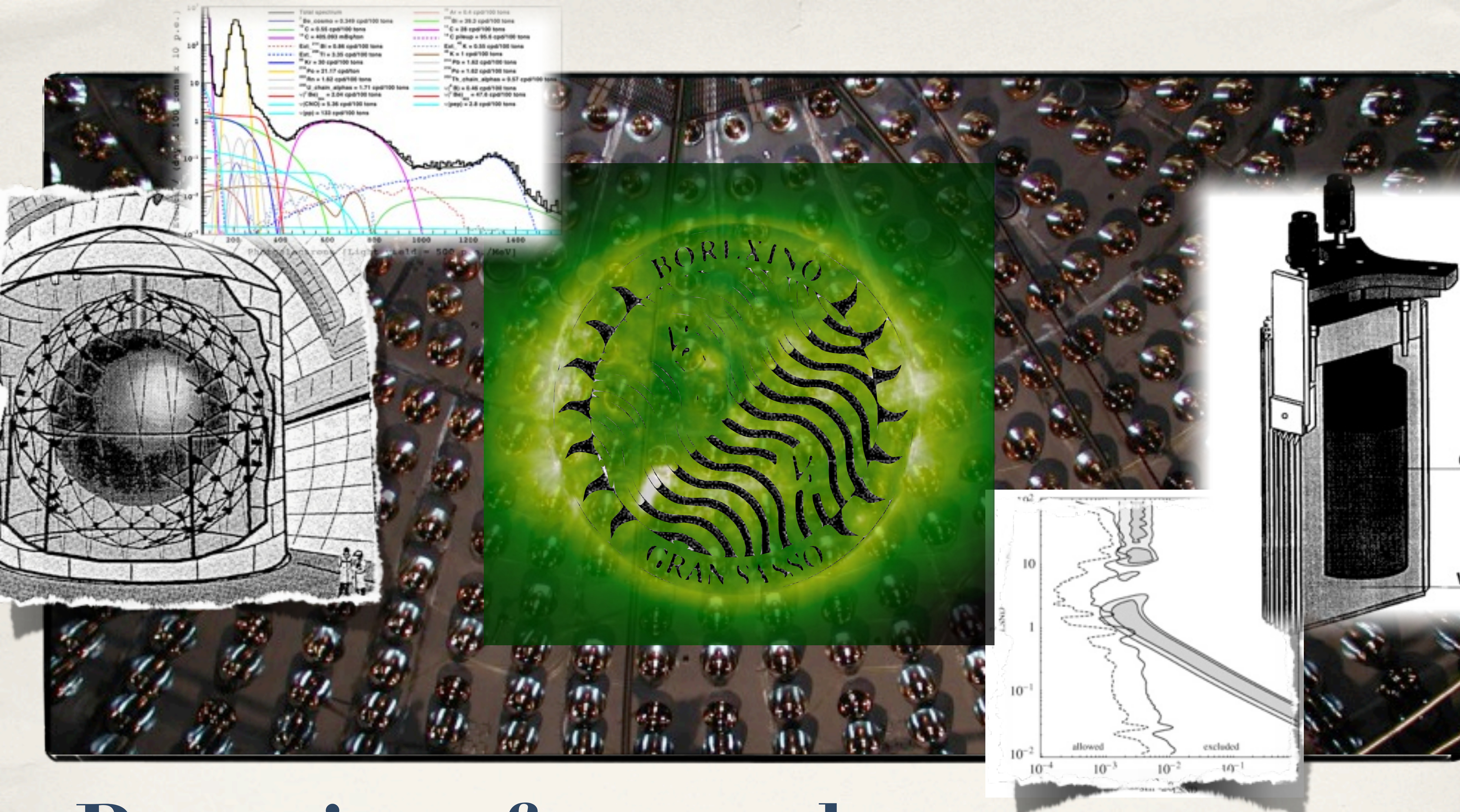


Borexino: from solar to source νs

(and geo!)

IPA 2013 (Madison, WI, USA)

May 12th, 2013

David Bravo Berguño (Virginia Tech)
on behalf of the Borexino collaboration

Borexino detector overview

- Graded shielding (onion structure)
- Situated in LNGS, 3400 mwe
- Based on liquid scintillator (PseudoCumene + PPO (1.5g/L) in IV, for more scintillation or DMP (5g/L lowered to 2g/L for buoyancy reasons) in OV for less) neutrino scattering, Čerenkov light also produced to a lesser extent
- Ultrapure nylon vessels for OuterVessel/InnerVessel and OV/buffer separation, "virtual" fiducial volume

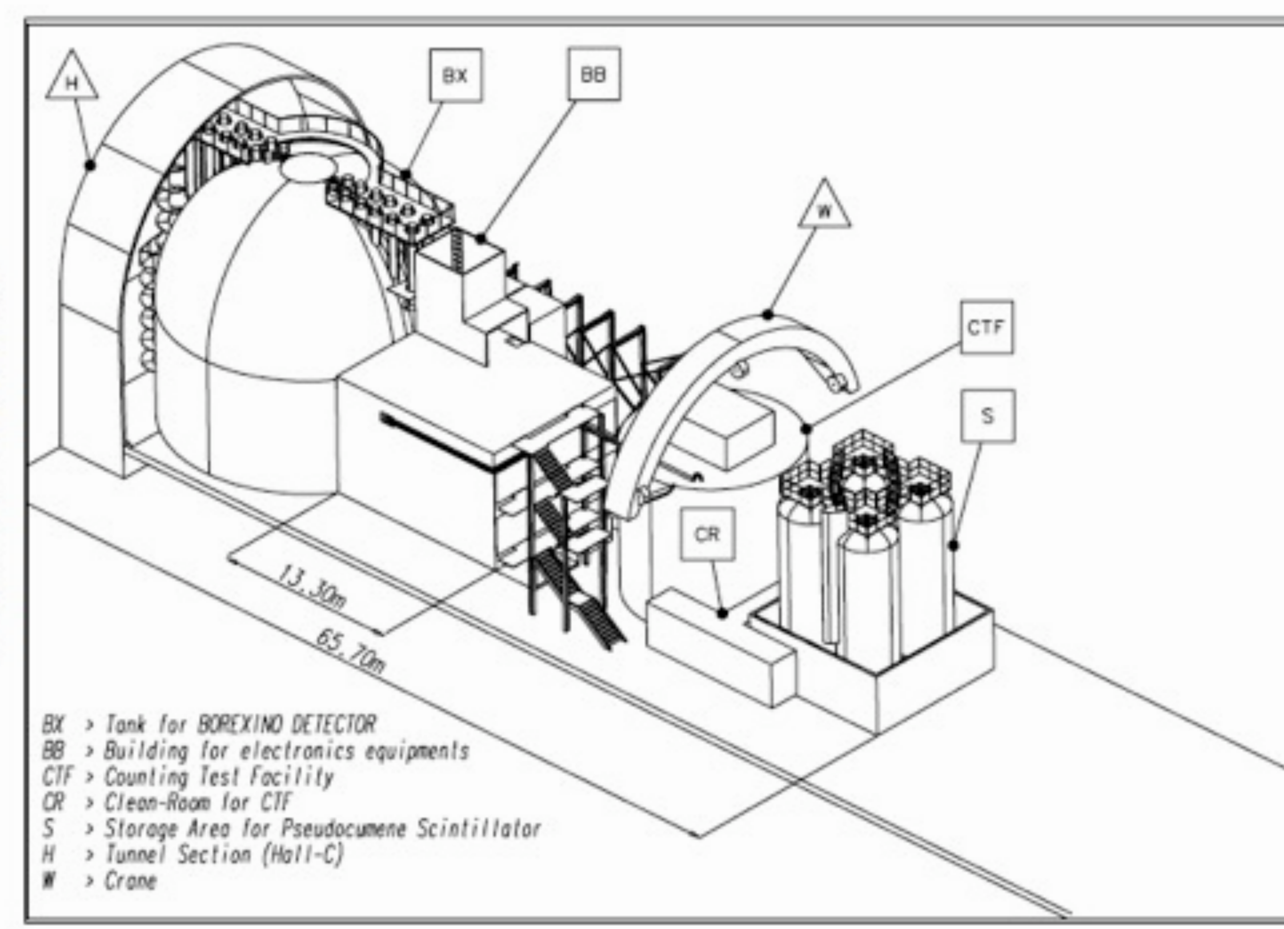
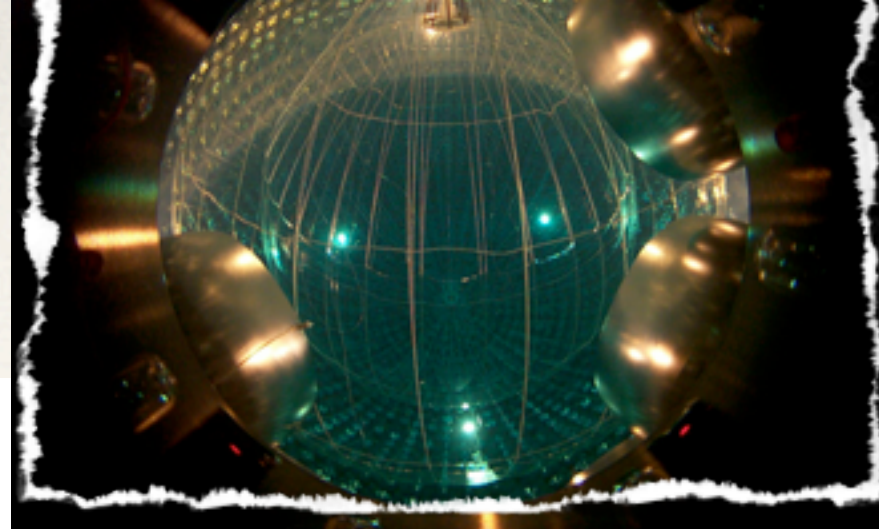
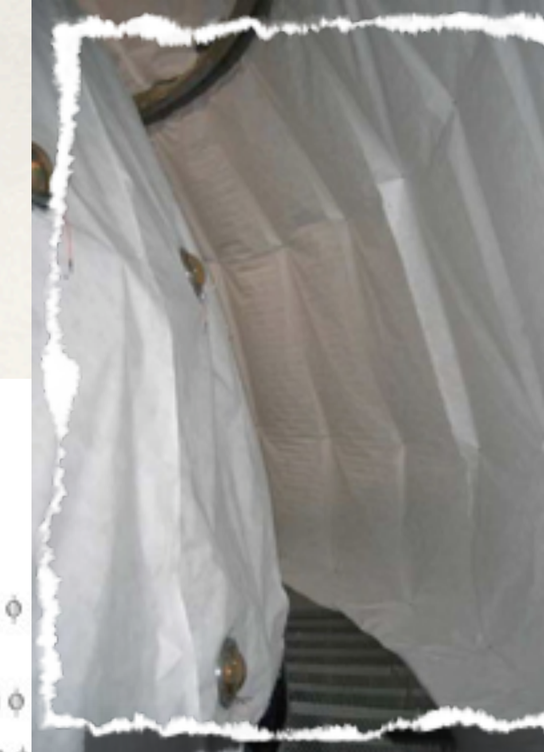


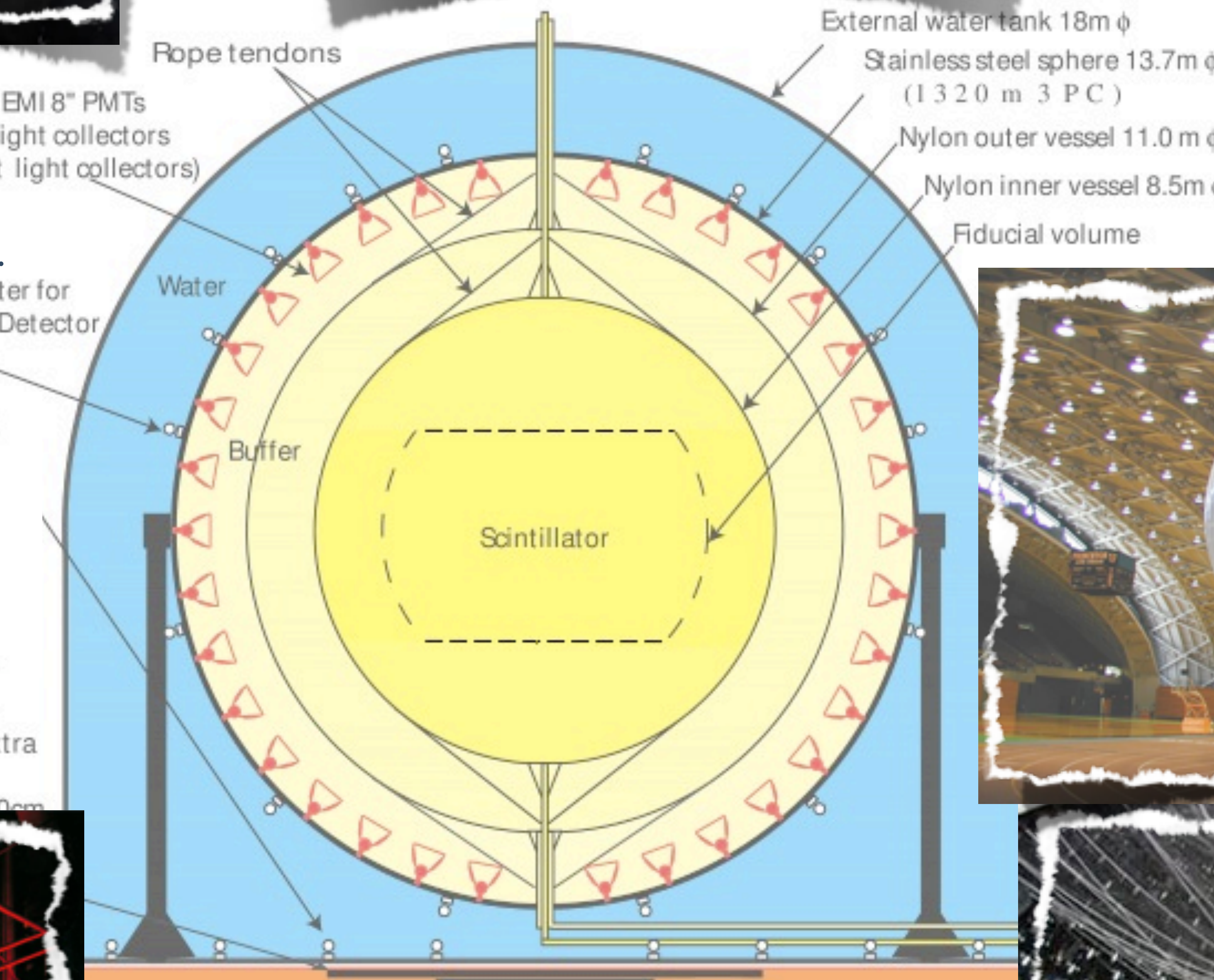
Figure 2.1: Borexino installation





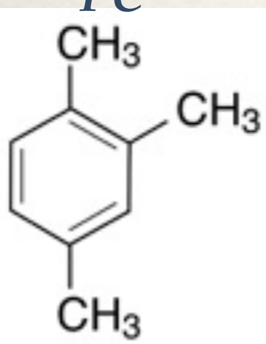
~488 pe/MeV

~19% eff.

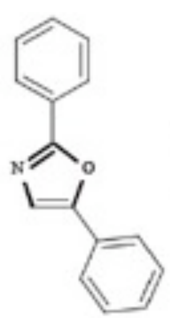


99.33% eff.

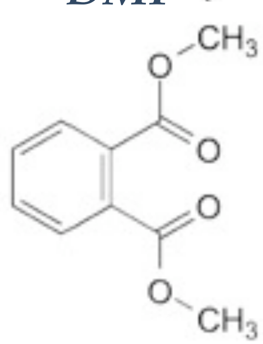
PC



PPO



DMP

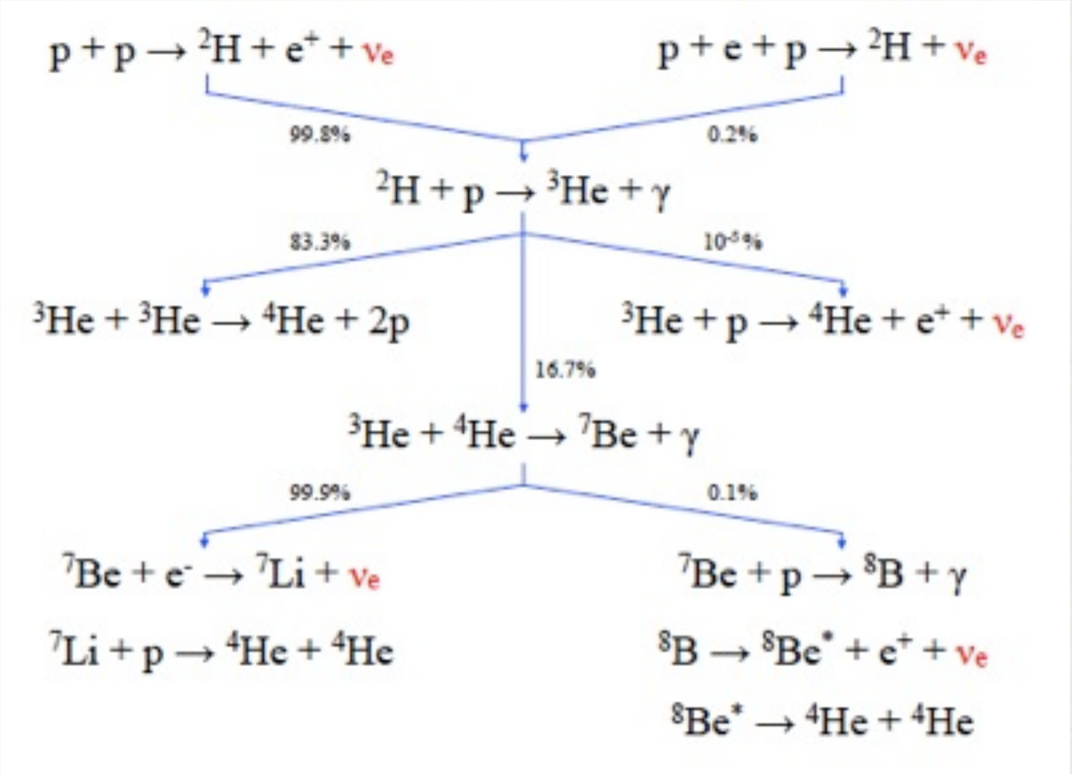


300 tons of PC (+PPO in IV & DMP in OV)

100 tons FV (spherical)

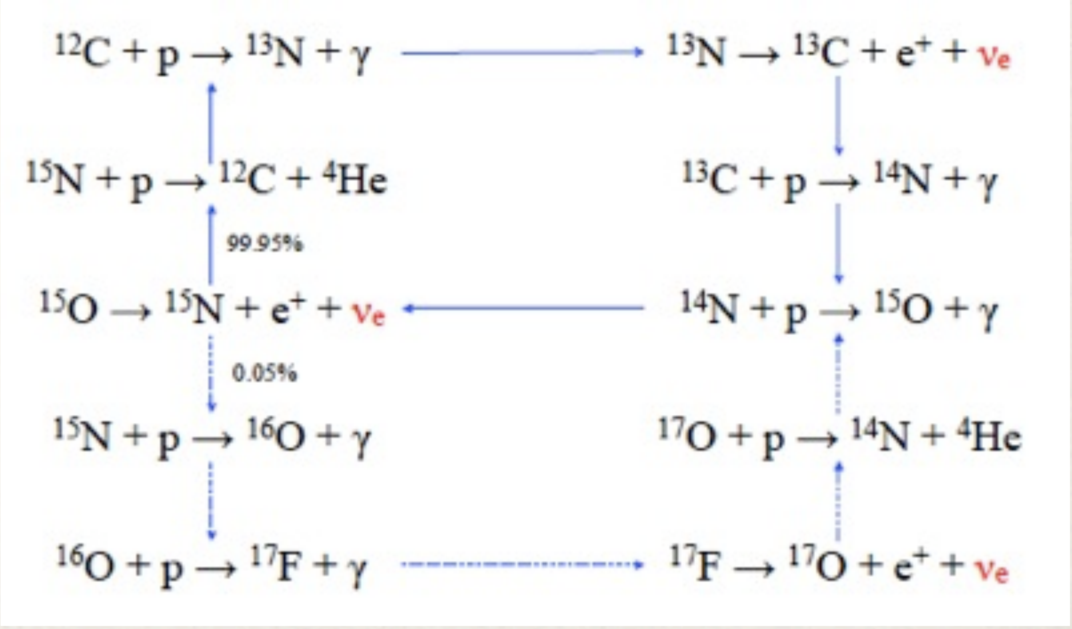
Fusion mechanisms in the Sun

- Main chains fueling the Sun:
  - pp chain $4p^{+} \rightarrow {}^{4}He + 2e^{+} + 2\nu_{e}(26.7MeV)$



  - CNO chain

$${}^{14}C + 4p^{+} \rightarrow {}^{12}C + {}^{4}He + 2e^{+} + 2\nu_{e}(26.7MeV)$$



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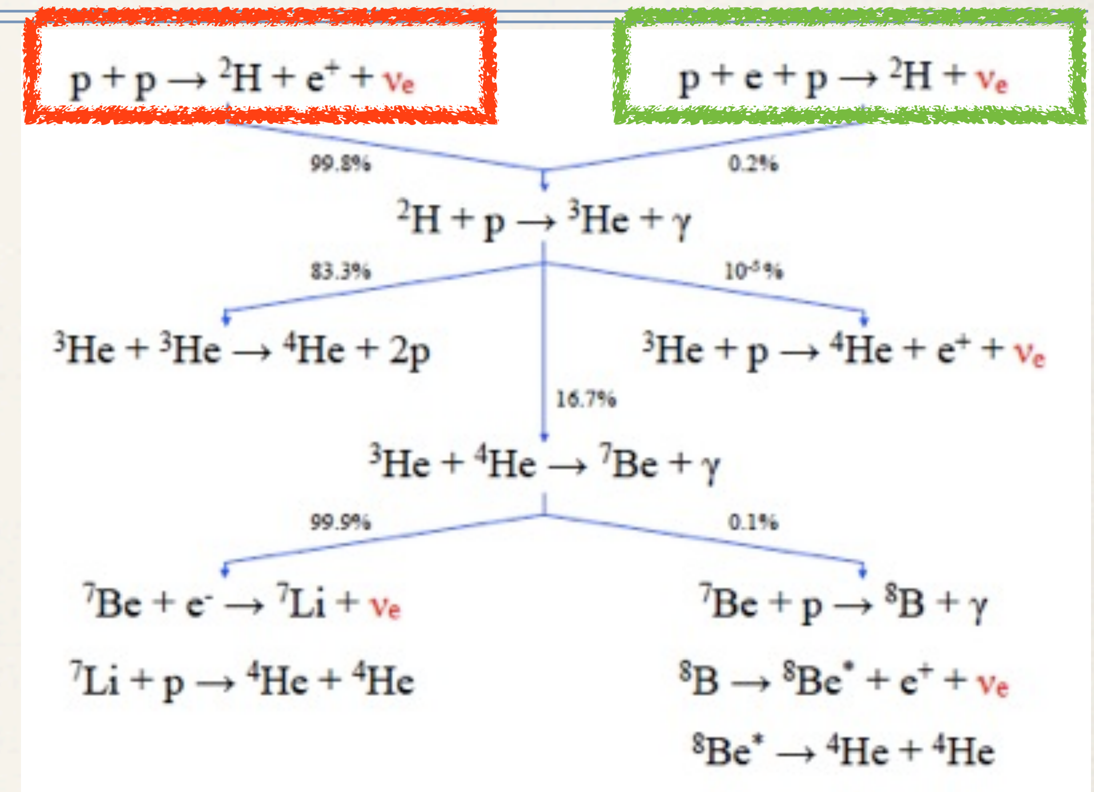

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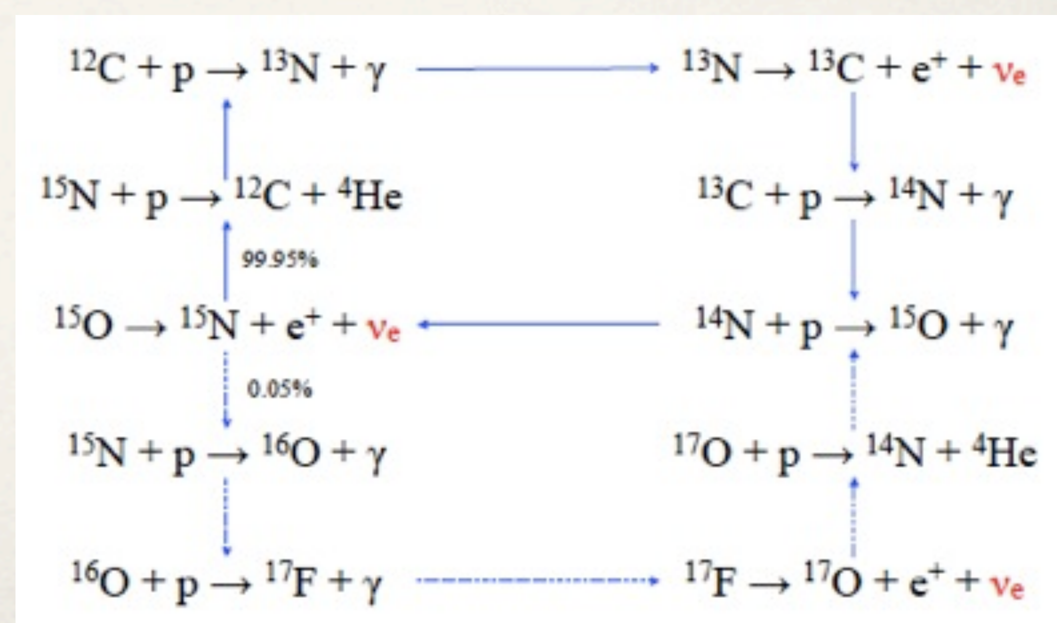

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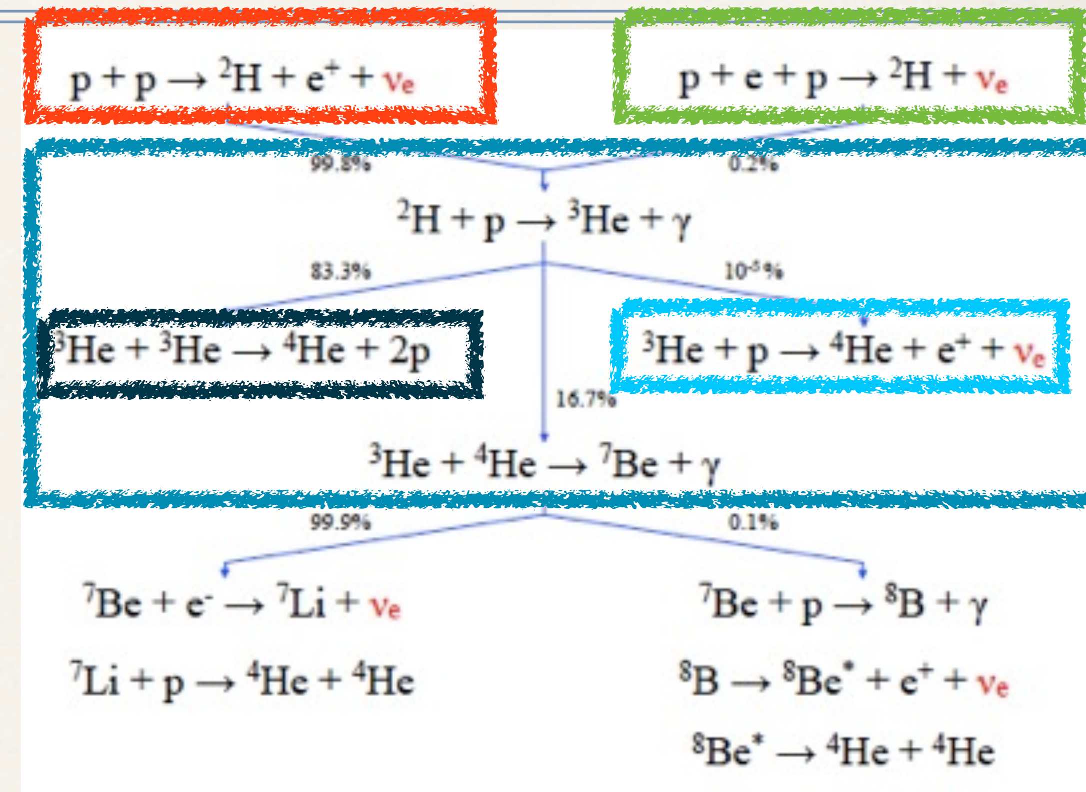

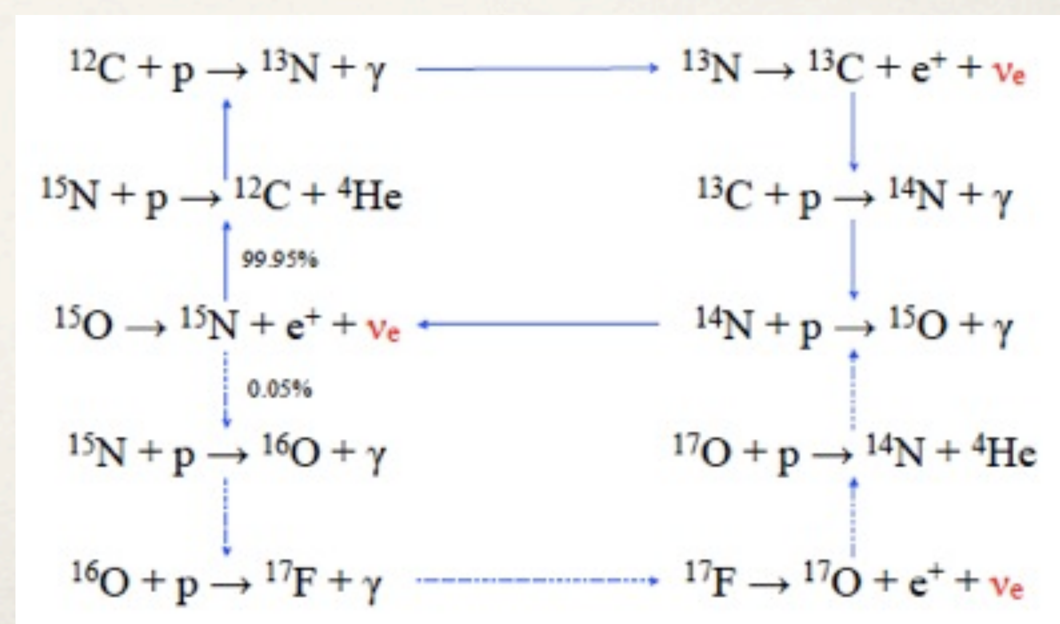

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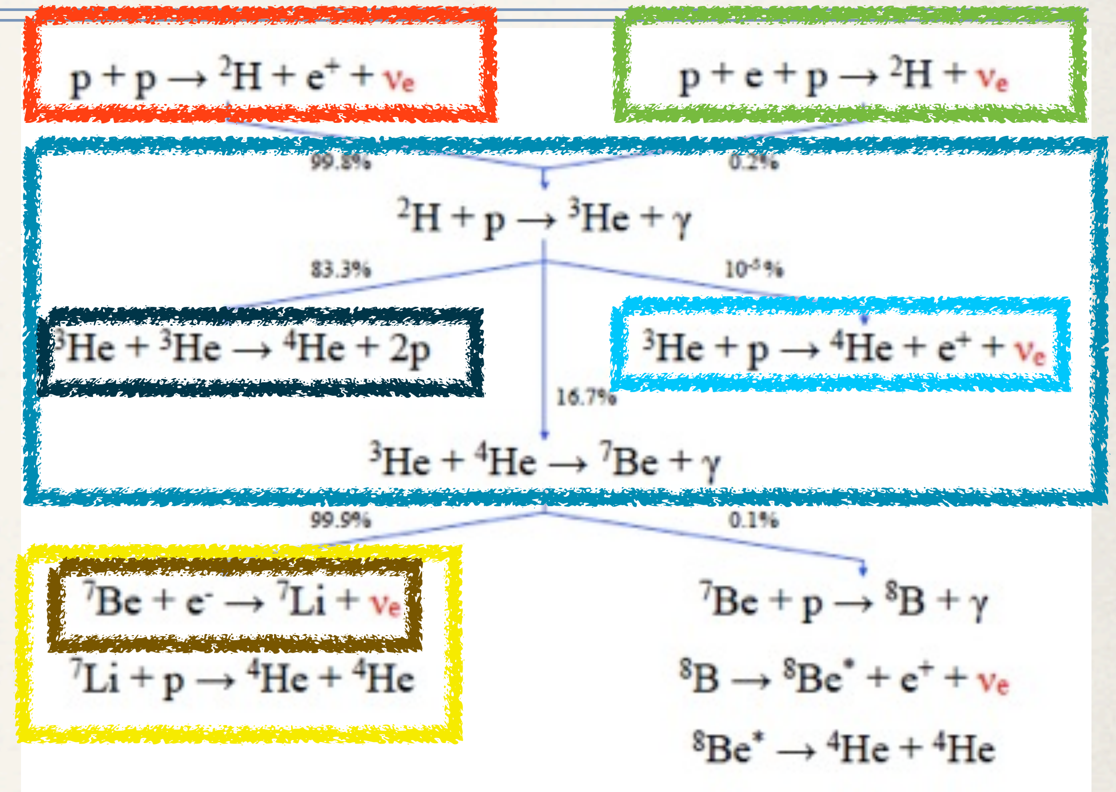

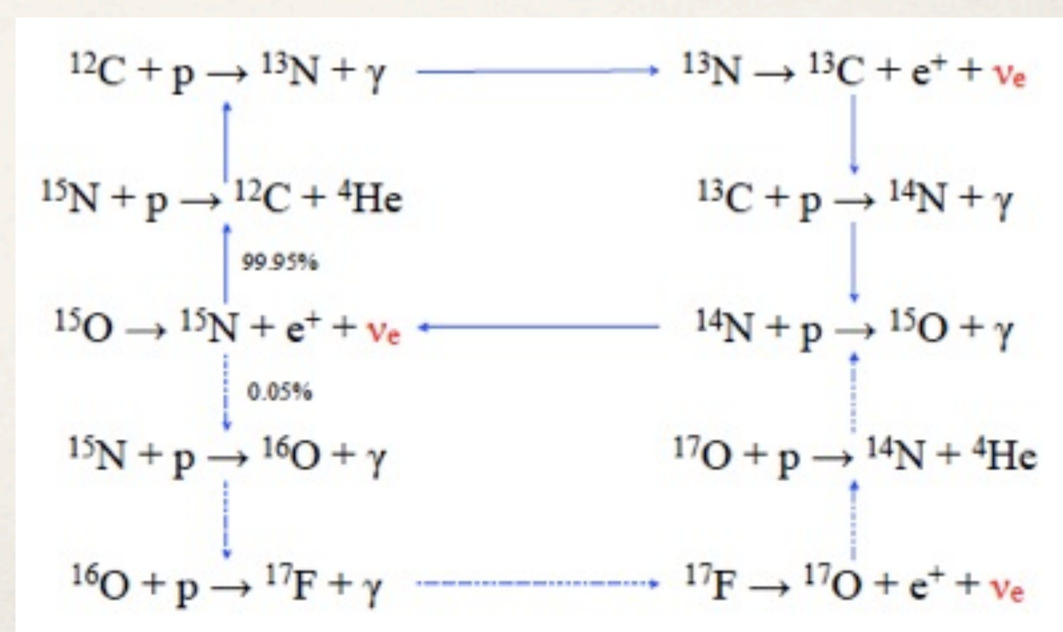

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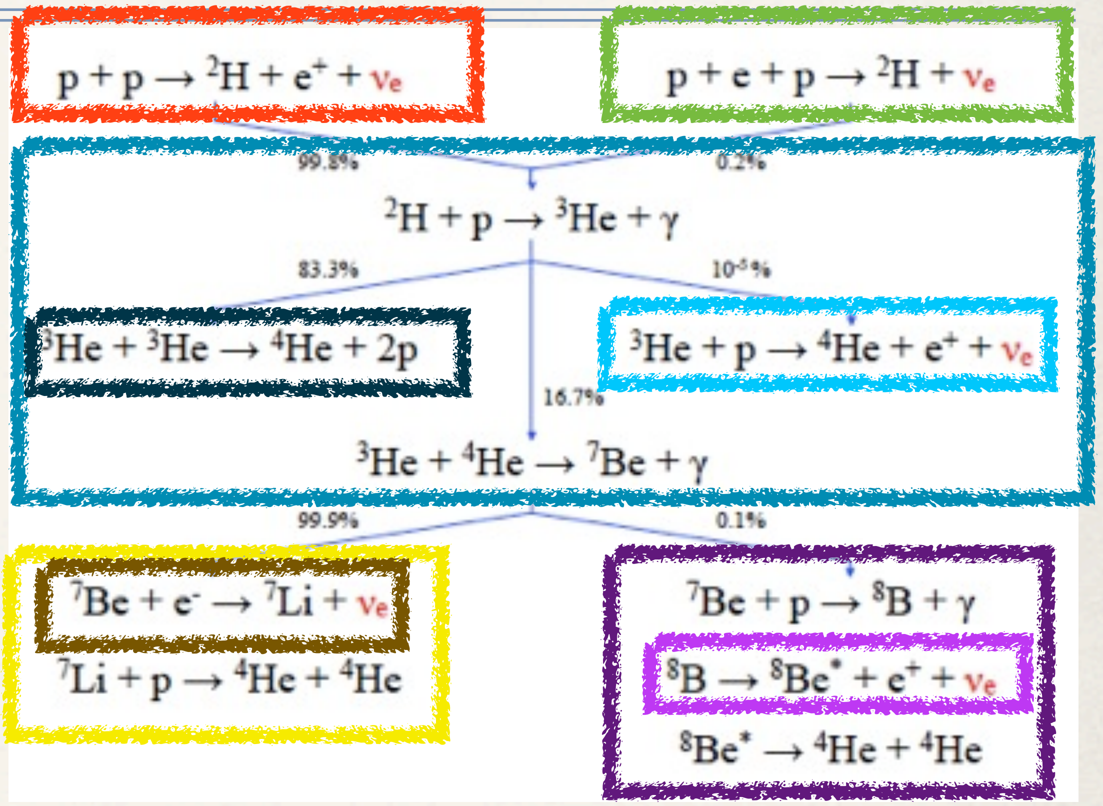

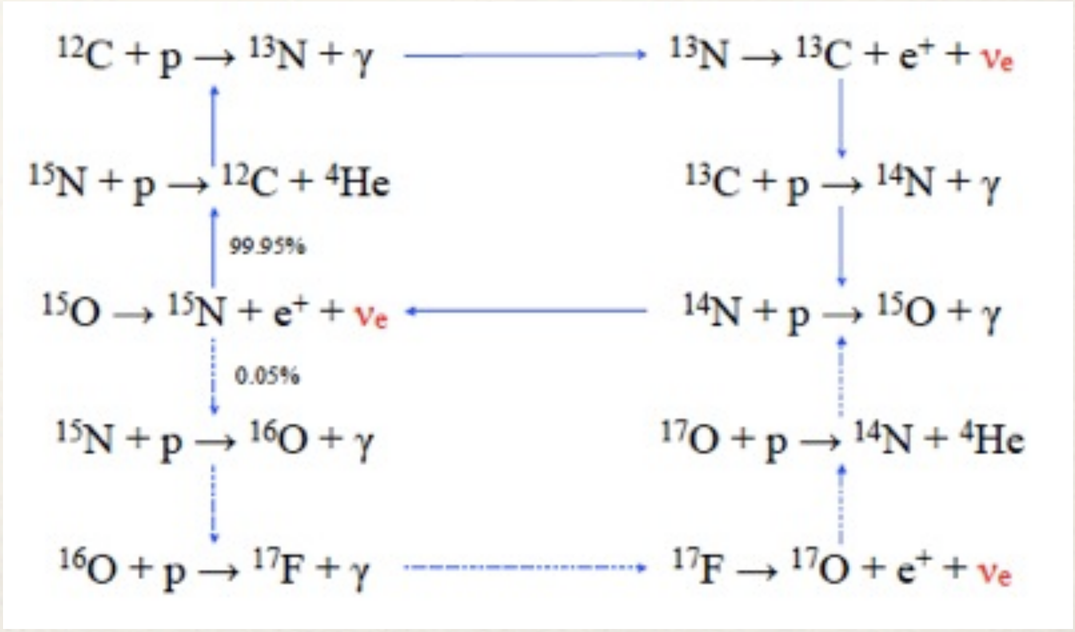

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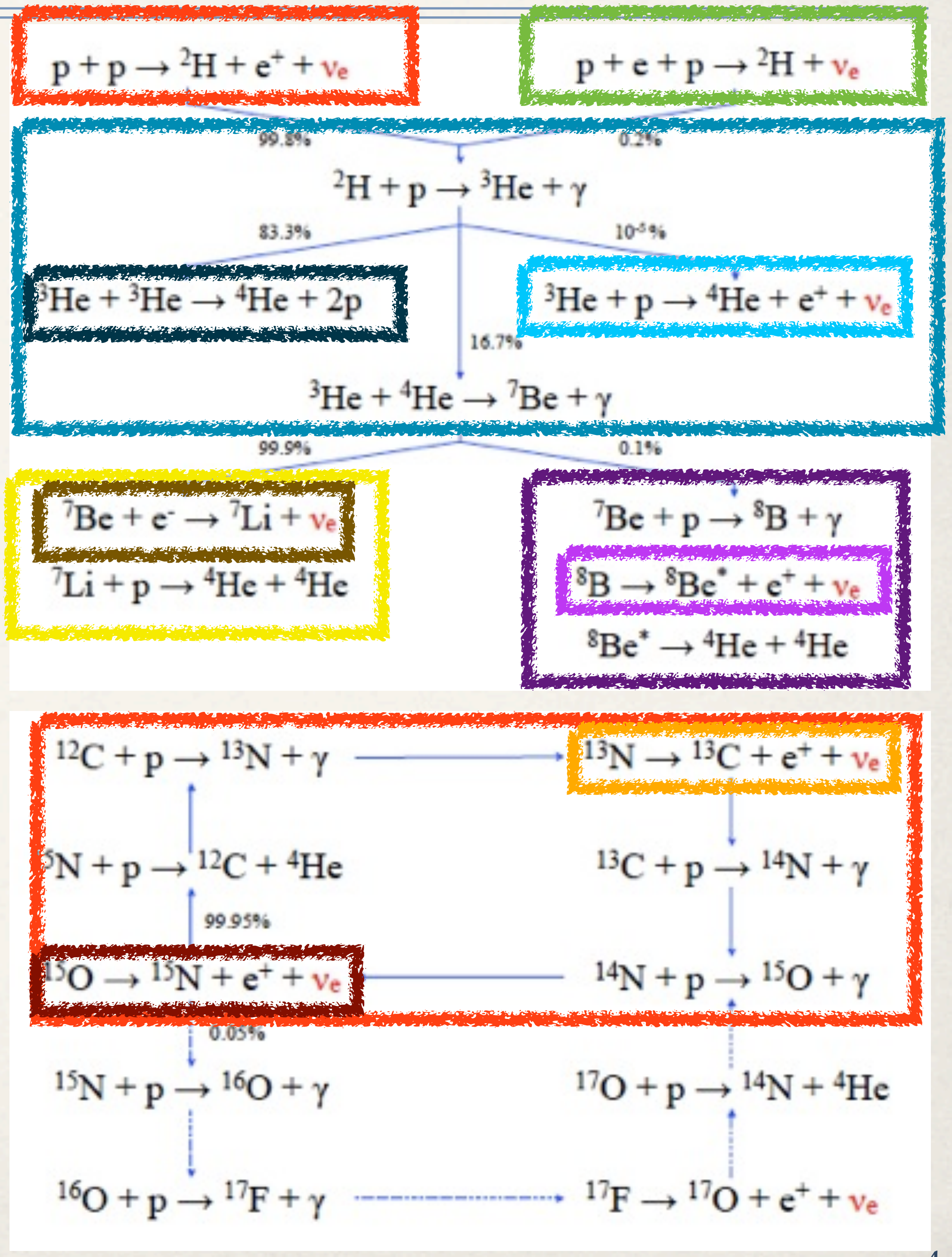

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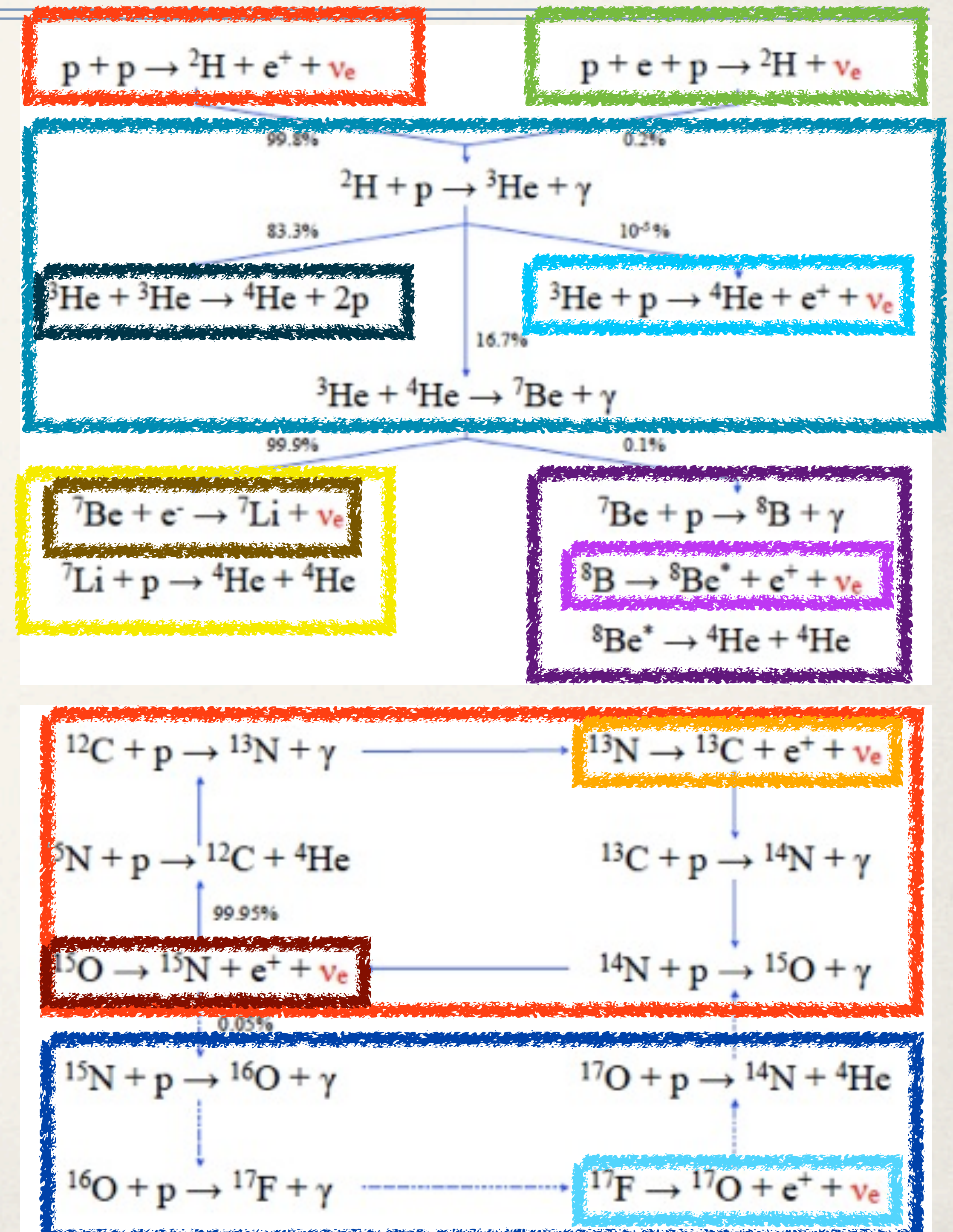

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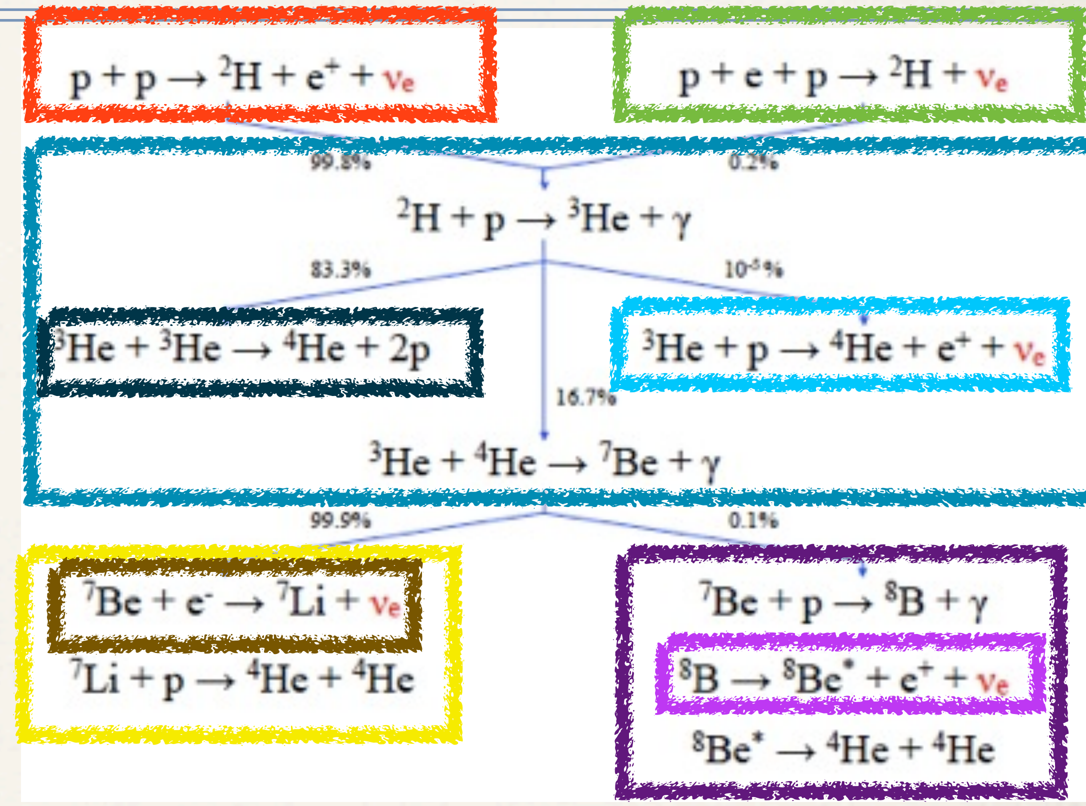
    - 18% ppIII branch - rare (1/5000) but leads to ^{8}B neutrinos



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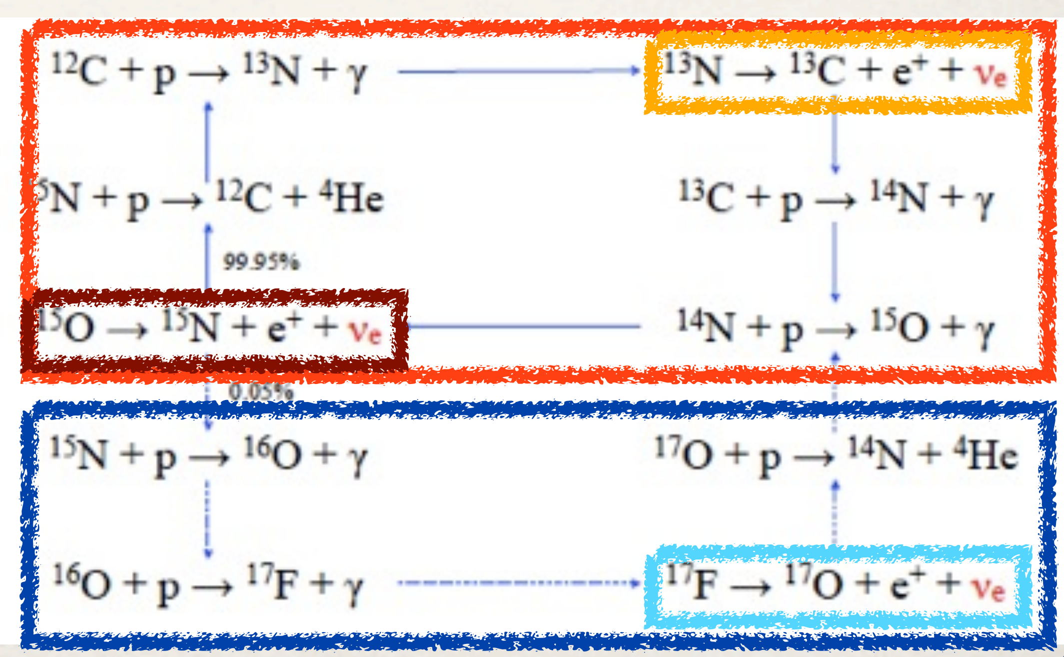

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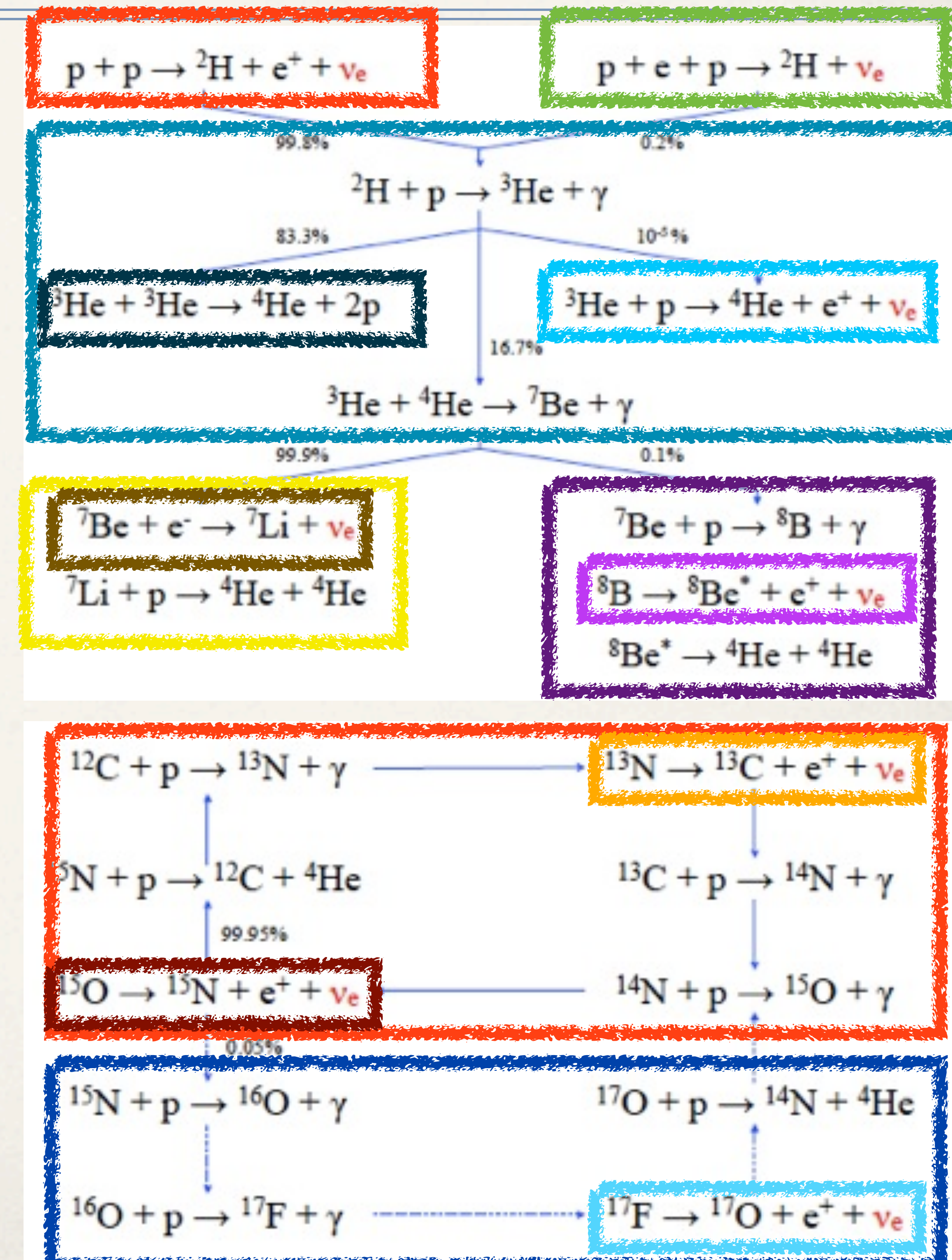
<5%

18%

(limit)



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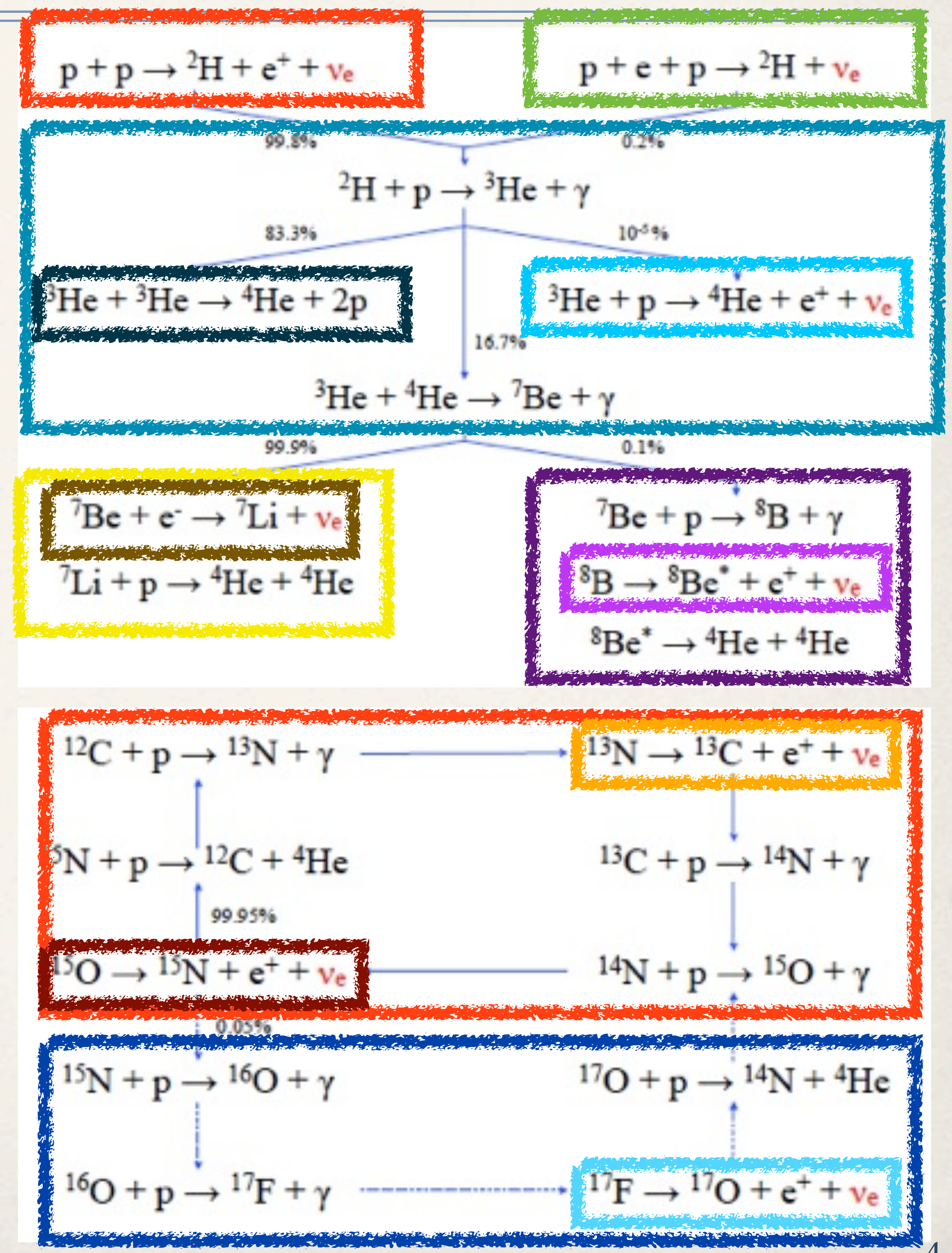
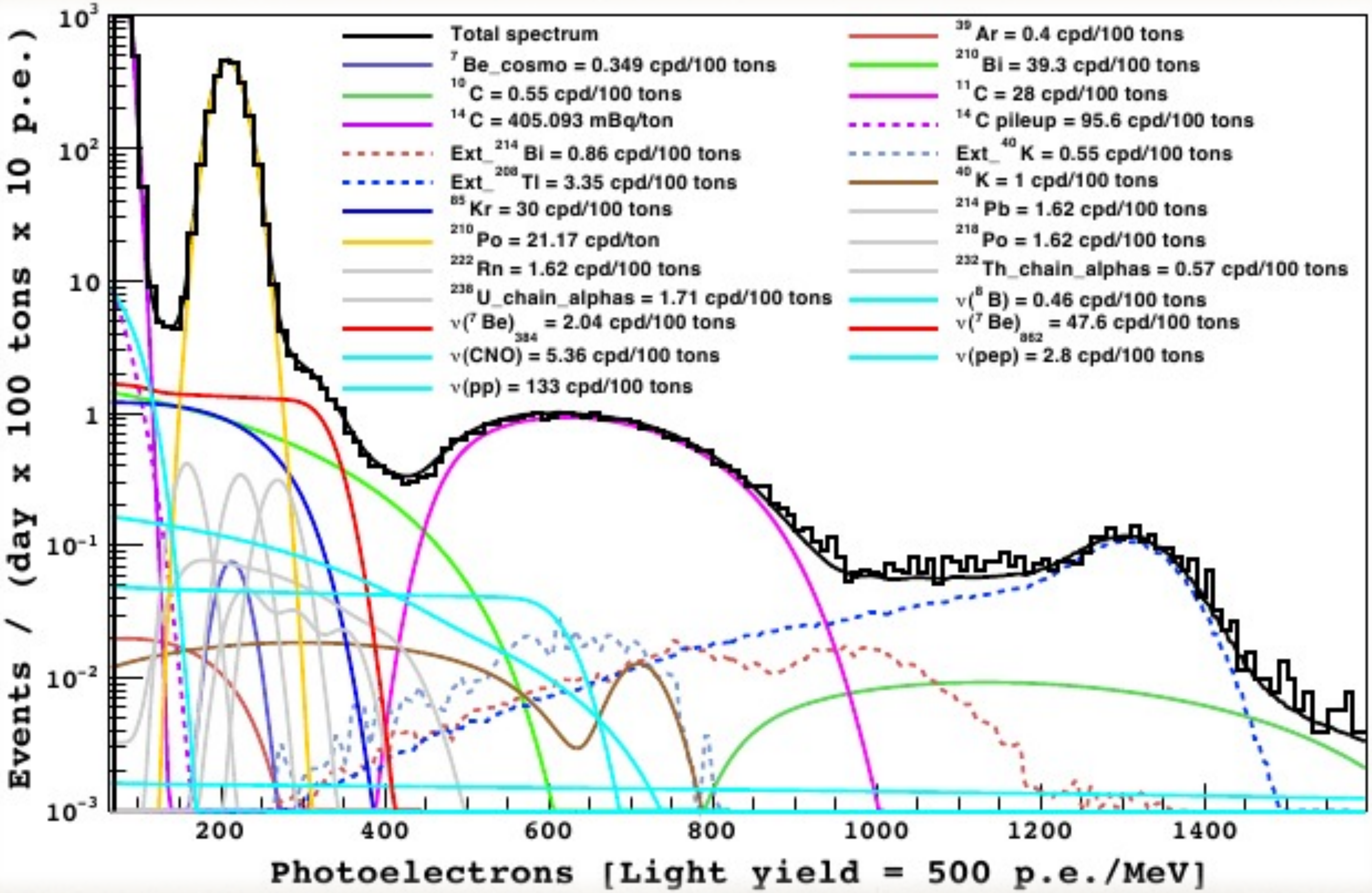


Borexino's spectrum

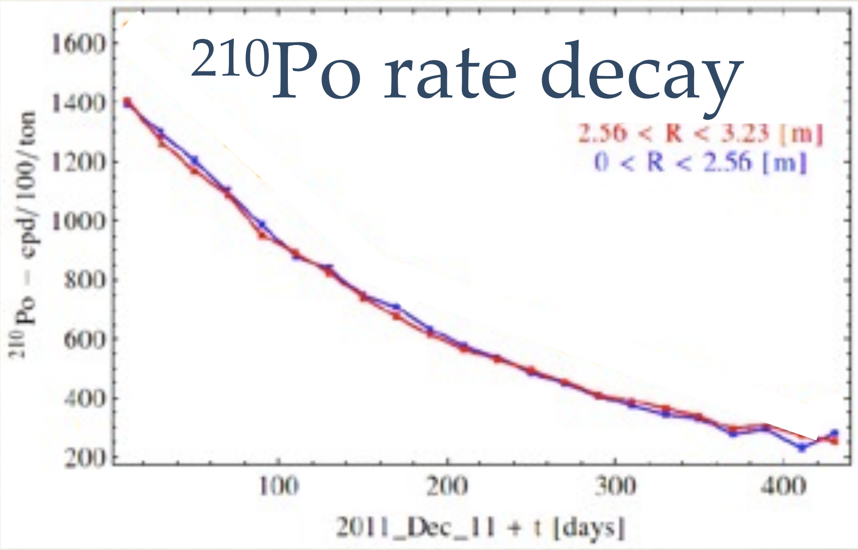
Compton-scattered synthetic sample spectrum



Background reductions: purifications

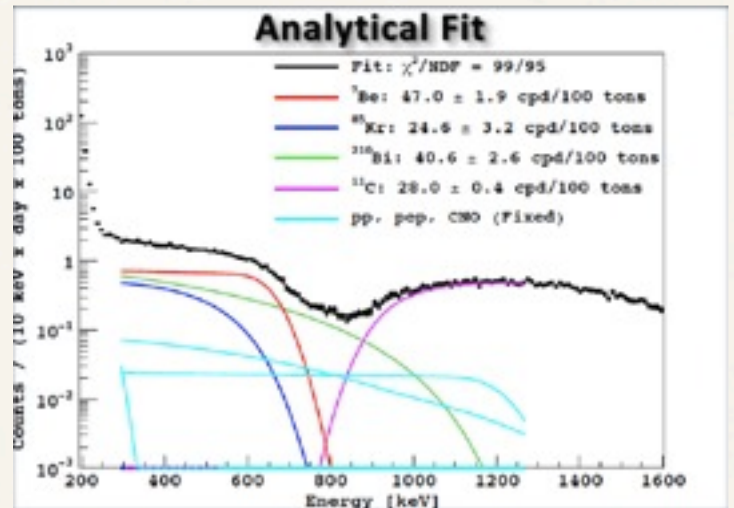
Radioisotope		Concentration/flux		
Name	Source	Typical	Required	Achieved
muon	Cosmic	200 Hz/m^2	~10^{-10}	<10^{-10}
Ext. gamma	Rock			negligible
Int. gamma	PMTs, SSS, Water, Vessels			negligible
^{14}C	Intrinsic	~10^{-12}	~10^{-18}	~10^{-18}
^{238}U/^{232}Th	Dust	~10^{-5} - 10^{-6}g/g	<10^{-16} g/g	**~<10^{-18}g/g**
^{40}K	Dust, PPO	~2·10^{-6} Bq/ton	<10^{-14} scint <10^{-11} PPO	~5cpd/100t (estimate)
^{210}Bi	Surface contamination	Initial stable: ~40 cpd/100t		**18 cpd/100tons**
^{210}Po	Surface contamination	Initial stable: ~10^3 cpd/100t		**~300 counts/ day·100tons**
^{222}Rn	Air, emanation	~10-100 Bq/L (air-water)	<1count/day·100tons	**<10^{-19} g/g**
^{39}Ar	Air (nitrogen)	~17 mBq/m3	<1count/day·100tons	?
^{85}Kr	Air (nitrogen)	~1 Bq/m3	<1count/day·100tons	~8 cpd/100tons

- Purifications in 2010/2011.
- Very effective on ^{85}Kr, good on ^{210}Bi and excellent for ^{238}U and ^{232}Th
- NO ^{222}Rn events since June 2012. Two candidate ^{232}Th events since October 2011.
- Five ^{85}Kr candidates since 2010

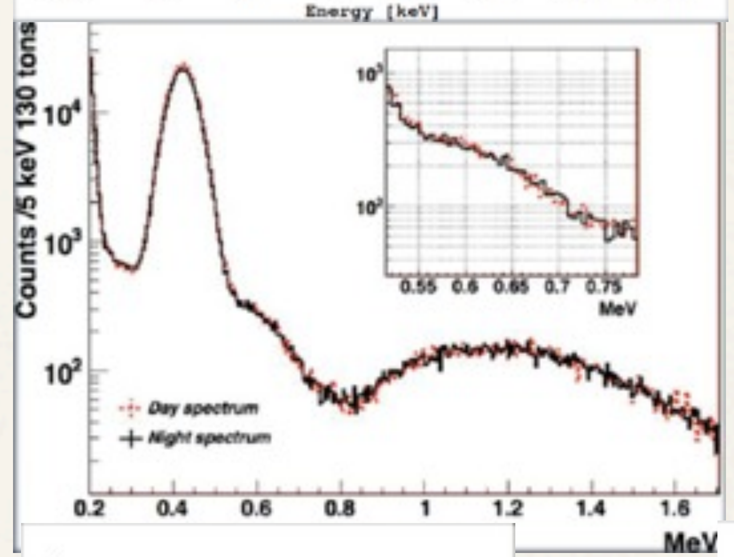


Solar ^{7}Be precision result

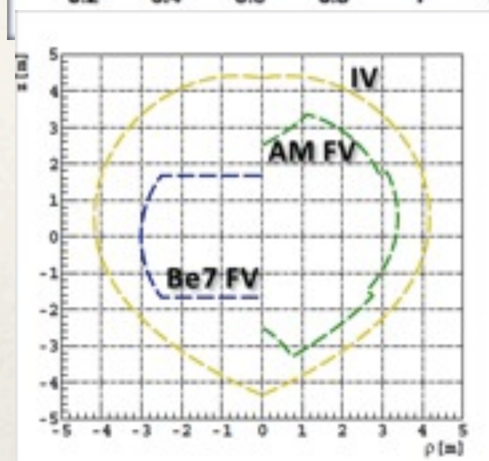
- <5% measurement (2011)
- ***Day-night assymetry*** null result in ^{7}Be window (2012) : **L**arge**M**ixing**A**ngle solution confirmed (90%c.l. with Borexino data alone)
- **Annual flux *modulation*** (2013) - Fiducial volume control, verified no anomalous oscillations



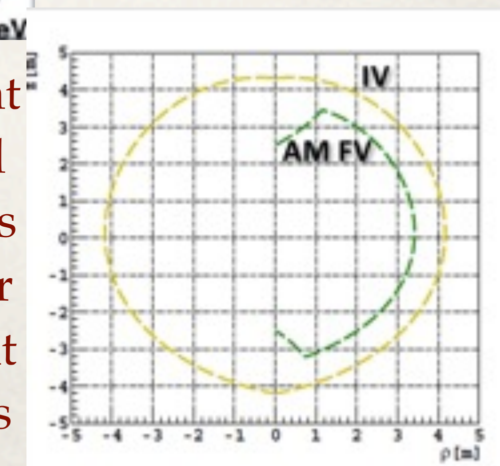
$^{7}Be = 46.0 \pm 1.5_{stat} \pm ^{1.6}_{1.5\,syst}$ cpd/100t



$A_{dn} = 0.001 \pm 0.012_{stat} \pm 0.007_{syst}$ cpd/100t



Different fiducial volumes used for different datasets

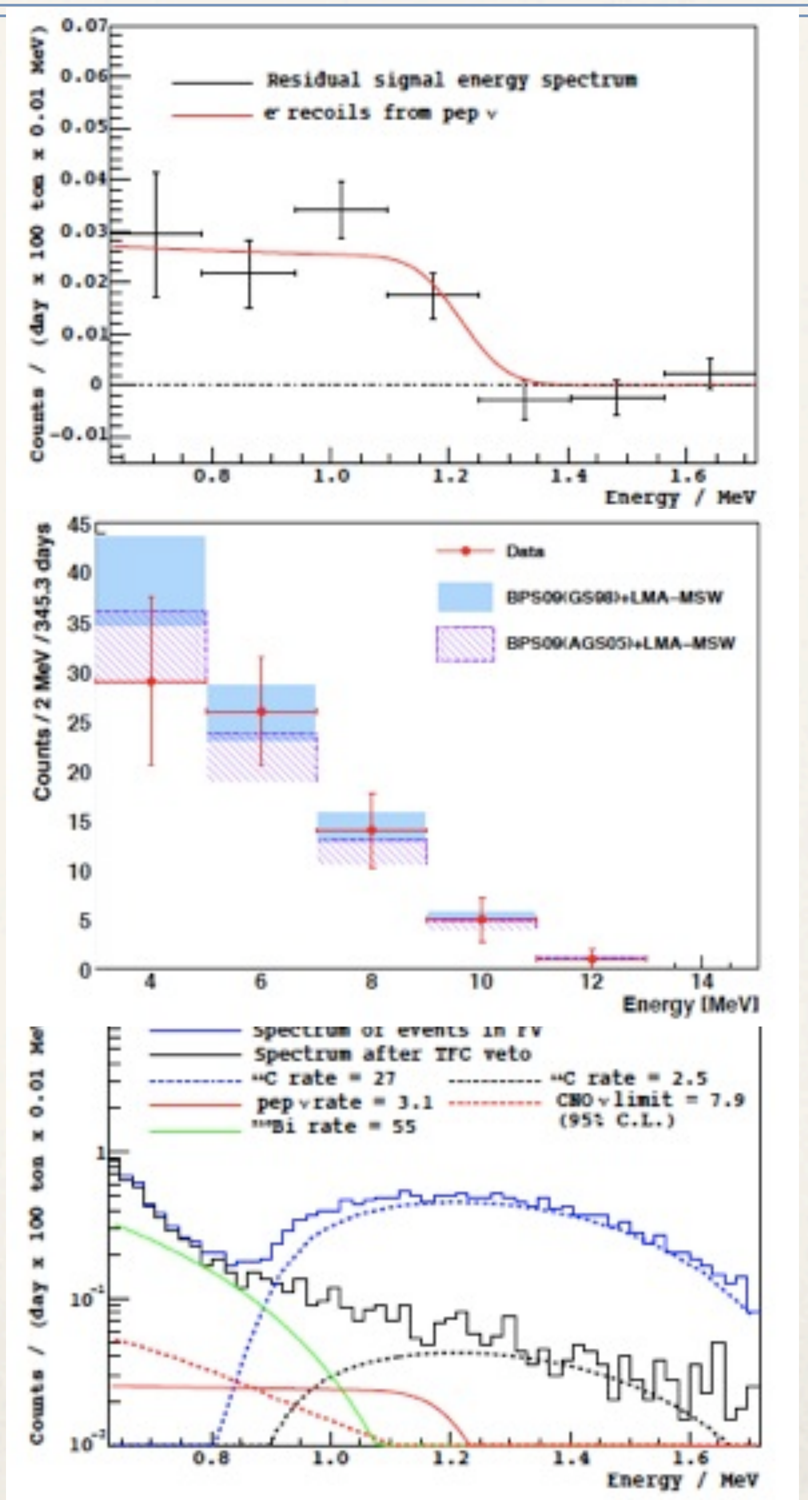


Other solar neutrino results

- ***pep* neutrinos** detected thanks to extreme radiopurity

- ^{8}***B*** result in MSW-dominated energy range

- ***CNO* limit**, pushing for more stringent measurement (^{210}Bi background fluctuations have hindered efforts so far)



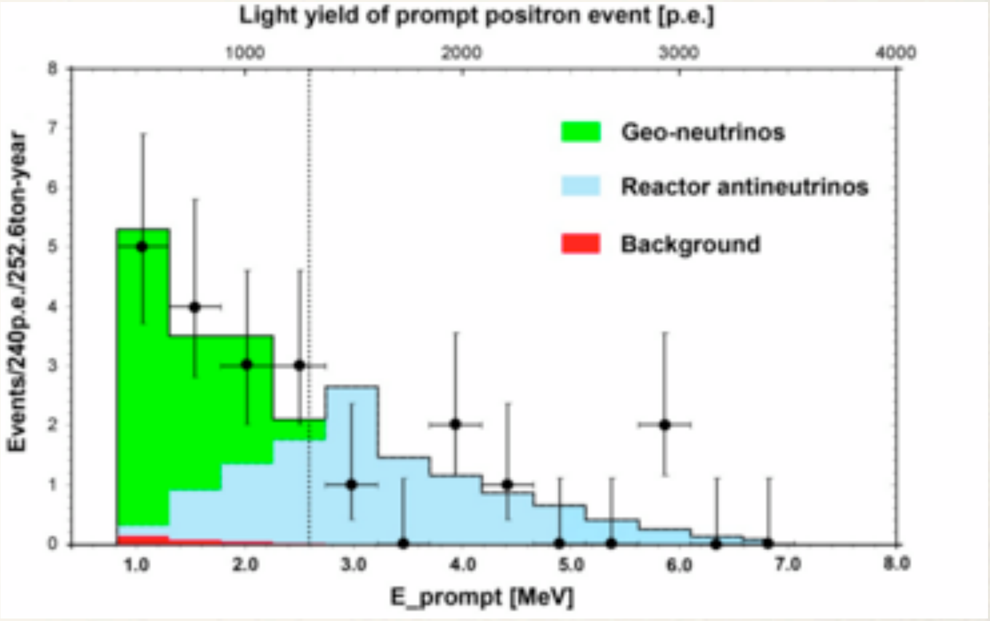
pep=3.1 ± 0.6$_{stat}$ ± 0.3 $_{syst}$ cpd/100t

^{8}B=0.217 ± 0.038$_{stat}$ ± 0.008 $_{syst}$ cpd/100t

CNO<7.9 cpd/100t

Geoneutrino result

$$\overline{\nu_e} + p^{+} \rightarrow e^{+} + n^{0}$$



- Prompt-delayed signal from positron annihilation and neutron capture γs (2x0.511MeV + 2.22MeV): **coincidence tagging - allows for full detector FV**

- Backgrounds
  √ Nuclear reactor contribution from Europe (97.5%) and the world (2.5%)
  √ Cosmogenics (mainly ^{9}Li-^{8}He)
  √ Fast neutrons...

- Rate of **3.9+1.6/-1.3(stat)+5.8/-3.2(sys) counts per year/100tons** - 50:1 signal-to-noise for reactor+geoneutrinos

p^{+}

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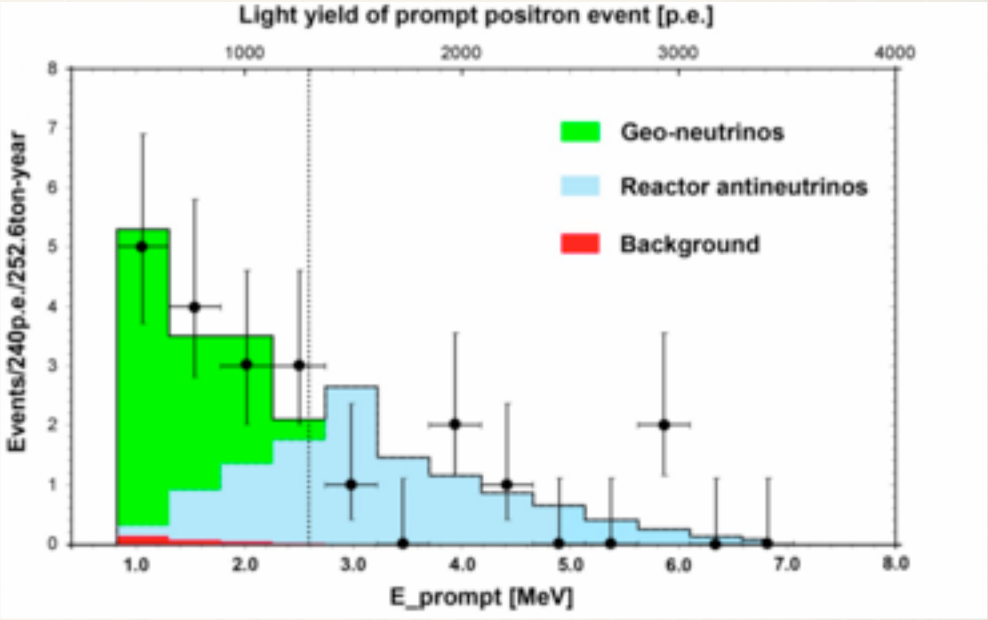
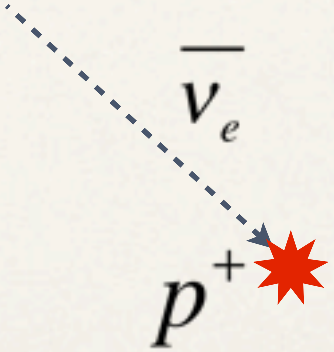


Inverse beta decay



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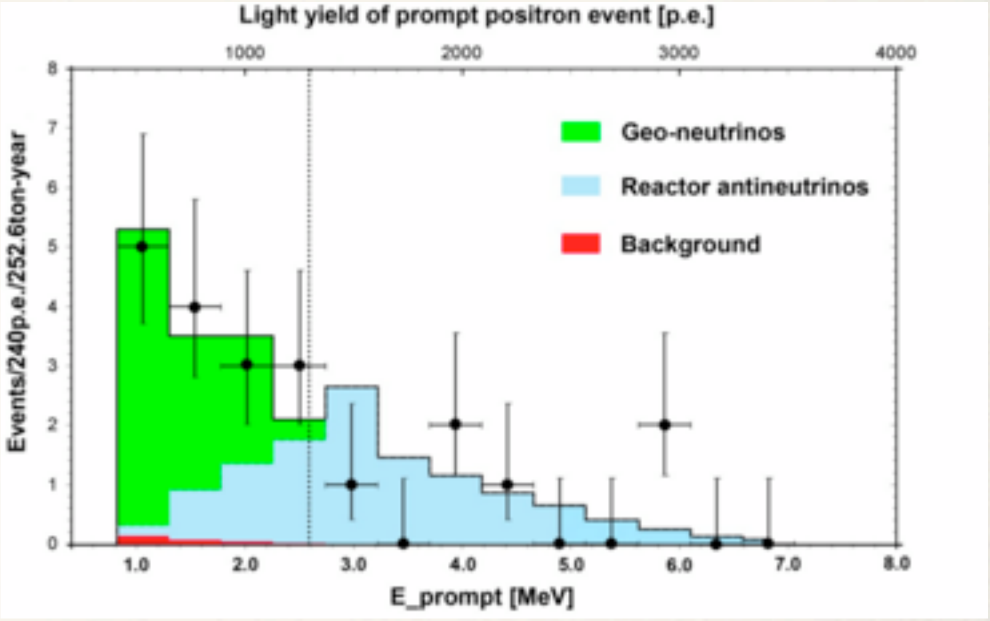

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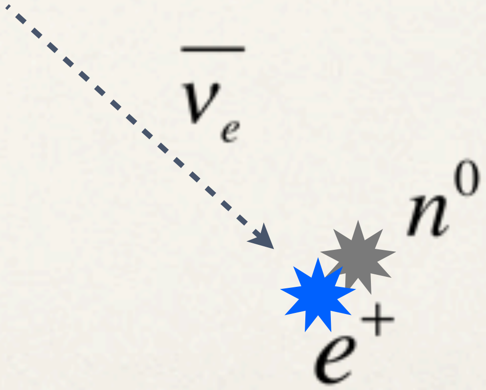

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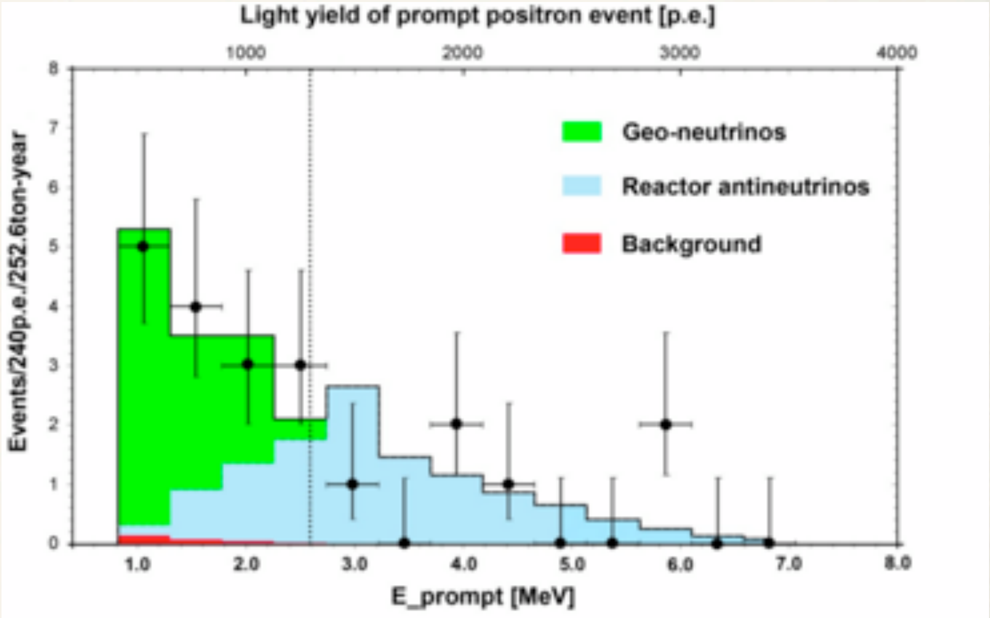
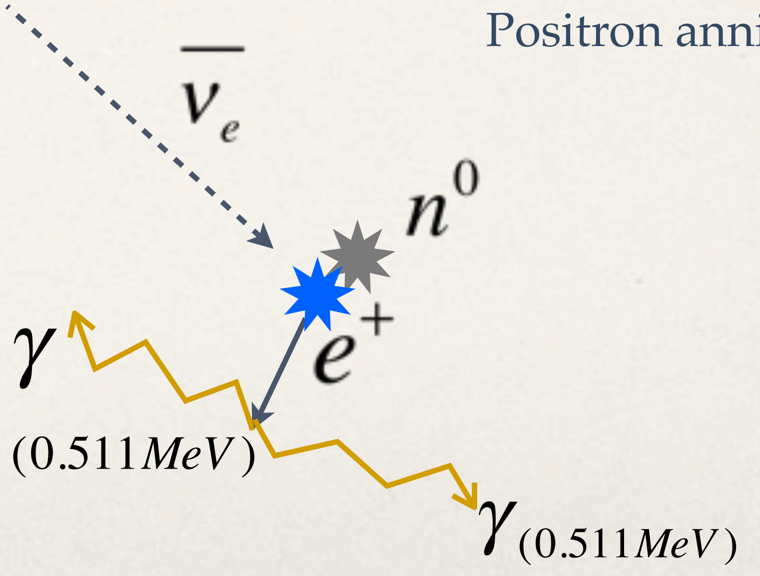


Positron annihilation



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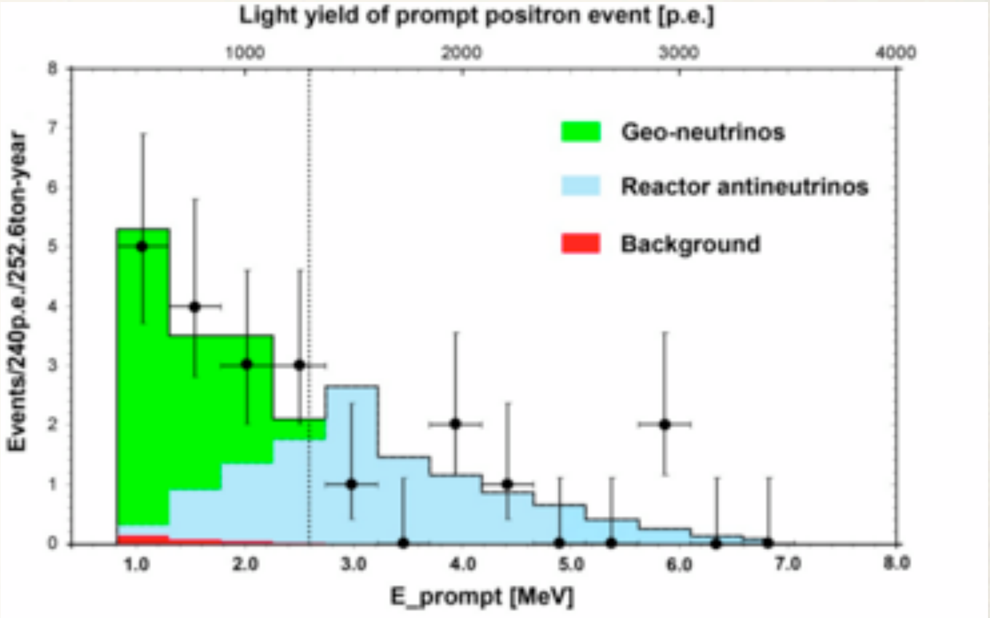
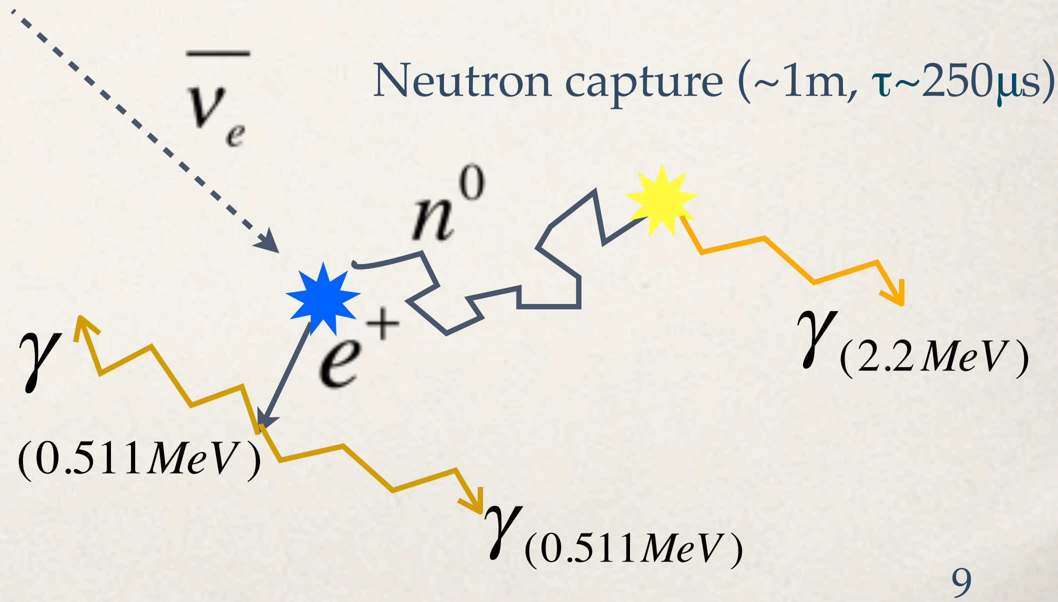
√ Cosmogenics (mainly ^{9}Li-^{8}He)
√ Fast neutrons...

- Rate of **3.9+1.6/-1.3(stat)+5.8/-3.2(sys) counts per year/100tons** - 50:1 signal-to-noise for reactor+geoneutrinos

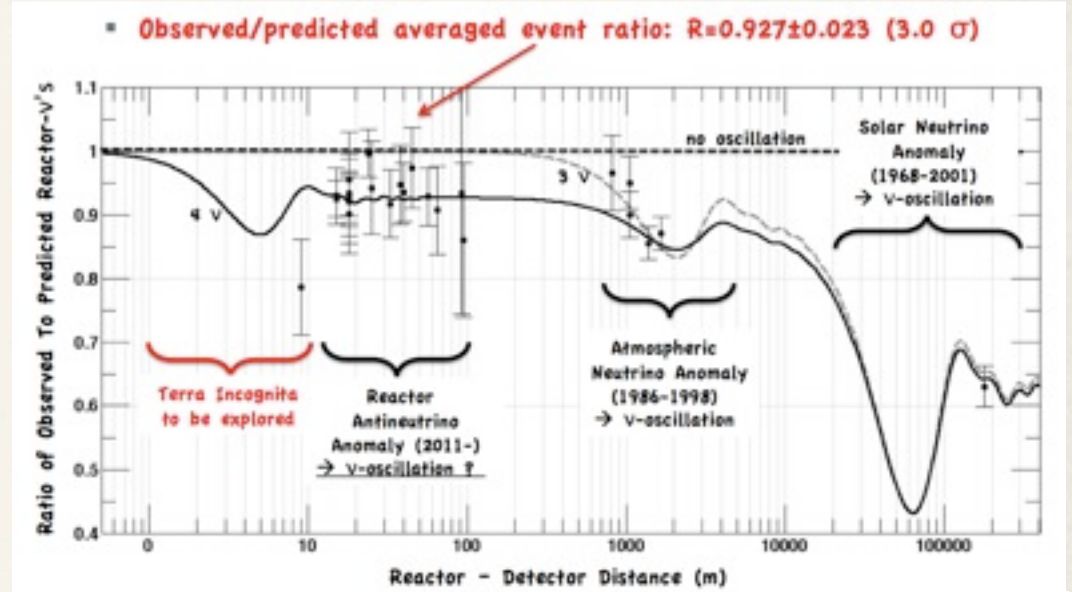
$$\overline{\nu_e} + p^+ \rightarrow e^+ + n^0$$





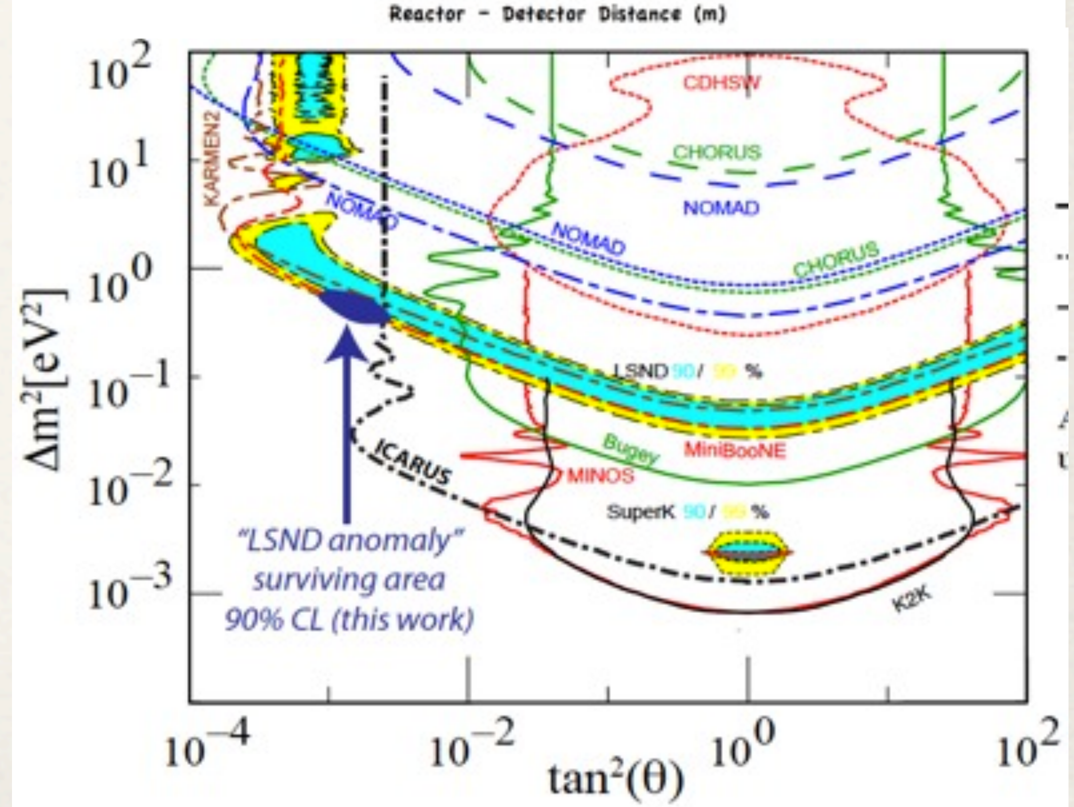
The future: light sterile neutrino short-baseline search

T. Lasserre(NNN12)



Can there be a fourth (or fifth...) neutrino that doesn't couple with the Z^0 boson - STERILE?

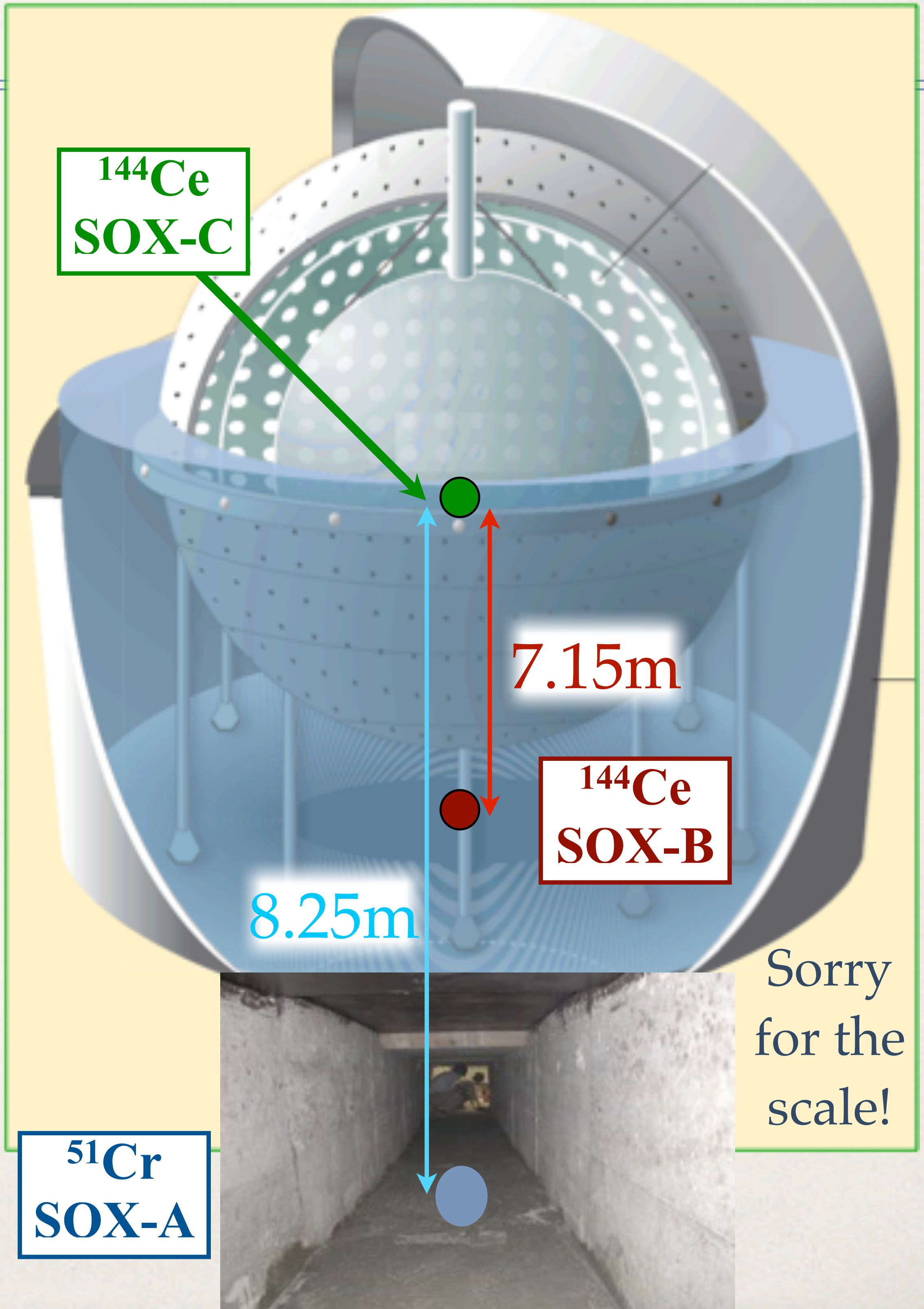
- Existing (ambiguous) hints from experiments supported by theoretical framework
- Most promising mass scale ~<1eV^2, (see-saw type I with light sterile neutrinos, **3+1** or **3+2** models); many other models proposed
- Visible oscillation in short-baseline experiments (other short-distance oscillation effects on P_{ee}?)
- Sterile neutrino as a dark matter candidate



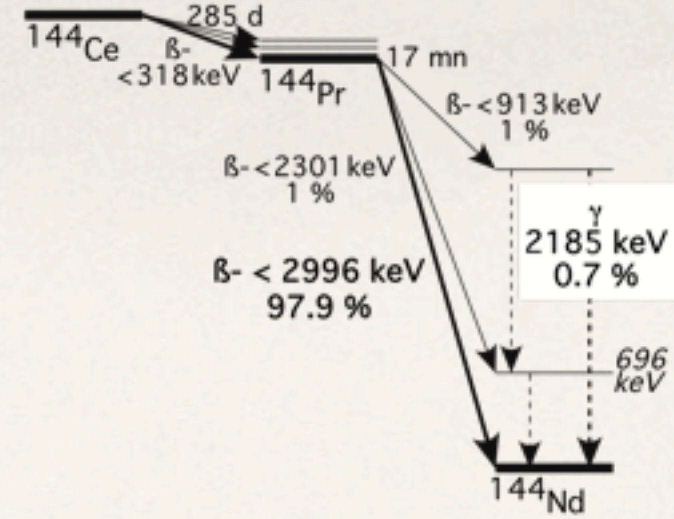
M. Cribier (NuTel2013)

Short-distance Oscillations with BoreXino

- Borexino aims to test **low L/E** (anti) neutrino anomalies using well-known external or internal sources in a well-understood detector
- Concept successfully implemented (in a smaller scale) in GALLEX and SAGE
- Also:
  - Weinberg angle precision measurement at low energy (~1MeV)
  - Neutrino magnetic moment determination
  - Check of g_A and g_V at low energy



Borexino sources



- **^{51}Cr - neutrino source**

  √ Placed in Icarus Pit under the detector

  $$^{51}Cr + e^{-} \rightarrow {}^{51}V + \nu_e (\tau = 27.706 days)$$

  Four monochromatic lines

  √ 10MCi, 10-11 kg (36 available), 200 days

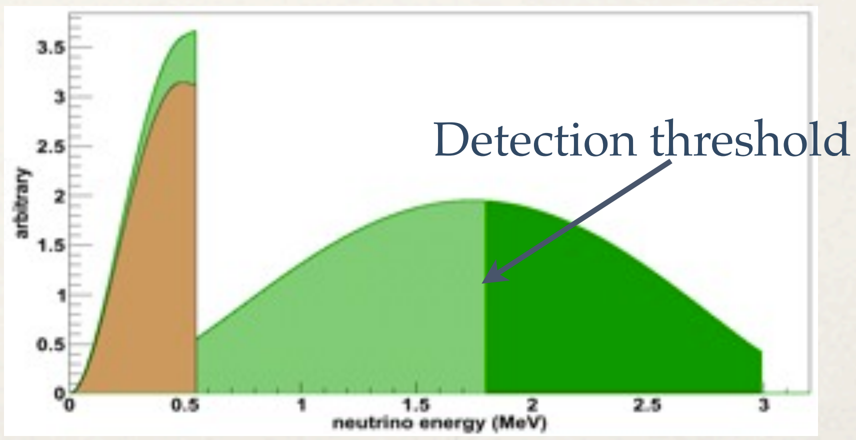
  √ Needs quick transportation

- **$^{144}Ce/^{144}Pr$ - antineutrino source**

  √ 75-50 kCi (296 days halflife) - 14 g and 1 year for statistics

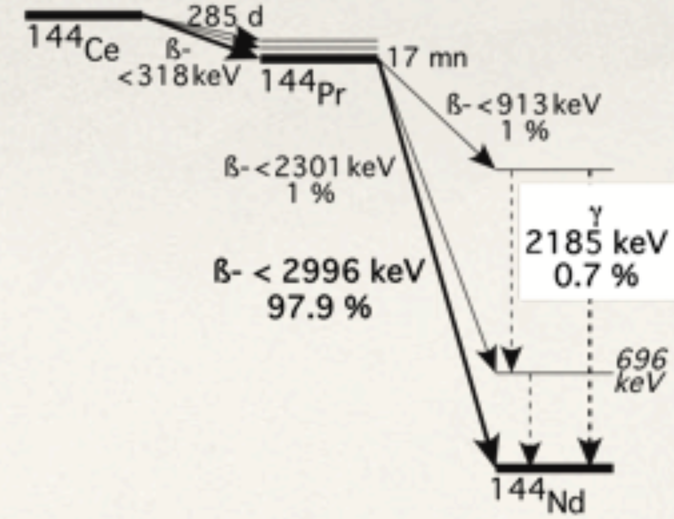
  √ Needed refrigeration with scintillator, copper coldfinger... need to avoid convection

  √ More shielding requirements, better exclusion



- Both sources need 1% error in FV and 1% source activity measurement

Borexino sources



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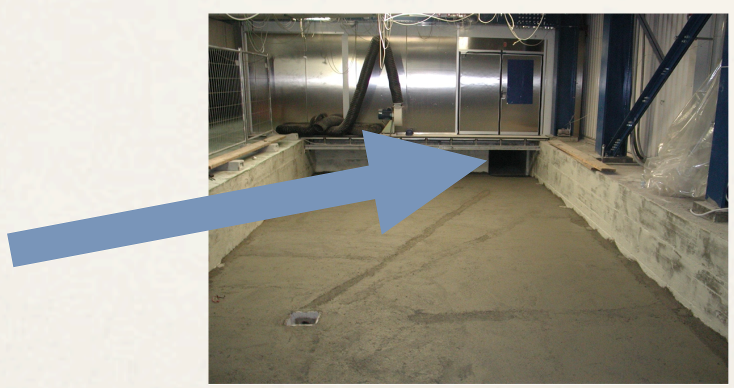

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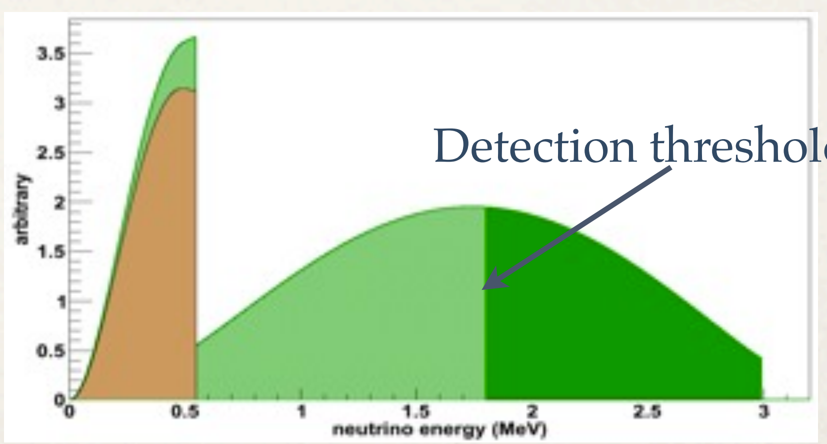
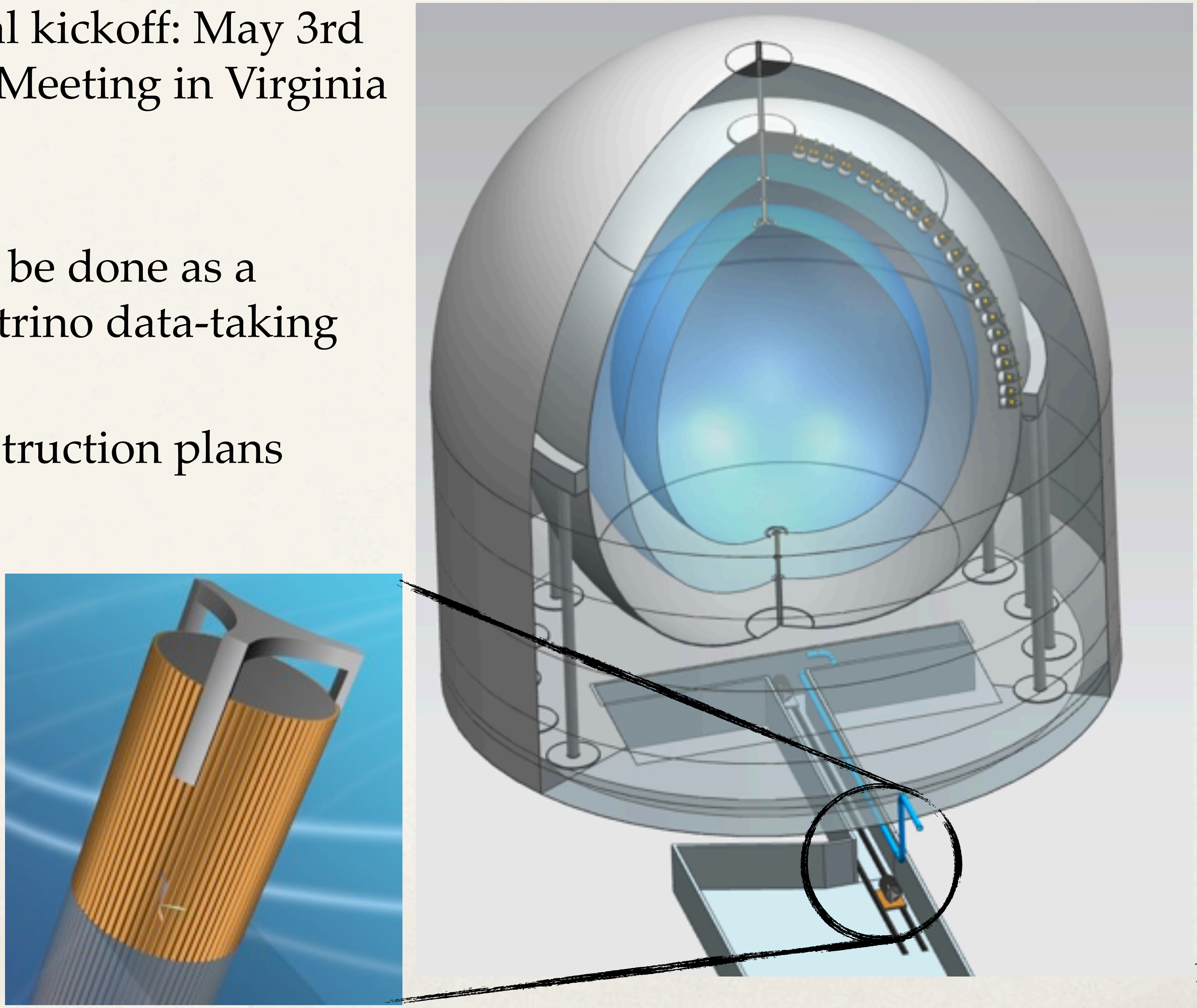


- Both sources need 1% error in FV and 1% source activity measurement

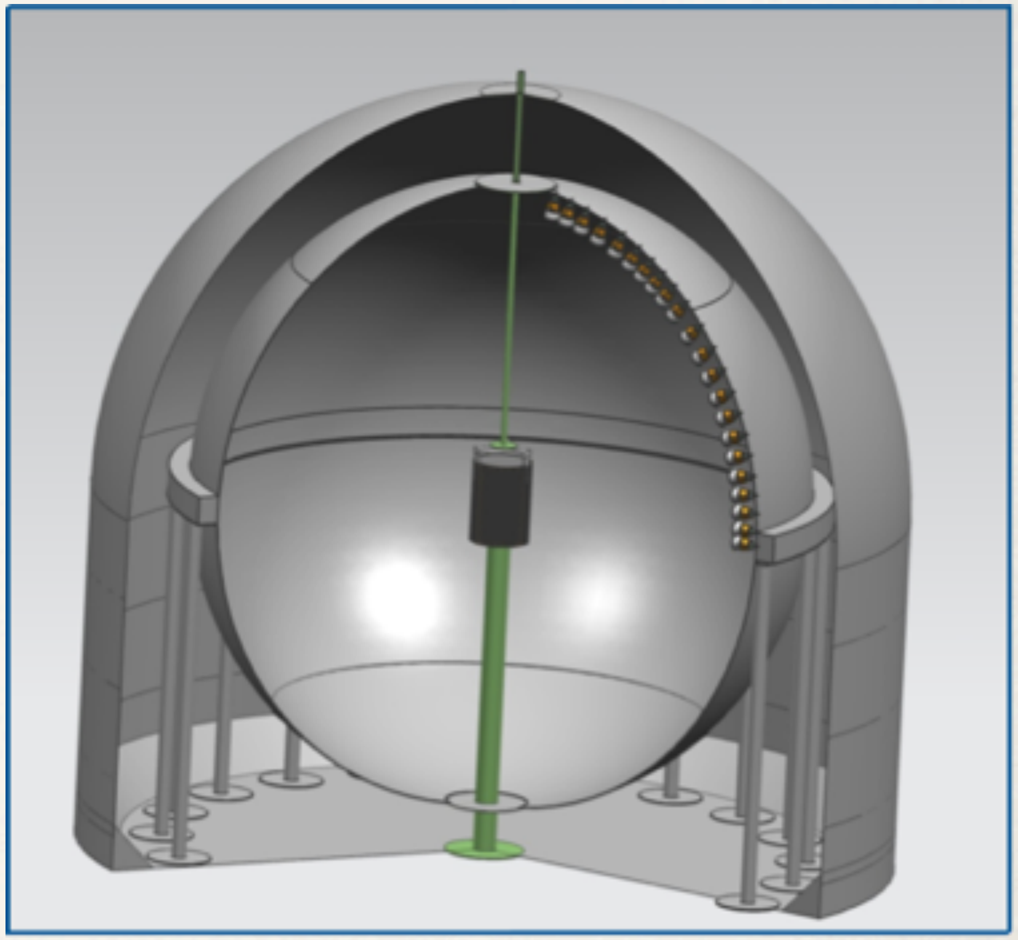
SOX-A (external ^{51}Cr source)

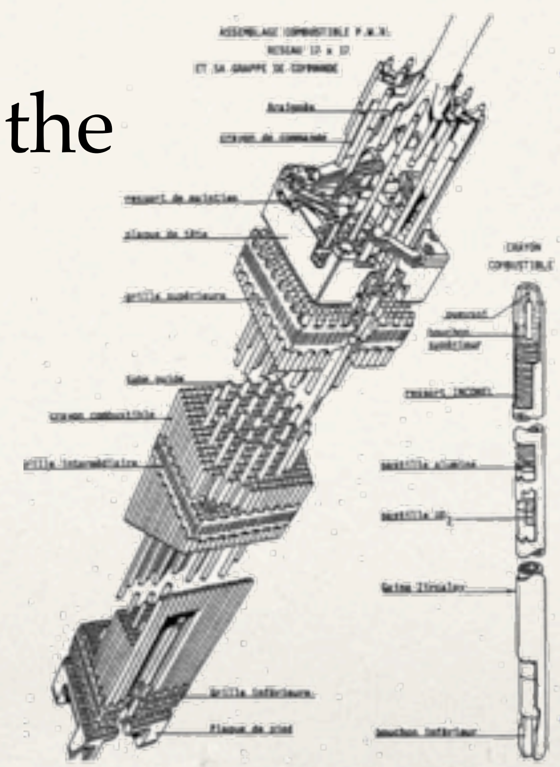
- Timeframe: 2015-16 - official kickoff: May 3rd during Borexino's General Meeting in Virginia Tech
- Uninvasive to detector, can be done as a campaign during solar neutrino data-taking
- Irradiation and source construction plans being finalized
- Enrichment of 38% ^{51}Cr possible up to ~99%(9kg)
- ~2 month datataking



SOX-B / C (internal ^{144}Ce-Pr sources)

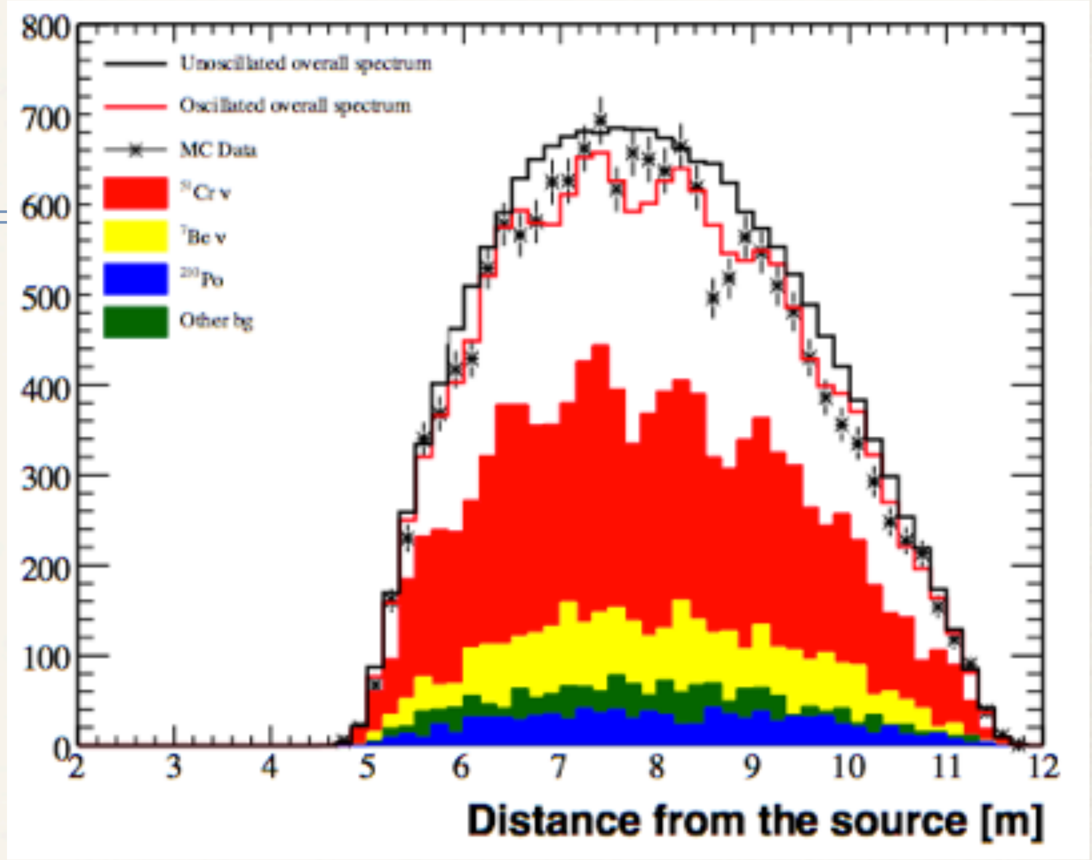
- **SOX-B**: ^{144}Ce-Pr source inside the water tank (2015-16 timeframe)
- PPO in OV for enhanced sensitivity
- **SOX-C**: ^{144}Ce-Pr source in the center of the detector
- Major refurbishment, modifications - after solar program (>2016-17)

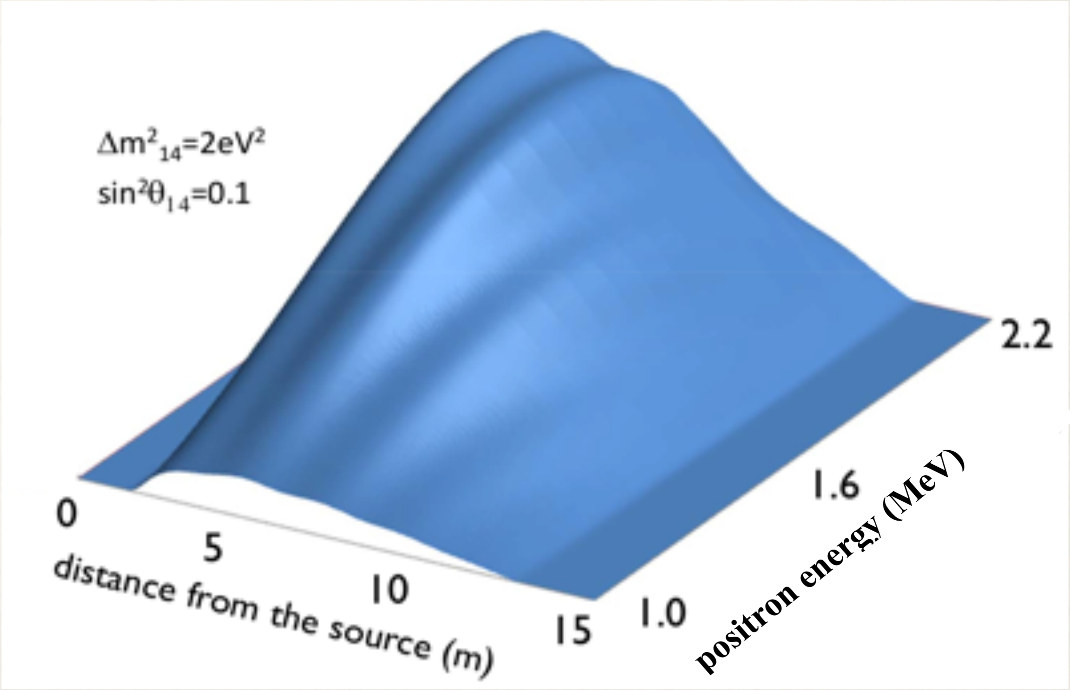




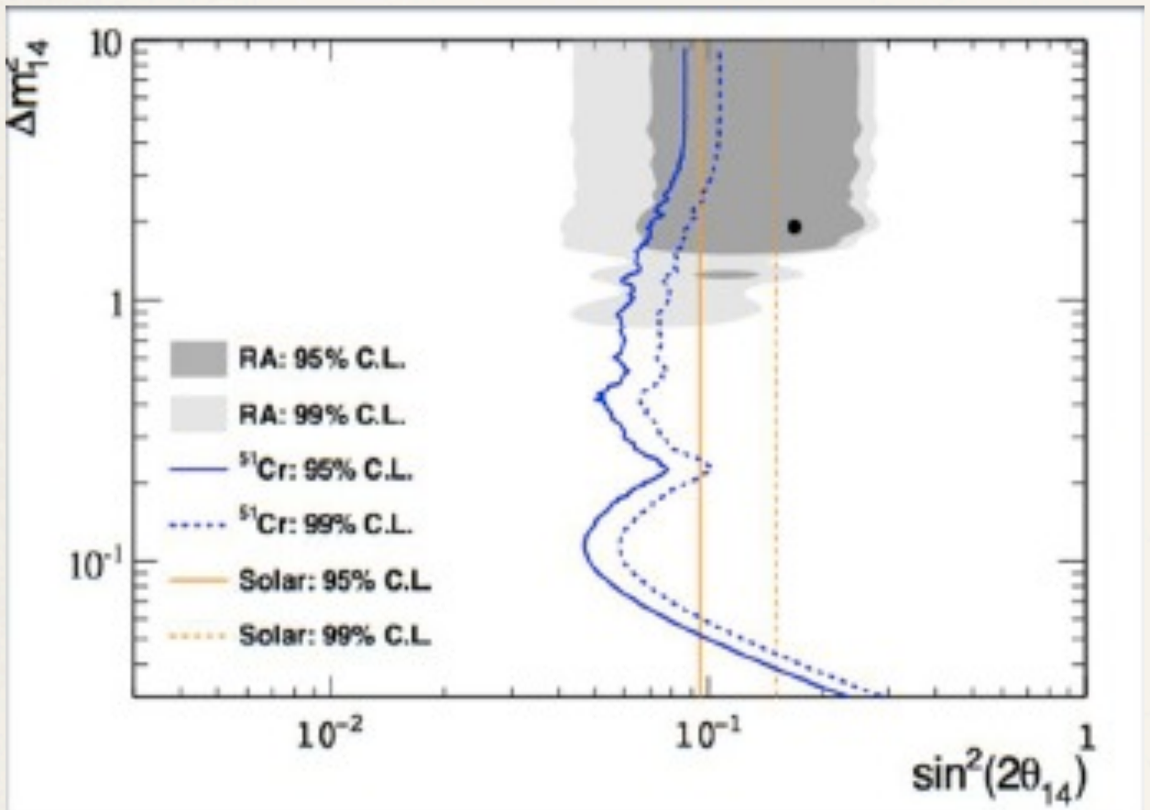
Analysis techniques

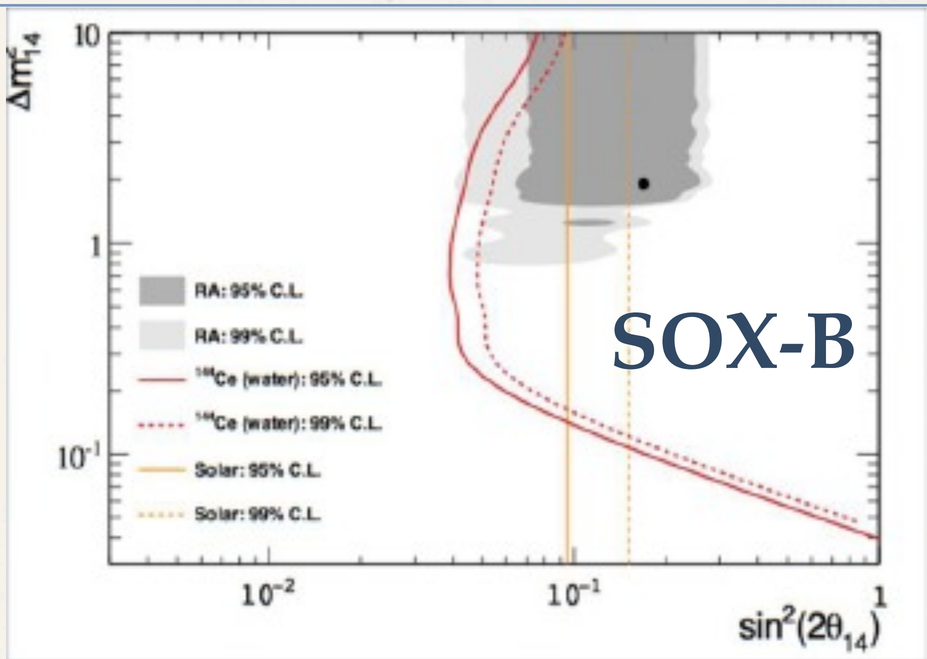
- **Rate+shape strategy** (count rate combined with powerful direct spatial oscillation detection)
  - Rate analysis (disappearance):
    √ Counting strategy, more sensitive to mixing angle than Δm^2 (no spatial information)
  - Rate+shape analysis
    √ Observes spatial oscillations - expected wavelength range shorter than detector size, but bigger than resolution. **Direct measurement of Δm_{14}^2 and θ_{14}.**
    √ Doesn't need such precision on activity determination





Sensitivities





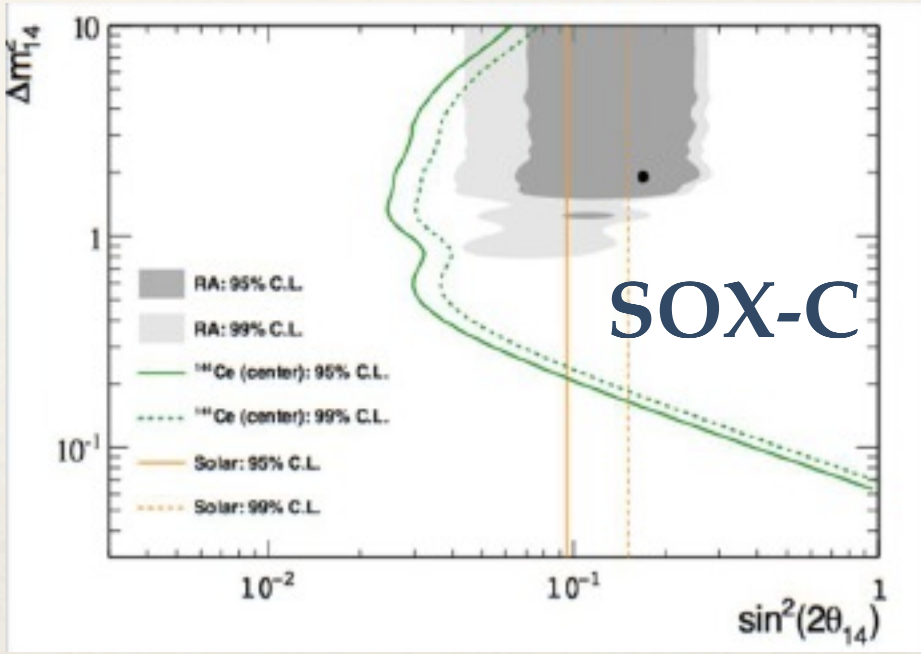
2% bin-to-bin to include systematics

1.5% source activity uncertainty

SOX-A

1% FV determination

1% source activity uncertainty



Activity measurement

- **Sampling**
  √ Samples extracted from several positions in mixed material, at reactor
  √ Ionization chamber measurements
  √ Gamma-ray spectroscopy (HPGe) of dissolved samples

- **<u>Calorimetry</u>**
  √ Emmited radiations will heat up source and shield
  √ ~216W/PBq with thermocouples
  √ Less precision but doesn't depend on representative samples
  √ Suspended and isolated container: designed as vacuum chamber, water flow measurement

- **Neutronics/gamma-scanning**
  √ Neutron flux in reactor + relevant capture cross-section
  √ Gamma-ray measurement from the 320keV line from irradiation to hot-cell

- **Measurement of vanadium**
  √ Only daughter of ^{51}Cr
  √ Also produced ***<u>during</u>*** irradiation, complicating analysis
  √ Ratio Cr/V constant

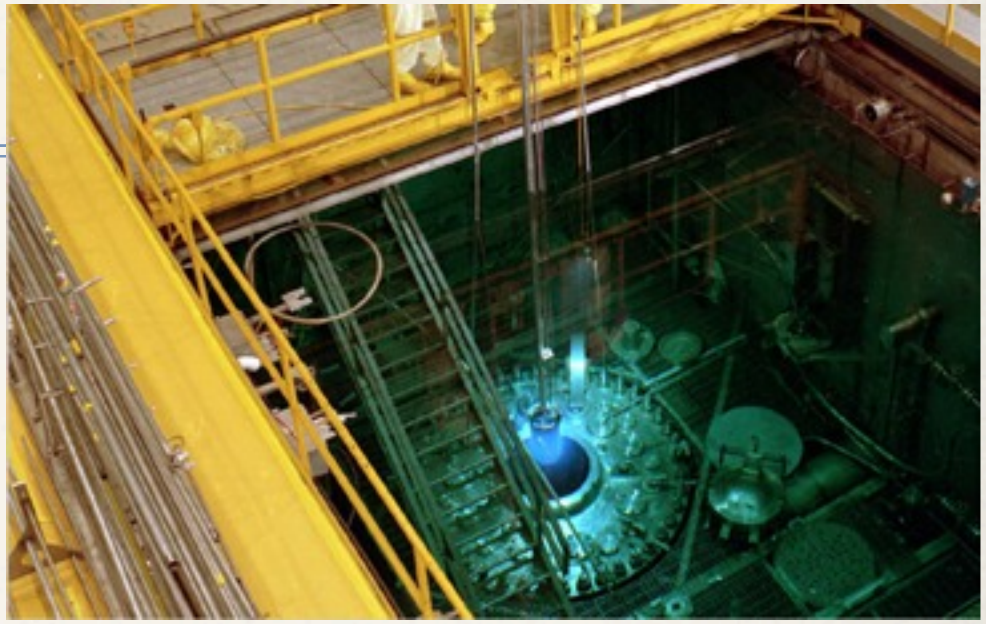
^{51}Cr source design latest

- **Shielding** for biological (<200μSv/h in contact with shield) and background gammas (mainly activated <u>*contaminants*</u> dangerous for signal)

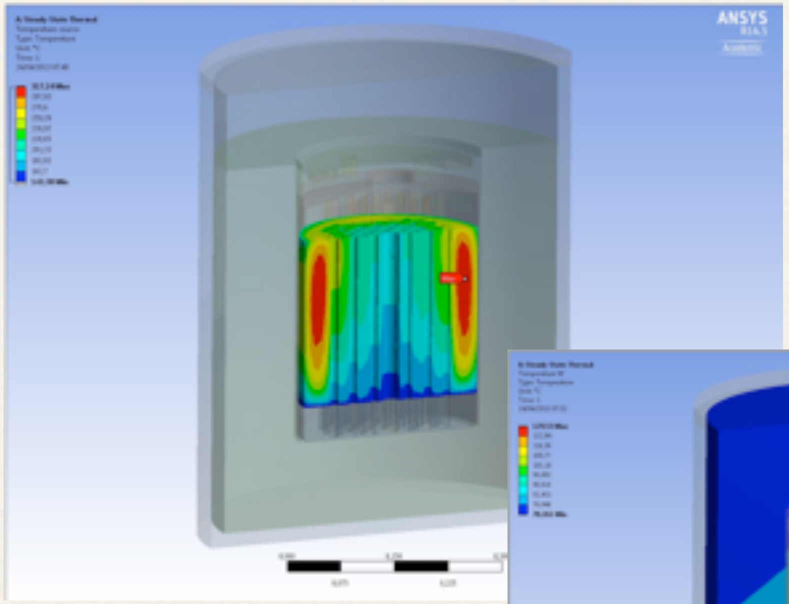
- **Transportation** issues (up to 5 days - 88% of initial activity), transport container apart from W shield

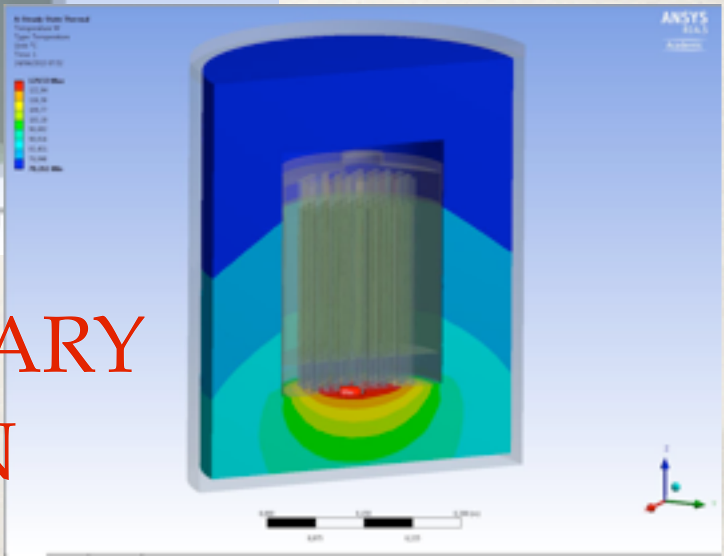
- **Thermal**: not severe problem (0.19kW/MCi) for external source. ***Current design***: 90ºC outside, ~300ºC hottest point inside source, considering chipped chromium and no active cooling (well below sinterization at 750ºC)

- **Irradiation** possible in HFIR (ORNL, Tennessee, USA), Mayak (Russia), or Petten (Netherlands). **Tests with 33mg of 97% enriched ^{51}Cr starting now in ORNL - soon to be followed by existing GALLEX 38% ^{51}Cr.**



Oak Ridge National Laboratory's (ORNL) HFIR reactor (Tennessee, USA)



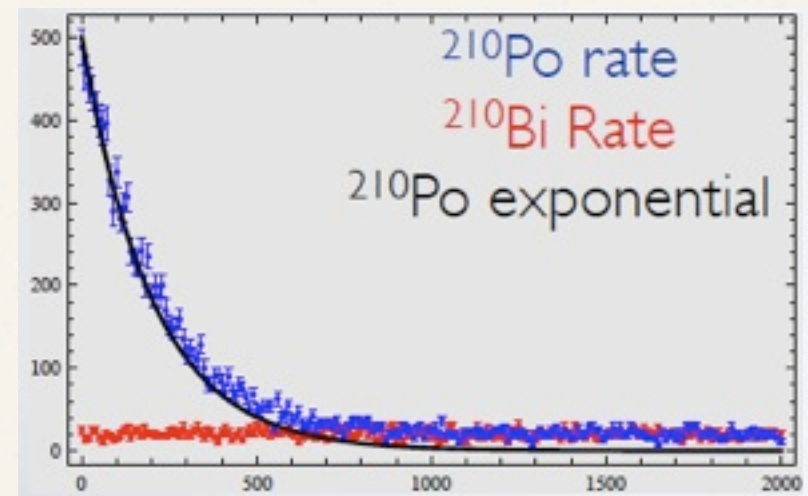


PRELIMINARY DESIGN

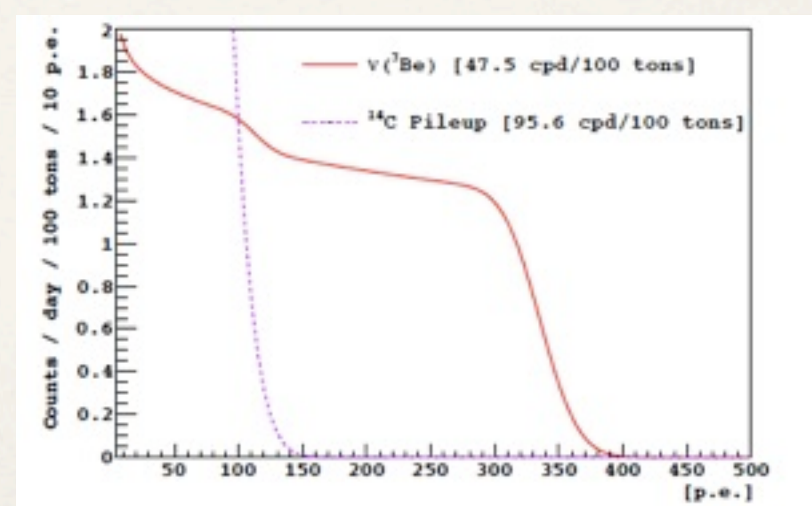
Summary

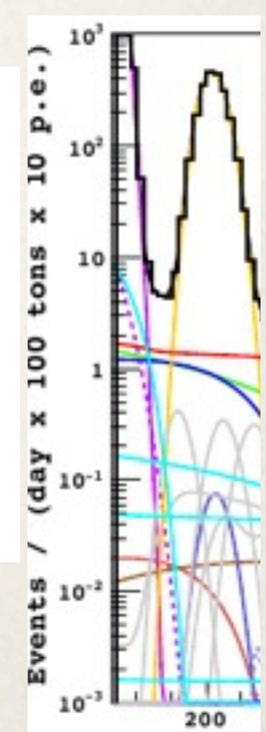
- Results over a broad range of energies already achieved
  - ^{7}Be (<5%), ^{8}B, geo, *pep*, CNO limit...
  - Excellent (and improving) backgrounds
- Promising future: sterile neutrino searches (SOX-A,B&C)
- Meanwhile: pp measurement, improvement of CNO limit

$$n_{\mathrm{Po}}(t) = n^{0}_{\mathrm{Po}} \exp(-t/\tau_{\mathrm{Po}}) + \langle n_{\mathrm{Bi}}(t) + S_{\mathrm{Po}}(t)\rangle$$



^{210}Bi variation - stability needed for improvement of CNO





^{14}C and pileup - precise fit modelling to disentangle from pp signal - analysis ONGOING

The End

This work is possible thanks to all the Borexino Collaboration

Astroparticle and Cosmology Laboratory - Paris, France
INFN Laboratori Nazionali del Gran Sasso - Assergi, Italy
INFN e Dipartimento di Fisica dell'Università degli Studi - Genova, Italy
INFN e Dipartimento di Fisica dell'Università degli Studi - Milano, Italy
INFN e Dipartimento di Chimica dell'Università degli Studi - 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 Istitute fuer Kernphysik - Heidelberg, Germany
Princeton University - Princeton, NJ, USA
Technische Universität - Muenchen, Germany
University of Massachusetts - Amherst, MA, USA
University of Moscow - Moscow, Russia
Virginia Tech - Blacksburg, VA, USA

Thank you for your attention!