Revisiting the optimum PMT size for water-Cherenkov megaton detectors

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Overview

- PHOTONIS
- Physics is challenging
- Traditional PMTs
- Optimal size <=> cost
- Capacity & investments
- Sub-conclusions
- Discussion
- R&D prospects

1937
PHILIPS BRIVE

1963
HYPERELEC

1986
RTC Compelec

1990
PHILIPS
COMPONENTS

1992
PHILIPS
PHOTONICS

1998
PHOTONIS

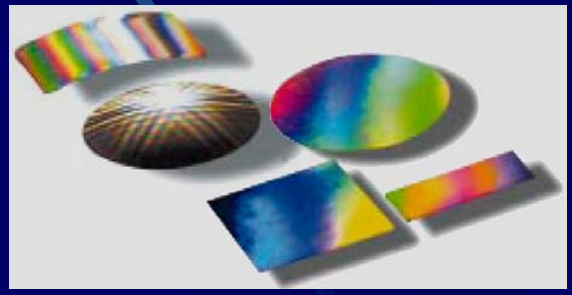
2005
PHOTONIS-DEP

PHOTONIS

- ***Photomultipliers***
- ***Image intensifiers***

PHOTONIS-DEP
image intensifiers

- **Streak tubes**
- **Microchannel plates**
- **Single-channel electron multipliers**
- **Neutron detectors**



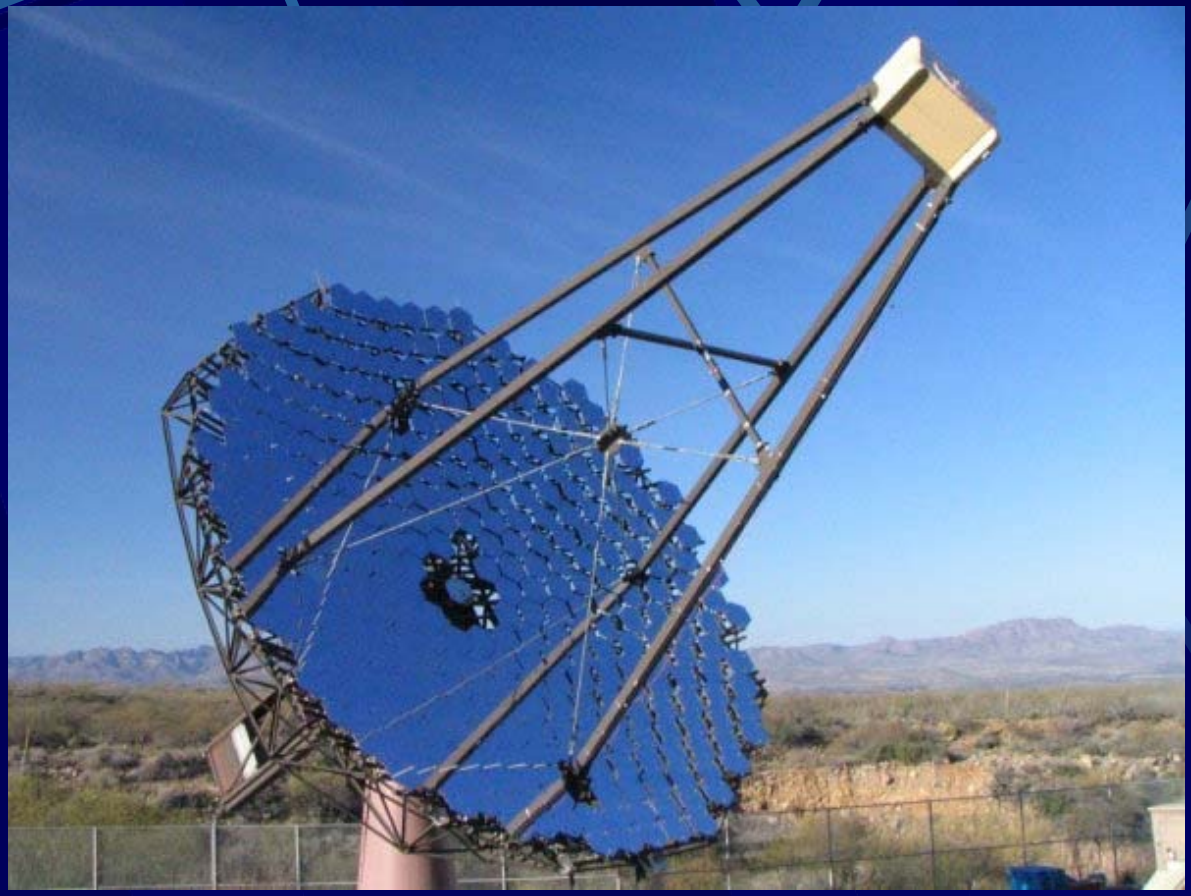
PMTs

- Nuclear medicine (~80%)
  - gamma cameras
  - PET scanners
- Analytics/industrial (~10%)
- Physics (~10%)

H.E.S.S. in Namibia

(very-low after-pulse PMT)

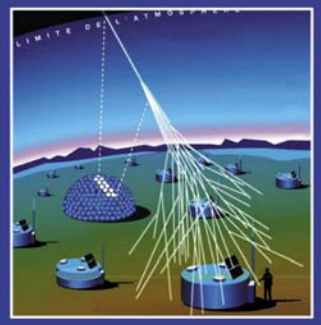
Veritas in Arizona



Pierre Auger Observatory

The World's Largest Cosmic Ray Detector

Southern site: Malargüe, Argentina
3000 km² detector



Hybrid Detection

4 air fluorescence detectors
detection of fluorescence induced by cosmic-ray air showers in the atmosphere

24 to 30 cameras each with 440 XP3062 tubes

array of Cherenkov water tanks
detection of air-showering particles reaching the ground

1600 tanks spaced 1.5 km apart, each with 3 XP1805 tubes

Courtesy of Auger collaboration

Auger in Argentina

Photonis

Traditional PMTs

Hemispherical

5“, 8“, 9“,

10.6“, 12“, 15“

Very many PMTs

Example: UNO >50,000x 20“

- ***PMT size <=> cost***
  - Embedded inside water volume
  - Sensitivity
  - Timing
  - SE pulse-height resolution
  - Granularity

PMT size <=> cost

• Diameter	20“	<=>	(20“)17“	<=>	12“	
• projected area	1660		1450		615	cm²
• QE(typ)	20		20		24	%
• CE	60		60		70	%
• Cost	2500		2500		800	€

- *Cost/cm² per useful PE_U* = cost/(cm² x QE x CE)

12.6 **14.4** **7.7** **€/PE_U/cm²**

Timing-Weight

Size	20“	17“	12“
Rise time (ns)	10	6	5
Jitter (ns)	5.5	3.4	2.4
Weight (kg)	8	8	2.2

Single-electron resolution

Need good P/V for exact gain calibration:

- **20“ difficult? (P/V = 1.1 - 1.7:1)**
- **17“ P/V = 1.5 - 2.5:1 (reality better)**
- **12“ P/V = 1.5 - 2.3:1 (reality better)**

Quantities and total cost

- 20“ ***50,000*** x € 2500 = € 125M
- 17“ 57,200 x € 2500 = € 143M
- 12“ 135,000 x € 800 = € ***108M***

New pump capacity needed?

- Delivery over 6 years
- 300 working days/year
  - *20“ tube*

    50,000/6/300 => 28 good tubes x yield 0.7 = 40 starts/day

    (1 start/pump/day) => 40 pumps (€ 7M or so)
  - *12“ tube*

    135,000/6/300 => 75 good tubes x yield 0.7 = 110 starts/day.

    A multi-array computerised pump at Photonis handles 20 starts/day

    => 6 pumps (€ 2M or so)

+ Sub-conclusions

12“ seems much better than 20“/17“

- *cost per useful photoelectron & total PMT cost*
- *timing*
- *single-electron resolution (17“ equal)*
- *granularity*
- *weight and handling*
- *implosion risk*
- *investments and start-up*

- Sub-conclusions

- *cost of more cables and electronics*
- *12“ tubes may also need a shield at 60 m depth (or thicker glass?)*

Discussion

- The 12“ tube is a cost-optimum for Photonis pumping systems - maybe other cost-optima in 8“ - 15“ for other suppliers?
- Can be made by at least 4 suppliers - without major R&D!

- Photonis is willing, able and prepared up to 15“
- However, ***non-industry*** investments needed!

Optimise!

Cost/cm² per useful PE_U=

cost/(**cm²xQExCE**)

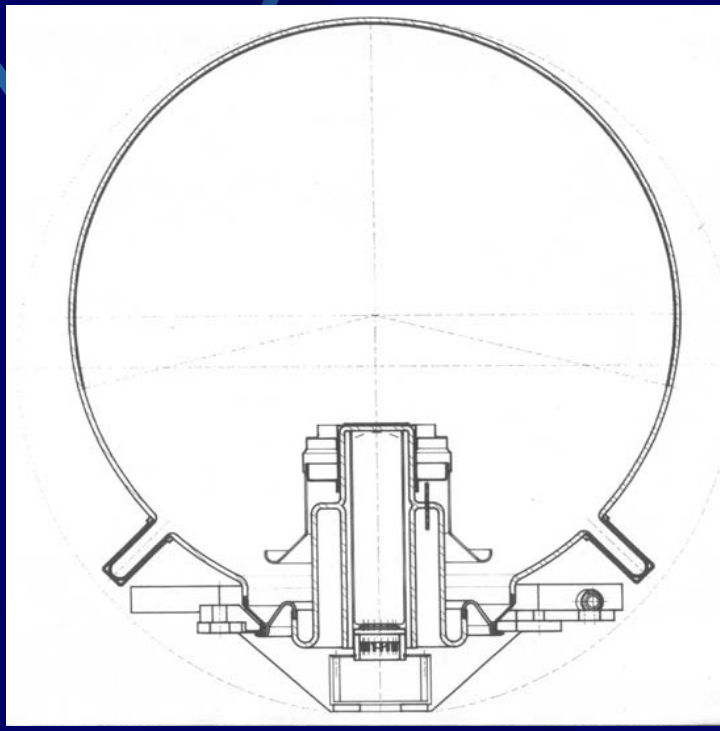
Invest in QE now!

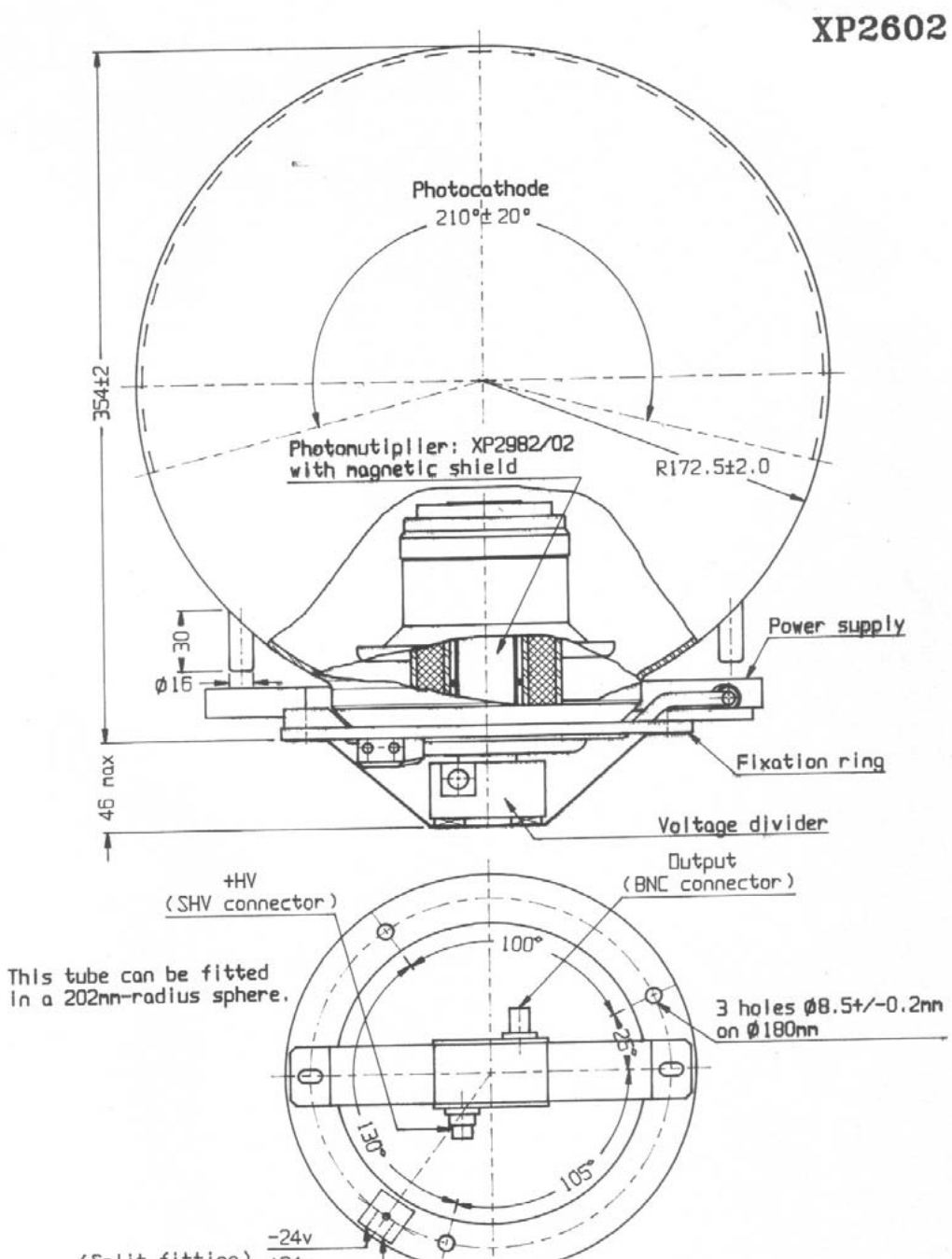
- Instead of investing € 7M (or so) for 20“ it is better to
  - invest € 2M (or so) for 12“ and
  - *another* ***€ 0.5M in getting the QE up to > 30 %***
- Photonis has such a QE programme
- Characterisation with French institutes

„Smart“ PMTs so far

- „smart“ => PHR => elimination of single PE noise (for DUMANDs)
- Patented by Philips (Photonis)
- Copied (faster mushrom shape) by INR, Moscow, into the „QUASAR“

Philips (spherical)

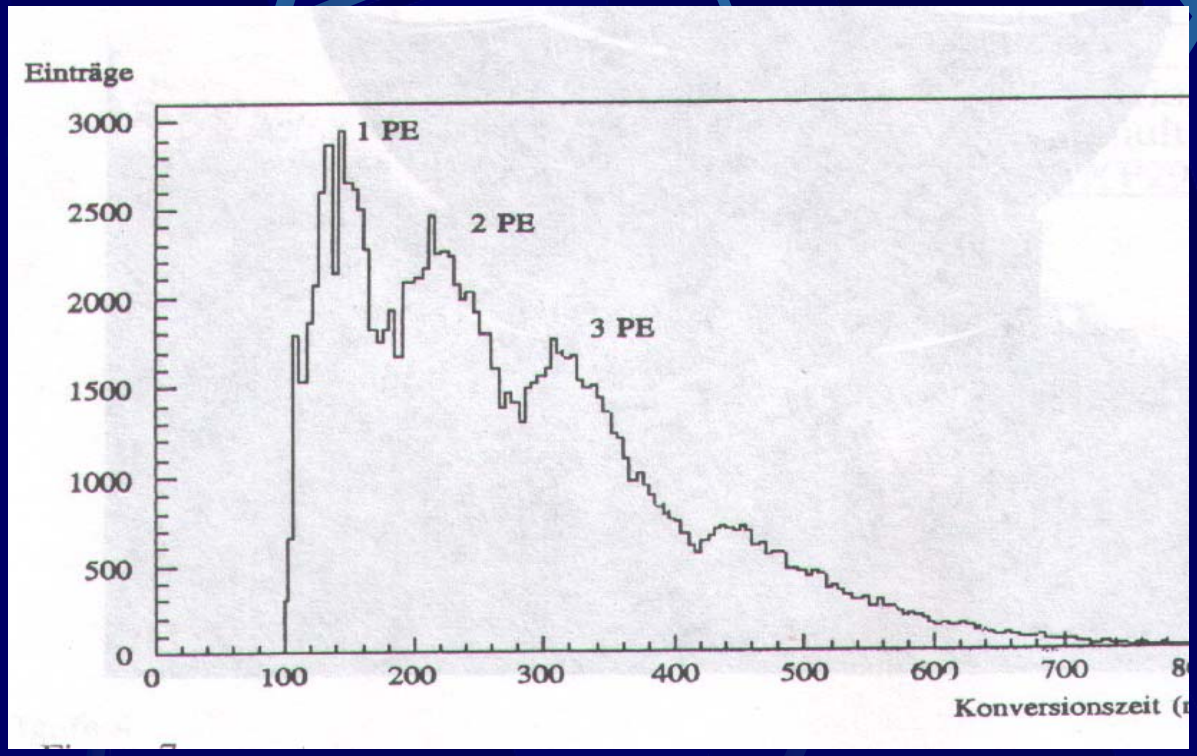




- anode target was YSO single-crystal at +25-30 kV
  =>
- *photocathode at ground potential!*

- partly sensitive from the back

Pulse-height resolution



S/N 8 & 10 deployed in Lake Baikal

Status „smart“ PMTs

- Philips/Photonis made ~ 30; invested 1M €!
- 200 QUASARs operating for many years in Lake Baikal
  => *proof of concept as to life time!*
- No ongoing production!
- Could be made (and improved) again!

Possible „smart“ PMTs

- Reproduce and improve former tubes
- Redesign (target)
  - Better scintillator (LSO, ZnO:Ga, ...)
  - Si diode/Si diode array
  - APD/APD array
  - Multianode multiplier
  - Quadrant PMT (inside/outside)
  - ??

On-going R&D

„smart“ 8 => 12“ tubes with:

- *electron-bombarded scintillator in a preamplifier tube, read-out by a small, fast PMT*
- *electron-bombarded Si diode as the anode*

Both will resolve 1, 2, 3, several photoelectrons but - need to stand > 15 - 20 kV

*Is such „smartness“ worth a factor **2-3** in cost?*

Photonis has all the technical capability needed!

R&D cooperation: detailed & intensive talks are going on with the MEMPHYS collaboration to define a balanced programme

Workshop planned in the spring

Questions?