The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2047-10

Workshop Towards Neutrino Technologies

13 - 17 July 2009

Prospects and status of LENA

Lothar OBERAUER

Technical University of Munich
Department of Physics
James-Franck-Strasse, 1
D-85747 Garching, GERMANY

LENA

Prospects and Status of LENA

(Low Energy Neutrino Astronomy)

Lothar Oberauer, TUM

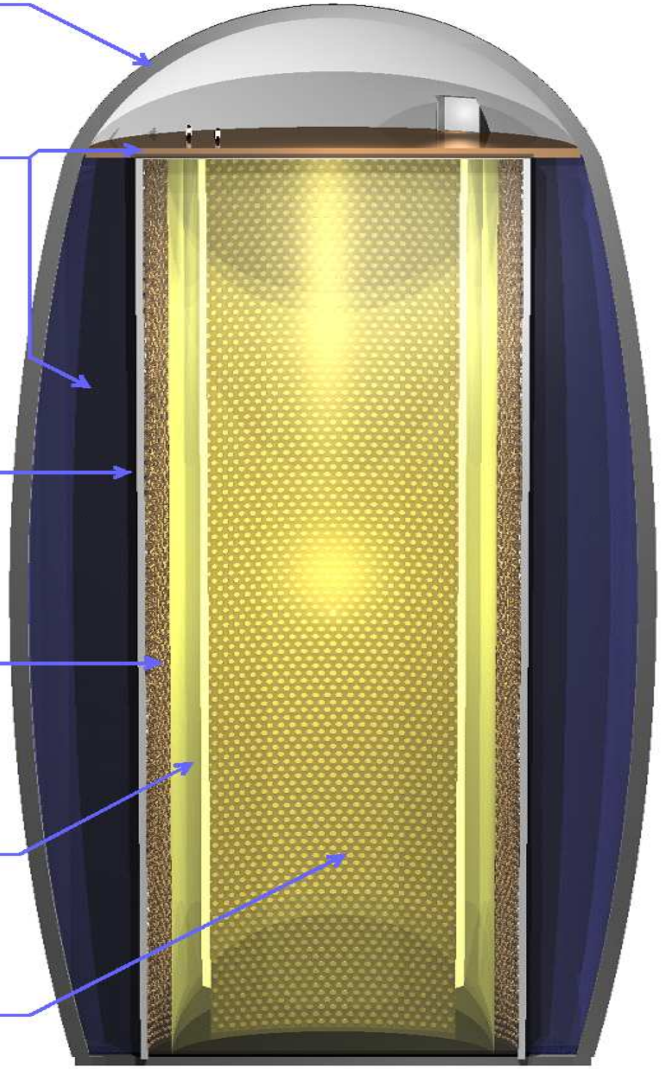
Nutech, Trieste, July 14, 2009

Physics Goals of LENA

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

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

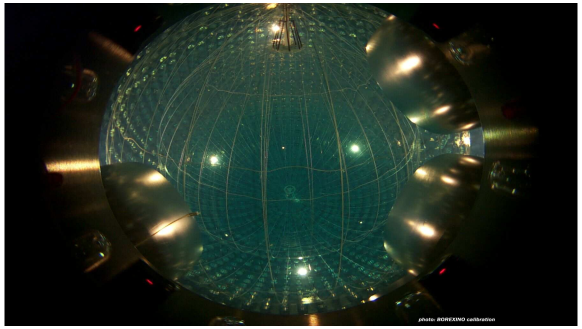
Buffer
thickness: 2 m
non-scintillating organic liquid
shielding external radioactivity

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

Liquid Scintillator Detectors



- Poltergeist; first neutrino detection (inverse beta decay)
- Several neutrino oscillation experiments at low energies (e.g. Gösgen, Bugey, Karmen…)
- LVD, MACRO, BAKSAN
- BOREXINO at Gran Sasso; 300 t active mass
- KamLAND (Japan); 1kt scintillator
- SNO+; 1kt

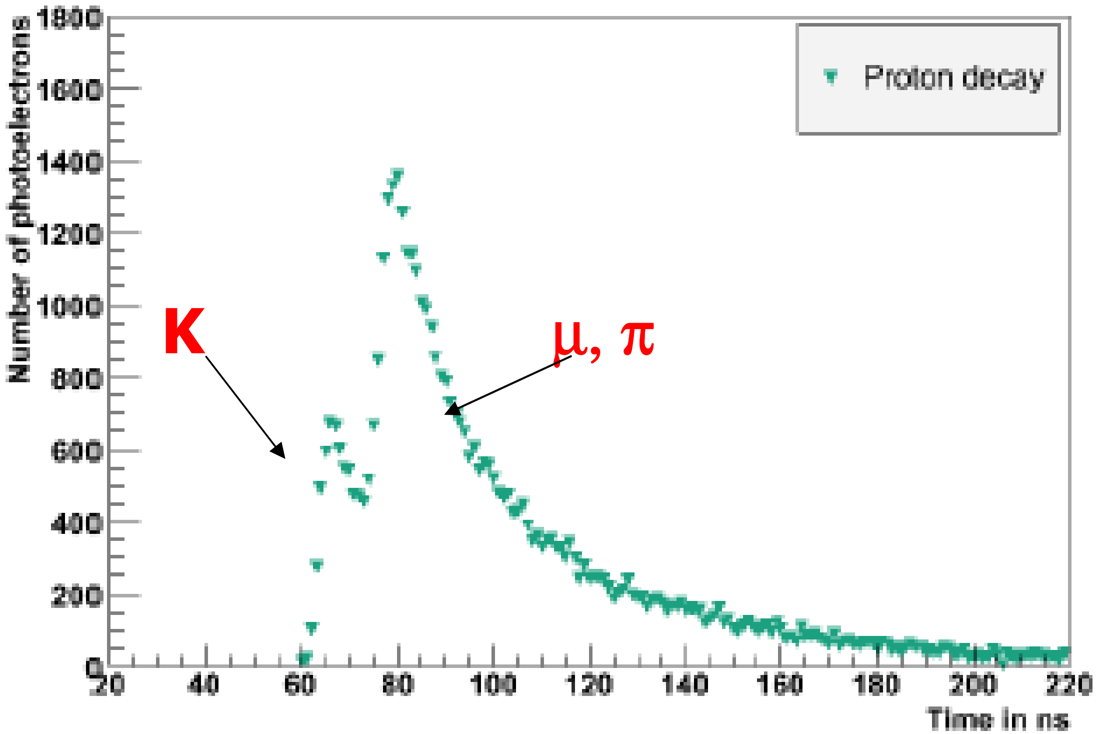
LENA and proton decay

Proton Decay

- Non supersymmetric Grand Unified Theories
  Dominant decay mode: $p \to e^+\pi^0$ $\tau \sim 10^{36}$ y
- Supersymmetry (SUSY)
  Dominant decay mode: $p \to K^+\overline{\nu}$ $\tau \sim 10^{34}$ y
- Superkamiokande current limits:
  $\tau(p \to e^+\pi^0) \gtrsim 5.4 \cdot 10^{33}$ y (90% C.L.)
  $\tau(p \to K^+\overline{\nu}) \gtrsim 2.3 \cdot 10^{33}$ y (90 % C.L.)

LENA and proton decay

- High efficiency and very good background rejection for p –> K^+ ν



K and μ, π from successive K decay

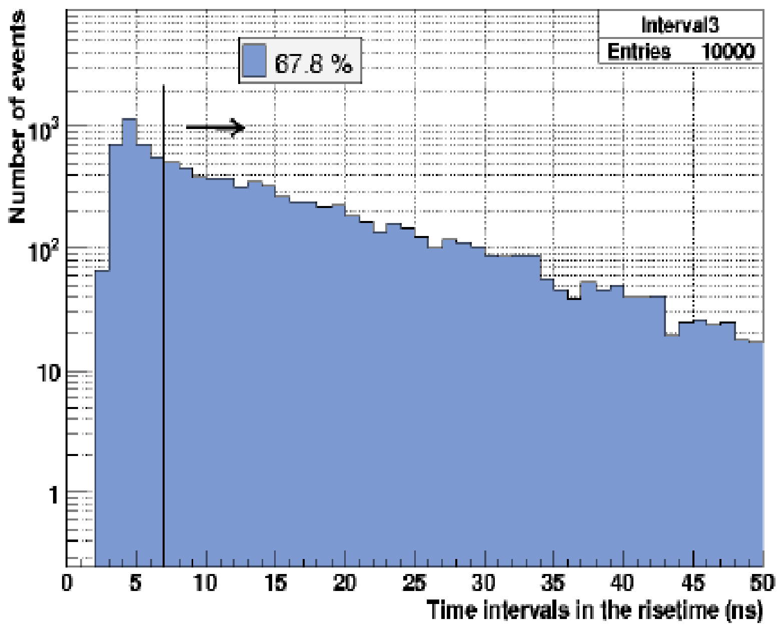
K -> μ ν (68 %)

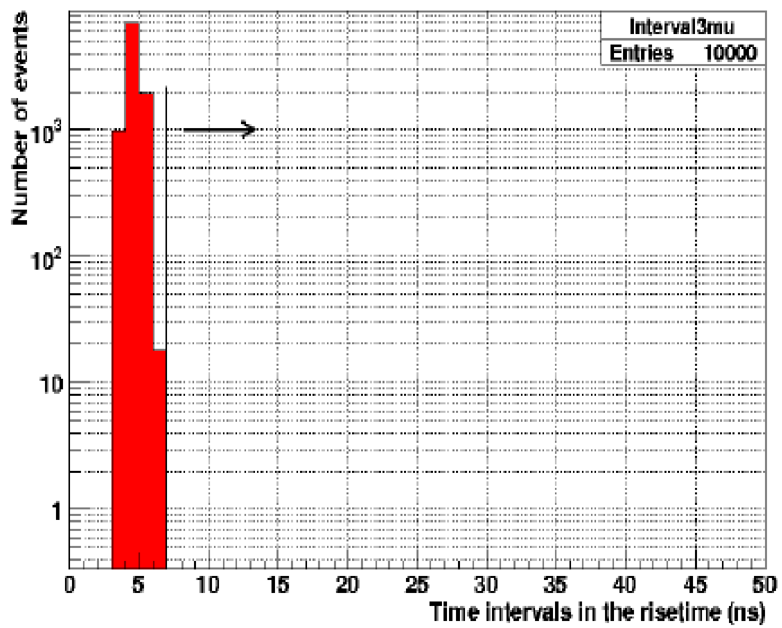
K -> 3 π (31 %)

(12 nsec)

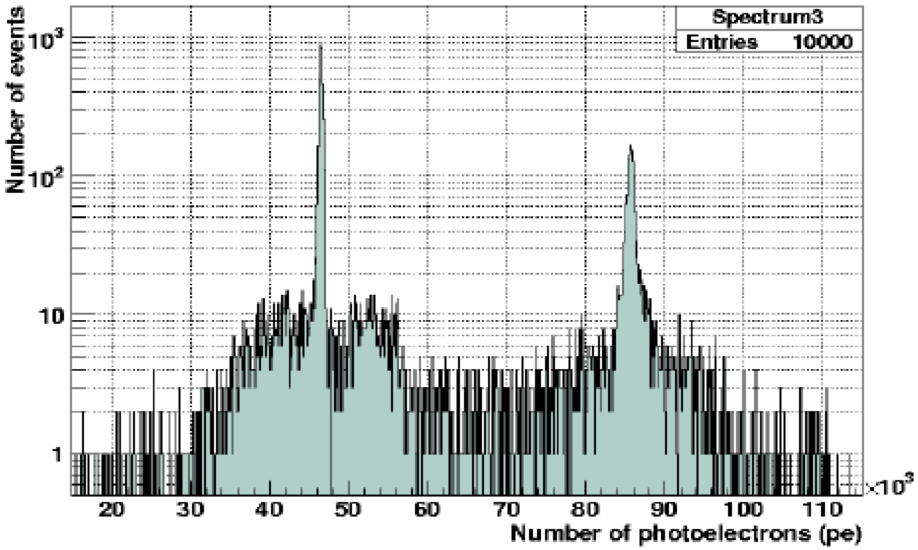
Background rejection

- Proton decay efficiency: 68%
- Background rejection 10^{-4}





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}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. ~ 68% 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)

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**

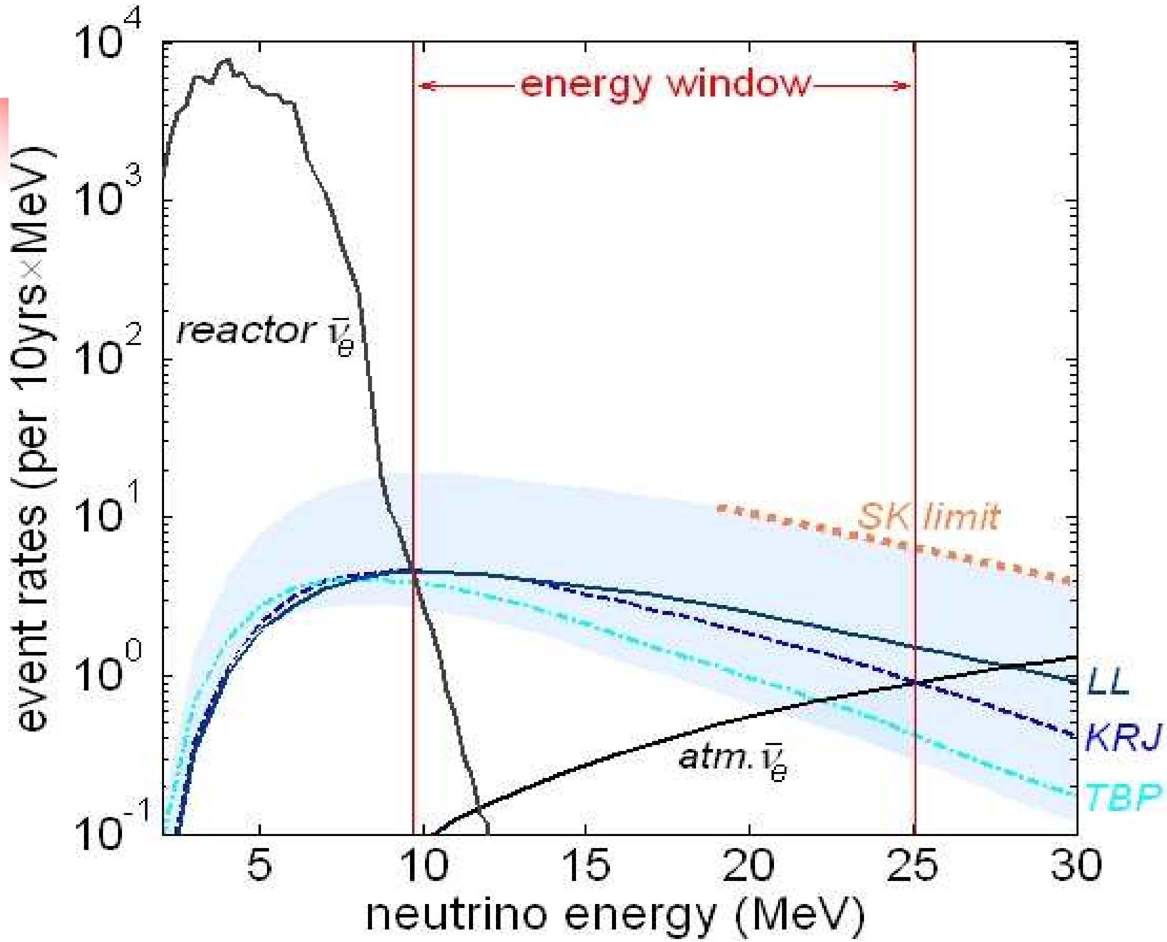
• **$E_\nu \sim E_e$ - Q (ν *spectroscopy*)**

• **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

LL:	110
KRJ:	100
TBP:	60

dependent on SNR

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

background events < 1 y^{-1}

Diffuse Supernova Neutrino Background Detection

- Excellent background rejection
- Energy window 10 to 30 MeV.
- High efficiency (100% with 50 kt target)
- High discovery potential in LENA

  ~2 to 20 events per year are expected (model dependent)

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: ~15000 events

Possible reactions in liquid scintillator

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

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

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

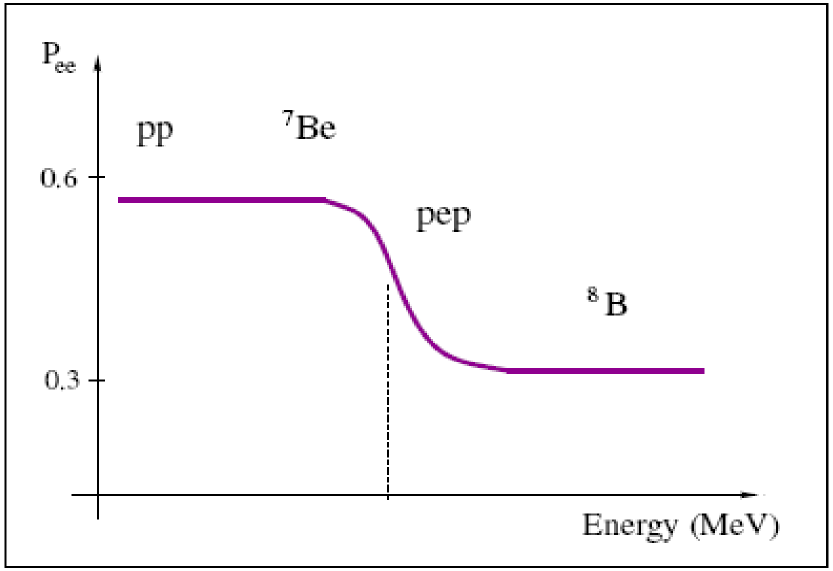
Supernova neutrinos with LENA

- Antielectron ν spectrum with high precision
- Electron ν flux with ~ 10 % 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)
- Coincidence with gravitational wave detectors

Solar Neutrino Detection in LENA

Solar Neutrinos and LENA

$\nu + e \rightarrow \nu + e$ and $^{13}C + \nu_e \rightarrow {}^{13}N + e$



Spectrum deformation due to the MSW effect

Rates of solar neutrino events

In the LENA fiducial volume:

$$18 \cdot 10^3 \ m^3$$

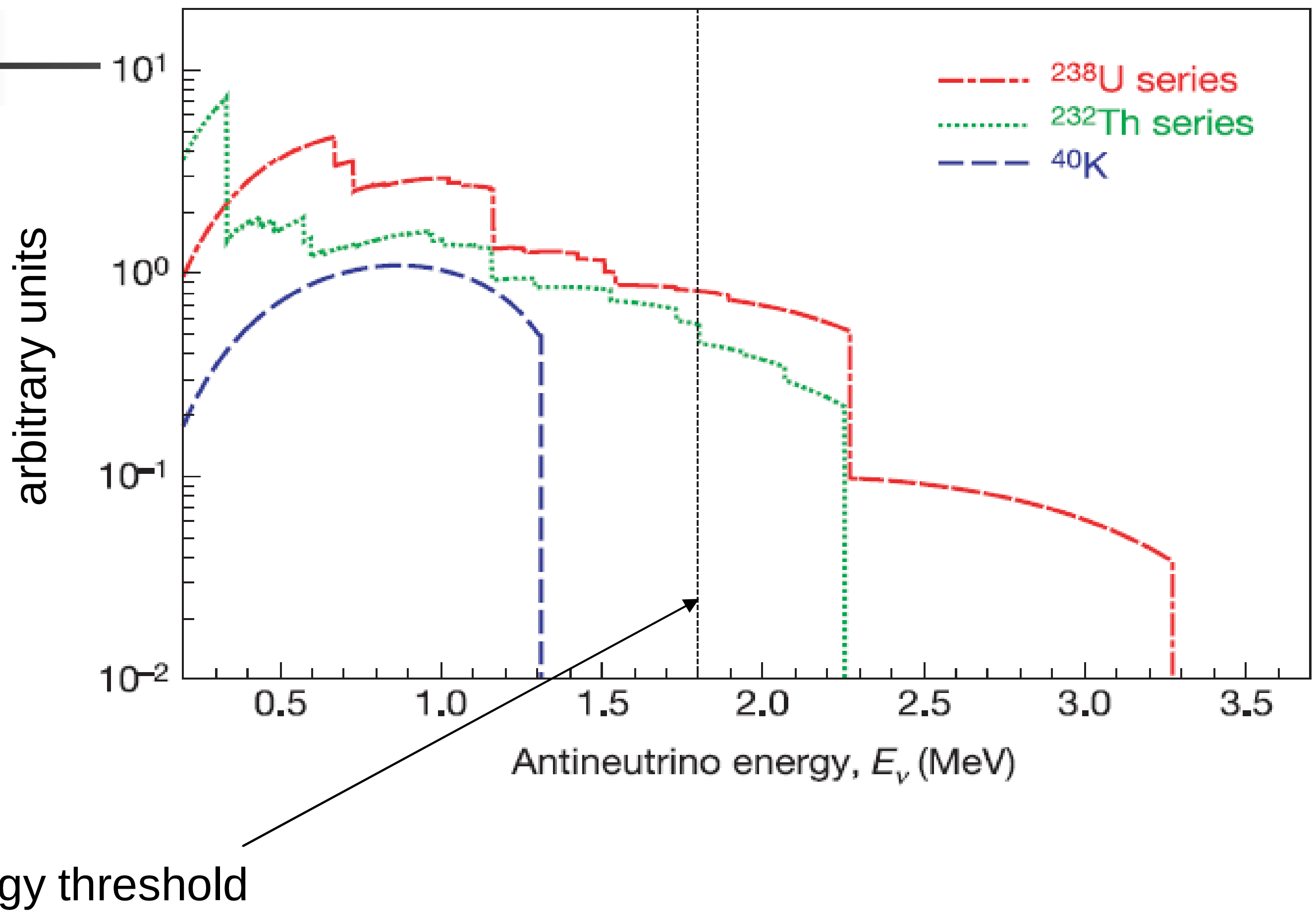
- ^{7}Be ν's: $\sim 5400 \ d^{-1}$
  - Small time fluctuations
- pep ν's: $\sim 150 \ d^{-1}$
  - Information about the pp-flux $\rightarrow$ Solar luminosity in ν's
- CNO ν's: $\sim 210 \ d^{-1}$
  - Important for heavy stars
- ^{8}B ν's: CC on ^{13}C: $\sim 360 \ y^{-1}$

Solar Neutrinos and LENA

- High statistics in 7-Be
- Search for time fluctuations
- CNO and pep ν
- Test of MSW effect
- CC and NC measurements of 8-B
- Search for spectrum deformation
- Search for non-standard ν interactions
- Search for solar $\nu_e \rightarrow \bar{\nu}_e$ transitions

LENA and neutrinos from the Earth

Sensitivity on U, Th



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

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

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

(not covered in this talk...)

-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:
- $\Delta \mathbf{m^2_{12}} \sim 1\%$
- $\Theta_{12} \sim 10\%$

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

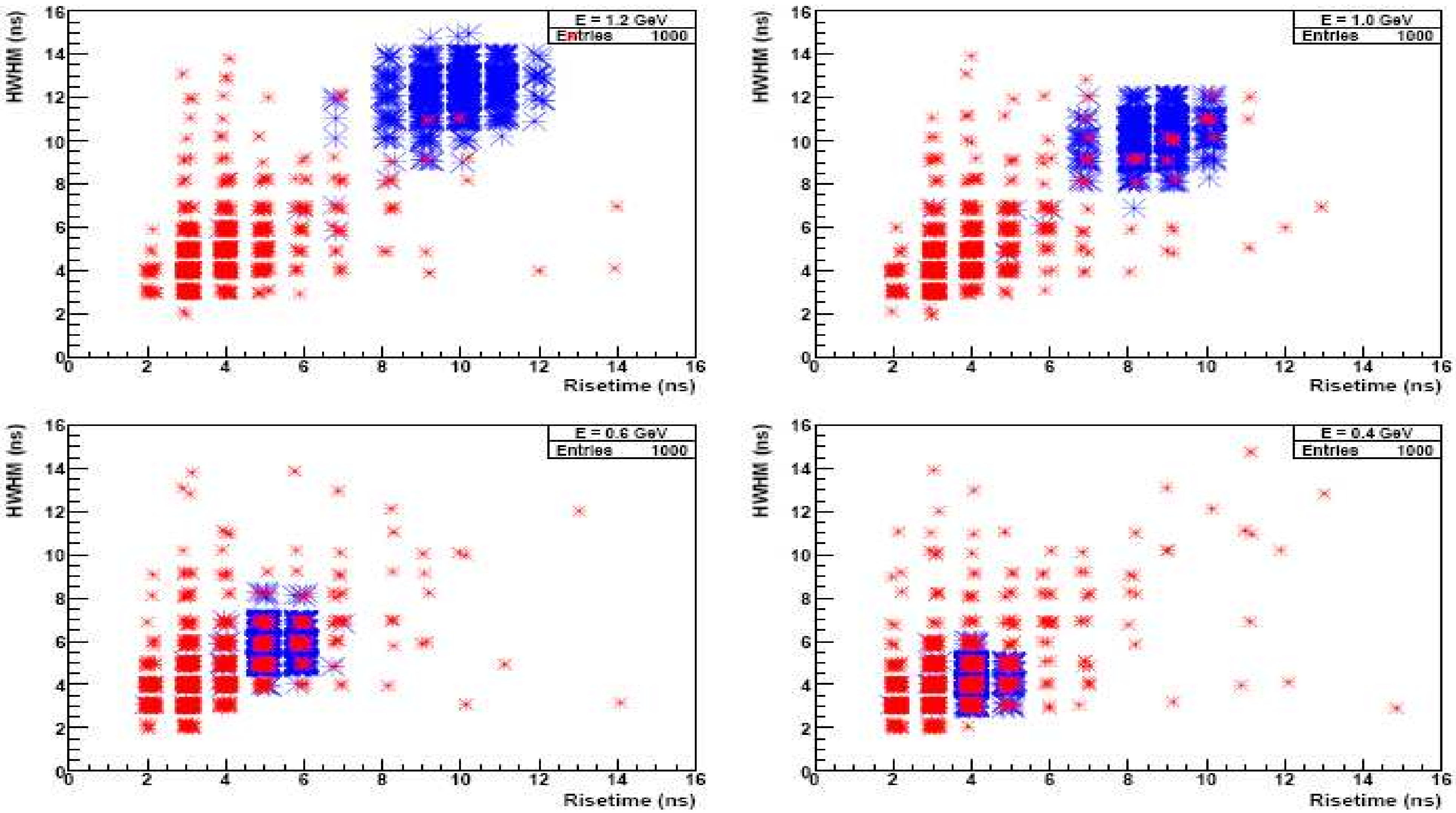


Figure 10.3: Scatter plots for electrons (red) and muons (blue) with energies of 1.2 GeV, 1.0 GeV, 0.6 GeV and 0.4 GeV, respectively. On the x axis the risetime of the pulses is plotted and on the y the half width at half maximum (HWHM). At higher energies (> 1 GeV), a pulse shape analysis gives good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

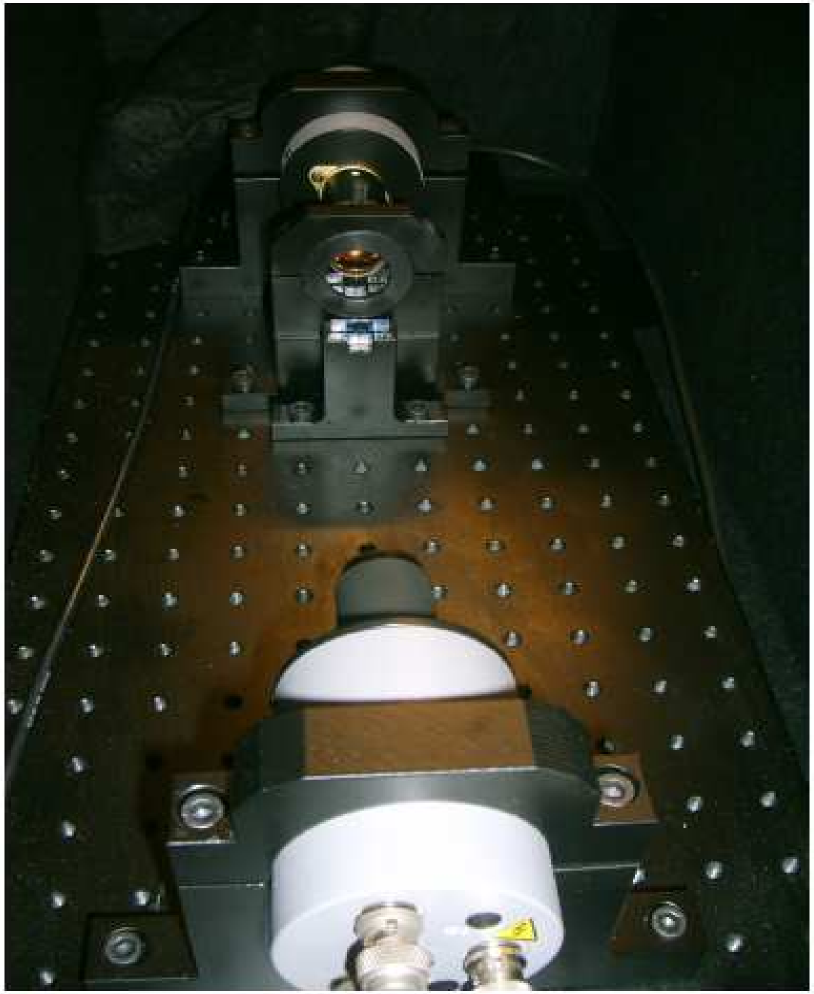
S. Palomares-Ruiz, S. Pascoli, Phys. Rev. D 77, 025025 (2008)

Technology studies for LENA

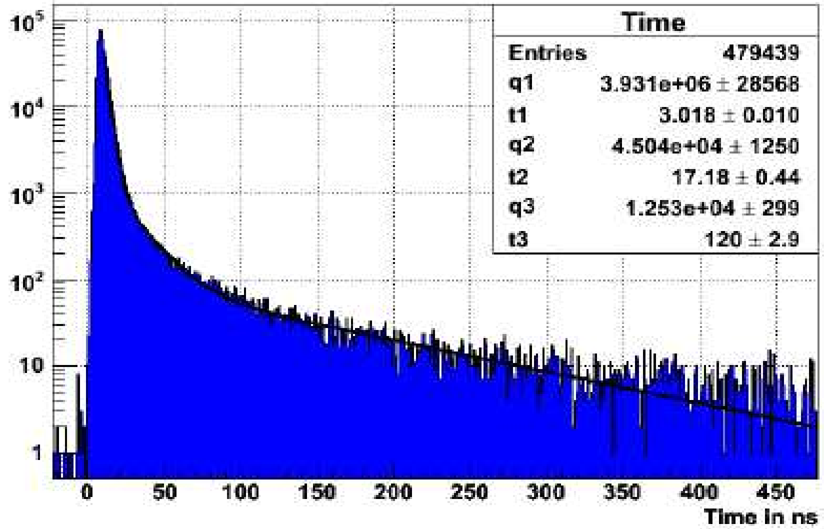
Liquid Scintillator Technology

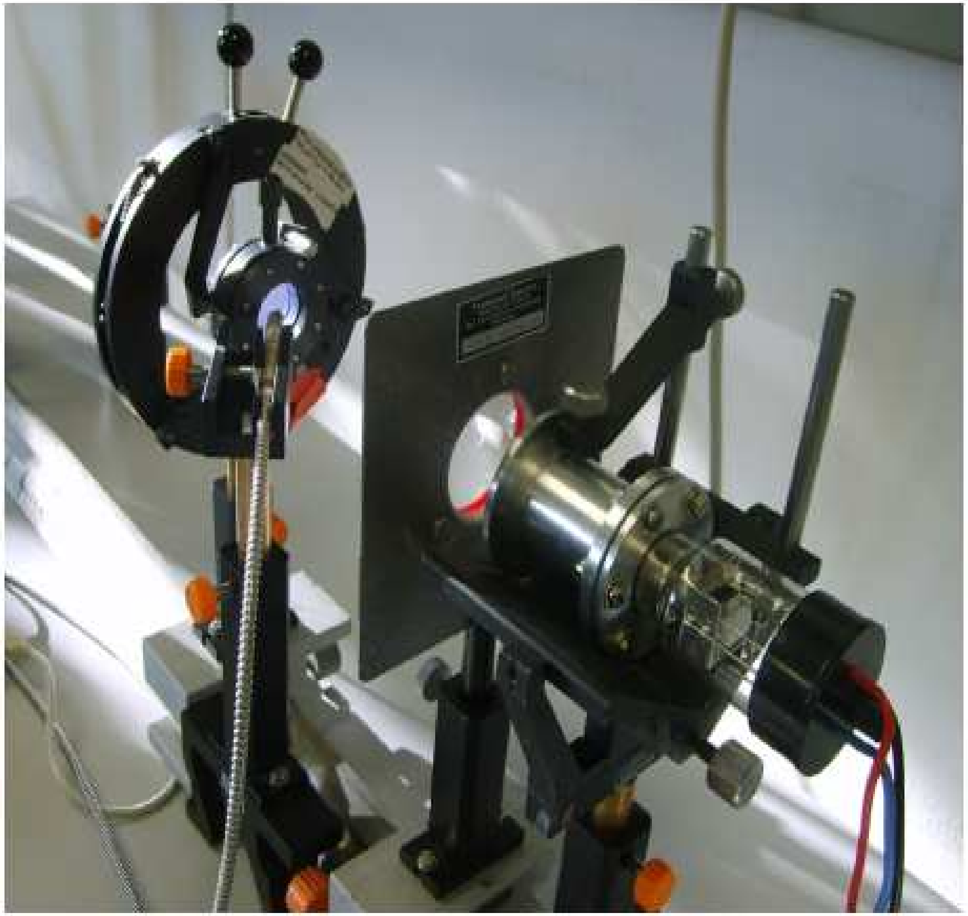
- High light output
- Low energy threshold (sub MeV)
- Good energy, timing, and position resolution
- Variety of neutrino detection channels
- Inverse beta decay detection basically background free

Fluorescence decay constants:

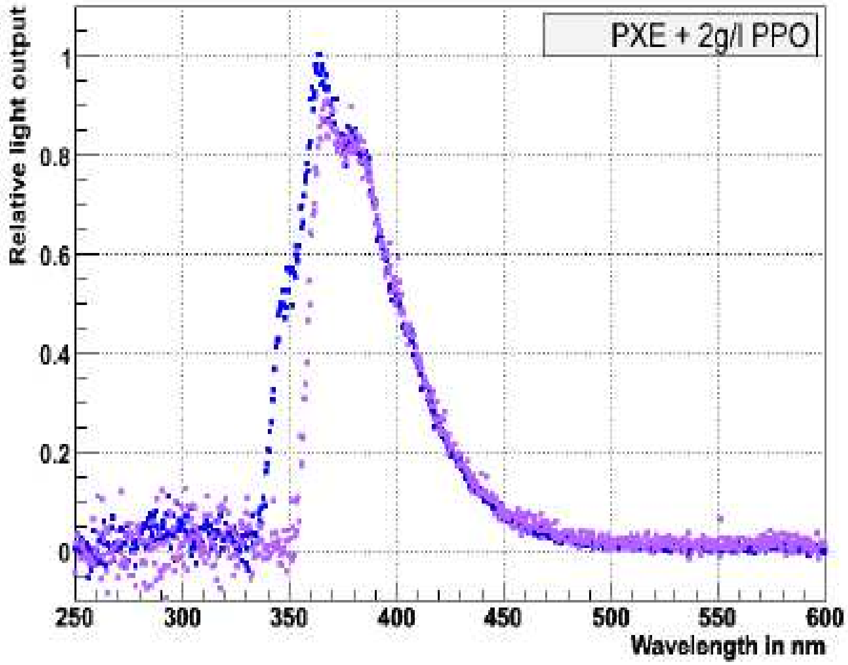


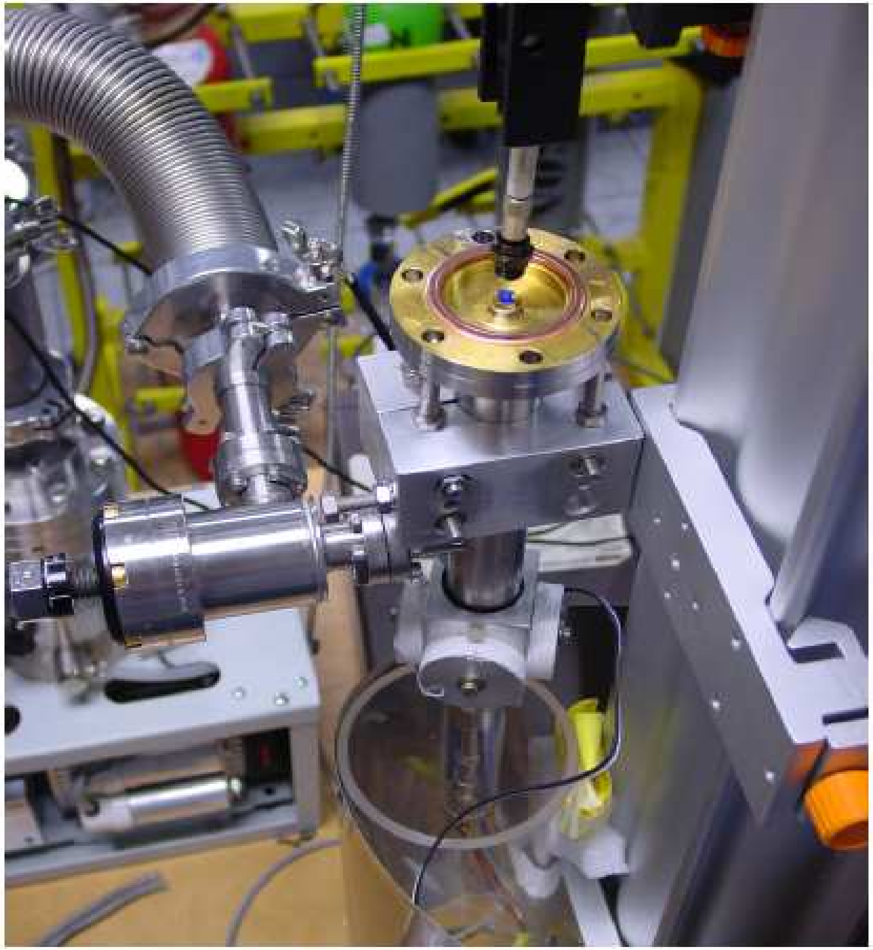
- Single photon counting method
- Exponential time constants
  - Dependence on solvent (PXE/LAB/Dodecan)
  - Dependence on wavelength shifter type and concentration (PPO/bisMSB/PMP)



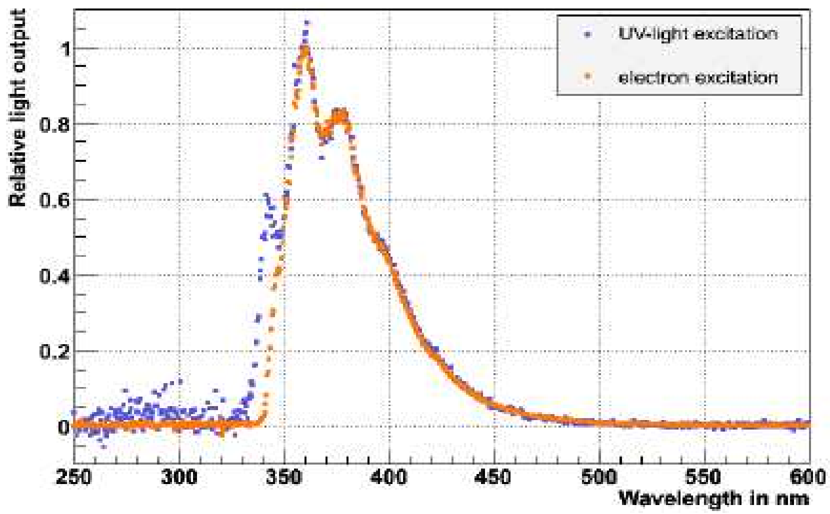


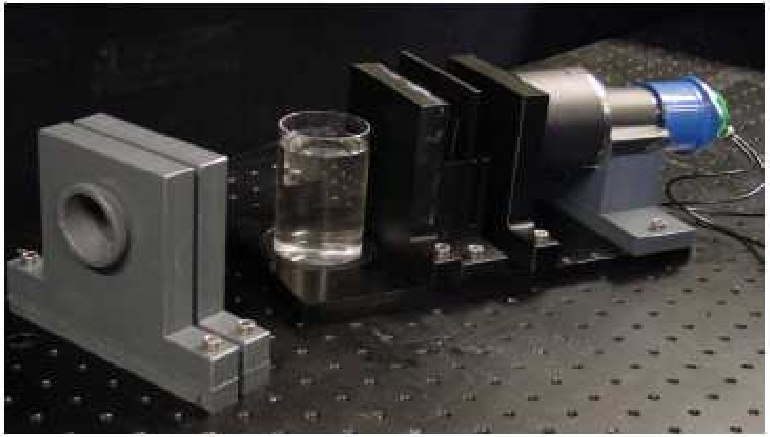
- UV-radiation: Deuterium lamp
- Spectroscopy of the emitted light

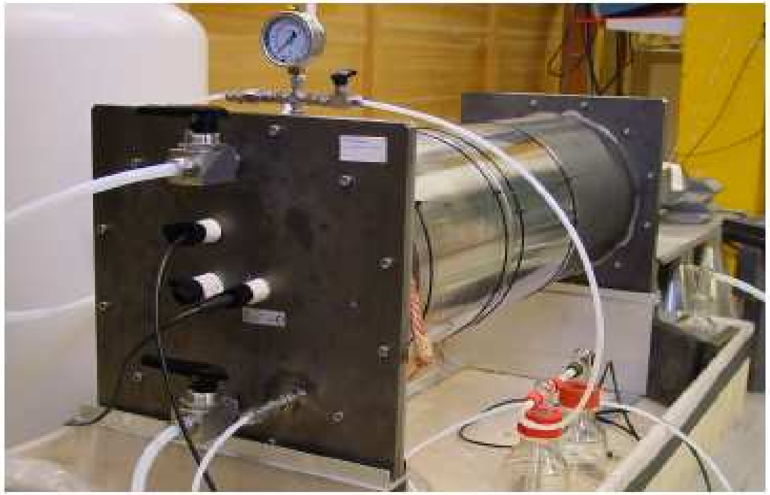




- ~10 keV electron beam
- Evacuated small accelerator (10-15 kV)
- Window for the electrons: thin (300 nm) silicon nitrate membrane







- Scattering length $\lambda_s \sim 20\,\text{m}$
  - Angle dependence of the scattered light
  - Study of polarized and unpolarized light
- Attenuation length $\lambda > 10\,\text{m}$
  - Effects of absorption and scattering in the propagation

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

$\Rightarrow$Absorption length > 20 m

Scattering length ~ 20 m (@ 430 nm)

Results optical properties

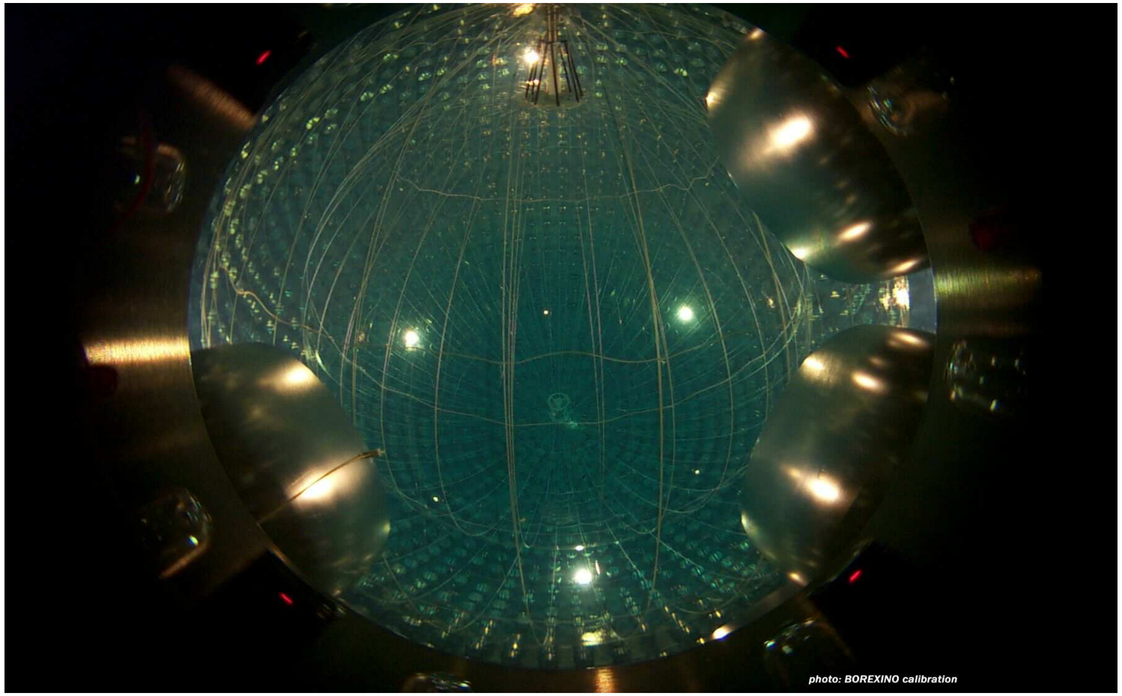
- PXE, LAB as candidates for the solvent
- C14, Dodecane as additives
- PPO, PMP, bis-MSB as wavelengthshifters
- **L ~ 180 pe/MeV**

  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

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

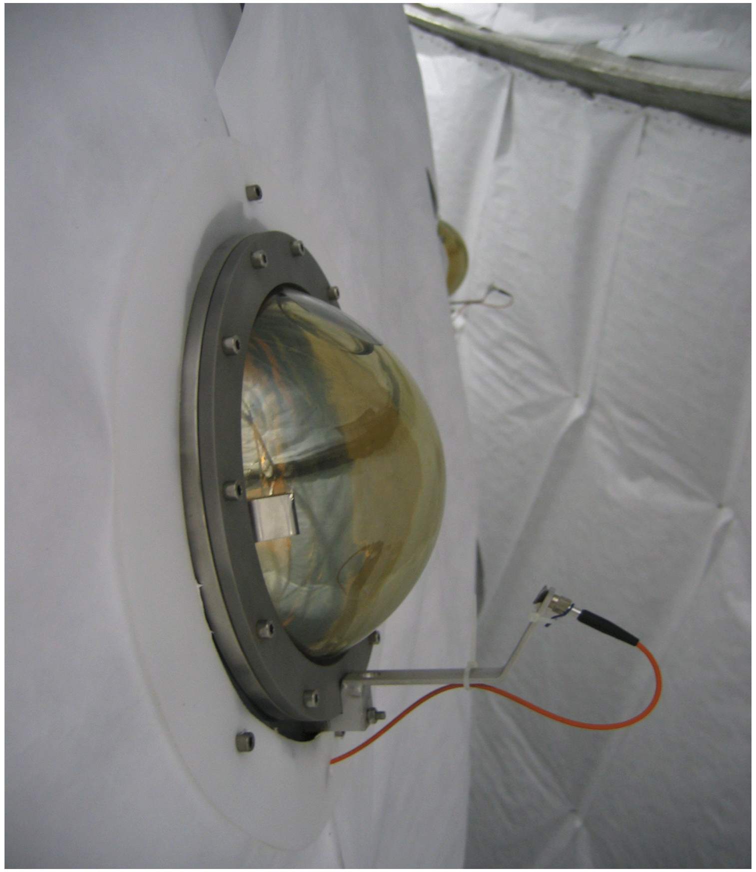
BOREXINO,

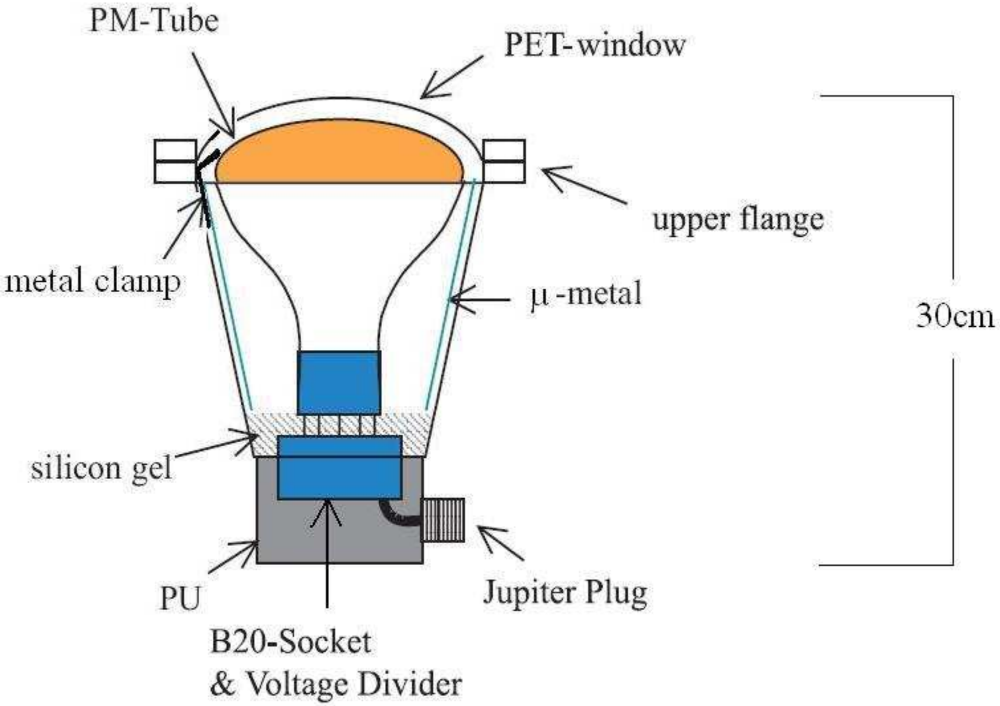
CRESST,

DOUBLE-CHOOZ, LENA

Martin Hofmann, Niels Haag

PM encapsulation





Designed at TUM

Under successful operation in Borexino

Similar design for GERDA, DOUBLE-CHOOZ (Vetos)

Photosensors & Electronics

- PICS (Projet Internationaux de Cooperation Scientific): Collaboration with APC Paris (Memphis)
- Test of high efficient PMs
- Development of HV and read-out electronics
- Cost reduction

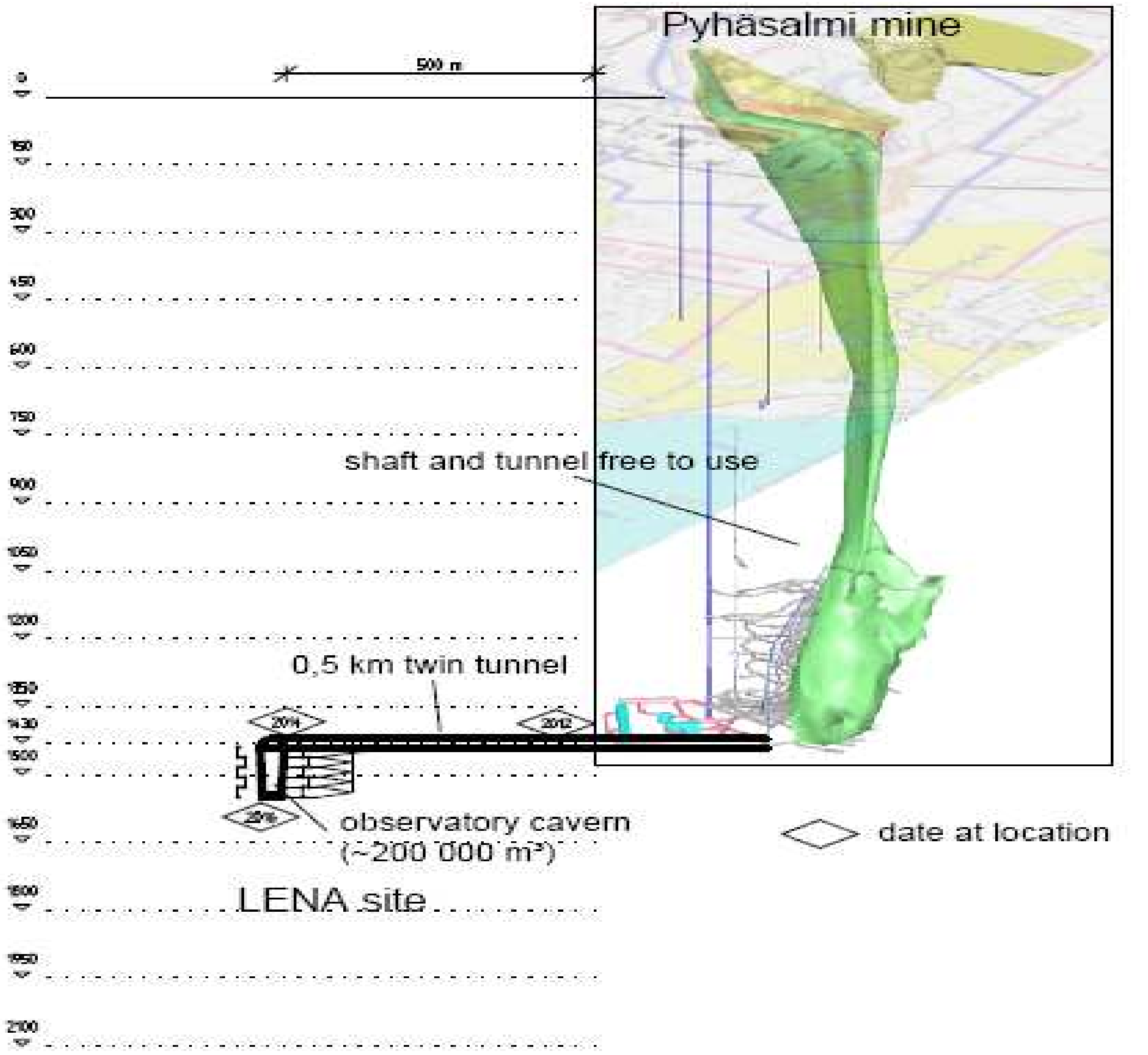
LAGUNA

- Feasibilty studies for European underground sites (Frejus, Boulby, Pyhäsalmi, Canfranc, Sunlab, Slanic)
- LENA, MEMPHIS, GLACIER
- European Funding (FP 7)
- Report in 2010

Pre-feasibility study for LENA at Pyhäsalmi (TUM and company Rockplan, Finland)

- **Depth at 1400 m – 1500 m possible**
- Geological study completed
- Vertical detector position
- Logistics (Vent, Electricity, etc.) considered
- Construction time of cavern ~ 4 years
- 1st costs estimate for the whole project

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 successfully completed (Rockplan)
- Rich R&D program running

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

T. Marrodan et al., Rev. Sci. Instr., (2009)

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

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

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