Borexino unravels the Sun and Earth with neutrinos

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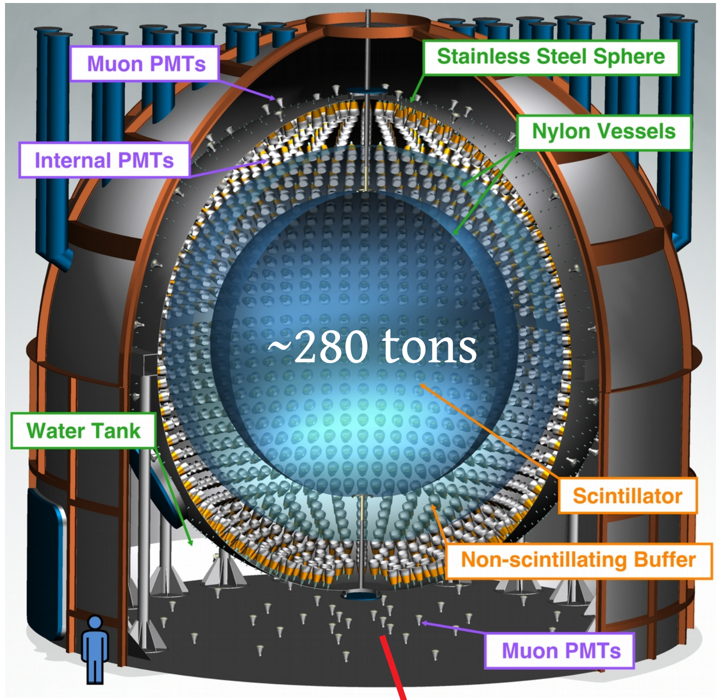
24th to 25th November, 2021| Helmholtz MU meeting

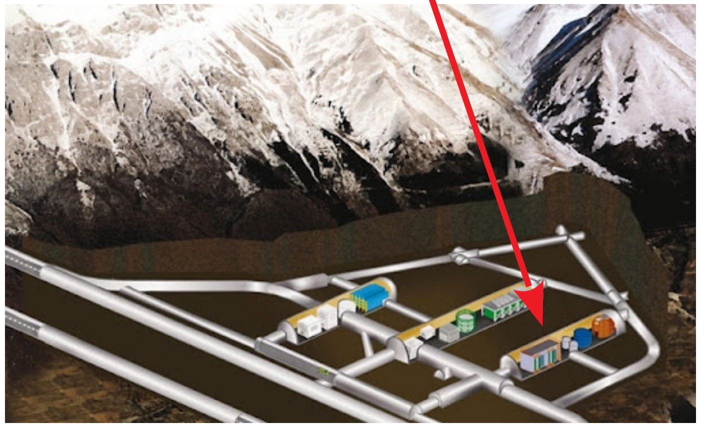
RWTH AACHEN UNIVERSITY

JÜLICH Forschungszentrum

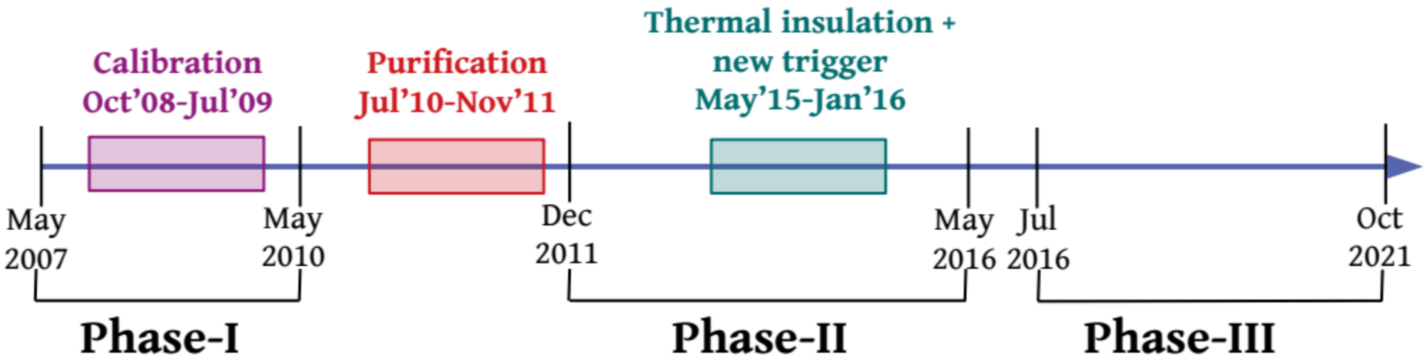
The Borexino detector



@ LNGS, Italy



- 3800 m w.e. depth, muon flux $(3.432 \pm 0.003) \cdot 10^{-4} m^{-2} s^{-1}$
- Most radio-pure liquid scintillator (LS) in the world: $^{238}U < 9.5 \cdot 10^{-20}$ g/g (95% C.L.), $^{32}Th < 7.2 \cdot 10^{-19}$ g/g (95% C.L.)
- Energy resolution: 5%/√E(MeV)
- Position resolution: ~10 cm @ 1 MeV

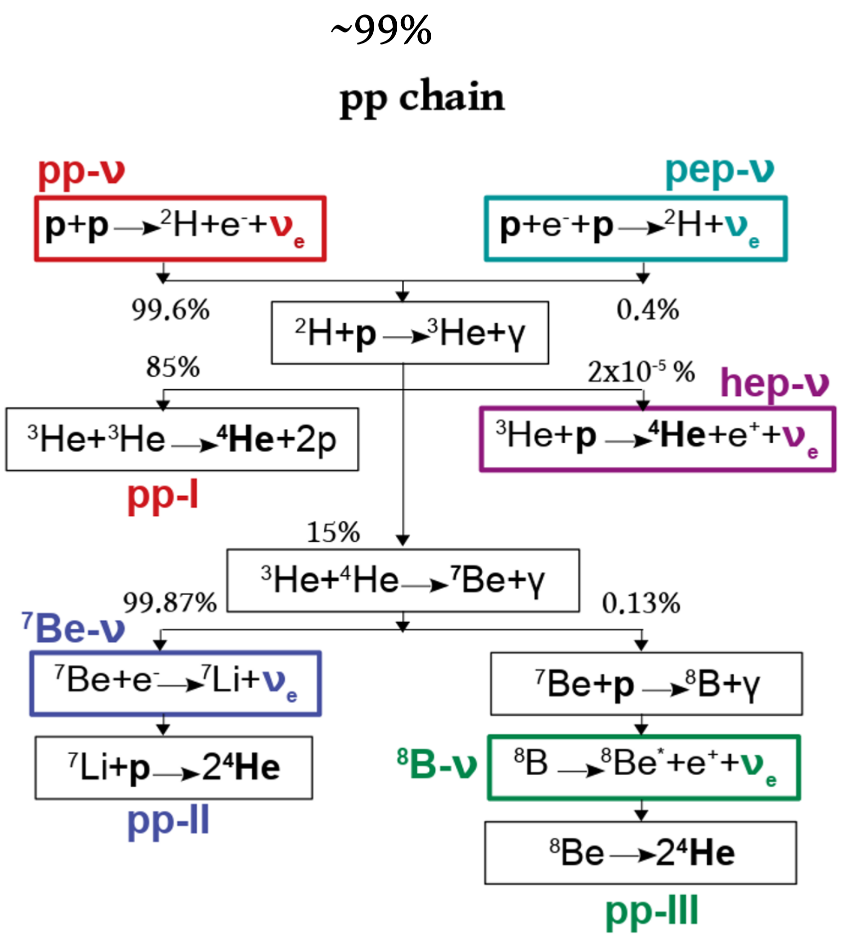


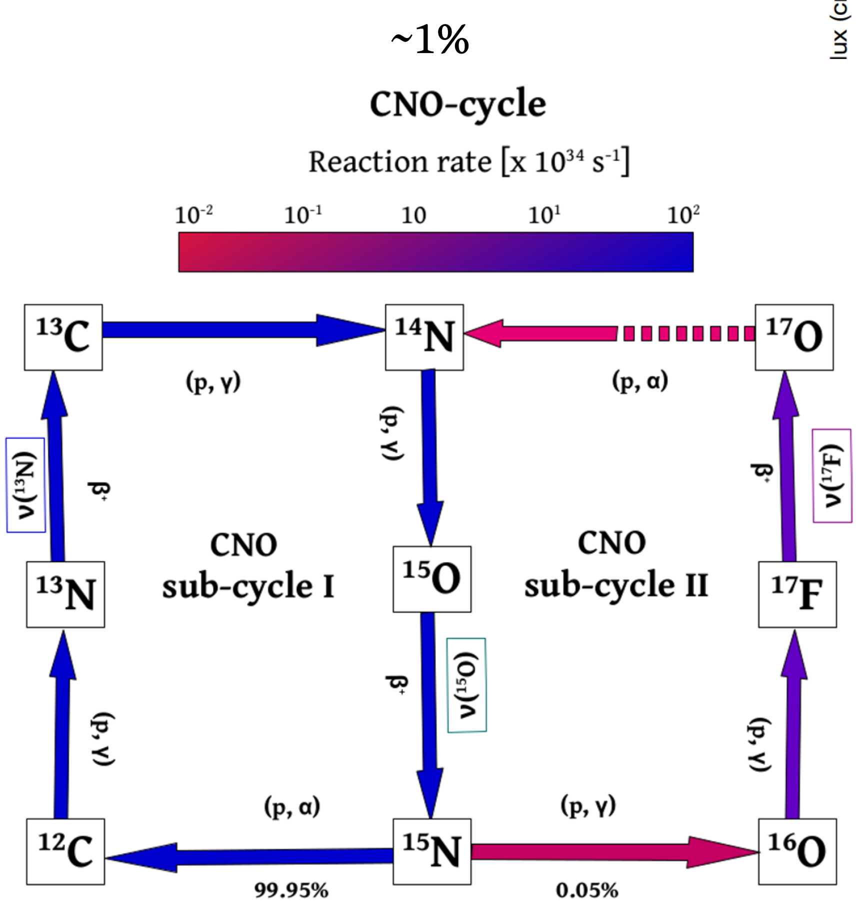
Today:

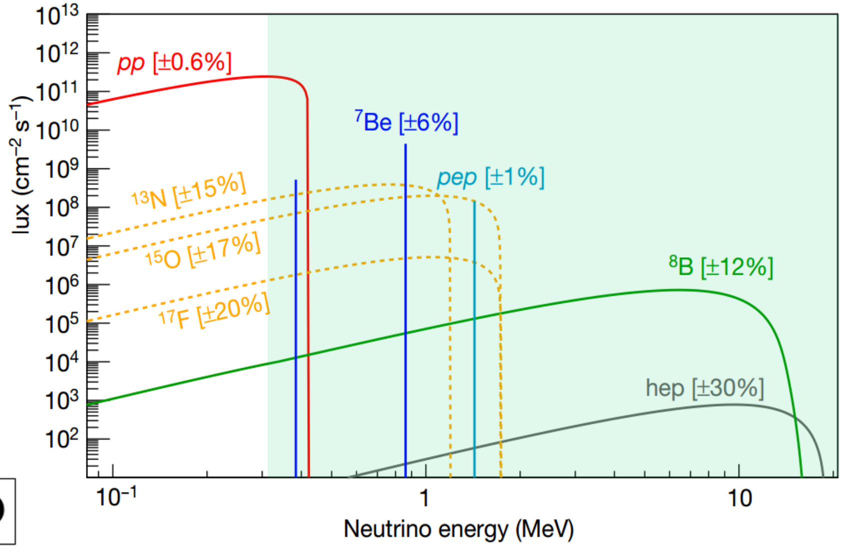
- ✓ First experimental evidence of CNO-cycle solar neutrinos
- ✓ First directional measurement of sub-MeV solar neutrinos
- ✓ Updated geoneutrino measurement

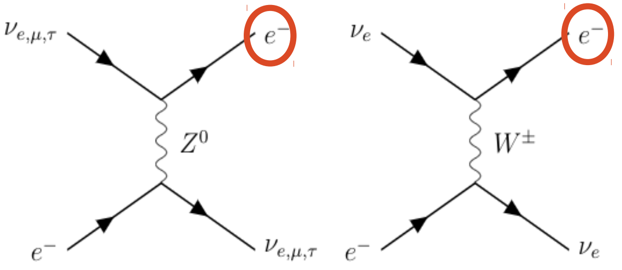
Solar neutrinos and Borexino

Flux on Earth ~10^{11} cm^{-2} s^{-1}

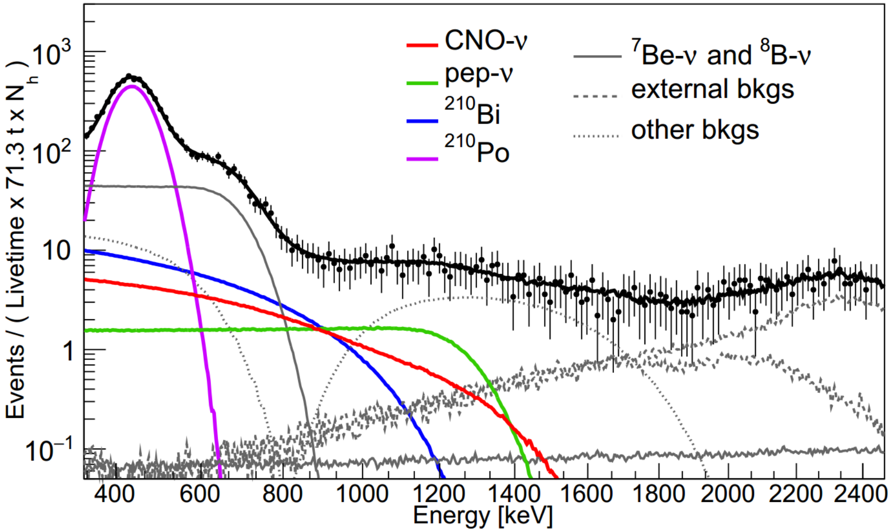






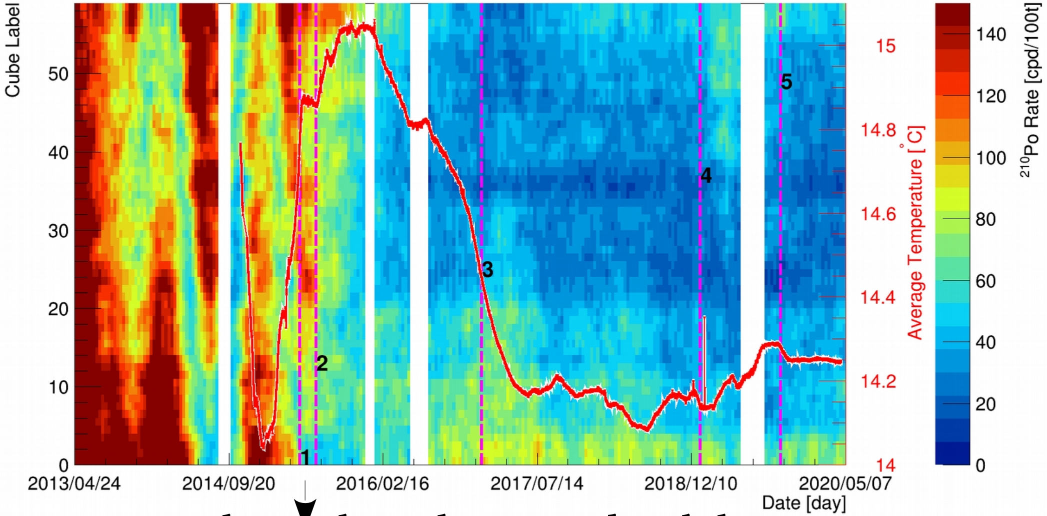


CNO-cycle solar neutrinos

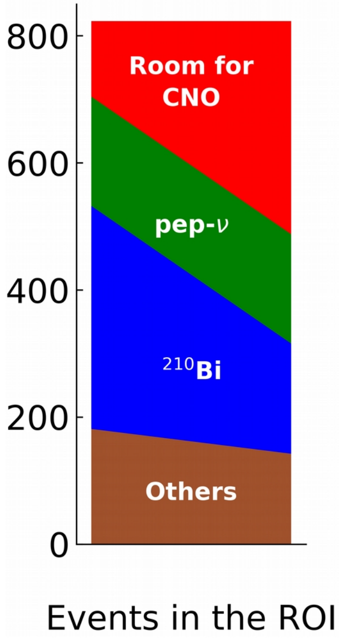


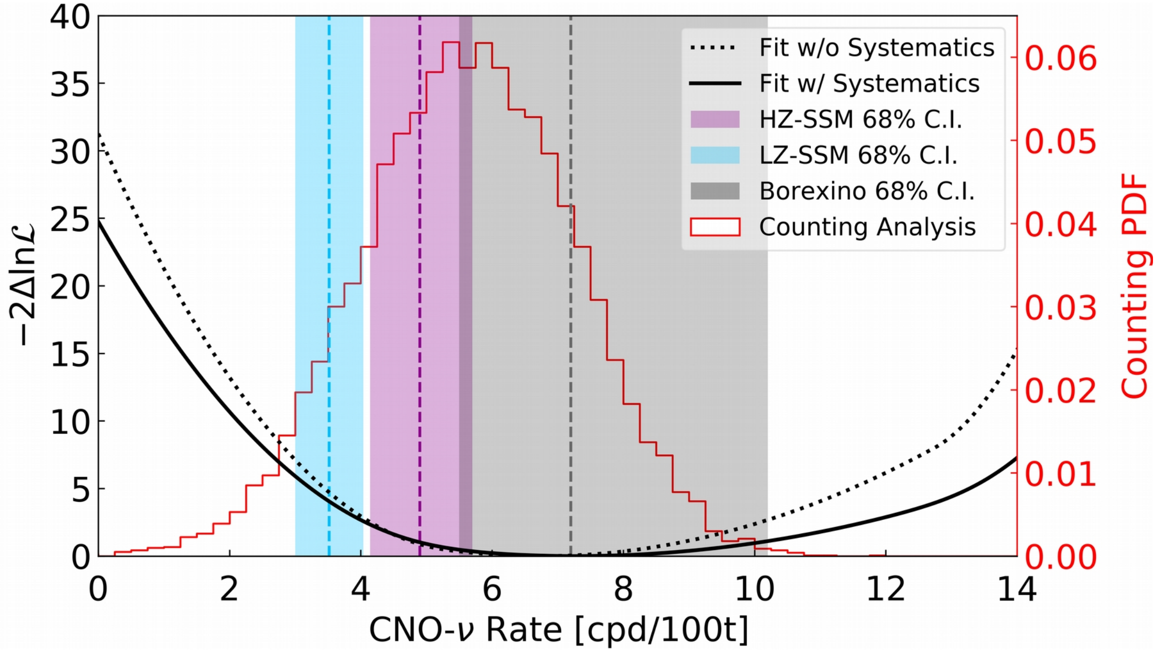
^{210}Pb → ^{210}Bi → ^{210}Po

^{210}Po distribution



Thermal insulation and stabilisation





pep constraint: 2.74 ± 0.04 cpd/100t → from theory and global analysis
^{210}Bi upper limit: 11.5 ± 1.3 cpd/100t → from ^{210}Po
Multivariate fit: energy + radial + specialised tagging of cosmogenic ^{11}C

Borexino results highlights **Nature 587 (2020)**

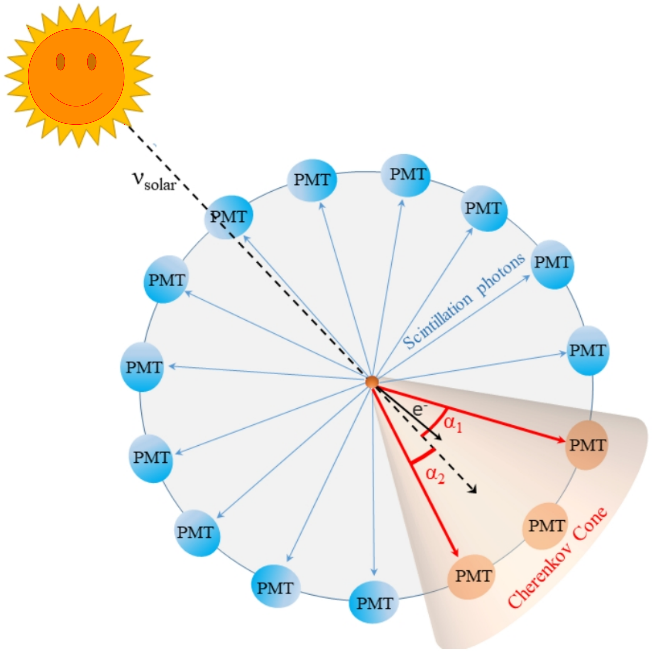
- First direct experimental evidence of CNO-cycle neutrinos > 5σ rejection of no-signal

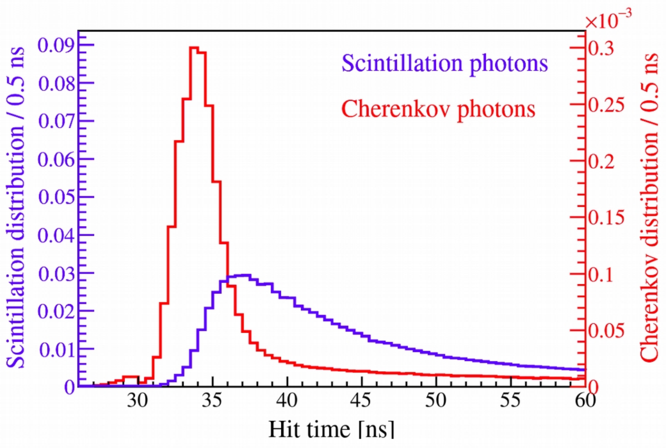
$$\nu(\mathrm{CNO}) = 7.2^{+3.0}_{-1.7}\ \mathrm{cpd/100t}$$

- Low metallicity (abundance of metals in the Sun) solar models disfavored at 2.1σ (CNO + Phase-II results)

Directionality of solar neutrinos

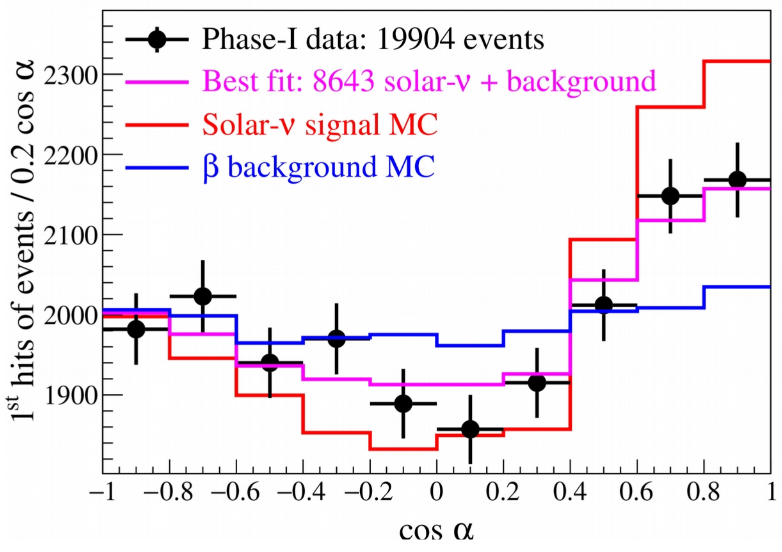
Correlated and Integrated Directionality (CID)





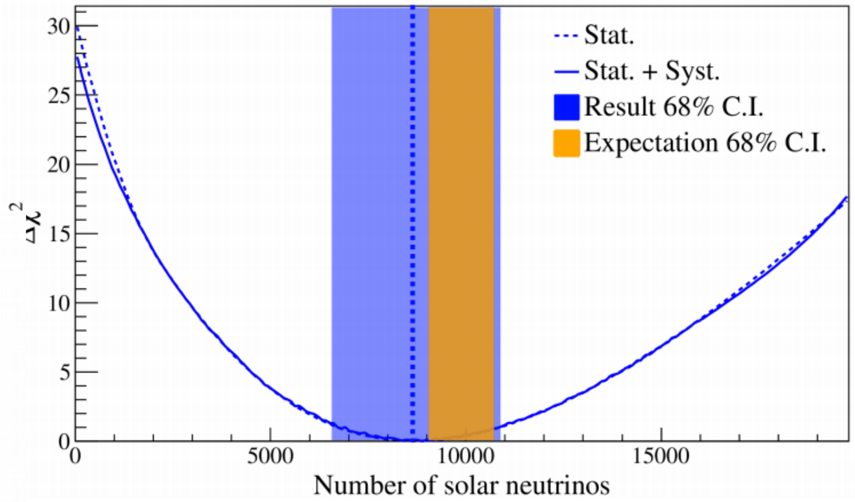
- Photon hit-based directional measurement using well-known position of the Sun

- Why? Next-generation hybrid detectors: need to combine advantages of Cherenkov and scintillation light



Borexino results highlights arXiv: 2109.04770

- ✓ First directional measurement of sub-MeV solar neutrinos > 5σ rejection of no-solar signal using Cherenkov photons
- ✓ Readily applicable for next-generation LS detectors without specialised hardware or LS mixtures
- ✓ Can be further combined with a typical energy spectral fit



$$N_{solar} = 8643^{+2171}_{-1969}\ \text{(stat.)} \pm 597\ \text{(sys.) events}$$

$$R(^{7}\text{Be}) = 39.7^{+12.0}_{-11.0}\ \text{(stat.+sys.) cpd/100t}$$

Geoneutrinos

Flux on Earth ~10^6 cm^{-2} s^{-1}

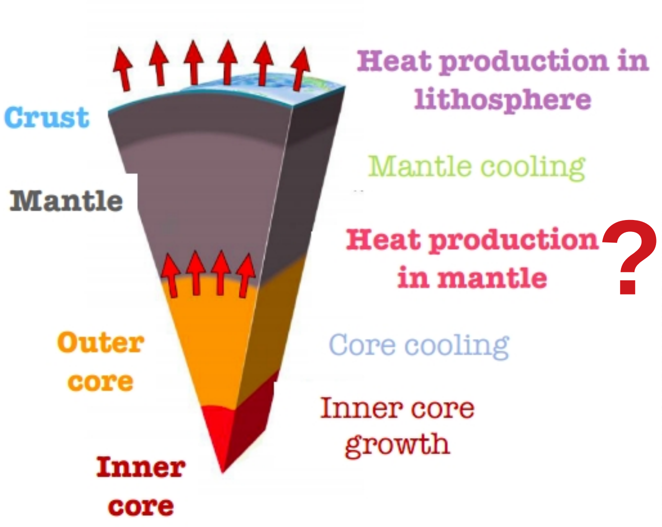
$$^{238}\mathrm{U} \to {}^{206}\mathrm{Pb} + 8\alpha + 8e^- + \boxed{6\bar{\nu}_e} + 51.7\,\mathrm{MeV}$$

$$^{235}\mathrm{U} \to {}^{207}\mathrm{Pb} + 7\alpha + 4e^- + \boxed{4\bar{\nu}_e} + 46.4\,\mathrm{MeV}$$

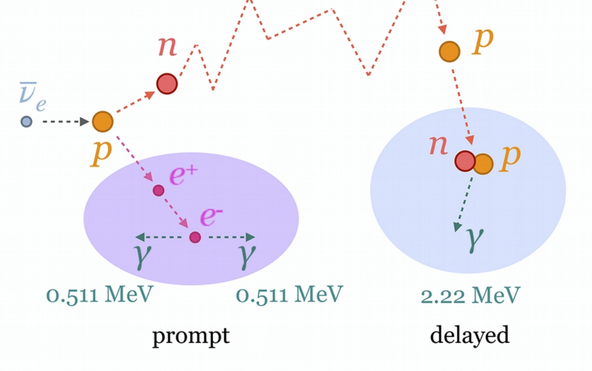
$$^{232}\mathrm{Th} \to {}^{208}\mathrm{Pb} + 6\alpha + 4e^- + \boxed{4\bar{\nu}_e} + 42.7\,\mathrm{MeV}$$

$$^{40}\mathrm{K} \to {}^{40}\mathrm{Ca} + e^- + \boxed{\bar{\nu}_e} + 1.31\,\mathrm{MeV}\ (89.3\%)$$

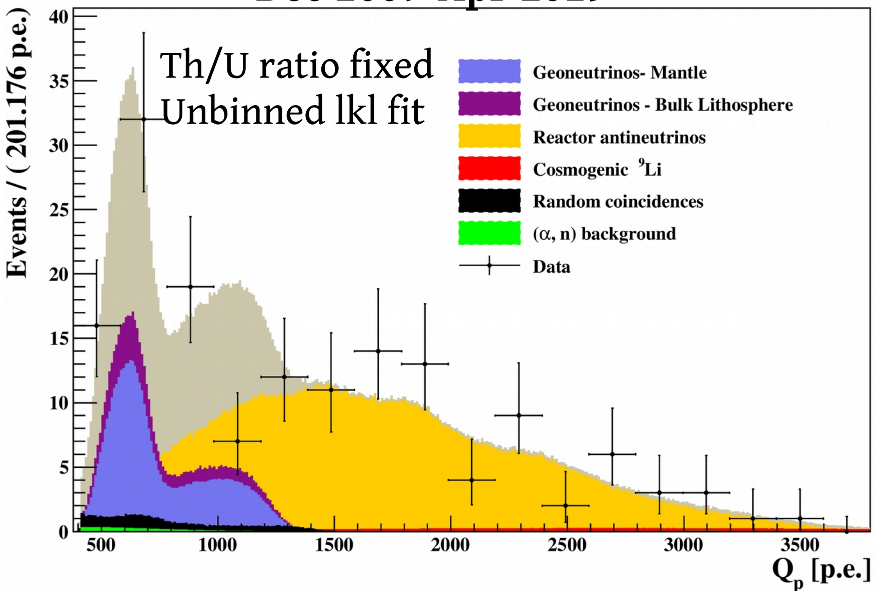
Integrated surface heat flux:
H_{tot} = (47 ± 2) TW



Inverse beta decay (IBD)



Dec 2007-Apr 2019

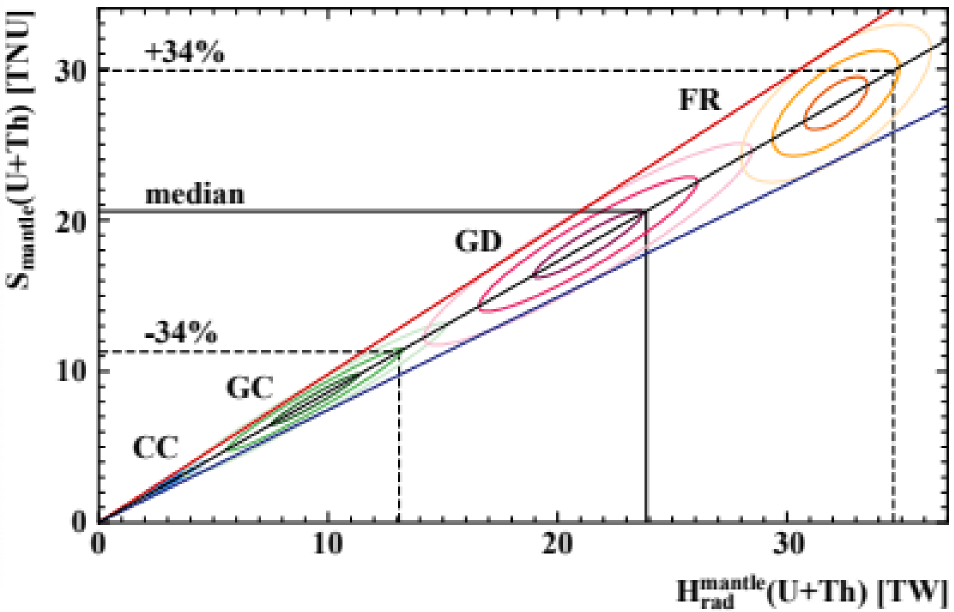


$$N_{geo} = 52.6^{+9.4}_{-8.6}\ (\mathrm{stat.})^{+2.7}_{-2.1}\ (\mathrm{sys.})\ \mathrm{events}$$

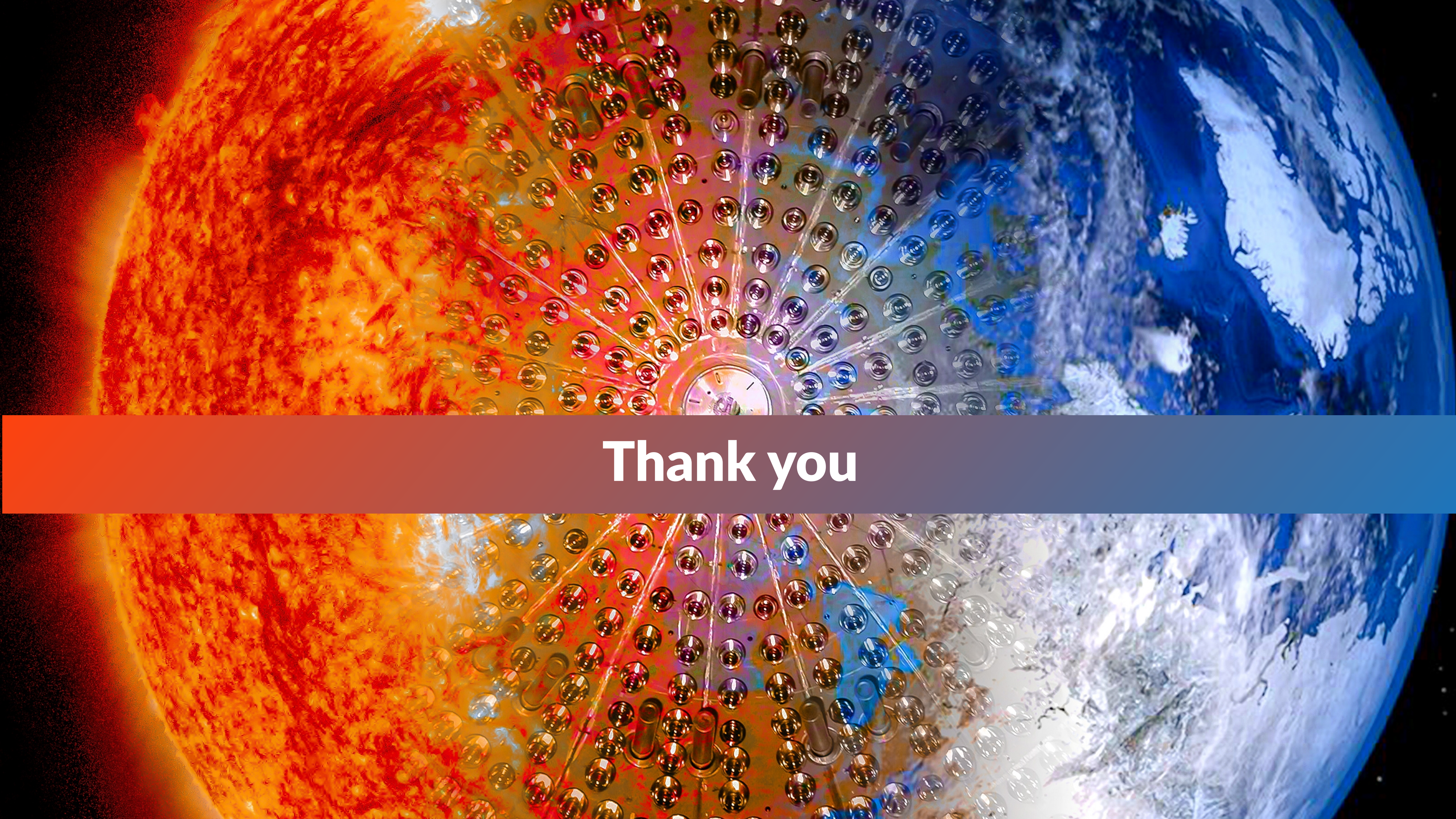
$$N_{mantle} = 23.7^{+10.7}_{-10.0}\ (\mathrm{stat.})^{+1.2}_{-1.0}\ (\mathrm{sys.})\ \mathrm{events}$$

Borexino results highlights Phys. Rev. D 101 (2020)

- Uncertainty reduction from ~27% to 18%
- First 99% CL rejection of no-mantle signal
- 2.4σ tension with models predicting low mantle heat



$$H_{rad}^{tot} = 38.2^{+13.6}_{-12.7}\ \mathrm{TW}$$


Thank you