

# TeV Particle Astrophysics

13-15 July 2005. Fermilab, Batavia, IL



Image courtesy of NASA



Image courtesy of A. Leahars

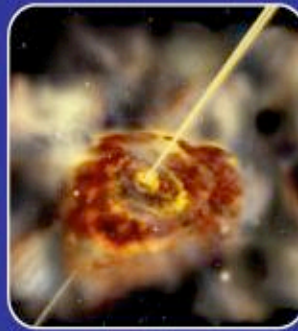


Image courtesy of NASA



Image courtesy of CERN

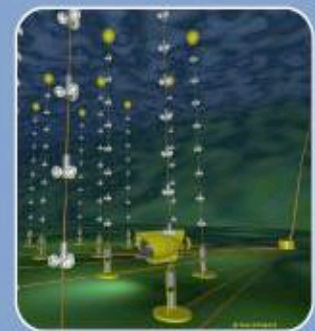
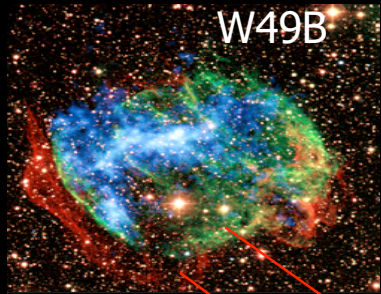


Image courtesy of MCGM3

# PARTICLE PHYSICS ON ICE

LUIS ANCHORDOQUI

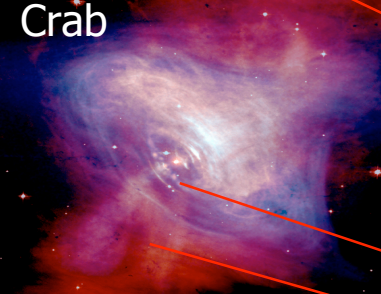
W49B



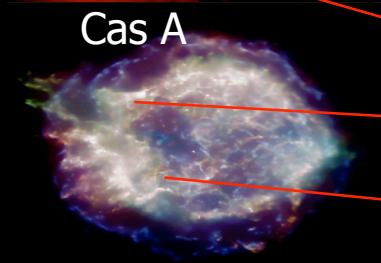
SN 0540-69.3



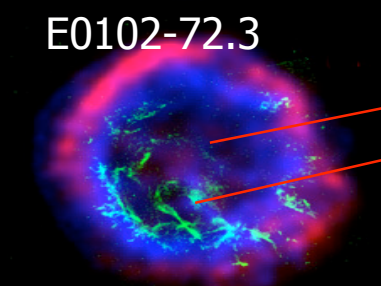
Crab



Cas A



E0102-72.3



NORTHEASTERN UNIVERSITY, BOSTON



# ICEHEP

## LUIS ANCHORDOQUI

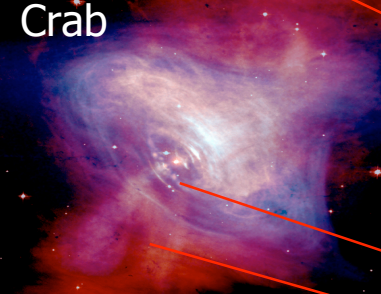
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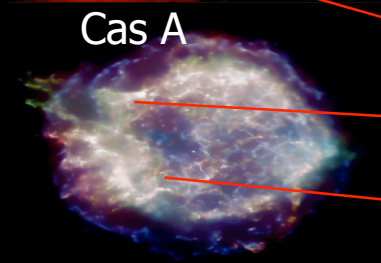
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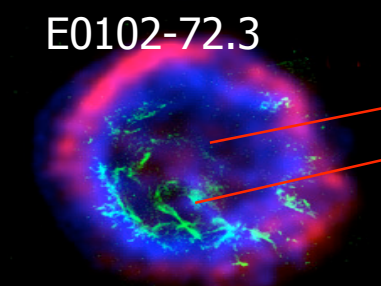
Crab



Cas A



E0102-72.3



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# OUTLINE

GENERAL IDEA

LESSONS FROM AMANDA

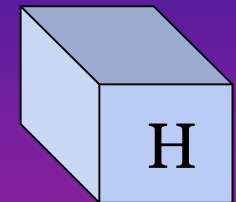
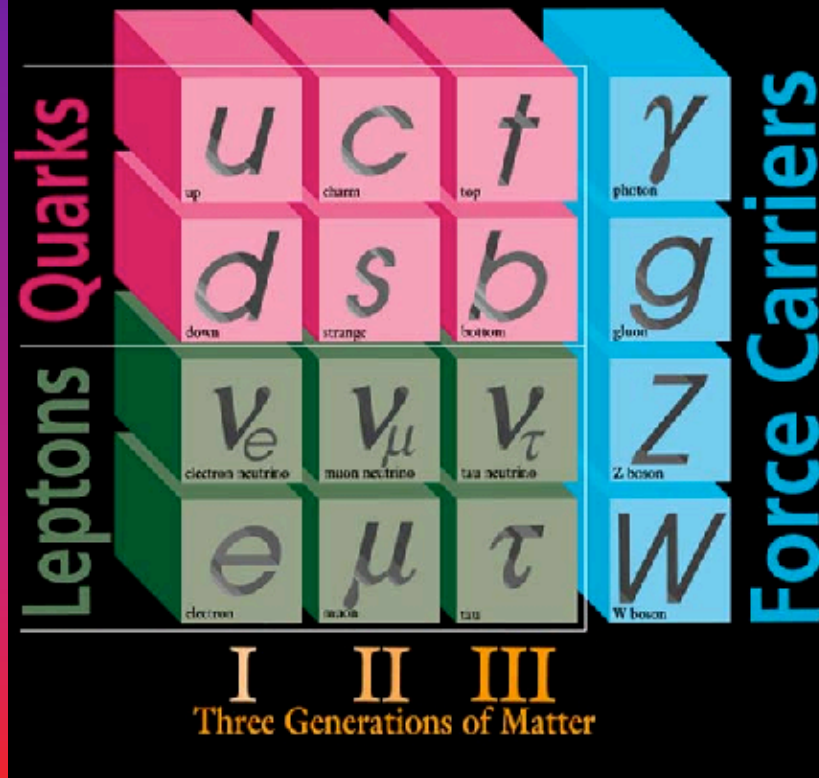
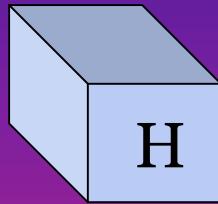
IceCube INTEGRATED LUMINOSITY

PROBES OF TeV- SCALE GRAVITY

CONCLUSIONS

# STANDARD MODEL

## ELEMENTARY PARTICLES



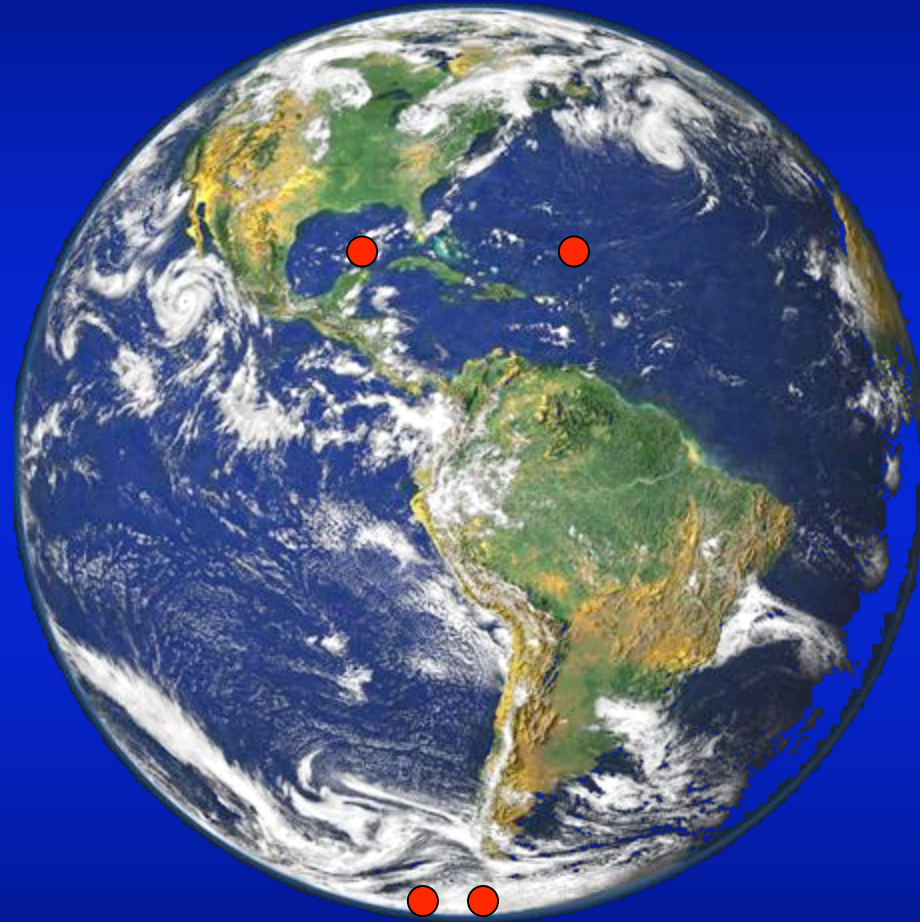
Outstanding success in describing all physical phenomena up to a few hundred GeV  
but is not a fundamental theory of nature

**Extraterrestrial  $\nu$ 's  $\rightarrow$  unique window to probe physics beyond SM**



**Known interactions are so weak  
that new physics may easily alter neutrino properties**

# Event classification

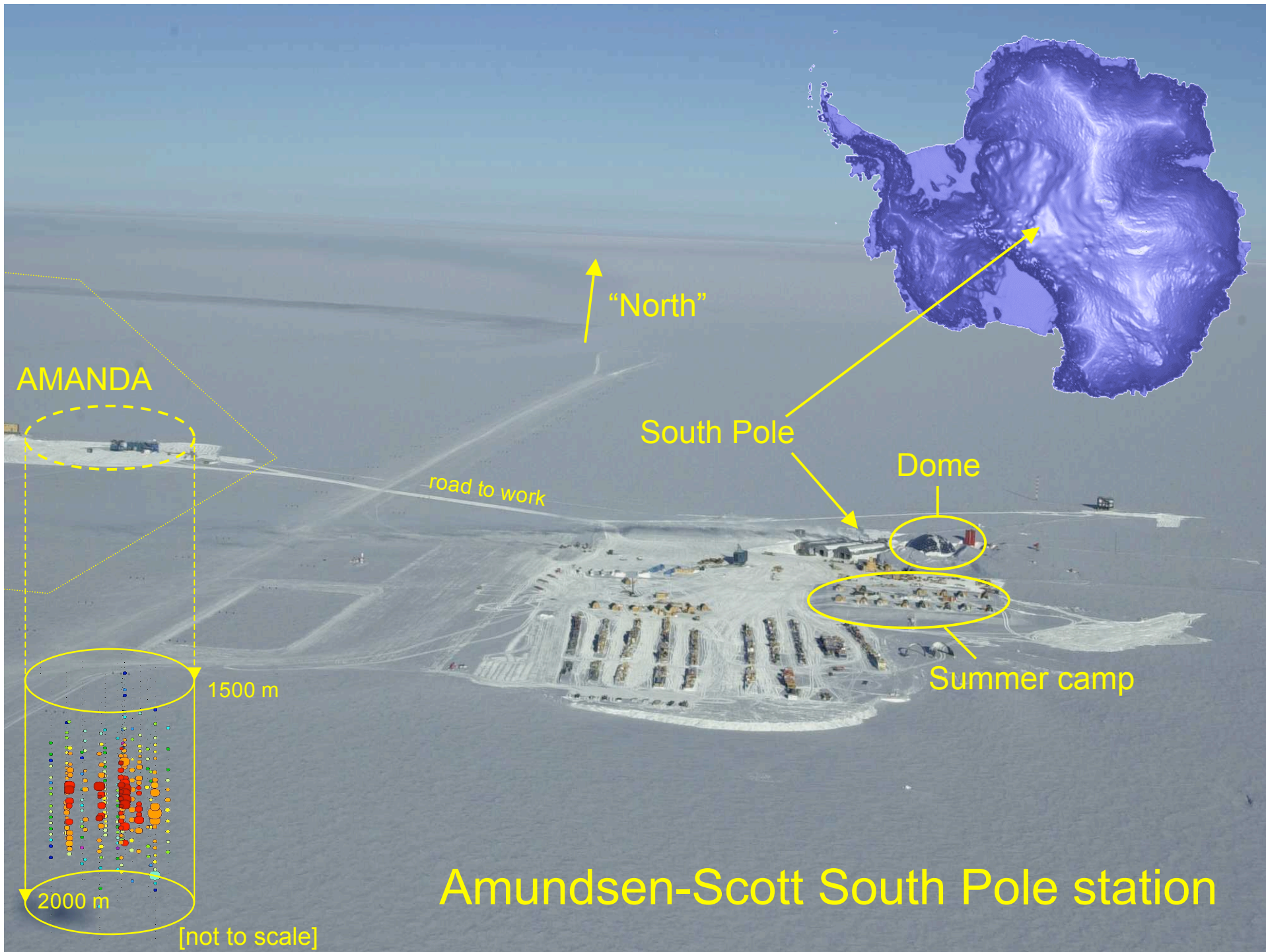


UP - GOING EVENT

DOWN - GOING EVENT

Kusenko & Weiler, Phys. Rev. Lett. 88 (2002) 161101

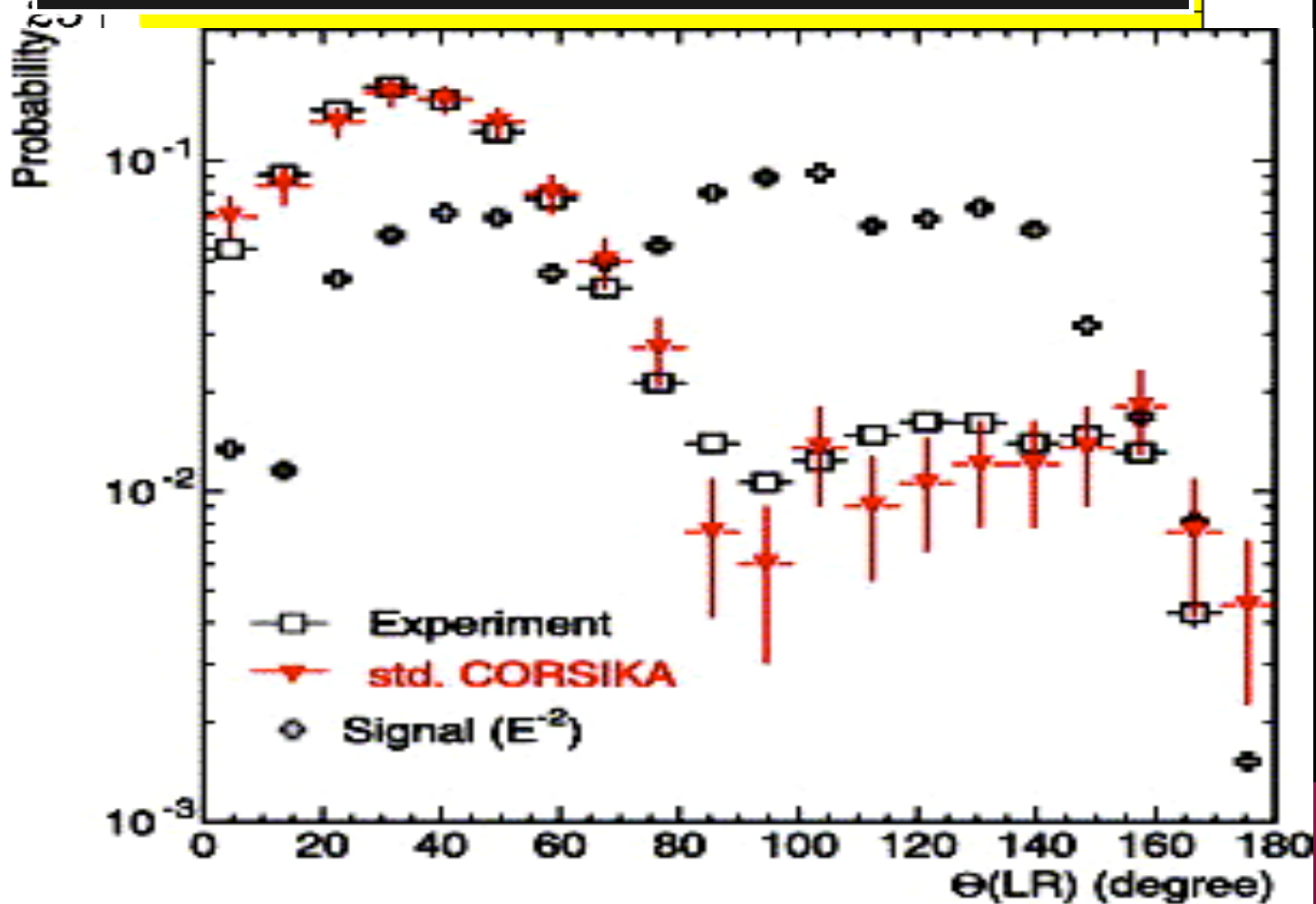
LAA, Feng, Goldberg & Shapere, Phys.Rev.D 65 (2002) 124027





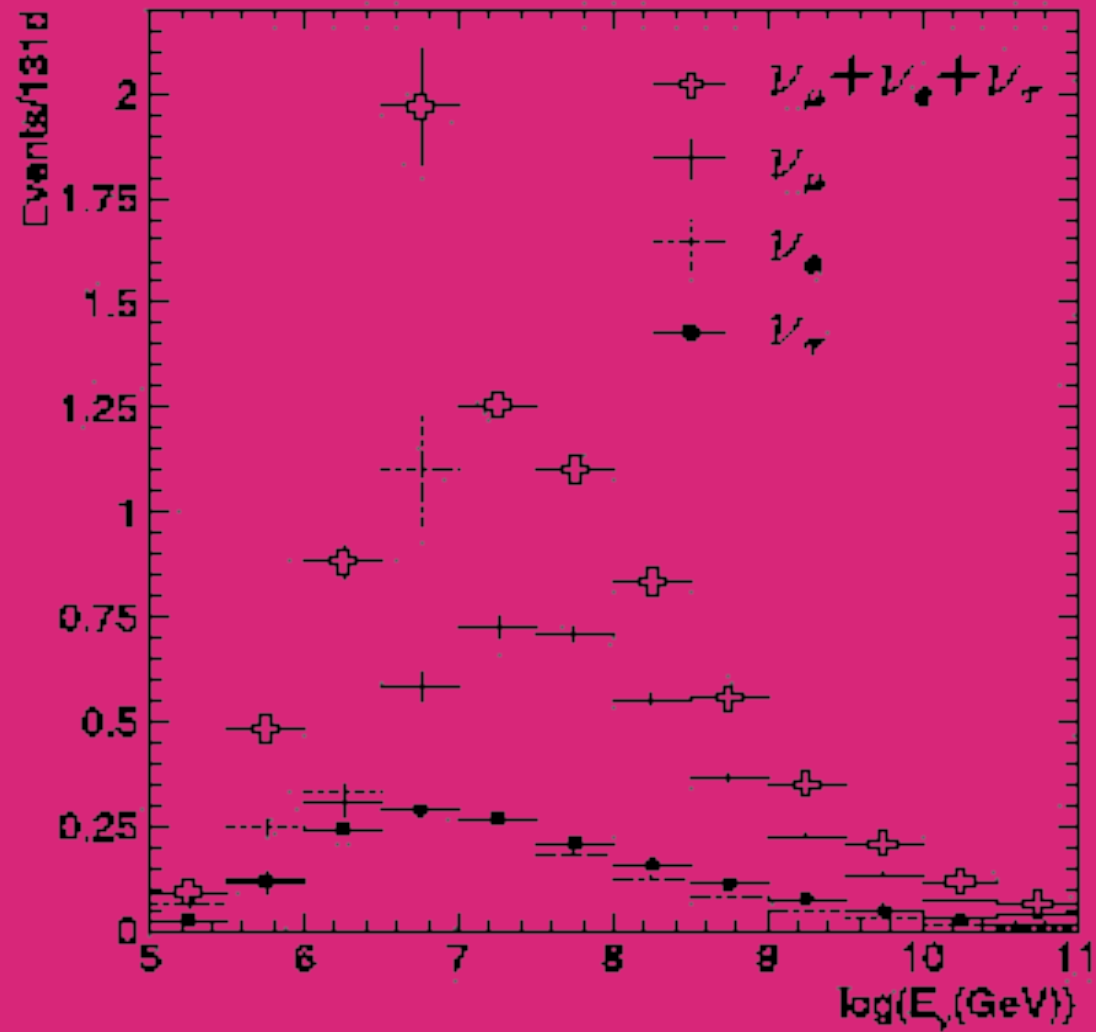
# CONSTRAINTS ON NEUTRINO INTERACTION FROM AMANDA DATA

$$E^2 \phi_{\max}^{\nu}(E) = 3.30 \times 10^{-7} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$



# AMANDA

## Energy distribution



# PROBES OF NEUTRINO INTERACTIONS FAR ABOVE THE WEAK SCALE

$$\sqrt{s} \simeq 6 \text{ TeV}$$

$$\text{neutrino lab energy } E / \text{GeV} \in [10^7, 10^{7.5}]$$

## UP-GOING EVENTS

$$\mathcal{N}_{\text{up}} = C_{\text{up}}^{\tau} \frac{\phi^{\nu} / \phi_{\text{WB}}^{\nu}}{(\sigma_{\nu N} / \sigma_{\text{SM}})^2}$$

## DOWN-GOING EVENTS

$$\mathcal{N}_{\text{down}} = C_{\text{down}}^{\nu_e} \frac{\phi^{\nu}}{\phi_{\text{WB}}^{\nu}} \frac{\sigma_{\nu N}}{\sigma_{\text{SM}}}$$

$$\phi_{\text{max}}^{\nu}(\langle E \rangle) = 1.04 \times 10^{-21} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

$$\phi_{\text{WB}}^{\nu}(\langle E \rangle) = 4 \times 10^{-23} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

**Increases event rates**

$$\phi^{\nu} > \phi_{\text{WB}}^{\nu}$$

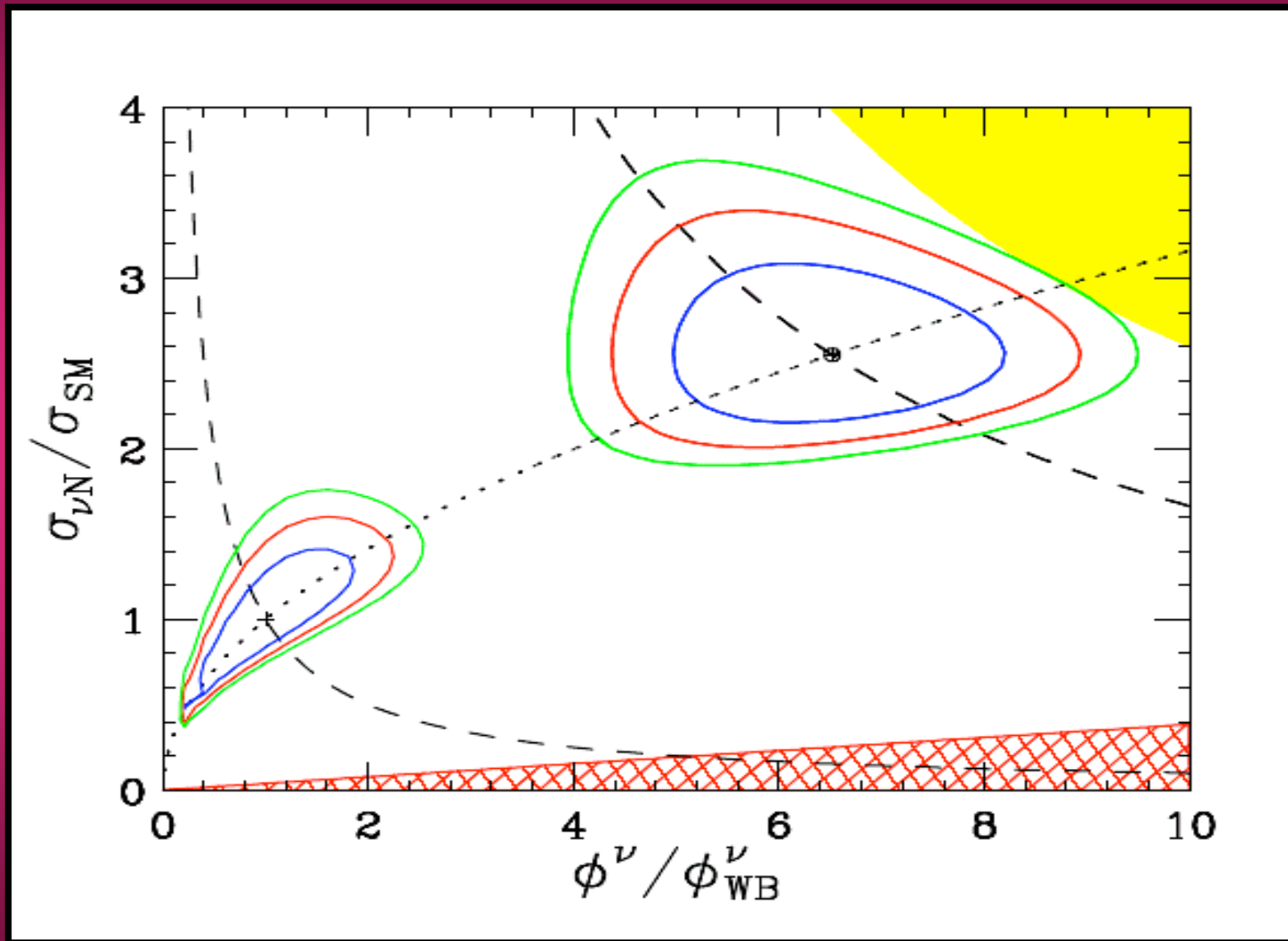
**Increases event rates**

**Rate suppressed**

$$\sigma_{\nu N} > \sigma_{\text{SM}}$$

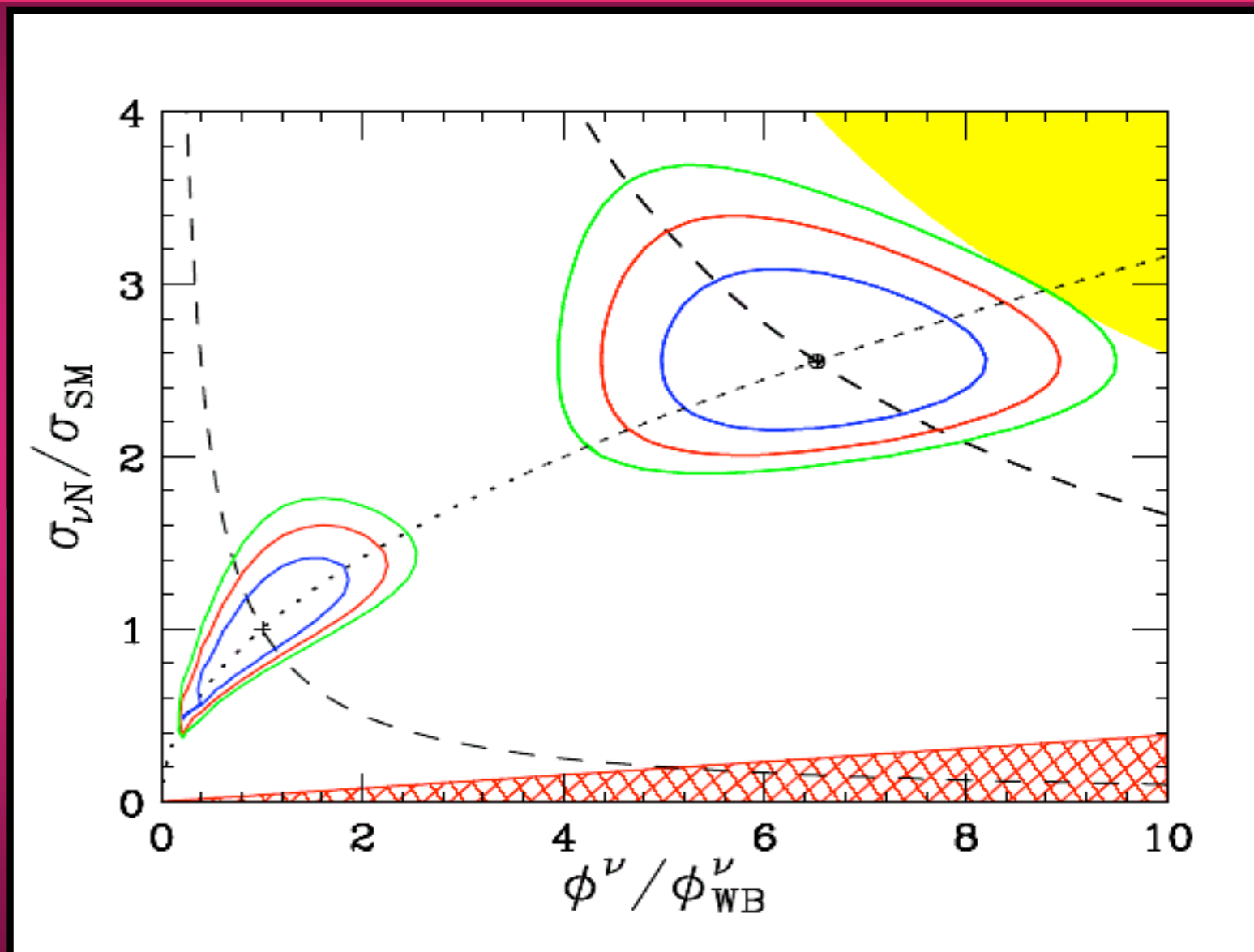
**Increases event rates**

# PROBES OF NEUTRINO INTERACTIONS FAR ABOVE THE WEAK SCALE



LAA, Feng & Goldberg, hep – ph / 0504228

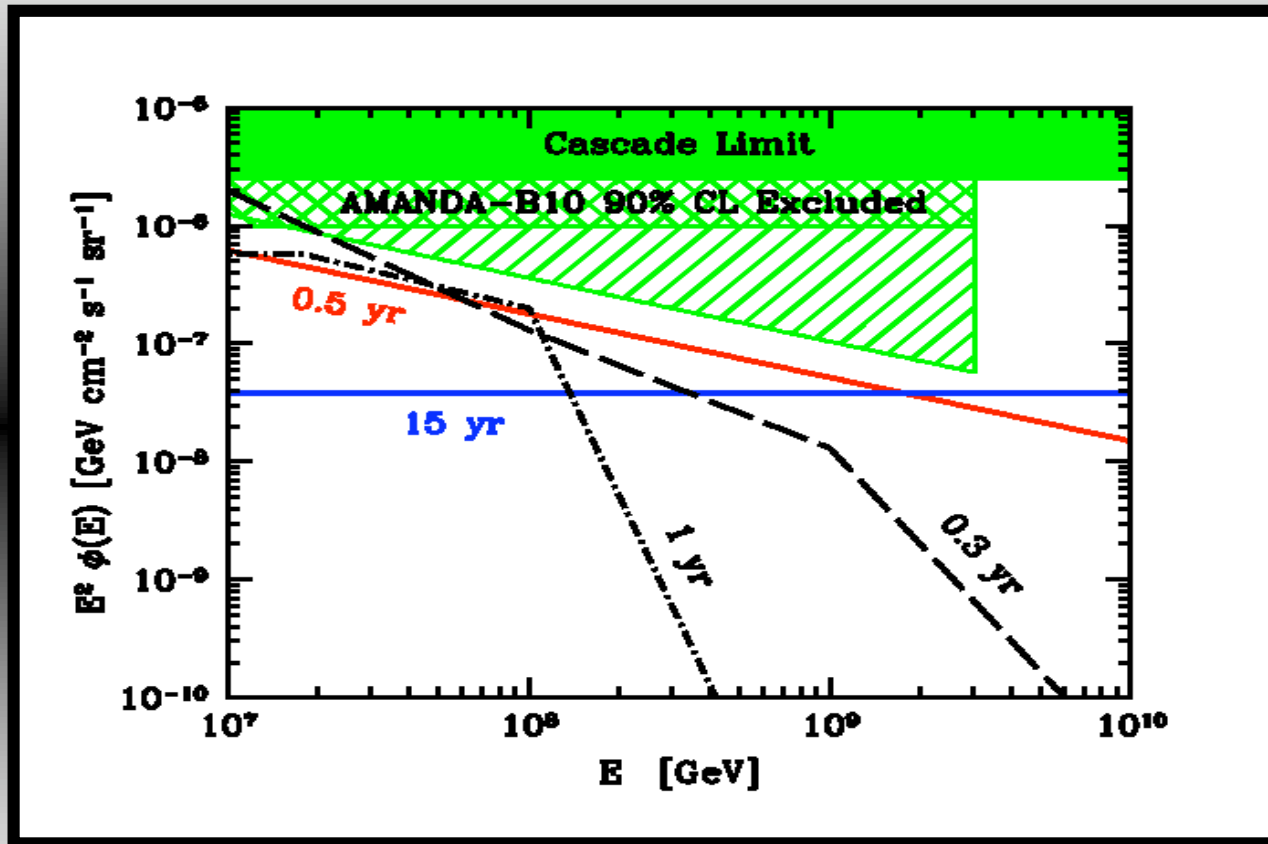
# PROBES OF NEUTRINO INTERACTIONS FAR ABOVE THE WEAK SCALE



LAA, Feng & Goldberg, hep – ph / 0504228

# IceCube integrated luminosity @ $\sqrt{s} \simeq 6$ TeV

$$\mathcal{L} \approx 25 \text{ nb}^{-1}$$



Waxman & Bahcall Phys. Rev. D 59 (1999) 023002

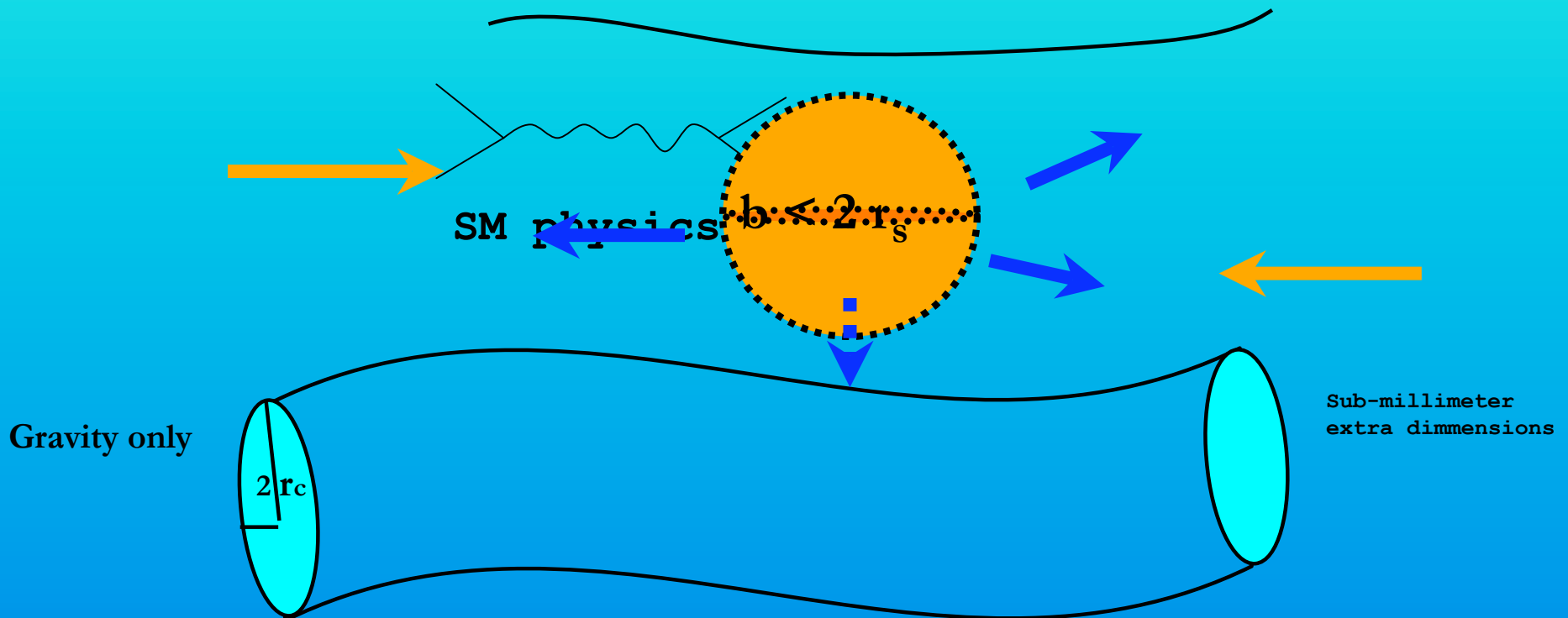
Ahlers, LAA, Goldberg, Halzen, Ringwald, & Weiler, Phys. Rev. D 72 (2005) 023001

Stecker, Done, Salamon & Sommers, Phys. Rev. Lett. 69 (1992) 2738

Neronov, Semikoz, Aharonian & Kalashev, Phys. Rev. Lett. 89 (2002) 051101

# Spacetime's unseen dimensions

**Hypothesis: Universe has  $D = 4 + n$  dimensions**



• SM lives in 4 dimensions

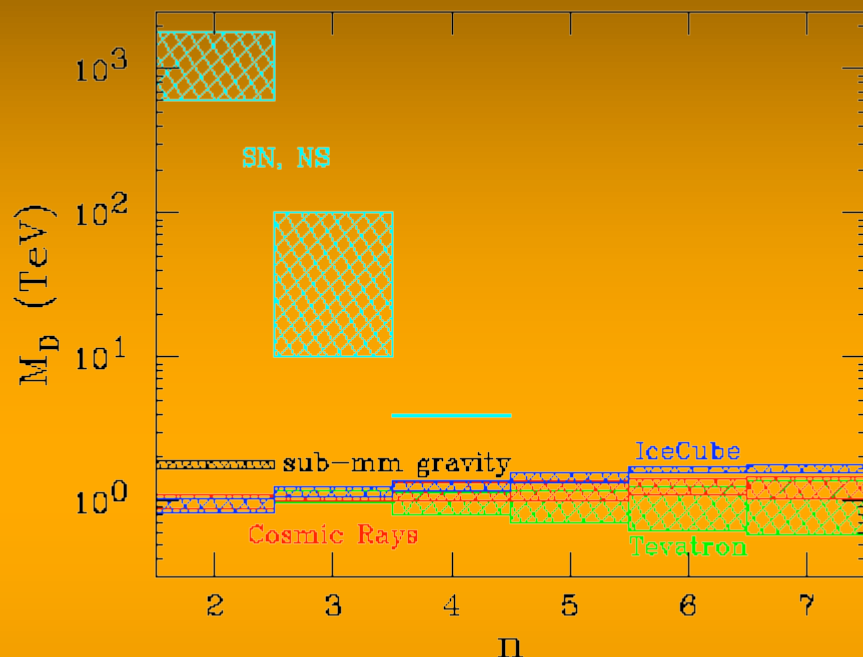
• Dimopoulos & Landsberg, Phys. Rev. Lett. 87 (2001) 161602

• Gravity spills into internal dimensions

Giddings & Thomas, Phys. Rev. D 65 (2002) 056010

Arkani-Hamed, Dimopoulos, & Dvali, Phys. Lett. B 439 (1998) 263

# Probes of TeV – Scale Gravity



$$\sigma_{\nu N \rightarrow BH} \propto \left[ \frac{1}{M_D^2} \right]^{\frac{2+n}{1+n}}$$

- Tests of Newton's law on sub- millimeter scale  
Hoyle – Schmidt – Heckel – Adelberger – Gundlach – Kapner – Swanson PRL 86 (2001) 1418
- Bounds from supernova cooling and neutron star heating  
Hannestad – Raffelt PRL 87 (2002) 071301
- Searches for sub-Planckian signals at the Tevatron  
D0 Collaboration PRL 86 (2001) 1156
- Absence  $\nu$  - showers mediated by BH  
LAA – Goldberg – Feng – Shapere PRD 68 (2003) 104025



# CONCLUSIONS

Because of absorption in traversing the Earth  $\Rightarrow$  simultaneous consideration  
up-coming and down-going event rates can serve to constrain  
the extraterrestrial neutrino flux and anomalous contributions to the neutrino cross sections

## AMANDA - B10

- ◆ Irrespective of cross section assumptions existing data exclude  $\phi^\nu > 26 \phi_{\text{WB}}^\nu$   
at 90 % CL for  $E/\text{GeV} \in [10^7 - 10^{7.5}]$
- ◆ This constraint has significance consequences for what may be seen at IceCube  
 $\mathcal{N}_{\text{down}} < 10 \text{ yr}^{-1}$  for  $E/\text{GeV} \in [10^7 - 10^{7.5}]$

## IceCube $\Rightarrow$ new era in High Energy Physics

- ◆ Integrated luminosity  $\sqrt{s} \simeq 6 \text{ TeV} \Rightarrow \mathcal{L} \approx 25 \text{ nb}^{-1}$
- ◆ 40% (70%) enhancements from SM predictions may be excluded at 90 % (99%) CL
- ◆ “Smoking- ice” of TeV-scale gravity models  $\Rightarrow$  Probes of fundamental Planck scale

THANKS

&

QUESTIONS