Reconstruction of GeV neutrino events in LENA

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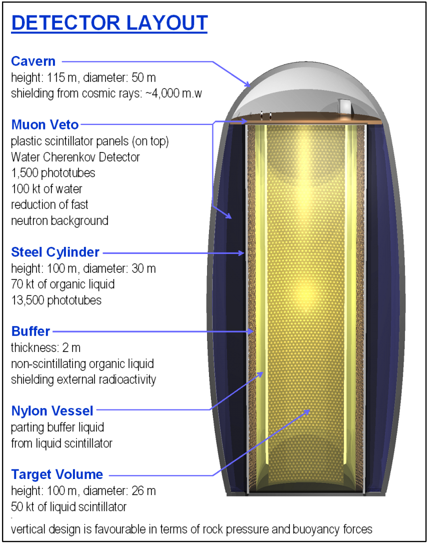


DETECTOR LAYOUT

Cavern
height: 115 m, diameter: 50 m
shielding from cosmic rays: ~4,000 m.w

Muon Veto
plastic scintillator panels (on top)
Water Cherenkov Detector
1,500 phototubes
100 kt of water
reduction of fast
neutron background

Steel Cylinder
height: 100 m, diameter: 30 m
70 kt of organic liquid
13,500 phototubes

Buffer
thickness: 2 m
non-scintillating organic liquid
shielding external radioactivity

Nylon Vessel
parting buffer liquid
from liquid scintillator

Target Volume
height: 100 m, diameter: 26 m
50 kt of liquid scintillator

vertical design is favourable in terms of rock pressure and buoyancy forces

Physics Goals

Low-energy physics

- Solar Neutrinos
- Galatic Supernova Neutrinos
- Diffuse Supernova Neutrinos
- Geoneutrinos

GeV physics

- Proton Decay
- Atmospheric Neutrinos
- Neutrino Beams

Possible Detector Locations

Frejus (France)

- 4800 m.w.e. shielding
- 130 km distance to CERN
- Energy of the 1^{st} Osc. Max. is 0.26 GeV

Pyhäsalmi (Finland)

- 4000 m.w.e. shielding
- 2300 km distance to CERN
- Energy of the 1^{st} Osc. Max. is 4.65 GeV

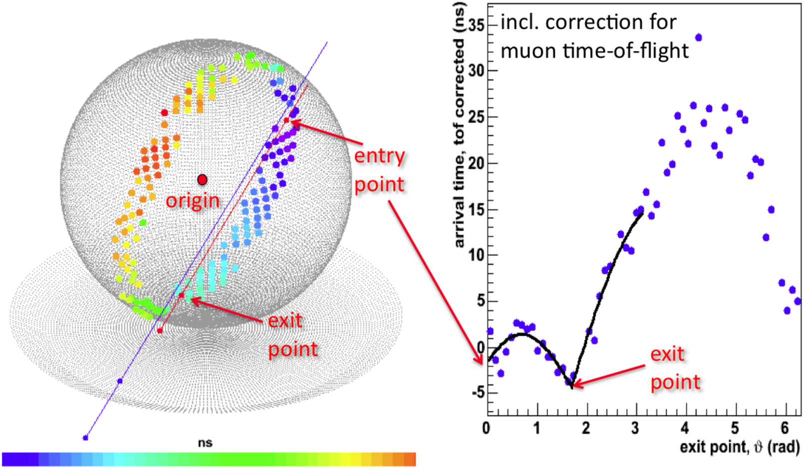
Basic Strategy

- The light emission is isotropic in a liquid scintillator

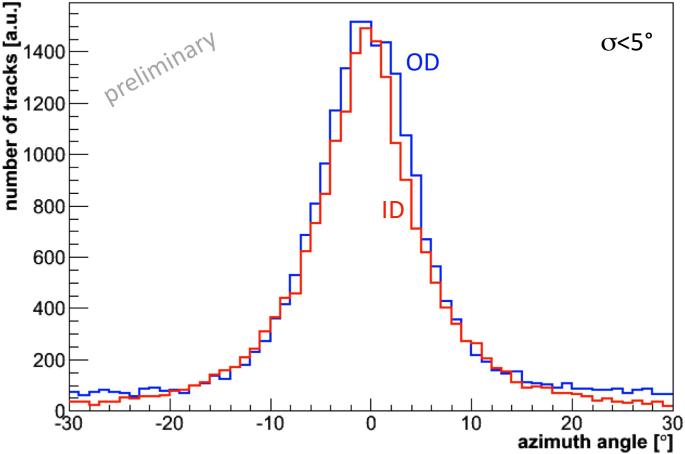
$$\Downarrow$$

- No directional information for point like events
- For track lengths greater than $\sim 10\,\mathrm{cm}$ it is possible to reconstruct the track from the superposition of the spherical light waves along the track

Reconstruction of Muon Tracks in Borexino



Reconstruction of CNGS Neutrinos in Borexino



- Quasi-elastic scattering is the dominant channel

$$\Downarrow$$

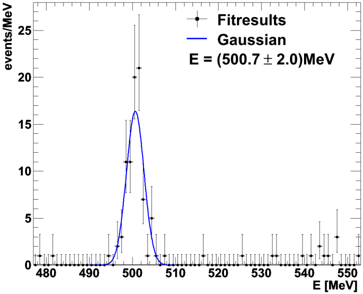
- Easy reconstruction of the neutrino event from the lepton track
- ν_μ and ν_e can be discriminated by the muon decay and the different typical pulse shapes
- Background from NC events and resonance/deep-inelastic CC events

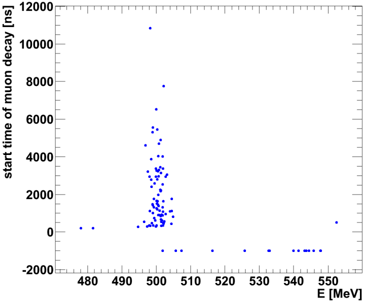
Basic Track Fitting Principle

- $P\left(\overrightarrow{p},\overrightarrow{S}\right)$: PDF that an event with parameters $\overrightarrow{p}$ has the signal $\overrightarrow{S}$
- Minimize $\mathcal{L} = -\ln\left(P\left(\overrightarrow{p},\overrightarrow{S}\right)\right) \Rightarrow$ most probable $\overrightarrow{p}$
- Assume all PMTs to be independant and equal
  $\Rightarrow \mathcal{L} = -\sum_{i=1}^{N_{PMT}} \ln\left[P_s\left(\overrightarrow{p},\overrightarrow{S_i},\overrightarrow{r_i},\overrightarrow{n_i}\right)\right]$
- Calculate $P_s\left(\overrightarrow{p},\overrightarrow{S_i},\overrightarrow{r_i},\overrightarrow{n_i}\right)$

Result of the Energy Fit

500 MeV μ^-, origin: center of LENA (0,0,0), direction perpendicular to the symmetry axis of the cylinder





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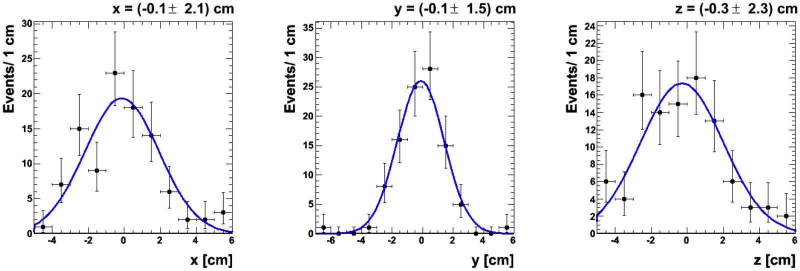

Result of the Track Fit

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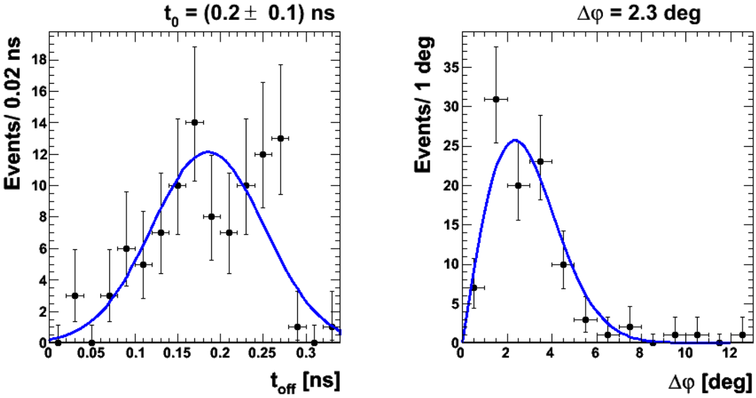
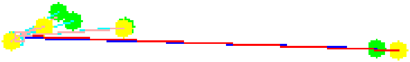


- Contribution of resonance pion production and deep-inelastic (DIS) events not negligible

$$\Downarrow$$

- Multiple tracks need to be reconstructed in one event
- Energy resolution limited by the non-linear relation between neutrino energy and detected light, caused by nuclear effects, quenching of scintillation light and track position uncertainty

Reconstruction of a 4 GeV DIS ν_μ event



- blue: muon track
- cyan: proton/pion track
- green: gamma track
- red: rec. muon track
- yellow: rec. gamma track
- pink: rec. proton/pion track

- DIS event with a muon (2.0 GeV), proton (0.14 GeV) and 3 pions (0.61 GeV,0.35 GeV,0.32 GeV) in the final state
- Reconstructed lepton energy error 5%
- Reconstructed vertex position error 0.11 m

Results

- 3% photocoverage is sufficient for all high-energy events
- $\sim 3\,\text{ns}$ time resolution of the photosensors is necessary
- Pulse shape of every read out channel needs to be recorded
- Good positional and angular accuracy ($\sim 10\,\text{cm}$, few degrees)
- 1-2 tracks in one event can always be reconstructed
- 3 tracks in one event can only be reconstructed if they are clearly separated and long enough ($\sim 1\,\text{m}$)
- Energy resolution 1% to 5% dependant on the event type
- Lepton flavour indentification better than 99%

- Two possible baselines for LENA, 130 km (CERN-Frejus) and 2300 km (CERN-Pyhäsalmi)
- Single particle tracks can be reconstructed precisely at low energies (0.2 GeV-1 GeV)
- At high energies (1 GeV-5 GeV) up to 3 tracks in one event can be reconstructed
- Good lepton energy resolution at low energies (0.5%)
- Good neutrino energy resolution at high energies (1% to 5%)
- Good lepton flavour identification at low and high energies
- Background from NC events, needs to be analyzed in future Monte-Carlo studies