Das Neutrinoprojekt LENA - Physics with the large liquid-scintillator detector LENA

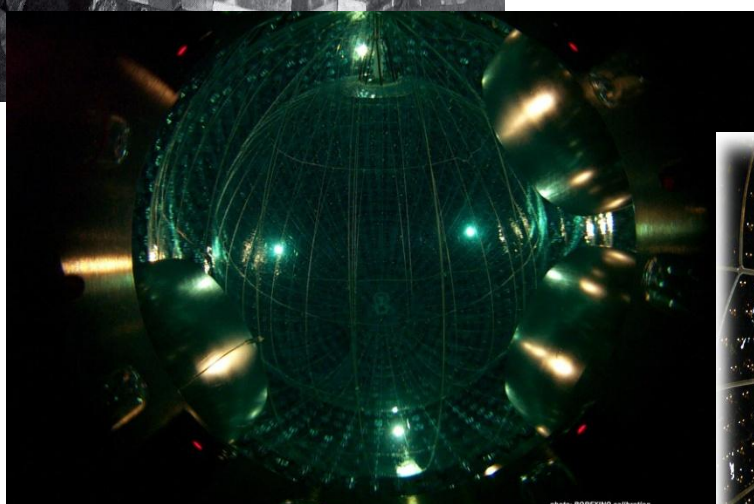
Tobias Lachenmaier
Kepler Center for Astro and Particle Physics
Universität Tübingen

Schule für Astroteilchenphysik, 11. Oktober 2010, Obertrubach-Bärnfels

Liquid Scintillators are well known as neutrino targets

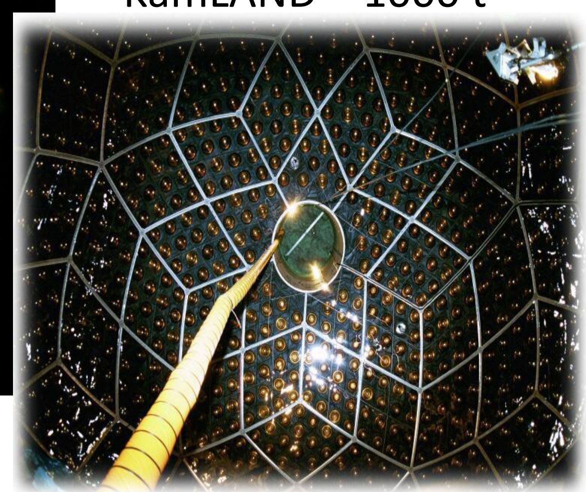
Poltergeist ~ 1 t

Double-Chooz ~ 10 t

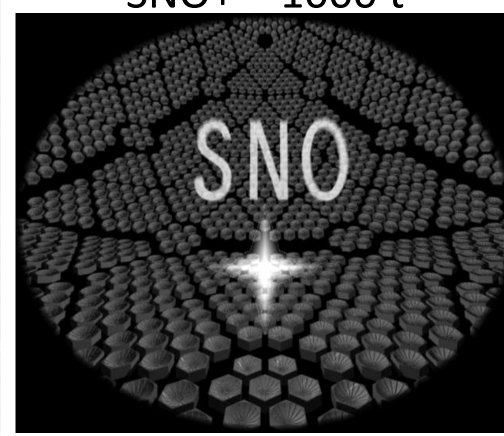


BOREXINO ~ 300 t

KamLAND ~ 1000 t



SNO+ ~ 1000 t



LENA

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

Liquid Scintillator
ca. 50kt PXE/LAB

Inner Nylon Vessel
radius: 13m

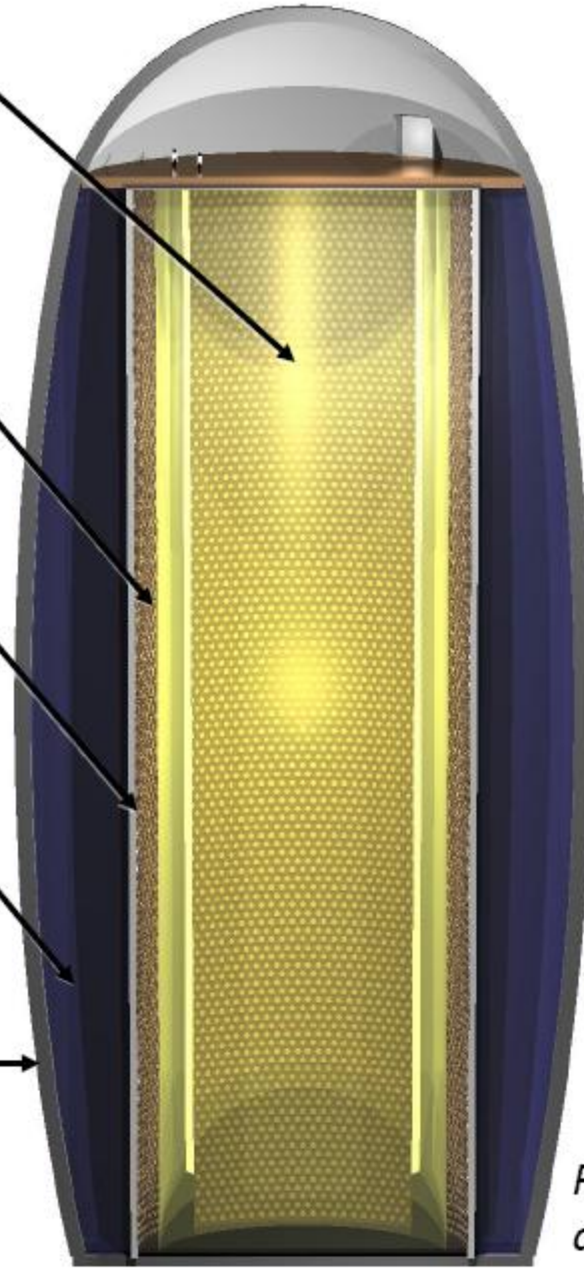
Buffer Region
inactive, Δr = 2m

Steel Tank, 13500 PMs
r = 15m, h = 100m,
optical coverage: .3

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

Egg-Shaped Cavern

Overburden: 4000 mwe



Pyhäsalmi design

Why large neutrino detectors?

With the discovery of neutrino oscillations, there is a clear sign for physics beyond the Standard Model.

GUT

proton decay

baryon/ anti-baryon asymmetry

leptogenesis

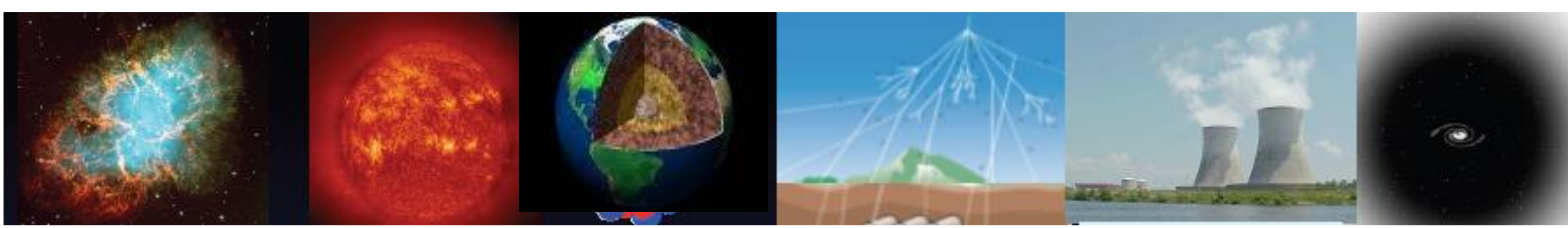
There are still open questions to understand neutrino mixing in detail and to complete our knowledge on fundamental neutrino properties: θ_{13}, CP-violation, mass hierarchy, absolute mass scale, nature of the neutrino.

Strong interest and growing effort for large-volume neutrino detectors in Europe, US, and Asia.
Complementary to **LHC**:

LHC: Higgs mechanism, SUSY, rare decays
Large neutrino detector: Proton decay, neutrino astronomy, CP violation in the leptonic sector

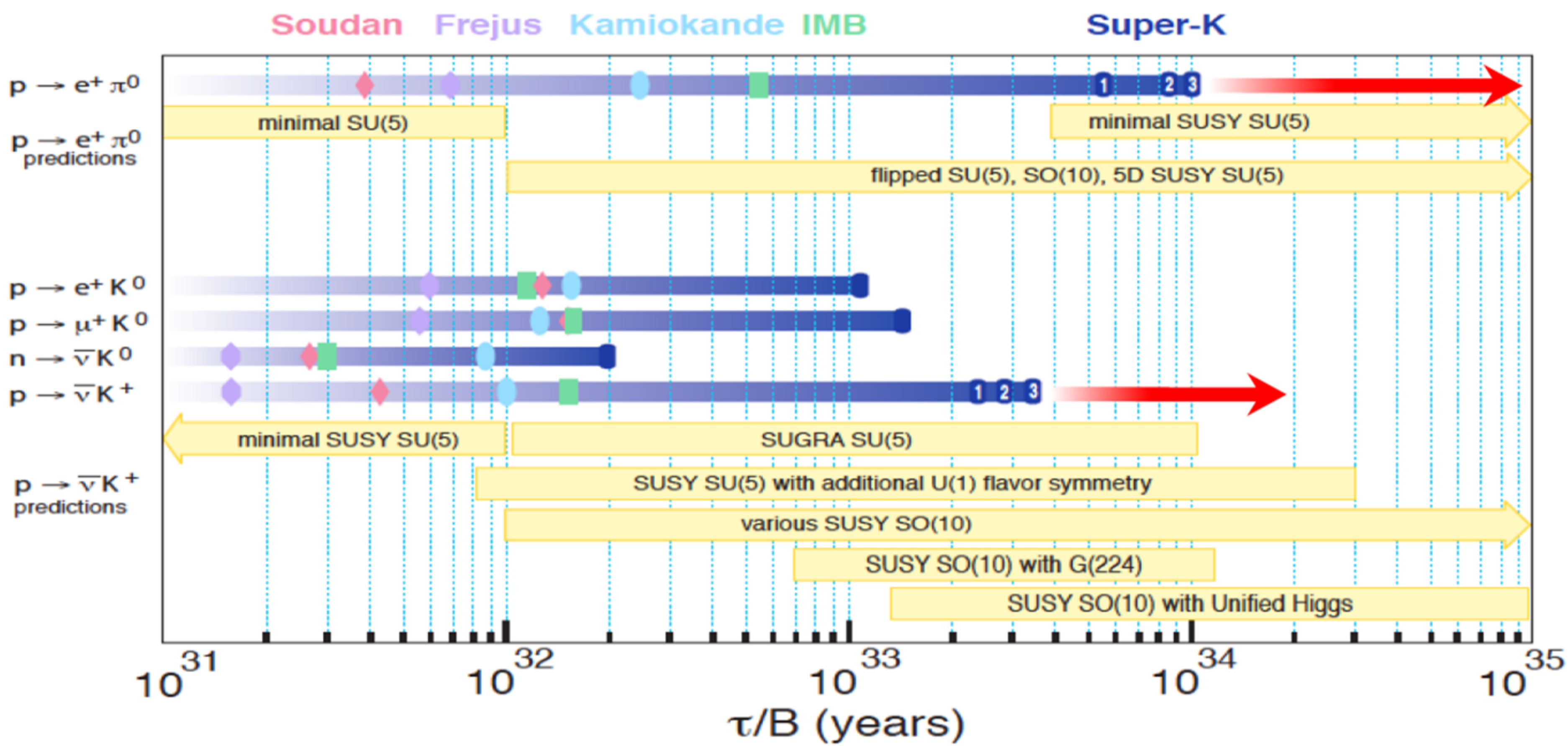
Why large neutrino detectors?

- Proton Decay Search
- Far detector for long baseline neutrino oscillation expt’s
- Galactic Supernova Burst
- Diffuse Supernova Neutrino Background
- Solar Neutrinos
- Geo neutrinos
- Reactor neutrinos
- Neutrino oscillometry
- Atmospheric Neutrinos
- Dark Matter



Search for proton decay

- current limits in most channels dominated by Super-Kamiokande. Want to improve at least factor of 10.
- observation would be de-facto discovery of Grand Unification



CP violation in the leptonic sector

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & c_{13}s_{12} & e^{-i\delta}s_{13} \\ -s_{12}c_{23} - e^{-i\delta}c_{12}s_{13}s_{23} & c_{12}c_{23} - e^{i\delta}s_{12}s_{13}s_{23} & c_{13}s_{23} \\ -e^{i\delta}c_{12}s_{13}c_{23} + s_{12}s_{23} & -e^{i\delta}s_{12}s_{13}c_{23} - c_{12}s_{23} & c_{13}c_{23} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

If there ***does*** exist a RH heavy partner for the LH neutrinos, ***and*** if such a partner violates CP in its decay, it could influence the baryon/anti-baryon symmetry of the universe (leptogenesis).
CP violation in the light neutrinos does not *prove* that neutrinos have a heavy CP-violating partner, but it is strong circumstantial evidence.

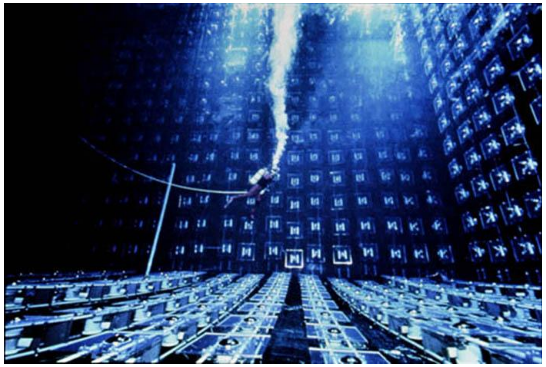
Search for CP violation with the channels $\nu_\mu \to \nu_e$ / $\bar{\nu}_\mu \to \bar{\nu}_e$
in long baseline neutrino experiments by looking for a difference between
$\nu_e/\bar{\nu}_e$ appearance probability

-> size of observable effect is depending on $\sin\theta_{13}$
-> sensitive to any mechanism that creates nu/anti-nu asymmetry, separation of non-CPV effects needed

Detector technologies under discussinon

- Water Cherenkov detector
- Liquid Argon TPC
- Liquid Scintillator detector

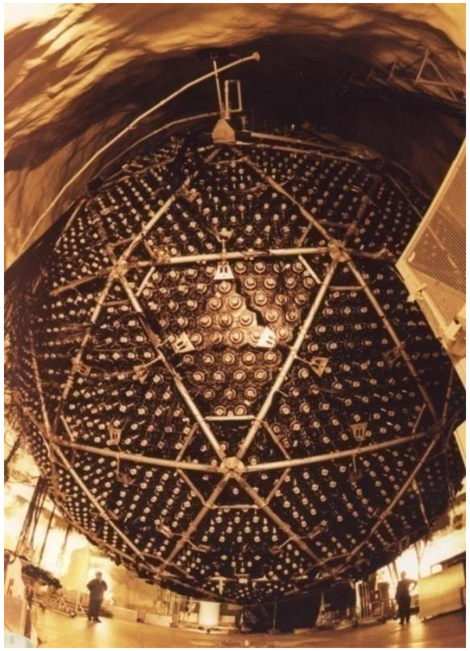
Water Cherenkov detectors



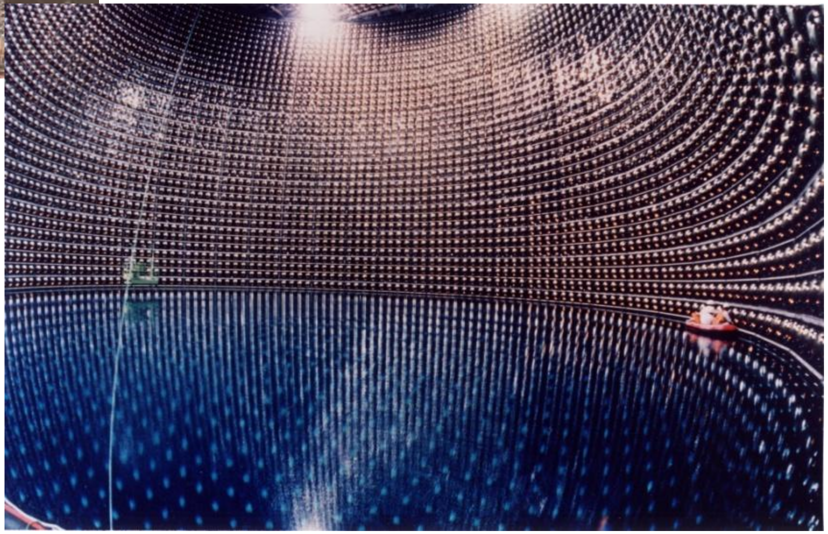
IMB
3 ktons

Kamiokande
1 kton

Large and useful experience: performance, calibration and operation are well established.



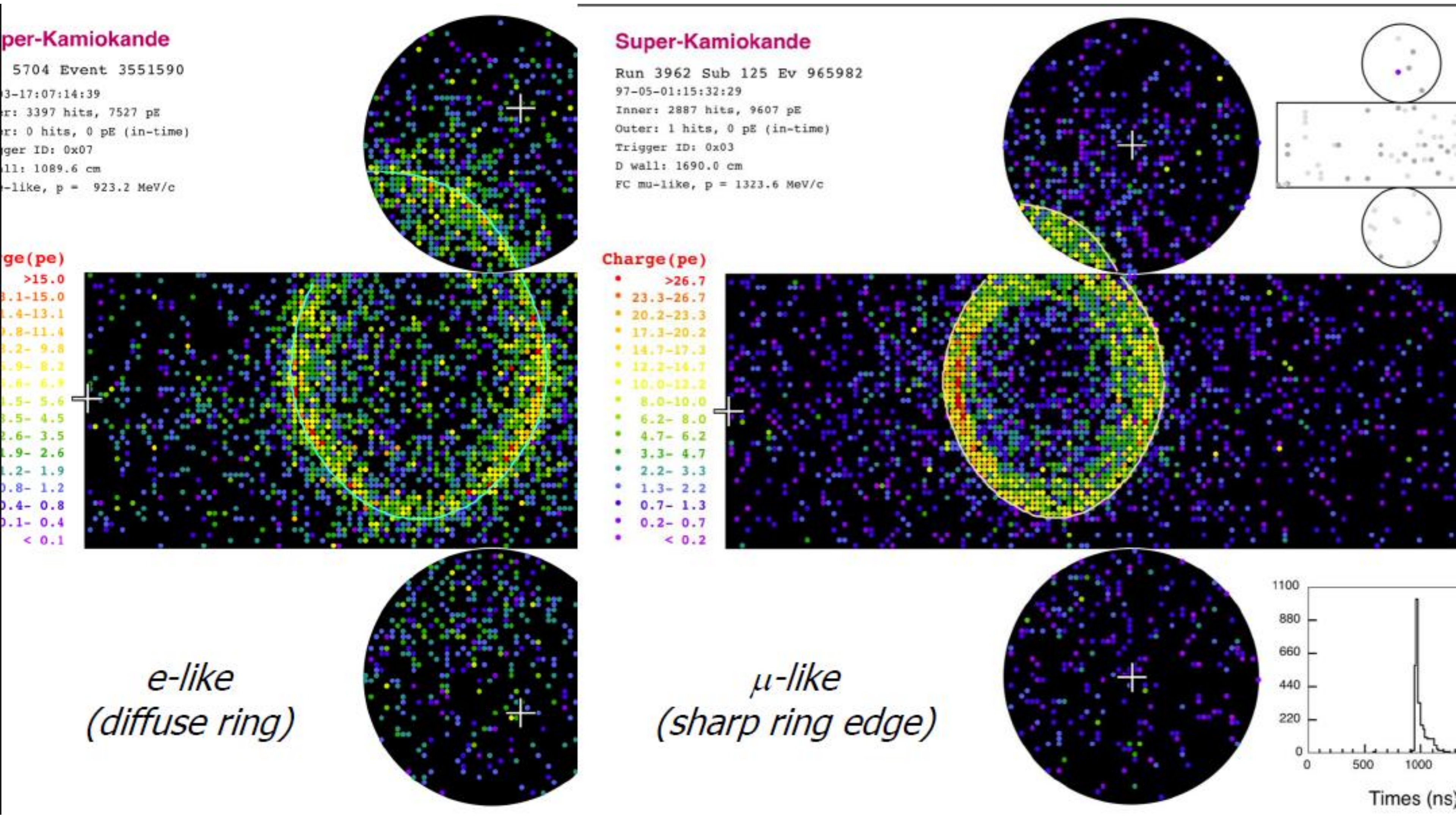
SNO
1 kton D_2O



Super-Kamiokande
22 ktons

Water Cherenkov technique

Ring imaging water Cherenkov technique



Water Cherenkov technique

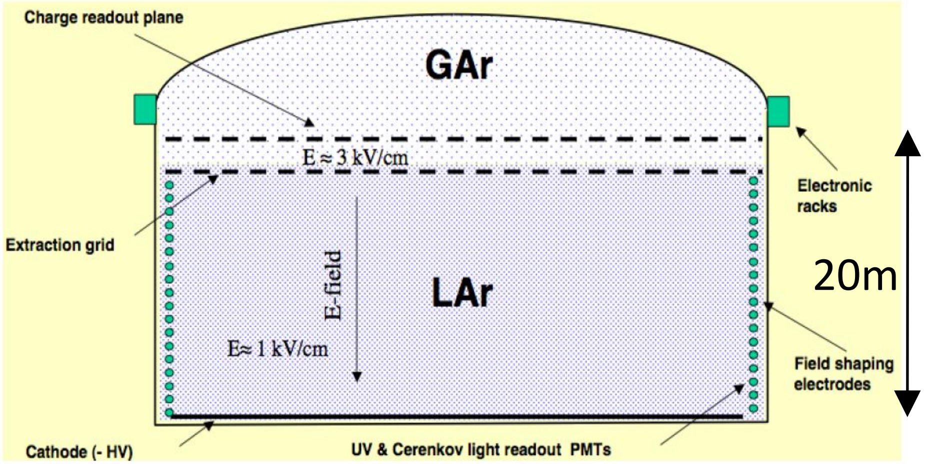
- basic techology is well established (SK-I to IV)
- aim is to go to 0.5-1 Megaton

- good tracking especially at 1 GeV or less
- good PID capability at low energy
- energy resolution for e and μ ~3% (SK)
- for long-baseline beam experiment:
  good at low E (< 1GeV) narrow band beam
- technique is still evolving: e.g. better efficiency for muon decay electrons

Challenges:

- huge amount of photosensors needed (~200.000 for 40% coverage as SK). Reduction by a factor of 2 works well for high energy applications (beam and proton decay). To what extent is additional reduction possible?
- very large underground cavities needed
- cost implied by these two points

Liquid Argon TPC



70m diameter

- electronic "bubble chamber", detailed event topology
- brilliant energy reconstruction and track resolution of every particle, capable up to higher energies
- PID with dE/dx and separation of tracks possible
- basically background-free for many applications
- aim at O(100kt)

Challenges:

- "complicated" detector technology
- huge number of channels (depending on position resolution)
- limited drift length leads to large span of the cavity
- staged R&D program: prototypes detecting cosmics and beam, ICARUS T600 @ Gran Sasso, ArgoNeuT @Fermilab, KEK 250lt

Liquid Scintillator technology

- mature technology (Borexino, KamLAND, SNO+)
- good energy and position resolution, very low energy threshold
- aim at 50kt

Challenges:

- cavity excavation (size comparable to SuperK)
- improvement for PMs and electronics needed
- keep Borexino purity in larger volume (surface-to-volume ratio is advantageous)
  -> relevant for sub-MeV neutrino detection

LENA

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

Liquid Scintillator
ca. 50kt PXE/LAB

Inner Nylon Vessel
radius: 13m

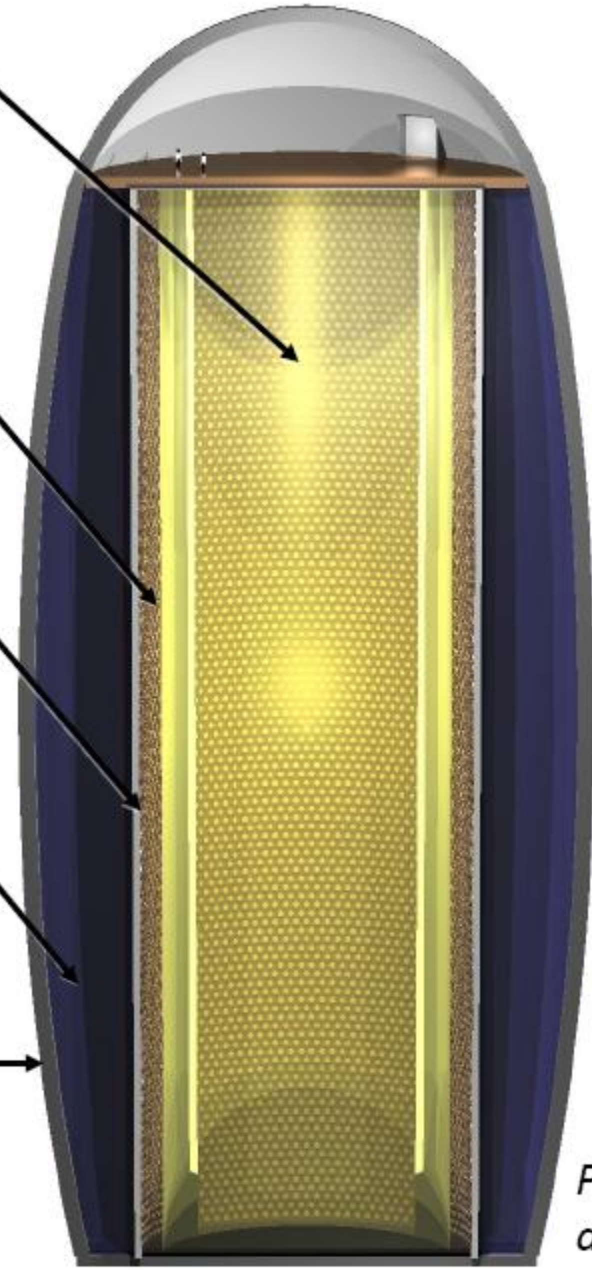
Buffer Region
inactive, Δr = 2m

Steel Tank, 13500 PMs
r = 15m, h = 100m,
optical coverage: .3

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

Egg-Shaped Cavern

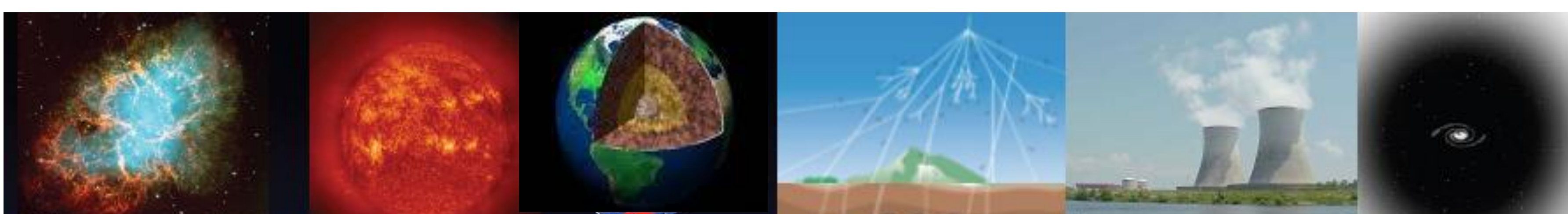
Overburden: 4000 mwe



Pyhäsalmi design

Why large neutrino detectors?

- Proton Decay Search
- Galactic Supernova Burst
- Diffuse Supernova Neutrino Background
- Solar Neutrinos
- Geo neutrinos
- Reactor neutrinos
- Neutrino oscillometry
- Atmospheric Neutrinos
- Dark Matter
- Far detector for long baseline neutrino oscillation expt's



Proton decay – Motivation

Non supersymmetric Grand Unified Theories

Dominant decay mode: $p \rightarrow e^+\pi^0$ $\tau \sim 10^{36}$ y

current best limit (Super-K): $\tau(p \rightarrow e^+\pi^0) \gtrsim 8.2 \cdot 10^{33}$ y (90% C.L.)

Phys.Rev.Lett. 102, 141801 (2009)

Supersymmetry (SUSY)

Dominant decay mode: $p \rightarrow K^+\overline{\nu}$ $\tau \sim 10^{34}$ y

current best limit (Super-K): $\tau(p \rightarrow K^+\overline{\nu}) \gtrsim 2.3 \cdot 10^{33}$ y (90 % C.L.)

Phys.Rev. D72, 052007 (2005)

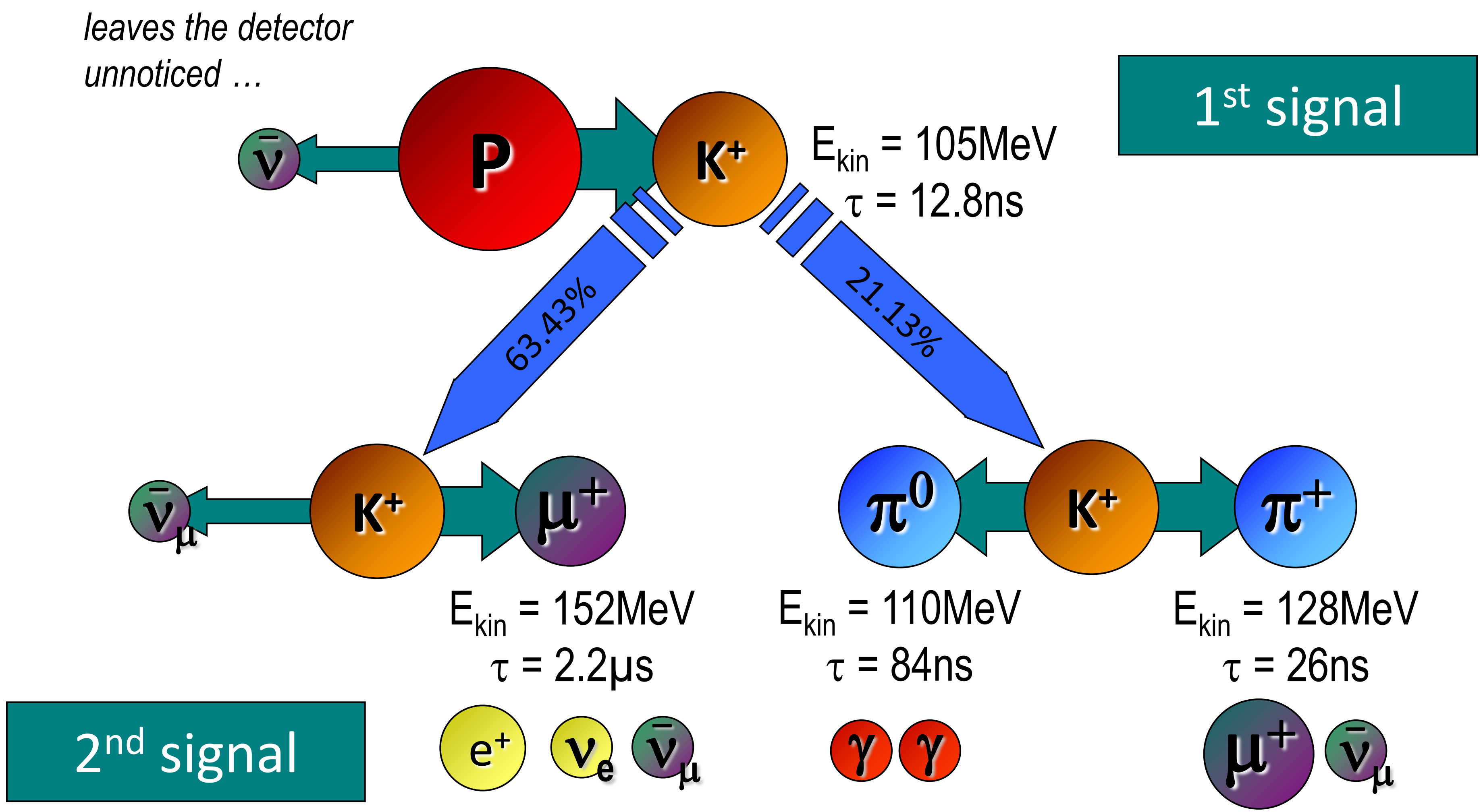
LENA: high sensitivity to $p \rightarrow K\nu$ (efficiency 68%)

90% C.L. limit of $\boldsymbol{\tau(p\rightarrow K\nu) > 4 \cdot 10^{34}}$ **y** reachable

T. Marrodan et al., Phys. Rev. D72, 075014 (2005)

Proton decay channel $p \rightarrow K^+\bar{\nu}$

Event signature

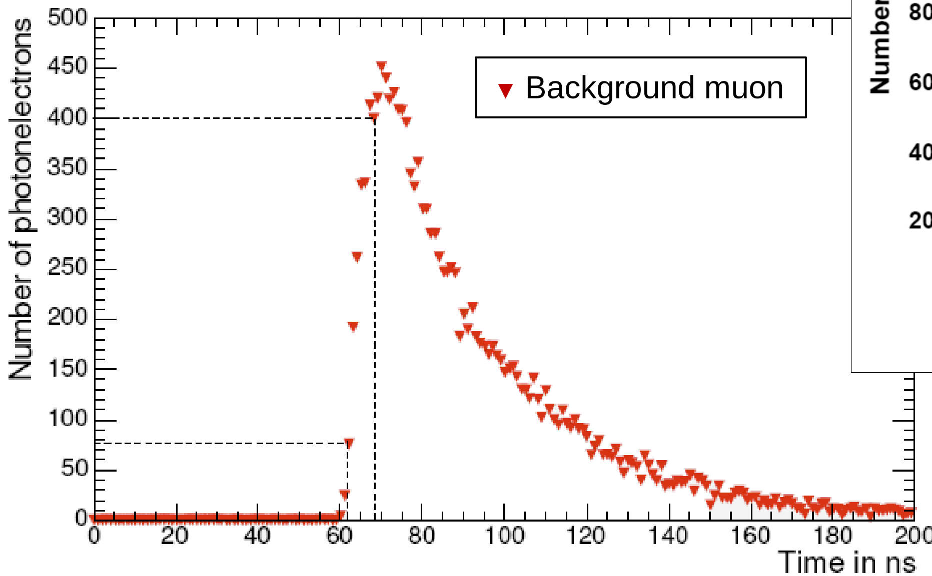


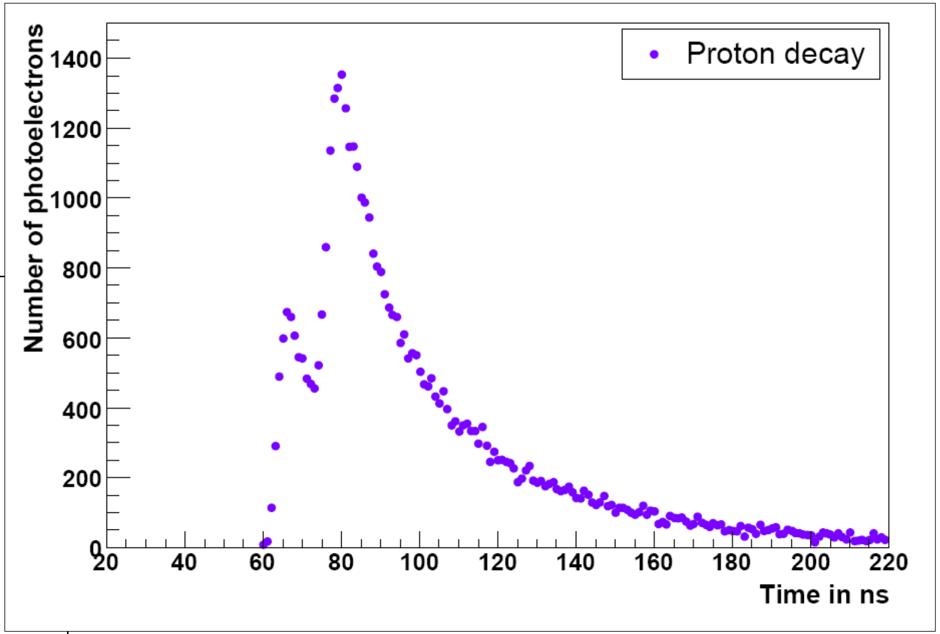
Proton decay channel $p \rightarrow K^+\bar{\nu}$

In a liquid scintillator detector: K^+ visible

$\Rightarrow$ 3-fold coincidence, the first 2 events are monoenergetic! (plus position correlation)

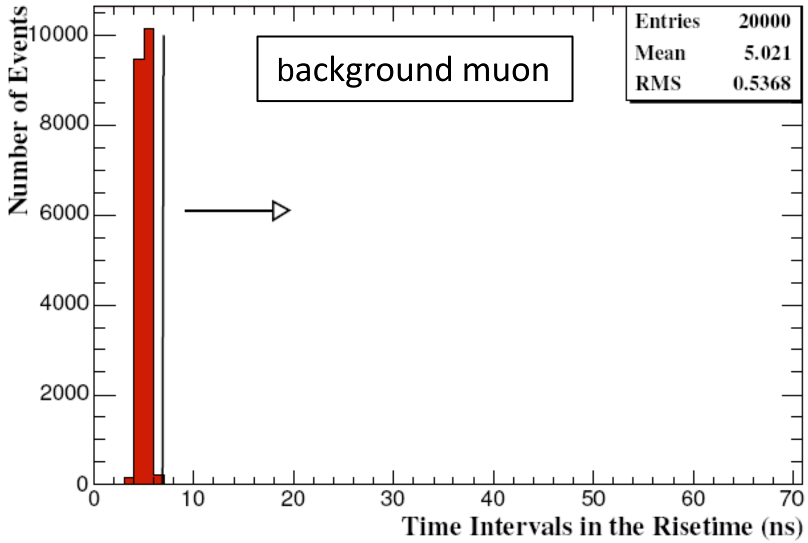
$\Rightarrow$ high efficiency and very good background rejection in L.S.

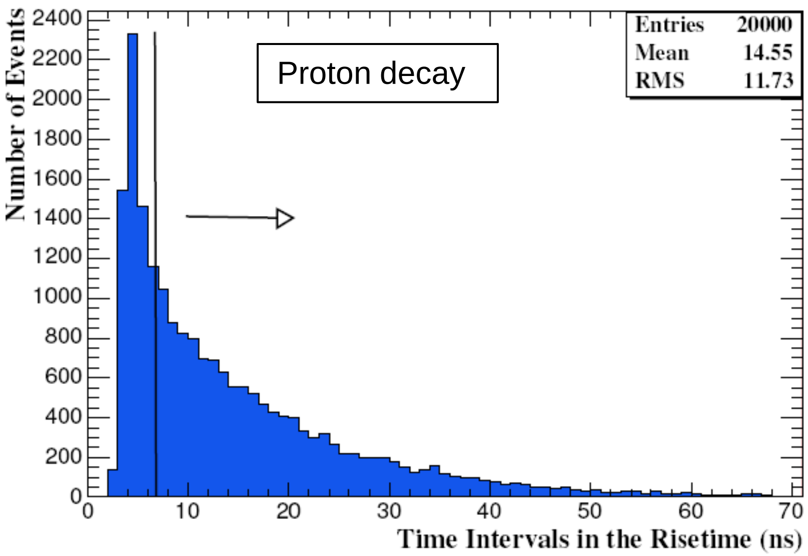




MC simulation with LY=180 p.e./MeV optical model of the detector using GEANT4

Background rejection for p → K$^+$ν





Efficiency of the rise-time cut for proton decay events: 68%

Background reduction factor
$B \approx 5 \times 10^{-5}$

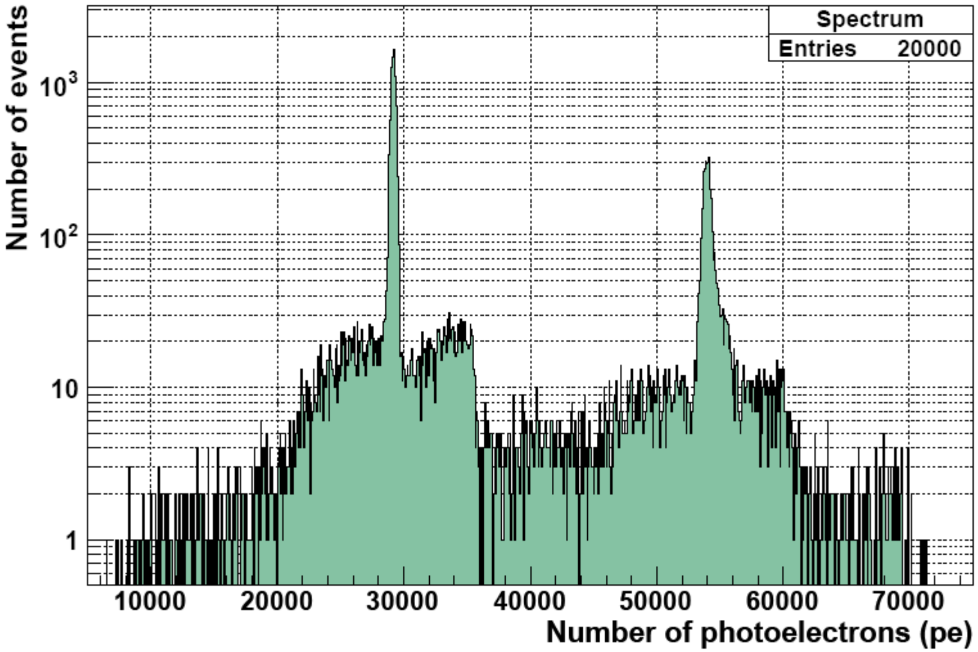
Main (remaining) background from atmospheric ν_μ

$$\nu_\mu + p \rightarrow \mu^- + \pi^+ + p'$$

$$\nu_\mu + p \rightarrow \mu^- + K^+ + p$$

estimated rate: 0.06 yr^{-1}

Sensitivity to proton decay $p \rightarrow K^+\bar{\nu}$



Simulated energy spectrum of 20000 proton decay events into Kaon channel (light yield 180 p.e./MeV)

Two peaks:

- Kaon + Muon ~ 257 MeV
- Kaon + Pions ~ 459 MeV

Energy-cut efficiency ε_E=99.5%

Bound protons of ^{12}C included.

Potential of LENA (10 y measuring time)

- For Superkamiokande current limit: $\tau = 2.3 \cdot 10^{33}$ y
  - About 40 events in LENA and $\lesssim$ 1 background
- Limit at 90% (C.L) for no signal in LENA:
  - $\tau > 4.1 \cdot 10^{34}$ y with $\epsilon = 65\%$

A galactic SN in LENA

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

In LENA detector: $\sim$15000 events

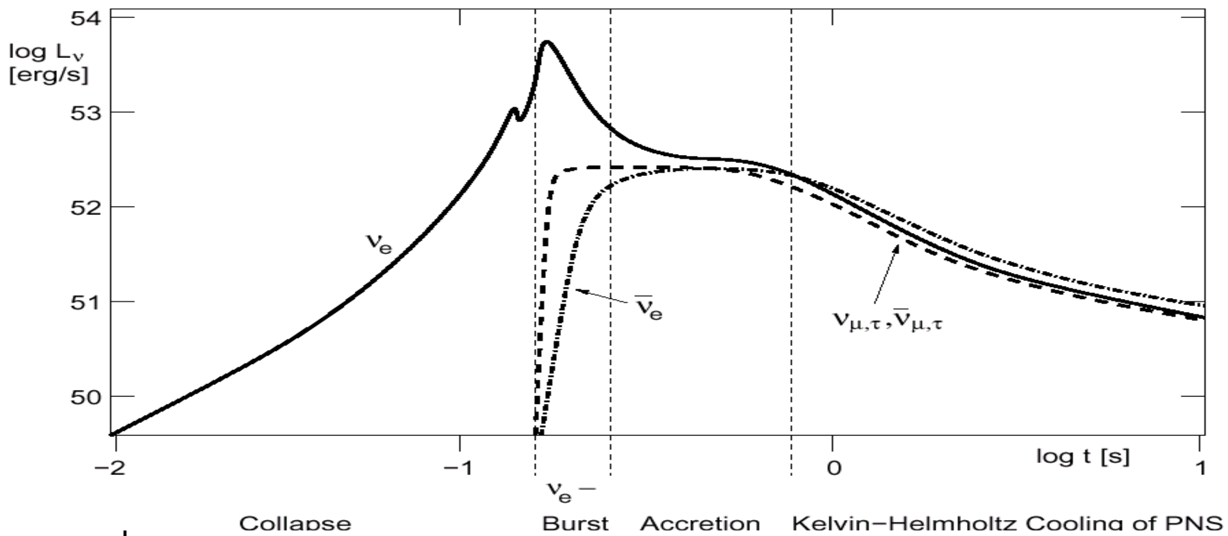
Possible reactions in liquid scintillator

- $\overline{\nu}_e + p \rightarrow n + e^+;\ n + p \rightarrow d + \gamma$ $\sim$ 7 500 - 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) $\sim$ 680
- $\nu_x + p \rightarrow \nu_x + p$ (elastic scattering) $\sim$ 1 500 - 5 700

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

A galactic SN in LENA

High statistics
energy dispersive
time dispersive
flavour resolving



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

A galactic SN in LENA

Separation of SN models

	TBP	KRJ	LL
$\nu_x + {}^{12}\mathrm{C}$	700	950	2100
$\nu_x + p$	1500	2150	5700

for a progenitor of $8M_\odot$ (10kpc distance)

Discrimination is possible independent from (collective) oscillations or resonant flavour transformation in the NC reactions

$$\nu_x + {}^{12}\mathrm{C} \rightarrow {}^{12}\mathrm{C}^* + \nu_x; \quad {}^{12}\mathrm{C}^* \rightarrow {}^{12}\mathrm{C} + \gamma$$

$$\nu_x + p \rightarrow \nu_x + p$$ (elastic scattering)

Observation of a galactic SN

What can we learn?

- 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

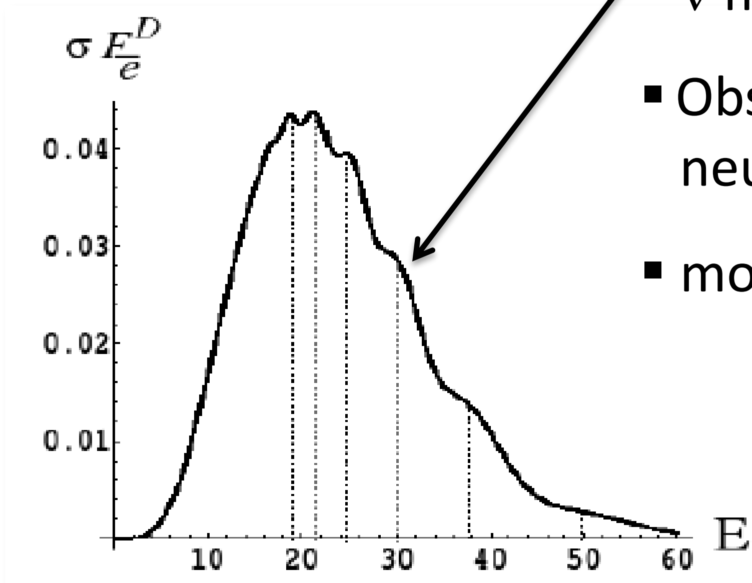
Scientific gain of a SN observation

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

- Survival probability of ν_e in neutronisation burst
  $P_{ee} \approx 0 \rightarrow$ normal mass hierarchy
- Resonant flavor conversions in the SN envelope: hierarchy, θ_{13}
- Earth matter effect:
  ν mass hierarchy, θ_{13}
- Observation of collective neutrino oscillations
- more exotic effects ...



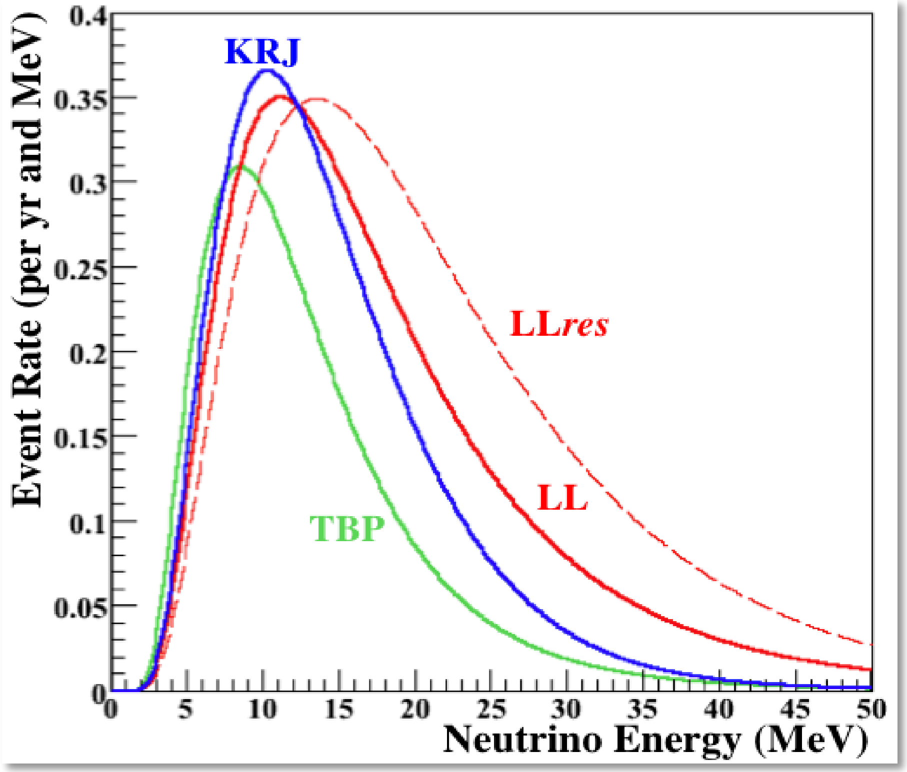
Diffuse SN Neutrinos in LENA

Regular galactic Supernova rate: 1-3 per century?

$$\frac{\mathrm{d}F_\nu}{\mathrm{d}E_\nu} = \frac{c}{H_0}\int_0^{z_{\max}} R_{\mathrm{SN}}(z)\frac{\mathrm{d}N_\nu(E'_\nu)}{\mathrm{d}E'_\nu}\frac{\mathrm{d}z}{\sqrt{\Omega_{\mathrm{m}}(1+z)^3+\Omega_\Lambda}}$$

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: 4-30 $\overline{\nu}_e$ per year (50kta)

Diffuse Supernova Neutrino Background

DSNB detection via inverse beta decay

- Free protons as target

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

Delayed signal (~200 μs)

Prompt signal

- **Threshold 1.8 MeV**

Spectroscopy of antineutrino flux: $E_e = E_\nu - 0.8$ MeV

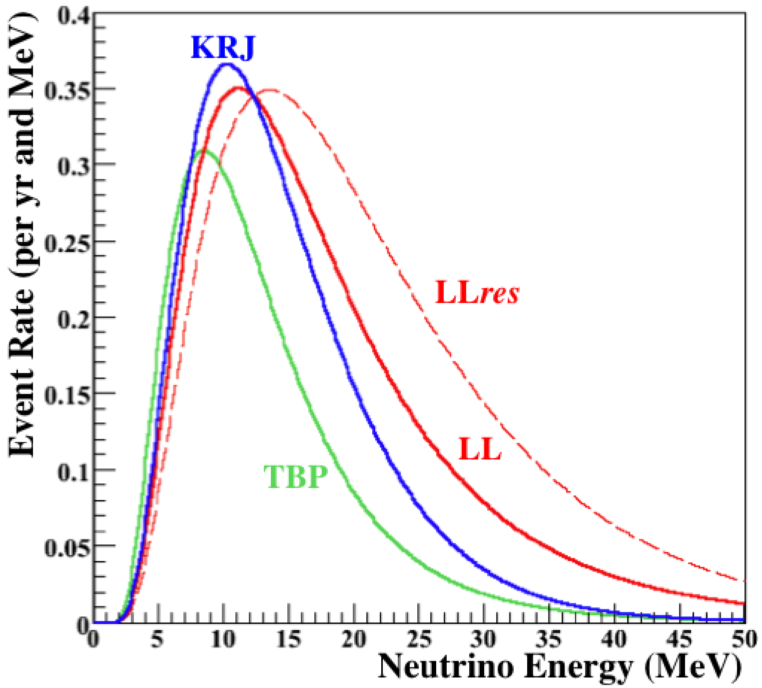
Suppress background via delayed coincidence method

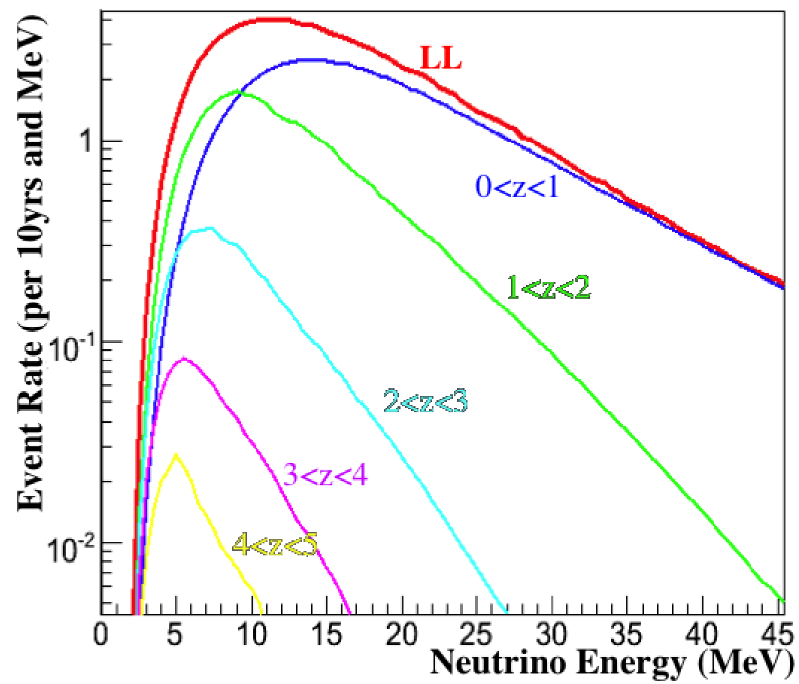
$$n + p \rightarrow D + \gamma \quad (2.2\ \mathrm{MeV})$$

Position reconstruction allows to define a fiducial volume (suppress external background)

Diffuse Supernova Neutrino Background

Expected rates in LENA





... depend strongly on the used SN model.

Integral rate for 44 kt yrs   and f_{SN}=1.0:

TBP	KRJ	LL	LL_{res}
4.7	6.1	6.8	7.7

Dominant flux contribution:

z<1 for E>10MeV
z>1 for E<10MeV

due to cosmic redshift.

Background in Liquid Scintillators

Detection via Inverse Beta Decay

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

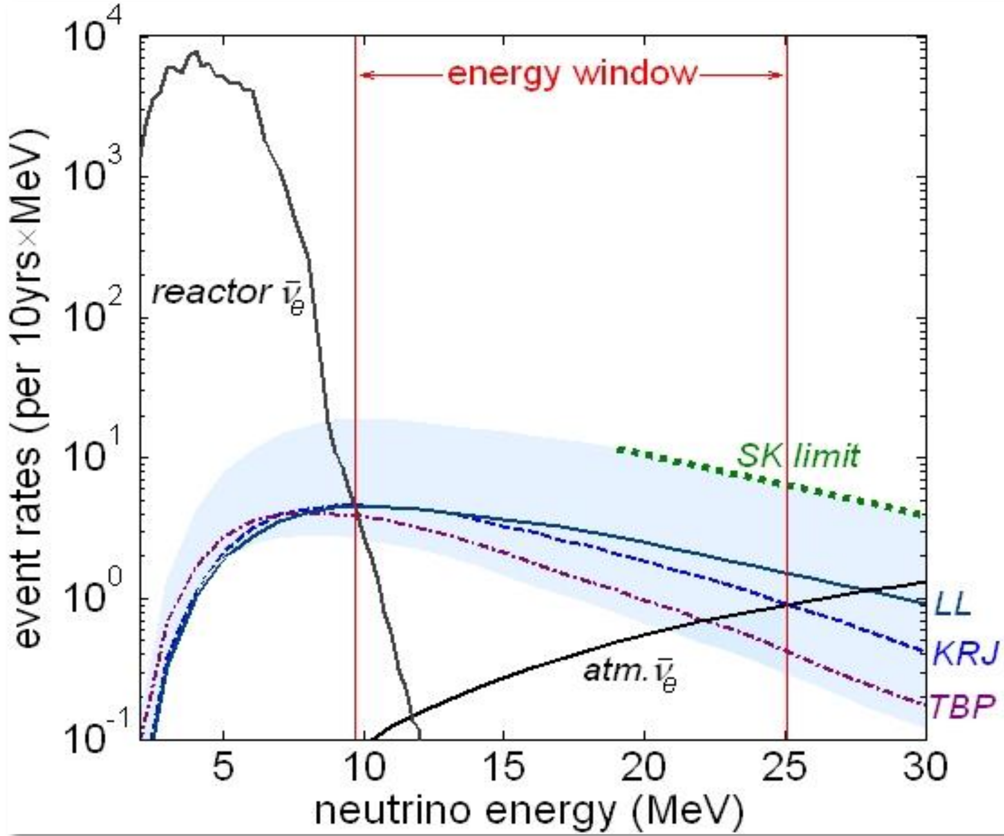
allows discrimination of most single-event background limiting the detection in SK

Remaining Background Sources

- reactor and atmospheric $\bar{\nu}_e$'s
- cosmogenic βn-emitters: ^{9}Li
- fast neutrons
- solar $\bar{\nu}_e$'s (?)
- neutrons from atm. ν's (NC on ^{12}C)

- **Expected rate: 2-20 ev/50kta**

(in energy window from 10-25MeV)

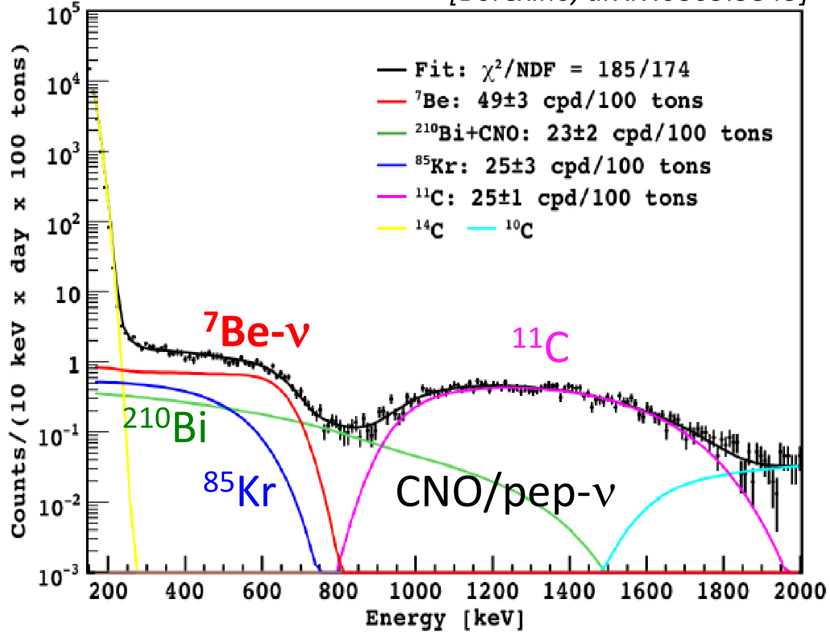


Scientific Gain

- first detection of DSN
- information on SNν spectrum
- check on star formation rate

Solar Neutrinos in LENA

[Borexino, arXiv:0805.3843]



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 νe scattering, E > 0.2MeV

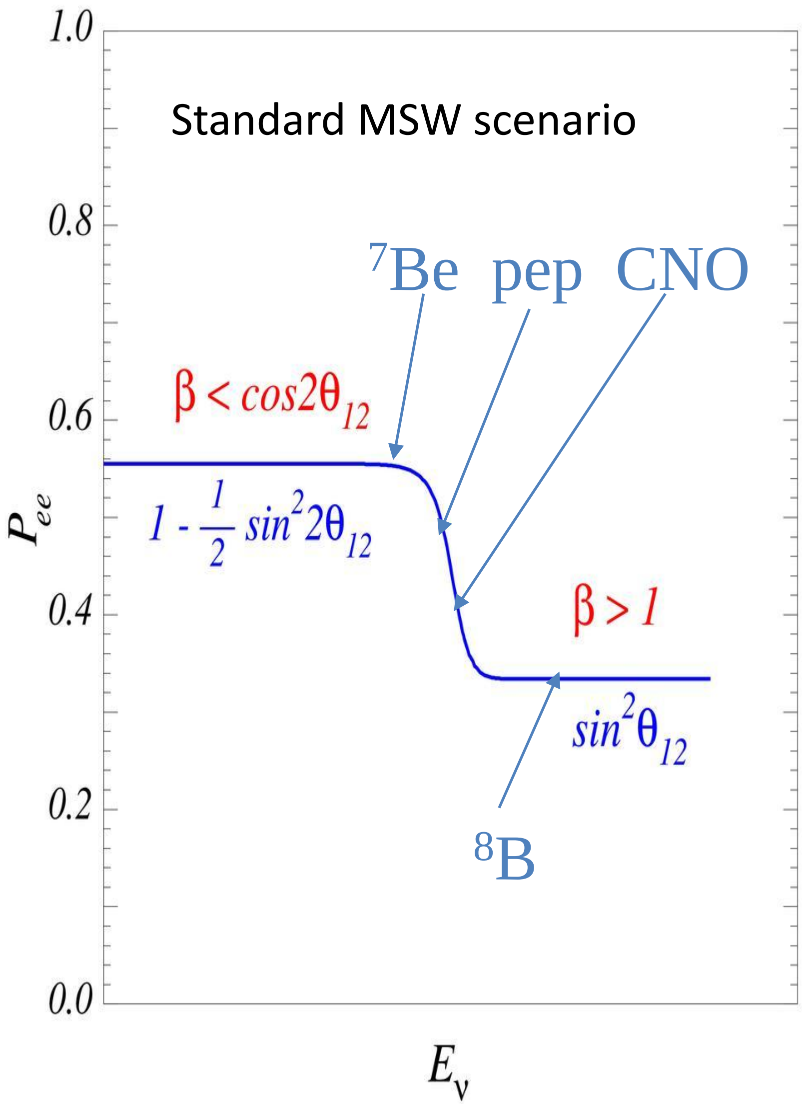
Background Requirements

- U/Th concentration of 10^{-18} g/g (achieved in Borexino)
- shielding of >3500 mwe for CNO/pep-ν measurement

Scientific Motivation

- determination of solar parameters (e.g. metallicity, contribution of CNO)
- search for temporal modulations in ^{7}Be-ν (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

Solar neutrinos in LENA



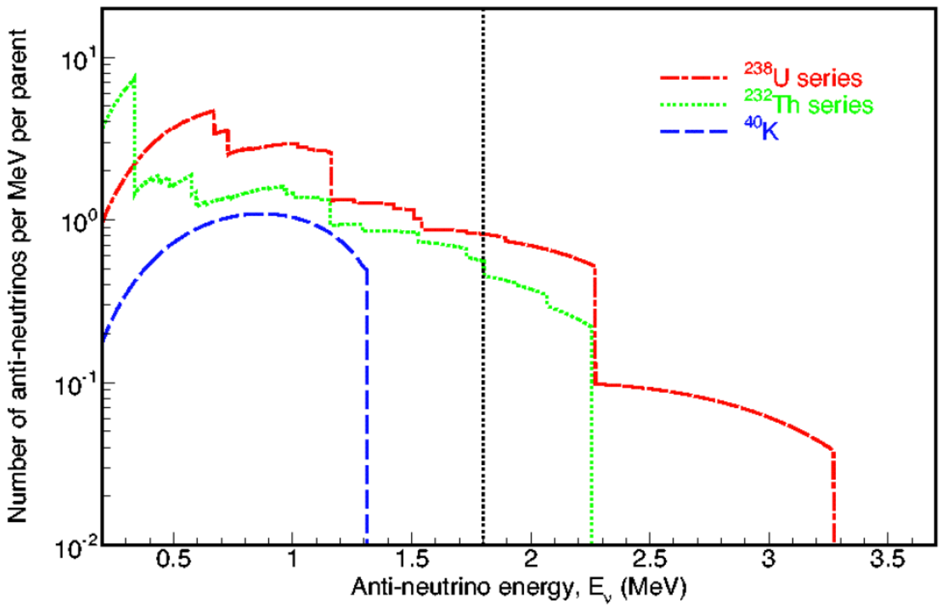
Rates of solar neutrino events

In the LENA fiducial volume:

18 kt (7m shielding)

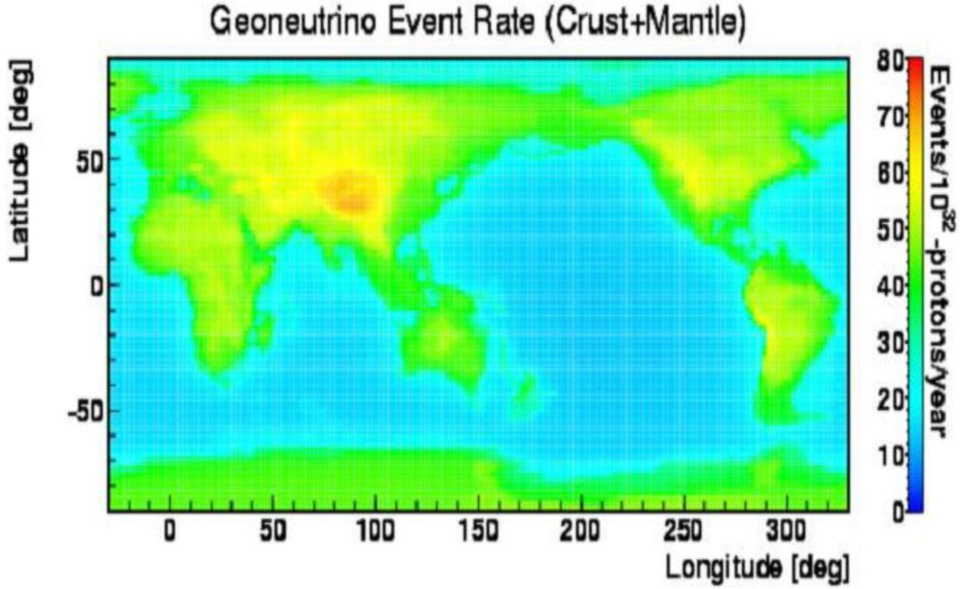
- ^{7}Be ν's: $\sim$ **4460 d^{-1}**
  - Small time fluctuations
- pep ν's: $\sim$ **375 d^{-1}**
  - Information about the pp-flux $\rightarrow$ Solar luminosity in ν's
- CNO ν's: $\sim$ **350 d^{-1}**
  - Important for heavy stars
- ^{8}B ν's: CC on ^{13}C: $\sim$ 360 y^{-1}

Geo-Neutrinos



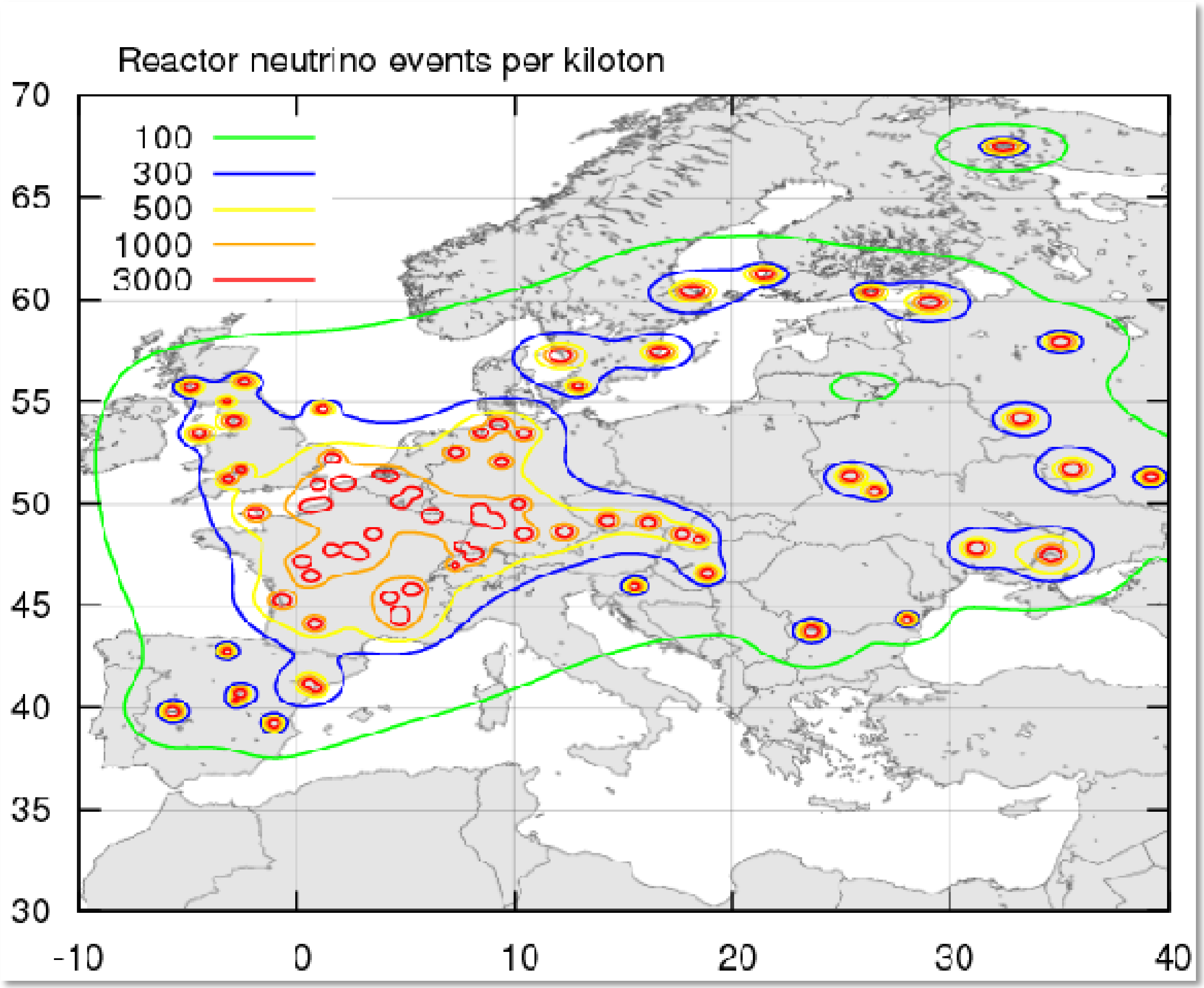
Detect anti-neutrinos of the U, Th decay chains (inverse β-decay energy threshold is 1.8 MeV).

Expected event rate at Pyhäsalmi :
2000 events/year in 50 kt
Background from reactors:
240 (x2) events/year in 50 kt
in the relevant energy window



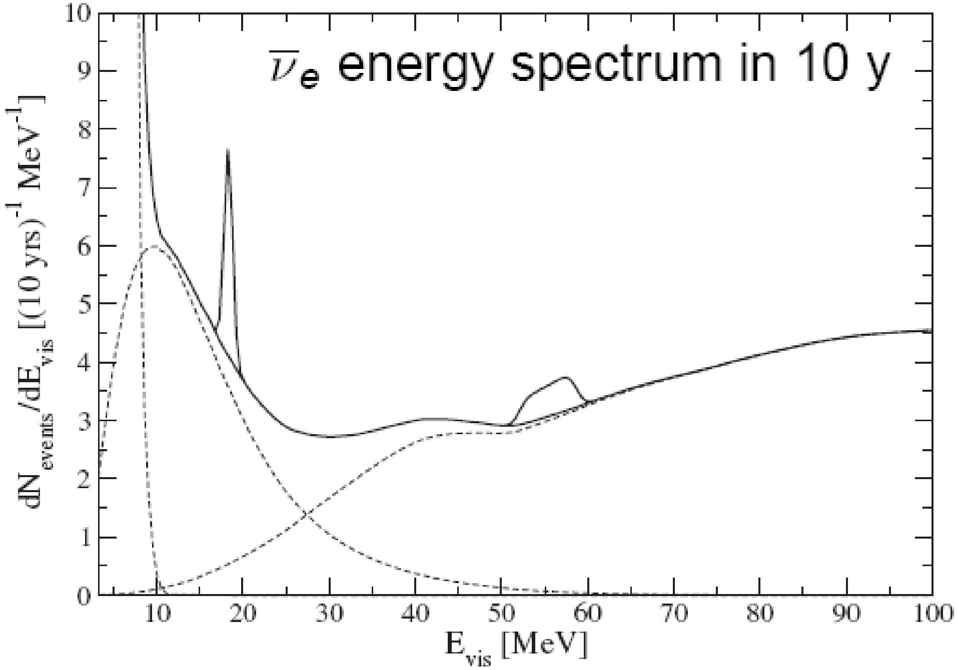
- ► measure flux from crust and mantle
- ► determine U/Th ratio
- ► disentangle continental/oceanic crust with more than one detector location
- ► only detector within LAGUNA able to detect geo-neutrinos

Influence of Detector Location



K. Loo

Indirect WIMP detection



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

- Annihilation of light WIMPs

$$\chi\chi \rightarrow \nu\overline{\nu}$$

  - Clear signature of $\overline{\nu}_e$ in liquid scintillator
  - Background from reactor, atmospheric and diffuse supernove neutrinos

- Light WIMP mass between 10 and 100 MeV
- Annihilation under neutrino emission in the galactic halo
- Monoenergetic electron-antineutrino detection in LENA

LENA as Long Baseline Detector

Baseline

- CERN to Pyhäsalmi: 2288 km ($>10^3$ km for mass hierarchy)
- 1st oscillation maximum 4 GeV
- on-axis detector

Beam properties

- wide band: energy 1-6 GeV
- beam power: 3.3×10^{20} pot/yr
- 5 yrs ν + 5 yrs $\bar{\nu}$

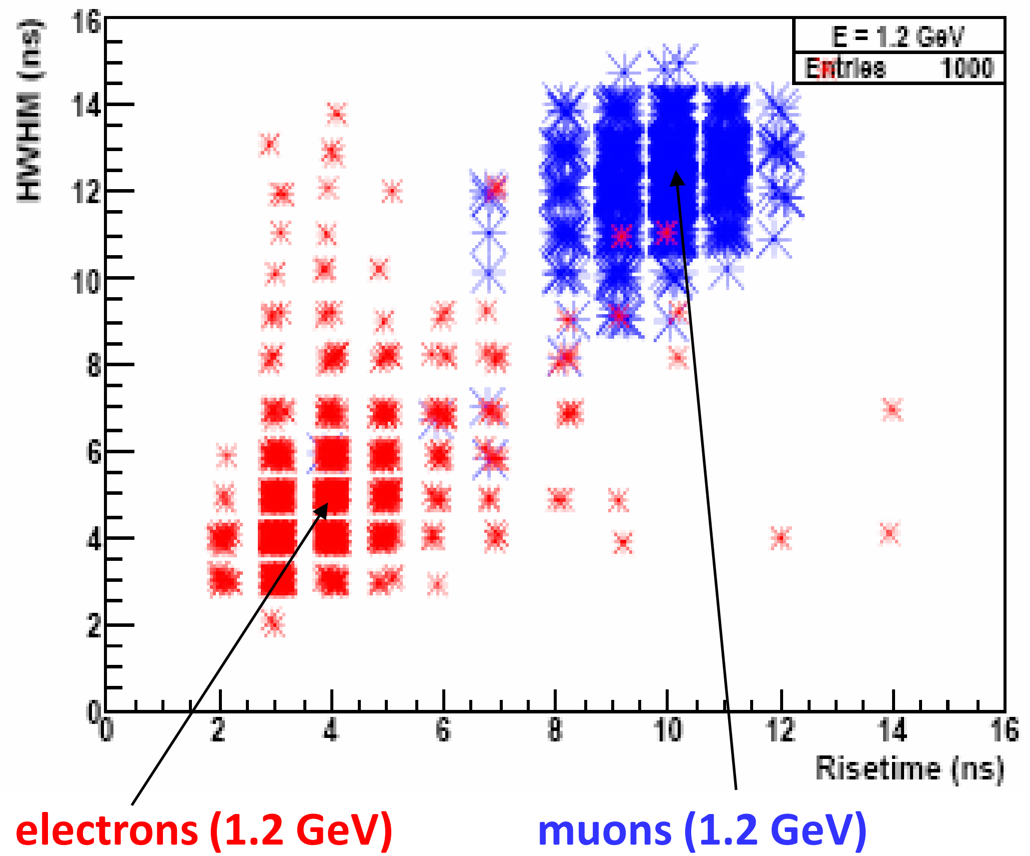
Preliminary GLoBES result

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

Long baseline neutrino oscillations

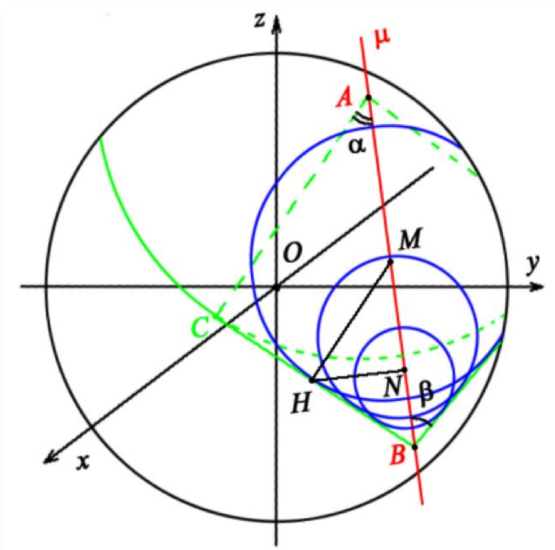
Flavour recognition (à la Super-Kamiokande) ?

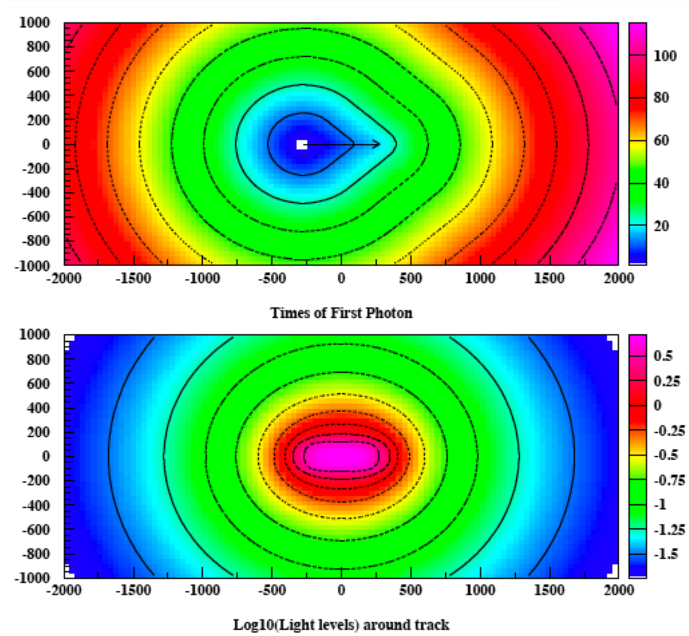
- Separation between e- and μ-like events
- Pulse shape discrimination (risetime, width)
- Track reconstruction
- Muon decay $\mu \rightarrow e\nu\nu$
- Work in progress



Very simple method works amazingly well. With more sophisticated methods, flavour resolution is almost absolute (i.e. negligible compared to „wrong flavour“ beam contamination).

Tracking of Single Particles





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

Single track reconstruction based on:

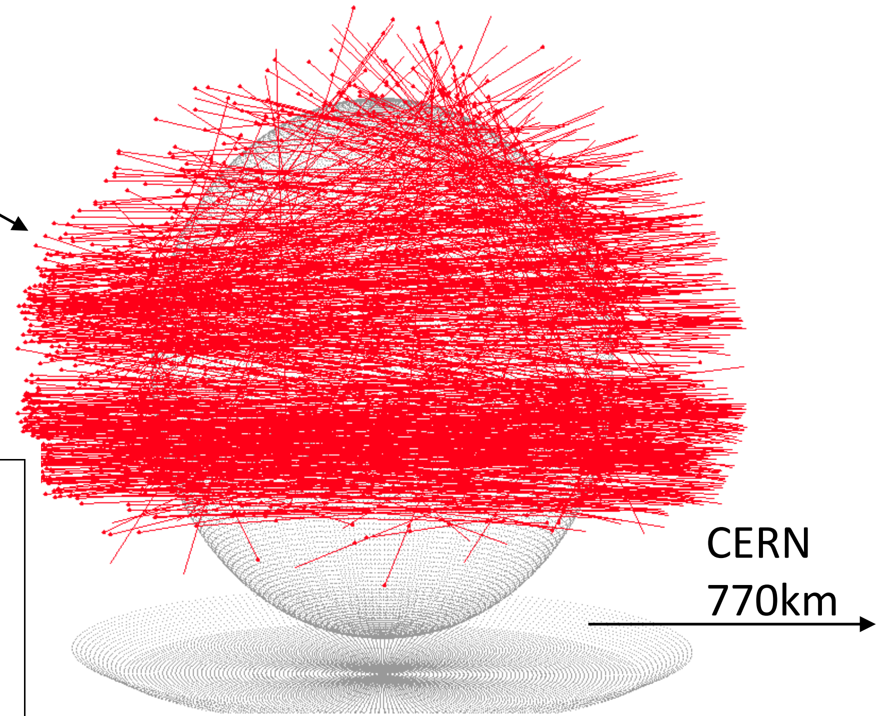
- Arrival times of 1st photons at PMTs
- Number of photons per PMT

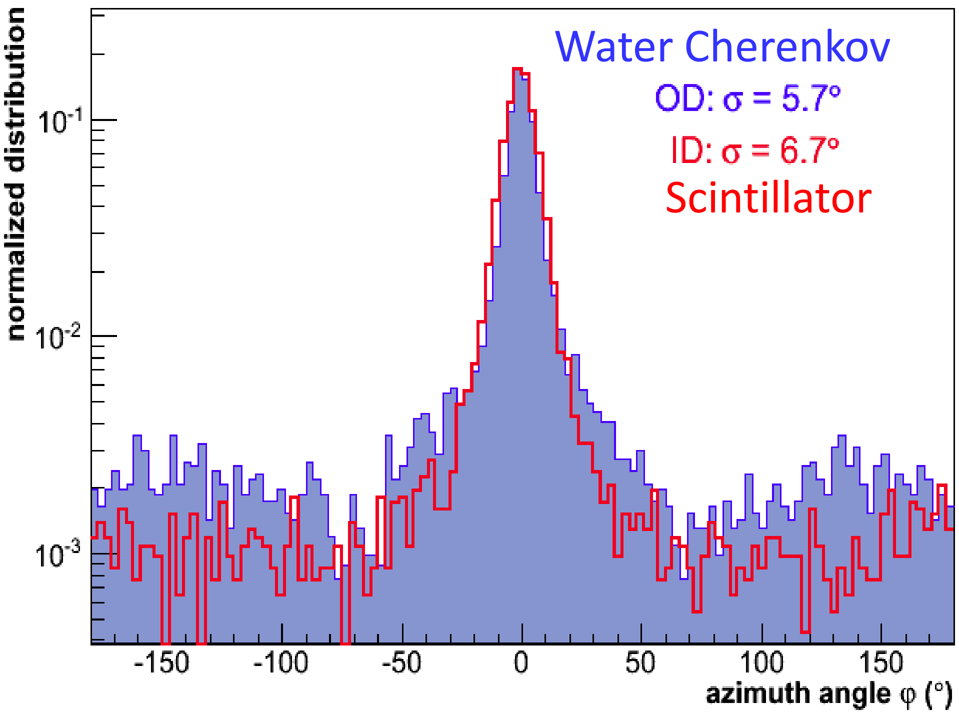
Sensitive to particle types due to the ratio of track length to visible energy.

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

Work in progress for LENA within LAGUNA and a scintillator option in the U.S.

CNGS neutrino induced muons in BOREXINO





Direction from CERN

(azimuth = 0 degree)

real Data – no Monte-Carlo !

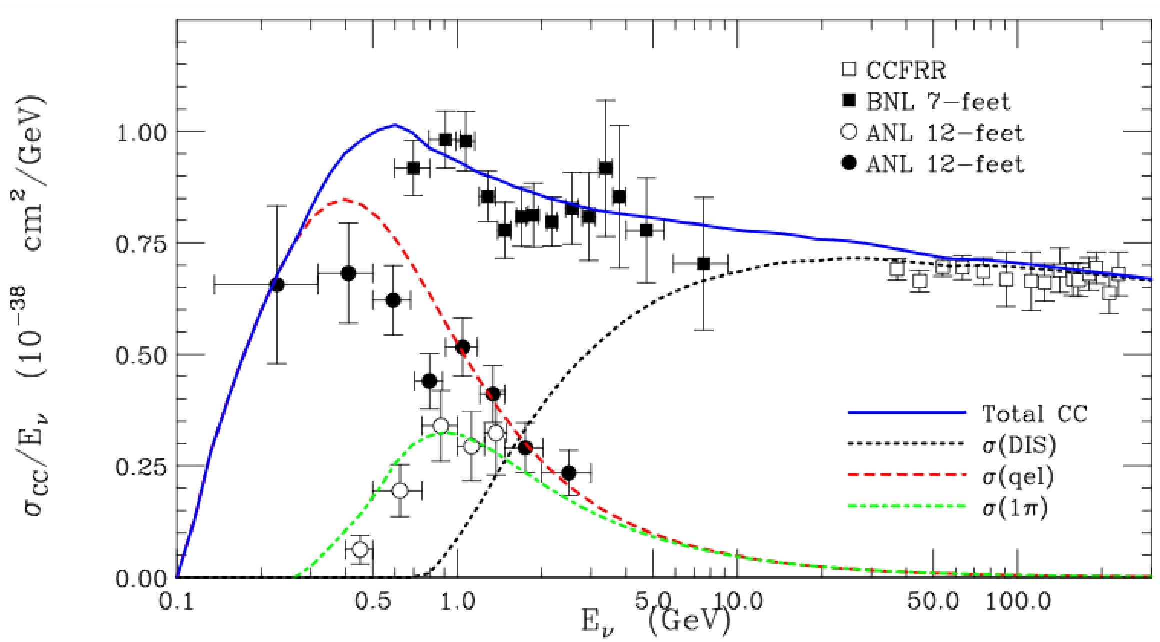
BOREXINO is NOT optimized for tracking !

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

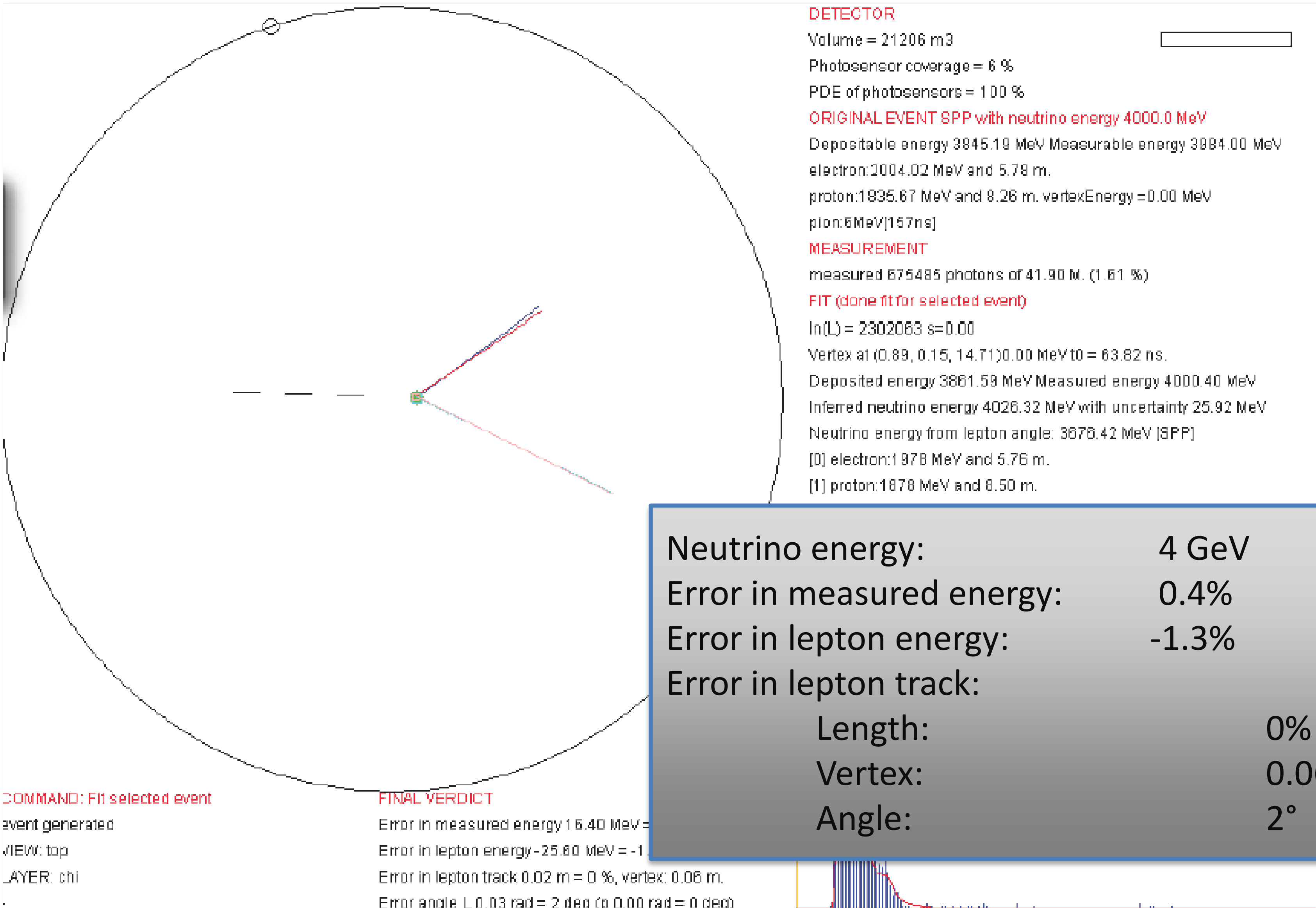
Multi-Particle Approach:

(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.

Monte Carlo Sample Event:

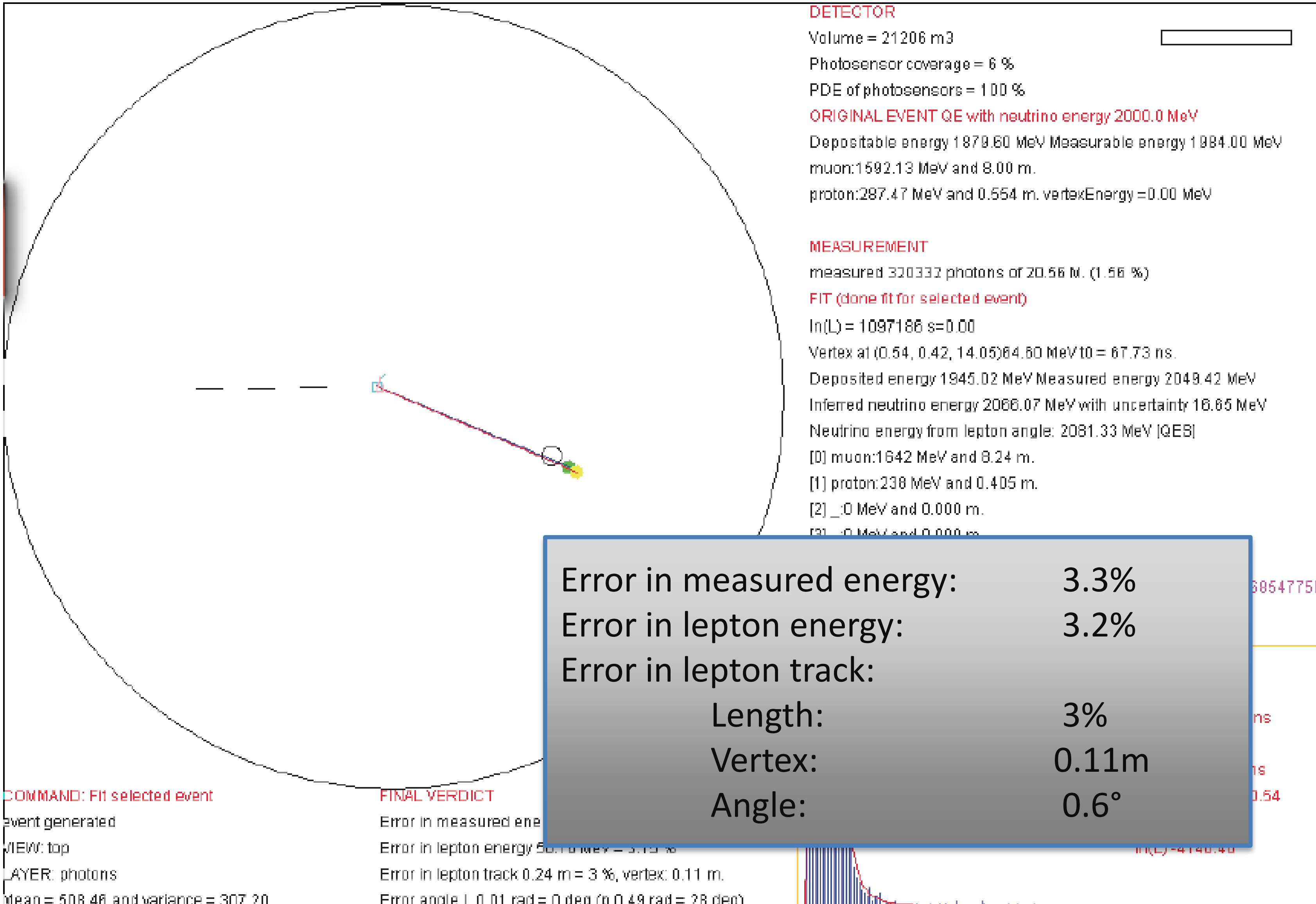
ν_e Single-Pion Production



Neutrino energy:	4 GeV
Error in measured energy:	0.4%
Error in lepton energy:	-1.3%
Error in lepton track:	
Length:	0%
Vertex:	0.06m
Angle:	2°

Scinderella Sample Event:

ν_μ Quasi-Elastic Scattering



Error in measured energy: 3.3%
Error in lepton energy: 3.2%
Error in lepton track:
- Length: 3%
- Vertex: 0.11m
- Angle: 0.6°

Tracking Performance

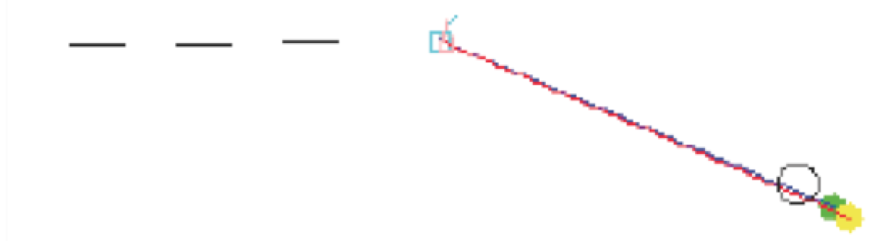
Single Tracks:

- 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

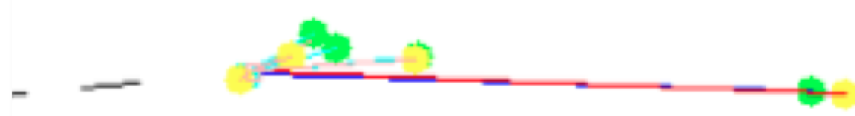
Multiparticle Events:

- 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



LENA as Long Baseline Detector

Baseline

- CERN to Pyhäsalmi: 2288 km ($>10^3$ km for mass hierarchy)
- 1^{st} oscillation maximum 4 GeV
- on-axis detector

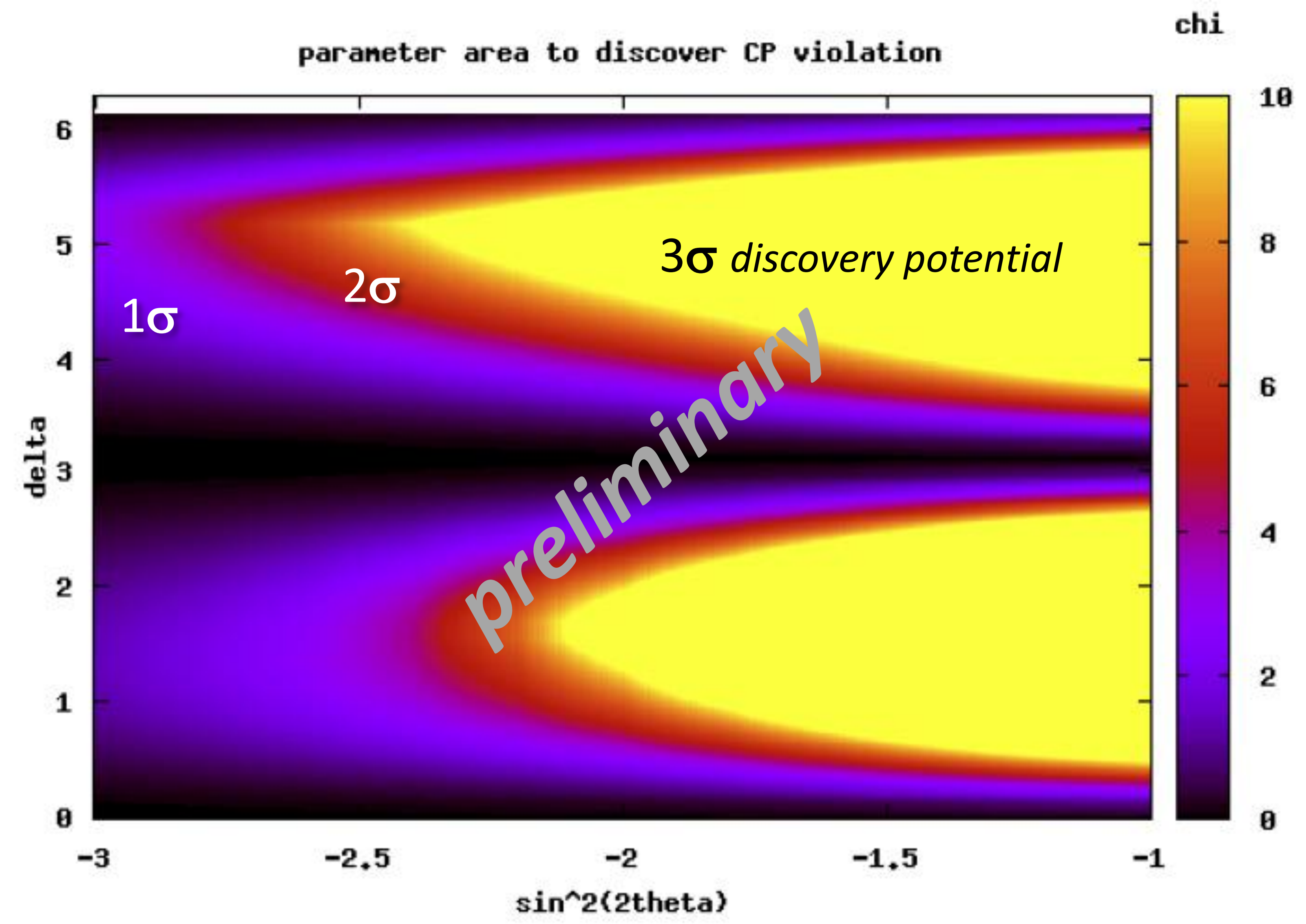
Beam properties

- wide band: energy 1-6 GeV
- beam power: 3.3×10^{20} pot/yr
- 5 yrs ν + 5 yrs $\overline{\nu}$

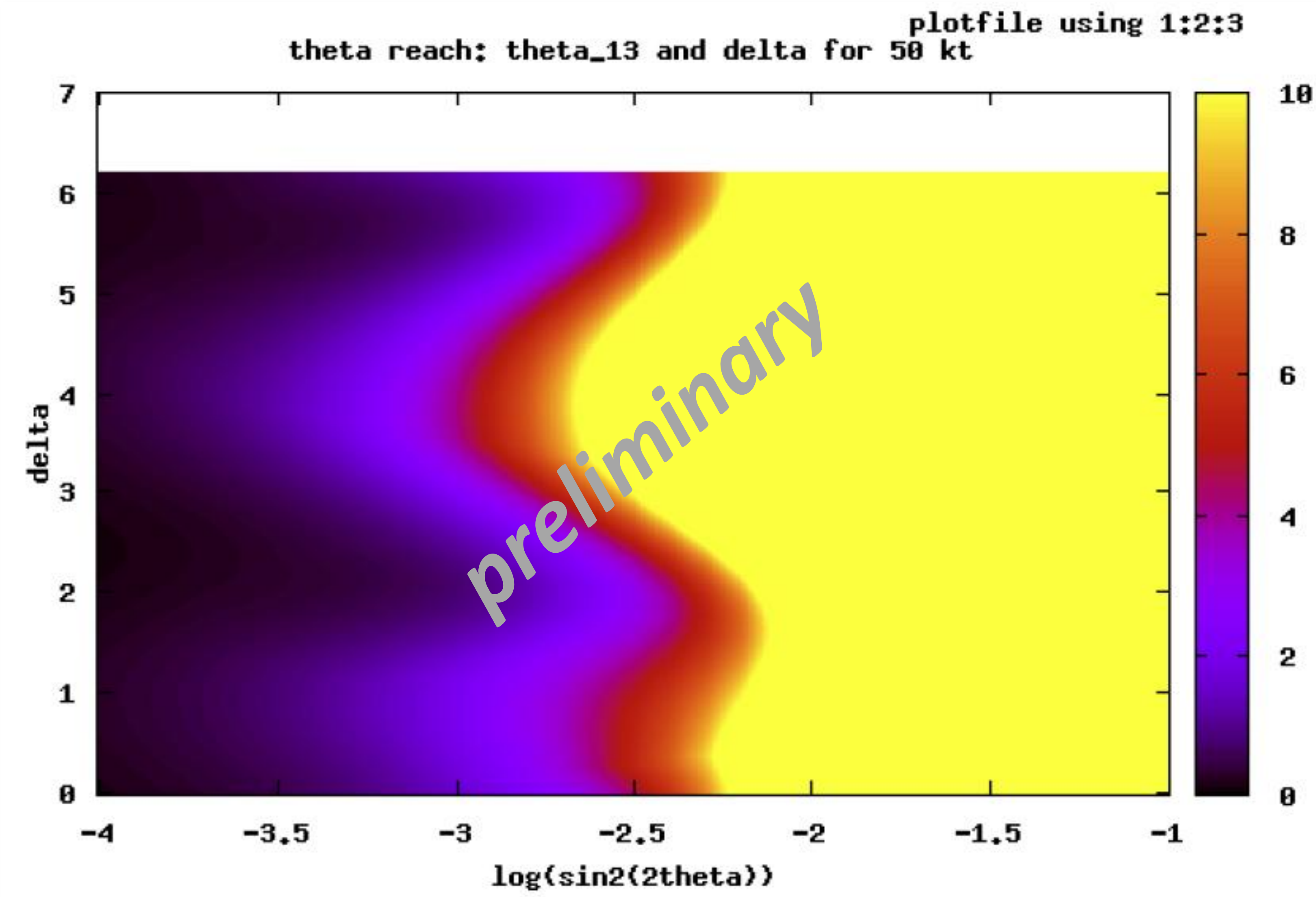
Preliminary GLoBES result

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

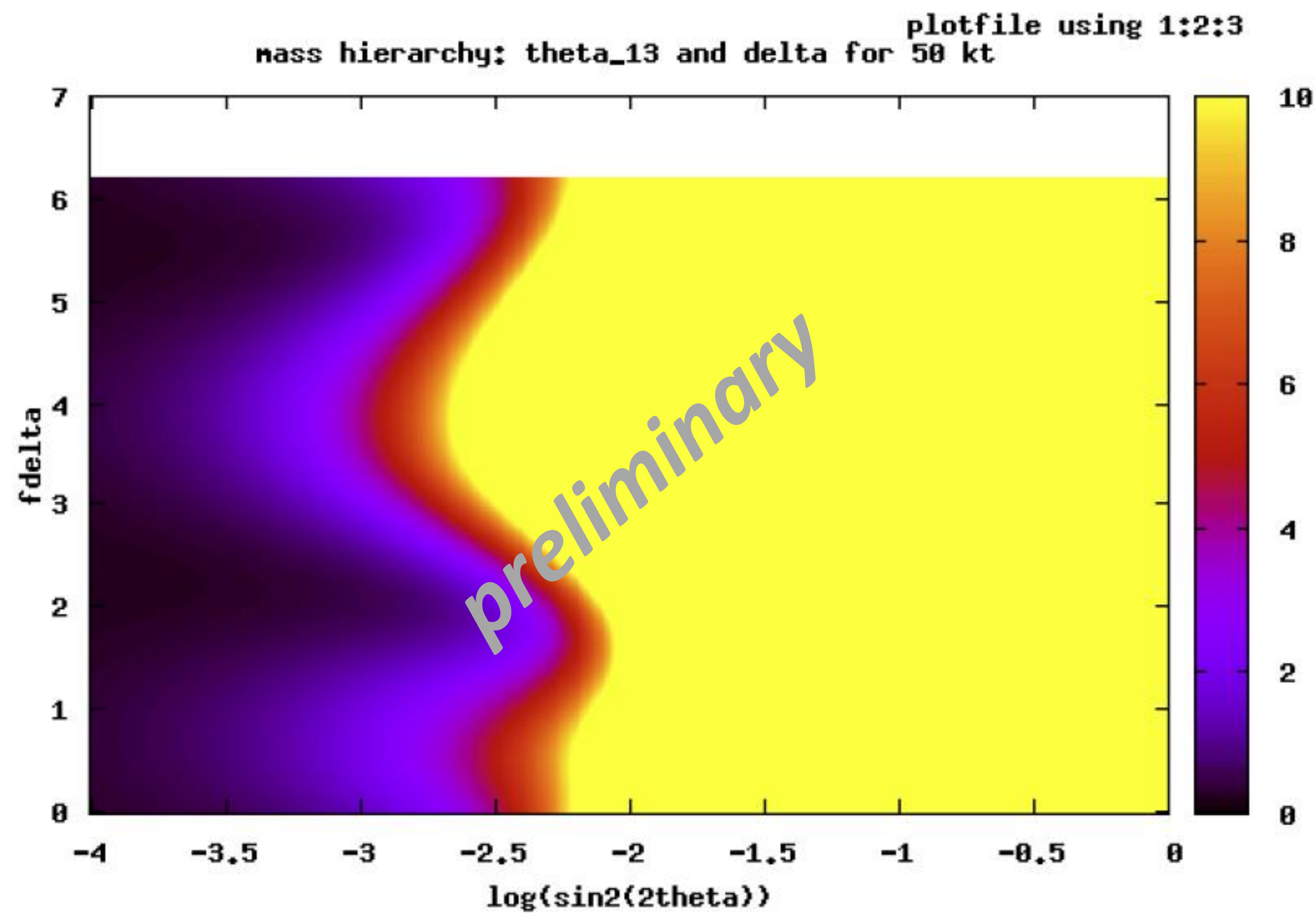
Sensitivity to CP-Violating Phase



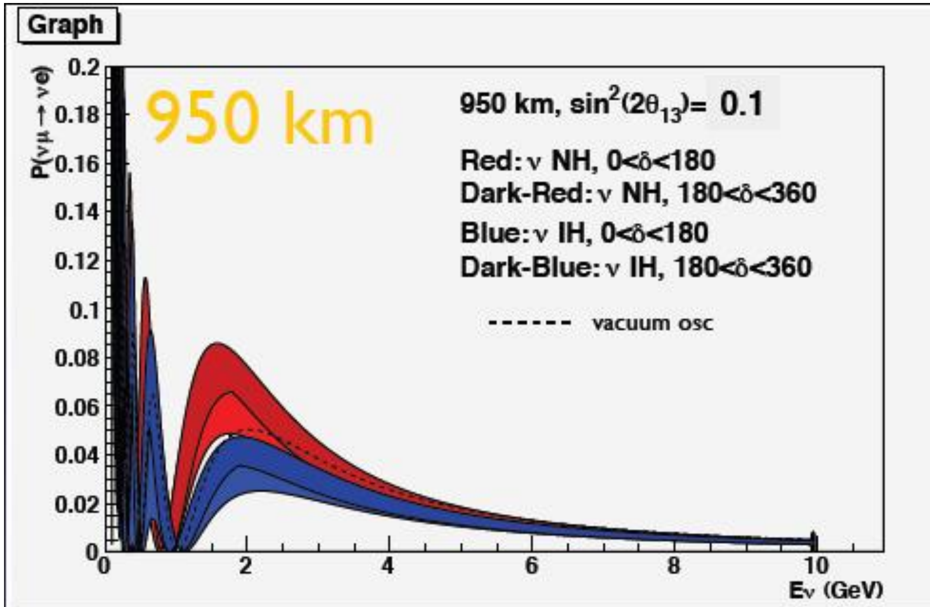
Sensitivity to Mixing Angle θ_{13}

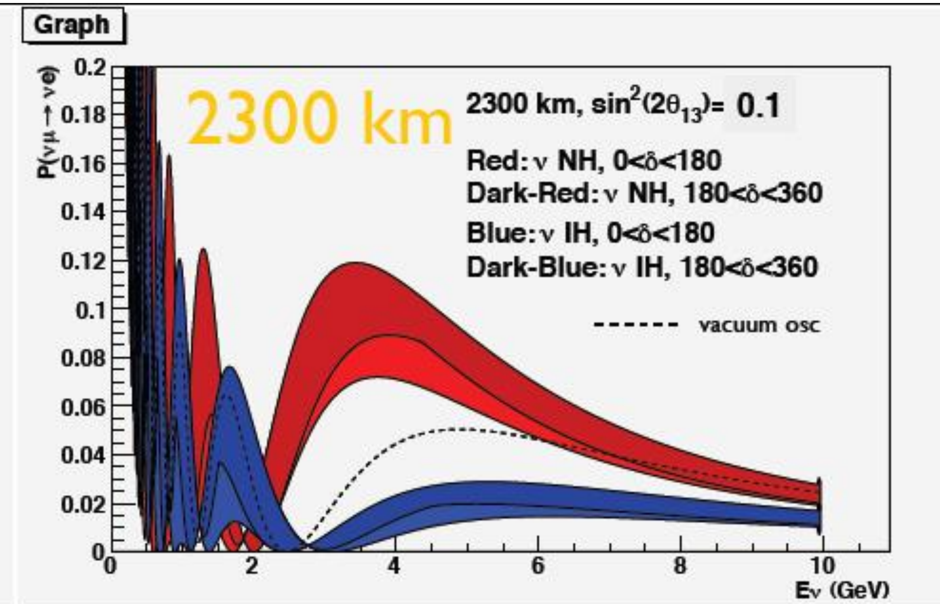


Sensitivity to Mass Hierarchy



2300km baseline

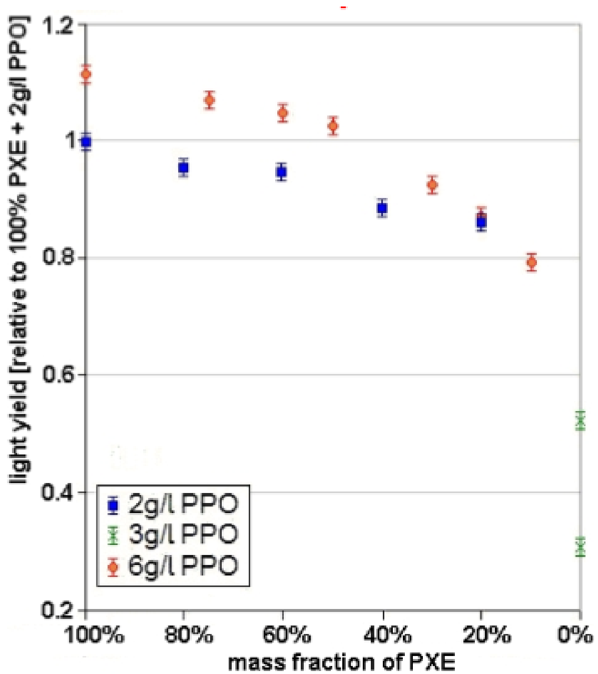


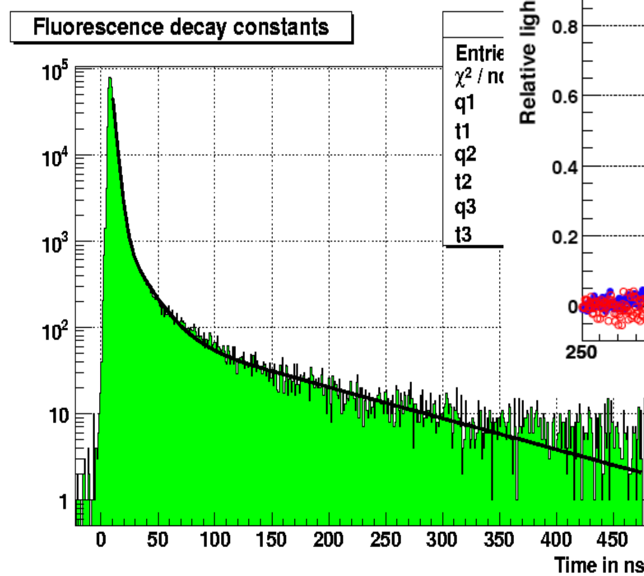


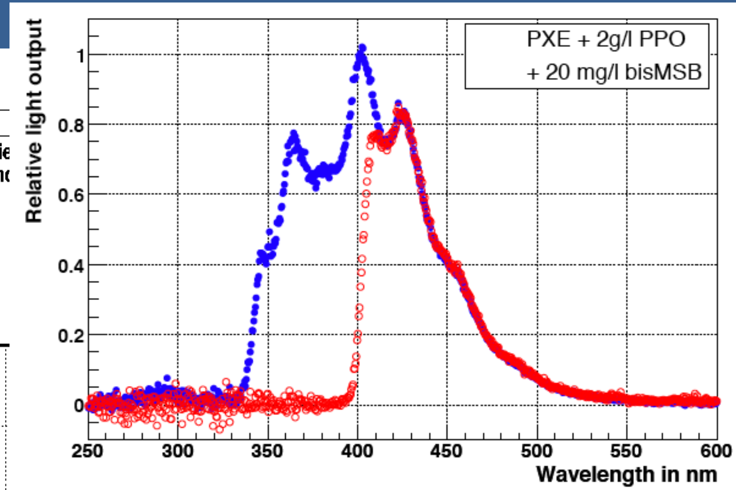
CPV and mass hierarchy degeneracy

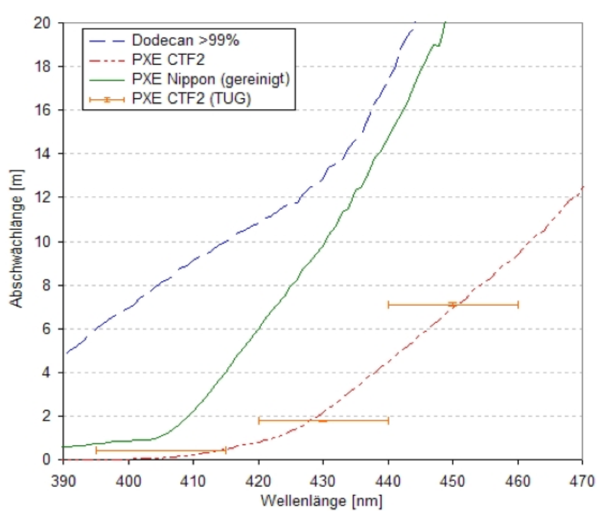
- The determination of the CP violation effect is plagued by the mass hierarchy degeneracy
  - NH, 0<δ<180° degenerate with IH, 180<δ<360° at shorter baselines
  - Degeneracy is lifted by matter effects (L > 900km, improves with L)
- At a given energy (E≈3GeV for 2300km and IH) probability is independent of CP phase δ ➡ clean mass hierarchy determination

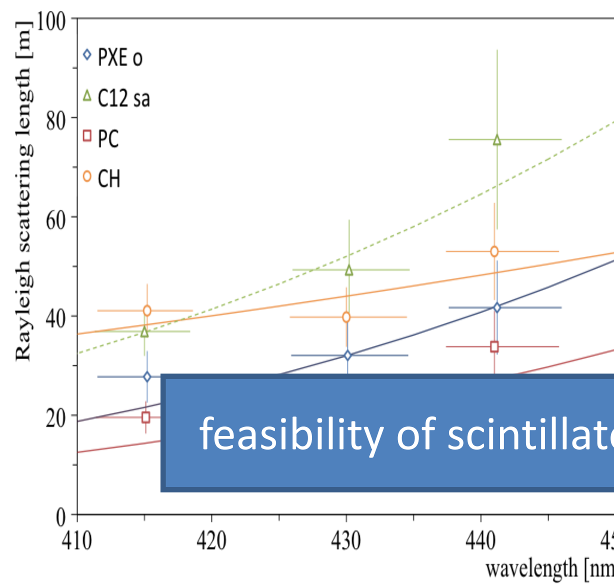
Liquid Scintillator R&D











Solvent candidates

Light Yield

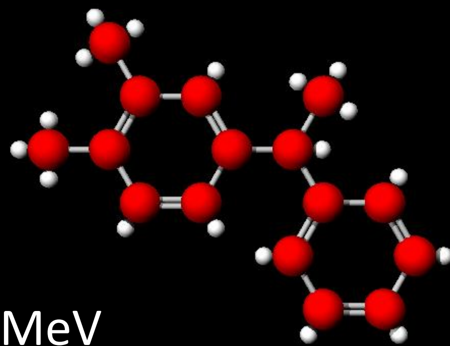
Scintillation decay times

Emission spectra

Wavelength shifters

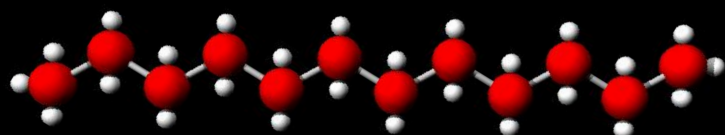
feasibility of scintillator performance shown

Solvent Candidates



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

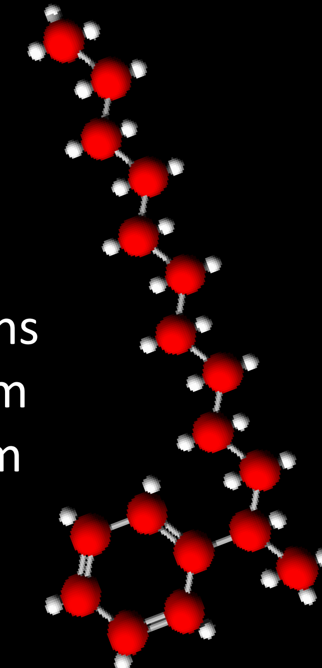
density: 0.99 kg/l
light yield:
ca. 10.000 ph/MeV
fluorescence decay: 2.6ns
attenuation length: ≤12m (purified)
scattering length: 23m



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



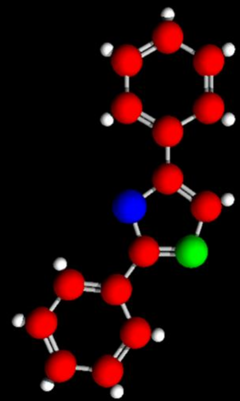
density: 0.86 kg/l
light yield: comparable
fluorescence decay: 5.2ns
attenuation length: <20m
scattering length: 25m

- **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.

Wavelength Shifters

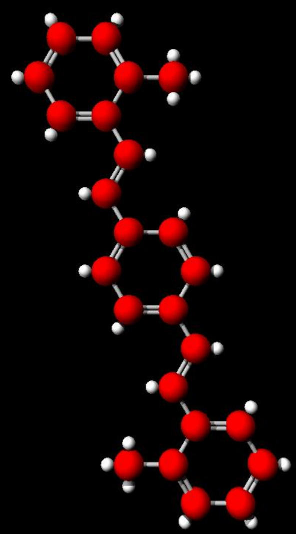
PPO, $C_{15}H_{11}NO$

primary fluor
absorption band:
280-325nm
emission band:
350-400nm



bisMSB, $C_{24}H_{22}$

secondary fluor
absorption band:
320-370nm
emission band:
380-450nm



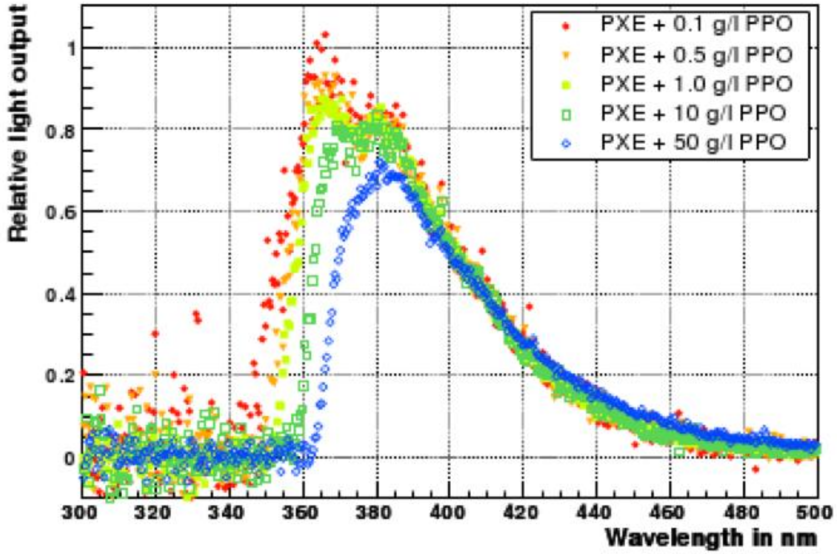
PMP, $C_{18}H_{20}N_2$

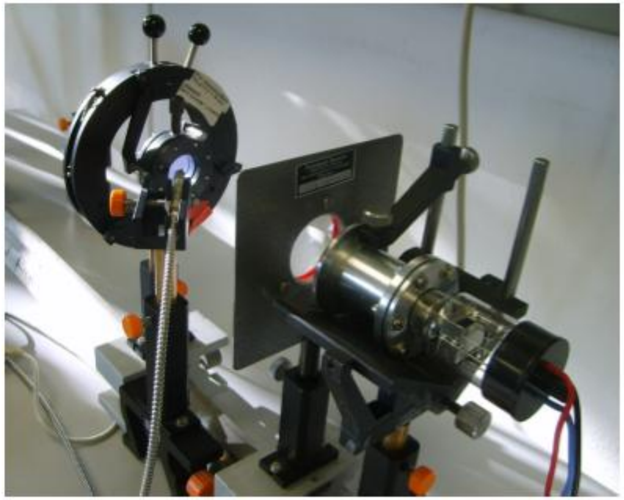
large Stoke-shift fluor
absorption maximum:
294nm
emission maximum:
415nm

used in the KARMEN experiment, currently not commercially produced

- Adding bisMSB to PPO has no significant effect on timing.
- PMP is slower than PPO: in PXE, 4.2ns instead of 2.6ns

Fluorescence Spectrum

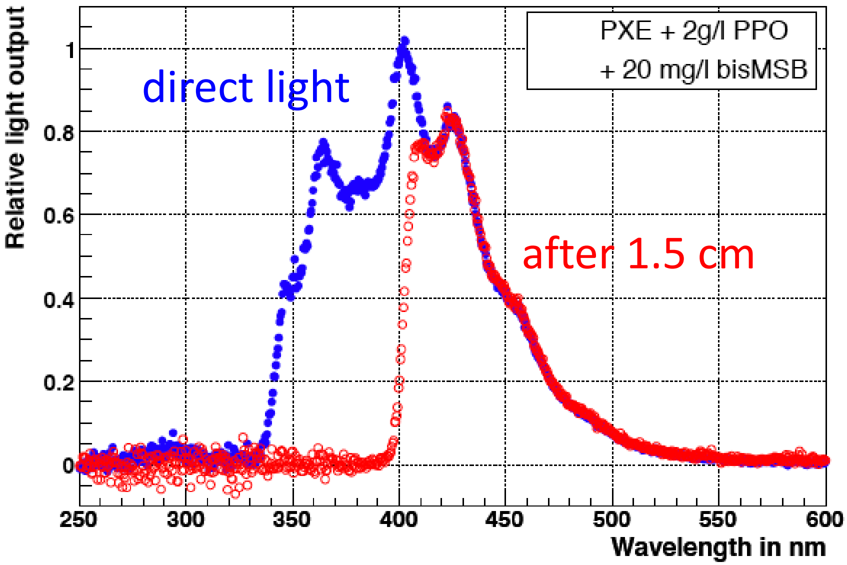


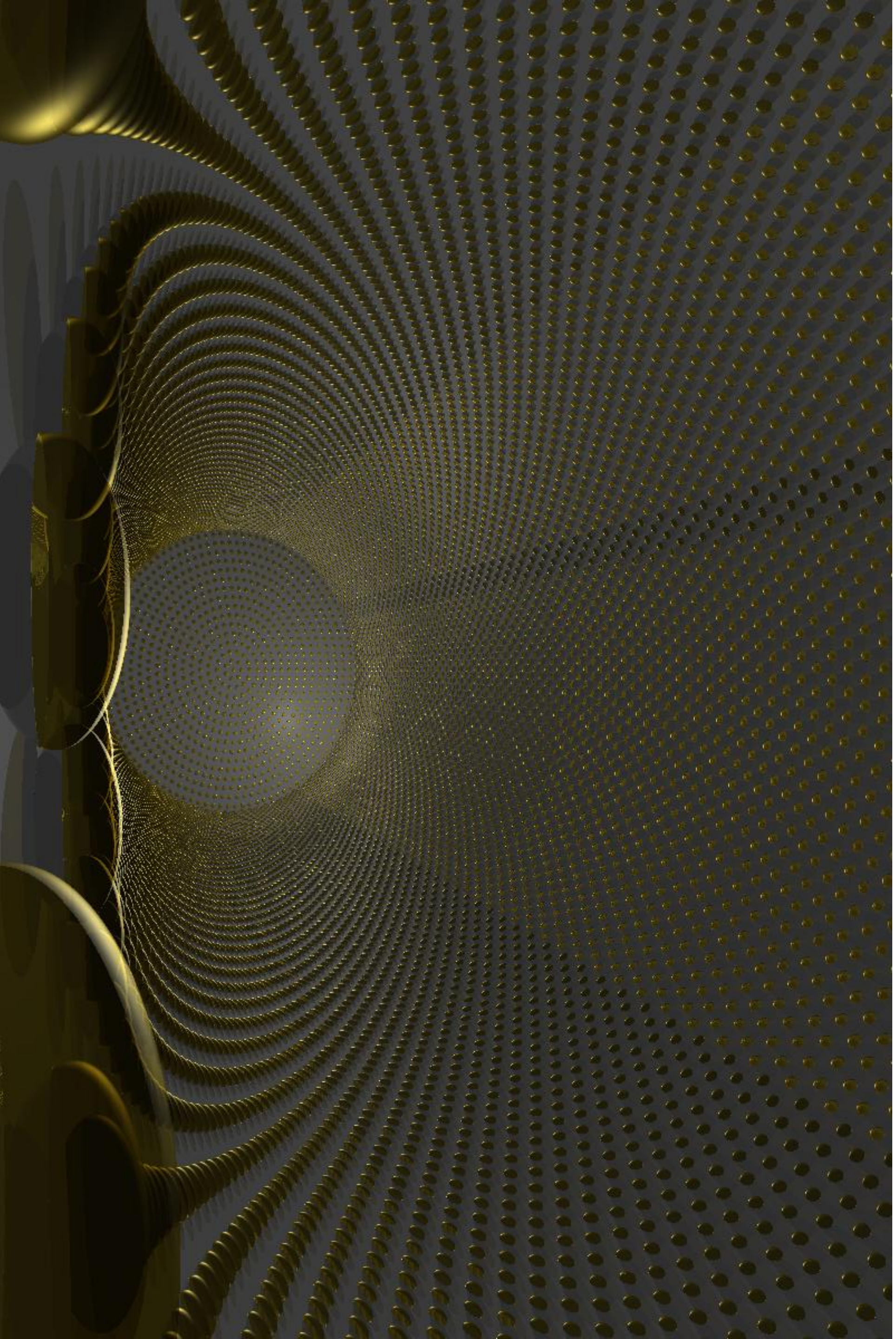


Influence of fluor type and concentration on the light emission spectrum.

Excitation by UV light and/or electrons

Light emission of primary and 2nd shifters
PPO+bisMSB 400-430 nm





Light sensors

Default Configuration

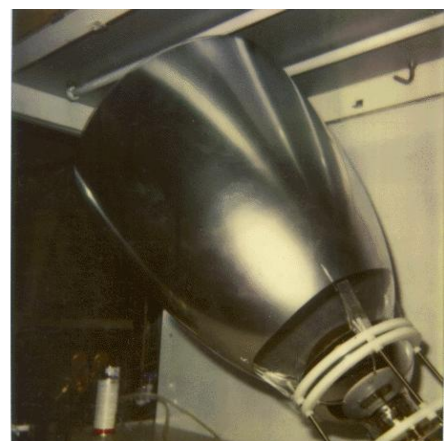
- 13,500 PMs of 20'' cathode diameter
- optical coverage: 30%

Smaller Photomultipliers

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

Usage of Light Concentrators

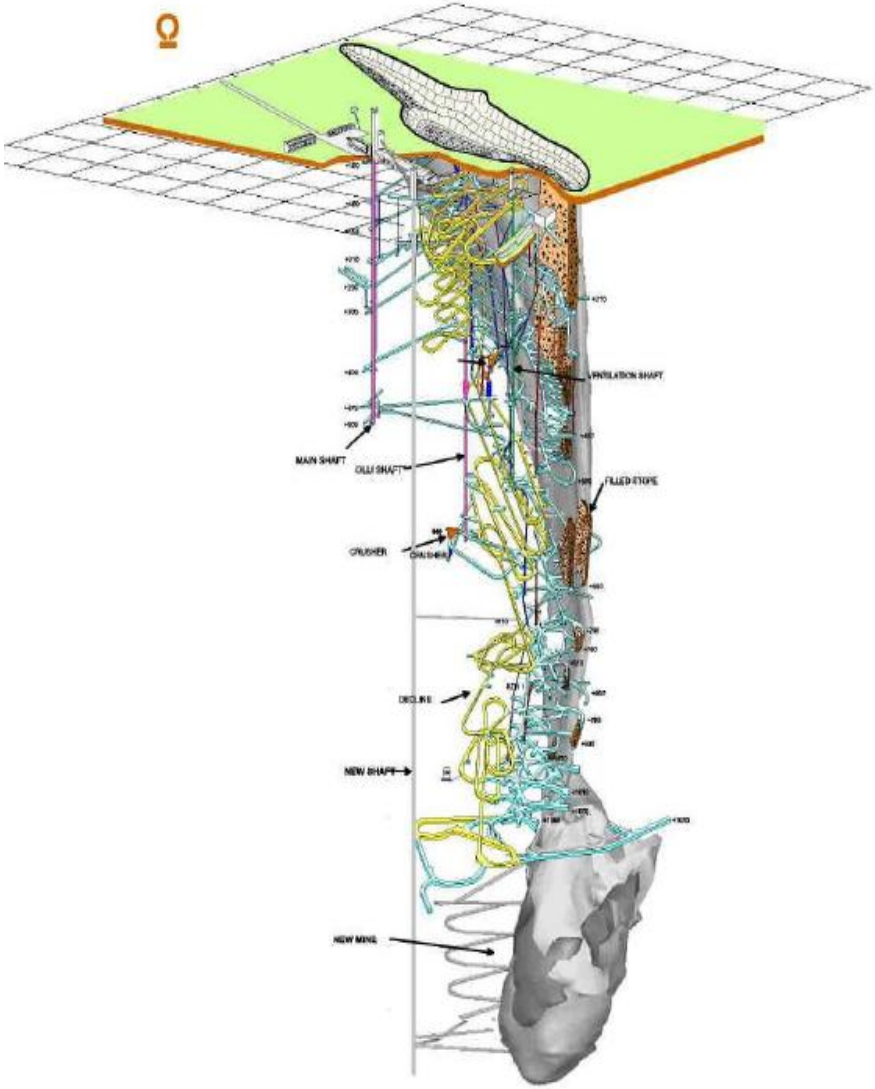
- Borex cones double optical coverage
- Larger cones seem possible in LENA



Light cone used in the Borexino prototype CTF

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

Pre-feasibility study within LAGUNA



ROCKPLAN, Finland, together with TU München: pre-feasibility study for **a LENA detector at Pyhäsalmi**

- depth of 1400-1500 m possible
- geological study completed
- vertical detector position
- infrastructure (ventilation, electricity, etc.) considered
- construction time of cavern ~ 4 yrs
- first cost and time estimate for the whole project
- Tank feasibility study completed May 2010

Strategy in

Europe

U.S.

Japan

Europe: LAGUNA

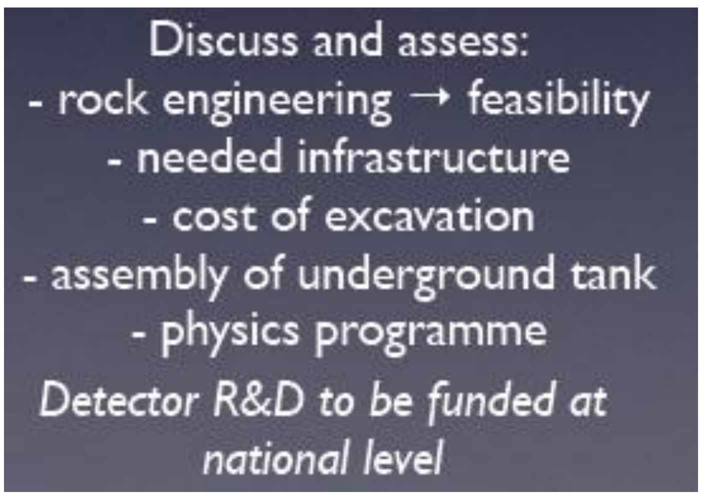
Consortium composed of 21 beneficiaries in 9 countries

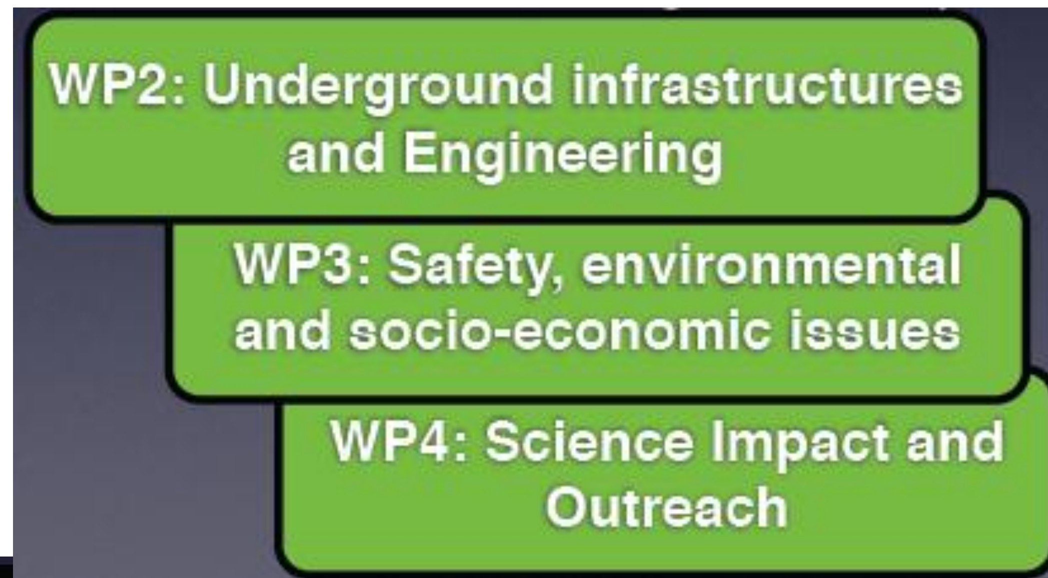
9 university entities (ETHZ, Bern, Jyväskylä, OULU, TUM, UAM, UDUR, USFD, UA)

8 research organizations (CEA, IN2P3, MPG, IPJ PAN, KGHM CUPRUM, GSMiE PAN, LSC, IFIN-HH)

4 private companies (Rockplan, Technodyne, AGT, Lombardi)

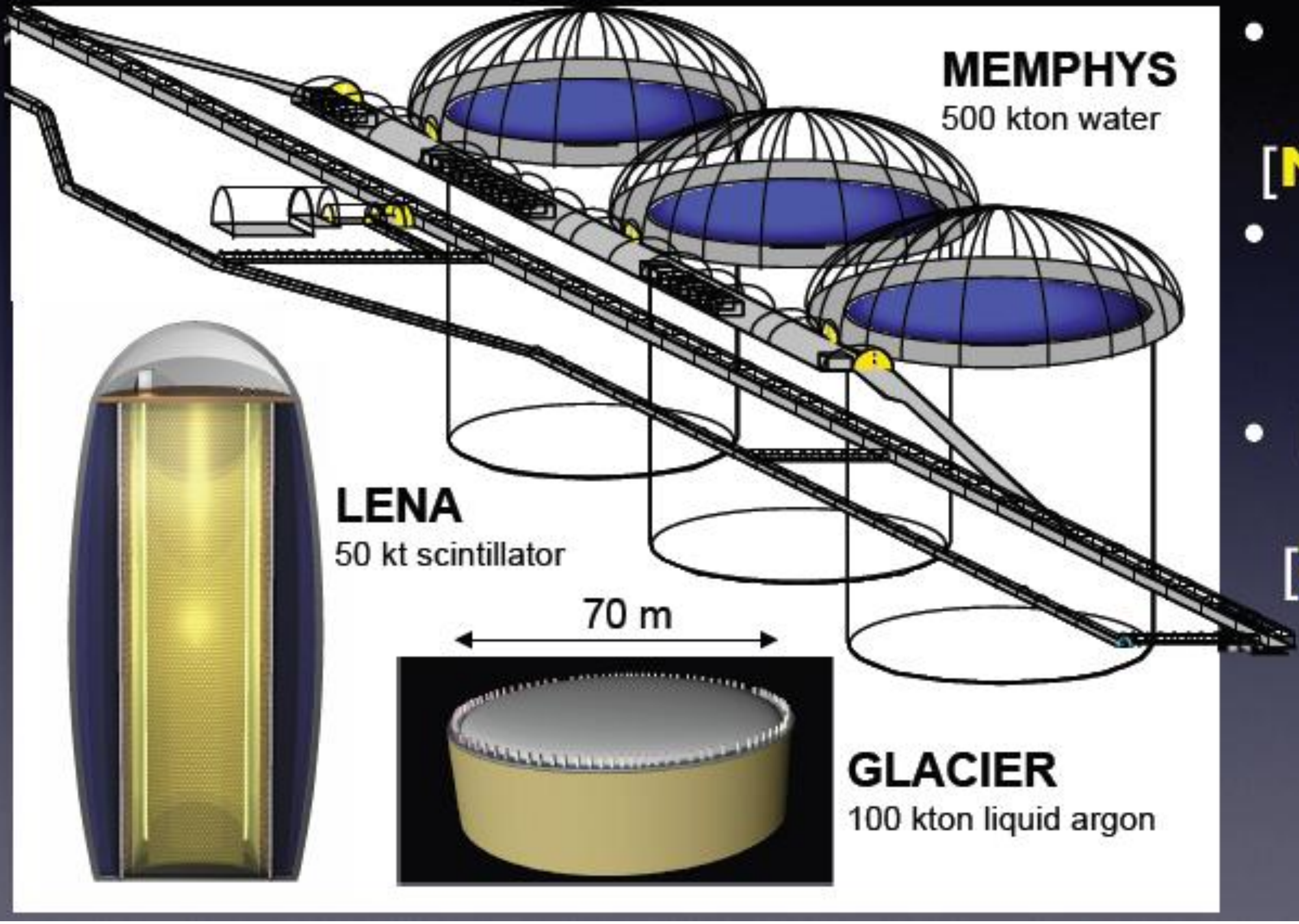
Additional university participants (IPJ Warsaw, Silesia, Wroclaw, Granada)





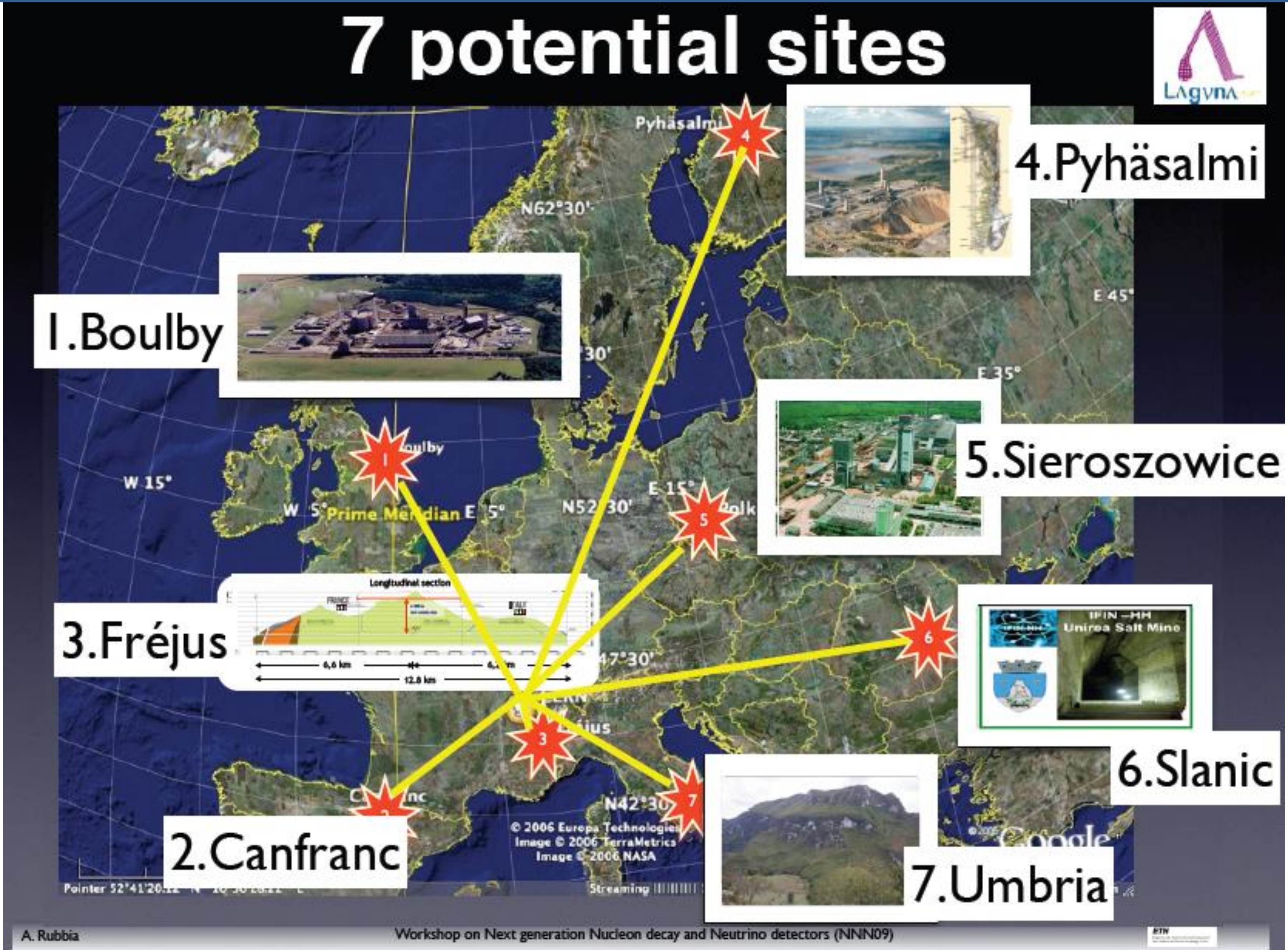
Europe: LAGUNA

- three options considered (MEMPHYS, LENA, GLACIER) with total mass in the range 50-500 kton



- Water Cerenkov [**MEMPHYS**]
- Liquid scintillator [**LENA**]
- Liquid Argon TPC [**GLACIER**]

Europe: LAGUNA

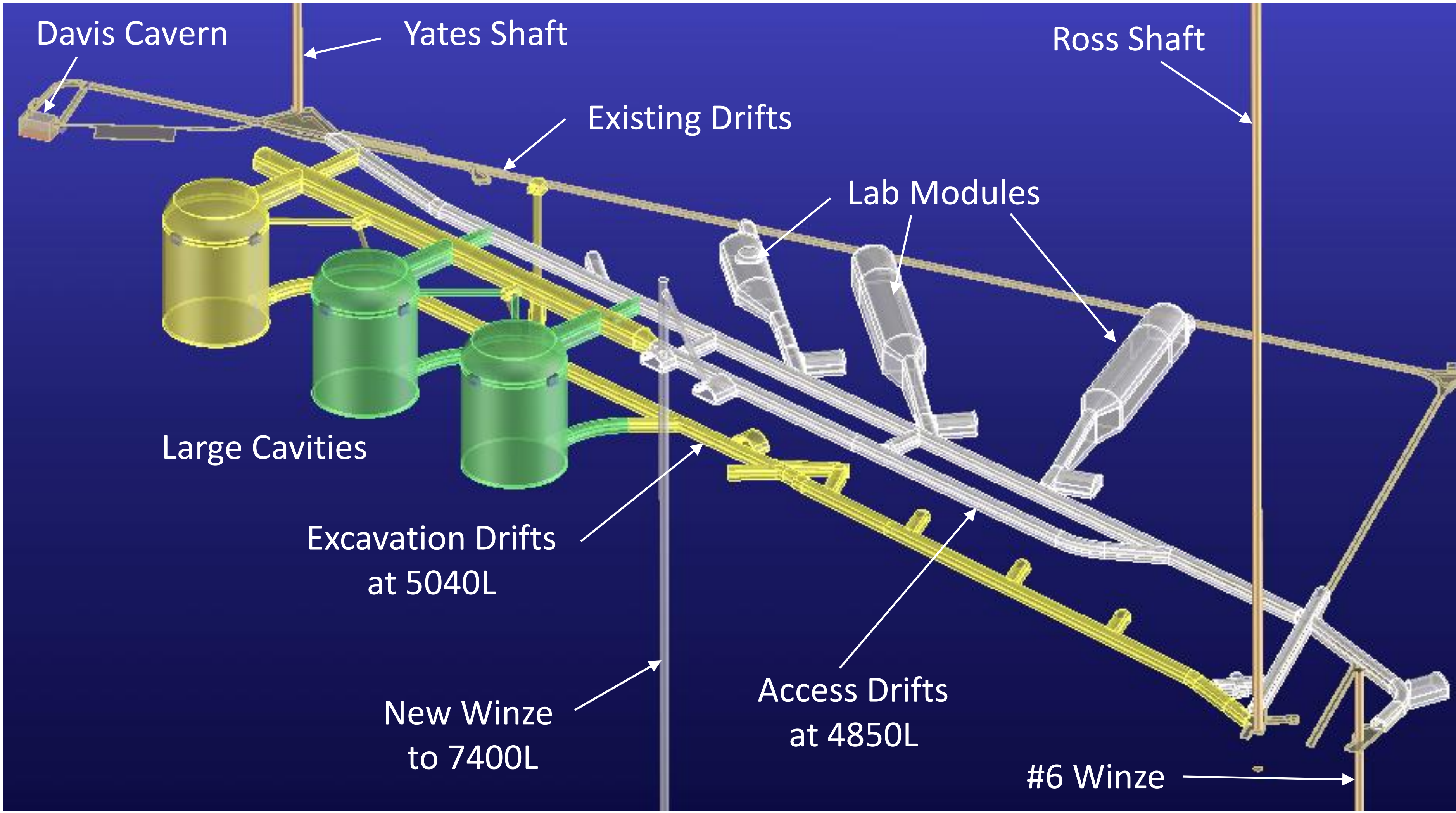


Europe: LAGUNA

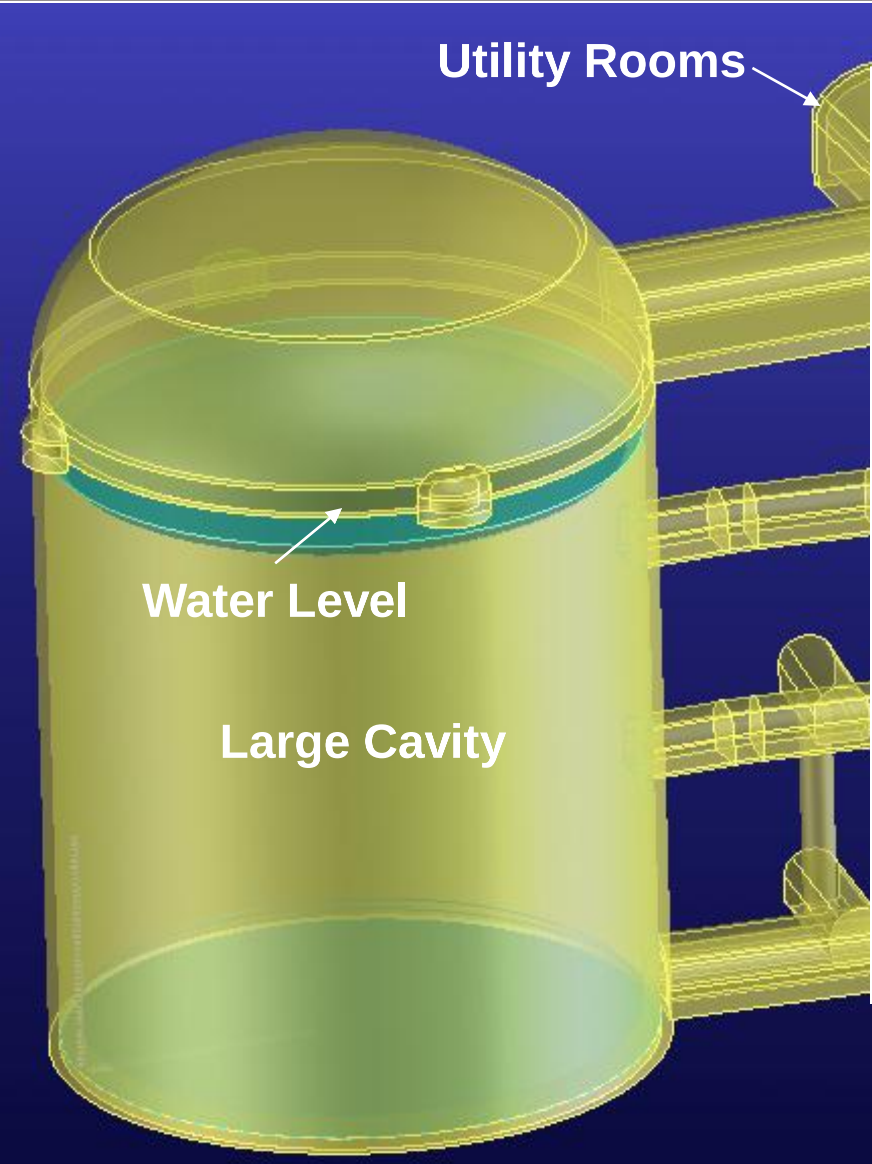
Design Study (EU FP7 funded):	2008 - 2010
Interim safety, socio-economic, environmental report:	finished
Interim geotechnical reports on the seven sites:	finished
Prioritize the sites and down-select:	2010

US: Long Baseline Neutrino Experiment

US: DUSEL Excavation Plan



Large Cavity, Water Cerenkov Detector
Water: 53m Dia. x 54m vertical,
Fiducial Volume: 50m Dia. x 51m vertical



Conceptual design parameters:

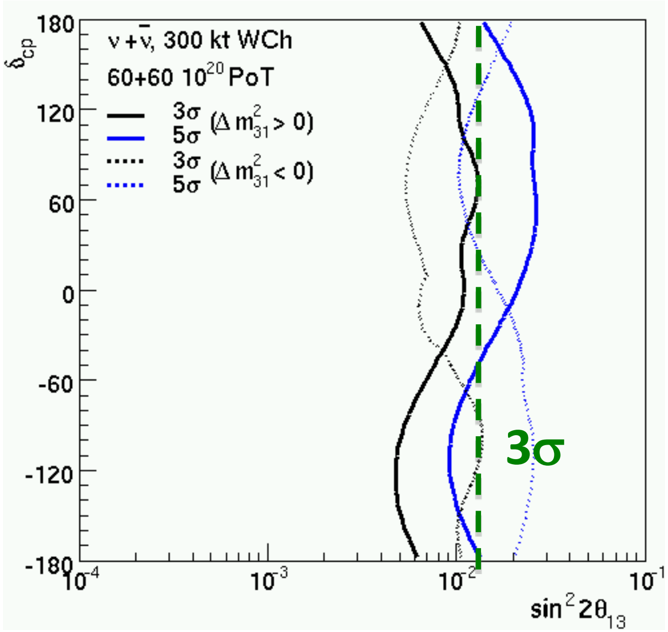
- PMT coverage: 6(3) p.e./Mev for LE(HE) option.
- Could achieve with 40k to 80k 25 cm HQE PMT's
- veto: top only or "thin" option being studied.
- cavern size/shape
- gadolinium loading option
- Initial costing going well

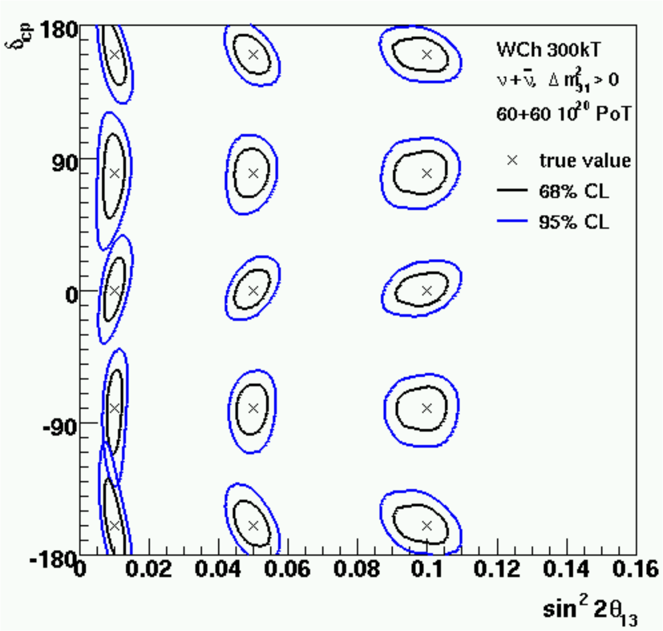
LBNE Science Collaboration

US: LBNE Water Cherenkov

Long Baseline Neutrino Experiment

Sensitivity to mass hierarchy and CP violation





700 kW, 8+8 years

$2\text{x}10^7$ s/yr, 120 GeV

Gadolinium doping option

- Sensitivity to neutron capture via 8 MeV gamma cascade
- Technical challenges:

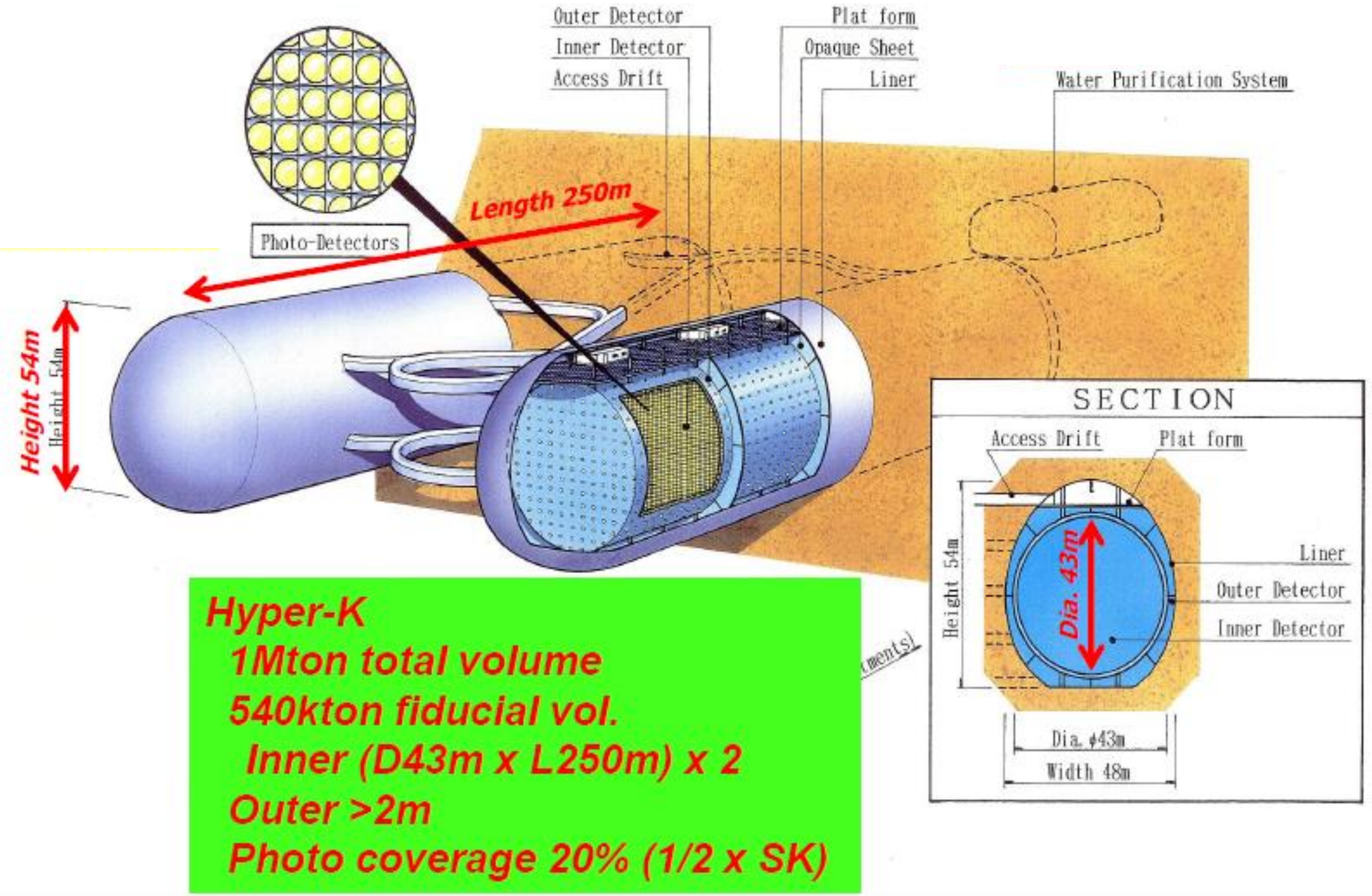
  - material compatibility. Chose materials that do not contaminate the water.

  - water treatment. Remove impurities but leave gadolinium in solution.

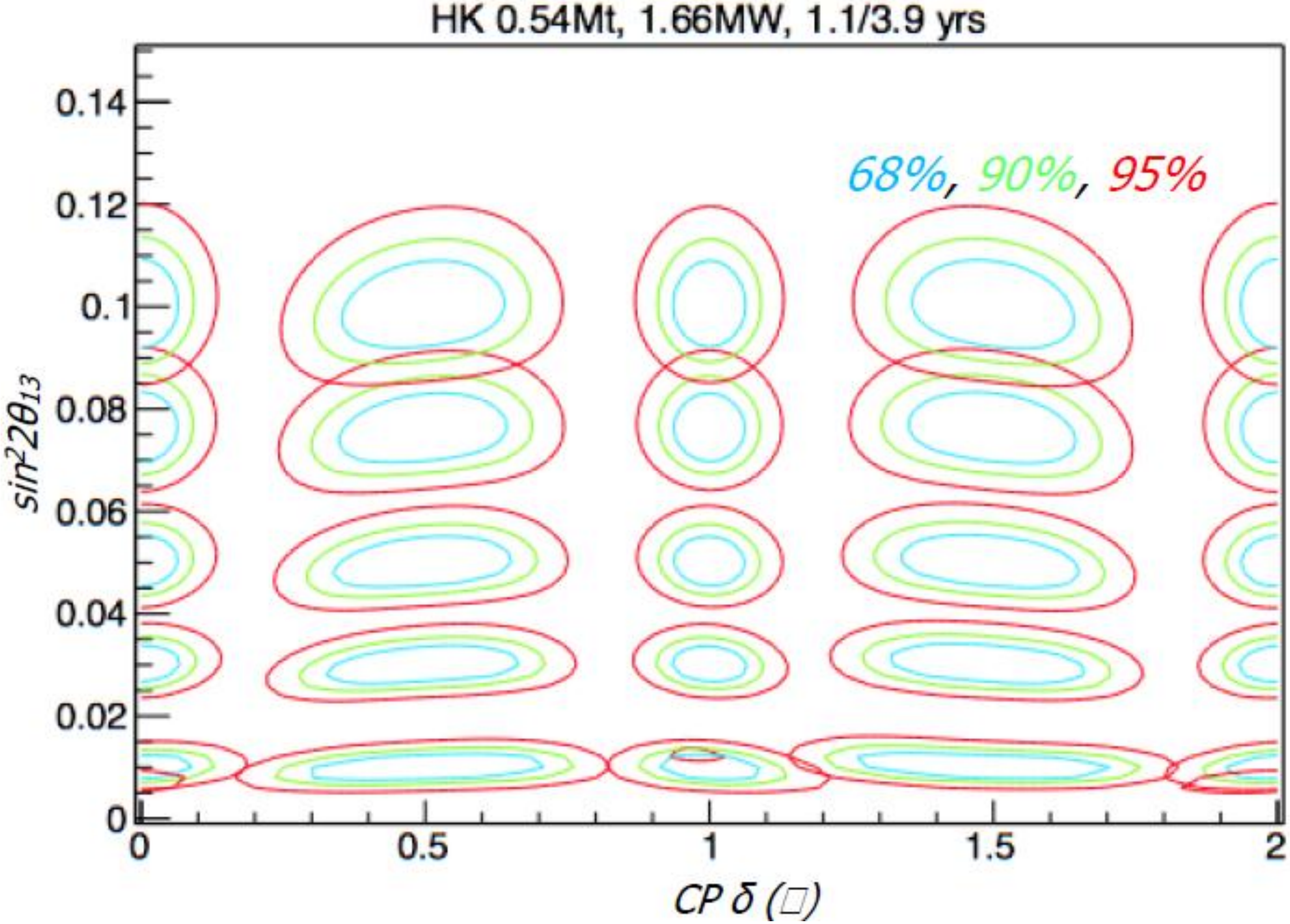
LBNE Schedule

- Initial design and costing complete by Fall, 2010
- Detector(s) choice for FD/Science Program defined by Science Collaboration: end of 2010
- DOE CD-1, late 2010 or early 2011
- National Science Board, Summer 2011
- Preliminary Design (~CD-2), end of 2012
- DUSEL construction start, end of 2013
- LBNE construction, 2015-2019 (this could be earlier depending on DUSEL lab readiness)

Japan: Hyper-Kamiokande



Japan:
Three possible scenarios under discussion



HK 0.54Mt, 1.66MW, 1.1/3.9 yrs
68%, 90%, 95%
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
$sin^2 2\theta_{13}$
0
0.5
1
1.5
2
CP δ (□)

Summary

LENA is a multi-purpose detector with high discovery potential.

Scintillator technique opens potential in physics fields that are unique within LAGUNA.

Future physics program covers particle physics, astrophysics and geo physics.

Very rare event searches as well as high-statistics measurements of astrophysical sources are possible.

Main advantages are good energy resolution, low energy threshold, and excellent background reduction capabilities.

„White paper“ in preparation (45 authors).