Borexino Collaboration

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Milano

ICHEP 2012, Melbourne, 4-11 July 2012

Livia Ludhova (Borexino collaboration)
Neutrinos & Nuclear reactions in the Sun

**PP cycle… 99% of energy**

- $p + p \rightarrow ^2\text{H} + e^+ + \nu_e$ (99.77%)
- $p + ^2\text{H} \rightarrow ^3\text{He} + \gamma$ (84.7%)
- $^3\text{He} + ^3\text{He} \rightarrow ^4\text{He} + 2p$ (13.8%)
- $^7\text{Be} + e^- \rightarrow ^7\text{Li} + \nu_e$ (13.78%)
- $^7\text{Li} + p \rightarrow ^4\text{He} + ^4\text{He}$ (0.02%)

**CNO cycle… <1% of energy**

- $p + e^- + p \rightarrow ^2\text{H} + \nu_e$ (0.23%)
- $^3\text{He} + ^4\text{He} \rightarrow ^7\text{Be} + \gamma$ (2\times10^{-5}%)
- $^7\text{Be} + p \rightarrow ^8\text{Be} + e^+ + \nu_e$ (13.8%)
- $^8\text{Be} \rightarrow ^7\text{Be} + e^+ + \nu_e$ (0.02%)
- $^8\text{Be} \rightarrow ^4\text{He} + ^4\text{He}$ (0.23%)

**Poorly known**

- Not directly measured

Livia Ludhova (Borexino collaboration)
Solar-neutrino energy spectrum

Borexino energy threshold

previous real-time measurements
(SNO, SuperKamiokande)
Čerenkov radiation
< 1/10,000 of the total solar neutrino flux

Solar-neutrino energy spectrum

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Livia Ludhova (Borexino collaboration)
What can we learn from solar neutrinos (1)?

Astrophysics: resolving “metallicity problem”

New 3D Standard Solar Models -> lower metallicity -> discrepancy with helioseismology… where is the problem?

<table>
<thead>
<tr>
<th>Sources</th>
<th>(\Phi(\nu \text{ sec}^{-1} \text{ cm}^{-2})) high-metallicity</th>
<th>(\Phi(\nu \text{ sec}^{-1} \text{ cm}^{-2})) low-metallicity</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>pp</td>
<td>((5.98(1\pm0.006)\times10^{10}))</td>
<td>((6.03(1\pm0.006)\times10^{10}))</td>
<td>0.8%</td>
</tr>
<tr>
<td>pep</td>
<td>((1.44(1\pm0.012)\times10^{8}))</td>
<td>((1.47(1\pm0.012)\times10^{8}))</td>
<td>2.0%</td>
</tr>
<tr>
<td>hep</td>
<td>((8.04(1\pm0.300)\times10^{3}))</td>
<td>((8.31(1\pm0.300)\times10^{3}))</td>
<td>3.3%</td>
</tr>
<tr>
<td>(^7\text{Be})</td>
<td>((5.00(1\pm0.070)\times10^{9}))</td>
<td>((4.56(1\pm0.070)\times10^{9}))</td>
<td>9.4%</td>
</tr>
<tr>
<td>(^8\text{B})</td>
<td>((5.58(1\pm0.140)\times10^{6}))</td>
<td>((4.59(1\pm0.140)\times10^{6}))</td>
<td>19.8%</td>
</tr>
<tr>
<td>(^{13}\text{N})</td>
<td>((2.96(1\pm0.140)\times10^{8}))</td>
<td>((2.17(1\pm0.140)\times10^{8}))</td>
<td>31.6%</td>
</tr>
<tr>
<td>(^{15}\text{O})</td>
<td>((2.23(1\pm0.150)\times10^{8}))</td>
<td>((1.56(1\pm0.150)\times10^{8}))</td>
<td>33.5%</td>
</tr>
<tr>
<td>(^{17}\text{F})</td>
<td>((5.52(1\pm0.170)\times10^{6}))</td>
<td>((3.40(1\pm0.160)\times10^{6}))</td>
<td>53.0%</td>
</tr>
</tbody>
</table>

Solar neutrino fluxes depend on metallicity!

- High metallicity GS98 = Grevesse et al. S. Sci. Rev. 85,161 (‘98);
What can we learn from solar neutrinos (2) ?

Neutrino Physics: precision measurement of solar $\nu$ fluxes vs survival probability $P_{ee}$

$P_{ee} = \text{electron neutrino survival probability from the Sun's core to the detector}$

**Vacuum regime**

Low energy neutrinos: 
flavor change dominated by vacuum oscillations;

**Matter regime**

High energy neutrinos: 
Resonant oscillations in matter (MSW effect): 
Effective electron neutrino mass is increased due to the charge current interactions with electrons of the Sun

**Transition region:**
Decrease of the $\nu_e$ survival probability ($P_{ee}$)
What can we learn from solar neutrinos (2) ?

Neutrino Physics: precision measurement of solar $\nu$ fluxes vs survival probability $P_{ee}$

**Low energy neutrinos:**
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**Transition region:**
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Borexino experimental site

Borexino is located at the Laboratori Nazionali del Gran Sasso, near L’Aquila, cca.120 km from Rome in Italy, shielded by 1400 m of limestone rocks (3800 m water equivalent)

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

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

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

**Water Tank:**
γ & neutron shield μ Water Čerenkov detector 208 PMTs in water 2100 m³

**Stainless Steel Sphere:**
R = 6.75 m 2212 PMTs 1350 m³

**Carbon steel plates**

**20 steel legs**

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Livia Ludhova (Borexino collaboration)
Detection principle

- Neutrino elastic scattering on electrons of liquid scintillator: \( e^- + \nu \rightarrow e^- + \nu \);
- Scattered electrons cause the scintillation light production;
- **Advantages:**
  - Low energy threshold (~ 0.2 MeV);
  - High light yield and a good energy resolution;
  - Good position reconstruction;
- **Drawbacks:**
  - Info about the \( \nu \) directionality is lost;
  - \( \nu \)-induced events can’t be distinguished from the events of \( \beta/\gamma \) natural radioactivity;

End October 2006
March 2007
May 2007

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**Detection principle**

\[
\text{# of photons} \rightarrow \text{energy} \\
\text{time of flight} \rightarrow \text{position} \\
\text{pulse shape} \rightarrow \alpha/\beta \beta^+/\beta^-
\]

**ENERGY RESOLUTION**
- 10% @ 200 keV
- 8% @ 400 keV
- 6% @ 1 MeV

**SPATIAL RESOLUTION**
- 35 cm @ 200 keV
- 16 cm @ 500 keV

Extreme radiopurity is a must for a precision spectroscopy measurement!!!

DAQ STARTS: May 2007
Calibration with radioactive sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (MeV)</th>
<th>γ</th>
<th>β</th>
<th>α</th>
<th>n (AmBe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>57Co</td>
<td>0.122</td>
<td>0.122</td>
<td>0.165</td>
<td>0.279</td>
<td>0.514</td>
</tr>
<tr>
<td>139Ce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>203Hg</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>85Sr</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>54Mn</td>
<td></td>
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</tr>
<tr>
<td>65Zn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60Co</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>40K</td>
<td></td>
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</tr>
<tr>
<td>14C</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>214Bi</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>214Po</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>n-p</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>n+12C</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>n+Fe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Absolute source position: LED and CCD cameras (± 2cm);
- cca. 300 points through the whole scintillator volume;

- Detector response as a function of position;
- Fiducial volume definition and tuning of the spatial reconstruction algorithm;
- Energy scale definition
  - precise calibration in the 0-7 MeV range.
- Tuning of the full Monte Carlo simulation

SYSTEMATIC ERROR REDUCTION
For ALL SOLAR NEUTRINO RESULTS
\( ^{7}\text{Be} \) neutrino (862 keV) rate @ 4.6% (SSM prediction @ 7%)


\[ 46.0 \pm 1.5 \text{(stat)} \pm 1.5 \text{(syst)} \]

- Spectral fit including neutrino signal + background components;
- Two independent methods: MC based and the analytical one;
- Fit with and without \( \alpha \)'s statistical subtraction;

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Implications of the $^7$Be measurement

- comparing to non-oscillated SSM: **no oscillation excluded @ 5.0 \( \sigma \)**
  (electron equivalent flux (862 keV line): \((2.78 \pm 0.13) \times 10^9 \text{ cm}^{-2} \text{ s}^{-1}\))

- assuming MSW-LMA: \( f (^7\text{Be}) = \text{measured flux} / \text{SSM} = 0.97 \pm 0.09 \)

- including all solar experiments + luminosity constrain:
  \[
  f_{\text{pp}} = 1.013^{+0.003}_{-0.010} \\
  f_{\text{CNO}} < 2.5 \text{ at } 95\% \text{ C.L.}
  \]

\[ \text{Pee} = 0.51 \pm 0.07 \text{ at } 867 \text{ keV} \] (experiment + SSM high metallicity)

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Livia Ludhova (Borexino collaboration)
Absence of day-night asymmetry for $^7$Be rate ($R$)


- MSW: a possible regeneration of electron neutrinos in the matter (within the Earth during night): effect depends on the oscillation parameters and on energy;

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

- LOW prediction

- **Nigh-day spectrum**

- Regions allowed @ 68.27%, 95.45%, 99.73% CL

- $A_{dn} = 0.001 \pm 0.012(\text{stat}) \pm 0.007(\text{syst})$

- in agreement with MSW-LMA;
- LOW region excluded at > 8.5 $\sigma$ with solar neutrinos only: for the first time without the use of reactor ANTIneutrinos and therefore the assumption of CPT symmetry;
- constrains non standard interacitons (MaVaN in Holanda 2009 excluded)

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Livia Ludhova (Borexino collaboration)
First observation of pep neutrinos (1442 keV)

PHYSICAL REVIEW C 74, 045805 (2006)

- Main background $^{11}\text{C} \left( e^+ \right)$ with $\tau = 29.4 \text{ min}$:
  1. Three Fold Coincidence (TFC): space-time veto removes 90% of $^{11}\text{C}$ payed with 50% loss of exposure
  2. $b^+ / b^-$ pulse-shape discrimination: positronium formation + annihilation

- TEST SAMPLES

- $n + p \rightarrow D + \gamma$ (2.2 MeV)

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Livia Ludhova (Borexino collaboration)
Multivariate maximum likelihood fit

Energy spectral fit
- Spectrum of events in FV
- Spectrum after TPC veto
  - $^{14}$C rate = 27
  - $^{14}$C rate = 2.5
  - pepV rate = 3.1
  - CNOV limit = 7.9
  - $^{210}$Bi rate = 55

Pulse shape variable
- Data (0.9 - 1.8 MeV)
- $e^+: V_{S, 214}$Pb, $^{210}$Bi, External $\gamma$
- $e^+: 11^C, 15^C$
- Best Fit

Radial fit
- Data (1.2 - 2.8 MeV)
- Bulk: $V_{S, 11^C, 15^C}$
- External $\gamma$
- Best Fit

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Livia Ludhova (Borexino collaboration)
First observation of pep neutrinos II.

- **Pep rate:** \(3.1 \pm 0.6_{\text{stat}} \pm 0.3_{\text{sys}} \text{ cpd/100 t}\)
- Assuming MSW-LMA: \(\Phi_{\text{pep}} = 1.6 \pm 0.3 \times 10^8 \text{ cm}^{-2} \text{ s}^{-1}\)
- No oscillations excluded at 97% c.l.
- Absence of pep solar ν excluded at 98%

**CNO neutrinos**

- only limits, correlation with \(^{210}\text{Bi}\);
- CNO limit obtained assuming pep @ SSM
- **CNO rate** < 7.1 cpd/100 t (95% c.l.)
- Assuming MSW-LMA:
  \(\Phi_{\text{CNO}} < 7.7 \times 10^8 \text{ cm}^{-2} \text{ s}^{-1}\) (95% C.L.)
  the strongest limit to date
  not sufficient to resolve metallicity problem
**8B neutrino rate with 3 MeV energy threshold**


**lower energies limited by 208Tl**

<table>
<thead>
<tr>
<th>Rate [cpd/100 t]</th>
<th>3.0–16.3 MeV</th>
<th>5.0–16.3 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Phi_{\text{exp}}^{\text{ES}} ) ([10^6 \text{ cm}^{-2} \text{ s}^{-1}])</td>
<td>0.22 ± 0.04 ± 0.01</td>
<td>0.13 ± 0.02 ± 0.01</td>
</tr>
<tr>
<td>( \Phi_{\text{exp}}^{\text{ES}} / \Phi_{\text{th}}^{\text{ES}} )</td>
<td>2.4 ± 0.4 ± 0.1</td>
<td>2.7 ± 0.4 ± 0.2</td>
</tr>
</tbody>
</table>

**TABLE VI.** Results on \(^8\)B solar neutrino flux from elastic scattering, normalized under the assumption of the no-oscillation scenario reported by SuperKamiokaNDE, SNO, and Borexino.

<table>
<thead>
<tr>
<th>Threshold [MeV]</th>
<th>( \Phi_{\text{ES}}^{\text{S}8\text{B}} ) ([10^6 \text{ cm}^{-2} \text{ s}^{-1}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuperKamiokaNDE I [3]</td>
<td>5.0</td>
</tr>
<tr>
<td>SuperKamiokaNDE II [2]</td>
<td>7.0</td>
</tr>
<tr>
<td>SNO D_2O [4]</td>
<td>5.0</td>
</tr>
<tr>
<td>SNO Salt Phase [25]</td>
<td>5.5</td>
</tr>
<tr>
<td>SNO Prop. Counter [26]</td>
<td>6.0</td>
</tr>
<tr>
<td>Borexino</td>
<td>3.0</td>
</tr>
<tr>
<td>Borexino</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Background subtracted
To conclude, we put all together..... $P_{ee}$ after Borexino I

The diagram shows the survival probability of $P_{ee}$ as a function of $E_{\nu}$ [MeV]. The data points are categorized into different sources:

- pp - All solar
- $^7$Be - Borexino
- pep - Borexino
- $^8$B - SNO + SK
- MSW-LMA Prediction

The MSW-LMA gets constrained....
Future and Borexino phase II

- since July 2010 we have undertaken a series of purification campaigns to decrease the radioactive background;
  - Nitrogen stripping has been successful in removing $^{85}$Kr:
    $$^{85}\text{Kr} < 8.8 \text{ cpd / 100 t} \quad (2007-2010: 31.2 \pm 5)$$
  - moderate success at removing $^{210}$Bi by water extraction:
    $$^{210}\text{Bi} : (16 \pm 4) \text{ cpd / 100 t} \quad (2007-2010: 41.0 \pm 2.8)$$
  - unprecedented purity in $^{238}$U and $^{232}$Th:
    $$^{238}\text{U} < 9.7 \times 10^{-19} \text{ g/g} \quad \text{and} \quad ^{232}\text{Th} < 2.9 \times 10^{-18} \text{ g/g}$$
  - $^{210}$Po decreasing, $\sim 5$ cpd / t;

- Borexino phase II just started…
  - continue solar neutrino program:
    - Improve $^7$Be, $^8$B $\rightarrow$ test of MSW
    - Confirm pep at more than $3\sigma$ and reduce error
    - Improve upper limit on CNO $\rightarrow$ probe metallicity
    - Attempt direct pp measurement
  - more statistics for an update of geo-neutrino measurement;
  - another long-term scientific goals under discussion.
More about Borexino solar results in:


**7Be @ 5%**: G. Bellini et al.: Precision measurement of the 0.862 MeV $^7$Be solar neutrino interaction rate in Borexino, Phys. Rev. Lett. 107 (2011) 141302.


Thank you!
Backup
NEuTRINO SPEED - Preliminary RESULTS

internal delay stability

MC simulation of expected width

38 events

97 events

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Livia Ludhova (Borexino collaboration)
**β+ - β- discrimination**

- Positrons form ortho-positronium in ~ 50% of cases (in PC)
  - Scintillation signal **delayed** by ~ 3 ns
  - Pulse shape is different
  - Parameters measured in a dedicated experiment

- A Pulse Shape discriminating variable was developed, based on a **Boosted Decision Tree (BDT)**

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Livia Ludhova (Borexino collaboration)
# The internal background in Borexino

- Careful selection of the construction materials and operational procedures;
- Special procedures for fluid procurement;
- Scintillator and buffer purification during the filling;
- Sparging with high purity N2;
- More than 15 years of work…

**Extreme radiopurity is a must!!!**

<table>
<thead>
<tr>
<th>Background</th>
<th>Typical abundance (source)</th>
<th>Goal</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{14}\text{C}/^{12}\text{C}$</td>
<td>$10^{-12}$ (cosmogenic) g/g</td>
<td>$10^{-18}$ g/g</td>
<td>$\sim 2 \times 10^{-18}$ g/g</td>
</tr>
<tr>
<td>$^{238}\text{U}$ (by $^{214}\text{Bi}$-$^{214}\text{Po}$)</td>
<td>$2 \times 10^{-5}$ (dust) g/g</td>
<td>$10^{-16}$ g/g</td>
<td>$(1.6 \pm 0.1) \times 10^{-17}$ g/g</td>
</tr>
<tr>
<td>$^{232}\text{Th}$ (by $^{212}\text{Bi}$-$^{212}\text{Po}$)</td>
<td>$2 \times 10^{-5}$ (dust) g/g</td>
<td>$10^{-16}$ g/g</td>
<td>$(5 \pm 1) \times 10^{-18}$ g/g</td>
</tr>
<tr>
<td>$^{222}\text{Rn}$ (by $^{214}\text{Bi}$-$^{214}\text{Po}$)</td>
<td>100 atoms/cm$^3$ (air) emanation from materials</td>
<td>$10^{-16}$ g/g</td>
<td>$\sim 10^{-17}$ g/g (&lt;1 count/day/100t)</td>
</tr>
<tr>
<td>$^{210}\text{Po}$</td>
<td>Surface contamination</td>
<td>$\sim 1$ c/day/t</td>
<td>May 2007: 70 c/d/t Sep 2008: 7 c/d/t</td>
</tr>
<tr>
<td>$^{40}\text{K}$</td>
<td>$2 \times 10^{-6}$ (dust) g/g</td>
<td>$&lt; 3 \times 10^{-18}$ (90%) g/g</td>
<td></td>
</tr>
<tr>
<td>$^{85}\text{Kr}$</td>
<td>1 Bq/m$^3$ (air)</td>
<td>$\sim 1$ c/d/100t</td>
<td>$(28 \pm 7)$ c/d/100t (fast coinc.)</td>
</tr>
<tr>
<td>$^{39}\text{Ar}$</td>
<td>17 mBq/m$^3$ (air)</td>
<td>$\sim 1$ c/d/100t</td>
<td>$&lt;&lt;^{85}\text{Kr}$</td>
</tr>
</tbody>
</table>
Data structure and detector performance

- Charged particles and $\gamma$ produce scintillation light: photons hit inner PMTs;
- DAQ trigger: > 25 inner PMTs (from 2212) are hit within 60-95 ns:
  - 16 $\mu$s DAQ gate is opened;
  - Time and charge of each hit detected;
  - Each trigger has its GPS time;
  - “cluster” of hits = real physical event

- Outer detector gives a muon veto if at least 6 outer PMTs (from 208) fire;

**Light yield:** $(500 \pm 12)$ p.e./MeV taking into account quenching factor

**Energy resolution (s):**
- 10% @ 200 keV
- 8% @ 400 keV
- 6% @ 1000 keV

**Spatial resolution:**
- $35 \text{ cm} @ 200 \text{ keV}$
- $16 \text{ cm} @ 500 \text{ keV}$

Livia Ludhova (Borexino collaboration)
Muon and neutron detection

- **μ** are identified by the OD and by the ID
  - OD eff: > 99.28%
  - ID analysis based on pulse shape variables
    - Cluster mean time, peak position in time
  - **Combined overall efficiency** > 99.992%
  - After cuts, μ not a relevant background for 7Be
    - Residual background: < 1 count /day/ 100 t

**New**:
Muon tag with ID

- Muon track reconstruction

After each μ, 1.6 ms gate opened to detect neutrons:
- Example with several tens of neutrons.

NEW: Muon and Cosmogenic Neutron Detection in Borexino.
Sent to JINST 2 weeks ago, arXiv:1101.3101
B analysis details

External backgrounds (FV CUT):
- High energy $\gamma$ from neutrons
- $^{214}$Bi and $^{208}$Tl from Rn emanated from nylon or detector

Internal radiocative backgrounds:
- $^{214}$Bi ($^{238}$U chain) via $^{214}$Bi-$^{214}$Po coincidences;
- $^{208}$Tl ($^{232}$Th chain) from bulk: stat. subtr.;

Cosmogenic background rejection:
- **FAST COSMOGENIC CUT**: 6.5 s dead time after all ID muons to reject fast cosmogenic isotopes; (29.2 % dead time, 4300 muons/day passing ID)
- **NEUTRON REJECTION**: 2 ms after all muons (neutron capture time 256 $\mu$s, AmBe source);
- **$^{10}$C SUBTRACTION**: 3-fold coincidence with parent muon and neutron;
- **$^{11}$Be STATISTICAL SUBTRACTION**;

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Background: $^{232}$Th and $^{238}$U content

Assuming secular equilibrium:

$^{232}$Th chain

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

$\tau = 432.8$ ns

$2.25$ MeV $\sim 800$ keV eq.

(6.8 ± 1.5) $\times$ $10^{-18}$ g(Th)/g

$^{238}$U chain

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

$\tau = 236$ $\mu$s

$3.2$ MeV $\sim 700$ keV eq.

(1.6 ± 0.1) $\times$ $10^{-17}$ g(U)/g

Only few bulk candidates

Bulk contamination

$^{212}$Bi-$^{212}$Po centre of mass position distribution

278 days
Background: $^{210}$Po and $^{85}$Kr

$^{210}$Po: end of $^{238}$U chain:

$^{210}$Po $\rightarrow$ $^{210}$Bi $\rightarrow$ $^{210}$Po $\rightarrow$ $^{206}$Pb

- $\beta^-$ (61 keV)
- $\beta^-$ (1.2 MeV) $\alpha$
- $t_{1/2} = 22.3$ y
- 5.01 d
- 138.38 d
- stable

$^{85}$Kr $\beta$-decay energy spectrum similar to the $^7$Be recoil electron

- $^{85}$Kr $\beta$ $\rightarrow$ $^{85}$Rb
- 687 keV

- $\tau = 10.76$ y - BR: 99.56%

$^{85}$Kr is studied through:

- $^{85}$Kr $\beta$ $\rightarrow$ $^{85}$mRb
- 173 keV

- $^{85}$mRb $\gamma$ $\rightarrow$ $^{85}$Rb
- 514 keV

- $\tau = 1.46$ ms - BR: 0.43%

PRELIMINARY: the $^{85}$Kr contamination \( (30 \pm 5) \) counts/day/100 ton

- The bulk $^{238}$U and $^{232}$Th contamination is negligible
- The $^{210}$Po background is NOT related neither to $^{238}$U nor to $^{210}$Pb contamination
- May 2007 ~80 counts/day/ton, $\tau = 204.6$ days
- $^{210}$Bi no direct evidence --- free parameter in the total fit, cannot be disentangled, in the $^7$Be energy range, from the CNO

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