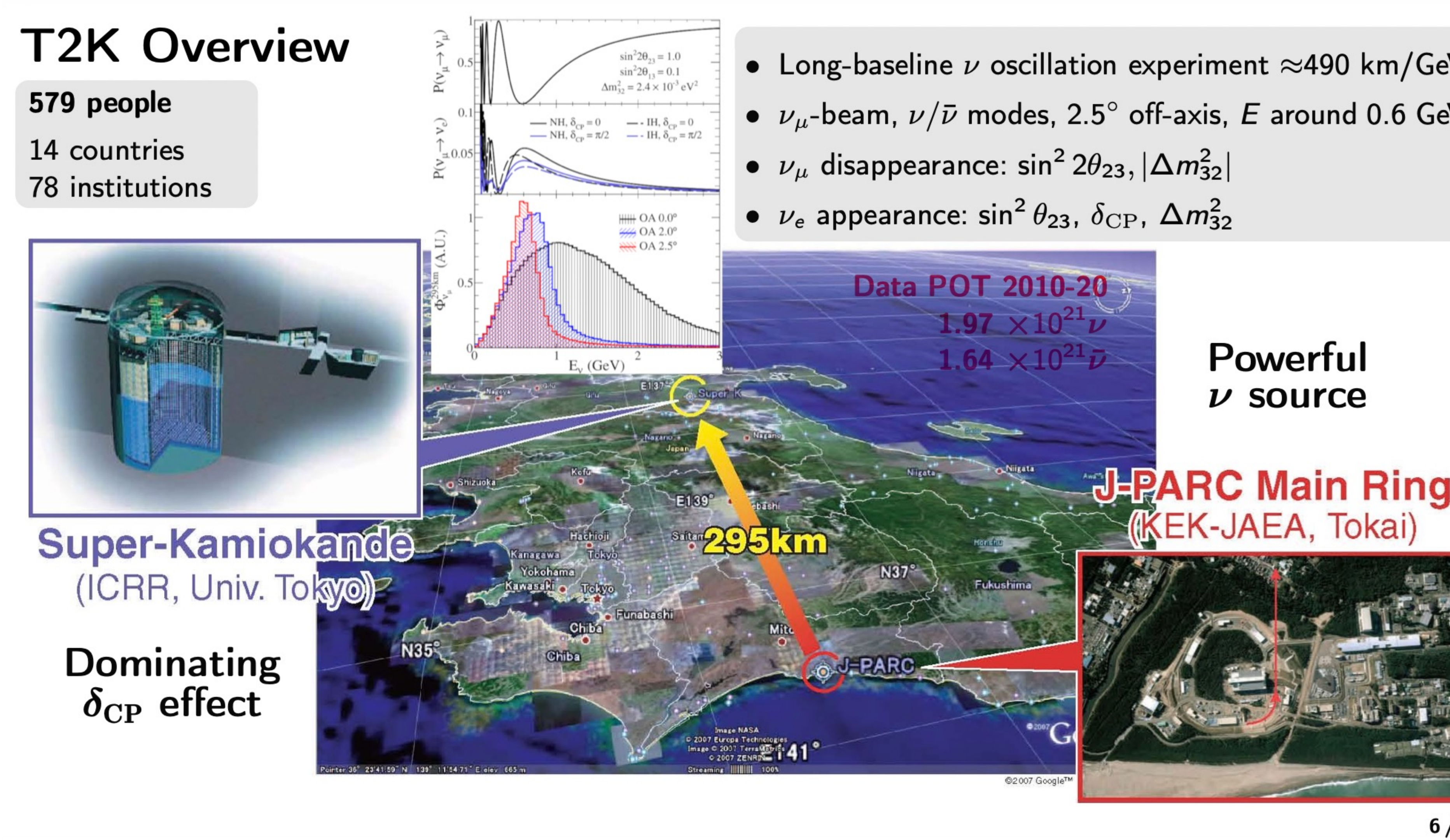
Moriond Electroweak Conference Update

With the Run



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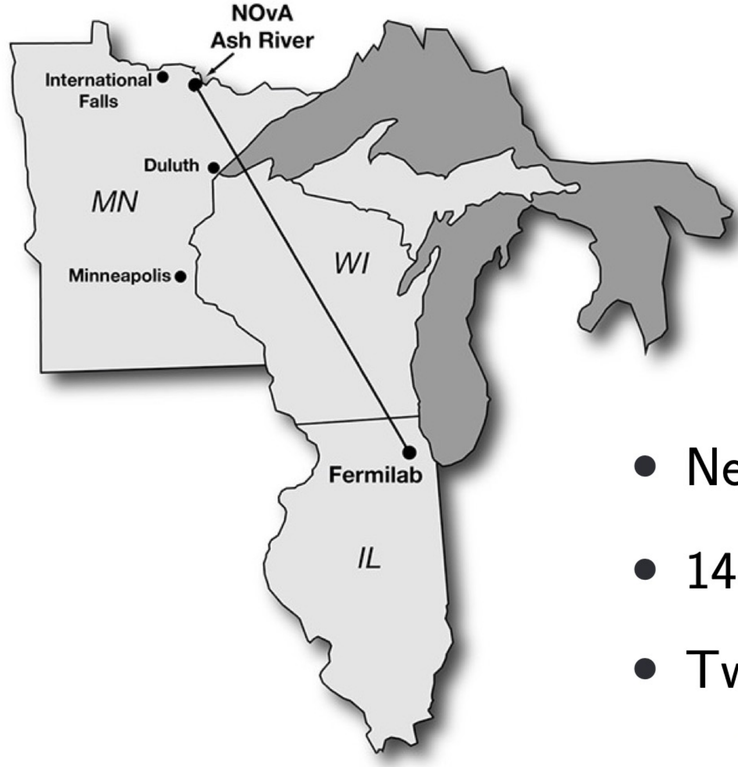

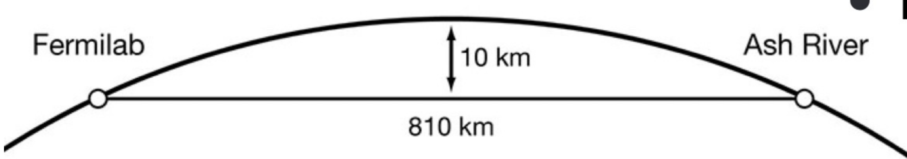

- Neutrino beam from Fermilab's NuMI Beamline.
- 14 mrad off-axis beam narrowly peaked at $\sim$2 Ge
- Two functionally identical detectors:
  - Near Detector (ND), 0.3 kton, 1 km baseline.
  - Far detector (FD), 14 kton, 810 km baseline.

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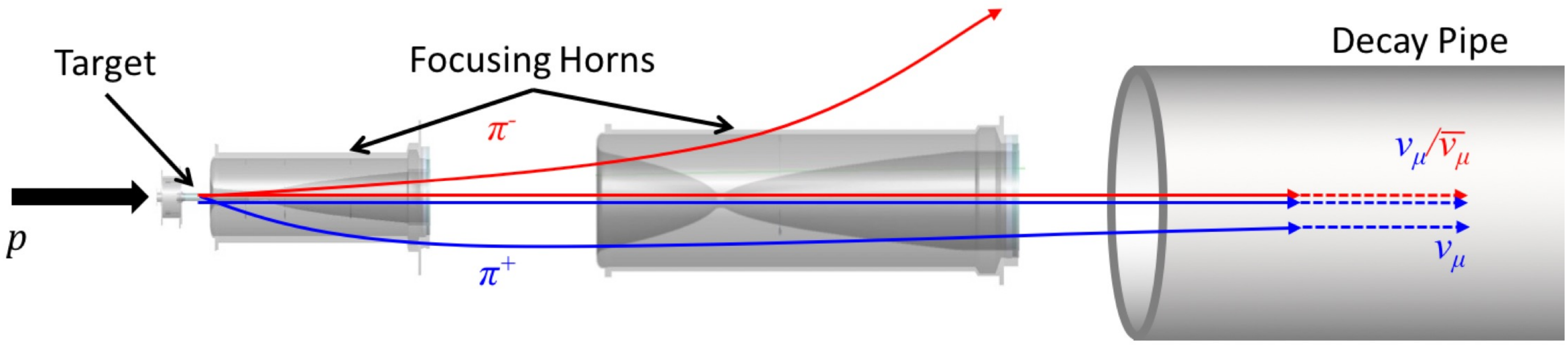
With the Run

Focusing +ve mesons to get mostly ν_μ (Neutrino mode)



- Beam of 120 GeV protons incident on carbon target.
- Focusing +ve or -ve mesons to obtain mostly ν_μ or $\bar{\nu}_\mu$.
  - Achieved by reversing the polarity of the magnetic horns.
- Neutrinos appear from the decaying mesons. 675 m decay pipe.

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With the Run

ν Oscillation Parameters of the 3ν-paradigm

NuFIT global analysis *JHEP 09, 178 (2020)*

	Normal ordering (best fit)		Inverted ordering	
	Best fit $\pm 1\sigma$	3σ range	Best fit $\pm 1\sigma$	3σ range
$\sin^2\theta_{12}$	0.304 ± 0.012	$0.269 - 0.343$	$0.304^{+0.013}_{-0.012}$	$0.269 - 0.343$
$\sin^2\theta_{23}$	$0.573^{+0.016}_{-0.020}$	$0.415 - 0.616$	$0.575^{+0.016}_{-0.019}$	$0.419 - 0.617$
$\sin^2\theta_{13}$	$0.02219^{+0.00062}_{-0.00063}$	$0.02032 - 0.02410$	$0.02238^{+0.00063}_{-0.00062}$	$0.02052 - 0.02428$
$\frac{\Delta m^2_{21}}{10^{-5}\ \text{eV}^2}$	$7.42^{+0.21}_{-0.20}$	$6.82 - 8.04$	$7.42^{+0.21}_{-0.20}$	$6.82 - 8.04$
$\frac{\Delta m^2_{3l}}{10^{-3}\ \text{eV}^2}$	$2.517^{+0.026}_{-0.028}$	$2.435 - 2.598$	-2.498 ± 0.028	$-2.581 - -2.414$
$\frac{\delta_{CP}}{\pi}$	$1.09^{+0.15}_{-0.13}$	$0.67 - 2.05$	$1.57^{+0.14}_{-0.17}$	$1.07 - 1.96$

What is there to measure, anyway?

- Ordering of the mass states (mass ordering or hierarchy), is ν_3 the heaviest or the lightest: **NORMAL** vs. **INVERTED**?
- θ_{23} =, > (UO), < (LO) 45°? 23, $\mu\tau$ symmetry?
- CP violation in lepton sector, δ_{CP}?
- Tests of unitarity, 3ν-paradigm completeness, sterile ν etc.?

Long-baseline accelerator experiments $L/E \sim 10^{2-3}$ km/GeV are sensitive to

NO/IO, θ_{23} and δ_{CP}
(also θ_{13})

T2K (Japan) 295 km / 0.6 GeV
NOvA (USA) 810 km / 2 GeV

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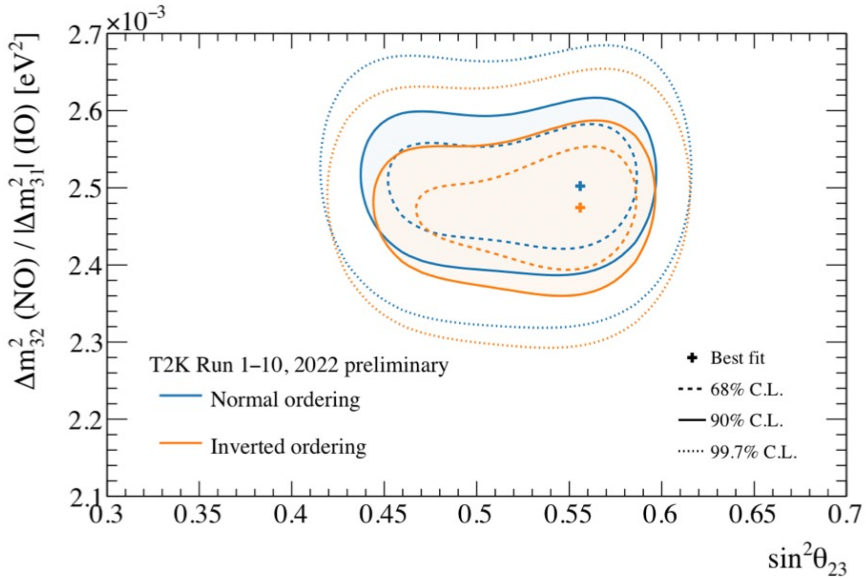
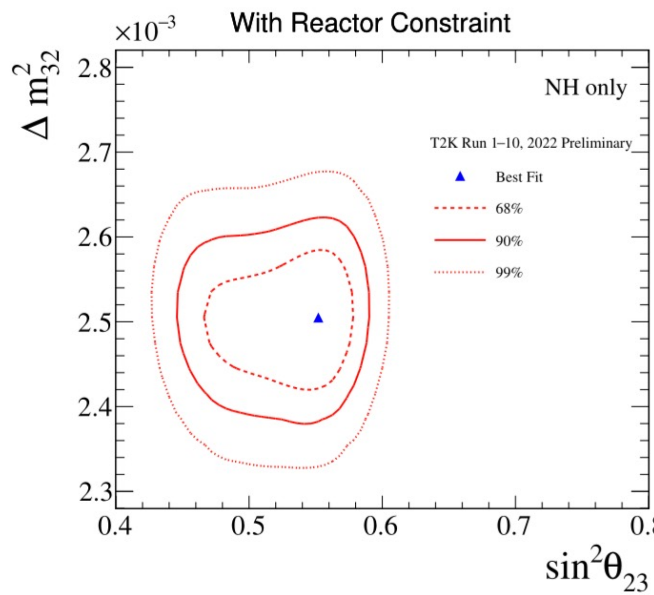
Results 2022 – Δm^2_{32} vs. $\sin^2\theta_{23}$

- Leading measurements of θ_{23} and Δm^2_{32}
- Excellent agreement of both frequentist and bayesian analyses

Frequentist





Bayesian

	$\sin^2\theta_{23} < 0.5$	$\sin^2\theta_{23} > 0.5$	Line total
Normal ordering	0.236	0.540	0.776
Inverted ordering	0.049	0.174	0.224
Column total	0.285	0.715	1.000

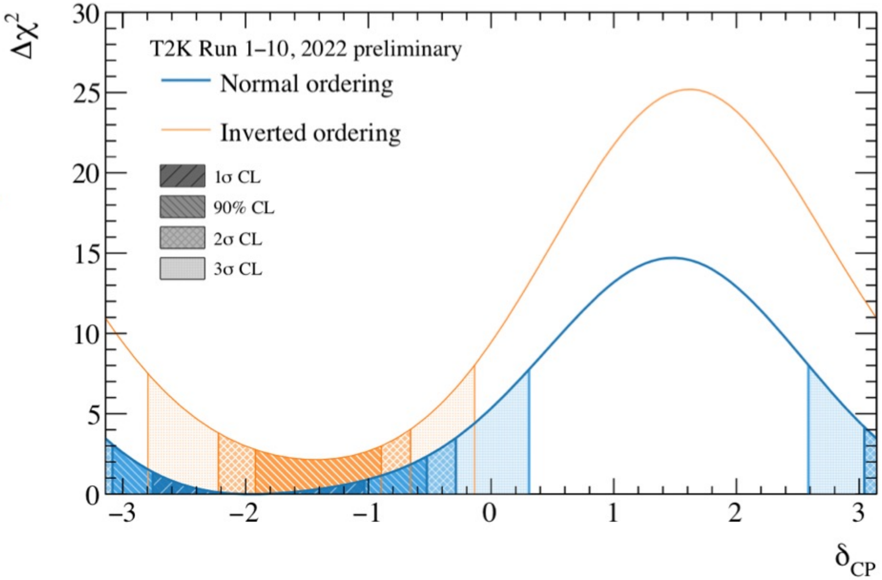
T2K Run 1-10, preliminary

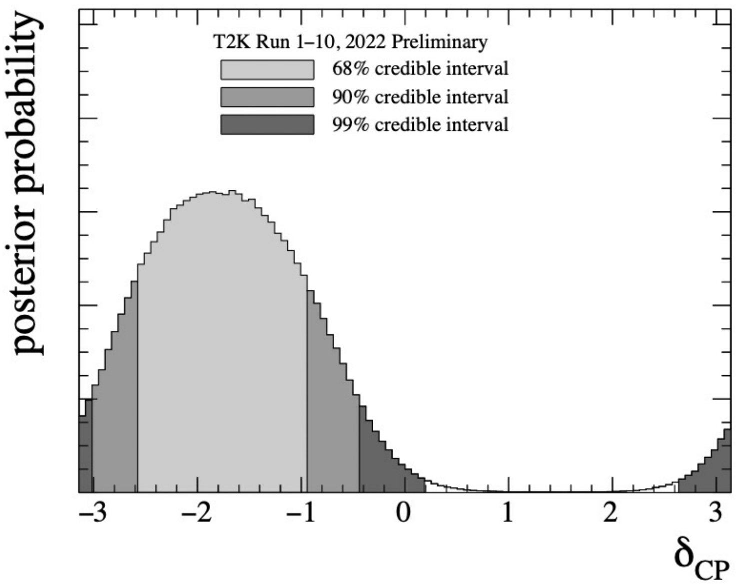
Slight preference for UO of θ_{23} (2.51) and NO (3.46) of ν mass states (from Bayes factors)

Using reactor constraints for θ_{13}

Results 2022 – δ_{CP}

Frequentist





Bayesian

δ_{CP} best fit at -2.18 (-0.694π), CP conserving values 0 and π are outside of 90% CL intervals

Using reactor constraints for θ_{13}

- Frequentist p-value 0.35
- Bayesian posterior predictive p-value 85%
- No biases to undermine the statements found in a test with an alternative interaction model

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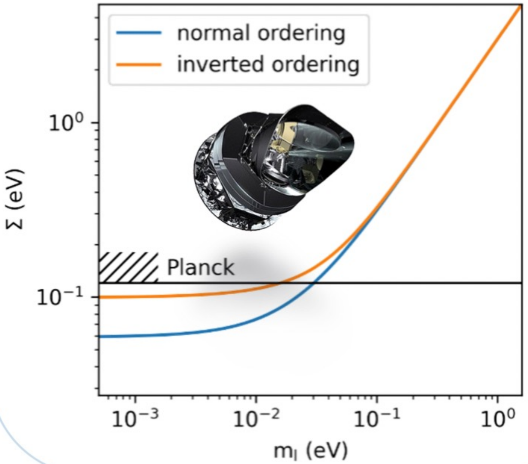
Neutrino mass(es)

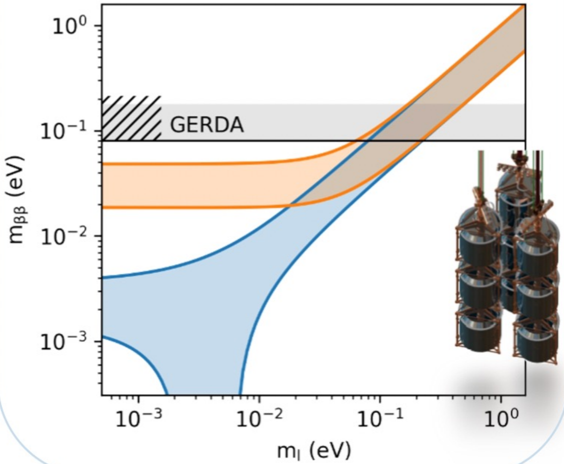
Cosmology

$$\Sigma = \sum_i m_i$$



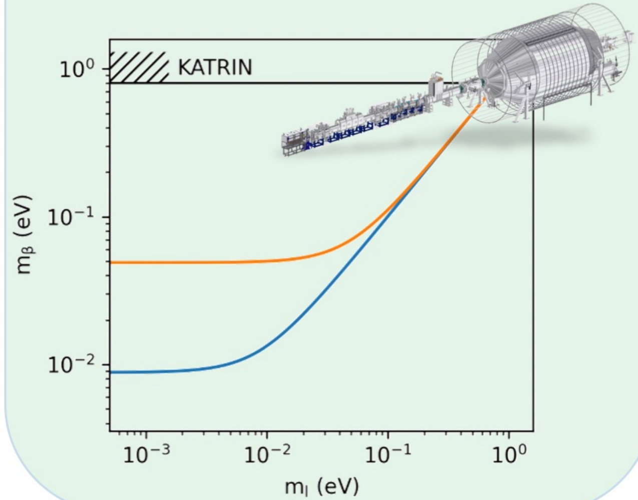
Neutrinoless ßß decay

$$m_{\beta\beta} = \sum_i {U_{ei}}^2 \cdot m_i$$



ß-decay kinematics

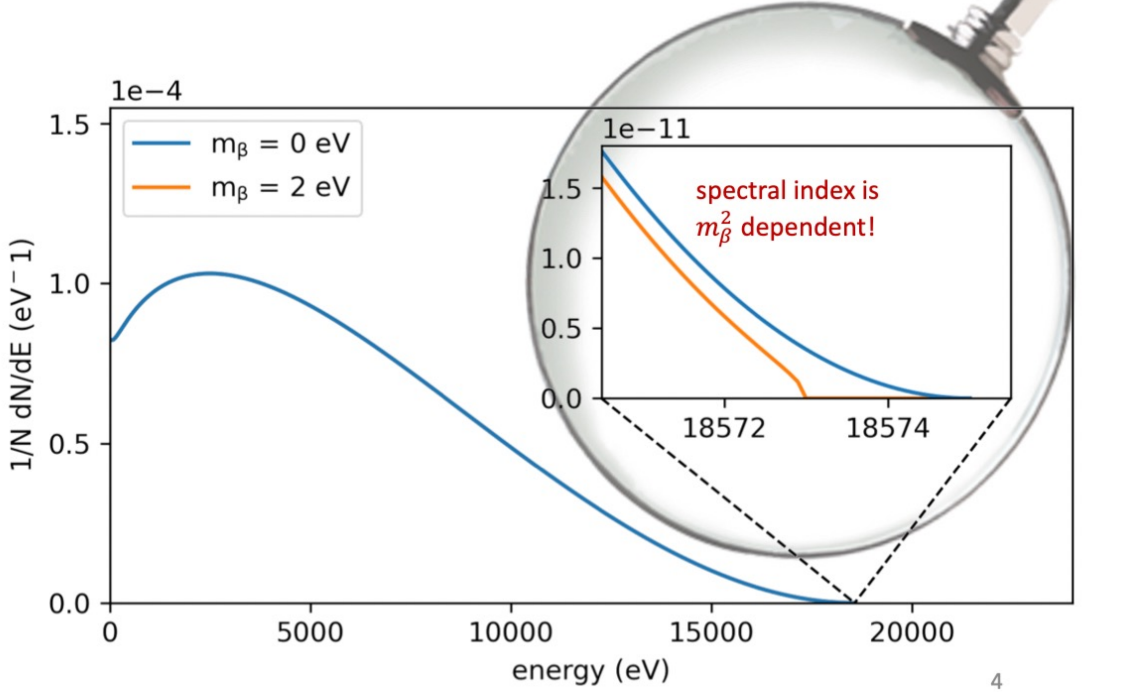
$$m^2_{\nu/\beta} = \sum_i |U_{ei}|^2 \cdot m_i^2$$



KATRIN experimental challenges

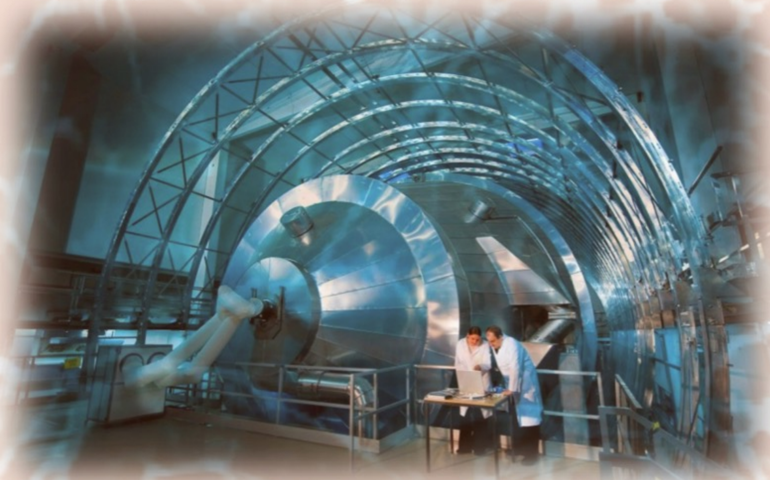
- ✓ strong tritium source: 10^{11} decays/s
- ✓ < 0.1 cps background level
- ✓ ~1 eV energy resolution
- ✓ 0.1% level understanding of the spectrum shape
- ✓ 0.1% level hardware stability controlled over the years

10^{-8} of all decays in last 40 eV



Conclusion & Outlook

- ✓ first **sub-eV neutrino mass limit** from a direct experiment, $m_\nu < 0.8$ eV (90% C.L.)
- ✓ next data release by end 2023 (<0.5 eV sensitivity)
- ✓ target sensitivity: $m_\nu < 0.2\text{-}0.3$ eV by 2025
- ✓ complementary limits for **eV-scale sterile** neutrinos
- ✓ new limit on **relic neutrino** overdensity
- ✓ search for **keV-scale sterile neutrinos** will follow



Thierry Lasserre - Moriond EW 2023 26

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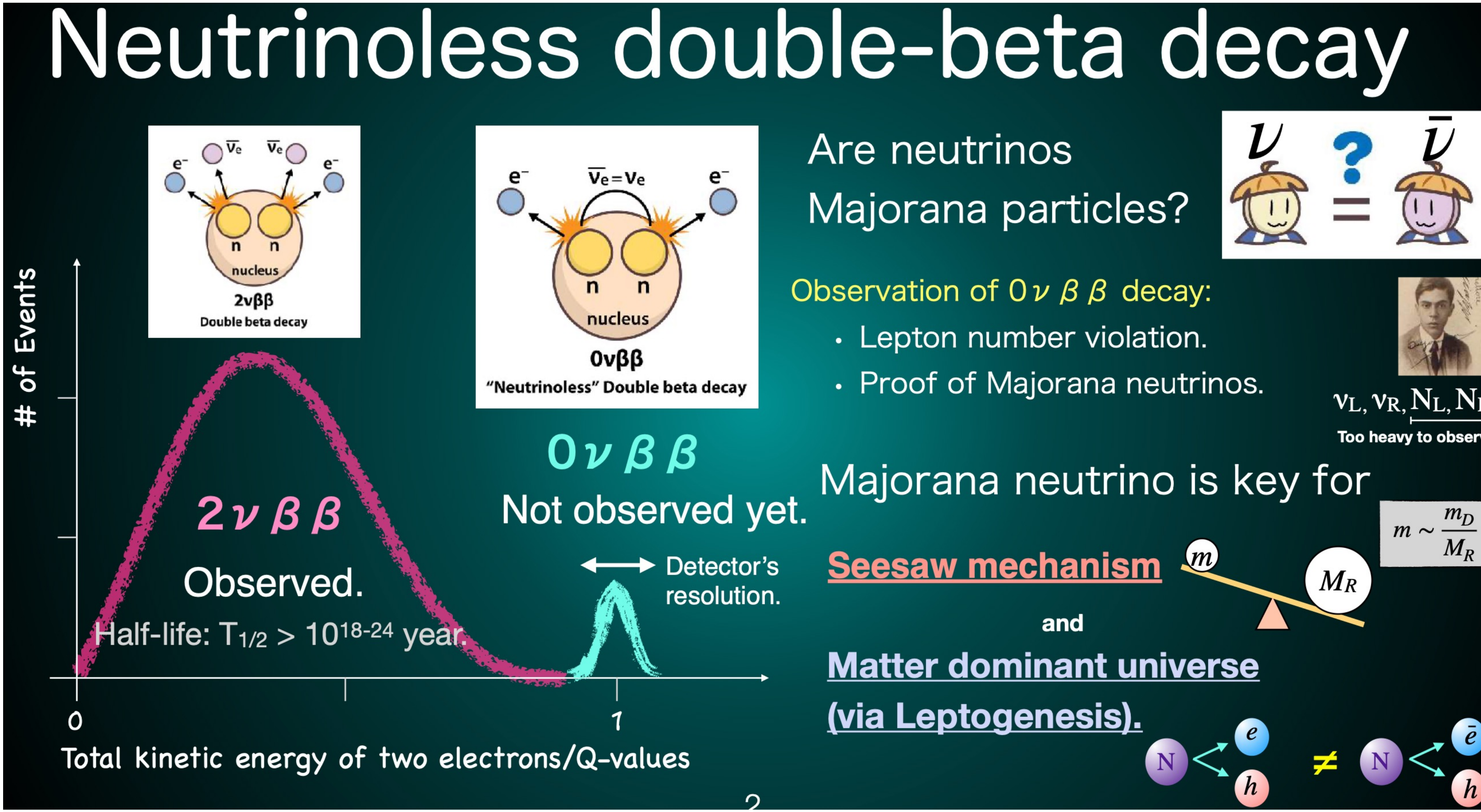

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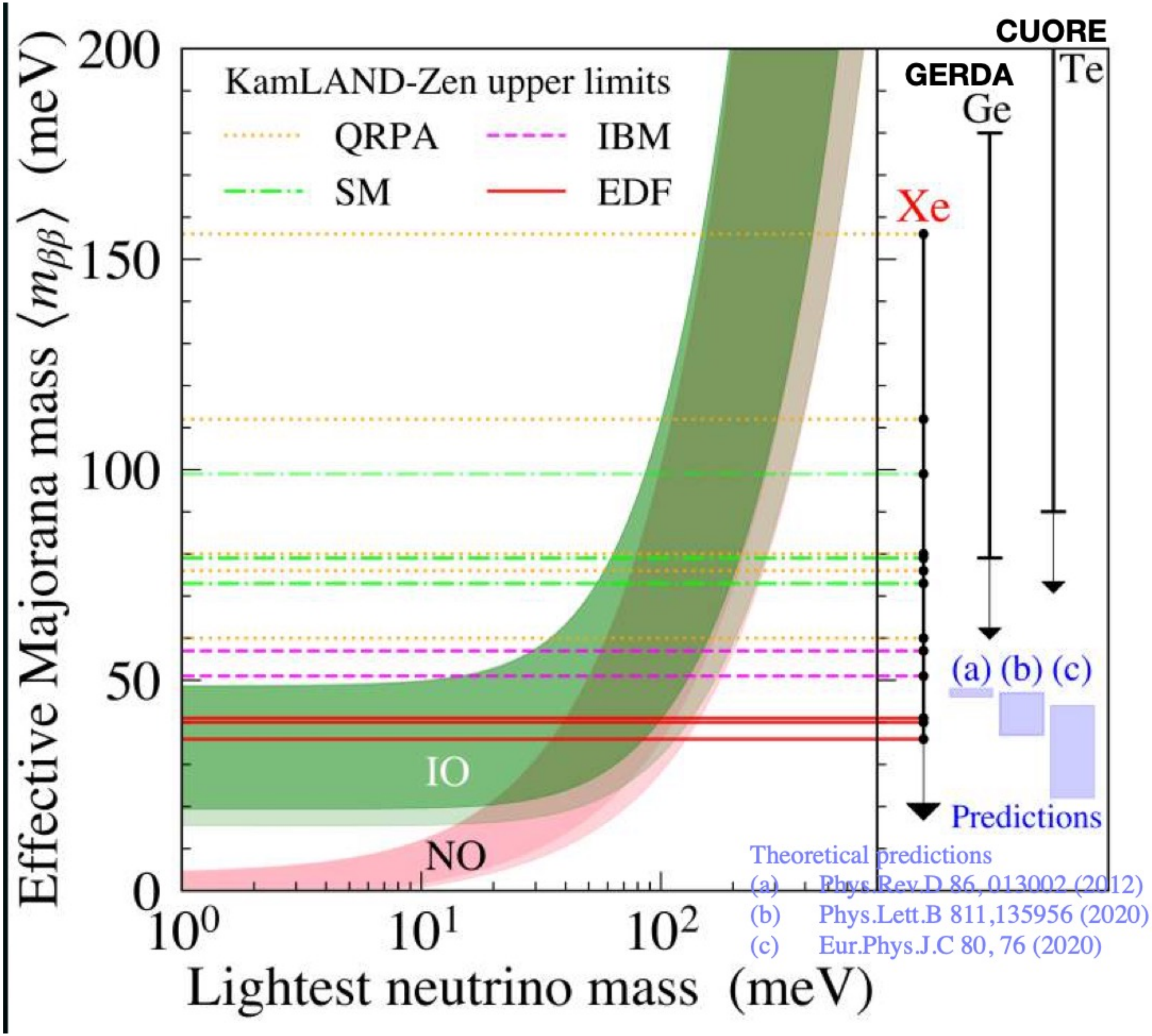

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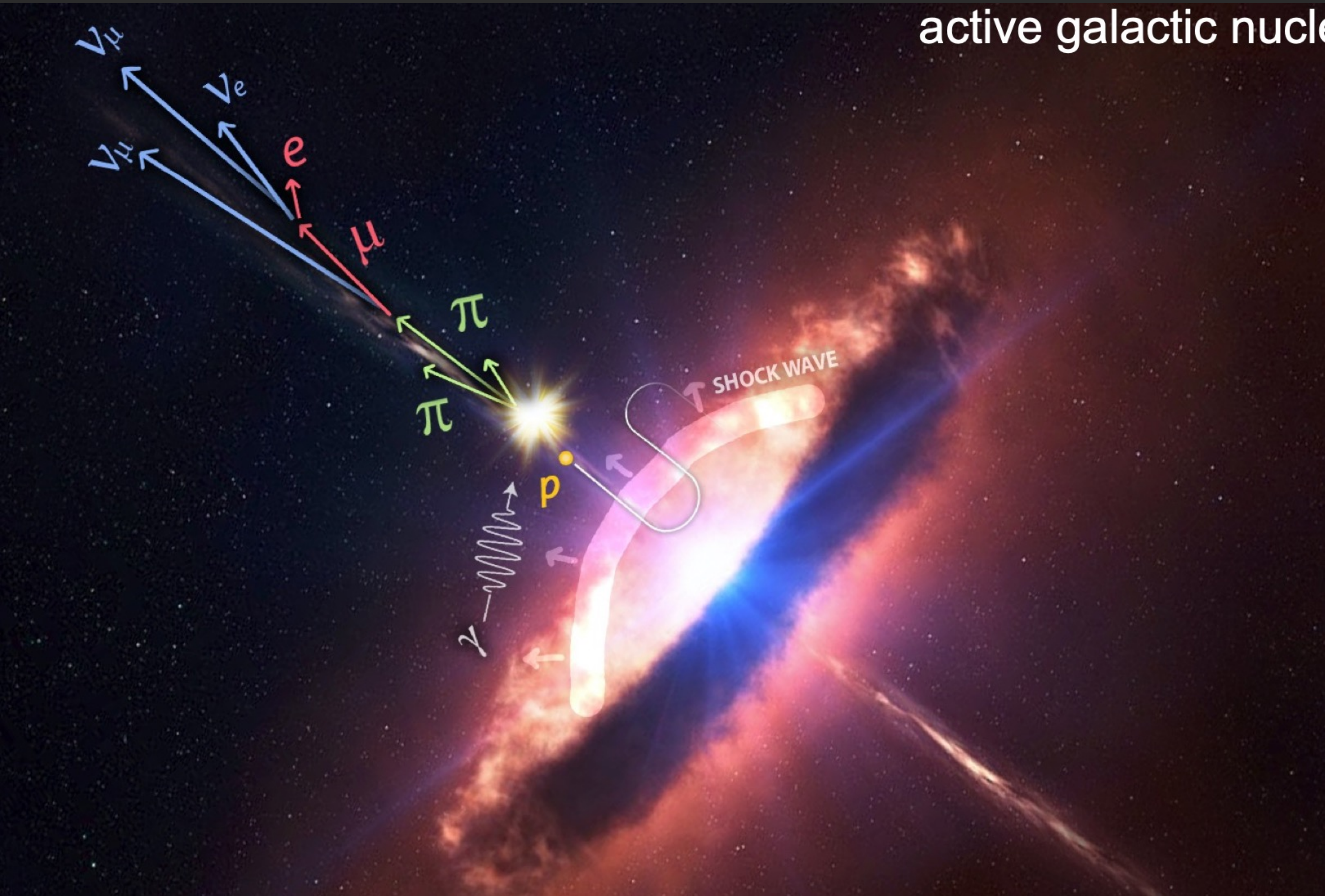

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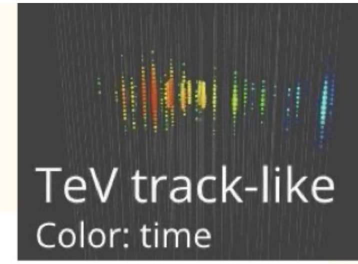
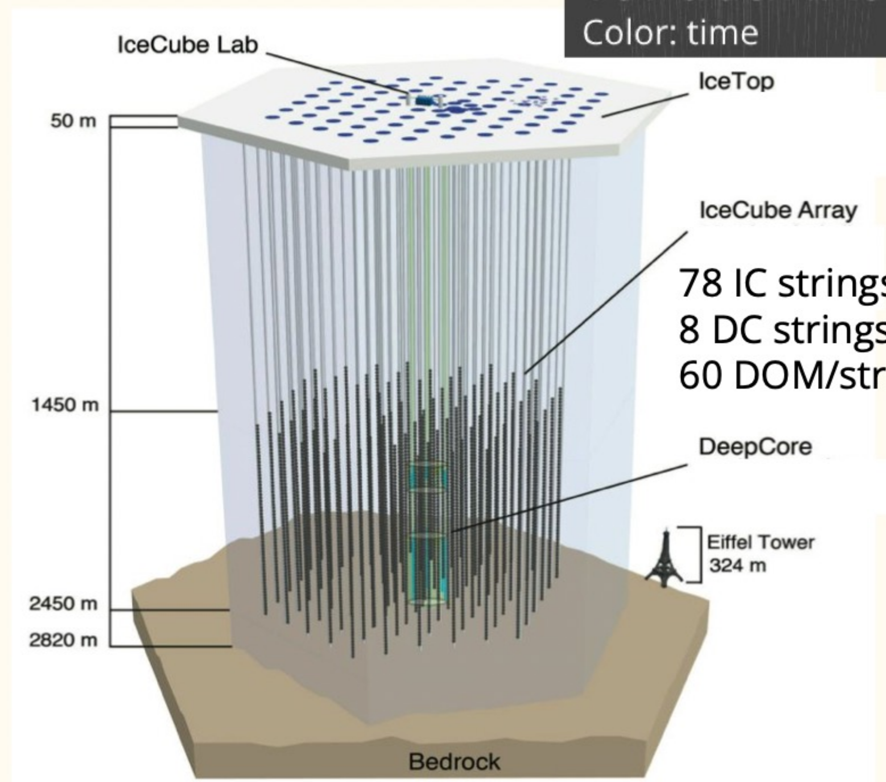
IceCube Neutrino Observatory



- 1 km^3 neutrino detector deep under South Pole ice;
- 5160 digital optical modules (DOMs) detect Cherenkov photons emitted during neutrino interactions;
- DOMs record pulse charges & times;
- **DeepCore**: denser configured sub-detector, can observe **GeV-scale neutrinos**.



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- muon produced by neutrino near IceCube
- comes through the Earth
- 2,600 TeV inside detector
- not atmospheric