SIGNALS FOR UNIVERSAL EXTRA DIMENSIONS IN NEUTRINO TELESCOPES

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UED Detection in ν Telescopes

Direct detection of long lived charged NLKPs

- UED scenario (analogy with gravitino as LSP)
- Production of charged NLKPs from HE ν interactions in the Earth. (HE $\gtrsim 10^5$ GeV)
- Monte Carlo Simulation of Energy Loss and Propagation of Charged NLKPs through the Earth.
- Rate and Signatures of Charged NLKPs in Neutrino Telescopes.
- $\mu^+\mu^-$ Background

IA, G. Burdman, Z. Chacko, C. Krenkel

UED Scenario

- Large Extra Dimensions: gravity propagates in compact extra dimensions

  Extra Dimensions NOT available for other SM fields

- Universal Extra Dimensions:

  Appelquist,Cheng and Dobrescu, Phys. Rev. D **64**, 2001

  - ALL fields propagate in ED
  - Lightest state of $1^{\rm st}$ KK level cannot decay (from KK-parity conservation)

  $\Rightarrow$ LKP IS STABLE (and a Dark Matter candidate)

UED Scenario

- UED
  - $\boldsymbol{\Delta m \sim \frac{1}{R}}$ ($R \equiv$ compactification radius)
  - Experimental Constraints (Tevatron + Electroweak):

$$\frac{1}{R} \gtrsim \begin{cases} \mathbf{300} & \text{GeV for 5D} \\ \mathbf{(400-600)} & \text{GeV for 6D} \end{cases}$$

  - Cutoff on energy levels from Naive Dimensional Analysis:

$$\Lambda R \propto \frac{8\pi}{\mathrm{g}^2} \qquad \text{we take} \qquad \Lambda R = 20$$

Important NLKP features

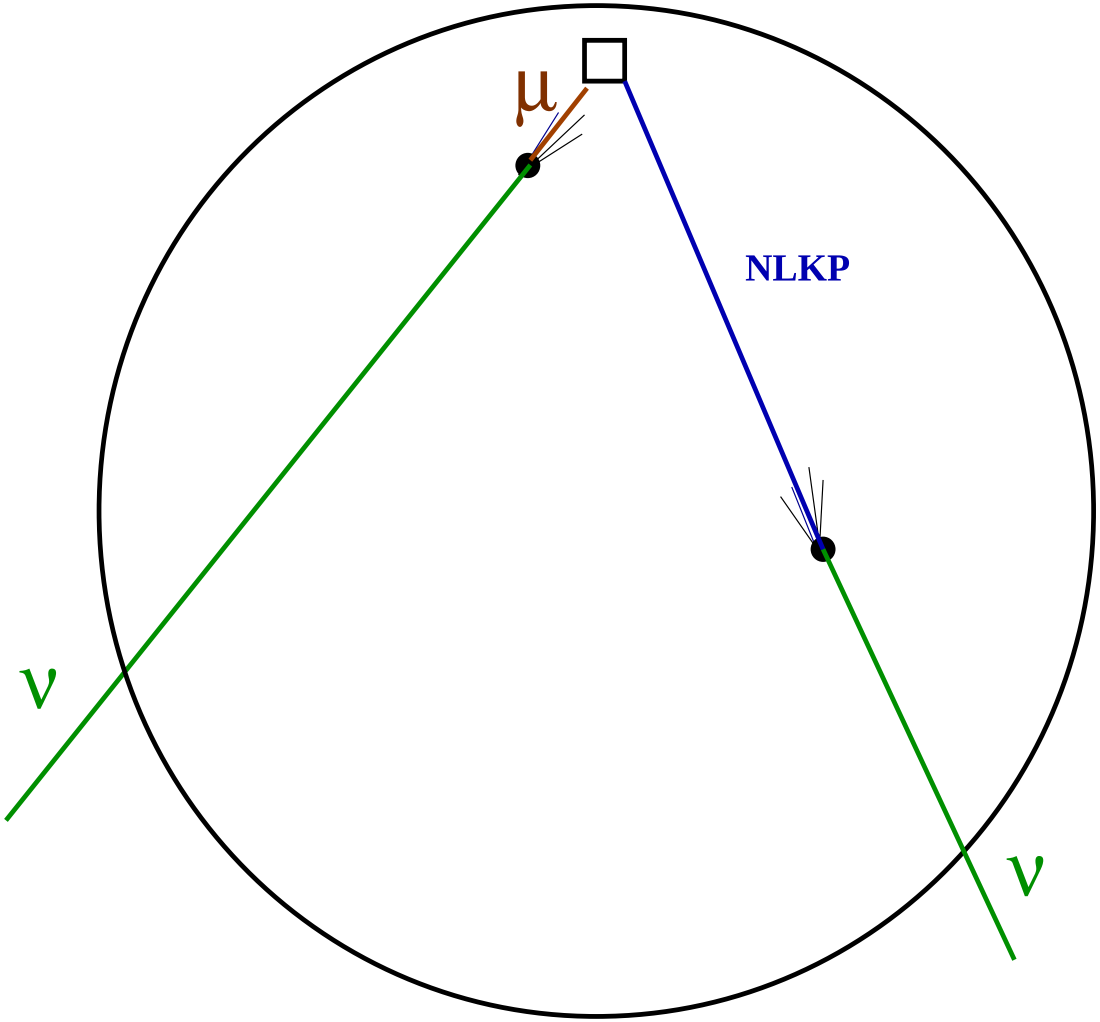
- KK graviton as LKP (analogy to gravitino in SUSY)
  - we assume NLKP is a long lived charged KK RH lepton (analogy with a slepton as NLSP)
- from neutrino interaction they will always be produced in pairs
- mass $\gtrsim$ 300 GeV (we take $\mathbf{300,\ 600,\ 900}$) GeV

NLKP Production in the Earth

- High Energy neutrinos interacting in the Earth will produce NLKP
- HE ν flux hitting the Earth $\Rightarrow$ Waxman-Bahcall limit
- NLKP production $\sigma < \sigma_{SM}$
  - NLKP production $\sigma > \mathbf{NLSP}\ \sigma$
- However NLKP range $>>$ μ range!
  - energy loss due to radiation NLKP$<<$ μ !!
  - NLKP range is typically in the 100s to 1000s of km

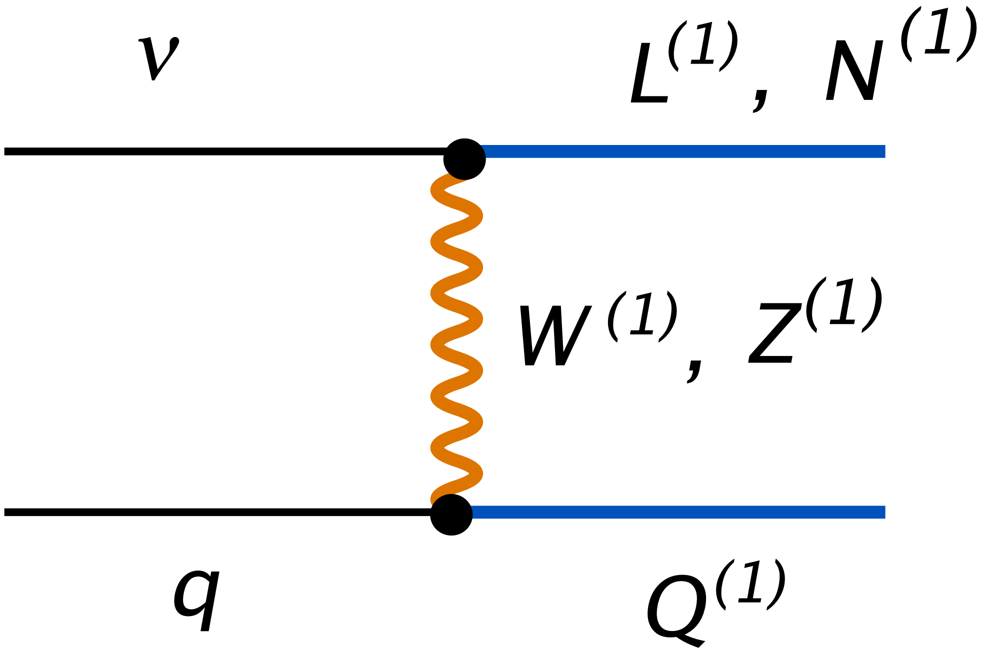
$\Rightarrow$ Large range compensates for low σ $\Leftarrow$

NLKP Production in the Earth



NLKP Production Cross Section

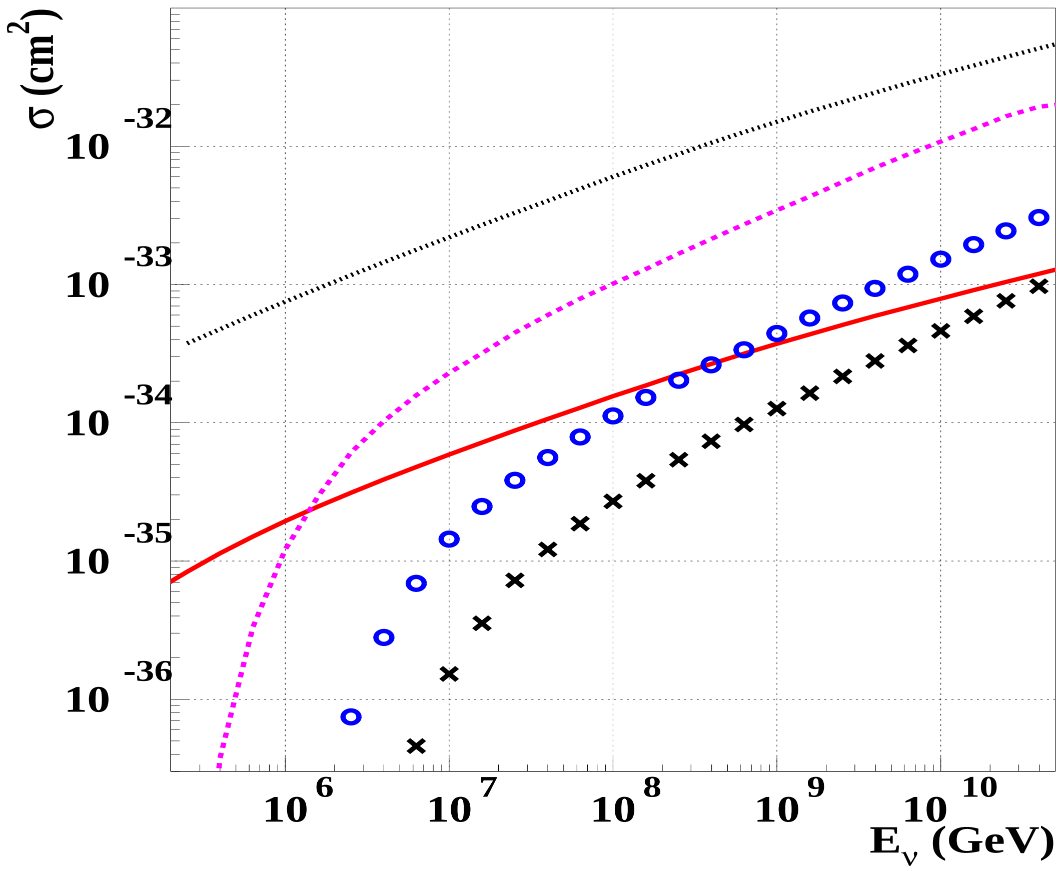
Dominant process analogous to SM CC interations: $\nu\,\mathrm{N} \;\rightarrow\; \mathrm{L}_{\mathrm{L}}^{(1)}\,\mathrm{Q}$



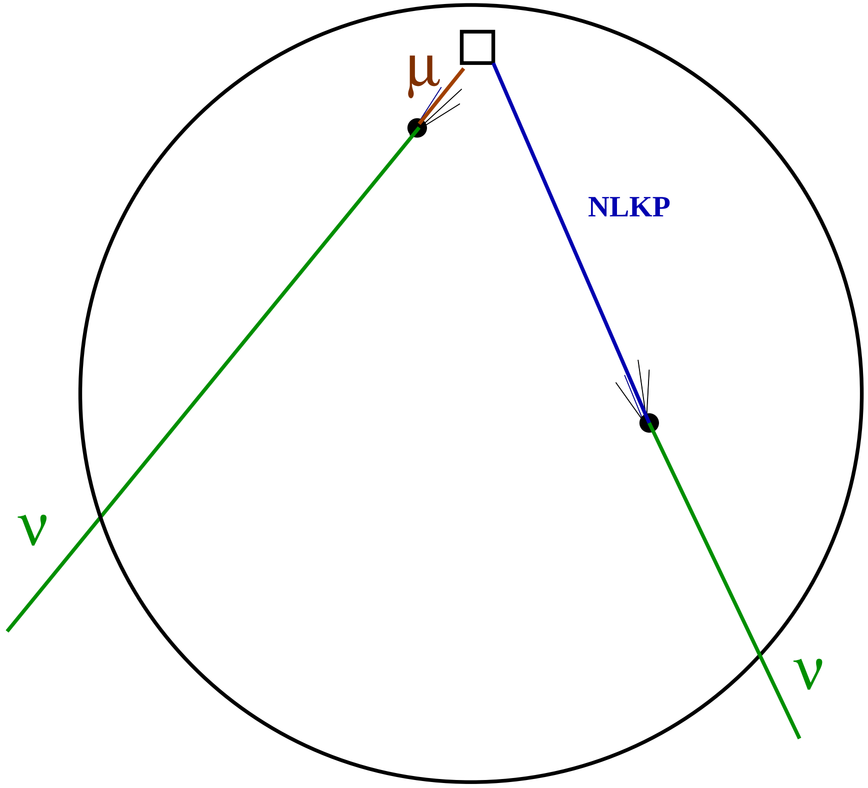
$(\mathbf{NLKP})_{\mathbf{L}}$ and Q promptly decay into X + 2 $(\mathbf{NLKP})_{\mathbf{R}}$

$m(\mathrm{NLKP})_{\mathrm{R}} = 300, 600, 900$ GeV

XSections



Detection of Charged NLKPs in Neutrino Telescopes



$$\phi_{l \text{ or } NLKP} = \phi_{\nu \oplus} \times P_s \times P_I$$

$$P_s = \exp^{-\int n\,\sigma(E)\,dl}$$

$$P_I = 1 - P_s$$

HE ν Flux

- neutrino flux at the Earth is taken to be as the Waxman-Bahcall limit

$$\frac{d\phi_{\nu_\mu+\overline{\nu}_\mu}}{dE} = \frac{4\times 10^{-8}}{E^2} \ \ \mathrm{GeV\,cm^{-2}s^{-1}sr^{-1}}$$

  - $\phi_{\nu_e} \sim \phi_{\nu_\mu} \sim \phi_{\overline{\nu}_\mu}$
  - flavor of initial neutrino does not affect result
  - mixing due to oscillation also does not affect result

Monte Carlo Simulation of NLKP production and detection

- $\sim \mathbf{30}$ K events for each NLKP mass and for background
- interaction point is chosen based on P$_I$

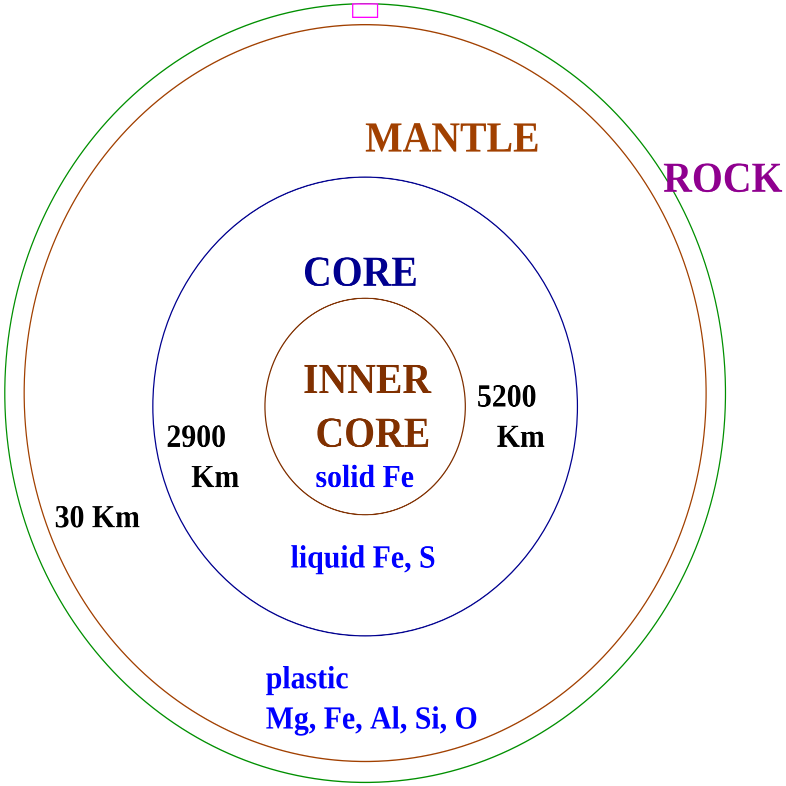
  interaction point within range $\Rightarrow$ event is taken

- CM angular distribution based in differential $\boldsymbol{\sigma}$

$$\boldsymbol{\Theta}_{CM} \Rightarrow \mathbf{P}_{\mathbf{CM}} \Rightarrow \mathbf{P}_{\mathbf{LAB}} \Rightarrow \boldsymbol{\Theta}_{\mathbf{LAB}}$$

- NLKP (or $\mu^{+}\mu-$) separation $= \boldsymbol{R} \times \boldsymbol{\Theta}_{LAB}$

Model of Earth density profile



Density profile as in Gandhi, Quigg, Reno and Sarcevic - Phys. Rev. D **58** (1998)

NLKP Energy Loss

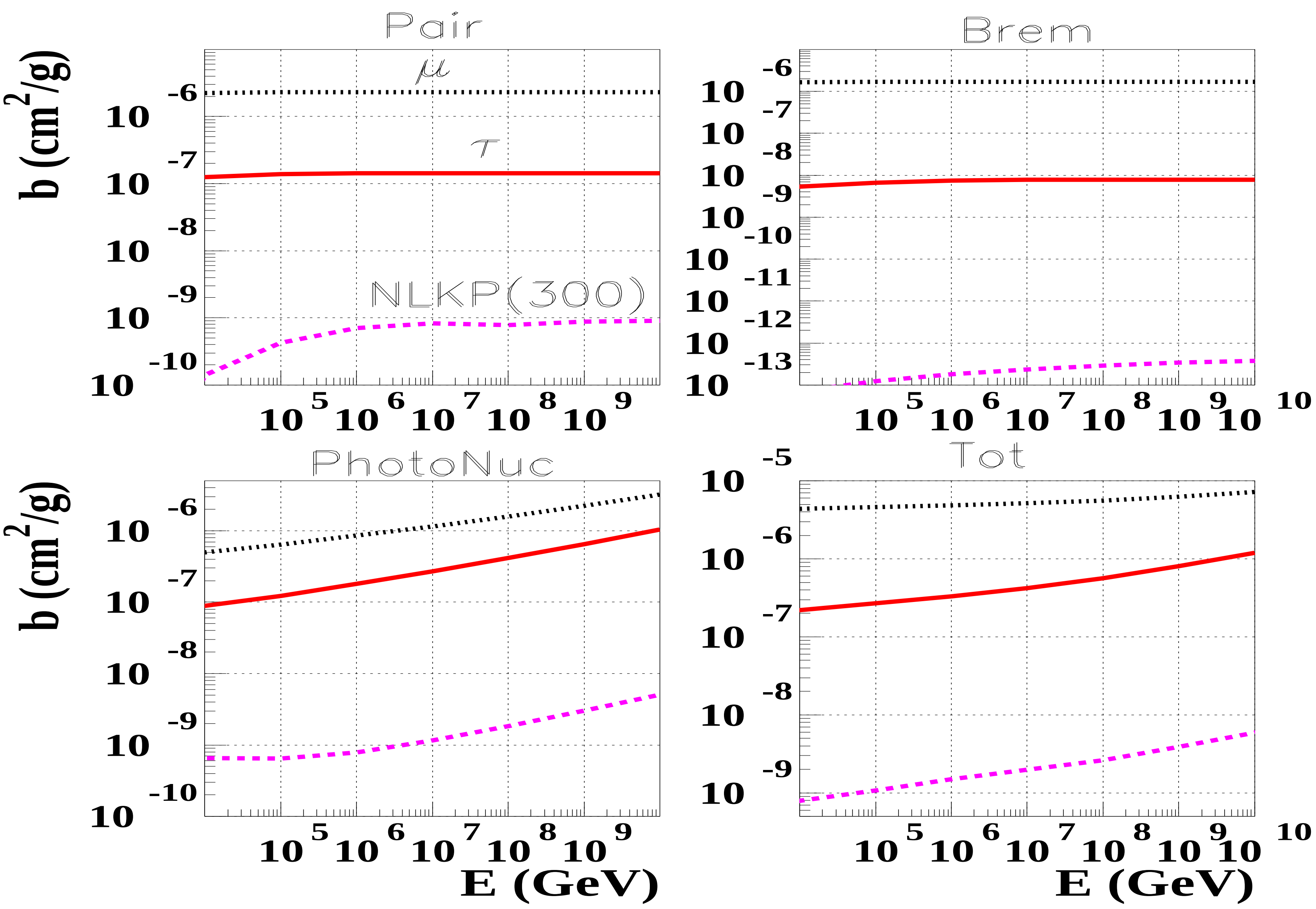
Energy Loss:

$$-dE/dx = a(E) + b(E)\, E$$

with $a(E)$ and $b(E)$ slowly varying functions of E.

- a(E) $\Leftrightarrow$ ionization losses
- b(E) $\Leftrightarrow$ radiation losses

NLKP Energy Loss



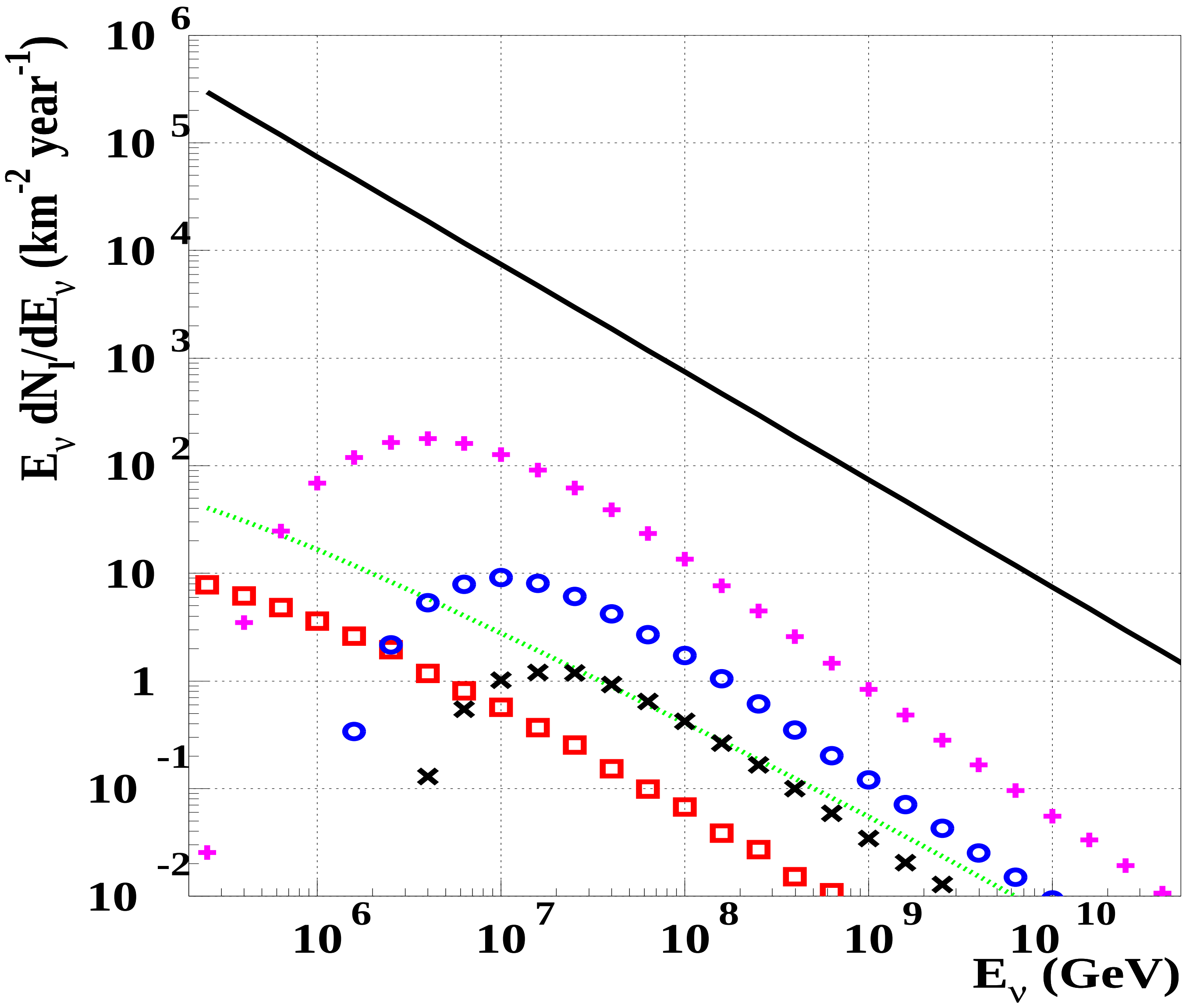
Background

$$\boldsymbol{\nu N \to \mu^- H_c \to \mu^- \mu^+ H_x \nu}$$

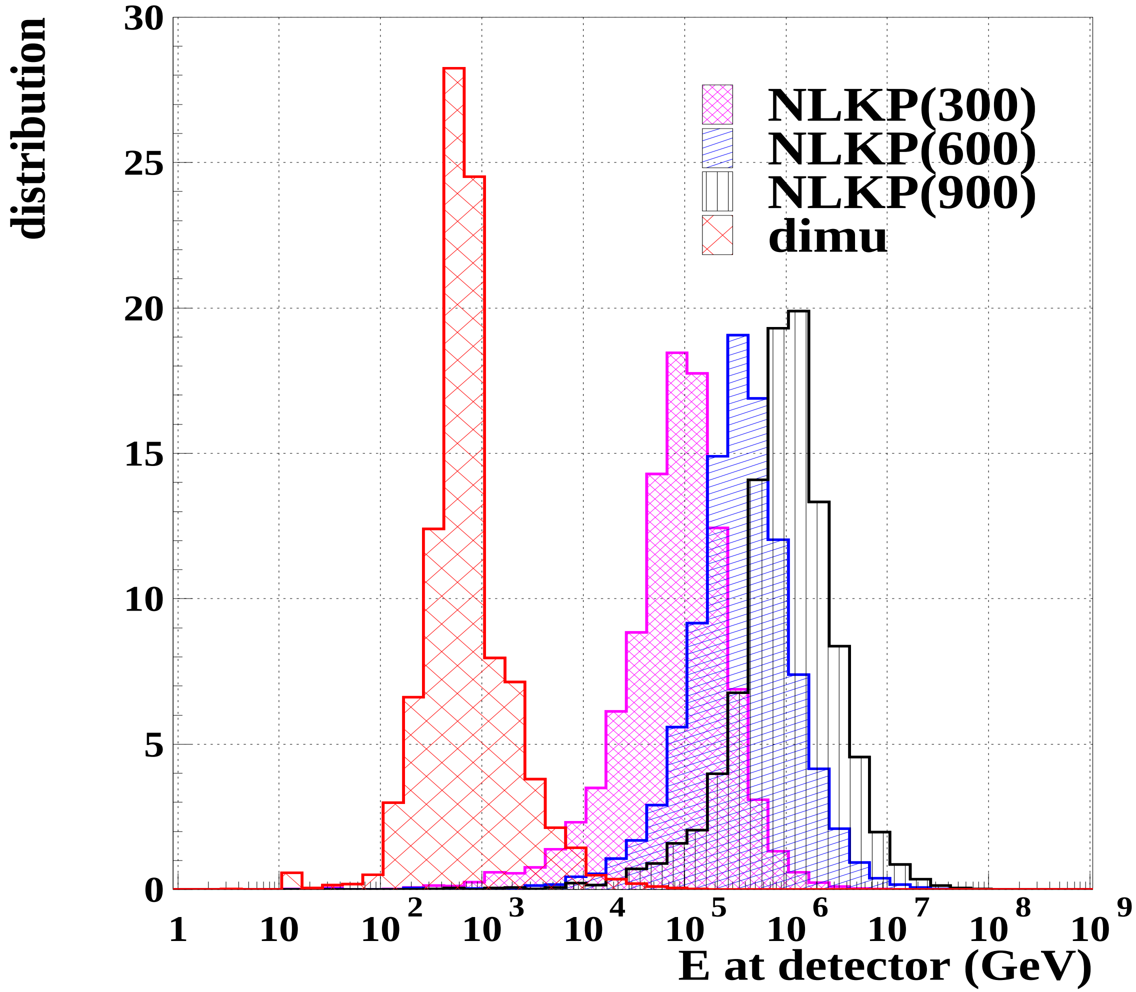
Has to be produced much closer to detector

$\Rightarrow$ smaller track separation.

NLSP energy distribution



NLKP Energy distribution at Detector

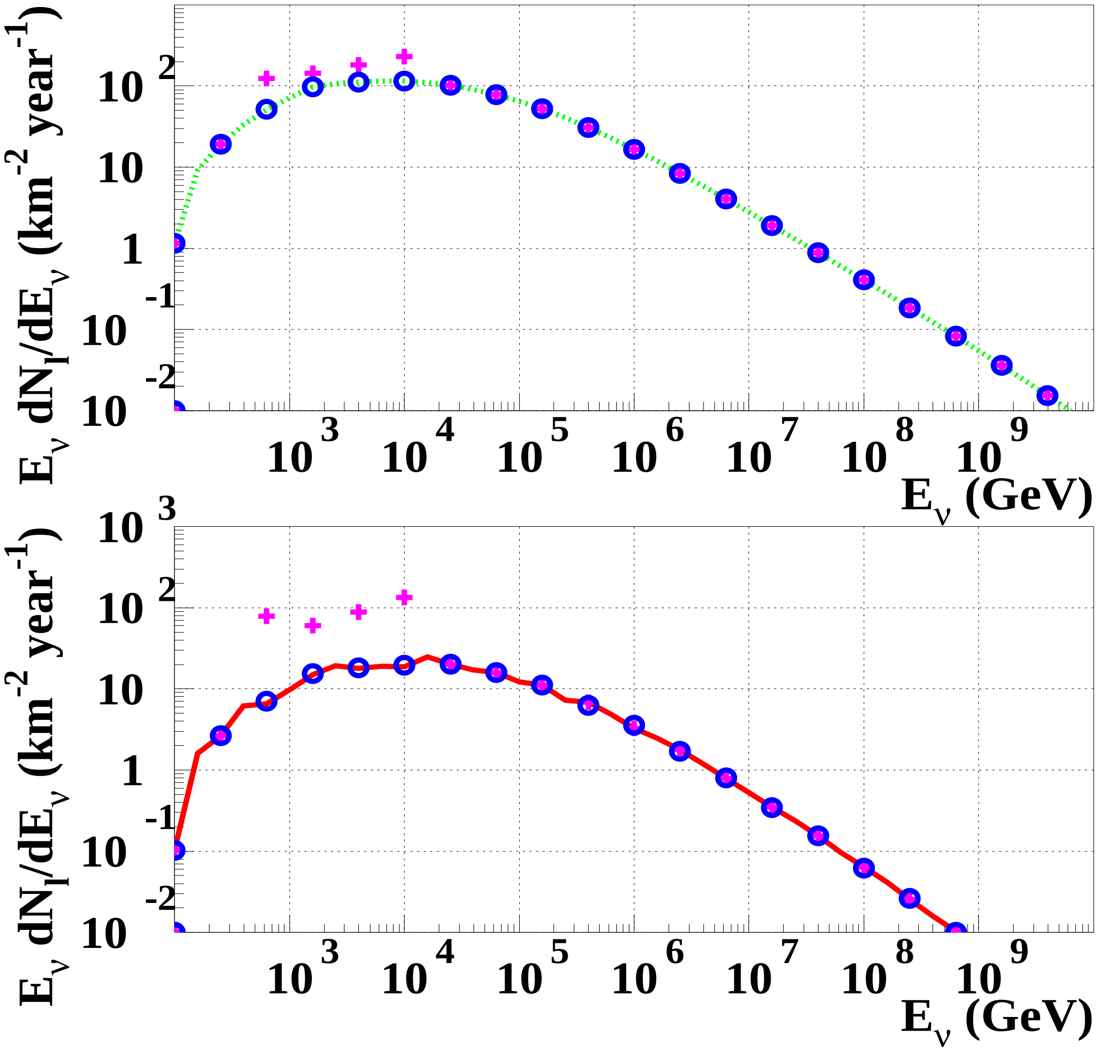


Number of Events

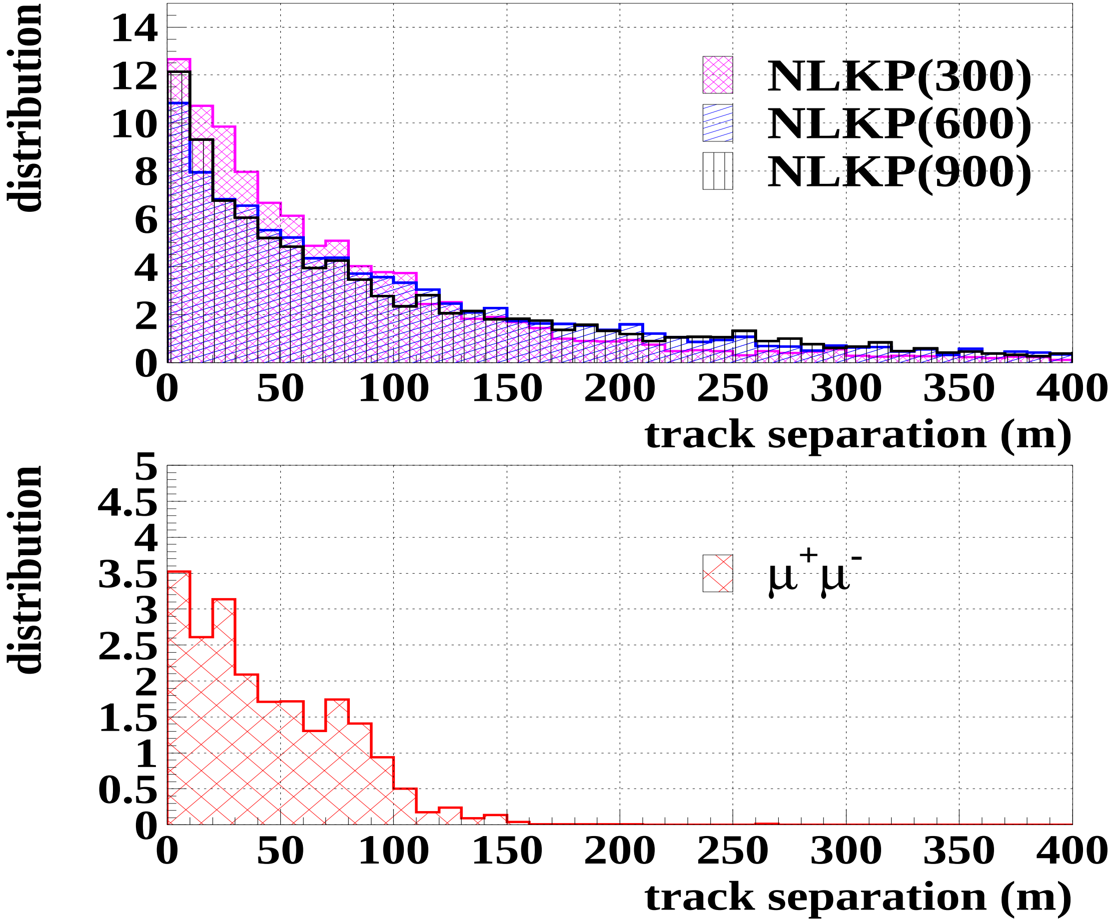
	μ	$\mu^+\mu^-$	$m = 300$	600	900 (GeV)
WB	552	30	489	21	3

Table 1: Number of events per km^2 per year assuming the WB limits. The first column refers to upgoing muons. The second to upgoing dimuon events. The last three columns correspond to upgoing NLKP pair events, for three different choices of masses: 300 GeV, 600 GeV and 900 GeV. The number of muon and di-muon events are given for energies above 10^3 GeV and of NLKPs above threshold for production.

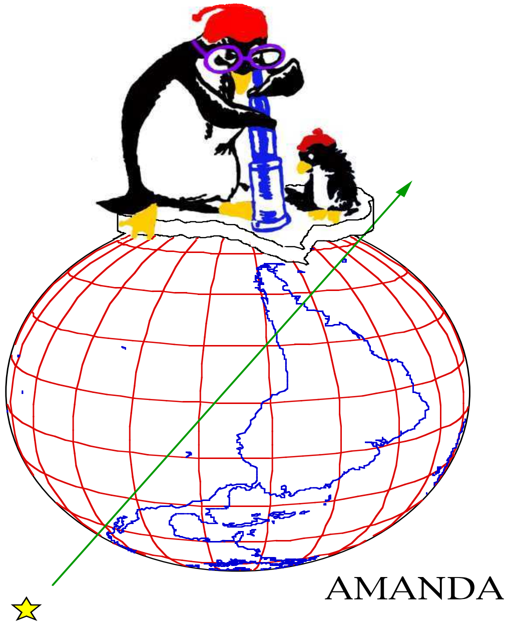
NLKP BUMP


$E_\nu\, dN_l/dE_\nu$ (km^{-2} year^{-1})
10^{-2}
10^{-1}
1
10
10^{2}
10^{3}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
E_ν (GeV)

Track Separation in Detector



Conclusions and Outlook



Km^3 neutrino telescopes can detect long-lived charged NLKPs

$\mu^+\mu^-$ background can be subtracted

- Potential to discover the NLKP and consequently determine indirectly the dark matter particle