Possible Application for PID Detectors

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Workshop on Micro-channel Plate Based Detectors
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This talk

Possible application of “improved MCP-PMT” for PID

- Time-Of-Propagation Counters
- Precision TOF
- Proximity focusing RICH

These are my personal comments.

May not be specific to Belle II (out of scope of the on-going project).

Comparison of Photodetectors

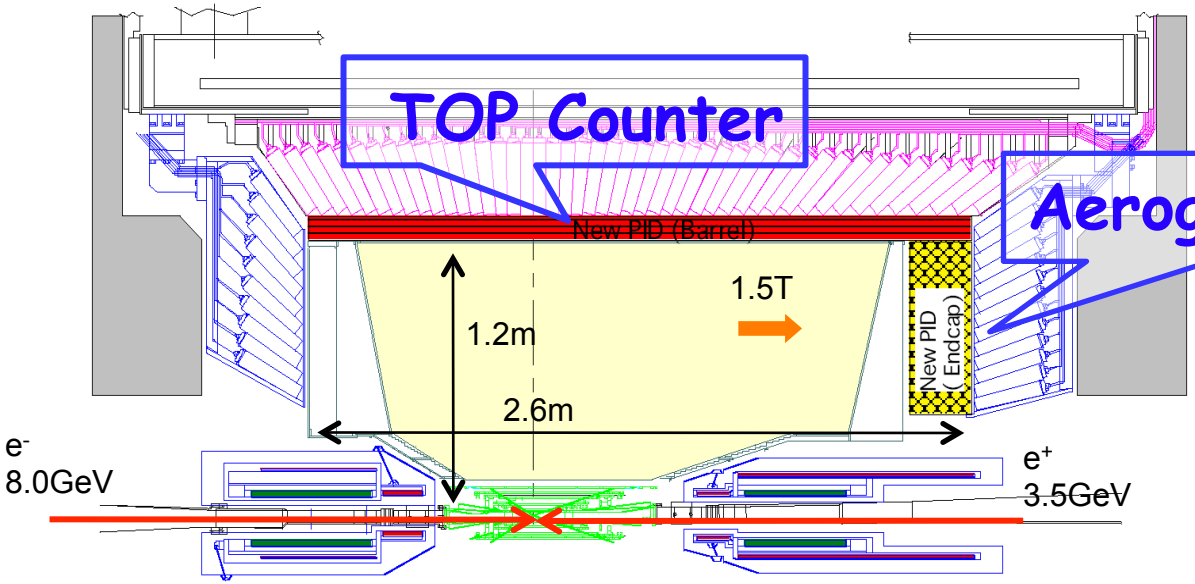
- HAPD: Hybrid Avalanche Photodiode
- MCP-PMT: Micro-channel-plate PMT
- G-APD: Giger-mode APD

	PMT	**MCP-PMT**	HPD / HAPD	G-APD
Gain	>10^6	**~10^6**	~10^3 X10~100 w/ APD	~10^6
Quantum Eff.	~20%, ~400nm (bialkali)		⇒ ~30-40%	~80%, ~600nm
Collection Eff.	70%	**60%**	100%	50%
Time resolution	~300ps	**~30ps**	~150ps Depends on readout	<100ps To be checked
B-field immunity	×	△ Depends on angle		○
Problems		**lifetime**		Noise, size, Rad. hardness

& Cost

Belle II PID System

- To cope with increased background (present x ~20)
- To improve the performance.
  - Target: > 4σ at 4 GeV/c
  - Novel Ring Imaging Cherenkov Counters
    w/ advanced radiator & photo-detection technologies
- We use photodetectors
  - TOP : MCP-PMT (SL10 w/ 4x4 matrix)
  - A-RICH : HAPD (12x12 matrix)

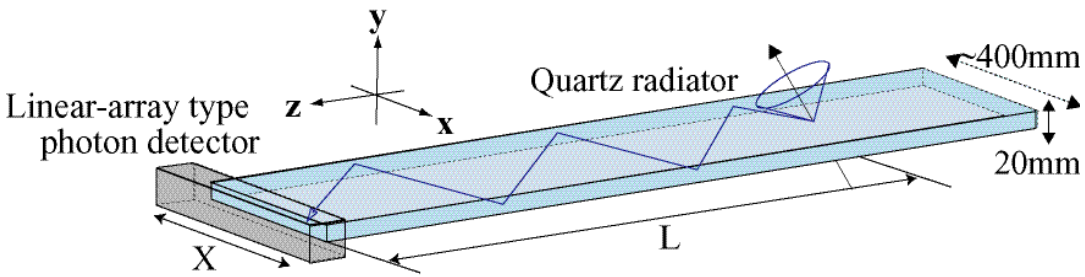


Tight space limitation
Barrel: ΔR = 10-20cm
Endcap: ΔZ = 28cm

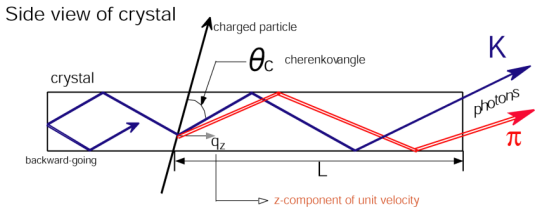
TOP Counter

Simulation
2GeV/c, θ=90 deg.

Cherenkov ring imaging using timing information

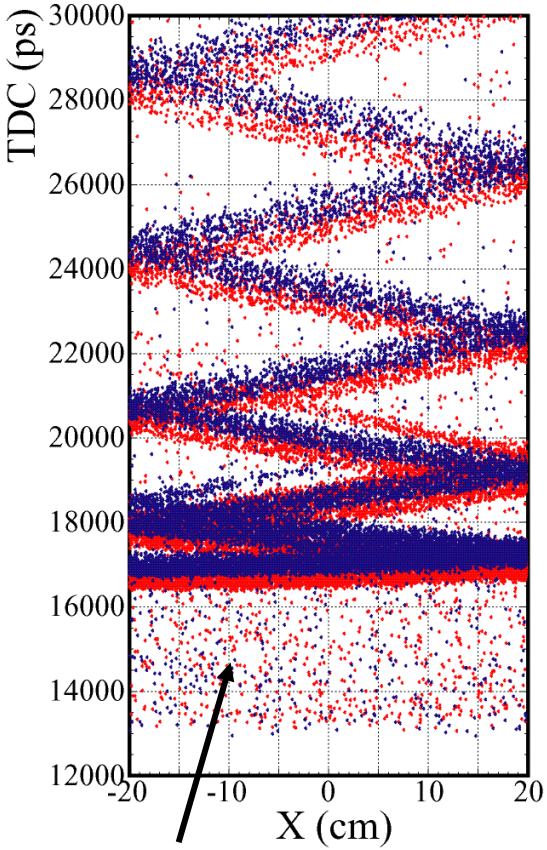


$$cos\theta_c = \frac{1}{n(\lambda)\beta}$$



Difference of path length
→ Difference of time of propagation (TOP)

150~200ps from TOP + TOF from IP with precise time resolution (σ~40ps) for each photon

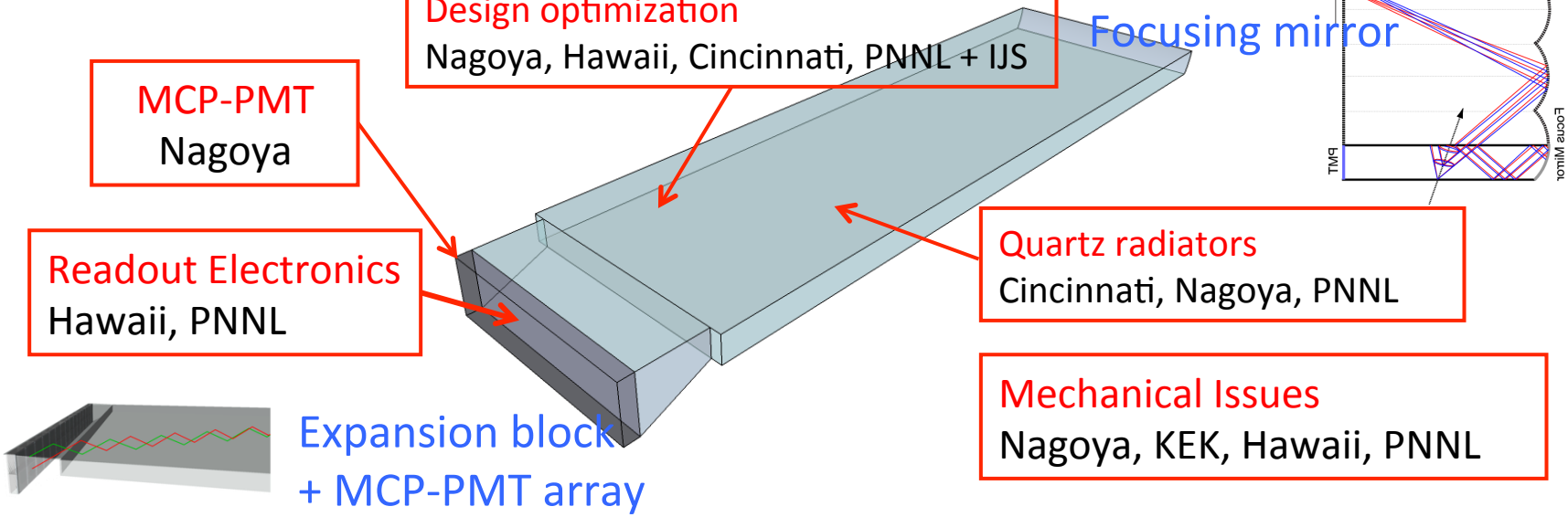


δ-ray,
had. int.

Photodetector parameters:
Time resolution, position resolution, lifetime, effective area, collection efficiency, quantum efficiency, chromatic dispersion

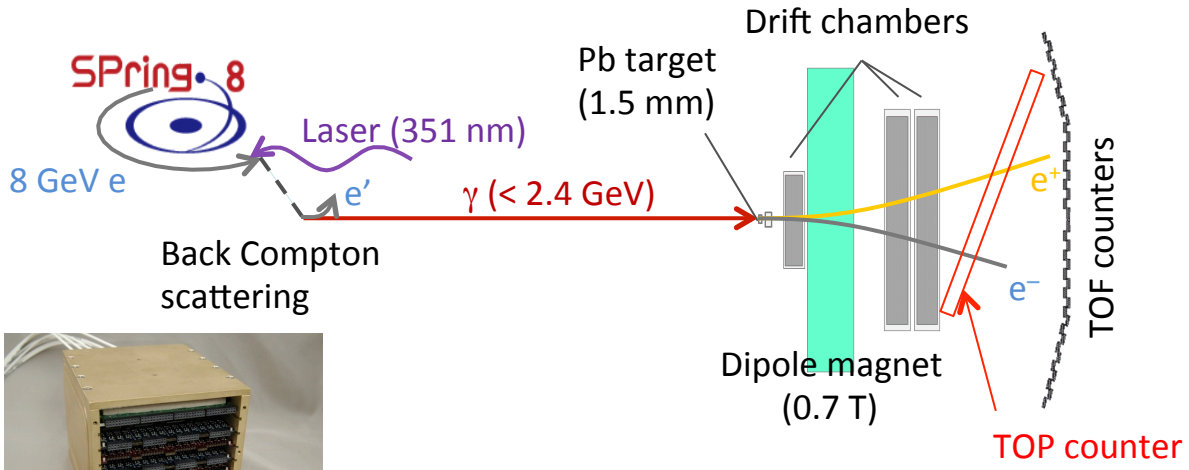
Belle II TOP Project

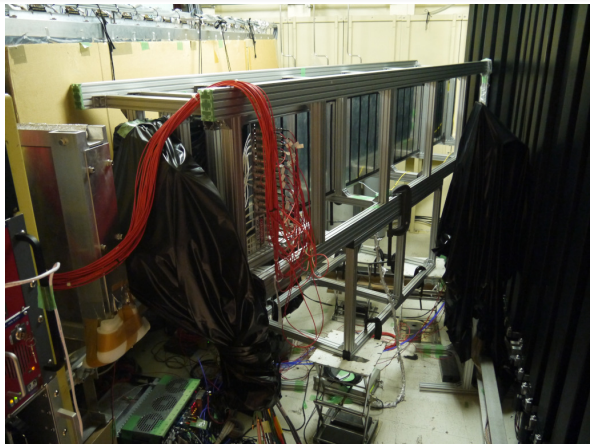
- Focusing mirror for correcting chromatic dispersion effect.
- Imaging w/ expansion block + 2-layer MCP-PMT (SL10 w/4x4ch).



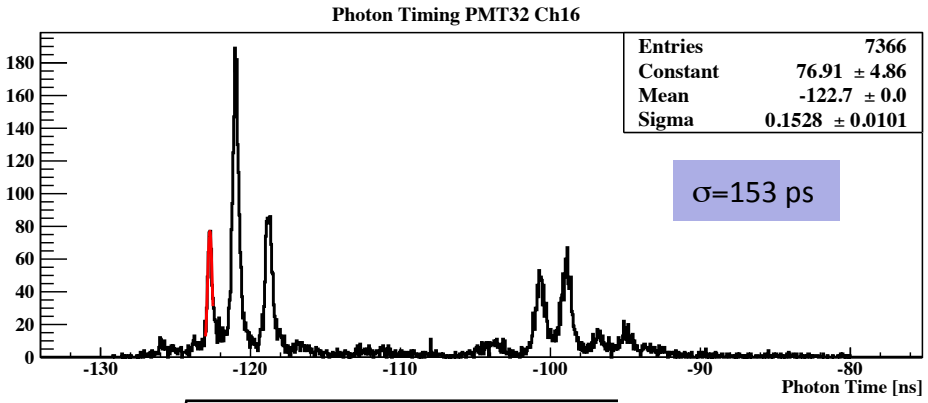
Collaboration of
Japan (Nagoya, KEK) + US (Hawaii, Cincinnati, PNNL, …) + Slovenia (IJS)

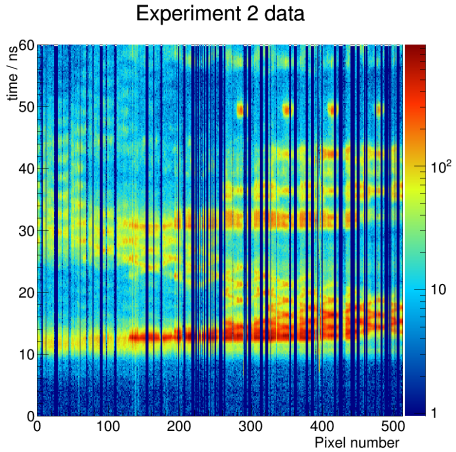
Beam Test @ Spring-8/LEPS (June 2013)

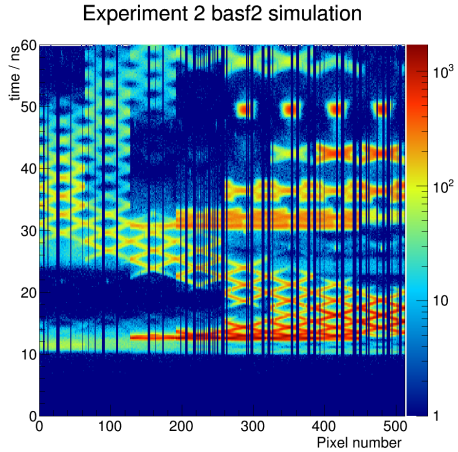




IRS3B readout







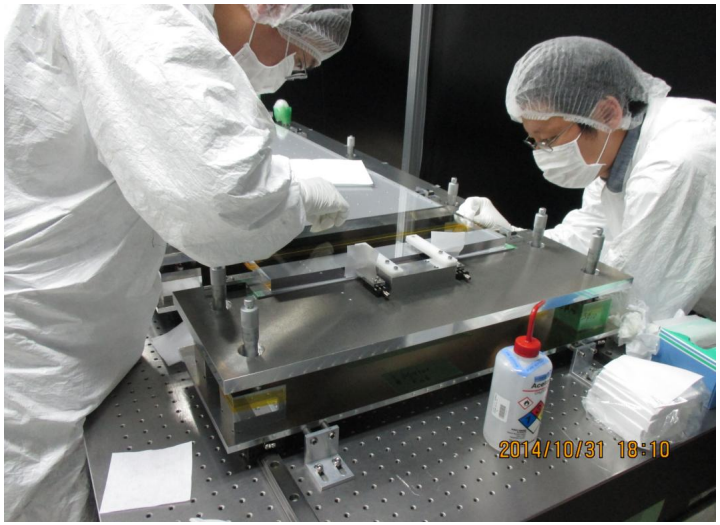
$$\sqrt{(120\,ps)^2 + (100\,ps)^2} = 156\,ps$$

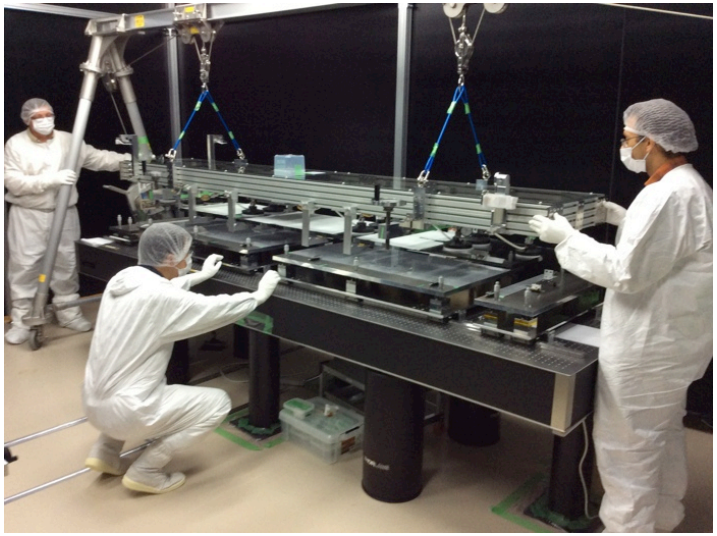
ITOP Physics

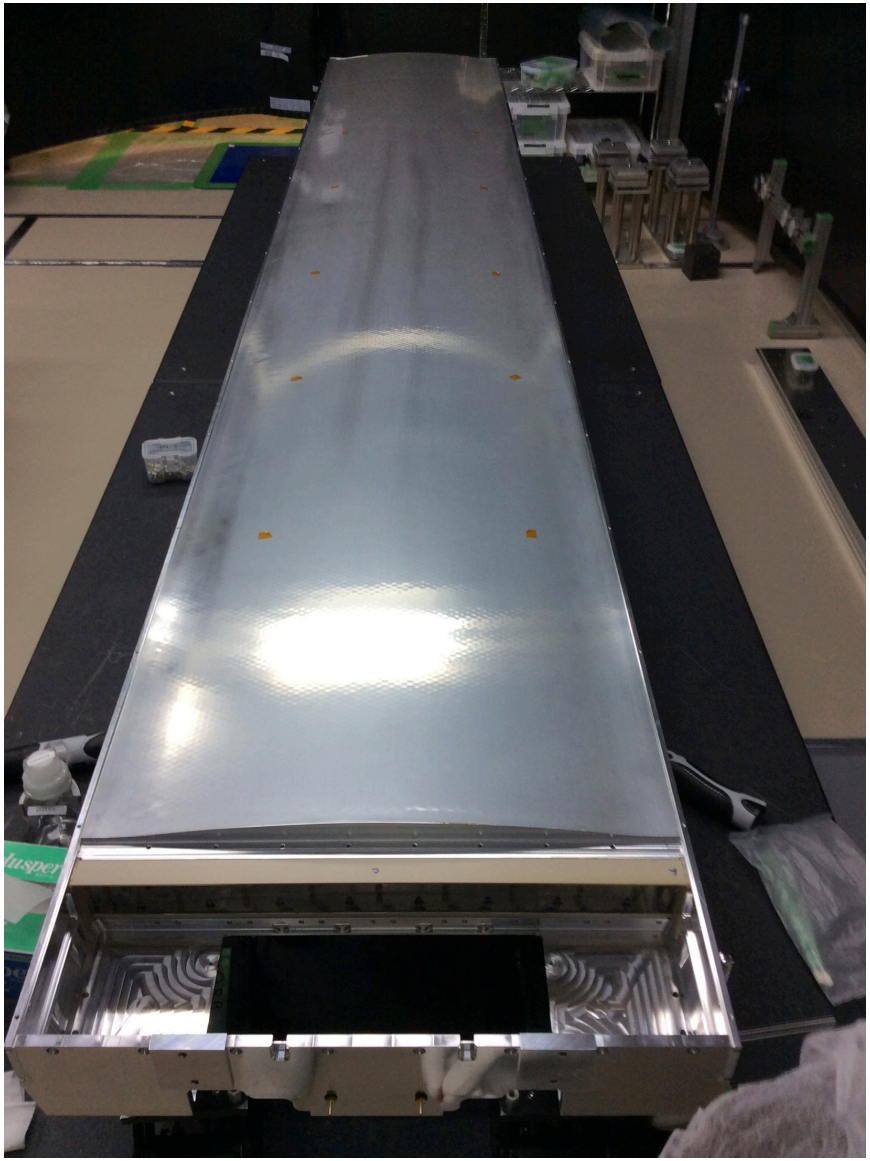
IRS3B, PMTs, CAMAC, FTSW, RF, …

Performance demonstrated with final form of optics, PMT and readout (IRS).

Completion of Optics + QBB (Nov.10)

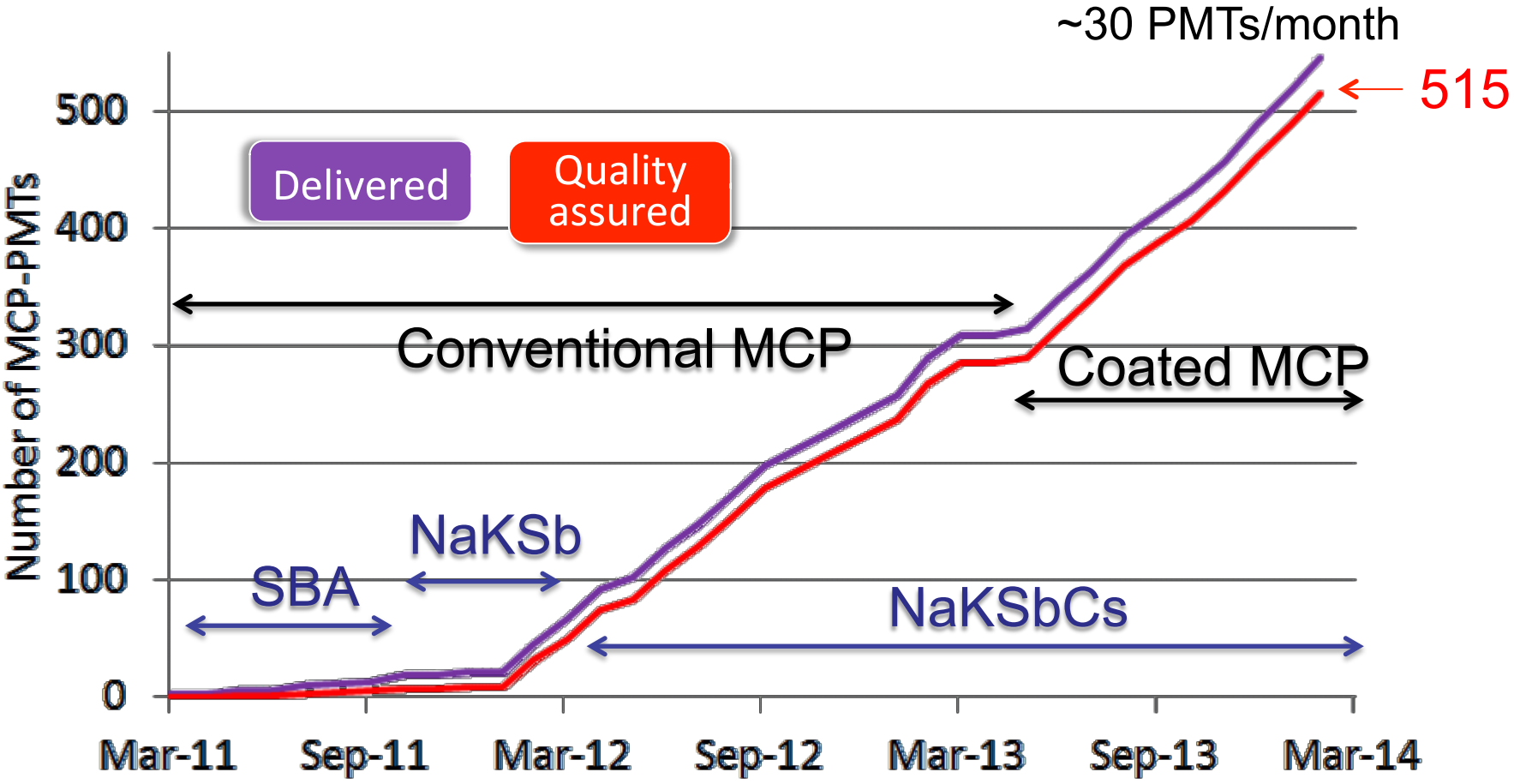






Progress of the mass production

- Mass production started in March 2011 and finished in March 2014.

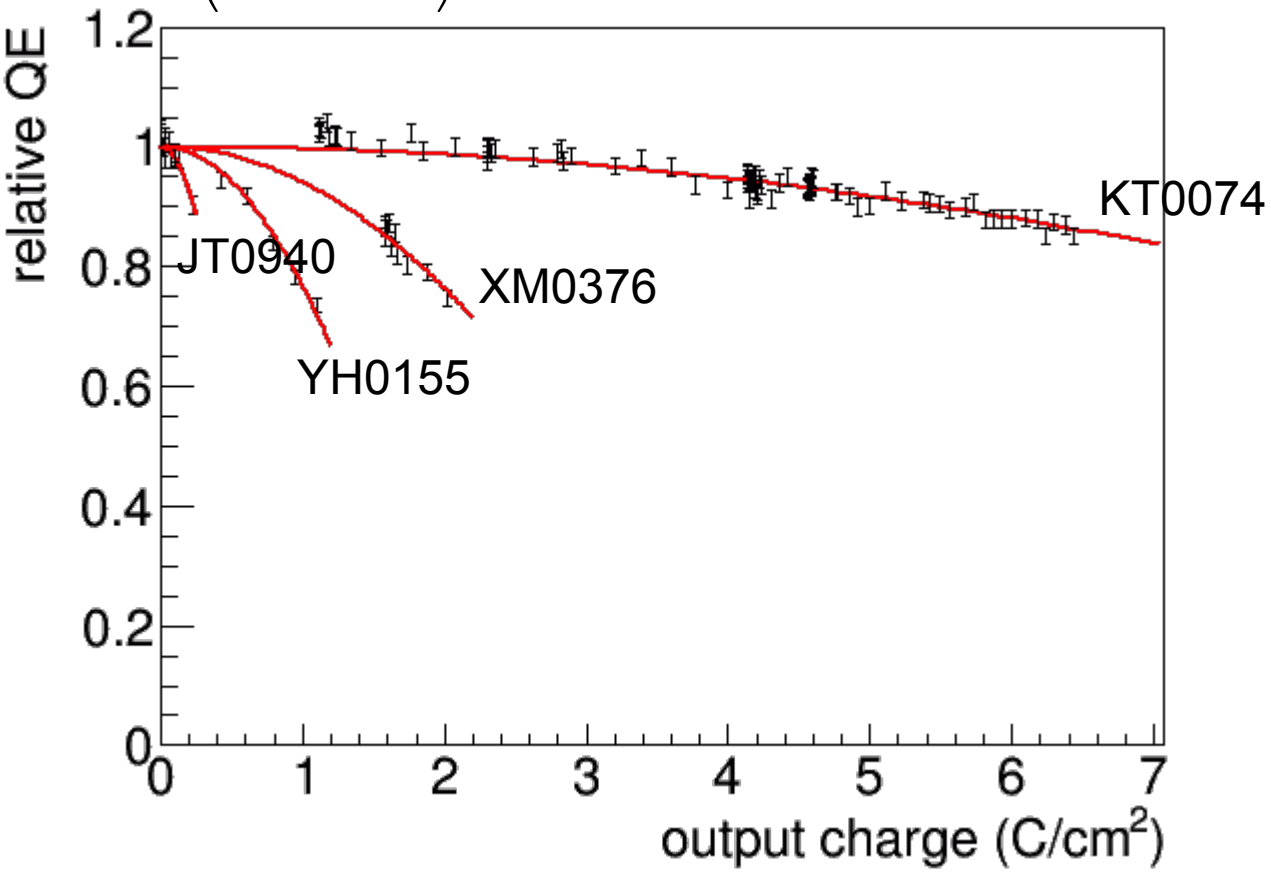


Lifetime Improvement

- QE declines as a quadratic function of total output charge:

$$\frac{\mathrm{QE}(Q)}{\mathrm{QE}(0)} = 1 - \left(\frac{0.447}{Life} Q\right)^2$$

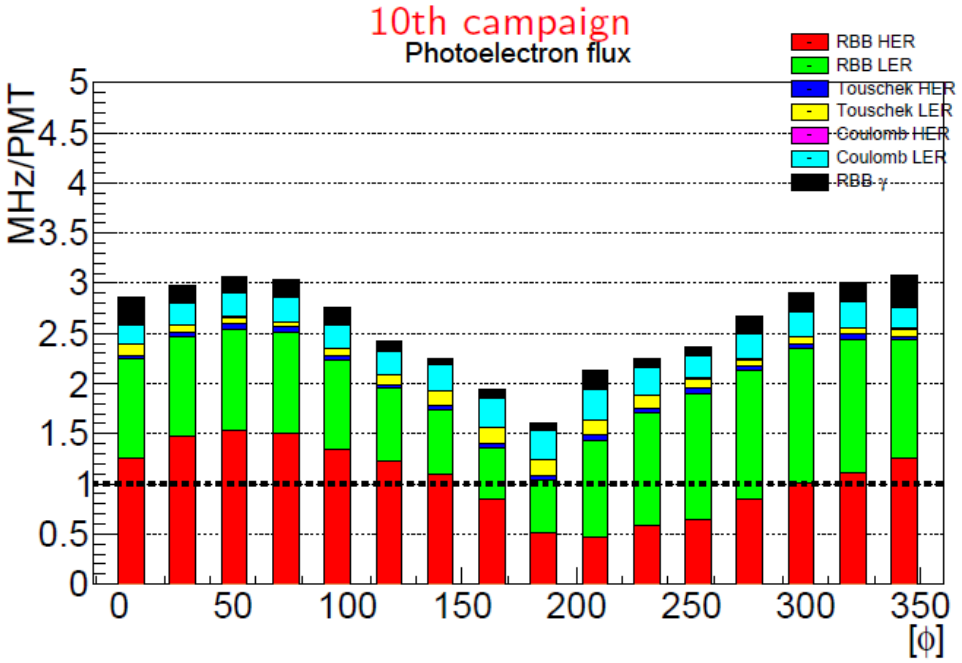
Life: Output charge at QE(*Q*)/QE(0) = 0.8



Photoelectron flux on PMTs at Belle II

- 1 MHz/PMT at 5 10^5 gain at design luminosity

  → about 1 C/cm^2/50ab^{-1} (dashed line)
- Normal type MCP PMTs (55%): average max. charge ~1.1 C/cm^2
- Coated MCP PMTs (45%): average max. charge ~8.6 C/cm^2
- Too high for normal MCP PMTs to survive the full experiment.



Lifetime Issue

- For Belle II TOP, we need replacement of conventional MCP-PMT in middle of the experiment, unless background is much lower than expectation.
- We like to maximize and stabilize lifetime improvement, taking account of uncertainties in MC.

⇒ We are studying how to improve the SL10 lifetime.

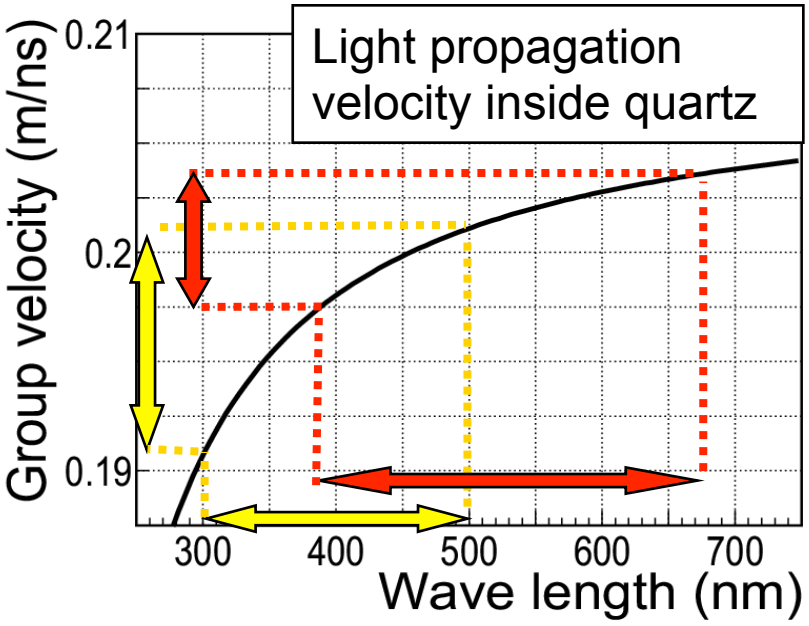
⇒ Exchange of information in this community and feedbacks are highly appreciated.

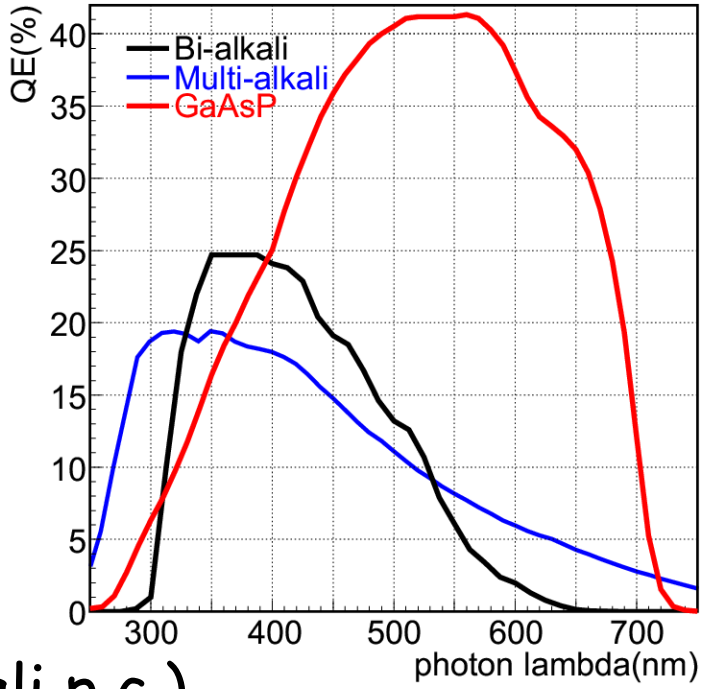
- Improvement of lifetime would be important also for general applications.

Some more points of improvement for TOP applications (in general) are discussed in the following slides.

Chromatic Dispersion

Variation of propagation velocity depending on the wavelength of Cherenkov photons

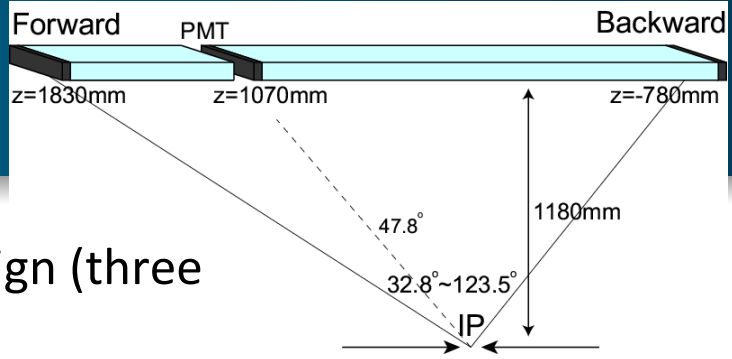




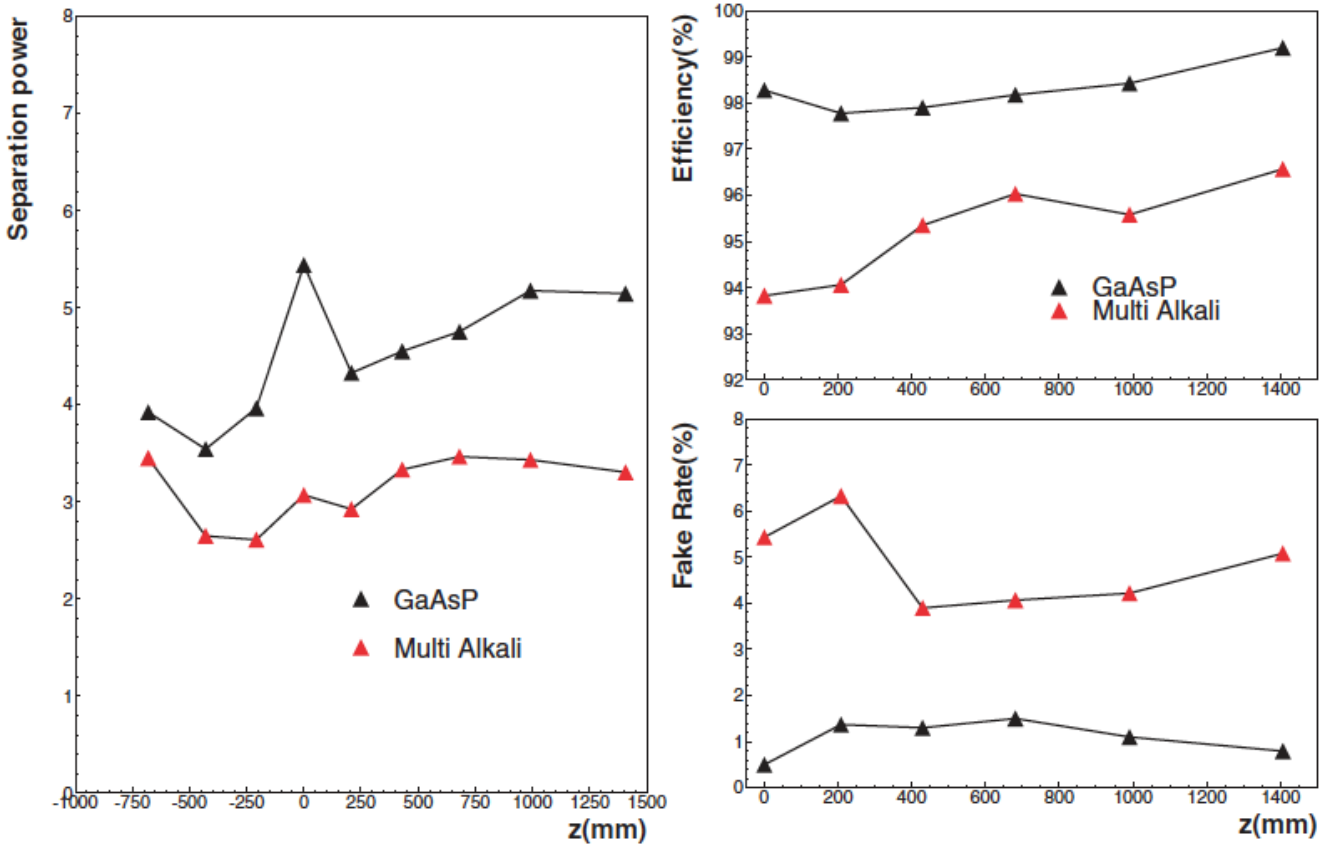
- GaAsP photo-cathode (←→ alkali p.c.)
  - Higher quantum-efficiency
  - at longer wavelength → less chromatic error

    Photon sensitivity at longer wavelength shows the smaller velocity fluctuation.

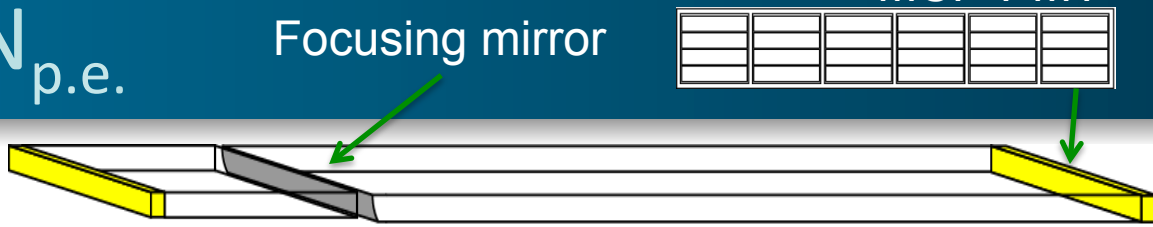
Improvement w/ GaAsP



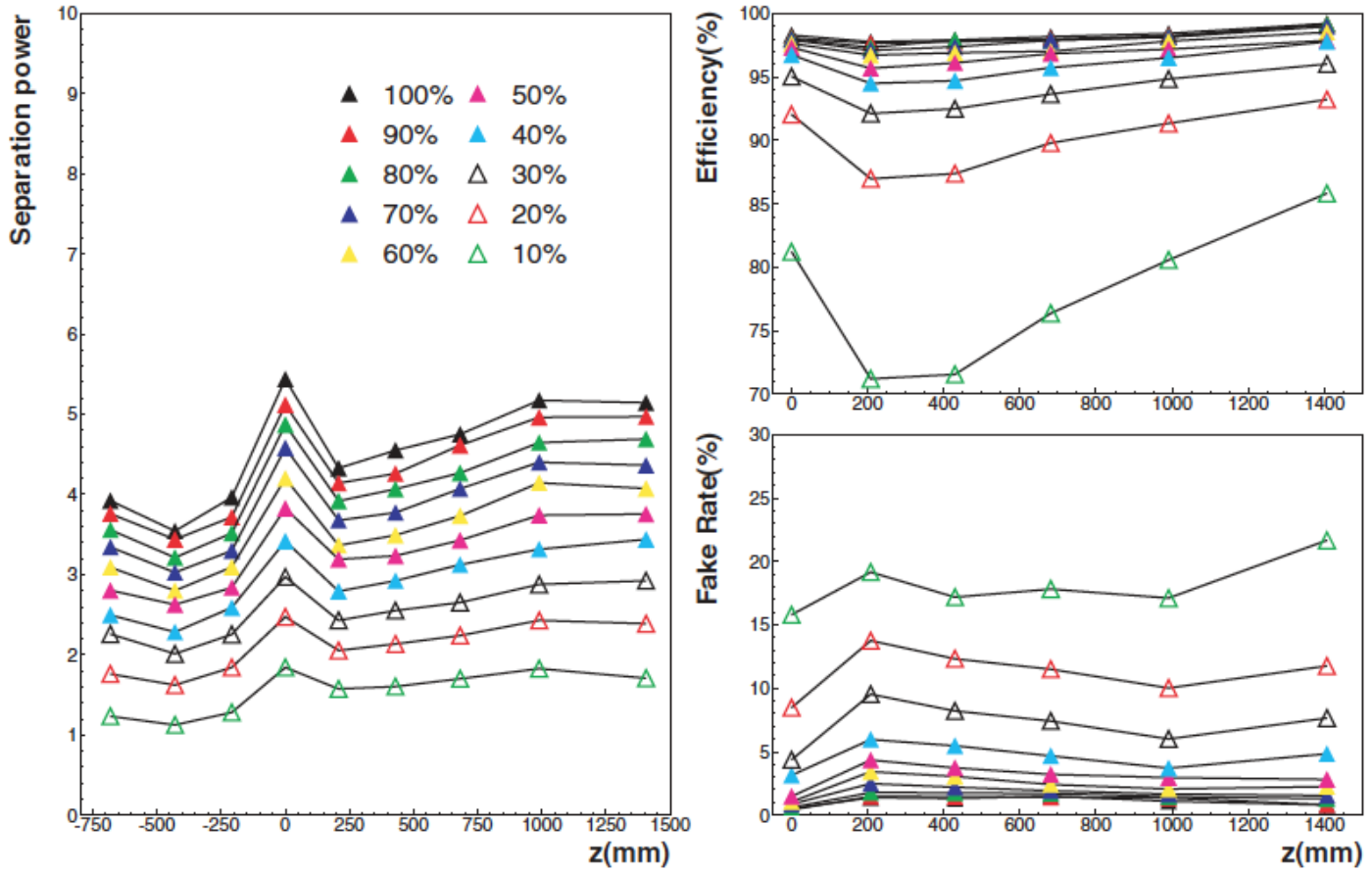
- Old MC studies based on earlier Belle II TOP design (three readout concept).
- QE's in the previous page are assumed (<QE>~28% for Belle II real system).



Dependence on $N_{p.e.}$



- Old MC study with the “focusing TOP” configuration.
- Np.e. is propotional to QE, CE, effective area.



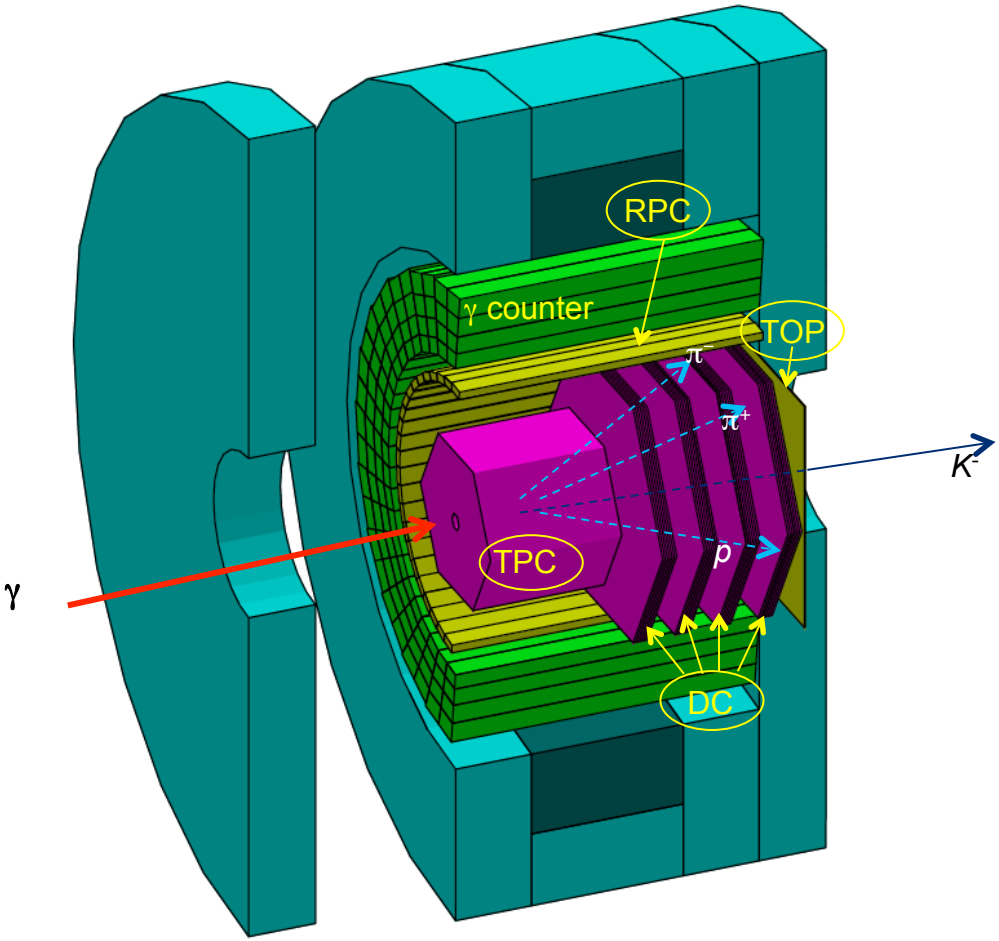
Possible improvement of TOP counter

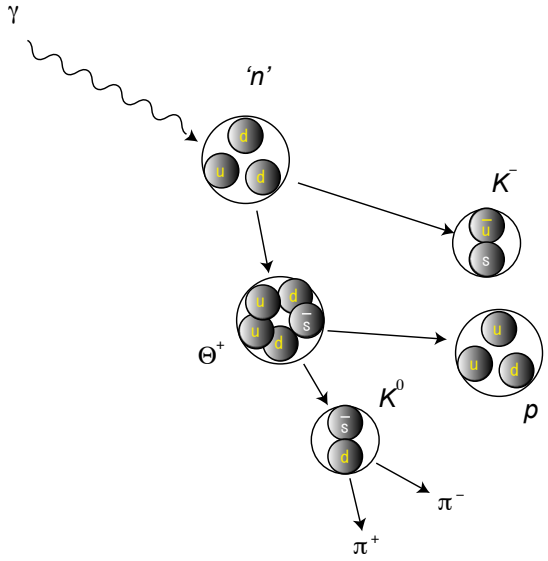
Item	Present (SL10)	Target
Lifetime	1.1C/cm^2 (conventional), 8.9C/cm^2 (coated)	> 10 C/cm^2
Effective area	66%	> 80%
Quantum efficiency	28% (avg)	> 35 % (avg)
Collection efficiency	55%	> 70 %
Chromatic dispersion	Multi-alkali	GaAsP (or similar)

- Smaller pixel size, better time resolution does not help before improving chromatic dispersion.

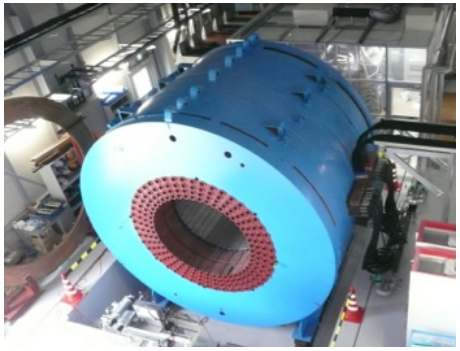
Application to LEPS2 @ SPring-8

- TOP is considered for the forward PID in the new LEPS2 spectrometer at Spring-8.





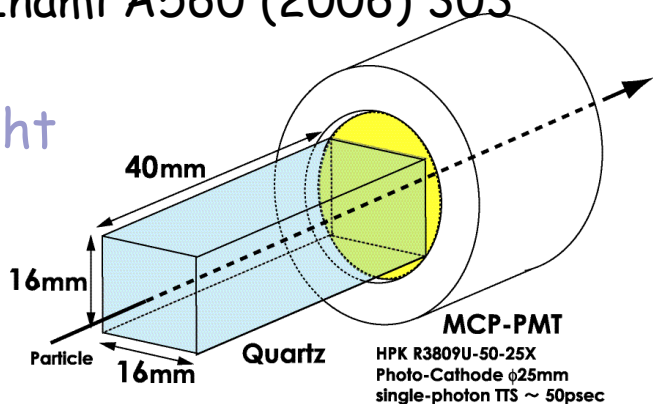
E787/E949 solenoid spectrometer shipped from BNL to Spring-8



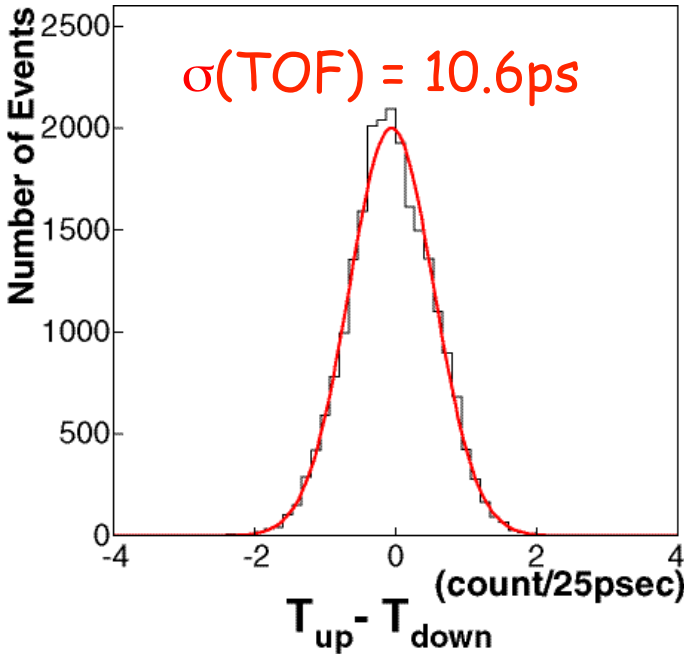
TOF w/ MCP-PMT

Y.Enari NIM A547 (2005) 490
K.Inami A560 (2006) 303

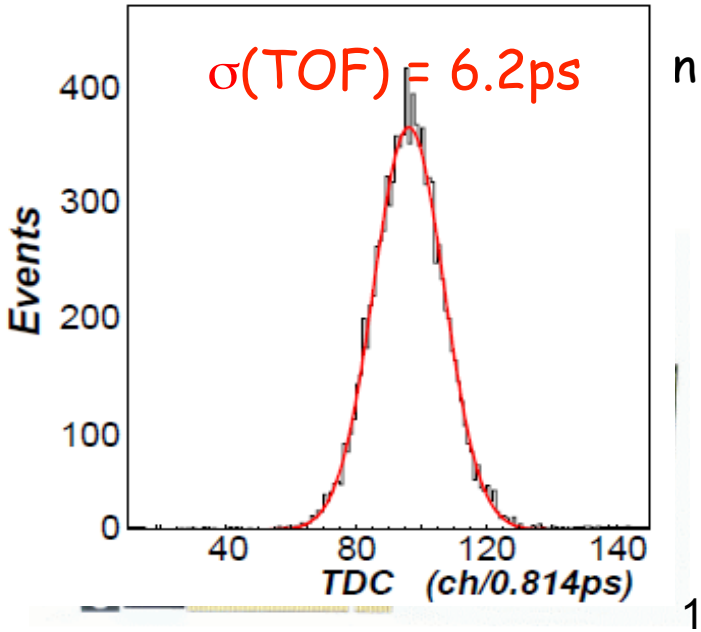
- High-resolution TOF using Cherenkov light
  - Small-size quartz :
    Cherenkov light (Decay time ~ 0)
  - MCP-PMT :
    TTS < 50ps for single photon



- Results 1
  4cm quartz radiator
  σ(elec.) = 8.8psec



- Results 2 w/ improved σ(elec)
  1cm quartz radiator
  σ(elec.) = 4.7psec

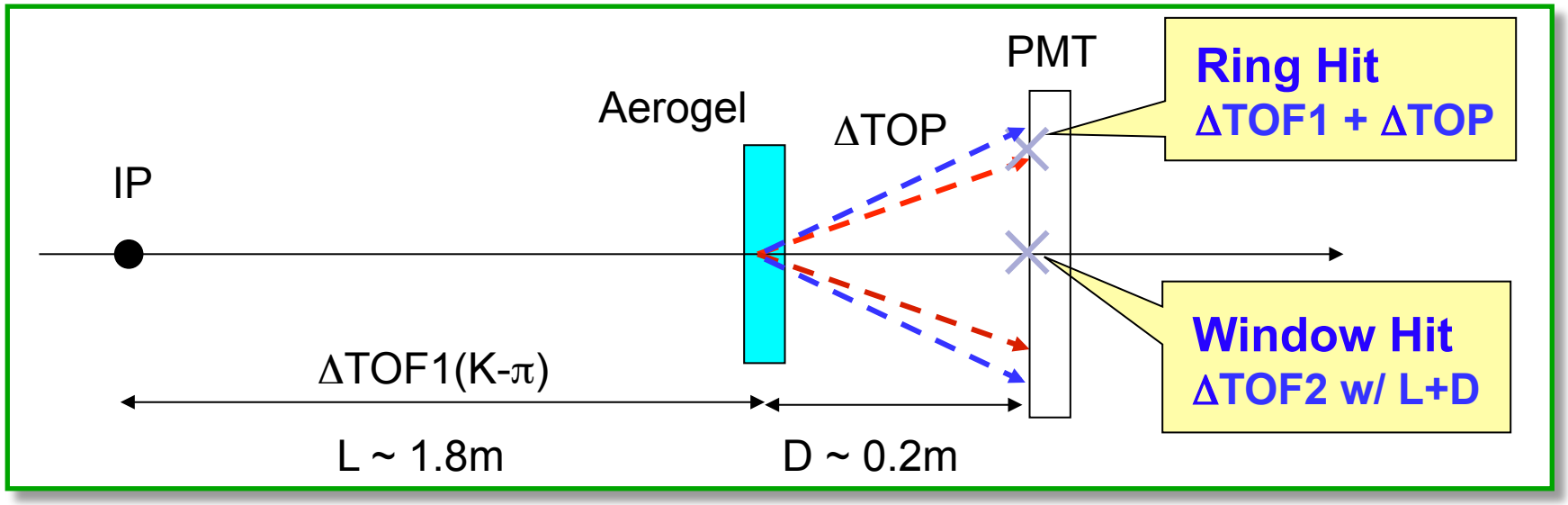


RICH w/ TOF Capability

- Possible PID improvement in low momentum region.
- Two timings can be used;
  - "Ring hit" : Cherenkov photons from aerogel.

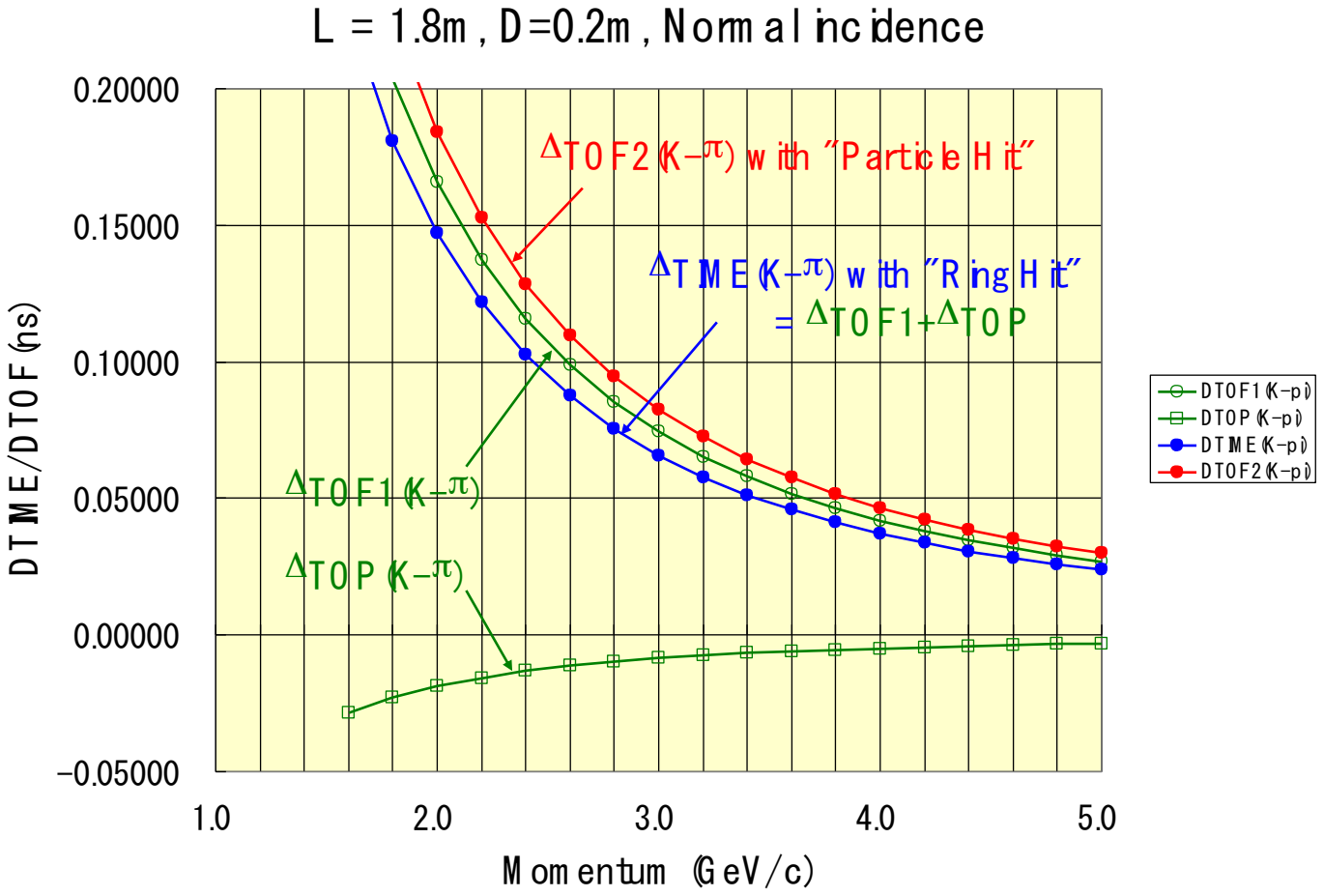
    σ_{photon} ~ 60ps ⇒ σ_{track} ~ 60ps/sqrt(9) =20ps
  - "Window hit": Cherenkov photons from glass window of PMT

    σ_{track} ~10ps possible (from the TOF R&D @ Nagoya).



Output from the 2nd MCP will help for the "Window Hit" TOF

TOF in Aerogel-RICH in Belle II configuration



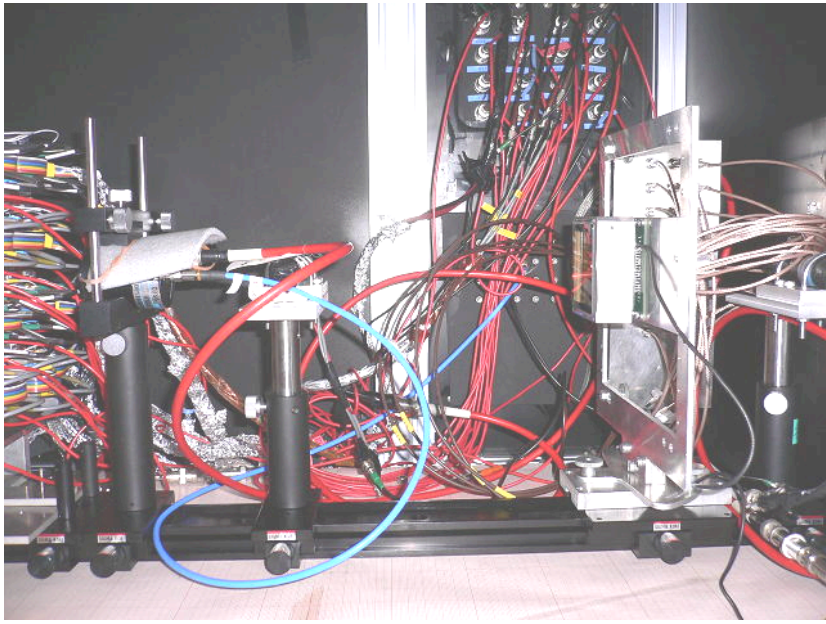
	1.5GeV/c	2GeV/c	4GeV/c
Ring Hit	--	147ps	37ps
Window Hit	323ps	184ps	47ps

Worth for studying !

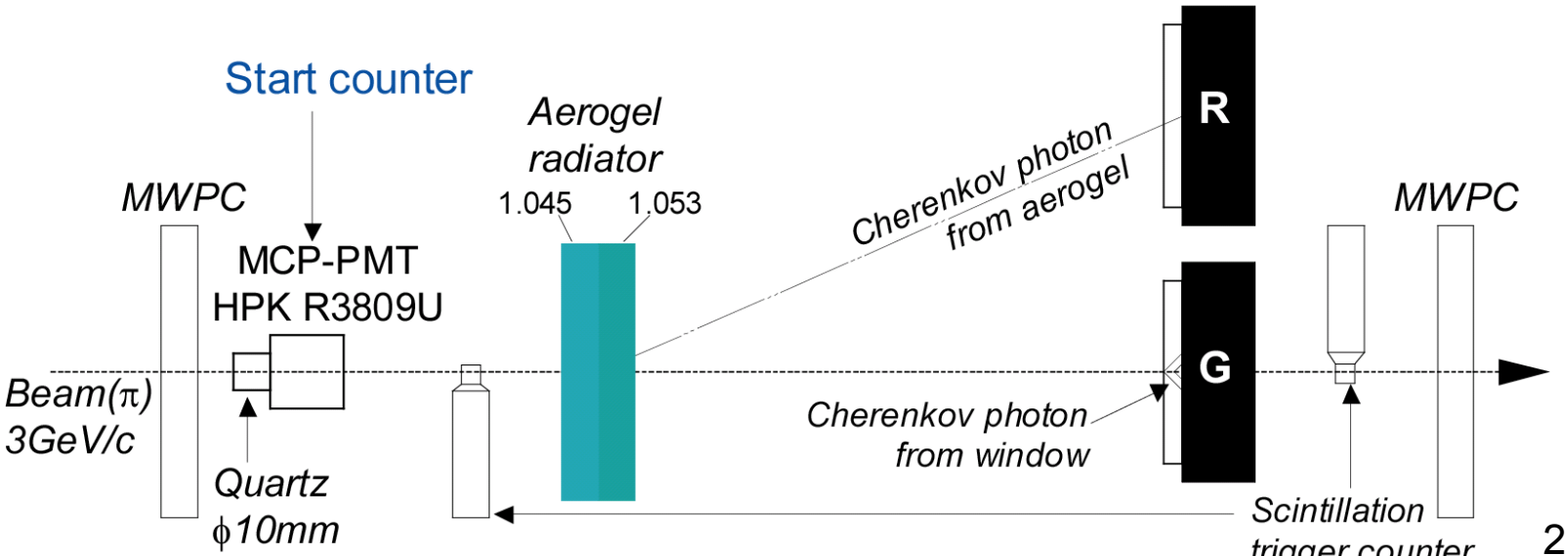
Beam Test Setup

- BURLE 85011-501 to measure the ring and window photons.
  - 13 channels are readout by
    FTA820 amplifier (ORTEC)
    L-edge discri (Phillips)
    KC3781A TDC (Kaizu works)
- Start counter: HPK R3809U MCP-PMT + 1cm quartz radiator
  - Start time resolution = 10ps (pre calibrated using two identical sets.)

December 2005 @ KEK-PS T2



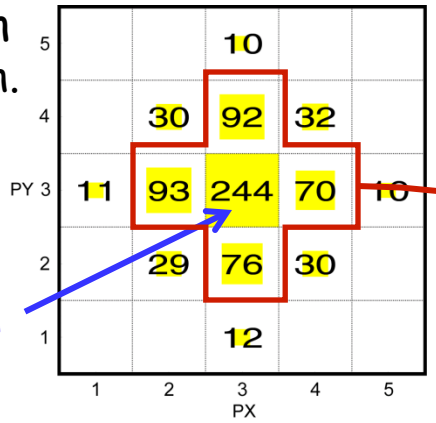
Multi-anode MCP-PMT
BURLE 85011-501



Time Resolution for Window Hits (cont'd)

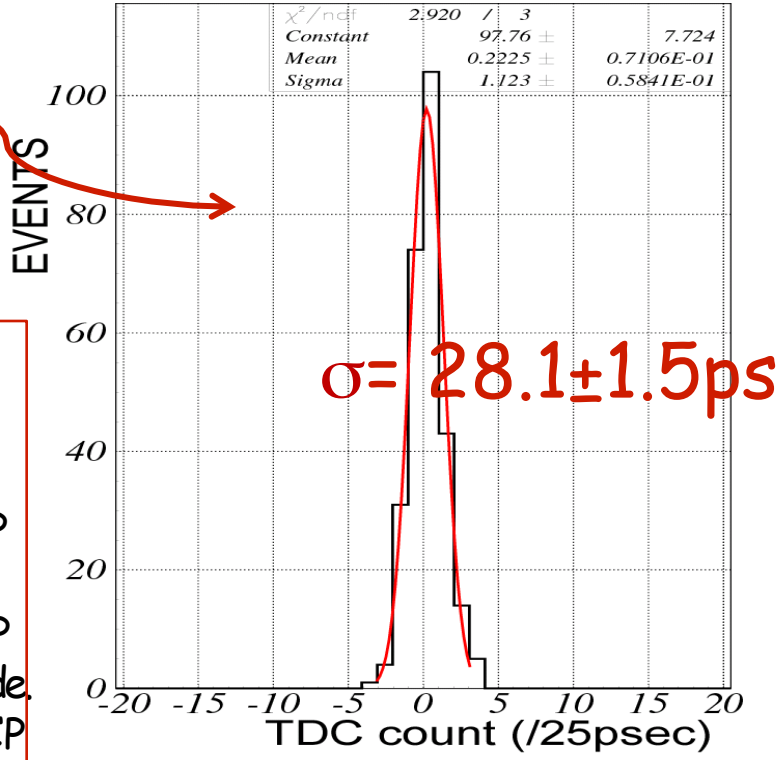
- Signals are observed also in the neighboring channels.
- Time resolution can be improved by combing hits.

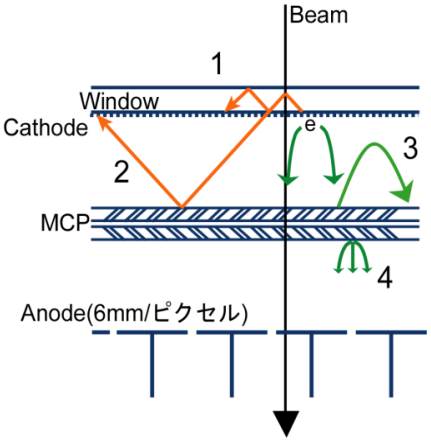
Hit distribution
<ADC> for each ch.



pixel hit by beam

Result using average over 5 pixels $\sum_{I=1}^{5} TDC_I \Big/ 5$



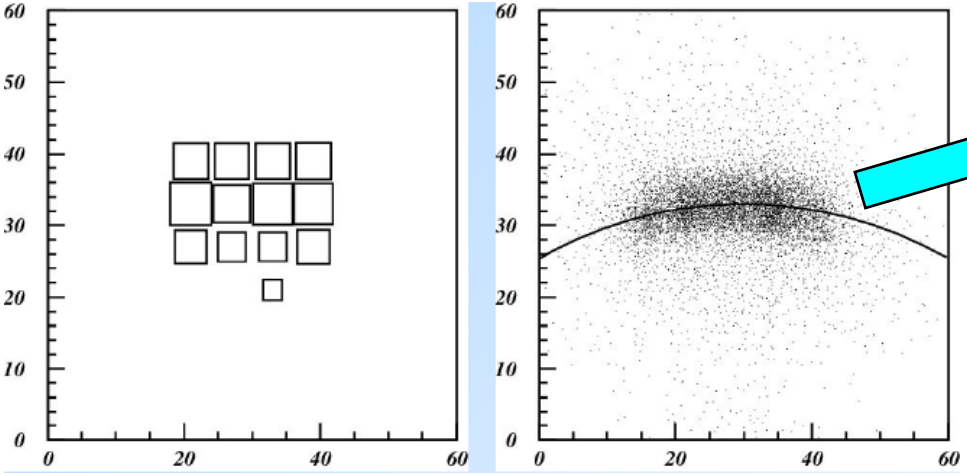


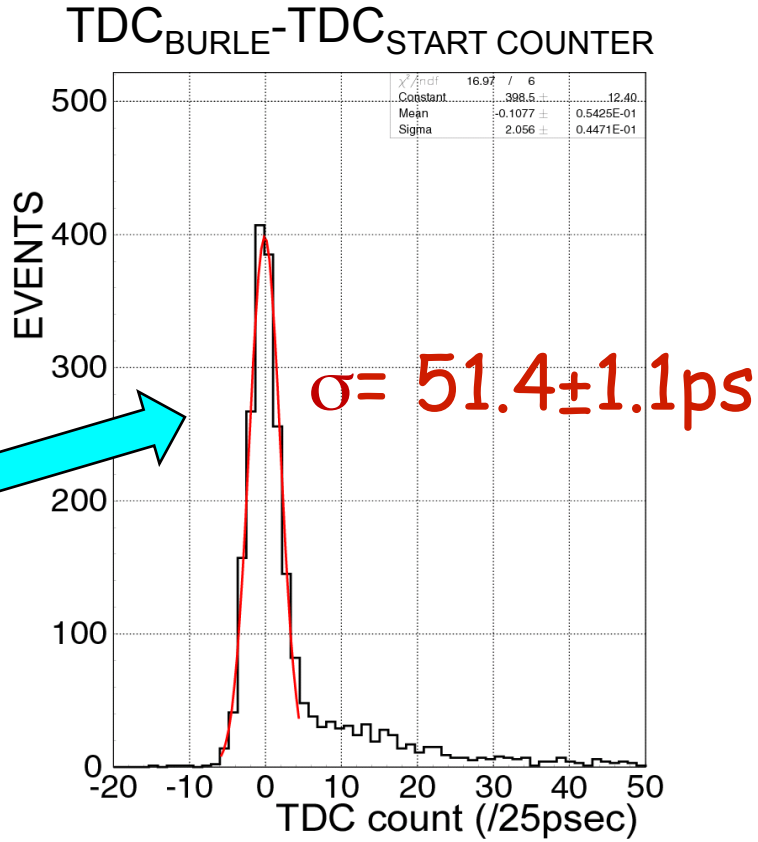
Possible sources
Photon reflections
1. in window
2. betw. PC and MCP
Electrons '
3. reflection at MCP
4. spread @ MCP-> anode.
5. spread @ PC->MCP

Time resolution for Ring Hits

- Obtained time resolution for Cherenkov photons from aerogel agrees well with the value from the bench tests.
- Resolution for the full ring (N_{pe}~10) would be about 20ps.

- Distribution of the hits on MCP-PMT (13 channels were readout).
- Corrected distribution using the track information.





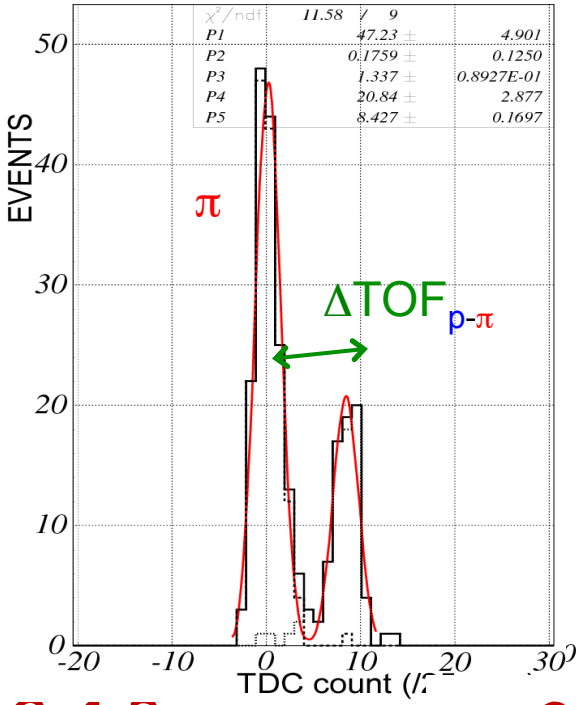
Cherenkov ring imaging is much more useful than TOF for "ring hits"

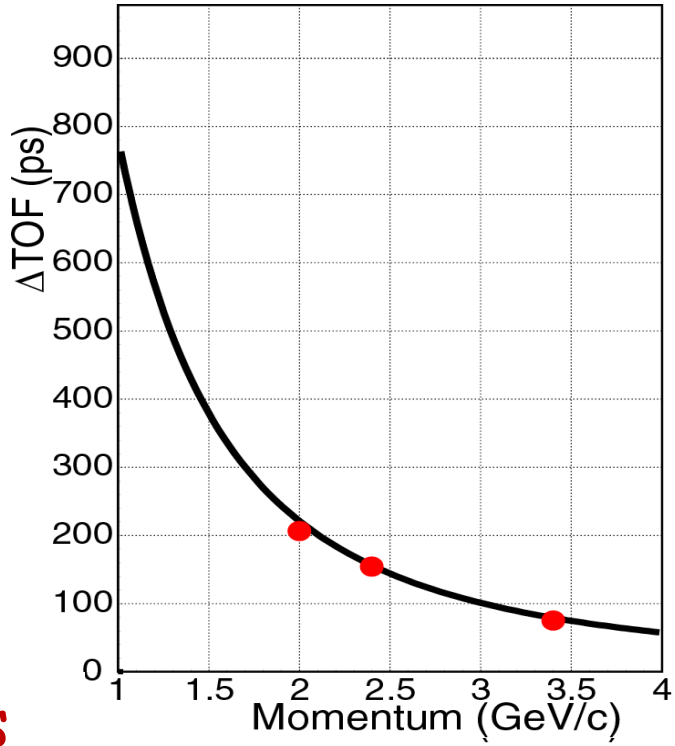
TOF Tests w/ pions and protons

- TOF tests using 2, 2.4, 3.4 GeV/c beam of pions + protons.
- Distance (start counter - MCP-PMT) = 65cm

5- pixel result (window hits)

TDC_{BURLE}-$TDC_{START\ COUNTER}$ @ 2 GeV/c





σ= 36.2±1.3ps (1-pixel)

σ= 33.4±2.2ps (5-pixel)

Summary

- MCP-PMT is unique photodetector with advantage w.r.t. other devices (esp. G-APD)
  - Superior timing resolution
  - Low noise
  - Radiation hardness

Ideal for PID
with precision timing

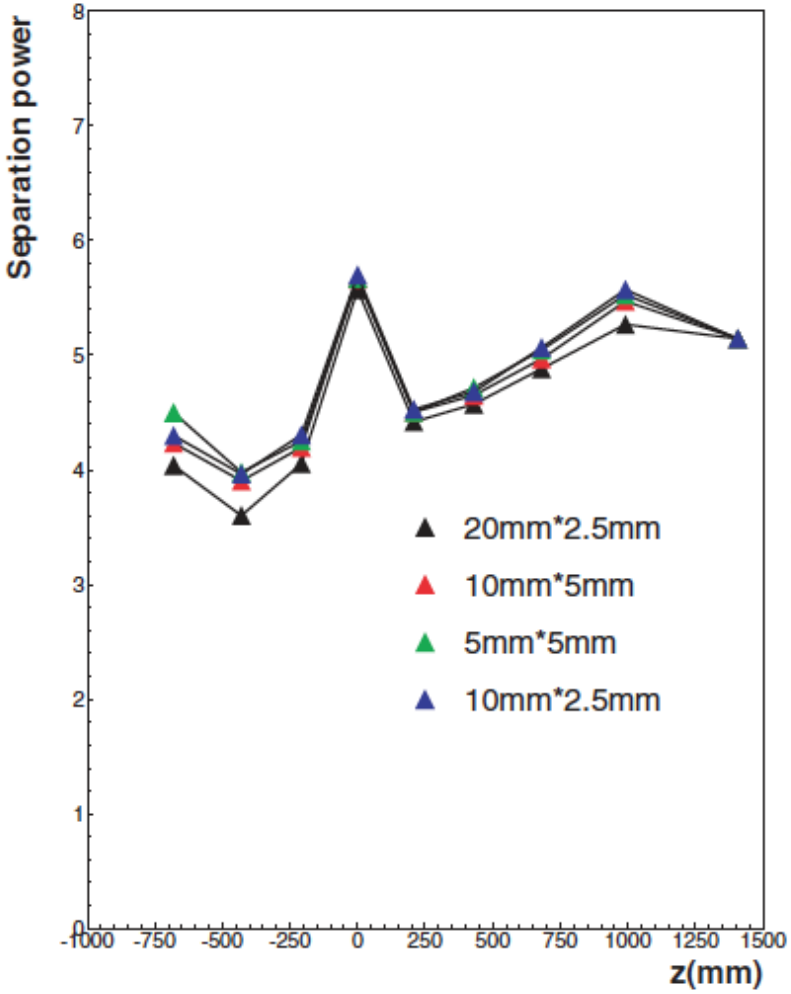
- Further improvement in lifetime, size, effective area, QE(λ), CE, cost down would make it more unique.

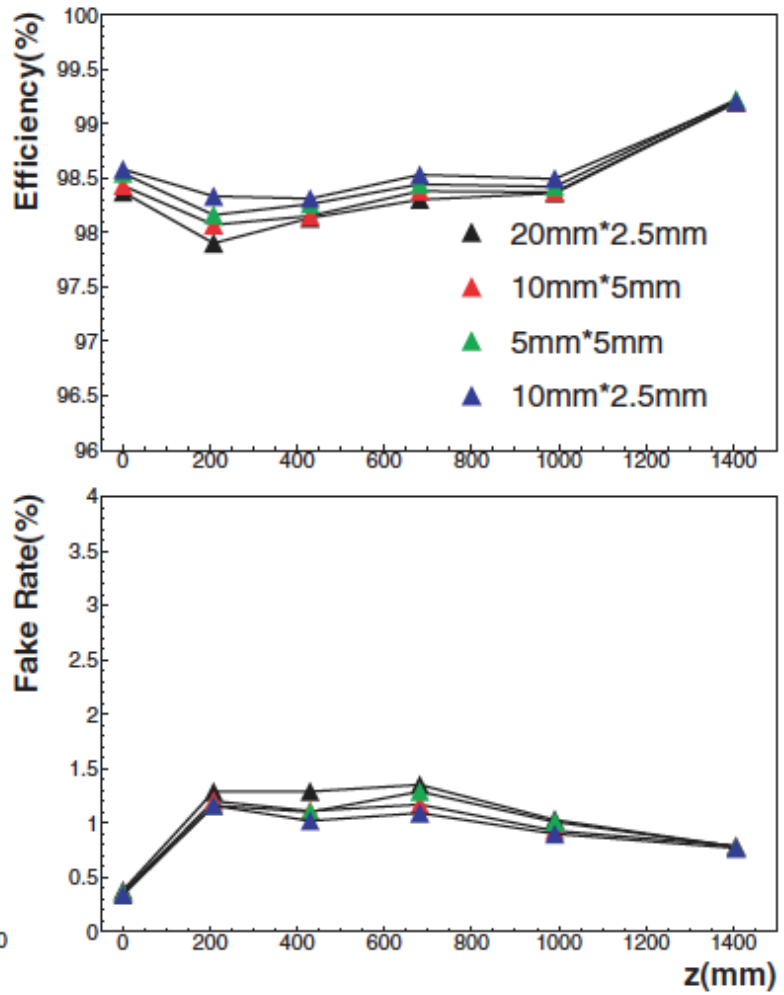
I hope that this MCP-PMT community will develop !

Backup

Dependence on pixel size

- Old MC studies based on earlier Belle II TOP design (three readout concept).

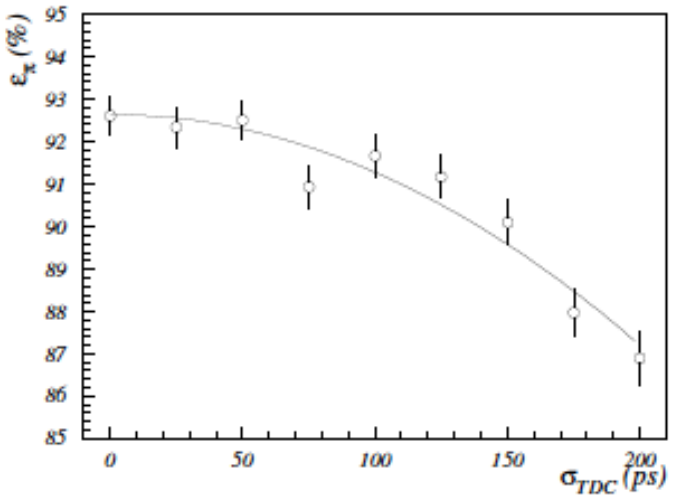


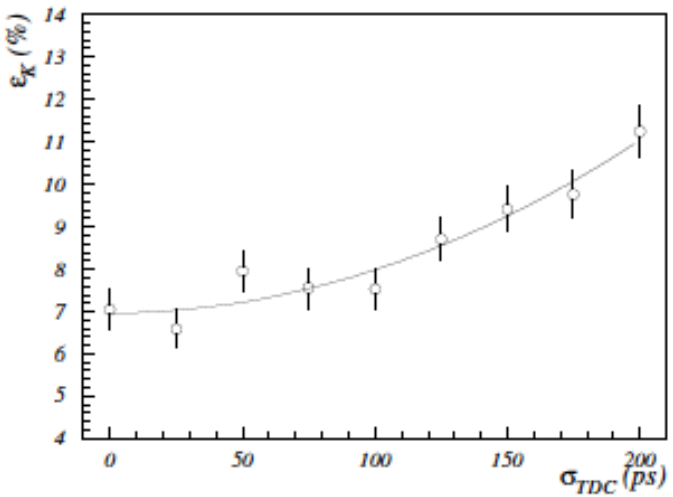


Dependence on timing jitter

Impact of electronics jitter — $B \to K\pi$ signal MC

- Additional Gaussian smearing of photon arrival times (up to 200 ps)
- For each data point different MC sample used

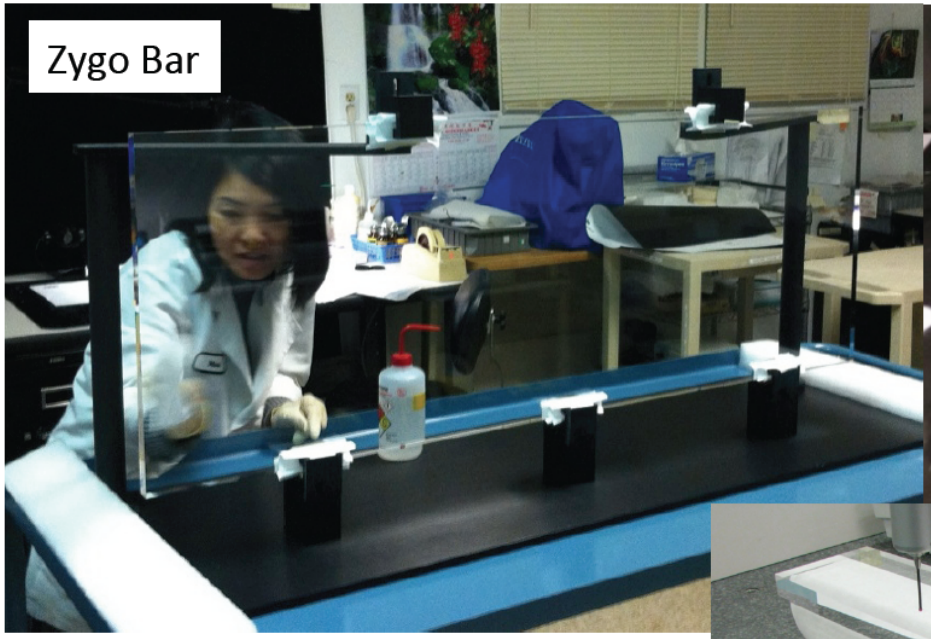


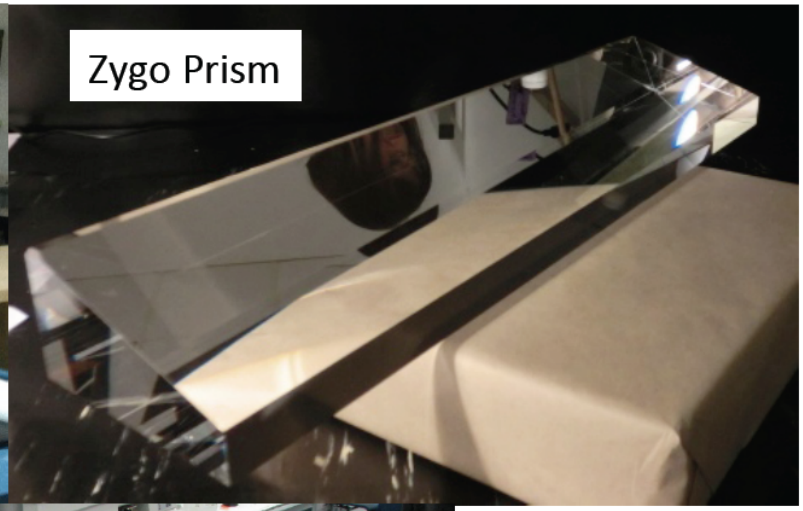


- Quadratic dependence
- Negligible up to 50 ps
- Small performance degradation observed for 100 ps (∼1%)

Status

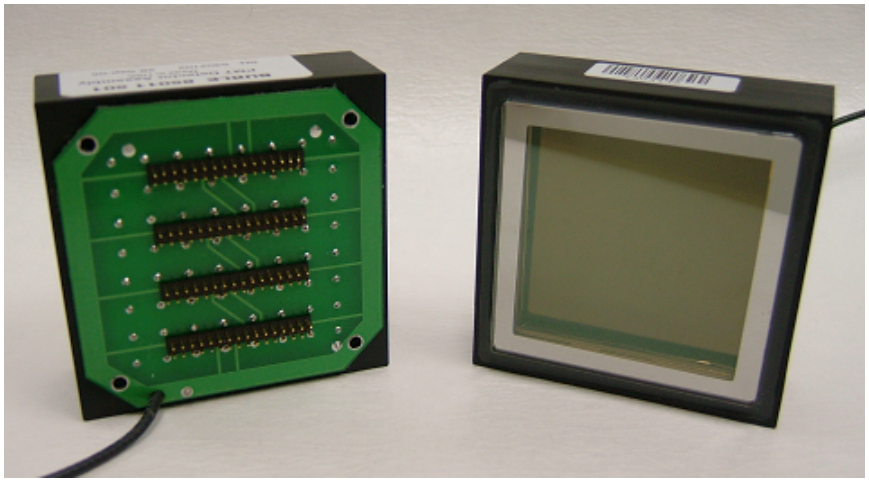
US-Japan has been essential in preproduction of quartz bars, mirrors and prisms, and verify the vendor performance.





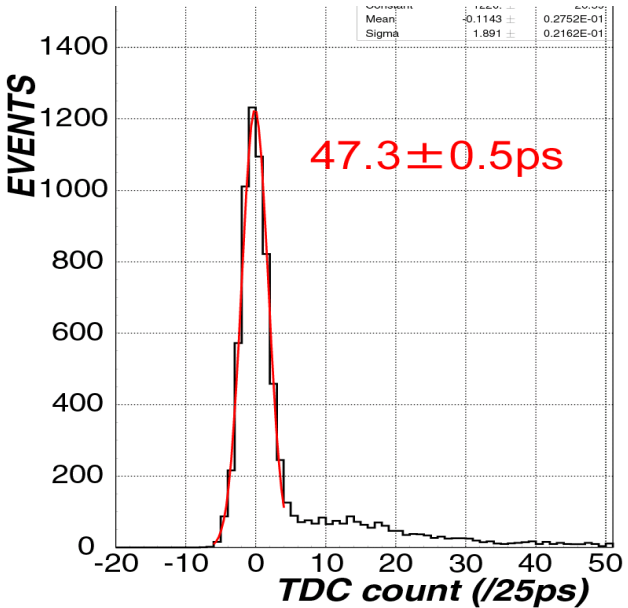
Burle MCP-PMT (85011-501)

- 8x8 multi-anode.
  - Pitch = 6.45mm / gap=0.5mm
- Bialkali photocathode
- 2MCP steps
- Gain ~ 0.6×10^6
- 25m pores

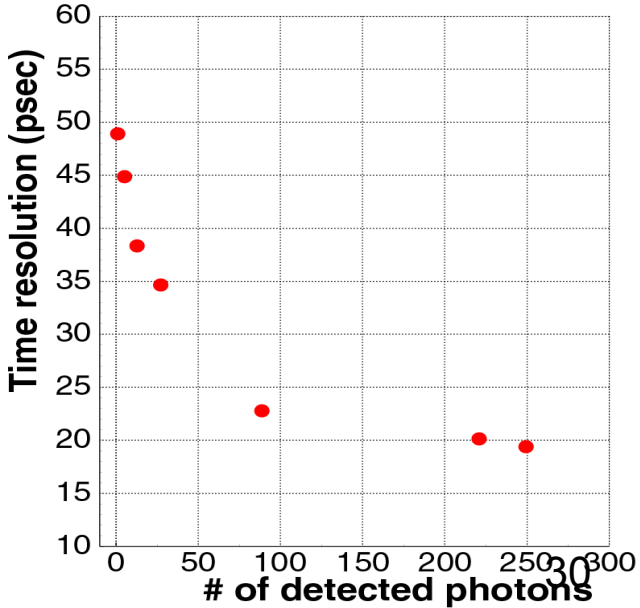


Bench test w/ pulse laser (HPK PLP-02)

Single photon irradiation



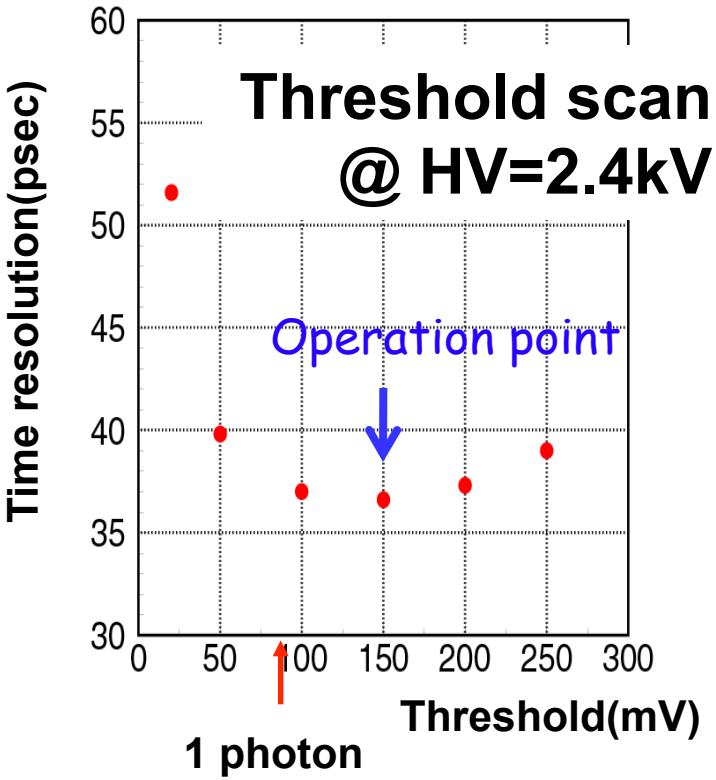
<Npe> dependence



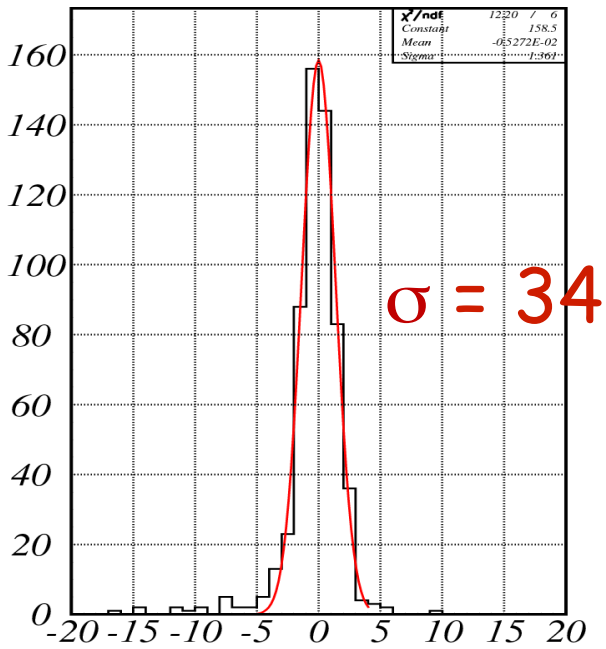
Time Resolution for Window Hits

- Optimization of discriminator threshold and HV.
- Time walk correction applied.

1- pixel result



TDC_{BURLE}-$TDC_{START\ COUNTER}$



σ = 34.3±1.1ps

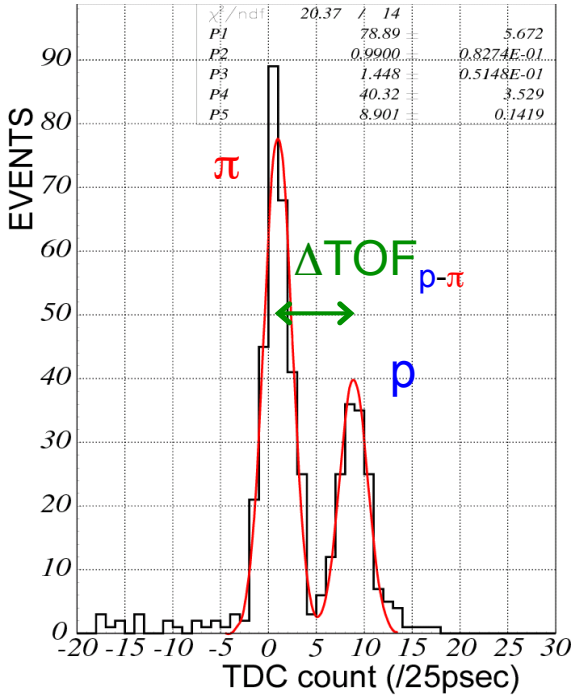
(Time walk corrected)

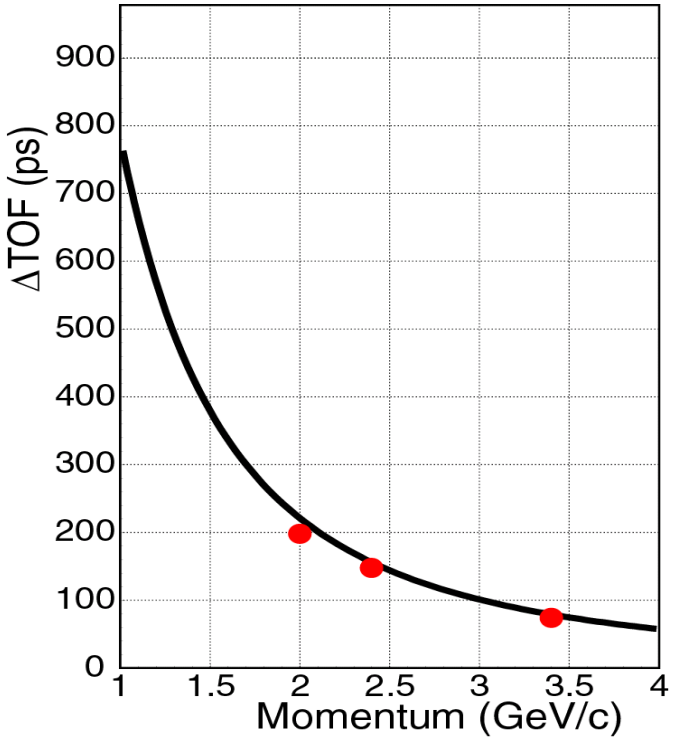
TOF Tests w/ pions and protons

- TOF tests using 2, 2.4, 3.4 GeV/c beam of pions + protons.
- Distance (start counter - MCP-PMT) = 65cm

1- pixel result

TDC_{BURLE}-$TDC_{START\ COUNTER}$ @ 2 GeV/c





σ= 36.2±1.3ps