



Mass Production of MCP-PMT for JUNO and Development of 20-inch MCP-PMT with TTS Improved

Ling Ren

On behalf of MCP-PMT Group



NVT North Night Vision Technology Co., Ltd

5th International Workshop on New Photon-Detectors (PD18)

Outline

- ◆ **1. Mass production of 20-inch MCP-PMT for JUNO**
 - ✓ *The process of R&D , from 8-inch to 20-inch*
 - ✓ *The improvement of QE in 2018*
 - ✓ *Delivery 7392 tubes to JUNO*
- ◆ **2. The batch test of MCP-PMTs in NNVT**
 - ✓ *The brief of batch test system*
 - ✓ *Batch test process*
 - ✓ *Test result of 7392 MCP-PMTs for JUNO*
- ◆ **3. Development of 20-inch MCP-PMT with TTS improved**
 - ✓ *Simulation and analysis*
 - ✓ *Test result of the new MCP-PMT*
 - ✓ *Get a new order from LHAASO*

1.1 The process of large area MCP-PMT R&D

2011

MCP-PMT
group

2012

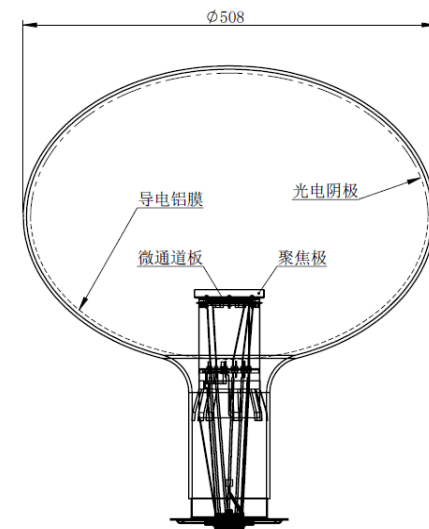
8-inch
MCP-PMT
prototype

2014

20-inch
MCP-PMT
prototype

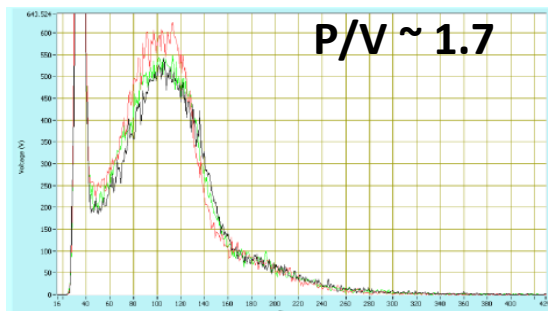
2014

Optimize the
constructor



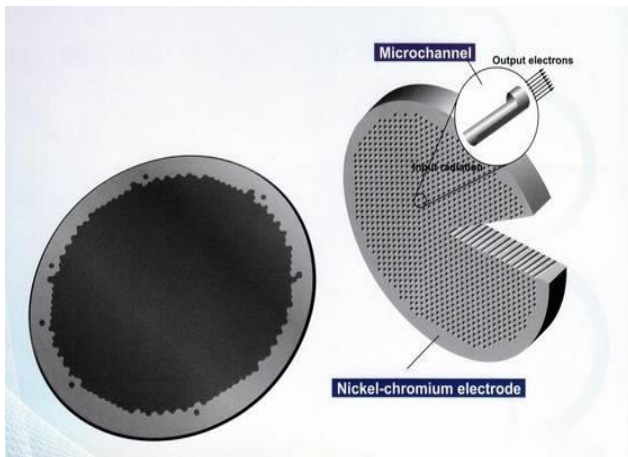
Group members:

IHEP
NNVT
OPT
NJU

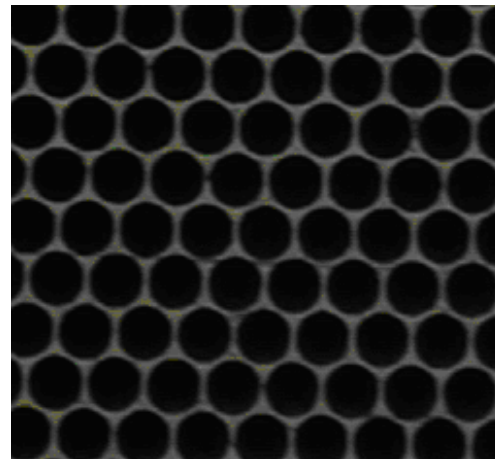


The collection efficiency was about 65% by optimizing the glass bulb constructor.

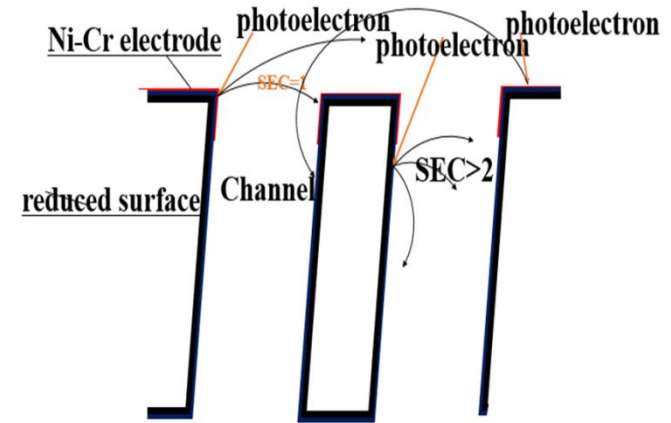
1.1 The process of large area MCP-PMT R&D



Traditional technology MCP

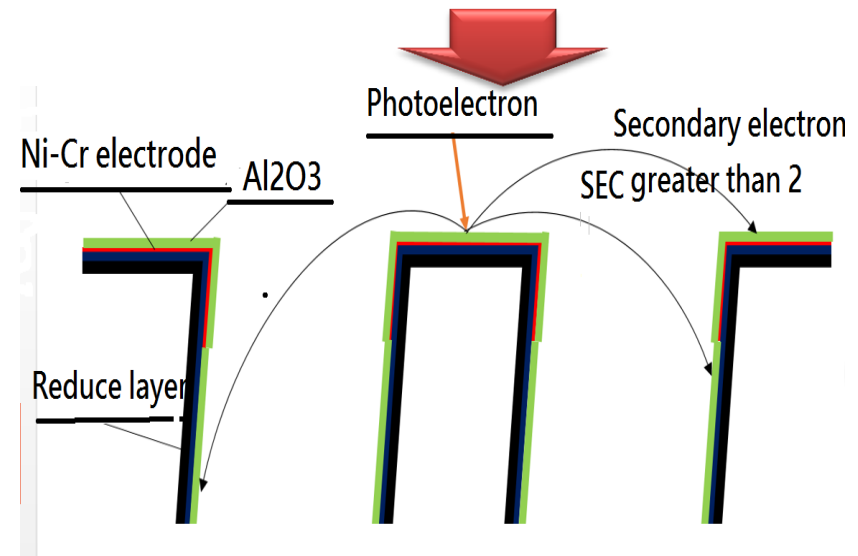


Open area ratio is difficult to achieve more than 70%



It is decided that the collection efficiency can not reach more than 70%.

The collection efficiency of MCP is over 98%. This is a direct benefit of ALD technology, and the secondary emission coefficient of Aluminum oxide film is higher than that of traditional MCP.



1.1 The process of large area MCP-PMT R&D

2015

20-inch
MCP-PMT

2015

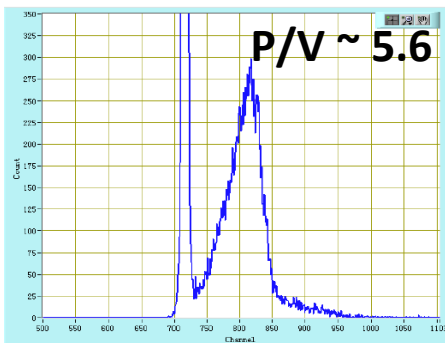
Bidding for the
75% order of
JUNO

2016

Production
line

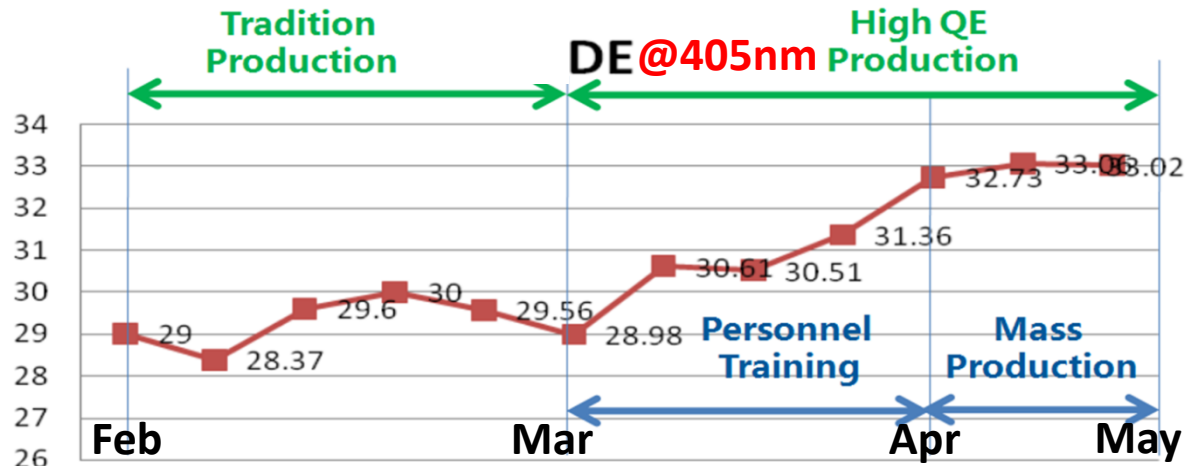
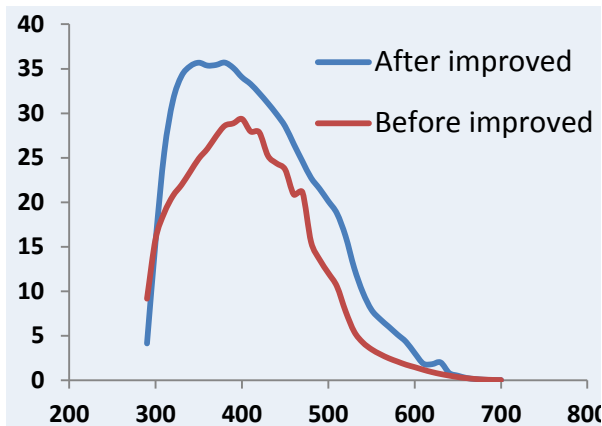


In mass
production
.....

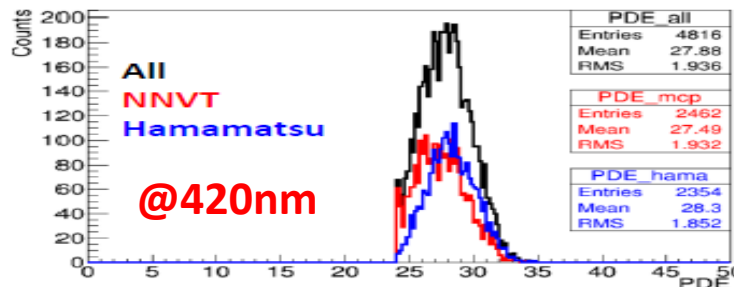


In order to finish the mass production of 20-inch MCP-PMT for JUNO, a production line of 7500 tubes per year was built on November 25th 2016.

1.2 The improvement of QE in 2018



- For the early delivered PMTs (batch # 1 to #17)



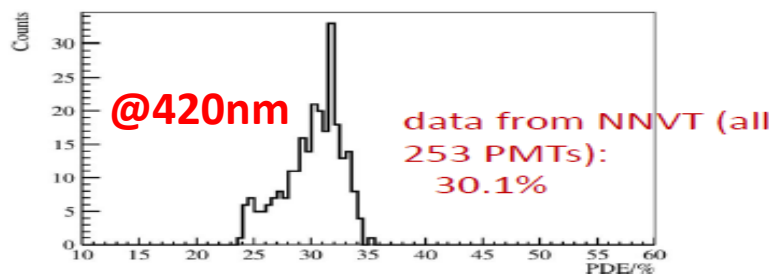
Averaged PDE: 27.9%

-NNVT: 27.5%

-Hamamatsu: 28.3%

- For the newly delivered NNVT PMTs (Batch # 18, 253 pieces)

PDE is largely improved : 30.1% in average, 35% for the highest



The result was published in ICHEP2018 in Seoul by IHEP. PDE is largely improved to 30.1% from 27.5%.

1.3 Delivery 7392 tubes to JUNO

Till now, NNVT had delivered a total of 7392 PMTs, among which 4000 PMTs were delivered in last year.



HDE MCP-PMT

All the PMTs were of high detection efficiency (DE) since June 2018, and the average DE was increased to above 30% by optimizing photocathode process to improve QE.

Studies for reducing the dark count rate are ongoing with reconsidering material or structure of photocathode.

Outline

- ◆ 1. Mass production of 20-inch MCP-PMT for JUNO
 - ✓ *The process of R&D , from 8-inch to 20-inch*
 - ✓ *The improvement of QE in 2018*
 - ✓ *Delivery 7392 tubes to JUNO*
- ◆ 2. The batch test of MCP-PMTs in NNVT
 - ✓ *The brief of batch test system*
 - ✓ *Batch test process*
 - ✓ *Test result of 7392 MCP-PMTs for JUNO*
- ◆ 3. Development of 20-inch MCP-PMT with TTS improved
 - ✓ *Simulation and analysis*
 - ✓ *Test result of the new MCP-PMT*
 - ✓ *Get a new order from LHAASO*

2.1 The brief of batch test system

Single station test system

(2013.12~2014.03)



W1.5*L1.6*H1.8m

Features:

- *Fiber-optic source*
- *Spot light source*
- *Geomagnetic shielding under 50mGs*
- *Adjustable high voltage*
- *Manual operation*
- *Lower test efficiency*
- *R&D*

Batch test system

(2016.10~2017.02)

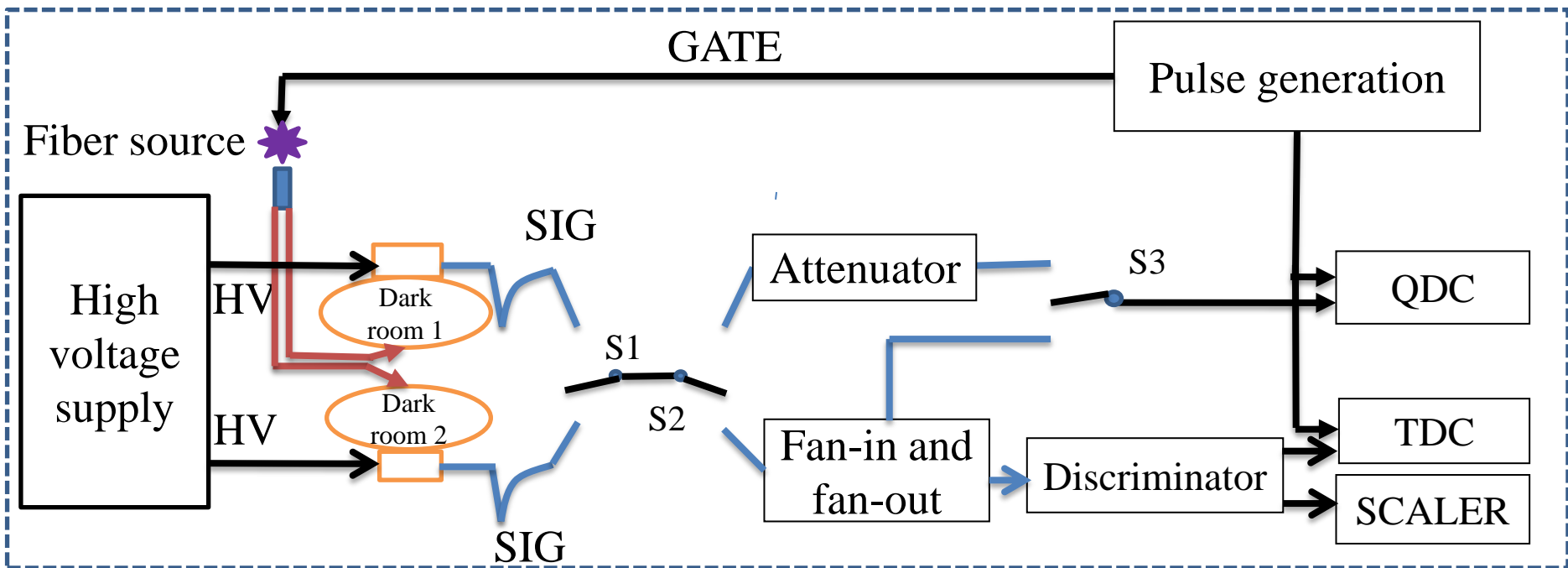
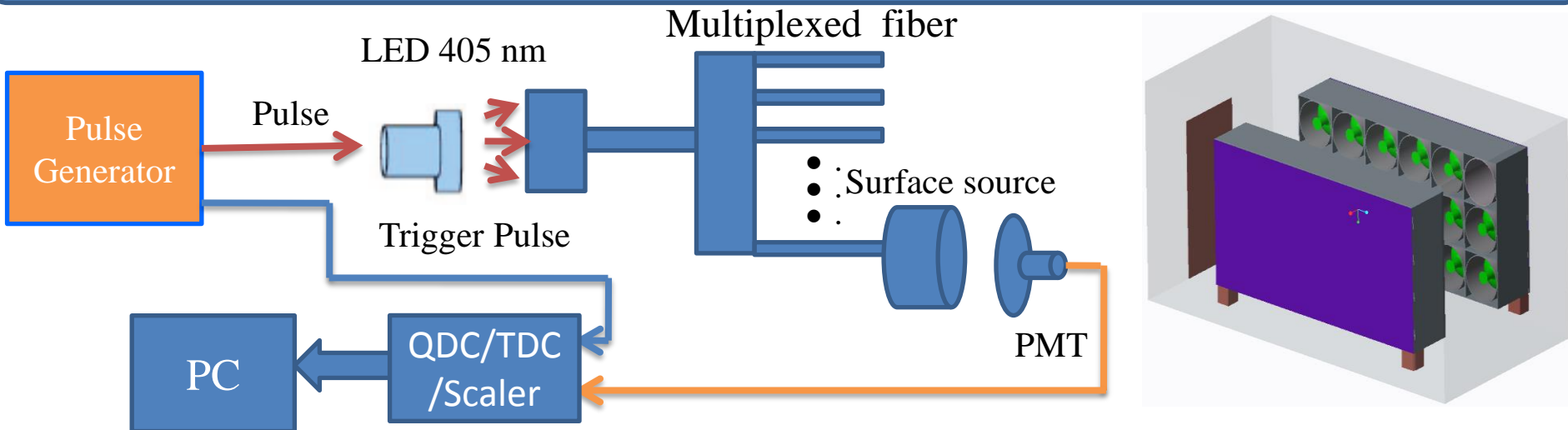


W3.3*L5*H2.5m

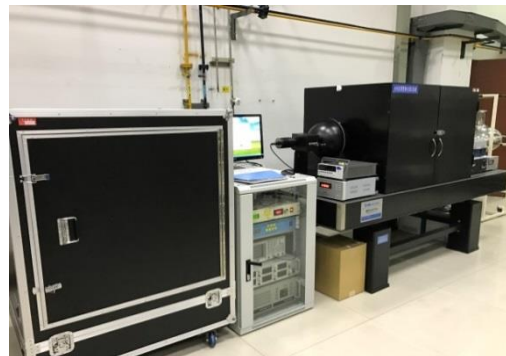
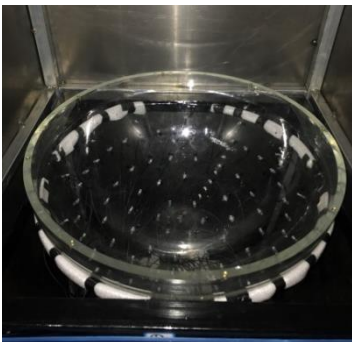
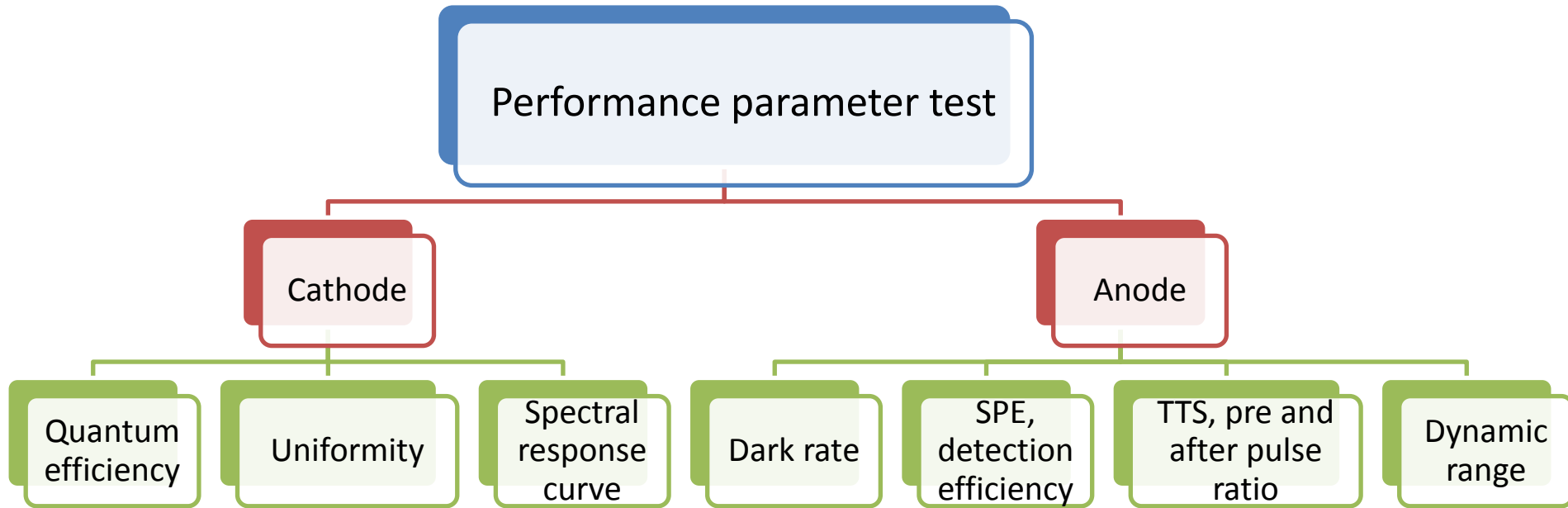
Features:

- *multiplexed fiber-optic source*
- *Surface light source*
- *Geomagnetic shielding under 50mGs*
- *Semi-automation*
- *Test 32 tubes every time*
- *Three dark rooms*
- *Mass production*

2.1 The brief of batch test system

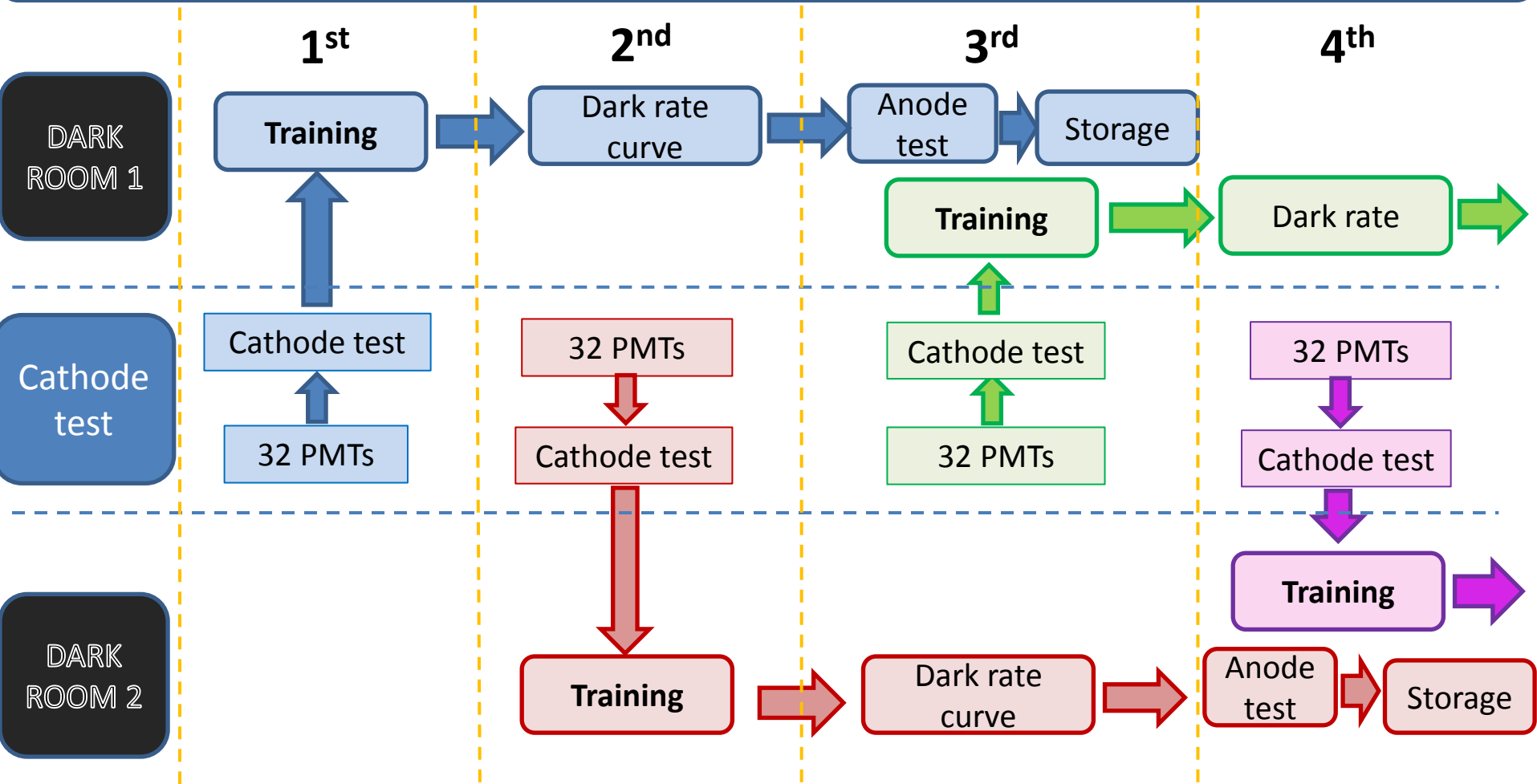


2.2 Batch test process



The batch test system of MCP-PMT in NNVT includes static parameter test system(cathode performance) and dynamic parameter test system(anode output performance).

2.2 Batch test process



To retest the MCP-PMTs produced 15 days ago.



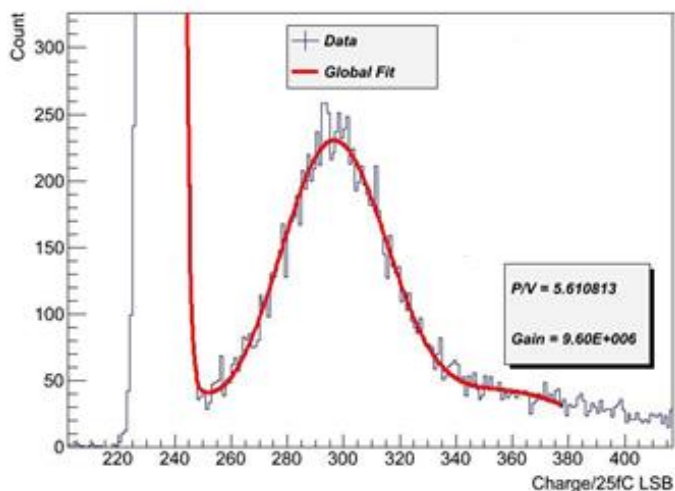
2.3 Test result of 7392 MCP-PMTs for JUNO

| PMTs | MCP-PMT prototype | ~300 MCP-PMTs | ~1000 MCP-PMTs | ~7392 MCP-PMTs |
|--------------------------|-------------------|---------------|----------------|----------------|
| DE @ Gain~1E7 | 26% | 28.9% | 29.3% | 30.2% |
| Uni-QE @ 405nm | < 10.5% | 8.1% | 7.8% | 7.3% |
| Dark count rate@ 0.25 PE | 30.0 kHz | 33.5 kHz | 36.9 kHz | 38.2 kHz |
| Peak valley ratio | 5.6 | 8.2 | 7.1 | 7.1 |
| Energy resolution | 41% | 30.9% | 33.1% | 30.1% |
| High voltage | 1930V | 1780V | 1767V | 1747V |
| Rise time | 1.2ns | 1.4ns | 1.4ns | 1.4ns |
| After pulse rate | 2.5% | 1.2% | 0.8% | 0.6% |
| Linearity <10% | 1000 P. E. | 1175 P. E. | 1160 P. E. | 1308 P. E. |

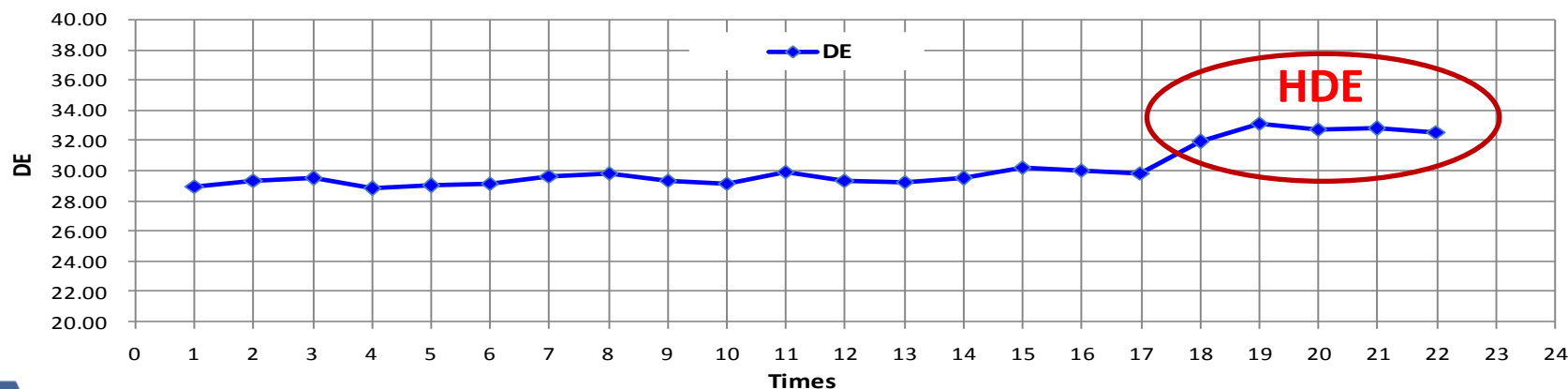
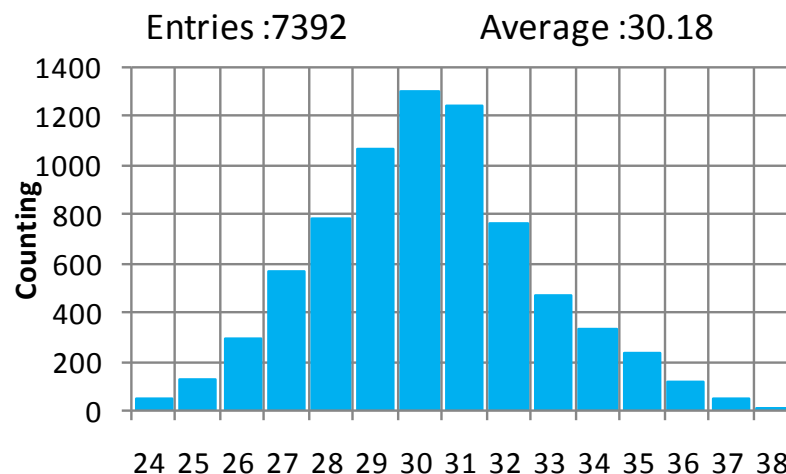
2.3 Test result of 7392 MCP-PMTs for JUNO

| PMTs | MCP-PMT prototype | ~300 MCP-PMTs | ~1000 MCP-PMTs | ~7392 MCP-PMTs |
|---------------|-------------------|---------------|----------------|----------------|
| DE @ Gain~1E7 | 26% | 28.9% | 29.3% | 30.2% |

MCP-PMT SPE



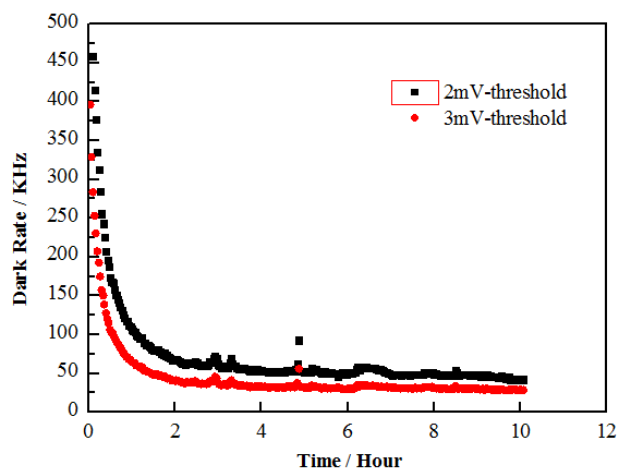
Total shipped MCP-PMTs: ~7392



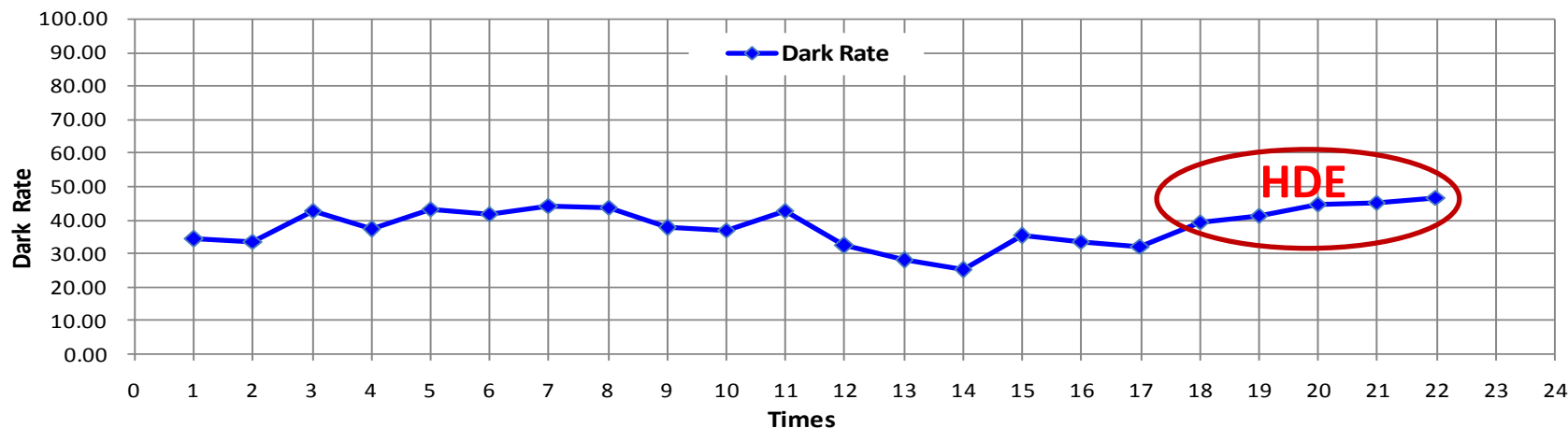
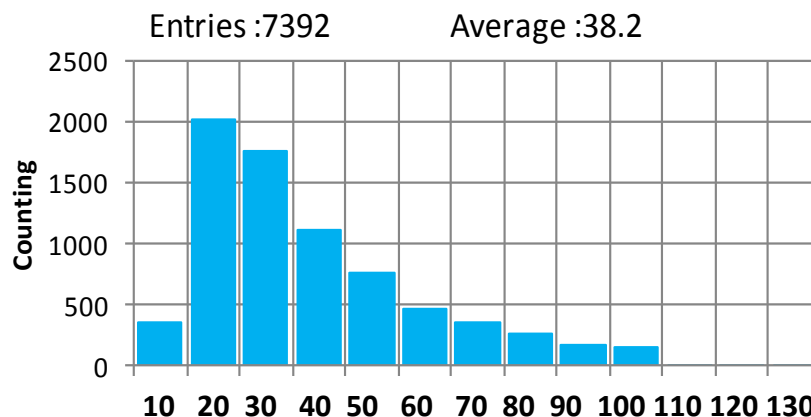
2.3 Test result of 7392 MCP-PMTs for JUNO

| PMTs | MCP-PMT prototype | ~300 MCP-PMTs | ~1000 MCP-PMTs | ~7392 MCP-PMTs |
|----------------|-------------------|---------------|----------------|----------------|
| DR @ 0.25 P.E. | 30 kHz | 33.5 kHz | 36.9 kHz | 38.2 kHz |

MCP-PMT Dark Rate



Total shipped MCP-PMTs: ~7392

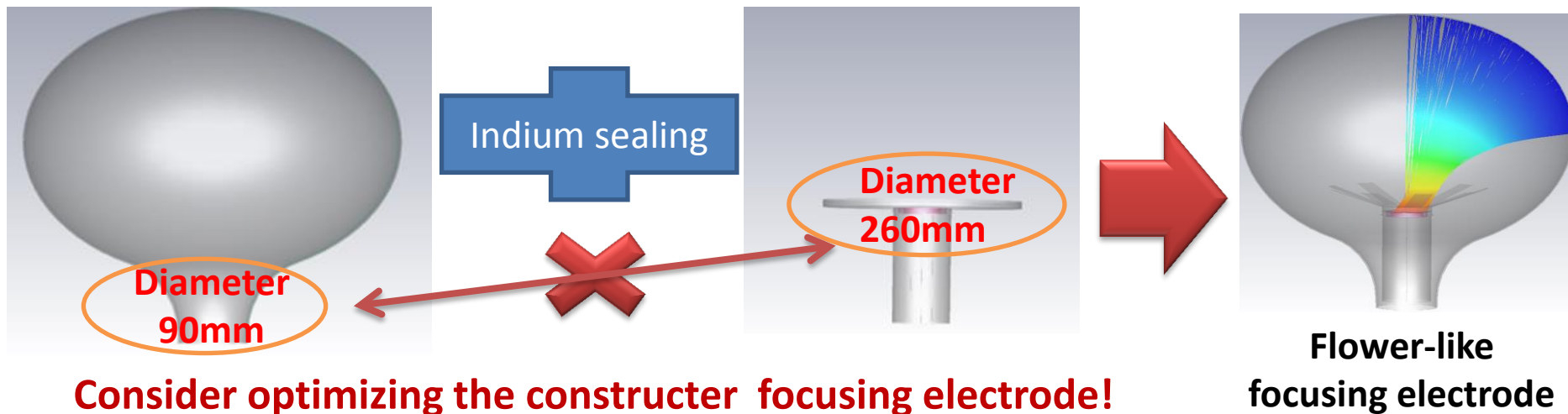
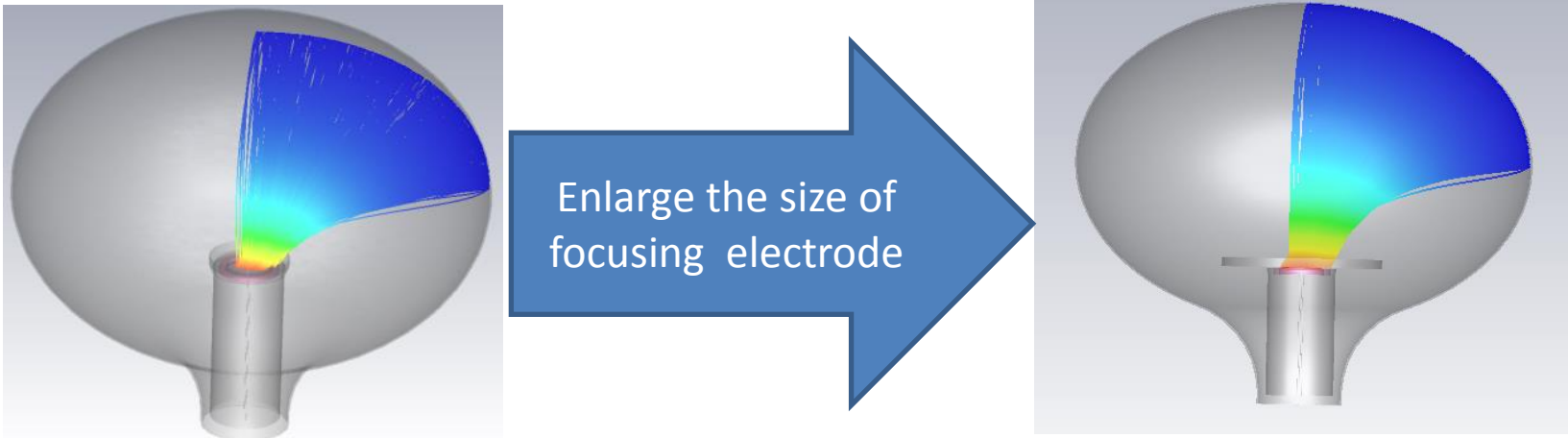


Outline

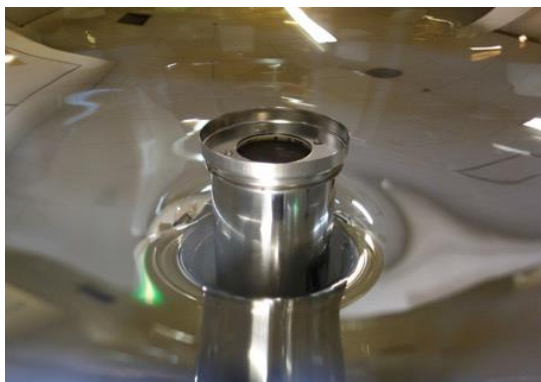
- ◆ 1. Mass production of 20-inch MCP-PMT for JUNO
 - ✓ *The process of R&D , from 8-inch to 20-inch*
 - ✓ *The improvement of QE in 2018*
 - ✓ *Delivery 7392 tubes to JUNO*
- ◆ 2. the batch test of MCP-PMTs in NNVT
 - ✓ *The brief of batch test system*
 - ✓ *Batch test process*
 - ✓ *Test result of 7392 MCP-PMTs for JUNO*
- ◆ 3. Development of 20-inch MCP-PMT with TTS improved
 - ✓ *Simulation and analysis*
 - ✓ *Test result of the new MCP-PMT*
 - ✓ *Get a new order from LHAASO*

3.1 Simulation and analysis

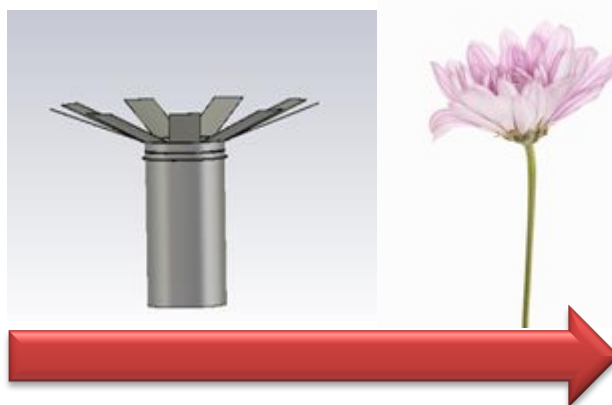
The TTS of the original 20-inch MCP-PMT couldn't meet the requirement of Hyper-K project, and how to improve it?



3.2 Test result of the new MCP-PMT

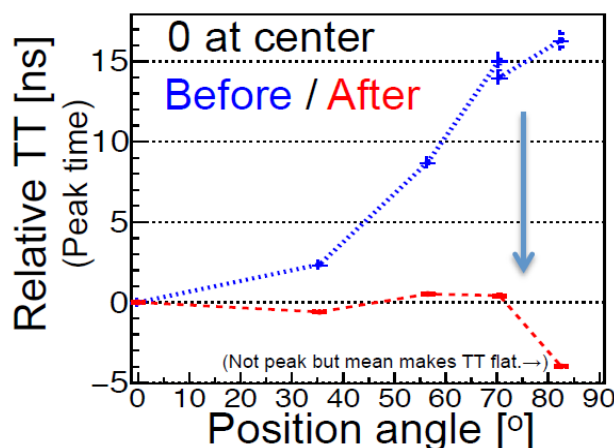
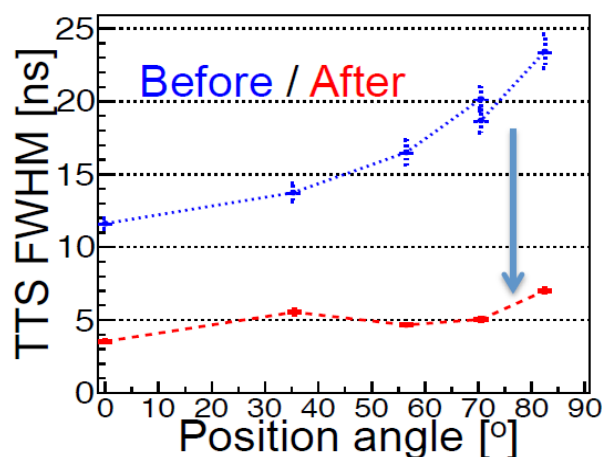


Normal focusing electrode



Flower-like focusing electrode

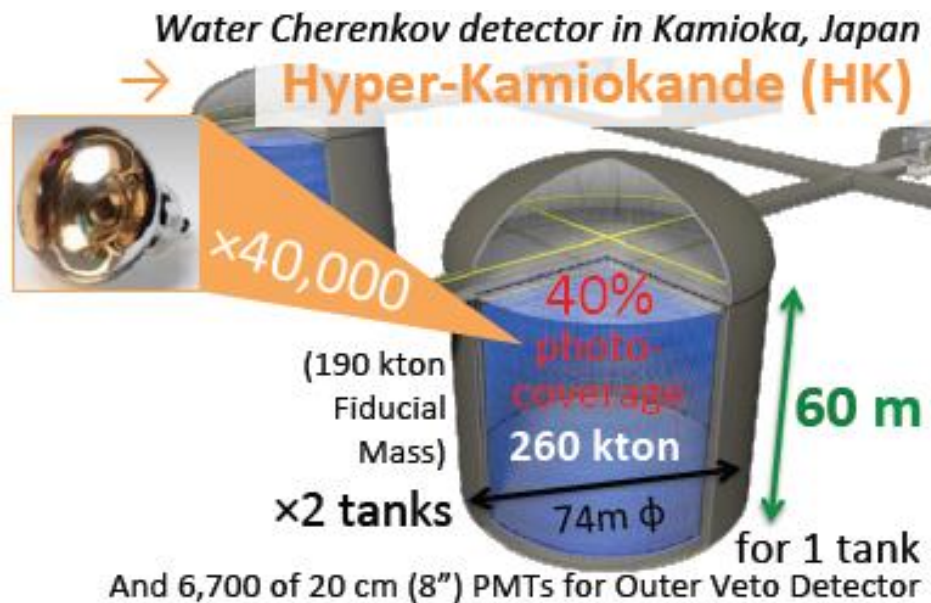
By changing the constructor of the focusing electrode, using the flower-like one, the TTS of the PMTs is improving from 14ns to 5ns, but the CE of the prototype is decreasing to 85%.



| | Normal focusing electrode | Flower-like focusing electrode |
|-----|---------------------------|--------------------------------|
| QE | ~30% | ~30% |
| CE | ~98% | ~85% |
| P/V | ~7 | ~5 |
| TTS | ~14ns | ~5ns |

Thanks for the data supplied by Y. Nishimura (Hyper-K).

3.2 Test result of the new MCP-PMT



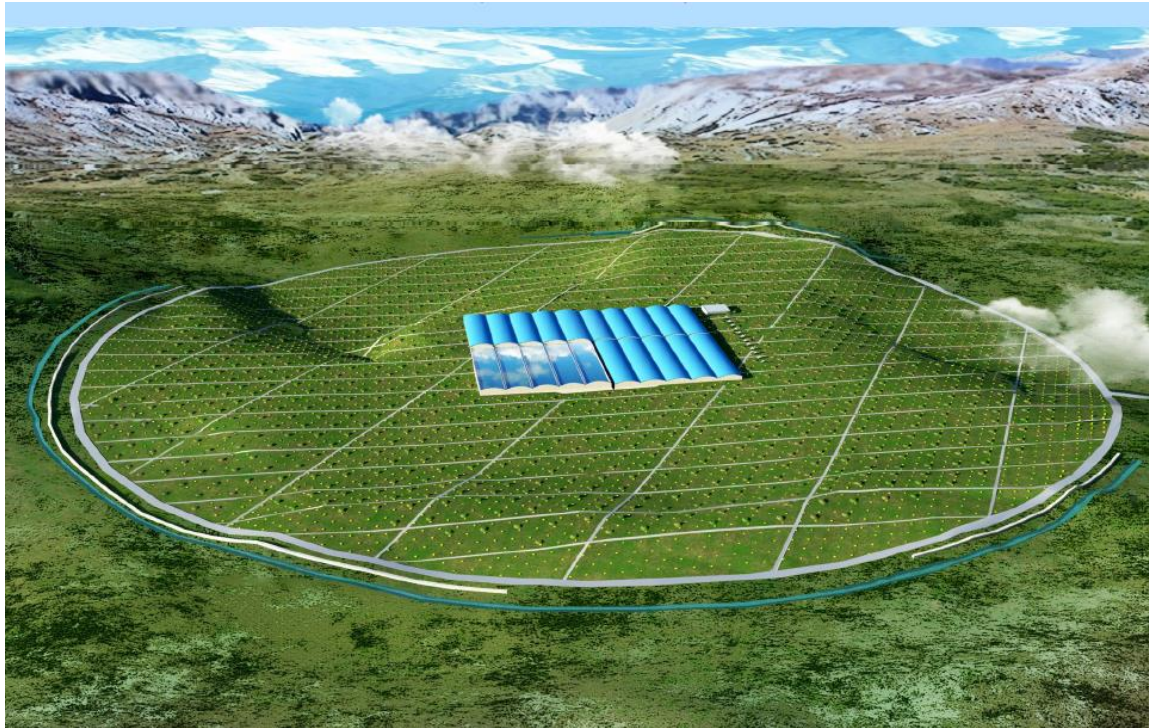
The picture was from the report of Y. Nishimura (Hyper-K).

Tested in NNVT

| tube ID | QE | Voltage | P/V | Energy Resolution | Dark Count Rate | Rise Time | TTS | Dynamic range <10% | After Pulse Rate |
|--------------|-------|---------|-----|-------------------|-----------------|-----------|-------|--------------------|------------------|
| PC1709-2 | 26.7% | 1848V | 4.4 | 38.3% | 11.7kHz | 1.6ns | 6.0ns | 1450 P.E. | 0.15% |
| PC1804-2205 | 32.4% | 1893V | 5.5 | 38.0% | 26.9kHz | 1.6ns | 5.4ns | 1426 P.E. | 0.30% |
| PC1807-2205C | 30.1% | 1885 V | 3.5 | 40.0% | 14.7kHz | 1.4 ns | 5.2ns | 2059 P.E. | 0.29% |

3.3 Get a new order from LHAASO

Large High Altitude Air Shower Observatory (LHAASO), Sichuan Province, China.



On 3rd Sep 2018, the 20-inch MCP-PMT with TTS improved successfully had bided for a new order from LHAASO project, which required for 2270 pieces. Recently, the new 20-inch MCP-PMT is also in mass production.

Conclusion

- NNVT had delivered a total of 7392 PMTs, among which 4000 PMTs were delivered in last year.
- All the PMTs were of high DE since June 2018, and the average DE was increased from 27% to 30%.
- The batch test system could test 32 pieces at the same time, and measure performance parameters such as relative DE, gain, SPE, working voltage, dark count rate, TTS, rise time, after pulse ratio, and dynamic range.
- The TTS of the new 20-inch MCP-PMT with the flower-like focusing electrode were about 5 ns, namely FWHM, better than the one of the original 20-inch MCP-PMT.
- The research on the dark count rate and TTS will be ongoing in future.



Many thanks!

Welcome to visit NNVT in Nanjing, China.

rl@nvt.com.cn