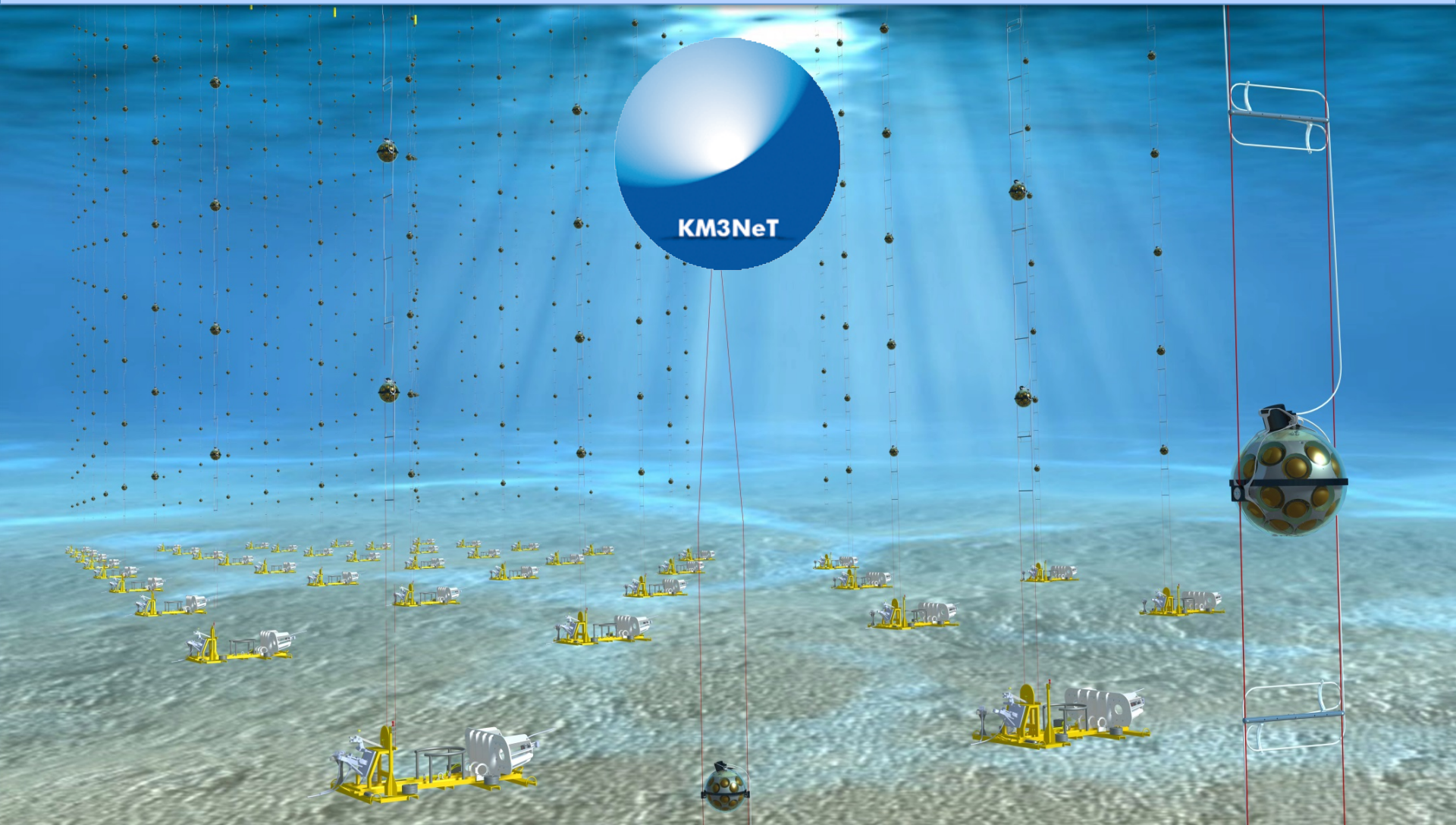


The KM3NeT DOM and PMTs



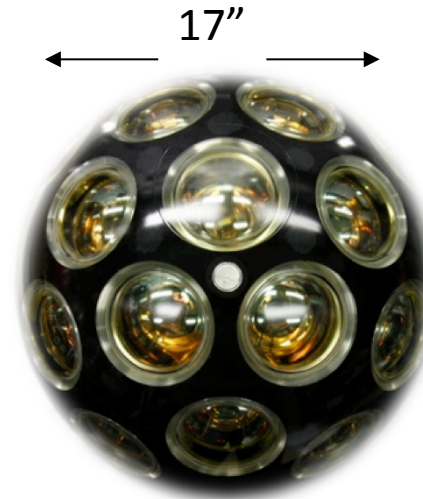
7th Open HK meeting
Queen Mary University
11 July 2016

Paschal Coyle
Centre de Physique des Particules de Marseille

Building Block (115 strings)

- **115** strings
- **18** DOMs / string (**~50 kt ~ 2 × SK**)
- **31** PMTs / DOM (**~3 kt ~ MINOS**)
- Total: **64k*3"** PMTs

Digital Optical Module

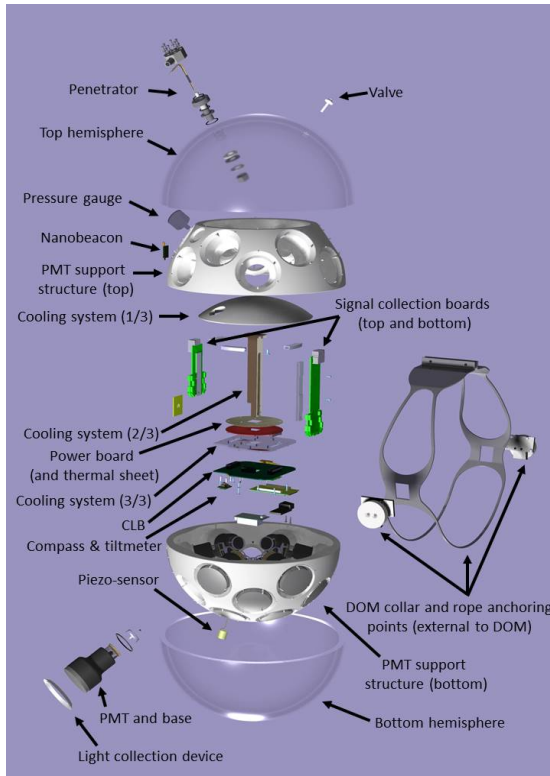


- 31 x 3" PMTs
- Uniform angular coverage
- Directional information
- Digital photon counting
- Background rejection
- All data to shore

Depth=2475m/3400m

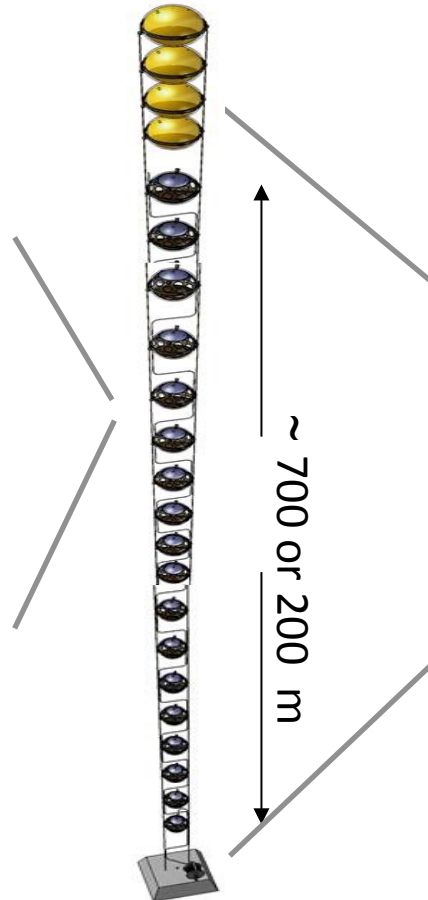
KM3NeT Technology

Digital Optical Module



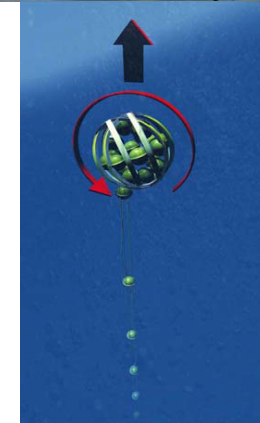
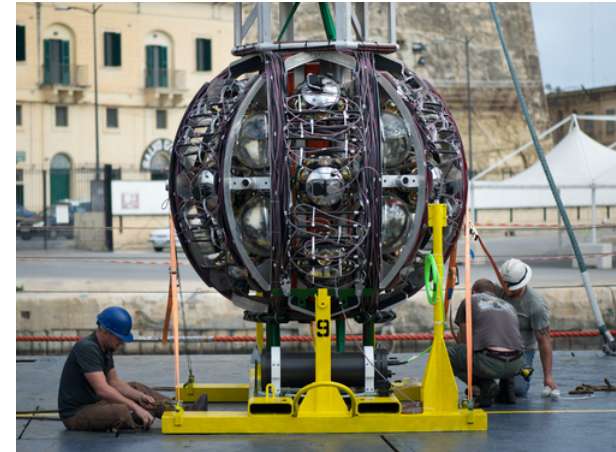
- 31 x 3" PMTs
- Gbit/s on optical fibre
- Hybrid white rabbit
- LED flasher & acoustic piezo
- Tiltmeter/compass
- Low power (7 W)

String



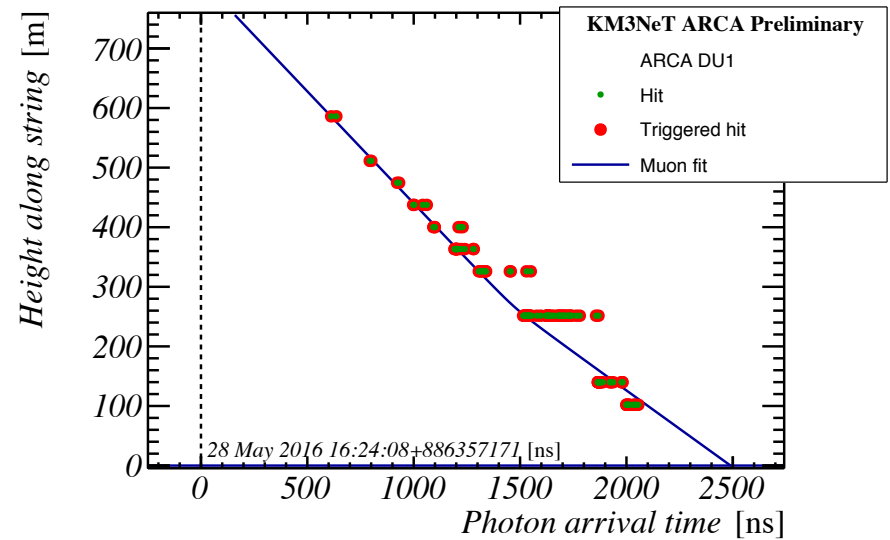
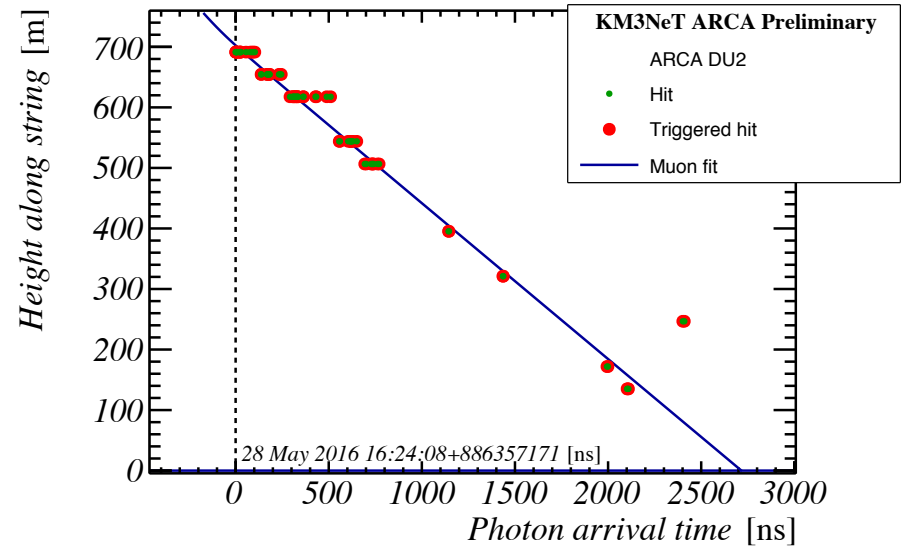
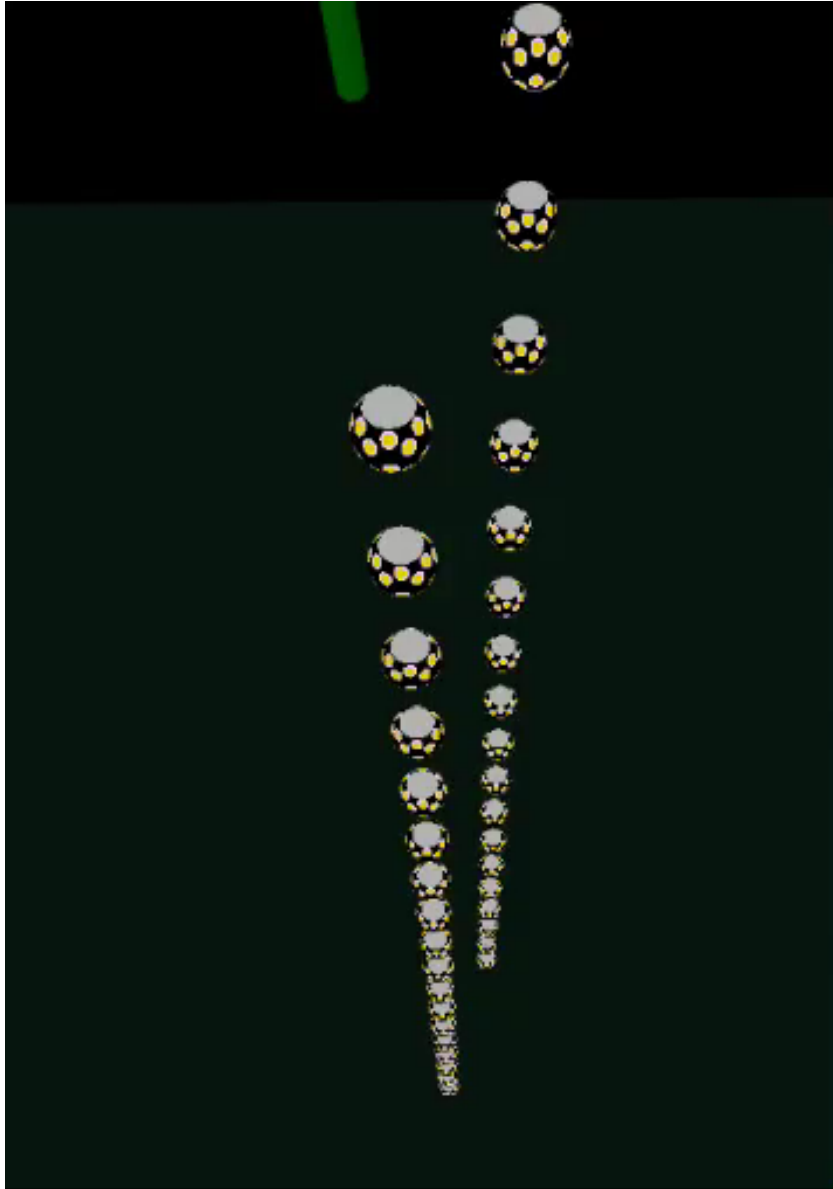
- 2 dyneema ropes
- Oil filled PVC tube
- Low drag
- Low cost

Deployment Vehicle



- Rapid deployment
- Multiple strings/cruise
- Autonomous/ROV unfurling
- Reuseable

Two String Event (ARCA)



KM3NeT Development Plan

Phase	Blocks/ strings	Primary deliverables / site(s)	PMTs needed
1	0.2/ 31	Proof of feasibility and first science results; KM3NeT-Fr + KM3NeT-It sites	18,000
2.0	2/ 230	Measurement of neutrino signal reported by IceCube; All-flavor neutrino astronomy; KM3NeT-It site	+175,000
	1/ 115	Neutrino mass hierarchy; KM3NeT-Fr site	
3	6+1/ 805	Neutrino astronomy including Galactic sources Multiple Sites	+385,000

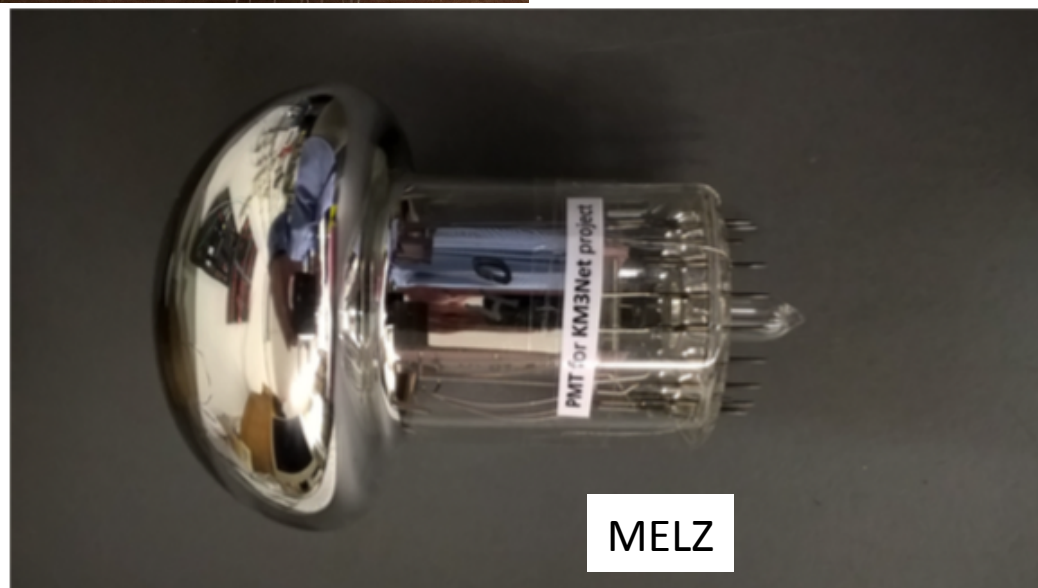
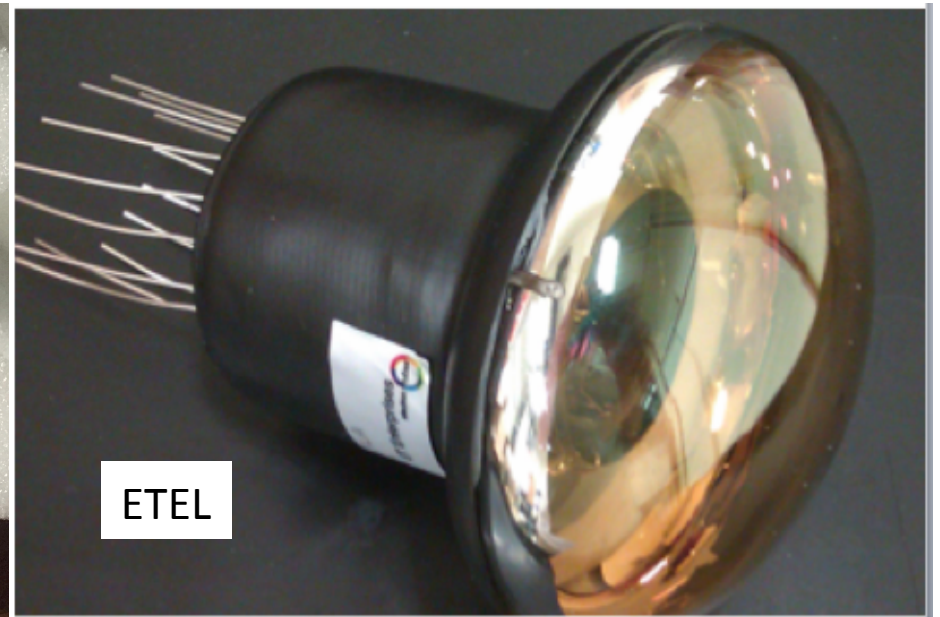
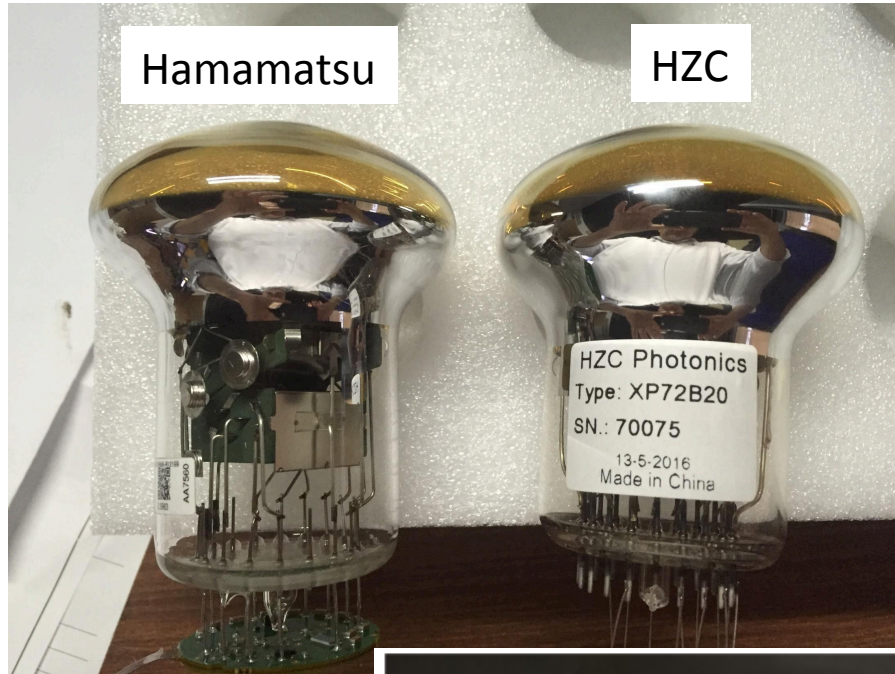
PMT specifications

Parameter	Requirement
Photocathode diameter	> 72 mm
Nominal Voltage for Gain 3×10^6	900 – 1300 V
Gain slope = $\log_{10}(\text{gain})/\log_{10}(\text{HV})$	6.5 – 8.0
QE at 404 nm	> 23 %
QE at 470 nm	> 18 %
TTS (FWHM)	< 5 ns
Dark count rate (0.3 p.e. threshold)	< 2 kHz
Pre-pulses	< 1 %
Delayed pulses	< 3.5 %
Early afterpulses	< 2 %
Late afterpulses	< 10 %

PMTs for KM3NeT

- Phase I
 - 15000 PMTs have been purchased from Hamamatsu
 - Each PMT is equipped with an active base (developed @NIKHEF): it provides the correct HV (going from 3.3 V to about 1000 V), set the threshold and provides the Time over Threshold (ToT) for the measured signal
 - Each single PMT is fully characterized and calibrated (see next slide): about 97% of the tested PMTs fulfils the requirements
- Phase II
 - We are working with several companies (ETEL, Hamamatsu, HZC/Photonis, Melz) in order to improve the Signal/Costs ratio.
 - Preliminary results are very encouraging

PMT pictures



FEATURES

- High Gain
- $\phi 80$ mm hemisphere

APPLICATIONS

- High Energy Physics

SPECIFICATIONS

GENERAL

Parameter		Description / Value	Unit
Spectral Response		300 to 650	nm
Wavelength of Maximum Response		420	nm
Window Material		Borosilicate glass	—
Photocathode	Material	Bialkali	—
	Minimum Effective Area	$\phi 72$	mm
Dynode	Structure	Circular and linear-focused	—
	Number of Stages	10	—
Base		JEDEC No. B14-38	—
Operating Ambient Temperature		-30 to +50	°C
Storage Temperature		-30 to +50	°C
Suitable Socket		E678-14W (Sold separately)	—

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter	Value	Unit
Supply Voltage	Between Anode and Cathode	1500
	Between Anode and Last Dynode	300
Average Anode Current	0.1	mA

CHARACTERISTICS (at 25 °C)

Parameter	Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2856 K)	60	100	$\mu\text{A/lm}$
	Radiant at 420 nm	—	80	mA/W
	Blue Sensitivity Index (CS 5-58)	7	10	—
	Quantum Efficiency at 390 nm	—	25	%
Anode Sensitivity	Luminous (2856 K)	—	500	A/lm
	Radiant at 420 nm	—	4.0×10^5	A/W
Gain	—	5.0×10^6	—	—
Anode Dark Current (After 30 minute storage in darkness)		50	400	nA
Time Response	Anode Pulse Rise Time	—	3.6	ns
	Electron Transit Time	—	43	ns
	Transit Time Spread (FWHM)	—	4.5	ns

NOTE: Anode characteristics are measured with a voltage distribution ratio and supply voltage shown below.

VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	P
Ratio	3	1	1	1	1	1	1	1	1	1	1	1
Supply Voltage: 1000 V, K: Cathode, Dy: Dynode, P: Anode												



PHOTOMULTIPLIER TUBE R12199

Figure 1: Typical Spectral Response

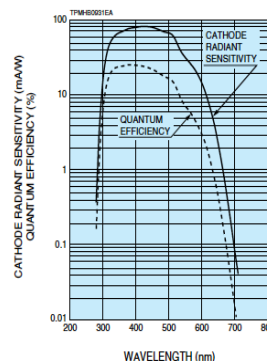


Figure 2: Typical Gain

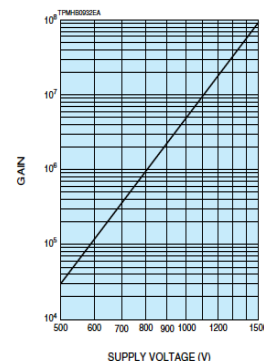


Figure 3: Typical Dark Current

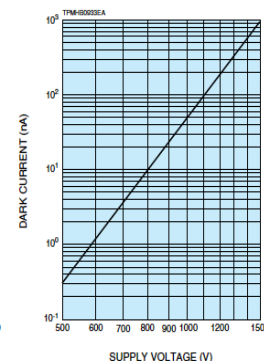
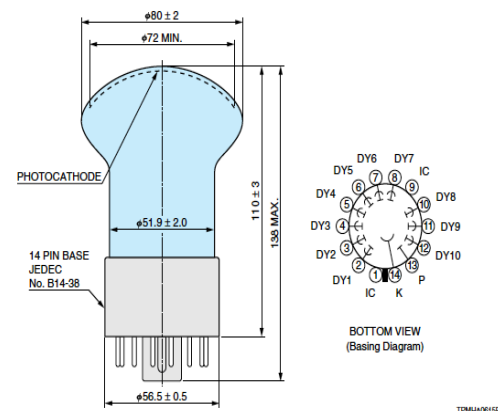


Figure 4: Dimensional Outline and Basing Diagram (Unit: mm)



* HAMAMATSU also provides C11152 series compact high voltage power supply modules.

HAMAMATSU PHOTONICS K.K. www.hamamatsu.com

HAMAMATSU PHOTONICS K.K., Electron Tube Division

314-5, Shimokanzo, Iwata City, Shizuoka Pref., 438-0193, Japan, Telephone: (81)539/62-5248, Fax: (81)539/62-2205

U.S.A.: Hamamatsu Corporation, 360 Foothill Road, Bridgewater, N.J. 08807-0910, U.S.A., Telephone: (1)908-231-0960, Fax: (1)908-231-1218 E-mail: usa@hamamatsu.com

Germany: Hamamatsu Photonics Deutschland GmbH, Arzbergerstr. 10, D-82211 Hirsching am Ammersee, Germany, Telephone: (49)8152-375-0, Fax: (49)8152-3658 E-mail: info@hamamatsu.de

France: Hamamatsu Photonics France S.A.R.L., 19, Rue de la Gare, 91882 Massy Cedex, France, Telephone: (33)1 69 53 71 00, Fax: (33)1 69 53 71 10 E-mail: info@hamamatsu.fr

United Kingdom: Hamamatsu Photonics UK Limited, 2 Howard Court, 10 Tewin Road, Welwyn Garden City, Hertfordshire AL7 1BW, United Kingdom, Telephone: (44)1707-294888, Fax: (44)1707-325777 E-mail: info@hamamatsu.co.uk

North America: Hamamatsu Photonics Norden AB, Torshamnsgatan 35 SE-164 40 Kista, Sweden, Telephone: (46)8-509-031-00, Fax: (46)8-509-031-01 E-mail: info@hamamatsu.se

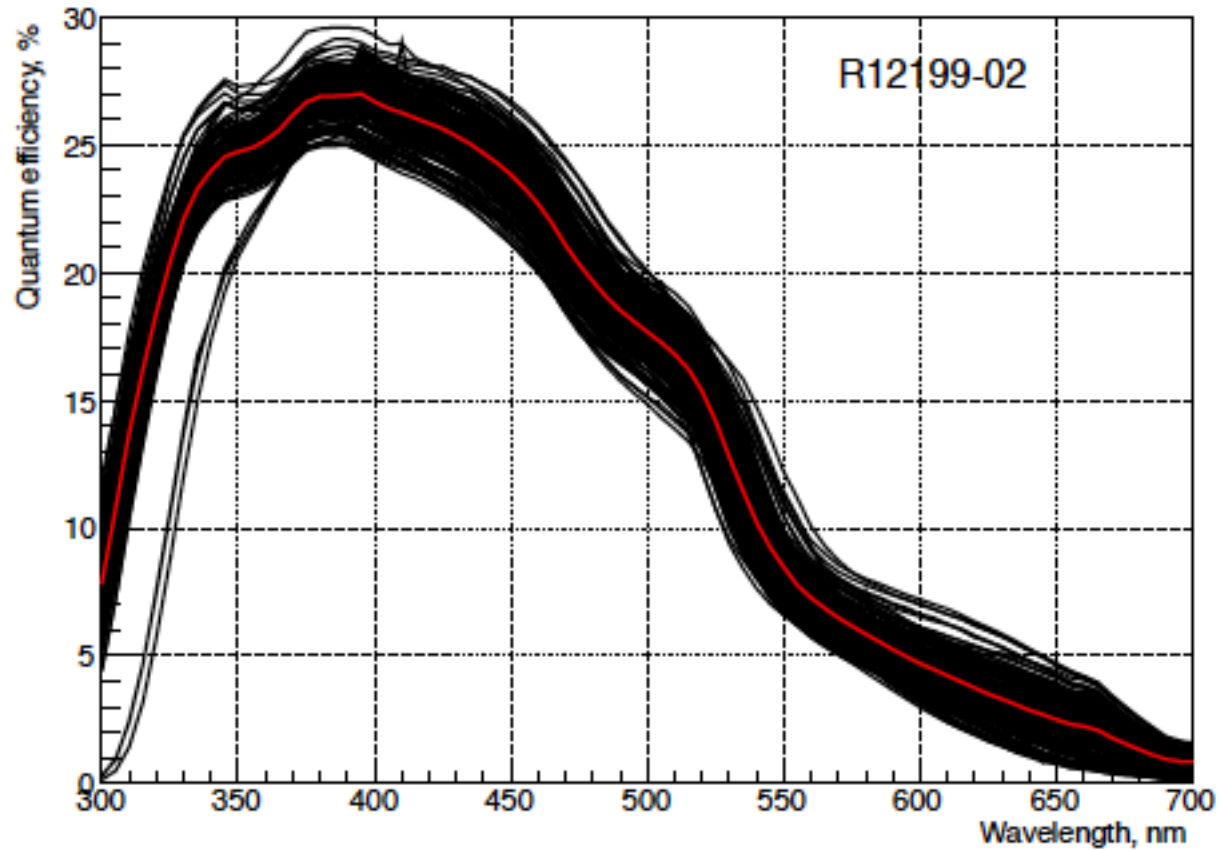
Italy: Hamamatsu Photonics Italia S.r.l., Strada della Mota, 1 Mt. 6, 20020 Anese (Milano), Italy, Telephone: (39)02-95581733, Fax: (39)02-95581741 E-mail: info@hamamatsu.it

China: Hamamatsu Photonics (China) Co., Ltd., B1201 Jiaxing Center, No.27 Dongqianhuo Street, Chaoyang District, Beijing 100020, China, Telephone: (86)10-6586-6008, Fax: (86)10-6586-2966 E-mail: hpc@hamamatsu.com.cn

Subject to local technical requirements and regulations, availability of products included in this promotional material may vary. Please consult with our sales office. Information furnished by HAMAMATSU is believed to be reliable. However, no responsibility is assumed for possible inaccuracies or omissions. Specifications are subject to change without notice. No patent rights are granted to any of the circuits described herein. ©2015 Hamamatsu Photonics K.K.

TPMH1356E01
JUL. 2015 IP

Hamamatsu QE



Each single PMTs is tested and calibrated. 120 PMTs are tested daily



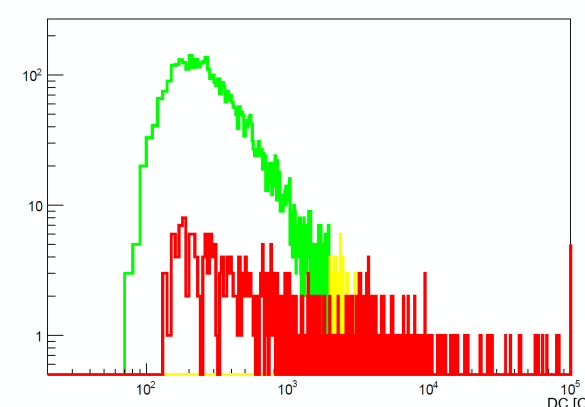
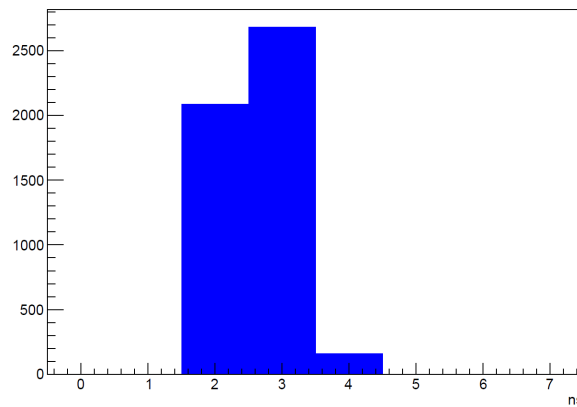
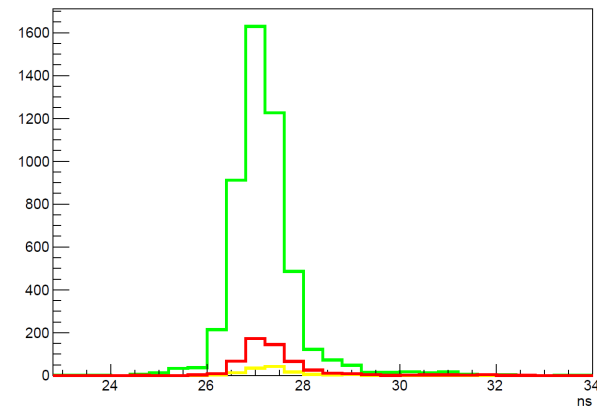
DarkBox developed @INFN-Napoli



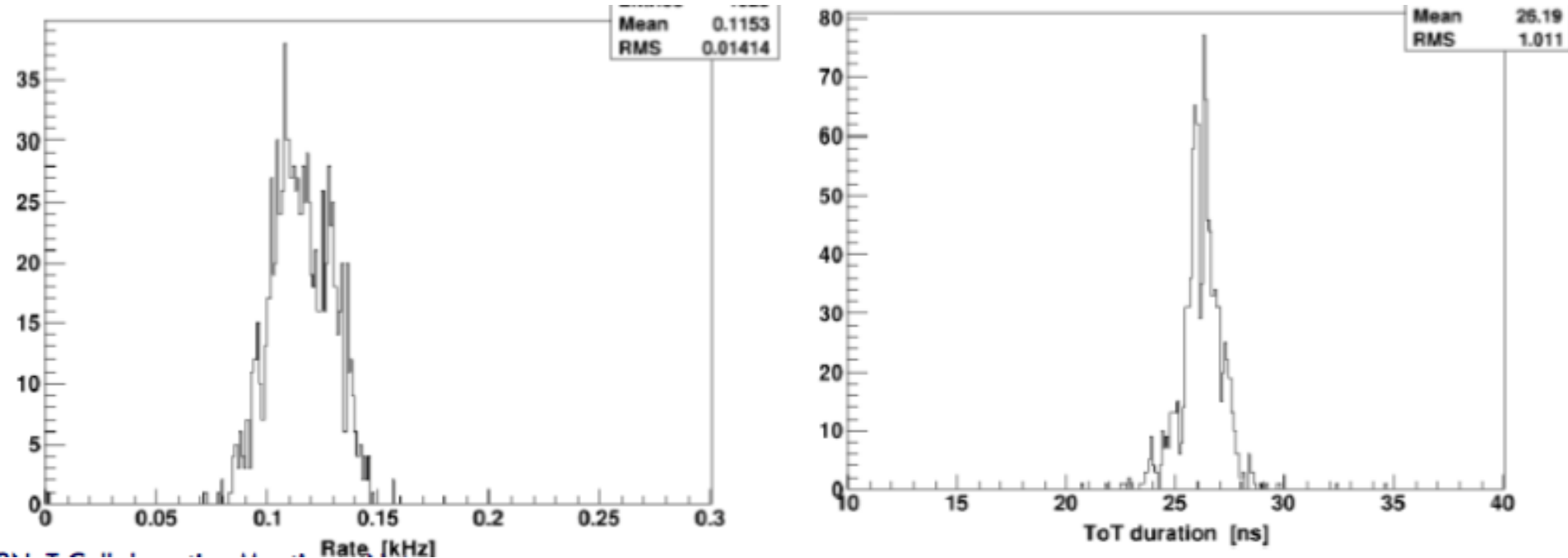
ToT

Transit Time Spread (FWHM)

Dark Rate



Underwater PMT performance (very preliminary)



Measured rates, by using ^{40}K events, for L1 triggers and ToT as measured with PMTs (1054 in total) installed onto the DOMs presently taking data at 3500 m underwater.

There is a good uniformity among the different channels

Photomultiplier Preliminary XP82B20 Photomultiplier

XP82B20

10-stage
88mm (3.5"), Round tube

Application

- ✓ High energy physics

Features

- ✓ High Quantum Efficiency
- ✓ Low profile

Description

Window material	Borosilicate low K
Photocathode	Bi-alkali
Refr. Index at 420nm	1.54
Multipier structure	Box and Linear focused

Photocathode characteristics

	Min	Typ	Max	Unit
Spectral range:		290-700		nm
Maximum sensitivity at		440		nm
Sensitivity:				
Luminous		110		$\mu\text{A/lm}$
Blue *	10	12		$\mu\text{A/lmF}$
Radiant, at 420 nm		110		mA/W

Characteristics with voltage divider A

	Min	Typ	Max	Unit
Gain slope (vs supp. Volt., log/log)		6.8		
For an anode blue sensitivity of		50		A/lmF
Supply voltage *	1000	1200	1400	V
Gain		3×10^6		
Anode dark current *		20	300	nA
Noise		TBD	1500	Hz

Mean anode sensitivity deviation

Long term (16h)	1	%
After change of count rate	1	%
Vs temperature between 0 and +40°C at 420 nm	-0.3	%/K

For a supply voltage of : 1000V

	Min	Typ	Max	Unit
Linearity (2%) of anode current up to		30		mA
Anode pulse:				
Rise time		3.5		ns
Duration at half height		5		ns
Transit time		49		ns
Center to edge difference (C.E.D)		1		ns
Time resolution at 511 keV with LSO		1.3		ns

Recommended Voltage Divider

Type A for maximum gain

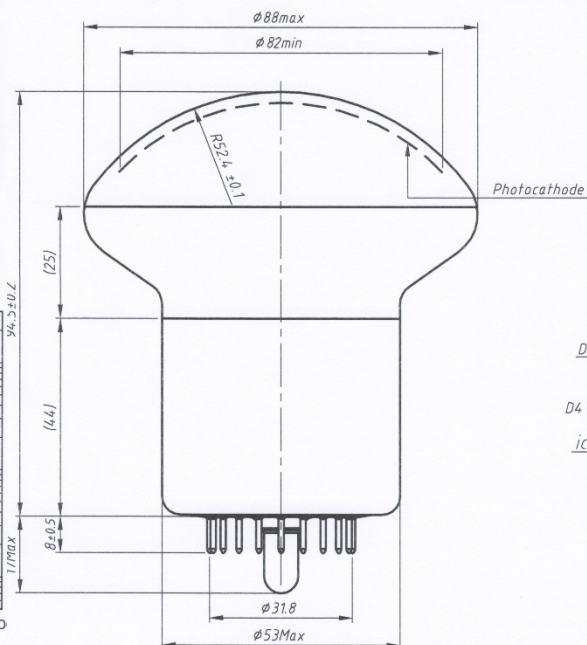
K	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	A
3	2	1	1	1	1	1	1	1	1	1	1

(total: 14)

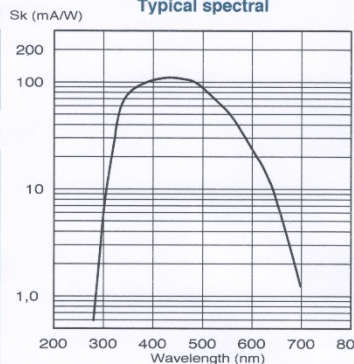
* characteristic mentioned on the test ticket of the tube



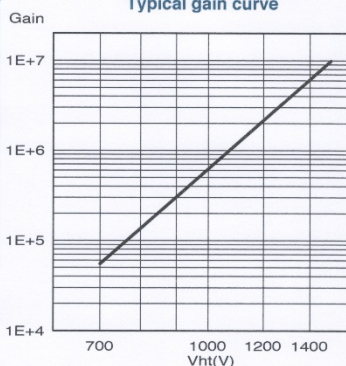
Outline (dimensions in mm)



Typical spectral



Typical gain curve



K: cathode
A: anode

sp: short pin
Dn: dynode

n: plane of symmetry of the multiplier
ic: internal connection

Limiting values

	Min	Max	Unit
Anode blue sensitivity		130	A/lmF
Supply voltage		2000	V
Continuous anode current		0.2	mA
Voltage between:			
D1 and photocathode	150	500	V
Consecutive dynode		300	V
Anode and D10	40	300	V
Ambient temperature:			
Short operation (<30 mn)	-30	+80	°C
Continuous operation & storage	-30	+50	°C

Variants

Finishing

- B with plastic base
- F with flying leads $\varnothing 0.5$
- FB with flying leads and plastic base

Option

- C with electrostatic coating (conductive paint connected to the cathode + insulating coating)

Also, other variants can be made. Please, contact us to discuss any specific product requirements.

10-stage
80mm (3.1"), Round tube

Application

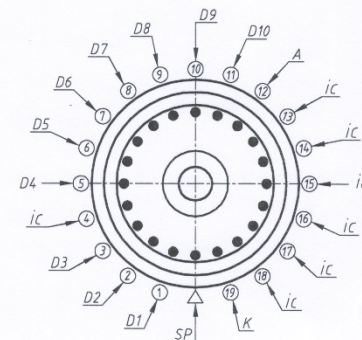
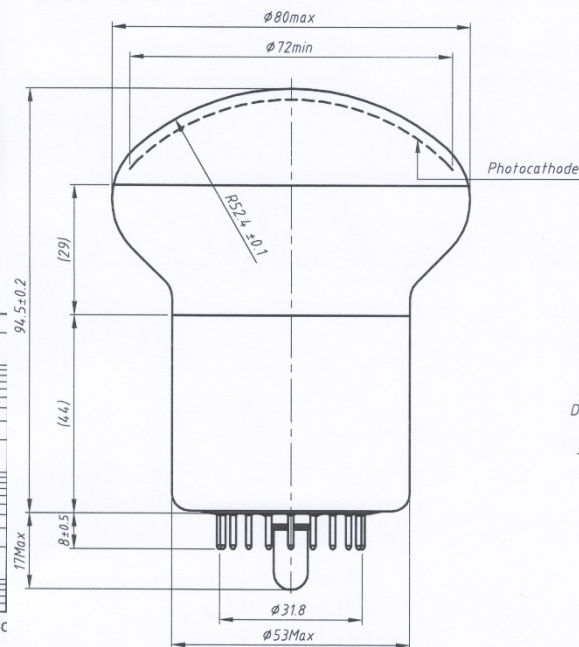
- ✓ High energy physics

Features

- ✓ High Quantum Efficiency
- ✓ Low profile



Outline (dimensions in mm)



Description

Window material	Borosilicate low K
Photocathode	Bi-alkali
Refr. Index at 420nm	1.54
Multiplier structure	Box and Linear focused

Photocathode characteristics

	Min	Typ	Max	Unit
Spectral range:		290-700		nm
Maximum sensitivity at		440		nm
Sensitivity:				
Luminous		110		μA/lm
Blue *		12		μA/lmF
Radiant, at 420 nm	10	110		mA/W

Characteristics with voltage divider A

	Min	Typ	Max	Unit
Gain slope (vs supp. Volt., log/log)		6.8		
For an anode blue sensitivity of		50		A/lmF
Supply voltage *	1000	1200	1400	V
Gain		3x10 ⁶		
Anode dark current *		20	300	nA
Noise		TBD	1500	Hz

Mean anode sensitivity deviation

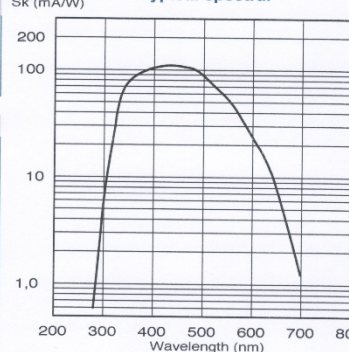
Long term (16h)	1	%
After change of count rate	1	%
Vs temperature between 0 and +40°C at 420 nm	-0.3	%/K

For a supply voltage of : 1000V

	Min	Typ	Max	Unit
Linearity (2%) of anode current up to		30		mA
Anode pulse:				
Rise time		3.5		ns
Duration at half height		5		ns
Transit time		49		ns
Center to edge difference (C.E.D)		1		ns
Time resolution at 511 keV with LSO		1.3		ns

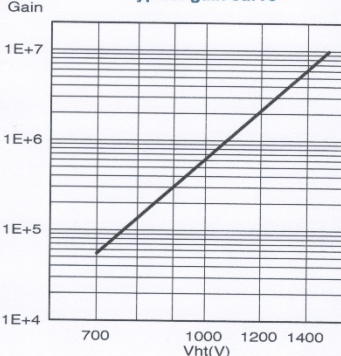
Sk (mA/W)

Typical spectral



Gain

Typical gain curve



K: cathode
A: anode

sp: short pin
Dn: dynode

n: plane of symmetry of the multiplier
ic: internal connection

Limiting values

	Min	Max	Unit
Anode blue sensitivity		130	A/lmF
Supply voltage		2000	V
Continuous anode current		0.2	mA
Voltage between:			
D1 and photocathode	150	500	V
Consecutive dynode		300	V
Anode and D10	40	300	V
Ambient temperature:			
Short operation (<30 mn)	-30	+80	°C
Continuous operation & storage	-30	+50	°C

Variants

Finishing

- B with plastic base
- F with flying leads $\varnothing$ 0.5
- FB with flying leads and plastic base

Option

- C with electrostatic coating (conductive paint connected to the cathode + insulating coating)

Also, other variants can be made. Please, contact us to discuss any specific product requirements.

Type A for maximum gain

K	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	A
3	2	1	1	1	1	1	1	1	1	1	1

(total: 14)

* characteristic mentioned on the test ticket of the tube

Datasheets HZC Photonis

3.1" HZC/Photonis

XP72B20	Reference	#1	#2	#3	#4	#5	#6
QE@404nm	25	26	26	26,8	26	25,5	25,1
QE@470	18	19,4	19,4	20,7	20,2	19,7	18,8
HV@3x106	900-1300	1231	1129	1134	1085	1154	1146
GainSlope	6,5-8,0	7,19	7,55	7,19	7,22	7,38	7,41
DCR	2000	378	121	875	588	419	211
PTV	2	3,4	3,1	3,5	3,8	3,7	3,1

3.5" HZC/Photonis

XP72B20	Reference	#1	#2	#3	#4	#5	#6
QE@404nm	25	25,9	25,5	26,1	26,2	25,2	25,7
QE@470	18	19,6	18,5	20,7	20,5	19,3	19
HV@3x106	900-1300	1240	1233	1153	1172	1256	1110
GainSlope	6,5-8,0	6,93	7,07	7,06	7,17	6,95	7,24
DCR	2000	537	443	1616	904	784	1037
PTV	2	3,9	4,4	4,8	4,2	3,6	3,6

90 mm Photomultiplier

Photomultiplier Type

Provisional Data

9320KFLA



Description

Compact 90 mm (3.5") diameter end-window photomultiplier with thin domed entrance window, blue-green sensitive alkali photocathode and 10 high gain, high stability, SbCs dynodes of linear focused design for fast timing, good pulsed linearity, and low afterpulse. The pmt window is suitable for optical coupling to a plastic lens and is designed to optimize collection efficiency and time response.

Electrical Characteristics and Ratings

Spectral response & window	No., type & material of dynodes	Effective cathode dia. mm (in)	CATHODE SENSITIVITY						ANODE SENSITIVITY			
			μA/lm	Corning blue	Corning red	Infra red	QE %	At λ nm	A/lm @ V _{ka} #	Gain		
			nom.	typ.	min. typ.	typ.	min. typ.		nom.	typ. max.	nom.	
Bialk / B	10LF SbCs	78 (3.1)	75	8	11.5	1.5	-	18 20	470	50	750 1100	0.7 x 10 ⁶

= measured in voltage divider distribution A

DARK EMISSION @ NOM. A/lm & 20 deg. C			RATINGS											NOTES	
I _s (dark) nA		Counts cps	1pe Rise time ns	1pe FWHM ns	1pe TTS ns	A/lm	V _{k-d1}	V _{d-d}	V _{k-a}	I _k (av.) nA	I _a (av.) μA	Ambient Temp °C			
typ.	max.	typ.	typ.	typ.	typ.	max.	max.	max.	max.	max.	max.	min.	max.		
0.5	1.5	500	2.5	5	1.9	500	450	300	1800	100	100	-60	+60		

Mechanical (dimensions are nominal unless otherwise stated and in mm with inches in brackets)

DIAMETER 87.0 mm Max. without Sleeve				LENGTH	
Note: this type may be supplied with a graphite coating connected to the cathode pin to prevent charging of the glass envelope. Protective sleeving is provided for insulation purposes and should not be removed without consulting ET Enterprises. Unless otherwise stated this adds 0.8 mm (0.03") to the maximum quoted diameter.				Glass base (Excluding pins)	95 +/- 3 mm
				Temporary Cap	178 mm max.
				Lead Length	82 mm nom.

Pin Connections (viewed from below, counting clockwise from short pin or key)

Pin No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Socket
Electrode Uncapped	k	f1	cl	f2	cl	d1	d2	cl	d3	d4	cl	d5	d6	cl	d7	d8	cl	d9	d10	cl	a	FL
Electrode Capped	f1	f2	d1	d2	d3	d4	d5	d6	d7	d8	d9	d10	a	k								B14A

ic=internal connection, socket contact not to be used. cl=out wire, not to be used

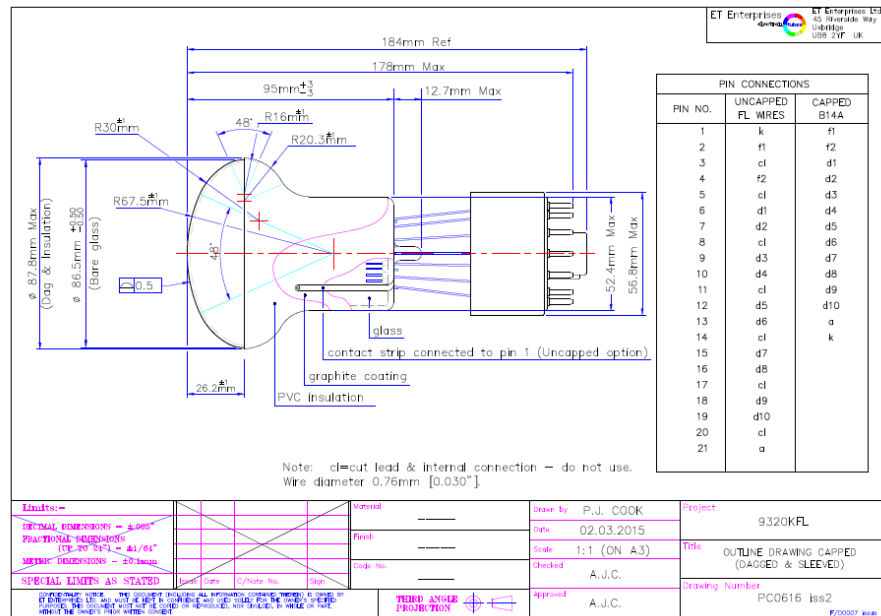
Additional Information

Voltage divider distribution

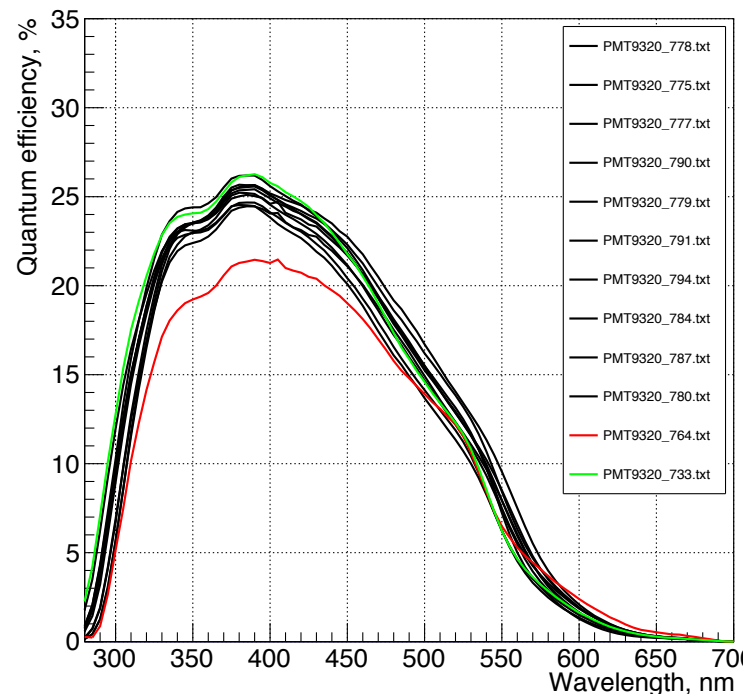
Standard (A): 0.2R k-f1, 1.8R f1-f2, 1R f2-d1, then Linear

Selected for good SER p/v, 5x10⁶ gain < 1400 V, and low afterpulse

ET Enterprises Ltd 45 Riverside Way, Uxbridge, Middlesex UB8 2YF England Telephone +44 (0) 1895 200880 Fax +44 (0) 1895 270873 E-mail info@et-enterprises.com www.et-enterprises.com The company reserves the right to modify these designs and specifications without notice. Developmental devices are intended for evaluation and no obligation is assumed for future manufacture. Whilst every effort is made to ensure accuracy of published information the company cannot be held responsible for errors or consequences arising therefrom.		For general notes on the operation of photomultiplier tubes see ET Enterprises photomultiplier catalogue, which is available on request. Equipment manufacturers are advised to consult ET Enterprises before designing tubes into production instruments.		ISSUE: 1
				DATE: 27 Jul 2015
				APPROVED AJC
				© ET Enterprises 2015



Absolute calibration, ETEL



Prototype from MELZ FEU (Moscow)



MELZ FEU
Photomultiplier Tubes

FEU - KM3Net

*The specialized Photomultiplier tube
FEU-KM3Net is designed for abyssal neutrino
telescope.*

GENERAL INFORMATION

Photocathode diameter, mm	76
Input window material	C52-1 glass
Optical input	front
Dynode assembly	box-trough-shaped
Number of dynodes	10
Design	glass with pins
Operating position	any
Bulb diameter, mm, max	78
Bulb height without pins , mm, max	105

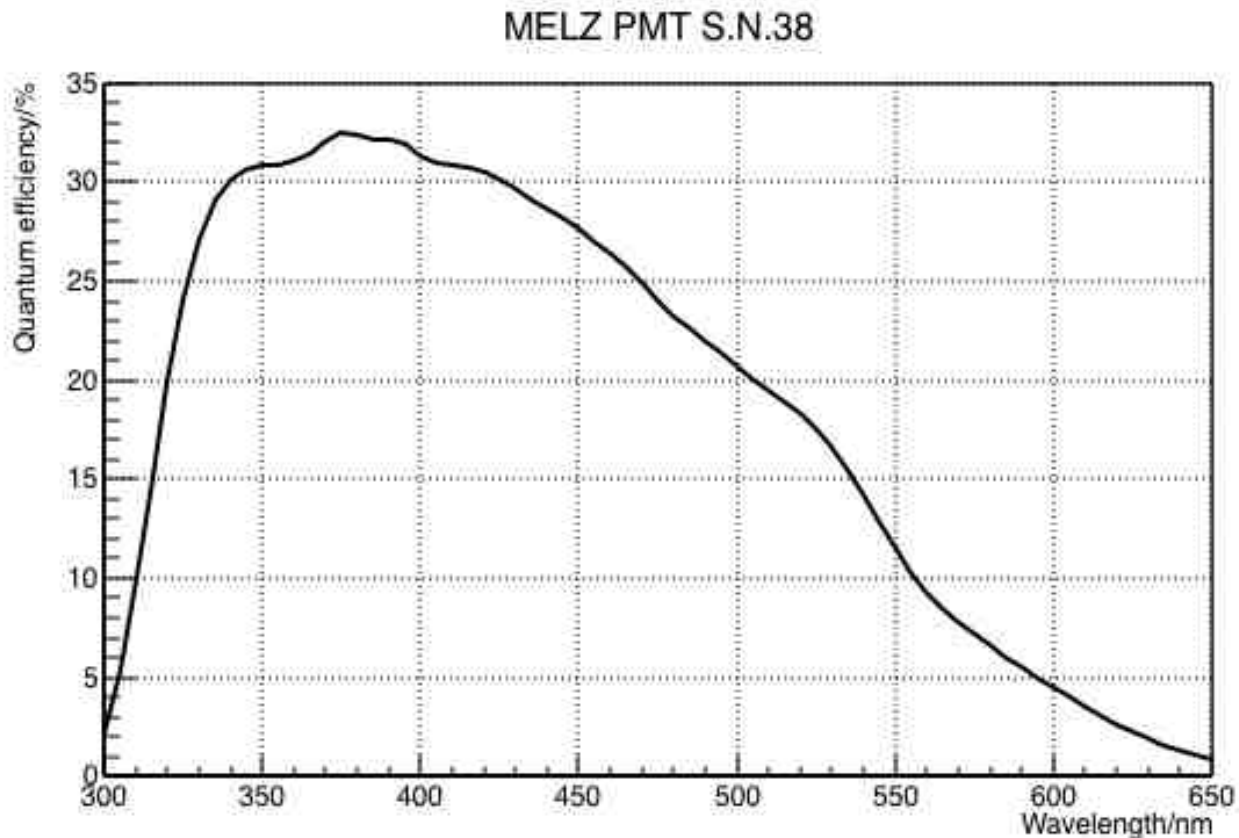
MAIN PARAMETERS at $t=25^{\circ}\text{C}$

	Min.	Typ.	Max.
Wavelength, nm	320	-	650
Spectral photocathode sensitivity at 404 nm, mA/W	130	-	-
Supply voltage at anode sensitivity 100 A/lm, V	-	-	1400
Heterogeneity of photocathode sensitivity, %	-	-	10
Gain	-	5×10^6	-
Pulse length at half-height, ns	-	-	3
Quantum efficiency at 450 nm, %	-	30	-



MELZ PMTs

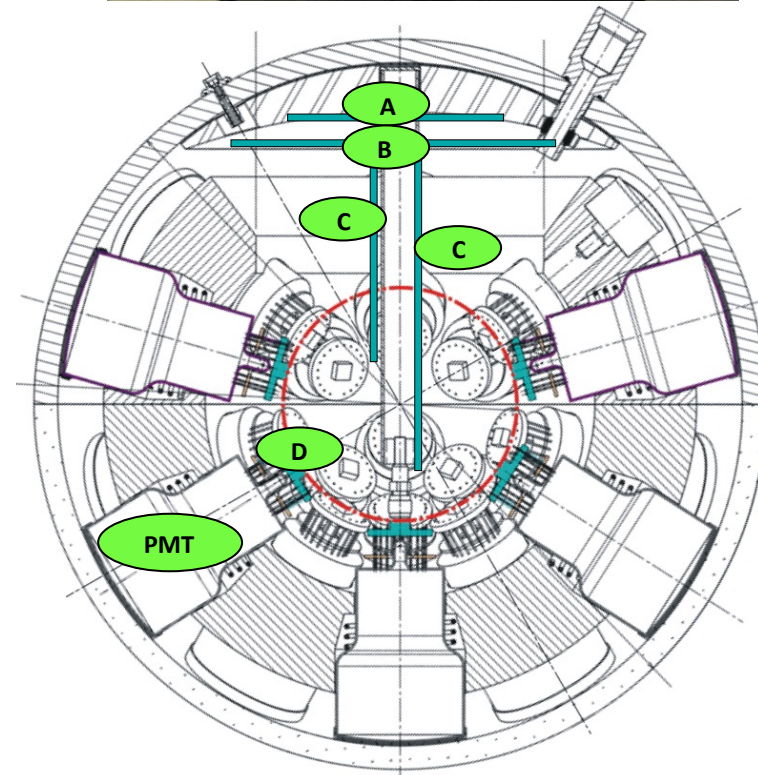
Q.E. measurement by Oleg (ECAP)



but charge resolution is bad – eager to test latest prototype

The KM3NeT DOM

- 17 inch glass sphere (two hemispheres)
- 31 3-inch (cathode area~ 3x10-inch PMTs)
 - 19 in lower, 12 in upper hemisphere
- 31 PMT bases (total ~140 mW) (D)
- Front-end electronics (B,C)
- Al cooling shield and stem (A)
- Single penetrator
- No mu-metal shield
- Optical gel between glass and PMTs



A method to stabilize the performance of negatively fed KM3NeT photomultipliers

ABSTRACT: Instability in terms of dark counts has been investigated for photomultipliers with negative HV on the photocatode and held in insulating support structures made of 3D printed nylon material. As the support structure is rigid, small gaps between it and the photomultipliers in the presence of electric fields can lead to sparks that produces dark count rates that are highly variable. A solution was found by applying an insulating paint directly to the outside of the KM3NeT photomultipliers. The liquid coating provides a convenient and inexpensive method of insulation.

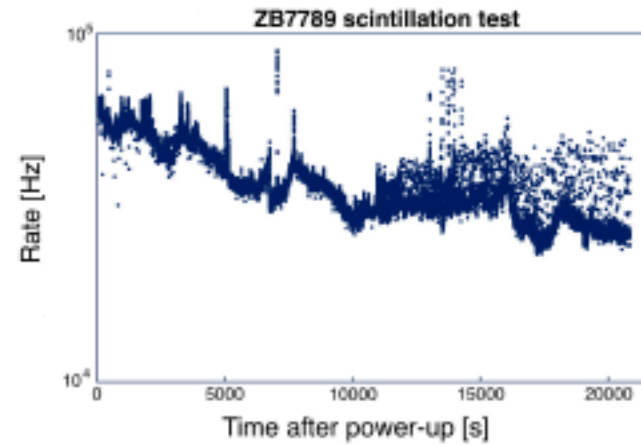
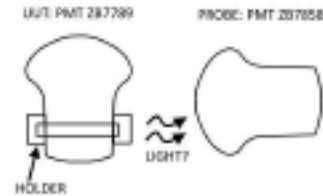


Figure 3. Left: setup where the UUT is a PMT supported by an insulating frame without any kind of coating. The PROBE is covered with insulating tape and has a dark count rate within the Vendor specifications; Middle: scheme of the setup; Right: dark count rate measured for a UUT supported by an insulating holder.

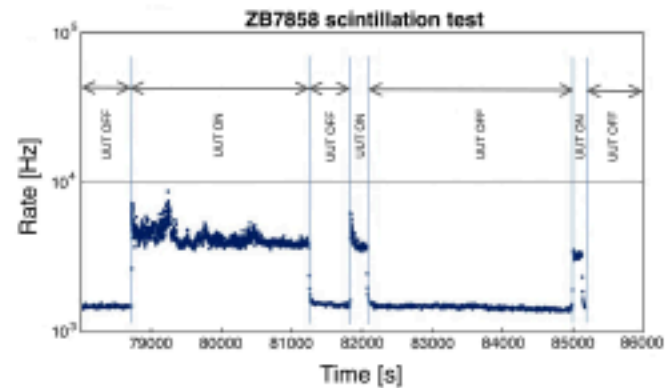
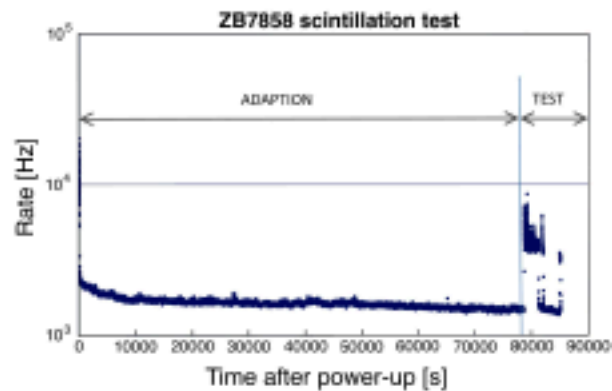


Figure 4. Left: dark count rate measured by the PROBE when the UUT is OFF, region indicated with *Adaption*; Right: dark count rate measured by the PROBE when the UUT is switched ON.

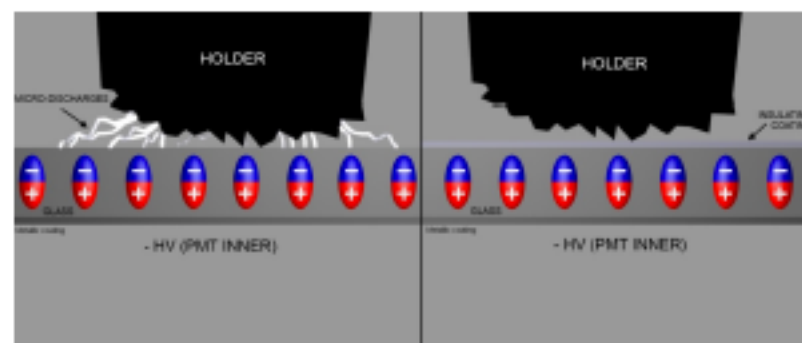


Figure 7. Schematic view of the effect of adding an insulating coating to PMT glass.

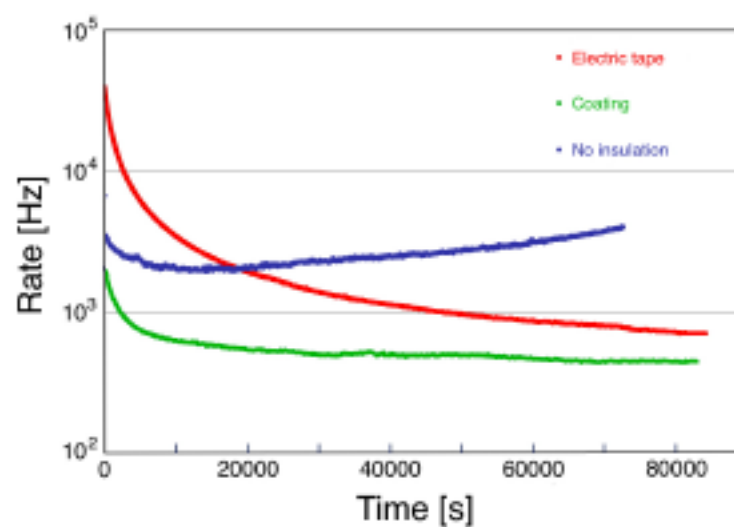
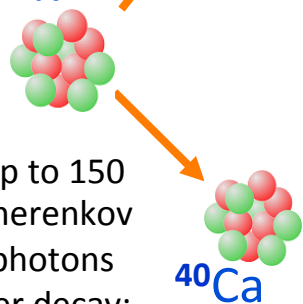


Figure 9. Dark count rate as measured for different configurations: naked PMT (blue), covered with insulating tape (red), covered with liquid coating (green).

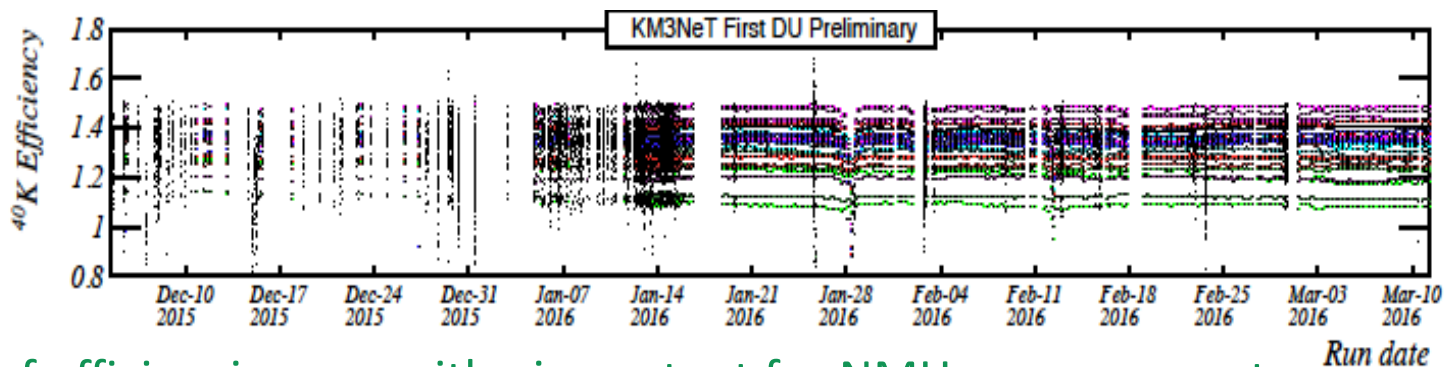
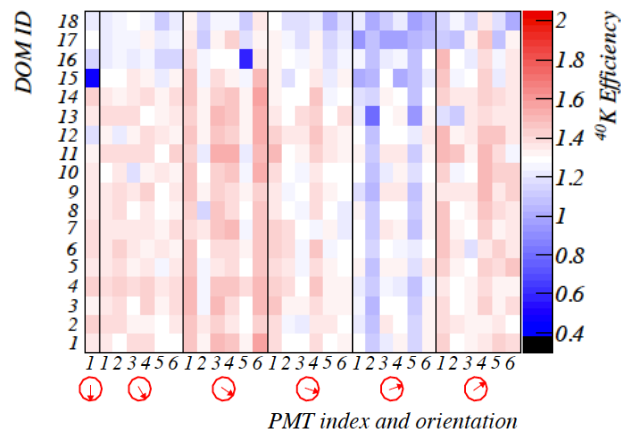
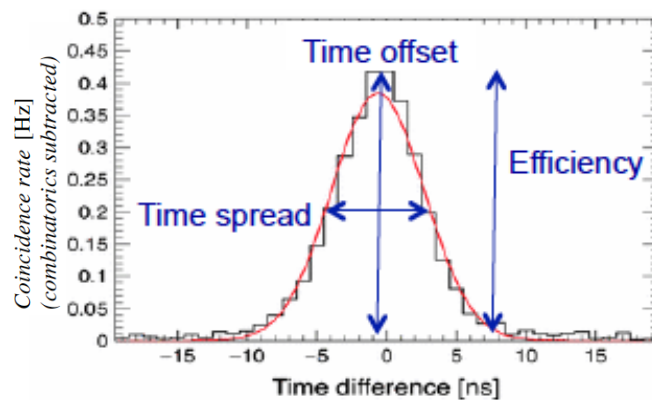
^{40}K : Inter-PMT Calibration



^{40}K e^- (β decay)

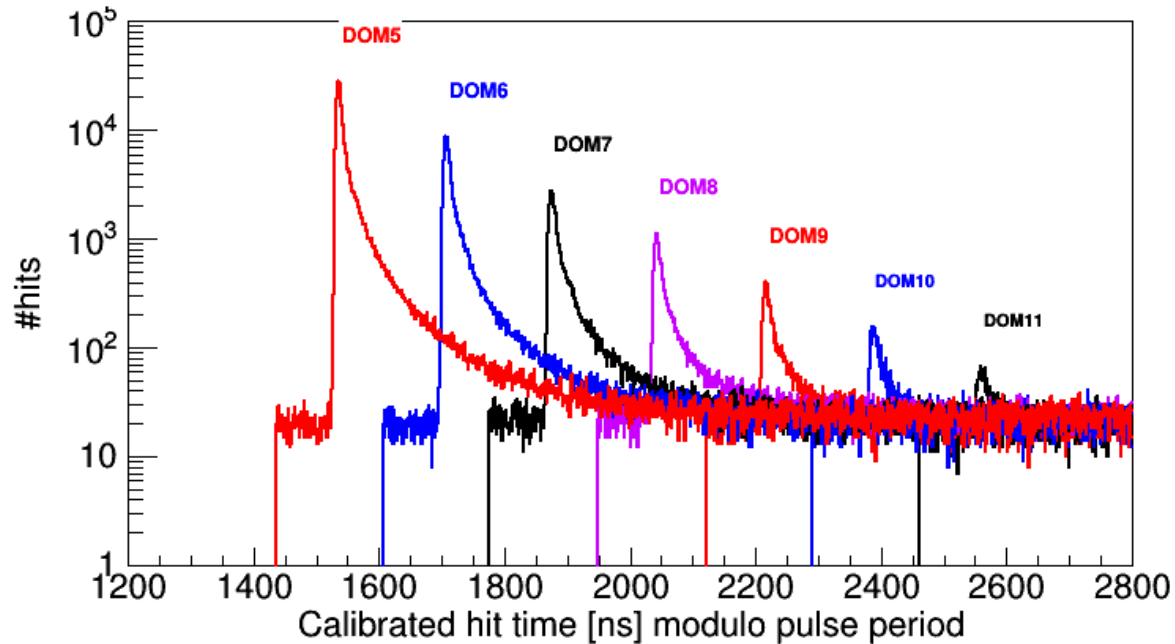


Up to 150
Cherenkov
photons
per decay;
stable ^{40}K
concentration

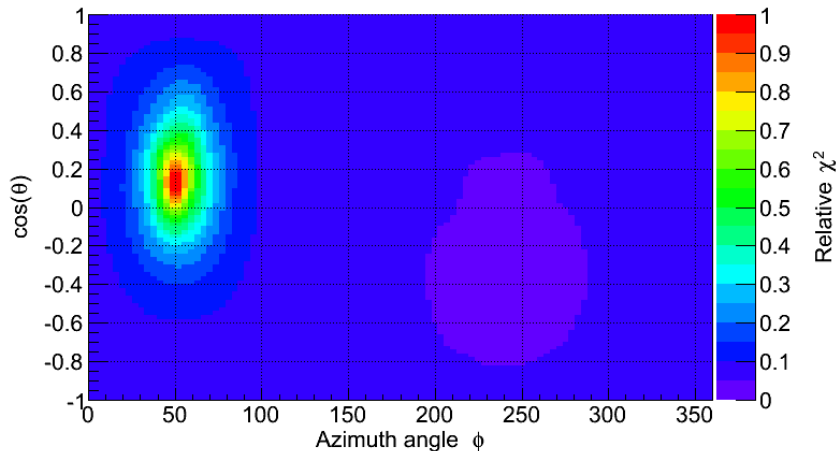


Knowledge of efficiencies vs zenith - important for NMH measurement

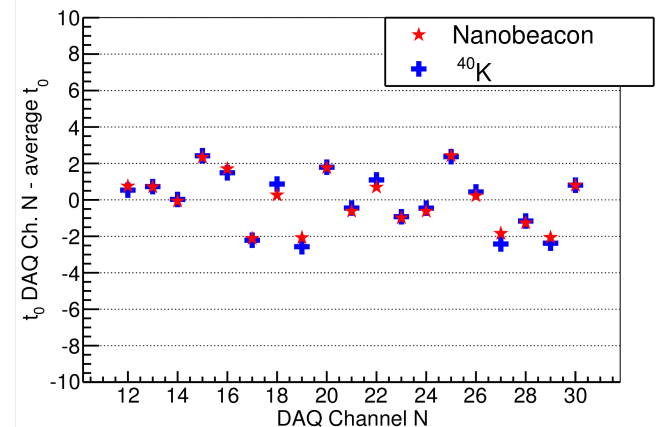
ARCA-DU1 nanobeacon visibility (run #3493)



Nanobeacon direction fit



Inter-PMT time calibration DOM4 (run 1649)



KM3NeT Integration Sites



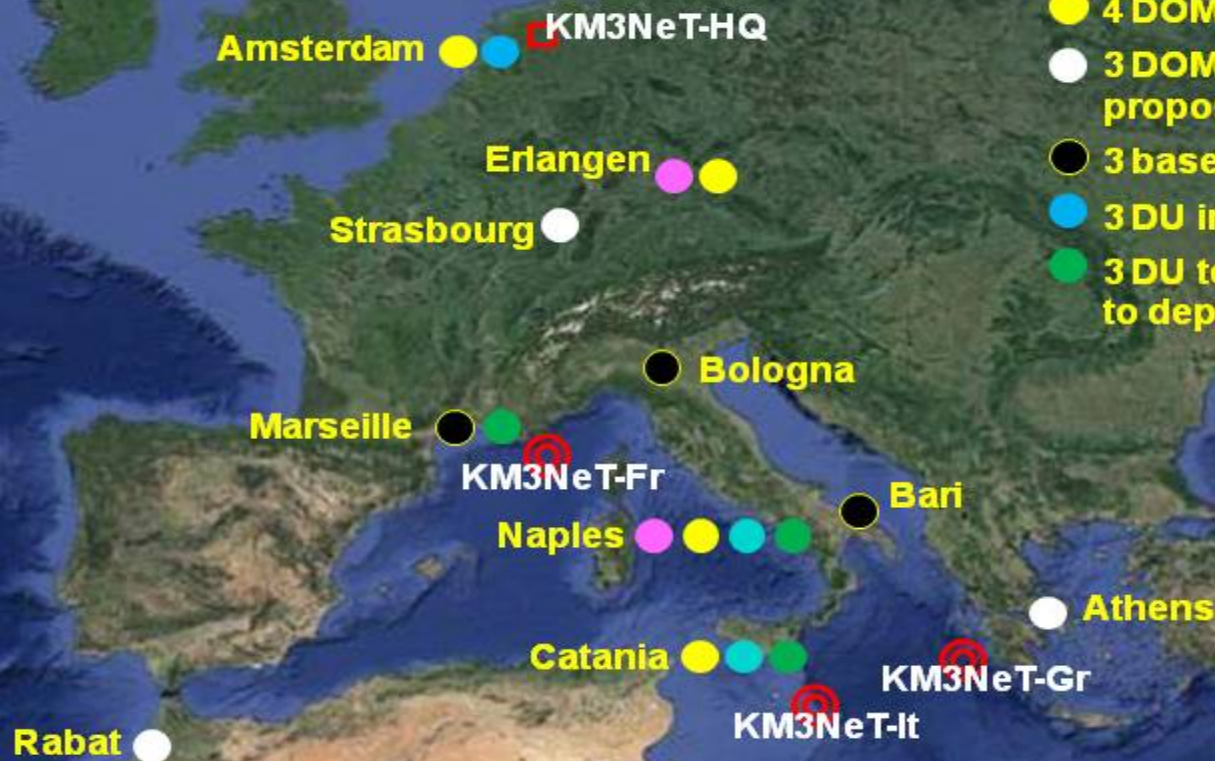
Av. integration speed of DOMs: 4 DOMs/week/site

Av. construction speed of DUs: 1 DU/month/site

Av. integration speed of base modules: 1 module/week/site

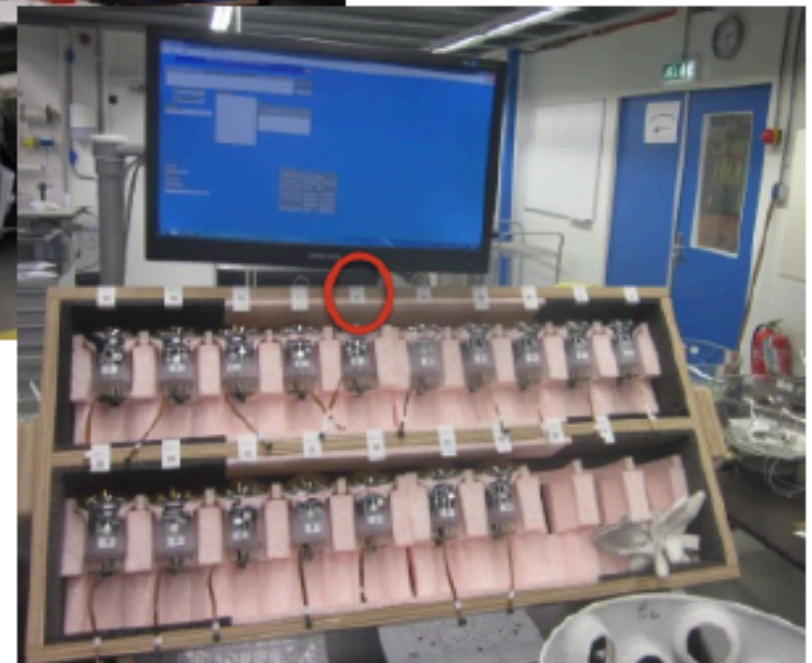
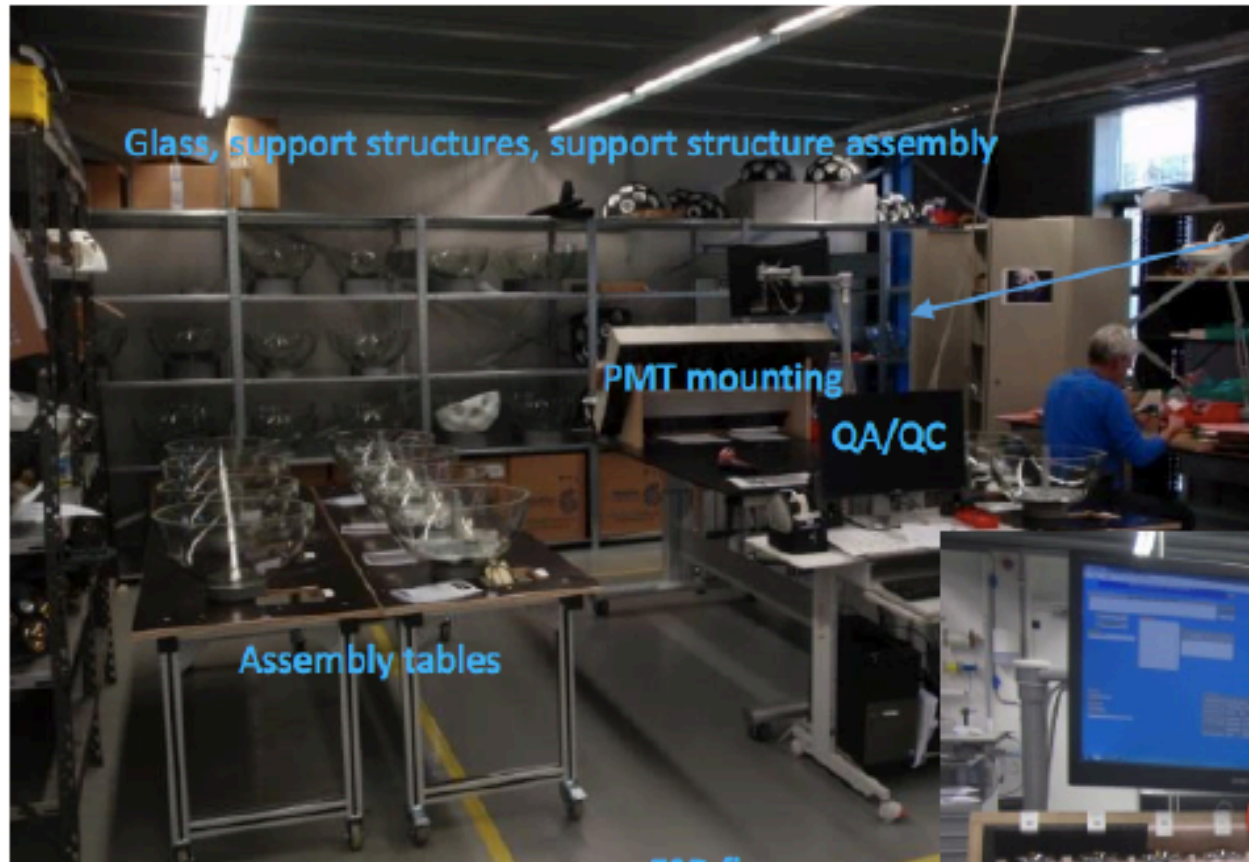
KM3NeT Phase-1 Infrastructure (March 2016):

- 3 Installation sites
- 2 PMT preparation sites
- 4 DOM integration sites
- 3 DOM integration sites proposed/planned
- 3 base module integration sites
- 3 DU integration sites
- 3 DU test and preparation to deployment sites



DOM PRODUCTION SITE AMSTERDAM

4



- Large DOM production facility operational since March 2015
- Steadily producing DOMs
- Lab includes a dark room with storage capability of up to 10 DOMs

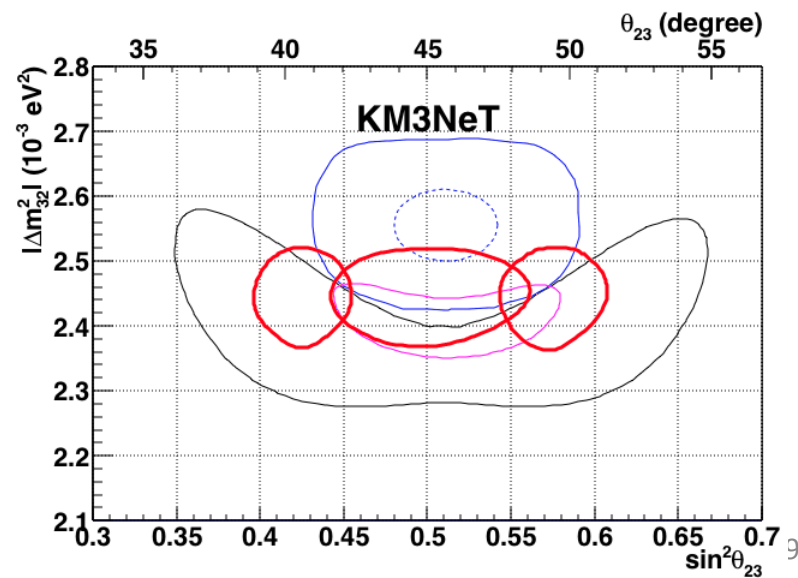
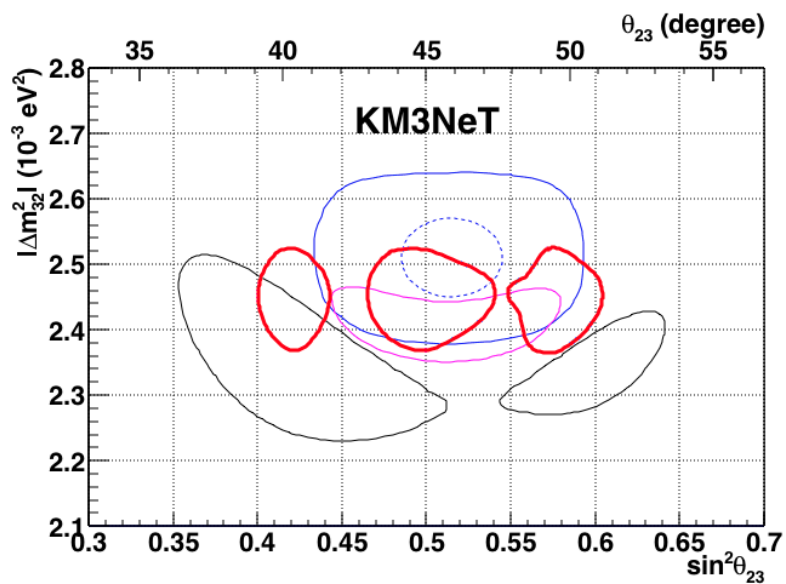
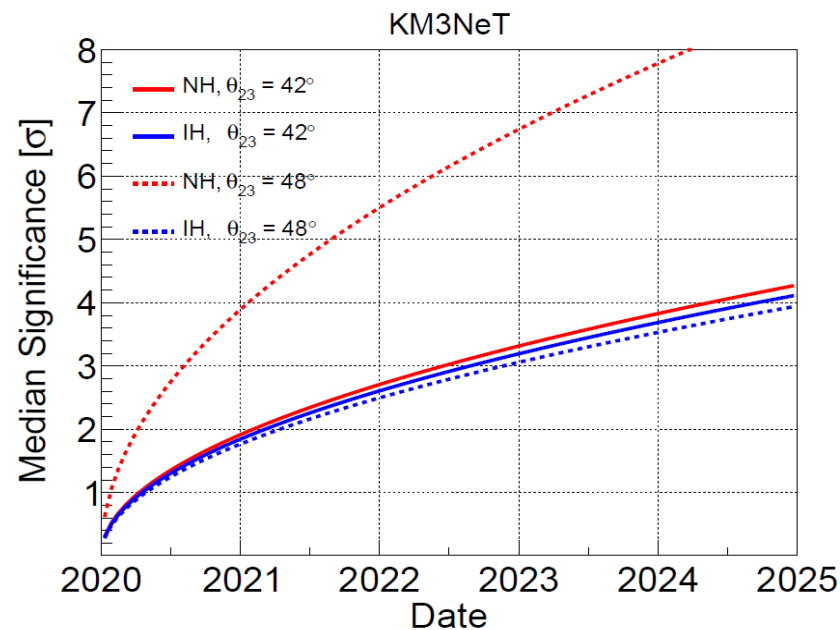
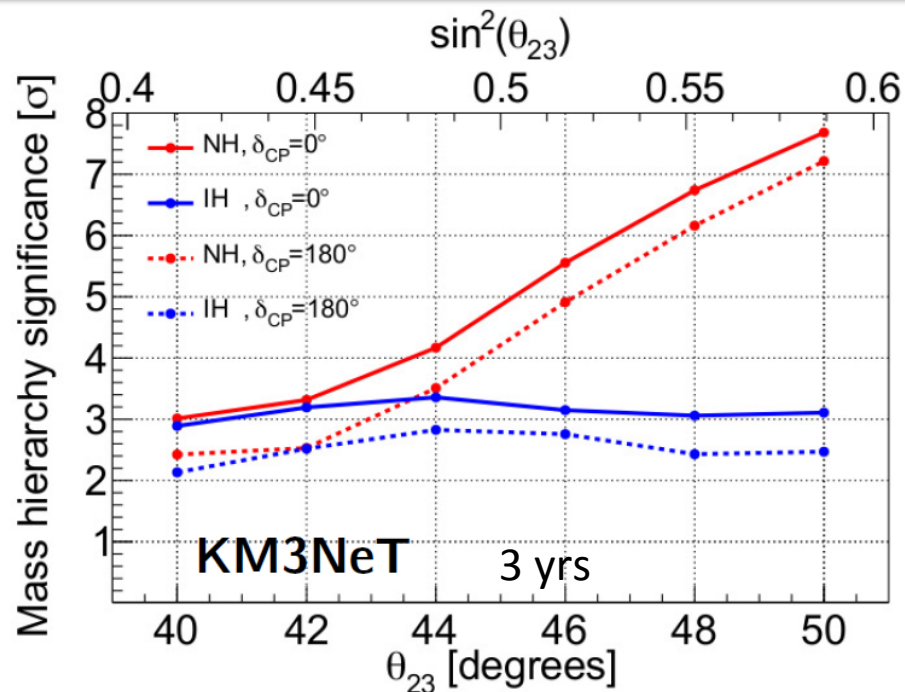
Summary

- 15,000 3inch PMTs (Hamamatsu) - Working well
- Big effort to test all PMTs
- Push to improve performance/cost ratio for Phase 2
 - ETEL, HZC, MELZ
- Aiming for <100euro/item – combined orders?
- Think carefully about specs
- Be careful with negative photocathode –liquid coating
- In-situ 40K calibration useful for KM3NeT
- MOU with HyperK to share knowledge – meeting at Nikhef
- Volume instrumented HK may have some advantages?

Thank you!



Sensitivity to Mass Hierarchy



The KM3NeT Glass Sphere

- Glass sphere (two hemispheres)

Glass properties

- Rate

- Outer

Refractive index

1.47

- VITR

Transmission

>95% (14 mm, $\lambda > 350$ nm)

- Refr

Density at 20°C

2.23 g cm⁻³

- Titar

Thermal conductivity

1.2 W m⁻¹K⁻¹

- Man

Characteristics of spheres

- Inter

- Pene

13 inch

17 inch

- Arou

Depth rating (m)

10000

6700

- singl

Overall diameter (mm)

330

432

Wall thickness (mm)

11

14

Mass (kg)

7.89

17.2

Buoyancy (empty) (N)

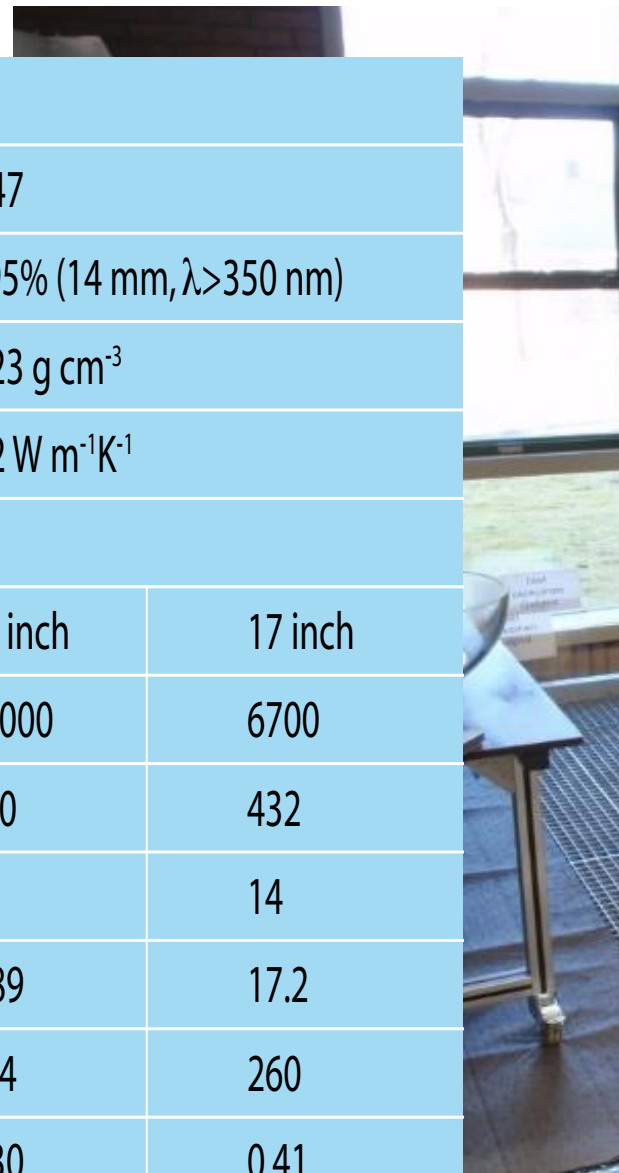
114

260

Diameter shrinkage per 1000m depth (mm)

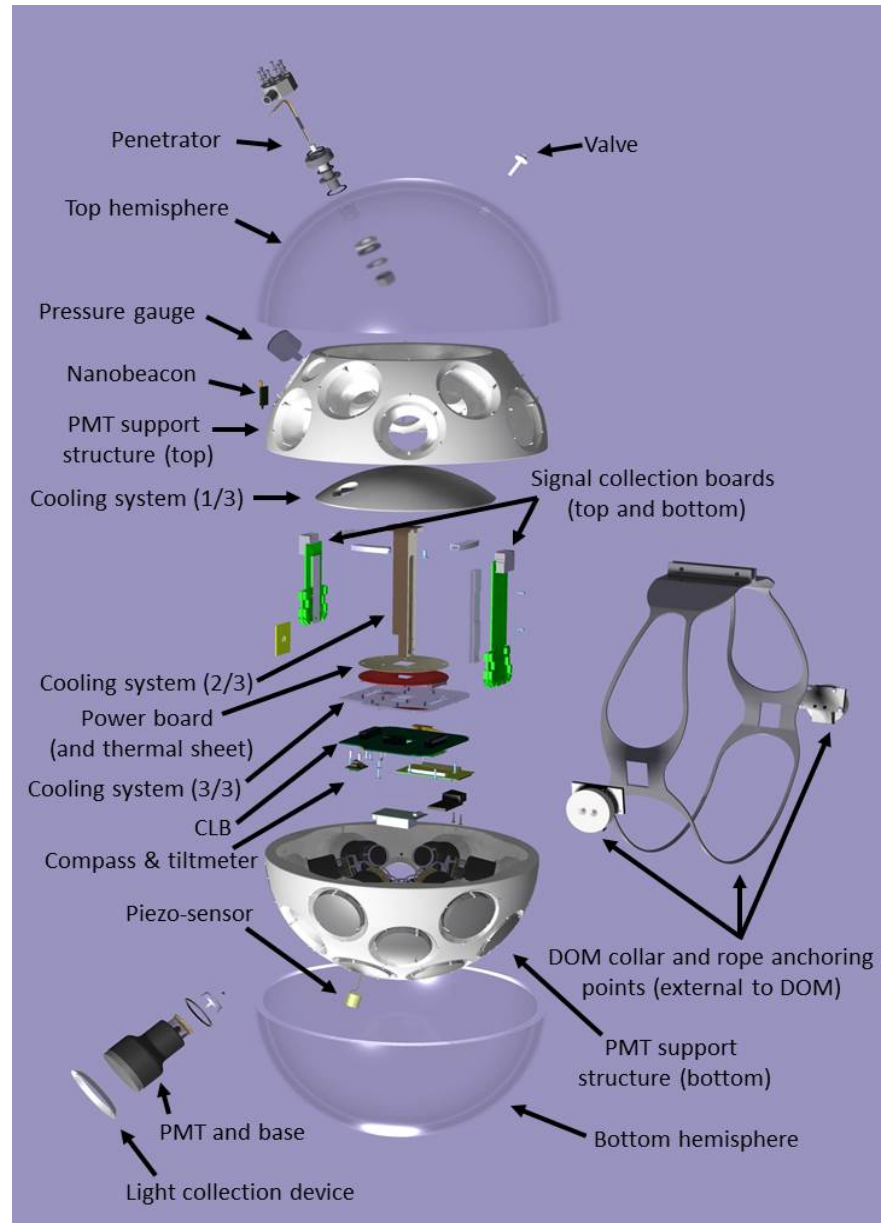
0.30

0.41

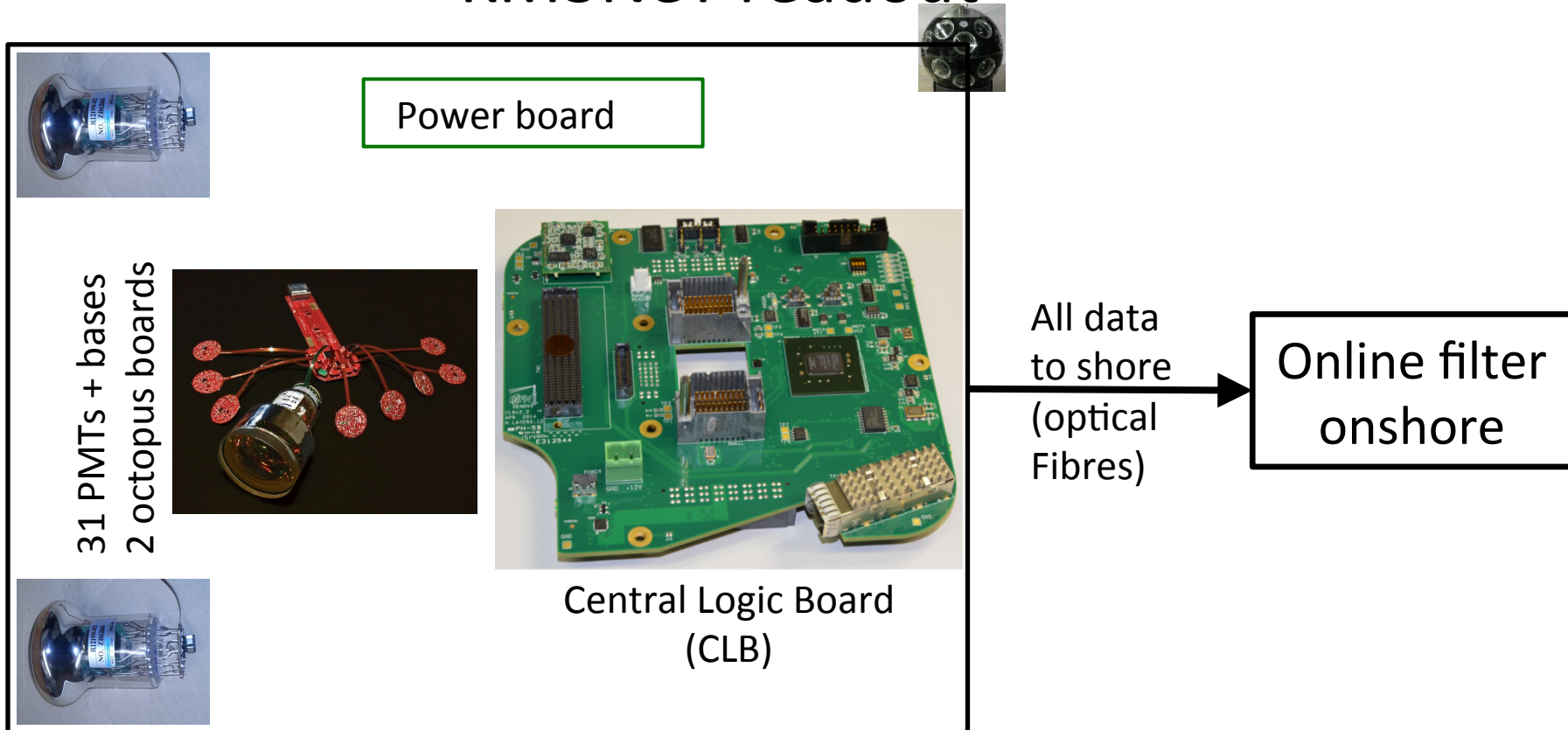


Implementation in DOM

- Reflective rings around PMTs (+27% light detection, see JINST 8 (2013) T03006)
- PMTs supported by plastic structure produced by 3D-printing
- Calibration: Acoustic sensor, compass + tiltmeter, nano-LED beacon
- Electronics components attached to cooling structure
- One single penetrator for connection to vertical cable
- Low power (7W per DOM)
- Optical fibre data transmission
 - DWDM with 80 wavelengths
 - Gb/s readout



KM3NeT readout



HV for PMTs

Discrimination
w.r.t. predefined
threshold

FPGA for TDC (time & time over threshold),
Time stamping (1 ns precision);
Interface for time synchronisation (white rabbit);
Control of calibration devices;
Communication;