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R&D on Proton Extinction Monitor for COMET Project

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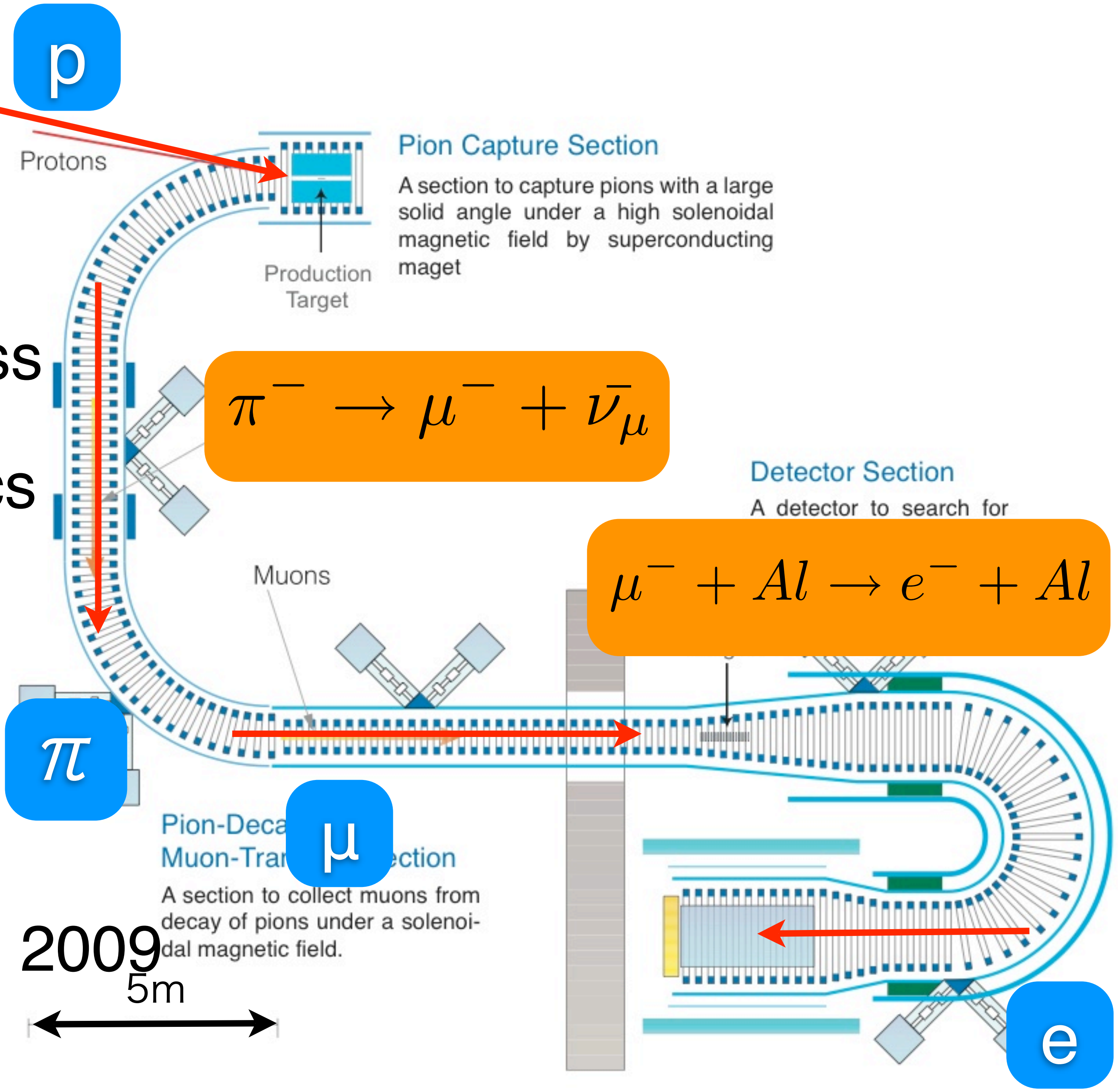
on behalf of the COMET Collaboration

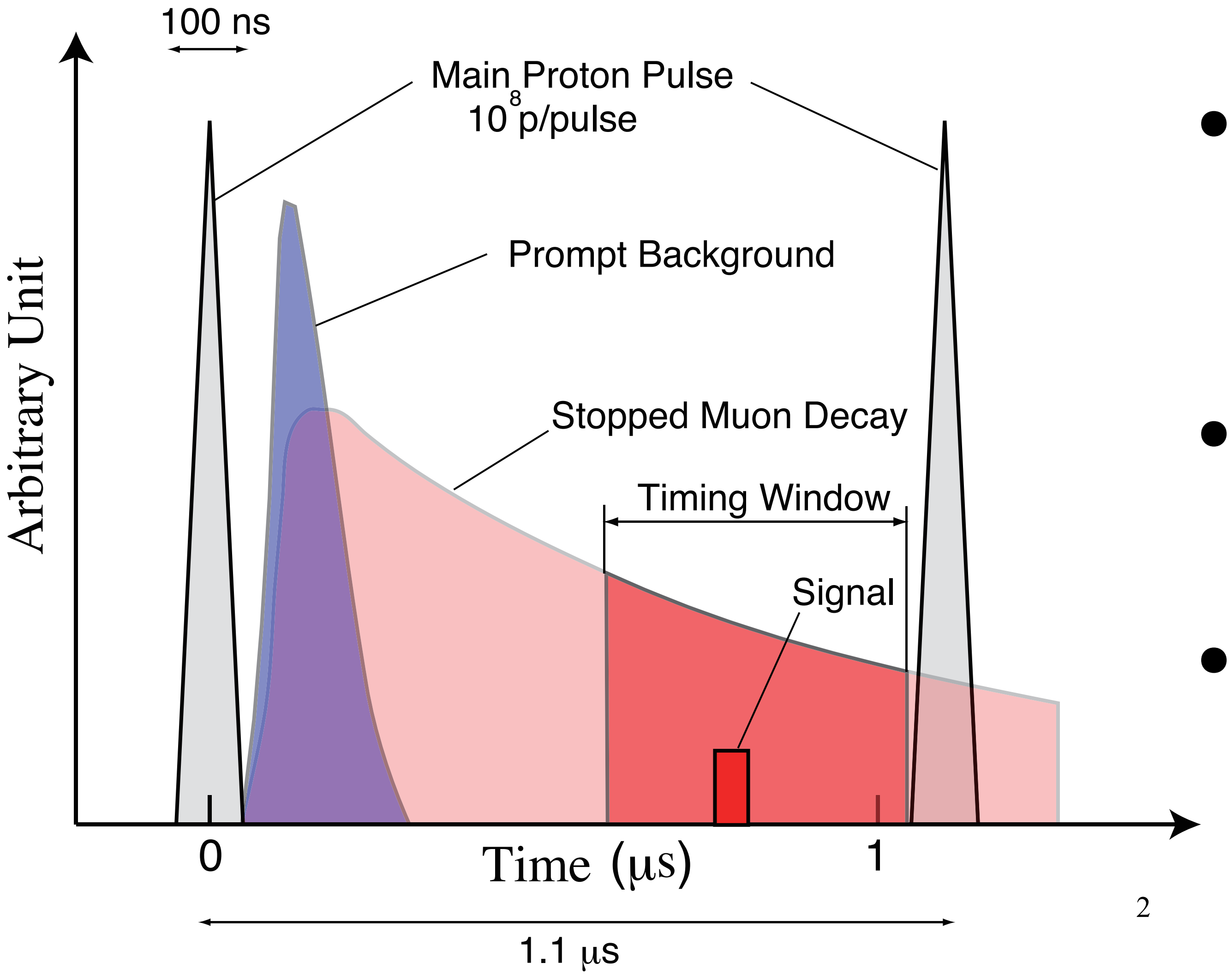
Contents

COMET

- As A. Sato talked on Monday ...
- We are interested in c-LFV process
- This process is sensitive to physics beyond SM
- search μ-e conversion
- Sensitivity goal is 10^{-16} of B.R.
- submitted CDR to J-PARC in July, 2009



Pulsed Proton Beam



- Signals of μ-e conversion will be detected in the region 880nsec after the proton beam pulse
- Most of major BGs are related to primary protons
- In order to avoid BGs effectively, we make use of a pulsed proton beam

Radiative Pion Capture

$$\pi^- + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$$
$$\gamma \rightarrow e^+ e^-$$

Muon Decay in Flight

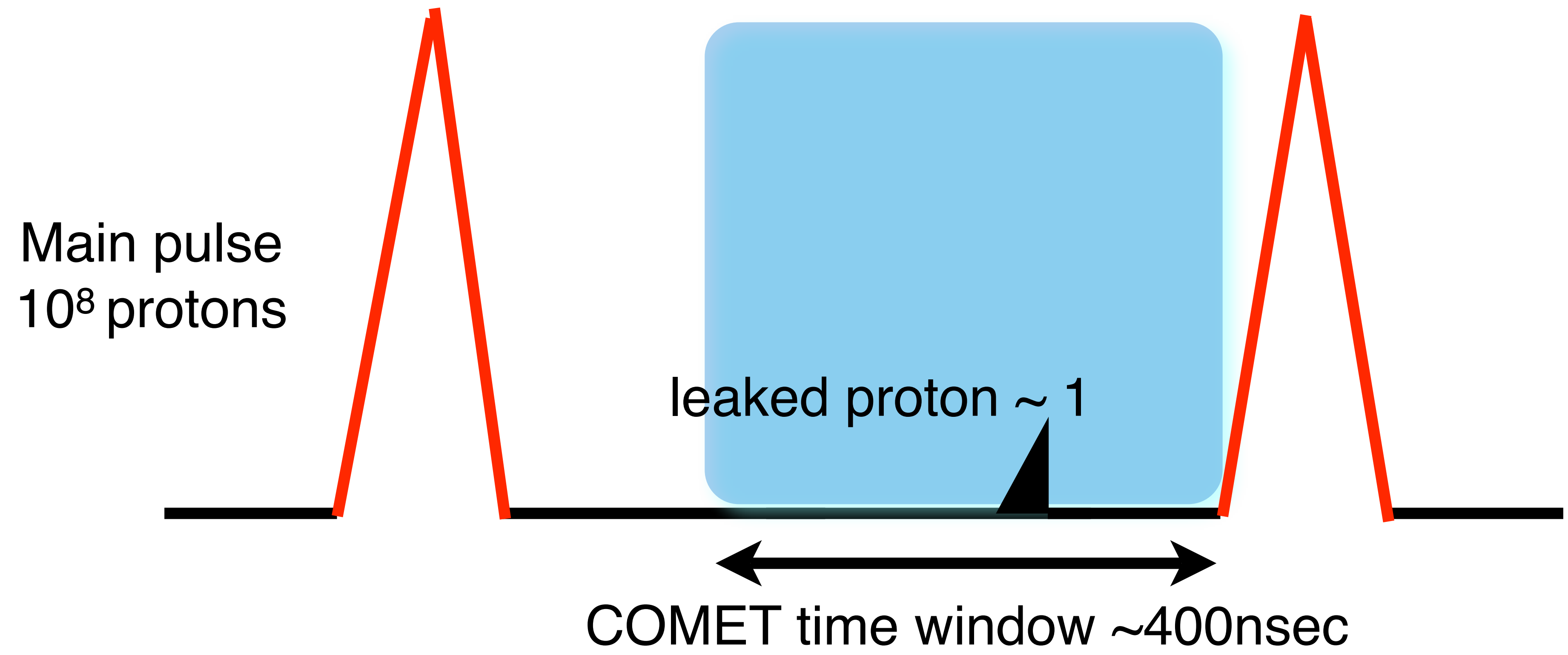
$$\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$$

Pion Decay in Flight

$$\pi^- \rightarrow e^- + \bar{\nu}_e$$

- 10^8 protons/pulse
- 8-GeV
- ~1MHz

Proton Extinction



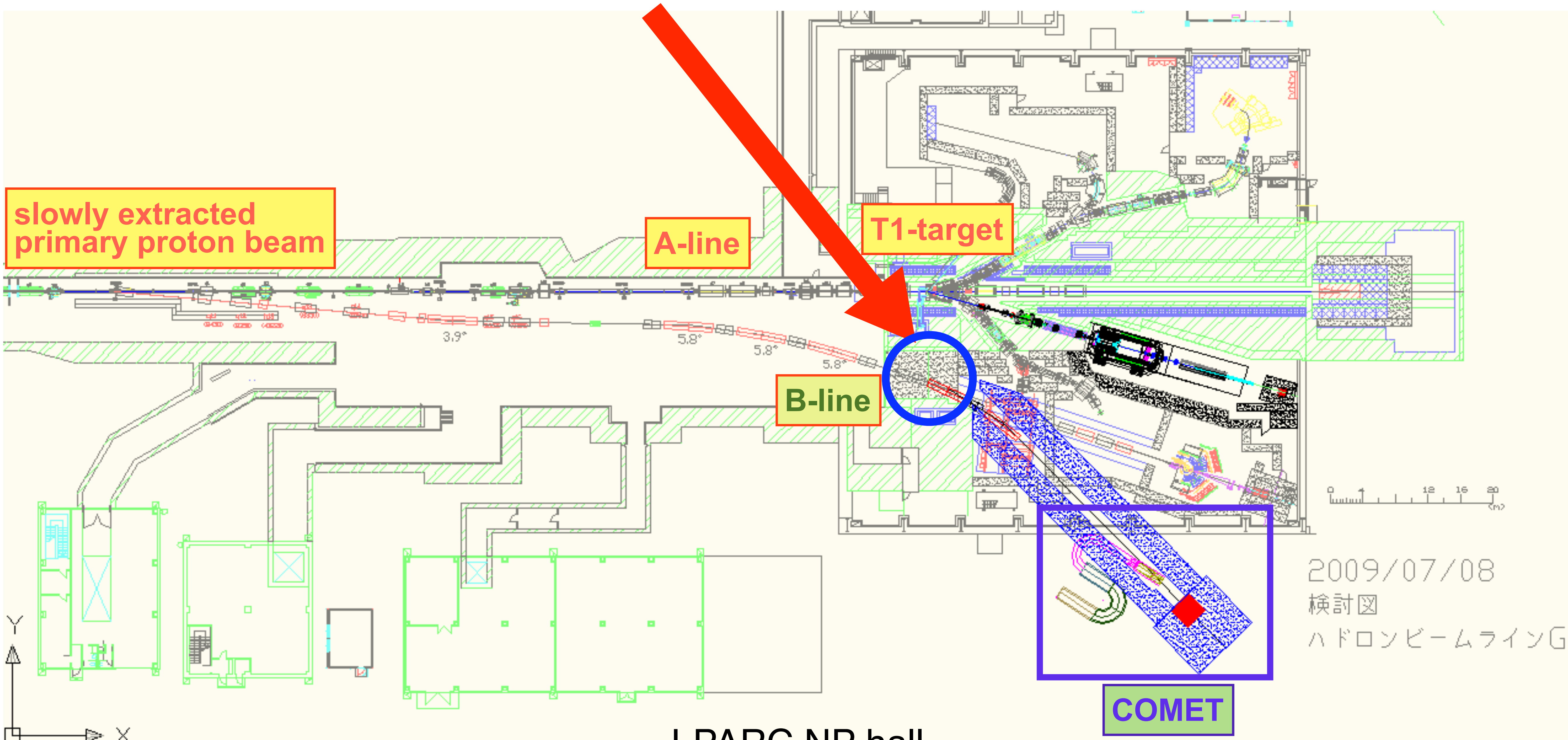
- In order to achieve 10^{-16} of B.R.,

$$R_{Ext} = \frac{\#\,\text{of p b/w pulses}}{\#\,\text{of p in a pulse}} < 10^{-9}$$

- Measurement of the Proton Extinction : Proton Extinction Monitor

Location of Proton Extinction Monitor

Proton Extinction Monitor will be set on a proton beam line in J-PARC



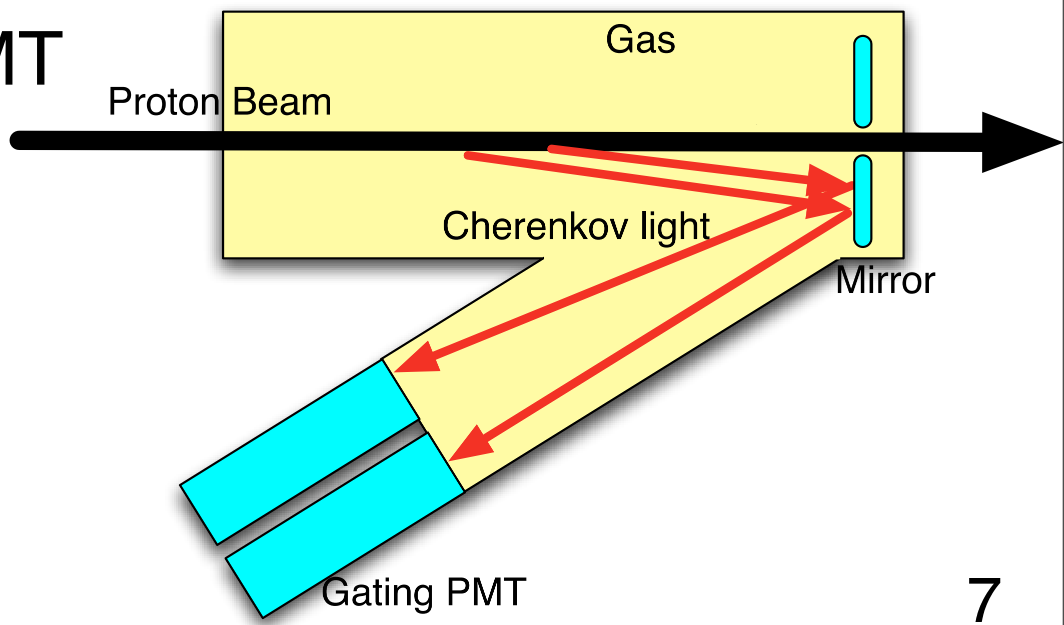
J-PARC NP hall

Concepts of Proton Extinction Monitor

Direct measurement of the protons in-between pulses,
pulse-by-pulse base to reject the "bad" pulse

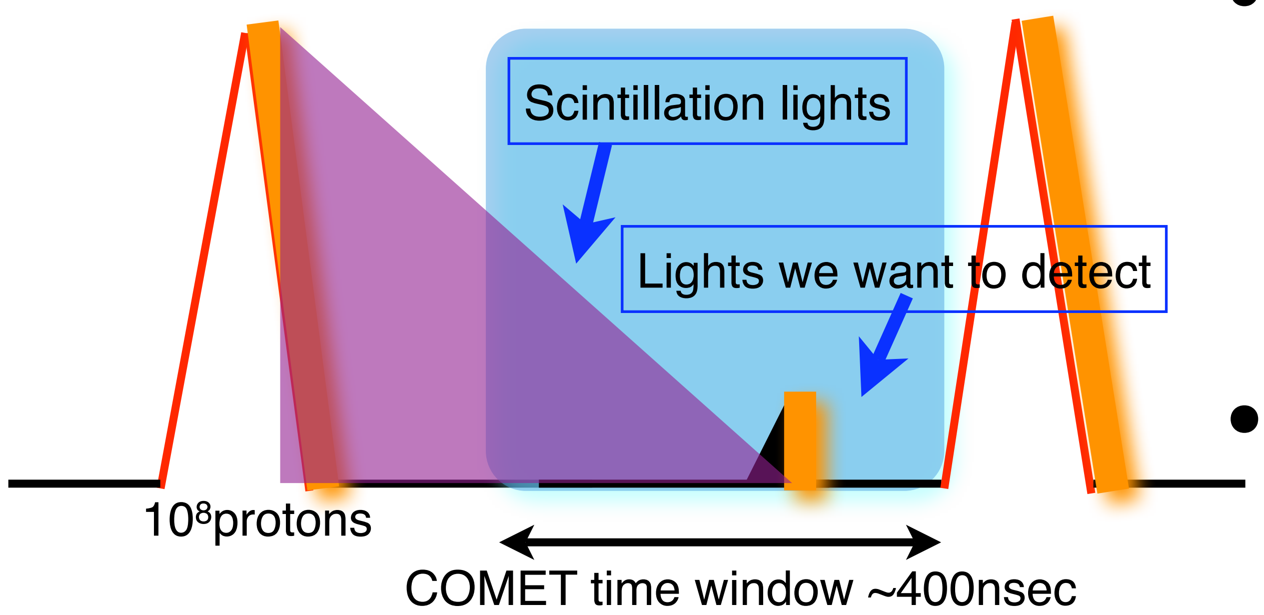
- Radiation hardness
  --- 10^{10}Gy/2yrs
- Fast response
  --- enable to see in B.G. by Main pulse
- Good S/N
  --- low delayed component of scintillation lights
- Resistance to flash by Main pulse
  --- ~10^9 Cherenkov lights/100nsec/PMT

⇒ Gas Cherenkov counter
Gating PMT



Gas Selection

Gas Candidates

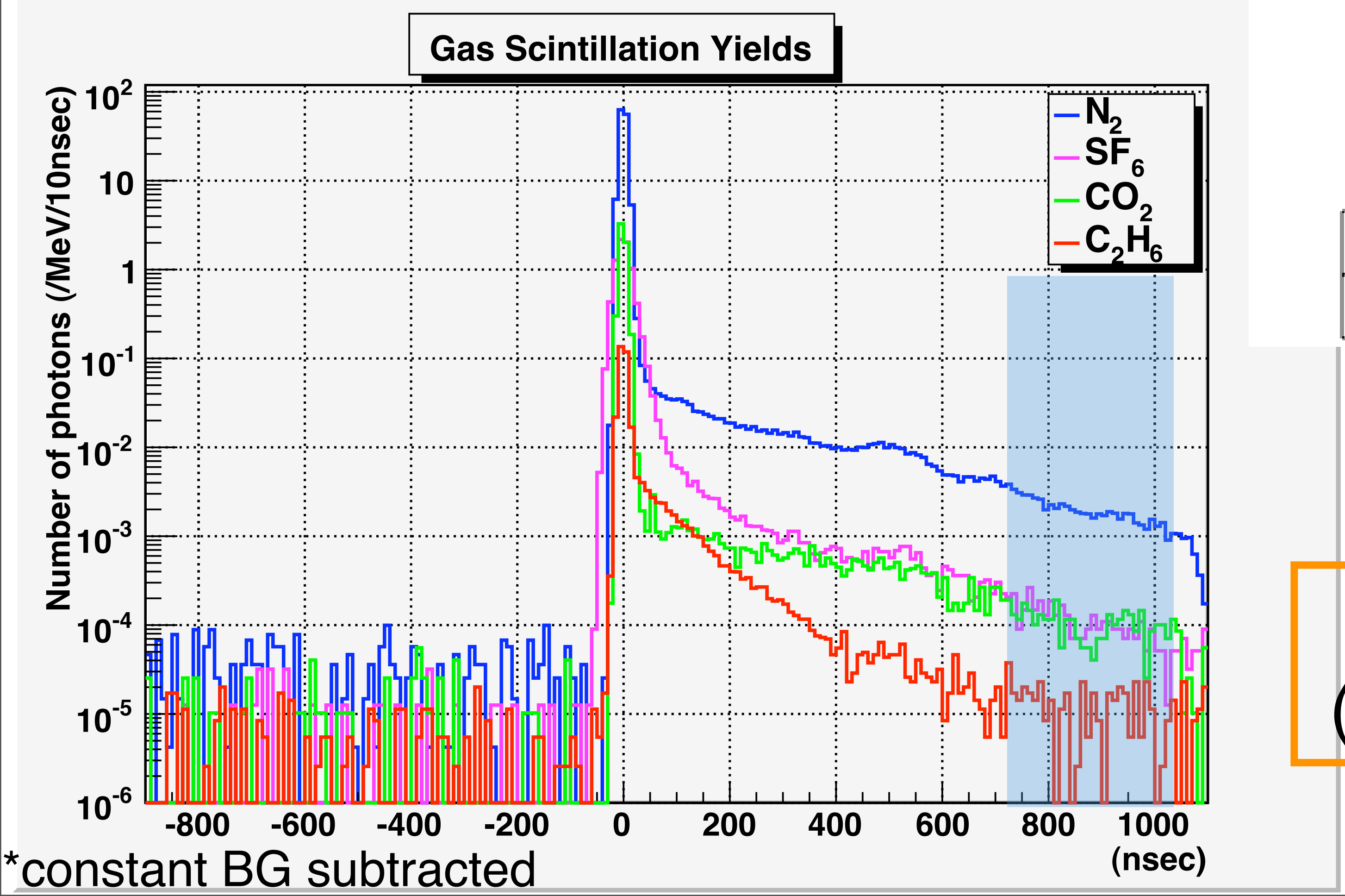


- We have to distinguish Cherenkov lights by leaked protons from scintillation lights by main pulse
  -> Small gas scintillation yield
- Gas can be pressured in order to make it sensitive to 5-GeV/c protons
  -> Refractive index > 1.02

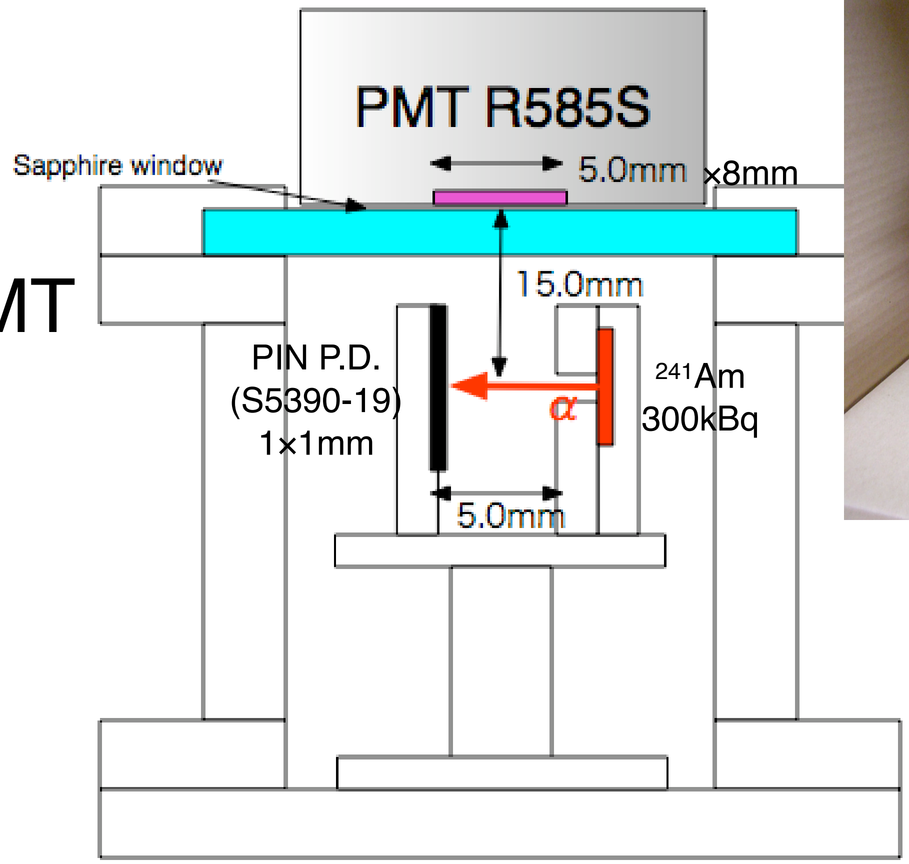
	N_2O	CO_2	C_2H_2	C_2H_4	C_2H_6	SF_6
molecular mass	44	44	26	28	30	146
refractive index	1.024	1.038	1.048	1.060	1.046	1.018
pressure(atm)	50	50	43.3	50	38.5	16.6

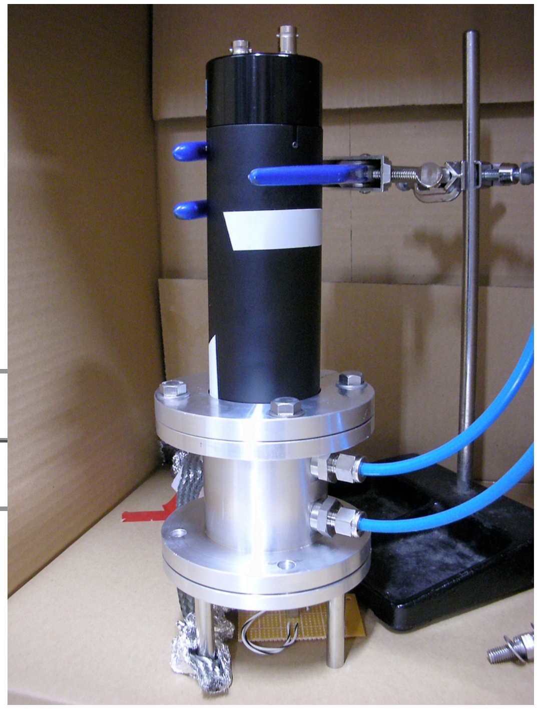
Measurements of Gas Scintillation

- under 1-atm
- dE/dx by α rays
- Trigger DAQ by α on PIN diode
- photon-count scintillation light by PMT
- Tag dE on gas by PIN diode



*constant BG subtracted





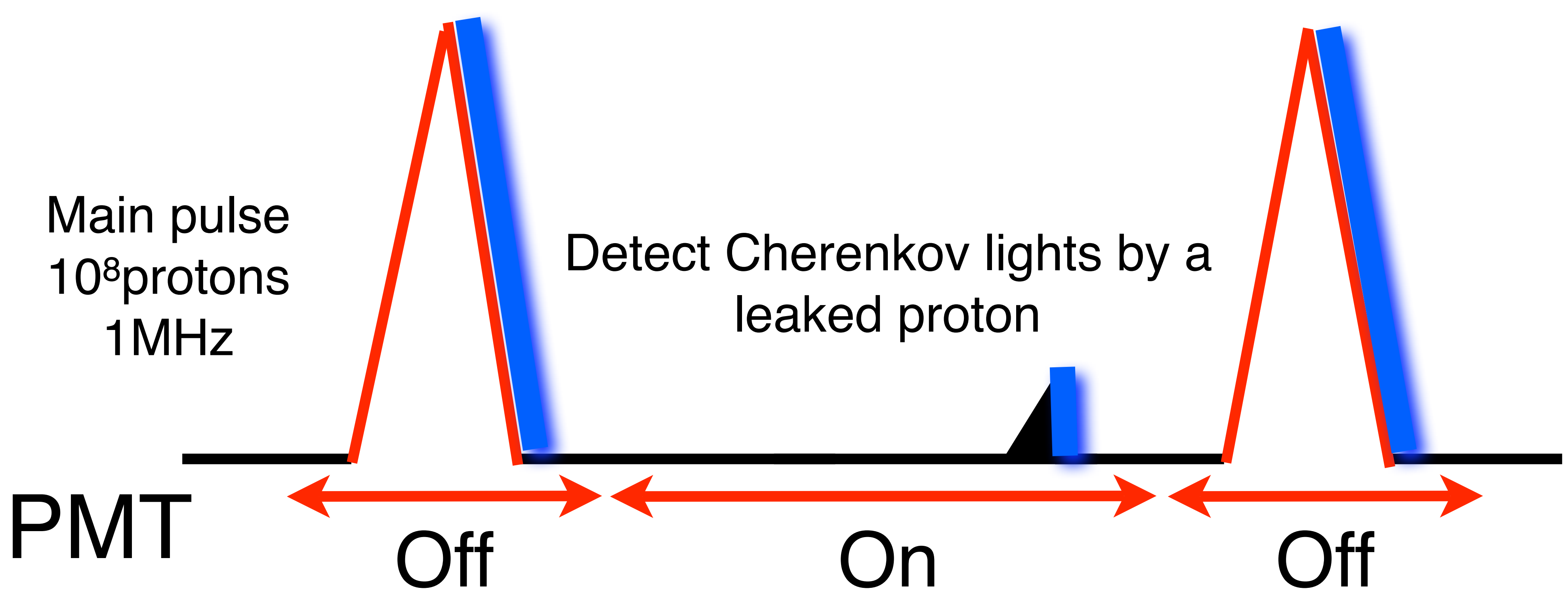
Ethane is promising

$(1.11 +/- 0.09)\times10^{-6}$ photons/MeV/sec

Gating PMT

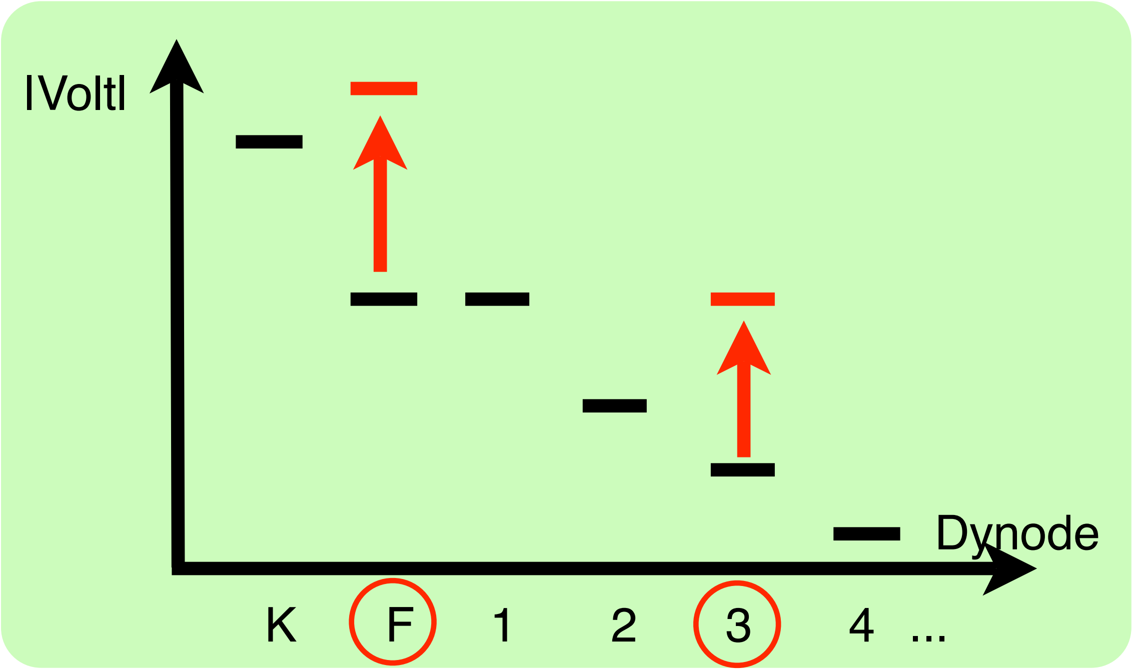
Gating PMT

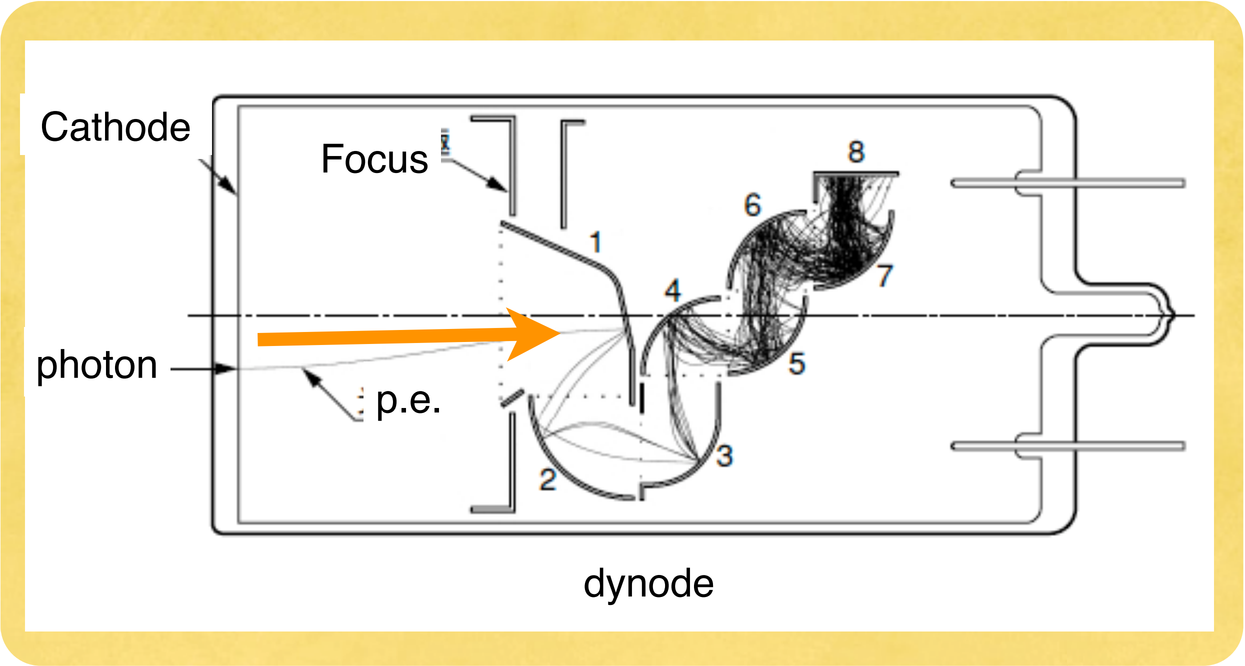
Cherenkov lights from Main pulse is too strong (10^9 photons/100nsec)



Anode current of PMT is 10A when the PMT gain is 10^6
In order to protect PMT,
We switch the PMT gain rapidly synchronizing with main pulses

Gating PMT





- In normal divided voltage, the voltage of dynodes go down as dynodes go
  -> p.e. are multiplied
- If raise the voltage of a dynode than that of former one
- the p.e. will be cut, and PMT gain will be down
- This technique is called Gating PMT

Requirements

- 1MHz repetition
- Cutoff ratio (gain@off/gain@on) < 10^{-6}
  Anode current : 10A->10μA
- Photocathode coverage ~100%
  to maximize Cherenkov detection efficiency
- Switching speed < 100nsec

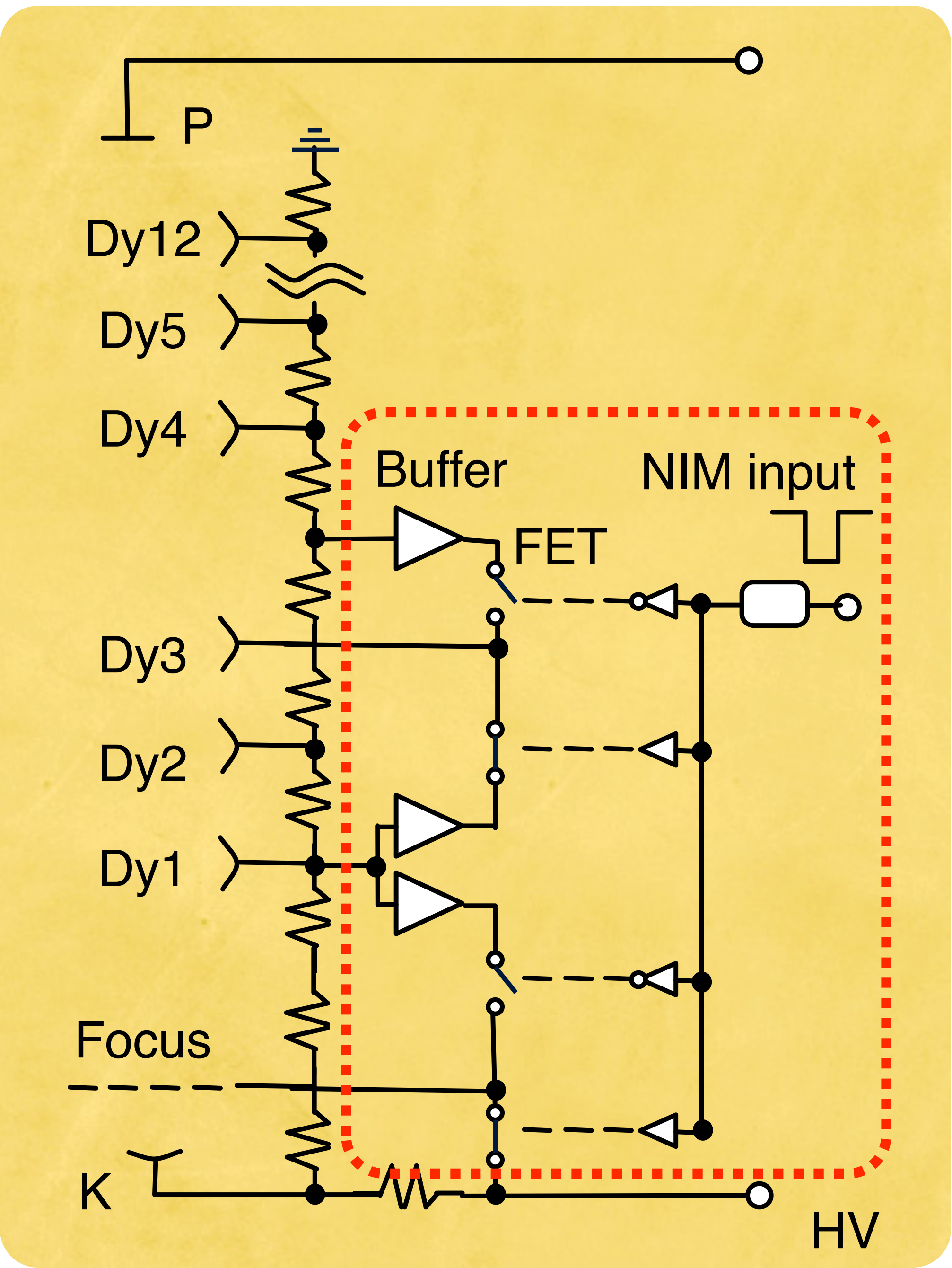
Comparison

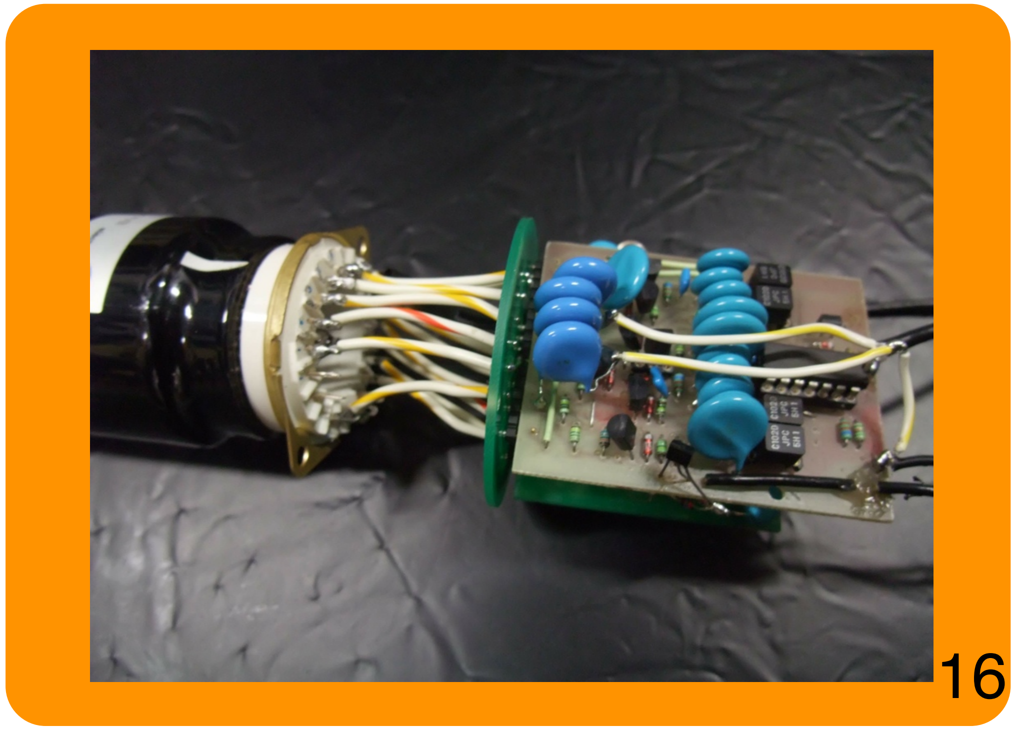
H10304-01

	Repetition(Hz)	Cutoff ratio	Photosensitive Area (mm)
Creasey, Rev.Sci.Instrum, 69(1998)p4068	10k	$< 10^{-5}$	2.5x2.5
H10304 (Hamamatsu K.K.)	10k	10^{-7}	8 dia.
Requirements to Extinction Monitor	1M	$< 10^{-6}$	52 dia.

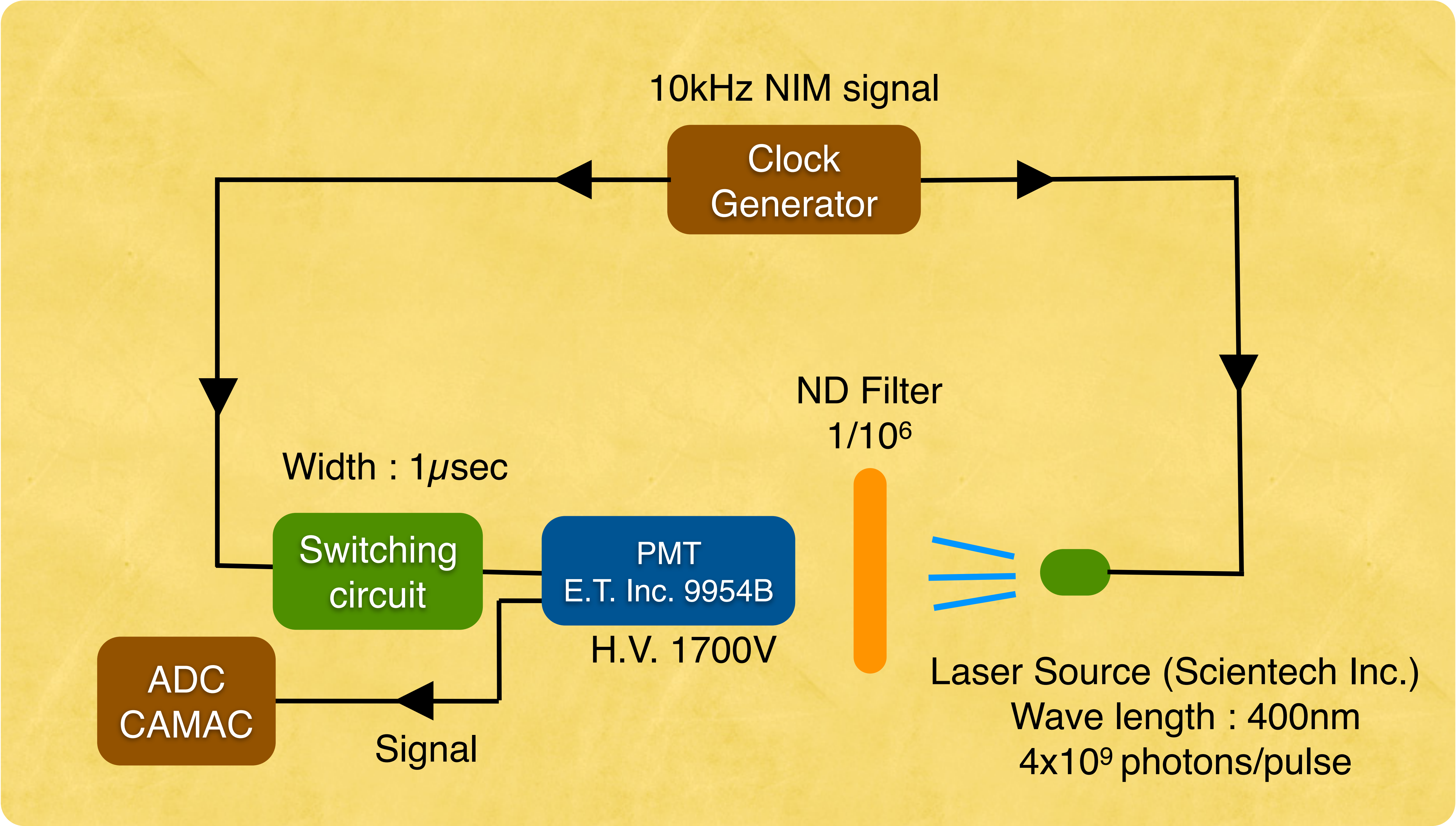
Prototype

- We made 10kHz switching prototype and tested
- We raised the voltage of Focus and 3rd dynode by 400V and 300V respectively (when applied H.V. is 1700V)
- PMT is 9954B made in Electron Tubes which is linear focus type and has 12 dynodes and 2” photocathode
- The switching divider circuit is designed by T. Taniguchi (KEK)





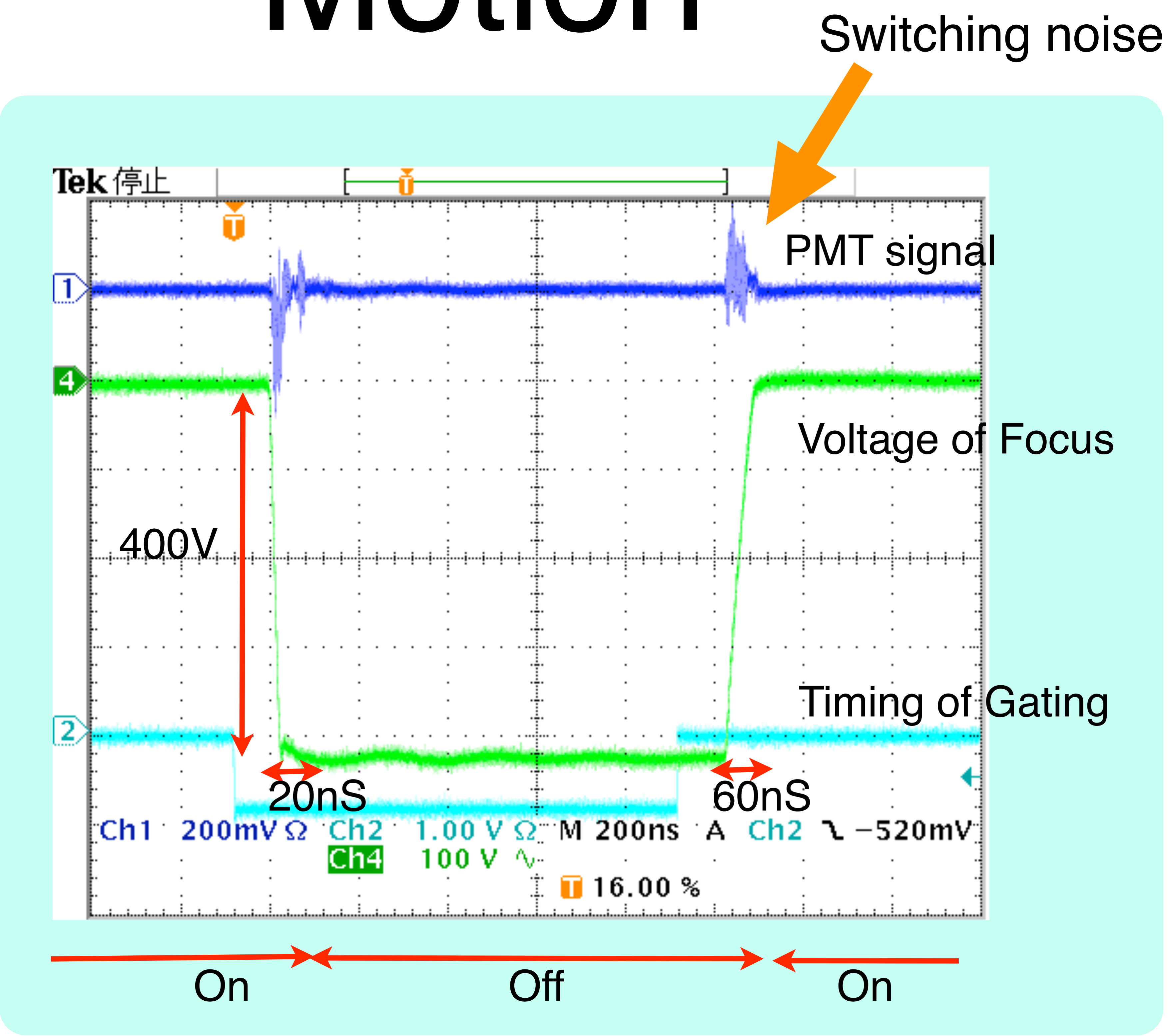
Setup



10kHz NIM signal
Clock Generator
ND Filter
1/10^6
Width : 1μsec
Switching circuit
PMT
E.T. Inc. 9954B
H.V. 1700V
ADC
CAMAC
Signal
Laser Source (Scientech Inc.)
Wave length : 400nm
4x10^9 photons/pulse

Motion

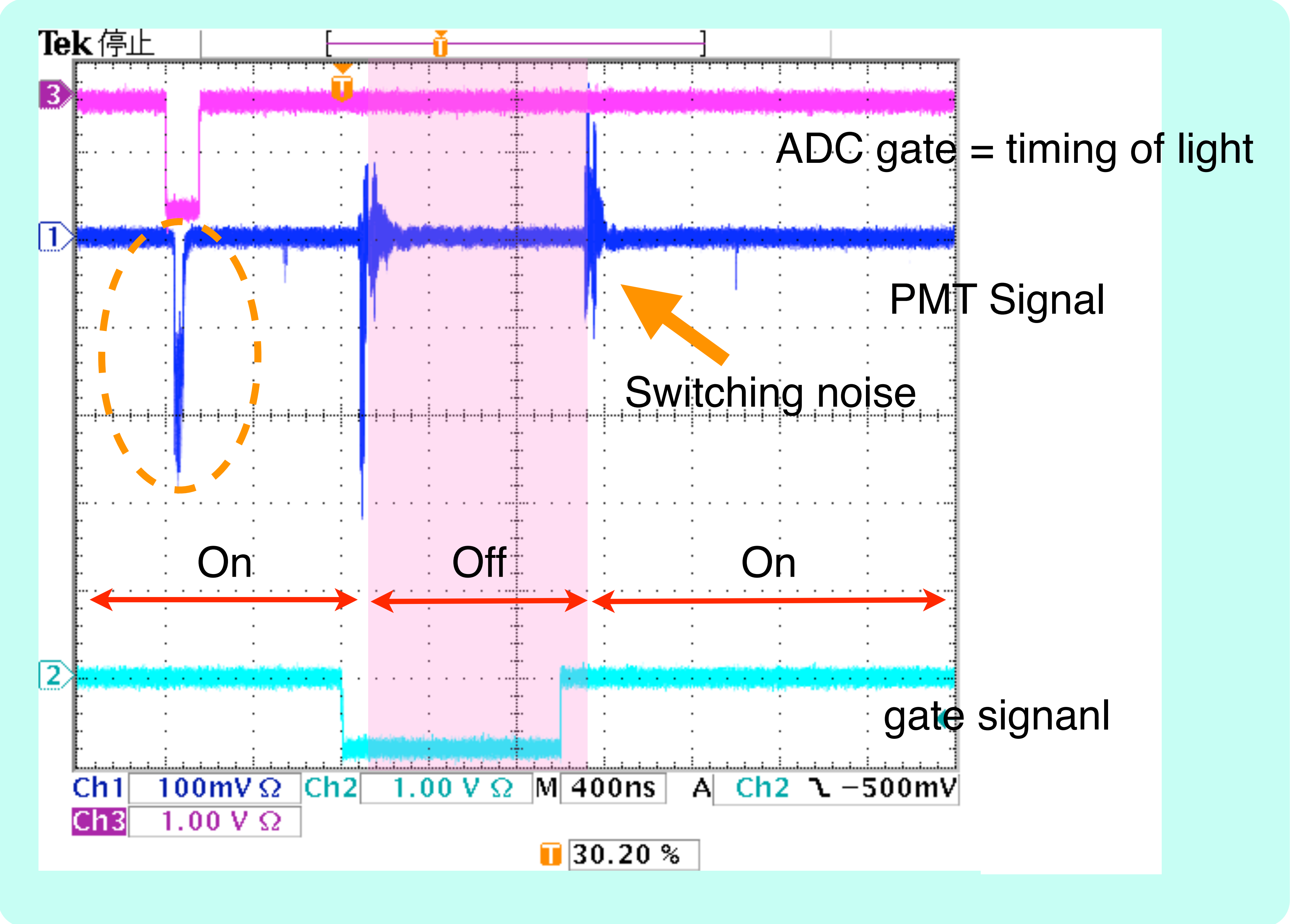
HV: 1700V
Repetition:10kHz
Gate width: 1μS



Switching noise is visible but within 100ns, there is no problem

On/Off switching

HV: 1700V
Repetition:10kHz
Gate width: 1µS
~10^3 photons



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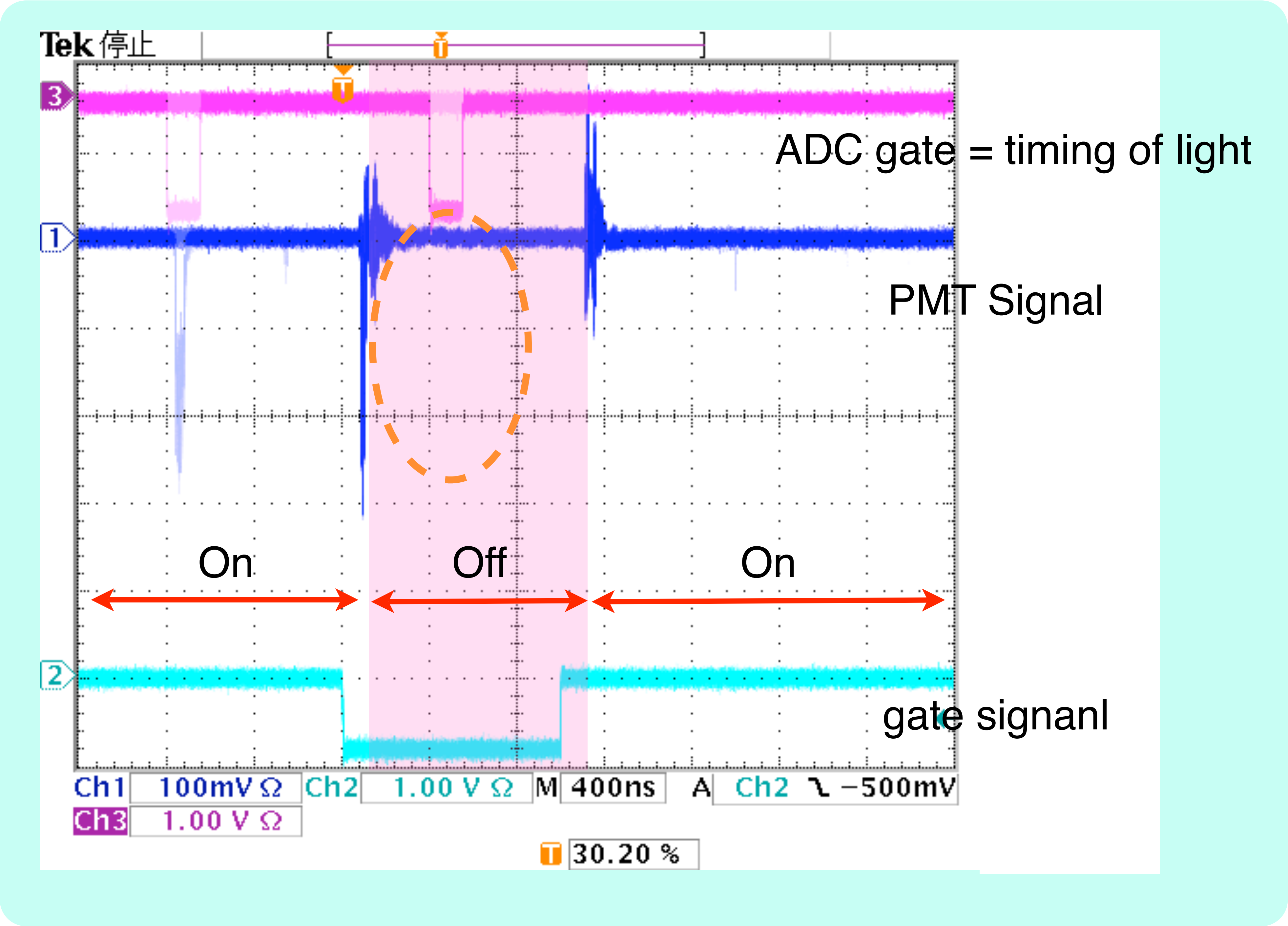

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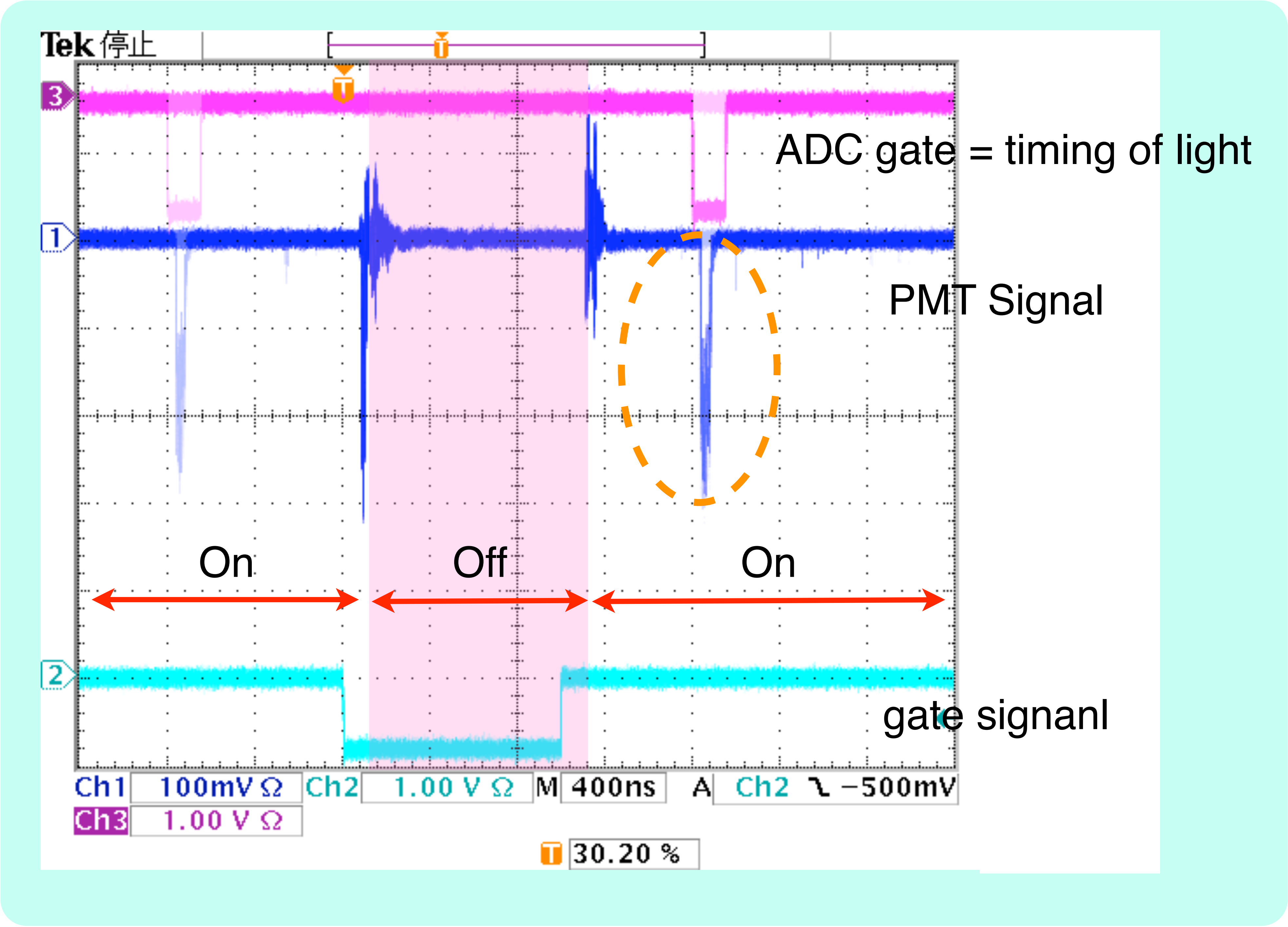
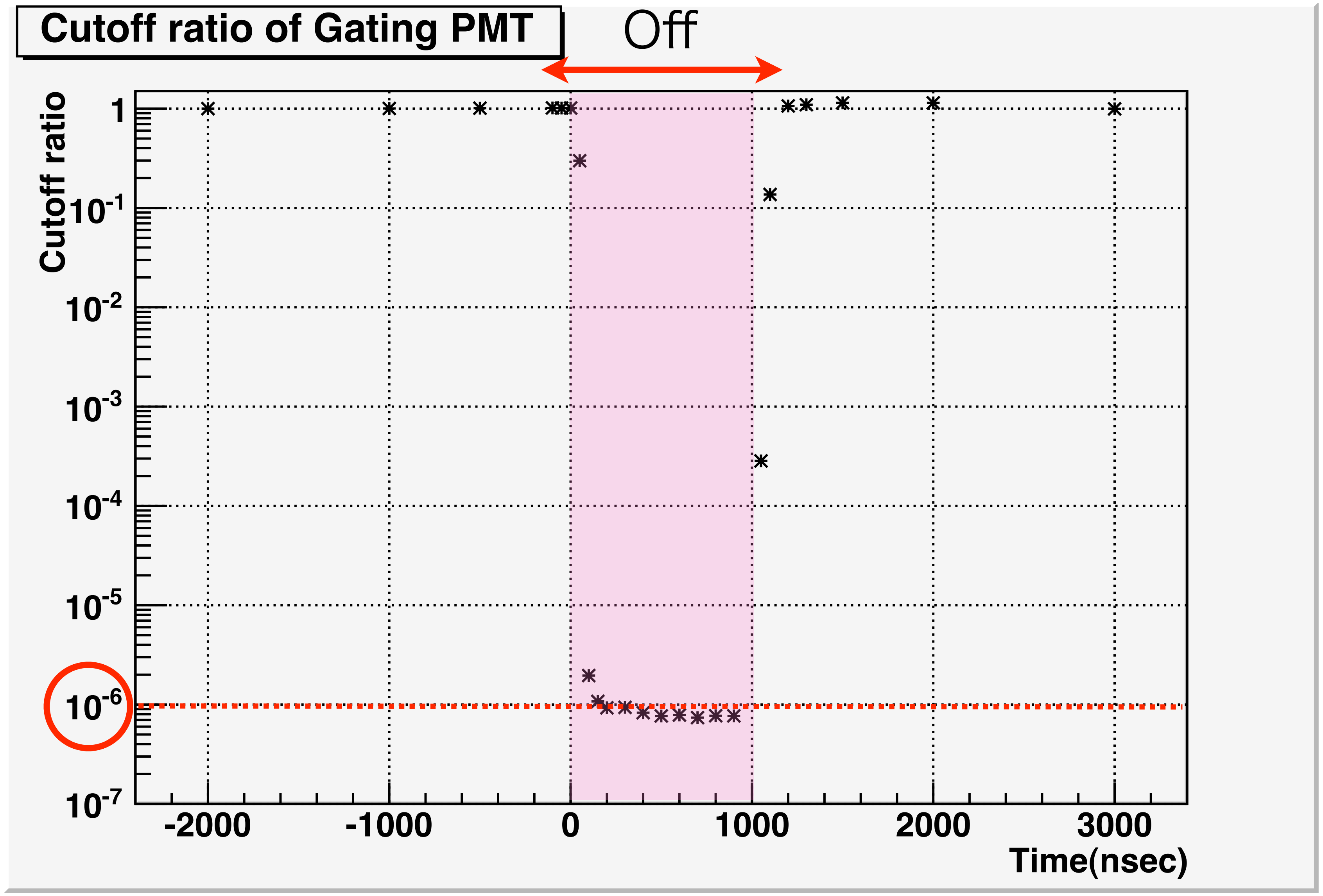


Gating PMT work well !

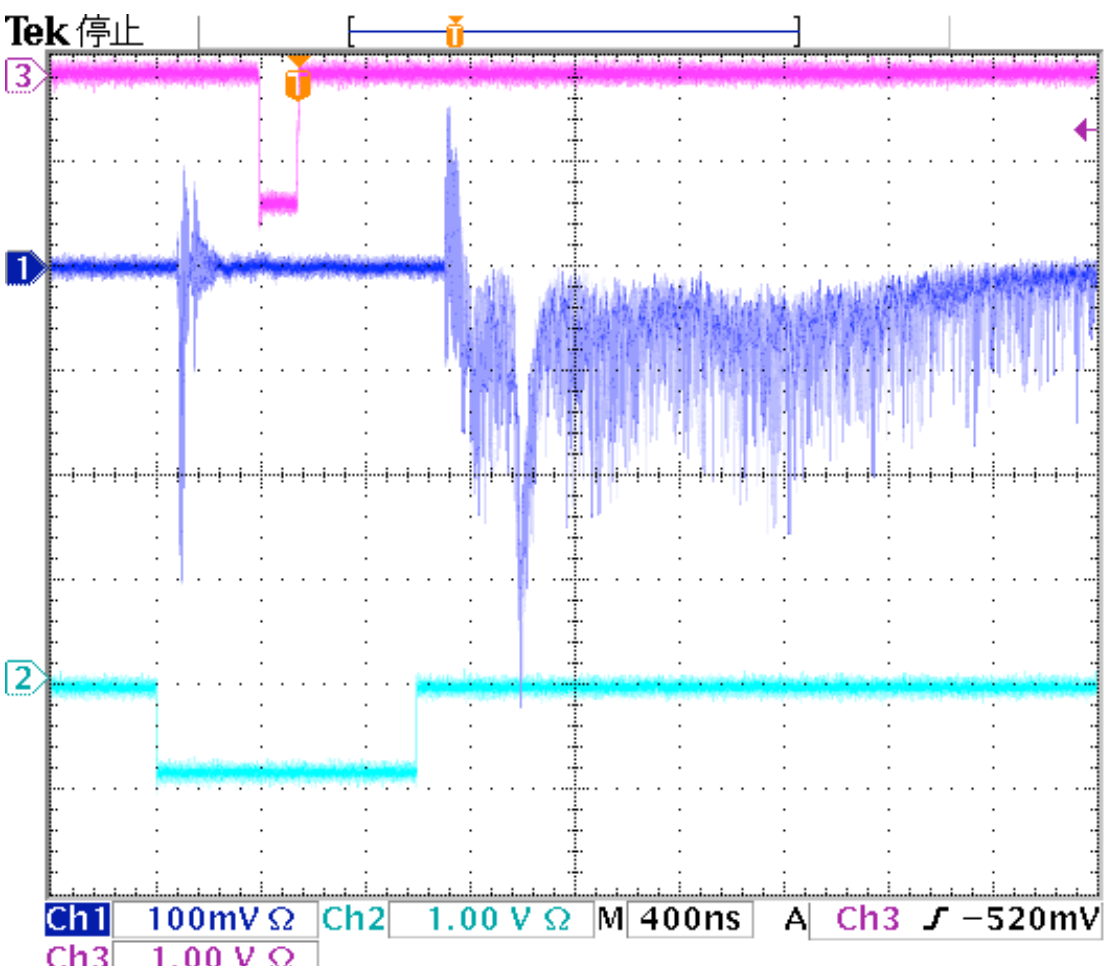
Cutoff ratio

By changing the timing of light, we measured the cutoff ratio



- Cutoff ratio achieved 10^{-6}
- Raise time of ~200nsec is still fast enough

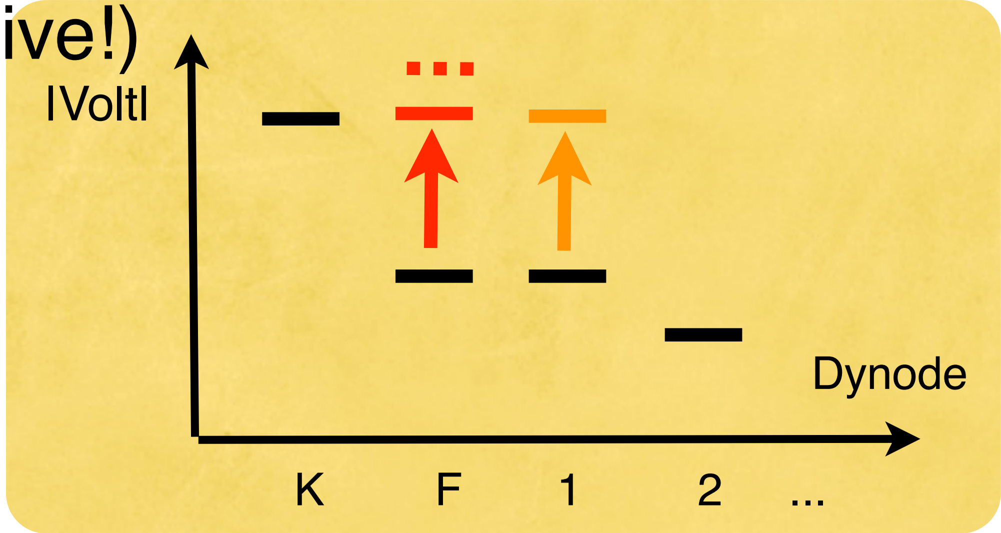
Problem : Afterpulse

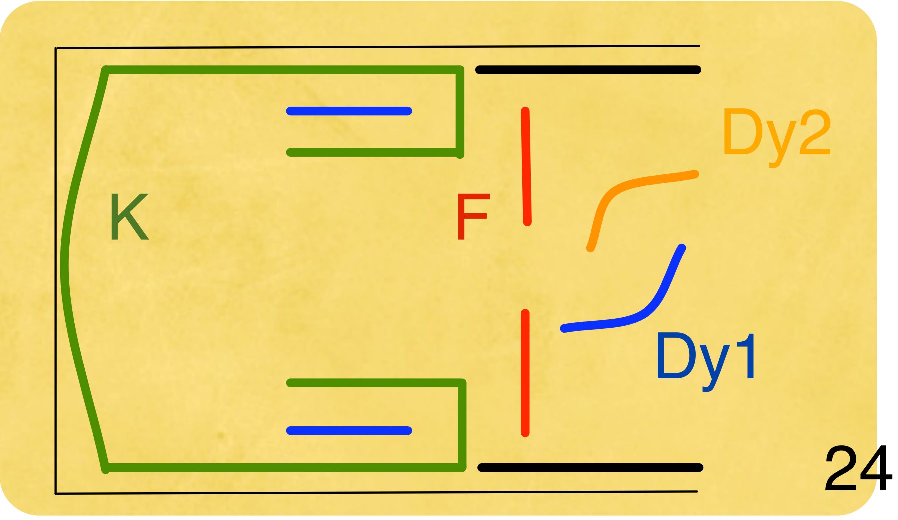


- There are a number of afterpulses(~10^5 p.e.) after turning on
- In order to identify Cherenkov lights, these afterpulses should be less than 2 p.e.
- We think these afterpulses is caused by + ions produced in-between Cathode and Focus because transverse time of + ions (a few μ sec) is consistent with calc.
- We must reduce this ionization feedback

Problem : Afterpulse

- We have some ideas to improve aftepulse
  - Ionization energy of gas in tubes is about 10V, so by changing the voltage b/w Cathode and Focus less than 10V, + ions will not produced. The thesis (Hagen, Guy M. et al, Rev.Sci.Instrum, 76(2005)pp.083117) reports they could reduce afterpulses by this technique.
  - In order to wipe p.e. staying space, also change the voltage of Dy1
  - Inject light at a angle with Cathode's surface in order not to produce p.e. from dynodes
  - final choice : use another device like MCP-PMT(small afterpulses but very expensive!)





Summary

- COMET is experiment to search μ-e conversion
- Proton Extinction is very important and monitoring device is developing
- Proton Extinction Monitor consists of Gas Cherenkov counter and Gating PMT
- Ethane gas is promising for Cherenkov gas
- Gating PMT is developing and prototype was tested
- 10kHz switching and cutoff ratio of 10^{-6} was achieved
- We have to improve afterpulse
- Go to 1MHz switching

Thank you