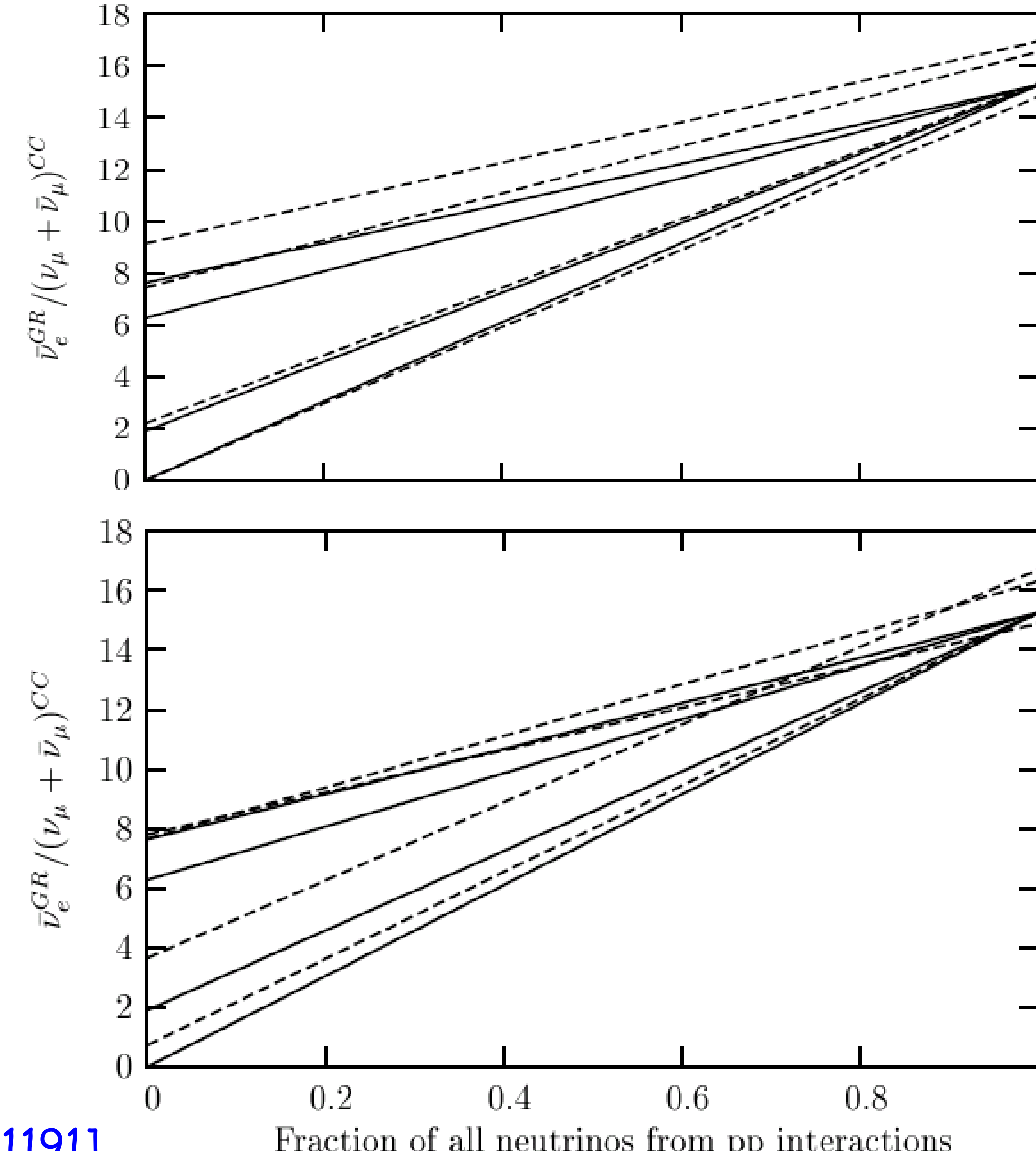
θ_{13}=0°

θ_{12}=45°

θ_{12}=32.5°

θ_{12}=15°

θ_{12}=0°



θ_{23}=45°

———— θ_{13}=9°

——— θ_{23}=0°

θ_{12}=45°

θ_{12}=32.5°

θ_{12}=15°

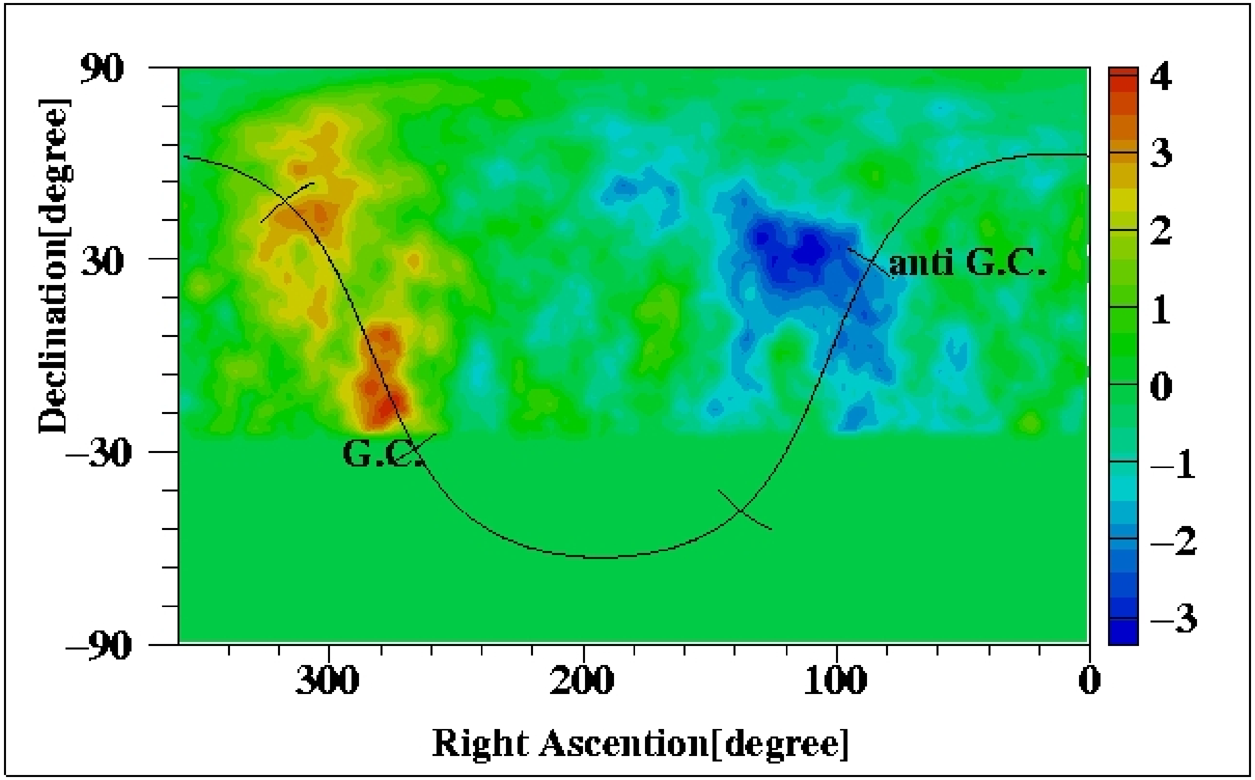
θ_{12}=0°

Bhattacharjee & Gupta [astro-ph/0501191]

An interesting Galactic Anisotropy in CR: neutron source(s)?

A Galactic Plane excess in Cosmic Rays

AGASA reported a 4% excess in HECR around 10^{18} eV (1 EeV) from a couple of hot-spots in the galactic disk



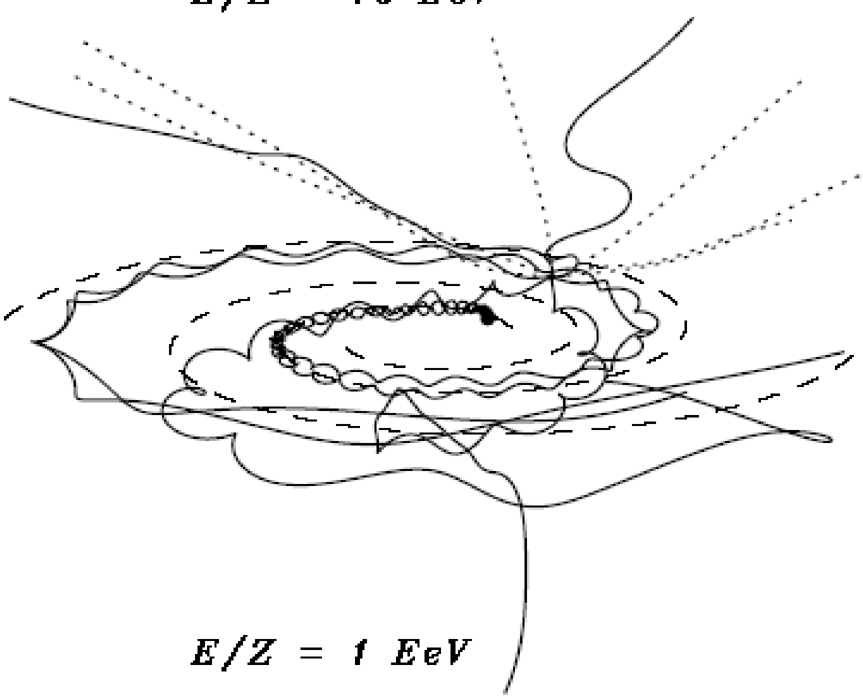
Confirmed also by SUGAR and Fly's Eye: a rare case of concordance in a field where experiments often disagree each other!

The birth of Galactic neutron Astronomy?

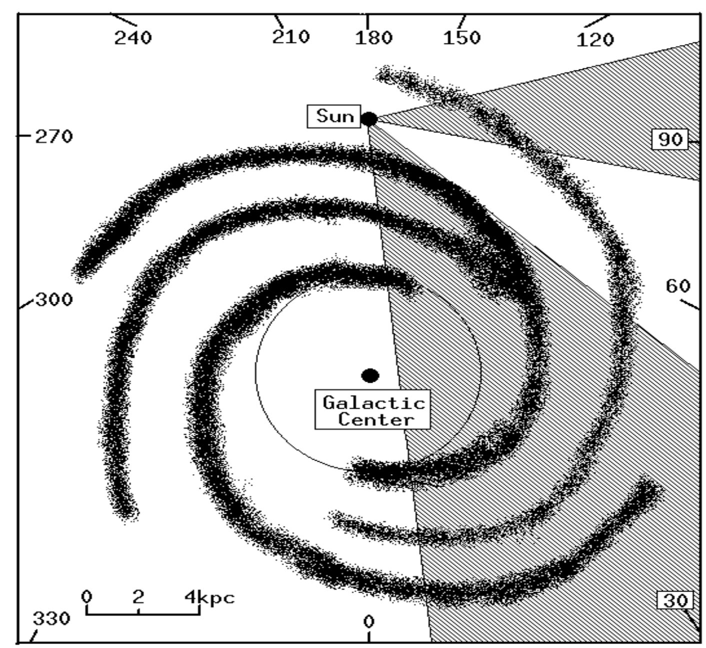
Neutrons are natural candidates to explain the signal

no GMF bending (huge for p too!)

Signal Energy-range ≈ boosted n-lifetime on galactic scales



$$c\tau_n \approx 10 \text{ kpc } (E_n / \text{EeV})$$



The associated ν-flux: a promising point-like target for ν-telescopes

From Neutrons to Neutrinos

If n explain the excess, a garanteed ν flux is the one below PeV from n-decay

$$E_\nu / E_n \sim Q / m_n \sim 0.8 \times 10^{-3}$$
$$\rightarrow E_\nu \sim \text{PeV}, \text{ for } E_n \sim \text{EeV}$$

The energy-window accessible to "conventional" ν-telescopes is from ~100 GeV up to ~ 10^{16-17} eV (10-100 PeV).

Can we observe them?

Conservative!
- Lower energy n undetectable in CR (decay & GMF bending)
- Further ν's from decay of associated meson decay (to be discussed at the end)

Detectability in IceCube

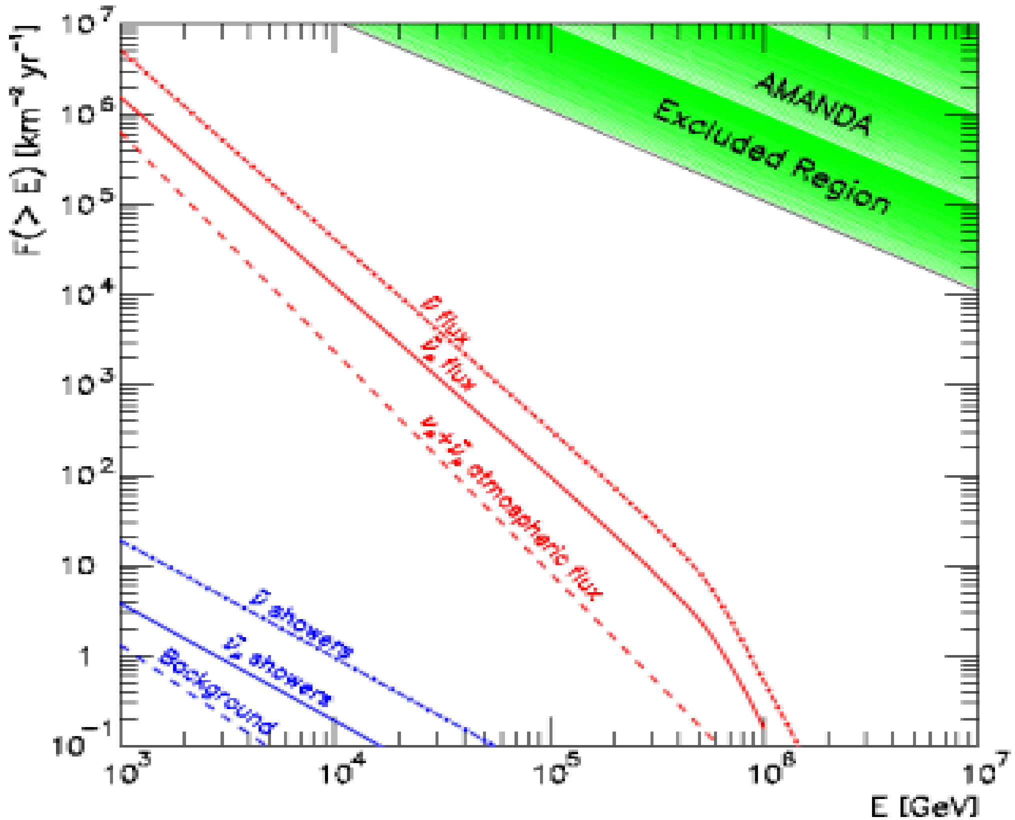
Normalizing to the CR anisotropy, ~ 20 events per year from Cygnus region in **IceCube** (under construction at the South pole)

Standard ν oscillation phenomenology implies

$\approx$ 4 ν_μ /yr tracks in 0.7° circle
(Atm. background is~2.3 ν_μ /yr)

$\approx$ 16 $\nu_e + \nu_\tau$ showers/yr in 25°, cone, due to poor resolution.
(Atm. background *fluctuation* is~12 *showers*/yr)

In a few years, IceCube will attain discovery sensitivity for $n \to \nu_e \to \nu_\mu$!!!



L. Anchordoqui, H. Goldberg, F. Halzen & T.J. Weiler
PLB 593 (2004) 42

A chance for galactic β-beams

ν Mixing

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \underbrace{\begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{\rm CP}} \\ -s_{12}c_{23}-c_{12}s_{13}s_{23}e^{i\delta_{\rm CP}} & c_{12}c_{23}-s_{12}s_{13}s_{23}e^{i\delta_{\rm CP}} & c_{13}s_{23} \\ s_{12}s_{23}-c_{12}s_{13}c_{23}e^{i\delta_{\rm CP}} & -c_{12}s_{23}-s_{12}s_{13}c_{23}e^{i\delta_{\rm CP}} & c_{13}c_{23}\end{pmatrix}}_{\text{Mixing Matrix U}} \begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Mixing Matrix U

$s_{lk} \equiv \sin\theta_{lk}$, $c_{lk} \equiv \cos\theta_{lk}$

From a pure $\bar{\nu}_e$ flux, the probability $P_{e\beta}$ to observe the flavour β at a distance much larger than the oscillation lengths (as for galactic scales, E≈ TeV and the actual values of Δm^2's) is

$$P_{e\beta} = \delta_{e\beta} - 2\sum_{j>k} \mathrm{Re}(U^*_{\beta j} U_{\beta k} U_{ej} U^*_{ek})$$

Present experiments give at 3 σ [Maltoni et al., NJP 6 (2004) 122]

Solar/Kamland	Atmospheric/K2K	CHOOZ+Others	
$28.7^\circ < \theta_{12} < 37.5^\circ$	$35.7^\circ < \theta_{23} < 54.3^\circ$	$\theta_{13} < 12.5^\circ$	δ_{CP}???

Sensitivity to mixing angles-I

The peculiar state in flavour space at source

$(\phi_e:\phi_\mu:\phi_\tau = 1:0:0)$

allows to perform a combined

- disappearence experiment (of ν_e)
- appearence experiment (ν_μ and ν_τ)

that is sensitive to mixing angles via the observable ratio of tracks to showers

$$R = \frac{\phi_\mu}{(\phi_e + \phi_\tau)}$$

Chance for "Galactic β-beams"!

In particular, what is the sensitivity of such a signal to the unknown parameters θ_{13} and δ_{CP}?

Sensitivity to mixing angles - II

For $\theta_{12}=\pi/3$ and $\theta_{23}=\pi/2$ one has

$$P_{ee} \approx \frac{5}{8} - \frac{5}{4}\vartheta_{13}^2$$

$$P_{e\mu} \approx \frac{3}{16} + \frac{\sqrt{3}}{8}\vartheta_{13}\cos\delta_{CP} + \frac{5\vartheta_{13}^2}{8}$$

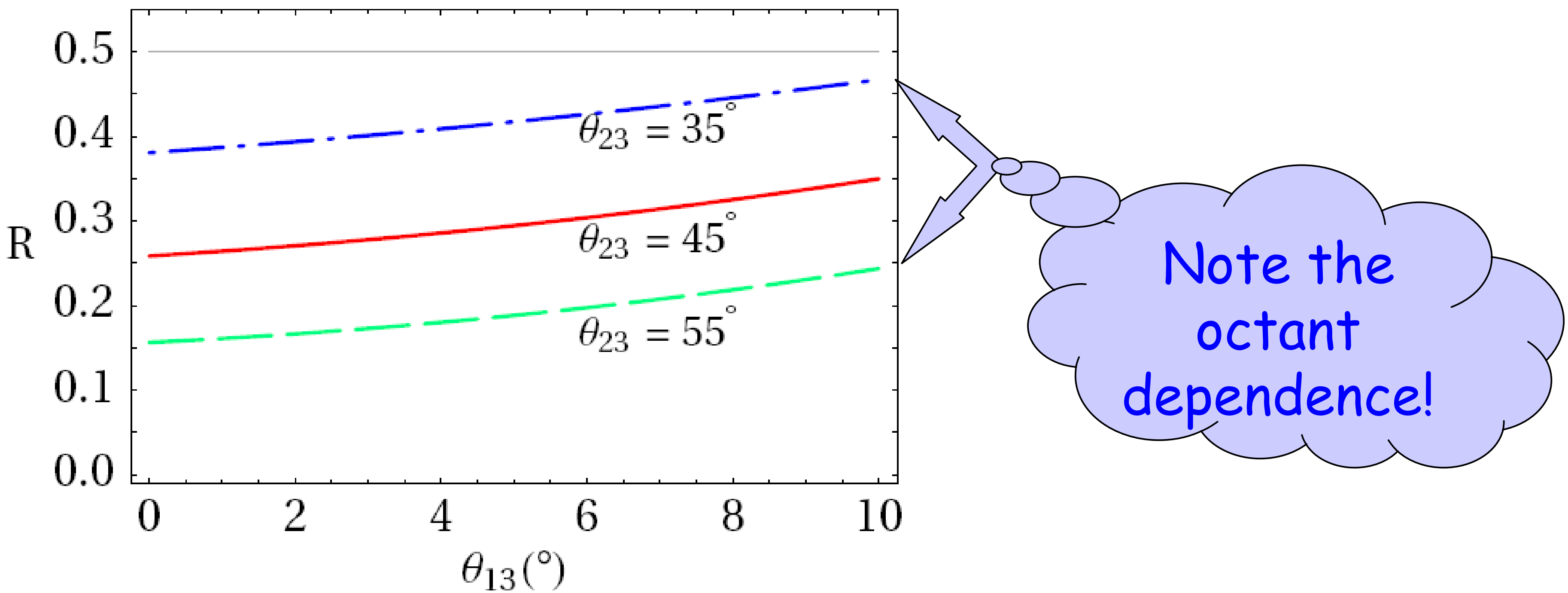
$$P_{e\tau} \approx \frac{3}{16} - \frac{\sqrt{3}}{8}\vartheta_{13}\cos\delta_{CP} + \frac{5\vartheta_{13}^2}{8}$$

Though in the following we will use the exact formulae, they show some key-features of the signal.

Sensitivity to θ_{13} (and θ_{23})

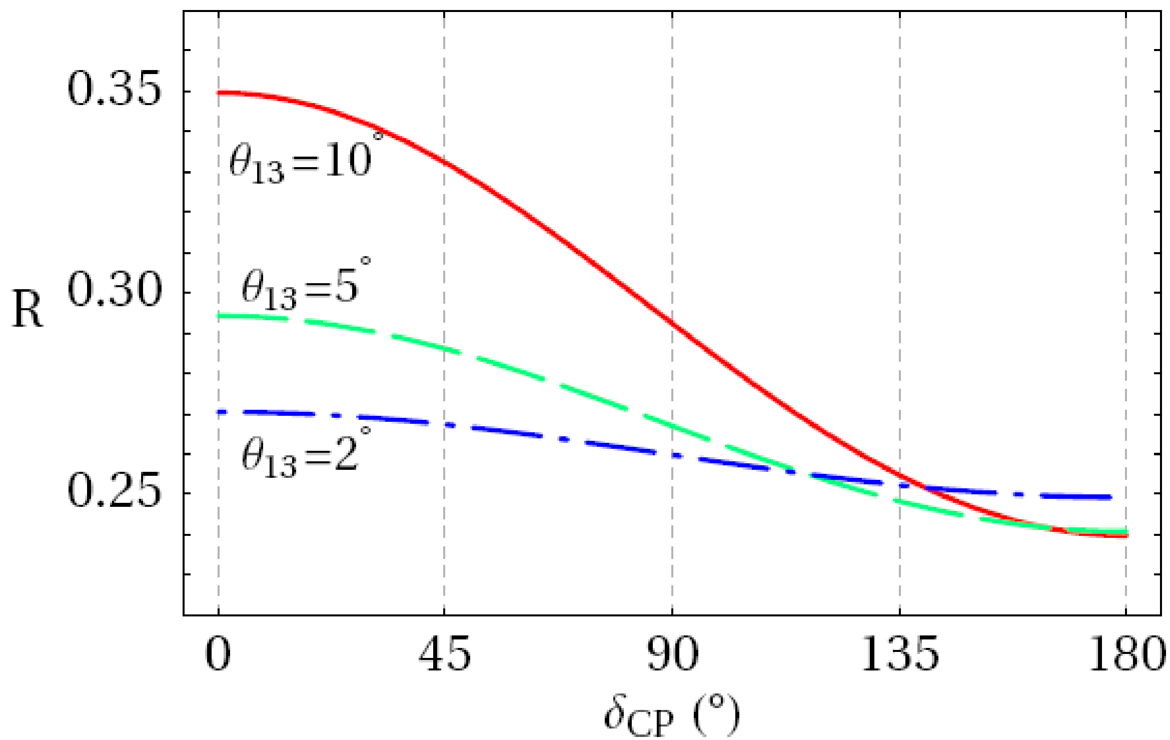
For best fit θ_{12}=32.5° and in the best case $\delta_{CP}=0$ one has a variation of order 30-50% in 0°< θ_{13}< 10°, depending on θ_{23}.

In the most likely case θ_{12}=45°, the flux ratio differs up to a factor 2 with respect to the expected flavor ratio of generic astrophysical sources, R=0.5



Sensitivity to δ_{CP}

For experimental best fit θ_{12}=32.5° and θ_{23}=45°, the flux ratio has a maximal variation of about 30% and differs up to a factor 2 with respect to the expected flavor ratio of generic astrophysical sources



Discussion: models, π-background

Discussion: Nuclei & Pions…

The usually discussed astrophysical ν sources
are based on $pp \rightarrow \pi X$, $p\gamma \rightarrow \pi X$.
After oscillations $\rightarrow$ ν flavour ratio 1:1:1
insensitive to θ_{13} and δ_{CP} !!!

Is it possible/realistic to neglect ν from these channels?

One has to check that

Neutrons from Nuclei at EeV in (some) Galactic sites are expected

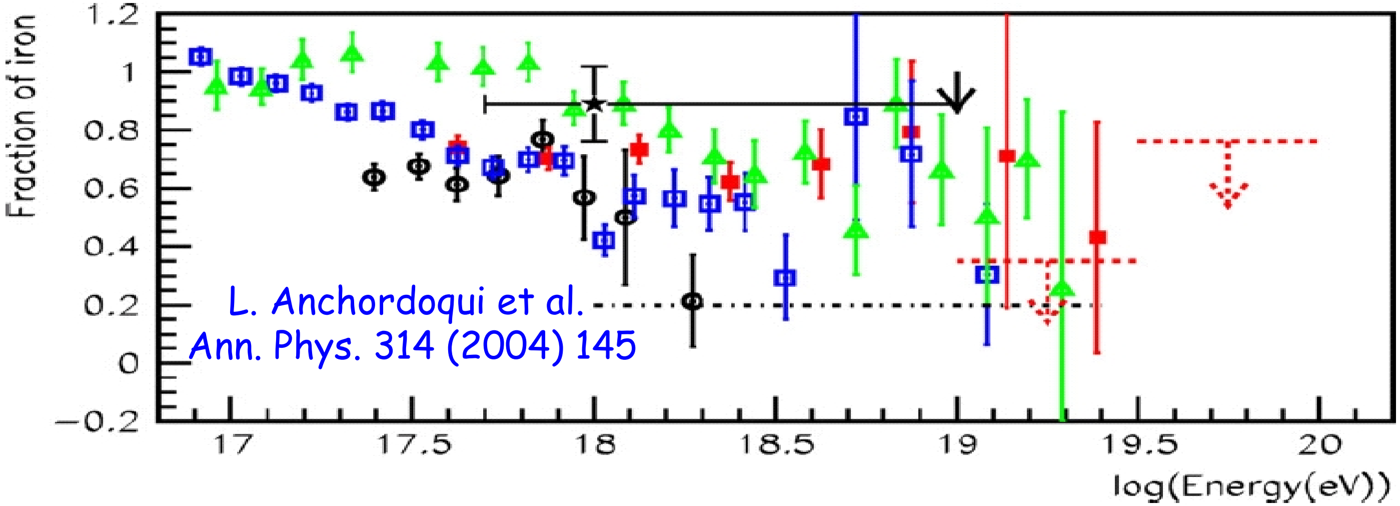
Viable models can be built compatible with observations and constraints

It is experimentally possible to *disprove* the $A \rightarrow n \rightarrow \nu$ scenario

Neutrons (and ν) from Nuclei?

At E ≈ EeV, few galactic sources match the right acceleration requirments, and the GMF hardly confines cosmic rays.
Higher charged particles are easily accelerated and confined.

Within a factor of a few, E ≈ O(1 EeV) is the transition region between the Heavy-nuclei end of the Galactic Spectrum and the p-dominated Extragalactic contribution. Recent CR data support this scenario



Conceivable that the n from nuclei dissociations in matter and γ–fields in (a few) galactic accelerators may become visible. Favored regions are the Nuclear Bulge and dense clouds of higher B-field intensity…

Discussion: Nuclei & Pions…

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What's the expected "contamination"?

Viable models of the $A \rightarrow n \rightarrow \nu$ scenario exist, e.g.:
Cygnus region: L. Anchordoqui et al. PLB 593 (2004) 42
SGR A East SN remnant: Grasso and Maccione [astro-ph/0504323]

From astrophysical data e.g. on the Cygnus region (e.g. UV γ density) and hadronic physics data (e.g. secondary population yields in hadronic interactions) an effective volume for nuclear dissociation 27 times larger than for hadronic interactions has been estimated.

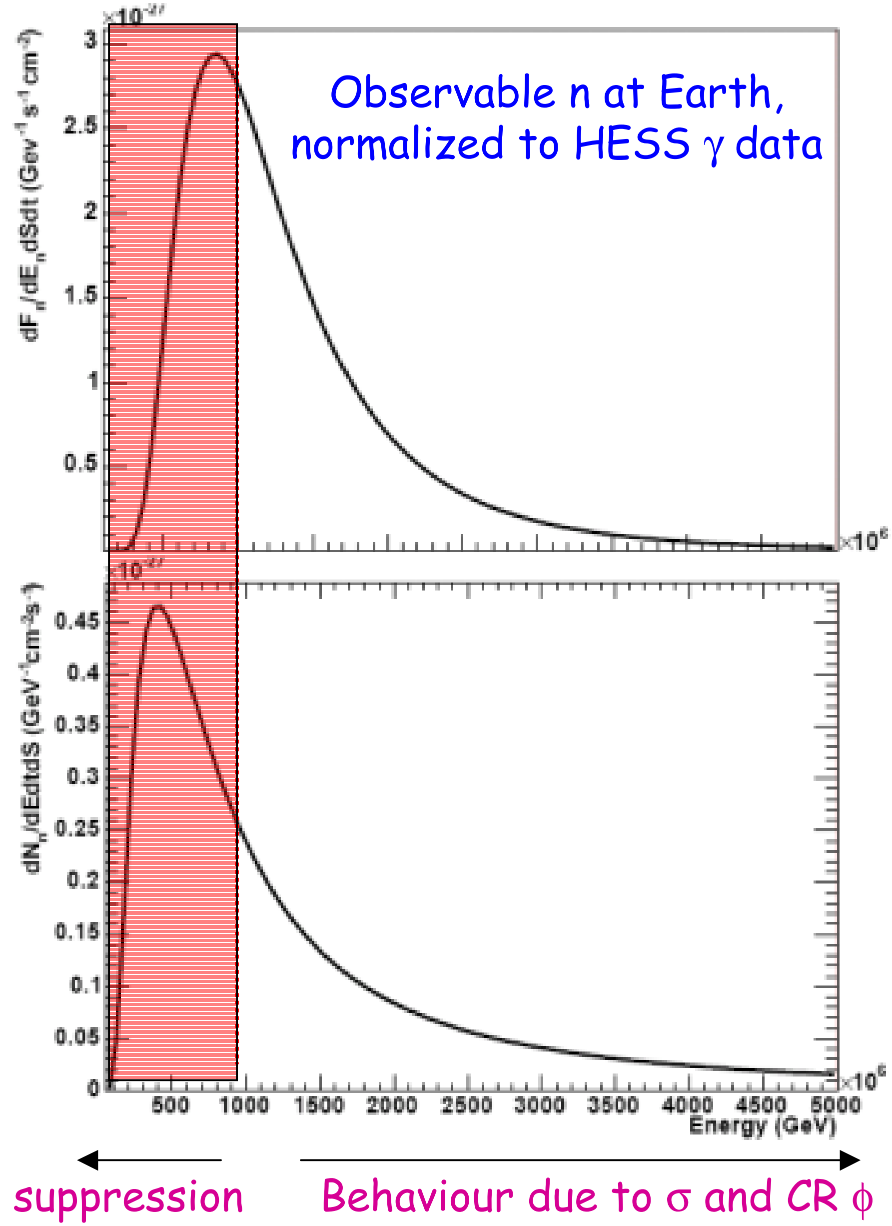
In this case, likely π contaminations to ν flux are at the O(10%) level $\rightarrow \Delta R \approx + 0.02$ only!

Within the expected statistical accuracy of IceCube & at the same subleading level of other effects neglected in our first estimate (NC role, tracks from $\tau \rightarrow \mu$ events, etc.)

What's the expected "contamination"? - II

Lower limit to n from nuclei:
Only He contribution,
metallicity at solar level
(SGR A East is known for
a high metallicity, ≈ 4 solar)
Only single nucleon stripping
Only effects of IR background

Extreme pp,
assuming $E_p^{max} = \infty$



Again, reasonable to expect a nuclear contribution to n much larger than the one from pp

D. Grasso and L. Maccione
[astro-ph/0504323]

Discussion: Nuclei & Pions…

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Is the Scenario Falsifiable?

Provided that the "n-chain" explains the anisotropy,
ν–fluxes (from n-decay alone!) are easily observable
in IceCube, with a detailed measurement in a decade.
(normalized to CR data, not a model !!!)

If the π–chain dominates, the flux should be much higher
(factor>100!) though with a flavour ratio of about 1:1:1
Possible discovery already in AMANDA-II

Also γ-rays constraints!

High ν flux and R=0.5 would disprove
the dominance of $A \to n \to \nu$!

Overview

If the CR anisotropy around the EeV is confirmed to be of neutronic origin, a likely possibility is that in a next generation ν-telescope like IceCube it provides a measurement sensitive to θ_{13} and δ_{CP}

Both improved CR data (AUGER, KASCADE-Grande) and direct measurement of ν-flux (AMANDA, IceCube, Mediterranean Telescopes) can falsify the proposed mechanism, thus making feasible in forthcoming years to assess the effective viability of the method

Conclusions

On Earth, the hunting for θ_{13} and δ_{CP} is open.
Terrestrial beta-beam facilities have been proposed, of O(1) G€ cost, with the main issue in the beam preparation

ν-telescopes are optimized for astrophysical purposes, but they may have a potential for ν-mixing physics, too.

The scenario discussed here shows that it is conceivable that Nature might provide β-beams "for free", that could be studied at ν-telescopes already in construction.

As for the Solar neutrino problem, the Heavens might still be helpful to ν–physicists! ☺

The Bavarian way to "overcome" obstacles
or...
...a Bavarian allegory of Neutrino Oscillations & See-Saw Mechanism!

Neutrino Parameters

Solar/Kamland

Best Fit: $\sin^2\theta_{sol} = 0.29$, $\Delta m_{sol}^2 = 8.1 \times 10^{-5}\ eV^2$

3 σ range: $0.23 < \sin^2\theta_{12} < 0.37$, $7.3 \times 10^{-5} < \Delta m_{sol}^2/eV^2 < 9.1 \times 10^{-5}$

Best Fit: $\theta_{sol} = 32.6^\circ$

3 σ range: $28.7^\circ < \theta_{sol} < 37.5^\circ$

Atmospheric/K2K

Best Fit $\sin^2\theta_{atm} = 0.5$, $\Delta m_{atm}^2 = 2.2 \times 10^{-3}\ eV^2$

3 σ range $0.34 < \sin^2\theta_{atm} < 0.66$; $1.4 \times 10^{-3} < \Delta m_{atm}^2/eV^2 < 3.3 \times 10^{-3}$

Best Fit: $\theta_{atm} = 45^\circ$

3 σ range: $35.7^\circ < \theta_{sol} < 54.3^\circ$

Global (CHOOZ+others)

Best Fit: $\sin^2\theta_{13} = 0$

3 σ range: $\sin^2\theta_{13} < 0.047$,

$\theta_{13} < 12.5^\circ$

Maltoni et al.,
NJP 6 (2004) 122