Development of a hybrid phototube with ZnO:Ga luminescent screen and GaN photocathode

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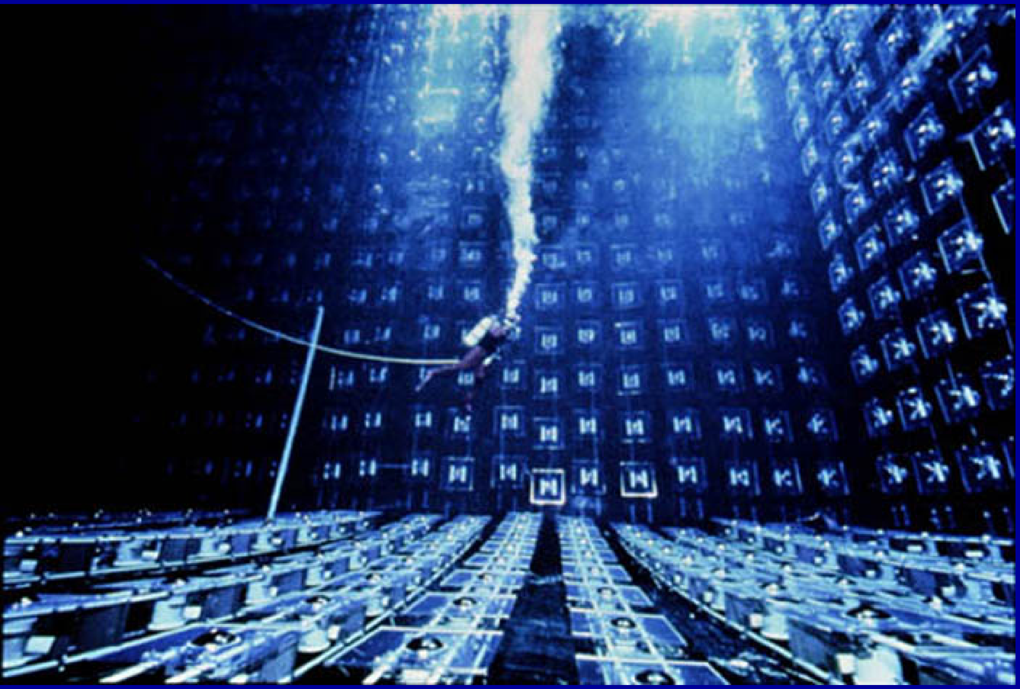
"Any big experiment should boost development of new experimental techniques which will pave the way for new, more sensitive experiments ….."

A.E.Chudakov

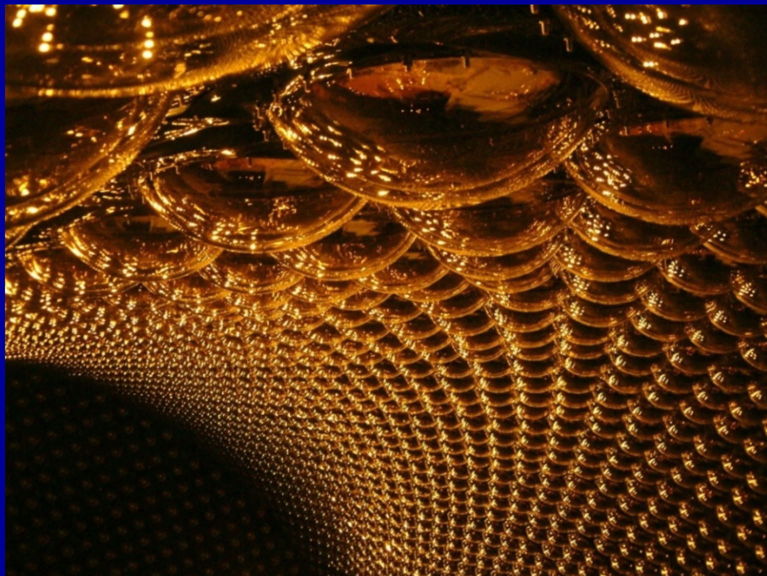
First generation of large scale neutrino experiments (underground water Cherenkov arrays)

IMB



8” R1408

Kamiokande - Super-Kamiokande

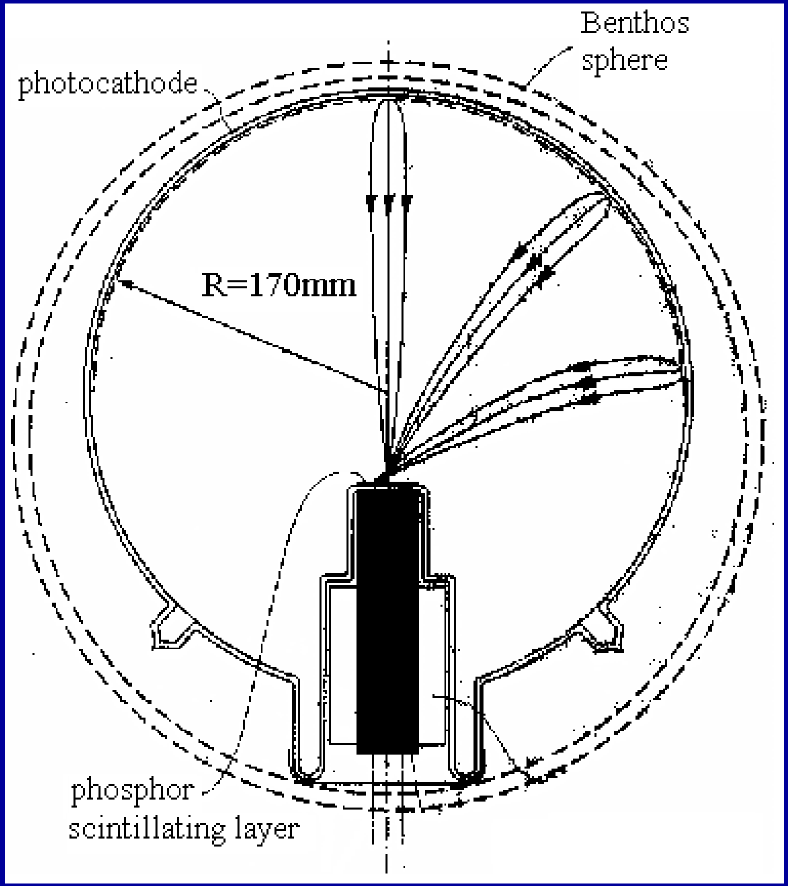


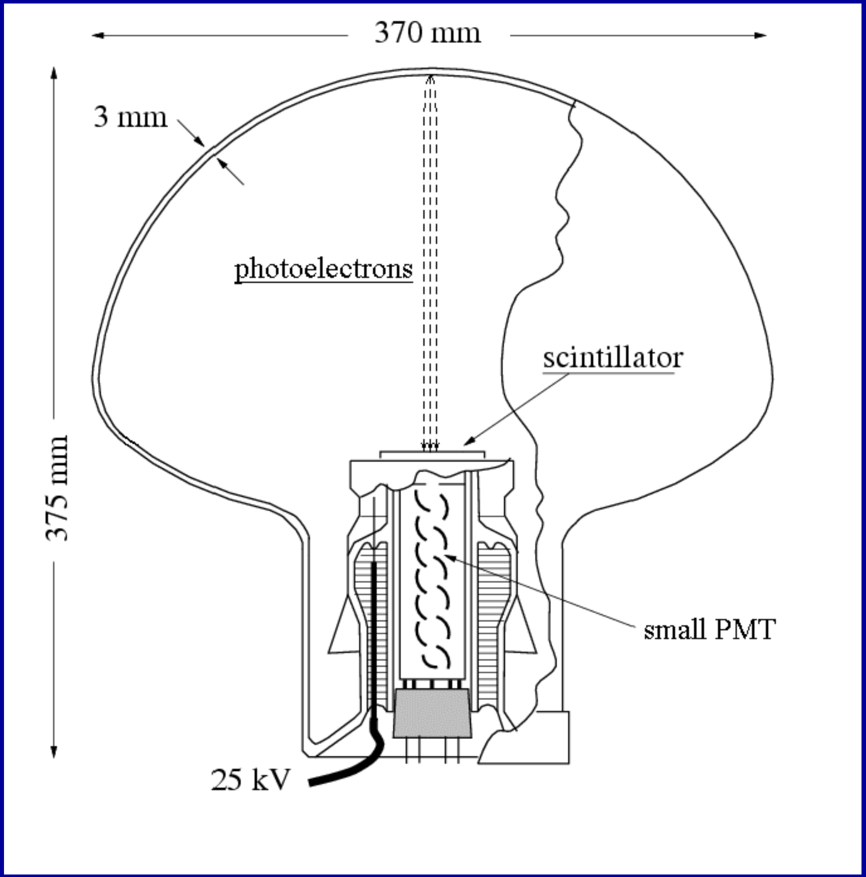
20” R1449
20” R3600

- Detection of neutrino signal from SN1987A
- Discovery of neutrino oscillation

Deep underwater neutrino experiments

XP2600 PHILIPS/PHOTONIS   QUASAR-370 KATOD/INR



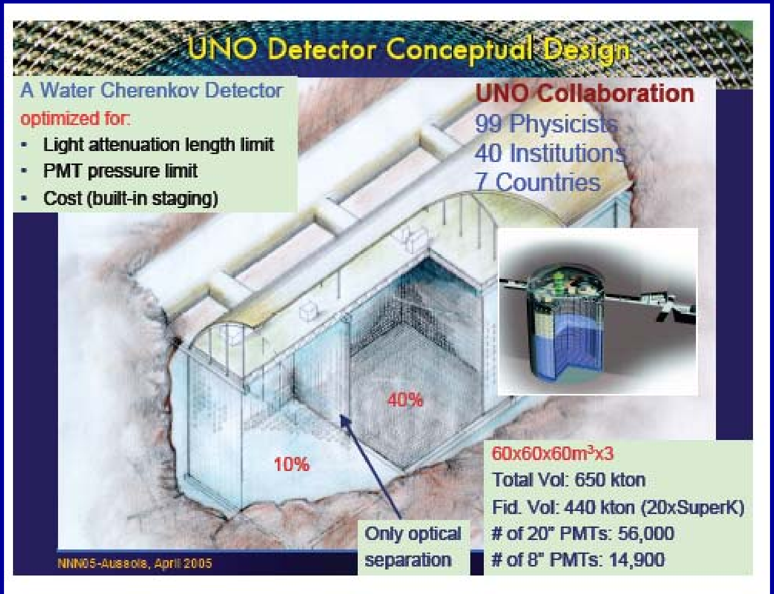


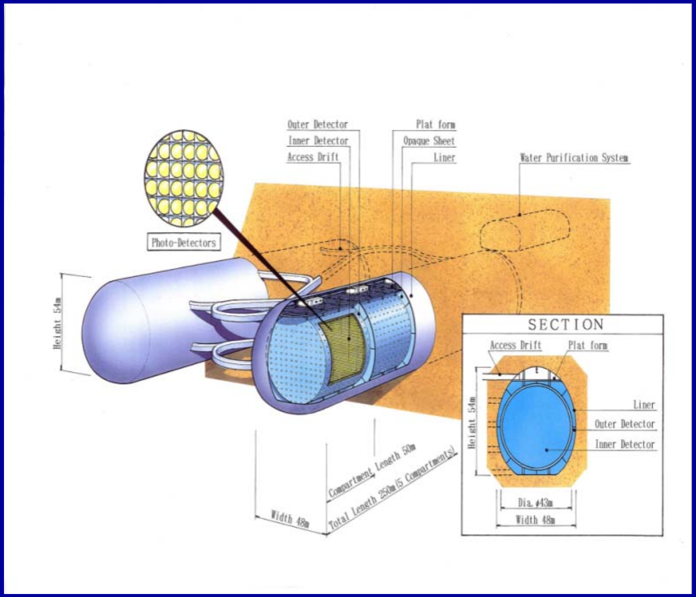
Record timing and excellent SER

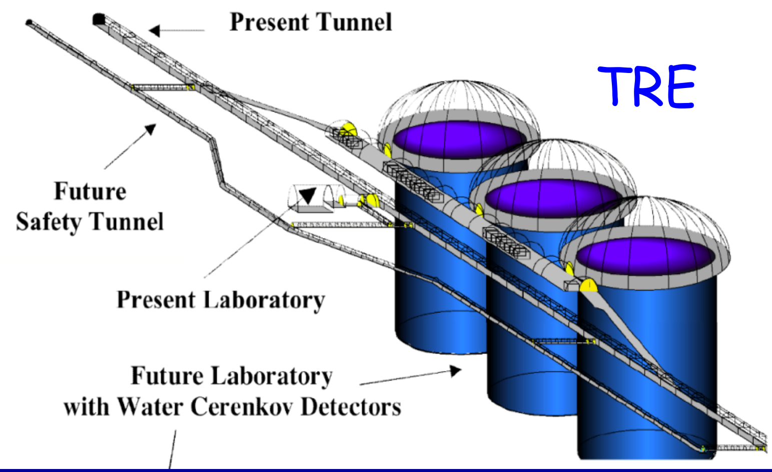
- Proof of principle of high energy neutrino detection
- Discovery of fresh water luminescence
- Discovery of fresh water bioluminescent microflashes

Next generation neutrino experiments

Water Cherenkov experiments







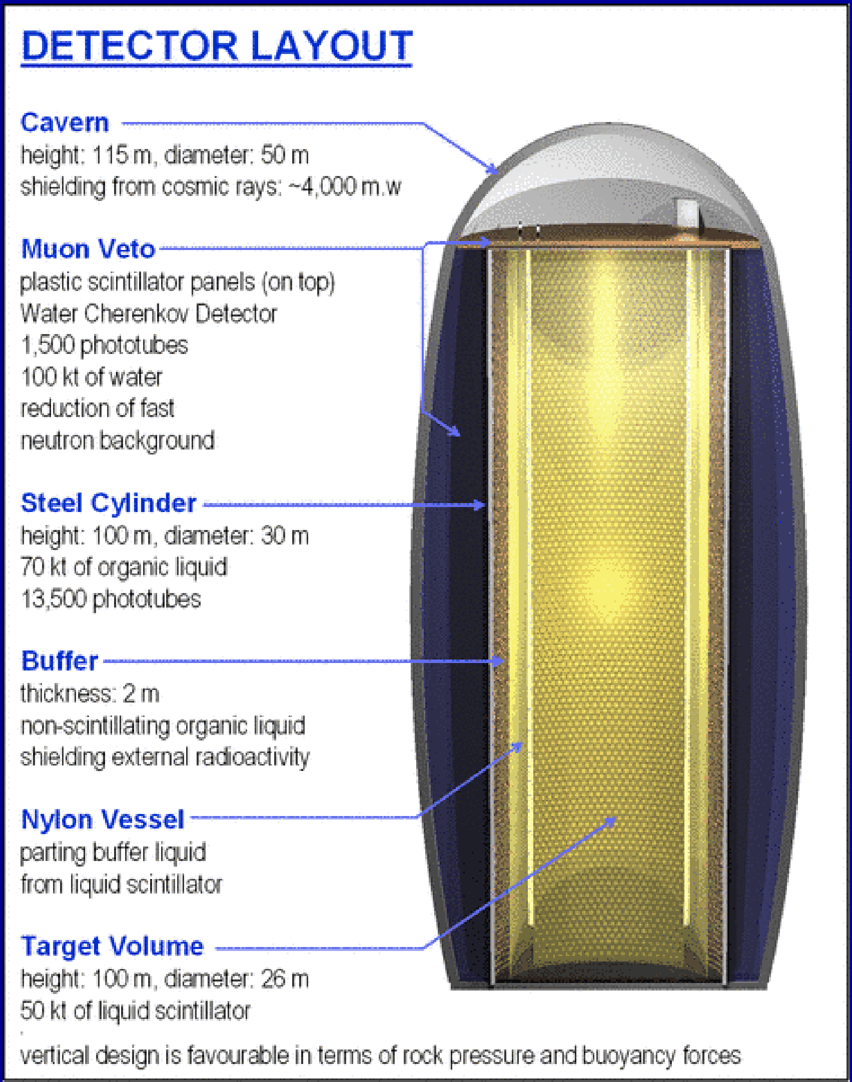
UNO, DUE, TRE

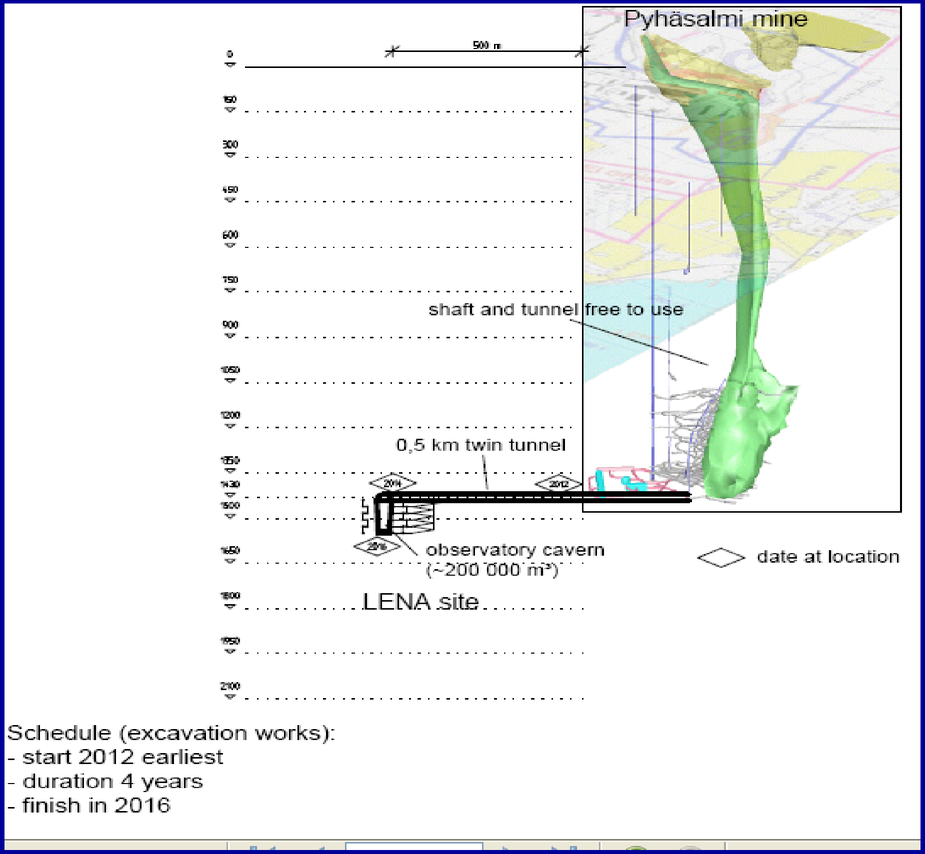
UNO: 80 000 20” PMTs

DUE: ~200 000 20” PMTs

TRE: ~200 000 20”PMTs

Liquid scintillator experiment LENA





Challenge to the development of large sensitive area photodetectors

Conventional PMTs or Hybrid Tubes?

Hybrid tubes have record timing and excellent SER

BUT

There is one substantial drawback --- slow time response due to scintillator light emission kinetics

Solution ---- fast high efficiency scintillators

G - the first stage amplification factor of hybrid tubes

$$G = Y \times k \times \eta(eff)$$

Y - scintillator light yield

k - collection efficiency of photons on the small PMT's photocathode

$\eta(eff)$ - effective quantum efficiency of the small PMT

Small PMT with higher effective QE will provide better parameters

Requirements for scintillators:

- high light yield
- fast emission kinetics
- vacuum compatibility
- compatibility with phocathode manufacturing procedure: high temperature, aggressive chemical environment etc.

Scintillators have to be:

Inorganic

Nonhygroscopic

Time resolution of hybrid phototubes and scintillator parameters

$W(t) \sim \exp(-(G/\tau)t)$

G - the first stage amplification factor

$G = n_{p.e.} / N_{p.e.}$

$n_{p.e.}$ - # of p.e. detected by small PMT; $N_{p.e.}$ - # of p.e. on the phototube cathode

$G \sim Y(E_e)$

Y - scintillator light yield

τ - scintillator decay time

Scintillator should have Y/τ as high as possible

ZnO:Ga

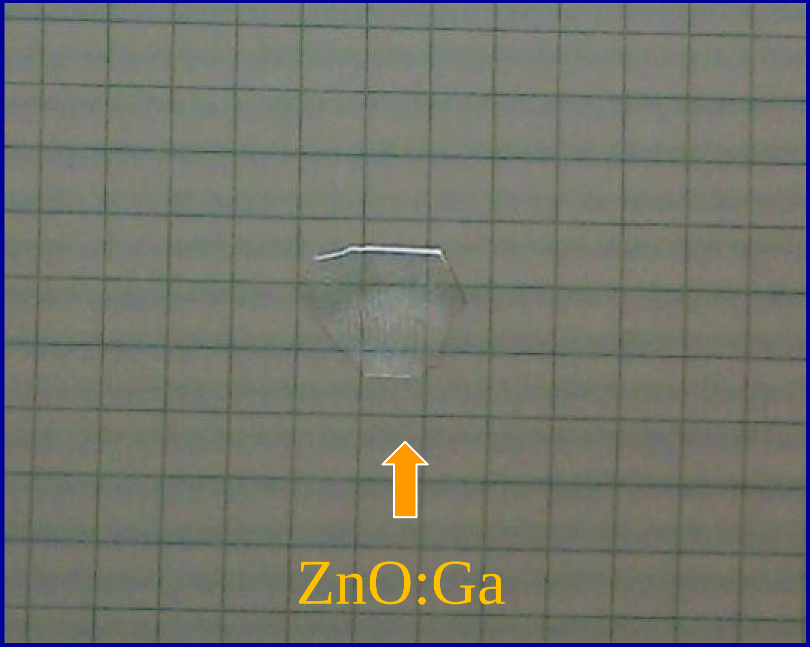
Luckey D., 1968 NIM
Light yield = NaI(Tl); Decay time - 0.4 ns!

W.Moses. NIMA (LBNL-50252)
Light yield - 15000 γ/MeV; Decay time - 0.4 ns.

Hypothetical hybrid tube with ZnO:Ga and high QE fast small PMT would be a fantastic photodetector with <1ns jitter (FWHM) and <1ns anode pulse width!

"ZnO:Ga – ideal scintillator for hybrid tubes" *B.Lubsandorzhiev and B.Combettes TNS 2008*

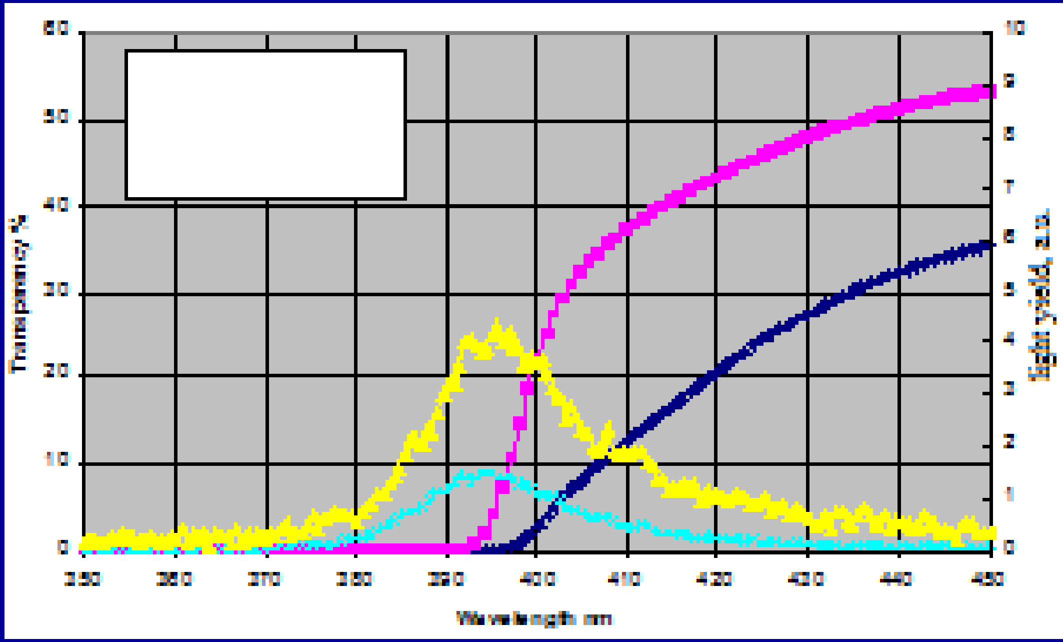
ZnO:Ga crystals from Cermet Inc. Atlanta, GA, USA



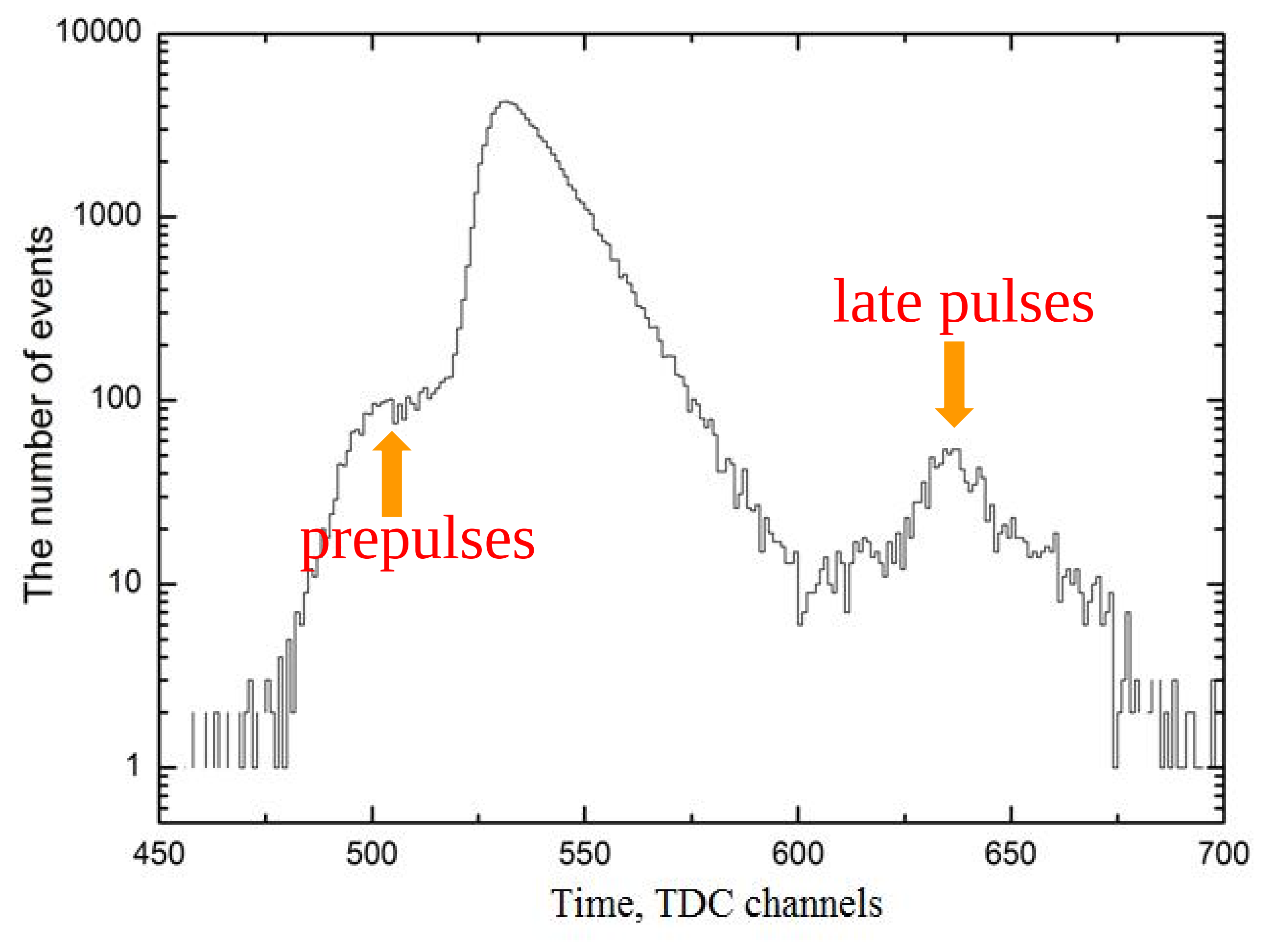
~300 μ thickness

~1cm^2 area

λ_{max} ~ 390 nm



τ~ 650 ps, light yield ~ 1200 γ/MeV

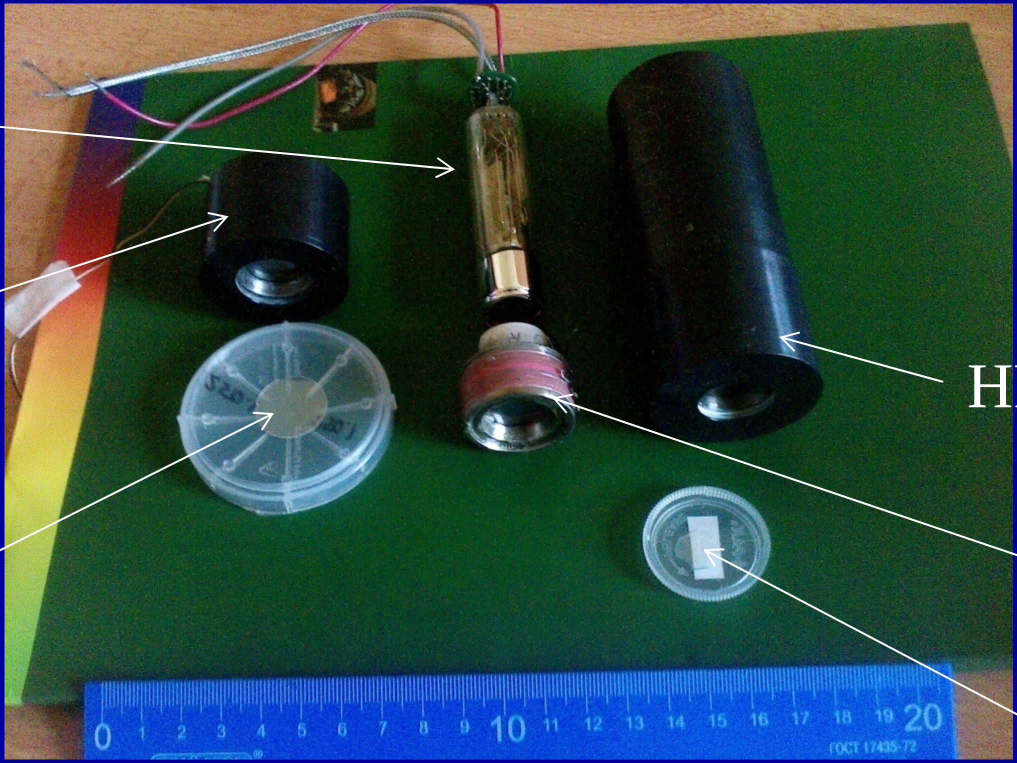


Pilot sample of HPD with ZnO:Ga crystal based on image intensifier

PMT

HPD+HV

GaN on Sapphire wafer

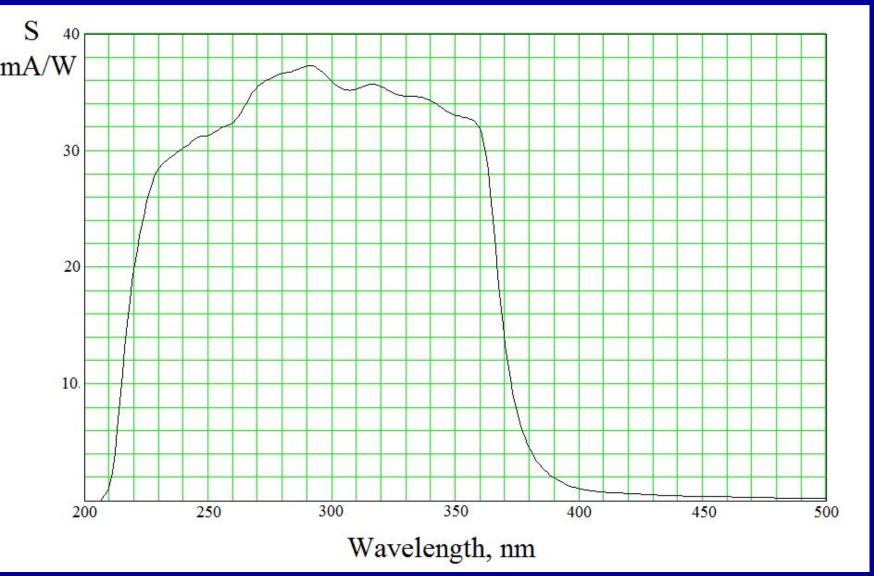


HPD+PMT module

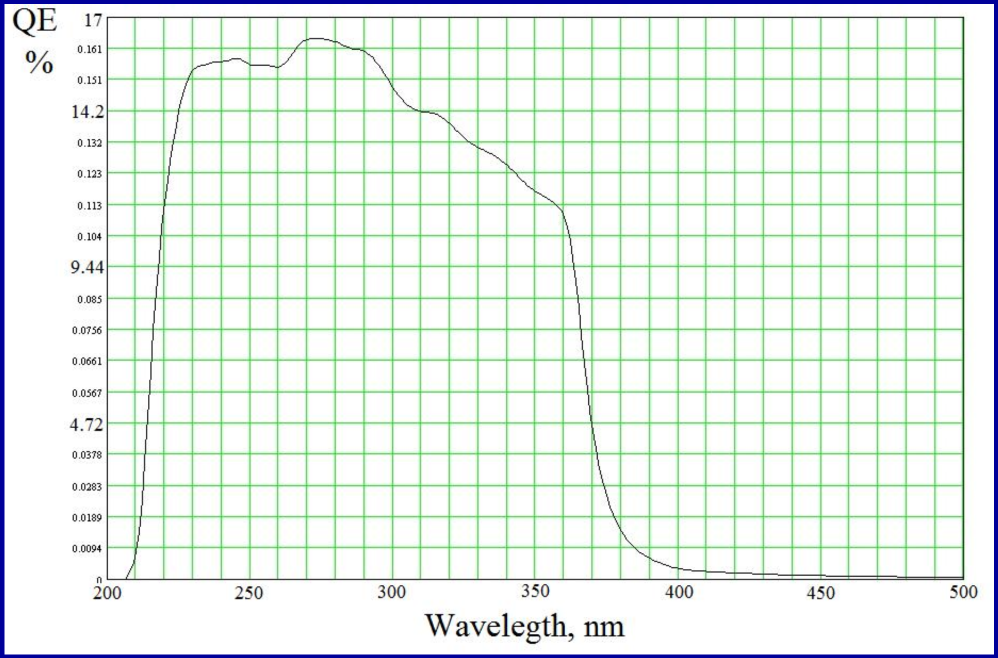
HPD

ZnO:Ga

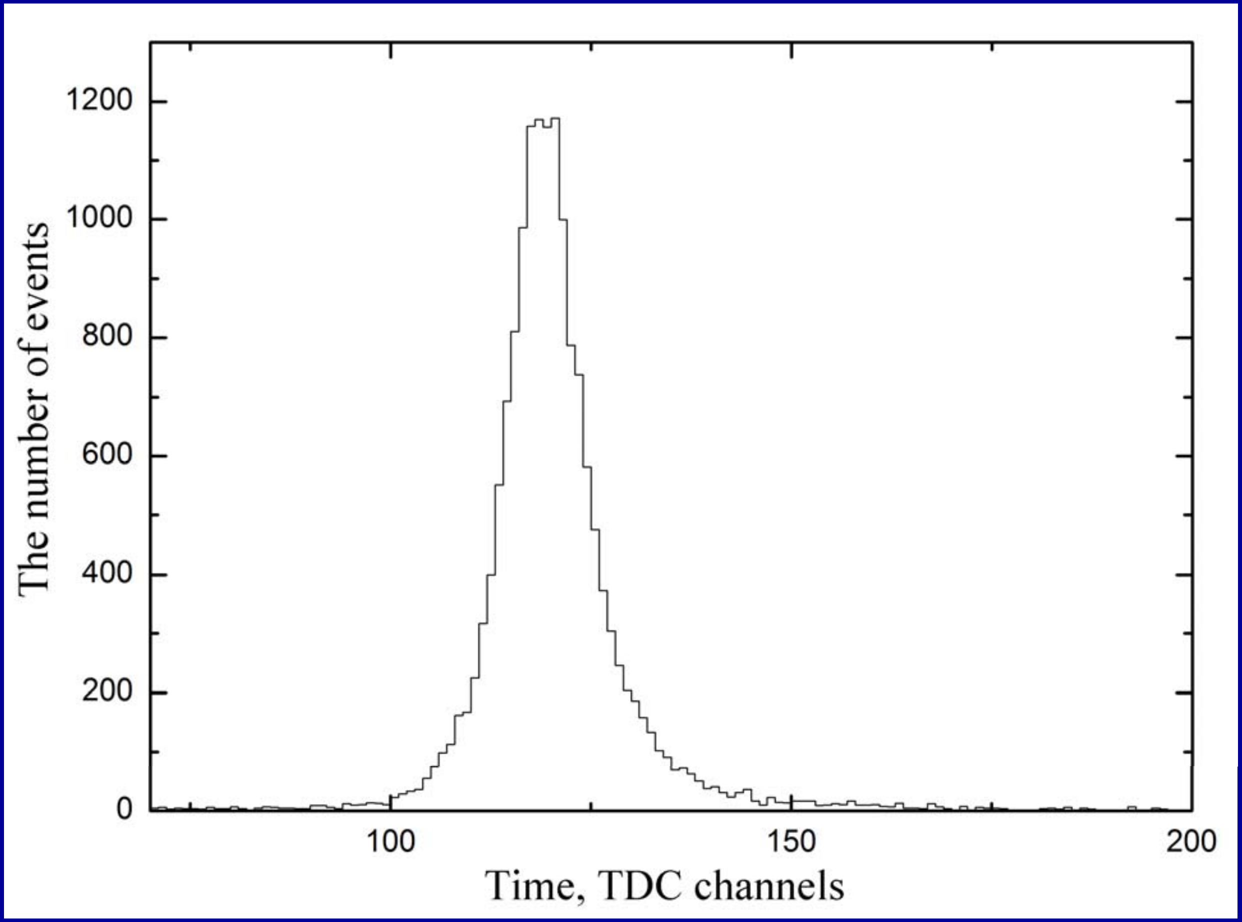
Pilot sample's GaN photocathode sensitivity



QE ~ 17%

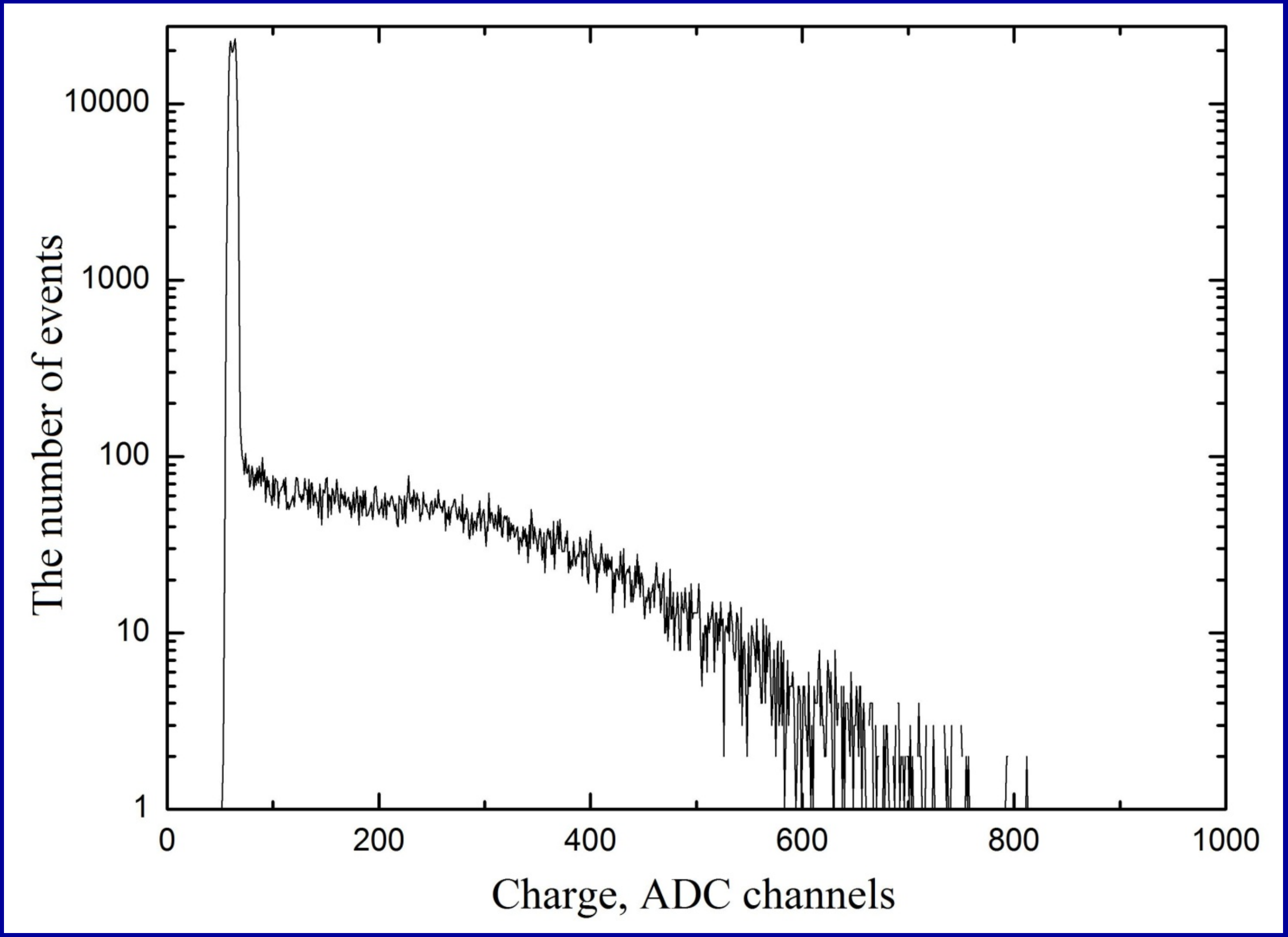


Jitter (TTS)



Δt_{hpd} ~ 750 ps (FWHM); Δt_{LED} ~ 700 ps

Single electron response



Practically no single pe peak

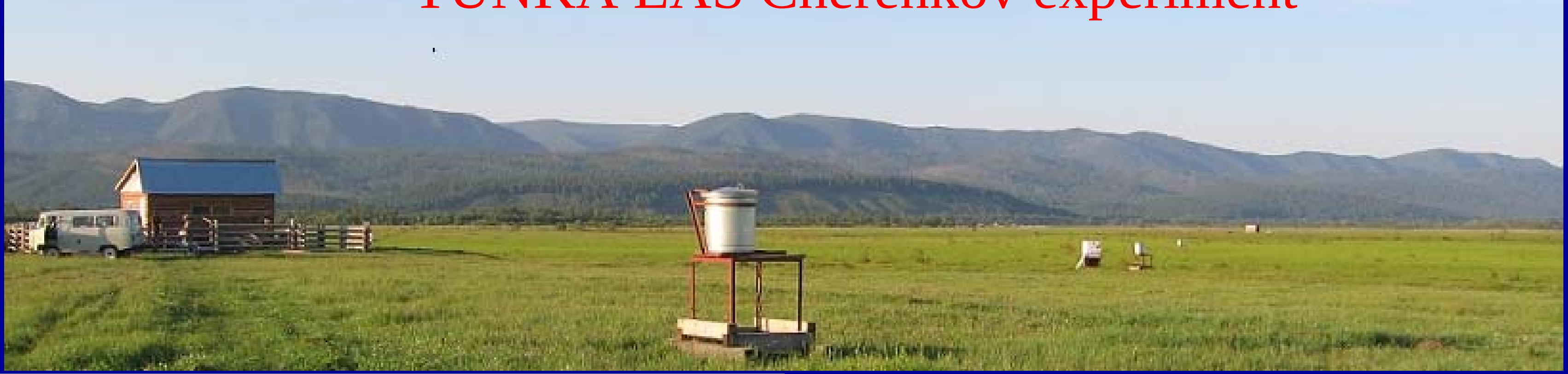
There is at least one application for which hybrid tubes equipped with the ZnO:Ga crystals with the light yield even at present level are very interesting

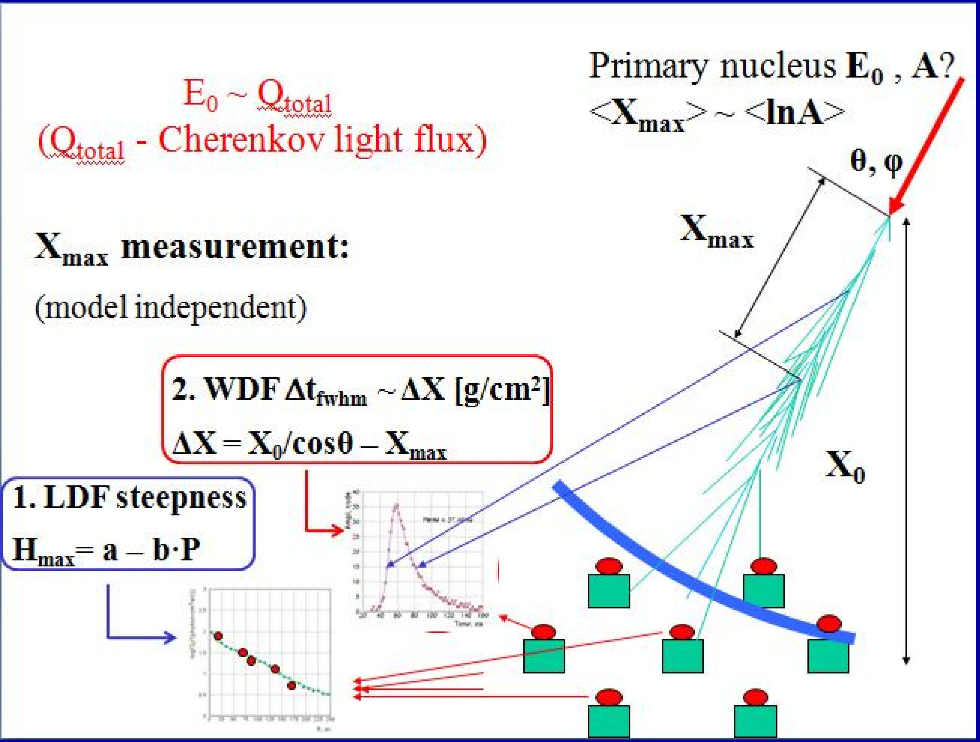
↓

Wide angle EAS Cherenkov Arrays

(TUNKA, SCORE, LHAASO, Auger-Next etc)

TUNKA EAS Cherenkov experiment





Primary cosmic rays studies in the energy range of 10^{15}-10^{18} eV

Width of EAS Cherenkov signals is sensitive to the mass composition of primary cosmic rays

No need to operate in 1 pe mode (threshold ≥ 100 pe)

CONCLUSION

ZnO:Ga is a very promising scintillator for hybrid phototubes with luminescent screens

It is necessary to increase the light yield of the crystals

The search for new fast scintillator materials of high efficiency should be continued