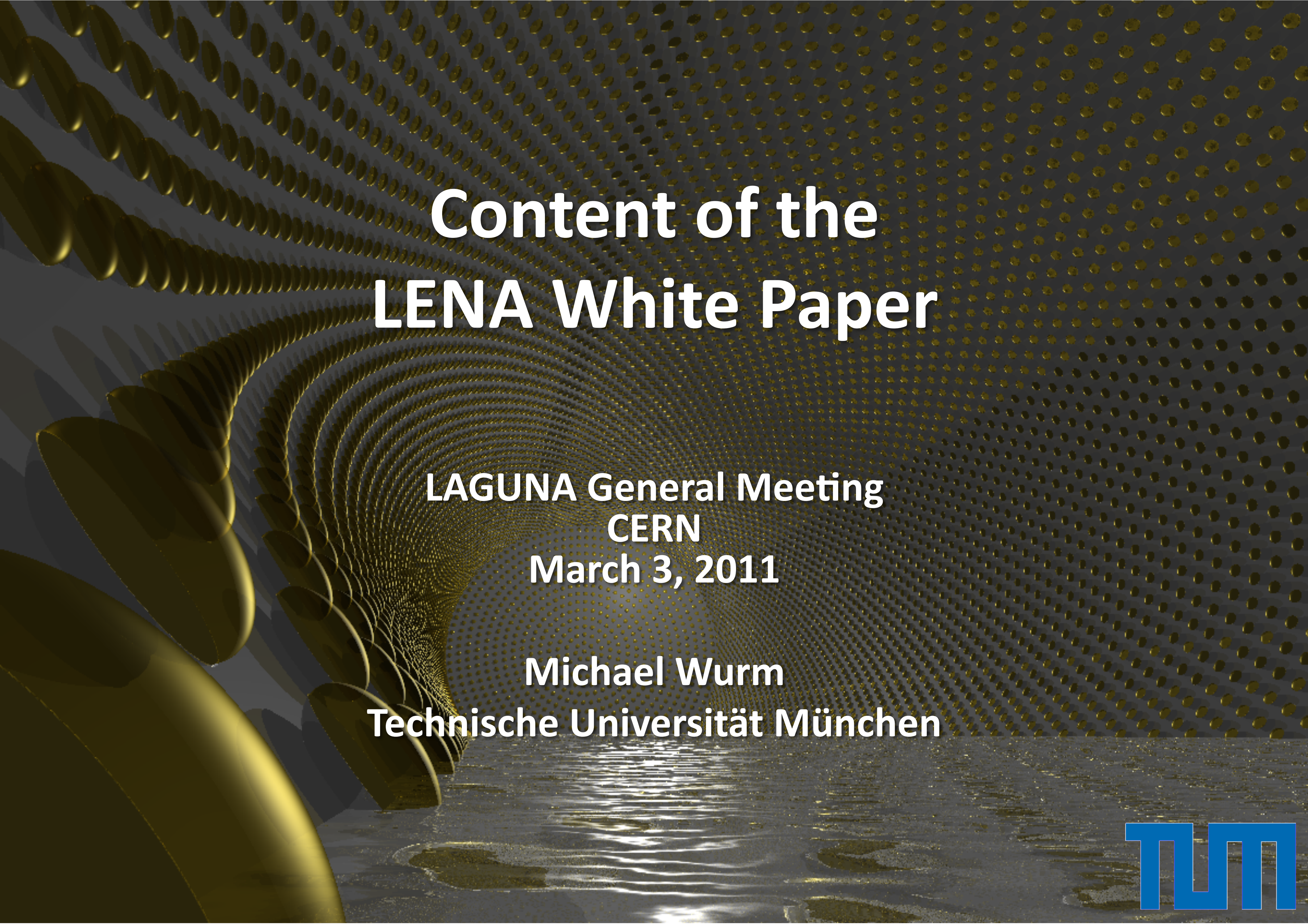


Content of the LENA White Paper

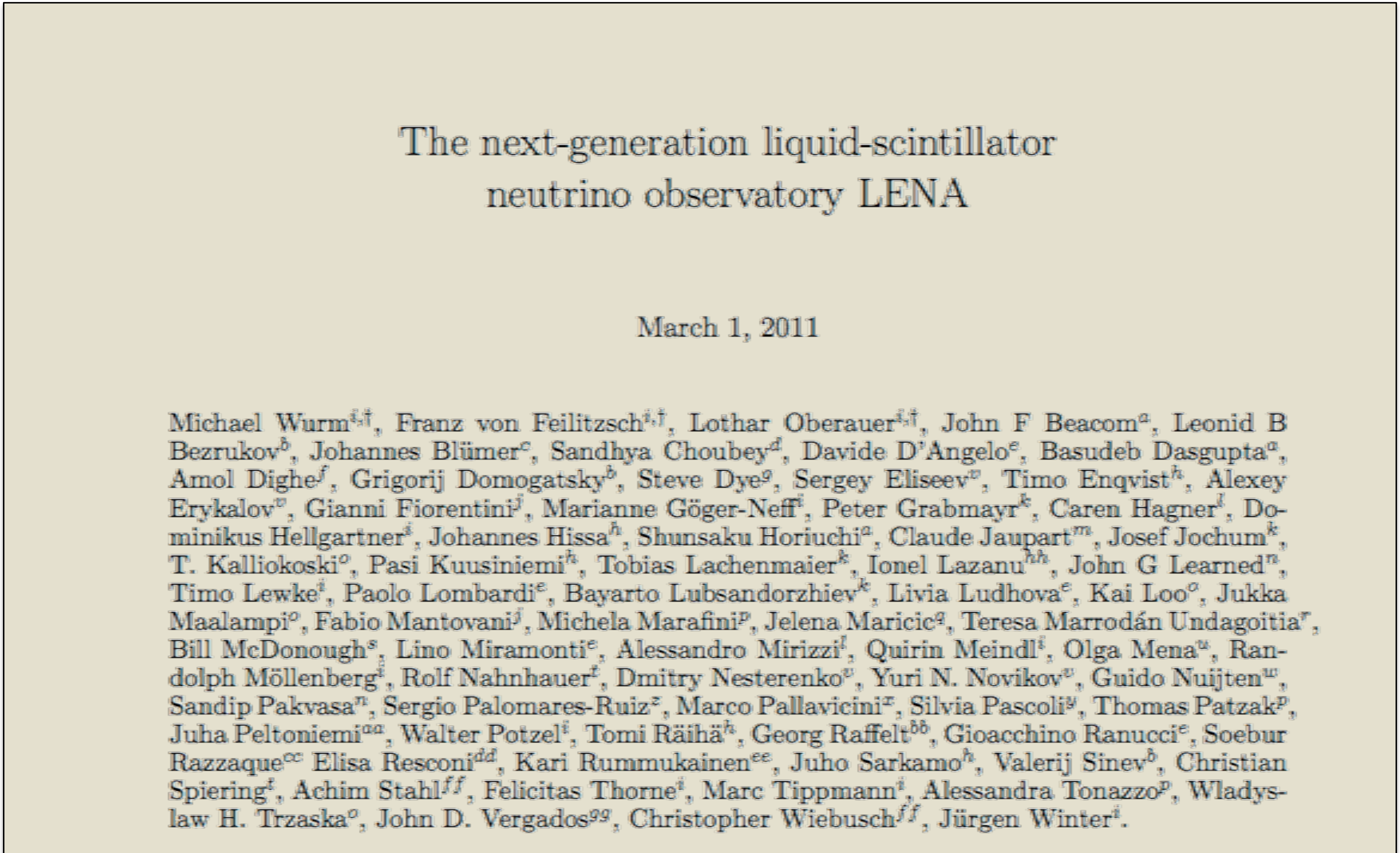
LAGUNA General Meeting
CERN
March 3, 2011

Michael Wurm
Technische Universität München

Motivation

- Collect all available information on liquid scintillator
  → present an overview to the scientific community
- Gather the people interested in the physics program specific to LENA and their various ideas

Who is writing?



The next-generation liquid-scintillator neutrino observatory LENA

March 1, 2011

Michael Wurm[i,†], Franz von Feilitzsch[i,†], Lothar Oberauer[i,†], John F Beacom[a], Leonid B Bezrukov[b], Johannes Blümer[c], Sandhya Choubey[d], Davide D'Angelo[e], Basudeb Dasgupta[a], Amol Dighe[f], Grigorij Domogatsky[b], Steve Dye[g], Sergey Eliseev[v], Timo Enqvist[h], Alexey Erykalov[v], Gianni Fiorentini[j], Marianne Göger-Neff[i], Peter Grabmayr[k], Caren Hagner[l], Dominikus Hellgartner[i], Johannes Hissa[h], Shunsaku Horiuchi[a], Claude Jaupart[m], Josef Jochum[k], T. Kalliokoski[o], Pasi Kuusiniemi[h], Tobias Lachenmaier[k], Ionel Lazanu[hh], John G Learned[n], Timo Lewke[i], Paolo Lombardi[e], Bayarto Lubsandorzhiev[k], Livia Ludhova[e], Kai Loo[o], Jukka Maalampi[o], Fabio Mantovani[j], Michela Marafini[p], Jelena Maricic[q], Teresa Marrodán Undagoitia[r], Bill McDonough[s], Lino Miramonti[e], Alessandro Mirizzi[l], Quirin Meindl[i], Olga Mena[u], Randolph Möllenberg[i], Rolf Nahnhauer[t], Dmitry Nesterenko[v], Yuri N. Novikov[v], Guido Nuijten[w], Sandip Pakvasa[n], Sergio Palomares-Ruiz[z], Marco Pallavicini[x], Silvia Pascoli[y], Thomas Patzak[p], Juha Peltoniemi[aa], Walter Potzel[i], Tomi Räihä[h], Georg Raffelt[bb], Gioacchino Ranucci[e], Soebur Razzaque[cc] Elisa Resconi[dd], Kari Rummukainen[ee], Juho Sarkamo[h], Valerij Sinev[b], Christian Spiering[t], Achim Stahl[ff], Felicitas Thorne[i], Marc Tippmann[i], Alessandra Tonazzo[p], Wladyslaw H. Trzaska[o], John D. Vergados[gg], Christopher Wiebusch[ff], Jürgen Winter[i].

Who is writing?

73 authors from **32 institutions** in **13 countries**

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Univ. of Oulu
Rockplan Ltd.
Neutrinica Oy

France
APC Paris
IPG Paris

Greece
Univ. of Ioannina

Germany
RWTH Aachen
Univ. Hamburg
KIT Karlsruhe
MPP München
TU München
Univ. Tübingen
DESY Zeuthen

Italy
INFN Ferrara
INFN Genova
INFN Milano

India
HCRI Allahabad
TIFR Mumbai

Portugal
IST Lisboa

Romania
Univ. of Bucharest

Russia
INR Moscow
NPI Petersburg

Spain
Univ. of Valencia

Switzerland
Univ. Zürich

UK
Durham Univ.

USA
Hawaii Pacific Univ.
Univ. of Hawaii
Univ. of Maryland
Ohio State Univ.
Univ. of Philadelphia
NRL Washington

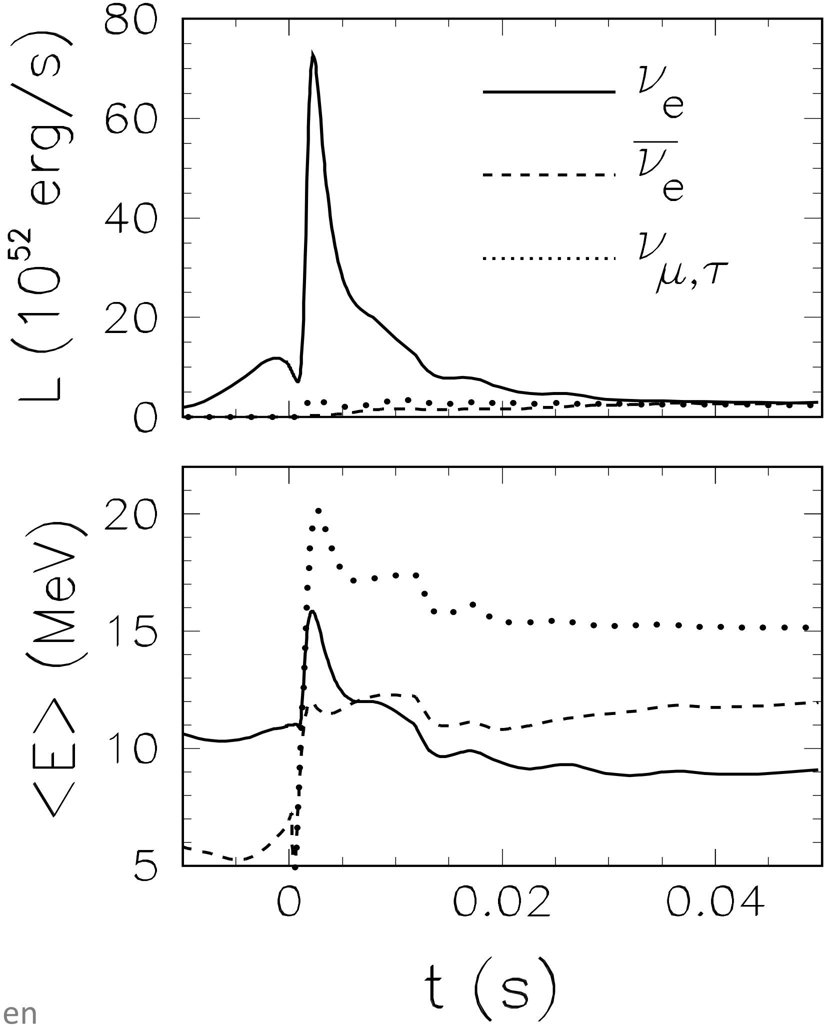
Table of Contents

2.1 Galactic Supernova neutrinos

Coordinator: Alessandro Mirizzi

- **Basic picture of SN observations**
- **Expected neutrino signal**
- **Detection channels in LENA:**
  mostly $\bar{\nu}_e$ by inverse beta decay
  $\nu_e/\bar{\nu}_e$ separation by ^{12}C CC
  ν_x separation by ν-p scattering
- **Signatures of flavor oscillations:**
  Earth matter effect
  collective oscillations (ν-ν)
  SN shock wave propagation
  → energy resolution and variety
  detection of channels important!

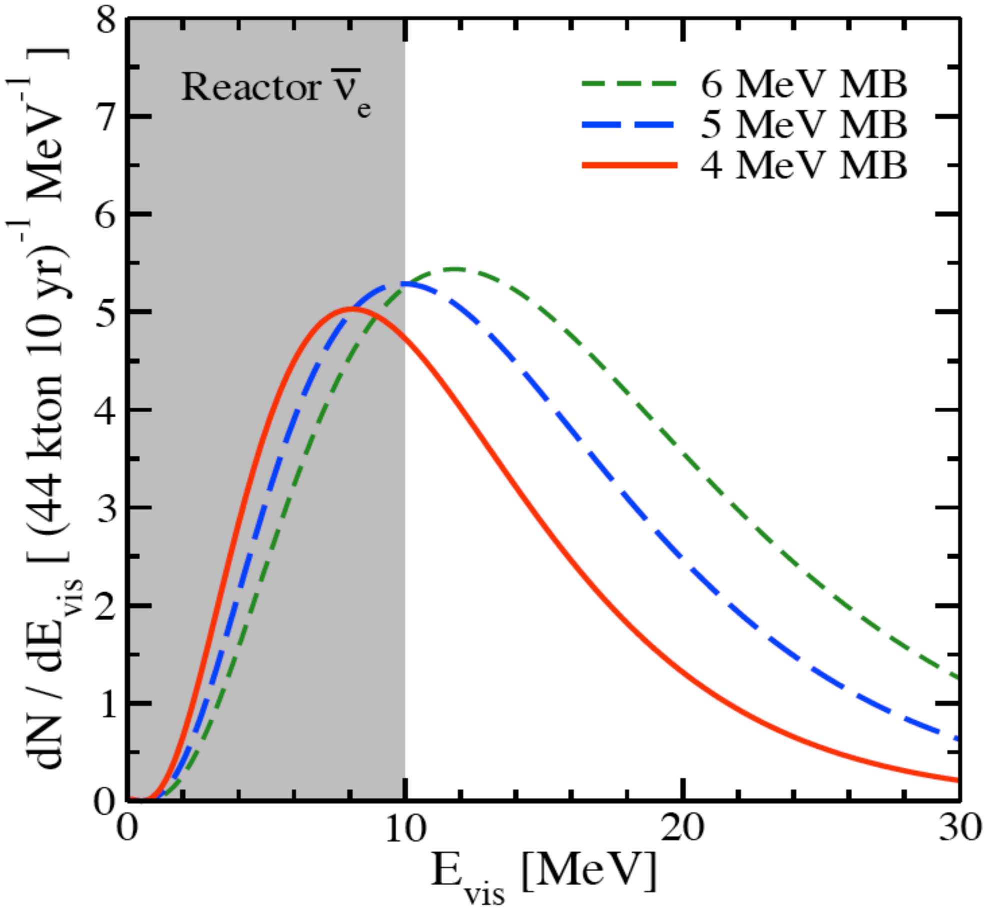
Neutrino fluxes and energies during the neutronization burst.



2.2 Diffuse Supernova neutrinos

Coordinators: John Beacom, Georg Raffelt

- **Motivation:**
  detection of the average SN neutrino spectrum
- **Expected neutrino signal:**
  35-70 $\bar{\nu}_e$ events in 10 yrs
- **Background conditions:**
  favorable compared to WCDs, but new background due to NC of atmospheric neutrinos



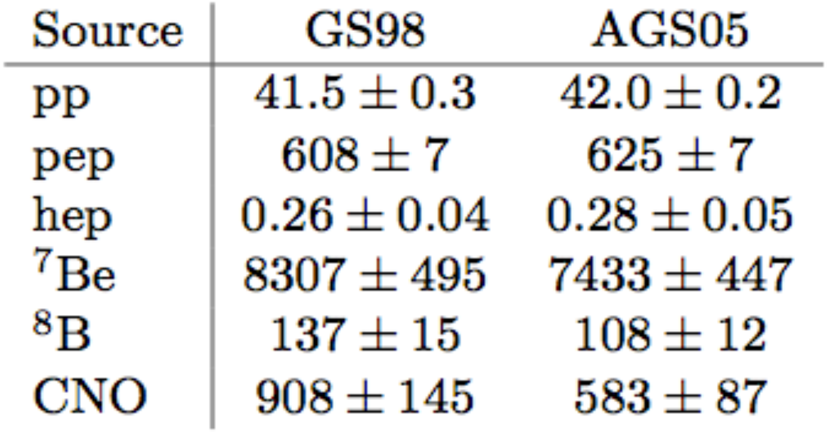
Expected DSNB signal and reactor neutrino background

2.3 Solar neutrinos

Coordinator: Gioacchino Ranucci

- **Basic picture**
  SSM and MSW-LMA
- **Experimental status**
  what is left to do?
  P_{ee} in MSW transition region
  solar metallicity
- **Spectral measurements**
  high statistics
- **Search for time-variations**
  matter effects
  spin-flavor conversion
  helioseismic g-modes

Solar neutrino rates (per day) in LENA for 30 kt fiducial mass

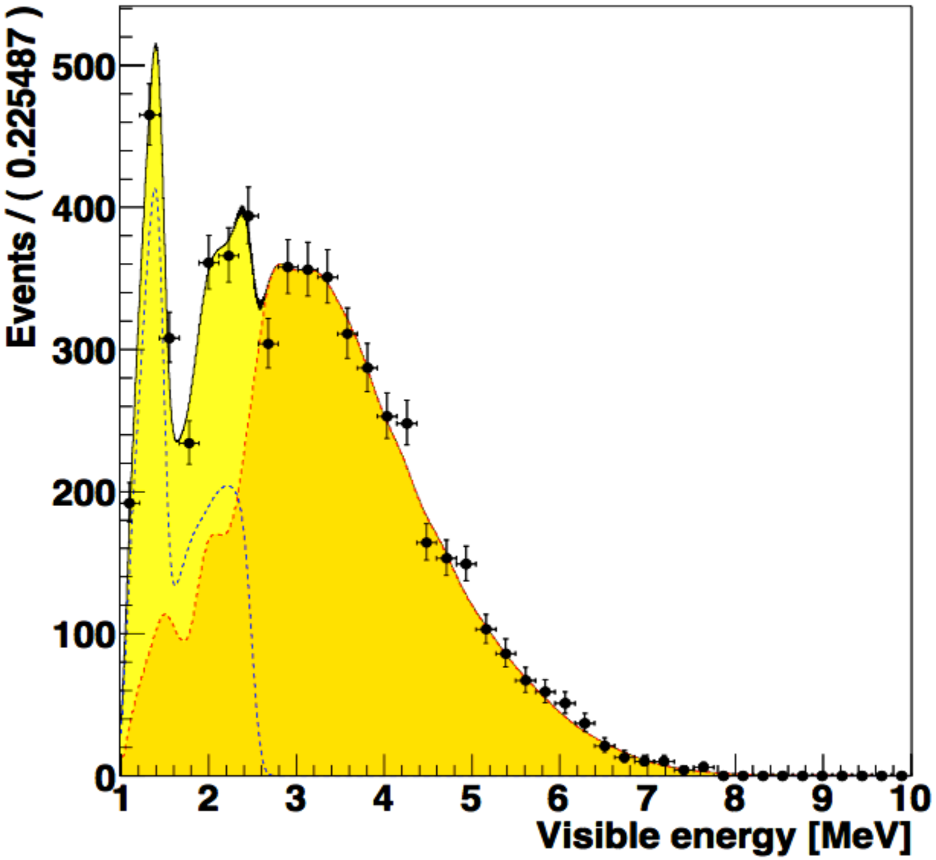


Source	GS98	AGS05
pp	41.5 ± 0.3	42.0 ± 0.2
pep	608 ± 7	625 ± 7
hep	0.26 ± 0.04	0.28 ± 0.05
^{7}Be	8307 ± 495	7433 ± 447
^{8}B	137 ± 15	108 ± 12
CNO	908 ± 145	583 ± 87

2.4 Geoneutrinos

Coordinator: Livia Ludhova

- **Introduction**
  Geochemical models and
  U/Th abundances
- **Signal rates and reactor neutrino background**
- **Precise flux determination**
  accuracy of 1% after 10 yrs
- **Measurement of U/Th ratio**
  accuracy of 5% after 10 yrs
- **Directionality**



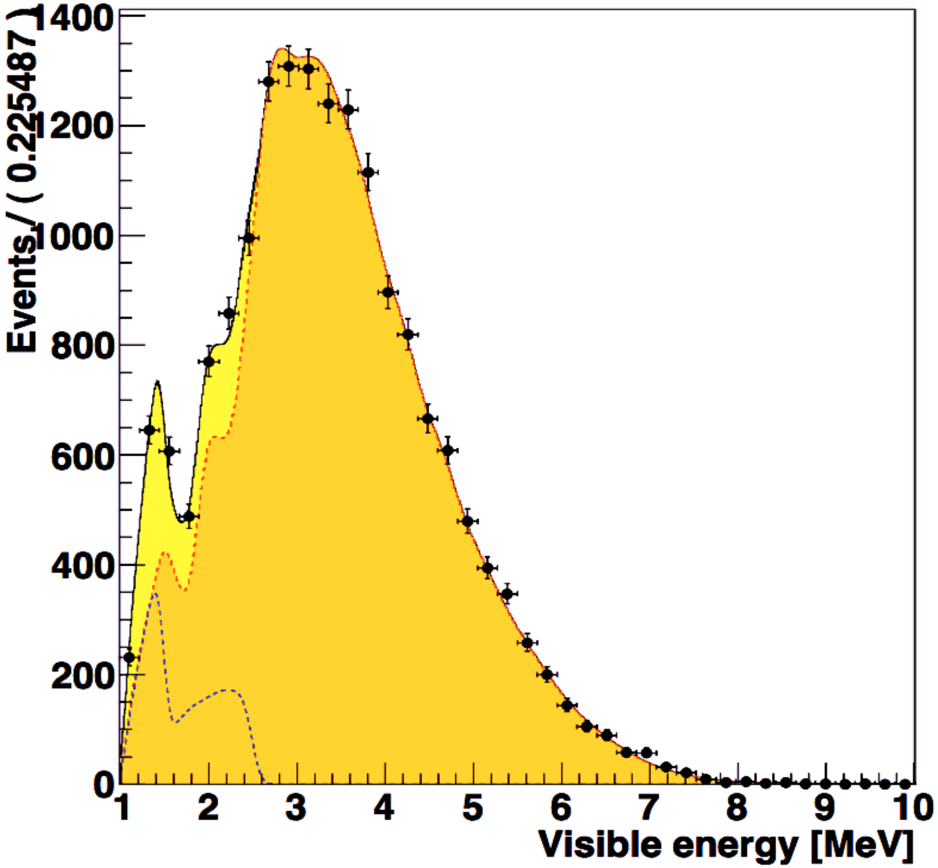
Geoneutrino and reactor neutrino rates for 1 year of measurement in Pyhäsalmi

2.5 Reactor neutrinos

Coordinator: Tobias Lachenmaier

- Precise measurement of solar mixing parameters
- **Based on 7 yrs in Fréjus:**
  $\Delta(\sin^2\theta_{12}) = 10\%$
  $\Delta(\Delta m^2_{12}) = 1\%$ (3σ!)

→ significant improvement compared to the current uncertainty on Δm^2_{12}

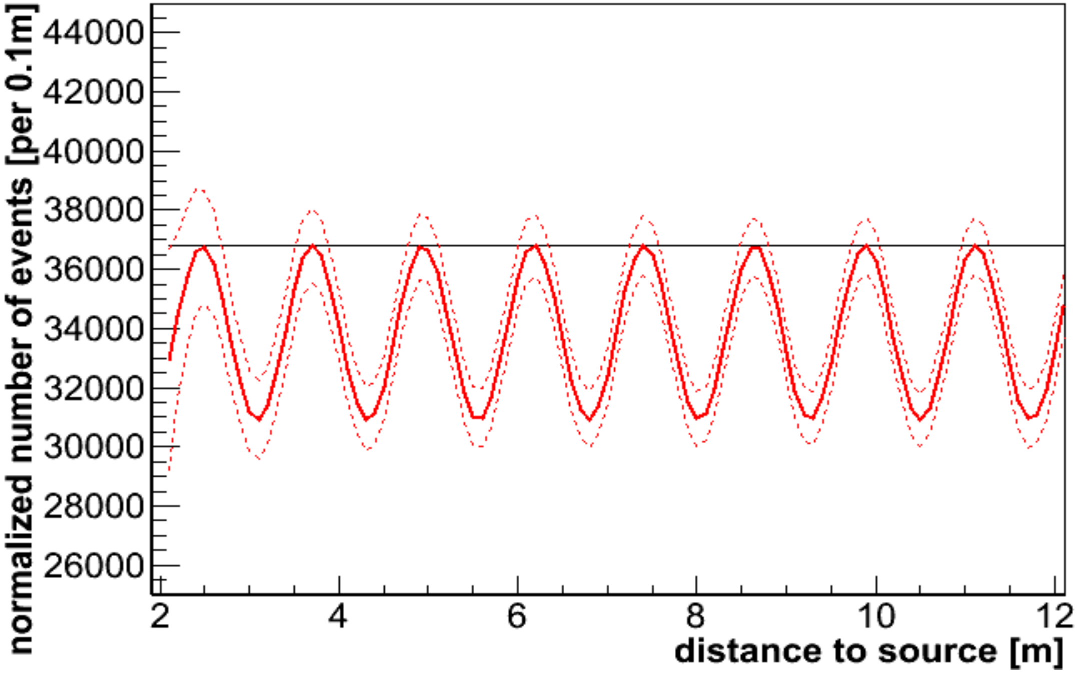


Geoneutrino and reactor neutrino rates for 1 year of measurement in Fréjus

2.6 Neutrino Oscillometry

Coordinator: Yuri Novikov

- **Introduction**
  ^{51}Cr/^{75}Se EC MCi-sources
  for mononergetic neutrinos
- **Detection by νe-scattering**
  background by solar νs
- **Short baseline oscillations**
  some sensitivity on θ_{13}
- **Sterile neutrinos**
  excellent sensitivity on
  both θ_{14} and Δm^2_{14}



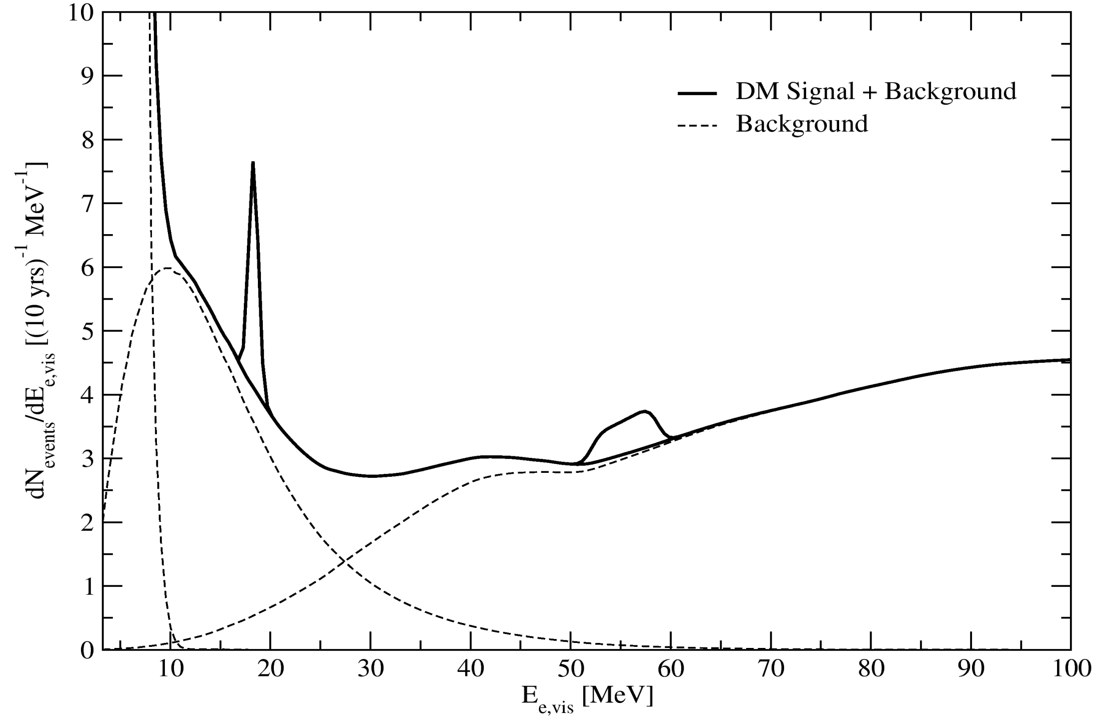
ν_e scattering rate as a function of distance. Dashed lines indicate rate uncertainties.

2.7 Indirect dark matter search

Coordinator: Silvia Pascoli

- **Introduction**
  $\nu_e\bar{\nu}_e$-annihilation of MeV dark matter particles
- **Expected signal rates**
- **$\bar{\nu}_e$ detection in LENA**
  backgrounds from reactor neutrinos, atmospheric neutrinos and the DSNB

LENA in Pyhäsalmi



Annhilation neutrinos are visible as a sharp peak at the DM-particle mass in the spectrum.

2.8 Neutrinoless double-beta decay

Coordinator: Marco Pallavicini

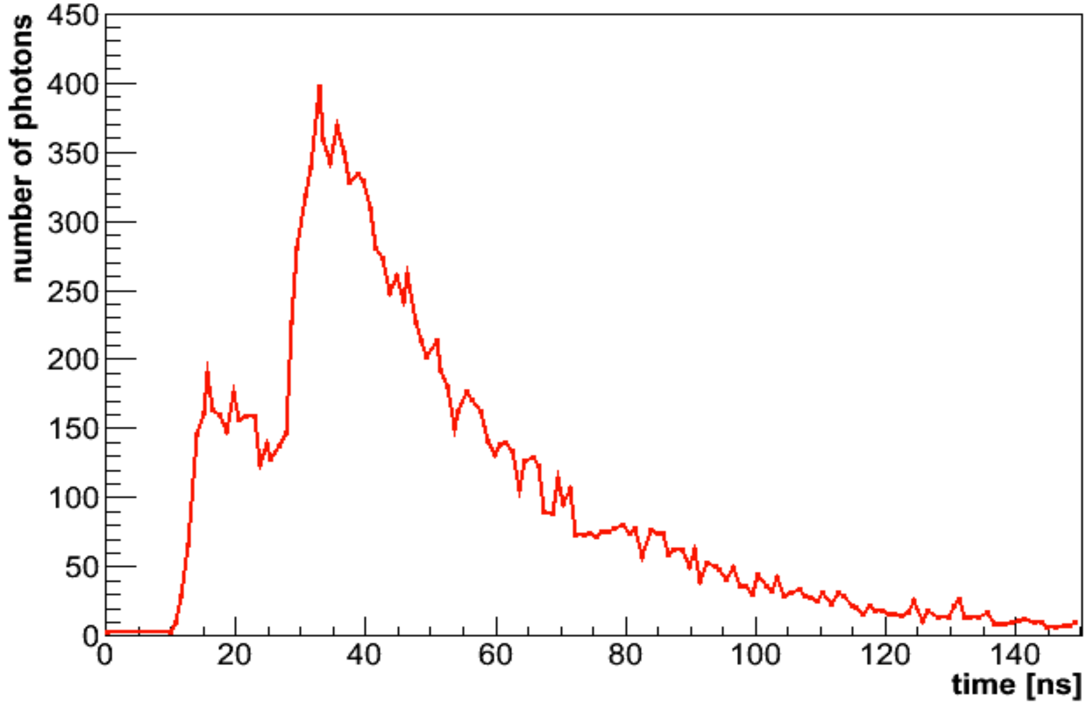
- **Isotope:**
  ^{136}Xe dissolved in the scintillator
- **solubility:**
  2 weight-% → 200 ton or more
- increase in photodetection efficiency will be necessary
- a realistic way to attack the normal hierarchy mass region?

Table of Contents

3.1 Nucleon decay search

Coordinator: Teresa Marrodán Undagoitia

- **Theoretical predictions**
  SUSY-favored decay mode
  into K^+ and $\bar{\nu}$
- **Coincidence signature**
  in liquid scintillator
- **Background**
  atmospheric neutrinos,
  esp. hadronic channels:
  less than 1 event/10 years
- **Expected sensitivity (10yrs)**
  $\tau_p > 4\text{x}10^{34}$ yrs (90%C.L.)



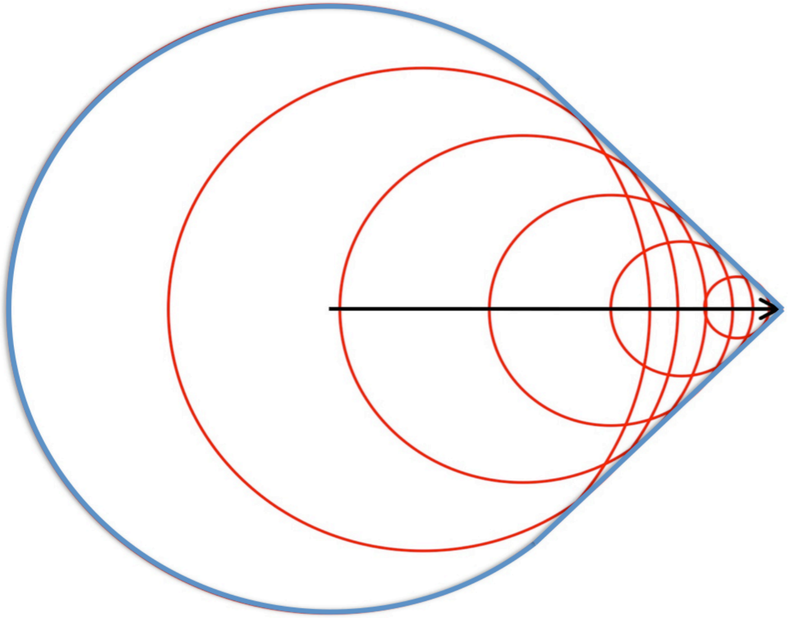
Coincidence signature caused by the Kaon signal and ist subsequent decay particles.

3.2 Tracking at GeV energies

Coordinator: Michael Wurm

- **Introduction**
  directionality from scintillator “light cone“
- **Sub-GeV energies**
  based on first-photon arrival times and integral charge per PMT
- **Multi-GeV range**
  based on full pulse shape per PMT (FADCs)

→ *see talk tomorrow*



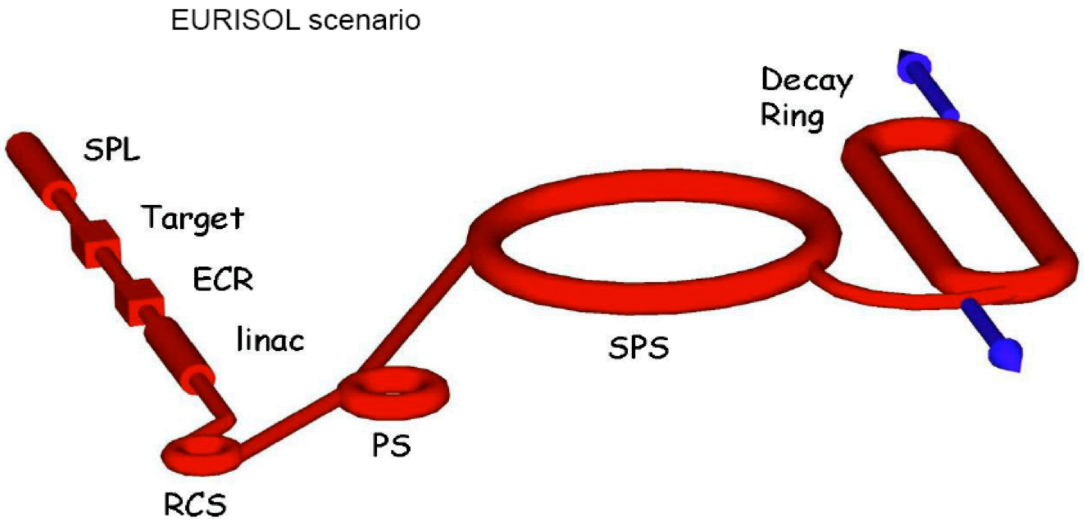
The light cone created by superposition of spherical waves along the particle track

3.3 Long-baseline neutrino beams

Coordinator: Achim Stahl

- **Goals and Concepts**
  search for θ_{13}, θ_{23}, δ_{CP},
  mass hierarchy
- **Super-Beams**
- **Beta-beams**
- **Baseline scenarios for LENA**
  Superbeam to Pyhäsalmi
  Beta beam to Fréjus

Conceptual layout of a beta-beam facility at CERN from EURISOL design study.



3.4 Atmospheric neutrinos

Coordinator: Christopher Wiebusch

- **Broad range of physics**
  atmospheric mixing parameters, but also mass hierarchy, δ_{CP}, θ_{13}
- **Broad energy range in LENA**
  from hundreds of MeV to 20 GeV
- accessible physics depend on LENA's tracking performance

Flavor conversion of atmospheric ν's induced by matter effects .

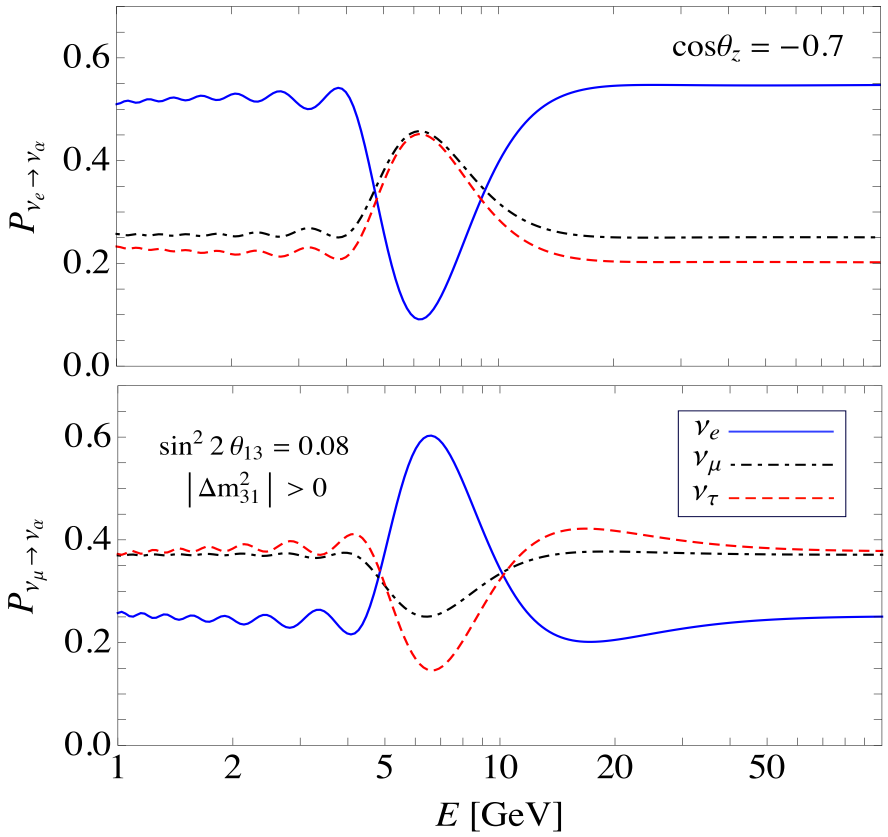
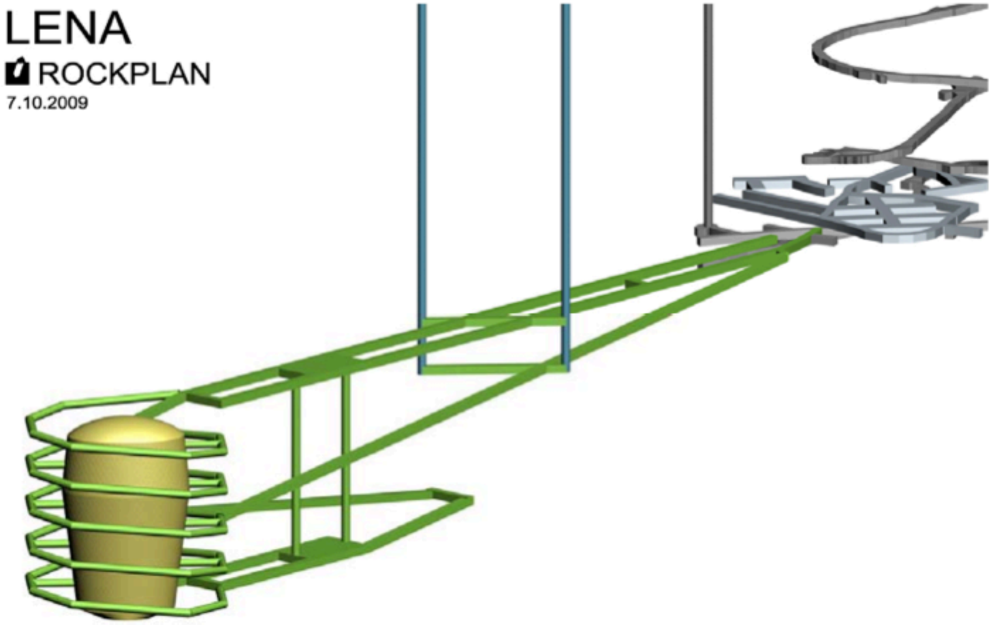


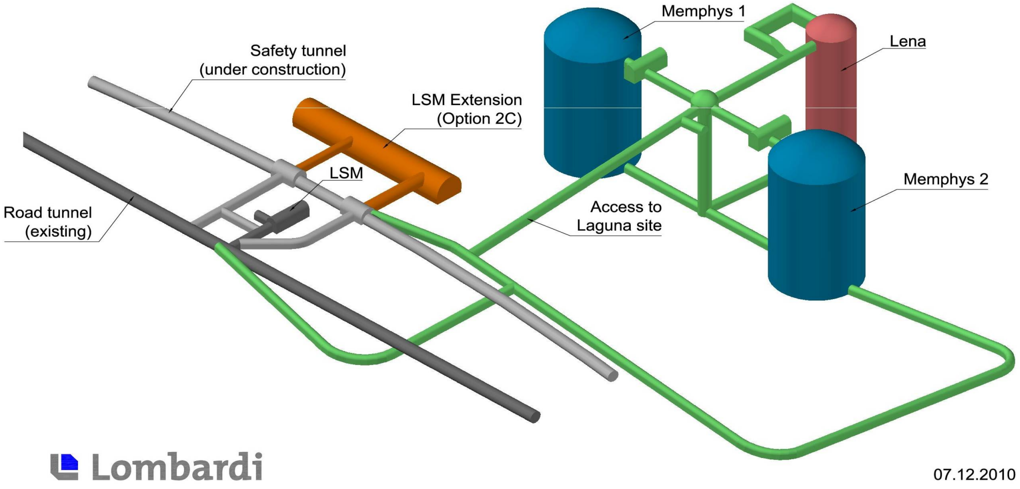
Table of Contents

4.1 Laboratory Sites

Coordinator: Michael Wurm

- **Geology**
- **Background levels**
- **Excavation**
- **Infrastructure**
- **most likely sites in Europe:** Pyhäsalmi, Fréjus



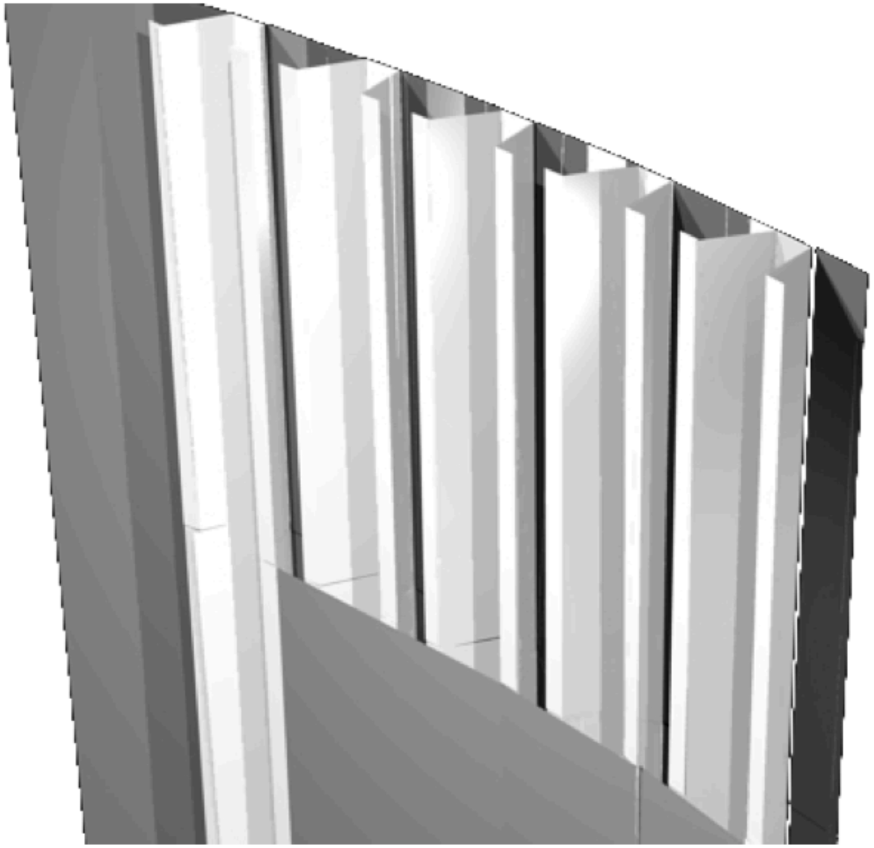


4.2 Detector Tanks

Coordinator: Michael Wurm

Based on Rockplan study:

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



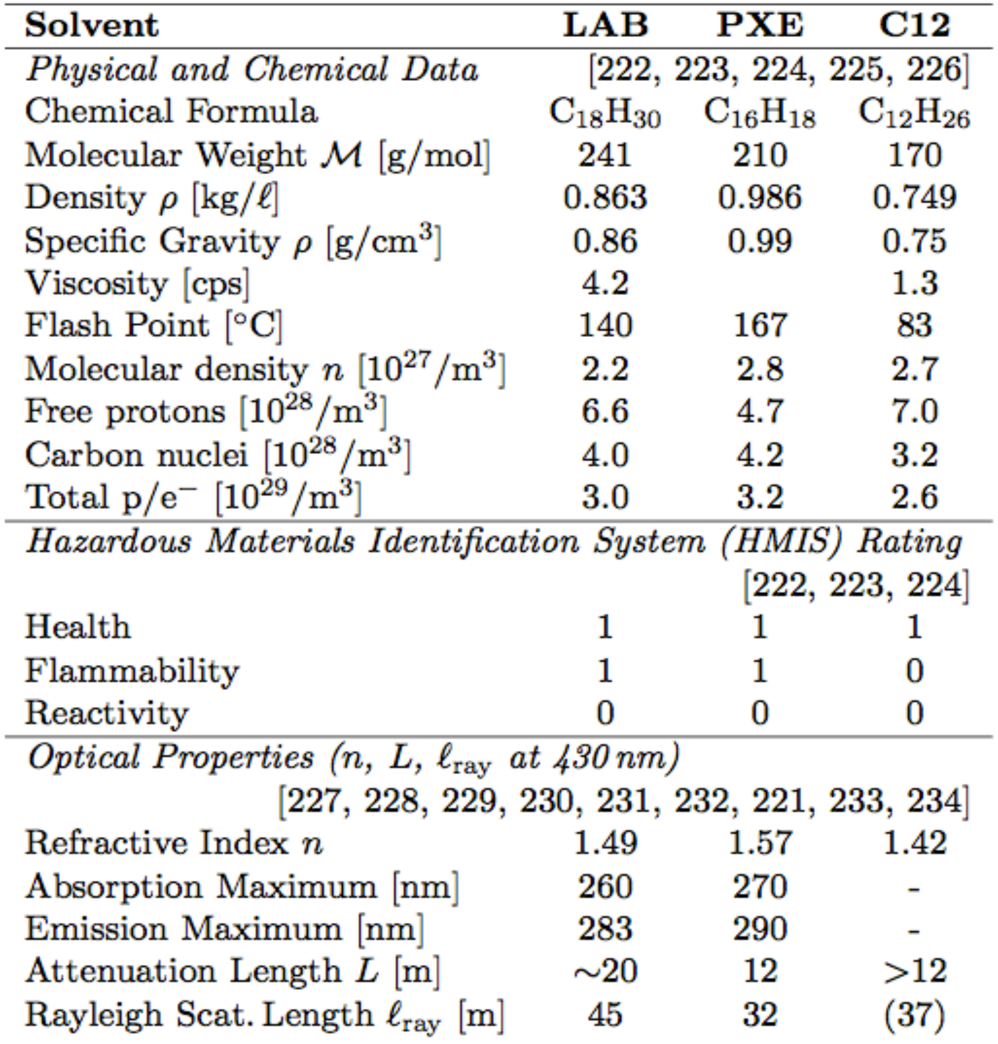
Cross section of a tank wall based on the sandwich steel tank appraoch

4.3 Liquid Scintillator

Coordinator: Quirin Meindl/Jürgen Winter

- **Scintillator properties**
  light yield and decay times,
  optical transparency,
  radiopurity
- **Impact on detector design**
  geometry, liquid handling
- **Investigated mixtures**
  LAB + PPO + bis-MSB
  is the preferred candidate

Important parameters of organic solvents



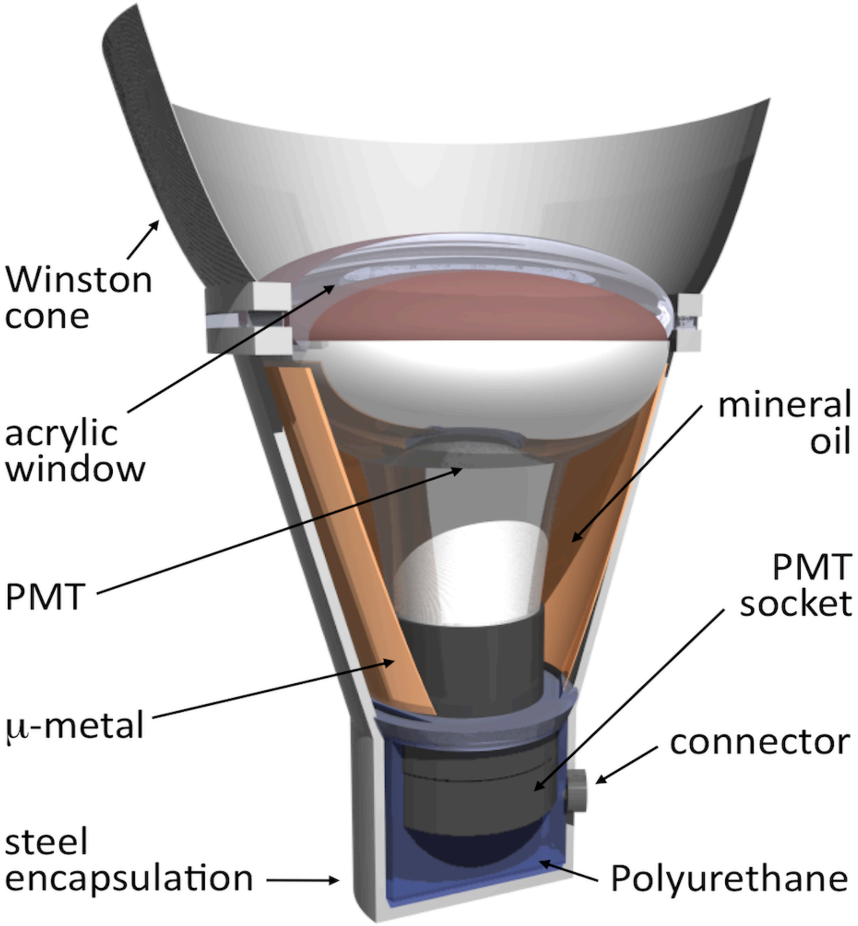
Solvent	**LAB**	**PXE**	**C12**
Physical and Chemical Data	[222, 223, 224, 225, 226]		
Chemical Formula	$C_{18}H_{30}$	$C_{16}H_{18}$	$C_{12}H_{26}$
Molecular Weight $\mathcal{M}$ [g/mol]	241	210	170
Density ρ [kg/ℓ]	0.863	0.986	0.749
Specific Gravity ρ [g/cm^3]	0.86	0.99	0.75
Viscosity [cps]	4.2		1.3
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
Hazardous Materials Identification System (HMIS) Rating		[222, 223, 224]	
Health	1	1	1
Flammability	1	1	0
Reactivity	0	0	0
Optical Properties (n, L, ℓ_{ray} at 430 nm)	[227, 228, 229, 230, 231, 232, 221, 233, 234]		
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)

4.4 Photosensors

Coordinator: Marc Tippmann

- **Photosensor requirements**
- **Survey of Bialkali PMTs**
- **Ways of optimization**
  Light-collecting cones
  HQE tubes
  pressure resistance
- **Alternative photosensors**
  Silicon PMs
  Hybrid PMs

Artistic impression of the PMT encapsulation



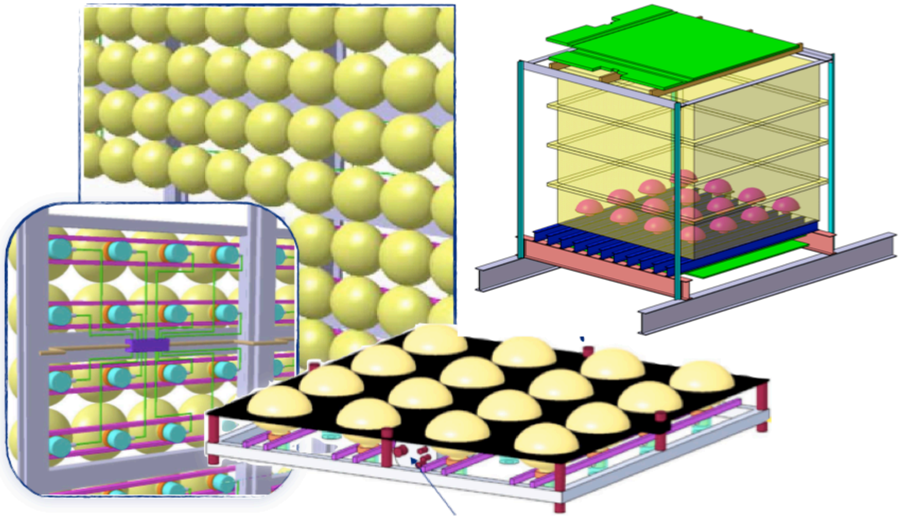
4.5 Readout electronics

Coordinator: Thomas Patzak

Two alternatives are discussed:

- **Full FADC readout**
  front-end electronics
  close to the PMTs,
  external FADCs featuring
  1-2 GS/s and 10-12 or 2x8bit
- **Custom ASIC readout**
  all electronics close to arrays
  of PMTs (PMm2),
  including digitization
  by ADCs and TDCs

Artistic impression of the PMm2 concept and the MEMPHYNO prototype



Timeline

- Writing started in July 2010.
- Now, the paper is nearly finished.
- Submission to the arXiv: end of next week.
- Submission to a journal (APP): end of March.

Thanks a lot to everybody who contributed to this huge effort!