Neutrinophysics with Liquid Scintillator

LEXI Meeting 2012

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LEXI LANDESEXZELLENZINITIATIVE HAMBURG

UHH Universität Hamburg
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Overview

1. Neutrino Detection with Liquid Scintilator
2. (Some) Activities in our Group
   - Borexino
   - LENA
   - Tracking
3. Conclusions

Motivation

Why do we need neutrino detectors?

- To better understand astrophysical an 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!

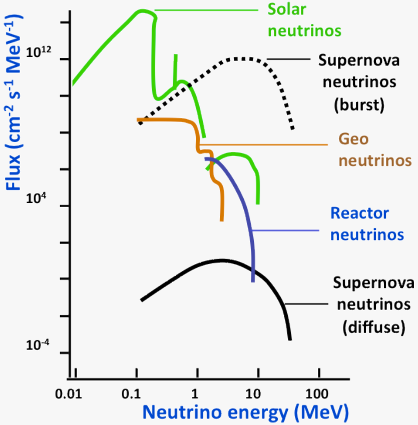
Physics with Liquid Scintillator

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



Low Energy Neutrino Detection

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 ($\approx 200\,\text{keV}$)
- good energy resolution ($\approx 7\%$ @ $1\,\text{MeV}$)
- proven purification techniques for high radiopurity

Background rejection

- pulse shape analysis
- coincidence signals

Real time spectroscopic neutrino detection using LS

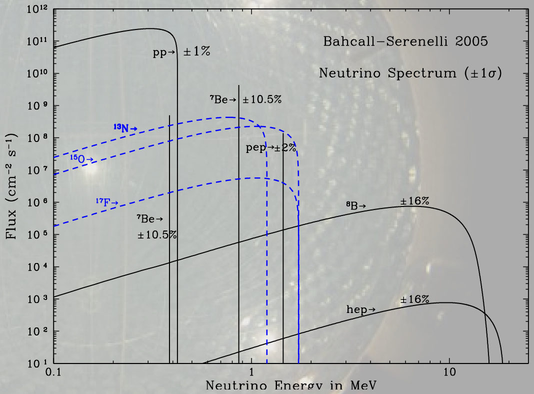
Taking data since May 2007:

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

Phase II:

- Precision measurements
- Sterile neutrinos

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



Real time spectroscopic neutrino detection using LS

Taking data since May 2007:

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  - ^{7}Be neutrinos ✓
  - ^{8}B neutrinos ✓
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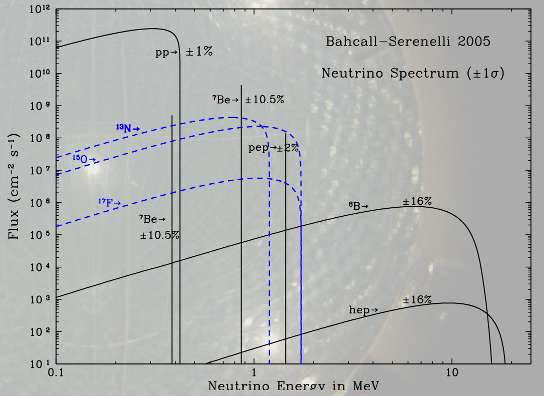
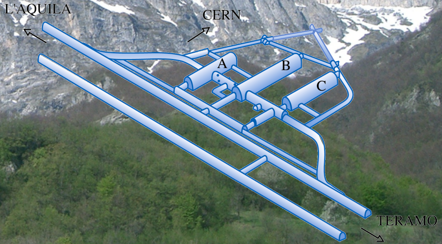


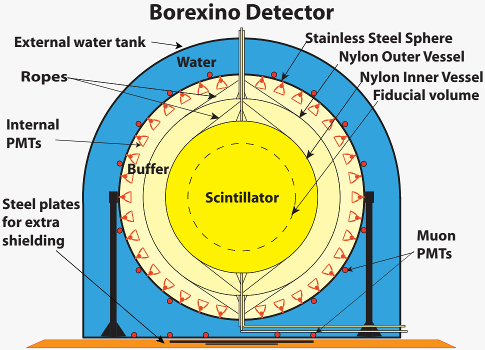
Laboratori Nationali del Gran Sasso

Gran Sasso Massive

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



Borexino Detector Setup



Outer Detector

2100 tons ultra pure water

- Active shielding
- 208 PMTs ⇒ Cherenkov veto

Steel dome: 18 m⌀– 16.9 m high

Inner Detector

278 tons of liquid scintillator in nylon vessel (⌀8.5 m) (125 µm)

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

Two buffer layers

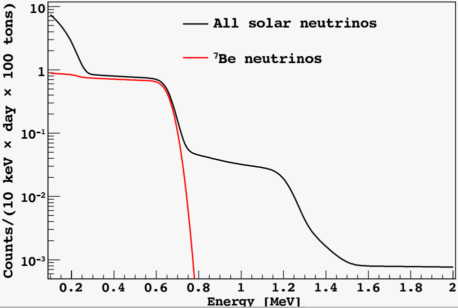
- Same liquid
- Light quencher DMP

stainless steel sphere (⌀13.7 m) holding 2212 inward facing PMTs

Neutrino Detection

- 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 form e^+e^--annihilation and neutron capture

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



Advantages

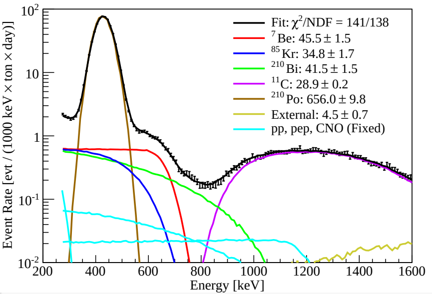
- Low energy threshold
- Good position reconstruction ($\sim$ 16 cm)
- Energy resolution ($6\%/\sqrt{E}$)

Disadvantages

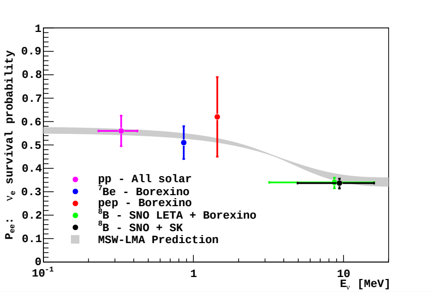
- No directional measurement

Solar ν fluxes

- ^{7}Be rate:
  $46 \pm 1.5 \pm 1.6$ cpd/100t
- ^{8}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

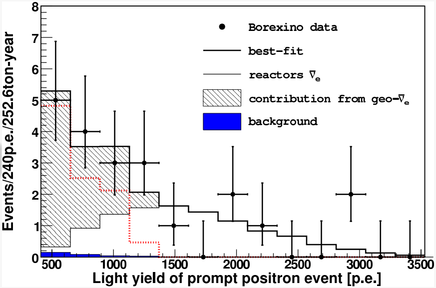


Confirms MSW-LMA prediction



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

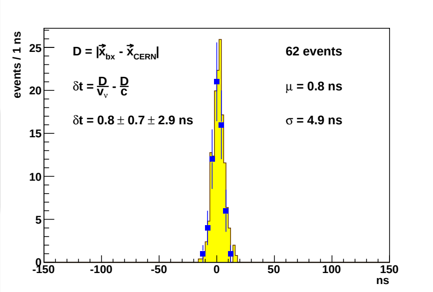
Evidence of geoneutrinos



Neutrino velocity of CNGS

$\delta t = 0.8 \pm 0.7 \pm 2.9$ ns

consistent with 0



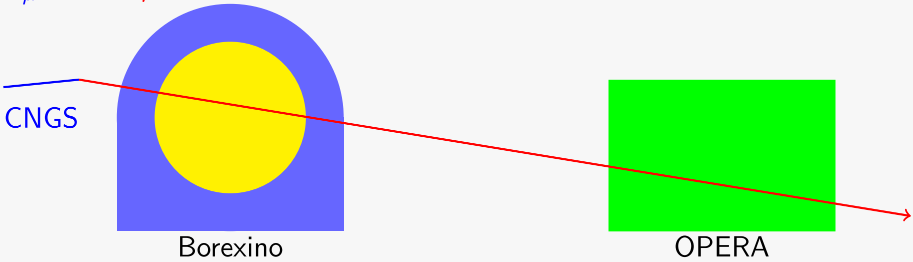
Rock Muons in Borexino and OPERA

About one year ago...

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

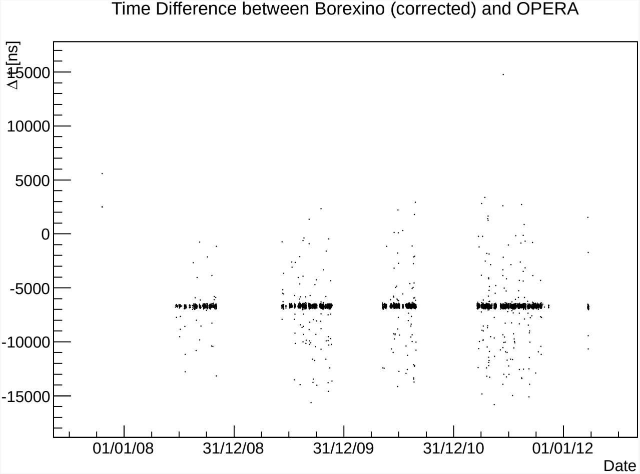
- Then they found a loose cable connection – was this the error?
- Need a lot of statistics or bunched beam for new measurement
- Quick check: relative timing between Borexino and OPERA

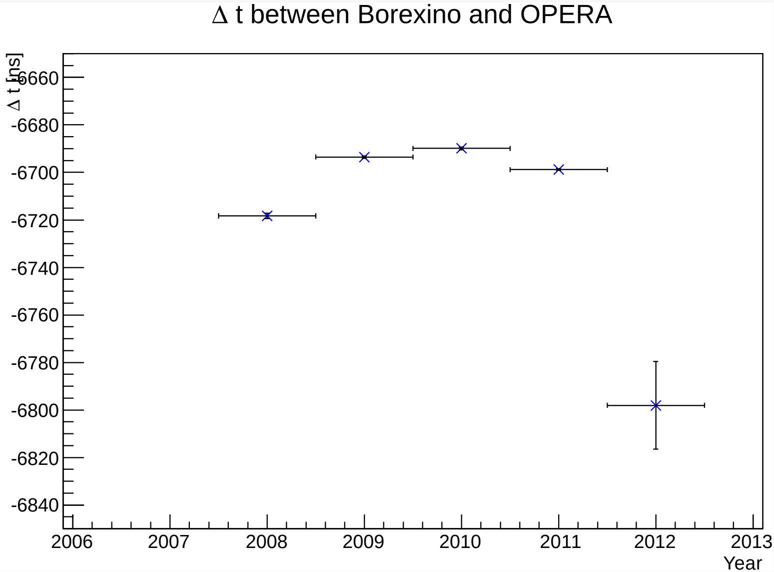
$$\nu_\mu + X \rightarrow \mu + X'$$



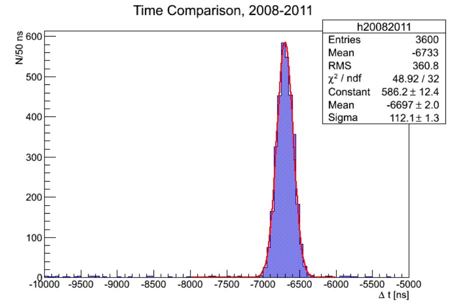
Comparison of CNGS Timestamps

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




Δ t between Borexino and OPERA
Δ t [ns]
-6660
-6680
-6700
-6720
-6740
-6760
-6780
-6800
-6820
-6840
2006
2007
2008
2009
2010
2011
2012
2013
Year

Before 2012 vs. First Week of 2012



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

- average offset 2008 to 2011: (-6697.0 ± 2.0) ns
- offset first week 2012 run: (-6798.1 ± 18.5) ns

$\Rightarrow$ shift of OPERA clock to larger values

shift: (101.1 ± 18.6) ns

Egg shaped cavern

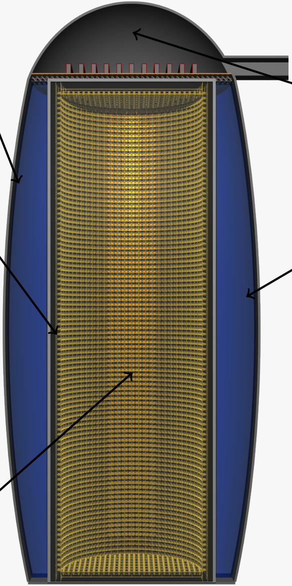
- ↕ 120 m
- $\varnothing > 36$ m

Detector Tank

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

Target

- 50 kt scintillator



Electronics hall

- 15 m high
- top muon veto

Water-filled cavern

- $\sim$ 2000 12" PMTs
- veto for inclined muon tracks
- shielding for fast neutrons

LENA Detector

LENA Detector

LENA vs. Elbphilharmonie

- slightly larger

LENA Detector

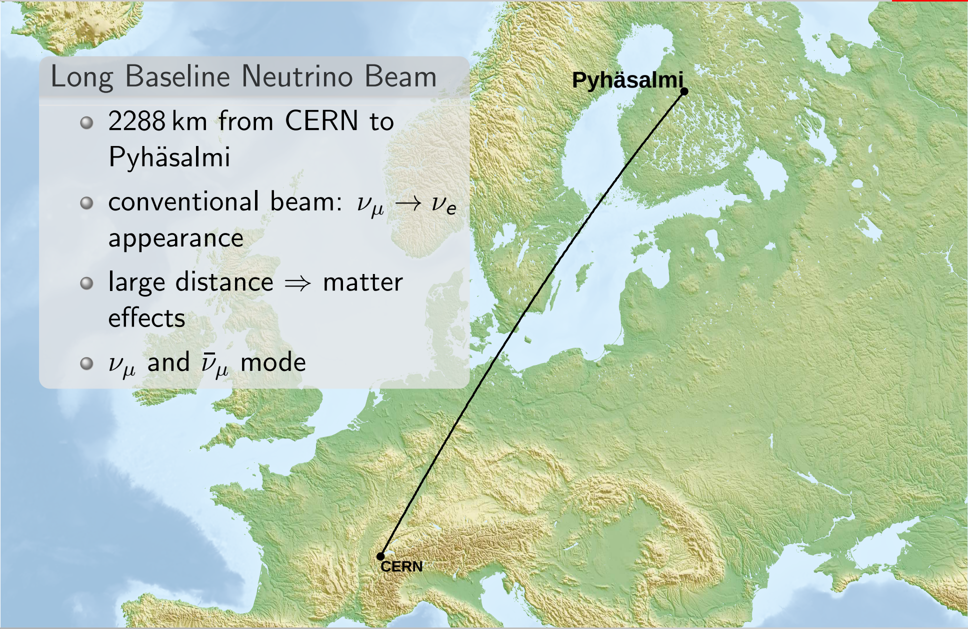
LENA vs. Elbphilharmonie

- slightly larger
- slightly cheaper

Possible Beam from CERN

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



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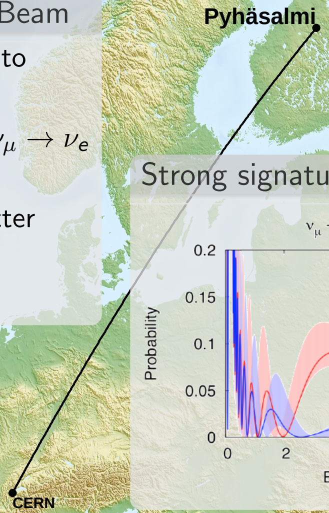

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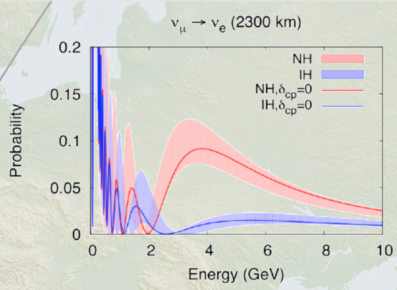
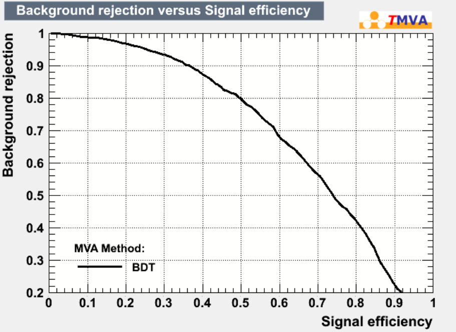
Strong signature for MH



LENA as a Target for a ν_μ Beam

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

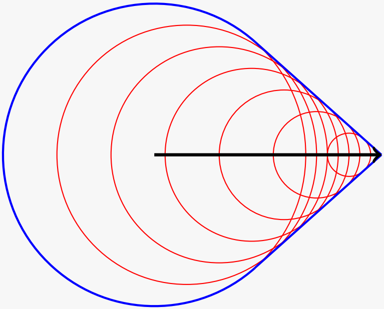
Tracking in Liquid Scintillator

- homogeneous light emission in liquid scintillator

⇒ no directional information

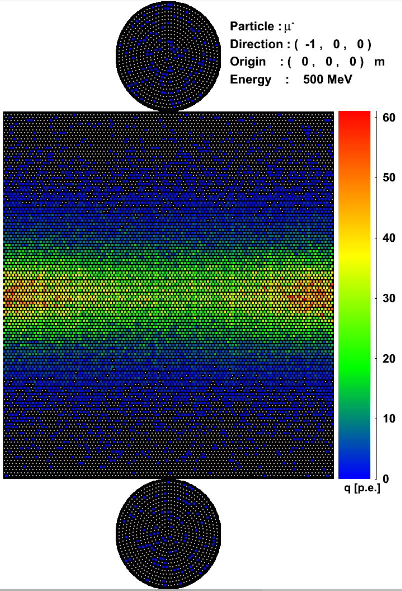
BUT

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

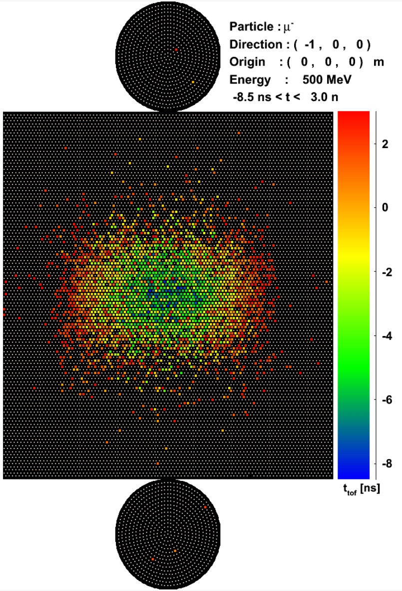


Monte Carlo Events

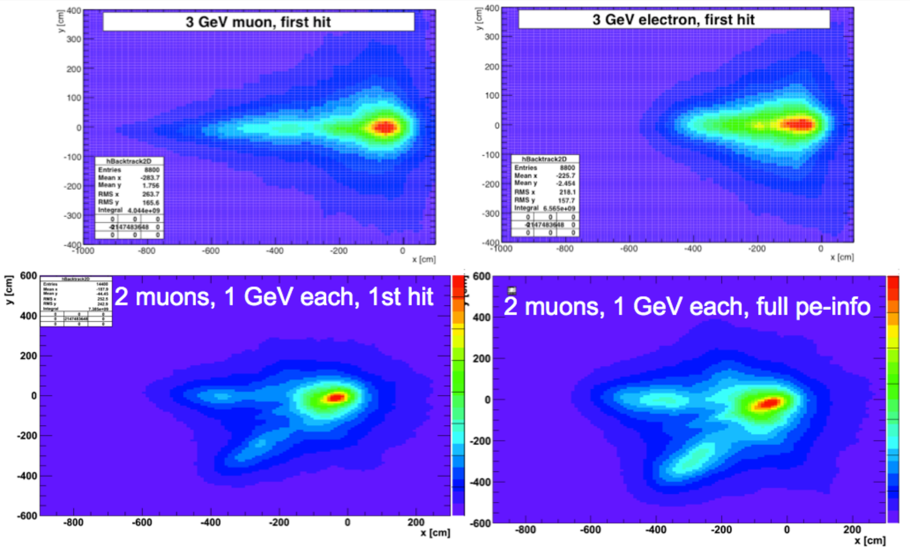
Charge distribution



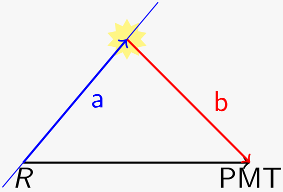
Arrival times



Event Reconstruction



A New Approach



- 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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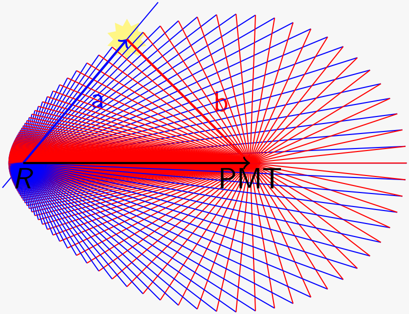

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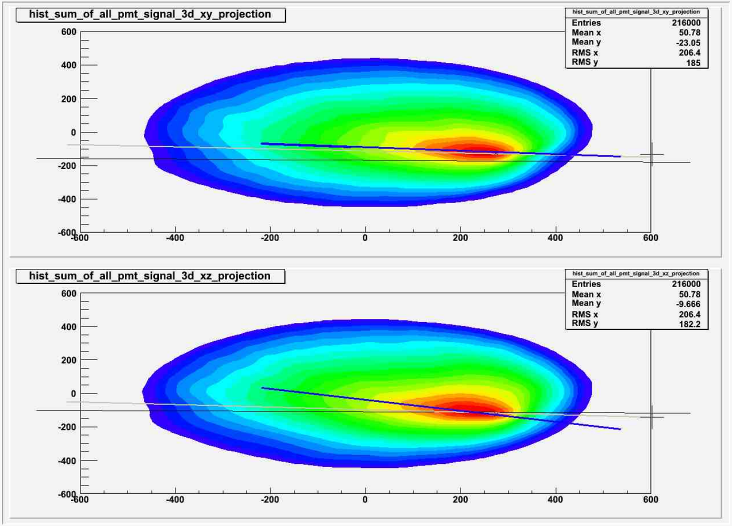
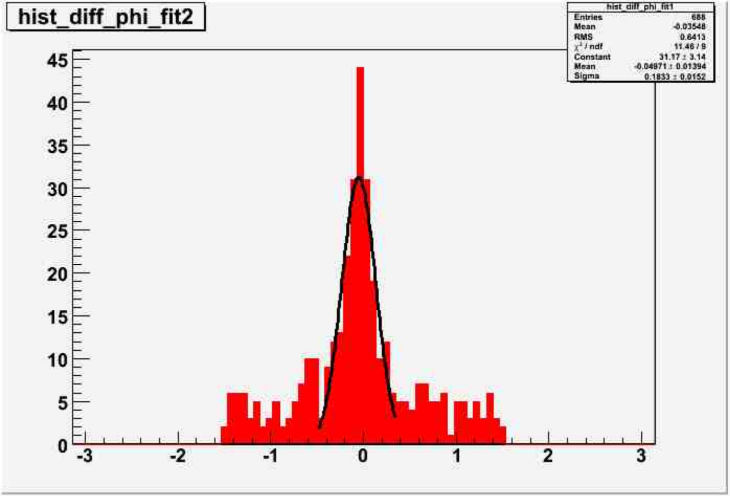
Test on Borexino Data



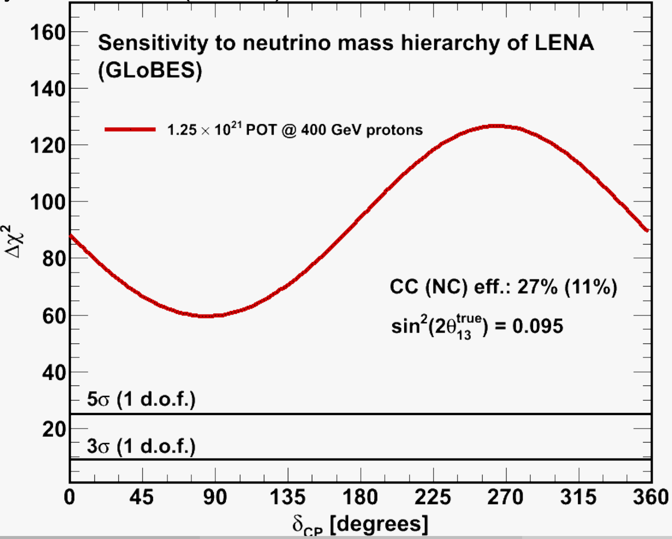
Very Preliminary Results compared to BX Tracking



Angular resolution achieved: 10° after only a few weeks of effort.
A lot of potential for optimizations (reference point finding, fitting, . . .)

Mass Hierarchy

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



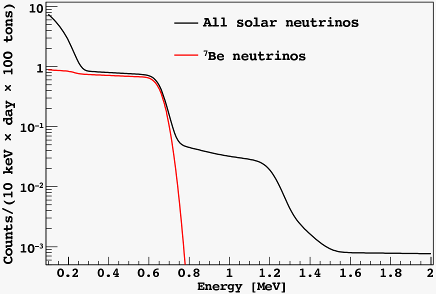
Conclusions

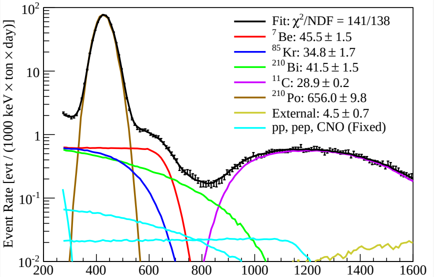
- Liquid scintillator is optimal for neutrino detection in the MeV range.
- Rich physics program includes SN neutrinos, solar neutrinos, geo neutrinos, reactor neutrinos, neutrino oscillometry ...
- Borexino has successfully measured the solar neutrino flux to 5% precision!
- For more precision we need 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

Detection of Solar Neutrinos

The (monoenergetic) ^{7}Be siginal





pep neutrinos