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

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

B.K.Lubsandorzhiev, NDIP2011
Lyon 6 July 2011
L.M. Balyasniy⁴, S.A. Belyanchenko³, L.B. Bezrukov¹, S. Dolinsky⁵, R. Falkenstein², P. Grabmayr², Yu.N. Gordienko⁴, G. Hallewell⁷, J. Jochum², B.K. Lubsandorzhiev¹,², N.B. Lubsandorzhiev¹, J. Nause⁶, B. Nemeth, V.A. Poleshuk¹, R.V. Poleshchuk¹, 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 - Super-Kamiokande

20” R1449
20” R3600
• Detection of neutrino signal from SN1987A

• Discovery of neutrino oscillation
Deep underwater neutrino experiments
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

**DETECTOR LAYOUT**

- **Cavern**
  - height: 115 m, diameter: 50 m
  - shielding from cosmic rays: ~4,000 m

- **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: 25 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?
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
\[ G = Y \times k \times \eta(\text{eff}) \]

- \( Y \) - scintillator light yield
- \( k \) - collection efficiency of photons on the small PMT’s photocathode
- \( \eta(\text{eff}) \) - 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 photocathode manufacturing procedure: high temperature, aggressive chemical environment etc.
Scintillators have to be:

Inorganic

Nonhygroscopic
Time resolution of hybrid phototubes and scintillator parameters

\[ W(t) \sim \exp\left(-\frac{G}{\tau}t\right) \]

\( G \) - the first stage amplification factor

\( G = \frac{n_{\text{p.e.}}}{N_{\text{p.e.}}} \)

\( n_{\text{p.e.}} \) - # of p.e. detected by small PMT; \( N_{\text{p.e.}} \) - # of p.e. on the phototube cathode

\( G \sim Y(E_e) \)

\( Y \) - scintillator light yield

\( \tau \) - scintillator decay time

Scintillator should have \( Y/\tau \) 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 $\gamma$/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

~1 cm² area

λ_{max} \sim 390 \text{ nm}
τ ~ 650 ps, light yield ~ 1200 γ/MeV
Pilot sample of HPD with ZnO:Ga crystal based on image intensifier
Pilot sample’s GaN photocathode sensitivity

QE ~ 17%
Jitter (TTS)

$\Delta t_{\text{hpd}} \sim 750 \text{ ps (FWHM)}$; $\Delta t_{\text{LED}} \sim 700 \text{ ps}$
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)
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 $\geq 100$ 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