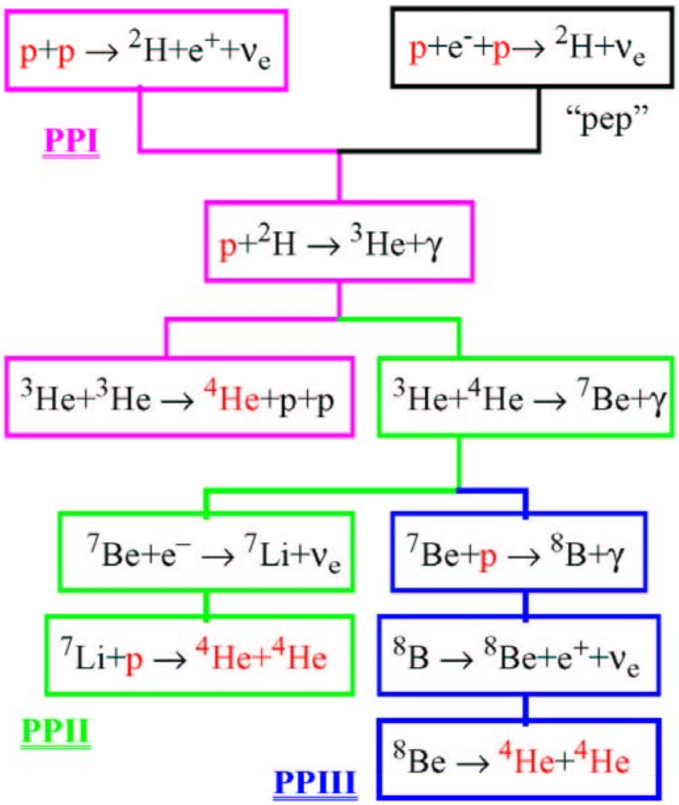
The first year of Borexino data

Heavy Quarks and Leptons
June 5-9, 2008 - Melbourne (Victoria)

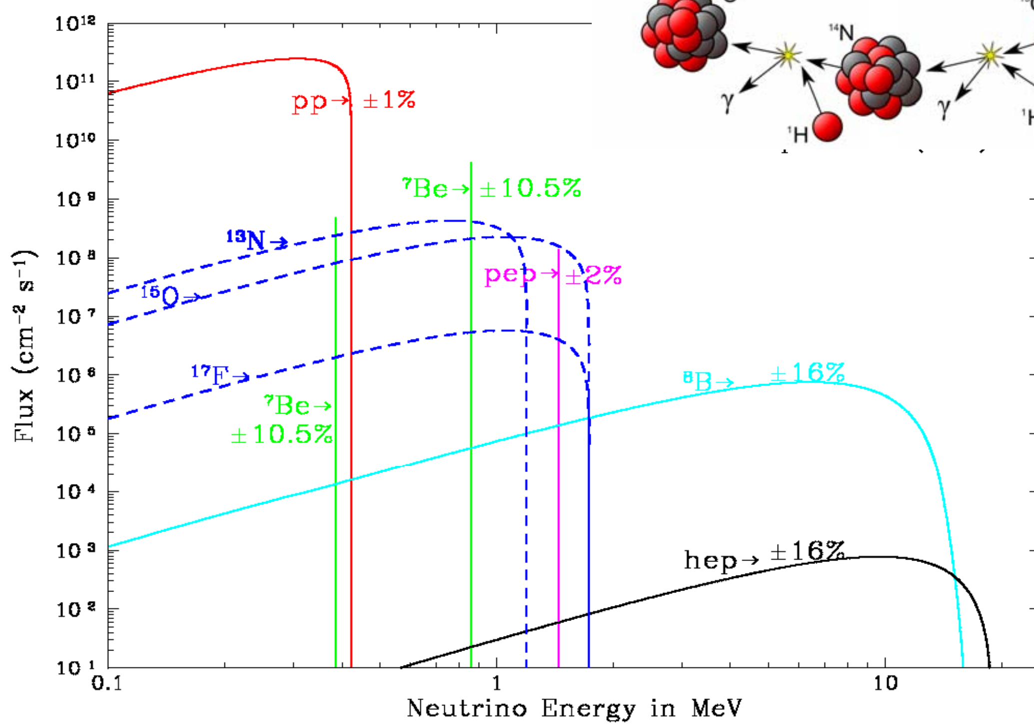
Davide Franco
on behalf of the Borexino Collaboration
Milano University & INFN

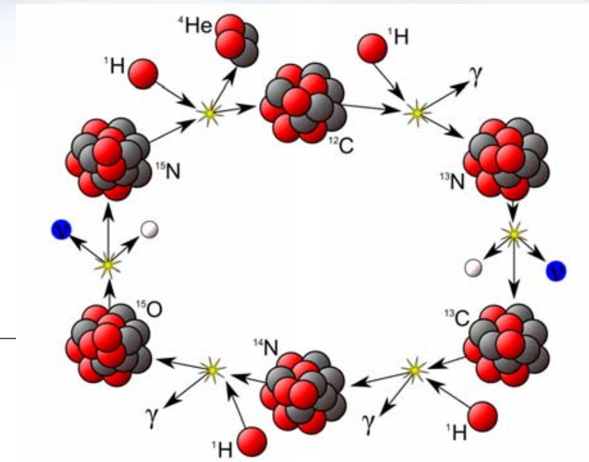
Neutrino Production In The Sun

pp chain:
pp, *pep*, ^{7}Be, and ^{8}B ν

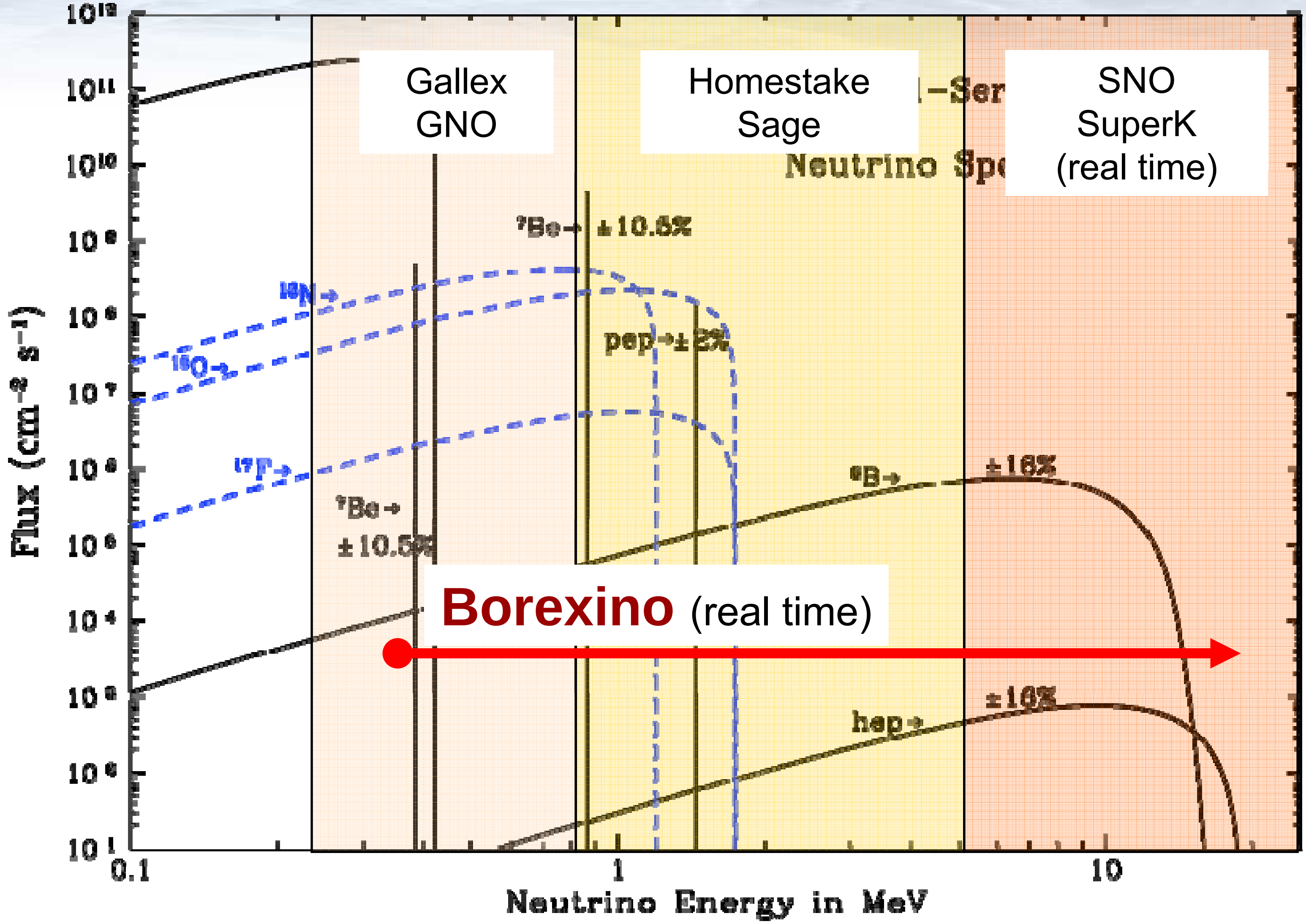


CNO cycle:
^{13}N, ^{15}O, and ^{17}F ν





Solar Neutrino Spectra



The Solar Physics with Borexino

One fundamental input of the Standard Solar Model is the **metallicity** of the Sun - abundance of all elements above Helium:

• The Standard Solar Model, based on the old metallicity derived by Grevesse and Sauval (Space Sci. Rev. **85**, 161 (1998)), is **agreement within 0.5 in %** with the solar sound speed measured by helioseismology.

• Latest work by Asplund, Grevesse and Sauval (Nucl. Phys. A **777**, 1 (2006)) indicates a metallicity **lower by a factor ~2**. This result destroys the agreement with helioseismology

[cm^{-2} s^{-1}]	pp (10^{10})	pep (10^{10})	hep (10^{3})	^{7}Be (10^{9})	^{8}B (10^{6})	^{13}N (10^{8})	^{15}O (10^{8})	^{17}F (10^{6})
BS05 AGS 98	6.06	1.45	8.25	4.84	5.69	3.07	2.33	5.84
BS05 AGS 05	5.99	1.42	7.93	4.34	4.51	2.01	1.45	3.25
Δ	-1%	-2%	-4%	-12%	-23%	-42%	-47%	-57%

Solar neutrino measurements can solve the problem!

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Solar Physics Goals

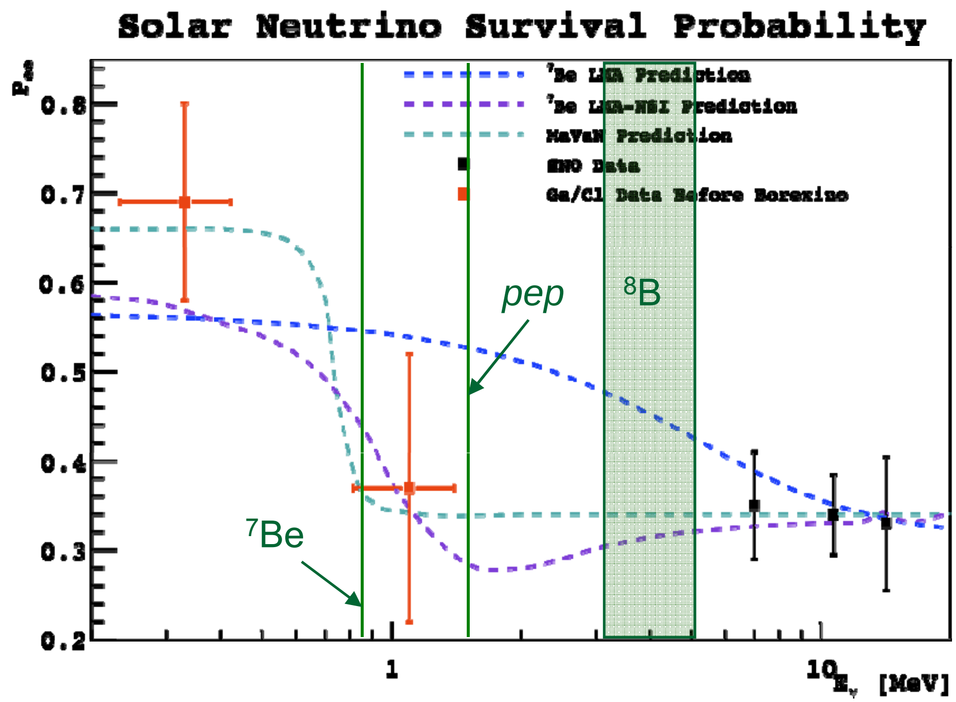
- First ever observations of **sub-MeV neutrinos** in real time
- Check the balance between photon **luminosity** and neutrino luminosity of the Sun
- **CNO** neutrinos (direct indication of metallicity in the Sun's core)
- ***pep*** neutrinos (indirect constraint on *pp* neutrino flux)
- Low energy (**3-5 MeV**) ^{8}B neutrinos
- Tail end of ***pp* neutrino spectrum**?

Neutrino Physics Goals

Test of the **matter-vacuum oscillation transition** with ^{7}Be, *pep,* and low energy ^{8}B neutrinos

Check of the **mass varying neutrino model** (Barger et al., **PRL** 95, 211802 (2005))

Limit on the **neutrino magnetic moment** by analyzing the 7Be energy spectrum and with Cr source



Moreover: **geoneutrinos** and **supernovae**

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Borexino Collaboration

Genova

Milano

Perugia

APC Paris

Princeton University

Virginia Tech. University

INFN

LNGS Laboratori Nazionali del Gran Sasso

Istituto Nazionale di Fisica Nucleare INFN

Dubna JINR (Russia)

Kurchatov Institute (Russia)

Jagiellonian U. Cracow (Poland)

Max-Planck-Institut für Kernphysik

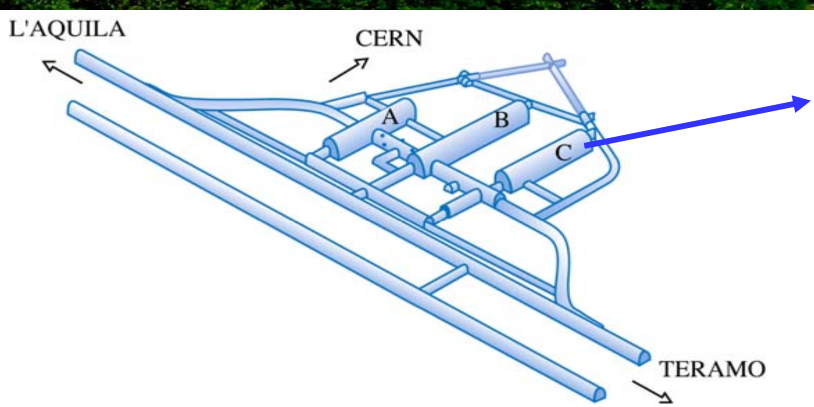
Heidelberg (Germany)

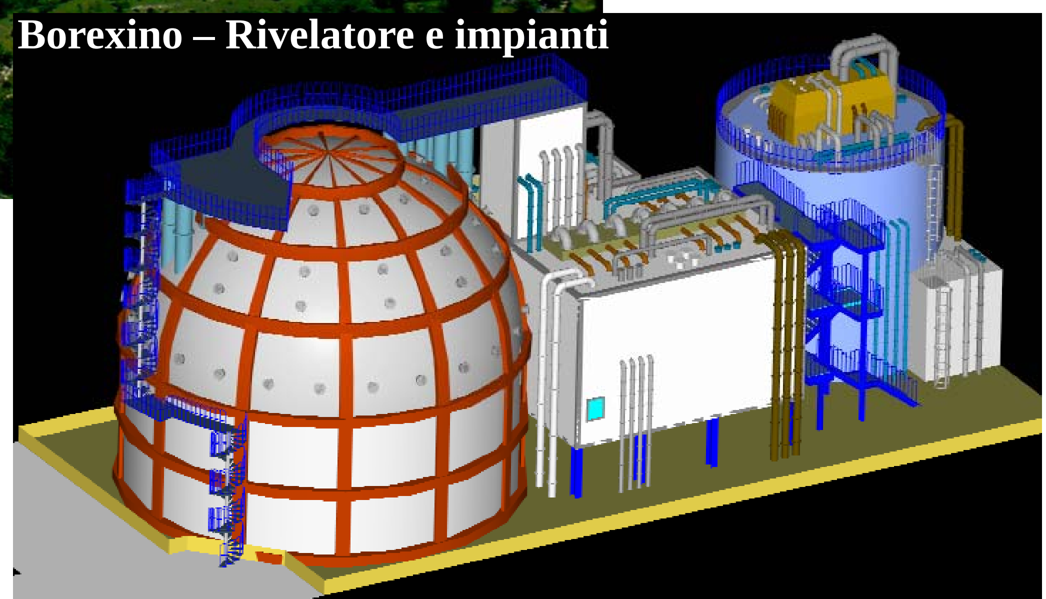
Technische Universität München

Munich (Germany)

Laboratori Nazionali del Gran Sasso

Assergi (AQ) Italy
~3500 m.w.e





Detection principles and ν signature

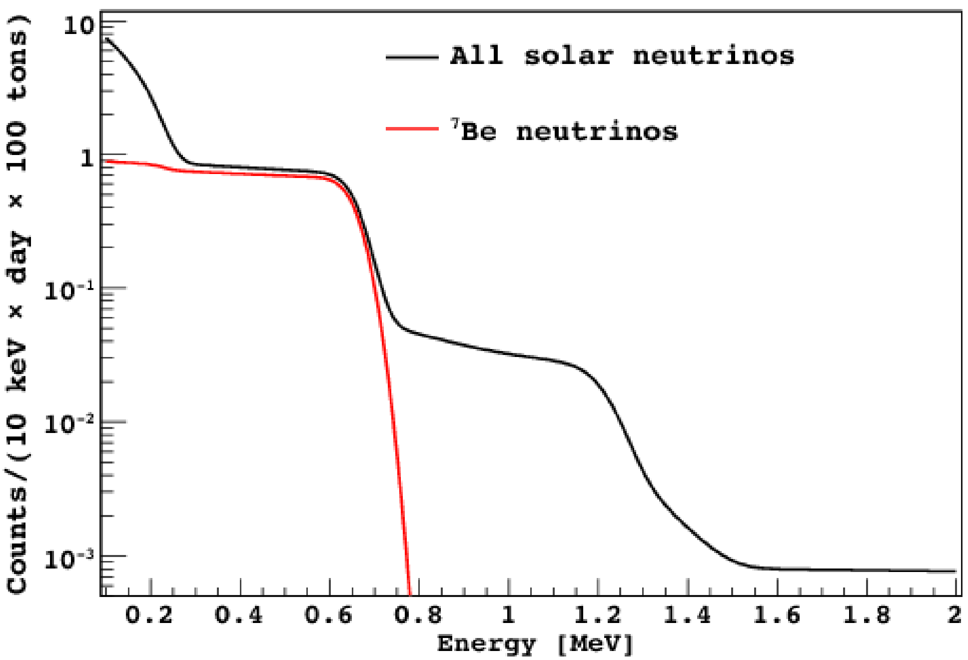
- Borexino detects solar ν via their **elastic scattering off electrons** in a volume of **highly purified** **liquid scintillator**
  - Mono-energetic **0.862 MeV ^{7}Be** ν are the main target, and the only considered so far
  - Mono-energetic pep ν , CNO ν and possibly pp ν will be studied in the future

- Detection via scintillation light:
  - Very low energy threshold
  - Good position reconstruction
  - Good energy resolution

  BUT…
  - No direction measurement
  - The ν induced events can't be distinguished from other β events due to natural radioactivity

- **Extreme radiopurity of the scintillator is a must!**

Typical ν rate (SSM+LMA+Borexino)



Borexino Background

Expected solar neutrino rate in 100 tons of scintillator ~ 50 counts/day (**~ 5 10^{-9} Bq/Kg**)

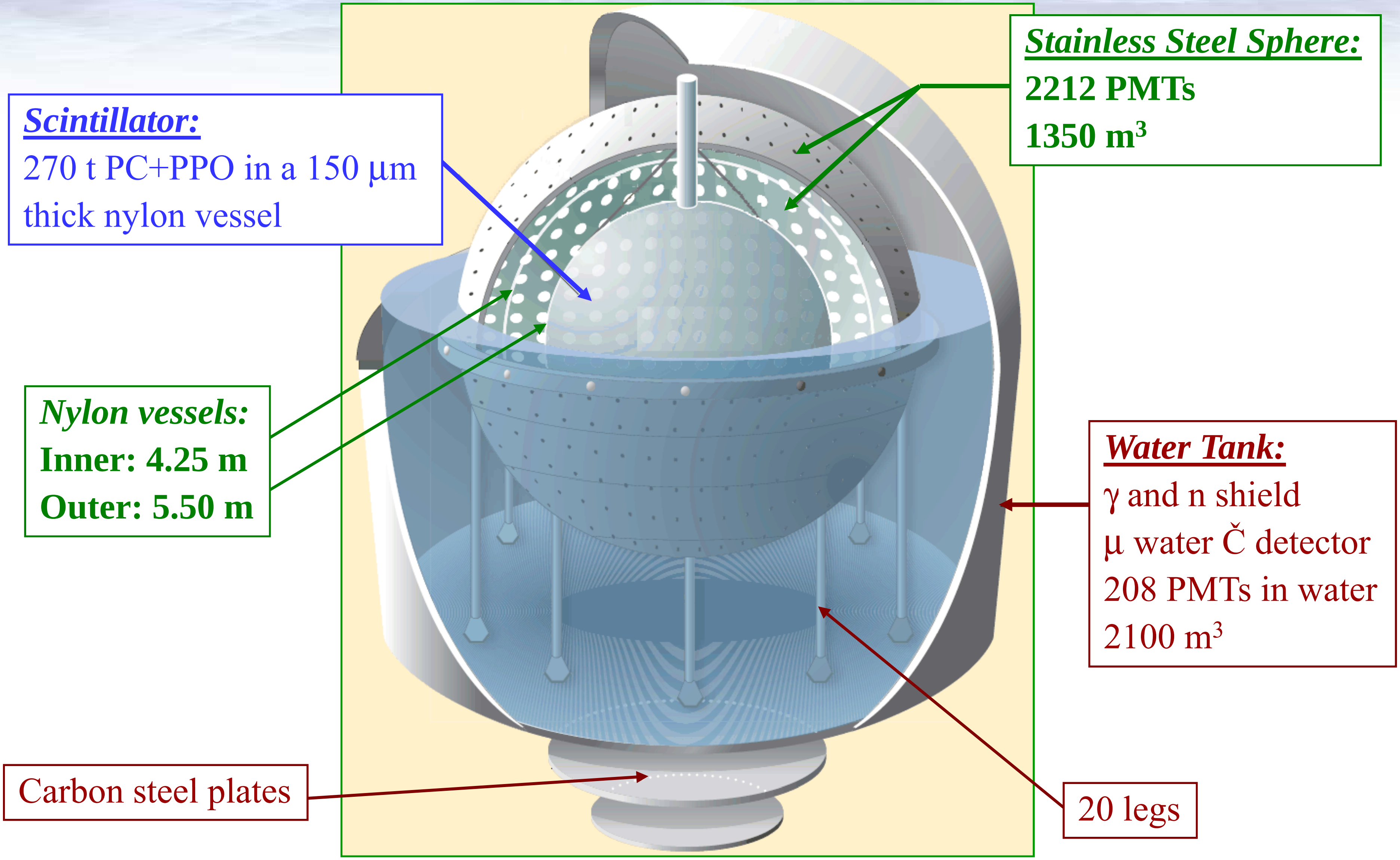
Just for comparison:

Natural water	~ 10 Bq/Kg in ^{238}U, ^{232}Th and ^{40}K
Air	~ 10 Bq/m^3 in ^{39}Ar, ^{85}Kr and ^{222}Rn
Typical rock	~ 100-1000 Bq/m^3 in ^{238}U, ^{232}Th and ^{40}K

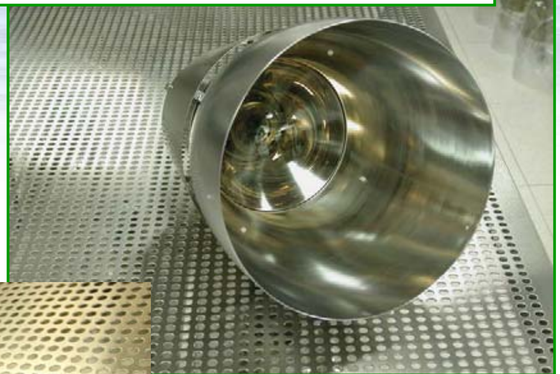
BX scintillator must be **9/10 order of magnitude less** radioactive than anything on earth!

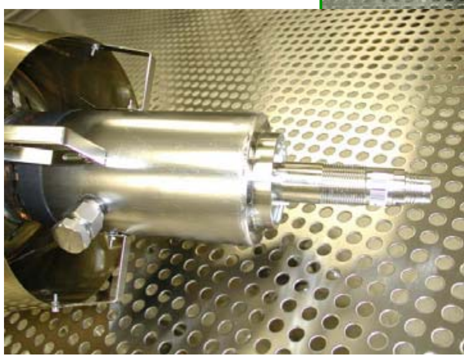
- **Low background nylon vessel** fabricated in hermetically sealed low radon clean room (~1 yr)
- **Rapid transport** of scintillator solvent (PC) from production plant to underground lab to avoid cosmogenic production of radioactivity (^7Be)
- Underground **purification plant** to distill scintillator components.
- **Gas stripping** of scintlllator with special nitrogen free of radioactive ^{85}Kr and ^{39}Ar from air
- All materials **electropolished SS or teflon**, precision cleaned with a dedicated cleaning module

Detector layout and main features

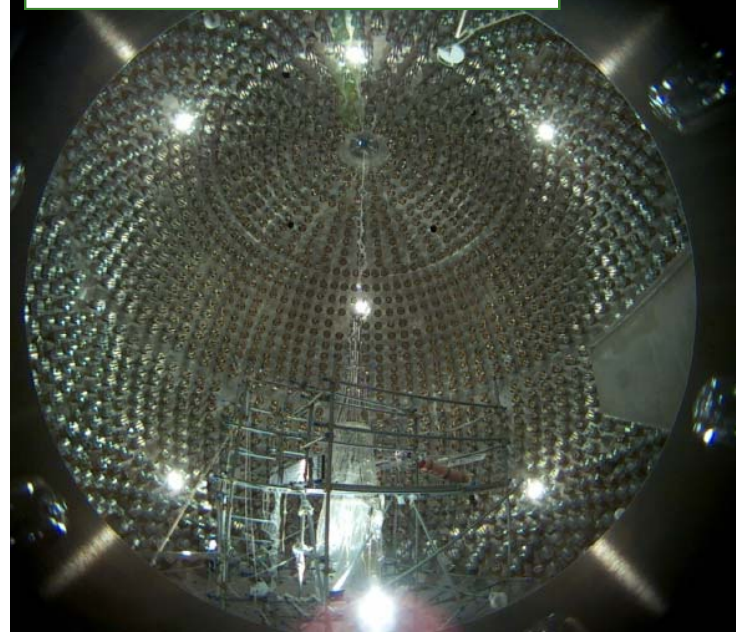


PMTs: PC & Water proof

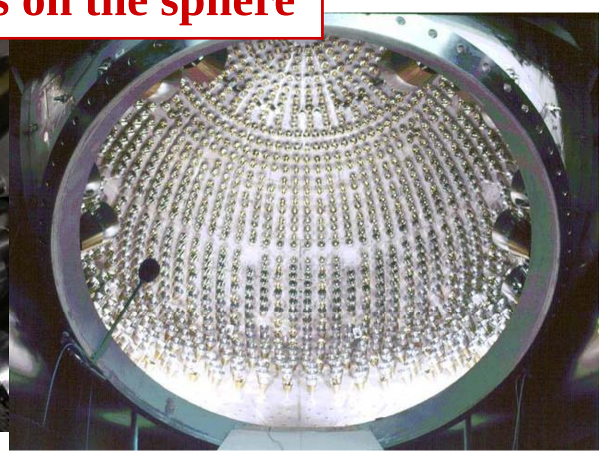




Nylon vessel installation



Installation of PMTs on the sphere



Water Plant

Storage area and Plants

May 15, 2007

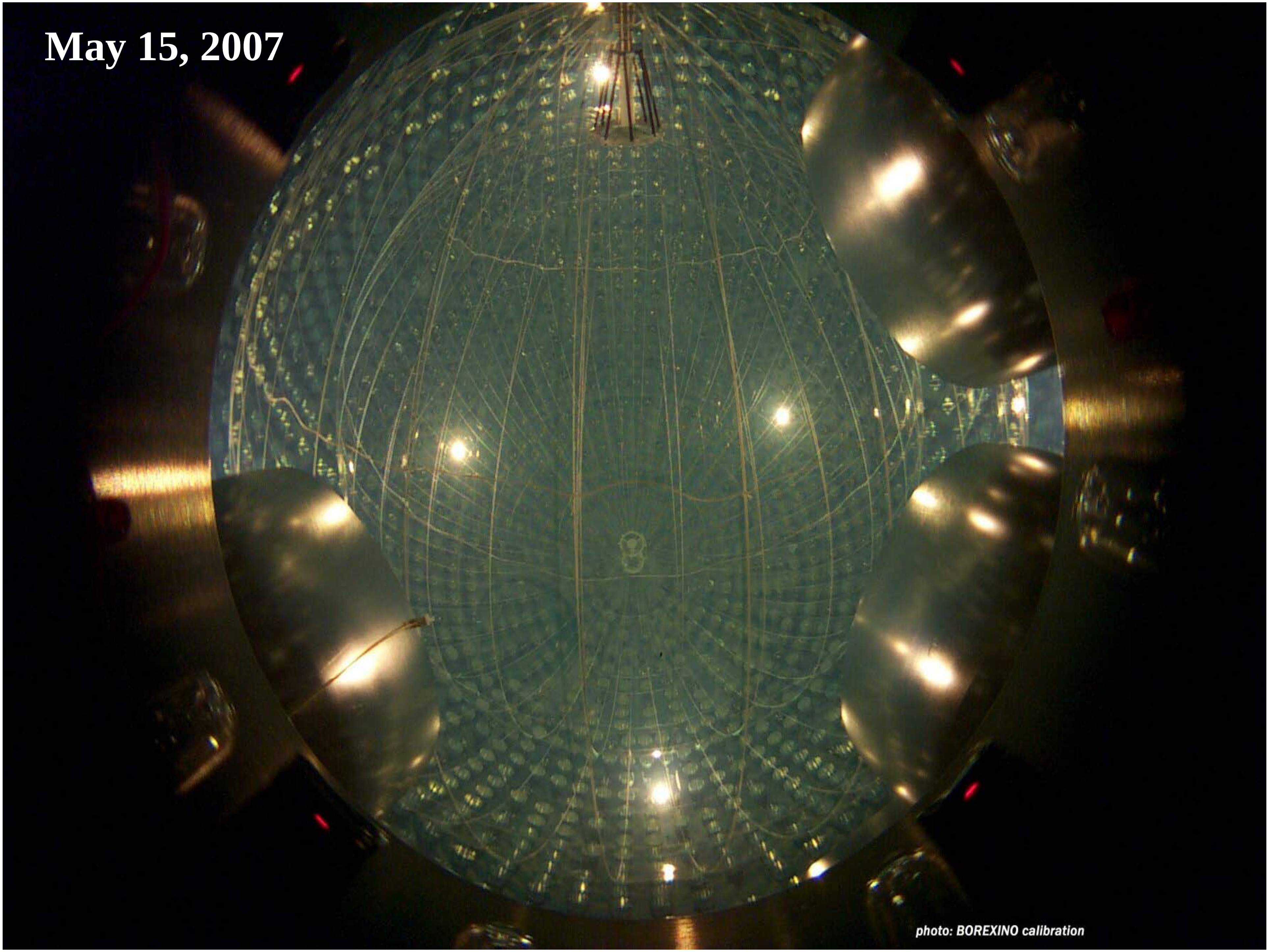
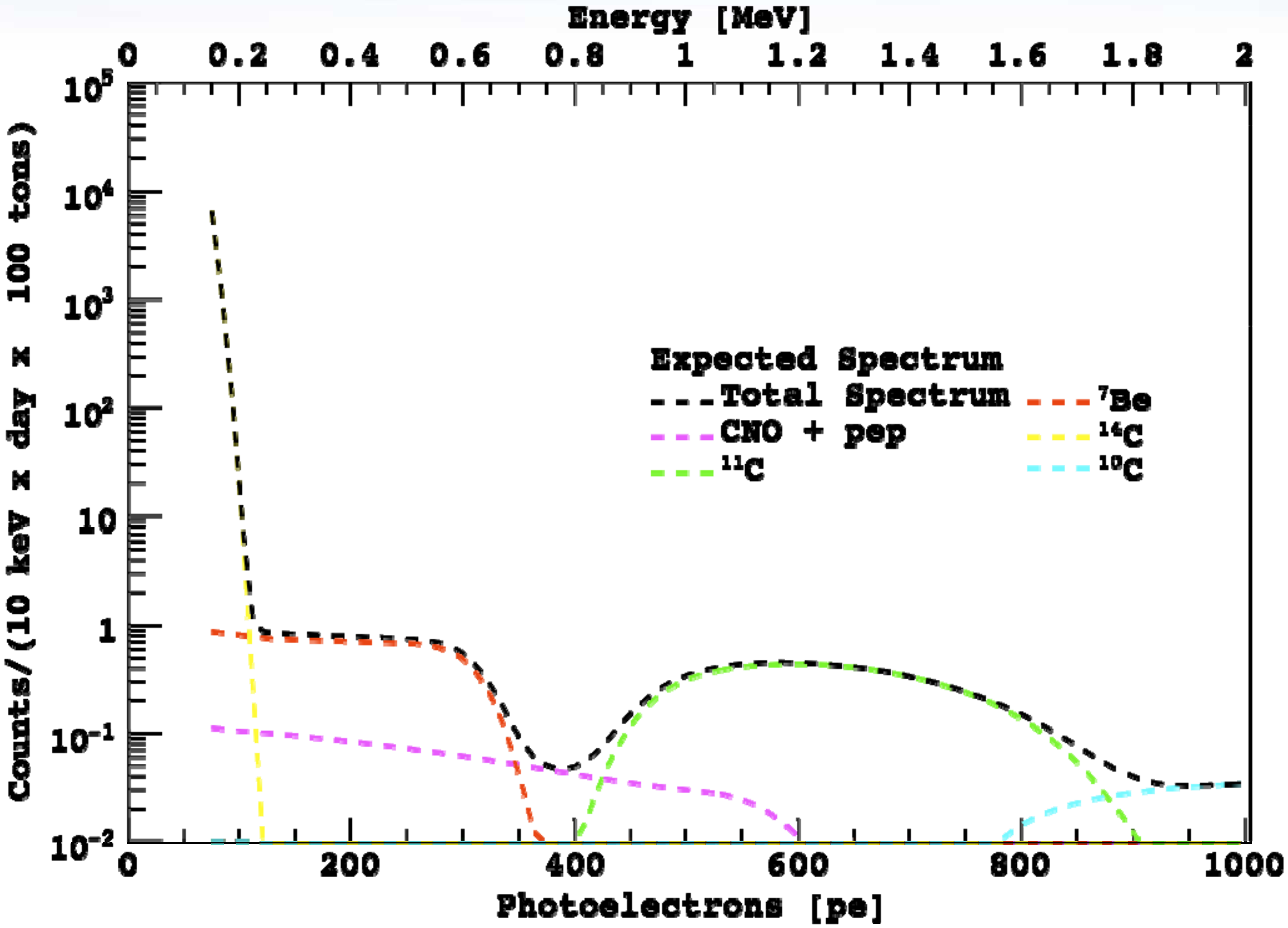


photo: BOREXINO calibration

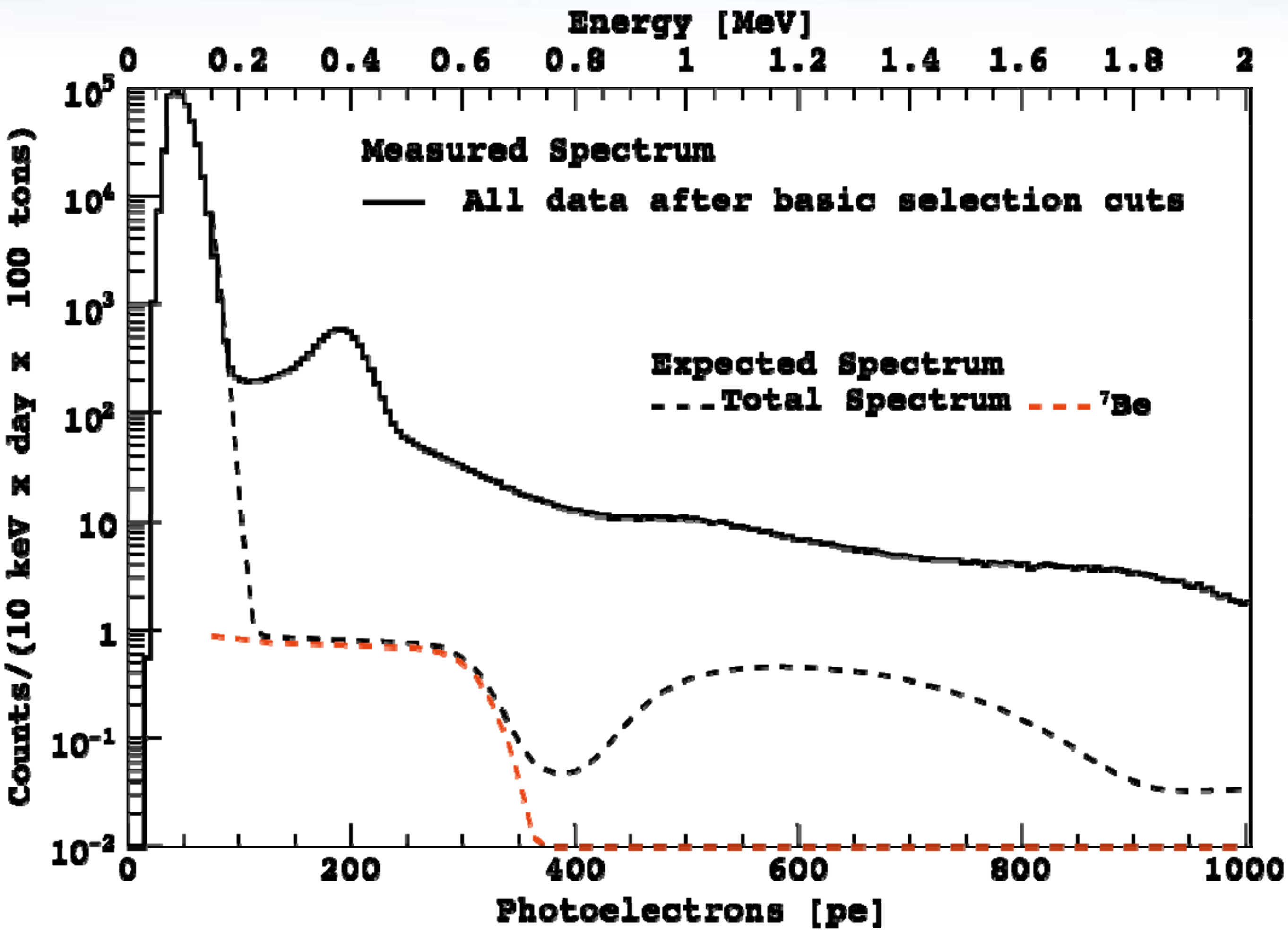
Borexino background

Radiolsotope		Concentration or Flux		Strategy for Reduction		
Name	**Source**	**Typical**	**Required**	**Hardware**	**Software**	**Achieved**
μ	cosmic	~200 s^{-1} m^{-2} at sea level	**~ 10^{-10}**	Underground Cherenkov detector	Cherenkov signal PS analysis	**<10^{-10}** (overall)
Ext. γ	rock			Water Tank shielding	Fiducial Volume	negligible
Int. γ	PMTs, SSS Water, Vessels			Material Selection Clean constr. and handling	Fiducial Volume	negligible
^{14}C	Intrinsic PC/PPO	~ 10^{-12}	**~ 10^{-18}**	Old Oil, check in CTF	Threshold cut	**~ 10^{-18}**
^{238}U **^{232}Th**	Dust Organometallic (?)	~ 10^{-5}-10^{-6} g/g (dust)	**< 10^{-16} g/g** (in scintillator)	Distillation, Water Extraction Filtration, cleanliness		**~ 2 10^{-17}** **~ 7 10^{-17}**
^{7}Be	Cosmogenic (^{12}C)	~ 3 10^{-2} Bq/t	< 10^{-6} Bq/ton	Fast procurement, distillation	Not yet measurable	?
^{40}K	Dust, PPO	~ 2 10^{-6} g/g (dust)	< 10^{-14} g/g scin. < 10^{-11} g/g PPO	Water Extraction Distillation	Not yet measurable	?
^{210}Pb	Surface contam. from ^{222}Rn decay			Cleanliness, distillation	Not yet measurable (NOT in eq. with ^{210}Po)	?
^{210}Po	Surface contam. from ^{222}Rn decay			Cleanliness, distillation	Spectral analysis α/β stat. subtraction	**~ 14** **~ 0.01 c/d/t**
^{222}Rn	air, emanation from materials, vessels	~ 10 Bq/l (air) ~100 Bq/l (water)	< 1 c/d/100 t (scintillator)	Water and PC N_2 stripping, cleanliness, material selection	Delayed coincidence	< 0.02 c/d/t
^{39}Ar	Air (nitrogen)	~17 mBq/m^3 (air)	< 1 c/d/100 t	Select vendor, leak tightness	Not yet measurable	?
^{85}Kr	Air (nitrogen)	~ 1 Bq/m^3 in air	< 1 c/d/100 t	Select vendor, leak tightness (learn how to measure it)	Spectral fit fast coincidence	**= 25±3** **= 29±14**

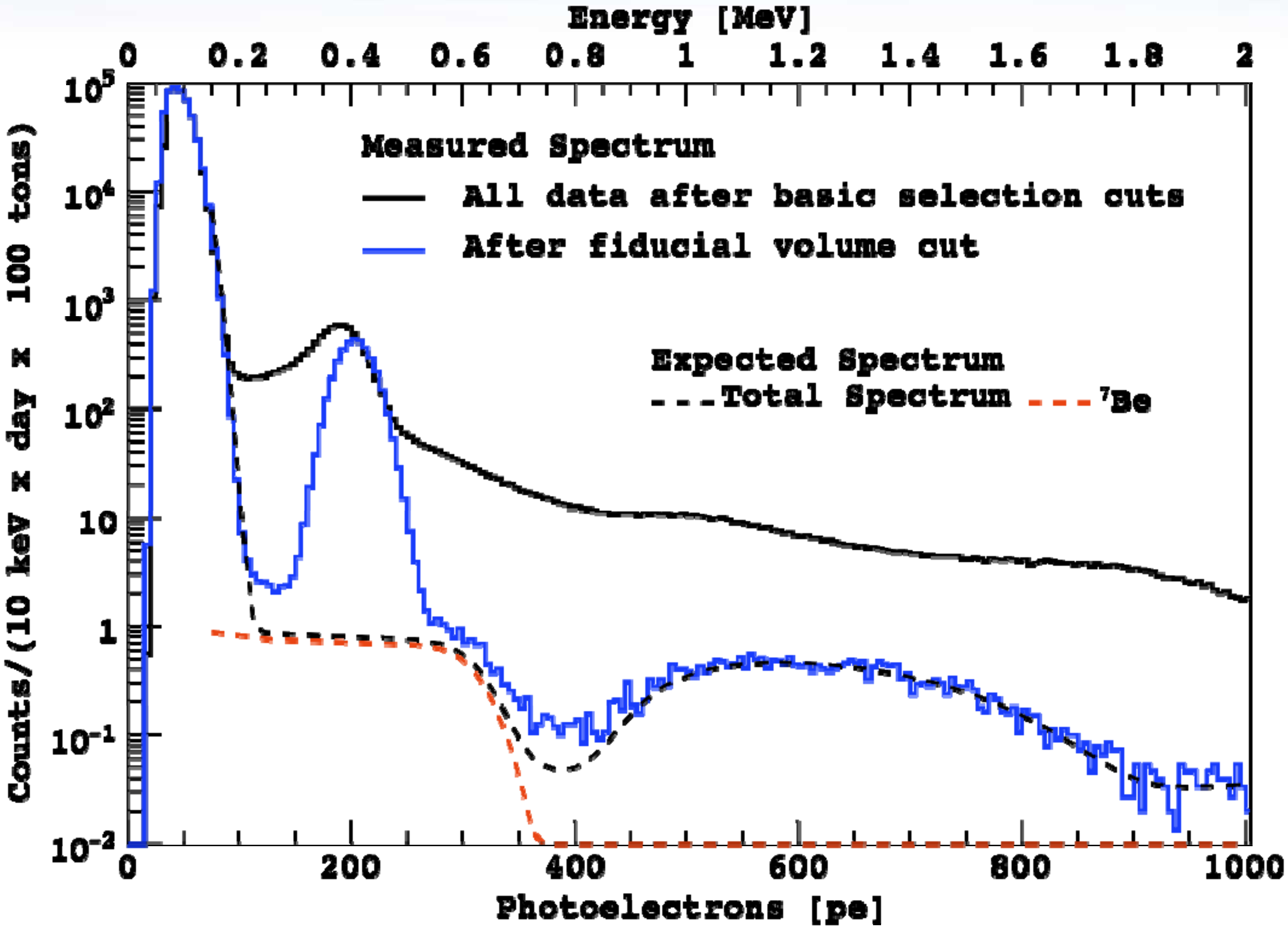
Expected Spectrum

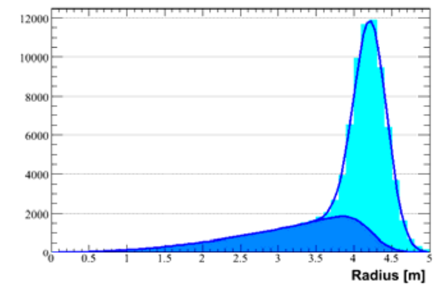


The starting point: no cut spectrum

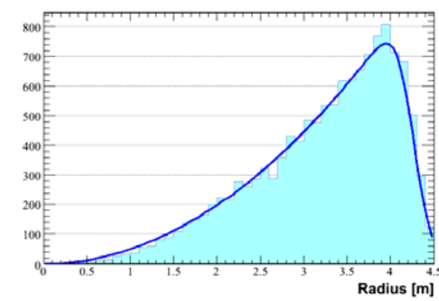


Spectrum after FV cut (100 tons)





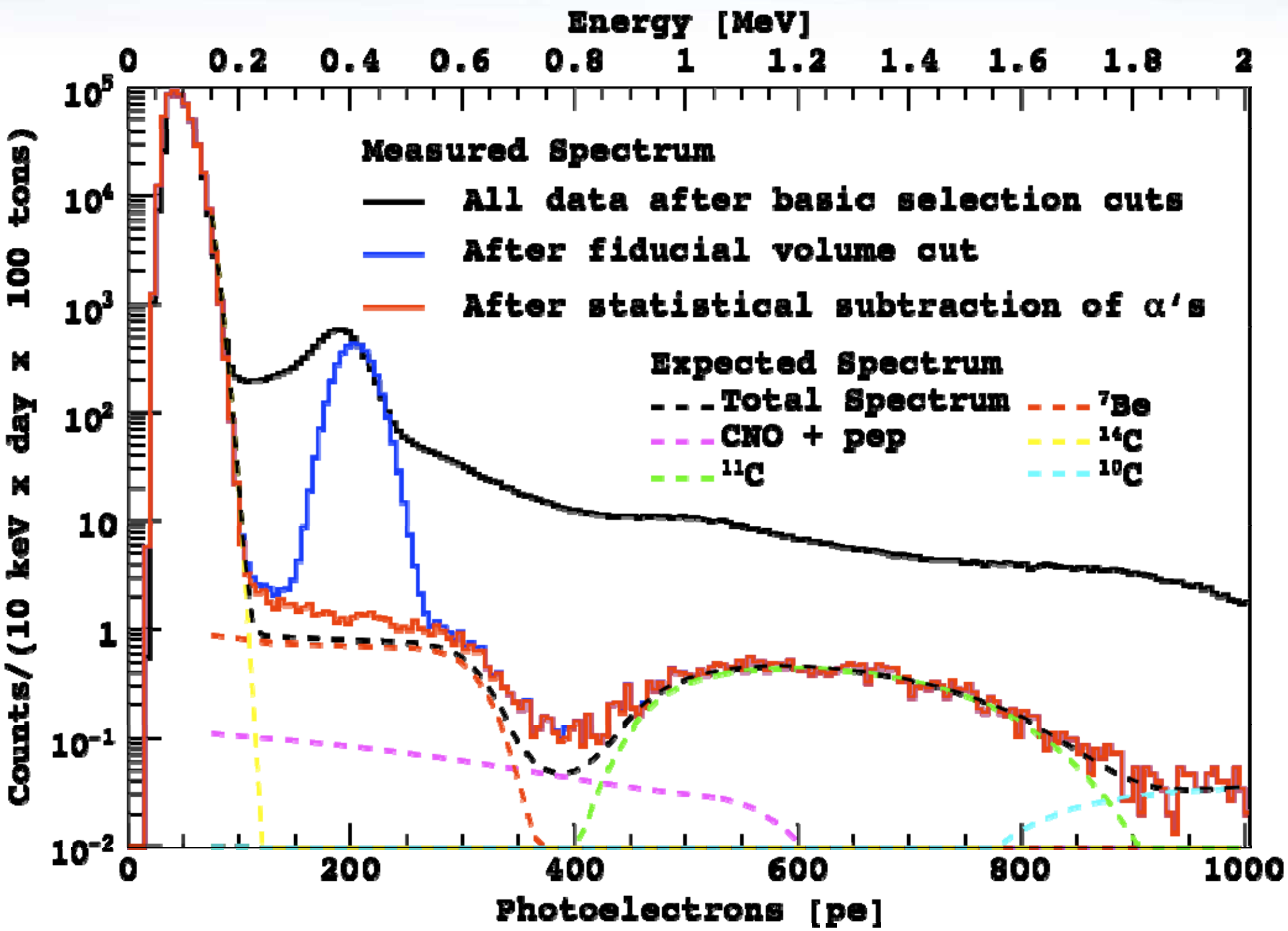
Radial distribution in the ^{7}Be energy range

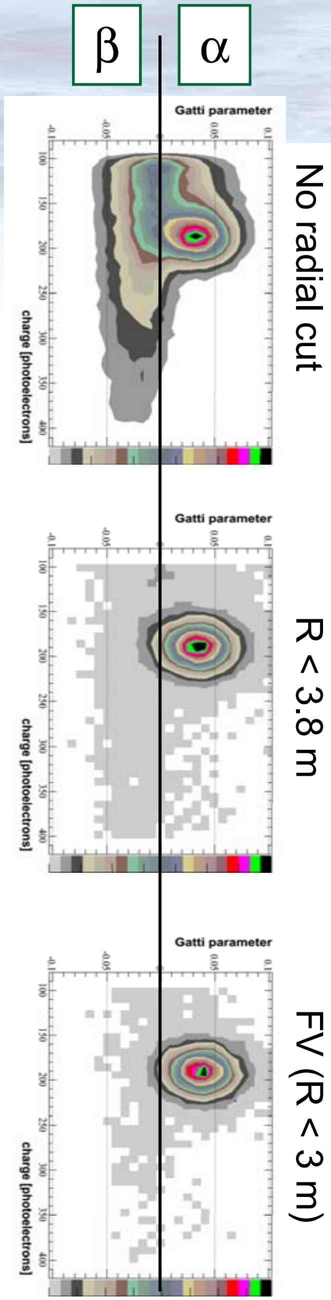


Radial distribution of muon induced neutrons

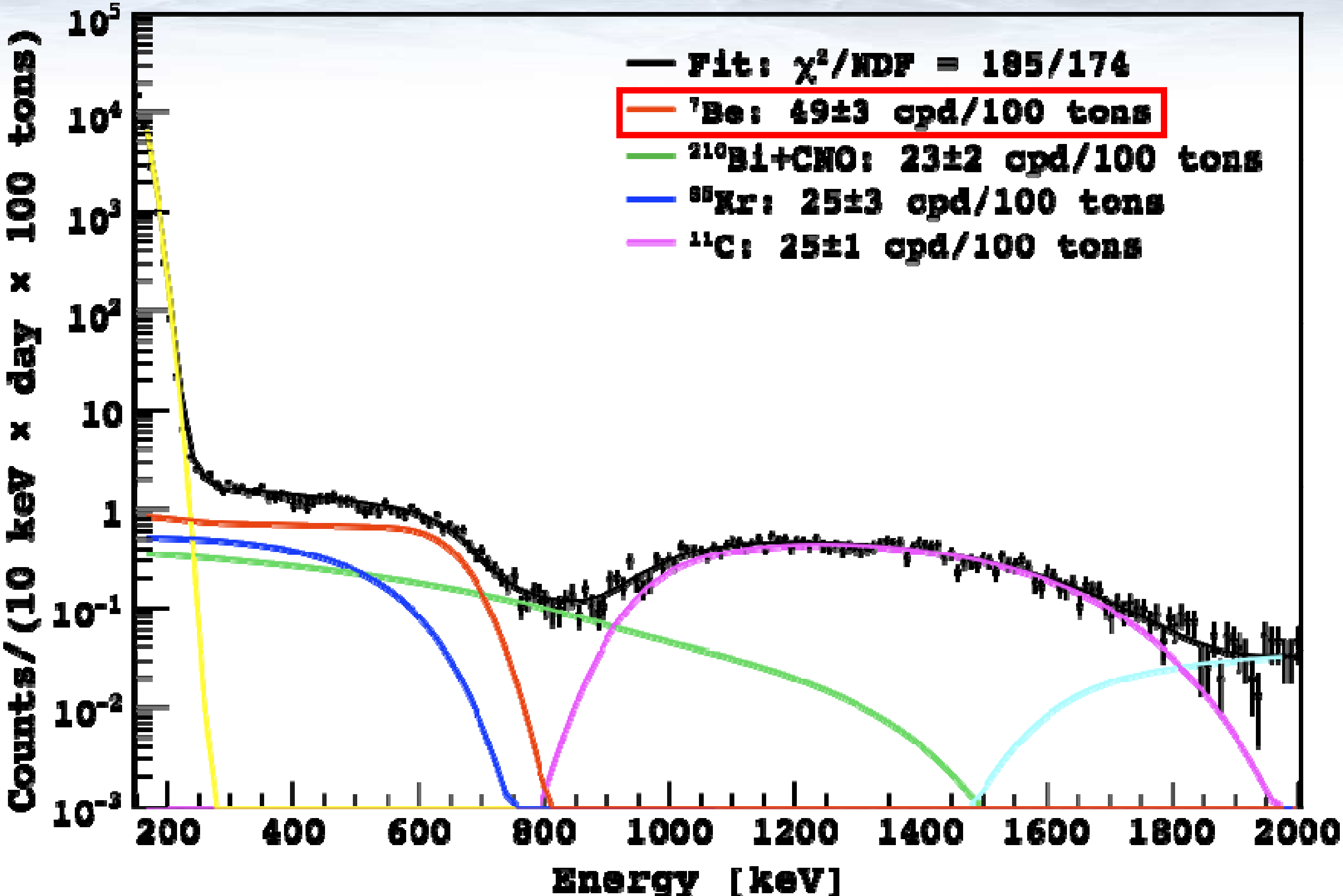
α/β statistical subtraction

pulse shape analysis





New results with 192 days of statistics



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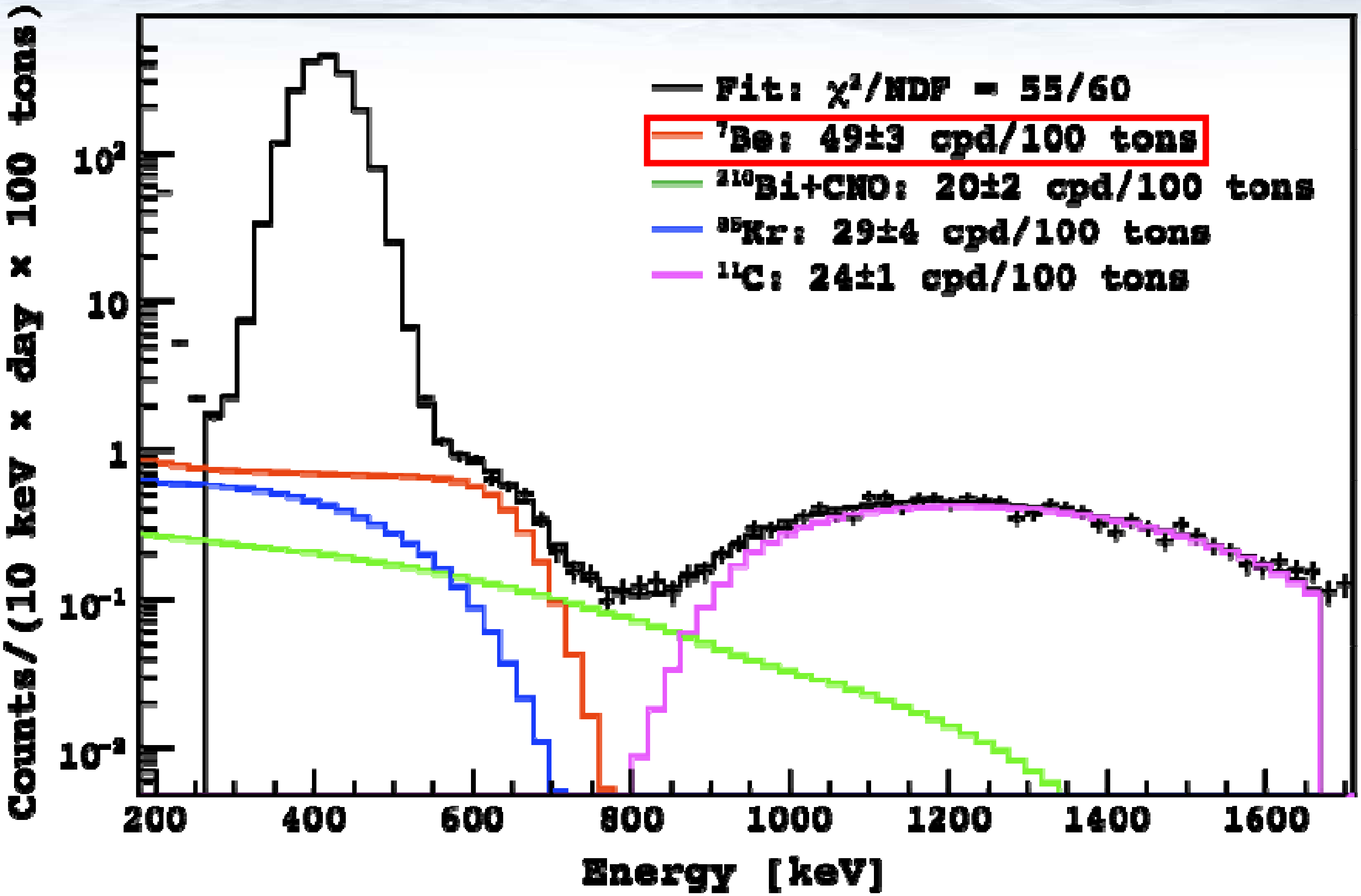


Systematic and Final Result

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

Expected interaction rate in absence of oscillations:
75±4 cpd/100 tons

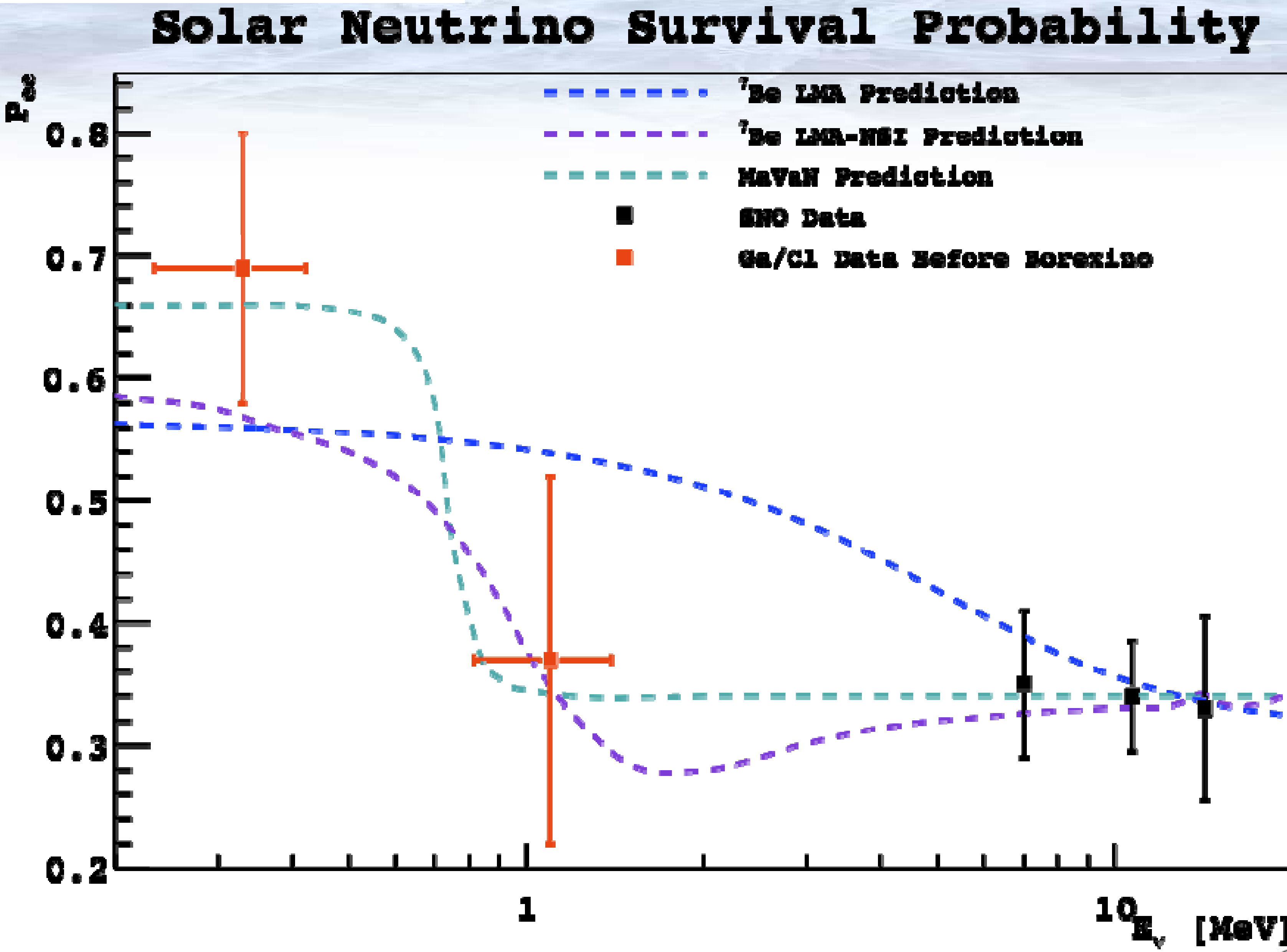
for LMA-MSW oscillations:
48±4 cpd/100 tons, which means:

$$f_{Be} = 1.03^{+0.24}_{-1.03}$$

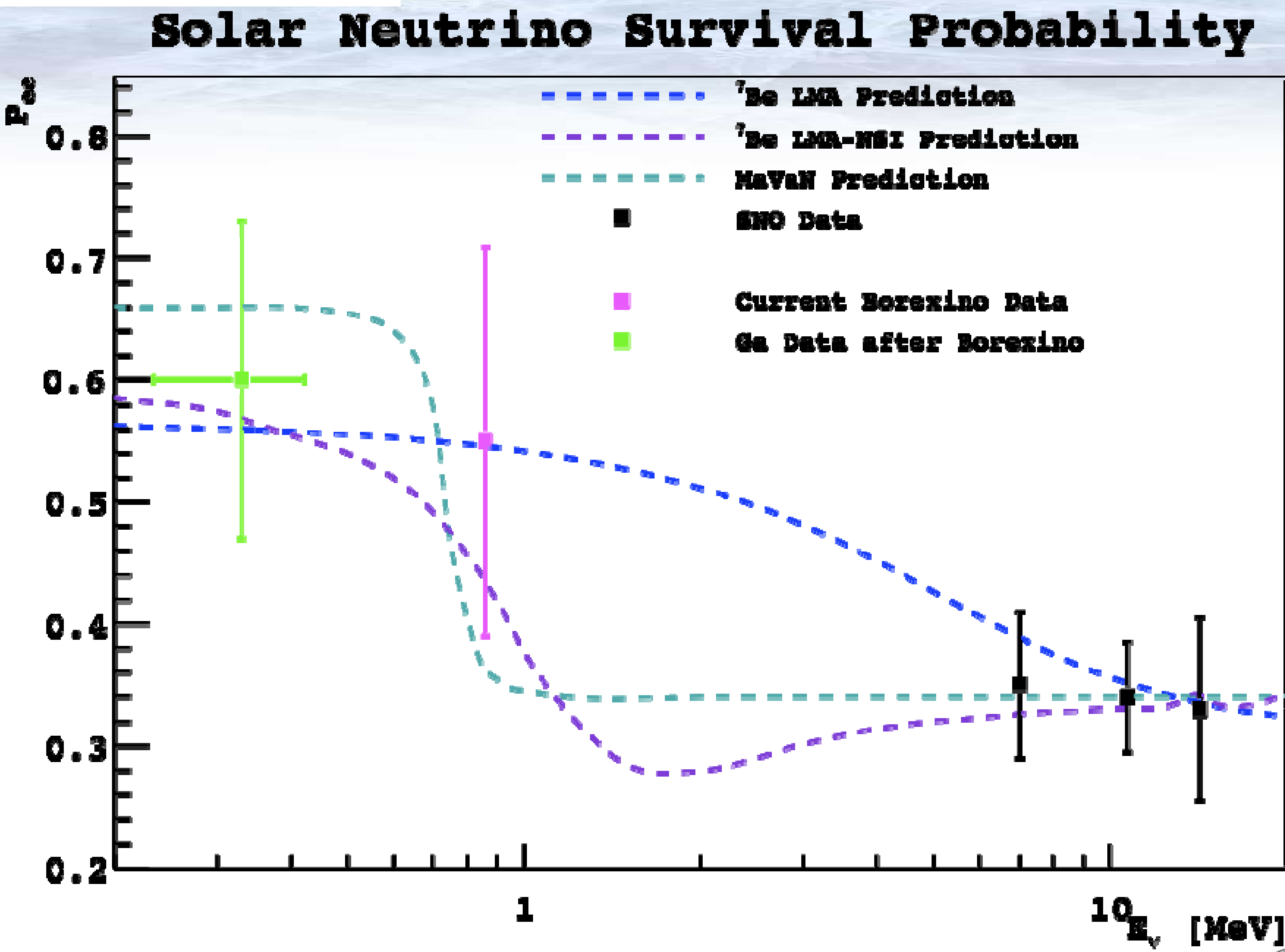
^{7}Be Rate: $49 \pm 3_{stat} \pm 4_{syst}$ cpd/100 tons , which means

$$f_{Be} = 1.02 \pm 0.10$$

Before Borexino



After Borexino



Constraints on *pp* and CNO fluxes

Combining Borexino 7Be results with other experiments,the expected rate in Clorine and Gallium experiments is

$$R_l\ [\mathrm{SNU}] = \sum_i R_{l,i} f_i P_{ee}^{l,i}$$

where

$l = \{\mathrm{Ga}, \mathrm{Cl}\}$

$i = \{pp, pep, \mathrm{CNO}, {}^7\mathrm{Be}, {}^8\mathrm{B}\}$

f_i measured over predicted flux ratio

$P_{ee}^{l,i}$ Survival Probability

- $R_{i,k}$ and $P_{i,k}$ are calculated in the hypothesis of high-Z SSM and MSW LMA
- Rk are the rates actually measured by Clorine and Gallium experiments
- f^8B is measured by SNO and SuperK to be 0.87 ±0.07
- f^7Be =1.02 ±0.10 is given by Borexino results

Plus luminosity constraint: $0.919 f_{pp} + 0.075 f_{\mathrm{Be}} + 0.0068 f_{\mathrm{CNO}} = 1$

$$f_{pp} = 1.004^{+0.008}_{-0.020}$$

$$\mathcal{L}_{\mathrm{CNO}}/\mathcal{L}_{\odot} < 6.2\%\ 3\sigma$$

best determination of pp flux!

Neutrino Magnetic Moment

Neutrino-electron scattering is the most sensitive test for μ_ν search

$$\left(\frac{d\sigma}{dT}\right)_W = \frac{2G_F^2 m_e}{\pi}\left[g_L^2 + g_R^2\left(1-\frac{T}{E_\nu}\right)^2 - g_L g_R \frac{m_e T}{E_\nu^2}\right]$$

EM current affects cross section: spectral shape sensitive to μ_ν sensitivity enhanced at low energies (c.s.≈ 1/T)

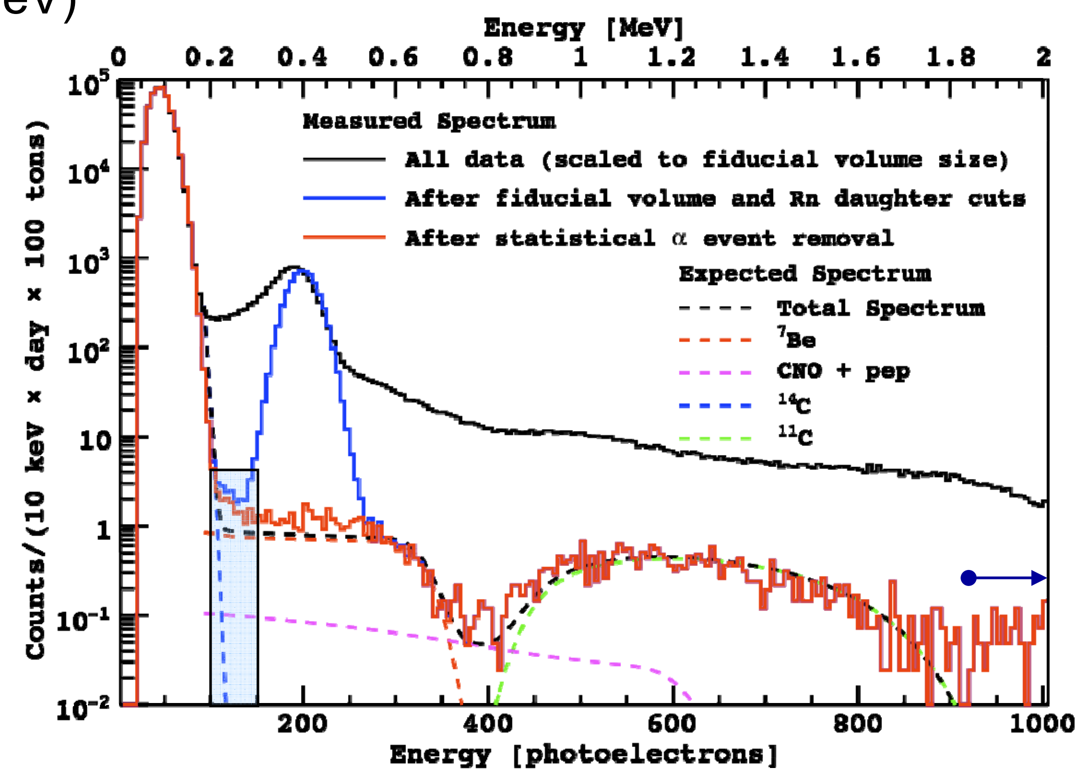
$$\left(\frac{d\sigma}{dT}\right)_{EM} = \mu_\nu^2 \frac{\pi \alpha_{em}^2}{m_e^2}\left(\frac{1}{T}-\frac{1}{E_\nu}\right)$$

A fit is performed to the energy spectrum including contributions from ^{14}C, leaving μ_ν as free parameter of the fit

Estimate	Method	10^{-11} μ_B
SuperK	^8B	<11
Montanino et al.	^7Be	<8.4
GEMMA	Reactor	<5.8
Borexino	^7Be	<5.4

What next?

- *pep* and CNO ν fluxes
  - software algorithm based on a three-fold coincidence analysis to subtract efficiently cosmogenic ^{11}C background
  - Muon track reconstruction
- ^{8}B at low energy region (3-5 MeV)
- pp seasonal variations (?)
- High precision measurements
  - systematic reduction
  - calibrations
- geoneutrinos

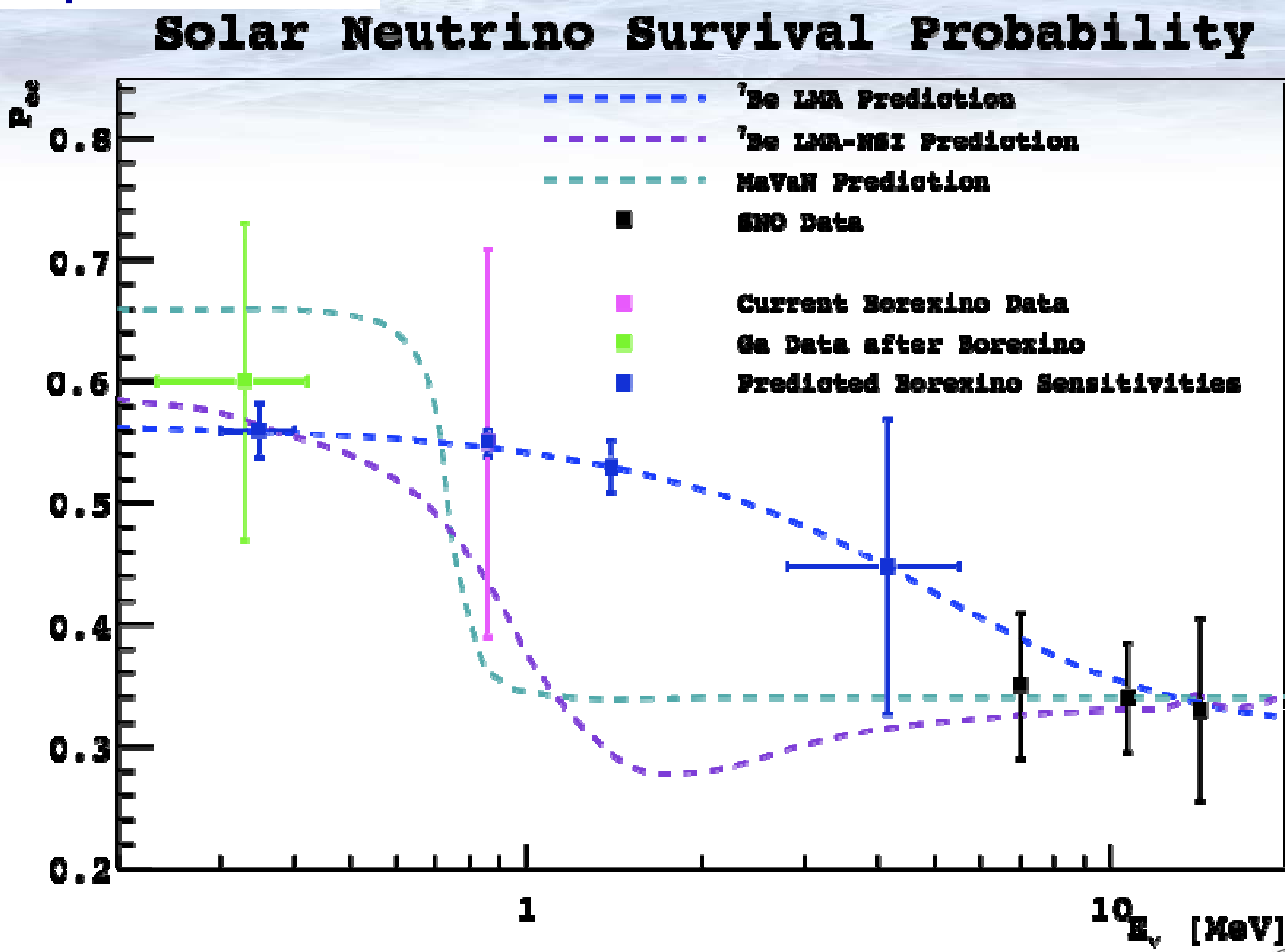


Conclusion

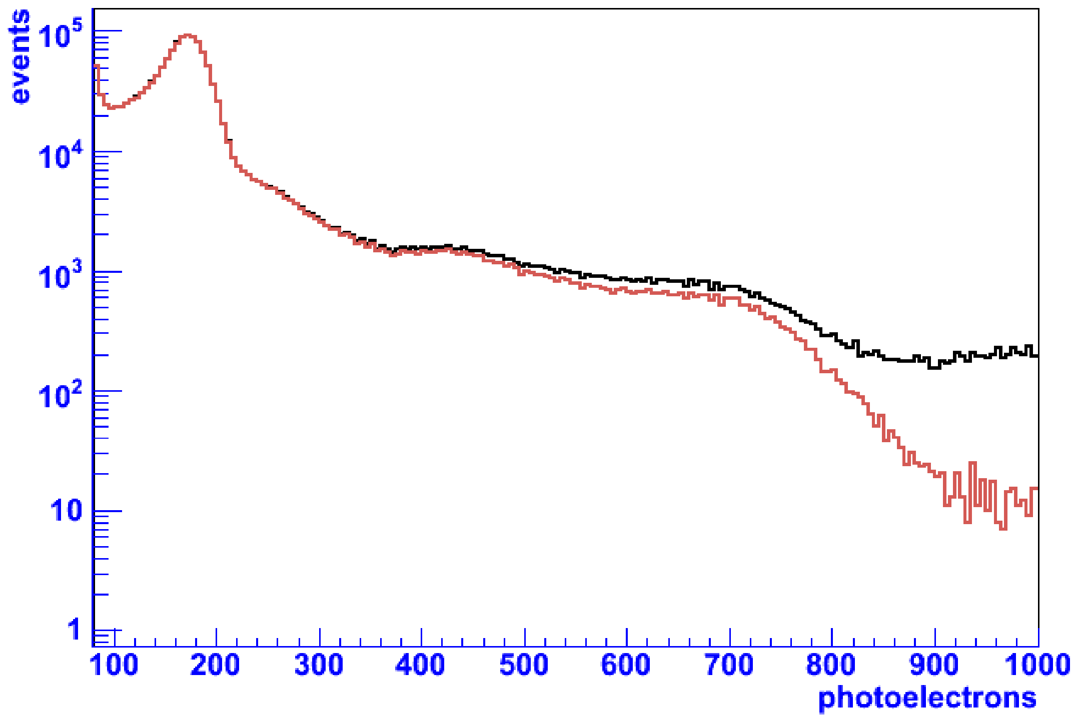
- Borexino opened the study of the solar neutrinos in real time below the barrier of natural radioactivity (4 MeV)
  - Two measurements reported for ^{7}Be neutrinos
  - Best limits for *pp* and CNO neutrinos, combining information from SNO and radiochemical experiments
  - Opportunities to tackle *pep* and CNO neutrinos in direct measurement
- Borexino will run comprehensive program for study of antineutrinos (from Earth, Sun, and Reactors)
- Borexino is a powerful observatory for neutrinos from Supernovae explosions within few tens of kpc
- Best limit on neutrino magnetic moment. Improve by dedicated measurement with ^{51}Cr neutrino source

BackUp

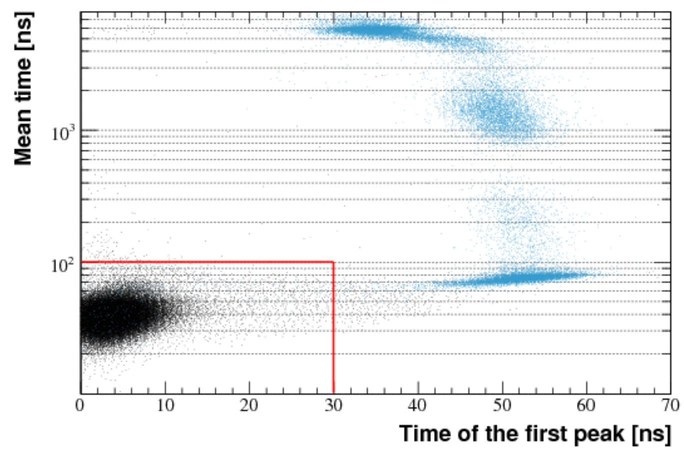
Expectations



Spectrum after μ subtraction (above ^{14}C)



- μ are identified by the OD and by the ID
  - OD eff: ~ 99%
  - ID analysis based on pulse shape variables
    - Pulse mean time, peak position in time
  - Estimated overall rejection factor:
    - > 10^4 (still preliminary)



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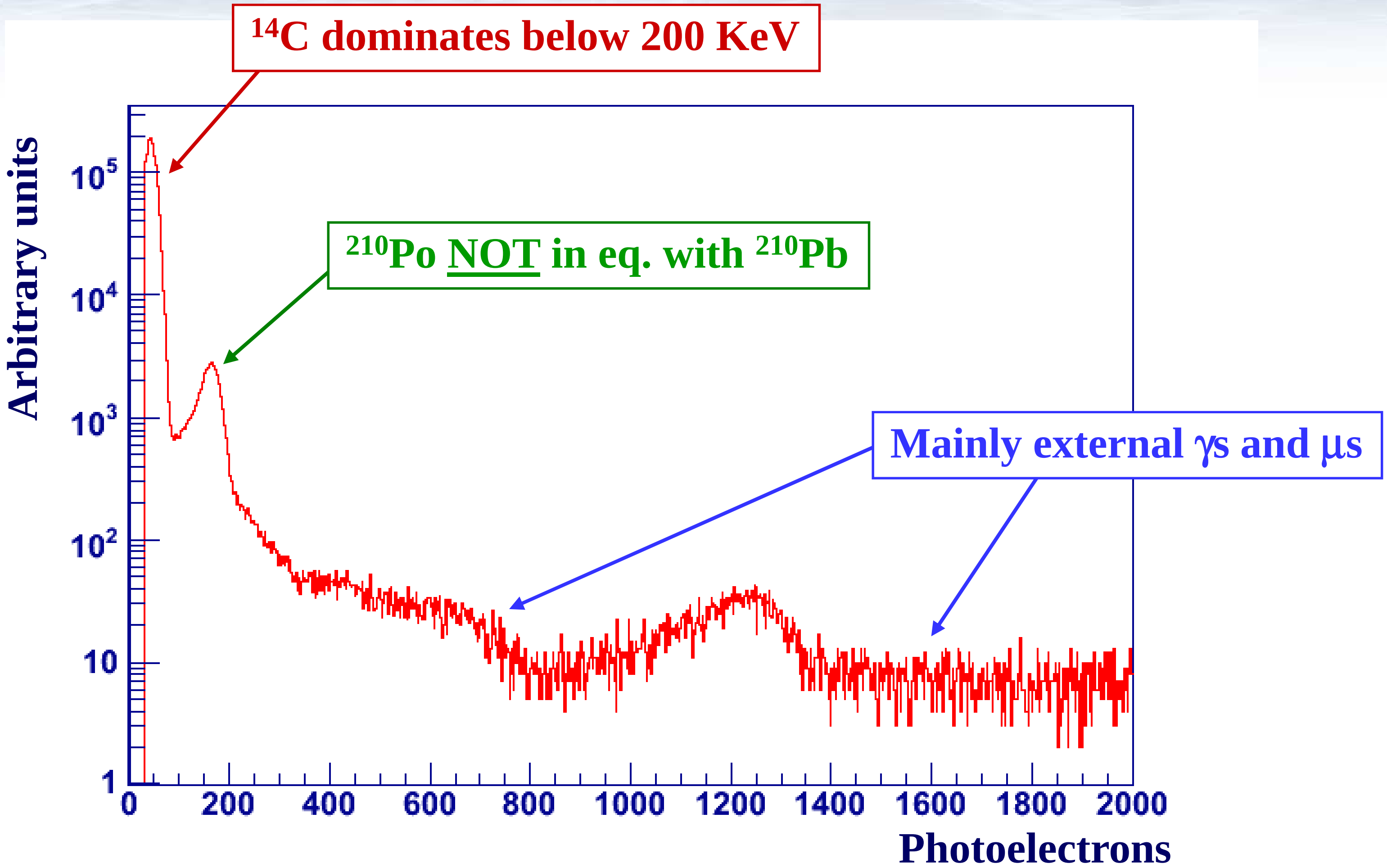
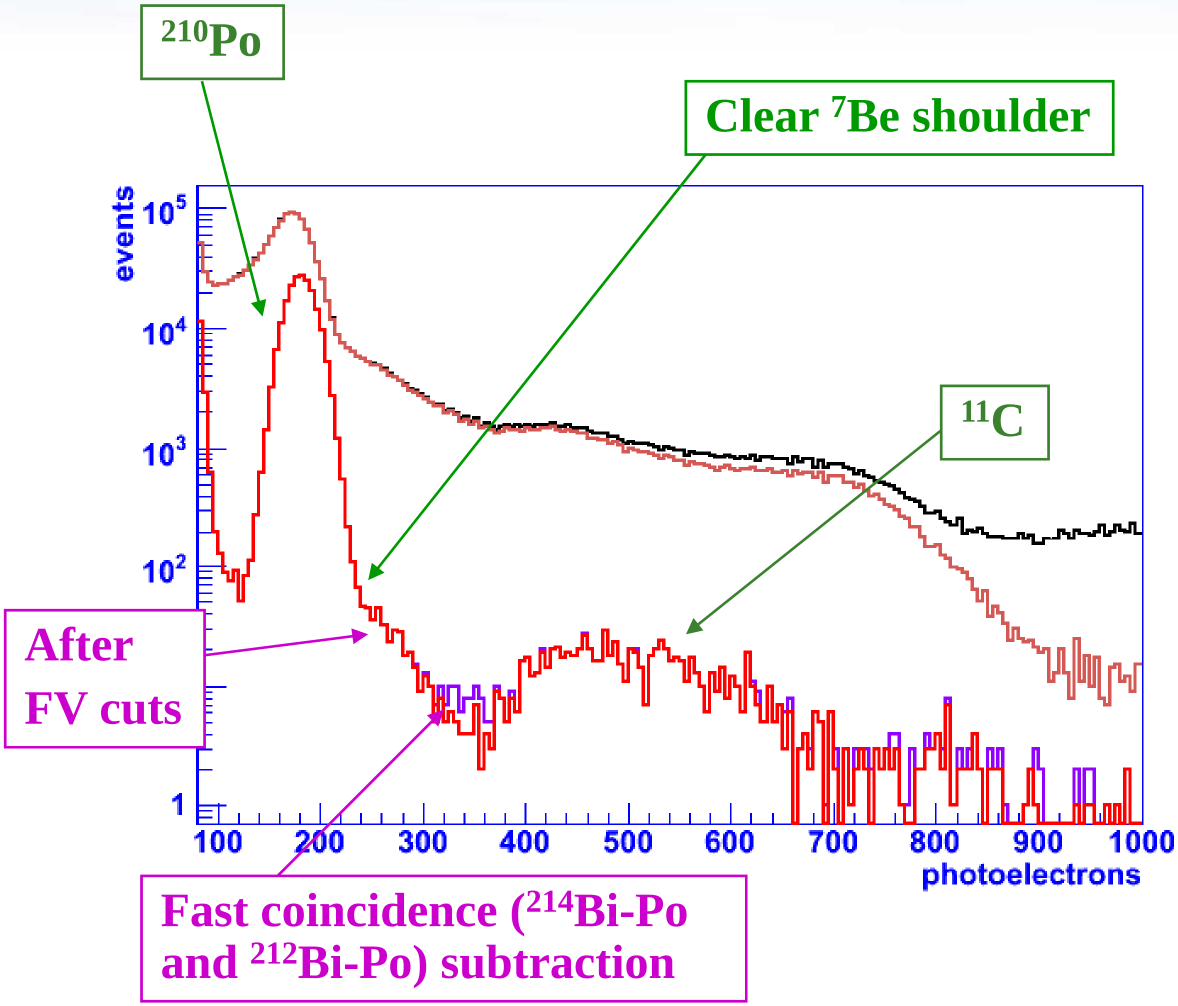
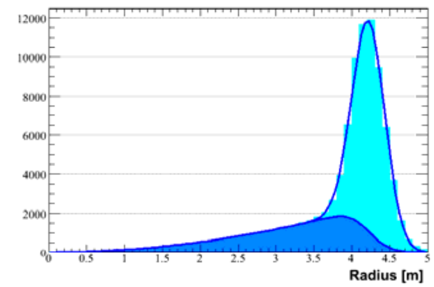


Statistics of this plot: ~ 1 day

Spectrum after FV cut (100 tons)





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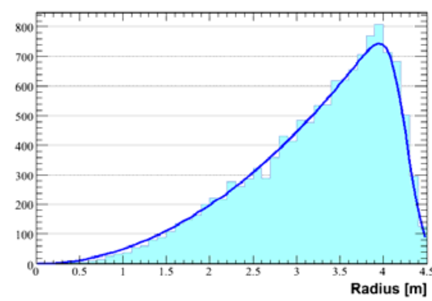

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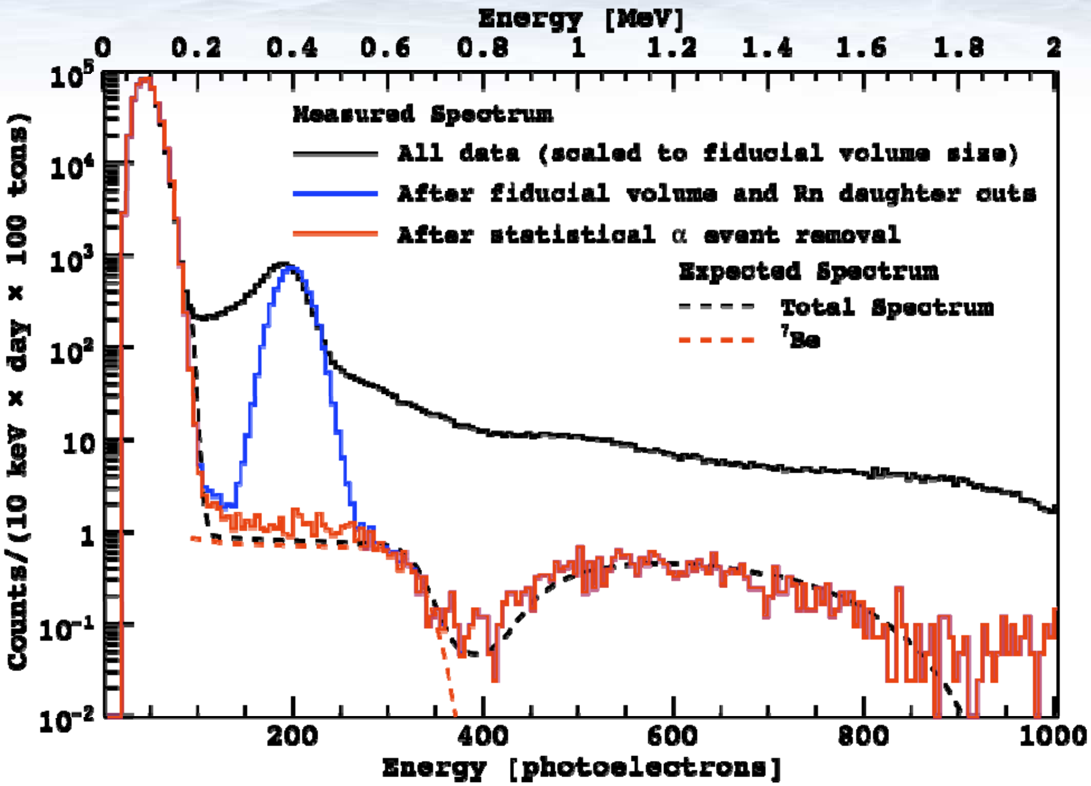
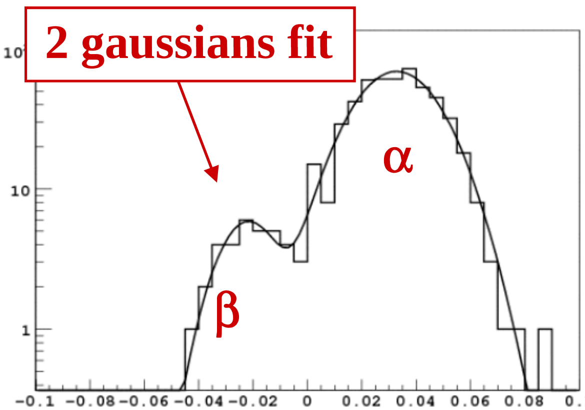


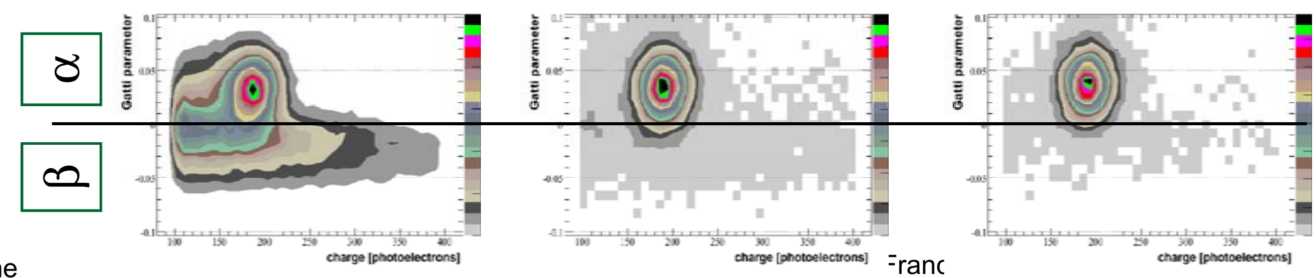


Pulse shape analysis

No radial cut

R < 3.8 m

FV (R < 3 m)



Large scintillator detector potential