LENA
Low Energy Neutrino Astronomy

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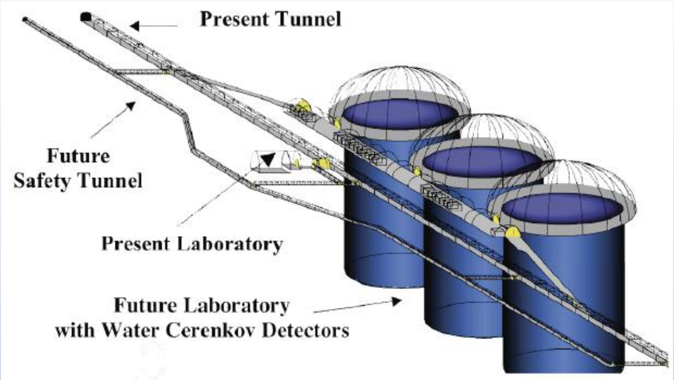
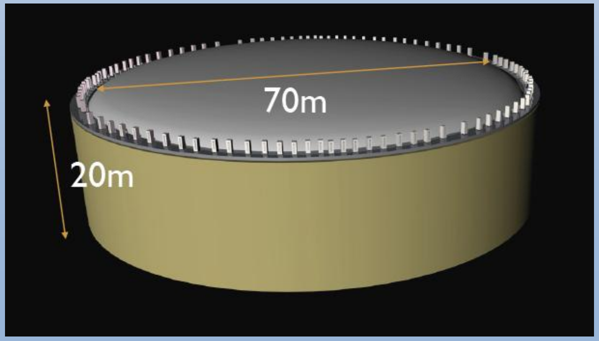
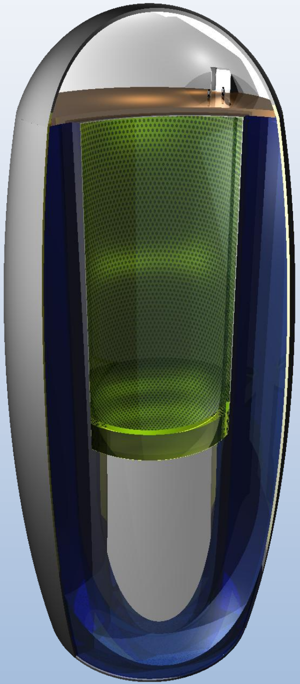
LAGUNA

MEMPHYS: Water Cherenkov Detector, 0.5Mton



GLACIER: Liquid Argon TPC, 100kton

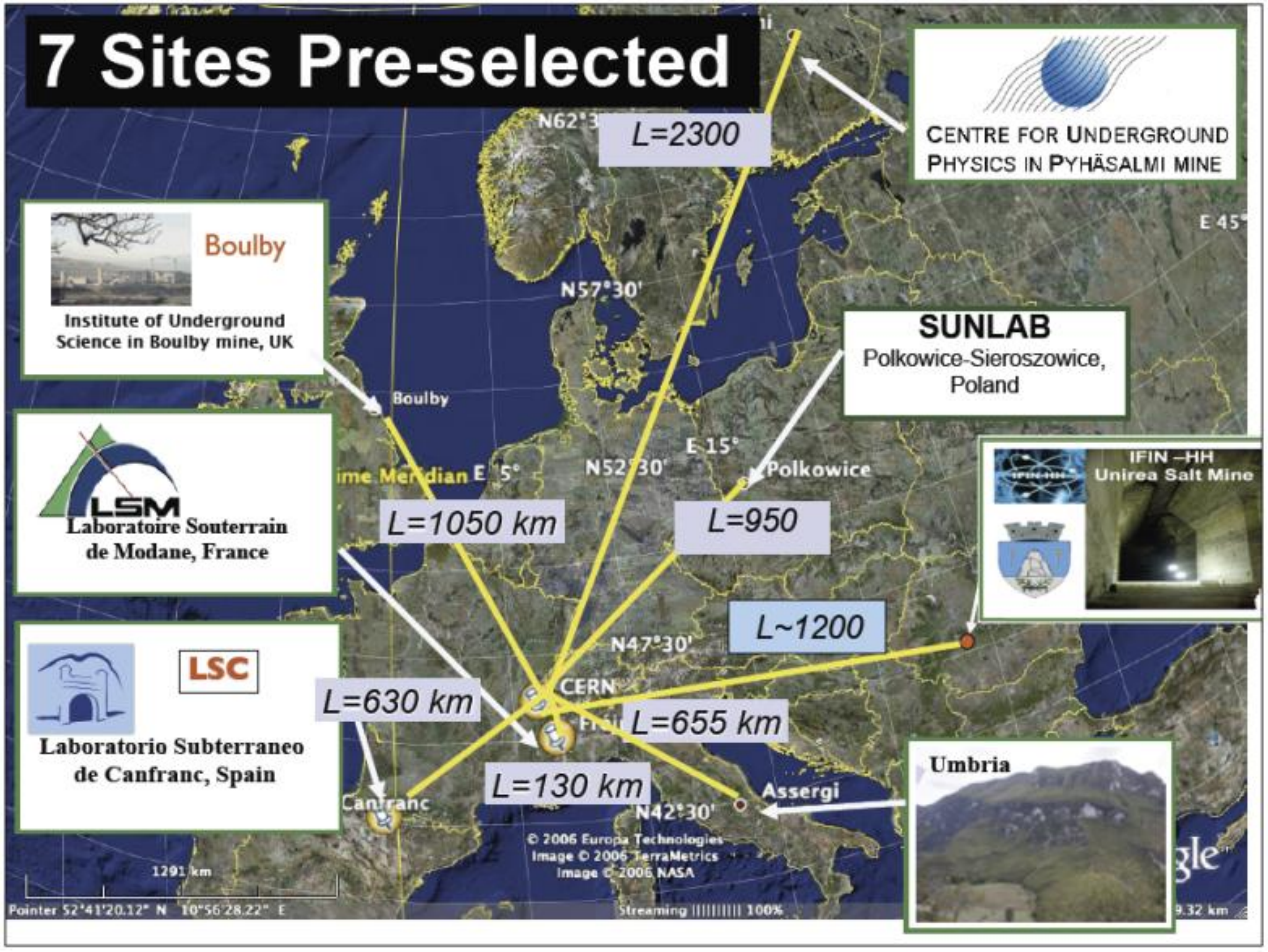




LENA: Liquid Scintillator Detector, 50kton

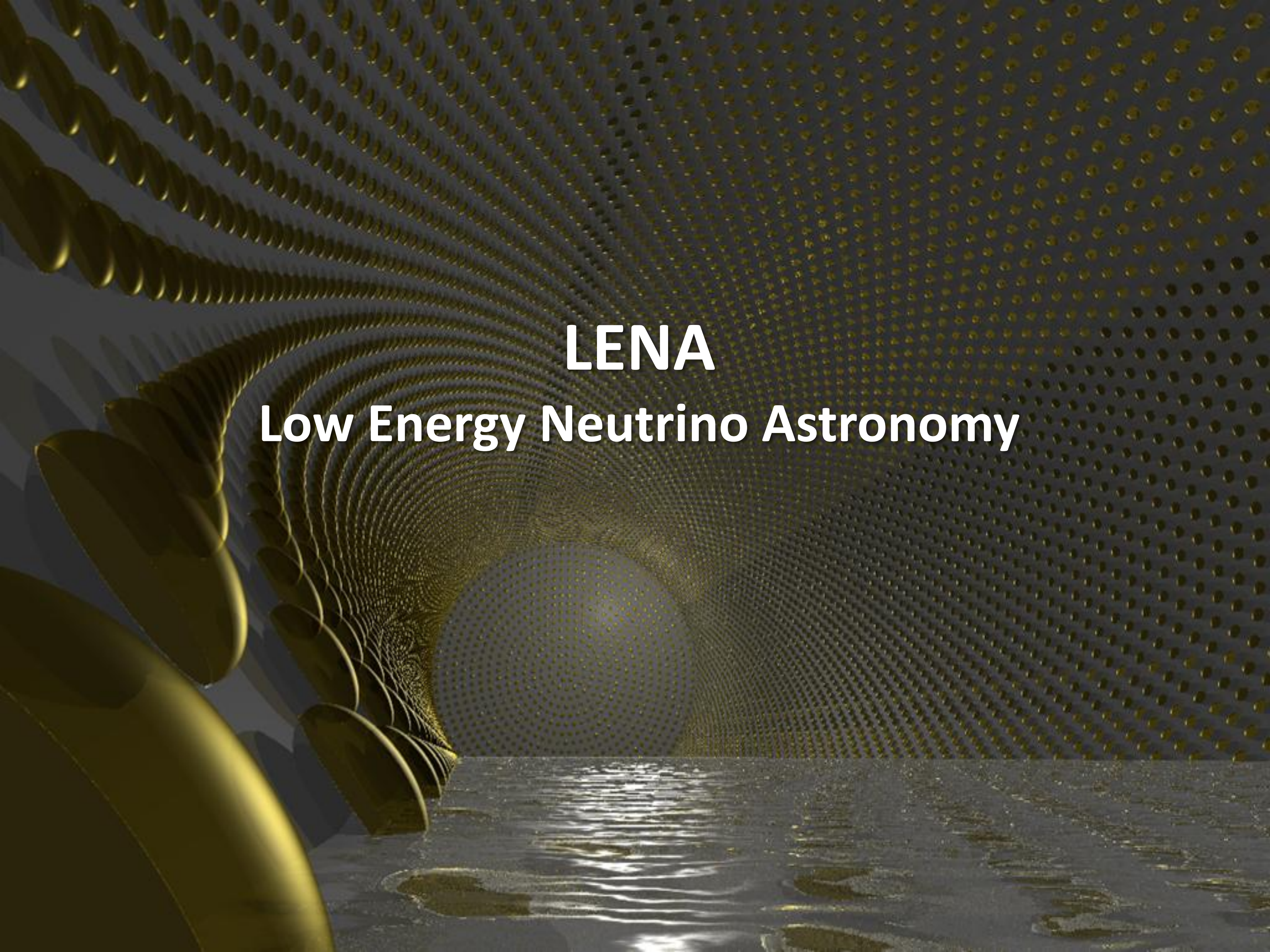
- LAGUNA = Large Apparatus for Grand Unification and Neutrino Astrophysics
- LAGUNA design study: feasibility and physics potential of 3 next-generation neutrino + p-decay detectors on 7 sites within Europe
- Proposed experiments: GLACIER, LENA, MEMPHYS

LAGUNA



- Design study has been carried through
- Will request subsequent design study:

  focussing on detector design and neutrino oscillometry with a CERN neutrino beam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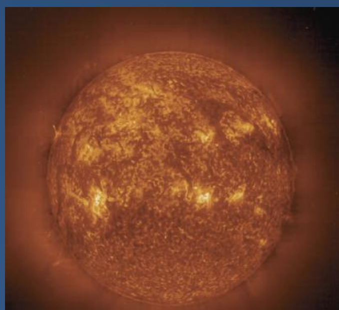
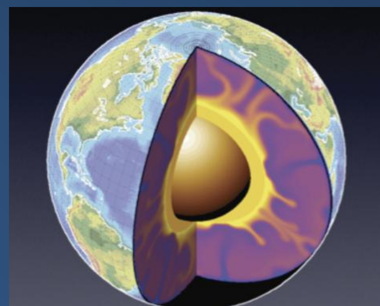
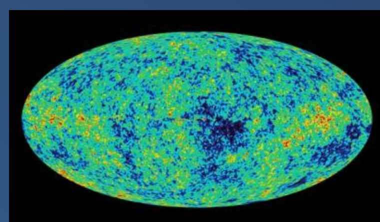




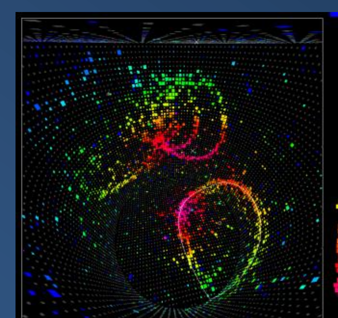


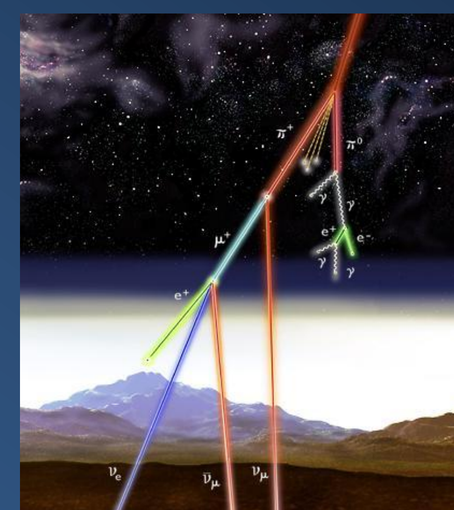
Low Energy Physics

- Neutrinos from galactic Supernovae
- Diffuse Supernova neutrinos
- Solar neutrinos
- Geoneutrinos
- Reactor neutrinos
- Indirect dark matter search

Physics in the GeV energy range

- Proton decay
- Long baseline neutrino beams
- Atmospheric neutrinos





LENA (Low Energy Neutrino Astronomy)

Detector layout:

Liquid scintillator
46kt LAB/PPO+ bisMSB

Inner vessel (nylon)
Radius (r) = 13m

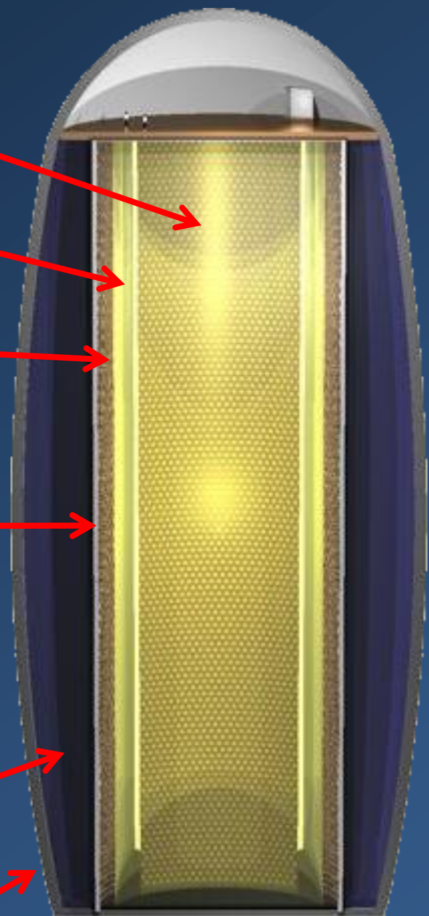
Buffer
15kt LAB, Δr =2m

Cylindrical steel tank,
55,000 PMTs (8“) with Winston Cones (2x area)
r = 15m, height = 100m,
optical coverage: 30%

Water cherenkov muon veto
5,000 PMTs, Δr > 2m to shield fast neutrons

Cavern egg-shaped for increased stability

Rock overburden: 4000 mwe



Desired energy resolution
→ 30% optical coverage
→ 3000m² effective photo-sensitive area

Light yield ≥ 200 pe/MeV

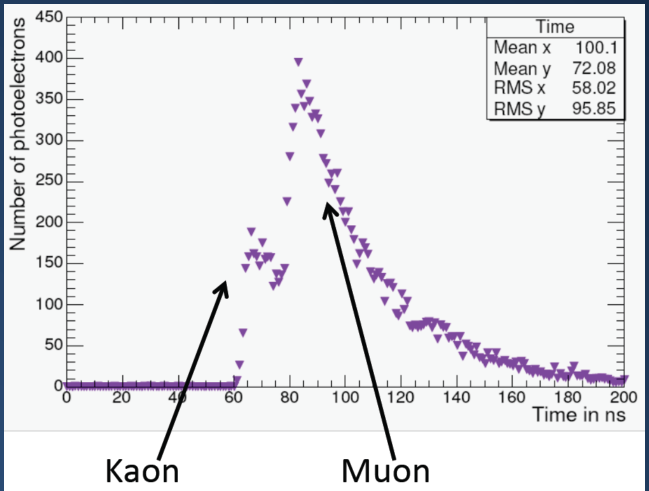
Requirements on photo sensors
- Sensor performance
- Environmental properties
- Availability until start of construction
- Cost-performance-ratio

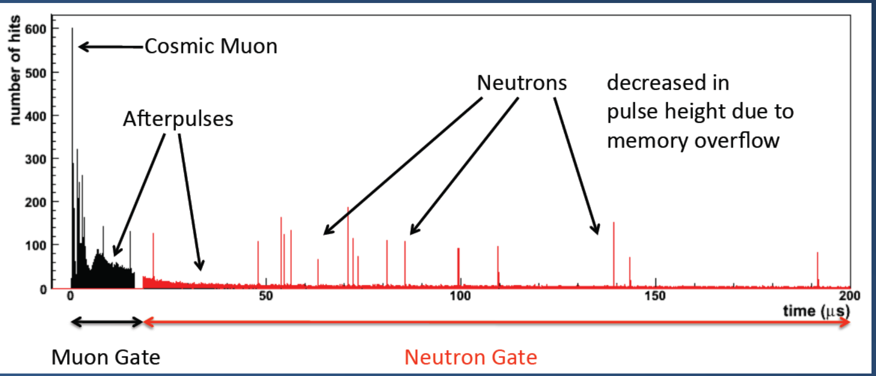
PMTs are probably the only photo sensor type which can fulfil all requirement classes

Sensor performance
Preliminary requirements for PMTs

Type: Bialkali (HQE) photocathode, borosilicate (low background) glass, hemispherical window, diameter 5“-10“

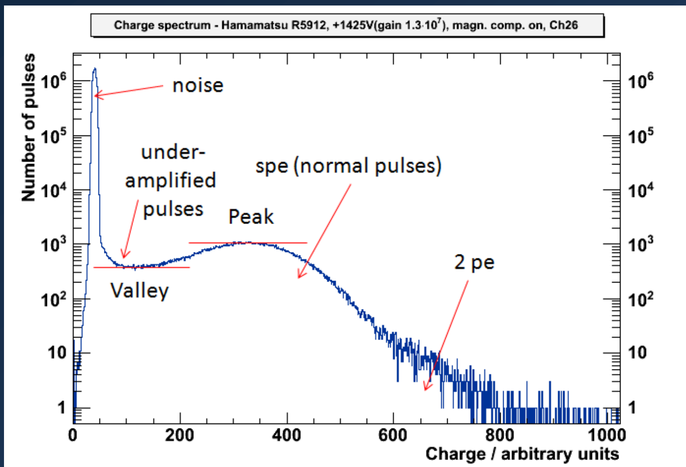
- Transit time spread (TTS): lower → improves time + position resolution and tracking → **TTS < 3.0ns (single pe, FWHM)**
- Bremsstrahlung Afterpulses (fast AP): can blur out proton decay coincidence (τ_{kaon}=13ns) → **probability fast AP < 5% (?)**
- Ionic Afterpulses (slow AP) can corrupt position reconstruction of neutrons knocked out of C12 by muons → decreases exclusion probability of C11, which is main background for CNO + pep ν-flux → **probability Ionic AP < 5%, maybe even < 1% (?)**
- Dark Noise Rate: DN worsens energy resolution and can cause fake events by random coincidences → **DN < 15Hz/cm²**

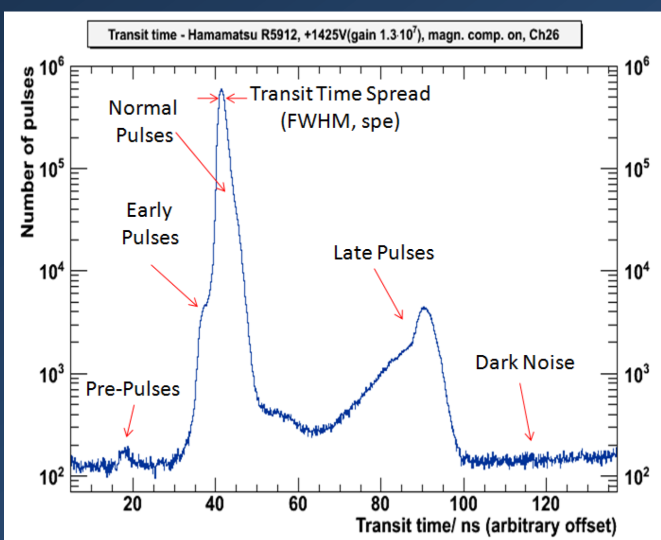




Sensor performance

Preliminary requirements for PMTs





- Single photo electron peak-to-valley ratio (p/V): higher ⟶ single photon pulses have less overlap with noise ⟶ more pulses usable ⟶ **p/V > 2**
- Gain: same as for p/V ⟶ **gain > $3 \cdot 10^6$**
- Dynamic range: Detector must be able to detect events with only one photon on most hit PMTs as well as HE events (muon, proton decay, neutrino beam) ⟶

  1pe – >0.17pe/(cm^2 effective photosensitive area) (?)

  = 1pe – >100pe for 8" PMT with 2x Winston Cone
- Quantum efficiency + collection efficiency: higher ⟶ energy resolution and to a lesser extent position + time resolution improve and energy threshold decreases;

  Losses through back-scattering: Should be minimal

  ⟶ $\overline{\mathrm{QE} \cdot \mathrm{CE} \cdot (1 - \mathrm{LBS})} > 25\% \ @ \ 420\mathrm{nm}$ **(?)**
- Early Pulses, Prepulses + Late Pulses: worsen time + position resolution, tracking (assumes "first pulses = first photons") ⟶ **EP <1% , LP < 4%**

Sensor performance

Preliminary requirements for PMTs

- Area per sensor:

  Smaller → higher granularity, dynamic range of sensor need not be as high, transit time spread in general smaller

  Bigger → less sensors + channels → cost-performance-ratio better (if not too big)

  → generally sensor area as small as affordable

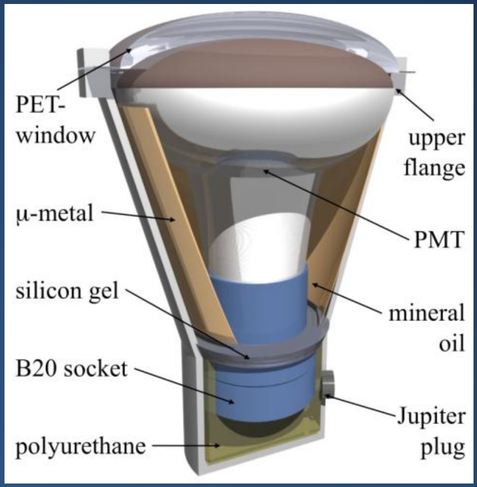
PMT diameter	Number of PMTs using 2x Winston Cones
5“	165,000
8“	55,000
10“	41,000

need more test PMTS from several series to assess currently achievable performance + simulations to establish final limits

Environmental properties

- Radioactive contamination
  - ^{238}U $< 3 \cdot 10^{-8}$ g/g,
  - ^{232}Th $< 1 \cdot 10^{-8}$ g/g,
  - ^{nat}K $< 2 \cdot 10^{-5}$ g/g
- Pressure resistance: **> 13-15bar**

  at the moment no PMTs meet the pressure requirements → increase glass thickness or use pressure encapsulations
- Long-term reliability for 30+ years



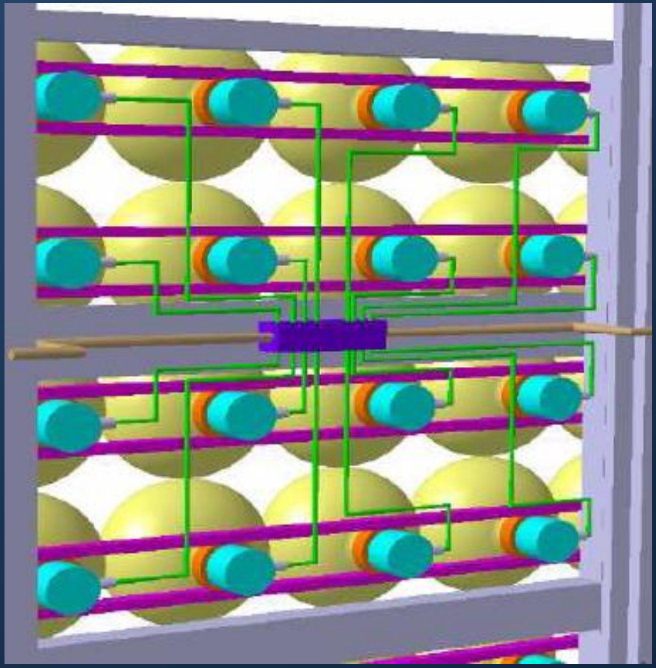
Borexino Outer Detector PMT encapsulation

Cost-performance-ratio (CPR)

- Crucial variable for energy, position and time resolution:

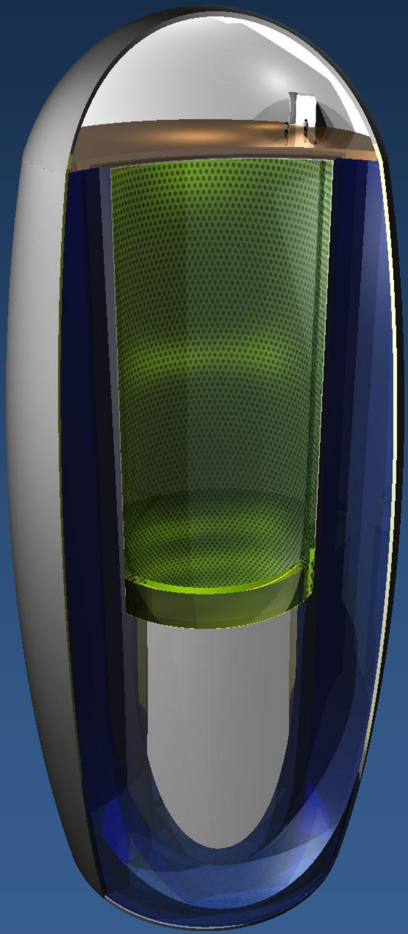
$$\frac{\text{Cost}}{\text{photo electrons/MeV}} \propto \frac{\text{Cost}}{\text{Area}_{\text{PMT}} \cdot \text{Detection Efficiency}}$$

- Total costs $\propto N_{PMTs} \propto$ light yield → lower light yield;
  however: lower light yield → worse physics performance
- Possibilities of improving the CPR → lower costs
  - Light concentrators : Winston Cones → enlarge PMT area by max. a factor 2 → less PMts; WC bigger than that → field of view smaller than fiducial volume → limits physics
  - High QE photocathodes → less PMts
  - High CE electron optics → less PMts
  - PMT arrays: front-end readout electronics + HV distribution on FPGA in detector for matrices of 16 PMTs → greatly reduces number of cables + channels → lowers incidental costs
    collaboration with MEMPHYS within PICS-framework
  - Automatize production (glass encapsulation, dynode chain)



- **Total PMT costs**: ***Question for manufacturers!***
  How much would it cost for 5“/ 8“/ 10“ PMTs with all these cost reduction measurements?

PMT R&D



- Close collaboration with manufacturers needed during design phase (ongoing, until end of 2013) to fulfil requirements ⟶ if necessary R&D
- Desired photo sensor R&D at the moment:
  - Lower fast + ionic afterpulsing
  - High QE photocathodes
  - High CE electron optics
  - Automatize production (glass encapsulation, dynode chain) -> lower production costs
  - Higher pressure resistance: thicker glass or spherical shape; or develop pressure encapsulations

  ⟶ new PMT type for LENA would be best
- Very similar PMT requirements for other planned neutrino experiments (KM3NET, LBNE, MEMPHYS,HyperKamiokande, GLACIER) ⟶ common benefit from these R&D projects + larger production facilities
- Direct benefits for products on the market from higher QE, higher CE, automatized production, larger production facilities, …

⟶ Extensive collaboration(s) of experiments + manufacturers possible!
Goal: develop next-generation PMTs ⟶ share the costs, EU funding?

Timeline + Risks

- Timeline:
  - decision on photo sensor type until end of 2013
  - production time begin 2014 – mid 2019
  - photo sensor installation mid 2019 – begin 2020
- Risks: no potential show-stoppers, proven technology
- Challenges:
  - Scintillator: optical transparency + radiopurity
  - PMTs: afterpulse reduction, pressure resistance

→ all in all making good progress