Magellan workshop
Connecting Neutrino Physics and Astronomy

Monte Carlo simulations in neutrino physics: the example of the SOX experiment

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for the SOX collaboration

March 18th 2016

Experimental hints

- ν_e, $\bar{\nu}_e$ disappearance
- Reactor anomaly: reanalysis of $\bar{\nu}$ flux from short baseline experiments shows a small deficit (R=0.943±0.023) [1]
- Gallex-Sage anomaly: deficit of neutrinos coming from ^{51}Cr and ^{37}Ar sources (R= $0.76^{-0.08}_{+0.09}$) [2]

- ν_e, $\bar{\nu}_e$ appearance
- Accelerator anomaly: appearance of ν_e / $\bar{\nu}_e$ in a ν_μ / $\bar{\nu}_\mu$ beam [3]

[1] G.Mention et al, Phys.Rev.D83, 073006 (2011), A.Mueller et al.Phys.Rev.C 83, 054615 (2011)

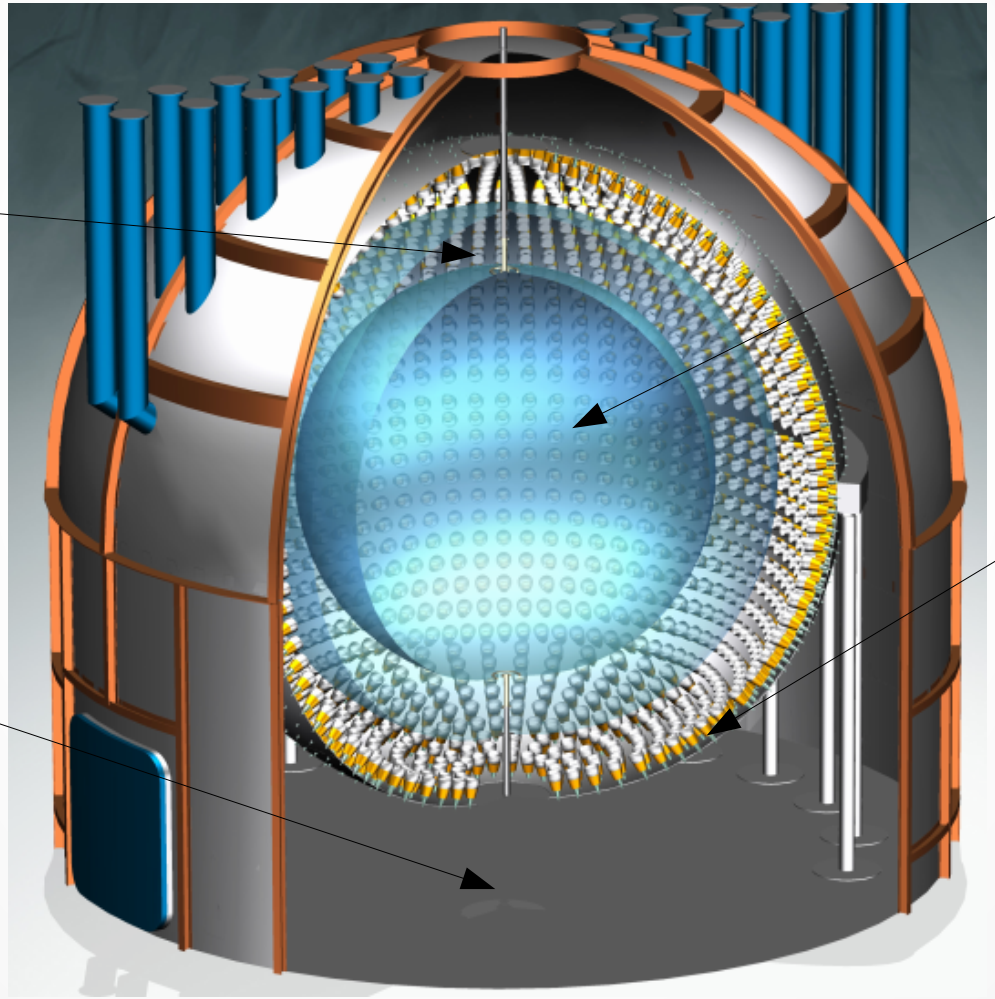
[2]C. Giunti and M. Laveder, Phys.Rev. C83, 065504 (2011), arXiv:1006.3244 [hep-ph]

[3]A.Aguilar et al. LSND Collaboration Phys.Rev.D 64, 112007 (2001), A.Aguilar et al. (MiniBooNE Collaboration) Phys.Rev.Lett. 110 161801 (2013)

Possible mixing of active flavors with sterile neutrinos $\Delta m^2 \sim 1$ eV^2

SOX: Short distance neutrino Oscillations with boreXino

The Borexino detector



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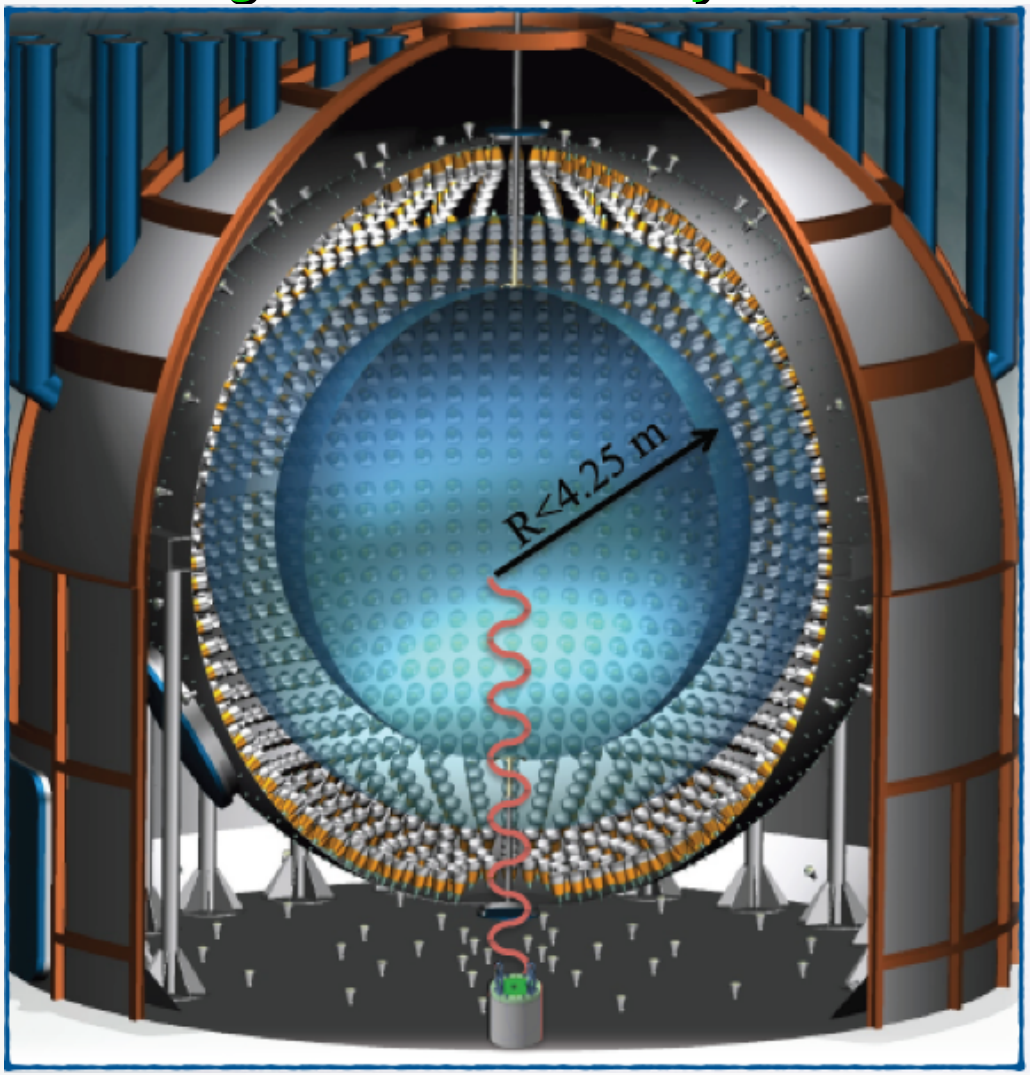
Aim: clear and unambiguous discovery or definitive disproof of the anomalies



JHEP 08 (2013) 038

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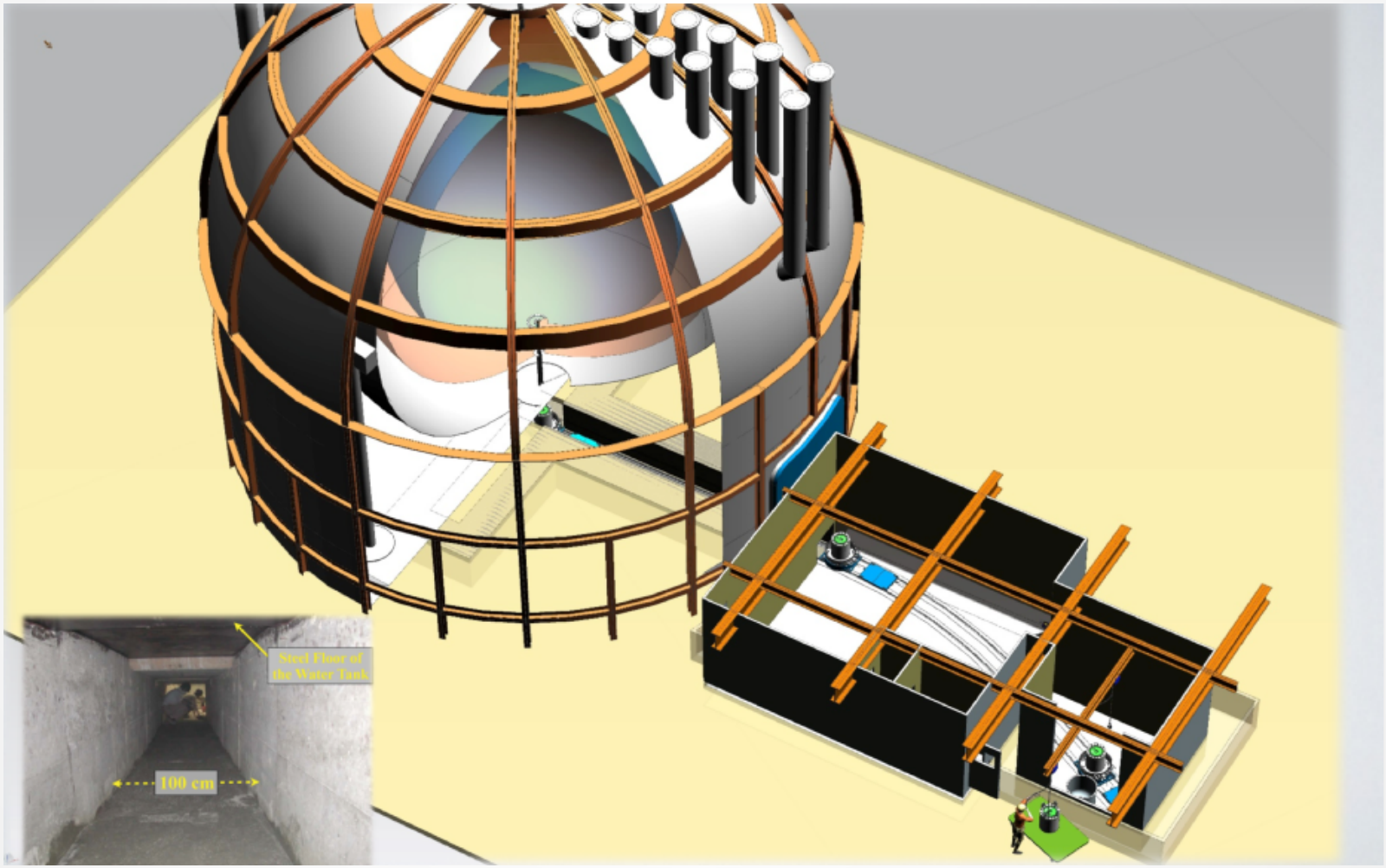
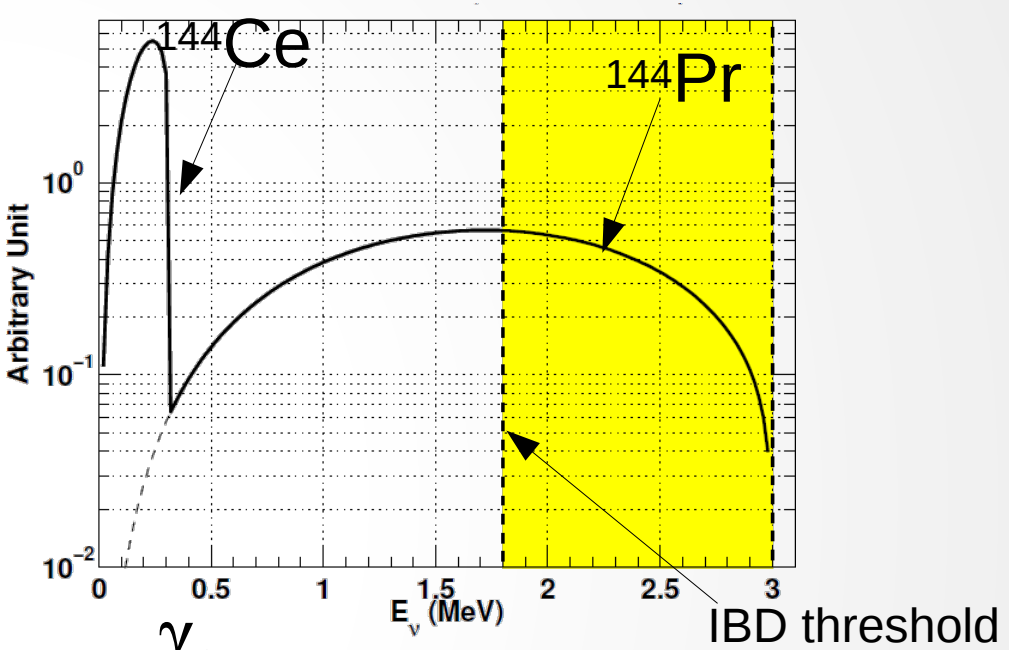
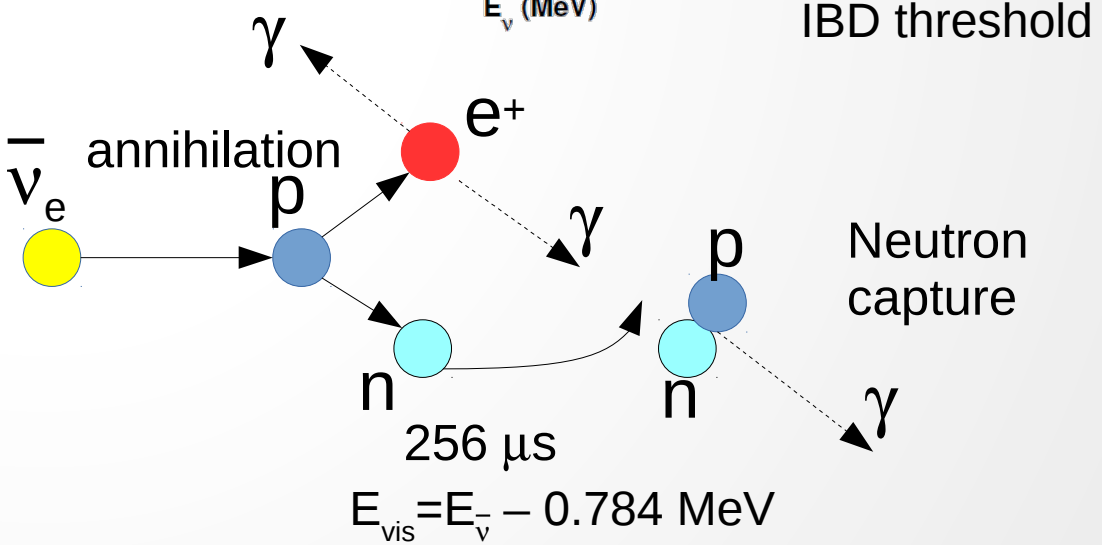


SOX: $\bar{\nu}$ source

- ^{144}Ce-^{144}Pr source
  - $\tau(^{144}\text{Ce})$=285 days
  - $\tau(^{144}\text{Pr})$=17 min
- Produced by exhausted nuclear material
- Activity ~ 100-150 kCi
- Detected using IBD (T= 1.8 MeV) → **almost negligible background!**





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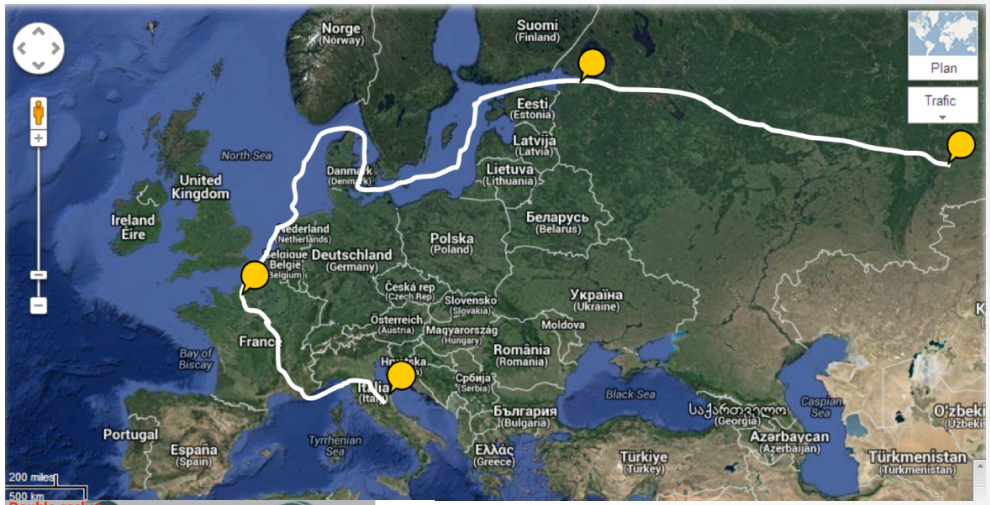
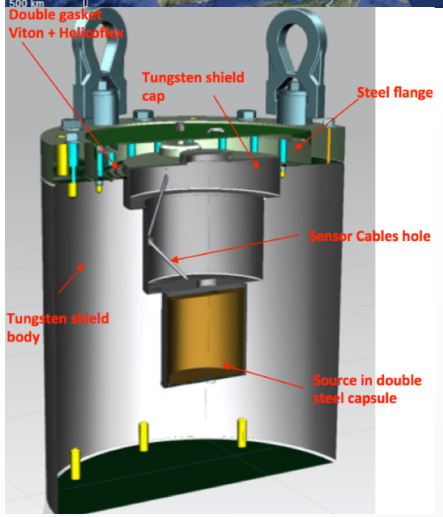




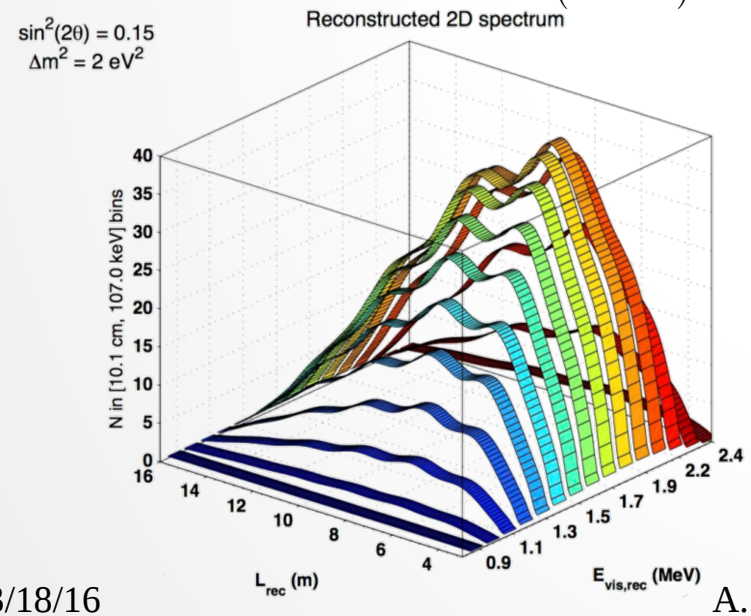
19-cm thick high density Tungsten shield

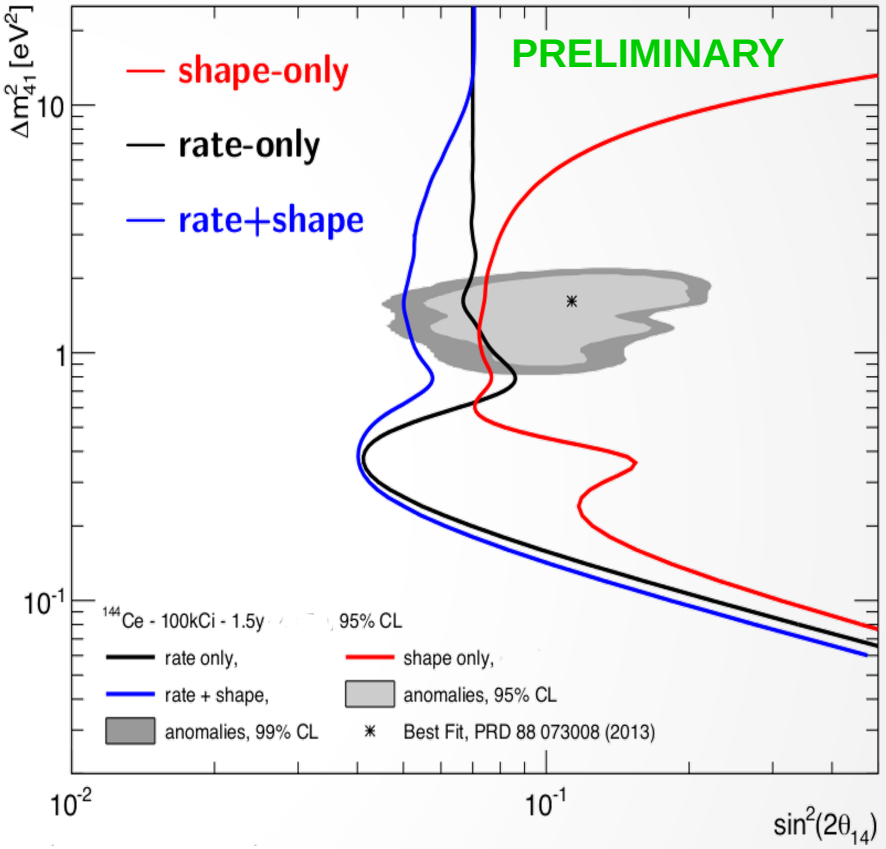
Dimensions driven by ^{144}Pr 2.185 MeV deexcitation γ (br =0.7%)

SOX: analysis

- **Rate analysis**: standard disappearance experiment
- **Shape analysis**: waves inside Borexino!

$$P_{ee} = 1 - \sin^2 2\theta_{14} \sin^2 \frac{1.27\,\Delta m^2_{14}(eV^2)\,L(m)}{E(MeV)}$$





Precise evaluation of neutron detection efficiencies, energy and vertex resolution necessary

Need of a reliable simulation of the whole experiment

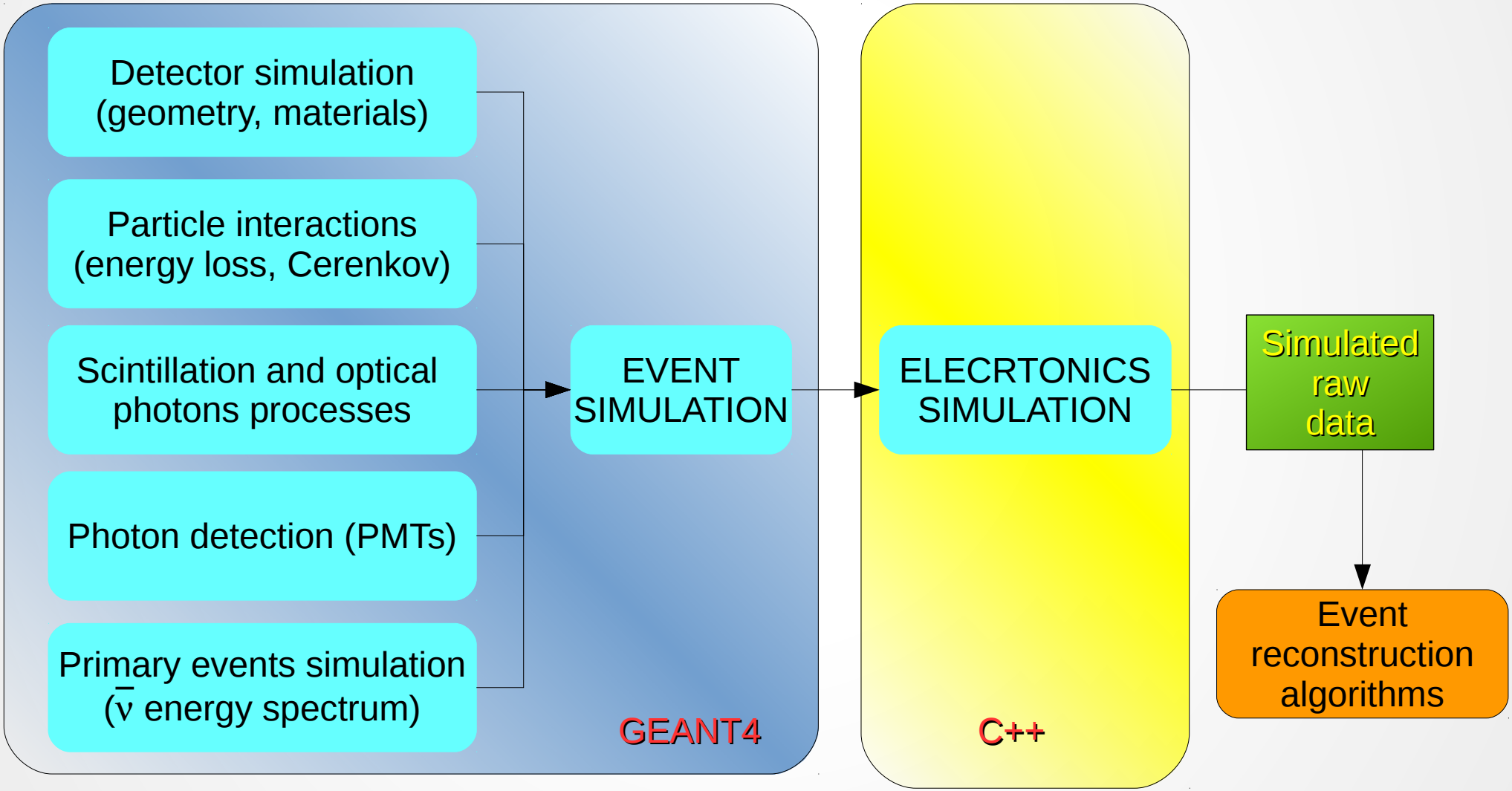
Knowing our detector

A precise knowledge of the detector response is fundamental for the data analysis. We have to relate measured and physical quantities.

- Measurable quantities
  - Number of photons detected by each PMT
  - Time of arrival of each photon on PMT
- Physical quantities
  - Energy of the event
  - Position of the event
  - Particle identification

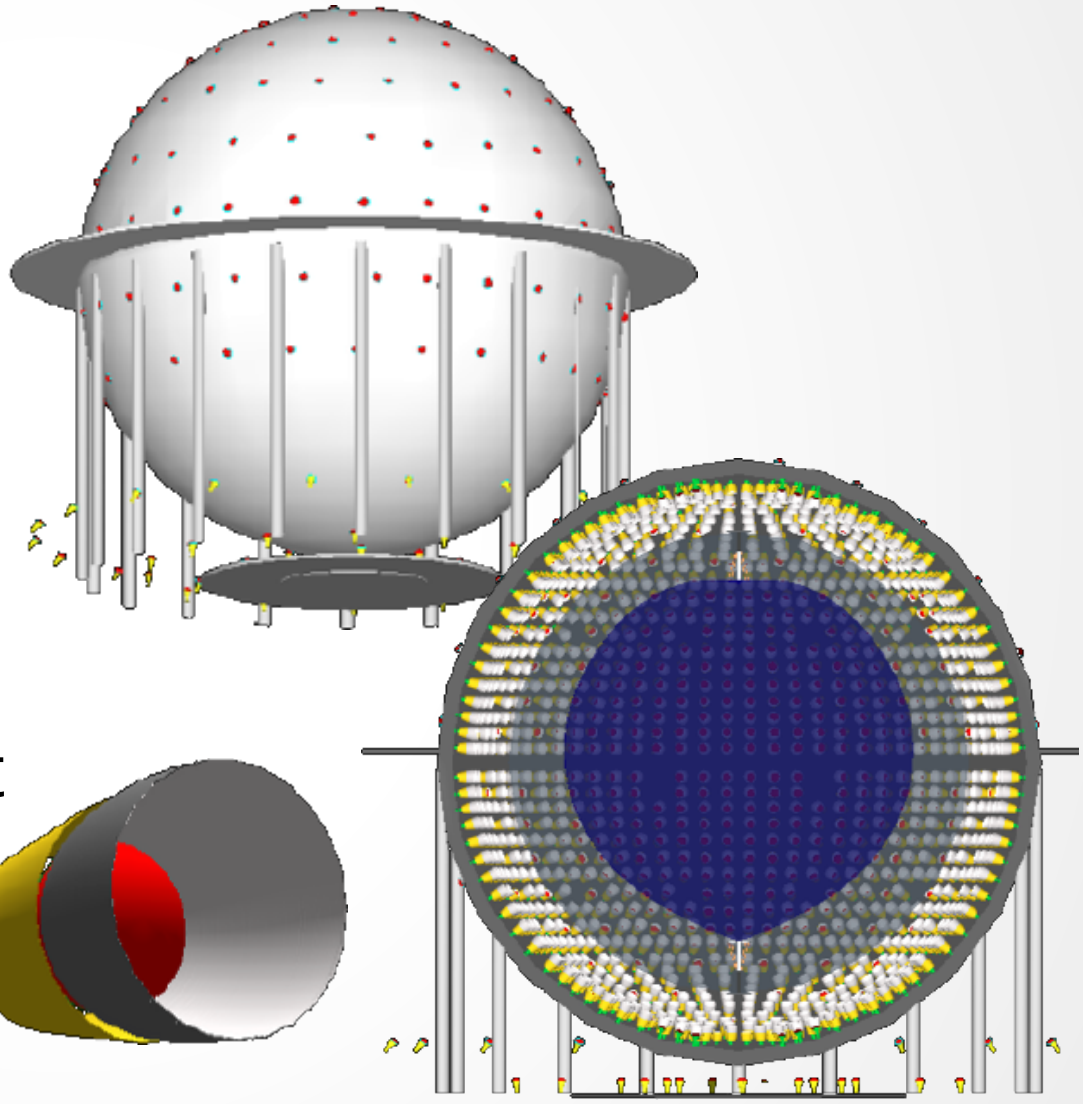
Simulation of the detector's response

The Sox simulation code is an extension of the Borexino code



Detector simulation

- Detailed geometry of the detector implemented
- Attenuation lengths emission spectra from previous measurements
- Details in PMTs light concentrators very important for reliable light collection far from the center



Detector simulation

- Detailed geometry of the detector implemented
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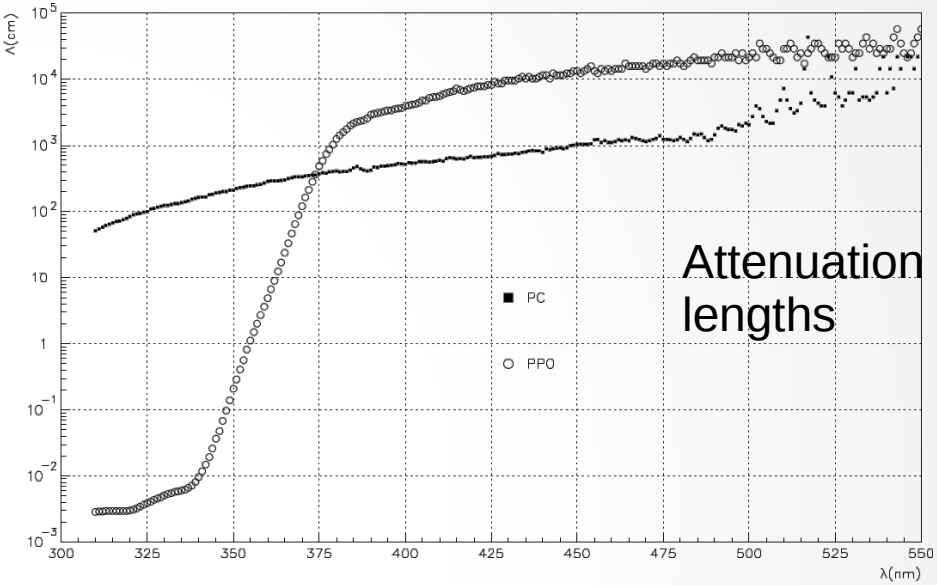
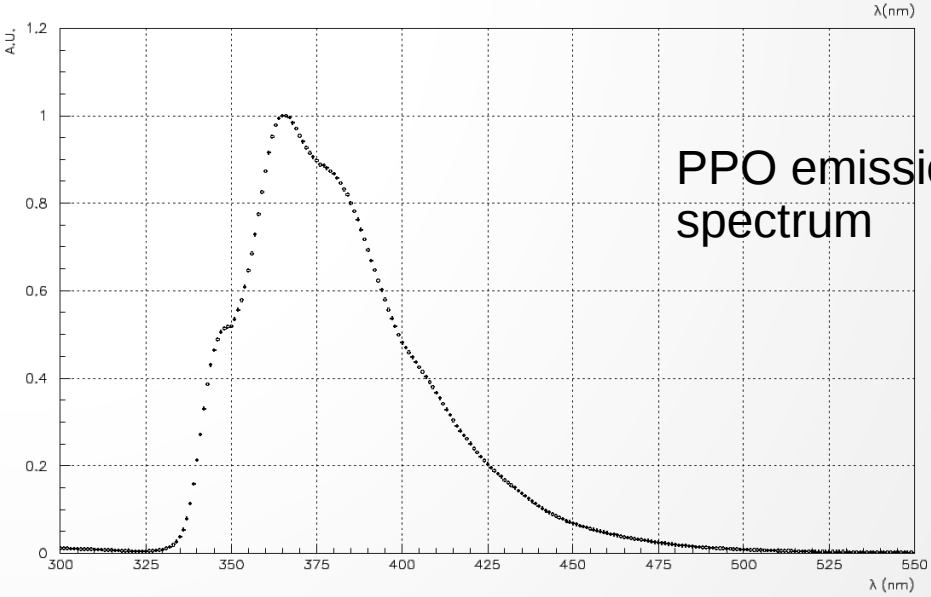


Attenuation lengths



PPO emission spectrum

[1] Nucl.Instrum.Meth.A600:568-593,2009

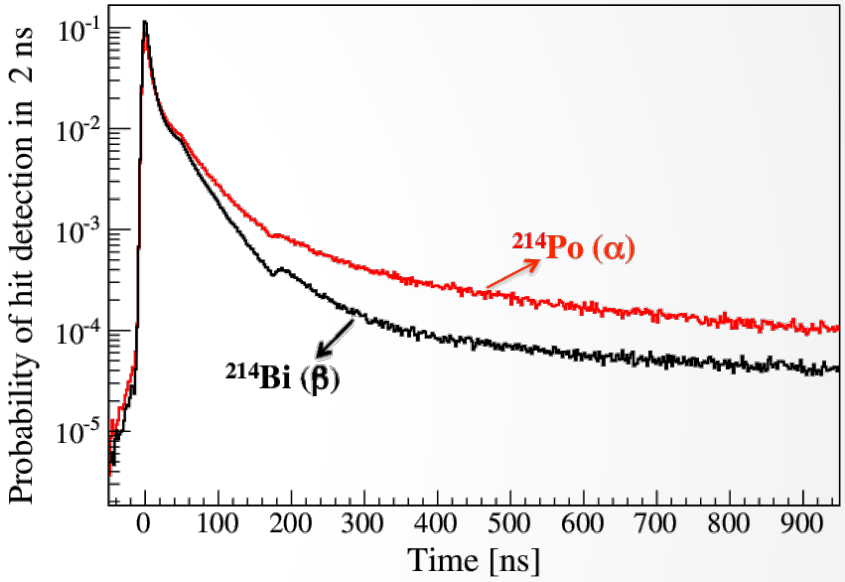
Scintillation and energy response

- Scintillation light different for α and β → Particle identification

$$P(t) = \sum_i \frac{w_i}{\tau_i} e^{\frac{-t}{\tau_i}}$$

- Birk's model applied to take into account the quenching of the scintillator

$$\frac{dY^{ph}}{dx} = \frac{Y_0^{ph}\, dE/dx}{1 + k_B\, dE/dx}$$



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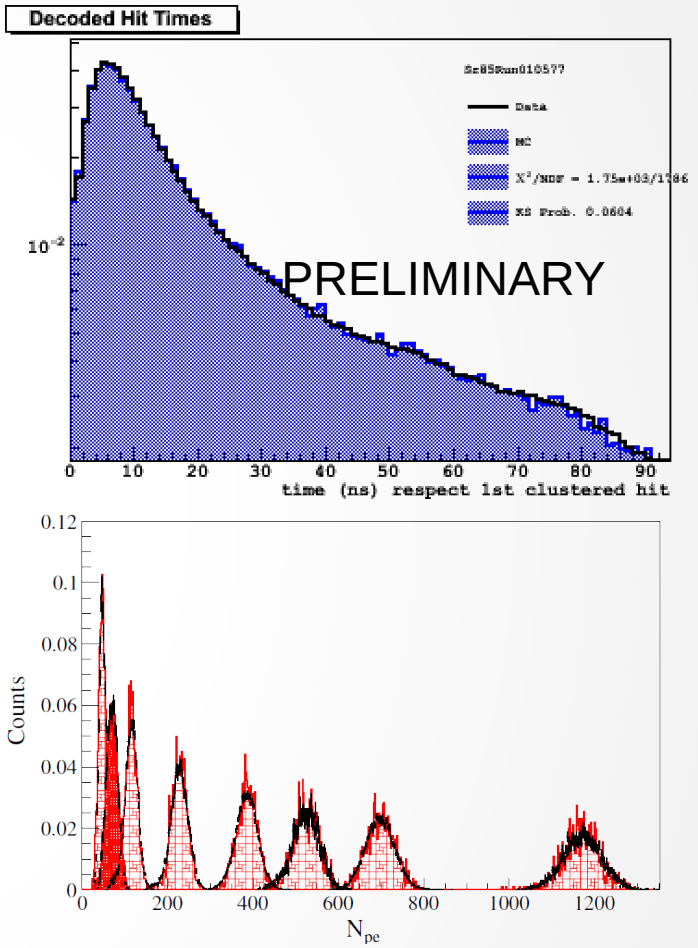
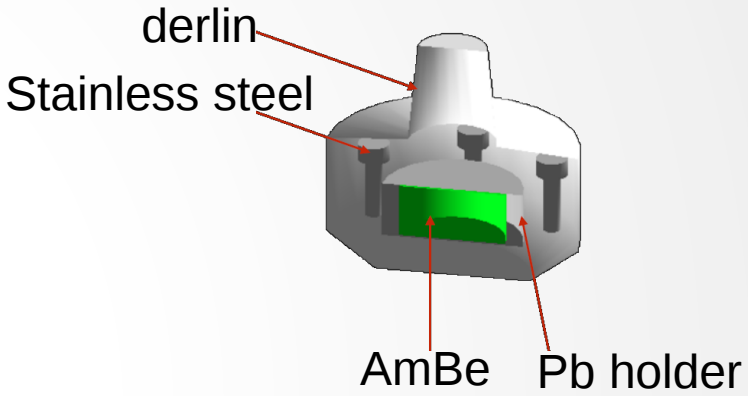
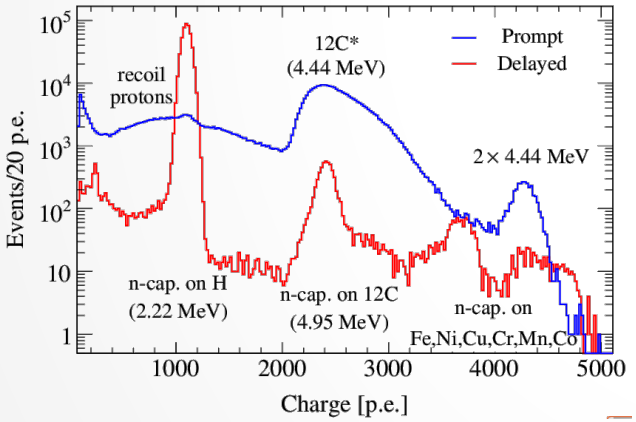
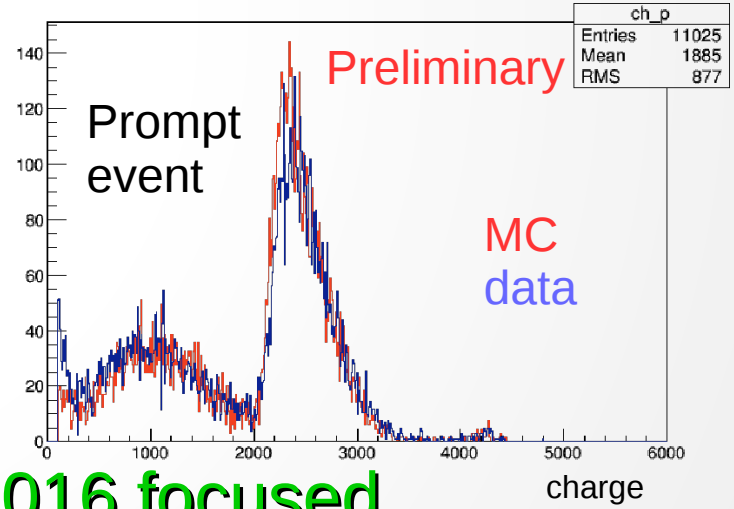


Scintillation and energy response

- ^{241}Am-^{9}Be neutron source helpful to test IBD-like events (prompt – delayed signals)
- Helpful to test MC performances in view of evaluating the neutron detection efficiencies







New calibration campaign in fall 2016 focused on Borexino Phase II and SOX needs (Poster ID 22)

Simulation of the ^{144}Ce-^{144}Pr source

- $\bar{\nu}$ are not directly simulated in Geant4. IBD vertex is directly simulated. Geant4 takes care of e+ annihilation and n capture
- $\bar{\nu}$ spectrum takes into account the corrections to the β decay spectrum as reported in [1].
- Since ^{144}Pr $\rightarrow$ ^{144}Nd is a forbidden transition, shape factor has to be taken into account
- The decay spectral shape measurement is foreseen in view of the data analysis

[1] Patrick Huber Phys. Rev. C 84, 024617

Perspective and outlook

- The SOX experiment aims a unambiguous discovery or a complete disproof of the neutrino anomalies
- Monte Carlo simulations will play a key role in the SOX analysis both for sensitivity studies and for efficiencies estimations
- In view of the Borexino Phase II (S. Marcocci / S. Davini talks) and SOX analyses the Borexino simulation code have been extended
- In late 2016, a new calibration campaign is foreseen. The choice of the calibration points (and deployed sources) will be particularly driven by SOX needs
- SOX data taking will start at the end of 2016, stay tuned ;)


Thank you
for your attention!!
SOX: ERC project N. 320873 – P.I. Prof. M. Pallavicini
photo: BOREXINO calibration