Borexino results and plans.

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Princeton

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UMass
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Paris

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Neutrinos From the Sun

p-p Solar Fusion Chain

$p + p \rightarrow {}^{2}H + e^{+} + \nu_e$ $\quad$ $p + e^{-} + p \rightarrow {}^{2}H + \nu_e$

$\downarrow$

${}^{2}H + p \rightarrow {}^{3}He + \gamma$

$\downarrow$

${}^{3}He + {}^{3}He \rightarrow {}^{4}He + 2\,p$ $\quad$ ${}^{3}He + p \rightarrow {}^{4}He + e^{+} + \nu_e$

${}^{3}He + {}^{4}He \rightarrow {}^{7}Be + \gamma$

$\downarrow$

${}^{7}Be + e^{-} \rightarrow {}^{7}Li + \gamma + \nu_e$ $\quad$ ${}^{7}Be + p \rightarrow {}^{8}B + \gamma$

$\downarrow$ $\quad$ $\downarrow$

${}^{7}Li + p \rightarrow \alpha + \alpha$ $\quad$ ${}^{8}B \rightarrow 2\,\alpha + e^{+} + \nu_e$

CNO Solar Fusion Cycle

${}^{12}C + p \rightarrow {}^{13}N + \gamma$

$\downarrow$

${}^{13}N \rightarrow {}^{13}C + e^{+} + \nu_e$

$\downarrow$

${}^{13}C + p \rightarrow {}^{14}N + \gamma$

$\downarrow$

${}^{14}N + p \rightarrow {}^{15}O + \gamma$

$\downarrow$

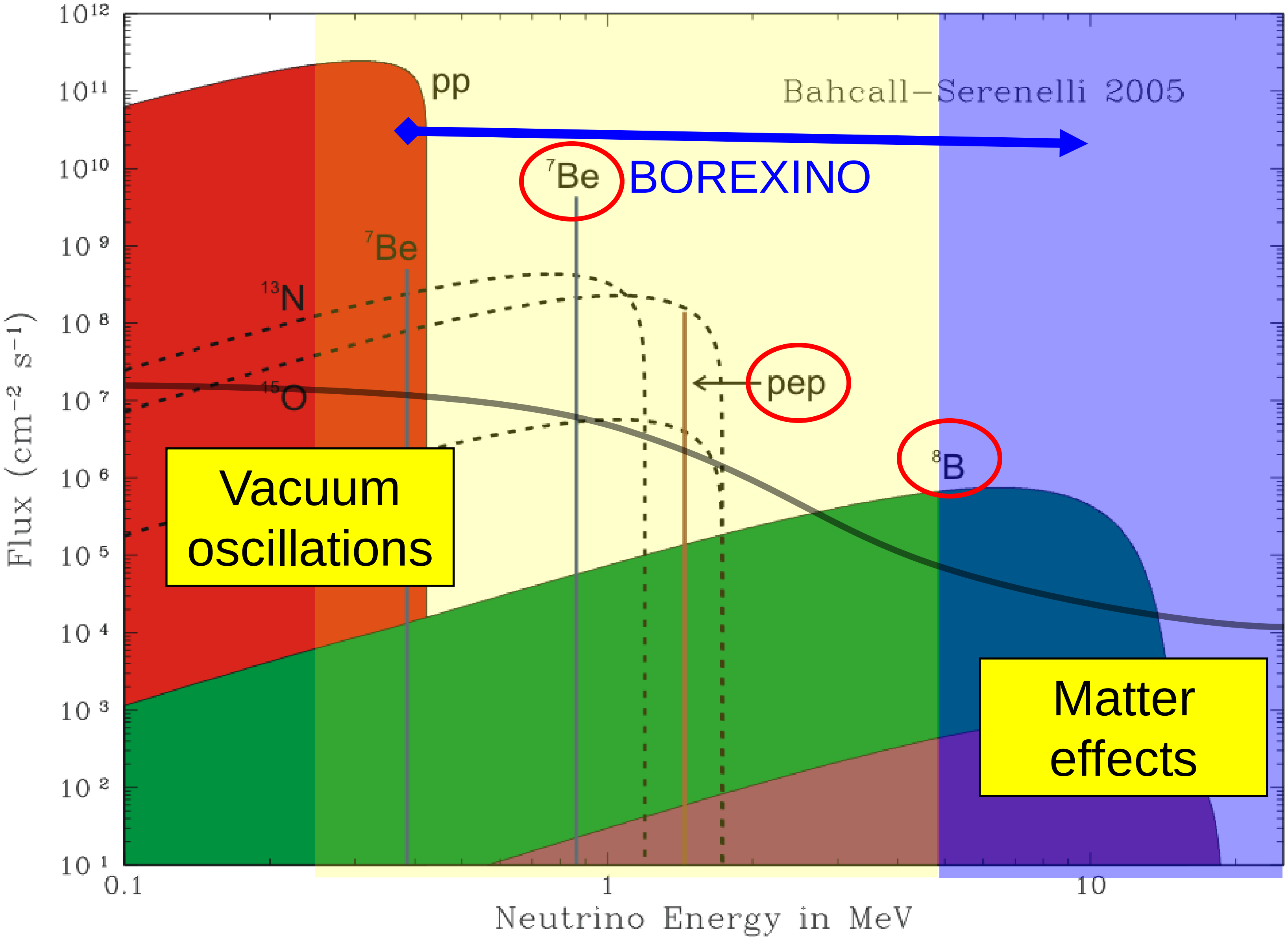
${}^{15}O \rightarrow {}^{15}N + e^{+} + \nu_e$

$\downarrow$

${}^{15}N + p \rightarrow {}^{12}C + {}^{4}He$

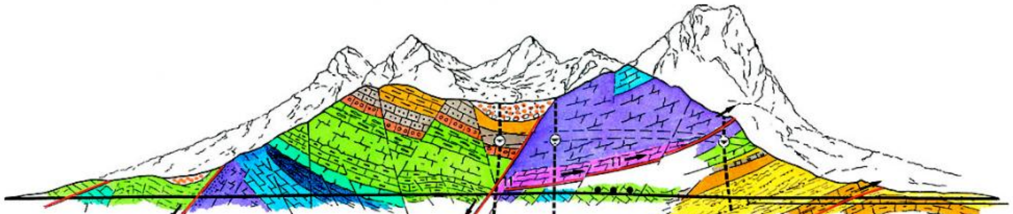
Image: bbc.co.uk

Solar neutrino spectrum



Borexino

Designed according to the idea of
graded shielding



L'AQUILA Tunnel of 10.4 km TERAMO

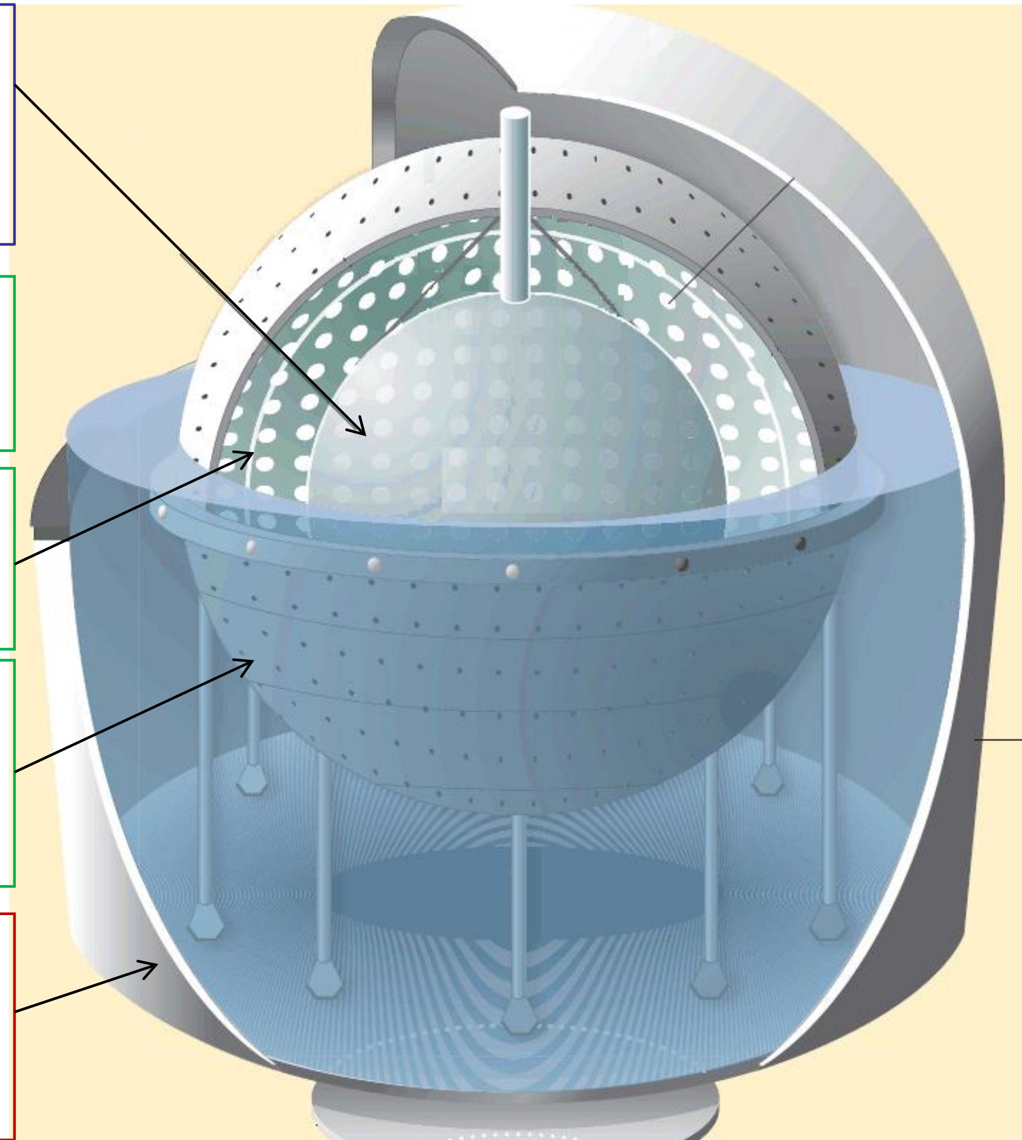
Scintillator:
270 t PC+PPO (1.5g/l)
in a 150μm thick
Inner nylon vessel (R=4.25m)

Buffer region:
PC+DMP quencher (5g/l)
4.25m<R<6.75m

Outer nylon vessel:
R=5.50m
(222Rn Barrier)

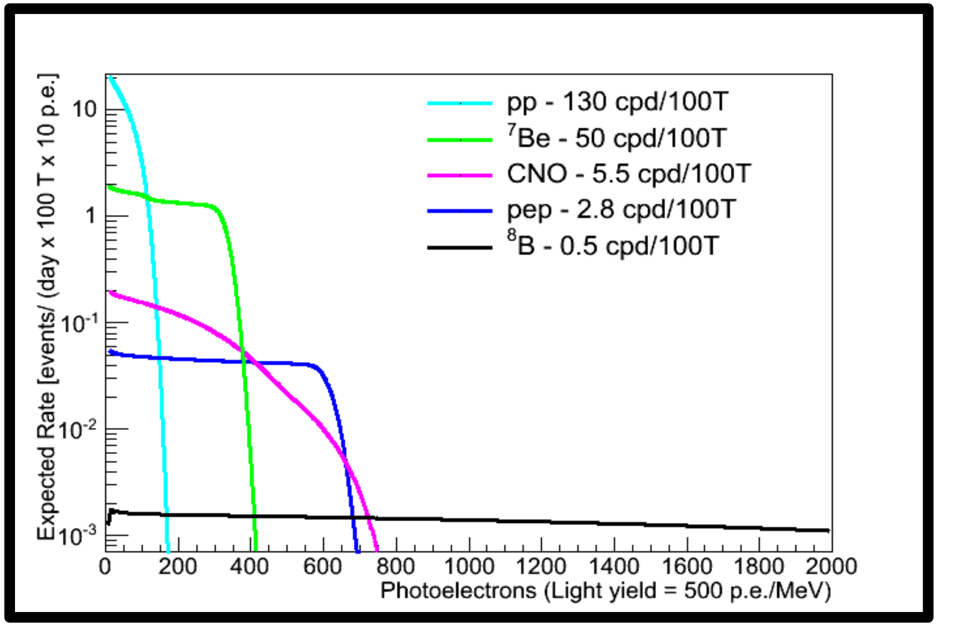
Stainless Steel Sphere:
R=6.75m
2212 8" PMTs with
light guide cone. 1350m3

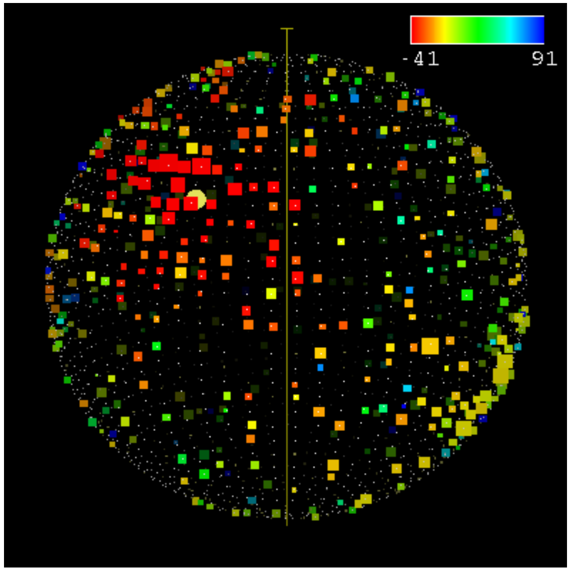
Water tank:
γ and n shield
μ water cherenkov detector
208 PMTs in water 2100m3



Neutrino Detection.

Neutrinos interact by elastic scattering with target electrons

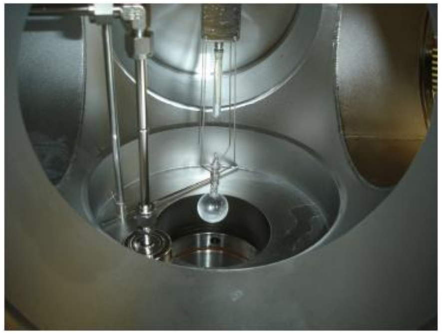




- Organic scintillator (PC+ PPO)
- Light is detected by the photomultipliers
- ~12,000 photons/MeV
- ~500 photoel./MeV

Detector calibration

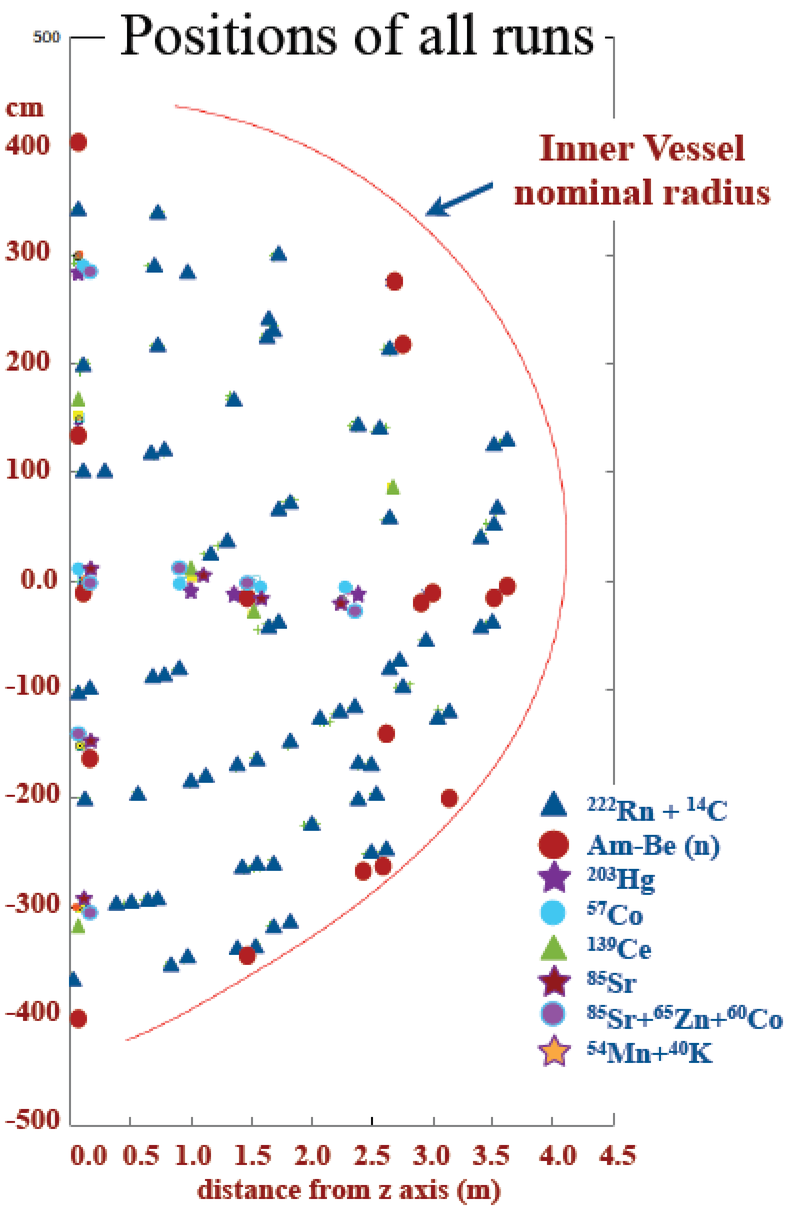
Source insertion



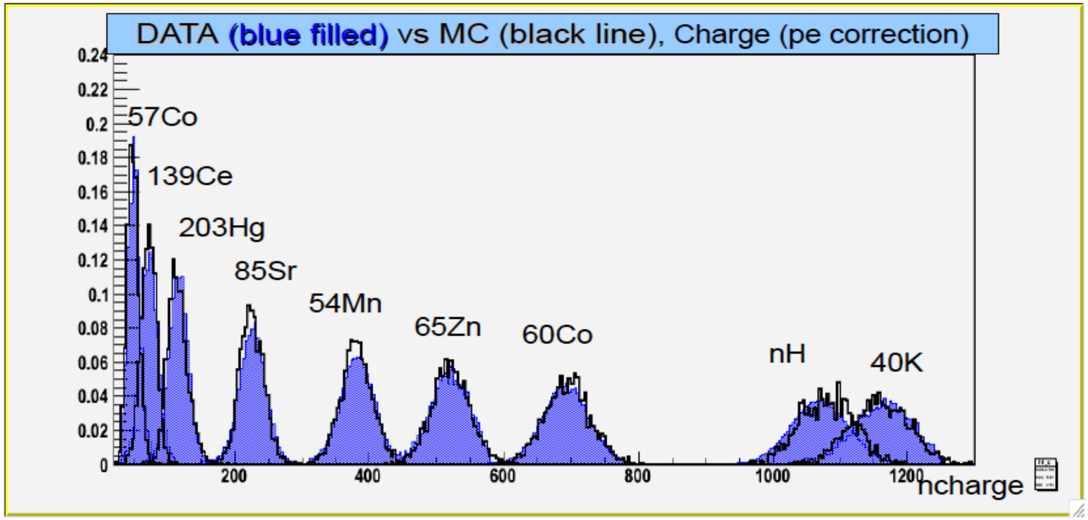
Radioactive source

	γ								β		α	n		
	dopant dissolved in small water vial								^{222}Rn loaded liq. scint. vial			Am-Be		
	^{57}Co	^{139}Ce	^{203}Hg	^{85}Sr	^{54}Mn	^{65}Zn	^{60}Co	^{40}K	^{14}C	^{214}Bi	^{214}Po	n-p	n +^{12}C	n+Fe
Energy (MeV)	0.122	0.165	0.279	0.514	0,834	1.1	1.1 1.3	1.4	0.15	3.2	(7.6)	2.2	4.94	~7.5

Position and Energy calibration

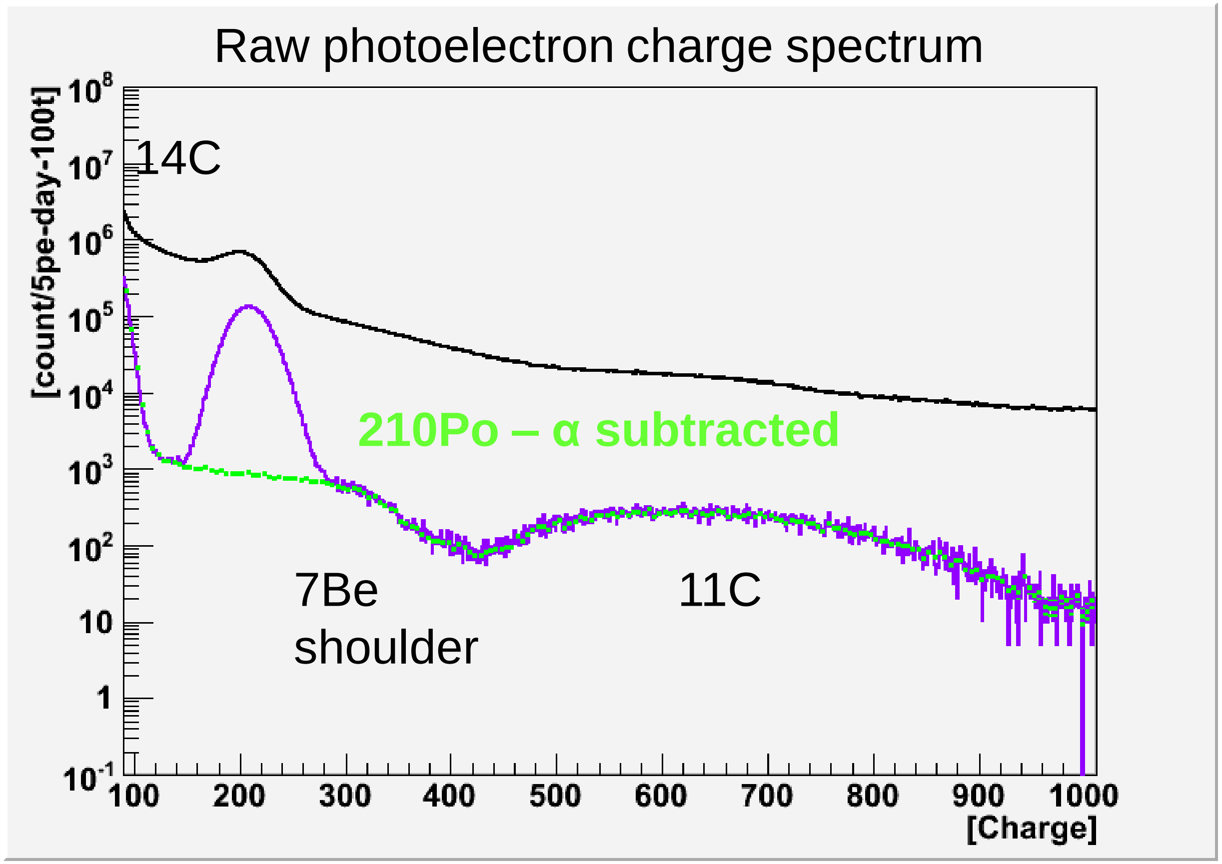


With 184 points of Rn calibration data, the fiducial volume uncertainty is 1.3%



The energy scale uncertainty is less than 1.5% between 0~2MeV

Selection of neutrino events



- Major cuts :

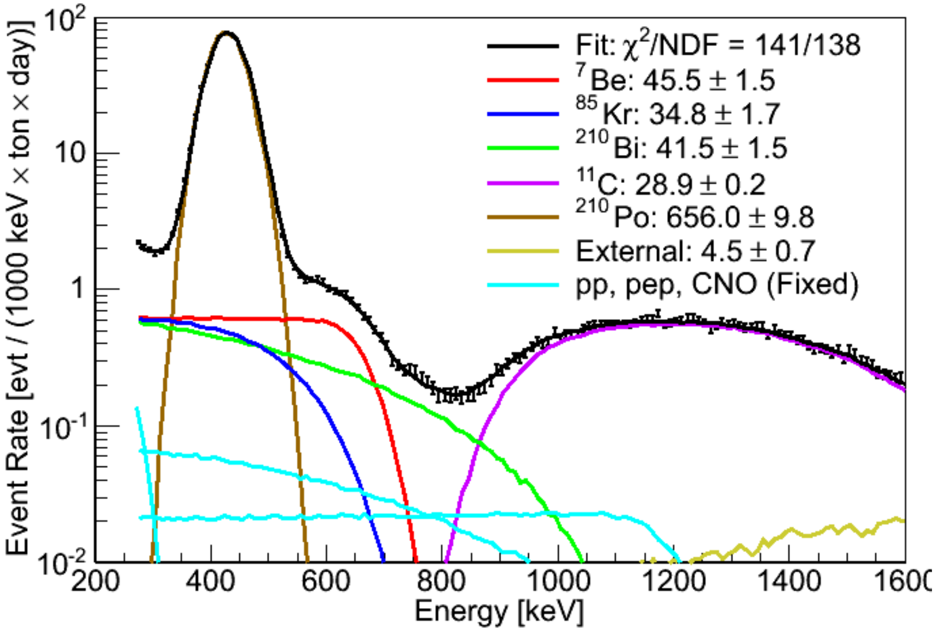
1) Muons, and fast cosmogenics, electronics noise

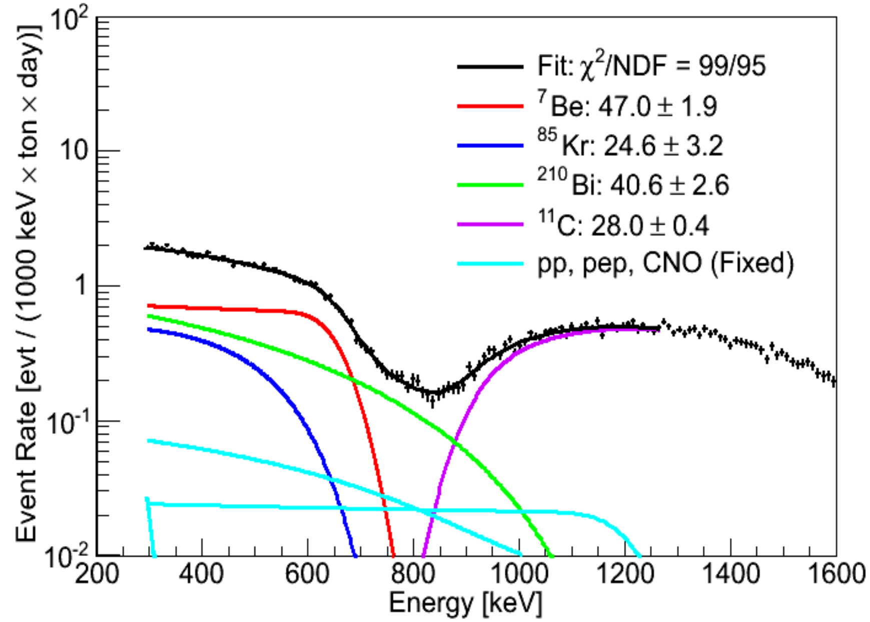
2) Fiducial Volume 1/3 active mass

3) α- subtraction (Gatti parameter)

Measurement of ^{7}Be neutrino flux.

740 days live time





MC fit range: 250-1600 keV
Soft α subtraction

Analytical fit range 300-1250 keV
statistical α subtraction

Precision ^{7}Be Flux Result

(Phys. Rev. Lett. **107**:141302 (2011))

Source of systematic error	
Trigger eff. And stability	<0.1 %
Live time	0.04%
Scintillator density	0.05 %
Sacrifice of cuts	0.10 %
Fiducial volume	+0.5 –1.3%
Fit methods	2.0 %
Energy response	2.7 %
Total syst. error	**+3.4 –3.6%**

^{7}Be rate (E=862 keV line)

in 750 days of data

$$46.0 \pm 1.5(stat)^{+1.5}_{-1.6}(sys)$$

counts/(day x 100t)

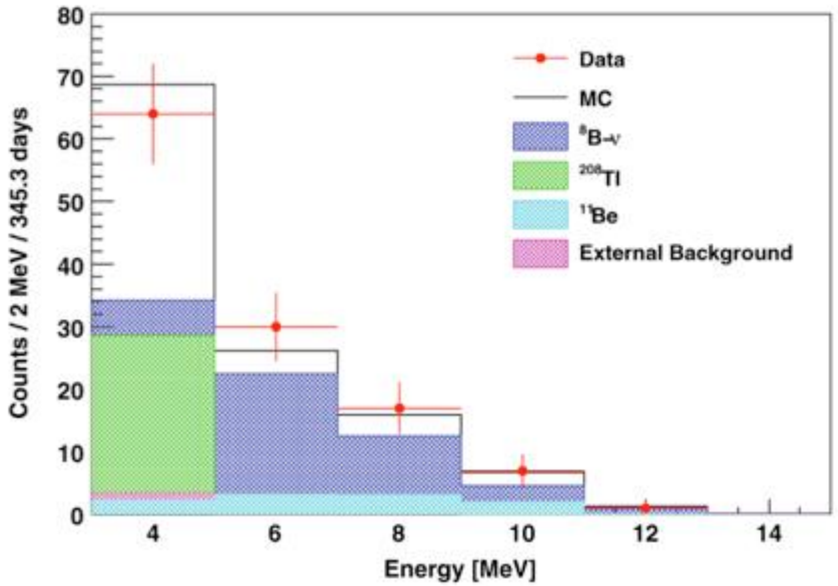
(total uncertainty is 4.7%)

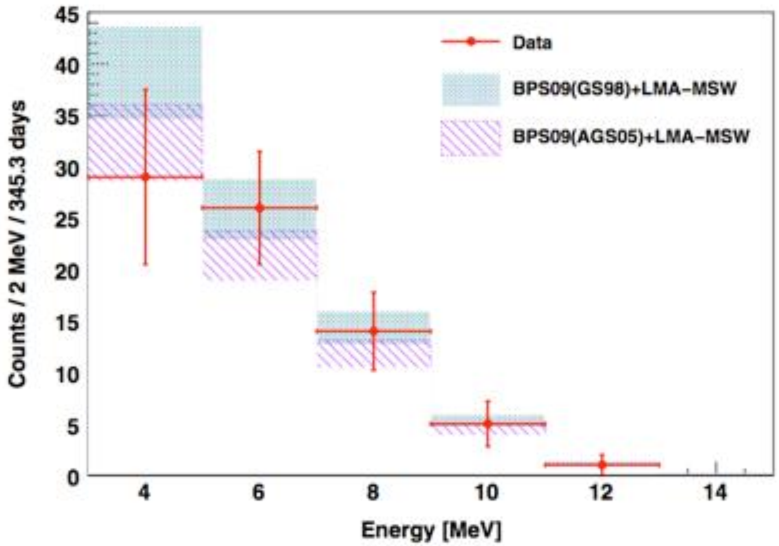
$$\Phi_{7Be} = (4.84 \pm 0.24) \times 10^9\ cm^{-2}s^{-1}$$

$$P_{ee}(862\ keV) = 0.51 \pm 0.07$$

Measurement of ^{8}B neutrino flux.

Phys.Rev.D82 (2010) 033006

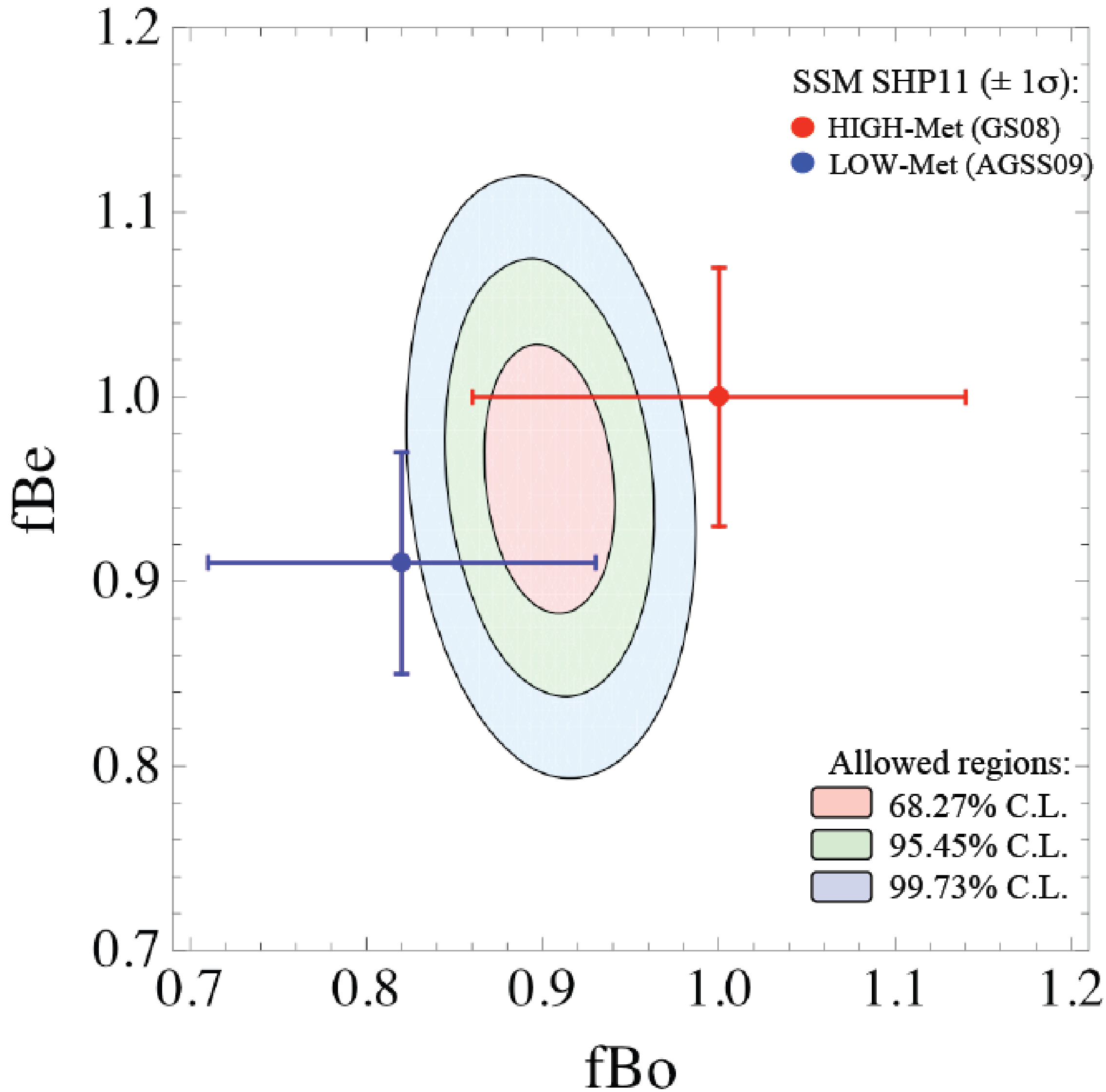




Φ (E>3 MeV) = 0.22±0.04(stat)±0.01(syst) cpd/100 t
Φ (E>5 MeV) =0.13±0.02(stat)±0.01(syst) cpd/100 t

- **Exposure: 345 days in 100 tons**
- **no oscillation hypothesis excluded at 4.2σ**

Comparison with SSM metallicity

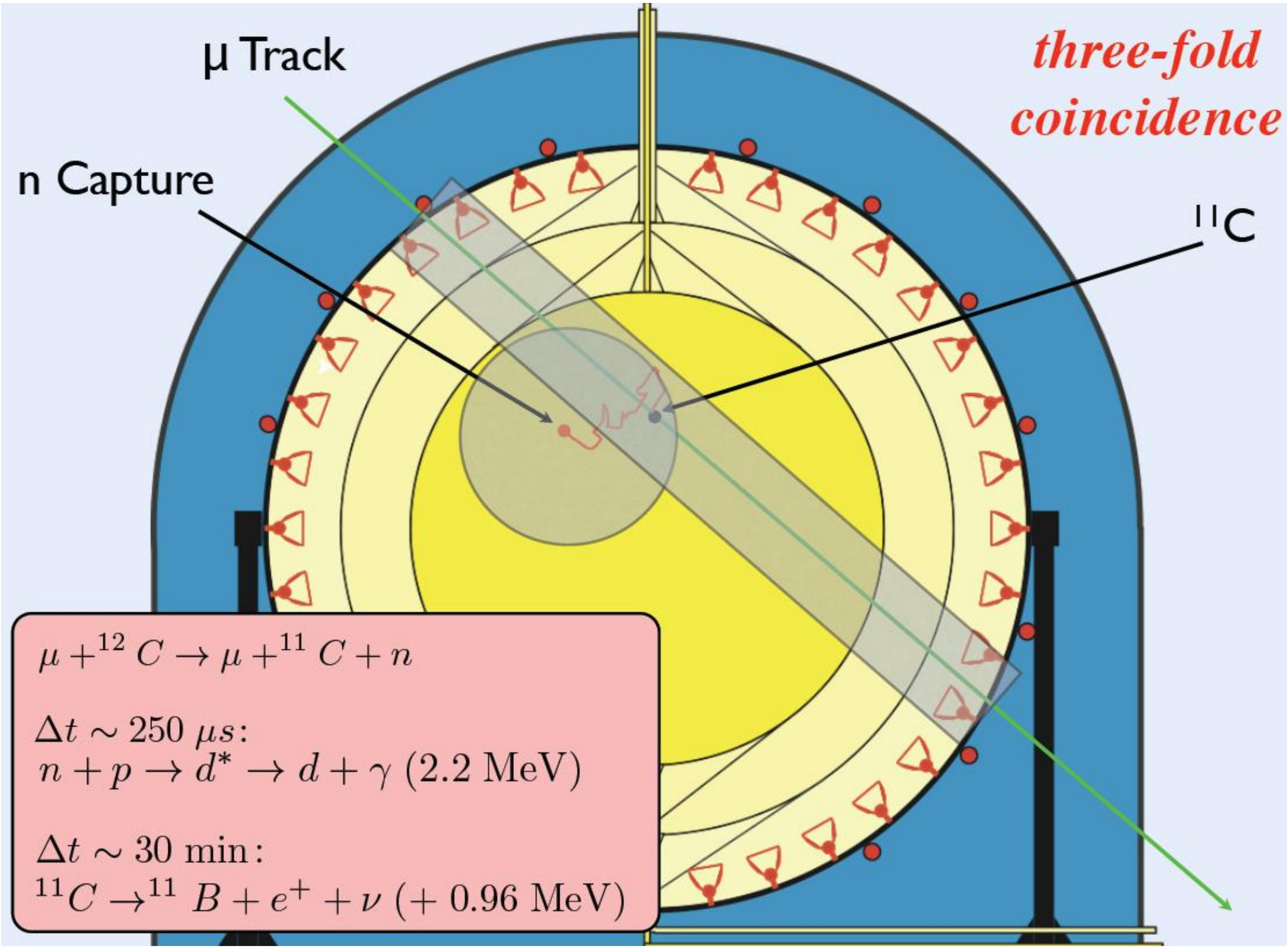


SHP11:
A.M. Serenelli, W. C.Haxton and C. Pena-Garay, arXiv:1104.xxxx [astro-ph]

GS98:
N. Grevesse and A. J. Sauval, Space Sciences Reviews 85, 161 (1998)

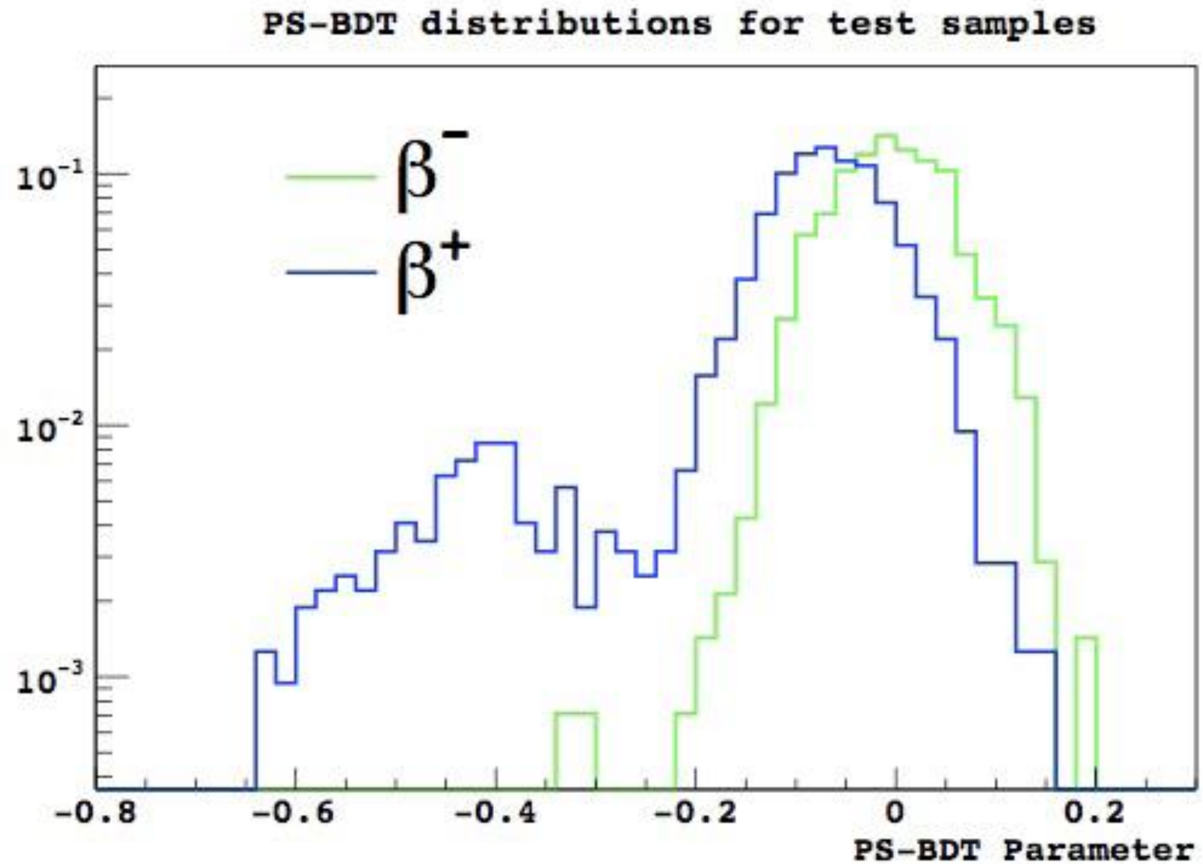
AGSS09:
Aldo M. Serenelli *et al 2009*
ApJ ***705 L123***

pep and CNO measurement



Three Fold Coincidence technique (use of space + time correlation with μ + n veto regions of the detector with higher 11C background).

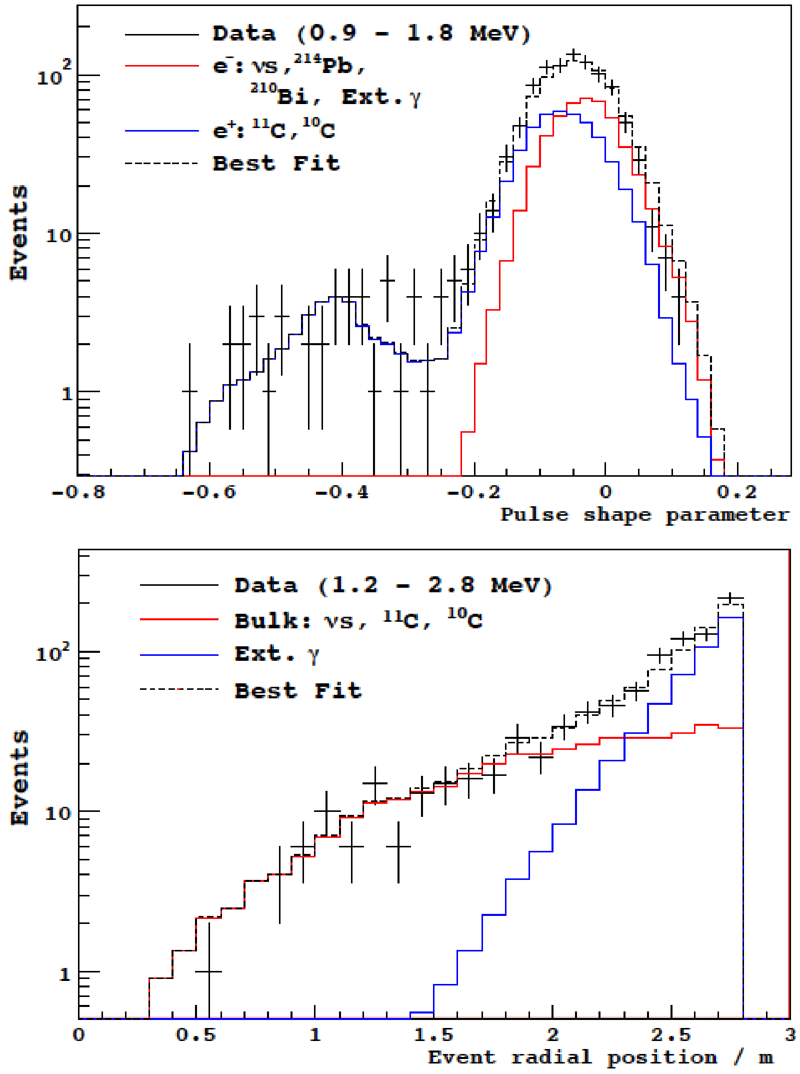
e^+/e^- Pulse Shape Discrimination



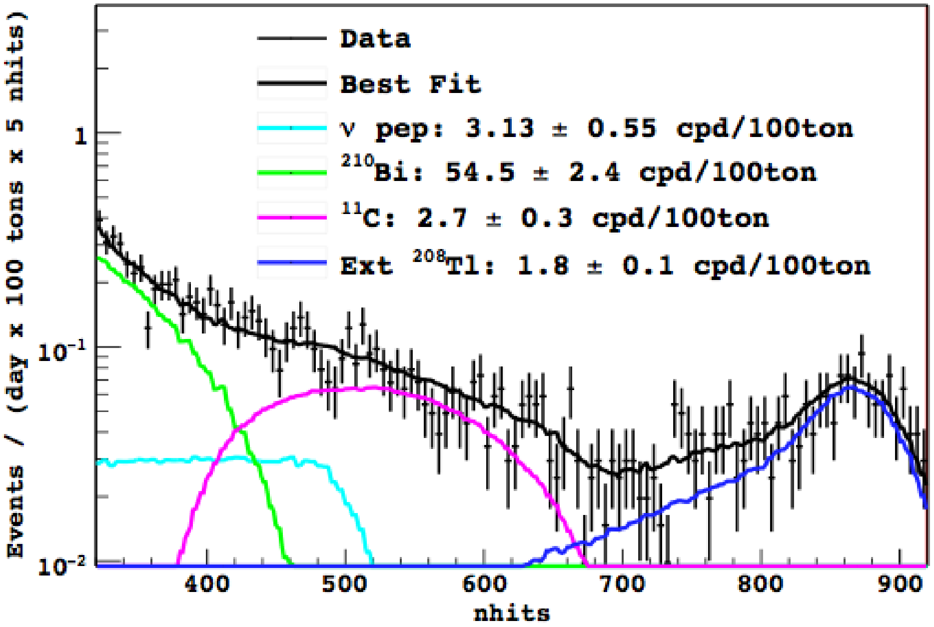
Boosted decision tree (BDT) discrimination parameter from pulse shape information.

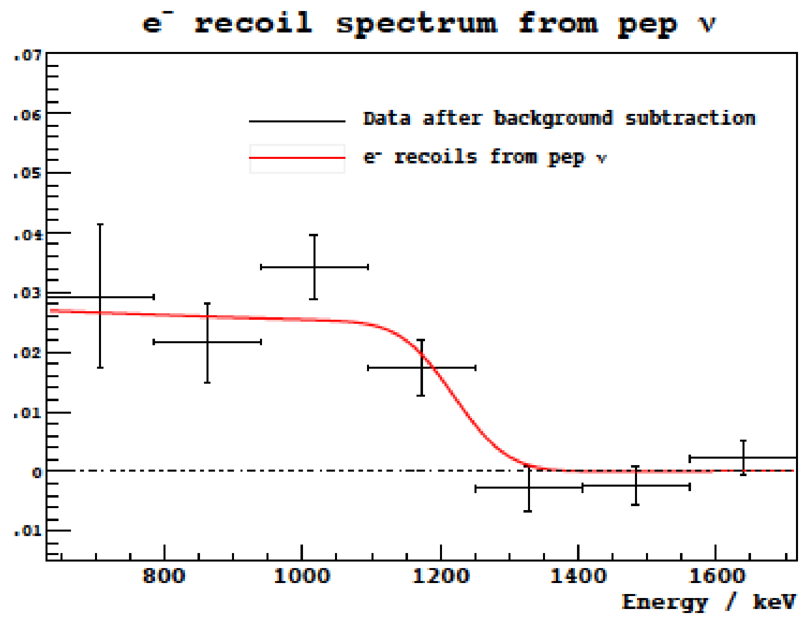
pep/CNO Fit

- Fit in energy, radius, and BDT
- Radial and BDT distributions are energy dependent
- Simultaneously fit the TFC “signal-like” and “background-like” spectra
  - Double background statistics



Results in pep and CNO





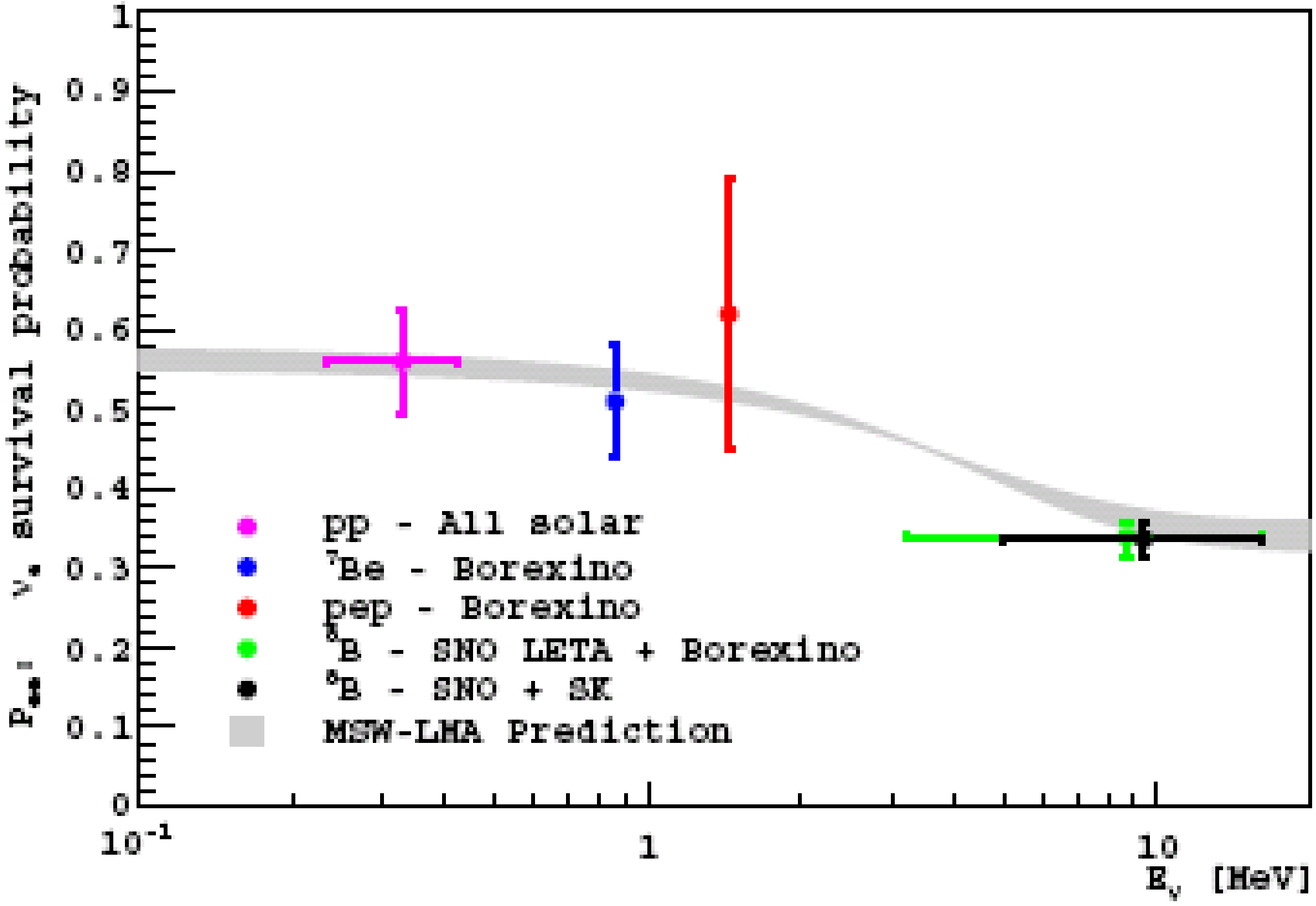
pep: 3.1±0.6(stat.)±0.3(syst) cpd/100 tons

CNO: <7.9 cpd/100 tons (95% C.L.)

Φ (pep)= 1.6±0.3 10^{8} cm^{-2} s^{-1} f_{pep}(GS98)=1.1±0.2

Φ (CNO) < 7.7 10^{8} cm^{-2} s^{-1} f_{CNO}(GS98)<1.5

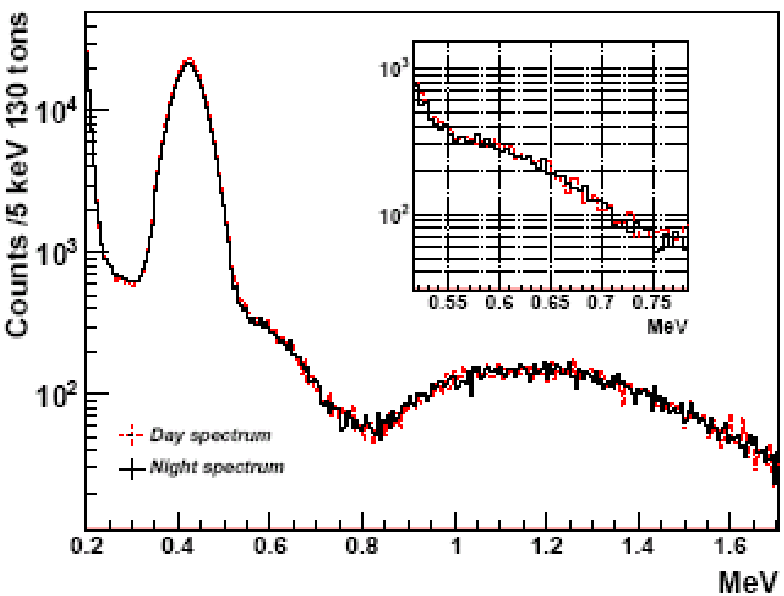
ν_e survival probability (Pee)



Day-Night Asymmetry

arXiv:1104.2150 (2011), accepted by Phys. Lett. B

- In the MSW scenario, the flux rate in Night should be higher than Day because of the regeneration effect.
- In the ^{7}Be energy region, no effect expected in MSW-LMA region, but large in MSW-LOW region (~20%).

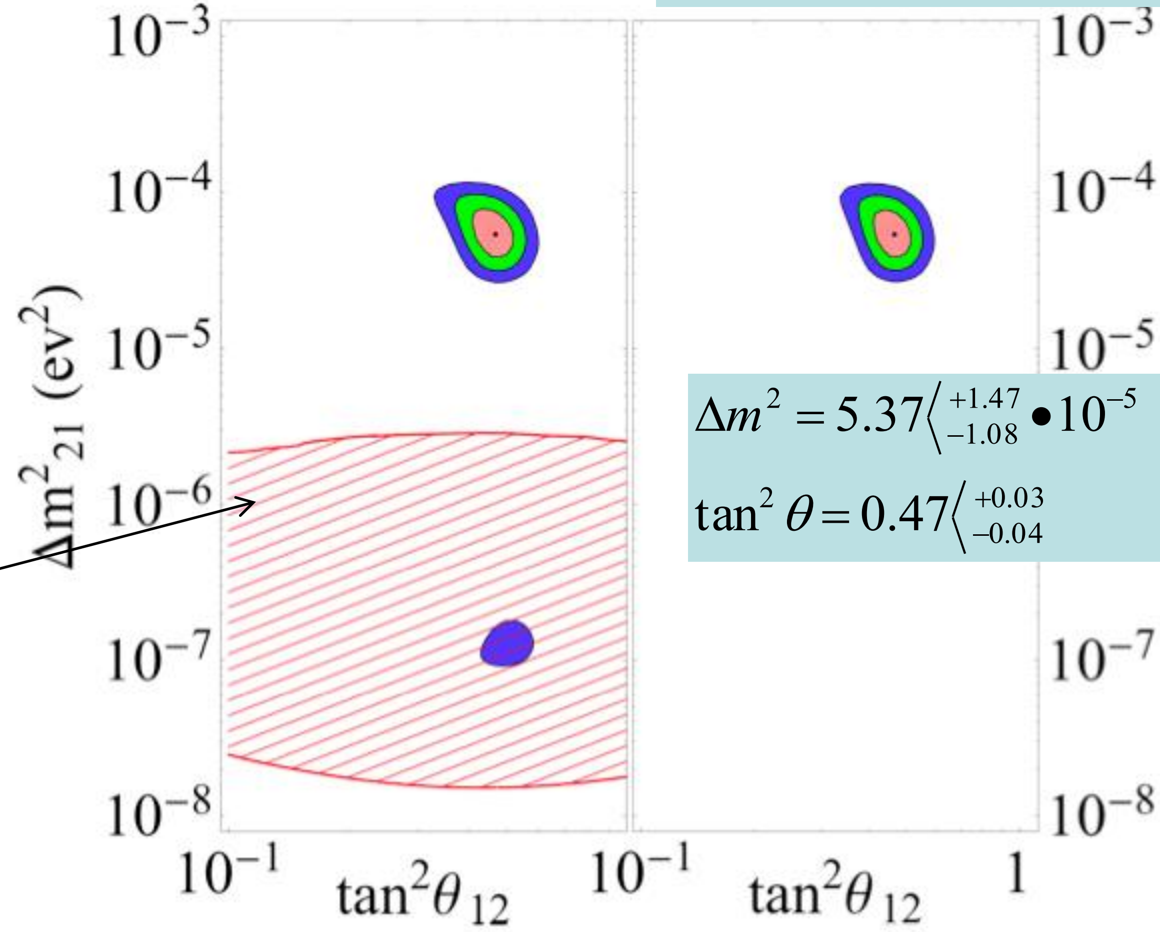


$$Adn = \frac{N-D}{(N+D)/2}$$
$$= 0.001 \pm 0.012\,(stat.) \pm 0.007(sys.)$$

Implications on oscillations model

All solar without Borexino

All solar + Borexino
(^7Be flux and day/night)



$$\Delta m^2 = 5.37\left\langle {}^{+1.47}_{-1.08} \right. \bullet 10^{-5} \;\; eV^2$$

$$\tan^2\theta = 0.47\left\langle {}^{+0.03}_{-0.04} \right.$$

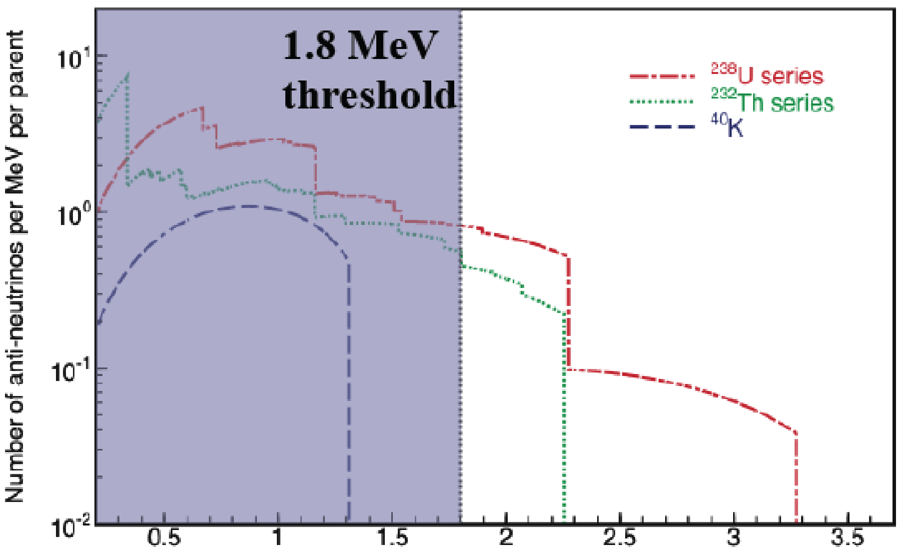
Excluded by
Day/Night
99.73% CL

LOW is excluded
at > 8.5 σ

Geo-neutrinos in Borexino

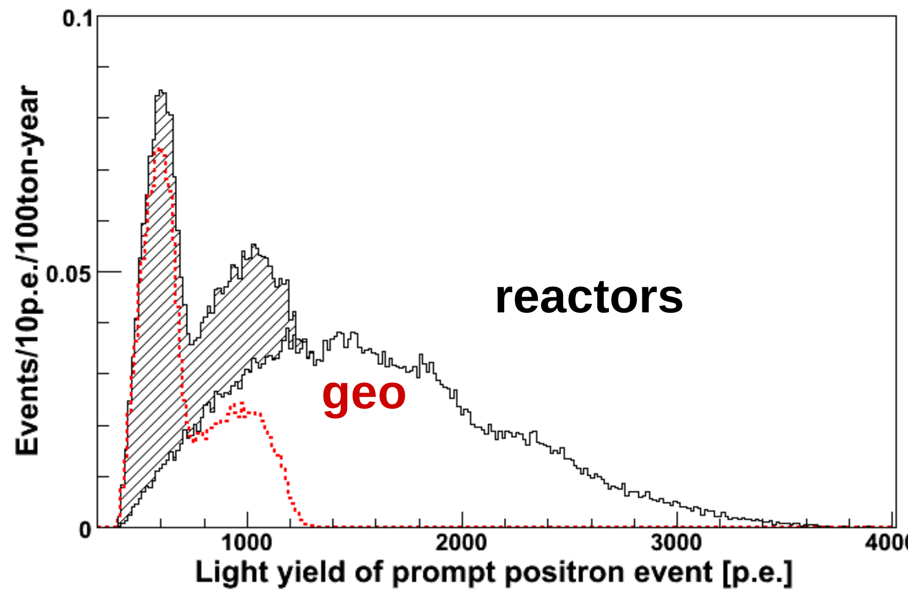
Phys. Lett. B **687**:299-304 (2010)

Expected signal shape



Energy of anti-neutrino

MC energy spectra in Borexino



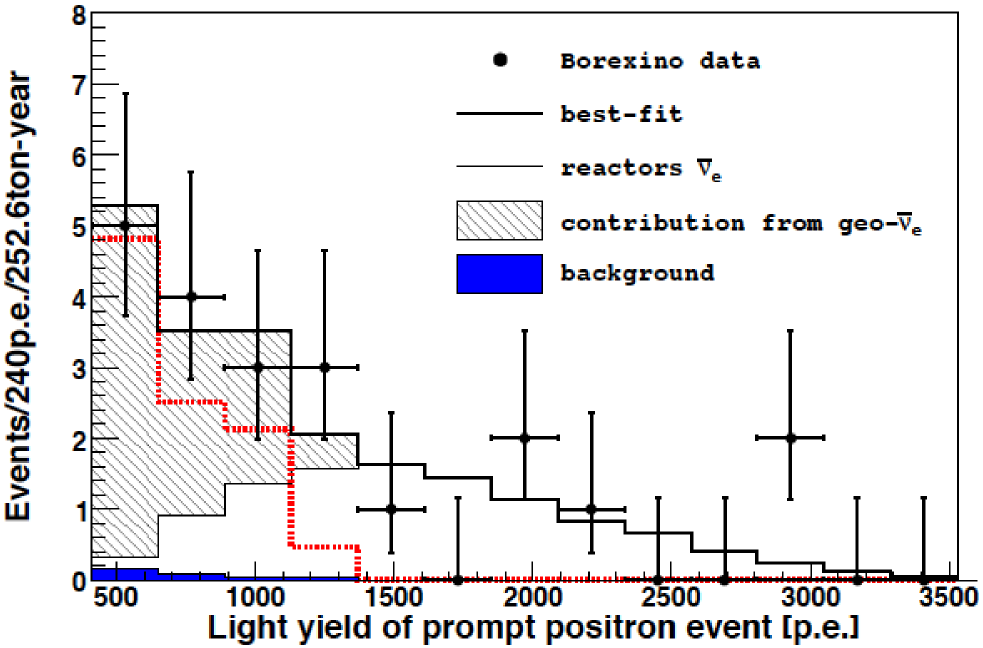
- Antineutrinos from β- decay of K, U and Th in the earth's mantle and crust

- Models suggest that these decays are responsible for 40-100% of the earth's heat

Detection in $\overline{\nu}_e + p \rightarrow n + e^+$

Delayed co-incidence gives powerful background rejection

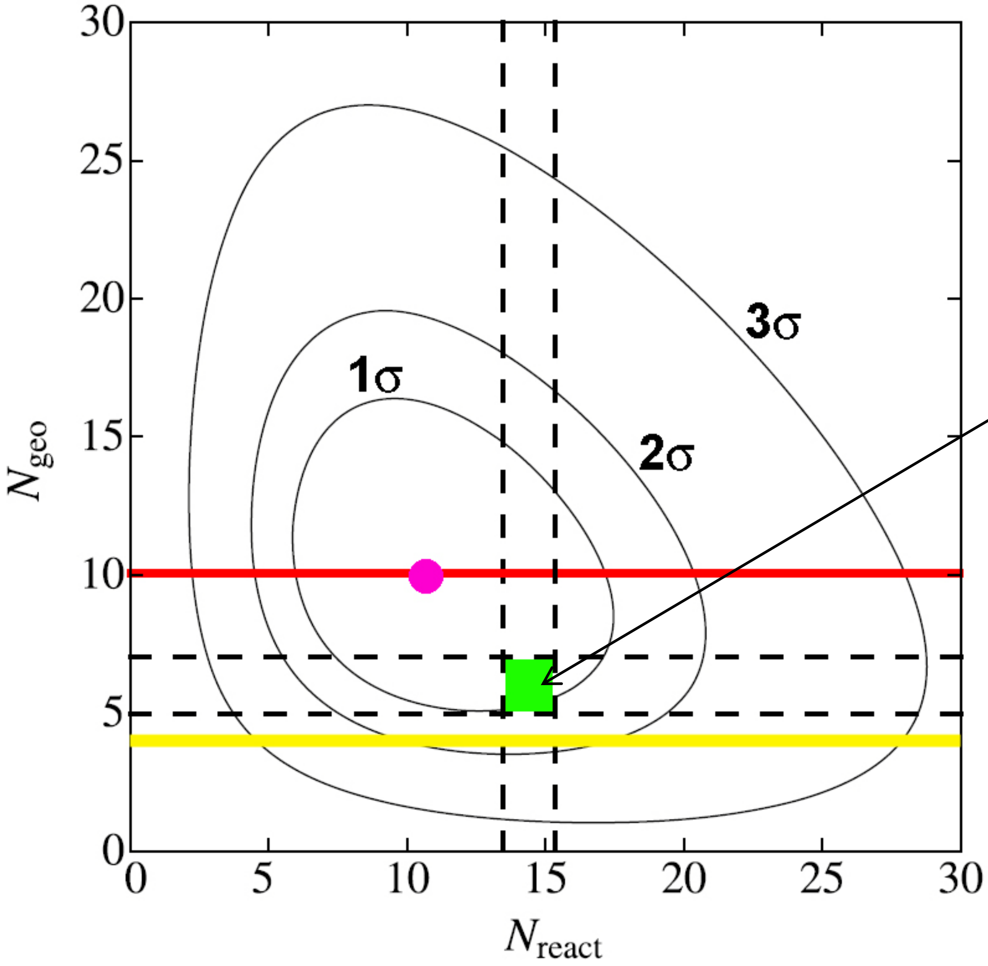
Geo-neutrinos in Borexino



Source	Background [events/(100 ton·yr)]
^{9}Li–^{8}He	0.03±0.02
Fast n's (μ's in WT)	<0.01
Fast n's (μ's in rock)	<0.04
Untagged muons	0.011±0.001
Accidental coincidences	0.080±0.001
Time corr. background	<0.026
(γ,n)	<0.003
Spontaneous fission in PMTs	0.0030±0.0003
(α,n) in scintillator	0.014±0.001
(α,n) in the buffer	<0.061
Total	0.14±0.02

Borexino Geo-Neutrino Rate: $3.9^{+1.6}_{-1.3}$ ev/100t/yr

Geo and Reactor events



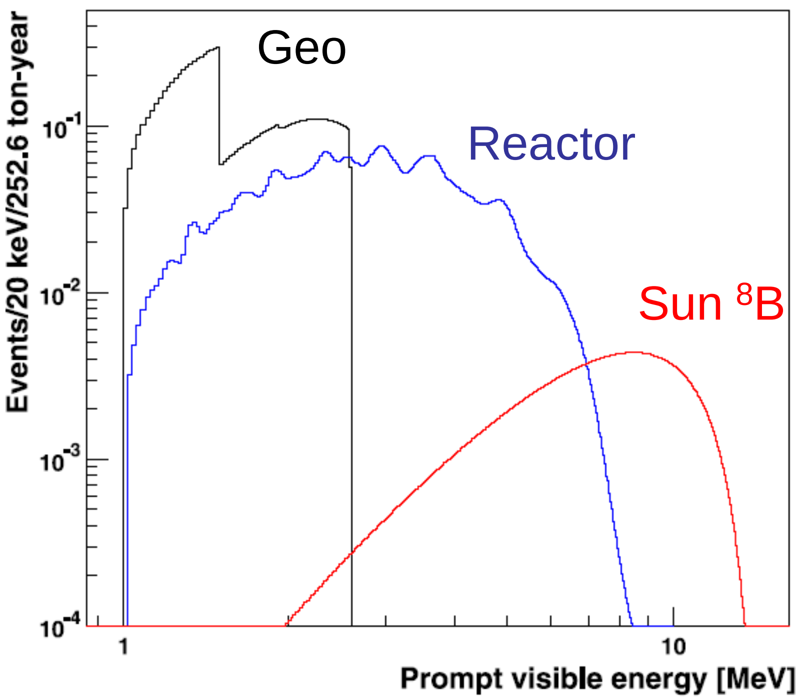
"standard" BSE model, expected reactor rate

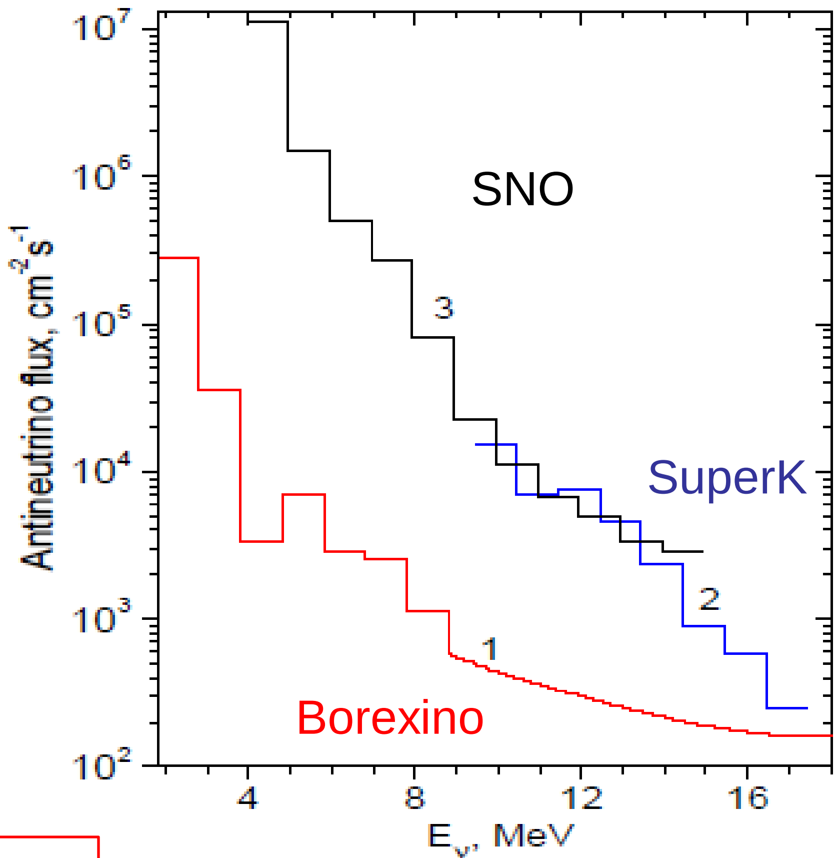
full radiogenic model

minimal radiogenic model

Study of solar and other unknown anti-neutrino fluxes with Borexino

Physics Letters B 696 (2011)





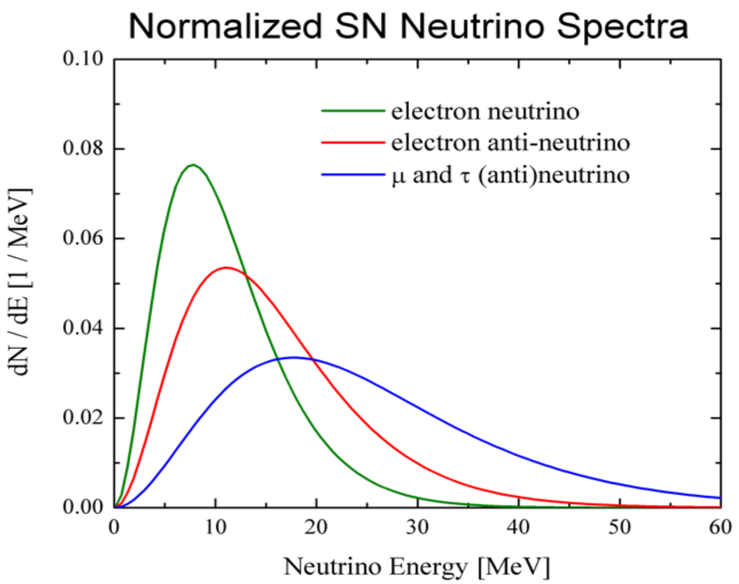
$$p(\nu \rightarrow \bar{\nu}) < 1.3\times10^{-4}\varphi_{SSM}(^8B)\ \ 90\%\ \ \text{C.L.}$$

Supernova detection

- Borexino is the part of the "SuperNova Early Warning System" (SNEWS) (~90% duty cycle)

Standard SN at 10kpc

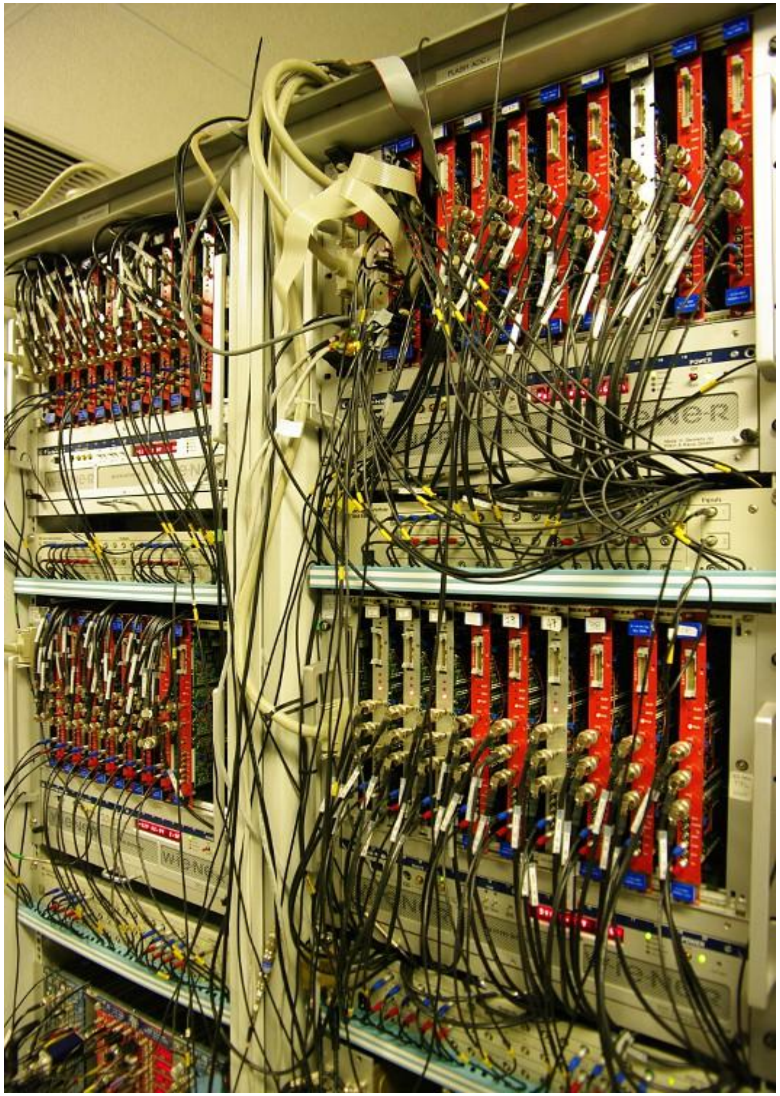
Detection channel	Events in Borexino
Inverse-Beta Decay ($E_\nu > 1.8$ MeV)	79
ν-p ES ($E_\nu > 0.25$ MeV)	55
$^{12}C(\nu,\nu)^{12}C^*$ ($E\gamma = 15.1$ MeV)	17
$^{12}C(\text{anti-}\nu, e^+)^{12}B$ ($E_{\text{anti-}\nu} > 14.3$ MeV)	3
$^{12}C(\nu,e)^{12}N$ ($E_\nu > 17.3$ MeV)	9
ν-e ES ($E_\nu > 0.25$ MeV)	5



FADC System for Supernova

- APC Paris
- NRC “Kurchatov Institute”
- SINP MSU

- System is able to cover energy range up to ~30-40 MeV. Thus, SN plus all the “high energy” physics is available.
- System is taking data even when main DAQ is blocked (if of course HV is ON).



Future plans

- Tackle down CNO neutrinos by reducing 210Bi contamination – Water Extraction purification in progress
- Nitrogen stripping has already removed 85Kr and this will improve 7Be measurement and might allow to probe pp neutrinos
- Improve statistics for geo-neutrinos: already doubled previous statistical sample
- Put forward a program to use a neutrino artificial sources (^{51}Cr, ^{144}Ce or ^{85}Sr) in Borexino for sterile neutrino search
- Check of the Opera superluminal neutrino results.

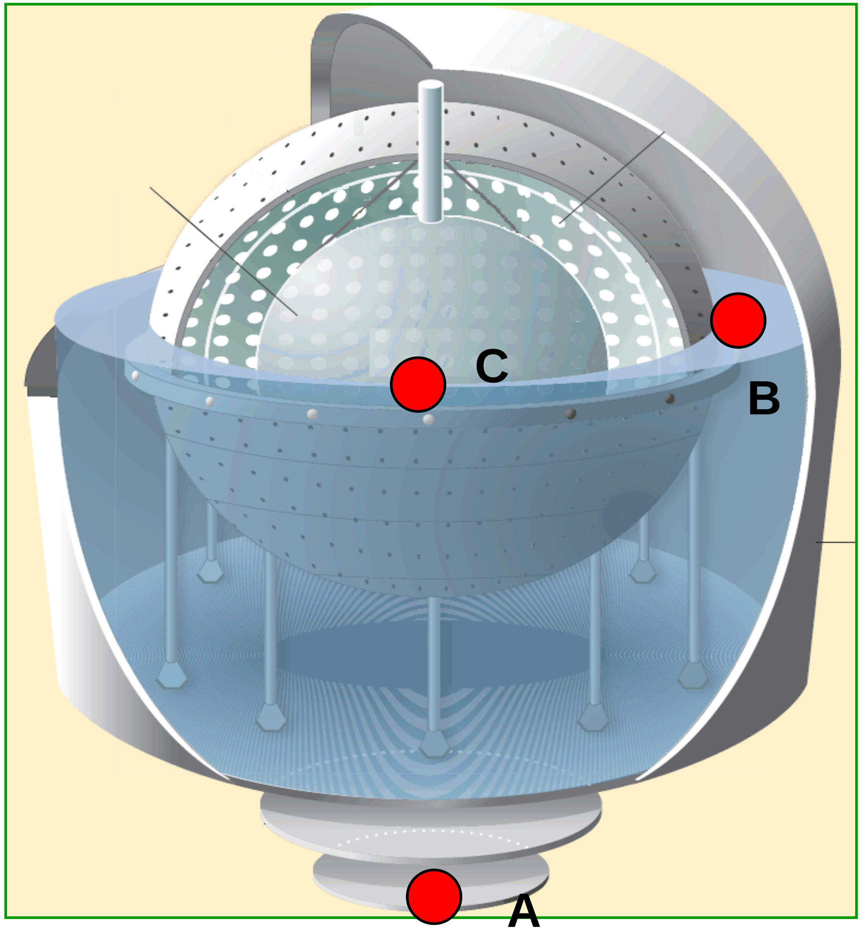
Artificial Neutrino Source Experiment with Borexino

- LSND: 3.8σ excess of $\tilde{\nu}_e$ in a $\tilde{\nu}_\mu$ beam L/E ~ 0.5 – 2 [m/MeV]
- MiniBooNE: 99.4% CL evidence of $\tilde{\nu}_e$ -> $\tilde{\nu}_\mu$ oscillations with L/E ~ 1 [m/MeV]
- Ga calibration (SAGE)neutrino anomaly
- Reactor antineutrino anomaly: 98.6 % CL deficit which could be explained in the framework of a forth sterile ν

Neutrino source experiment coupled with a large low background LS underground detector can
– Search for new physics with L/E ~ 1
– Probe neutrino‐electron sca\ering interacAon at 1 MeV scale
– Probe neutrino magnetic moment

• A source experiment in Borexino was one of the research goals in the early proposal back in 1991

Artificial Neutrino Source Experiment with Borexino



- **A**: underneath WT
  – D=825 cm
  – No change to present configuration

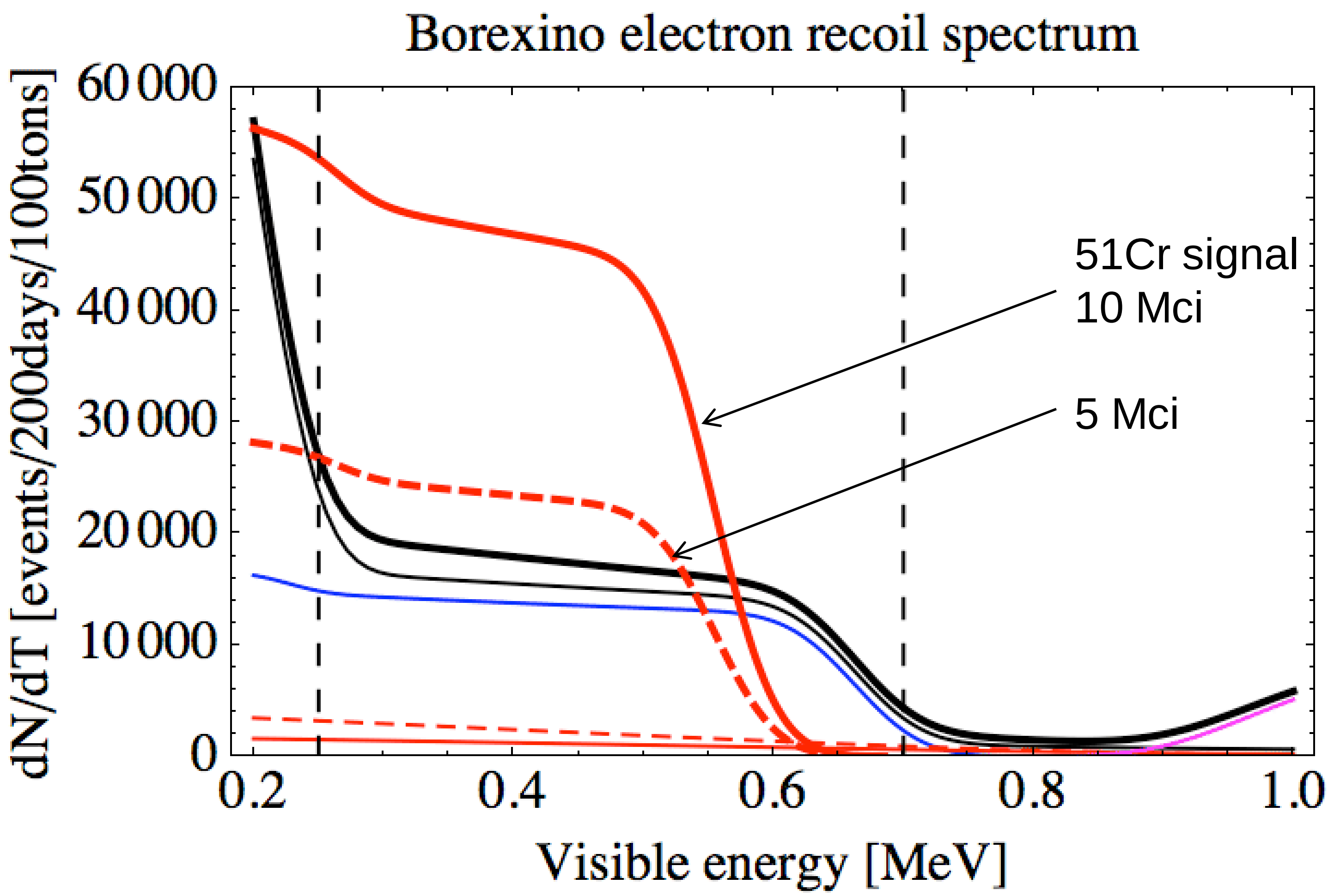
- **B**: inside WT
  – D = 700 cm

- **C**: center
  – Major change
  – Can be done at the end of solar neutrino physics

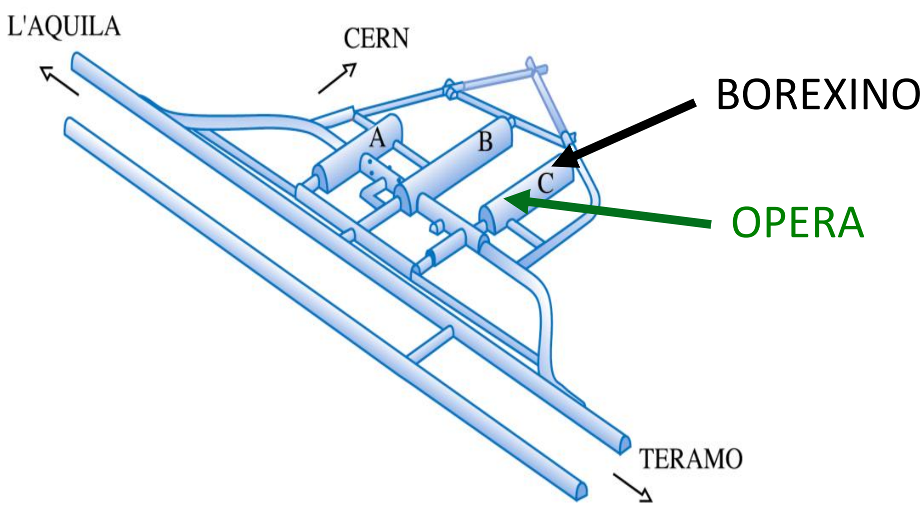
Source features

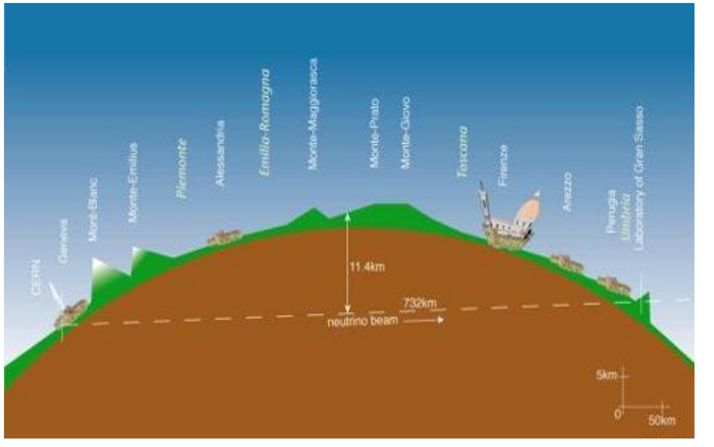
Source origin	origin	τ [days]	Energy [MeV]	Kg/MCi	W/kCi
^{51}Cr	e-capture (E_γ=0.32 MeV 10%)	40	0.746 81%	0.011	0.19
^{90}Sr-^{90}Y	Fission product β^-	15160	<2.28 MeV	7.25	6.7
^{144}Ce-^{144}Pr	Fission Product β^-	411	<2.9975 MeV	0.314	9.3

370 PBq ^{51}Cr source outside BX

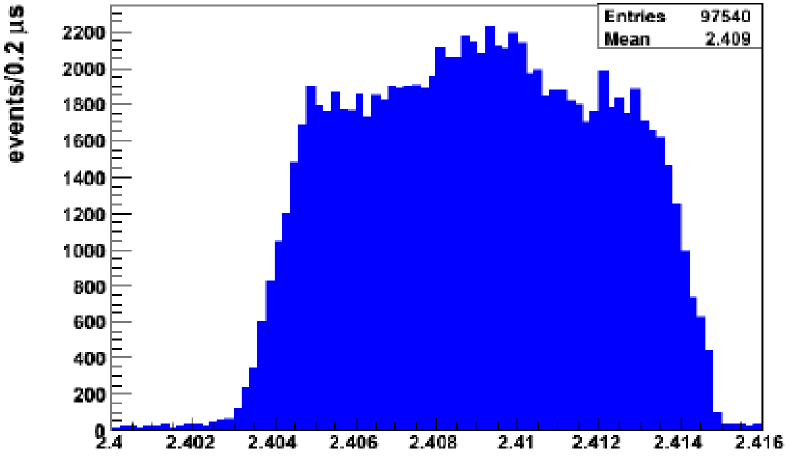


Neutrino velocity measurement with beam from CERN





- Borexino is located before OPERA in the same hall
- Borexino already detects CNGS neutrinos (JINST **6**:P05005 (2011))
- New fast GPS and fast trigger electronics for Borexino are under construction

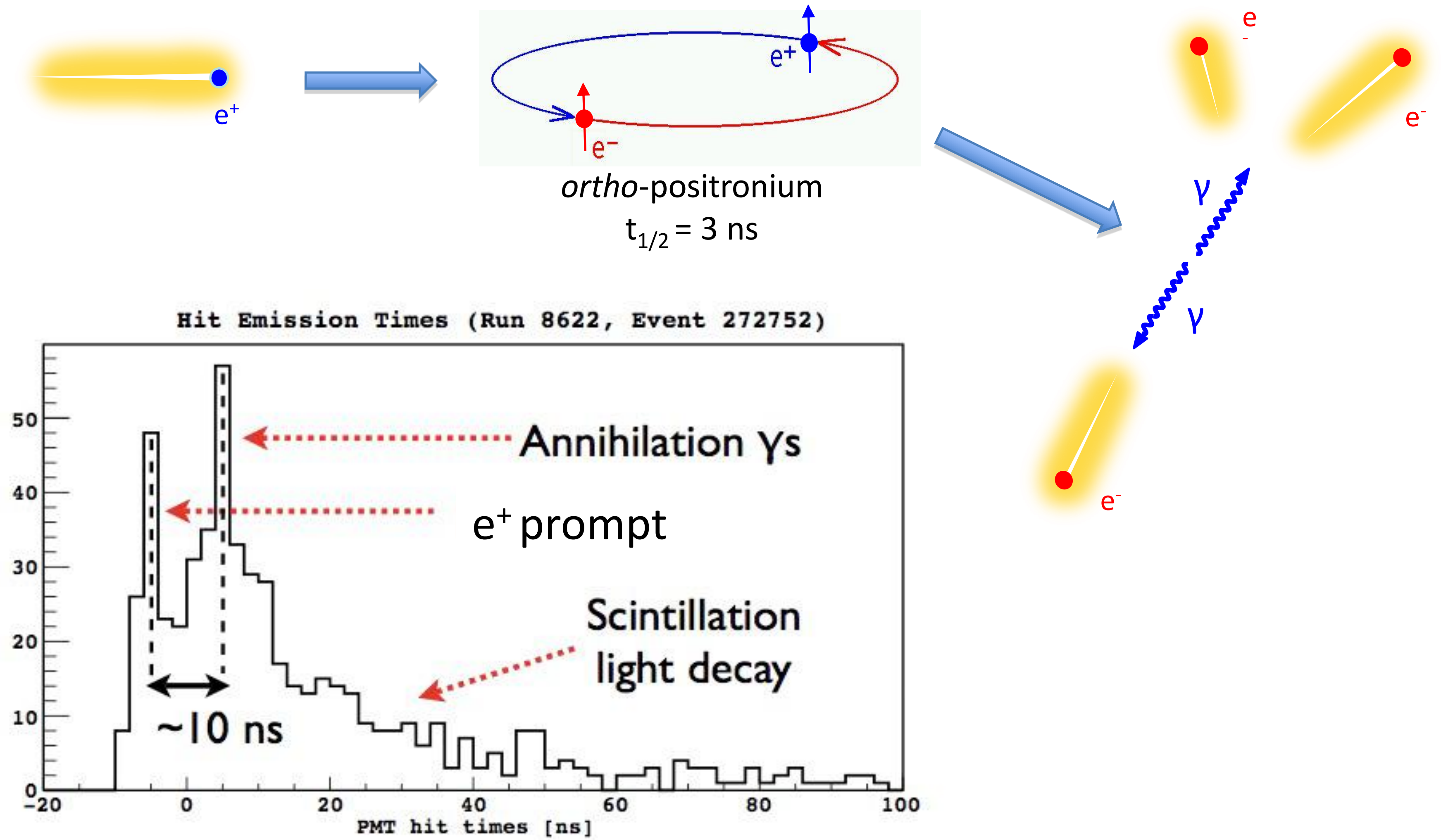


Time Distribution of CNGS Events in Borexino

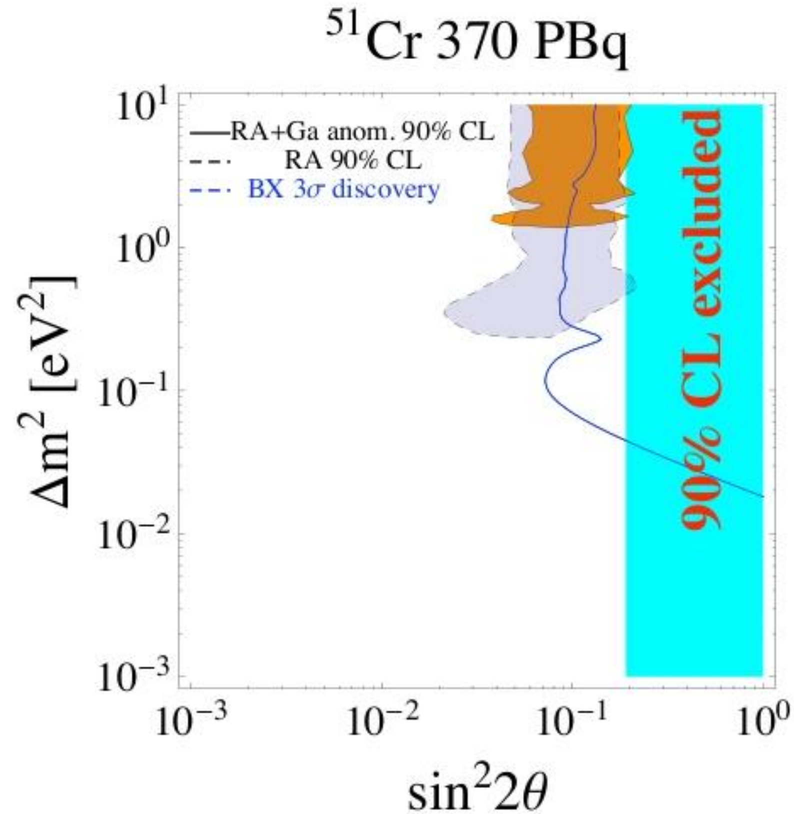
Addition

e^+/e^- Pulse Shape Discrimination

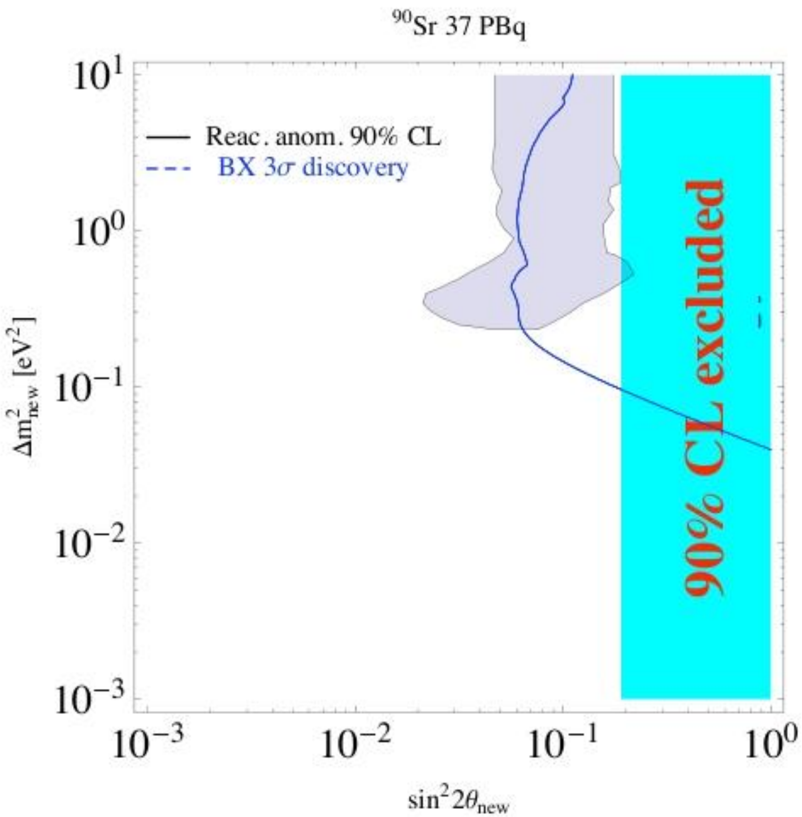
(PRC 83:015522 (2011))



Discovery power with ^{51}Cr source outside BX



Discovery power with ^{90}Sr source outside BX



Discovery with ^{144}Ce @ center

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