Astro-particle neutrino experiments KM3NeT, IceCube, GVD (Baikal)

ECFA – 22nd of February 2021

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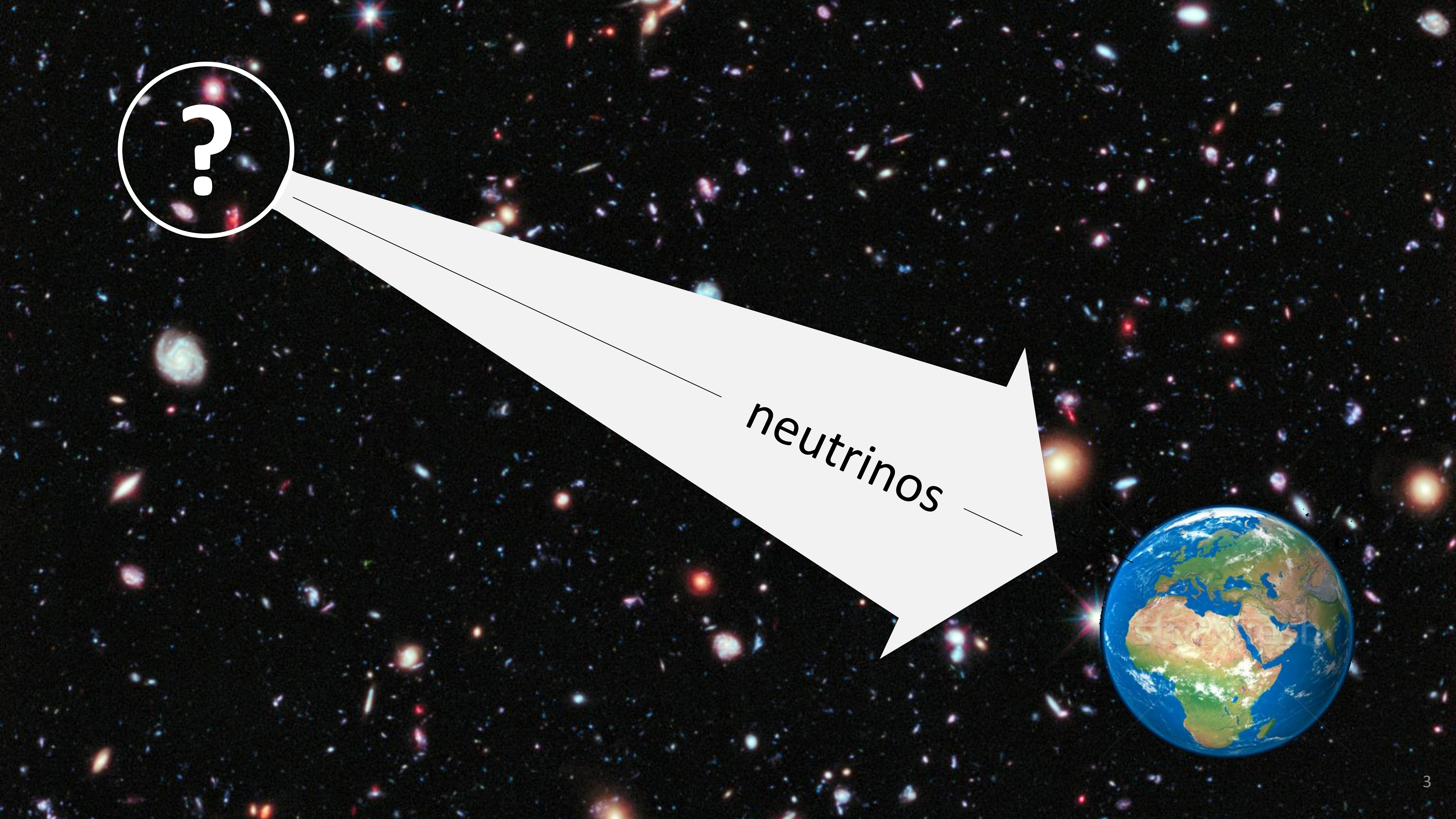
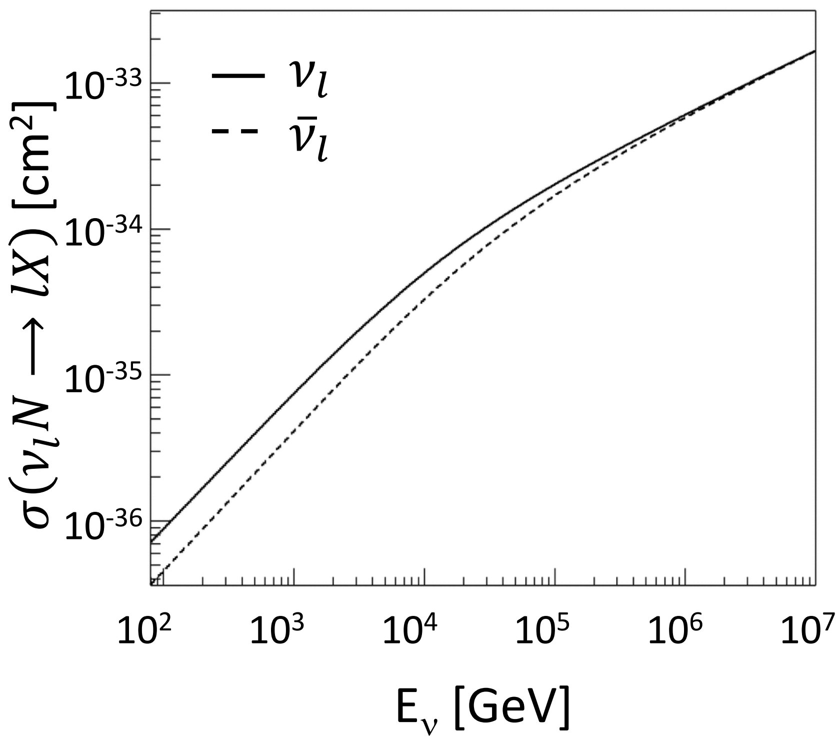
Disclaimer:

- Numbers are indicative and should be taken with a pinch of salt;
- Visions are meant for discussion and may be biased;

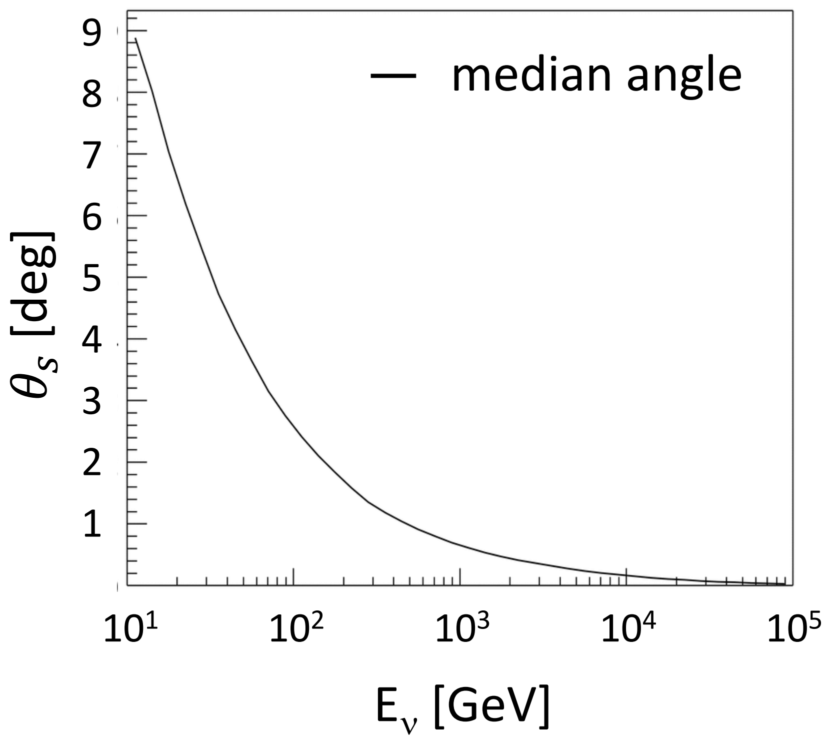

?
neutrinos

The case for TeV–PeV neutrino astronomy

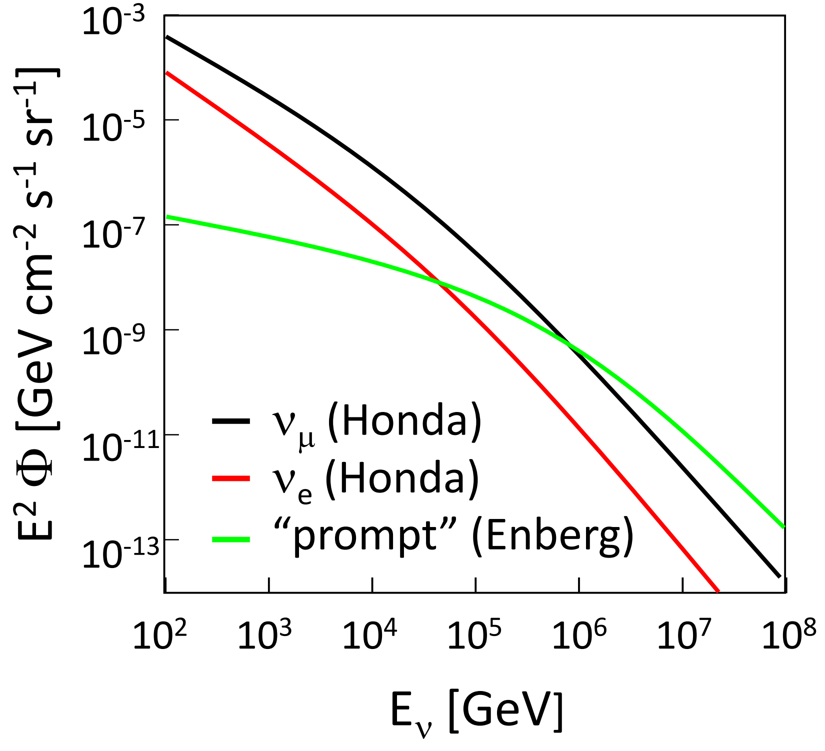
cross section



scattering angle

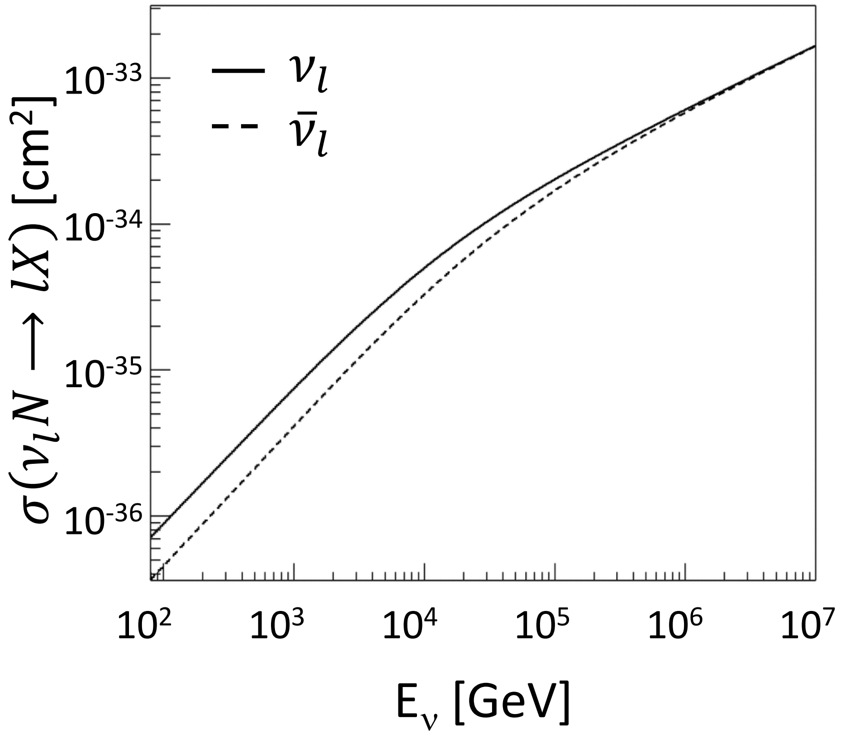


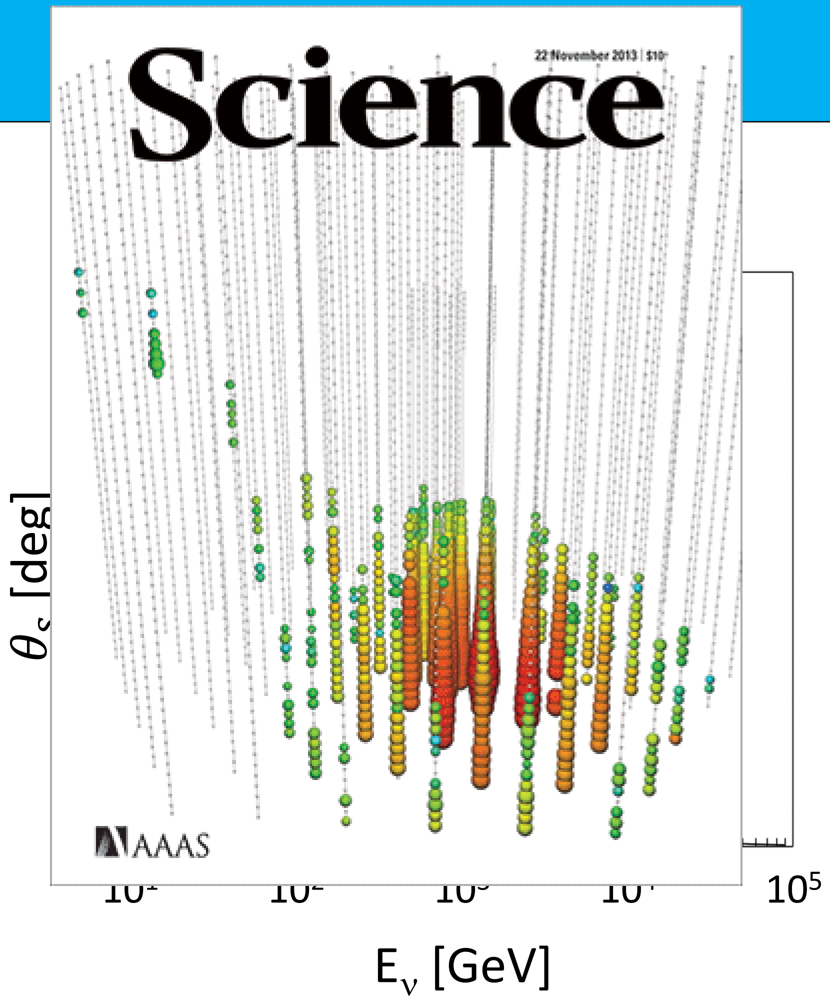
background



The case for TeV–PeV neutrino astronomy

cross section





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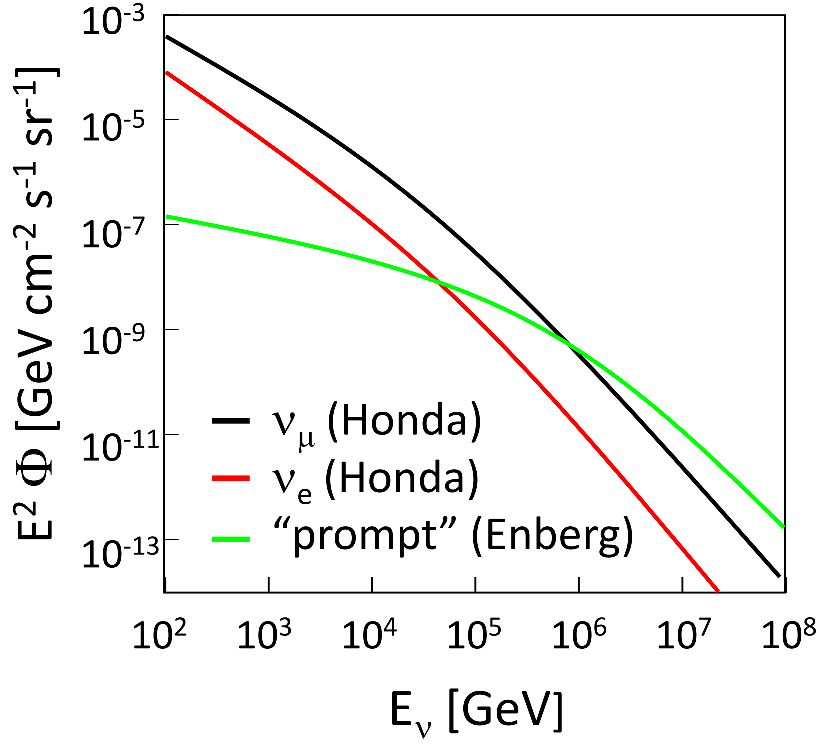


Neutrino propagation

weak states		mass states
=	$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \times \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$	=
"what you see"		*"what you get"*

CP-violation — Majorana

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

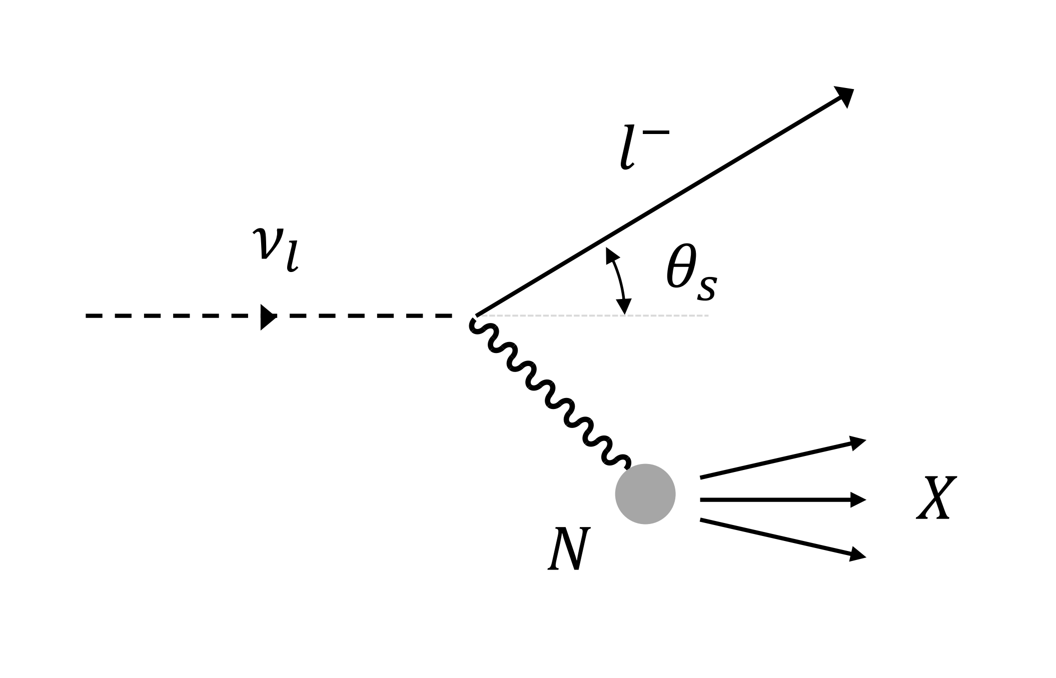
$c_{ij} = \cos\theta_{ij} \qquad s_{ij} = \sin\theta_{ij}$

Test of fundamental physics

Neutrino telescope

Cherenkov (1934):
H_2O as detector

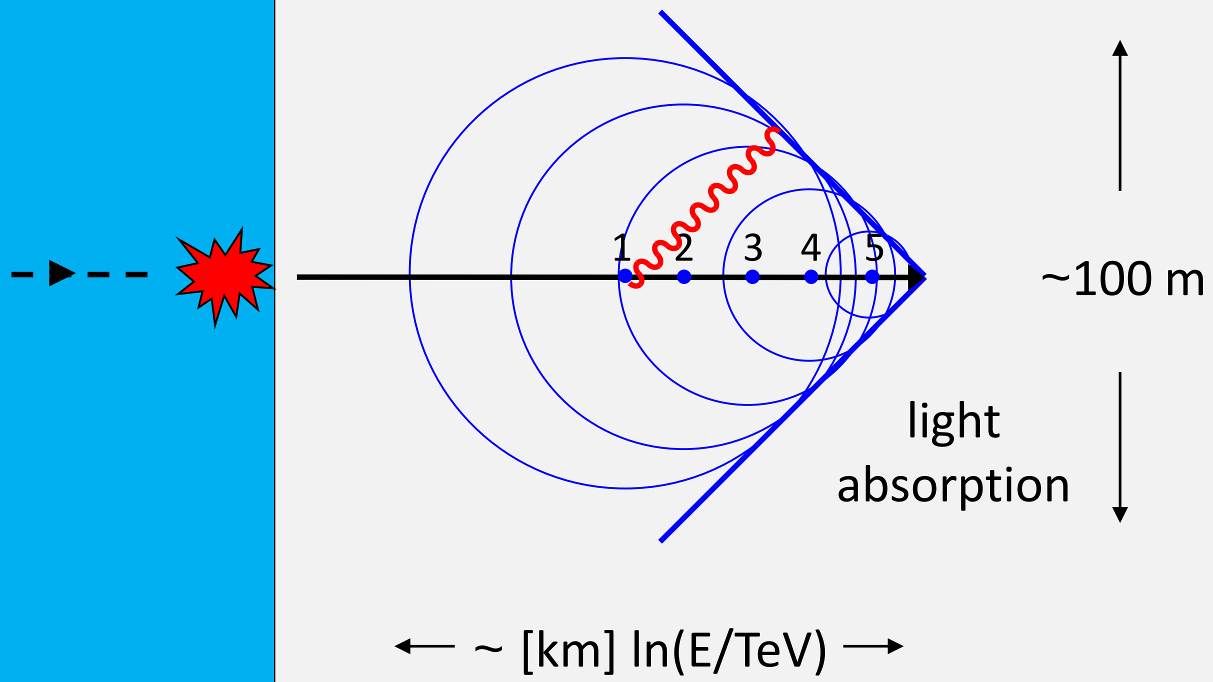
Markov (1960):
H_2O as target



1. target mass
   overcome small x-section
2. muon range
   good angular resolution
3. transparency
   sparse detector

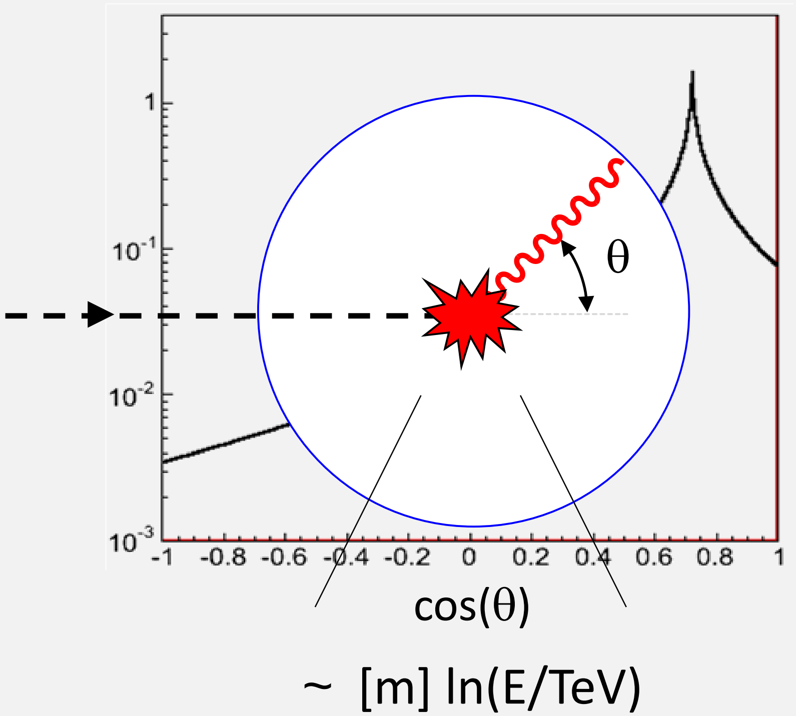
Neutrino detection

muon neutrino



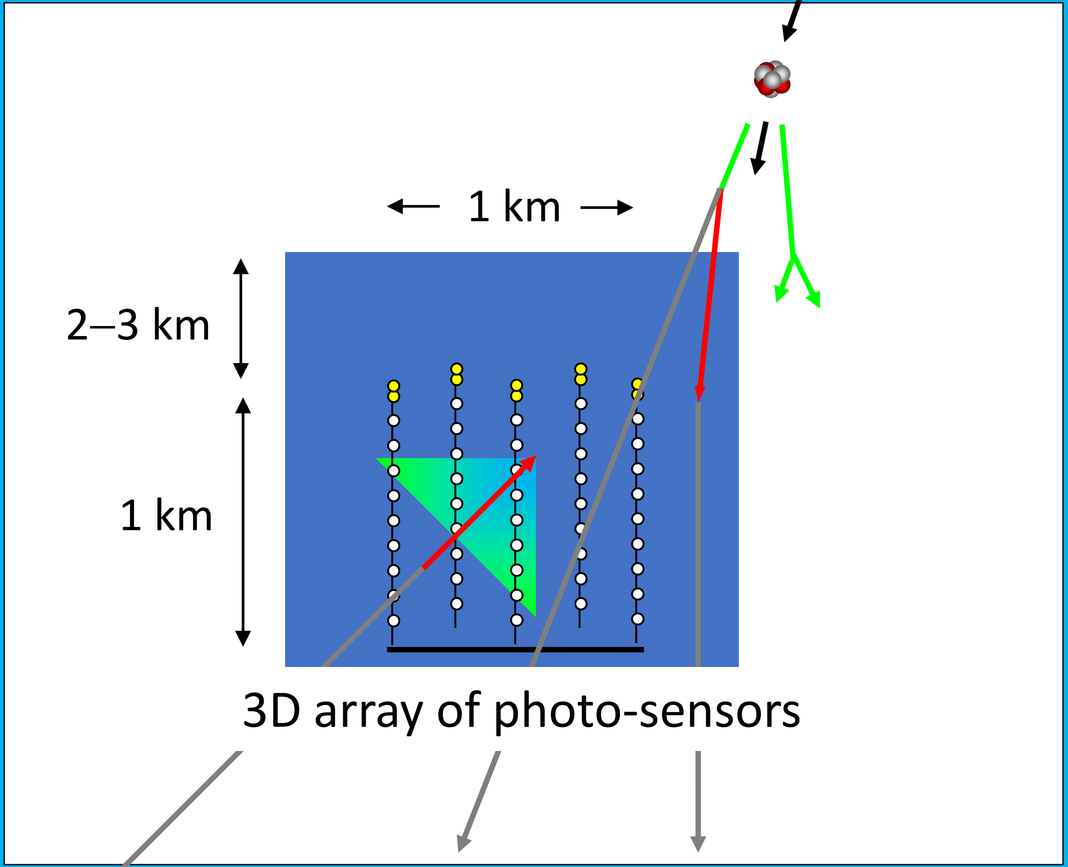
muon energy loss

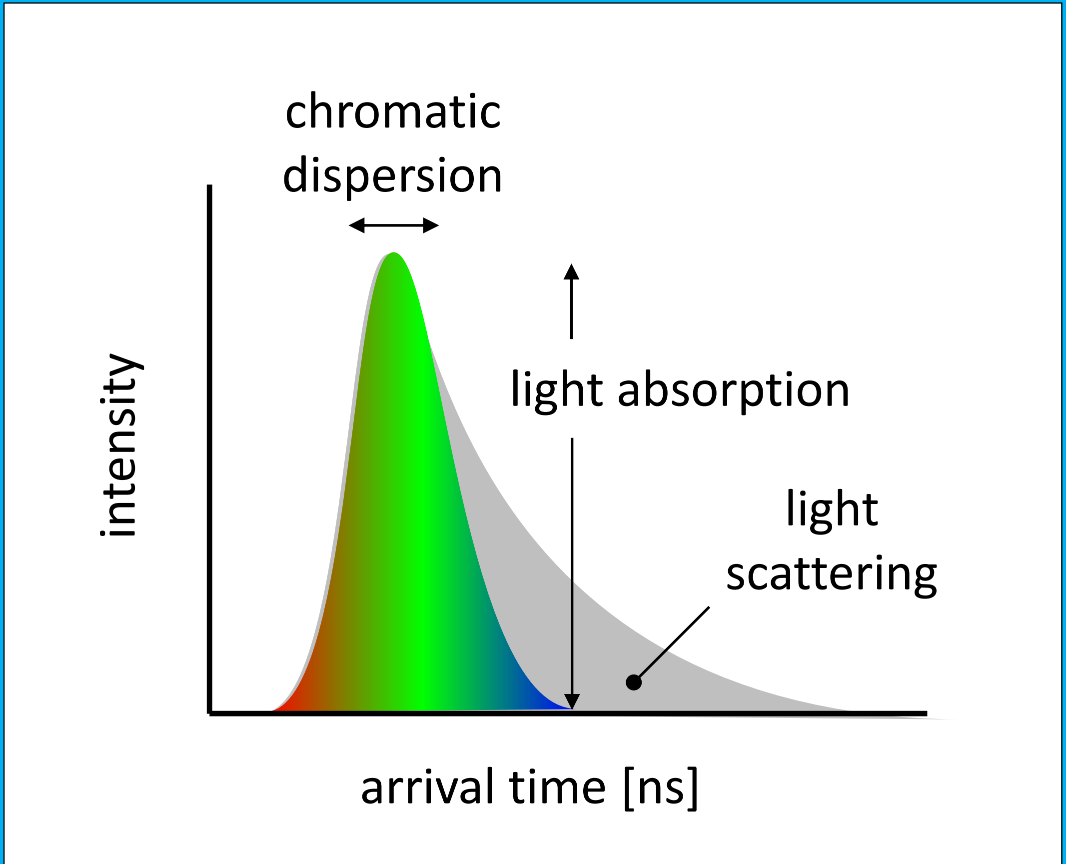
electron neutrino

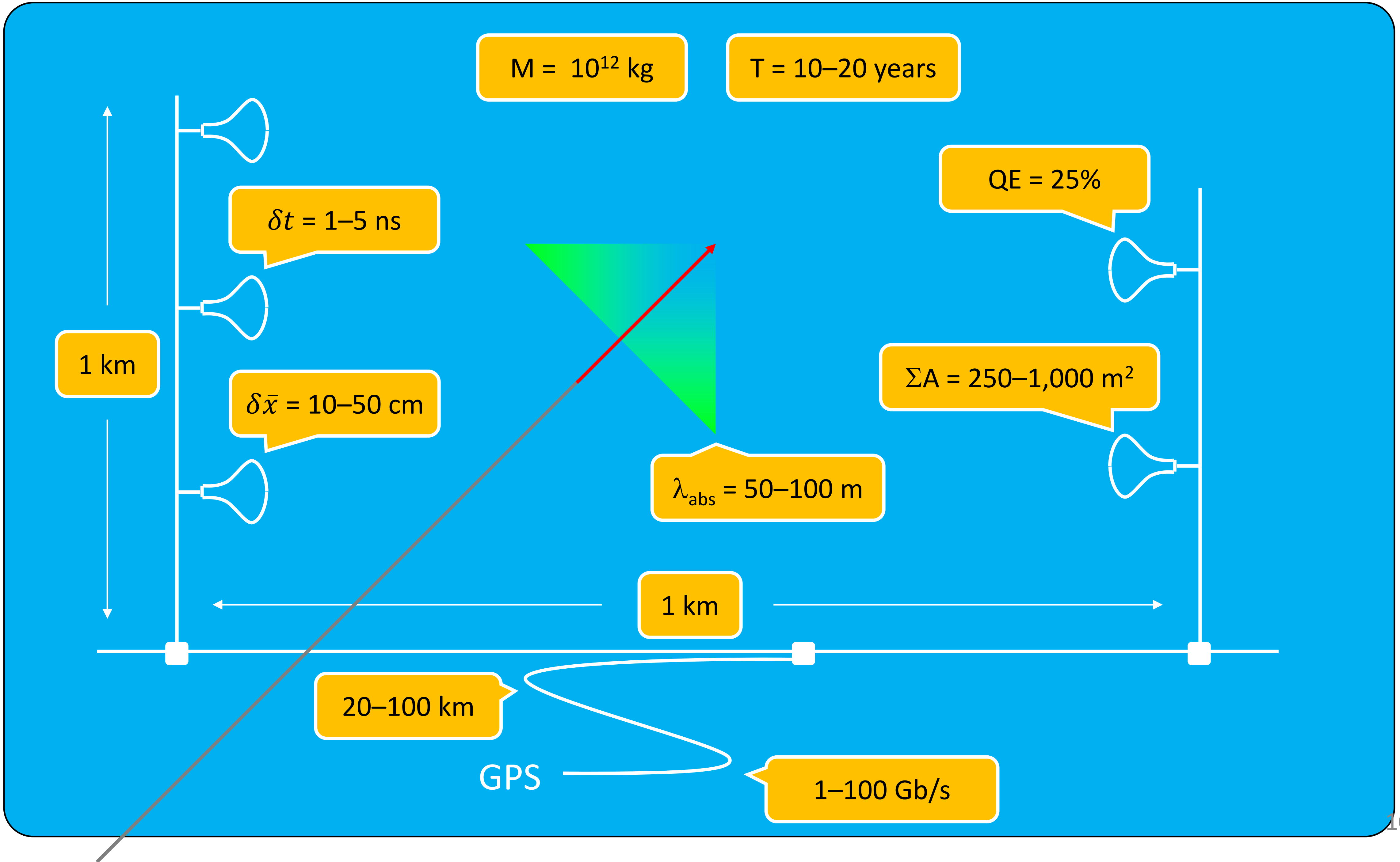


radiation length

Neutrino detector







M = 10^{12} kg
T = 10–20 years
QE = 25%
δt = 1–5 ns
1 km
$\delta\bar{x}$ = 10–50 cm
ΣA = 250–1,000 m^2
λ_{abs} = 50–100 m
1 km
20–100 km
GPS
1–100 Gb/s

$M = 10^{12}$ kg

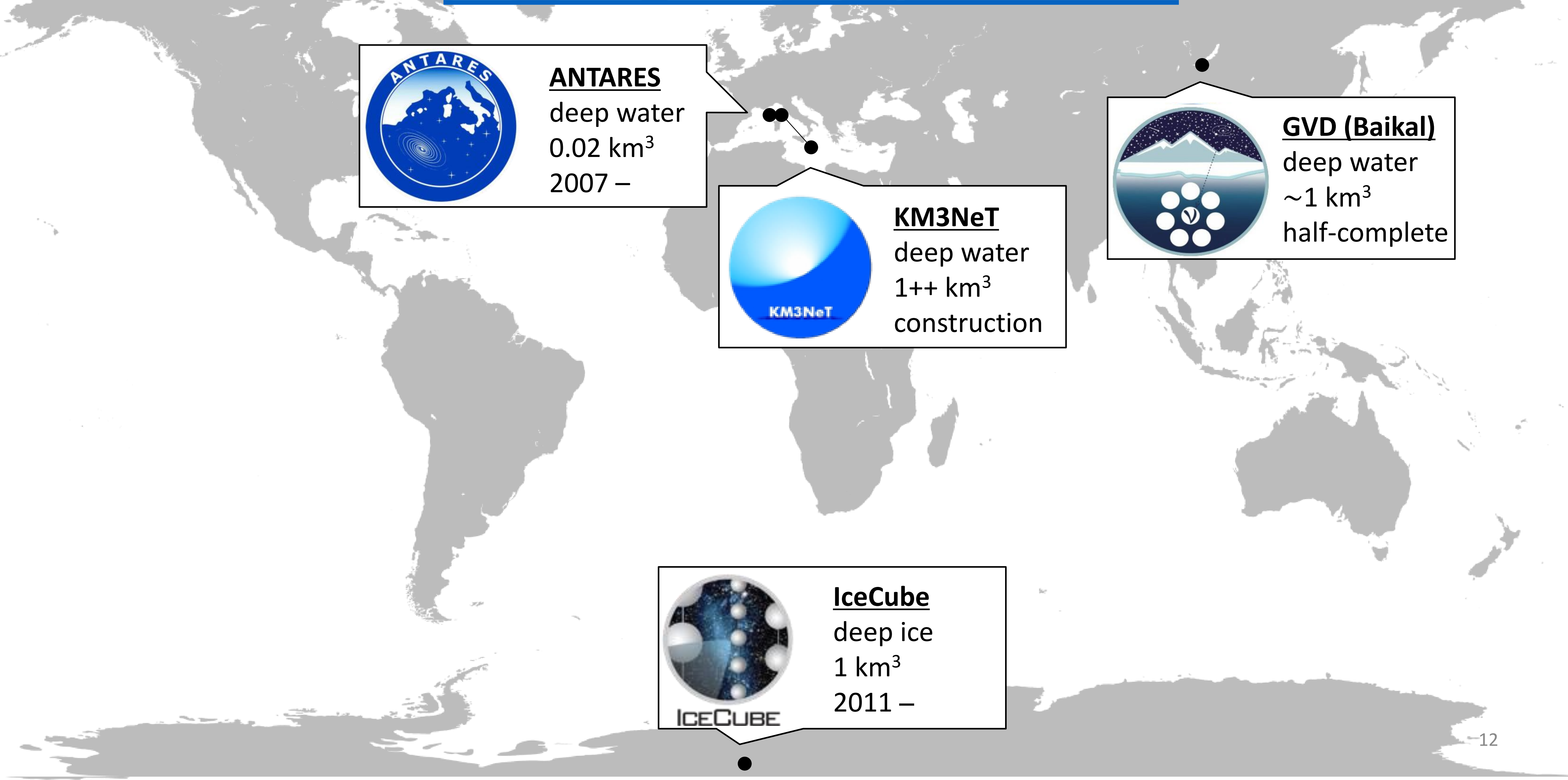
$\lambda_{abs} = 50–100$ m

$\$ \ll 10^{-4}$ €/kg

Artic ice

deep sea

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	0.05 deg / 1.5 deg
Noise	extremely low	medium	medium	
PMT size (QE)	10” (25%)	10” (35%)	10” (20%)	3” (30%)

Photo-sensors: 10” → 3” PMTs

- timing ≤ 2.5 ns
- QE ≥ 25–30%
- collection efficiency ≥ 90%
- photon counting purity 100% (by hits, up to 7)
- price/cm^2 ≤ 10” PMT

more pixels
=
better physics

ETEL D792

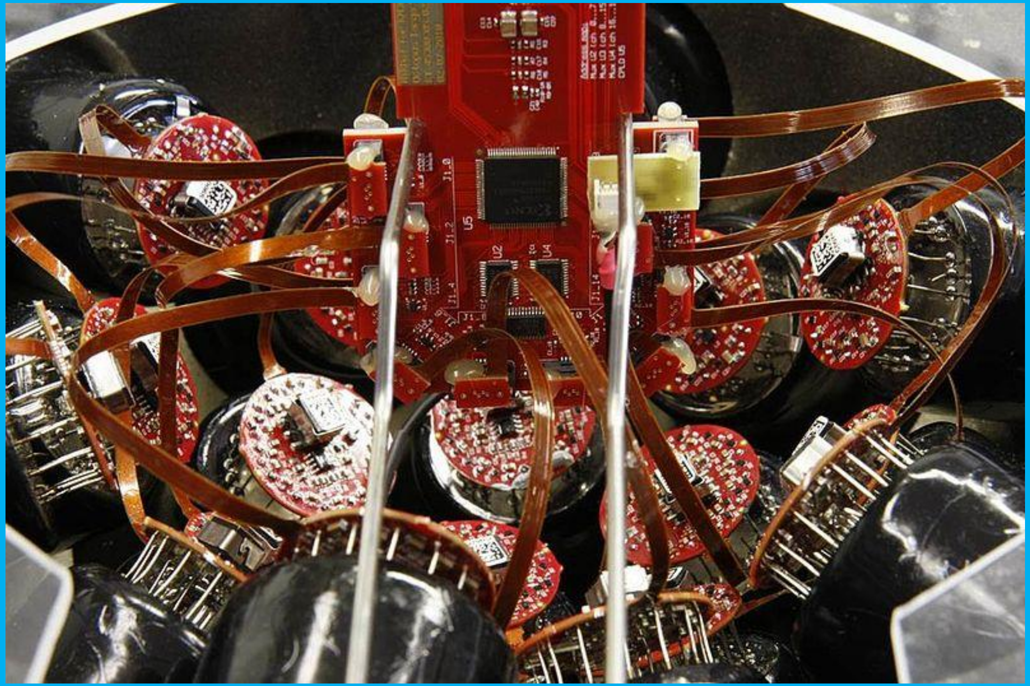
Hamamatsu R12199

HZC XP53B20

Front-end electronics

IceCube

KM3NeT



custom low-power HV, TDC and ADC

Housing

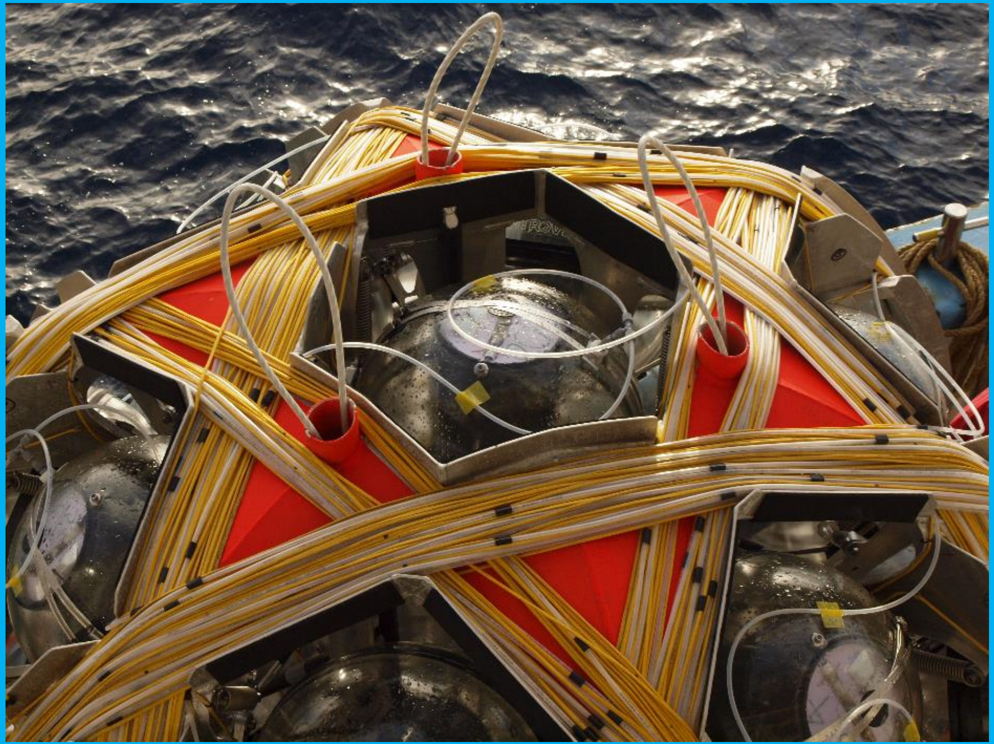
commercial floatation devices

Cabling

IceCube

commercial

KM3NeT



custom → commercial

Civil engineering (1/3)

IceCube:

- hole drilling in ice (custom)
- shore station (custom)

Civil engineering (2/3)

GVD (Baikal):

- deployment from ice surface (custom)
- shore station (commercial)

Civil engineering (3/3)

KM3NeT:

- deployment with surface vessel (commercial)
- shore station (commercial)

Clock – DAQ – Computing

	IceCube	GVD, Baikal	KM3NeT
clock	custom	custom + White-Rabbit	White-Rabbit
data transfer	wire	wire	fibre
Tier-0	custom	custom	CPU (100)
Tier-1+2	?	CPU (450)	CPU (500)

APPEC roadmap (to be published)

"Computing resources are relatively modest …"

"Filtering of the rare neutrino signal from the high background … poses challenges"

"… machine learning and use of GPUs can improve the science output"

Present

- Era of multi-messenger astronomy
  - EM-radiation – cosmic rays – neutrinos – gravitational waves
  - alerts (from astronomy)
    - point telescopes world-wide to astrophysical event in real time

- Fundamental particle physics with atmospheric and cosmic neutrinos
  - neutrino mass ordering
  - ν_τ appearance
  - sterile neutrinos, Lorentz invariance, non-standard interactions, …

Future (1/2)

- Benefit from serendipities
  - Earth and sea sciences
    - climate change
    - marine life (e.g. noise pollution)
    - tsunami warnings

- Explore alternative technologies for EeV neutrino detection
  - radio detection (e.g. GRAND, RNO)
  - acoustics neutrino detection (e.g. KM3NeT)

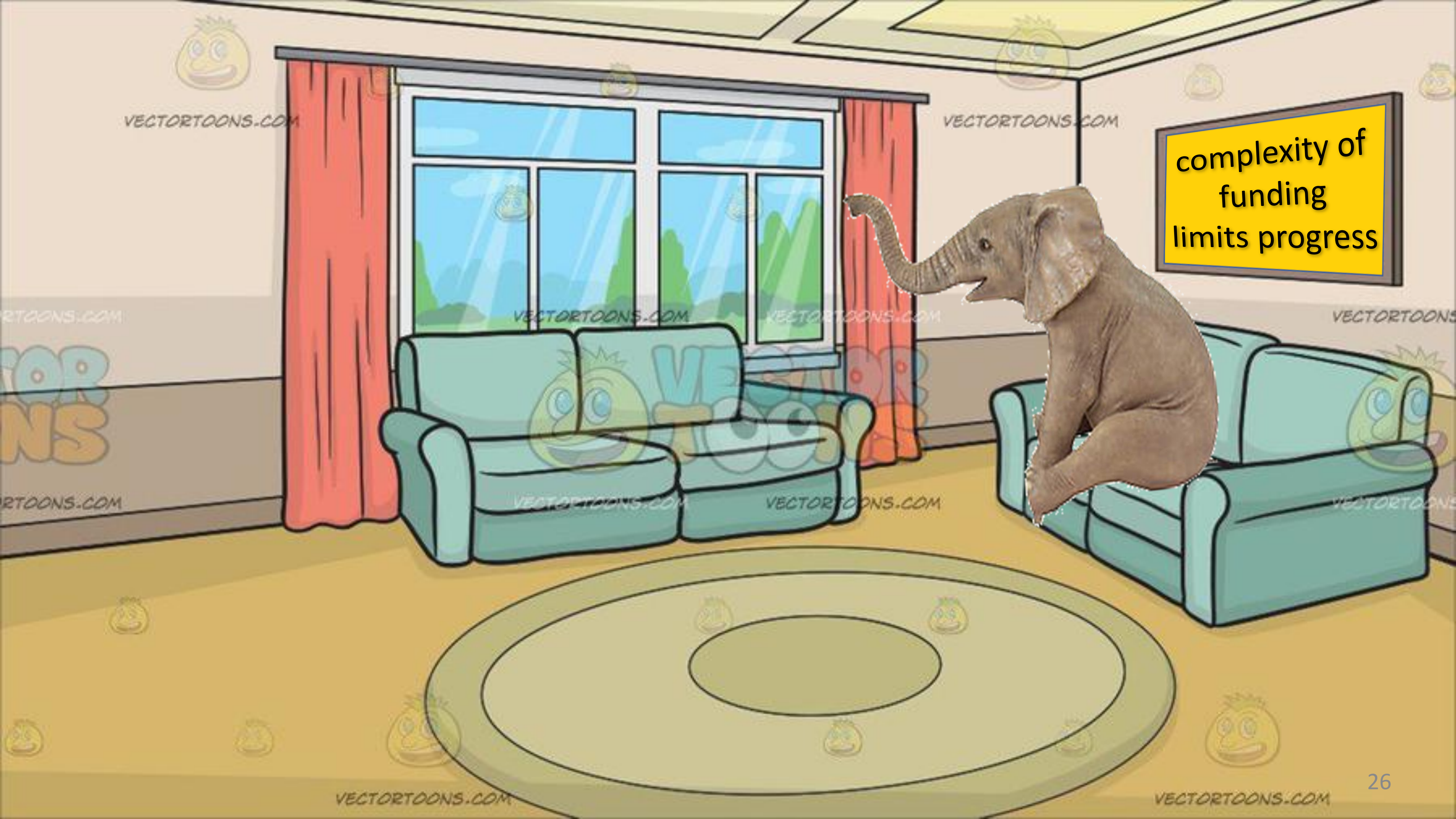
Future (2/2)

- Make cosmic-ray detector on bottom of sea
  - 2D-array à la KM3NeT "*Pierre Auger in the North*"
    - involvement of offshore industry

- Make long baseline neutrino experiment
  - δ_{CP} measurement with [tagged] neutrino beam from Protvino to KM3NeT
    - ps-tracking detectors in decay tunnel

Summary & Outlook

- Technology for 10^{12} kg neutrino detectors now is affordable
  - standardise – maximise – capitalise
    - price photo-sensors important (high QE – low dark count)
    - costs civil engineering significant but much less than excavation
- Global Neutrino Network (GNN)
  - [European] astro-particle neutrino experiments could benefit from interaction with particle physics centres, in particular CERN
    - know-how, reviews, collaboration
- Lone baseline neutrino and/or cosmic-ray experiments
  - use & push technology to limit


complexity of
funding
limits progress