Recent highlights of Astrophysical neutrino detection from GeV to EeV

Lu Lu

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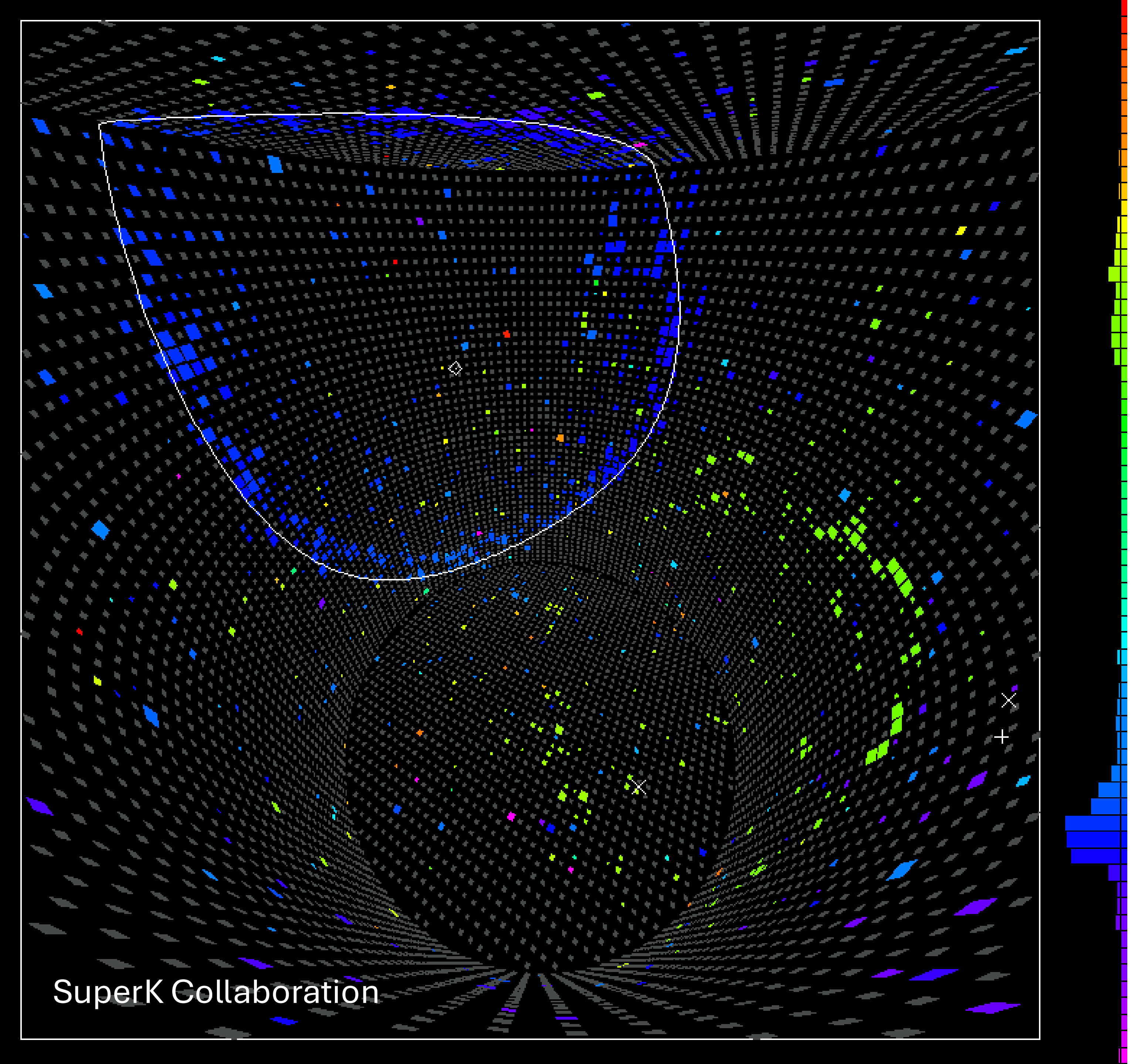
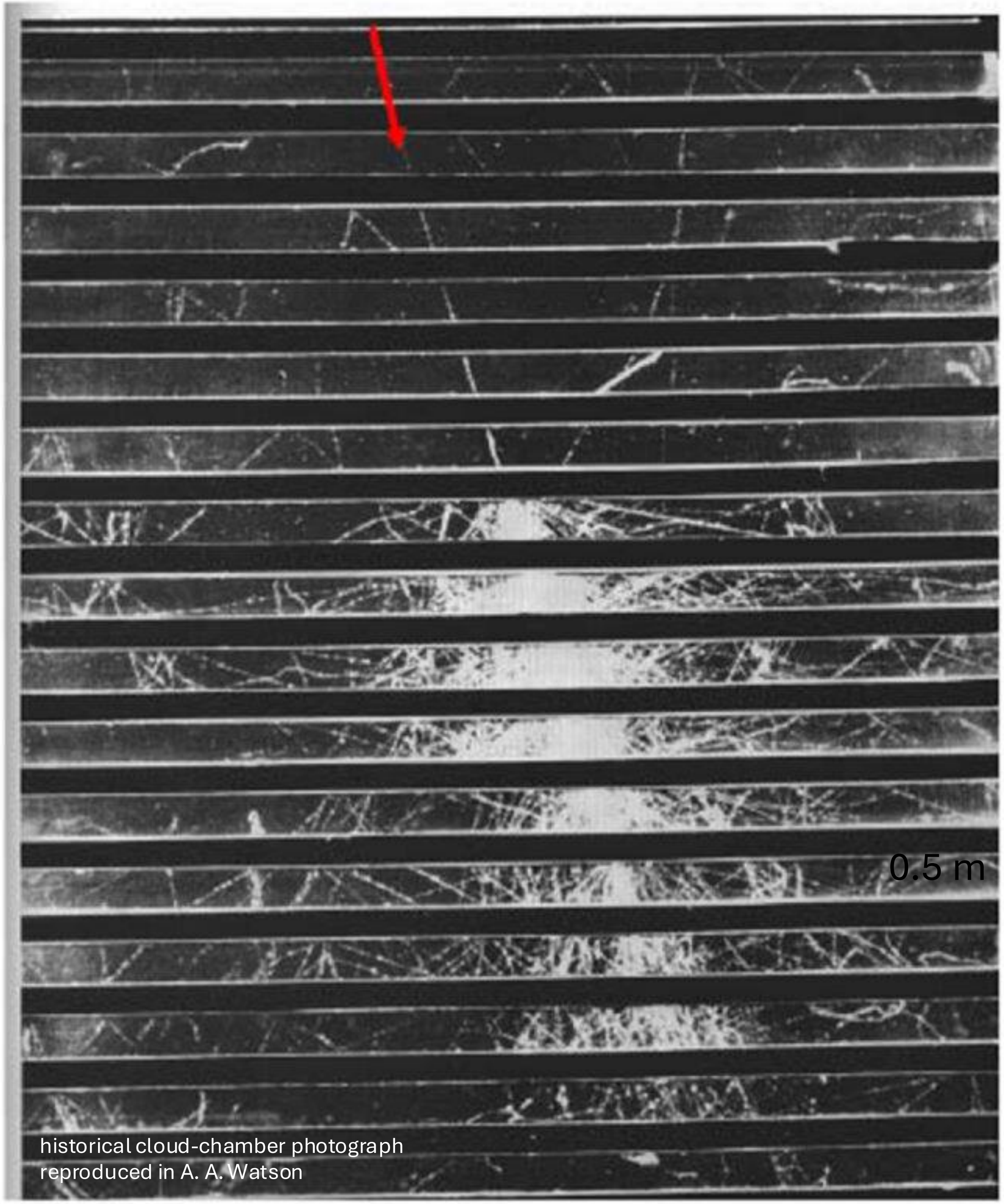


481 MeV muon neutrino from SuperK

- 394 MeV muon + Michel electron
- Cherenkov rings
- 50 tons of water
- Detector scale ~40 m

microscopic event seen by an instrument the size of a building



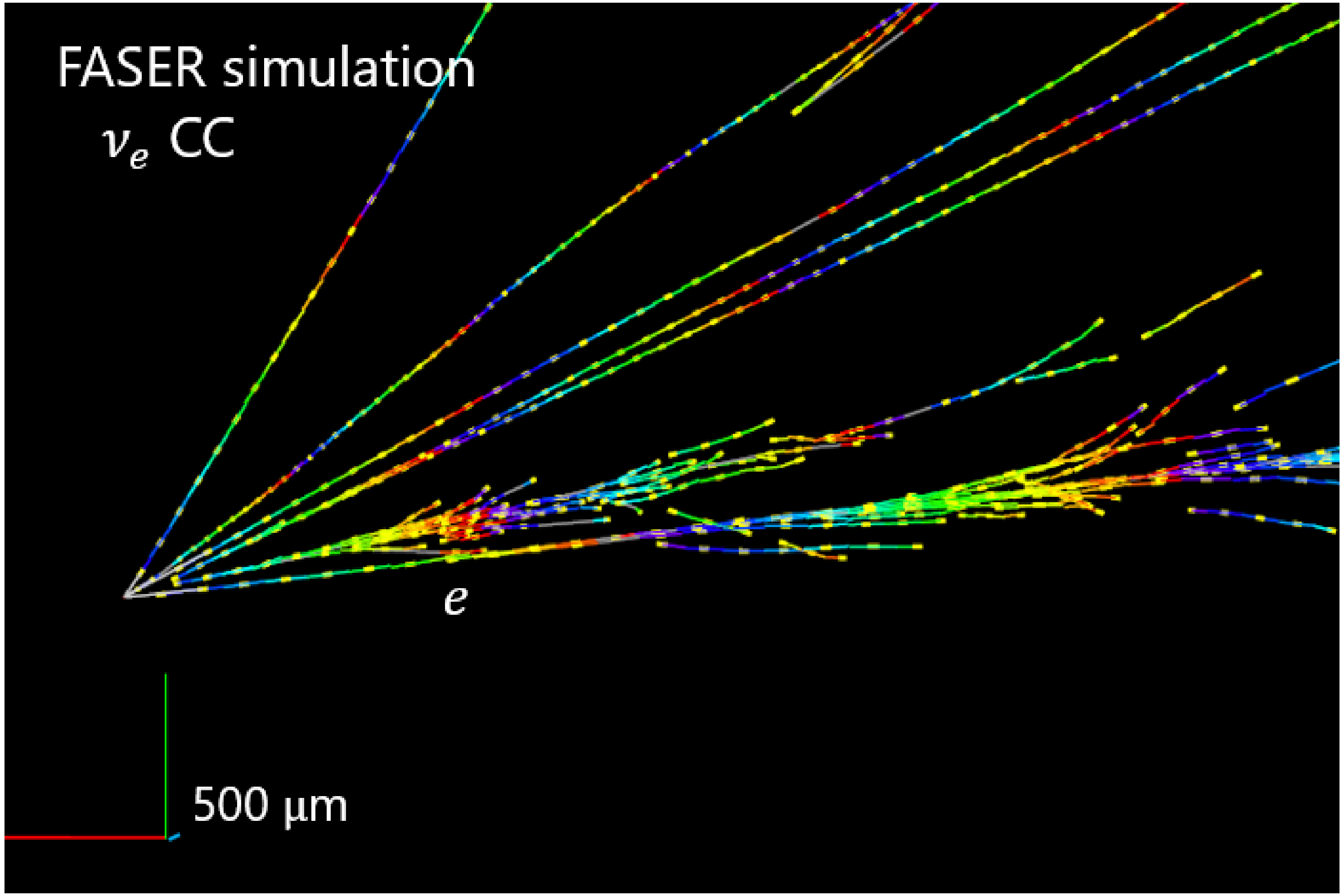
historical cloud-chamber photograph
reproduced in A. A. Watson

At 10 GeV, a proton shower seen in a cloud chamber

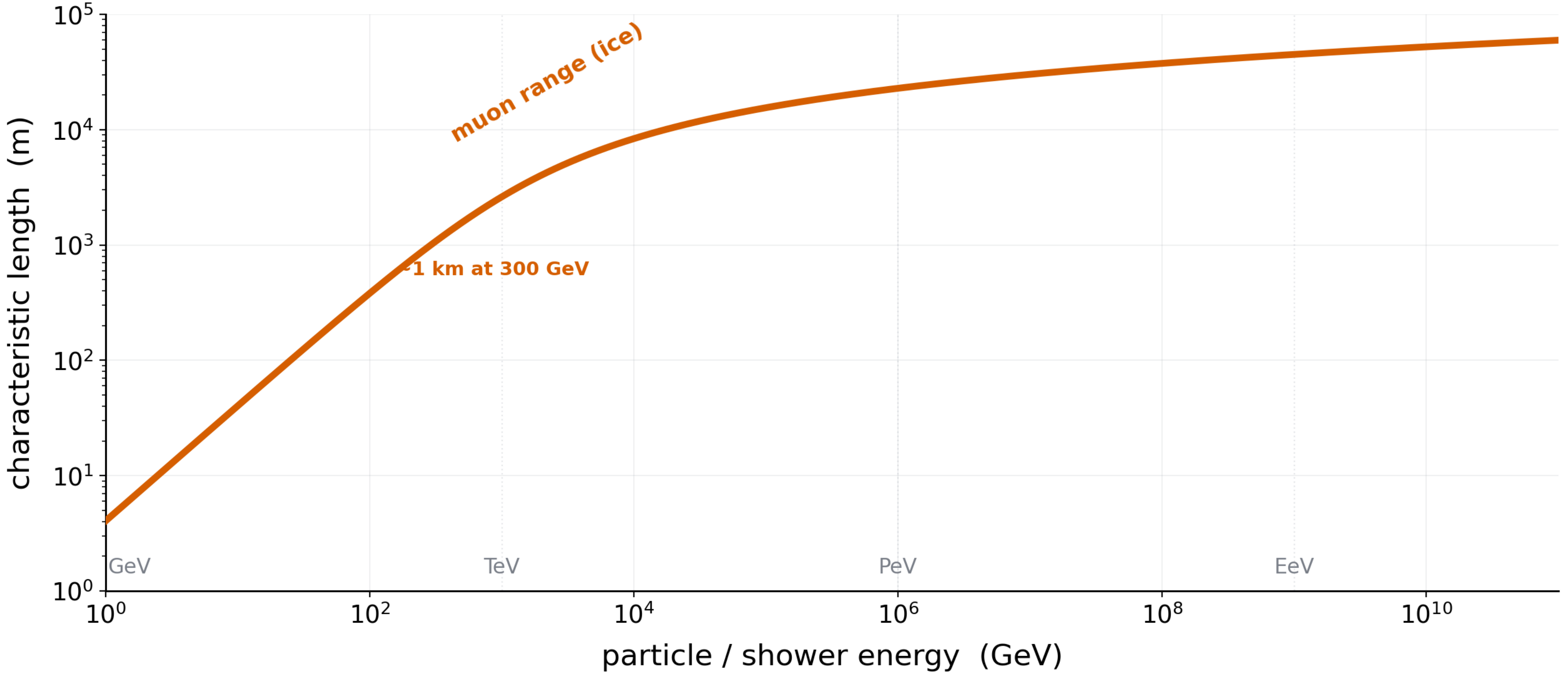
- Hadronic interactions create secondary particles and an extended cascade.
- Visible shower scale through the lead plate: ~0.5 m

The higher the energy, more particles are produced and more information can be learned about the event

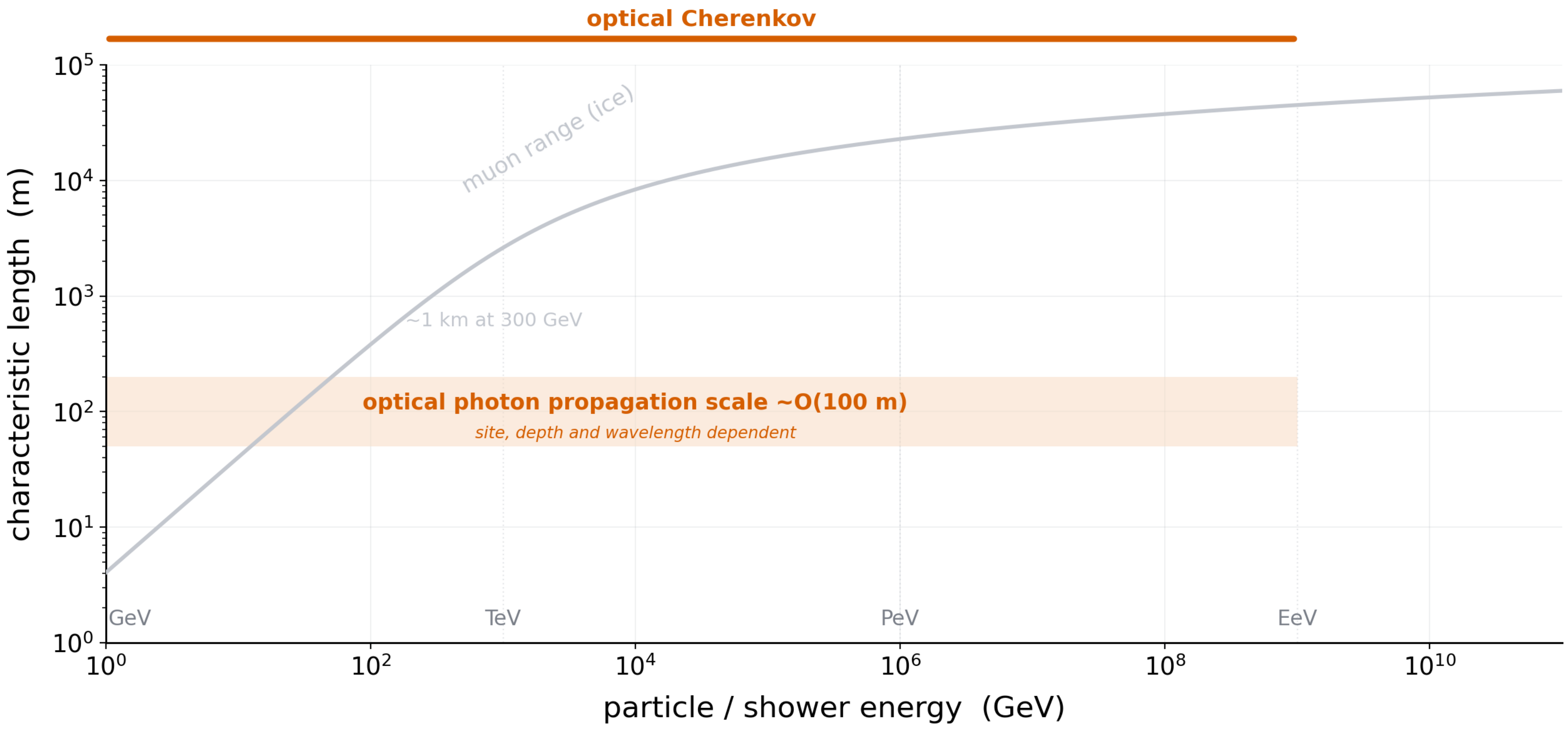
TeV neutrino in emulsion



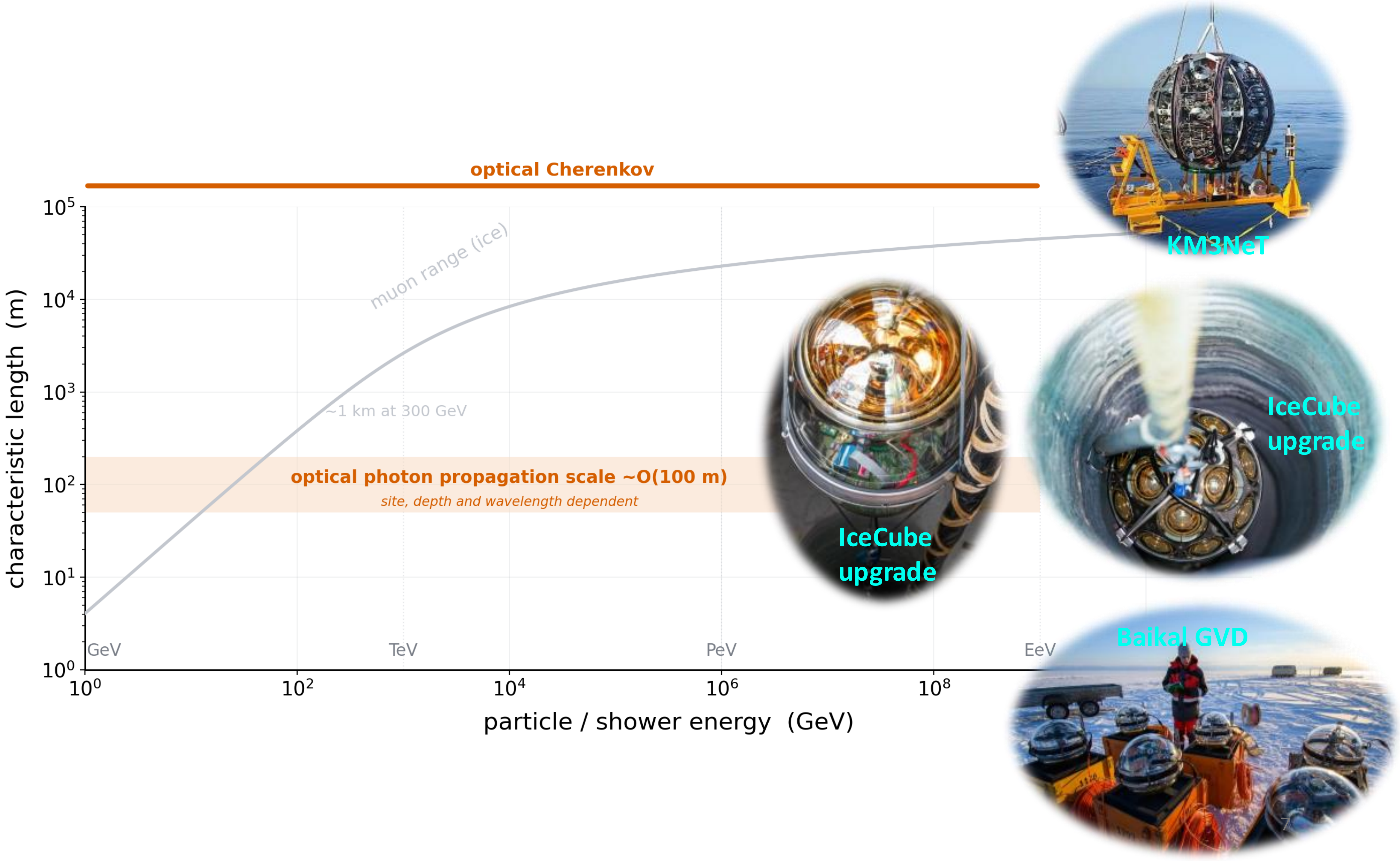
- Neutrinos from LHC
- TeV neutrino interaction reconstructed at micron scale
- High-energy neutrino events carry rich topological information



muon range (ice)
~1 km at 300 GeV
characteristic length (m)
particle / shower energy (GeV)
GeV
TeV
PeV
EeV
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^8
10^{10}



optical Cherenkov
muon range (ice)
~1 km at 300 GeV
optical photon propagation scale ~O(100 m)
site, depth and wavelength dependent
characteristic length (m)
particle / shower energy (GeV)
GeV
TeV
PeV
EeV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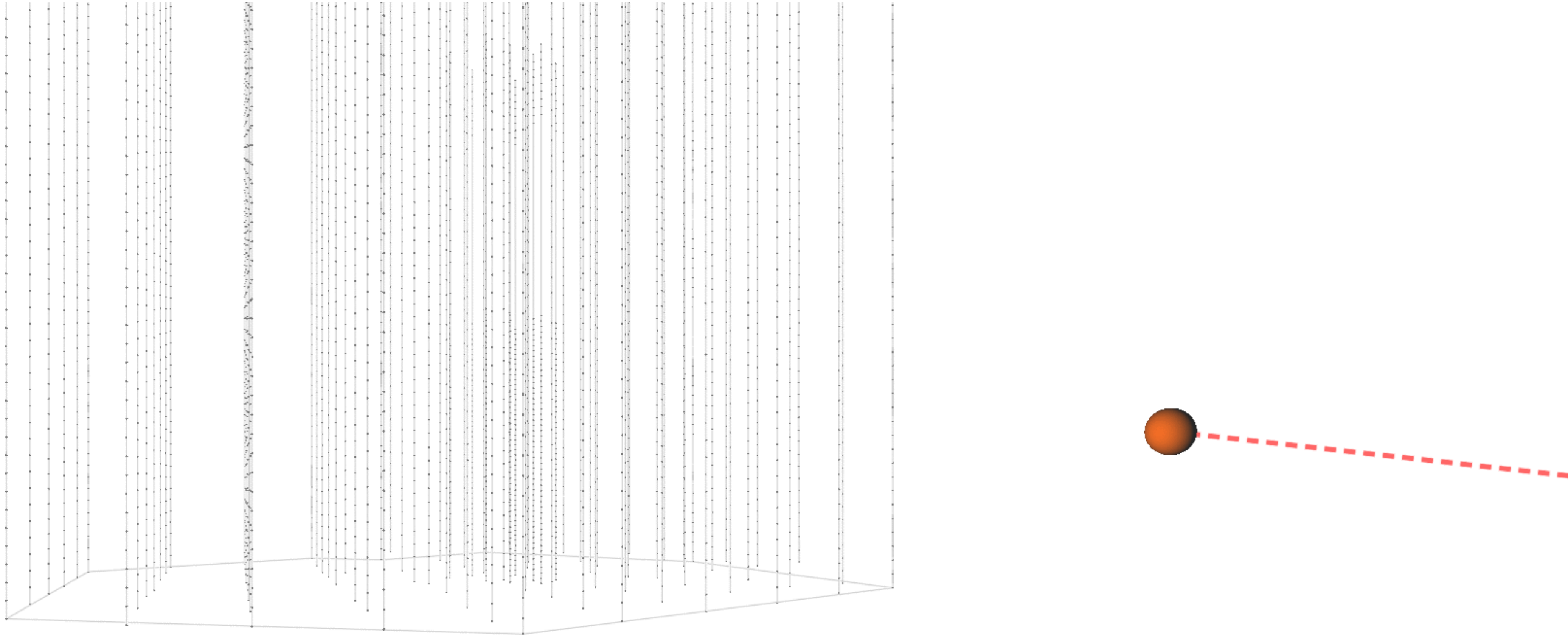
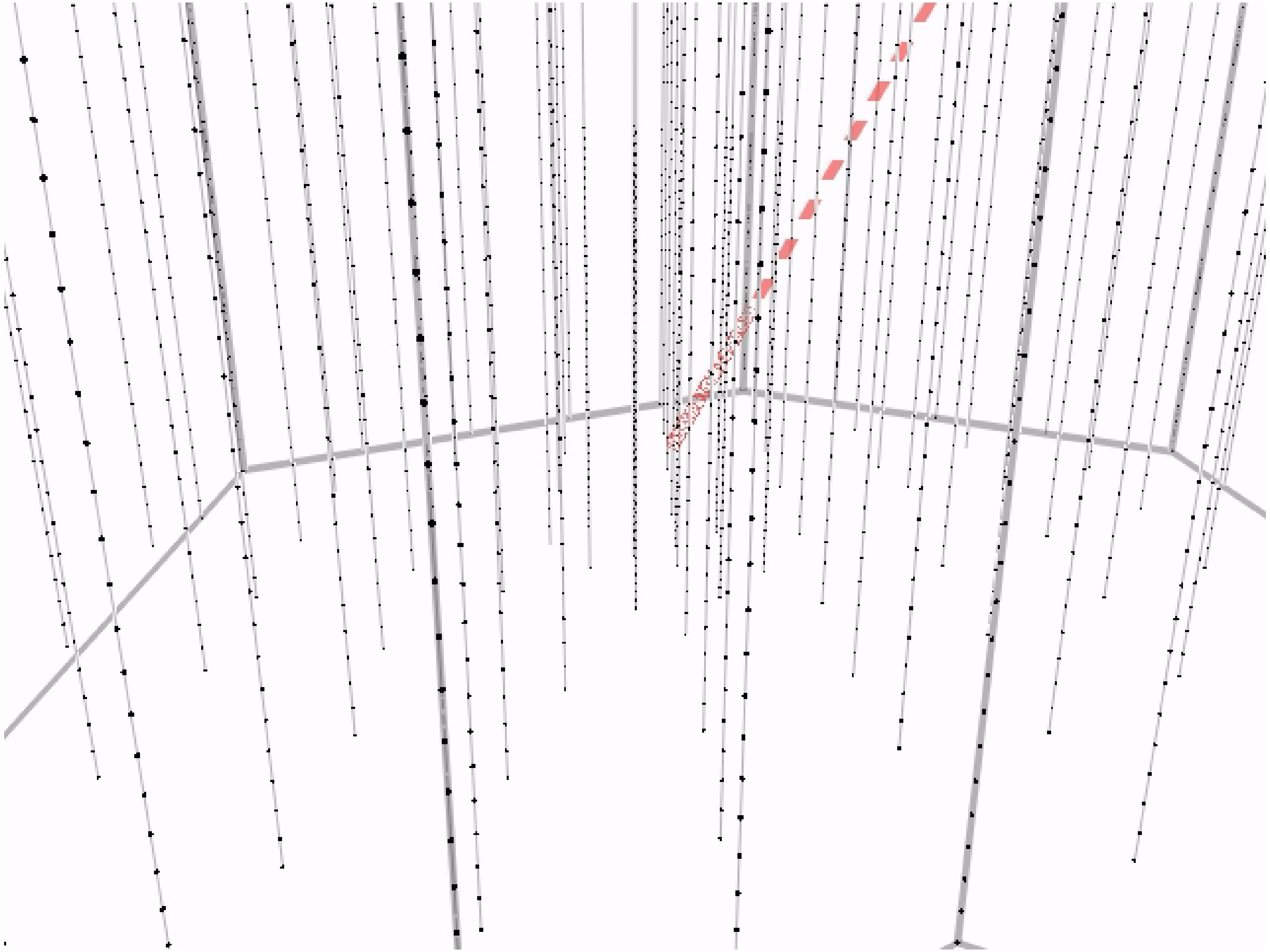
10^8
KM3NeT
IceCube upgrade
IceCube upgrade
Baikal GVD

Example: high-energy ν_μ



A 200 TeV muon neutrino simulation from the direction of 170922A

Example: high-energy ν_τ



KM3NeT: A Growing Array

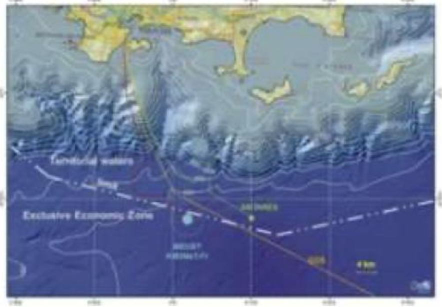
ARCA (1 GTon)

Astroparticle Research
with Cosmics in the Abyss

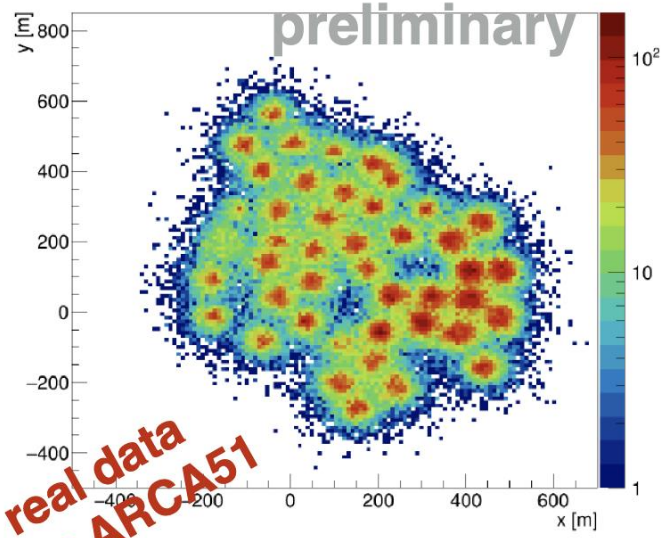
3500 m depth,
offshore Sicily

ORCA (6 MTon)

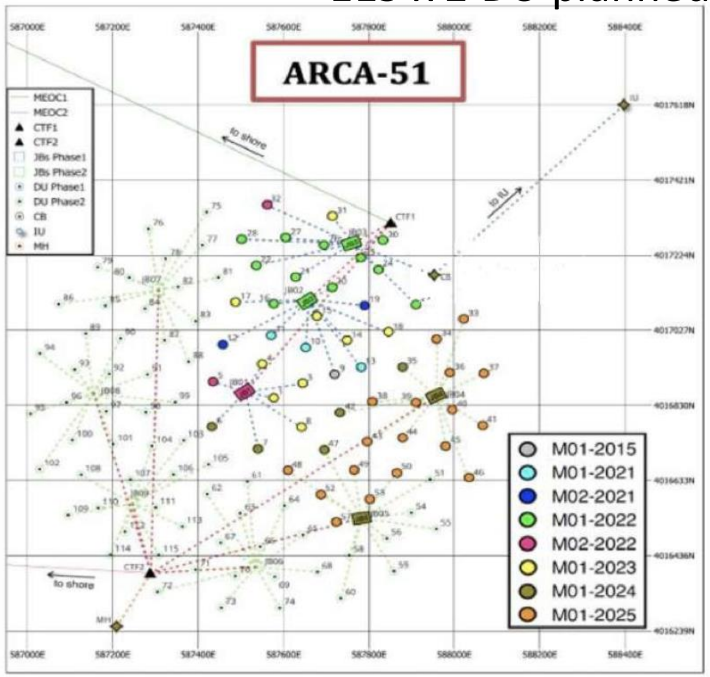
Oscillation Research
with Cosmics in the Abyss



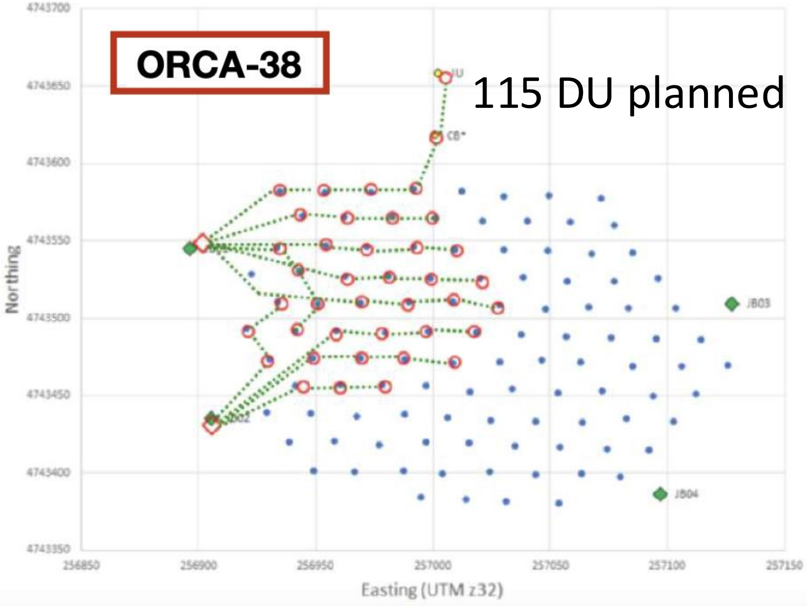
2500 m depth,
offshore Toulon



115 x 2 DU planned



115 DU planned



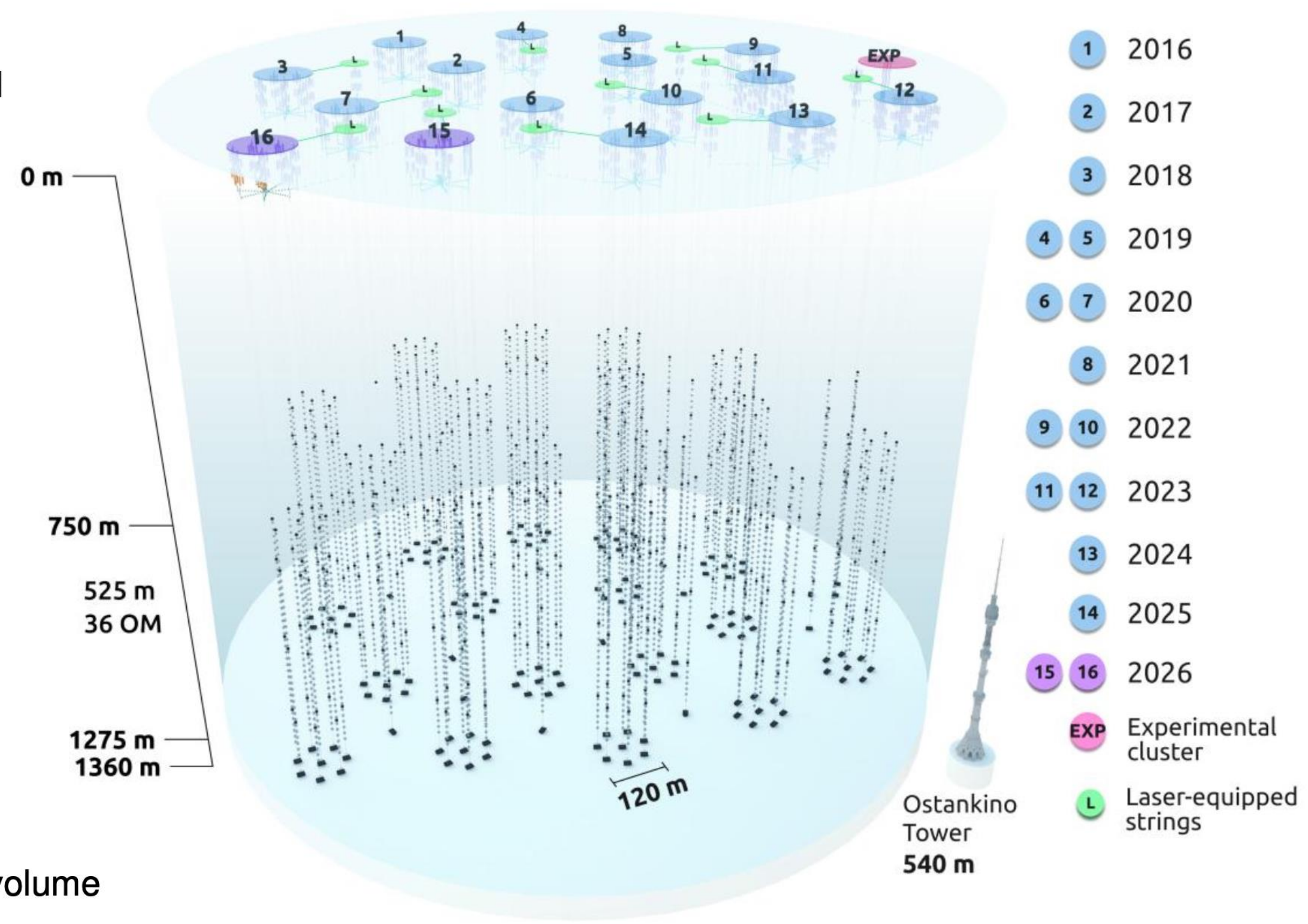
Baikal-GVD: steadily towards to 1 km^3

After the 2026 deployment campaign the detector consists of 135 vertical strings arranged into 16 independent detectors - **clusters**

- 4896 optical modules (OM) in total
- 0.8 km^3 detection volume (1 PeV cascades)

Baikal-GVD cluster:

- 8 regular strings, 525 m are instrumented with OMs
- 60m cluster radius
- 11 inter-cluster string carrying lasers, 8 of which are instrumented with OMs
- Cluster has its own control, trigger and readout systems

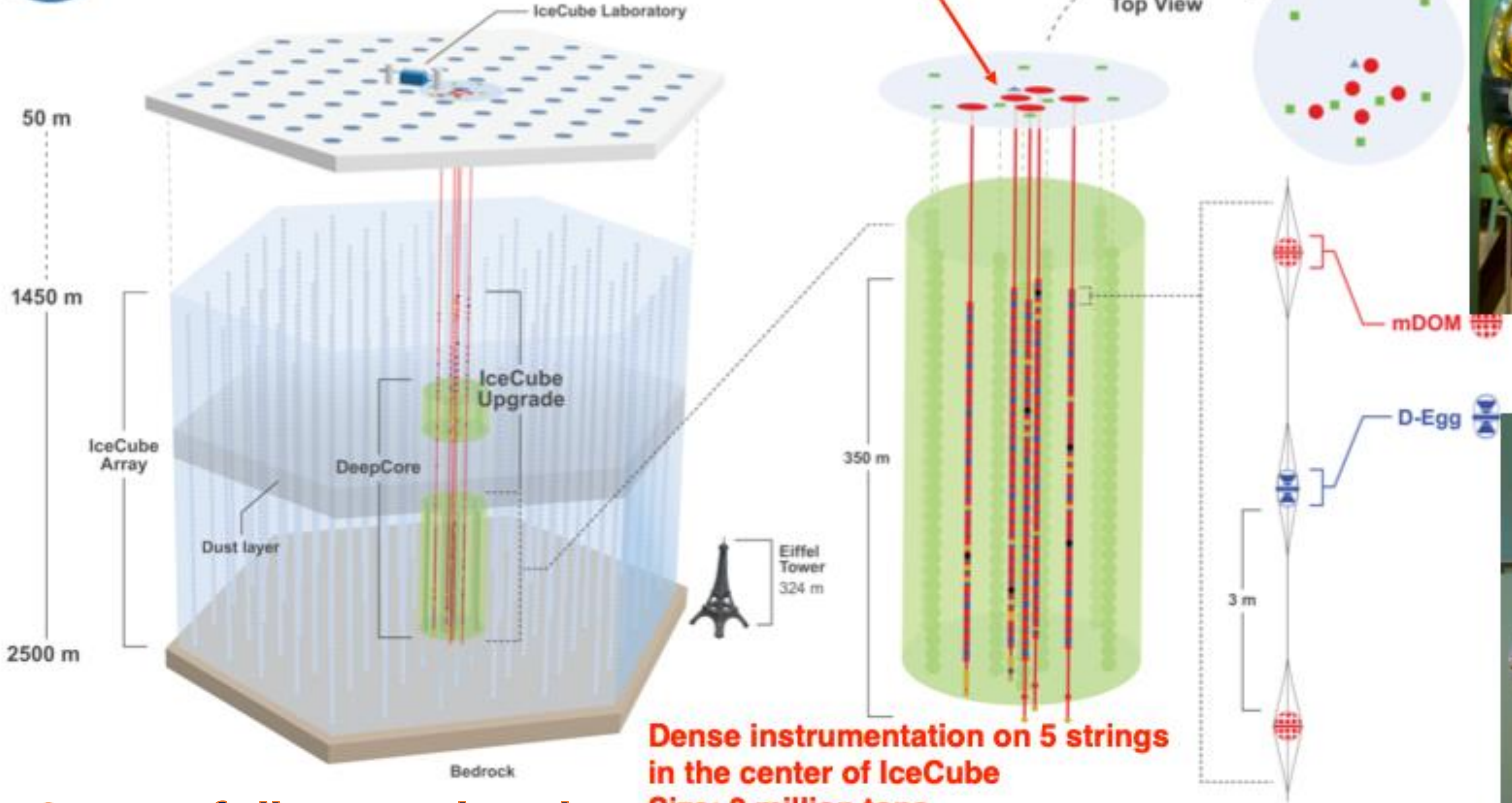


In the next 2-3 years it is planned to expand the detector to ~1 km^3 detector volume employing ~6000 OMs

Albrecht Karle, SCAR 2026

IceCube Upgrade

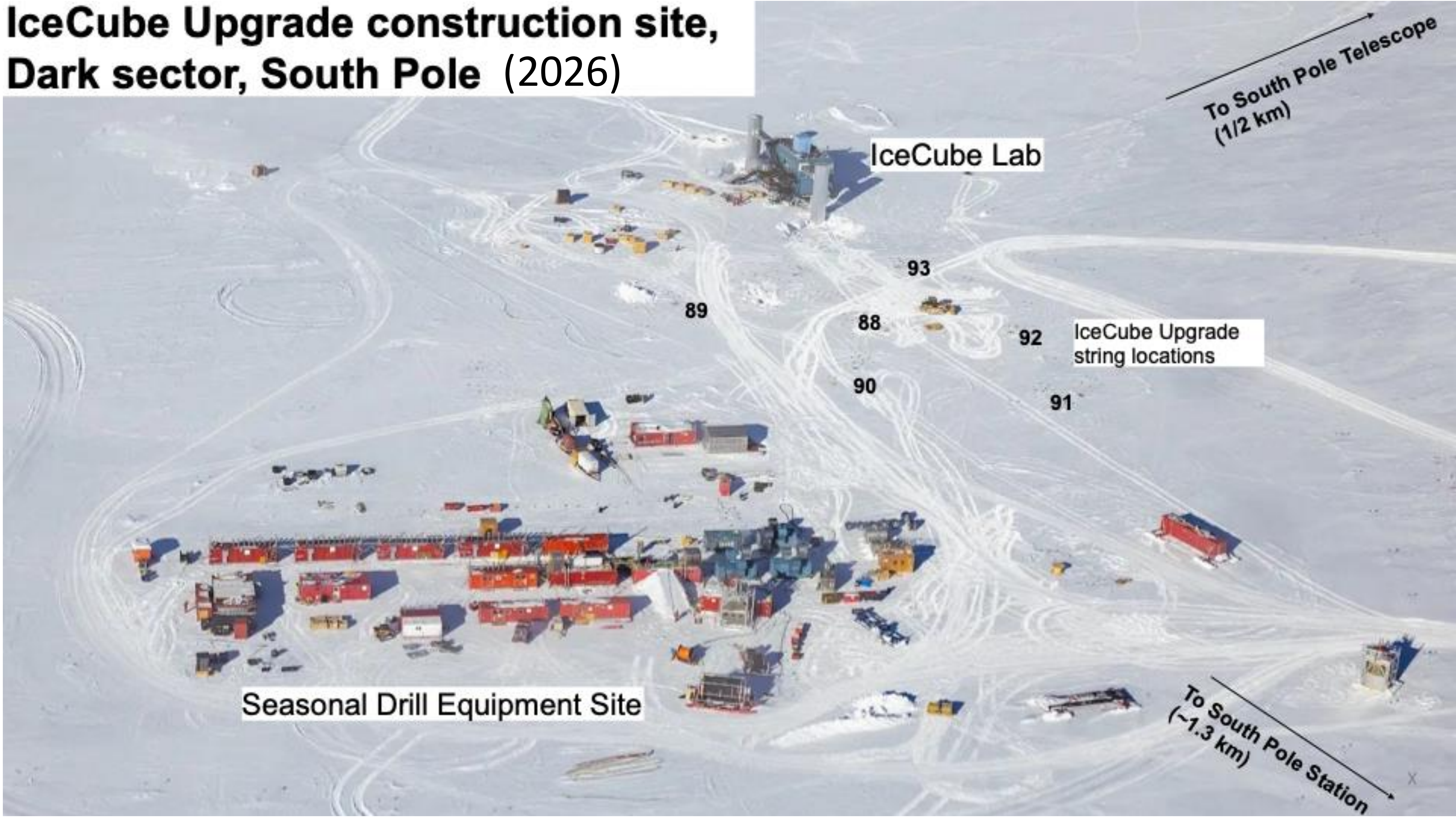
Upgrade sensors strings

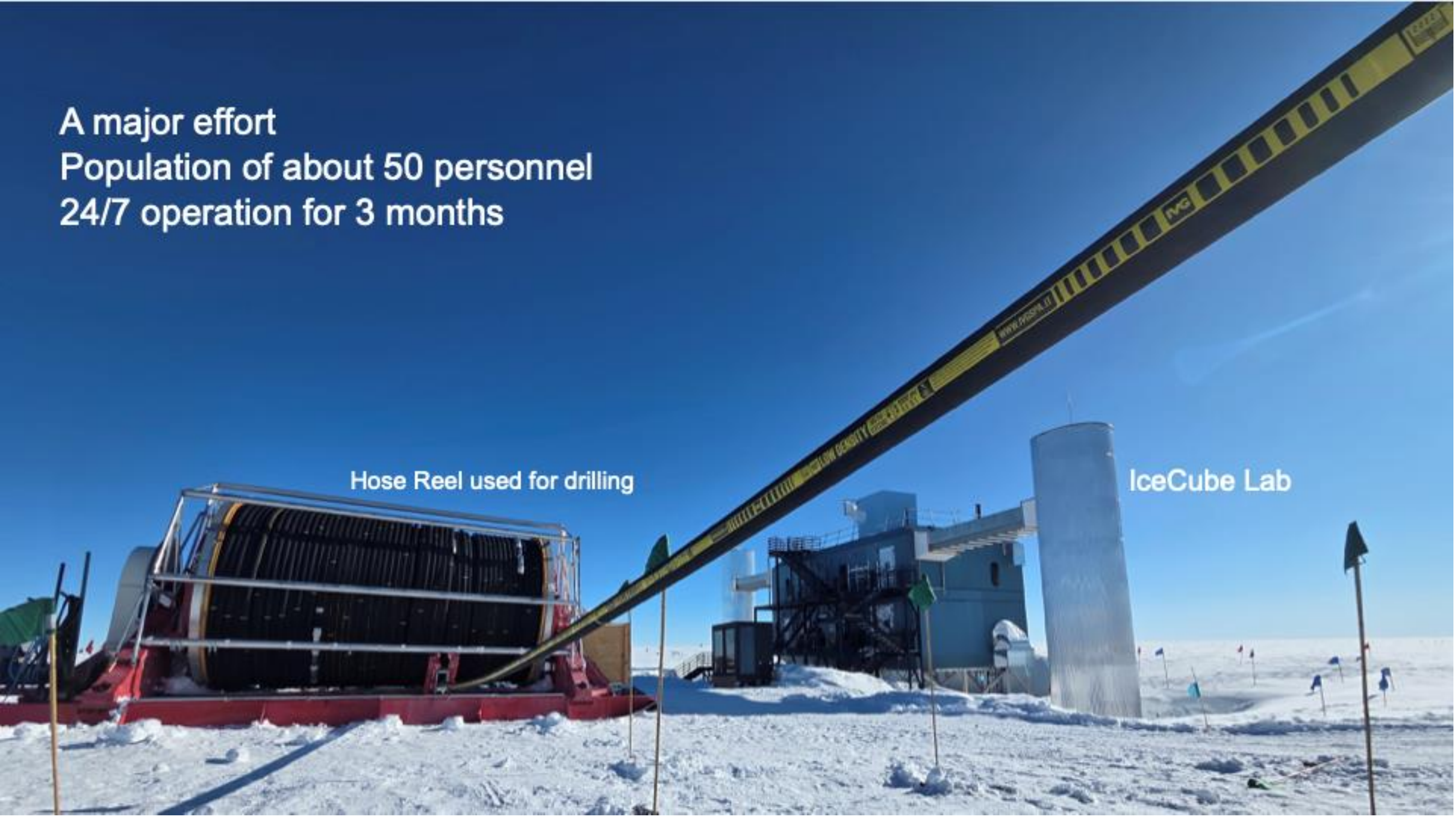


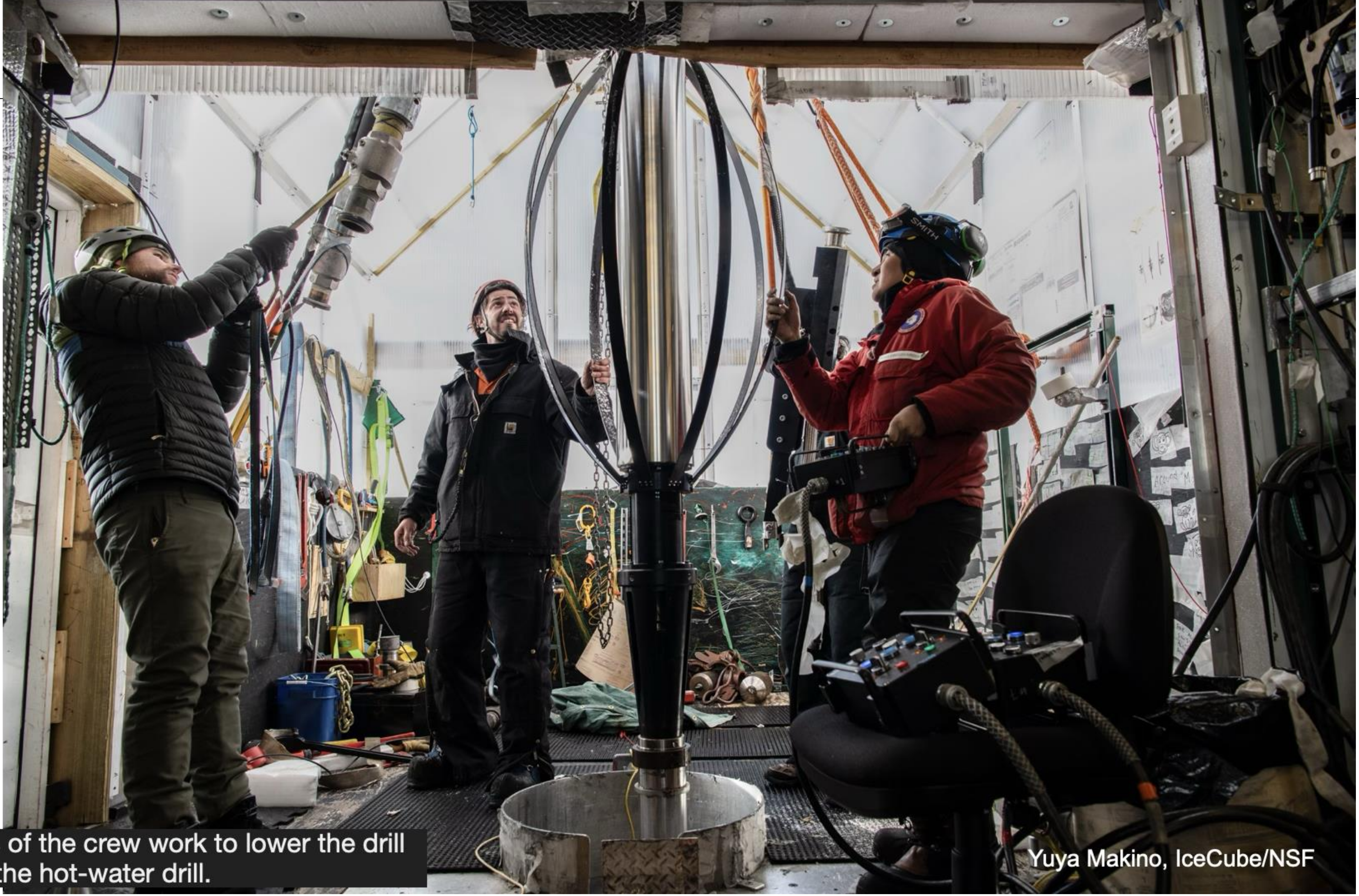
Dense instrumentation on 5 strings in the center of IceCube
Size: 2 million tons
—> access to much lower energy neutrinos (GeV scale)

Successfully completed deployment in 2026!

IceCube Upgrade construction site, Dark sector, South Pole (2026)




A major effort
Population of about 50 personnel
24/7 operation for 3 months
Hose Reel used for drilling
IceCube Lab



Members of the crew work to lower the drill head for the hot-water drill.

Special instruments for calibration and interdisciplinary science:

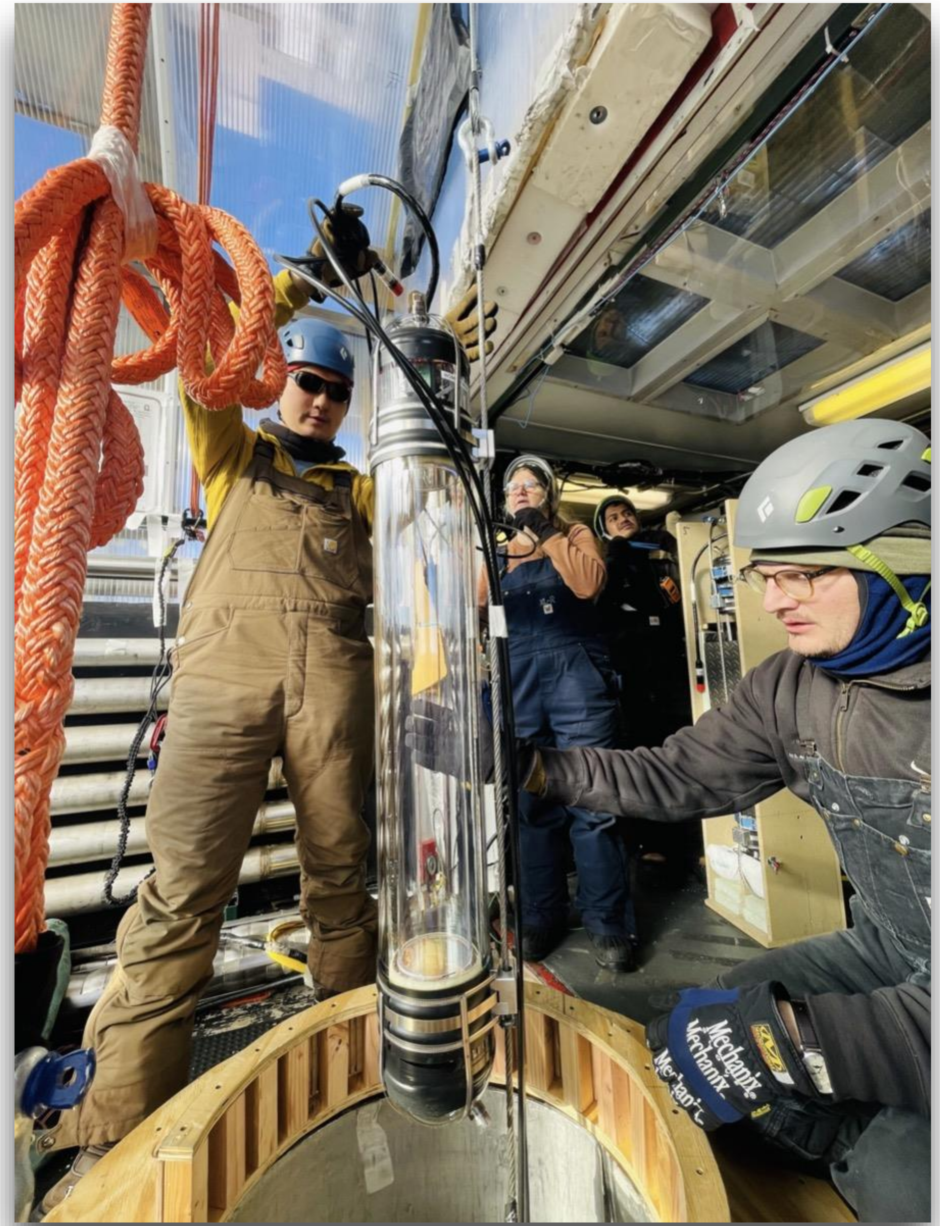
Seismometers (coll w USGS)

Video cameras

Installation team

New sensor prototype

505 optical modules were successfully deployed last austral summer


Mechanix

Logistical Support

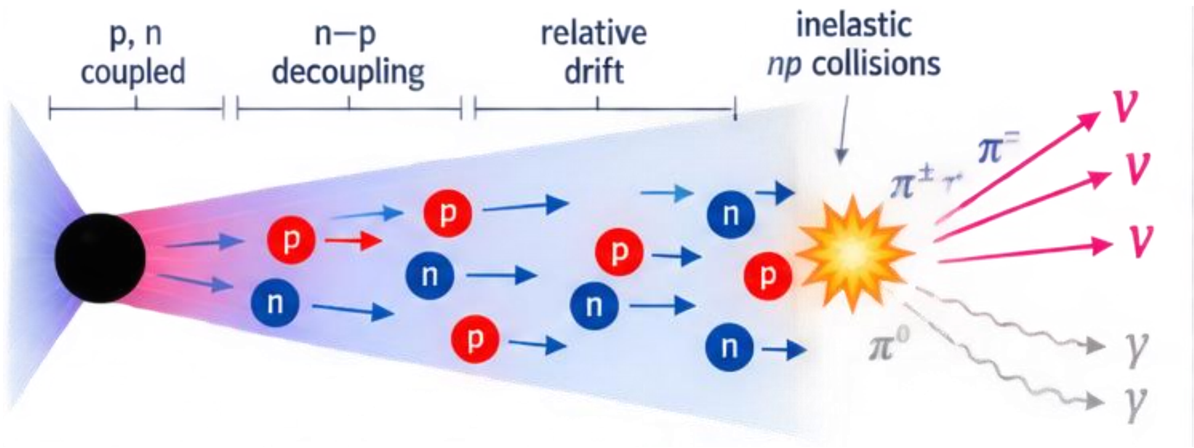
Received outstanding logistical Support by NSF's Office of Polar Programs, through the Antarctic Support Contractor. - Thank You!
IceCube recently received $52M funding support for operation and maintenance for the upcoming 5 years

Cables arrive with Traverse

GeV neutrinos: a new gateway to transient multi-messenger astrophysics

1 Quasithermal GeV neutrinos

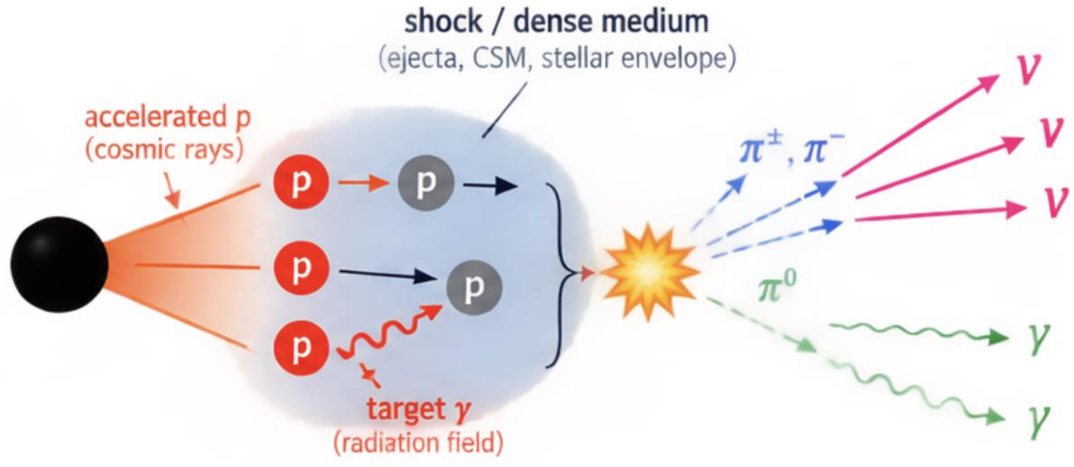
neutron-rich outflows - no nonthermal CR acceleration required



$$n + p \to n + p + \pi^{0,\pm} + \cdots$$

2 Nonthermal hadronic neutrinos

accelerated protons - pp / pγ interactions



$$p + p \to \pi^{\pm}, \pi^{0} + \cdots$$

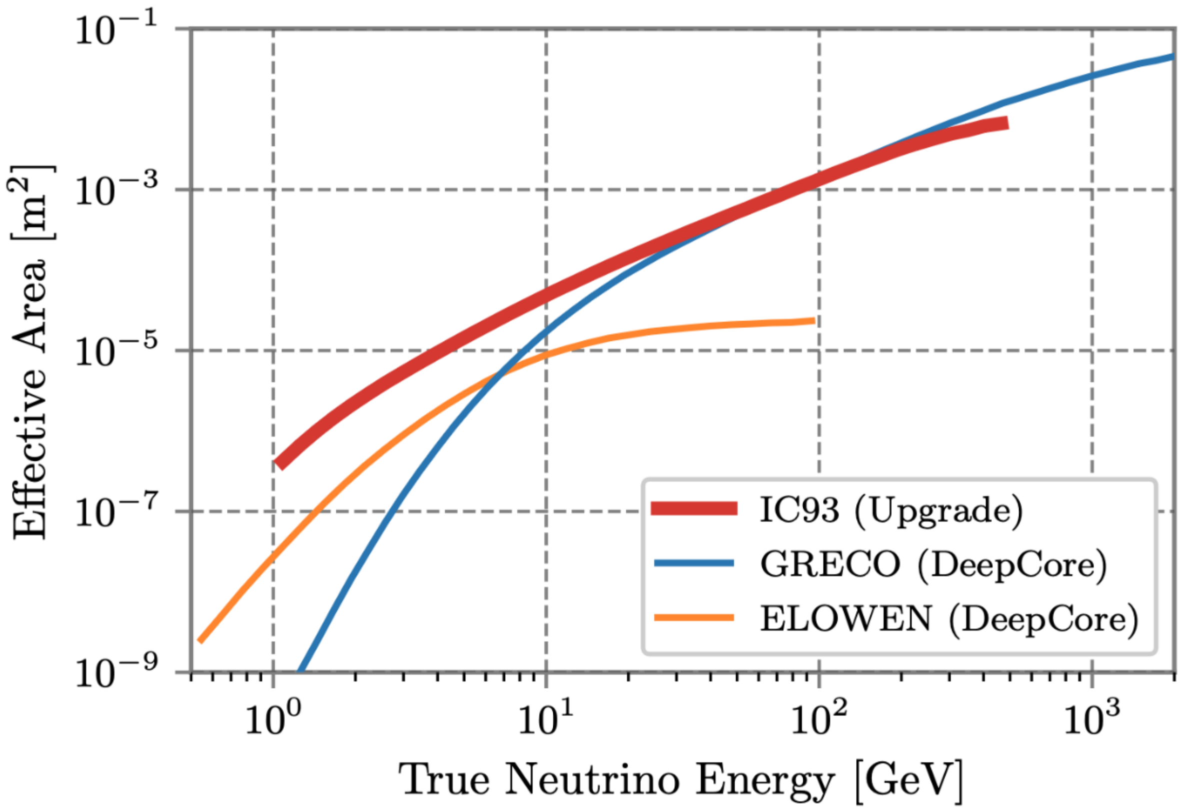
$$p + \gamma \to \pi^{\pm}, \pi^{0} + \cdots$$

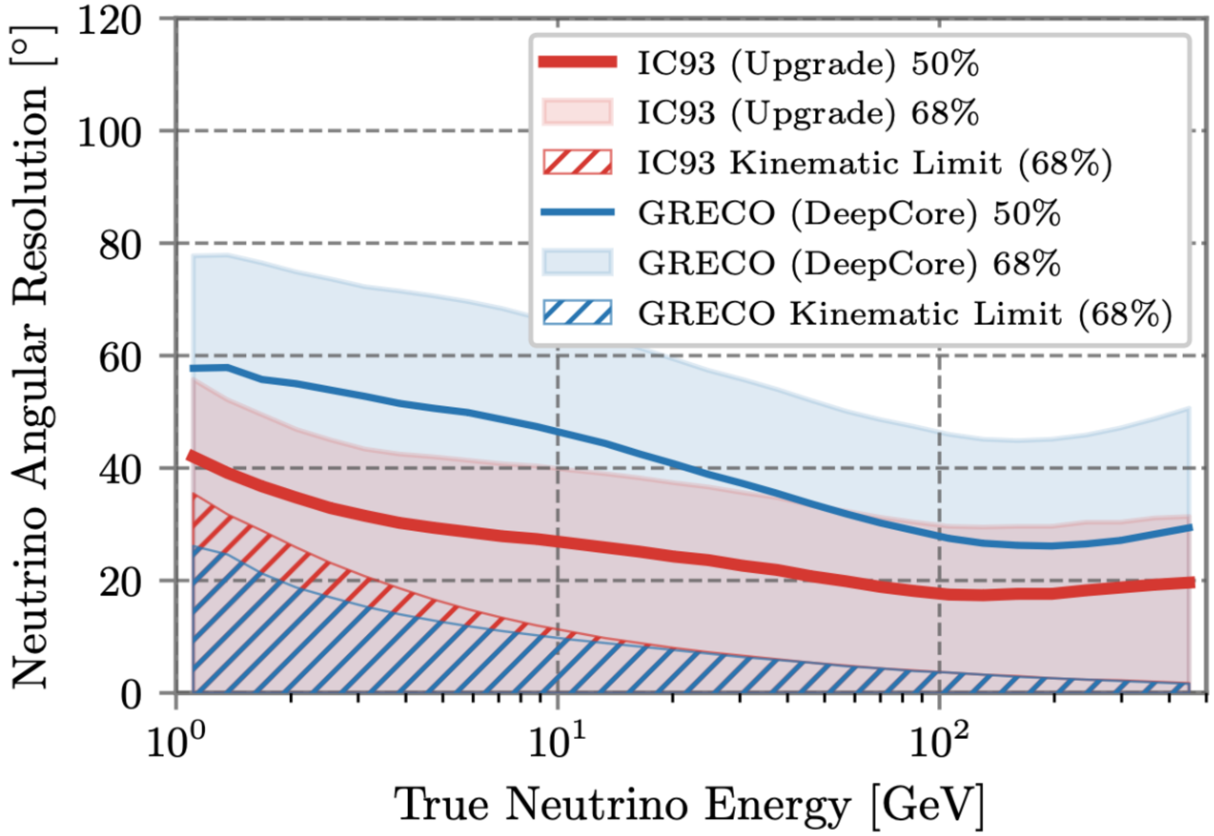
$$\pi^{\pm} \to \mu^{\pm} + \nu \to e^{\pm} + 3\nu$$

complementary views of transient engines.

IceCube Upgrade: new opportunities at GeV range

- IceCube serves as veto layer for the IceCube upgrade

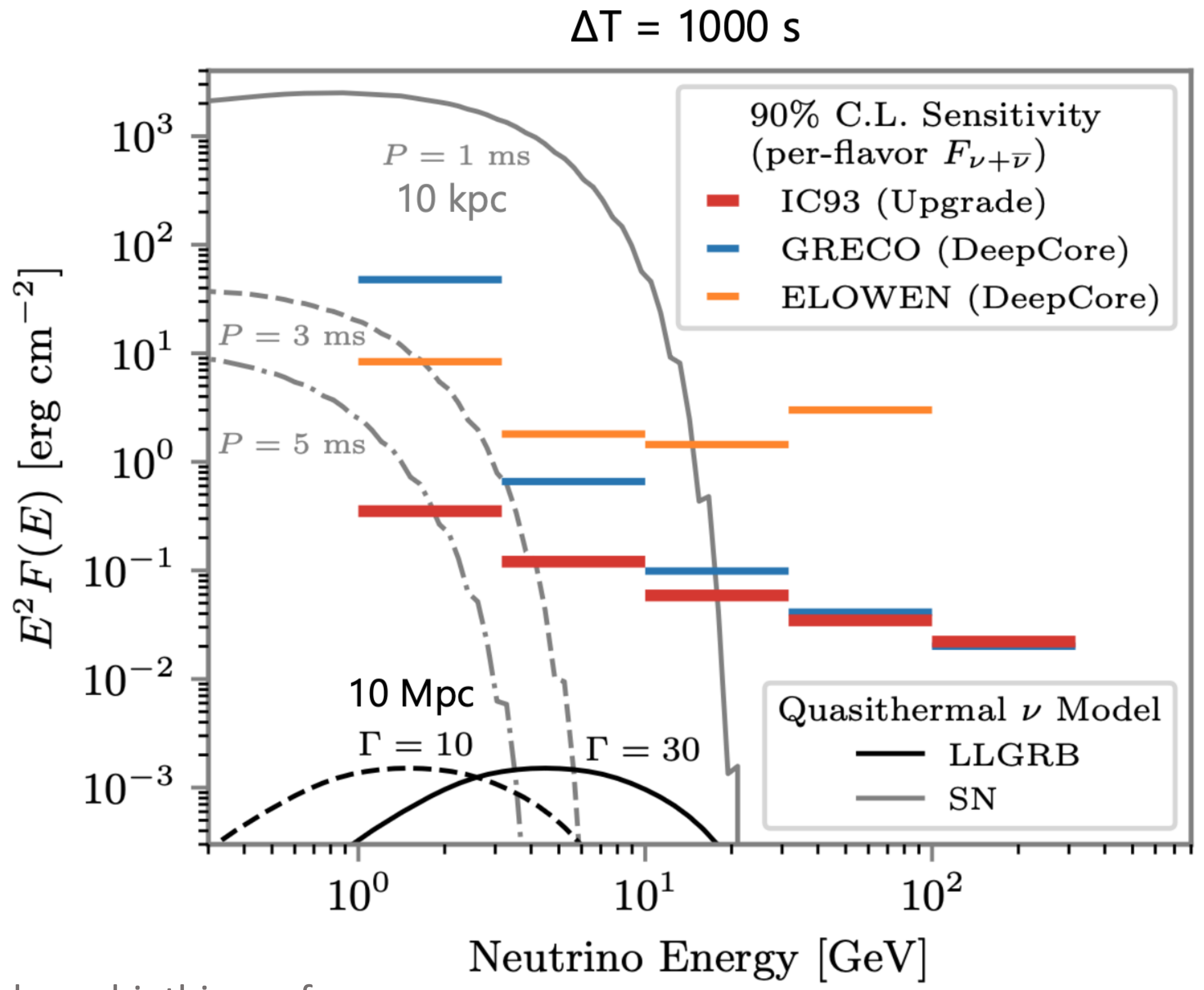




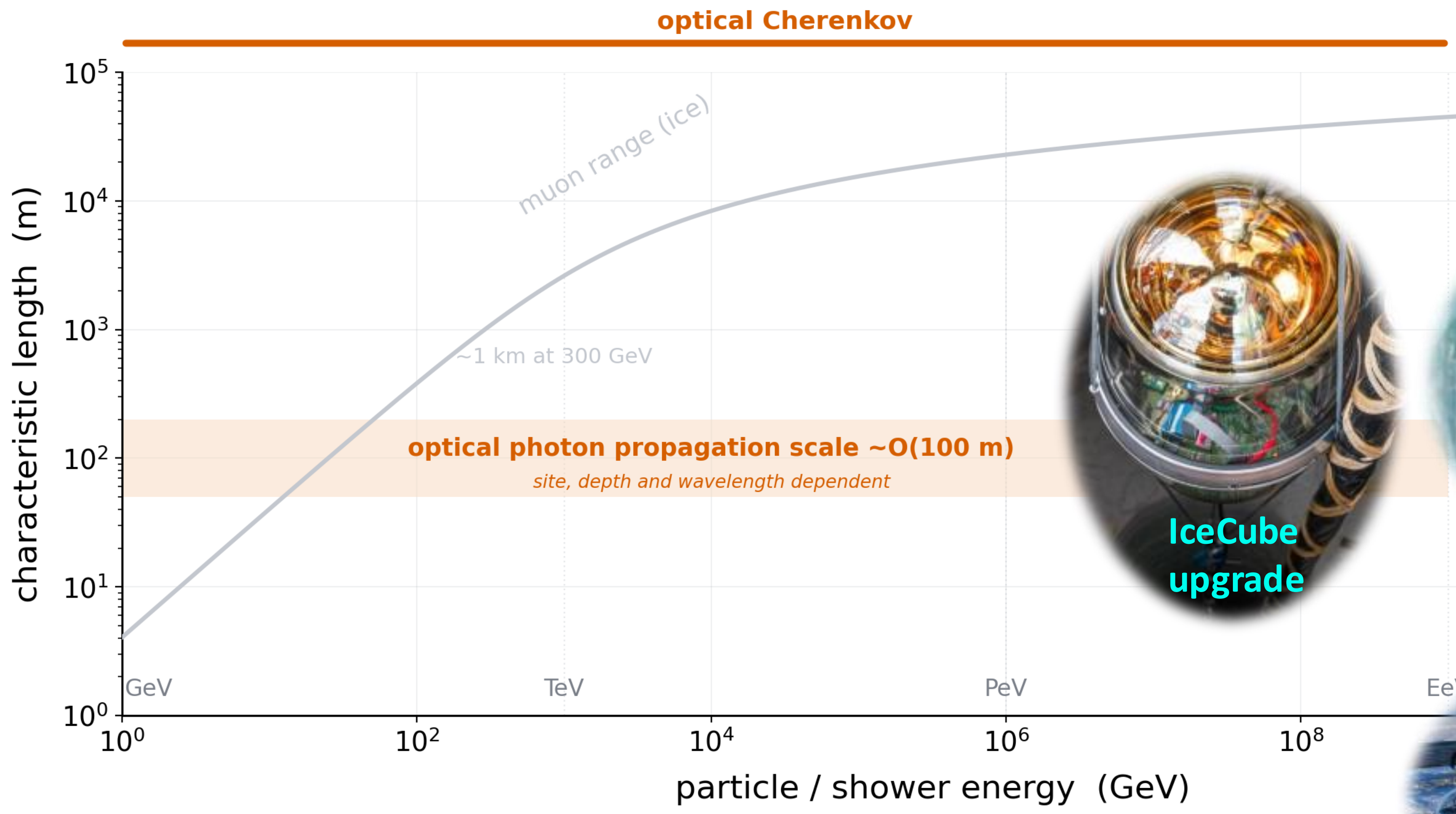
Yukiho Kobayashi, this conference

Differential Sensitivity with Singal Predictions

- **Unprecedented sensitivity to 1-10 GeV neutrinos**
  - Improvement by an order of magnitude from DeepCore
- **Galactic SN forming PNS with B=10^{15} G and P $\lesssim$ 5 ms will be detectable**
- Sensitivity **reach for low-luminosity GRBs is ~1 Mpc**
  - May be challenging to detect, given a burst rate estimate of ~10^{-7}-10^{-6} Mpc^{-3}yr^{-1}



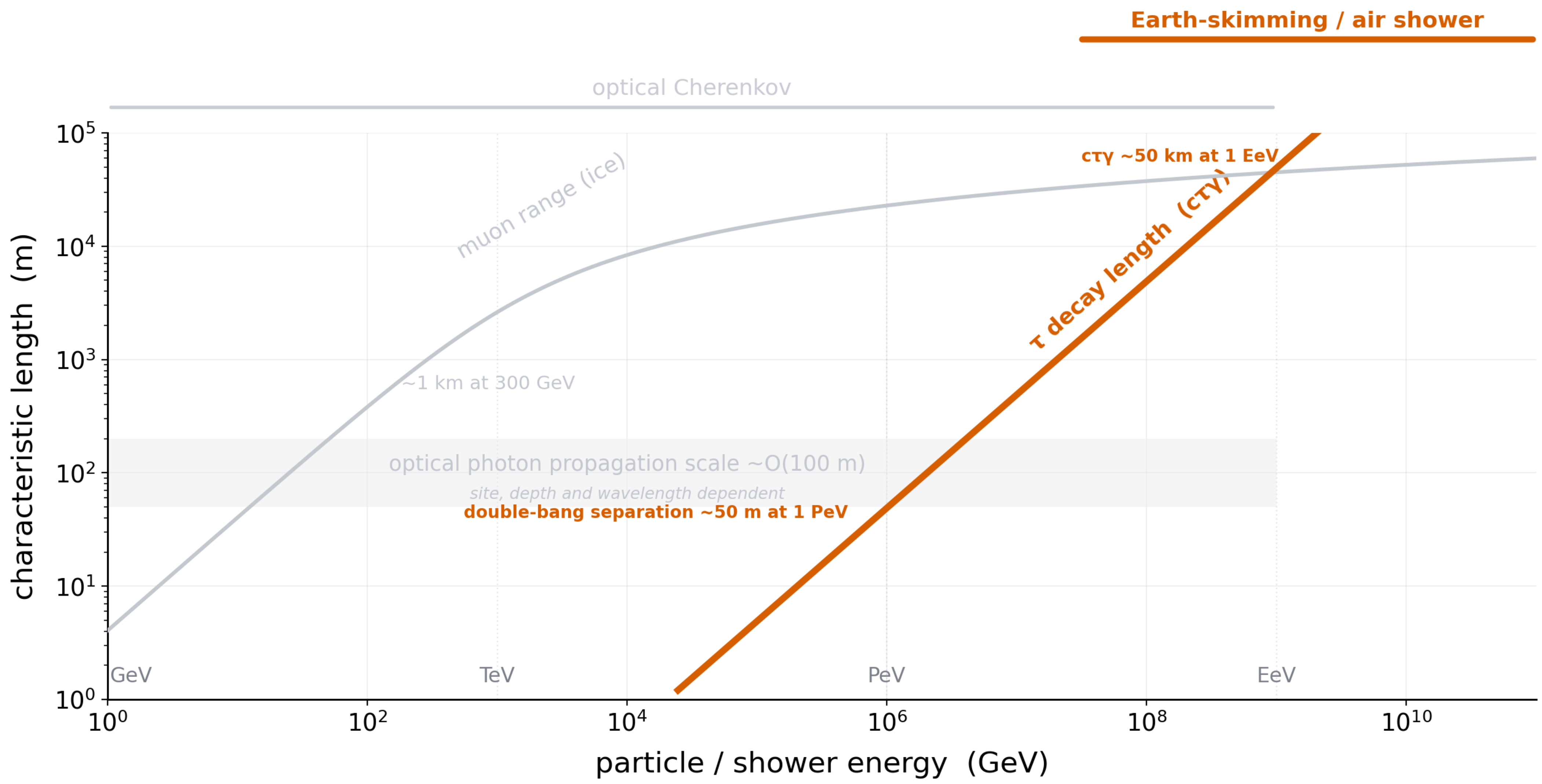
Yukiho Kobayashi, this conference

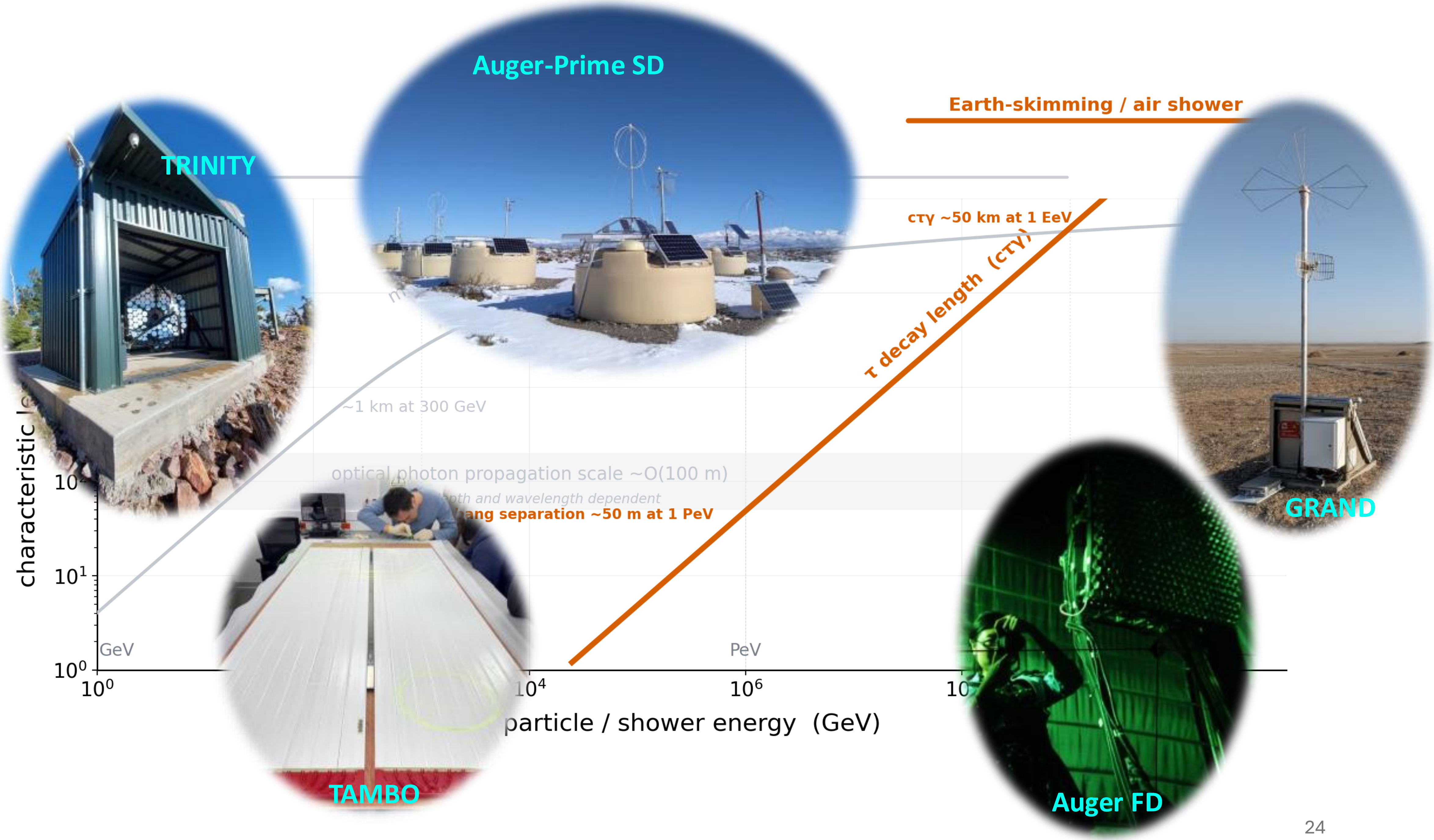

optical Cherenkov
characteristic length (m)
particle / shower energy (GeV)
10^5
10^4
10^3
10^2
10^1
10^0
10^0
10^2
10^4
10^6
10^8
GeV
TeV
PeV
EeV
muon range (ice)
~1 km at 300 GeV
optical photon propagation scale ~O(100 m)
site, depth and wavelength dependent
IceCube upgrade


KM3NeT

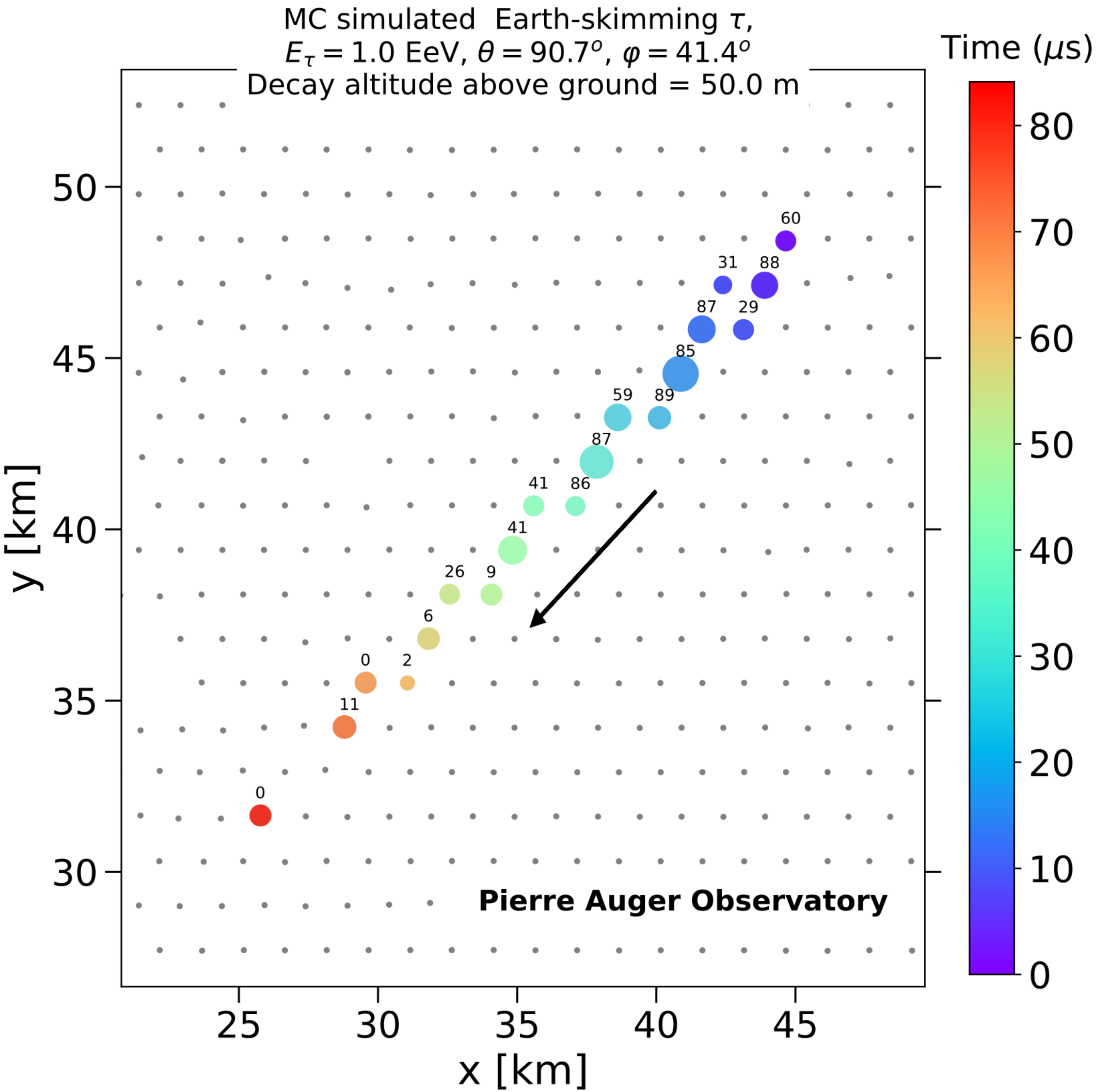

IceCube upgrade

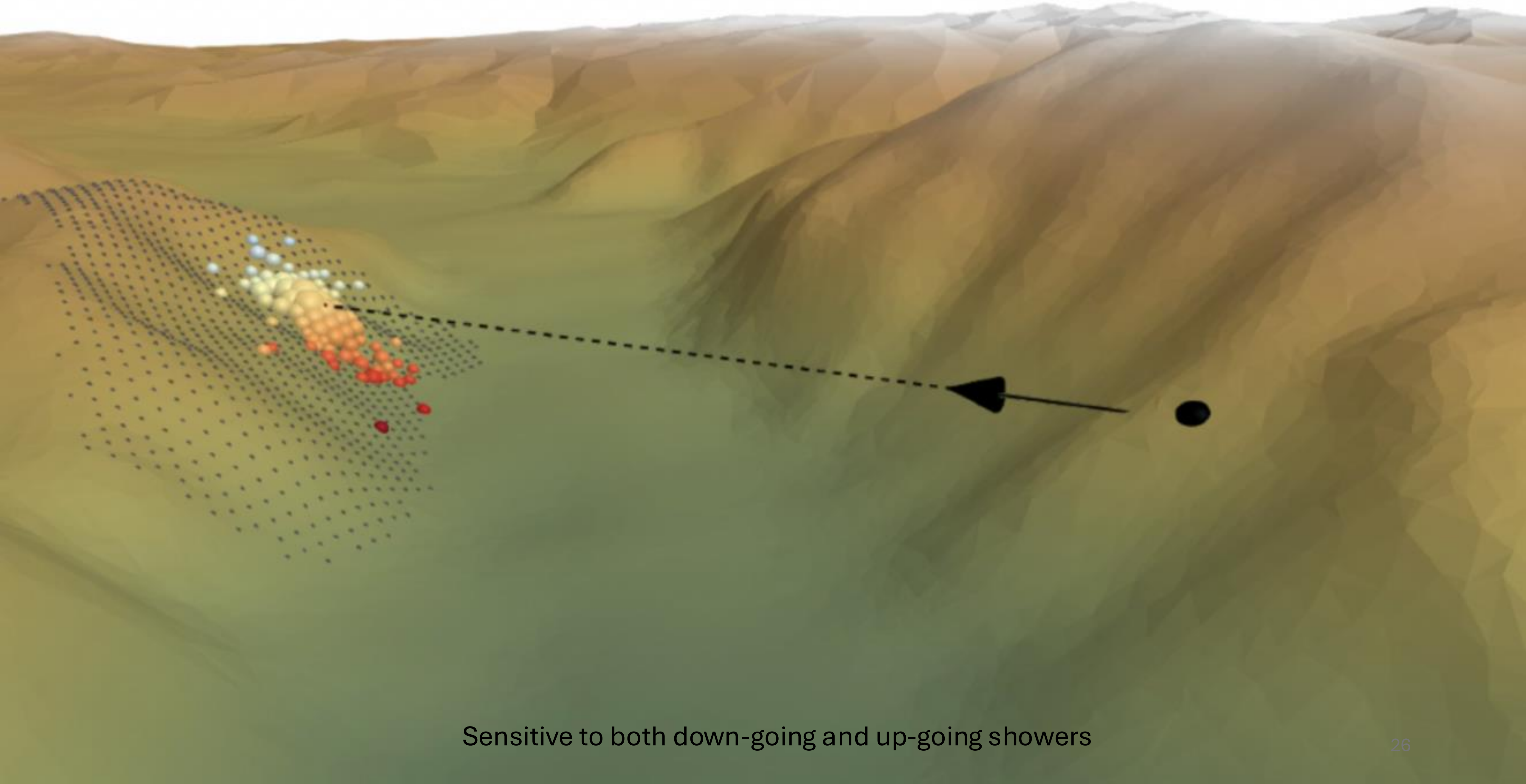

Baikal GVD


Earth-skimming / air shower
optical Cherenkov
muon range (ice)
~1 km at 300 GeV
cτγ ~50 km at 1 EeV
τ decay length (cτγ)
optical photon propagation scale ~O(100 m)
site, depth and wavelength dependent
double-bang separation ~50 m at 1 PeV
GeV
TeV
PeV
EeV
characteristic length (m)
particle / shower energy (GeV)
10^0
10^1
10^2
10^3
10^4
10^5
10^0
10^2
10^4
10^6
10^8
10^10



Auger-Prime SD
TRINITY
Earth-skimming / air shower
cτγ ~50 km at 1 EeV
τ decay length (cτγ)
~1 km at 300 GeV
optical photon propagation scale ~O(100 m)
ang separation ~50 m at 1 PeV
GRAND
characteristic le
GeV
PeV
10^0
10^1
10^0
10^4
10^6
particle / shower energy (GeV)
TAMBO
Auger FD


MC simulated Earth-skimming τ,
$E_\tau = 1.0$ EeV, $\theta = 90.7^o$, $\varphi = 41.4^o$
Decay altitude above ground = 50.0 m
Time (μs)
0
10
20
30
40
50
60
70
80
y [km]
30
35
40
45
50
x [km]
25
30
35
40
45
60
31
88
87
29
85
59
89
87
41
86
41
26
9
6
0
2
11
0
Pierre Auger Observatory



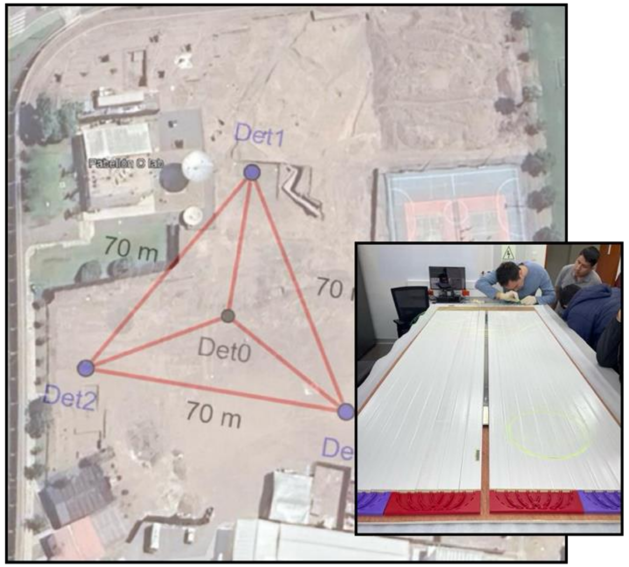
Sensitive to both down-going and up-going showers

Carlos Argüelles, this conference

Timeline of TAMBO

Today

TAMBO-4

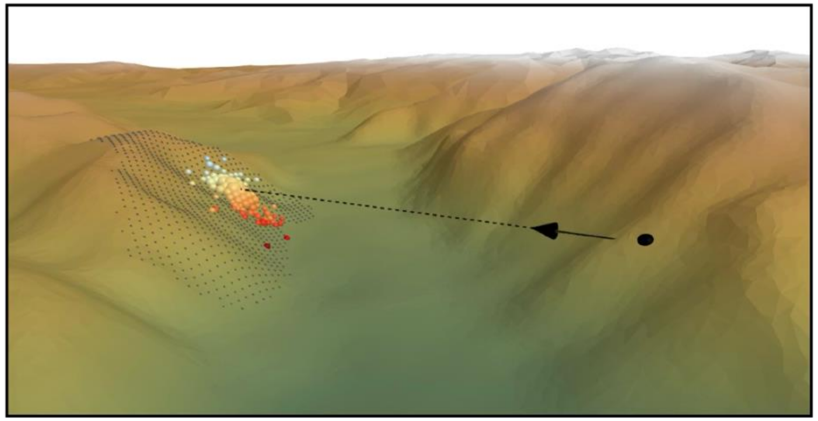


Small test array at PUCP campus in Lima

Electronics, detector prototypes

2025-2028

TAMBO-100
(aka TAMBITO)



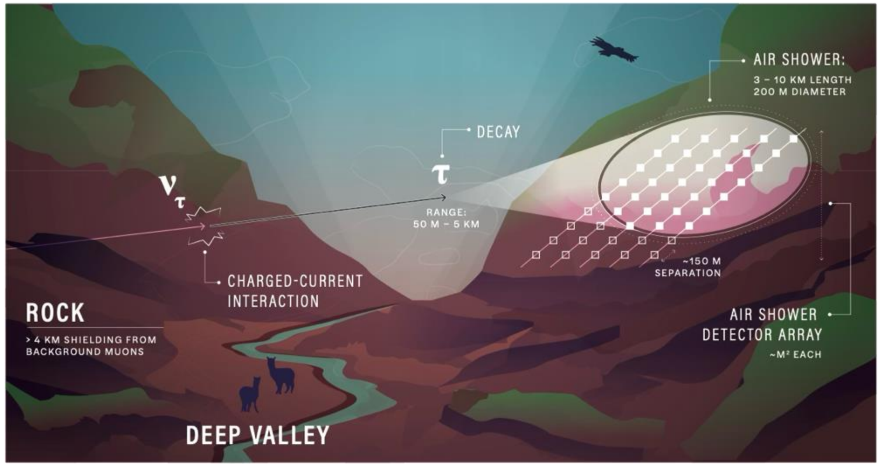
Pilot array
Deployment techniques, background, and social science

JOHN TEMPLETON FOUNDATION

Funded!

2028 - ...

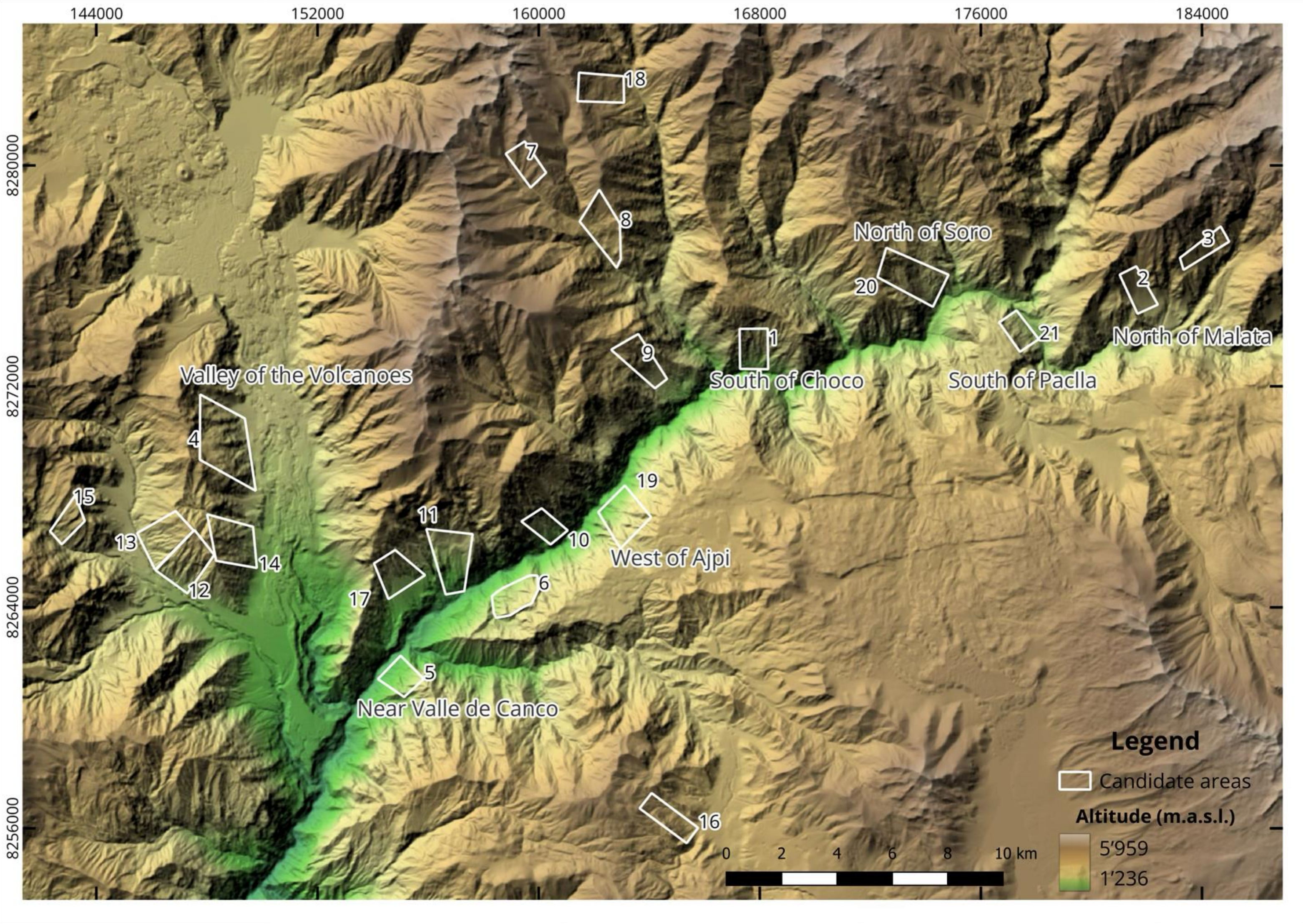
TAMBO-5k



TAU AIR-SHOWER MOUNTAIN-BASED OBSERVATORY (TAMBO)

Array capable of detecting O(1) neutrinos per year in the PeV to 100 PeV energy range

Potential locations for TAMBO



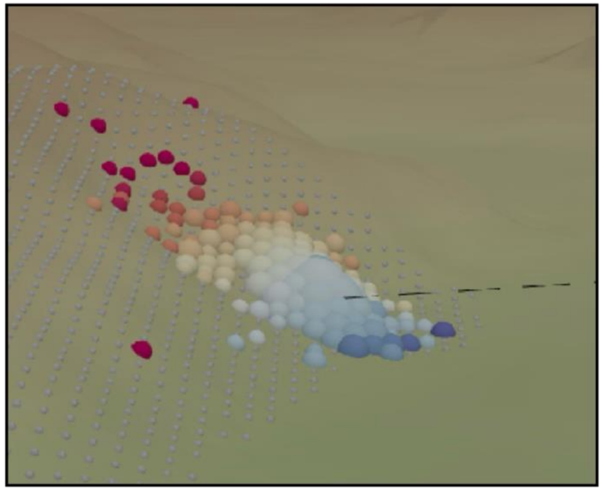
Initial requirements:

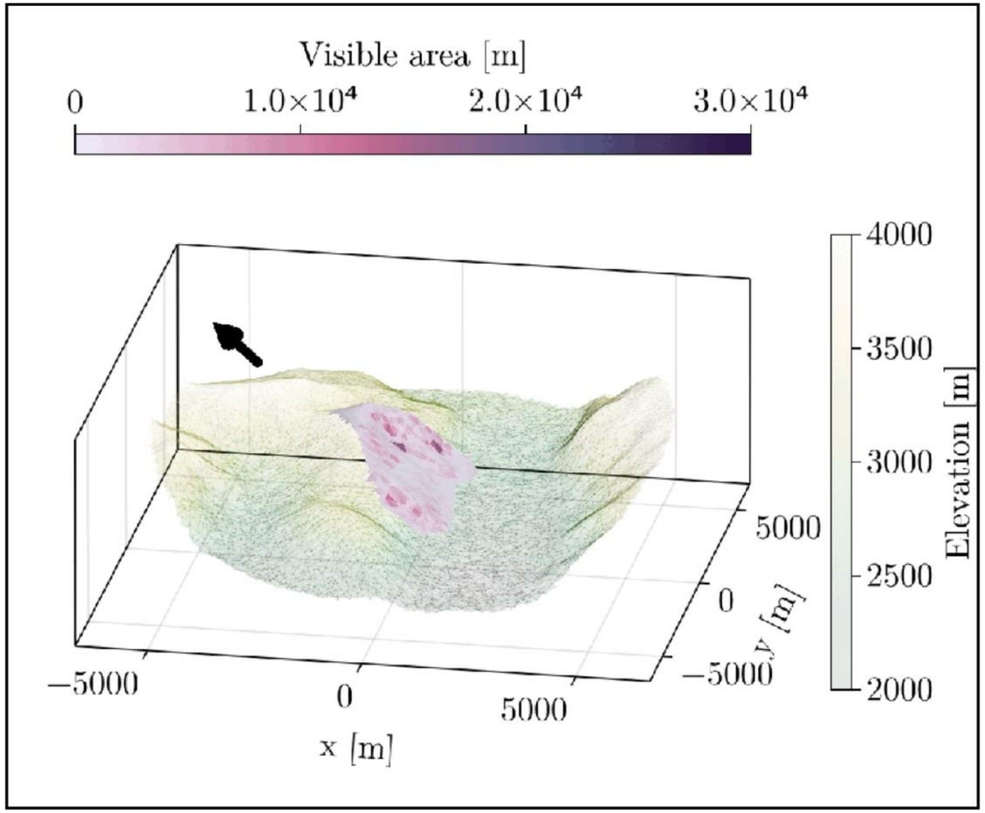
- Large enough to fit 100 detectors (125m spacing)
- Max slope 35°
- Opposite face 3-8 km away

At least, two sites have been identified (near Soro [9] and north of Malata [2]) that have easy roads and nearby city access.

These are candidate locations for initial deployment.

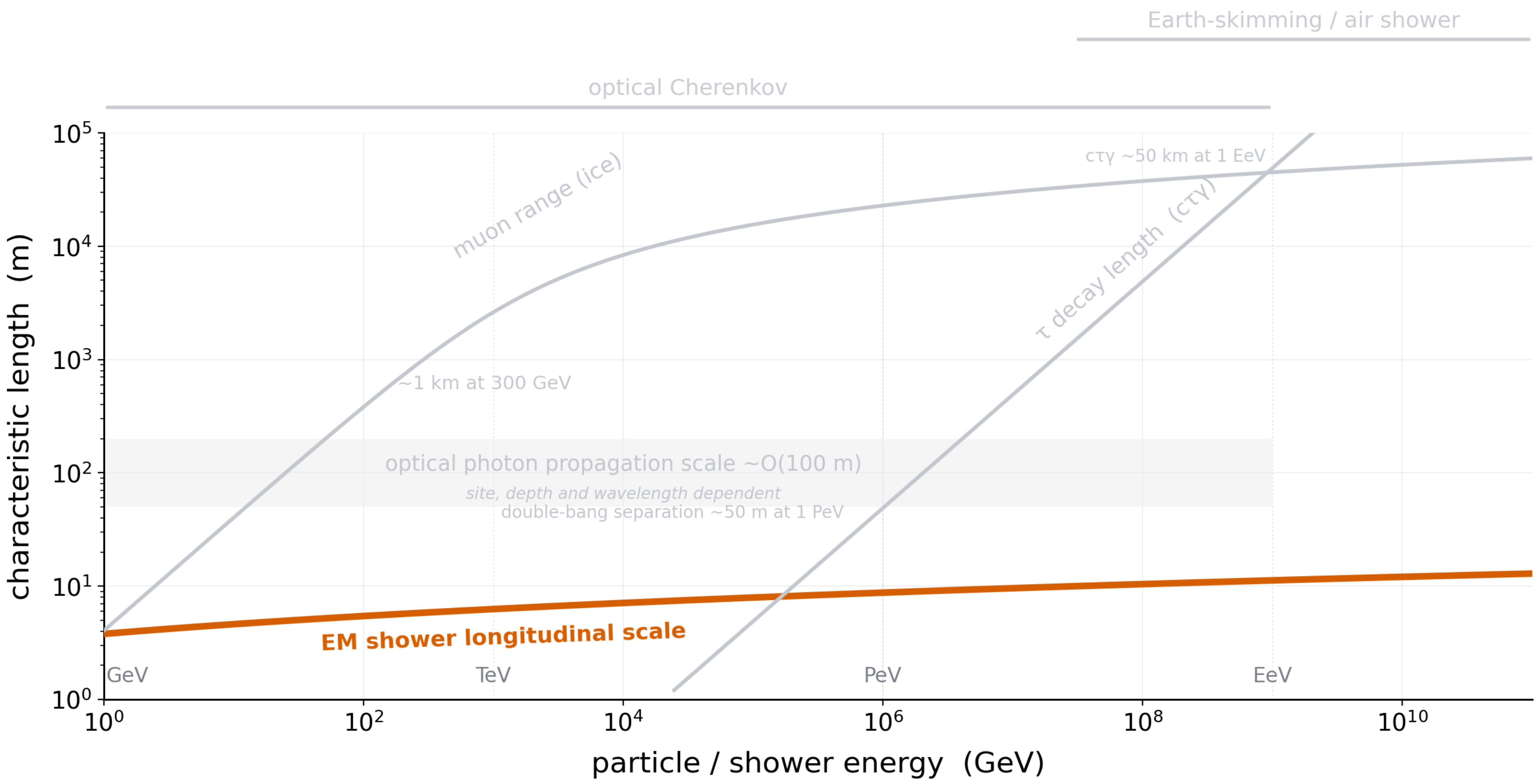
Open-source detection and neutrino simulation





- Arbitrary geometries.
- Full three-dimensional grid.
- CORSIKA-8 for shower development.

https://github.com/TAMBO-Observatory/TamboSim


Earth-skimming / air shower
optical Cherenkov
cτγ ~50 km at 1 EeV
muon range (ice)
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optical photon propagation scale ~O(100 m)
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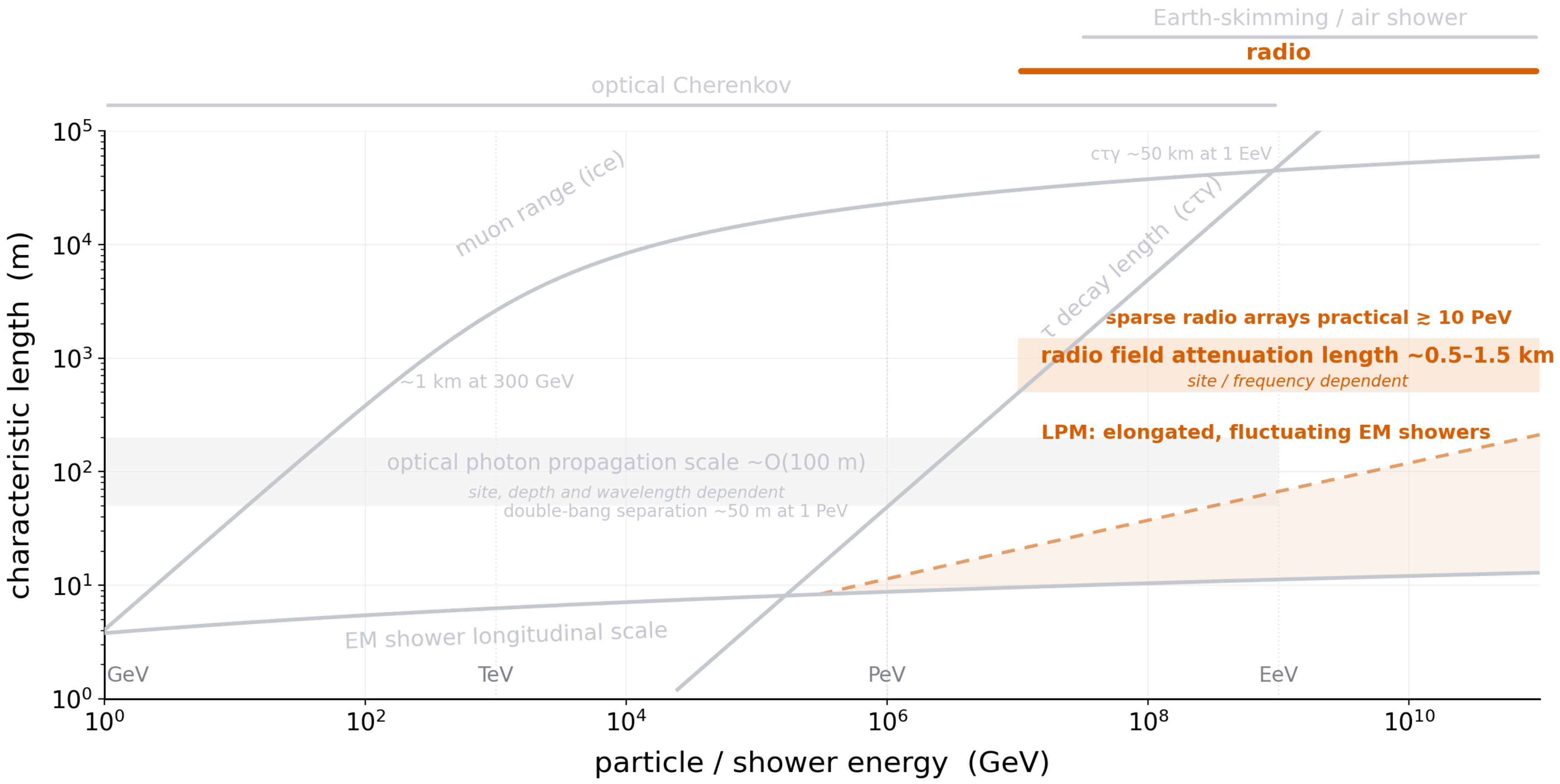
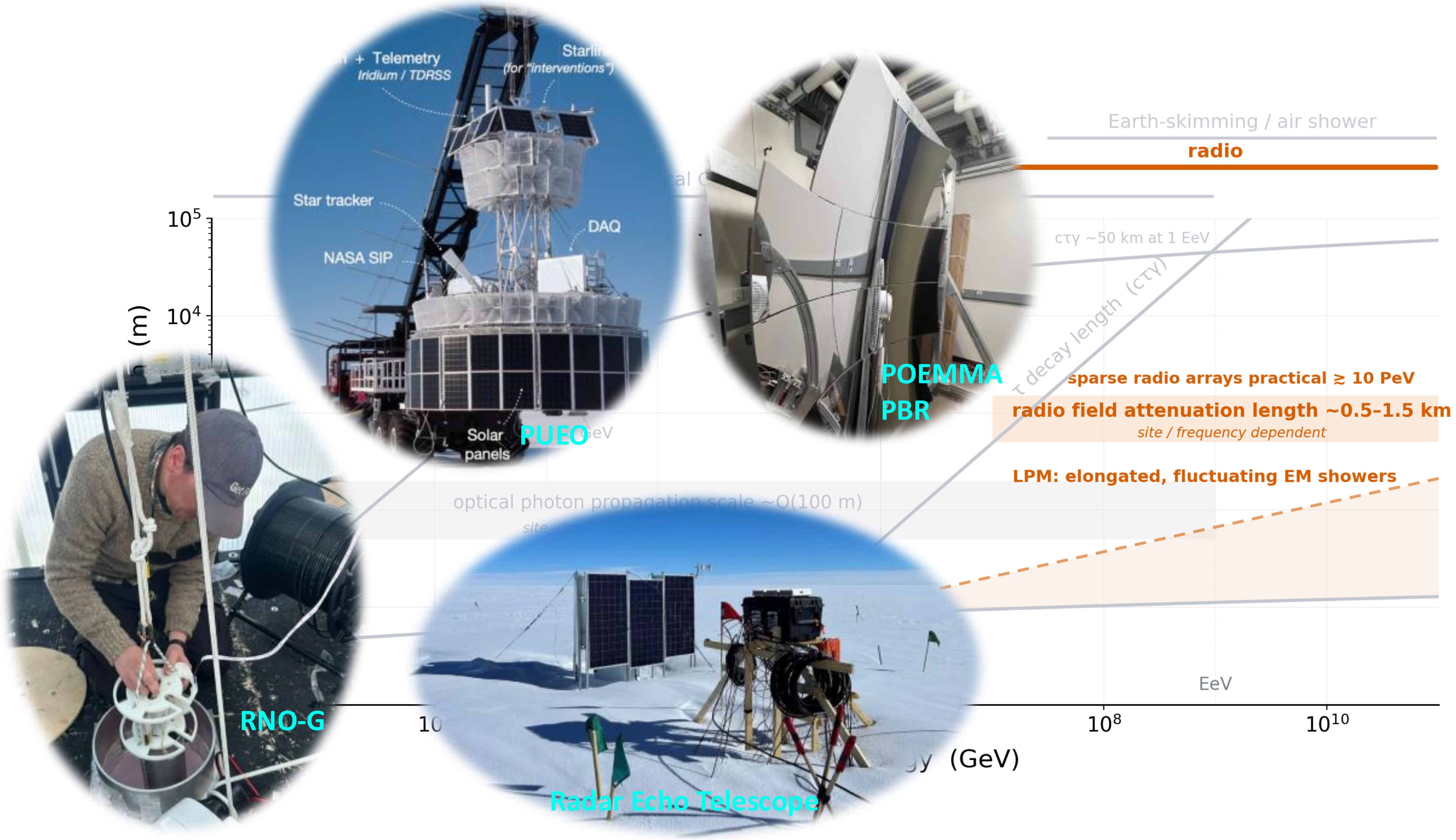

Earth-skimming / air shower
radio
optical Cherenkov
cτγ ~50 km at 1 EeV
muon range (ice)
τ decay length (cτγ)
sparse radio arrays practical ≳ 10 PeV
radio field attenuation length ~0.5–1.5 km
site / frequency dependent
~1 km at 300 GeV
LPM: elongated, fluctuating EM showers
optical photon propagation scale ~O(100 m)
site, depth and wavelength dependent
double-bang separation ~50 m at 1 PeV
EM shower longitudinal scale
GeV
TeV
PeV
EeV
characteristic length (m)
particle / shower energy (GeV)


Telemetry
Iridium / TDRSS
(for "interventions")
Star tracker
NASA SIP
DAQ
Solar
panels
PUEO
POEMMA
PBR
RNO-G
Radar Echo Telescope
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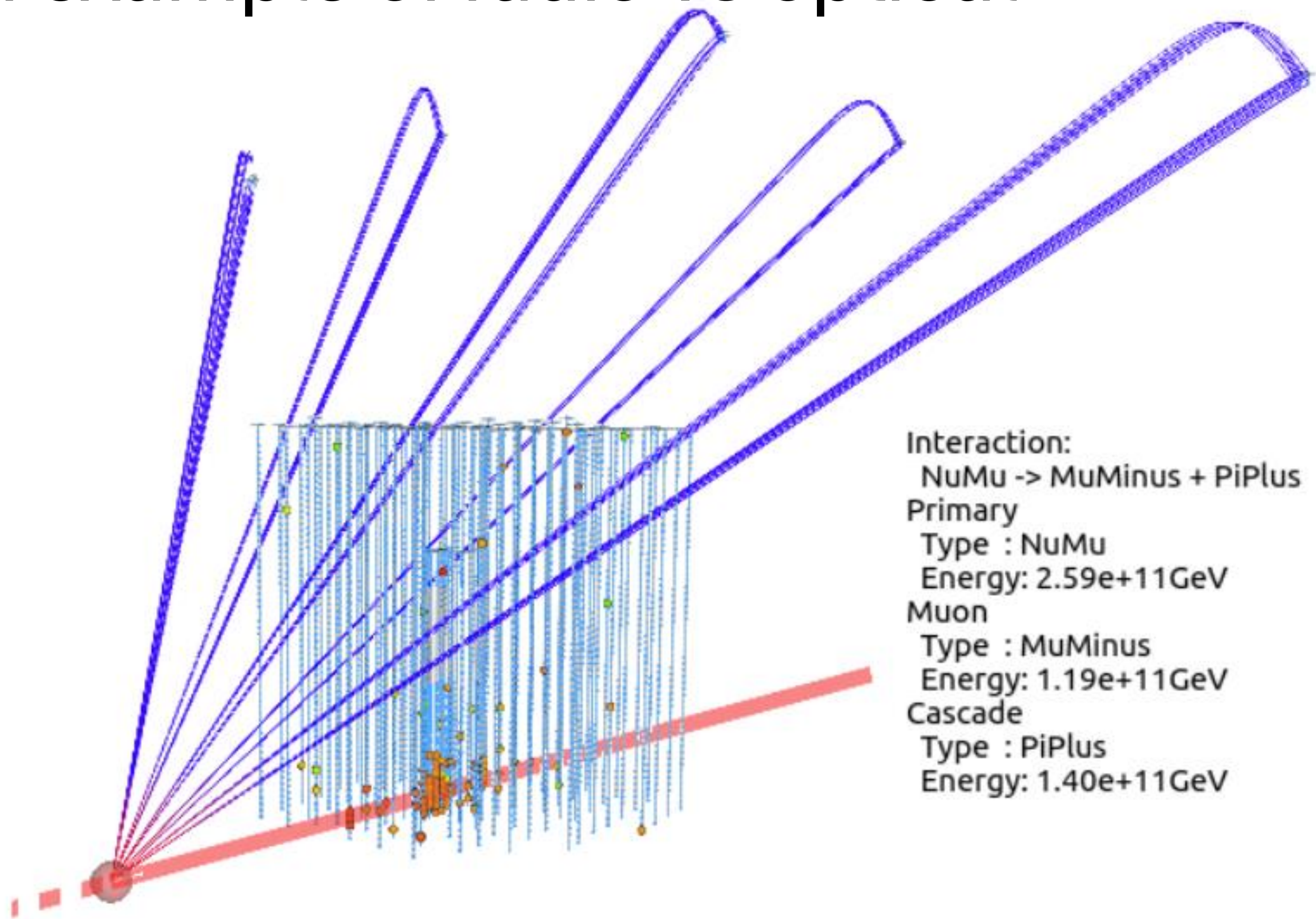
EeV
(m)
10^5
10^4
10^8
10^{10}
(GeV)

An example of radio vs optical

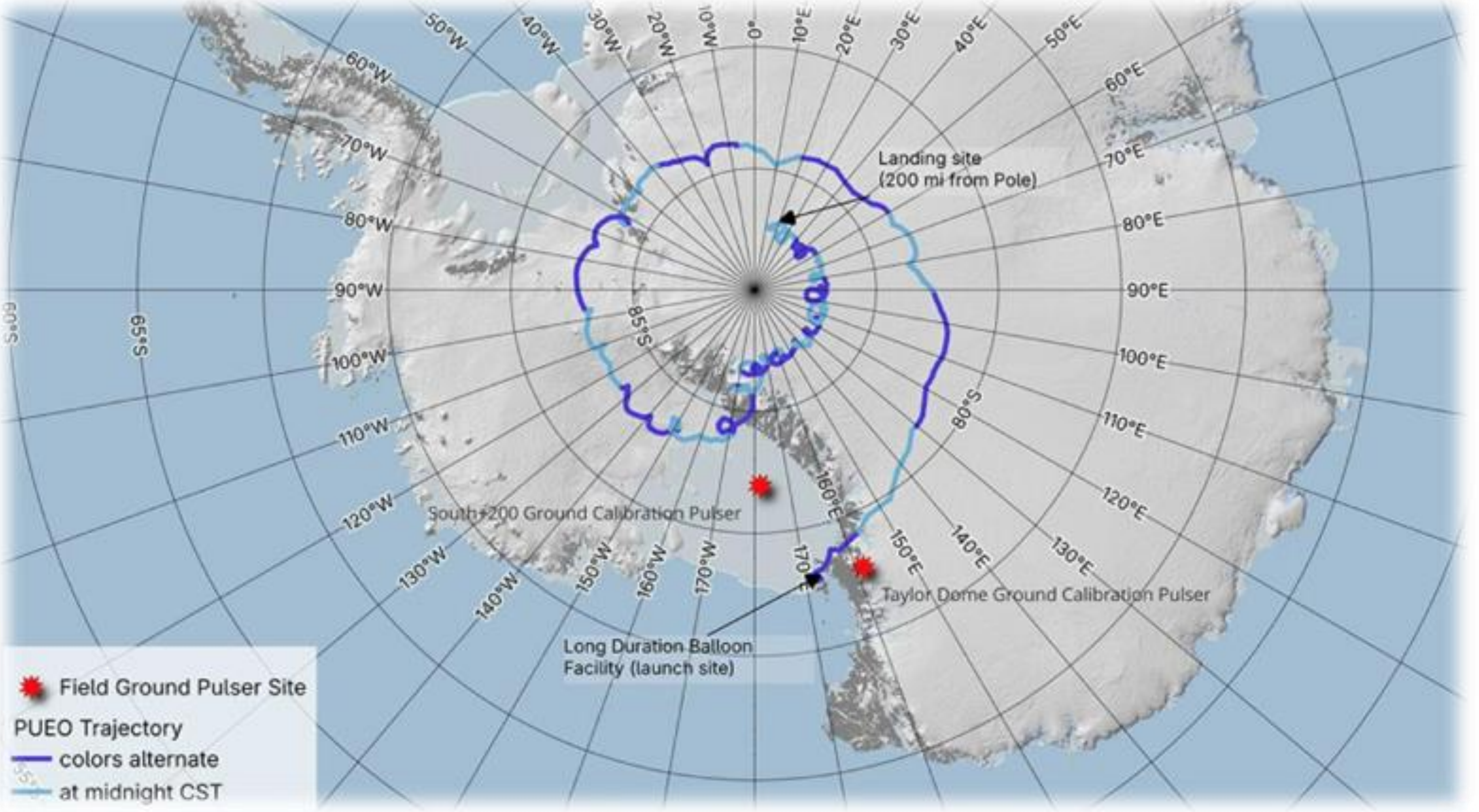


Bishop, Lu, Karle
PoS-ICRC2021-1182

New: PUEO Instrument & Flight

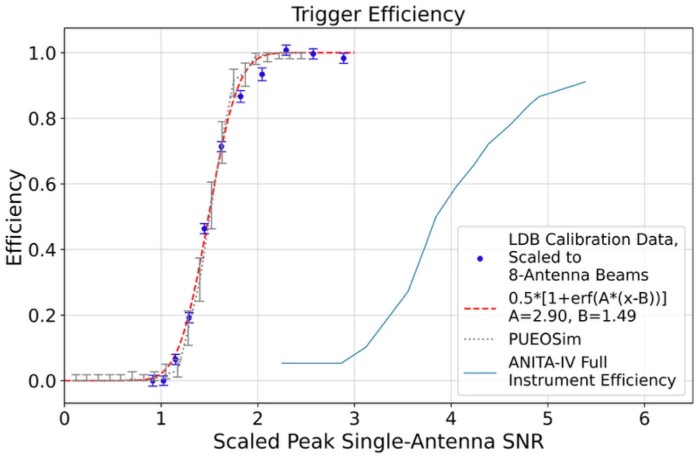
Stephanie Wissel

- **Main Instrument:**
  - 96 Dual-polarized horn antennas (300-1300 MHz)
  - 16-antenna, dual-polarization beamforming trigger.
- **Low Frequency Instrument:**
  - 8 Dual Polarized deployable sinuous antennas (50-500 MHz)
  - Triggered by MI
- Triply redundant navigation suite
- 23-day flight
  - Successful deployment of both solar panels (just after launch) and LF instrument (at float)
  - 53% duty cycle



PUEO: First Look at the Data

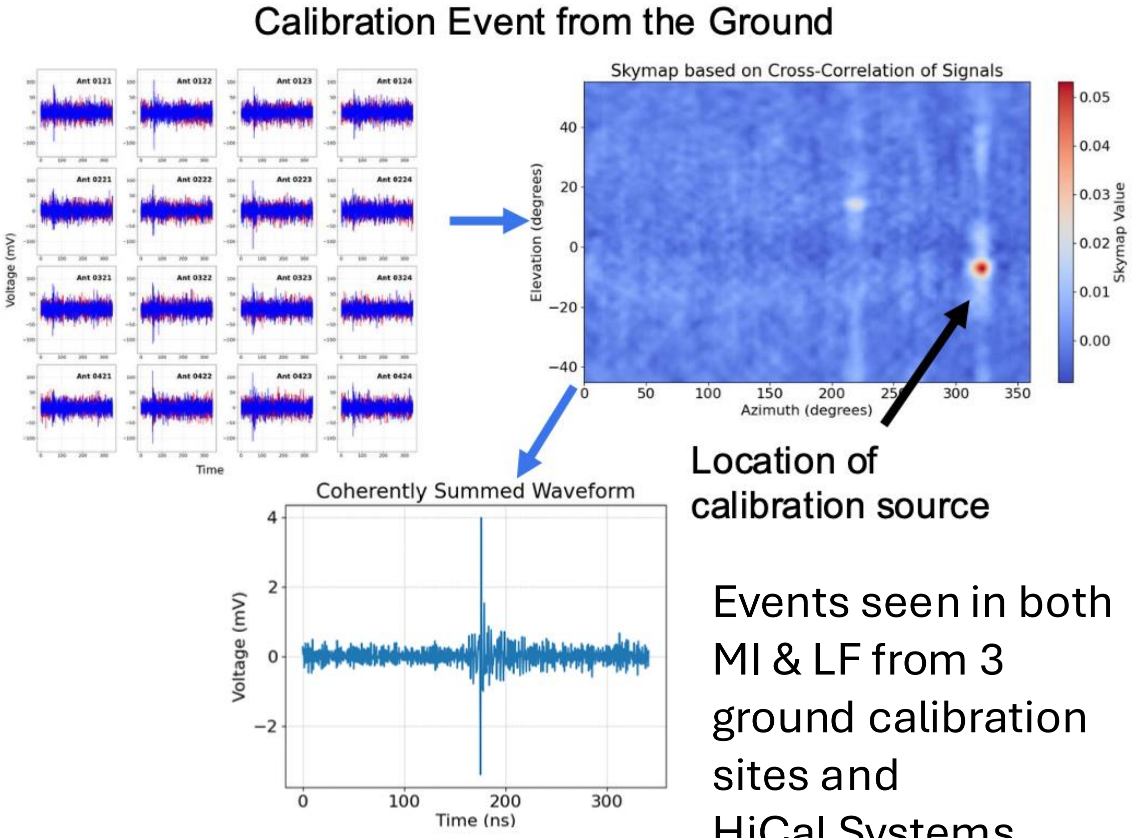
Most sensitive radio trigger to date



As-flown trigger efficiency compared to ANITA: Events triggered with phased array on weak signals ($<2 \times V_{rms}$ of thermal noise in single antenna)

L. Beaufore, C. Welling

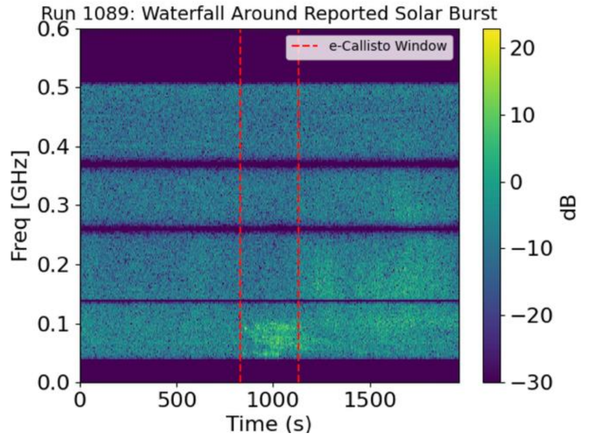
Cal pulses reconstruct well



Events seen in both MI & LF from 3 ground calibration sites and HiCal Systems (direct + reflected)

R. Scrandis, K. Coulbery, J. Alfaro, Z. Martin

Solar Flares seen in LF data



- ~130 solar radio bursts (eCallisto) coincident with PUEO's flight.
- ~10,000 unbiased LF events are associated with solar bursts and reconstruct back to sun location

Y. Ku

Stephanie Wissel

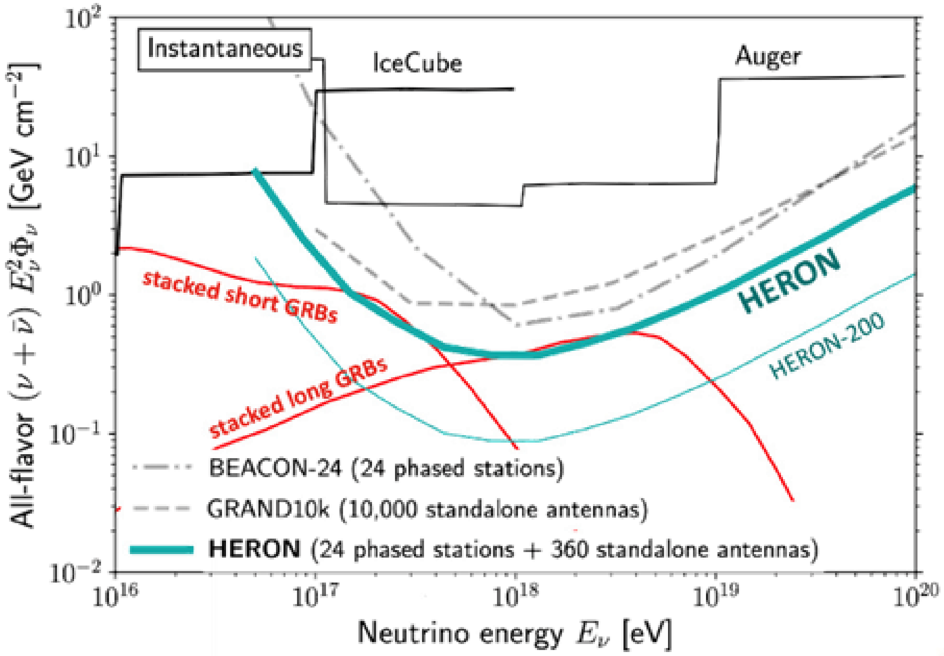
HERON: Hybrid Elevated Radio Observatory for Neutrinos

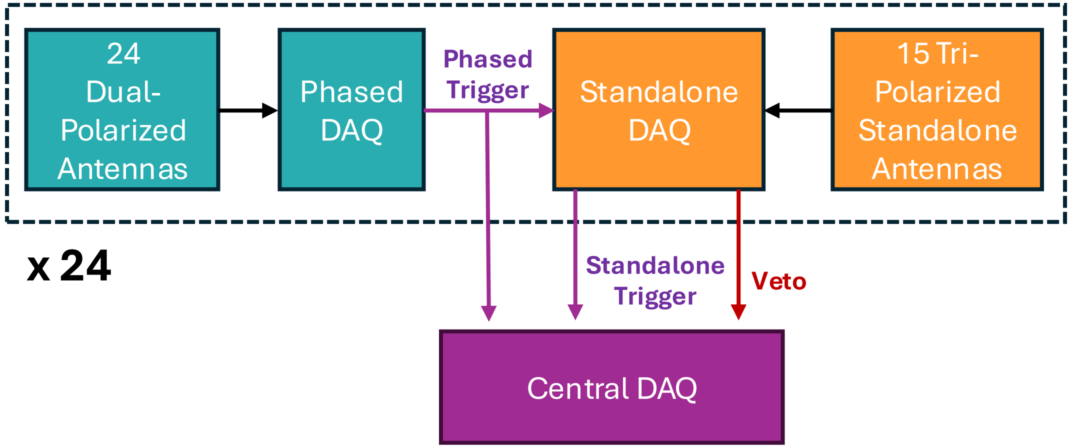
Mid-scale Instrument targeting astrophysical neutrinos (E ≳ 100 PeV). Optimized for transients due to high sensitivity and angular reconstruction

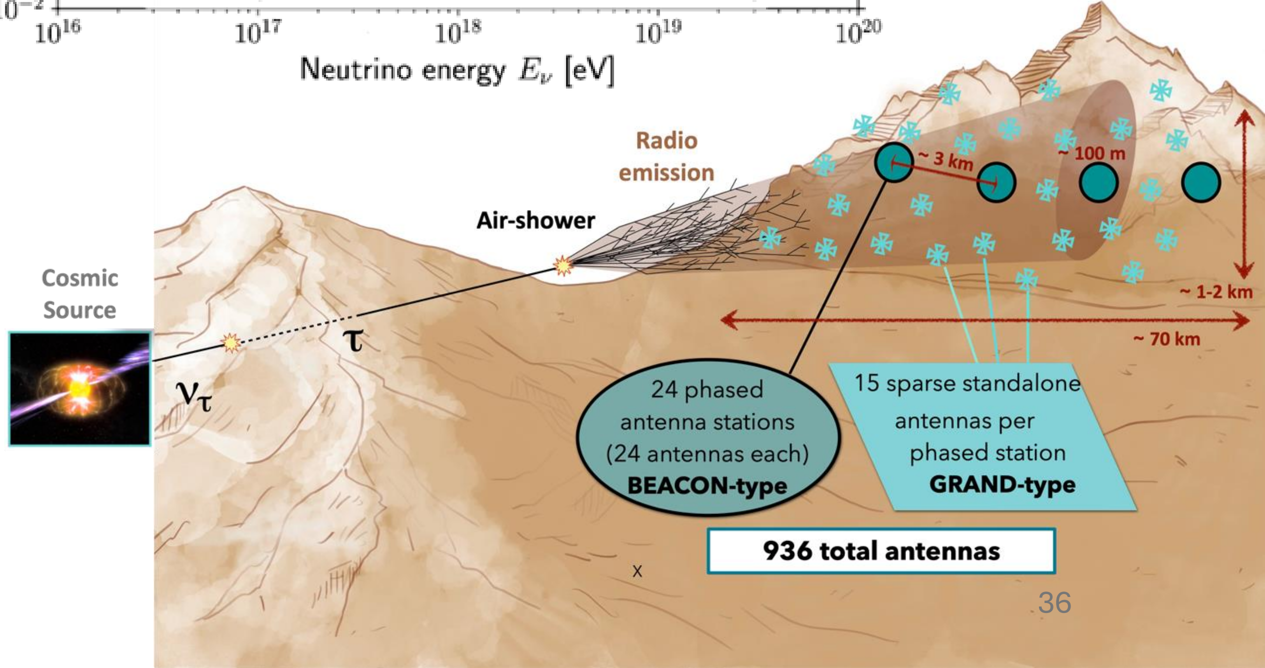
Hybrid Design:

- **Elevated Phased Arrays:** Enhanced sensitivity ~10x compared to ground arrays
- **Sparse Standalone Arrays:** sub-degree angular resolution
- **Key:** Low threshold trigger from phased arrays transmitted to sparse arrays

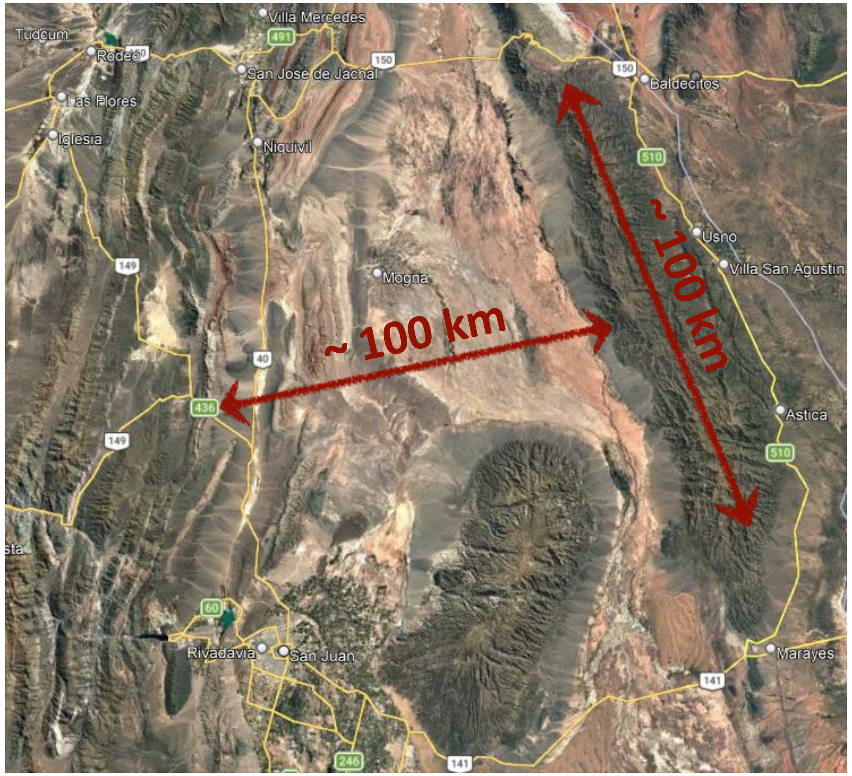
Status: ERC funding for 6-year project. Site surveys underway and initial prototypes expected in 2 years

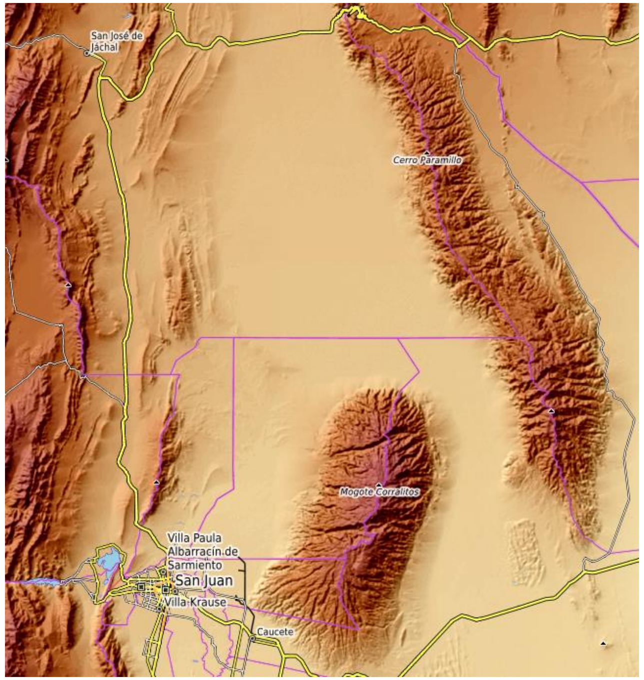




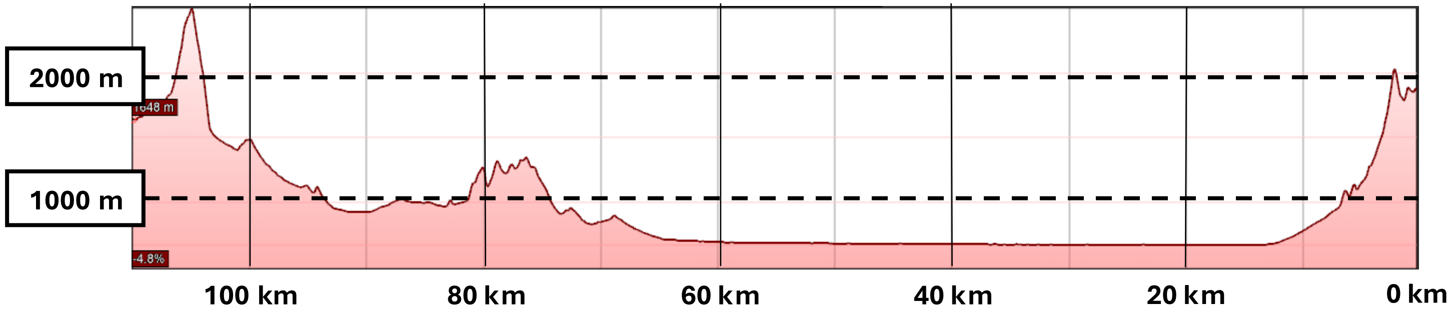


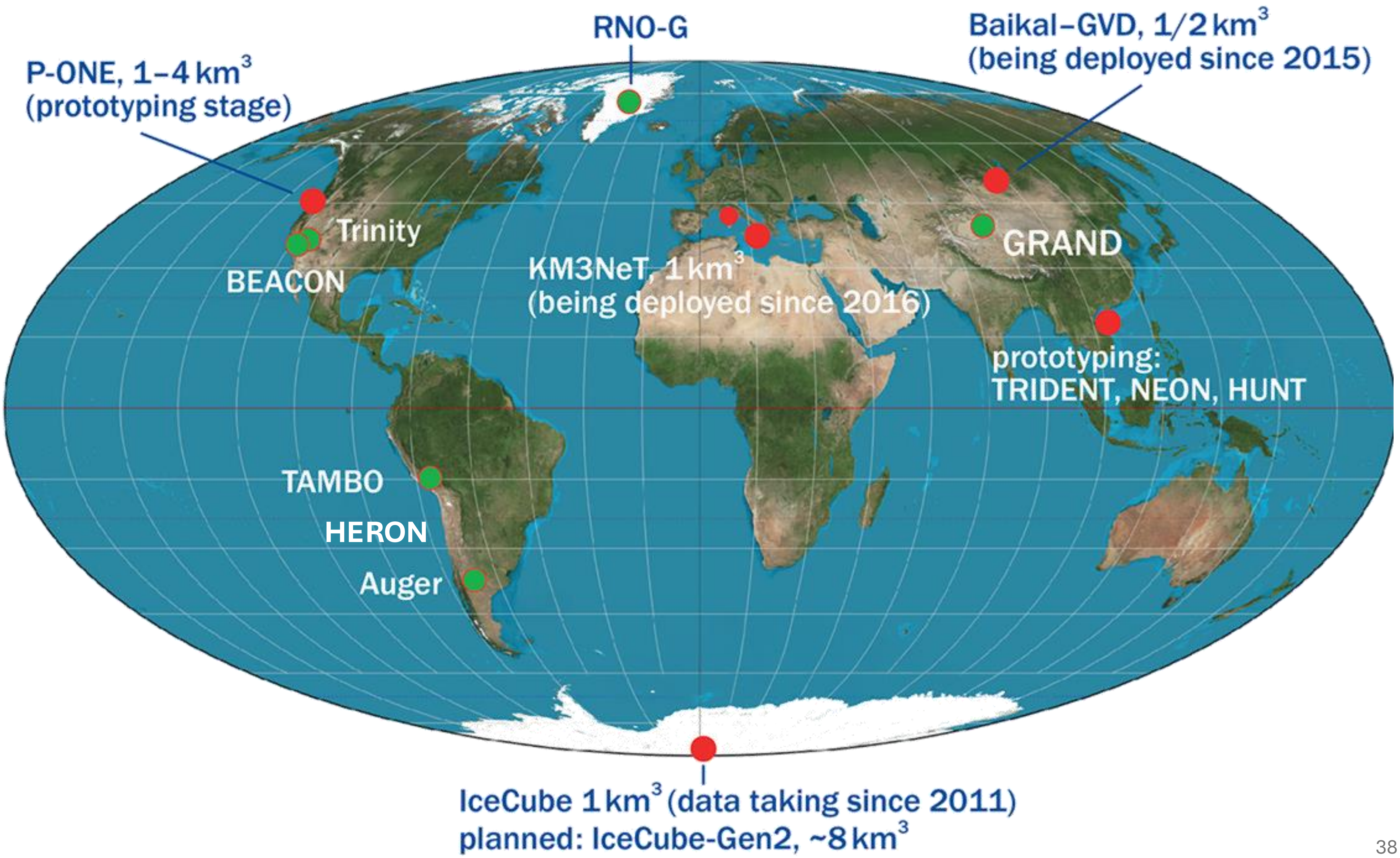
Site: San Juan Province, Argentina





- **Mountain ranges Sierra de Valle Fértil (east) and Sierra del Tontal (west):** Ideal topography for detecting Earth-skimming tau neutrinos
- **Partner in Argentina (CNEA):** 20+ yr experience operating Auger Observatory
- **Support from local authorities** of San Juan Province




RNO-G
Baikal–GVD, 1/2 km³
(being deployed since 2015)
P-ONE, 1–4 km³
(prototyping stage)
Trinity
BEACON
KM3NeT, 1 km³
(being deployed since 2016)
GRAND
prototyping:
TRIDENT, NEON, HUNT
TAMBO
HERON
Auger
IceCube 1 km³ (data taking since 2011)
planned: IceCube-Gen2, ~8 km³

Global neutrino telescope progresses in 2026

IceCube: Upgrade successfully installed in January 2026; important milestone toward IceCube-Gen2.

KM3NeT: Four DUs added to ORCA; ARCA deployment and acoustic calibration planned in Italy.

Baikal-GVD: Clusters 15 and 16 deployed; effective volume now ~0.8 km^3 with nearly 4900 OMs.

RNO-G: Successful drilling season; 12 stations now operating.

ARA: Five-station unblinding yields no neutrino candidates; paper in preparation.

P-ONE: Successful shallow-water test of the first detector-line concept off Vancouver; first full line planned for Fall 2026.

PUEO: Successful 23-day flight in early 2026; solar-flare detected, nu analysis ongoing.

POEMMA: POEMMA-Balloon with Radio (PBR) pathfinder under integration; field tests in 2027 and NASA super-pressure-balloon flight planned for Spring 2028

GRAND / BEACON / HERON: Joint hybrid effort through HERON; six-year ERC support, site surveys on-going, prototypes expected in ~2 years.

TAMBO: TAMBO-100 funded; site selection and geometry optimization ongoing.

Radar Echo Telescope: RET-CR analysis in progress; unblinding expected soon.

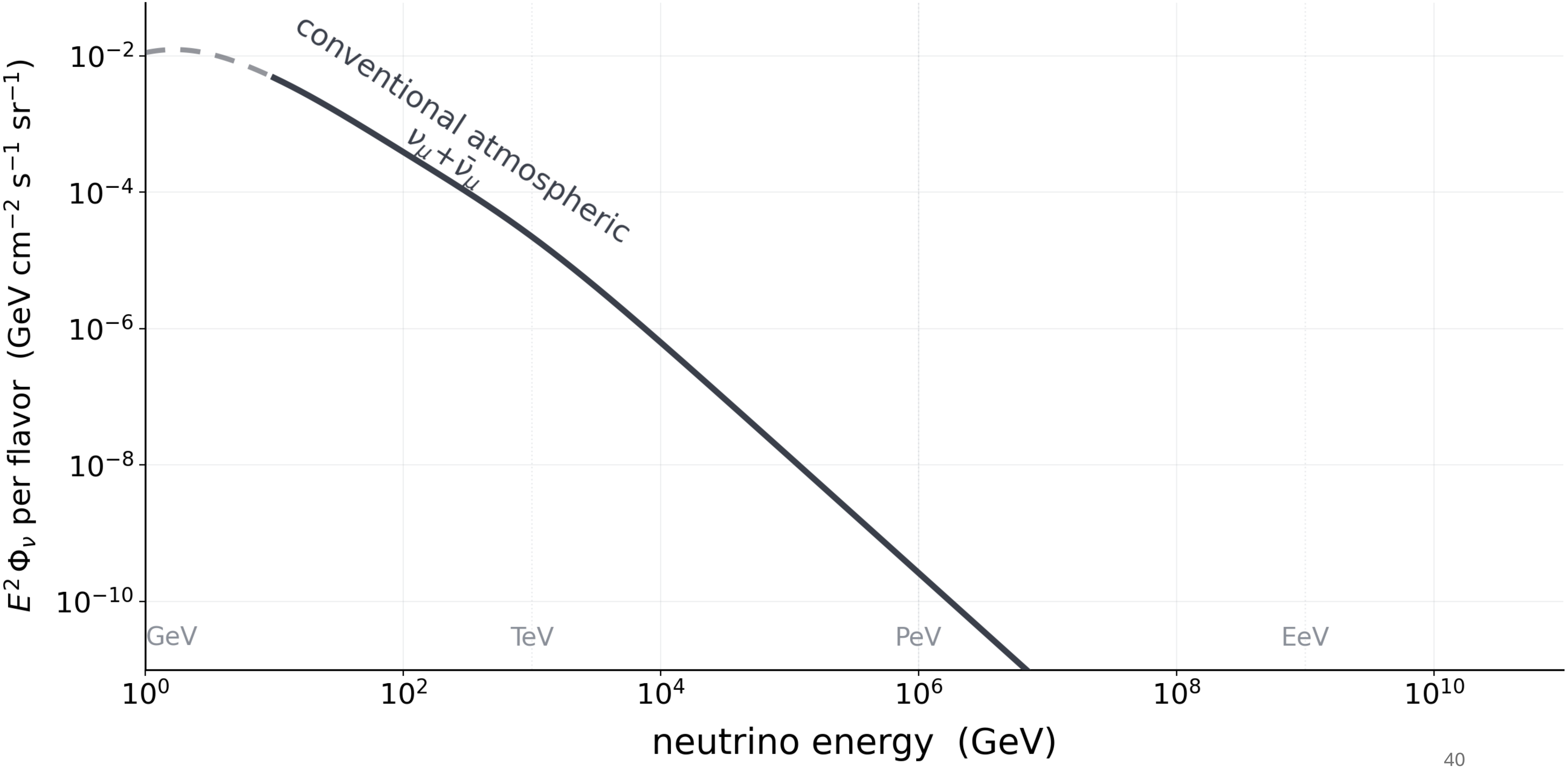
TRIDENT: Phase-1 deployment of 10 optical strings + 1 calibration string planned for 2027.

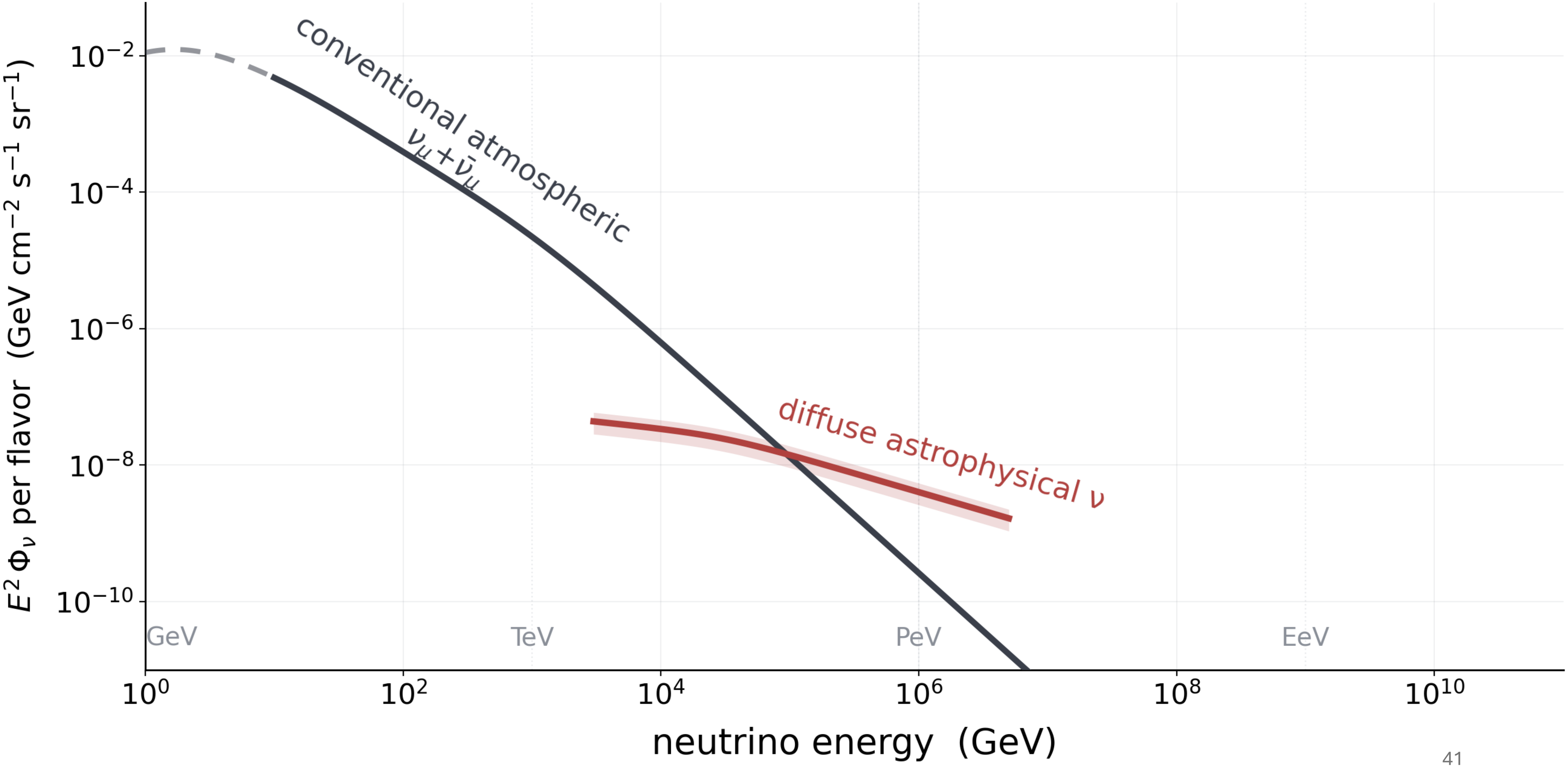
HUNT: Prototype tests completed at Baikal and in the South China Sea; 7-string prototype under development.

TRINITY: Demonstrator background consistent with expectation; planning TRINITY-ONE.

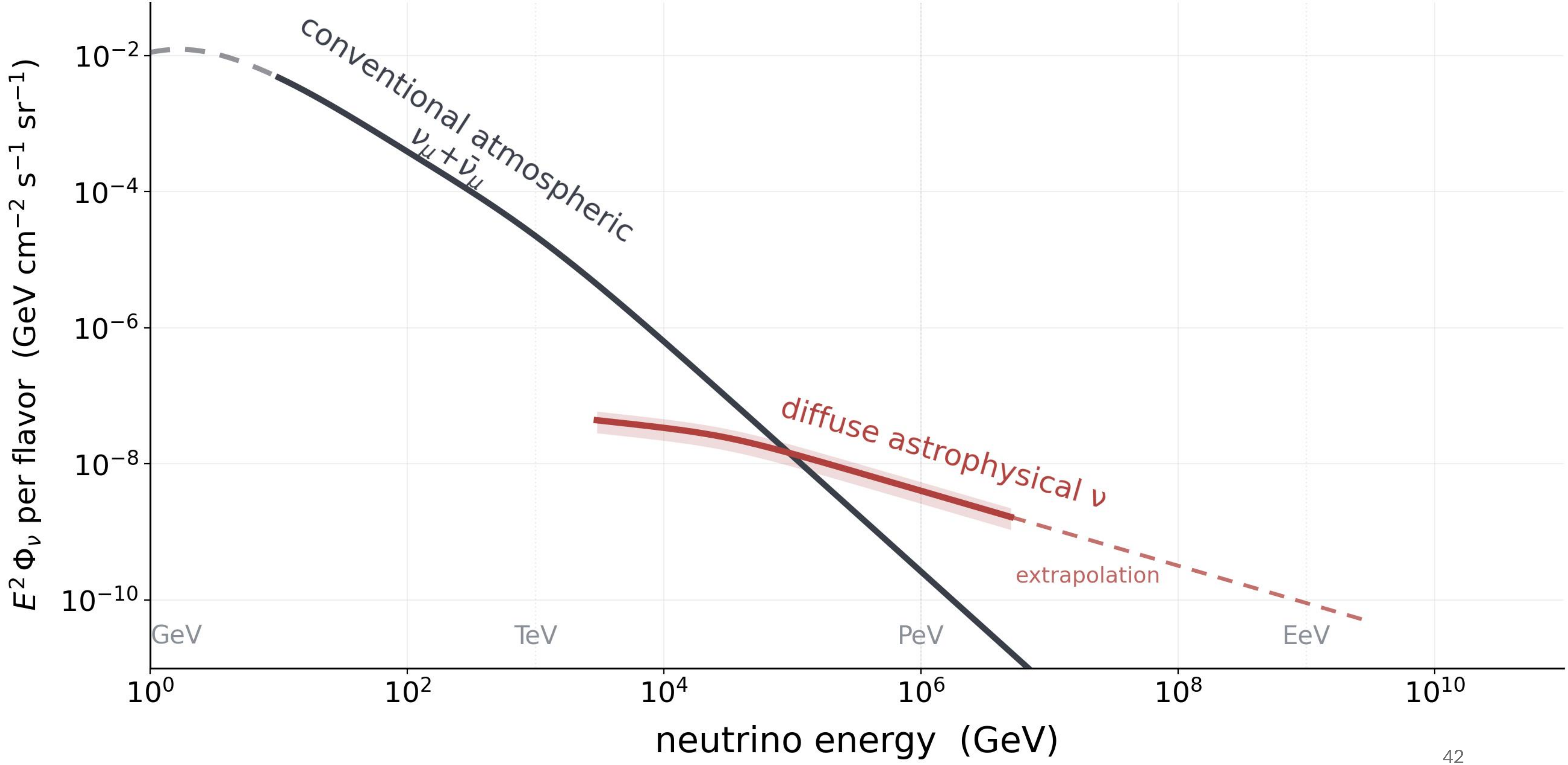
POLARIS: New Taiwan-led sparse Pacific deep-water concept optimized for horizontal multi-TeV–PeV ν_μ tracks.

Auger: See Antonella’s plenary talk on Tuesday.

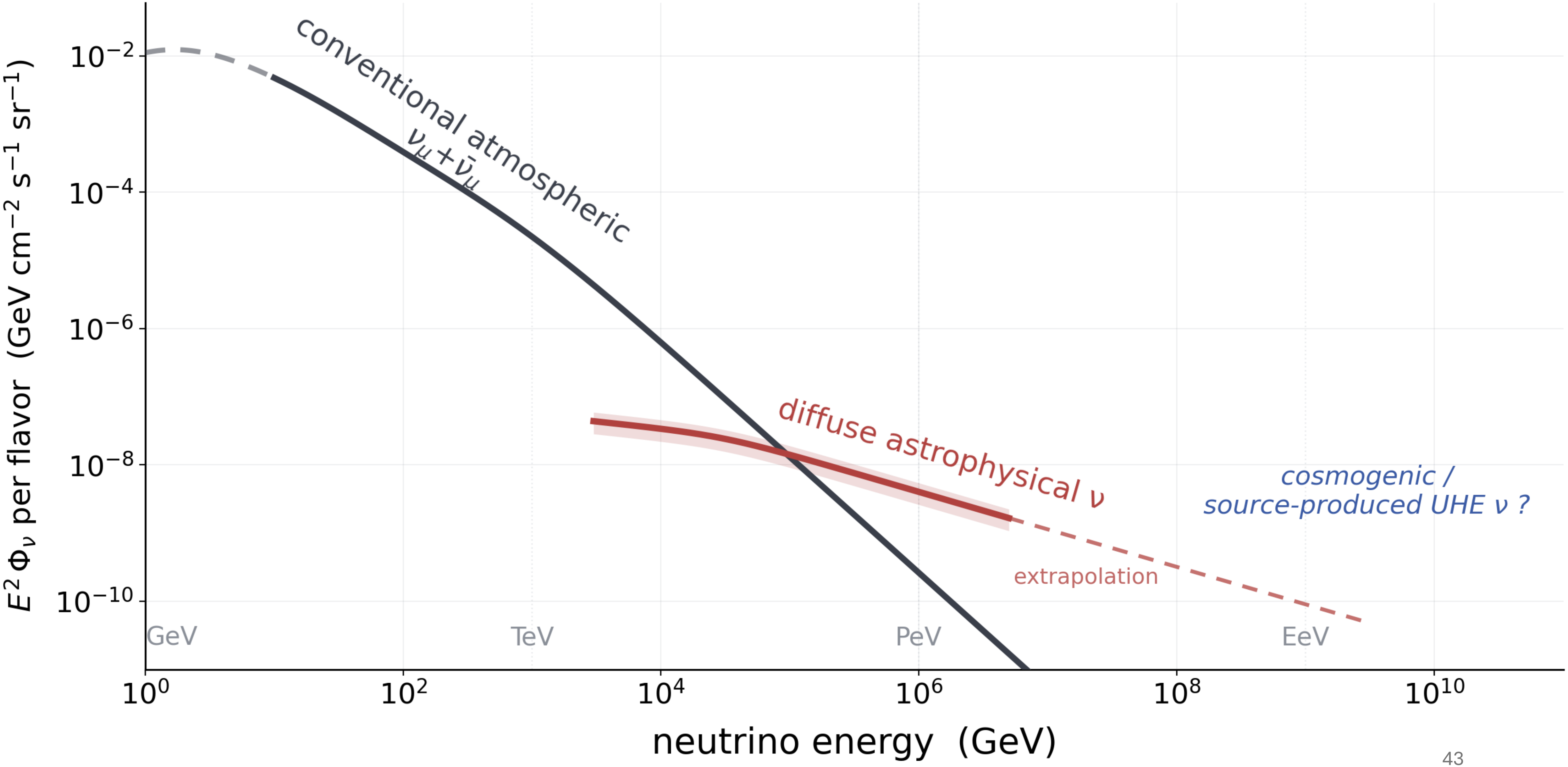

conventional atmospheric
$\nu_\mu + \bar{\nu}_\mu$
$E^2\,\Phi_\nu$ per flavor (GeV cm^{-2} s^{-1} sr^{-1})
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
GeV
TeV
PeV
EeV
10^0
10^2
10^4
10^6
10^8
10^{10}
neutrino energy (GeV)



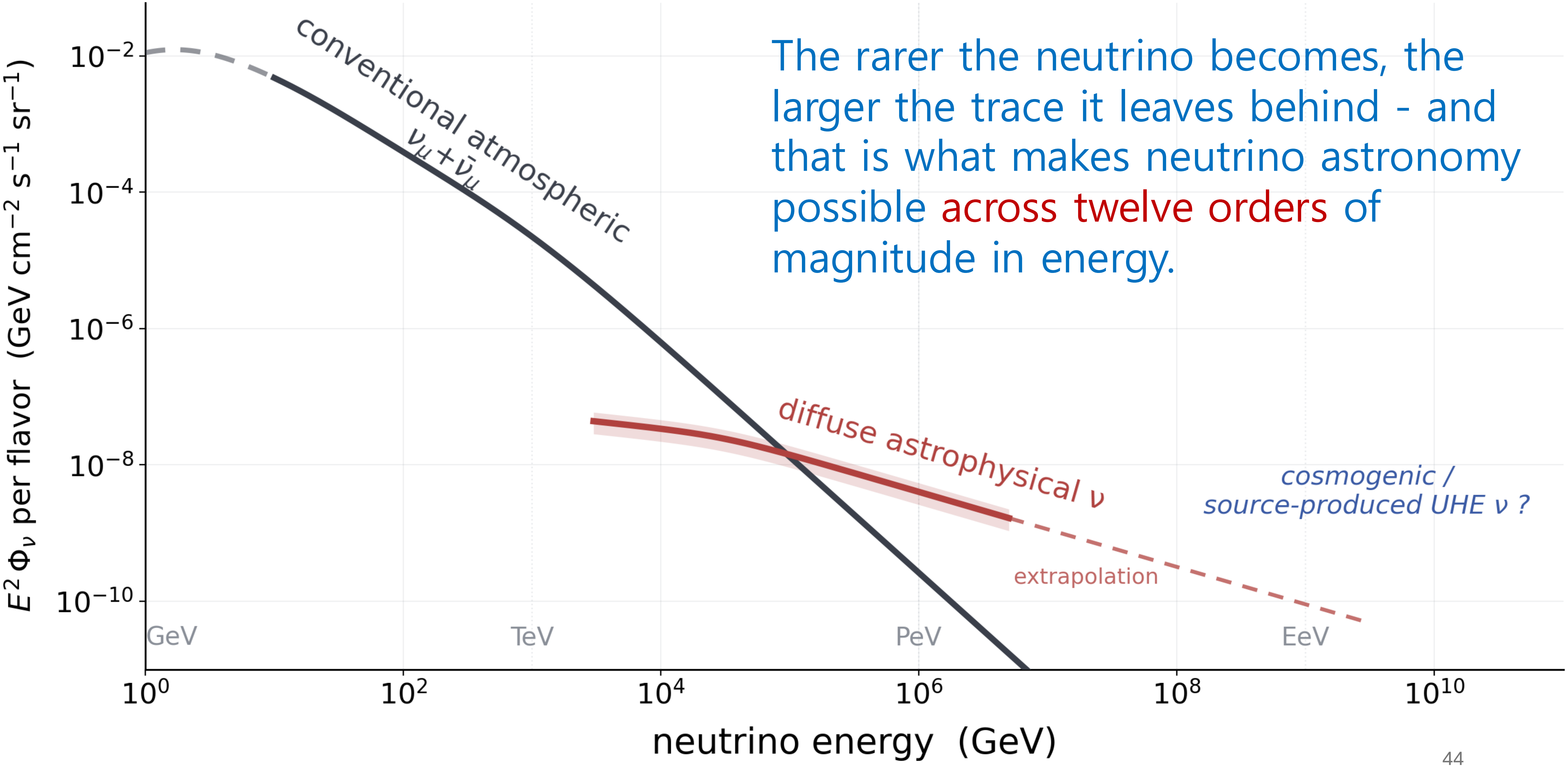
conventional atmospheric
$\nu_\mu + \bar{\nu}_\mu$
diffuse astrophysical ν
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
$E^2\,\Phi_\nu$ per flavor (GeV cm^{-2} s^{-1} sr^{-1})
GeV
TeV
PeV
EeV
10^0
10^2
10^4
10^6
10^8
10^{10}
neutrino energy (GeV)



conventional atmospheric
$\nu_\mu + \bar{\nu}_\mu$
diffuse astrophysical ν
extrapolation
GeV
TeV
PeV
EeV
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^0
10^2
10^4
10^6
10^8
10^{10}
$E^2\,\Phi_\nu$ per flavor (GeV cm^{-2} s^{-1} sr^{-1})
neutrino energy (GeV)



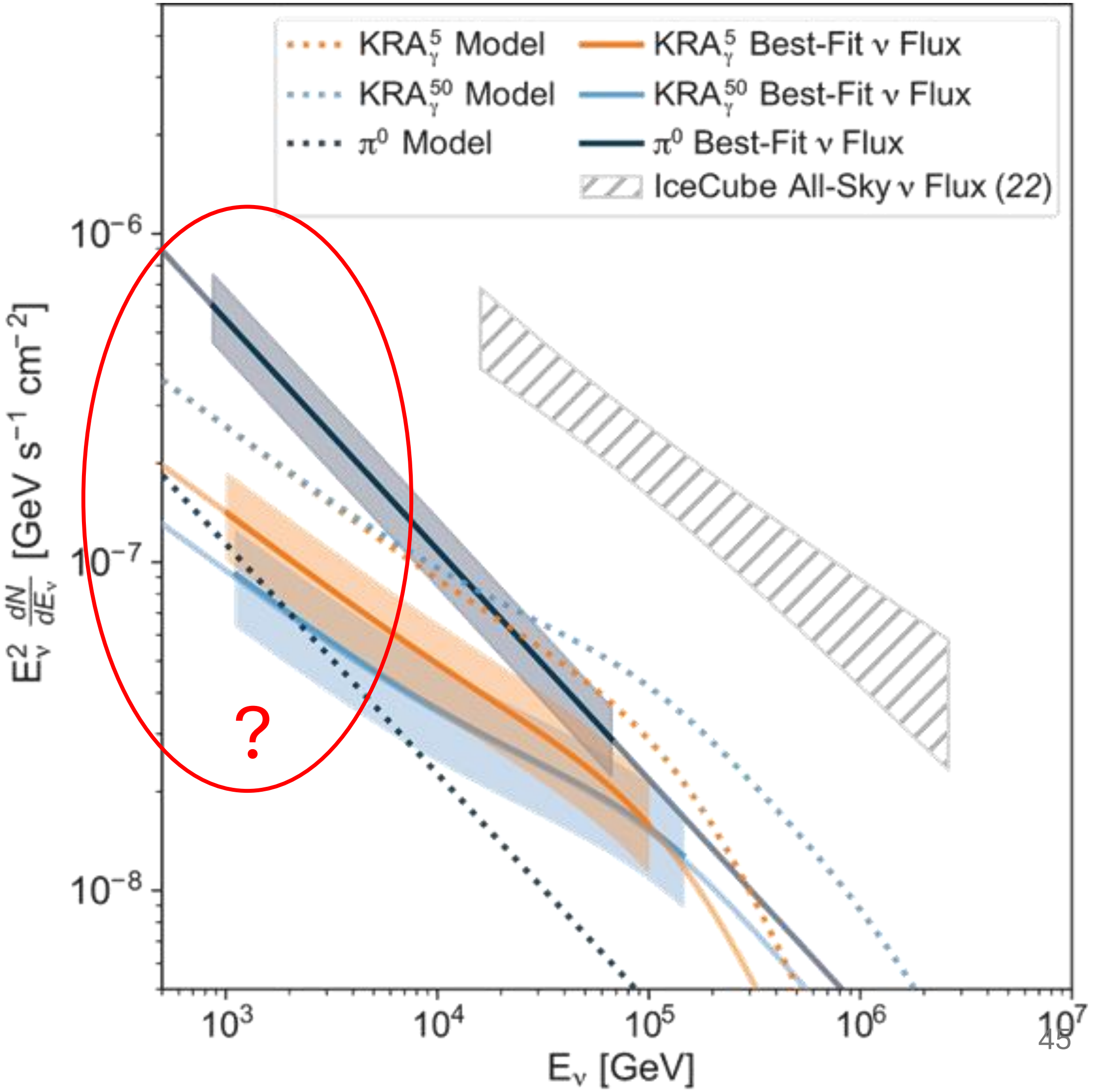
conventional atmospheric
$\nu_\mu + \bar{\nu}_\mu$
diffuse astrophysical ν
extrapolation
cosmogenic /
source-produced UHE ν ?
GeV
TeV
PeV
EeV
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{0}
10^{2}
10^{4}
10^{6}
10^{8}
10^{10}
$E^2\,\Phi_\nu$ per flavor (GeV cm^{-2} s^{-1} sr^{-1})
neutrino energy (GeV)



The rarer the neutrino becomes, the larger the trace it leaves behind - and that is what makes neutrino astronomy possible across twelve orders of magnitude in energy.

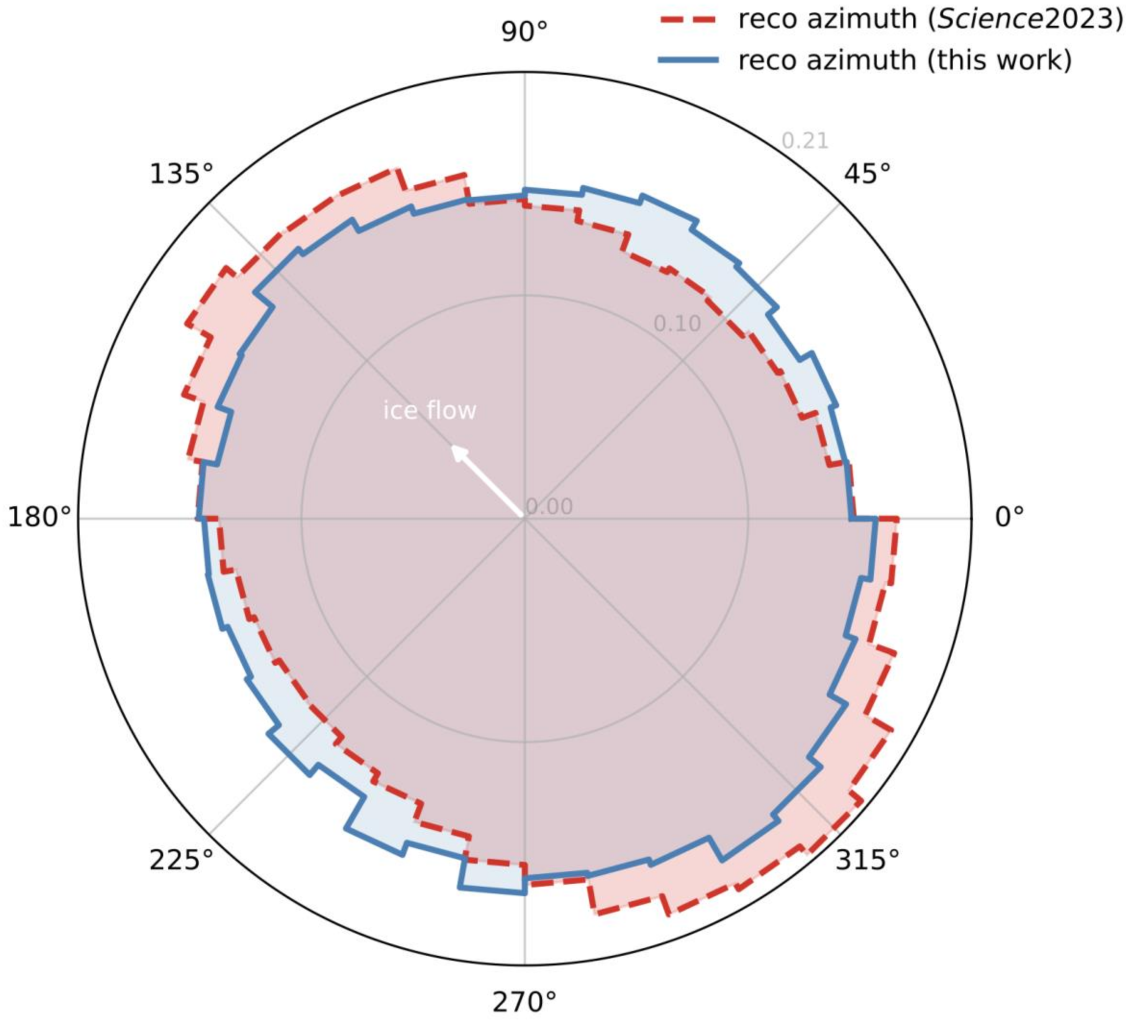
Physics highlight: neutrinos from our Galaxy

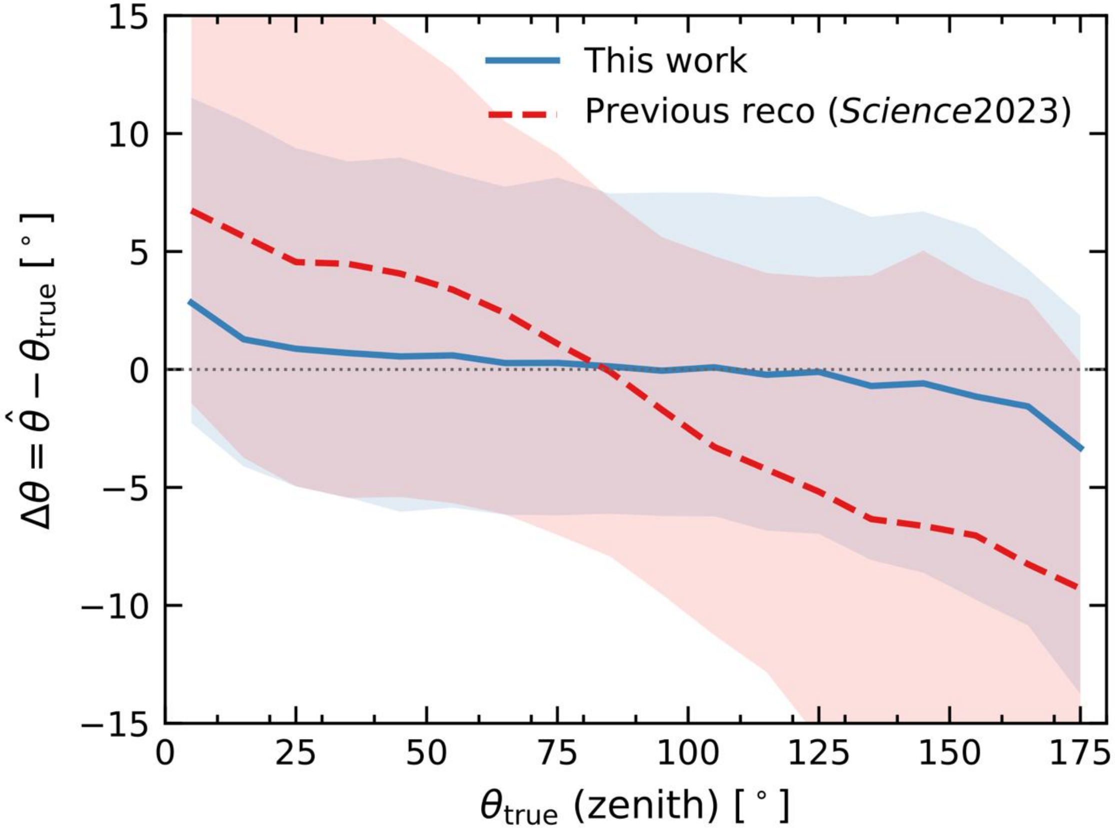
Science 380, 6652, 1338-1343 (2023)



arXiv:2607.25966

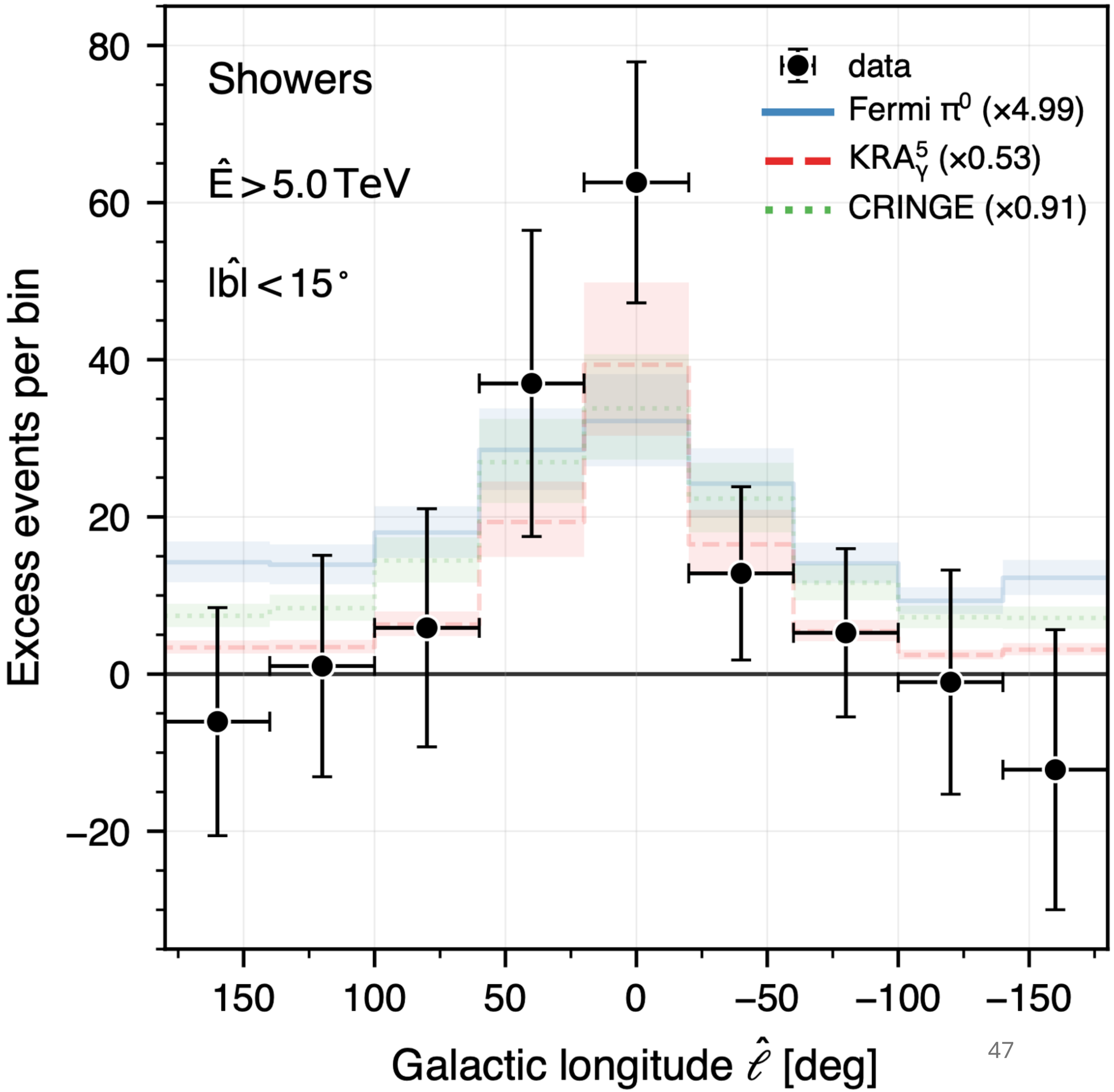
New: Improved shower direction reconstruction





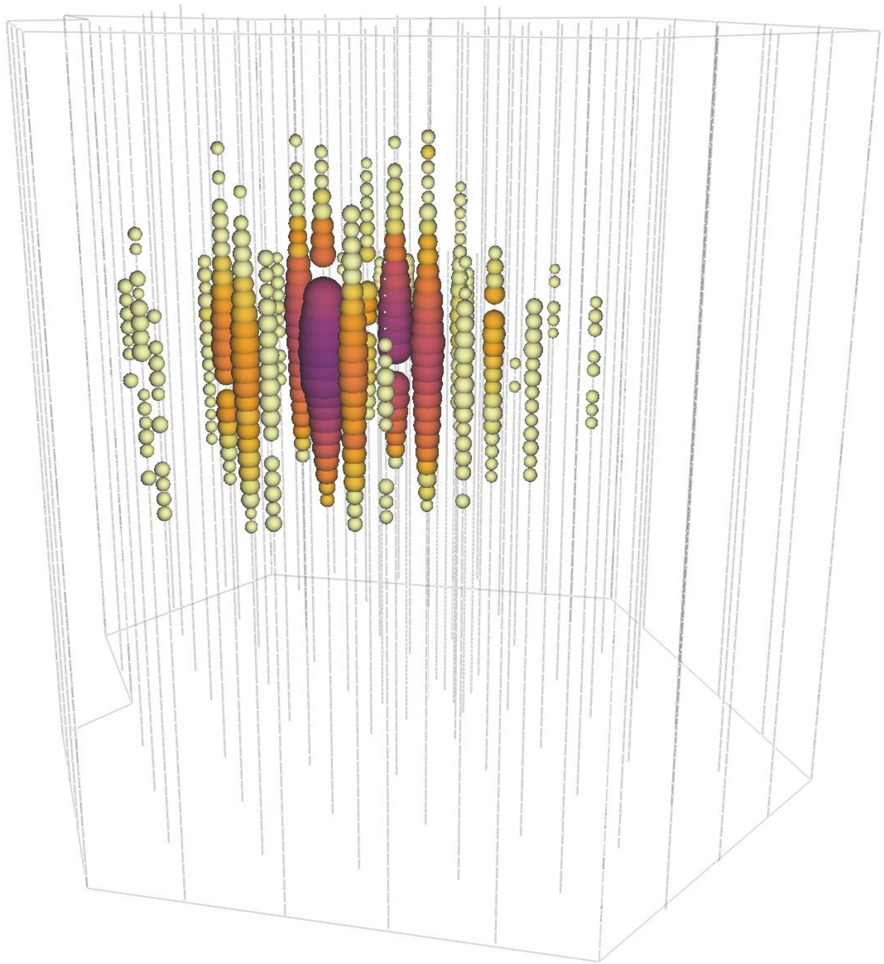
arXiv:2607.25966

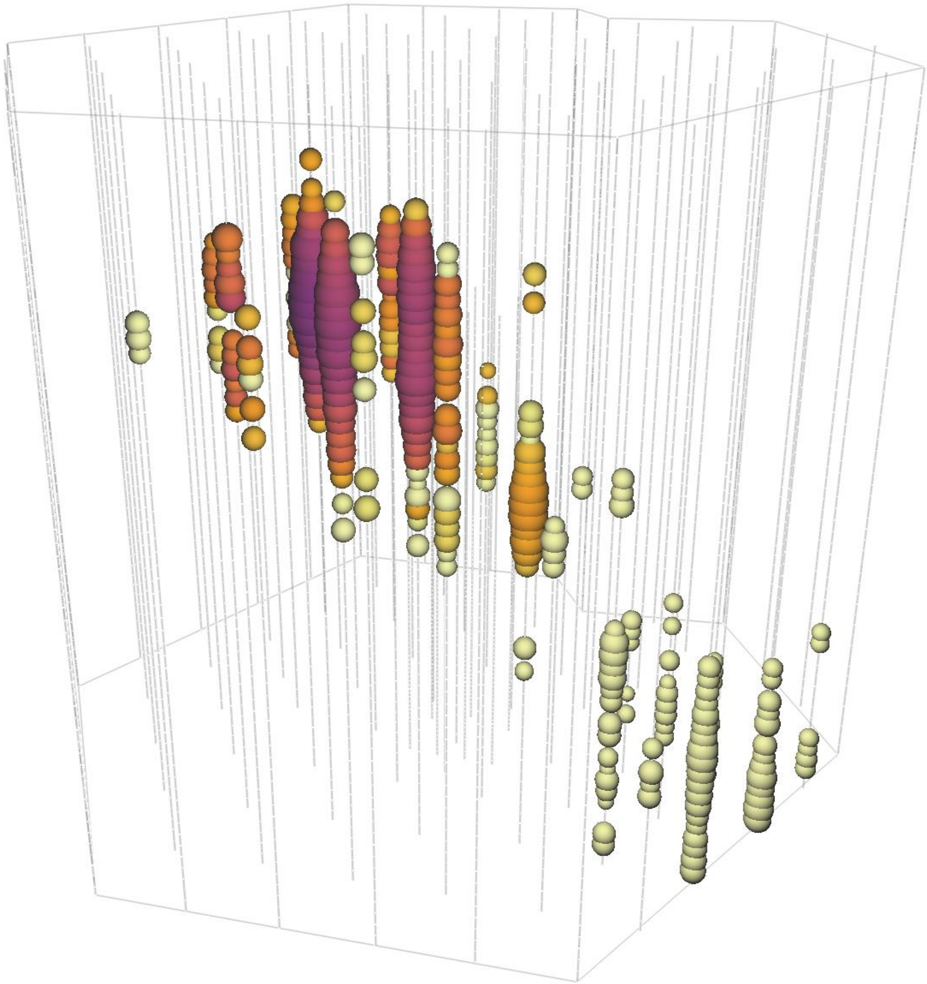
- Model independent
- Subtract background in off-plane region
- Data excess in the inner galaxy, where fitted models agree although significantly different pre fit

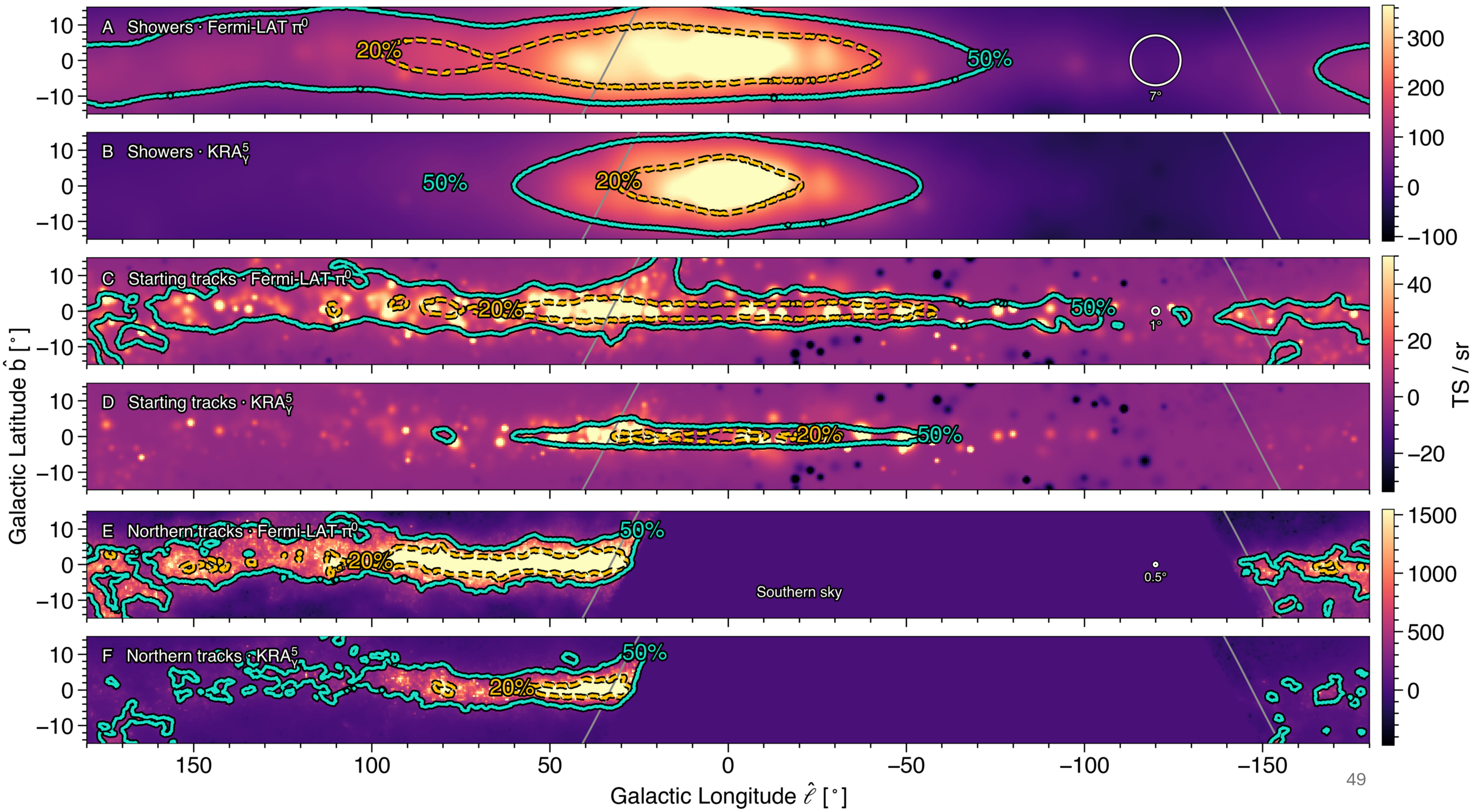


arXiv:2607.25966

New: all-flavor with inclusion of beyond showers

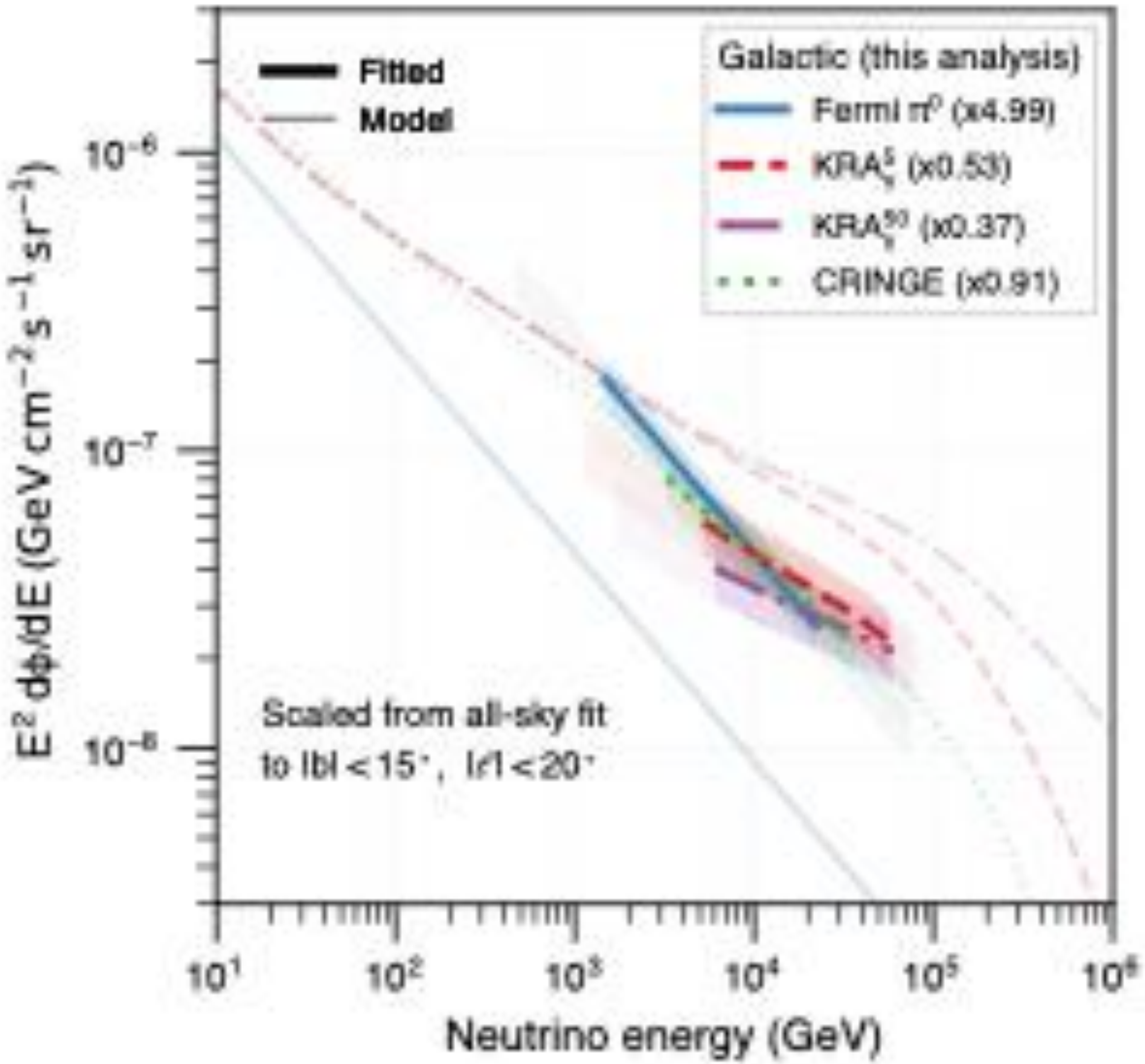






A Showers · Fermi-LAT π⁰
B Showers · KRA$_\gamma^5$
C Starting tracks · Fermi-LAT π⁰
D Starting tracks · KRA$_\gamma^5$
E Northern tracks · Fermi-LAT π⁰
F Northern tracks · KRA$_\gamma^5$
20%
50%
7°
1°
0.5°
Southern sky
Galactic Latitude $\hat{b}$ [°]
Galactic Longitude $\hat{\ell}$ [°]
TS / sr
150 100 50 0 −50 −100 −150
10 0 −10
300 200 100 0 −100
40 20 0 −20
1500 1000 500 0

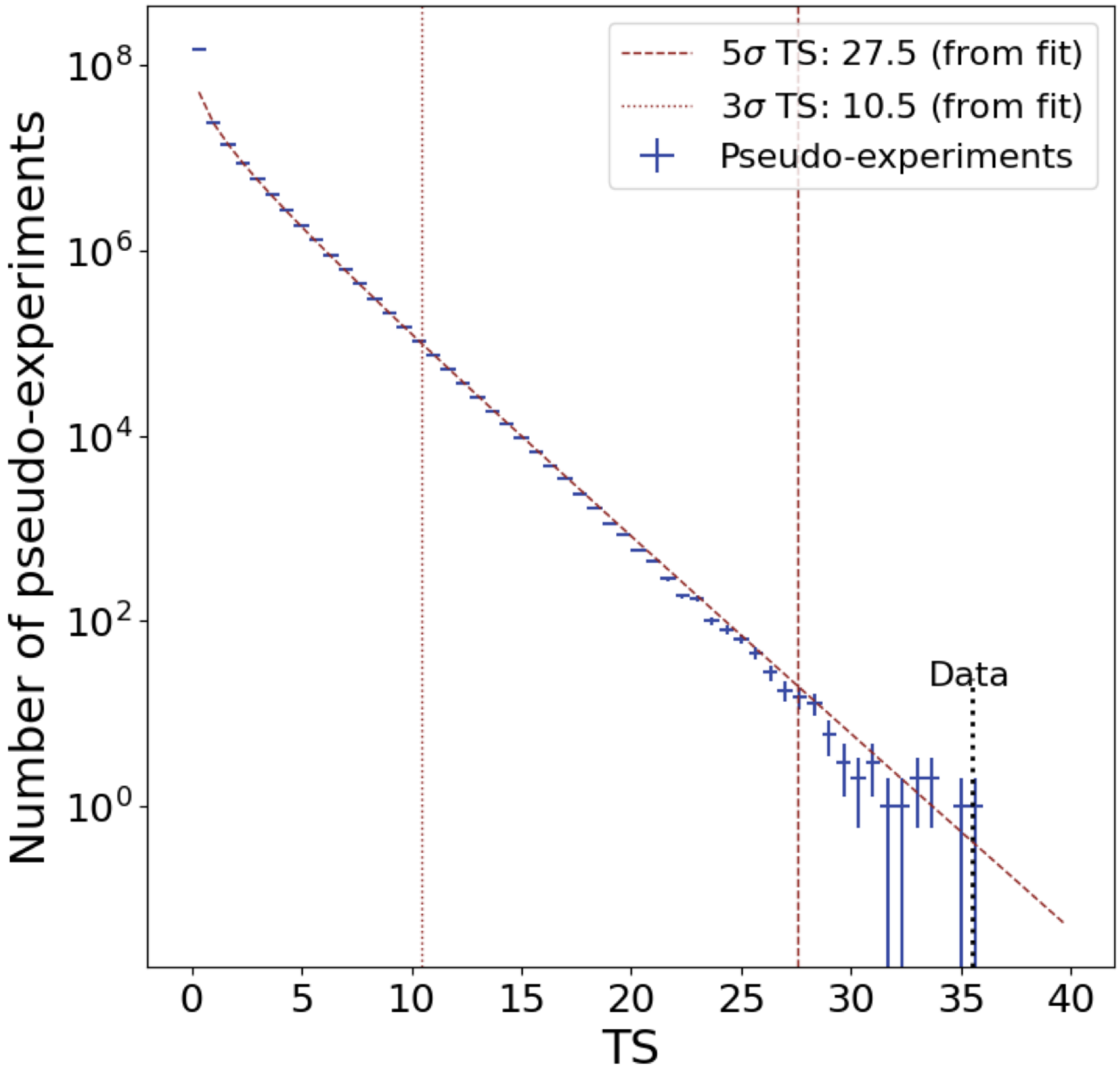
arXiv:2607.25966



Previous result 10 year cascades (Science 2023) post trial p value= 3.4×10^{-6}

New result 12 year all-flavor post trial (over four galactic templates) p value $=6 \times 10^{-9}$

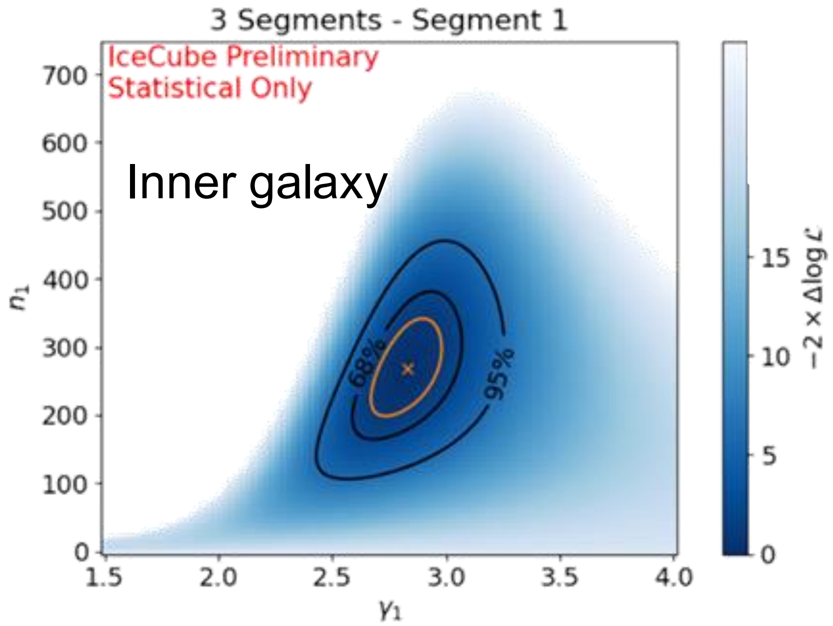
That corresponds to 5.7σ!

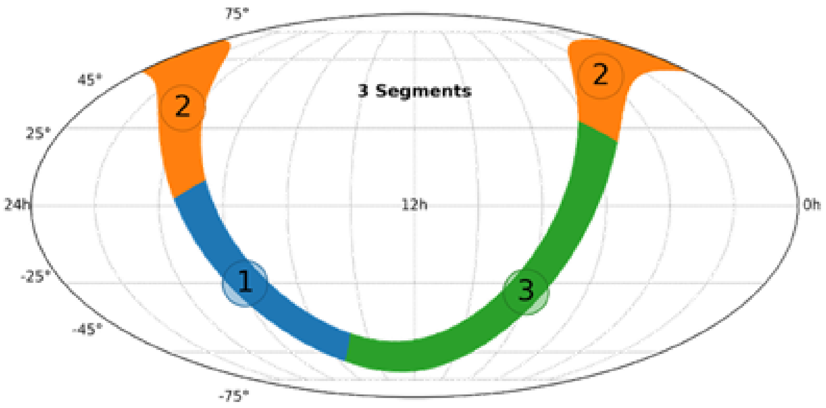


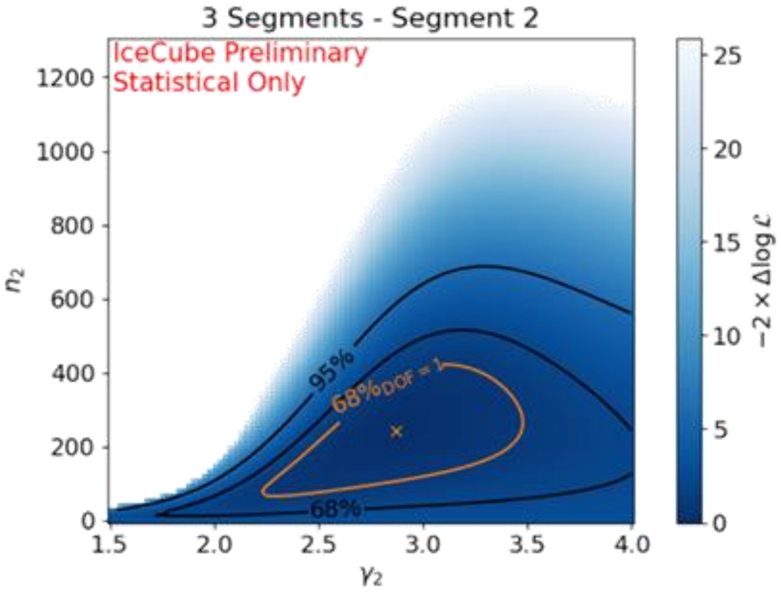
Spatially segmented flux

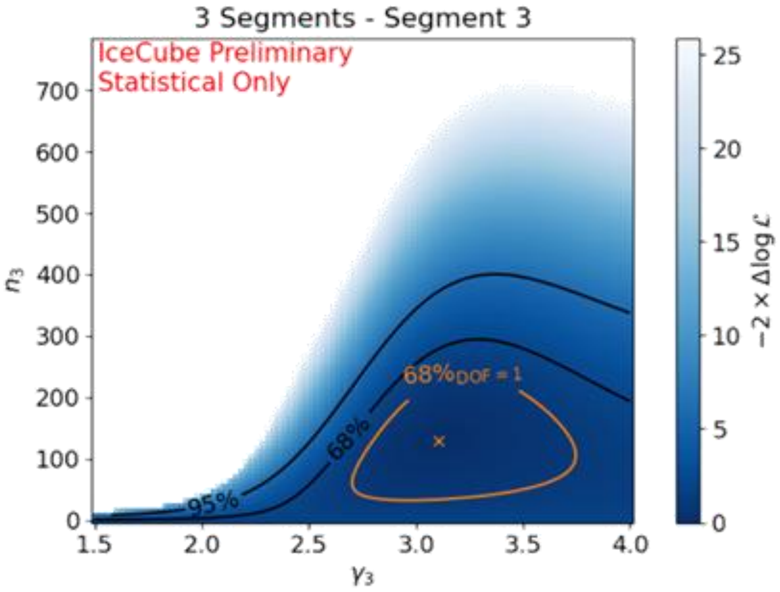
Ludwig Neste PoS-ICRC2025-1130 and this conference

- Inner galaxy flux well constrained
- Outer galaxy flux norm consistent with 0



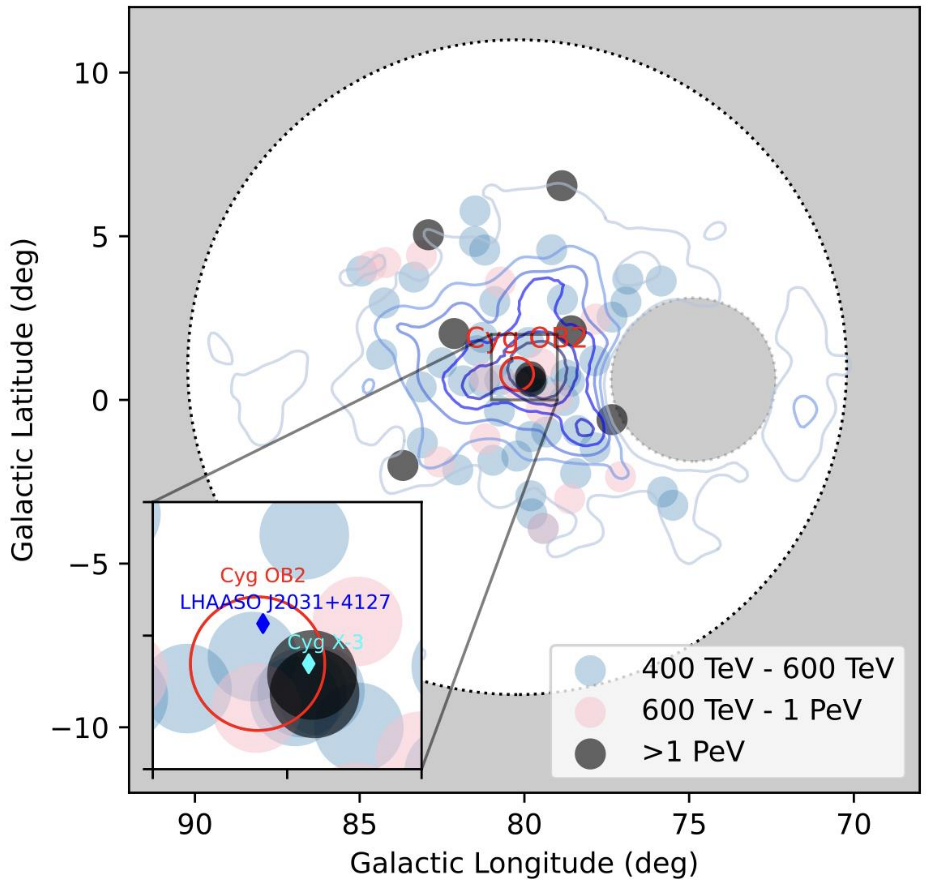




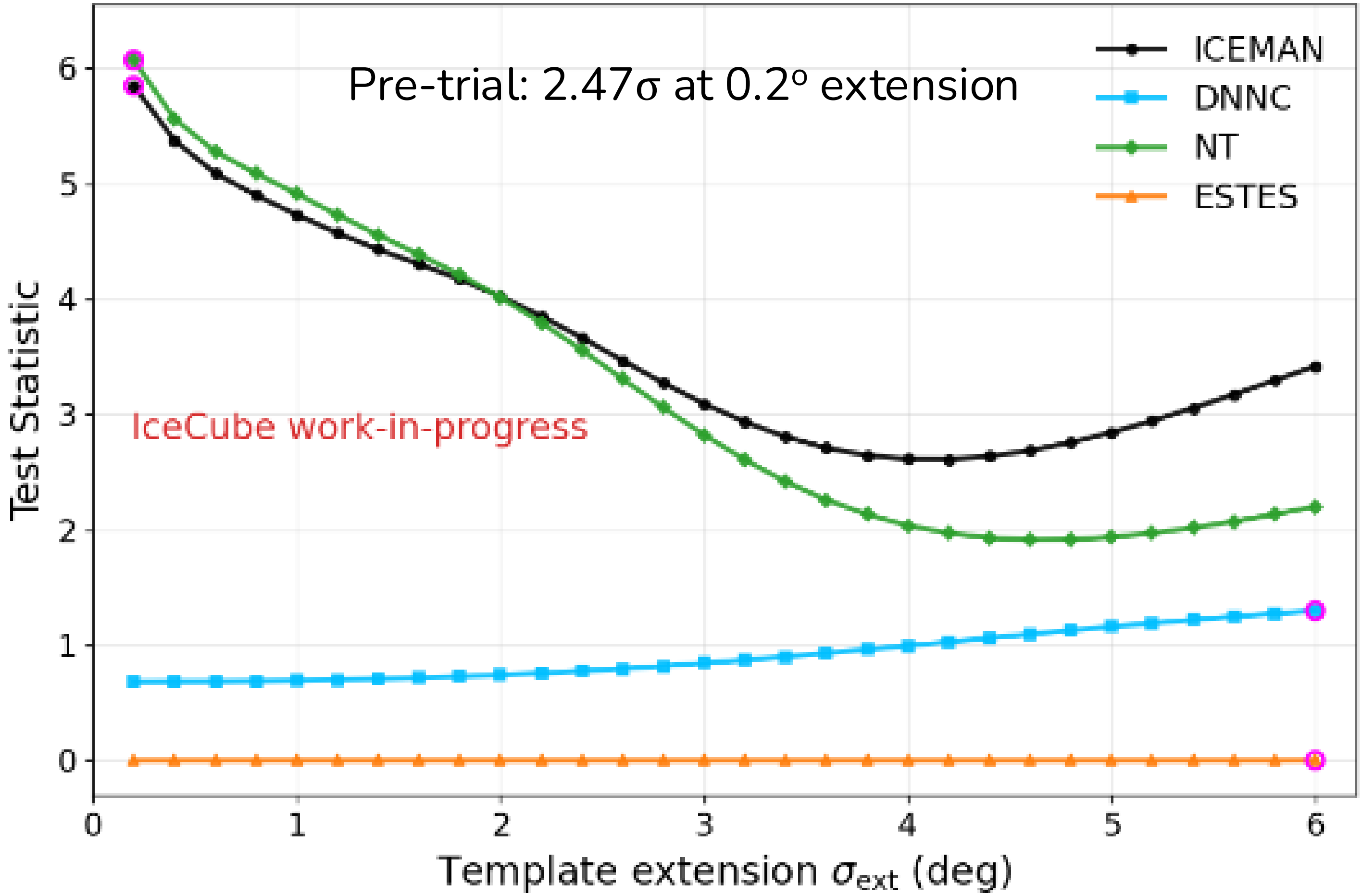


PeVatrons or diffuse emissions?

Leo Seen, Yuhua Yao et al, this conference

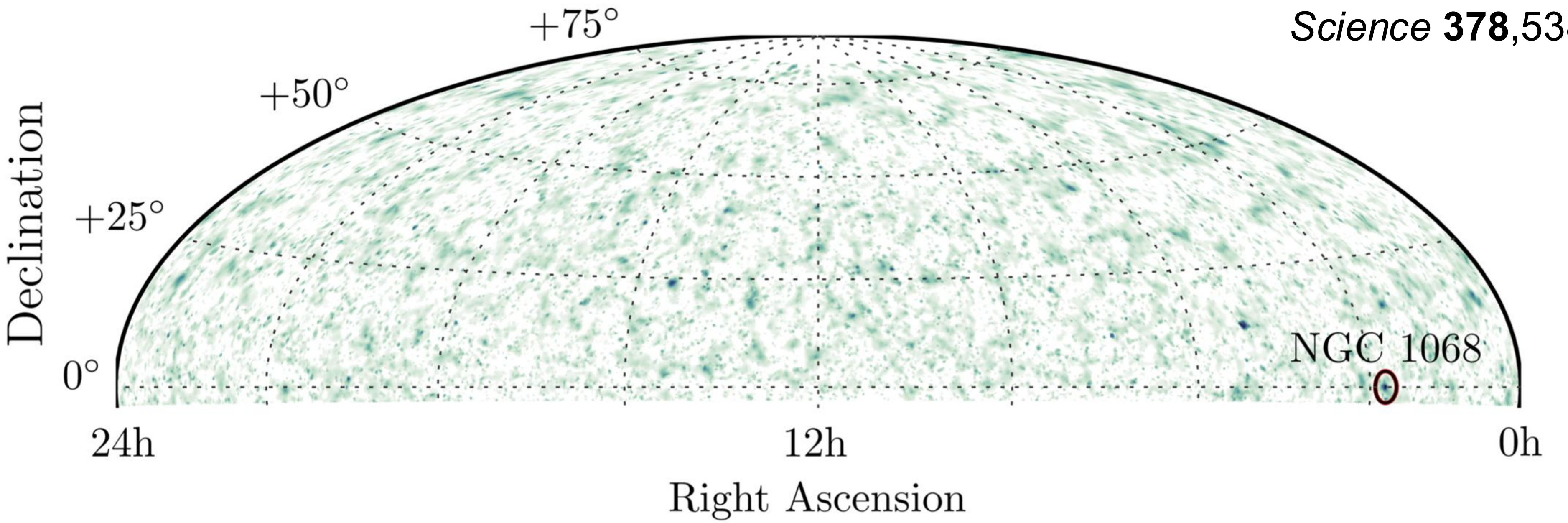


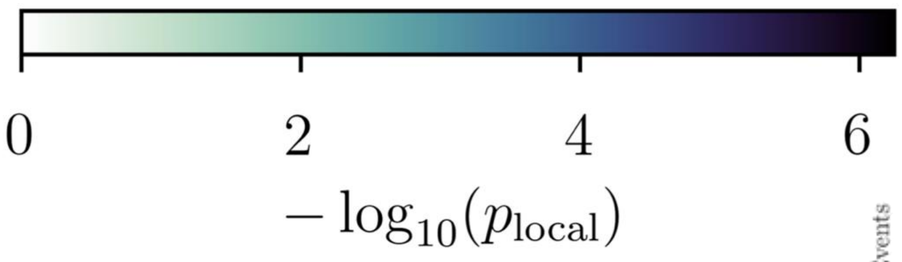
LHAASO Collaboration
Science bulletin, Volume 69, Issue 4, 2024

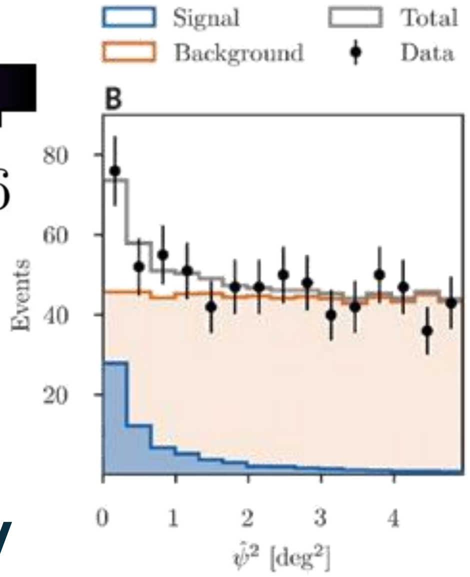


Ultra-high-energy gamma follow ups work in progress

Science **378**,538-543 (2022)



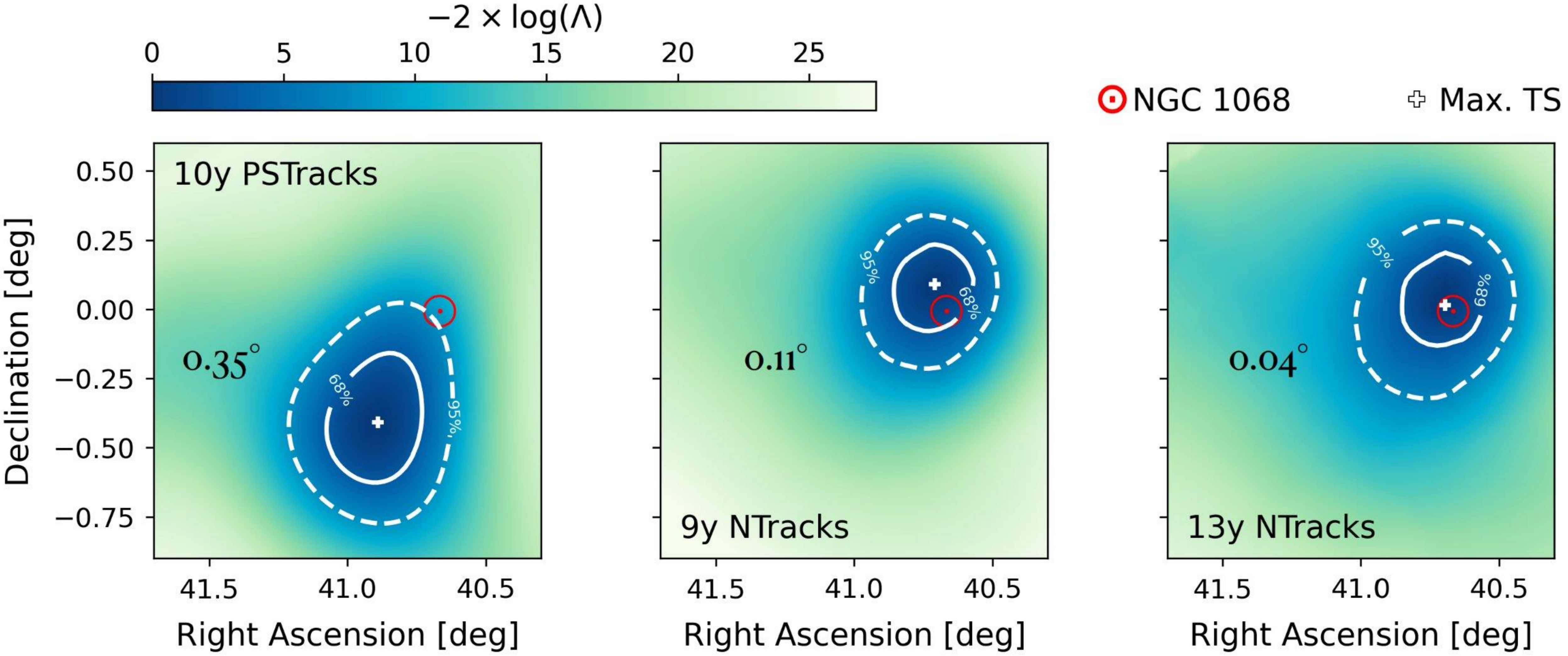




- Tracks (muon, tau) from the Northen sky provide highest sensitivities for~TeV point sources
- NGC1068: the brightest point source
- Astrophysical neutrino events = 79 (+22 -20)
- 5.2σ pre trial and 4.2σ post trial

Looking further than our galaxy

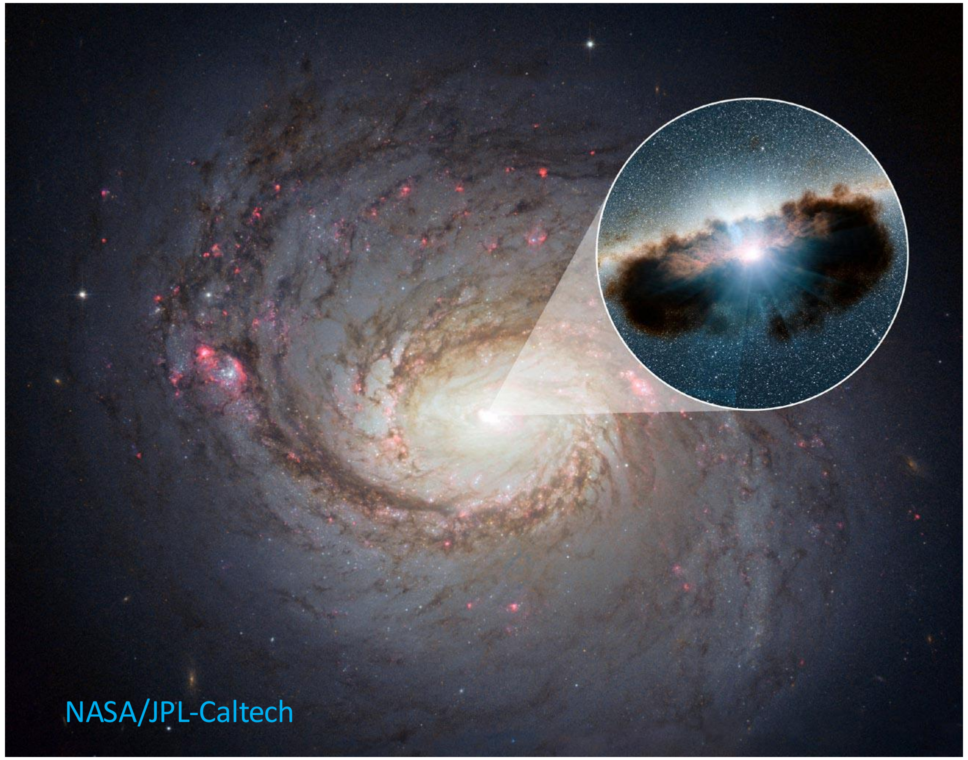
New result: hotspot gets closer to NGC1068



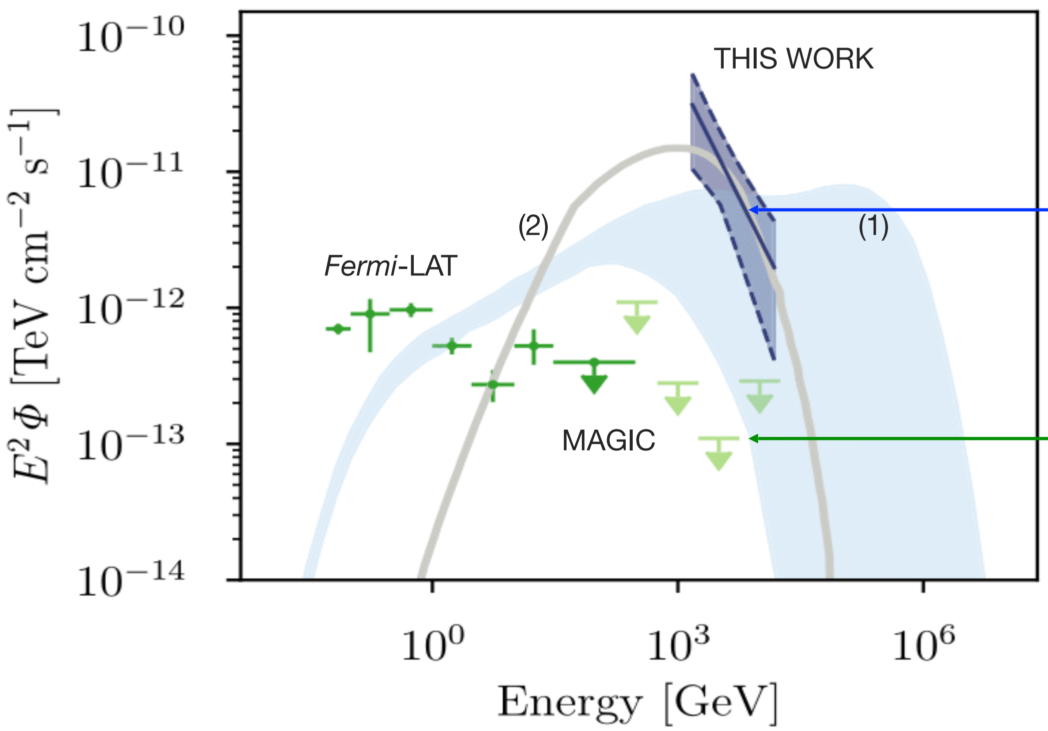
ApJL 1000 L26 (2026)

Gamma-ray obscured

~14 Mpc, $\mathrm{Log}L_X$ 2-10keV~42.9 erg/s



Gamma Rays (photons) and Neutrinos



We know that neutrinos and gamma rays are produced together

Neutrinos are coming out

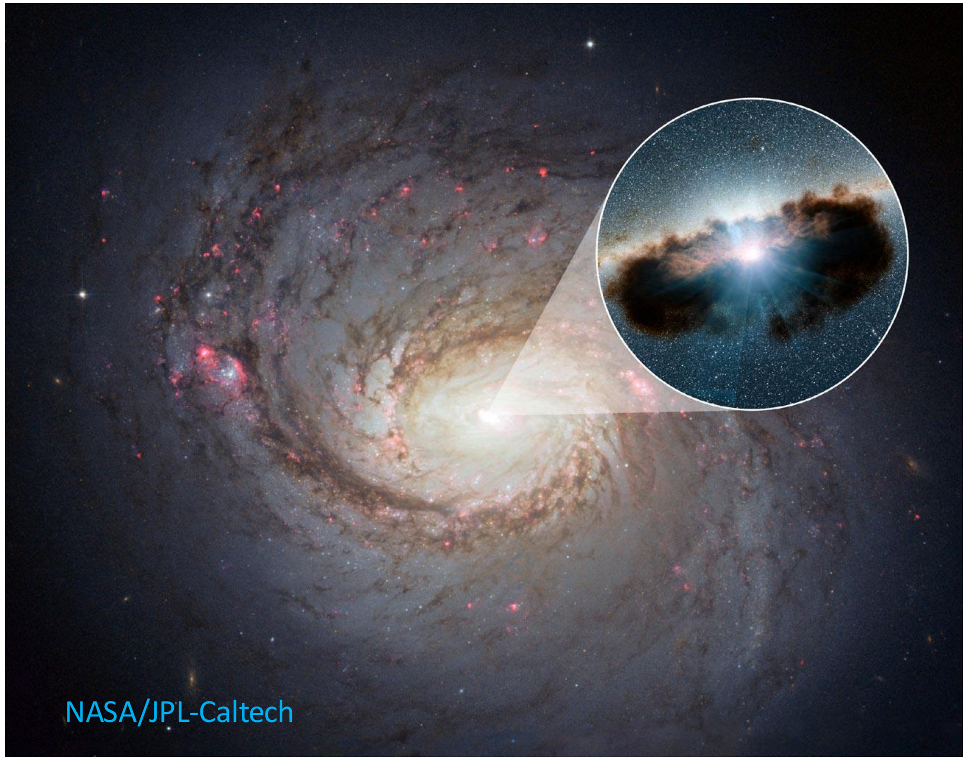
Gamma rays are missing
- and it is not a surprise.

(1) Y. Inoue et al., ApJL'20
(2) K. Murase et al., PRL'20

Neutrinos escape dense gas region: excess neutrinos but gamma rays are attenuated / absorbed

X-ray bright

~14 Mpc, $\mathrm{Log}L_X$ 2-10keV~42.9 erg/s



PeV scaled protons naturally interact with keV photons in mildly relativistic sources.

$$p + \gamma \rightarrow \Delta^+ \rightarrow N + \pi$$

$$\varepsilon\gamma \simeq 1.4\ \mathrm{keV} \cdot (\mathrm{Ep} / 1\ \mathrm{PeV})^{-1} \cdot (\Gamma / 3)^2$$

$$\pi^+ \rightarrow \mu^+ + \nu\mu$$
$$\mu^+ \rightarrow e^+ + \nu e + \bar{\nu}\mu$$

$$\mathbf{E\nu \approx 0.05\ Ep}$$

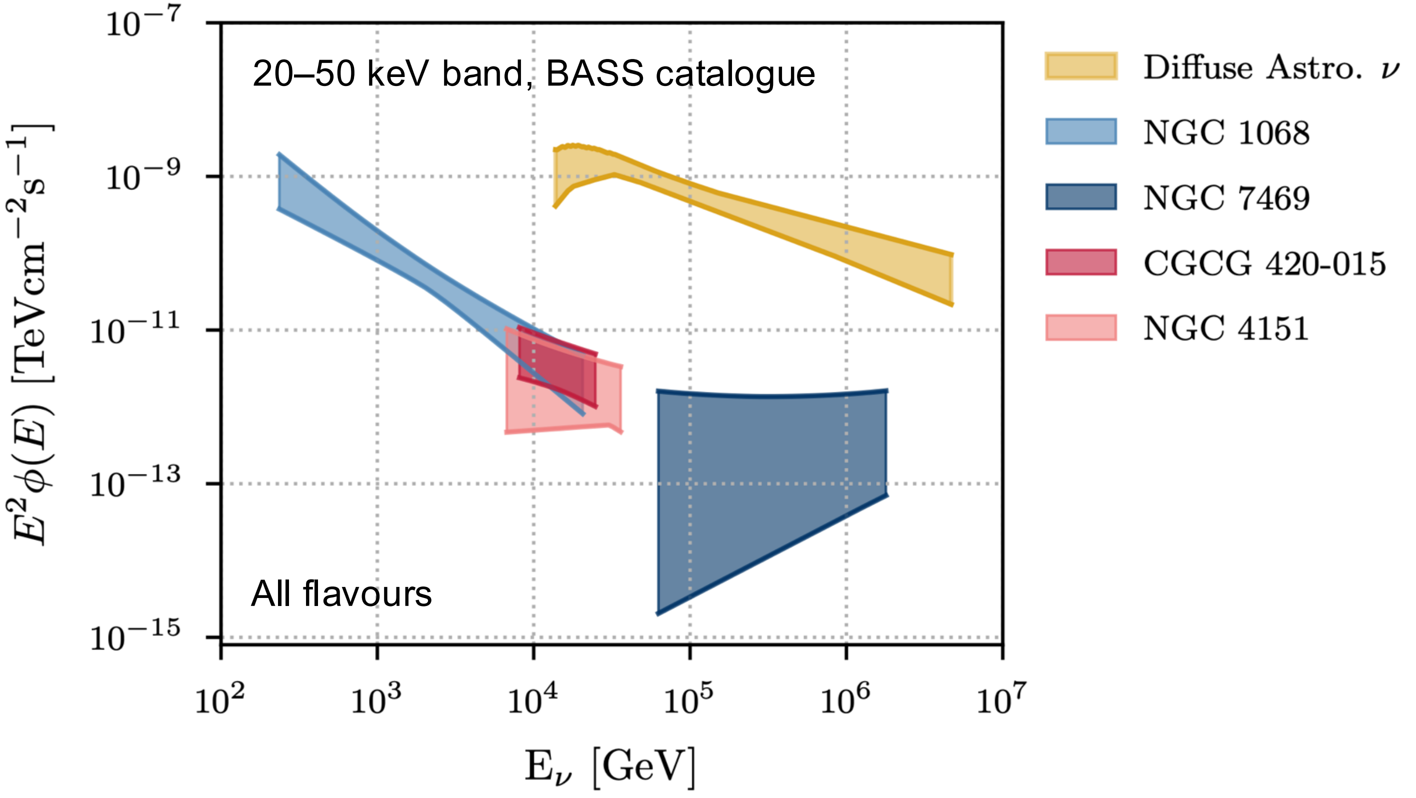
Ep ~ 1 PeV → Ev ~ 50 TeV

X-rays can be both a target photon field and an observable counterpart.

X-ray bright Seyfert (non-jetted) galaxy

* 3.3σ over binomial test (11 sources, excluding NGC1068)

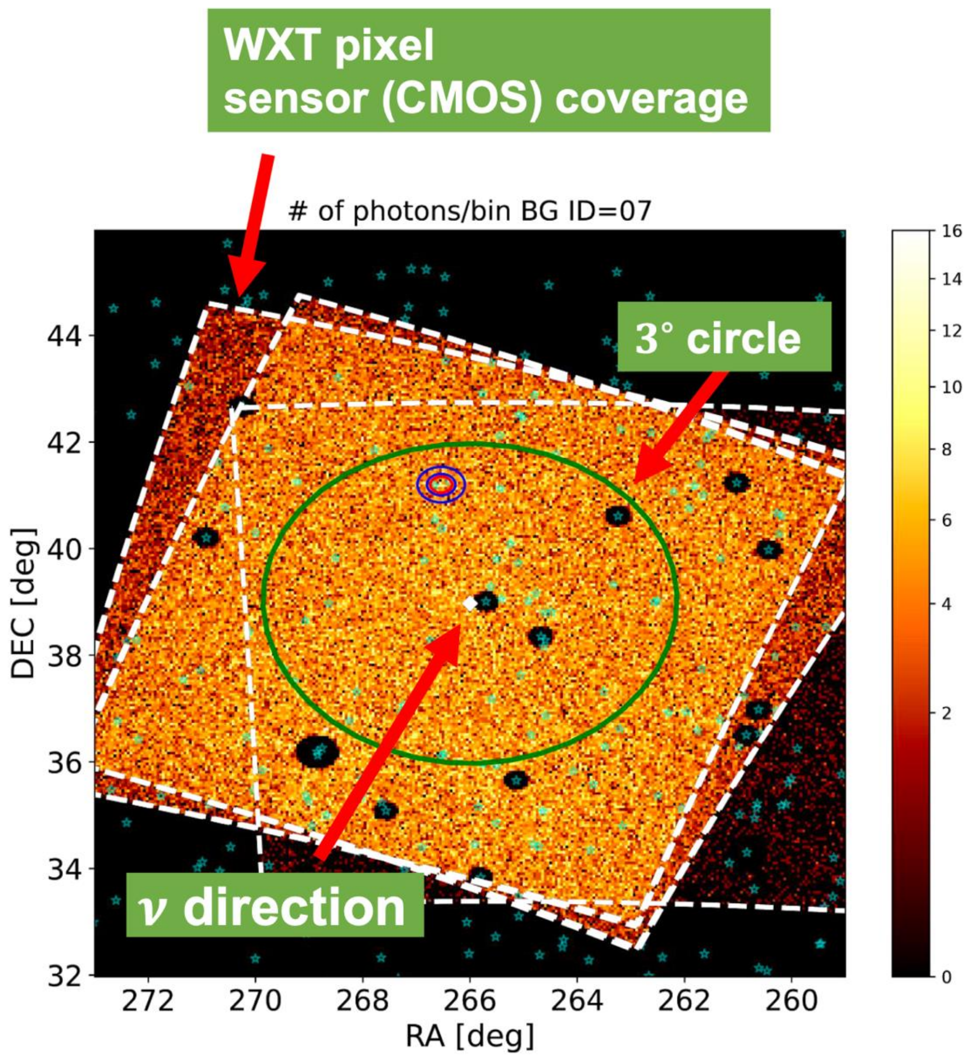
NGC 7469	345.82	8.87	5.5	1.9	4.1 (3.8σ)
11 Sources					4.8 (4.2σ)
NGC 4151	182.64	39.41	27.6	2.7	2.9 (3.1σ)
CGCG 420-015	73.36	4.06	35.3	2.7	2.4 (2.7σ)
Cygnus A	299.87	40.73	3.4	1.6	2.2 (2.5σ)
LEDA 166445	42.68	54.70	57.1	4.4	1.8 (2.1σ)
NGC 4992	197.27	11.63	27.3	2.9	1.6 (2.0σ)
NGC 1194	45.95	−1.10	43.2	4.4	1.5 (1.8σ)
Mrk 1498	247.02	51.78	39.9	3.6	1.4 (1.7σ)
MCG +4-48-2	307.15	25.73	36.7	3.2	1.4 (1.7σ)
NGC 3079	150.49	55.68	33.8	3.6	1.3 (1.7σ)
Mrk 417	162.38	22.96	4.4	2.0	1.3 (1.6σ)



Shimizu Nobuhiro, this conference

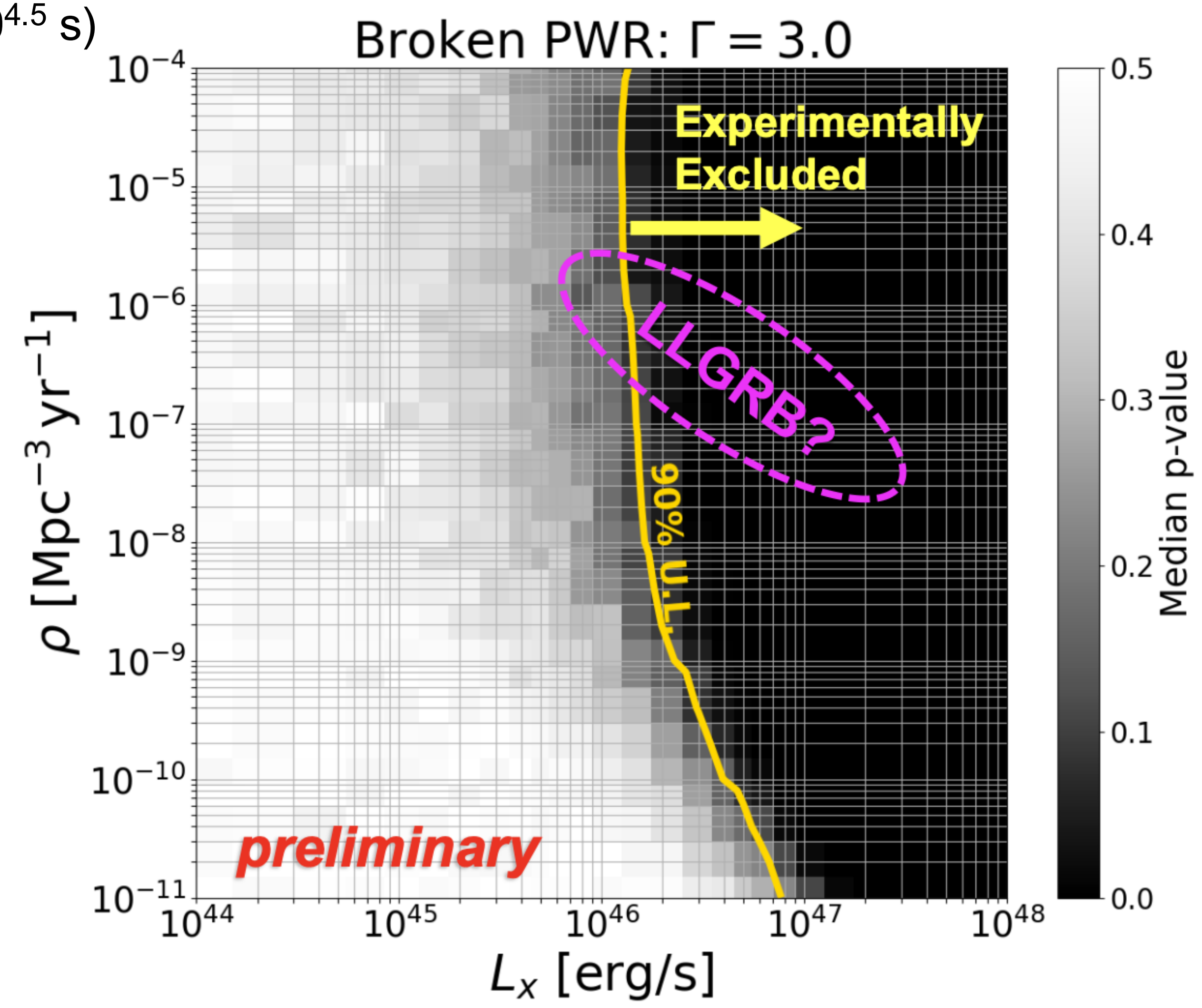
Transient search with X-ray

(Einstein Probe from July 2024, $\pm 10^3$ s and $\pm 10^{4.5}$ s)



No X-ray signal found in time*spatial coincidence

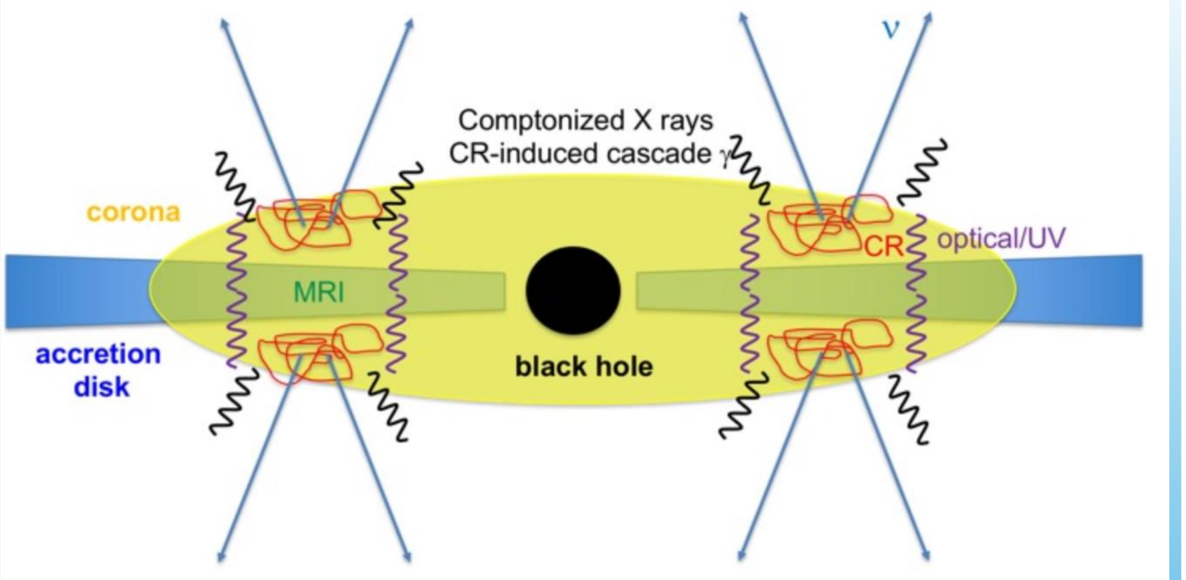
Short time scale transients (10^3 s)



Strongly disfavors p+γ transients as origins of neutrinos in broad range of phase space.

Possible linking gamma-ray obscured X-ray bright populations with extragalactic diffuse flux

$$E_p\,\varepsilon_\gamma \approx \frac{m_\Delta^2 - m_p^2}{4} \approx 0.2\ \mathrm{GeV}^2 \qquad E_\nu\,\varepsilon_\gamma \approx 10^{-2}\ \mathrm{GeV}^2$$

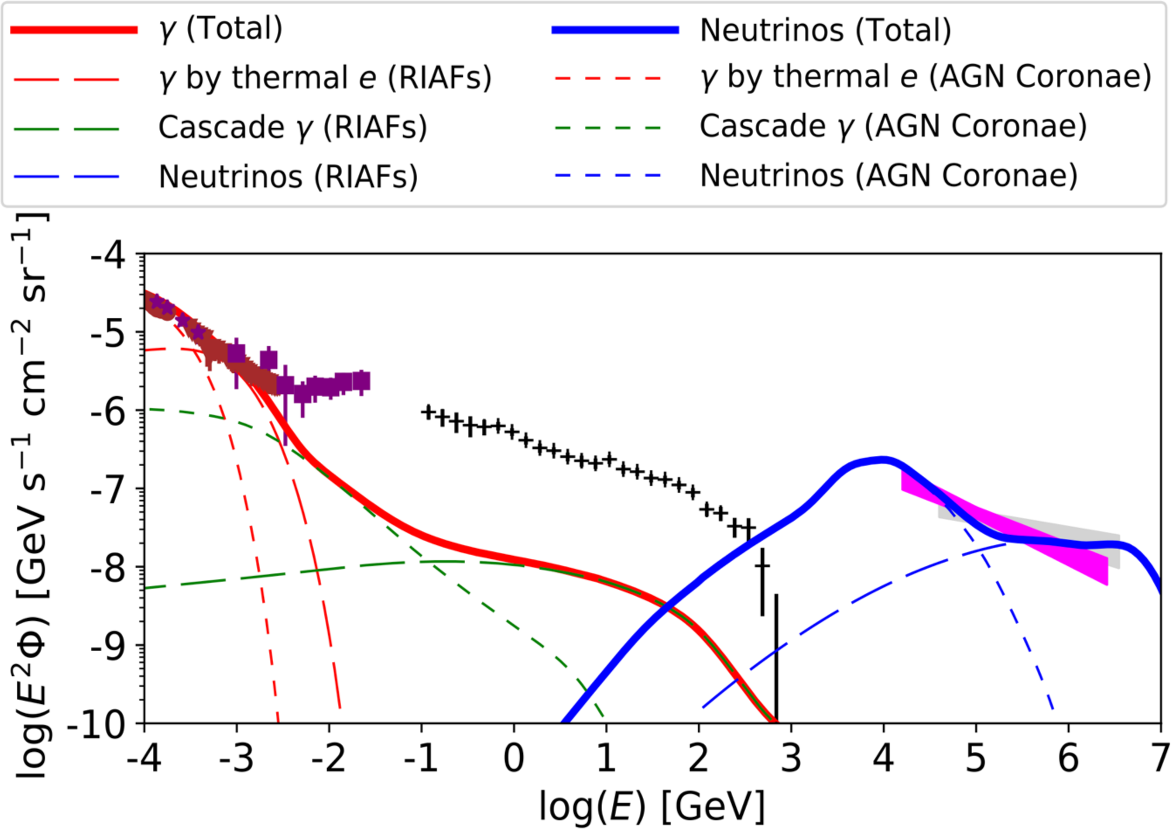


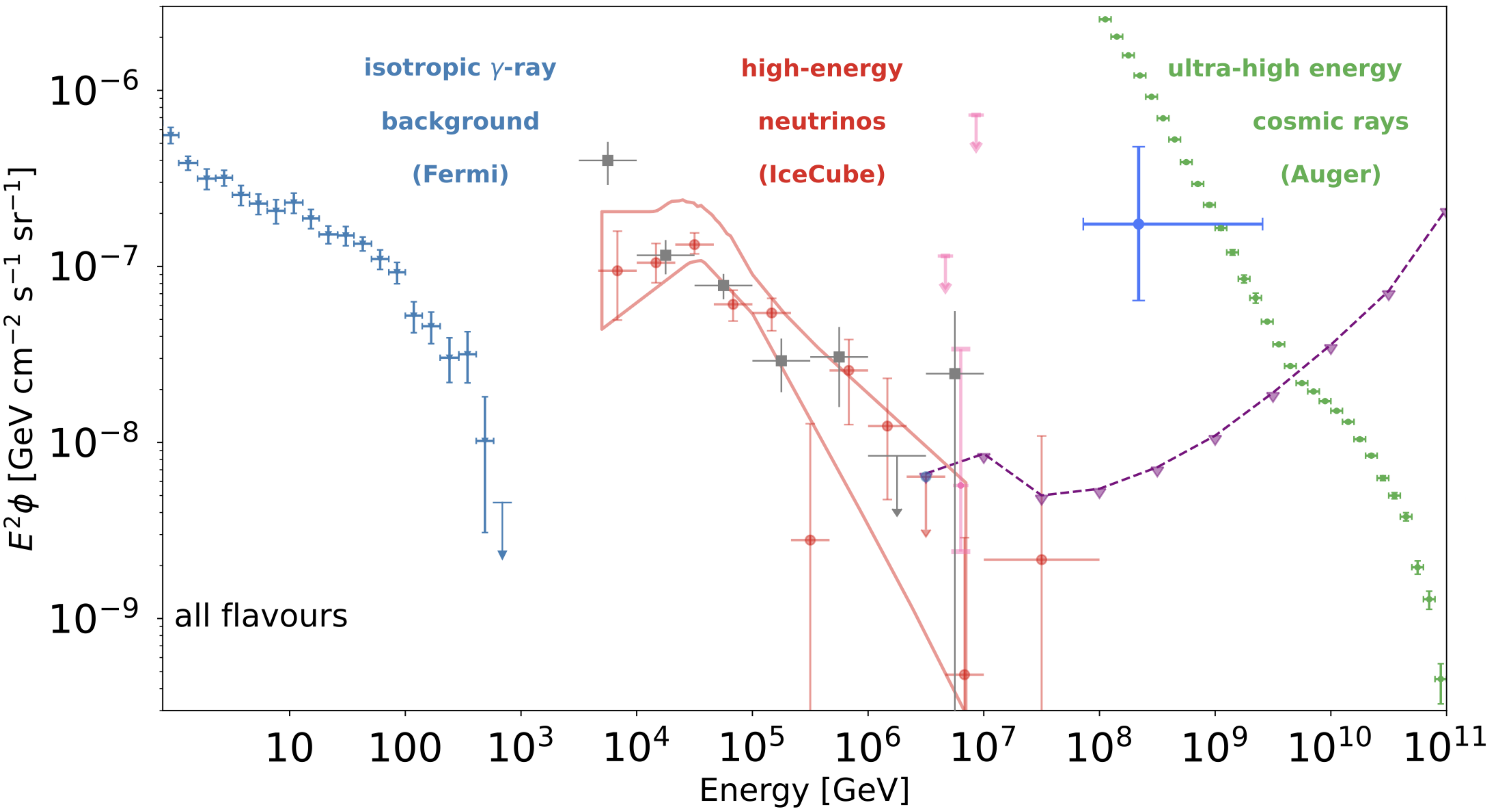
accretion disk + "corona"

opt/UV=multi-temperature blackbody

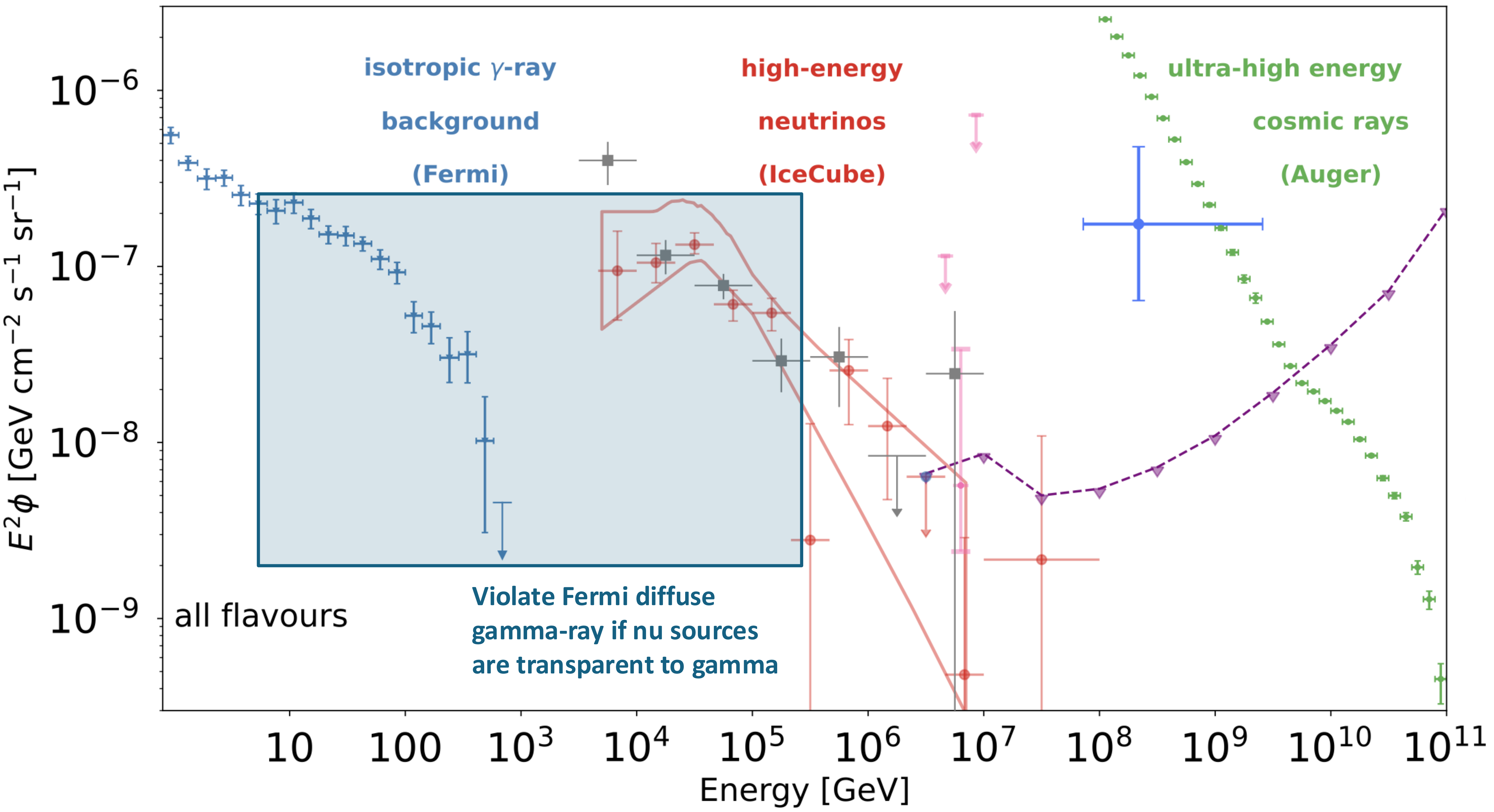
X-ray=Compton by thermal electrons

KM, Kimura & Meszaros 20 PRL
Kimura, KM & Meszaros 21 Nature Comm.

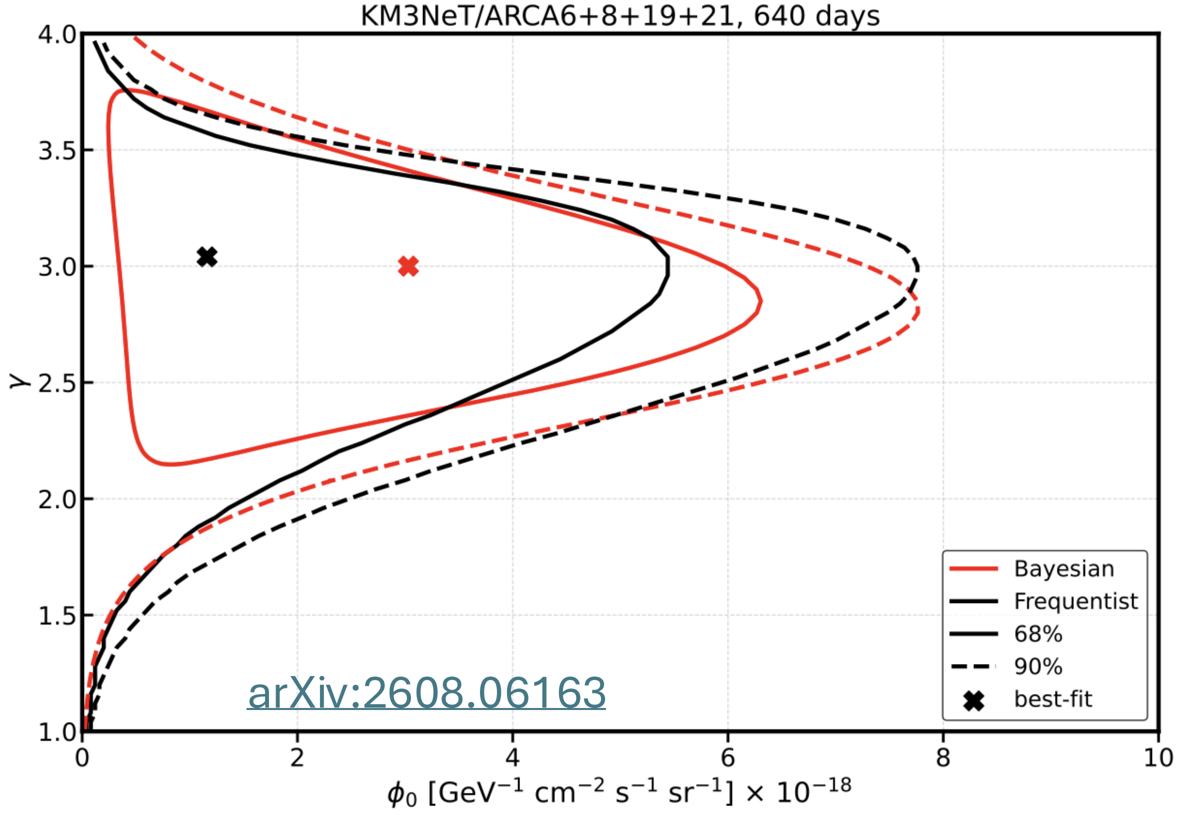




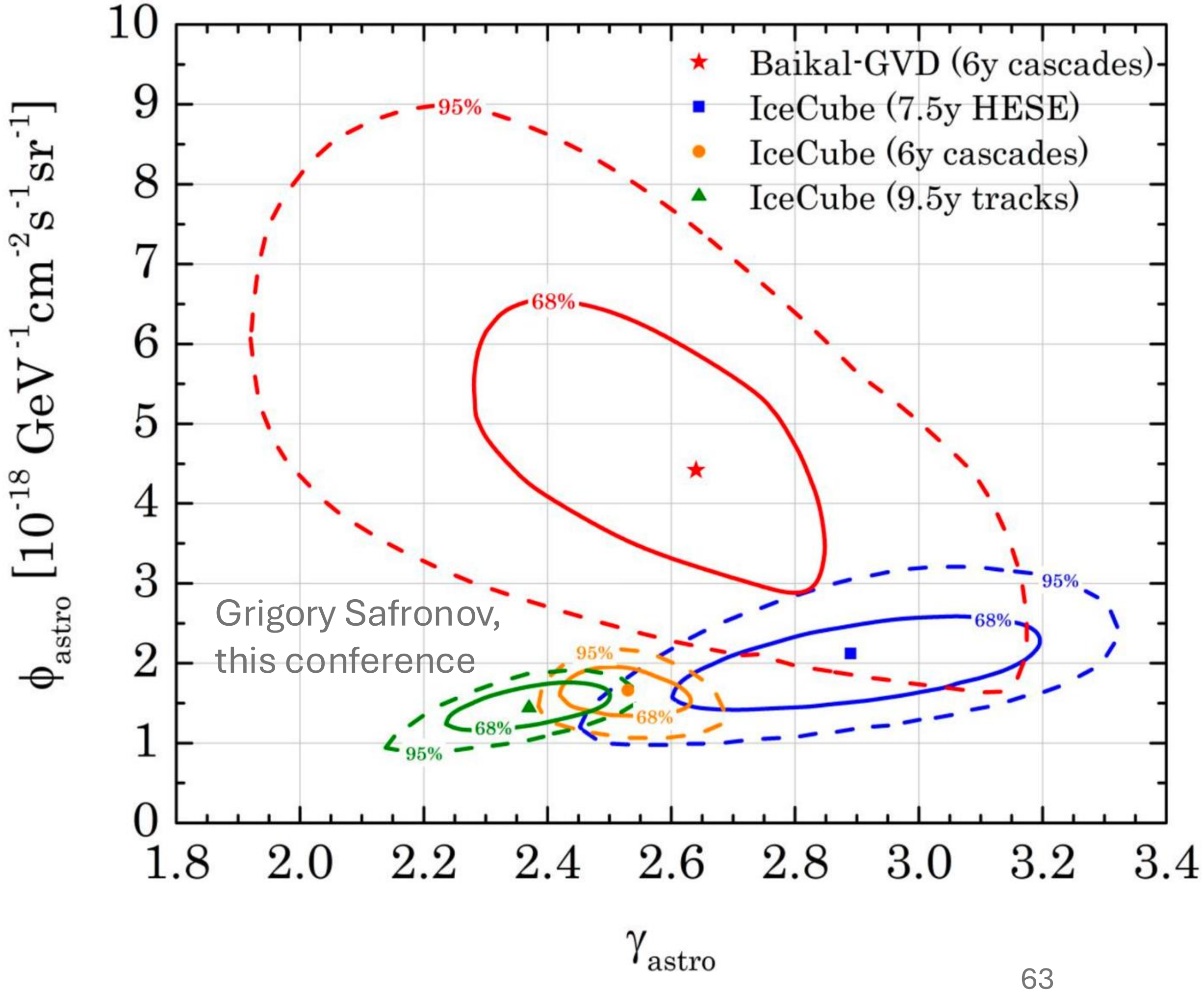
isotropic γ-ray
background
(Fermi)
high-energy
neutrinos
(IceCube)
ultra-high energy
cosmic rays
(Auger)
all flavours
$E^2\phi$ [GeV cm^{-2} s^{-1} sr^{-1}]
Energy [GeV]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10
100
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}


isotropic γ-ray
background
(Fermi)
high-energy
neutrinos
(IceCube)
ultra-high energy
cosmic rays
(Auger)
Violate Fermi diffuse
gamma-ray if nu sources
are transparent to gamma
all flavours
$E^2\phi$ [GeV cm^{-2} s^{-1} sr^{-1}]
Energy [GeV]

Extragalactic flux by KM3NeT and Baikal-GVD



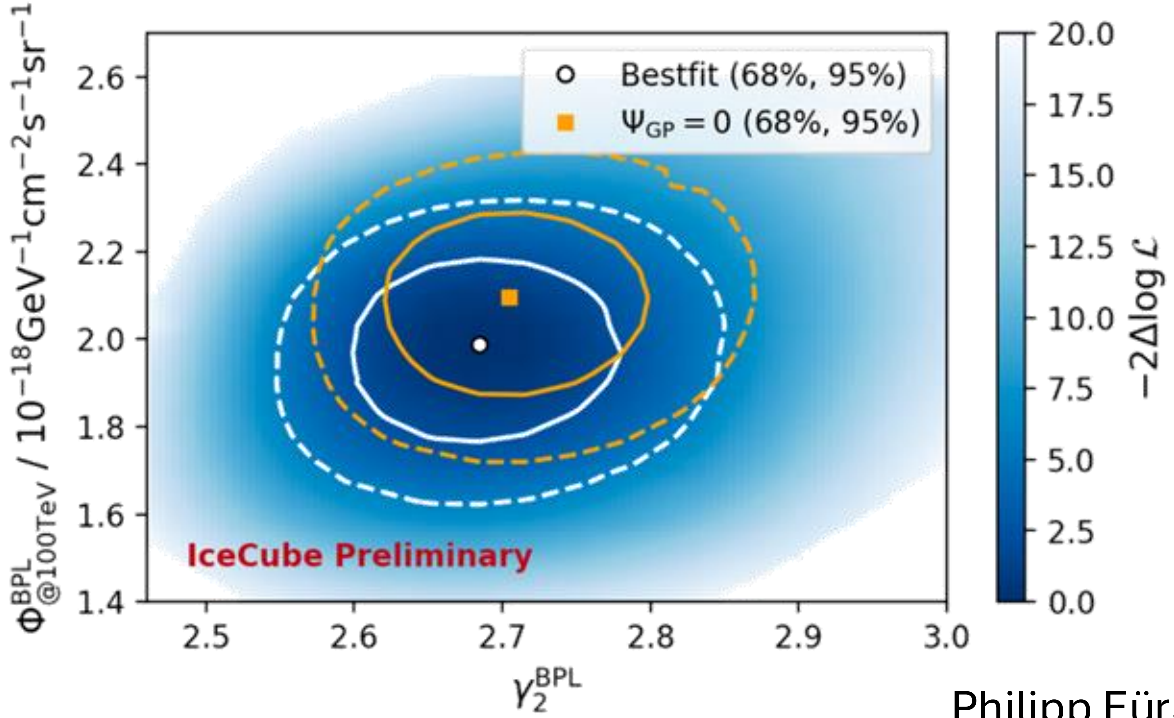
arXiv:2608.06163

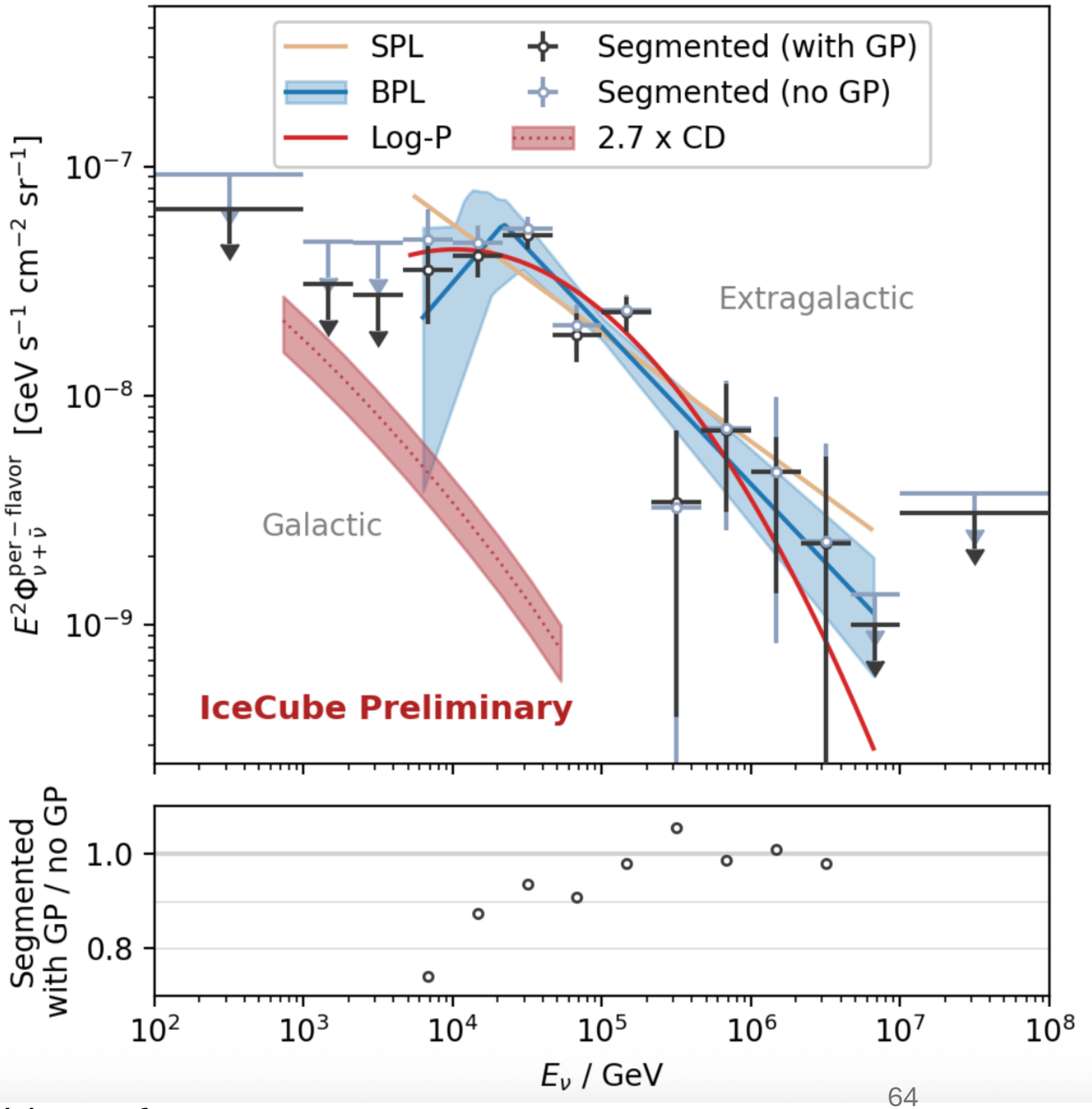


Grigory Safronov,
this conference

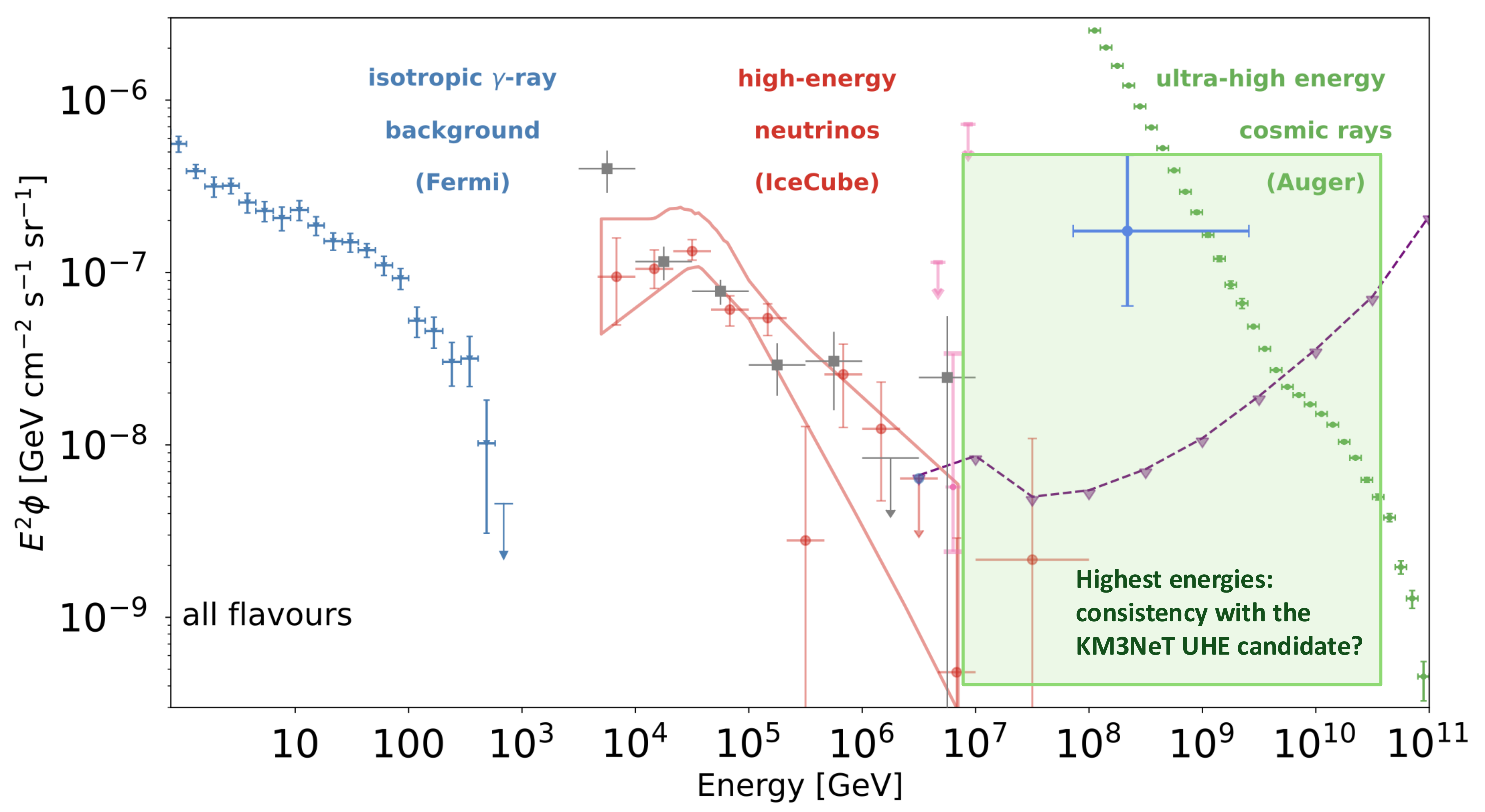
Combined diffuse fit for Galactic and Extragalactic

- ~20% effect from galactic directions at ~10 TeV
- Agree within uncertainties





Philipp Fürst, this conference

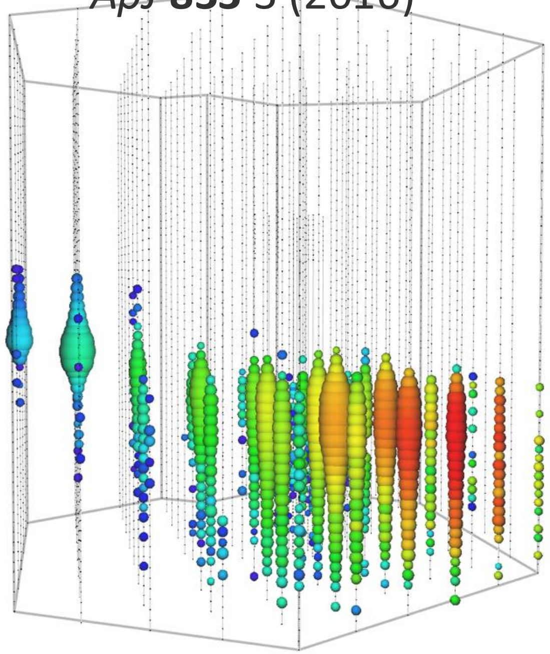


isotropic γ-ray
background
(Fermi)
high-energy
neutrinos
(IceCube)
ultra-high energy
cosmic rays
(Auger)
Highest energies:
consistency with the
KM3NeT UHE candidate?
all flavours
$E^2\phi$ [GeV cm^{-2} s^{-1} sr^{-1}]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10
100
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
Energy [GeV]

The highest energy neutrinos in Cherenkov detectors

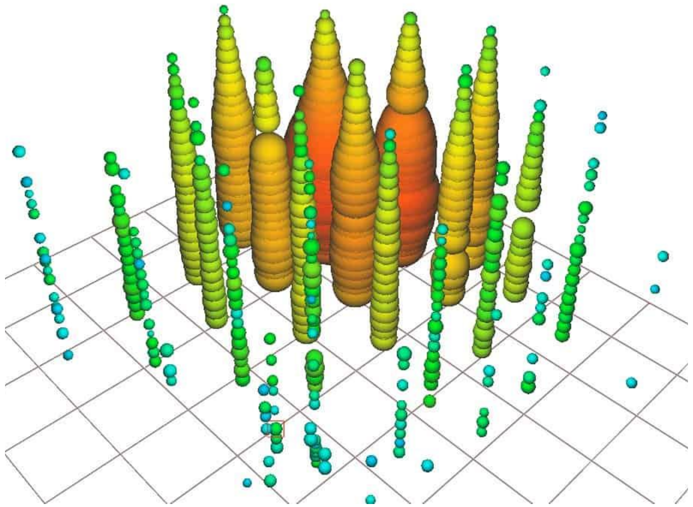
4 events with neutrino energy > 5 PeV over a decade of data taking

ApJ **833** 3 (2016)



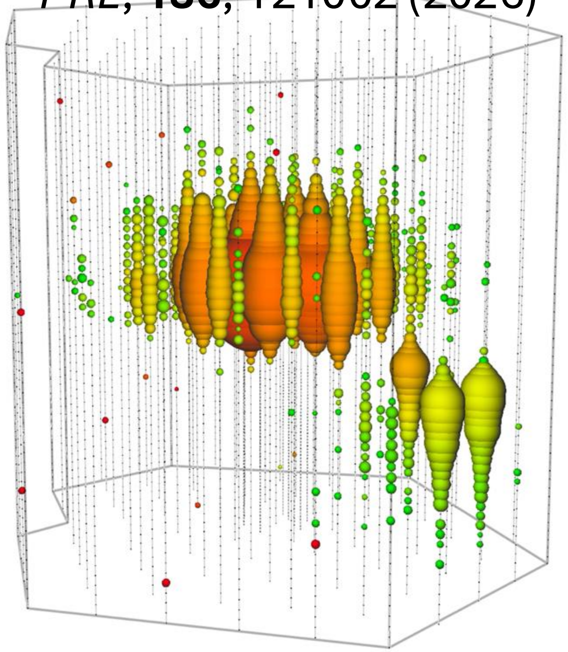
Muon energy: 4.5±1.2 PeV
Nu energy ~ 9 PeV

Nature **591**, 220–224 (2021)



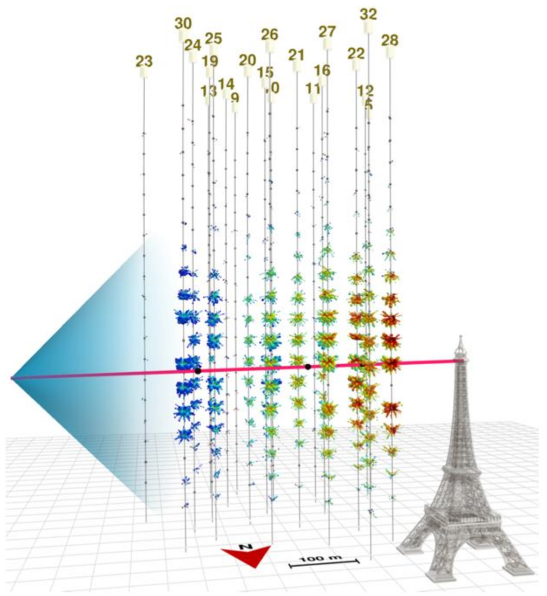
Deposited energy: 6.05 ±0.72 PeV
Nu energy ~6.3 PeV

PRL, **136**, 121002 (2026)



Nu energy ~11.4±2.5 PeV

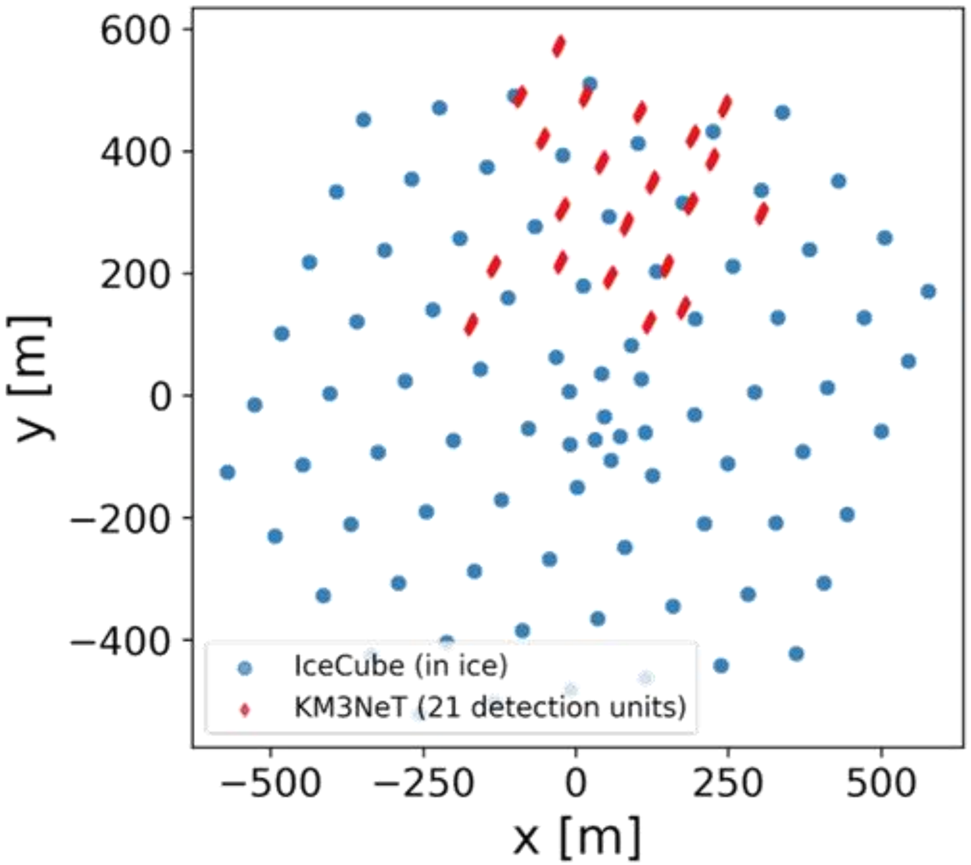
Nature **638**, 376-382 (2025)

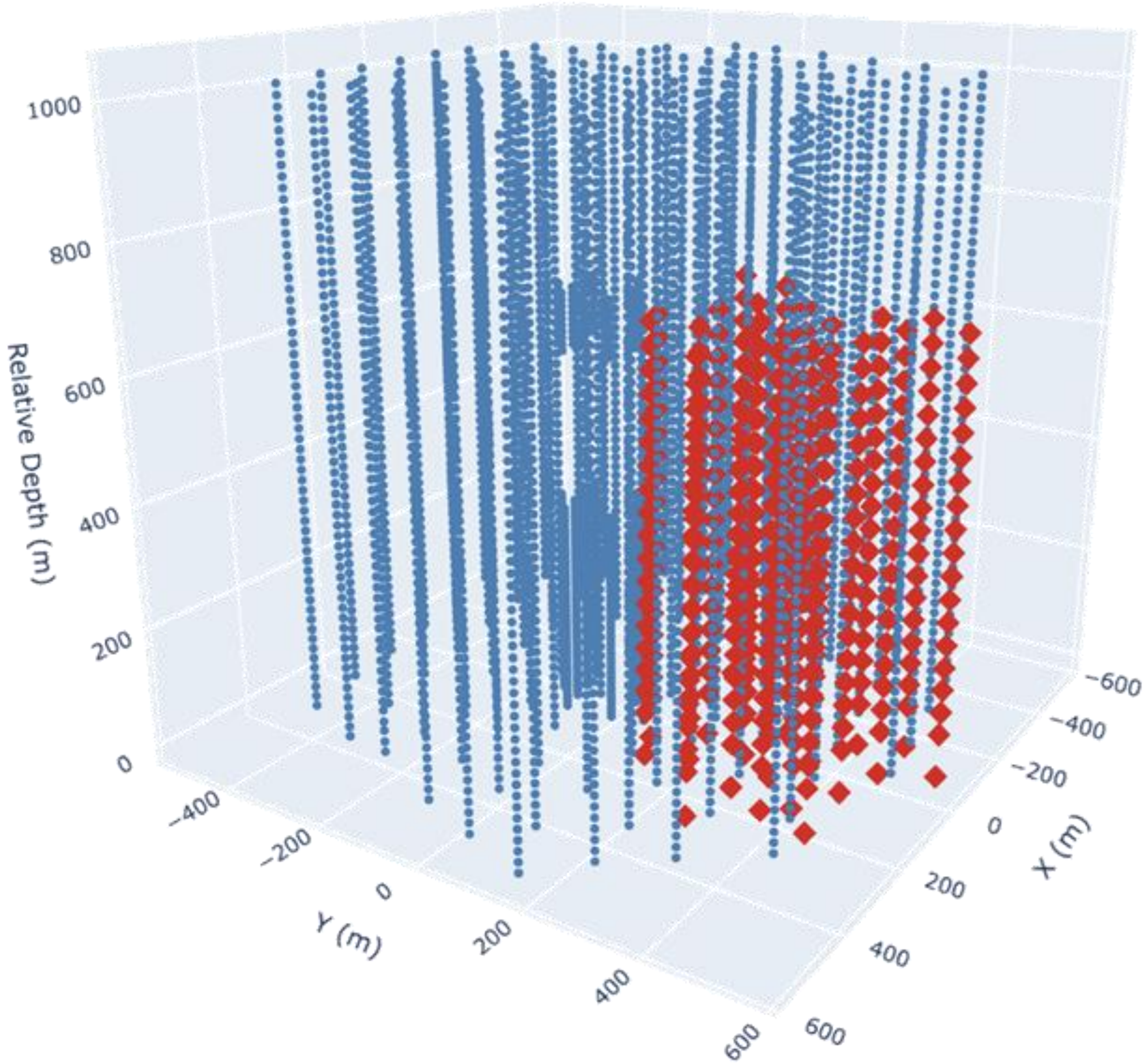


Nu energy ~ 220^{+570}_{-110} PeV

IceCube vs KM3NeT

Lu, Yuan. Highlights in High-Energy Physics 2025, 1(2)





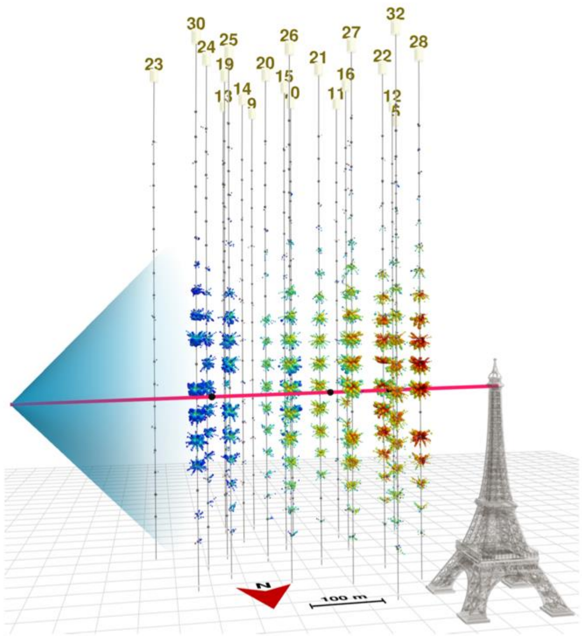
The KM3NeT UHE candidate

Nature 638, 376–382 (2025)

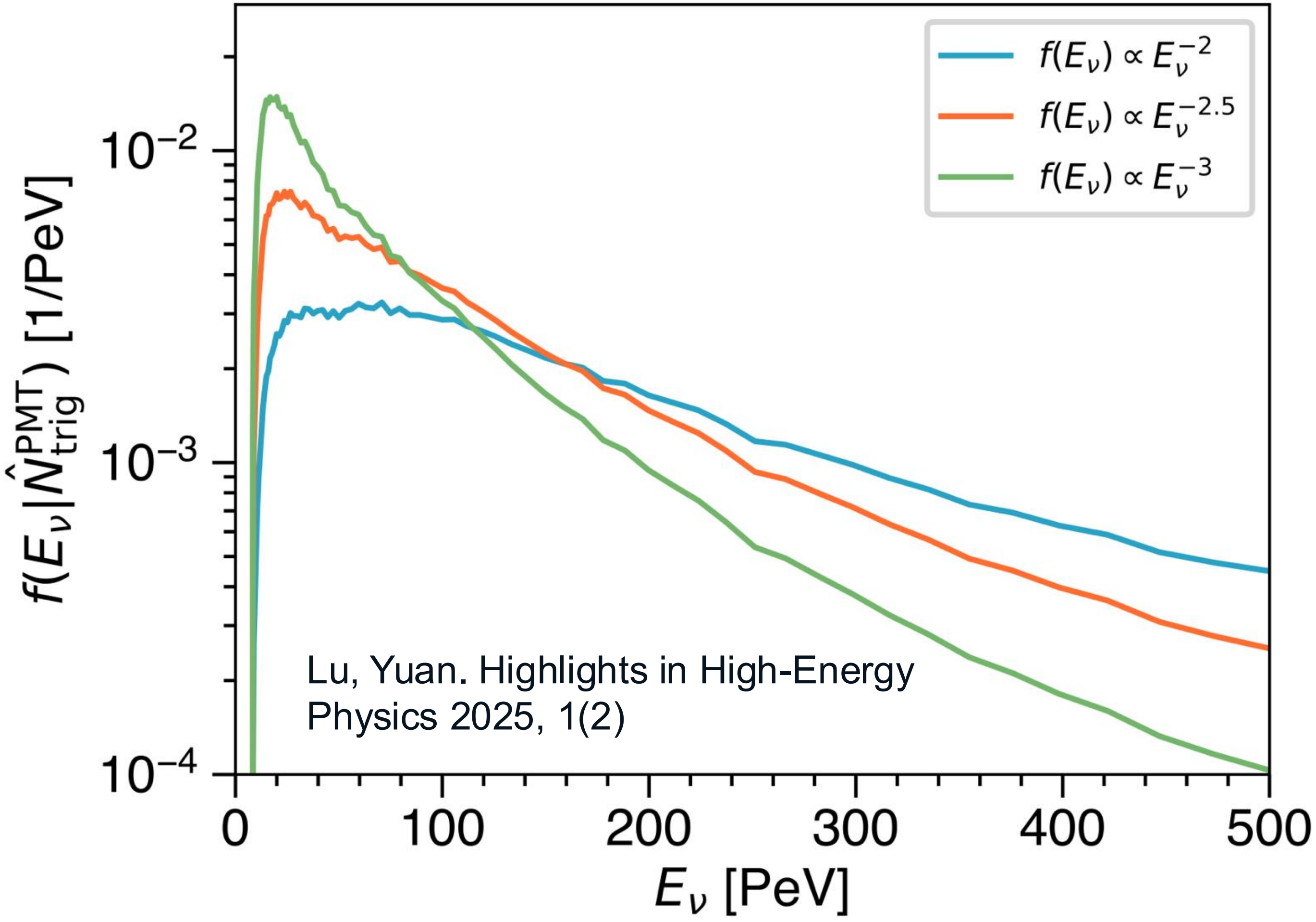
Assuming E^{-2} spectrum:

→ $E_\nu = 220^{+570}_{-110}$PeV

→ Strong prior dependence, large energy uncertainty



Mode ~25 PeV assuming -2.5 spectrum



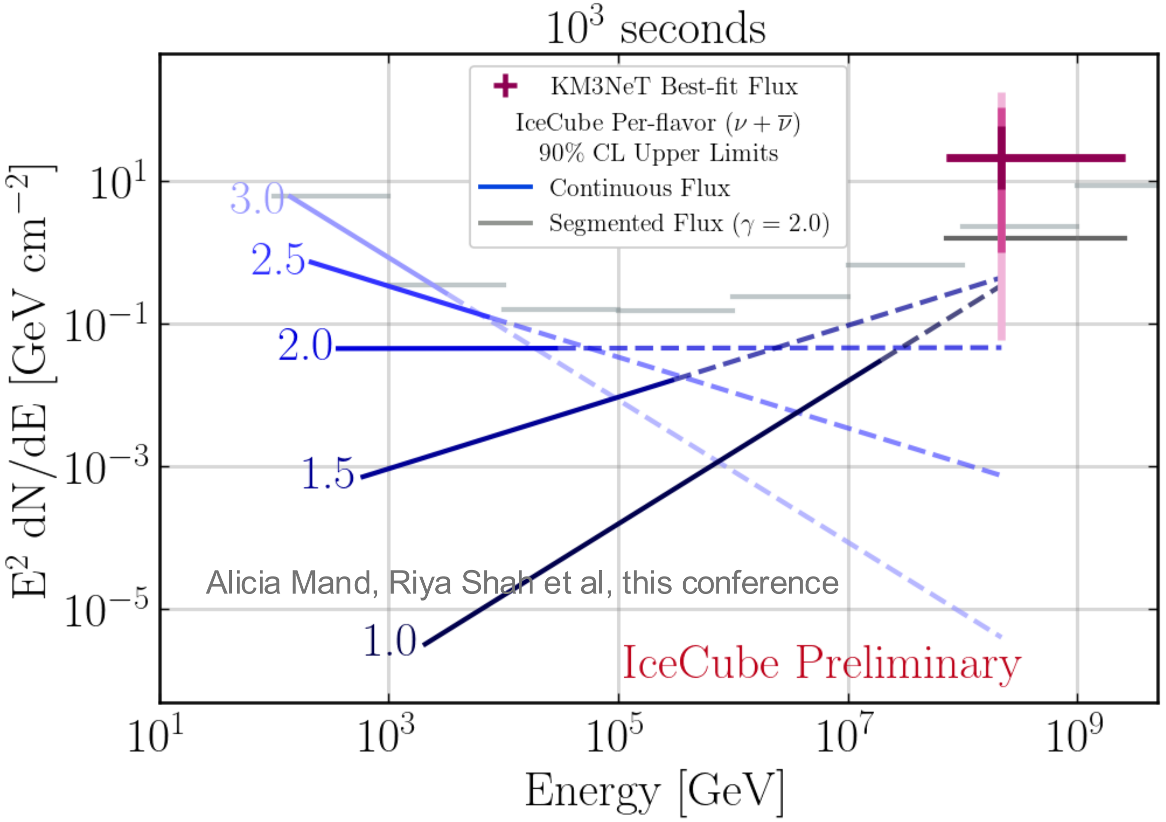
Tension and possible origins

KM3NeT–only flux: expect >70 events 72 PeV – 2.6 EeV from IceCube's EHE analysis (2025 PRL 135 031001)

Combined analysis (IceCube + KM3NeT + Pierre Auger): Tension reduces to ~2–3σ. (arXiv:2502.04508, 2025 PRX 15 031016)

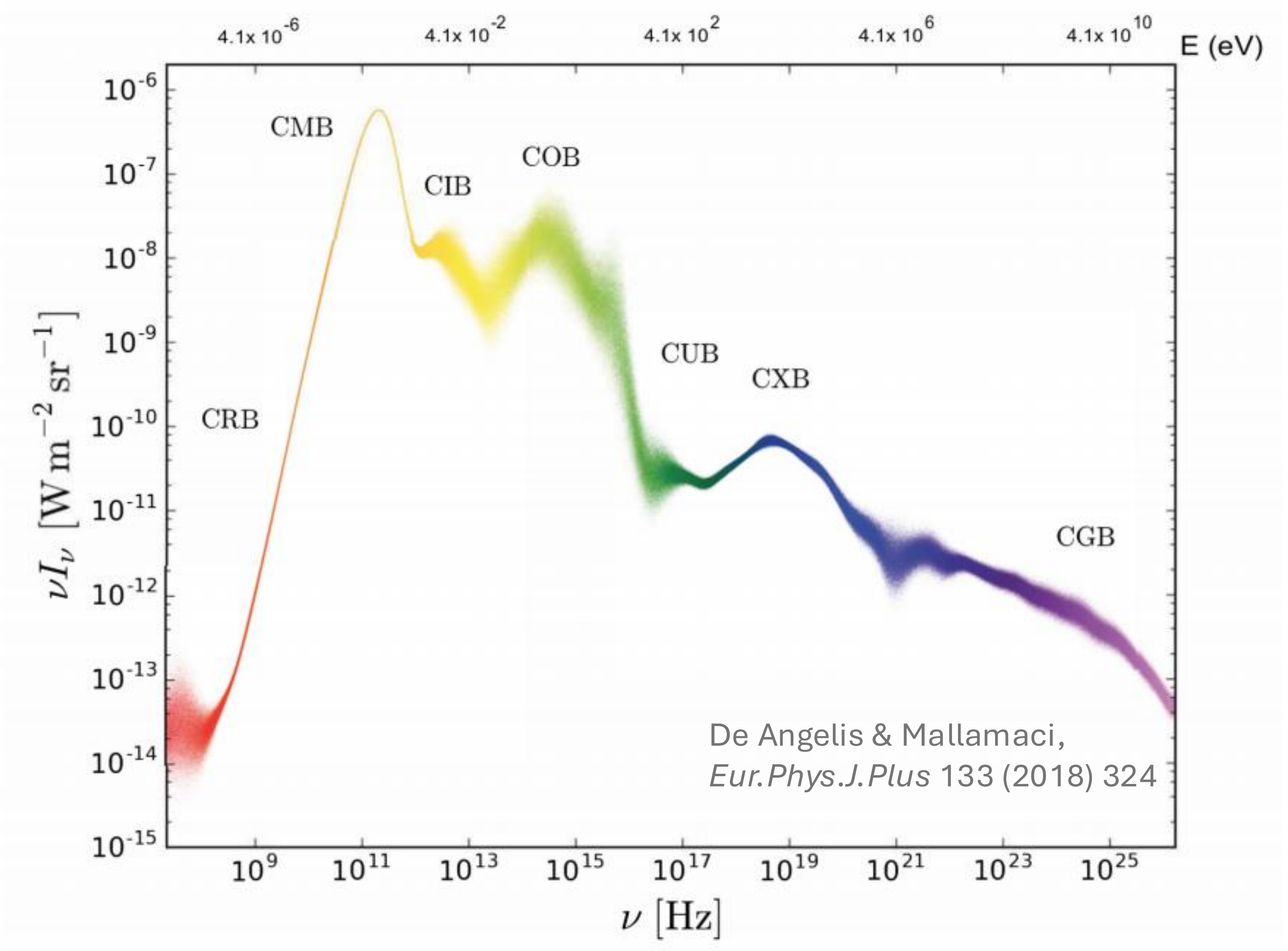
Dedicated time dependent follow-ups yields null results. (Alicia Mand, Riya Shah et al, this conference)

Possible origins of the KM3NeT candidate?

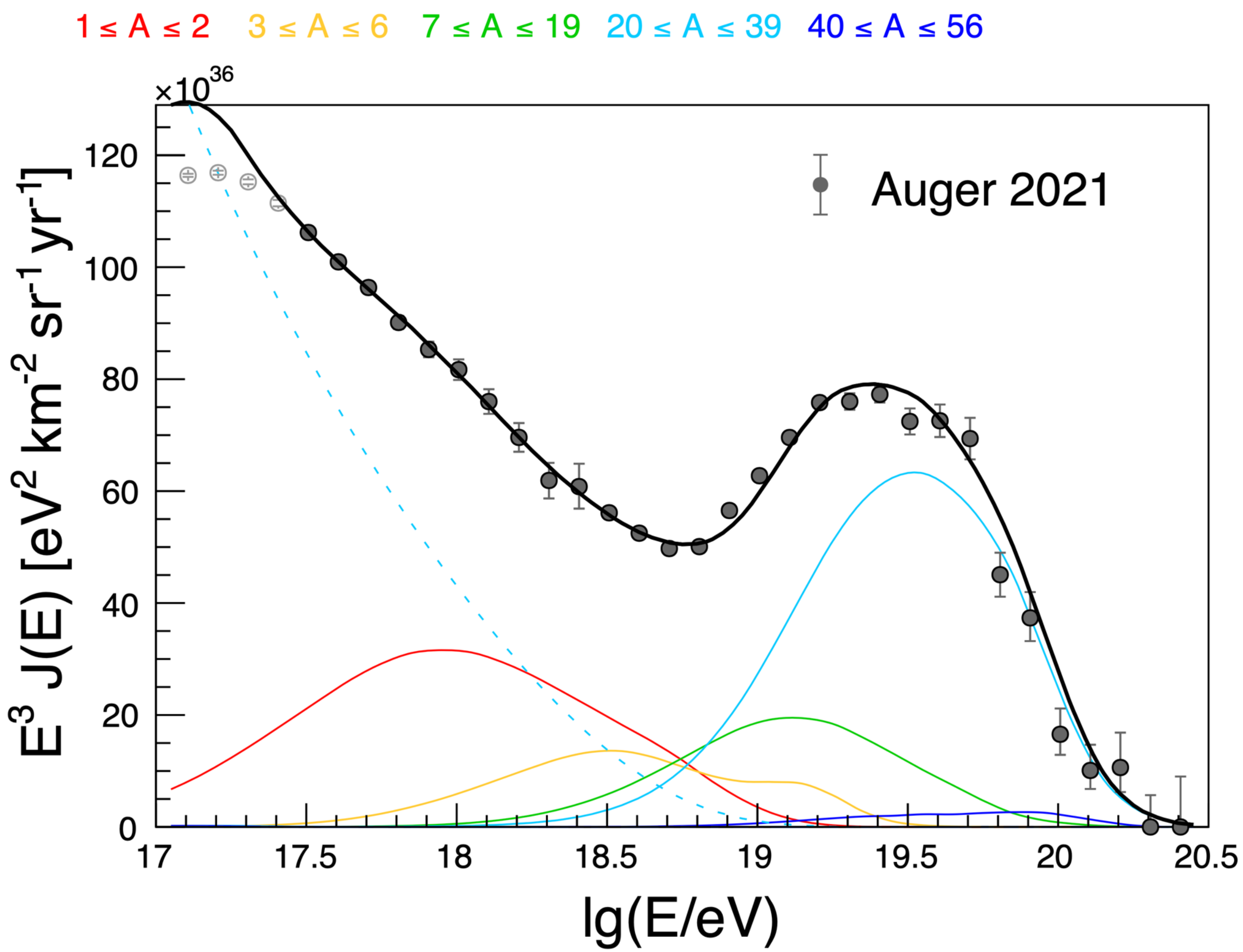


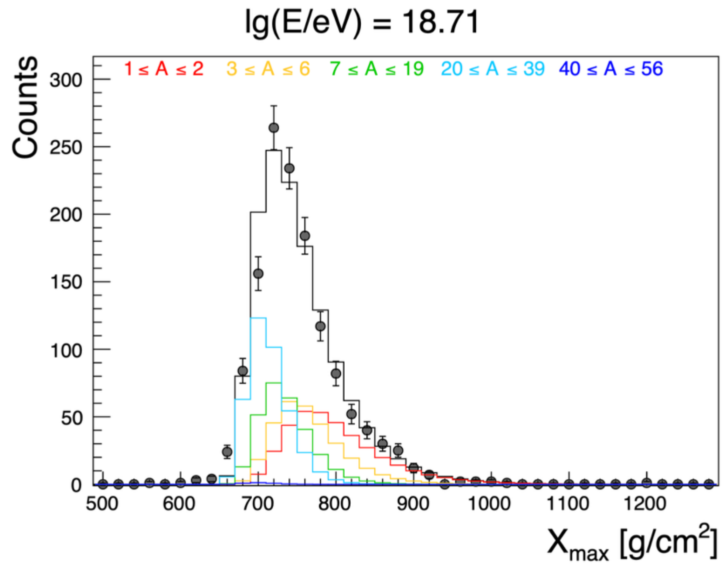
UHE neutrinos: a smoking gun signature

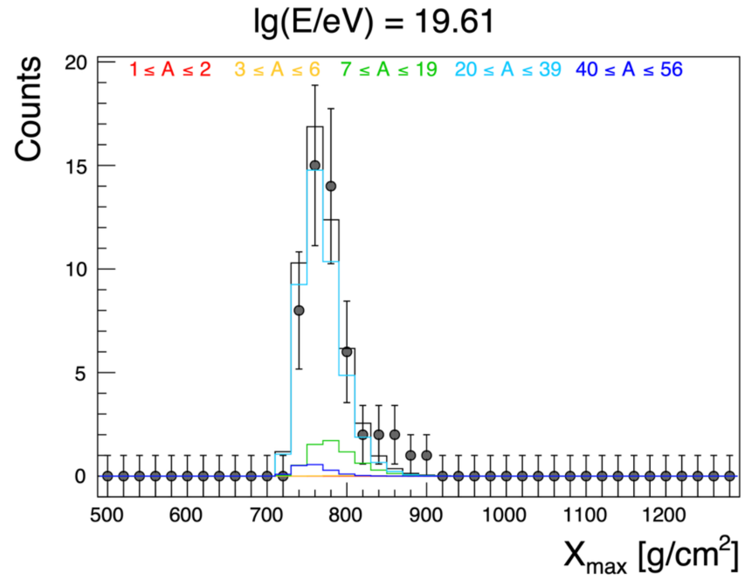
- Photopion produced neutrinos have 1/20 the primary energy-per-nucleon
- CMB target: $10^{19.7}$ eV energy threshold => EeV energy neutrinos
- CIB target: 10^{18} eV energy threshold => **O(10 PeV)** neutrinos
  - **Ambient photons** in **source** can also serve as target



De Angelis & Mallamaci, *Eur.Phys.J.Plus* 133 (2018) 324







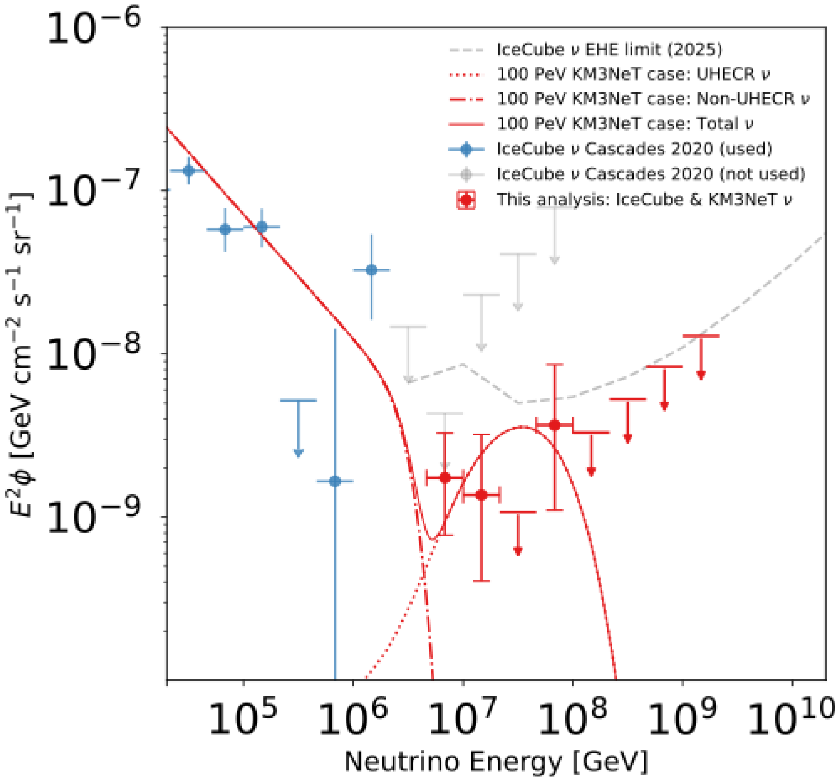
Muzio, Yuan, Lu arXiv:2502.06944

Common origin with UHECR?

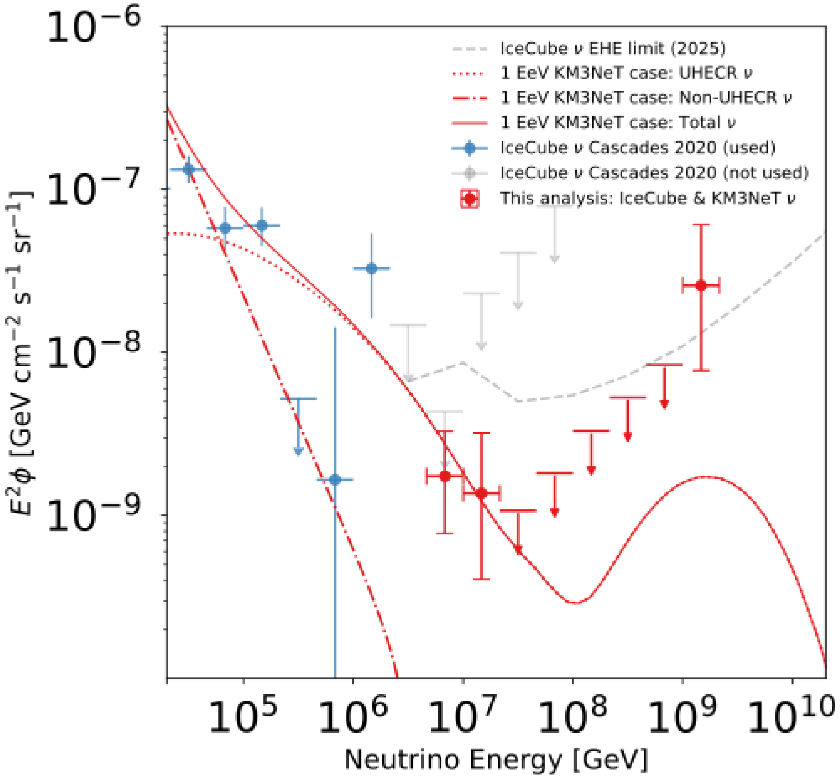
Muzio, Yuan, Lu arXiv:2502.06944

Assume KM3Net/ARCA exposure is ~2% of IceCube NT

Test 100 PeV and 1 EeV+additional proton component as two distinct scenarios // combined fit with Auger mass/flux



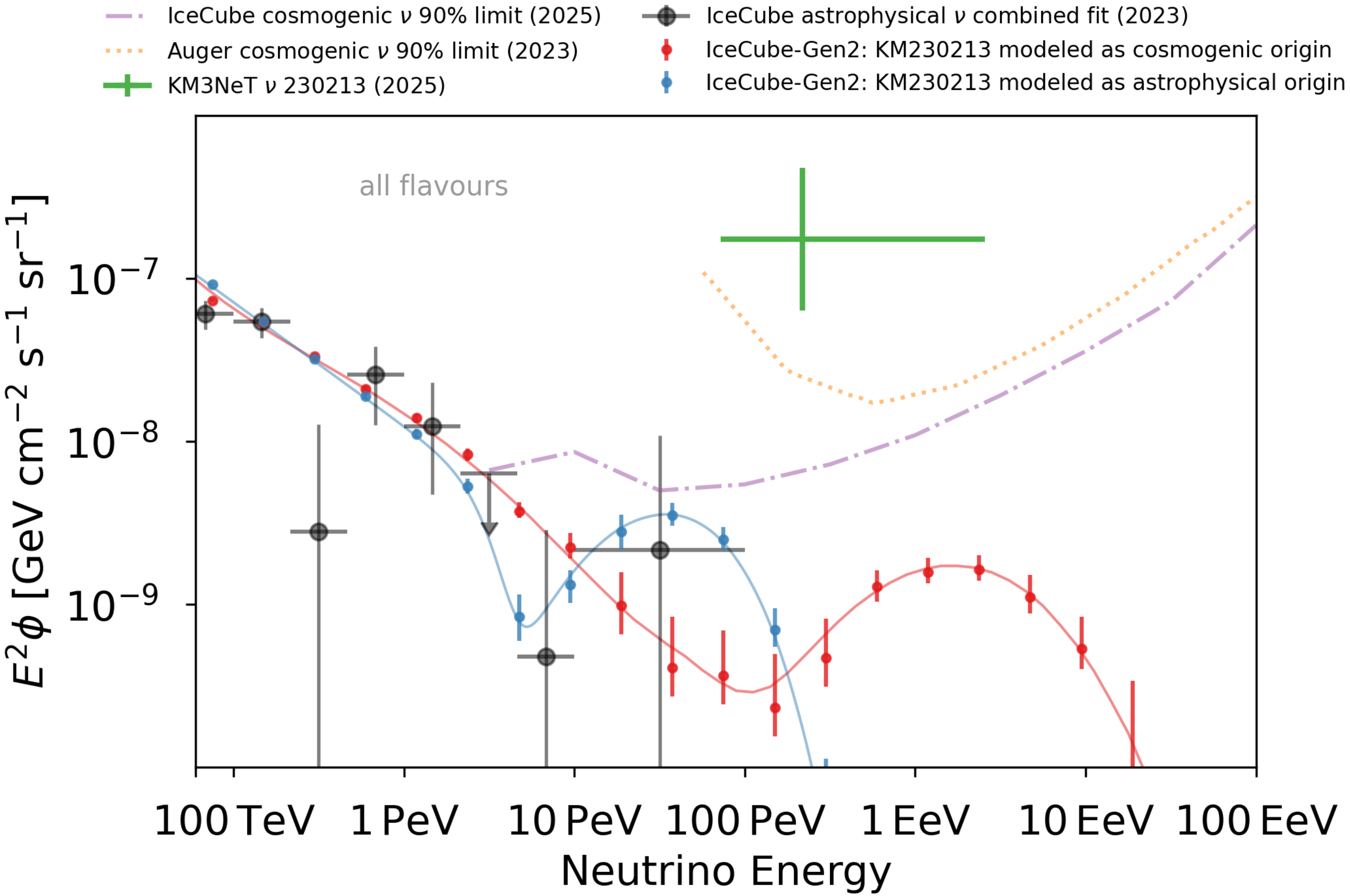
100 PeV scenario
Possible recovery at 30 PeV from UHECR

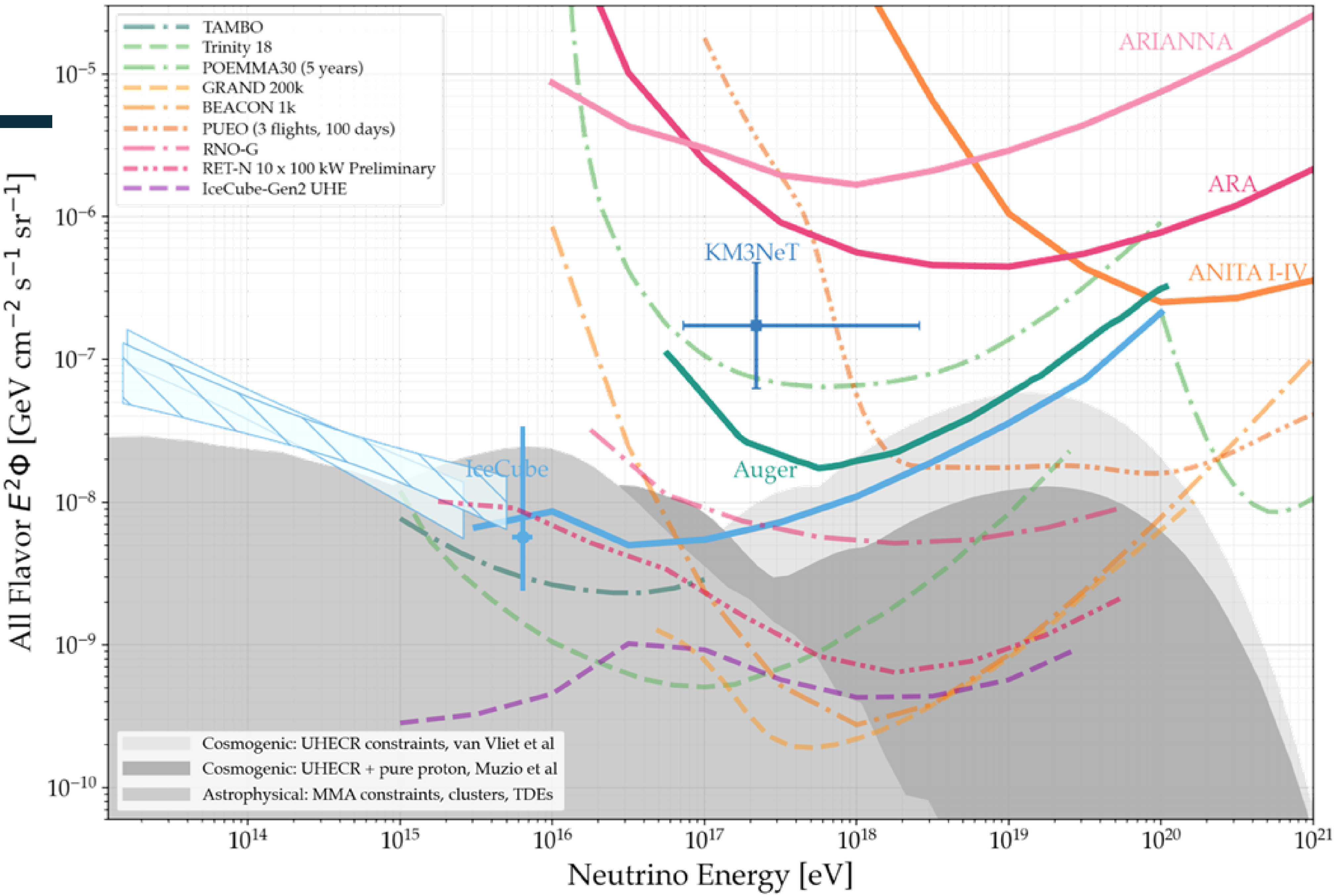


1 EeV + pure proton component scenario
Possibly a cosmogenic neutrino via GZK mechanism

Decisive conclusion of the >1 PeV population

Projecting IceCube-Gen2





A Snowmass white paper. J. High Energy Astrophys. 2022, 36, 55–110

KM3NeT / KM3-230213A session

Real-time astronomy with KM3NeT — M. Marconi (MM6)
Time-dependent neutrino search during gamma ray flares with the ANTARES and KM3NeT and neutrino telescopes — R. Jaimes (MM6)
IceCube's MeV to sub-TeV KM3-230213A Follow-up — J. Vara (MM5)
Results from the IceCube Follow-up of the KM3-230213A Event — R. Shah (MM5)
Can a gamma-ray dim radio blazar produce a 200-PeV neutrino? The case of PMN J0606 −0724 and KM3-230213A — P. Kivokurtseva (MM5)
Cosmogenic Origin of KM3-230213A: Delayed Gamma-Ray Emission from A Cosmic-Ray Transient — S. Boxi (MM5)

Optical (water / ice)

The Baikal-GVD Neutrino Telescope: status and recent results — G. Safronov (NU3)
Earth Tomography with Atmospheric Neutrino Absorption at TRIDENT — J. Huang (NU1)
Potential to detect prompt atmospheric neutrinos with TRIDENT — Y. Feng (NU1)
A Cost-Effective Optimization of the hybrid-DOM Design for TRIDENT — H. Shao (NU2)
Development of a real-time in-situ calibration system for deep-sea neutrino telescopes — T. Zhu (NU2)
The First Long Term In-situ Performance of a Prototype Demonstrator for TRIDENT Neutrino Telescope — F. Zhang (NU3)
Capturing neutrons in deep-sea neutrino telescopes — R. Cao (NU4)
The P-ONE Data Acquisition System — J. Garriz (NU2)
Status of the Pacific Ocean Neutrino Experimen — I. Taboada (NU3)
POLARIS: A Sparse Radial Neutrino Telescope Design for the Pacific Ocean — K. Hymon (NU3)
Development of a Fiber Optic Module (FOM) for improving Veto capability in IceCube-Gen2. — K. Yuasa (NU2)
Towards Deep Learning-Based Event Reconstruction and Selection for Point-Source Searches with the IceCube-… — F. Vara Carbonell (NU3)
GeV Neutrino Transient Search with IceCube Upgrade — Y. Kobayashi (MM6)

Radio & radar

Status and Science of the Radio Neutrino Observatory in Greenland — S. Toscano (NU5)
The Radio Neutrino Observatory in Greenland (RNO-G): Simulation Progress towards a Diffuse Neutrino Search — Y. Liu (NU5)
Progress Toward a Sub-Threshold Search for the Radar Echo Telescope for Cosmic Rays — C. Mclennan (CR2)
Status of the Radar Echo Telescope Experiment — I. Loudon (NU5)
Explaining Signal Properties in Context of Reconstruction methods for the Radar Echo Telescope for Neutrinos — J. Loonen (NU5)
The Payload for Ultrahigh Energy Observations (PUEO): 2025-2026 Flight and Experiment Overview — L. Beaufore (NU5)

Earth-skimming / air / space · GeV

The Trinity Neutrino Observatory: Probing the PeV–EeV Neutrino Sky — D. Raudales (NU5)
Trinity's sensitivity to UHE Tau Neutrinos from X-ray Bright and Obscured AGN — S. Saini (NU5)
TAMBO and TAMBITO: Progress Towards a Next-Generation Tau Neutrino Observatory — C. Argüelles (NU5)
POEMMA Balloon with Radio — G. Filippatos (CR2)
The NUSES space mission — D. Pattanaik (CR2)
Overview and Latest Physics Results in JUNO — Q. Liu (NU4)

IceCube related

Follow-up observations of IceCube events using ZTF: Lessons Learned — M. Tanaka (MM-pre)
Connecting IceCube to Rubin: Prospects of Physics Based on the Subaru Experience — S. Kimura (MM-pre)
Connecting IceCube to MAXI: Constraining the Origin of Ultra-High-Energy Cosmic Rays with X-ray Observations — W. Iwakiri (MM-pre)
Follow-up observations of IceCube events using Einstein Probe — N. Shimizu (MM-pre)
Filling the Energy Gap: Measurement of the DIS Neutrino Cross Section Using 10 Years of IceCube Data — C. Hill (NU1)
Visible inelasticity as a probe of tau flavor content of astrophysical neutrinos — A. Wen (NU1)
High-Energy Emission Analysis from the Galactic Center Region with HAWC and IceCube — S. Yun Carcamo (MM2)
Characterising the Galactic Neutrino Emission with IceCube — L. Neste (MM2)
Searching for Galactic PeVatrons with ICEMAN — L. Seen (MM2)
In-Situ Afterpulse Modeling in IceCube — T. Kim (NU2)
A Joint Characterization of Galactic and Extragalactic Neutrino Fluxes — P. Fürst (NU3)
Measuring the Cosmic Ray Sun and Moon Shadow with IceCube* — N. Krieger (CR5)
IceCube Realtime Program: Connecting high-energy neutrinos to the multi-messenger sky — A. Zegarelli (MM6)
IceCube Search for Neutrinos from Thousands of Fast Radio Bursts — A. Mand (MM6)
Optical Counterpart search for a Month-timescale IceCube Neutrino Multiplet Event — S. Toshikage (MM6)
From Atmospheric Muons to Prompt Neutrinos: Unfolding the Muon Flux in IceCube to Constrain Charm Production — P. Gutjahr (CR7)
Search for neutrinos from optically-identified AGNs with IceCube — S. Fukami (MM8)

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