Developing the MCP-based 20-inch spherical Photomulitipliers

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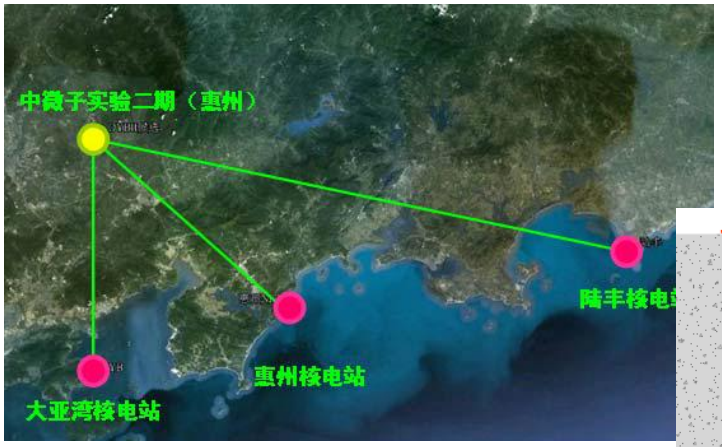
On behalf of the collaboration group

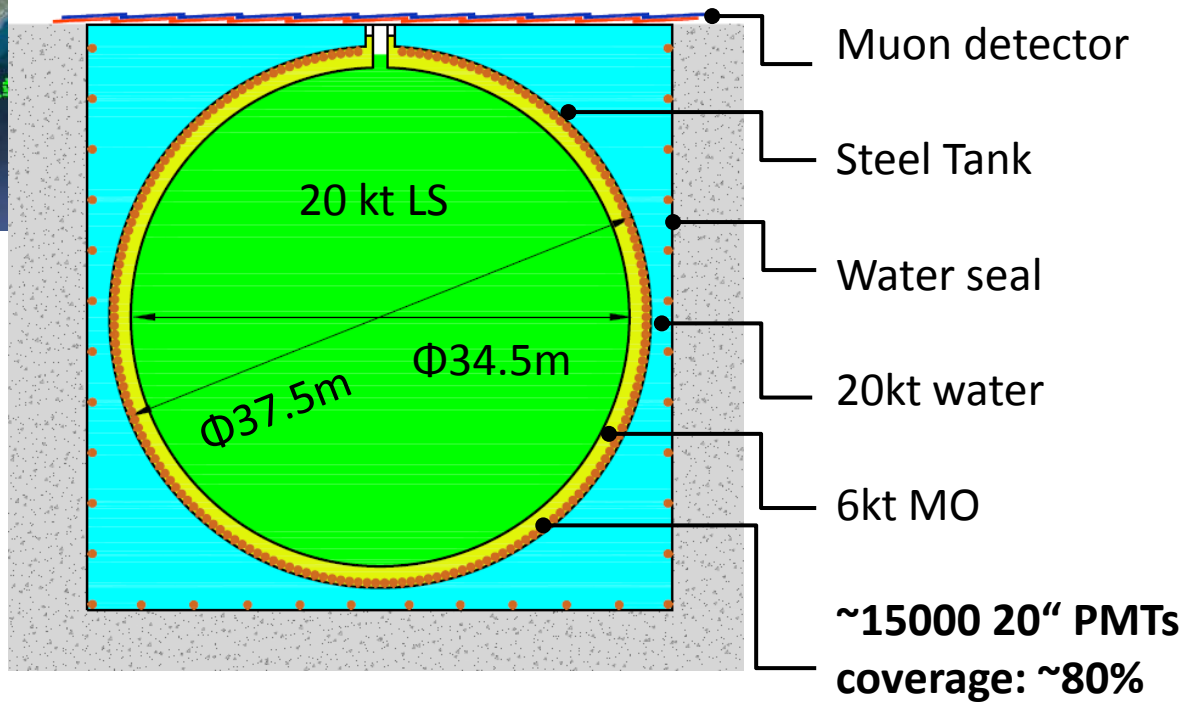
Motivation

For the next generation neutrino experiments in China

To solve the mysteries of the universe by measuring neutrino particles. Relies on a large number of 20-inch diameter photomultipliers.



JUNO, Jiangmen Underground Neutrino Observatory (Former Daya Bay II)



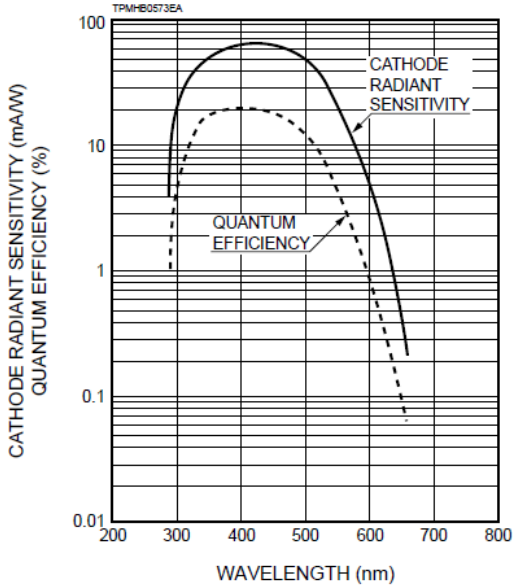
- **Rich physics possibilities**
  - Mass hierarchy
  - Precision measurement of mixing parameters
  - Atmospheric Neutrinos
  - Geo-Neutrinos
  - Solar Neutrinos

Challenges

Challenges compared with **KamLAND (**Kamioka Liquid Scintillator Antineutrino Detector, Japan 2002)

	KamLAND	JUNO
Detector	~1 kt Liquid Scintillator	20 kt Liquid Scintillator
Energy Resolution	6%/√E	3%/√E
Light yield	250 p.e./MeV	1200 p.e./MeV
More photons, how and how many?		
High transparent LS	15m	25m
High light yield LS	1.5g/l PPO	5g/l PPO
Photocathode coverage	**34%**	**80%**
High QE PMT	**20%**	**30%**

Large area PMTs of Hamamatsu



The QE of 20” PMT-R3600

❑ Requirements for photodetectors

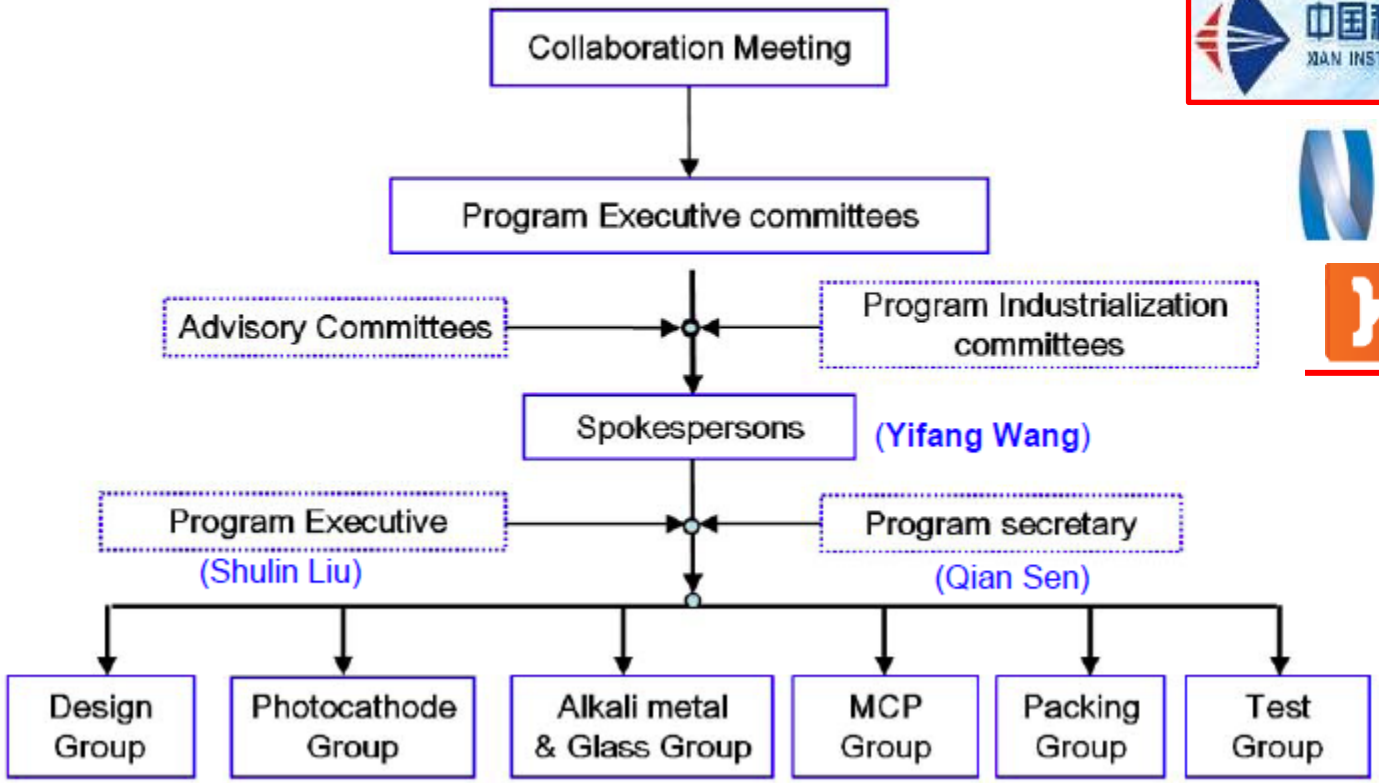
- Large area photocathode
- Temperature /Magnetic environment
- Low cost
- High QE

MCP-PMT R&D collaboration

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Started at 2009, the same time as LAPPD

Microchannel-Plate-Based Large Area Photomultiplier Collaboration (MLAPC)



中国科学院西安光学精密机械研究所
XIAN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS

北方夜视技术股份有限公司
NORTH NIGHT VISION TECHNOLOGY CO.,LTD

海南展创光电技术有限公司
HZC PHOTONICS

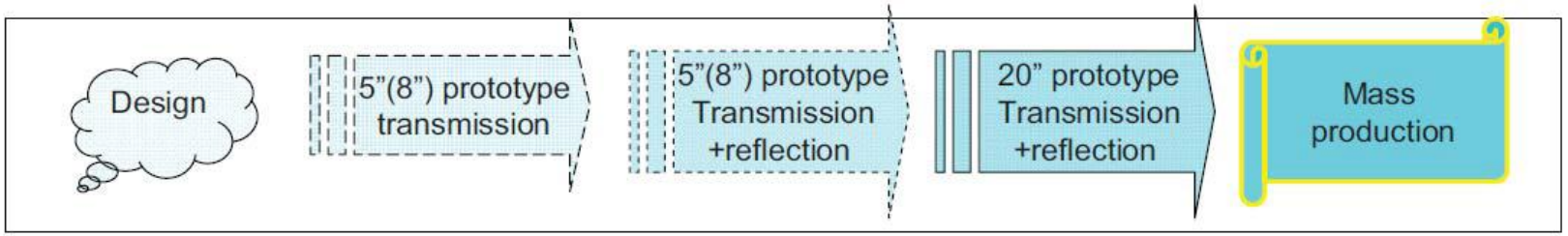
中核（北京）核仪器厂
CNNC Beijing Nuclear Instrument Factory

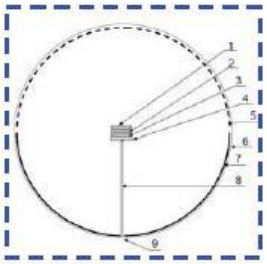
南京大学

宝光股份
BAOGUANG

2 Institutes , 1 University, 4 Companies

The R&D plan





The design of the IHEP-MCP-PMT

The project of Daya Bay II

2009~2010
IHEP
Beginning
5” MCP-PMT

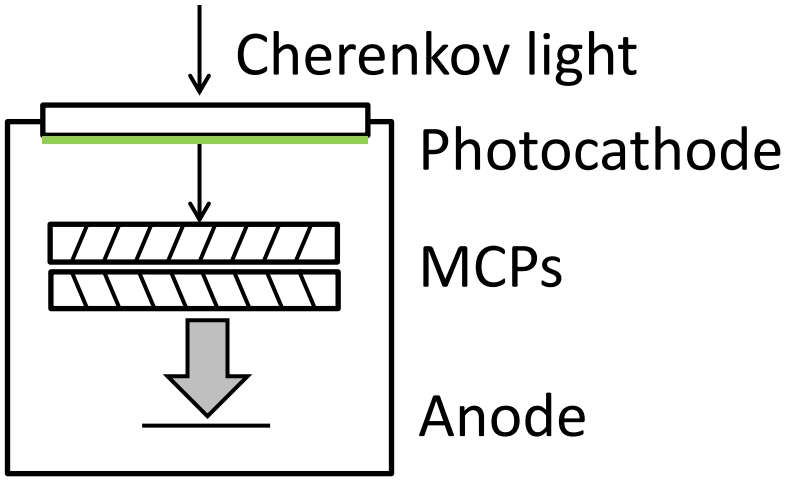
2011 Prototype
Collaboration
8” Dynode PMT
QE=20%
Collaboration
8” MCP-PMT
QE=20%
Trans--photocathode

2012 Prototype
Collaboration
8” Dynode PMT
QE=20%
Collaboration
8” MCP-PMT
QE=20%
Trans—photocathode
Ref--Photocathode

2013 Prototype
Collaboration
12” Dynode PMT
QE=SBA
Collaboration
20” MCP-PMT
QE=20%
Trans—photocathode
Ref--Photocathode

2014 Prototype
Collaboration
20” Dynode PMT
QE=SBA
Collaboration
20” MCP-PMT
QE=SBA
Trans—photocathode
Ref--Photocathode

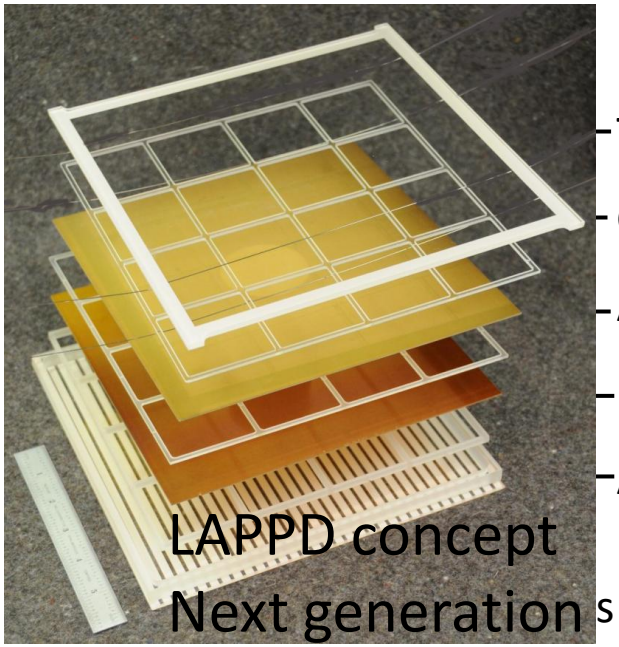
Status

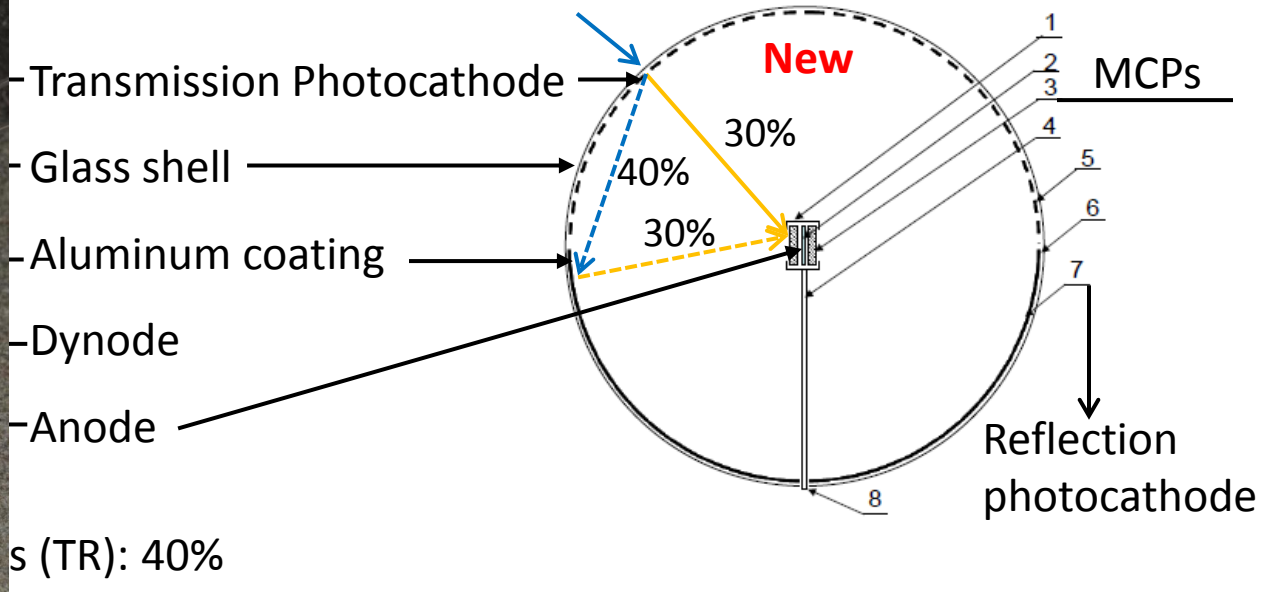


- Design
- Glass shell
- MCP
- Photocathode
- Prototype

The design of new MCP-PMT

- **Using two sets of Microchannel plates (MCPs) to replace the dynode chain**
- **Using transmission photocathode (front hemisphere) and reflection photocathode (back hemisphere)**



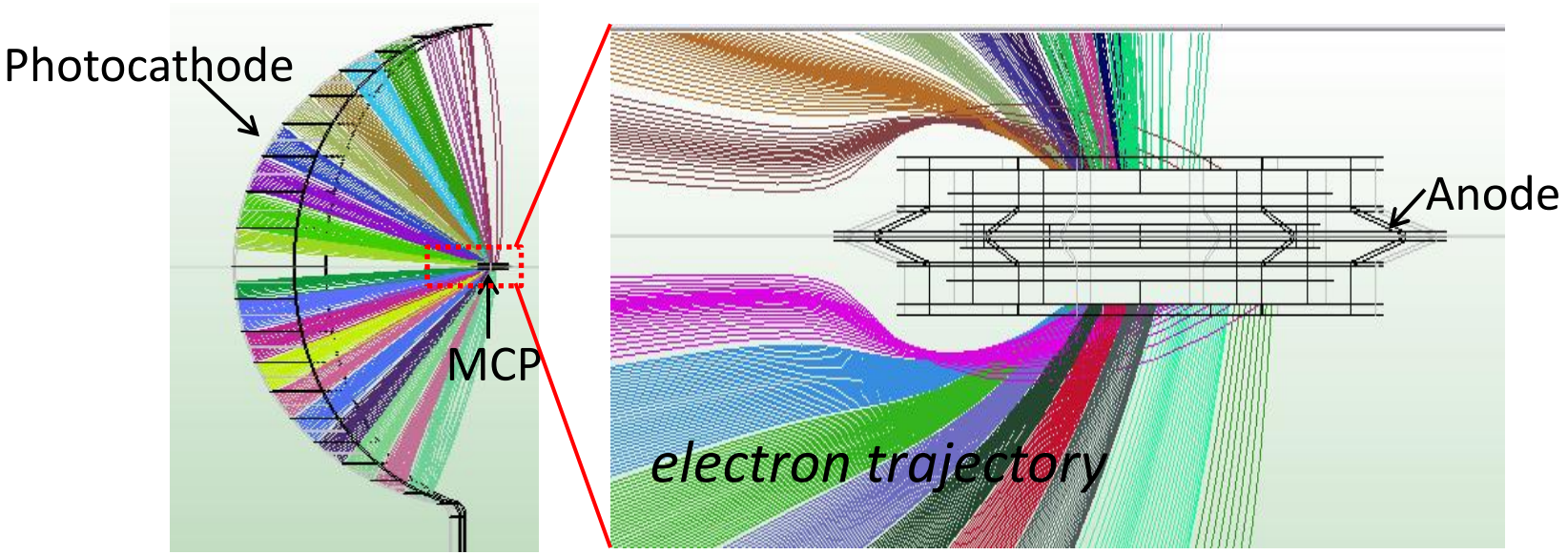


s (TR): 40%

	Conventional PMT	New PMT
Quantum Efficiency (QE)	20%	QE_{Trans}=30%, QE_{Ref}=30%
Collection Efficiency (CE)	70%	70%
Detection Efficiency (DE)	QE_{Trans}*CE=14%	QE_{Trans}*CE +TR*QE_{Ref} *CE = 30%

The Simulation work

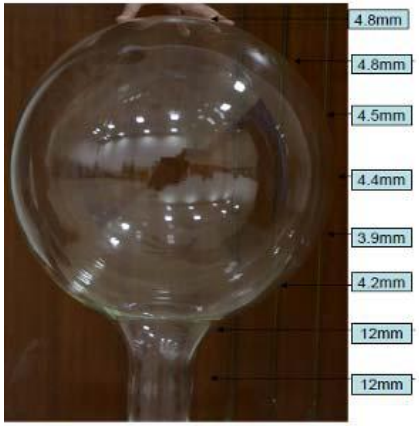
- **Simulate the possibility of the 20” spherical MCP-PMT**
  - Electron Multiplier: small size MCP (ϕ=18mm);
  - Photocathode area: transmission + reflection, nearly 4π effective area ;
  - Could the small MCP collect all the photoelectrons from the photocathode?



Lorentz-3D EM simulation results shows that nearly all the photoelectrons could be collected by the small MCP

The large area glass shell

- **We have already got the 5inch ~20-inch glass shell**
  - with very good **water resistance** characteristics (to be submerged in liquid for long time)
  - With very low **radioactive background** (to reduce the background rates)



20-inch glass shell

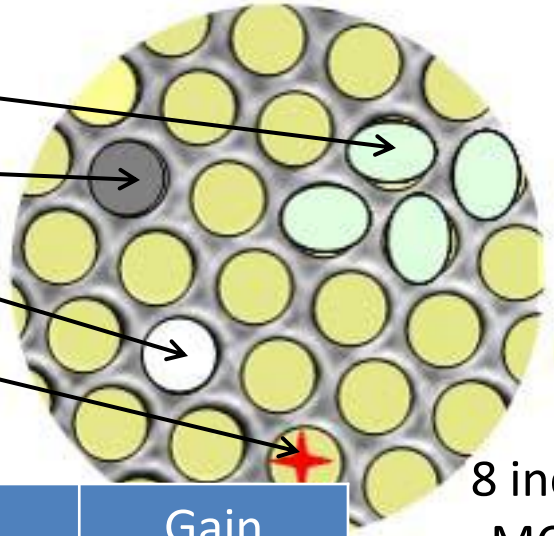
Sample	U238	Th232	K	U238	Th232	K
	Bq/kg	Bq/kg	Bq/kg	ppb	ppb	ppm
Glass--YC	4.31 ±0.23	3.46 ±0.30	6.95 ±0.81	349.1 ±18.6	851.2 ±73.8	224.0 ±26.1
quartzite—YC	3.14 ±0.48	4.03 ±0.32	14.87 ±1.70	141.8 ±38.9	639.6 ±78.7	237.1 ±54.9
quartzite --7#	≤0.50	≤0.33	≤1.82	≤40.5	≤81.2	≤58.8
quartzite –8#	≤0.47	≤0.31	≤1.72	≤38.1	≤76.3	≤55.6
DayaBay	0.64	0.5	2.7	51.8	123.0	87.2
JUNO	0.149	0.106	0.403	12.1	26.1	13.0

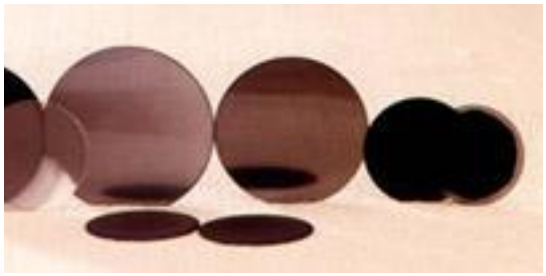
Low background gamma spectrometer measurements

The low cost MCP

Based on our design, we can accept **small** MCP with **some defects.**

- Asymmetric surface
- Blind channels
- Non-uniform gains
- Flashing channels



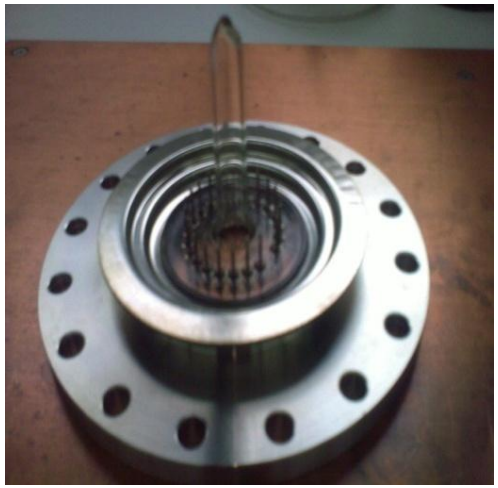


Diameter mm	Pore size μm	Volume resistance MΩ	Gain (800V)
18	6	70-250	>7000
26	10	50-300	>2500
33	12	80-300	>3000

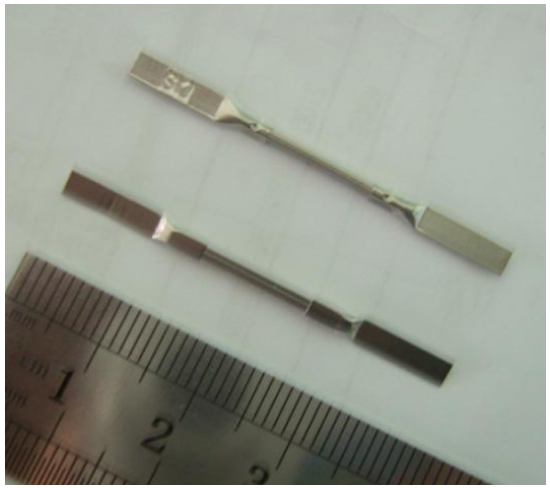
8 inches x 8 inches uniform MCP, Gain~10000, LAPPD

Low cost, 18mm and 33mm MCPs are supplied by North Night Vision Technology Limited Company (NNVT)

Assembly

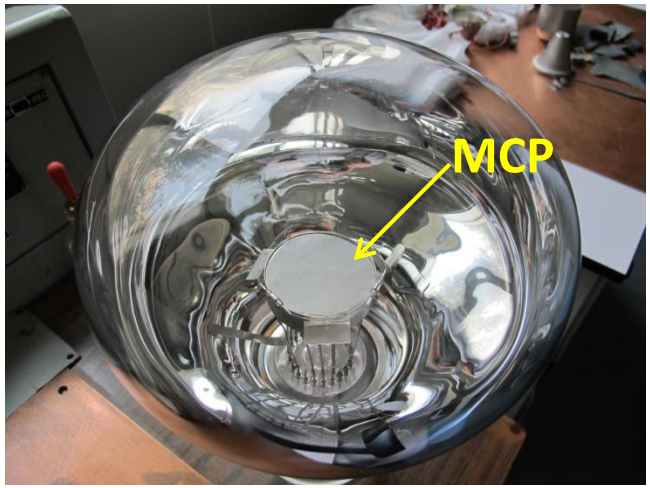


Stem and Connector pins



Alkali sources

Glass shell

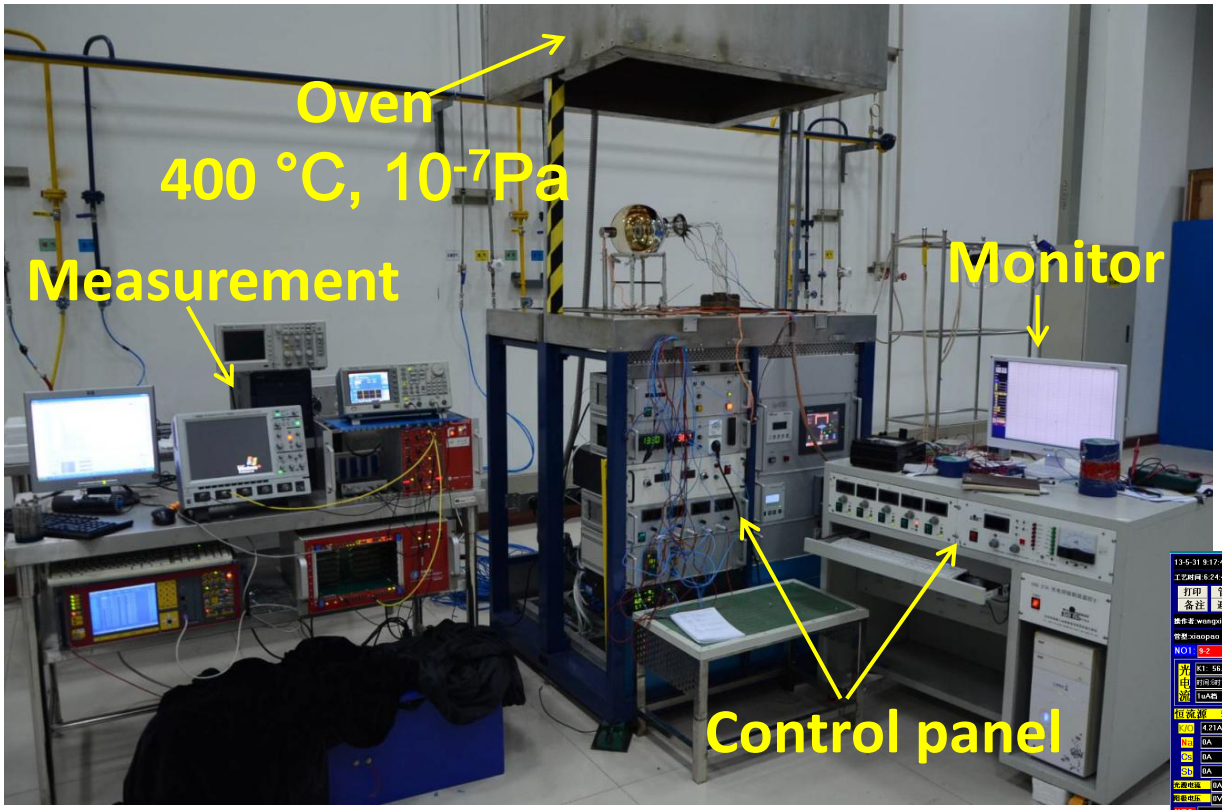


Ready for photocathode deposition

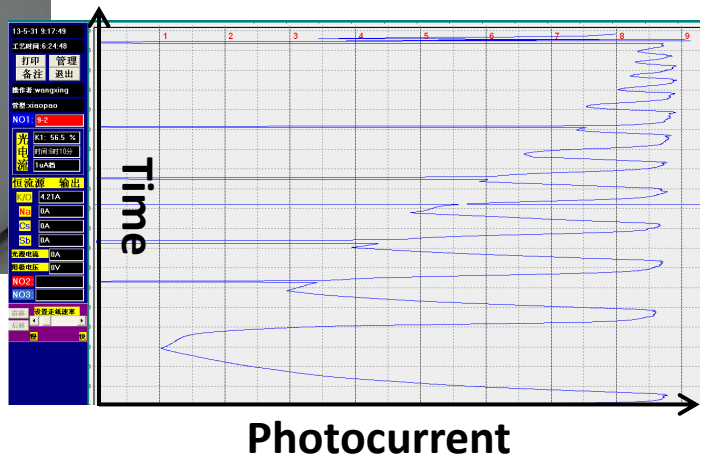
Main processes in PMT production

① Cleaning of all materials
② Selecting of MCPs
③ Assembling and wiring of the electrodes
④ Sealing of the glass shell and stem
⑤ Leak detection
⑥ Photocathode activation
⑦ Sealing in vacuum

The photocathode deposition



Non-transfer system

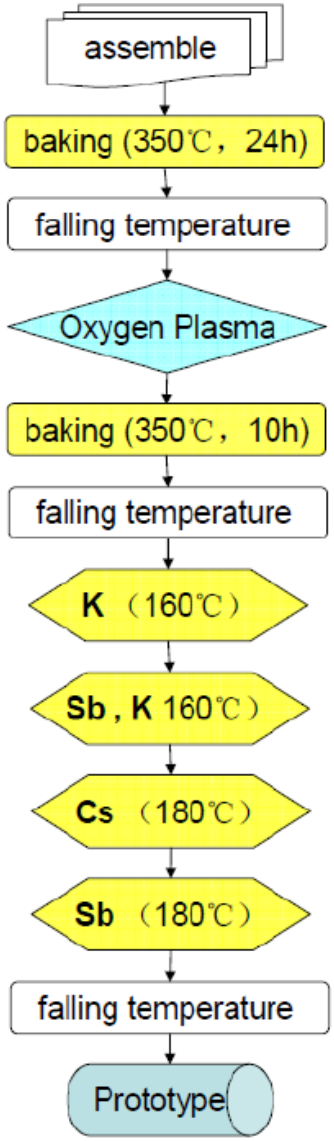


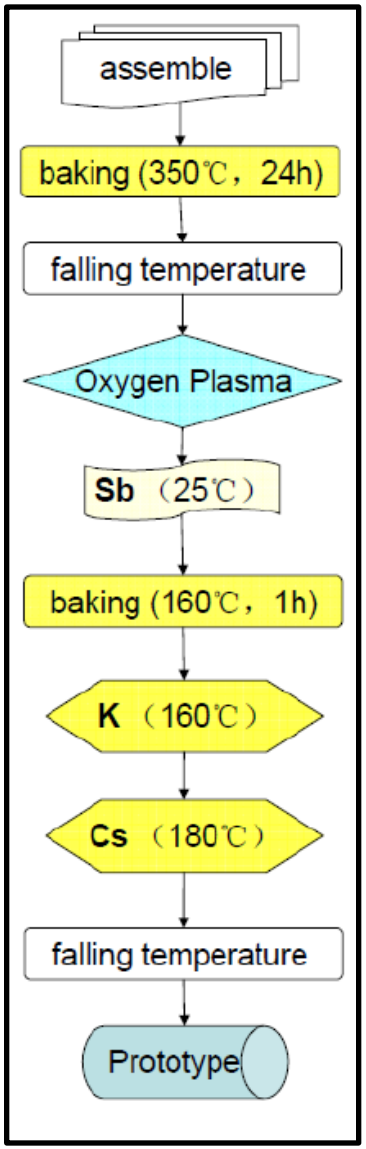
Different deposition processes

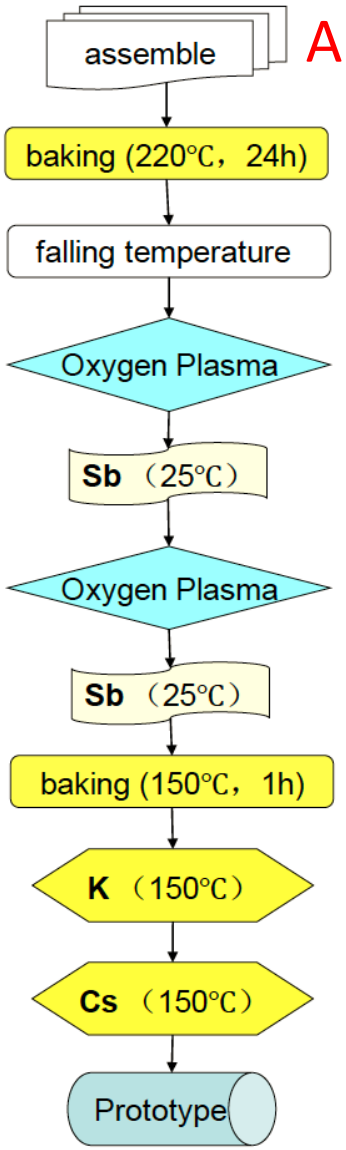
Bialkali (Sb-K-Cs):
matches the wavelength of Cherenkov light (350-410 nm)

$$Sb + K \longrightarrow K_3Sb$$

$$K_3Sb + Cs \longrightarrow K_2CsSb$$

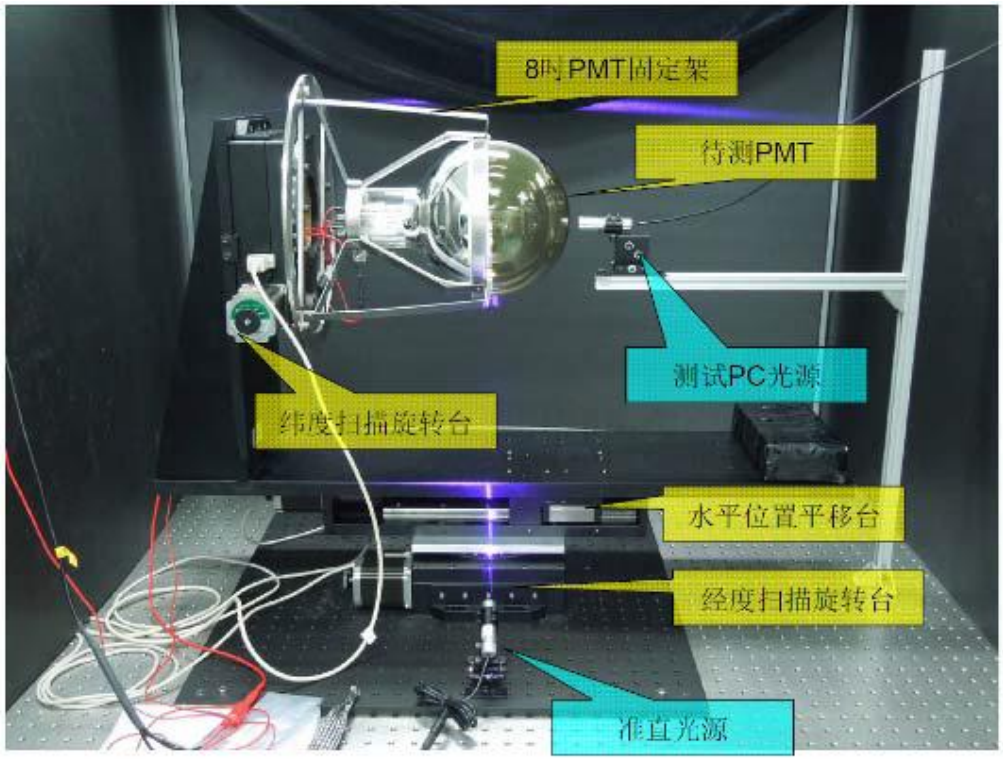


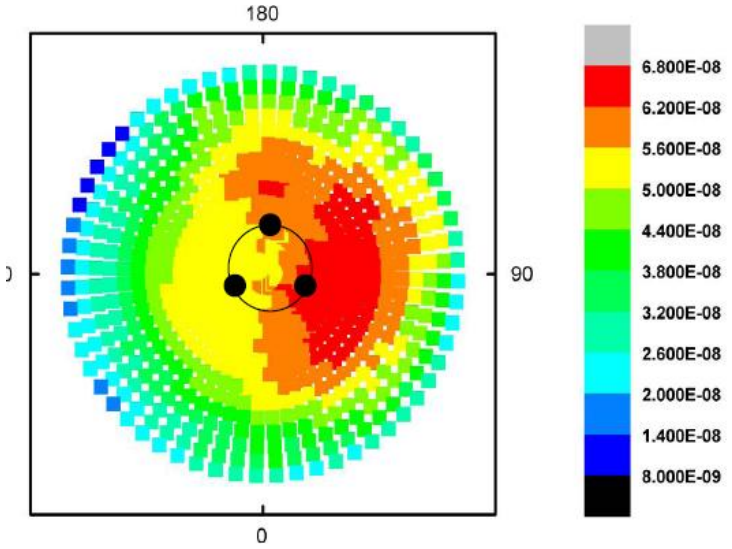




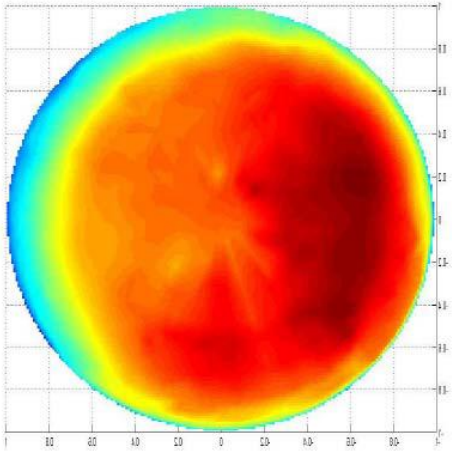
ANL

Uniformity





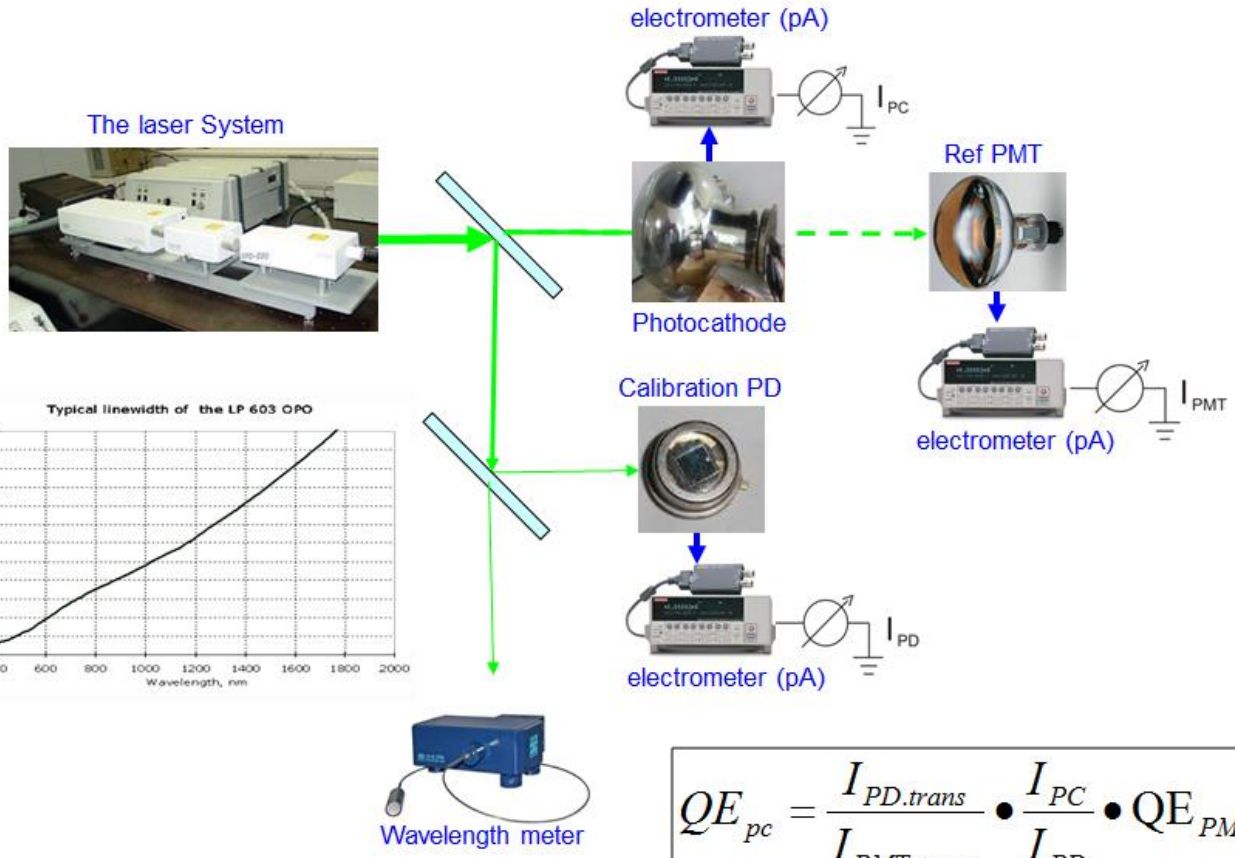
2D display of the PC



3D display of the PC in Matlab software

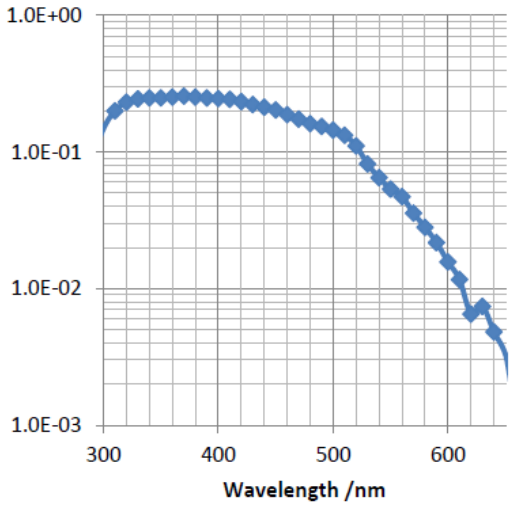
- Scanning photocathode platform
  - 3D rotation
  - 8-inch PMT
  - Moveable in x, y, z
  - QE, uniformity

Quantum efficiency



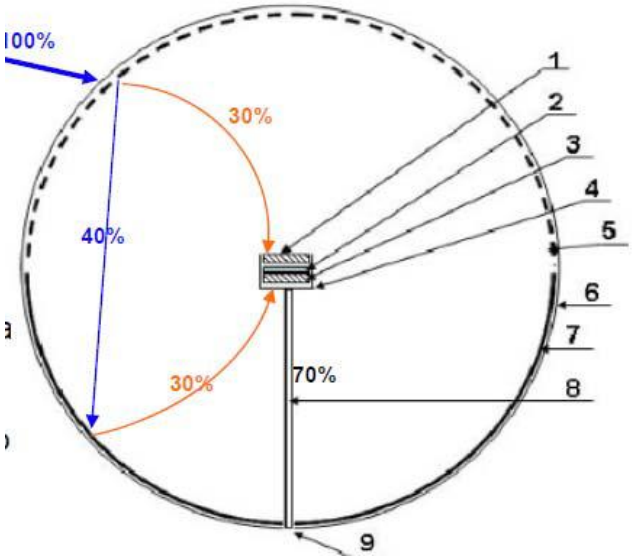
$$QE_{pc} = \frac{I_{PD.trans}}{I_{PMT.trans}} \bullet \frac{I_{PC}}{I_{PD}} \bullet \mathrm{QE}_{PMT}$$

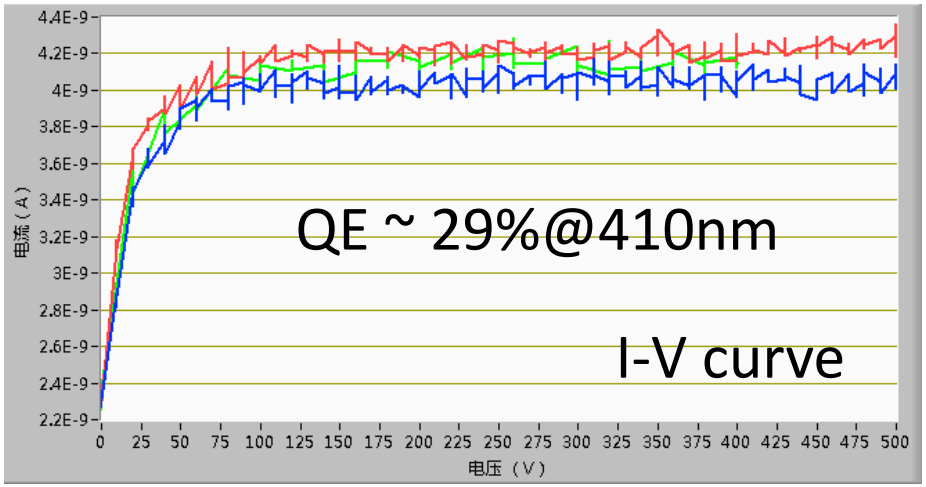
QE

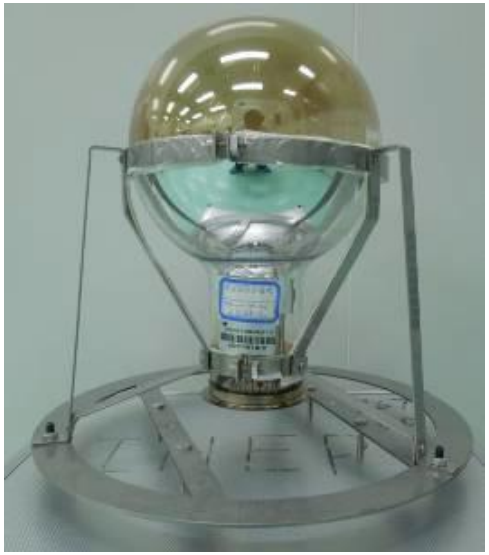


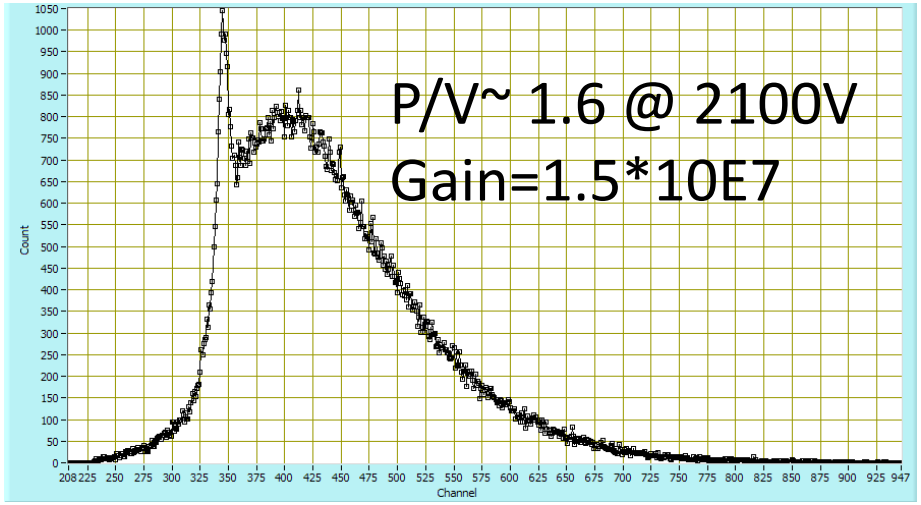
QE test system and result

Prototype with horizontal MCPs



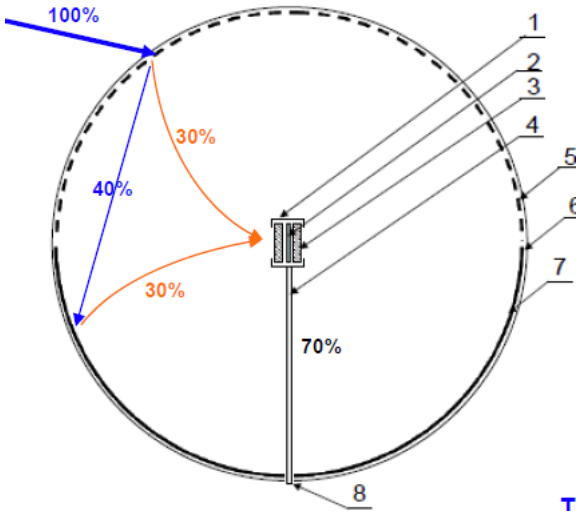


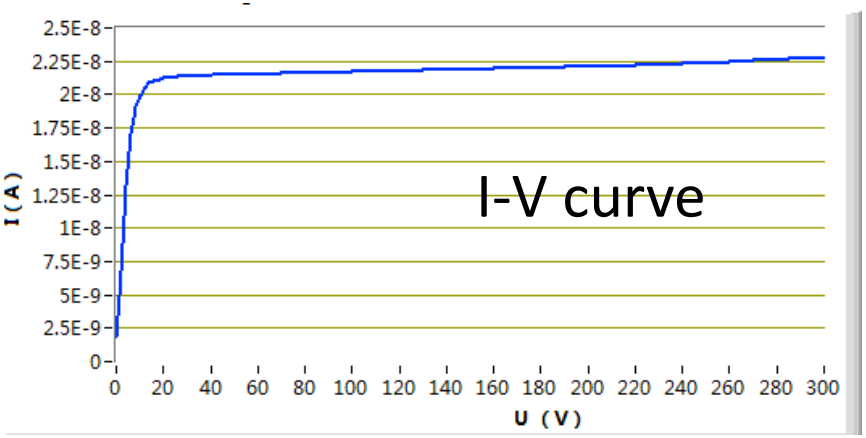


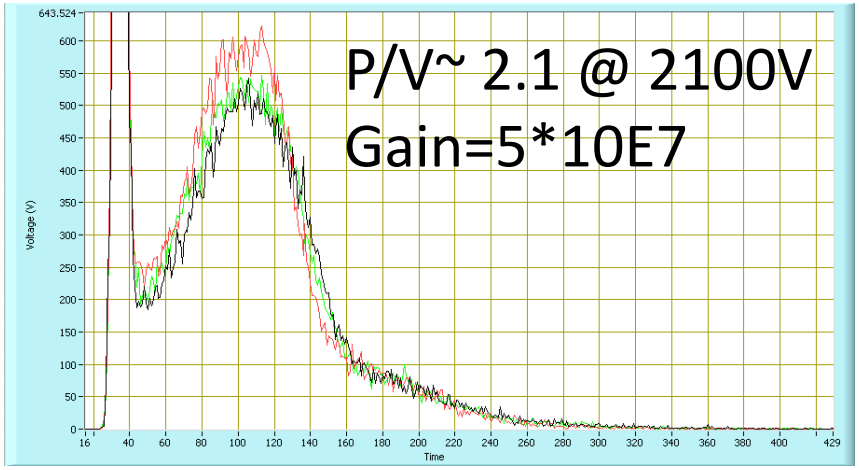


Single Photoelectron Spectrum

Prototype with vertical MCPs



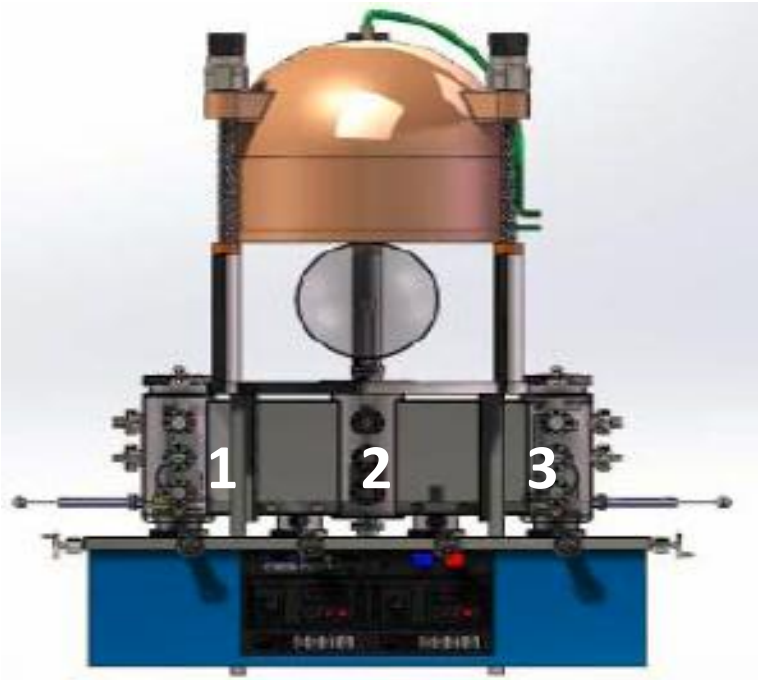




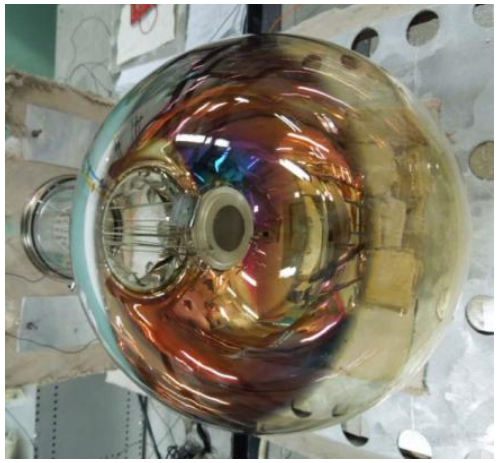
Single Photoelectron Spectrum

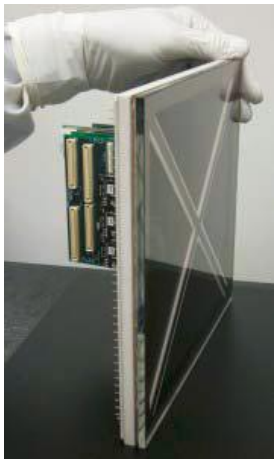
Near future work

- Vacuum transfer system
  - 8, 12, 20 inch PMT prototype
  - Chamber 1: alkali source, anode, and other glow discharge part
  - Chamber 2: photocathode deposition, hot seal
  - Chamber 3: MCP scrubber
- 20-inch PMT mass production




Transfer system at ANL





Effective area	20 inches x 20 inches	8 inches x 8 inches
Quantum efficiency	30%	24%
Readout electronics	Simple	Complicated
Time resolution	2-3 nanoseconds	< 100 picoseconds
Volume	Large	Small
Cost	Low	Low
Applications	Neutrino experiments	Neutrino experiments, medical applications, etc
	Success in 8 inches MCP-PMT, 20 inches PMT will come on June	**The first 6 cm photodetector will come to world on May**

Other Research Areas in XIOPM

- Streak camera

The streak camera is an ultra high-speed detector which captures light emission phenomena occurring in extremely short periods

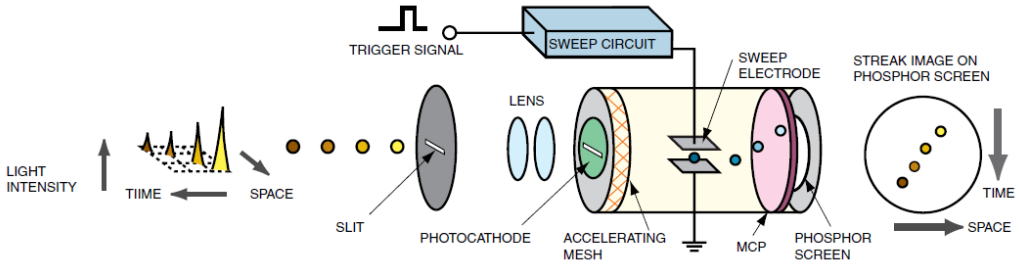


Fig.1 Operating Principle of the Streak Tube

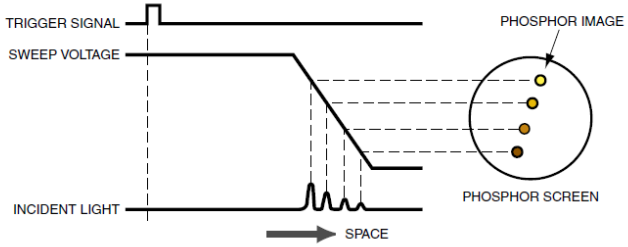


Fig.2 Operation Timing (at time of sweep)

Guide to streak cameras, Hamamatsu

Features

- Simultaneous measurement of light intensity on both temporal and spatial axis
- Superb temporal resolution (<0.2 ps)
- Measurement ranges from X-rays to the near infrared rays
- Ultrahigh sensitivity (single photoelectron can be detected)

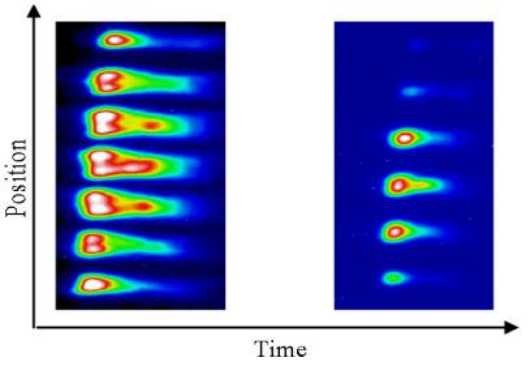
Other Research Areas in XIOPM

- Streak camera *National funding: 160M CNY for 42 months*

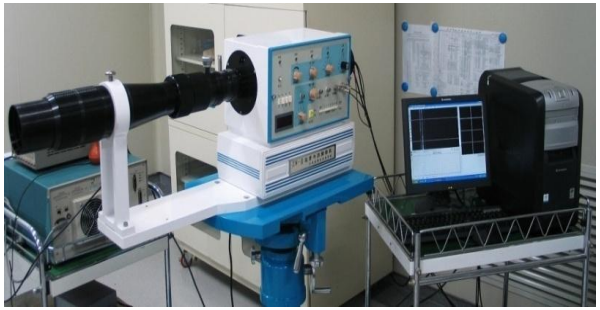
Applications

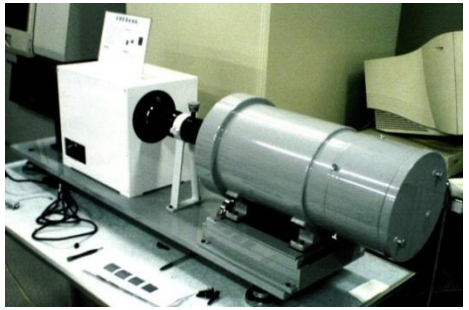
- Dynamics: semiconductor physics, photochemistry
- Diagnostics: electron and photon beam profile in advanced light source and accelerator (APS/AWA)
- Plasma physics: high energy laser nuclear fusion
- Ultrafast electron diffraction

Z-Pinch result



Streak tubes made in XIOPM



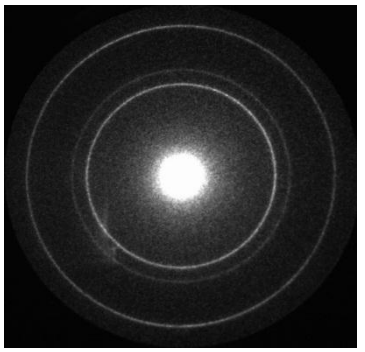


Compact streak camera

Other Research Areas in XIOPM

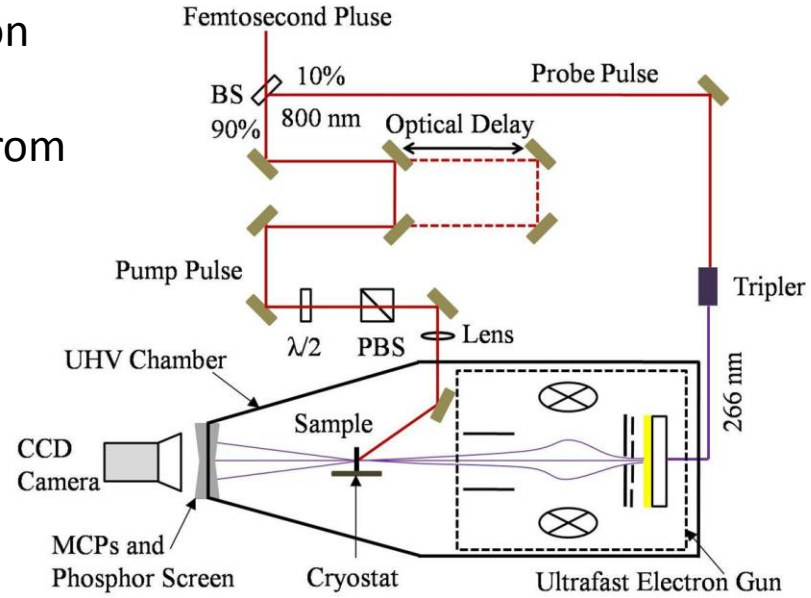
- Ultrafast electron diffraction

Ultrafast electron diffraction (UED) has the potential for **real-time imaging of structural changes on atomic length scales**, thus promising to make a profound impact on a large area of science including **biology, chemistry, nano and material sciences™**

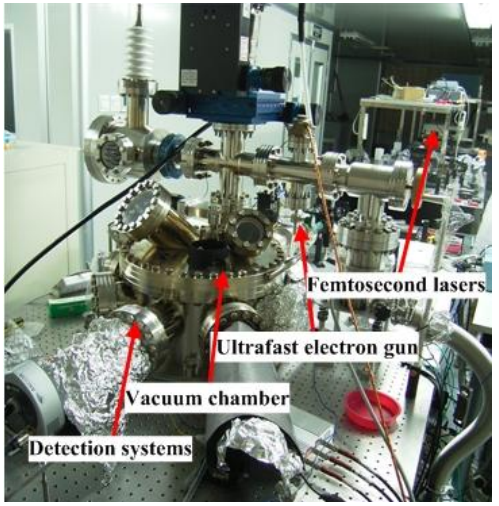


Diffraction pattern of poly-crystalline Al film (20 nm)

High resolution
- 100 fs
- sub-Angstrom



Experimental setup



UED facility in XIOPM

™ *P. Musumeci et al., Ultramicroscopy 108 (2008) 1450– 1453*

Summary

- 8-inch MCP-PMT prototype using non-transfer system (finished)
  - Fabrication and evaluation
  - High QE, single photoelectron spectrum, good uniformity
- 20-inch MCP-PMT prototype production using transfer vacuum system (coming soon)
- Streak cameras and ultrafast electron diffraction (possible collaboration?)

Thanks

What I learned

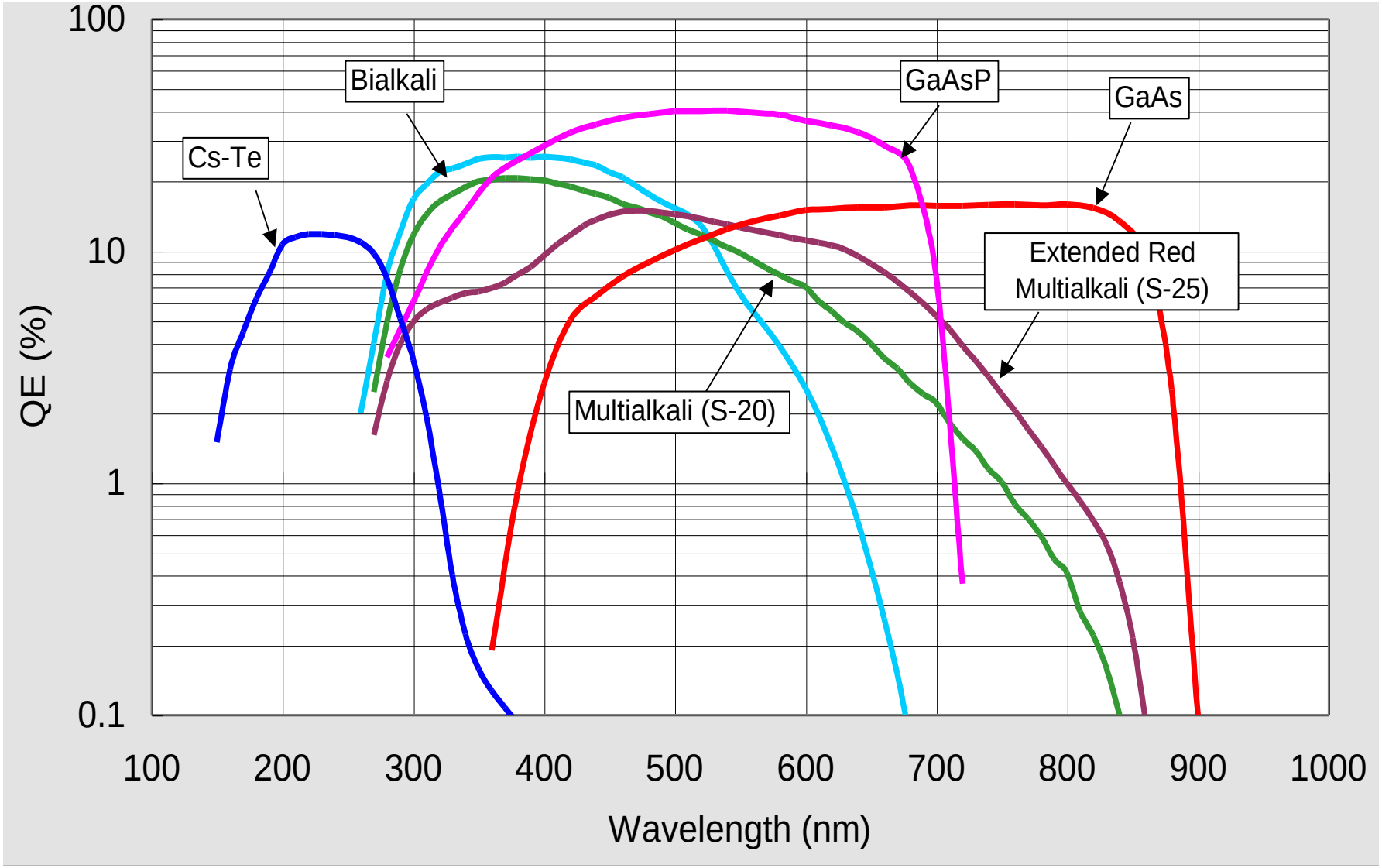
- Advanced design of MCP-PMT
- Sealing of a nonfunctional MCP-PMT
- Photocathode growth by MBE
- MCPs and their measurements using phosphor screen and cross delay lines

- The cooperation with a large team
- The American style of writing a proposal
- The management of a big project in America

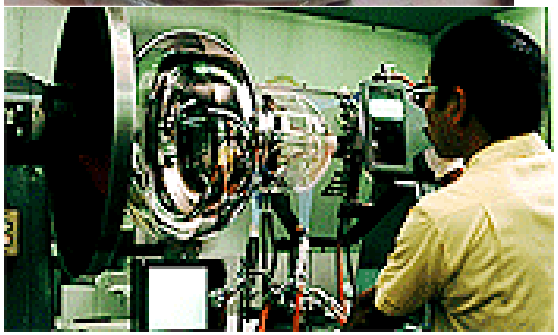
- Very appreciate the two business trips to Berkeley and Cornell
- Communications and potential cooperation with ANL, BNL, LBNL and UIUC

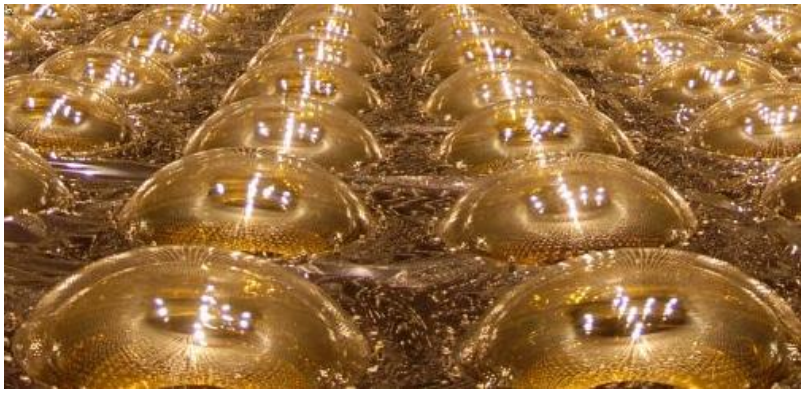
Thanks all of you! Hope I have chance to come here again! Welcome to Xi'an!

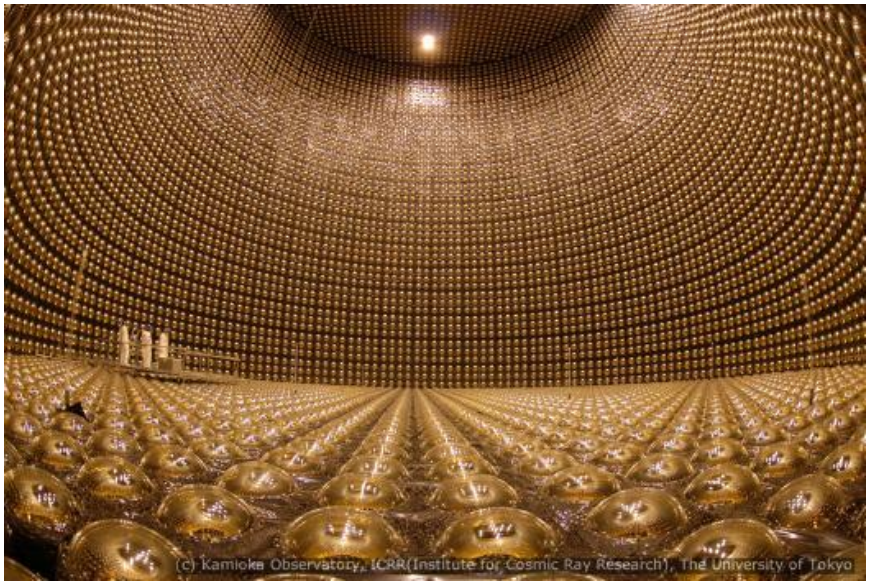
QE curves of 6 types



Super-K and Hamamatsu







Hyper-Kamiokande Overview

- Water Cherenkov, proved technology & scalability:
  - Excellent PID at sub-GeV region >99%
  - Large mass → statistics always critical for any measurements.

Total Volume	0.99 Megaton
Inner Volume	0.74 Mton
Fiducial Volume	0.56 Mton (0.056 Mton × 10 compartments)
Outer Volume	0.2 Megaton
Photo-sensors	•99,000 20"Φ PMTs for Inner Detector (ID) (20% photo-coverage) •25,000 8"Φ PMTs for Outer Detector (OD)
Tanks	•2 tanks, with egg-shape cross section 48m (w) × 50m (t) × 250 m (l) •5 optically separated compartments per tank

25 x Super-Kamiokande

Overall Schedule