Let There be Light

Next-generation neutrino detection at THEIA

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UC Berkeley & LBNL
BNP NPP colloquium
28th Mar, 2023

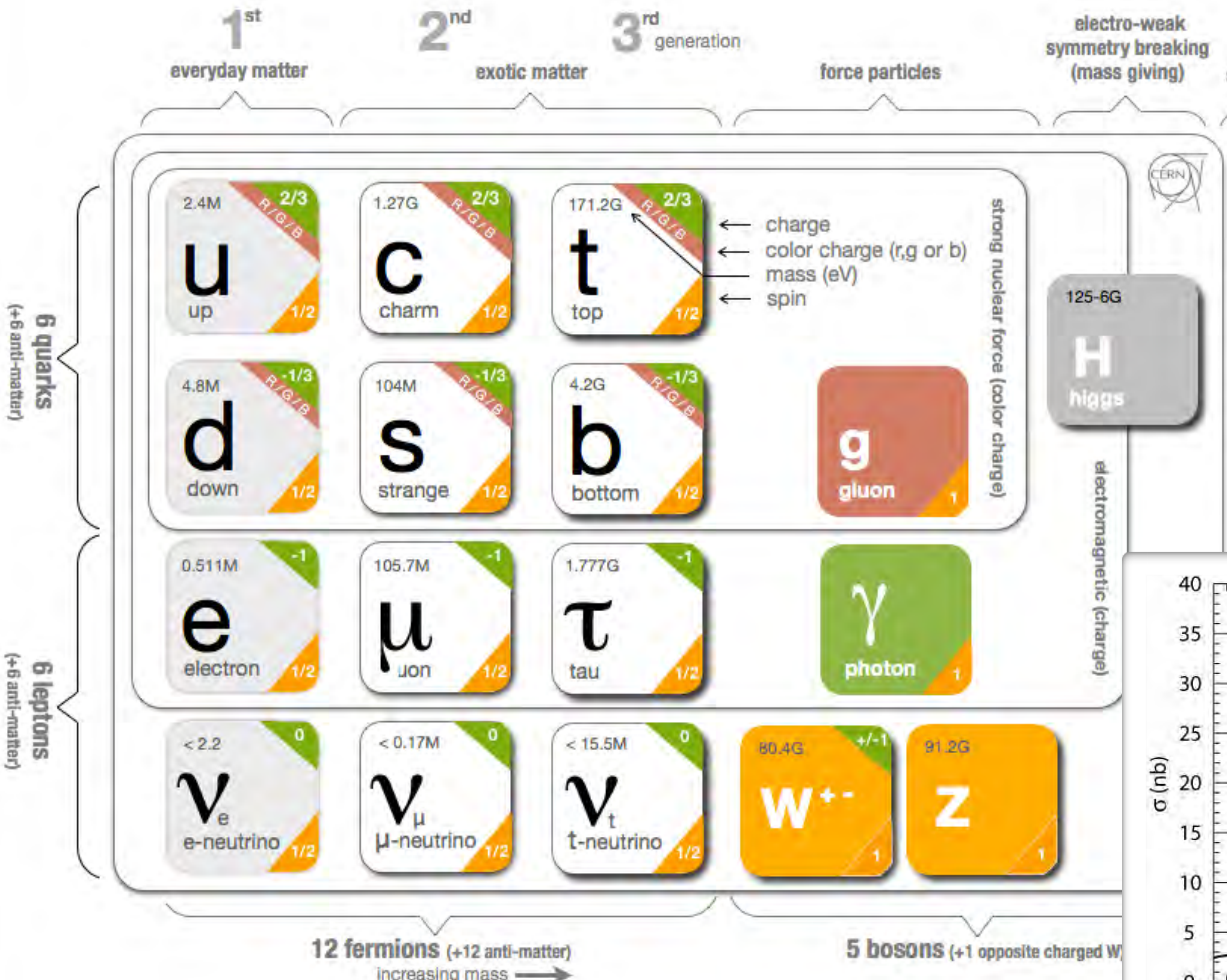
THEIA

- Hybrid Cherenkov/ scintillation detector
- Multi-messenger astrophysics
- Probe the fundamental nature of matter: CPV and Majorana ν
- Unique opportunity to engage a broad community in world-leading “big science”

Overview

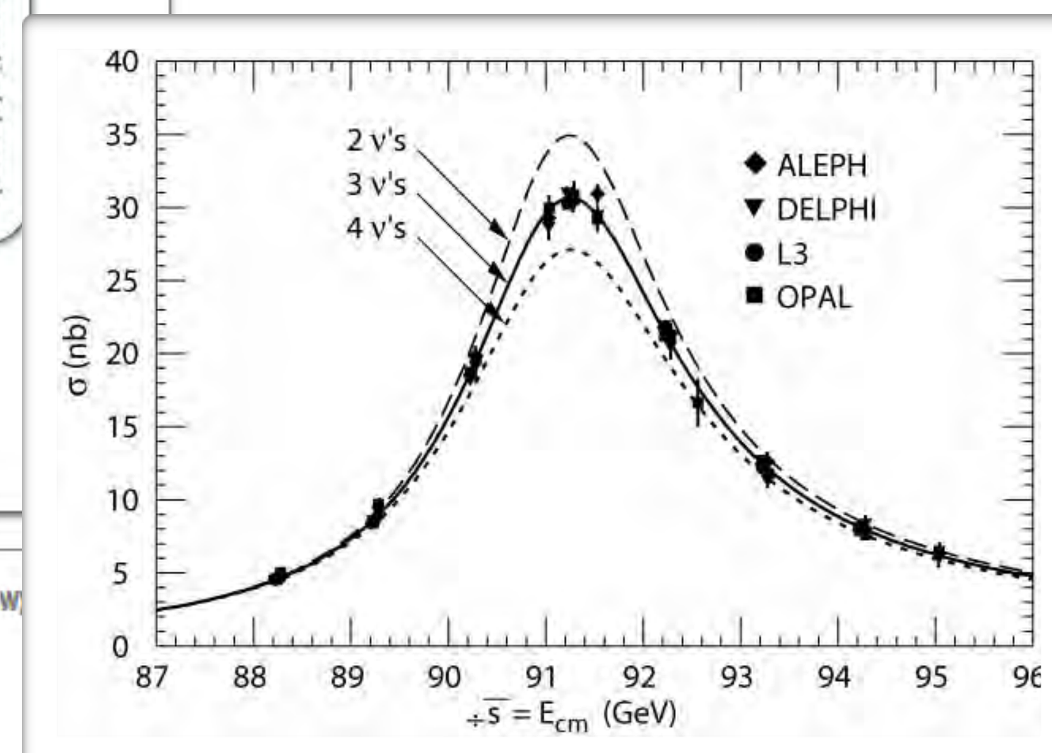
- Introduction to neutrinos
- Neutrino oscillation: *water Cherenkov detectors*
- Open questions: *liquid scintillator detectors*
- Next-generation sensitivity: *hybrid detectors*
  - *Physics reach*
  - *Technology development*

Standard Model Neutrinos

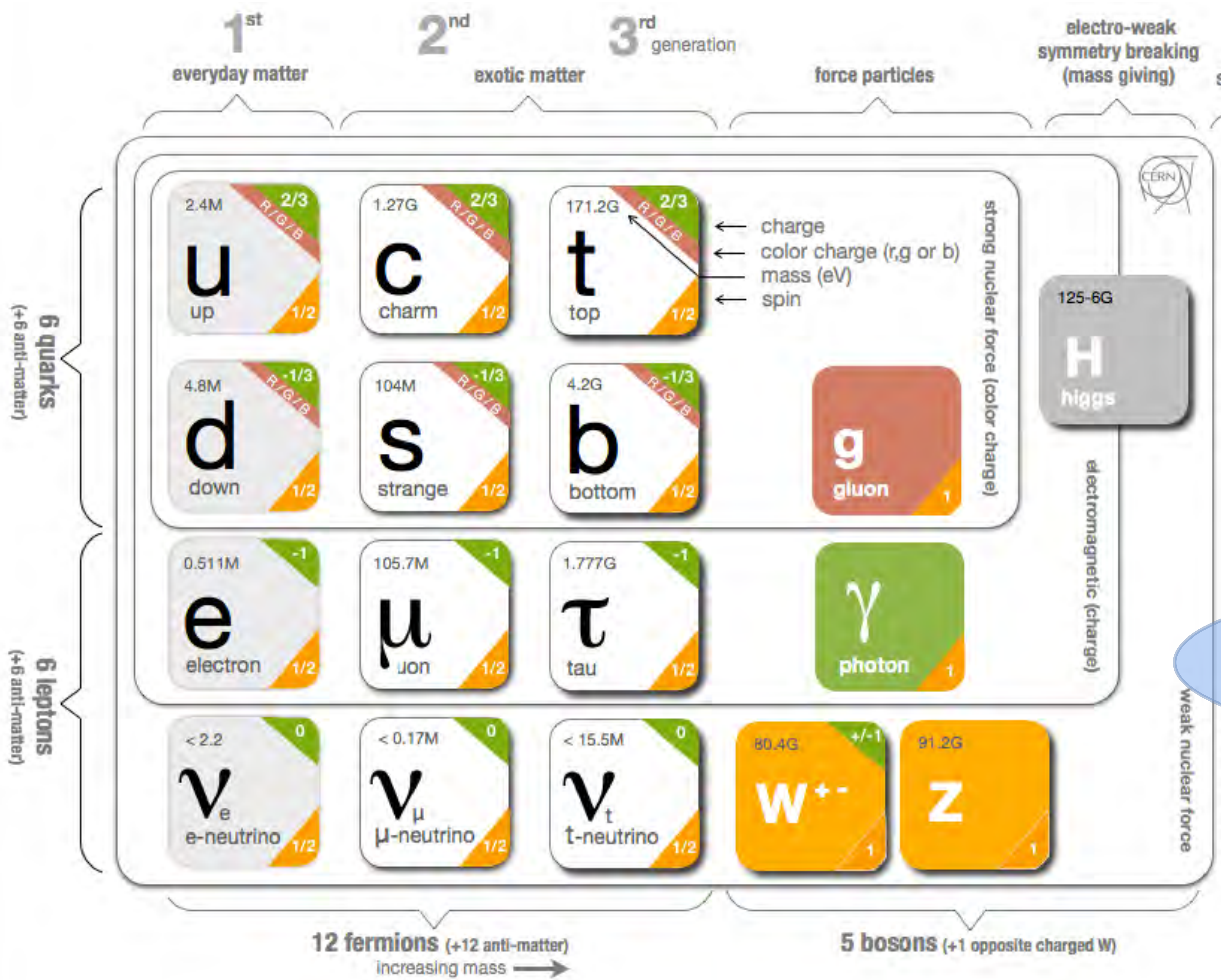


Neutrino properties:

1. Interact weakly
2. Very tiny masses
3. Three flavours



Standard Model Neutrinos



Neutrino properties:

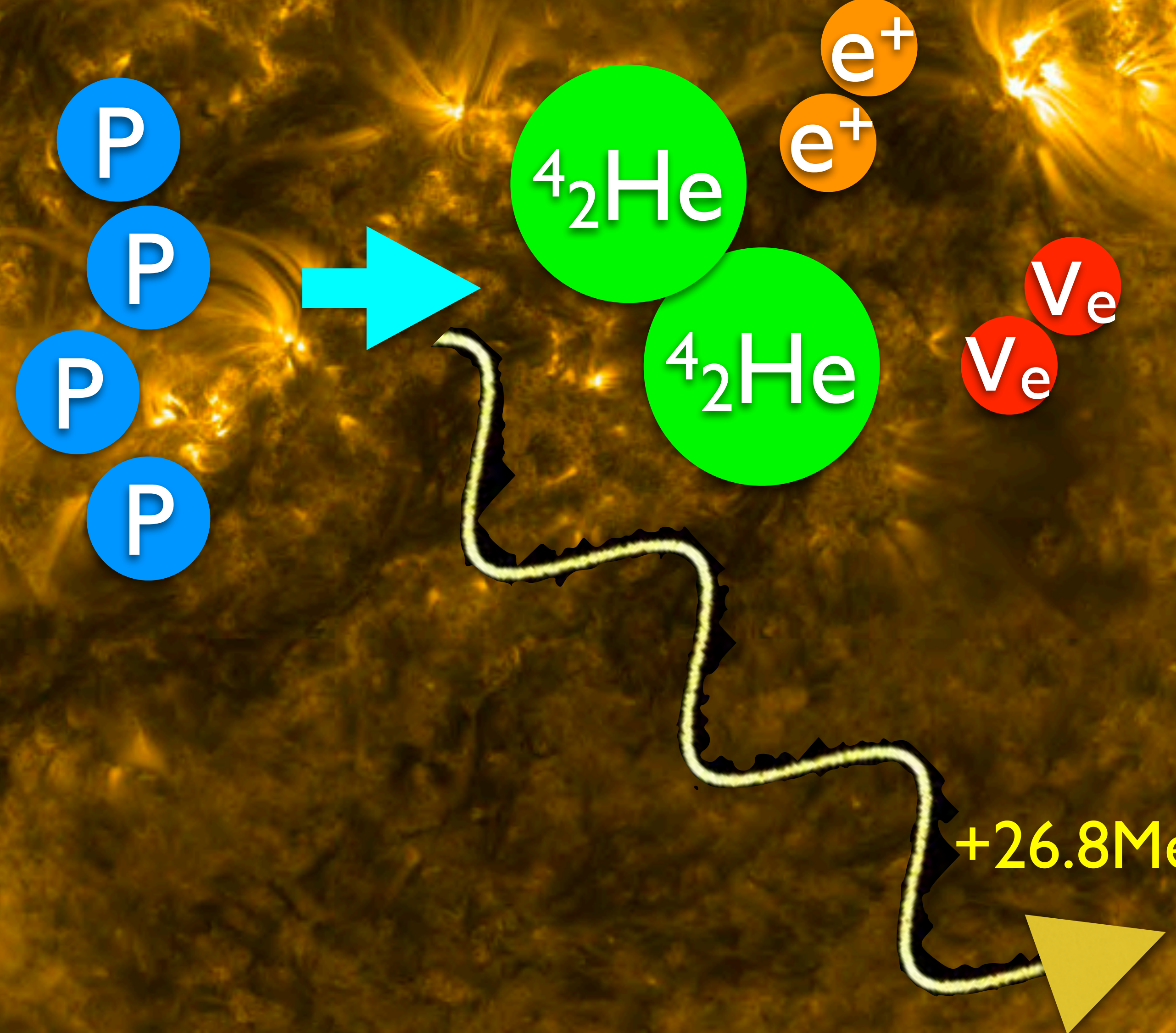
1. Interact weakly
2. Very tiny masses
3. Three flavours

ν_e - The Sun, nuclear reactors

ν_μ - Cosmic rays, man-made

ν_τ - Man-made beams
First observation in 2000

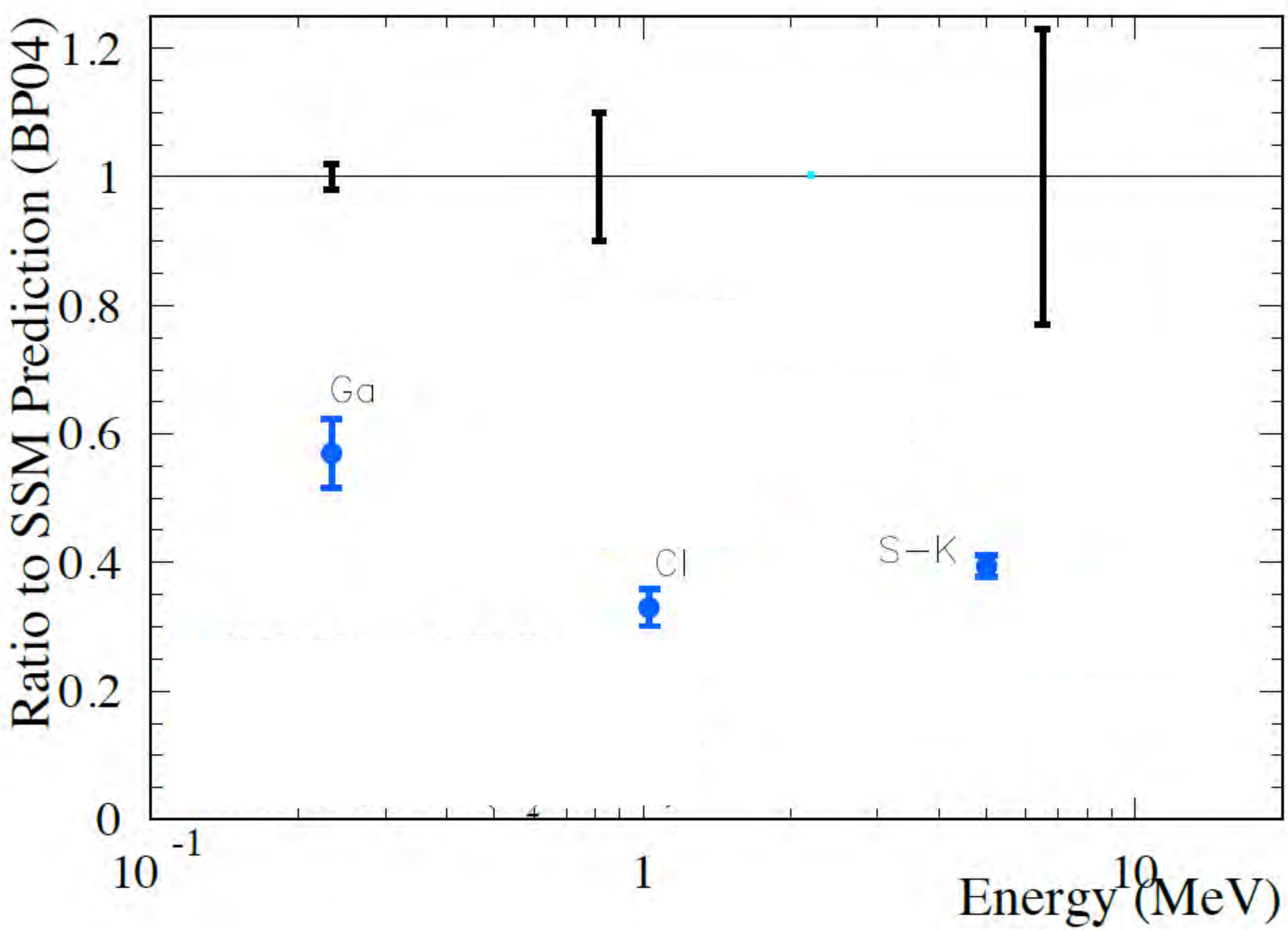
How Does the Sun Shine?



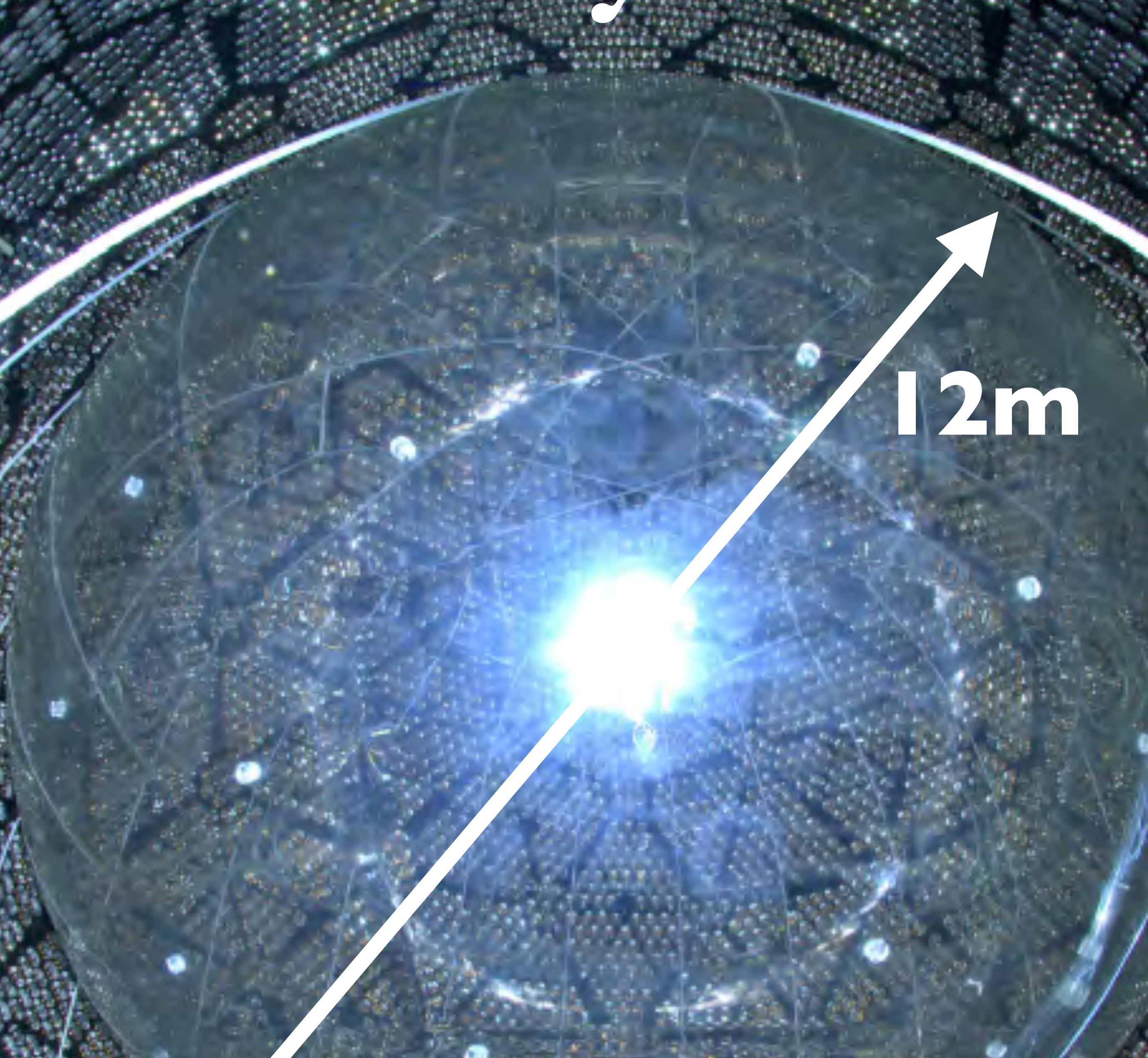
Nuclear fusion reactions in the core produce:

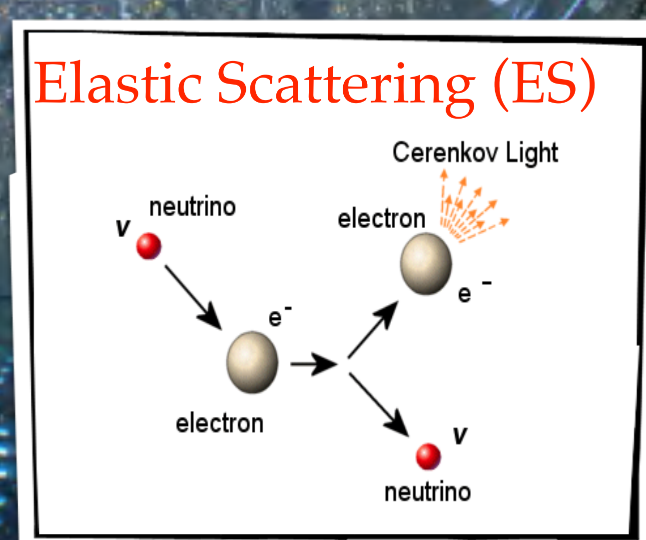
- Helium
- Energy (heat, light)
- Neutrinos

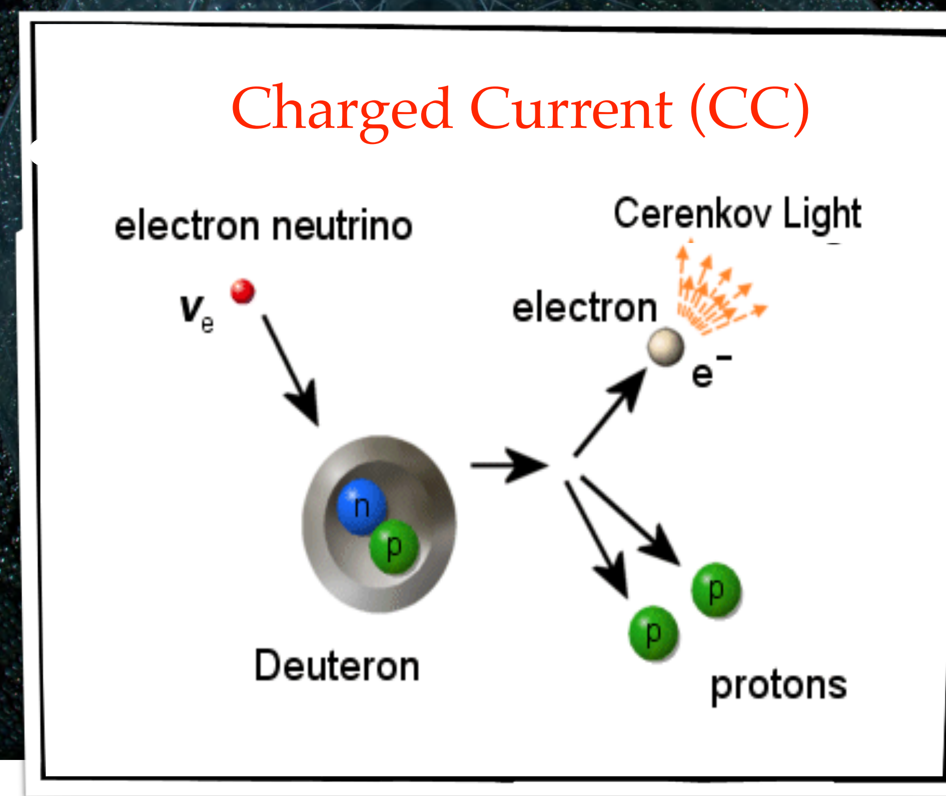
Solar Neutrino Problem

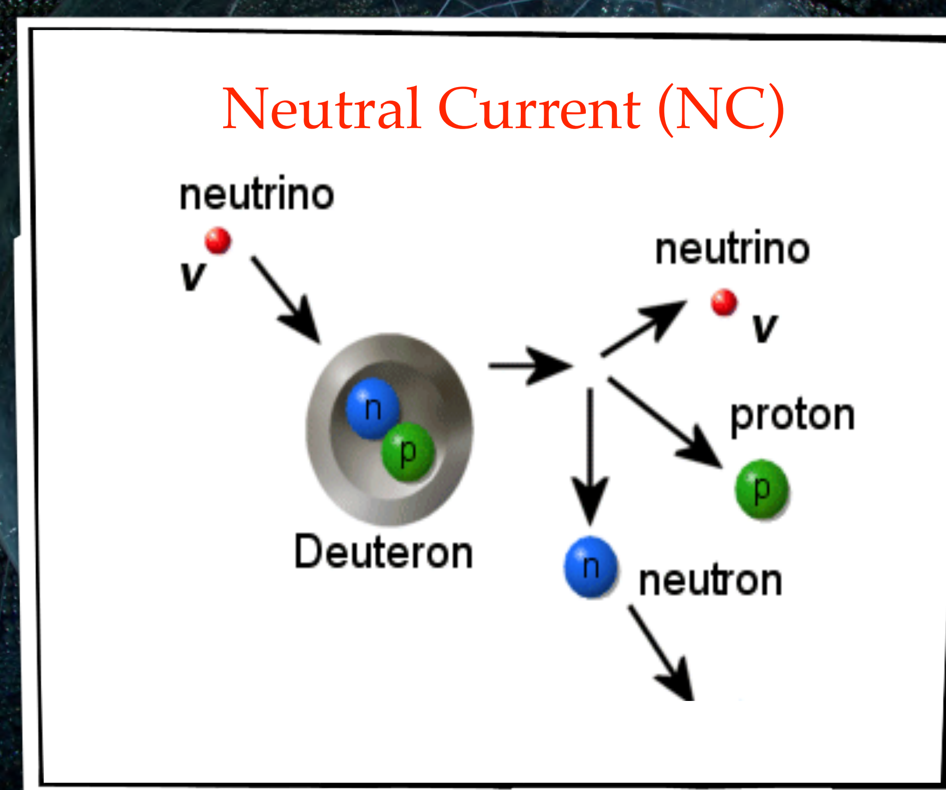


Sudbury Neutrino Observatory

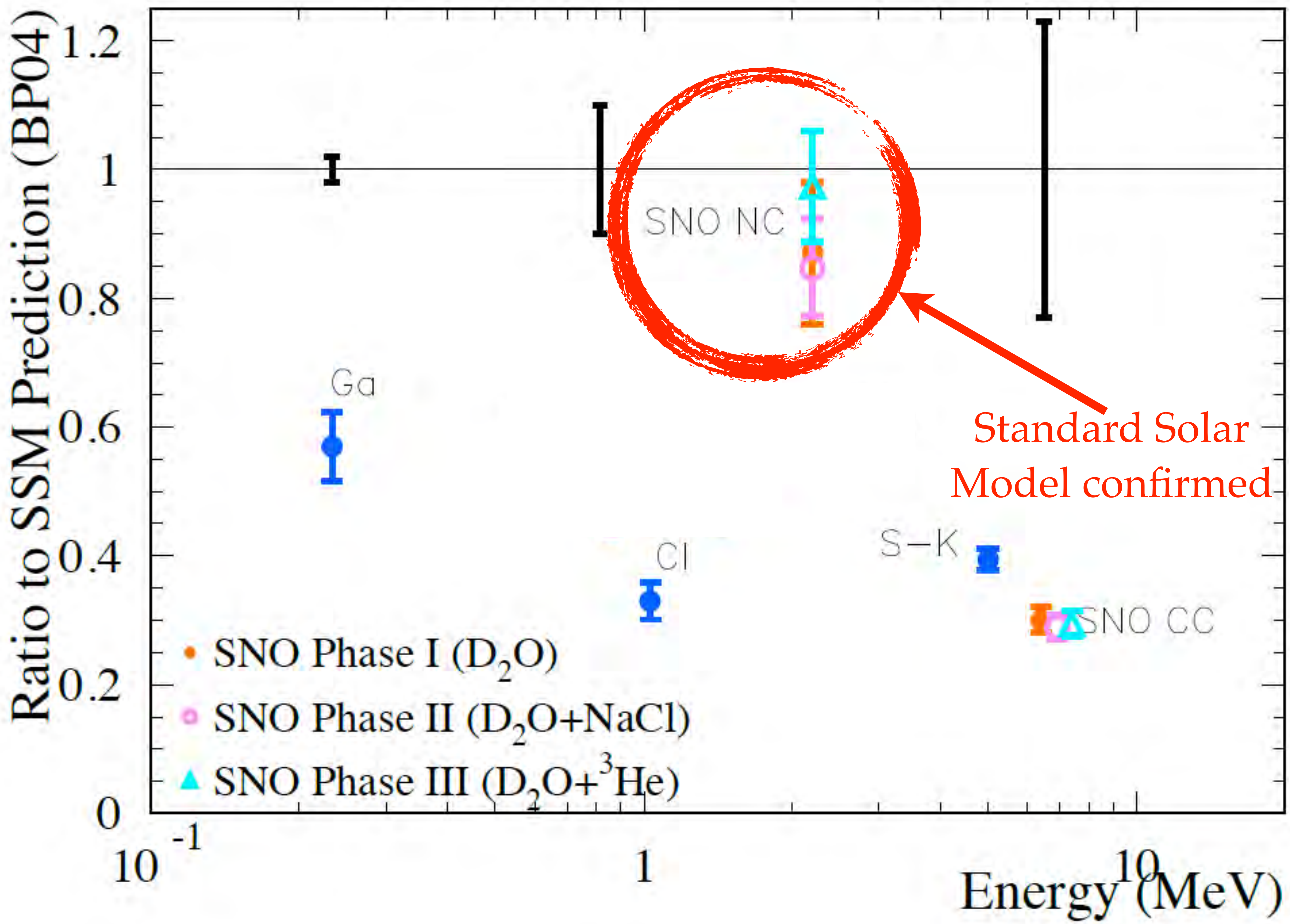


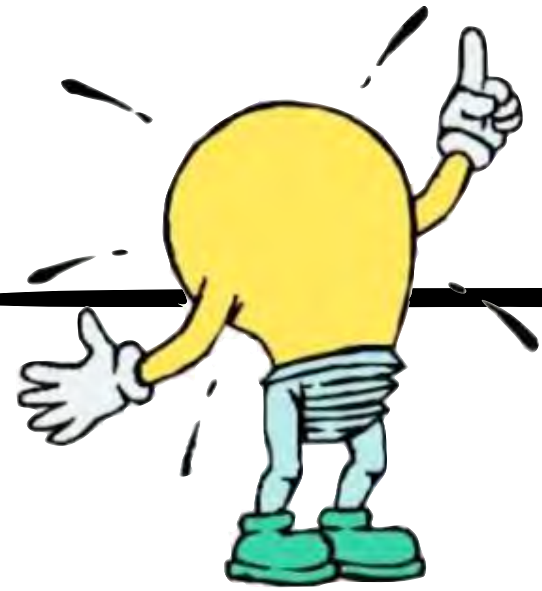






Solar Neutrino Problem Resolved

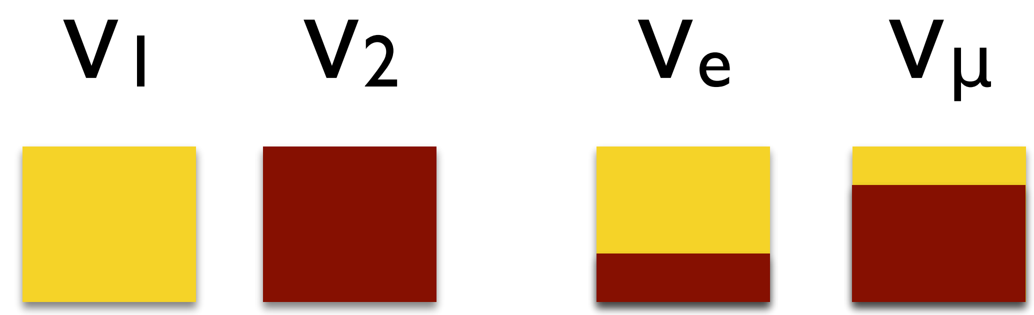


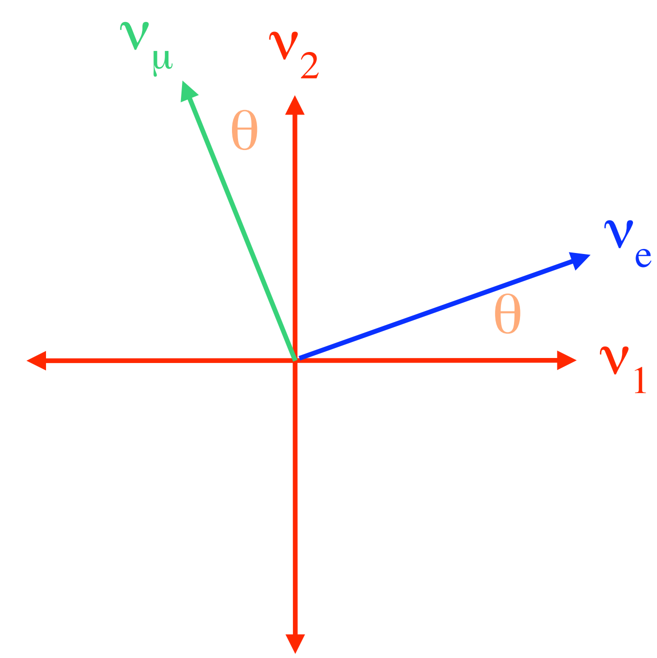


Neutrino Oscillation

Produced as weak (flavour) eigenstates (ν_e, ν_μ, ν_τ)
Propagate as physical (mass) eigenstates (ν_1, ν_2, ν_3)

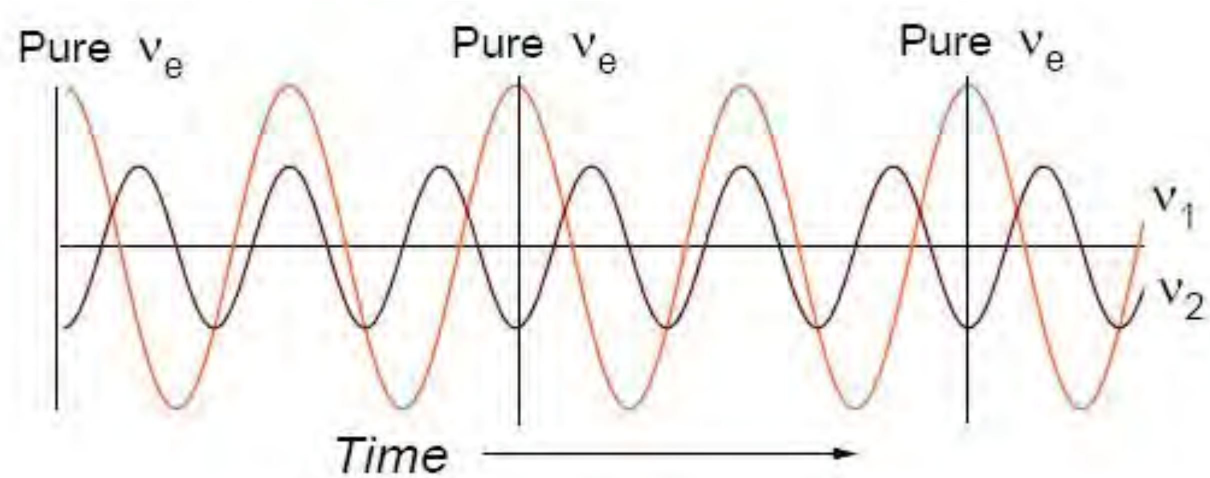
Simplified 2-neutrino scenario:





$$P_{\nu_e \to \nu_x} = \sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2 L}{E_\nu}\right)$$

$$\begin{bmatrix} \nu_e \\ \nu_\mu \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \end{bmatrix}$$



$\Delta m^2 = m_2^2 - m_1^2$: requires non-zero neutrino mass!

2015 Nobel Prize in Physics

SuperK

Takaaki Kajita

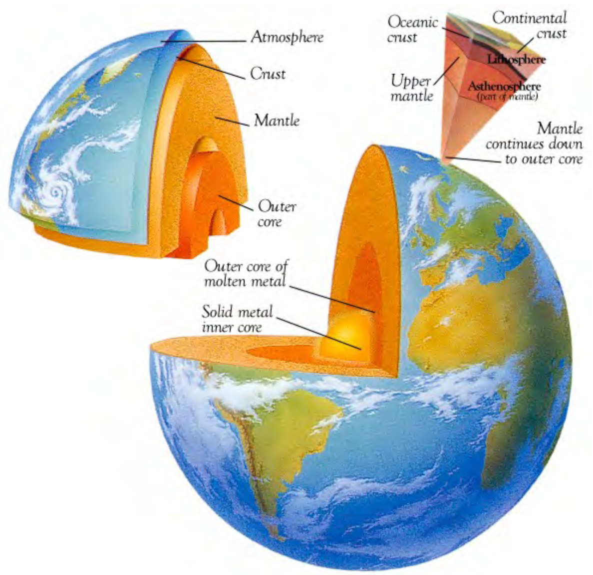
SNO

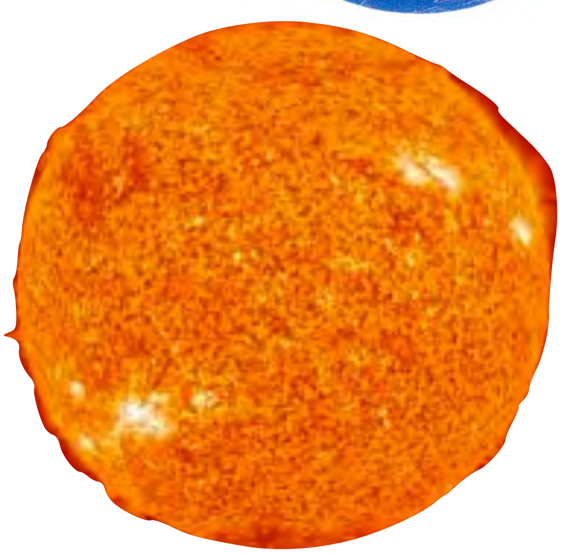
Arthur B. McDonald

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald "for the discovery of neutrino oscillations, which shows that neutrinos have mass"

Neutrinos 101: Why do we (still) study them?

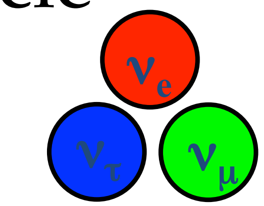
Unique probe of otherwise unreachable regions

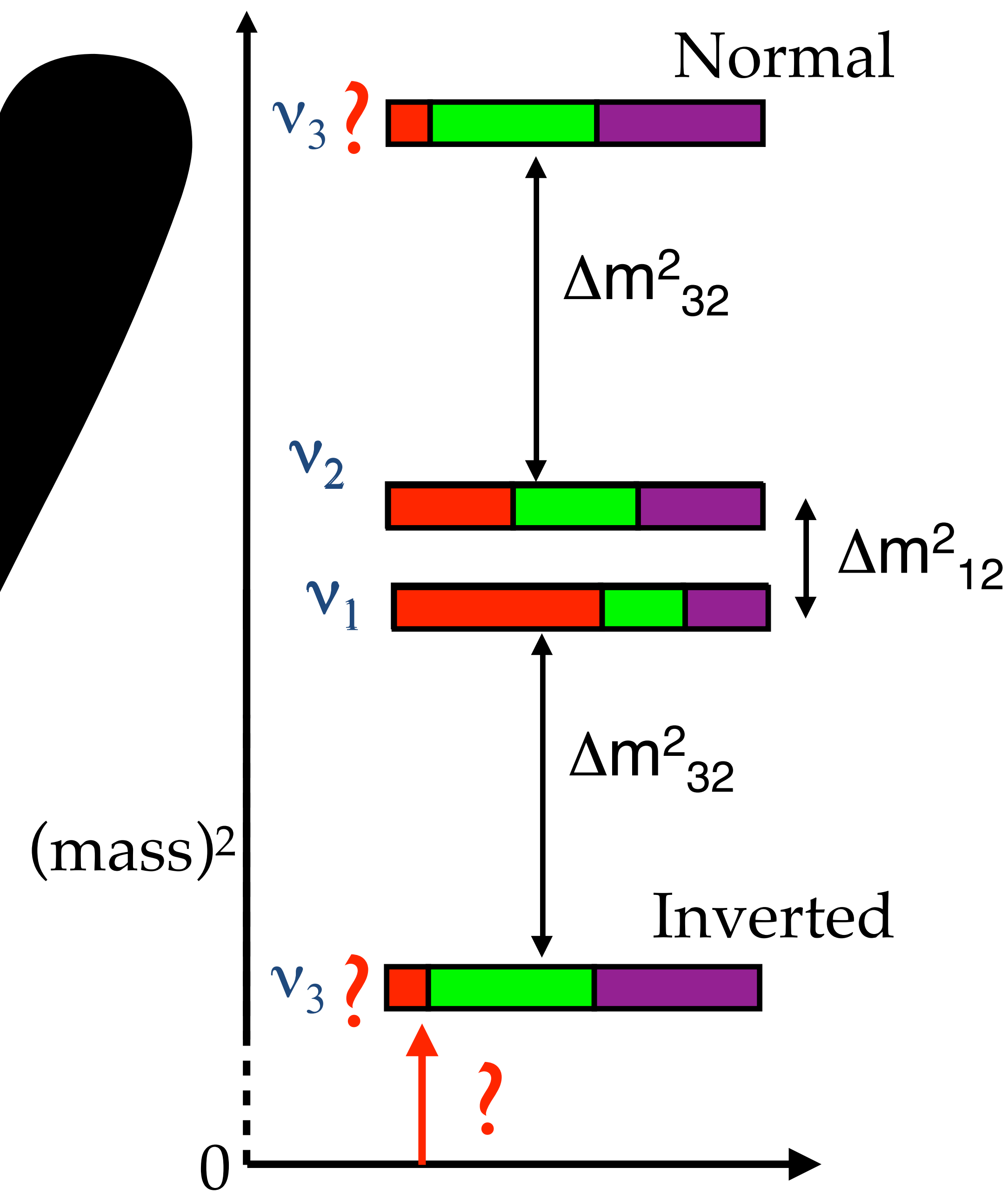


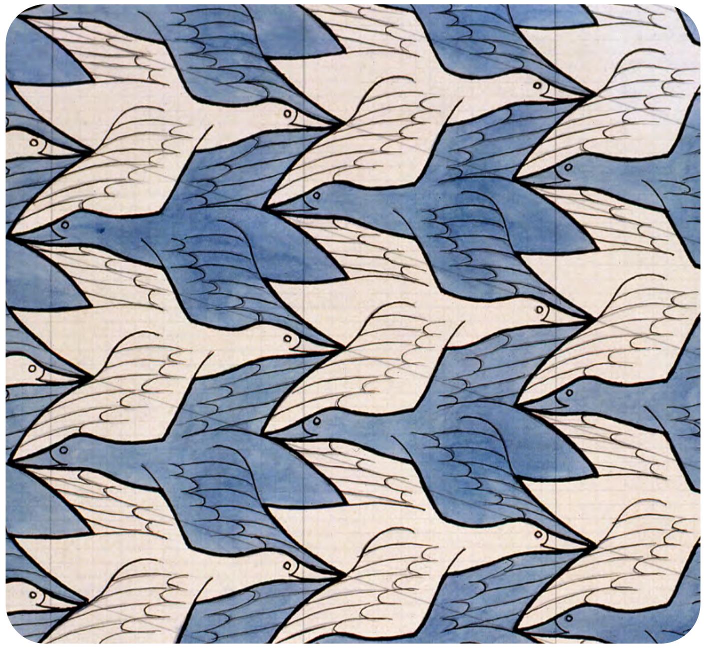


ν

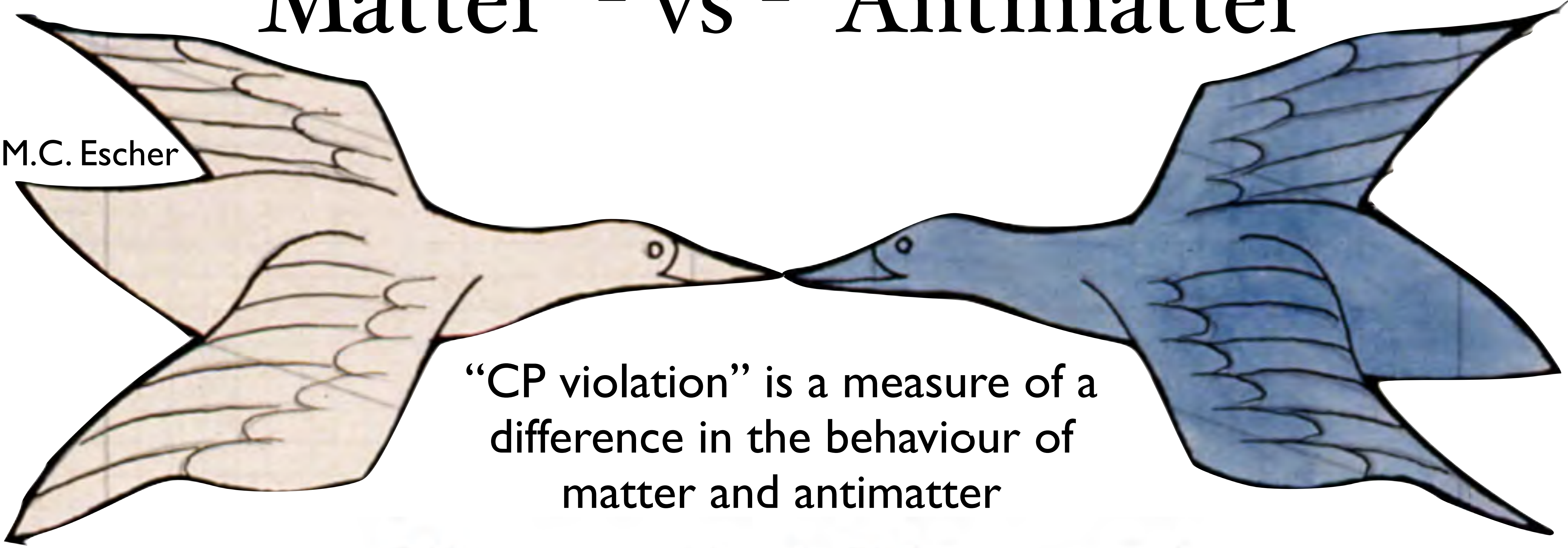
Fascinating particle in its own right







Matter - vs - Antimatter

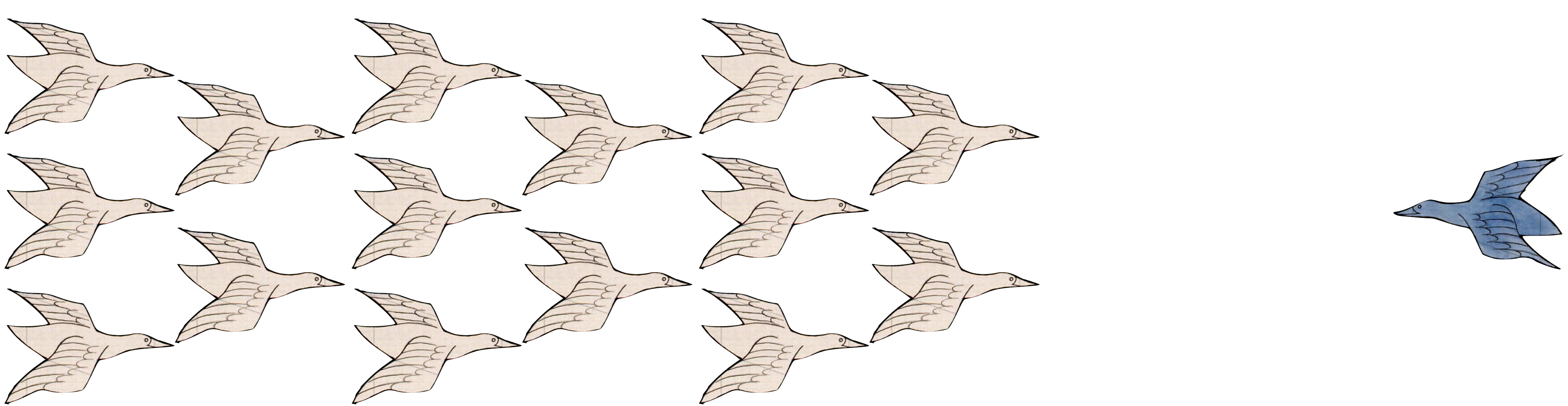


M.C. Escher

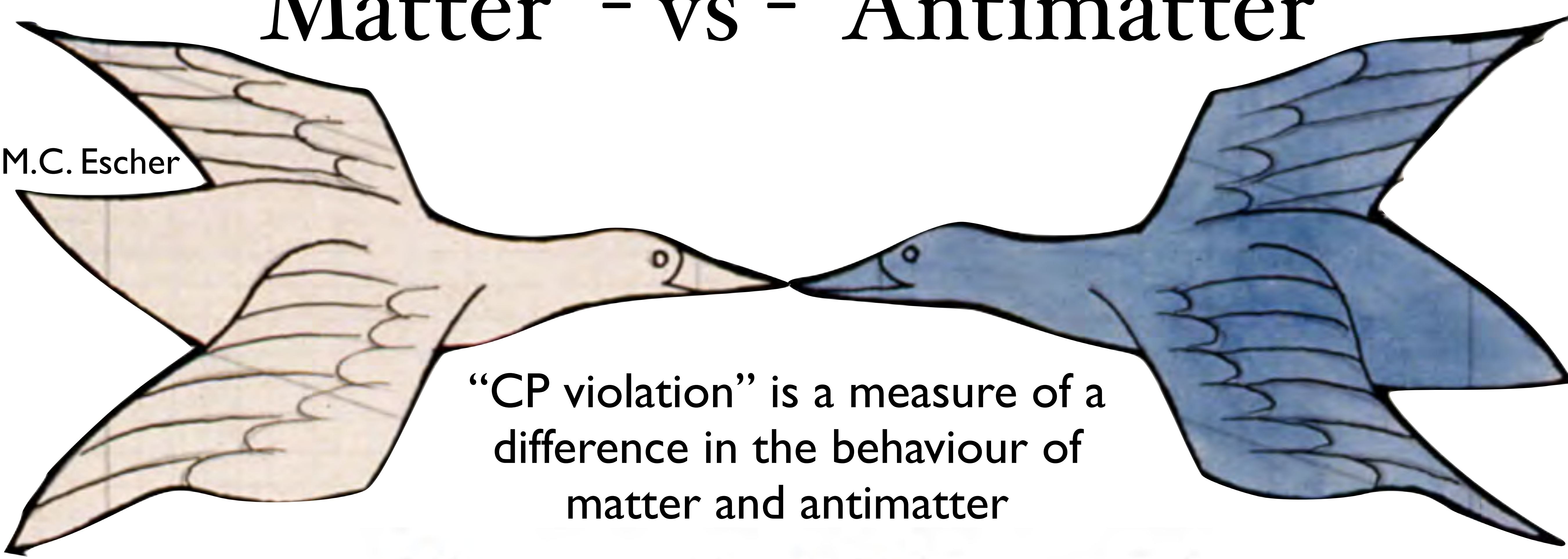
"CP violation" is a measure of a difference in the behaviour of matter and antimatter

$$P(\nu_\mu \rightarrow \nu_e) \neq P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$$

The Universe is out of balance: matter far outweighs antimatter



Matter - vs - Antimatter



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$$P(\nu_\mu \to \nu_e) \neq P(\bar{\nu}_\mu \to \bar{\nu}_e)$$

The Universe is out of balance: matter far outweighs antimatter

fortunately for us!

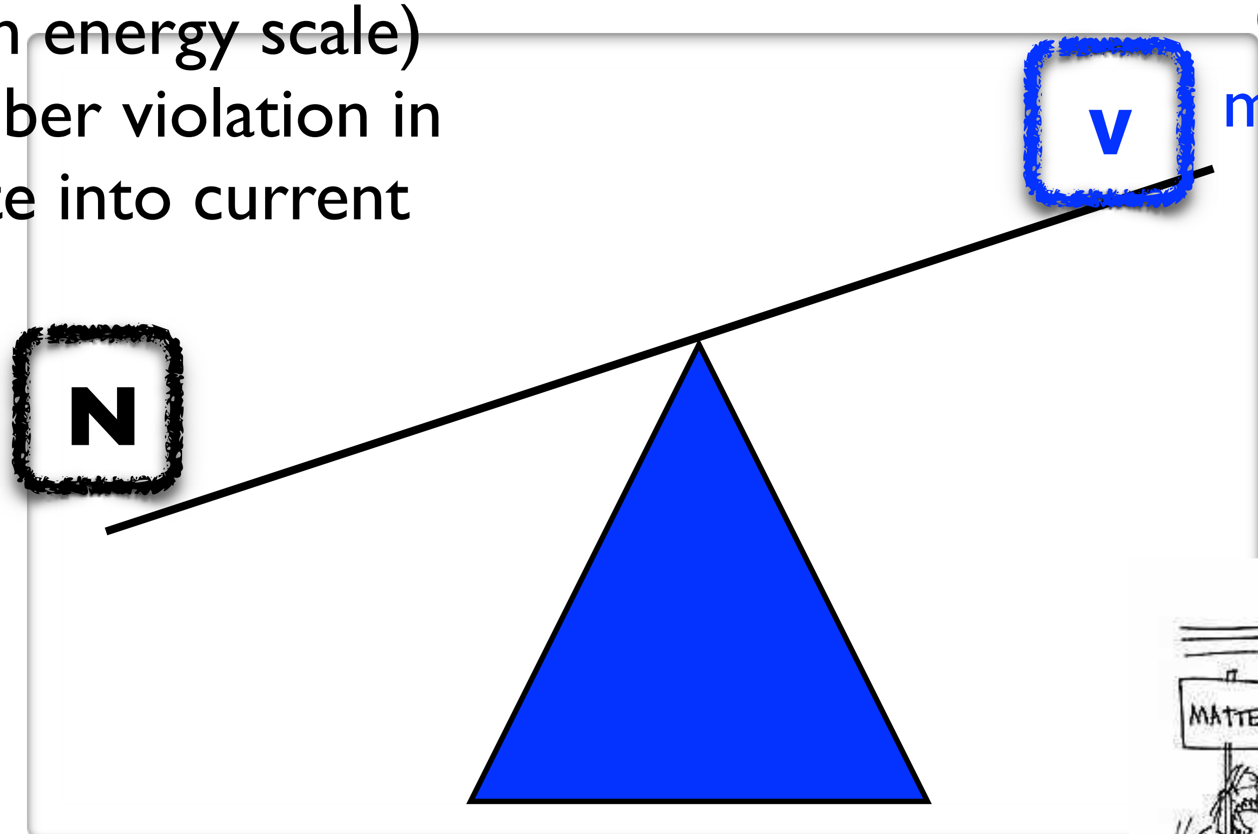
Majorana Neutrinos

M.C. Escher

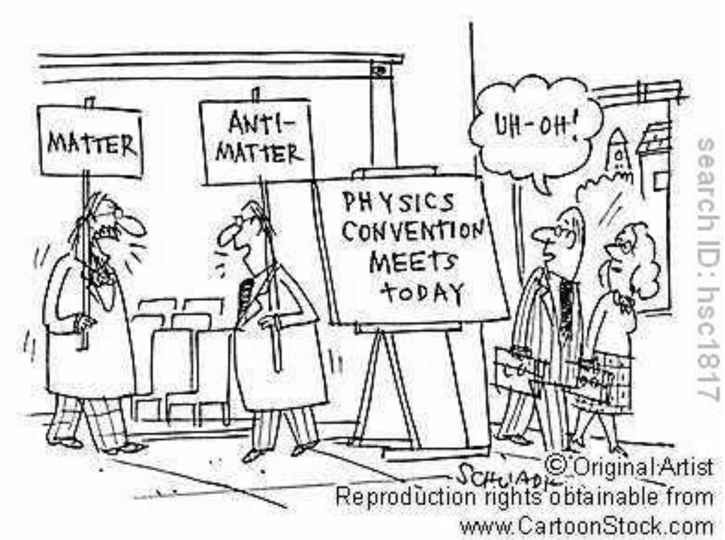
Can undergo the "See-Saw" mechanism

A big Majorana mass splits the Dirac neutrino into two neutrinos: the light neutrino **ν** and a heavy neutrino **N**

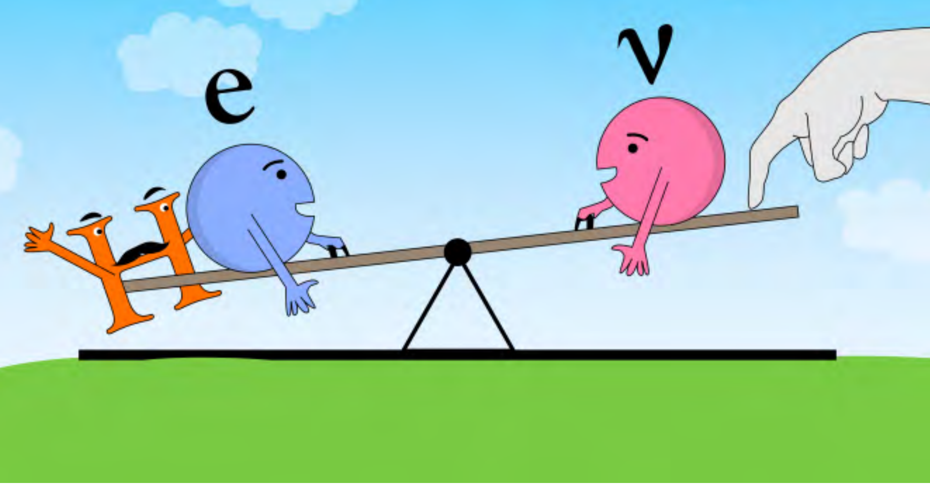
Made in the Big Bang (high energy scale) CP violation + lepton number violation in their decay could translate into current asymmetry



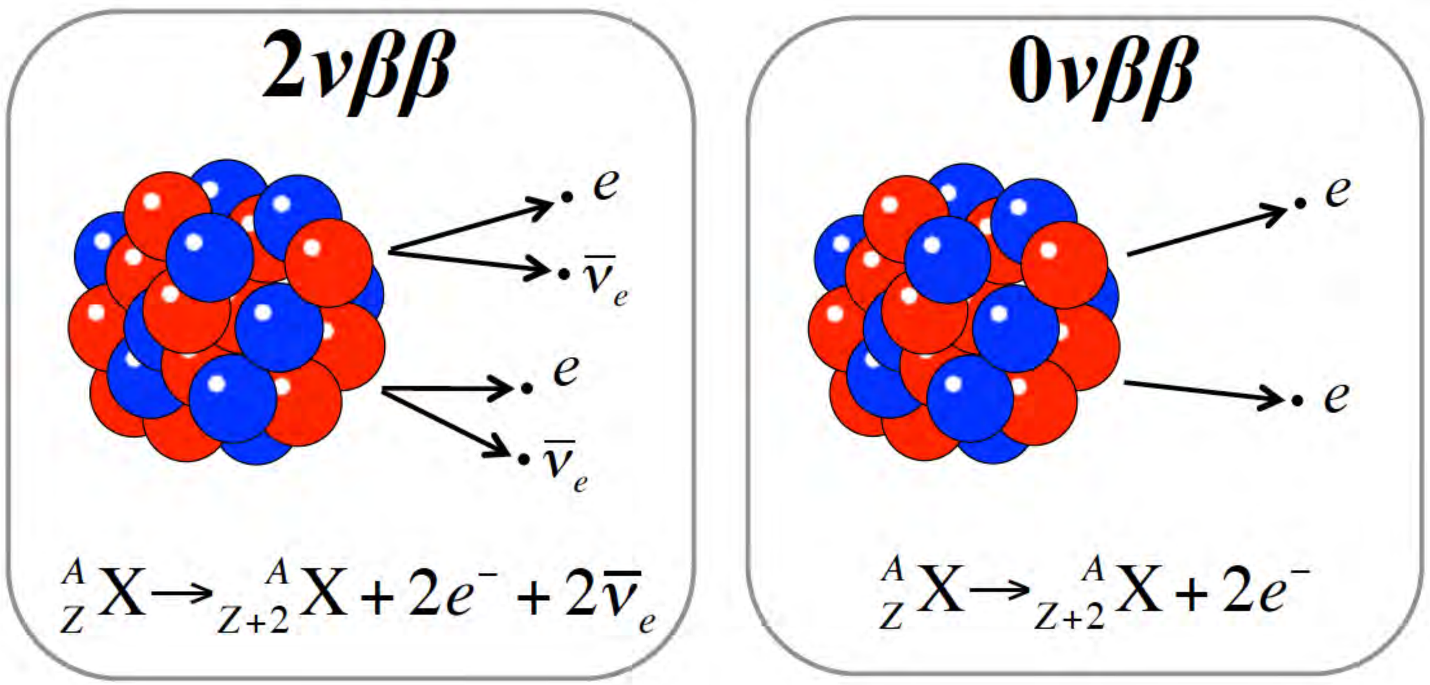
Our familiar light ν, made and detected in terrestrial experiments



http://www.research.vt.edu/resmag/sciencecol/2002asymmetry.html



0ν double beta decay

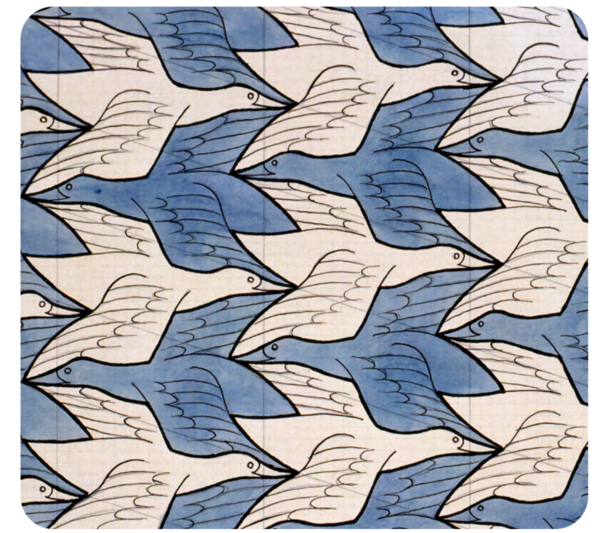


$\tau \geq 10^{19}$ y

$\tau \geq 10^{26}$ y

Fortunately,
N_A is very large!

M.C. Escher

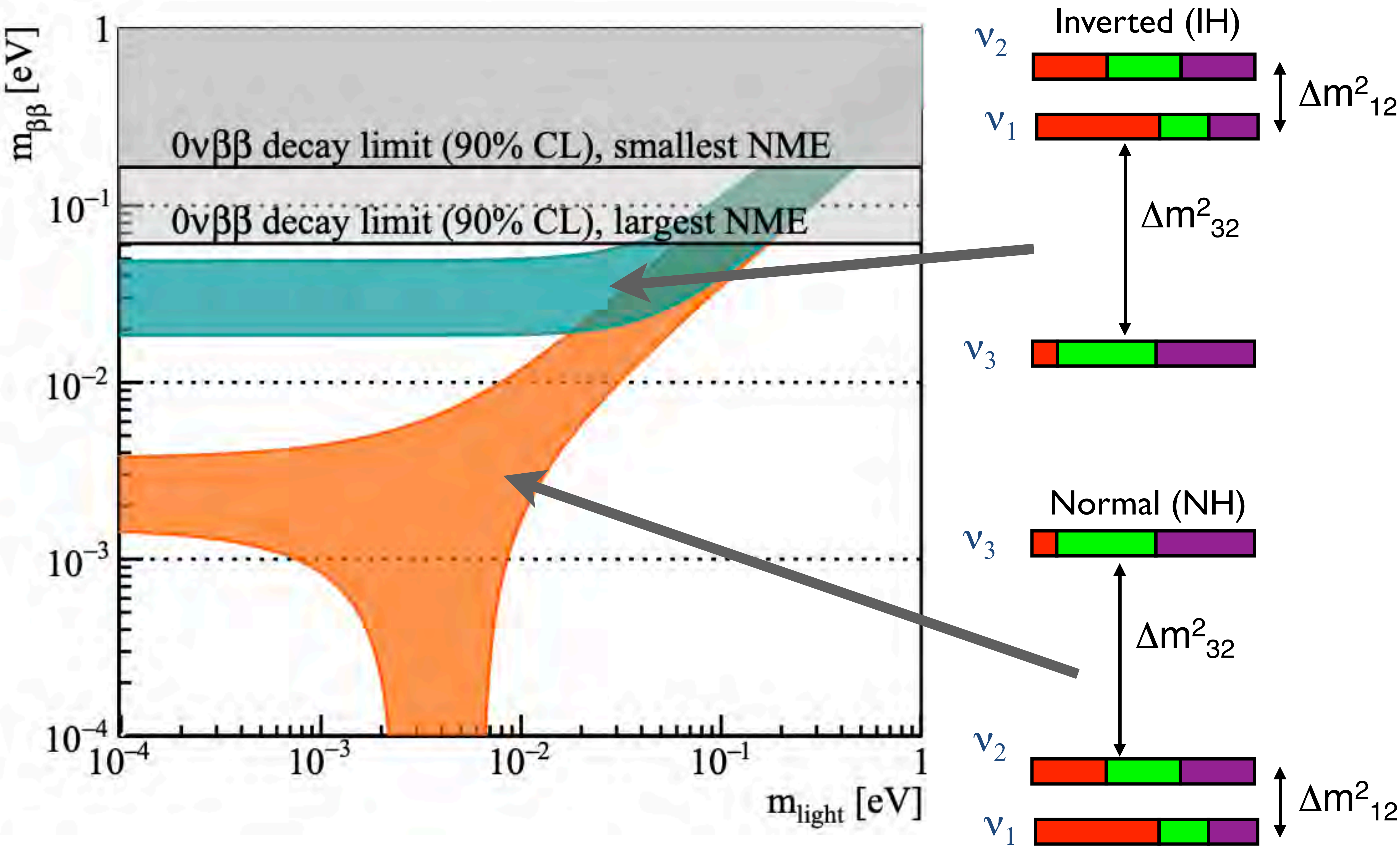


1. *Lepton number violation*
2. *Majorana nature of neutrinos*
3. *Rate measures (effective) $m_{\nu e}$*

The 2015
LONG RANGE PLAN
for NUCLEAR SCIENCE

We recommend the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment.

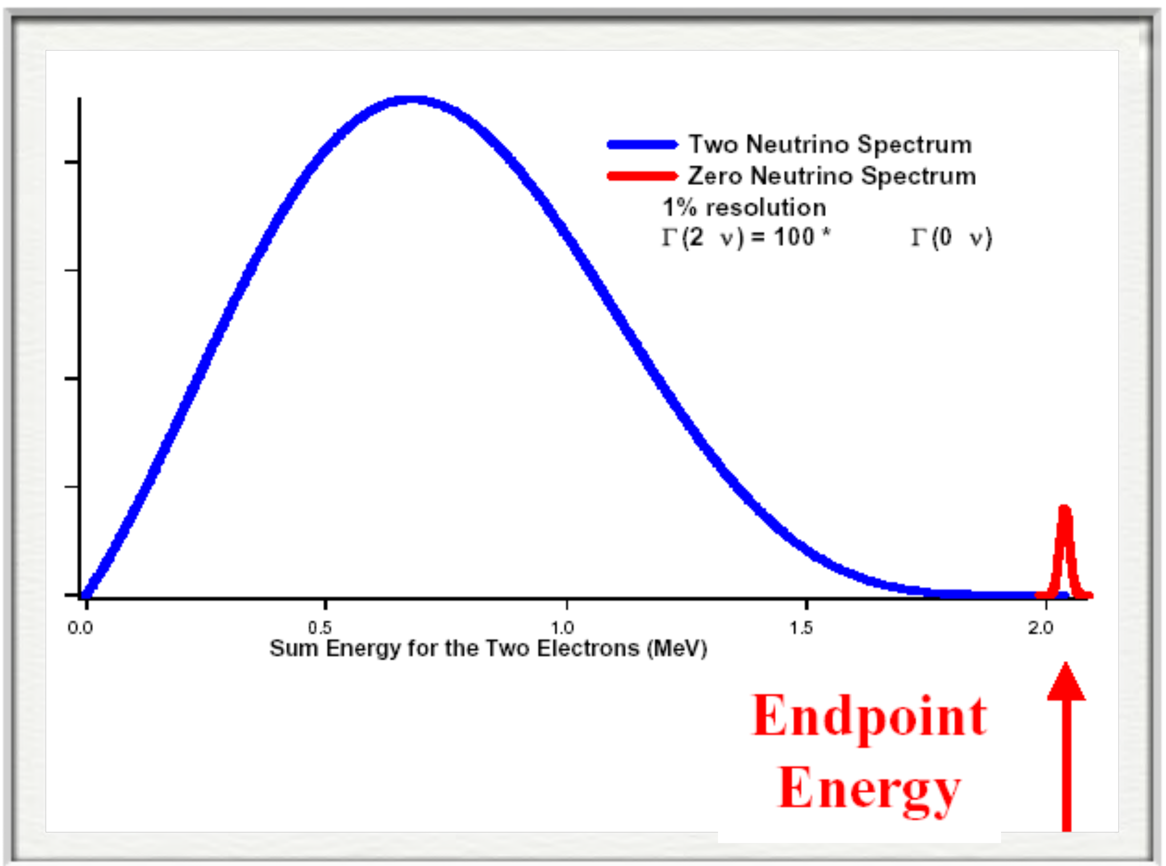
Phase space



$m_{\beta\beta}$ [eV]
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0νββ decay limit (90% CL), smallest NME
0νββ decay limit (90% CL), largest NME
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
m_{light} [eV]
Inverted (IH)
ν_2
ν_1
Δm^2_{12}
Δm^2_{32}
ν_3
Normal (NH)
ν_3
Δm^2_{32}
ν_2
ν_1
Δm^2_{12}

Experimental Challenges

Ultra small signal ⇒



- Large mass (signal stats)
- Low bkg
  - Deep underground
  - Purification
  - Bkg ID methods
- Good E resolution
- Interchangeable isotopes
- Tracking

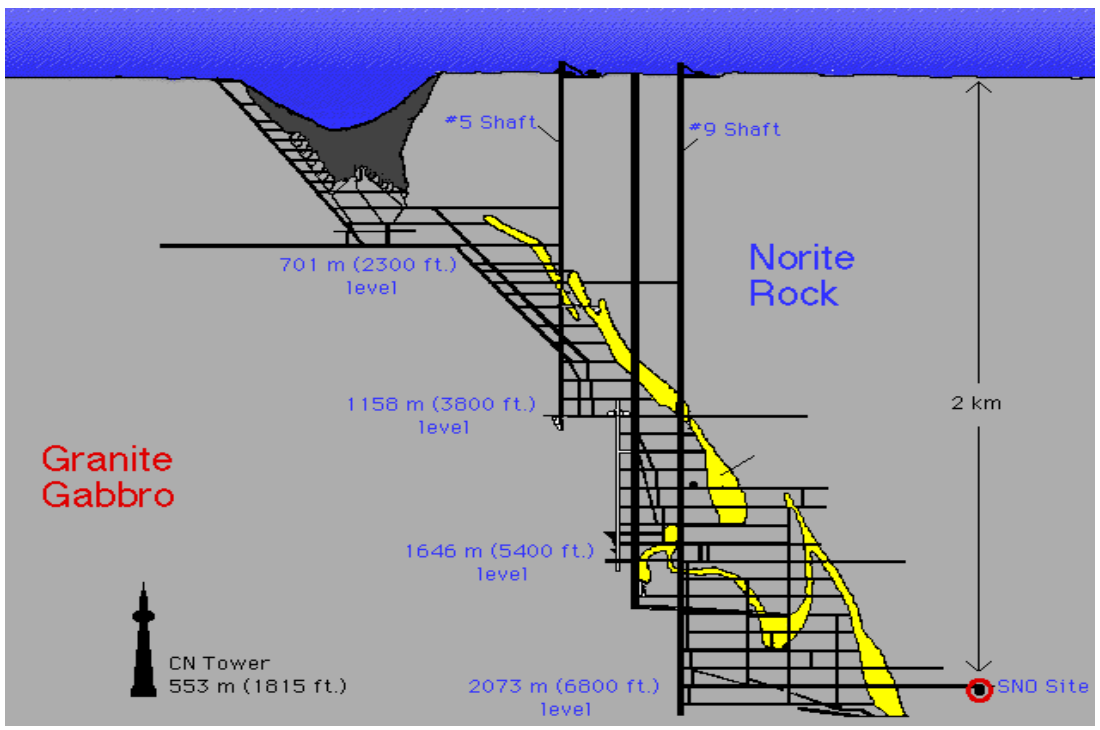
New physics: a light in dark places

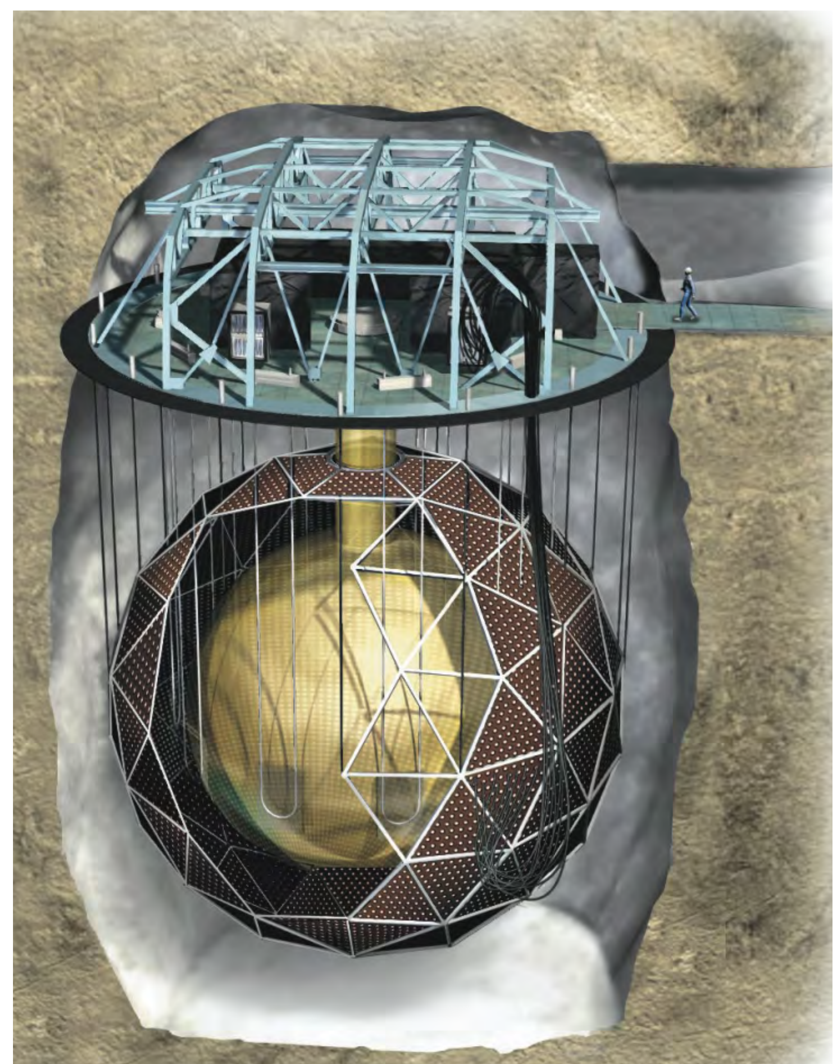
High intensity signal

SNO ⇛ SNO+

DEEP UNDERGROUND

Liquid scintillator + ^{130}Te





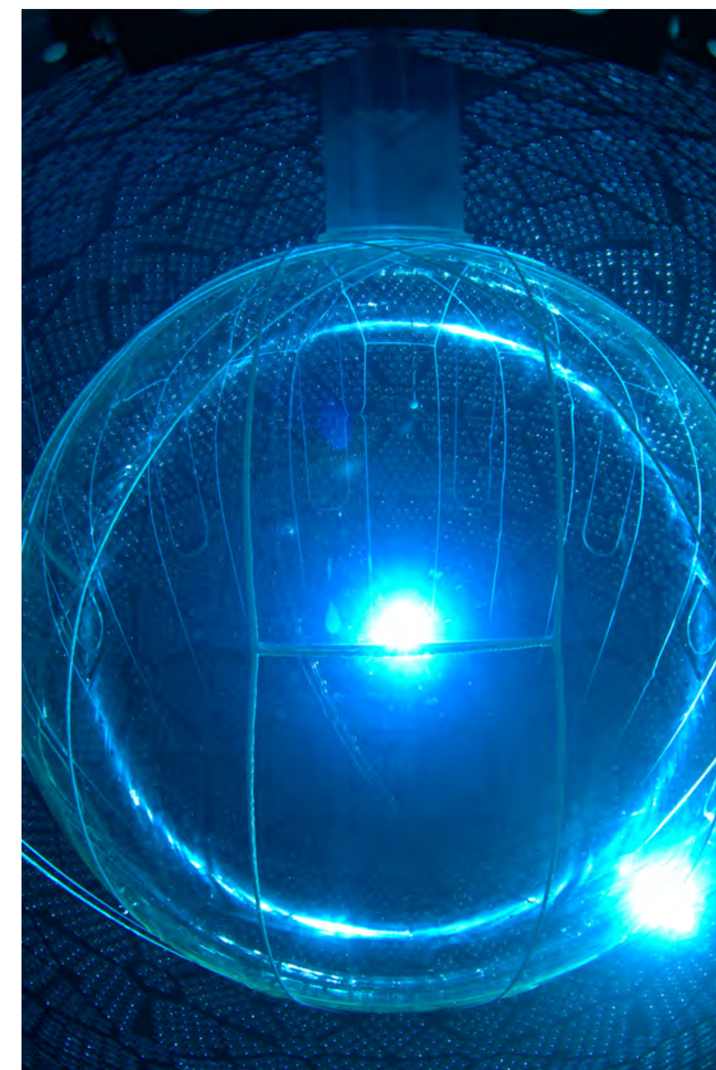
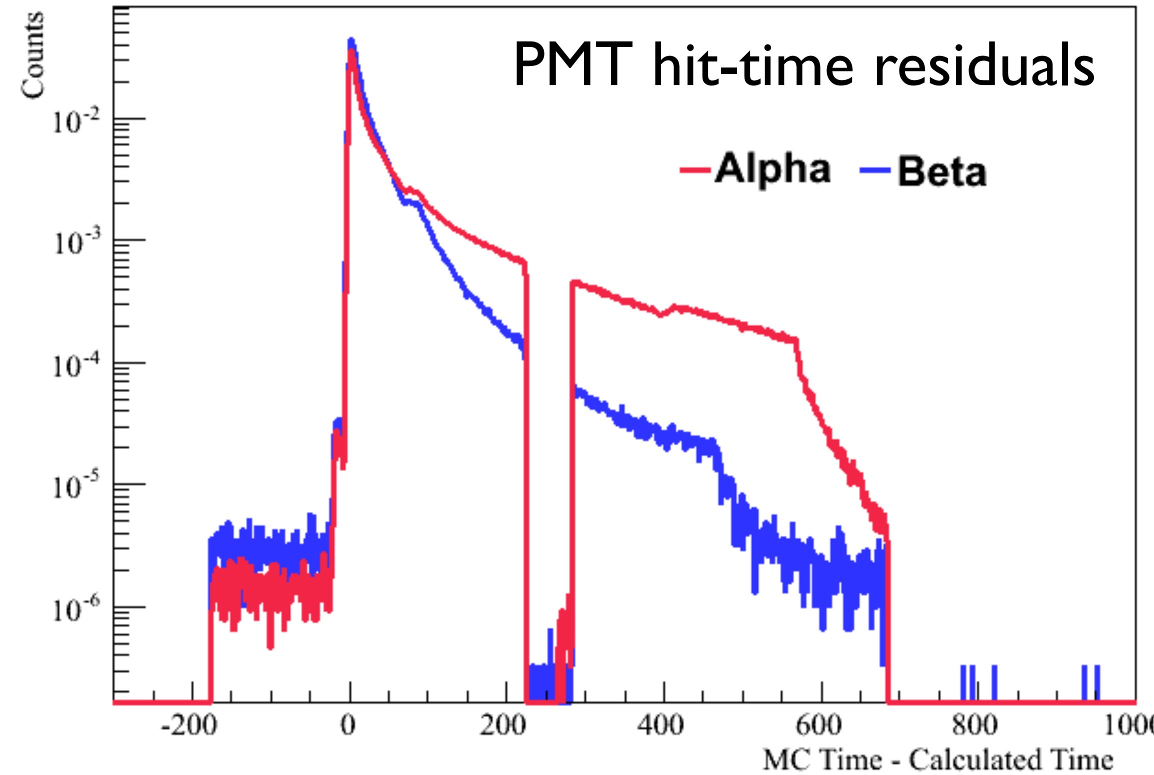


Image from www.northernontariobusiness.com

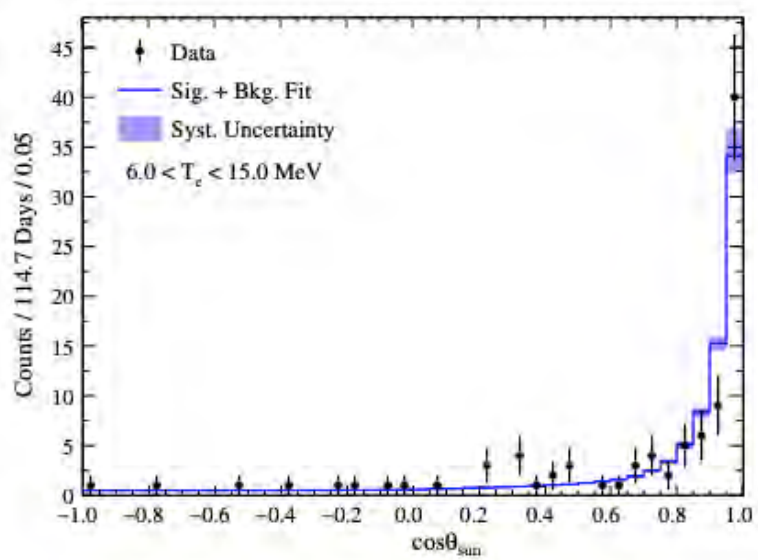

ess.com
6800 ft down...

Advantages of LS approach

- Low backgrounds (dominated by ^{8}B solar neutrinos)
  - Fiducialisation ⇒ self-shielding
  - Background rejection via particle ID and coincident timing
  - Deep location (6000 m.w.e.)
- High detection efficiency
- Source in / out calibration
- Large target mass, easy scaling
- *Bonus: broad program includes solar, geo, reactor, supernova ν & nucleon decay*



SNO+ physics results

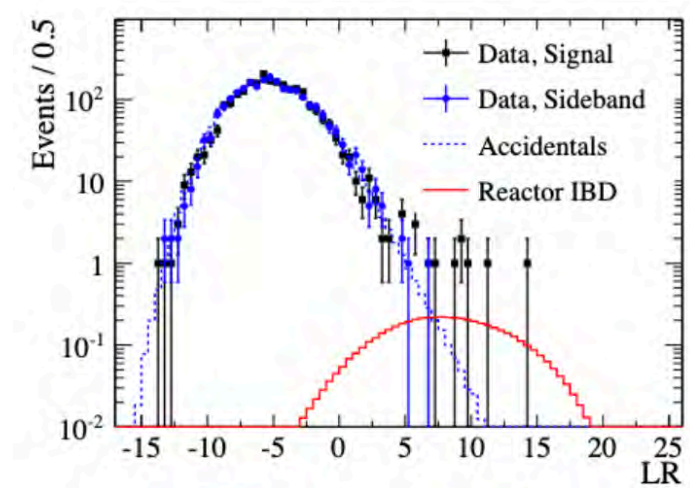


Measurement of 8B solar ν flux with very low backgrounds: 0.25 +0.09/-0.07 ev/kt-day

$$\Phi_{^8B} = 5.95^{+0.75}_{-0.71}(\text{stat})^{+0.28}_{-0.30}(\text{syst}) \times 10^6\ \text{cm}^{-2}\,\text{s}^{-1}$$

Phys. Rev. D ***99*** *012012 (2019)*

Evidence of antineutrinos from distant reactors using pure water at SNO+

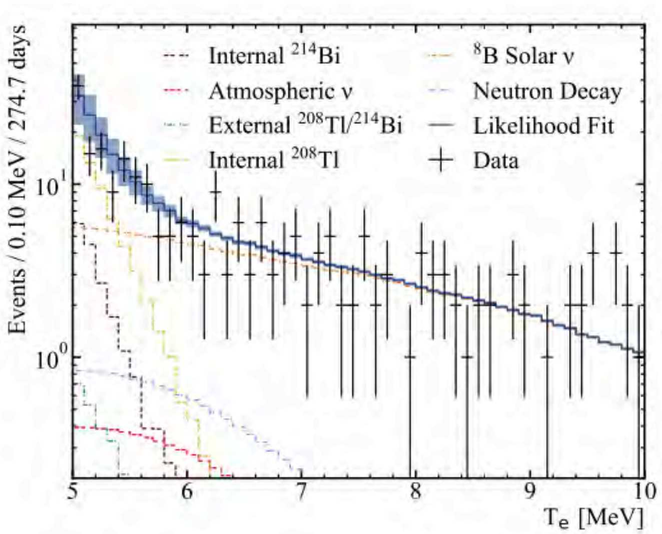


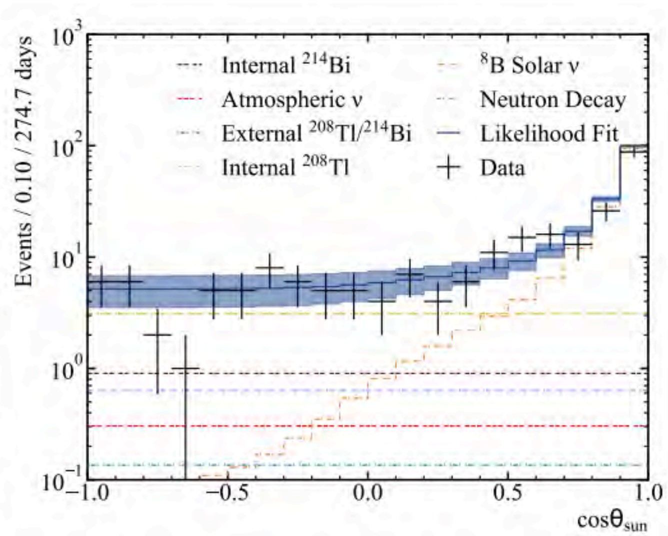
Collaboration, SNO+, et al. "Observation of Antineutrinos from Distant Reactors using Pure Water at SNO+." *arXiv preprint arXiv:2210.14154* (2022).

PRL ***130*** *091801 (2023)*

Searches for invisible modes of nucleon decay via observable de-excitation γs

Phys. Rev. D ***105*** *112012 (2022)*

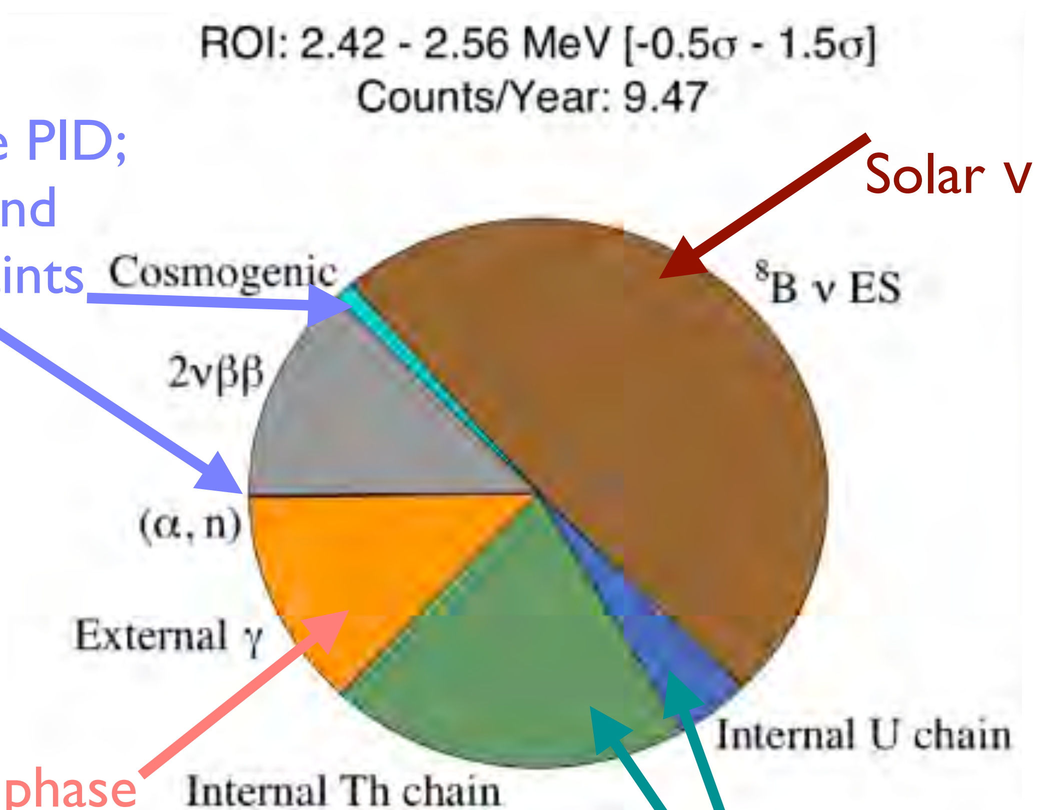




Decay Mode	Partial Lifetime Limit	Existing Limits
n	9.0×10^{29} y	5.8×10^{29} y [5]
p	9.6×10^{29} y	3.6×10^{29} y [6]
pp	1.1×10^{29} y	4.7×10^{28} y [6]
np	6.0×10^{28} y	2.6×10^{28} y [6]
nn	1.5×10^{28} y	1.4×10^{30} y [5]

SNO+ sensitivity

Detector configuration:
0.5% natural Te
5 years live time
Ex-situ optics (Penn/BNL)
3.3m fiducial volume (20%)

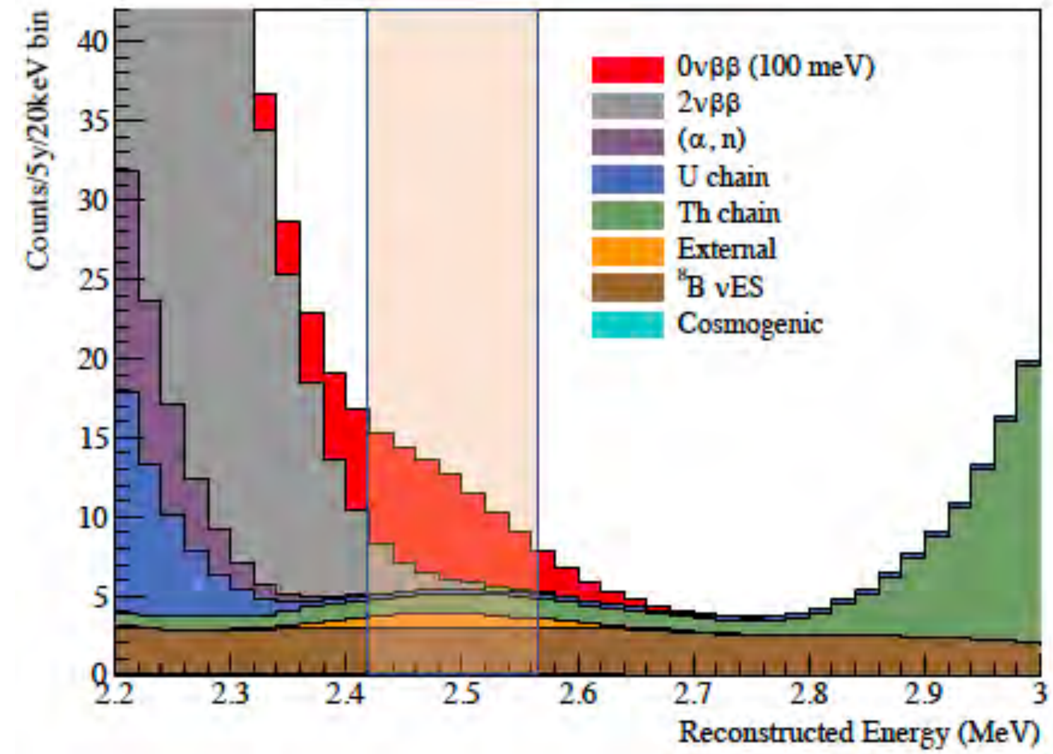


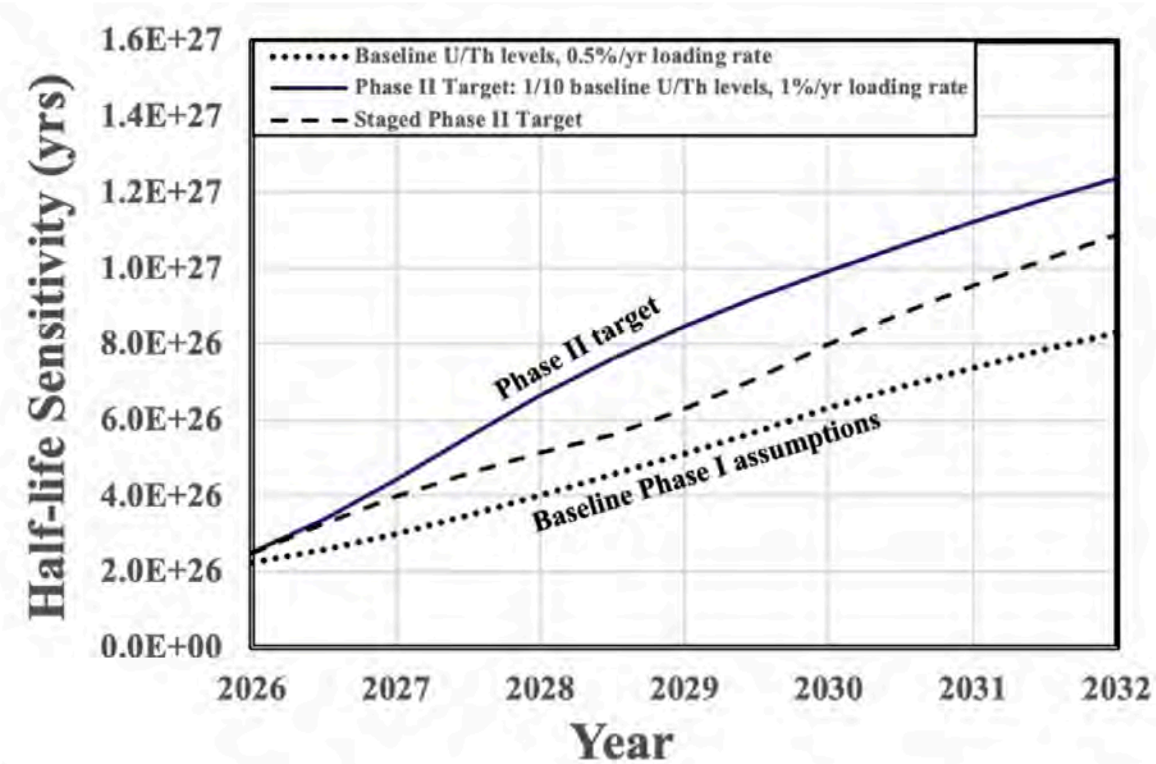
Multi-site PID; sideband constraints

Solar ν data

Water phase measurement; sideband constraints

LAB-PPO component measured during partial fill; sideband constraints





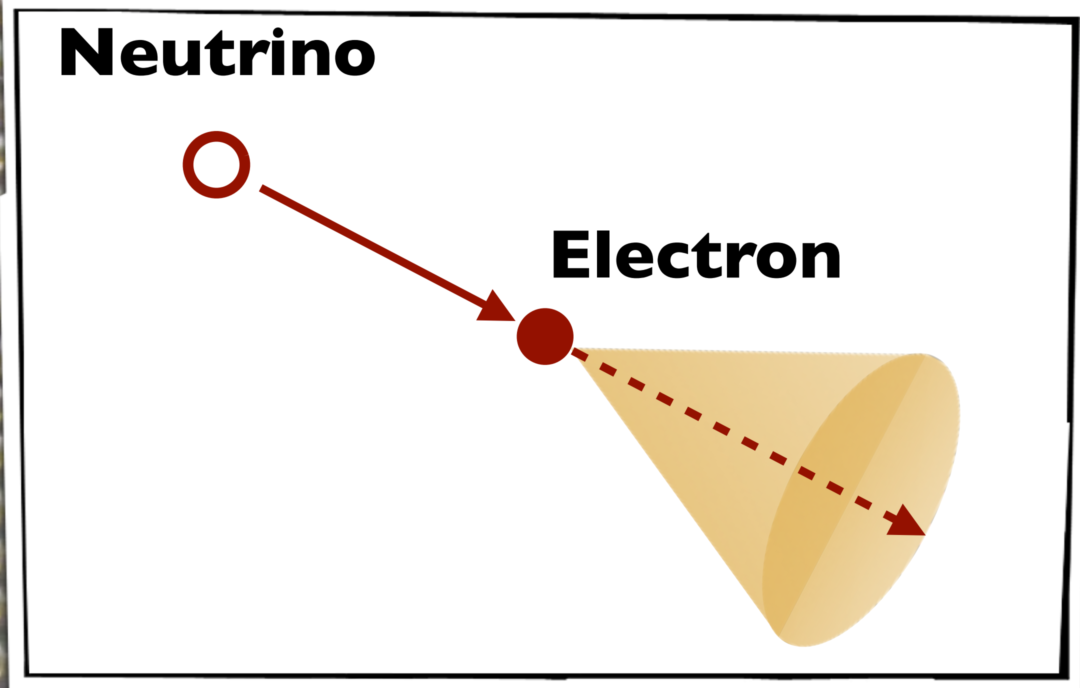
SNO+ status

- LS fill complete, end of March, 2021 (780kg LAB+PPO)
- Largest, deepest operating LS detector
- Ultra-low background
- Neutrinoless double beta decay target backgrounds achieved!
- Broad ongoing physics program

Related work:
Phys. Rev. Lett. ***130*** *091801 (2023)*
Phys. Rev. D ***105*** *112012 (2022)*
JINST 16 P10021 (2021)
JINST 16 P08059 (2021)
JINST 16 P05009 (2021)
Phys. Rev. C 102, 014002 (2020)
Phys. Rev. D 99, 032008 (2019)
Phys. Rev. D 99, 012012 (2019)

Let there be light: the path forwards

Water Cherenkov detectors



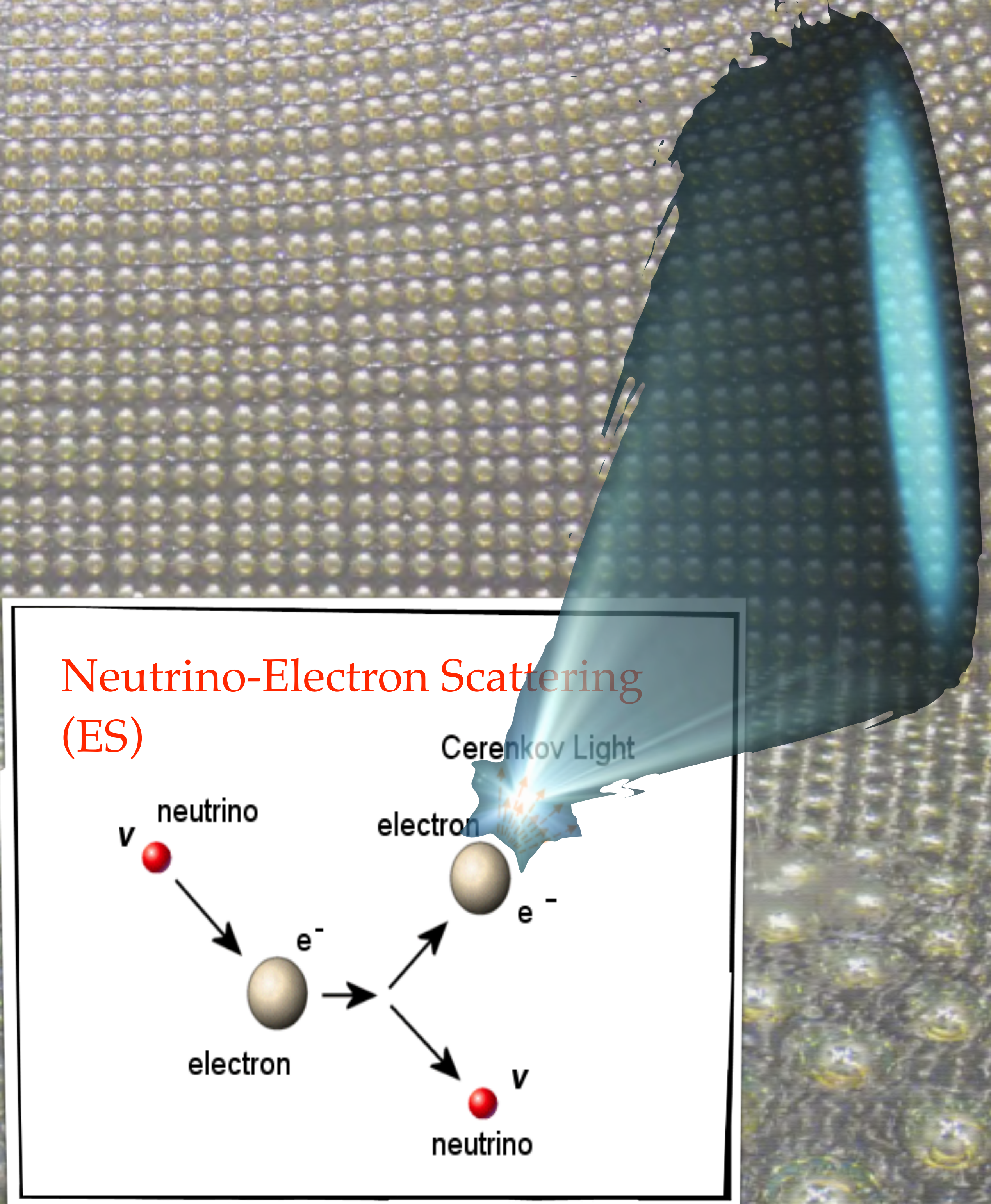
Cherenkov light

Steeply falling spectrum

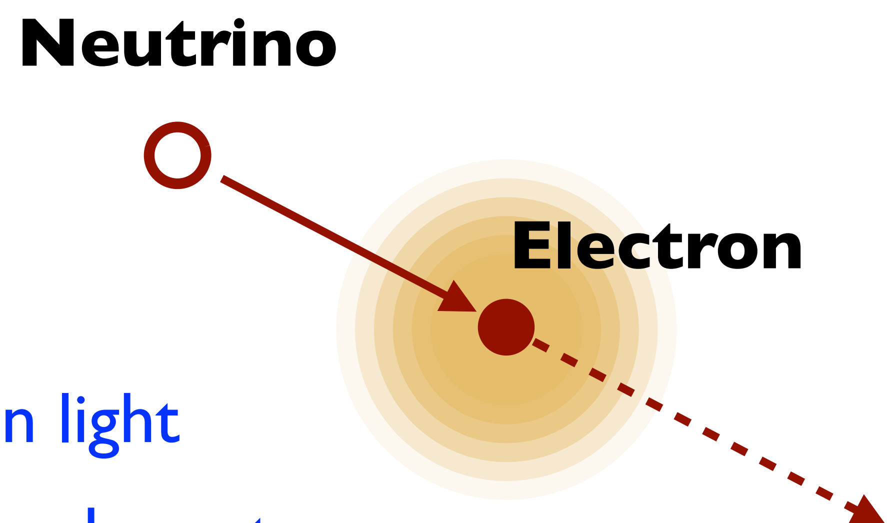
Emitted with cone-like topology

Directional information

⇒ identify event source



Scintillation detectors



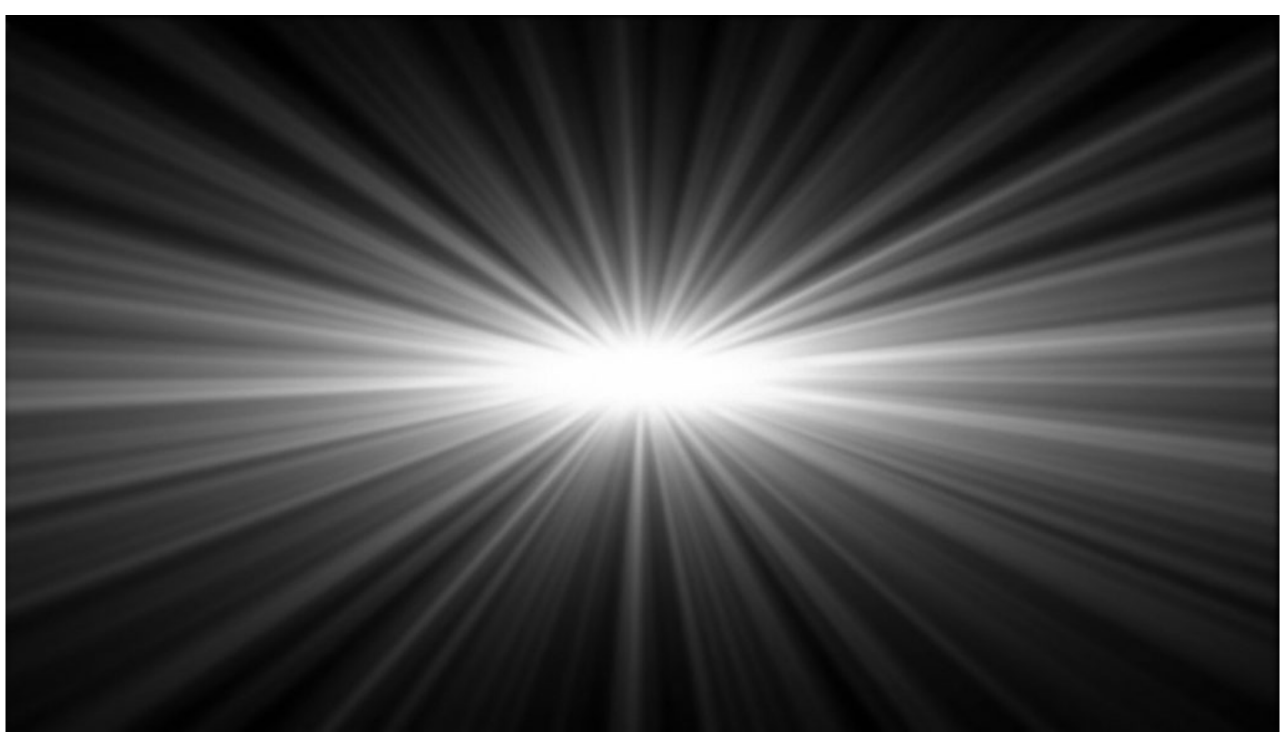
Scintillation light

Narrow-band spectrum

Emitted isotropically

Significantly higher light yield

⇒ improved detector resolution

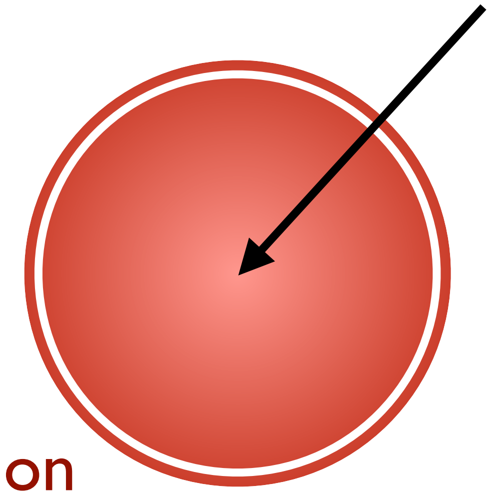


New technology: Hybrid Detectors

Cherenkov

- Cherenkov topology: directional sensitivity, particle ID
- Optical transparency: scaling

Scintillation



- High light yield: threshold, resolution
- Pulse shape discrimination: Particle ID
- Radiopure

The whole is greater than the sum of the parts!

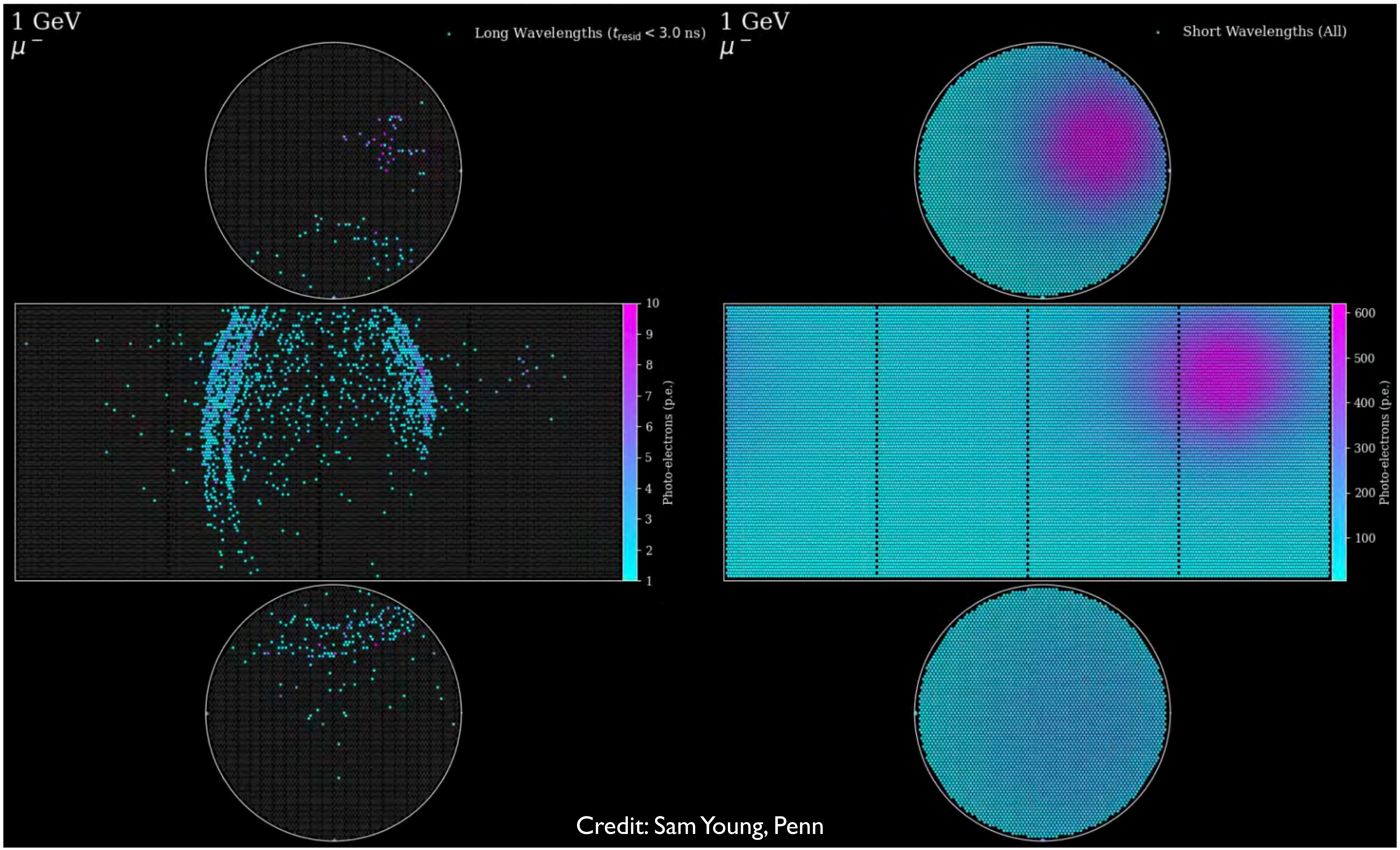
The ratio of the two signals gives us additional information on the type of particle interacting

Improved background rejection for precision ν measurements

Facilitates broad program!

Neutrinoless double beta decay, Particle astrophysics (solar, supernova)
Long baseline physics (CPV, NMH), Nucleon decay, Geo neutrinos

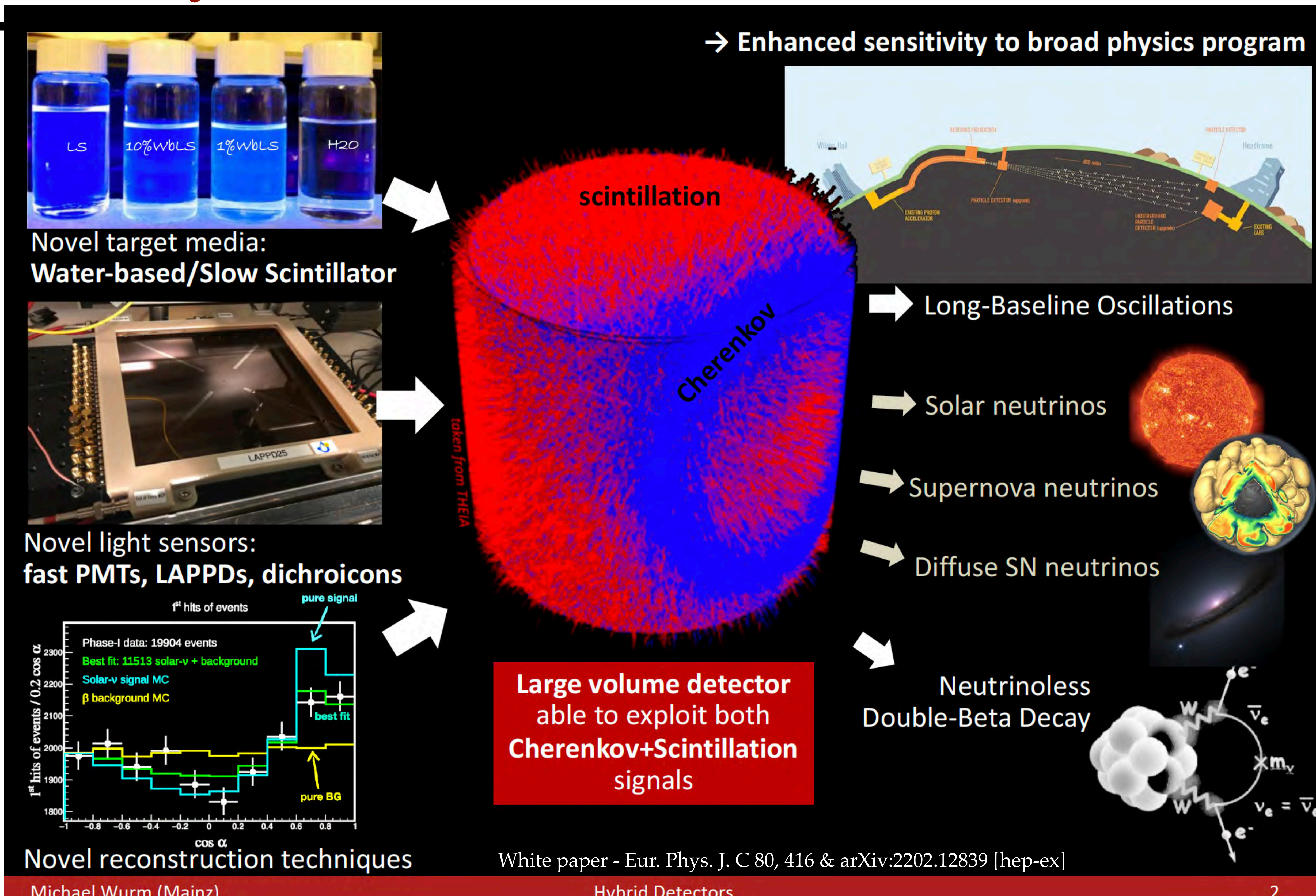
Goal: 2-in-1



Cherenkov

Scintillation

Hybrid neutrino detection



THEIA

THEIA

The Goddess THEIA

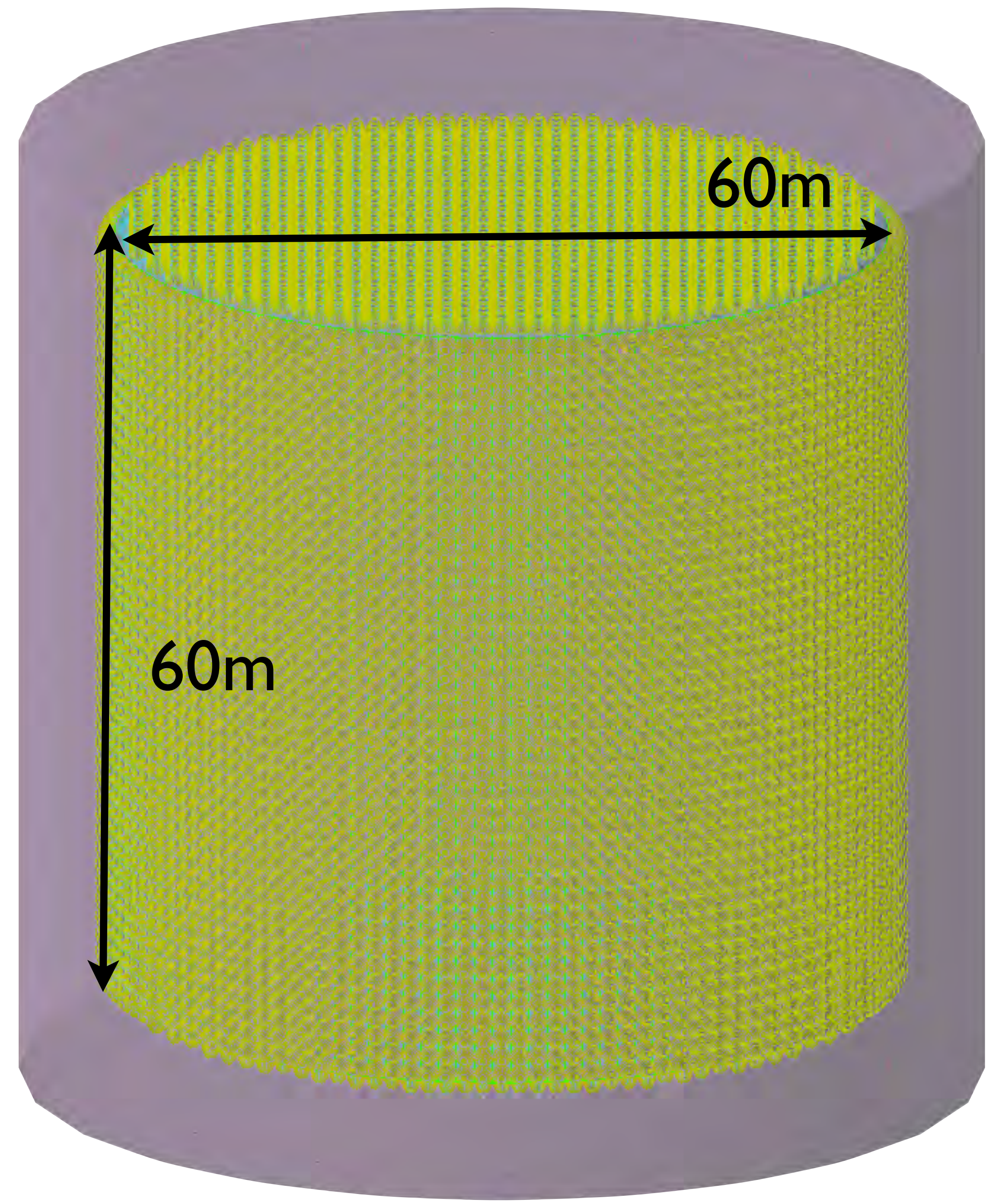
The THEIA collection was created to bring out a women's inner goddess

THEIA Detector Concept

Theia

- Large-scale detector (25-100 kton)
- Novel LS target e.g. WbLS
- Fast, high-efficiency spectrally sensitive photon detection with high coverage
- Deep underground (Homestake)
- Isotope loading (Gd, Te, Li...)
- *Flexible*! Target, loading, configuration

➡ Broad physics program!



White paper - Eur. Phys. J. C 80, 416 (2020)

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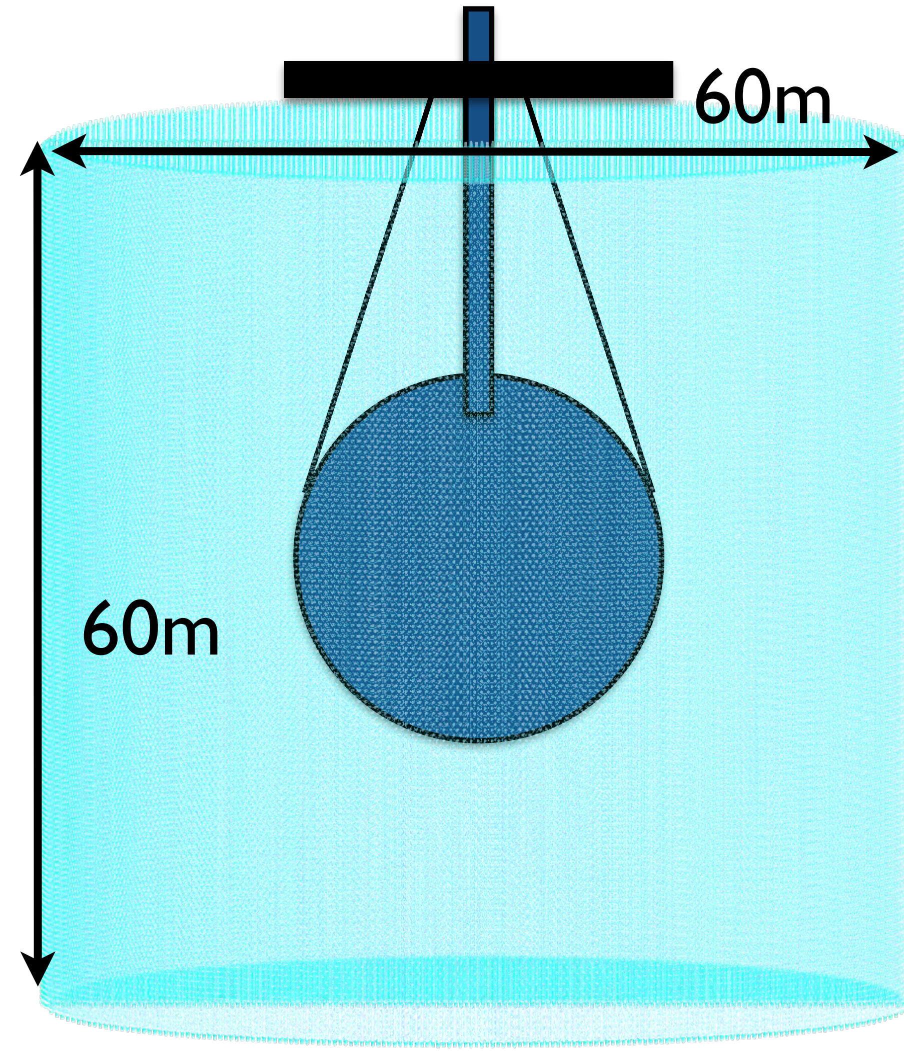


White paper - [Eur. Phys. J. C 80, 416 (2020)]

Hybrid detectors at Snowmass

Neutrino Frontier report *(also BSM, terrestrial & astrophysical sections)*

- *NF: Detectors: one of 5 priorities for development*

  - **Pursuit of hybrid Cherenkov/scintillation Detectors:** Many different technologies are being developed for these, including water-based liquid scintillator, slow fluors, fast timing with LAPPDs and other devices, and spectral photon sorting with dichroicons. At very large scales like the proposed Theia detector, these could have very broad physics programs.

- *NF: Long-term outlook*

  ordering region. These next-generation LAr detector ideas go by different names, such as "SLoMo", "SoLAr", and "LArXe." Another idea is the proposed Theia detector, which is a hybrid Cherenkov/scintillation detector that could do precision measurements of very low-energy solar neutrinos, diffuse supernova neutrino detection, perform searches for sterile neutrinos, and also push well beyond DUNE in precision tests of the three-flavor mixing model (including, for example, studies of the second oscillation maximum). On the low-threshold side, much will depend on what the

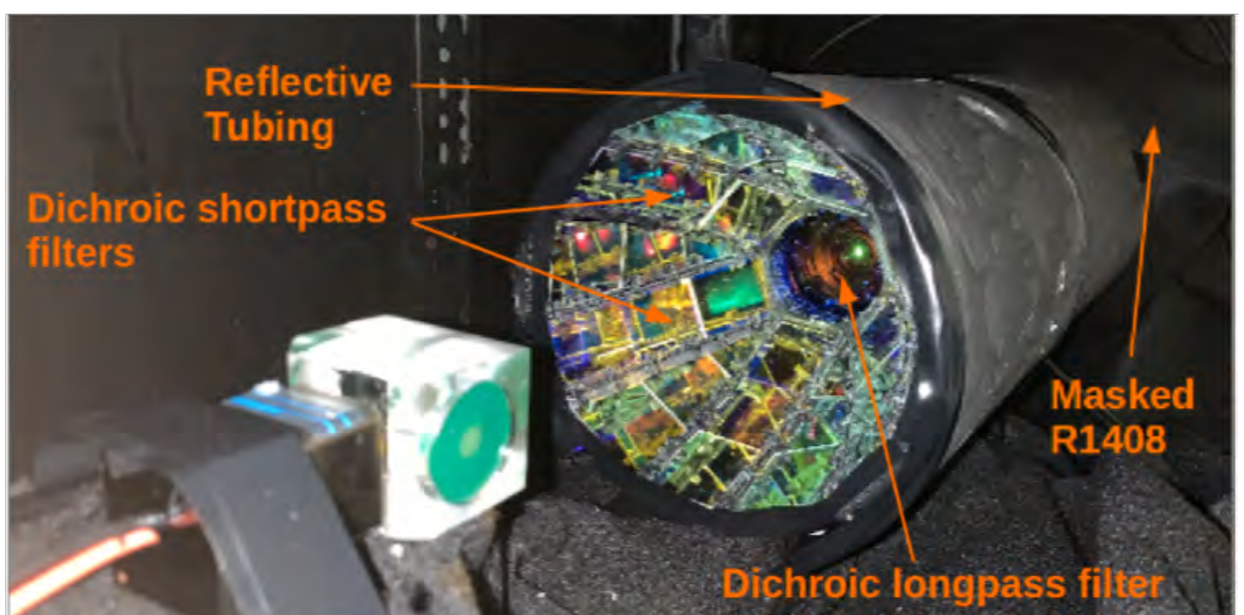
Instrumentation Frontier report *(also photon detectors & spectral sorting)*

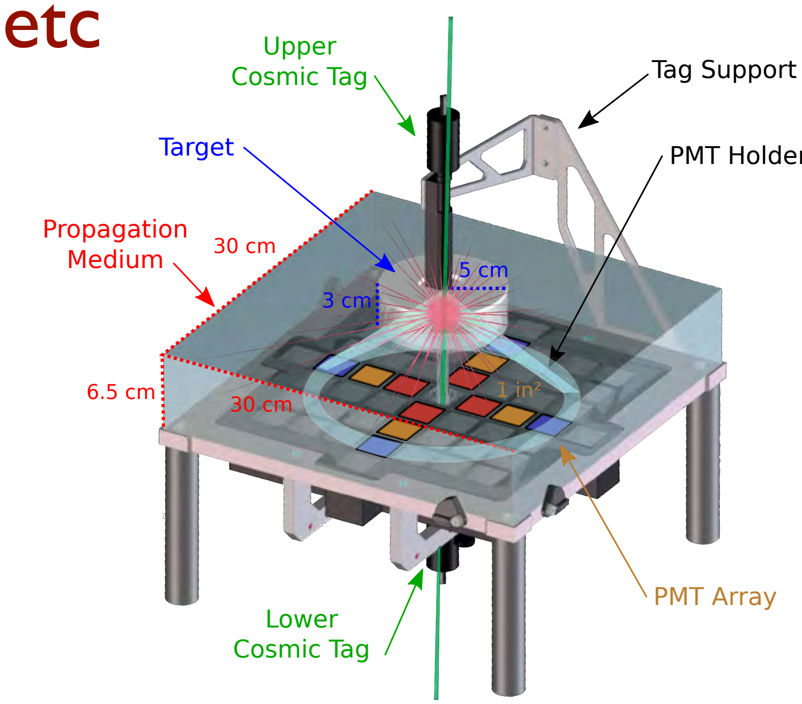
- *IF: Going beyond DUNE*

  Of particular community interest is the development of hybrid Cherenkov-scintillation detectors, which can simultaneously exploit the advantages of Cherenkov light's reconstruction of direction and related high-energy particle identification (PID) and the advantages of scintillation light, high light-yield, low-threshold detection with low-energy PID. Hybrid Cherenkov-scintillation detectors could have an exceptionally broad dynamic range in a single experiment, allowing them to have both high-energy, accelerator-based sensitivity while also achieving a broad low-energy neutrino physics and astrophysics program. Recently the Borexino

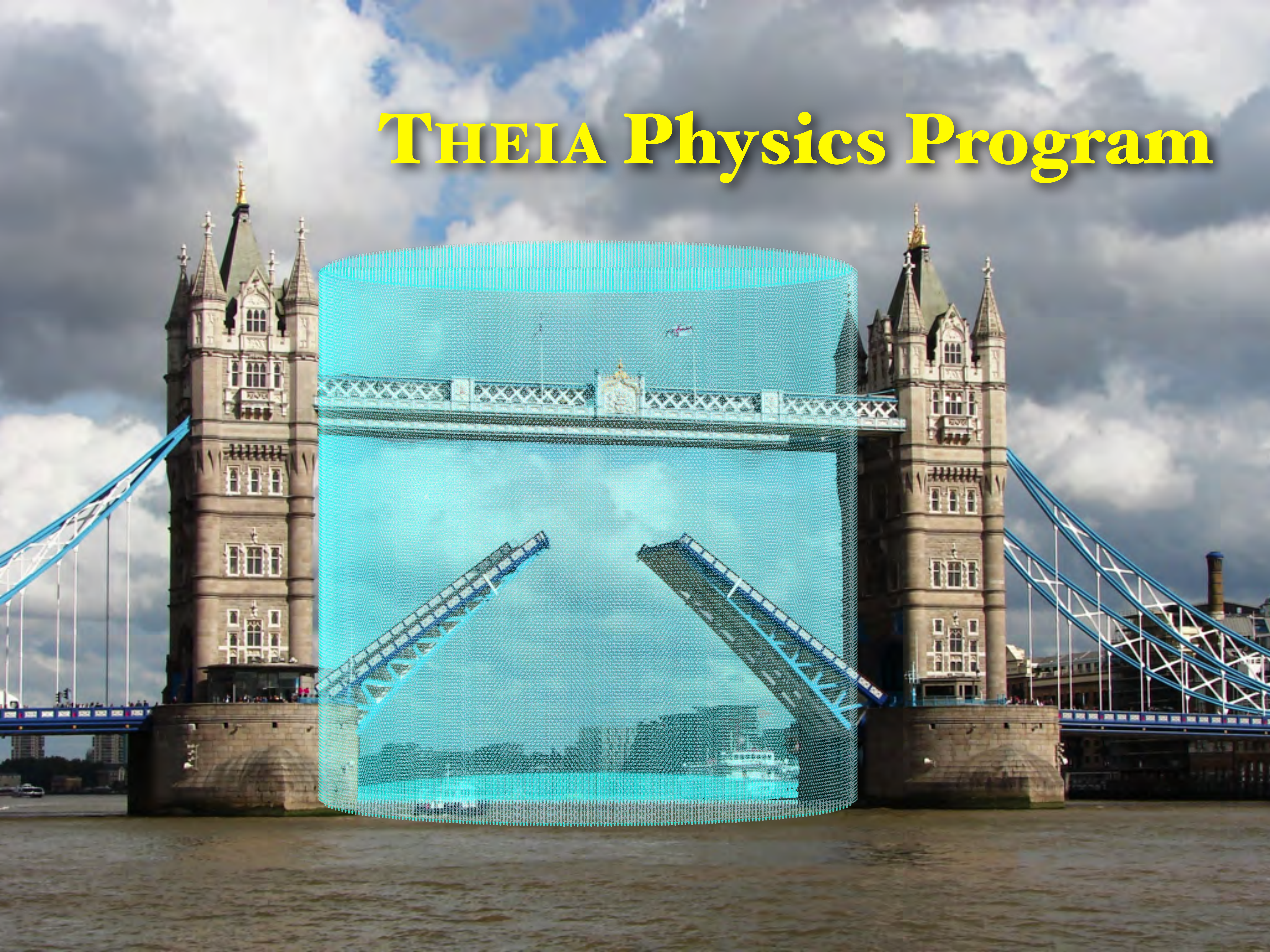
THEIA as a tool for increasing diversity in STEM

- Central tenet of this project from day zero, active ongoing effort
- The science of THEIA is inspirational & motivational
- Opportunity for under-represented groups to make meaningful contributions to "big science", in an EPSCOR state
- Readily accessible to smaller institutions with more limited resources
    - Benchtop measurements are critical component in design efforts
    - No need for cryogenics, purification etc





THEIA Physics Program



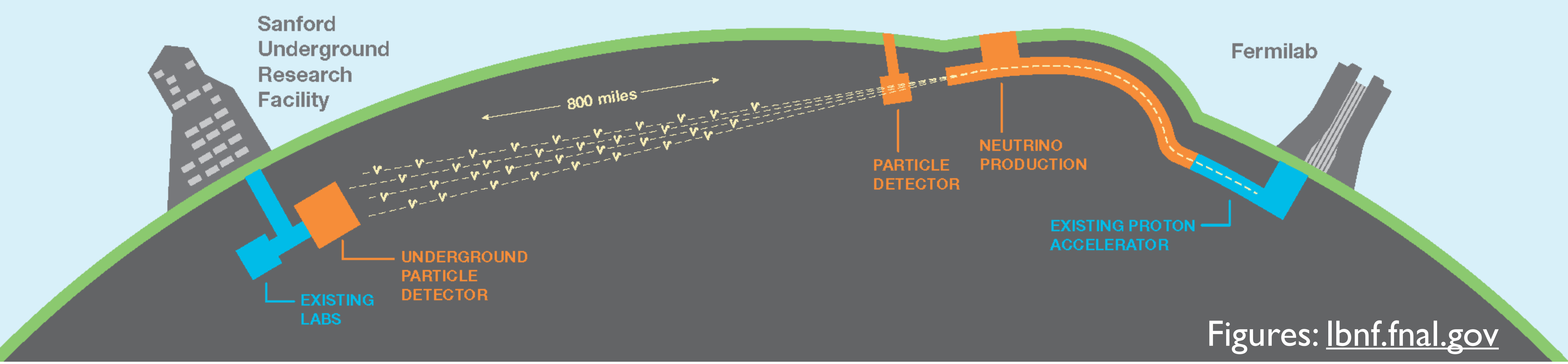
(Phased) Physics program

	Primary physics goal	Reach	Exposure/assumptions
	Long-baseline oscillations	>5σ for 30% of δ_{CP}	524kt-MW-year
	Nucleon decay $p\rightarrow\bar{\nu}K^+$	T>3.8 x 10^{34} year	800 kt-year
	Supernova burst	<1(2)° pointing 20K(5K) events	100(25)kt, 10kpc SN
I	**Diffuse Supernova Neutrino**	5σ	125kt-year
II	**CNO neutrinos**	<5(10)%	300(62.5)kt-year
	Geoneutrinos	< 7 %	25 kt-year
III	**$0\nu\nu\beta$**	$T_{1/2}$ > 1.1 x 10^{28} year (90%C.L.)	800 kt-year (Multi-tonne loaded LS in suspended vessel search)

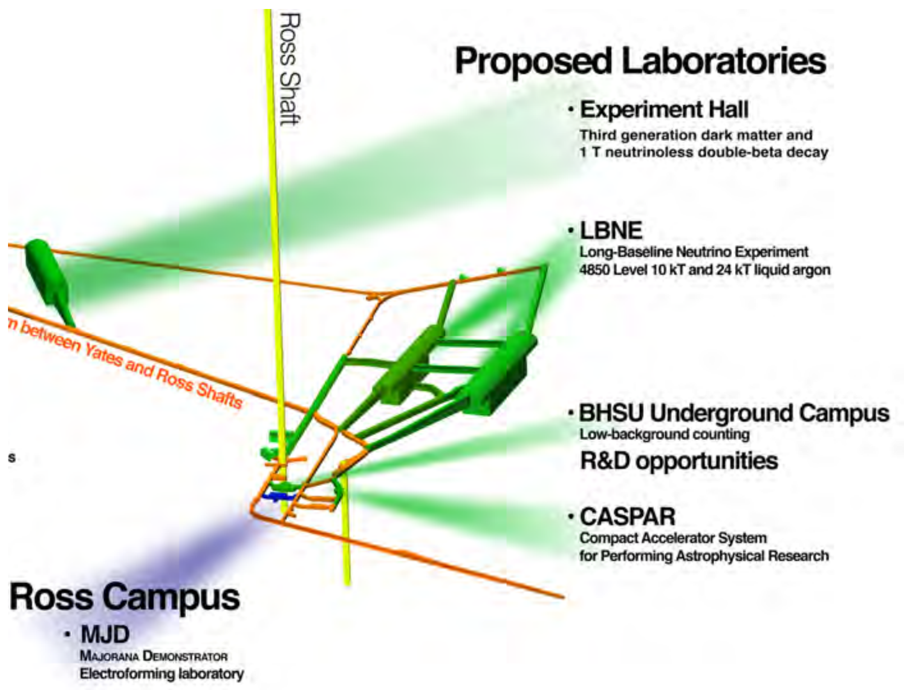
The Missing Ingredient: CP Violation

Deep Underground Neutrino Experiment (DUNE)

“Sending neutrinos on an 800-mile journey”



Figures: lbnf.fnal.gov



Full DUNE scope:

1. 1.2 MW beam, upgradeable to 2.4MW
2. Four Far Detector (FD) modules, 40kt+ fiducial
3. Near Detector suite (ND)

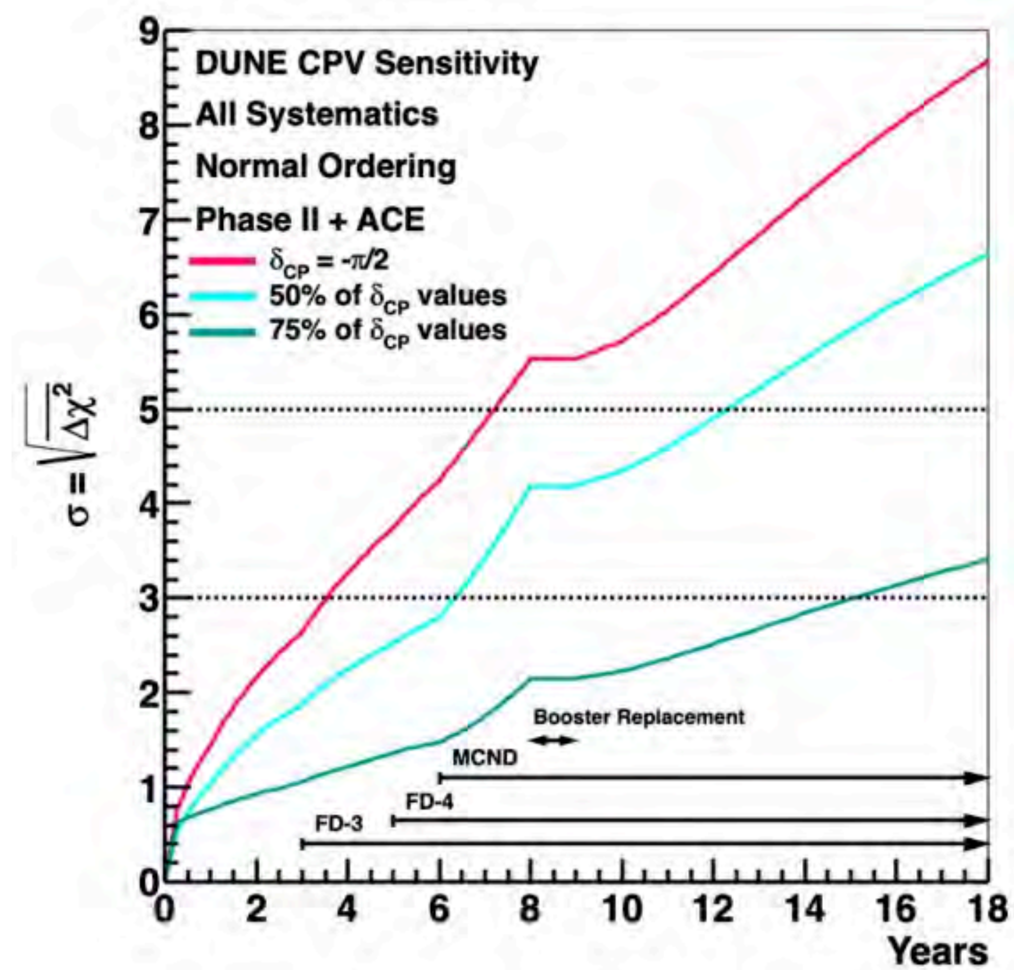
DUNE phasing

DUNE Phase I:

1. 1.2 MW beam
2. Two Far Detector (FD) modules, 2x10 kt liquid argon TPC
3. Reduced Near Detector suite (ND)

DUNE Phase II:

1. Upgraded beam
2. Two additional Far Detector (FD) modules, technology TBD
3. More Capable Near Detector (MCND)



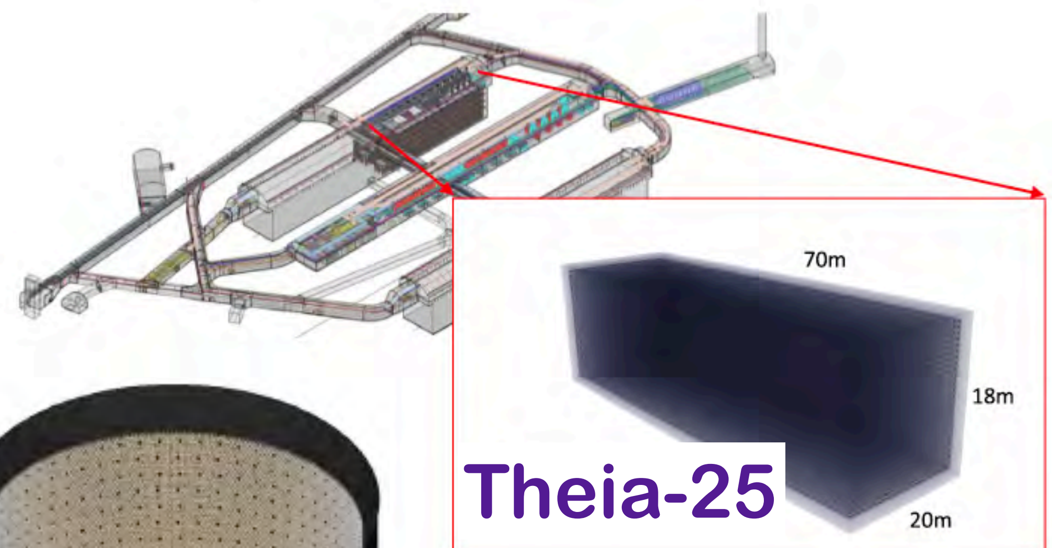
Theia as a DUNE module in Phase II

Long-baseline sensitivity comparable to a LAr DUNE module

Complementary supernova sensitivity (primarily anti-ν, fast response: can act as trigger)

+ broad (new!) additional physics program

Cutting-edge developments in target material and photon detection



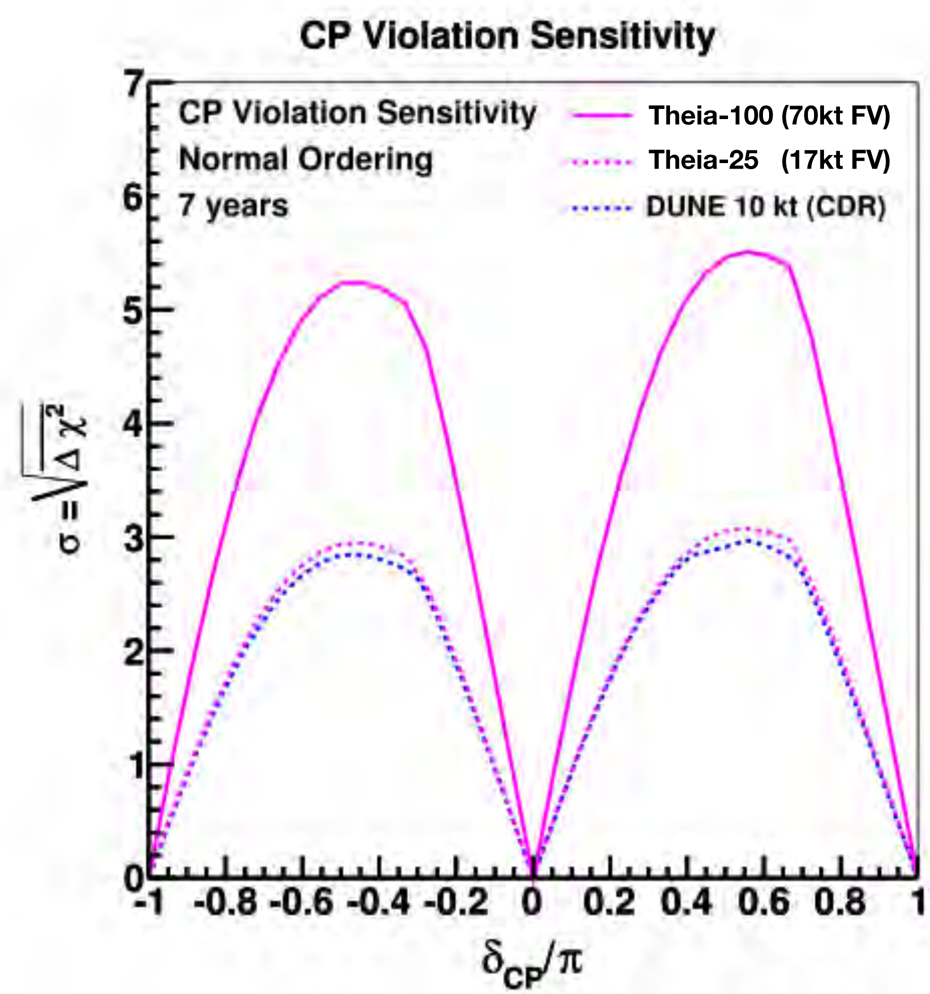
Large, multipurpose detector

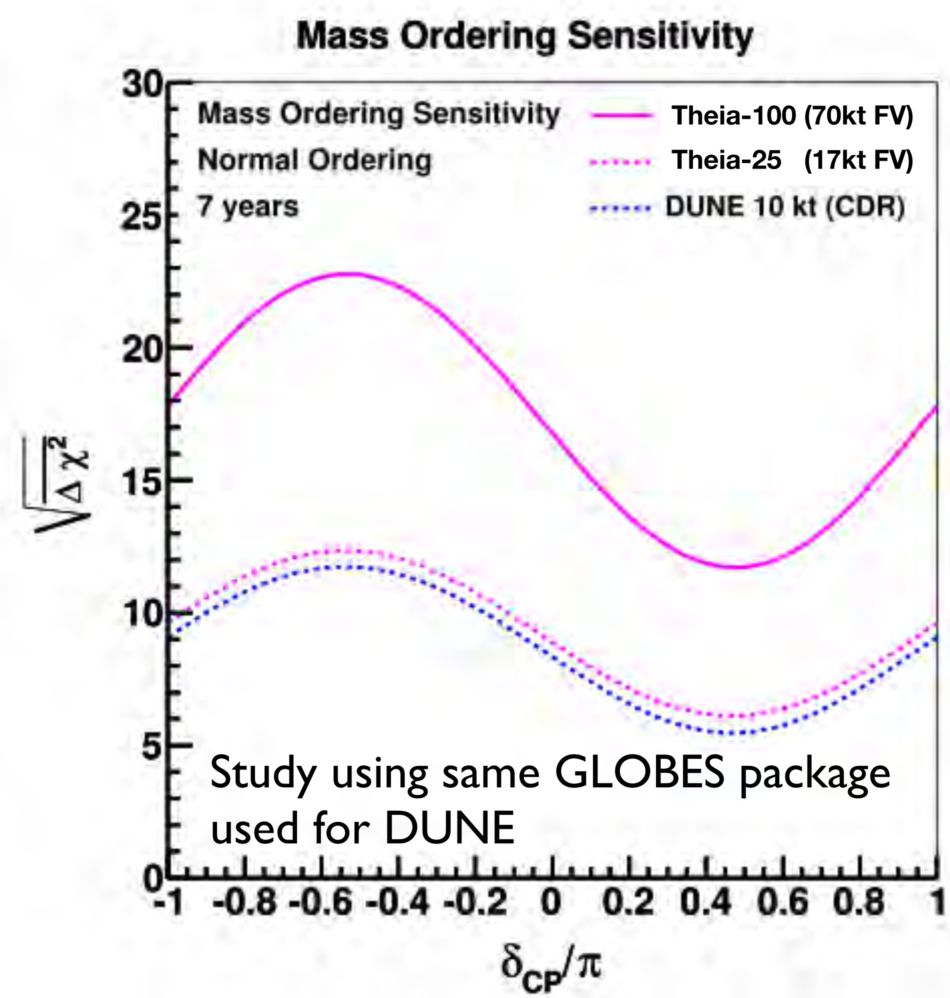
- Baseline: 25ktonne (17kt FV)
- Ideal: 100 ktonne (70kt FV)

Broad physics program: Studying neutrino fundamental properties and astrophysical objects

THEIA: An advanced optical neutrino detector
Eur. Phys. J. C 80, 416 (2020)

Long-Baseline Sensitivity





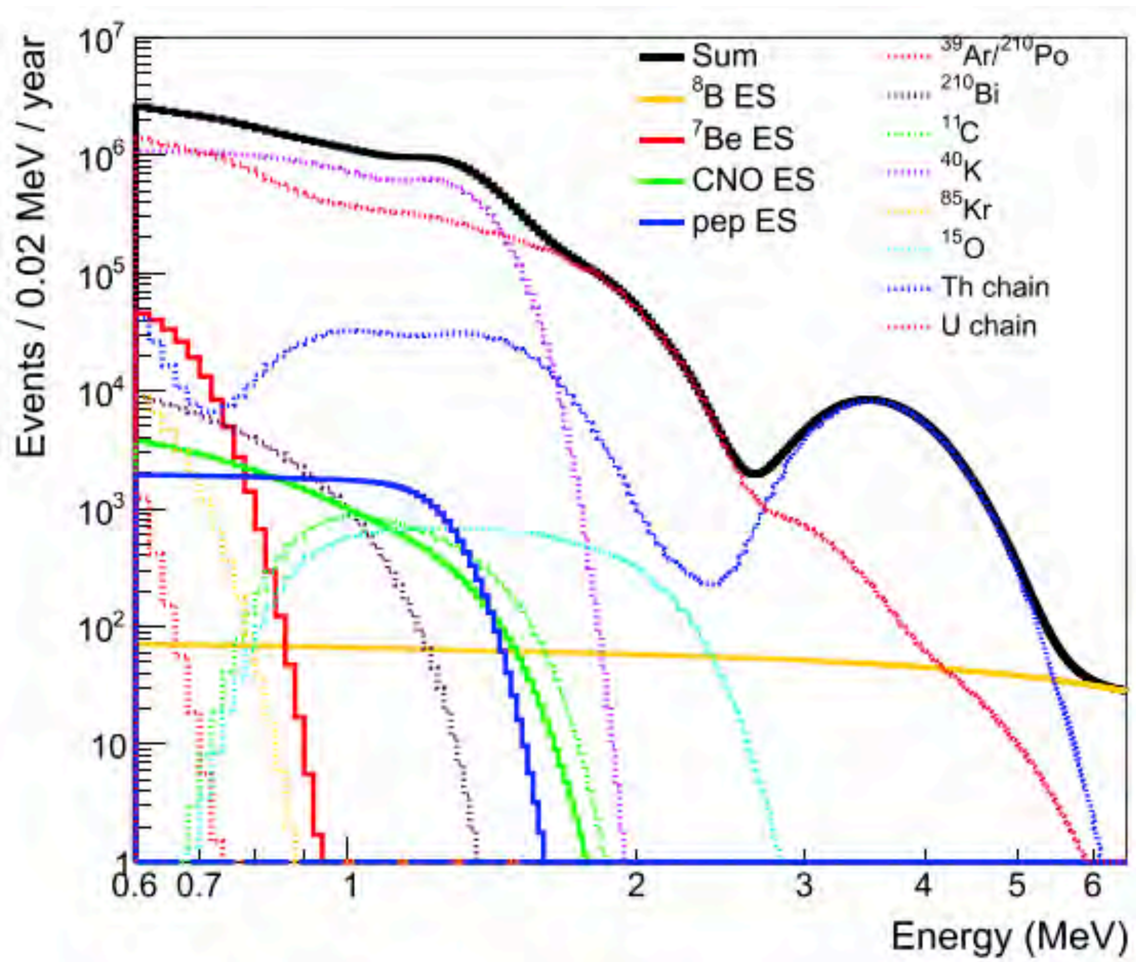
Performance of small (25kt) Theia module competitive with 10kt LAr TPC

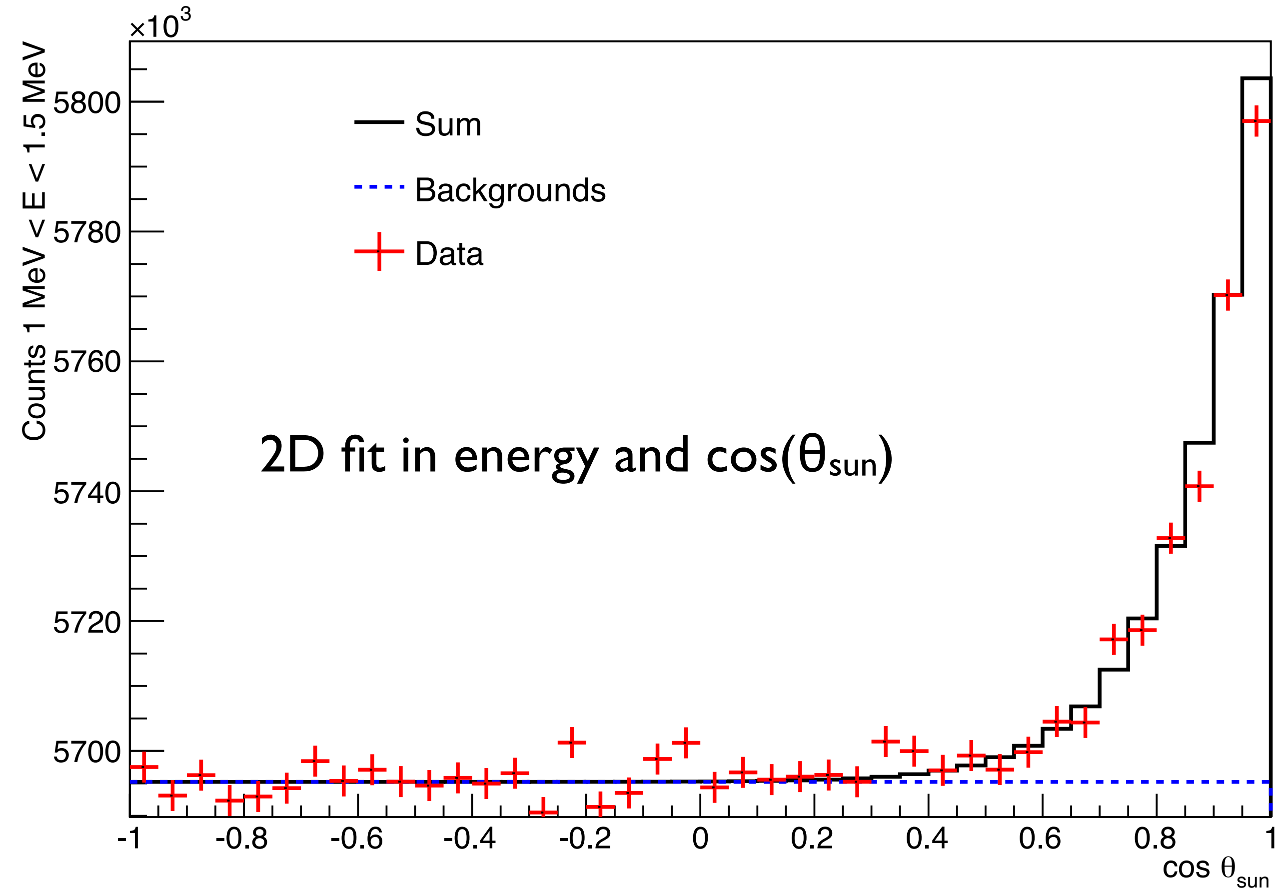
Synergy with LAr TPC

Independent systematics

Unique cross check of HK/DUNE comparison!

The challenge of backgrounds



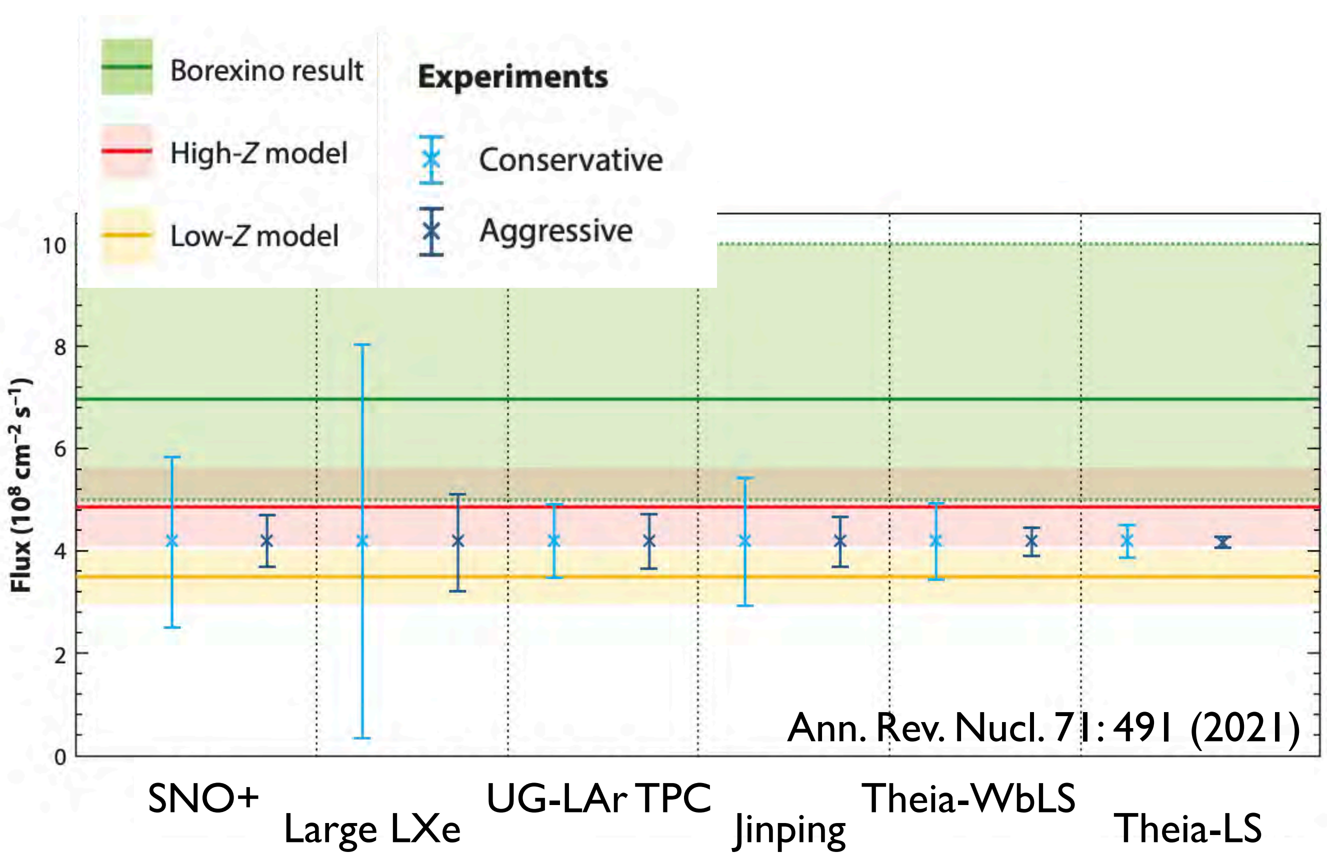


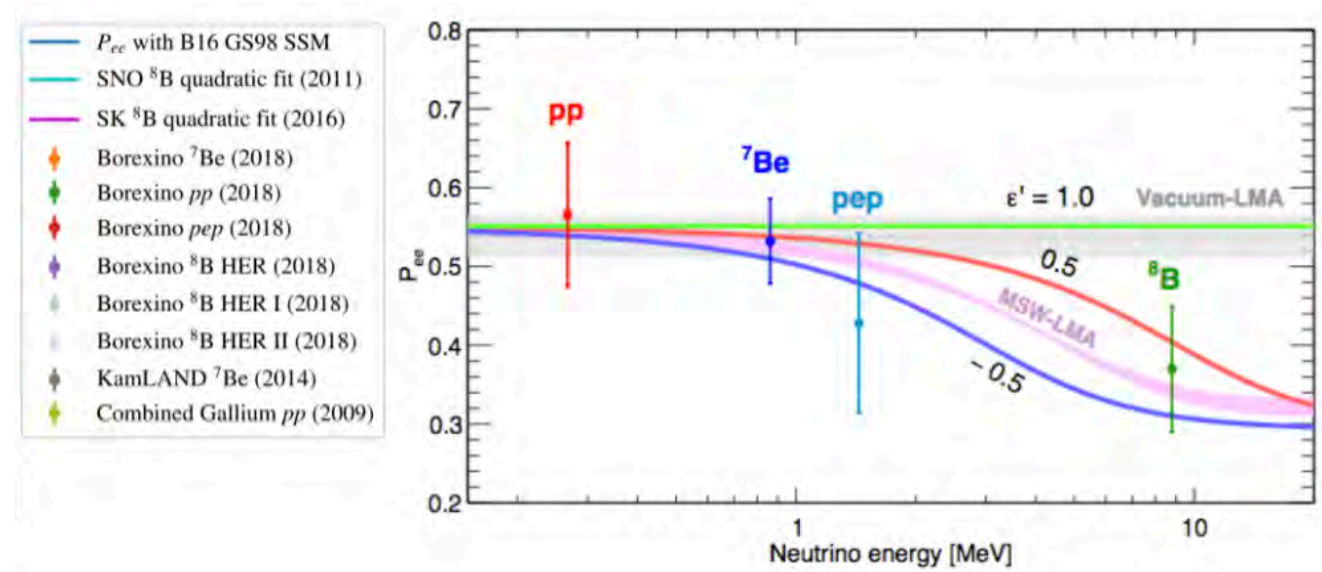
Eur. Phys. J. C 80, 416 (2020); Eur. Phys. J. C (2018) 78: 435

Solar Neutrinos with THEIA

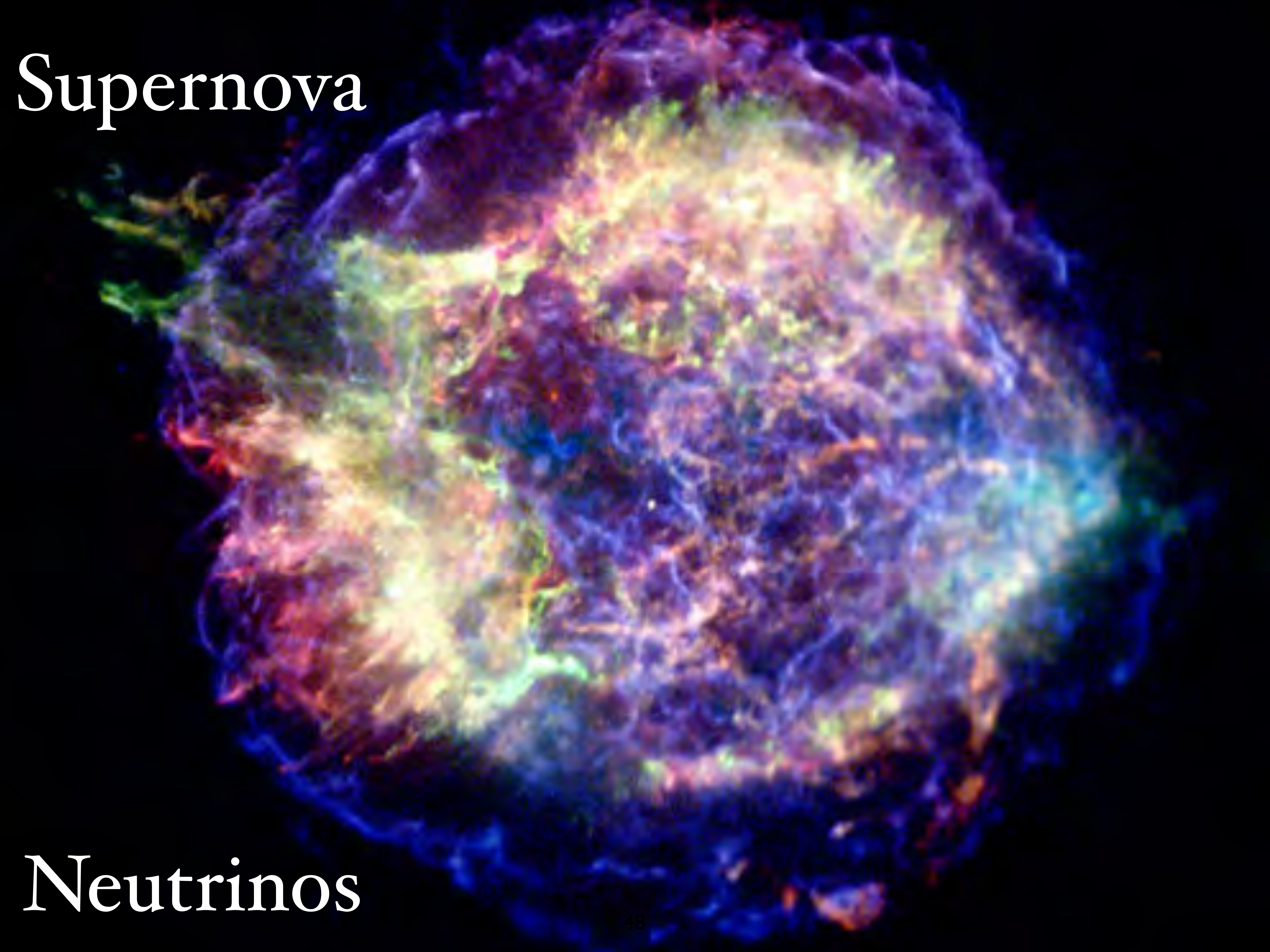
- Dominant background: natural radioactivity e.g. ^{210}Bi
- Theia offers unique low-threshold, directional detection
- Particle and event ID from LS time profile, quenching, Ch/S ratio

- Unique few-% level sensitivity to CNO ν
- Precision pp: luminosity, understand solar energy production
- Unique probe of matter effect / matter-vacuum transition
- Potential Li loading for CC (Haxton)





Supernova



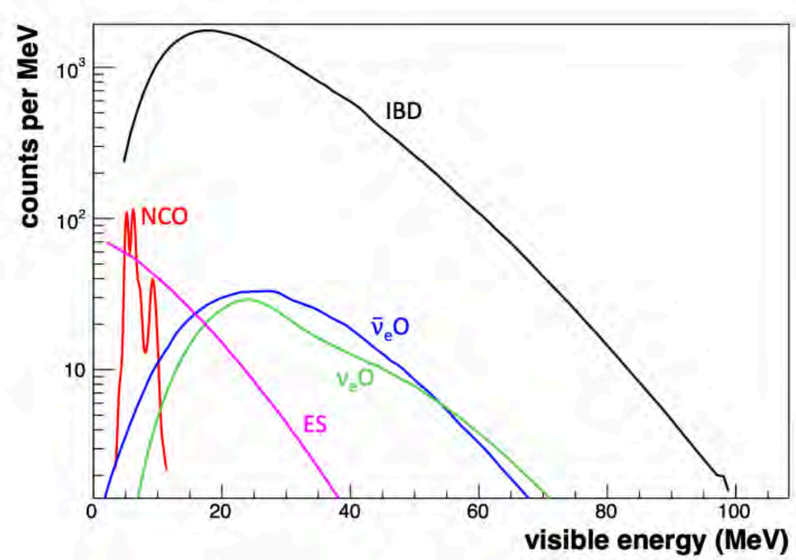
Neutrinos

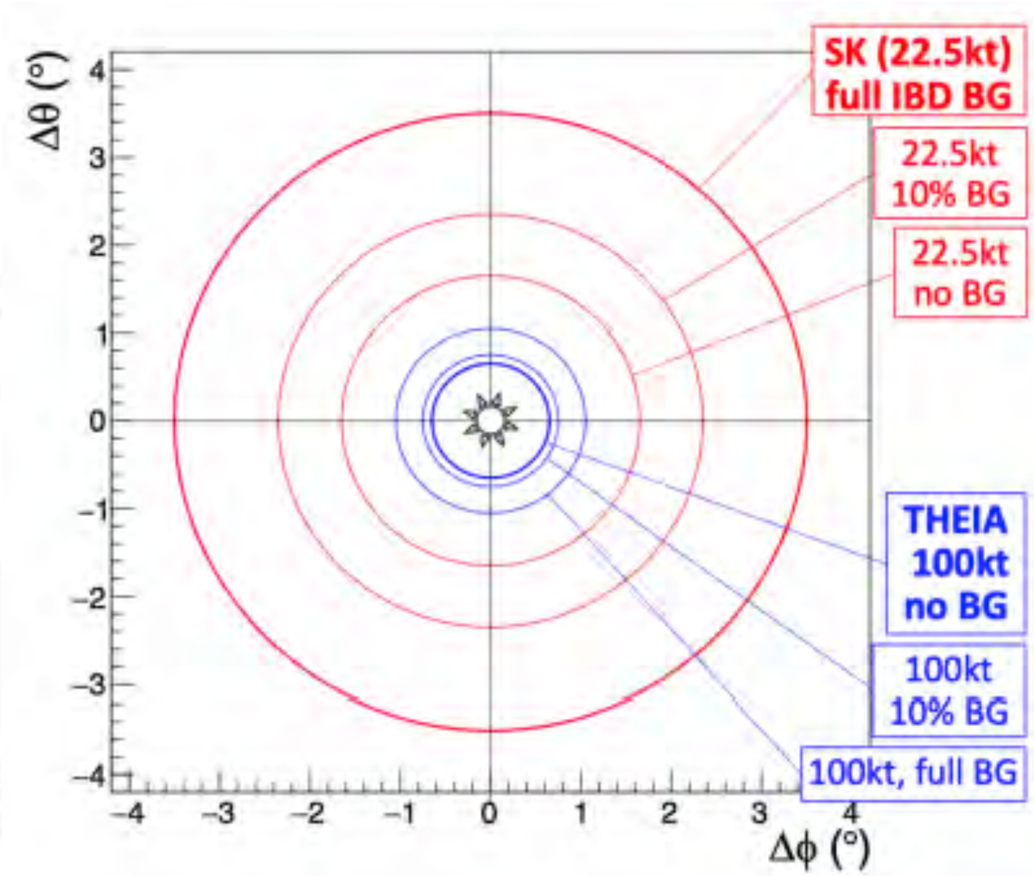
Supernova Detection

- ~90% events are IBD
  Highly complementary to ν_e LAr signal
  Fast, can act as trigger for DUNE
- ES ⇒ pointing accuracy < 1°
- CC & monoE γ from NC ⇒
  burst T & subsequent mixing
- Flavour-resolved neutrino spectra
- High-stats, low-threshold signal with good resolution
- Pre-supernova ν sensitivity
- Enhanced CC sensitivity with Li doping

Event rate in 100-kt WbLS, SN at 10 kpc

Reaction		*Rate*
(IBD)	$\bar{\nu}_e + p \to n + e^+$	19,800
(ES)	$\nu + e \to e + \nu$	960
(ν_eO)	$^{16}O(\nu_e, e^-)^{16}F$	340
($\bar{\nu}_e$O)	$^{16}O(\bar{\nu}_e, e^+)^{16}N$	440
(NCO)	$^{16}O(\nu, \nu)^{16}O^*$	1100

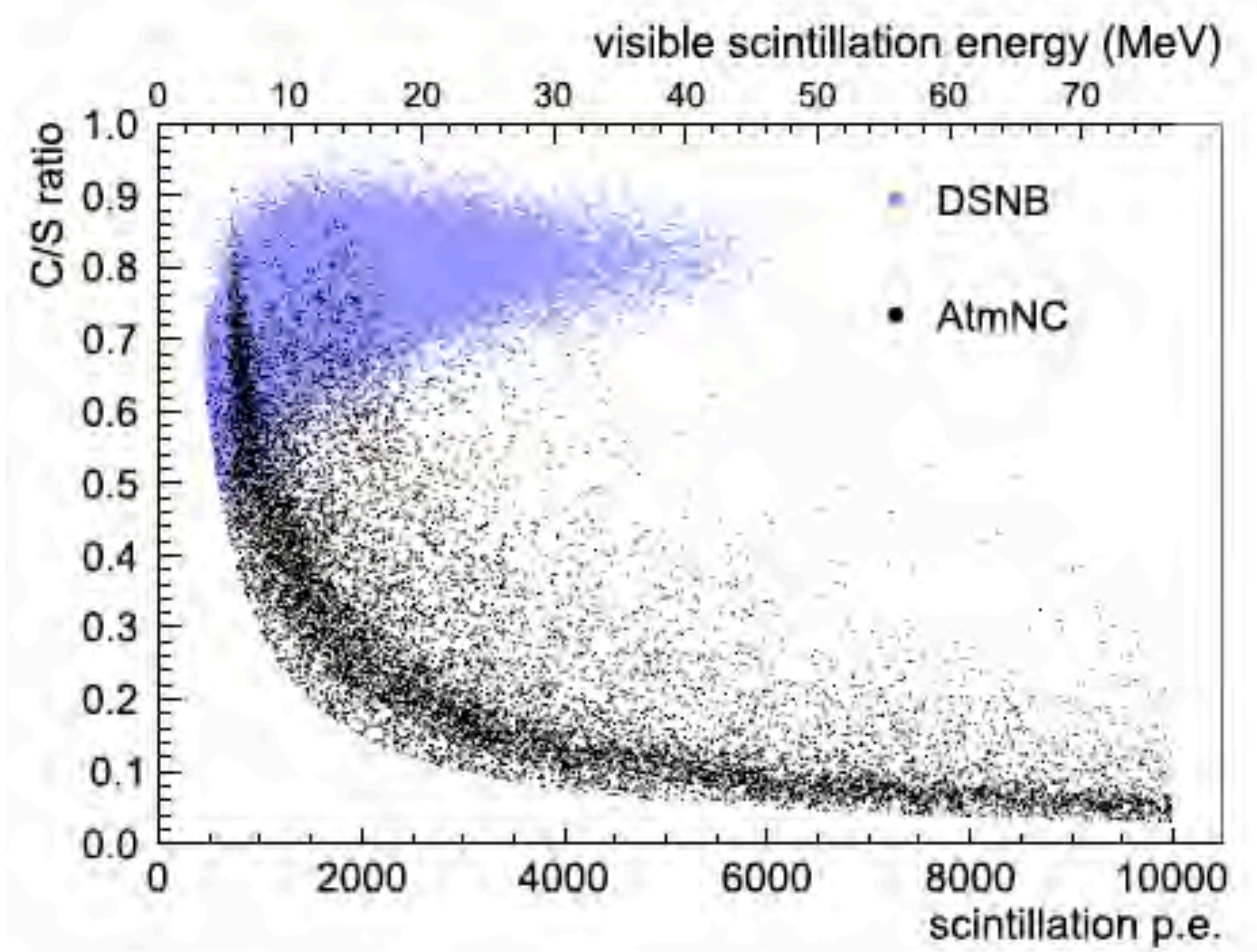




Eur. Phys. J. C 80, 416 (2020)

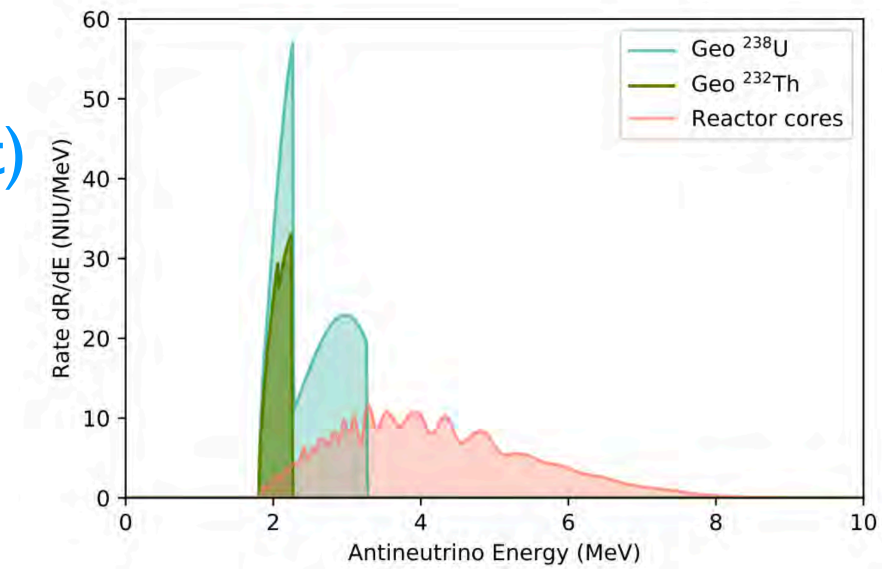
Diffuse Supernova ν Background

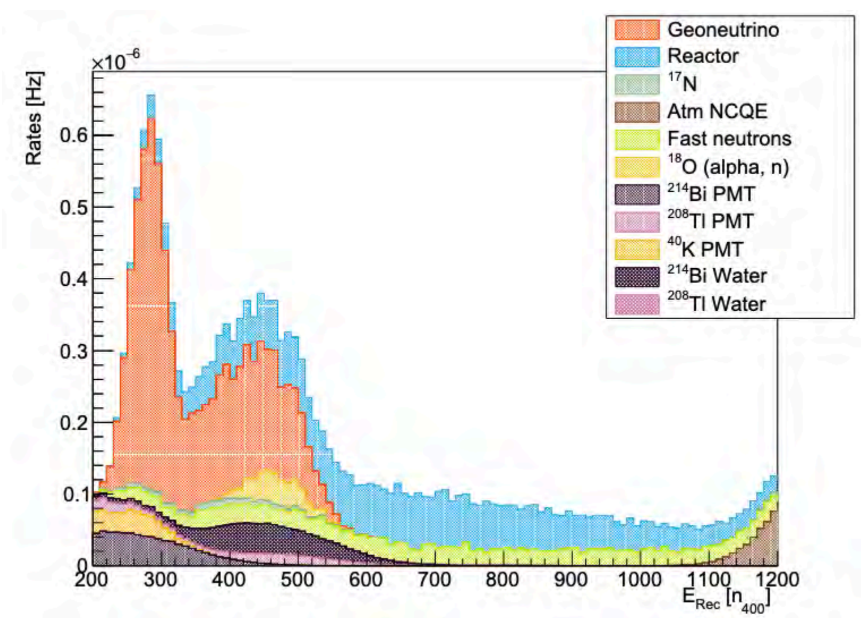
- Diffuse ν "glow" from past core-collapse supernovae
- Astrophysics of SNe
- Signature: IBD detection of antineutrino signal
  - Prompt e+ and delayed n-capture signal
- Main background: NC interaction of atmospheric ν
  - ν hits C nucleus, causing recoil
  - n captures
  - Can mimic signal
- Cherenkov/scintillation ratio provides a powerful handle for background discrimination
- 5σ in 125 kton-yrs

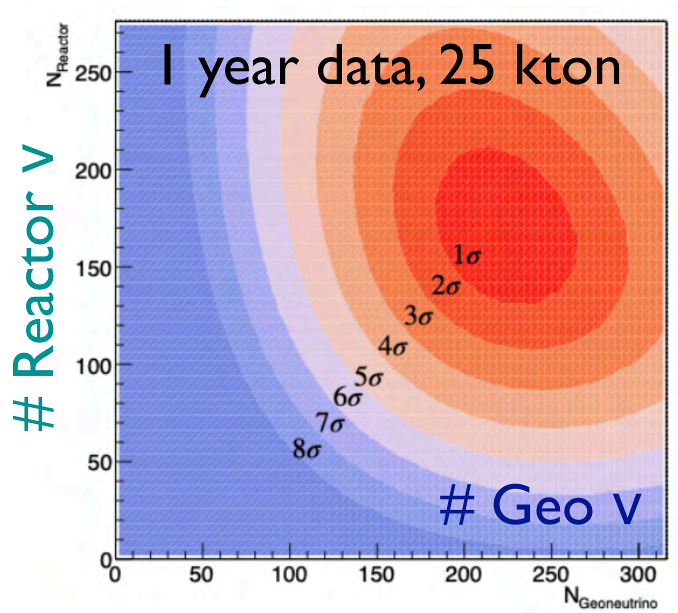


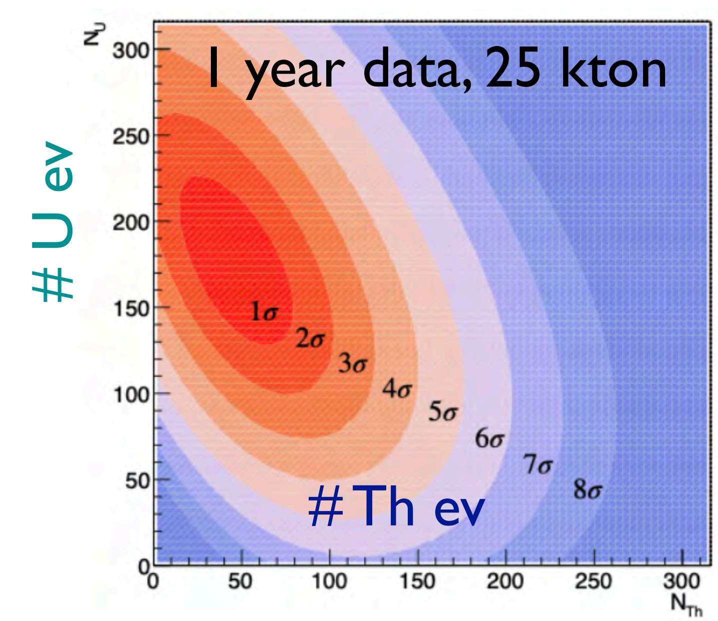
Anti-ν Detection

- **Geo-ν** observation by KL, Borexino (< 220 ev)
- **Theia**: large statistics, complementary site: 218 ev/yr (25 kt)
- Full spectral analysis with BDT for bkg rejection
- Future improvements: PID (p/e+, e-/e+)
- Could offer first evidence for surface variation
- U/Th ratio to 15% precision in 10 years
- **Reactor ν** prospects: ~ 20 reactor ev/kt-yr
- Demonstrate techniques for remote reactor monitoring
- Range & direction at >1000km standoff





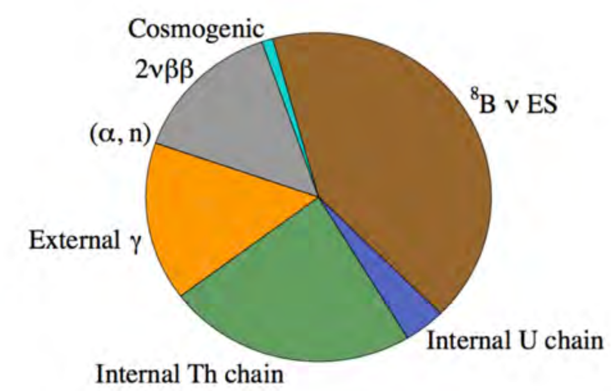




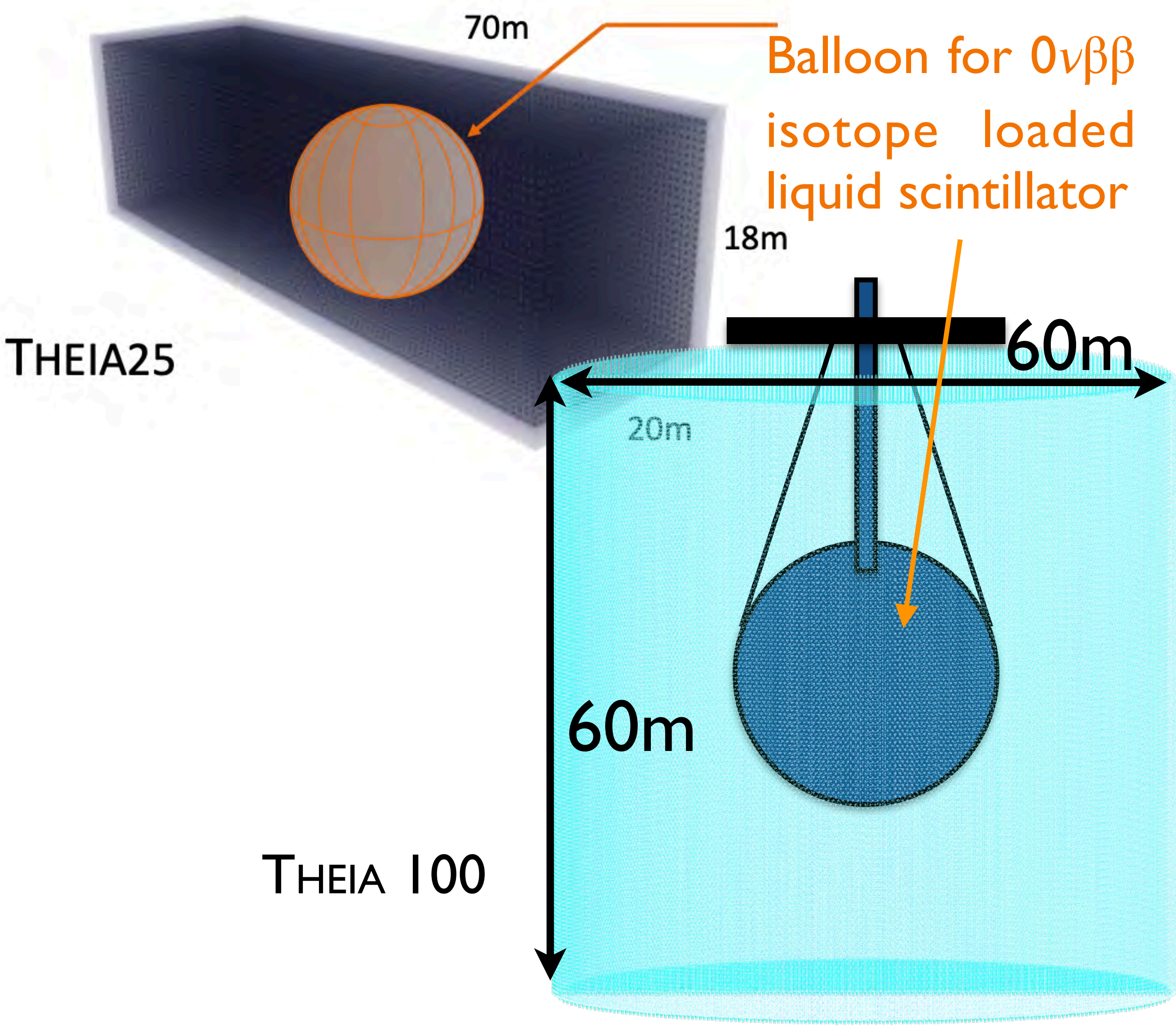
0νββ with THEIA

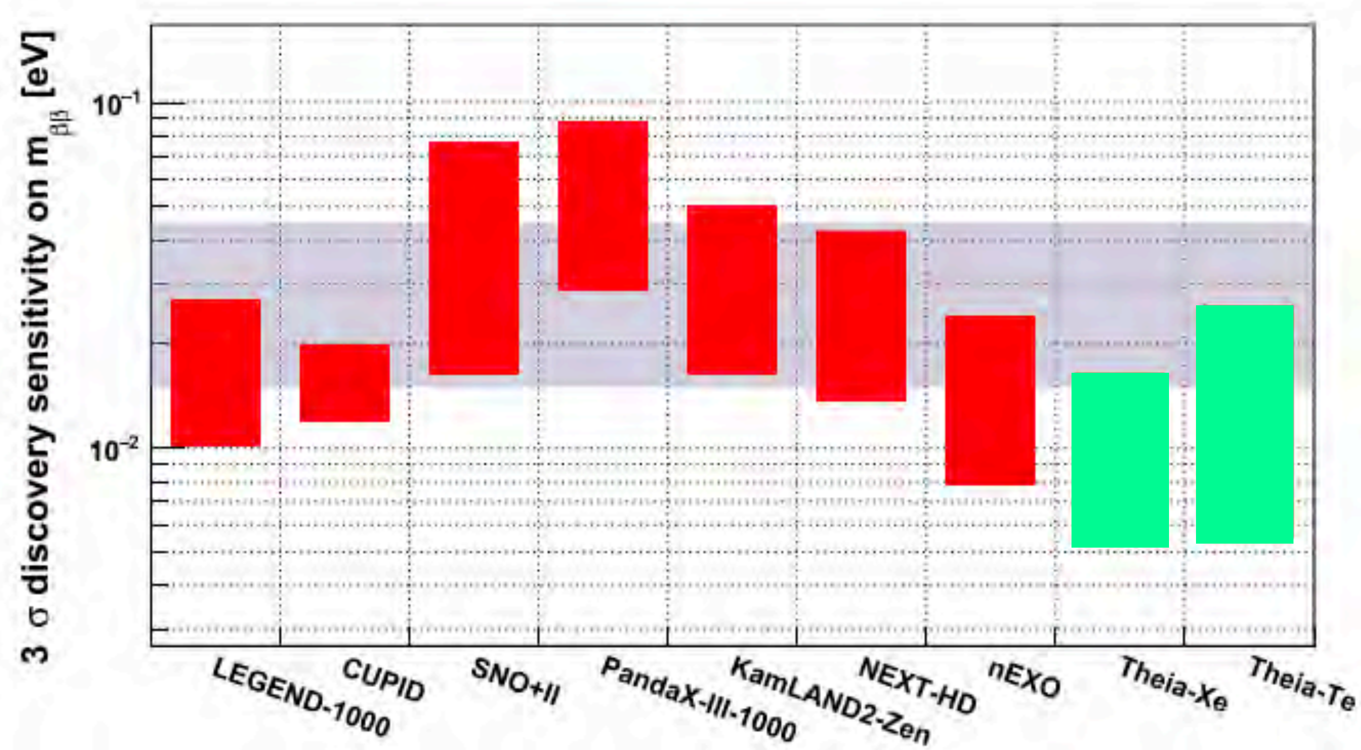
25-100 kton hybrid optical neutrino detector
8-m radius balloon with high-LY LS and isotope
7-m fiducial, 3% ^{nat}Te (or ^{enr}Xe), 10 years

SNO+ Collaboration



Background reduction via event imaging: PID, multi-site, directionality





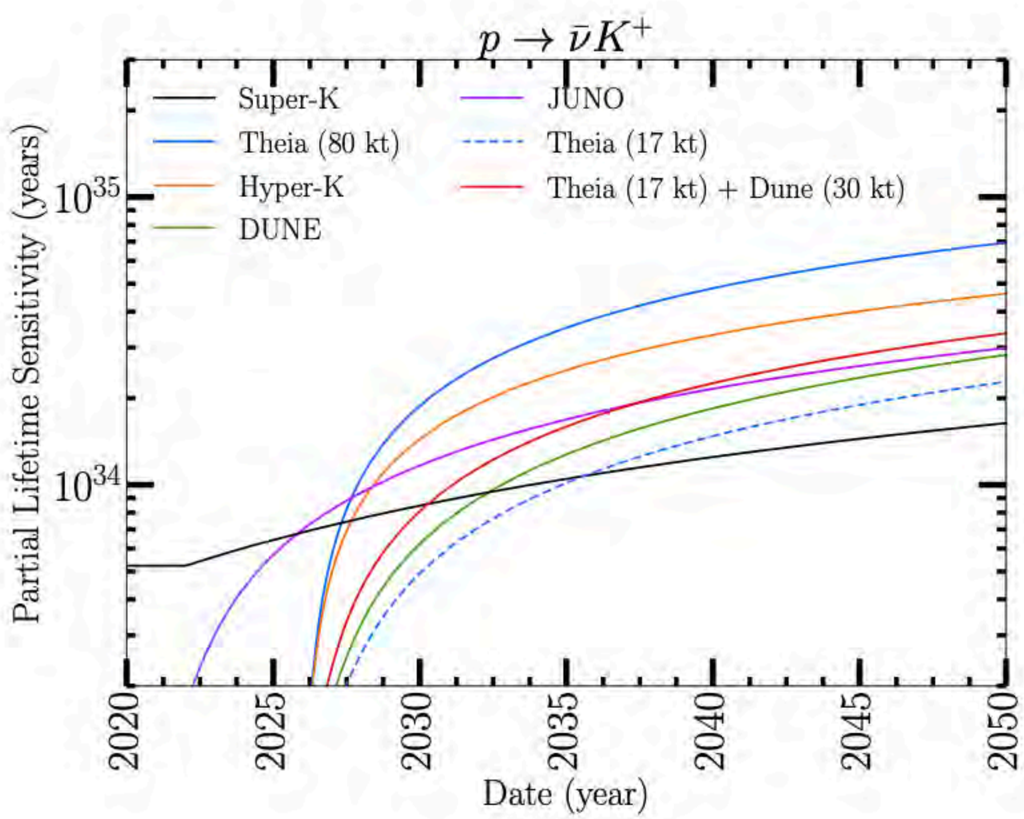
Builds on critical developments by KLZ & SNO+ collaborations

Phys.Rev.Lett.110 : 062502 (2013);Adv.High Energy Phys. 2016 (2016) 6194250; Phys. Rev. D 87 no. 7 : 071301 (2013)

Nucleon Decay

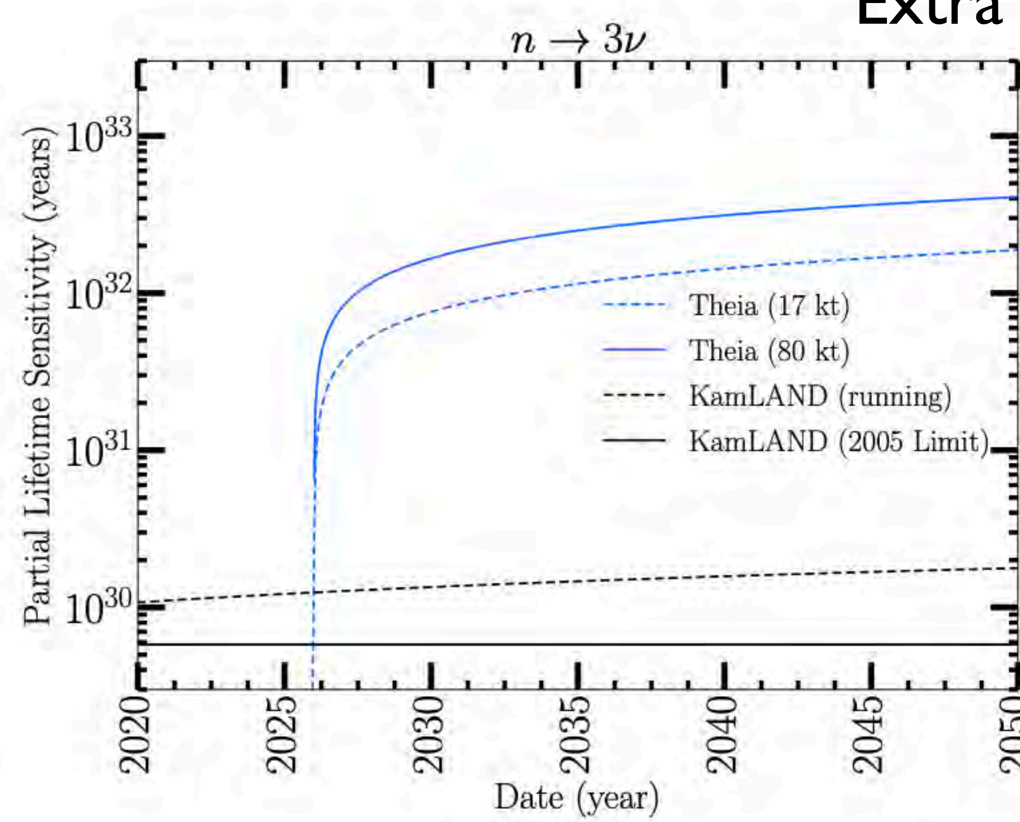
Testing the existence of GUTs with THEIA:

- Large size (statistics), deep location, very clean
- n tagging (low threshold plus potential isotope loading)
- Sub-Cherenkov threshold detection



Sub-Chr t/h detection
⇒ Directly visible K^+

Extra dimensions



Deep, low threshold
Directionality + n tag

Physics Program

Physics over 5 orders of magnitude

Neutrinos as a probe of nature

1. Solar neutrinos (solar metallicity, luminosity)
2. Supernova burst neutrinos & DSNB
3. Geo-neutrinos (& reactor neutrinos)

Particle astrophysics

Studying the fundamental nature of matter

4. Neutrinoless double beta decay
5. Source-based sterile searches
6. Nucleon decay
7. Long-baseline physics (mass hierarchy, CP violation)

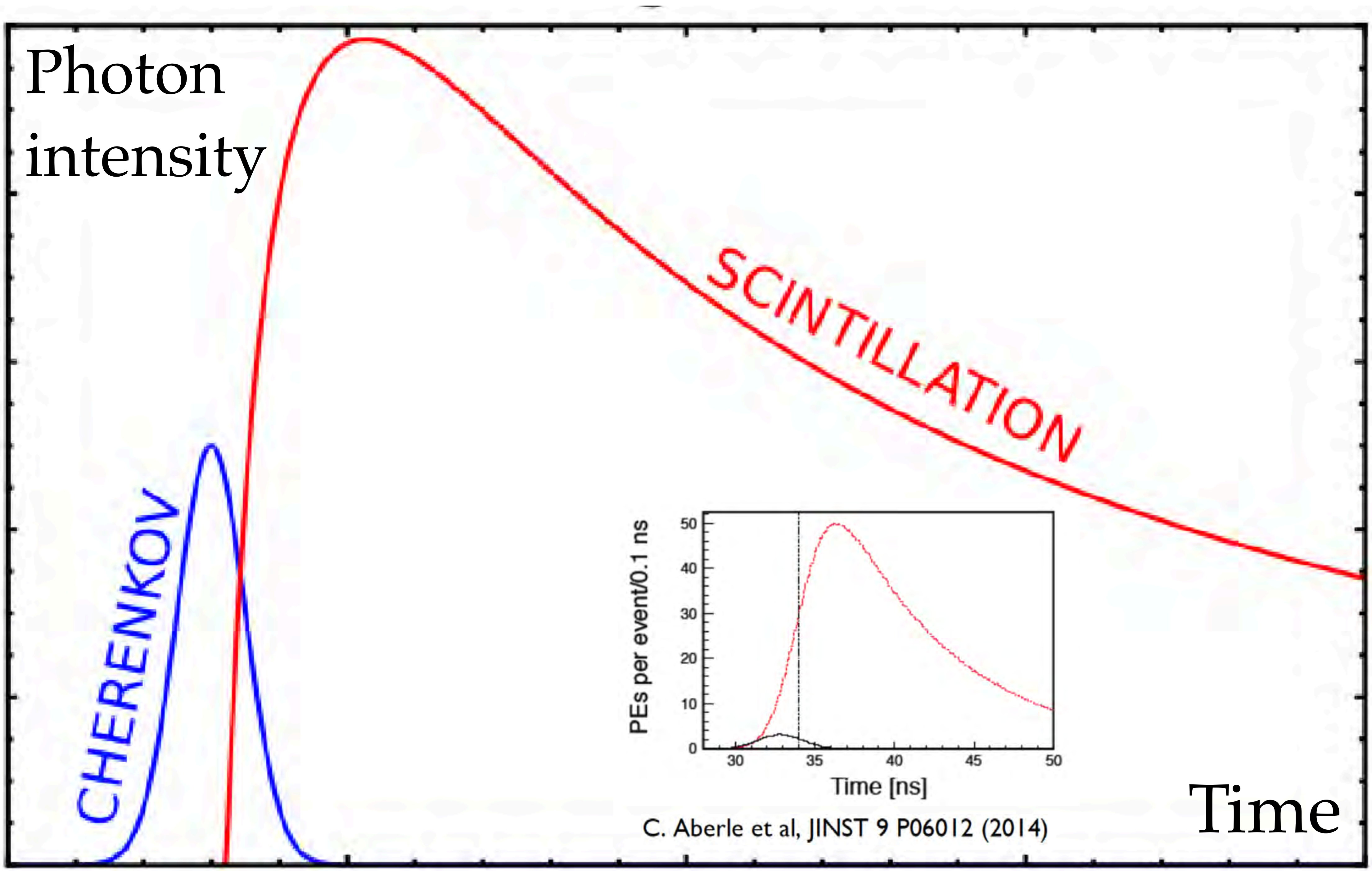
Nuclear physics

High energy physics

Remarkably, the same detector could show that neutrinos and antineutrinos are the same, ***and*** that "neutrinos" and "antineutrinos" oscillate differently

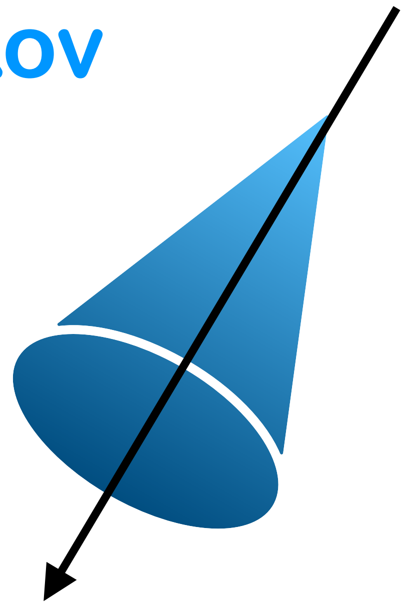
Matter-dominated universe

Why is it Hard?

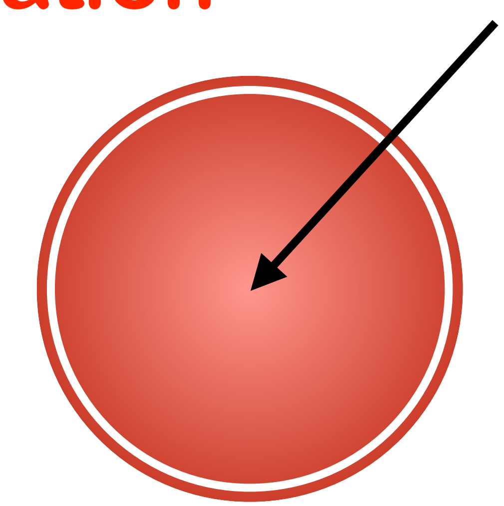


How can it be done?

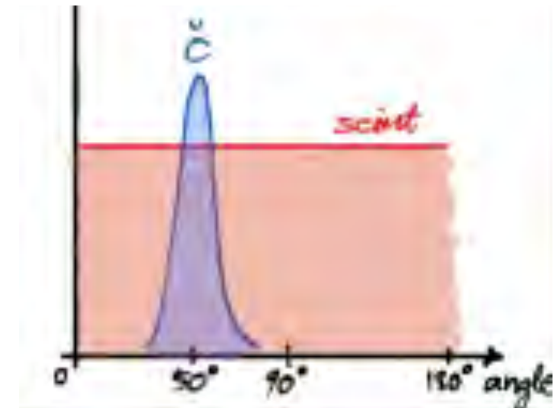
Cherenkov



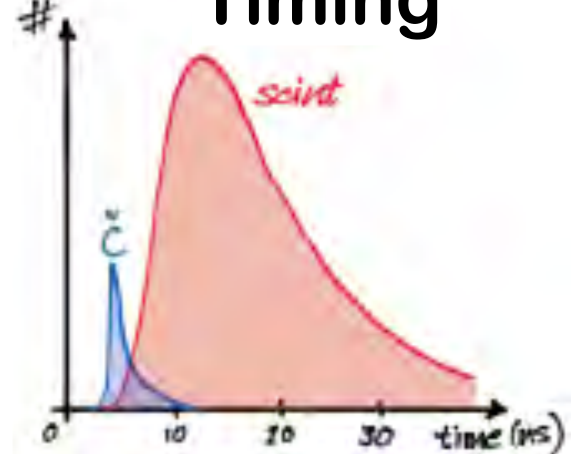
Scintillation



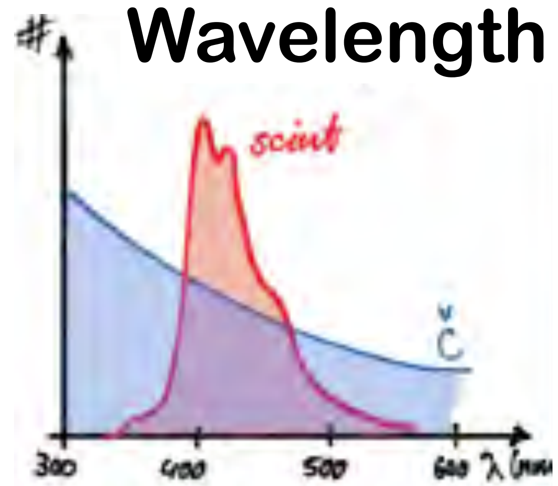
Angular distribution

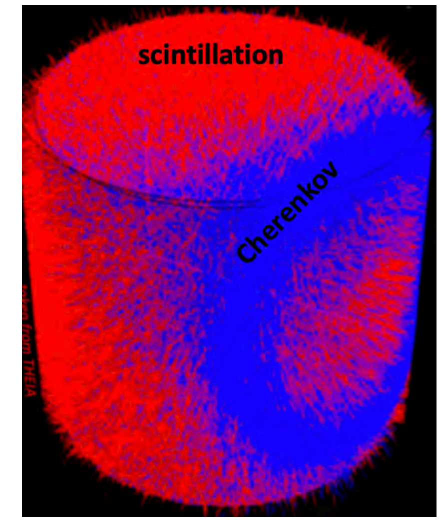


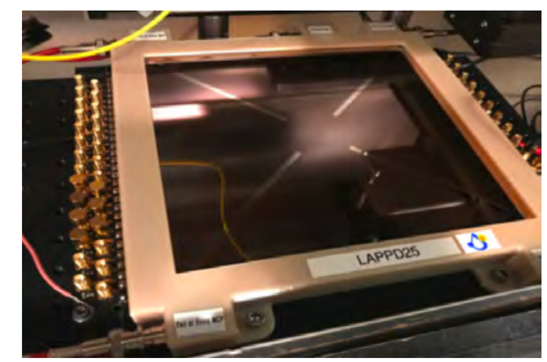
Timing



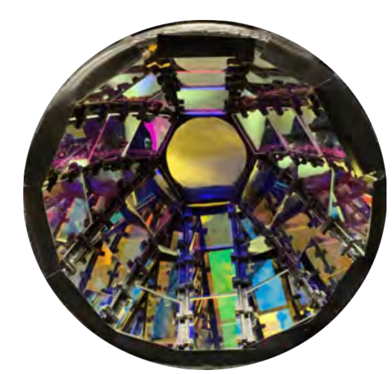
Wavelength







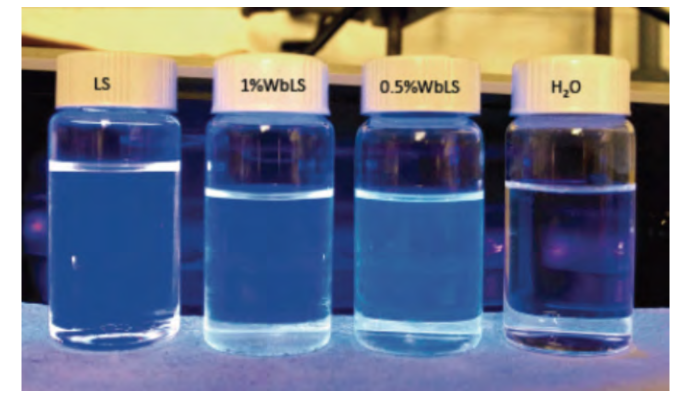
B.W.Adams et al. NIM A Volume 795, 1 (2015)



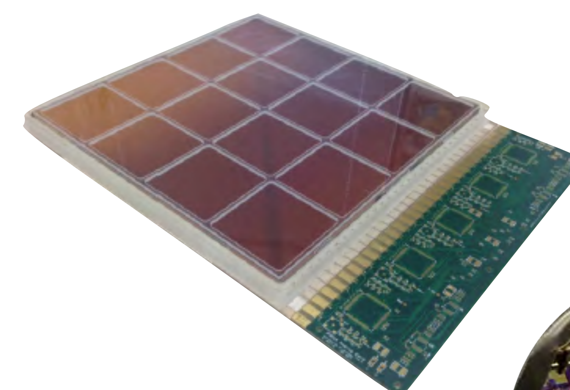
T. Kaptanoglu et al.
Phys. Rev. D 101, 072002 (2020)

Enabling technology

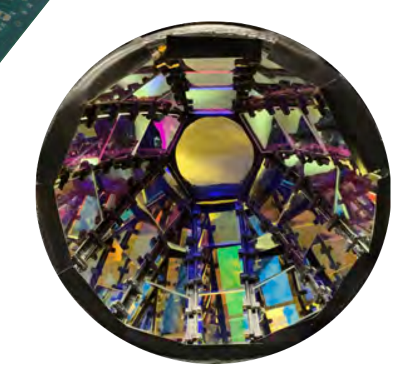
We focus our studies on three technologies that optimize hybrid Cherenkov/scintillation detection:



1. Novel targets, such as water-based liquid scintillator (WbLS). Enhances Cherenkov detection by "dialling down" or otherwise modifying the scintillation signal



2. Large-Area Picosecond Photon Detectors (LAPPDs). Fast-timing discrimination for vertex resolution and Cherenkov/scintillation separation



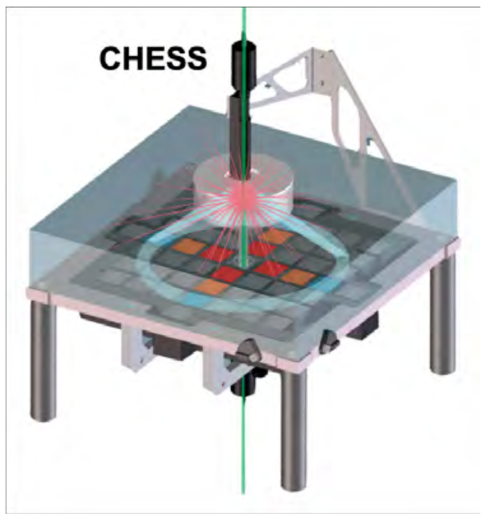
3. Dichroicons ("chromatic quantum sensing"). Cherenkov/scintillation separation via spectral sorting

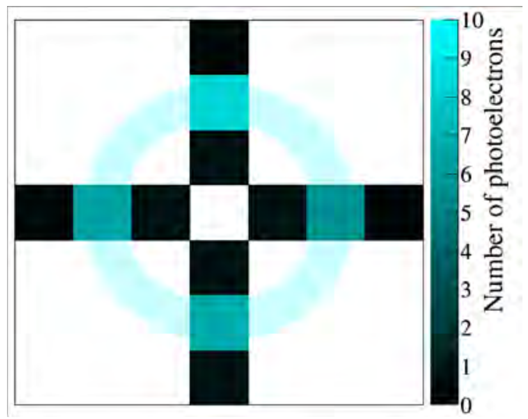
We seek to characterize behavior, understand and model performance at a microphysical level, and use results to extrapolate performance to kton scales.

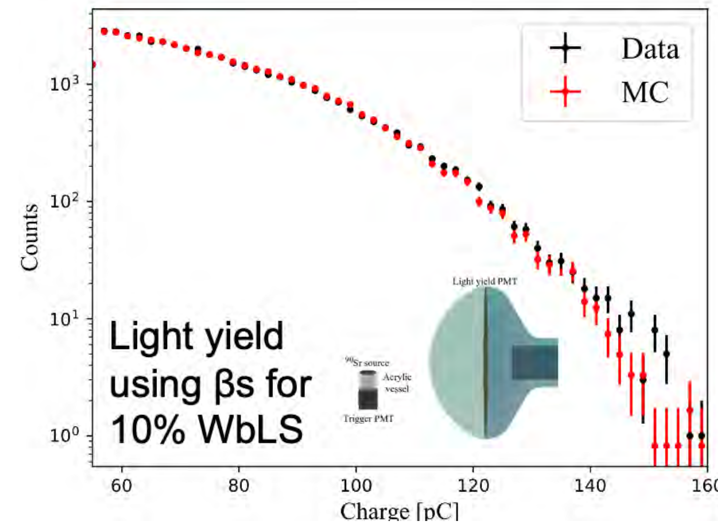
Builds on core (Wb)LS development at BNL (Yeh et al.)

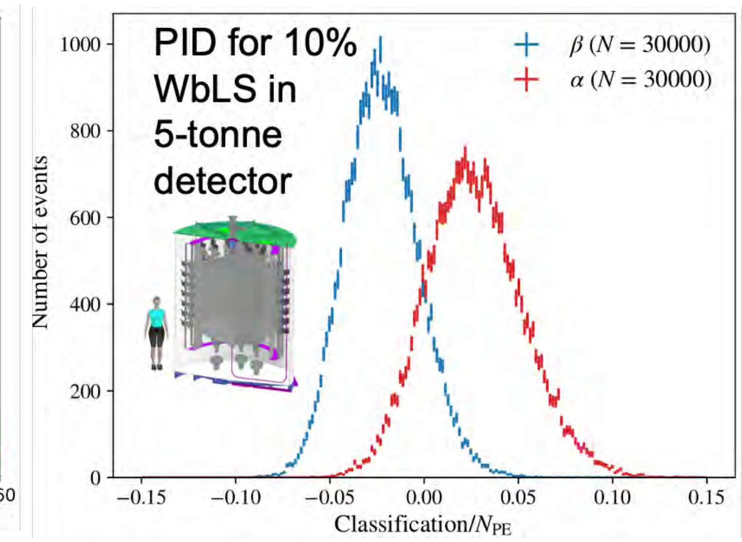
Technical accomplishments

WbLS characterization

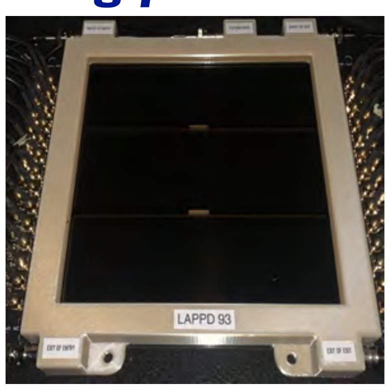


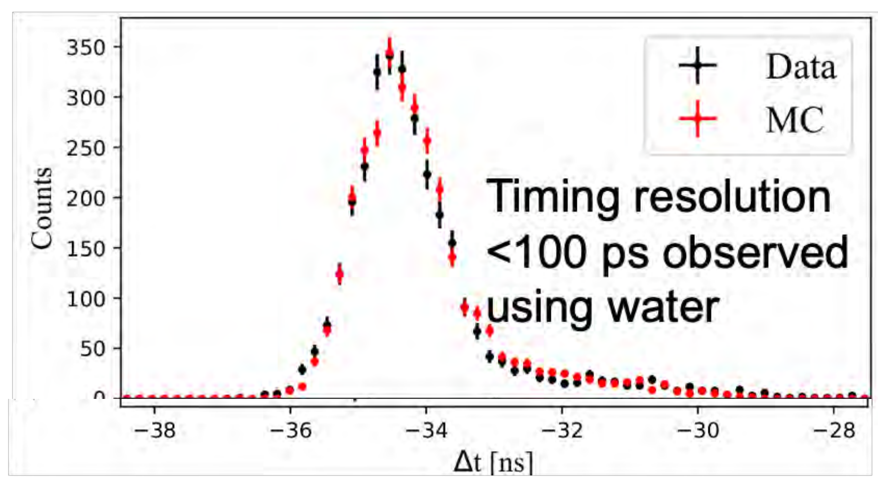


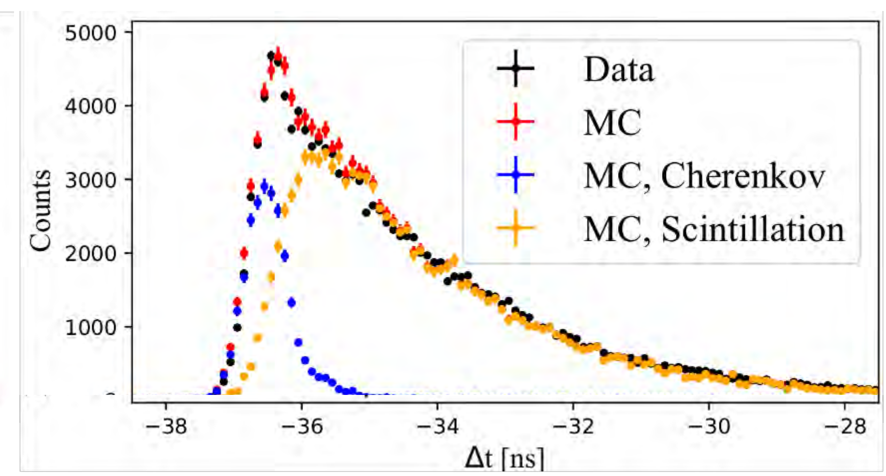




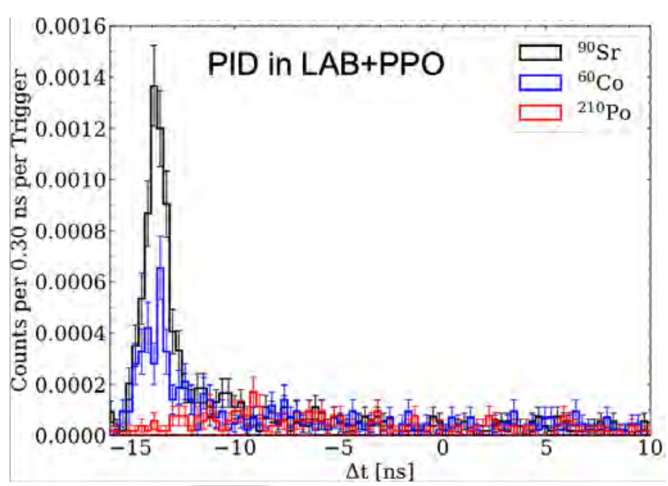
Fast timing photon detection







Quantum chromatic sorting



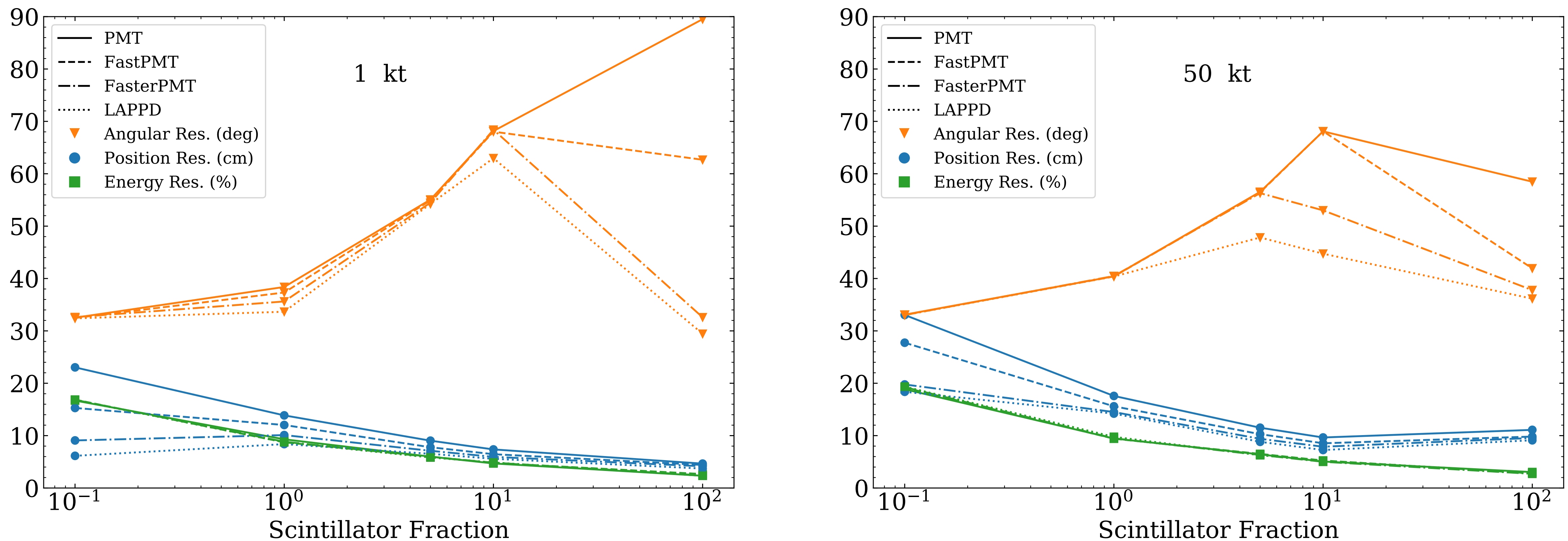
D. Onken et al., Mater. Adv. 1, 71-76 (2020); J. Caravaca et al., Eur. Phys. J. C 80, 867 (2020); E. Callaghan et al., Eur. Phys. J. C 83, 134 (2023); E. Callaghan, T. Kaptanoglu, M. Smiley et al., paper in prep.; J. Caravaca et al., Phys. Rev. C 95, 055801 (2017); J. Caravaca et al., Eur. Phys. J. C 77, 811 (2017); T. Kaptanoglu, E. Callaghan et al., Eur. Phys. J. C 82-2 (2022) 169; T. Kaptanoglu et al., Phys. Rev. D 101, 072002 (2020); S. Naugle et al., paper in prep.

Model validation

A number of metrics are considered for detector performance:

1. Energy resolution — *Reduce flux uncertainty, increase background rejection*
2. Vertex resolution — *Reduce flux uncertainty, increase background rejection*
3. Angular resolution — *Elastic scattering event ID, physics scope*
4. Cherenkov (C) / scintillation (S) separation — *Particle & event ID*

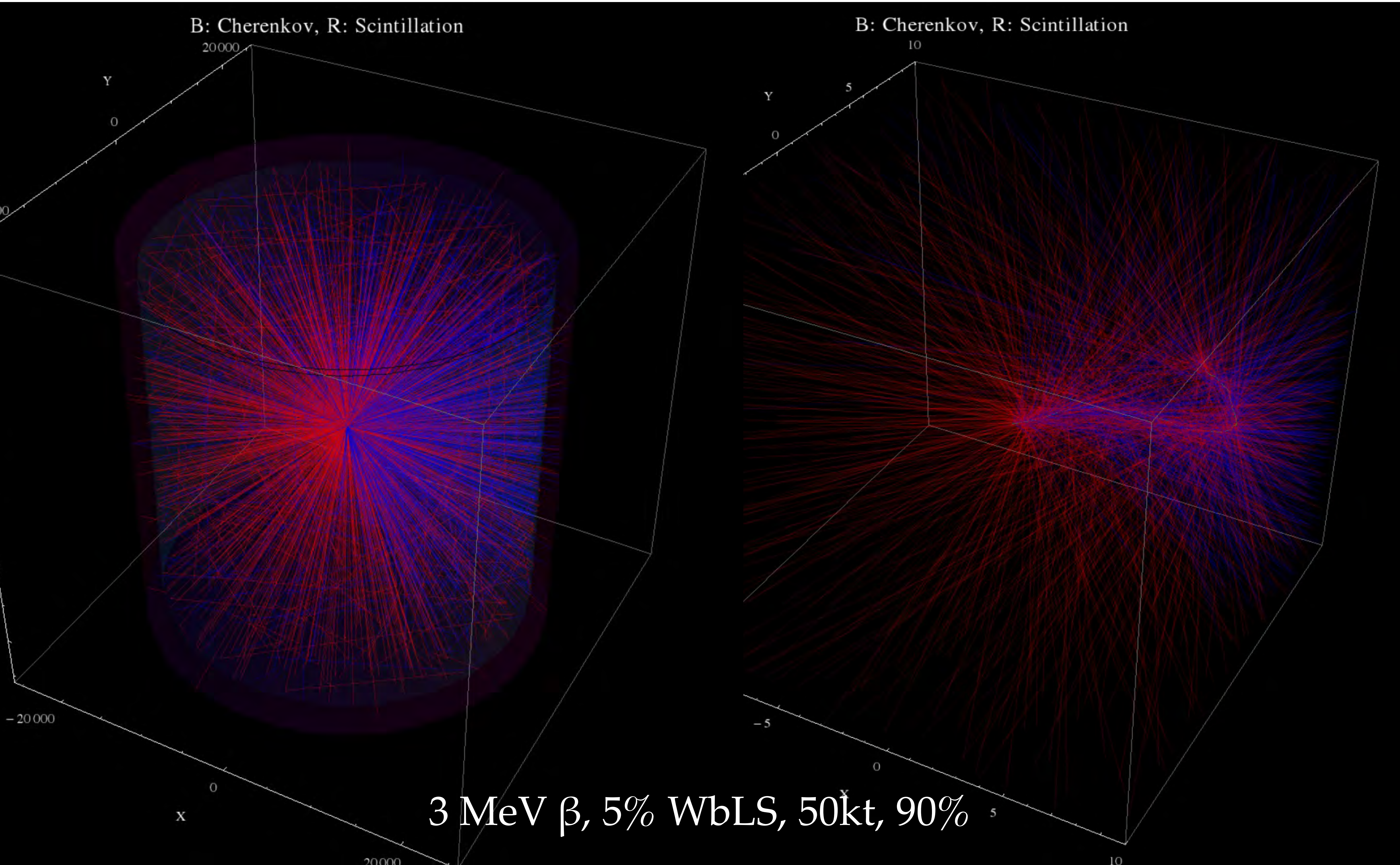
These tools can be used to define "desired" properties for WbLS



Impact of target properties and photon detector response on detector performance for (left) 1-kton and (right) 50-kton detectors

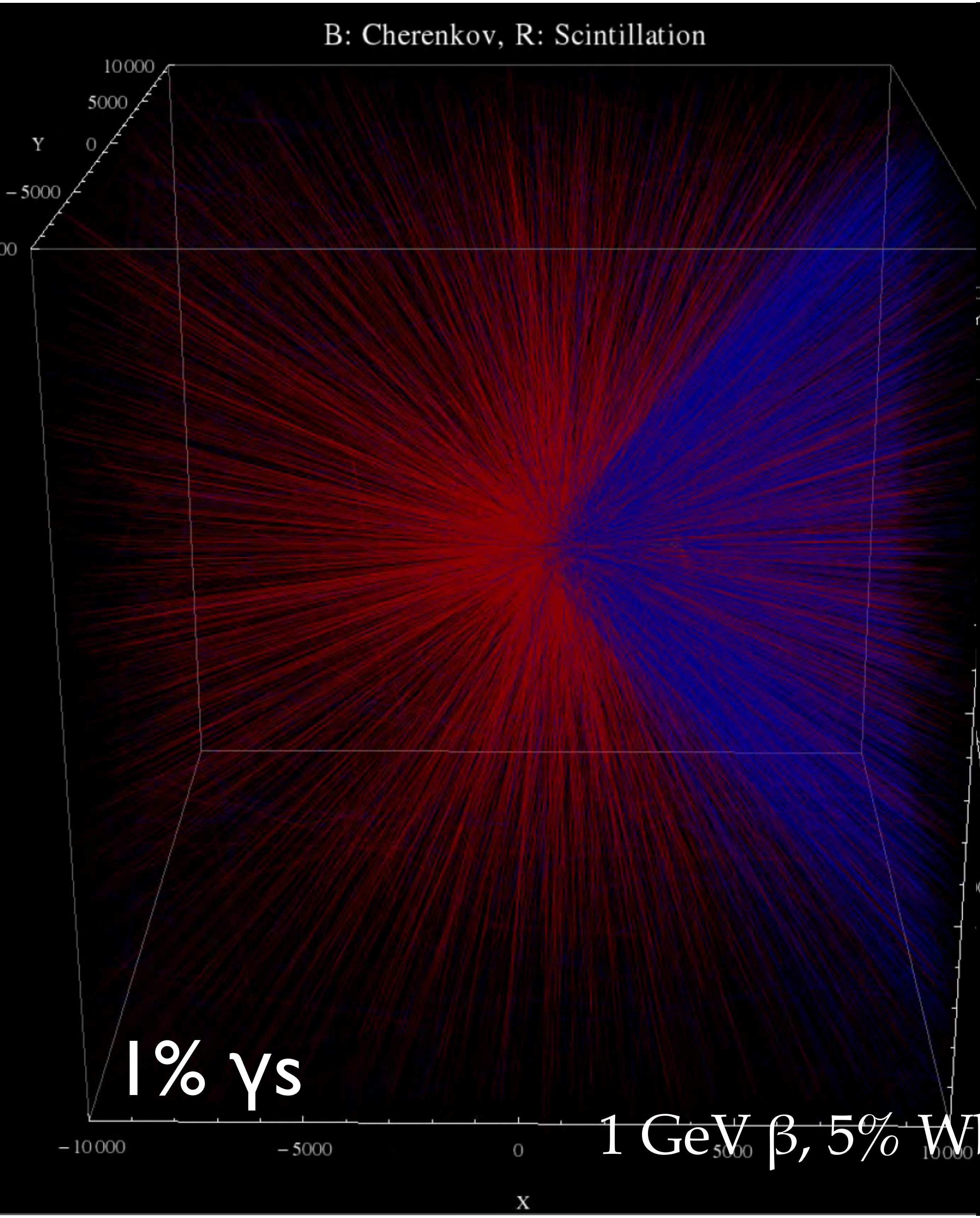
*Phys. Rev. D **103** 052004 (2021)*

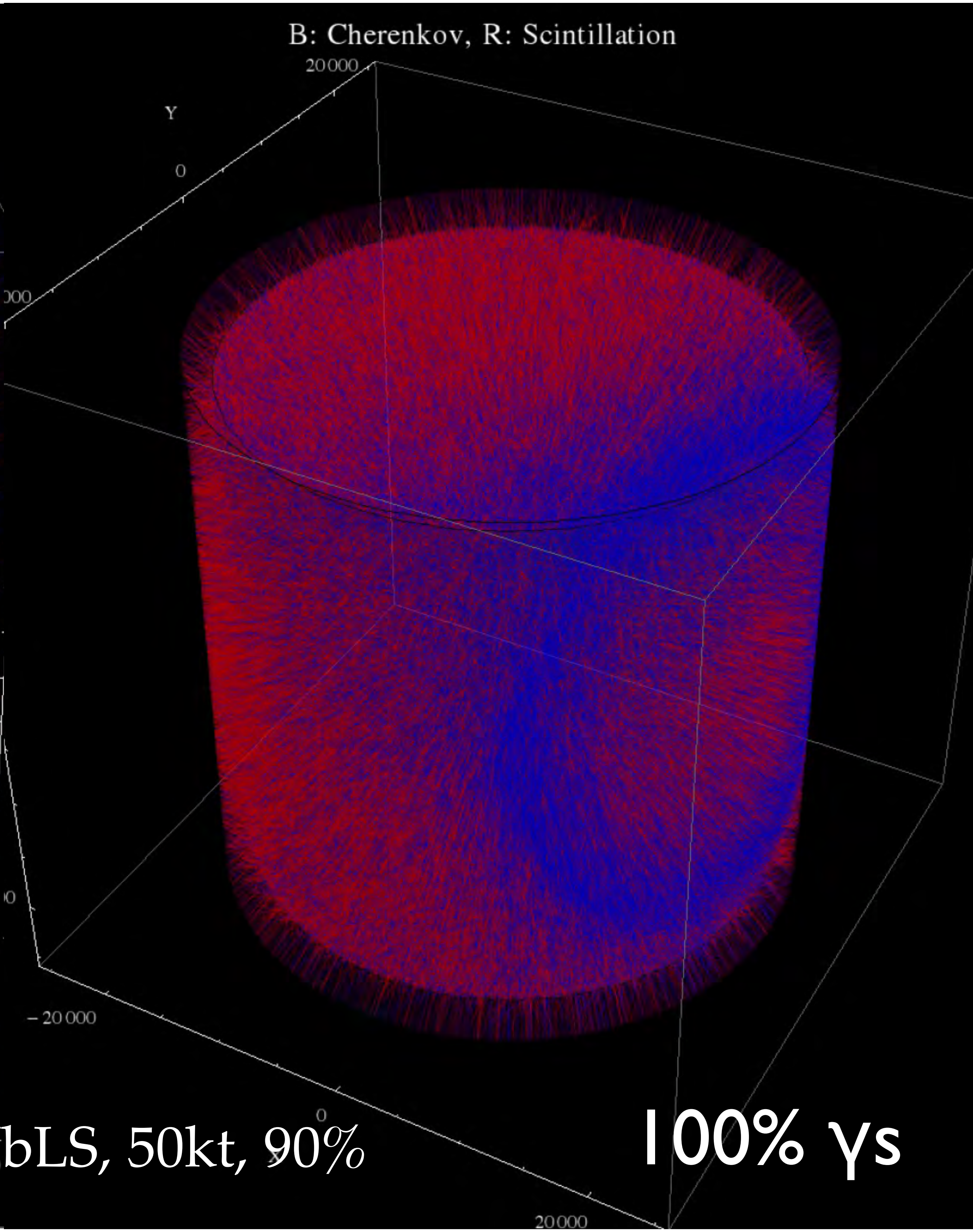
Signal Separation in Theia



3 MeV β, 5% WbLS, 50kt, 90%

Ring Imaging

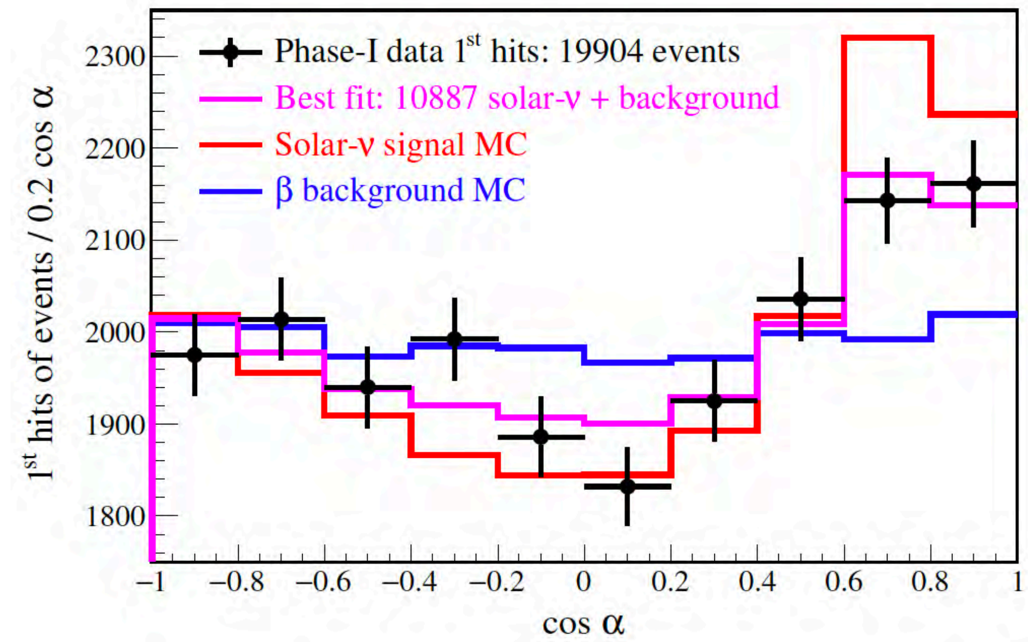




1 GeV β, 5% WbLS, 50kt, 90%

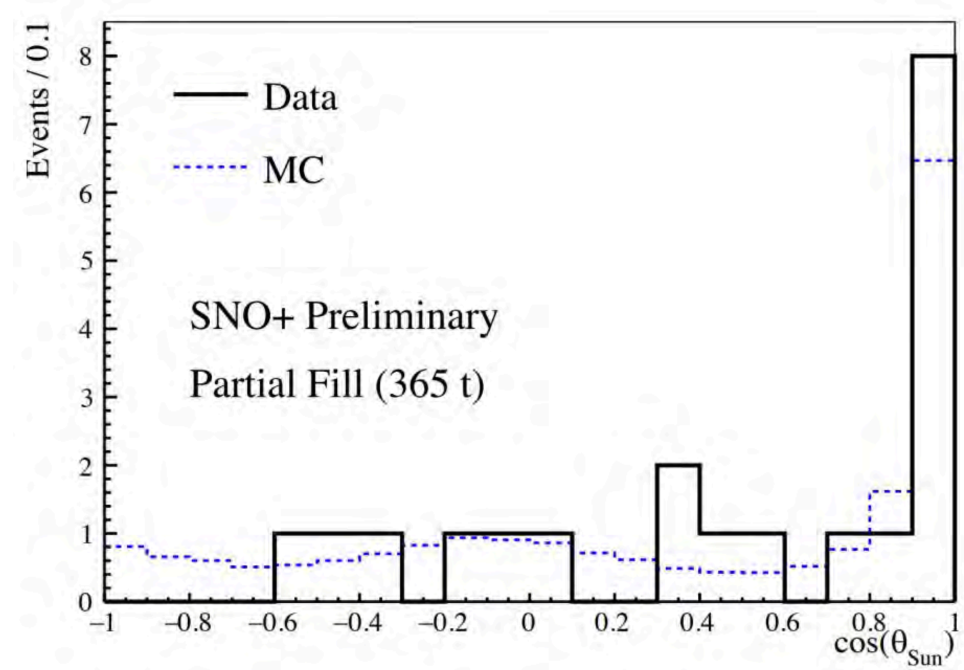
Full-scale demonstrations

- Integrated directionality at Borexino:
  - consider earliest photons in the event
  - take angle between early photons and solar direction
  - 6σ angular excess caused by Cherenkov photons
- Measurement of primarily 7Be ν demonstrates first directional detection of sub-MeV neutrinos



PRD 105.052002, PRL 128 (2022) 9, 091803

- Event-level directionality at SNO+:
  - Partial-filled detector (365 t LAB + 0.6 g/L PPO)
  - ToF and angular reconstruction
  - Demonstration with > 5MeV 8B ν
- First event-by-event demonstration of directional reconstruction for 8B solar ν in slow LS

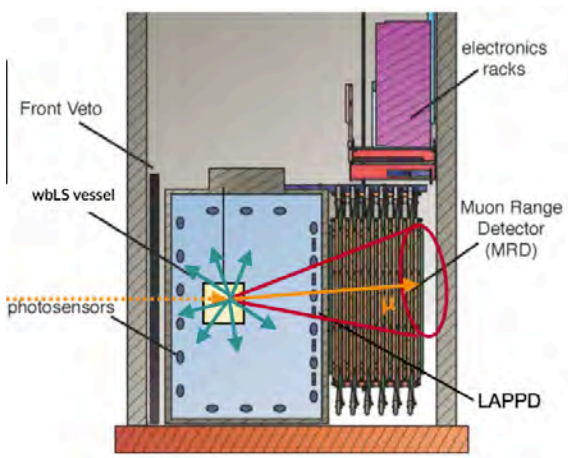


SNO+, L. Lebanowski APS talk

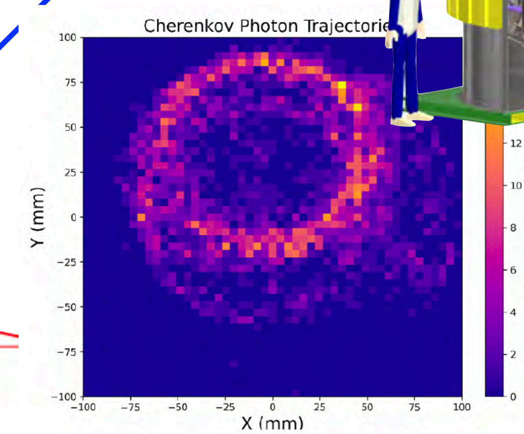
The path to THEIA

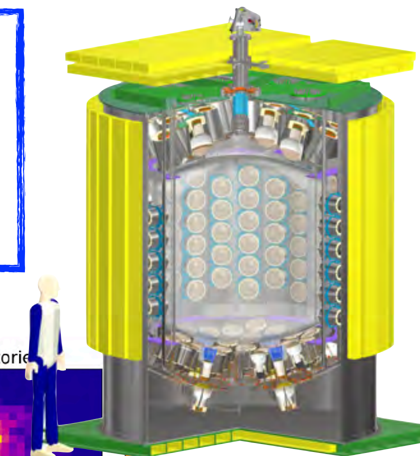
High-energy event reconstruction, neutrino detection

ANNIE: 365 kg

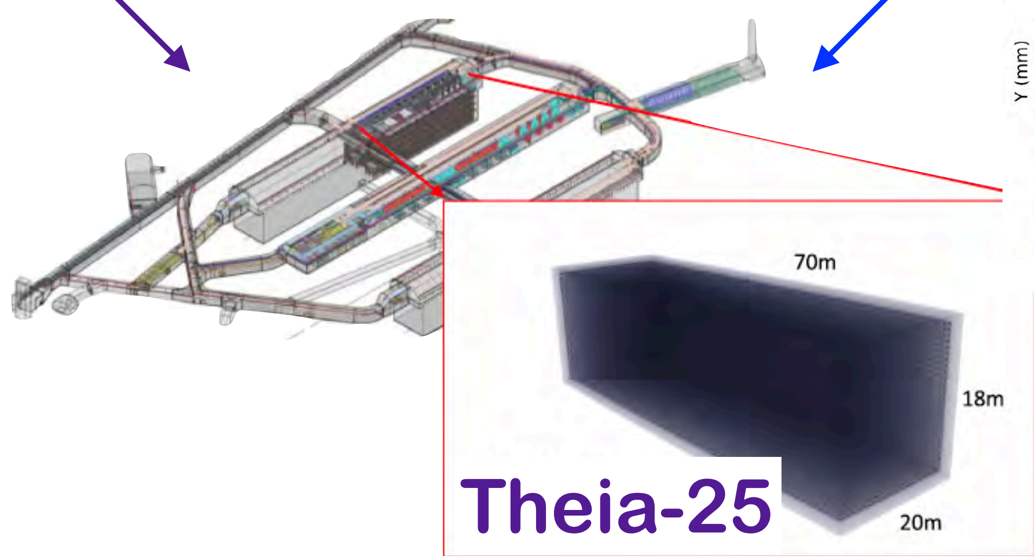


Low-energy event reconstruction, model validation





Eos: 4 ton



NuDot: 1 ton

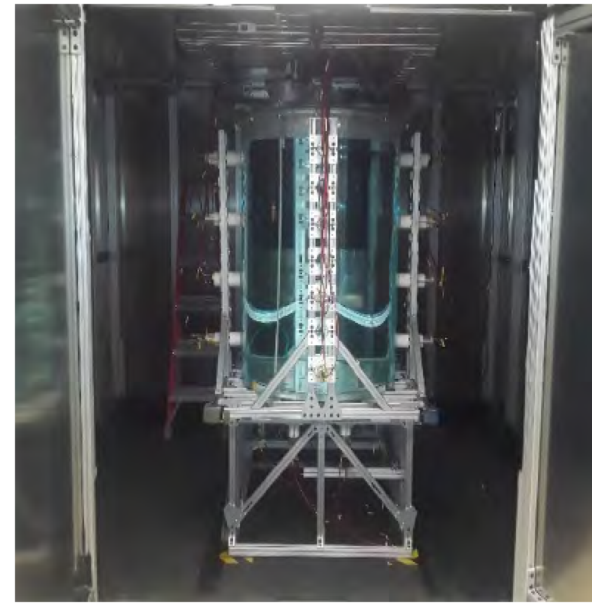
BNL: 1- and 30-ton

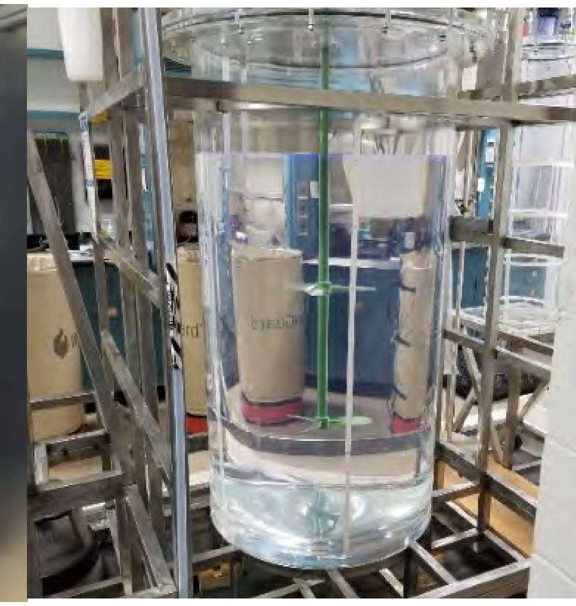
Deployment, purification, recirculation, transparency

Isotope loading, NLDBD topology

BNL 1- & 30-ton demonstrators FY 22-24

- First ton-scale deployment of WbLS
- First demonstration of:
  - Ton-scale production
  - Optical transparency in an operating detector
  - Optical stability over time
  - Recirculation of WbLS (nanofiltration)





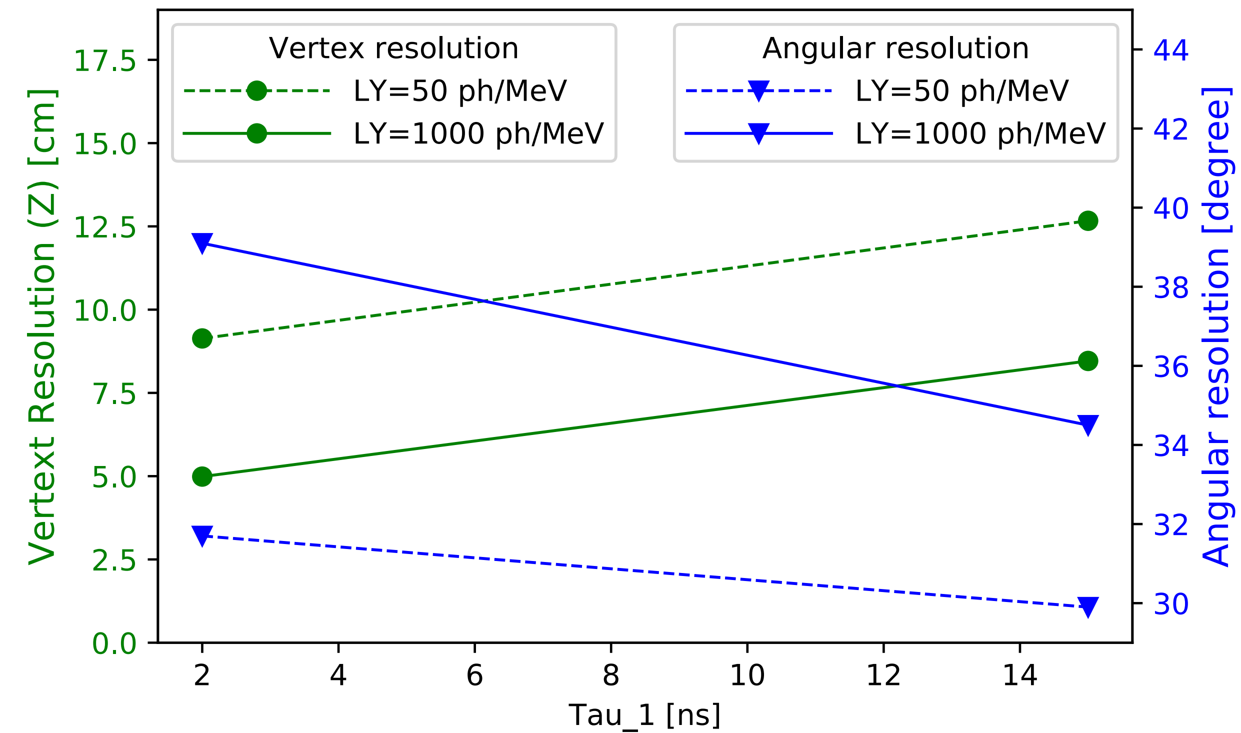
Together these prototypes will demonstrate the feasibility and capabilities of hybrid detectors for fundamental physics


Eos (Dawn)
Funded by NNSA,
DNN R&D
FY22-24
Let There be Light

EOS: performance demonstrator

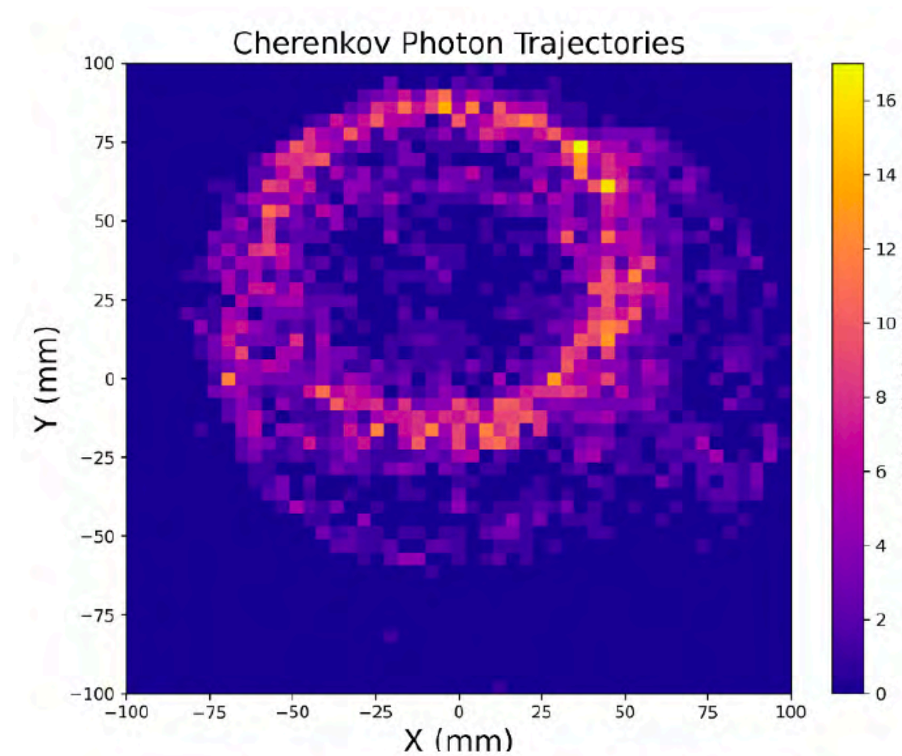
Project goals:

- Demonstrate event reconstruction using hybrid Cherenkov + scintillation signatures
- Validate models to support large-scale detector performance predictions
- Provide a flexible testbed to demonstrate impact of novel technology

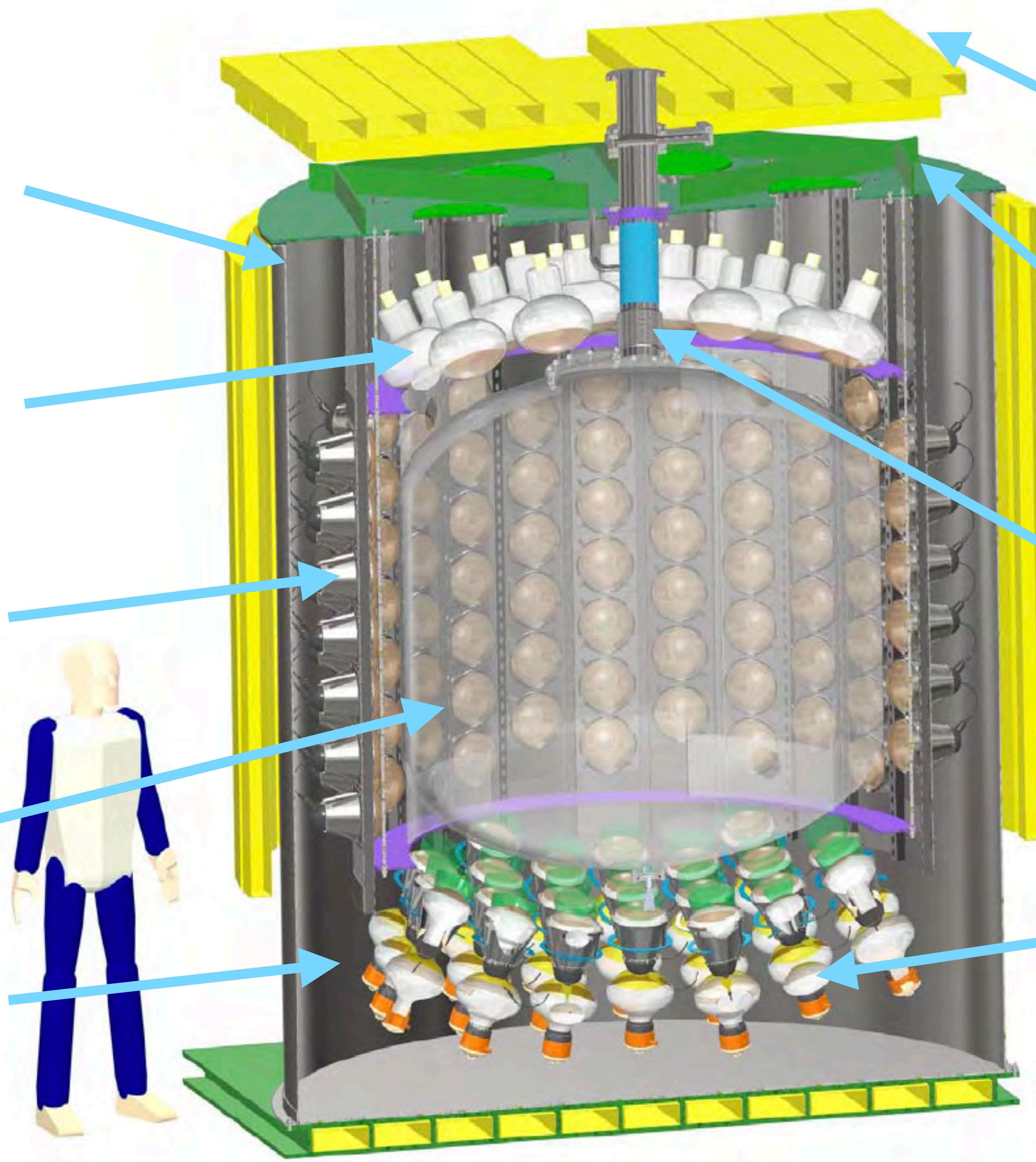


Approach: *design, construct and operate an integrated testbed to demonstrate the performance of novel technology*

- 4-ton target mass: *water, WbLS, organic LS*
- 200 8-" PMTs: *R14688-100, 900ps FWHM*
- CAEN V1730 readout
- Dichroicon deployment for spectral sorting
- Deployable sources for studies of vertex, energy, direction reconstruction & PID



EOS Detector design



~11-ft steel outer vessel (OV)

12-” PMTs for light collection

200x 8-” fast PMTs + B shielding

4-ton acrylic inner vessel (IV)

Water buffer region

Muon veto system surrounding detector

Edge ports for additional calibration, sensors, access

Central-axis calibration source deployment

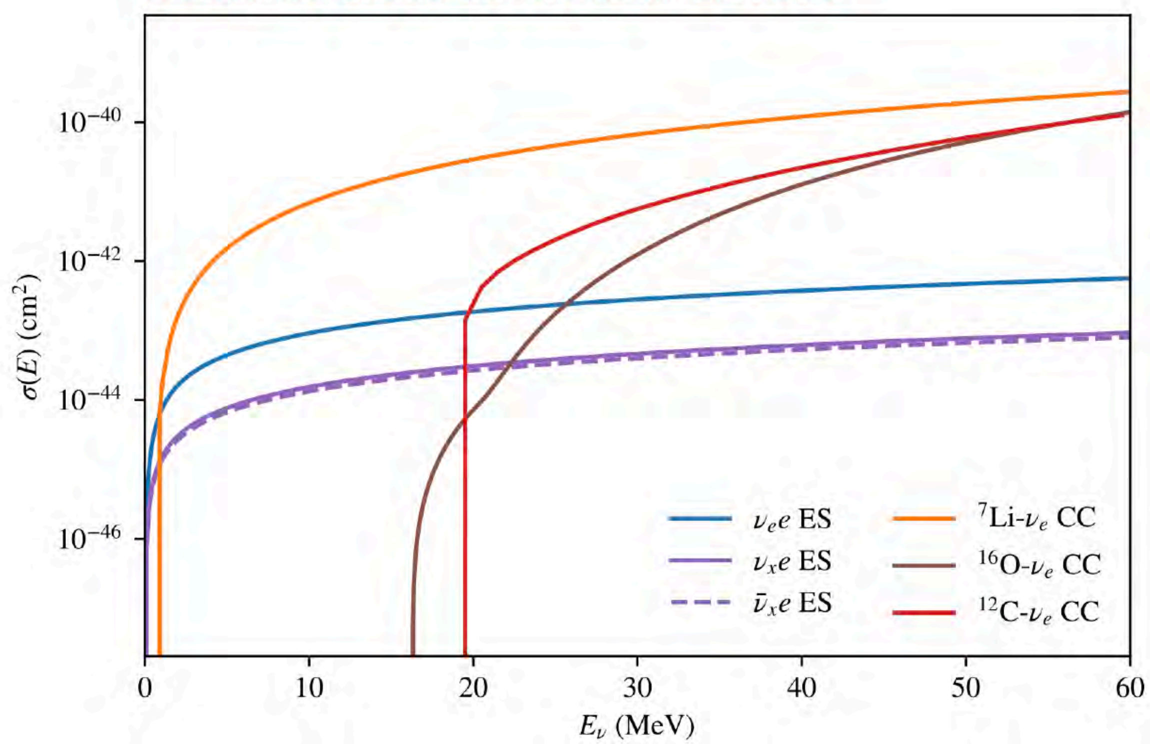
Dichroicon deployment

EOS paper published:
JINST 18 P02009 (2023), https://doi.org/10.1088/1748-0221/18/02/P02009

EOS @ SNS (ORNL)

- Detection of IBD and ES events: directionality
- Neutron studies: background rejection
- Too large for neutrino alley: alternative location
- Later stage: Li-loaded WbLS (5% organic, 10% Li)
  - Enhanced ν_e detection : CC on ^{7}Li

neutrino cross-sections in LiWbLS



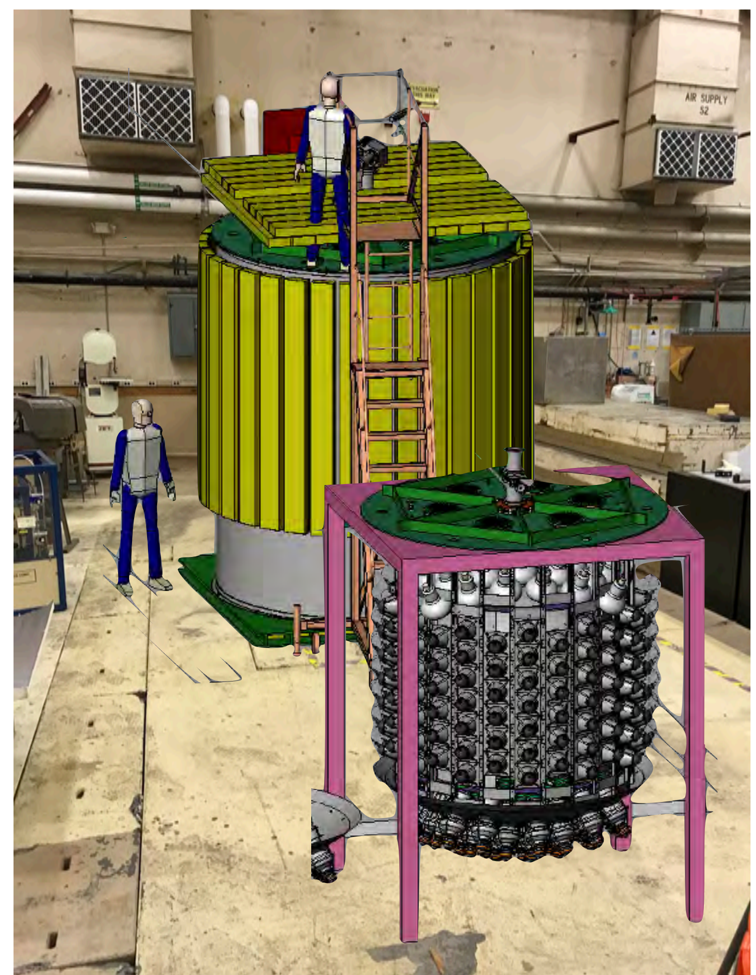
possible site for EOS deployment

Channel	Rate at 20m Standoff (ev/yr)
$\nu_e e$ ES	136.89
$\nu_\mu e$ ES	20.89
$\bar{\nu}_\mu e$ ES	22.48
ν_e-^{7}Li CC	533.30
ν_e-^{16}O CC	459.34
ν_e-^{12}C CC	37.08

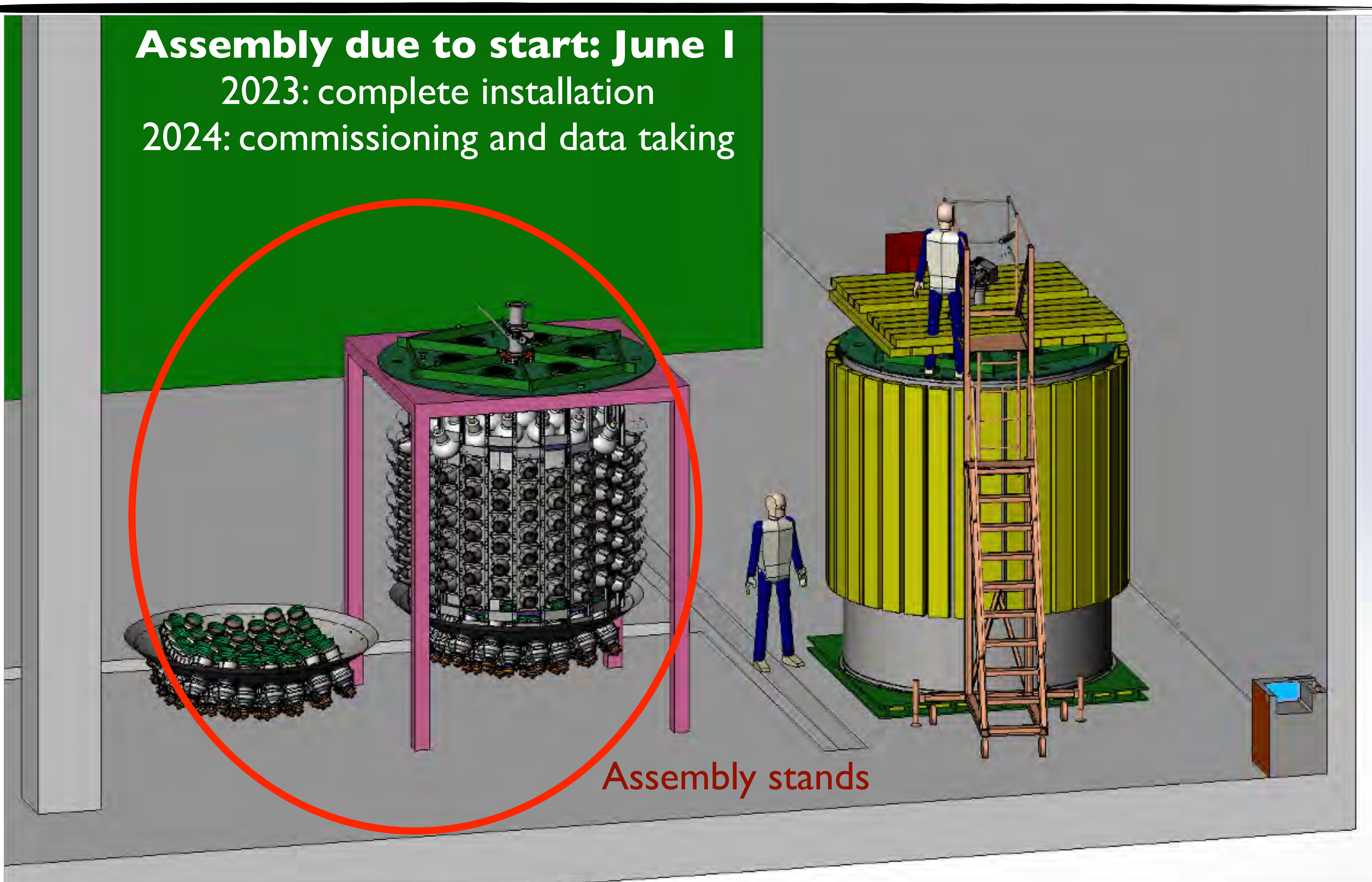
event rates expected for 4 tons of LiWbLS

Status

- IV under contract, delivery due May ’23 (Reynolds Polymer)
- OV: seismic engineering complete, under contract, delivery due May ’23 (C&C Industrial)
- PSUP design complete, moving to prototype and purchase
- Hamamatsu PMTs (200x fast 8”), batch delivery Nov ’22 — Jul ’23 (80 received), testing ongoing
- Digitisers & HV boards (CAEN), first batch received
- PMT support and calibration deployment systems designed
- Space available as of April 1



Deployment



Assembly due to start: June 1
2023: complete installation
2024: commissioning and data taking
Assembly stands

Thanks to the EOS team!

USA

Berkeley Lab
University of California, Berkeley
University of California, Davis
Penn (University of Pennsylvania)
Lawrence Livermore National Laboratory
Boston University
Penn State
Iowa State
Brookhaven National Laboratory
Fermilab
Rutgers
Iowa
Bartoszek Engineering
South Dakota School of Mines & Technology
University of Colorado Boulder
The University of Chicago
California State University Stanislaus

Germany

Johannes Gutenberg Universität Mainz
PRISMA+
Technische Universität München

Turkey

Erciyes University

Portugal

LIP
Universidade de Coimbra

Finland

Jyväskylän Yliopisto / University of Jyväskylä

Canada

SNOLAB


Rutgers, 2022

THEIA (proto-)Collaboration

Canada
Alberta
Laurentian
Queens
SNOLAB
Toronto

China
Tsinghua

Finland
Jyvaskyla

Germany
Aachen
Dresden
Hamburg
Jülich
Mainz
TU Munich
Tübingen

Italy
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Korea
CUP

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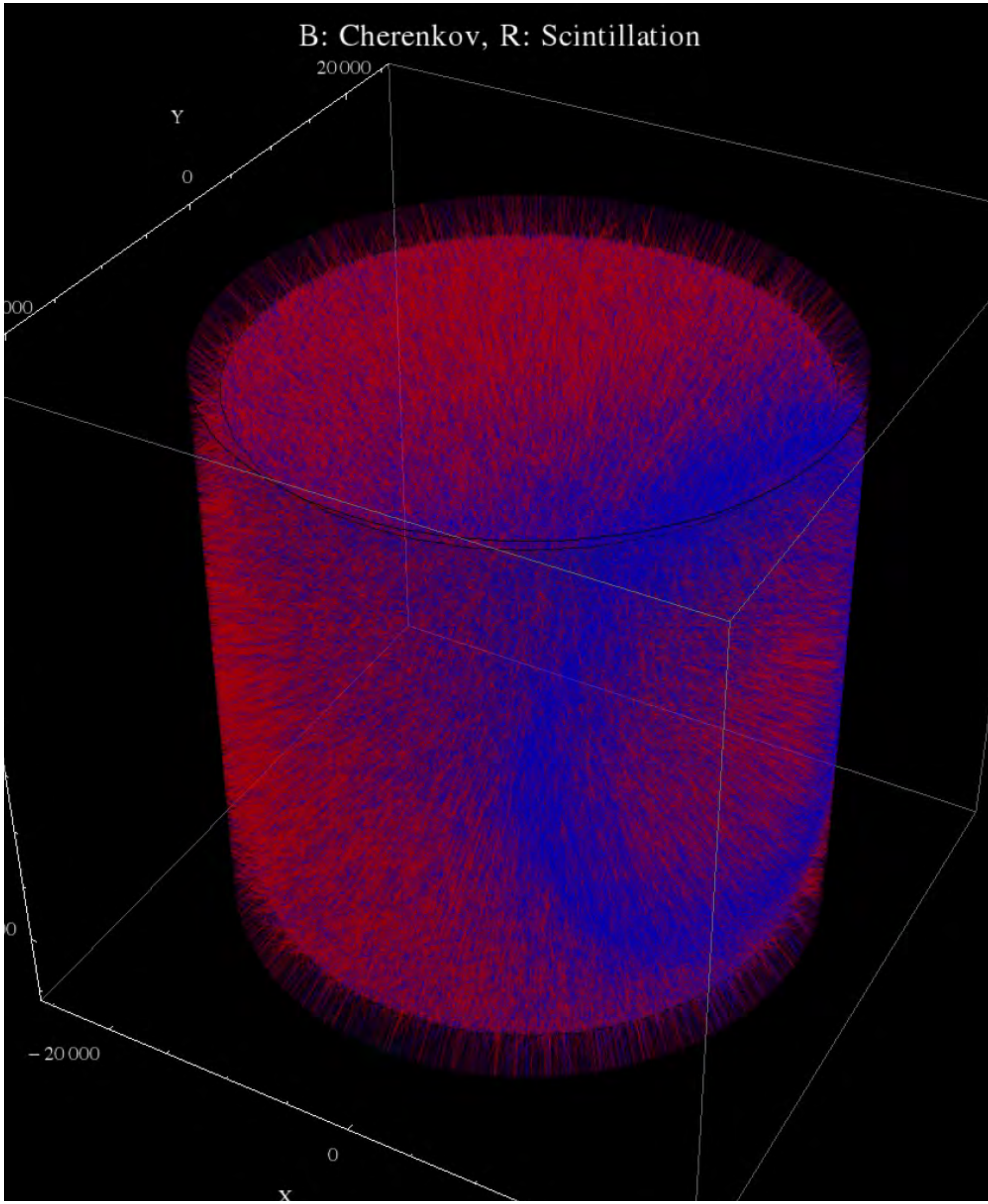
LLNL
LSU
MIT
U. Penn
PNNL
Rutgers
SD SMT
Stony Brook
SURF
Temple
UC Berkeley
UC Davis
UC Irvine
UCLA

Summary

- THEIA can interrogate a broad program of compelling science
- Conventional neutrino physics & rare-event searches in a single, large detector
- A hybrid detector module would add to the LBL program at DUNE and bring a broad program of additional physics
- THEIA offers inspirational physics to motivate a new, broad community of scientists
- Major technological developments have been achieved
- Results from existing large detectors demonstrate the conceptual feasibility
- Prototypes underway will demonstrate the full range of capabilities



Thank you

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