Precision Measurement of the Solar Neutrino Flux with the Borexino Detector

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Rencontres de Blois, 2011

Borexino

Location

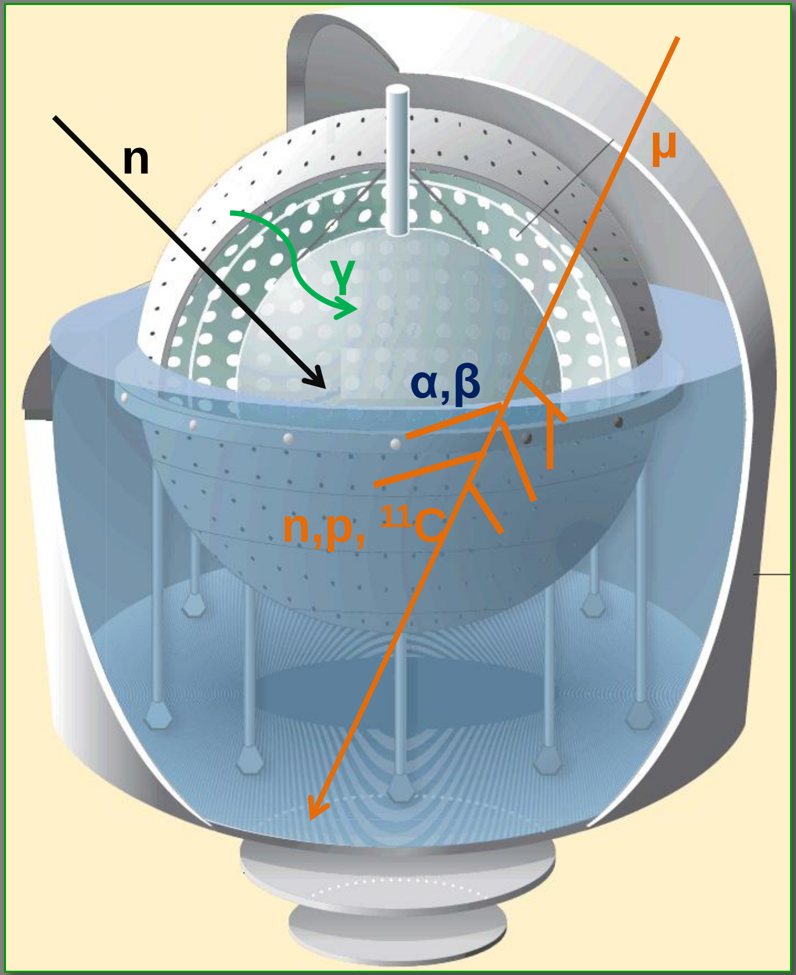
Laboratori Nazionali del Gran Sasso

Borexino detector is located in the Apennine mountains, with an access through one of the longest underground tunnels in the world.

Over a kilometer of limestone rock provide pristine muon shielding for the data

Borexino

Principles of graded shielding

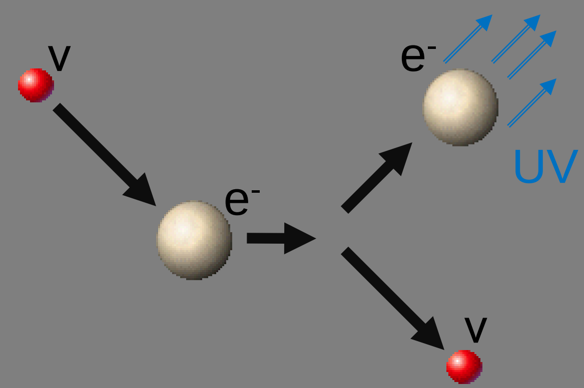


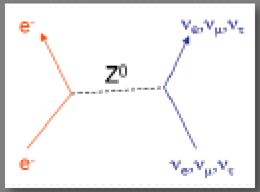
- 1400m of rock (μ)
- Cherenkov water detector
- Inner PMTs (Rn emanation)
- Quenched scintillator
- Active scintillator
- Fiducial mass (γ)
- Fast neutrons

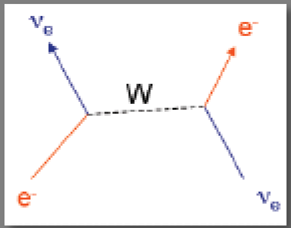
Radio-purity

Requirements

Interaction







Scintillation

- ν-e scattering effect
- Indistinguishable from β/γ backgrounds
- No directional signal

Critical to achieve lowest background levels

Contamination	Required	Achieved	Technique
$^{14}C/^{12}C$	$<5\cdot10^{-18}$	$2.7\cdot10^{-18}$	Crude oil / underground src
^{238}U	$<10^{-16}$ g/g	$1.6\cdot10^{-17}$ g/g	Water extraction / Distillation
^{232}Th	$<10^{-16}$ g/g	$6.8\cdot10^{-18}$ g/g	Water extraction / Distillation
^{222}Rn	<1 mBq/t	<1 mBq/t	Materials low in ^{226}Ra
^{210}Po	<1 mBq/t	initially ~1 mBq/t	Distillation, Decay(t_H=138 d)
^{85}Kr	<0.1 mBq/t	~3 mBq/t	LAKN sparging

Solar neutrinos

Borexino's major goal: the ^{7}Be monochromatic line

Total flux of ~ 6.5 x 10^{10} /cm^2/sec

$$p + p \rightarrow {}^{2}H + e^{+} + \upsilon_e$$

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

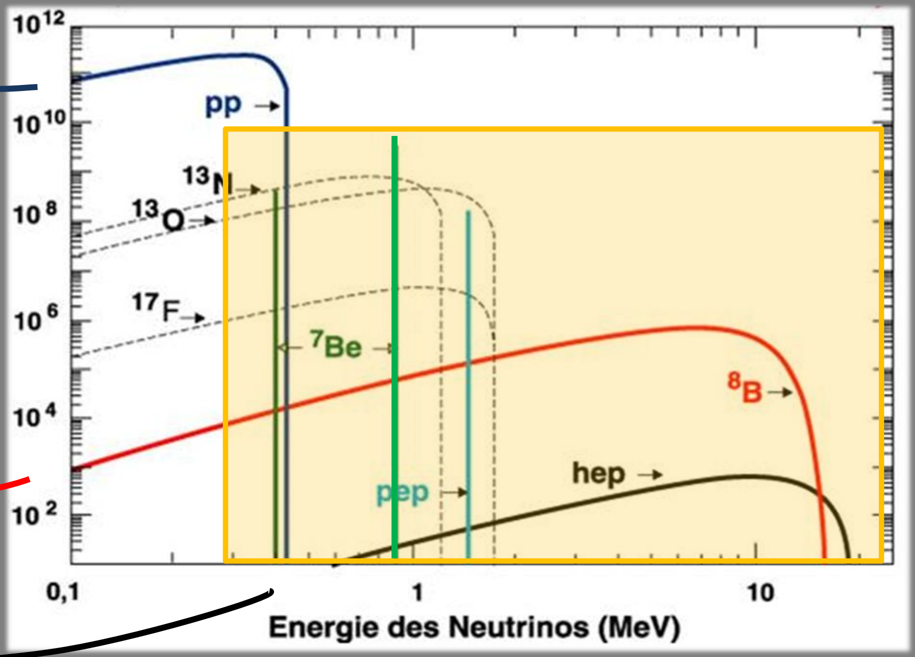
$$^{3}He + {}^{4}He \rightarrow {}^{7}Be + \gamma$$

$$^{7}Be + e^{-} \rightarrow {}^{7}Li + \gamma + \upsilon_e$$

$$^{7}Be + p \rightarrow {}^{8}B + \gamma$$

$$^{8}B \rightarrow 2\gamma + e^{+} + \upsilon_e$$

$$^{3}He + p \rightarrow {}^{4}He + e^{+} + \upsilon_e$$



Phase II also aims for measurement of the CNO lines

Solar neutrinos

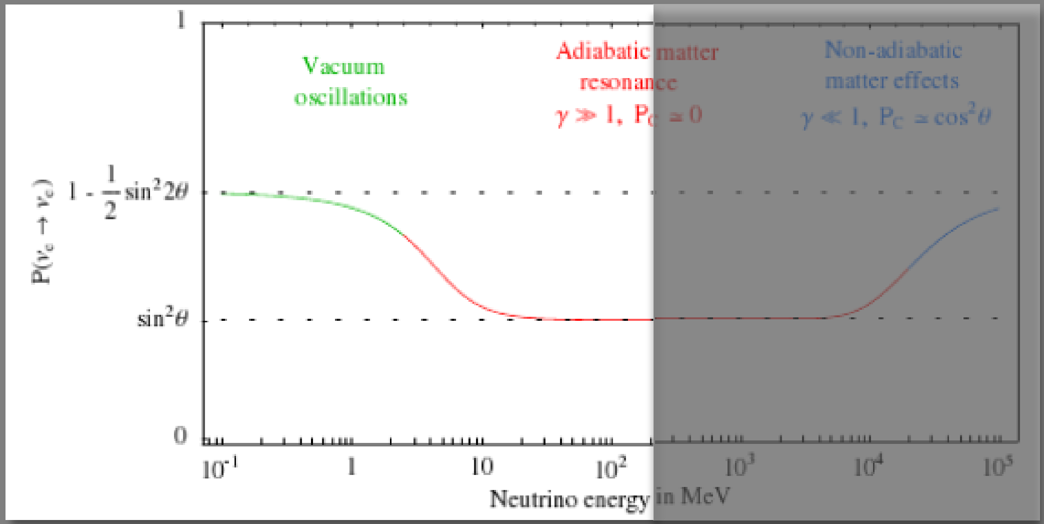
Beyond The Standard Model: neutrino oscillations

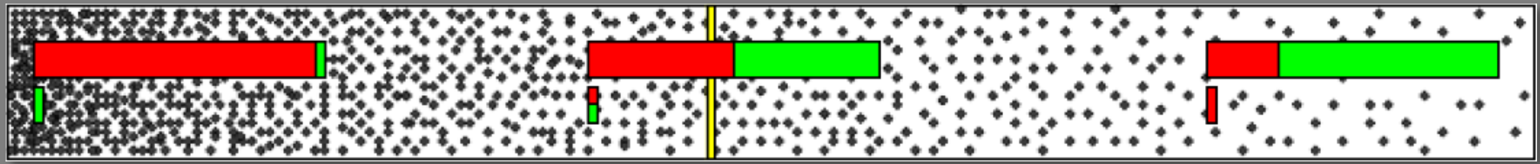
- Resonance

$$\cos(2\theta_V) = \frac{2\sqrt{2}G_F n_e E}{\Delta m^2}$$

- E_ν = *1.86 MeV*

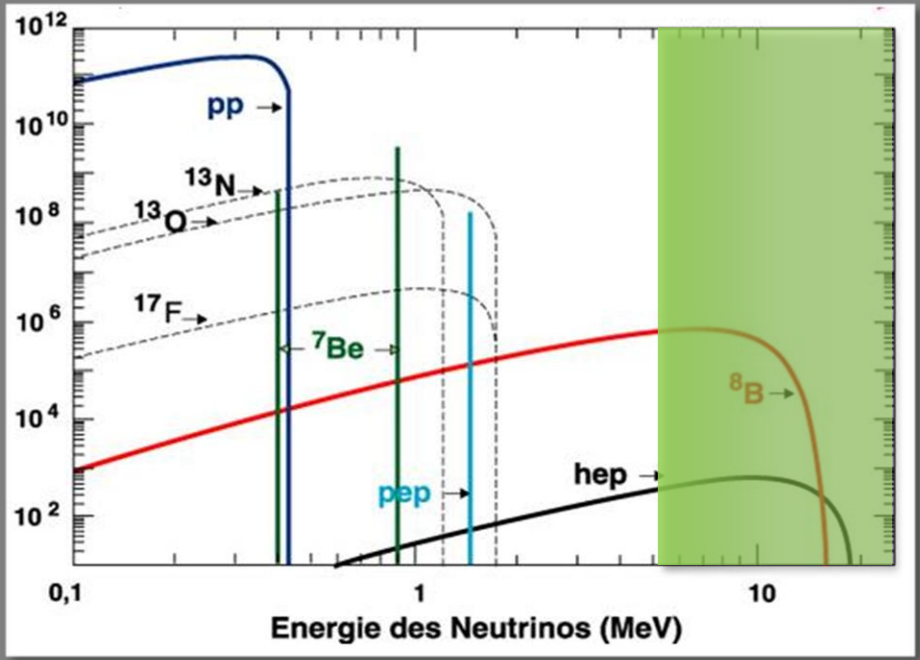
- Adiabatic effect:

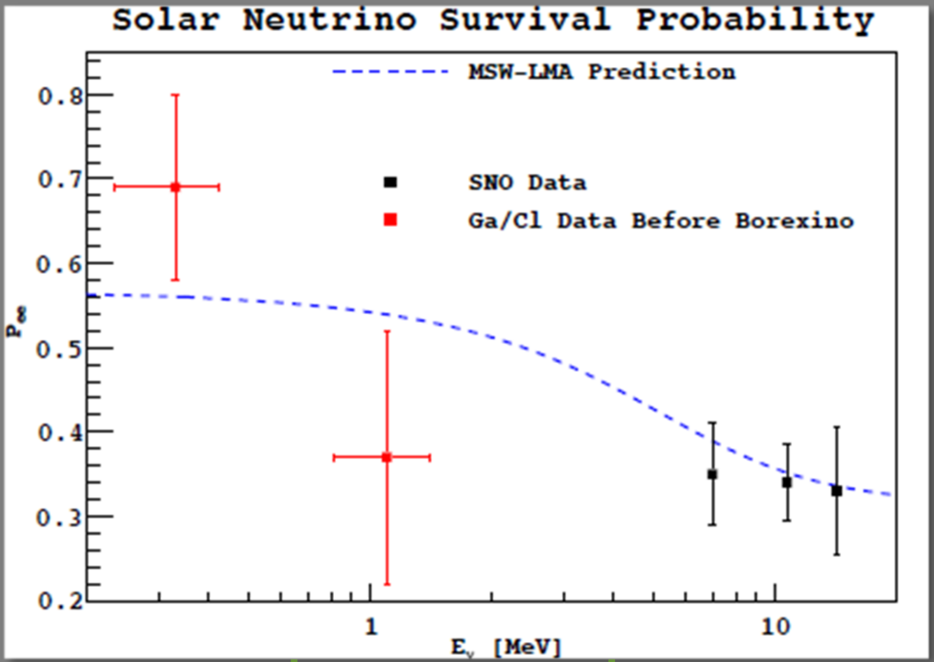




Before Borexino

Potential for new physics in the low energy oscillation transition region



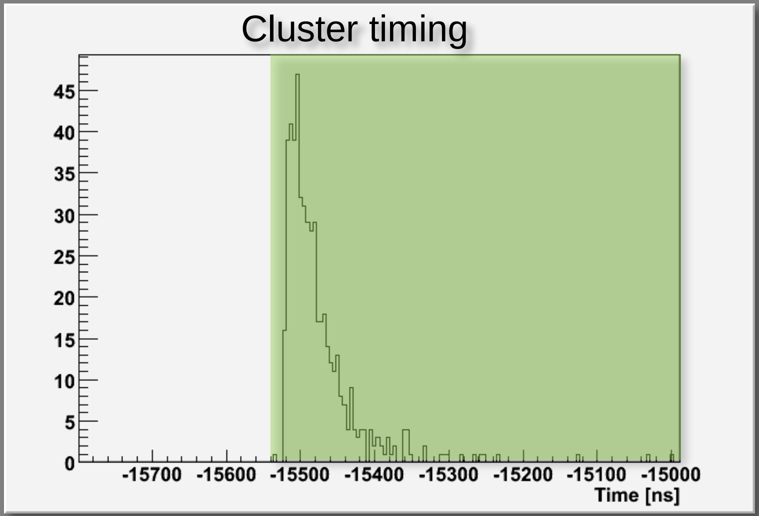


- Low region only from radiochemistry
- Real-time measurement above 5MeV

- Matter enhanced,
- and transition regions

Signal

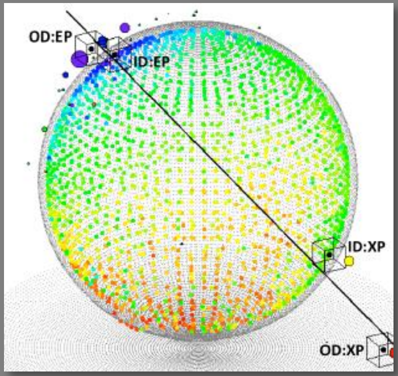
• PMTs receive scintillation light from scattered electrons and γ particles
• DAQ triggers when 25 PMTs receive signal within 60ns



PMT time-of-flight distribution used for position reconstruction

Number of hits, or charge used for energy determination

Resolution at 1 MeV:
5% [energy]; ~10-15cm [position]

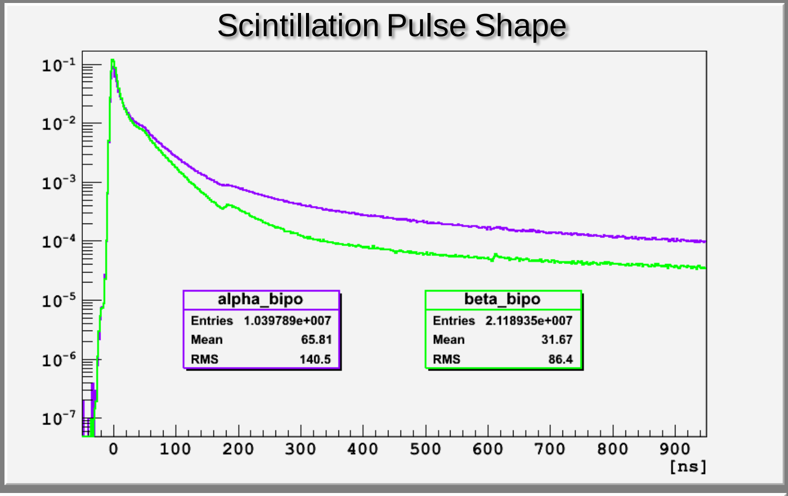


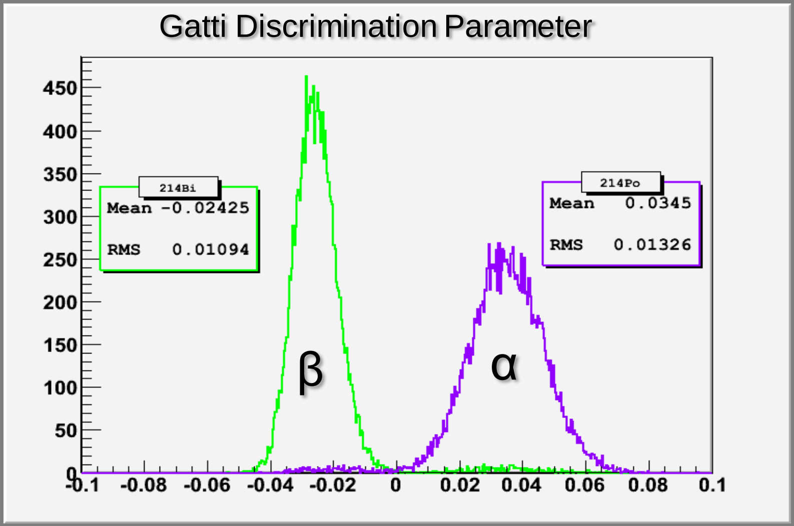
• Muons rejected by Outer Detector PMTs and Pulse Shape Analysis

Efficiency > 99.992%

Signal Shape

α/β discrimination method based on the Gatti parameter





Known time profiles of the two species are used as reference in determination of The Gatti parameter, defined as:

$$G = \sum_i \left(\frac{\alpha_i - \beta_i}{\alpha_i + \beta_i} \right) \cdot f_i$$

α,β - bin contents
f - spectral emission content

In the analytical approach it is applied as:

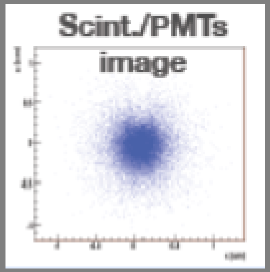
- Soft cut
  α-like correction
- Statistical subtraction
  complete α-removal

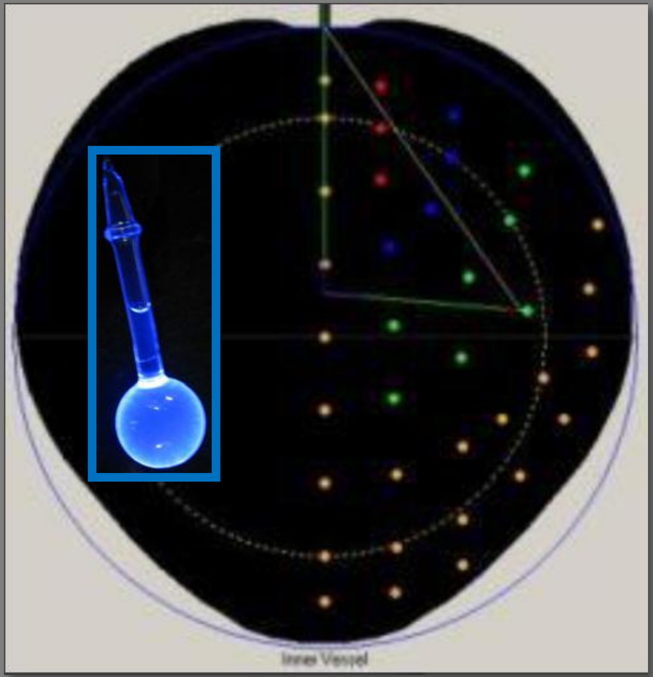
Calibration

- Understanding detector's response: position, energy, α/β discrimination
- Study Trigger Efficiency and PMT timing alignment
- Determine Fiducial Volume

Above all, preserve **radio-purity**

Source location based on CCD cameras

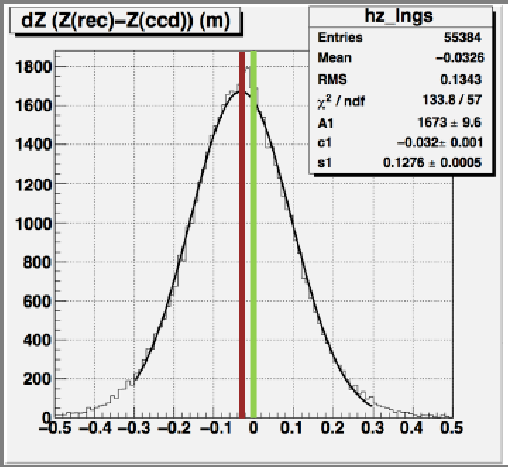


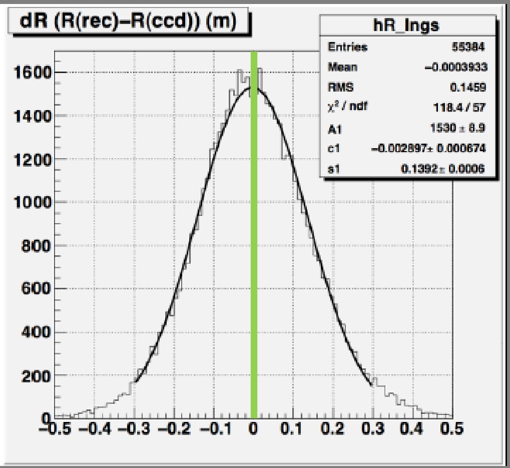


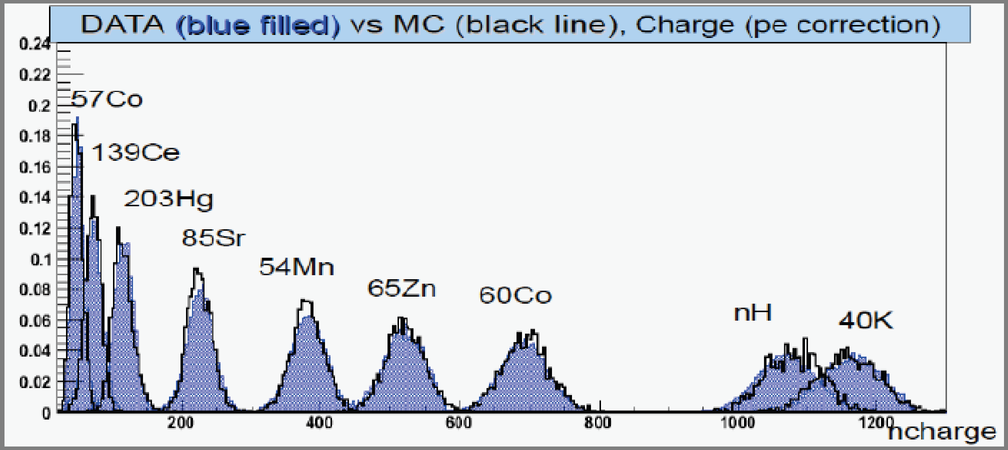
Type	γ								β		α	n		
Src.	^{57}Co	^{139}Ce	^{203}Hg	^{85}Sr	^{54}Mn	^{65}Zn	^{60}Co	^{40}K	^{14}C	^{214}Bi	^{214}Po	n-p	n-^{12}C	n-Fe
MeV	0.122	0.165	0.279	0.514	0.834	1.1	1.1, 1.3	1.4	0.15	3.2	7.69 (0.84)	2.23	4.94	~7.5

Calibration

Position and Energy Scale tuning





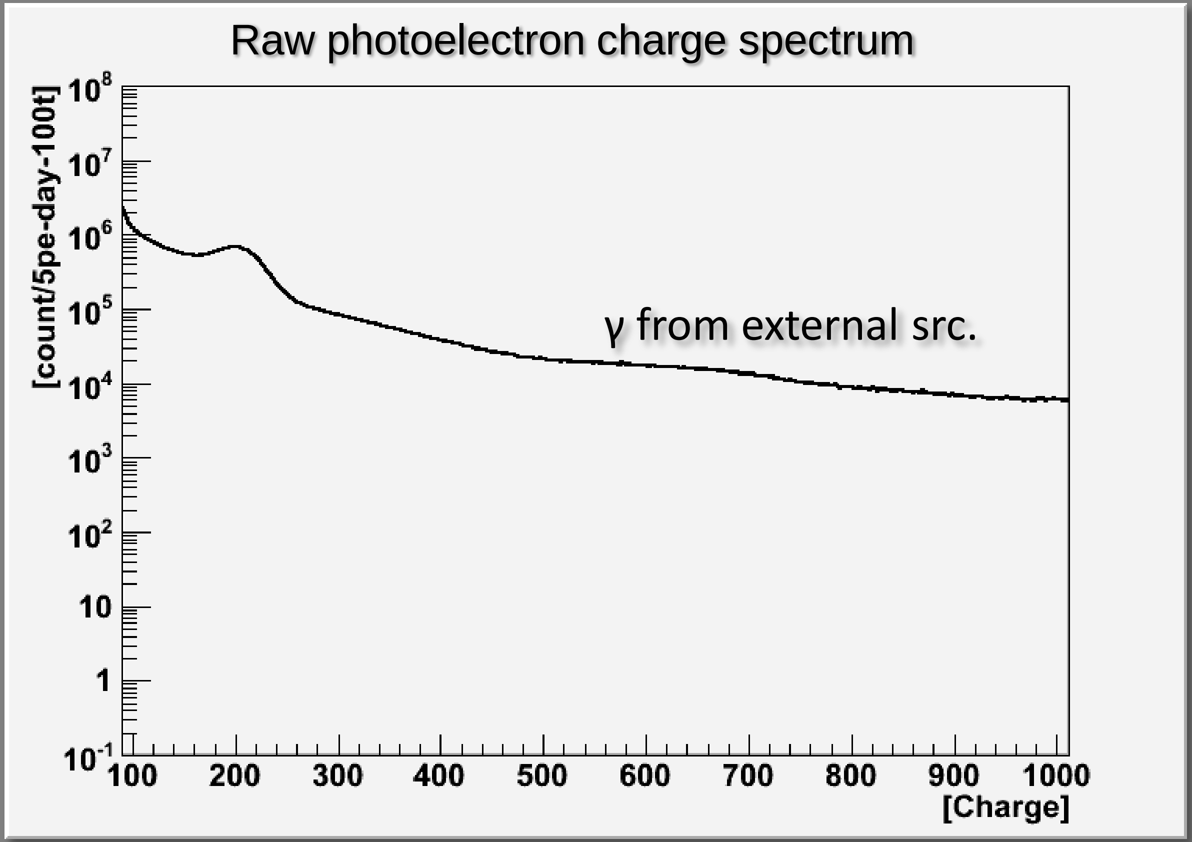


Improvements in precision:

Systematics		
Livetime	0.1%	0.04%
Scintillator ρ	0.2%	0.05%
Event Selection Loss	0.3%	0.1%
Position Reconstruction	6.0%	+1.3%/ -0.5%
Energy Scale	6.0%	2.7%
TOTAL	8.5%	+3.6%/ -3.4%

Spectrum

Selection of events



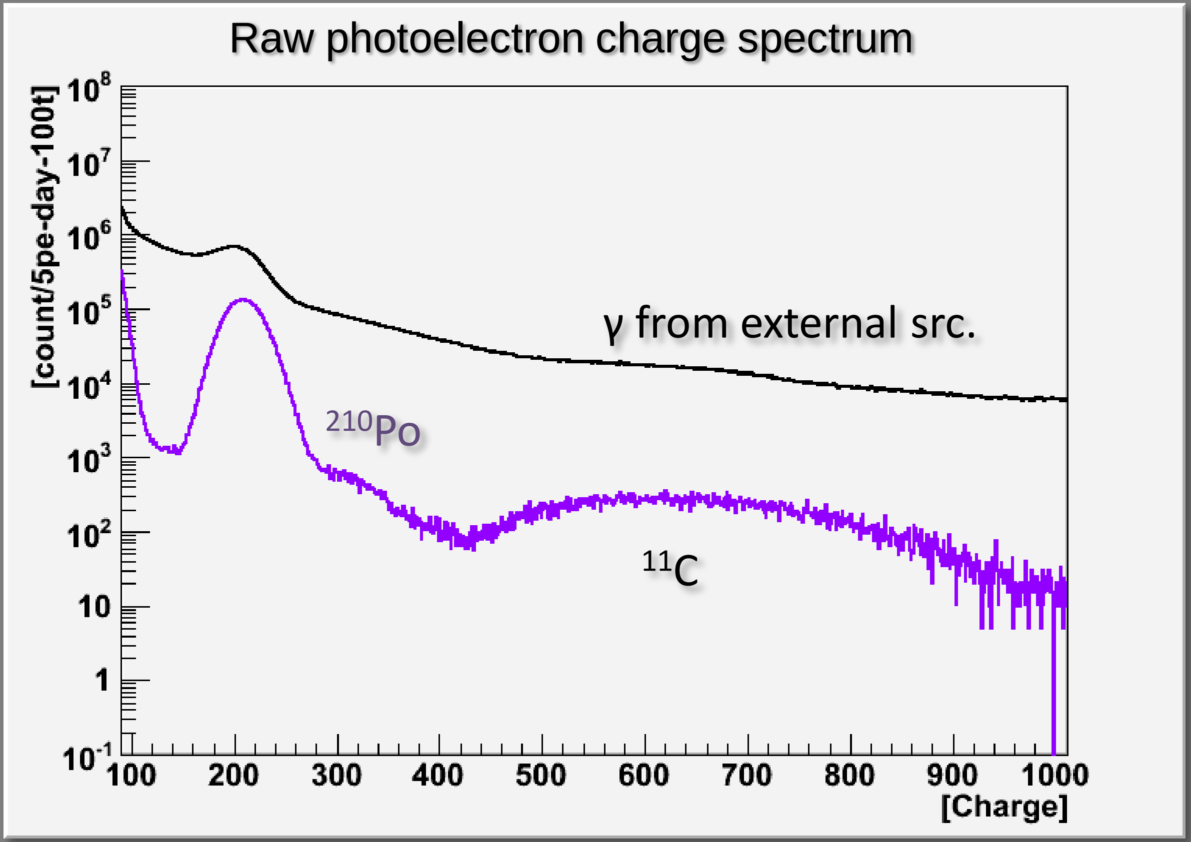
- Major cuts :

    1) Muons, and fast cosmogenics,

       Electronics noise

Spectrum

Selection of events



- Major cuts :

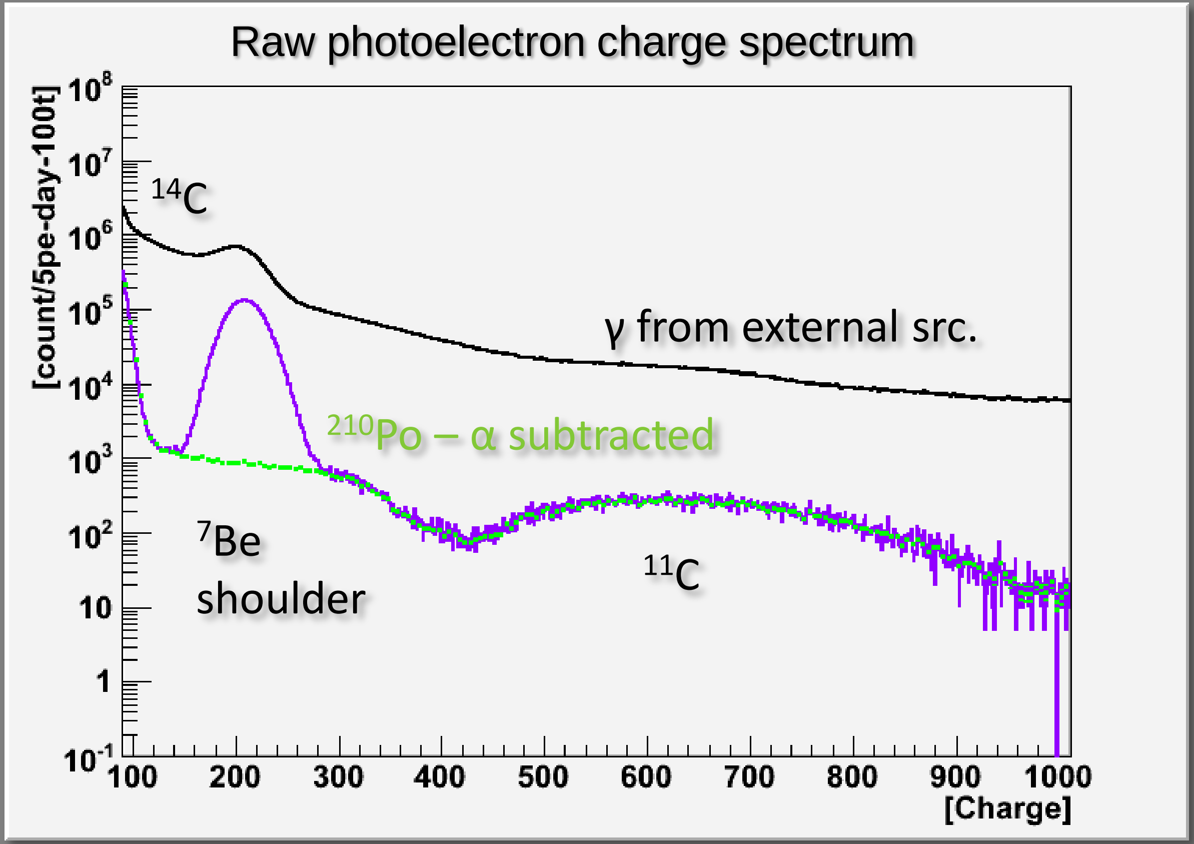
1) Muons, and fast cosmogenics,

   Electronics noise

2) Fodicial Volume
   1/3 active mass

Spectrum

Selection of events



- Major cuts :

1) Muons, and fast cosmogenics,

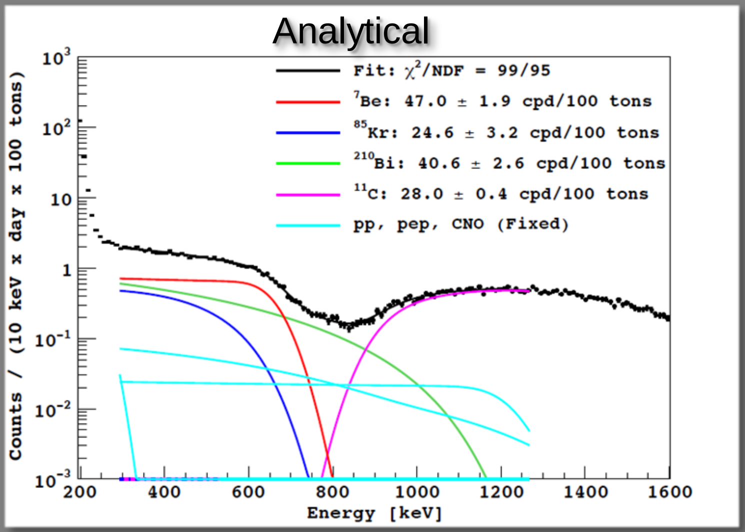
   Electronics noise

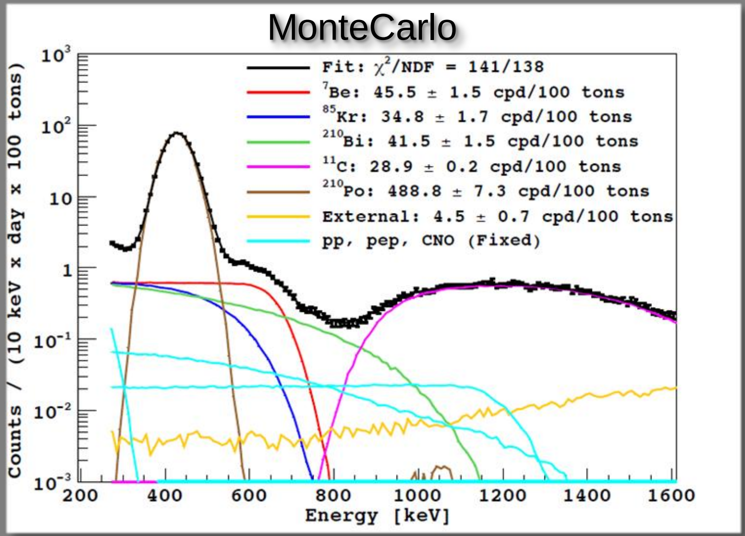
2) Fodicial Volume 1/3 active mass

3) α- subtraction (Gatti parameter)

Total of 15 fine cuts remove noise and background events.

^{7}Be Results





Consistent

MonteCarlo and Analytical Fits

Measured Rate:

^{7}Be: 46.0 $\pm 1.5_{stat}{}^{+1.6}_{-1.5\,sys}$ cpd/100t

SSM w/ no oscillations, HMetallicity

$74 \pm 5_{theor}$

MSW-LMA Prediction

47.2 ± 3.4

MSW-LMA scenario:

$\Phi(^{7}Be) = (4.87 \pm 0.24) \times 10^{9}$ /cm^2/sec

$f_{Be} = 0.97 \pm 0.05_{stat} \pm 0.07_{syst}$

Day-Night Asymmetry

Neutrinos on their way from the Sun can undergo additional flavor conversion when traversing Earth's matter at night.
Such daily asymmetry in count rate
is defined as

LOW

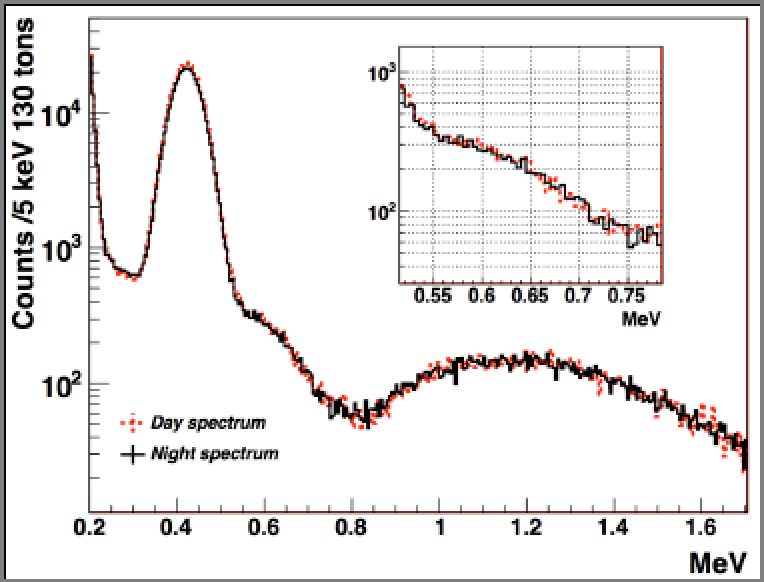
11% - 80% =

$$A_{dn} = 2 \times \frac{R_N - R_D}{R_N + R_D}$$

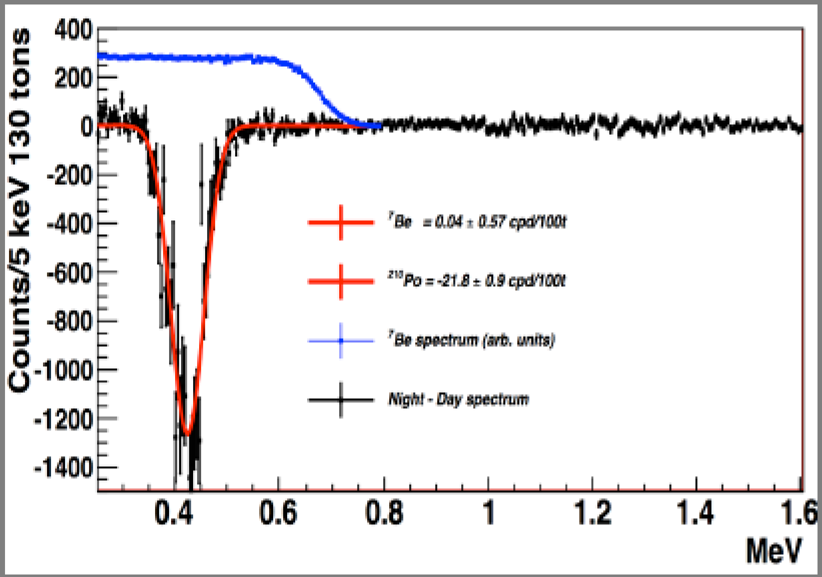
LMA

= < 0.1%

$A_{nd} = 0.007 \pm 0.073_{stat}$



$A_{nd} = 0.001 \pm 0.012_{stat} \pm 0.007_{sys}$



Day-Night Asymmetry

Neutrinos on their way from the Sun can undergo additional flavor conversion when traversing Earth's matter at night.
Such daily asymmetry in count rate is defined as

LOW

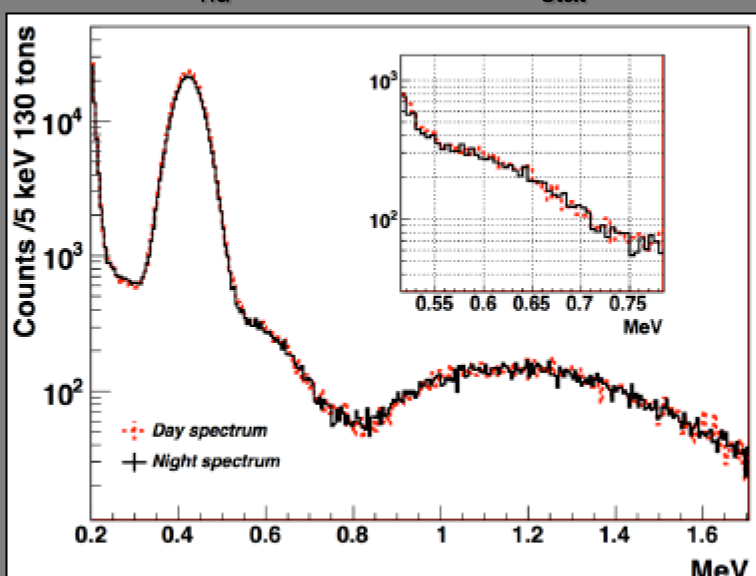
11% - 80% = REJECTED

$$A_{dn} = 2 \times \frac{R_N - R_D}{R_N + R_D}$$

LMA

= < 0.1%

$A_{nd} = 0.007 \pm 0.073_{stat}$



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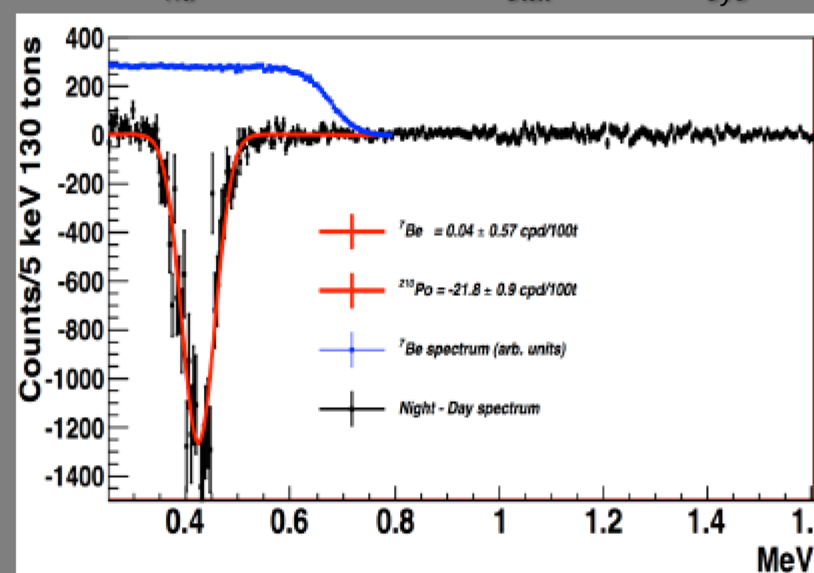
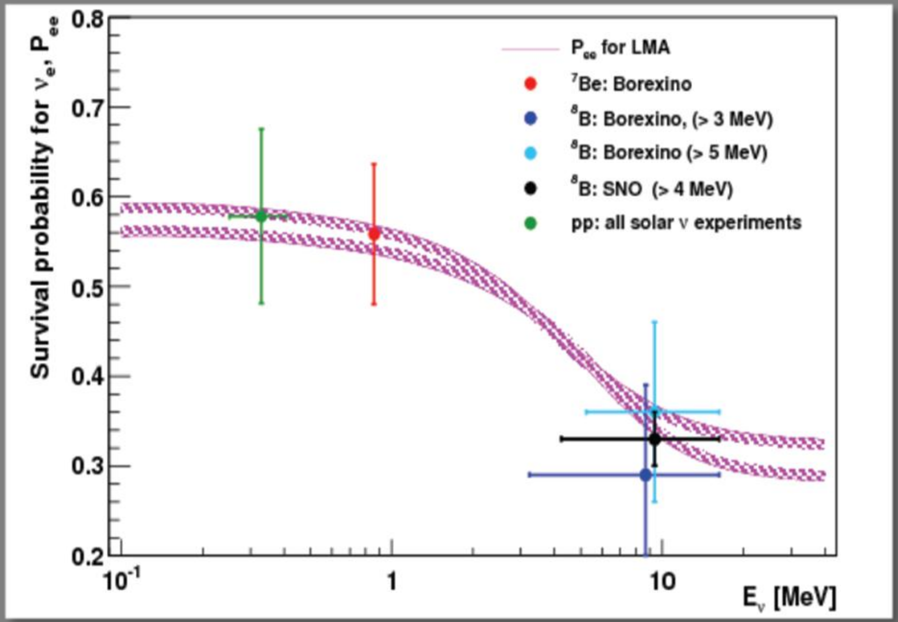
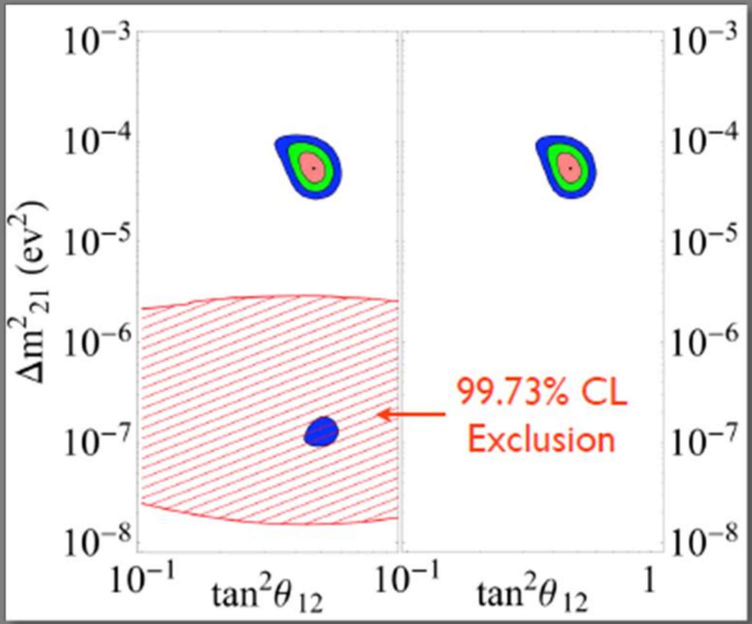


Impact of Recent Results

LOW solution to the solar deficit rejected at 8.5σ c.l.
Hypothesis of no oscillations for 7Be rejected at 4.9 σ





Under MSW-LMA and High Metallicity

$$P_{ee}(^7Be) = 0.52^{+0.07}_{-0.06}$$

From the Global Fit

$$\Delta m^2 = 5.3\times 10^{-5} eV^2$$
$$\tan^2\theta_{12} = 0.46$$

Future

- Borexino is entering phase II; purification of the scintillator will hopefully result in lower concentrations of ^{85}Kr and ^{210}Bi and open new perspectives for the CNO and pep flux measurements

- Further improvements in lowering the systematics will hopefully allow us to reach the ultimate goal of 3% uncertainty

- Measurement of ^{8}B flux with a threshold at 2.2MeV requires meticulous understanding of external backgrounds- current Monte-Carlo simulations are very promising

- Borexino has also a possibility of studying oscillations at short distances, which unfortunatley requires sources of highest activities (~MCi ^{51}Cr, ^{37}Ar, or ^{90}Y)

- In the free time Borexino is also ready for Supernovae (with ~90% duty cycle)

The End

Astroparticle and Cosmology Laboratory – Paris, France

INFN Laboratori Nazionali del Gran Sasso – Assergi, Italy

INFN e Dipartimento di Fisica dell’Università – Genova, Italy

INFN e Dipartimento di Fisica dell’Università– Milano, Italy

INFN e Dipartimento di Chimica dell’Università – Perugia, Italy

Institute for Nuclear Research – Gatchina, Russia

Institute of Physics, Jagellonian University – Cracow, Poland

Joint Institute for Nuclear Research – Dubna, Russia

Kurchatov Institute – Moscow, Russia

Max-Planck Institute fuer Kernphysik – Heidelberg, Germany

Princeton University – Princeton, NJ, USA

Technische Universität – Muenchen, Germany

University of Massachusetts at Amherst, MA, USA

University of Moscow – Moscow, Russia

Virginia Tech – Blacksburg, VA, USA

References

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- G. Bellini et al. (Borexino Coll.), article in preparation with details
  about 7Be data analysis, day-night search and solar neutrino oscillations analysis.
- G. Bellini et al. (Borexino Collaboration), paper on calibrations
  (in preparation)
- (1969); J.N. Bahcall and R. Davis, Science 191, 264