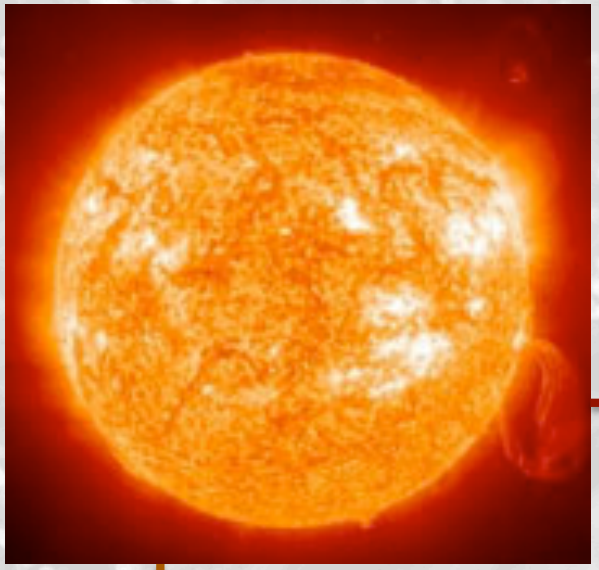
Experimental evidence of electron neutrino oscillations and validation of MSW-LMA model with Borexino

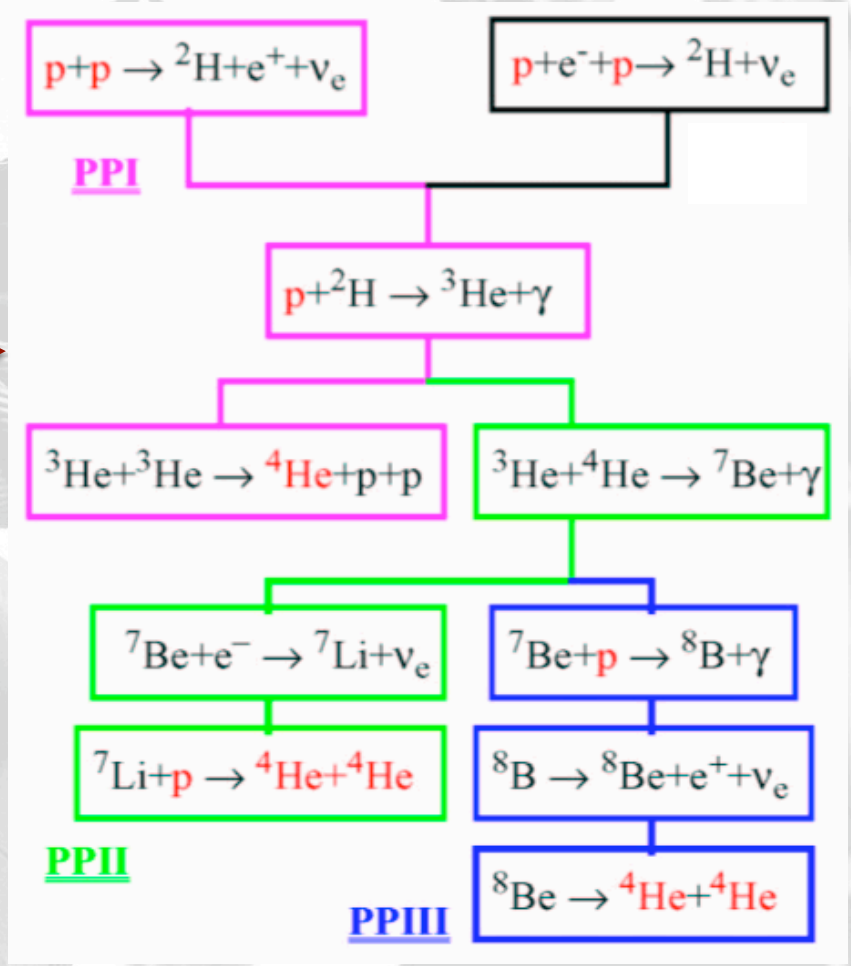
Margherita Buizza Avanzini
for the Borexino Coll.

International School of Nuclear Physics **Erice, 2010**

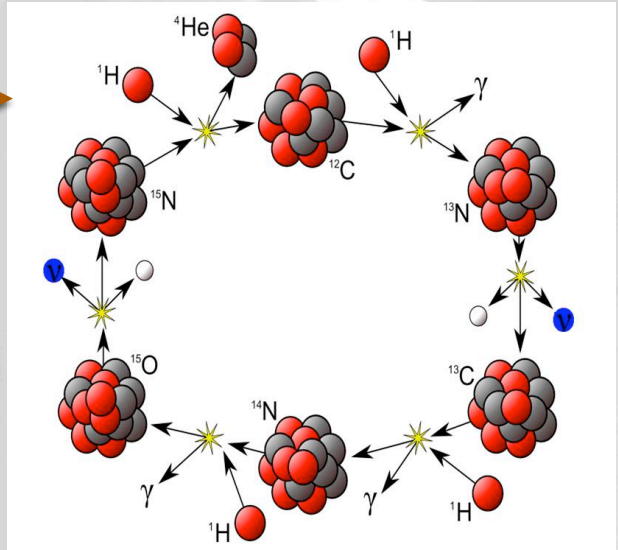
BEFORE SOLAR NEUTRINOS... THE SUN BURNING



98% of energy through the pp chain



CNO? Just 2% of energy...



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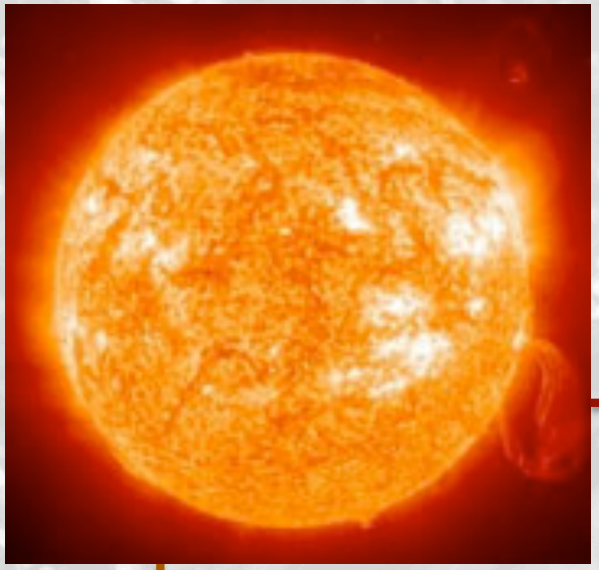

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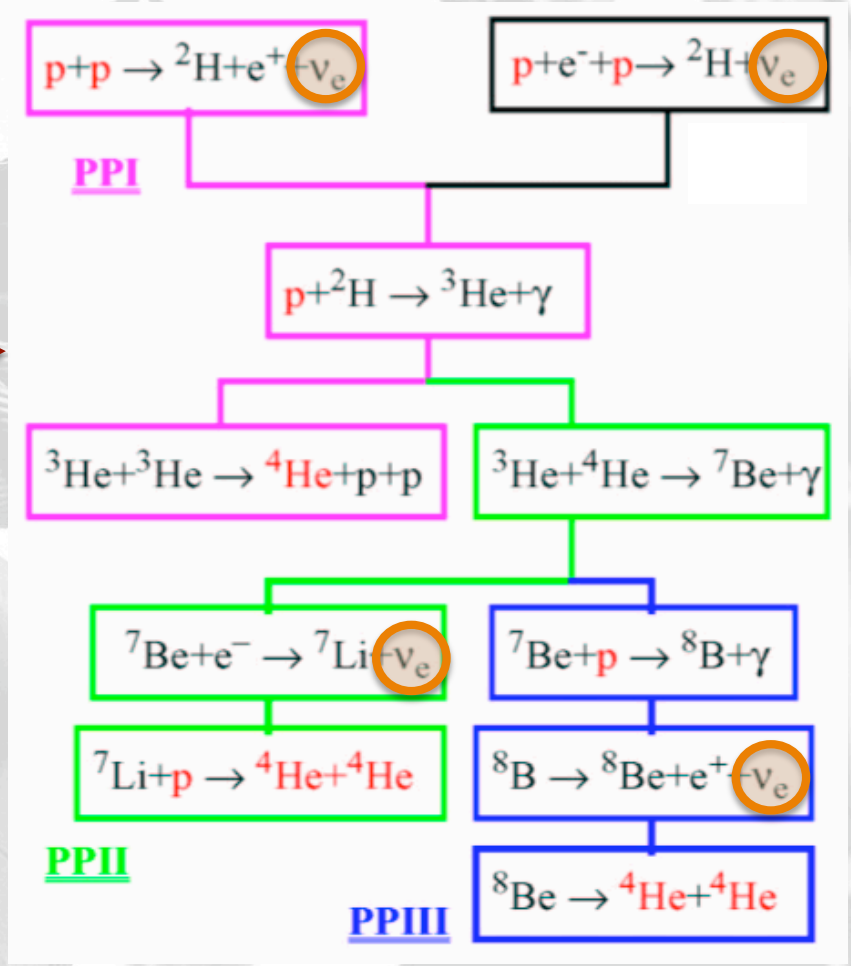

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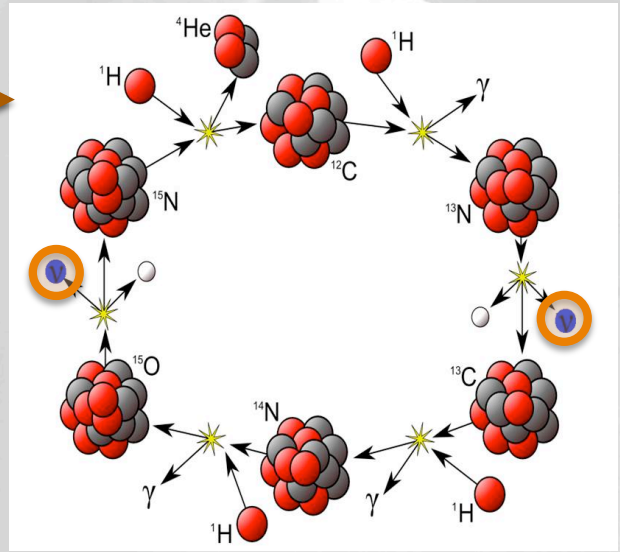
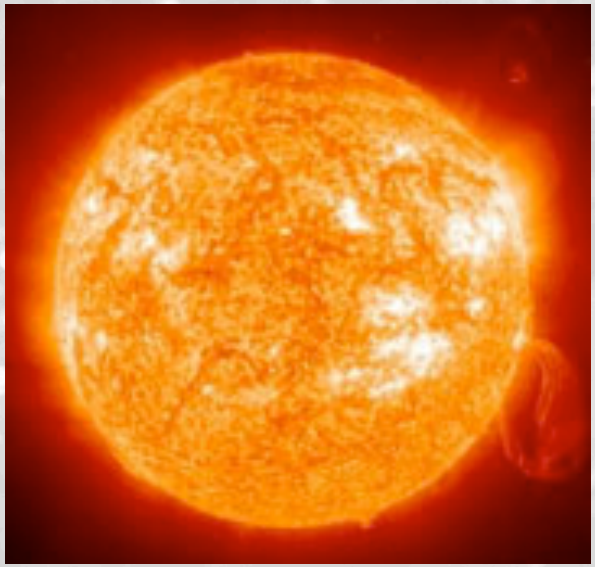
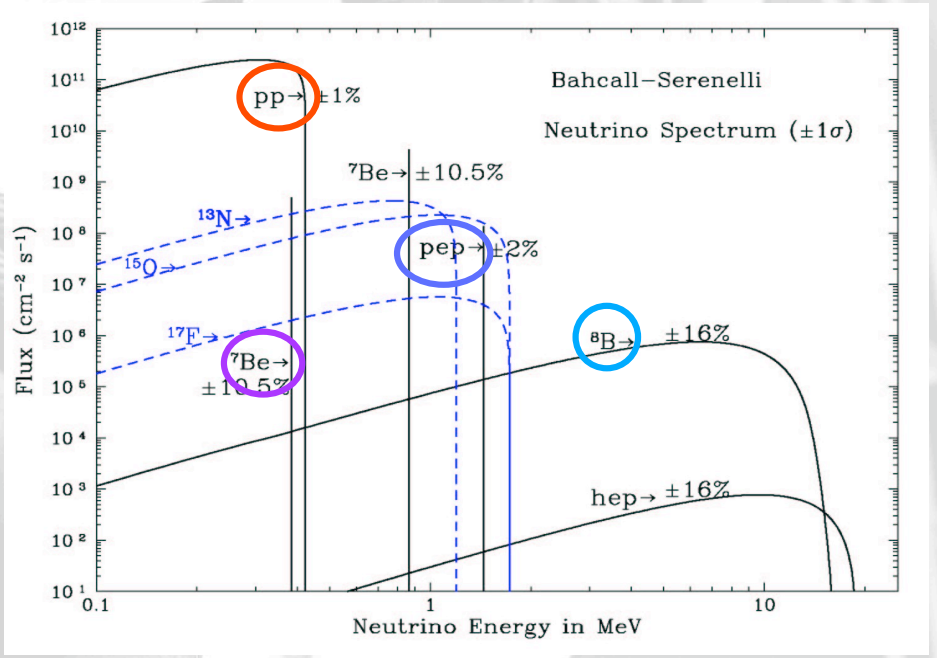


But what about neutrinos?!

SOLAR NEUTRINOS

Standard Solar Model (BPS09) predicts **fluxes** and **spectra** of ν_e:





Real time Cherenkov experiments can investigate only the final part of ^{8}B spectrum.

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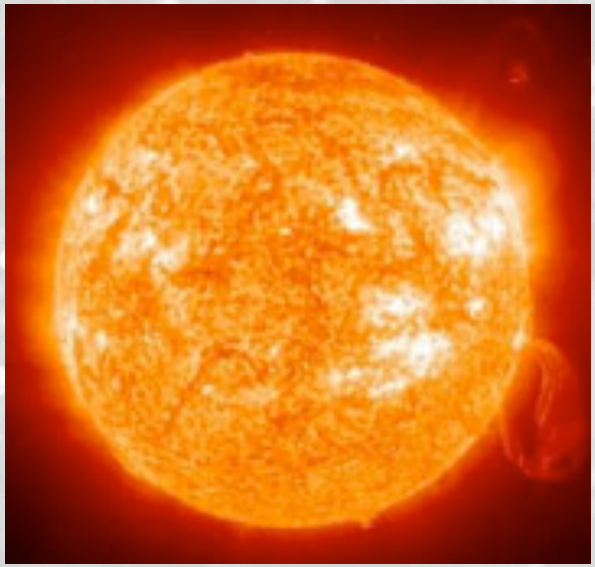

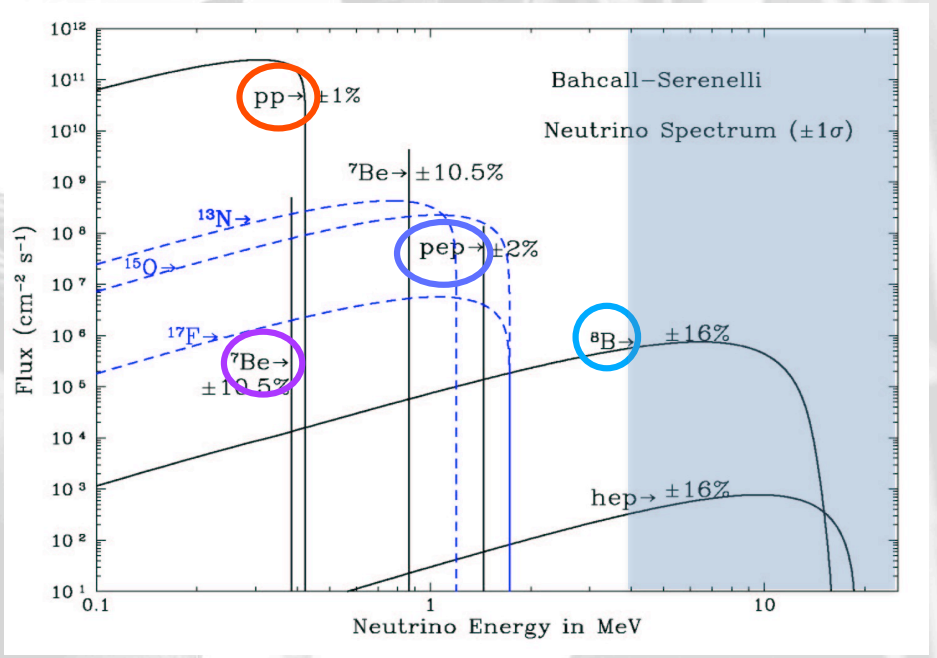

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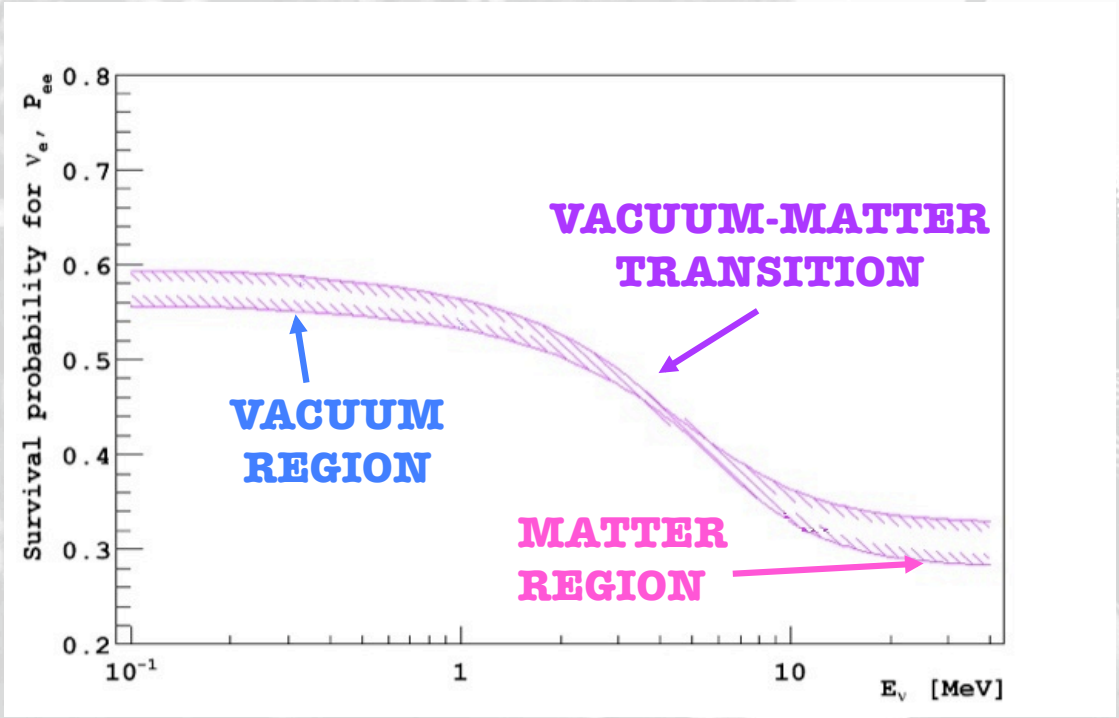
THE MSW-LMA SOLUTION

The **survival probability** of ν_e for the MSW-LMA solution:



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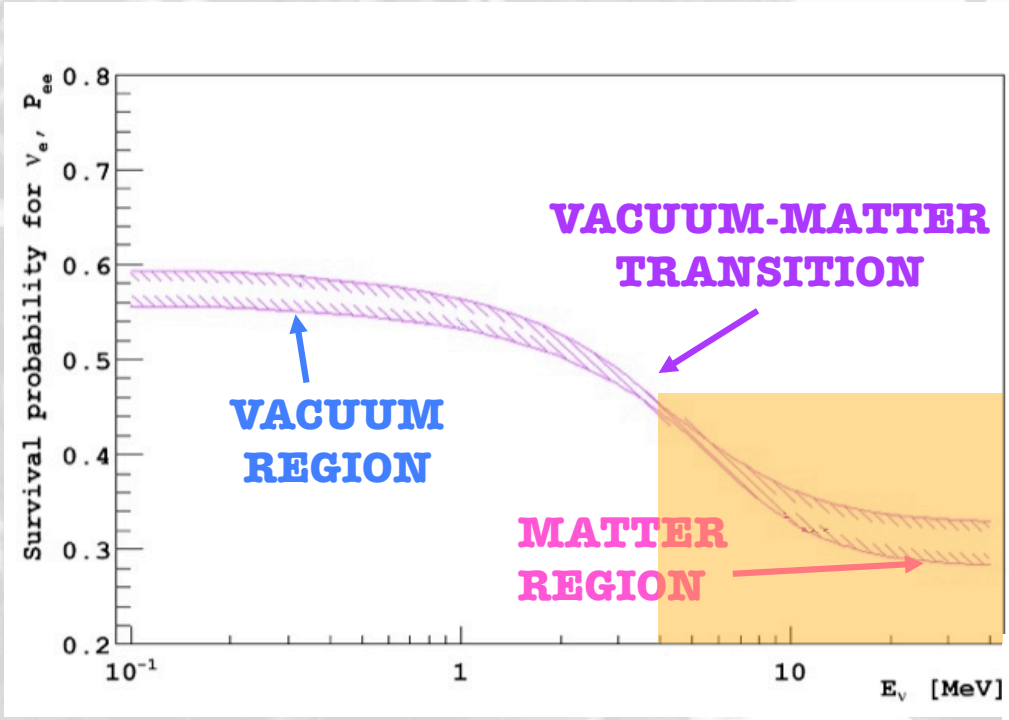

VACUUM REGION: low energy, oscillations like in the vacuum.

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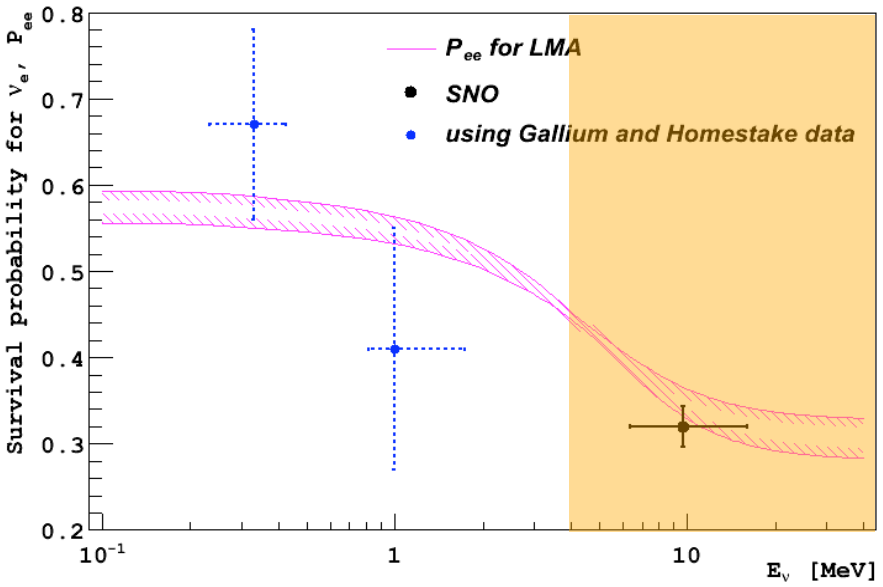
^{8}B: real time experiment with energy threshold of detected electron at about **4 MeV** ($\approx 10^{-4}$ of the total flux) ➔ **matter region.**

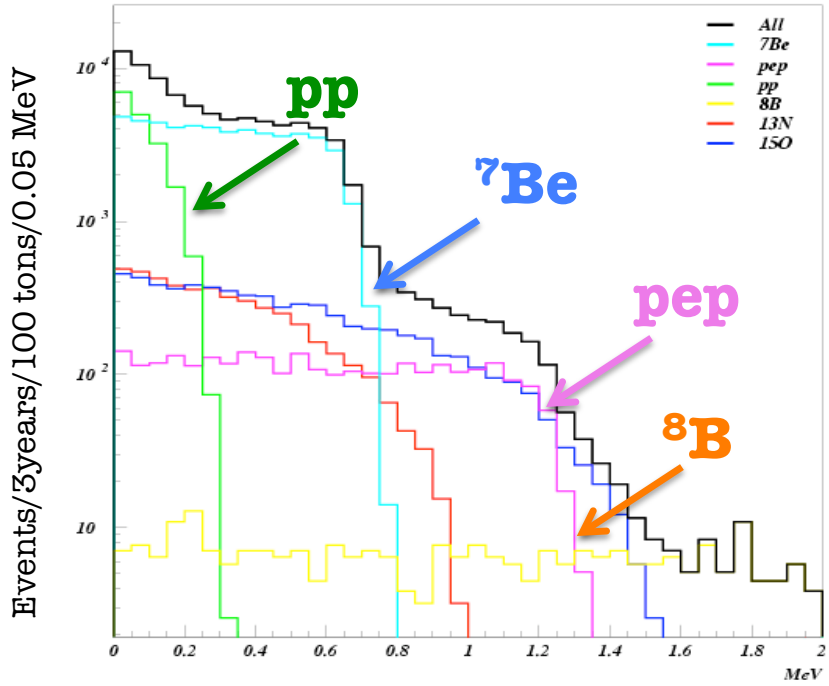
What new with Borexino???

WITHOUT BOREXINO



THE BOREXINO EXPERIMENT

MONTECARLO SPECTRA in BX



First real time experiment for **low energy solar neutrinos**!

✓ Main goal: ^{7}Be flux measurement

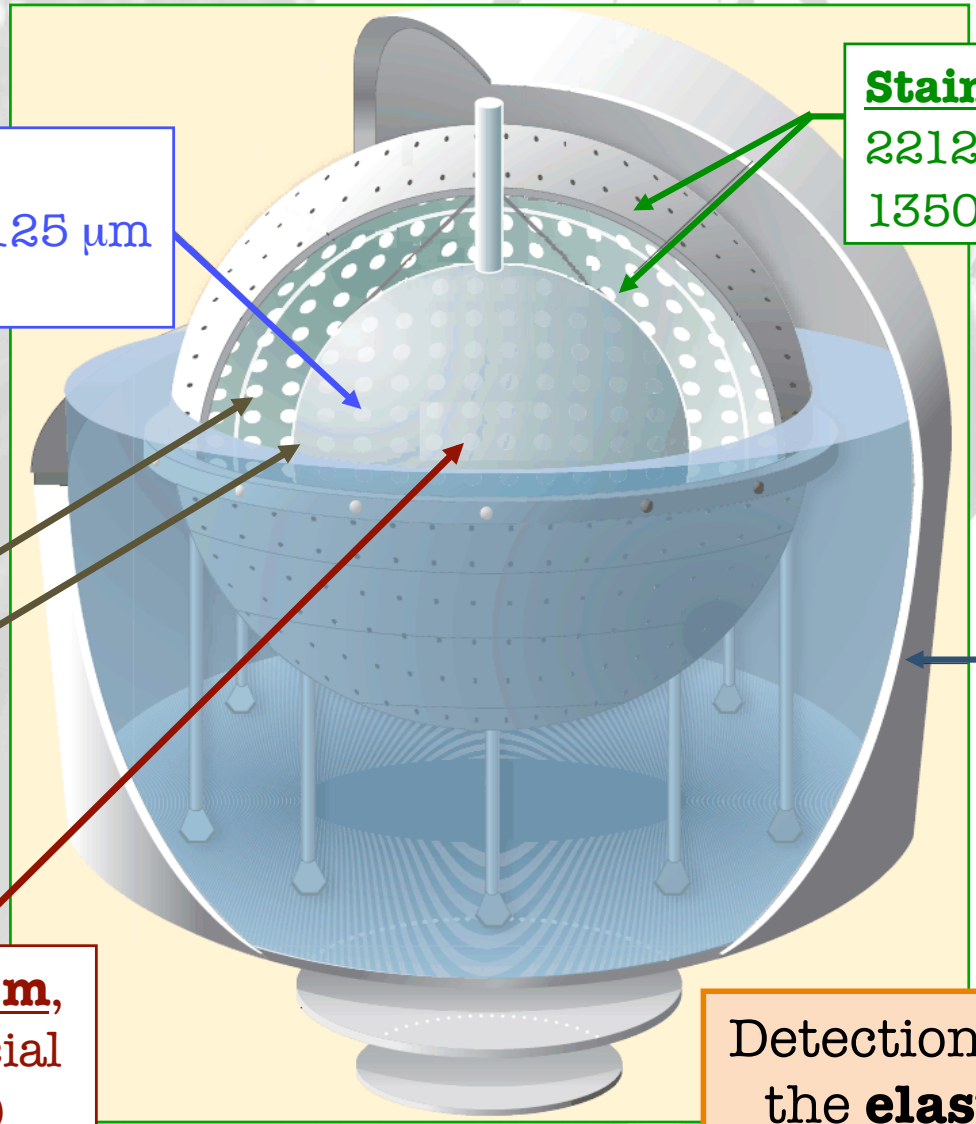
✓ But also: measure of ^{8}B neutrinos!!!

✓ And for the future... **pep** and **pp**

For the first time in real time:

- **Test of Standard Solar Model**: precise measurement of ^{7}Be ν flux!
- **Test of MSW-LMA solution** at low energy!
- BOREXINO can measure ALSO ^{8}**B neutrinos**!
- Energy threshold for ^{8}B neutrinos down to **3 MeV** (electron energy)!

THE BOREXINO DETECTOR



Stainless Steel Sphere:
2212 photomultipliers
1350 m^3

Scintillator:
270 t PC+PPO in a 125 μm thick nylon vessel

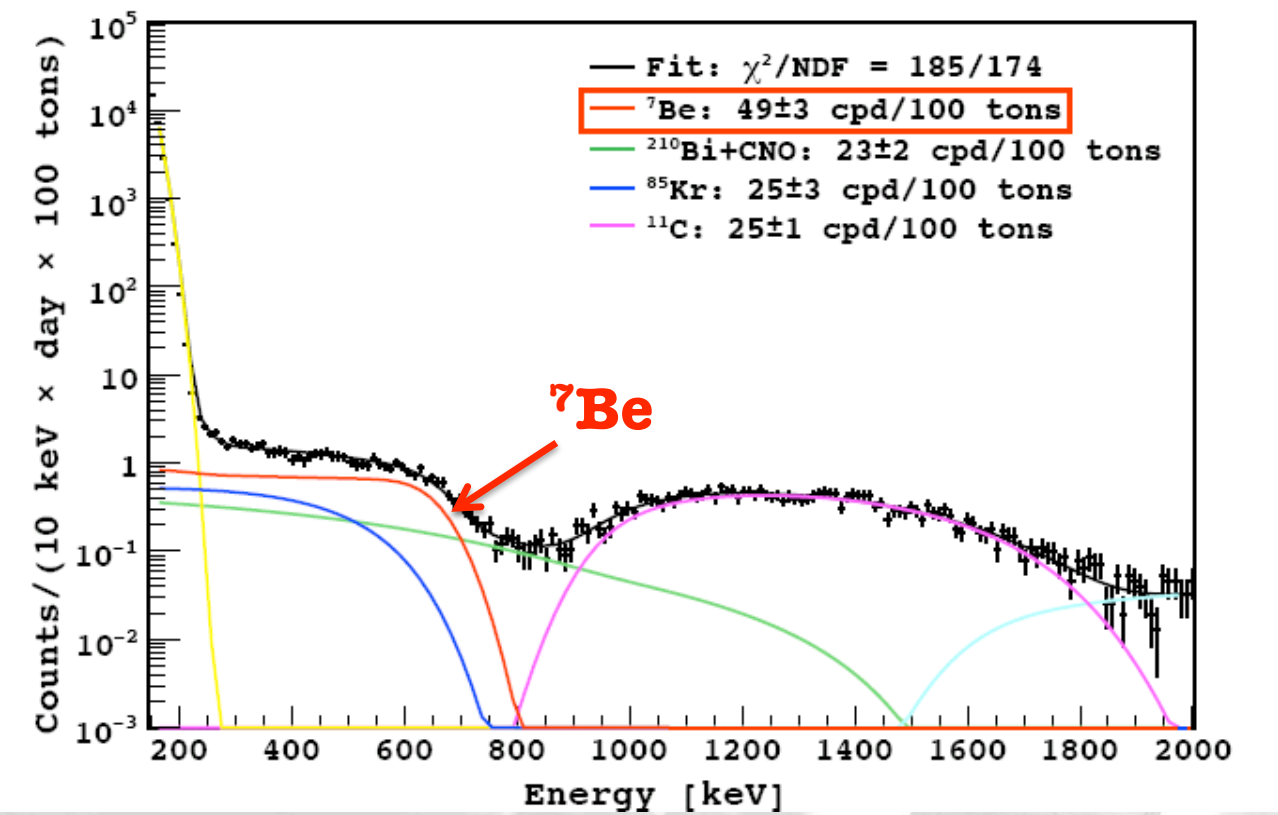
Water Tank:
γ and *n* shield
μ water Ch detector
208 PMTs in water
2100 m^3

Nylon vessels:
Inner: 4.25 m
Outer: 5.50 m

Software cut at 3m, defining the Fiducial Volume (100tons)

Detection of solar ν through the **elastic scattering** on electrons in high purified scintillator (300tons).

RESULTS ON THE ^{7}Be ν MEASUREMENT (192*d*)



- Fit in the region 0.2–2 MeV
- α removal
- ^{210}Bi, ^{11}C and ^{85}Kr as free parameters
- Other neutrino fluxes are fixed

Borexino Collaboration
PRL 101 (2008)

$$R_{^{7}Be} = 49 \pm 3_{stat} \pm 4_{sys}\ c/d/100\ tons$$

^{8}B NEUTRINO FLUX MEASUREMENT (1)

EXPECTED RATE SSM+MSW-LMA

Whole energy spectrum: **~ 0.5 c/d/100 tons**

Above **5 MeV**: **~ 0.14 c/d/100 tons**

BUT we can decrease the threshold down to **3 MeV** **!!!**

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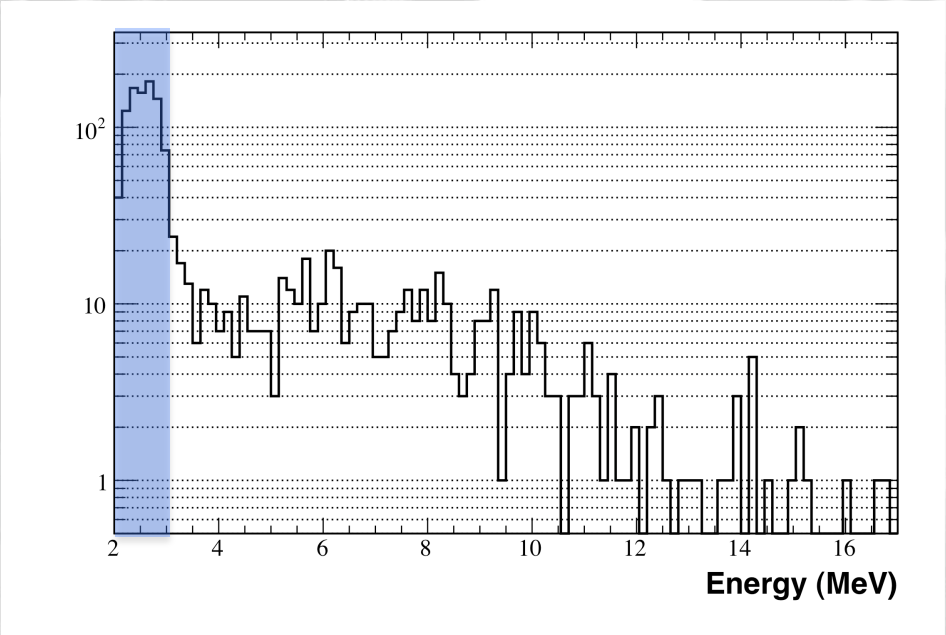
Why the energy threshold at 3MeV??



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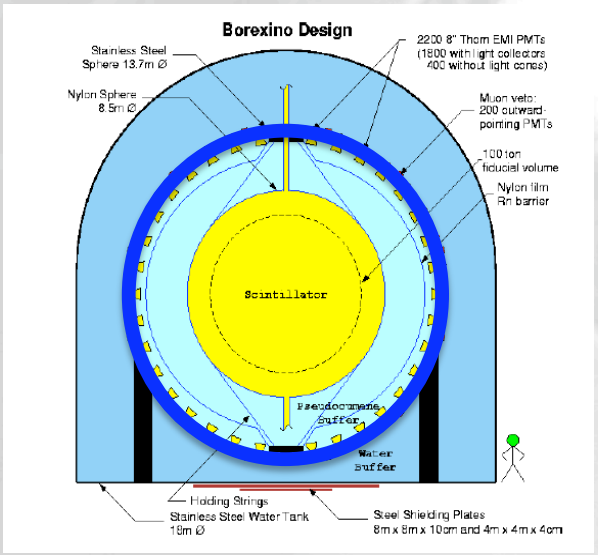
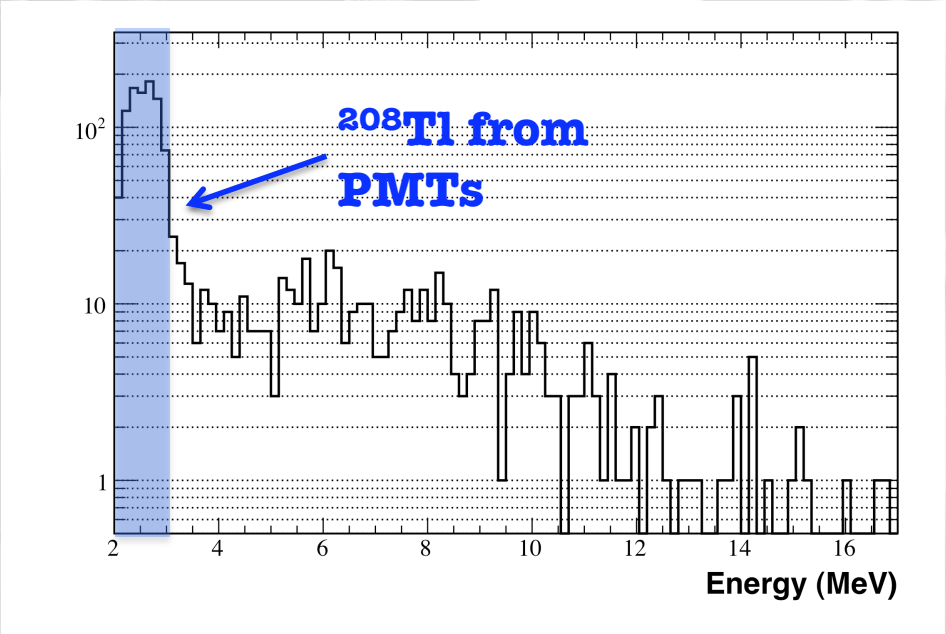
Why the energy threshold at 3MeV??
2.6MeV gammas from ^{208}Tl coming from the PMTs reaching the FV

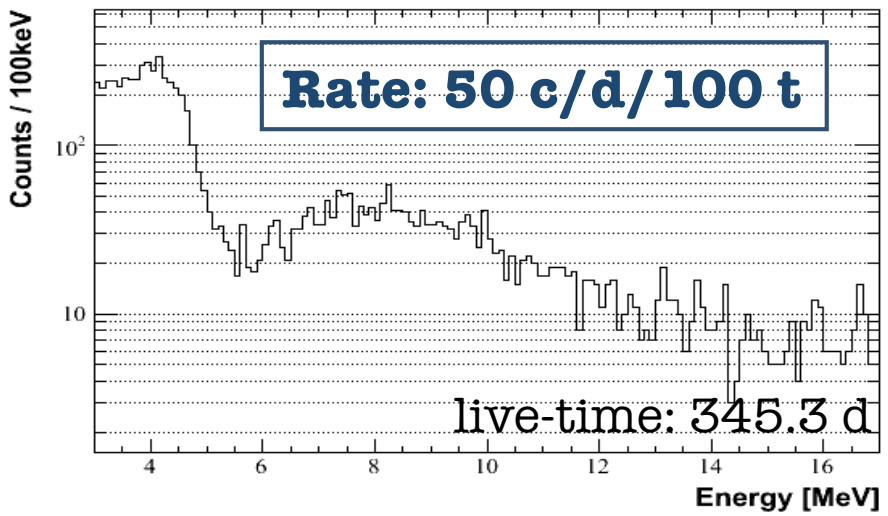




Setting the threshold at 3MeV

BACKGOUND SOURCES (above 3MeV)

DATA SPECTRUM BEFORE THE ANALYSIS



Signal/Bkg ratio < 1/150 !!!

HARD GOAL!

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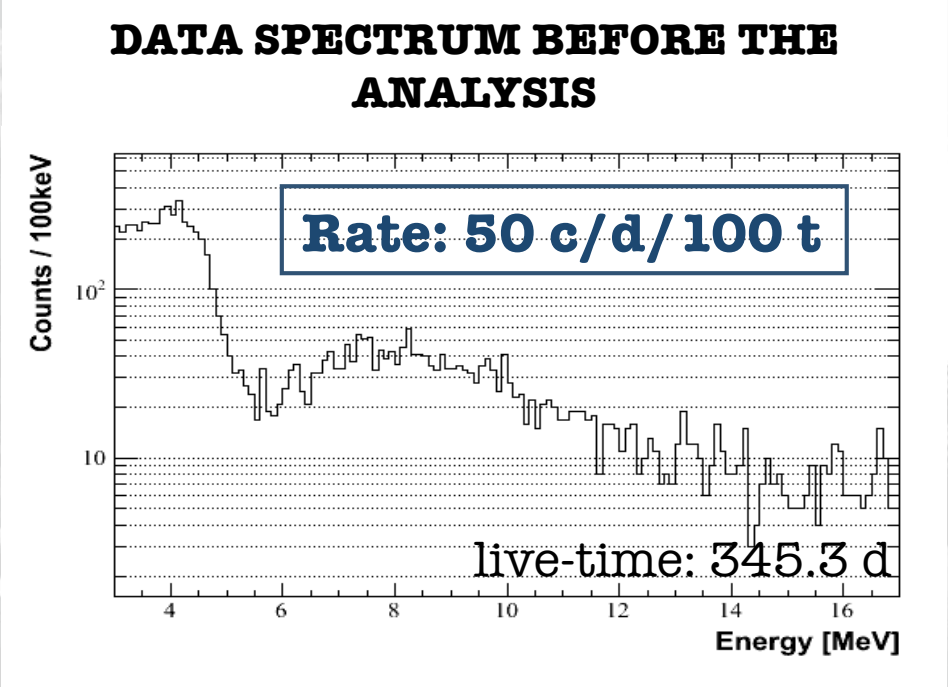


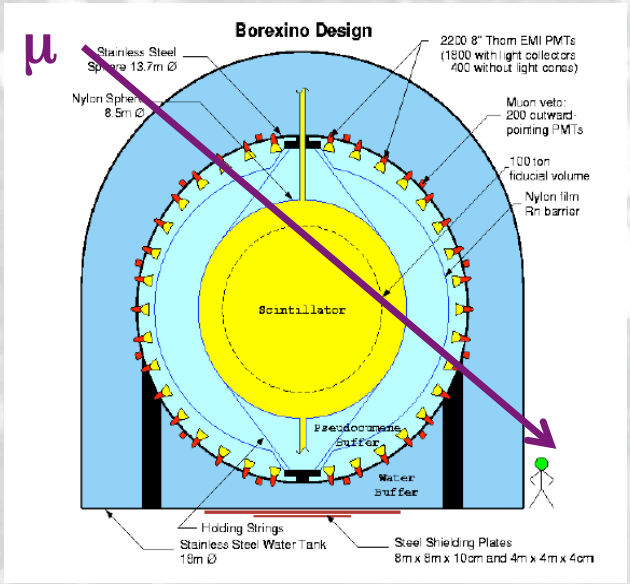
Signal/Bkg ratio < 1/150 !!!

HARD GOAL!

- **Cosmic muons**
- High energy γ (4.9 MeV) from **neutron capture** on ^{12}C
- **Cosmogenic isotopes**
- ^{214}Bi and ^{208}Tl from **vessel contamination** of ^{238}U and ^{232}Th
- ^{214}Bi and ^{208}Tl from **internal contamination** of ^{238}U and ^{232}Th

Ad hoc technique for each kind of background !!!

BACKGROUND SOURCES (above 3MeV)



MUONS AND COSMOGENIC NEUTRONS

Study of the pulse shape in the scintillator ≠ point-like events!!

+ rejection of gamma from n capture, in coincidence with the μ

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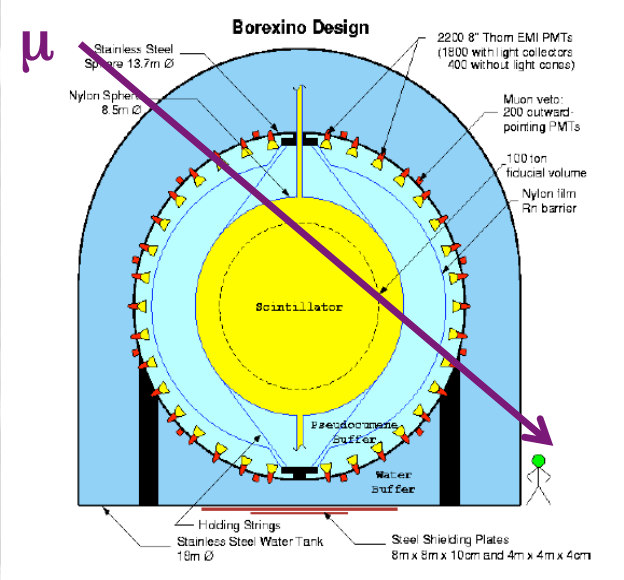

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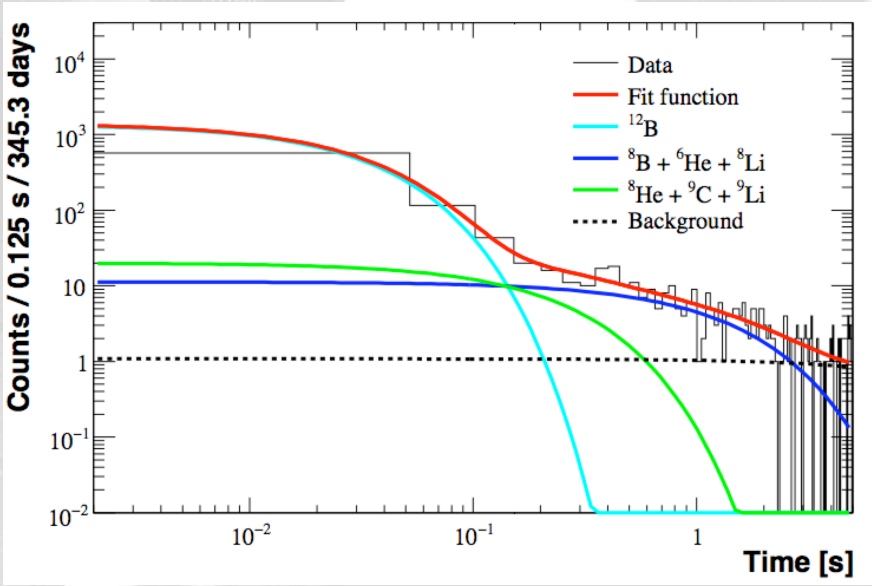
COSMOGENIC ISOTOPES

Study of cosmogenic isotopes through the coincidence with the father muon.

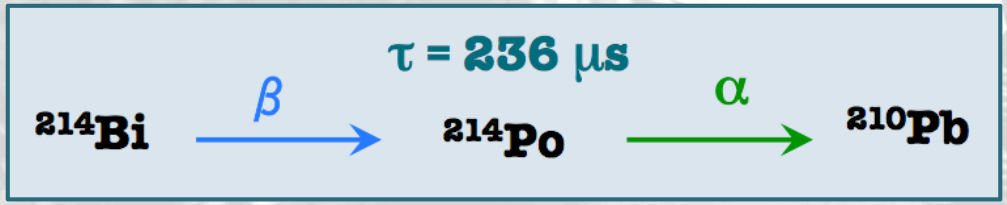
Rate measurements in agreement with Kamland results (arXiv:0907.0066)

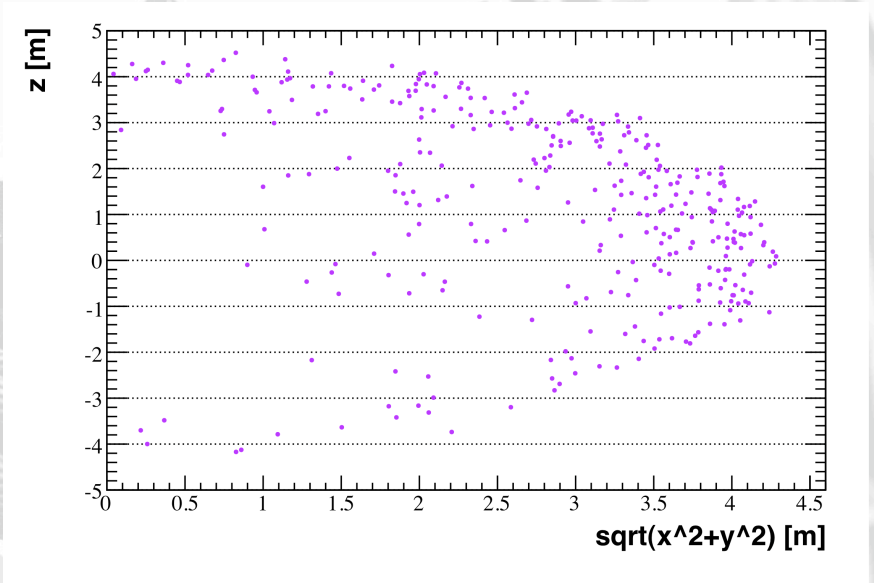


BACKGOUND SOURCES (above 3MeV)

^{214}Bi CONTAMINATION

Searching for fast coincidences in time and space between





BACKGOUND SOURCES (above 3MeV)

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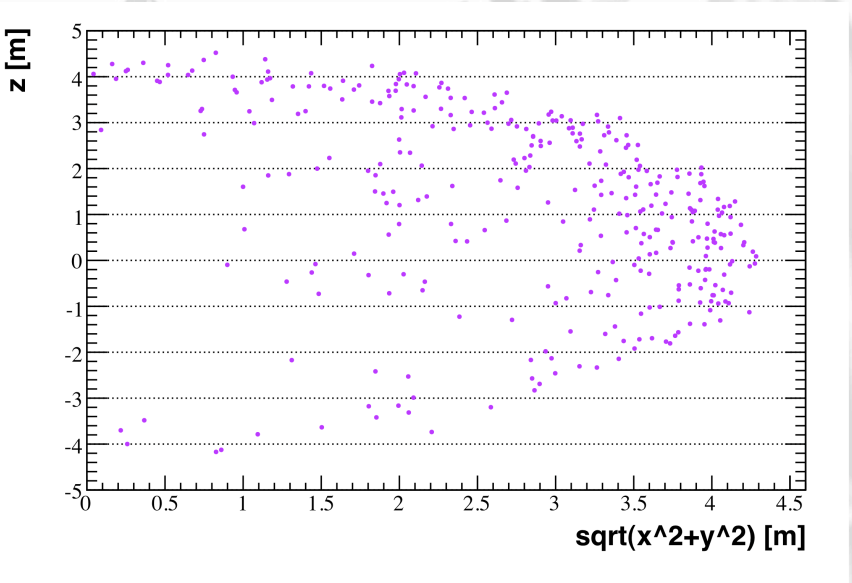
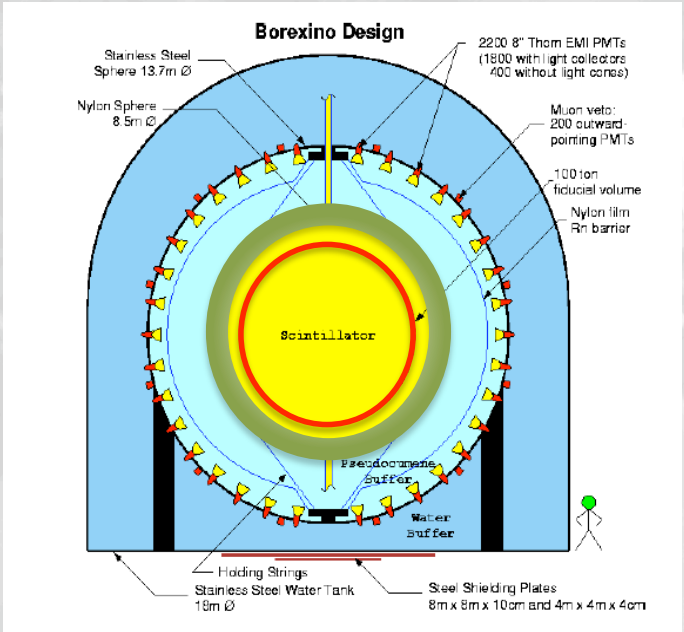
Searching for fast coincidences in time and space between

$$^{214}\text{Bi} \xrightarrow{\beta} {}^{214}\text{Po} \xrightarrow{\alpha} {}^{210}\text{Pb} \qquad \tau = 236\ \mu\text{s}$$



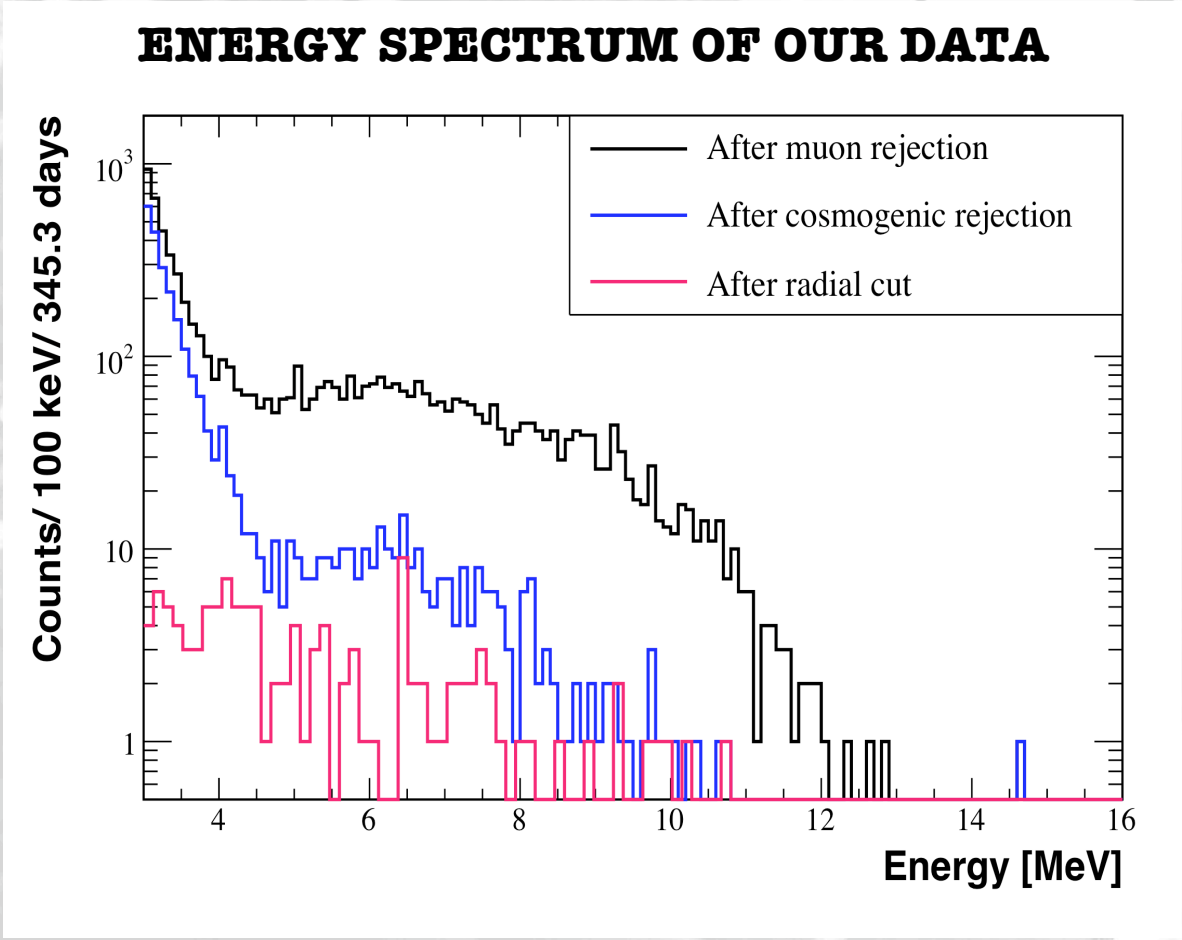


FIDUCIAL VOLUME CUT

Radon contamination from the vessel... diffusion and decay in ^{214}Bi and ^{208}Tl

➔ **Necessity of a radial cut at 3m**

^{8}B NEUTRINO FLUX MEASUREMENT (2)

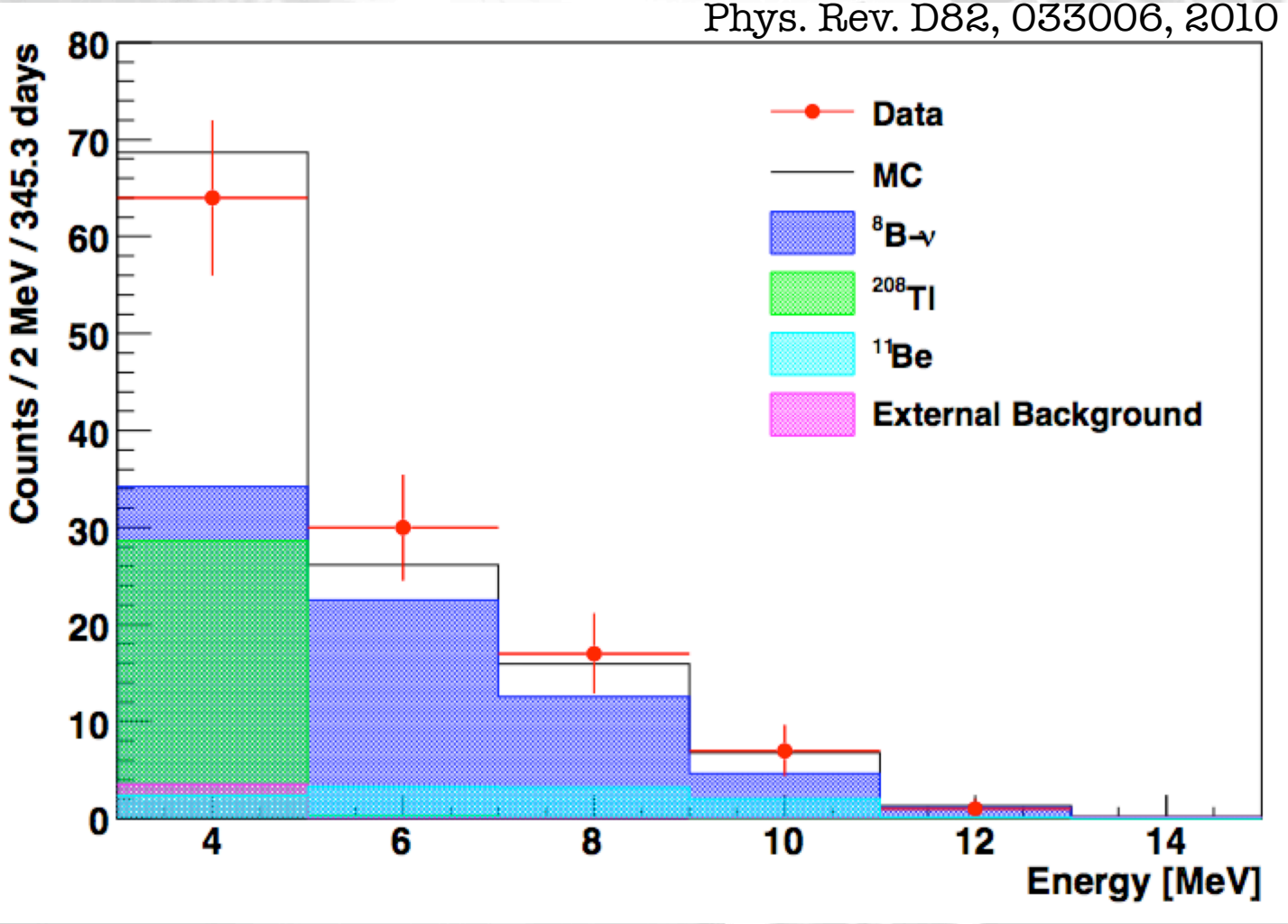


- After muons rejection
- After cosmogenic rejection
- After the radial cut

RESULTS ON THE ^{8}B ν MEASUREMENT (1)

Comparison data/MonteCarlo for 345.3 d of livetime:

Phys. Rev. D82, 033006, 2010



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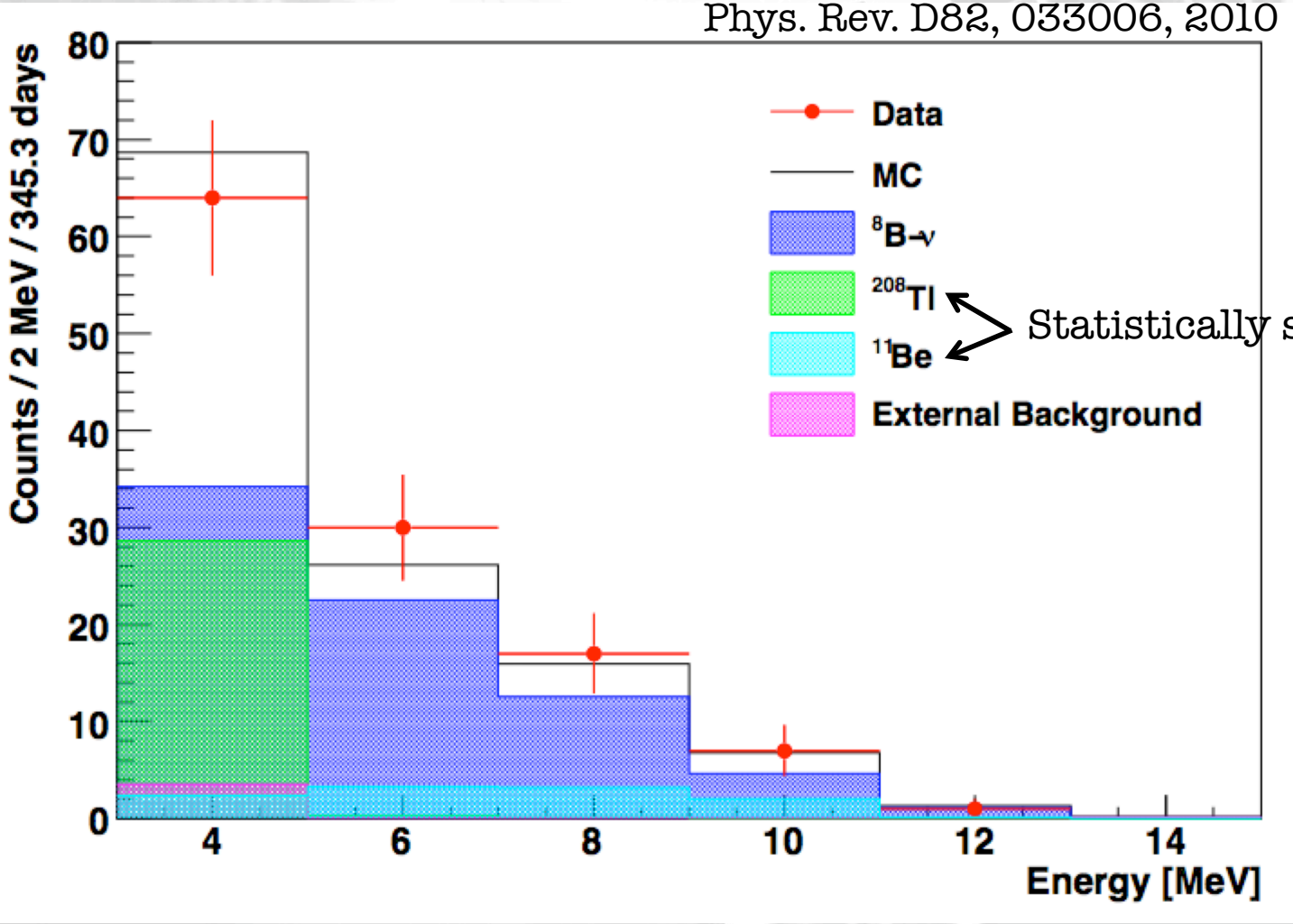

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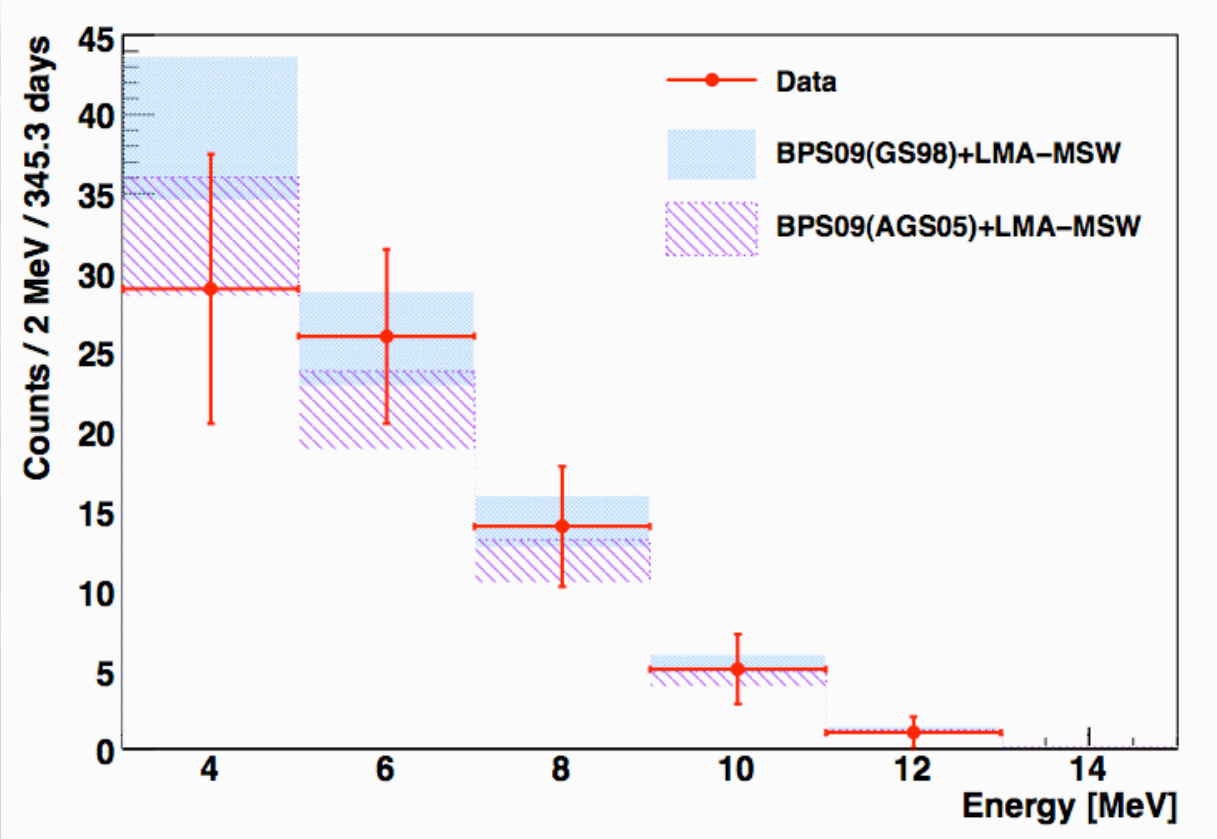
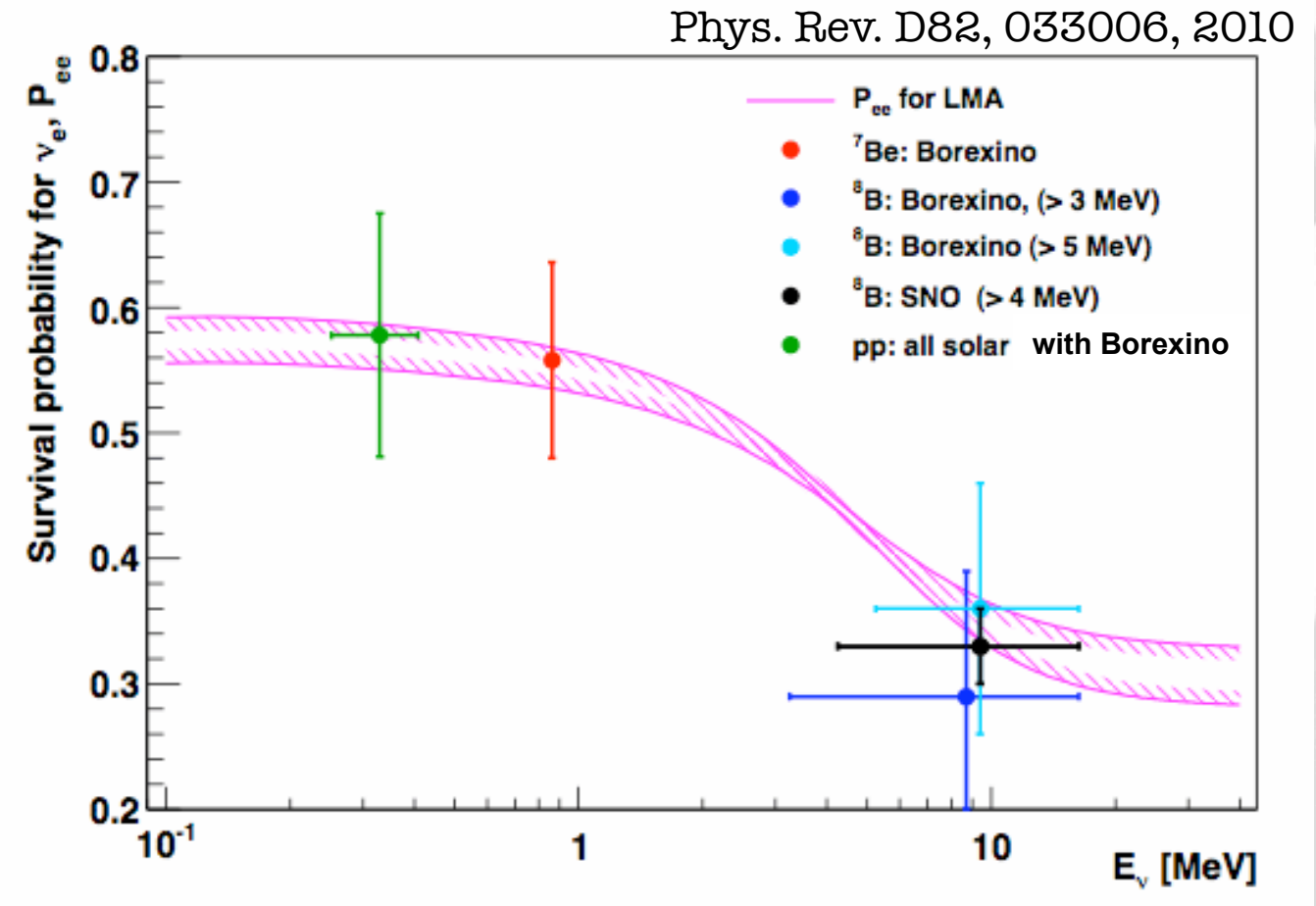


R_{8B} (E>3MeV) = 0.217 ± 0.038$_{stat}$ ± 0.008$_{sys}$ c/d/100 tons

R_{8B} (E>5MeV) = 0.134 ± 0.022$_{stat}$ ± 0.008$_{sys}$ c/d/100 tons

BOREXINO AND THE MSW-LMA SOLUTION (2010)

Phys. Rev. D82, 033006, 2010



- ^{7}Be + constraint on pp: experimental evidence in the vacuum region!!!
- ^{8}B: 2 new points in the matter region!!!

BOREXINO AND THE MSW-LMA SOLUTION (2010)

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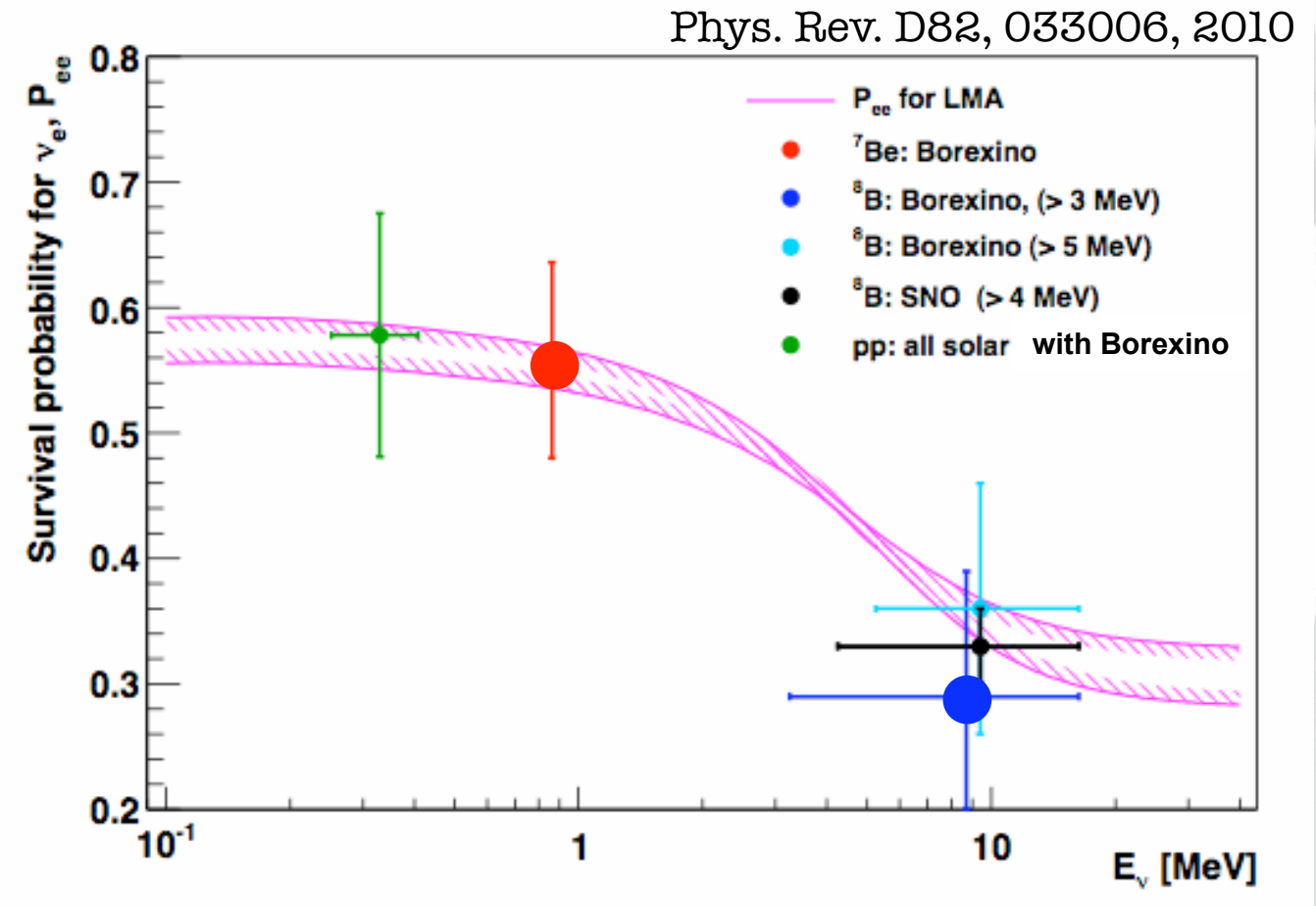

$$P_{ee}(^7Be) / P_{ee}(^8B) = 1.93 \pm 0.75$$

Vacuum/matter ratio @ 1.9 σ level !!

Using data from the same apparatus !!

WHAT ELSE?? DAY-NIGHT ASYMMETRY !!

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

- **MSW mechanism:** ν_μ interaction in the Earth could lead to a ν_e **regeneration effect**
- The size of the effect depends on:
  - detector **latitude**
  - neutrino **energy**
  - oscillation **parameters**
- Very **small effect expected with MSW-LMA**:
  - LOW solution predicts a large ADN effect
  - LMA and LOW predict similar ^{7}Be absolute values but very different ADN

Observable	LMA (±3 σ)	LOW (± 3 σ)
^{7}Be-ν_e P_{ee}	$0.64\ ^{+0.09}_{-0.05}$	0.58 ± 0.05
ADN(%) ^{7}Be	$0.0\ ^{+0.1}_{-0.0}$	$23\ ^{+10}_{-13}$

J. Bahcall et al., JHEP07(2002)05

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ν_e flux during night (average over 1 year)

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ADN STUDY IN BOREXINO

Although already excluded by reactor+radiochemical data, **Borexino alone** can add an independent confirmation.

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

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

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

Borexino alone validates the MSW-LMA model!!!

New analysis in progress with 2/3 times better sentitivity

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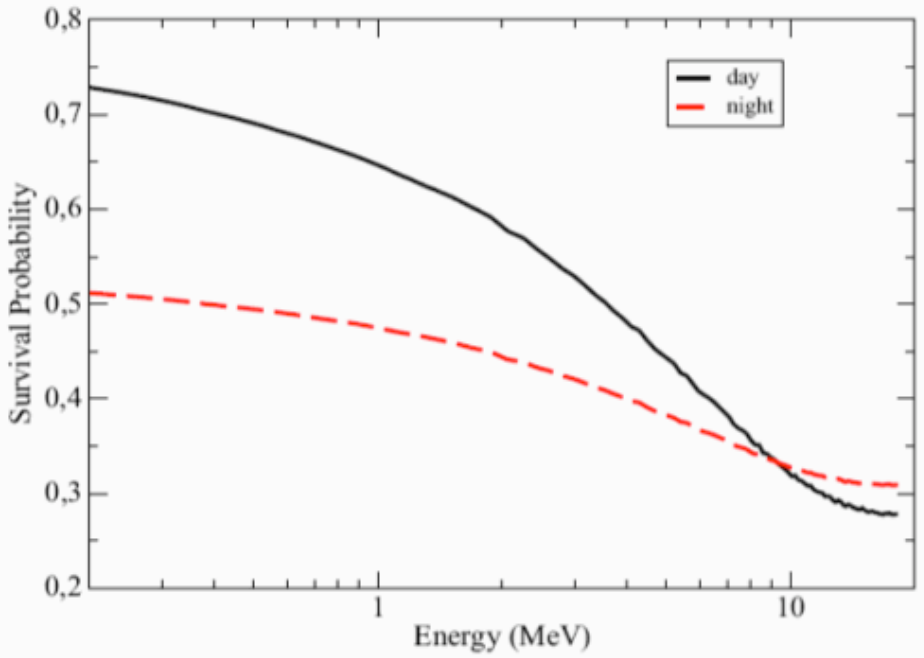
Preliminary

New analysis in progress with 2/3 times better sentitivity

ADN MAY PROBE NEW PHYSICS

Mass Varying Model

P. C. de Holanda, arXiv:0811:0567v1 (nov 2008)



Very large predicted effect:

ADN = -23%

(note negative sign!)

Borexino alone excludes the MassVarying Model !!!

AND FOR THE FUTURE?!
^{8}B and ^{7}Be NEUTRINOS!!

- Reduce the error on **^{7}Be** flux down to **5%**

➔ better constraint also on **pp neutrinos**

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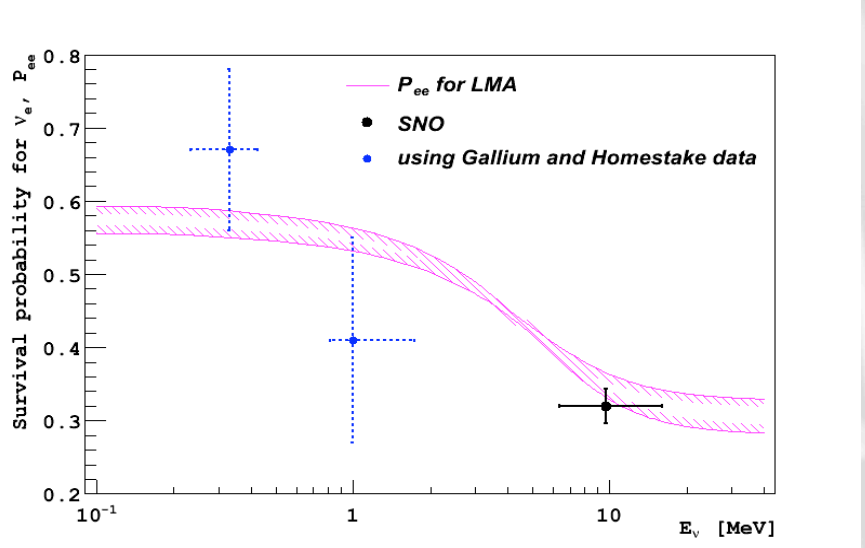

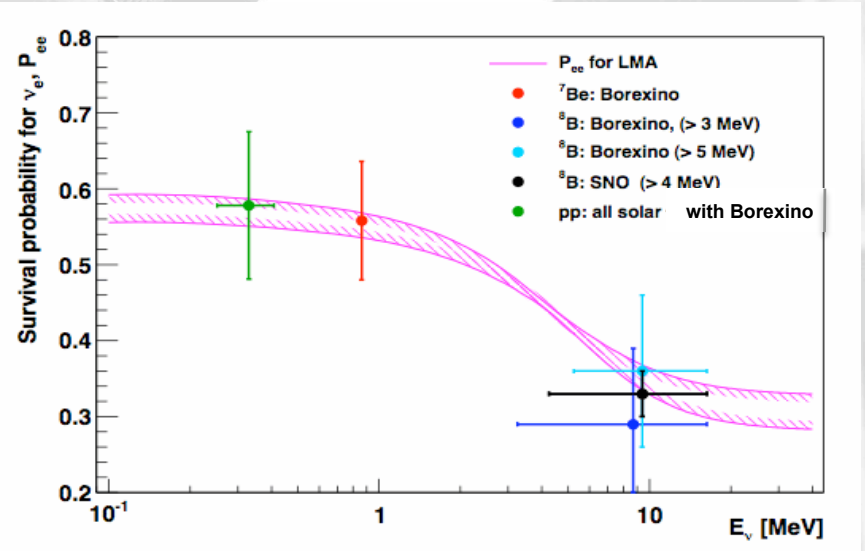

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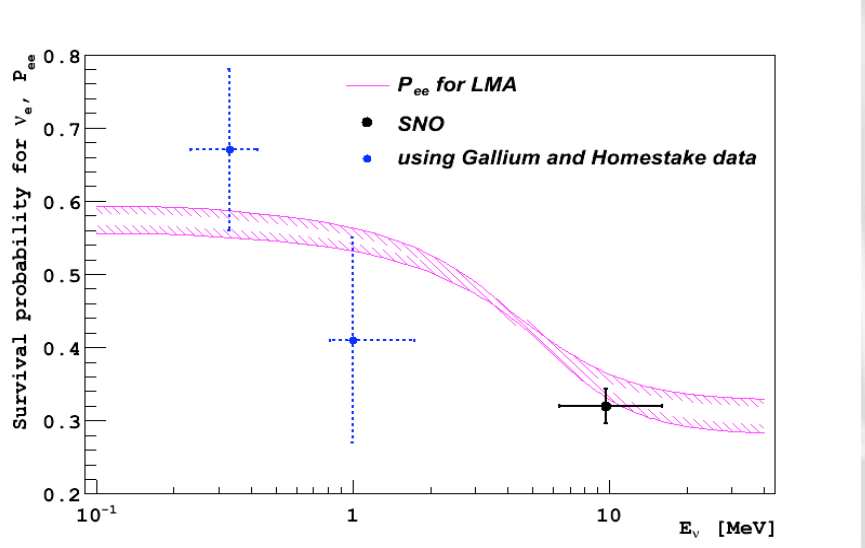
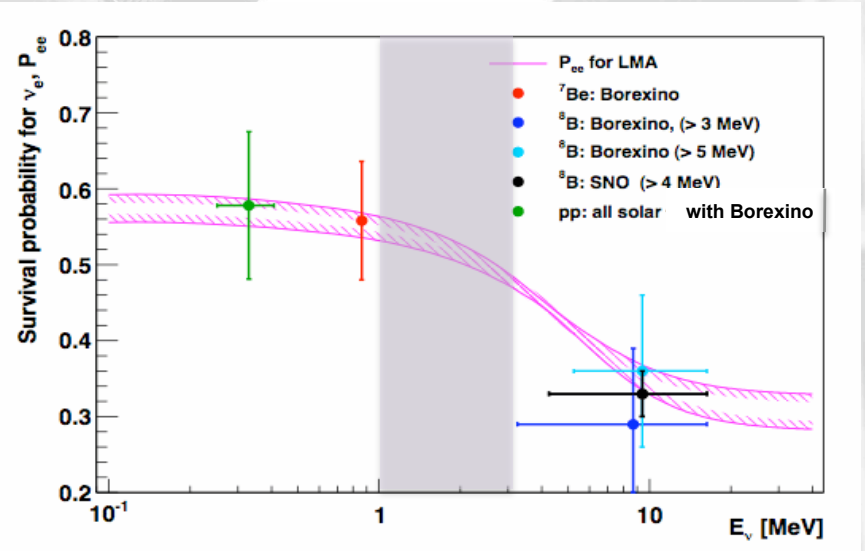
^{8}B and ^{7}Be NEUTRINOS!!

➢ Reduce the error on **^{7}Be** flux down to **5%**
➔ better constraint also on **pp neutrinos**

➢ Reduce the energy threshold on **^{8}B** neutrino measurment down to **2MeV**
➔ approching the inexplored region between 1 and 3 MeV !!!





AND FOR THE FUTURE?!
^{7}Be, ^{8}B and pep NEUTRINOS!!

- Reduce the error on **^{7}Be** flux down to **5%**

➔ better constraint also on **pp neutrinos**

- Reduce the energy threshold on **^{8}B** neutrino measurments down to **2MeV**

➔ approching the inexplored region between 1 and 3 MeV !!!

- **Pep measurement:** fundamental test of P_{ee} in an inexplored energy region!!