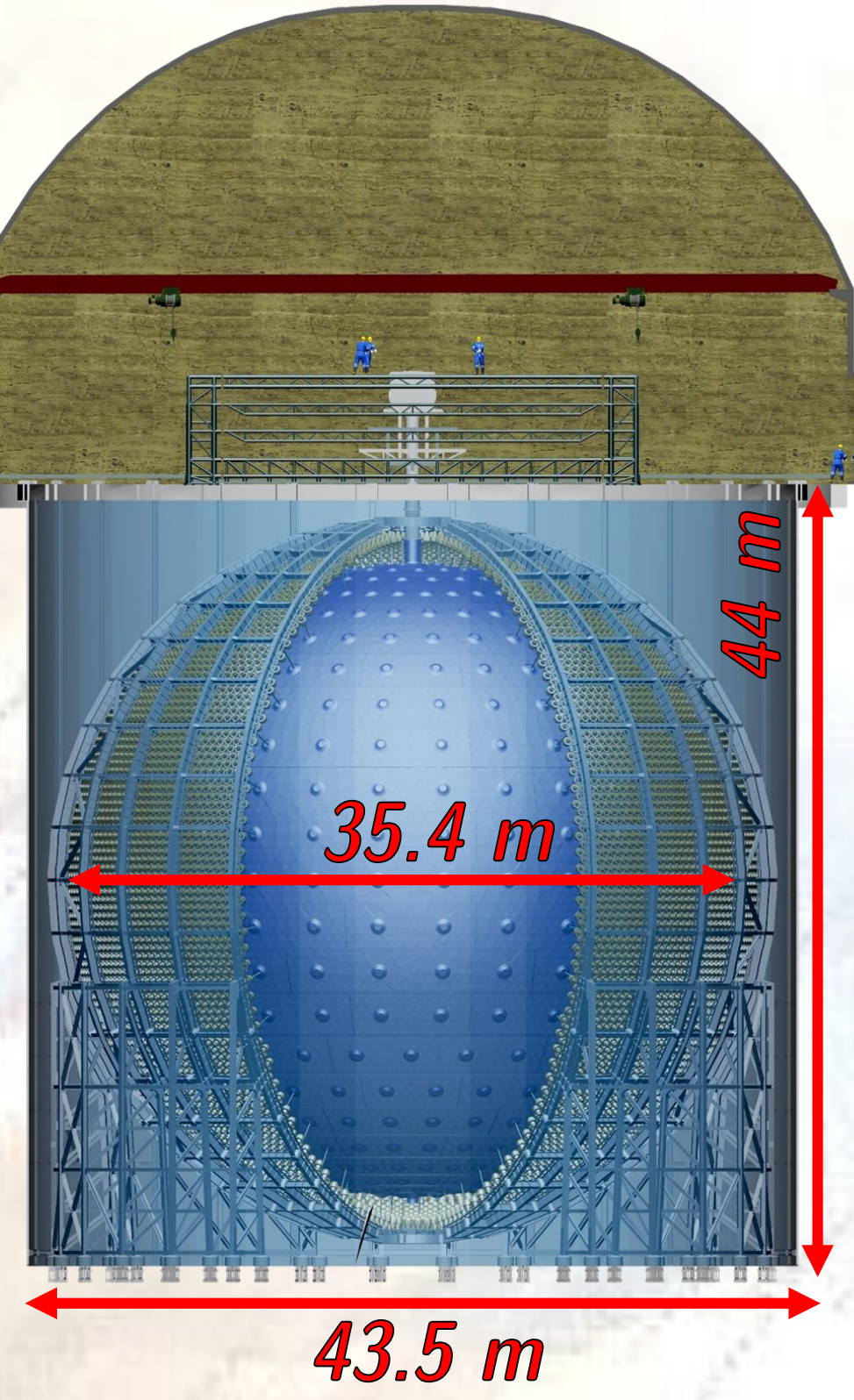


Alexander Tietzsch, on behalf of the JUNO collaboration

Physikalisches Institut, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, GERMANY; ☎ +49-7071-29-73286 ; ✉ alexander.tietzsch@uni-tuebingen.de

THE JUNO EXPERIMENT

- ✓ 650 m underground
- ✓ 20 kt LAB-based liquid scintillator
- ✓ 17600 20-inch PMTs + 25000 3-inch PMTs (*optical coverage* > 75%)
- ✓ Active Cherenkov muon veto with additional ~ 2400 20-inch PMTs
- ✓ Top Tracker for muon detection
- ✓ $3\%/\sqrt{E}$ [MeV] energy resolution
- ✓ Neutrino mass ordering with $>3\sigma$ after 6 yrs of data taking
- ✓ Broad physics program



WHY PMT TESTING?!

To achieve the aimed energy resolution of $3\%/\sqrt{E}$ [MeV] in JUNO, impeccably performing PMTs are necessary. This leads to a list of individual PMT requirements, which all tubes need to be tested for.

parameter	unit	requirements (Ham. / NNVT)
photon detection efficiency	%	> 24 (27 in avg.)
dark count rate (@ 22°C)	kHz	< 50 / < 100
gain	-	10^7
HV for 10^7 gain	V	< 2500
transit time spread of SPE pulses (FWHM)	ns	< 3.5 / < 15
rise time, SPE pulses	ns	< 8
fall time, SPE pulses	ns	< 16
peak-to-valley ratio in SPE spectrum	-	> 2.5 / > 2.8
pre-pulse probability	%	< 1.5 / < 1.0
after-pulse probability	%	< 15 / < 2
QE non-uniformity over photocathode	%	< 15

PMT TESTING FACILITY



Storage hall at *Pan-Asia* company in **Zhongshan, CHINA** (~ 2 h apart from JUNO experimental site)

- ✓ Storage place for 20000 20-inch PMTs before their installation into JUNO
- ✓ PMT testing stations
- ✓ PMT potting facility
- ✓ Storage for more JUNO hardware/components (e.g. Top Tracker modules)

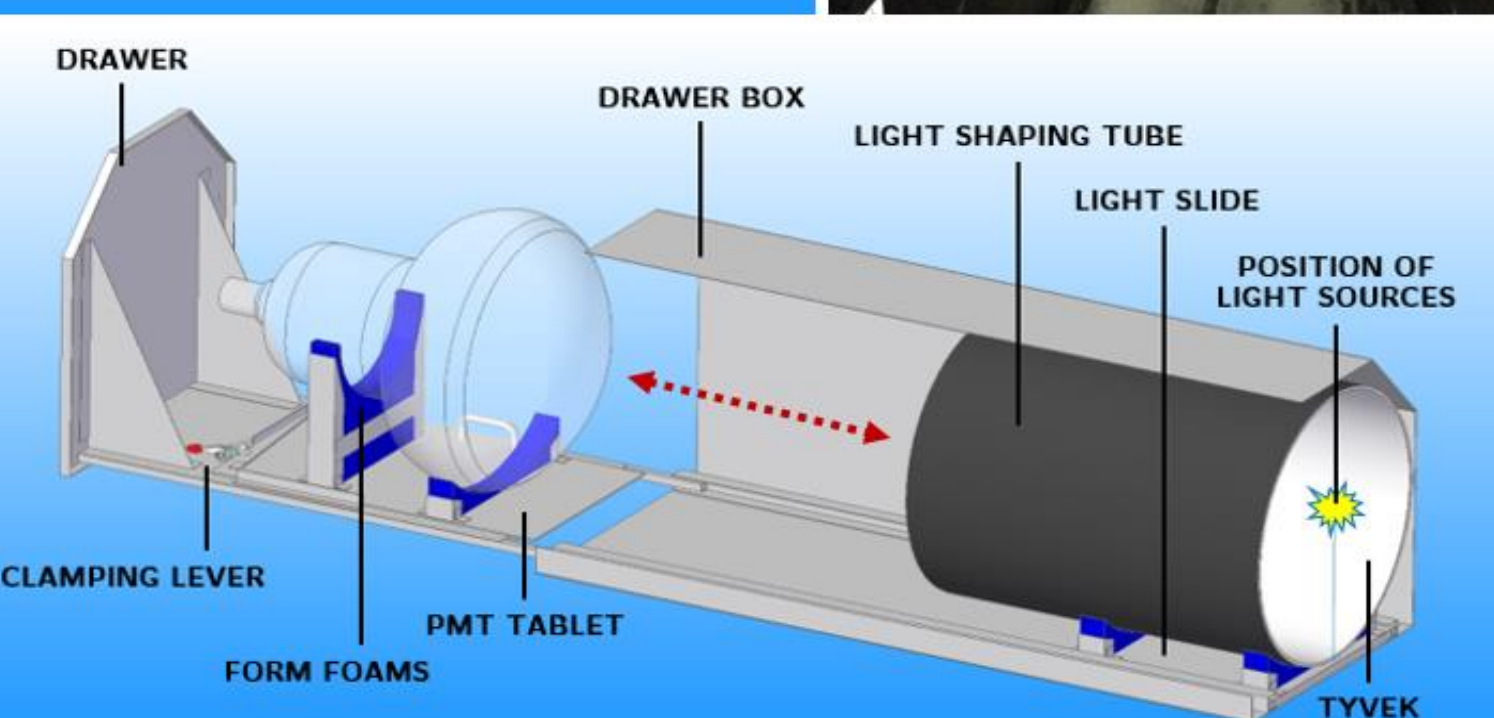
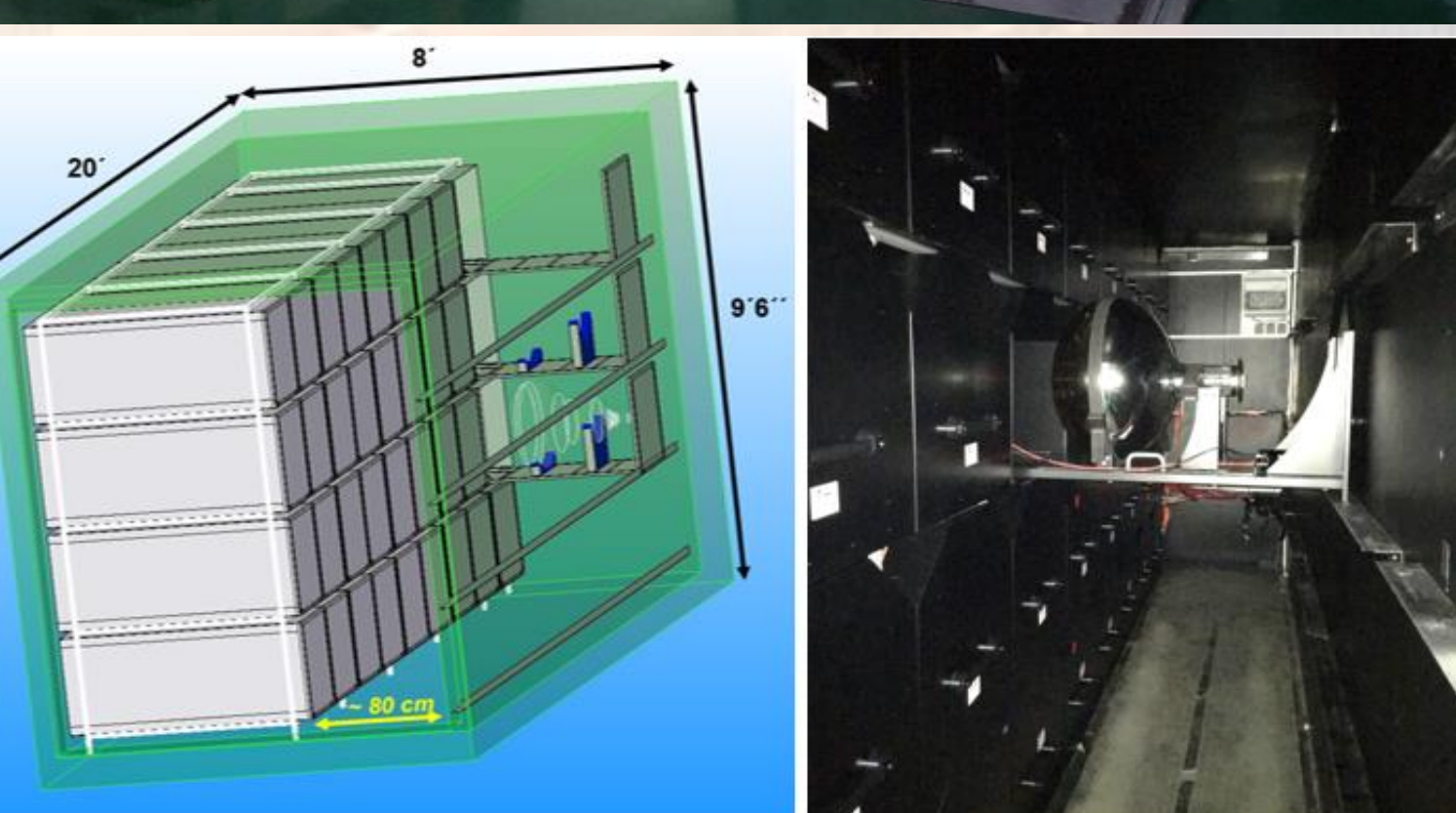
PMT TESTING STATUS

Bare PMTs tested with the containers:	22416	
Bare PMTs accepted for JUNO:	20077	100 %
→ Hamamatsu PMTs:	5001	
→ NNVT PMTs:	15076	
Total number of PMT characterizations performed with the container system (<i>including doubles, calibration runs, special tests etc.</i>):	54500+	
PMTs potted:	18100+	90 %
Potted PMTs tested with the containers:	6000+	30 %
Potted PMTs tested with final JUNO electronics:	1500+	
PMTs scanned in the scanning stations:	3288	15 %
→ Hamamatsu PMTs:	585	
→ NNVT PMTs:	2574	

THE PMT CONTAINER SYSTEM

4 commercial shipping containers, equipped with a drawer box system for parallel PMT characterizations (36 ch. / container)

- ✓ Two containers equipped with commercial read-out electronics and fully automated DAQ software based on LabView®, two containers for special purposes (*long-term PMT tests and test of PMTs + final JUNO electronics*)
- ✓ Two light-sources @ 420 nm in each drawer box:
 - (1) LED with stabilized output intensity (*main light source, calibrated*)
 - (2) fiber to ps-Laser system (*high timing resolution, only for TTS*)
- ✓ Homogeneous illumination of the PMT photocathode by PTFE diffuser and light shaping tube
- ✓ Magnetic shielding to ~ 5 μT (10% of Earth's magnetic field) by multi-layer shielding (4 mm Al/soft iron)



See [arxiv:2103.10193](https://arxiv.org/abs/2103.10193) for more information.

JUNO 20-INCH PMTs



5000 R12860HQ 20-inch dynode PMTs from HAMAMATSU Photonics K.K.

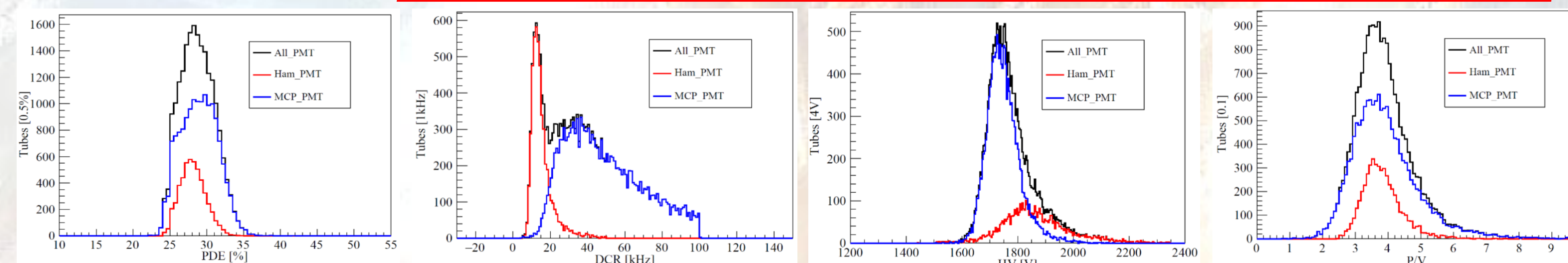
15000 GDB-6201 20-inch microchannel plate PMTs from Northern Night Vision Tech. Ltd.

PMT SCANNING STATIONS

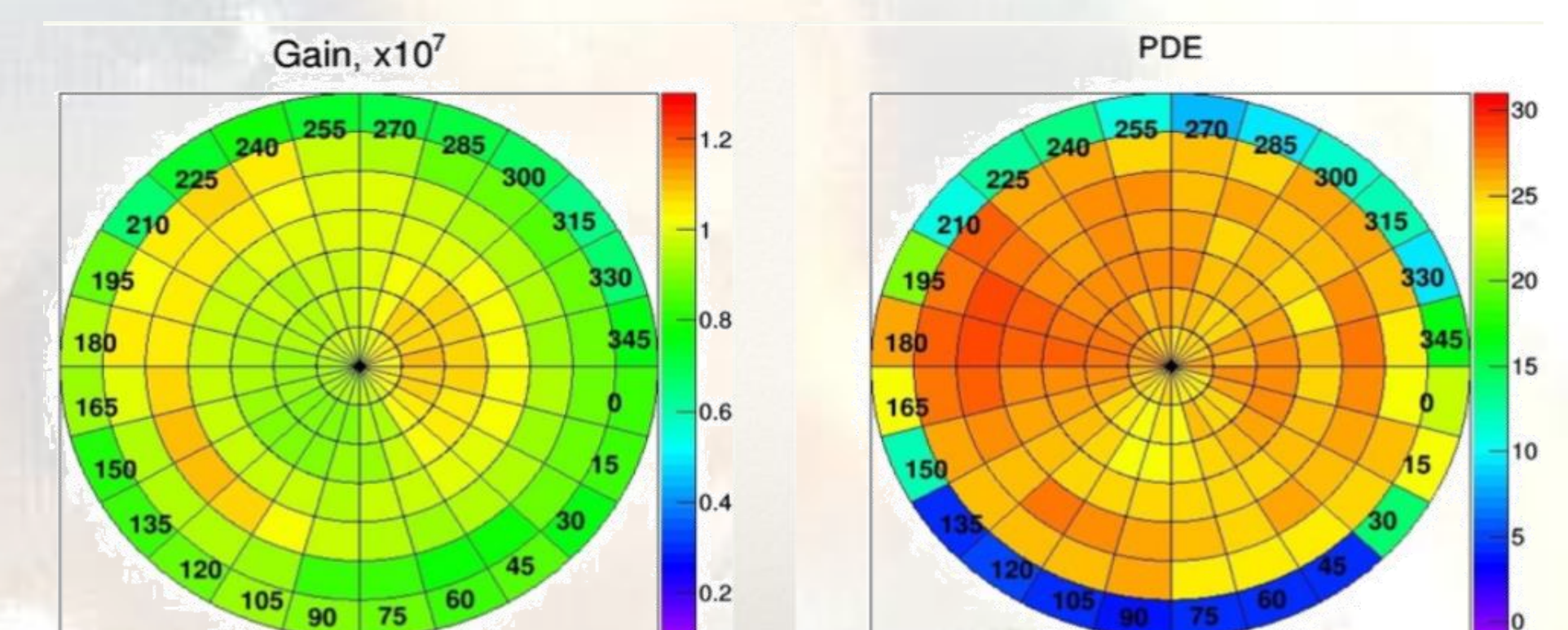


- 2 scanning stations, placed in separate dark rooms and able to scan one 20-inch PMT
- ✓ 7 LEDs with stabilized output intensity at different zenith angles on a rotatable arch
- ✓ Can perform precise PDE measurements and photocathode uniformity scans with high spatial resolution (*sample tests, not all PMTs*)
- ✓ Placed in dark rooms with active magnetic shielding (using Helmholtz coils, residual field ~ 2 μT at PMT)

BARE PMT MASS TESTING RESULTS (preliminary)



PMT Type	<PDE>	<DCR>	<HV>	<P/V>	<RT>	<FT>	<TTS (σ)>*	<QE N.U.>*
HAMAMATSU	28.1 %	15 kHz	1860 V	3.8	6.9 ns	10.2 ns	1.3 ns	4.5 %
NNVT	28.9 %	49 kHz	1750 V	3.9	4.8 ns	17.4 ns	7.5 ns	7.4 %



See [JINST 12 \(2017\) 06, C06017](https://arxiv.org/abs/1706.06061) for more information.

ACKNOWLEDGEMENTS

The PMT Testing campaign for JUNO is a joint work of colleagues from EKUT Tübingen, University of Hamburg, JINR Dubna, IHEP Beijing and SYSU Guangzhou.

funded by



The PMT container system was funded by the German Research Society (DFG).

*) Values based only on PMT subsample (n << 20000 PMTs), ongoing analyses