Review of Solar and Geo Neutrino Experiments

Physics in Collision 2024
Αθήνα, Ελλάδα

Mark Chen
Queen’s University
October 22, 2024

with thanks to J. Maneira, L. Ludhova (@ Neutrino 2024) and others

Solar Neutrino Experiments – by detection method

- Elastic Scattering, neutrino-electron
- Charged-Current reactions
- CEνNS, coherent neutrino-nucleus

Solar Neutrino Physics

- I’ll return to discussing the physics after setting the stage with the current experimental status…

Solar $\nu_e + e^- \rightarrow \nu_e + e^-$

Past experiments:
- Super-Kamiokande
- Borexino
- also SNO and KamLAND

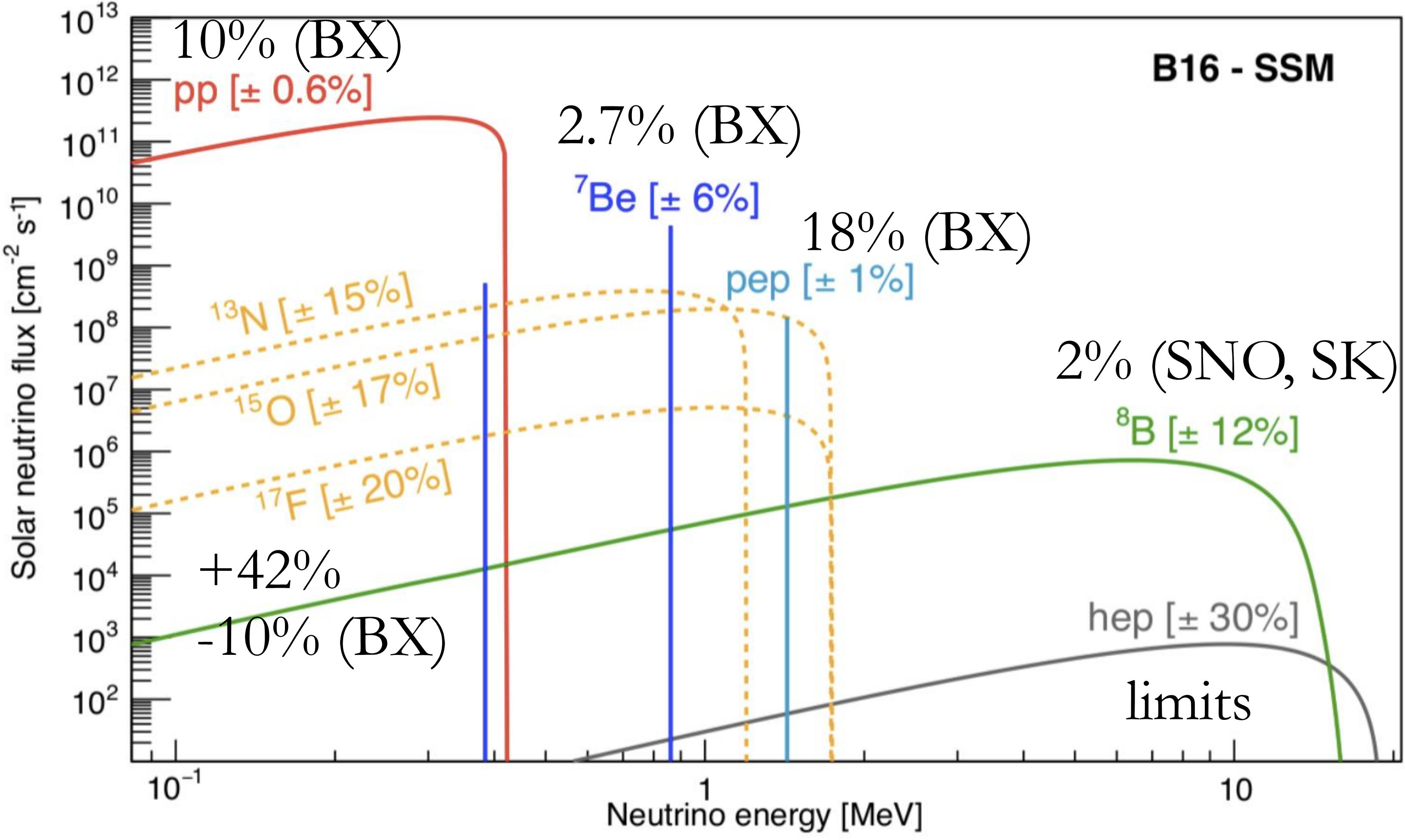


figure from J. Maneira

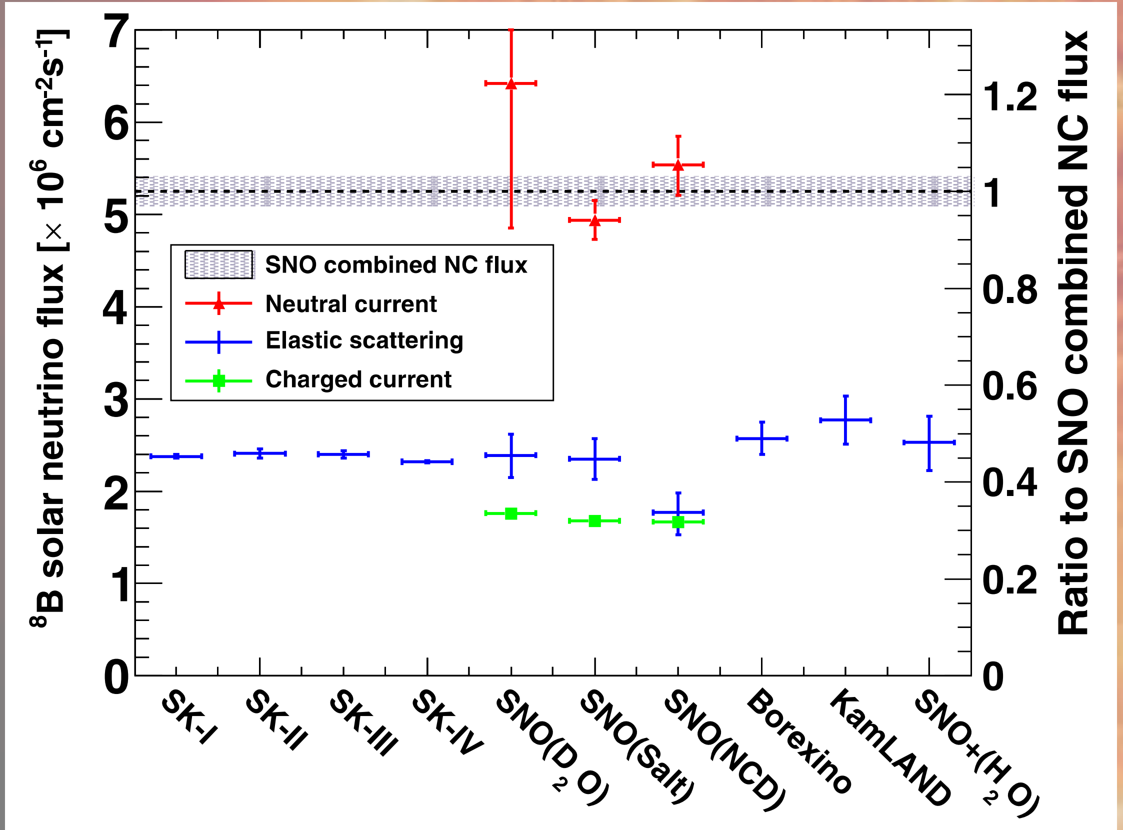
Talk by Marco Giammarchi on Wednesday reviewing the results from Borexino
- complete spectroscopy of solar neutrinos (*pp* chain and *CNO* neutrinos)

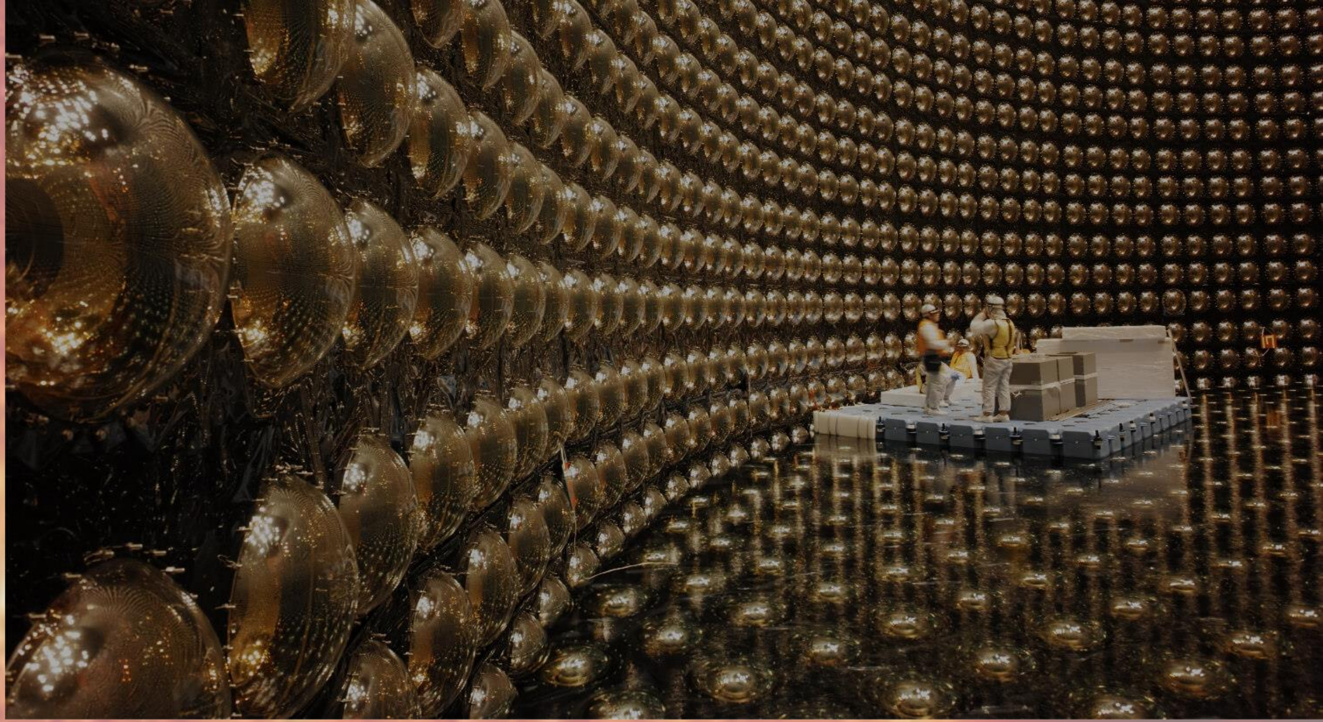
Current experiments:
- Super-Kamiokande
- SNO+
- PandaX-4T (and Xe DM expts)

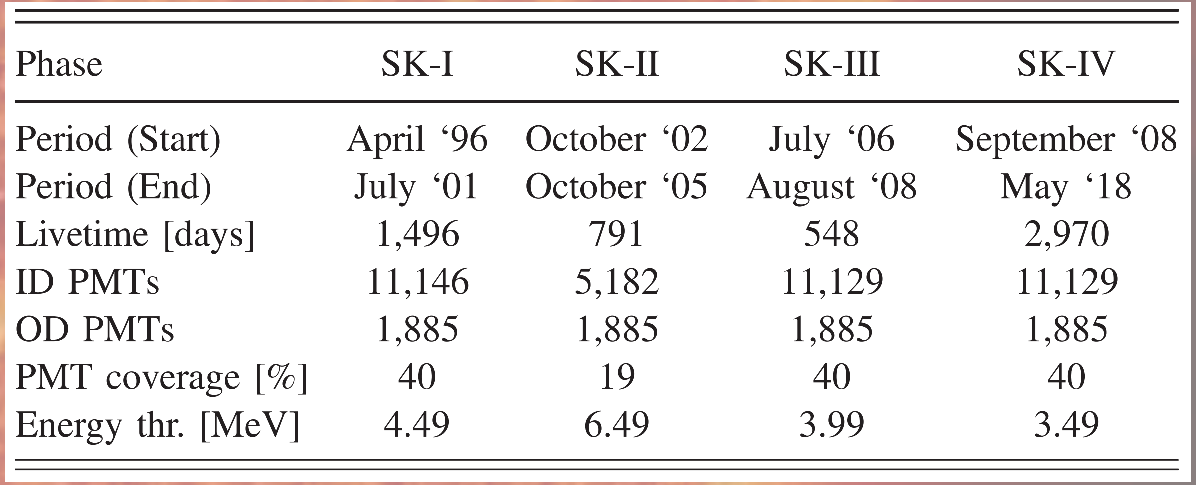
Future experiments:
- JUNO
- Hyper-K
- Jinping Neutrino Experiment
- THEIA

Super-Kamiokande

22.5 kton fiducial volume water Čerenkov detector
15.9 live-time years of data SK-I to IV
Threshold as low as 3.49 MeV (electron recoil, kinetic)







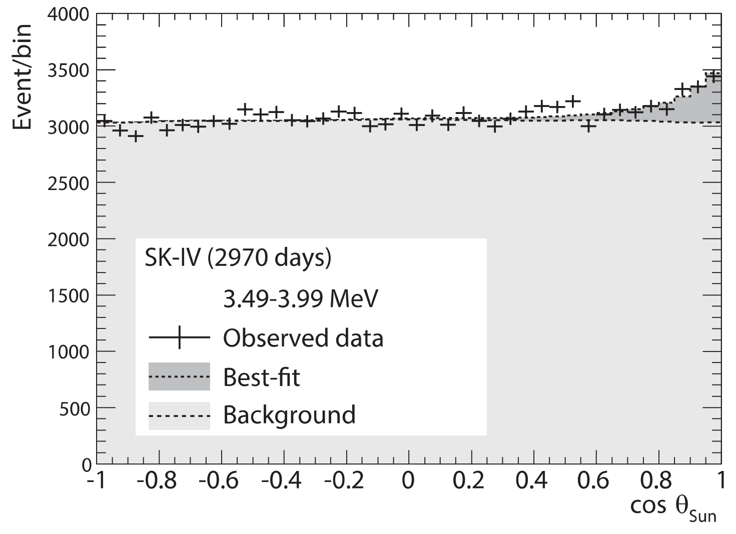
Phase	SK-I	SK-II	SK-III	SK-IV
Period (Start)	April ‘96	October ‘02	July ‘06	September ‘08
Period (End)	July ‘01	October ‘05	August ‘08	May ‘18
Livetime [days]	1,496	791	548	2,970
ID PMTs	11,146	5,182	11,129	11,129
OD PMTs	1,885	1,885	1,885	1,885
PMT coverage [%]	40	19	40	40
Energy thr. [MeV]	4.49	6.49	3.99	3.49

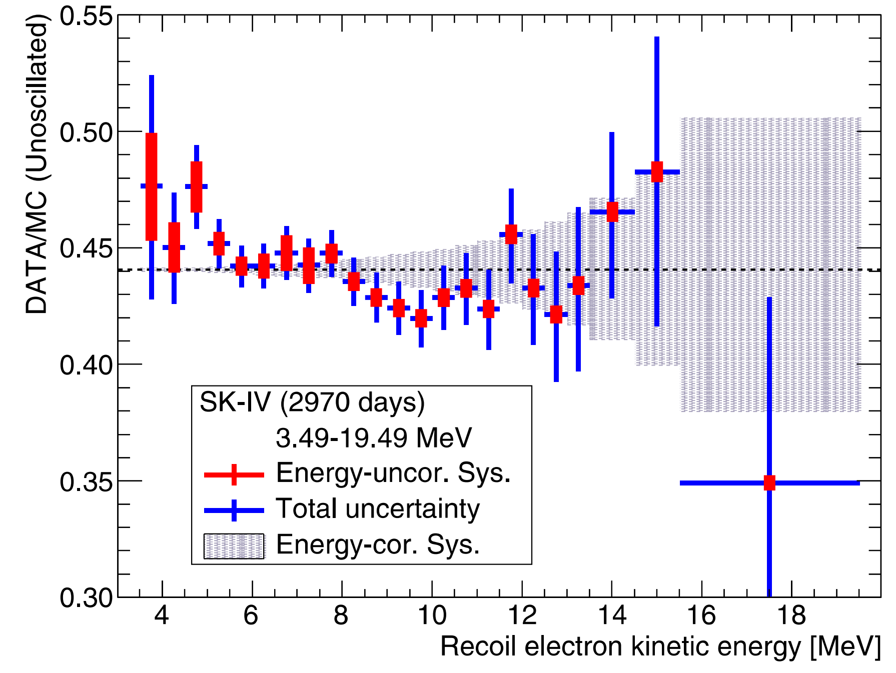
K. Abe et al., PRD **109**, 092001 (2024)

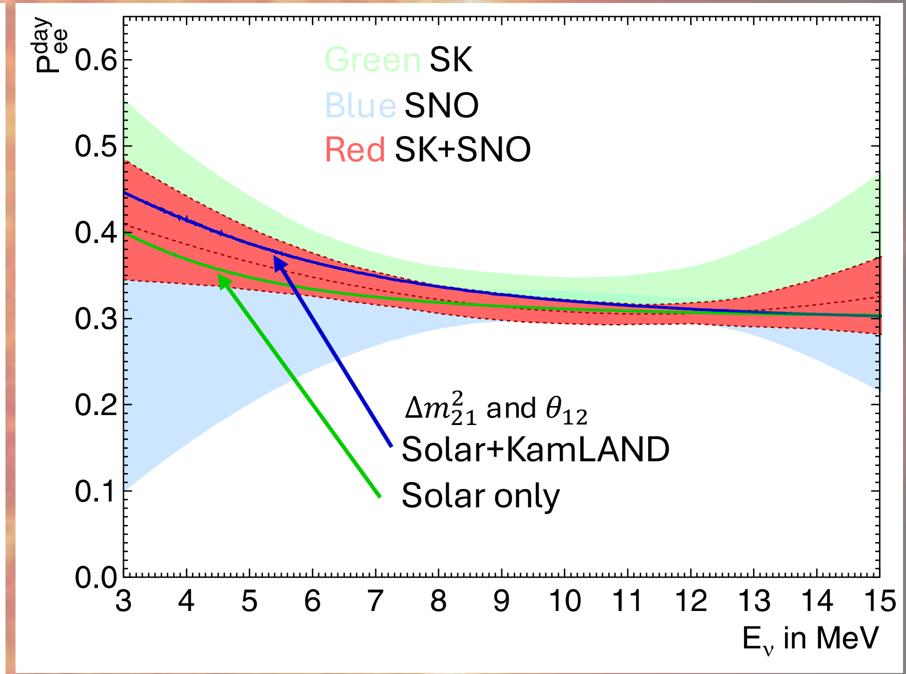
Super-Kamiokande

Threshold as low as 3.49 MeV (electron recoil, kinetic)

^{8}B neutrino spectrum sees hint of “low energy upturn” at 1.2σ (2.1σ if combined with SNO)





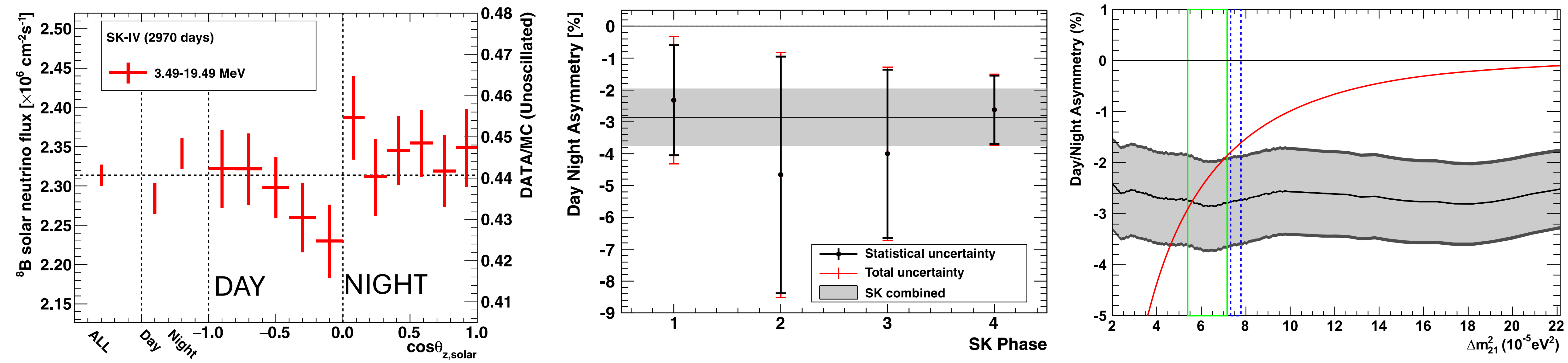


K. Abe et al., PRD **109**, 092001 (2024)

Super-Kamiokande

Day/Night asymmetry fit to zenith distribution: $A_{\mathrm{D/N}}^{\text{SK-IV, fit}} = -0.0262 \pm 0.0107(\text{stat.}) \pm 0.0030(\text{syst.})$

3σ significance non-zero asymmetry for SK-I to IV combined

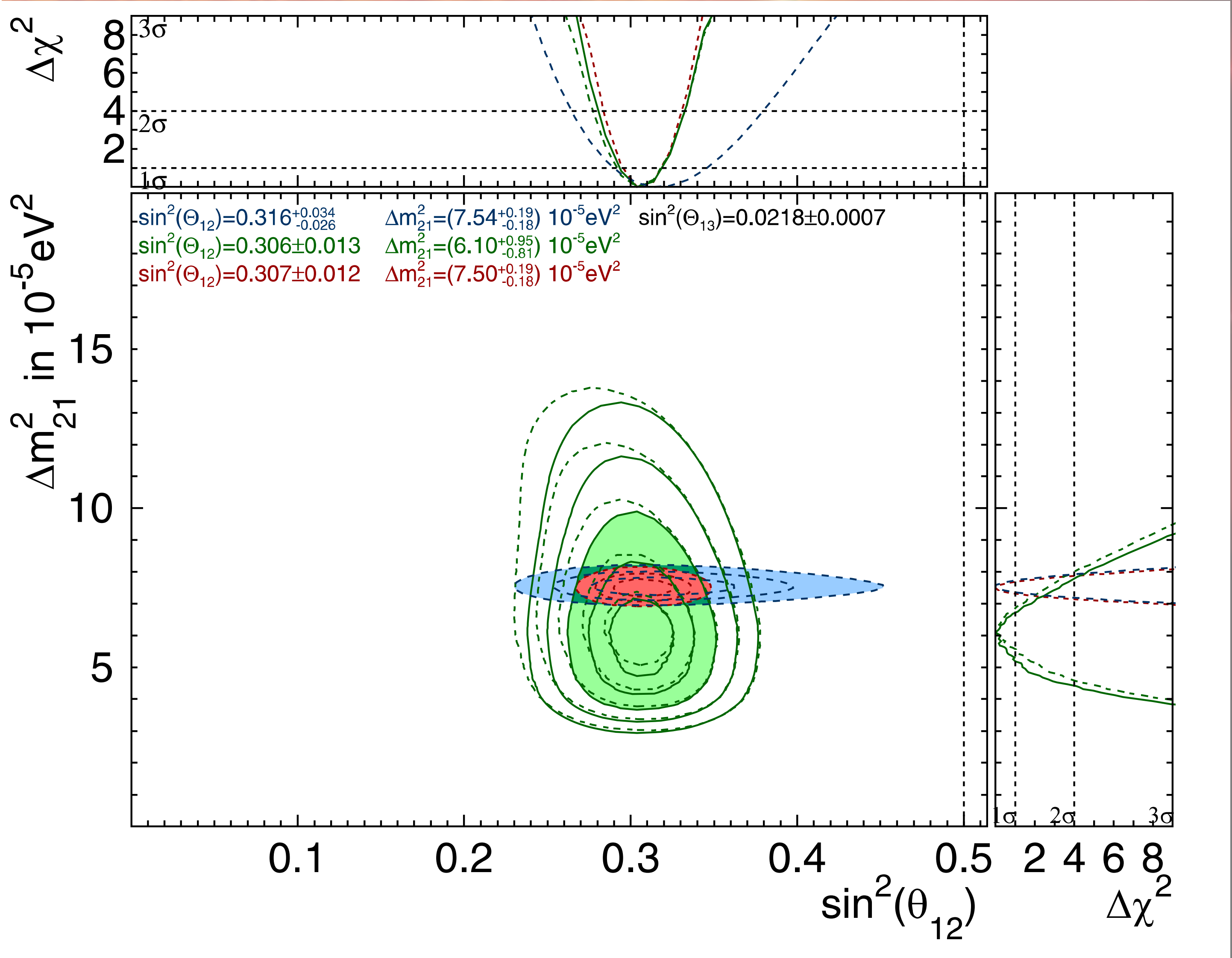


K. Abe et al., PRD **109**, 092001 (2024)

Super-Kamiokande

Oscillation parameters from global solar fit (by SK)

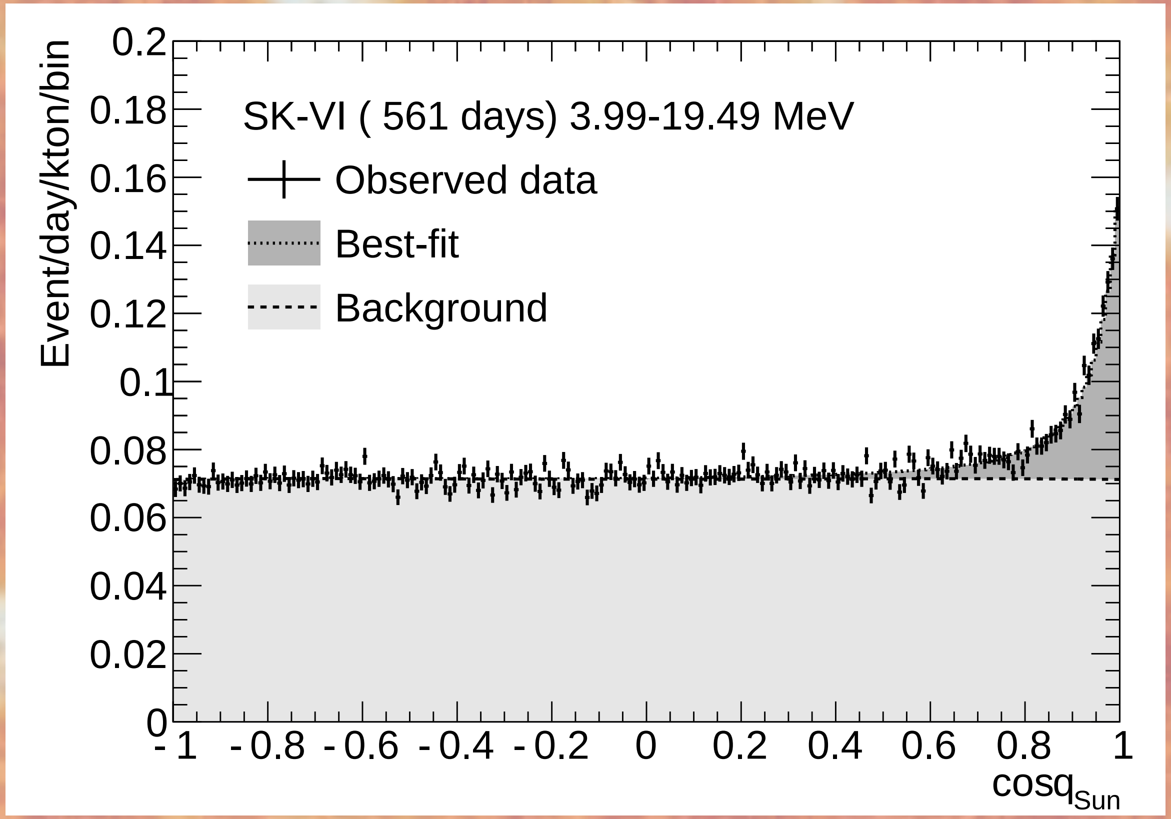
1.5σ tension between solar (neutrino) and KamLAND (antineutrino) values for Δm_{21}^2



K. Abe et al., PRD **109**, 092001 (2024)

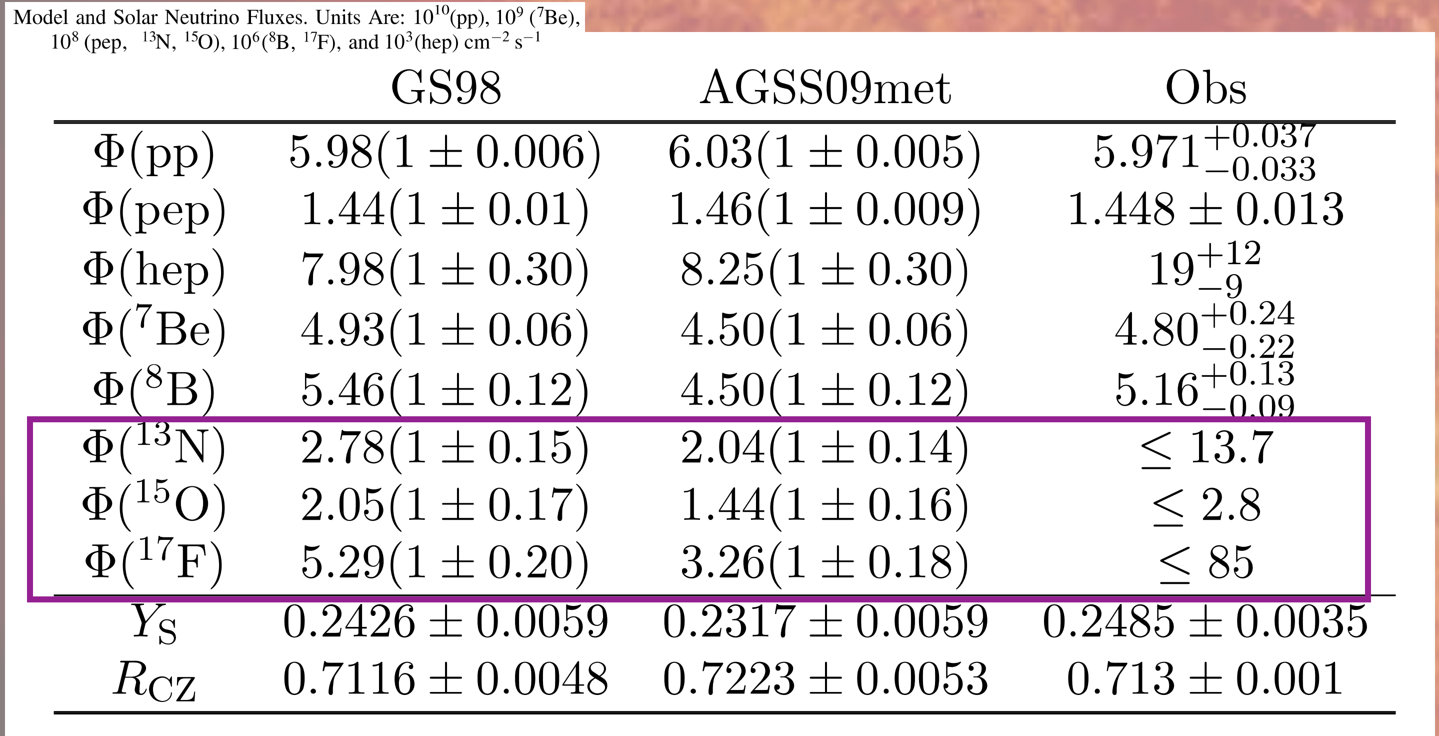
SK-Gd continues solar neutrino measurements

SK-VI (0.01% Gd, 2020-2022)
SK-VII (has 0.03% Gd, since July 2022) – thresholds are higher than SK-IV because backgrounds are higher



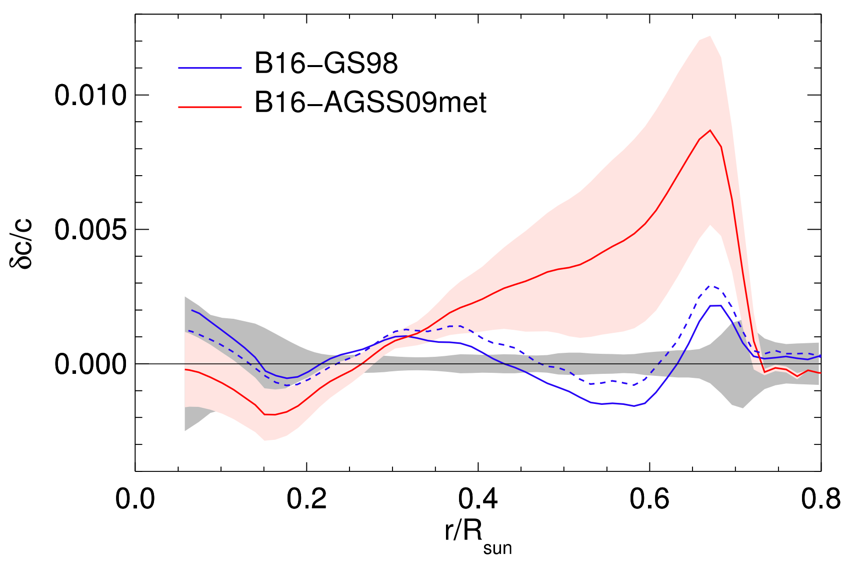
from M. Smy

CNO solar neutrinos and metallicity



Model and Solar Neutrino Fluxes. Units Are: 10^{10}(pp), 10^{9} (^{7}Be), 10^{8} (pep, ^{13}N, ^{15}O), 10^{6}(^{8}B, ^{17}F), and 10^{3}(hep) cm^{-2} s^{-1}

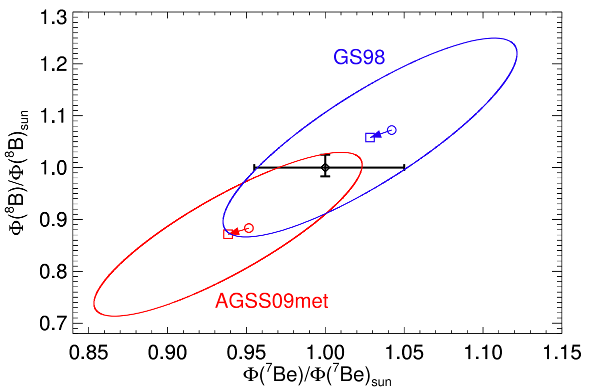
	GS98	AGSS09met	Obs
$\Phi(\mathrm{pp})$	$5.98(1 \pm 0.006)$	$6.03(1 \pm 0.005)$	$5.971^{+0.037}_{-0.033}$
$\Phi(\mathrm{pep})$	$1.44(1 \pm 0.01)$	$1.46(1 \pm 0.009)$	1.448 ± 0.013
$\Phi(\mathrm{hep})$	$7.98(1 \pm 0.30)$	$8.25(1 \pm 0.30)$	19^{+12}_{-9}
$\Phi(^{7}\mathrm{Be})$	$4.93(1 \pm 0.06)$	$4.50(1 \pm 0.06)$	$4.80^{+0.24}_{-0.22}$
$\Phi(^{8}\mathrm{B})$	$5.46(1 \pm 0.12)$	$4.50(1 \pm 0.12)$	$5.16^{+0.13}_{-0.09}$
$\Phi(^{13}\mathrm{N})$	$2.78(1 \pm 0.15)$	$2.04(1 \pm 0.14)$	≤ 13.7
$\Phi(^{15}\mathrm{O})$	$2.05(1 \pm 0.17)$	$1.44(1 \pm 0.16)$	≤ 2.8
$\Phi(^{17}\mathrm{F})$	$5.29(1 \pm 0.20)$	$3.26(1 \pm 0.18)$	≤ 85
Y_{S}	0.2426 ± 0.0059	0.2317 ± 0.0059	0.2485 ± 0.0035
R_{CZ}	0.7116 ± 0.0048	0.7223 ± 0.0053	0.713 ± 0.001



GS98 High-Z models predict sound speeds in agreement with helioseismology

AGS09 Low-Z models find photosphere (surface) solar composition has lower metallicity than from GS98 (worse for helioseismology agreement)

Solar neutrino fluxes are affected by core composition (metallicity)



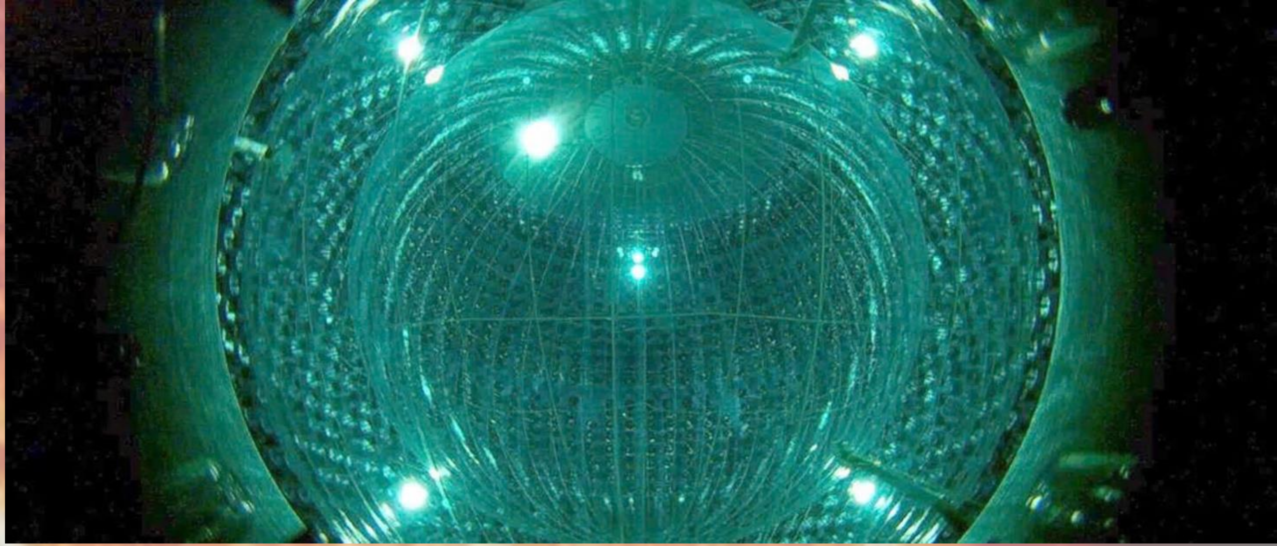
N. Vinyoles et al., ApJ **835**, 202 (2017)

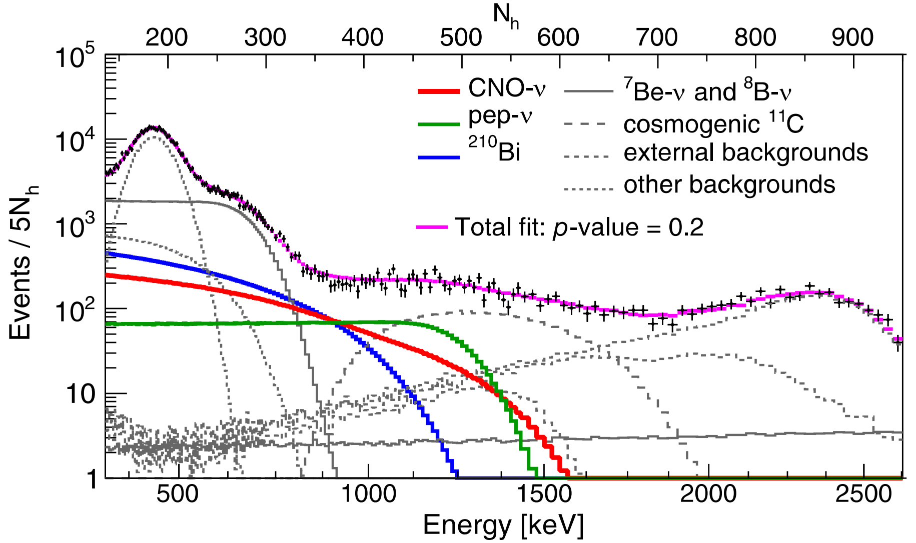
Borexino *CNO* solar

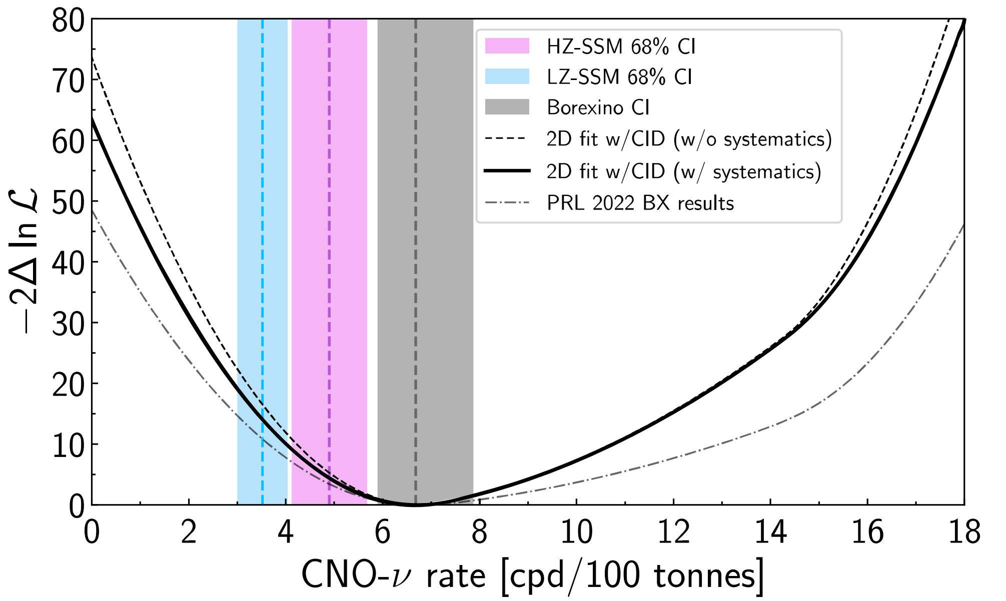
100 ton fiducial volume liquid scintillator detector
9.9 live-time years of data Phase I, II + III

Solar neutrino detection in a liquid scintillator requires very low radioactivity backgrounds; Čerenkov detectors reconstruct the direction of recoil e⁻, point to the Sun

Borexino developed "Correlated Integrated Directionality" uses *a priori* knowledge of solar direction to identify early Čerenkov hits in the forward direction, and fit for solar ν fluxes over background using those distributions







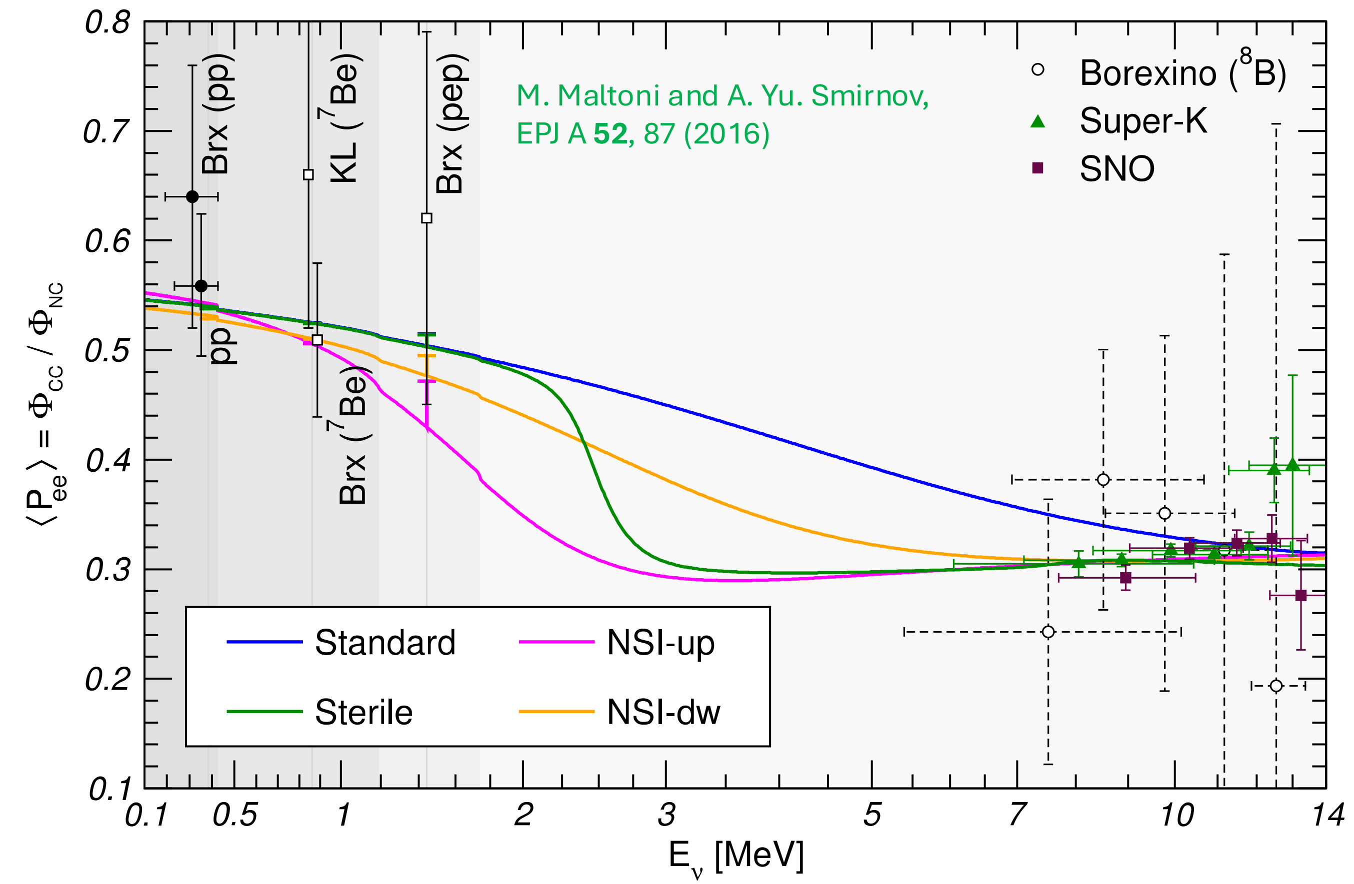
D. Basilico et al., PRD **108**, 102005 (2023)

talk by M. Giammarchi tomorrow!

Solar Neutrino Physics – a few comments

Matter effects – probe of potential new physics – we understand oscillations and have measured the oscillation parameters, but evidence for the "MSW low-energy upturn" is not completely strong, nor are all observables from the Day/Night asymmetry (hard!) convincingly in place; plus, persistent tension between Δm^2_{21} from solar ν_e and reactor $\bar{\nu}_e$

Borexino's CNO solar neutrino measurement agrees with High-Z solar composition neutrino flux predictions…but,



A&A 669, L9 (2023)
https://doi.org/10.1051/0004-6361/202245448
© The Authors 2023

Astronomy & Astrophysics

LETTER TO THE EDITOR

Higher metal abundances do not solve the solar problem

G. Buldgen[1,2], P. Eggenberger[1], A. Noels[2], R. Scuflaire[2], A. M. Amarsi[3], N. Grevesse[2,4], and S. Salmon[1]

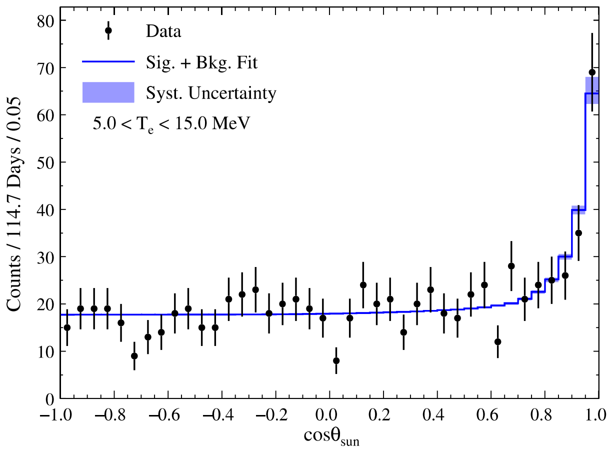
pp solar neutrino flux is a known source (±0.6%) *for potential "precision" future measurements*

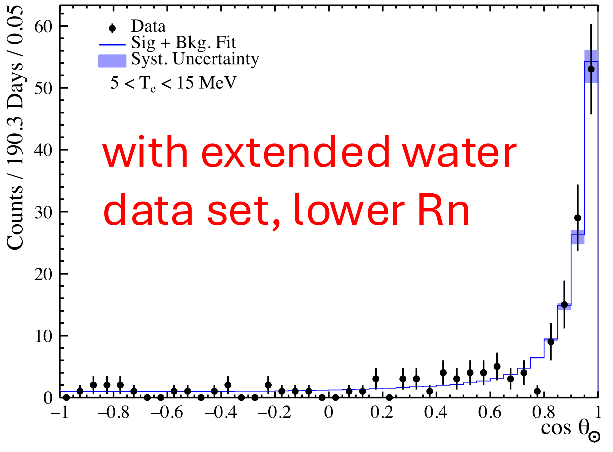
Solar neutrinos are still interesting; this sets the stage for new ways to look at solar neutrinos and/or new measurements!

SNO+ Water Phase solar

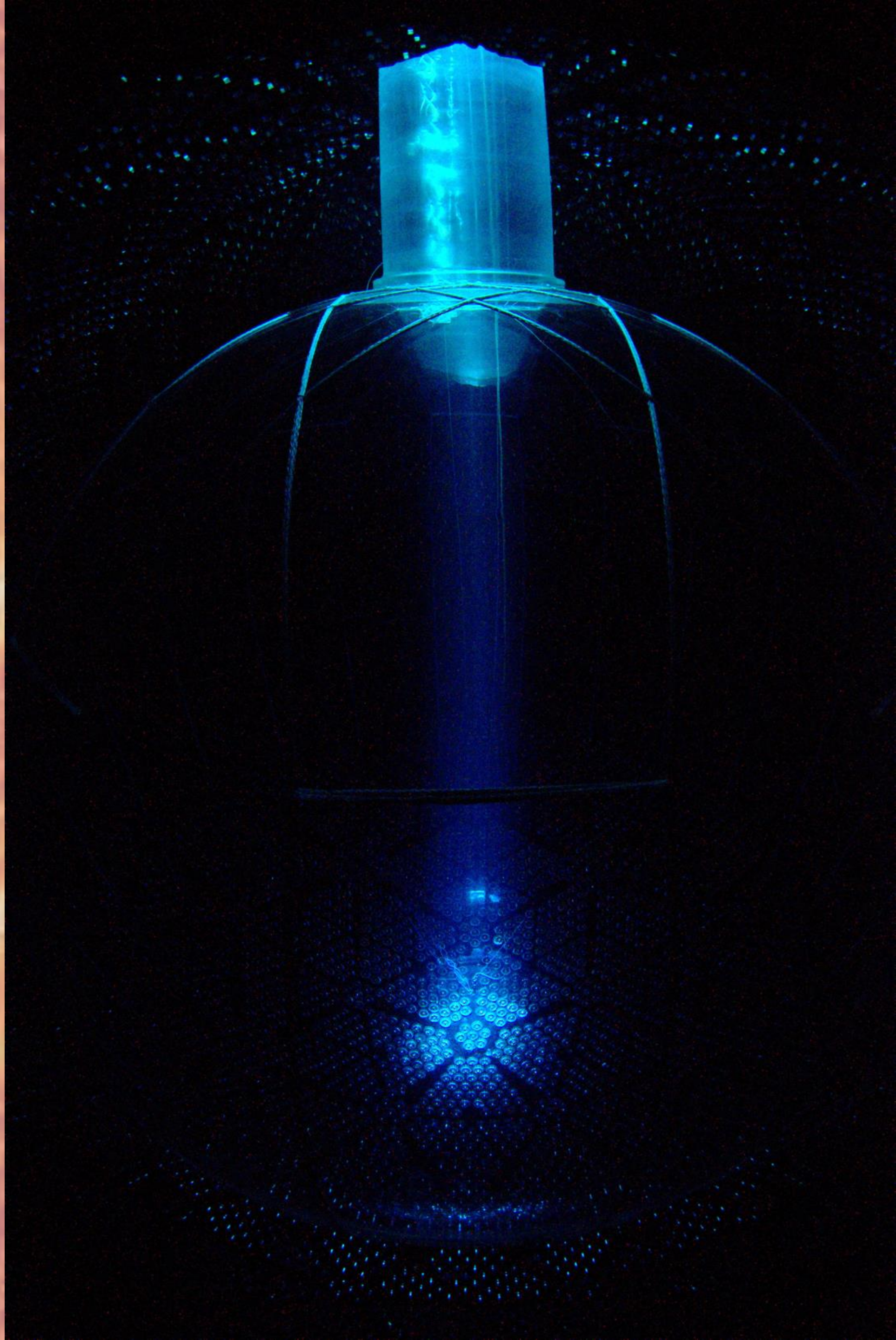
SNO+ is the follow-up to the Sudbury Neutrino Observatory
2017-2019: Water Phase, 905 tonnes, 282 live-time days
2020-2022: Filling with scintillator (paused by COVID) but including Partial-Fill Phase
2022-present: Scintillator Phase, 780 tonnes
2025/6- : Tellurium Double Beta Decay Phase (3.9+ tonnes)

In SNO+ Water Phase, we published “Measurement of the ^{8}B solar neutrino flux in SNO+ with very low backgrounds” M. Anderson et al., PRD **99**, 012012 (2019), then added an extended Water Phase data set, with *even lower backgrounds!*





with extended water data set, lower Rn



A. Allega et al., accepted by PRD, arXiv:2407.17595 (2024)

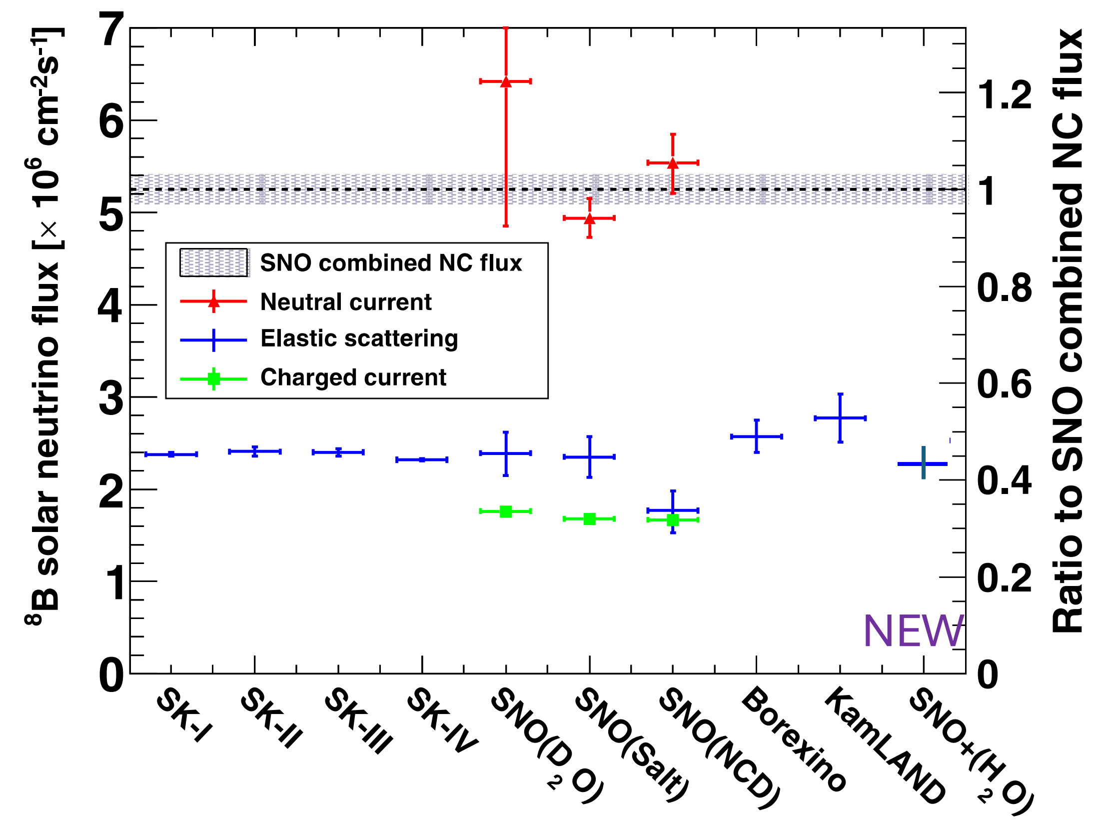
SNO+ Water Phase ^{8}B solar

SNO+

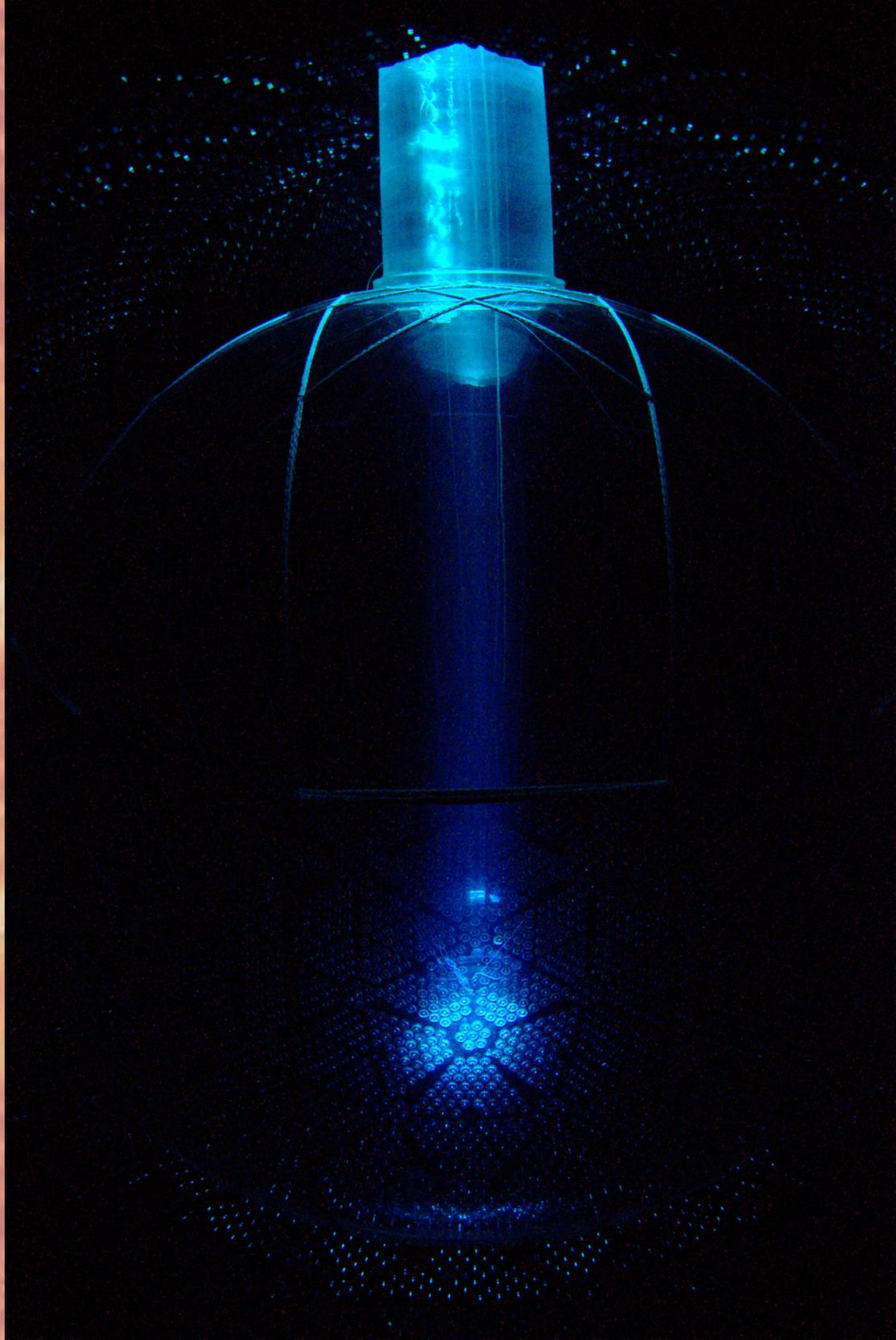
2017-2019: Water Phase, 905 tonnes, 282 live-time days

Energy threshold down to 3.5 MeV kinetic

Lowest backgrounds – deep location, radiopurity, Rn exclusion



A. Allega et al., accepted by PRD, arXiv:2407.17595 (2024)



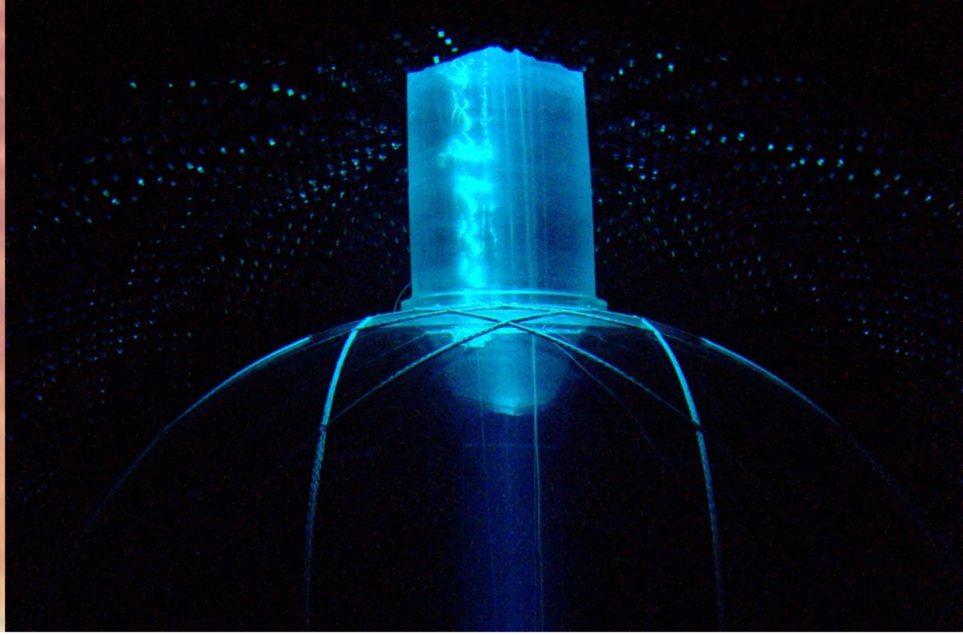
SNO+ Water Phase ^{8}B solar

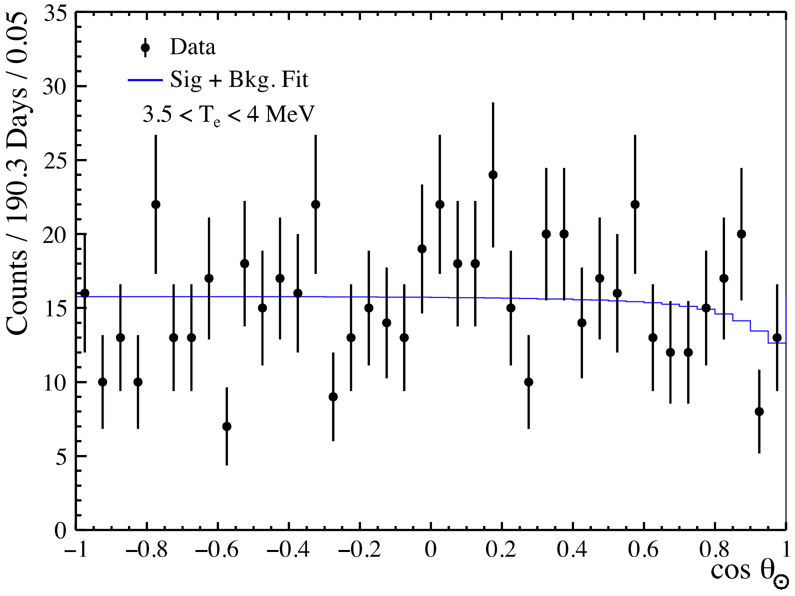
SNO+

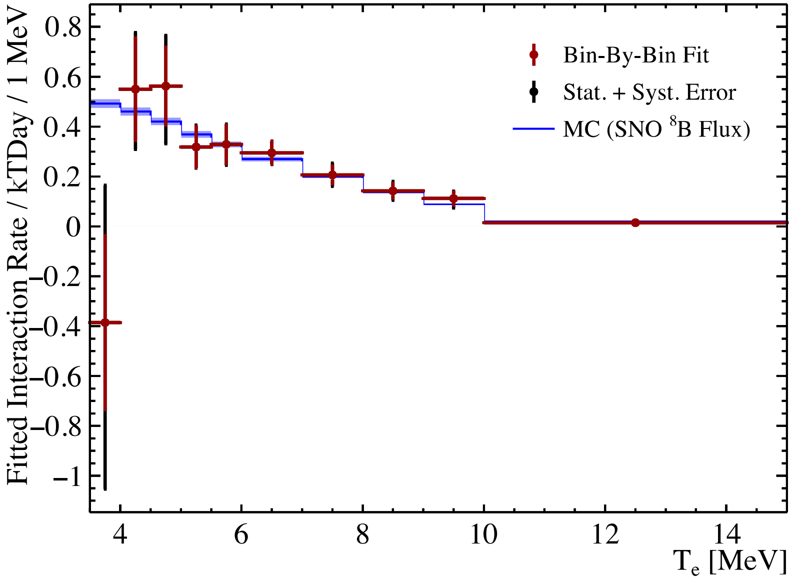
2017-2019: Water Phase, 905 tonnes, 282 live-time days

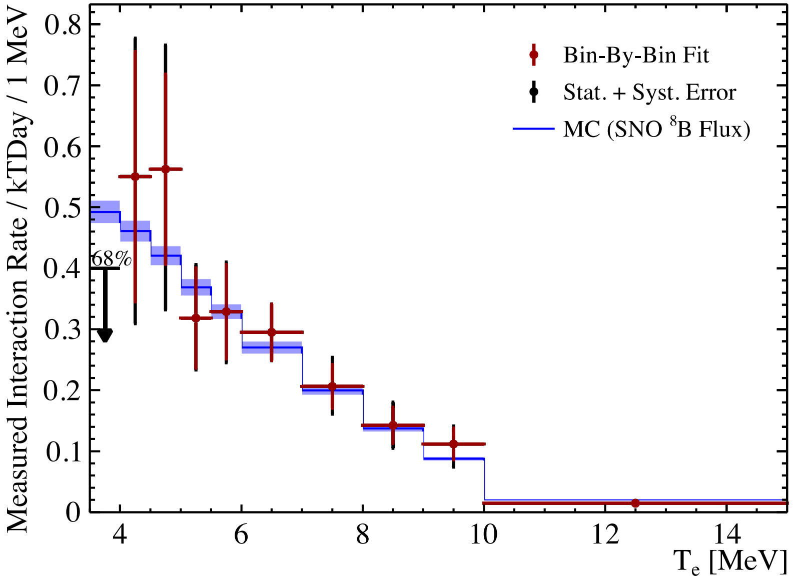
Energy threshold down to 3.5 MeV kinetic

Lowest backgrounds – deep location, radiopurity, Rn exclusion





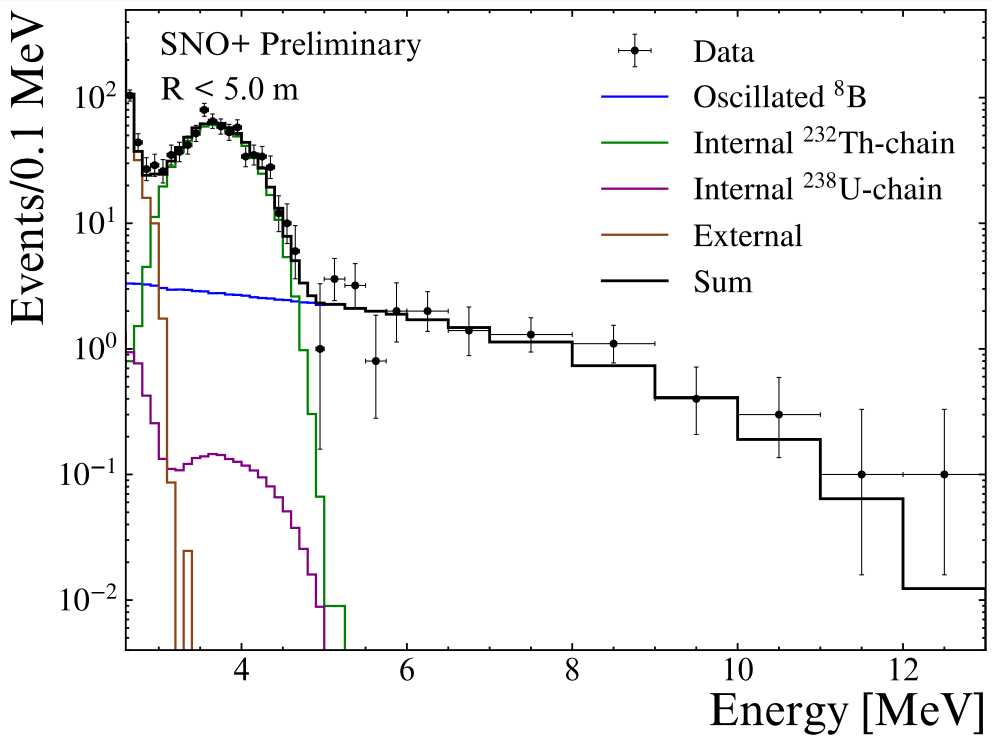


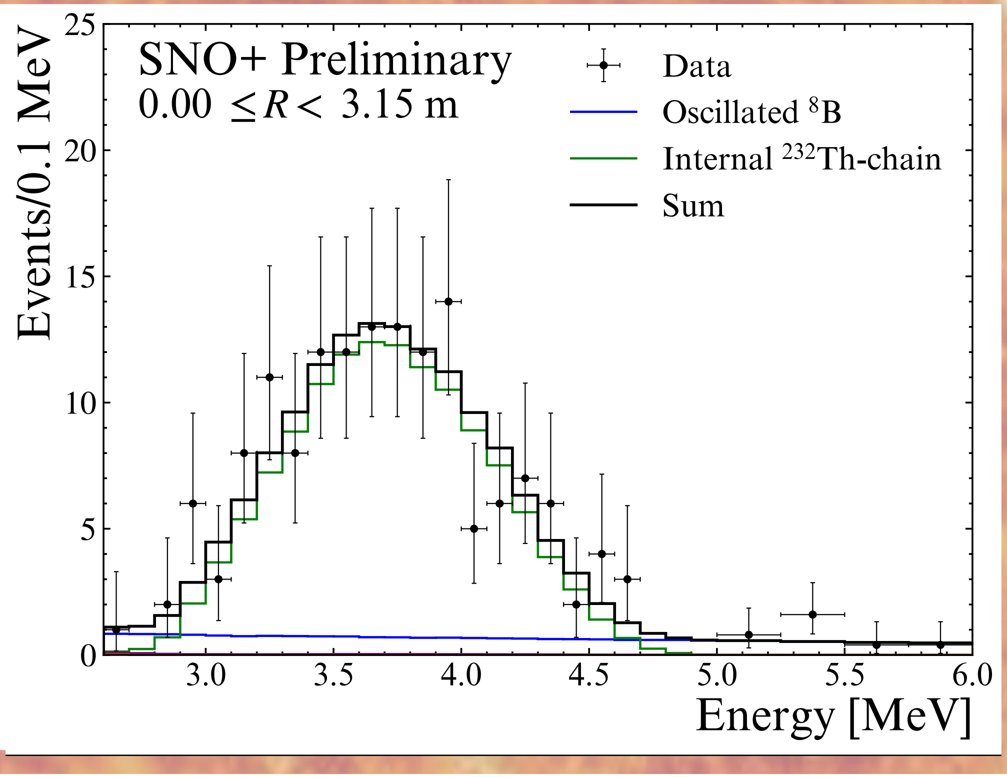


A. Allega et al., accepted by PRD, arXiv:2407.17595 (2024)

SNO+ Scintillator Phase ^{8}B solar

2022-present: Scintillator Phase, 780 tonnes, 140 live-time days analyzed so far
Scintillator radiopurity: U and Th at 5×10^{-17} g/g level



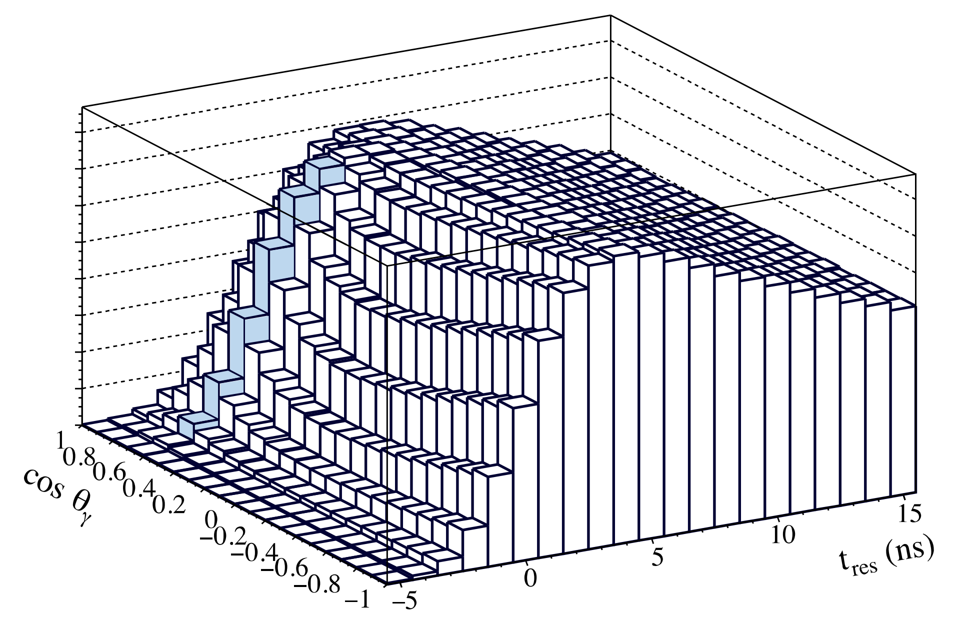


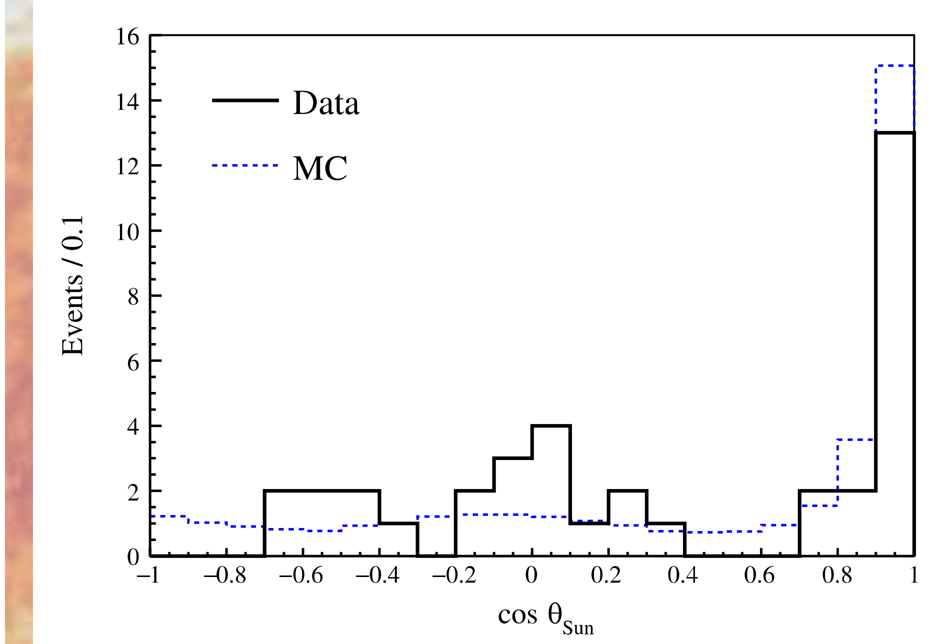
In the small fiducial volume, external backgrounds are negligible and below 3.0 MeV internal ^{208}Tl backgrounds are also small, enabling SNO+ Scintillator Phase to see ^{8}B solar neutrinos clearly below 3.0 MeV

Internal Th-chain backgrounds between 3-5 MeV can be constrained with multisite discriminator and possibly using Borexino-style Correlated Integrated Directionality

SNO+ Scintillator Phase Directionality

In SNO+ scintillator with low PPO concentration (0.6 g/L), we were able to perform event-by-event directionality – recoil-electron direction reconstructed without *a priori* knowledge of the Sun direction (a first at MeV energies in liquid scintillator)





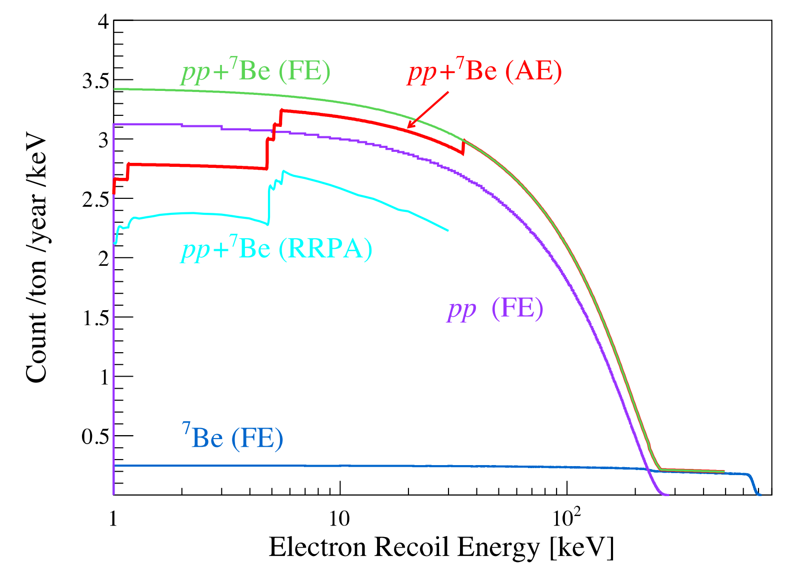
Uses Cherenkov-Scintillation angle and time residual as 2D-pdf to reconstruct the recoil-electron direction

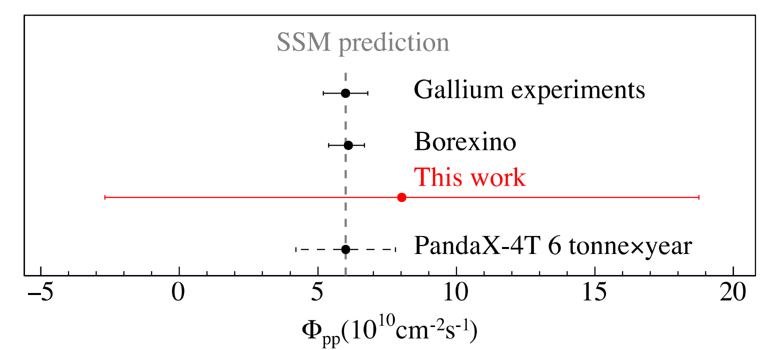
Now SNO+ scintillator has 2.2 g/L PPO and 2.2 mg/L bis-MSB, no more event-by event directionality

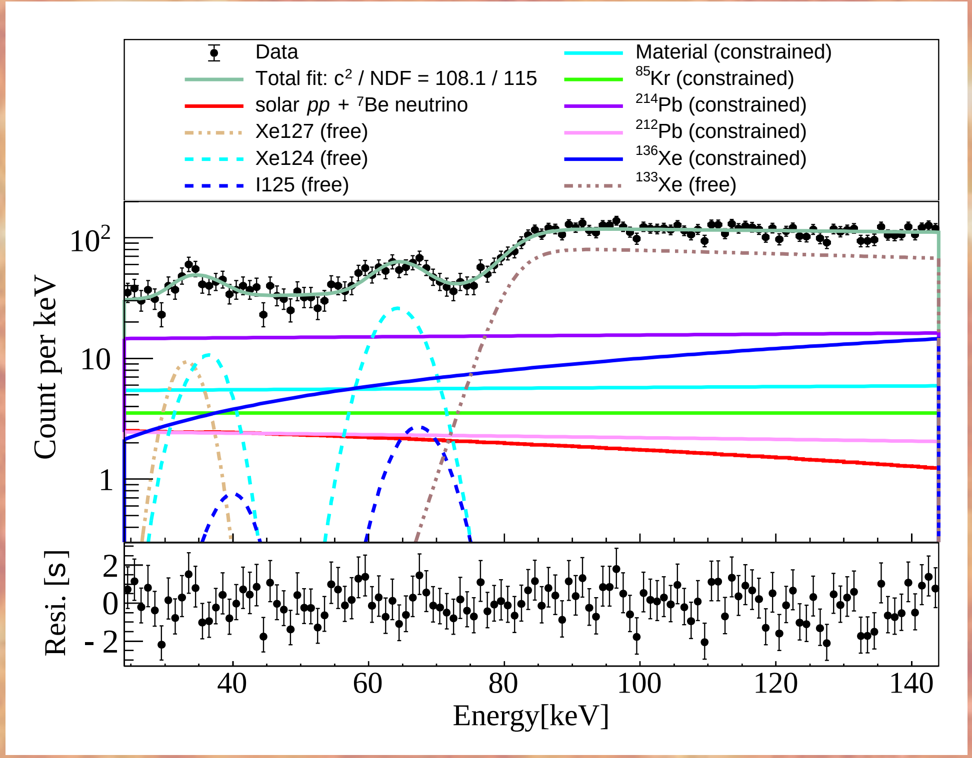
A. Allega et al., PRD **109**, 072002 (2024)

Solar ν_e-e^- Scattering in Xe DM Detectors

PandaX-4T commissioning data 0.63 tonne-year exposure
electron recoils 24-144 keV from *pp* solar neutrinos







PandaX-4T

Note: current/future Xe and Ar DM detectors (e.g. ARGO, 300 tonnes LAr) will be able to use electron scattering for *pp* and *CNO* solar neutrino measurements (depending on backgrounds)

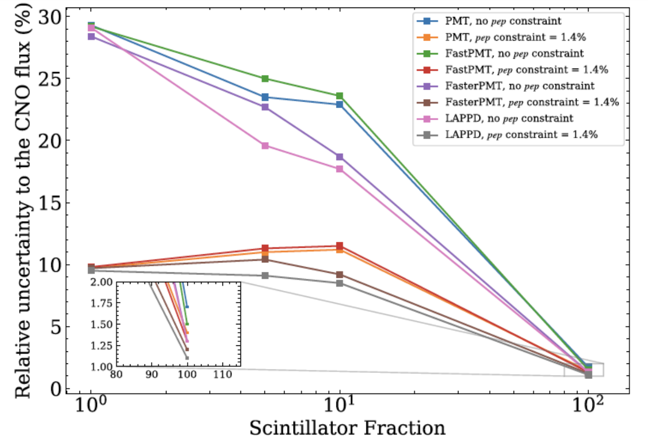
X. Lu et al., arXiv:2401.07045v2 (2024)

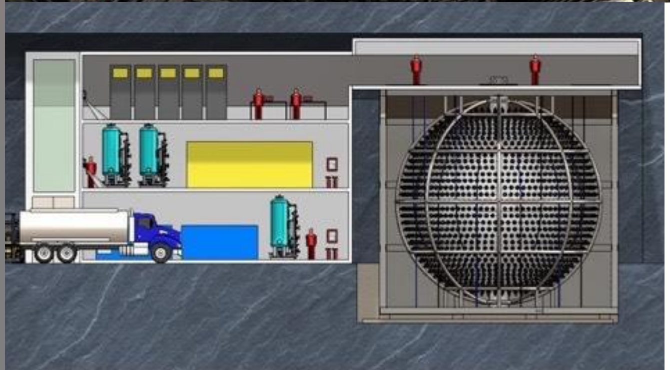
Future Solar $\nu_e + e^- \rightarrow \nu_e + e^-$

from S. Moriyama,
S. Chen, G. Orebi Gann

Hyper-Kamiokande (water Čerenkov detector)
3σ sensitivity to upturn after 10 yrs (threshold 4.5 MeV)
5σ observation of non-zero Day/Night asymmetry; 2σ test of Δm^2_{21} for $\nu_e/\bar{\nu}_e$

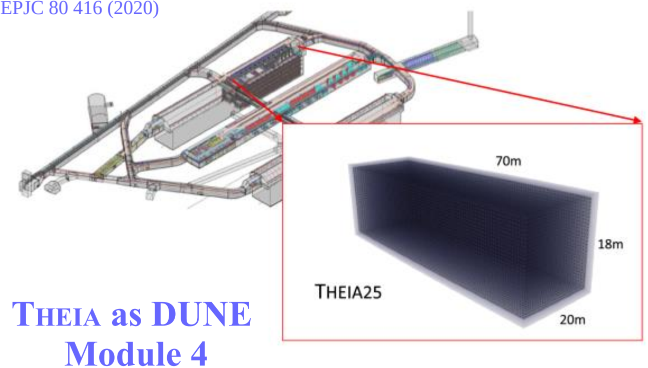
JUNO (20 kton liquid scintillator)
...more on the next slide





Jinping Neutrino Experiment (500 m³ detector, cavity has been constructed)
possible slow liquid scintillator or LiCl-LS

EPJC 80 416 (2020)

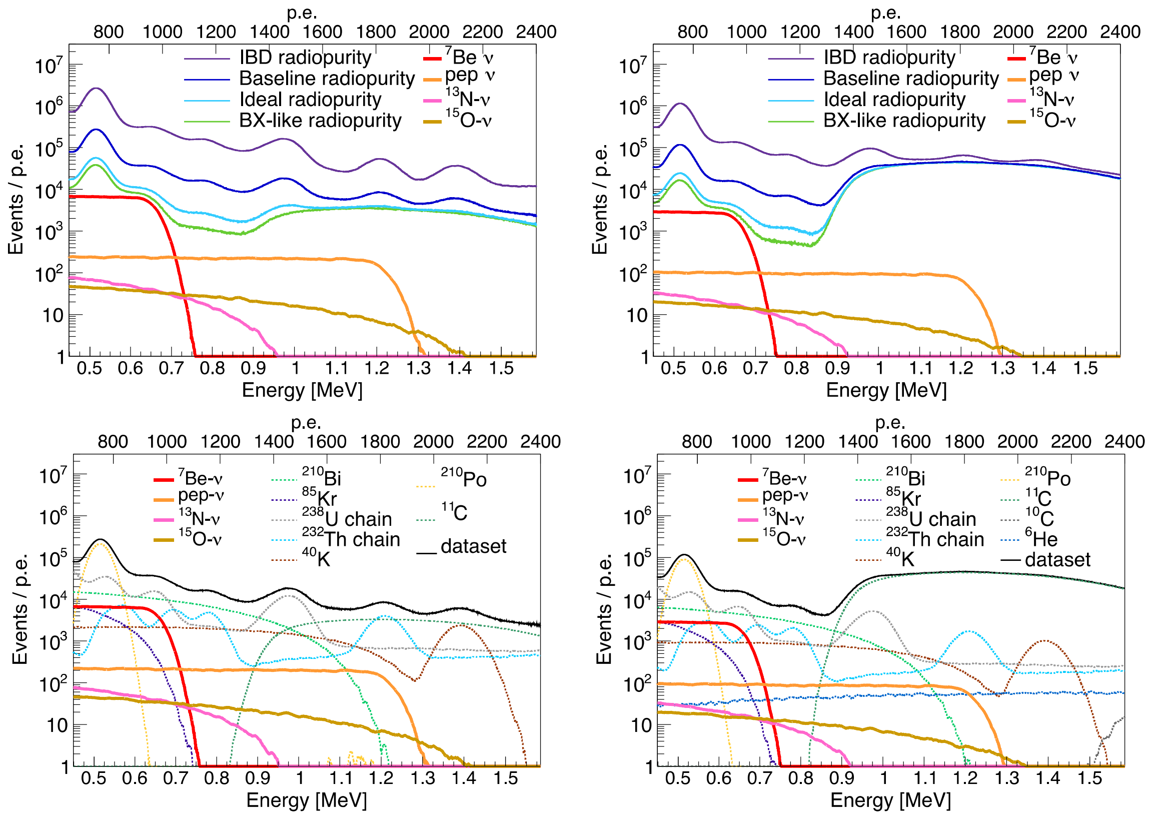


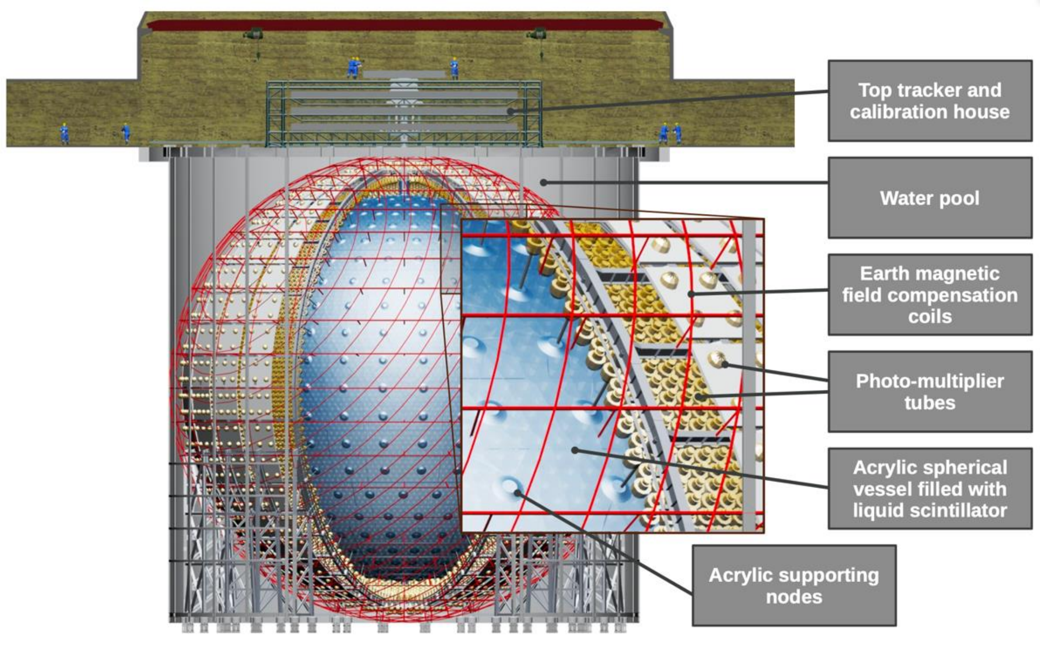
THEIA as DUNE Module 4

THEIA (50 kton hybrid Čerenkov-scintillator concept)
CNO uncertainty <10%

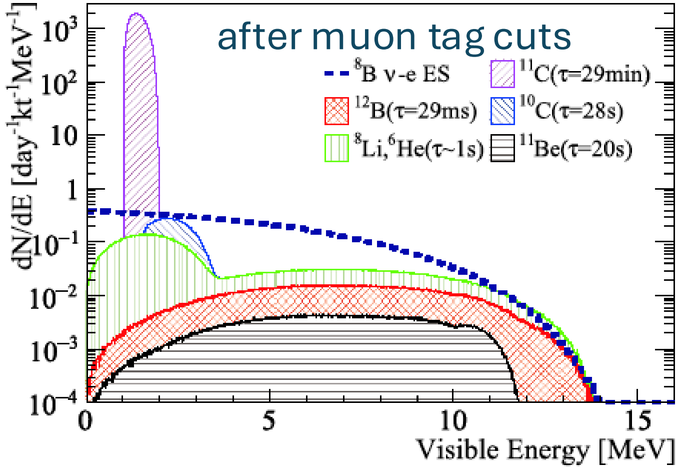
JUNO Solar $\nu_e + e^- \rightarrow \nu_e + e^-$

Impressive rates for ^{7}Be, *pep*, *CNO*, ^{8}B from its large target volume





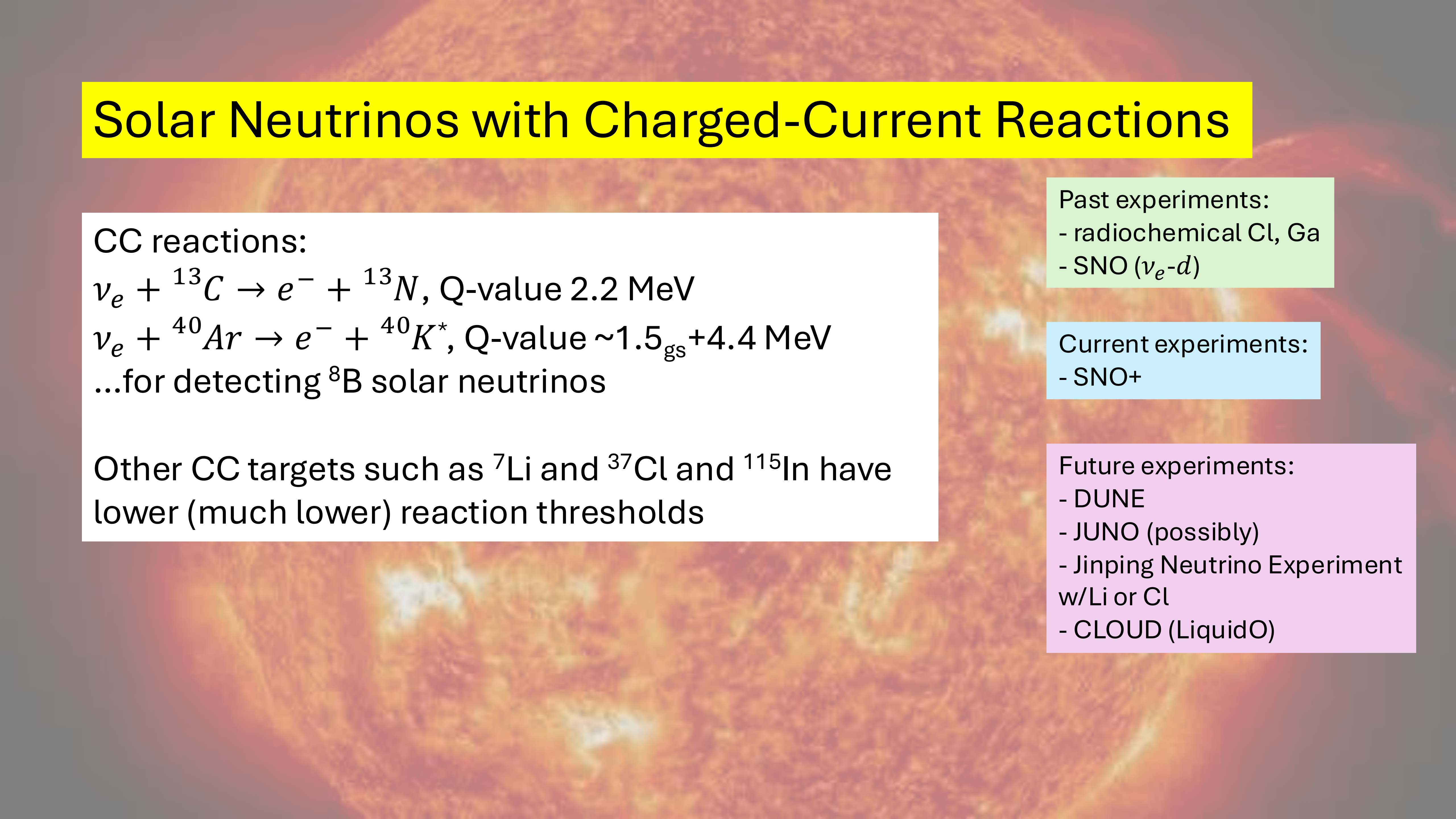
Solar neutrino measurements at low energy depend on radiopurity achieved (baseline radiopurity shown in lower two plots) and on three-fold coincidence rejection of cosmogenic backgrounds (^{11}C, ^{10}C, ^{6}He) shown in left plots (with) and right plots (without)



Cosmogenic backgrounds ~7× higher than Borexino but can be tagged (important for ^{8}B solar also)

talk by S. Dusini earlier today; E. Percalli on Thursday

A. Abusleme et al., JCAP **10**, 022 (2023) and
A. Abusleme et al., Chin. Phys. C **45**, 023004 (2021)



Solar Neutrinos with Charged-Current Reactions

CC reactions:

$\nu_e + {}^{13}C \rightarrow e^- + {}^{13}N$, Q-value 2.2 MeV

$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$, Q-value ~$1.5_{gs}$+4.4 MeV

...for detecting ^{8}B solar neutrinos

Other CC targets such as ^{7}Li and ^{37}Cl and ^{115}In have lower (much lower) reaction thresholds

Past experiments:
- radiochemical Cl, Ga
- SNO (ν_e-d)

Current experiments:
- SNO+

Future experiments:
- DUNE
- JUNO (possibly)
- Jinping Neutrino Experiment w/Li or Cl
- CLOUD (LiquidO)

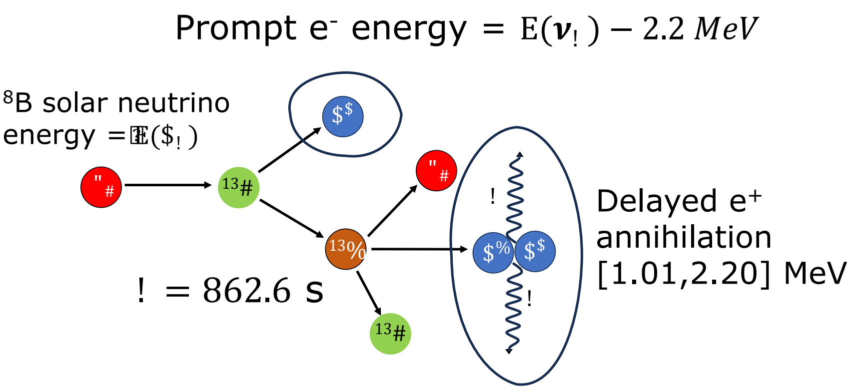
SNO+ Scintillator Phase ν_e CC on ^{13}C

only 1.1% isotopic abundance

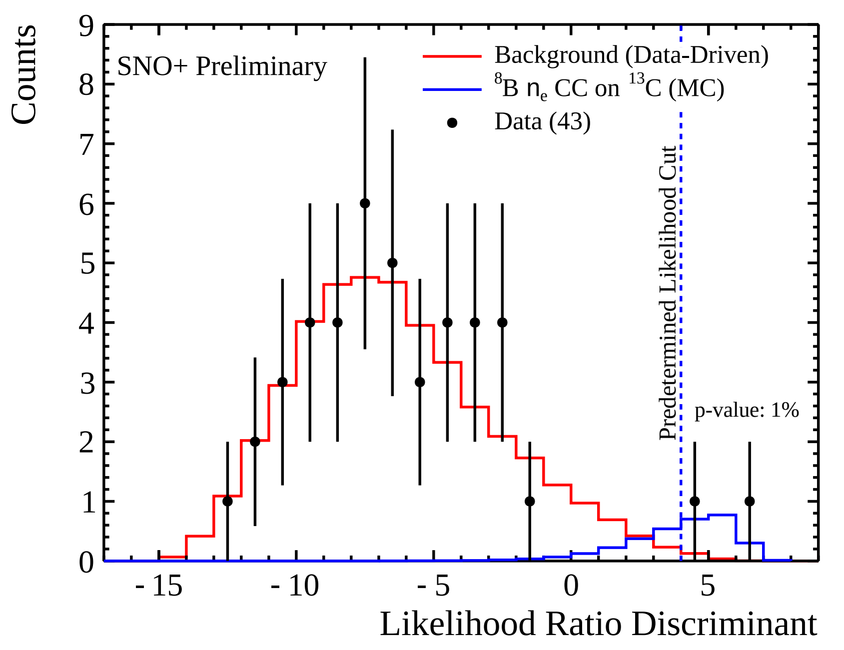
SNO+
2022-present: Scintillator Phase, 780 tonnes, 150.5 live-time days so far

Delayed coincidence helps reject backgrounds but τ = 14.4 min is long!

Cosmogenic backgrounds (e.g. ^{11}Be) are also a challenge that have prevented this from being observed…until ~now


Prompt e⁻ energy $= E(\nu_!) - 2.2\,MeV$

Cuts optimized before blind box opening:
- Fiducial volume R < 5.3 m
- Prompt energy 5.0 < E(e⁻) < 15.0 MeV
- Delayed energy 1.14 < E(e⁺) < 2.2 MeV
- ΔR < 0.36 m
- 0.01 < ΔT < 24 min
- Likelihood Ratio discriminant > 4



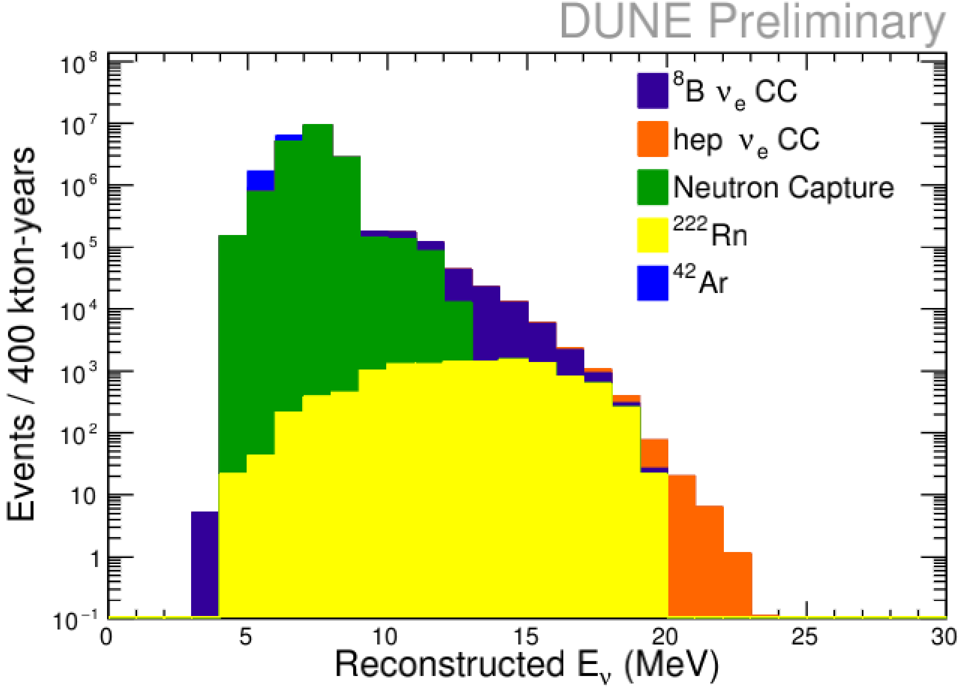
EXPECTED	BOX	LIKELIHOOD
BACKGROUND	0.31	0.17
SIGNAL	1.83	1.79

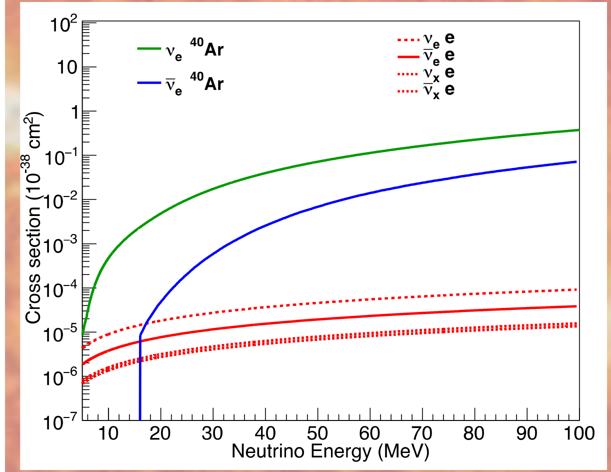
2 events were found after opening the box, consistent with expectations

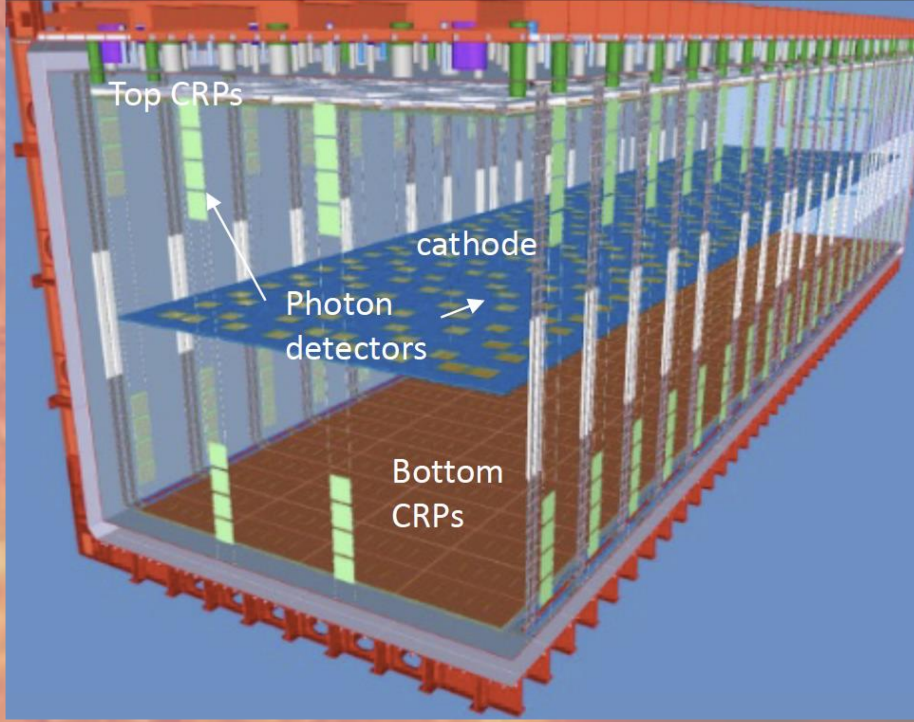
With more statistics (already accumulated) this will be only the 2nd real-time detection of solar neutrinos using a pure CC reaction (after SNO)!

Future Solar ν_e CC on ^{40}Ar in DUNE

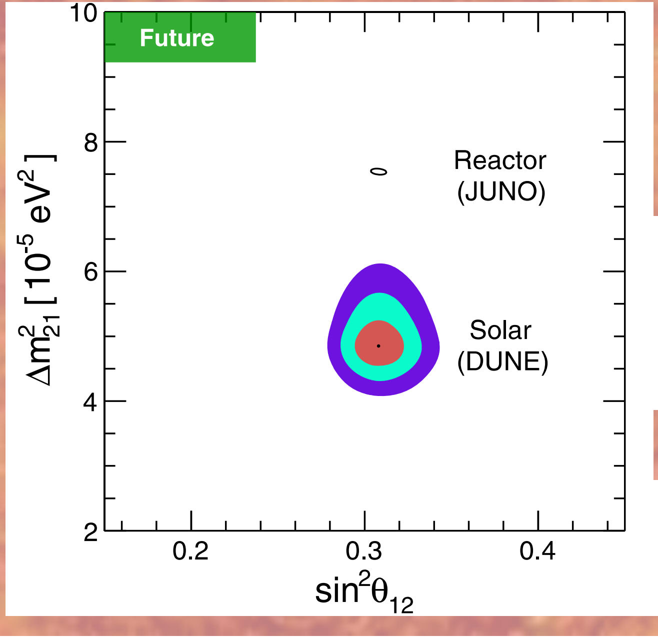
Phase-I with 27 kton active volume, LAr TPCs







Possible first observation of hep solar neutrinos by DUNE (benefits from higher CC cross section) "low-energy" backgrounds are important

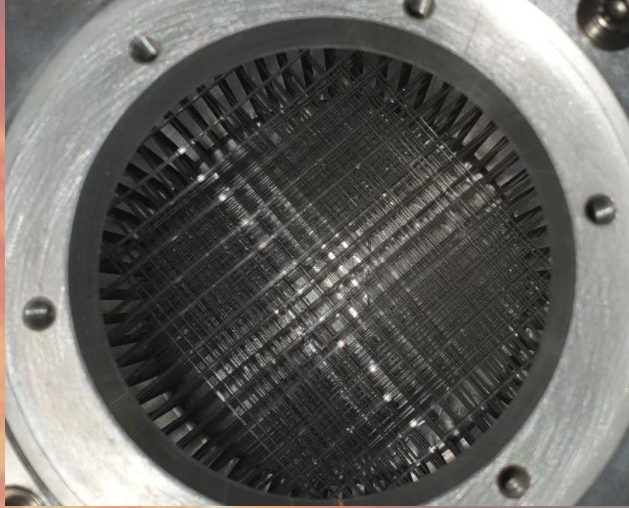


In the case the discrepancy between solar ν_e and reactor $\bar{\nu}_e$ is real; 100 kton-yr each

From Capozzi et al., PRL **123**, 131803 (2019)

from C. Cuesta

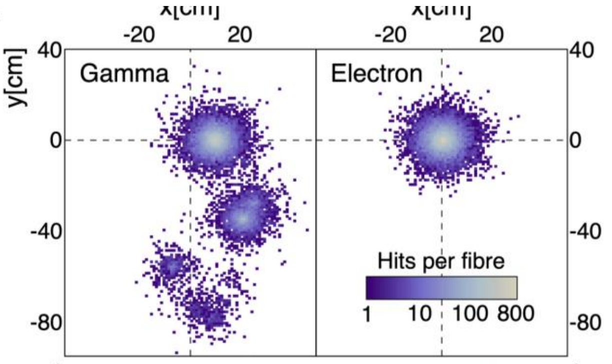
Future Solar CC on ^{115}In in CLOUD (LiquidO)

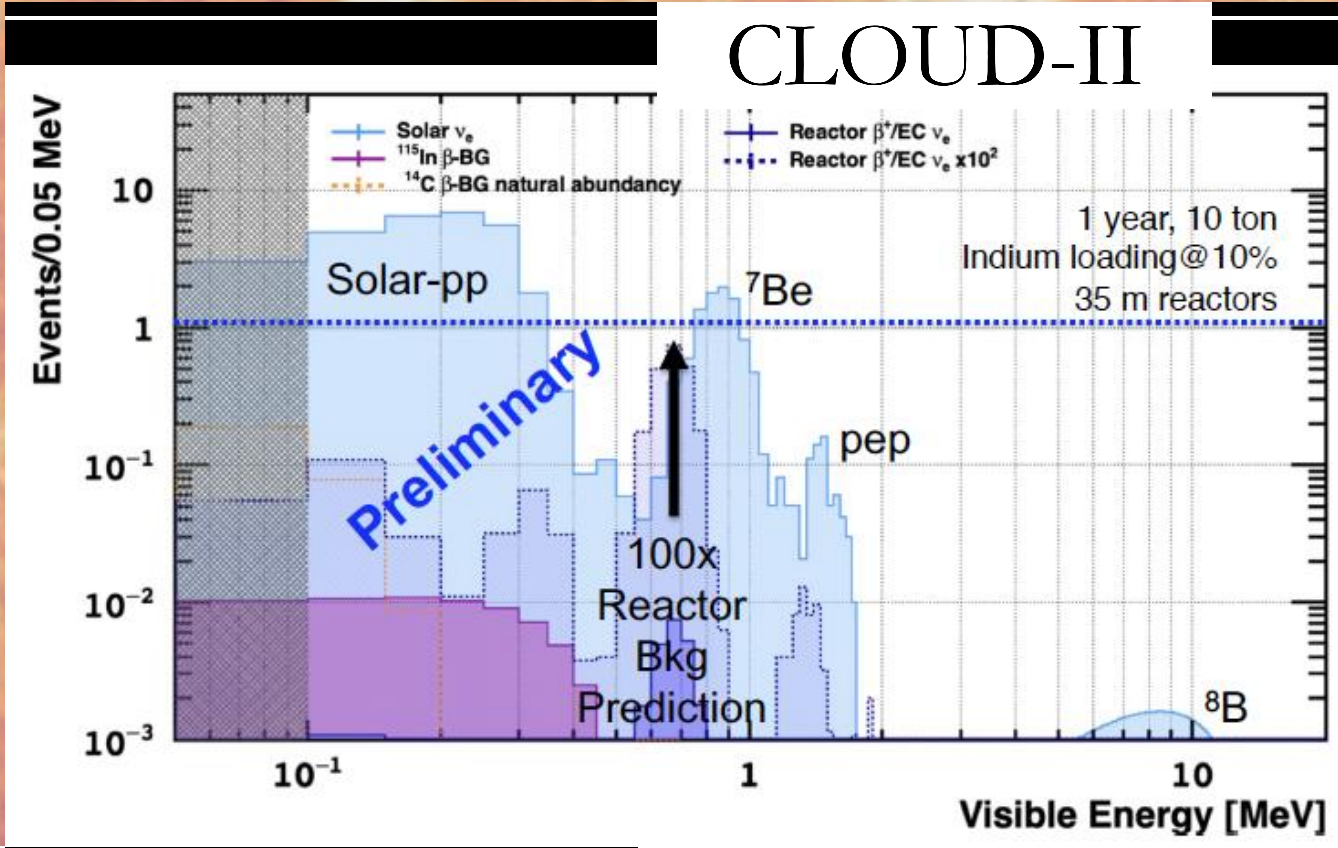


CLOUD is a planned/proposed 10-tonne detector with opaque liquid scintillator and WLS fibre readout (LiquidO technique) – CLOUD-II with 10% In loading

$$\nu_e + {}^{115}In \rightarrow e^- + {}^{115}Sn^* \\ \hookrightarrow \gamma/e^-\,(116\ keV) + \gamma\,(497\ keV)$$

Can achieve what R. Raghavan proposed (for LENS) because of better spatial resolution and event topology from LiquidO




CLOUD-II

Solar-pp
~25/year

Solar-^{7}Be
~9/year

^{115}In
intrinsic bkg
~negligible
(w/ LiquidO)

^{14}C
~negligible

from A. Cabrera, D. Navas

Solar Neutrinos with CEνNS in DM Detectors

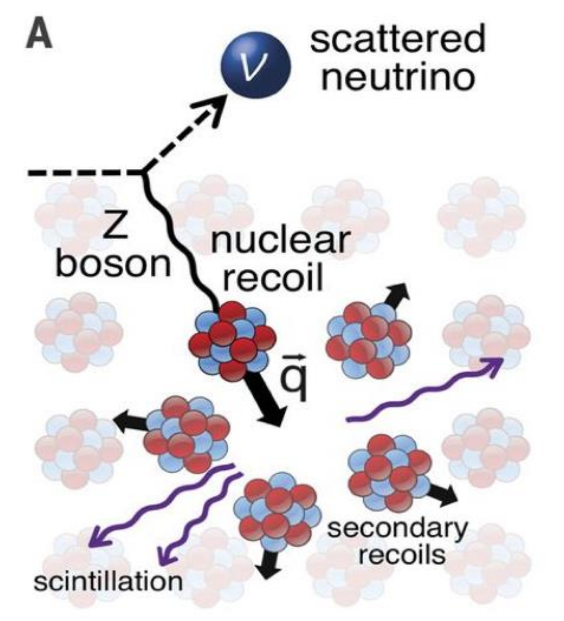
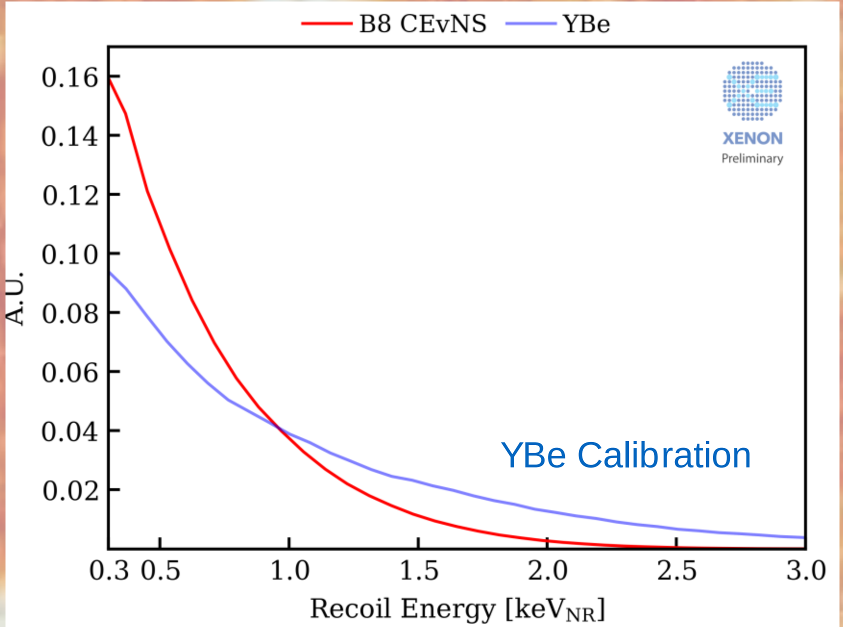
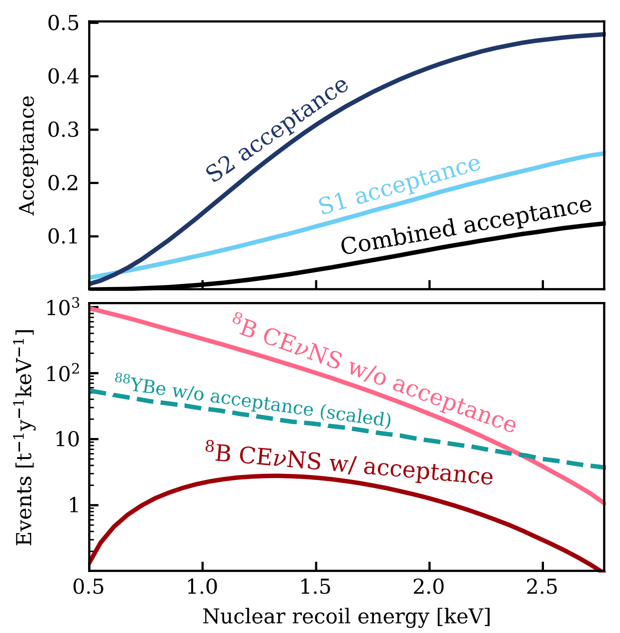


figure from D. Akimov et al., Science **357**, 1123 (2017)

Rate: ~600 events/(tonne-year Xe)



Current experiments:
- XENONnT
- PandaX-4T
- LZ perhaps?

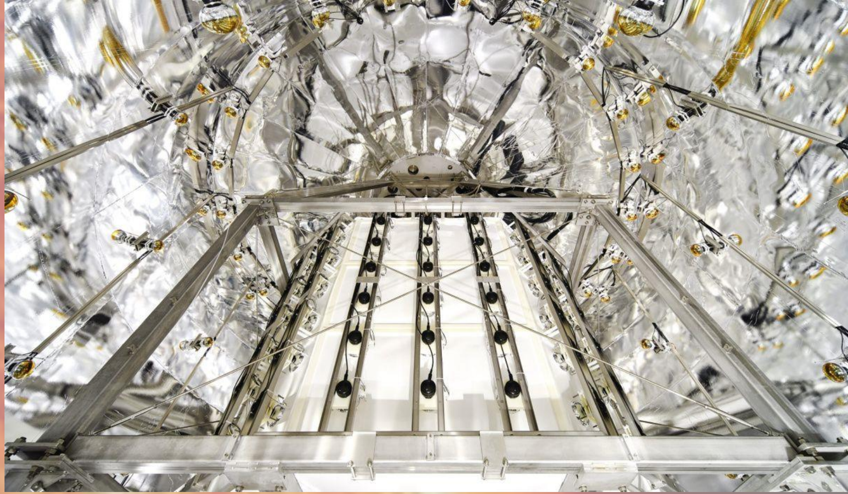


talk by M. Lindner in 1.5 hours!

These figures and numbers are from XENONnT but are meant to be representative of the technique...

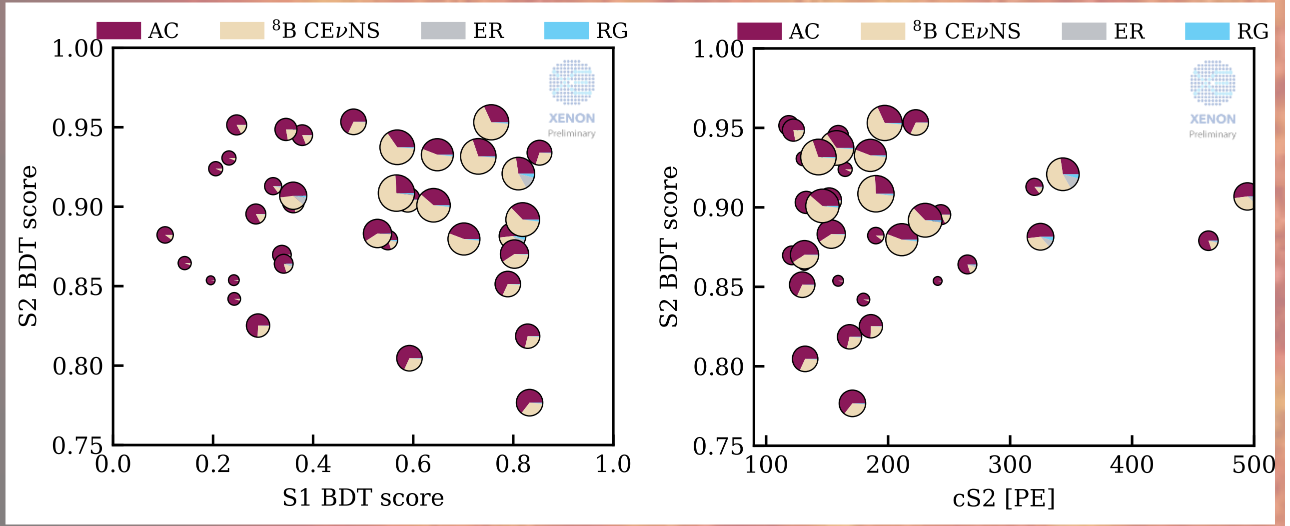
Future experiments:
- XLZD
- DarkSide-20k; ARGO

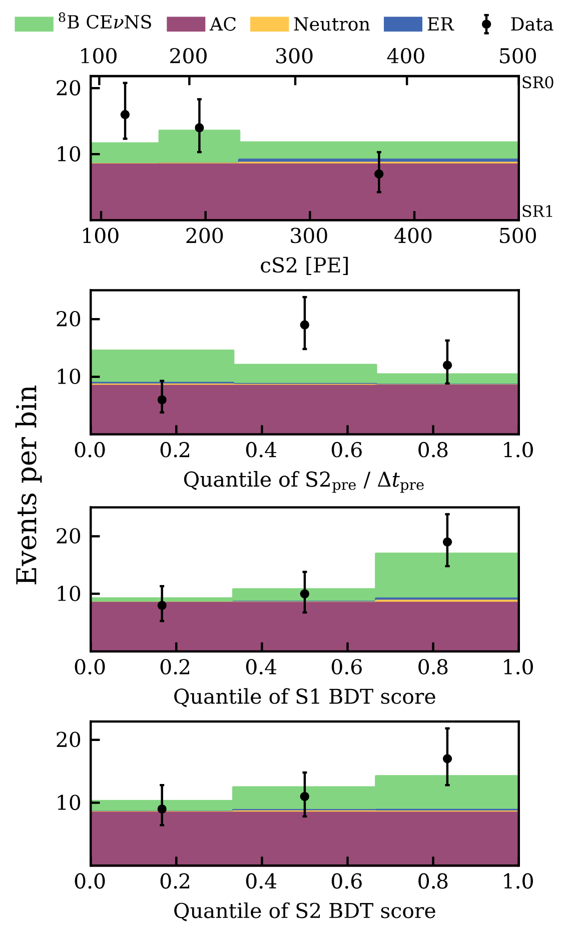
^{8}B Solar Neutrinos with CEνNS in XENONnT

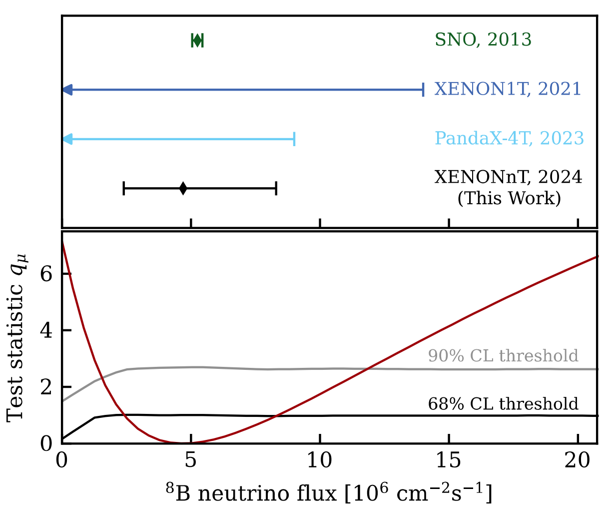


5.9 tonne LXe dual-phase TPC
July-November 2021; May 2022-August 2023 datasets
3.51 tonne-year exposure (316.5 live-time days)

37 events above 0.5 keV with $26.4^{+1,4}_{-1.3}$ expected background





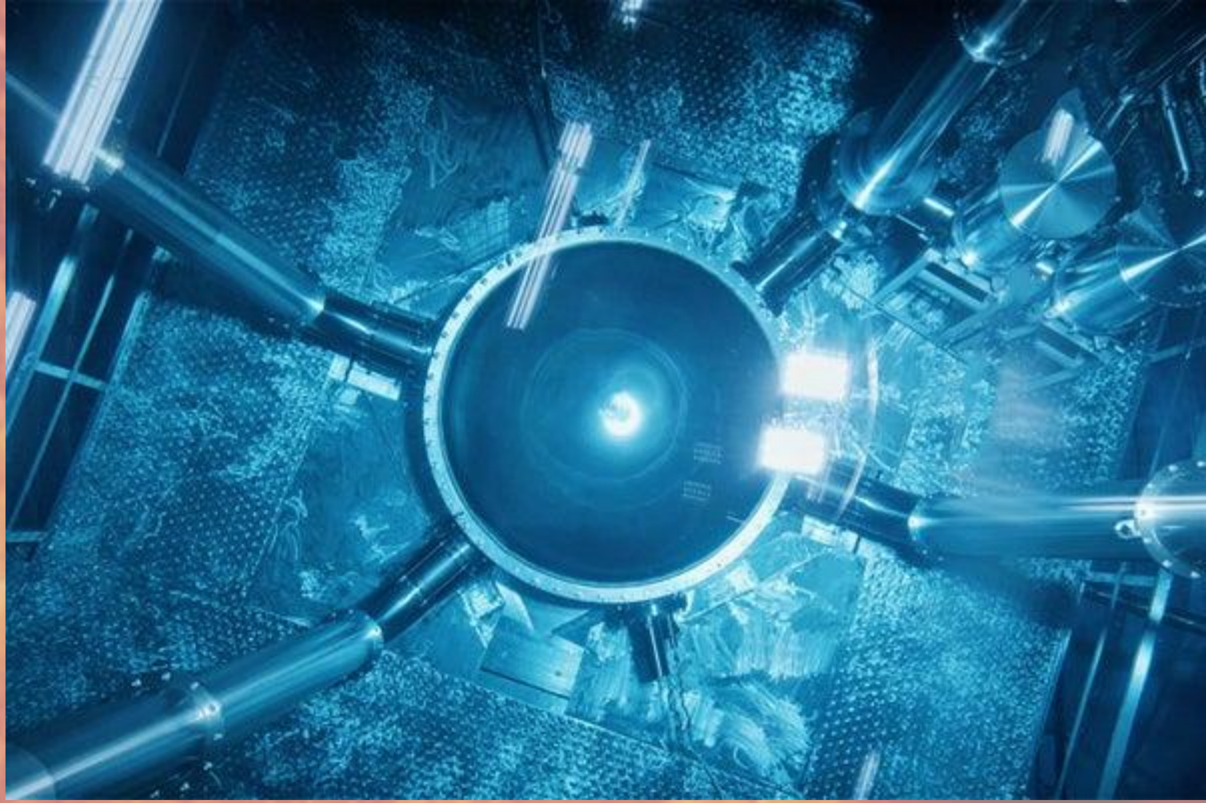


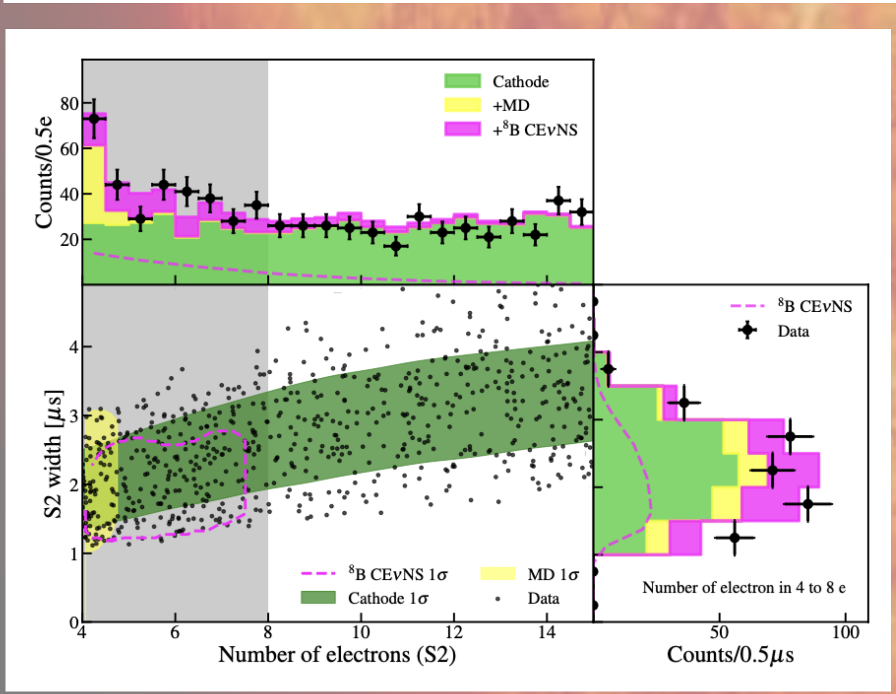
2.73σ observation of ^{8}B solar neutrinos

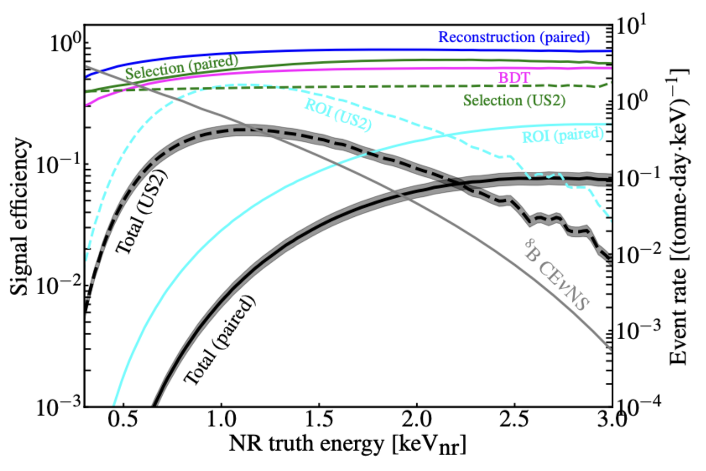
from F. Gao, IDM Workshop, July 2024
E. Aprile et al., arXiv:2408.02877 (2024)

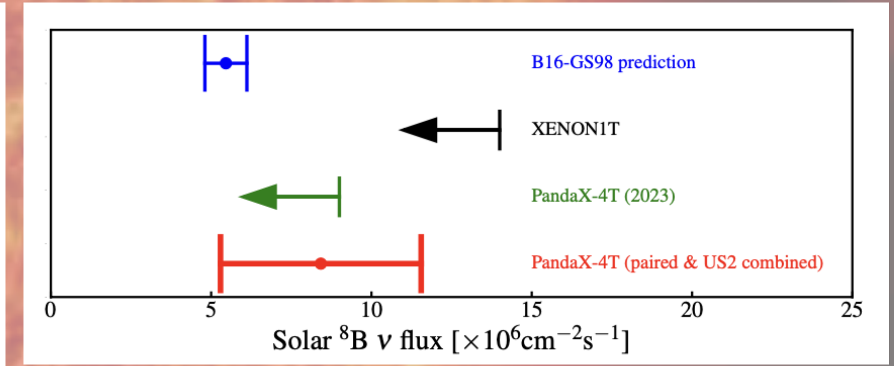
^{8}B Solar Neutrinos with CEνNS in PandaX-4T

3.7 tonne LXe dual-phase TPC
259 calendar days with 2.24 tonne-year exposure
S1-S2 paired 1.1 keV_{nr} threshold; unpaired S2 0.33 keV_{nr}
332 events (unpaired S2) observed with expected background of 251±32





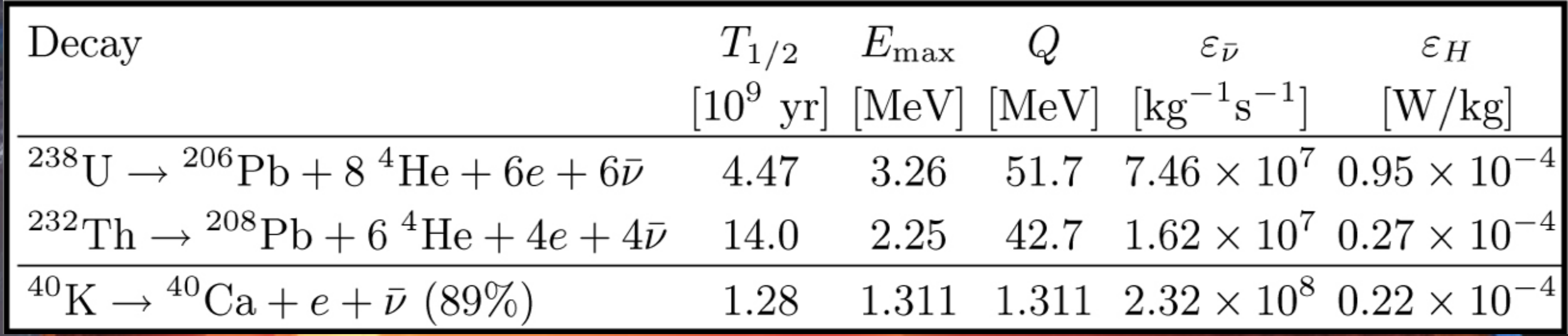




2.64σ observation of
^{8}B solar neutrinos

Z. Bo et al., arXiv:2407.10892 (2024)

Geo Neutrinos

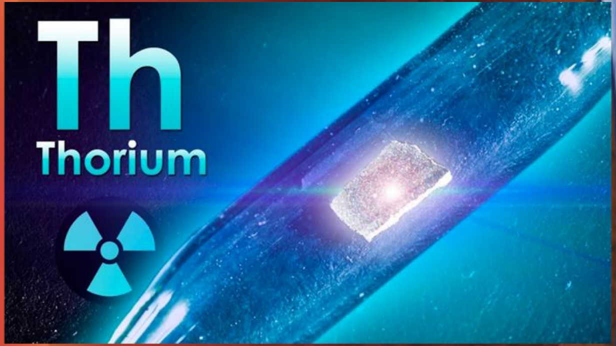


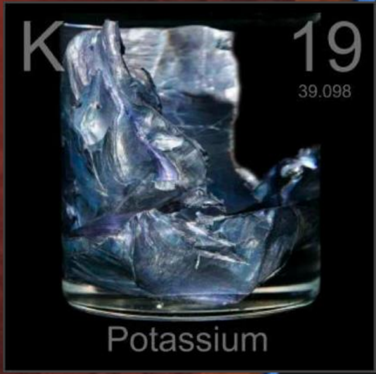
Decay	$T_{1/2}$ $[10^9\ \mathrm{yr}]$	$E_{\max}$ [MeV]	Q [MeV]	$\varepsilon_{\bar{\nu}}$ $[\mathrm{kg}^{-1}\mathrm{s}^{-1}]$	ε_H [W/kg]
$^{238}\mathrm{U} \rightarrow {}^{206}\mathrm{Pb} + 8\,{}^{4}\mathrm{He} + 6e + 6\bar{\nu}$	4.47	3.26	51.7	7.46×10^7	0.95×10^{-4}
$^{232}\mathrm{Th} \rightarrow {}^{208}\mathrm{Pb} + 6\,{}^{4}\mathrm{He} + 4e + 4\bar{\nu}$	14.0	2.25	42.7	1.62×10^7	0.27×10^{-4}
$^{40}\mathrm{K} \rightarrow {}^{40}\mathrm{Ca} + e + \bar{\nu}$ (89%)	1.28	1.311	1.311	2.32×10^8	0.22×10^{-4}

Antineutrinos emitted by natural radioactivity in the Earth

Goals:

1) Measure Earth's radiogenic heat – energetics responsible for mantle convection, plate tectonics, volcanism, the geodynamo – by detecting its neutrino glow
2) Test fundamental ideas (models) of bulk Earth chemical composition (and Earth's origin) including U/Th ratio
3) Explore the distribution of radioactive elements in the deep Earth – mantle heterogeneity





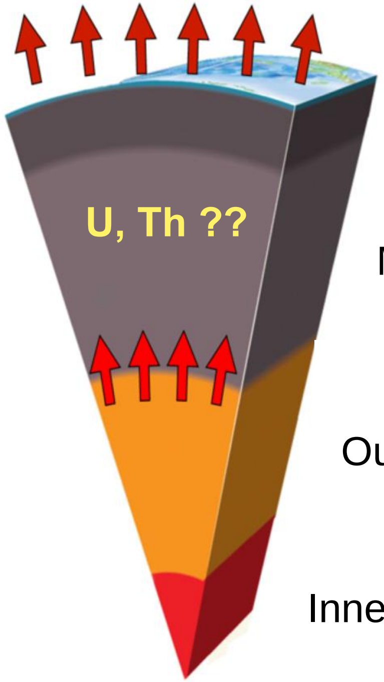
Images of elements from the Internet and may not accurately represent reality...

Earth’s Heat Flow

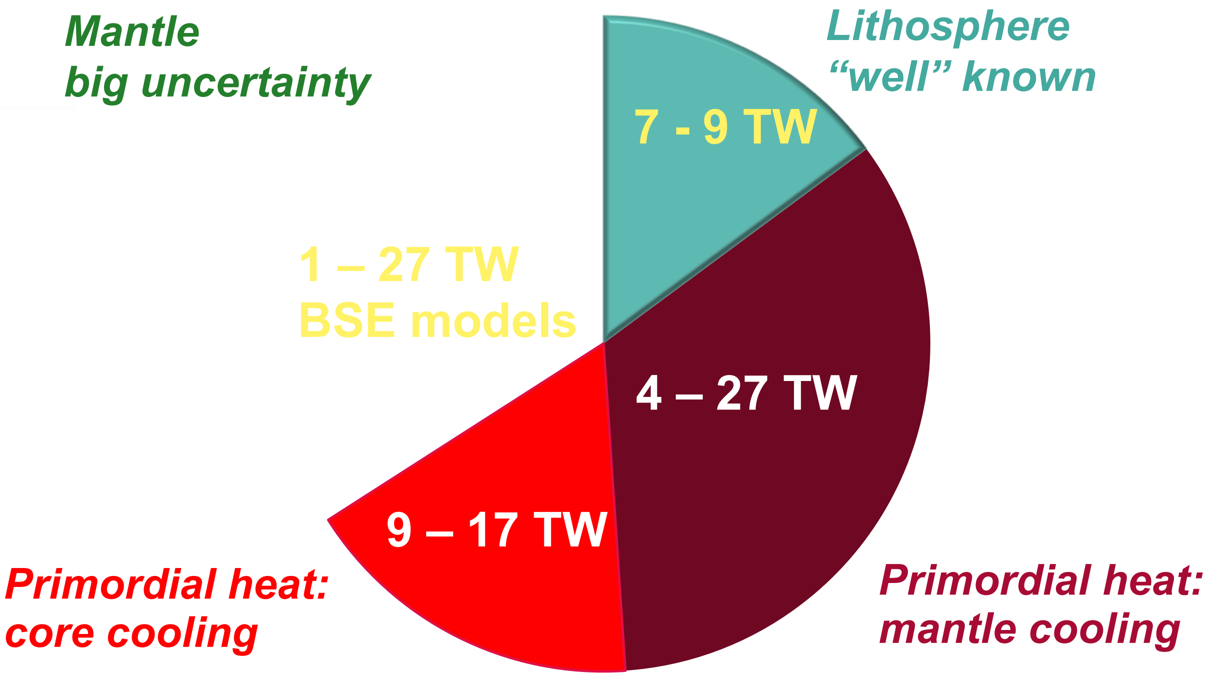
Integrated surface heat flux:

From measured T-gradients along bore-holes

H_{tot} = 47 ± 2 TW



Radiogenic heat & geoneutrinos



figures from L. Ludhova

Earth’s Bulk Chemical Composition

The model is that since chondritic abundances are similar to the solar photosphere, this represents the solar system’s primordial material from which the Earth formed

Bulk Silicate Earth (BSE)

Silicate primitive mantle became the present-day **crust** and ***mantle*** after differentiatiation

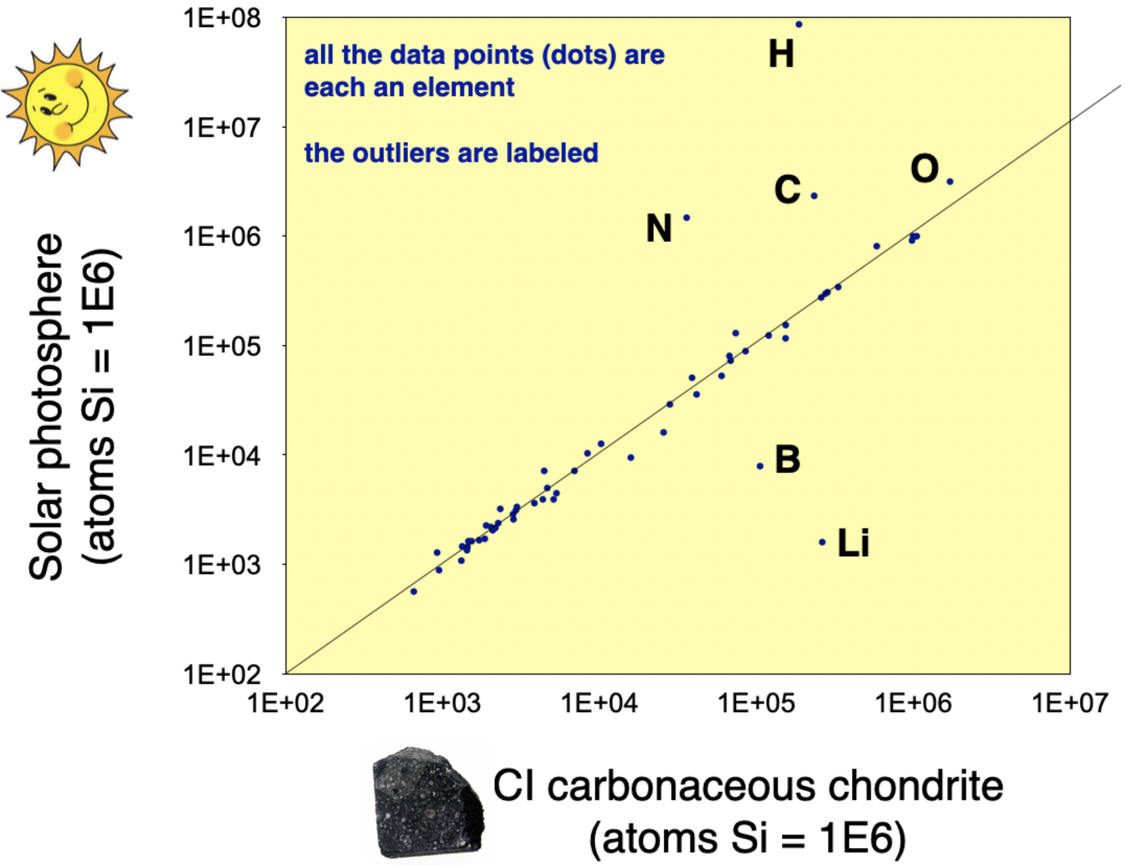
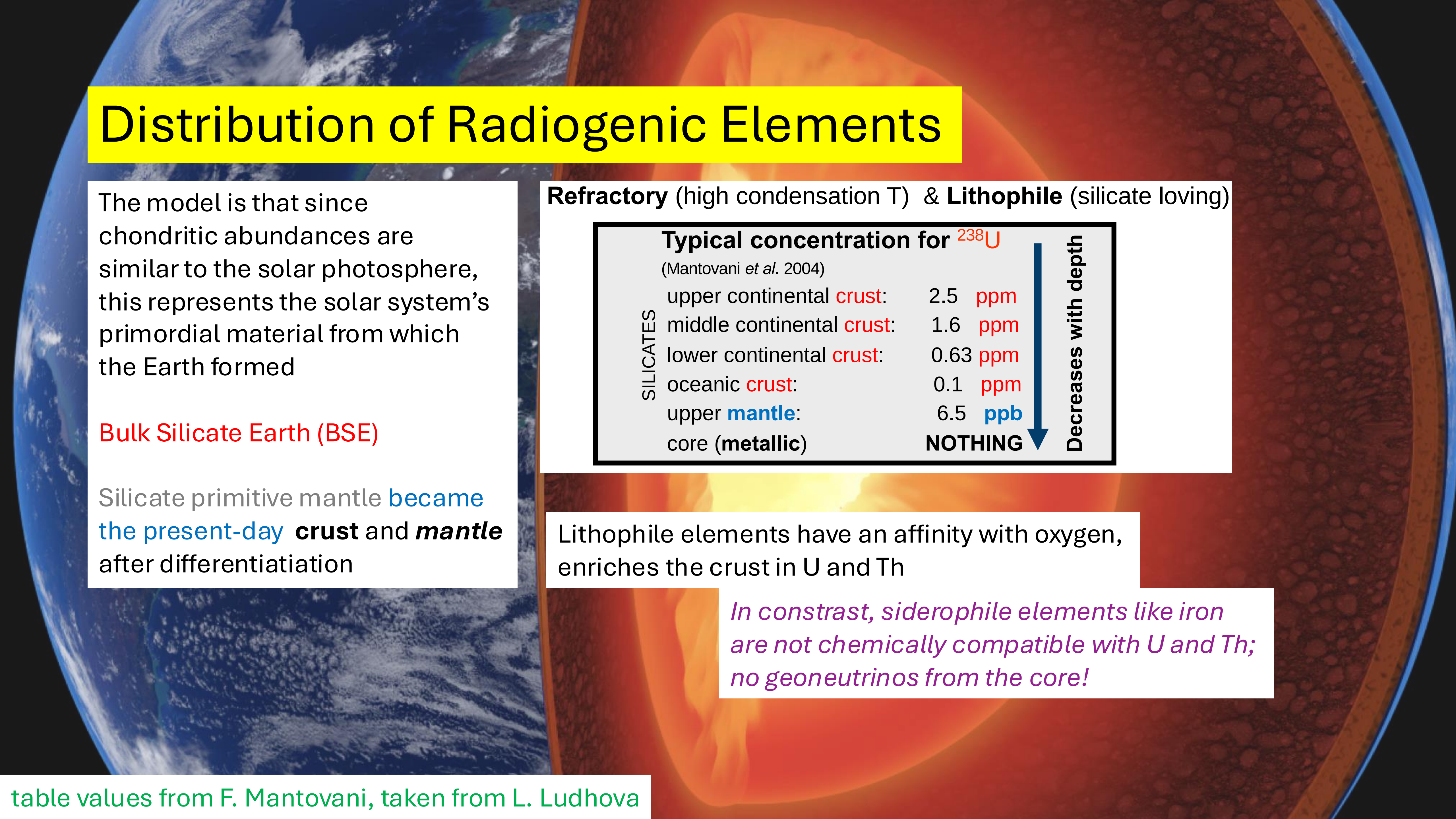


figure from W. McDonough



Distribution of Radiogenic Elements

The model is that since chondritic abundances are similar to the solar photosphere, this represents the solar system's primordial material from which the Earth formed

Bulk Silicate Earth (BSE)

Silicate primitive mantle became the present-day **crust** and ***mantle*** after differentiatiation

Refractory (high condensation T) & **Lithophile** (silicate loving)

Typical concentration for ^{238}U

(Mantovani *et al*. 2004)

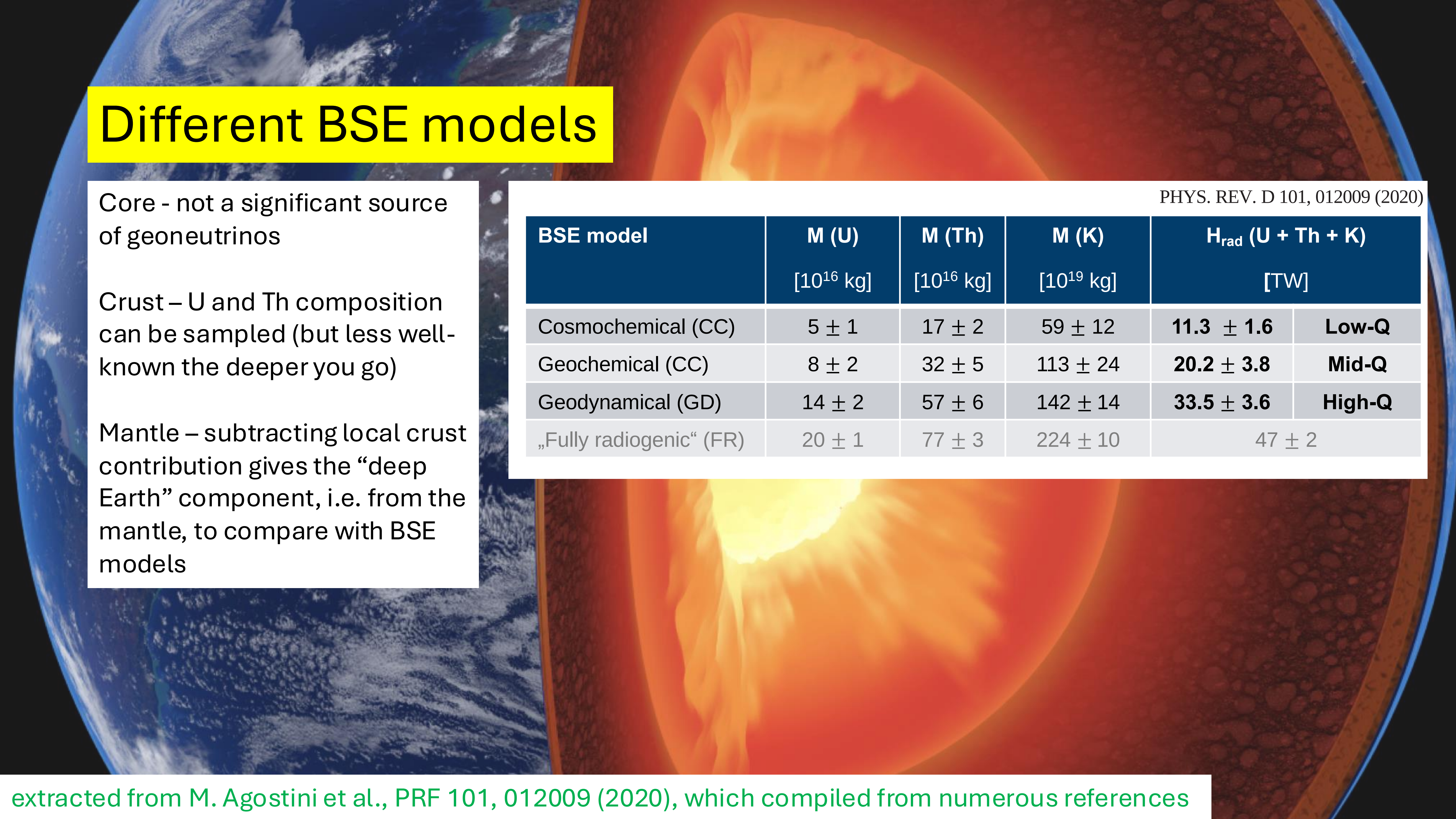
SILICATES	upper continental crust:	2.5 ppm
	middle continental crust:	1.6 ppm
	lower continental crust:	0.63 ppm
	oceanic crust:	0.1 ppm
	upper **mantle**:	6.5 **ppb**
	core (**metallic**)	**NOTHING**

Decreases with depth

Lithophile elements have an affinity with oxygen, enriches the crust in U and Th

In constrast, siderophile elements like iron are not chemically compatible with U and Th; no geoneutrinos from the core!

table values from F. Mantovani, taken from L. Ludhova



Different BSE models

Core - not a significant source of geoneutrinos

Crust – U and Th composition can be sampled (but less well-known the deeper you go)

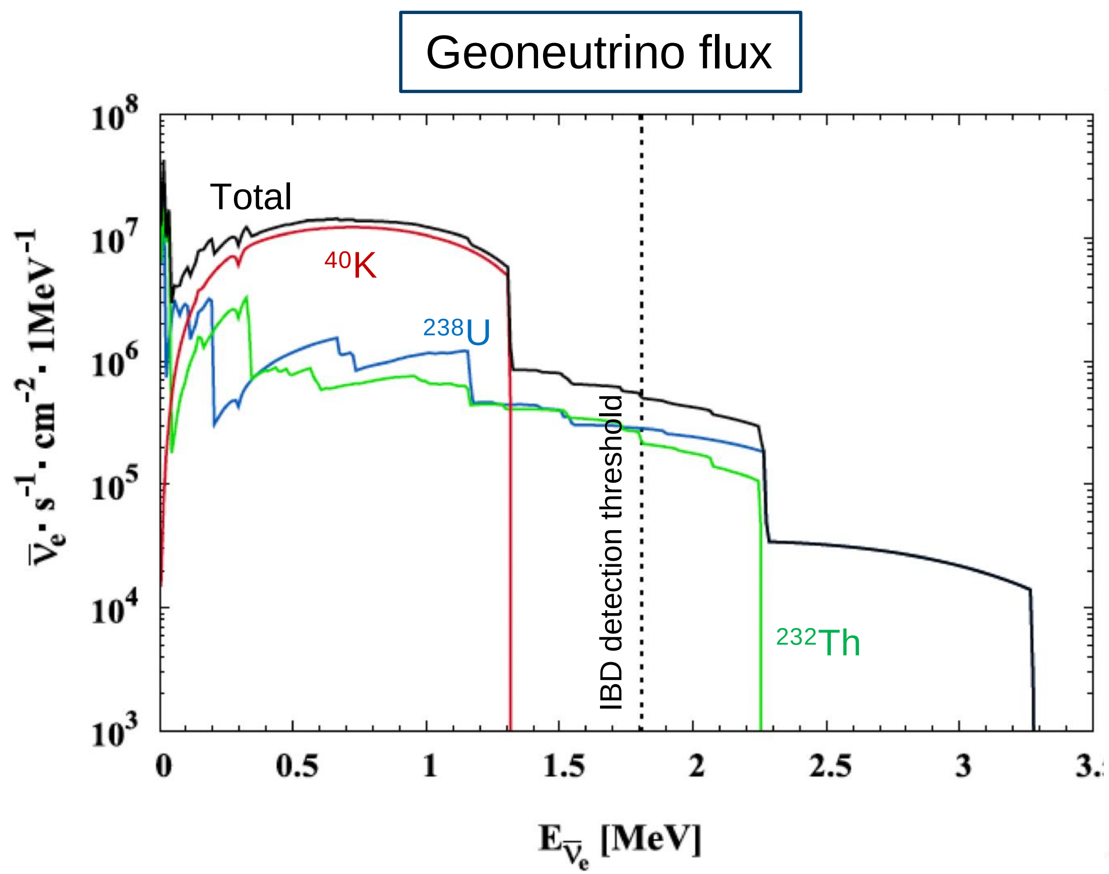
Mantle – subtracting local crust contribution gives the “deep Earth” component, i.e. from the mantle, to compare with BSE models

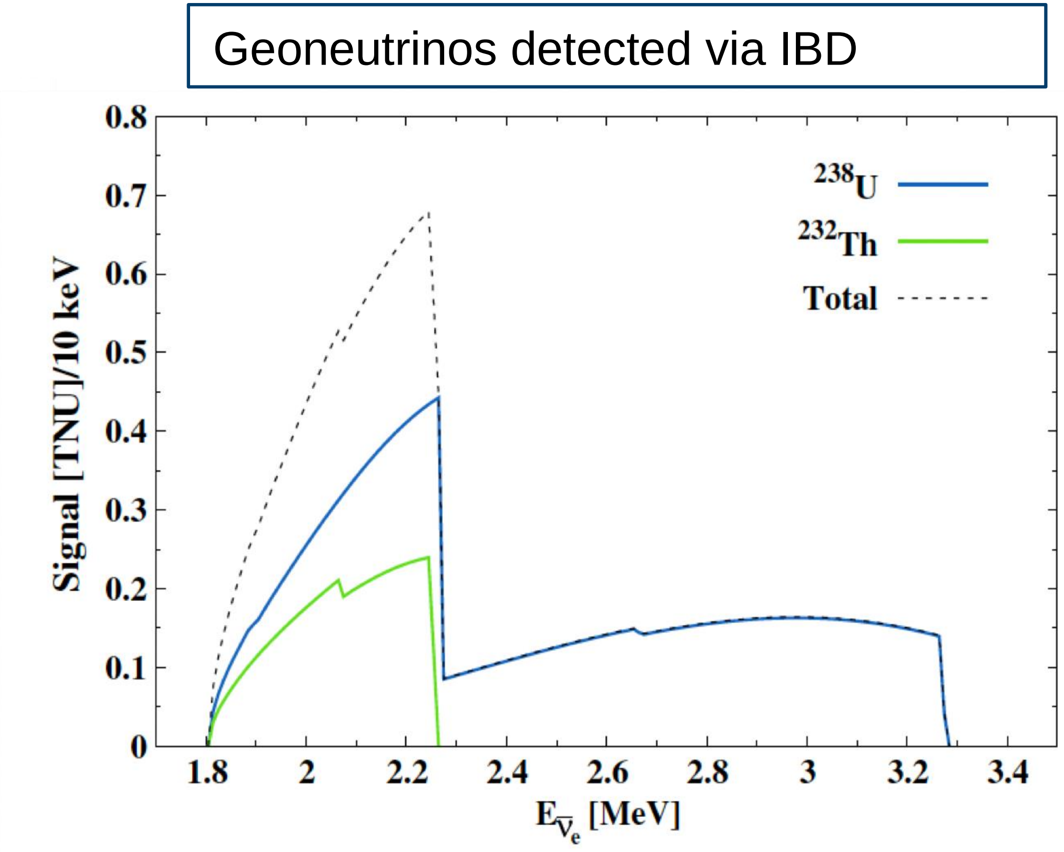
PHYS. REV. D 101, 012009 (2020)

BSE model	**M (U)** [10^{16} kg]	**M (Th)** [10^{16} kg]	**M (K)** [10^{19} kg]	**H_{rad} (U + Th + K)** [TW]	
Cosmochemical (CC)	5 ± 1	17 ± 2	59 ± 12	**11.3 ± 1.6**	**Low-Q**
Geochemical (CC)	8 ± 2	32 ± 5	113 ± 24	**20.2 ± 3.8**	**Mid-Q**
Geodynamical (GD)	14 ± 2	57 ± 6	142 ± 14	**33.5 ± 3.6**	**High-Q**
„Fully radiogenic“ (FR)	20 ± 1	77 ± 3	224 ± 10	47 ± 2	

extracted from M. Agostini et al., PRF 101, 012009 (2020), which compiled from numerous references

Geo Neutrino Detection via IBD $\bar{\nu}_e + p \rightarrow e^+ + n$

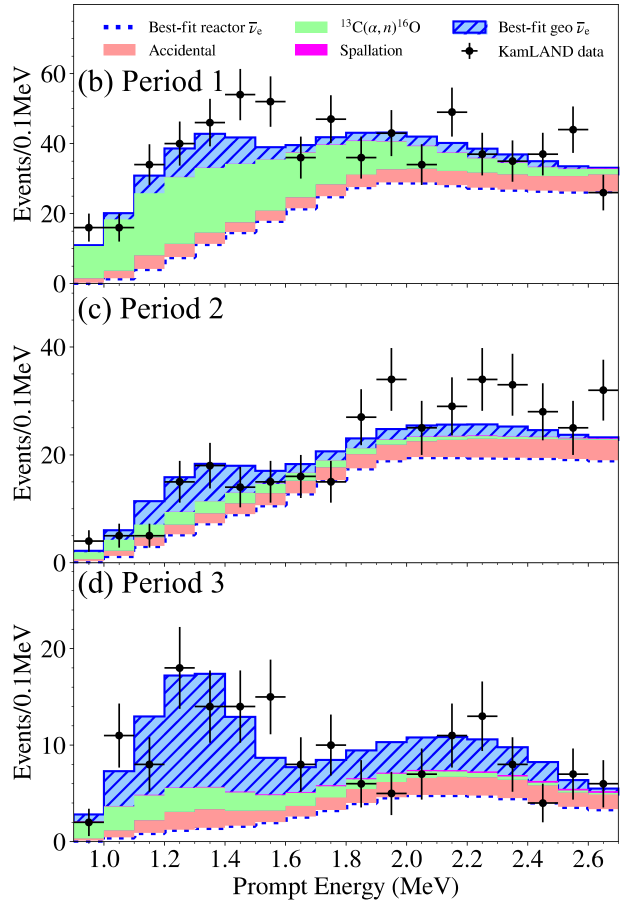

Geoneutrino flux


Geoneutrinos detected via IBD

Potassium geoneutrinos can't be detected by IBD on protons; but see A. Cabrera, M. Chen, F. Mantovani, A. Serafini, V. Strati et al., arXiv:2308.04154

figures from L. Ludhova

Geo Neutrino Experiments: KamLAND

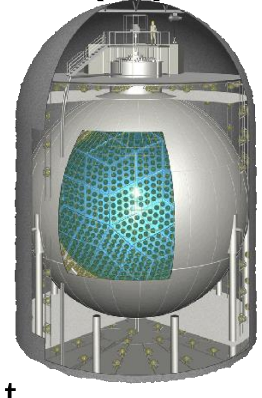


6.39×10^{32} proton-years, 14.3 live-time years

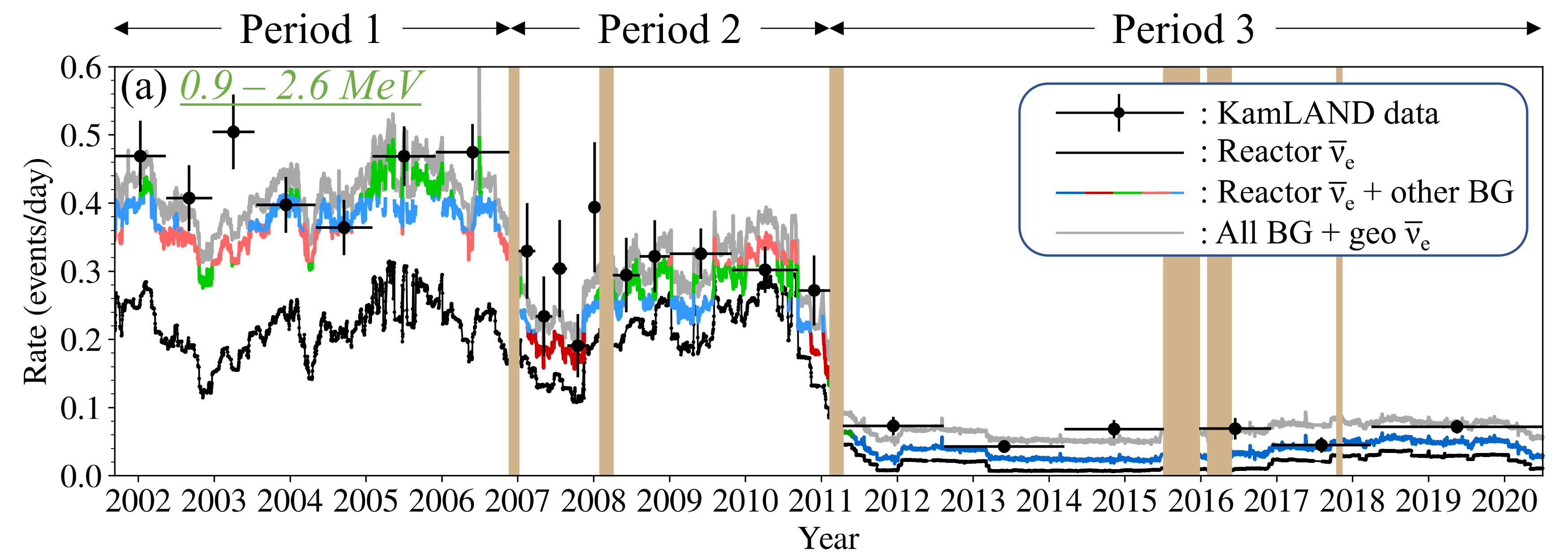
1178 candidate events (in the geo-ν region)

183^{+29}_{-28} geoneutrinos

KamLAND (Japan, 2002~)

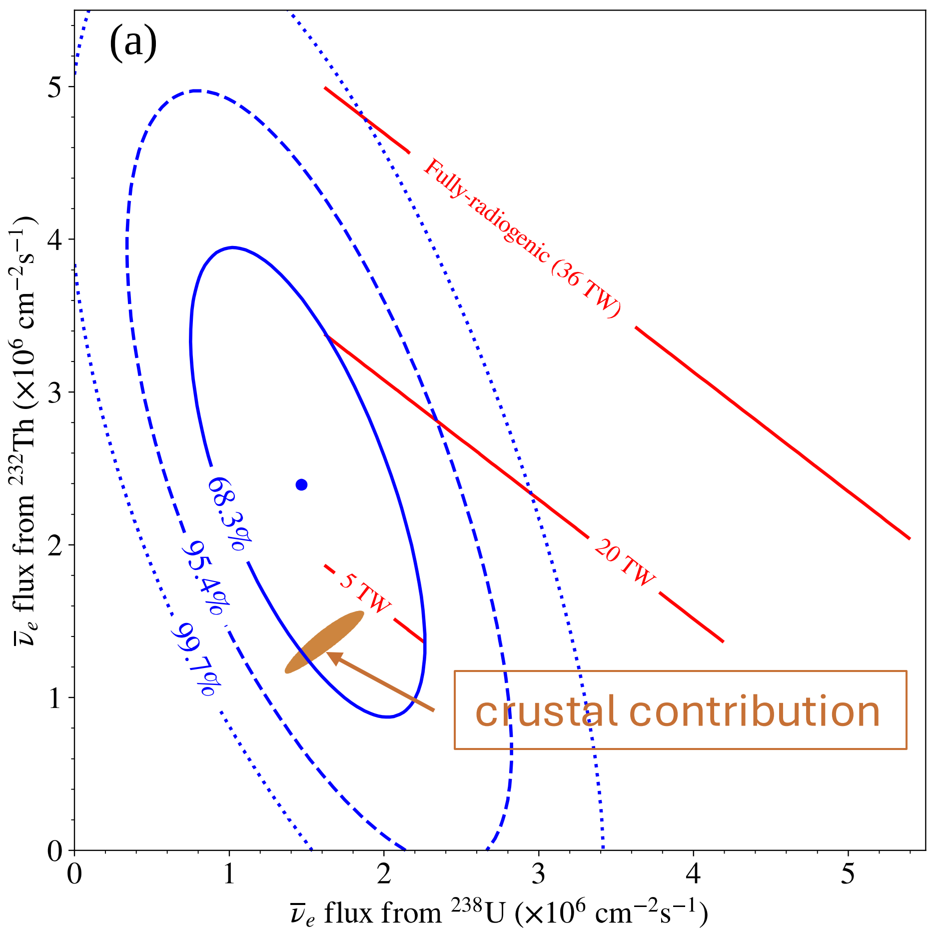


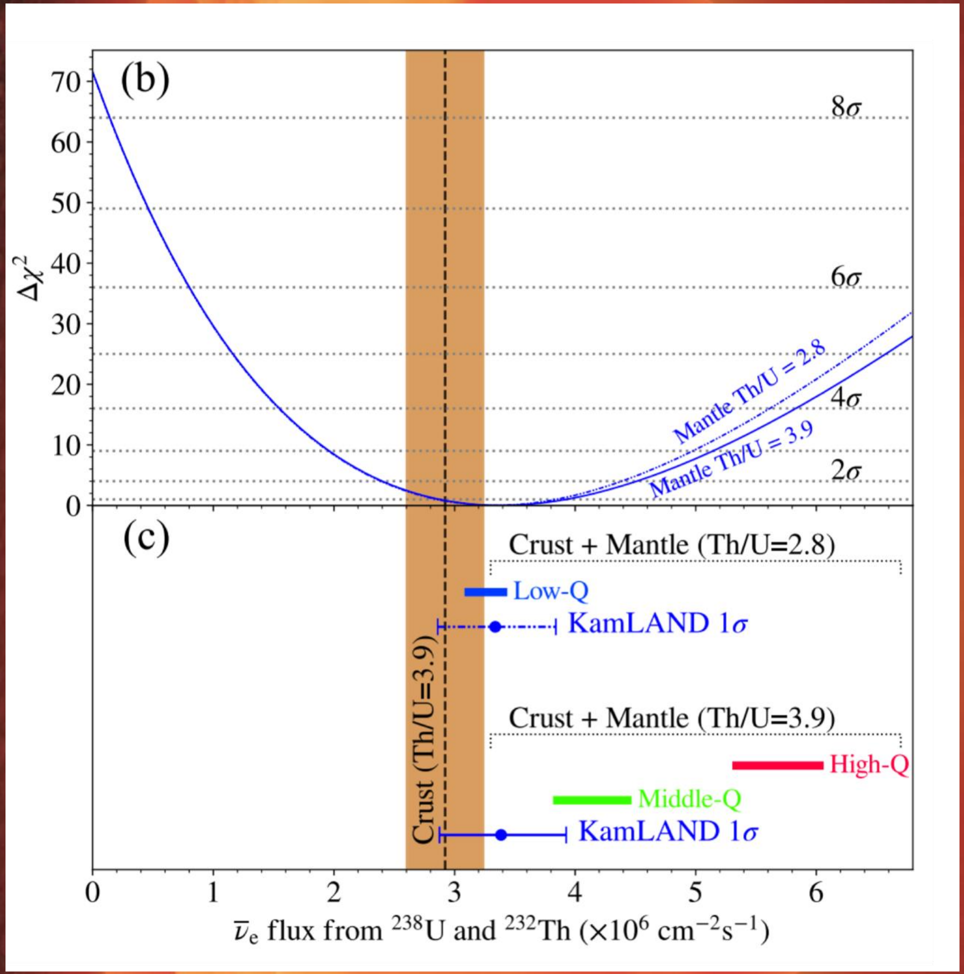
- LS : 1000 t
- Depth : 2700 m.w.e.
- expected event ratio
  reactor/geo ~**6.7** (up to 2010)
  ~**0.4** (2011~)
  w/o Japanese reactors



S. Abe et al., Geophys. Res. Lett. **49,** e2022GL099566 (2022)

KamLAND Geology Interpretation

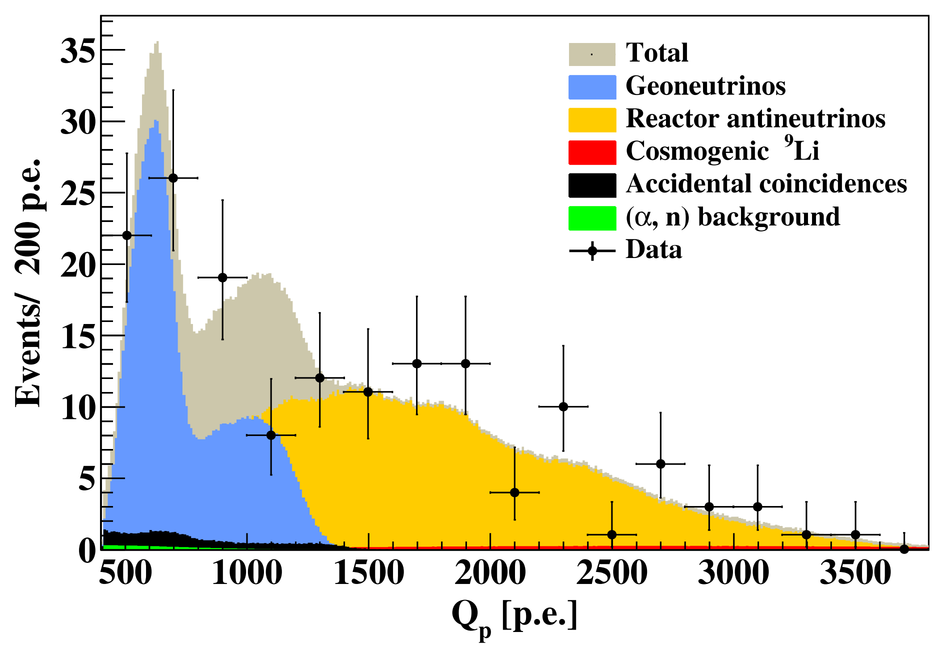




KamLAND prefers Low-Q and Mid-Q mantle; disfavours High-Q at 99.76% CL (homogeneous mantle; Th/U = 3.9)

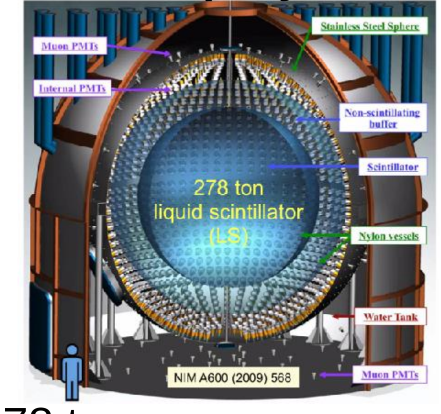
S. Abe et al., Geophys. Res. Lett. **49,** e2022GL099566 (2022)

Geo Neutrino Experiments: Borexino

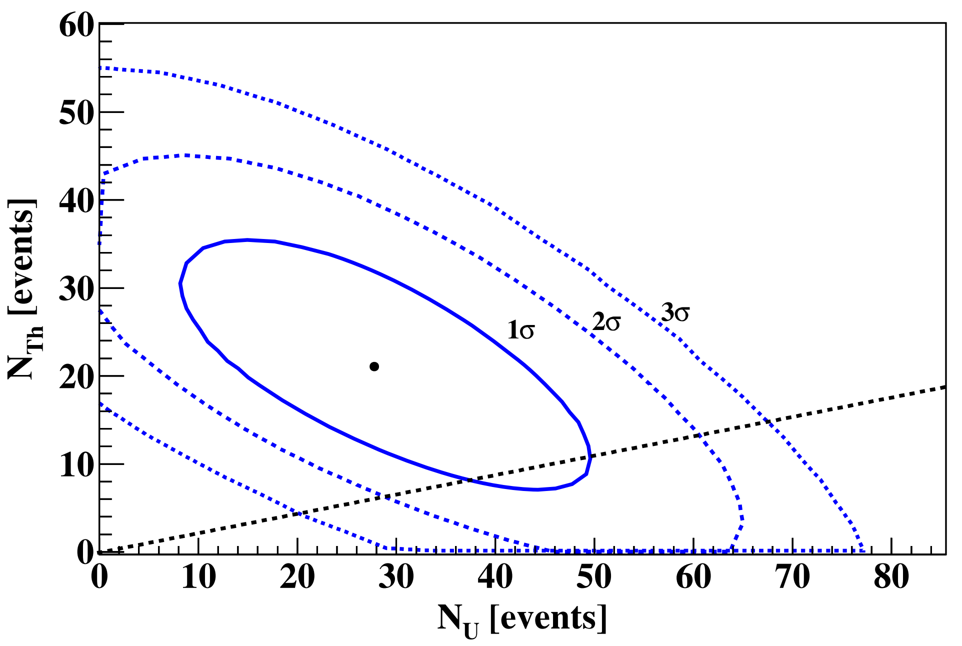


1.29×10^{32} proton-years,
8.7 live-time years
154 IBD candidate events
(~90 in the geo-ν region)
$52.6^{+9.4}_{-8.6}$ geoneutrinos

Borexino (Italy, 2007~)

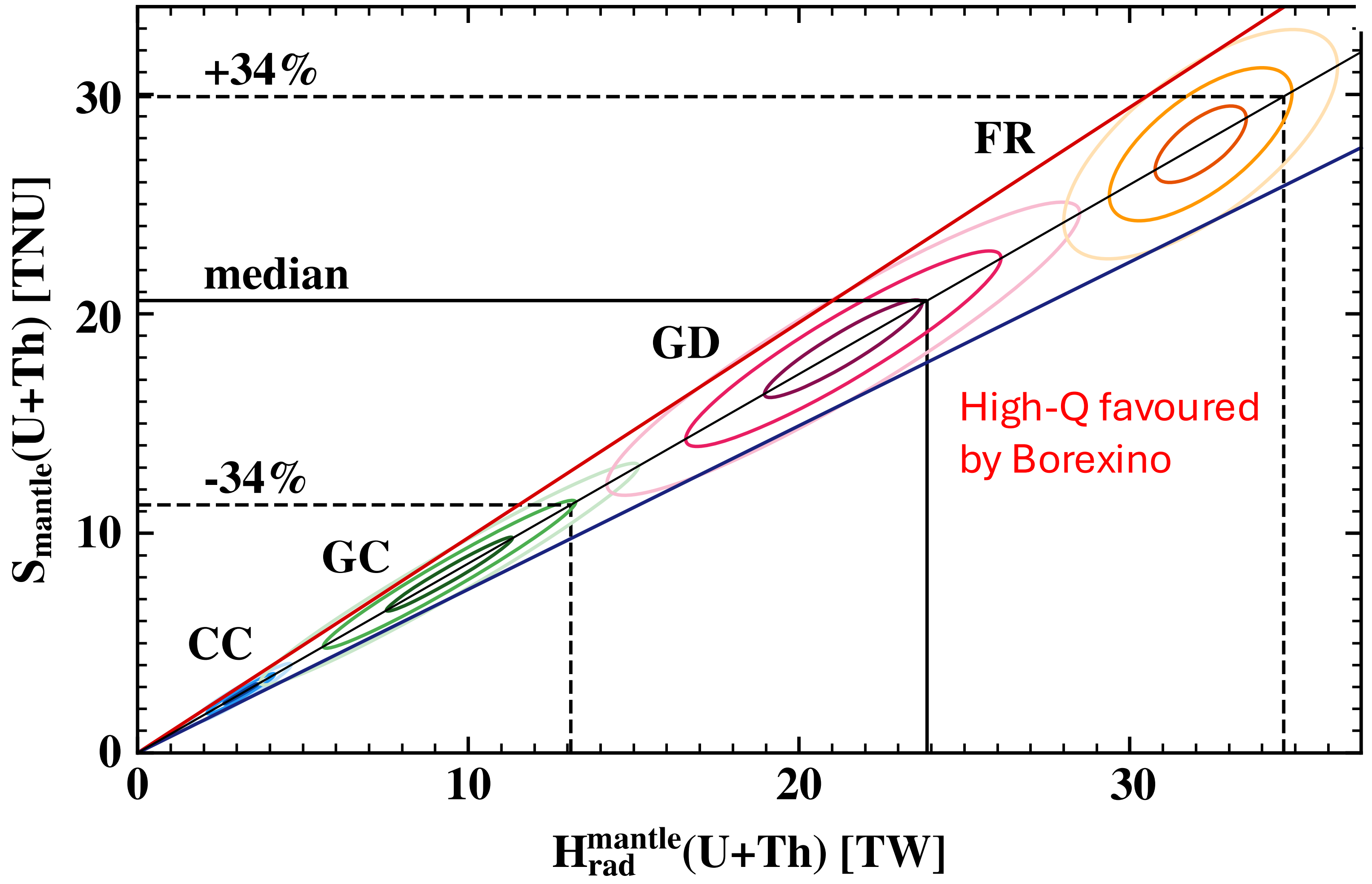


- LS : 278 t
- Depth : 3800 m.w.e.
- expected event ratio reactor/geo ~**0.3** (2007~)

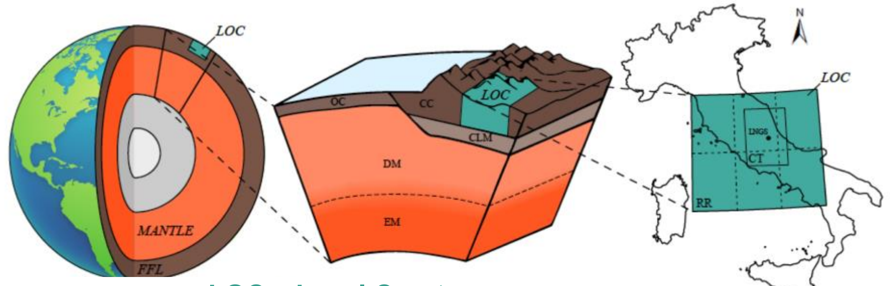


M. Agostini et al., PRF 101, 012009 (2020)

Borexino Geology Interpretation



High-Q favoured by Borexino



LOC – Local Crust
FFL – Far Field Lithosphere
Mantle

PRD101 (2020) 012009

Using LOC from M. Coltorti et al. and FFL from Y. Huang et al. and subtracting, Borexino finds non-zero mantle contribution at 99.0% CL

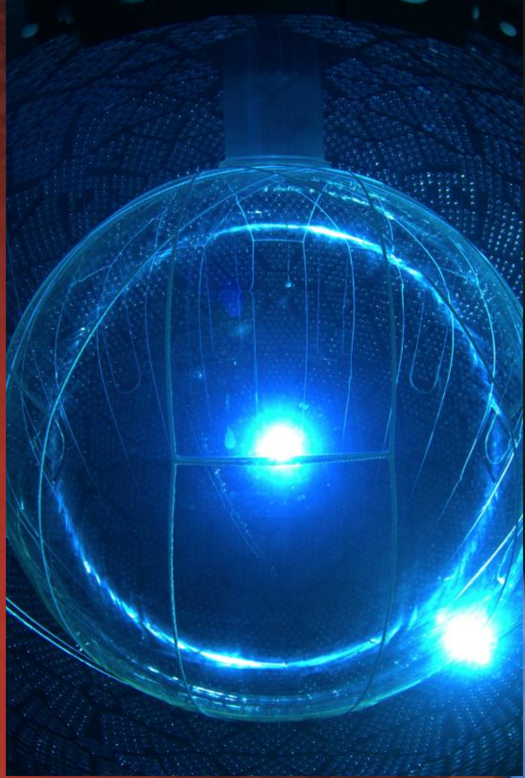
Mantle signal: $21.2^{+9.6}_{-9.1}$ TNU

Borexino prefers High-Q model; large radiogenic contribution to mantle “geo dynamics”

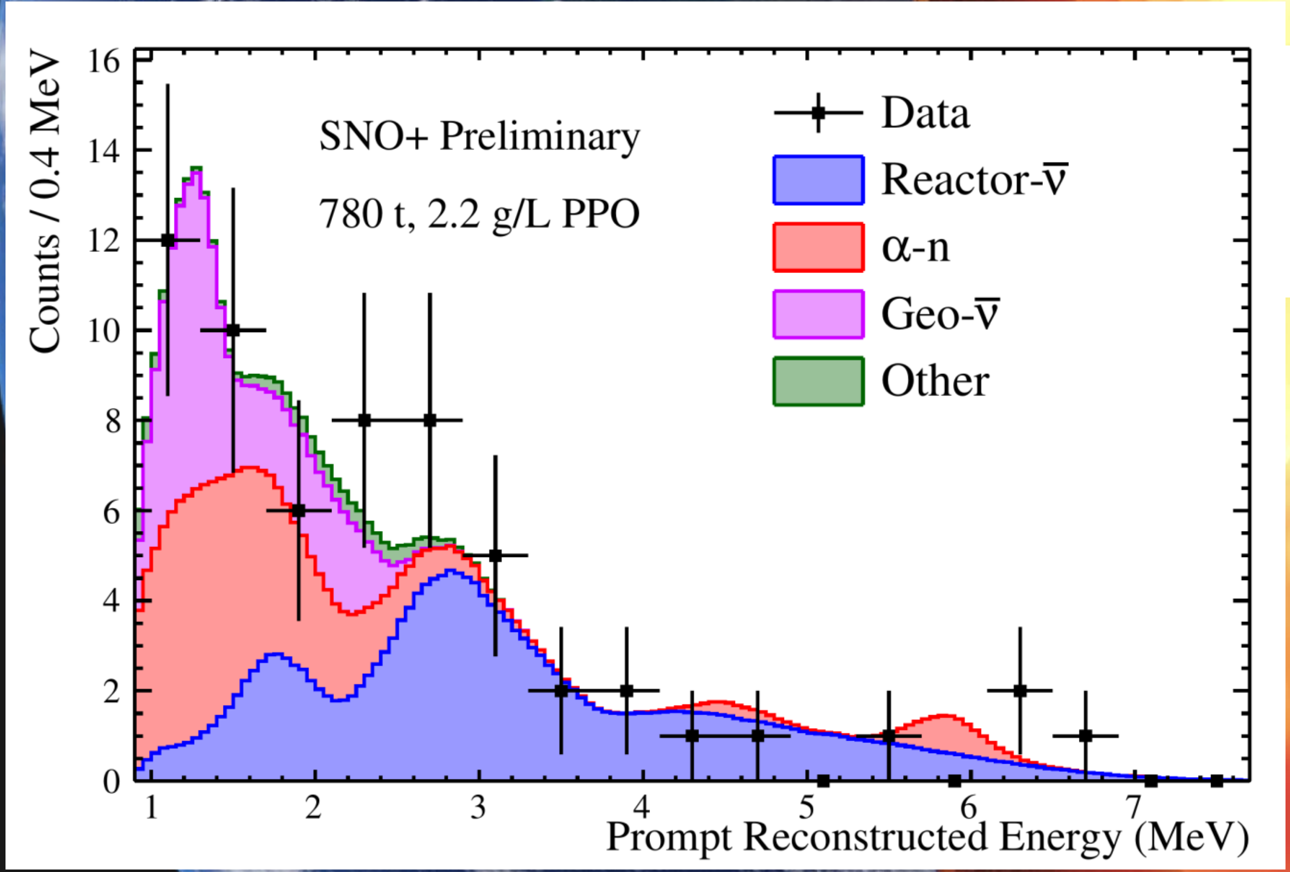
M. Agostini et al., PRF 101, 012009 (2020)

TNU (terrestrial neutrino unit) = 1 event per 10^{32} proton-year (100% eff.)

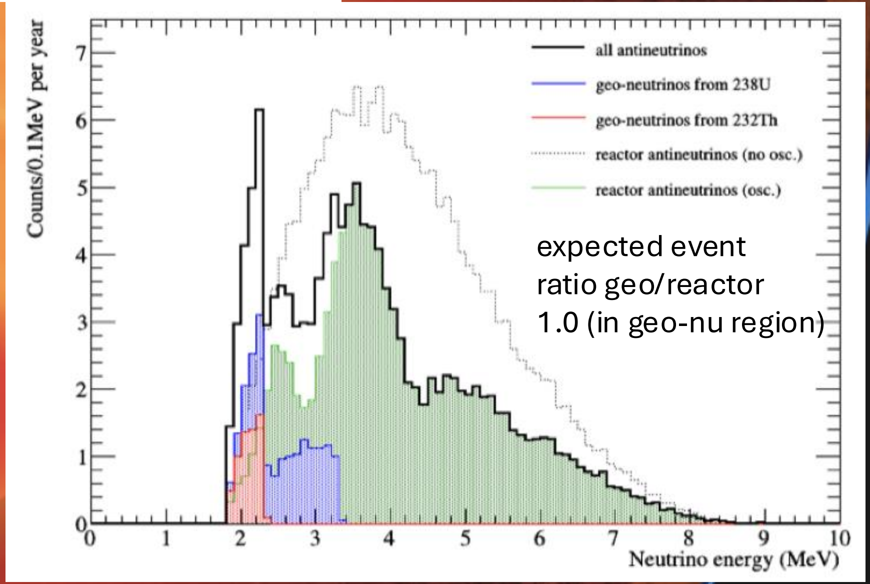
Geo Neutrino Experiments: SNO+ Scintillator (ultra preliminary)



0.18 × 10^{32} proton-years exposure, 286 tonne-year
59 IBD candidate events (36 in the geo-ν region)
9.9 ± 6.9 geoneutrinos



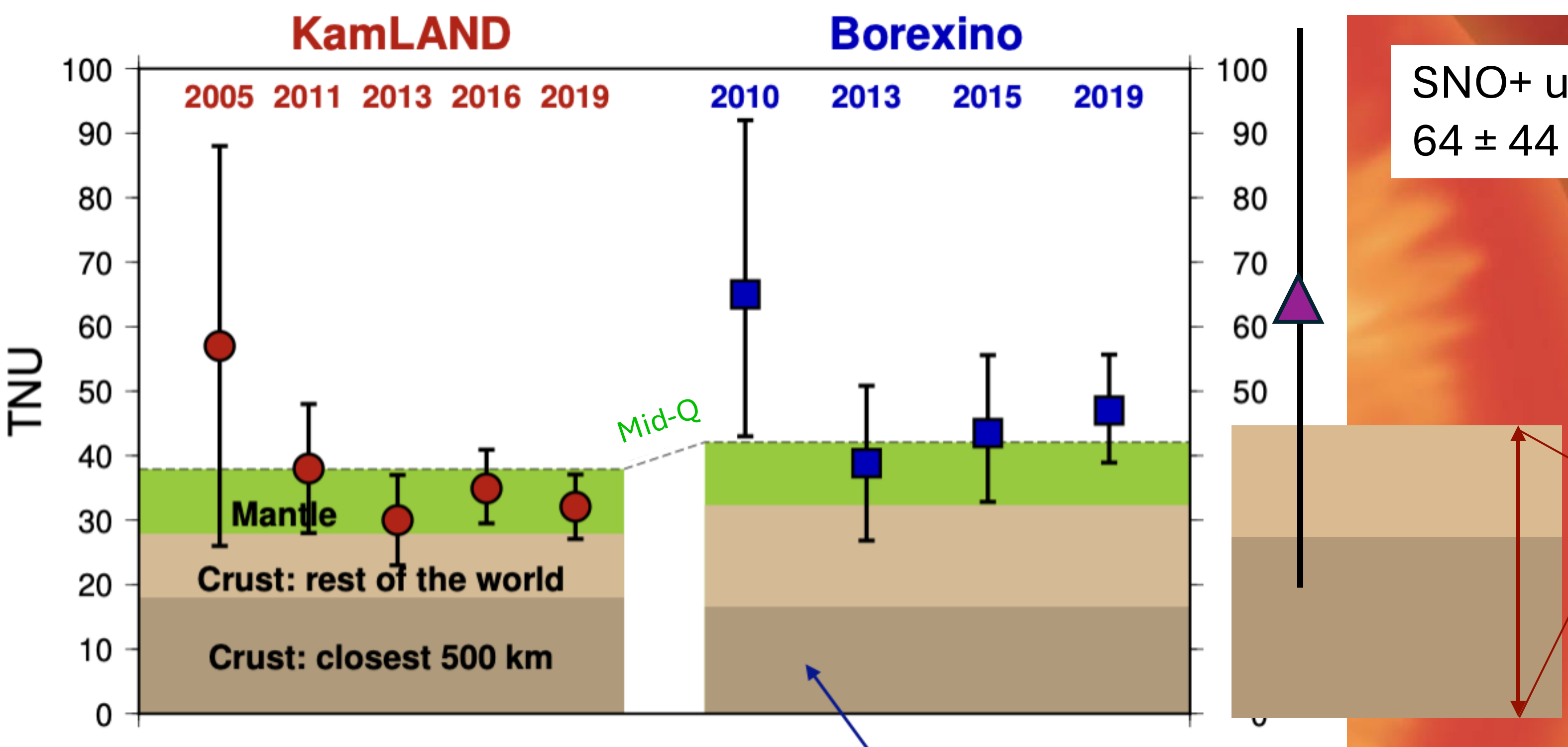
Large uncertainty comes from (α, n) backgrounds and their uncertain
cross section



expected event
ratio geo/reactor
1.0 (in geo-nu region)

Comparing Borexino and KamLAND *and SNO+*

SNO+ (ultra preliminary)



Geoneutrino prediction from Wipperfurth et al. 2020 JGR doi:10.1029/2019JB018433

SNO+ ultra-preliminary flux:
64 ± 44 TNU

being evalutated…

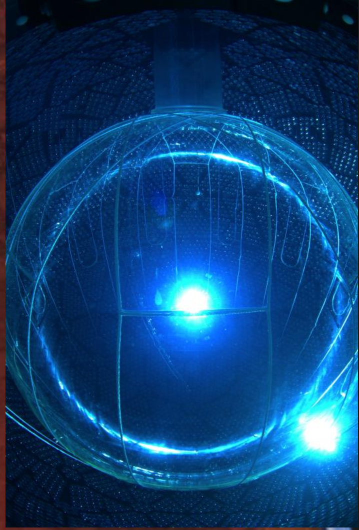
Lithospheric model *not* the one used by Borexino in their analysis

Note: this analysis (rightly or wrongly) erases the difference between Borexino and KamLAND mantle rates

TNU (terrestrial neutrino unit) = 1 event per 10^{32} proton-year (100% eff.)

figure comparing KamLAND and Borexino from H. Watanabe

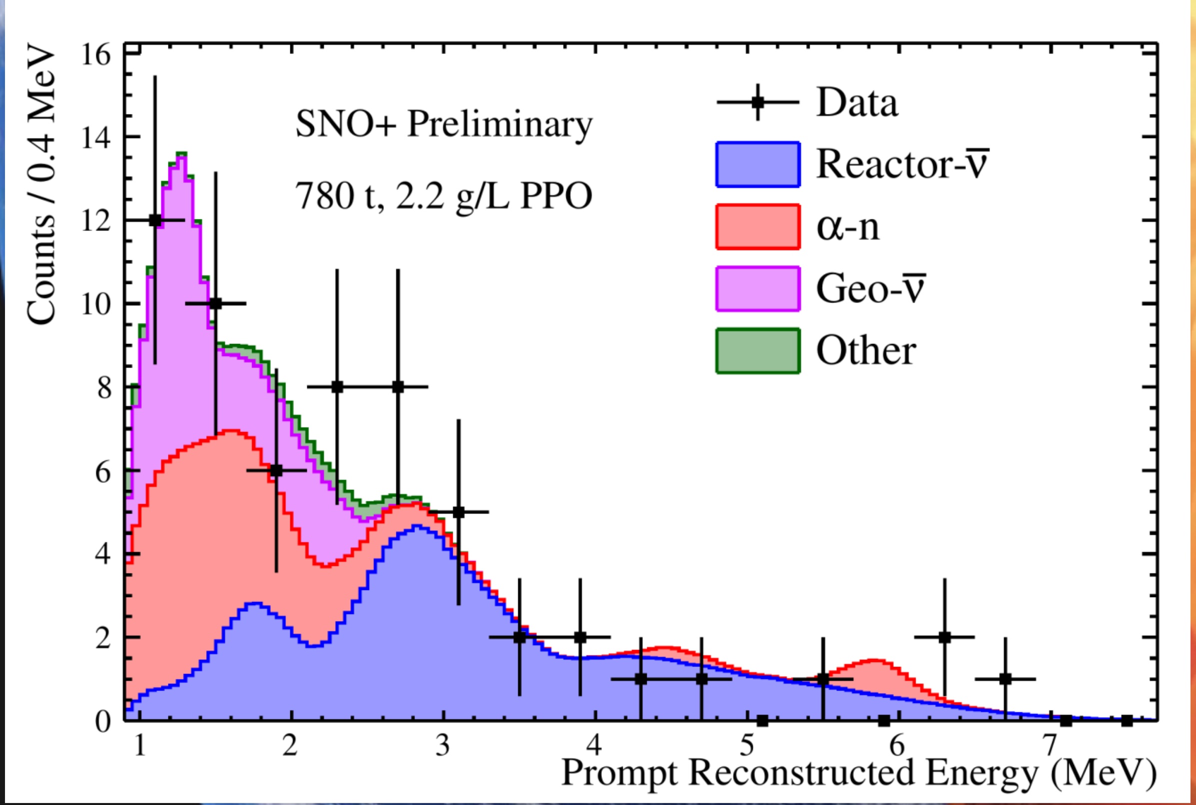
SNO+ Reactor Neutrino Oscillations (preliminary) – first time Δm^2_{21} is being tested

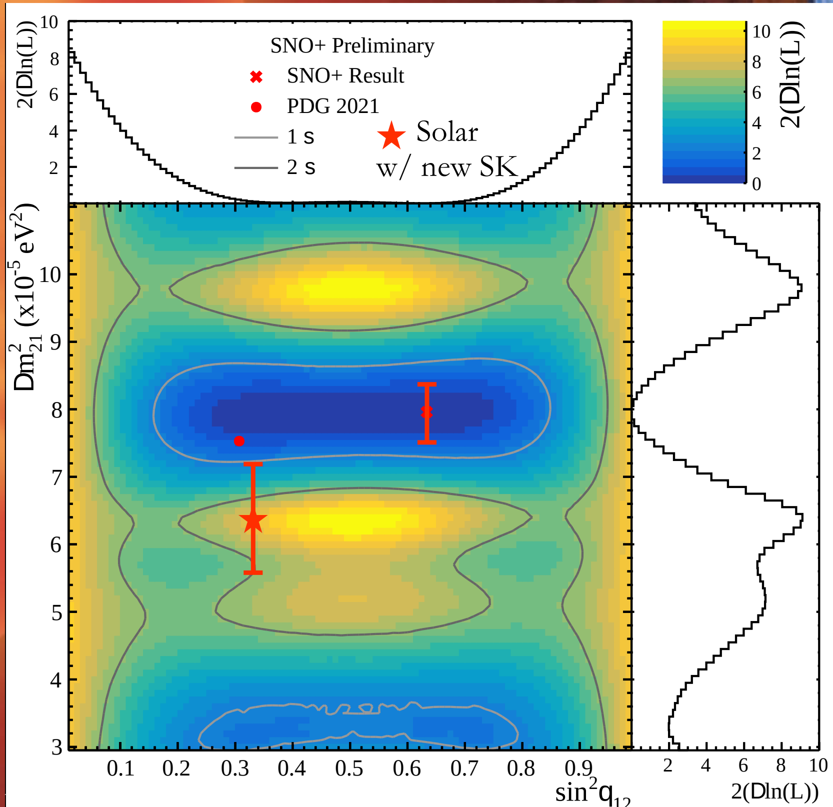


$\Delta m^2_{21} = 7.96^{+0.48}_{-0.41} \times 10^{-5}$ eV^2 from SNO+ Scintillator Phase, 286 tonne-year exposure

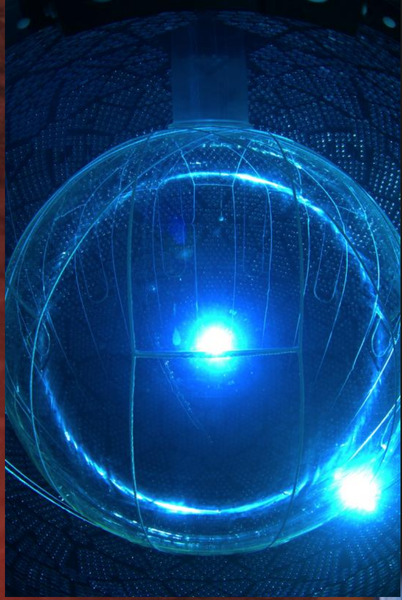
$\Delta m^2_{21} = 7.54^{+0.19}_{-0.18} \times 10^{-5}$ eV^2 from KamLAND

$\Delta m^2_{21} = 6.10^{+0.91}_{-0.85} \times 10^{-5}$ eV^2 from global solar ν_e

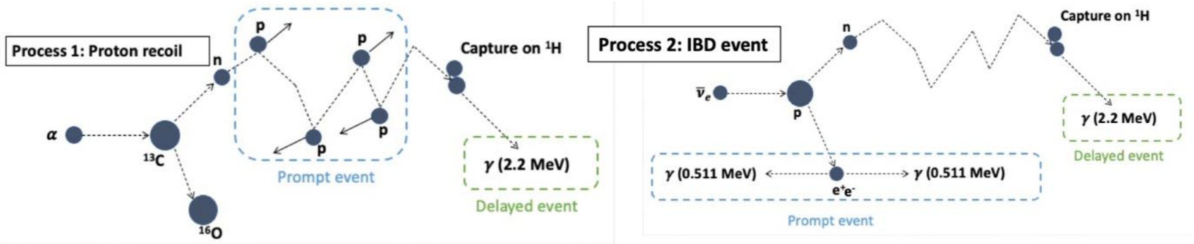


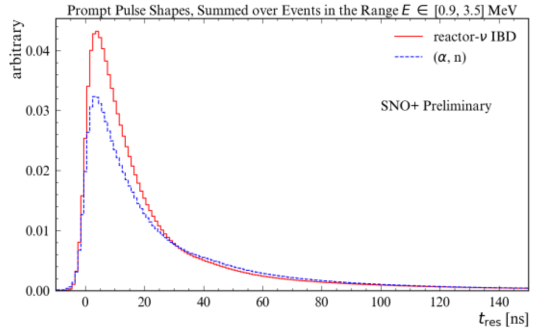


Future SNO+ Geo Neutrino Measurements



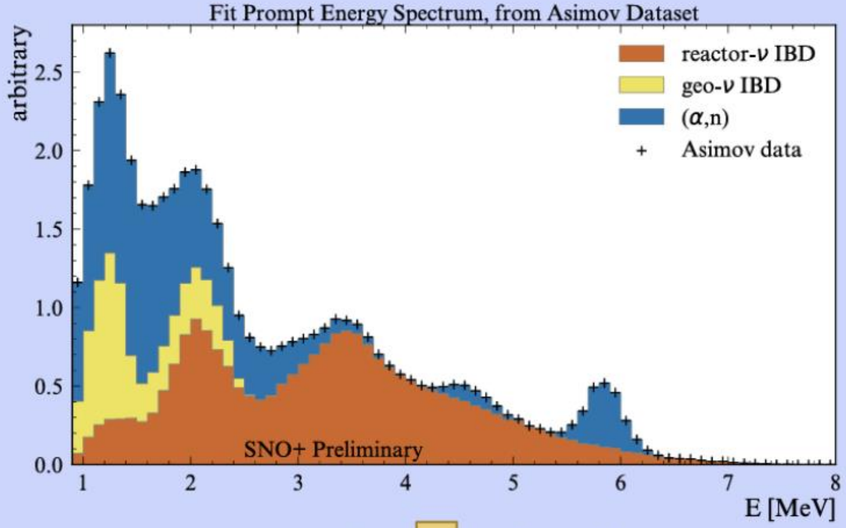
(α, n)-IBD Classifier



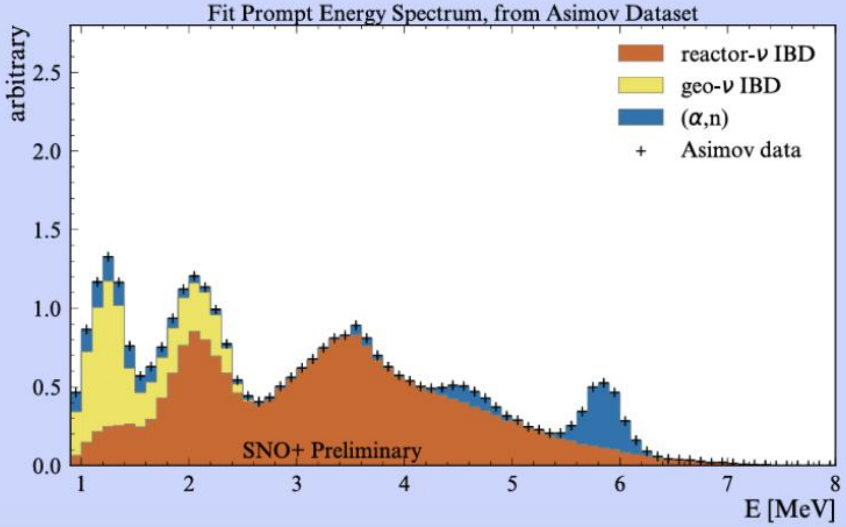


Newly developed classifier based on difference in time residuals for prompt proton recoils versus positron scintillation will greatly improve the SNO+ geoneutrino flux measurement (signal extraction), also improving reactor neutrino oscillation analysis too

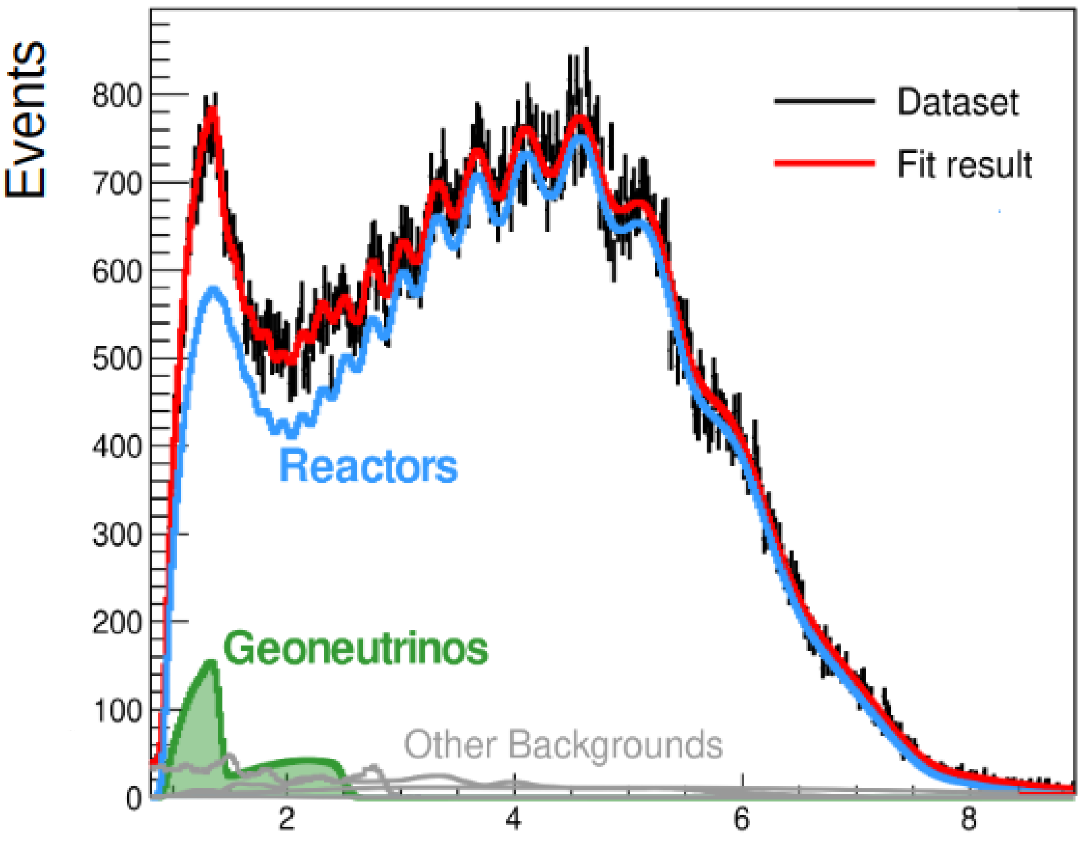
Impact on prompt energy spectrum:



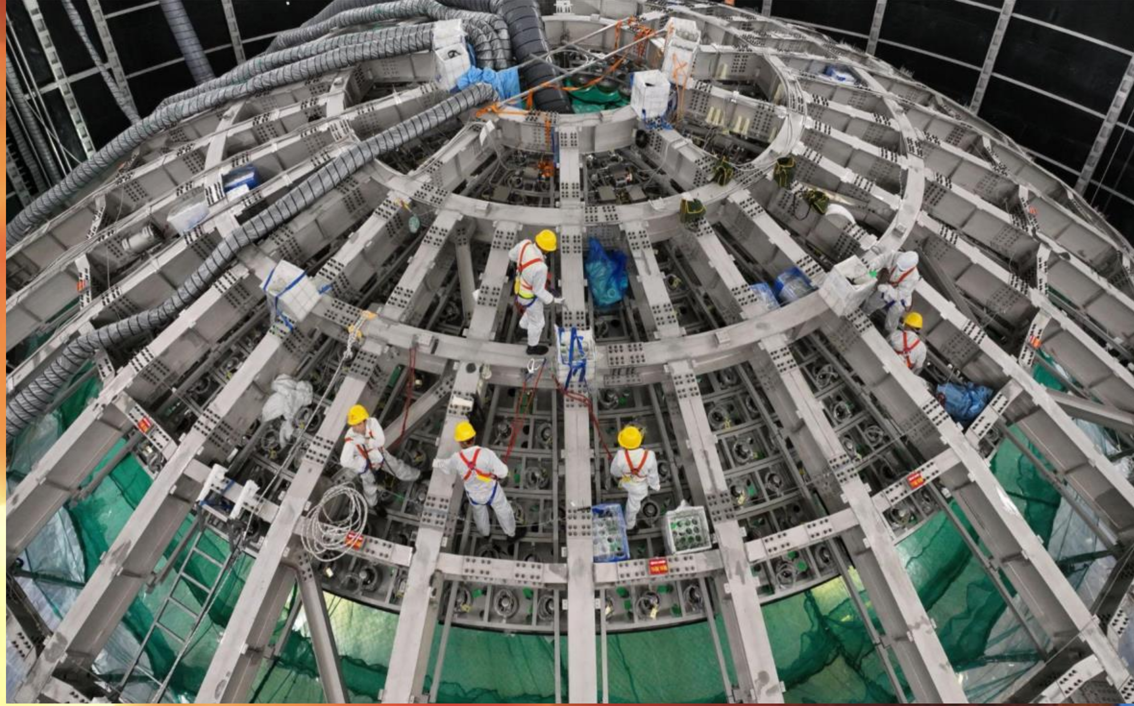
apply classifier



Future Geo Neutrino Experiment: JUNO



10 years expectation



400 geoneutrino events/year!
Despite the large reactor neutrino signal in the geo-nu region, the statistics are good to make a good measurement.

Preliminary expected sensitivity [%]

Th/U ratio fixed

Time	U+ Th
1 year	~22
6 years	~10
10 years	~8

Th and U free

Time	U	Th	U+Th	U/Th
6 years	~35	~40	~18	~70
10 years	~30	~35	~15	~55

KL 16%
BX 18%
SNO+ 5-yr 18%

talk by S. Dusini earlier today;
E. Percalli on Thursday

from C. Morales, L. Ludhova

Combining results in the future

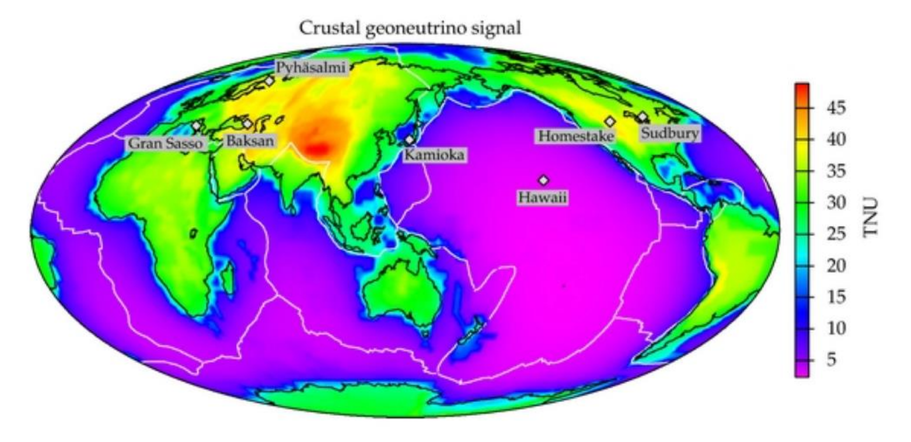


figure from O. Šrámek, W. McDonough, J. Learned, Adv. High Energy Phys. **2012**, 235686 (2012)

Using all geo neutrino results to determine the mantle contribution (homogeneity assumption)

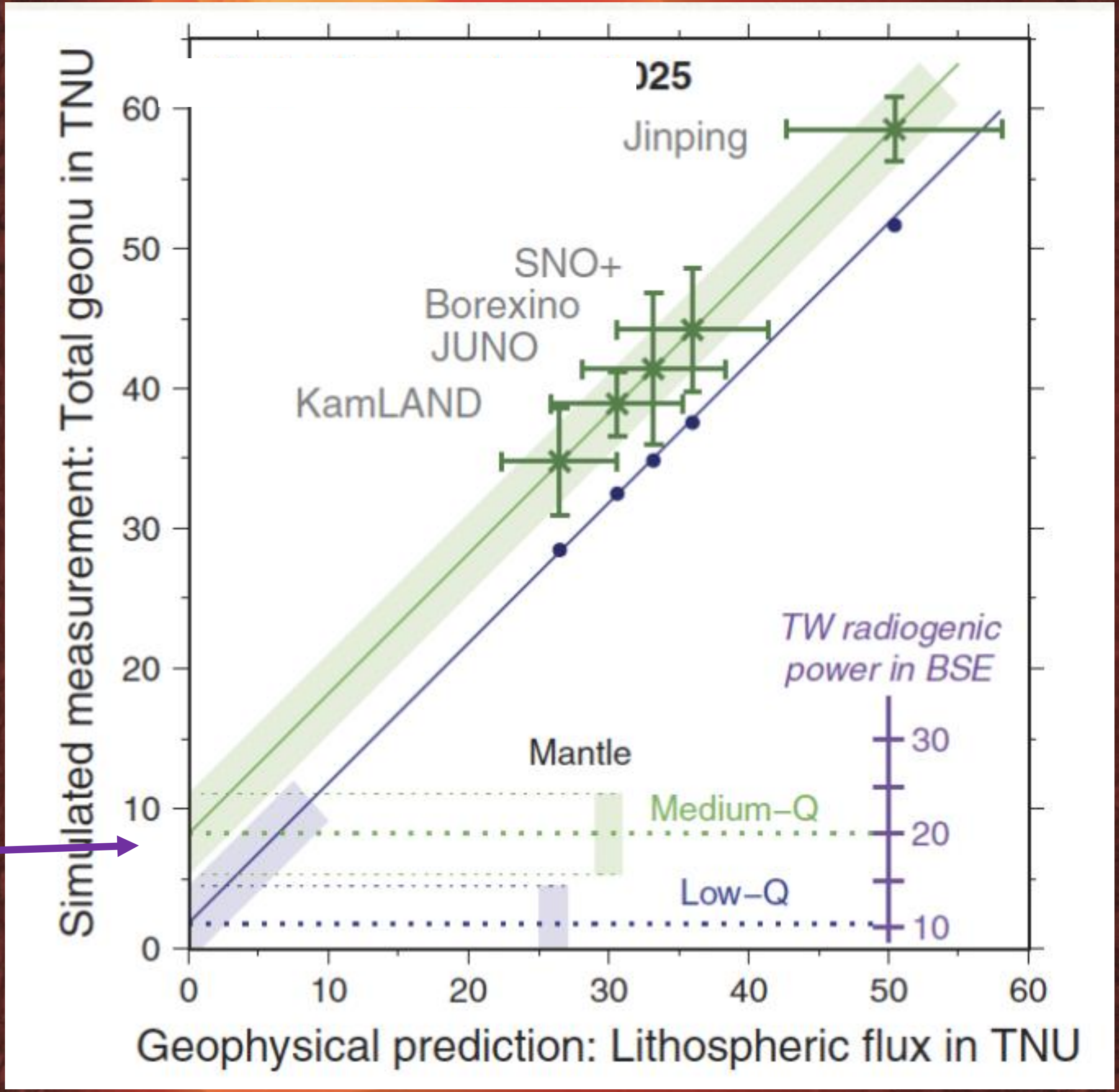


figure from W. McDonough

Conclusion

The “old” field of solar neutrino experiments sees new entrants to the game. Large experiments in the future will help scrutinize our understanding of the details of solar neutrino oscillations (and solar physics), with novelty and precision.

The “new” field of geo neutrino experiments is expanding with new measurements by SNO+ and JUNO. These add to the already interesting results and interpretations from KamLAND and Borexino.

Thank you! ΕΥΧΑΡΙΣΤΩ!