Large Area Phototubes for Next Generation Large Scale Astroparticle Physics Experiments

Bayarto Lubsandorzhiev
Institute for Nuclear Research RAS
Moscow Russia
and
University of Tuebingen
Tuebingen Germany

L.M. Balyasniy[4], S.A. Belyanchenko[3], L.B.Bezrukov[1], S. Dolinsky[5],
R. Falkenstein[2], P. Grabmayr[2], Yu.N.Gordienko[4], G. Hallewell[7],
J. Jochum[2], B.K. Lubsandorzhiev[1,2], N.B.Lubsandorzhiev[1], J. Nause[6],
B. Nemeth, V.A. Poleshuk[1], R.V. Poleshchuk[1], V. Rangarajan,
B.A. Shaibonov (Jr)[1]

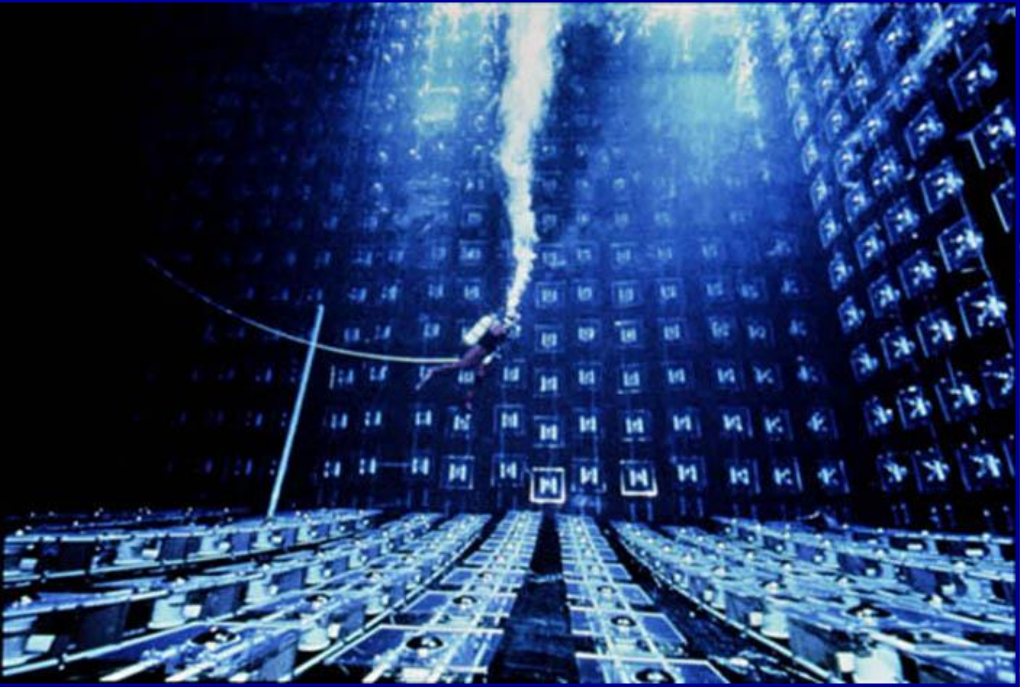
[1] *Institute for Nuclear Research of RAS, Moscow, Russia*
[2] *Kepler Centre for Astro and Particle Physics, University of Tuebingen Tuebingen, Germany*
[3] *JSC "MELZ-FEU", Moscow, Russia*
[4] *SC "SPU GEOFIZIKA-NV", Moscow, Russia*
[5] *GE Global Research, Niskayuna, NY, USA*
[6] *Cermet Inc., Atlanta, GA. USA*
[7] *CPPM, Marseille, France*

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

A.E.Chudakov

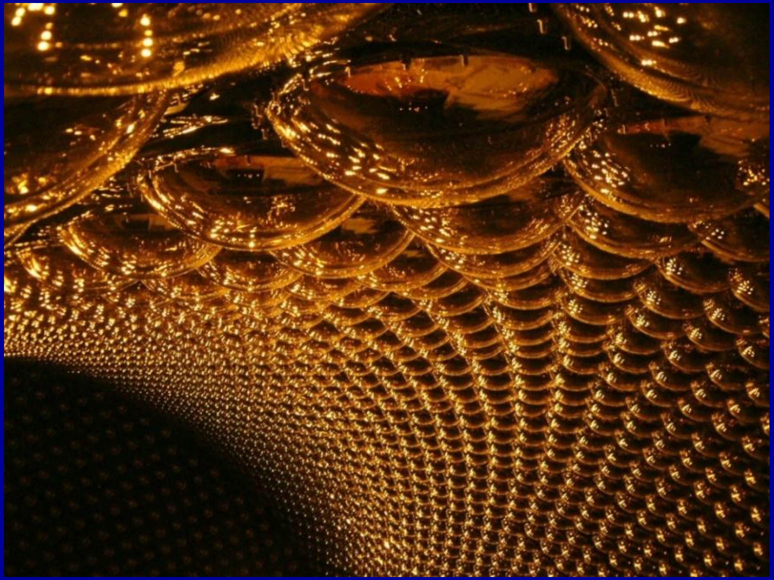
First generation of large scale neutrino experiments (underground water Cherenkov arrays)

IMB



8” R1408

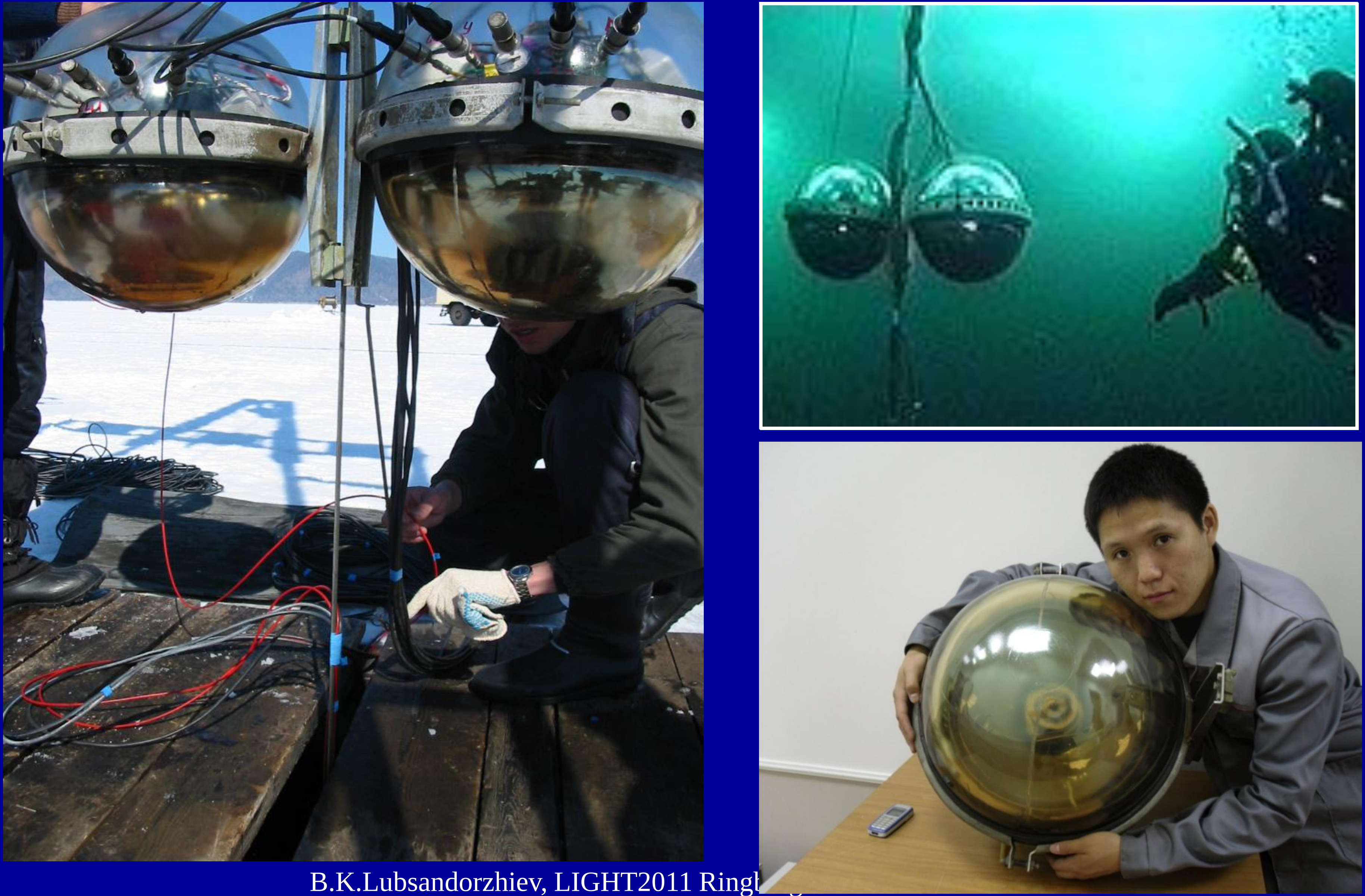
Kamiokande-I,II;   Super-Kamiokande



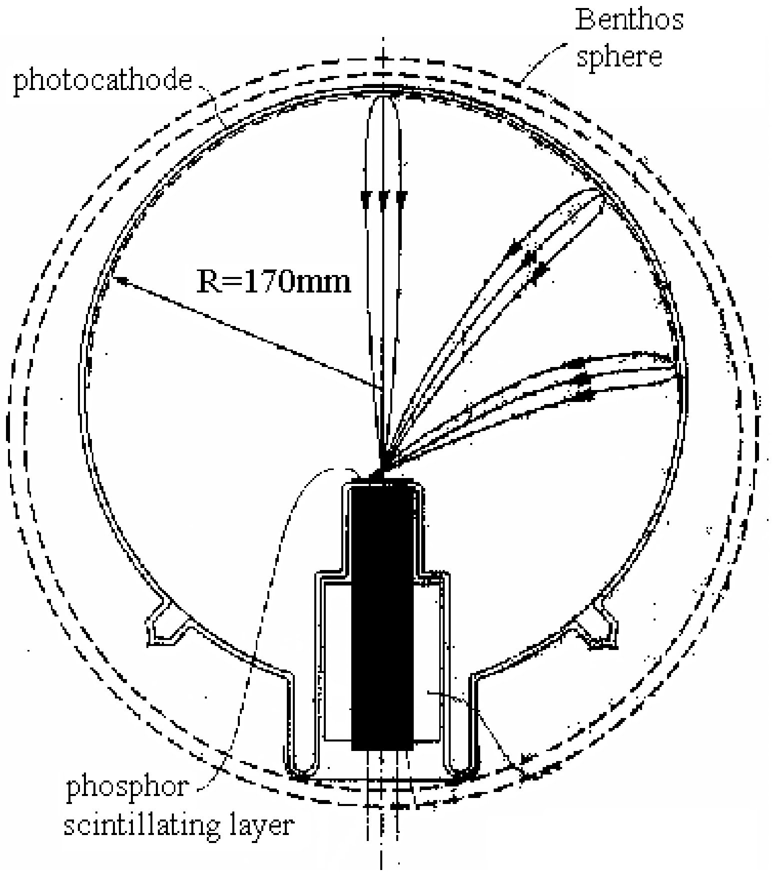
20” R1449
20” R3600

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

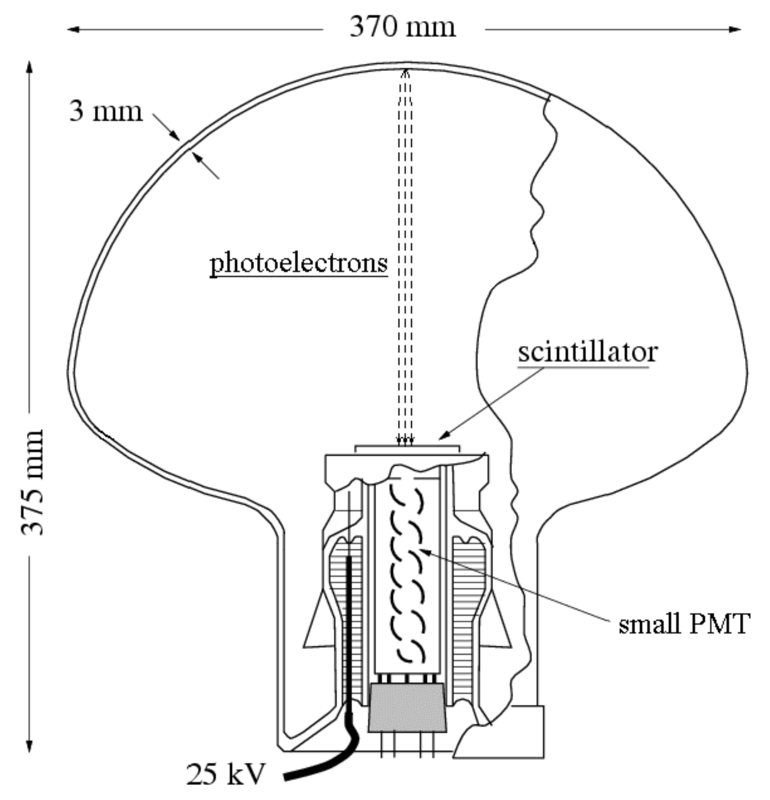
Deep underwater neutrino experiments



XP2600 PHILIPS/PHOTONIS



QUASAR-370 KATOD/INR

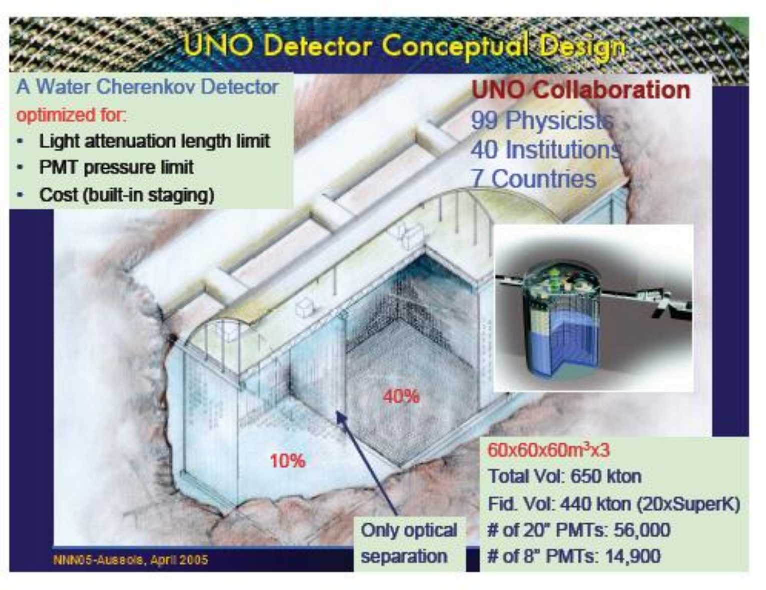


Record timing and excellent SER

- 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 Detector Conceptual Design

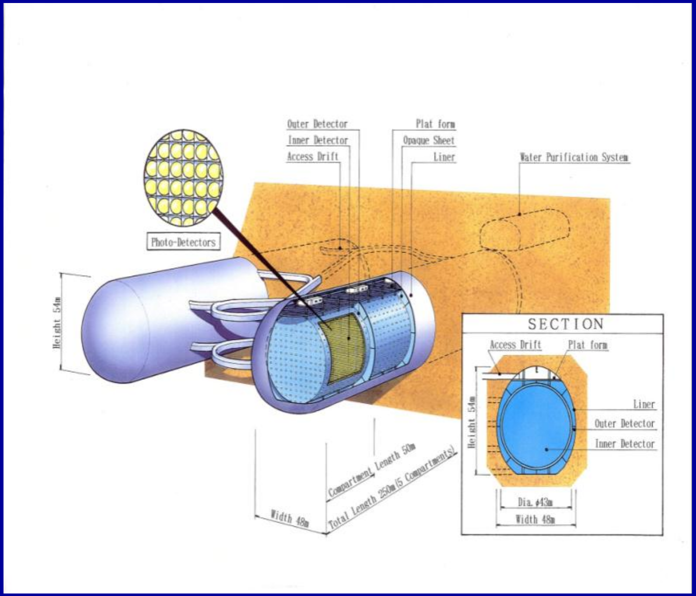
A Water Cherenkov Detector
optimized for:
- Light attenuation length limit
- PMT pressure limit
- Cost (built-in staging)

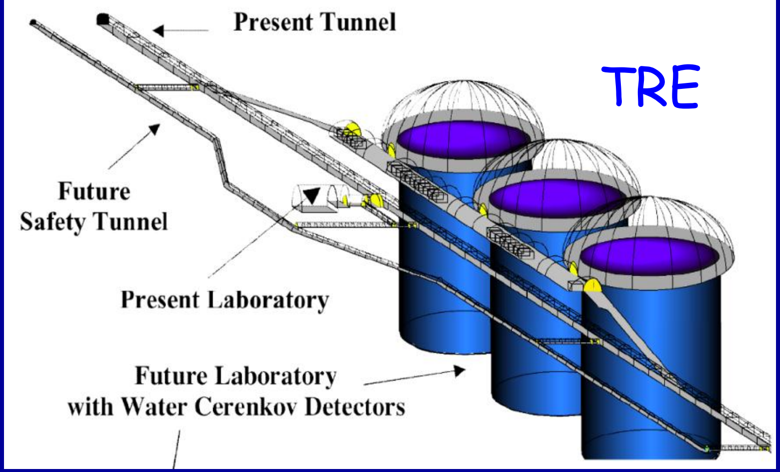
UNO Collaboration
99 Physicists
40 Institutions
7 Countries

$60x60x60m^3x3$
Total Vol: 650 kton
Fid. Vol: 440 kton (20xSuperK)
# of 20" PMTs: 56,000
# of 8" PMTs: 14,900

Only optical
separation

NNN05-Aussois, April 2005

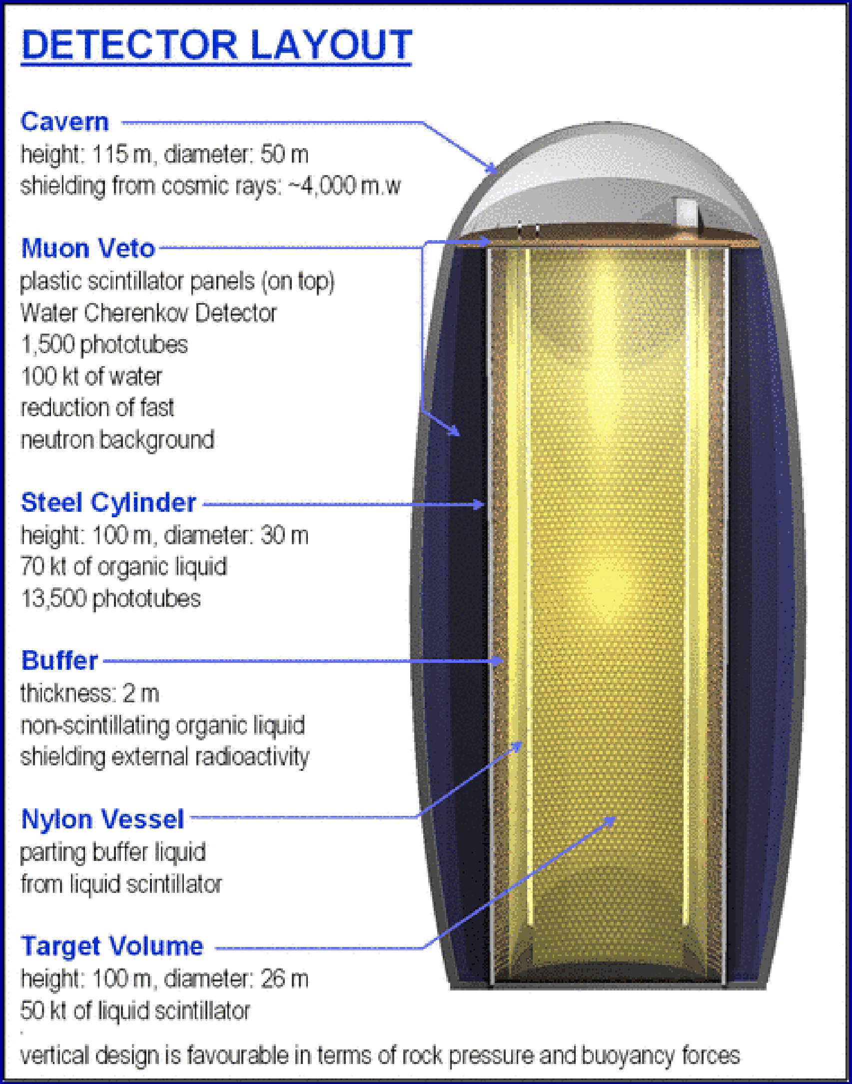




UNO, DUE, TRE

UNO: 80 000 20” PMTs
DUE: ~200 000 20” PMTs
TRE: ~200 000 20”PMTs

Liquid scintillator experiment LENA



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

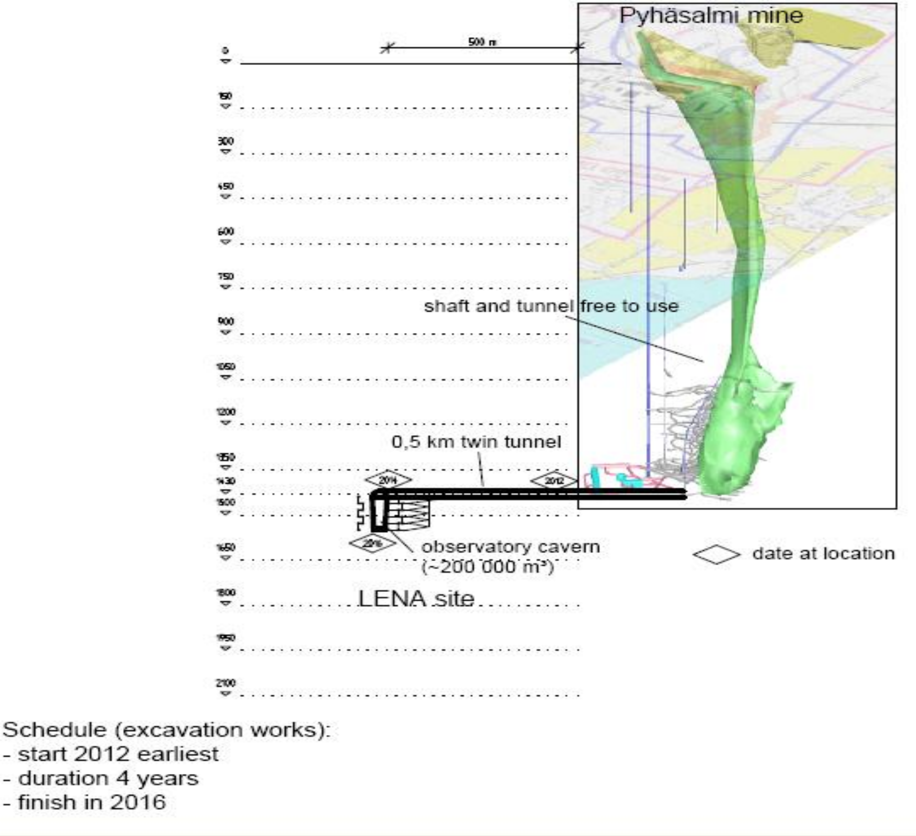
Steel Cylinder
height: 100 m, diameter: 30 m
70 kt of organic liquid
13,500 phototubes

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



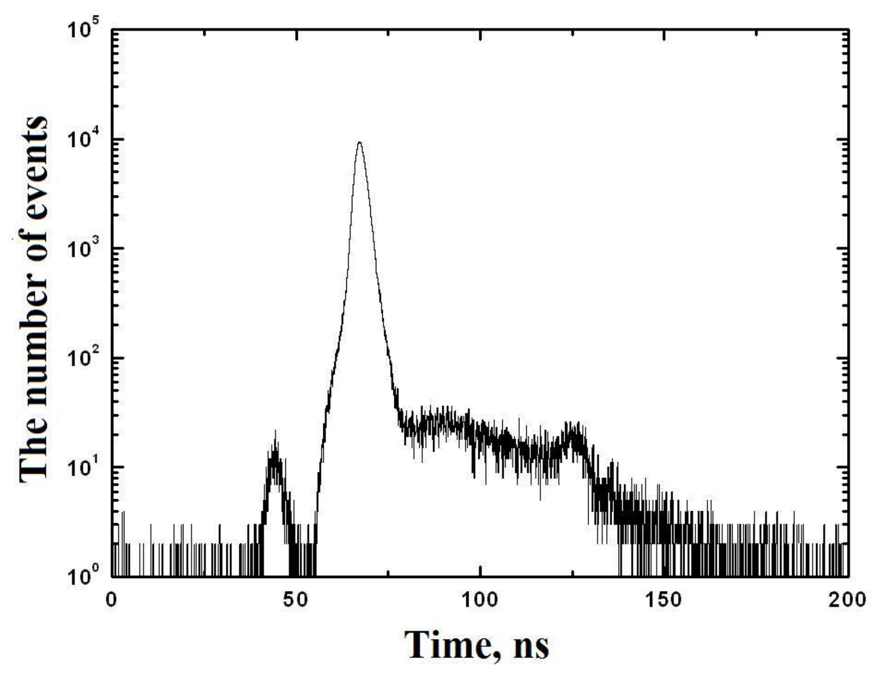
Schedule (excavation works):
- start 2012 earliest
- duration 4 years
- finish in 2016

Challenge to the development of large sensitive area photodetectors

Conventional PMTs or Hybrid Tubes?

Photoelectron backscattering in PMTs

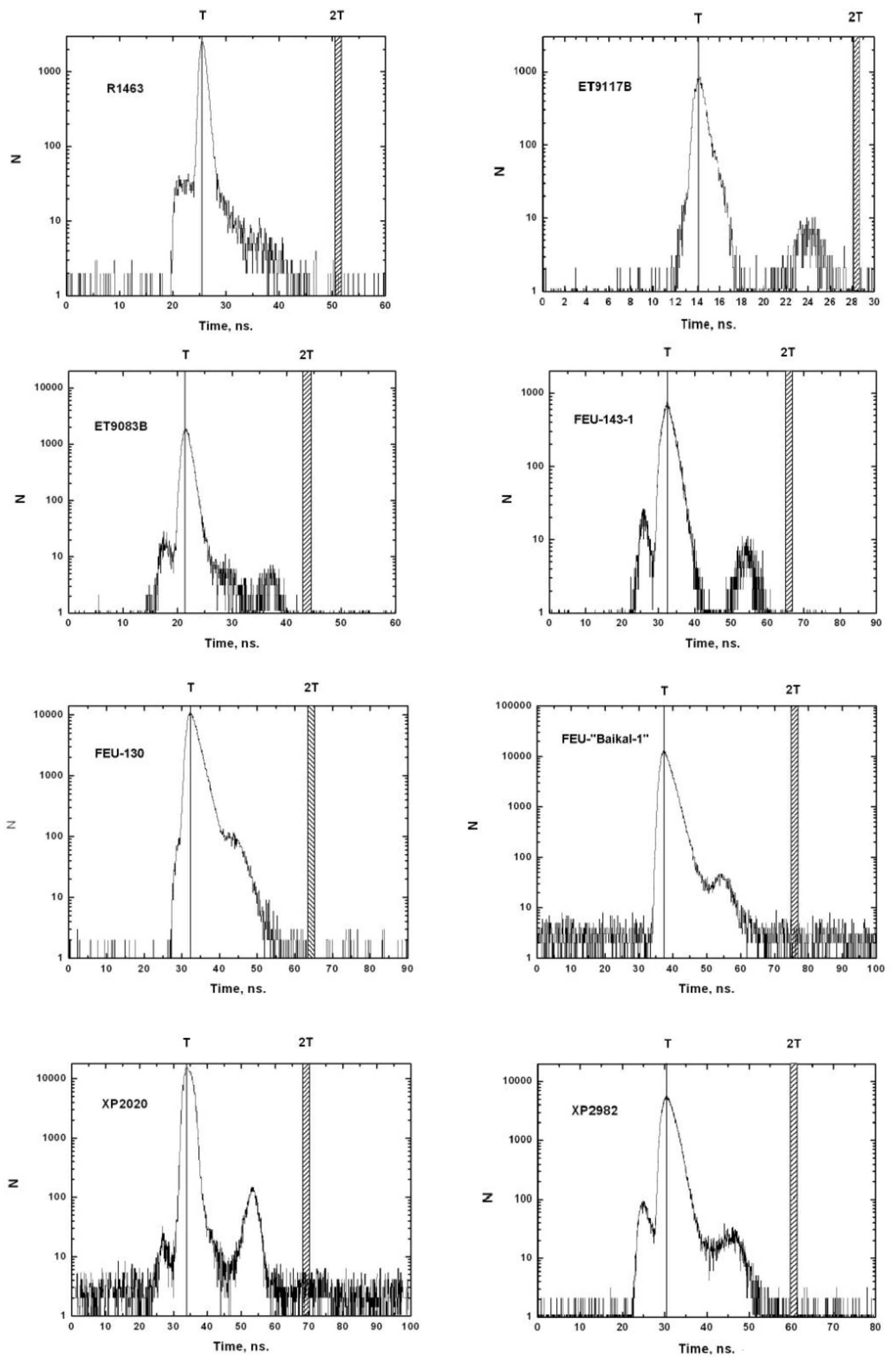
8” ET9350KB



Jitter ~ 2.5-3 ns (FWHM)

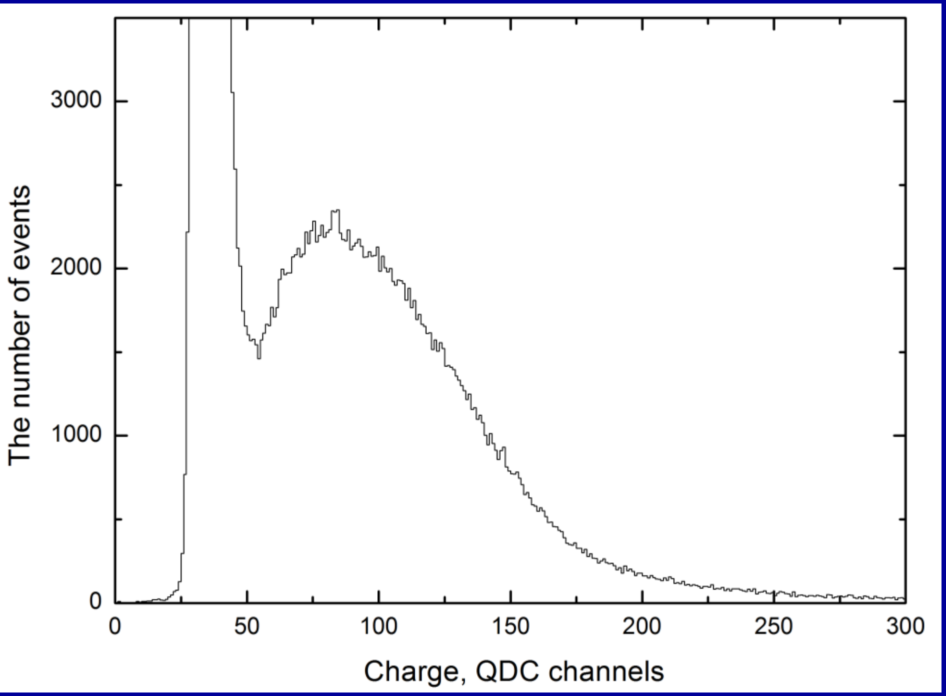
Prepulses - ~1%

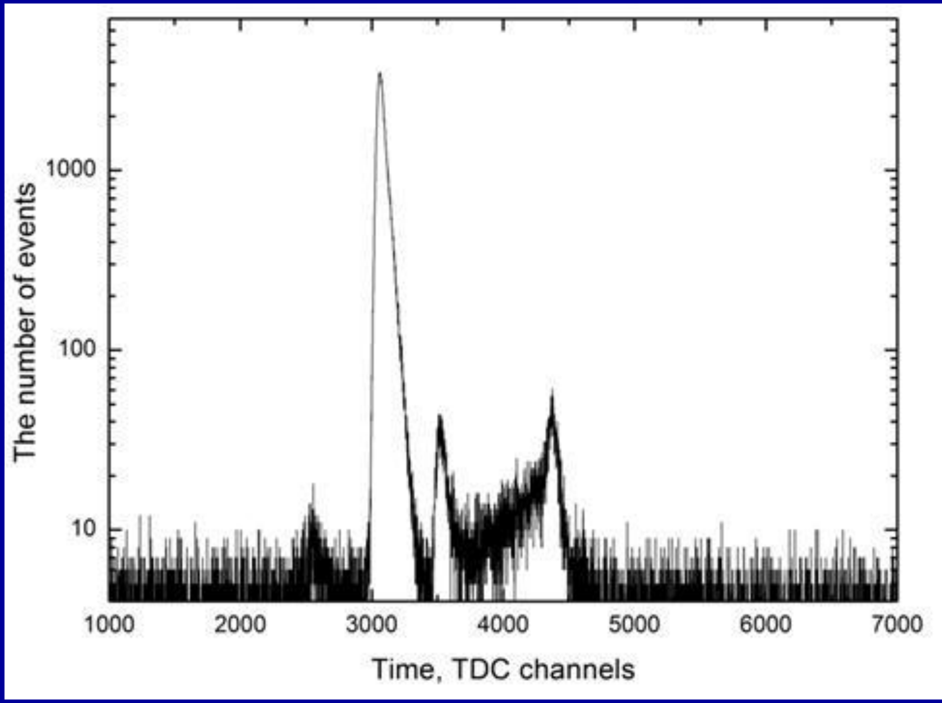
Late pulses - 4-5%



Photoelectron backscattering – general inherent phenomena of classical vacuum PMTs

R3600-06 0,5 m cathode





Jitter - ~4,7 ns (FWHM); QE~23% at 400 nm

8-9 kHz noise (>0.1 pe)

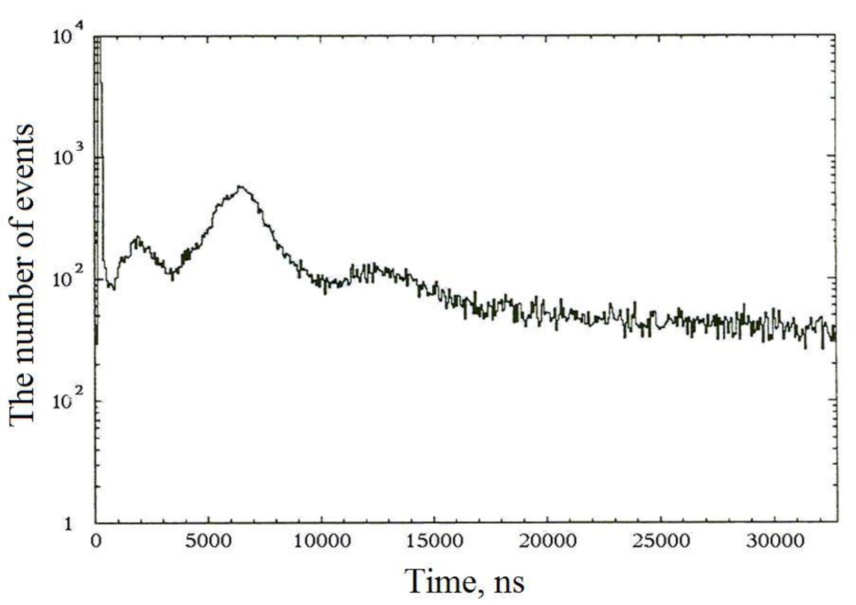
3 counts/cm^2 (20°C)!!!

<1 counts/cm^2 (0 °C)!!!

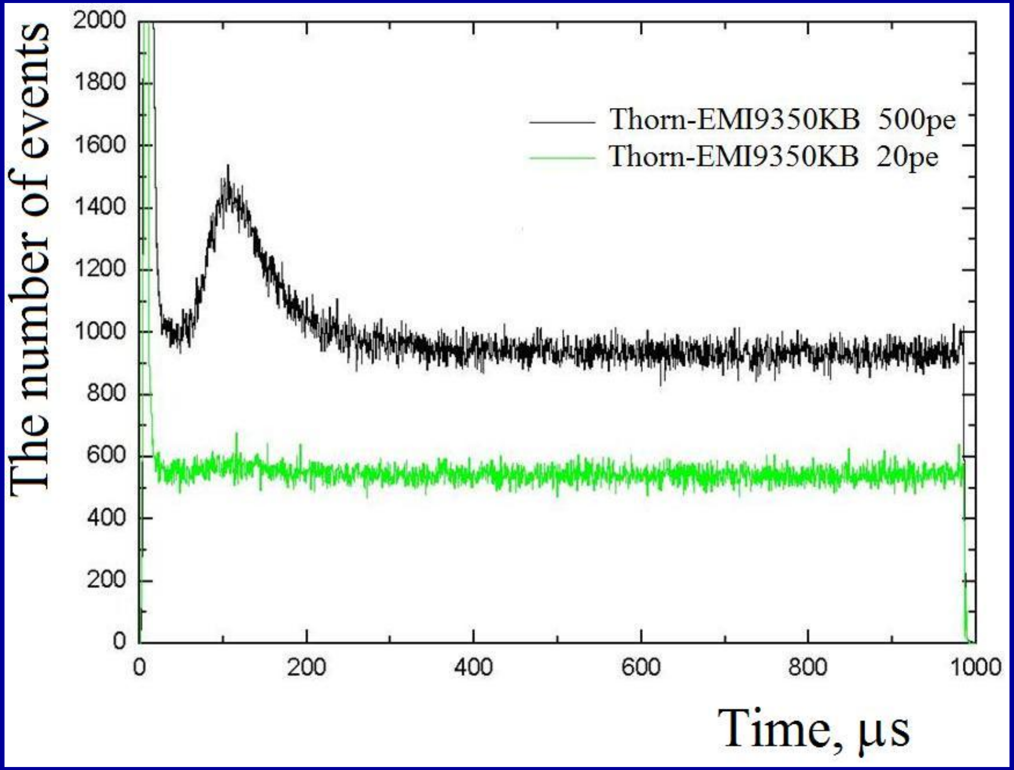
Afterpulses

Fast afterpulses – 300 ns; Long afterpulses – 300-15 μs

Long AP - 15 μs range

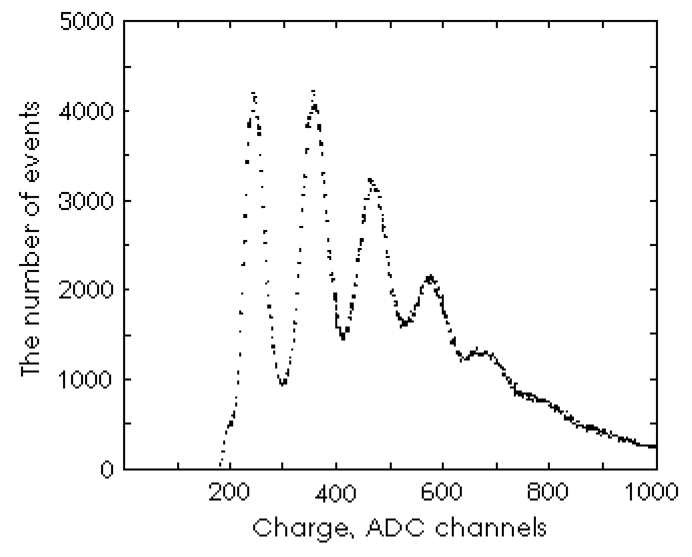


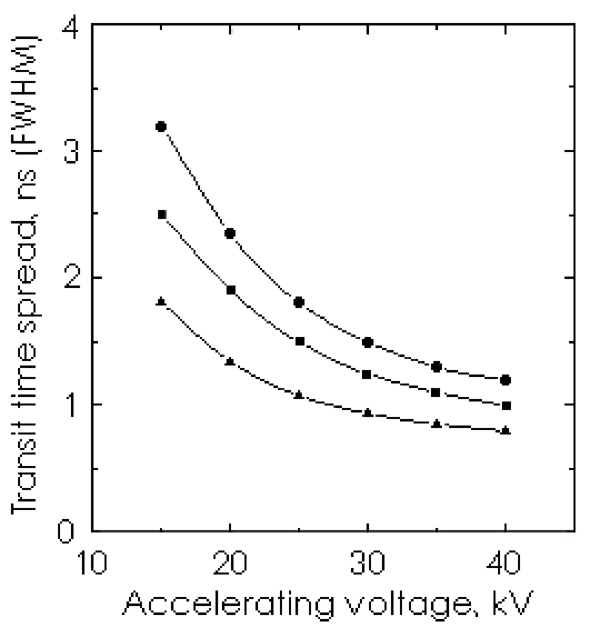
Extremely long AP 70-240 μs range!!!

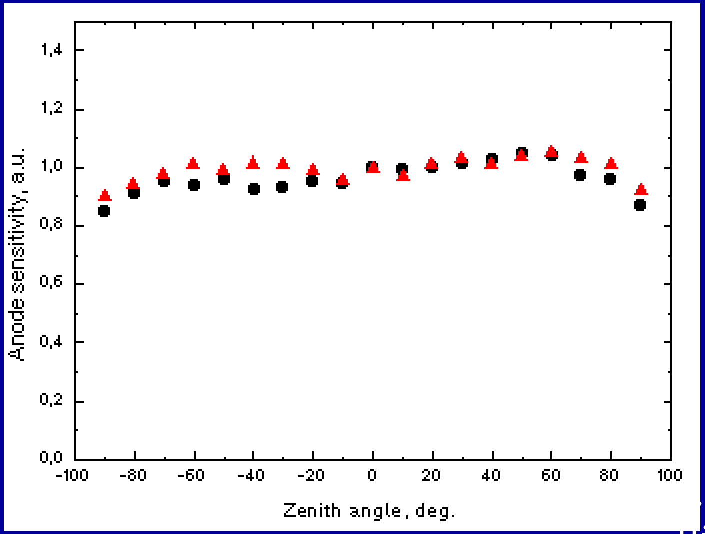


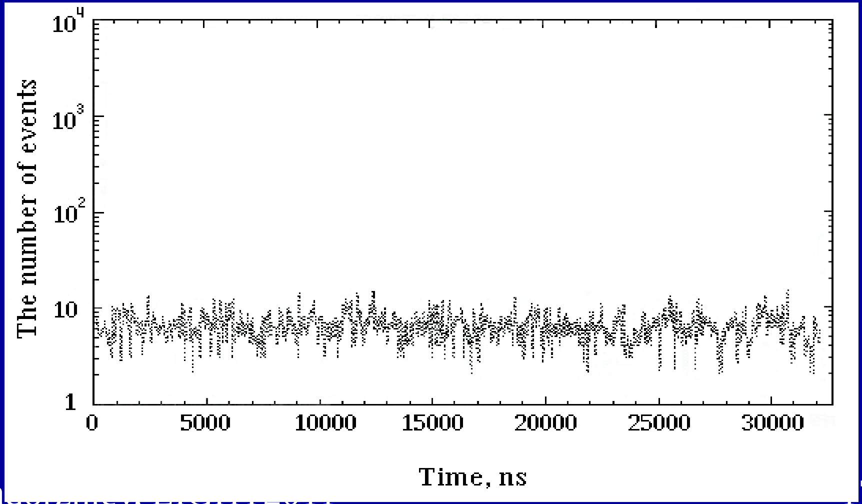
Observed only in two samples of 8” PMTs (EMI and Photonis)

QUASAR-370

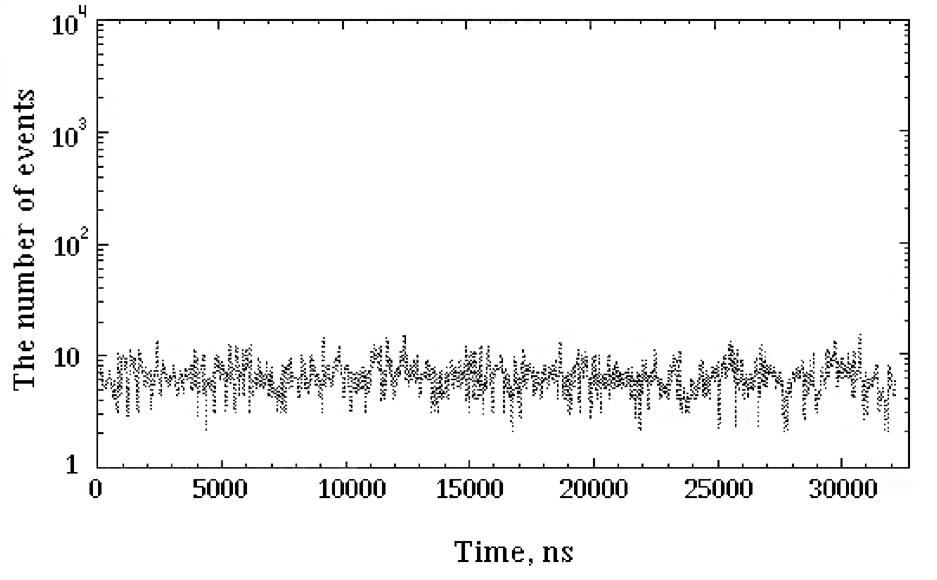

The number of events
5000
4000
3000
2000
1000
0
200
400
600
800
1000
Charge, ADC channels


Transit time spread, ns (FWHM)
4
3
2
1
0
10
20
30
40
Accelerating voltage, kV

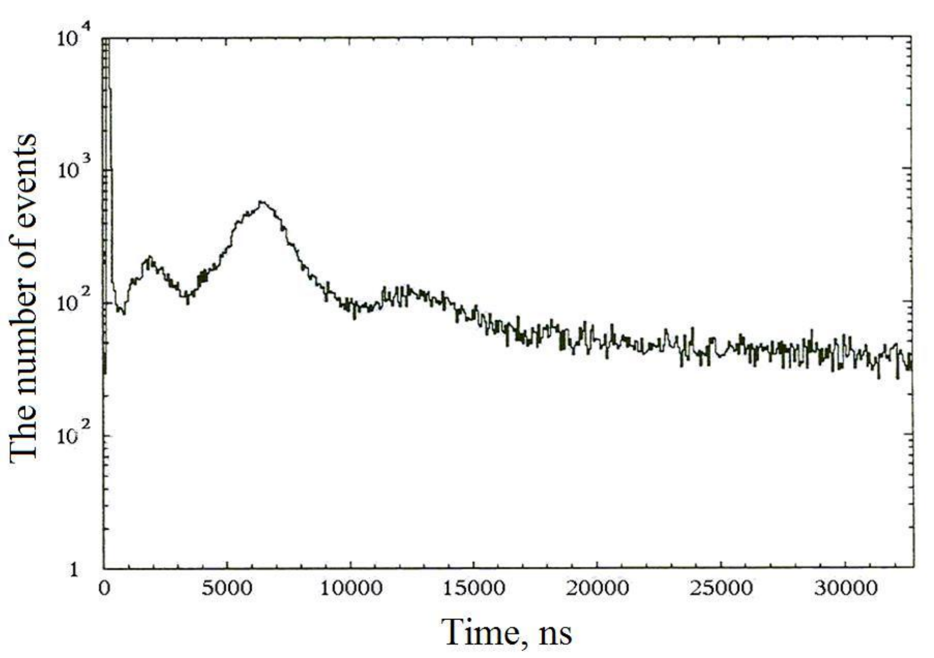

Anode sensitivity, a.u.
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
-100
-80
-60
-40
-20
0
20
40
60
80
100
Zenith angle, deg.


The number of events
10^4
10^3
10^2
10
1
0
5000
10000
15000
20000
25000
30000
Time, ns

Quasar-370 afterpulses - <1%



QUASAR-370



EMI9350KB

Effective QE

↕

Collection efficiency

↕

Phototelectron backscattering

Afterpulses

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

$$G = Y \times k \times \eta(\mathrm{eff})$$

Y - scintillator light yield

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

η(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

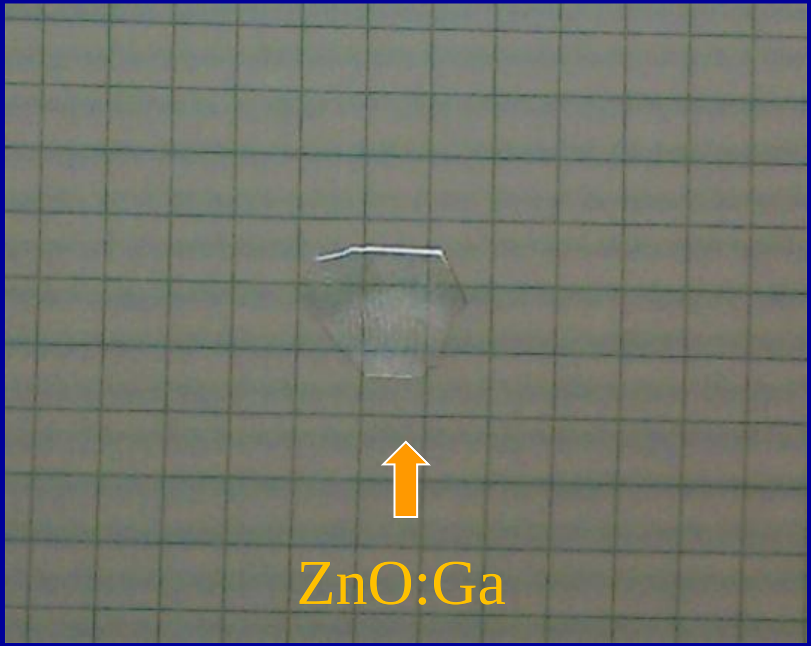
Luckey D., 1968 NIM
Light yield = NaI(Tl); Decay time - 0.4 ns!

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*

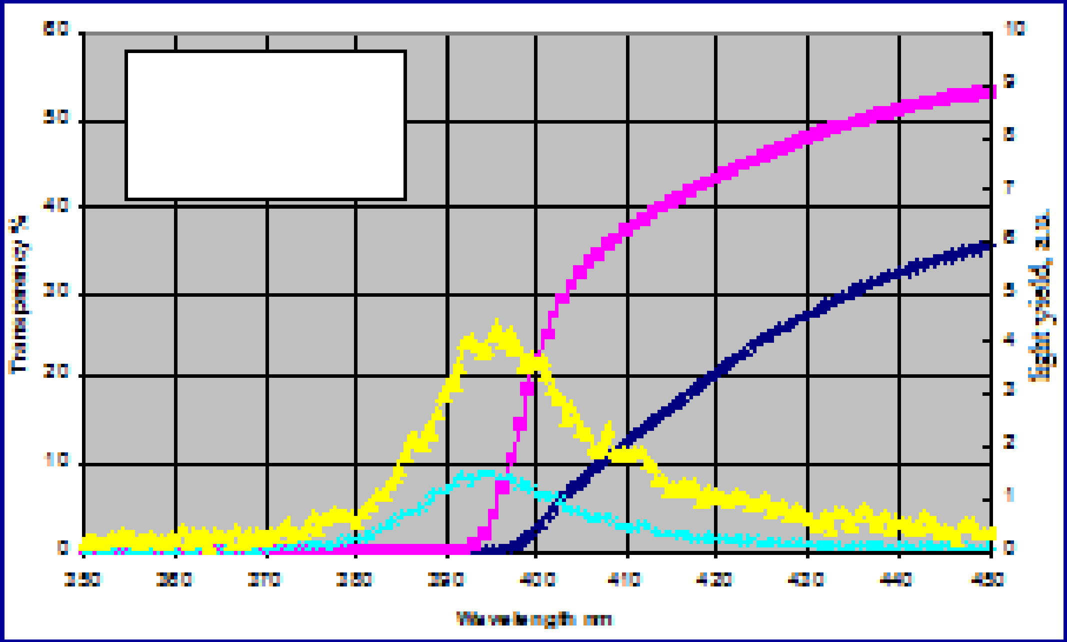
ZnO:Ga crystals from Cermet Inc. Atlanta, GA, USA



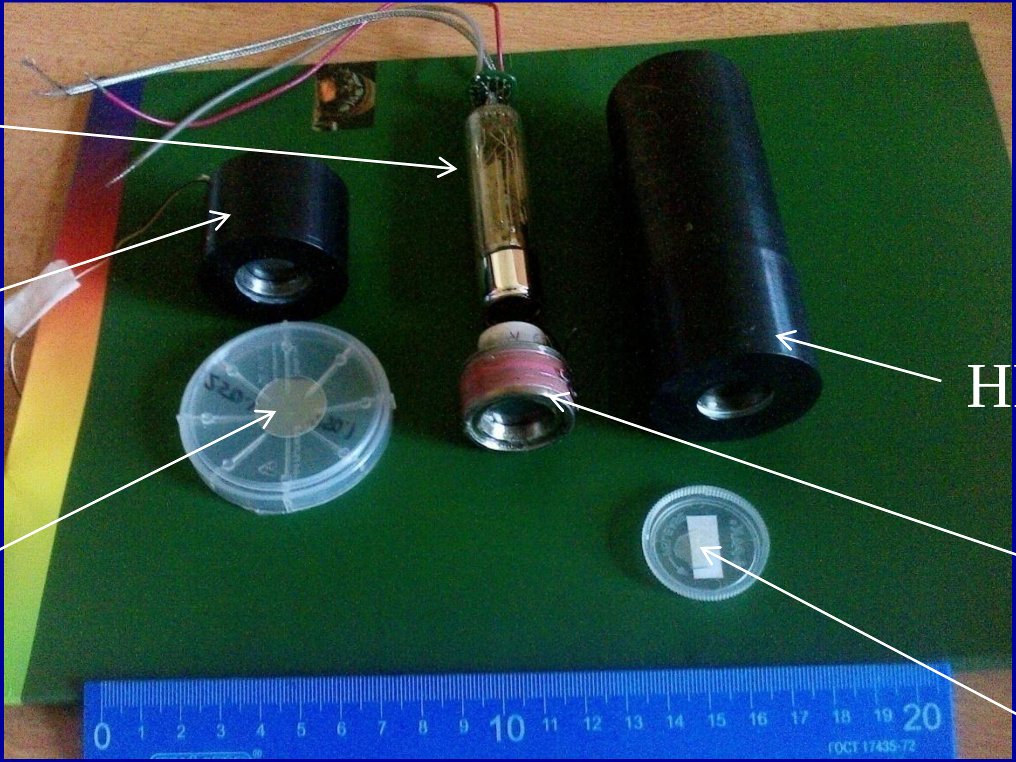
~300 μ thickness

~1cm^2 area

λ_{max} ~ 390 nm



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



PMT

HPD+HV

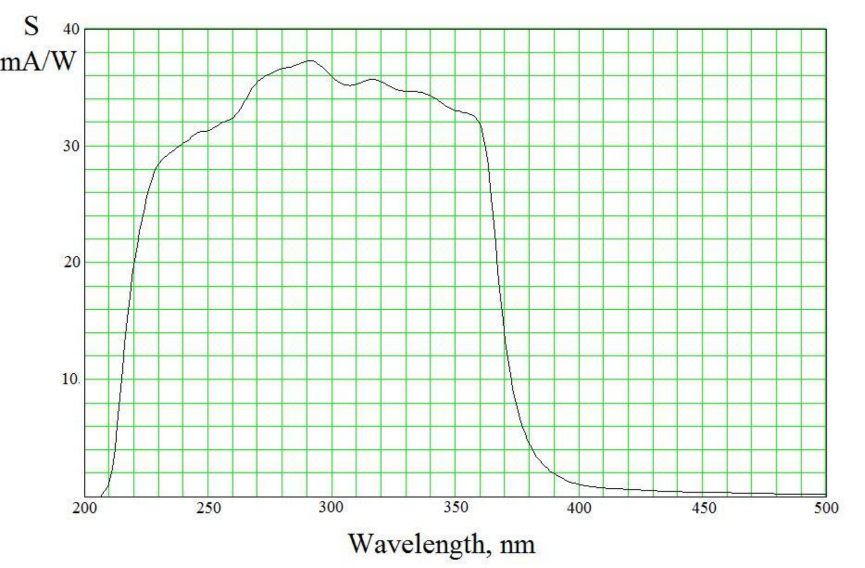
GaN on
Sapphire wafer

HPD+PMT module

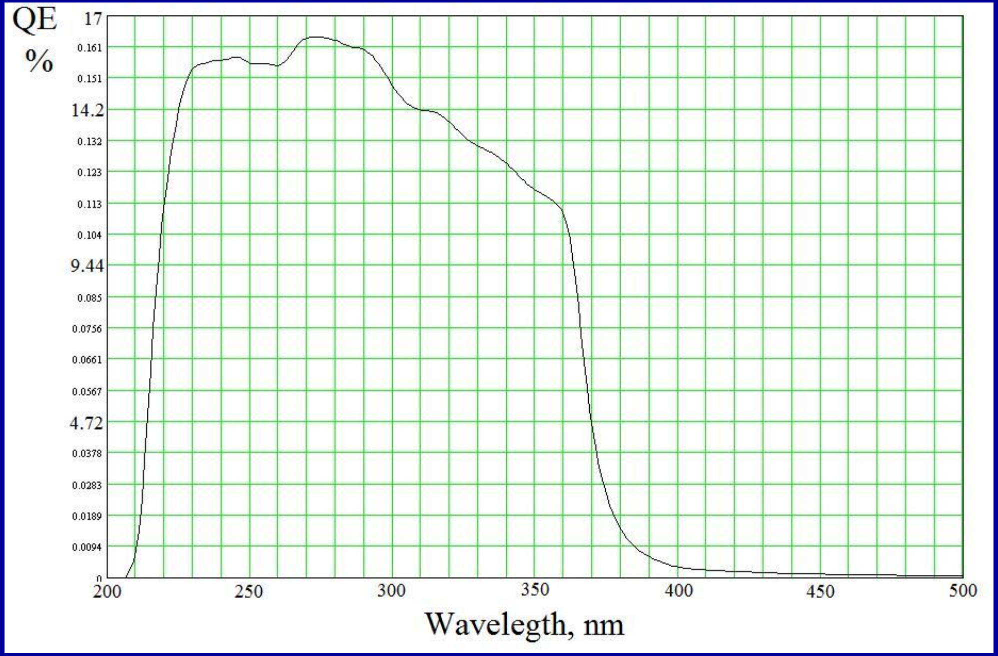
HPD

ZnO:Ga

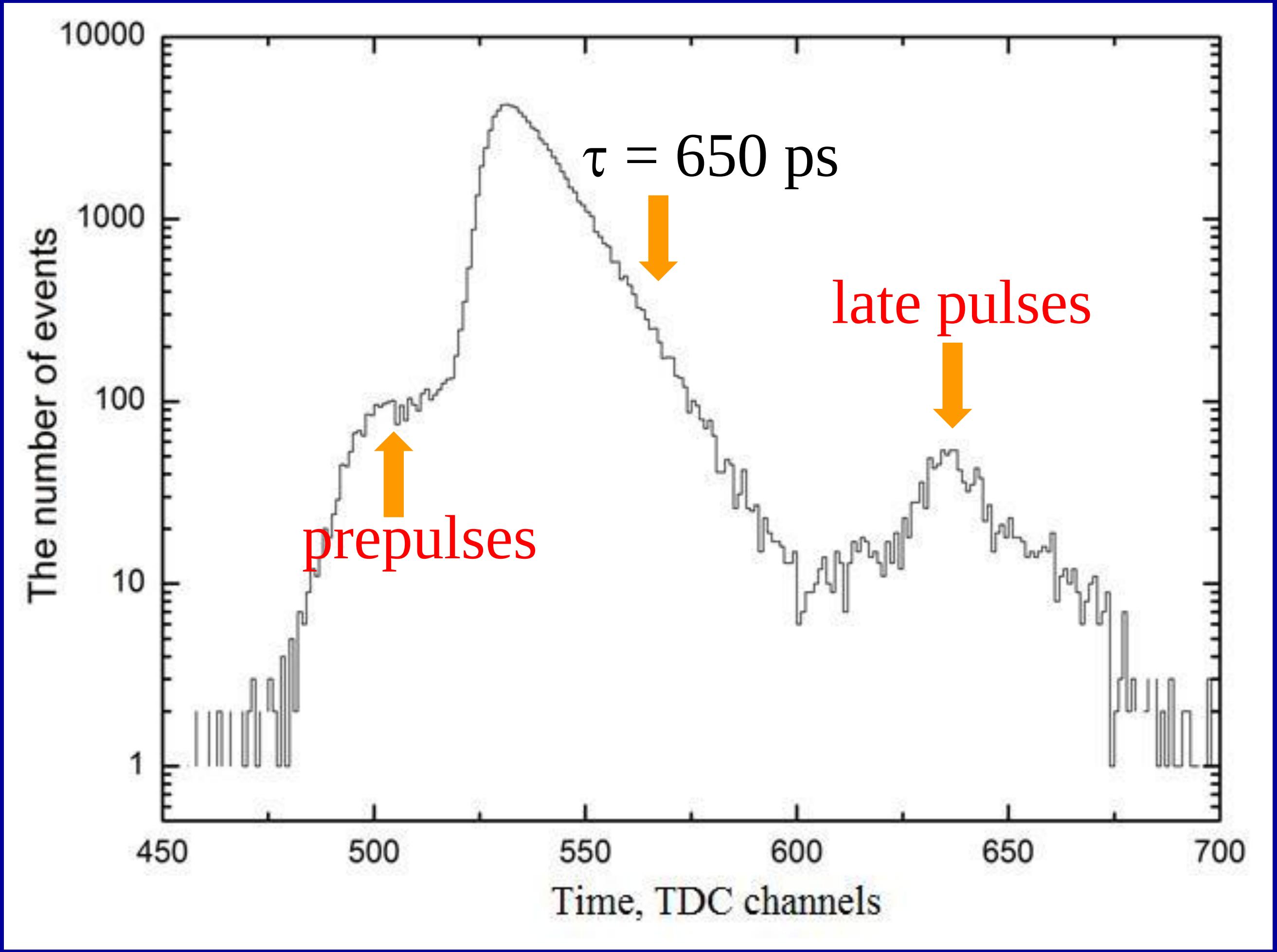
Pilot sample’s GaN photocathode sensitivity



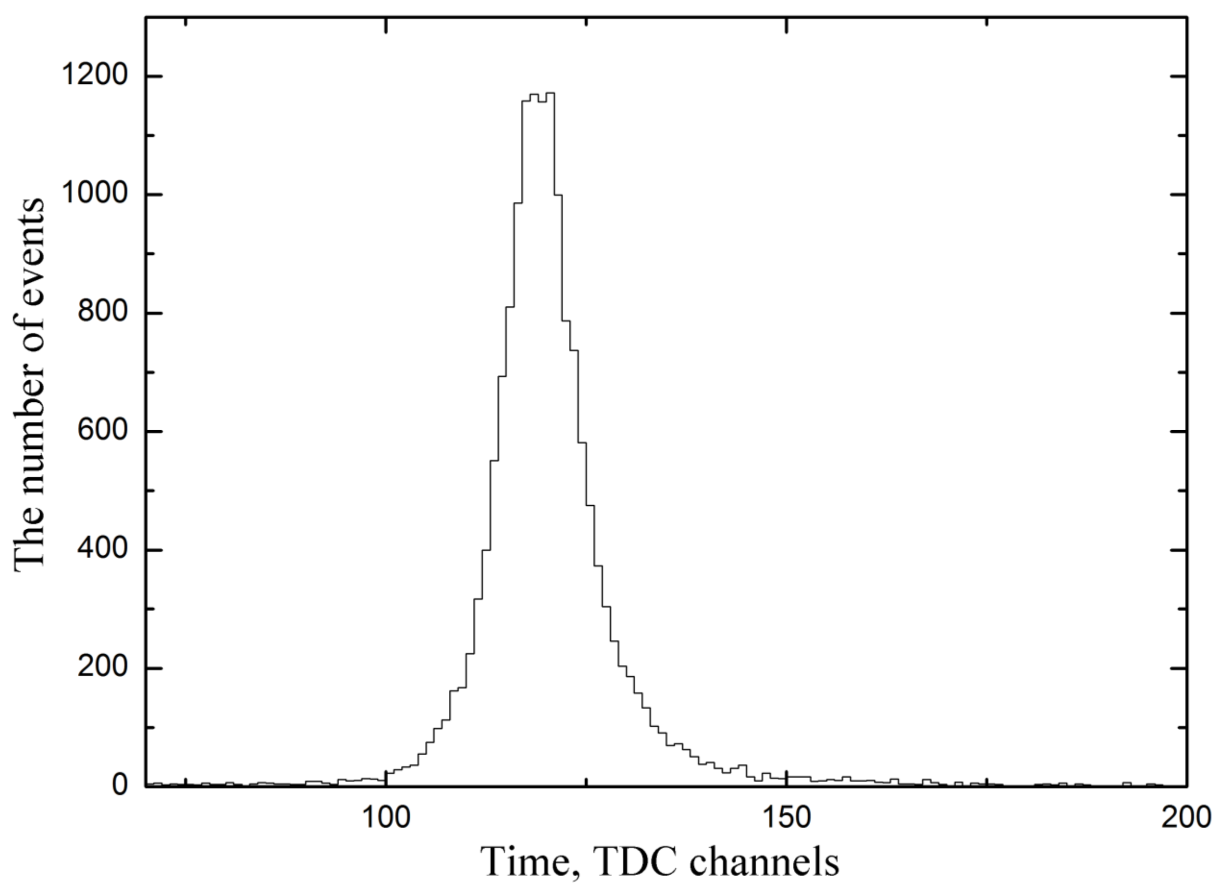
QE ~ 17%



τ~ 650 ps, light yield ~ 1200 γ/MeV

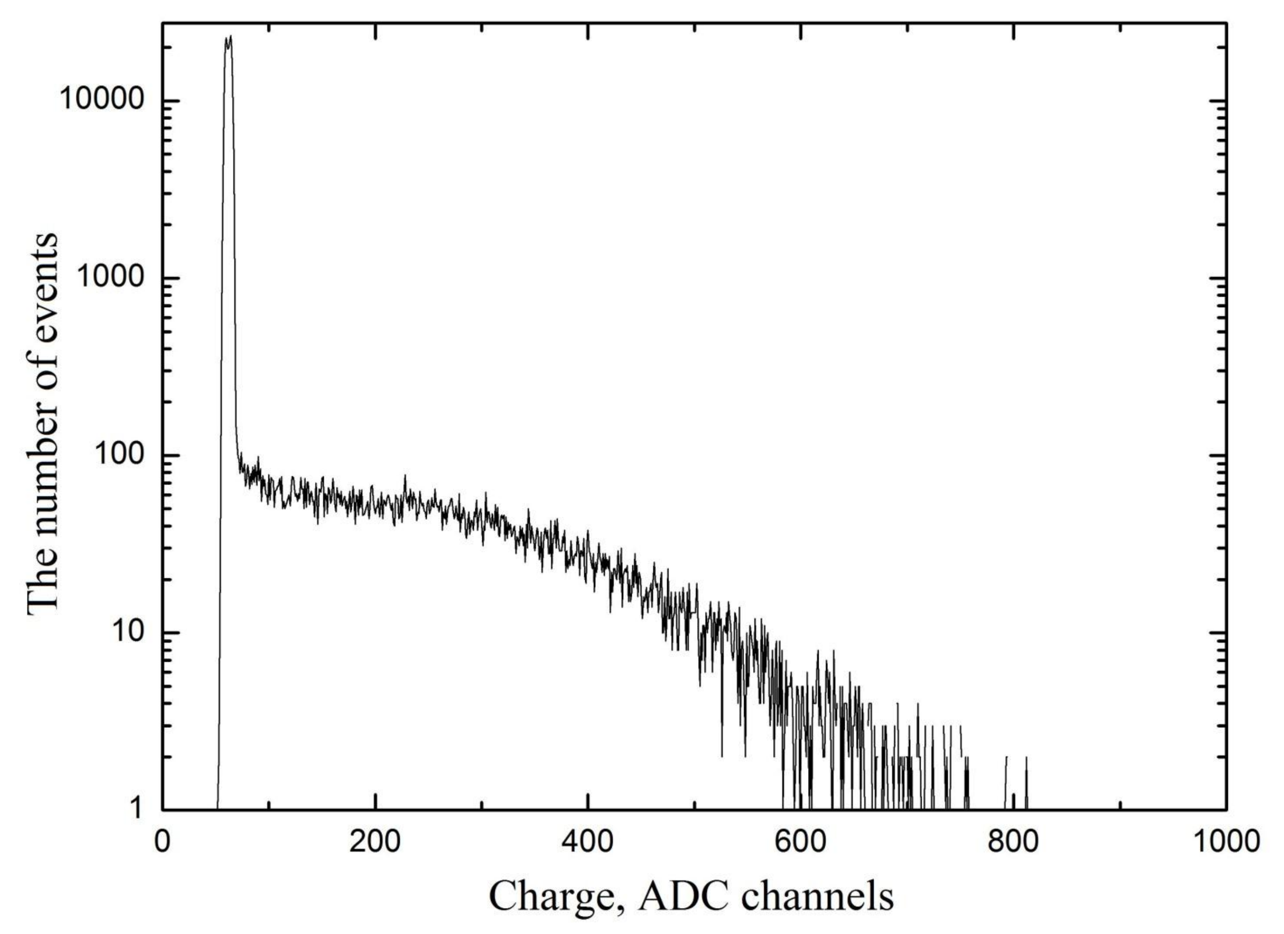


Jitter (TTS)



$\Delta t_{hpd} \sim 750$ ps (FWHM); $\Delta t_{LED} \sim 700$ ps

Single electron response



Practically no single pe peak

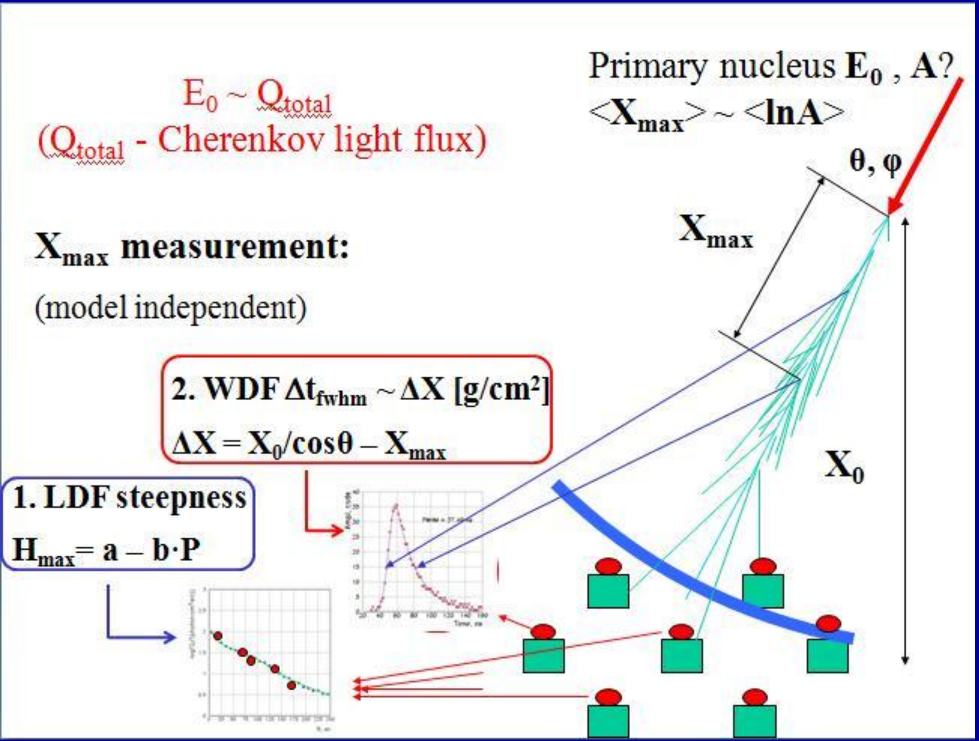
There is at least one application for which hybrid tubes equipped with the ZnO:Ga crystals with the light yield even at present level are very interesting

↓

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)

D.M.Seliverstov et al.

BaF_2:Tm - τ ~ 0.9 ns; slow component is suppressed!
Light yield – 4000-6000 γ/MeV

N.Surin et al.

Metal-organic scintillators – a few ns decay time;
light yield – ~10 000 γ/MeV
Vacuum compatible!
Temperature?

CONCLUSION

There are two good options for large are photodetectors for next generation astroparticle physics experiments –
Classical vacuum PMTs and Hybrid Phototubes.

Good news are coming for hybrid phototubes develeopment:
new fast high efficiency scintillators.

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

It is necessary to increase the light yield of the crystals.

Search for new fast scintillator materials of high efficiency should be continued. Fast “new” BaF2 and metal-organic scintillators are promising.