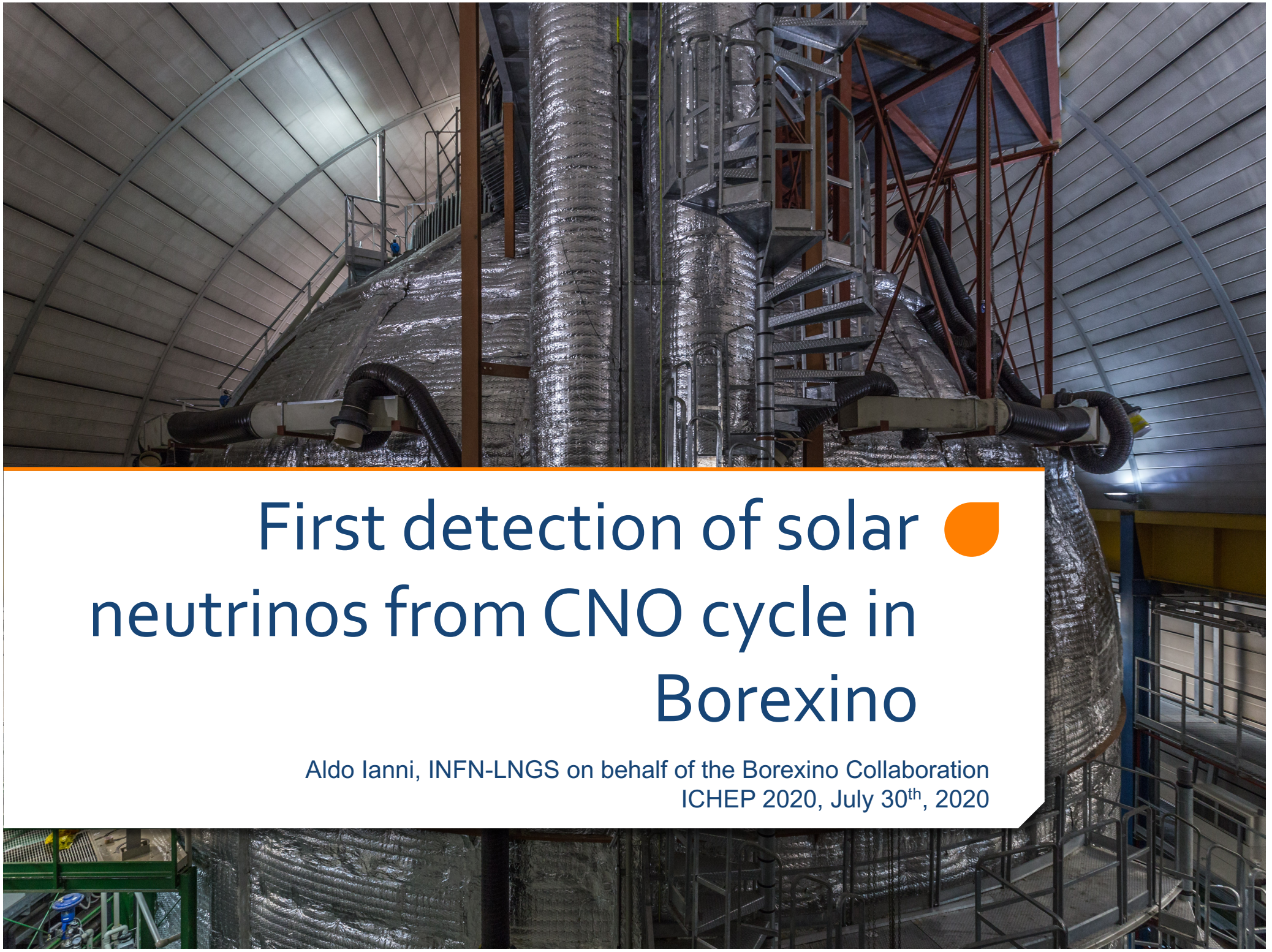


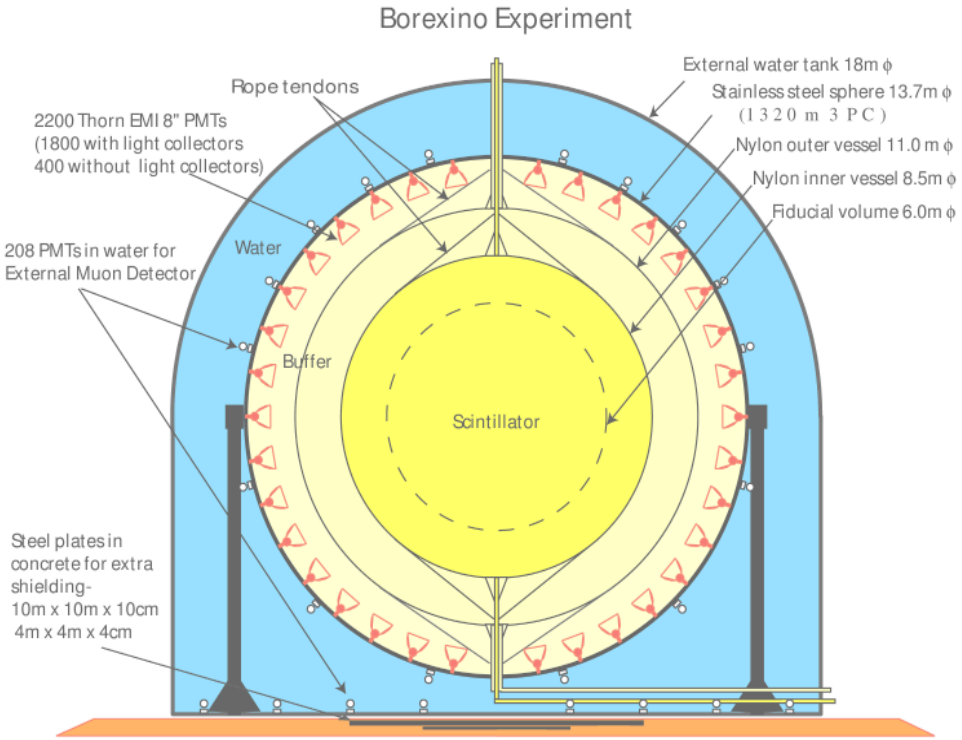
First detection of solar neutrinos from CNO cycle in Borexino

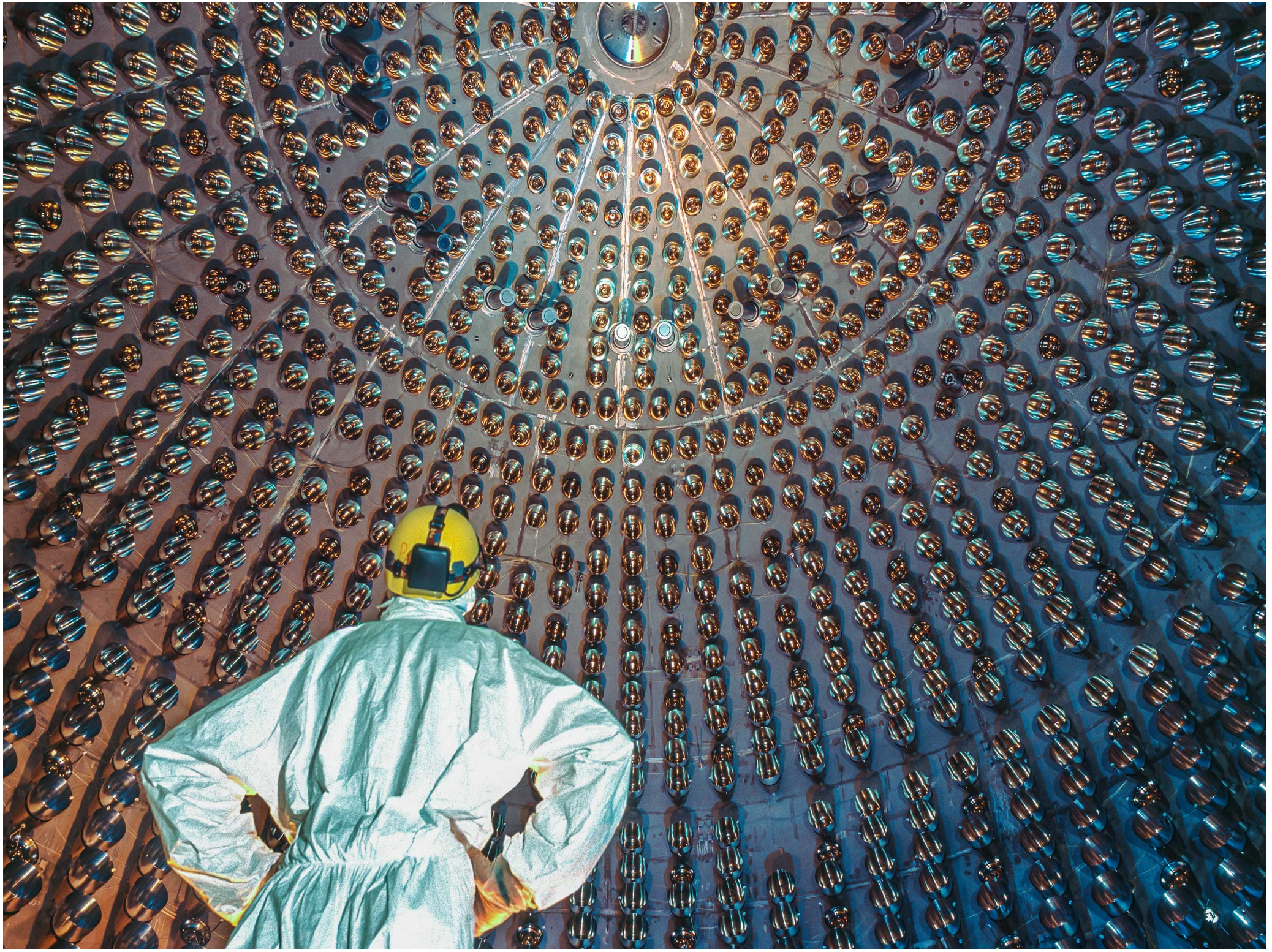
Aldo Ianni, INFN-LNGS on behalf of the Borexino Collaboration

ICHEP 2020, July 30th, 2020

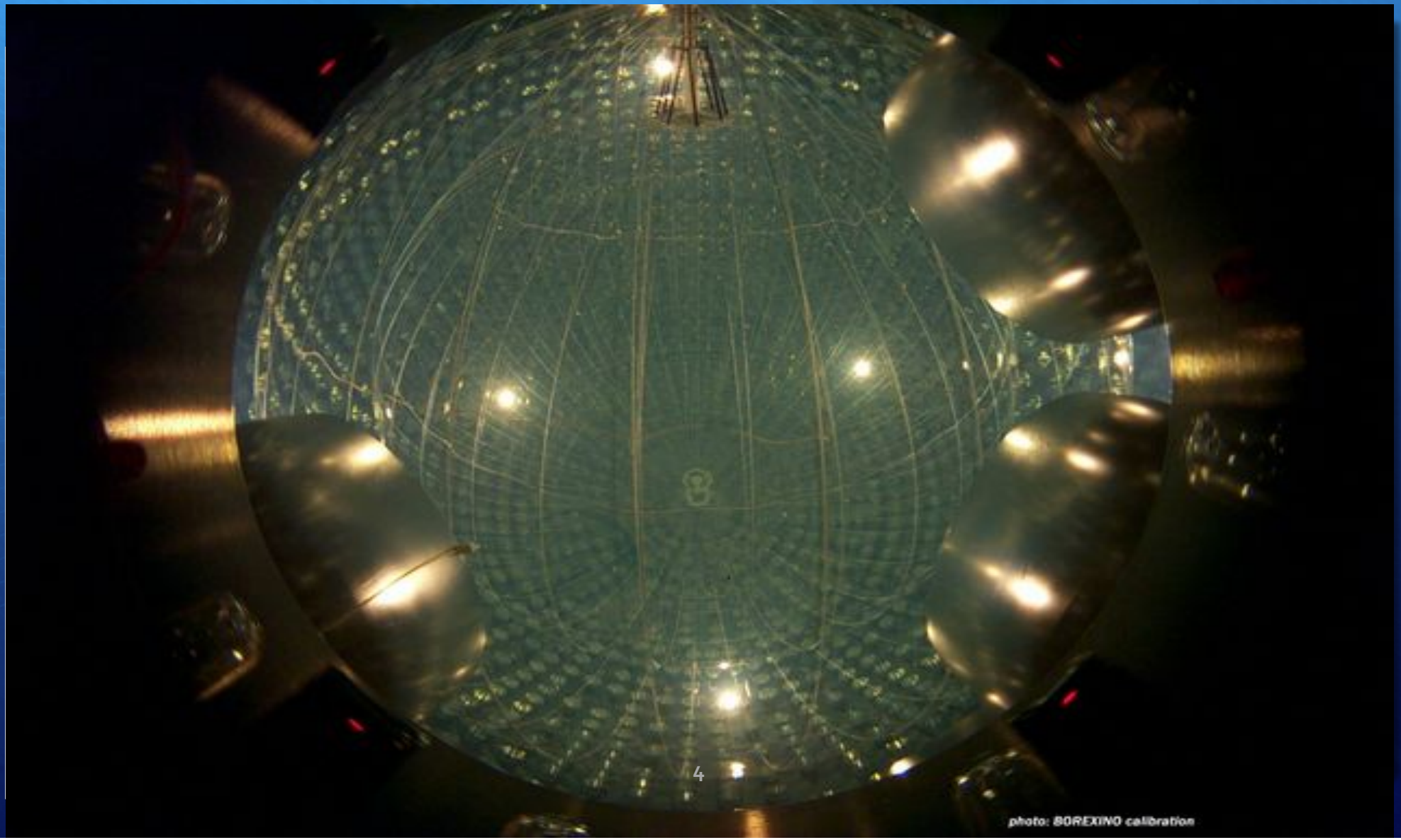
BOREXINO detector

- 280 tons of liquid scintillator
- 2212 8-inch PMTs
- Active Cherenkov muon veto
- Average number of active channels for this data set: 1238
- $\Delta E/E \sim 6\%$ and $\sigma_{x,y,z} \sim 11$cm at 1 MeV

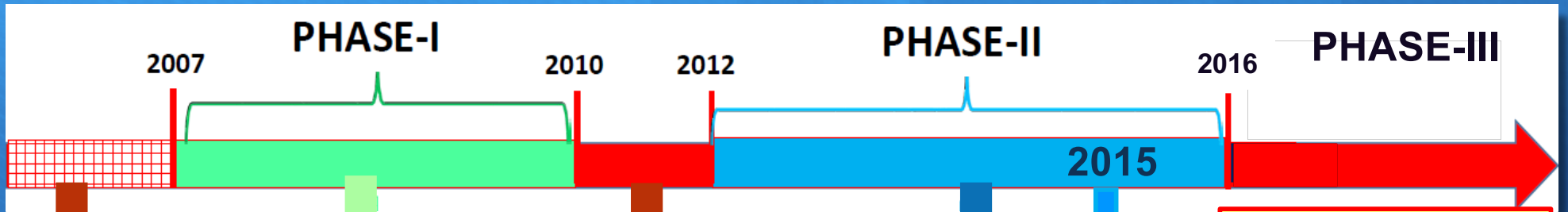




Start data taking: May 2007



Borexino operations and achievements



Filling and purification (distillation)

LS purification campaign
6 cycles of water extraction

Thermal insulation and active temperature Control system

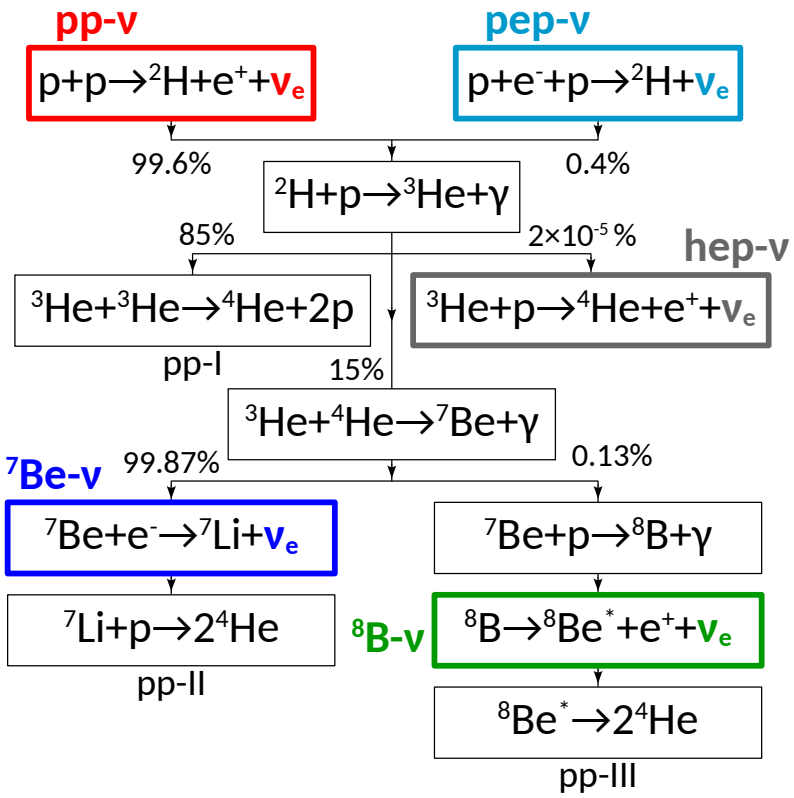
- R(^{7}Be) + D/N
- R(pep) – first observation
- R(^{8}B)– first with LS
- R(CNO) – limit

geo-ν – first robust observation

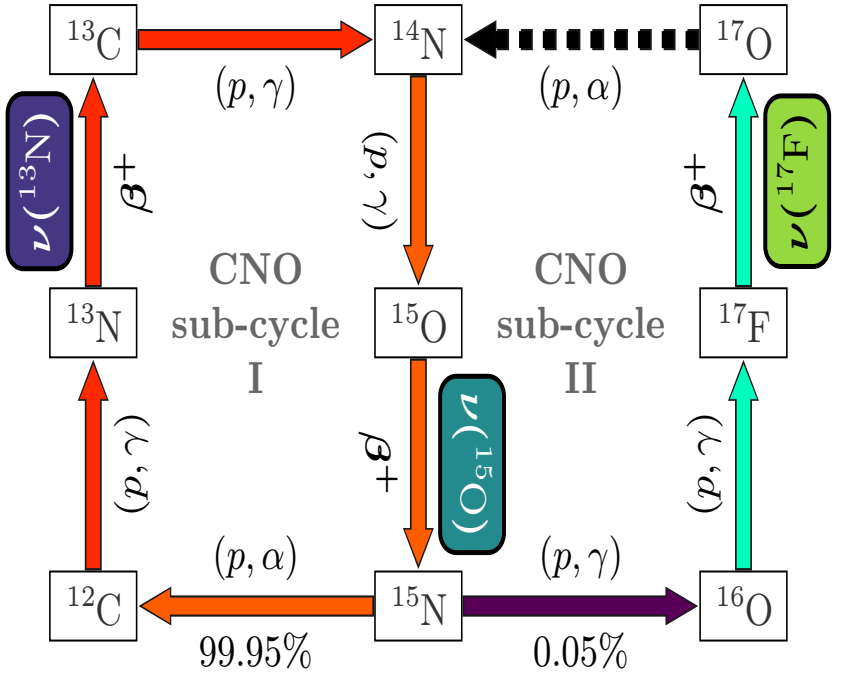
- R(pp) *first in real time*
- Seasonal variations of R(^{7}Be)
- Simultaneous spectroscopy of pp, ^{7}Be and pep ν
- R(^{8}B)–improved
- geo-ν

Solar neutrinos

pp chain



CNO cycle

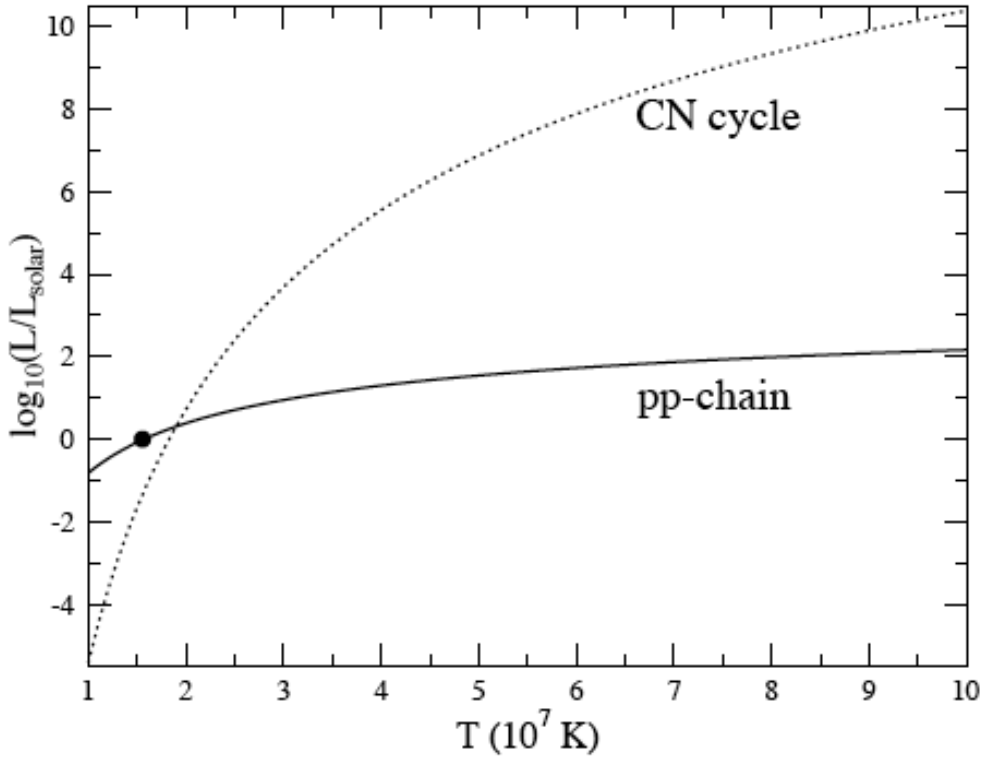


Solar neutrinos and energy production

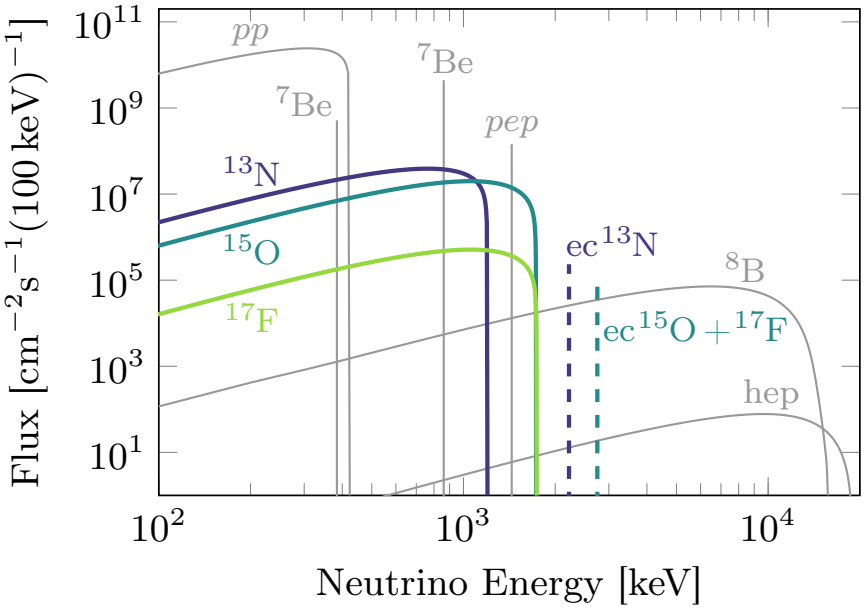
+ *Energy conservation*

$$\frac{L_\odot}{4\pi(A.U.)^2} = \sum_i a_i \phi_i^\nu$$

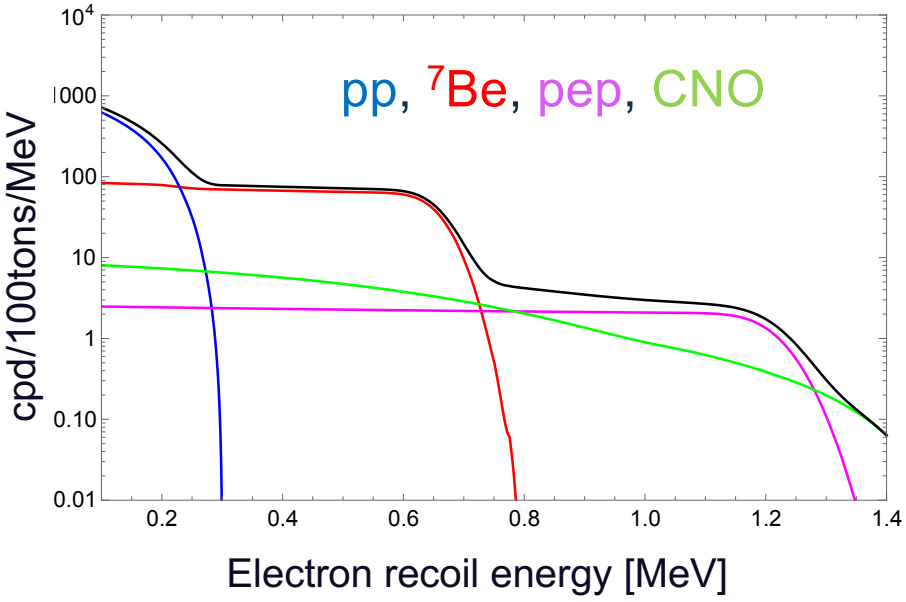
$L_\odot$=3.846±0.015 erg/s



Solar neutrino energy spectrum



Neutrino-electron elastic scattering expected spectrum in Borexino

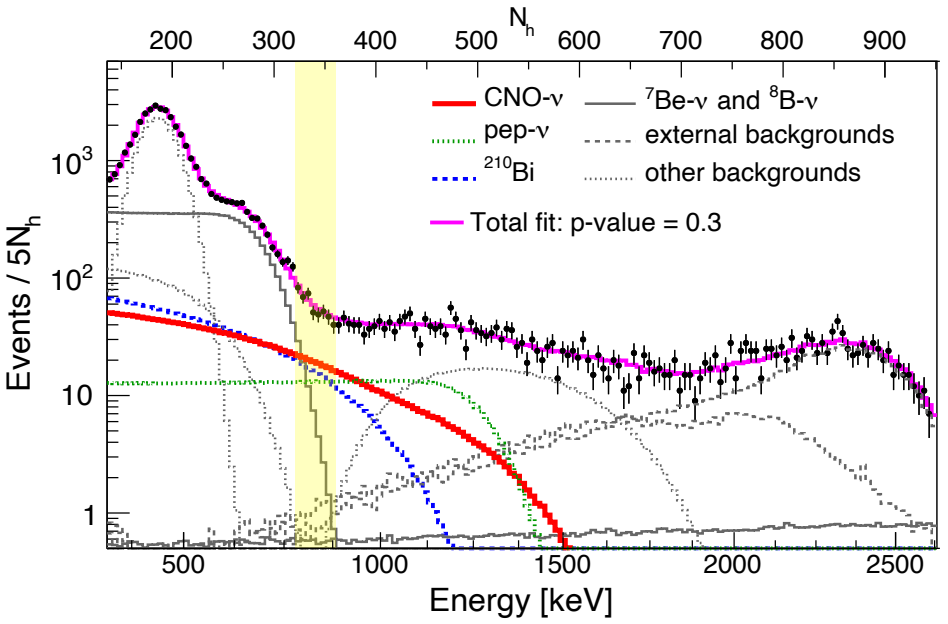


Borexino achievements on solar neutrinos

ν source	SSM-HZ/SSM-LZ [cm^{-2} s^{-1}]	Borexino rate [cpd/100tons]	Borexino flux [cm^{-2} s^{-1}]
pp	$5.98(1\pm0.006)\times10^{10}$ $6.03(1\pm0.006)\times10^{10}$	134^{+12}_{-14}	$6.1(1\pm0.10)\times10^{10}$
pep	$1.44(1\pm0.01)\times10^{8}$ $1.46(1\pm0.01)\times10^{8}$	$2.43^{+0.39}_{-0.42}$ $2.65^{+0.39}_{-0.43}$	$1.27(1\pm0.17)\times10^{8}$ $1.39(1\pm0.16)\times10^{8}$
^{7}Be	$4.93(1\pm0.06)\times10^{9}$ $4.50(1\pm0.06)\times10^{9}$	$48.3^{+1.2}_{-1.3}$	$5.0(1\pm0.027)\times10^{9}$
^{8}B	$5.46(1\pm0.12)\times10^{6}$ $4.50(1\pm0.12)\times10^{6}$	$0.223^{+0.016}_{-0.017}$	$5.68(1\pm0.076)\times10^{8}$
hep	$7.98(1\pm0.30)\times10^{3}$ $8.25(1\pm0.30)\times10^{3}$	<0.002 (90% C.L.)	$<2.2\times10^{5}$
CNO	$4.88(1\pm0.16)\times10^{8}$ $3.51(1\pm0.14)\times10^{8}$	?	?

Challenge for CNO solar neutrino observation in Borexino

- Expected signal rate: 3 – 5 cpd/100ton
- Main background: ^{210}Bi $\quad {}^{210}\mathrm{Pb} \xrightarrow[22.3\,\mathrm{years}]{\beta^-} {}^{210}\mathrm{Bi} \xrightarrow[5\,\mathrm{days}]{\beta^-} {}^{210}\mathrm{Po} \xrightarrow[138.4\,\mathrm{days}]{\alpha} {}^{206}\mathrm{Pb}$
- Strong correlation between CNO, pep, and ^{210}Bi
- Expected S/B ~ 0.2 – 0.3

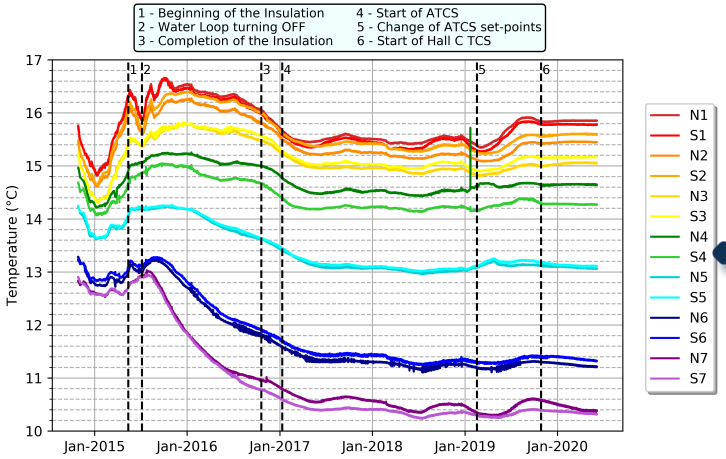


Strategy to observe CNO solar neutrinos in Borexino

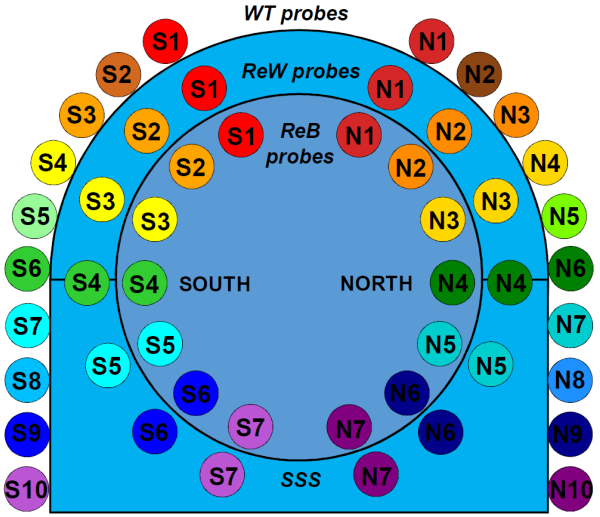
- Mitigate correlation with ^{210}Bi by reducing covenction currents which might take ^{210}Bi and ^{210}Po from nylon vessel into the fiducial volume
  - Thermal insulation and active temperature control system to establish a constant in time temperature gradient ($\Delta T/\Delta z \sim 0.5^{0}C/m$)
- Exploit PSD discrimination to determine ^{210}Po in inner volume
  - ^{210}Po consists of an intrinsic component in equilibrium with ^{210}Bi and in an «external» component carried by convective currents
  - Estimated migration length obtained from ^{210}Po radial distribution is of the order of 1m

Thermal insulation and temperature control

Borexino Water Tank with insulation



Deployment of T probes



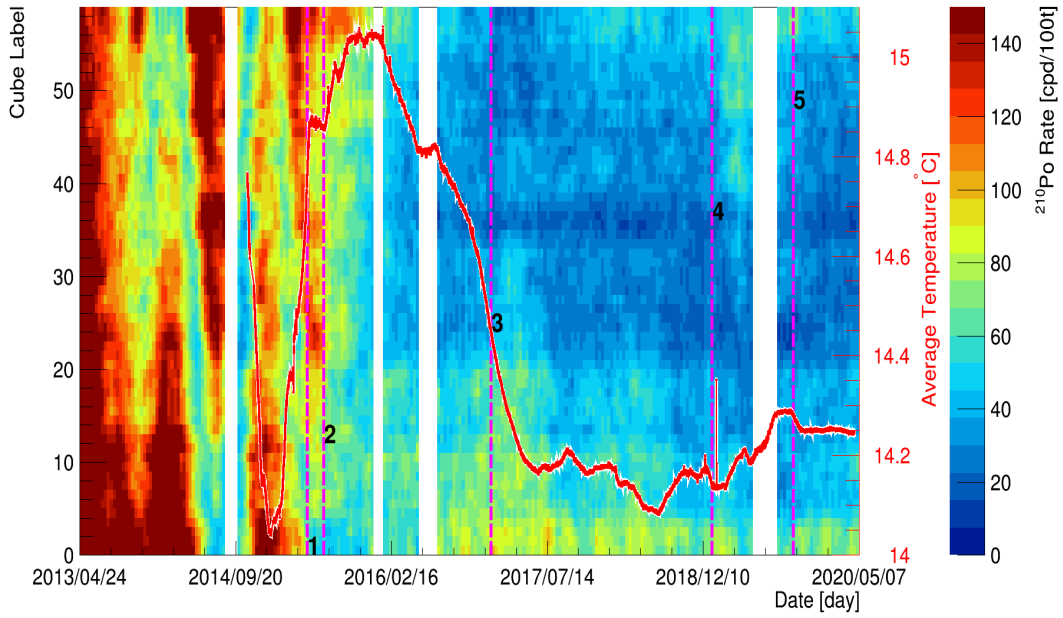
~15.8°C

~ 0.5°C/m

~7.5°C

Temperature as a function of time in different volumes of the detector

^{210}Po background in Borexino



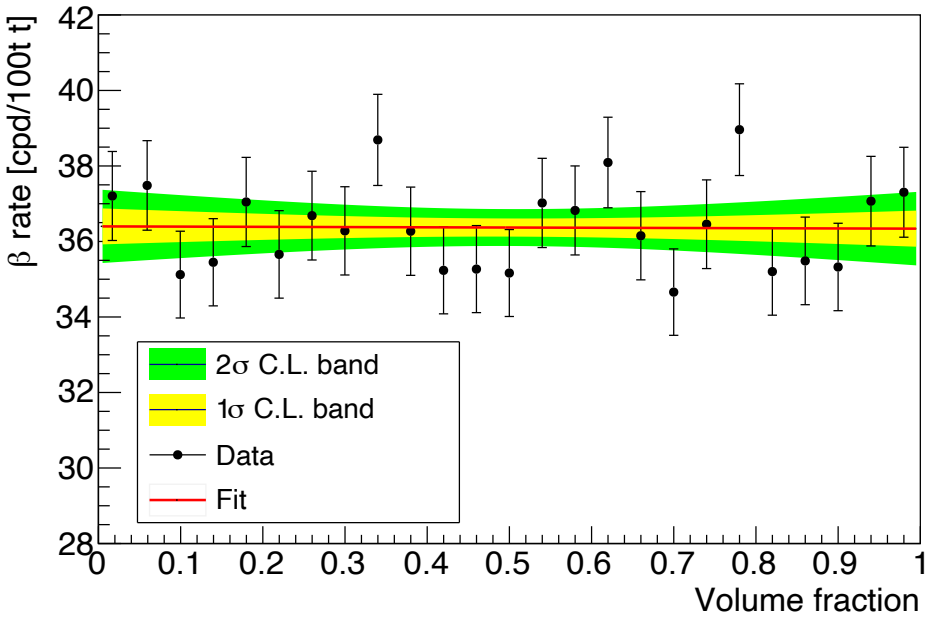
$$R(^{210}Po_{min}) = R(^{210}Bi) + R(^{210}Po^{Vessel})$$

- ^{210}Po rate in Borexino in cpd/100tons from bottom to top
- 3 tons cubes within 3m sphere

1. Beginning of thermal insulation
2. Water re-circulation loop in Water Tank off
3. Active temperature control system on
4. Change set point in the active control system
5. Air temperature control system in underground Hall

^{210}Bi constraint

- ^{210}Bi uniformity and time stability
  - ^{210}Bi from liquid scintillator must be uniform in FV and stable in time
- Select β-like events in specific energy window
  - study radial and angular distribution
  - study time stability

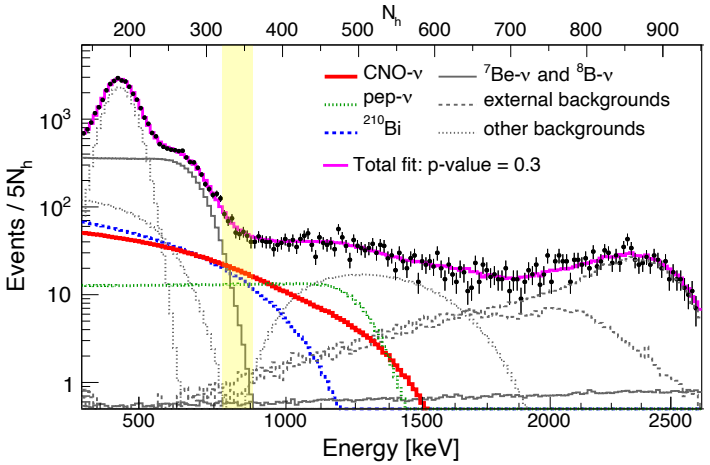


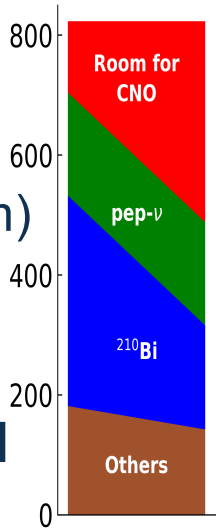
R(^{210}Bi) ≤11.5±1.3 cpd/100ton

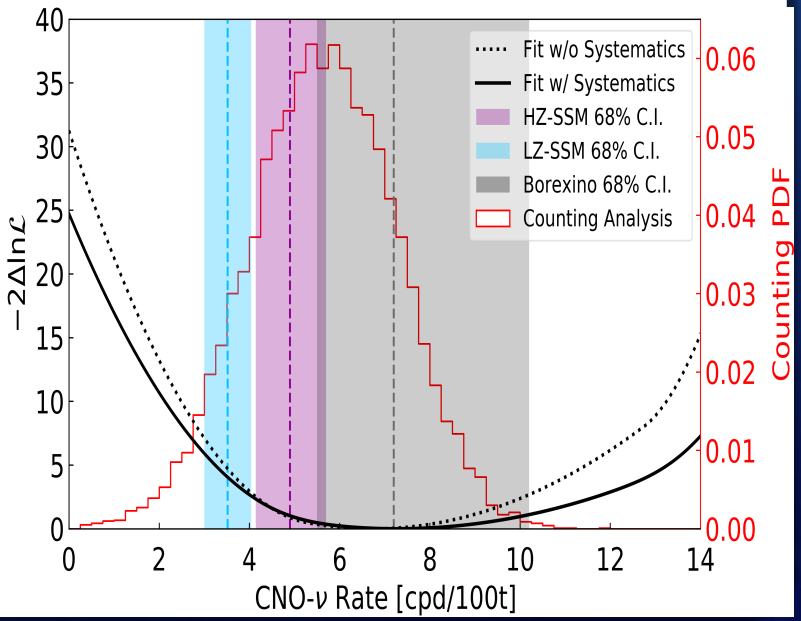
CNO analysis and result

- Energy window: 0.32-2.64 MeV
- Fit energy spectrum and radial distribution
- Free pars: CNO, ^{85}Kr, ^{11}C, ^{40}K, ^{208}Tl, ^{214}Bi, ^{7}Be
- pep constrained to 2.74±0.04 cpd/100ton
- ^{210}Bi constrained ≤ 11.5±1.3 cpd/100ton
- Data set July 2016 – Feb 2020
- 1072 days of livetime
- Selection cuts:
  - Muon and muon daughters
  - FV (R < 2.8 m && -1.8m<z<2.2m)
  - TFC

R(CNO) = 7.2 $^{+2.9}_{-1.7}$ cpd/100ton
Null hypothesis (CNO=0) rejected at 5.1σ







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Conclusions

- Borexino 12 years of data taking
- Full spectroscopy of solar neutrinos from pp-chain
  - pp at 10%; ^{7}Be at 2.7%; pep observed at 5σ; ^{8}B at 8% above 3MeV
- Detection of geo-neutrinos at > 5σ with 98% evidence of signal from the Mantle
- Annual modulation of muons and ^{7}Be rates
- No evidence for Day-night asymmetry for ^{7}Be neutrinos
- Rare events (some strong bounds)
- **Observation of CNO neutrinos (this talk!)**