Neutrino Astrophysics

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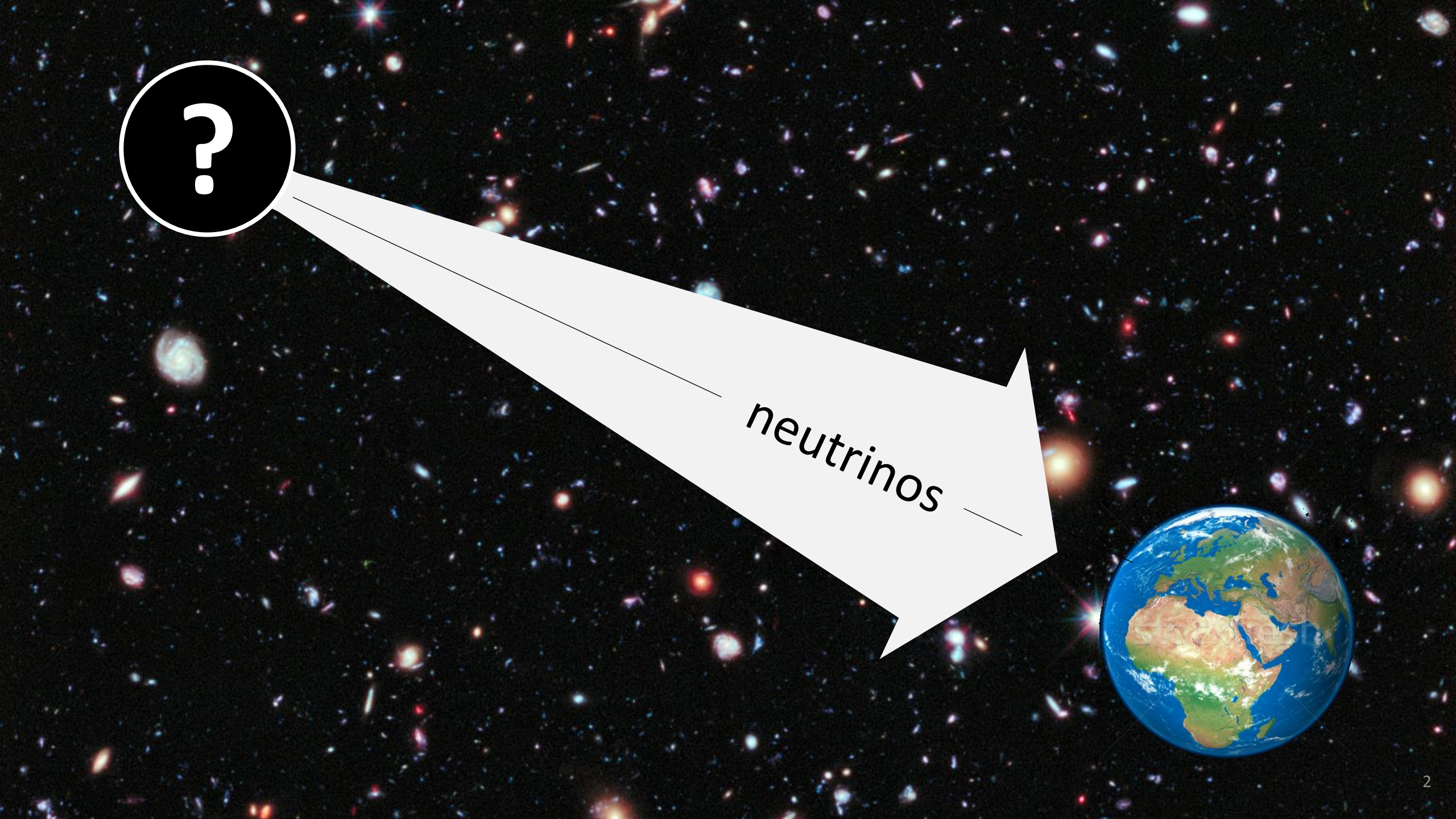
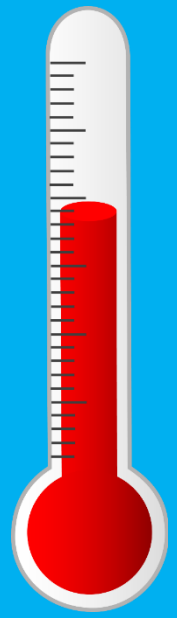
Venice
5–12 July 2017


?
neutrinos

Neutrino sources

Thermal

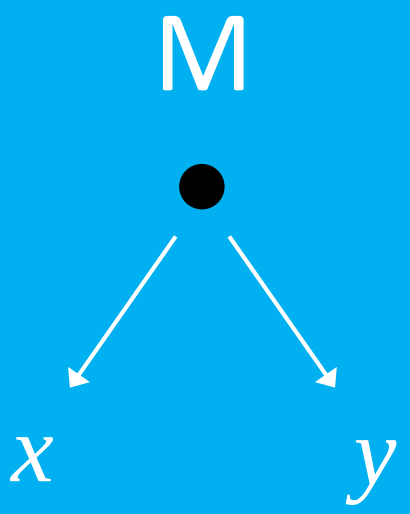


✓ Sun
✓ SN1987A

bottom-up

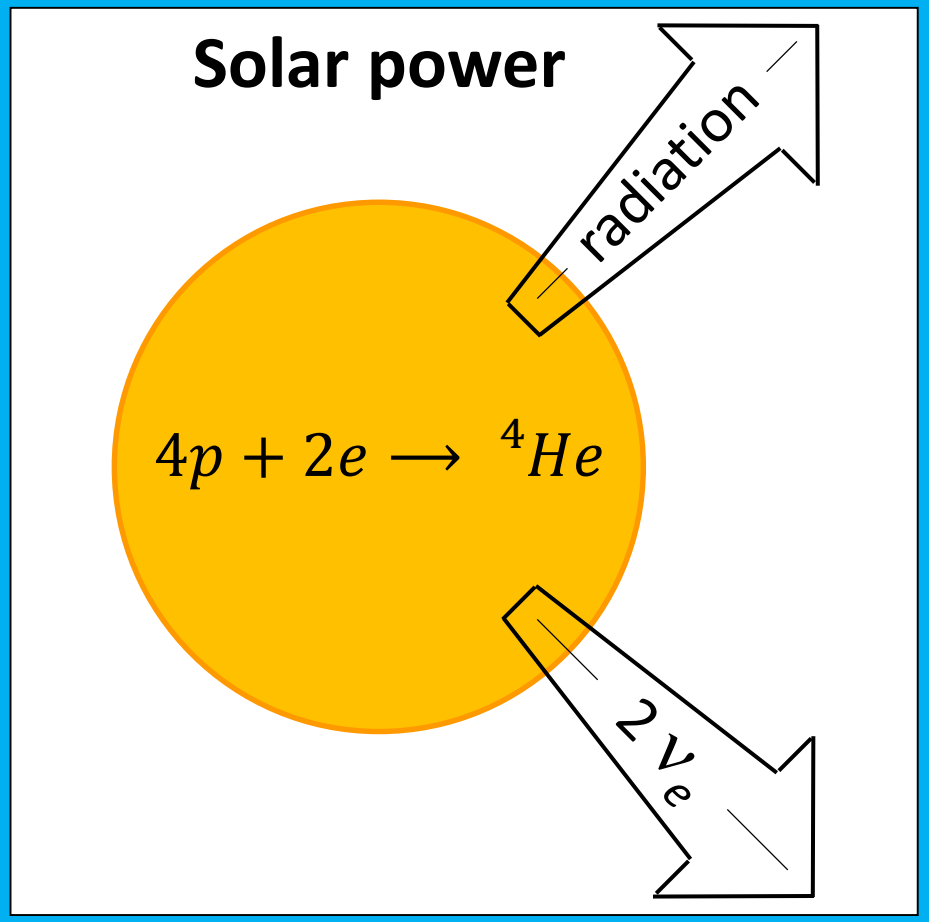
cosmic particle accelerators

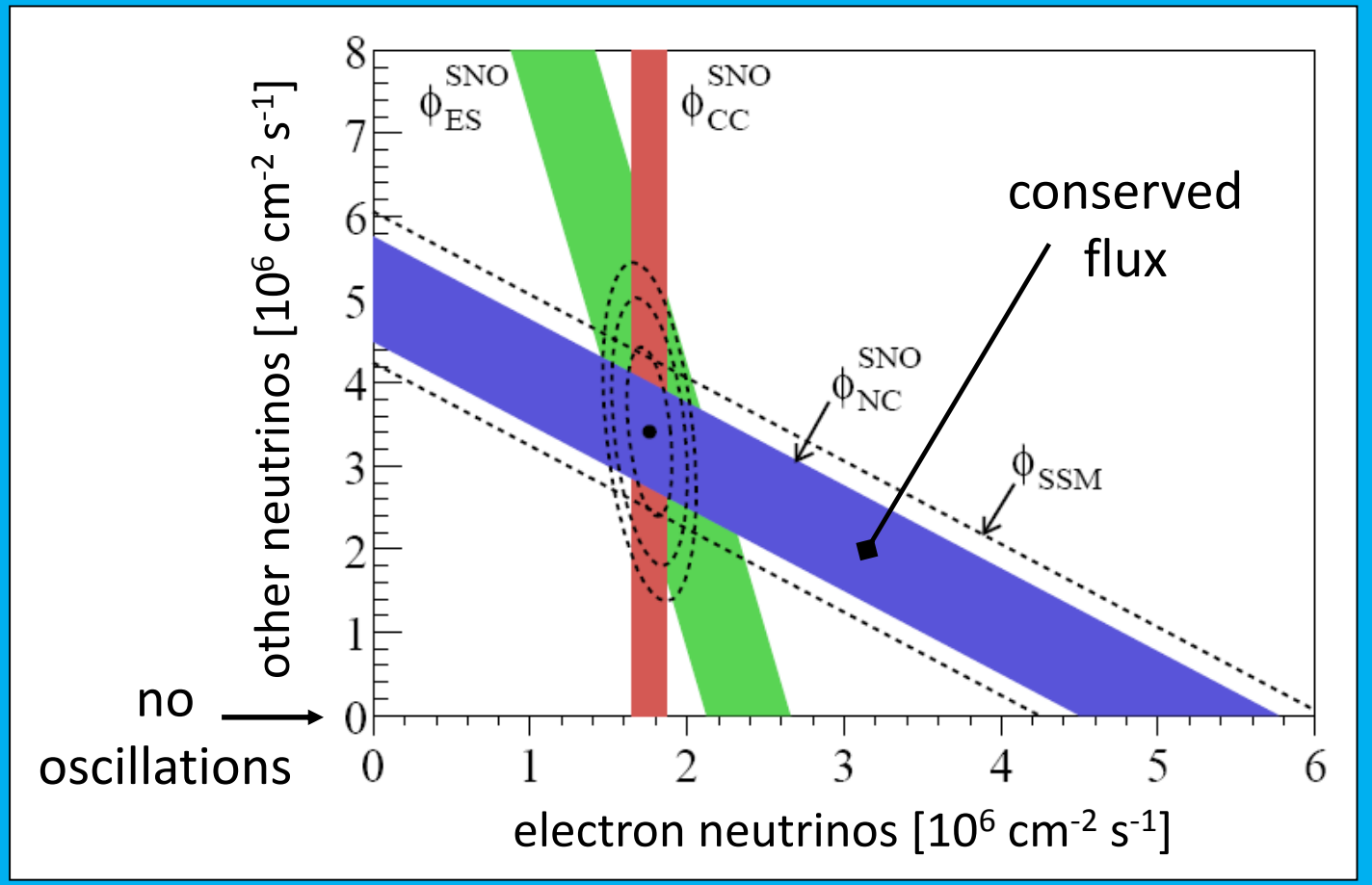
top-down



dark matter
GUT…

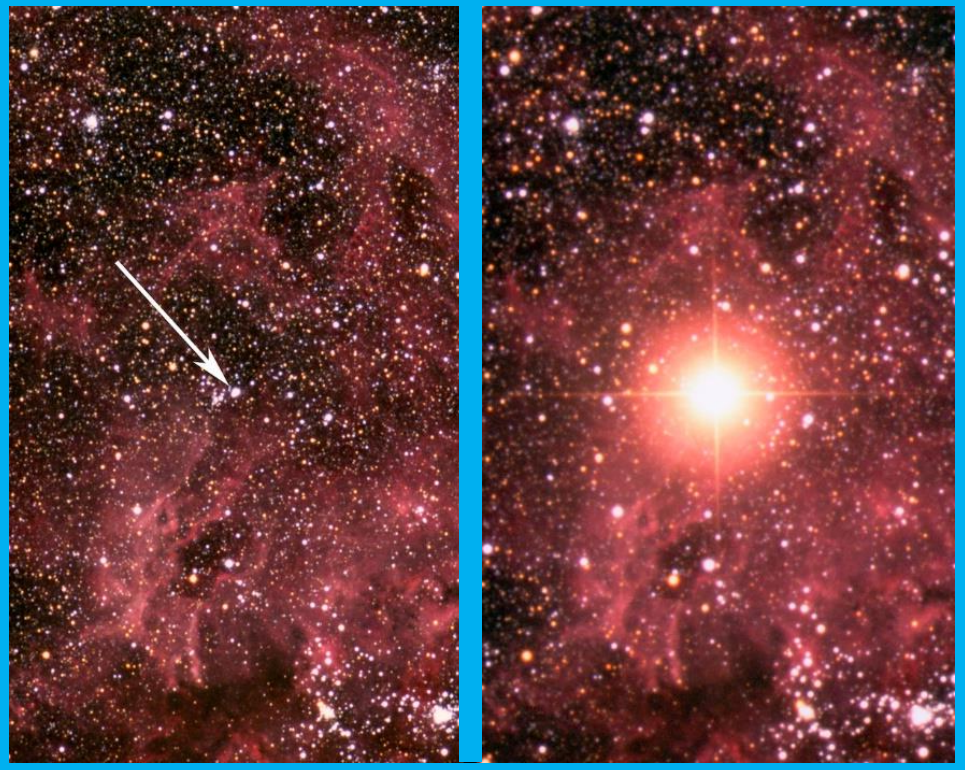
Solar neutrinos

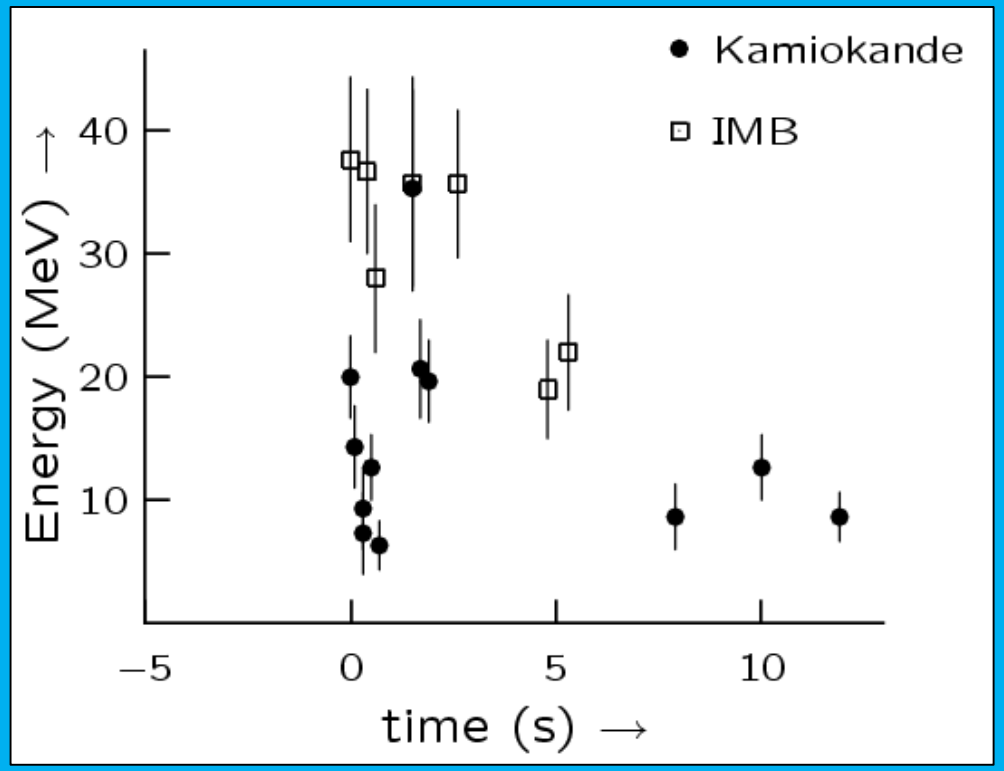




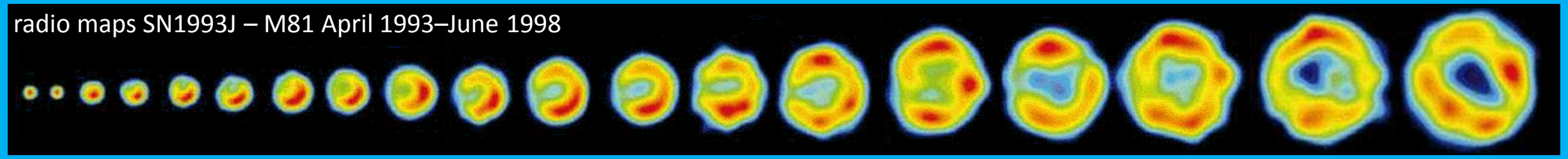
SN1987A

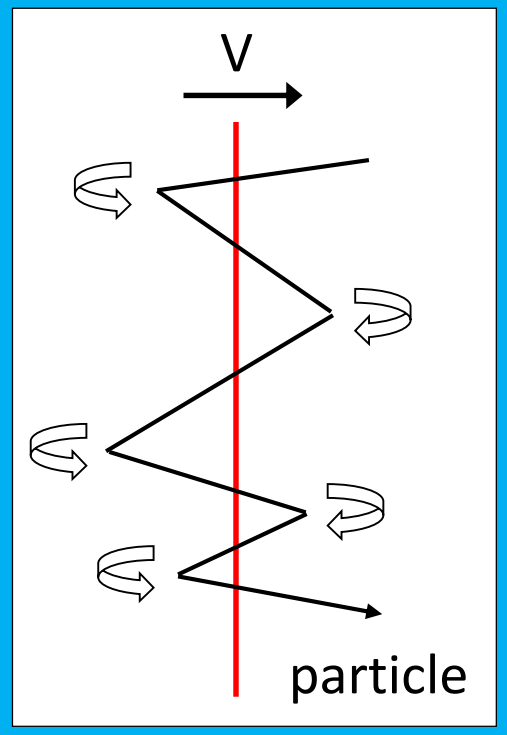
before **after**





Fermi shock acceleration





Acceleration $\Delta E = \alpha E$

Probability $P = \beta$

$\downarrow$

k steps $E = E_0(1+\alpha)^k$

$N = N_0(\beta)^k$

$$\frac{\ln(N/N_0)}{\ln(E/E_0)} = \frac{\ln(\beta)}{\ln(1+\alpha)}$$

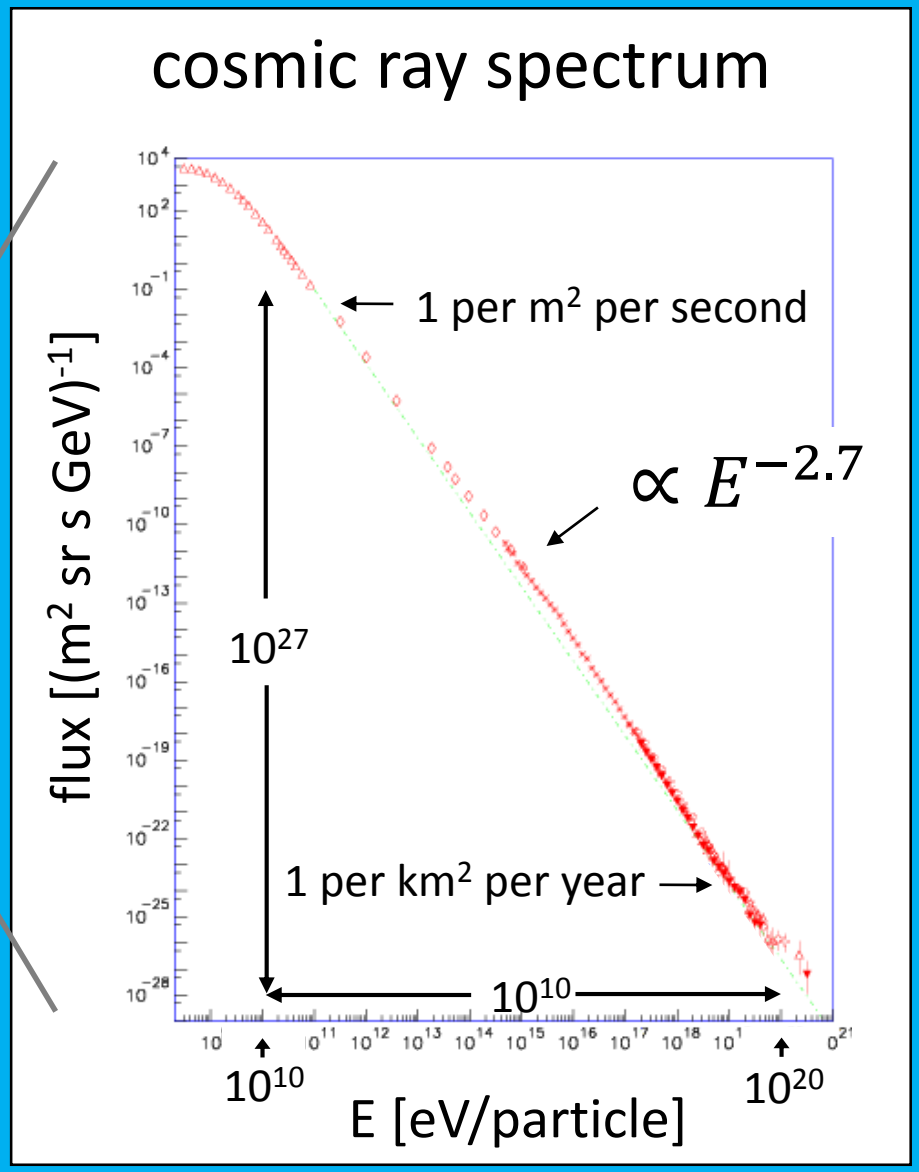
$$\frac{N}{N_0} = \left(\frac{E}{E_0}\right)^{\frac{\ln(\beta)}{\ln(1+\alpha)}}$$

$$\frac{dN}{dE} \propto E^{\frac{\ln(\beta)}{\ln(1+\alpha)} - 1}$$

Thermodynamics

$$\frac{dN}{dE} \propto E^{\frac{\ln(\beta)}{\ln(1+\alpha)} - 1} = E^{-2} \cong$$

Relativity

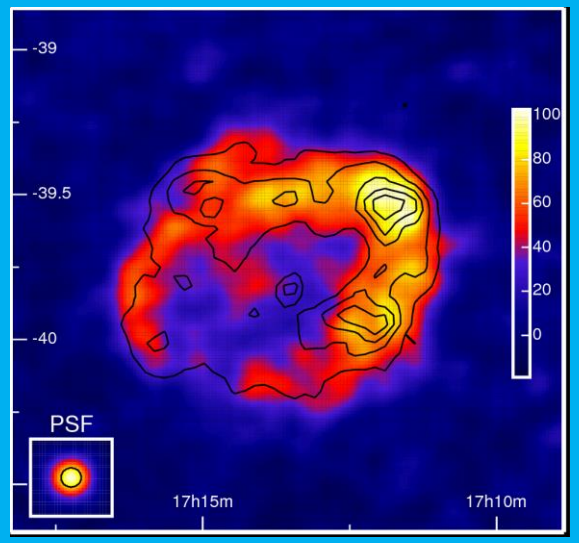


Origin of cosmic rays?

Possible cosmic particle accelerators

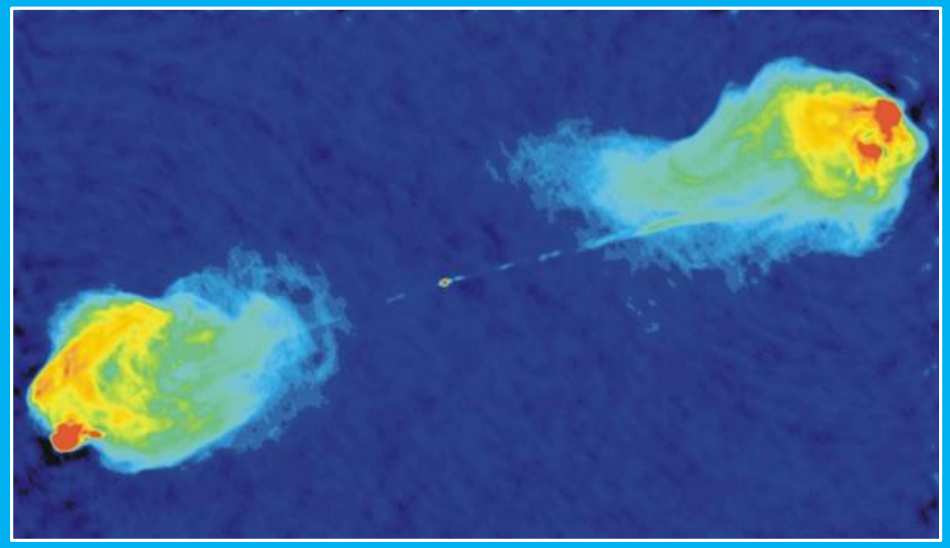
Galactic

- Supernova remnants



Extra-galactic

- Active Galactic Nuclei

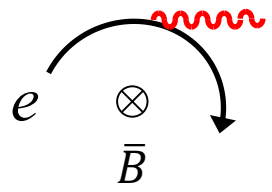


Missing link with cosmic rays

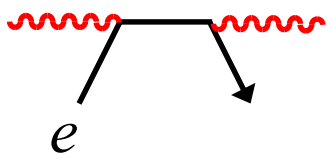
Astro-particle physics

electro-magnetic

Synchrotron radiation

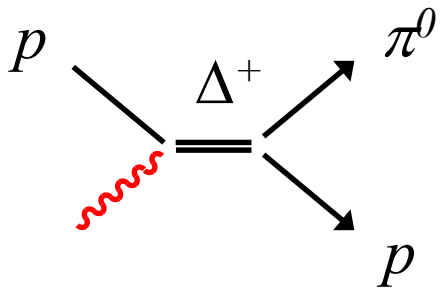


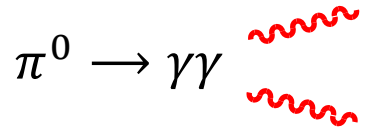
inverse Compton scattering



gamma rays

hadronic



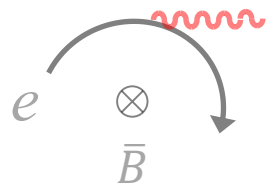


gamma rays

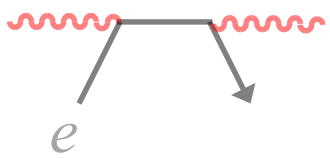
Astro-particle physics

electro-magnetic

Synchrotron radiation



inverse Compton scattering



gamma rays

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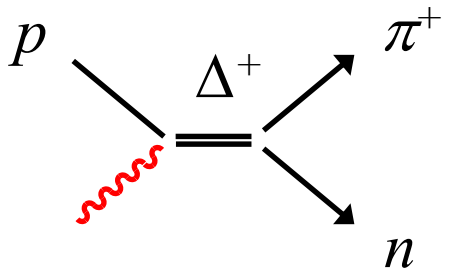
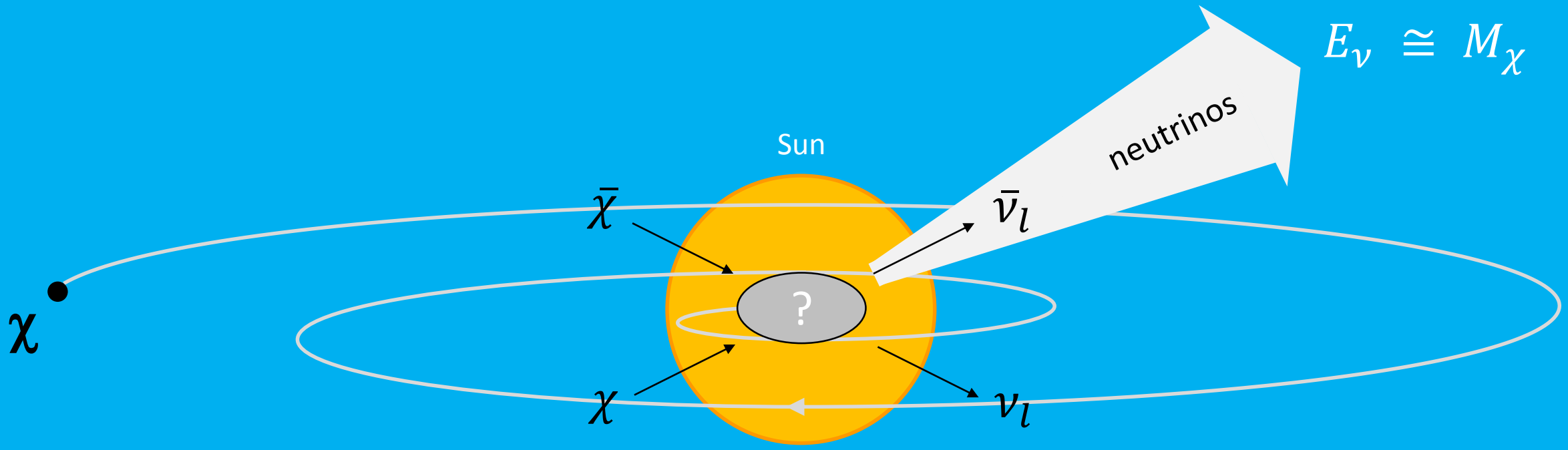


$$\pi^{\pm} \longrightarrow \mu^{\pm} + \nu_{\mu}/\bar{\nu}_{\mu}$$

$$\mu^{\pm} \longrightarrow e^{\pm} + \bar{\nu}_{\mu}/\nu_{\mu} + \nu_{e}/\bar{\nu}_{e}$$

neutrinos

Dark matter



Existence of dark matter?

Neutrino propagation

weak states = *"what you see"*

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \times \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

mass states = *"what you get"*

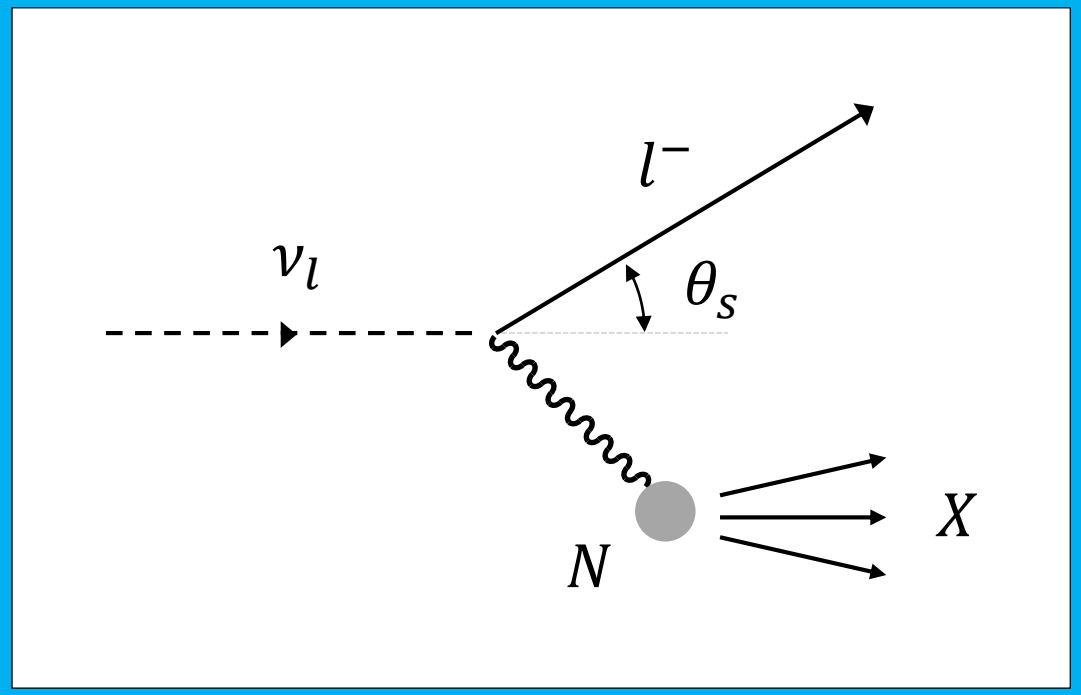
CP-violation Majorana

$$U = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha_1/2} & 0 \\ 0 & 0 & e^{i\alpha_2/2} \end{bmatrix}$$

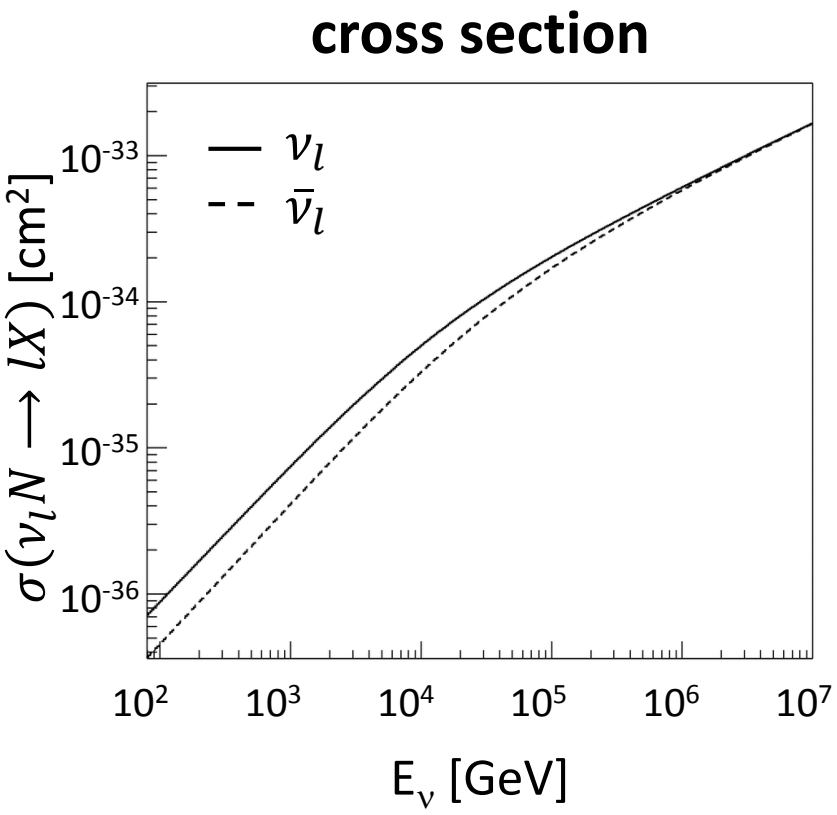
$c_{ij} = \cos\theta_{ij} \quad s_{ij} = \sin\theta_{ij}$

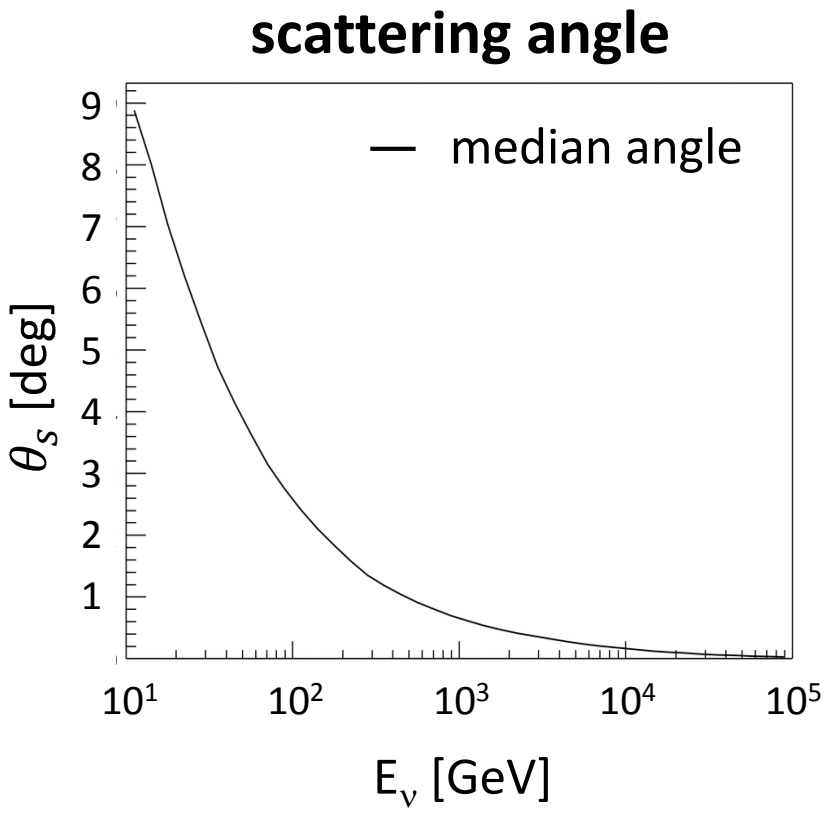
Test of fundamental physics

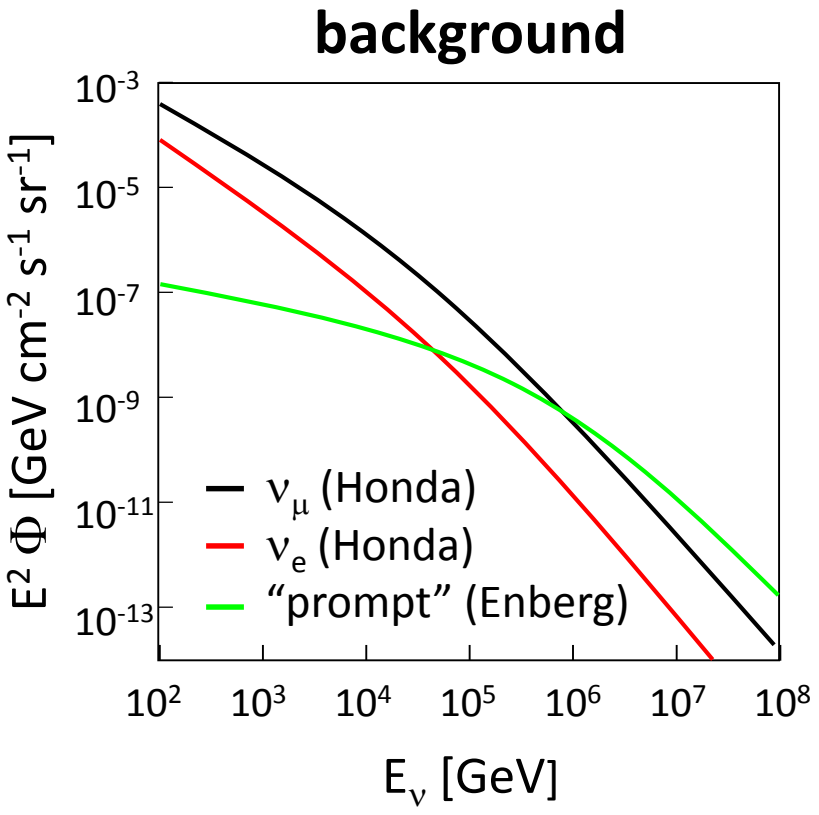
Neutrino telescope



The case for TeV–PeV neutrino astronomy

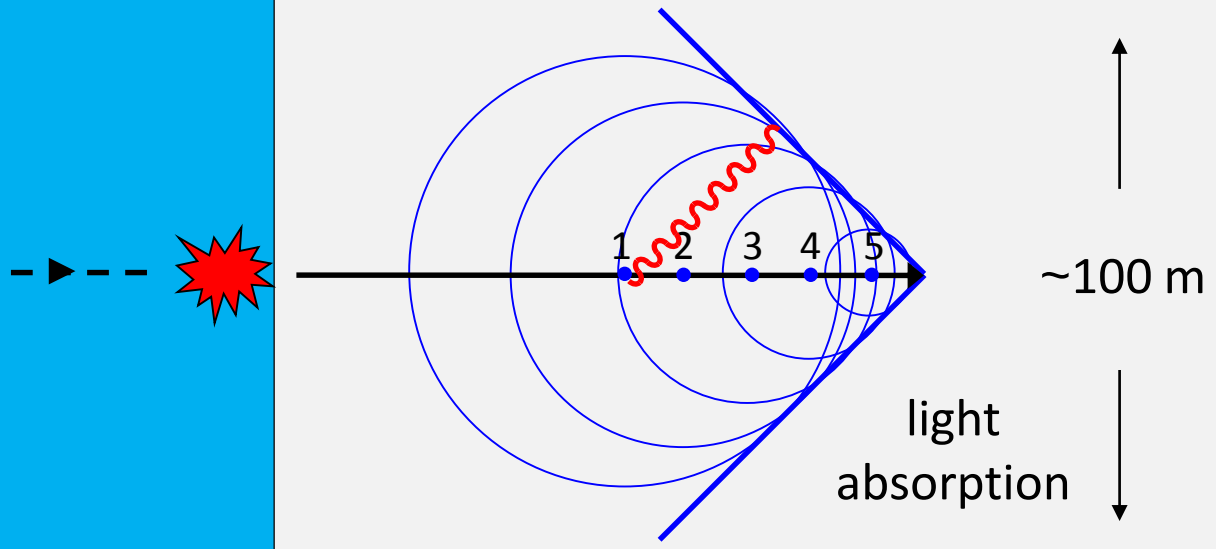






Neutrino detection

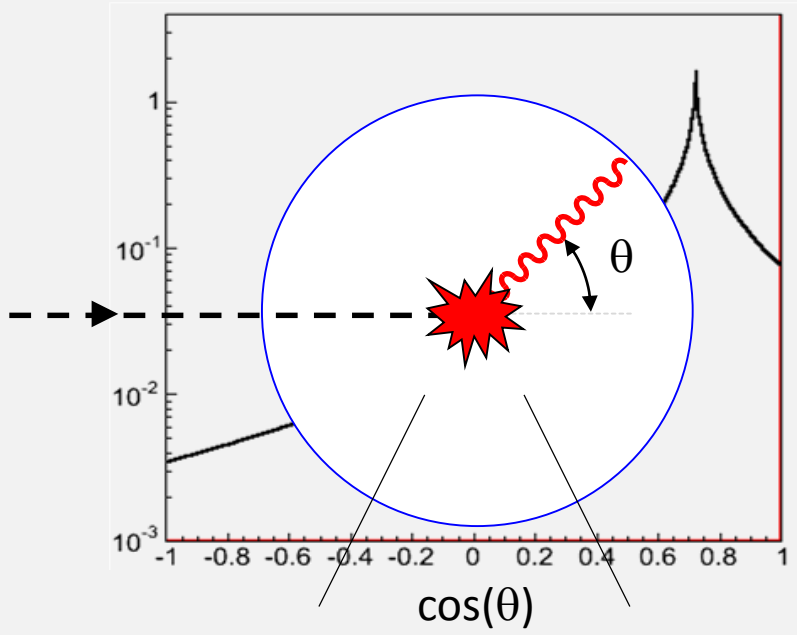
muon neutrino



← ~ [km] ln(E/TeV) →

muon energy loss

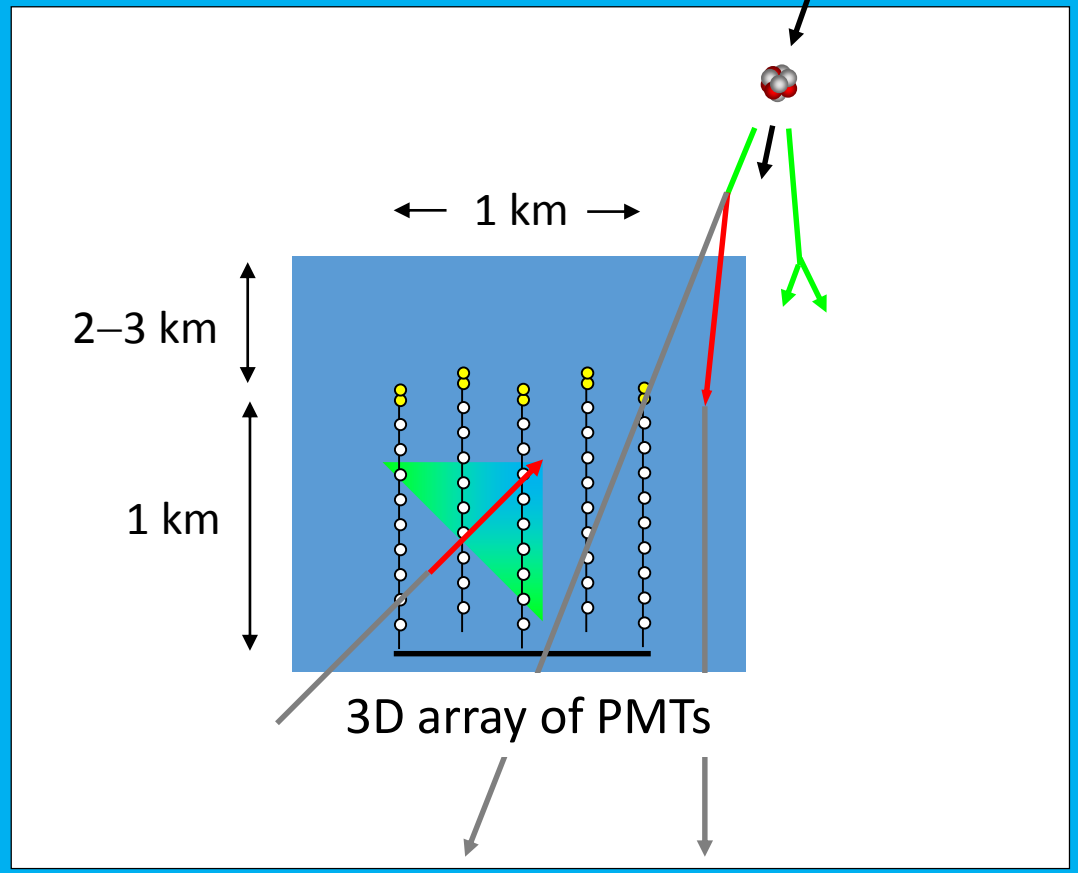
electron neutrino

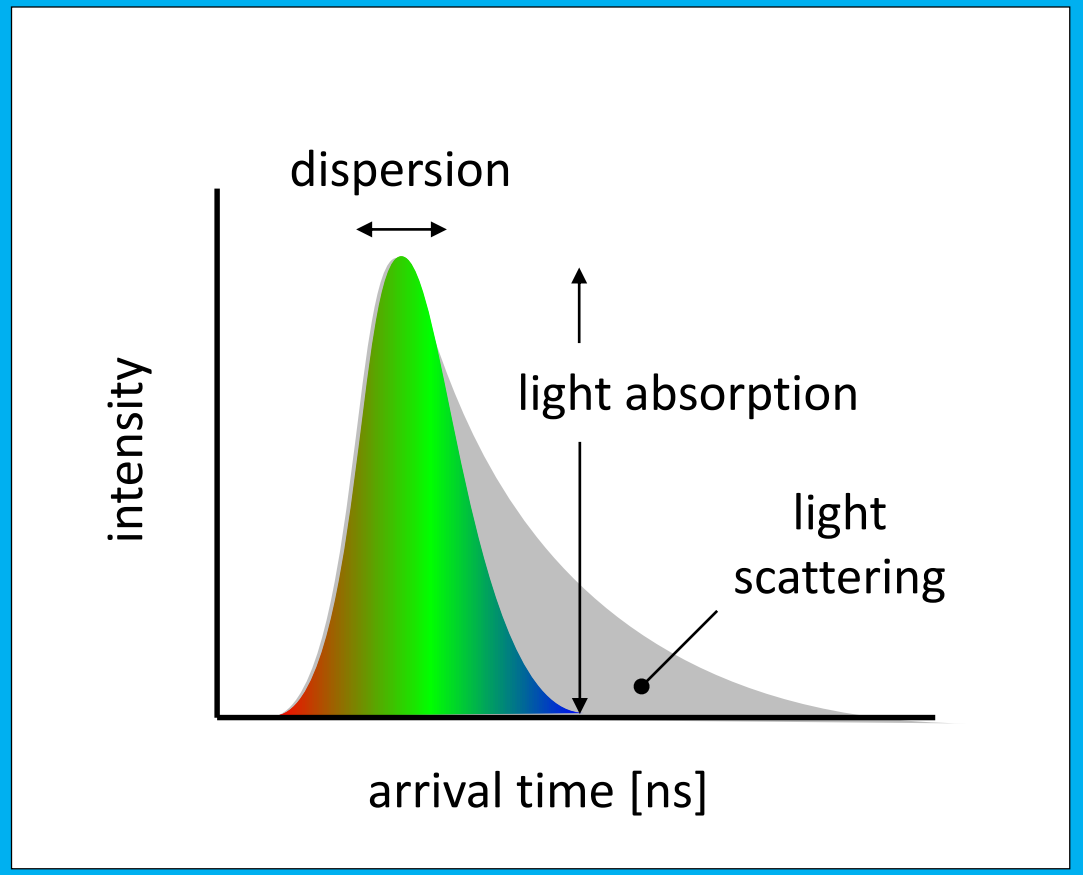


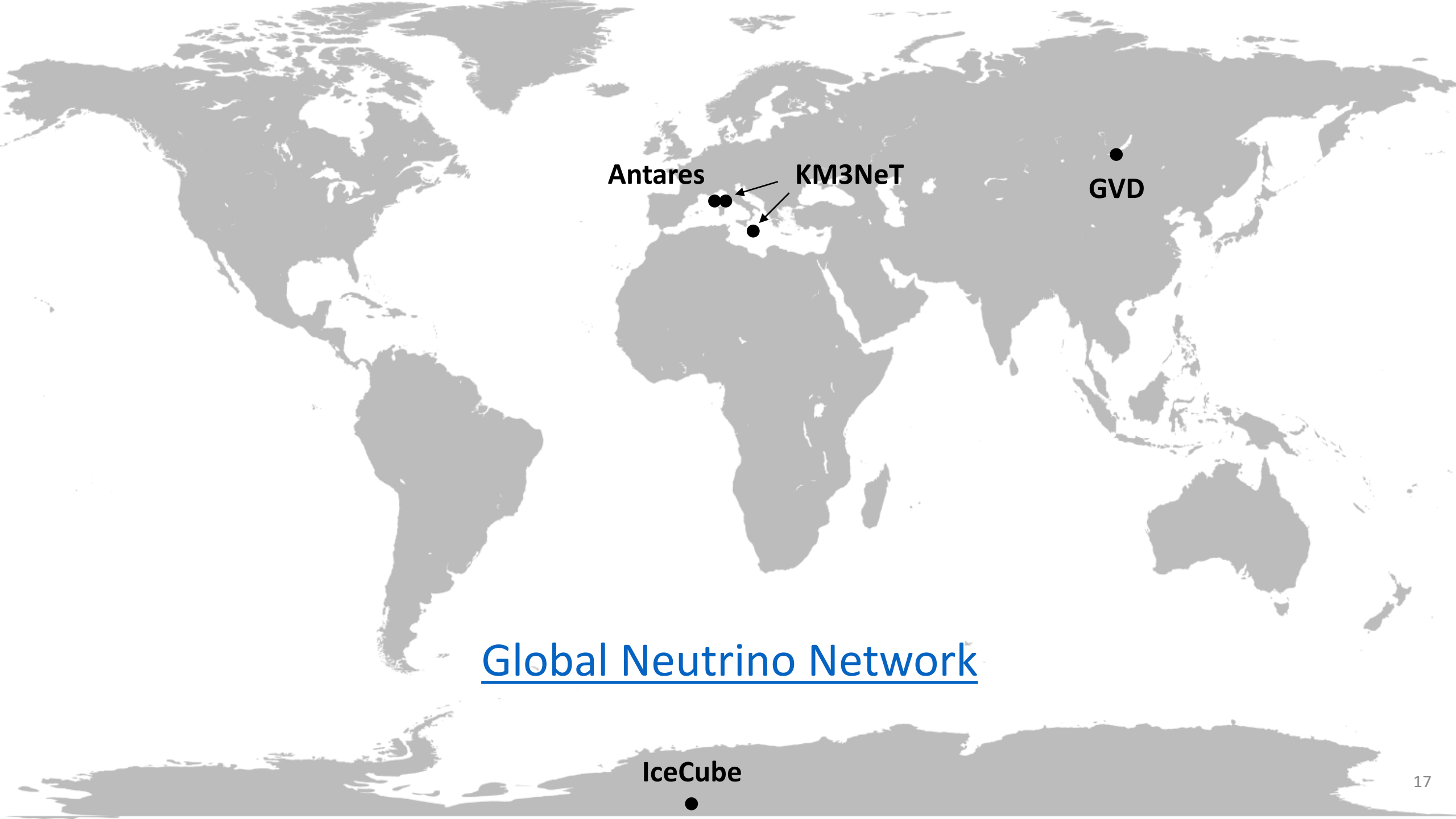
~ [m] ln(E/TeV)

radiation length

Neutrino detector





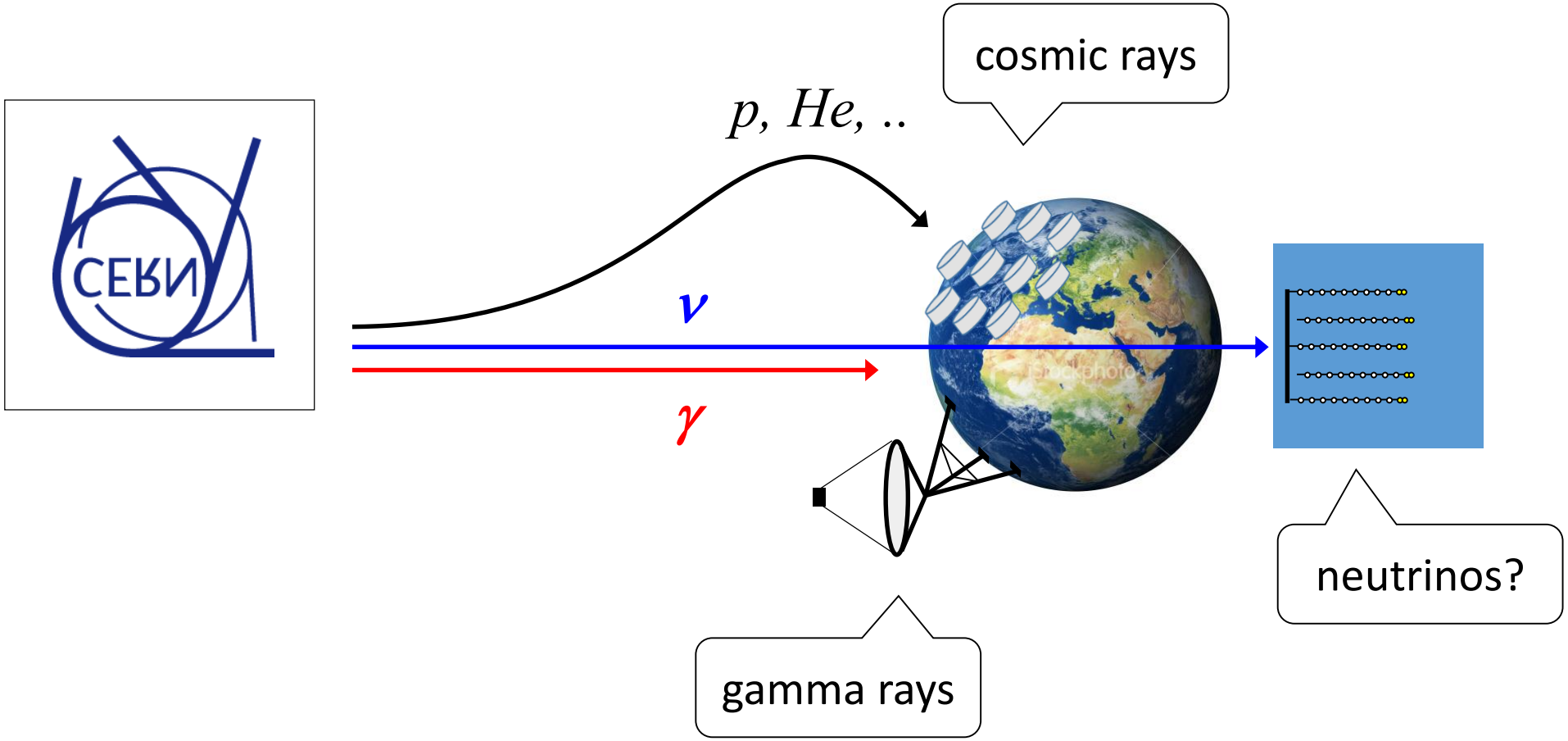


Global Neutrino Network

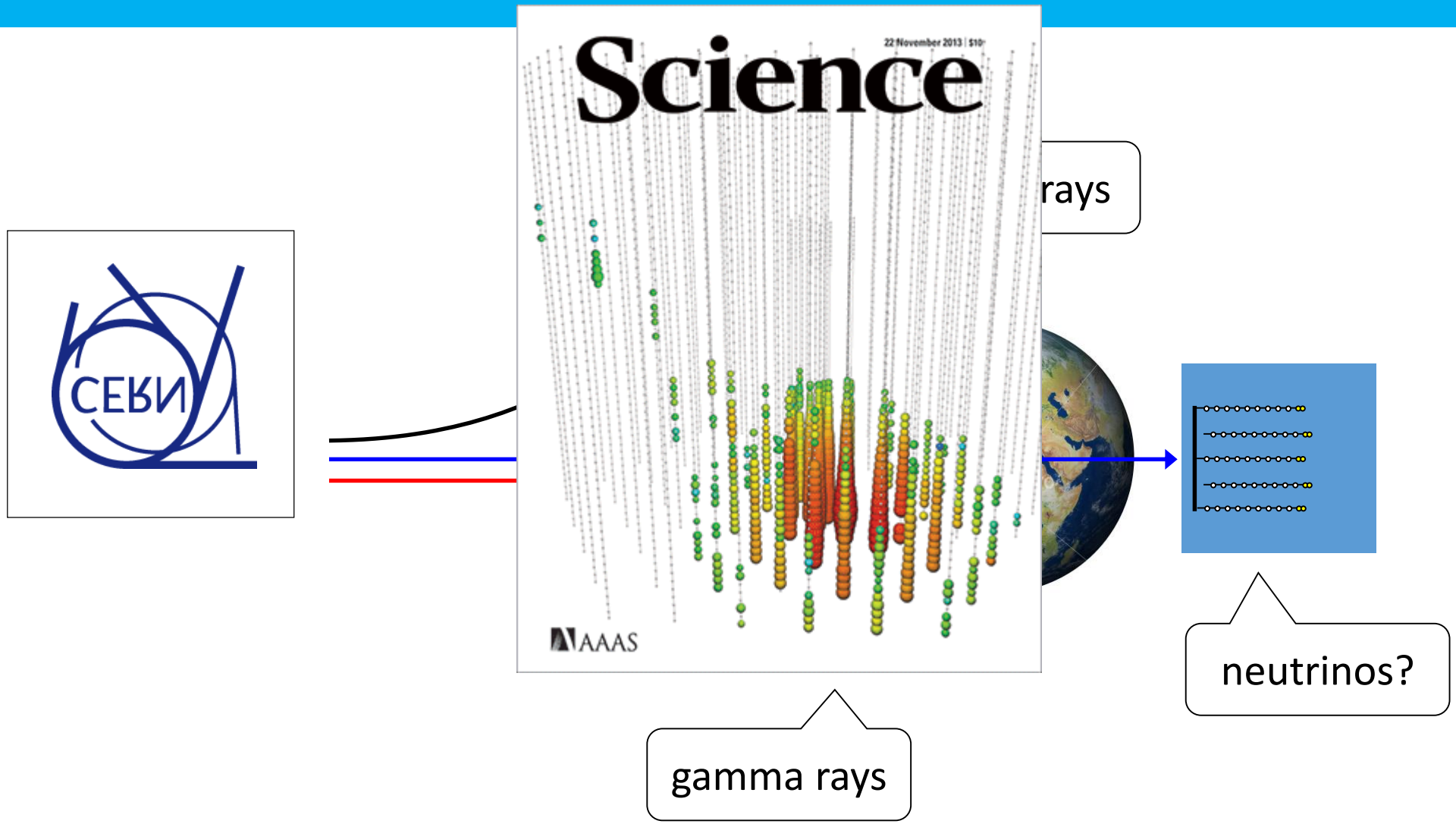
Neutrino telescopes

	IceCube	GVD	Antares	KM3NeT
Status	completed 2011	under construction	completed 2007	under construction
Location	South Pole	Lake Baikal	Mediterranean Sea	
Medium	ice	lake	sea	
Light transmission	$\lambda_s < \lambda_{abs}$	$\lambda_s \gg \lambda_{abs}$	$\lambda_s \gg \lambda_{abs}$	
Resolution ν_μ ν_e	0.4 deg 10 deg	0.5 deg 2 deg	0.4 deg 2 deg	0.1 deg 1.5 deg
Noise	extremely low	medium	medium	
PMT size (QE)	10” (25%)	10” (35%)	10” (20%)	3” (30%)

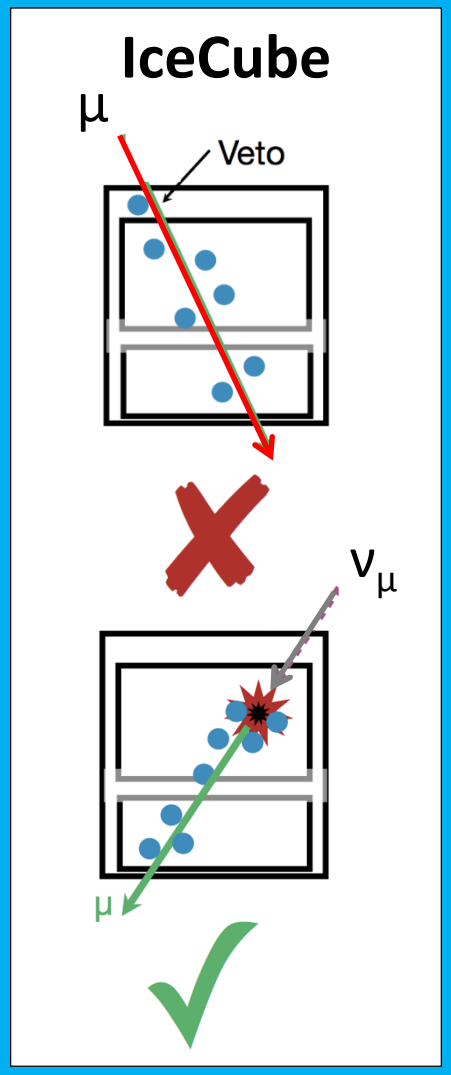
Multi-messenger astronomy

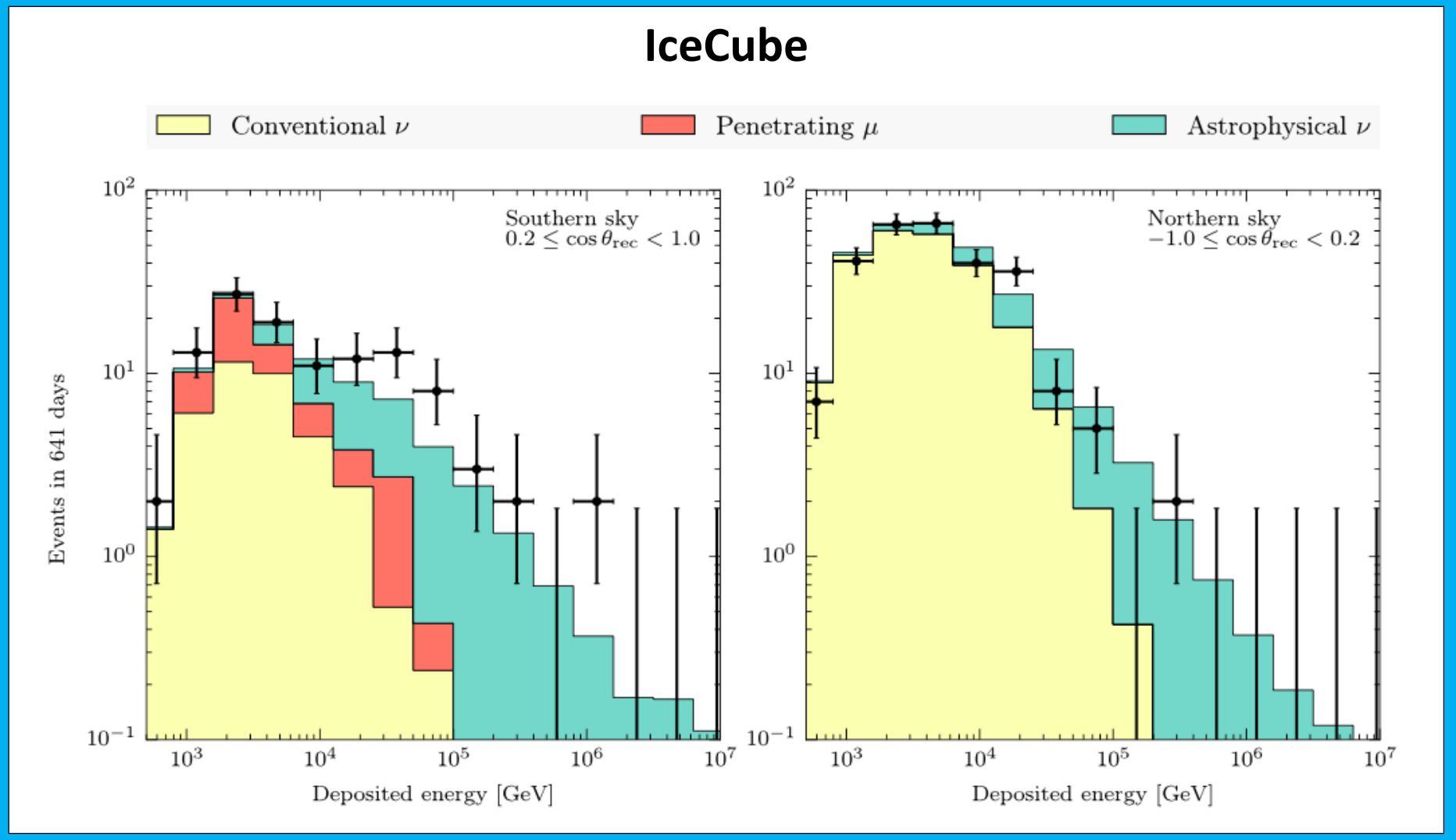


Multi-messenger astronomy

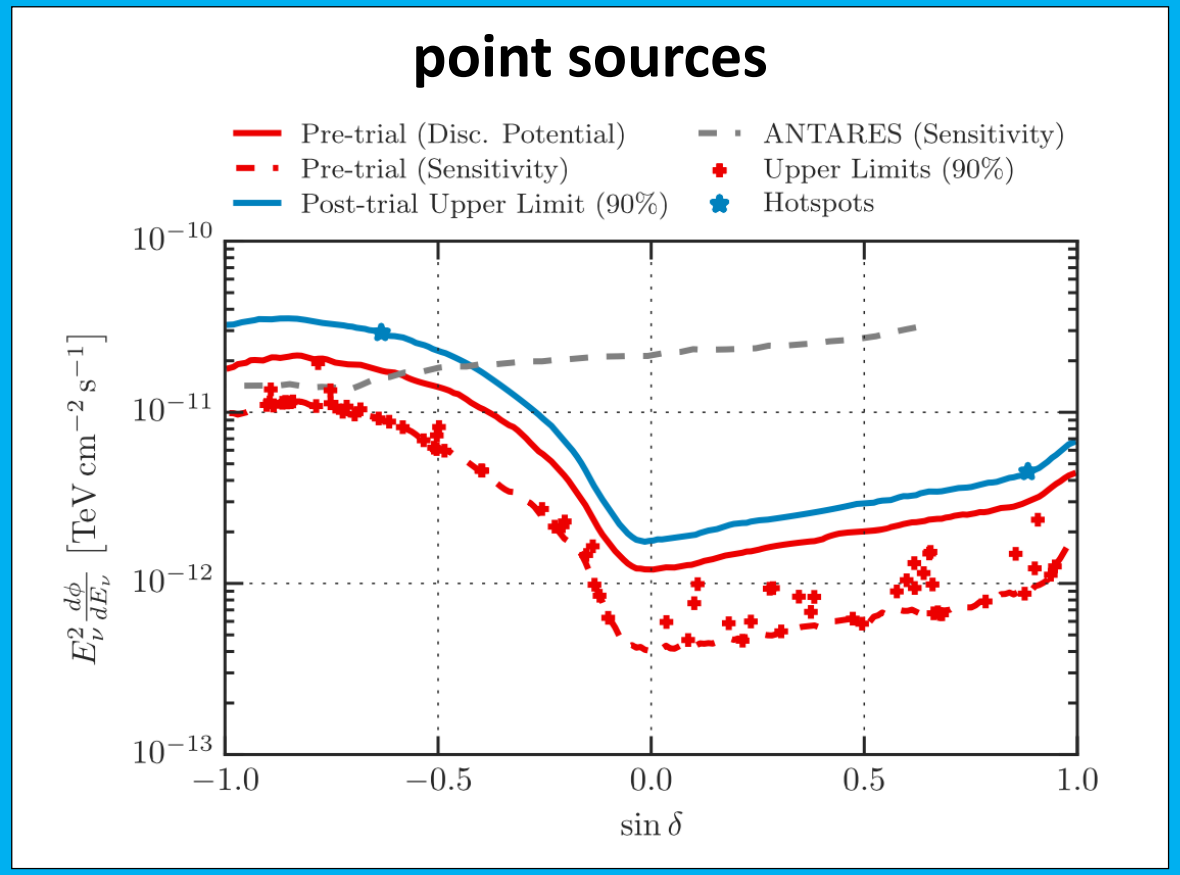


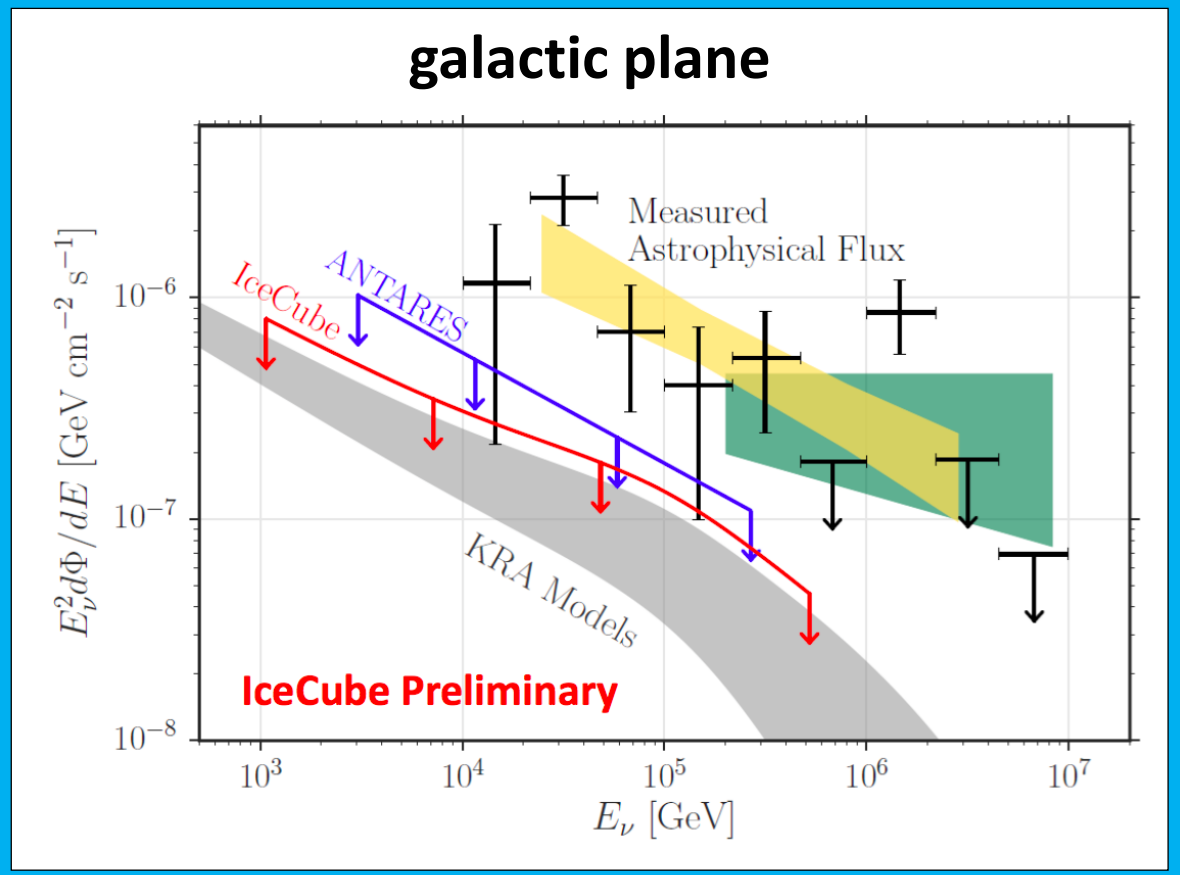
Diffuse flux



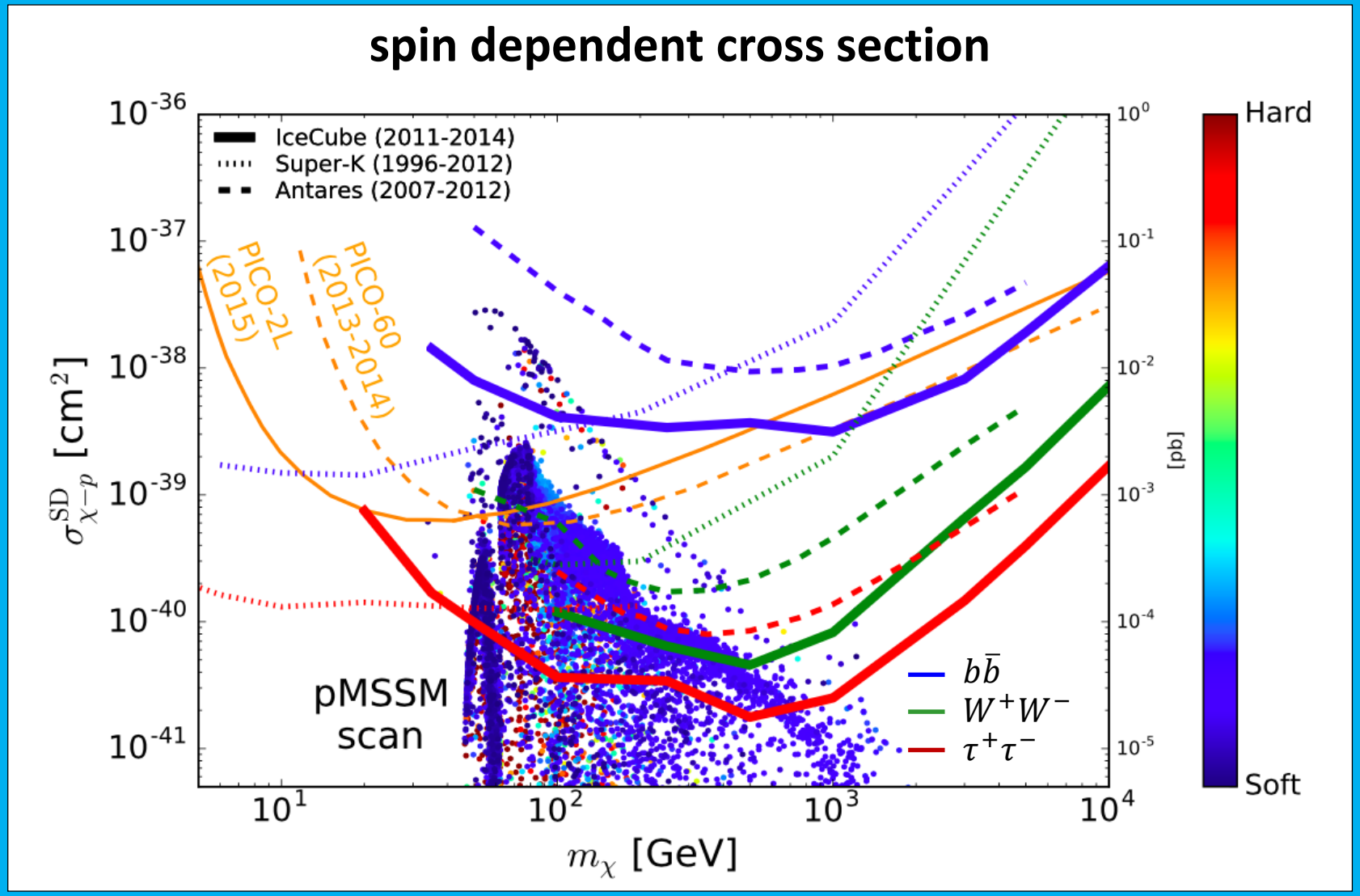


(point) source(s)

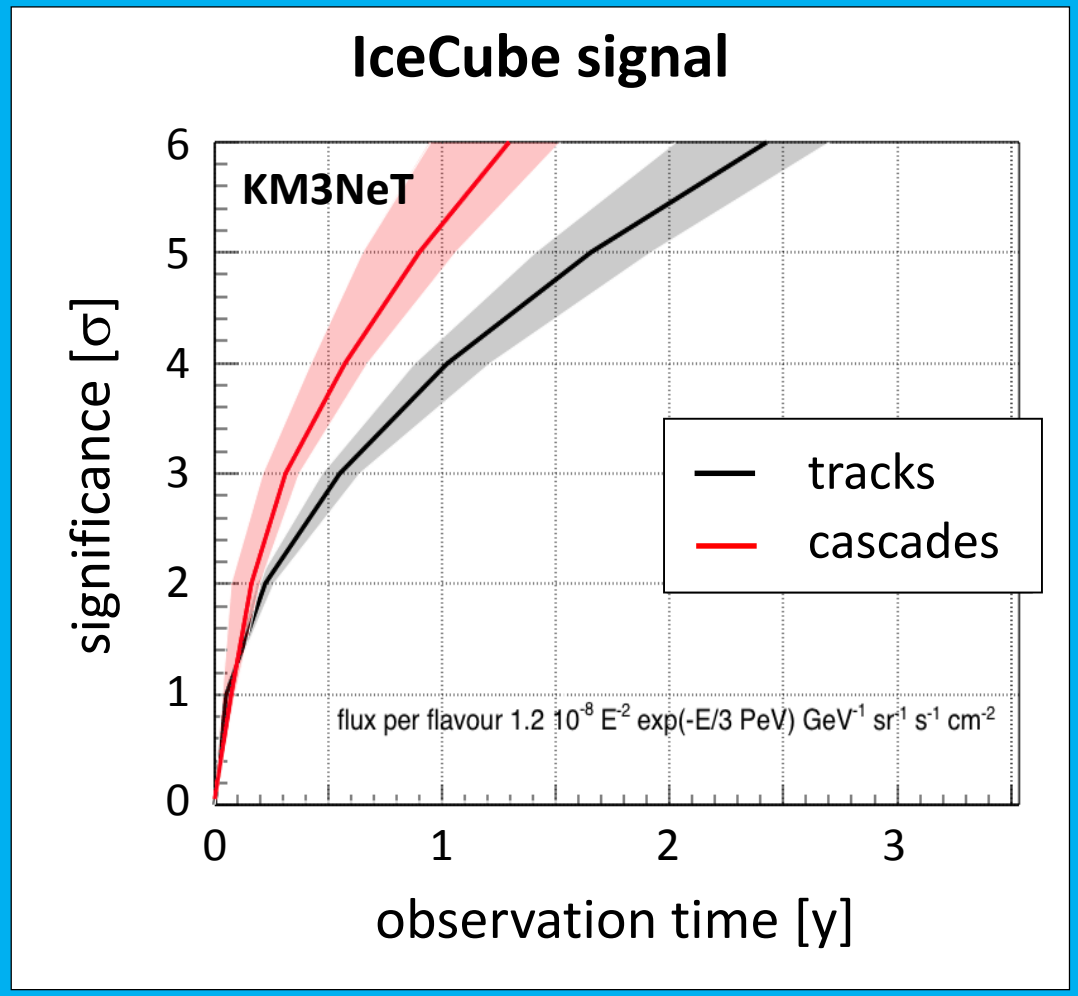


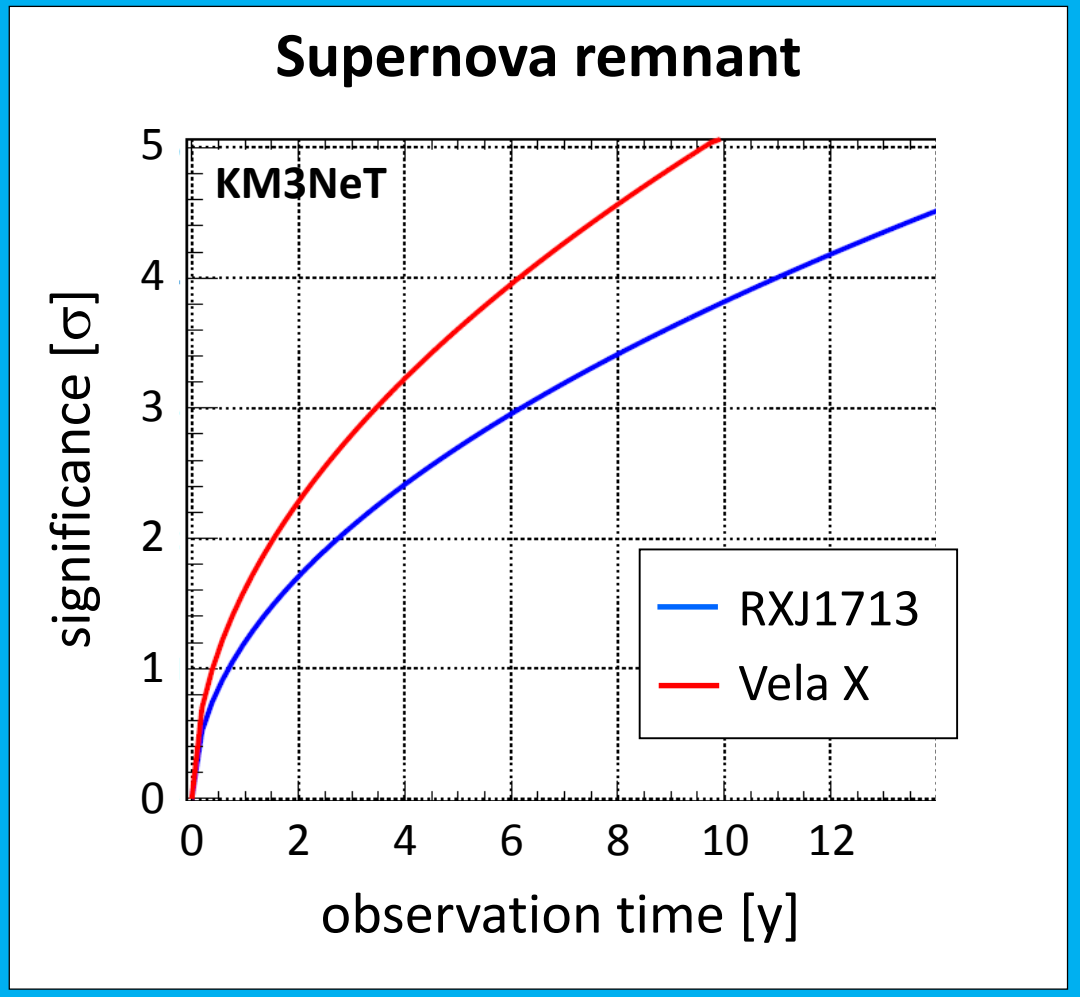


Dark matter


spin dependent cross section
IceCube (2011-2014)
Super-K (1996-2012)
Antares (2007-2012)
PICO-2L (2015)
PICO-60 (2013-2014)
pMSSM scan
$b\bar{b}$
W^+W^-
$\tau^+\tau^-$
$\sigma^{SD}_{\chi-p}$ [cm^2]
m_χ [GeV]
[pb]
Hard
Soft

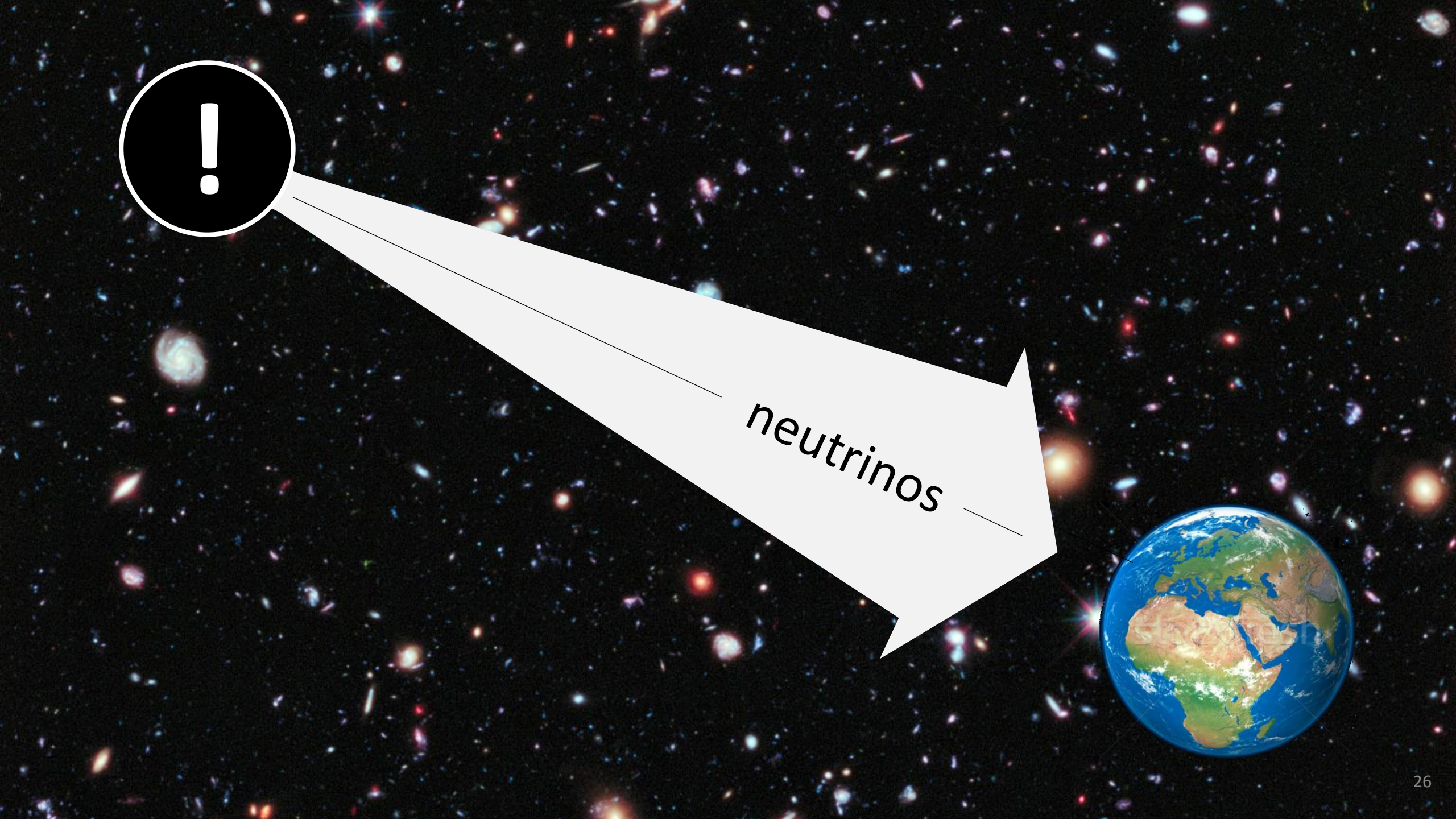
Future – KM3NeT





Future

- Point sources / catalogues
  - origin of cosmic rays
  - energy spectra
  - morphology of sources
- Galactic plane
  - probing interactions of cosmic rays with matter
- Neutrino flavour composition
  - tau appearance
  - Glashow resonance
  - test of fundamental physics
- Atmospheric neutrinos
  - determine neutrino mass hierarchy
- cosmogenic neutrinos
  - see GZK cut-off
- Supernova monitoring
  - link with astronomy
- Dark matter
  - links with particle physics, astrophysics and cosmology
- Long baseline experiments
  - Protvino to KM3NeT
- Serendipity
  - Earth and sea sciences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neutrinos