Neutrino Physics with Borexino

APC
January 26, 2010 – Paris

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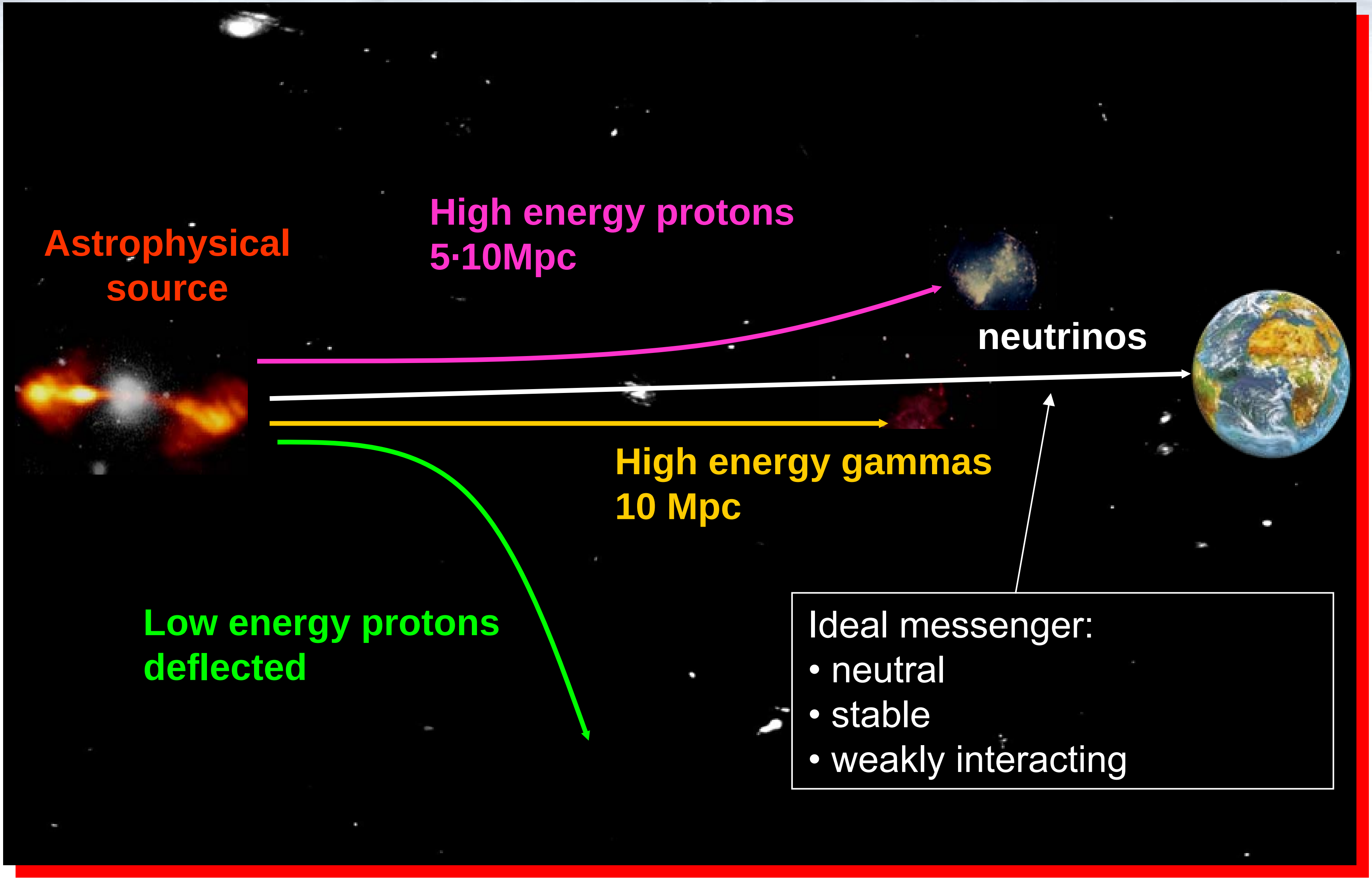
Outline

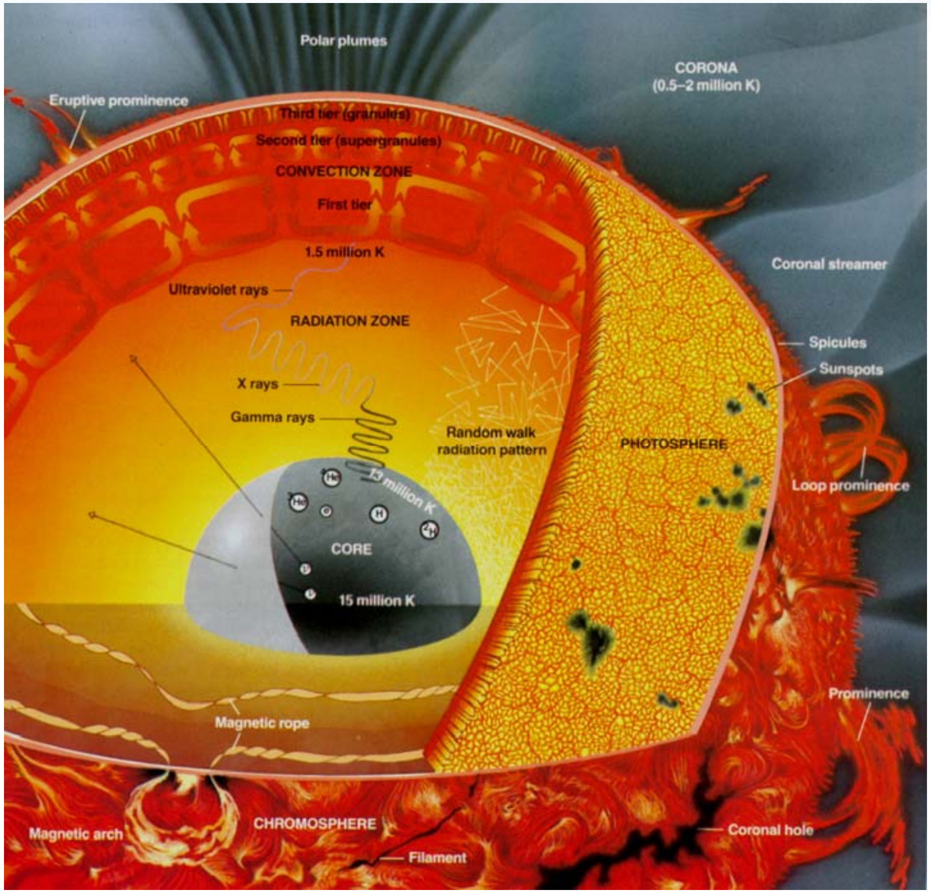
- ✓ Neutrinos from the Sun
- ✓ The physics of Borexino
- ✓ The Borexino detector
- ✓ The “radio-purity” challenge
- ✓ The reached goals (^{7}Be, ^{8}B and μ_{ν})
- ✓ Near and far future goals

Neutrinos: cosmic messengers



Messengers from the Sun’s core

- ✓ **Core (0-0.25 R_S)**
  - ✓ Nuclear reactions: T~1.5 10^7 °K
  - ✓ energy chains pp e CNO (neutrino production)
- ✓ **Radiative region (0.25-0.75 Rs)**
  - ✓ Photons carry energy in ~ 10^5 y
- ✓ **Convective region (0.75-1 Rs)**
  - ✓ Strong convection and turbulence
  - ✓ Complex surface phenomena
- ✓ **Corona (> 1 Rs)**
  - ✓ Complex magneto-hydrodynamic phenomena
  - ✓ Gas at T~ 10^6 °K



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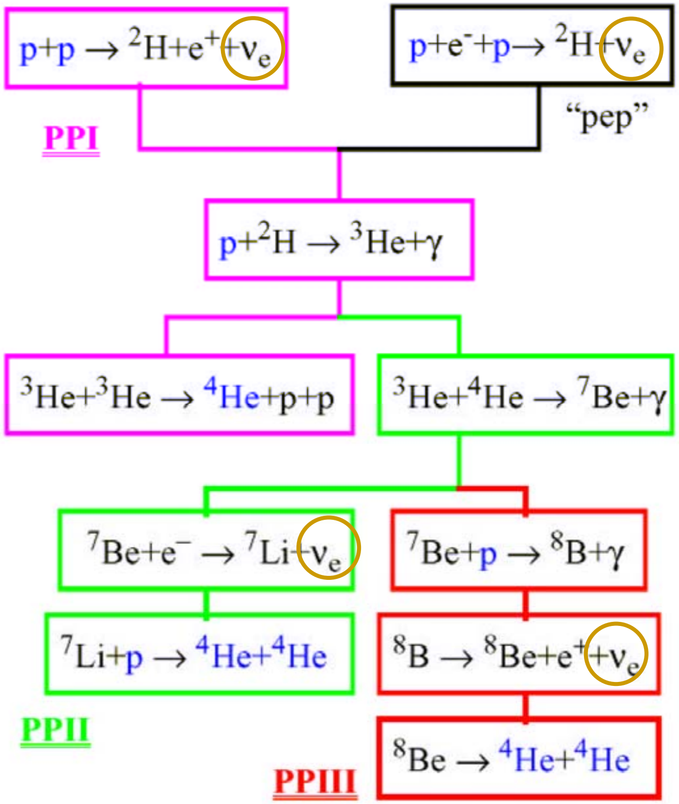
Neutrino Production In The Sun

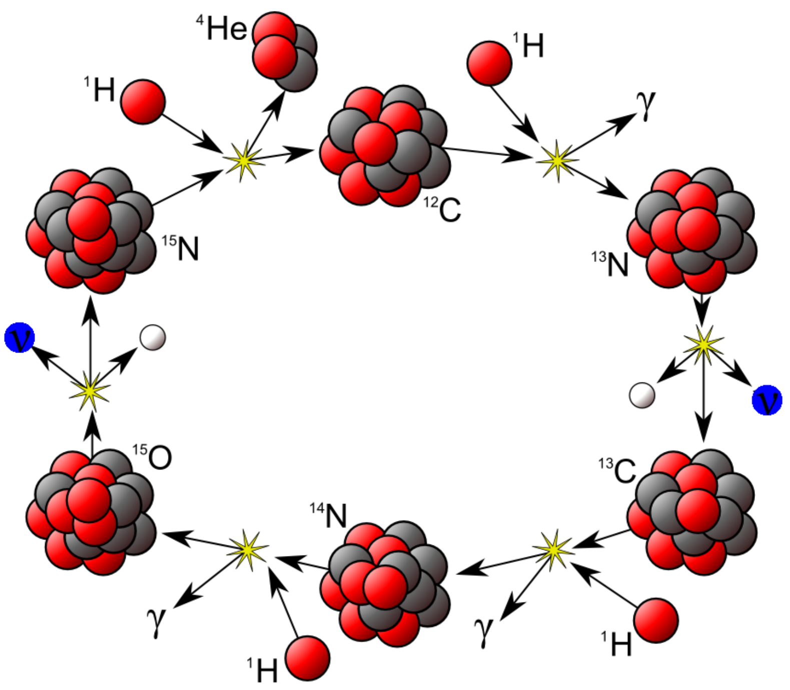
pp chain:

pp, *pep*, ^{7}Be, *hep* ,and ^{8}B ν

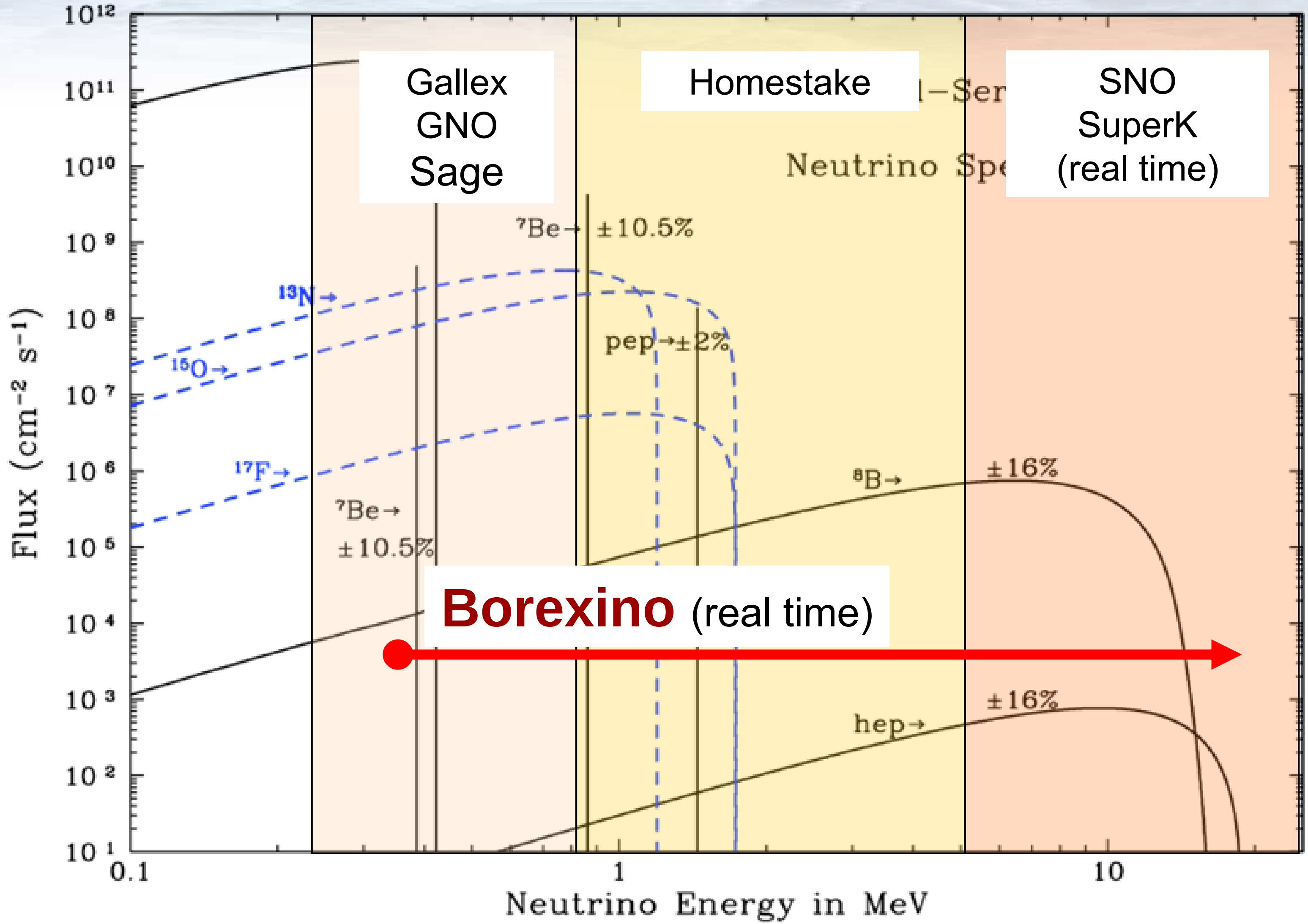


CNO cycle:

^{13}N, ^{15}O, and ^{17}F ν



Solar Neutrino Spectra



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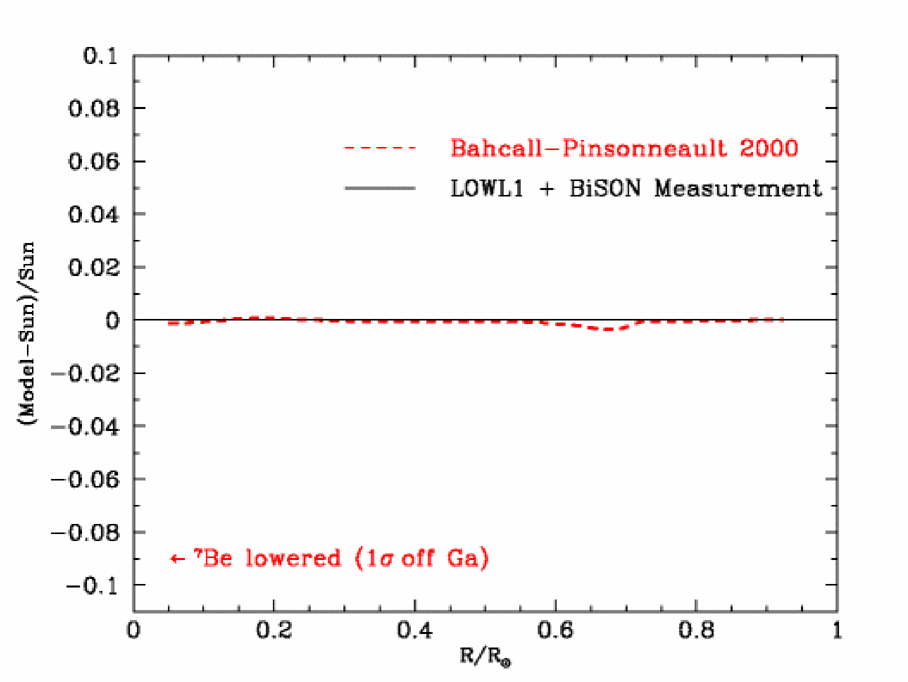
The Standard Solar Model before 2004

One fundamental input of the Standard Solar Model is the **metallicity** of the Sun - abundance of all elements above Helium:

The Standard Solar Model, based on the old metallicity derived by Grevesse and Sauval (Space Sci. Rev. **85**, 161 (1998)), was in **agreement within 0.5 in %** with the solar sound speed measured by helioseismology.



The Standard Solar Model after 2004

Latest work by Asplund, Grevesse and Sauval (Nucl. Phys. A **777**, 1 (2006)) indicates a **lower** metallicity **by a factor ~2**. This result destroys the agreement with helioseismology

[cm^{-2} s^{-1}]	pp (10^{10})	pep (10^{10})	hep (10^{3})	^{7}Be (10^{9})	^{8}B (10^{6})	^{13}N (10^{8})	^{15}O (10^{8})	^{17}F (10^{6})
BS05 AGS 98	6.06	1.45	8.25	4.84	5.69	3.07	2.33	5.84
BS05 AGS 05	5.99	1.42	7.93	4.34	4.51	2.01	1.45	3.25
Δ	-1%	-2%	-4%	-12%	-23%	-42%	-47%	-57%

Solar neutrino measurements can solve the problem!

Borexino goals: solar physics

✓ First ever observations of **sub-MeV neutrinos** in real time

✓ Check the balance between photon **luminosity** and neutrino luminosity of the Sun

✓ **CNO** neutrinos (direct indication of metallicity in the Sun's core)

✓ ***pep*** neutrinos (indirect constraint on *pp* neutrino flux)

✓ Low energy (**3-5 MeV**) ^{8}B neutrinos

✓ Tail end of ***pp* neutrino spectrum**?

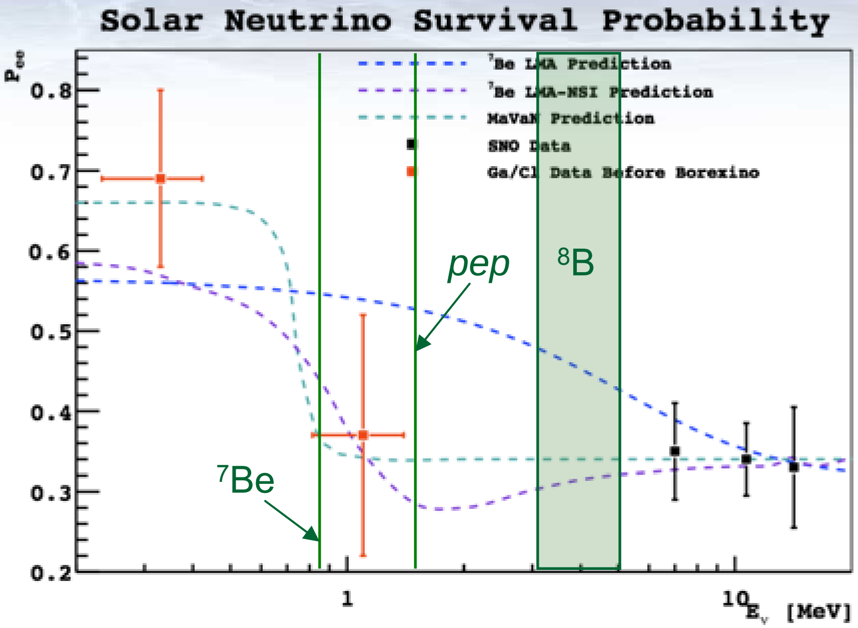
Borexino goals: neutrino physics

✓ Test of the **matter-vacuum oscillation transition** with ^{7}Be, *pep,* and low energy ^{8}B neutrinos

✓ Limit on the **neutrino magnetic moment** by analyzing the ^{7}Be energy spectrum and with Cr source

✓ SNEWS network for **supernovae**

✓ First evidence (>3σ) of **geoneutrinos**



Map of reactors in Europe

Borexino Collaboration

INFN

Genova

Perugia

Milano

APC Paris

Princeton University

Virginia Tech. University

LNGS Laboratori Nazionali del Gran Sasso

Istituto Nazionale di Fisica Nucleare INFN

Dubna JINR (Russia)

Kurchatov Institute (Russia)

Jagiellonian U. Cracow (Poland)

Max-Planck-Institut für Kernphysik

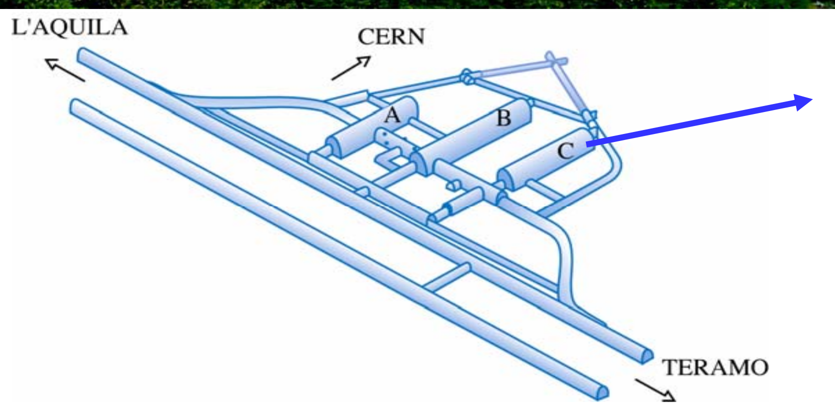
Heidelberg (Germany)

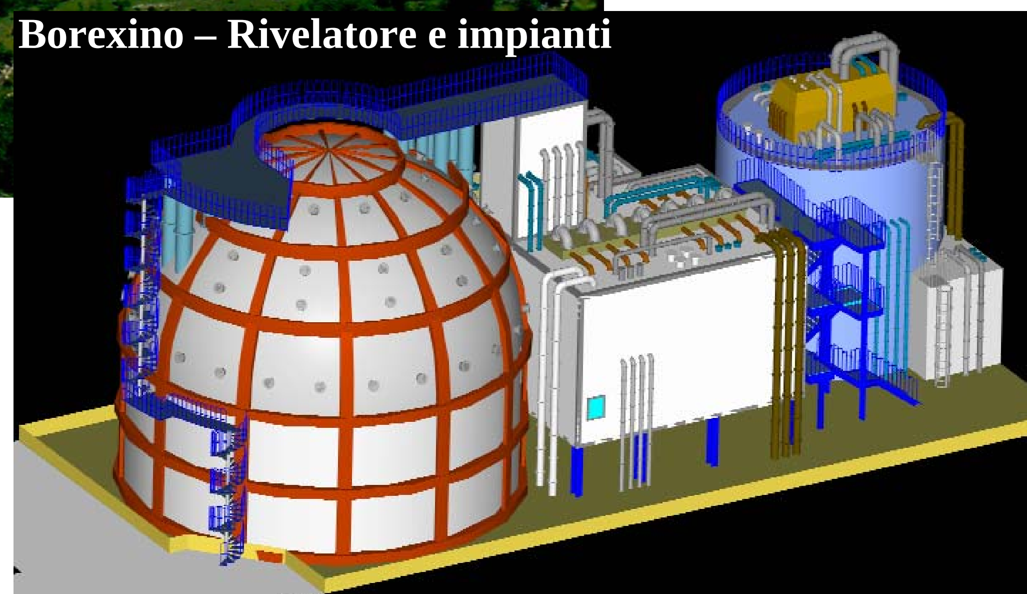
Technische Universität München

Munich (Germany)

Laboratori Nazionali del Gran Sasso

Assergi (AQ)
Italy
~3500 m.w.e





Detection principles and ν signature

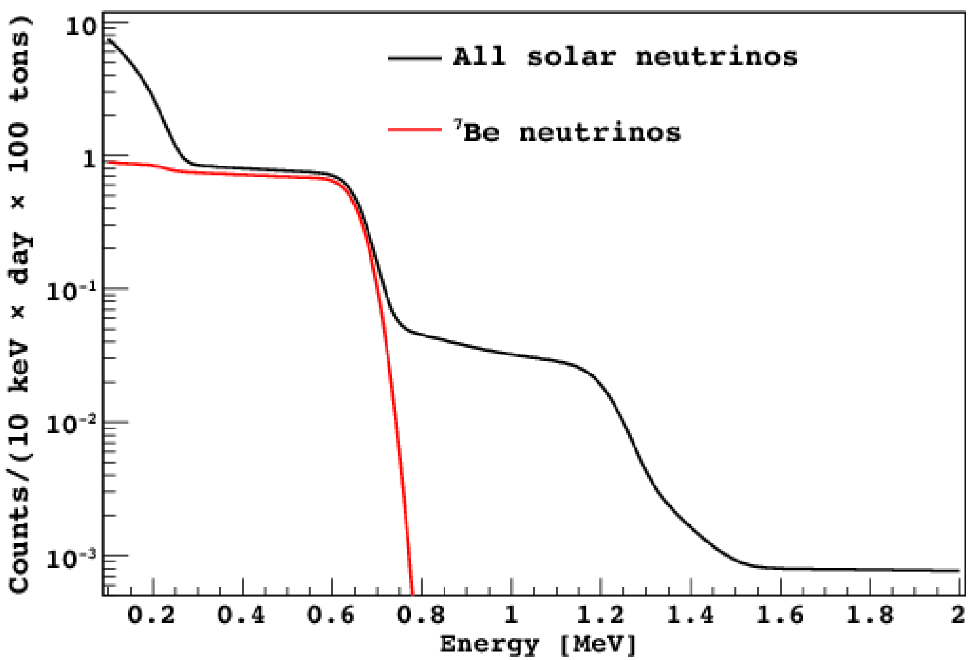
- Borexino detects solar ν via their **elastic scattering off electrons** in a volume of **highly purified liquid scintillator**
  - Mono-energetic **0.862 MeV ^{7}Be** ν are the main target, and the only considered so far
  - Mono-energetic pep ν , CNO ν and possibly pp ν will be studied in the future

- Detection via scintillation light:
  - Very low energy threshold
  - Good position reconstruction
  - Good energy resolution

  BUT…
  - No direction measurement
  - The ν induced events can't be distinguished from other β events due to natural radioactivity

- **Extreme radiopurity of the scintillator is a must!**

Typical ν rate (SSM+LMA+Borexino)



Borexino Background

Expected solar neutrino rate in 100 tons of scintillator ~ 50 counts/day (**~ 5 10^{-9} Bq/kg**)

Just for comparison:

Natural water	~ 10 Bq/kg in ^{238}U, ^{232}Th and ^{40}K
Air	~ 10 Bq/m^3 in ^{39}Ar, ^{85}Kr and ^{222}Rn
Typical rock	~ 100-1000 Bq/kg in ^{238}U, ^{232}Th and ^{40}K

BX scintillator must be **9/10 order of magnitude less** radioactive than anything on earth!

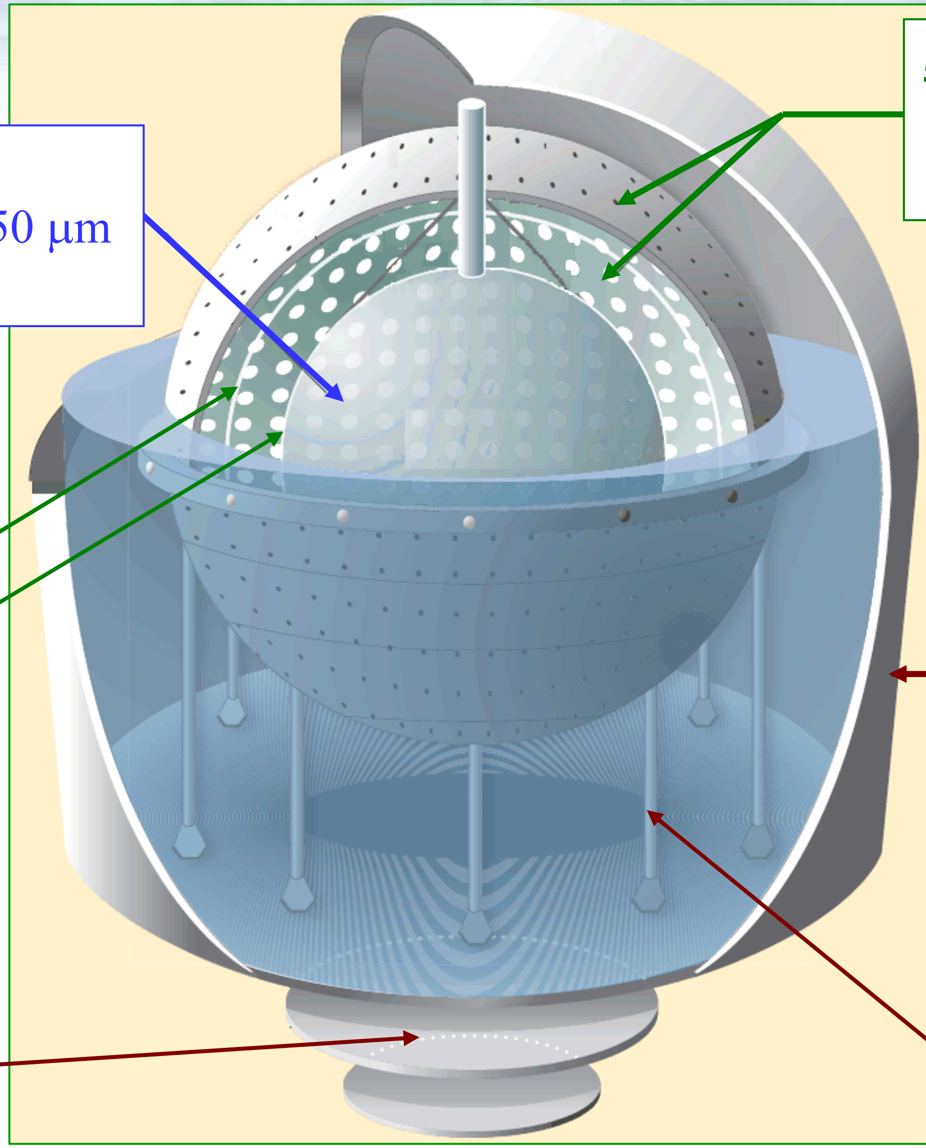
- ✓ **Low background nylon vessel** fabricated in hermetically sealed low radon clean room (~1 yr)
- ✓ **Rapid transport** of scintillator solvent (PC) from production plant to underground lab to avoid cosmogenic production of radioactivity (^7Be)
- ✓ Underground **purification plant** to distill scintillator components.
- ✓ **Gas stripping** of scintlllator with special nitrogen free of radioactive ^{85}Kr and ^{39}Ar from air
- ✓ All materials **electropolished SS or teflon**, precision cleaned with a dedicated cleaning module

Detector layout and main features

Scintillator:
270 t PC+PPO in a 150 μm thick nylon vessel

Stainless Steel Sphere:
2212 PMTs
1350 m^3

Nylon vessels:
Inner: 4.25 m
Outer: 5.50 m

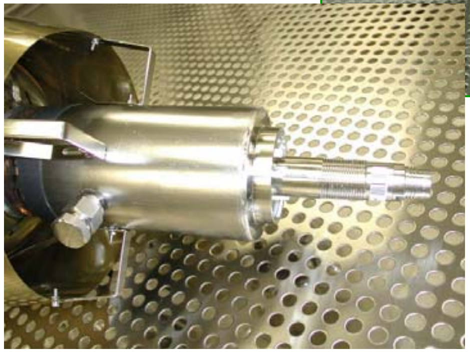


Water Tank:
γ and n shield
μ water Č detector
208 PMTs in water
2100 m^3

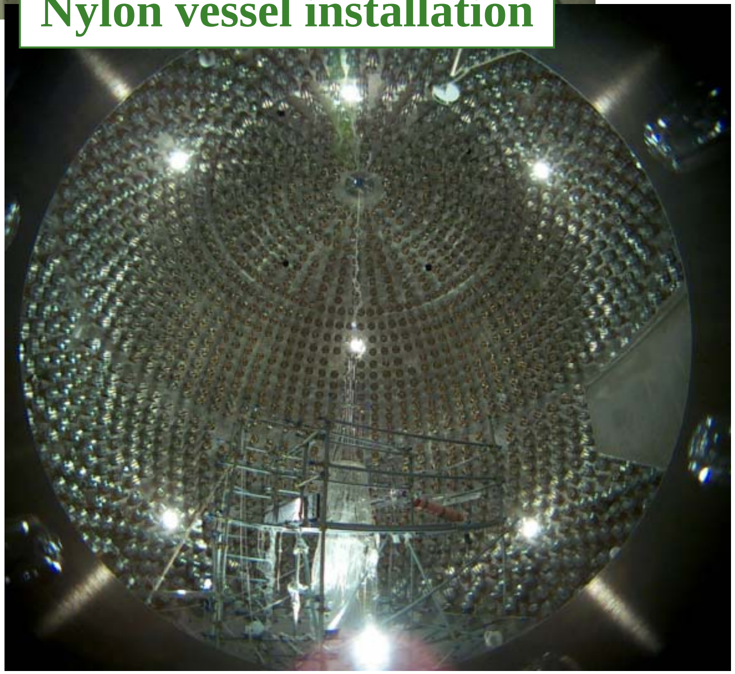
Carbon steel plates

20 legs

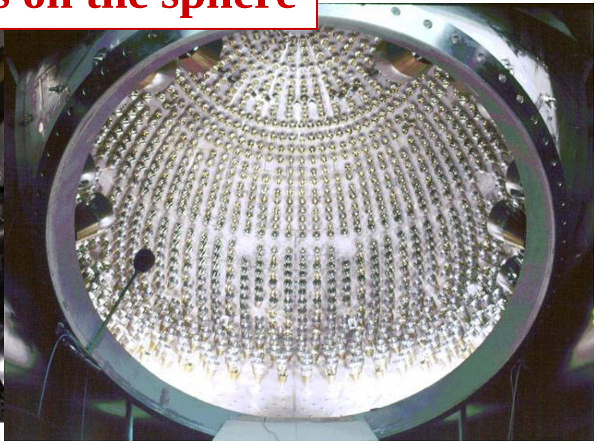
PMTs: PC & Water proof



Nylon vessel installation



Installation of PMTs on the sphere

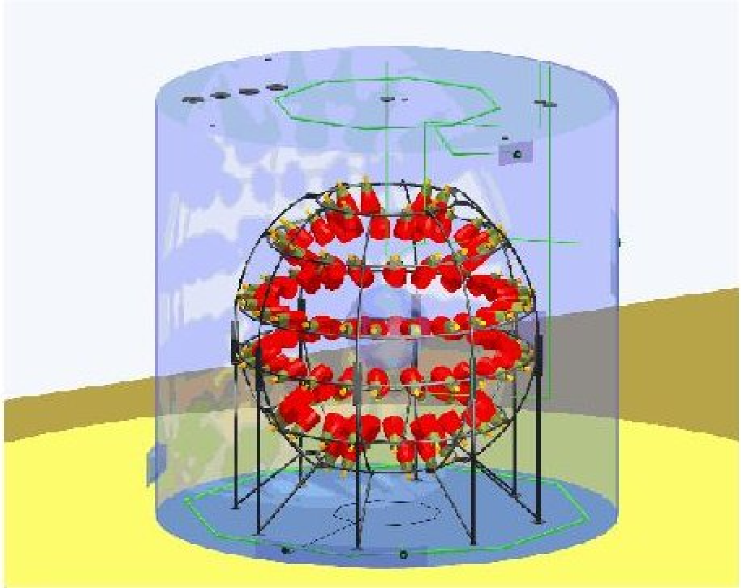


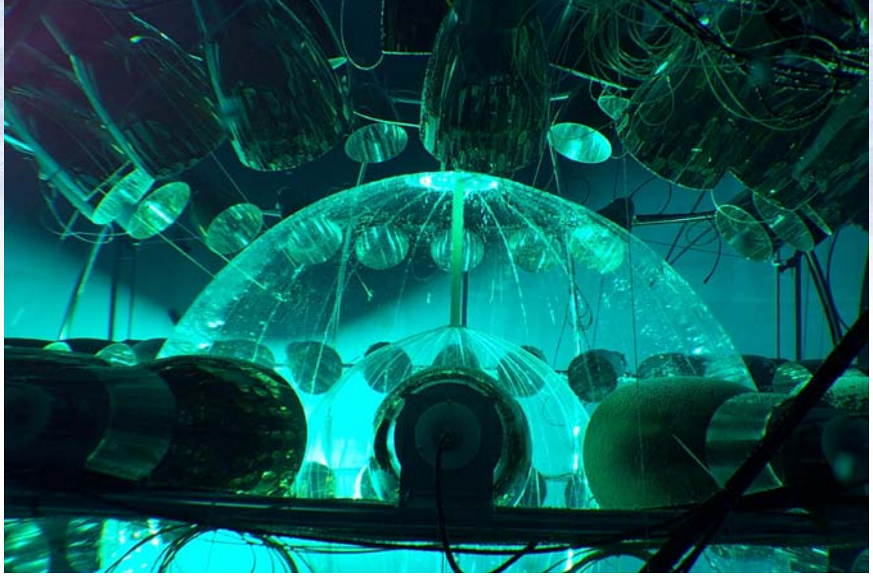
Water Plant

Storage area and Plants

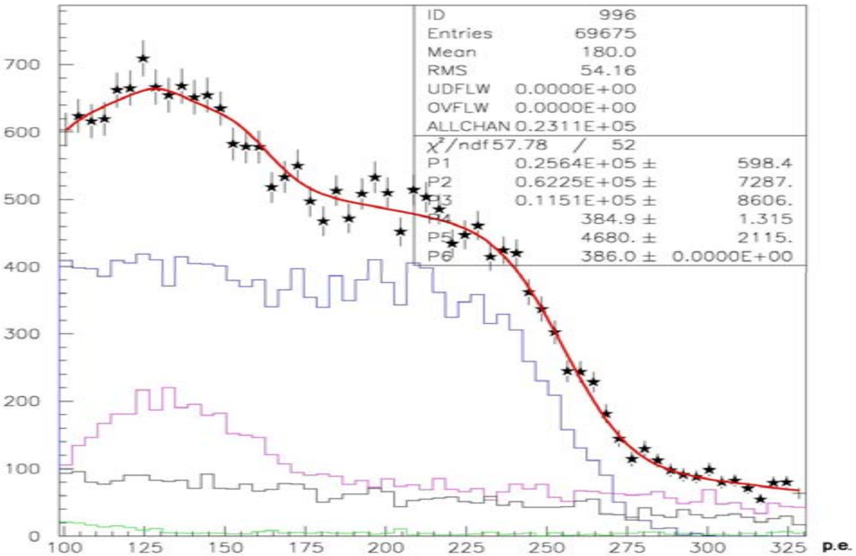
Counting Test Facility

✓CTF is a small scale prototype of Borexino:
- ✓ ~ 4 tons of scintillator
- ✓ 100 PMTs
- ✓ Buffer of water
- ✓ Muon veto
- ✓ Vessel radius: 1 m

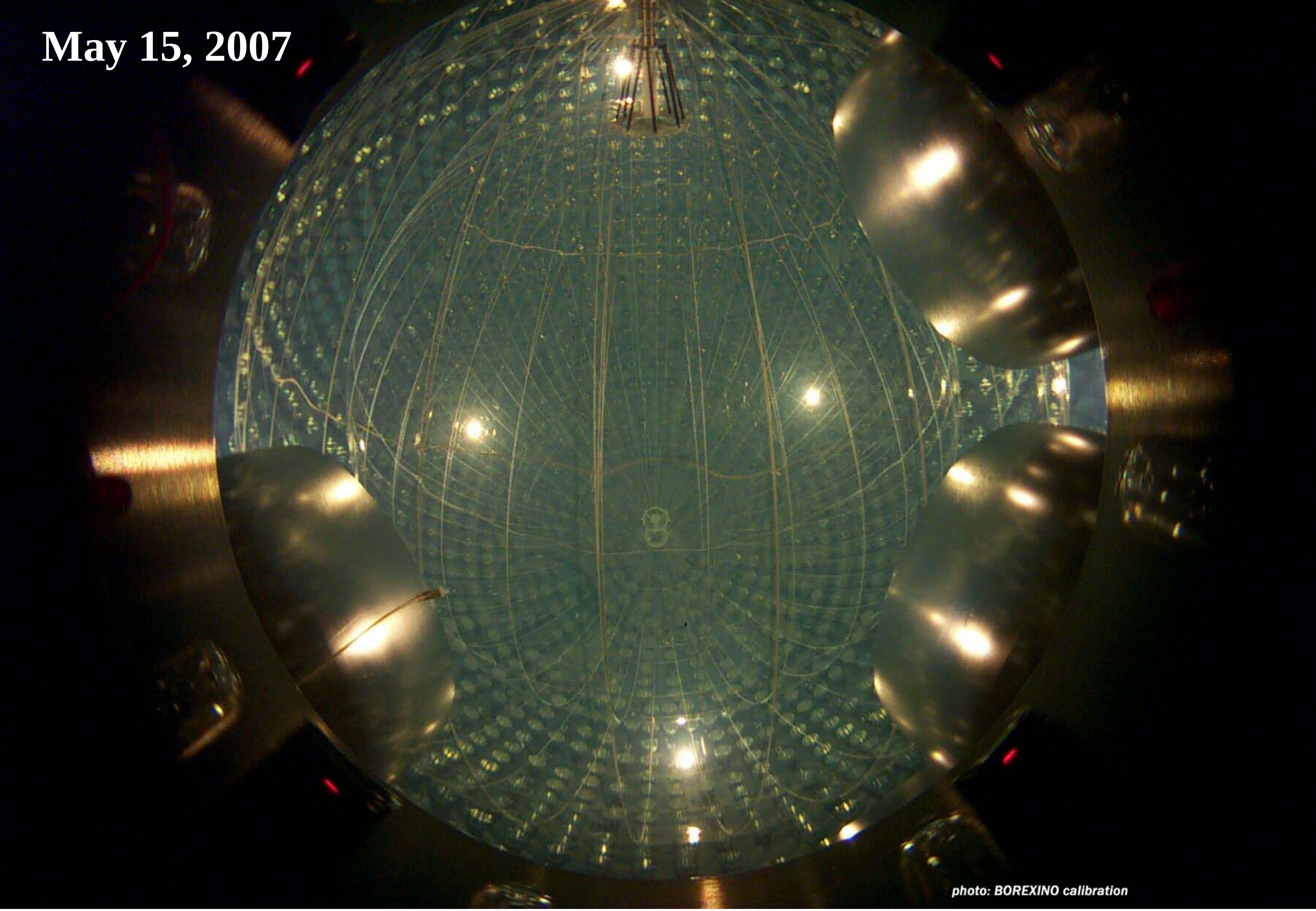




CTF demonstrates the Borexino feasibility



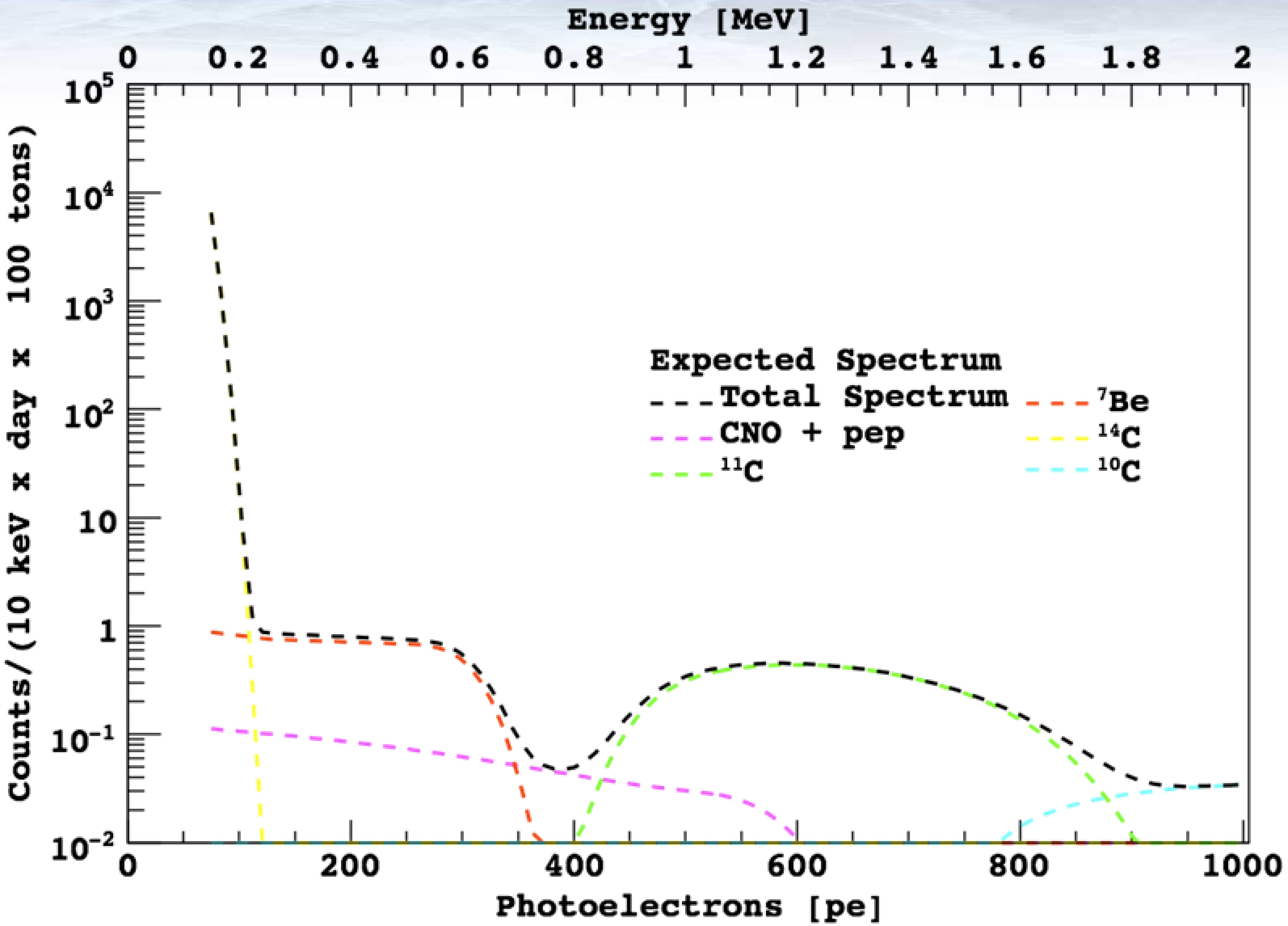
May 15, 2007



Borexino background

RadioIsotope		Concentration or Flux		Strategy for Reduction		
Name	**Source**	**Typical**	**Required**	**Hardware**	**Software**	**Achieved**
μ	cosmic	~200 s^{-1} m^{-2} at sea level	**~ 10^{-10}**	Underground Cherenkov detector	Cherenkov signal PS analysis	**<10^{-10}** (overall)
Ext. γ	rock			Water Tank shielding	Fiducial Volume	negligible
Int. γ	PMTs, SSS Water, Vessels			Material Selection Clean constr. and handling	Fiducial Volume	negligible
^{14}C	Intrinsic PC/PPO	~ 10^{-12}	**~ 10^{-18}**	Old Oil, check in CTF	Threshold cut	**~ 10^{-18}**
^{238}U ^{232}Th	Dust Organometallic (?)	~ 10^{-5}-10^{-6} g/g (dust)	**< 10^{-16} g/g** (in scintillator)	Distillation, Water Extraction Filtration, cleanliness		**~ 2 10^{-17}** **~ 7 10^{-18}**
^{7}Be	Cosmogenic (^{12}C)	~ 3 10^{-2} Bq/t	< 10^{-6} Bq/ton	Fast procurement, distillation	Not yet measurable	?
^{40}K	Dust, PPO	~ 2 10^{-6} g/g (dust)	< 10^{-14} g/g scin. < 10^{-11} g/g PPO	Water Extraction Distillation	Not yet measurable	?
^{210}Pb	Surface contam. from ^{222}Rn decay			Cleanliness, distillation	Not yet measurable (NOT in eq. with ^{210}Po)	?
^{210}Po	Surface contam. from ^{222}Rn decay			Cleanliness, distillation	Spectral analysis α/β stat. subtraction	**~ 14** **~ 0.01 c/d/t**
^{222}Rn	air, emanation from materials, vessels	~ 10 Bq/l (air) ~100 Bq/l (water)	< 1 c/d/100 t (scintillator)	Water and PC N_2 stripping, cleanliness, material selection	Delayed coincidence	< 0.02 c/d/t
^{39}Ar	Air (nitrogen)	~17 mBq/m^3 (air)	< 1 c/d/100 t	Select vendor, leak tightness	Not yet measurable	?
^{85}Kr	Air (nitrogen)	~ 1 Bq/m^3 in air	< 1 c/d/100 t	Select vendor, leak tightness (learn how to measure it)	Spectral fit fast coincidence	**= 25±3** **= 29±14**

Expected Spectrum



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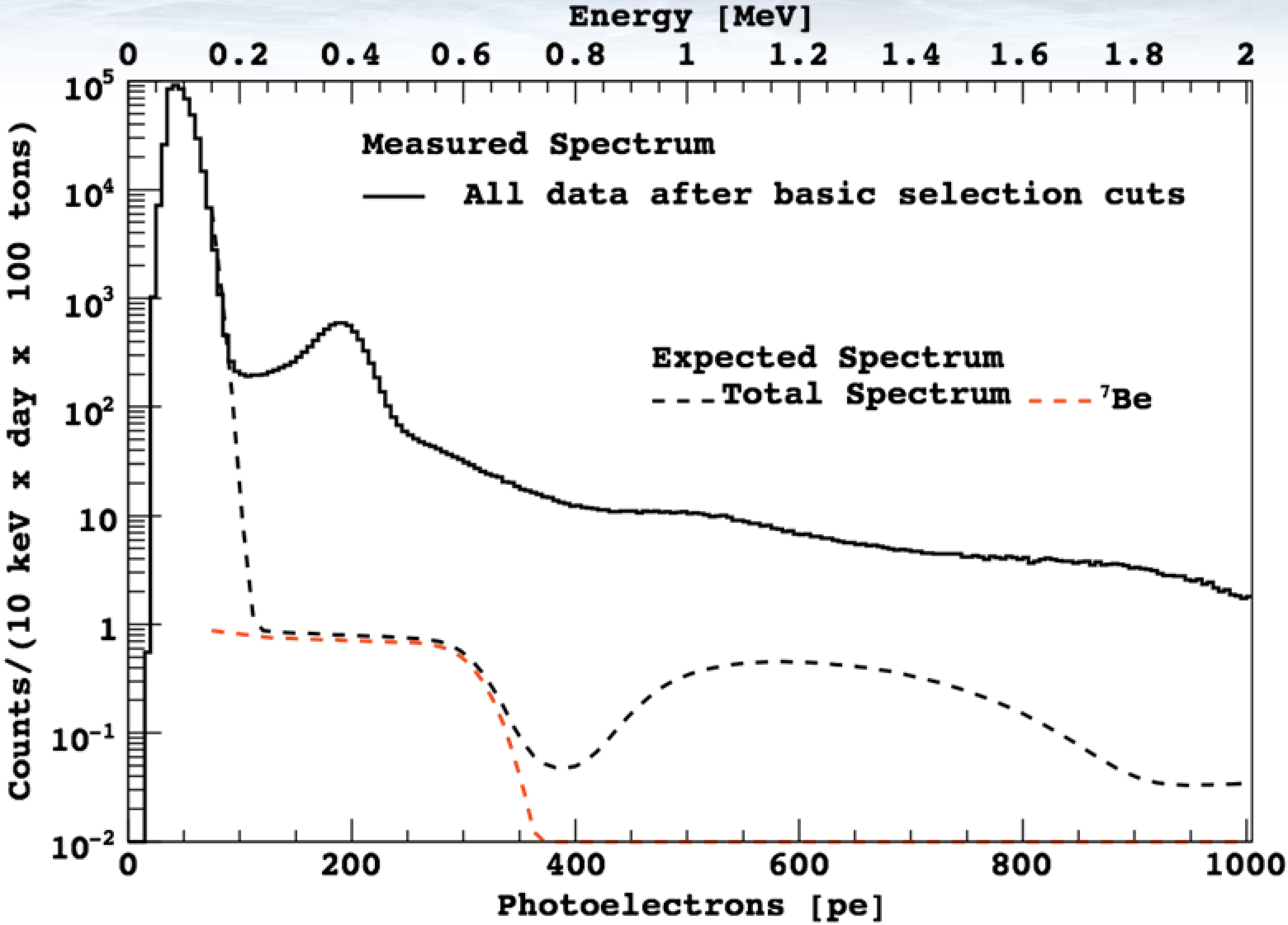
The starting point: no cut spectrum



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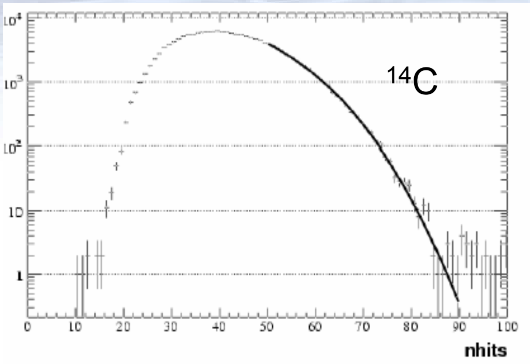
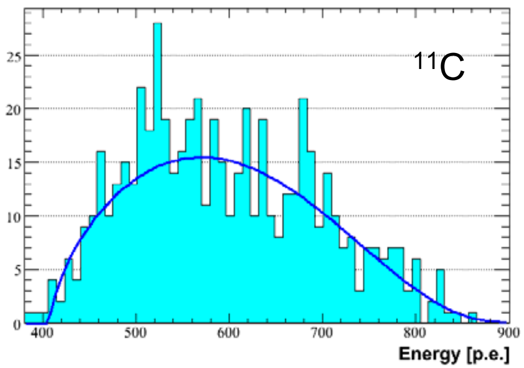
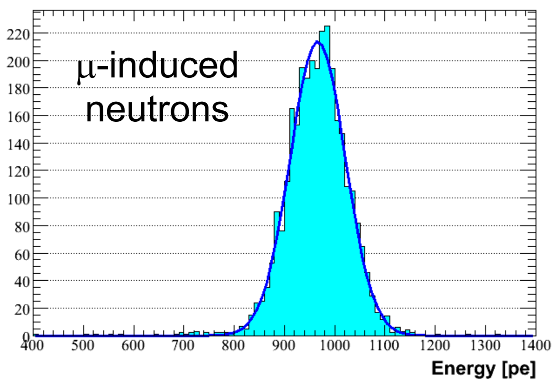
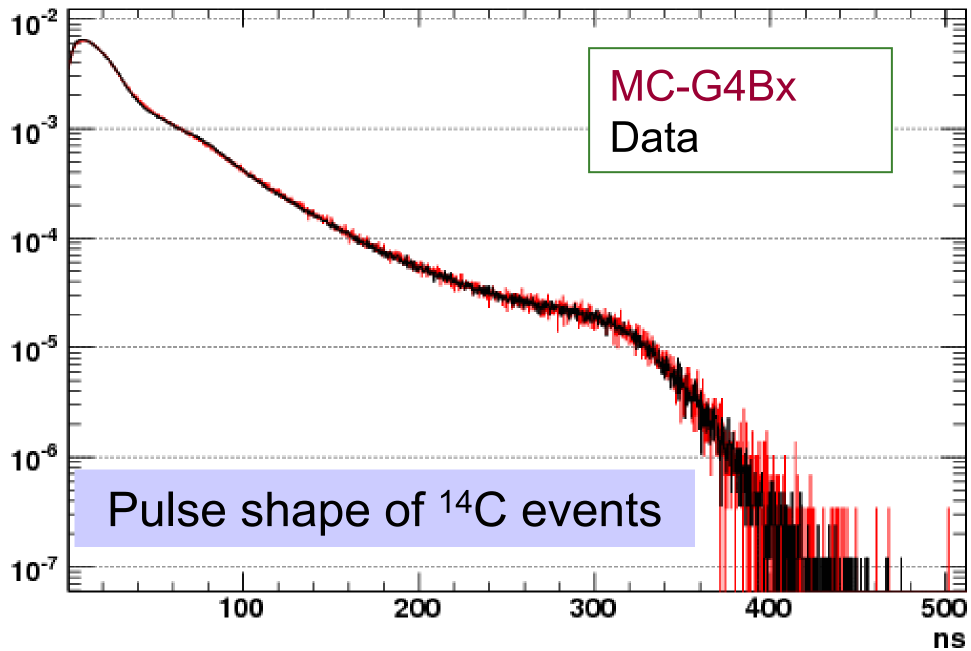
Energy scale







MC vs data comparison of photoelectron time distributions from ^{14}C



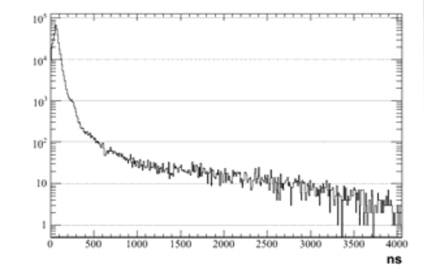
LY = 510 (1%) p.e./MeV
kB = 0.0197 (15%) cm/MeV
Ph.Y. ~ 12000 photons/MeV

Detecting (and rejecting) cosmic muons

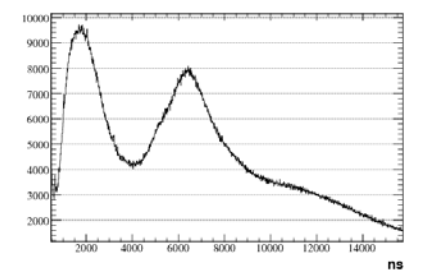
- μ are identified by ID and OD
  - OD eff: ~ 99%
  - ID based on pulse shape analysis

  - Rejection factor
    - > 10^3 (conservative)

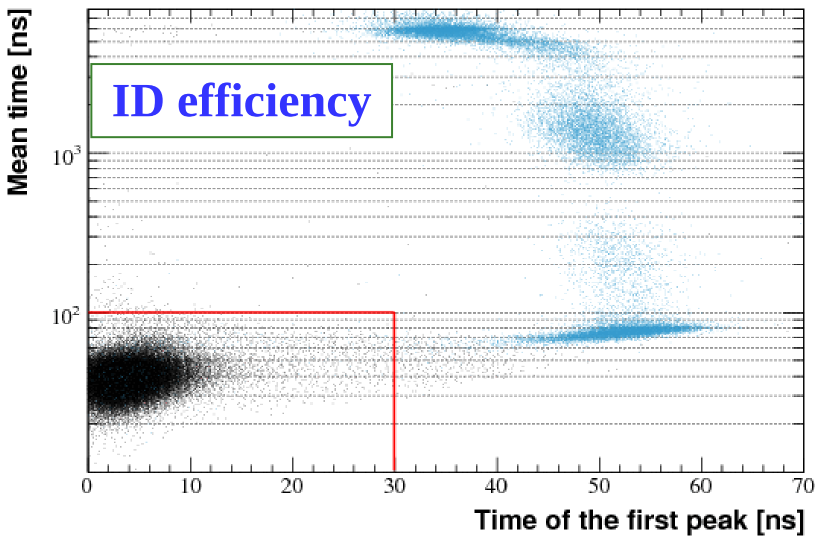
μ pulses

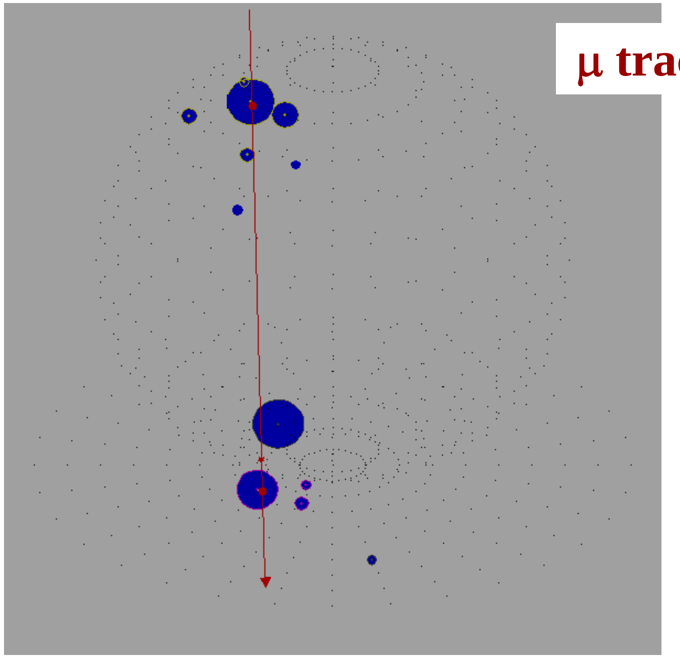


μ crossing the buffer only



μ crossing the scintillator





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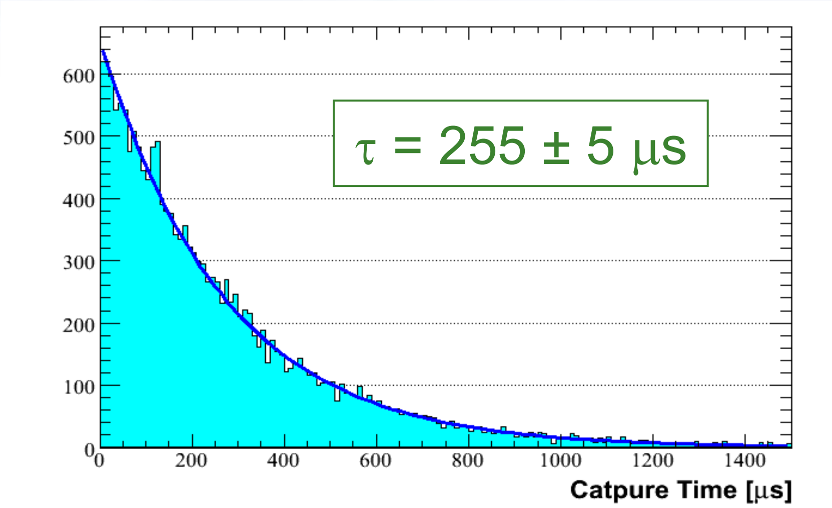
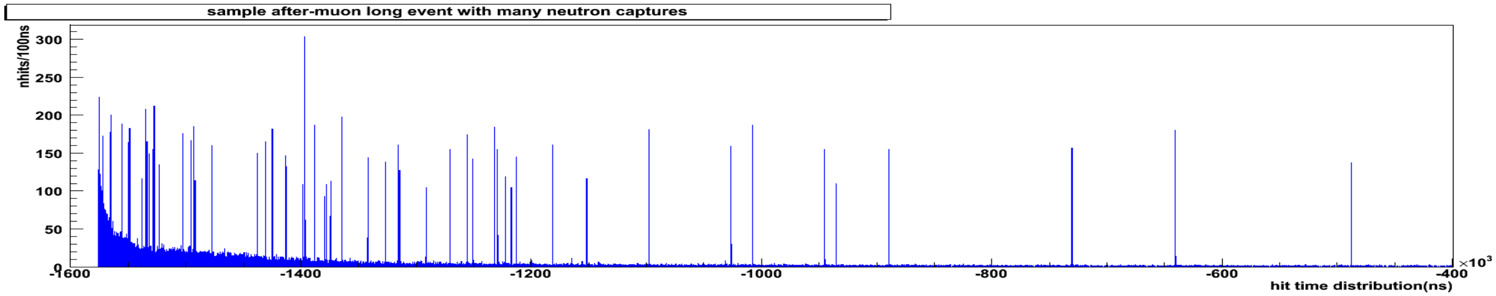
Detecting (and rejecting) cosmogenic neutrons

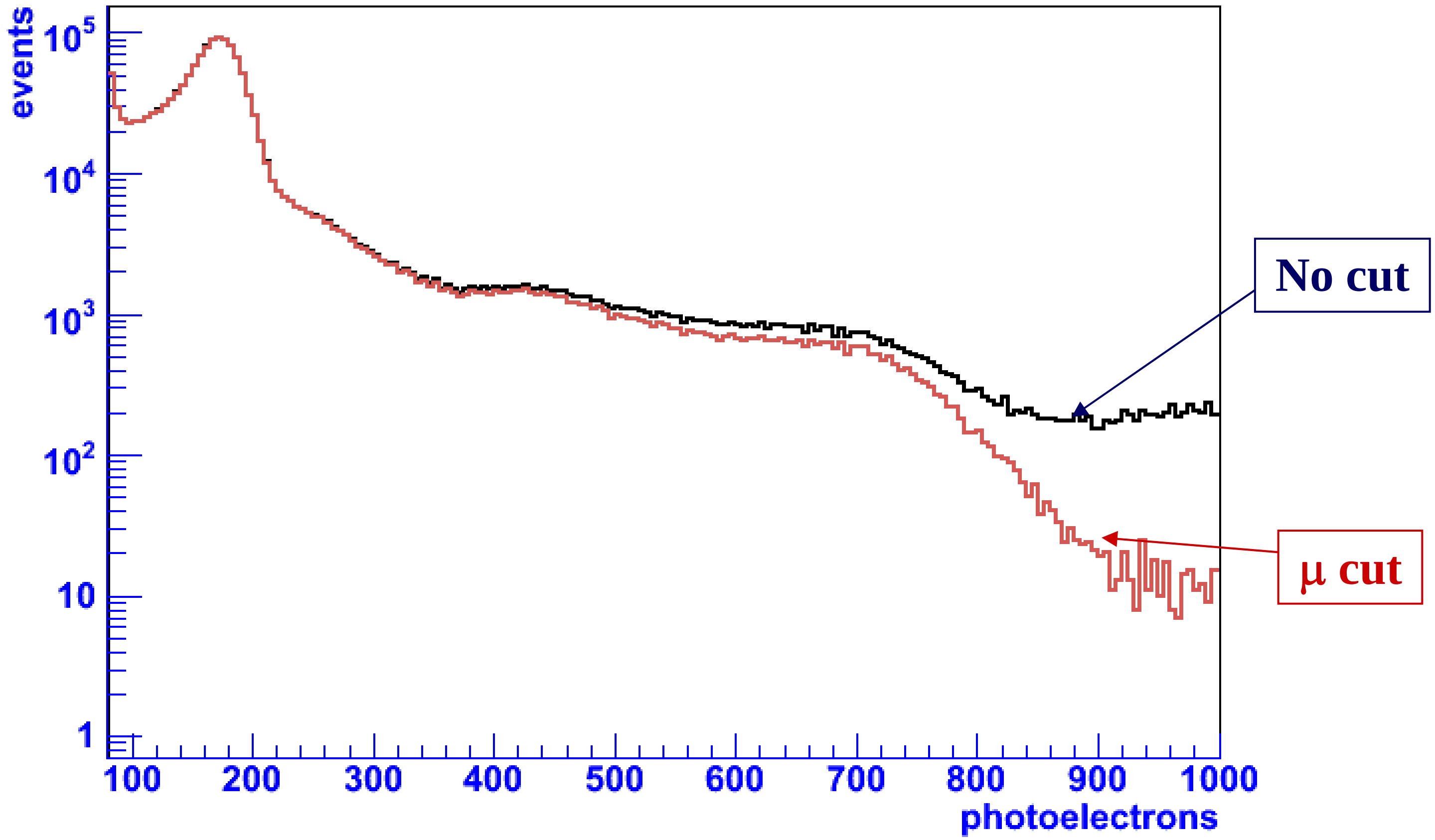
$$n + p \xrightarrow{\tau \sim 250\ \mu s} d + \gamma$$



A dedicated trigger starts after each muon opening a gate for 1.6 ms.
An offline clustering algorithm identifies neutron in high multiplicity events

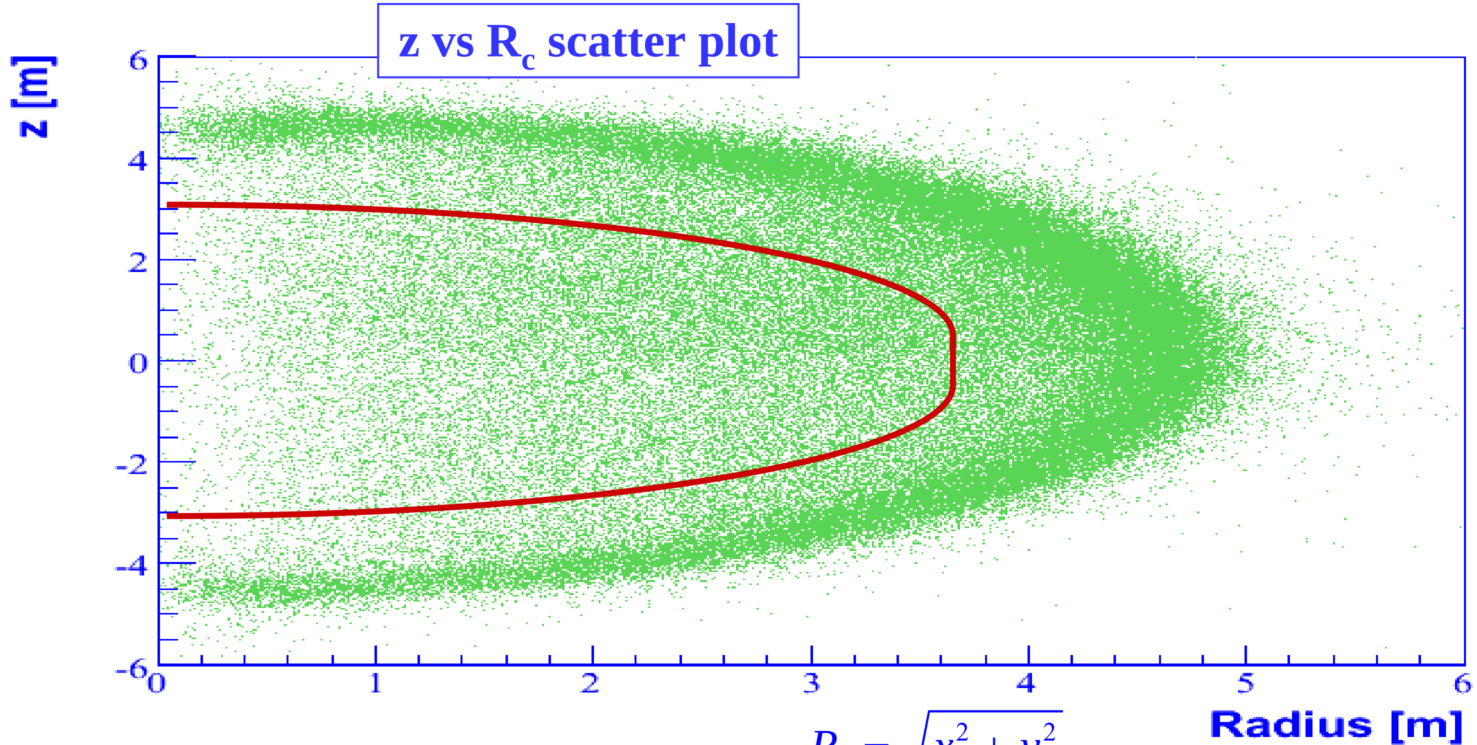


Muon and neutron cuts



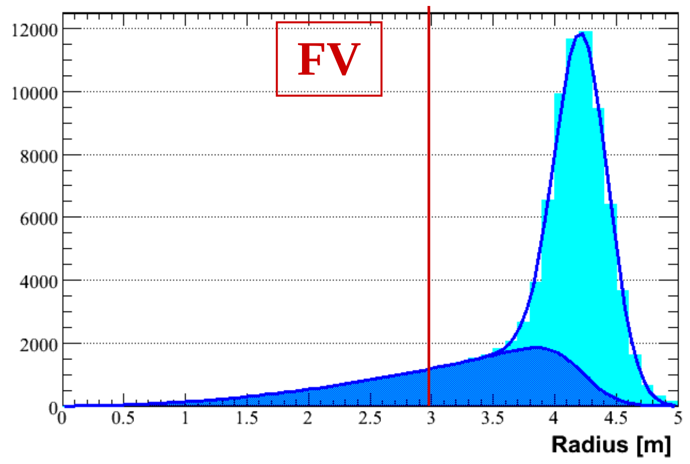
Position reconstruction

- Position reconstruction algorythms (we have 4 codes right now)
  - time of flight fit to hit time distribution
  - developed with MC, tested and validated in CTF
  - cross checked and tuned in Borexino with ^{214}Bi-^{214}Po events and ^{14}C events

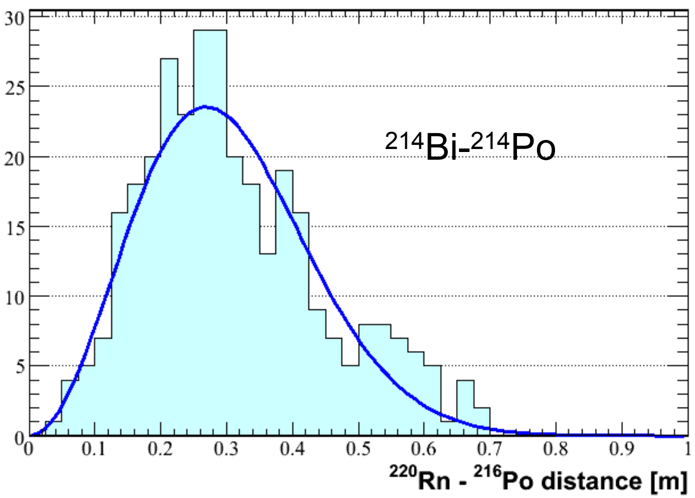


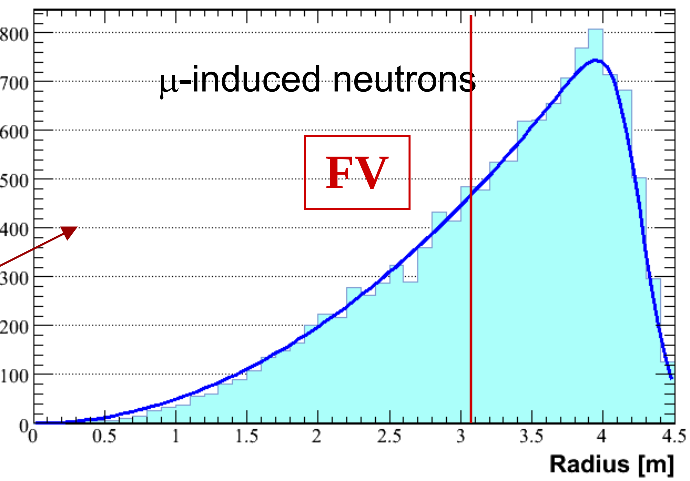
$$R_c = \sqrt{x^2 + y^2}$$

Spatial distributions and resolutions



^{7}Be energy region (mainly ^{210}Po)





11 cm @ ~2200 keV

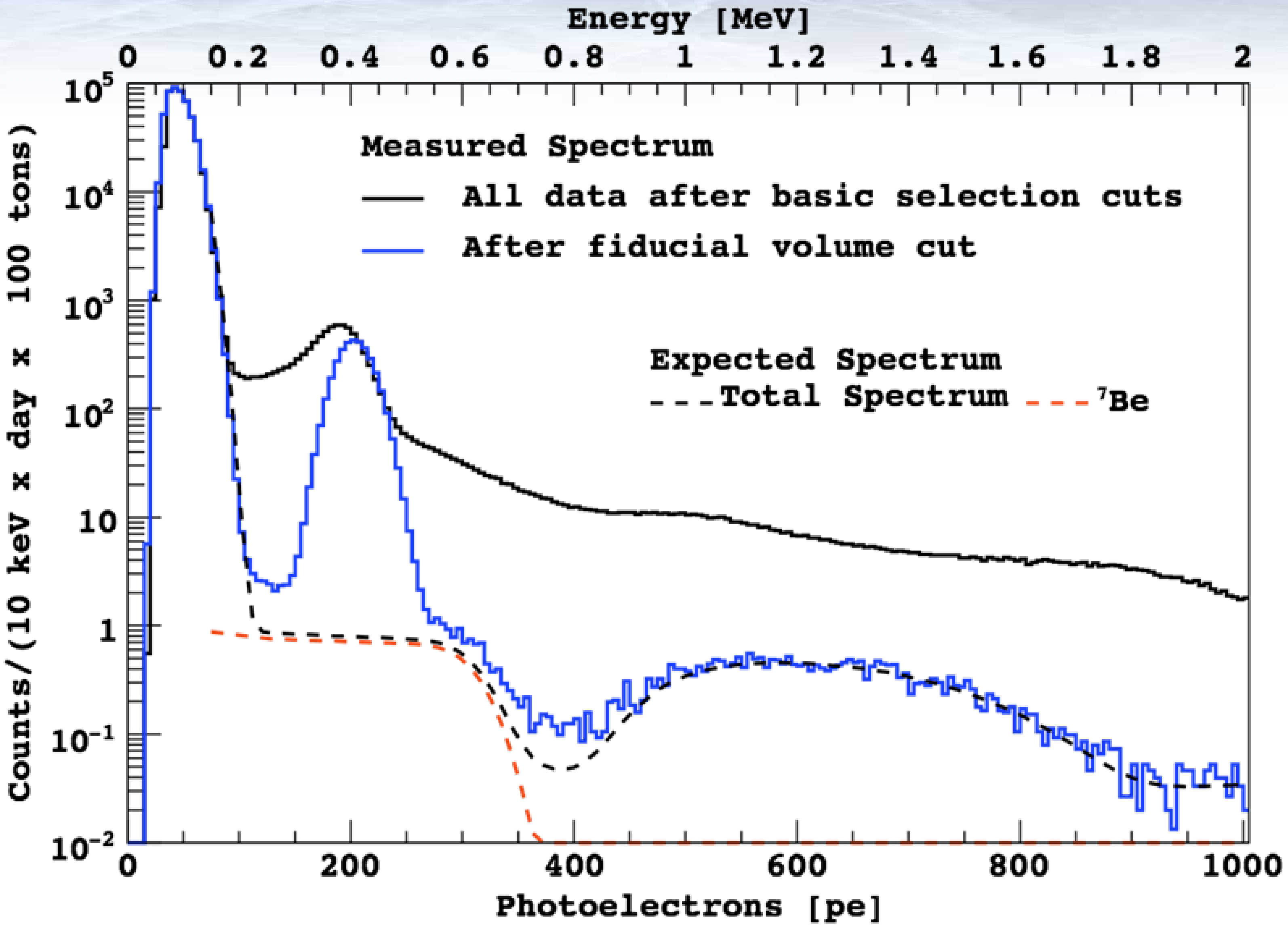
^{214}Bi-^{214}Po (~800 KeV)

14±2 cm

^{14}C (~100 KeV):

41±4 cm

Spectrum after FV cut (100 tons)

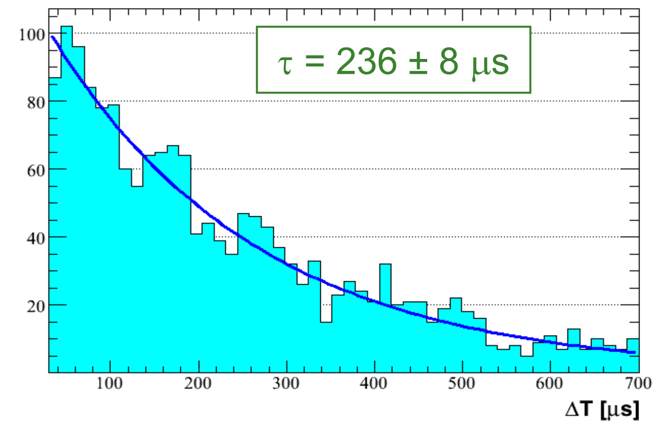


^{238}U content

τ = 236 μs

^{214}Bi $\xrightarrow{\beta}$ ^{214}Po $\xrightarrow{\alpha}$ ^{210}Pb

3.2 MeV ~700 keV eq.



Assuming secular equilibrium and looking in the FV only:

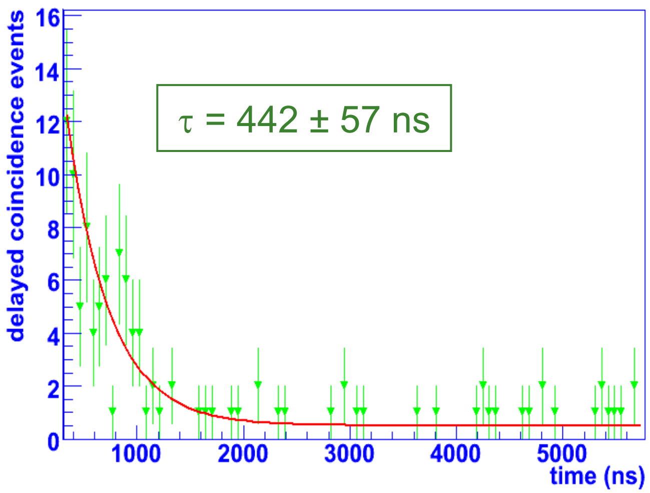
0.02 cpd/tons corresponding to **^{238}U = (1.9 ± 0.3)×10^{-17} g/g**

^{232}Th content

τ = 432.8 ns

^{212}Bi $\xrightarrow{\beta}$ ^{212}Po $\xrightarrow{\alpha}$ ^{208}Pb

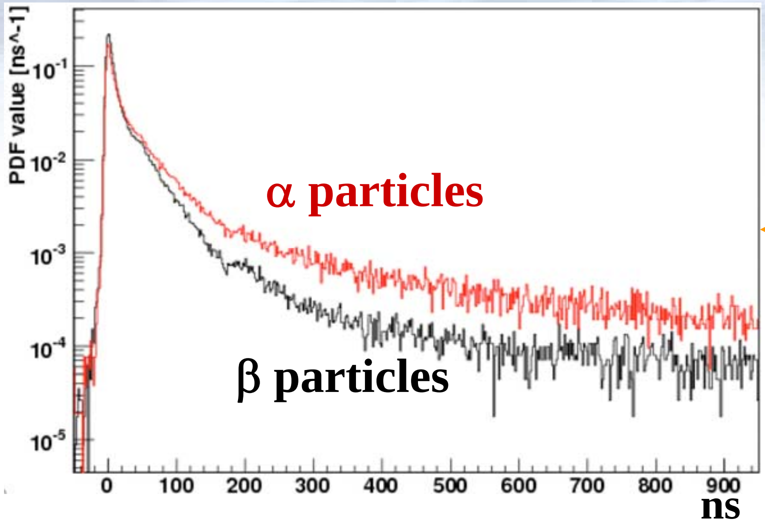
2.25 MeV ~1000 keV eq.



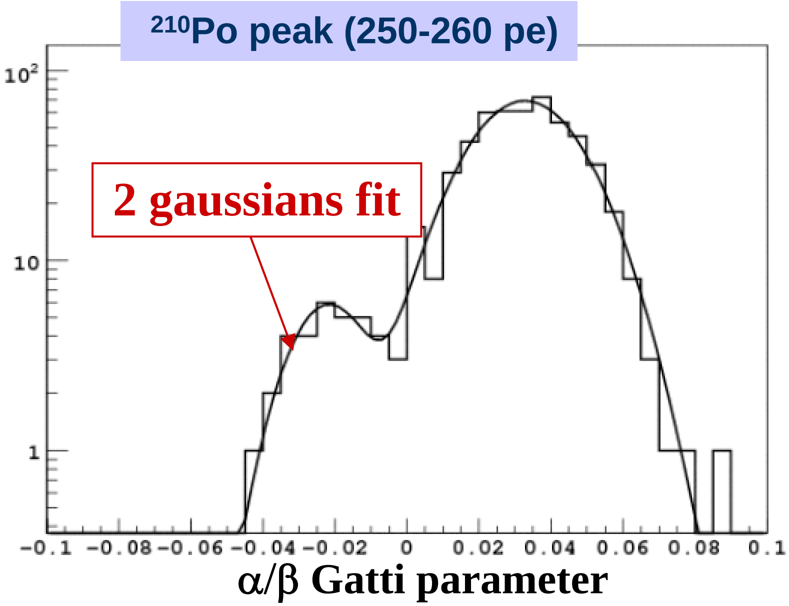
Assuming secular equilibrium and looking in the FV only_:

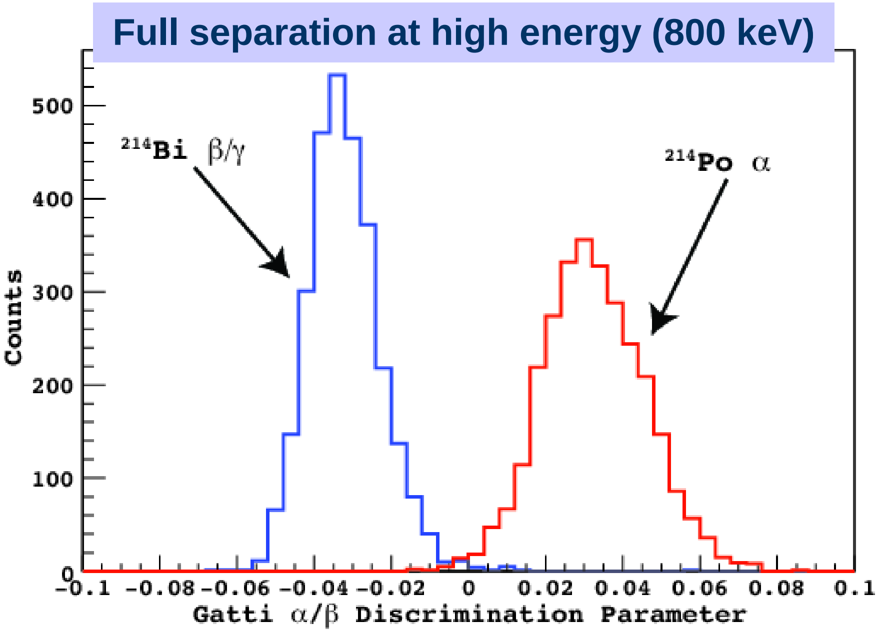
0.00256 cpd/ton corresponding to **^{232}Th = (6.8±1.5)×10^{-18} g/g**

α/β discrimination



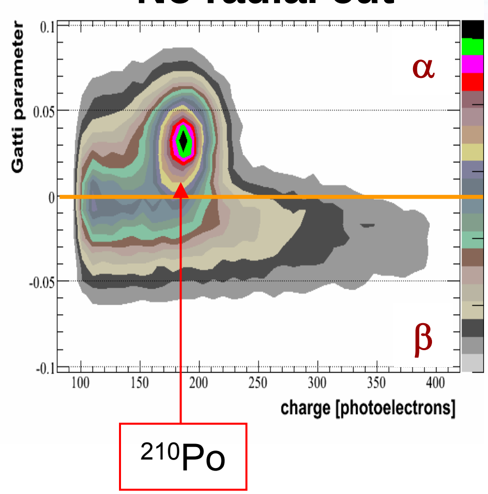
Average **time profiles of the scintillation pulses** emitted by a PC+PPO (1.5 g/l) mixture under alpha and beta irradiation



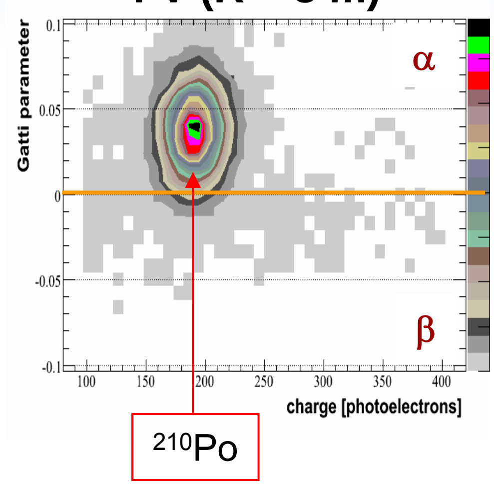


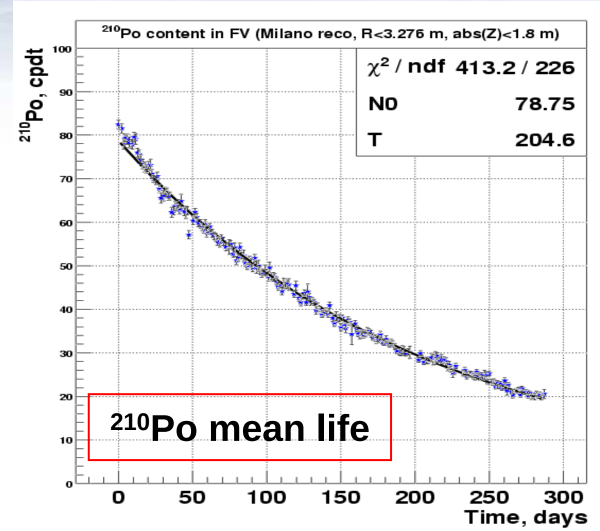
^{210}Po contamination

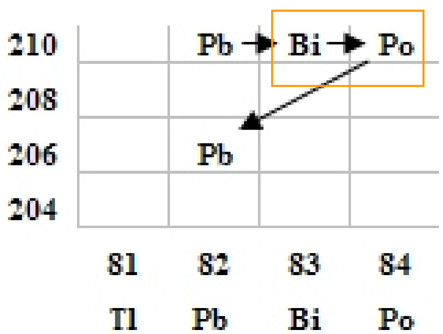
No radial cut



FV (R < 3 m)

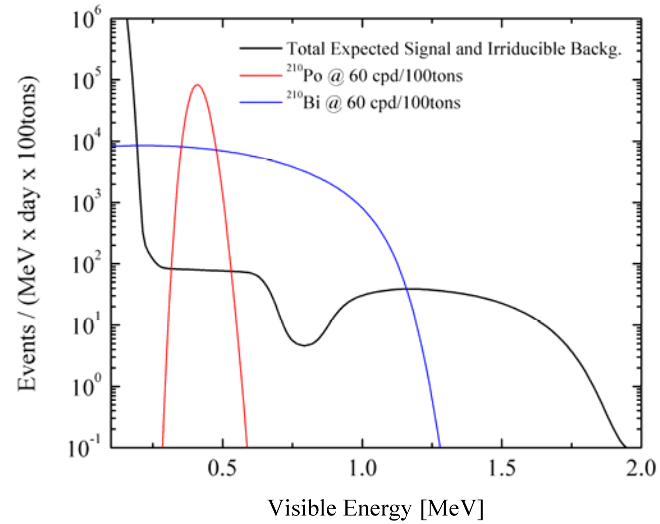




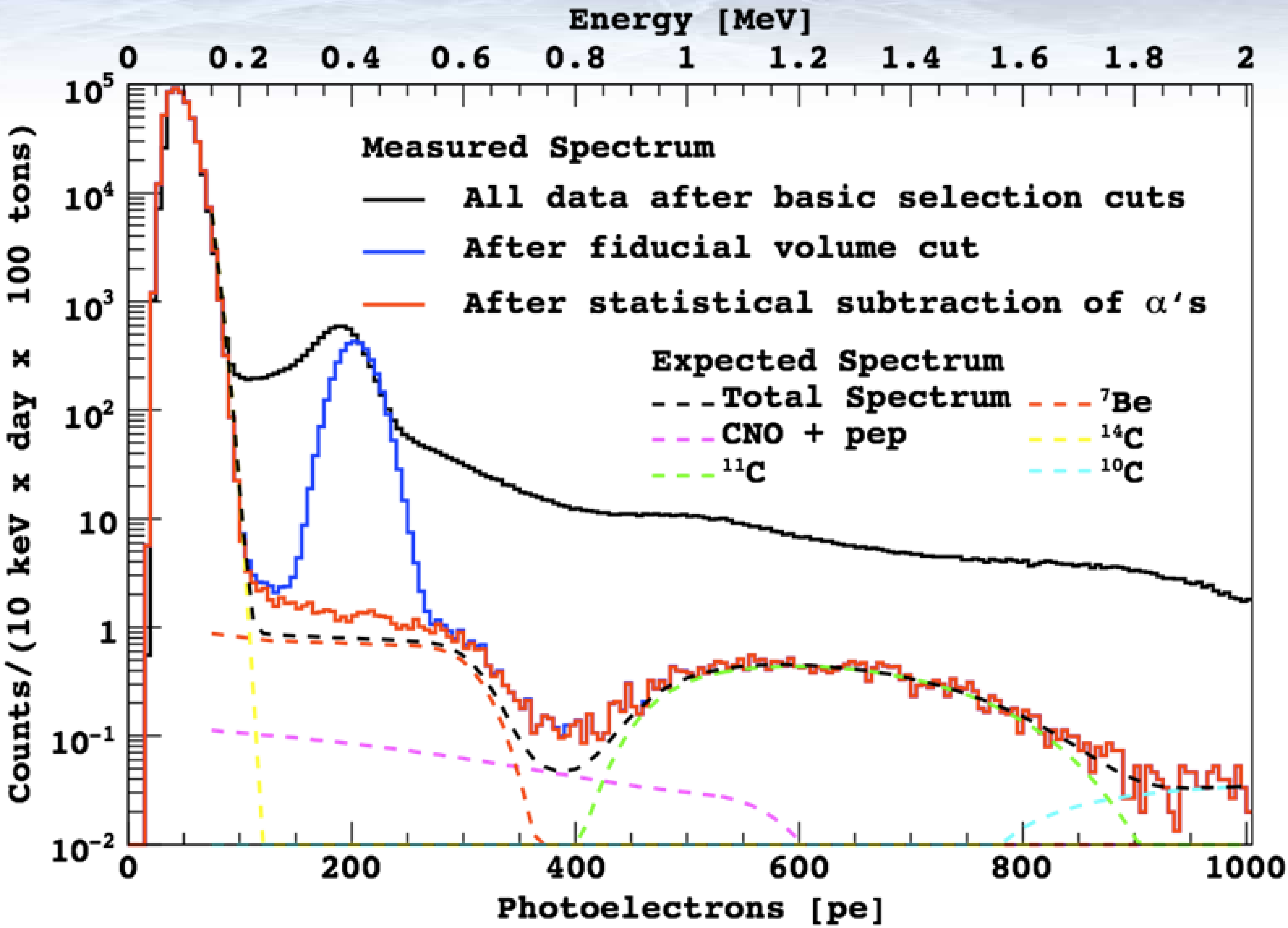


Not from ^{210}Pb

^{210}Po vs ^{210}Bi



α/β statistical subtraction



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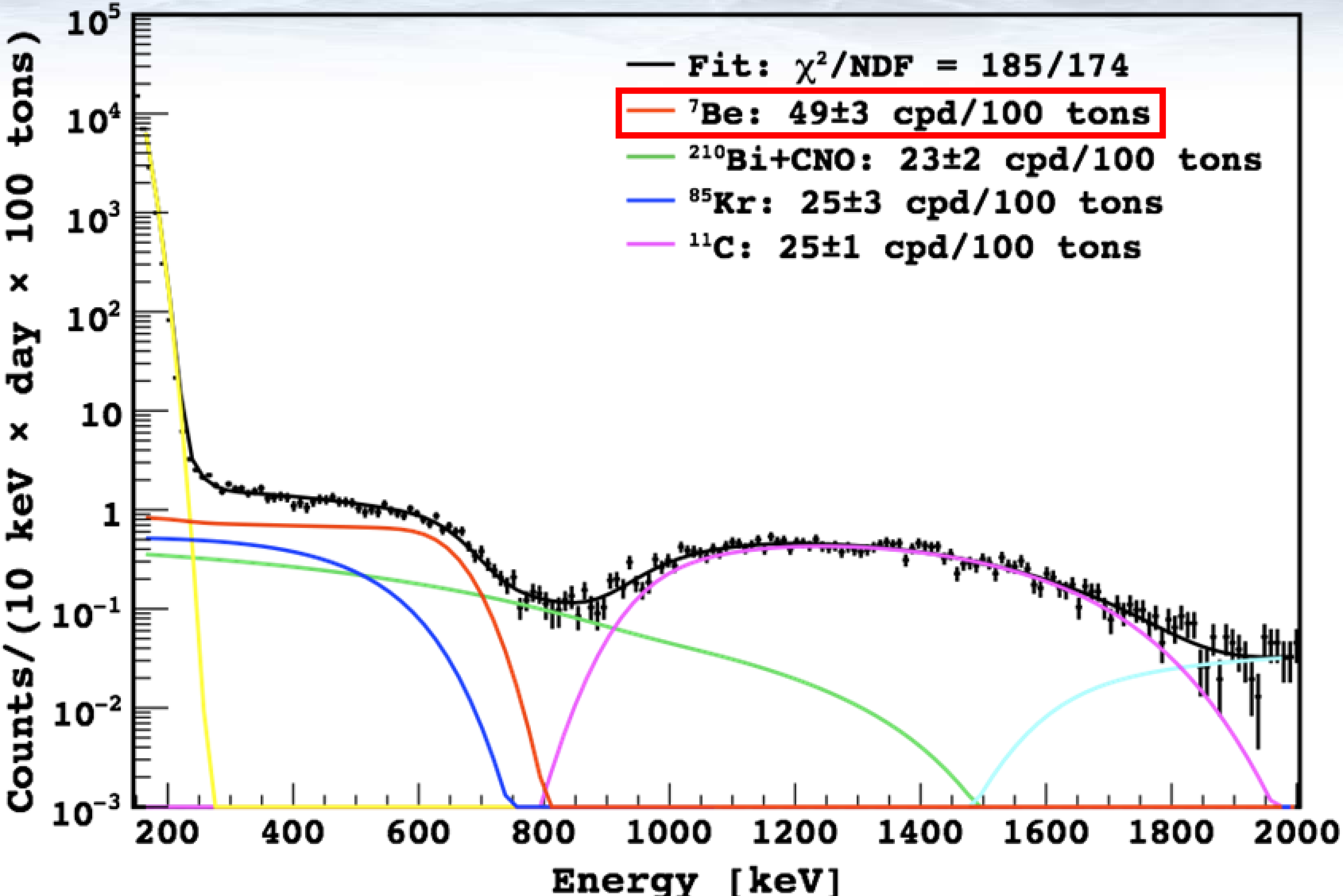
New results with 192 days of statistics



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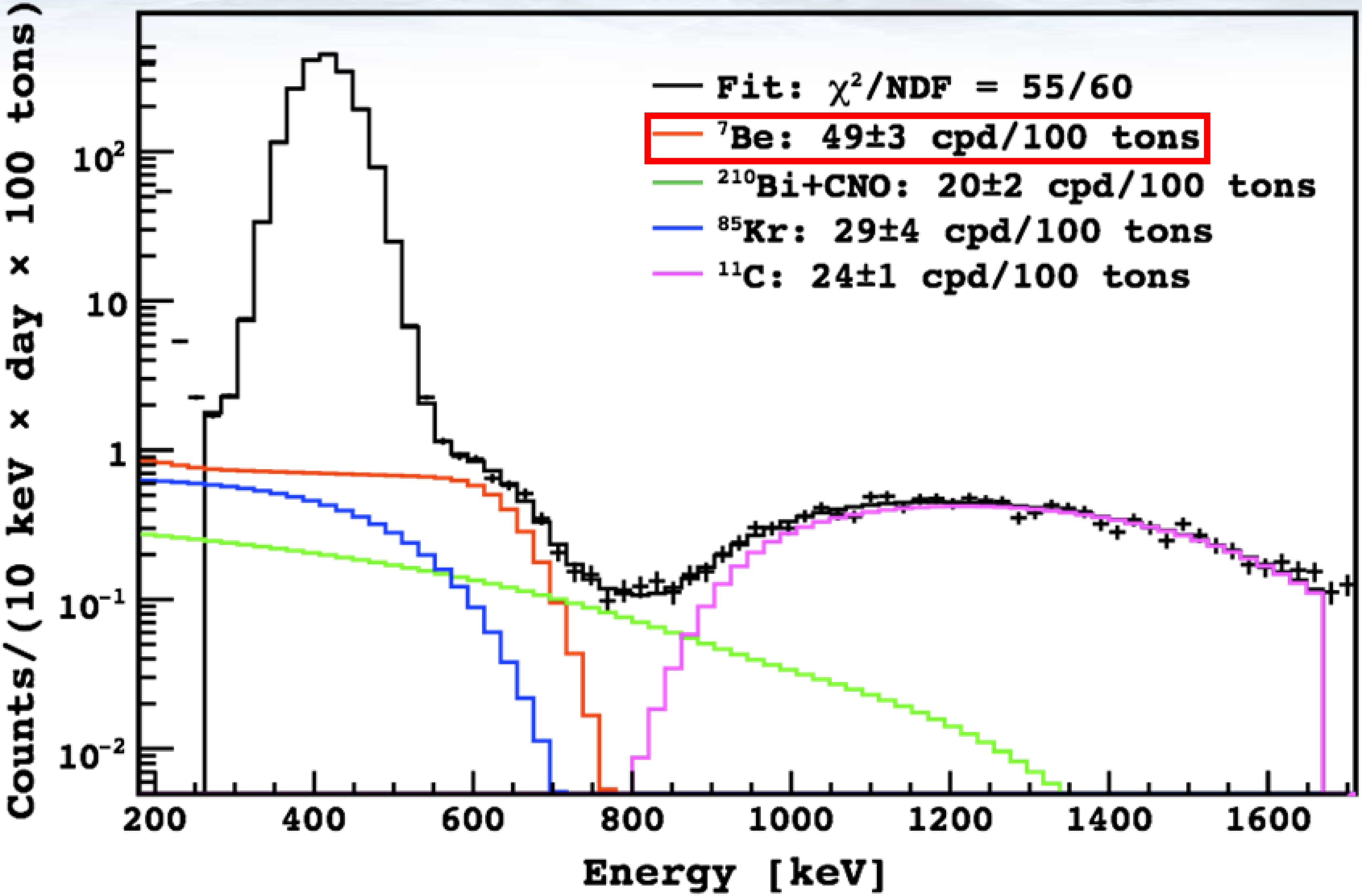
New results with 192 days of statistics



Systematic and Final Result

Estimated 1σ Systematic Uncertainties* [%]

Total Scintillator Mass	0.2
Fiducial Mass Ratio	6.0
Live Time	0.1
Detector Resp. Function	6.0
Cuts Efficiency	0.3
Total	8.5

*Prior to Calibration

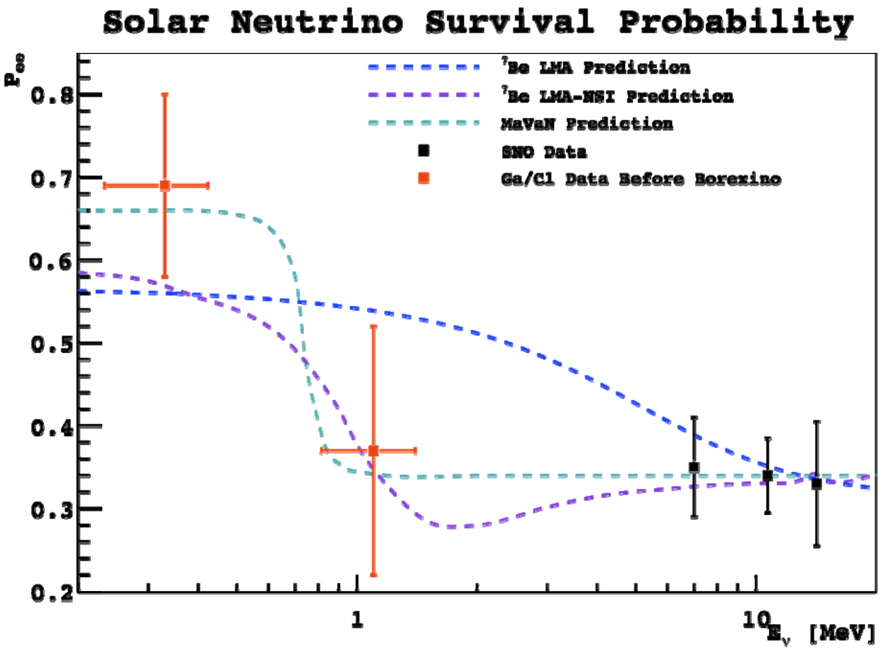
Expected interaction rate in absence of oscillations:
75±4 cpd/100 tons

for LMA-MSW oscillations:
48±4 cpd/100 tons, which means:

$$f_{\mathrm{Be}} = 1.03^{+0.24}_{-1.03}$$

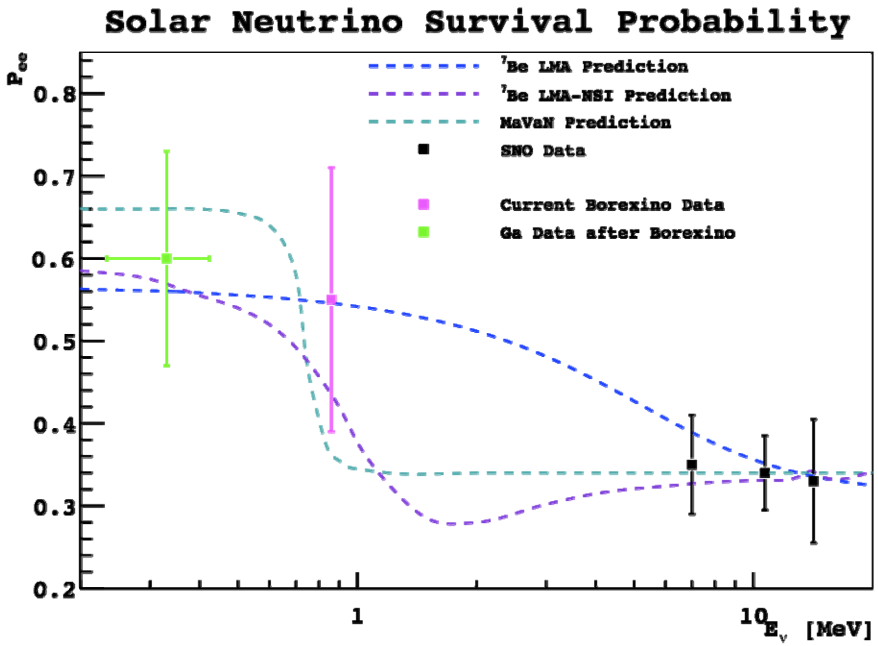
^{7}Be Rate: $49\pm3_{stat}\pm4_{syst}$ cpd/100 tons , which means

$$f_{\mathrm{Be}} = 1.02 \pm 0.10$$



Before Borexino

After Borexino



Constraints on *pp* and CNO fluxes

Combining Borexino 7Be results with other experiments,the expected rate in Clorine and Gallium experiments is

$$R_l \; [\mathrm{SNU}] = \sum_i R_{l,i} f_i P_{ee}^{l,i}$$

where

$l = \{\mathrm{Ga}, \mathrm{Cl}\}$

$i = \{pp, pep, \mathrm{CNO}, {}^7\mathrm{Be}, {}^8\mathrm{B}\}$

f_i measured over predicted flux ratio

$P_{ee}^{l,i}$ Survival Probability

- $R_{i,k}$ and $P_{i,k}$ are calculated in the hypothesis of high-Z SSM and MSW LMA
- Rk are the rates actually measured by Clorine and Gallium experiments
- f^8B is measured by SNO and SuperK to be 0.87 ±0.07
- f^7Be =1.02 ±0.10 is given by Borexino results

Plus luminosity constraint: $0.919 f_{pp} + 0.075 f_{\mathrm{Be}} + 0.0068 f_{\mathrm{CNO}} = 1$

$$f_{pp} = 1.004^{+0.008}_{-0.020}$$

$$\mathcal{L}_{\mathrm{CNO}}/\mathcal{L}_{\odot} < 6.2\% \; 3\sigma$$

best determination of pp flux!

Neutrino Magnetic Moment

Neutrino-electron scattering is the most sensitive test for μ_ν search

$$\left(\frac{d\sigma}{dT}\right)_W = \frac{2G_F^2 m_e}{\pi}\left[g_L^2 + g_R^2\left(1-\frac{T}{E_\nu}\right)^2 - g_L g_R \frac{m_e T}{E_\nu^2}\right]$$

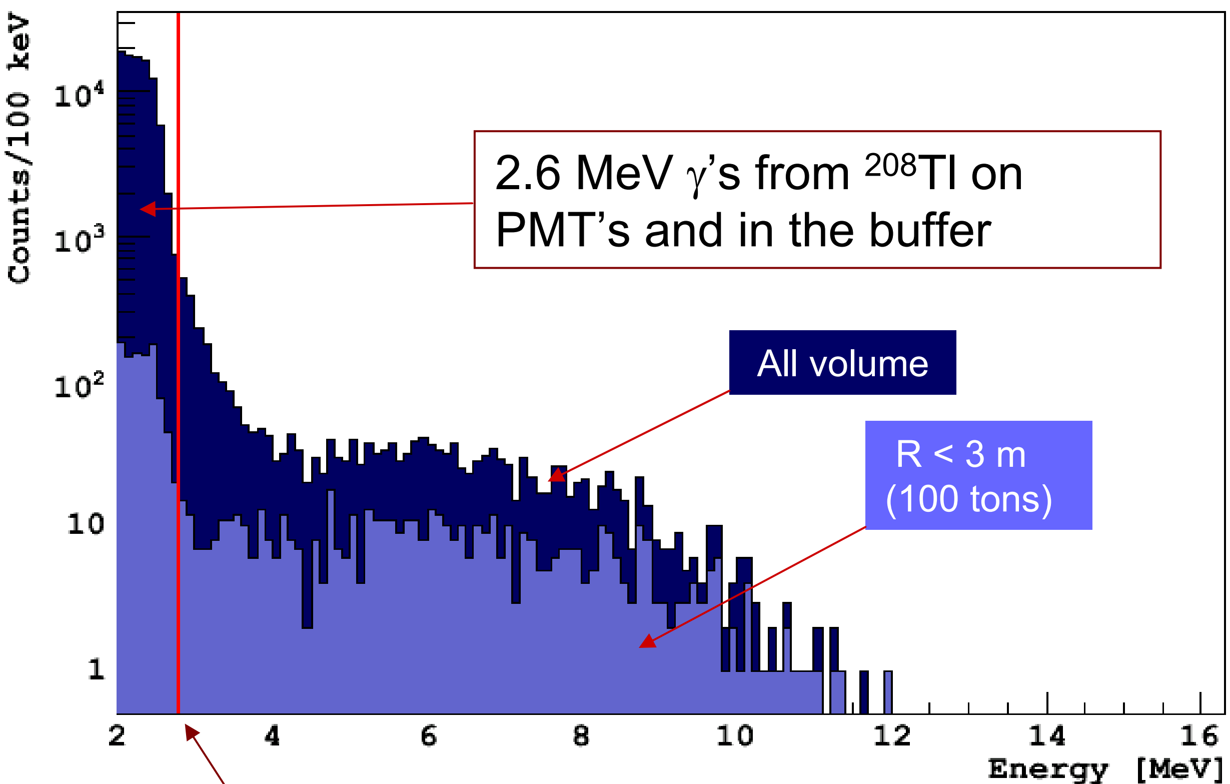
EM current affects cross section: spectral shape sensitive to μ_ν sensitivity enhanced at low energies (c.s.≈ 1/T)

$$\left(\frac{d\sigma}{dT}\right)_{EM} = \mu_\nu^2 \frac{\pi\alpha_{em}^2}{m_e^2}\left(\frac{1}{T}-\frac{1}{E_\nu}\right)$$

A fit is performed to the energy spectrum including contributions from ^{14}C, leaving μ_ν as free parameter of the fit

Estimate	Method	10^{-11} μ_B
SuperK	^8B	<11
Montanino et al.	^7Be	<8.4
GEMMA	Reactor	<5.8
Borexino	^7Be	<5.4

^{8}B neutrinos with the lowest threshold: 2.8 MeV

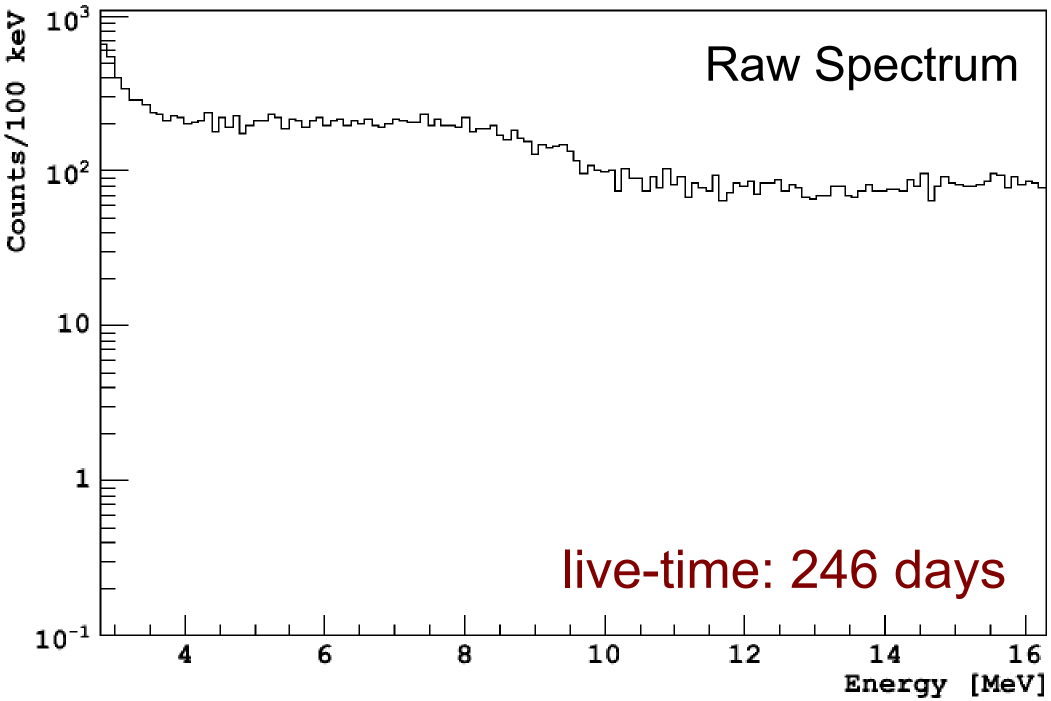


Energy spectrum in Borexino
(after μ subtraction)

> 5σ distant from the 2.6 MeV γ peak

Expected ^{8}B ν rate in 100 tons of liquid scintillator above 2.8 MeV:
0.26±0.03 c/d/100 tons

Background in the 2.8-16.3 MeV range



- ✓ Cosmic Muons
- ✓ External background
- ✓ High energy gamma's from neutron captures
- ✓ ^{208}Tl and ^{214}Bi from radon emanation from nylon vessel
- ✓ Cosmogenic isotopes
- ✓ ^{214}Bi and ^{208}Tl from ^{238}U and ^{232}Th bulk contamination

Count-rate: 1500 c/d/100 ton

S/B ratio < 1/6000!!!

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Muon and neutron cuts

Muon cut:

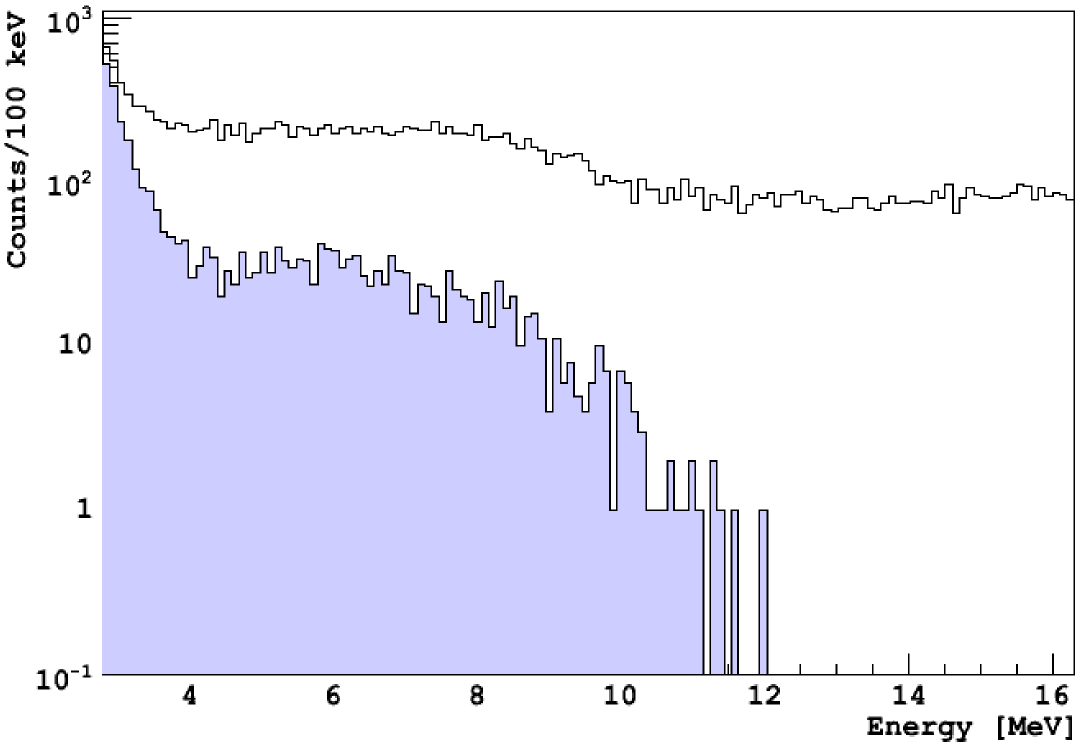
- All events detected by the outer detector are rejected

- Residual muon rate: **<10^{-3} c/d**

Neutron cut:

- 2 ms veto after each muon detected by the outer detector, in order to reject induced neutrons (mean capture time ~250 μs)

- Residual neutron rate: **~10^{-4} c/d**



Count-rate: 4.8 c/d/100 ton

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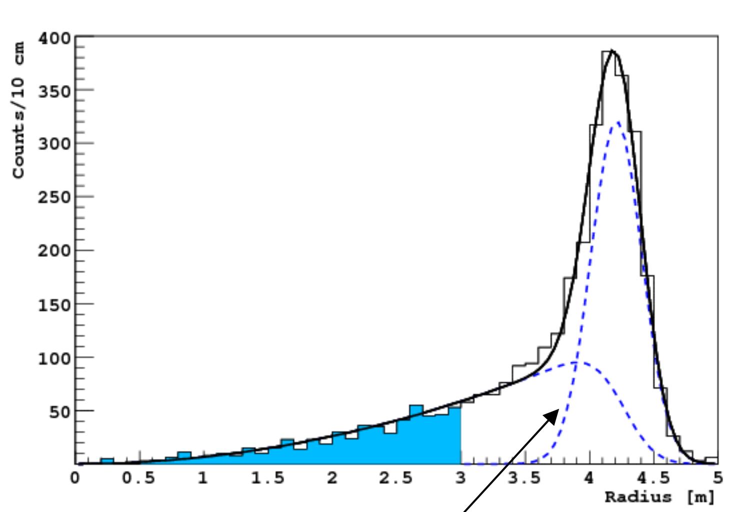
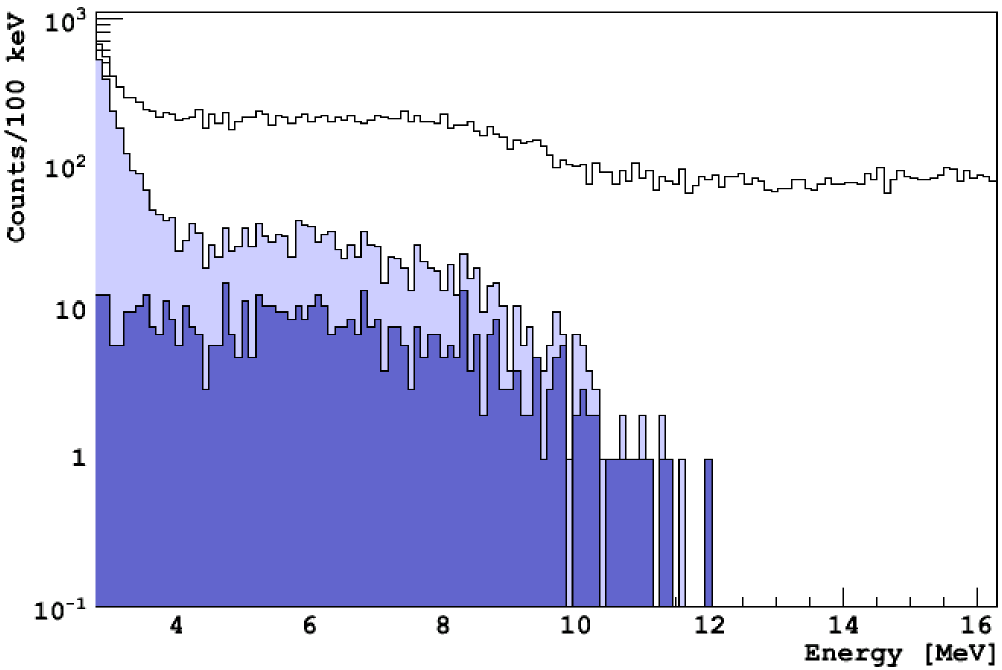
Fiducial Volume Cut
(radius < 3 m, ~100 tons)





Surface contamination:

- ^{222}Rn and ^{220}Rn emanated from the nylon vessel
- Effective attenuation length: ~5 cm
- Residual contamination: **~10^{-4} c/d**

Count-rate: 2.3 c/d/100 ton

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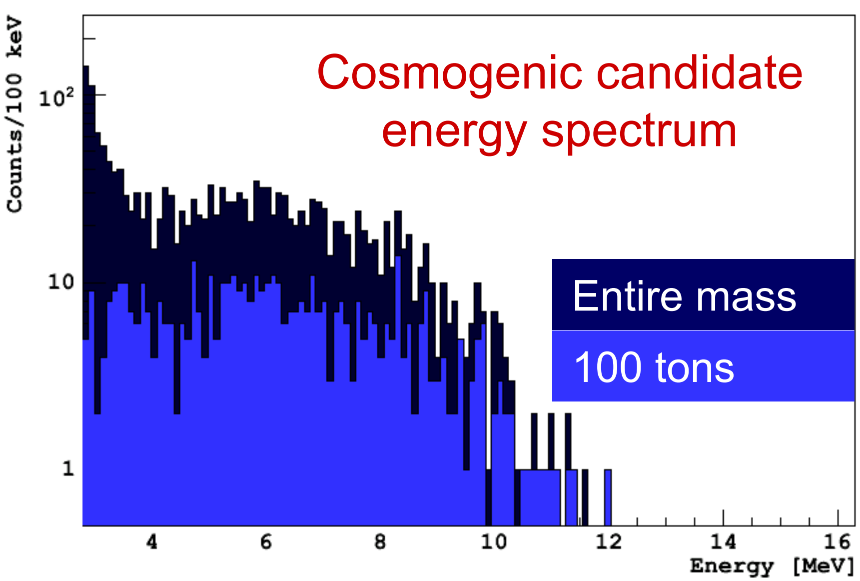
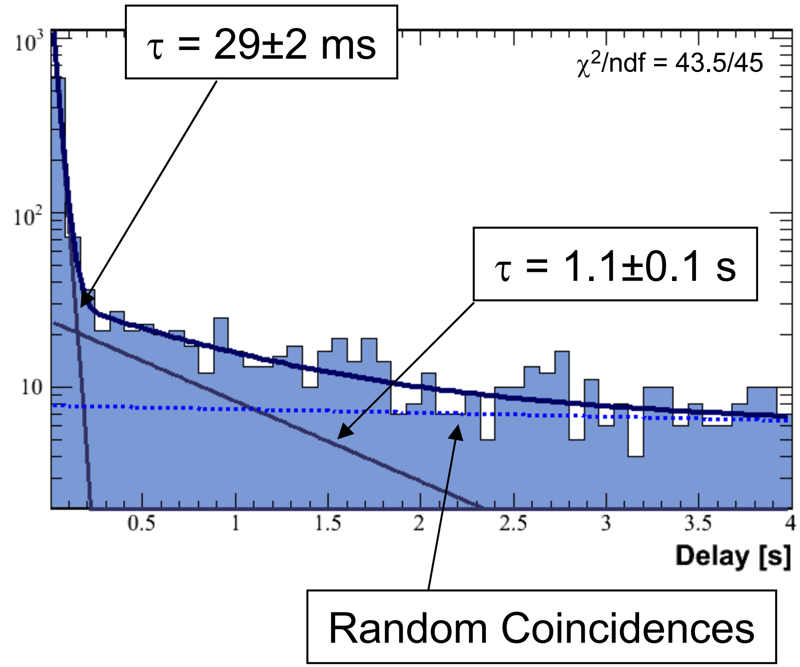
Muon induced radioactive nuclides

Isotopes	τ	Q [MeV]	Decay	σ [μbarn]	E_μ [GeV]
Short-lived ($\tau < 2s$)					
^{12}B	0.03 s	13.4	β^-	~4500	320
^{9}Li	0.26 s	13.6	β^-	<2	190
^{8}Li	1.21 s	16.0	β^-	5	320
^{8}He	0.17 s	10.6	β^-	<2	190
^{6}He	1.17 s	3.5	β^-	23	320
^{9}C	0.19 s	16.5	β^+	5	190
^{8}B	1.11 s	18.0	β^+	11	320



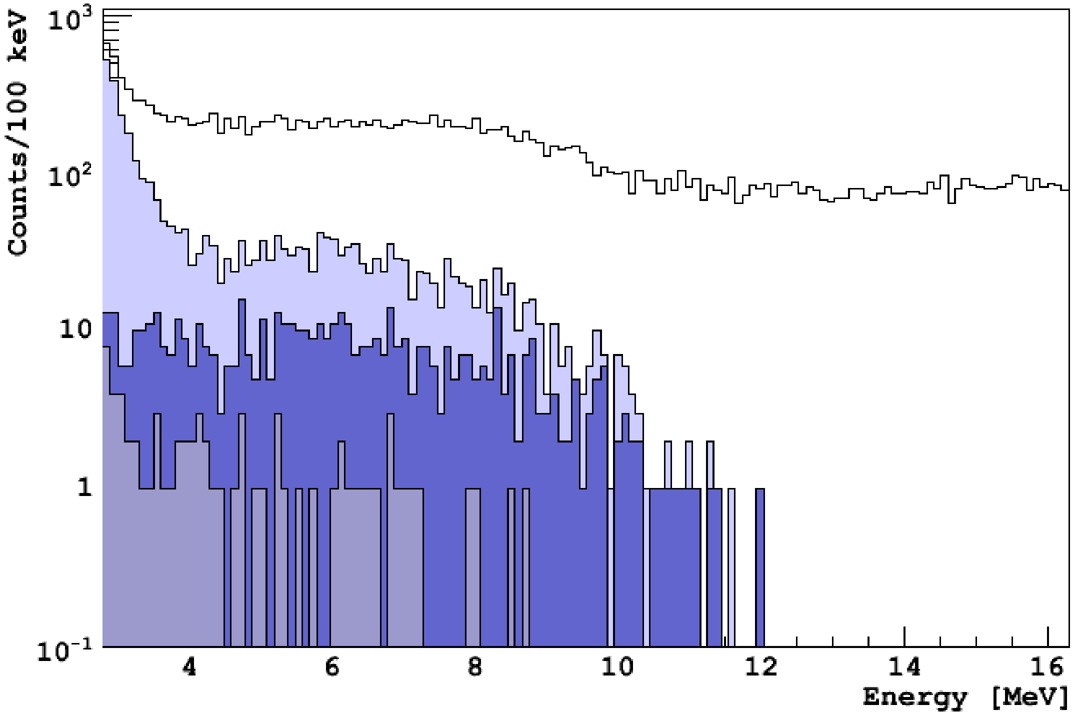
Event delay time after a μ



Cosmogenic cut

Cosmogenic cut:

- 5 s veto after each μ crossing the buffer
- Rejection efficiency cut: 99.7%
- Residual short-lived cosmogenic rate: **$3x10^{-3}$ c/d**
- Dead-time: 23.4%
- Effective detector live-time: 188 days



Count-rate: 0.4 c/d/100 ton

Summary of the Cuts and Systematic

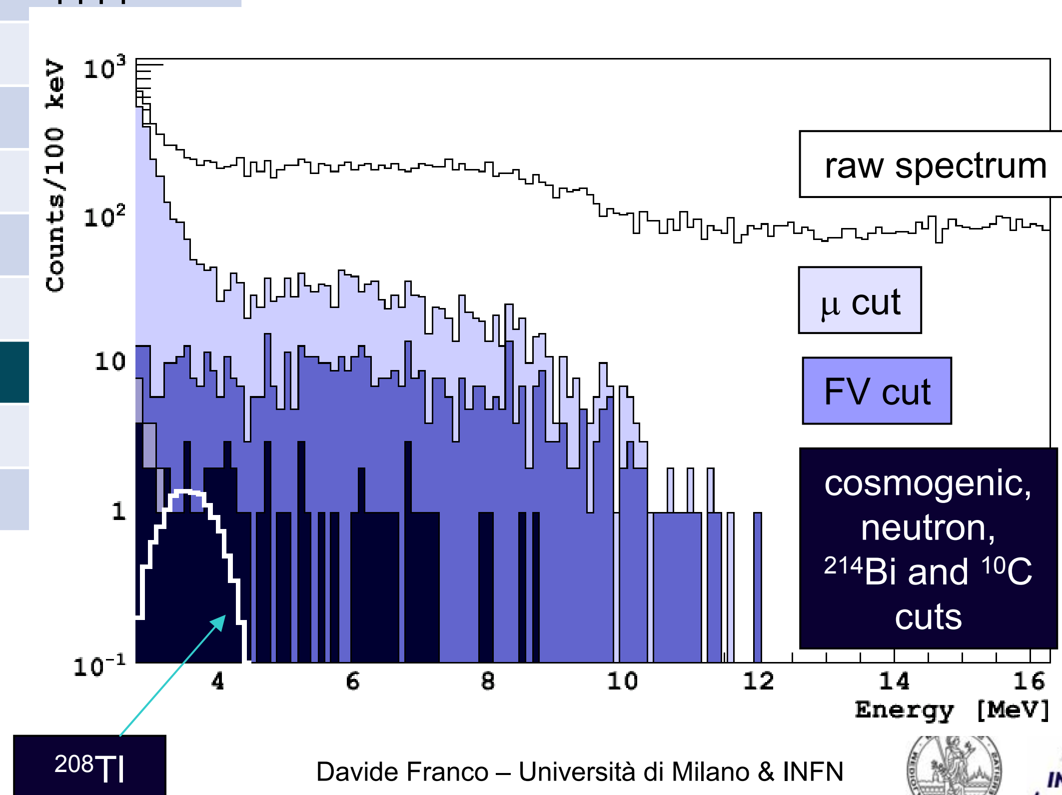
Cut	Counts 2.8-16.3 MeV	Counts 5.0-16.3 MeV
None	60449	42314
Muon cut	3363	1135
Neutron cut	3280	1114
FV cut	567	
Cosmogenic cut	71	
^{10}C removal	65	
^{214}Bi removal	62	
Expected ^{208}Tl	14 $\pm$ 3	
Measured ^{8}B-ν	48 $\pm$ 8	
BS07(GS98) ^{8}B-ν	50 $\pm$ 5	
BS07(AGS05) ^{8}B-ν	40 $\pm$ 4	

*MSW-LMA: $\Delta m^2=7.69\times10^{-5}$ eV^2, $\tan^2\theta=0.45$

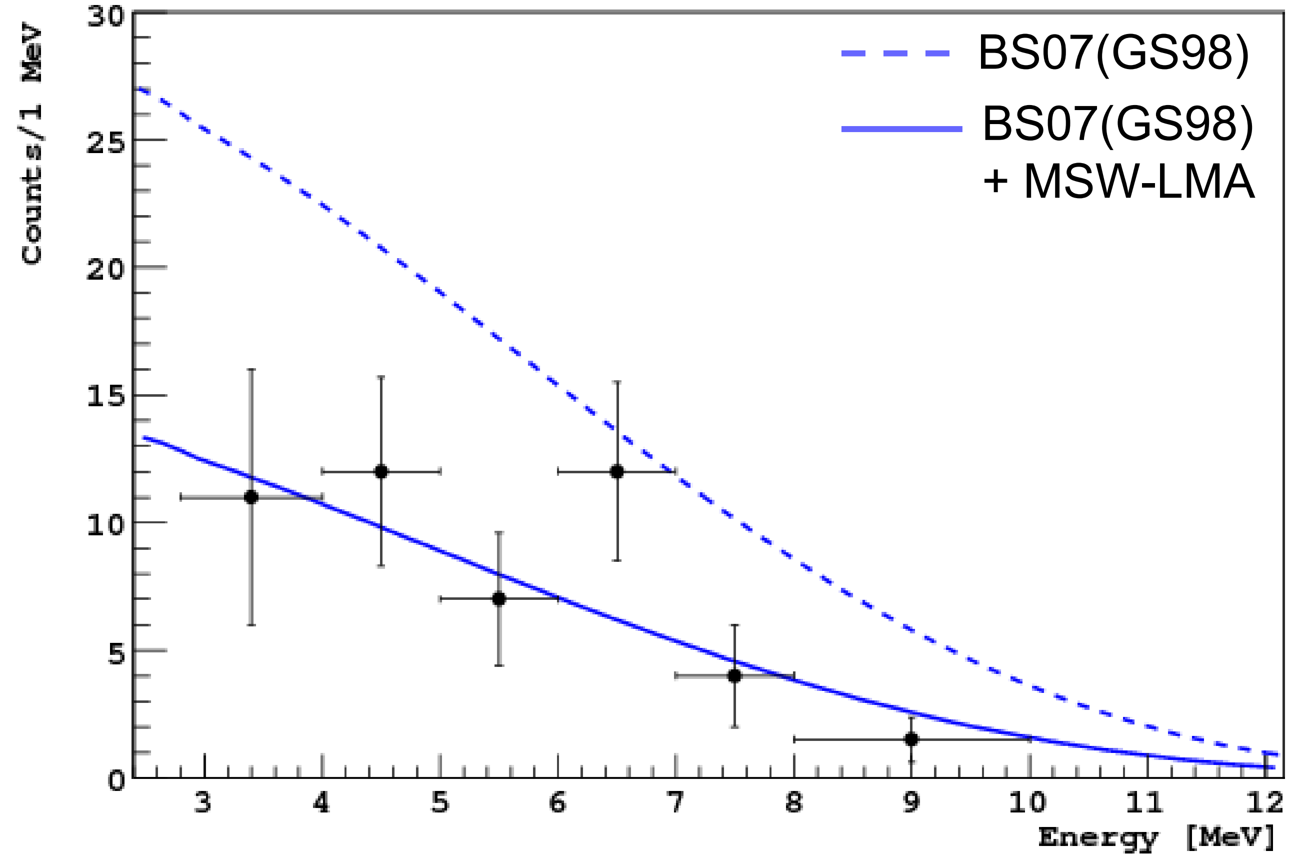
✓Systematic errors:

✓ 6% from the determination of the fiducial mass

✓ 3% (2%) uncertainty in the ^{8}B rate above 2.8 MeV (5.0 MeV) from the determination of the light yield (1%)



The ^{8}B ν spectrum

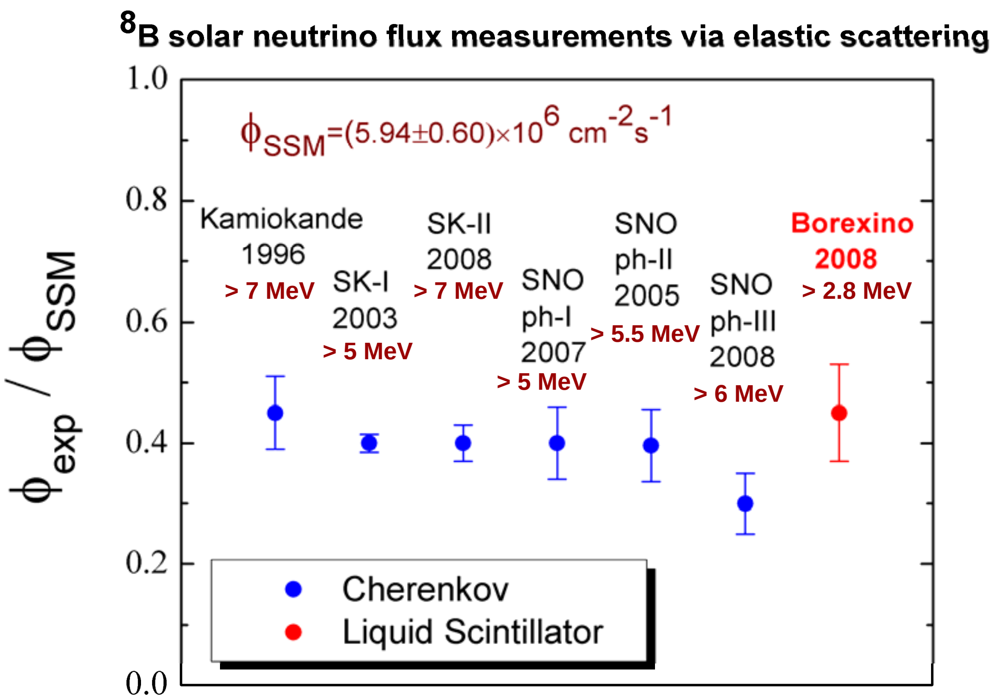


Neutrino oscillation is confirmed **at 4.2 σ**, including the theoretical uncertainty (10%) on the ^{8}B flux from the Standard Solar Model

^{8}B equivalent ν flux

Equivalent unoscillated ^{8}B neutrino flux, as derived from the electron scattering rate

	2.8-16.3 MeV	5.0-16.3 MeV
Rate [c/d/100 tons]	0.26±0.04±0.02	0.14±0.03± 0.01
Φ^{ES}_{exp} [10^6 cm^{-2}s^{-1}]	2.65±0.44±0.18	2.75±0.54±0.17
$\Phi^{ES}_{exp}/\Phi^{ES}_{th}$	0.96±0.19	1.02±0.23



*Threshold is defined at 100% trigger efficiency

Good agreement with the SK-I and SNO D20 measurements (same threshold at 5 MeV)

	Threshold [MeV]	Φ^{ES}_{8B} [10^6 cm^{-2} s^{-1}]
SuperKamiokaNDE I [8]	5.0	2.35±0.02±0.08
SuperKamiokaNDE II [9]	7.0	$2.38\pm0.05^{+0.16}_{-0.15}$
SNO D_2O [7]	5.0	$2.39^{+0.24}_{-0.23}{}^{+0.12}_{-0.12}$
SNO Salt Phase [6]	5.5	2.35±0.22±0.15
SNO Prop. Counter [10]	6.0	$1.77^{+0.24}_{-0.21}{}^{+0.09}_{-0.10}$
Borexino	5.0	2.75±0.54±0.17
Borexino	2.8	2.65±0.44±0.18

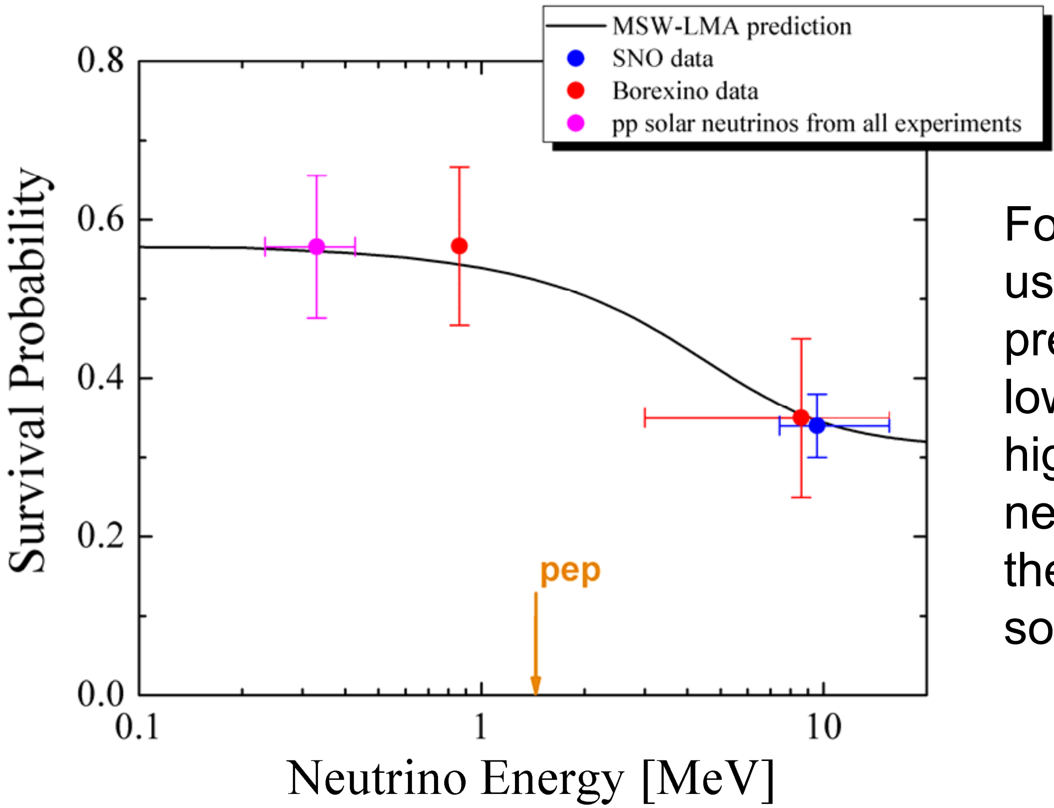
Electron Neutrino Survival Probability

$\overline{P}_{ee}$ is defined such that:

R: measured rate
E_ν and T_e: neutrino and recoiled electron energies
T_0 = 2.8 MeV: energy threshold

E_0 = 3.0 MeV: minimum neutrino energy at T_0
N_e: number of target electrons
σ_x (x=e,μ–τ): elastic cross sections

$$R = \int_{T_e > T_0} dT_e \int_{E_\nu > E_0} dE_\nu \left(\overline{P}_{ee} \cdot \frac{d\sigma_e}{dT_e}(E_\nu, T_e) + (1 - \overline{P}_{ee}) \cdot \frac{d\sigma_{\mu\text{-}\tau}}{dT_e}(E_\nu, T_e) \right) N_e \cdot \frac{d\Phi_e}{dE_\nu}(E_\nu)$$



$\overline{P}_{ee}(^8B)$ = 0.35±0.10 (8.6 MeV)

$P_{ee}(^7Be)$ = 0.56±0.10 (0.862 MeV)

For the first time, we confirm at 1.8 σ, using data from a single detector, the presence of a transition between the low energy vacuum-driven and the high-energy matter-enhanced solar neutrino oscillations, in agreement with the prediction of the MSW-LMA solution for solar neutrinos

Calibrations

Goal: <5% ^{7}Be measurement

Detector response vs position:

✓100 Hz ^{14}C+^{222}Rn in scintillator in >100 positions

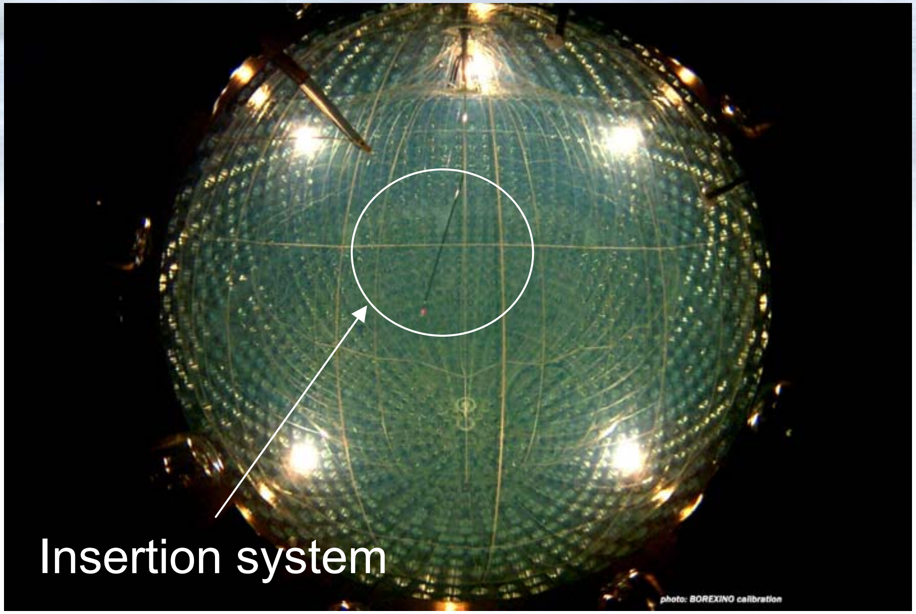
Quenching and energy scale:

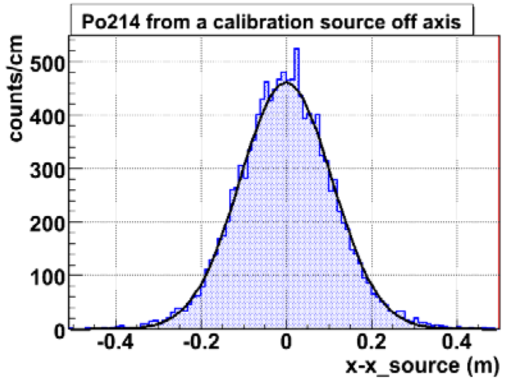
✓Beta: ^{14}C, ^{222}Rn in scintillator

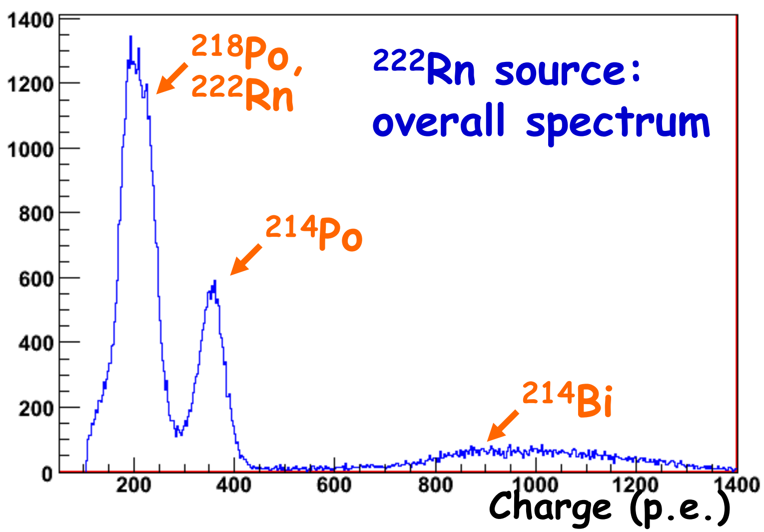
✓Alpha: ^{222}Rn in scintillator

✓Gamma: ^{139}Ce, ^{57}Co, ^{60}Co, ^{203}Hg, ^{65}Zn, ^{40}K, ^{85}Sr, ^{54}Mn

✓Neutron: AmBe







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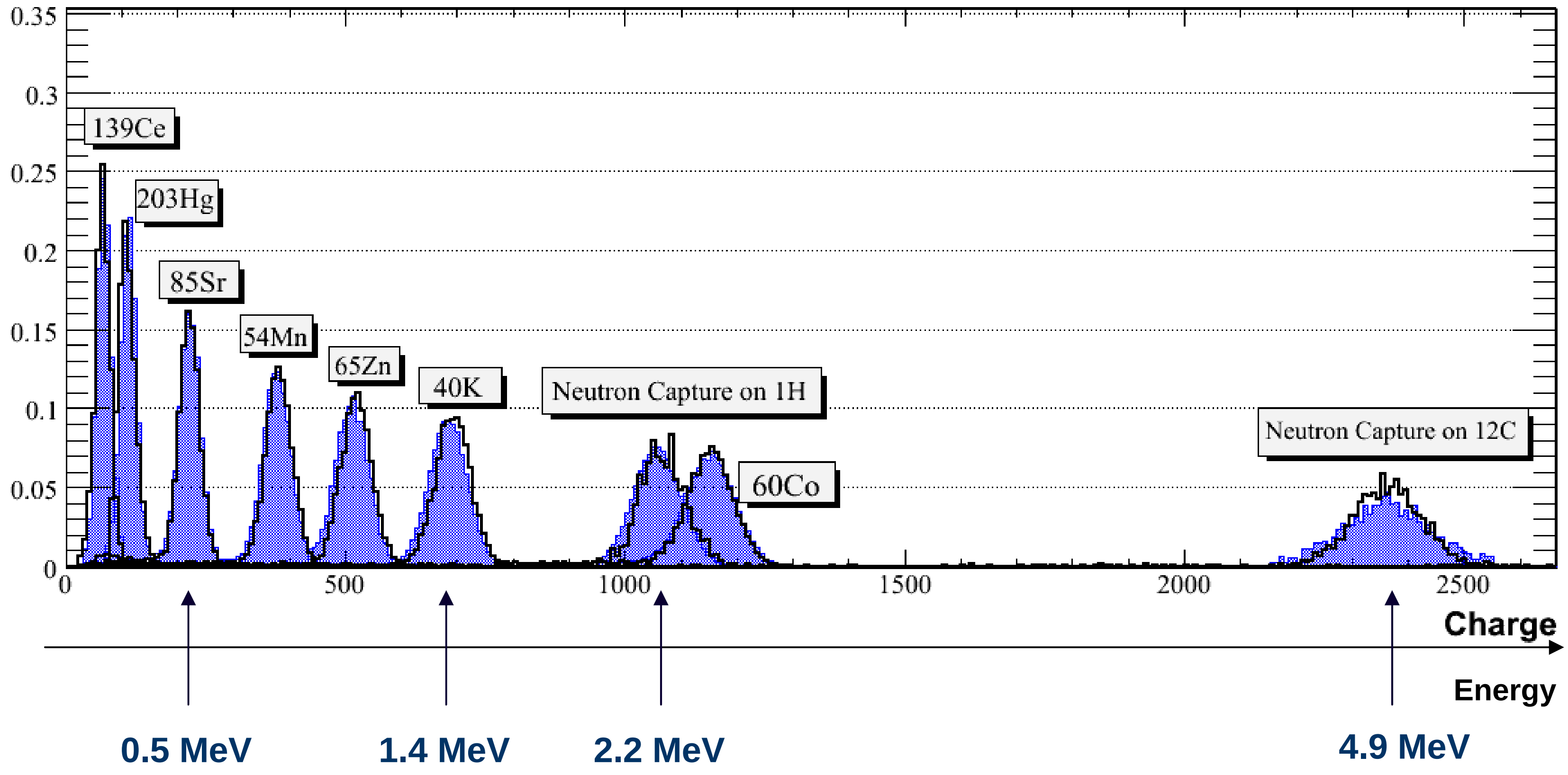
Calibrations: Monte Carlo vs Data

Gamma sources in the detector center



What next?

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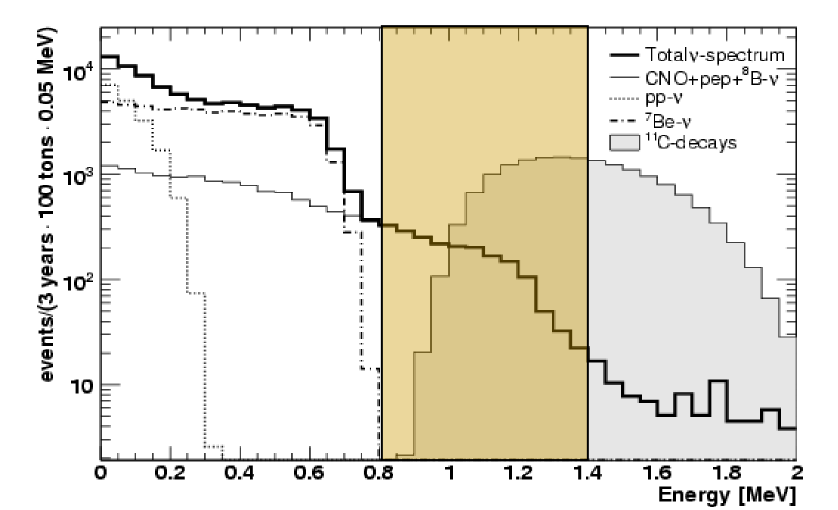
BOREXino

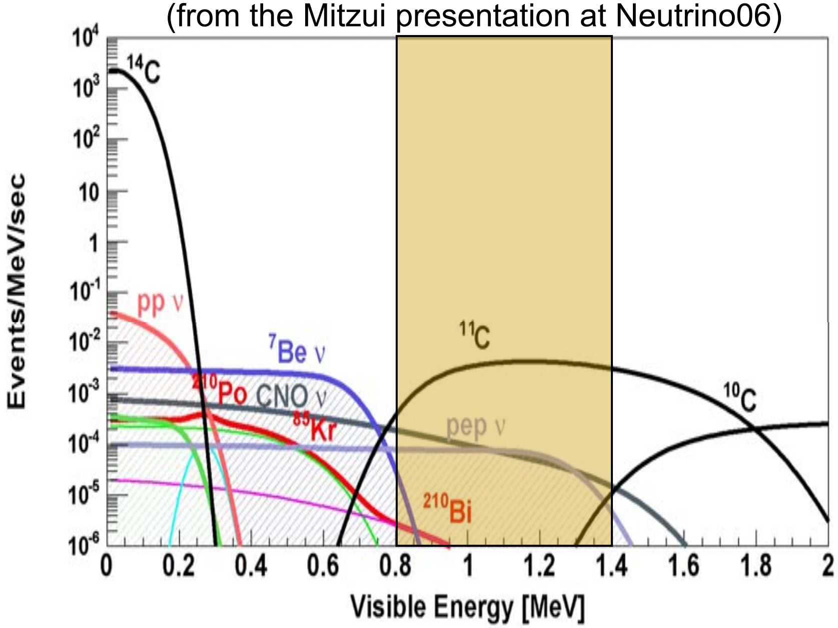


NA54 @ CERN: 100 and 190 GeV muon beams on a ^{12}C target: ^{11}C represents 80% of all the muon-induced contaminants and more than 99% in the CNO pep-ν energy window

Hagner et al., Astropart. Phys. ***14****, 33 (2000)*

KamLAND

(from the Mitzui presentation at Neutrino06)



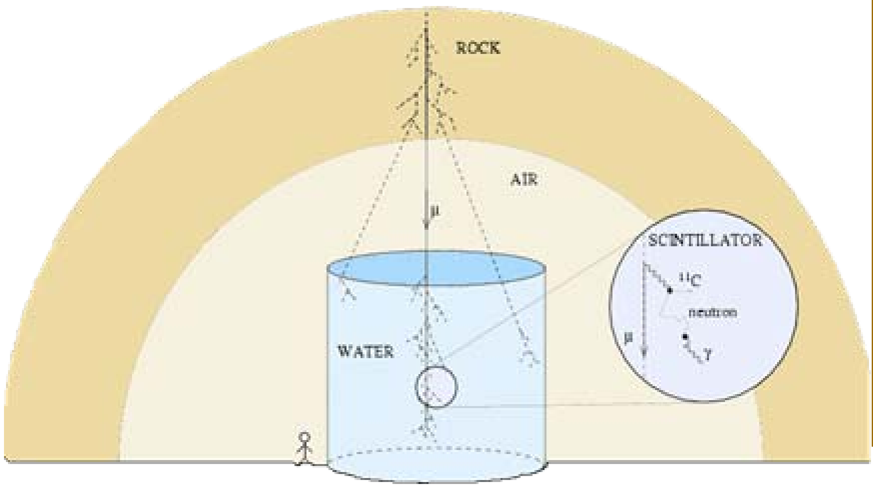
^{11}C Rate (cts / day / 100 tons)		
	All energy	0.8 – 1.4 MeV
KamLAND	107	55
BOREXino	15	7.4
SNO+	0.15	0.074

^{11}C production and decay

μ (+ secondaries) + $^{12}C \rightarrow \mu$ (+ secondaries) + ^{11}C + n

$n + p \rightarrow d + \gamma$

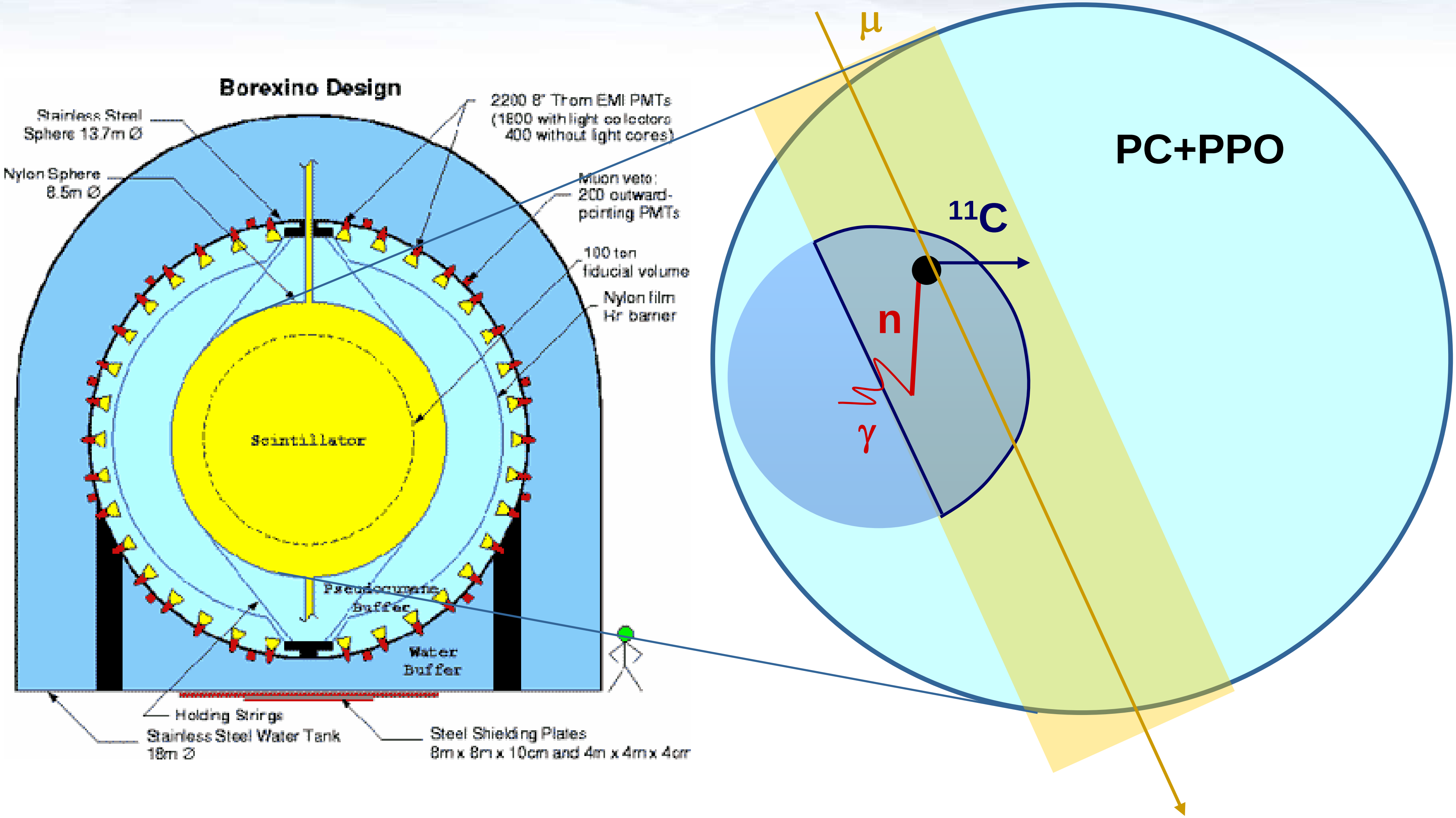
$^{11}C \rightarrow {}^{11}B + e^+ + \nu_e$



Coincidence among:

- cosmic muon:
  - rate at LNGS (3700 mwe): 1.16 hr^{-1} m^{-2}
  - average energy: 320 GeV
- gamma from neutron capture:
  - energy: 2.2 MeV
  - capture time: 250 μs
- positron from ^{11}C decay:
  - deposited energy between 1.022 and 1.982 MeV
  - mean life: 30 min

Large scintillator detector potential



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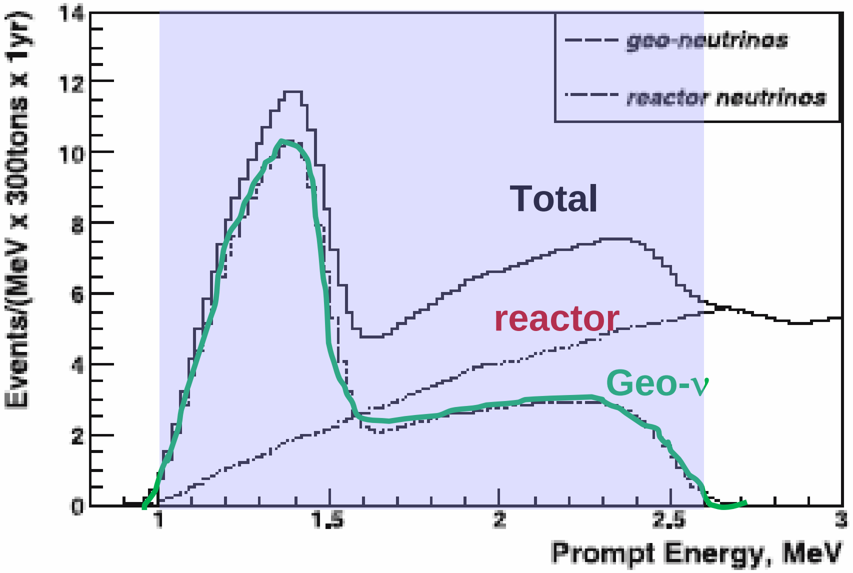
Borexino potential on geoneutrinos

Prompt signal energy spectrum (model)



• Detection technique: inverse β-decay and delayed coincidence:

$\bar{\nu}_e + p \longrightarrow e^+ + n$

$\Delta t \sim 250\ \mu s$

$n + p \longrightarrow d + \gamma\ (2.2\ \text{MeV})$

• Energy range: 1-2.6 MeV

• Efficiency: 80%

Cosmogenic β-n background (**^{8}Li and ^{6}He**) identified and rejected event by event

Prediction:

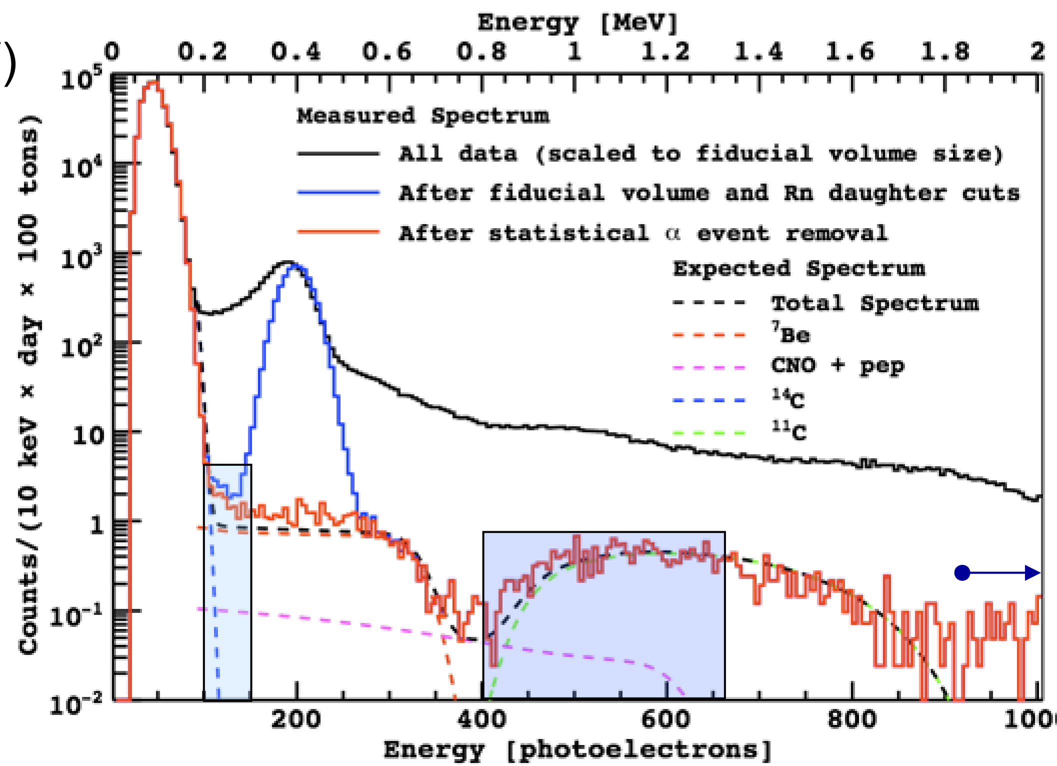
• geoneutrino signal: **6.3 / year / 300 tons**

• reactor antineutrinos (in the geo-ν range): **5.7 / year / 300 tons**

(Balata *et al.,* 2006, ref. model Mantovani *et al*., 2004)

Summary of the future measurements

- ***pep*** and **CNO** ν fluxes
  - software algorithm based on a three-fold coincidence analysis to subtract efficiently cosmogenic ^{11}C background
  - Muon track reconstruction
- **^{8}B** at low energy region (3-5 MeV)
- **pp** neutrinos
  - seasonal variations
  - ^{14}C subtraction
- **geoneutrinos**
- **^{7}Be** with errors < 5%
  - Systematic reduction
  - Calibrations
  - Purifications planned for 2010



Conclusion

- Borexino opened the study of the solar neutrinos in real time below the barrier of natural radioactivity (5 MeV)
  - Two measurements reported for ^{7}**Be** neutrinos
  - Best limits for ***pp*** and **CNO** neutrinos, combining information from SNO and radiochemical experiments
  - Opportunities to tackle ***pep*** and **CNO** neutrinos in direct measurement
  - First observation of ^{8}**B** neutrino spectrum below 5 MeV
- Borexino will run comprehensive program to study antineutrinos
  - **geoneutrino** analysis is coming soon!
- Borexino is a powerful observatory for neutrinos from **Supernovae** explosions within few tens of kpc
- Best limit on neutrino **magnetic moment**. Improve by dedicated measurement with ^{51}Cr neutrino source
- …and do not forget the technological success of the **high-radiopurity** scintillator!