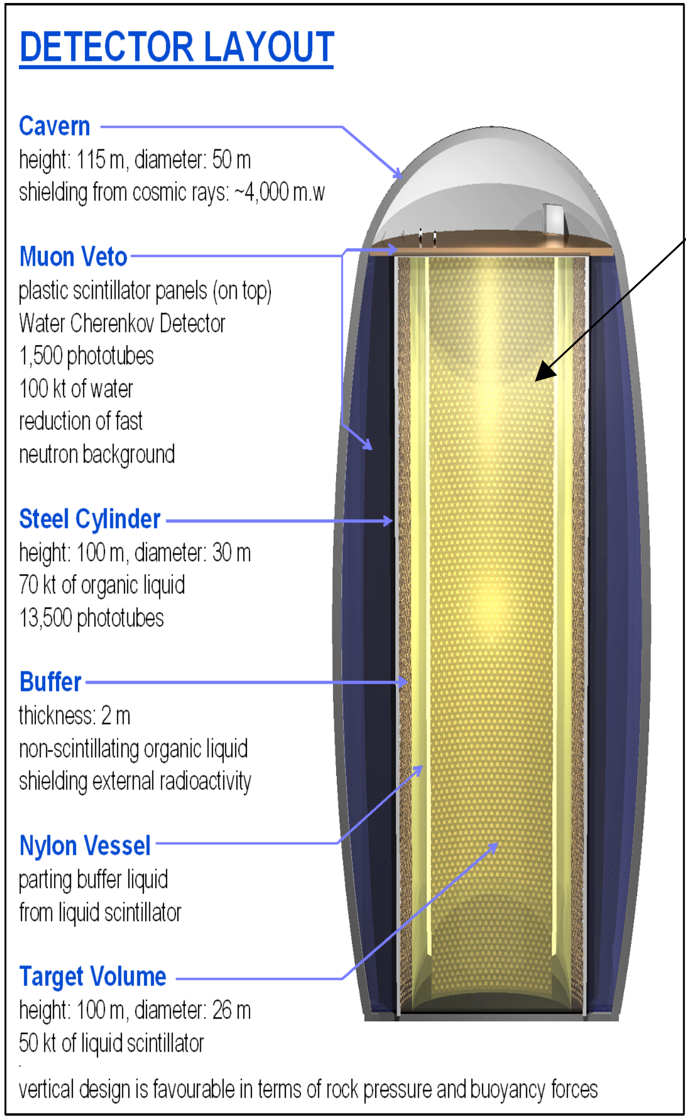
Lena, a new European Neutrino Observatory

Dubna

07.12. 2011

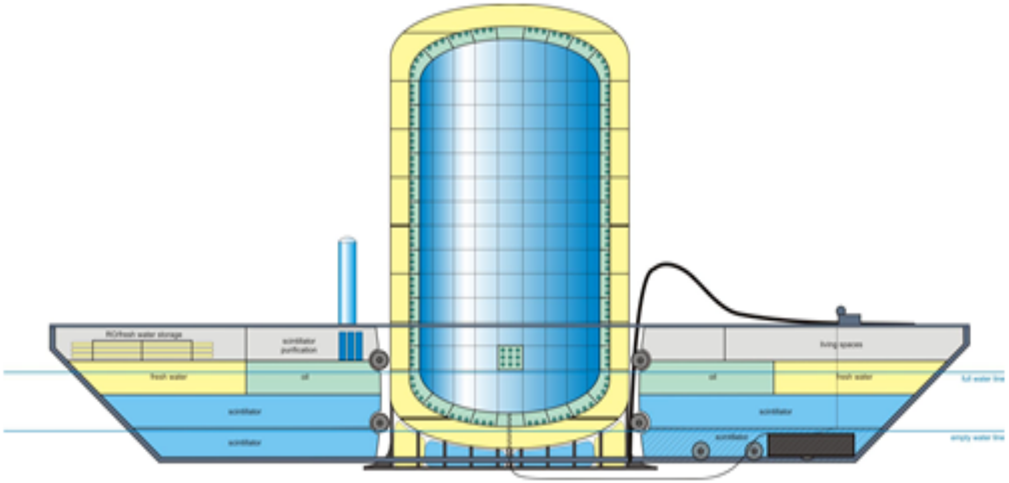
Franz von Feilitzsch, TUM

What's about a ~ 50 kt Detector based on a liquid scintillator?



LENA – Low Energy Neutrino Astronomy

(~50 kt deep underground detector)



Hanohano

(~10 kt deep ocean detector)

LENA Detector vertical lay out

DETECTOR LAYOUT

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

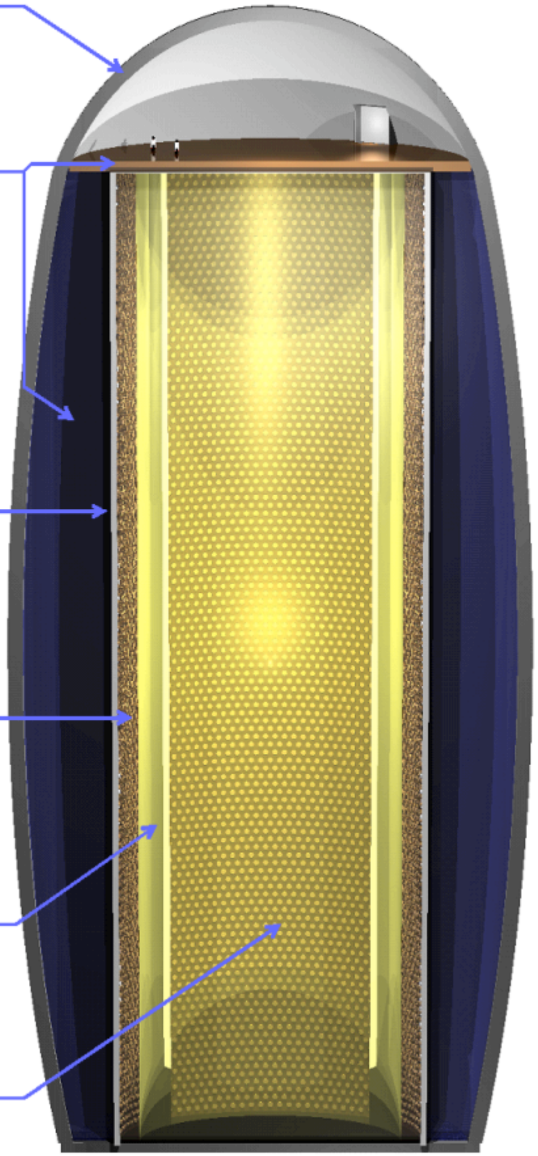
Muon Veto
plastic scintillator panels (on top)
Water Cherenkov Detector
1,500 phototubes
100 kt of water
reduction of fast
neutron background

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

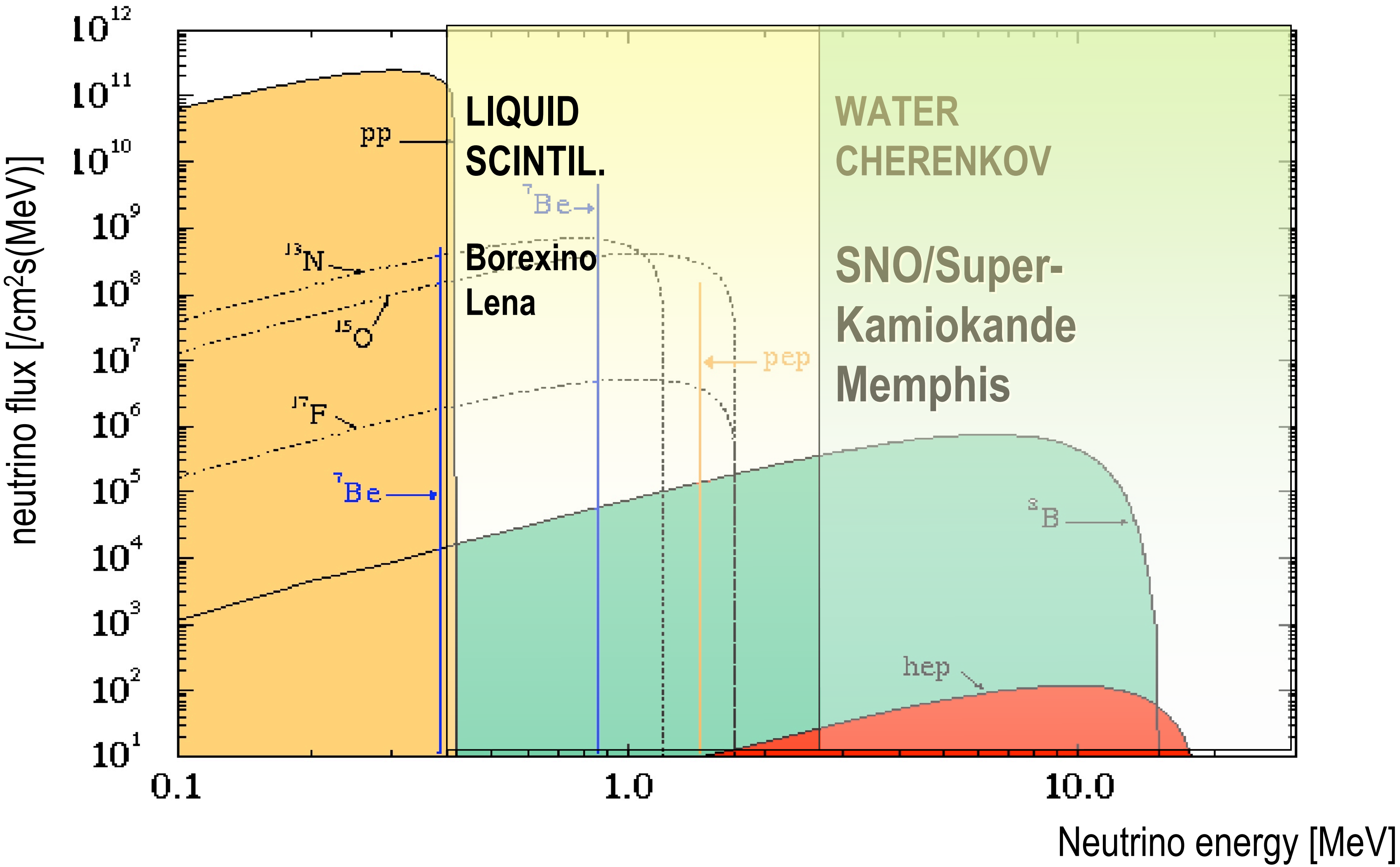


vertical design is favourable in terms of rock pressure and buoyancy forces

Neutrino physics with 50 kt Lena

Solar neutrinos

Solar Neutrino Spectrum



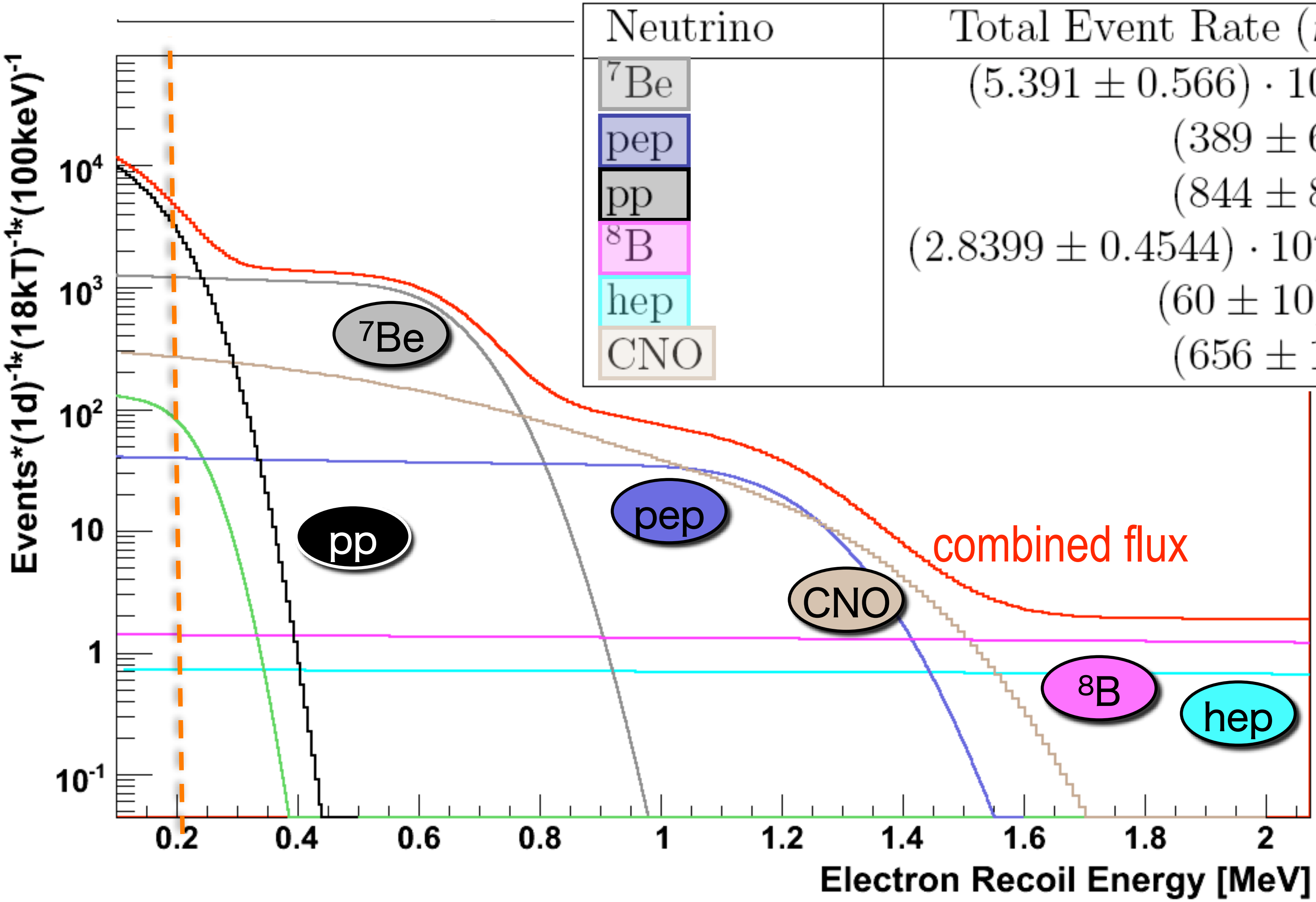
range of sensitivity

Electron Recoil Spectrum in LENA

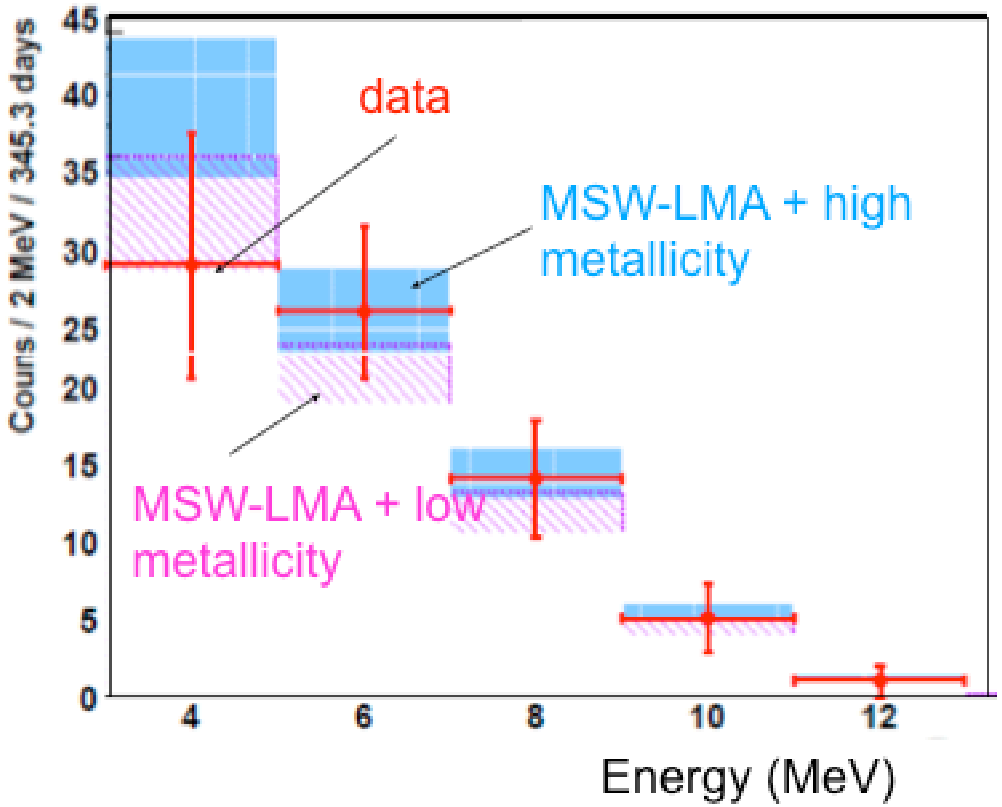
From solar neutrinos

$E_{thr} = 200\,\mathrm{keV}$

Neutrino	Total Event Rate ($\nu_{e,\mu,\tau}$)
^{7}Be	$(5.391 \pm 0.566) \cdot 10^3\,\mathrm{d}^{-1}$
pep	$(389 \pm 6)\,\mathrm{d}^{-1}$
pp	$(844 \pm 8)\,\mathrm{d}^{-1}$
^{8}B	$(2.8399 \pm 0.4544) \cdot 10^4\,\mathrm{yr}^{-1}$
hep	$(60 \pm 10)\,\mathrm{yr}^{-1}$
CNO	$(656 \pm 1)\,\mathrm{d}^{-1}$



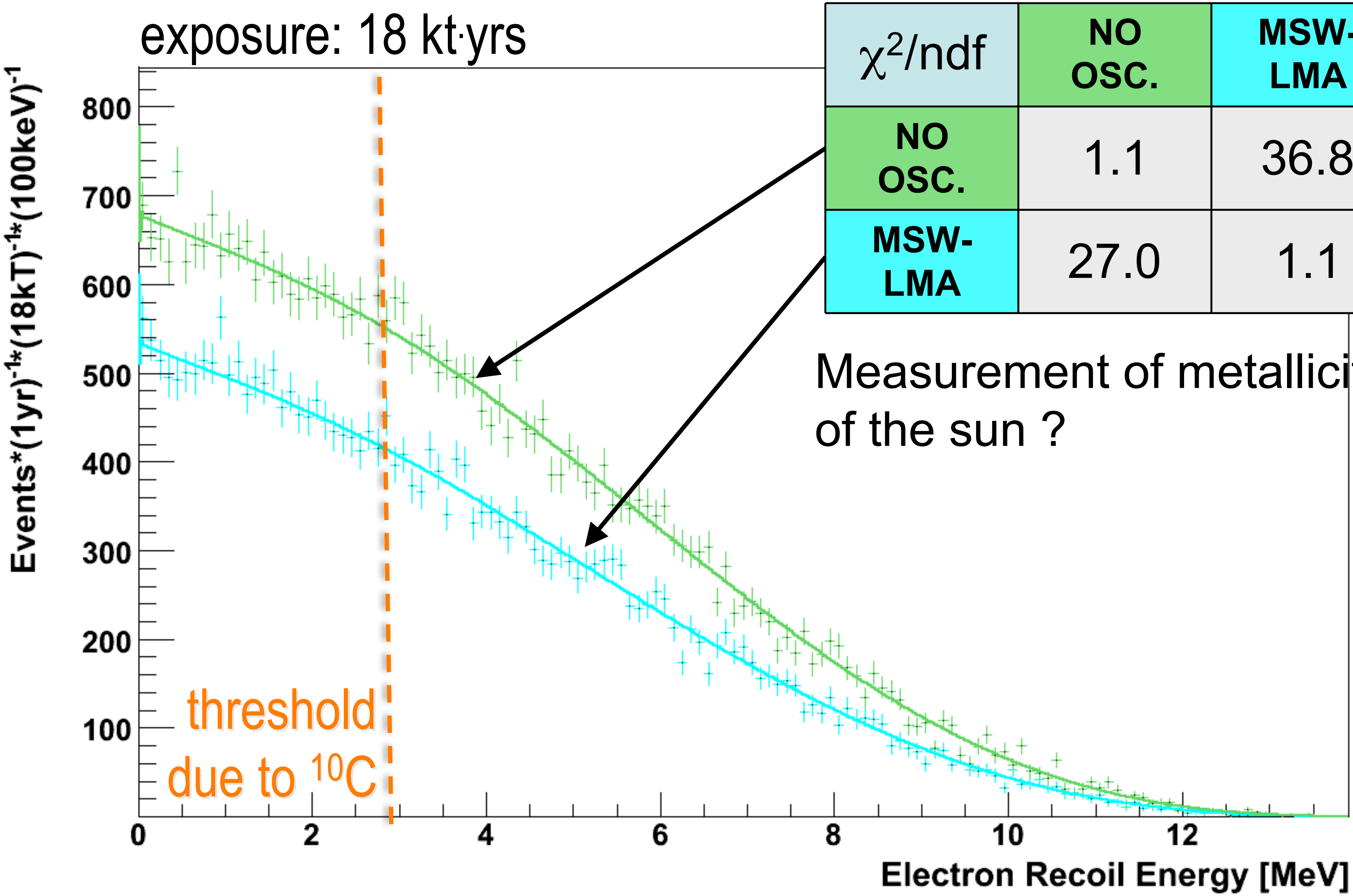
^{8}B-Spectrum by BOREXINO



^{8}B rate in BX above 3 MeV

0.217 ± 0.038 (stat) ± 0.008 (sys) counts/(day × 100t)

^{8}B neutrinos in LENA



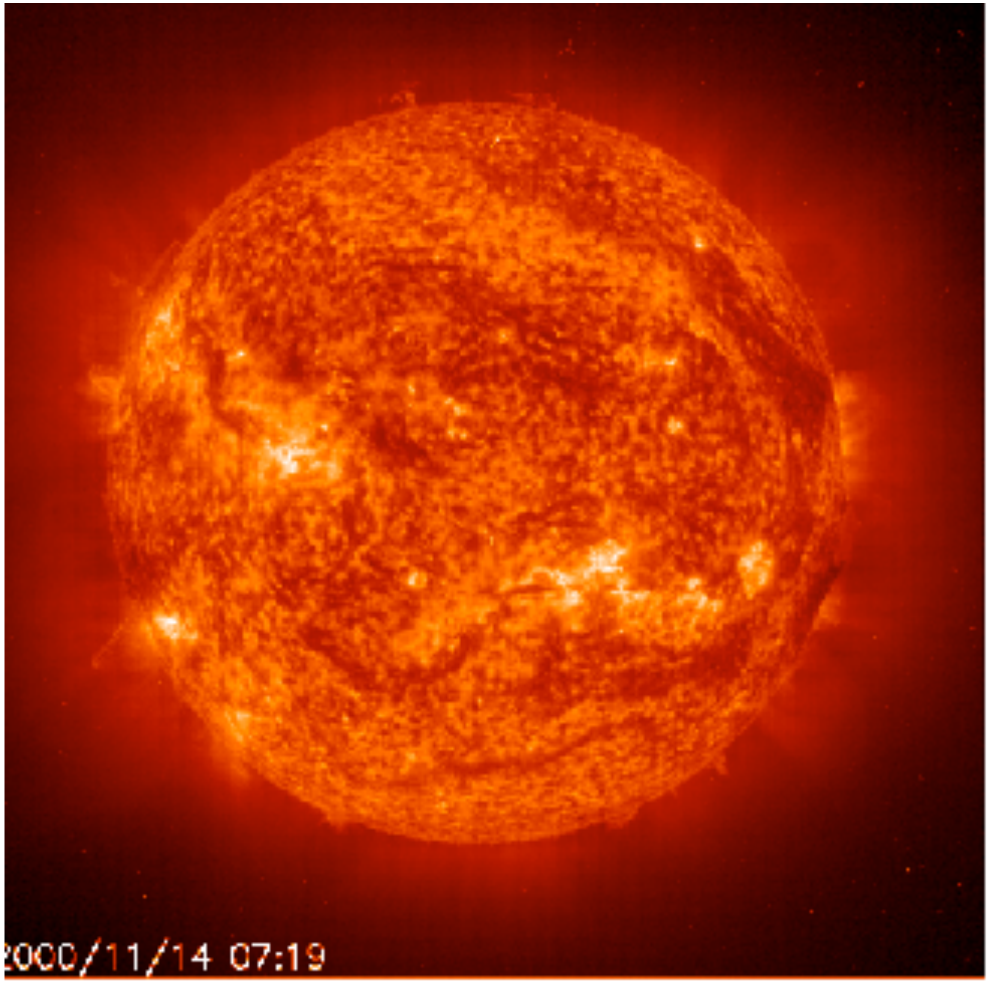
χ^2/ndf	NO OSC.	MSW-LMA
NO OSC.	1.1	36.8
MSW-LMA	27.0	1.1

Measurement of metallicity of the sun ?

Neutrino solar seismology

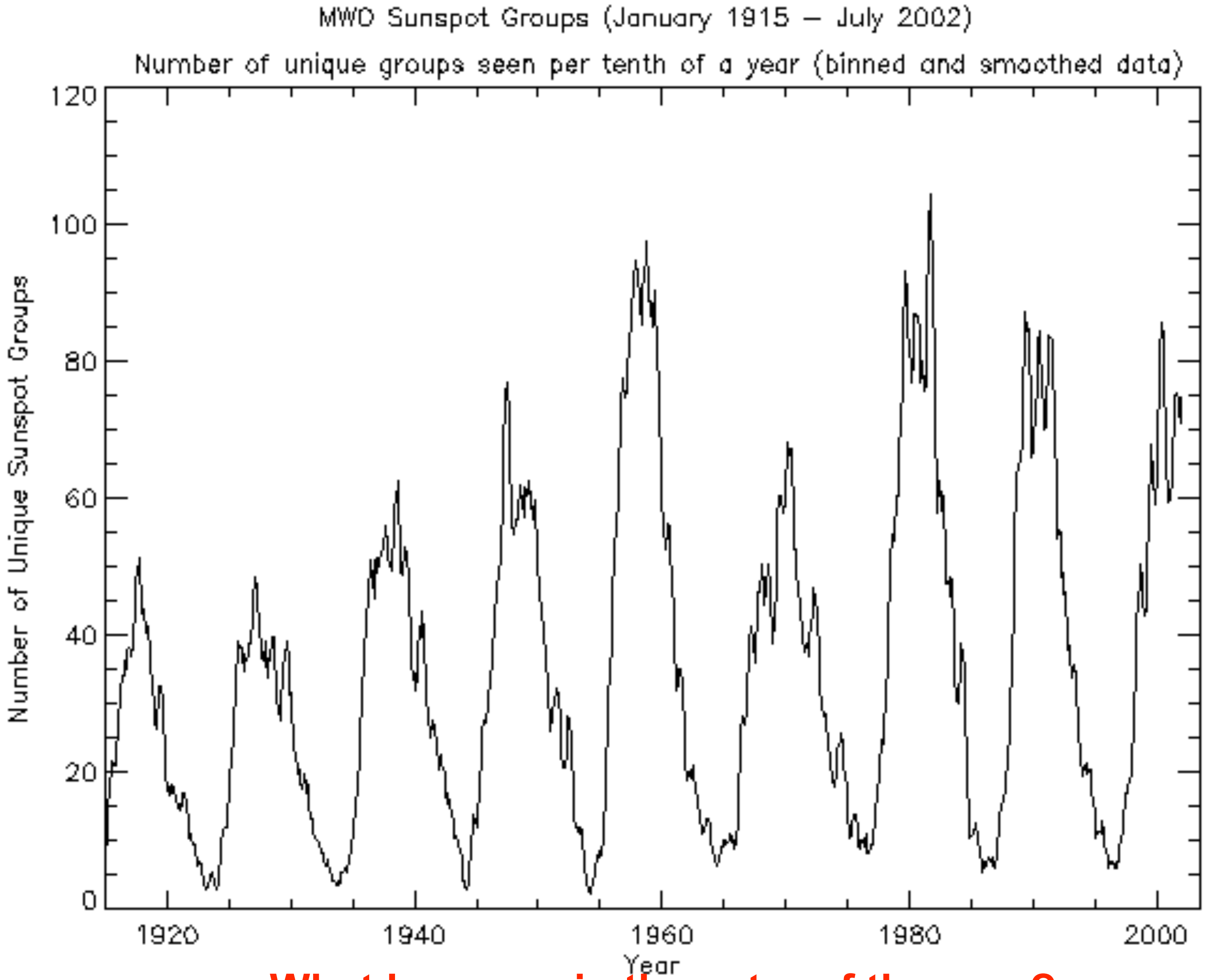
M. Wurm et al., Phys. Rev. D83, 032010 (2011),

Surface of the sun
is not quiet,
high sun spot activity



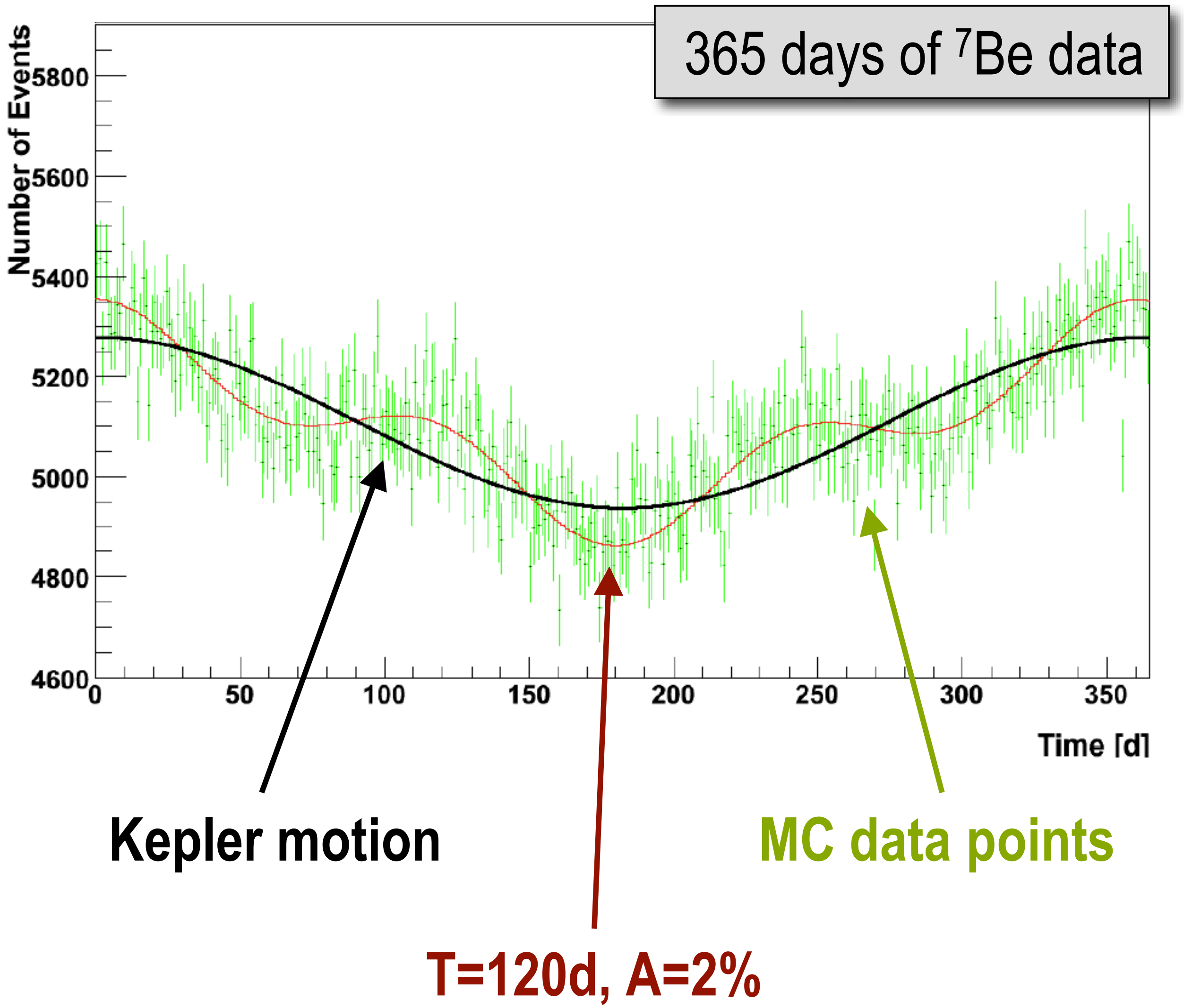
Mt. Wilson Sunspot Group Plots:

Variation of sun spot activity



What happens in the ceter of the sun ?

Modulations in ^{7}Be neutrino flux



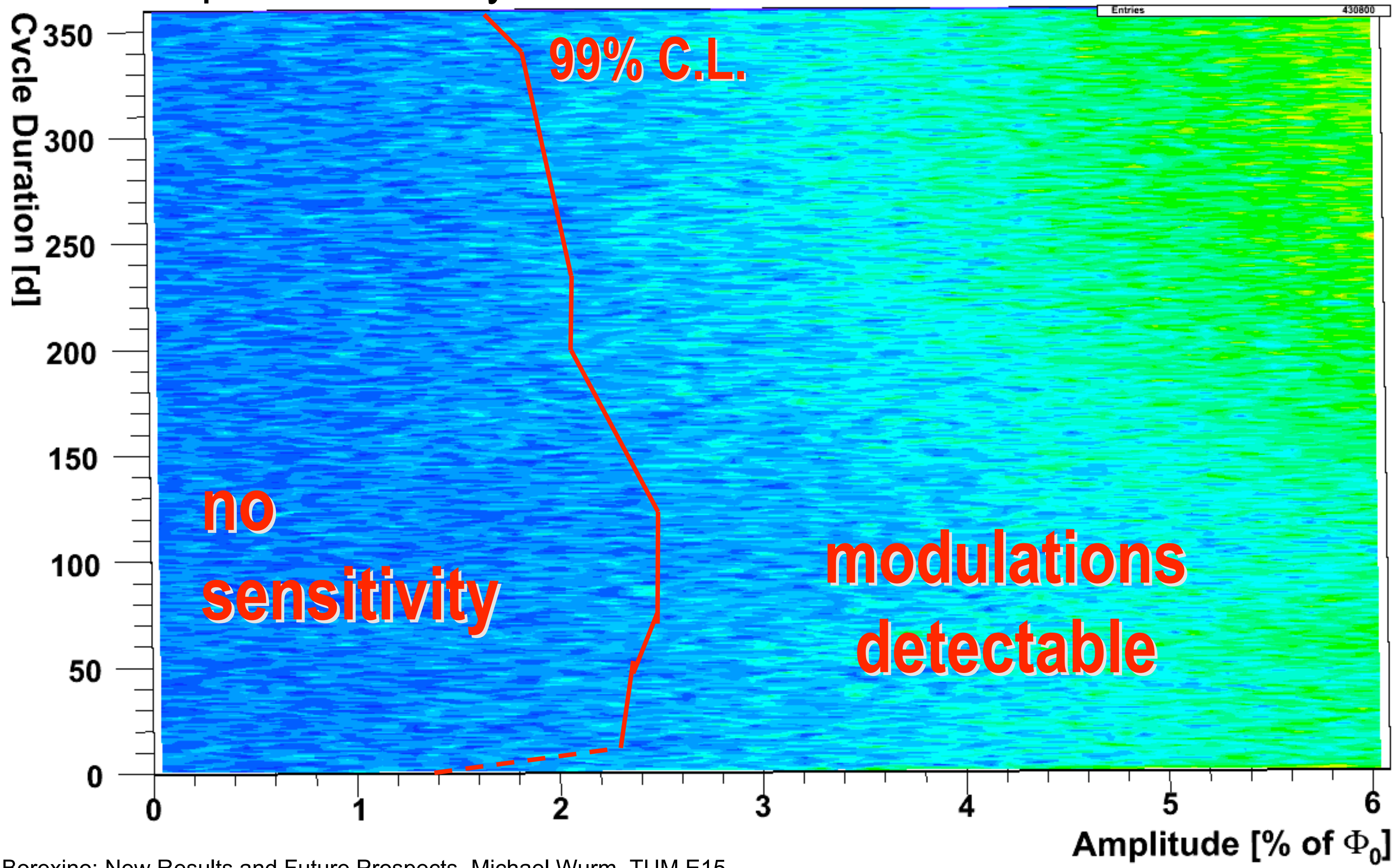
- ^{7}Be-ν mean rate: 5400 ev/day

Possible Modulation:

- Keplerian motion: 7% annual variation
- Day/Night-Effect: influence of matter on osc. probability 1% daily variation
- Density/temperature variations in the sun (e.g. by G-modes)?

Sensitivity for modulations in LENA

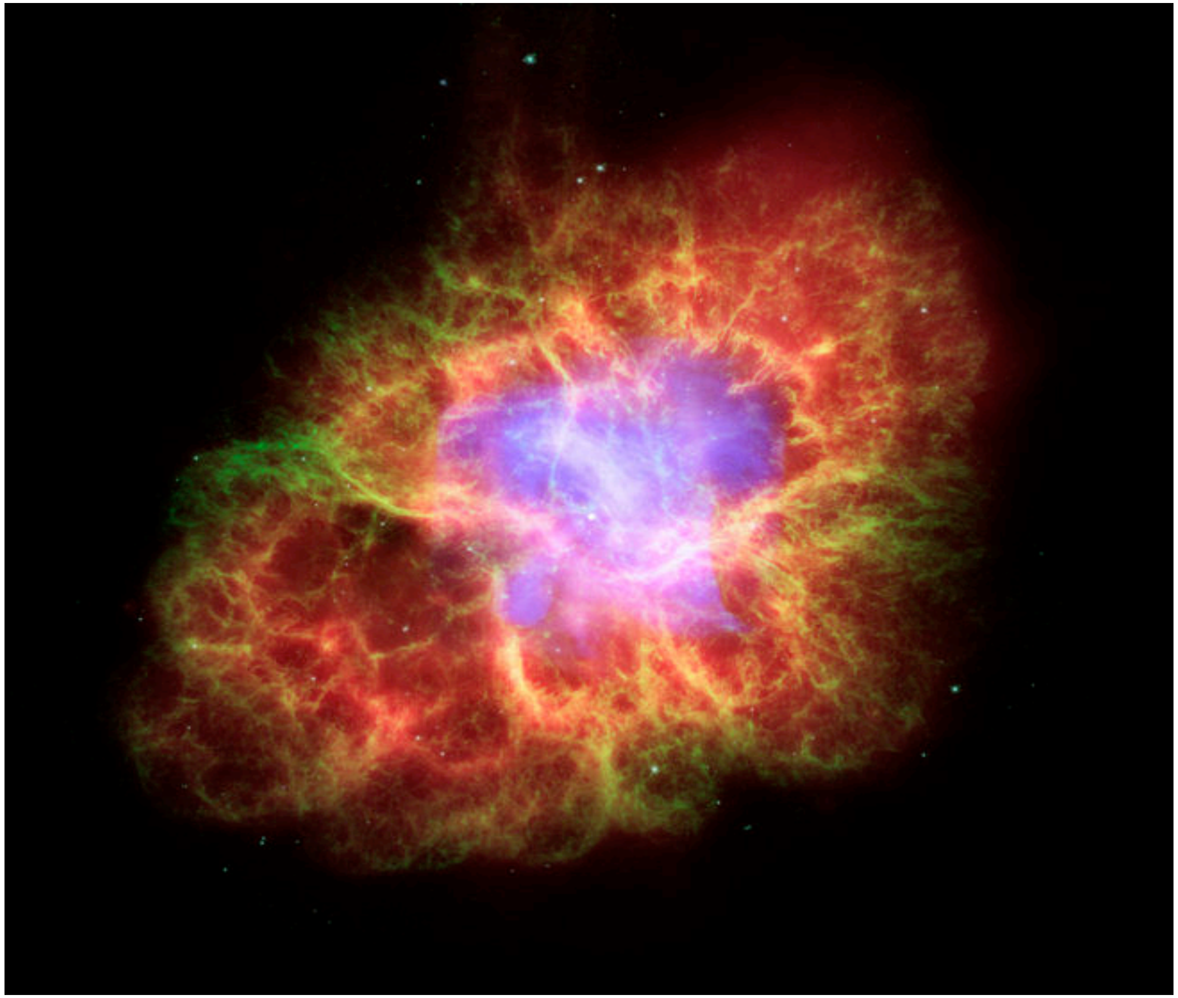
exposure: 18 kt·yrs



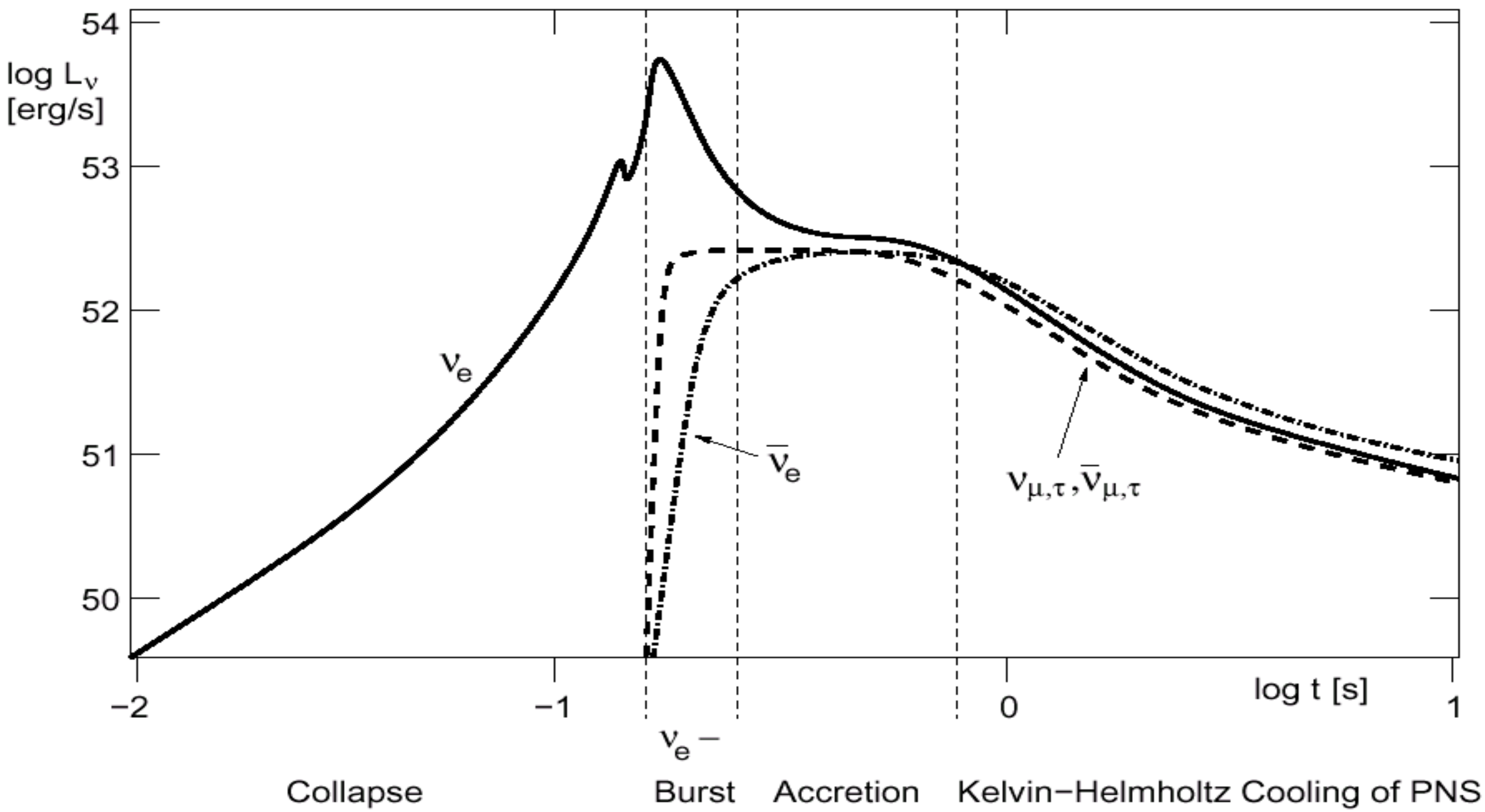
M. Wurm et al., Phys. Rev. D83, 032010 (2011),

Galactic Supernova in Lena

Super nova explosion :
due to high density of material only neutrinos can escape from the center, they carry 99% of the energy released in the explosion



Supernova neutrino luminosity (rough sketch)



T. Janka, MPA

Relative size of the different luminosities is ***not well*** known: it depends on ***uncertainties*** of the ***explosion mechanism*** and the ***equation of state*** of hot neutron star matter. **Info on all neutrino flavors and energies desired!**

LENA and a galactic supernova

- 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

1 • $\overline{\nu}_e + p \rightarrow n + e^+$; $n + p \rightarrow d + \gamma$ $\sim$7 000 - 13 800

2 • $\overline{\nu}_e + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{B} + e^+$; ${}^{12}\mathrm{B} \rightarrow {}^{12}\mathrm{C} + e^- + \overline{\nu}_e$ $\sim$150 - 610

3 • $\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}$; ${}^{12}\mathrm{N} \rightarrow {}^{12}\mathrm{C} + e^+ + \nu_e$ $\sim$200 - 690

4 • $\nu_x + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{C}^* + \nu_x$; ${}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C} + \gamma$ $\sim$680 - 2 070

5 • $\nu_x + e^- \rightarrow \nu_x + e^-$ (elastic scattering) $\sim$700

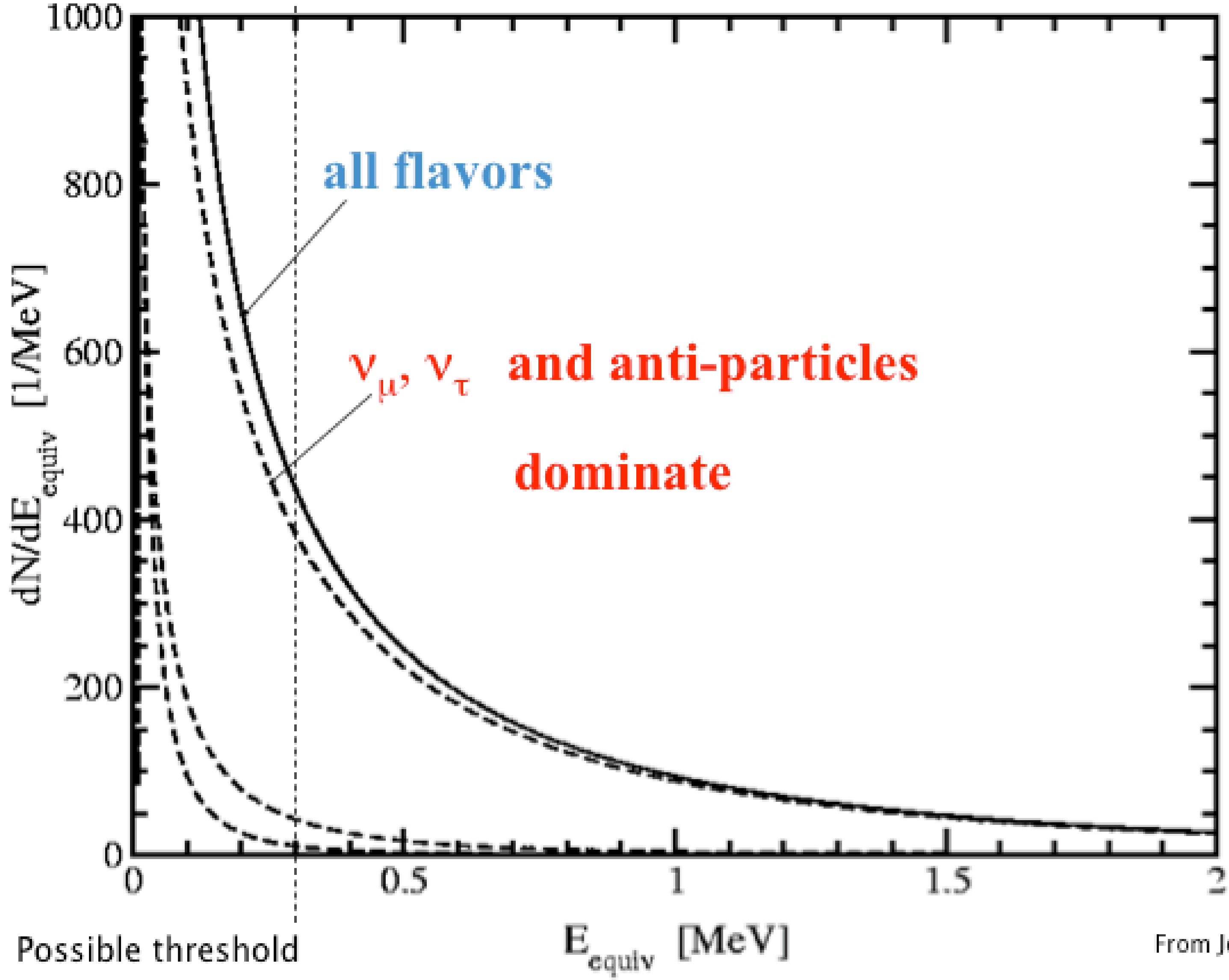
6 • $\nu_x + p \rightarrow \nu_x + p$ (elastic scattering) $\sim$1 500 - 5 700

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

Event analysis

- $\bar{\nu}_e$ spectrum (inverse beta decay on H #1) with very high statistics – basically free of background
- ν_e spectrum (inverse beta decay on ^{12}C) – {#2+#3 – norm.#1} with ~ (5–10) % accuracy
- Total flux of all active neutrinos (via ^{12}C–nc reaction #4)
- ν_μ ν_τ sum spectrum plus antineutrinos (#6–ν_e-ν_e)
- Everything as function of time
- Separation of SN models (due to large NC statistics – independent from oscillation physics)
- Information on Mass hierarchy, Theta_13

Neutrino elastic scattering off protons



From John Beacom

Detailed neutrino signal will be complimentary to gravitational wave signal for understanding a core collapse SN explosion

Lena will provide:

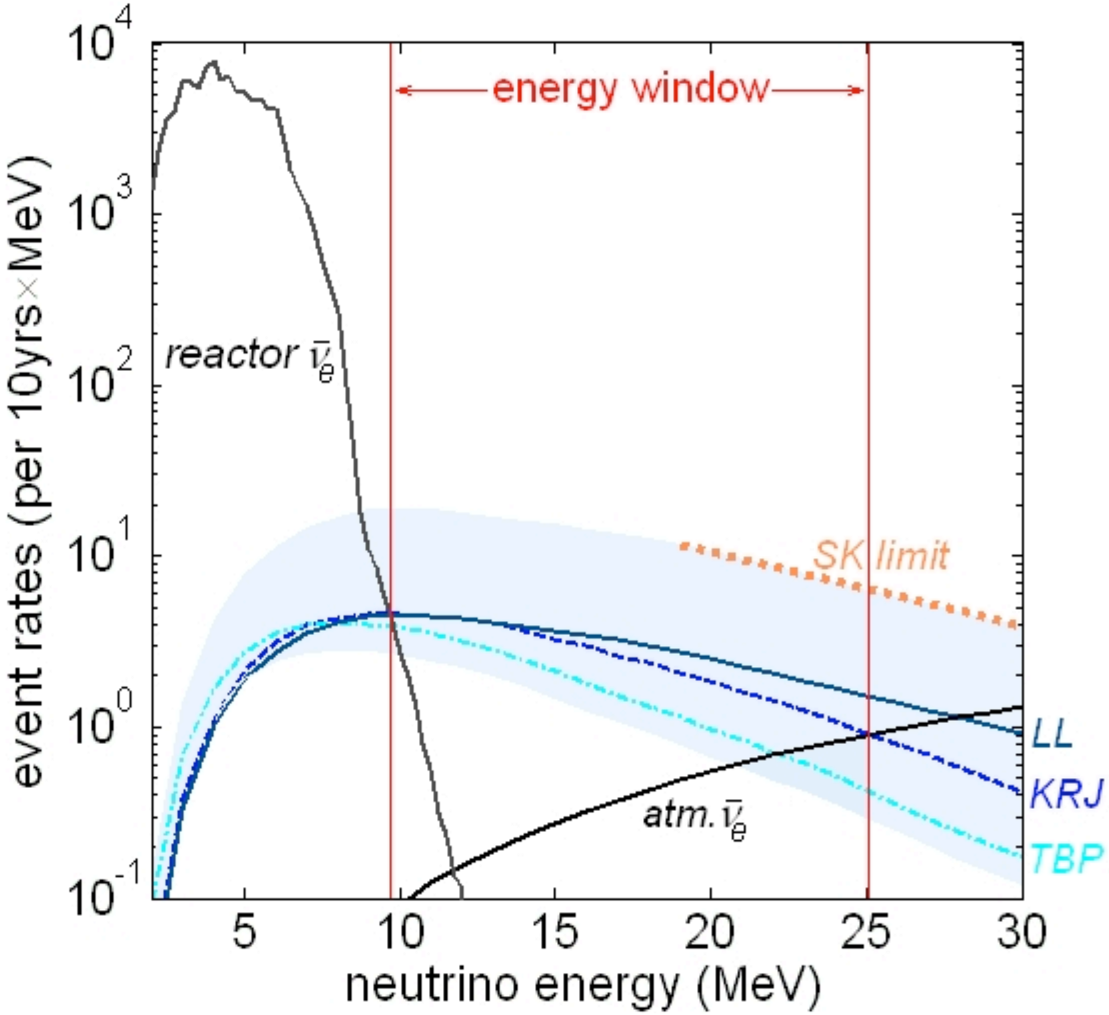
6 independent channels

For neutrino and antineutrino detection and excellent time information

Neutrinos from remnant Supernovae

Early star formation rate

LENA: Diffuse SN Background



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

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

Delayed coincidence

Spectral information

Event rate depends on

-Supernova type II rates

-Supernova model

Range: ***20 to 220 / 10 y***

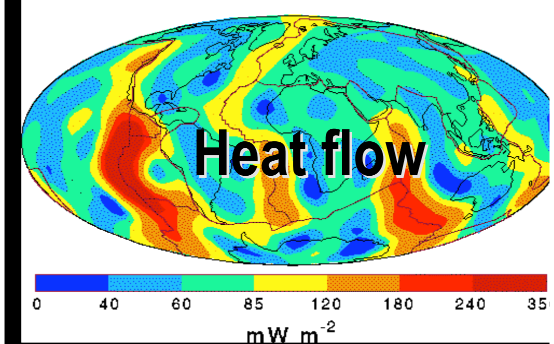
Background: ~ 1 per year

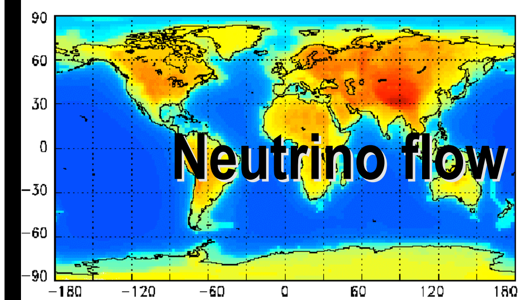
gianni fiorentini, ferrara univ. @ ν_{2004}

Geo-Neutrinos : a new probe of Earth’s interior

Antineutrino detection with inverse ß-decay reaction

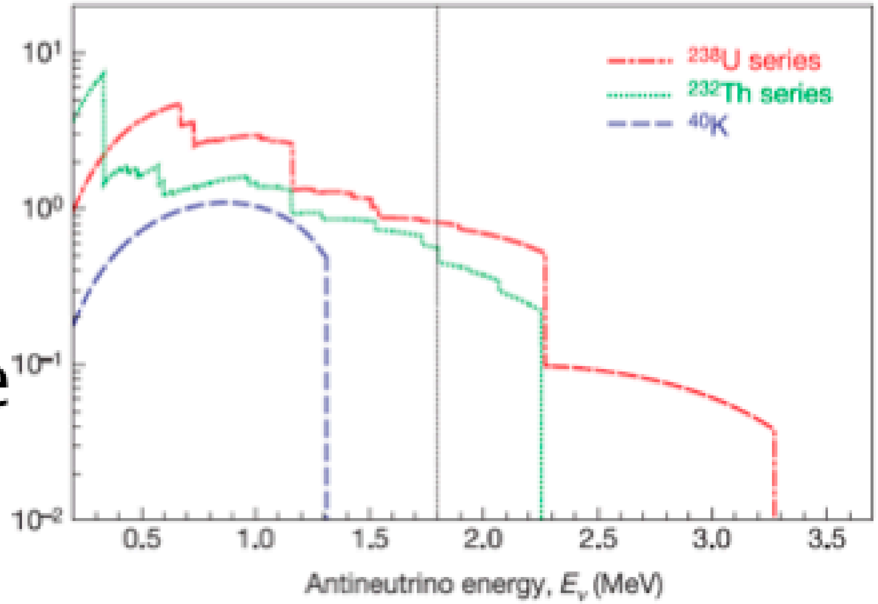
- Determine the radiogenic contribution to terrestrial heat flow, only half of the energy emission from the earth is understood
- Test a fundamental geochemical paradigm about Earh’s origin: the **B**ulk **S**ylicate **E**arth
- Test un-orthodox / heretical models of Earth’s interior (K in the core, Herndon giant reactor)
- A new era of applied neutrino physics ?





LENA and Geo-neutrinos

- LENA is the only detector within Laguna able to determine the geo neutrino flux
- In LENA we expect between 300 to 3000 events per year (~ 1500 / year)
- Good signal / bg ratio
  rather low reactor flux
- Separation of U/Th
- Test of geological mode



L. Oberauer, TUM

Determination of the U / Th ratio after 5 years, 50 kt of operation in Phyäsalmi, needed for test of geological models

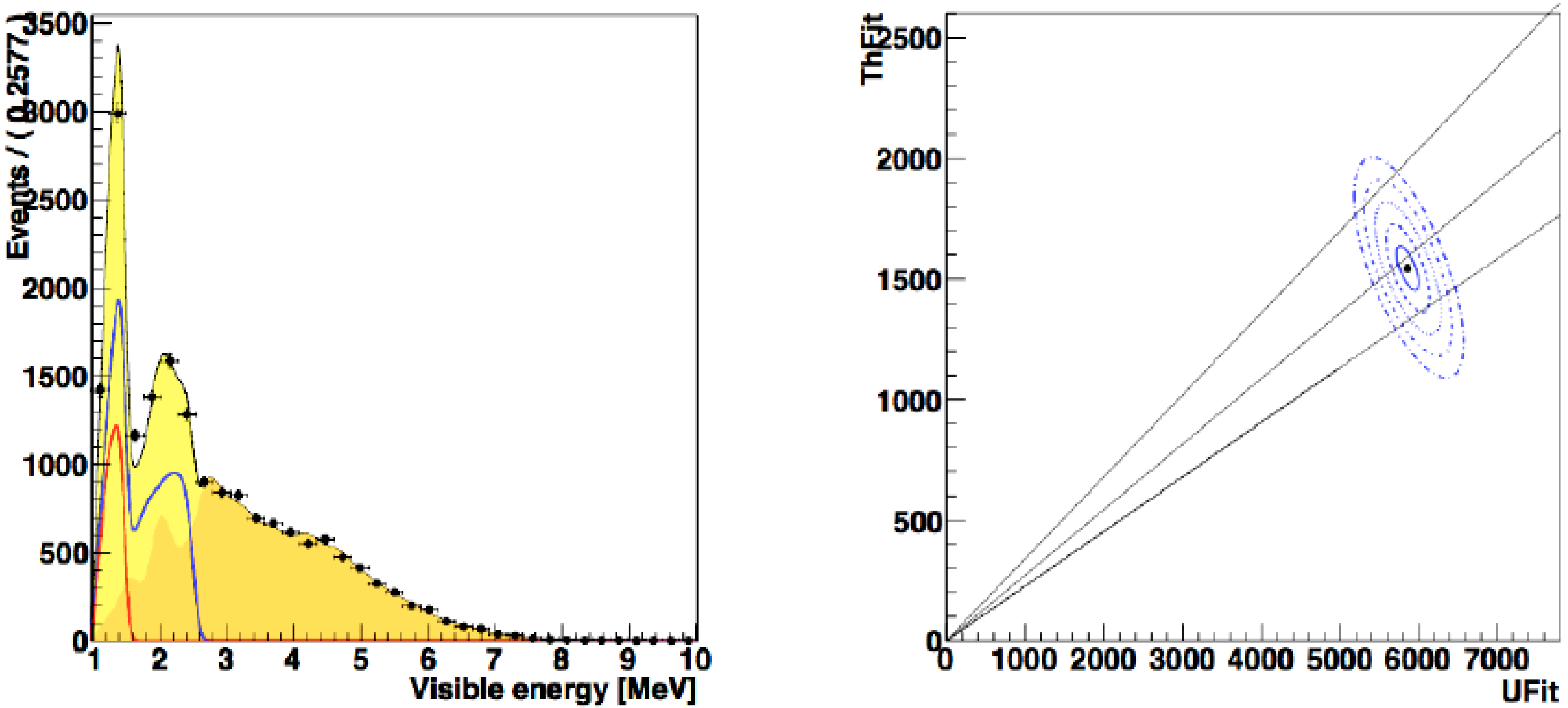
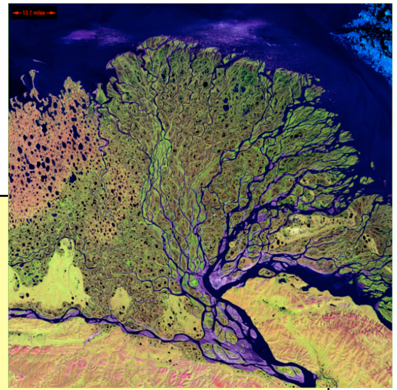


FIG. 9: Left: Expected 5-year reactor $\bar{\nu}_e$ (orange area) and geo-ν (U: blue line, Th: red line) energy spectrum at Pyhäsalmi site (future Finnish reactors not considered). The chondritic U/Th ratio was assumed. Right: Corresponding 1-5 σ C.L. contour plot for the absolute U and Th number of events resulting from the fit. The solid line corresponds to chondritic U/Th ratio with which the data were generated, the dashed lines correspond to the ratio $\pm 20\,\%$.

Proton Decay and LENA



$$p \rightarrow K\,\nu$$

- This decay mode is favoured in ***SUSY*** theories
- The primary decay particle K is ***invisible*** in Water Cherenkov detectors
- It and the K-decay particles are visible in scintillation detectors
- Better energy resolution further ***reduces background***

$P \rightarrow K^{\pm} \nu$ event structure:

$T(K^+) = 105\ MeV$

$\tau(K^+) = 12.8\ nsec$

$K^+ \rightarrow \mu^+ \nu$ (63.5 %)

$T(\mu^+) = 152\ MeV$

$K^+ \rightarrow \pi^+ \pi^0$ (21.2 %)

$T(\pi^+) = 108\ MeV$

electromagnetic shower

$E = 135\ MeV$

$\mu^+ \rightarrow e^+ \nu \nu$ ($\tau = 2.2\ \mu s$)

$\pi^+ \rightarrow \mu^+ \nu$ ($T = 4\ MeV$)

$\mu^+ \rightarrow e^+ \nu \nu$ ($\tau = 2.2\ \mu s$)

•3 - fold coincidence !

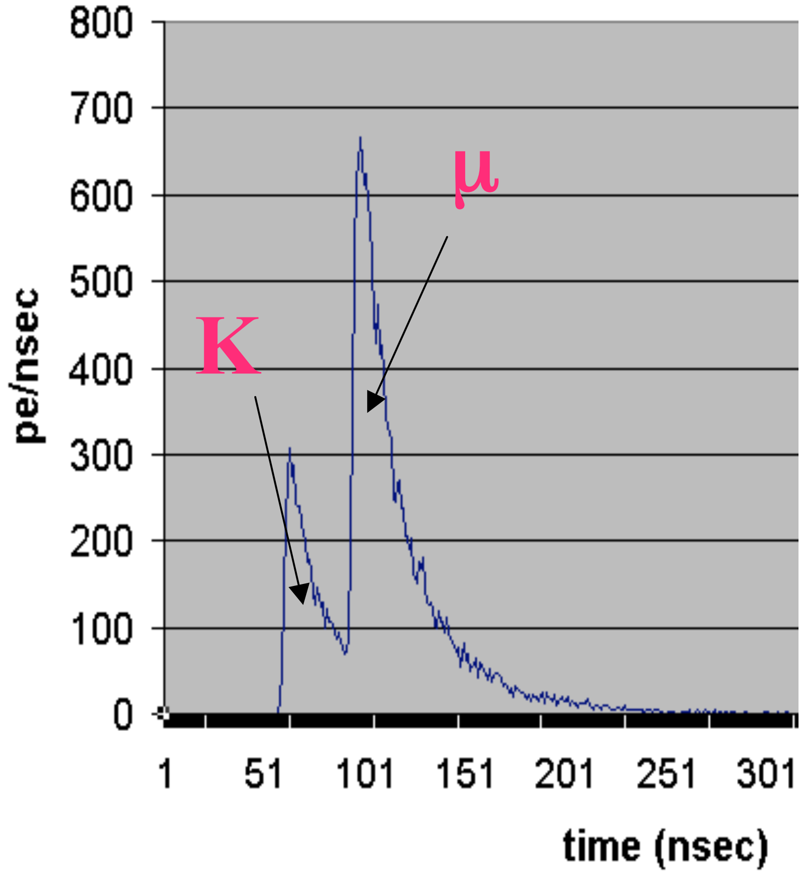
•the first 2 events are monoenergetic !

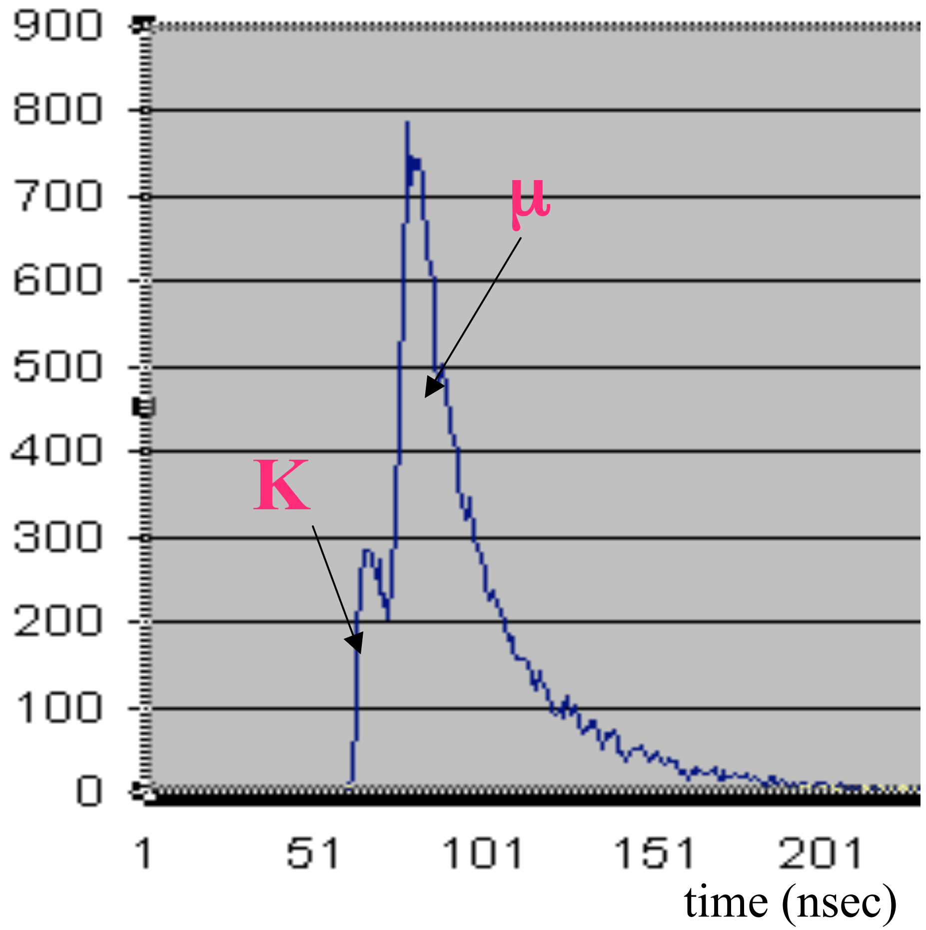
•use time- and position correlation !

How good can one separate the first two events ?

....results of a first Monte-Carlo calculation

P decay into K and ν



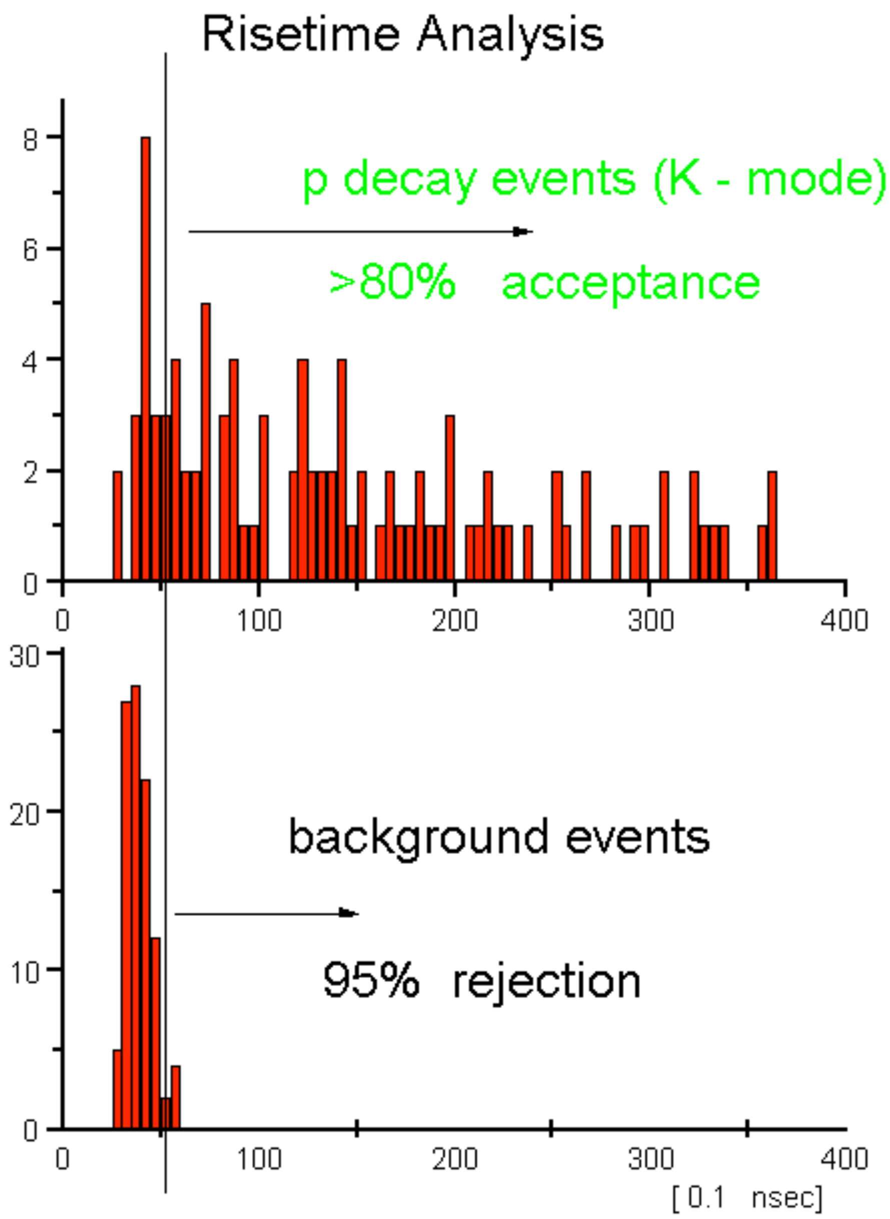


Signal in LENA

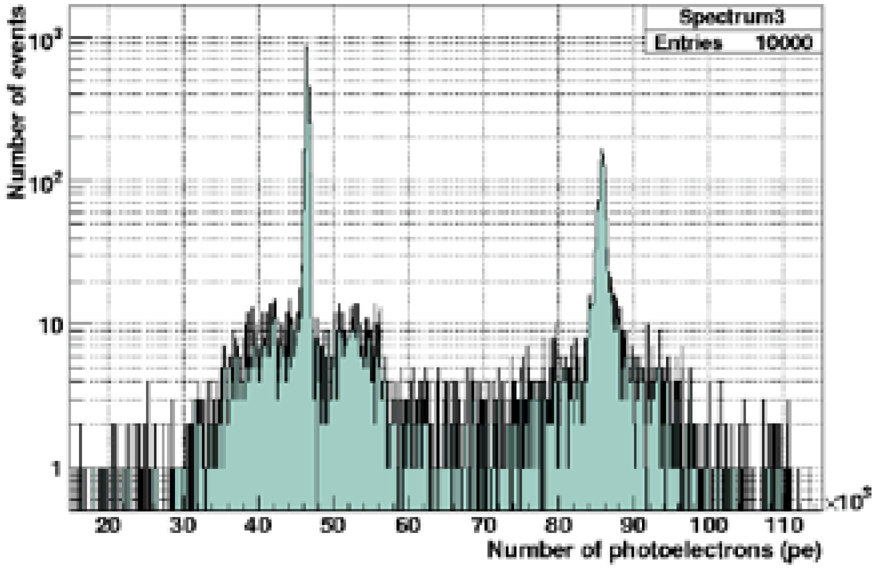
Background Rejection:

- **monoenergetic** K- and μ-signal!
- **position correlation**
- **pulse-shape analysis**

(after correction on reconstructed position)



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



- Energy spectrum (180 pe/MeV)
- Two peaks:
  - Kaon + Muon: $\sim$ 257 MeV
  - Kaon + Pions: $\sim$ 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

What can a scintillation detector tell about neutrino oscillation?

Teta 13

CP violation

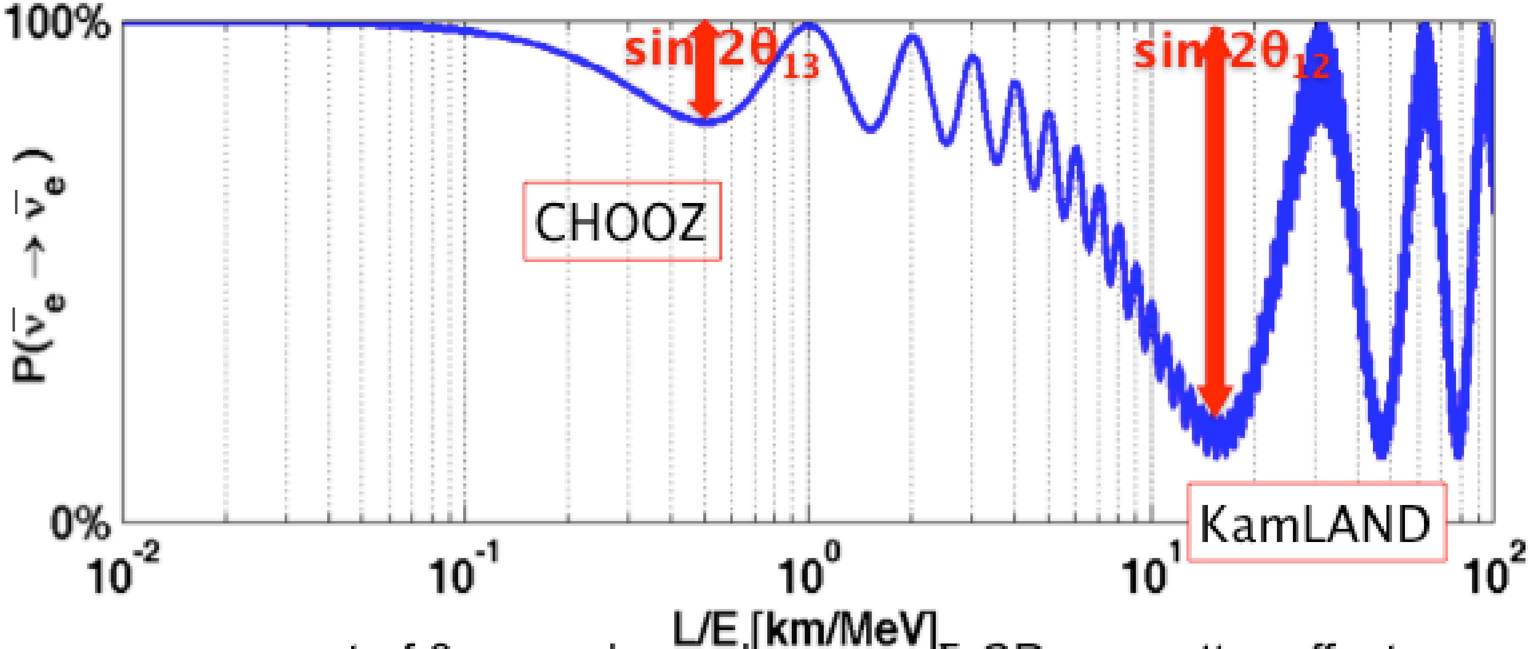
New measurement of mixing angle teta 13

Oscillation experiments at nuclear reactors

Nuclear reactors are intense sources of electron antineutrinos

Average neutrino energy: $\langle E_\nu \rangle \approx 4$ MeV => disappearance of $\bar{\nu}_e$

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m^2_{atm} L}{4E_{\bar{\nu}}} - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \frac{\Delta m^2_{sol} L}{4E_{\bar{\nu}}}$$



Clean measurement of θ_{13}, no dependence on δ-CP, no matter effects

Short baseline neutrino oscillations

in Lena

Neutrino source on top of Lena

Neutrino oscillometry

Concept: Short-baseline oscillation experiments using neutrinos from radioactive sources.

Radioactive neutrino sources

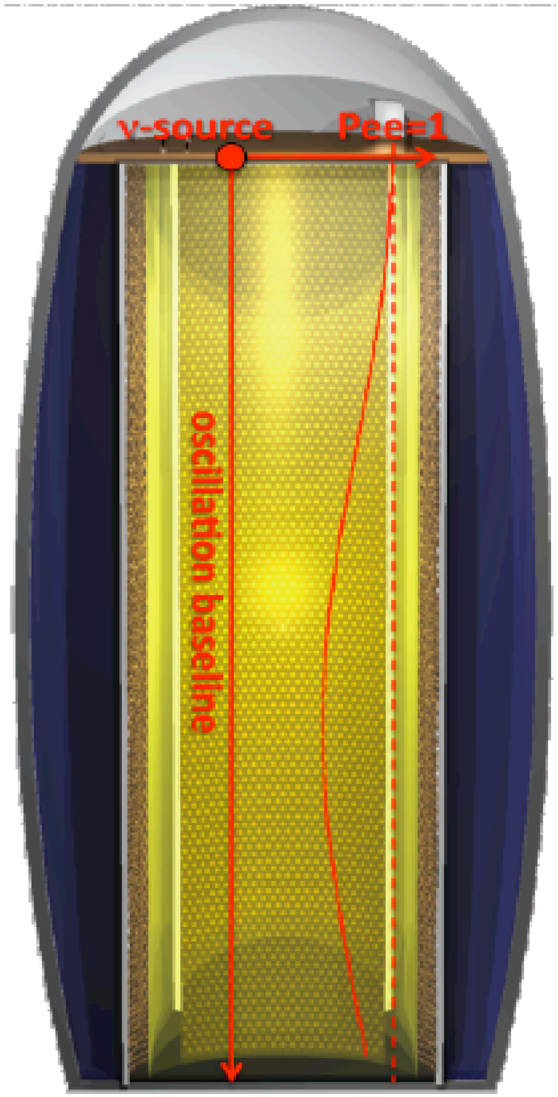
- ν_e (monoenergetic) from EC sources: ^{51}Cr, ^{37}Ar
- $\bar{\nu}_e$ (E=1.8-2.3MeV) from ^{90}Sr (^{90}Y)
- large activity necessary: 1MCi or more

Oscillation baseline

- for Δm^2_{32} (θ_{13}): 750m for ^{51}Cr (747keV)
- for Δm^2_{41} (sterile): 1.3m

Scientific objectives

- check $P_{ee}(r)$ if θ_{13} is relatively large
- check CPT for ν and $\bar{\nu}$
- very sensitive in sterile ν searches ($\sin^2 2\theta \approx 10^{-3}$)



J. D. Vergados and Y. N. Novikov, Nucl. Phys. B839, 1 (2010), arXiv:1006.3862

Coherence condition to be checked ?

Sensitivity to teta 13

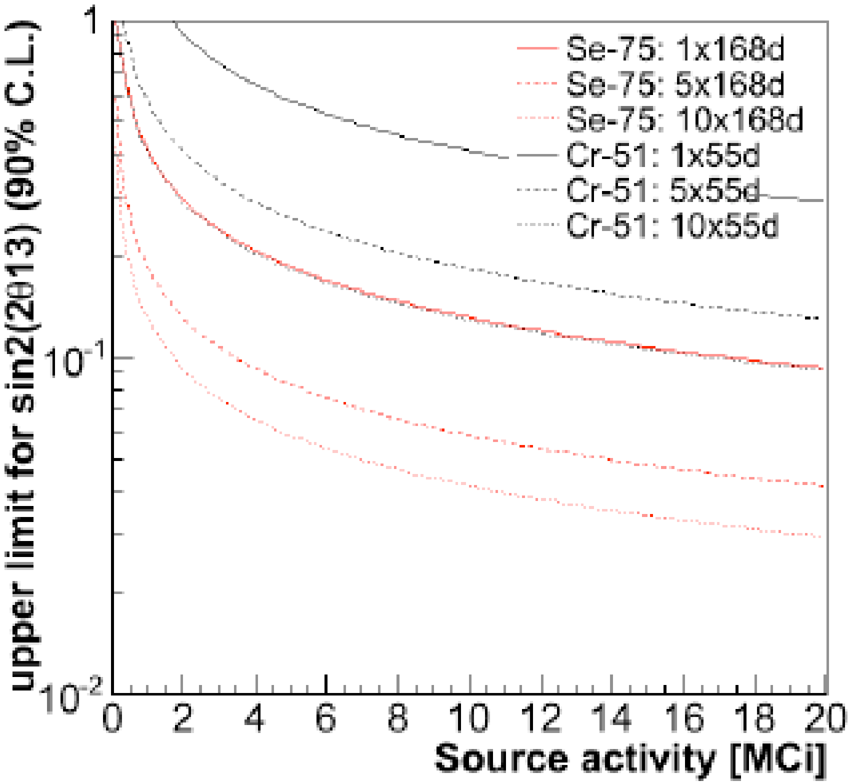


FIG. 11: Upper limits for $\sin^2 2\theta_{13}$ (90% C.L.) as a function of the initial source strength and measurement repetitions. Results for both ^{51}Cr and ^{75}Se are shown, considering statistical uncertainties only.

Sensitivity to Teta 14

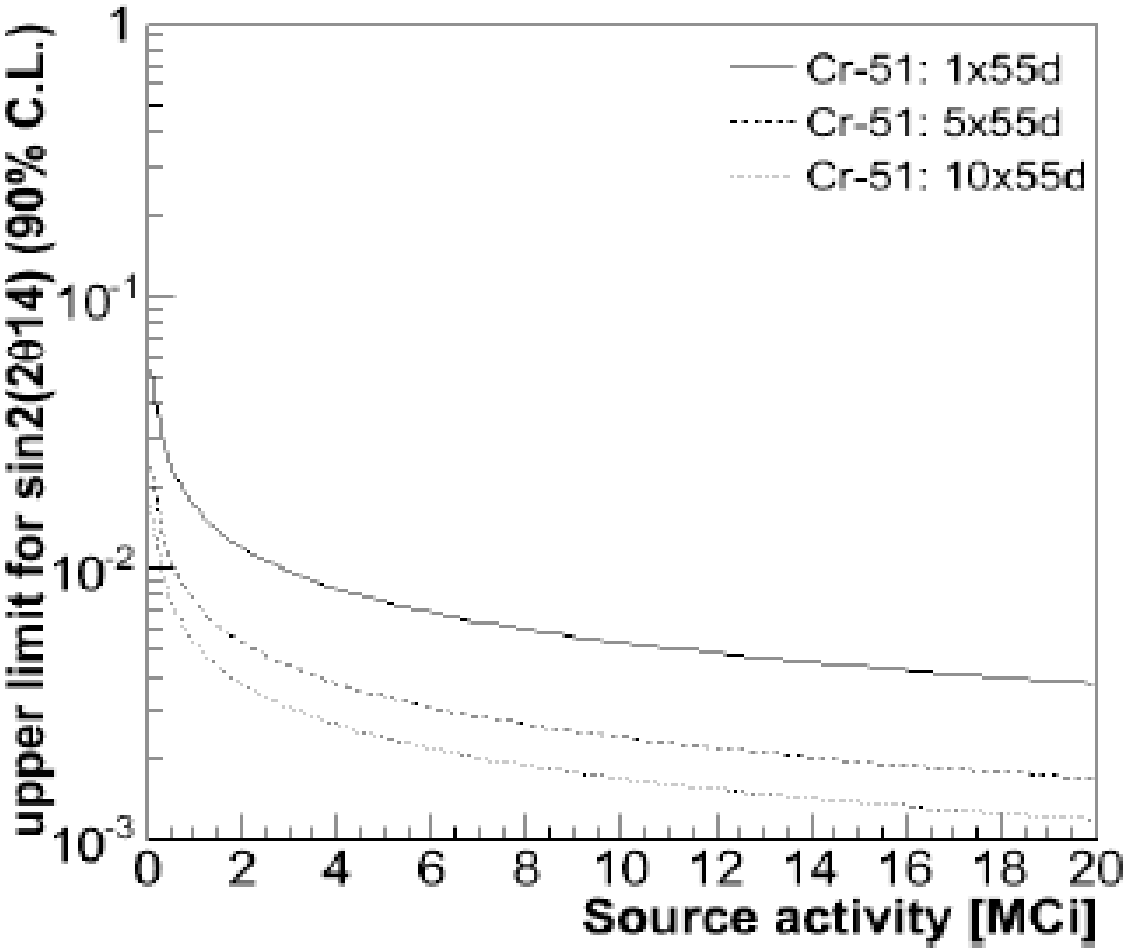


FIG. 13: Upper limits for $\sin^2 2\theta_{14}$ (90% C.L.) as a function of the initial source strength and measurement repetitions. Results for ^{51}Cr are shown, considering statistical uncertainties only.

Lena with neutrino source from "DAR"
Neutrino Decay At Rest:

May 26, 2011

Sanjib Kumar Agarwalla[a], J.M. Conrad[b], M.H. Shaevitz[c]

arXiv;1105.4984v1

P- accelerator with: E(p) = 800 MeV

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\hookrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

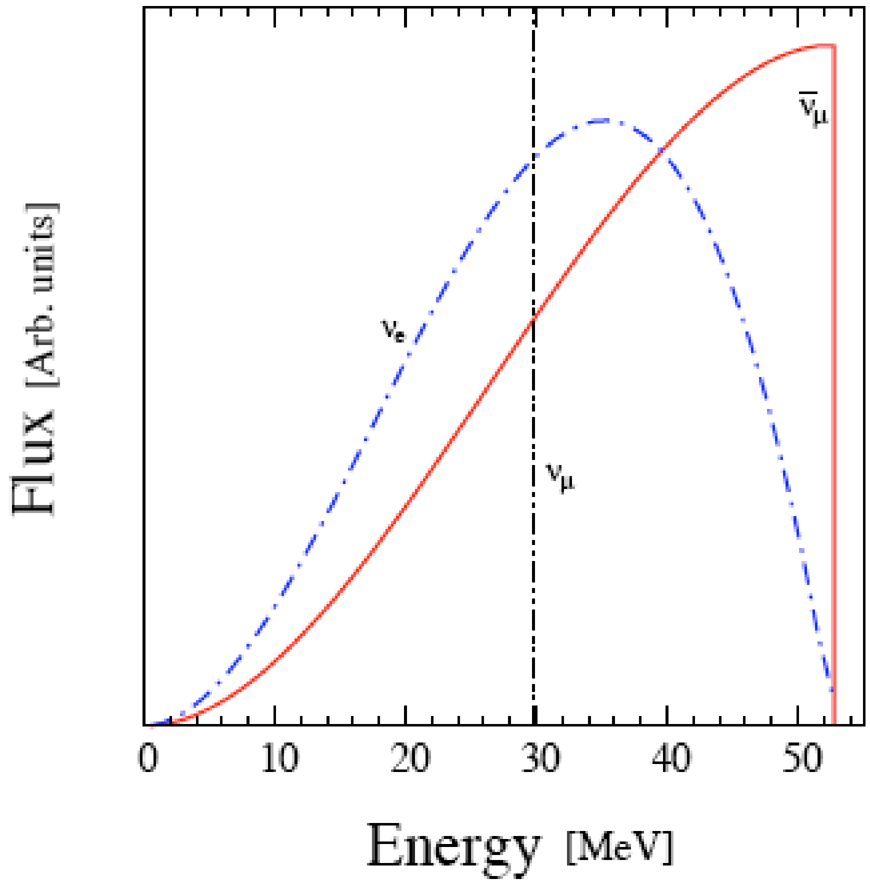


Figure 1: The energy distribution of different flavor of neutrinos in a DAR beam.

4×10^{21} per year, per flavor (ν_μ, $\bar{\nu}_\mu$ and ν_e),
1.6×10^{18} per year of $\bar{\nu}_e$ (4×10^{-4} compared to other flavors);
Delivered as 100 kW average power, with 200 kW instantaneous power,
(50% duty factor allowing equal beam-on and beam-off data sets);
800 MeV protons on target;
± 25 cm smearing (assumed flat) on neutrino production point;
20 m distance from average production point to face of detector fiducial region.

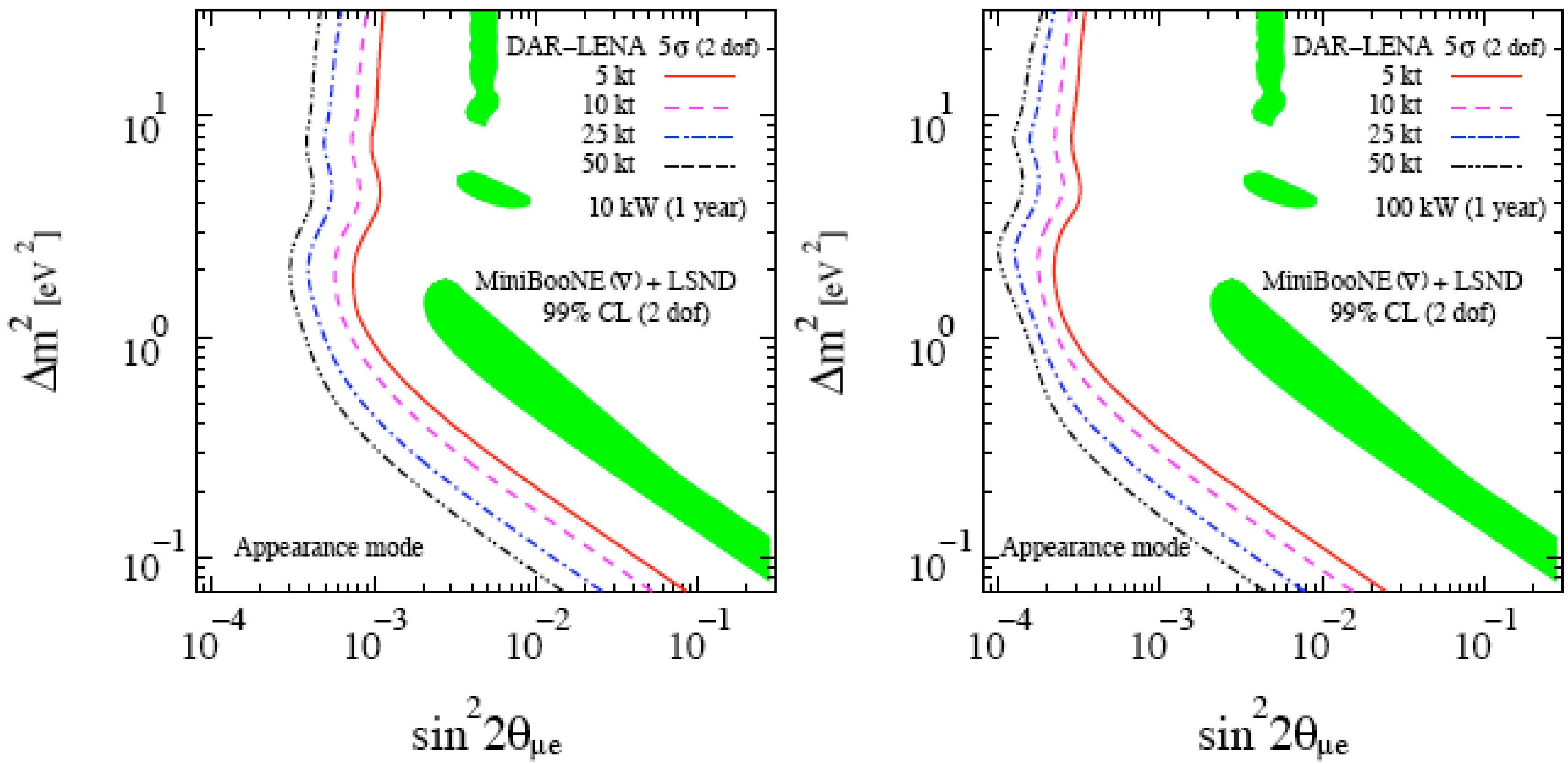


Figure 4: Sensitivity limit of DAR-LENA setup to sterile neutrino oscillation in the (3+1) model at $5\,\sigma$ CL (2 dof) using appearance mode. The green/gray shaded area is the allowed region at 99% CL (2 dof) from a combined analysis of the LSND and MiniBooNE anti-neutrino signals [26]. Left (right) panel shows the results for 10 (100) kW average power machine which can deliver 4×10^{20} (4×10^{21}) $\bar{\nu}_\mu$ in one year. In both the panels, results are shown for four different choices of the fiducial mass of the detector.

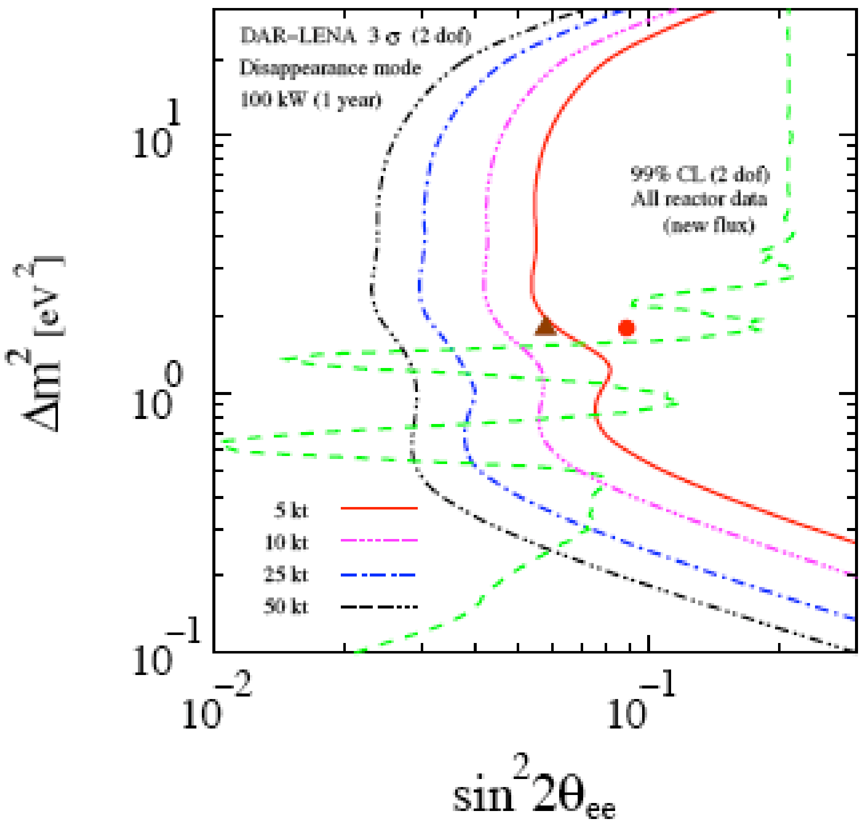


Figure 6: Expected constraints from DAR-LENA setup on sterile neutrinos in the (3+1) model at $3\,\sigma$ CL (2 dof) using disappearance search. The dashed green curve shows the 99% CL (2 dof) limit from reactor anti-neutrino data with new reactor fluxes [66]. The triangle and the bullet show the (3+1) best-fit values of all reactor data with old and new fluxes respectively. Results are shown for 5 to 50 kt LENA type detector with 4×10^{21} ν_e.

Long baseline neutrino physics

Cern- Phyhäsalmi

2300 km

Particle and track identification in a scintillator

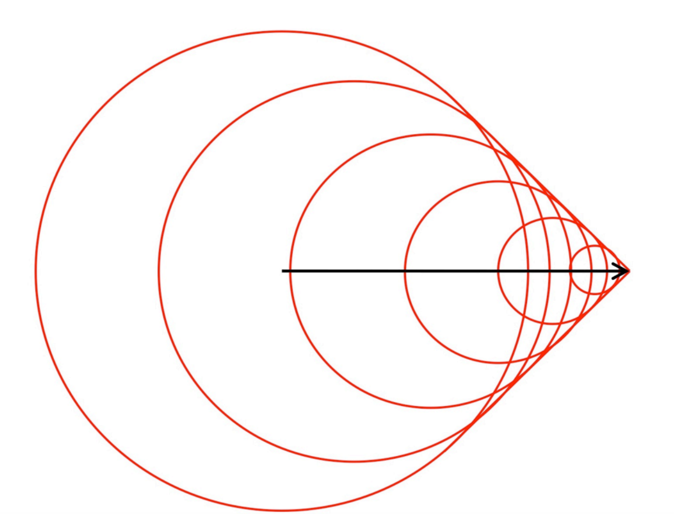
- With $\Delta T < 2$ ns
- Sufficient light det efficiency

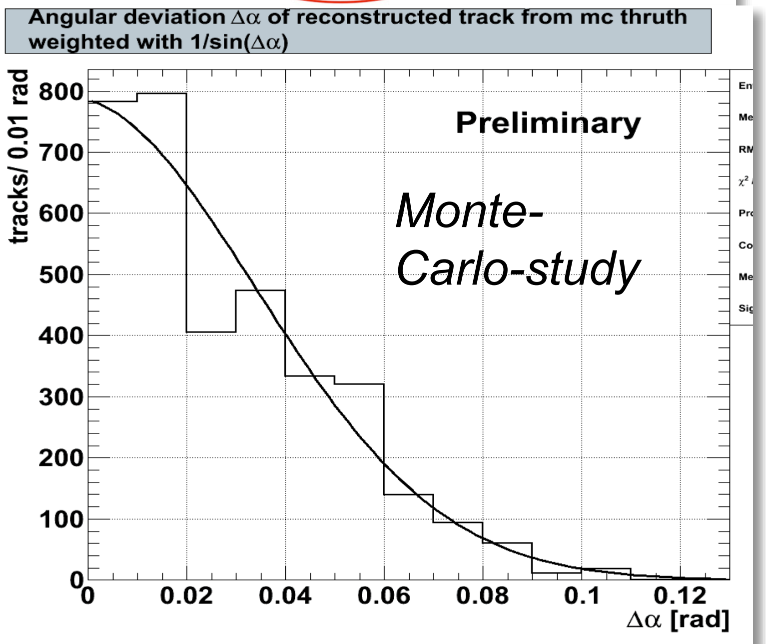
(10% photocathode coverage)

Good tracking and particle id possible

@ E (ν) ~ 4 GeV

Tracking in a scintillator detector?





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

Single track reconstruction based on:

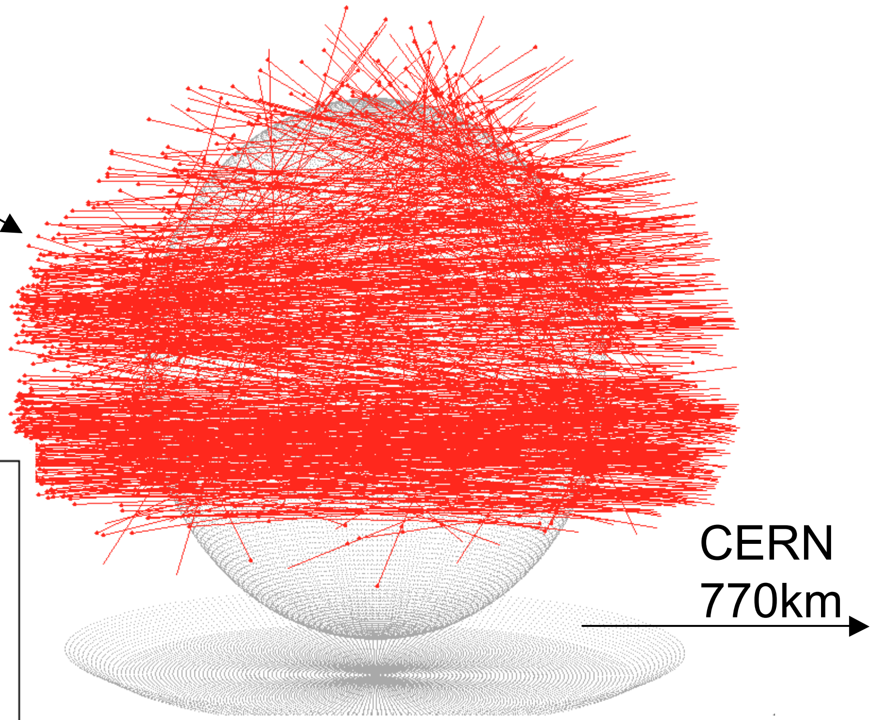
- Arrival times of 1st photons at PMTs
- Number of photons per PMT

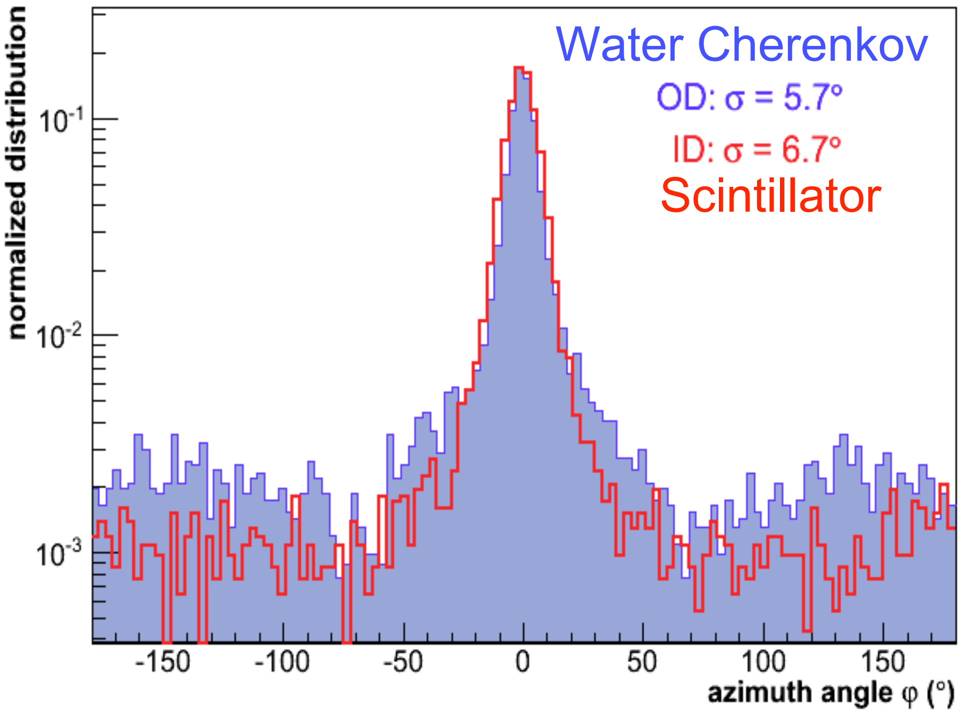
Sensitive to ***particle types*** due to the ratio of track length to visible energy.

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

Work under progress for **LENA** and scintillator **LBNE** option for DUSEL
-- *J. Learned, N. Tolich ...*

CNGS neutrino induced muons in BOREXINO





Direction from CERN

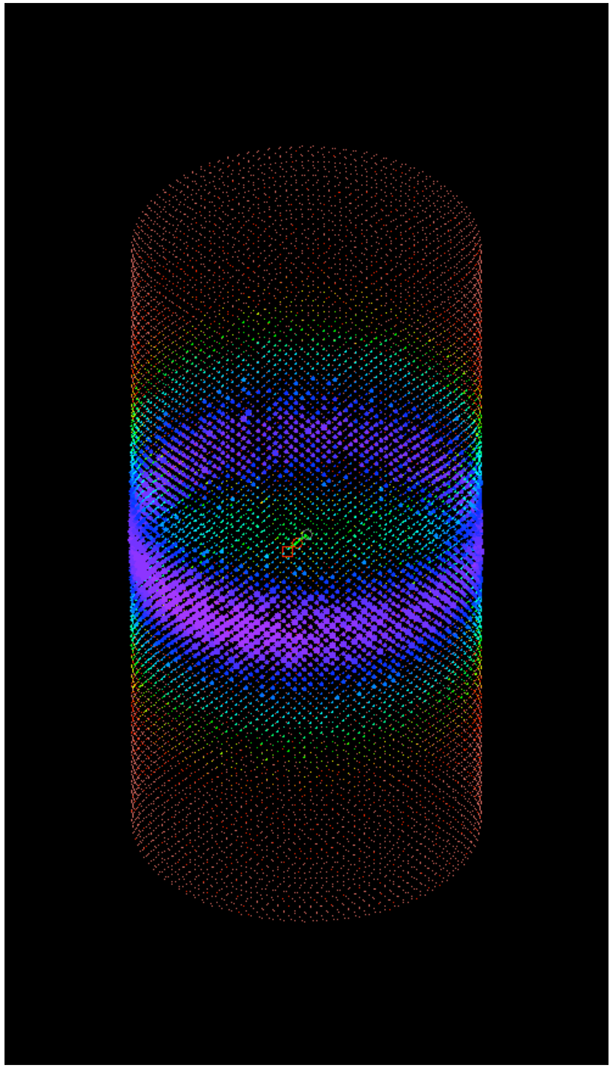
(azimuth = 0 degree)

real Data – no Monte-Carlo !

BOREXINO is NOT optimized for tracking !

Time distribution for first photon detection
(0-100 ns)

In Lena
Light detection



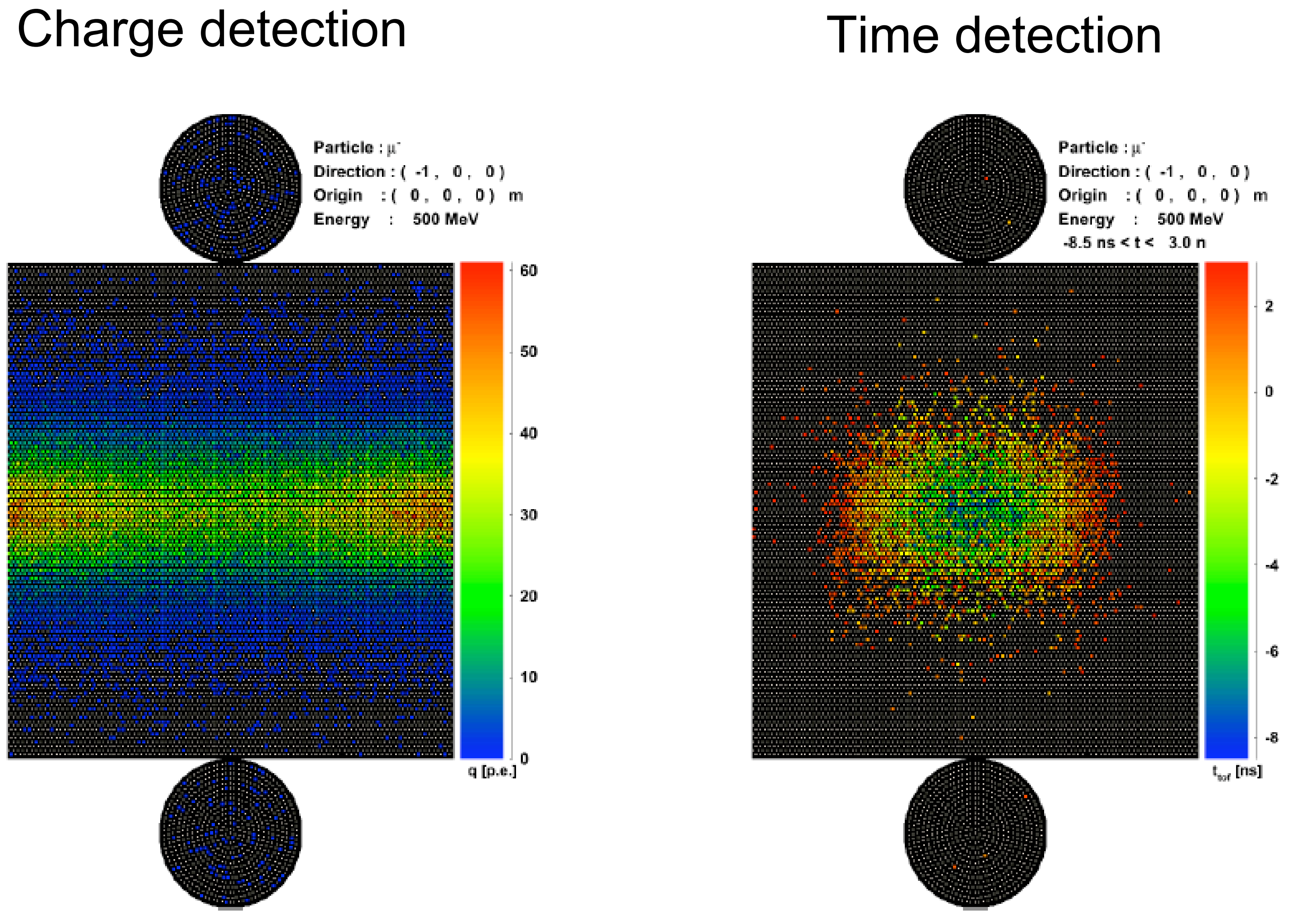
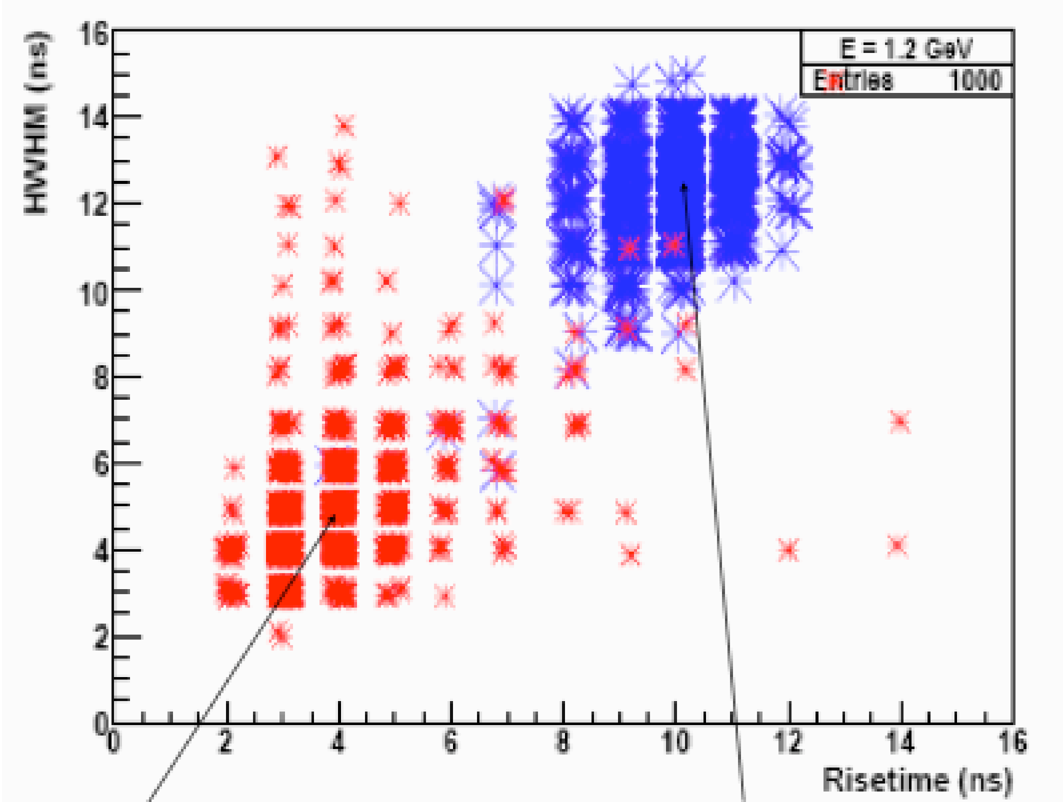


FIG. 18: A 500 MeV muon in LENA. On the left, the color coded information is the charge seen by each PMT, while the hit time of the first photon at each PMT is shown on the right, applying a time of flight correction with respect to the charge barycenter of the track.

Separation between e- and μ-like events possible

- Pulse shape discrimination (risetime, width)
- Track reconstruction
- Muon decay μ -> e ν ν
- Measuring the Michel electron
- Work under process



electrons (1.2 GeV) muons (1.2 GeV)

L. Oberauer, TUM

Signal shape analysis, time profile at the surface of the cylinder

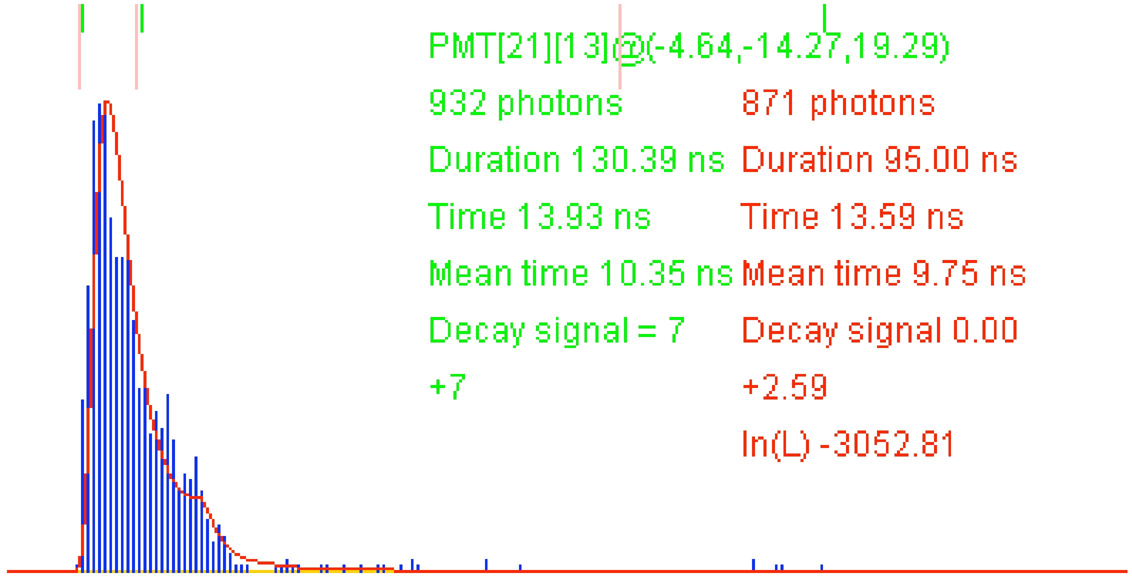
Single pion production with ν energy of 3 GeV

Depositable energy 2845.19 MeV Measurable energy 2984.00 MeV

electron:1661.13 MeV and 5.52 m.

proton:710.82 MeV and 2.29 m. vertexEnergy =0.00 MeV

pion:473MeV[104ns]



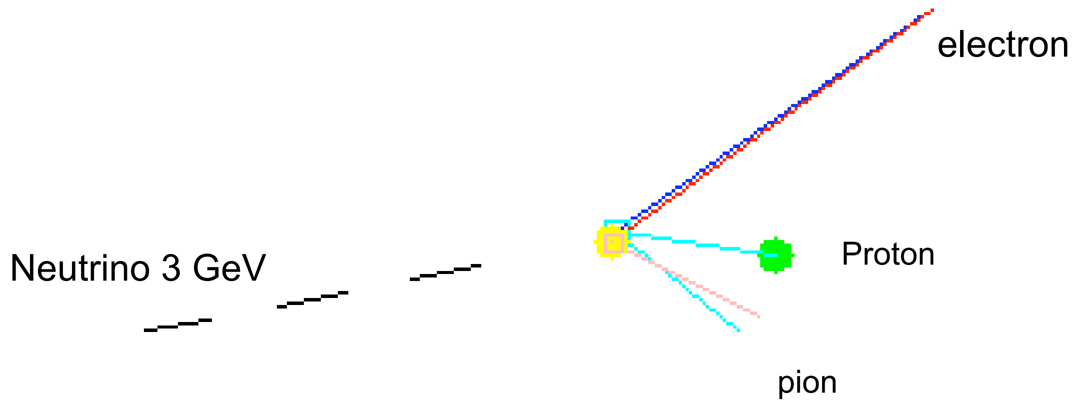
event reconstruction

Error in measured energy -58.27 MeV = -1.95 %

Error in lepton energy 385.84 MeV = 23.23 %

Error in lepton track 0.29 m = 5 %, vertex: 0.18 m.

Error angle L 0.04 rad = 2 deg (p 0.21 rad = 12 deg)



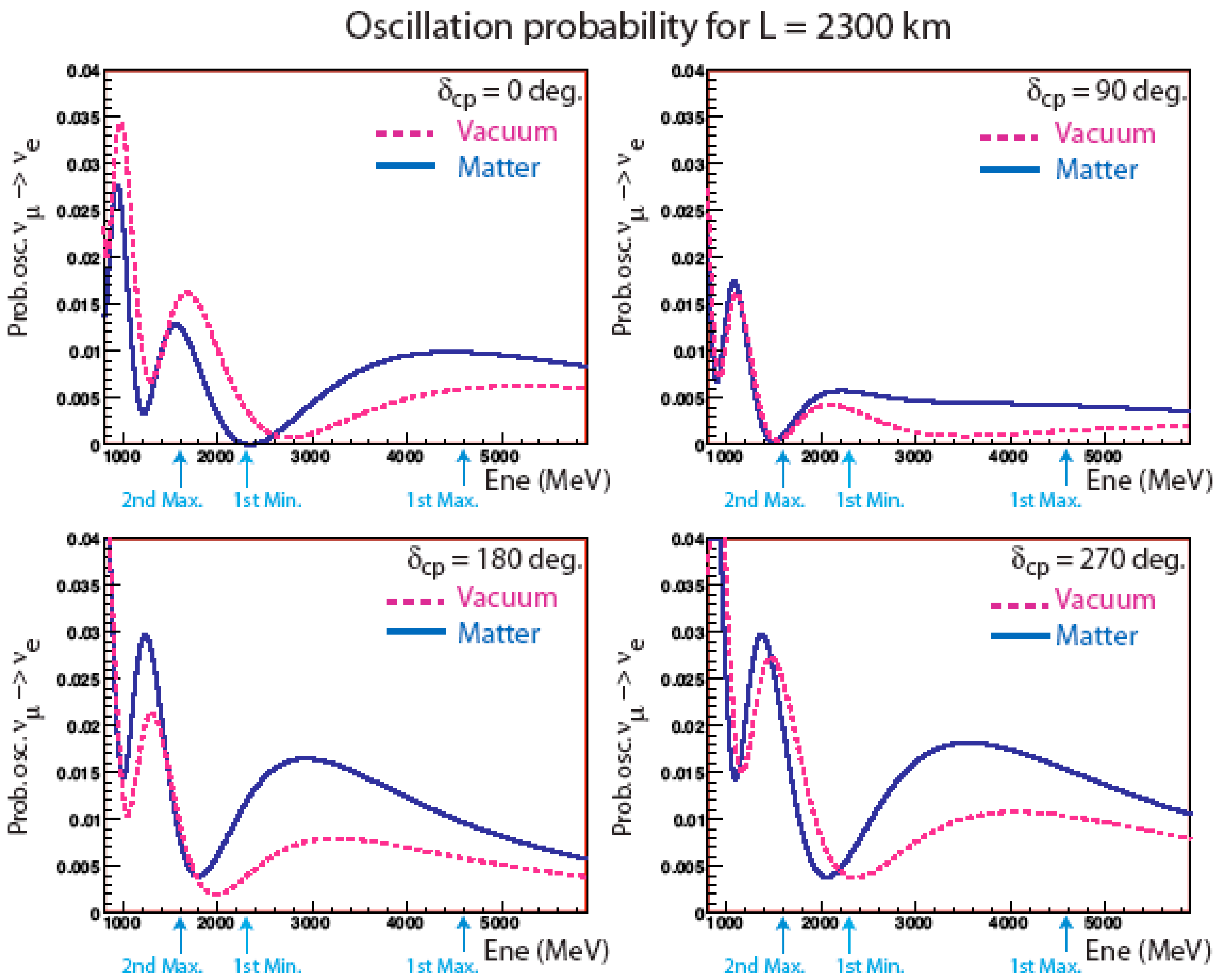
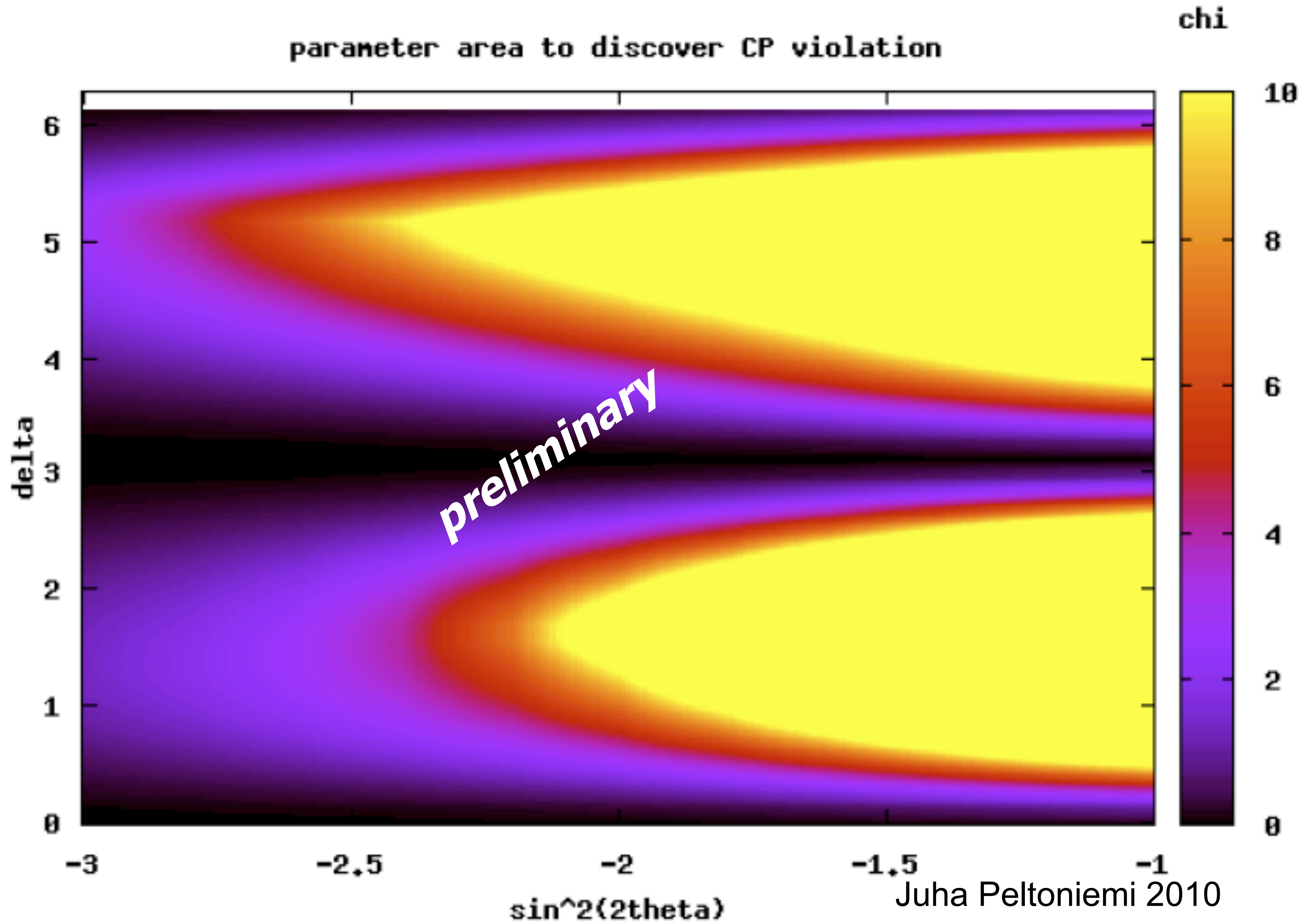
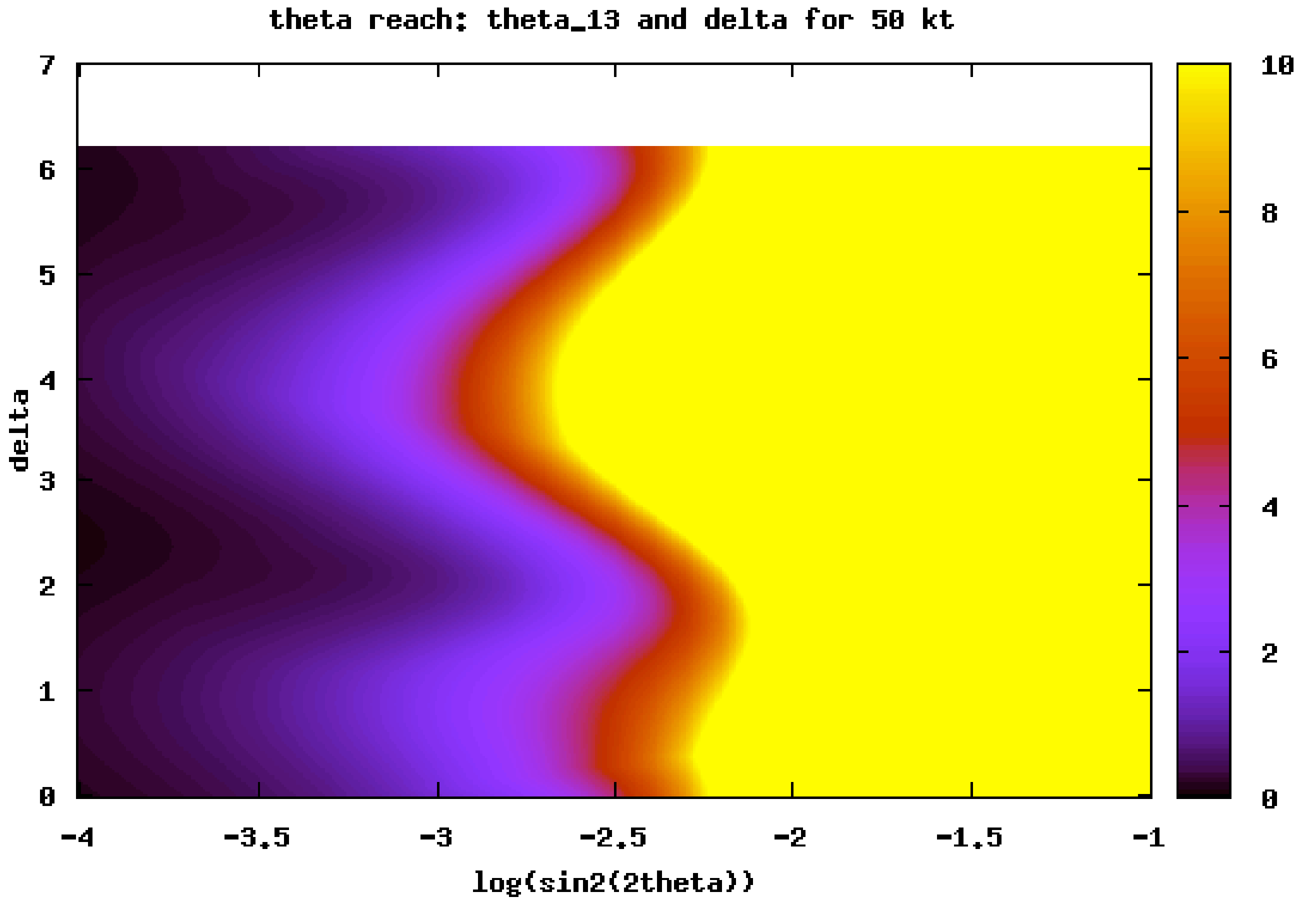


Fig. 1: Probability of $\nu_\mu \rightarrow \nu_e$ oscillation for different values of δ_{cp} with and without matter effects. In this example, the CERN-Pyhäsalmi baseline and $\sin^2 2\theta_{13} = 0.01$ were chosen.


parameter area to discover CP violation
chi
delta
sin^2(2theta)
preliminary
0
1
2
3
4
5
6
-3
-2.5
-2
-1.5
-1
0
2
4
6
8
10
Juha Peltoniemi 2010

2300 km baseline neutrino beam E(v) 3GeV
white band beam standard technology



Big future for low energy neutrino physics.

Lena site investigation within

LAGUNA:

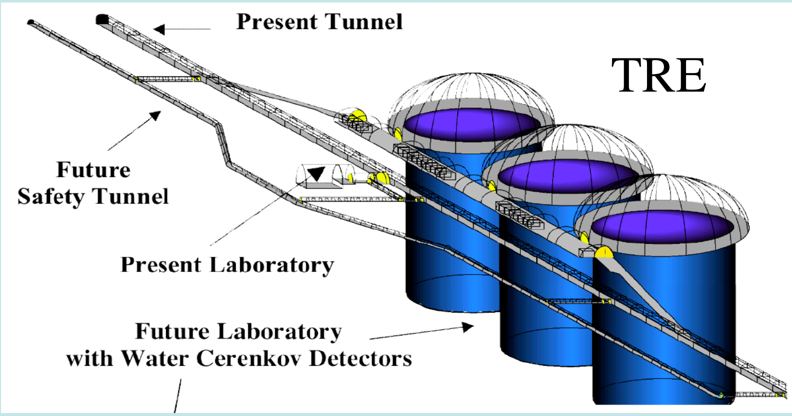
Large **A**pparatus for **G**rand **U**nification and **N**eutrino **A**strophysics

An new European large infrastructure for particle astrophysics at low energies: search for proton decay, low energy neutrino physics and neutrino astronomy

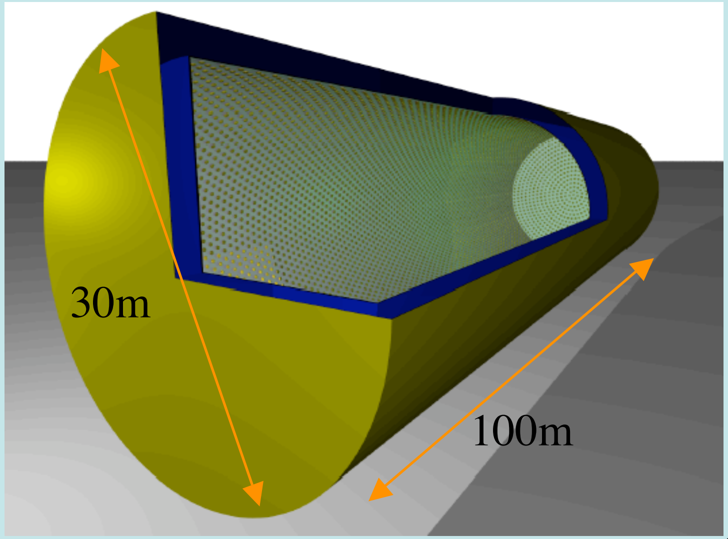
Franz v. Feilitzsch TUM

New large Underground Detectors

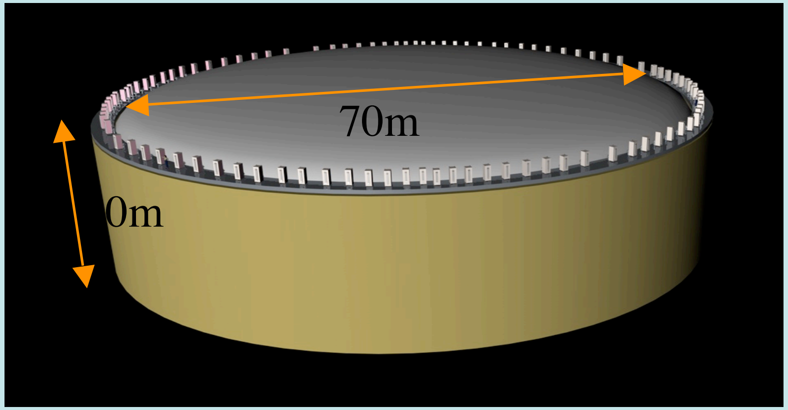
MEMPHYS



LENA Liquid Scintillator (→ 50 kton)



GLACIER Liquid Argon (≈10→100 kton)



List of people: J. Aystö, A. Badertscher, **A. de Bellefon**, *L. Bezrukov, J. Bouchez, A. Bueno, J. Busto, JE. Campagne, C. Cavata, R. Chandrasekharan, S.Davidson, J. Dumarchez, T. Enqvist, A. Ereditato, F. von Feilitzsch, S. Gninenko, M. Göger-Neff, C. Hagner, K. Hochmuth, S.Katsanevas, L. Kaufmann, J. Kisiel, T. Lachenmaier, M. Laffranchi, M. Lindner, J. Lozano, A. Meregaglia, M. Messina, M. Mezzetto, L. Mosca, S. Navas, L.Oberauer, P. Otyougova, T. Patzak, J. Peltoniemi, W. Potzel, G. Raffelt, A. Rubbia, N. Spooner, A. Tonazzo, T.M. Undagoitia, C. Volpe, M. Wurm, A. Zalewska, R. Zimmermann*

LAGUNA

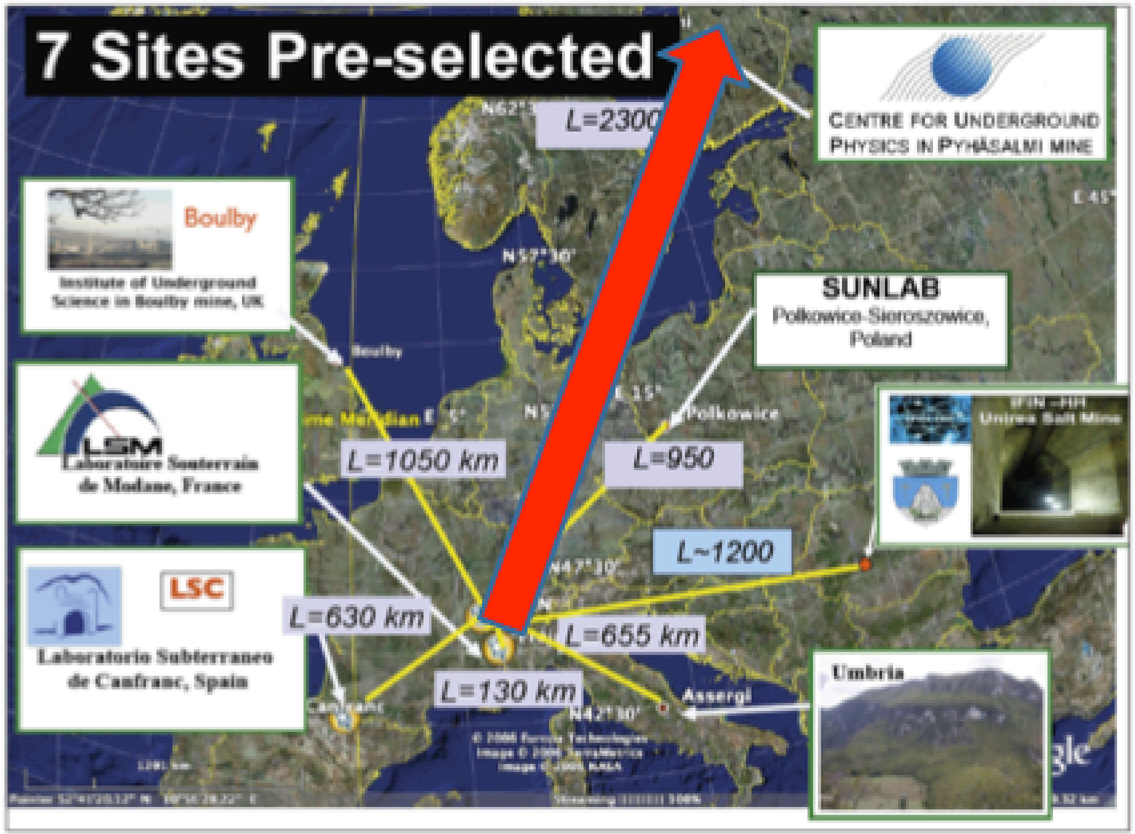
DETECTOR LOCATIONS

COLLABORATING INSTITUTES

APC, Paris, France
CEA, Saclay, France
CPPM, IN2P3-CBRS, Marseille, France
CUPP, Pyhäsalmi, Finland
ETHZ, Zürich, Switzerland
Institute for Nuclear Research, Moscow, Russia
IPNO, Orsay, France
LAL, IN2P3-CNRS, Orsay, France
LPNHE, IN2P3-CNRS, Paris, France
MPI-K Heidelberg, Germany
Max Planck für Physik, München, Germany
Technische Universität München, Germany
Universidad de Granada, Spain
Universität Hamburg, Germany
University of Bern, Switzerland
University of Helsinki, Finland
University of Jyväskylä, Finland
University of Oulu, Finland
University of Silesia, Katowice, Poland
University of Sheffield, UK

Institute of Physics and Nuclear Engineering, Bucharest IFIN-HH Romania

Laguna Design Study



LAGUNA:

- European site + design study for a next generation neutrino and p-decay detector
- 7 preselected sites
- Proposed experiments: GLACIER, LENA, MEMPHYS

  (Liq. Ar, Scint., Water Ch)

- **First design option: LENA (50 kt) and GLACIER (25 kt) at Pyhäsalmi**

Baseline 2300 km: Access to neutrino mass hierarchy & CP phase

unique oppurtunity („magic baseline")

New EU-design study approved

Laguna LBNO

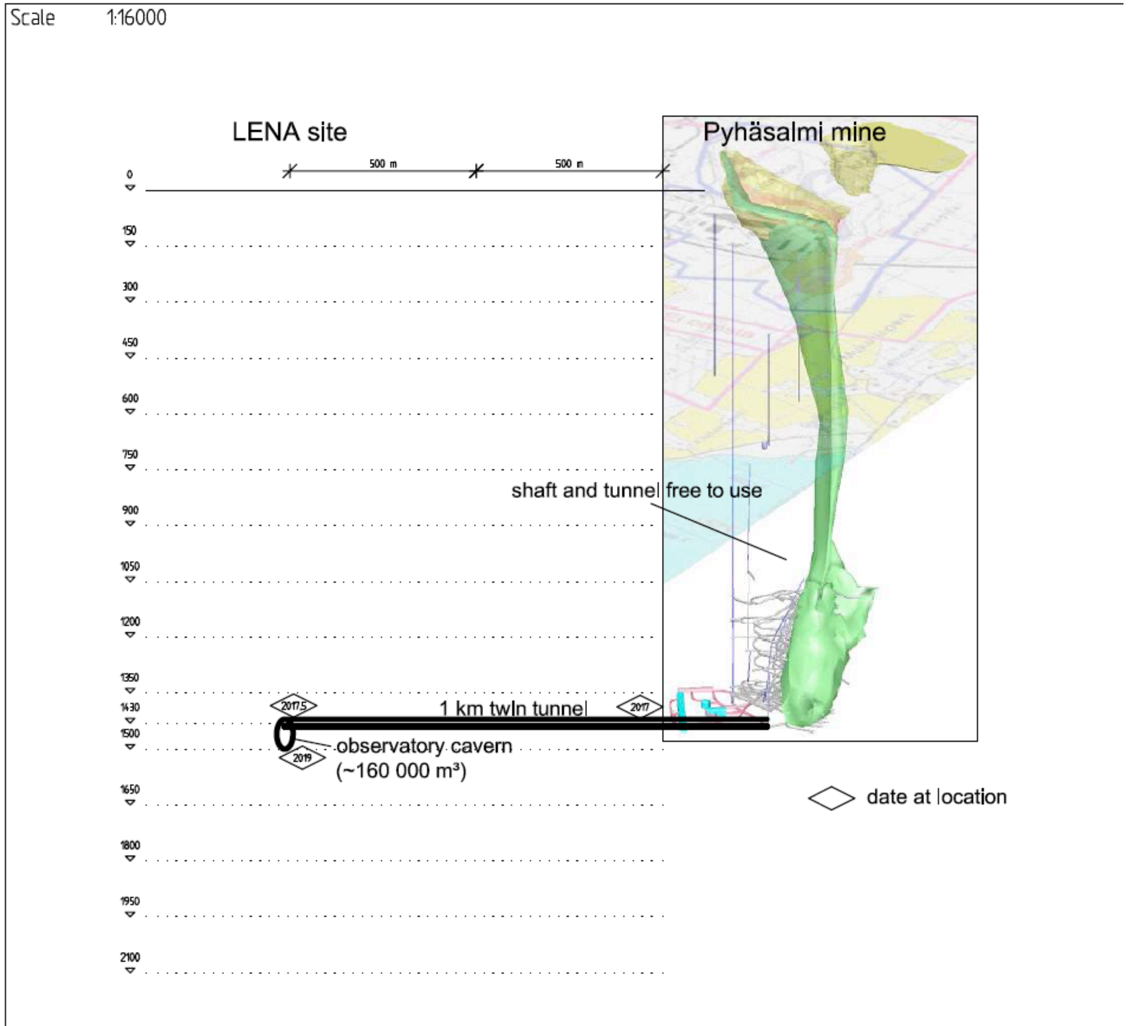
For long baseline neutrino beam and detector design

4.9 M€

For the 3 detectors

H_2O, Ar(L), Scintillator

Lena in Phyäsalmi laboratory at 1400 m depth

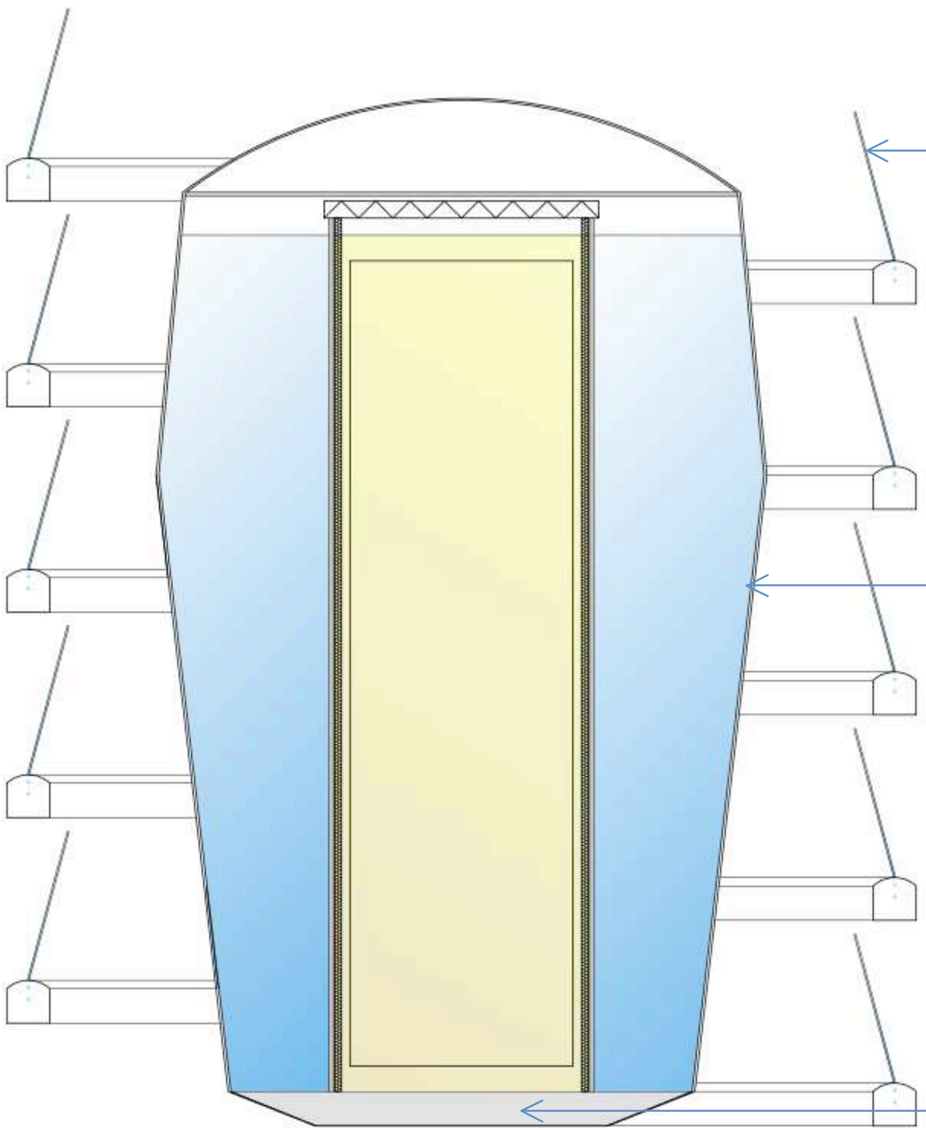


Schedule (excavation works):
- start 2017 earliest (after Pyhäsalmi mining has been shut down)
- duration 2 years
- finish in 2019

Tank design study

4 options studied

TANK SURROUNDINGS

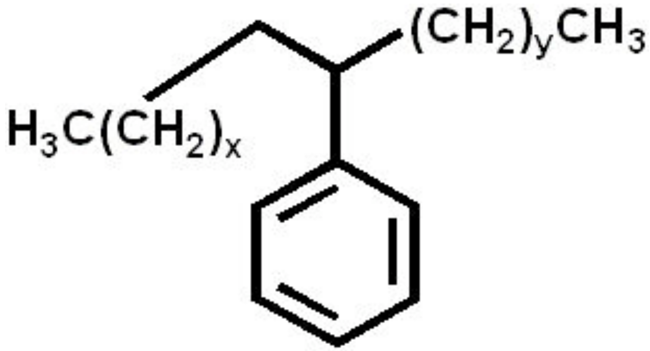


Drainage holes in case of water filled joints from spherical tunnel

Polyurethane membrane on shotcrete lining (like SNOLAB)

Tank foundation, anchored against buoyancy

LIQUIDS & PURITY REQUIREMENTS



Linear Alkylbenzene (LAB),
CAS 67774-74-7

density of LAB is ρ = 860 kg/m^3.

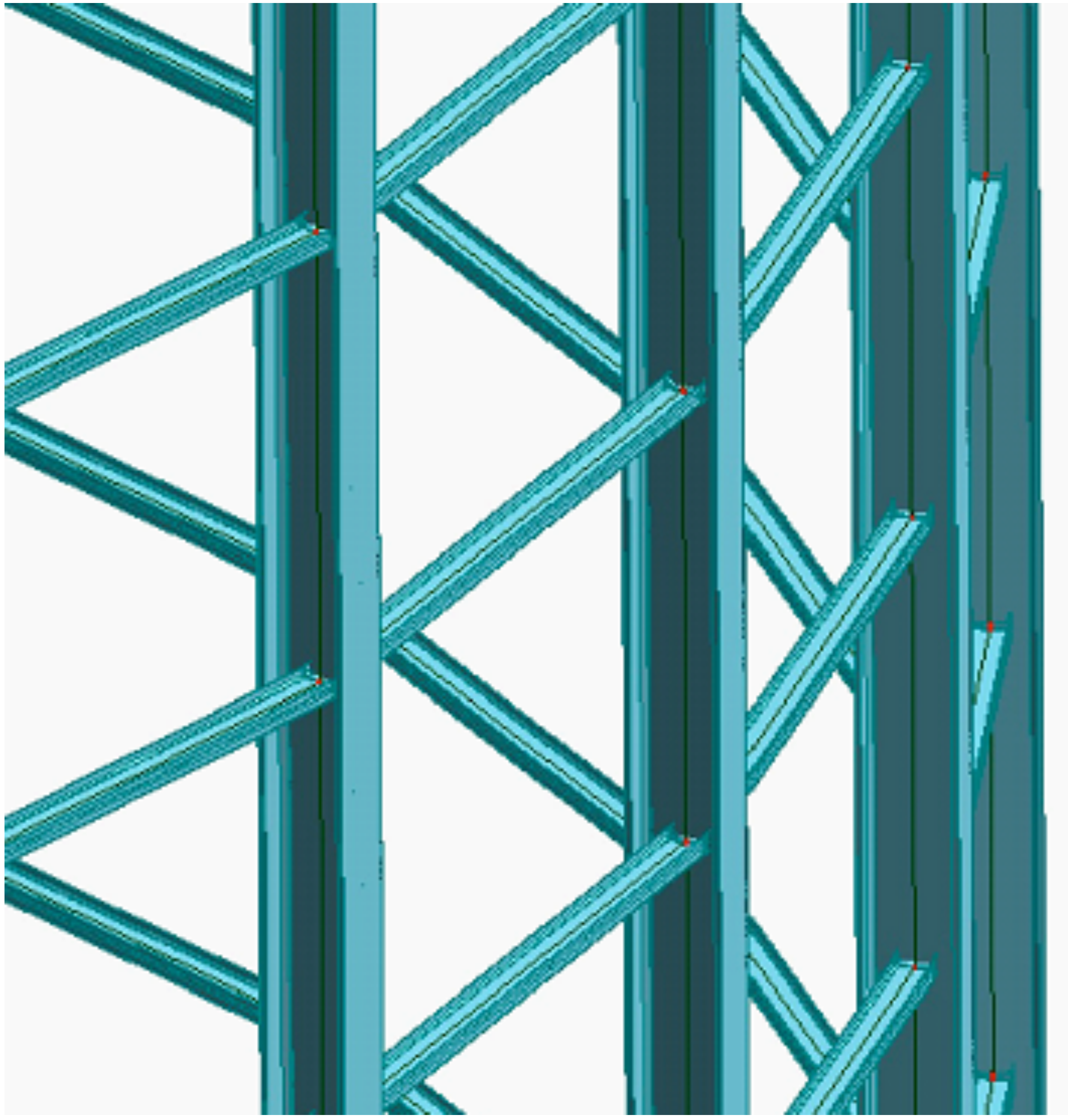
Solvent	PXE	LAB	C12	PC	CH	H_2O
Physical and Chemical Data [143, 144, 145, 146, 147]						
Chemical Formula	$C_{16}H_{18}$	$C_{18}H_{30}$	$C_{12}H_{26}$	C_9H_{12}	C_6H_{12}	H_2O
Molecular Weight $\mathcal{M}$ [g/mol]	210	241	170	120	84	18
Specific Gravity ρ [g/cm^3]	0.99	0.86	0.75	0.88	0.78	1.00
Viscosity [cps]		4.2	1.3		1.0	1.0
Flash Point [°C]	167	140	83	48	-18	
molecular density n [10^{27}/m^3]	2.8	2.2	2.7	4.4	5.5	33.5
free protons [10^{28}/m^3]	4.7	6.6	7.0	5.3	6.6	6.7
Carbon nuclei [10^{28}/m^3]	4.2	4.0	3.2	4.0	3.3	
total p/e$^-$ [10^{29}/m^3]	3.2	3.0	2.6	2.9	2.6	3.4
Hazardous Materials Identification System (HMIS) Rating [143, 144, 145, 146, 147]						
Health	1	1	1	2	1	0
Flammability	1	1	0	2	3	0
Reactivity	0	0	0	1	0	0
Optical Properties (n, L, ℓ_{ray} at 430 nm) [80, 140, 141, 142, 148, 107, 126, 149, 150]						
Refractive Index n	1.57	1.49	1.42	1.50	1.43	1.33
Relative Light Yield y	1.	1.	<0.4	$\leq 1.$		
Fast Decay Constant τ_1 [ns]	2.63	5.21		3.57		
Absorption Maximum [nm]	270	260		265	<120	
Emission Maximum [nm]	290	283		290		
Attenuation Length L [m]	12	~ 20	>12	8	44	90
Rayleigh Scat. Length ℓ_{ray} [m]	32	45	(37)	21	44	90

Table 8.2: Overview of the solvent parameters of PXE, LAB, dodecane (C12), PC, cyclohexane (CH) and water (H_2O). The information on physical parameters, HMIS rating, and refractive index are cited from material safety and product specification sheets of the producers [143,

Radio purity limits from materials within vicinity of the scintillator oil.

Symbol	Name	Mass limit	Radioactivity	*limit Conversion*
^{238}U or ^{226}Ra	Uranium	1E-9 g/g	0.50 Bq/kg	*0.12 Bq/kg*
^{232}Th	Thorium	1E-9 g/g	0.20 Bq/kg	*0.04 Bq/kg*
^{40}K	Kalium	1E-5 g/g	0.03 Bq/kg	*0.31 Bq/kg*

ALT. 1: CONVENTIONAL STEEL



Conventional Steel Tank

+ well known (e.g. submarine skeleton hulls, vacuum tanks etc.)

+ straightforward to build

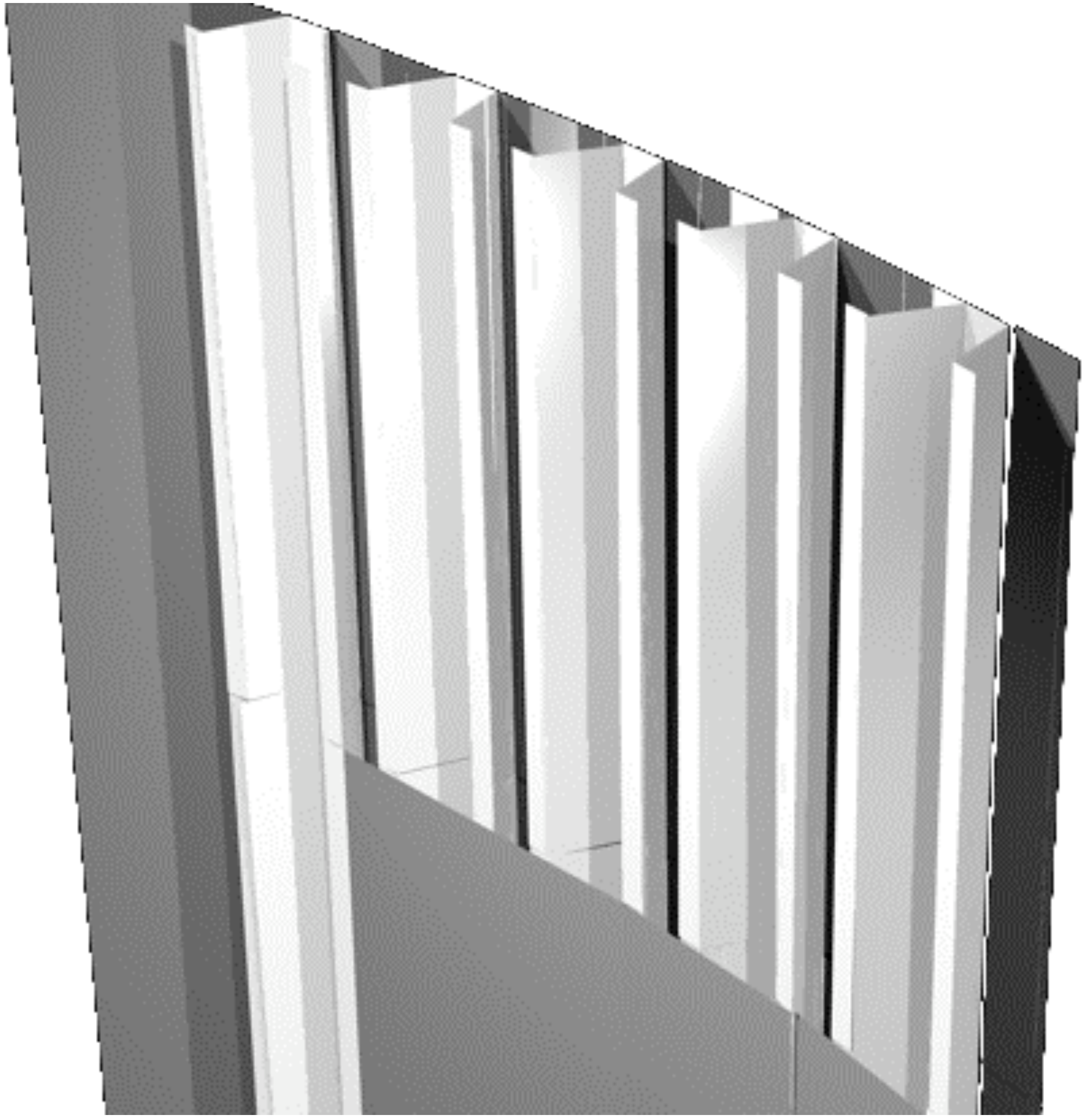
+ robust

- expensive (intensive use of stainless steel alloys)

- single passive layer defense against leak (risk of progressive failure)

- a lot of structural elements and on site connections

ALT. 2: SANDWICH STEEL TANK



<u>Sandwich Steel Tank</u>

+ cost effective

+ room for installation (e.g. cooling pipes)

+ fast to install

+ high quality control potential

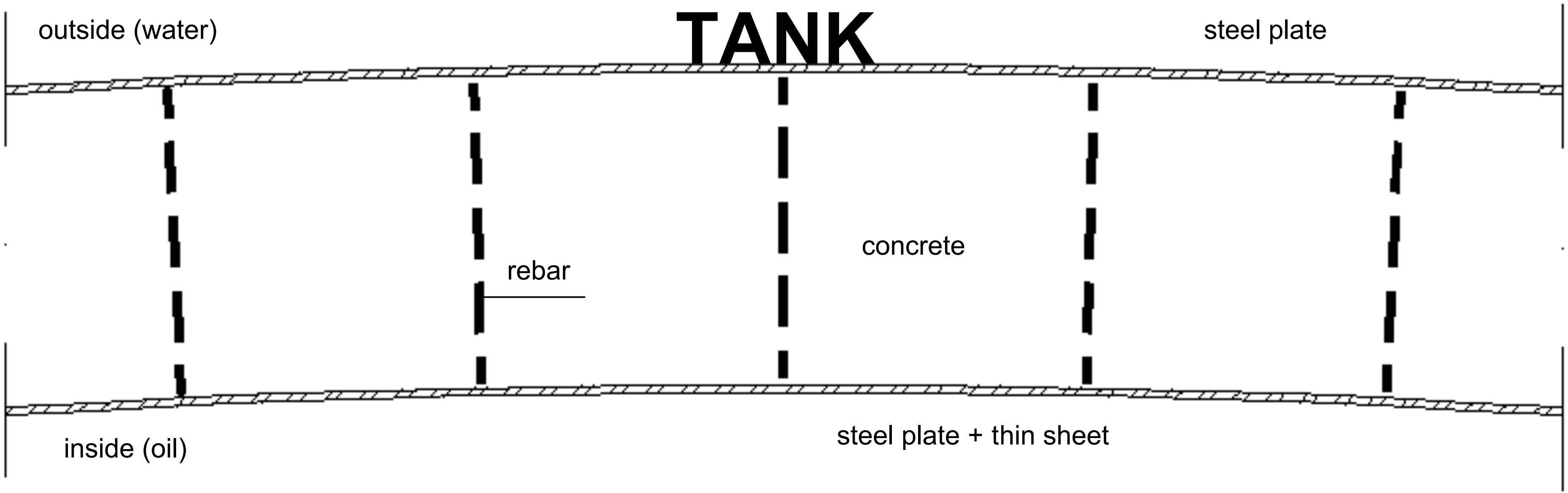
+ mechanized laser welding potential (quick and reliable)

- high amount of welded connections on site

- little used solution in tanks (widely used for walls and roofs)

- mechanically challenging to design for tangential compression

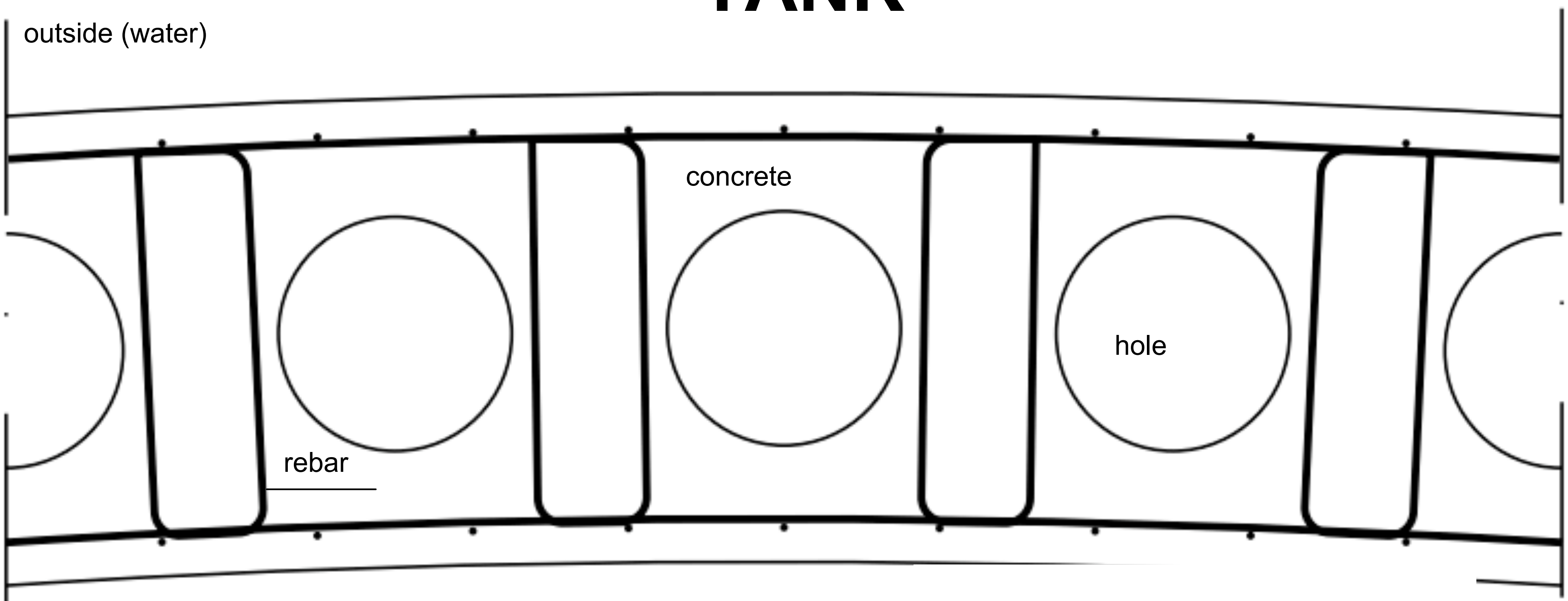
ALT. 3 SANDWICH CONCRETE TANK



<u>**Sandwich Concrete Tank**</u>

+ well known
+ straightforward to build
+ robust
+ additional volume increases physics potential
- steel plates and fixed rebar prevent use of continuous casting methods
- slow to build

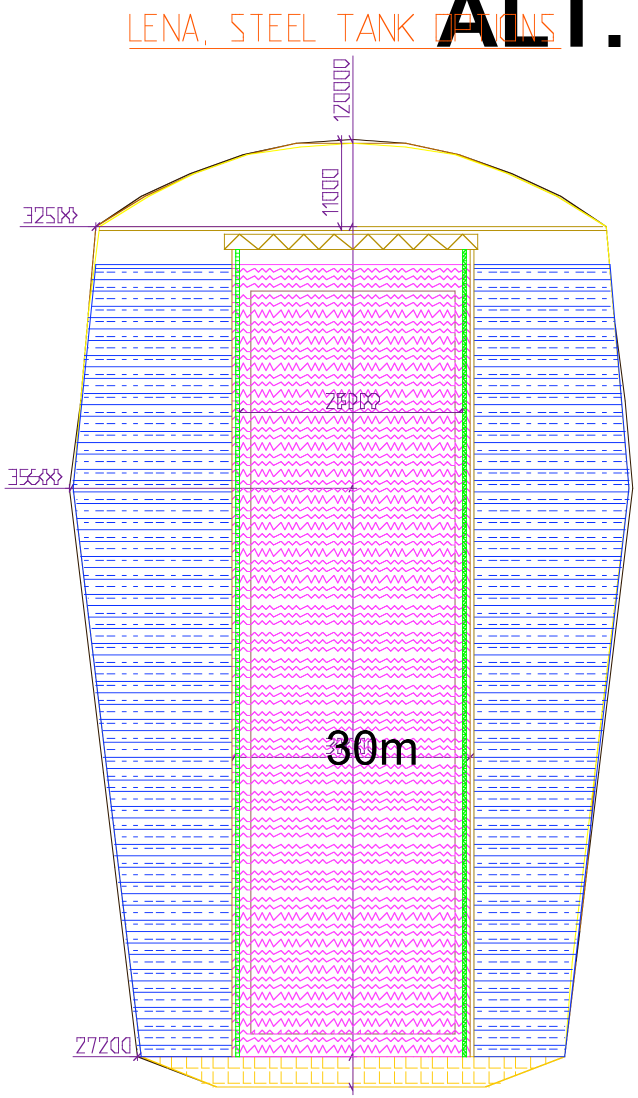
ALT. 4 HOLLOW CORE CONCRETE TANK

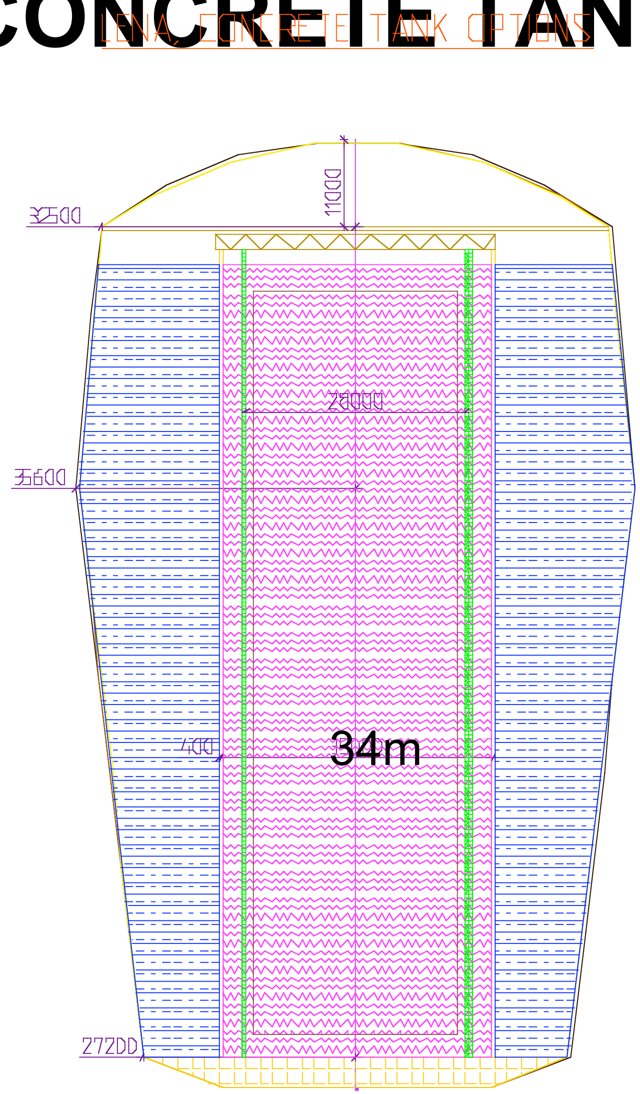


Hollow Core Concrete Tank

+ room for installation (e.g. cooling pipes)
+ mechanically the strongest option
+ additional volume increases physics potential
+ fairly quick to build (using continuous casting)
- little used solution in tanks (widely used as pretensioned floor slabs)
- using active leak prevention may lead to sustained pumping

ALT. 3 CONCRETE TANK





LIQUIDS: Steel Tank

Liquid scintillator oil
(51,000 m^3, 43.8 kton)

Non-scintillating oil
(19,700 m^3, 17.0 kton)

TOTAL: 70,700 m^3

LIQUIDS: Concrete Tank

Liquid scintillator oil
(51,000 m^3, 43.8 kton)

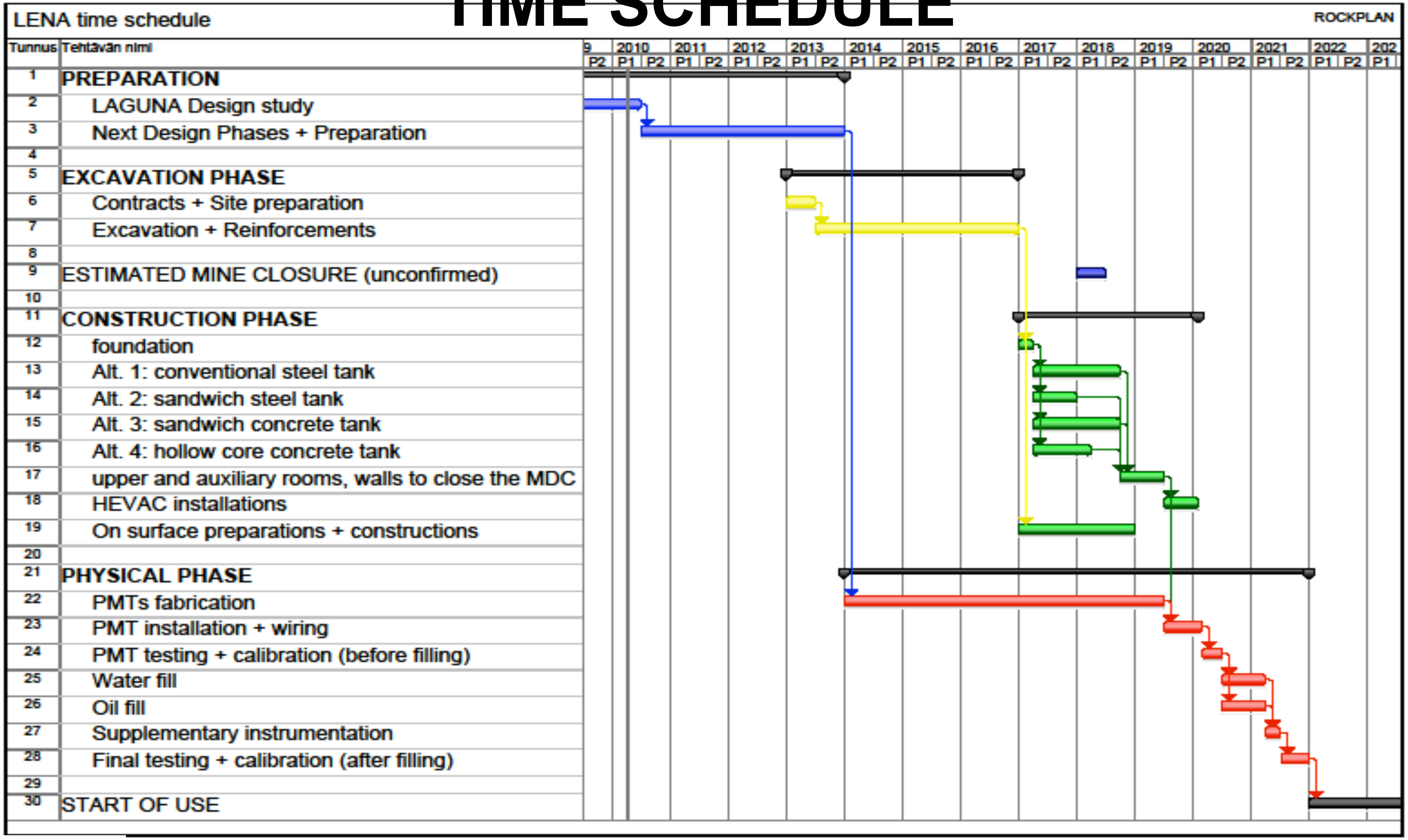
Non-scintillating oil
(39,800 m^3, 34.2 kton)

TOTAL: 90,800 m^3

E15 Chair for Experimental Physics and Astroparticle Physics

ROCKPLAN

TIME SCHEDULE



TOTAL COSTS

Sandwich Concrete Tank

Tank Construction	6 M€
Other Construction	11 M€
Scientific	196 M€
Design, Building and Management	31 M€
Combined comparison price	244 M€

Hollow Core Concrete Tank

Tank Construction	4 M€
Other Construction	11 M€
Scientific	196 M€
Design, Building and Management	31 M€
Combined comparison price	242 M€

Conventional Steel Tank

Tank Construction	25 M€
Other Construction	11 M€
Scientific	176 M€
Design, Building and Management	32 M€
Combined comparison price	244 M€

Sandwich Steel Tank

Tank Construction	18 M€
Other Construction	11 M€
Scientific	176 M€
Design, Building and Management	30 M€
Combined comparison price	235 M€

Underground engineering (excavation) 75 M€

Sandwich Concrete Tan	319 M€
Hollow Core Concrete Tank	317 M€
Conventional Steel Tank	319 M€
Sandwich Steel Tank	**310 M€**

Lena
Scintillators
LAB preferred

Solvent	**LAB**	**PXE**	**C12**
Physical and Chemical Data			[248–252]
Chemical Formula	$C_{18}H_{30}$	$C_{16}H_{18}$	$C_{12}H_{26}$
Molecular Weight $\mathcal{M}$ [g/mol]	241	210	170
Density ρ [kg/ℓ]	0.863	0.986	0.749
Specific Gravity ρ [g/cm^3]	0.86	0.99	0.75
Viscosity [cps]	4.2		1.3
Flash Point [°C]	140	167	83
Molecular density n [10^{27}/m^3]	2.2	2.8	2.7
Free protons [10^{28}/m^3]	6.6	4.7	7.0
Carbon nuclei [10^{28}/m^3]	4.0	4.2	3.2
Total p/e$^-$ [10^{29}/m^3]	3.0	3.2	2.6
HMIS Ratings			[248–250]
Health	1	1	1
Flammability	1	1	0
Reactivity	0	0	0
Optical Properties (n,L,ℓ_{ray} @ 430 nm)			[247, 253–260]
Refractive Index n	1.49	1.57	1.42
Absorption Maximum [nm]	260	270	-
Emission Maximum [nm]	283	290	-
Attenuation Length L [m]	~20	12	>12
Rayleigh Scat. Length ℓ_{ray} [m]	45	32	(37)

Construction time and cash flow (FINLAND + LENA)

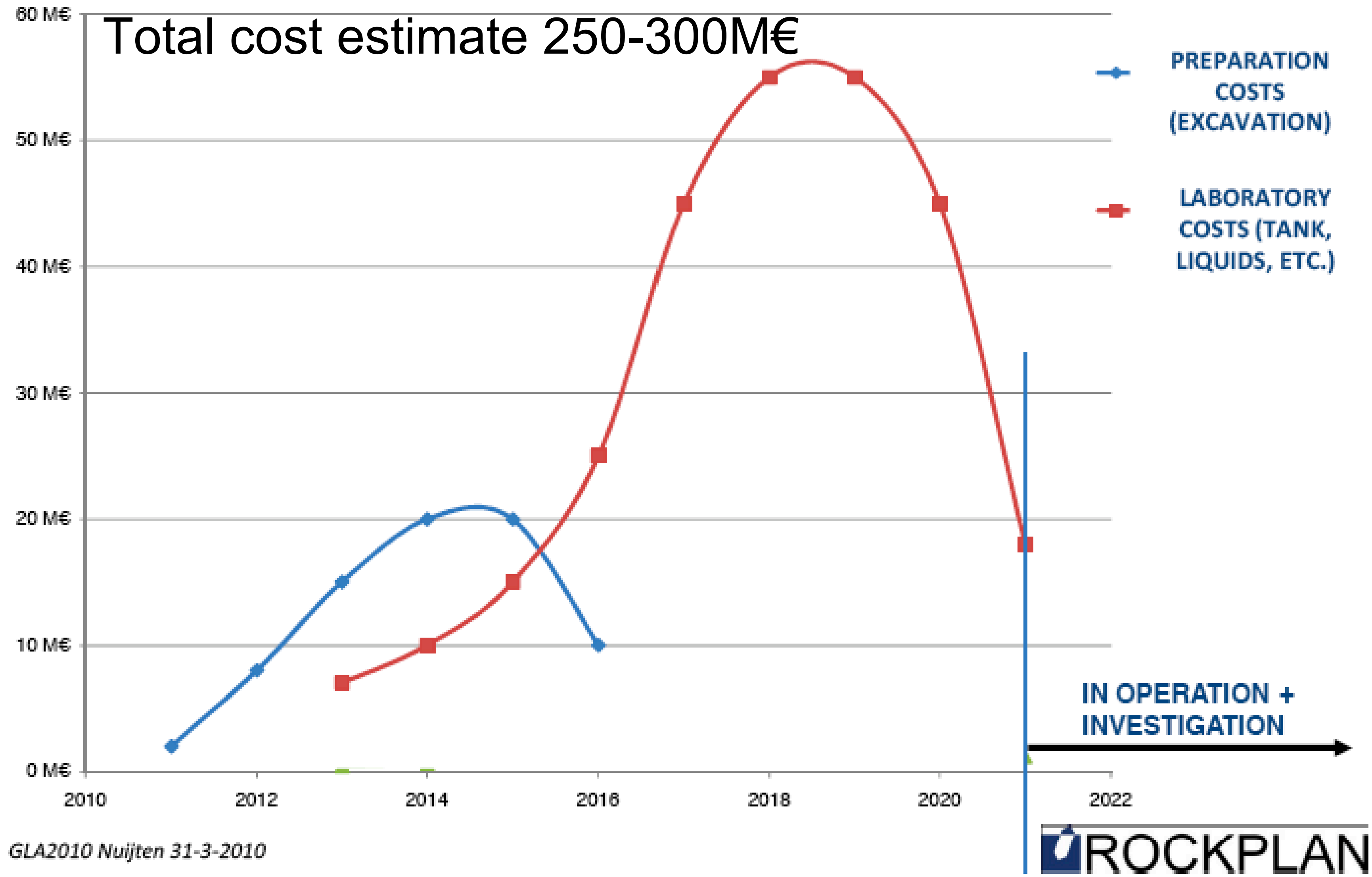


Figure 8-1. Distribution of Cash Flow (in M€)

Lena white paper

The next-generation liquid-scintillator neutrino observatory LENA

Michael Wurm,[1,2,*] John F. Beacom,[3] Leonid B. Bezrukov,[4] Daniel Bick,[2] Johannes Blümer,[5] Sandhya Choubey,[6] Christian Ciemniak,[1] Davide D'Angelo,[7] Basudeb Dasgupta,[3] Amol Dighe,[8] Grigorij Domogatsky,[4] Steve Dye,[9] Sergey Eliseev,[10] Timo Enqvist,[11] Alexey Erykalov,[10] Franz von Feilitzsch,[1] Gianni Fiorentini,[12] Tobias Fischer,[13] Marianne Göger-Neff,[1] Peter Grabmayr,[14] Caren Hagner,[2] Dominikus Hellgartner,[1] Johannes Hissa,[11] Shunsaku Horiuchi,[3] Hans-Thomas Janka,[15] Claude Jaupart,[16] Josef Jochum,[14] Tuomo Kalliokoski,[17] Pasi Kuusiniemi,[11] Tobias Lachenmaier,[14] Ionel Lazanu,[18] John G. Learned,[19] Timo Lewke,[1] Paolo Lombardi,[7] Sebastian Lorenz,[2] Bayarto Lubsandorzhiev,[14] Livia Ludhova,[7] Kai Loo,[17] Jukka Maalampi,[17] Fabio Mantovani,[12] Michela Marafini,[20] Jelena Maricic,[21] Teresa Marrodán Undagoitia,[22] William F. McDonough,[23] Lino Miramonti,[7] Alessandro Mirizzi,[24] Quirin Meindl,[1] Olga Mena,[25] Randolph Möllenberg,[1] Rolf Nahnhauer,[26] Dmitry Nesterenko,[10] Yuri N. Novikov,[10] Guido Nuijten,[27] Lothar Oberauer,[1] Sandip Pakvasa,[28] Sergio Palomares-Ruiz,[29] Marco Pallavicini,[30] Silvia Pascoli,[31] Thomas Patzak,[20] Juha Peltoniemi,[32] Walter Potzel,[1] Tomi Räihä,[11] Georg G. Raffelt,[33] Gioacchino Ranucci,[7] Soebur Razzaque,[34] Kari Rummukainen,[35] Juho Sarkamo,[11] Valerij Sinev,[4] Christian Spiering,[26] Achim Stahl,[36] Felicitas Thorne,[1] Marc Tippmann,[1] Alessandra Tonazzo,[20] Wladyslaw H. Trzaska,[17] John D. Vergados,[37] Christopher Wiebusch,[36] and Jürgen Winter[1]

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[33]*Max-Planck-Institut für Physik, München, Germany*
[34]*George Mason University, Fairfax, VA, USA*
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[36]*III. Physikalisches Institut, RWTH Aachen University, Germany*
[37]*Physics Department, University of Ioannina, Greece*
(Dated: April 28, 2011)

Conclusion

low energy astro particle physics

provide a unique complementary
research to

high energy physics with
accelerators

in fundamental particle physics
and neutrino astronomy