LENA

Low Energy Neutrino Astronomy

Seminar Universität Tübingen

11.7.08

Lothar Oberauer, TUM

Physics Goals

- Diffuse Supernova Neutrino Background
- Proton Decay
- Galactic Supernova Burst
- Solar Neutrinos
- Geo neutrinos
- Reactor neutrinos
- Beta-beam neutrinos
- Atmospheric neutrinos
- Dark Matter indirect search

Liquid Scintillator Technology

- High light output
- Low energy threshold
- Good energy, timing, and position resolution
- Variety of neutrino detection channels
- Inverse beta decay detection basically background free

DETECTOR LAYOUT

~ 50 kt Liquid Scintillator

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

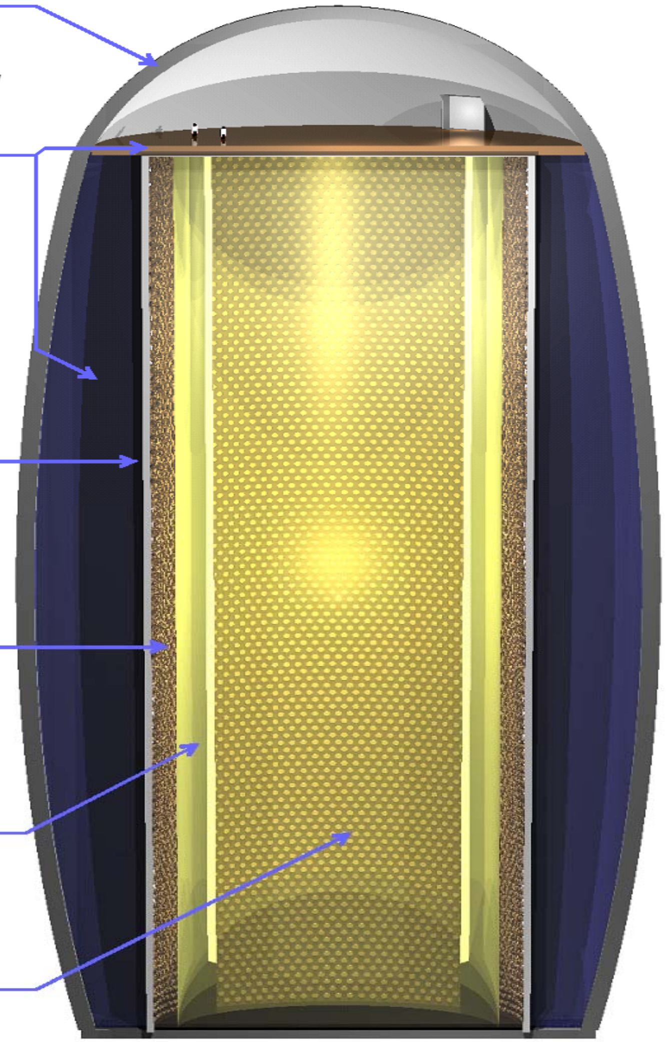
Muon Veto
plastic scintillator panels (on top)
Water Cherenkov Detector
1,500 phototubes
100 kt of water
reduction of fast
neutron background

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

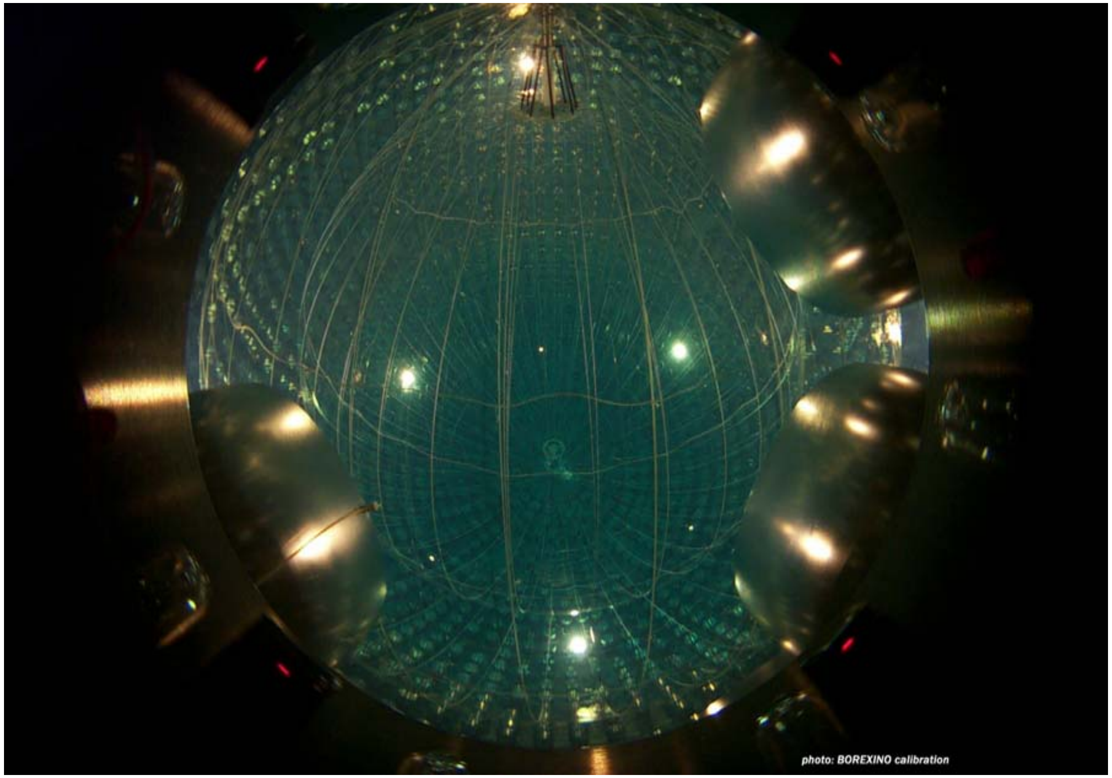


vertical design is favourable in terms of rock pressure and buoyancy forces

Large Liquid Scintillator Detectors

Counting Test Facility CTF at Gran Sasso (Italy)

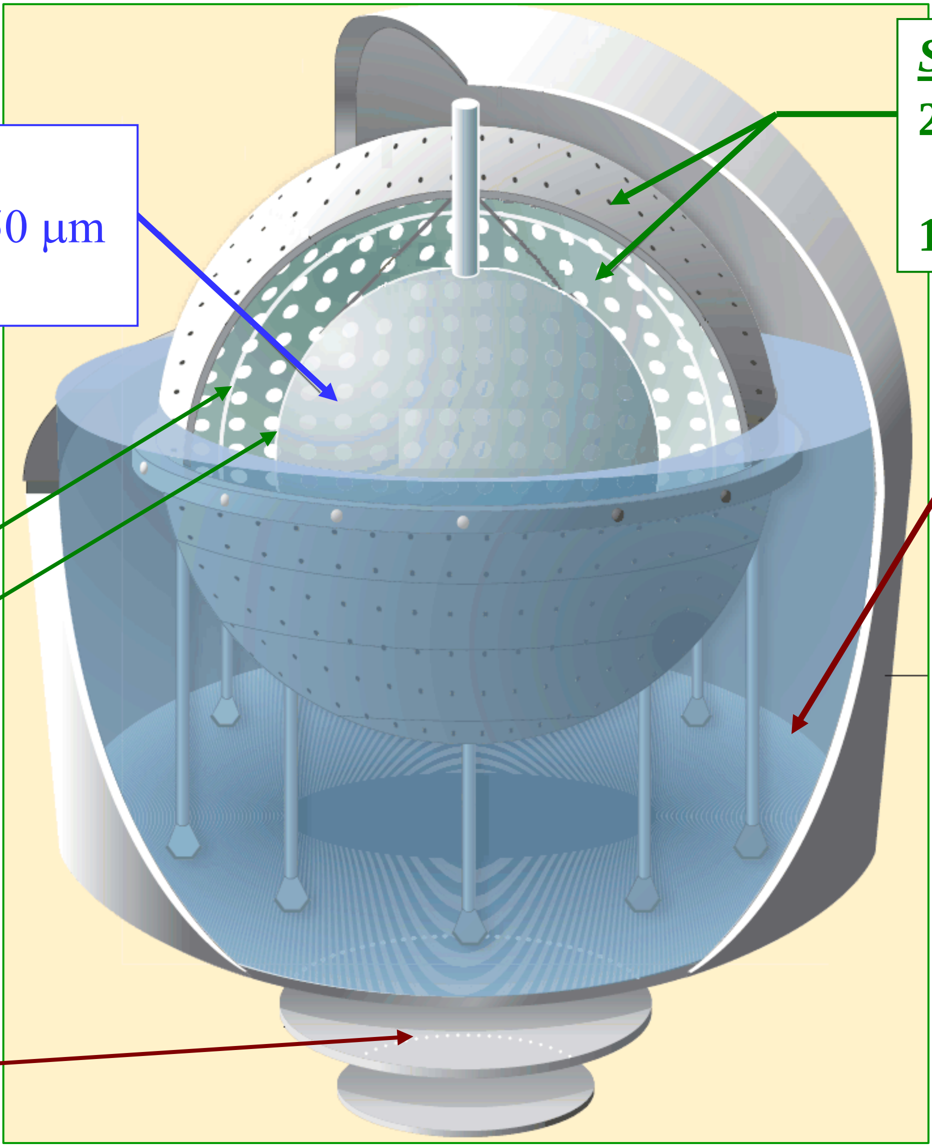
~ 5 t



BOREXINO at Gran Sasso; 300 t; incl. buffer 1,4 kt

KamLAND (Japan) with 1kt scintillator

BOREXINO Detector layout



Scintillator:
270 t PC+PPO in a 150 μm thick nylon vessel

Stainless Steel Sphere:
2212 PMTs + concentrators
1350 m³

Nylon vessels:
Inner: 4.25 m
Outer: 5.50 m

Water Tank:
γ and n shield
μ water Č detector
208 PMTs in water
2100 m³

Carbon steel plates

Excellent ***shielding*** of external background

Increasing ***purity*** from outside to the central region

BOREXINO

Neutrino electron scattering $\nu e \rightarrow \nu e$

Liquid scintillator technology (~300t):

→ Low energy threshold (~60 keV)

Good energy resolution (~4.5% @ 1 MeV)

Sensitivity on sub-MeV neutrinos

Online since May 16th, 2007

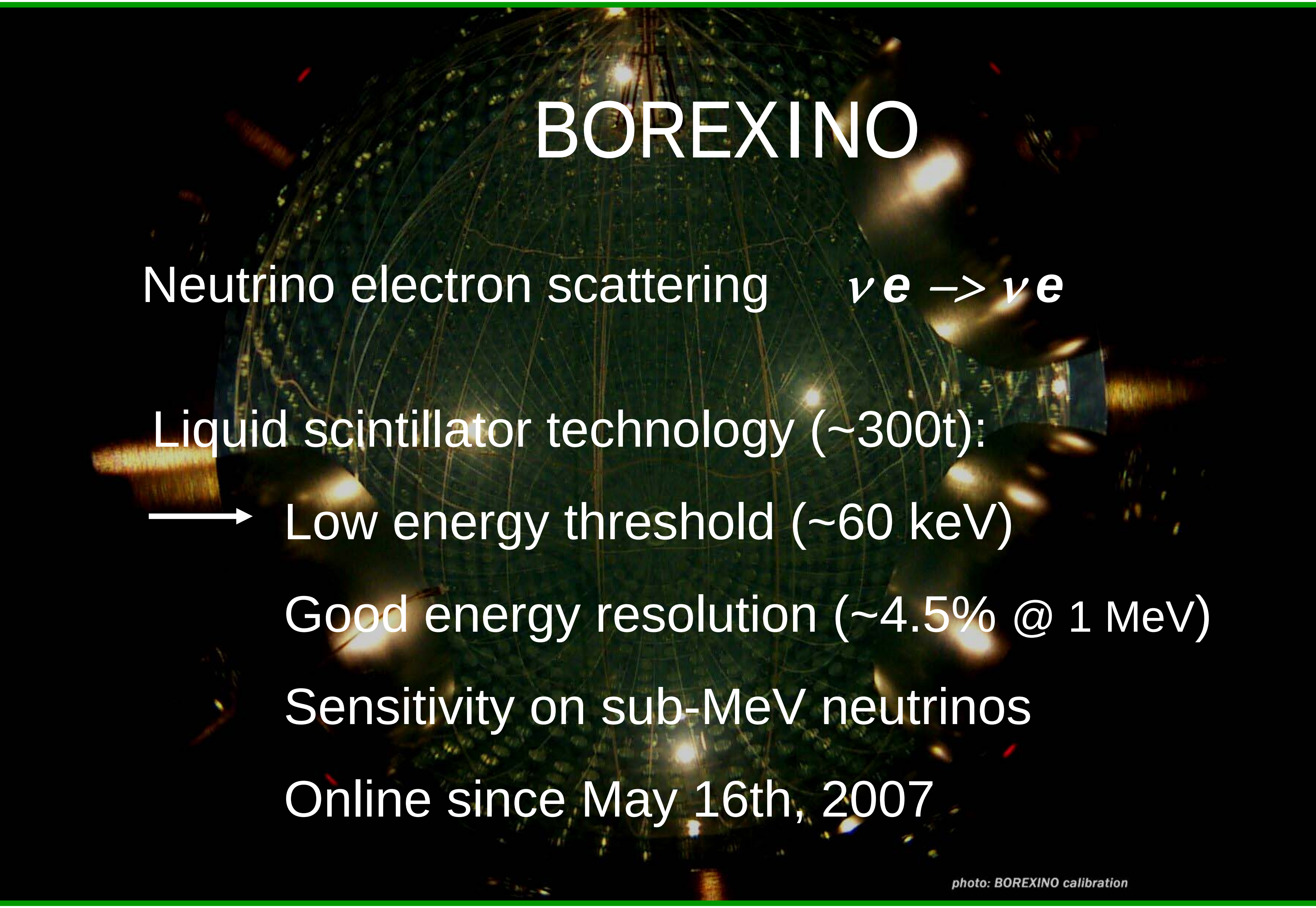
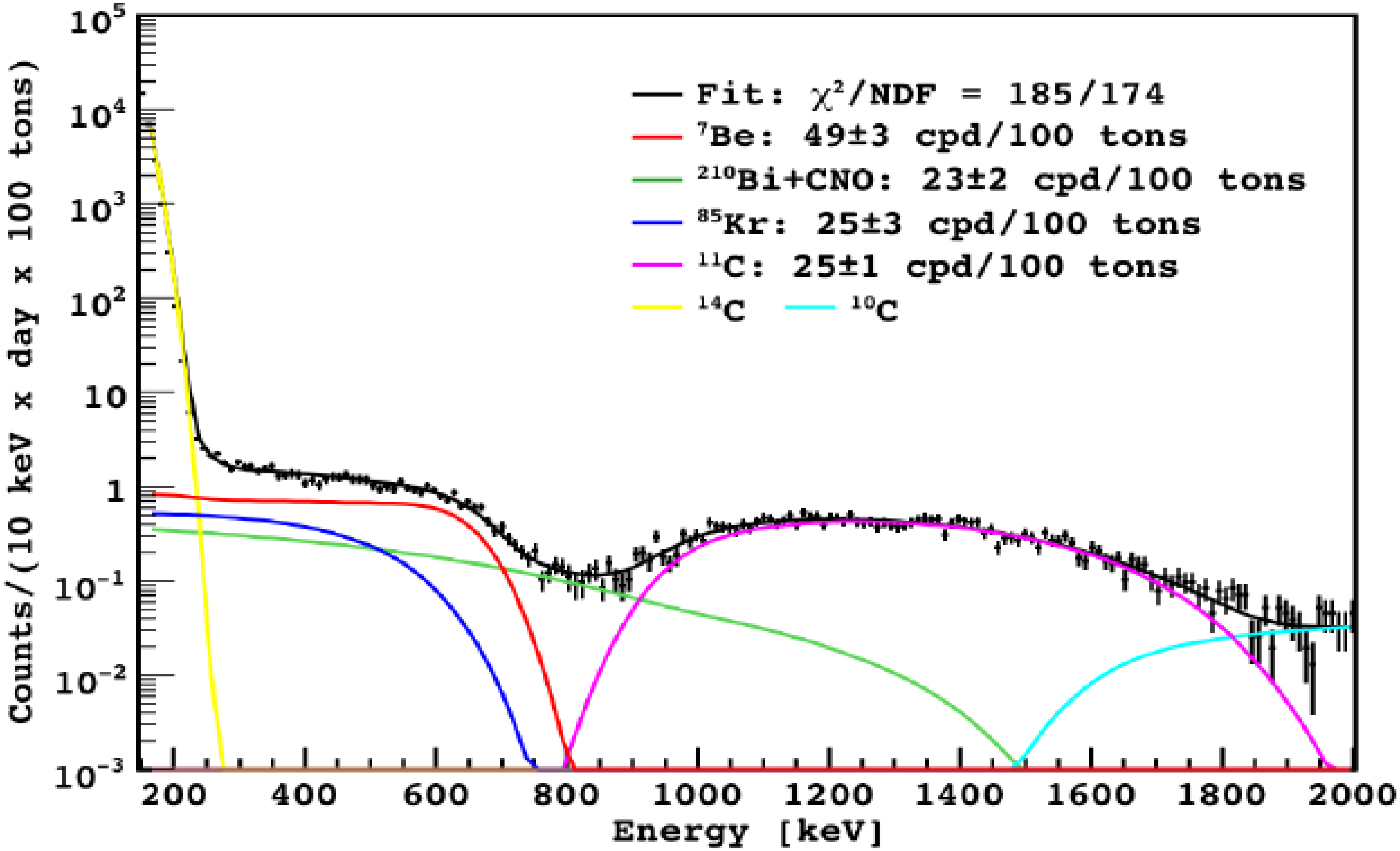


photo: BOREXINO calibration

First Detection of Solar 7-Be Neutrinos by BOREXINO



astro-ph:08053842

Borexino results

- $N(Be) = 49 \pm 3 \pm 4$ /(day x 100 t)
- $N(SM\text{-}no\text{-}osc) = 74 \pm 4$ /(day x 100 t)

$\Rightarrow$ ν-oscillation confirmed (large mixing angle solution)

$\Rightarrow$ $\Phi_{Be} = (5.18 \pm 0.51)\ 10^9\ /cm^2\ sec$

$\Rightarrow$ $f_{Be} = \Phi_{Be}/\Phi_{SM} = 1.02 \pm 0.10$

$\Rightarrow$ $f_{pp} = 1.005^{+0.008}_{-0.020}$

$\Rightarrow$ $f_{CNO} < 3.8$ (90% CL)

Search for the Diffuse Supernova Neutrino Background in LENA

Phys.Rev.D 75 (2007) 023007

M. Wurm, F. v. Feilitzsch, M. Göger-Neff,
T. Marrodán Undagoitia, L. Oberauer, W. Potzel, J. Winter
Technische Universität München
mwurm@ph.tum.de
http://www.e15.physik.tu-muenchen.de/research/lena.html

DSNB Detection via inverse beta decay

- Free protons as target

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

Delayed signal (~200 μs)

Prompt signal

• **Threshold 1.8 MeV**

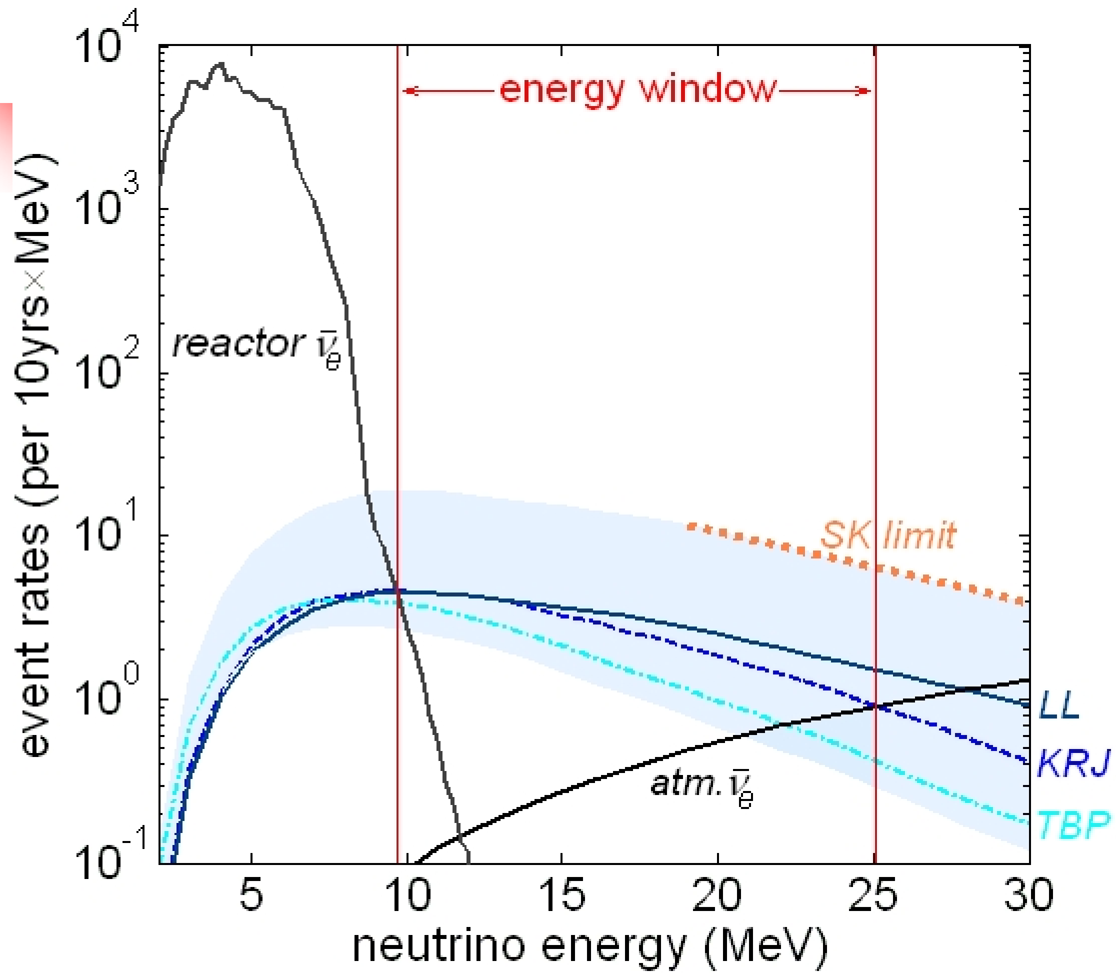
• **$E_\nu \sim E_e$ - Q (*ν spectroscopy*)**

• **suppress background via *delayed coincidence method***

n + p –> D + γ (2.2 MeV)

• ***position reconstruction => fiducial volume* (suppress external background)**

LENA at Pyhäsalmi *(Finland)*



~25% of events are due to ν's originating from SN @ z>1!

DSN event rate in 10yrs
inside the energy window from 9.7 to 25 MeV

dependent on SN model
(assumed f_{SN}=2.5)

LL:	113
KRJ:	100
TBP:	60

dependent on SNR

f_{SN}=0.7	17
f_{SN}=2.5	100
f_{SN}=4.2	220

background events: 13

Diffuse Supernova Neutrino Background Detection

- Due to the excellent background discrimination, a liquid-scintillator detector enables a detection of the Diffuse Supernova Neutrinos in an almost background-free energy window 10 to 30 MeV.

- The discovery potential for the DSN in LENA is very high. According to current models, **~2 to 20** events per year are expected.

- After 10 years, statistics will be large enough to give constraints on both Supernova Rate and SN explosion models.

Galactic Supernova neutrino burst in LENA

- $8\ M_\odot$ ($3 \cdot 10^{53}$ erg) at D = 10 kpc (center of our galaxy)

In LENA detector: $\sim$15000 events

Possible reactions in liquid scintillator

- $\overline{\nu}_e + p \rightarrow n + e^+; \;\; n + p \rightarrow d + \gamma$ $\sim$7 000 - 13 800
- $\overline{\nu}_e + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{B} + e^+; \;\; {}^{12}\mathrm{B} \rightarrow {}^{12}\mathrm{C} + e^- + \overline{\nu}_e$ $\sim$150 - 610
- $\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}; \;\; {}^{12}\mathrm{N} \rightarrow {}^{12}\mathrm{C} + e^+ + \nu_e$ $\sim$200 - 690
- $\nu_x + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{C}^* + \nu_x; \;\; {}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C} + \gamma$ $\sim$680 - 2 070
- $\nu_x + e^- \rightarrow \nu_x + e^-$ (elastic scattering) $\sim$700
- $\nu_x + p \rightarrow \nu_x + p$ (elastic scattering) $\sim$1 500 - 5 700

Diploma thesis by J.M.A. Winter (TU München)

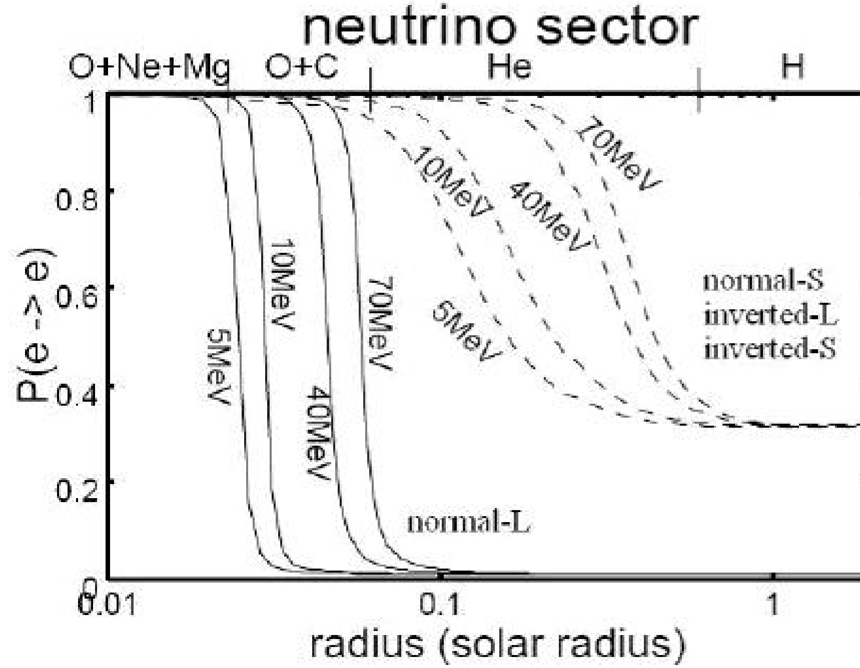
SN Neutrino predicted rates

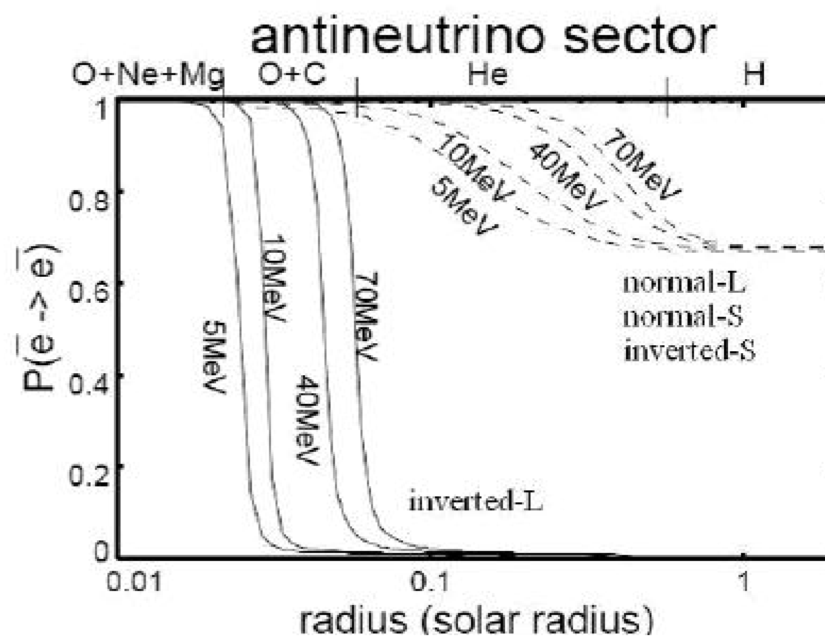
vary with …
- the used SN neutrino model
  (mean energies, pinching)
- neutrino physics
  (value of θ_{13}, mass hierarchy)

variation: 10-19 x10^3 ev @ 10kpc

Aims

- physics of the core-collapse
- constraints on neutrino parameters
- look for matter oscillation effects





Matter effects in the Earth

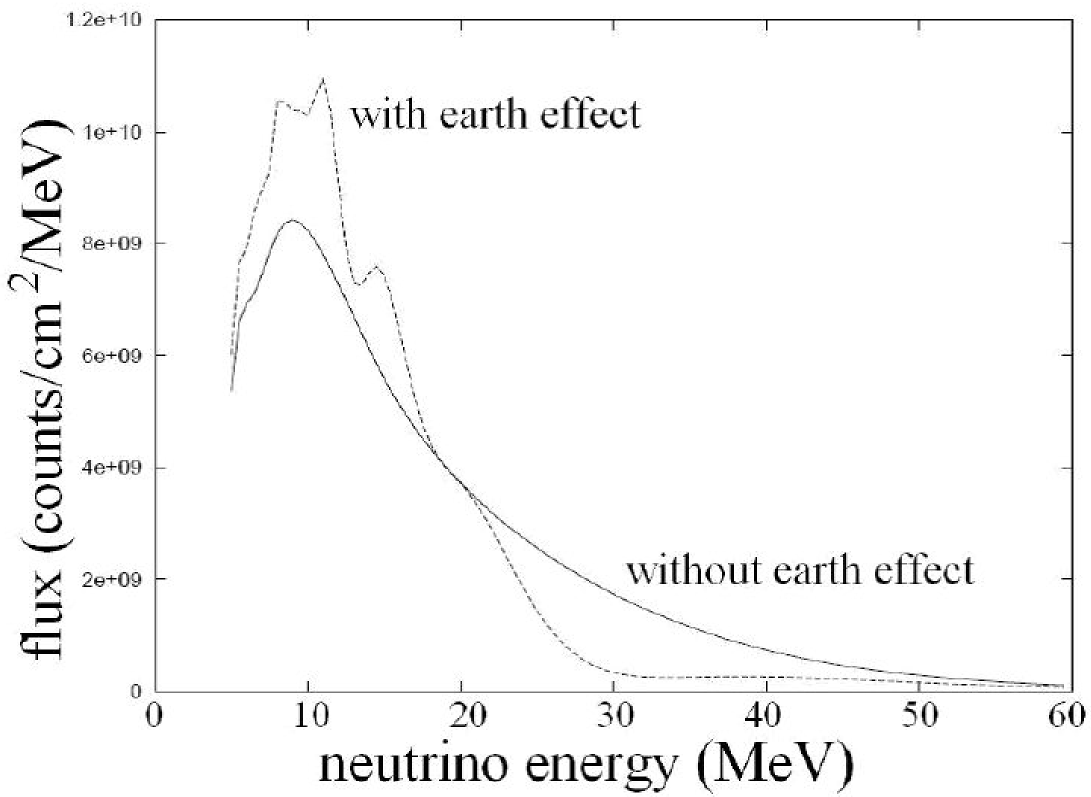
•mass hierarchy

•theta_13

Matter effects in the SN:

•mass hierarchy and theta_13

•time development of the shock wave?



• coherent neutrino oscillations ?

(neutrino self-interaction)

Separation of SN models ?

- Possible ***independent*** from oscillation model due to ***neutral current reactions*** *in LENA*

	TBP	KRJ	LL
12-C:	700	950	2100
Nu-p:	1500	2150	5700

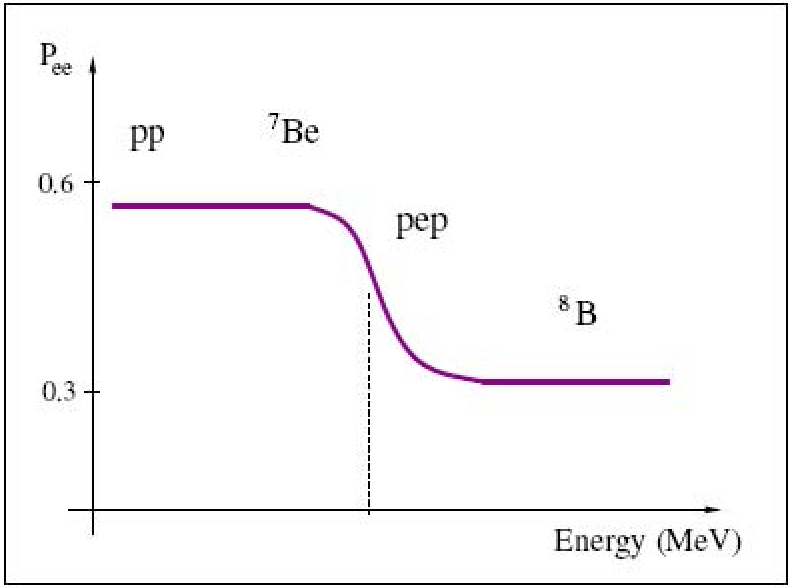
for 8 solar mass progenitor and 10 kpc distance

Supernova neutrinos with LENA

- Antielectron ν spectrum with high precision
- Electron ν flux with 8% - 11% precision
- Total flux via neutral current reactions
- Separation of SN models
- Spectroscopy of all ν flavors
- Time evolution of neutrino burst
- Details of SN gravitational collapse
- Chance to separate low/high Θ_{13} and mass hierarchy (normal/inverted)

Solar Neutrino Detection in LENA

Solar Neutrinos and LENA



Spectrum deformation due to the MSW effect

Rates of solar neutrino events

In the LENA fiducial volume:

$$18 \cdot 10^3 \text{ m}^3$$

- ^{7}Be ν's: $\sim 5400 \text{ d}^{-1}$
  - Small time fluctuations
- pep ν's: $\sim 150 \text{ d}^{-1}$
  - Information about the pp-flux $\rightarrow$ Solar luminosity in ν's
- CNO ν's: $\sim 210 \text{ d}^{-1}$
  - Important for heavy stars
- ^{8}B ν's: CC on ^{13}C: $\sim 360 \text{ y}^{-1}$

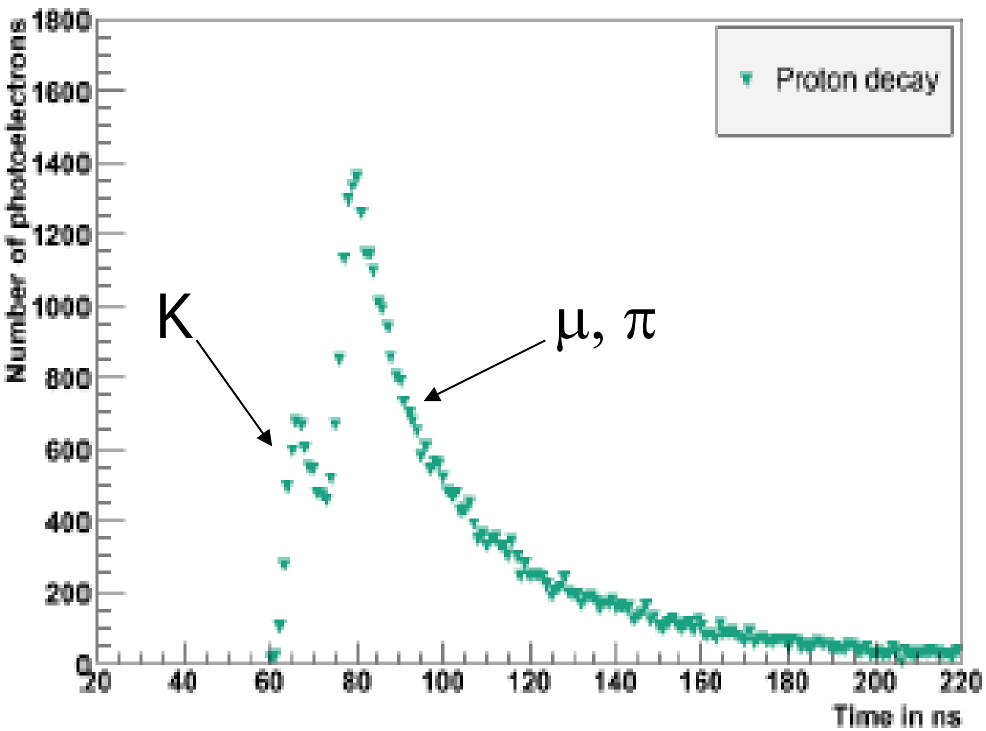
Solar Neutrinos and LENA

- High statistics in 7-Be
- Search for time fluctuations
- CNO and pep ν
- Test of MSW effect
- Search for non-standard ν interactions
- CC and NC measurements of 8-B
- Spectrum deformation

LENA and proton decay

LENA and proton decay

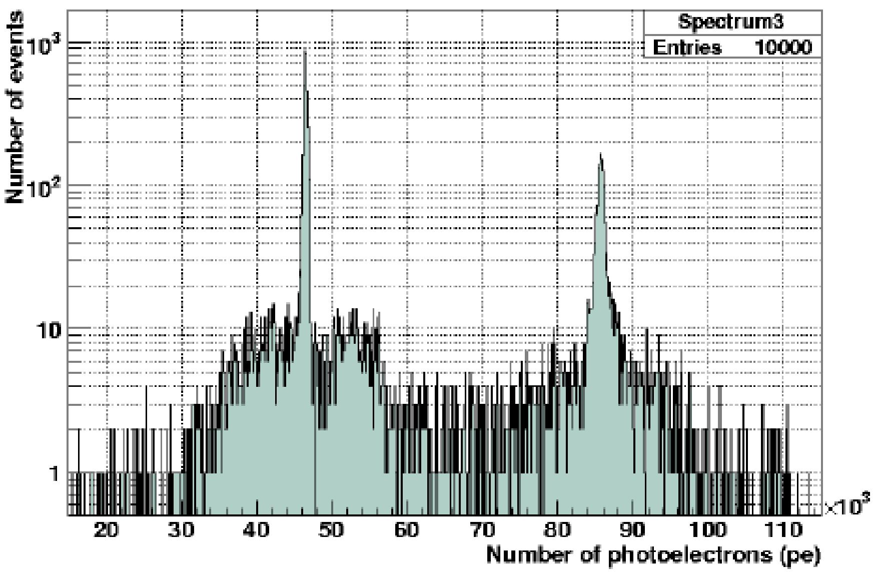
- High efficiency and very good background rejection for $p \to K^+ \nu$



Good time resolution:

K and μ, π from K decay (12 nsec)

Sensitivity to proton decay   P -> K$^+$ ν



- Energy spectrum (180 pe/MeV)
- Two peaks:
  - Kaon + Muon: ~ 257 MeV
  - Kaon + Pions: ~ 459 MeV
- Efficiency: $\varepsilon_E = 0.995$
- Included: protons from $^{12}\mathrm{C}$

Potential of LENA (10 y measuring time)

- For Superkamiokande current limit: $\tau = 2.3 \cdot 10^{33}$ y
  - 40 events in LENA and $\lesssim 1$ background
- No signal in LENA: $\tau > 4 \cdot 10^{34}$ y 90% (C.L)

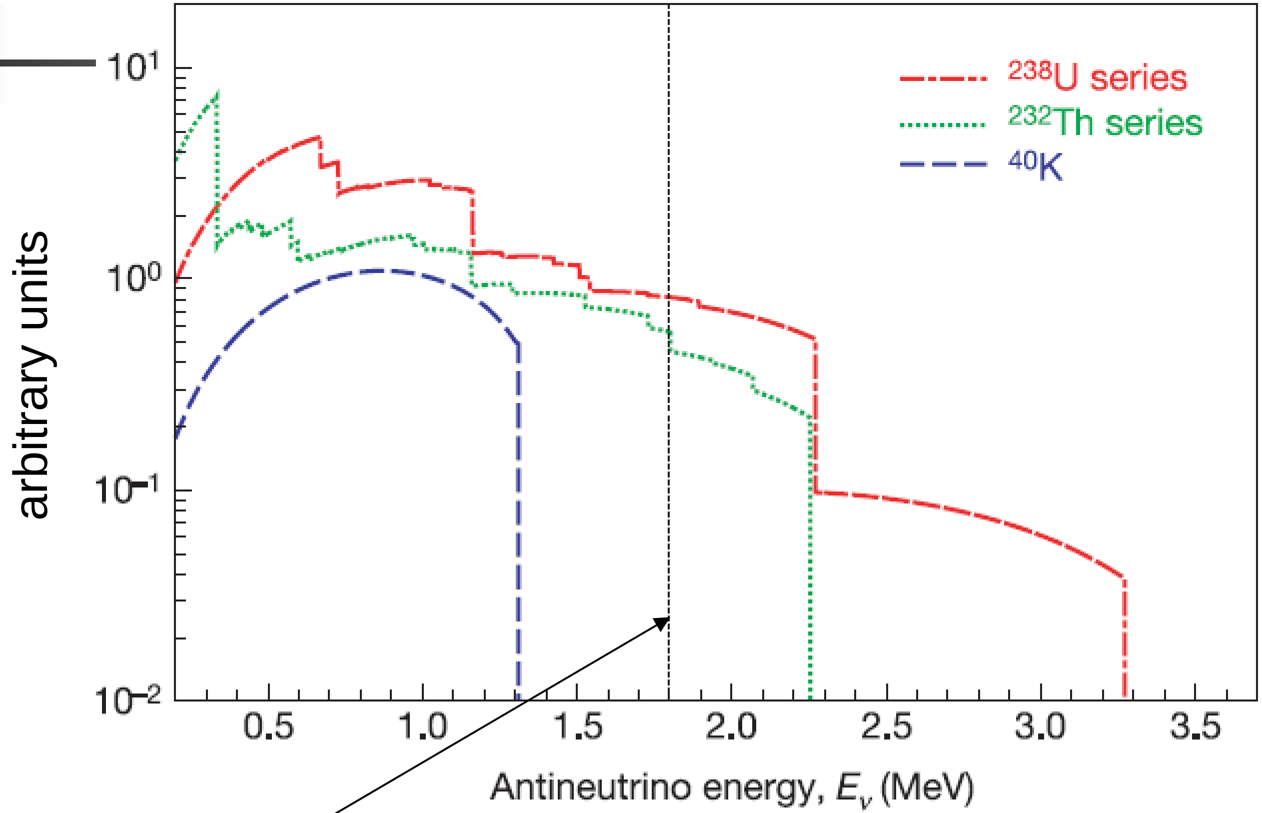
Phys. Rev. D72 075014 (2005) and hep-ph/0511230

LENA and proton decay

- High sensitivity to p -> K ν (eff. ~ 65% instead 6% in SK $\tau \sim 4 \times 10^{34}$ y)
- Sensitive to a variety of decay channels "invisible" modes, e.g. n -> $\nu\ \nu\ \nu$
- For e.g. p -> $e^+ \pi^0$ we expect ~ 10^{33} y (work in progress)

LENA and neutrinos from the Earth

Sensitivity on U, Th



Energy threshold

1st detection of Geo-neutrinos in KamLAND in 2005 (1kt liquid scintillator detector)

Expected event rates

- **BOREXINO**

  around ~ 10 per year

- **LENA**

  between ~ 3 x 10^2 and ~ 3 x 10^3 per year

  (in Pyhäsalmi, Finland, continental crust)

  this is extrapolated from KamLAND result

Backgrounds in LENA

- ~ 240 per year in [1.8 MeV – 3.2 MeV] from reactor neutrinos
- < 30 per year due to ^{210}Po alpha-n reaction on ^{13}C (Borexino purity assumed)
- ~ 1 per year due to cosmogenic background

  (^{9}Li - beta-neutron cascade)

Can be statistically subtracted

K. Hochmuth et al., Astropart.Phys. 27 (2007) 21-29

LENA and Geo-neutrinos

- In **LENA** we expect between 300 to 3000 events per year (“best bet” ~ 1500 / year)
- Good signal / background ratio

  most significant contribution can be subtracted statistically
- Separation of geological models

LENA and other topics

-Beta beams

-Reactor neutrinos

-Atmospheric neutrinos

-Dark Matter search

LENA and Reactor neutrinos

- At Frejus ~ 17,000 events per year
- High precision on solar oscillation parameter:
- $\Delta \mathbf{m^2}_{\mathbf{12}} \sim 1\%$
- $\Theta_{12} \sim 10\%$

S.T. Petcov, T. Schwetz, Phys. Lett. B 642, (2006), 487

J. Kopp et al., JHEP 01 (2007), 053

Atmospheric and beta beams

- Separation between e- and μ-like events
- Pulse shape discrimination (risetime, width)
- Muon decay $\mu \rightarrow e\ \nu\ \nu$
- Work in progress

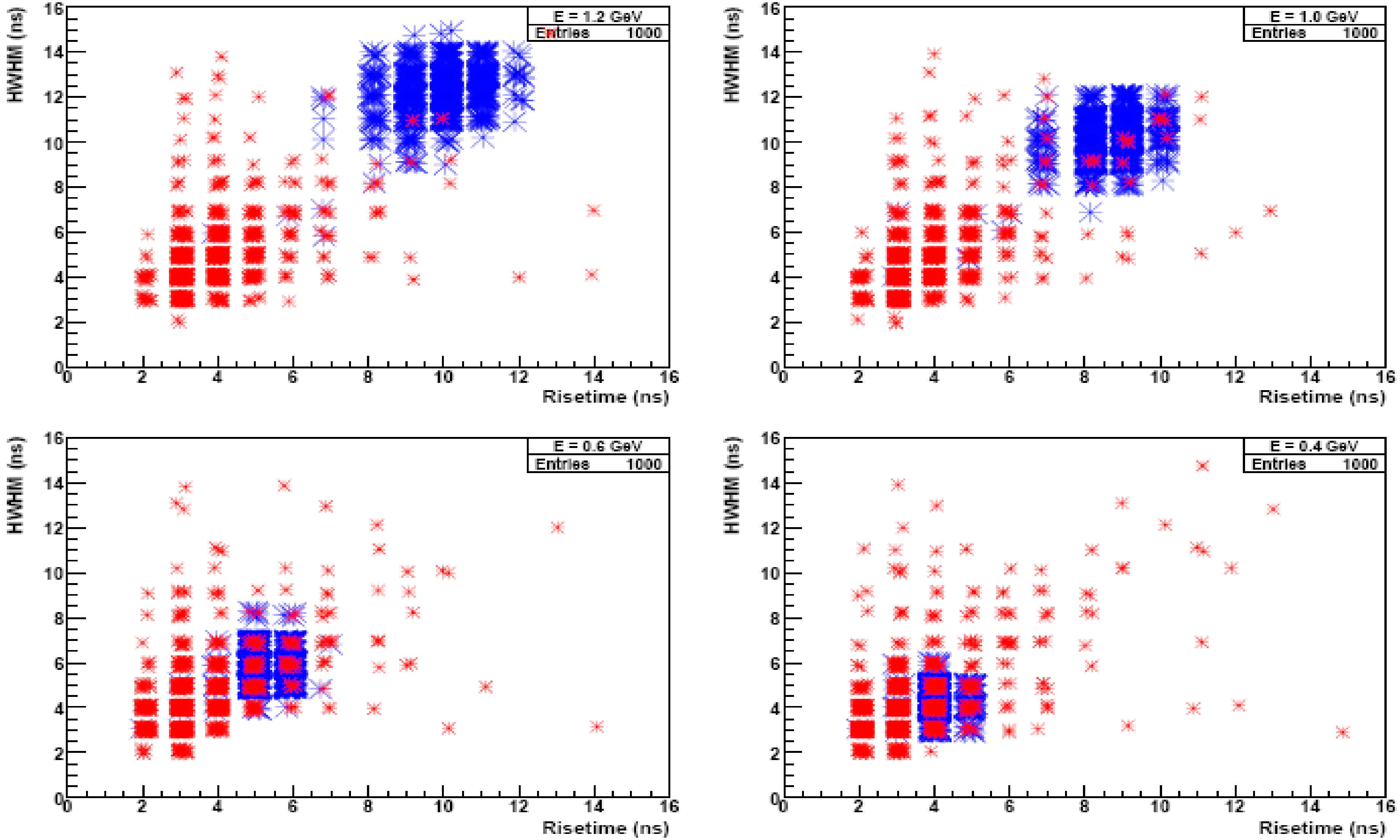


Figure 10.3: Scatter plots for electrons (red) and muons (blue) with energies of 1.2 GeV, 1.0 GeV, 0.6 GeV and 0.4 GeV, respectively. On the x axis the risetime of the pulses is plotted and on the y the half width at half maximum (HWHM). At higher energies (> 1 GeV), a pulse shape analysis gives good muon-electron separation.

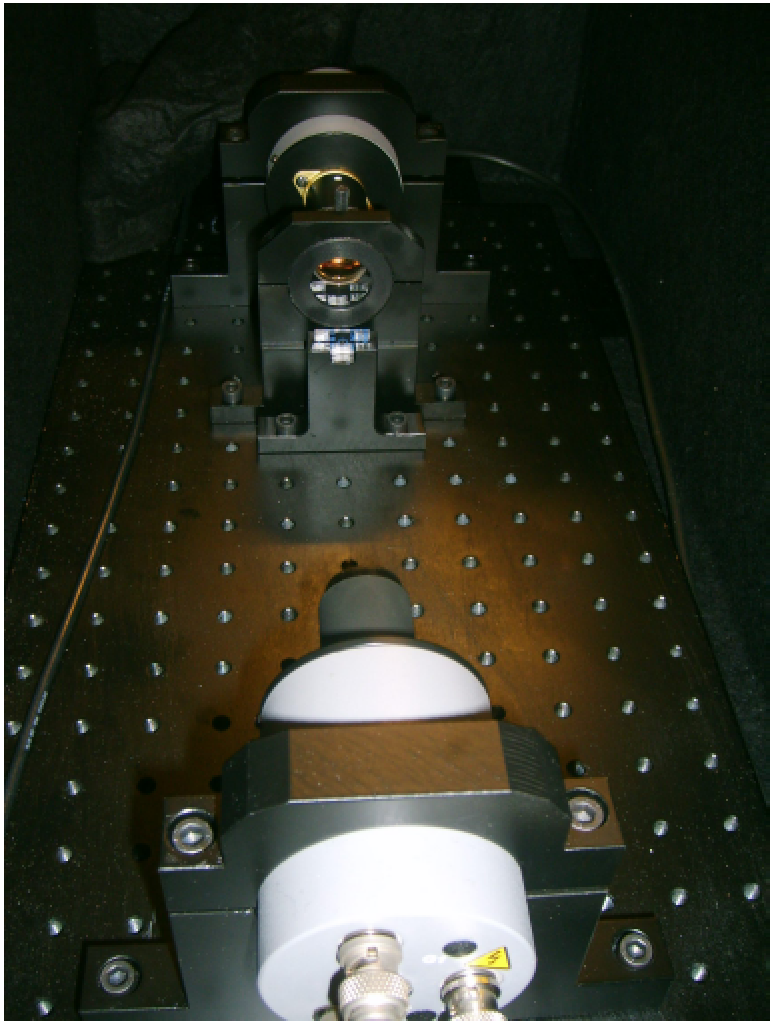
Dark Matter search

- Light Wimp mass between 10 and 100 MeV
- Annihilation under neutrino emission in the Sun
- Monoenergetic electron-antineutrino detection in LENA

S. Palomares-Ruiz, S. Pascoli, Phys. Rev. D 77, 025025 (2008)

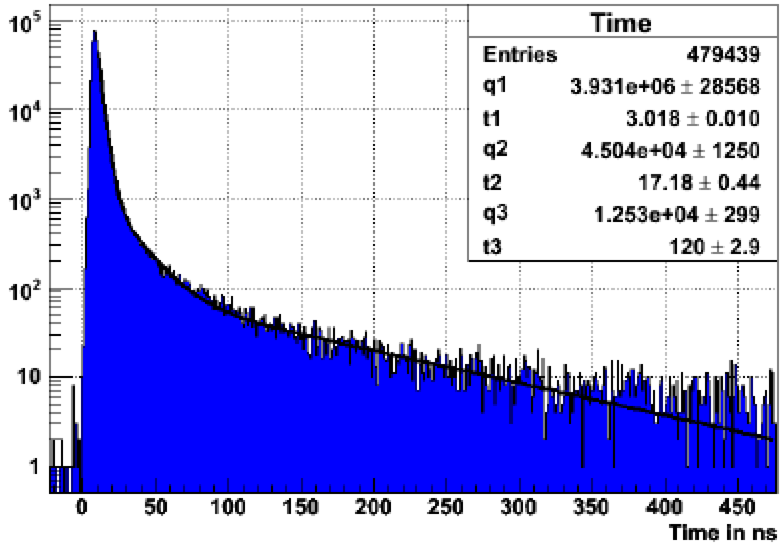
Technology studies for

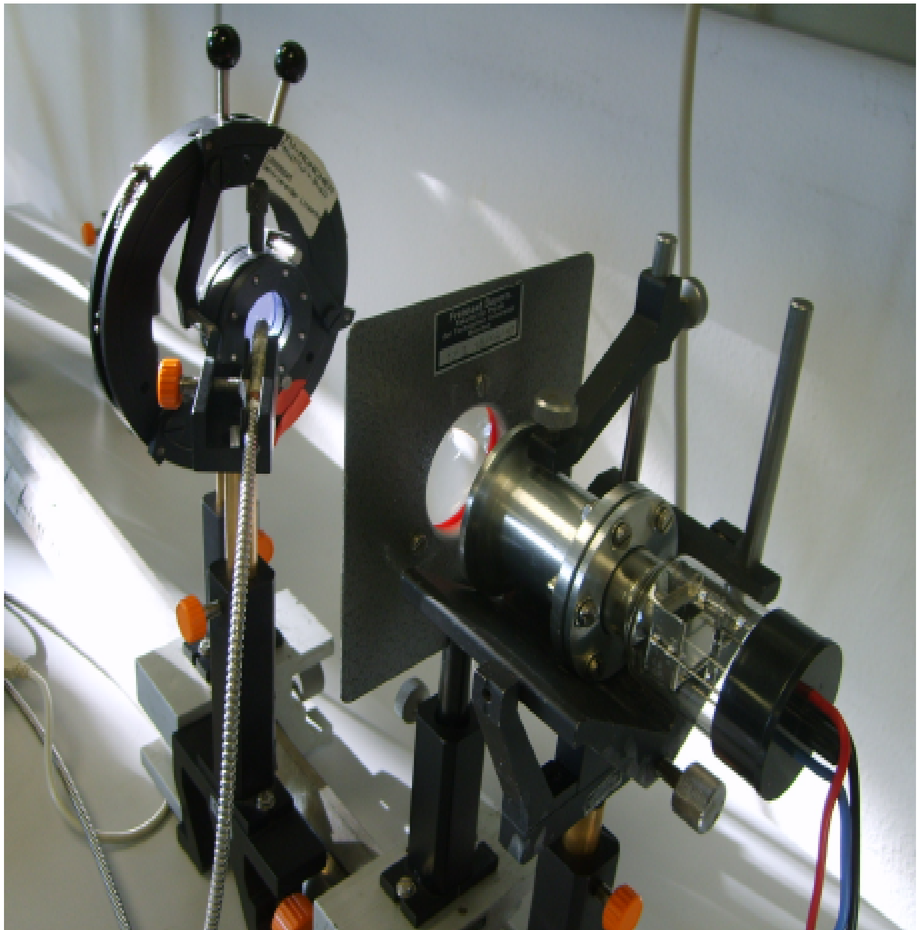
LENA



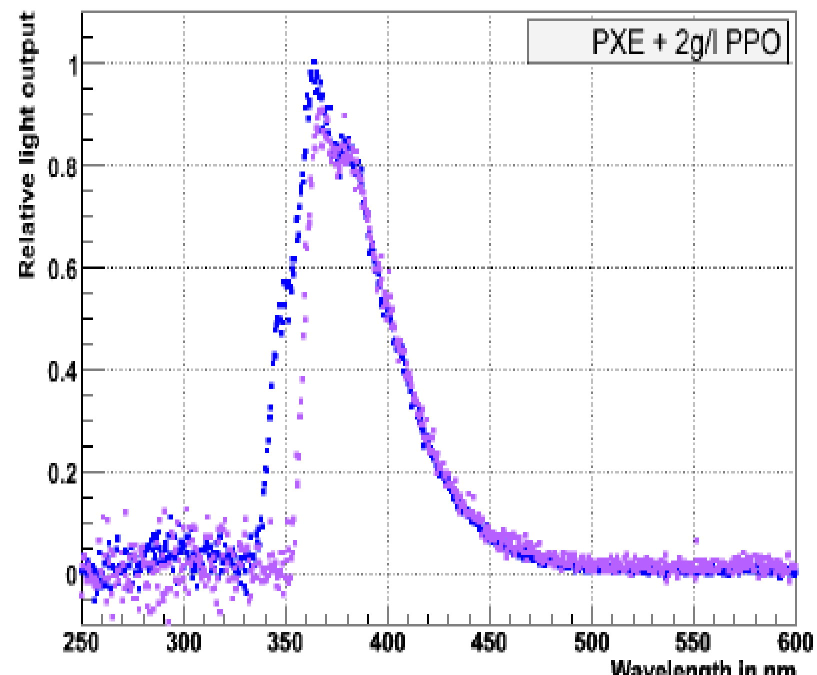
Fluorescence decay constants:

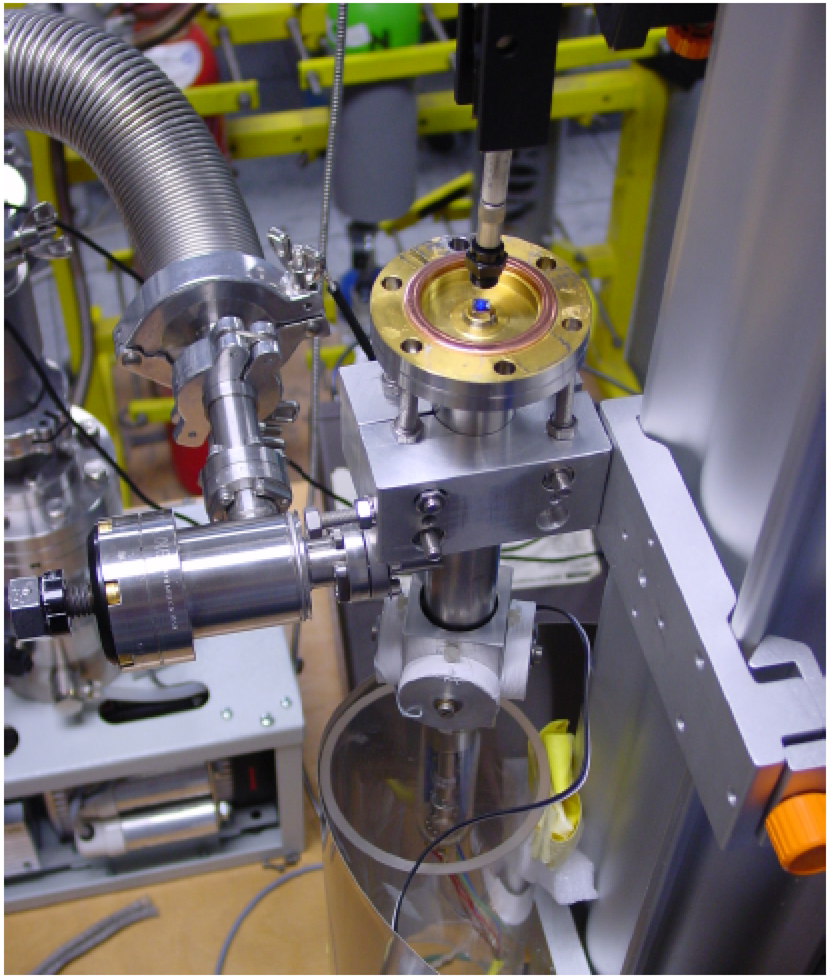
- Single photon counting method
- Exponential time constants
  - Dependence on solvent (PXE/LAB/Dodecan)
  - Dependence on wavelength shifter type and concentration (PPO/bisMSB/PMP)



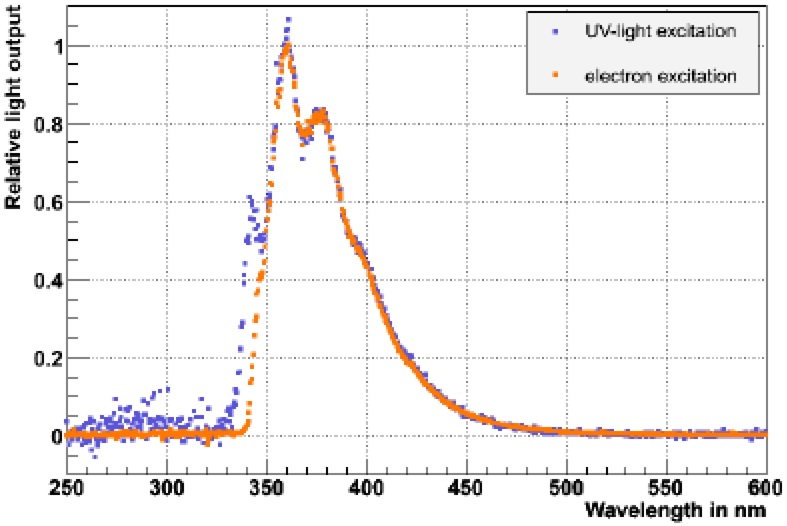


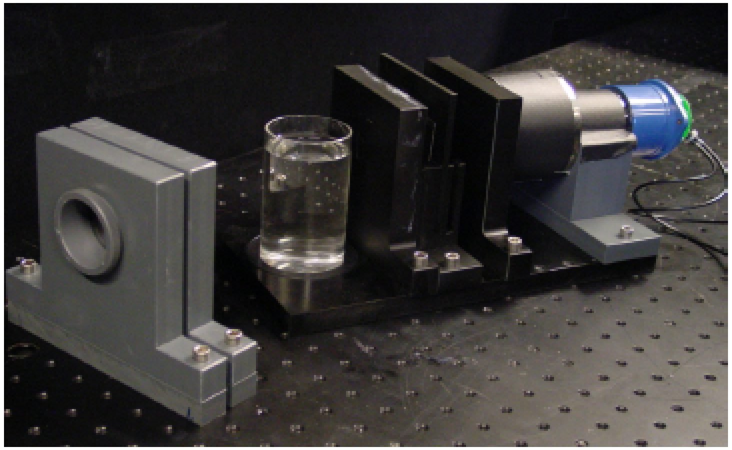
- UV-radiation: Deuterium lamp
- Spectroscopy of the emitted light



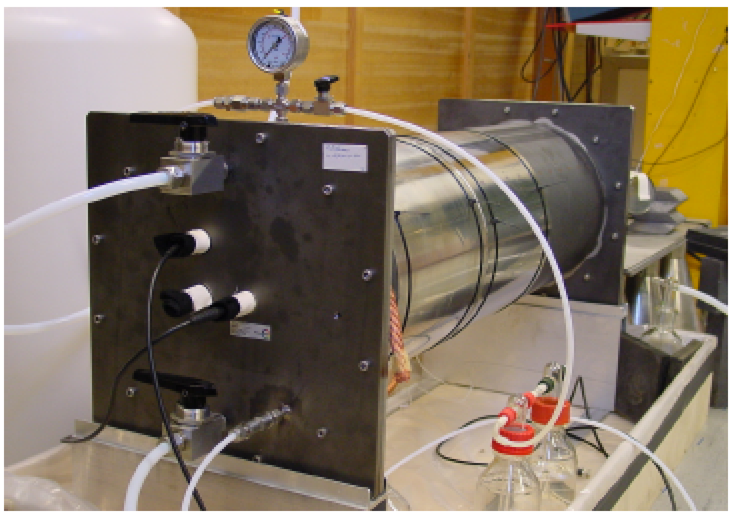


- $\sim$10 keV electron beam
- Evacuated small accelerator (10-15 kV)
- Window for the electrons: thin (300 nm) silicon nitrate membrane





- Scattering length $\lambda_s \sim 20\,\mathrm{m}$
  - Angle dependence of the scattered light
  - Study of polarized and unpolarized light



- Attenuation length $\lambda \gtrsim 10\,\mathrm{m}$
  - Effects of absorption and scattering in the propagation

$$\frac{1}{\lambda} = \frac{1}{\lambda_s} + \frac{1}{\lambda_a}$$

Preliminary result

$\Rightarrow$Absorption length > 20 m

Scattering length ~ 20 m (@ 430 nm)

Results optical properties

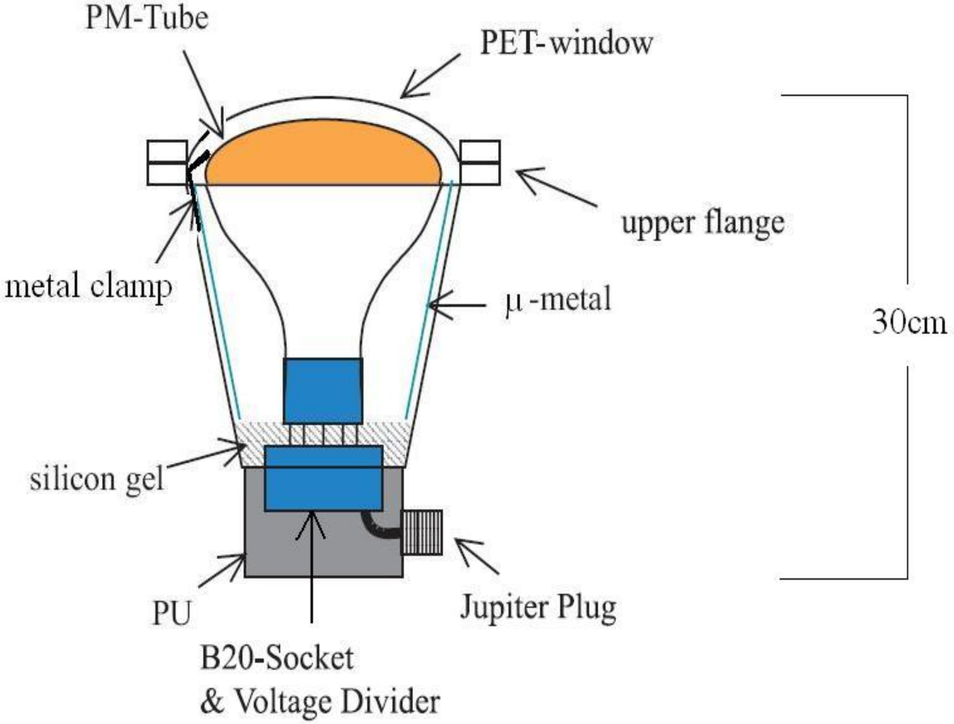
- PXE, LAB as candidates for the solvent
- C14, Dodecane as additives
- PPO, PMP, bis-MSB as wavelengthshifters
- **L ~ 180 pe/MeV**

  λ_{abs} > 20 m, λ_{sca} ~ 20 m

  τ_{sci} ~ 3 nsec (PXE)
- Suitable for LENA => Towards a full optical model for LENA

Teresa Marrodan, Michael Wurm, Patrick Pfahler, Jürgen Winter, Andreas Ulrich

PM encapsulation

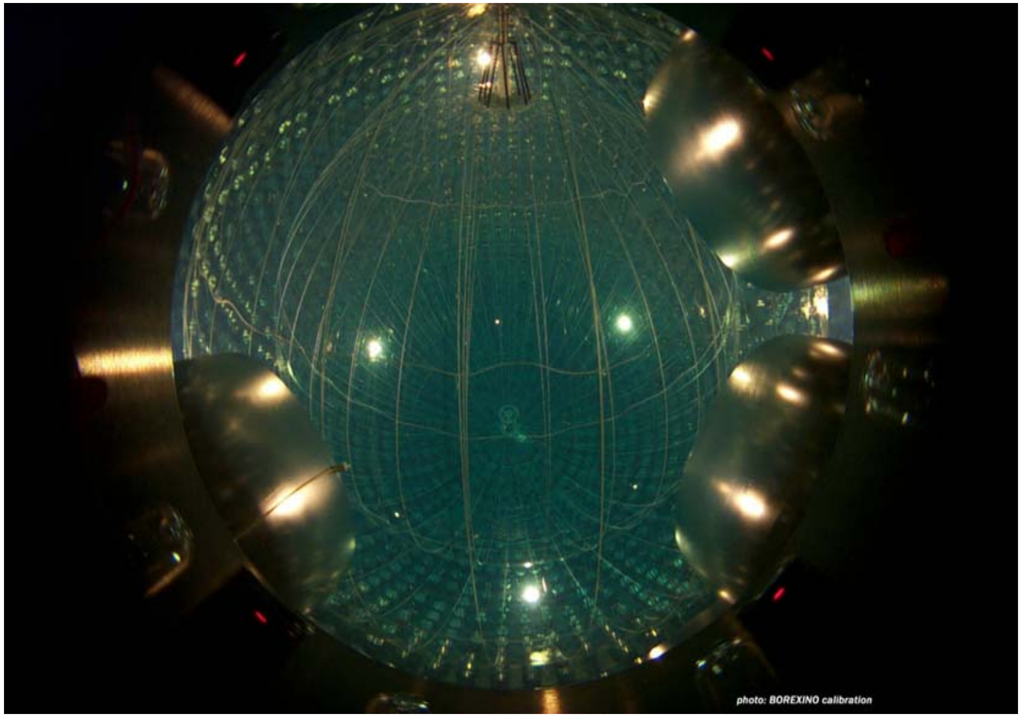


Designed at TUM

Under successful operation in Borexino

Similar design for GERDA, DOUBLE-CHOOZ (Vetos)

Light Cones



Designed and realized at TUM for

BOREXINO

Light enhancement ~ 2.5

Costs ~ 125 Euro / channel

Underground Lab at TUM

High sensitivity gamma spectroscopy

Neutron activation analysis at FRM II (close by)

•Low Background Technology for

BOREXINO,

CRESST,

DOUBLE-CHOOZ, LENA

Martin Hofmann, Niels Haag

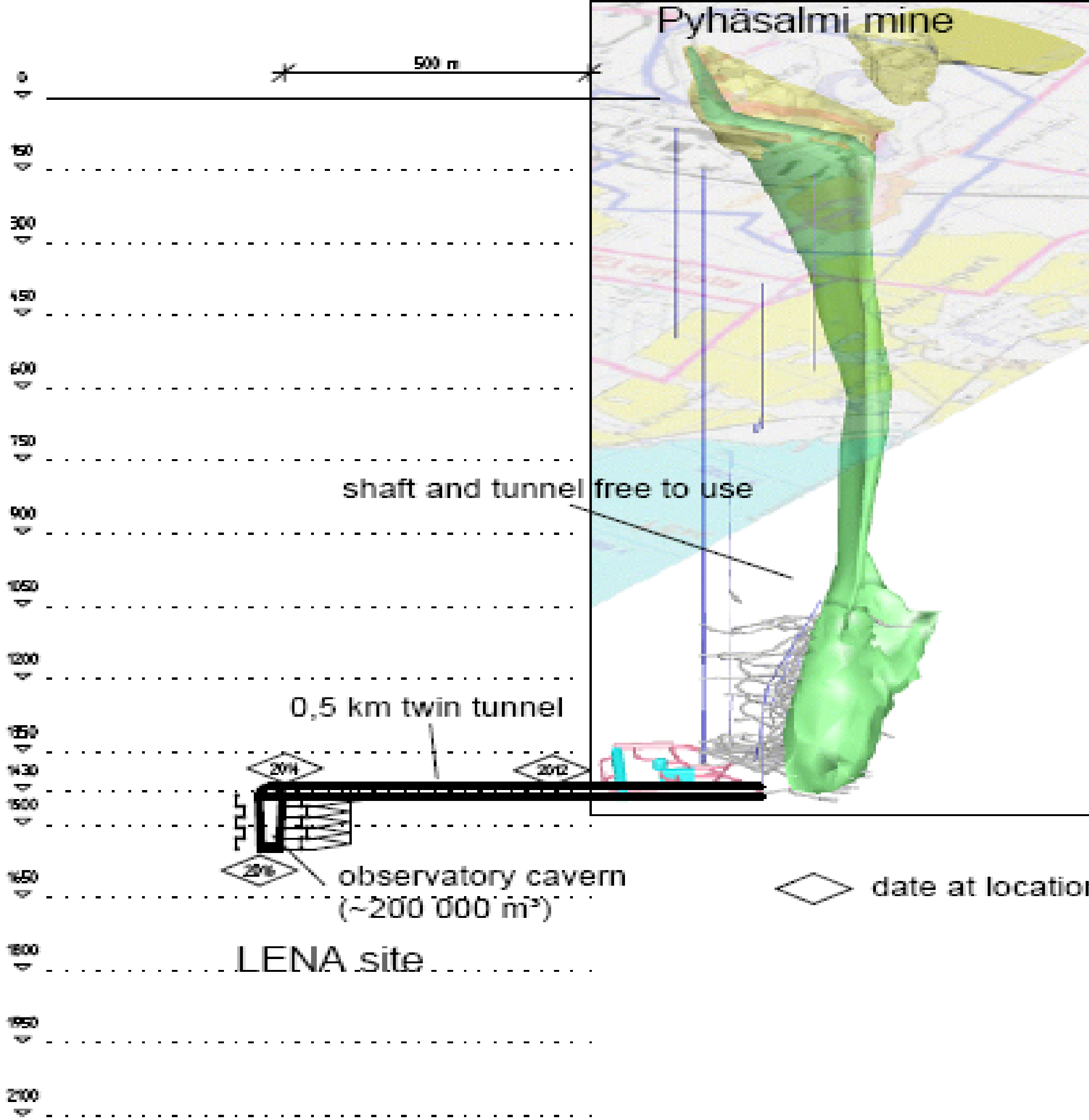
Pre-feasibility study for LENA at Pyhäsalmi

- Contract with Rockplan, Finland
- Depth at 1400 m – 1500 m possible
- Vertical position
- Logistics (Vent, Electricity, etc.)
- Construction time of cavern ~ 4 years
- Construction time of tank plus instrumentation ~ 4 years

Cost Overview

Excavation, reinforcements	47 M€
Infrastructure	28 M€
Detector construction	37 M€
Liquids, PMTs	185 M€
Design, consulting	30 M€
Reservations, uncertainty	82 M€
Sum	409 M€

One Option:



Schedule (excavation works):
- start 2012 earliest
- duration 4 years
- finish in 2016

+ Tank Construction: 8 years

Conclusions

- LENA has a high discovery potential
- Scintillator optical properties within specification

  Suitable candidates: LAB, PXE

  Various wavelength-shifters
- Pre-feasibility study for LENA at Pyhäsalmi completed (Rockplan)

LENA related papers

M. Wurm et al., Phys.Rev.D 75 (2007) 023007

K. Hochmuth et al., Astropart.Phys. 27 (2007) 21-29

T. Marrodan et al., Phys. Rev. D 72 (2005) 075014

S.T. Petcov, T. Schwetz, Phys. Lett. B 642, (2006), 487

J. Kopp et al., JHEP 01 (2007), 053

S. Palomares-Ruiz, S. Pascoli, Phys. Rev. D 77, 025025 (2008)