

Neutrino physics with Liquid Scintillator

LEXI Meeting 2012

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October 12, 2012

1 Neutrino Detection with Liquid Scintillator

2 (Some) Activities in our Group

- Borexino
- LENA
- Tracking

3 Conclusions

Why do we need neutrino detectors?

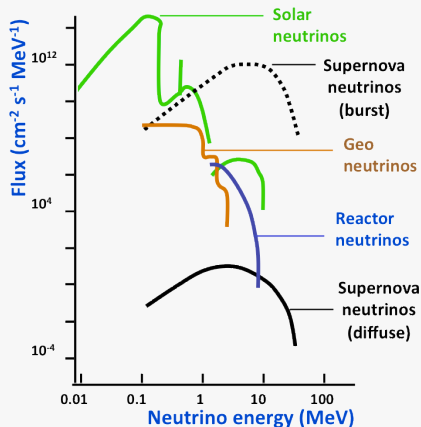
- To better understand astrophysical and terrestrial ν sources.
 - To investigate neutrino properties.
 - As a target for a neutrino beam.
-
- KamLAND and Borexino show the outstanding physics potential of liquid scintillator for neutrino detection.
 - Increase detection sensitivity and precision $\rightarrow$ higher target masses.
 - A large LS detector addresses a large range of physics!

Neutrino Physics

- Galactic supernova neutrinos
- Diffuse supernova ν background
- Solar neutrinos
- Geoneutrinos
- Reactor neutrinos
- Neutrino oscillometry
- Neutrino beams
- Atmospheric neutrinos
- π decay @ rest beam

Also

- Indirect dark matter search
- Proton decay



Detection channels

- ν : elastic scattering $\nu + e^- \rightarrow \nu + e^-$
proton recoil $\nu + p \rightarrow p + \nu$
reactions on ^{12}C (NC and CC)
- $\bar{\nu}_e$: inverse β -decay $\bar{\nu}_e + p \rightarrow e^+ + n$

Advantages of LS

- very low energy threshold (≈ 200 keV)
- good energy resolution ($\approx 7\%$ @ 1 MeV)
- proven purification techniques for high radiopurity

Background rejection

- pulse shape analysis
- coincidence signals

The Borexino Experiment

Real time spectroscopic
neutrino detection using LS

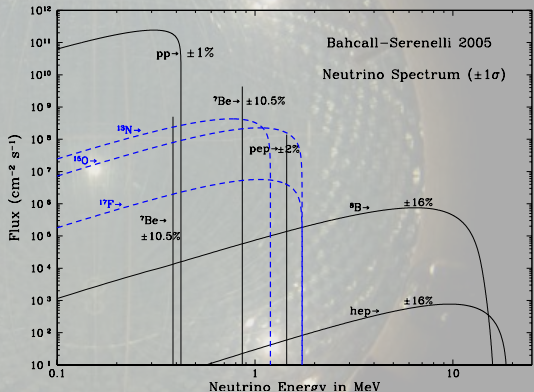
Taking data since May 2007:

- Solar neutrinos
 - ^7Be neutrinos
 - ^8B neutrinos
 - *pep* neutrinos
 - CNO neutrinos
- Geo neutrinos
- Supernova neutrinos (SNEWS)

Phase II:

- Precision measurements
- Sterile neutrinos

Solar ν on Earth: $6.6 \times 10^{10} \frac{\nu}{\text{m}^2\text{s}}$



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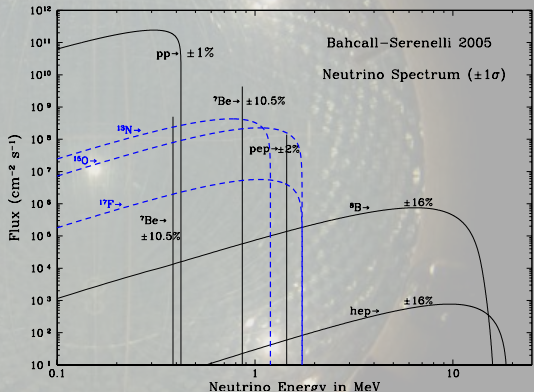
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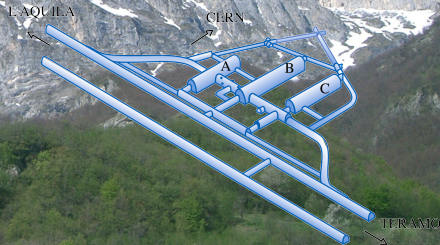
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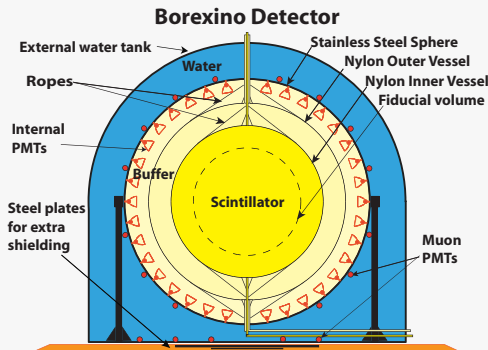




Gran Sasso Massive

- 1400 m rock (3800 m.w.e)
- $\Rightarrow \sim 1.2 \mu/\text{m}^2/\text{sec}$





Outer Detector

2100 tons ultra pure water

- Active shielding
- 208 PMTs $\Rightarrow$ Cherenkov veto

Steel dome: 18 m $\varnothing$ – 16.9 m high

Inner Detector

278 tons of liquid scintillator in nylon vessel ($\varnothing$ 8.5 m) (125 μ m)

- Detector = target
- Organic scintillator: pseudocumene (PC, C_9H_{12})
- ~ 1.5 g/l PPO

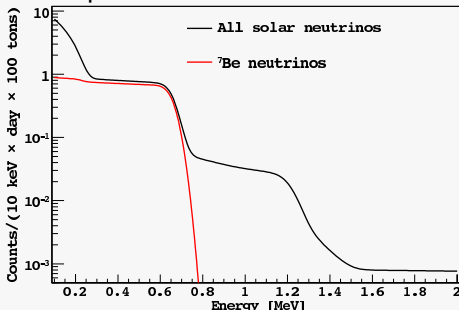
Two buffer layers

- Same liquid
- Light quencher DMP

stainless steel sphere ($\varnothing$ 13.7 m)
holding 2212 inward facing PMTs

- Neutrino detection via elastic scattering on electrons in the scintillator
 $\nu_e + e^- \rightarrow \nu_e + e^-$
Compton-like energy transfer to electron
- Anti neutrino detection via inverse β -decay
 $p + \bar{\nu}_e \rightarrow e^+ + n$
Delayed coincidence from e^+e^- -annihilation and neutron capture

Mono-energetic 862 keV ${}^7\text{Be}$ $\nu_e \Rightarrow$
Compton-like shoulder @ 665 keV



Advantages

- Low energy threshold
- Good position reconstruction (~ 16 cm)
- Energy resolution ($6\%/\sqrt{E}$)

Disadvantages

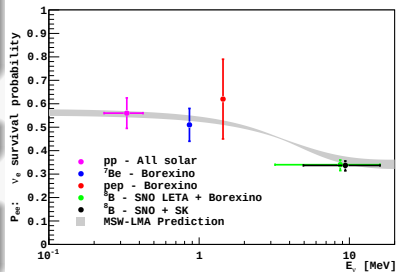
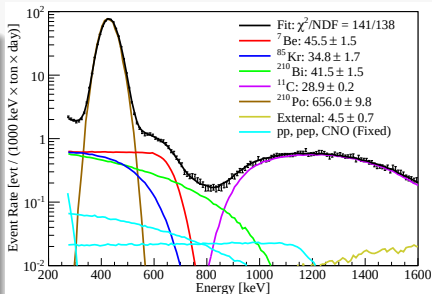
- No directional measurement

Solar ν fluxes

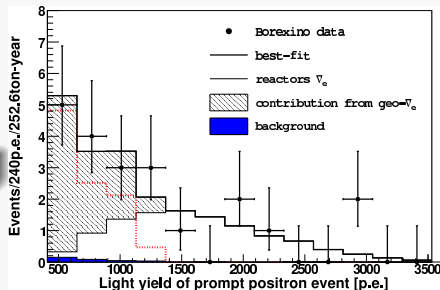
- ${}^7\text{Be}$ rate:
 $46 \pm 1.5 \pm 1.6$ cpd/100t
- ${}^8\text{B}$ rate (> 3 MeV):
 $0.217 \pm 0.038 \pm 0.008$ cpd/100t
- *pep* rate:
 $3.1 \pm 0.6 \pm 0.3$ cpd/100t
- *CNO* rate:
 < 7.9 cpd/100t

Confirms MSW-LMA prediction

No day-night asymmetry in ${}^7\text{Be}$ ν -flux

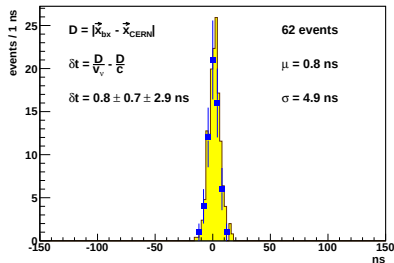


Evidence of geoneutrinos



Neutrino velocity of CNGS

$\delta t = 0.8 \pm 0.7 \pm 2.9 \text{ ns}$
consistent with 0

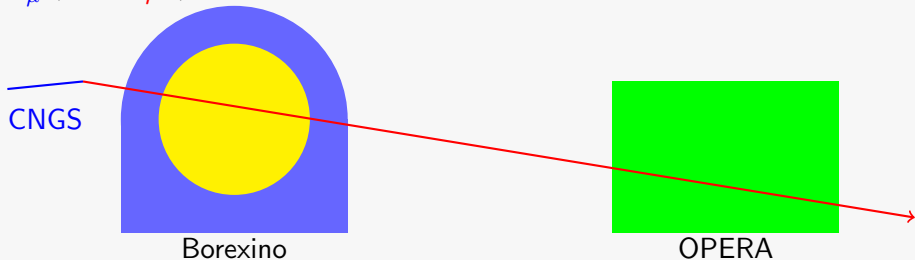


About one year ago...

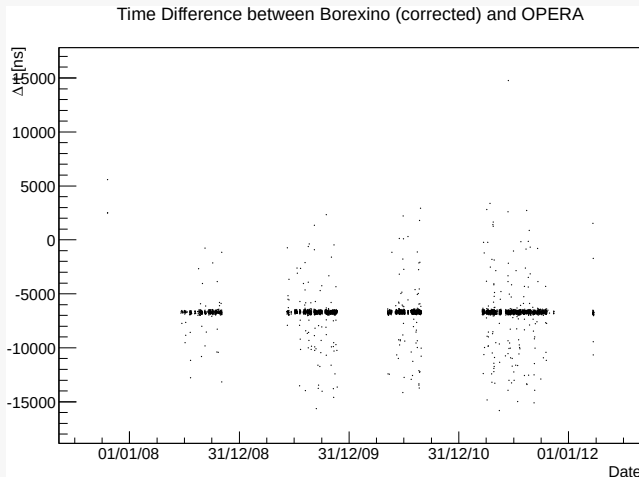
OPERA reports hints for a neutrino velocity $> c$.

- Then they found a loose cable connection – was this the error?
- Need a lot of statistics or bunched beam for new measurement
- Quick check: relative timing between Borexino and OPERA

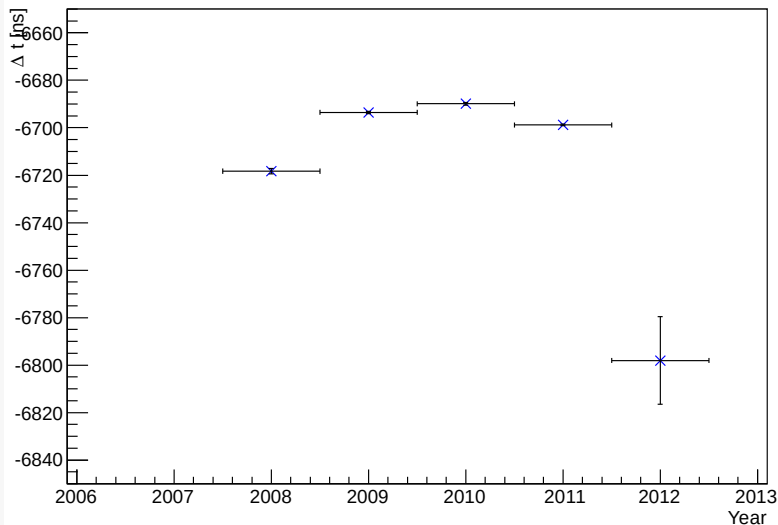
$$\nu_{\mu} + X \rightarrow \mu + X'$$



- Independent of any delays
- No need to know exact μ path - statistics cancel out uncertainties

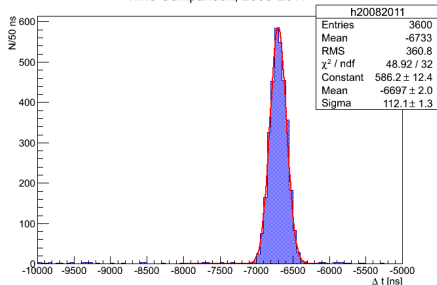


Δt between Borexino and OPERA



Before 2012 vs. First Week of 2012

Time Comparison, 2008-2011



- average offset 2008 to 2011:
 $(-6697.0 \pm 2.0) \text{ ns}$
- offset first week 2012 run:
 $(-6798.1 \pm 18.5) \text{ ns}$

⇒ shift of OPERA clock to larger values

shift: $(101.1 \pm 18.6) \text{ ns}$

Run	NEvt.	Mean Δt [ns]
2008	387	-6718.3 ± 1.2
2009	916	-6693.6 ± 0.5
2010	791	-6689.9 ± 0.6
2011	1506	-6698.8 ± 0.3
2012	37	-6798.1 ± 18.5
2008-11	3600	-6697.0 ± 2.0

Egg shaped cavern

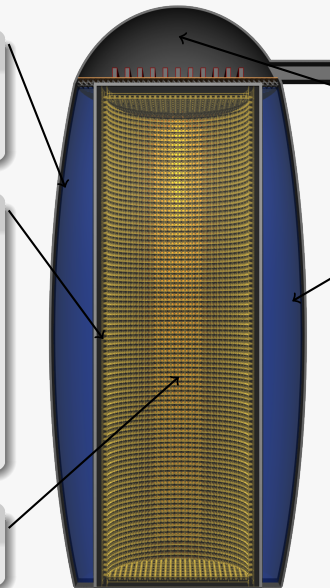
- $\updownarrow$ 120 m
- $\varnothing > 36$ m

Detector Tank

- concrete wall
- cylindrical –
 $\updownarrow = 100$ m
 $\varnothing = 32$ m
- ~ 30000 12" PMTs

Target

- 50 kt scintillator



Electronics hall

- 15 m high
- top muon veto

Water-filled cavern

- ~ 2000 12" PMTs
- veto for inclined muon tracks
- shielding for fast neutrons



LENA vs.
Elbphilharmonie

- slightly larger



LENA vs.
Elbphilharmonie

- slightly larger
- slightly cheaper



Long Baseline Neutrino Beam

- 2288 km from CERN to Pyhäsalmi
- conventional beam: $\nu_\mu \rightarrow \nu_e$ appearance
- large distance $\Rightarrow$ matter effects
- ν_μ and $\bar{\nu}_\mu$ mode

Pyhäsalmi

CERN

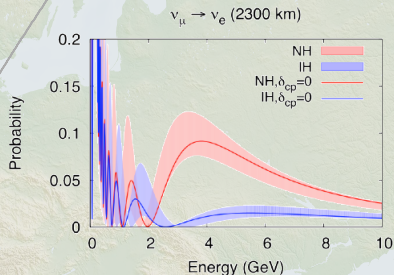
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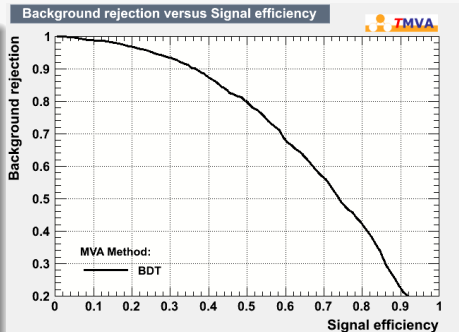
CERN

Strong signature for MH



To determine mass hierarchy

- Look for ν_e appearance in ν_μ beam
- Challenge: Discriminate ν_e CC events from NC π^0 events
- Multivariate analysis
- MC studies: 38% signal eff. with 11% remaining BG



Next Steps

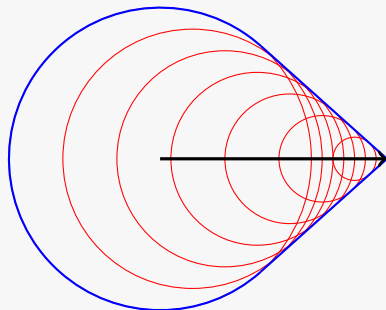
- Pulse shape analysis
- Tracking

- homogeneous light emission in liquid scintillator

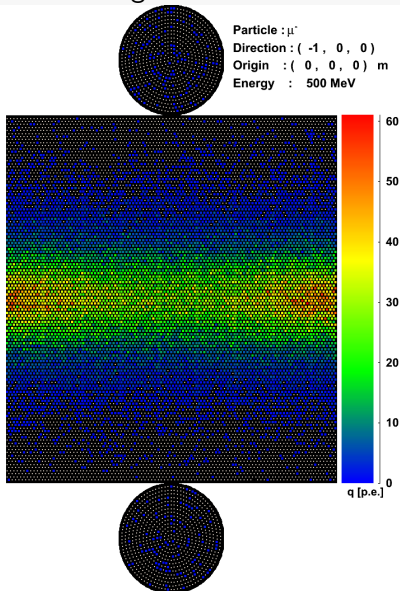
⇒ no directional information

BUT

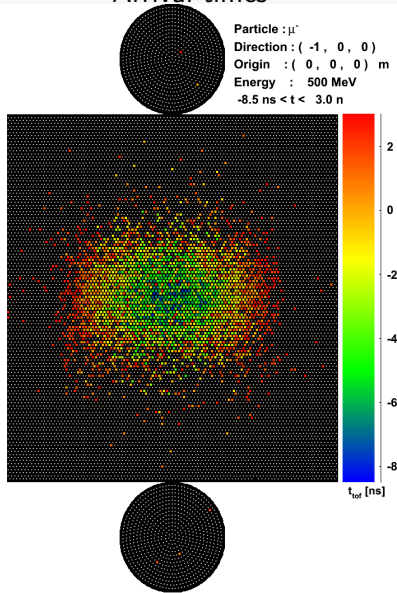
- tracks of a few 10 cm:
- distortion in first photon light front
- Cherenkov-like, $50\times$ more light

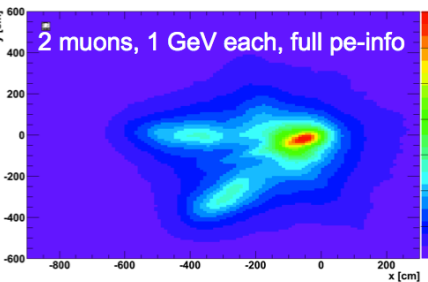
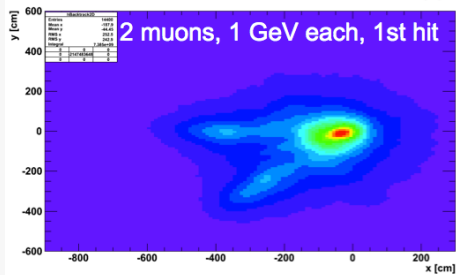
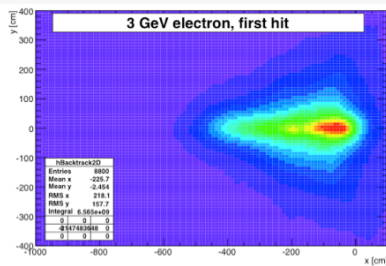
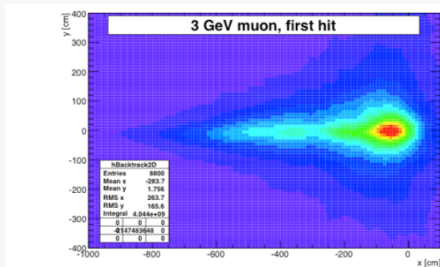


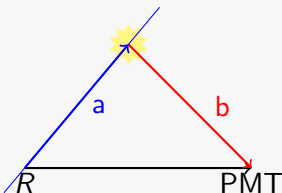
Charge distribution



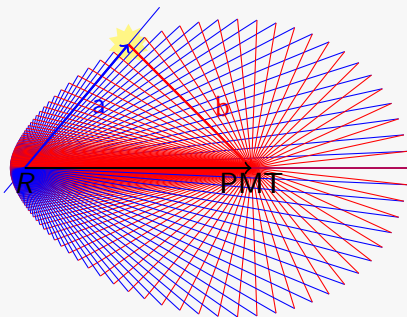
Arrival times





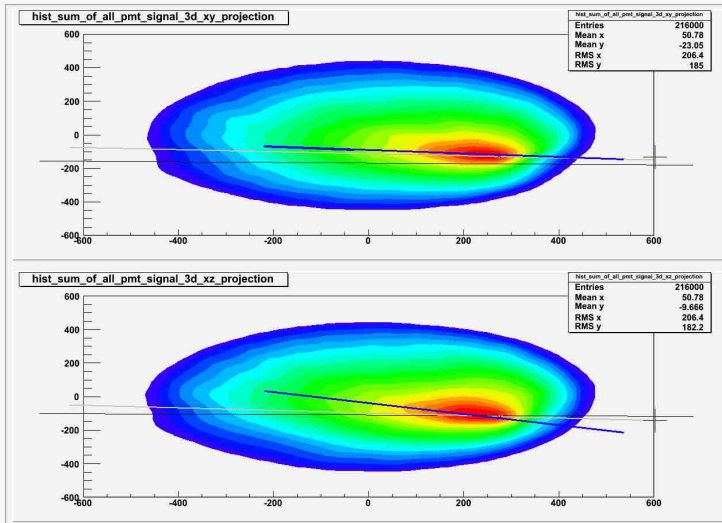


- Reference point R on track
($t = 0$)
 - For a photon at PMT:
 $a + nb = ct_{\text{pmt}}$
 - All possible paths: drop like
 - (Binned) superposition of drops
for all PMTs
 - Find bins with significant
overlap of drops
- $\Rightarrow$ reflects events spatial topology

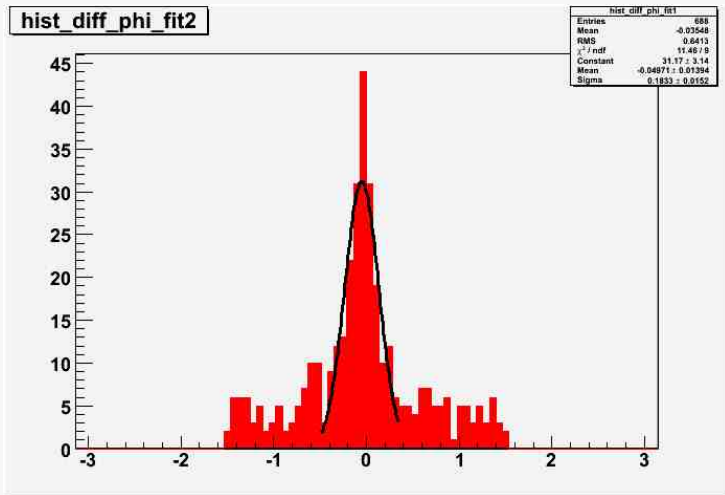


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Test on Borexino Data



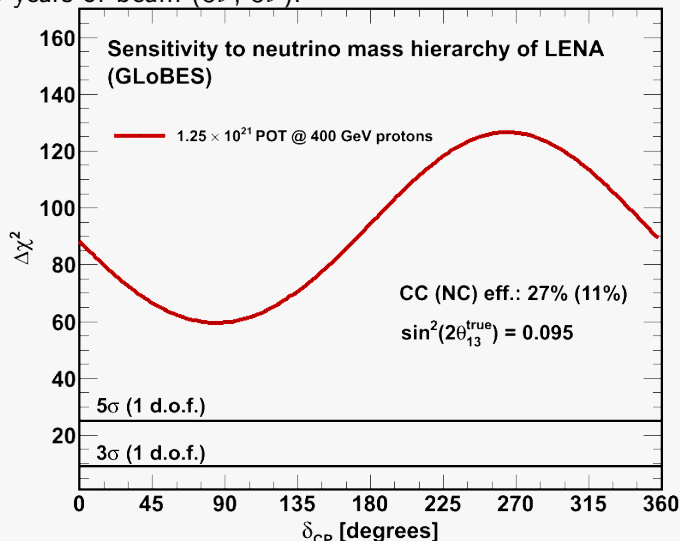
Very Preliminary Results compared to BX Tracking



Angular resolution achieved: 10° after only a few weeks of effort.

A lot of potential for optimizations (reference point finding, fitting, ...)

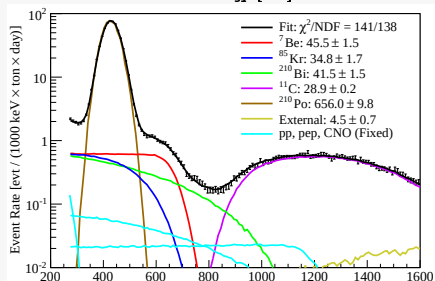
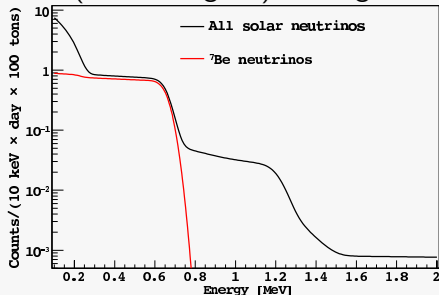
- Sensitivity plots created using GLoBES.
- 10 years of beam (5ν , $5\bar{\nu}$).



- Liquid scintillator is optimal for neutrino detection in the MeV range.
- Rich physics program includes SN neutrinos, solar neutrinos, geo neutrinos, reactor neutrinos, neutrino oscillometry ...
- Borexino has successfully measured the solar neutrino flux to 5% precision!
- For more precision we need a larger detector...
- ...which could also be used for high energy neutrino physics!
- Significant progress has been achieved with tracking in the GeV Range.
- Mass hierarchy can be determined at $> 7\sigma$

4 Additional Slides

The (monoenergetic) ^7Be signal



pep neutrinos

