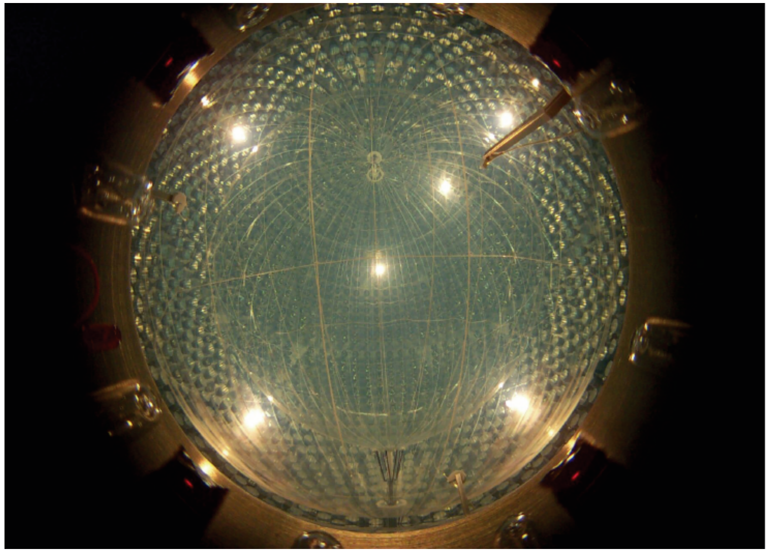


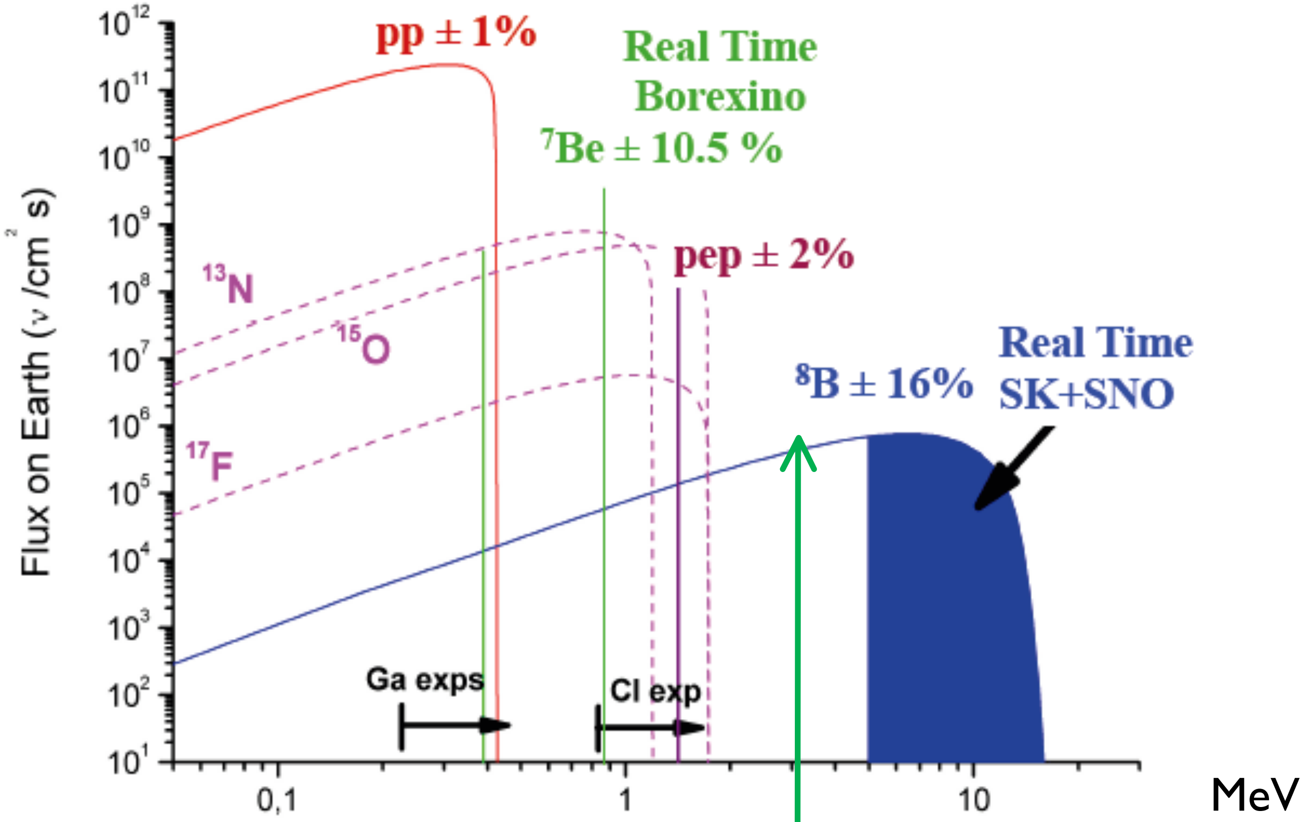
New results of the Borexino experiment at G. Sasso

Roma RICAP11, May 26 th 2011

Gemma Testera INFN Genova (on behalf of the Borexino collaboration)

Solar neutrino flux

Borexino is the only experiment measuring ^{7}Be



Borexino PRD 82, 033006 (2010)

Oscillations and MSW

Neutrino oscillations well established
Solar neutrinos : 2 flavours 1-2

With just 2 flavors and perfect coherence

$$P_{e\to\mu} = \sin^2(2\theta)\sin^2\left[\frac{1.27\Delta m^2 L}{E_\nu}\right]$$

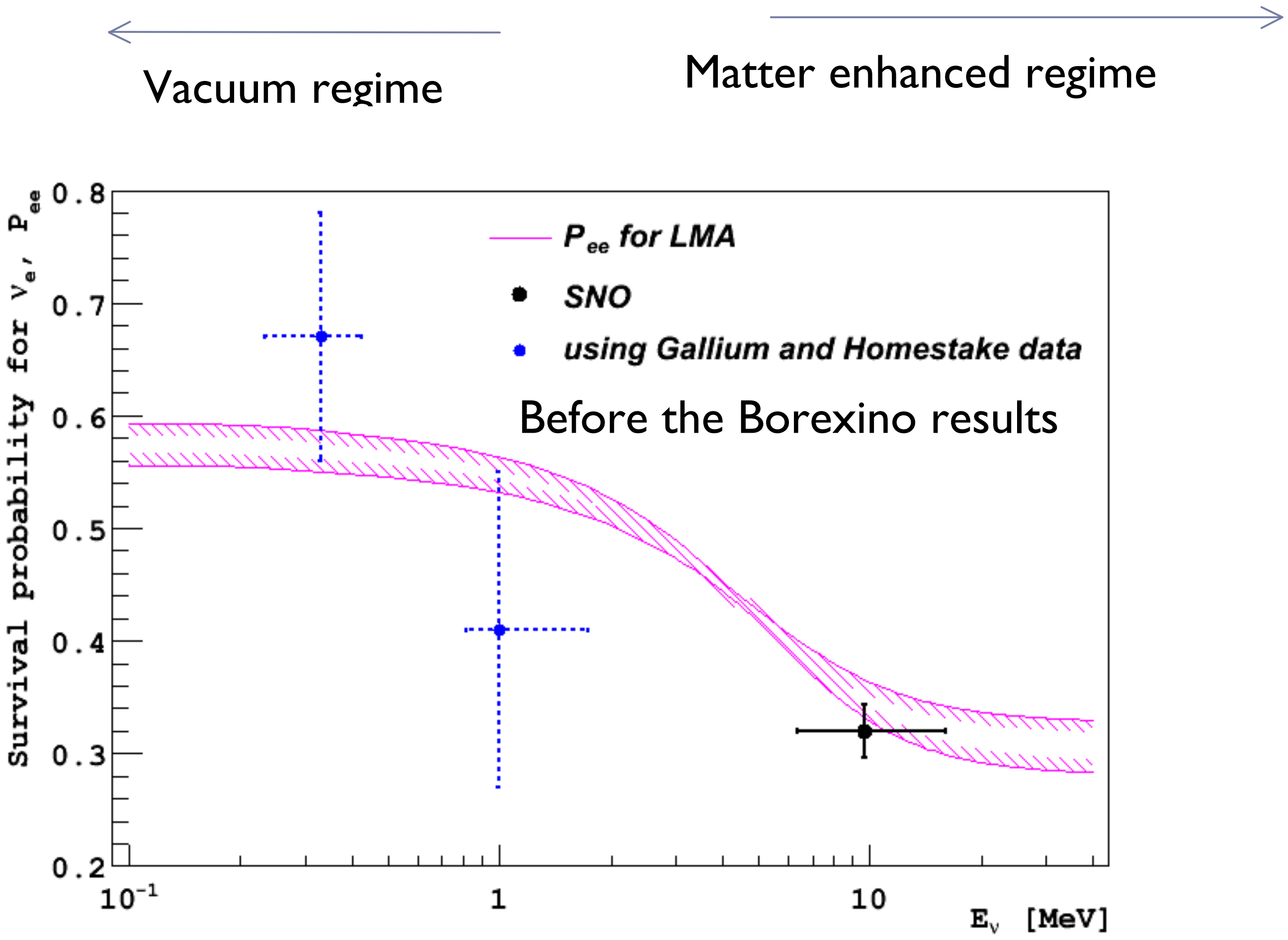
Δm in eV
L in m
E_ν in MeV

- Matter Effect plays a fundamental role
- Matter is made by electrons (not by muons or tau) and it affects the oscillations
- Neutral+ charged current interactions for e-, only neutral for others flavour
- Resonance conditions enhance the oscillation probability (Mikheyev, Smirnov,Wolfenstein-MSW)
- Energy dependent survival probability for νe

LMA $\Delta m^2_{12} = (7.6 \pm 0.2)\, 10^{-5}\, eV^2$

$\sin^2 2\vartheta = 0.87 \pm 0.03$

Electron neutrino survival probability



Background in the MeV-subMeV region

Signal : elastic scattering $\nu_{solar} + e \rightarrow \nu + e$ (ES)

Natural radioactivity

Signal ^{7}Be: about 50 ev/day 100 t 6 10^{-9} Bq/Kg

Liquid scintillators cannot distinguish signal and background event by event

- **BUT:**
  - **Good mineral water:** ~10 Bq/kg ^{40}K, ^{238}U, ^{232}Th
  - **Air:** ~10 Bq/m^{3} ^{222}Rn, ^{39}Ar, ^{85}Kr
  - **Typical rock** ~100-1000 Bq/kg ^{40}K, ^{238}U, ^{232}Th, + many others

The scintillator and the detector material must have about 10 order of magnitude less activity than standard materials

The Borexino detector

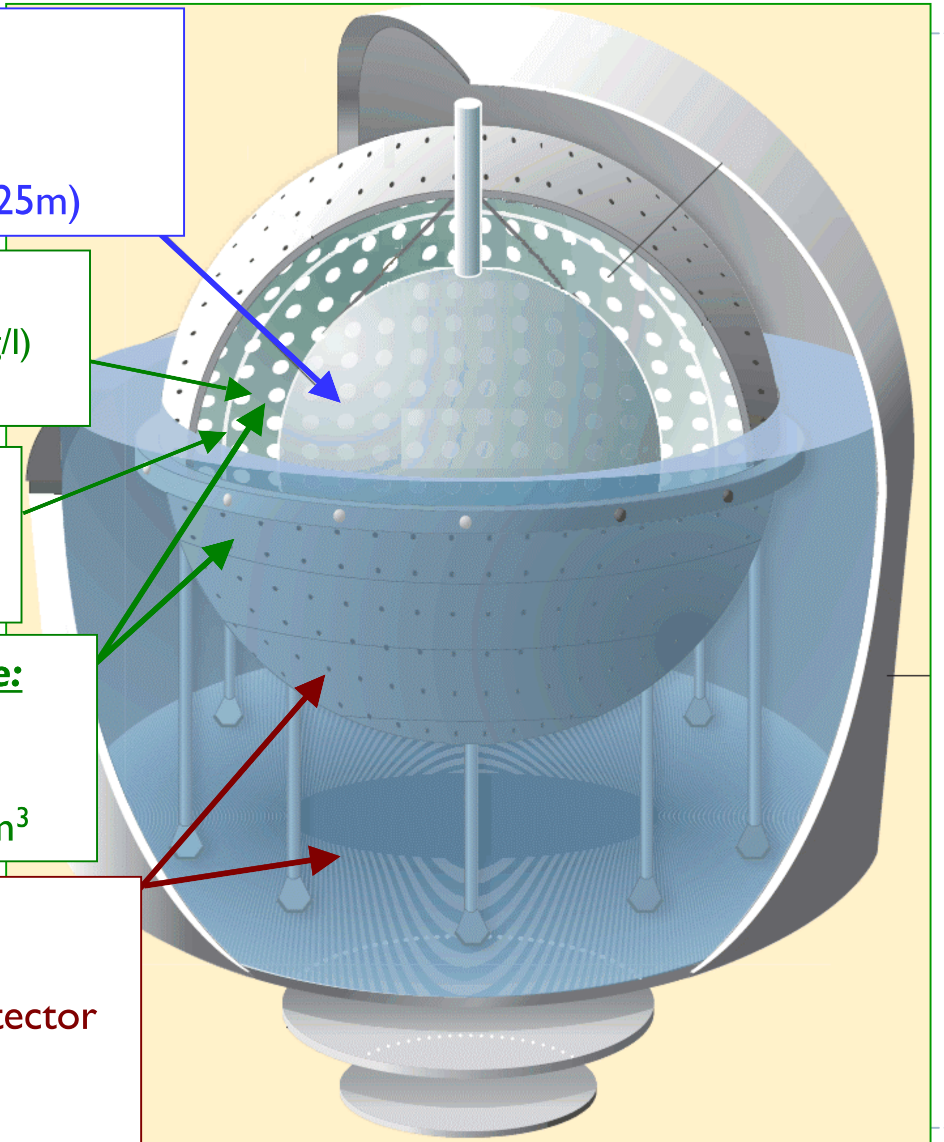
Scintillator:
270 t PC+PPO (1.5g/l)
in a 150μm thick
Inner nylon vessel (R=4.25m)

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

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

Stainless Steel Sphere:
R=6.75m
2212 8" PMTs with
light guide cone. 1350m^3

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



Physics target :

- Solar Neutrinos

$\nu_{solar} + e \rightarrow \nu + e$ (ES)

- Geo Neutrinos
- Supernova neutrinos
- etc

Background in Borexino

Radio-Isotope		Concentration or Flux		Strategy for Reduction		Final
Name	**Source**	**Typical**	**Required**	**Hardware**	**Software**	**Achieved**
μ	cosmic	~ 200 s^{-1} m^{-2} @ sea level	**<$10^{-10}s^{-1}$ m^{-2}**	underground water detector	Cerenkov PS analysis	**< 10^{-10} eff. > 0.9992**
γ	rock			water	fid. vol.	negligible
γ	PMTs, SSS			buffer	fid. vol.	negligible
^{14}C	intrinsic PC	~10^{-12} g/g	~10^{-18} g/g	selection	threshold	~ 2 10^{-18} g/g
^{238}U ^{232}Th	dust, metallic	10^{-5}-10^{-6} g/g	**<10^{-16} g/g**	distillation, W.E., filtration, mat. selection, cleanliness	tagging, α/β	$(1.67 \pm 0.06)10^{-17} g/g$ $(4.6 \pm 0.8)10^{-18} g/g$
^{7}Be	cosmogenic	~3 10^{-2} Bq/t	<10^{-6} Bq/t	distillation	--	not seen
^{40}K	dust, PPO	~2. 10^{-6} g/g (dust)	<10^{-18} g/g	distillation, W.E.	--	not seen
^{210}Po	surface cont. from ^{222}Rn		**<1 c/d/t**	distillation, W.E., filtration, cleanliness	fit	**May '07: 70 c/d/t Jan '10: ~1 c/d/t**
^{222}Rn	emanation from materials, rock	10 Bq/l air, water 100-1000 Bq rock	<10 cpd 100 t	N_2 stripping cleanliness	tagging, α/β	<1 cpd 100 t
^{39}Ar	air, cosmogenic	17 mBq/m^3 (air)	< 1 cpd 100 t	N_2 stripping	fit	<< ^{85}Kr
^{85}Kr	air, nuclear weapons	~ 1 Bq/m^3 (air)	**< 1 cpd 100 t**	N_2 stripping	fit	**30 ± 5 cpd/100 t**

Data taking history

- May 2007 : start data taking with scintillator
- After 47.7 days of live time: ^{7}Be (0.862 MeV) = 47+-7+-12 cpd/100t Phy. Lett. B 658 (2008) 101
- After 192 days : ^{7}Be = 49+-3+-4 cpd/100t PRL 101 091302 (2008)
- Limits or rare processes (Pauli exlusion principle) Phys.Rev. C 81, 3, 034317 (2010)
- Observation of geoneutrinos Phys. Lett. B 687 (2010)
- Measurem . of ^{8}B solar ν with 3 MeV threshold Phys. Rev. D 82, 3, 033006, (2010)
- Study of solar and other unknown anti-ν fluxes with Borexino at LNGS Phys. Lett. B696 191 (2011)
- Two new results:
- Precision measurement of the ^{7}Be solar ν interaction rate : arXiv:1104.1816v1 [hep-ex] 10 Apr 2011
- ^{7}Be = 46.0+-1.5 (stat) $^{+1.6}_{-1.5}$ (syst) cpd/100t
- Day night asymmetry of the ^{7}Be solar ν interaction rate : arXiv:1104.2150v1 [hep-ex] 12 Apr 2011

A_{dn} = 0.001 +-0.012 (stat) 0.007 (syst)

The road toward high precision

- 0.862 MeV solar ν detected by elastic scattering on e-
- Signature: shape of the energy spectrum
- Requirements:
- High yield and energy resolution

$$500\ phe/MeV; \quad \frac{5\%}{\sqrt{E(MeV)}}$$

- Extremely high radiopurity
- compare the back. rate with 46 cpd/100t
- Calibration of the detector (2008-2009)

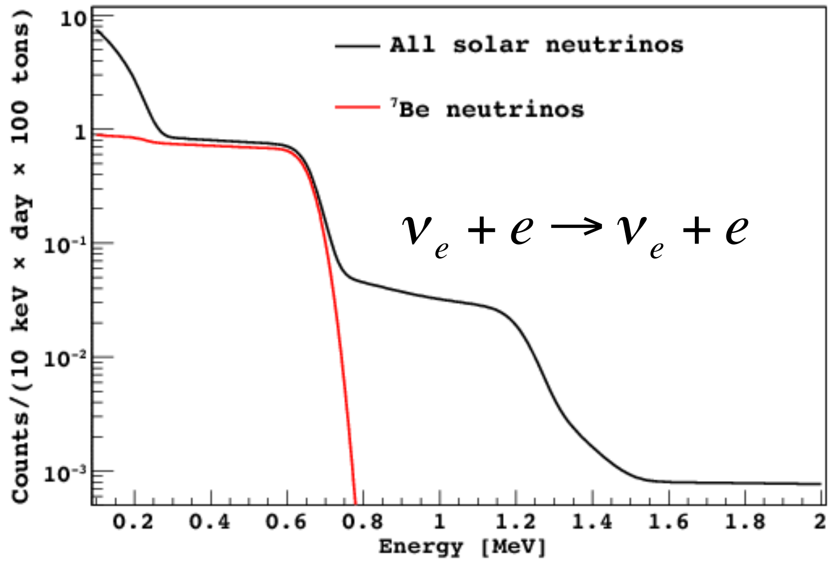
Reduction of the two main sources of errors:

1) position reconstruction

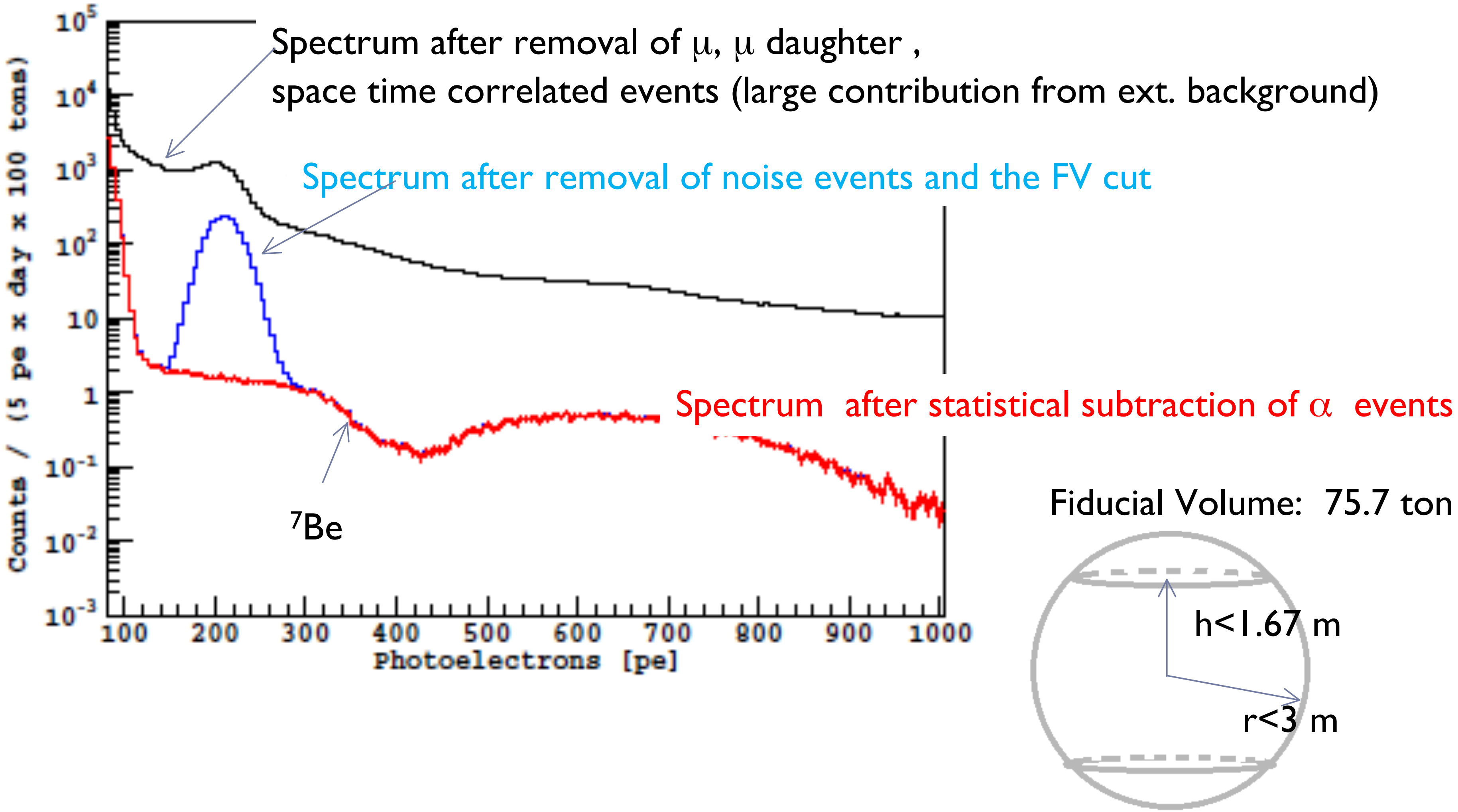
2) energy response

- Radiopurity of the detector saved (data set May07-May10)
- Increase of the statistic (about 4 X)

Expected neutrino signal (no background)



The energy spectrum after 740.6 days of livetime (757.8 before the cuts)



Analysis methods

- Fit of the energy spectrum of the events selected in the FV with background and signal
- Identify background
- Experimental energy estimators (number of detected hits, number of phe) ⟷ Event energy
- 2 complementary methods

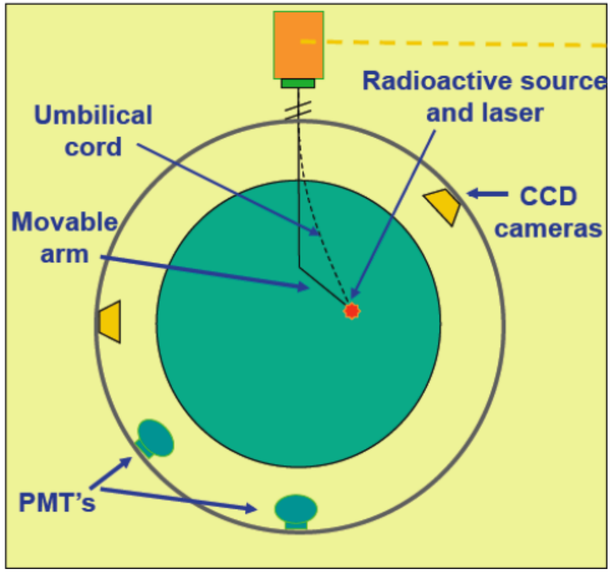
  1) Monte Carlo based

  2) Analytical models
- Both used $\alpha\beta$ statistical subtraction
- Common event selection procedure

  (removal of μ and μ daughter, noise events, taggable background, FV cut)

Both methods benefit from the calibration campaign

Calibration campaign



	γ							
	^{57}Co	^{139}Ce	^{203}Hg	^{85}Sr	^{54}Mn	^{65}Zn	^{60}Co	^{40}K
energy (MeV)	0.122	0.165	0.279	0.514	0.834	1.1	1.1, 1.3	1.4

n		
n-p	n $+^{12}C$	n+Fe
2.226	4.94	~7.5

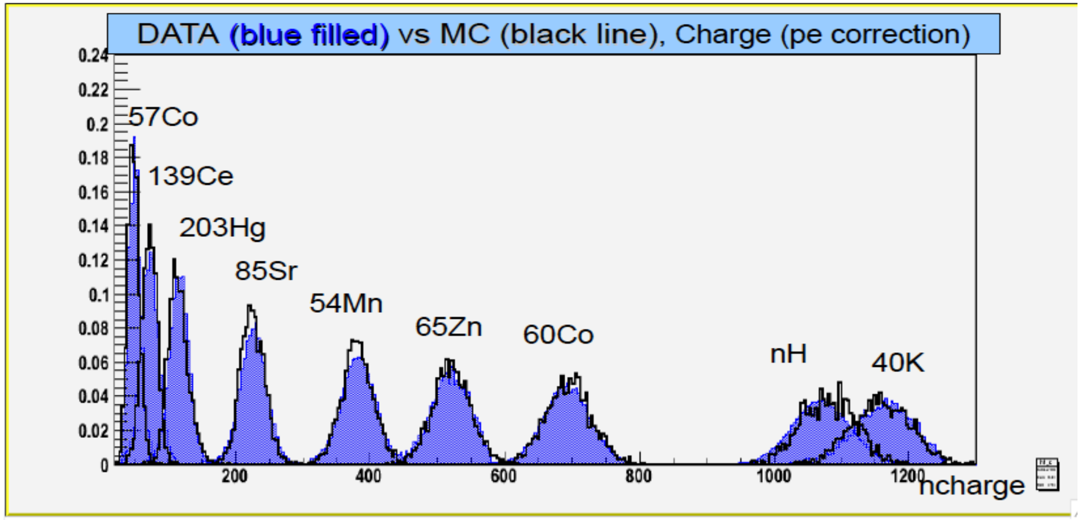
γ and n sources
- Absolute energy scale
- Energy resolution

^{222} Rn loaded scintillator (about 200 positions)

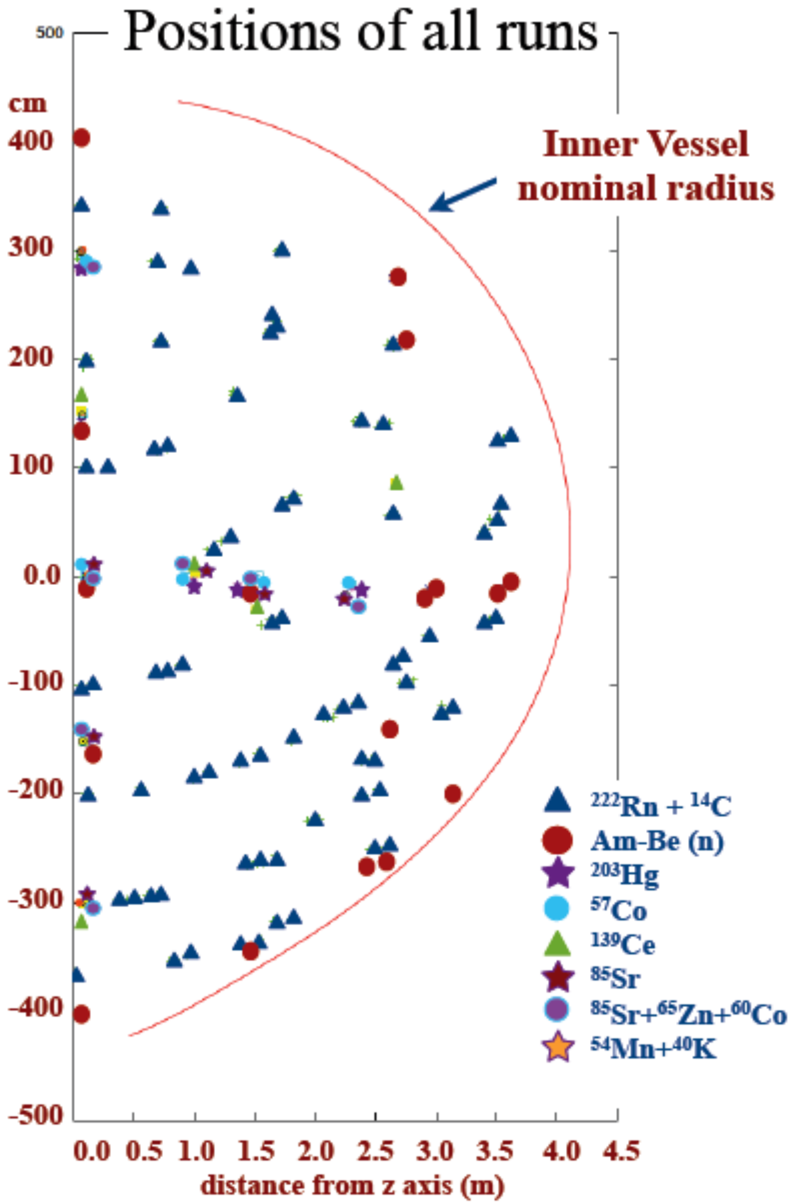
- ^{214}(Bi-Po) α/β discrim.
- Position
- energy response vs position

Source position measured with laser and CCD: 2 cm accuracy

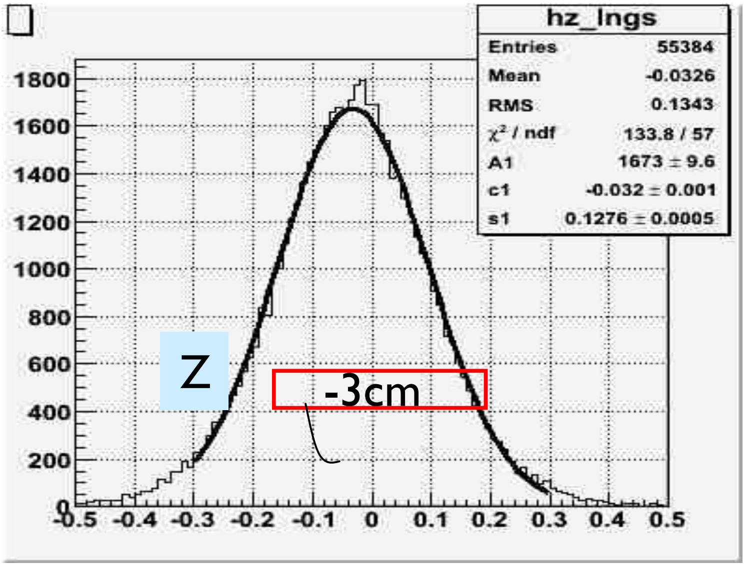
Energy calibration

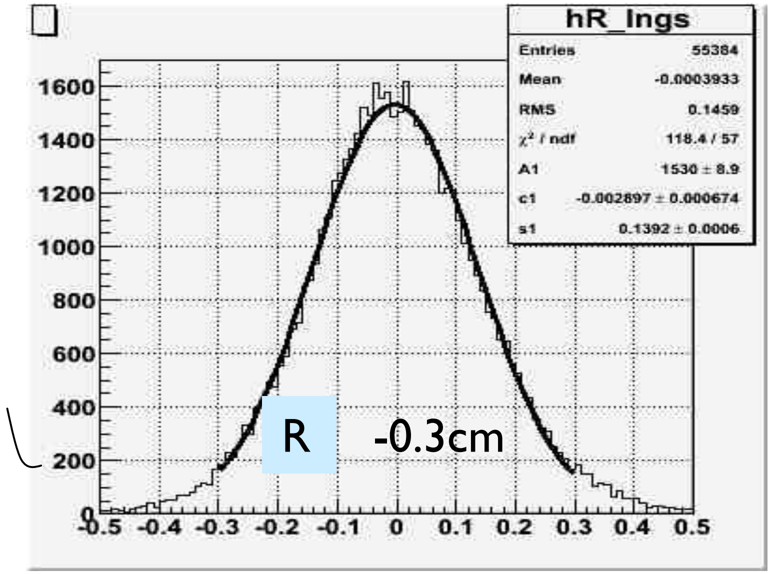


The energy scale uncertainty is less than 1.5% between 0~2MeV
Validation of the MonteCarlo



Position calibration



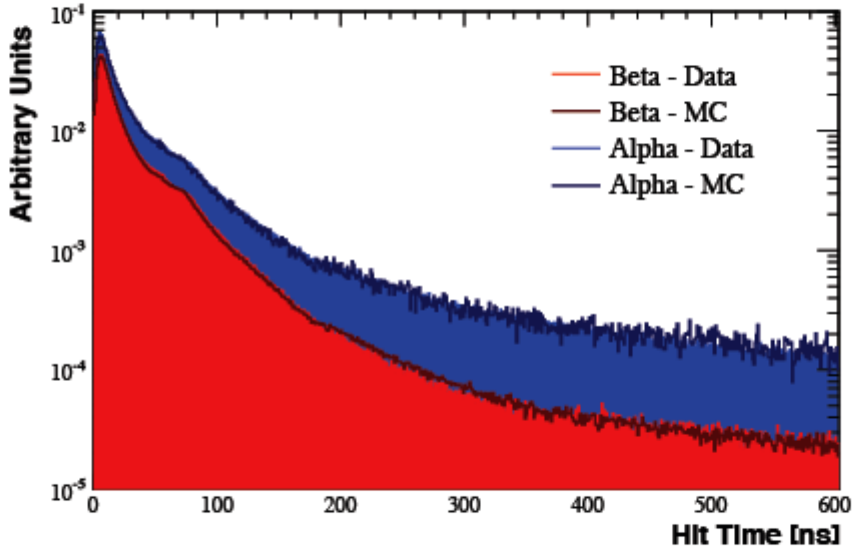


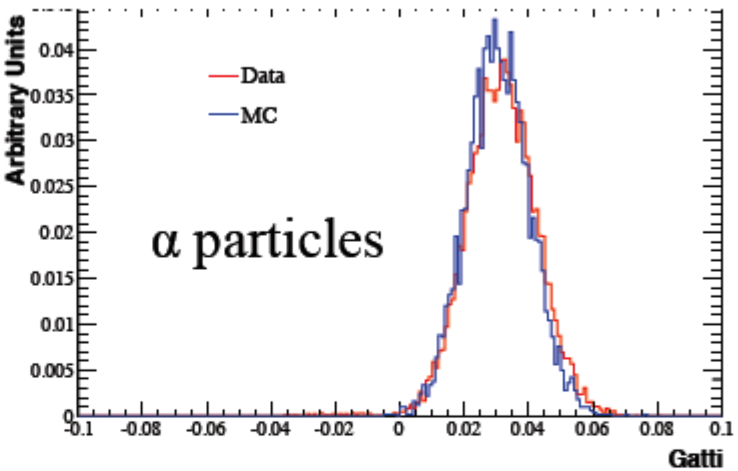
Using the 184 points of Rn calibration data, the fiducial volume uncertainty is +1.3% -0.5%

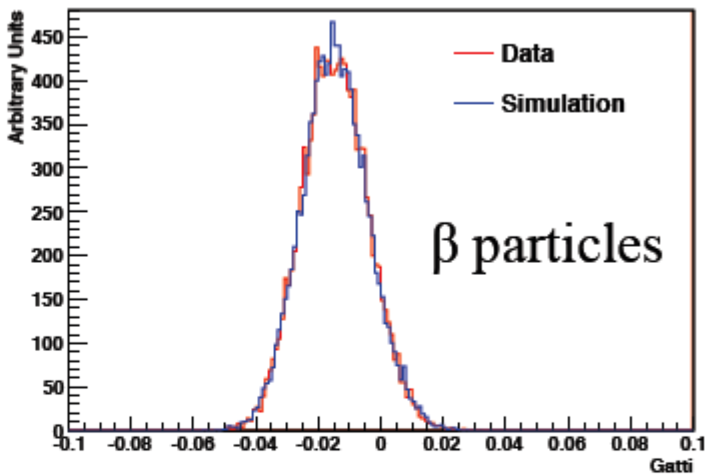
Reconstructed position shift from nominal

α/β discrimination

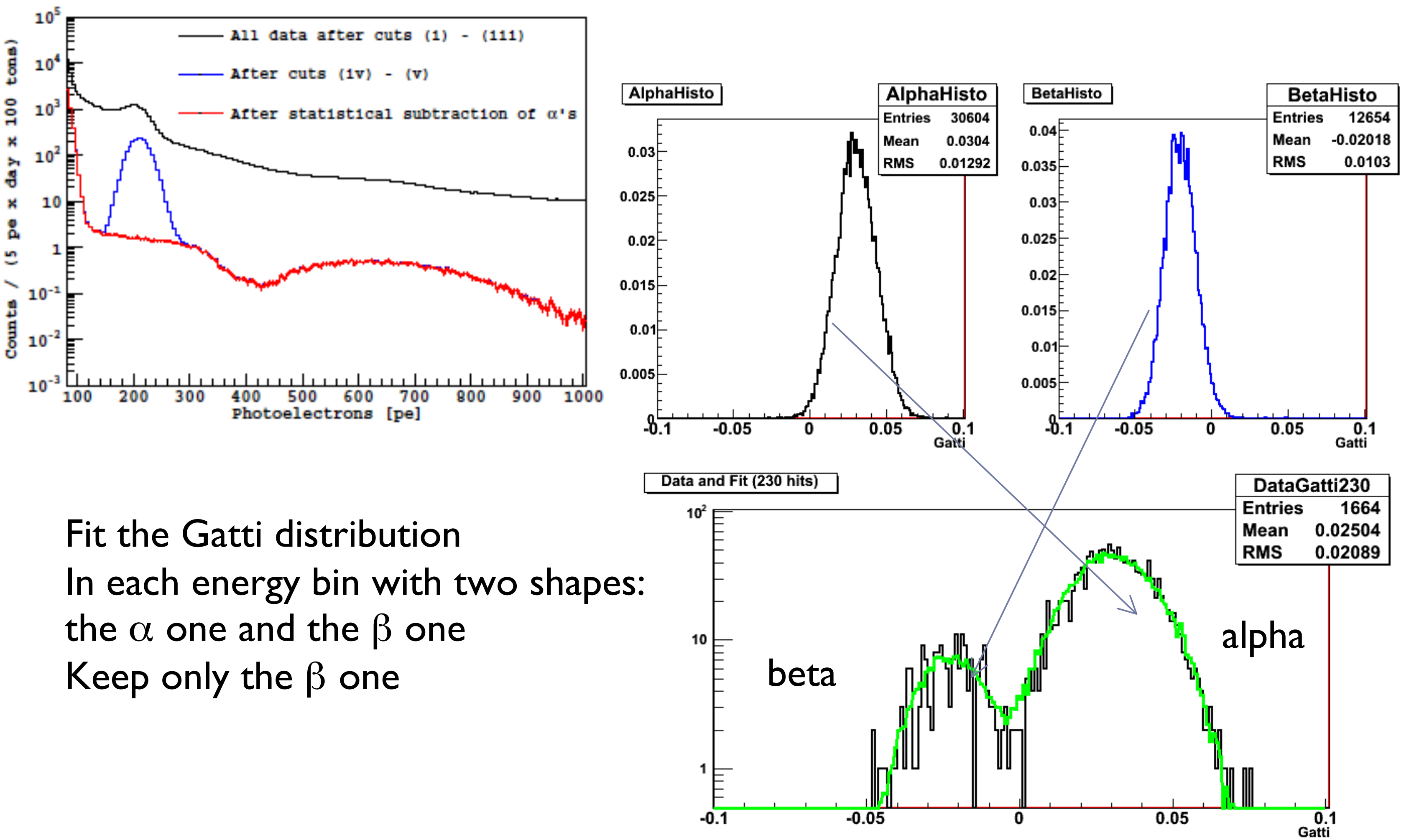
PMT hit timing distribution





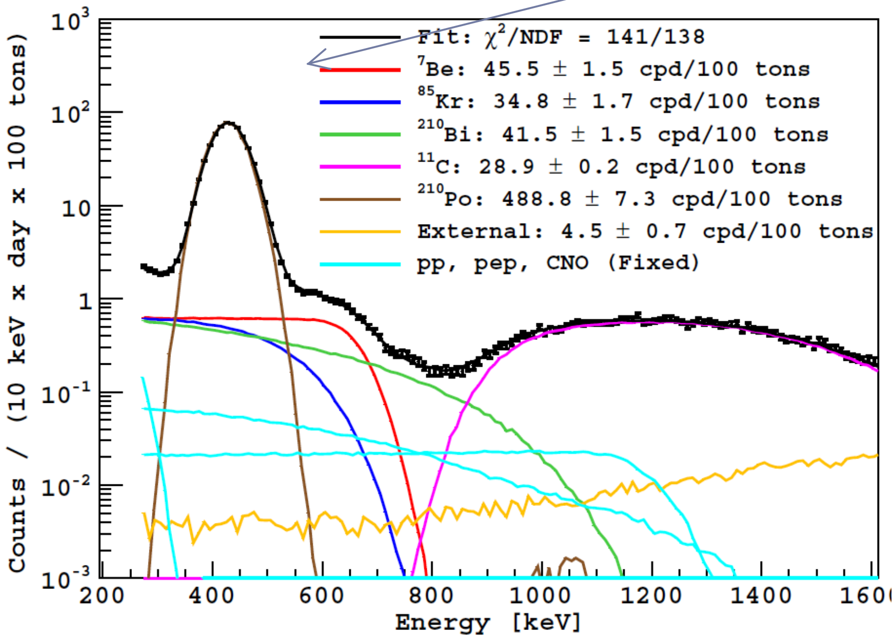


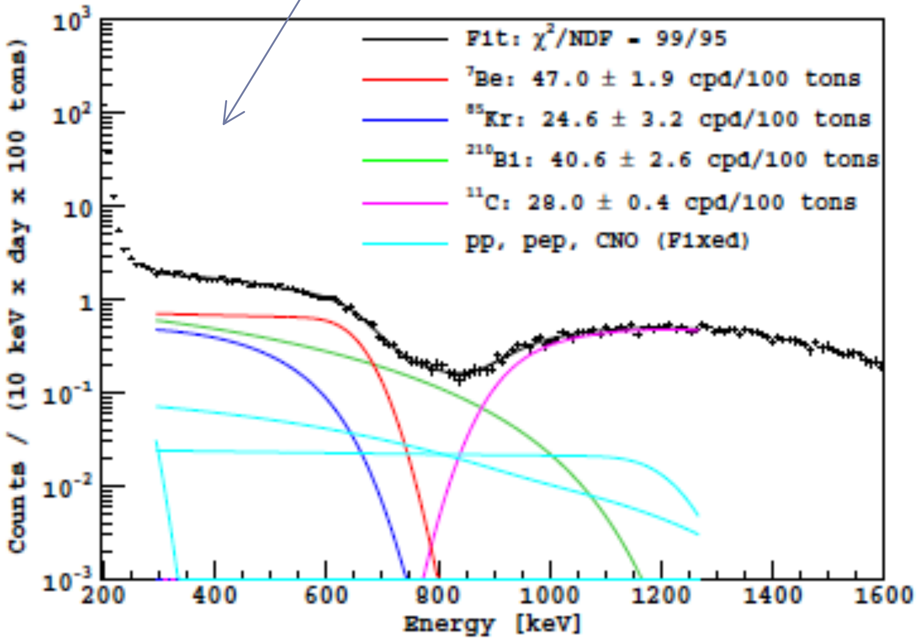
Statistical subtraction of α background



Fit the Gatti distribution
In each energy bin with two shapes:
the α one and the β one
Keep only the β one

Example of fit with the MC and analytical methods





RESULT:

^{7}Be (0.862 MeV) rate =
46.0+-1.5 (stat) $^{+1.6}_{-1.5}$ (syst) cpd/100t

No oscillations rejected at 4.8 σ 74+-5 cpd/100t

Results and Sources of errors

- ^{7}Be (0.862 MeV) rate = 46+-1.5 (stat) $^{+1.6}_{-1.5}$ (syst) cpd/100t

Systematic errors

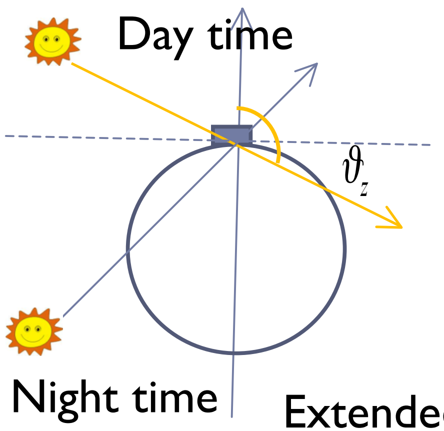
Estimated Systematic Uncertainties for ^{7}Be [%].

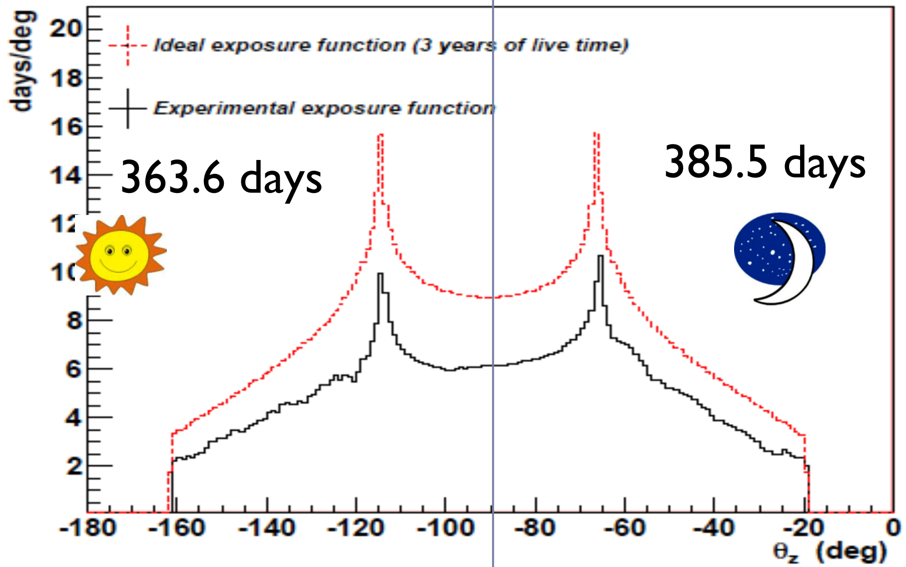
Source	[%]
Trigger efficiency and stability	<0.1
Live time	0.04
Scintillator density	0.05
Sacrifice of cuts	0.1
Position reconstruction	$^{+1.3}_{-0.5}$
Energy scale	2.7
Fit methods	2.0
Total Systematic Error	$^{+3.6}_{-3.4}$

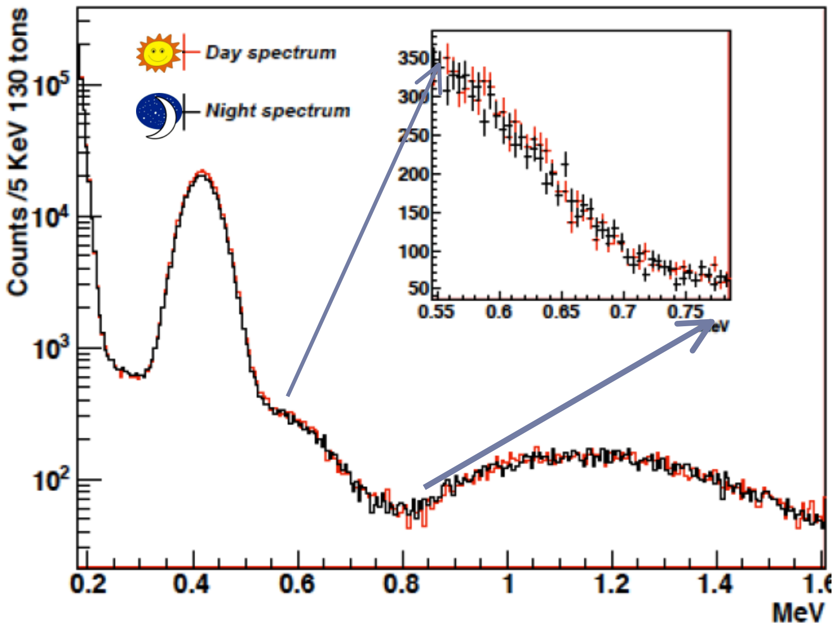
Spectral Fit Results [counts/(day·100 ton)].

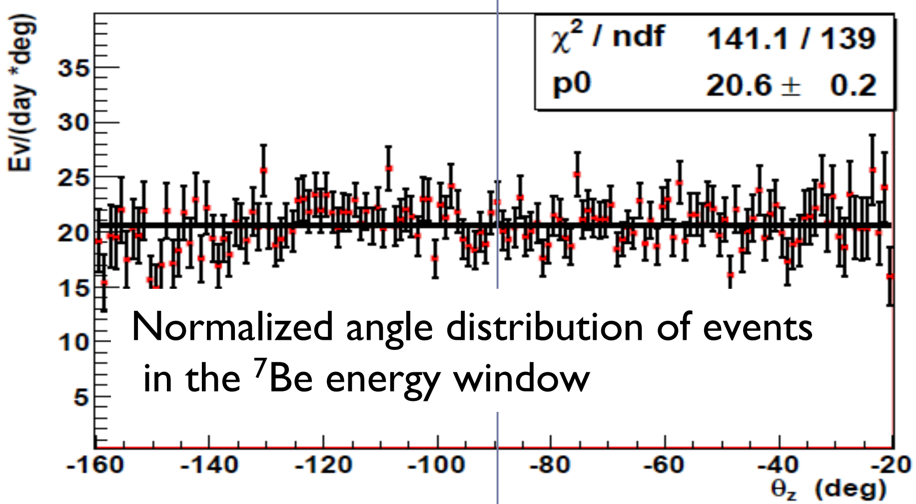
^{7}Be	$46.0\pm1.5(\text{stat})^{+1.6}_{-1.5}(\text{syst})$
^{85}Kr	$31.2\pm1.7(\text{stat})\pm4.7(\text{syst})$
^{210}Bi	$41.0\pm1.5(\text{stat})\pm2.3(\text{syst})$
^{11}C	$28.5\pm0.2(\text{stat})\pm0.7(\text{syst})$

Absence of the Day Night effect of ^{7}Be rate

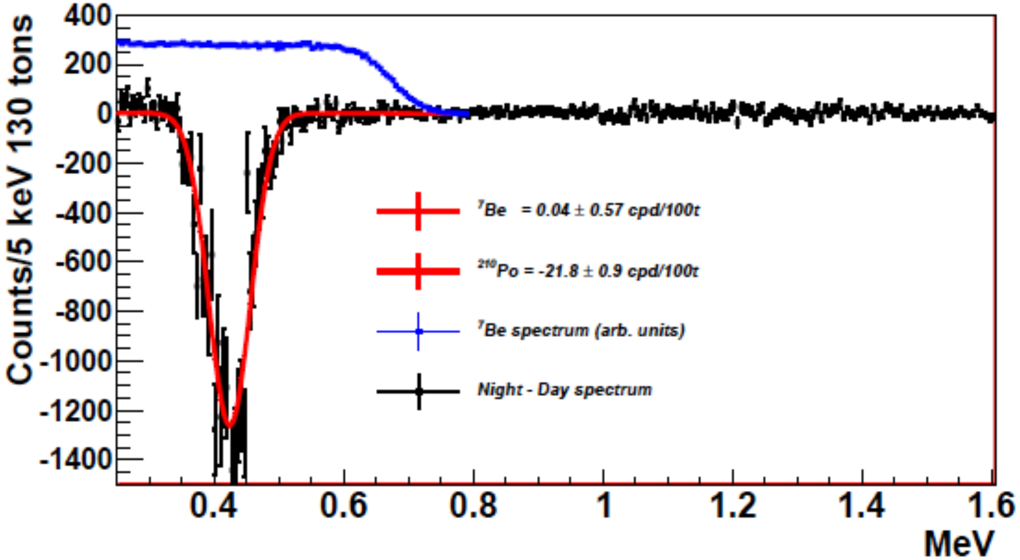








Absence of the Day Night effect of ^{7}Be rate



Search for a ^{7}Be component in the spectrum of the differences of the Night and Day counts

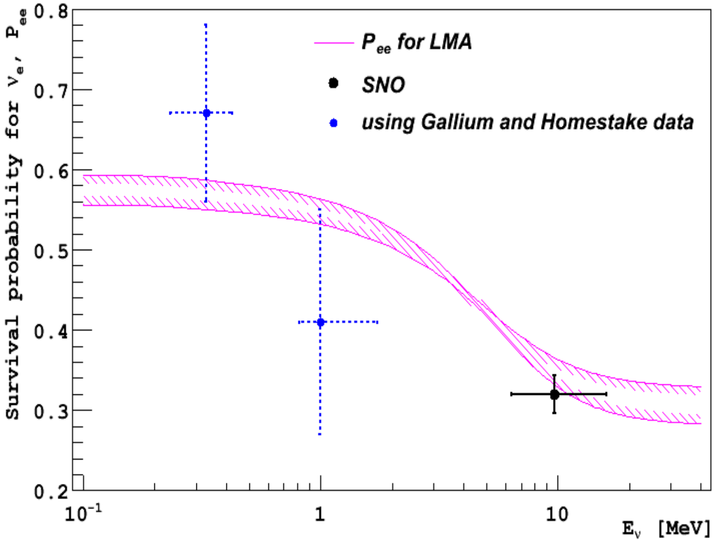
$$A_{dn} = 2\frac{R_N - R_D}{R_N + R_D} = \frac{R_{diff}}{\bar{R}}$$

Source of error	Error on A_{dn}
Live–time	$< 5{\cdot}10^{-4}$
Cut efficiencies	0.001
Variation of ^{210}Bi with time	$\pm$0.005
Fit procedure	$\pm$ 0.005
Total systematic error	0.007

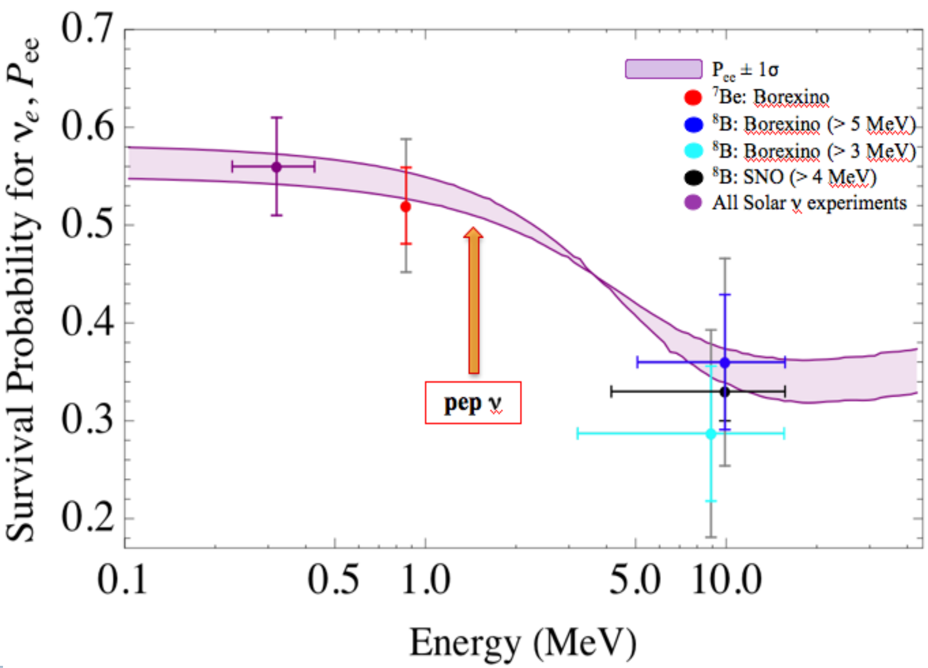
A_{dn} = 0.001 +-0.012 (stat) +- 0.007 (syst)

Consequences of our results

Neutrino survival probability
Before the Borexino results..



..and after the Borexino results

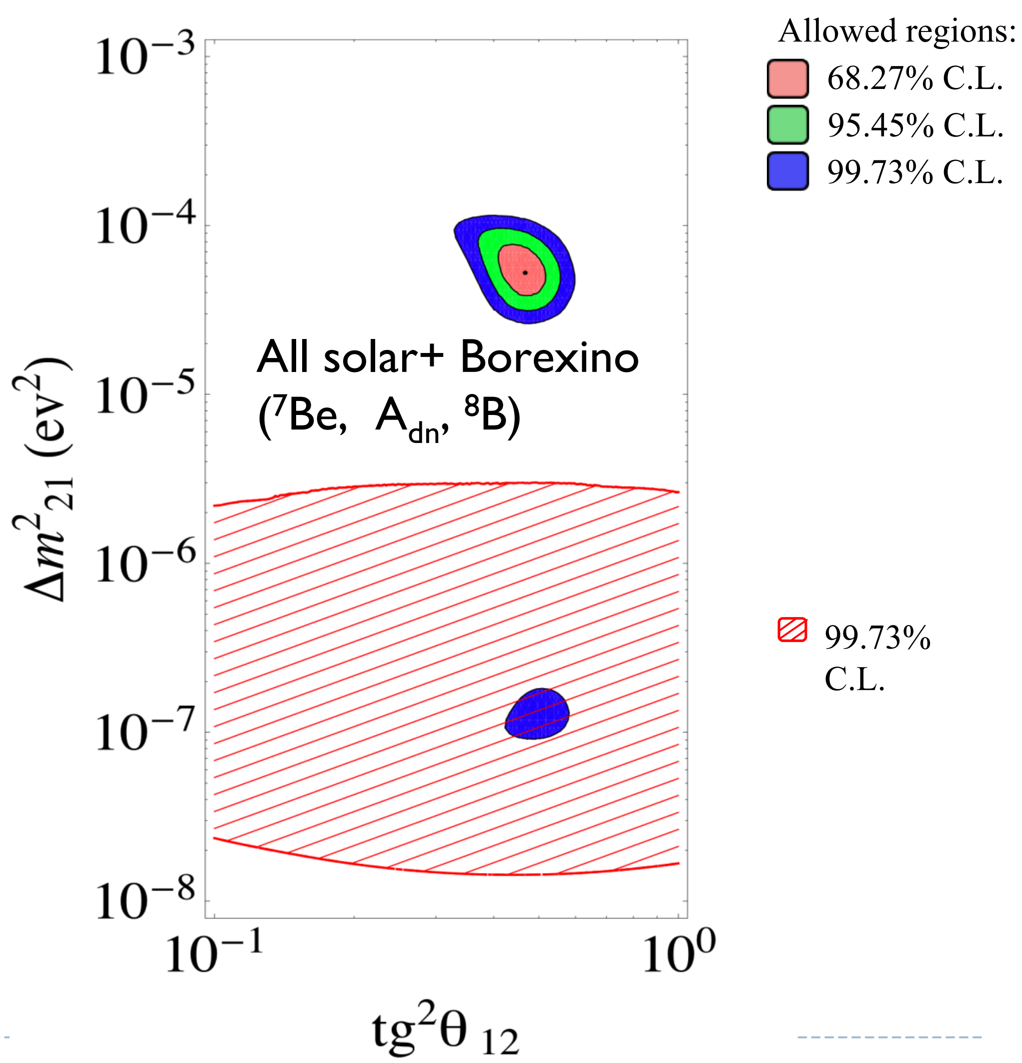


Consequences of our results

- The LOW region

is ruled out at 8.5 σ by solar ν (not anti ν) when Borexino data are included

NO need of CPT



Conclusions

- New ^{7}Be flux (4.8% error) and A_{dn} (1.5%) released
- Borexino is validating LMA-MSW in the vacuum regime
- Borexino and solar ν (without anti-ν) reject the LOW solution and select the LMA (no need for CPT)

- Purification of the scintillator is in progress
- Further solar ν results expected with the presently available data set
- ν or anti-ν sources (under discussion): probe sterile ν scenario

Backup:Consequences of our results

Constrain of pp and CNO fluxes

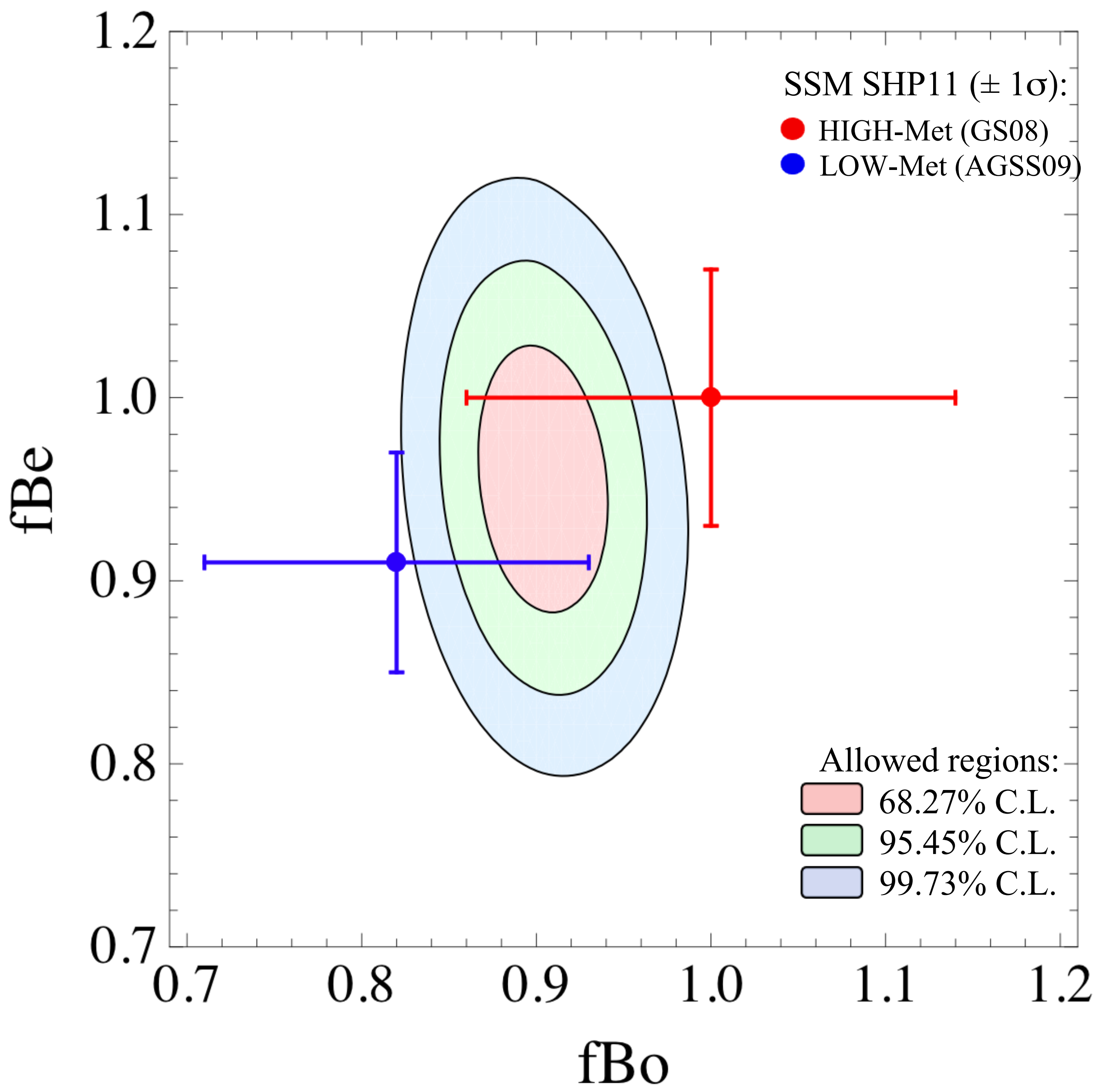
1)fpp = 1.008 +0.003-0.016

FCNO<2.3 109 cm-2s-1 (95% CL)

CNO contribution to the solar luminosity <3%

2)Solar models: high and low luminosity

Backup: Comparison with SSM- metallicity puzzle



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