LENA
Low Energy Neutrino Astronomy

PICS kick-off meeting
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Michael Wurm
Technische Universität München

LENA

Low-**E**nergy **N**eutrino **A**stronomy

Large-volume (50kt) liquid-scintillator detector

Outline

- Detector Layout
- Low Energy Physics
- Potential for High Energies
- Current R&D Activities

Detector Layout

Liquid Scintillator
ca. 50kt PXE/LAB

Inner Nylon Vessel
radius: 13m

Buffer Region
inactive, Δr = 2m

Steel Tank, 13500 PMs
r = 15m, h = 100m,
optical coverage: 30%

Water Cherenkov Veto
1500 PMTs, Δr > 2m
fast neutron shield

Egg-Shaped Cavern
about 10^5 m^3

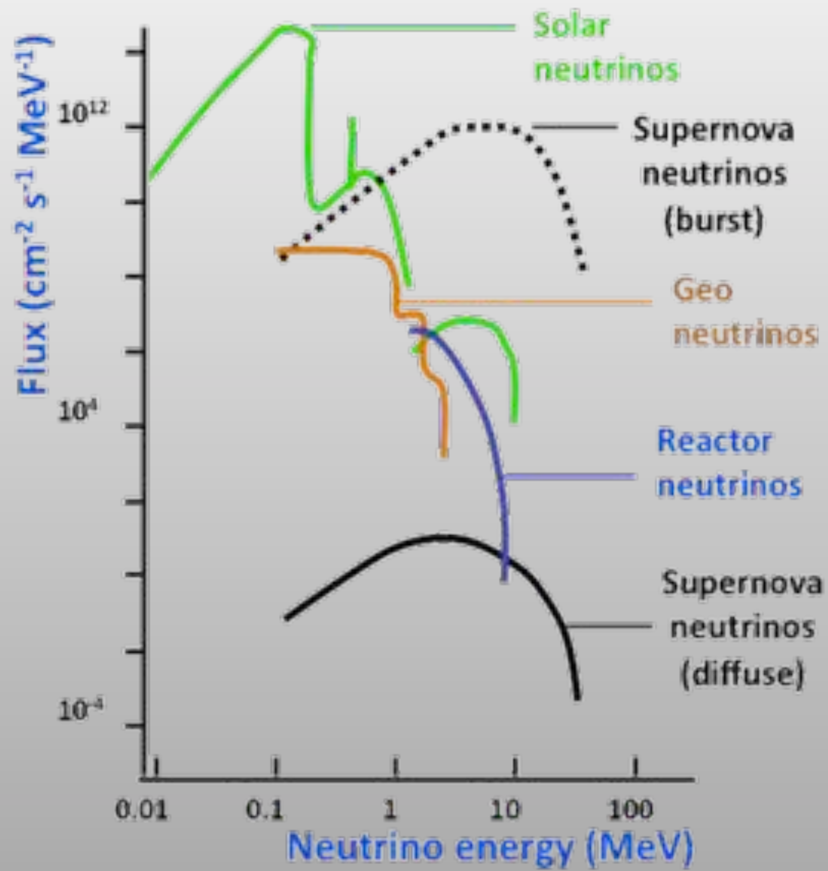
Overburden: 4000 mwe

- design based on experience with Borexino
- in total 70 ktons of organic solvent, 50 kt of scintillator
- cylindrical tank: 100m height, 30m diameter
- dimensions governed by liquid transparency

Low Energy Physics

Physics Objectives

- Neutrinos from galactic Supernovae
- Diffuse Supernova neutrinos
- Solar neutrinos
- Geoneutrinos
- Reactor neutrinos
- Indirect dark matter search

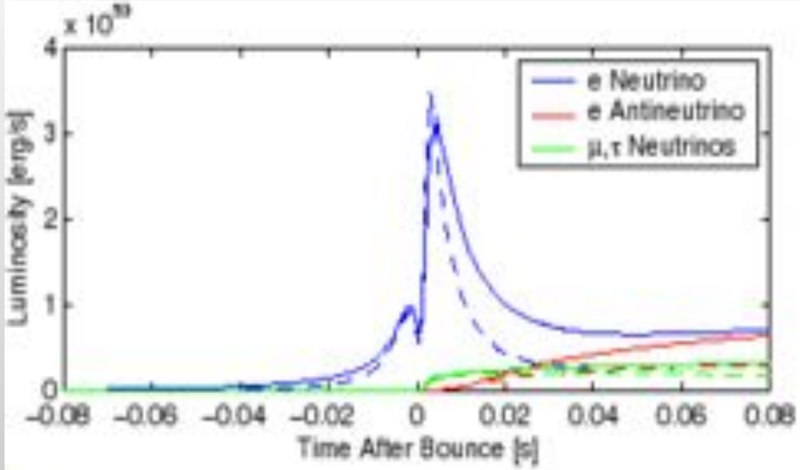


Detector Performance

- Good energy resolution
- Low detection threshold
- Excellent background discrimination
- Low background by purification
- No directional resolution

Galactic SN Neutrinos in LENA

ν_e from neutronisation burst
$\nu\bar{\nu}$ pairs of all flavors
from protoneutronstar cooling



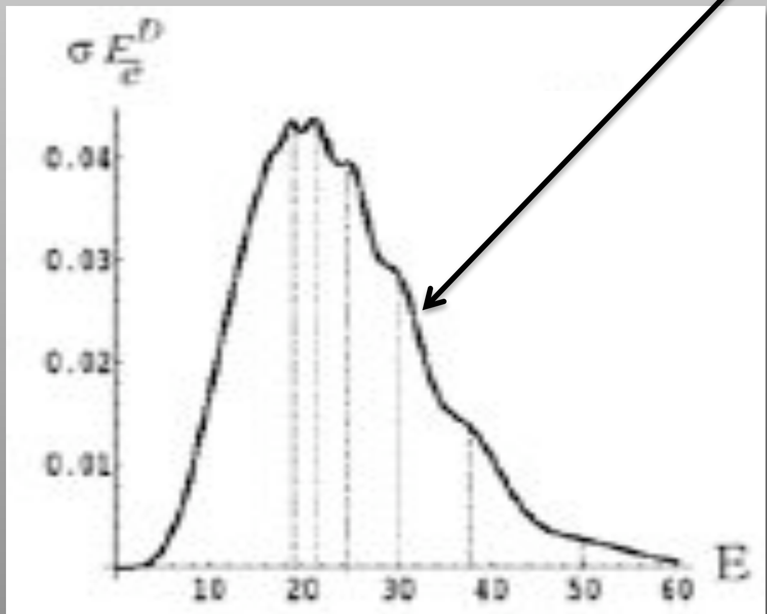
For "standard" SN (10kpc, 8M$_\odot$):
ca. 13k events in 50kt target

Channel	Rate	Threshold (MeV)	Spectrum
$\nu_e\, p \rightarrow n\, e^+$	8900	1.8	✓
$\nu_e\, ^{12}C \rightarrow ^{12}N\, e^-$	200	17.3	(✓)
$\bar{\nu}_e\, ^{12}C \rightarrow ^{12}B\, e^+$	130	13.4	(✓)
$\nu\, ^{12}C \rightarrow ^{12}C^*\, \nu$	860	15.1	✗
$\nu\, p \rightarrow p\, \nu$	2200	1.0	✓
$\nu\, e^- \rightarrow e^-\, \nu$	700	0.2	✓

Scientific Gain of SN Observation

Astrophysics

- Observe neutronisation burst
- Cooling of the neutron star
  flavor-dependent spectra and luminosity, time-dev.
- Propagation of the shock wave
  by envelope matter effects
- SNEWS



Neutrino physics

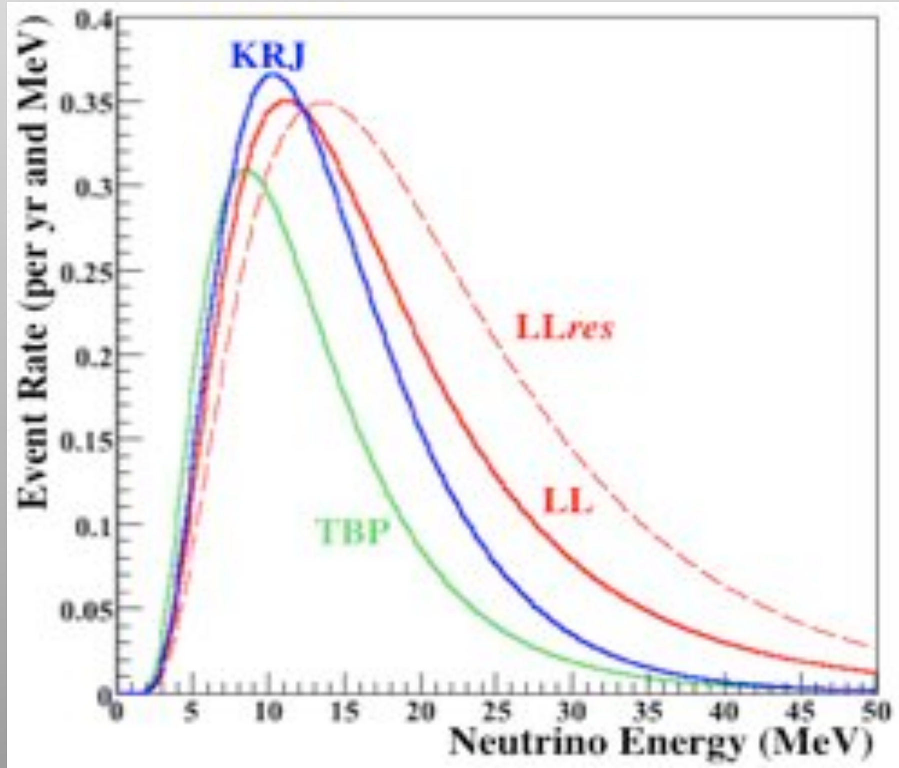
- θ_{13} and ν mass hierarchy:
  - neutronization burst
  - resonant flavor conversion in stellar envelope
  - Earth matter effect
- Observation of collective neutrino oscillations
- more exotic effects ...

Diffuse SN Neutrinos in LENA

Regular galactic Supernova rate:
1-3 per century

Alternative access:

- isotropic ν background generated by SN on cosmic scales
- redshifted by cosmic expansion
- flux: 100/cm^{2}s of all flavours
- rate too low for detection in current neutrino experiments



In LENA: 2-20 $\bar{\nu}_e$ per year (50kta)

Backgrounds for DSN Search in LENA

Detection via Inverse Beta Decay

$\bar{\nu}_e + p \rightarrow n + e^+$

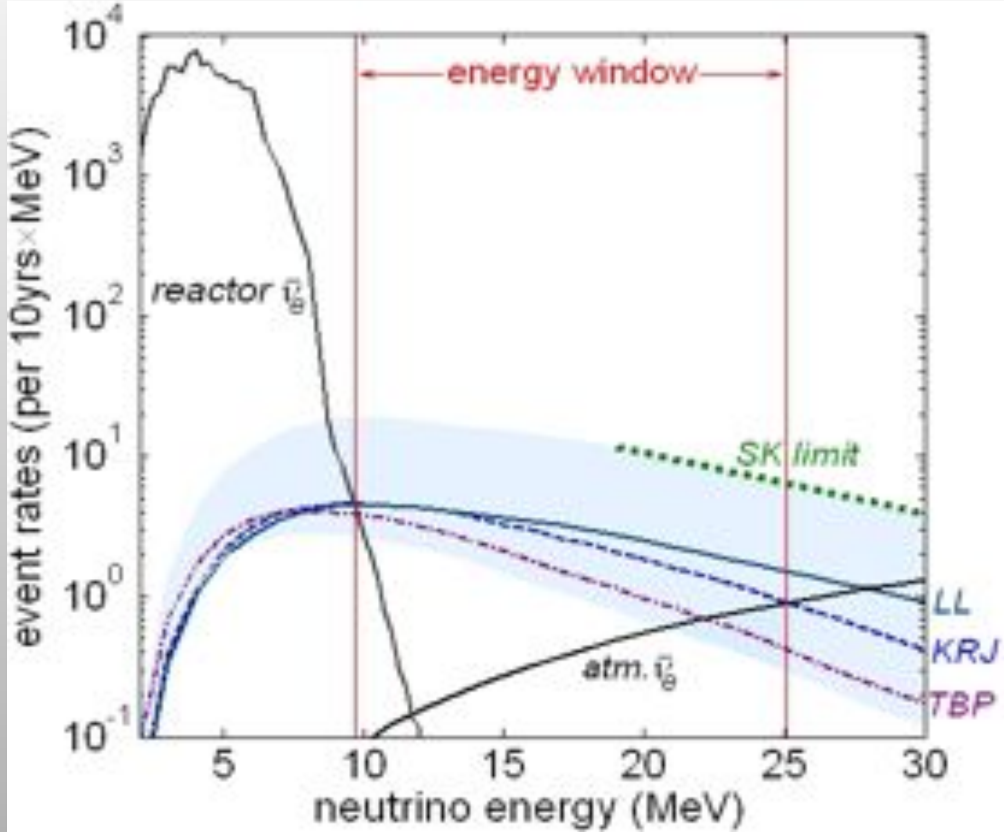
allows discrimination of most single-event background limiting the detection in SK

Remaining Background Sources

- reactor and atmospheric $\bar{\nu}_e$'s
- cosmogenic backgrounds

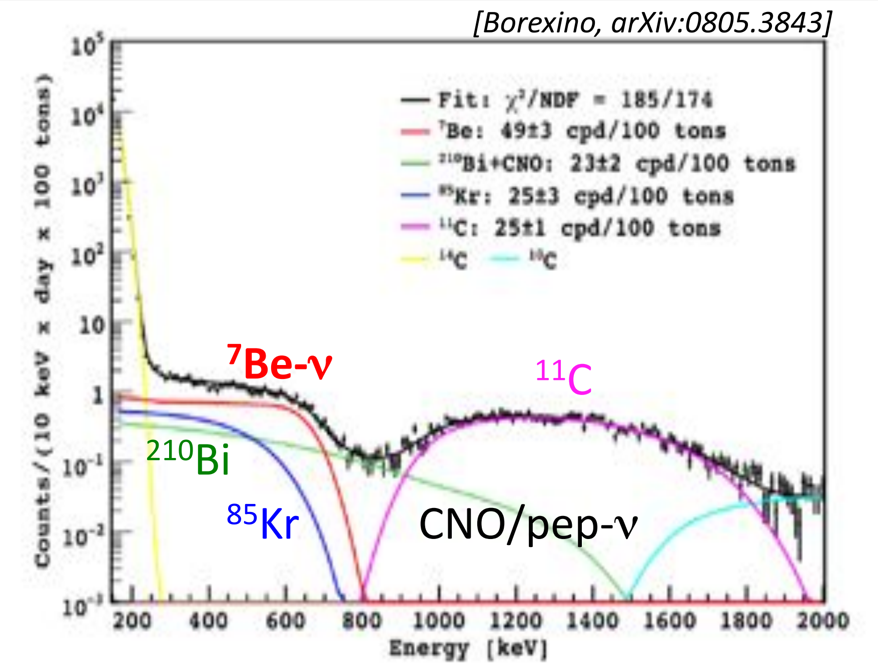
Scientific Gain

- first detection of DSN
- information on average SNν spectrum
- complementary information on cosmic star formation rate



Expected rate: 2-20 $\bar{\nu}_e$ /(50 kt yrs)
(in energy window from 10-25MeV)

Solar Neutrinos in LENA



Channel	Source	Neutrino Rate $[d^{-1}]$ BPS08(GS)	BPS08(AGS)
νe	pp	24.92±0.15	25.21±0.13
	pep	365±4	375±4
	hep	0.16±0.02	0.17±0.03
(18kt)	^{7}Be	4984±297	4460±268
	^{8}B	82±9	65±7
	CNO	545±87	350±52
^{13}C	^{8}B	1.74±0.16	1.56±0.14

Detection Channel

elastic ν-e scattering, E > 0.2MeV

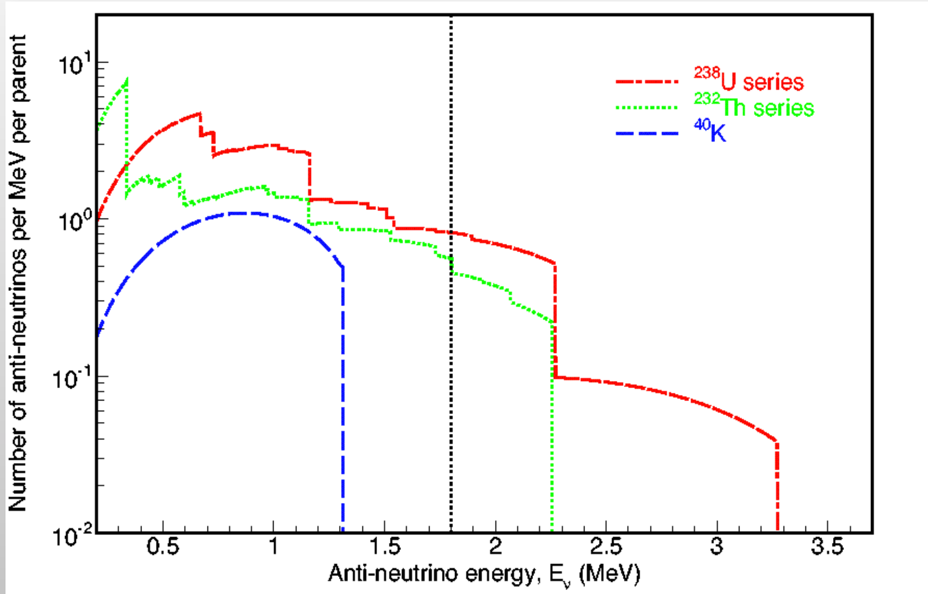
Background Requirements

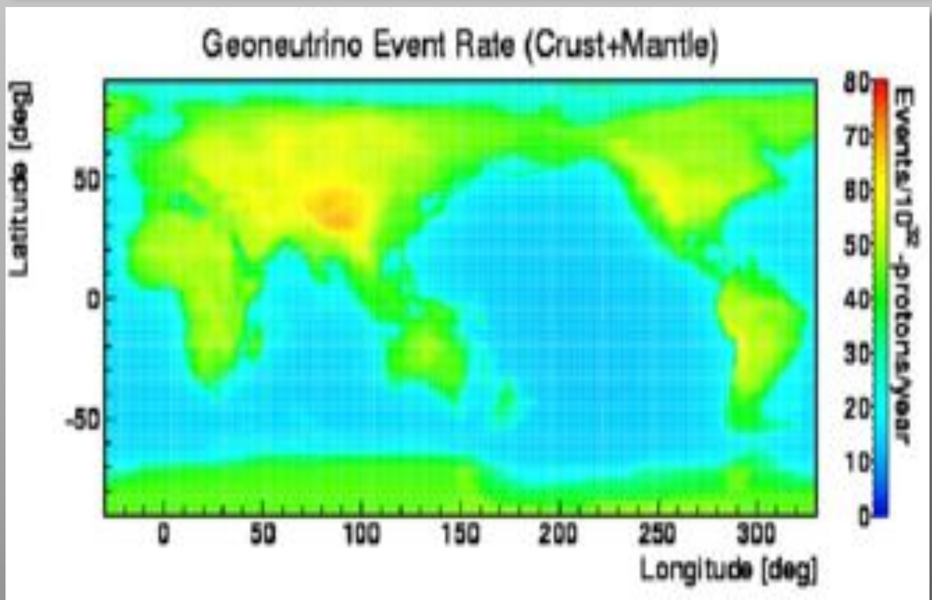
- U/Th concentration of 10^{-18} g/g (achieved in Borexino)
- shielding of >4000 mwe for CNO/pep-ν measurement

Scientific Motivation

- determination of solar parameters (metallicity, CNO contribution)
- search for temporal modulations in ^{7}Be-ν flux (on per mill level)
- probe the MSW effect in the vacuum transition region → new osc. physics
- search for $\nu_e \rightarrow \bar{\nu}_e$ conversion

Geoneutrinos





IBD threshold of 1.8 MeV

$\bar{\nu}_e$ by U/Th decay chains

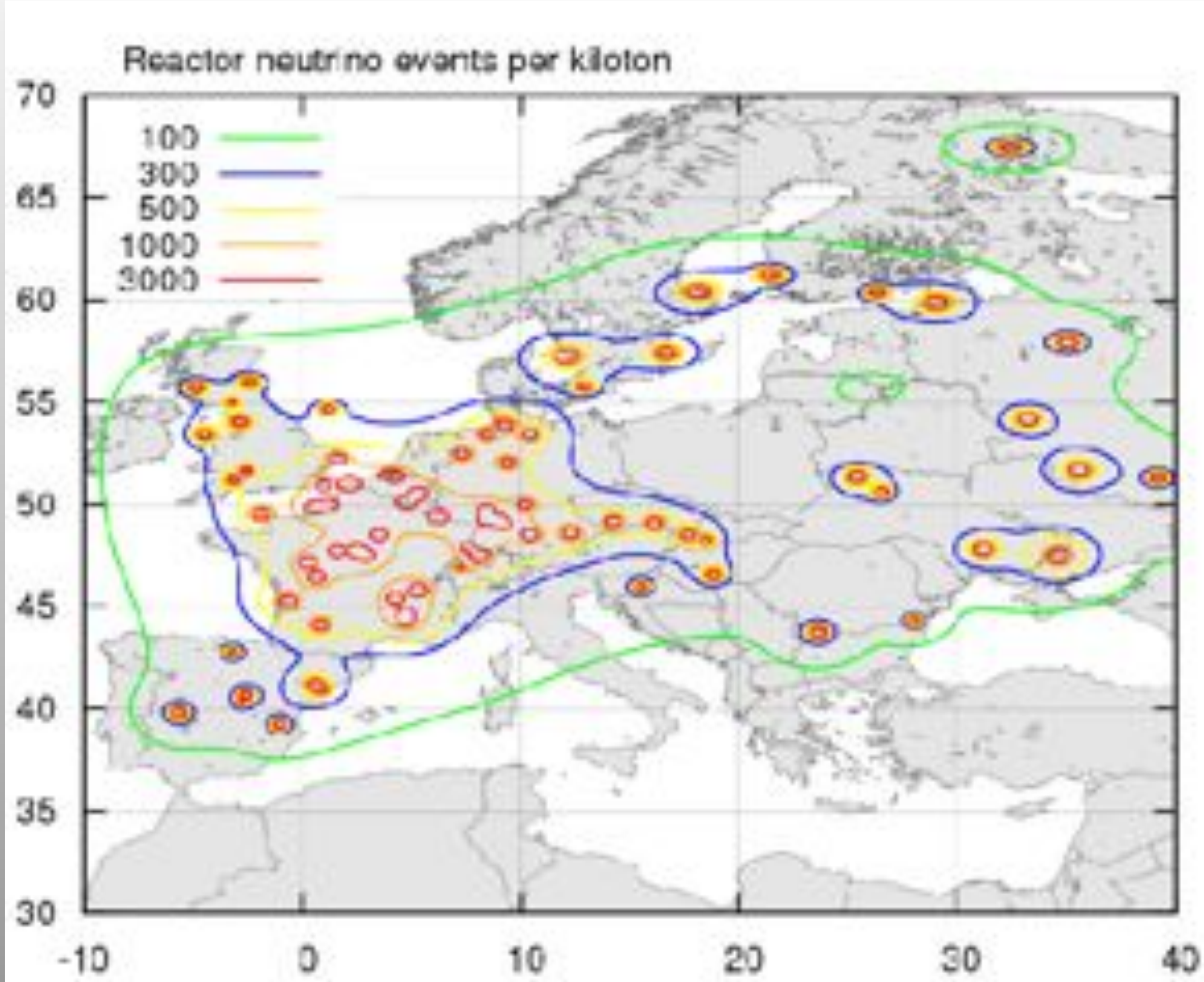
At Pyhäsalmi

expected rate	$2x10^3$ / 50 kta
reactor-ν bg	700

Scientific Gain

- determine relative ratio of U/Th
- measure contribution of U/Th decays to Earth's total heat flow
- with several detectors at different sites: disentangle oceanic/continental crust
- test for hypothetical georeactor

Influence of Detector Location



K. Loo

Potential at Higher Energies

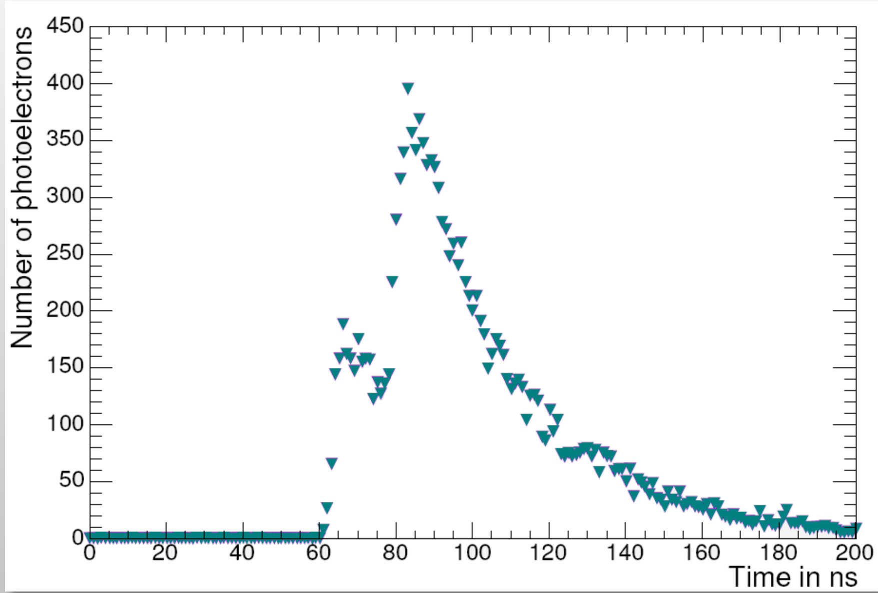
Physics Objectives

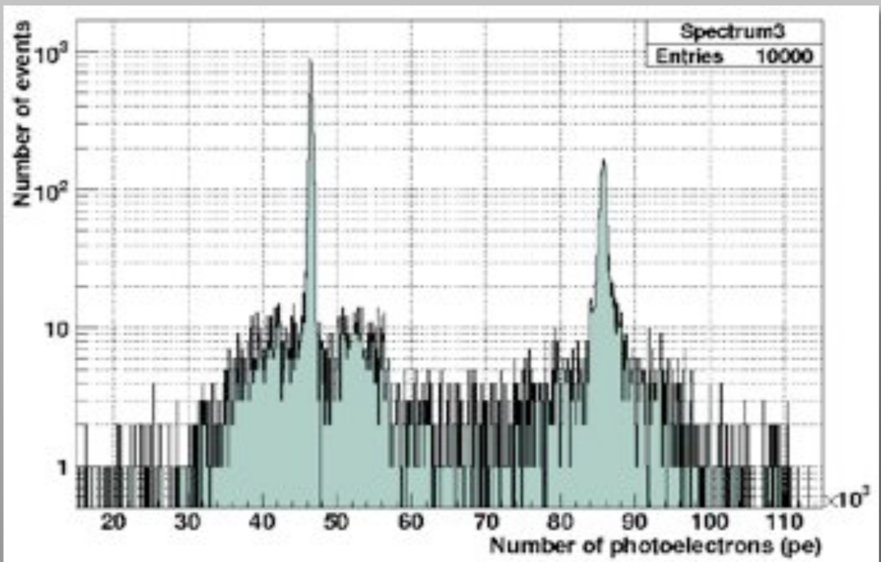
- Proton decay
- Long-baseline neutrino beams
- Atmospheric neutrinos

Detector Properties

- depends on tracking and particle identification capabilities
- all particles are visible
- some experience from cosmic muons in Borexino/KamLAND

Proton Decay into $K^+\bar{\nu}$





Signature $p \rightarrow K^+ \bar{\nu}$
↳ $\mu^+\nu_\mu$ / $\pi^0\pi^+$

coincidence: τ_K = 13 ns
energy: 250-450 MeV
modified by Fermi motion for ^{12}C

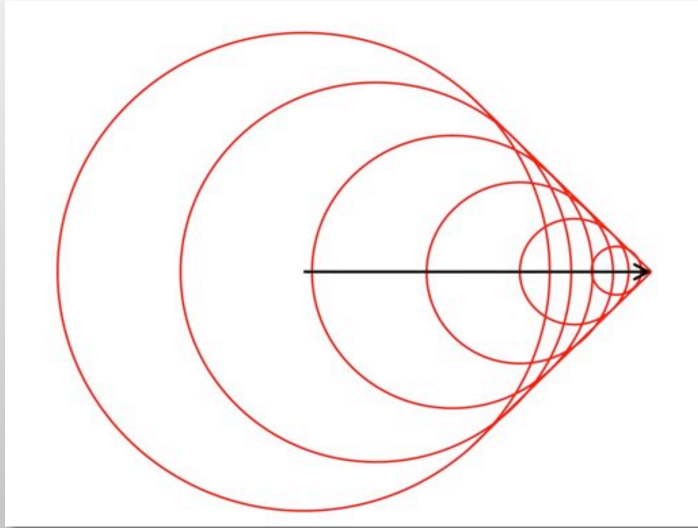
Background
atmospheric ν's rejected
by rise time cut: **efficiency 67%**
hadronic channel: <1 per 1 Mt yr
(Kaon production) @ 4kmwe

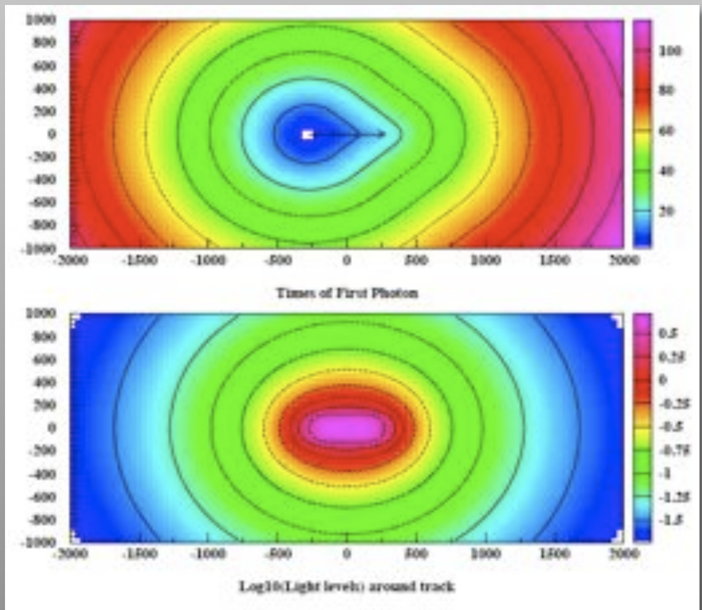
Current SK limit: 2.3×10^{33} yrs

Limit for LENA if no event is observed in 10 yrs:

$\tau_p > 4\times10^{34}$ yrs *(90%C.L.)*

Tracking of Single Particles





HE particles create along their track a light front very similar to a Cherenkov cone.

Single track reconstruction based on:

- Arrival times of 1st photons at PMTs
- Number of photons per PMT

Sensitive to particle types due to the ratio of track length to visible energy.

Angular resolution of a few degrees, in principal very accurate energy resolution.

Considerable effort is also made in connection with the scintillator LBNE option for DUSEL
-- *J. Learned, N. Tolich ...*

Tracking Performance

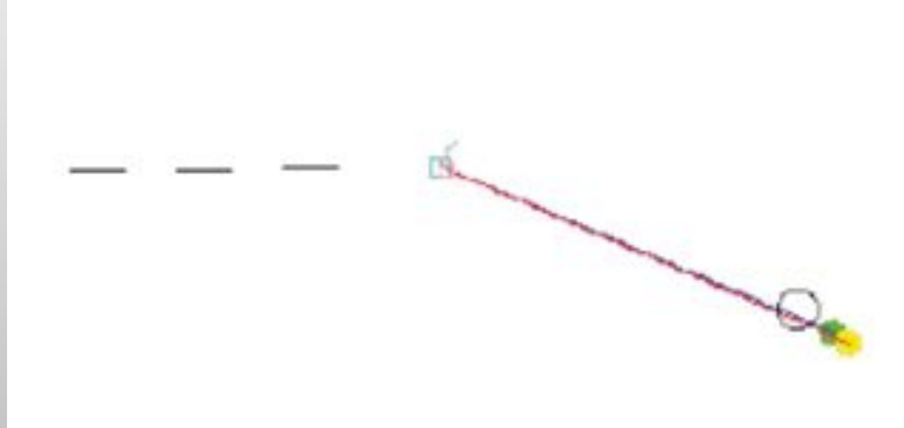
Single Tracks/Single Pion Prod.:

- Flavor recognition almost absolute
- Position resolution: few cms
- Angular resolution: few degrees
- Energy resolution: ca. 1%
  for 2-5 GeV range, depends on
  particle, read-out information

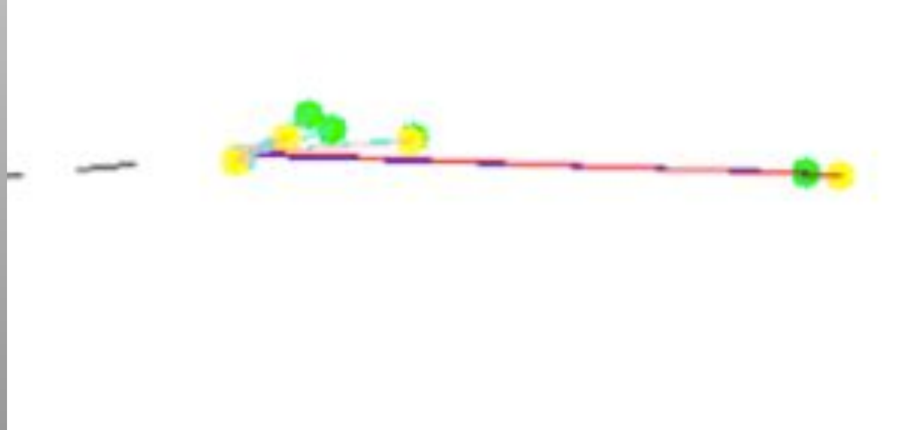
Multiparticle Events:

- 3 tracks are found if separated
- more tracks very demanding
- muon tracks always discernible
- overall energy resolution: few %
- track reconstruction less accurate

2GeV ν_μ quasielastic scattering



4GeV ν_μ deep-inelastic scattering

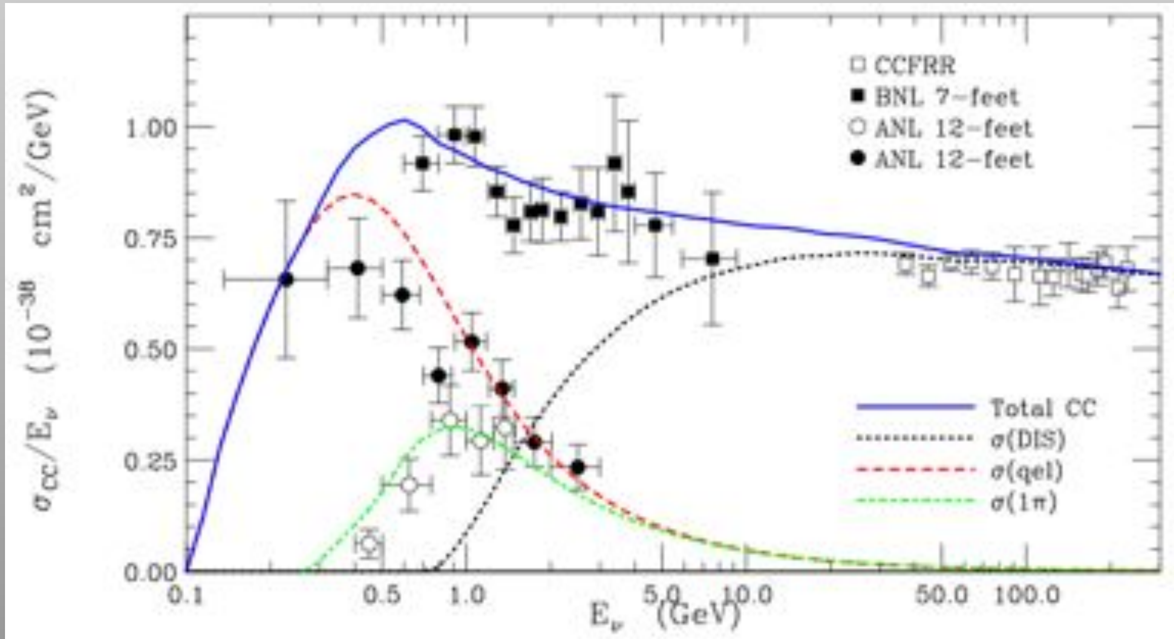


Resolution of HE Neutrino Events

CC events from HE ν's usually involve:

- Quasi-elastic scattering E < 1 GeV
- Single-pion production E = 1-2 GeV
- Deep inelastic scattering E > 5 GeV

→ Resulting light front/PMT signals are superposition of single-particle tracks.



CC neutrino reaction cross-sections on Carbon, MiniBooNE, hep-ex/0408019

Multi-Particle Approach:
(Juha Peltoniemi, arXiv:0909.4974)

- Fit MC events with combinations of test particle tracks.
- Single-event tracking as input.
- Use **full pulse-shape information of the individual PMTs** to discern the particles.
- Decay particles and capture processes (*n's*) provide additional information.

LENA as Long Baseline Detector

Baseline

- CERN to Pyhäsalmi: 2288 km ($>10^3$ km for mass hierarchy)
- 1^{st} oscillation maximum 4.2 GeV
- on-axis detector

Beam properties

- wide band (1-6 GeV): E_{max}=1.5 GeV
- power: 3.3 x 10^{20} pot/yr, 1.5 MW
- 5 yrs ν + 5 yrs $\bar{\nu}$

Preliminary GLoBES result

- 3σ sensitivity on θ_{13}, δ_{CP}, mass hierarchy for $\sin^2(2\theta_{13})>5\times10^{-3}$

[arXiv:0911.4876]

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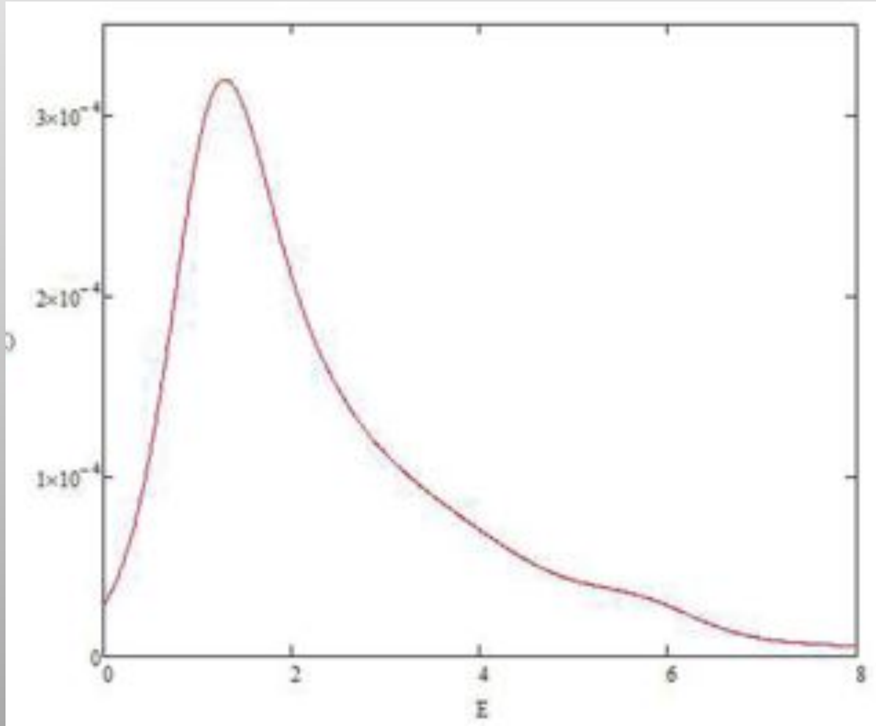

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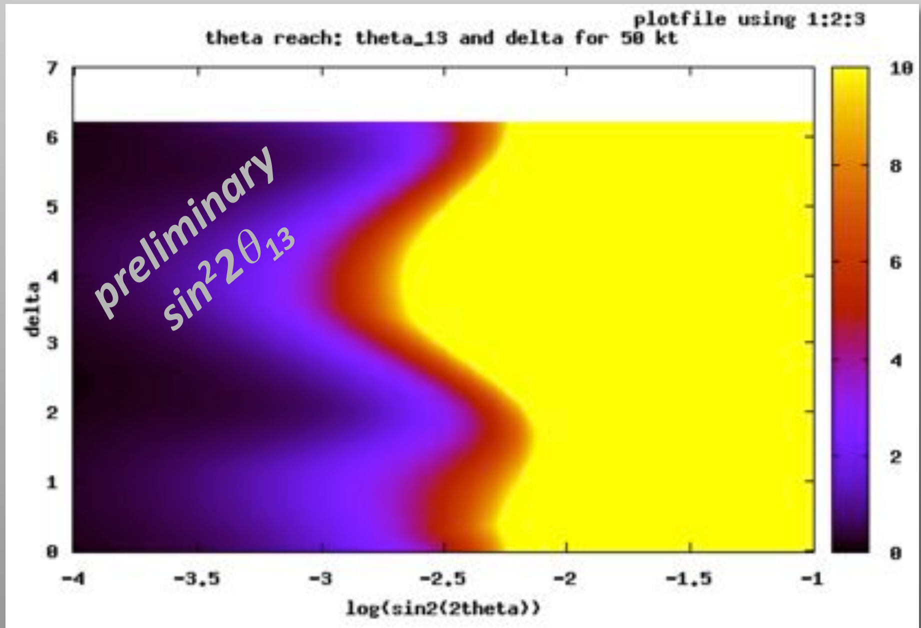

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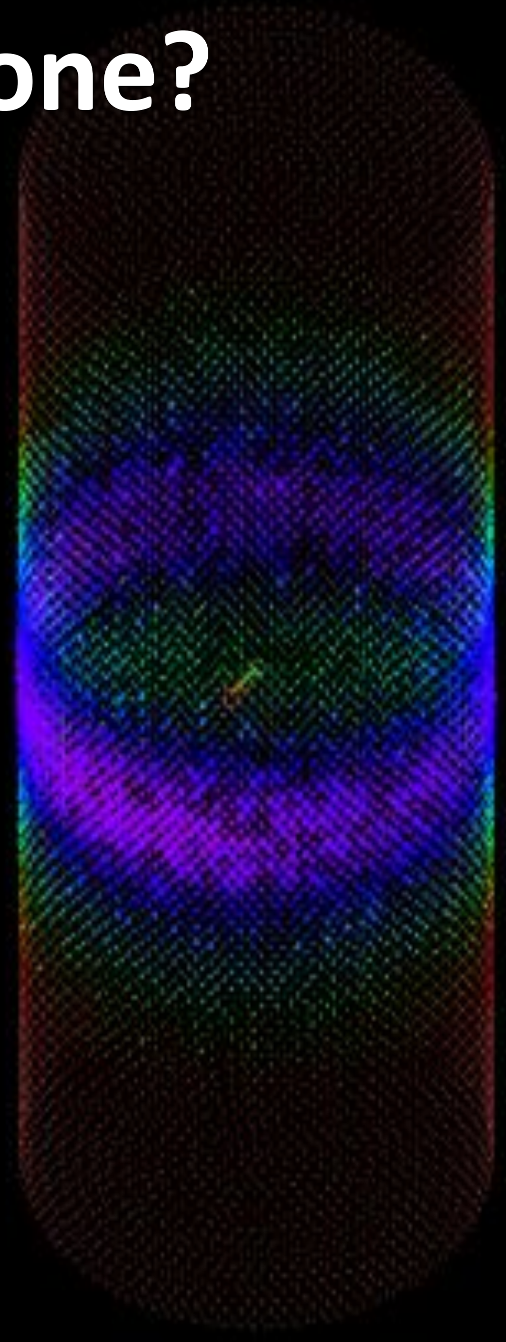
What remains to be done?

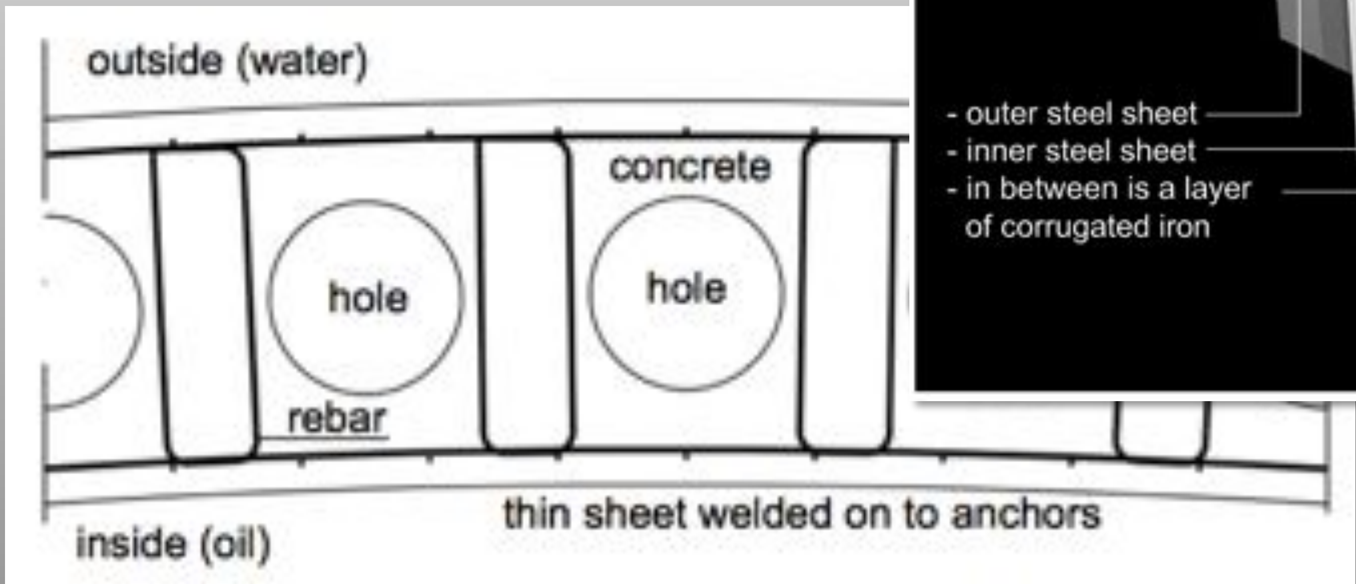
- Refinement of track reco in GEANT4.
  (light scattering, PM density, neutrons)
- Study of hadronic effects
  (quenching, secondary interactions)
- Evaluation of low-energy limit to directionality
  → proton decay into $\pi^0 e^+$
- Potential of atmospheric neutrino studies
  (from 50 MeV to 20 GeV)
- Minimum hardware requirements:
  - PM (number/size, dynamic range, time jitter)
  - read-out electronics (FADCs?)
  - ...

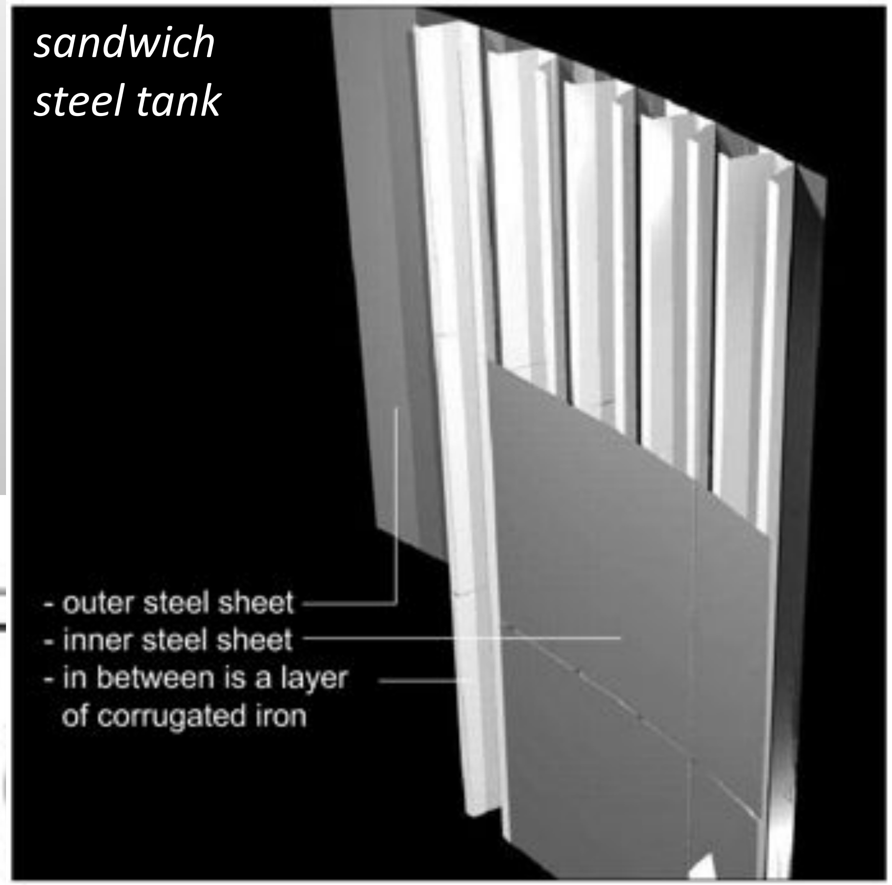


Tank Design Study

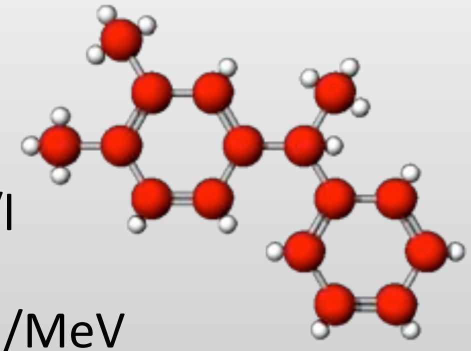
Four options:

- conventional steel tank
- sandwich steel tank
- sandwich concrete tank
- hollow-core concrete tank



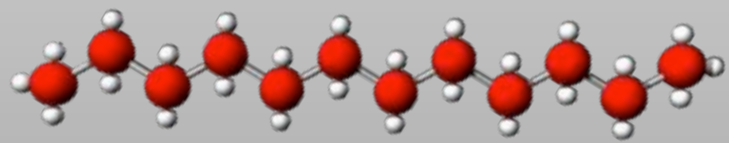


Scintillator Solvents



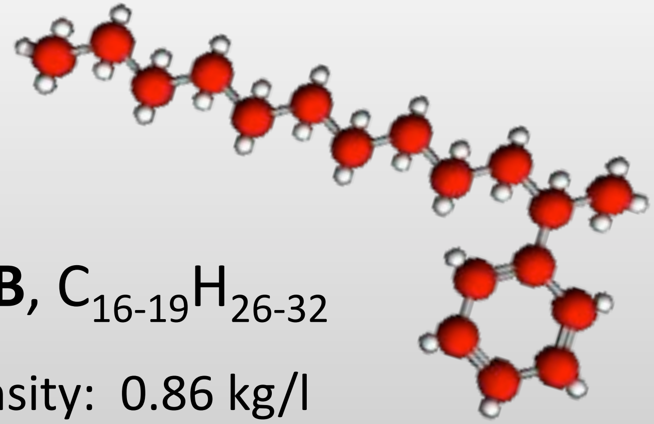
PXE, $C_{16}H_{18}$

density: 0.99 kg/l
light yield:
ca. 10.000 ph/MeV
fluorescence decay: 2.6ns
attenuation length: ≤12m *(purified)*
scattering length: 23m



+80% Dodecane, $C_{12}H_{26}$

density: 0.80 kg/l
light yield: ca. 85%
fluorescence decay slower
attenuation length: >12m
scattering length: 33m



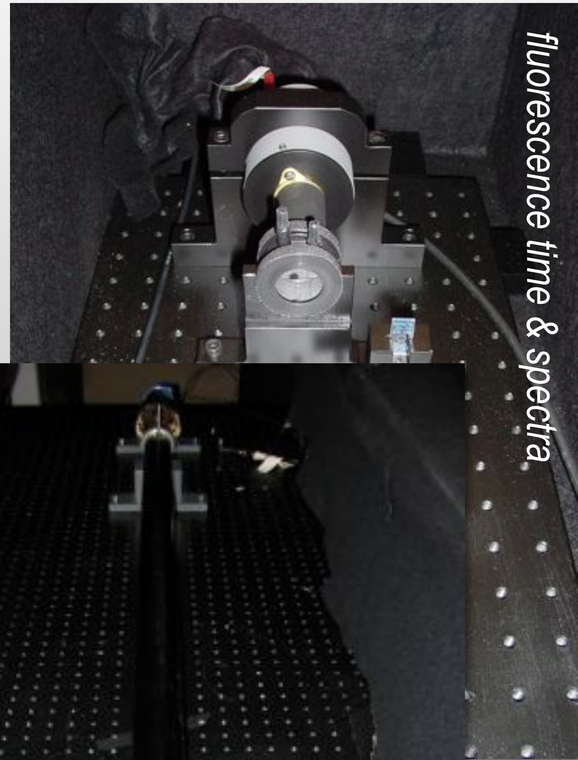
LAB, $C_{16\text{-}19}H_{26\text{-}32}$

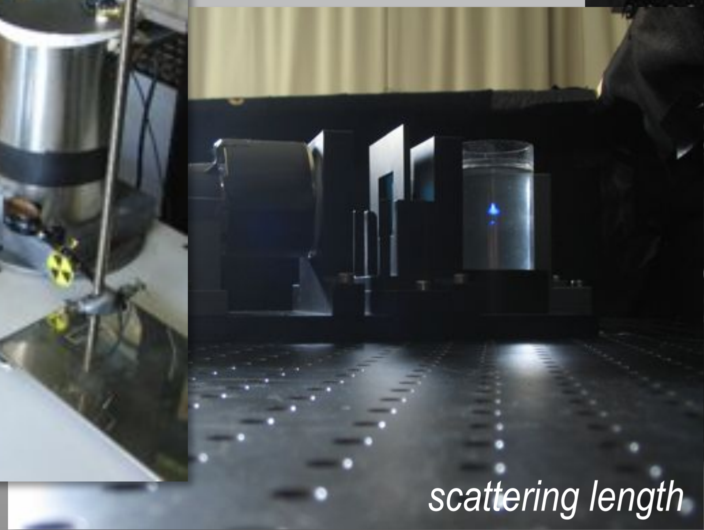
density: 0.86 kg/l
light yield: comparable
fluorescence decay: 5.2ns
attenuation length: <20m
scattering length: 25m

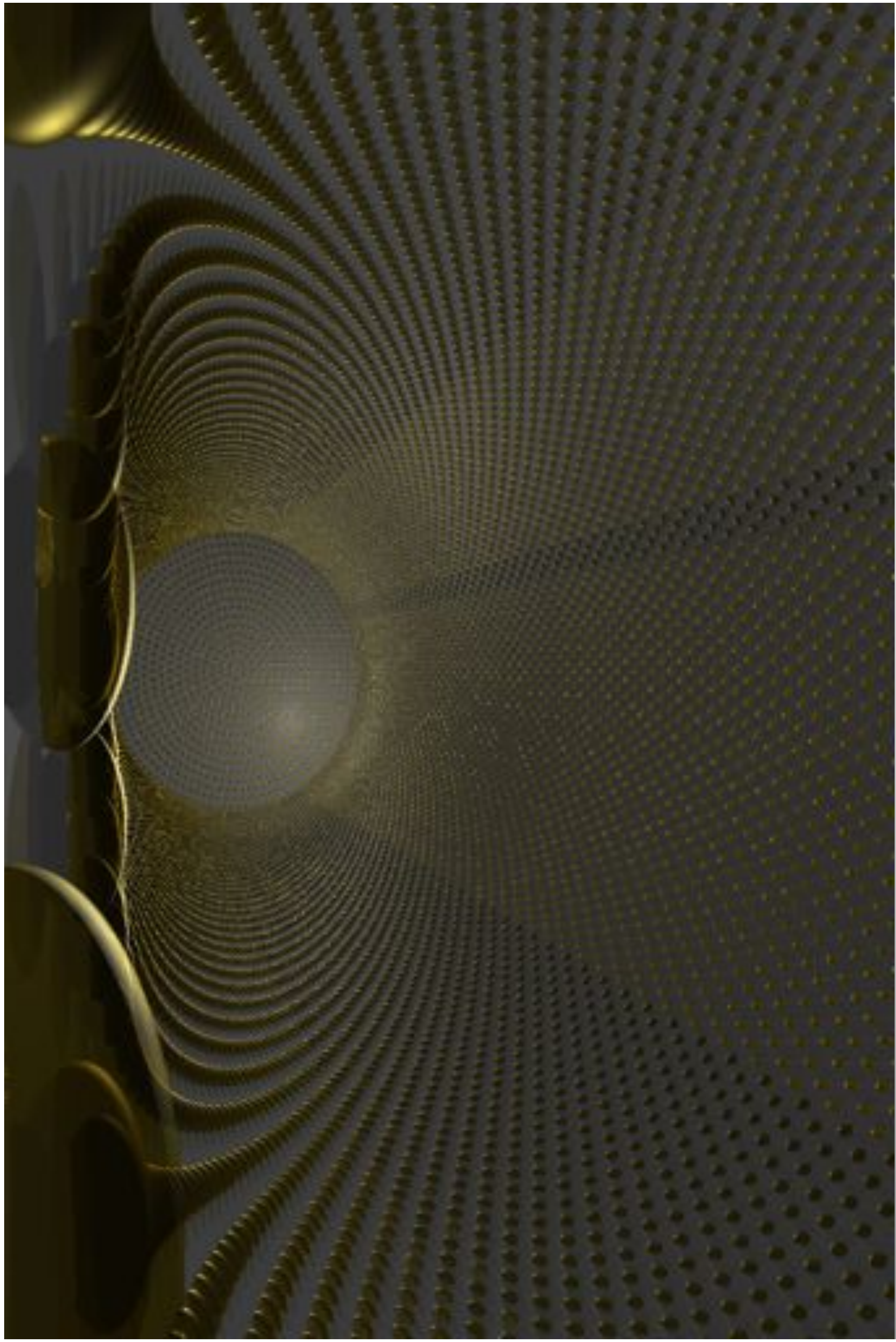
- **Detector diameter of 30m or more is well feasible!**
- Fluorescence times (3-5ns) and light yield (200-500pe/MeV) depend on the solvent.
- LAB is currently favored.

Status of Scintillator R&D

- Light yield, spectra and fluorescence:
  by now well understood
- Light transport: optical scattering and absorption length measured for small samples
  → precise measurement over large distances
- Scintillator response to different particles: gamma/neutron pulse shape and quenching *(MLL Garching, Rossendorf)*







Photomultipliers

Default Configuration

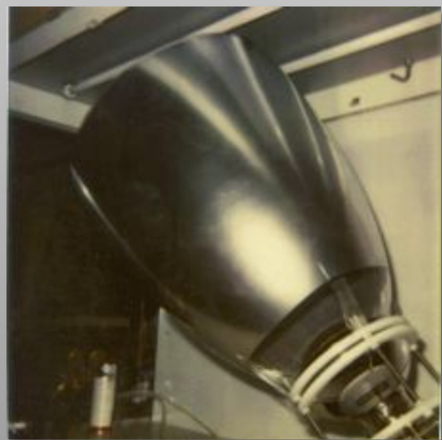
- 13,500 PMs of 20'' cathode diameter
- optical coverage: 30%

Smaller Photomultipliers

- machined PMs much cheaper
- depends on cost per DAQ channel

Usage of Light Concentrators

- Borex cones double optical coverage
- Larger cones seem possible in LENA



Light cone used in the Borexino prototype CTF, eight-fold light collection

Pressure resistance/encapsulation is needed for bottom PMTs (10 bar)

PMT Survey at LNGS

Test facility of Borexino

- very precise light source: laser diode (410nm), pulse FWHM 30 ps
- fast electronics: trigger and DAQ electronics jitter < 100 ps

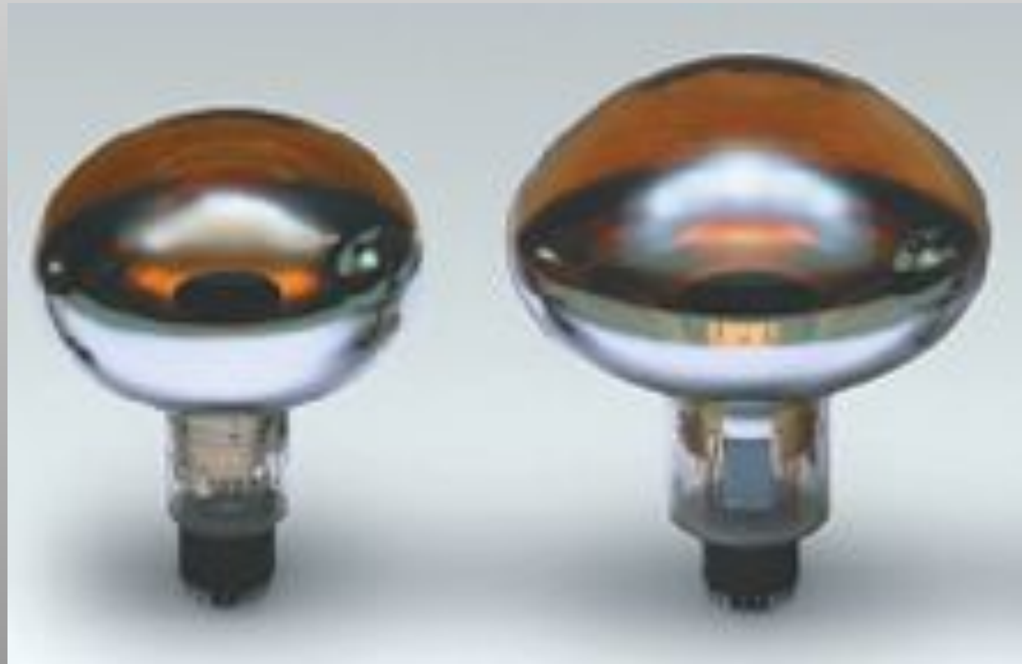
Studied properties

- time behavior (transit time spread)
- afterpulse rates
- dark noise levels
- SPE spectrum

Hamamatsu PMTs:

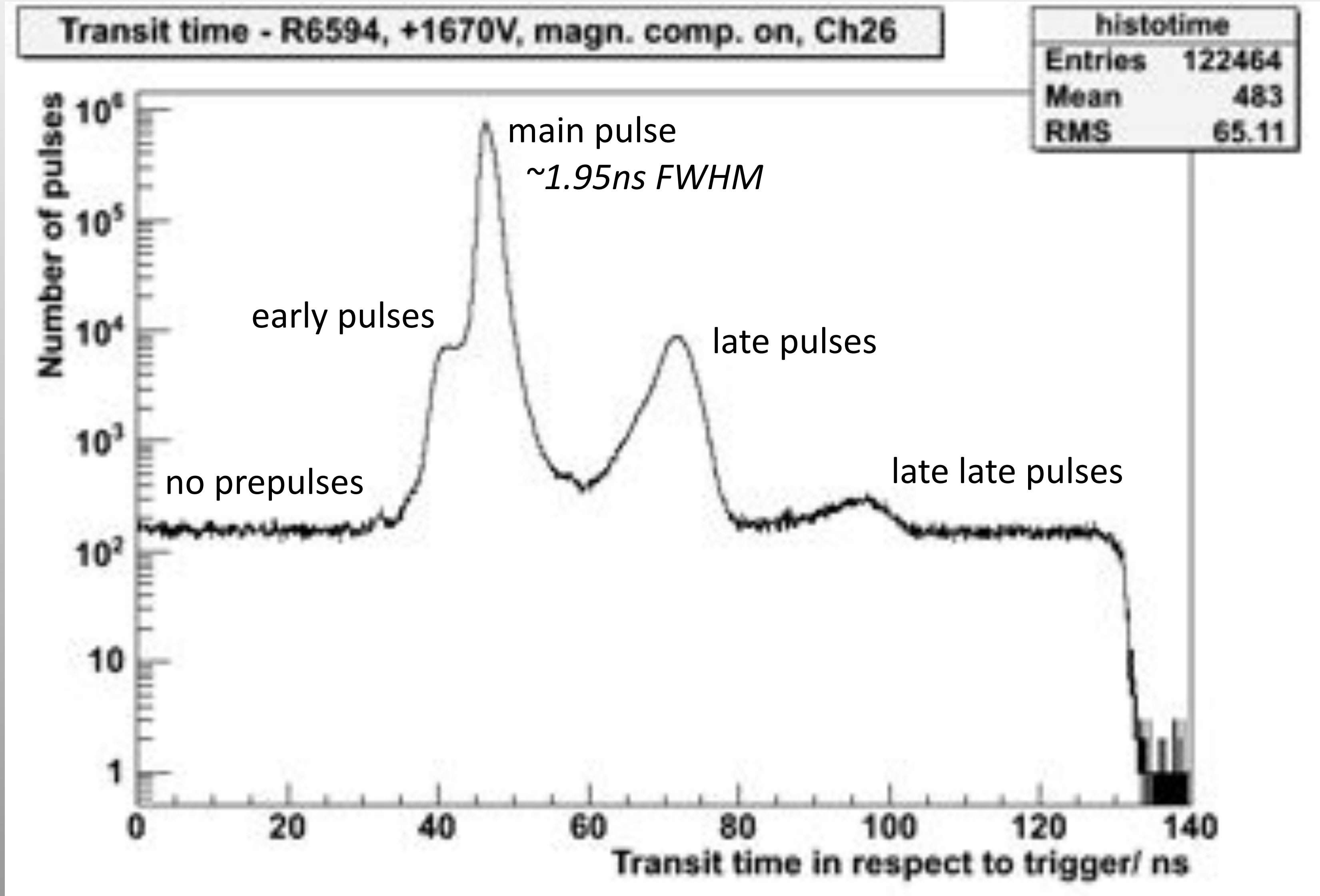
R6091 (3“)

R6594 (5“)



R5912 (8“) R7081 (10“)

Example: R6594 (5‘‘) transit time



PMT Survey: Current Status

Good candidates:

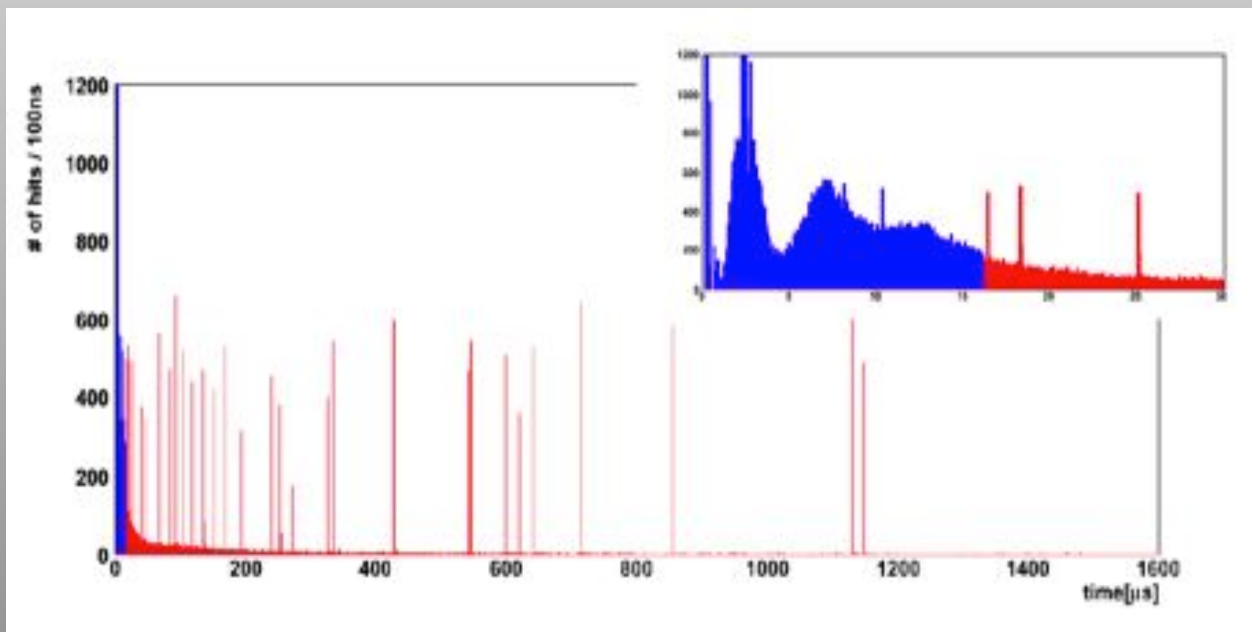
- R6594 (5''): low jitter, very few afterpulses, moderate dark noise
  many late pulses and early pulses
- ETL9351 (8''): *(used in Borexino)* low jitter (gaussian), low dark noise
  high after pulsing, many late pulses
- R5912 (8''): low jitter (strong exponential tail), low dark noise
  moderate after pulsing

Further steps (in Garching):

- test of PMT dynamic range
- ultrafast afterpulses ($\Delta t<30$ns), prepulses
- test of several tubes of the same type to reduce uncertainties
- close collaboration with Hamamatsu (modifications?)

Electronics and DAQ Requirements

- 45k 8''-PMs or 90k 5''-PMs: reduction of channels, cabling → PMm2
- Energies of 100 keV to 10 GeV: dynamic range 1 to >100 pe per PM
- reduce afterpulsing for cosmogenic neutrons and time resolution
- at least for groups of PMs ($1m^2$): FADC readout of analog sum for GeV-neutrino vertex reconstruction
- concrete tank: trigger rates of kHz



Summary

- LENA will be a multipurpose neutrino observatory
- low-energy neutrino detection well understood
- track reconstruction at GeV energies looks very promising, but further work is necessary
- work on liquid scintillator mostly completed, investigation of photomultipliers started, electronics and DAQ design needed