JUNO 20-inch PMT Testing Systems and Progress

presented by

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EBERHARD KARLS UNIVERSITÄT TÜBINGEN

JUNO

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MOTIVATION FOR PMT TESTING: ENERGY RESOLUTION

High optical coverage (**>75%**) of the central detector volume (20 kt LSc = neutrino target)

→ (mainly) consists of ~ **17600 20-inch PMTs**

→ additional ~ **2400 20-inch PMTs** used in the water pool (active Cherenkov veto)

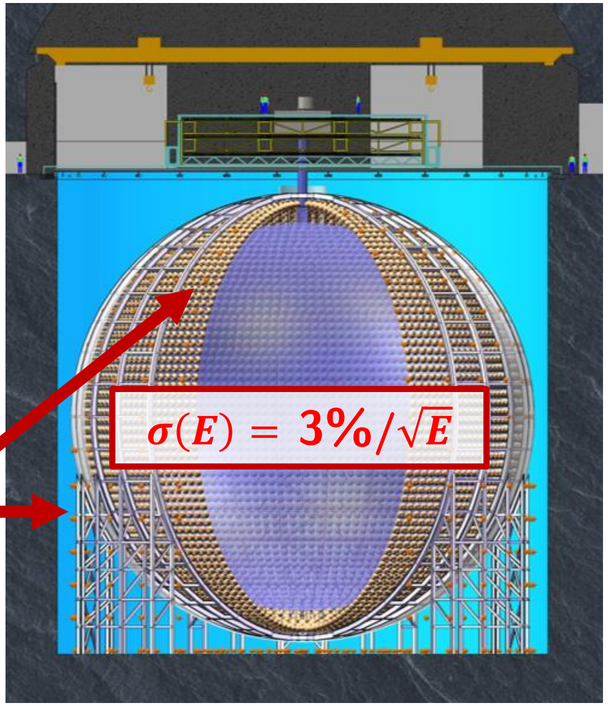
→ two PMT types in use in JUNO:

5000 *dynode PMTs*
type ***Hamamatsu*** *R12860*

15000 *MCP-PMTs*
type ***NNVT*** *N6201*

20‘000 20-inch PMTs in total

Main design goal:



Impeccable performing PMTs

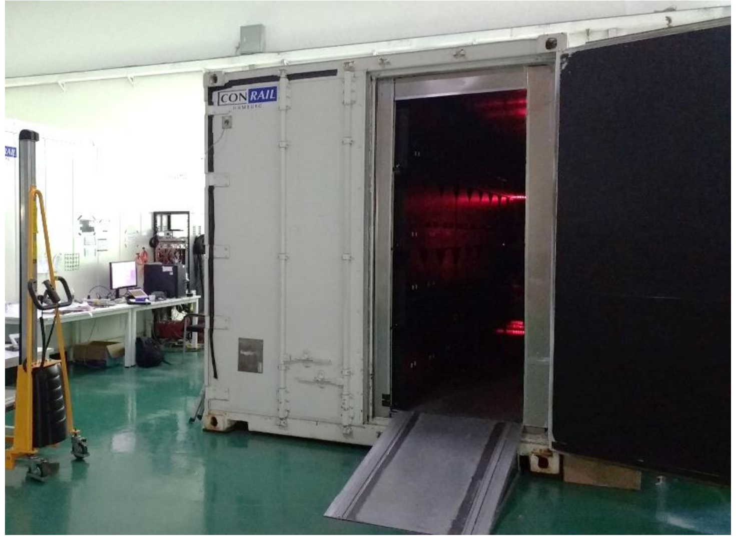
(high photon detection efficiency, low noise level, good timing/charge resolution, ...)

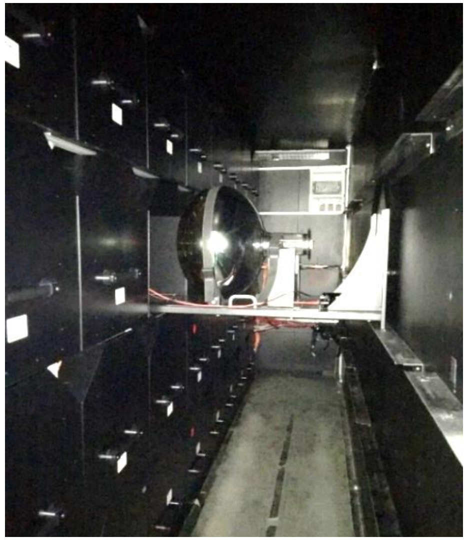
→ **list of individual PMT performance requirements**

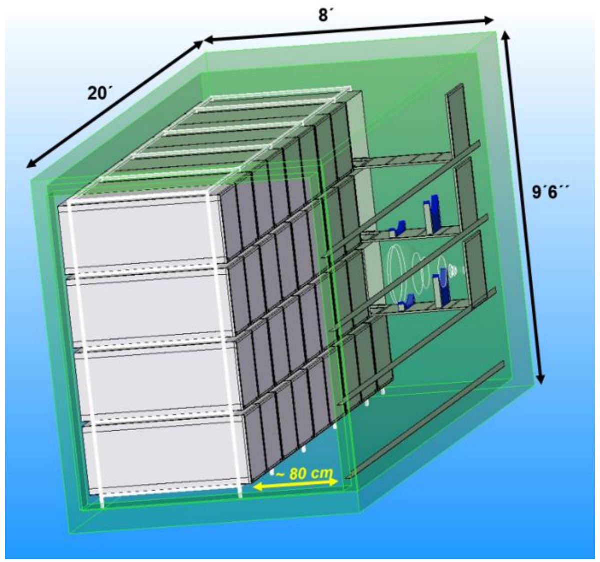
Parameter	unit	tube type	Min.	typical	Max.
PDE @ 420 nm	%	both	24.0	27.0	–
P/V ratio of SPE	–	Hamamatsu	2.5	3.0	–
		NNVT	2.5	3.5	–
DCR @ 0.25 PE	kHz	Hamamatsu	–	20	50
		NNVT	–	–	100
Rise Time	ns	Hamamatsu	–	–	8.5
Fall Time	ns	Hamamatsu	–	–	12.0
Supply HV (@ $G = 10^7$)	V	Hamamatsu	–	2000	2350
		NNVT	–	2000	2800
TTS (FWHM)	ns	Hamamatsu	–	2.7	3.5
		NNVT	–	12.0	15.0
PPR	%	Hamamatsu	–	0.8	1.5
APR	%	Hamamatsu	–	10	15
		NNVT	–	1	2
QE Non-Uniformity	%	both	–	5	15
Non-Linearity < 10 %	PE	both	1000	–	–
Spectral Response	nm	both	–	300–600	–
Res. Radioactivity of glass (^{238}U)	ppb	Hamamatsu	–	–	400
		NNVT	–	–	50
(^{232}Th)		Hamamatsu	–	–	400
		NNVT	–	–	50
(^{40}K)		Hamamatsu	–	–	40
		NNVT	–	–	20

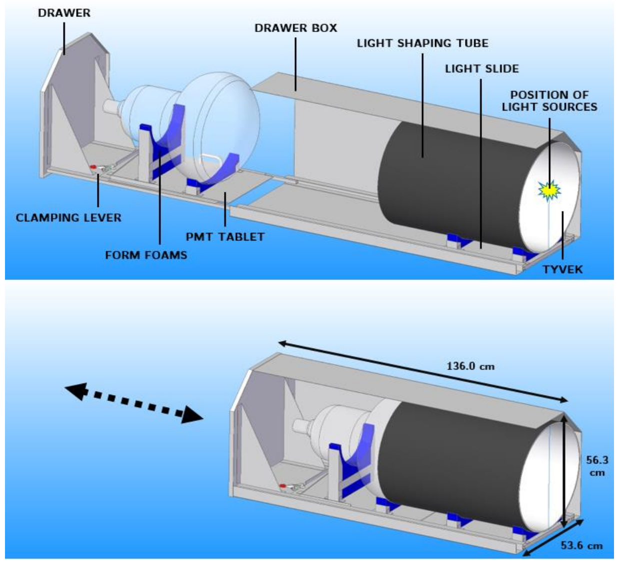
compare also talk of Hans Steiger:
JUNO Detector Design and Status (Feb. 22 18:10, ID #229)

(1) PMT MASS TESTING CONTAINER SYSTEM







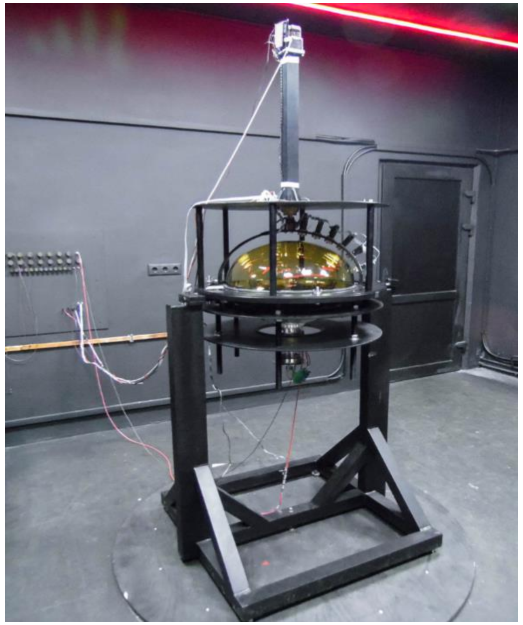


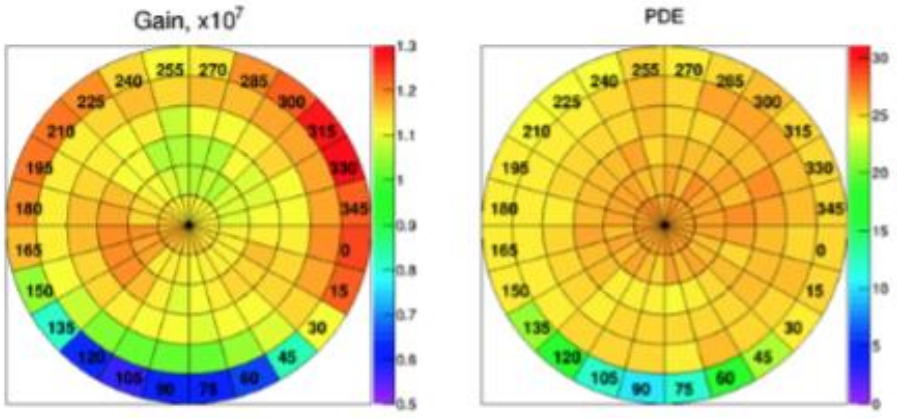
Two identical testing systems set up in commercial shipping (reefer) containers, capable for testing large numbers of 20-inch PMTs

- **36 drawer boxes** = channels for PMT testing per container
- **Climate control unit** + improved **magnetic shielding** of the container interior (down to 10% EMF)
- Every channel is equipped with **two light sources** @ **420 nm**:
  (1) self-stabilized LED (provided by *JINR Dubna*)
  (2) picosecond Laser system
- **Homogeneous illumination** of the whole PMT photocathode at very low light intensities ($\mu \sim 0.05 - 2$ p.e.)
- Fully equipped with **commercial data taking electronics**
- PMT characterization supervised by **fully automated data acquisition software** based on **LabView**
  → sequence of individual measurements
  → tailored to 24h cycle and optimized to PMTs

Paper to be published in the next few weeks

(2) PMT PHOTOCATHODE SCANNING STATION



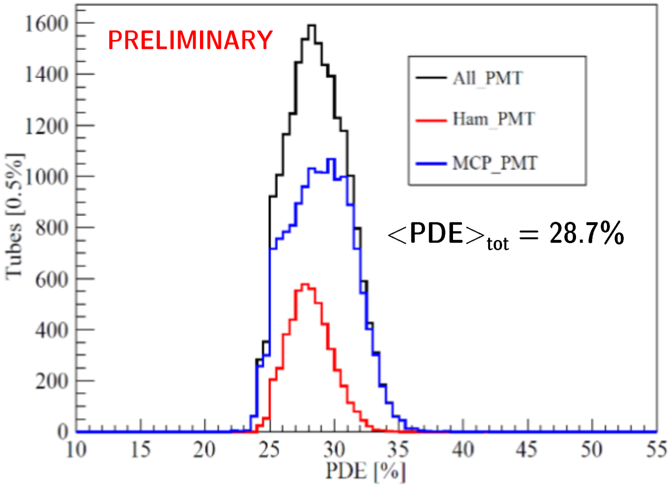


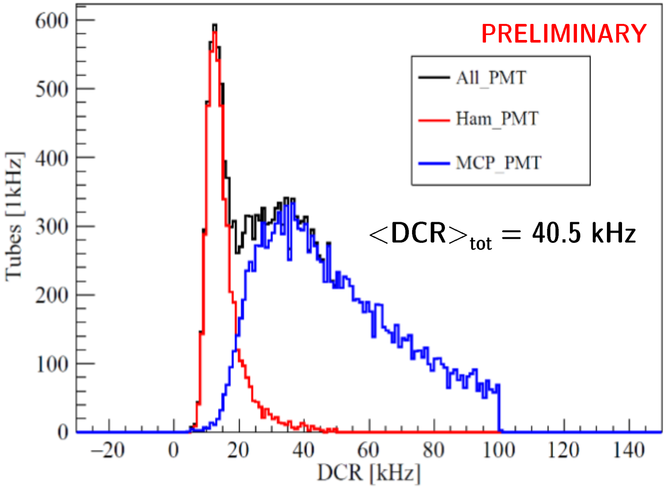
For more information see: arXiv:1705.05012

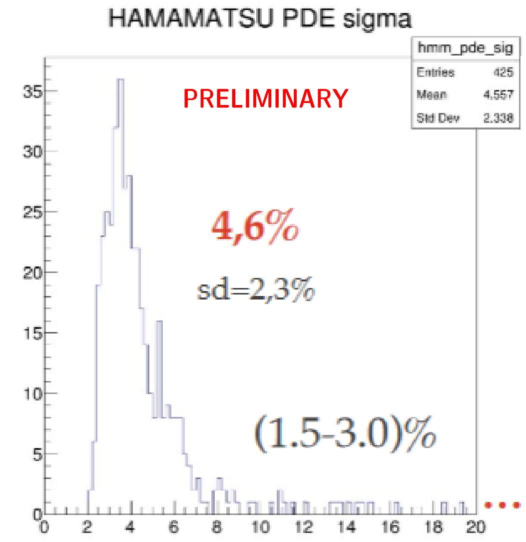
Two identical scanning stations operated in separate dark rooms, capable to perform detailed tests of a representative PMT sub-sample

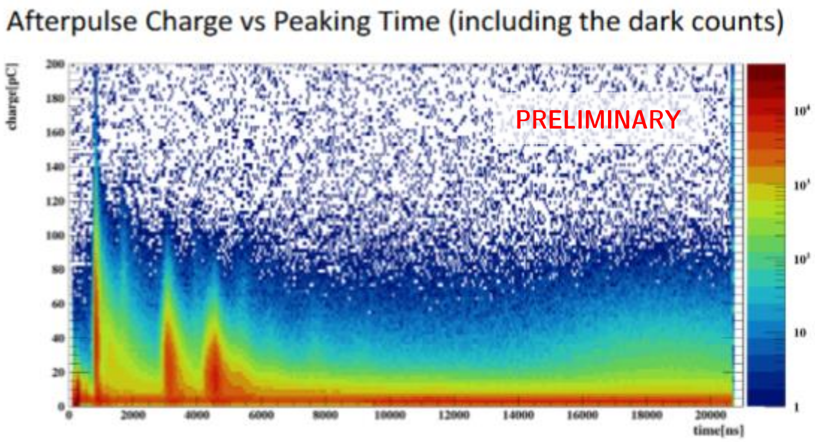
- **7 self-stabilized LEDs** @ **420 nm** at different zenith angles mounted on a **rotatable arch**
  - → individual measurements for each area surface element with very low light intensities (μ ~ 1.5 p.e.)
  - → enables **photocathode uniformity measurements** / scans of the whole PMT photocathode **with high spatial resolution**
- Can also act as complementary system for **cross-checking results** from the PMT mass testing in the containers
- **Active magnetic field suppression** (by Helmholtz coils in the walls)
  - → enables scans and surveys for influence of magnetic fields on the PMT performance (i.e. PDE)
- **Automated data acquisition and analysis**
- Additional setup with LED operated at higher light intensity (μ ~ 100 p.e.) optimized for **afterpulse measurements**

PMT TESTING STATUS AND RESULTS









- **75 containers x months** and **84 scanning stations x months** in total
- **> 22'000 PMT delivered + tested** with the containers
  - → **19950 PMTs accepted** by Jan. 2021
  - → Ham: <PDE> ~ **28.1 %** ; <DCR> ~ **15.3 kHz**
  - → NNVT: <PDE> ~ **28.9 %** ; <DCR> ~ **49.0 kHz**
- Potting of PMTs ongoing
  - → **~ 14500 PMT potted**, of which **4800 PMTs** have been **tested a second time**
  - → **1200 PMTs** additionally tested together with final JUNO readout electronics
- **> 3100 PMTs scanned** within the scanning stations
  - → **600 PMTs** randomly sampled (PDE uniformity)
  - → only **2-3%** with non-uniformity ≥15%
  - → **150 PMTs** tested for after-pulse contributions
- **Very good agreement of PMT testing results between container system and scanning station**
- PMT performance + testing result paper in preparation

Thank you.

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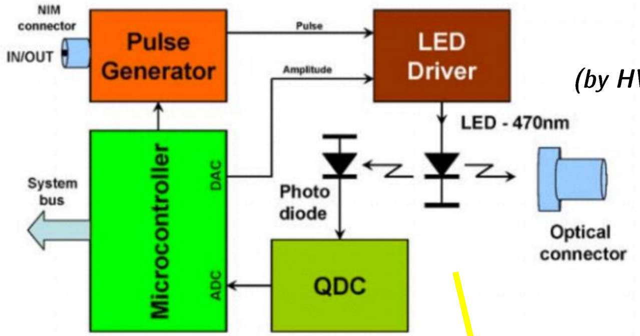
BACKUP

CONTAINER SYSTEM DETAILS

- ➢ **Capable to characterize all 20‘000 20-inch PMTs with good precision** (e.g. ΔPDE $<$ 1%, S/N $>$ 10)
- ➢ **Stable and comparable conditions for all PMT tests**
- ➢ **PMT testing must fit to the JUNO schedule**



(by HVSys Dubna)

ADVANTAGES OF REEFER CONTAINERS:

- ✓ ***Multi-channel system***
- ✓ Very good ***light tightness***
- ✓ ***Stable environmental conditions*** thanks to climate control units installed to the containers
- ✓ Good ***shielding against*** electromatic ***noise*** and stable ***magnetic fields*** (such as the EMF)
- ✓ High ***flexibility*** and ***versatility***

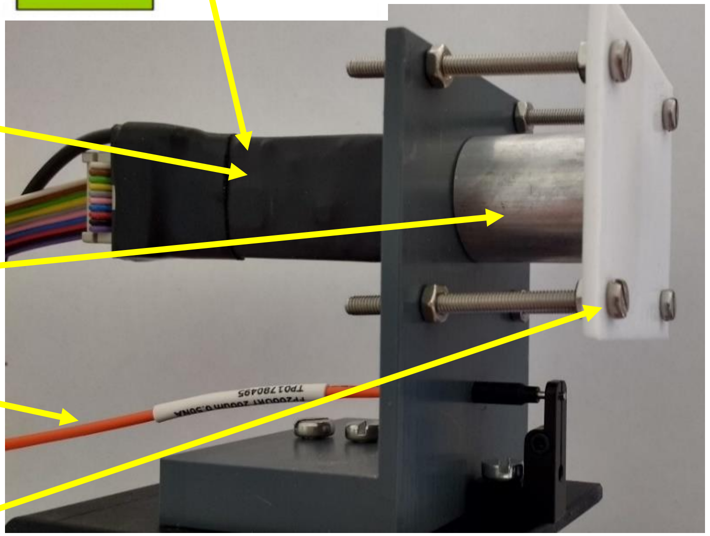
Main light source:

Self-stabilized LED (420 nm) by *HVSys*

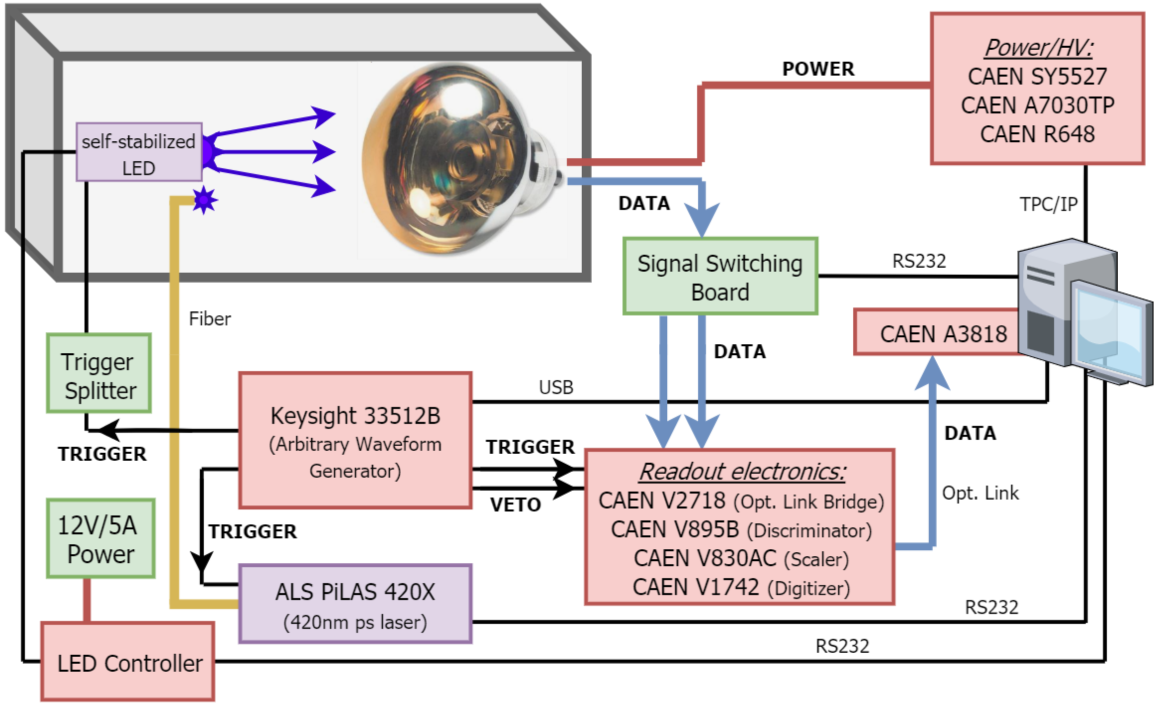
Collimator (aluminum, 1.2 mm hole), equipped with neutral density filter for light attenuation

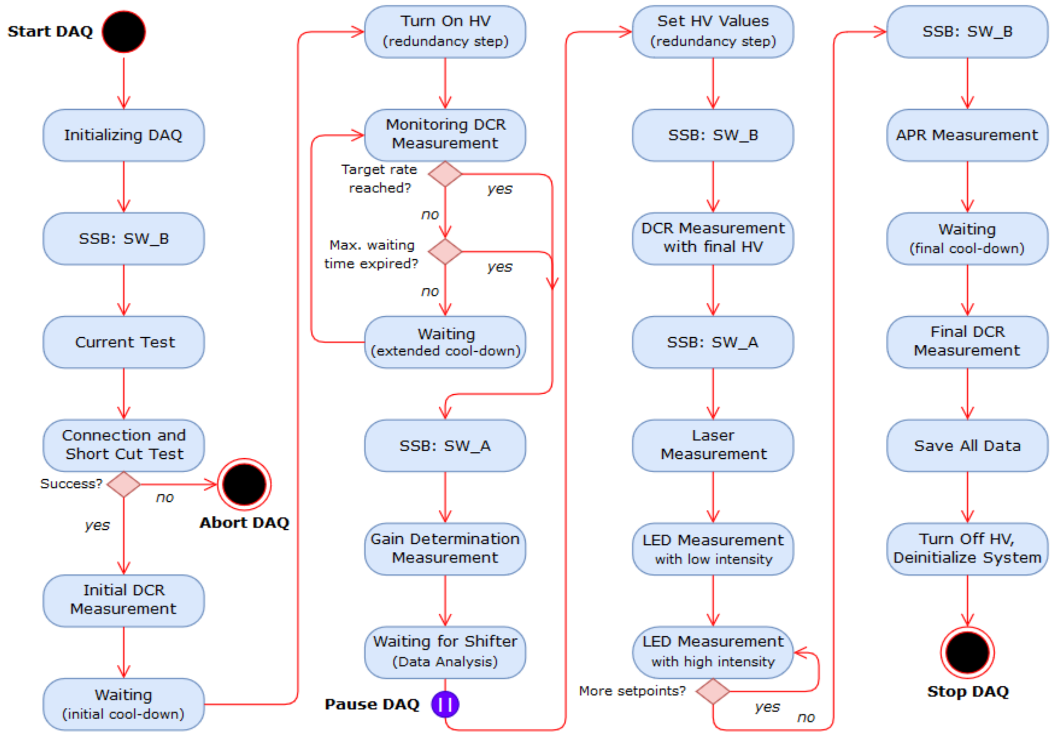
Optical fiber connected to ps-Laser (420 nm)

PTFE diffuser



CONTAINER SYSTEM DETAILS II

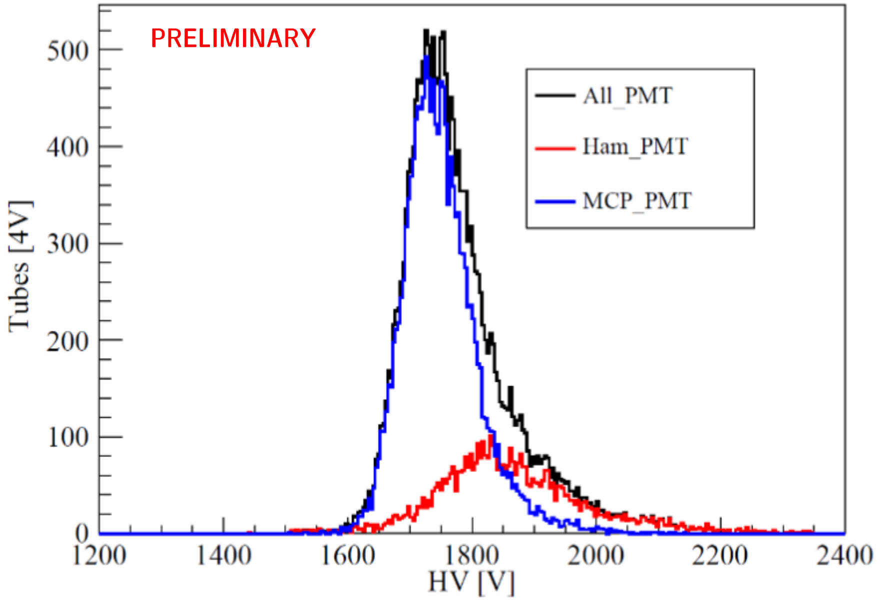


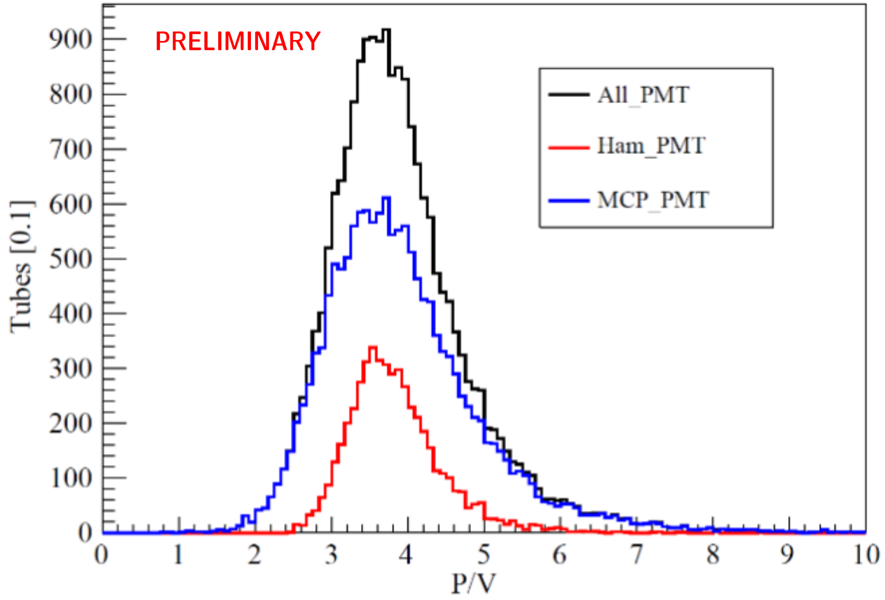


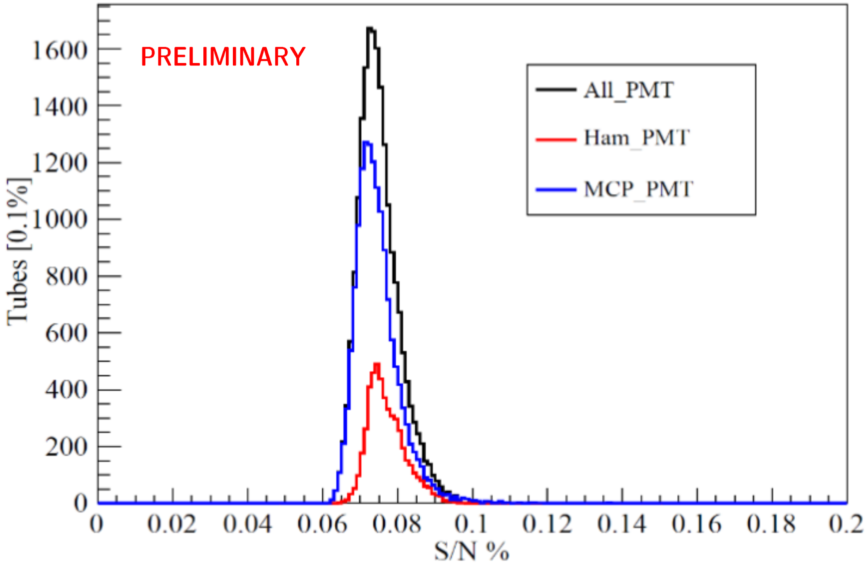
- ✓ Two containers equipped with **commercial data taking electronics** covering all 36 channels per container
- ✓ Controlled and monitored via PC (onsite and remotely)

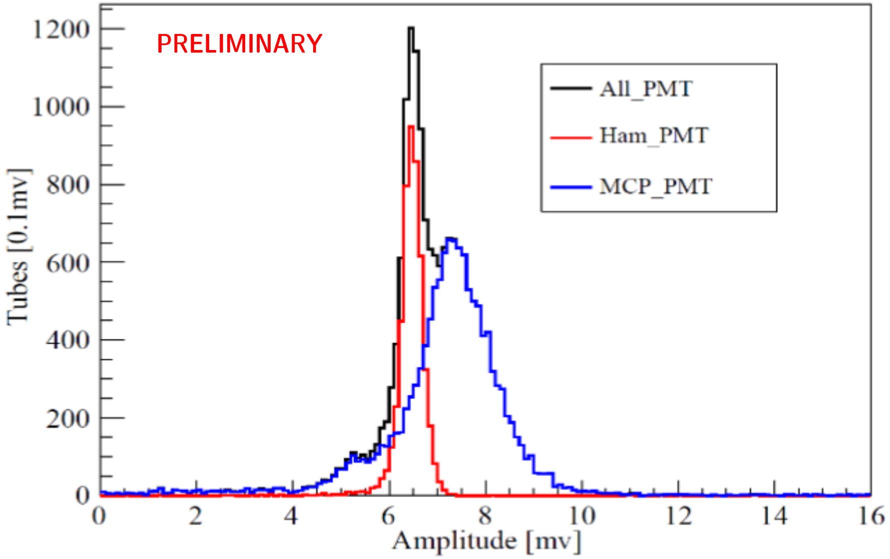
- ✓ **Fully automated data acquision software** (DAQ)
  - → based on LabView
  - → sequence of individual measurements, performing a **full PMT characterization**
  - → **remote operation during the Covid19 pandemic**

MORE (exemplary) PMT RESULTS ACQUIRED BY THE CONTAINER SYSTEM

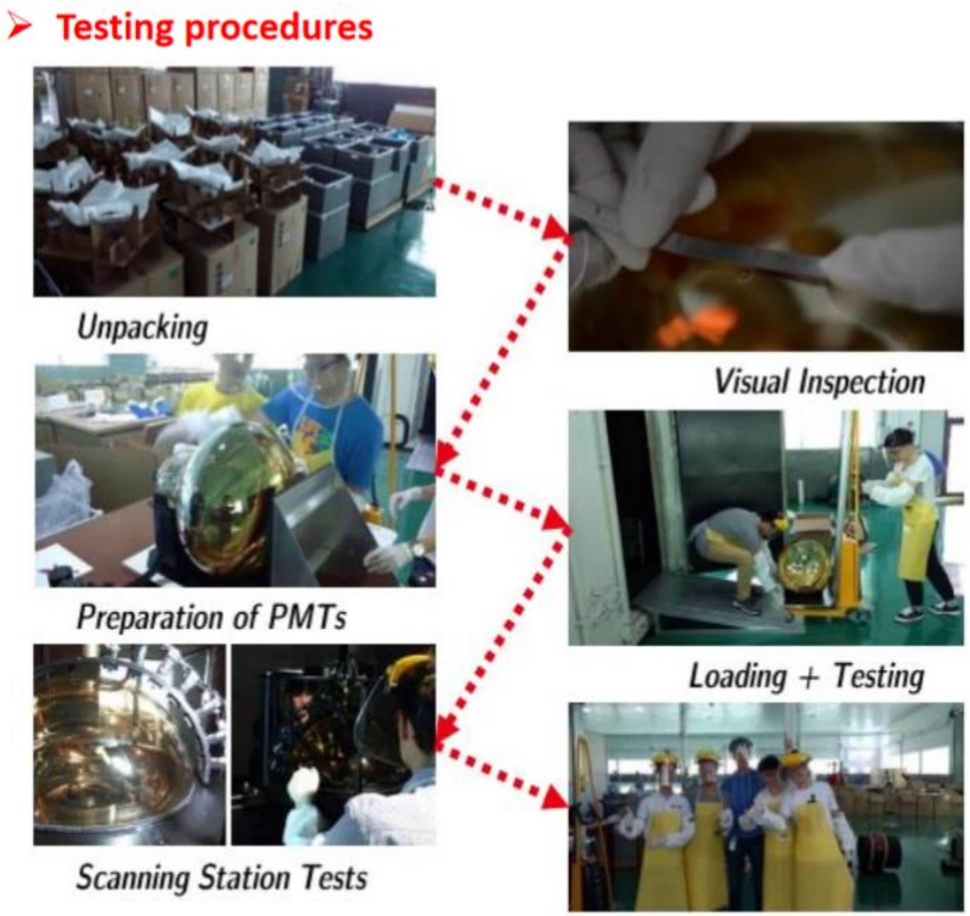


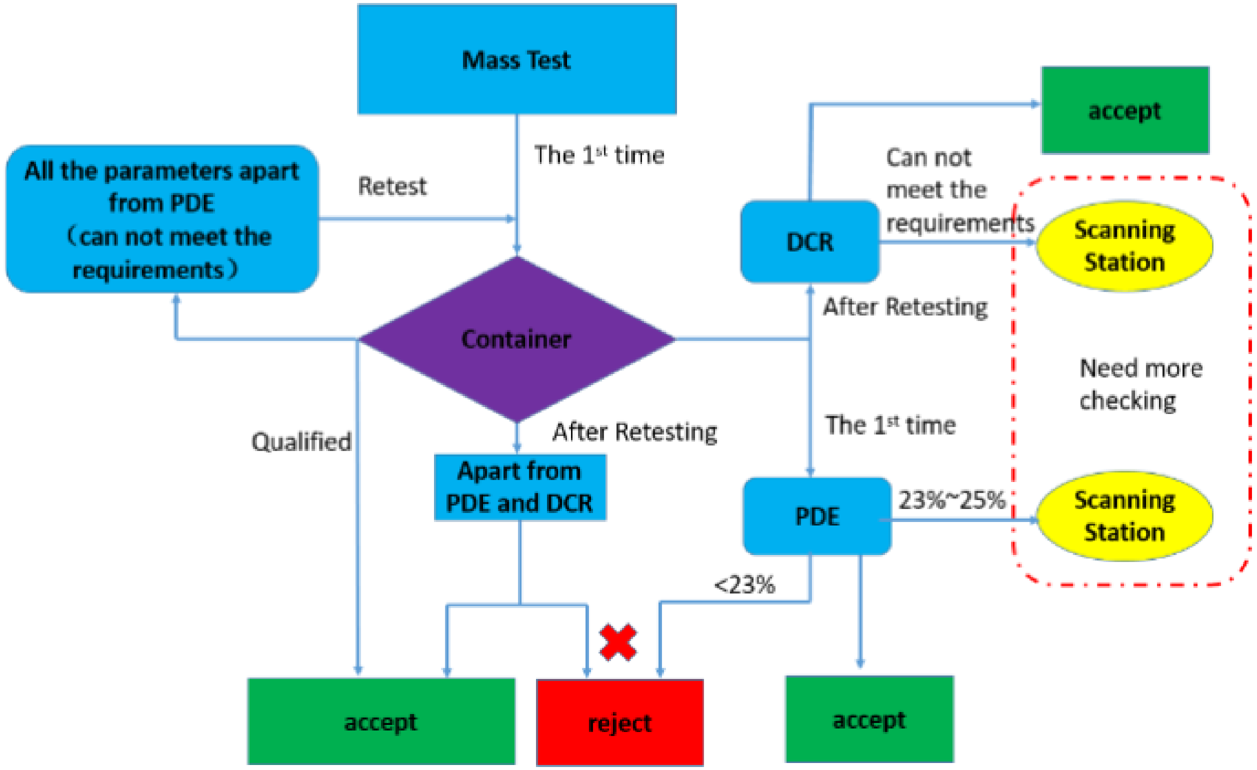






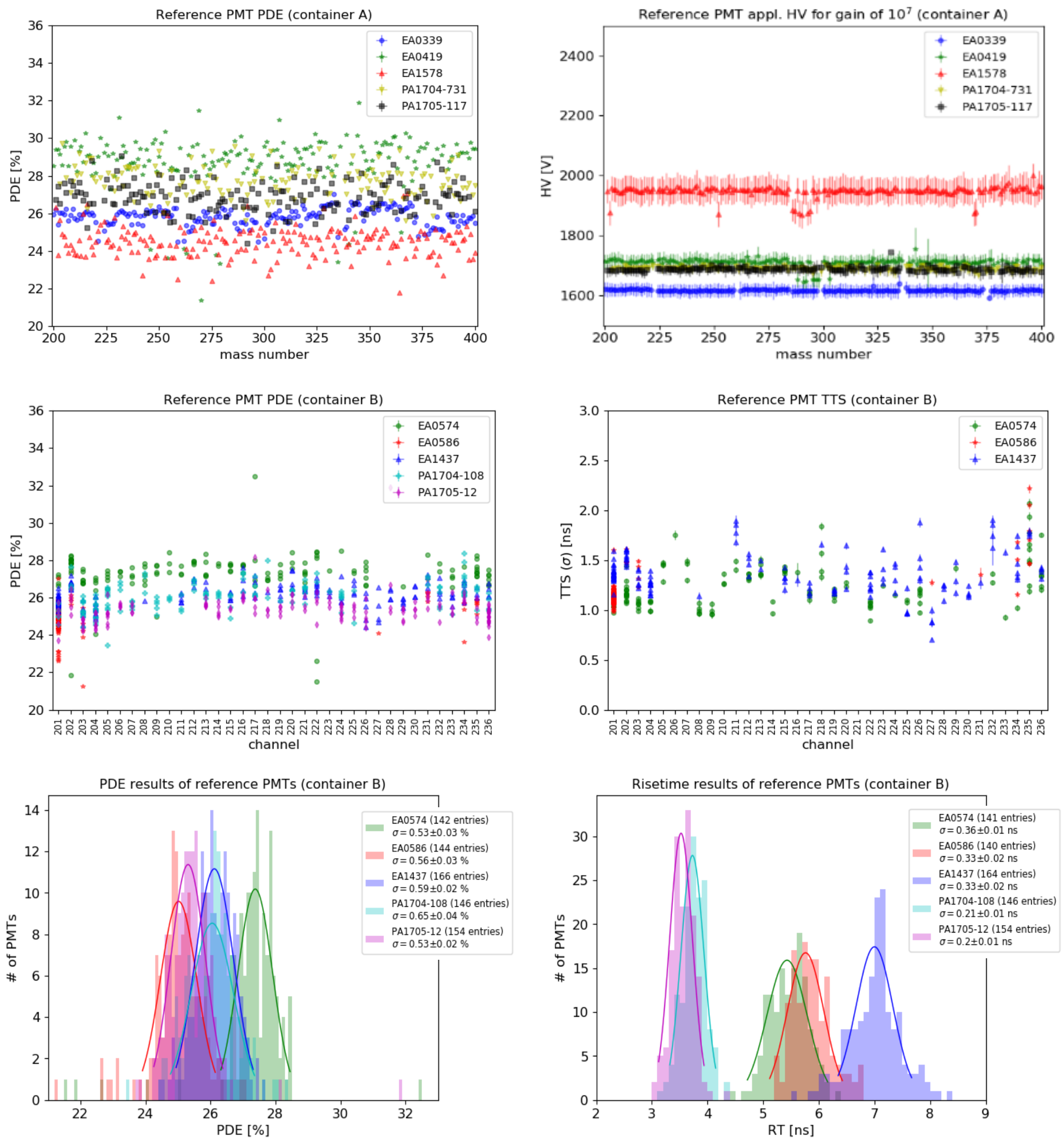
TESTING PROCEDURE AND PMT CLASSIFICATION CRITERIA





compare also *J.Phys.Conf.Ser.* 1468 (2020) 1, 012197

PERFORMANCE SURVEY FOR THE PMT CONTAINER SYSTEM



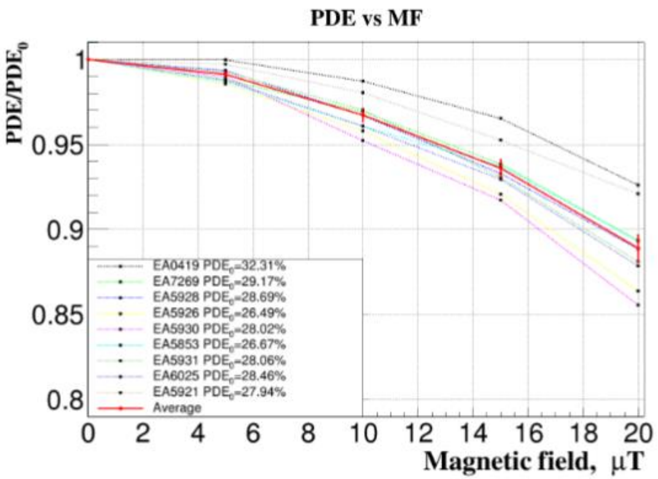
Several studies were made to proof the **capability of the container system** and **estimate its accuracy and systematics**:

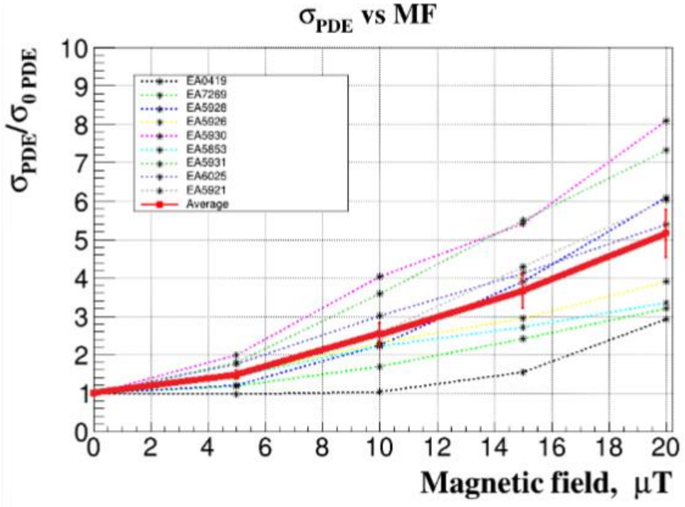
- Analysis of reference PMT* data from 200 consecutive runs of both containers
  - → very good stability over time for (almost) all parameters observed
  - → only negligible systematic effects between different channels
  - → accuracy / result reproducibility within the aimed specifications (e.g. **Δ(PDE) < 1%, Δ(RT, TTS) ≪ 1 ns, Δ(HV) < 5 V**, …)
- Cross-check of results between two containers using ~ 250 PMTs, showing consiting results between both containers
- Remaining differences / systematic effects between containers quantified and under control
- Additional surveys about noise level, light tightness, jitters, … performed

*) reference PMTs = up to 5 PMTs per container which are characterized together with the untested PMTs in each container run, with main purpose to monitor the system for stability over time and reproducibility of testing results

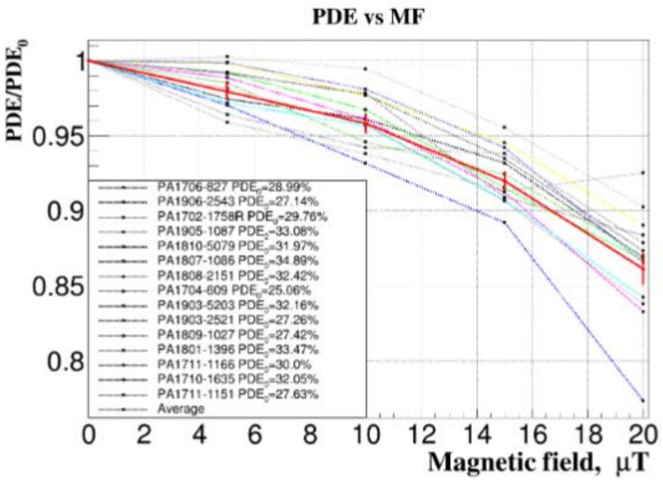
MAGNETIC SENSITIVITY OF PMTS

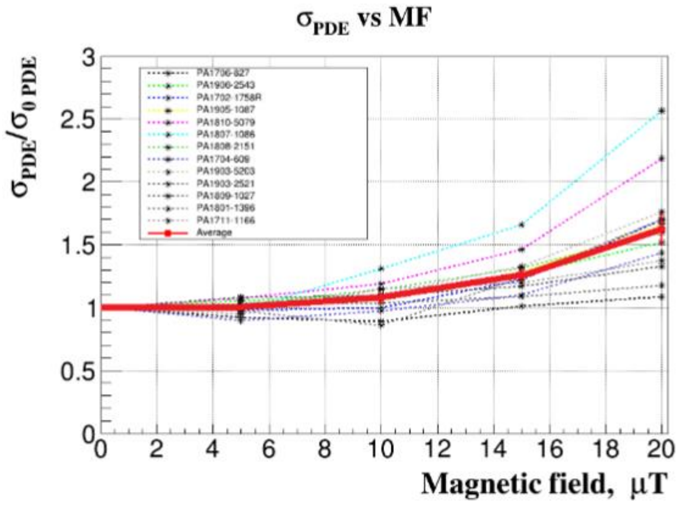
Hamamatsu PMTs





NNVT PMTs





SCANNING STATION CALIBRATION