THE QUEST FOR THE IDEAL PHOTODETECTOR FOR THE NEXT GENERATION OF NEUTRINO TELESCOPES

Bayarto Lubsandorzhiev

Institute for Nuclear Research RAS

Moscow Russia

J.Learned, L.Bezrukov, A.Roberts et al. 70-80s

requirements for pmts for deep underwater neutrino experiments.

DUMAND, BAIKAL

GRANDE, NEVOD

AMANDA, NESTOR,

ANTARES, NEMO,

ICECUBE, KM3net

Citius, Altius, fortius

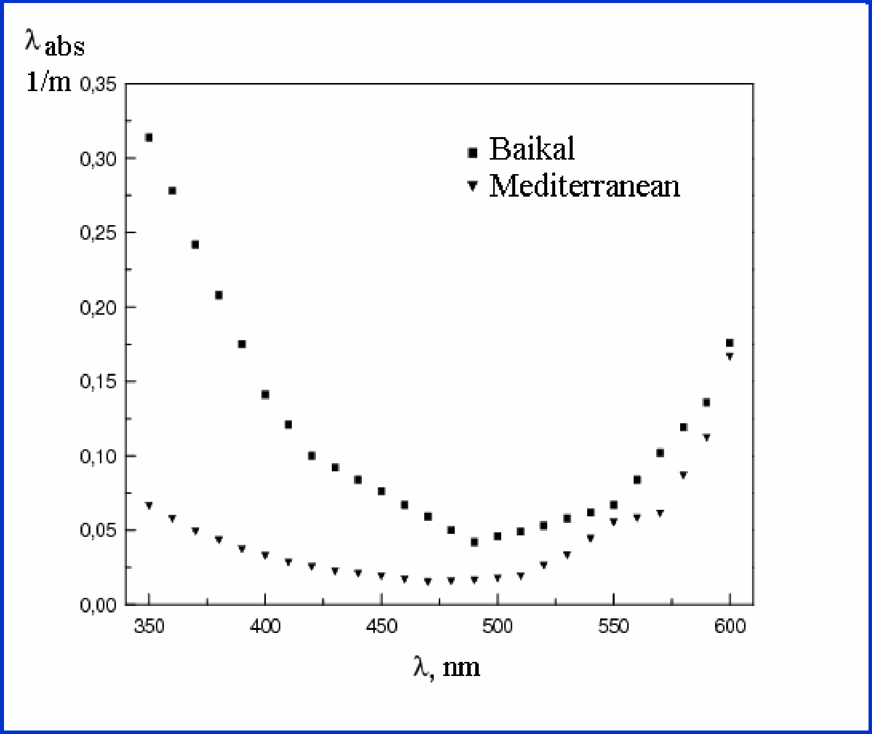
Faster, More Sensitive, Smarter

- High sensitivity to Cherenkov light - bialakali photocathode.
- Large sensitive area and 2π acceptance - hemispherical photocathode
- High time resolution (as low jitter as possible) - hemispherical cathode
- Good SER (as good as possible) to suppress background due to K40.
- Low dark current - bialkali photocathode
- Fast response (~10 ns width or less)

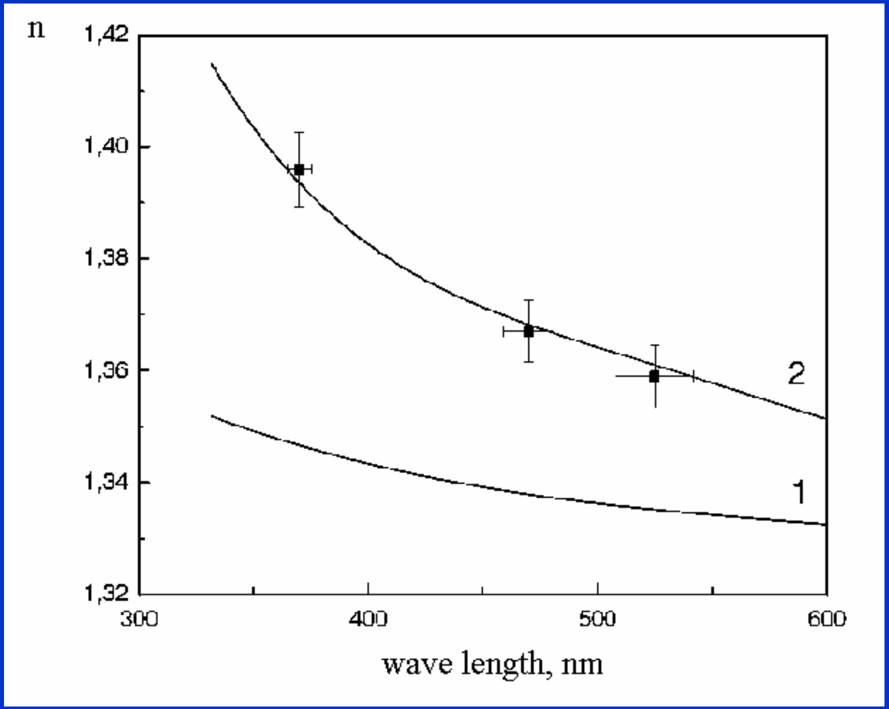
History of deep under water neutrino telescopes spans more than 30 years.

So far the Baikal Neutrino Telescope is the only deep under water neutrino telescope in the world.

Water transparency

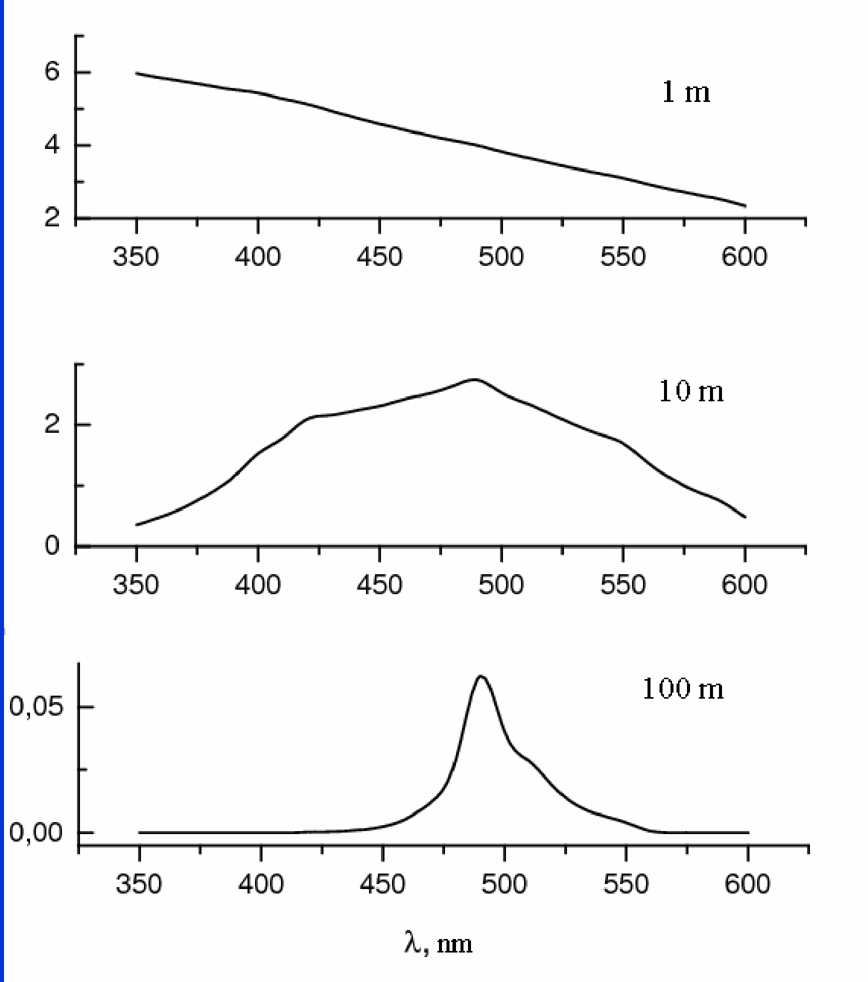


Light dispersion in deep Baikal water

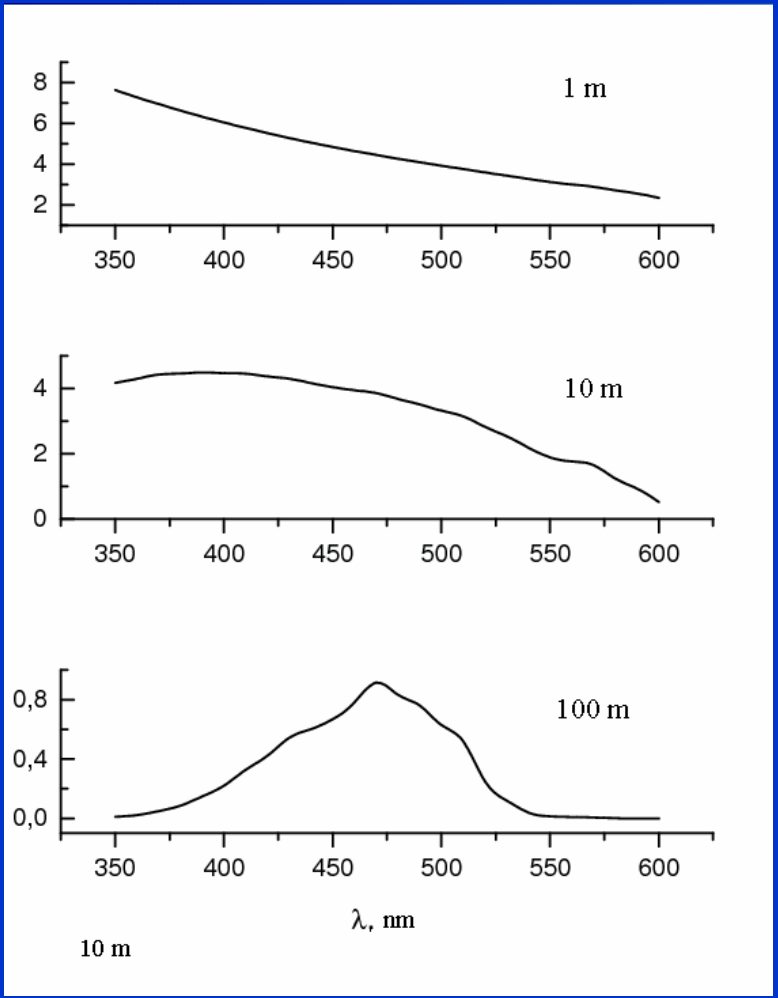


Cherenkov light spectrun transformation in water

Baikal



Mediterranean



Water parameters play crucial role

Light dispersion in water smears photons arrival times

e.g. 100 m - Δt~5ns for Mediterranean
PMT's jitter of ~3-4 ns (fwhm) is enough

sensitivity in wider range than conventional bialkali cathode (Ultra/Hyper Multialkali Cathode?)

Disadvantages of classical PMTs

- Poor collection and effective quantum efficiencies
- Poor time resolution???
- prepulses
- late pulses
- afterpulses
- sensitivity to terrestrial magnetic field
- larger PMT size - larger dynode system (Dph/Dd1), practically impossible to provide 2π acceptance

Hybrid phototubes with luminescent screen

A.E.Chudakov 1959 - hybrid tube with luminescent screen

Van Aller et al. 1981 - prototypes of «smart tube»

Van Aller et al. 1981-1986 - XP2600

L.Bezrukov, B.Lubsandorzhiev et al. 1985-1986 - Quasar-300 and Quasar-350 tubes

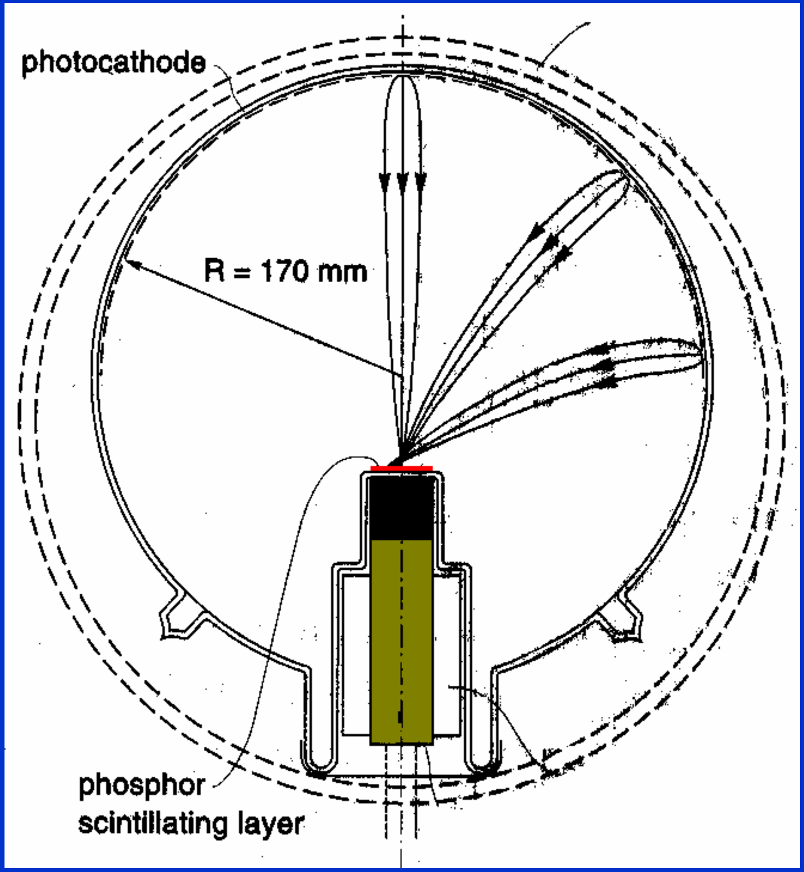
L.Bezrukov, B.Lubsandorzhiev et al. 1987 - Tests of XP2600 and Quasar -300 tubes in Lake Baikal

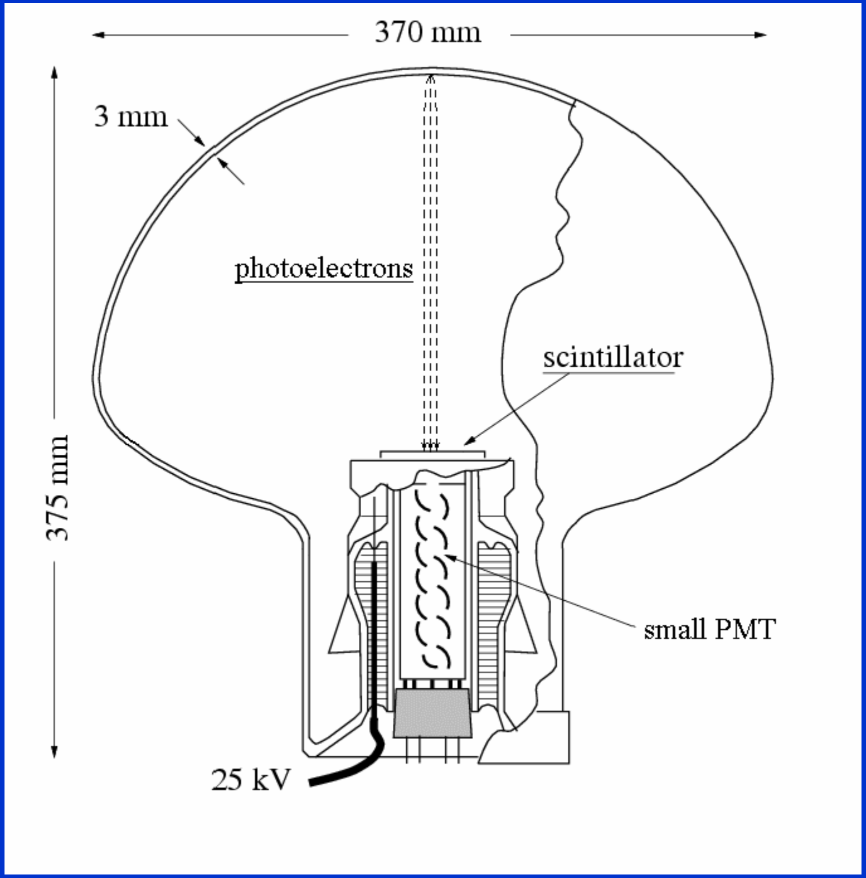
L.Bezrukov, B.Lubsandorzhiev et al. 1990 - Quasar-370 tube.

Hybrid phototube with luminescent screen

Light amplifier + small conventional type PMT

XP2600 QUASAR-370





Quasar-370 phototube has excellent time and very good single electron resolutions

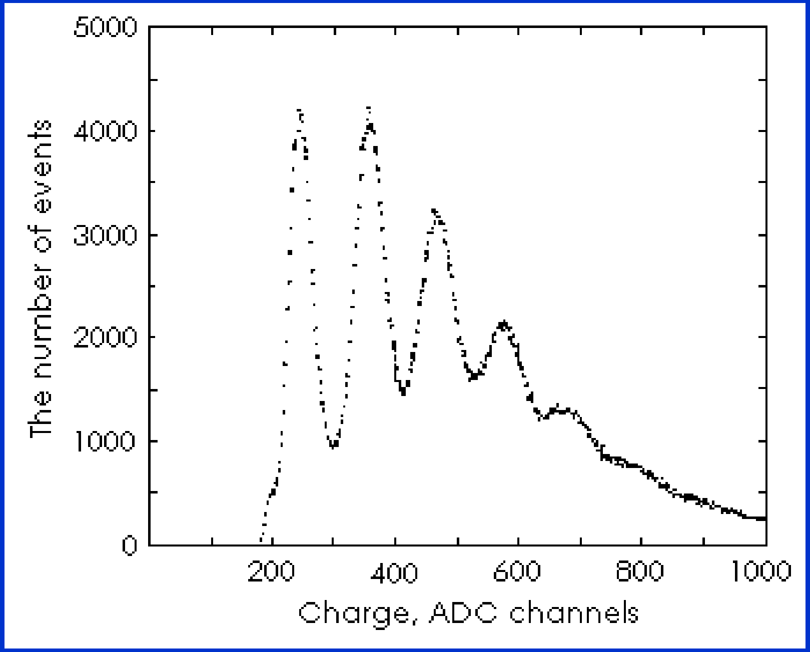
- no prepulses
- no late pulses in TTS
- low level of afterpulses
- ~100% effective collection effiency
- 1 ns TTS (FWHM)
- very good SER (competitive to HPD)
- immunity to terrestrial magnetic field

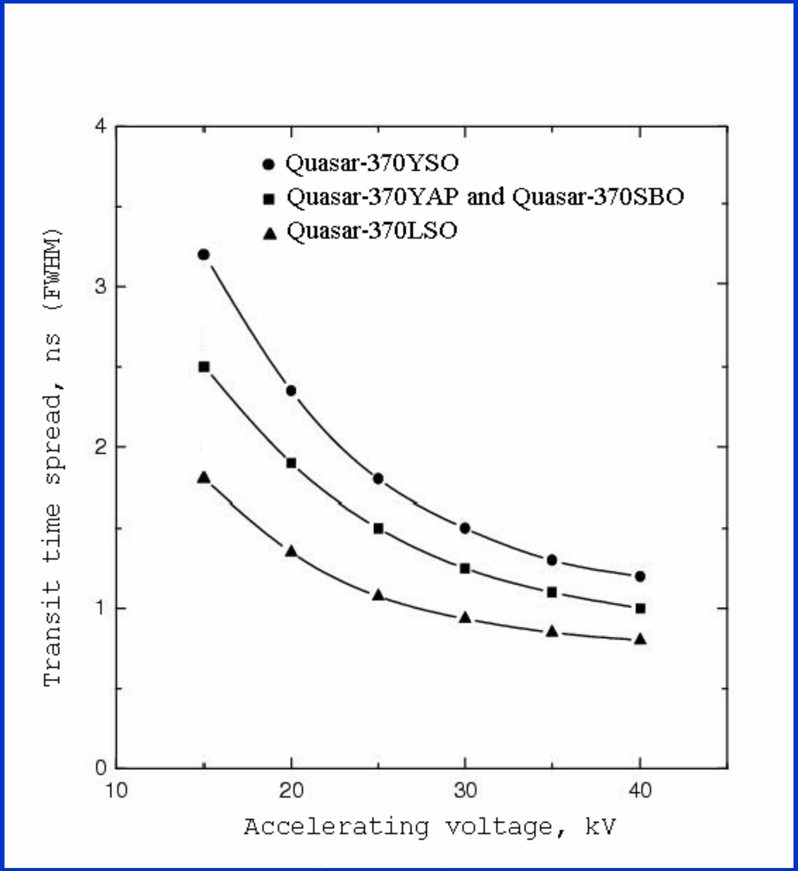
>2π sensitivity

ageing

Quasar-370LSO with LSO crystal

1996-97, ICRC1997





Single electron resolution ~35% (fwhm)

Jitter ~ 1 ns (fwhm)

The PMT used in the Quasar-370LSO had ~17% η(eff)

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

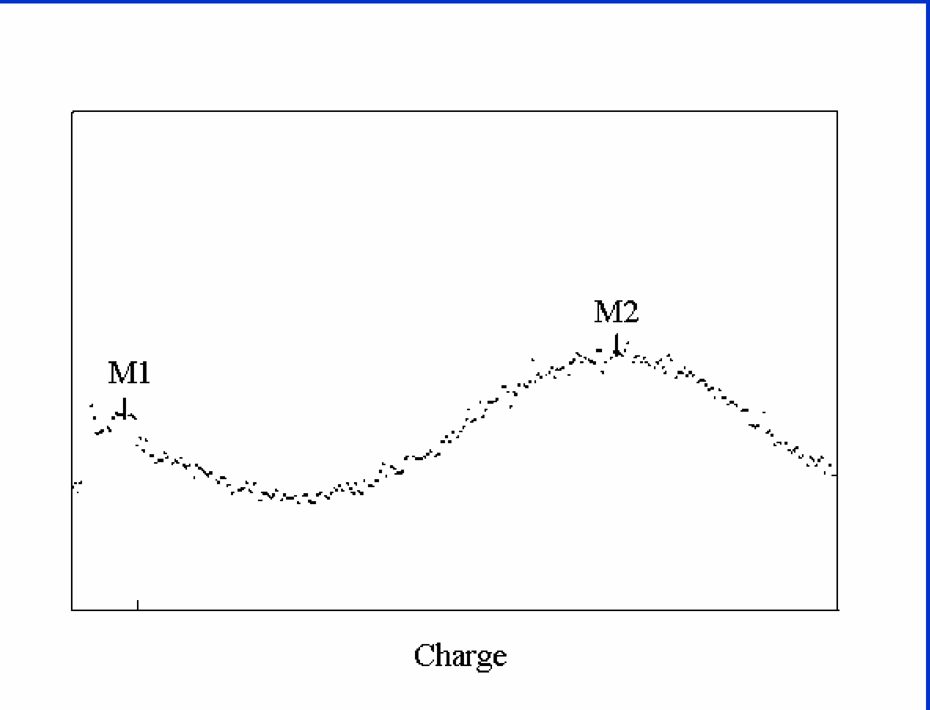
Y - scintillator light yield

k - colection efficiency of photons on small PMT's cathode

η(eff) - effective quantum efficiency of small PMT

PMT with higher η(eff) will provide even better parameters of Quasar-370!

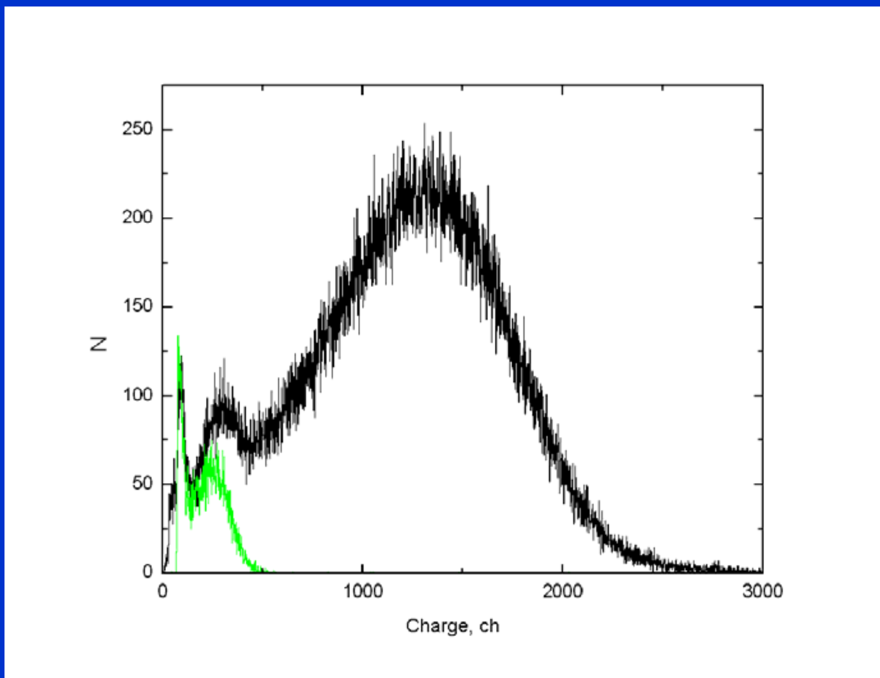
Studies of Quasar-370 at low thresholds

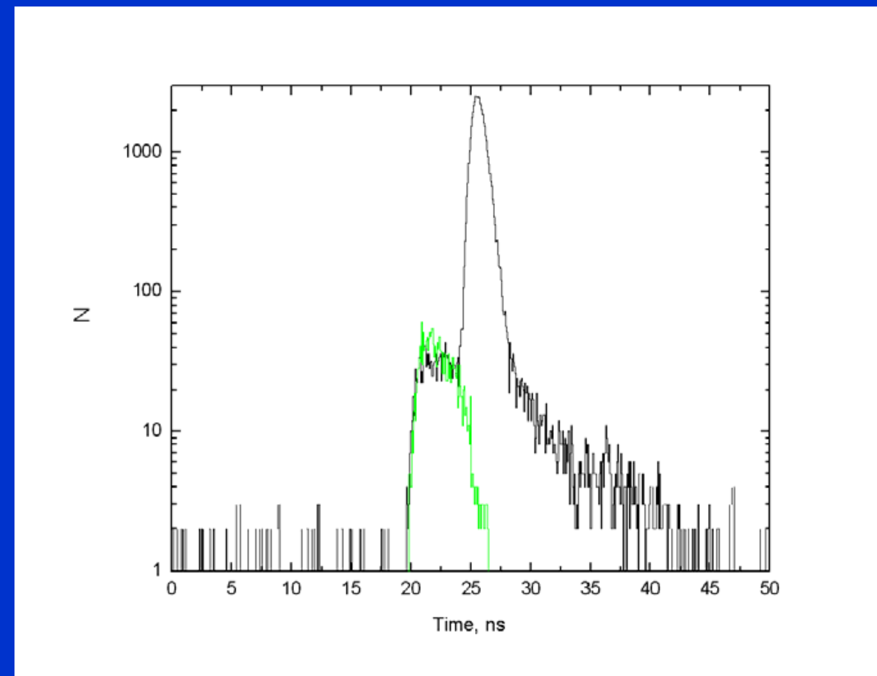


M1 - single pe peak of small PMT

M2 - single pe peak of Quasar-370

Studies of R1463 at a low threshold

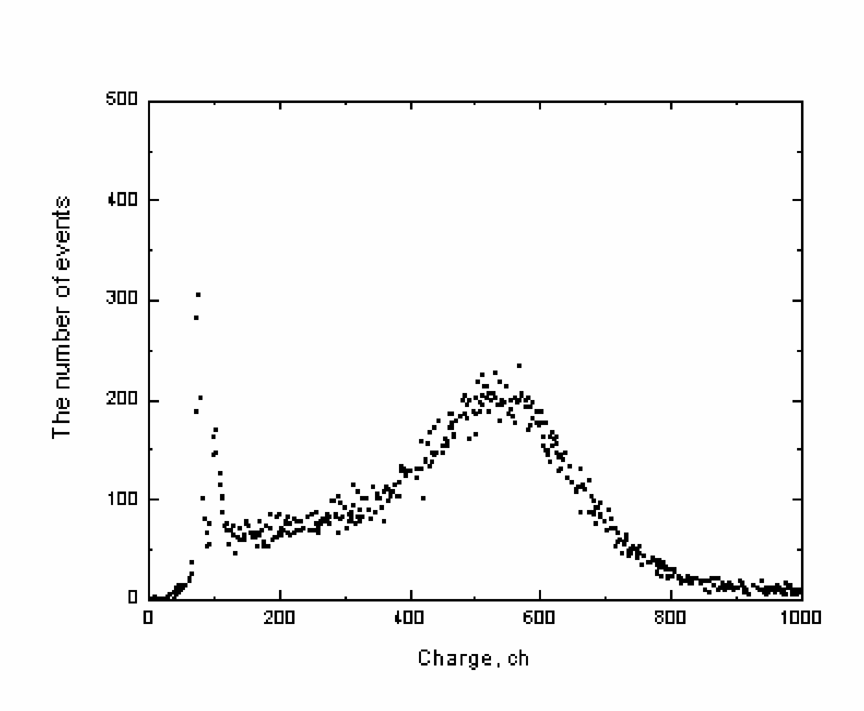


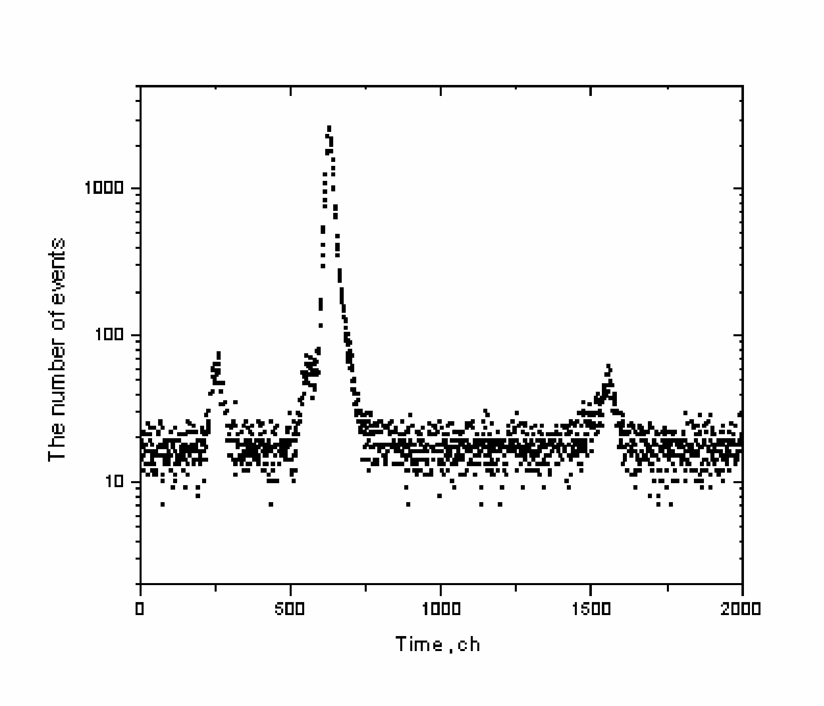


- Threshold - ~ 0.005 p.e.!
- Green - spectra measured with cathode camera switched off, i.e. cathode and 1 dynode are short circuited

Big hemispherical PMTs at low thresholds

Hamamatsu R8055 (13’’)

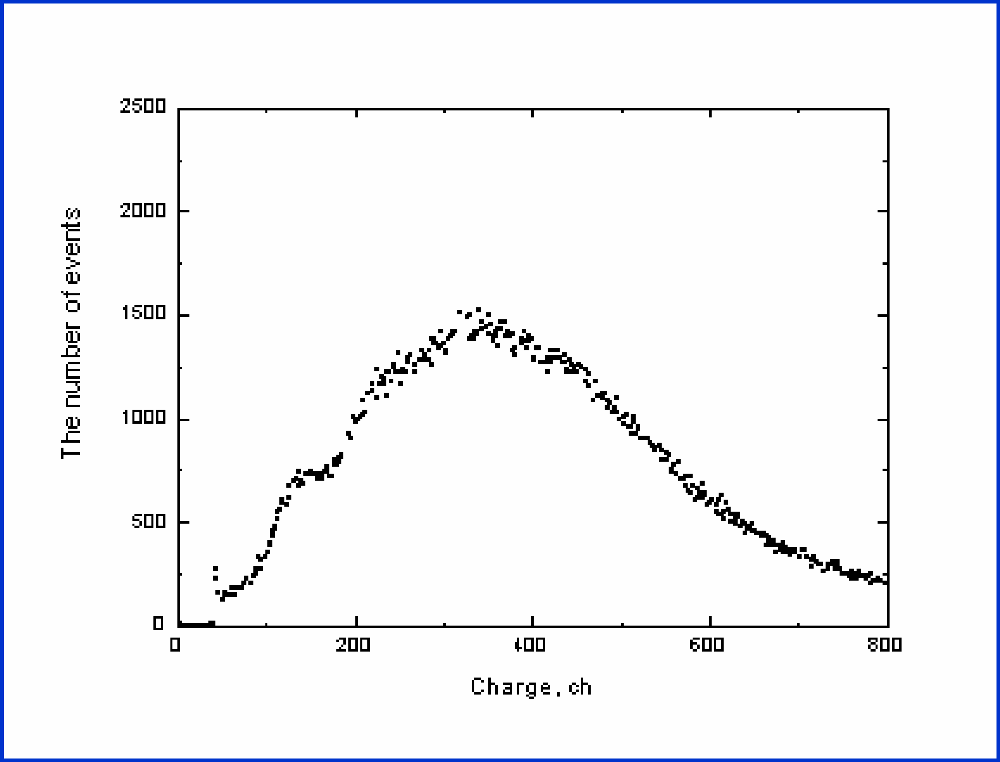




SER ~70% (fwhm)
0.005 pe threshold!

Jitter ~ 1.8 ns (fwhm)

Photonis XP1807 (12’’)



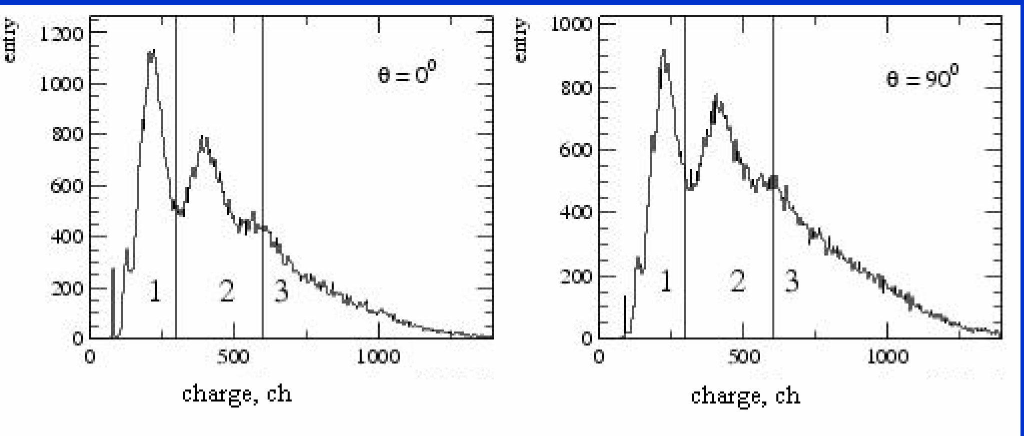
σ ~ 35

point like illumination at the pole of the PMT's photocathode

Afterpulses - ~20%

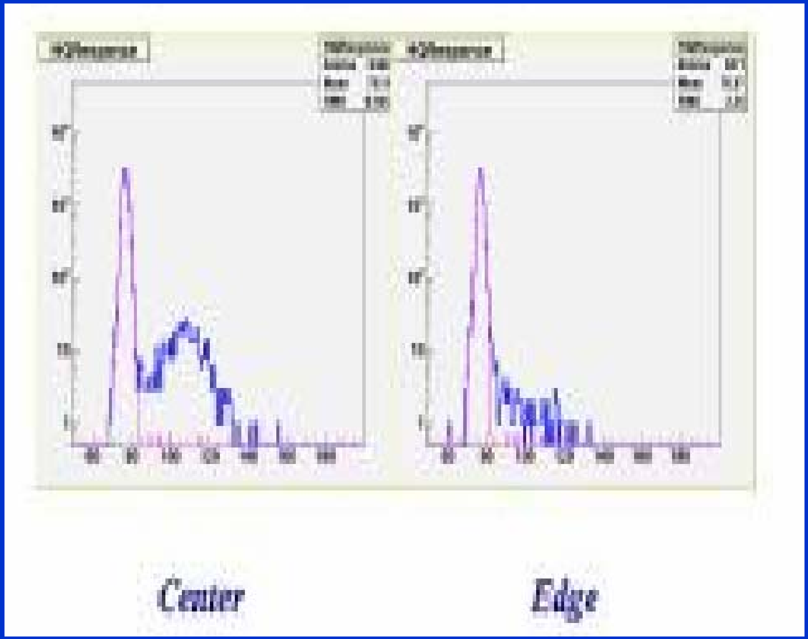
New parameter to evaluate PMT's quality - its ability to work at low threshoulds?

XP2600



C.Wiebusch, RWTH-Aachen 1995

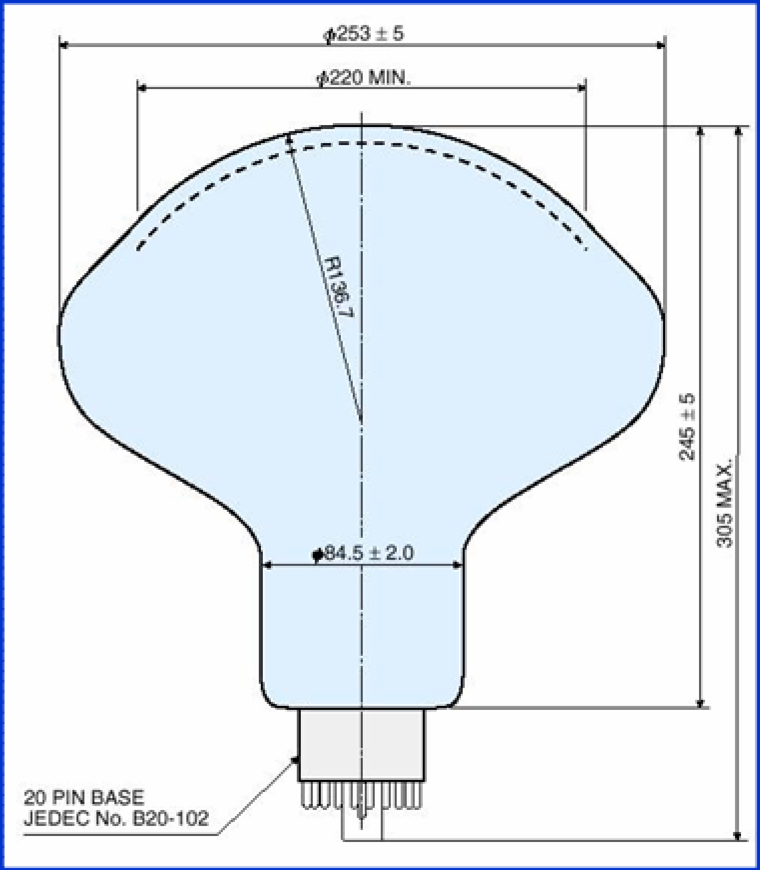
R7081

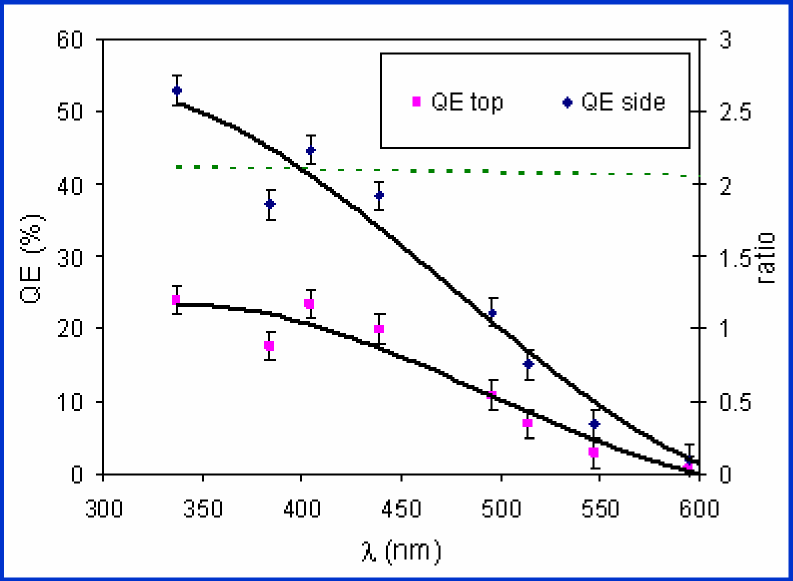


H.Miyamoto, Chiba University

Quasar-370

XP2600

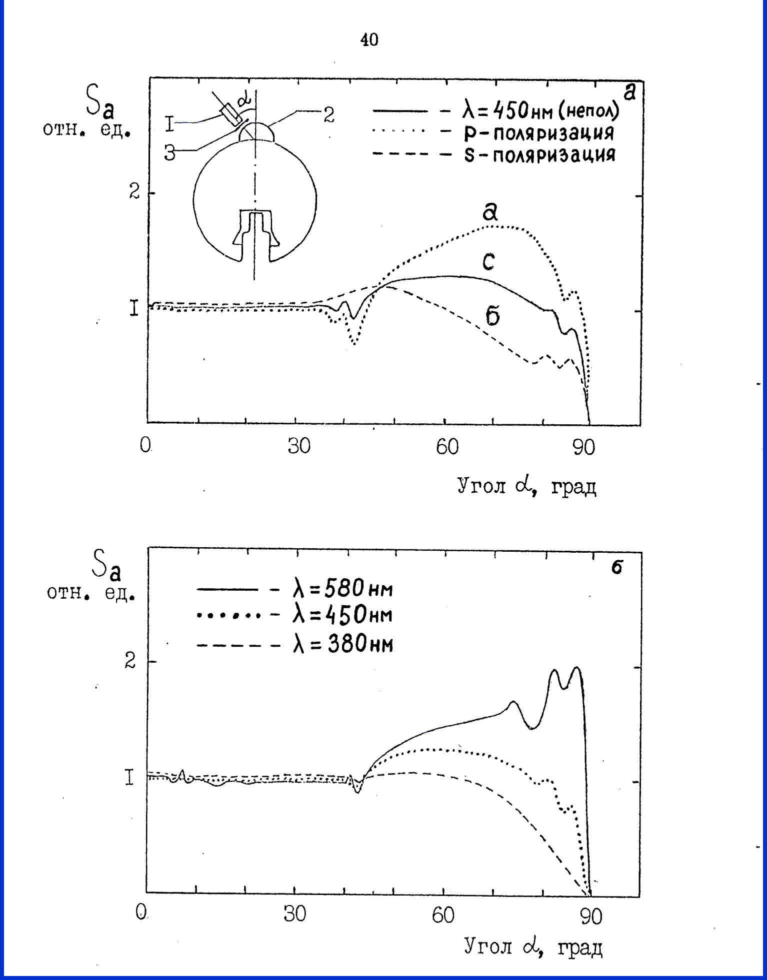

ϕ253 ± 5
ϕ220 MIN.
R136.7
245 ± 5
305 MAX.
ϕ84.5 ± 2.0
20 PIN BASE
JEDEC No. B20-102

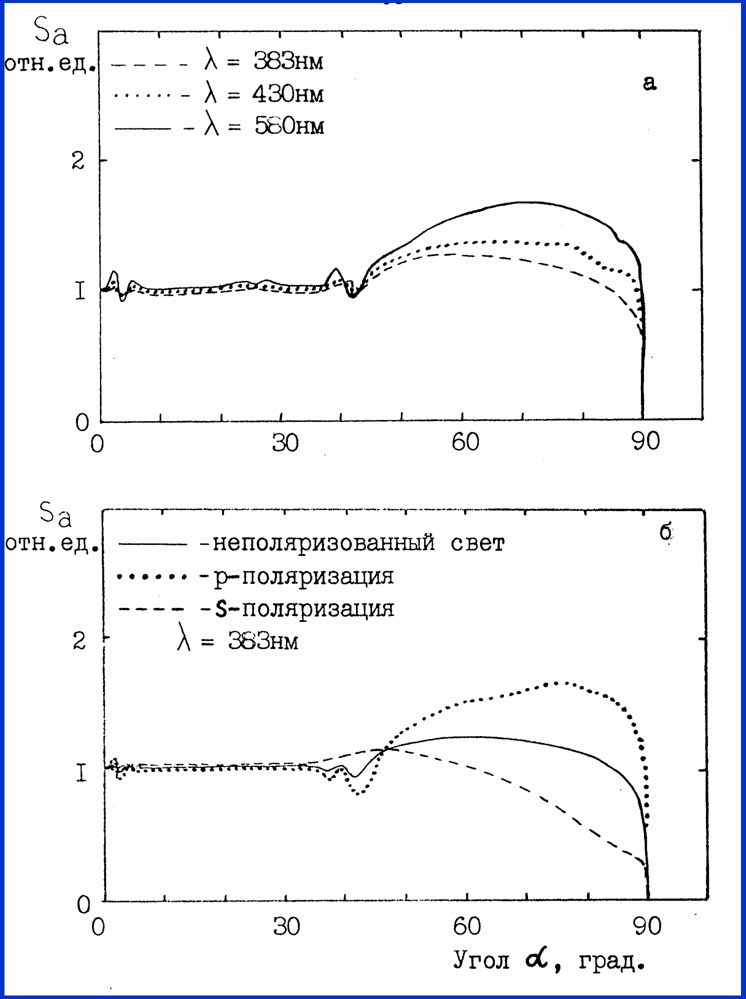


A.Braem et al. NIMA 570 (2007) 467
Photonis measurements

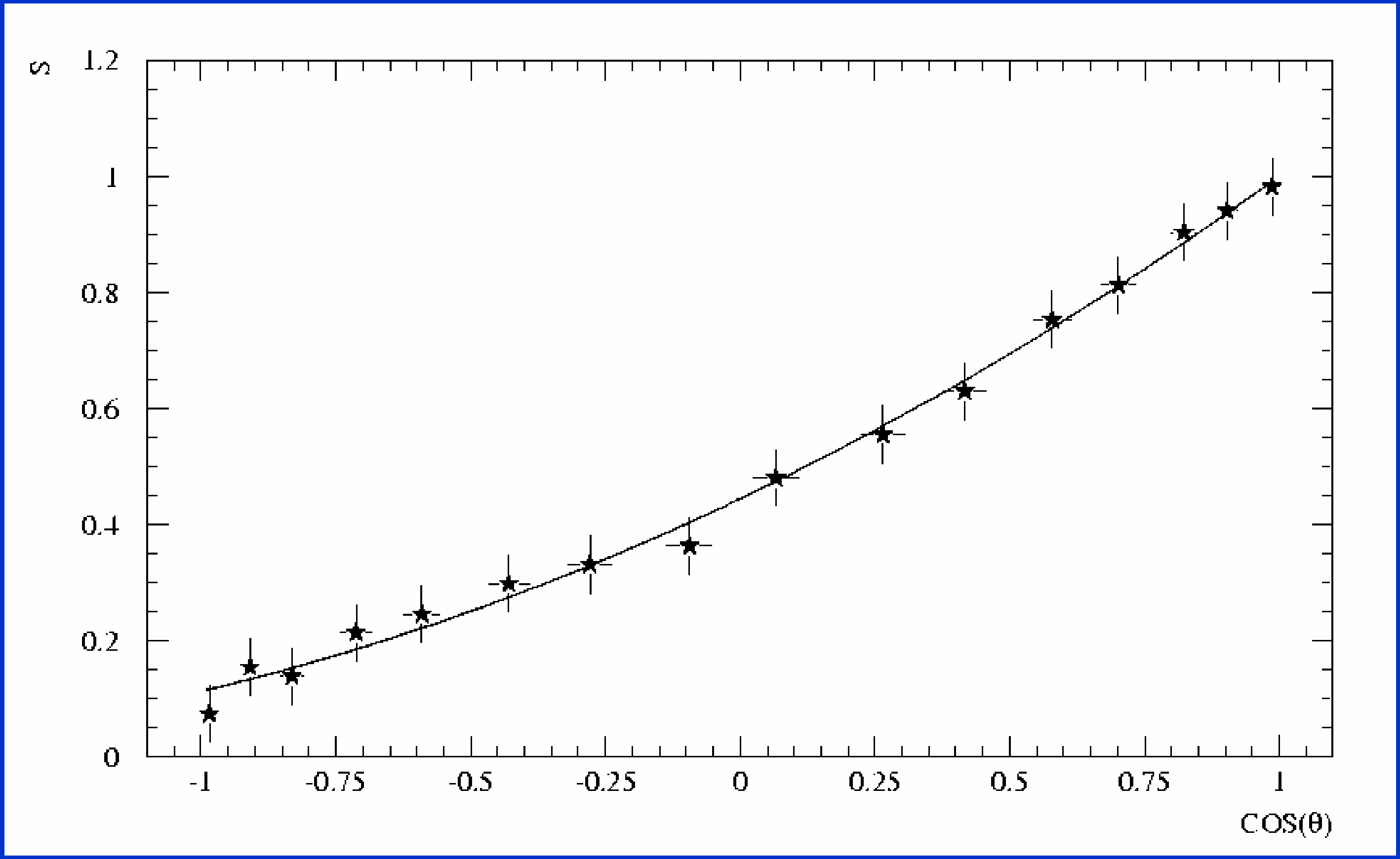
1987-1990 XP2600 30-50% effect
Quasar-370 - 10-20%

XP2600 and Quasar-370 sensitivity vs photons incident angle

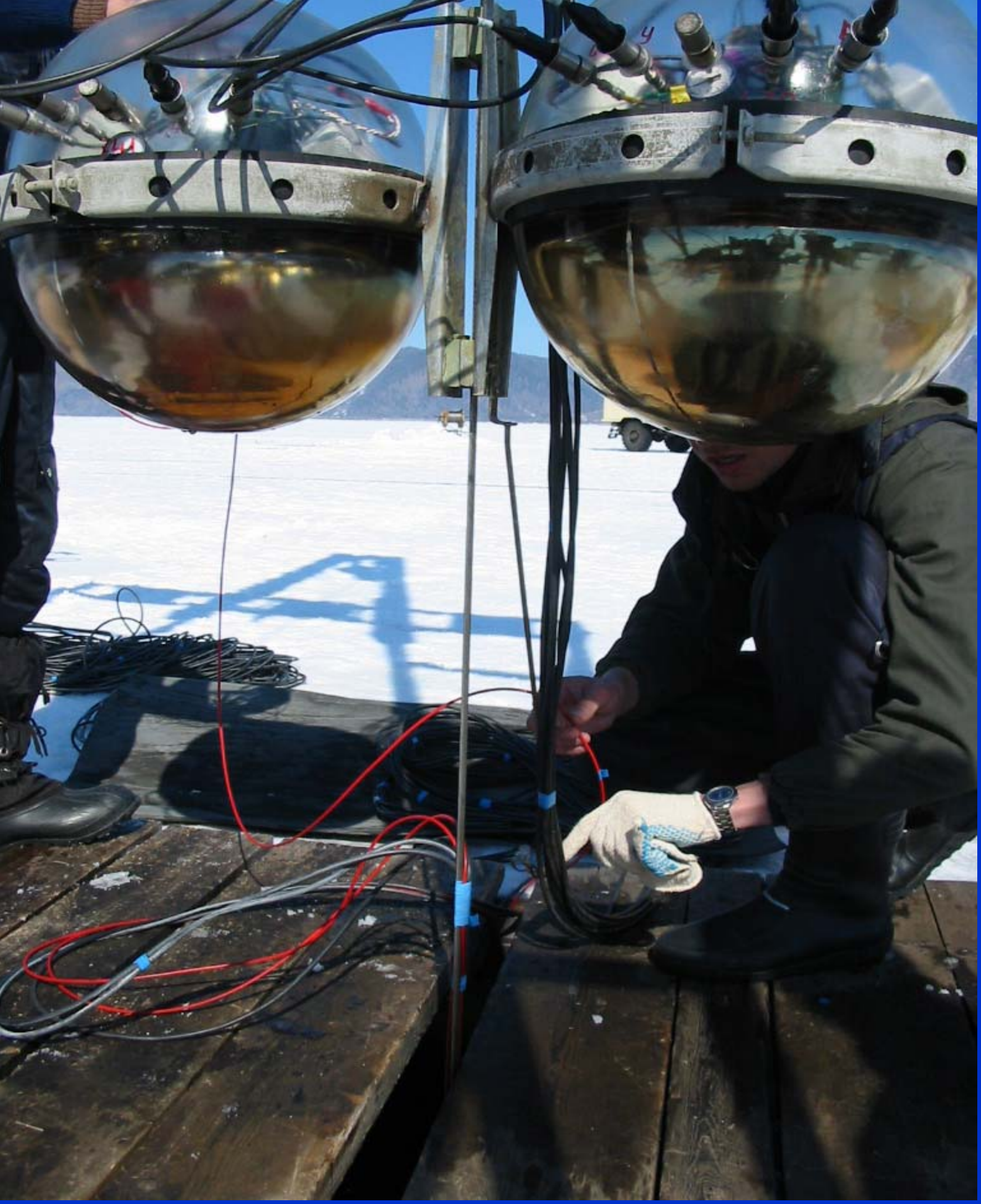


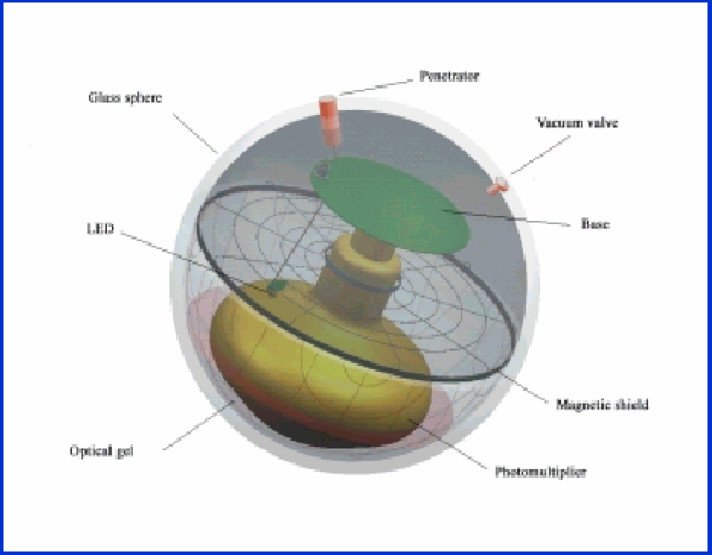


OM's response to plane wave vs incident angle of plane wave



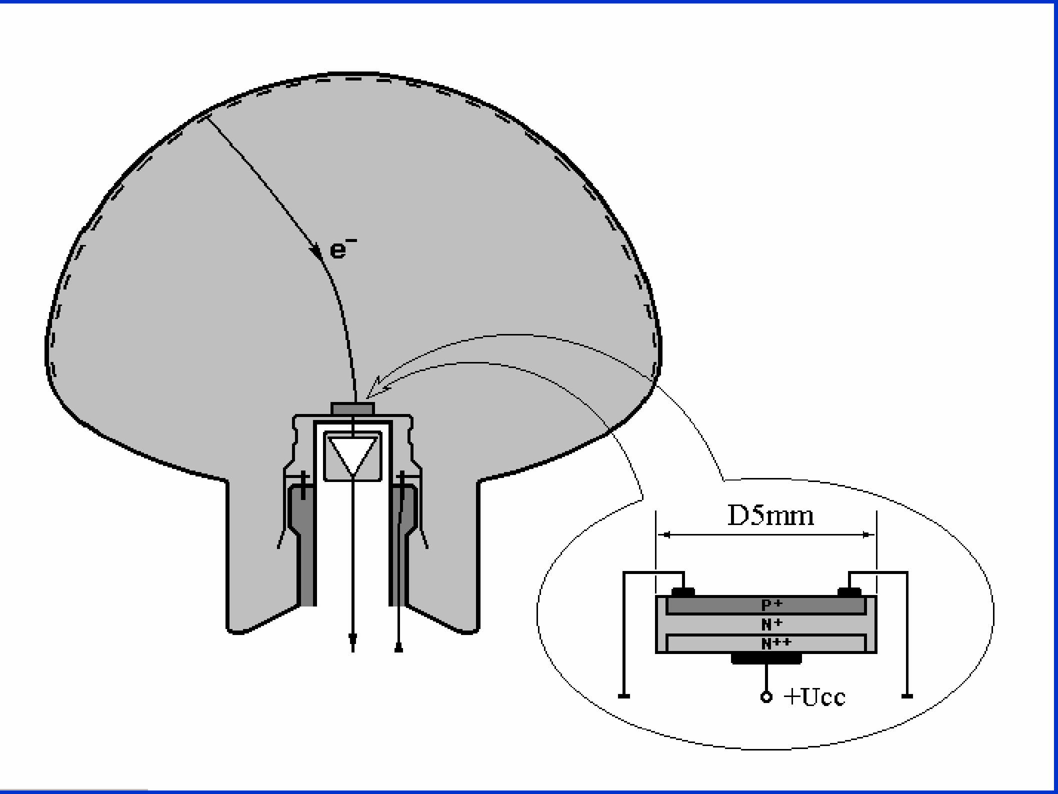
Quasar-370 - ~2000 cm**2
R7081 - ~500 cm**2





Quasar-370D

1995-1997 ICRC1997, COMO2001



- high mechanical precision
- diode protection
- terr. magnetic field infl.

The quest for the ideal scintillator for Quasar-370 like tubes

Requirements:

- Hight light yield
- Fast emission kinetics
- vacuum compatibility
- compatibility with phocathode manufacturing procedure: high temperature, aggressive chemical atmosphere etc.

Scintillators must be:

Inorganic scintillators

Nonhygroscopic?

Time resolution of hybrid phototubes and scintillator parameters

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

G - the first stage amplification factor

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

$G \sim Y(E_e)$

Y - scintillator light yield

τ - scintillator decay time

Figure of merits - F

$$F_1 = (Y/\tau)\times a$$

$$F_2 = (Y/\tau)\times a\times b$$

Y - light yield, τ - decay time,

a - detectibility by small PMT or SiPM

b - compatibility with photocathode manufacturing

	YSO	YAP	SBO	LSO	LS	Bril350	Bril380
F_1	1	1.3	1.3	1.8	4*	4.6	6.4
F_2	1	1.3	1.3	1.8	4*	0?	0?

* - using a photodetector with A3B5 photocathode

ZnO:Ga

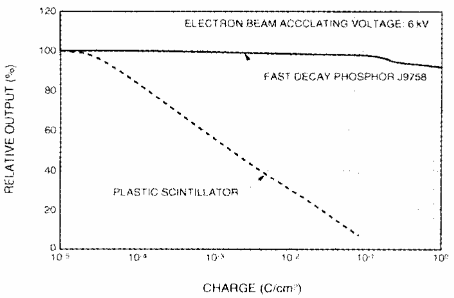
$$F1 = F2 = 250!$$

Challenge:

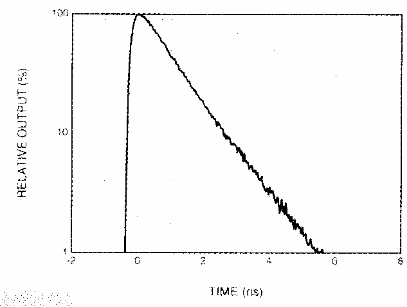
- the material should be extremelly pure
- problems with monocrystal growth but phosphor will be O'K for luminescent screen

Hamamatsu J9758 phosphor, τ~1ns, Y ~3 Y(YAP)

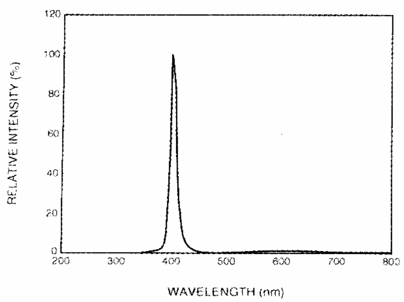
Phosphor life characteristics



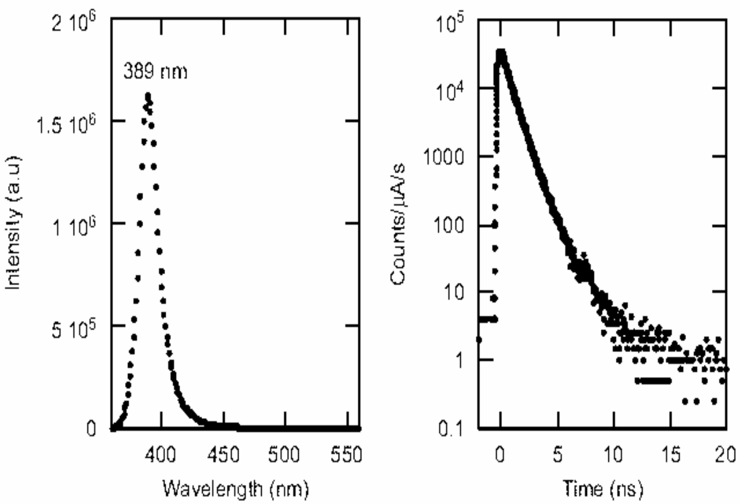
Phosphor decay characteristics



Phosphore spectral emission characteristics



ZnO(Ga)



Hamamatsu news 2006, pp18-19

E.D.Bourret-Courchesne et al. NIMA

Conclusions

What is the ideal photodetector for the next generation neutrino telescopes?

Spherical (up to 50 cm dia) with >2π angular acceptance

High sensitivity in a wider region than conventional bialkali cathode

High effective quantum efficiency - good SER

Time resolution - ~3-4 ns (fwhm)

Quasar-370 like tubes are very good competitor to HPDs with diodes

Cheap manufacturing cost, higher gain, simpler in operation etc.

good prospects for further developments

cheap production?

CLOSE TO THE IDEAL VACUUM PHOTODETECTOR? (Eilat 2006)

YES!!!

Photonis and INR collaboration on smart tube R&D is currently underway


Ф1
МГ-390