PMT Selection for 1km^2 scintillator array of LHAASO

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On behalf of LHAASO collaboration

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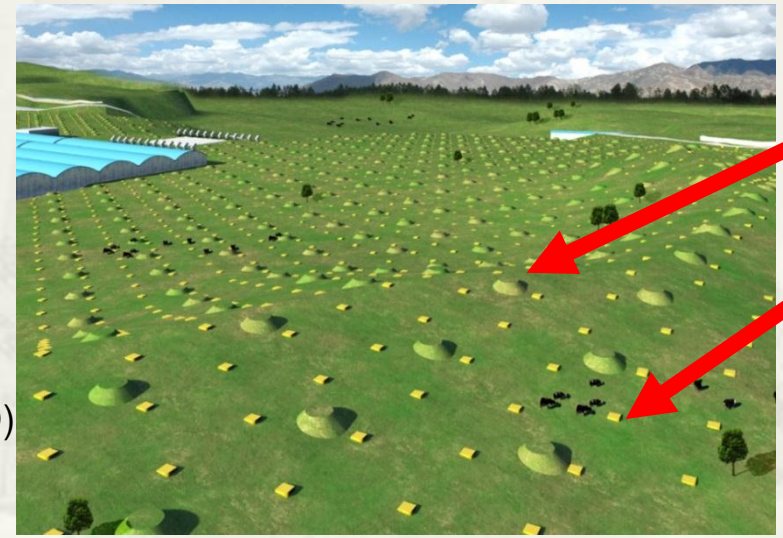
Outline

1. Introduction to LHAASO_KM2A
2. PMT Test Bench in SDU
3. Requirements and test for PMT
   - 3.1 PMT Gain
   - 3.2 Uniformity and CTTD
   - 3.3 Optimizing of PMT dynamic range
   - 3.4 Dark noise rate
   - 3.5 Improvement of TTS
4. Conclusion

LHAASO-KM2A

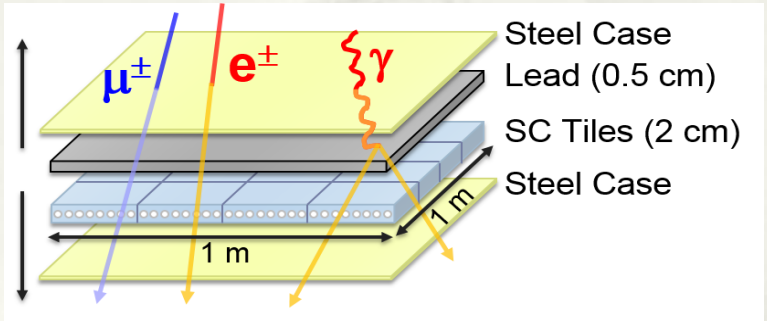
- As a main component of LHAASO, the 1km^2 array (KM2A) has several physics goals:
  - Origin of cosmic rays ;
  - UHE gamma sky survey ;
  - Energy spectrum measurement ;
  - …



- Performance of the KM2A:
  - 5635 eletromagnetic particle detectors (ED) and1221 muon detector (MD)
  - Energy range: 10TeV~100PeV
  - Sensitivity: 1%I_{Crab}@50TeV

Eletromagnetic particle detectors (ED) specifications

- **ED is designed to measure the density and arrival times of the particles in the EAS.**
- **ED consists of plastic scintillator, Pb with thickness of 5mm, 128 wavelength shifting fibers, voltage supply, electron system and one PMT.**

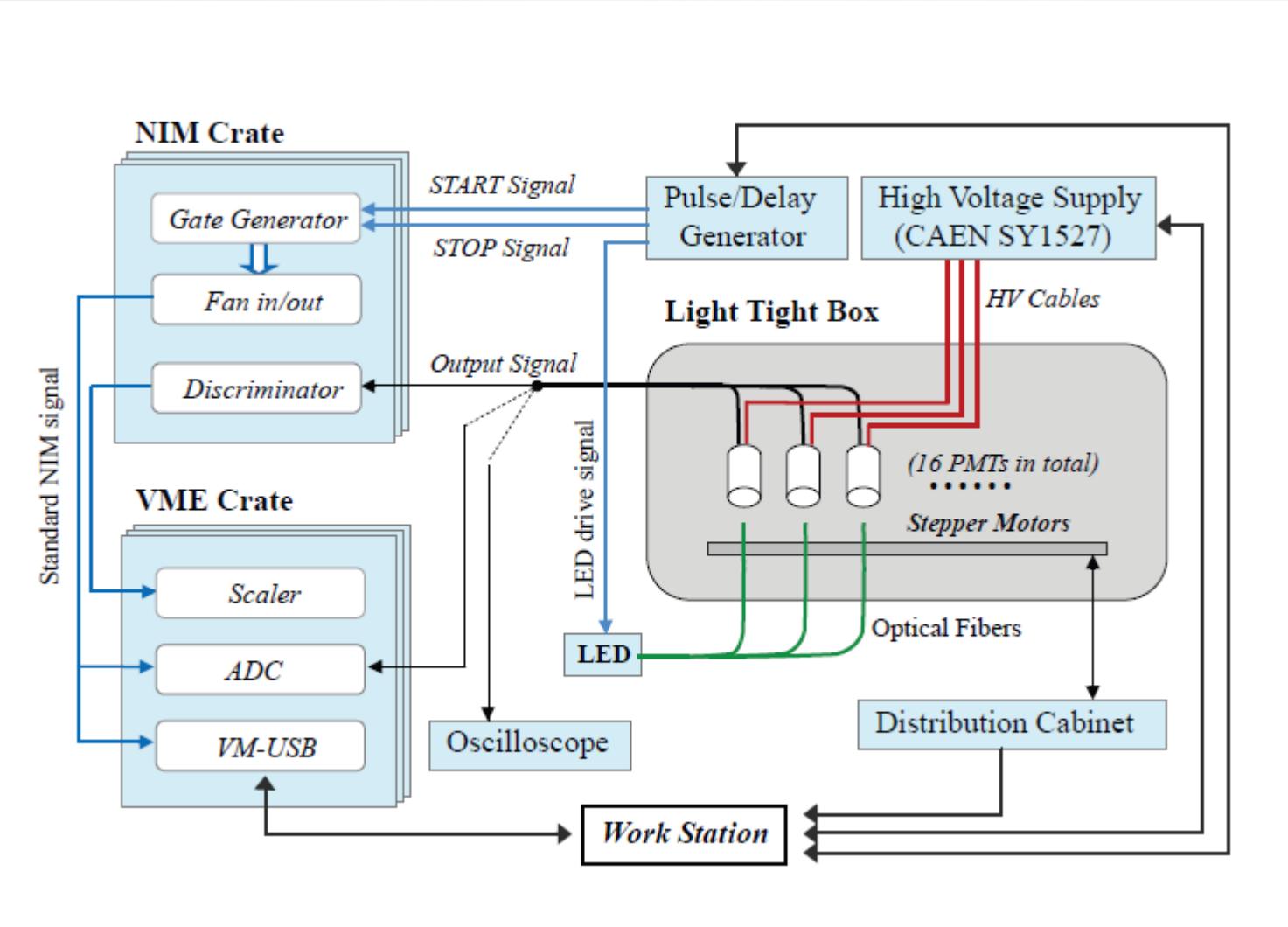


Item	Value
Detection efficiency (> 5 MeV)	> 95%
Dynamic range	1 – 10000particles/m^2 (20~200 000p.e. for PMT output)
Count Rate	<2kHz
Time resolution	< 2 ns

KM2A Prototype at YBJ

- 2014.8.10-2014.10.16, the prototype of KM2A with 39 EDs has been built up at Tibet, Yangbajing (4300 m a.s.l).
- PMT of XP2012B produced by PHOTONIS is used in ED and measured by the PMT test bench in SDU.

PMT Test Bench in SDU



PMT Test Bench in SDU

Aging box, 48h aging before testing

NIM Crate

VME Crate

High Voltage Supply

Light-tight-box with step motors

Laser Generator

Light-tight – box for TTS measurement

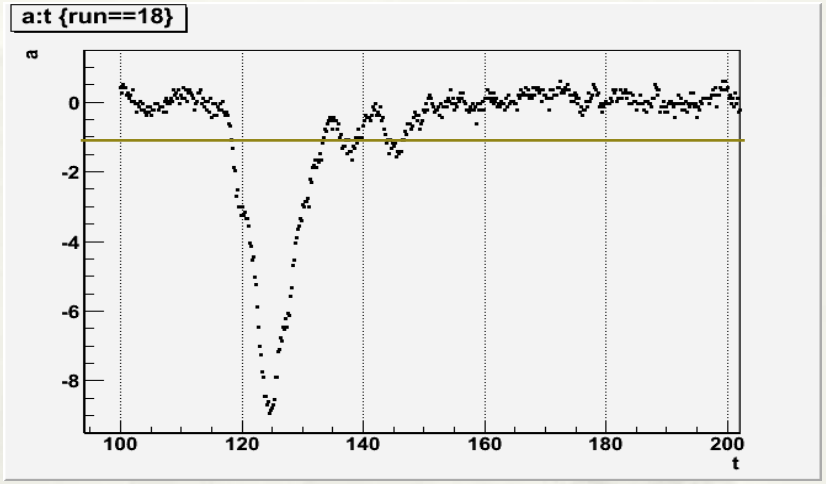
LED

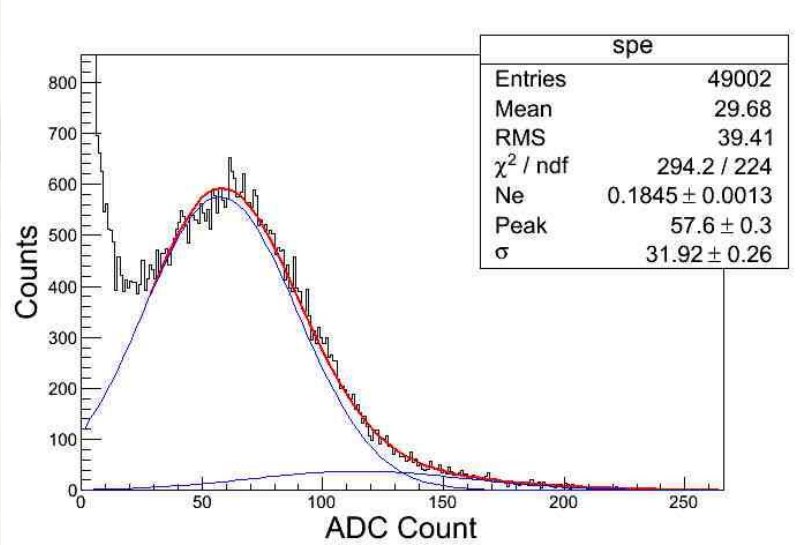
1. More than 10 PMTs for one test.
2. Scanning of PMT cathode.
3. Easy to operate.

Gain for PMT

PMT gain set at 4*10^5.

- Good signal to noise ratio with threshold of 1mV
- Good dynamic range
- Weak affect of time walking





1. Absolute Gain: testing single photoelectron spectrum(SPE)
2. High Voltage Response Curve: anode charge under different high voltage with constant LED light.
3. Calculate working voltage with formula $G = A * V^{\beta}$. With an error of $\pm 1.25\%$ of working voltage for 4*10^5.

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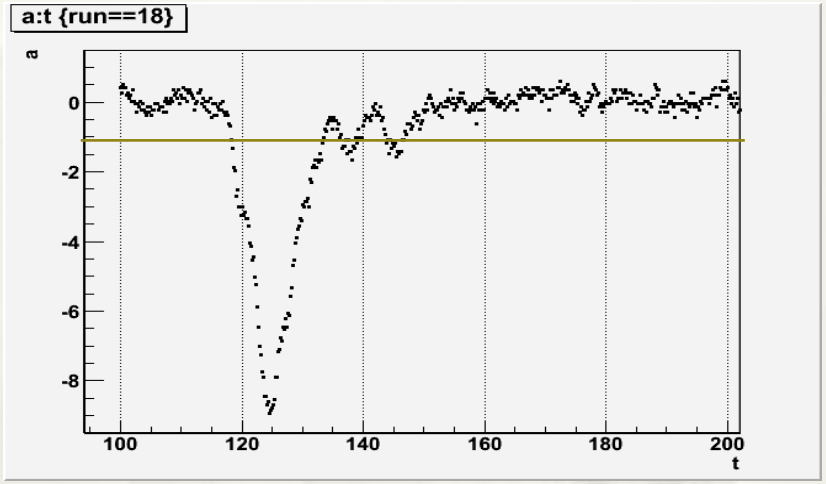

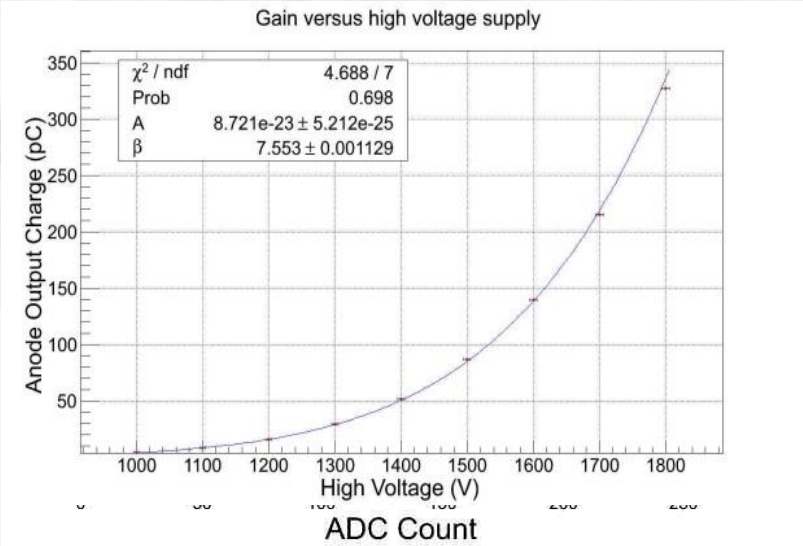

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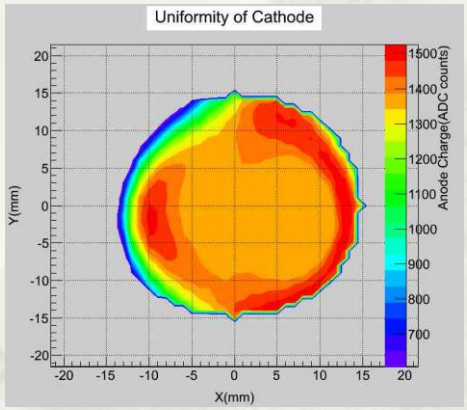
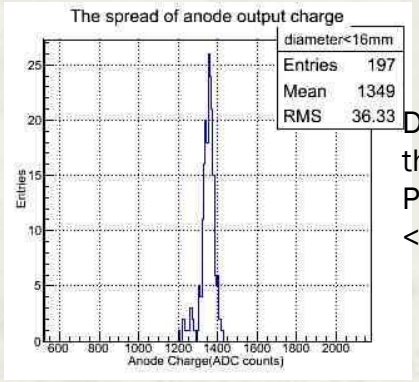
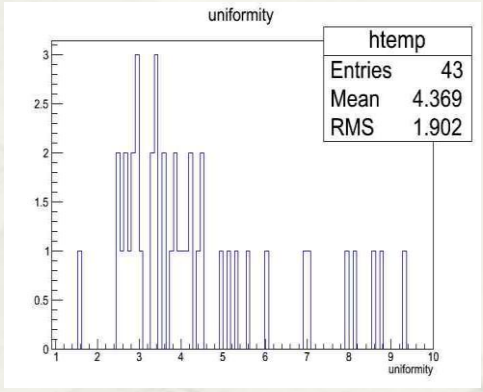
Uniformity and CTTD

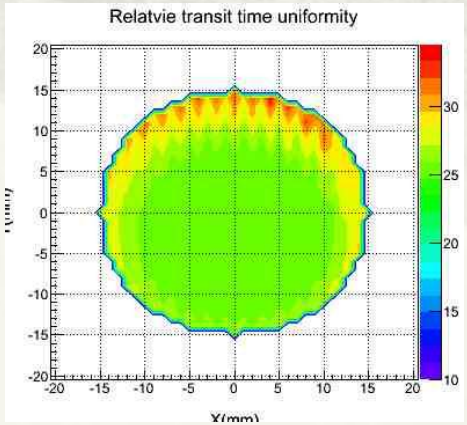
- ED has 128 fibers coupling with PMT cathode in the area with radius of 8mm.
- Uniformity: uniformity in different place of ED
- Cathode transit time difference(CTTD): time resolution for ED.

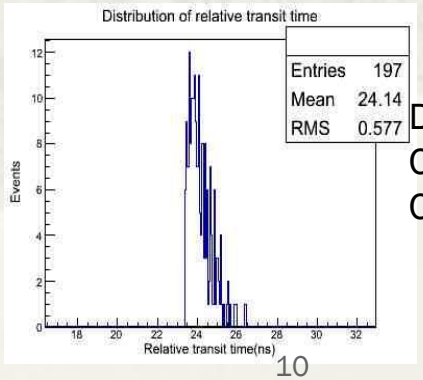




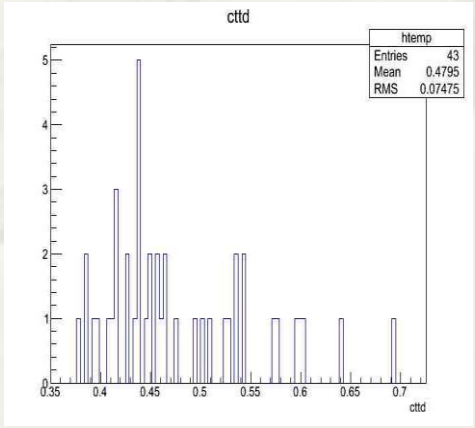
Define RMS/Mean as the uniformity for PMT. Uniformity <10%.





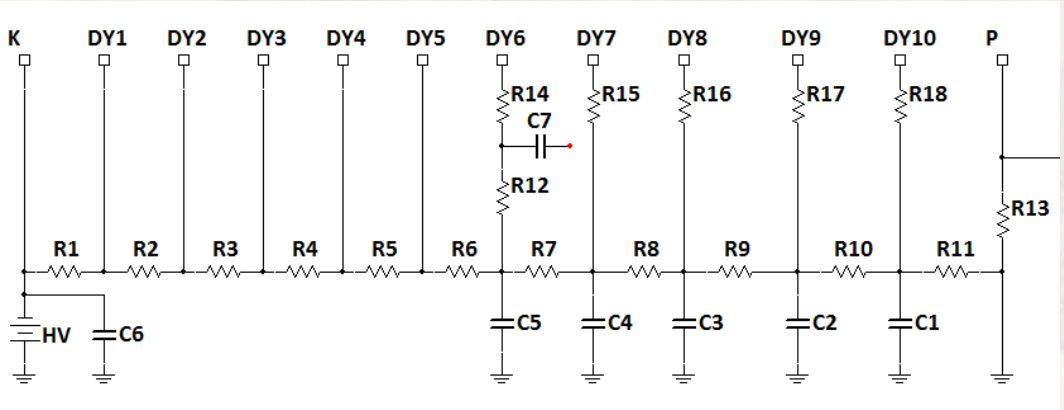


Define RMS as CTTD for this PMT. CTTD<1ns



Optimizing the PMT dynamic range

- Wide dynamic range (1-10000 particles/m^2) -> PMT keep linearity(better than -5%) until 1160mA
- Generally, the linear-focus PMT (10 dynodes) has a anode linearity current below 100 mA,
- dual-output with anode and dynode（DY6).



Point:

1. Good signal shape
2. Overlap between anode and dynode:100~200particles

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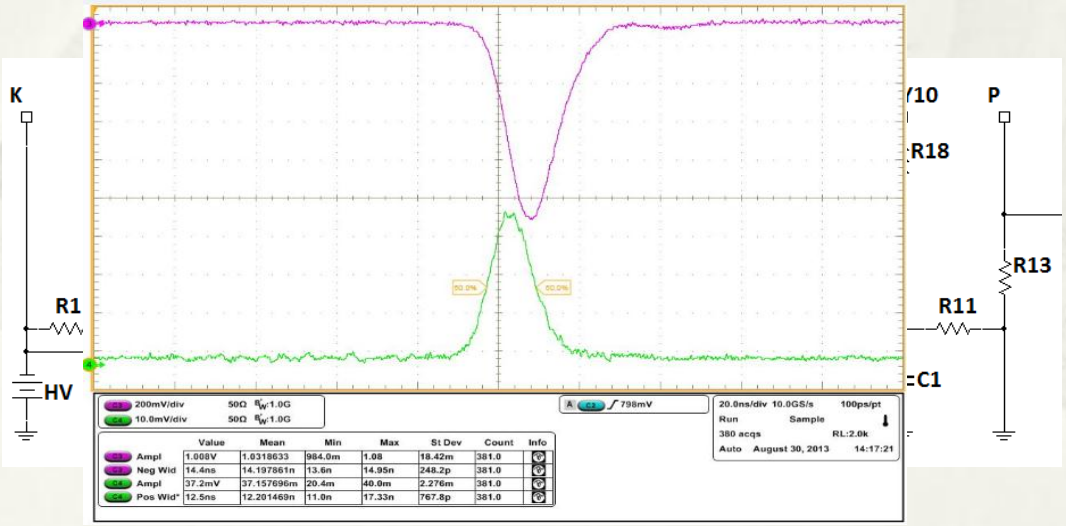

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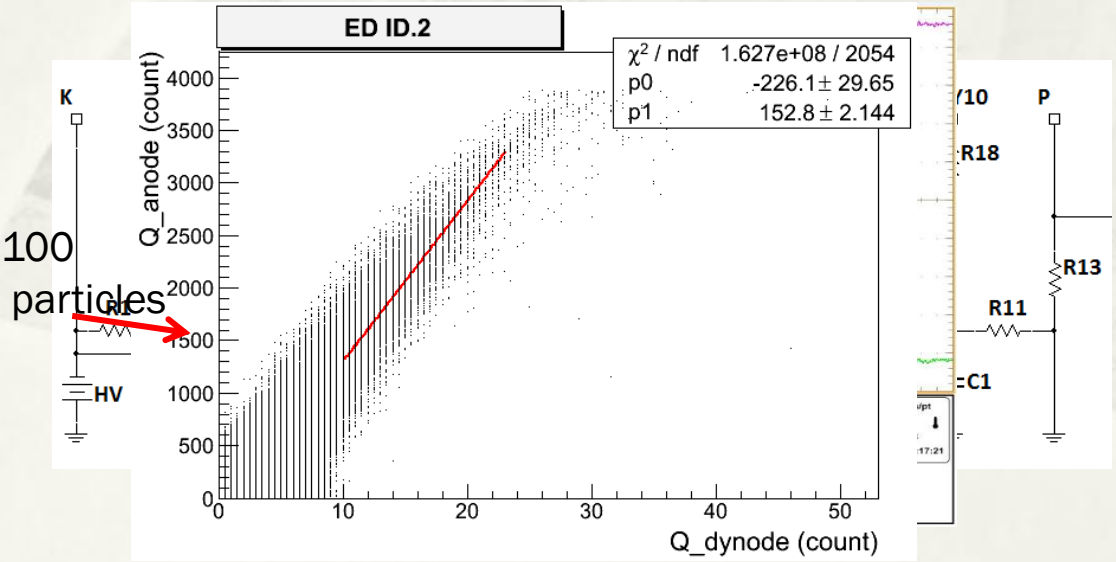

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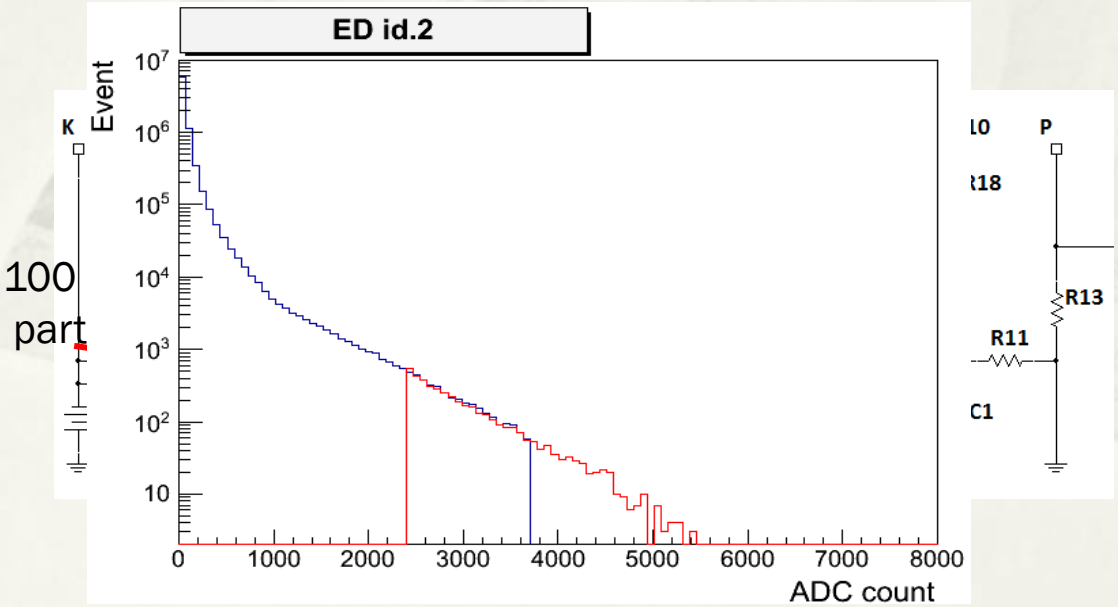

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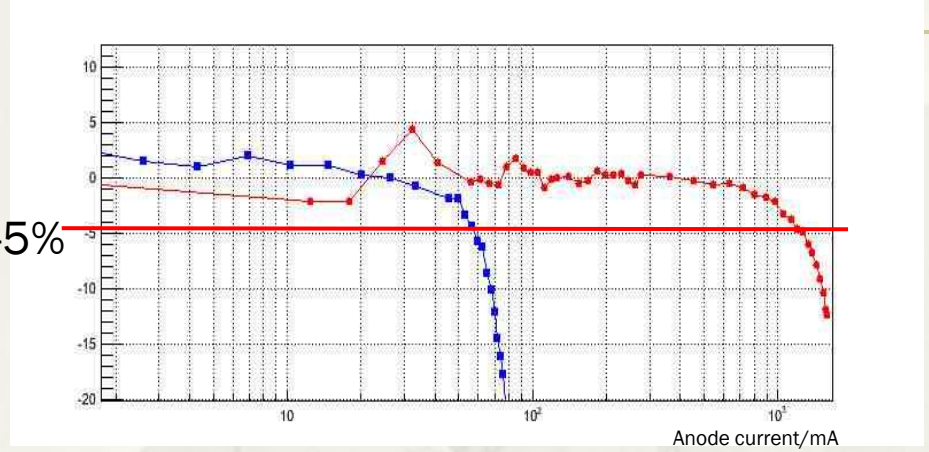
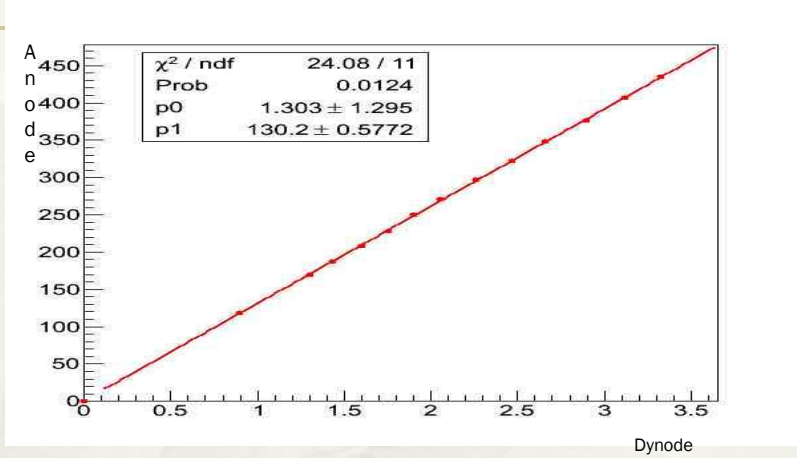
Linearity



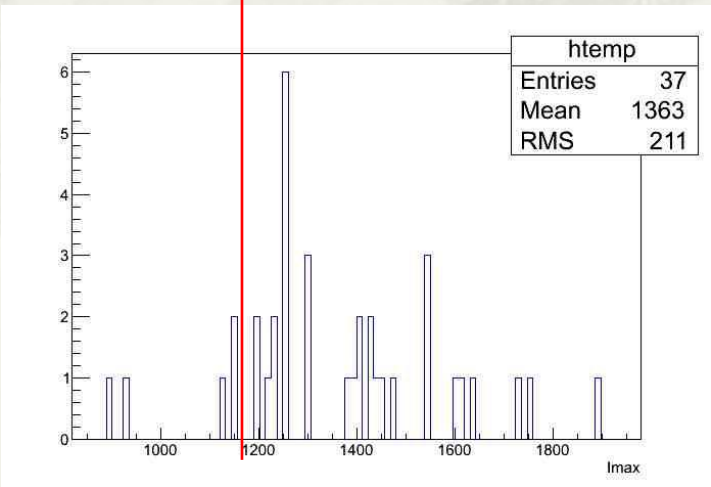


Blue: Linearity of Anode
Red: Linearity of Dynode. Multiplied by ***p*** to get the equivalent anode output.

Ratio between Anode output charge and Dynode, recorded as ***p***.

Equivalent anode maximum linear current for 37 XP2012B PMT.

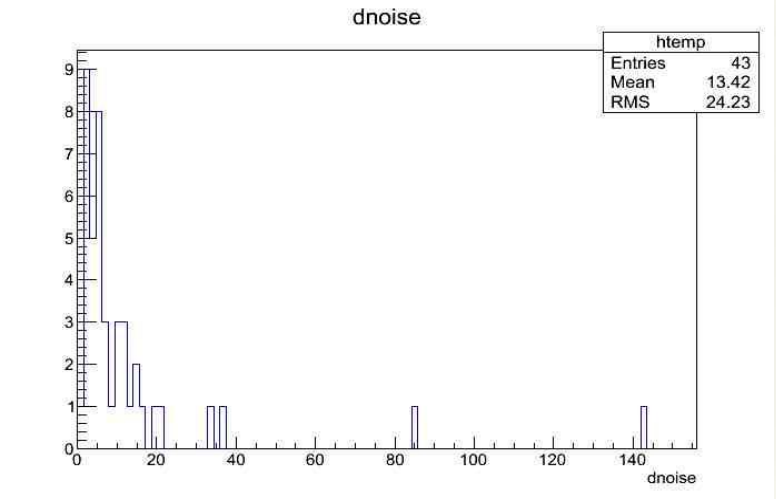
Dual-output with Anode and dynode can realize the wide dynamic range of ED.

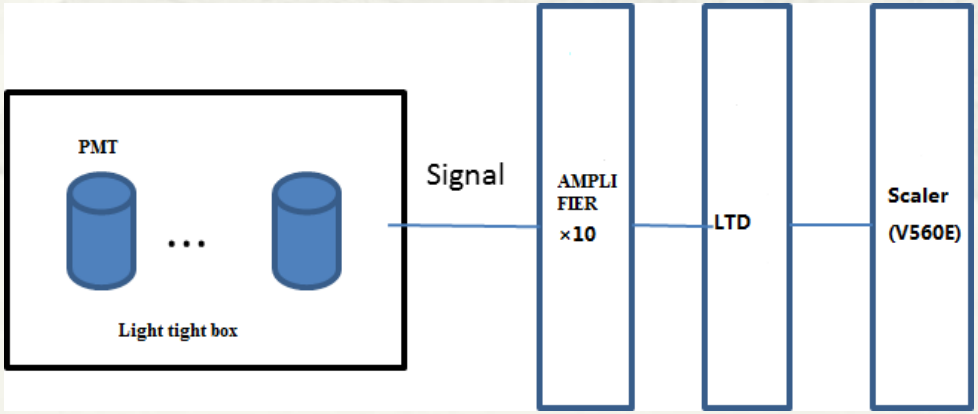


Dark Noise Rate

Dark noise rate lower than 200Hz.

1. Signal multiplied by 10 times before enter the LTD with a threshold of 10mV.
2. Waiting for 3h before test.

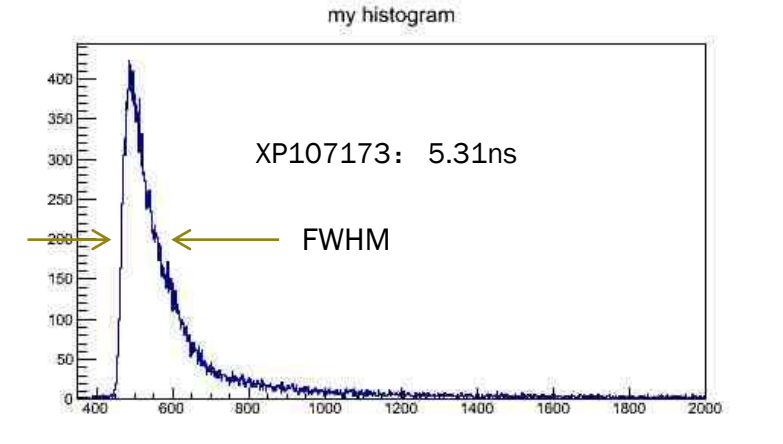


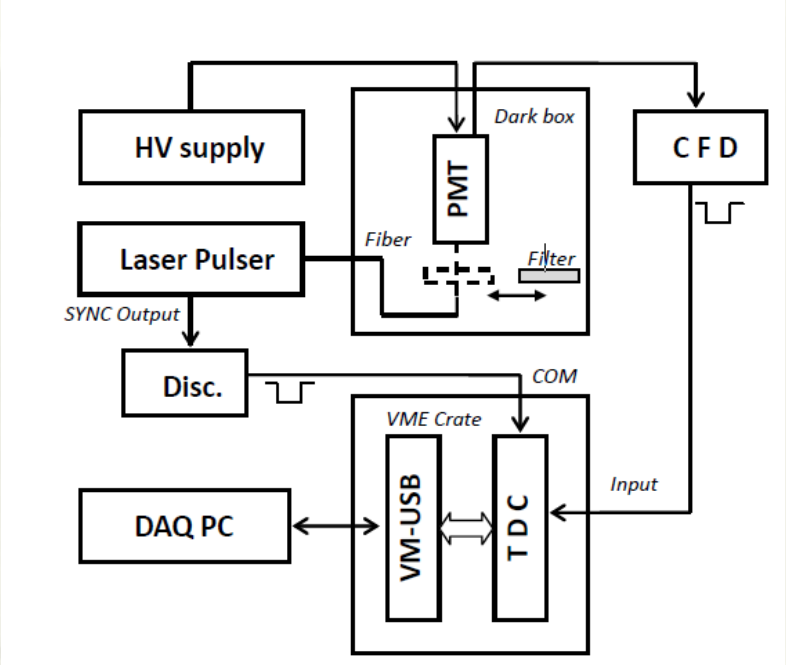


All the 43 XP2012B PMT reach the limit for dark noise rate.

TTS

- Transit time spread(TTS) affect ED's time resolution directly





- Working gain: 5*10^6
- Light source :Laser(70ps)
- CFD, weak effect from time walking

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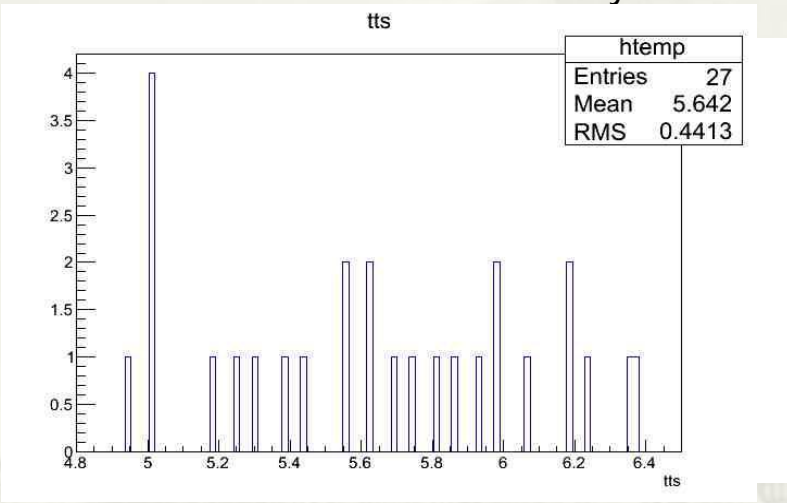
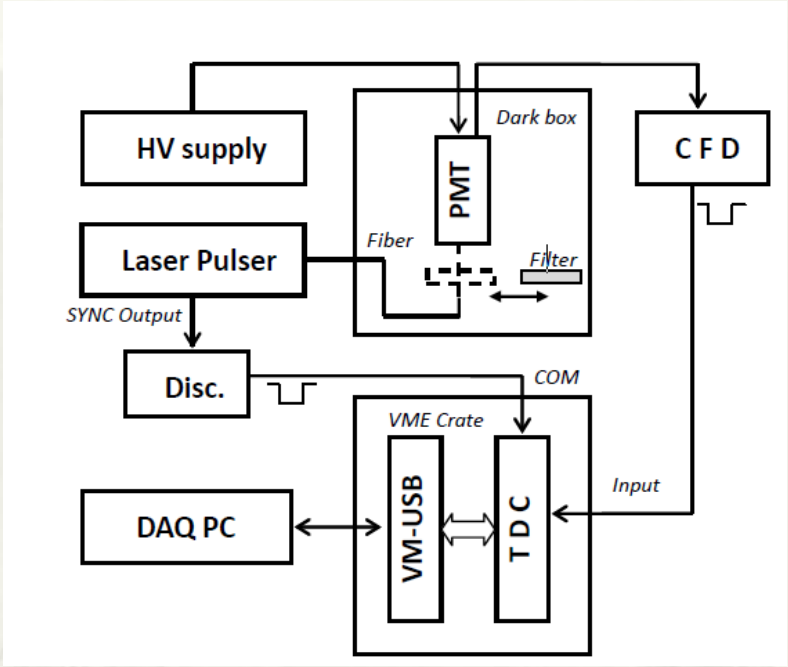


Results for 27 XP2012B PMTs. TTS of XP2012B is 5.6ns on average.



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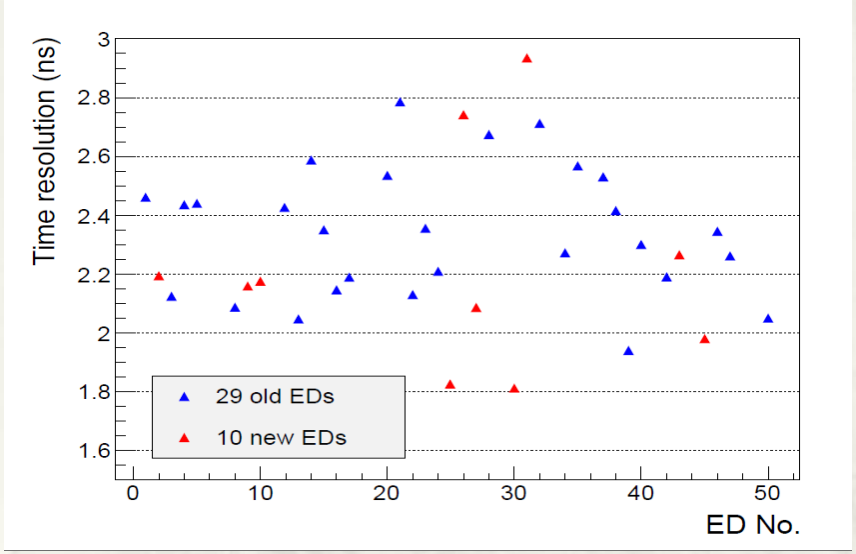
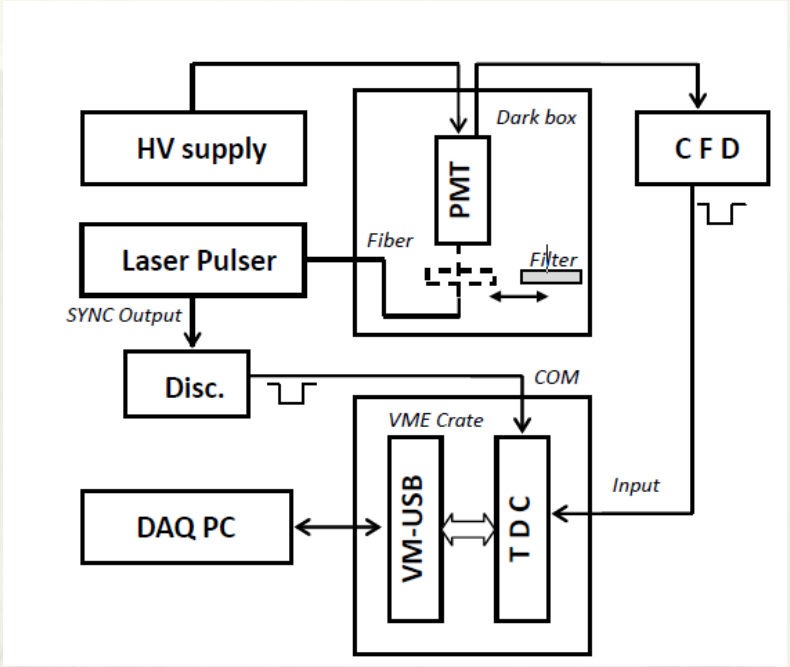


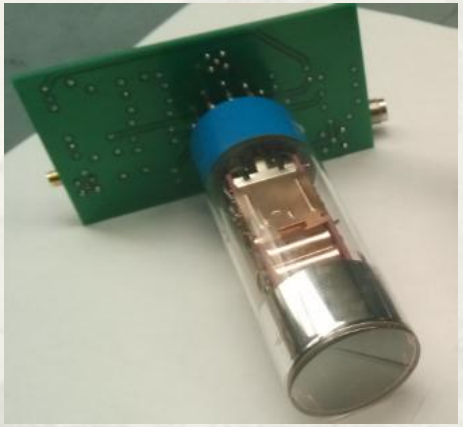


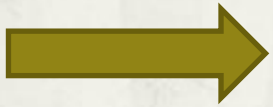
- Working gain: 5*10^6
- Light source :Laser(70ps)
- CFD, weak effect from time walking

Most ED failed to reach the limit of time resolution lower than 2ns.
Urgent job to improve TTS of PMT.

Improvement for TTS

PMT **with plano-concave window** has a better TTS.





XP2012B
Flat window.
TTS:5.6ns

CR285
Plano-concave window.
TTS:2.2ns

Improvement for TTS

PMT **with plano-concave window** has a better TTS.

PMT_No	Npe	Time Resolution(ns)
XP2012B_106741	18.9	2.05
CR285_CF4518	19.2	1.87
CR285_CF4520	19.9	1.82

Improvement for time resolution of ED

XP2012B
Flat window.
TTS:5.6ns

CR285
Plano-concave window.
TTS:2.2ns

Conclusion

1. PMT test bench in SDU fulfill the requirement for KM2A PMT test.

2. Dual-readout with anode and dynode can realize the wide dynamic range of ED.

3. PMT with plano-concave window has a better TTS ,which will improve time resolution of ED.

THANK YOU

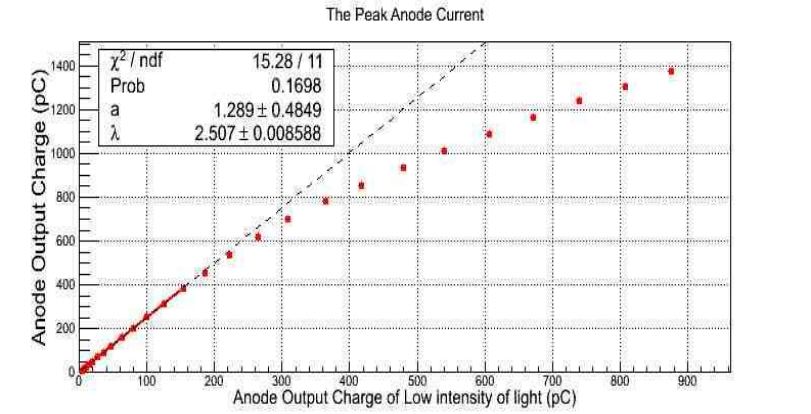
* BACKUP

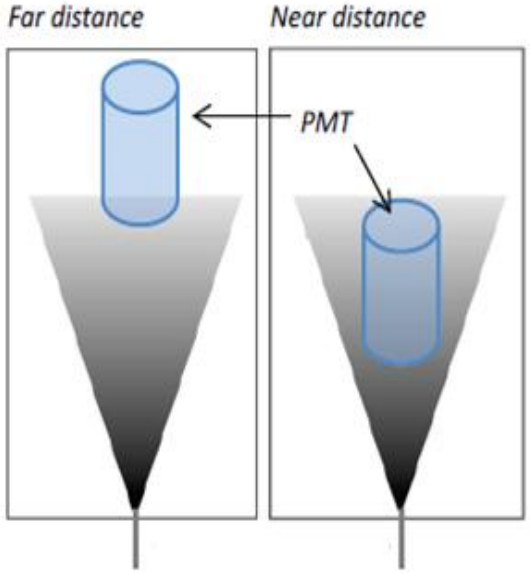
Optimizing the PMT dynamic range

- Dual-length method：

1. Test the out put charge and amplitude with OSC both in far distance and near distance under same LED driven level.
2. Increasing LED light intensity slowly and repeat the testing same as step 1.
3. Ratio between the output charge in two distance is constant under different LED light intensity, when PMT working in linear range.
4. When the ratio changed, PMT stepping into nonlinear range.

$$Non\text{-}Linearity = \left(\frac{(Anode\ Output\ Charge)_{near}}{(Anode\ Output\ Charge)_{far}} - \lambda\right)/\lambda$$





LED with teflon to make the light more uniform when reaching cathode.

Properties of Candidate PMTs

PMT type	XP2012B	XP2072	CR285	XP3060
Uniformity(%)	4.4	13.5	2.4	3.8
CTTD(ns)	0.48	0.65	0.17	0.14
TTS(ns)	5.64	4.95	2.20	1.11
Linearity of anode(mA)	50	85	46	42
Dark noise rate(Hz)	5.1	5.8	2.3	10.8

1. XP2012B and XP2072 with a flat window has a bad TTS compare with CR285 and XP3060 with plano-concave window.
2. Other properties of CR285 and XP3060 is no worse than XP2012B.

Using PMT with plano-concave window is a easy way to improve TTS for PMT.