Solar neutrino detection in Borexino

G. Testera (INFN Genova)
on behalf of the Borexino Collaboration

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~90 physicists from 16 istitutions:

Italy : INFN and Univ. of : *Milano, Genova, Perugia, Ferrara*
INFN Laboratori del Gran Sasso / *Assergi*
France: APC / *Paris*
Germany: Max-Planck-Institut für Kernphysik / *Heidelberg*
Technische Universität München (Phys. Dept.) / *Garching*
Poland: Marian Smoluchowski Inst. Of Phys., Jagellonian University / *Krakow*

Russia: J.I.N.R. / *Dubna*,
St. Petersburg Nucl. Phys. Inst./ *Gatchina*,
RRC Kurchatov Institute / *Moscow*
Ukraine: Kiev Institute for Nucl. Research/ *Kiev*

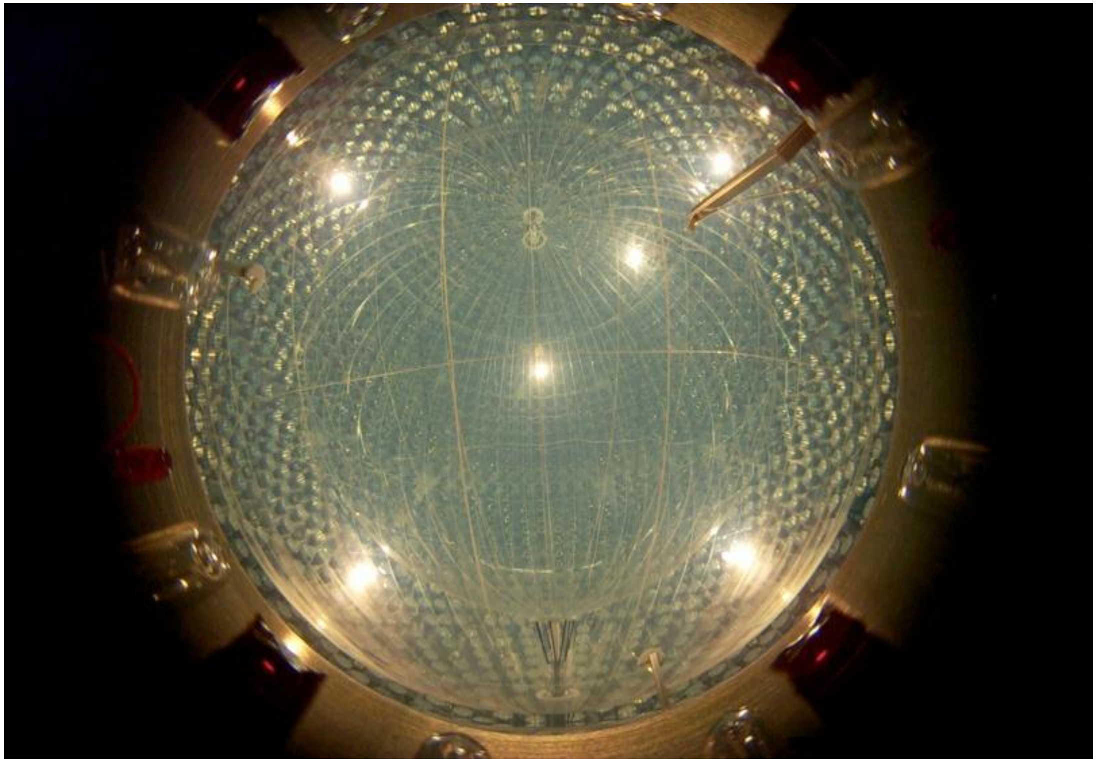
USA: Princeton University (Phys. and Chemical Eng. Dept.) */Princeton, NJ*,
Univ. of Mass. (Phys. Dept.)/*Amherst*, *MA*,
Virginia Polytechnic Inst. And State Univ. / *Blacksburg*, *VA*

Summary of the talk

- The Borexino detector: only few words
- The ^{7}Be measurement
- The calibration of Borexino and the reduction of the errors
- The Day Night asymmetry for the ^{7}Be neutrinos
- The ^{8}B result
- Toward the pep (and CNO) measurement

The Borexino Detector at Laboratori Nazionali Gran Sasso

- Low background
- High mass: 270 tons active mass, liquid organic scintillator PC + PPO (1.5 g/l)
- 2200 Photomultipliers

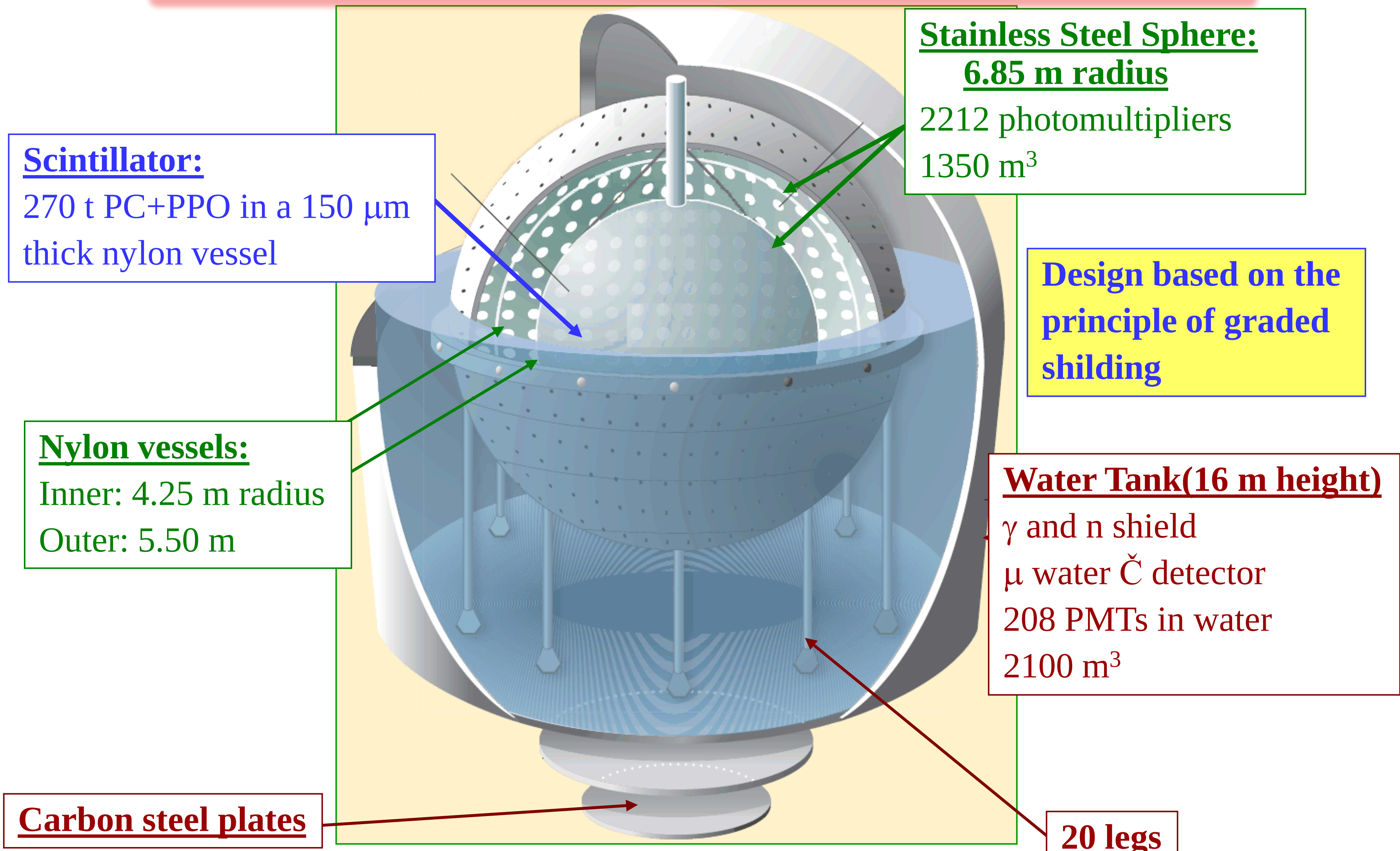


Borexino is continuosly RUNNING since May 16, 2007

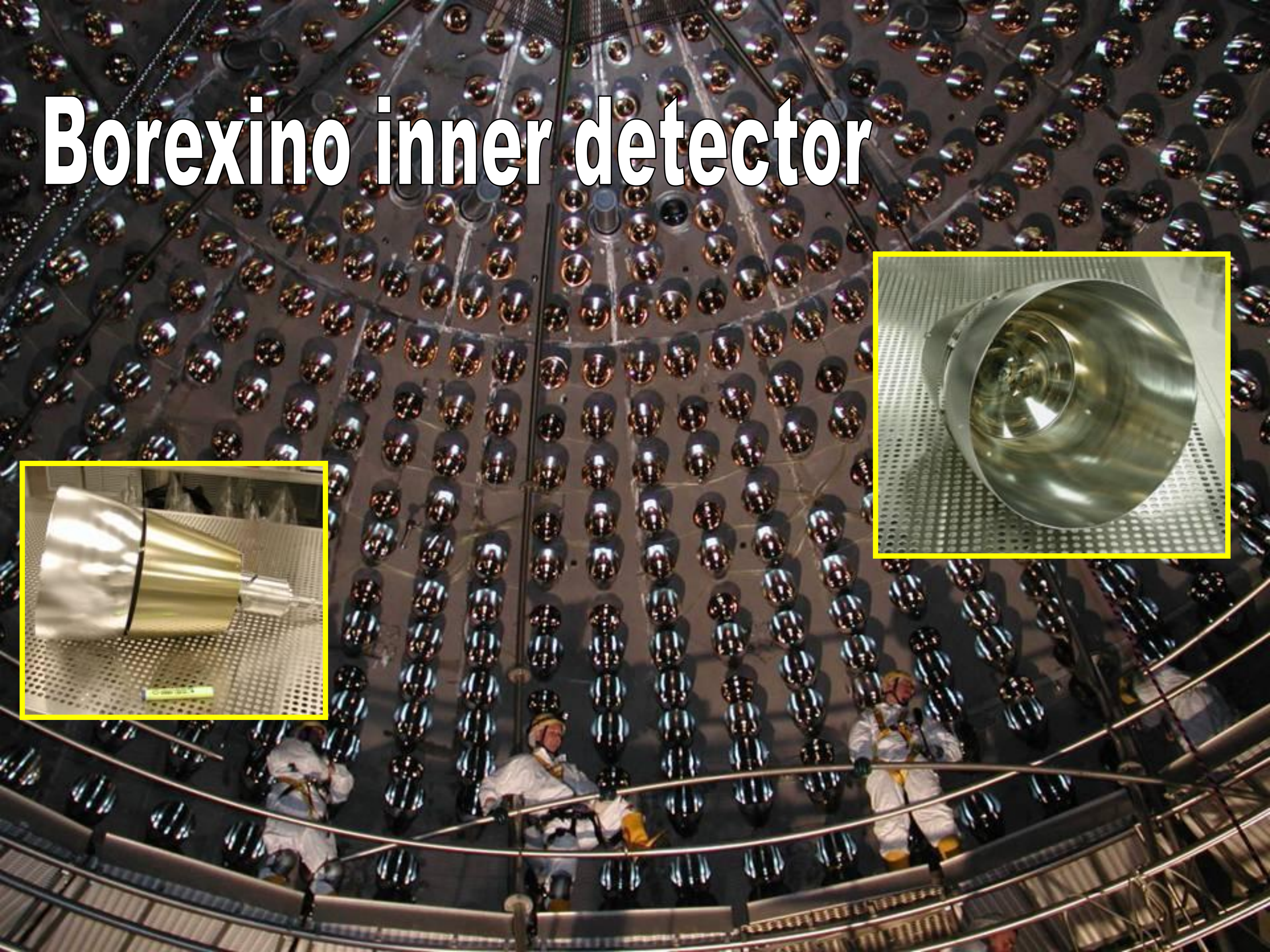
We have now more than 900 days of live time

Borexino is the results of almost 20 years of R&D and tests!!!

The Borexino Detector layout



Borexino inner detector



Nylon vessels installation

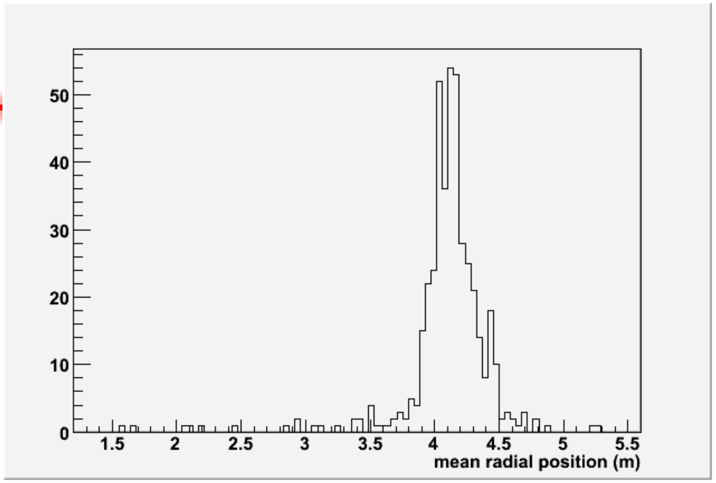
Nylon vessels installed and inflated

ν detection method

- Neutrino elastic scattering on electrons: $\nu + e \rightarrow \nu + e$;
- High scintillation yield: 500 phe/MeV (electron equivalent) and low threshold (0.2 MeV)
- No directionality
- Reconstruction of the scintillation position through time measurement; software definition of a " wall less" Fiducial Volume (r< 3m)
- Measure of the energy of the scintillation events (Npmts, nhits, charge)
- Alpha beta discrimination capability
- Active muon veto (see later)
- Solar neutrino signature: shape of the energy spectrum
- Extremely low background is essential

Background

^{232}Th: (6.8±1.5) 10^{-18} g/g
from ^{212}Bi-^{212}Po



^{238}U: (1.6±0. 1) 10^{-17} g/g
from ^{214}Bi-^{214}Po

^{nat}K ≤3 10^{-16} g/g
From spectrum

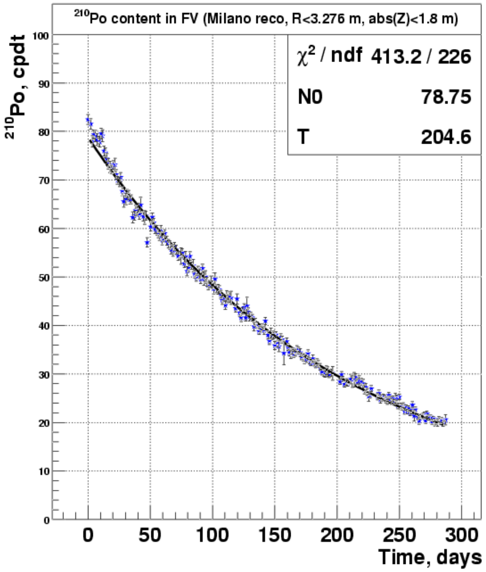
^{85}Kr β decay- 687 keV

32events → 30±5 c/d 100t

^{85}Kr —β→ ^{85m}Rb —γ→ ^{85}Rb

173 keV   514 keV

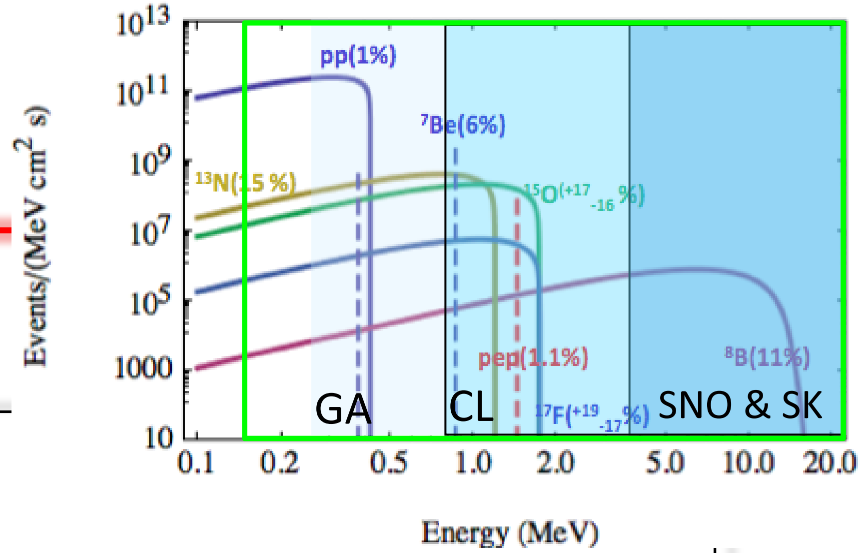
τ= 1.46 µs - BR: 0.43%



^{210}Po- α, Q=5.41 Mev quenched by ≈13-
no evidence of ^{210}Bi,initially 80 c/d/t

PhysSun 2010, G. Sasso, G. Testera INFN Genova

Borexino
and solar neutrinos



^{7}Be solar neutrinos

- This was the main physics motivation
- Borexino is measuring the real time spectrum and flux of the 0.862 MeV neutrinos
- Results after 192 days live time: $49 \pm 3_{stat} \pm 4_{sys}$ cpd/100t
- FIRST real time measurement!
- Toward higher precision : the Borexino calibration campaign
- Day night asymmetry

^{8}B solar neutrinos

- Low (3MeV) threshold detection

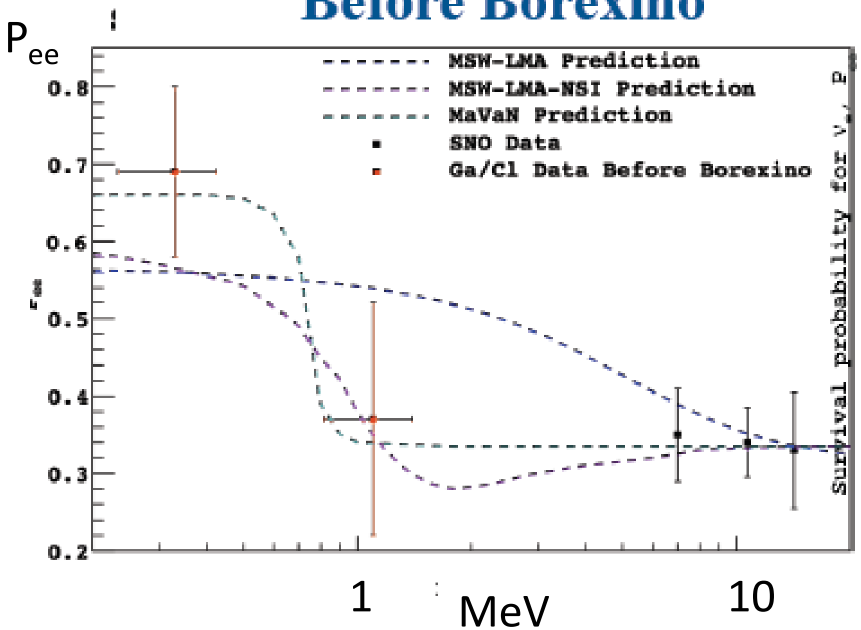
pp, pep, CNO:

- work in progress

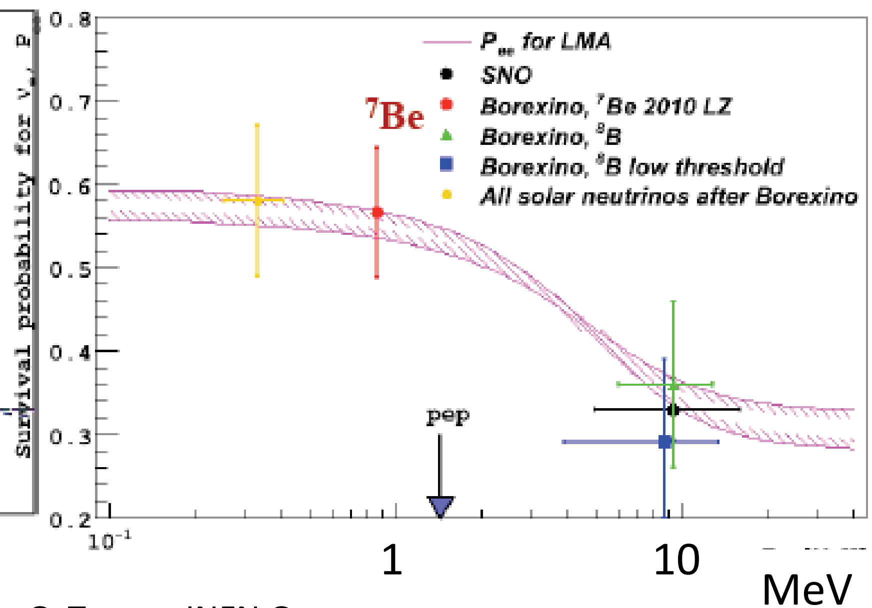
Solar neutrinos: the SUN and the neutrino physics

- Solar neutrinos change flavour (oscillate) during the travel from the Sun to the Earth
- Electron neutrinos emitted from the Sun may reach a detector as ν_μ, ν_τ
- Oscillation model : LMA-MSW
- P_{ee} : electron neutrino survival probability is energy dependent
- It has to be measured in all possible energy range
- Before Borexino: P_{ee} was poorly known below 1 MeV
- Is there room for exotic models (not standard?)

Before Borexino



2010



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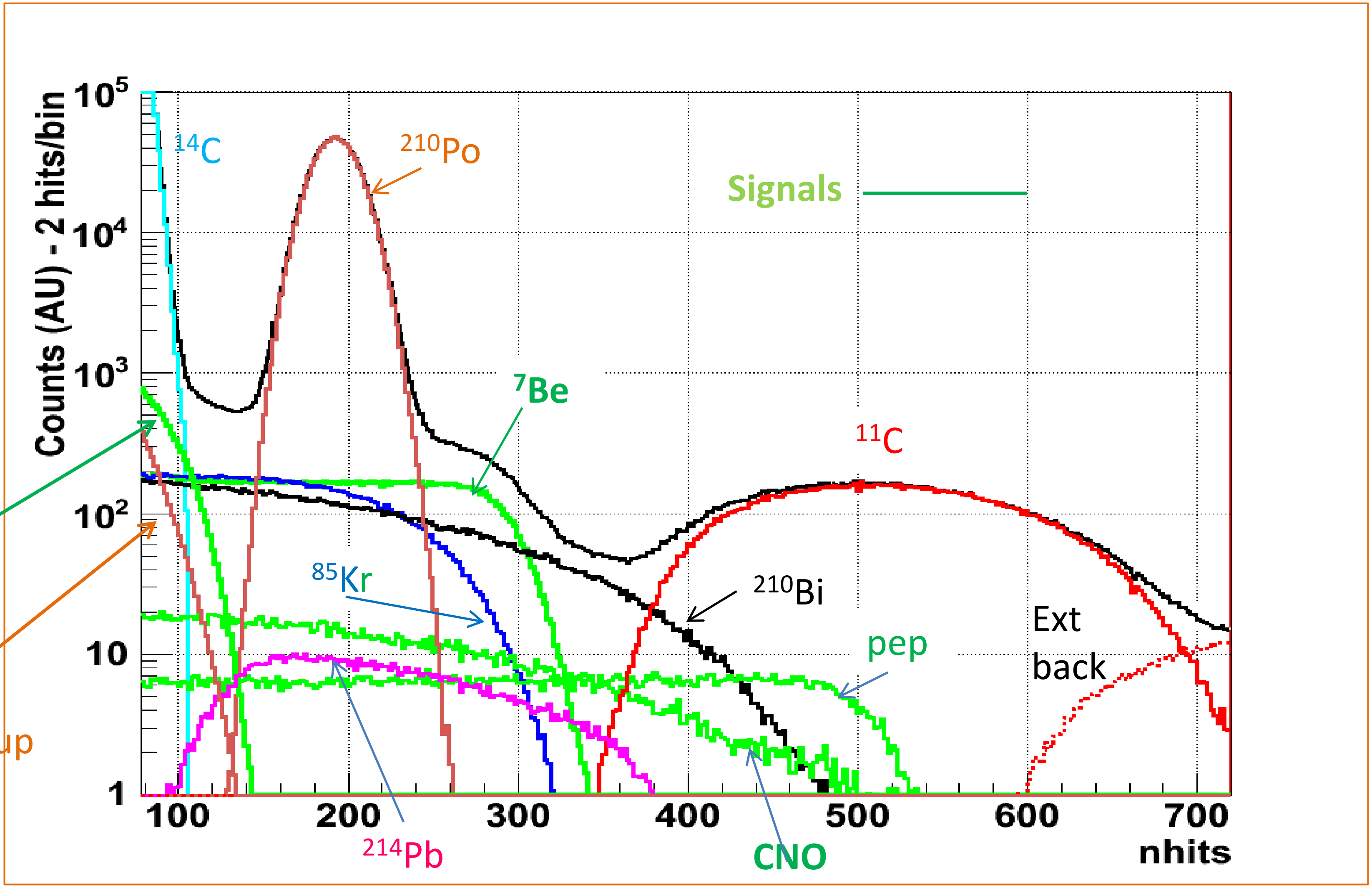
Solar neutrinos: the SUN and the neutrino physics

- Solar neutrinos flux and standard solar models

- CNO contribution: poorly known!
  a direct measurement is appealing

Signal and the main background in Borexino : the energy spectrum (MC simulation, no DATA)



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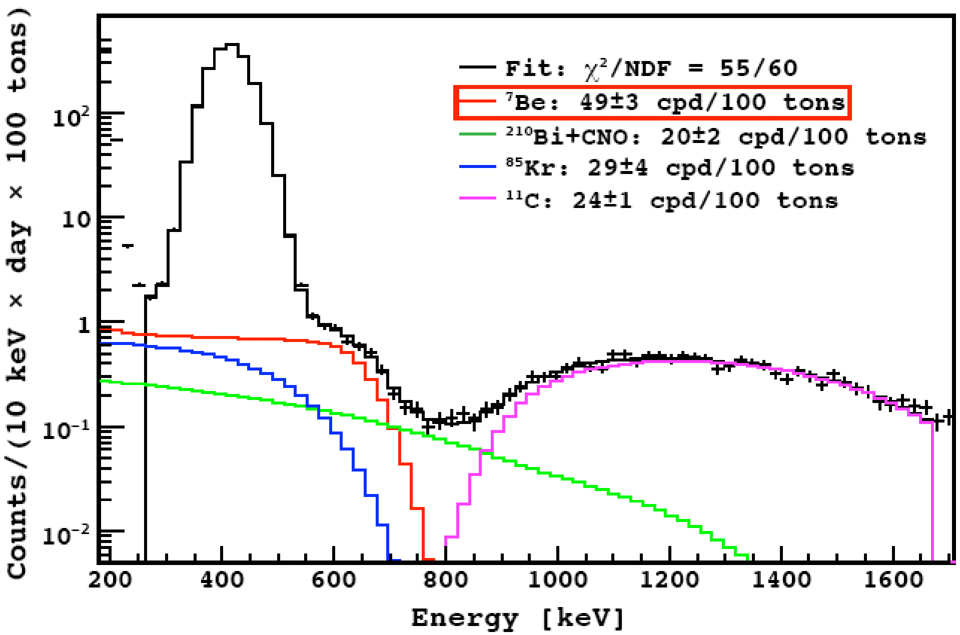
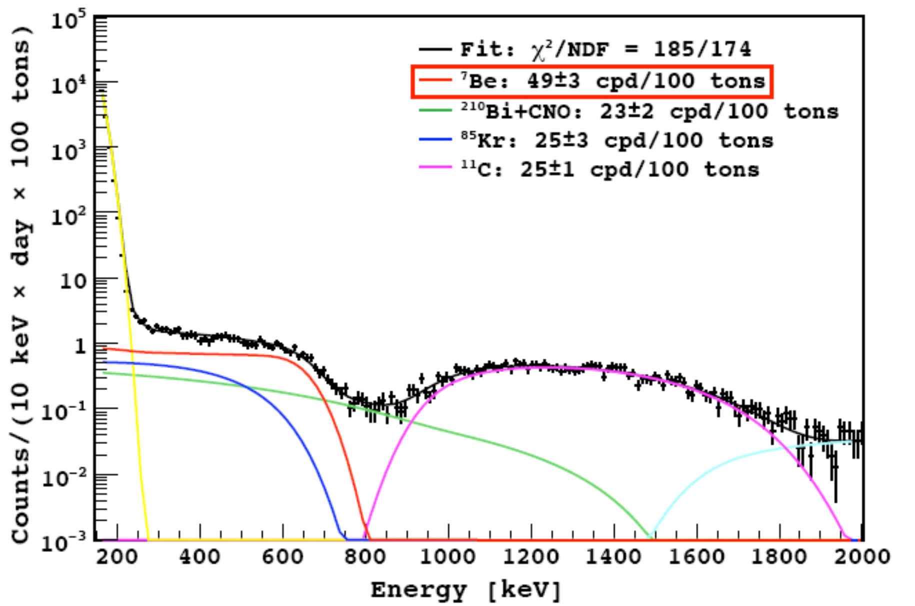
^{7}Be signal after 192 days and before the calibration campaign





R_{7Be}= 49 ± 3_{stat} ± 4_{sys} cpd/100 tons

Borexino Collaboration Phys. Lett. B 658 (2008) : after 2 months of data taking
Borexino Collaboration PRL 101 (2008) : 192 days of live time

Be7 signal after 192 days and before the calibration campaign

^{7}Be: (49 $3_{stat} \pm 4_{sys}$) cpd/100 tons (192 days)

No-oscillation hypothesis rejected at 4σ level

	Expected rate (cpd/100 t)
No oscillation	**75 ± 4**
BPS07(GS98) HighZ	**48 ± 4**
BPS07(AGS05) LowZ	**44 ± 4**

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

Strategies to reach higher precision for the ^{7}Be line and sensitivity to pep, CNO, pp neutrinos

1. Calibration of the detector with internal (and external) radioactive sources
2. Reduce the FV error
3. Reproduce the calibration data with a Full simulation (MonteCarlo) code an then use the MC to analyze the real data
4. Purify the detector to further reduce the background contaminants (Kr, ^{210}Bi)
5. Progresses in the muon tracking and ^{11}C removal

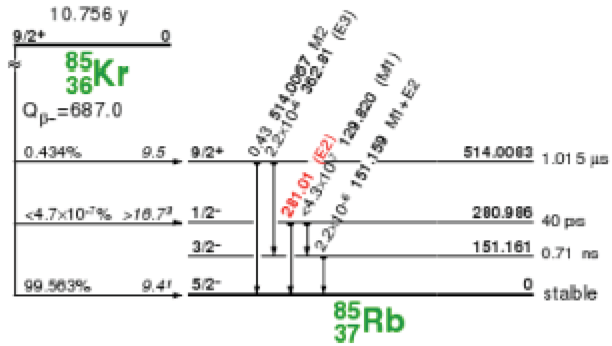
1. Completed during the year 2008 and 2009
2. Completed
3. In progress, almost completed
4. In progress: started during the summer 2010
   Preliminary promising results!
5. Almost completd

In addition: more statistics allows better Kr determination

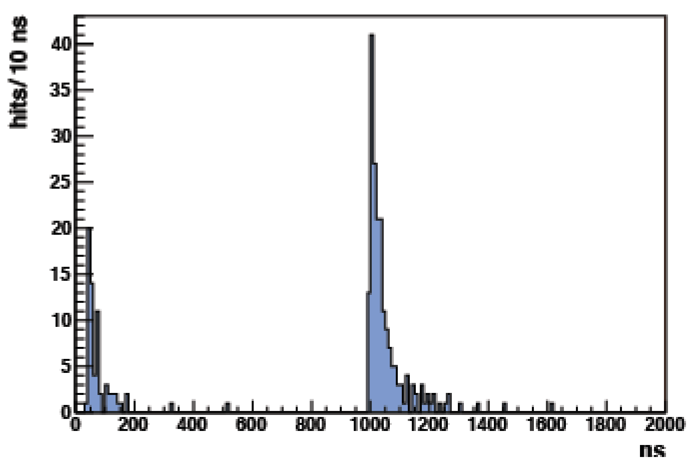
- ^{85}Kr can be measured directly by means of a relatively rare but easy-to-measure decay to excited ^{85}Rb* with following radiative decay [B.R. 0.434%]

$$^{85}\mathrm{Kr} \xrightarrow{\beta\ 173\ \mathrm{keV}} {}^{85}\mathrm{Rb}^{*} \xrightarrow{\gamma\ 514\ \mathrm{keV}} {}^{85}\mathrm{Rb}$$

$$\tau = 1.464\ \mu s$$



- Measured with 751 days of statistics
- 32 candidate events in final sample
- 2 analysis with very consistent results



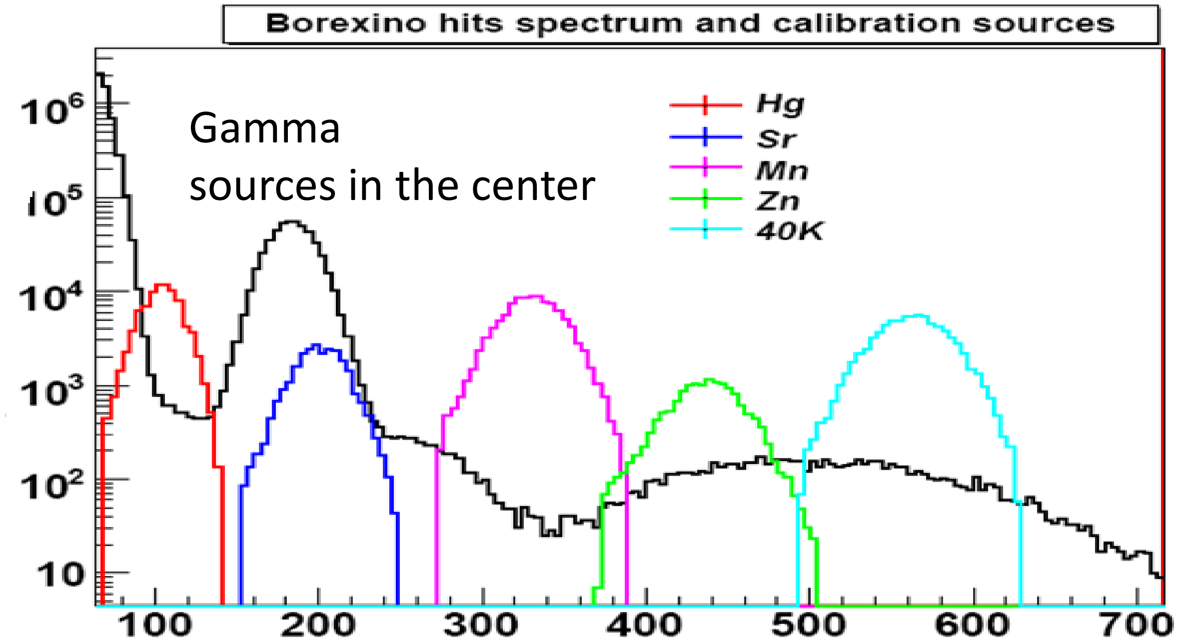
- Result on ^{85}Kr contamination (main β decay to ^{85}Rb ground state)

- **30 ± 5 c / 100 t / d**

Preliminary

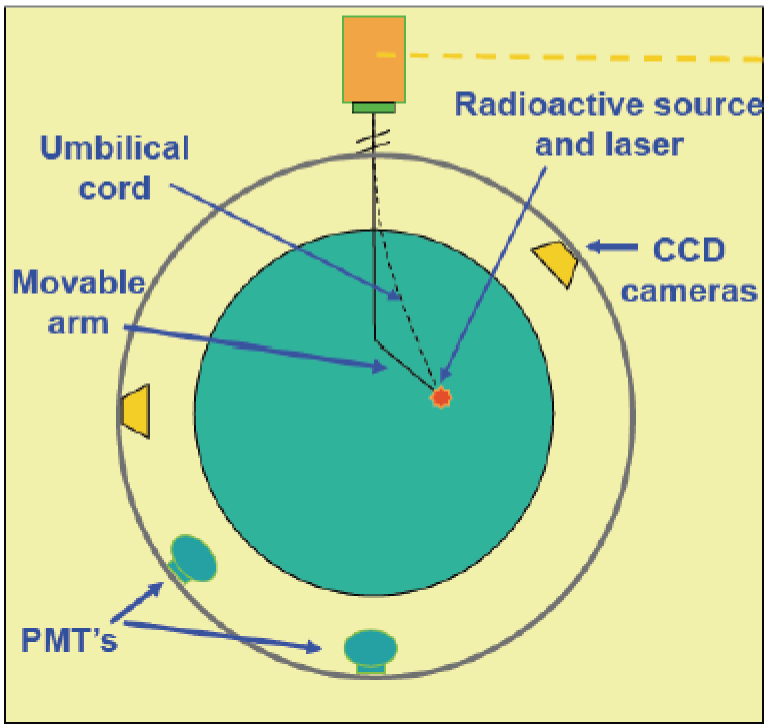
Borexino calibration

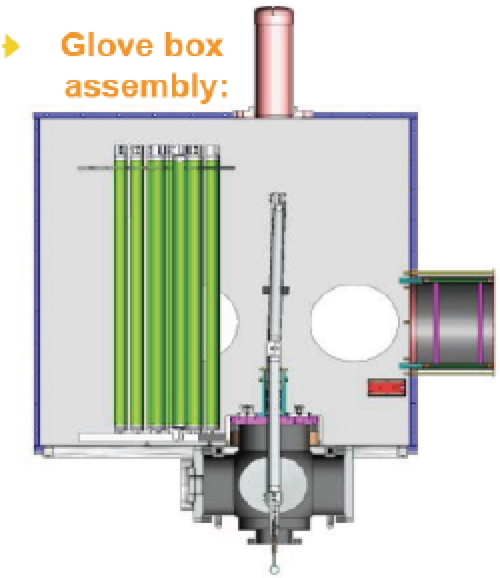
- α, β : scintillator vial loaded with ^{222}Rn
  - clean α β tag due to to ^{214}Bi-Po fast coincidence
- γ sources : dopant dissolved in a small vial (water solution)
- AmBe source

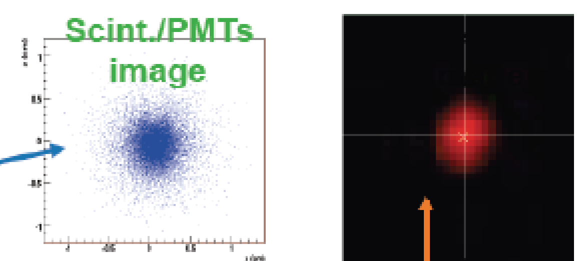


	γ								β		α	n		
	^{57}Co	^{139}Ce	^{203}Hg	^{85}Sr	^{54}Mn	^{65}Zn	^{60}Co	^{40}K	^{14}C	^{214}Bi	^{214}Po	n-p	n $+^{12}$C	n+Fe
energy (MeV)	0.122	0.165	0.279	0.514	0.834	1.1	1.1, 1.3	1.4	0.15	3.2		2.226	4.94	~7.5

Borexino calibration



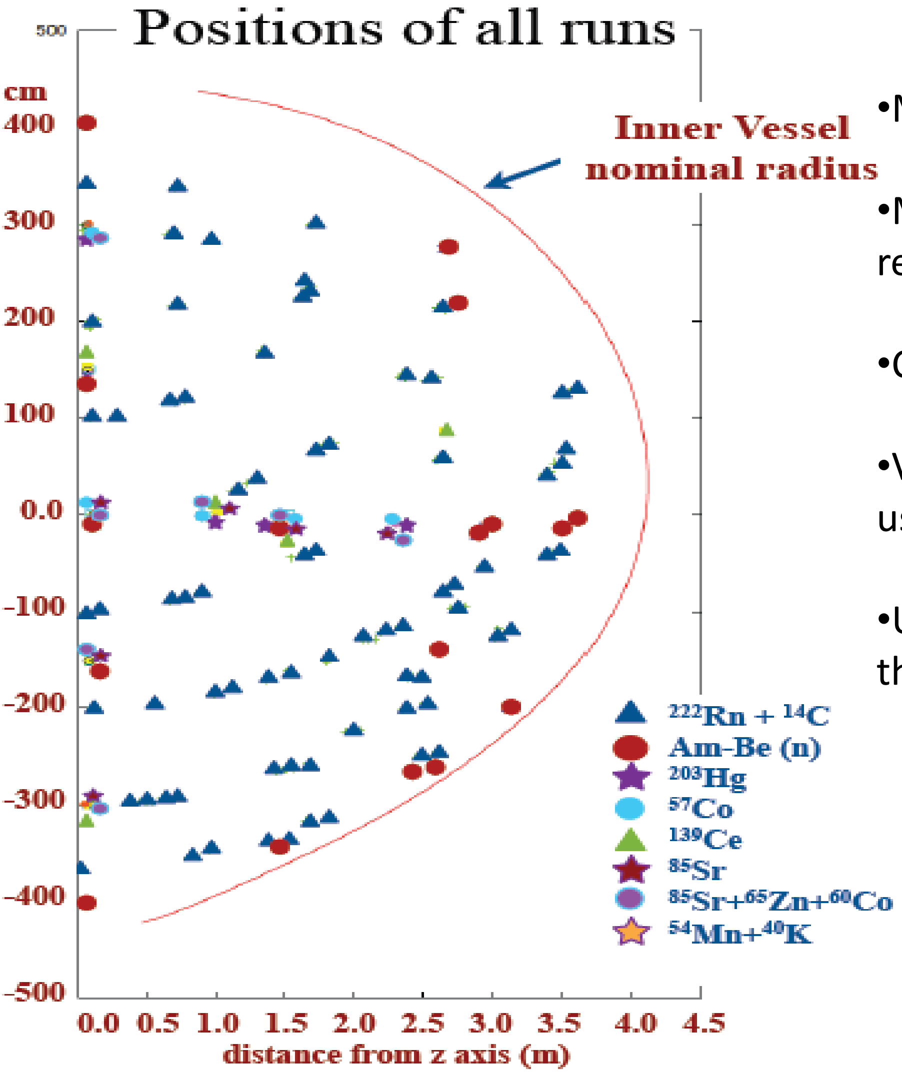




Source decays induced scintillation light/PMT's

Red laser light/CCD cameras (accuracy: < 2 cm)

Borexino calibration



- •Measure the accuracy of the position reconstruction
- •Measure the resolution of the position reconstruction
- •Check the energy scale
- •Validate the full simulation MonteCarlo code (MC) using the source calibration data
- •Use the MC code to model and reproduce the whole detector response function

The Borexino MonteCarlo code

•Full modeling of the detector geometry and material : Geant4
•Energy loss of all the particles in all the materials
•Scintillation and Cerenkov light
•Use measured spectrum of scintillation light and time response
•Use measured cross sections for absorption, re-emission, light scattering
•Single photon tracking
•Modelling of the Ionization quenching (Birks effect)
•Full simulation of the electronics chain (threshold, dead time, charge measurement, shape of each sphe peak)
•Follows pattern of working photomultipliers and changes in the electronics setup during time

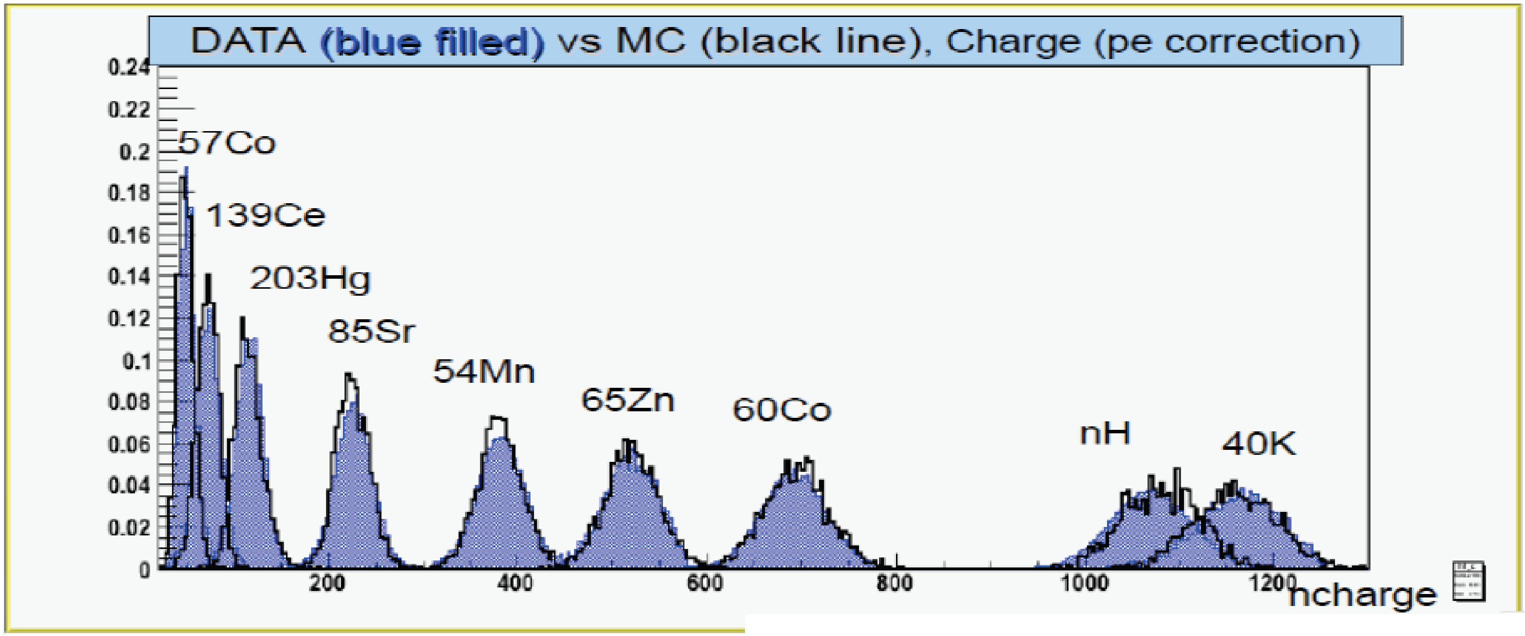
Reproduce the behavior vs Energy and position of the 3 Borexino energy estimators

Npmts : number of PMTs fired
Nhits : number of hits (including multiple hits on the same PMTS)
Charge : collected charge

Reproduce the time response

Final MC tuning using the calibration data

The energy calibration



The energy scale is known at 1.5 % in the region (0 -2 MeV)

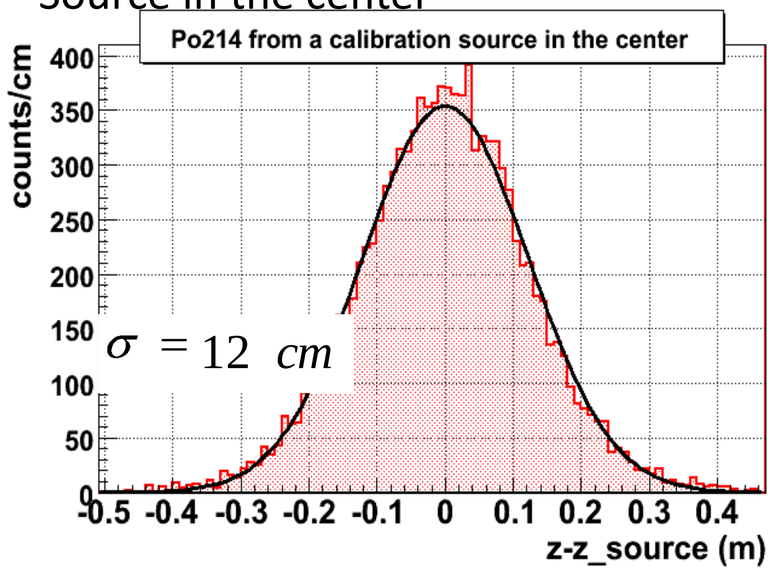
Energy resolution (σ):
10% @ 200 keV
8% @ 400 keV
6% @ 1000 keV

Source name	Data Peak (nhits)	MC Peak (nhits)	Peak error (nhits)
57Co	47,9	48,5	0,2
139Ce	68,3	69,4	0,3
203Hg	108,1	106,8	0,3
84Sr	205,3	204,2	0,4
54Mn	336,3	334,8	0,5
65Zn	443,4	445,4	0,5
40K	570,5	573,9	0,6
60Co	871,9	873	0,7

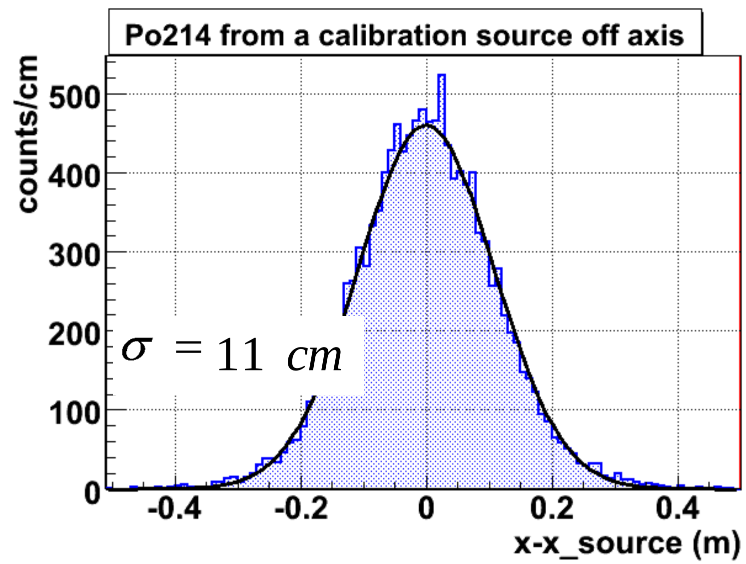
The position reconstruction

^{214}Po : α decay 0.8 MeV electron equivalent

Source in the center



Source in x=1.7 m y=0 m z=3m

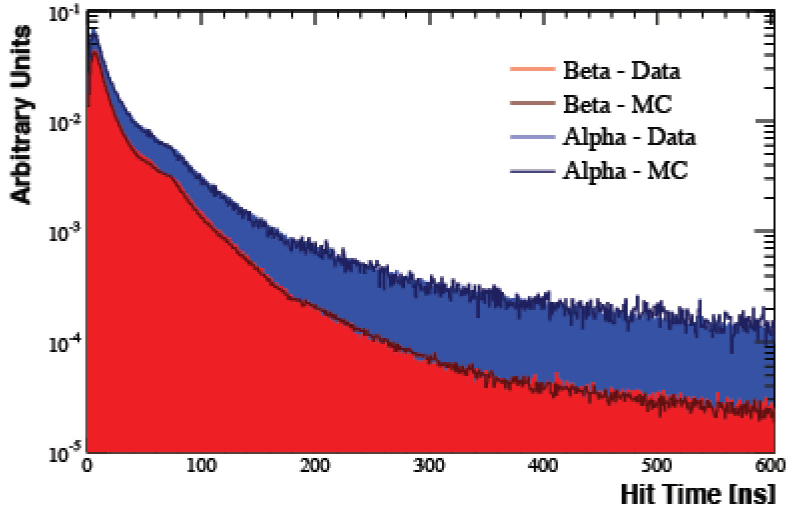


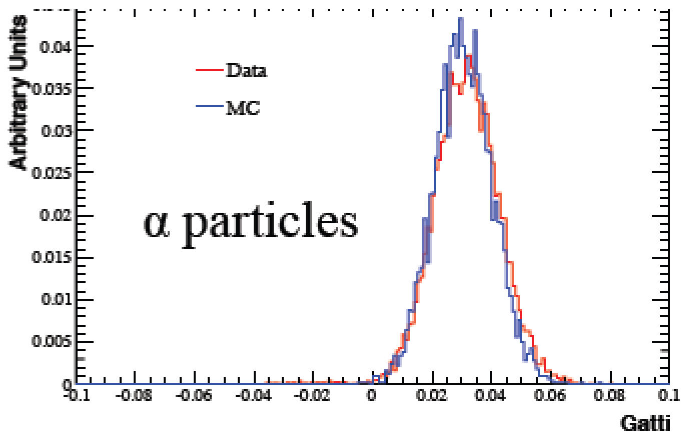
max difference between reconstructed and measured position= 3 cm !

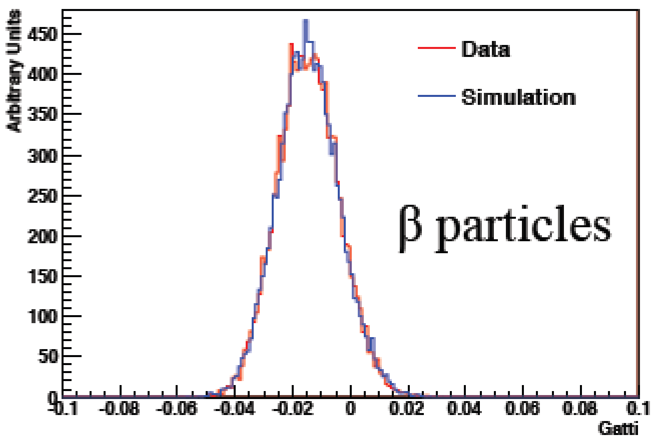
Spatial resolution : 12 cm @800 KeV
16 cm @500 KeV
35 cm @200 KeV

Fiducial volume known with +- 1.9 % accuracy compare with previous 6% !!!!

α β discrimination and MC reproduction







The expected accuracy of the ^{7}Be measurement: preliminary considerations

Stat. error : 1.5 cpd/100 (about 780 days of live time) : 3 %
Fiducial Volume : : 1.9 %
Work is in progress to control the additional systematic effects (event selection, fit model, accuracy of the energy scale…)
and reach a final global accuracy of 5% (or better??)

The day night asymmetry of ^{7}Be solar neutrinos

$$ADN = \frac{N - D}{(N + D)/2}$$

N = νe flux during night time (average over 1 year)
D = νe flux during day time (average over 1 year)

- MSW mechanism: ν interaction in the Earth could lead to a ν_e regeneration effect
- Solar ν_e flux higher in the night than in the day
- The size of the effect depends on the detector latitude, the oscillation parameter values and the energy of the neutrinos;

• Actual LMA solution : a very small effect is effect is expected

• A large ADN was expected if the LOW solution was allowed (in 2002, after the first SNO results and before the Kamland results)

•LMA and LOW predictions: large difference for the ADN effect and and small difference for the 7Be flux

•LOW is now already excluded but Borexino alone could exclude a large portion of the LOW space parameters if the ADN for 7Be is very small (independent confirmation of the results)

Observable	LMA	LOW
^{7}Be	0.64±0.07	0.58±0.05
ADN	~0%	23±11%

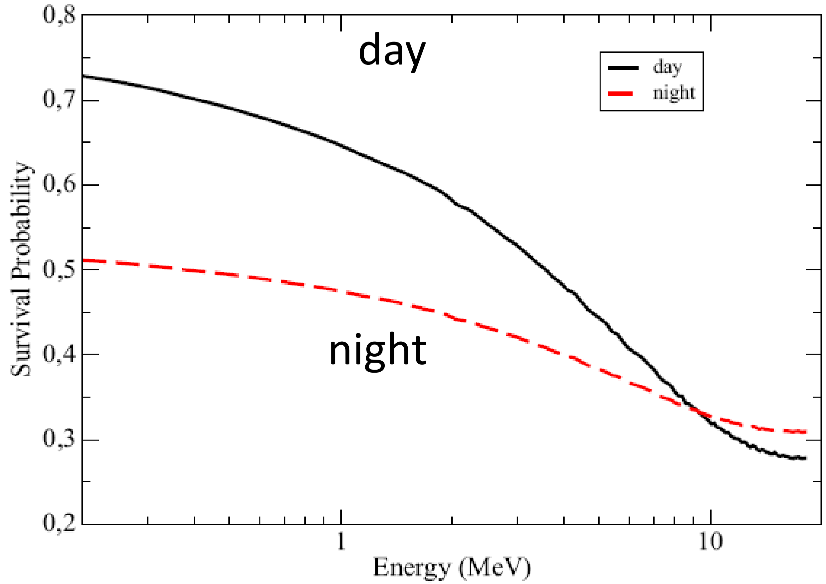
→ $\Delta m^2 \approx 10^{-7}\ eV^2$

J. Bahcall JHEP07(2002)054

The day night asymmetry of the ^{7}Be solar neutrinos: not standard oscillation scenario

Mass Varying Models

P.C. de Holanda JCAP07 (2009) 024

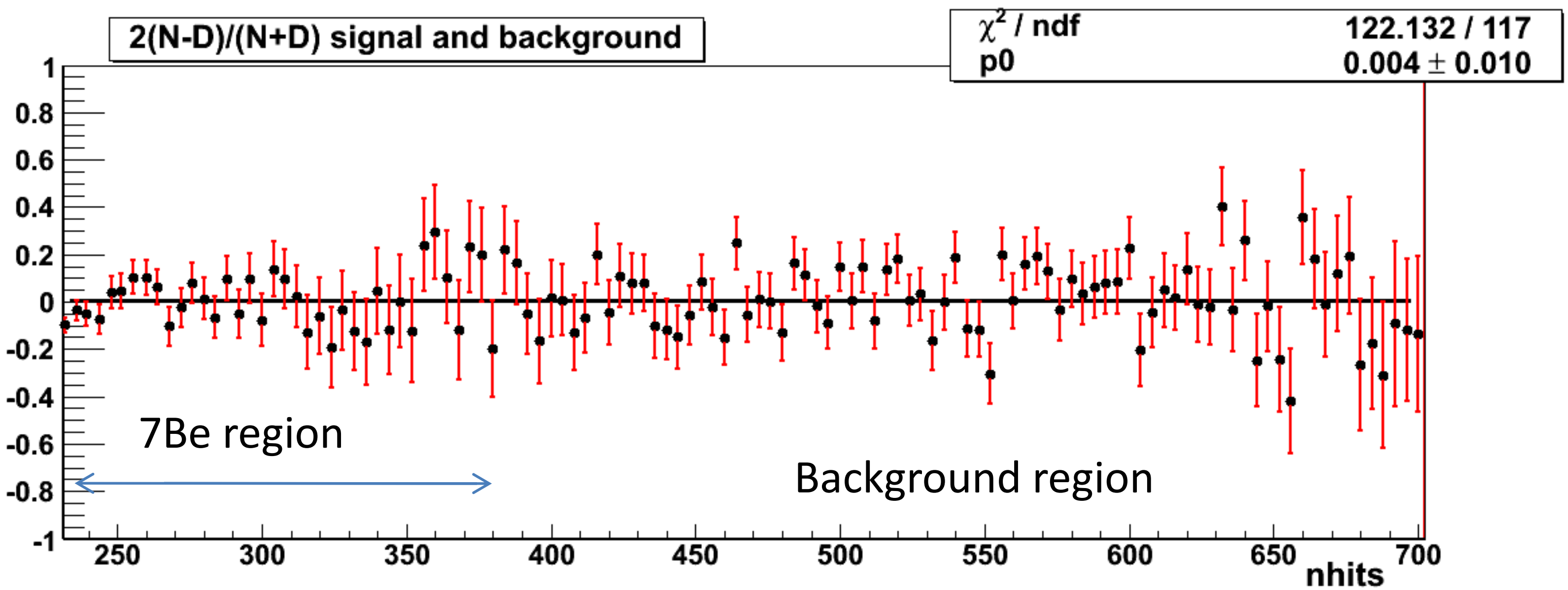


Expected effect in Borexino (including the $\nu_{\mu,\tau}$ detection)

$$ADN = \frac{N - D}{(N + D)/2} = -0.23$$

The day night asymmetry of the ^{7}Be solar neutrinos: a preliminary result

^{7}Be Day spectrum 387.46 days
^{7}Be Night spectrum 401.57 days



The day night preliminary result

^{7}Be Day spectrum 387.46 days
^{7}Be Night spectrum 401.57 days
Statistical error 2.3 c/d100t

The ^{7}Be flux is obtained from the separeted full fit of the day and night spectra

$$ADN = \frac{N - D}{(N + D)/2} = 0.007 +- 0.073 \ (stat)$$

G. Testera Neutrino Telescopes Feb 2009 (Venice)

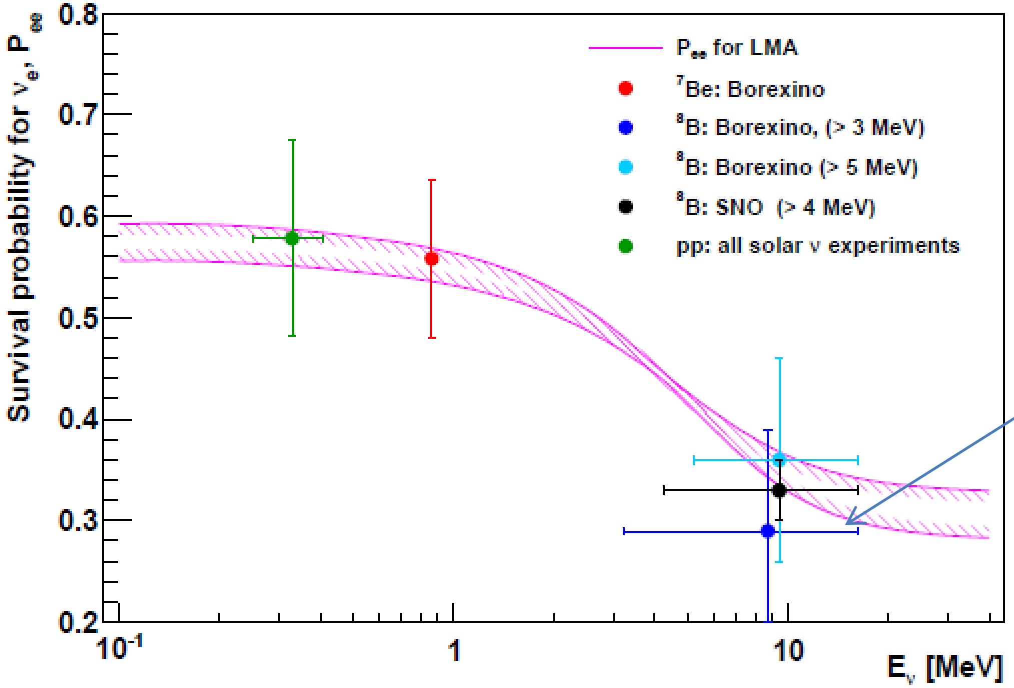
$$ADN = \frac{N - D}{(N + D)/2} = 0.02 +- 0.09$$

Preliminary (and conservative) result:

- The MaVaN prediction is disfavoured within 3 sigma
- ADN is well consistent with zero: further confirmation of the LMA!
- Unique measurement for solar ^{7}Be neutrinos
- More refined analysis is in progress aiming to significantly reduce the error
- Result not sensitive to many systematics effect influencing the ^{7}Be absolute measurement

^8B ν with 3 MeV energy threshold in Borexino

Important to probe the oscillation scenario



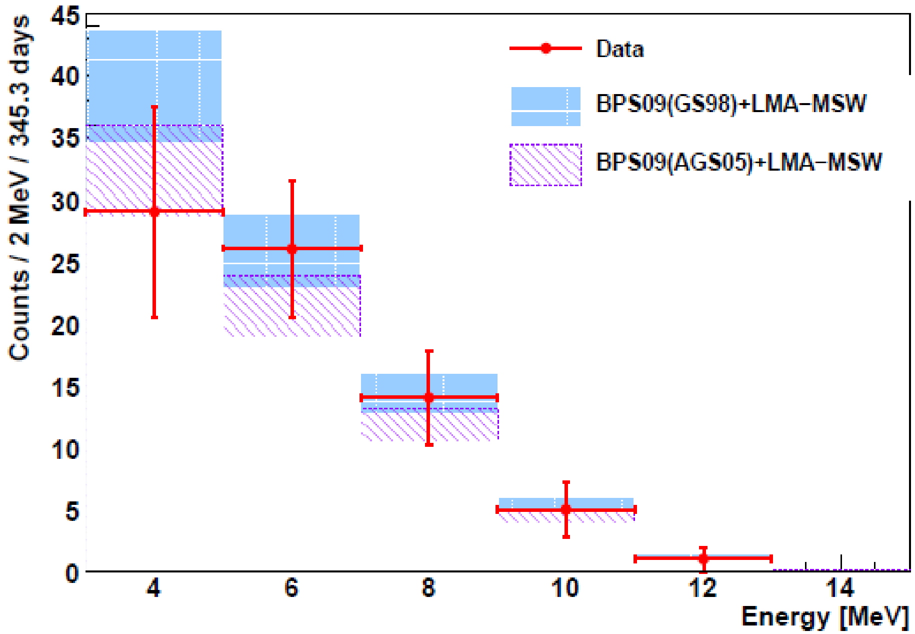
Borexino data

P_{ee} for ^8B neutrinos in Borexino

Borexino Coll. Phys. Rev. D, 82 (2010) 033006

^{8}B ν with 3 MeV energy threshold in Borexino

8 B solar neutrinos: electron recoil spectrum after the background subtraction and comparison with the models



High metallicity

Low metallicity

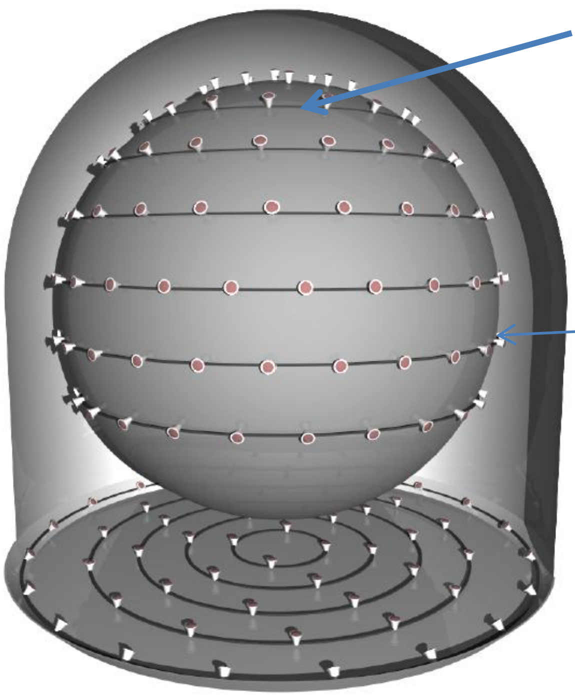
488 days live time
345 days after the cuts

	3.0–16.3 MeV	5.0–16.3 MeV
Rate [cpd/100 t]	0.22±0.04±0.01	0.13±0.02±0.01
Φ^{ES}_{exp} [10^6 cm^{-2}s^{-1}]	2.4±0.4±0.1	2.7±0.4±0.2
$\Phi^{ES}_{exp}/\Phi^{ES}_{th}$	0.88±0.19	1.08±0.23

^{8}B ν with 3 MeV energy threshold in Borexino : identification of the signal

Cut	Counts 3.0–16.3 MeV	Counts 5.0–16.3 MeV
All counts	1932181	1824858
Muon and neutron cuts	6552	2679
FV cut	1329	970
Cosmogenic cut	131	55
^{10}C removal	128	55
^{214}Bi removal	119	55
^{208}Tl subtraction	90±13	55±7
^{11}Be subtraction	79±13	47±8
Residual subtraction	75±13	46±8
Final sample	75±13	46±8
BPS09(GS98) ^{8}B ν	86±10	43±6
BPS09(AGS05) ^{8}B ν	73±7	36±4

High efficiency muon identification in Borexino

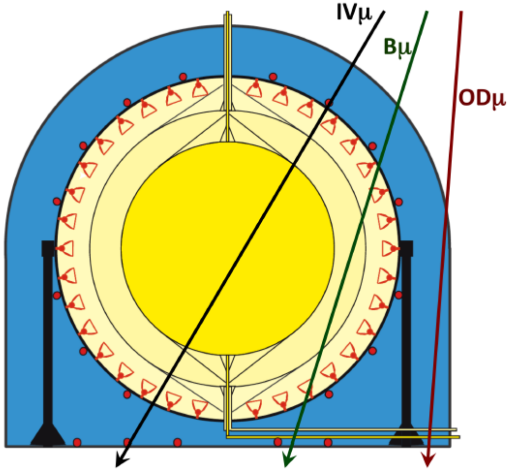


Inside the Stainless Steel sphere there are the nylon vessel and the scintillator seen by 2200 PMts

Borexino Stainless Steel sphere and the muon detector for the Cerenkov light in the water
208 Pmts + tyvek reflector on the external tank wall

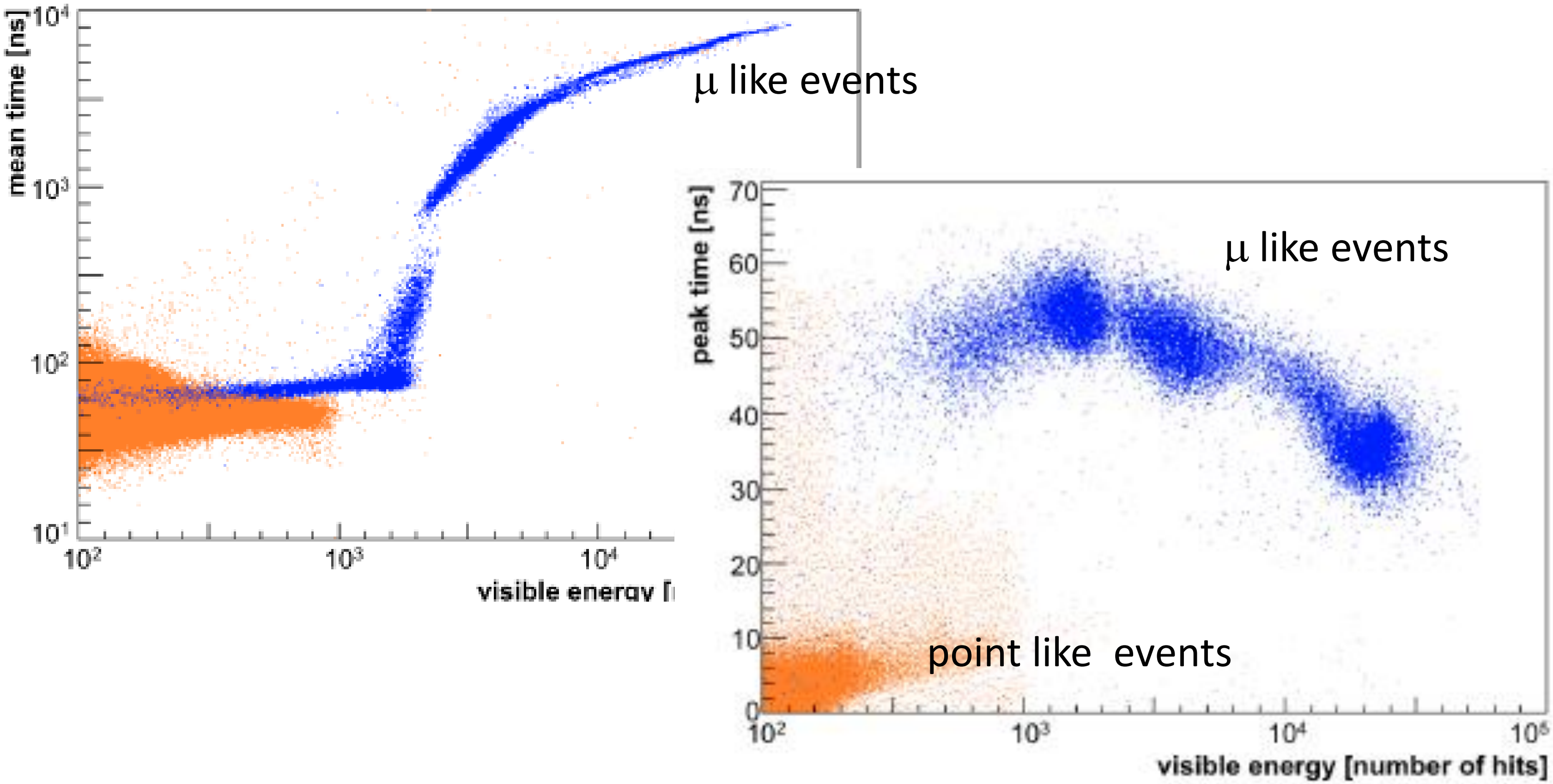
About 4300 μ/days cross the inner detector

Muons have to be removed from the data
Events following muons (cosmogenics, afterpulses)



About 4300 μ/days cross the inner detector
pep : 2.7 cpd/100 t (all recoil spectrum)
CNO ? : 5 cpd/100 t
^{8}B (E>3 MeV) 0.25 cpd/100 t

High efficiency μ identification in Borexino



Muons tagged by a combination of signals from the outer detector and pulse shape discrimination based on the inner detector data:

Residual muon rate : $(4.5\pm0.9)\times10^{-4}$ muons/day/100 t E> 3 MeV

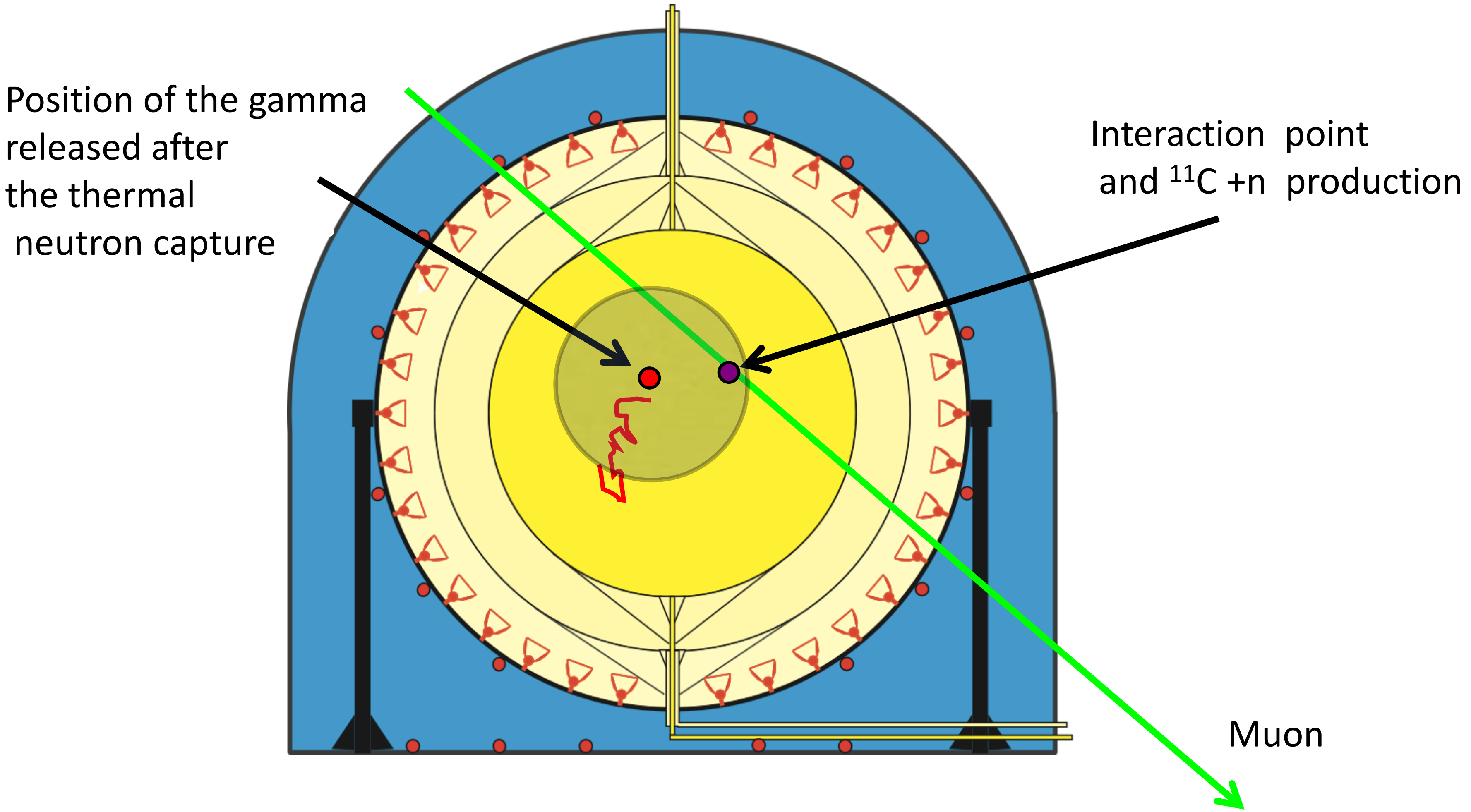
Toward a possible pep and CNO measurement?

^{11}C is one of the most important background: lifetime 29.4 minutes

^{11}C is produced by muons interaction in in the scintillator
Scintillator purification cannot help
95% of ^{11}C is produced with a neutron

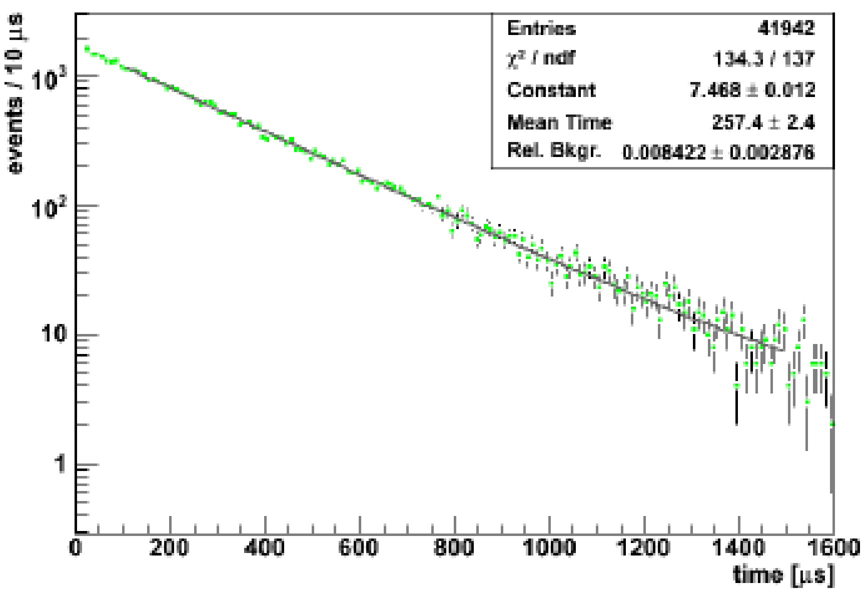
E_μ (GeV)	100	190	285	320	350
Interaction	Rate ($10^{-4}/\mu/m$)				
$^{12}C(p,p+n)^{11}C$	1.8	3.2	4.9	5.6	5.7
$^{12}C(p,d)^{11}C$	0.2	0.4	0.5	0.6	0.6
$^{12}C(\gamma,n)^{11}C$	19.8	27.0	34.1	46.6	38.4
$^{12}C(n,2n)^{11}C$	1.4	2.6	3.8	4.4	4.6
$^{12}C(\pi^+,\pi+N)^{11}C$	1.0	1.8	2.8	3.2	3.3
$^{12}C(\pi^-,\pi^-+n)^{11}C$	1.3	2.3	3.6	4.1	4.2
Invisible	0.9	1.6	2.4	2.7	2.9
Total	25.4	37.3	49.7	54.4	57
Measured	22.9±1.8	36.0±2.3			

Tagging of ^{11}C:
the Three-Fold Coincidence



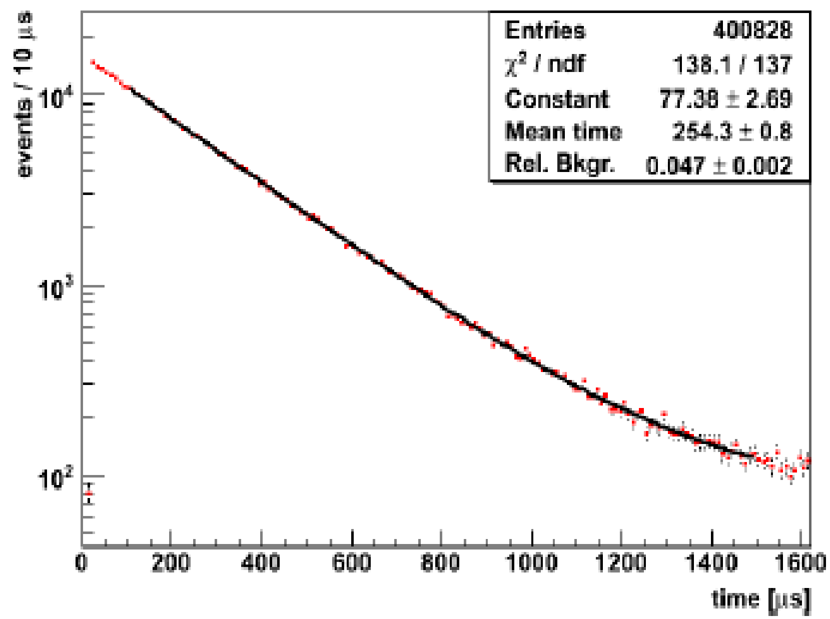
μ track+ gamma from neutron capture detection+ space and time cut

n detection



Cosmogenic neutrons

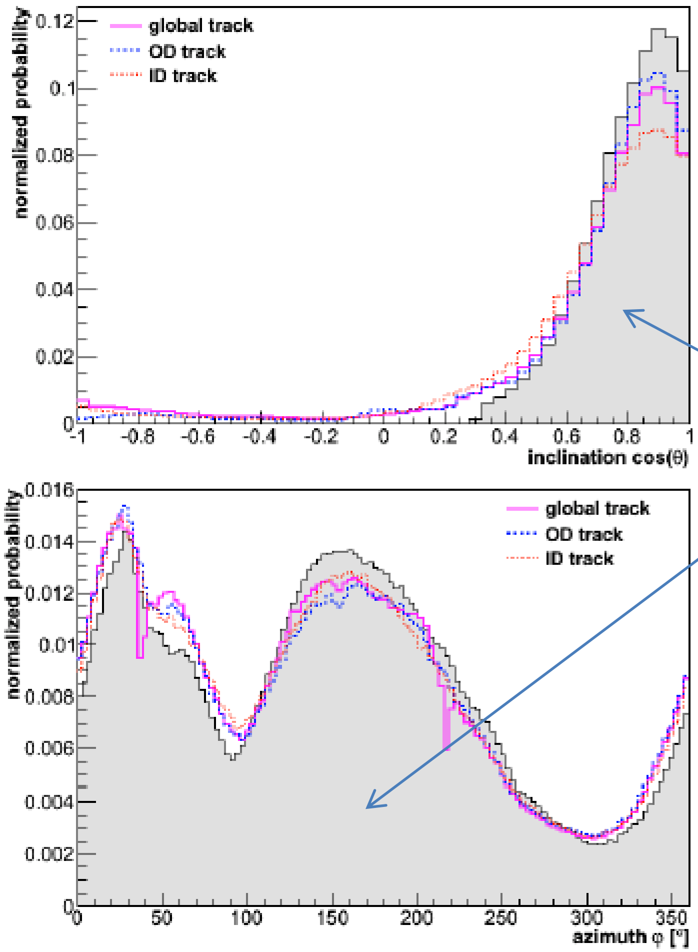
τ= 257.4 +-2.4 microsec



Am-Be calibration

τ= 254.3 +-0.8 microsec

Muon tracking in Borexino: about 10^0 accuracy



The distribution of the directions
of the muons measured by Borexino
(colored plots)
reproduce the one measured by MACRO

Shaded area:
Muon direction measured by the MACRO
High tracking accuracy

Conclusions

•Borexino already measured the flux of the 7Be solar neutrino line (real time)

•A more precise result will be released soon (thanks to the calibration campaign)

•^{8}B with 3 MeV threshold have been measured

•The Day Nigh asymmetry for the 7Be is under study: a result with reduced errors will be released soon

•The purification of the scintillator is in progress

•Work is in progress to measure pep, CNO and pp

NOT ONLY solar neutrinos!!: geoenutrinos and search for rare processes
see next days