Hypernuclear Investigation with Electro-magnetic Interaction 2022

TOHOKU UNIVERSITY

Development of scintillating fiber detector for photon beam profiling at ELPH

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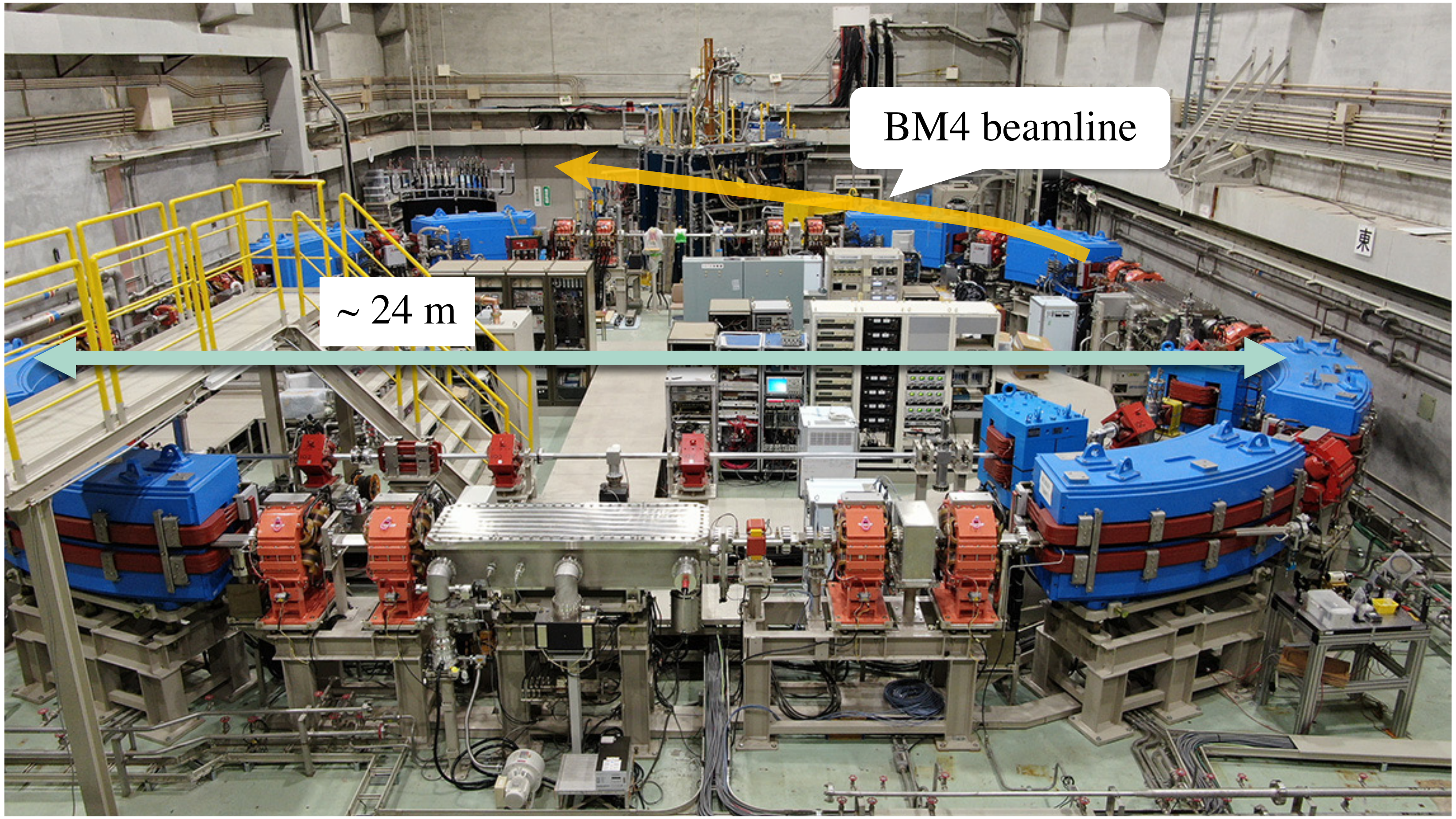
- Characteristics of ELPH photon beam line
- Basic design of the new Beam Position Monitor (BPM)
- Operation test experiment at ELPH
- Result of the analysis
- Summary and conclusion

Booster STorage ring at ELPH, Tohoku Univ.



Booster **ST**orage ring (BST ring)
at Reserch Center for **EL**ectron **PH**oton Science (ELPH)

- Electron syncrotron

  Injection Beam Energy: 90 MeV

  ↓

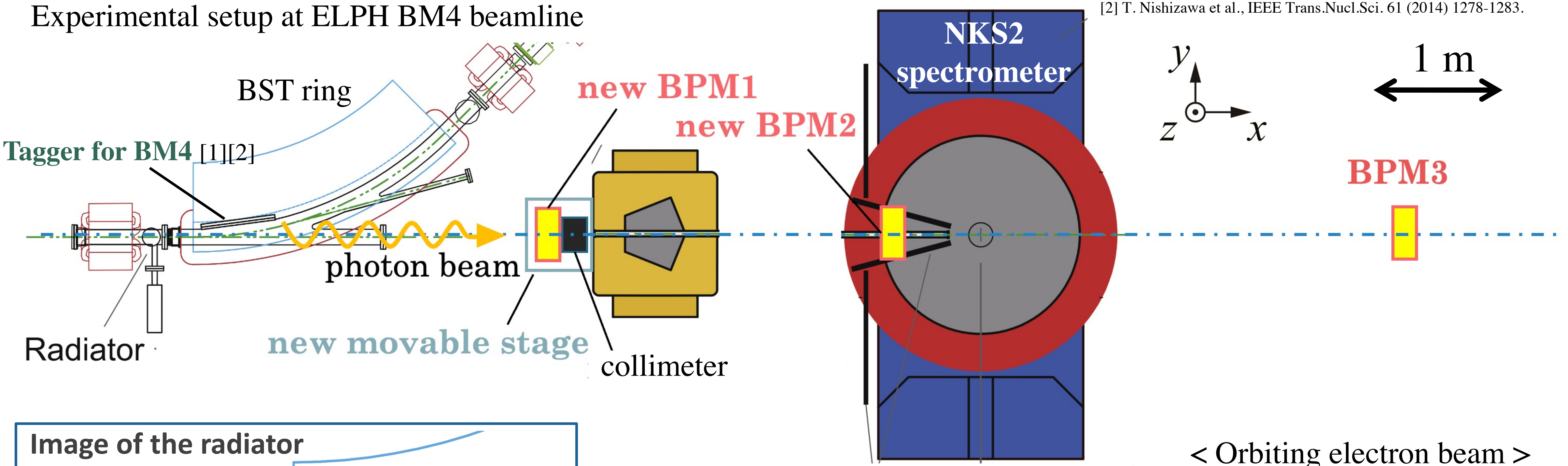
  Ring Top Energy: 0.8 ~ **1.3** GeV

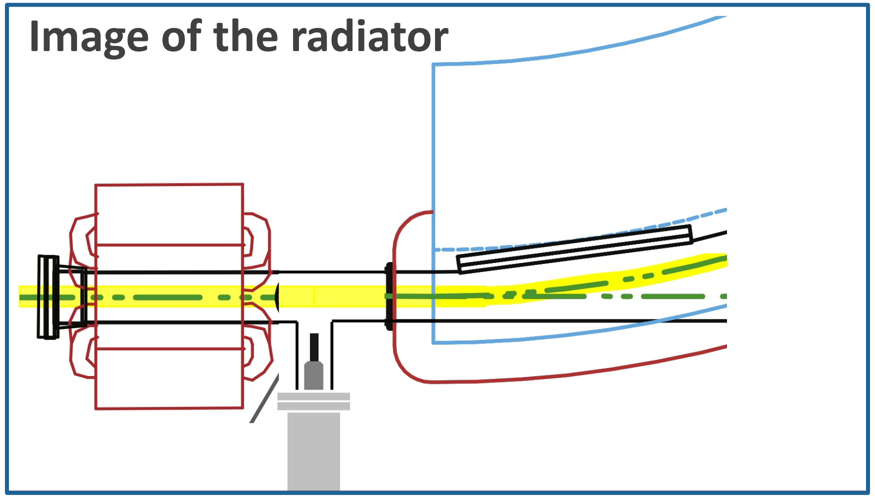
< Orbiting electron beam >
- Injection cycle: ~17 sec.
- Flat top : ~10 sec.

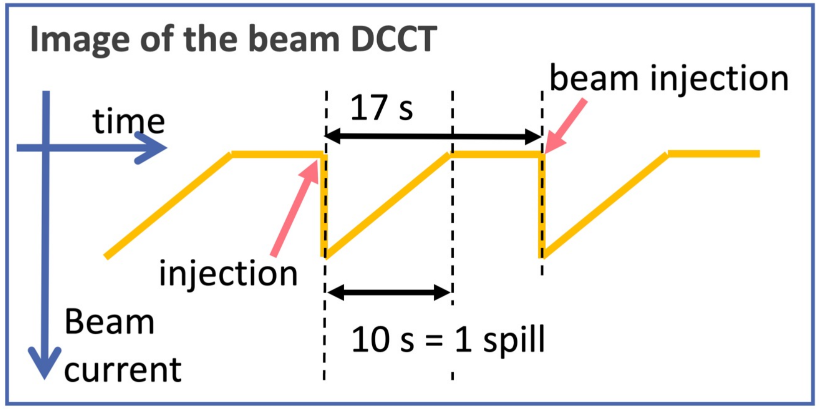
Characteristics of ELPH photon beamline

[1] H. Yamazaki et al., Nucl. Instrum. Meth. Phys. Res. A 536 (2005) 70.
[2] T. Nishizawa et al., IEEE Trans.Nucl.Sci. 61 (2014) 1278-1283.

Experimental setup at ELPH BM4 beamline







< Orbiting electron beam >

- Injection cycle: ~17 sec.
- Flat top : ~10 sec.

< Tagged Photon Beam >

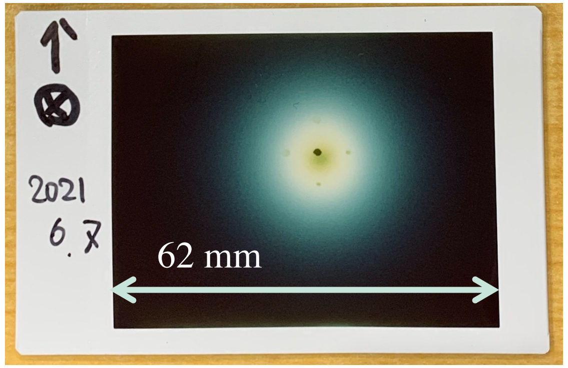
- Size : $\phi < 1$ cm
- Energy: 0.73 – 1.25 GeV
- Rate : ~MHz

Development of new Beam Position Monitor

Previous: instant camera films

Disadvantages

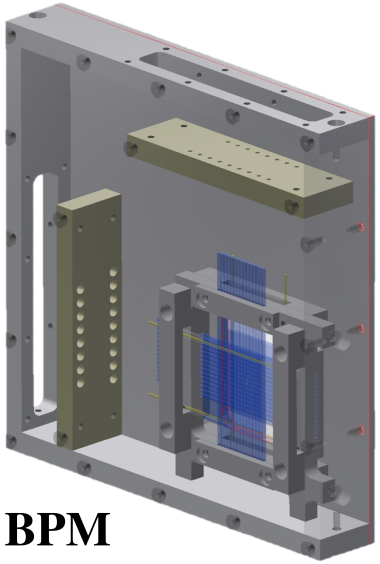
- detailed beam position and size
- in real time
- time dependence



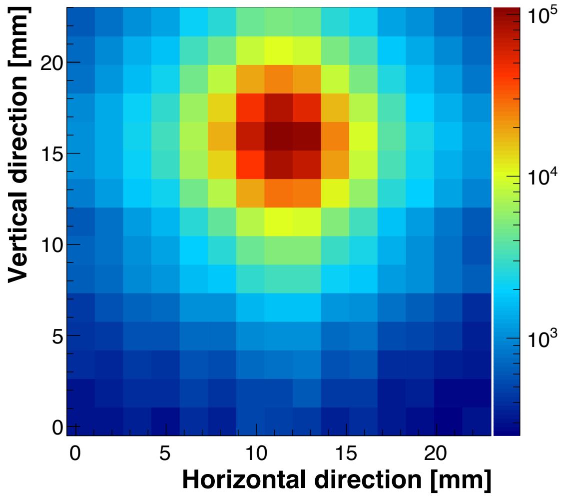
new Beam Position Monitor (BPM)

Requirements

- good position resolution
- real time monitoring
- quantitative measuring fine structure of the beam



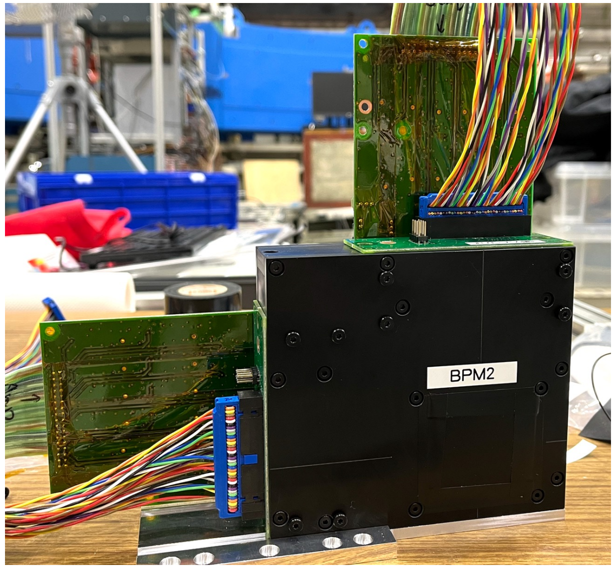
new BPM

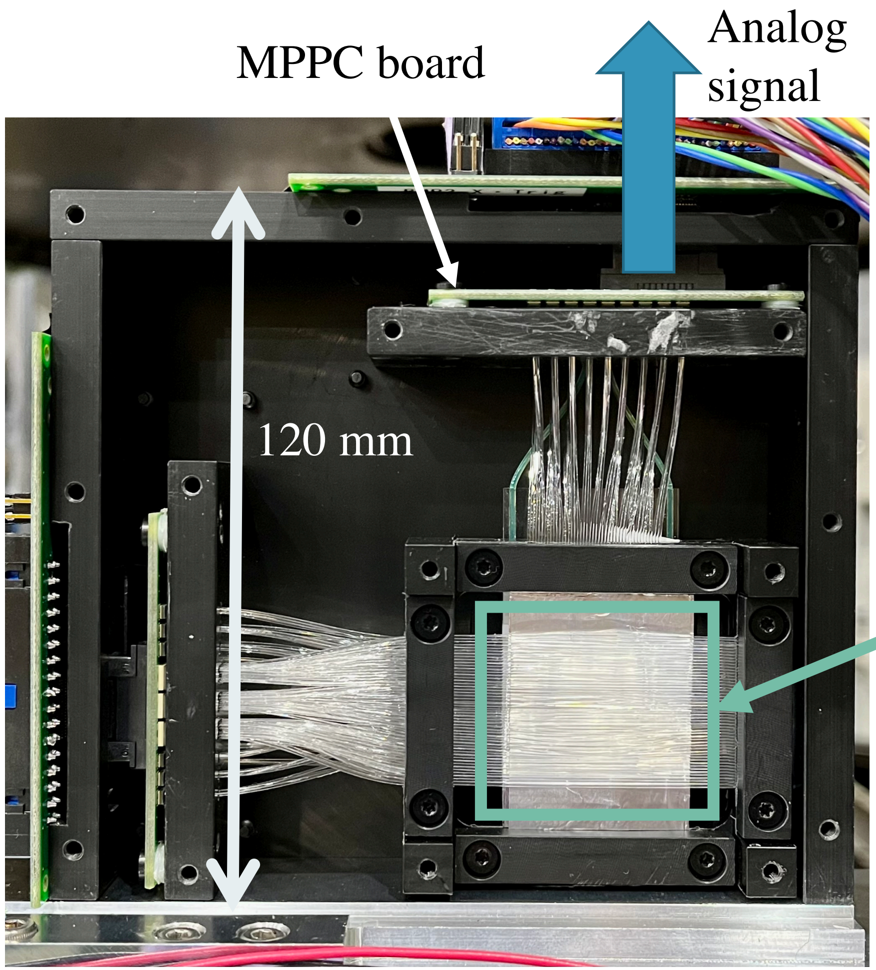


Basic design of the Beam Position Monitor

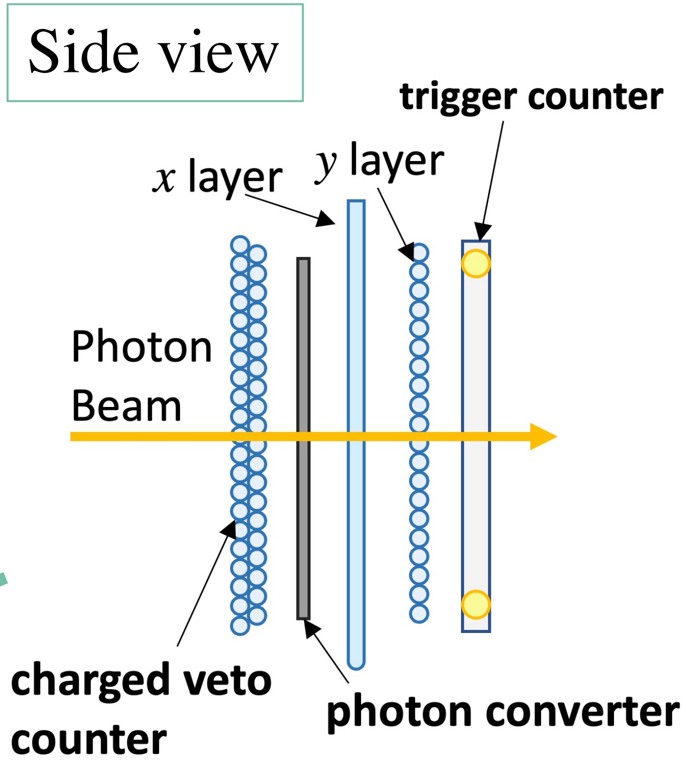
Basic Structure

- Scintillation Fibers (ϕ 0.5 mm)
  SCSF-78 (Kuraray)
  3 fibers / 1 ch = 1.5 mm / seg
- SiPM
  MPPC S13360-1350PE
  S13360-3050PE
  (Hamamatsu Photonics K.K.)





Beam Position Monitor (BPM)



effective area: 22.5 x 22.5 mm^2

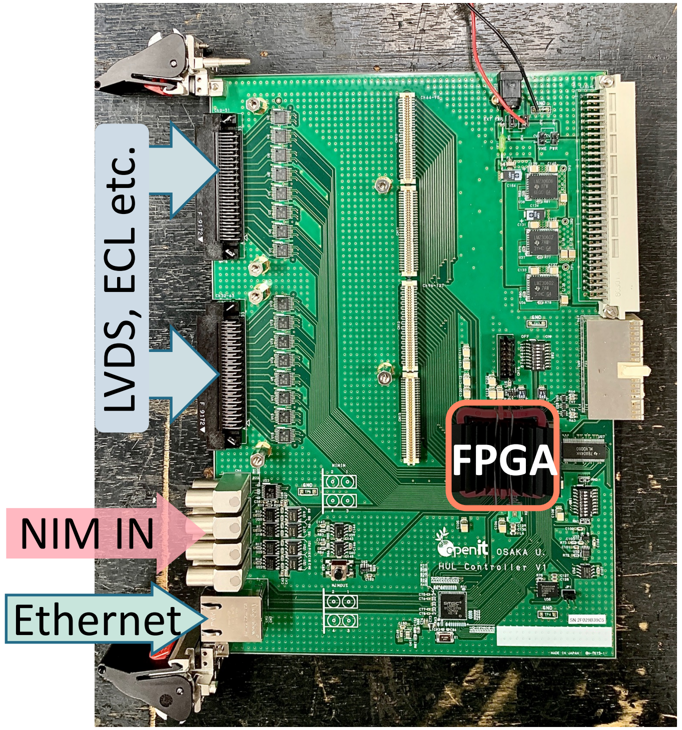
event ID:
[$\overline{\text{veto}}$] $\otimes$ [x layer] $\otimes$ [y layer] $\otimes$ [trig.]

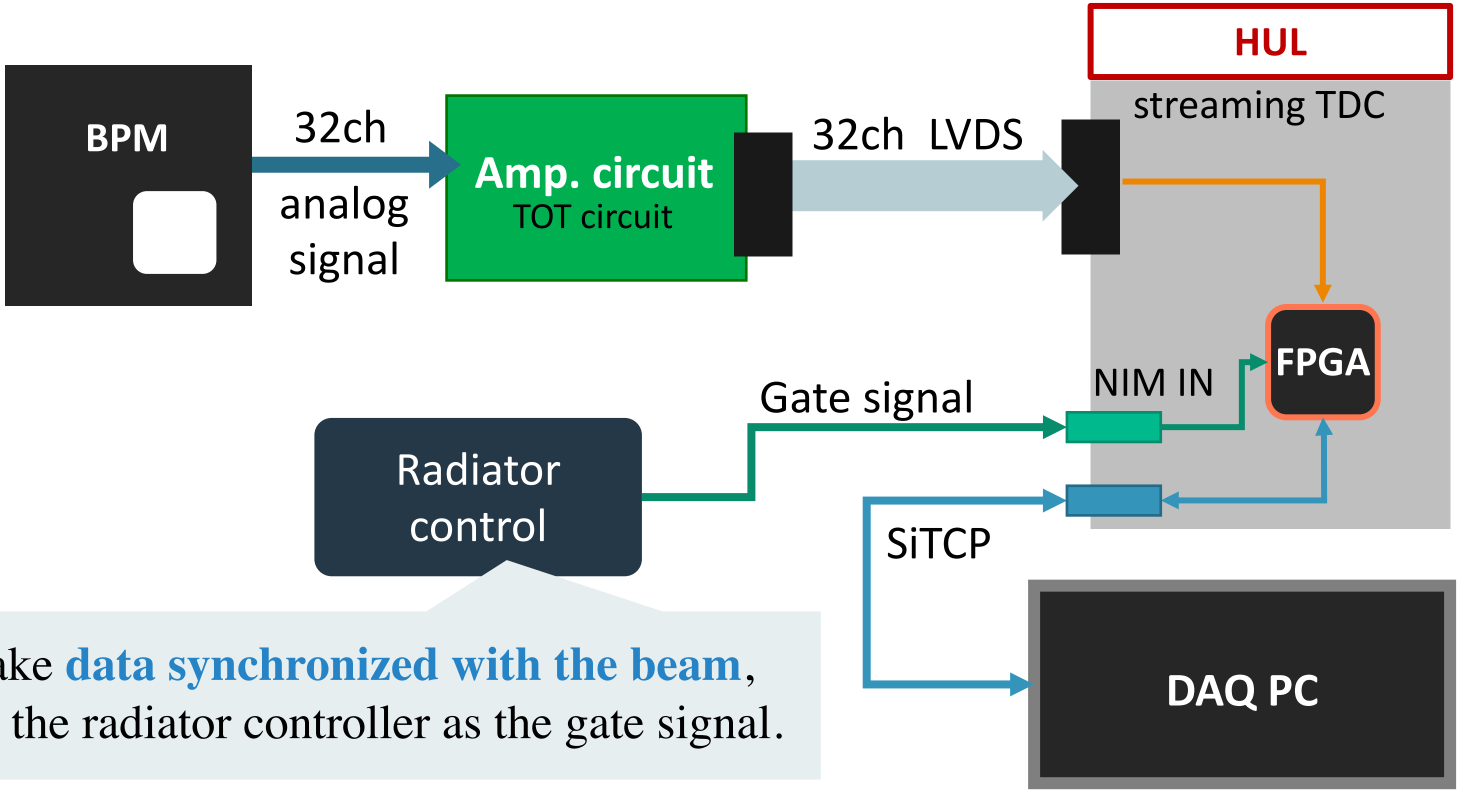
→ **Only photon events can be extracted!**

Data acquisition system

Expected event rate: ~ MHz / detector → **Not possible with traditional trigger type TDC**

Hadron **U**niversal **L**ogic
firmware: streaming TDC [3]





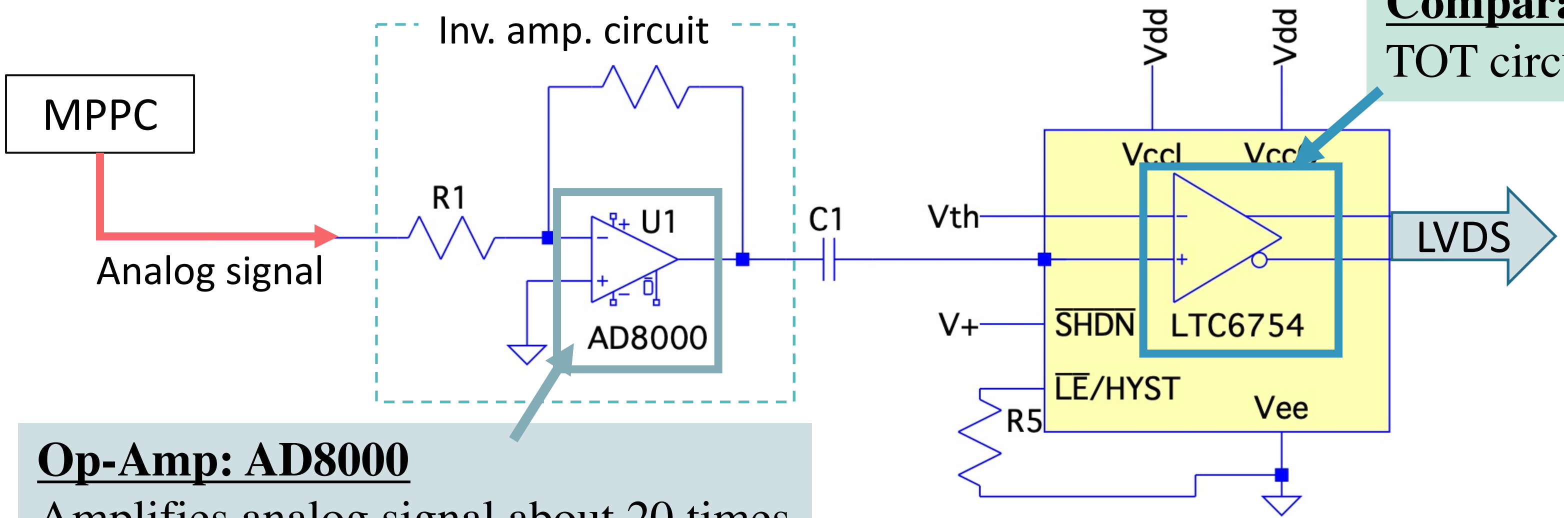
To take **data synchronized with the beam**, used the radiator controller as the gate signal.

- Trigger less
- Deadtime less

→ **High rate torelance !**

[3]R. Honda et al., Prog. Theor. Exp. Phys., Issue 12 (2021) 123H01.

Readout Circuit

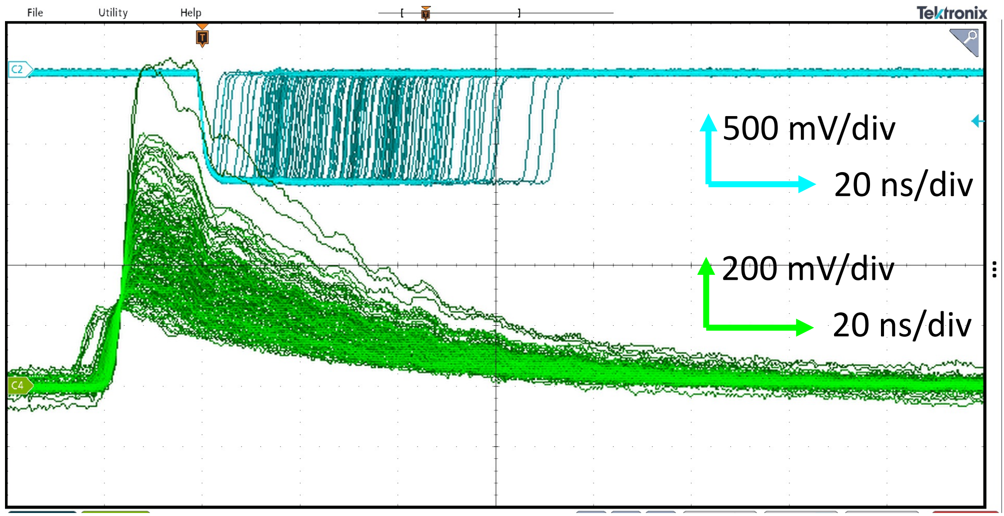


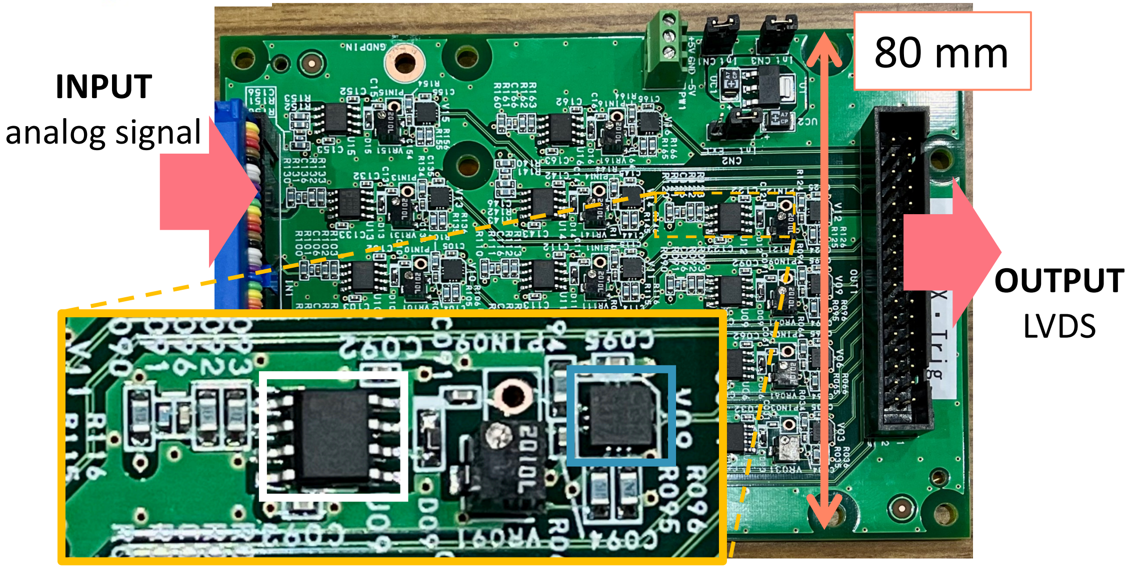
Comparator: LTC6754
TOT circuit: Output as LVDS signal

Op-Amp: AD8000
Amplifies analog signal about 20 times

veto	1 ch
trigger	1 ch
SciFi.	30 ch

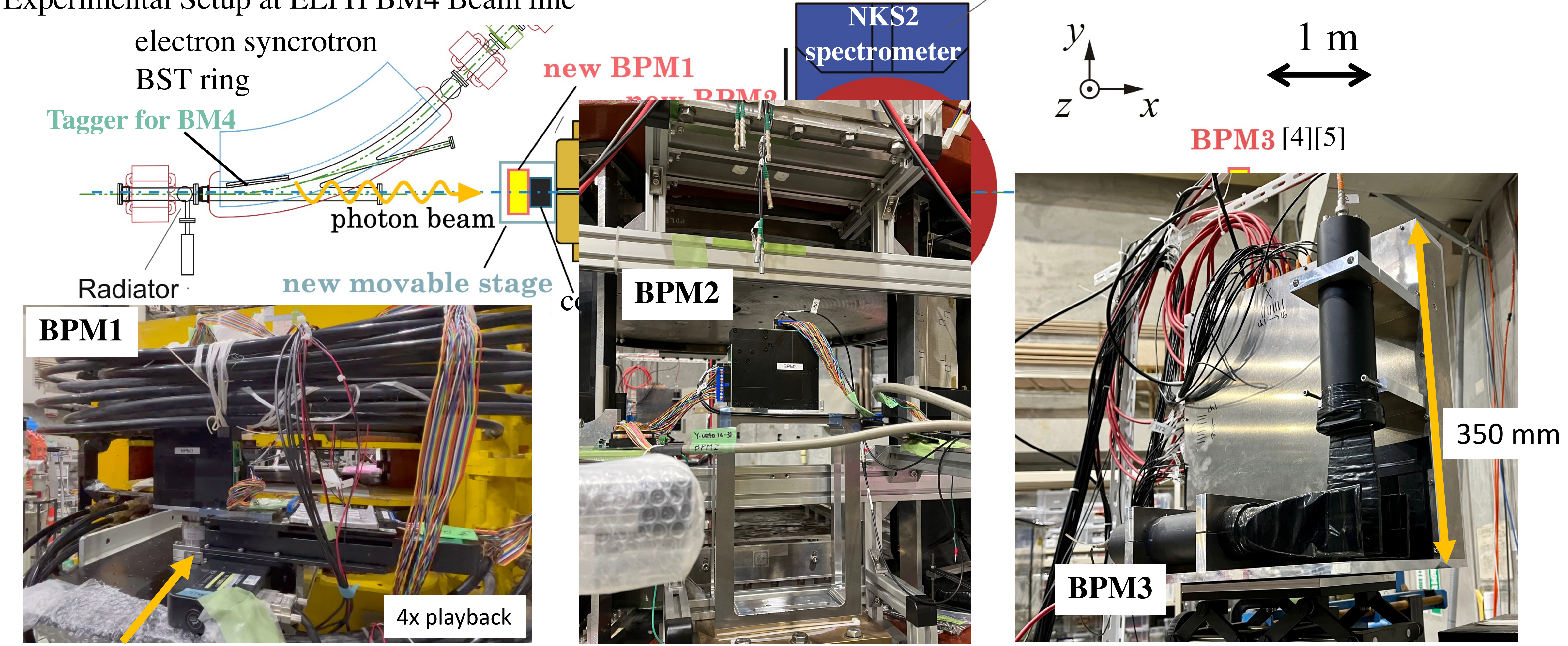
→ Read a total of 32 channels





Operation check at ELPH BM4 beam line

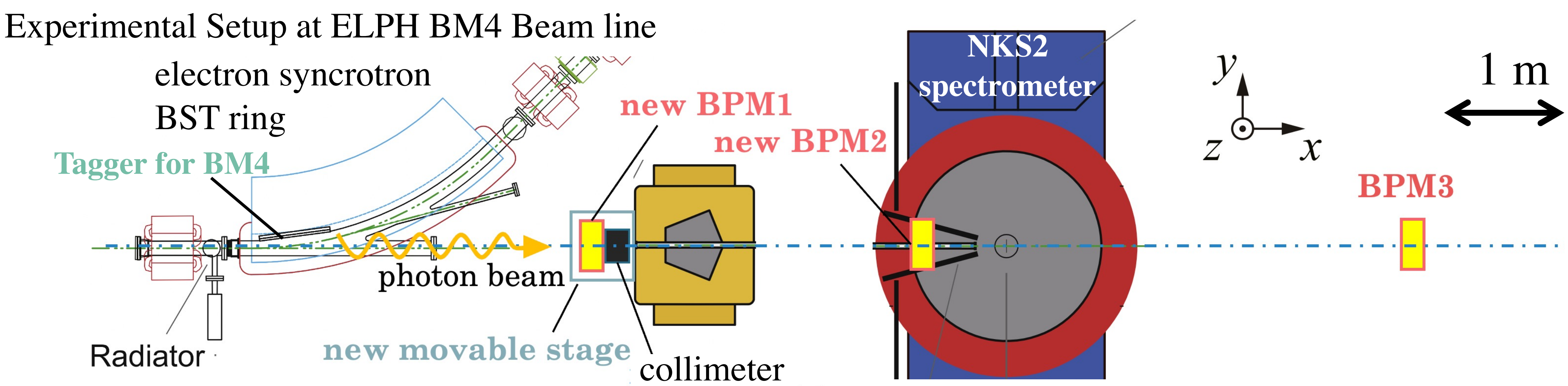
Experimental Setup at ELPH BM4 Beam line



automatic movable stage

[4] M. Nanao, T. Ishikawa, H. Shimizu, Research Report of LNS-Tohoku 36, 2003, p. 56.
[5] T. Ishikawa, et al., Nucl. Instrum. Methods Phys. Res. A 622 (2010) 1.

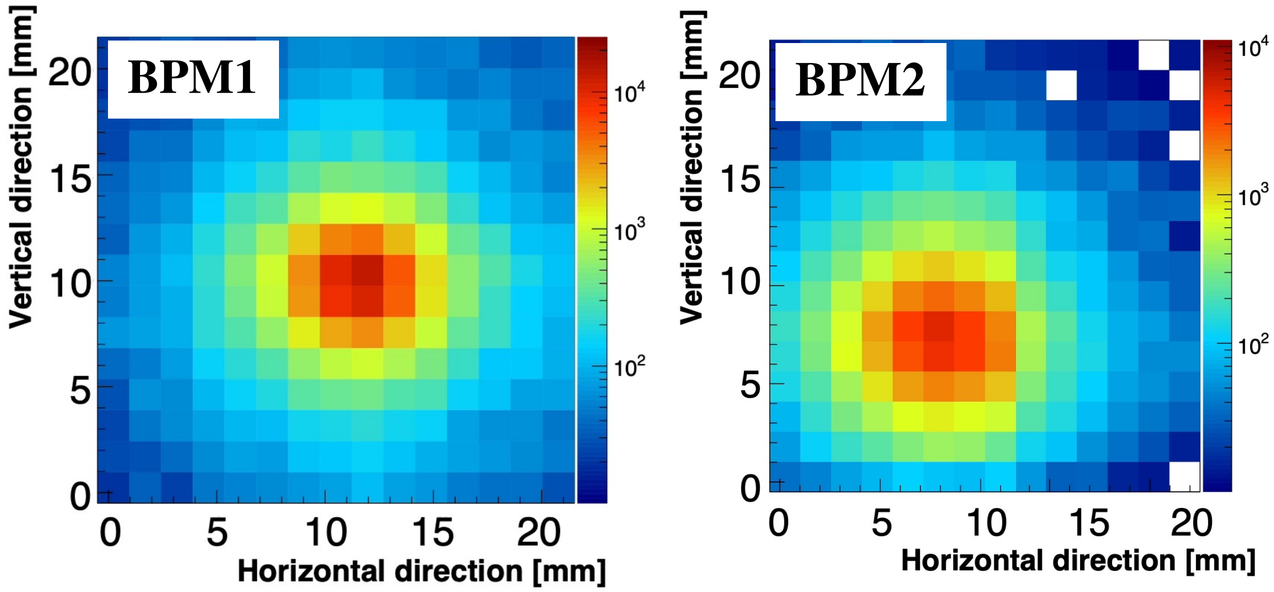
Operation check at ELPH BM4 beam line



It was confirmed that these are possible.

- Stable operation in a magnetic field (~ 0.3T)
- Separation of actual photon and background
- Beam fluctuation monitoring

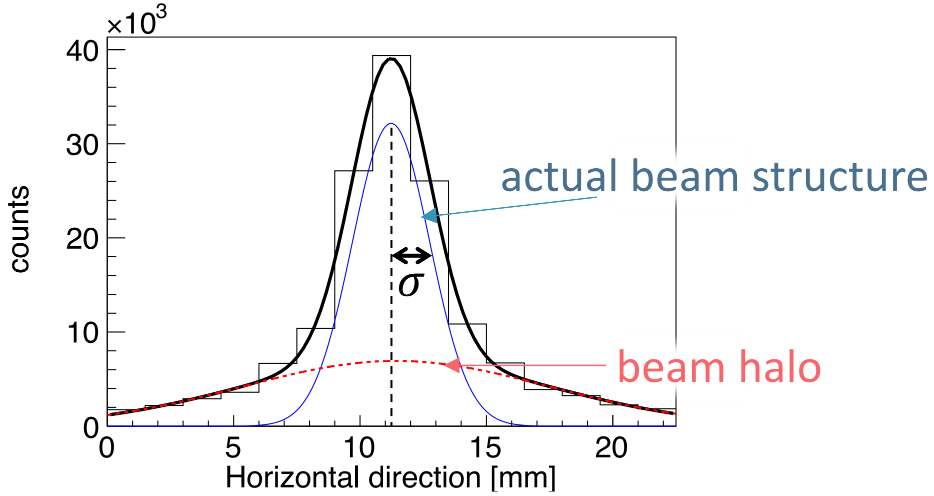
➢ Total count rate: ~ MHz
➢ Sampling rate: Can be monitored in 1ms



Quantitative beam profiling

Check the time dependence of
beam center position (μ) and size (σ).

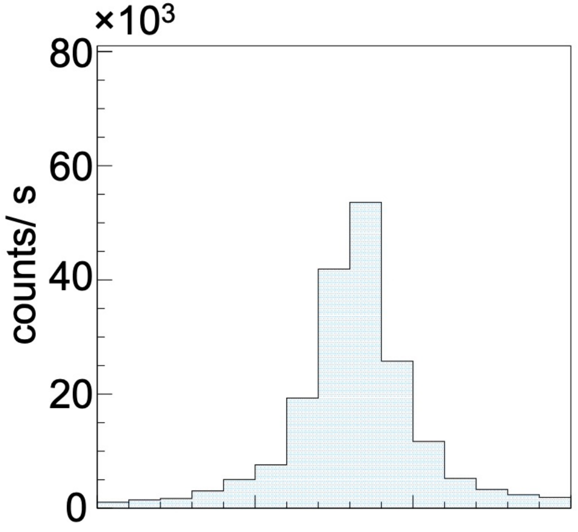
The hit distribution(/s) is plotted on the histograms in the horizontal and vertical directions, and determined by fitting.
Function: gaussian + gaussian

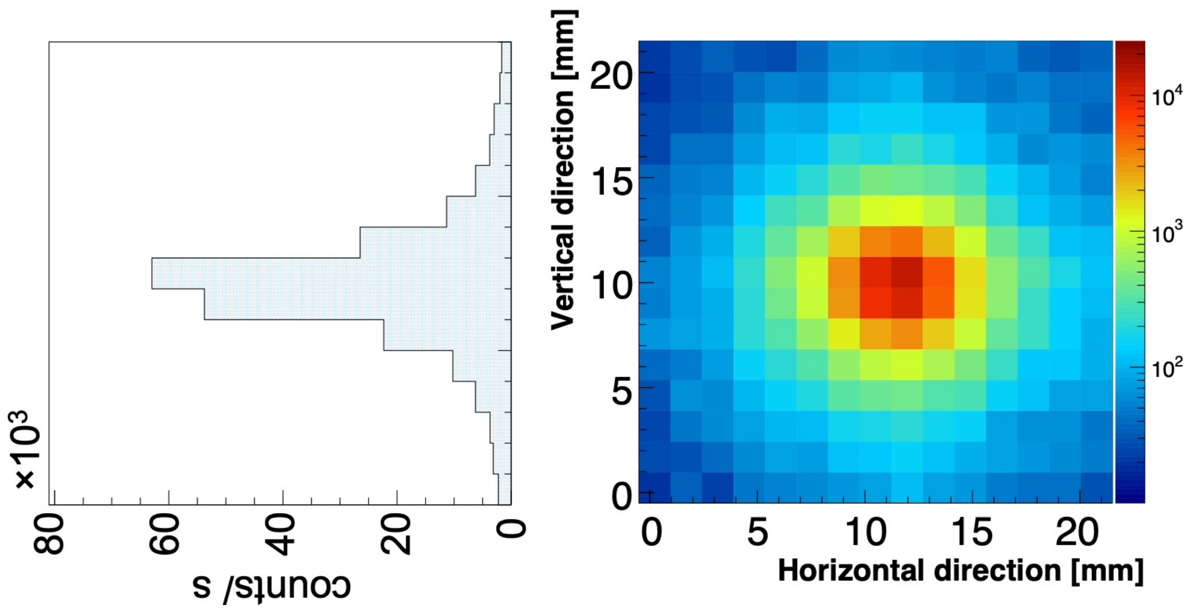


→ **Achieved accuracy $\Delta\mu$, $\Delta\sigma < 10\ \mu m$!**

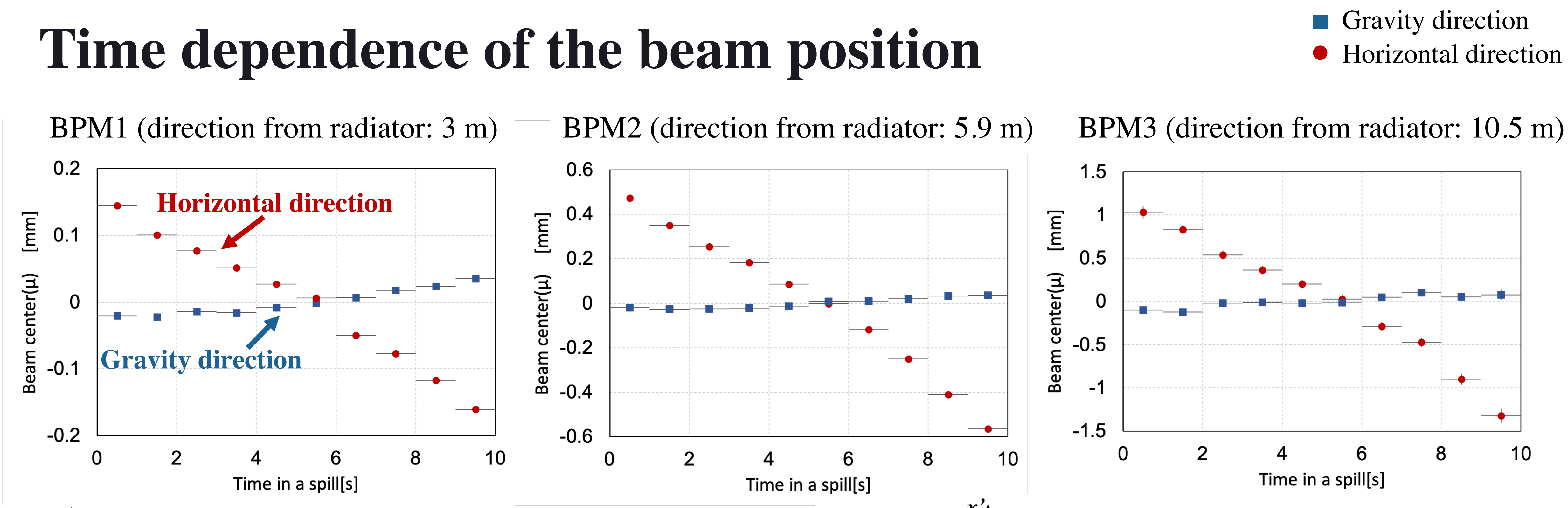
Hit distribution /1.0 sec

BPM1
beam current: 0.2 [mA]
bias voltage: 60.0 [V]
converter: 432 [μm]

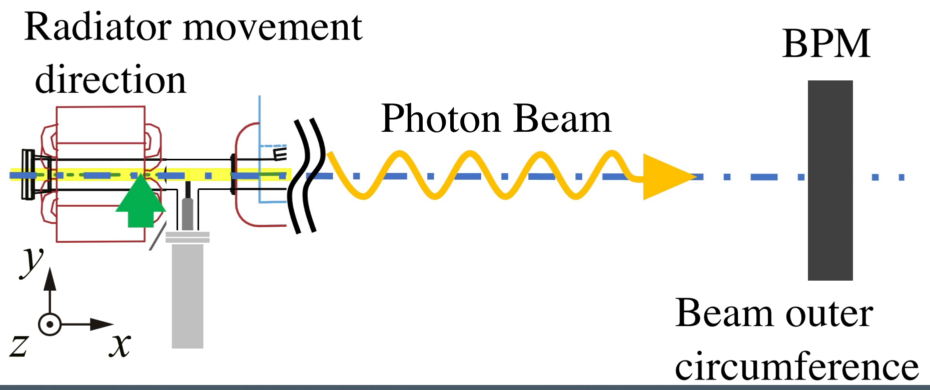


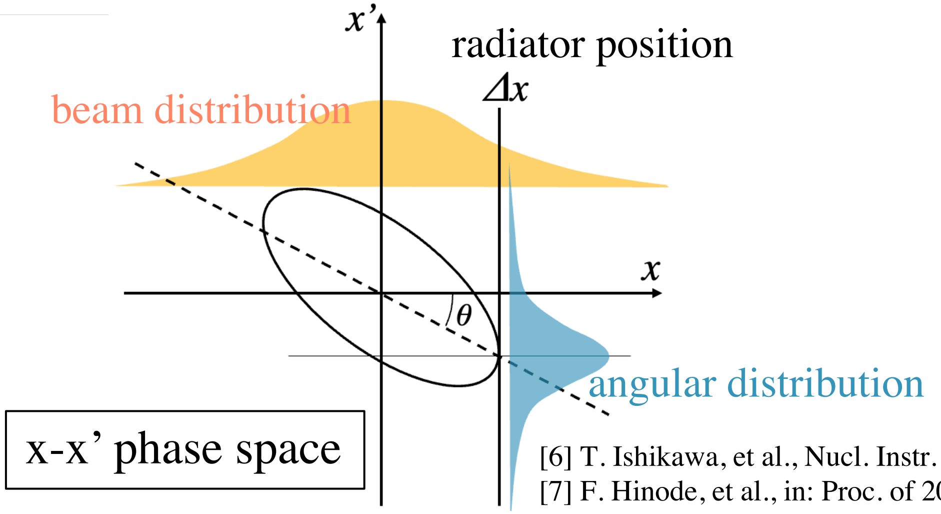


Time dependence of the beam position



- ➢ can be understood from the characteristics of the radiator and the electron synchrotron[6][7]



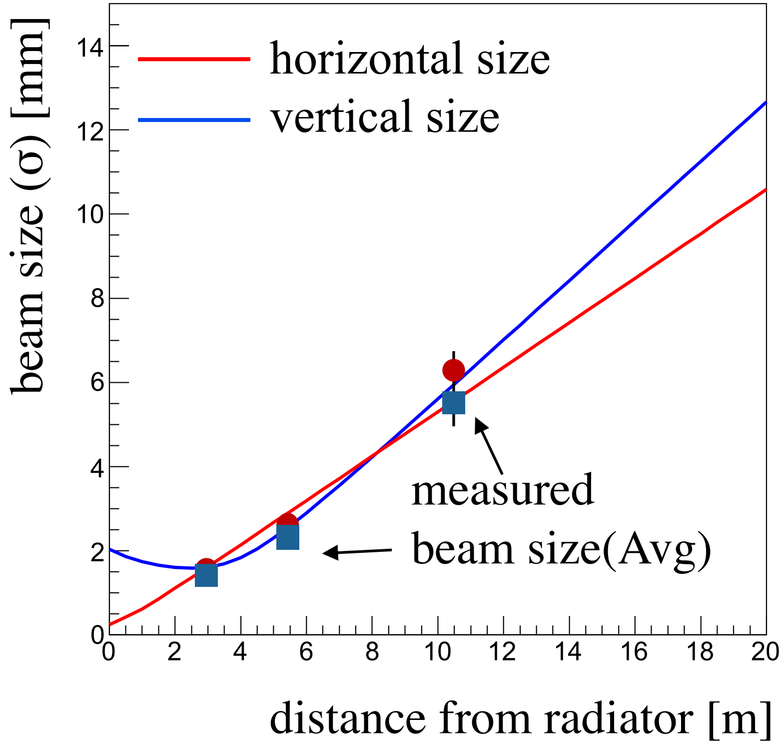


[6] T. Ishikawa, et al., Nucl. Instr. and Meth. A 811 (2016) 124–132
[7] F. Hinode, et al., in: Proc. of 2005 PAC 2458;

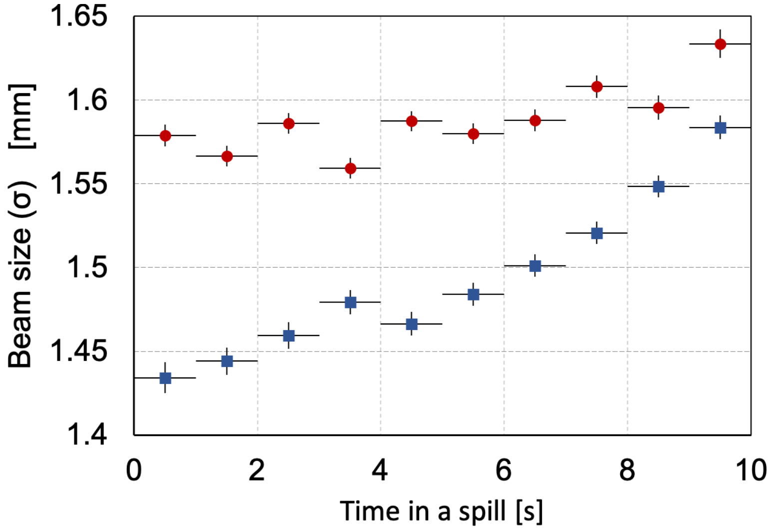
Fine measurement of beam size

- Horizontal direction (red circles)
- Vertical direction (blue squares)

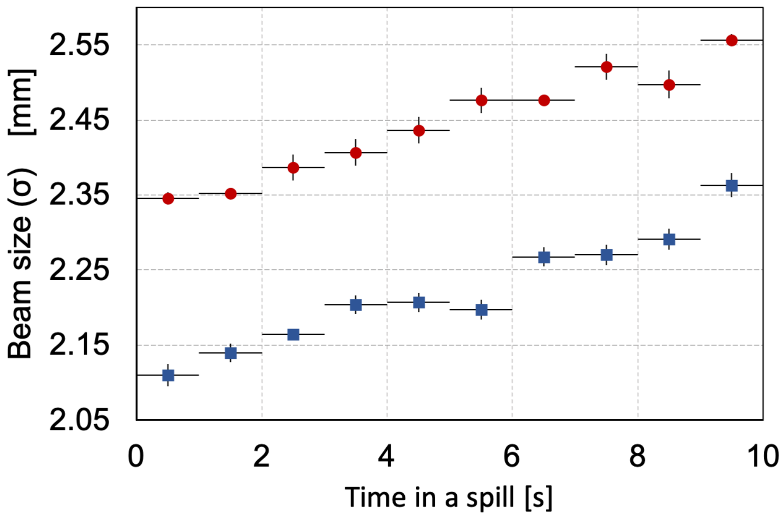
GeV gamma ray beam envelope[8]



BPM1 (direction from radiator: 3 m)



BPM2 (direction from radiator: 5.9 m)



- ➢ Beam size of each point:
  Approximately reproduces the theoretical value[8].
- ➢ Beam size increases significantly within a spill.

[8] T. Muto, PASJ2015 WEP003

Summary and conclusion

- **Developed photon Beam Position Monitor (BPM) for ELPH BM4 photon beam.**

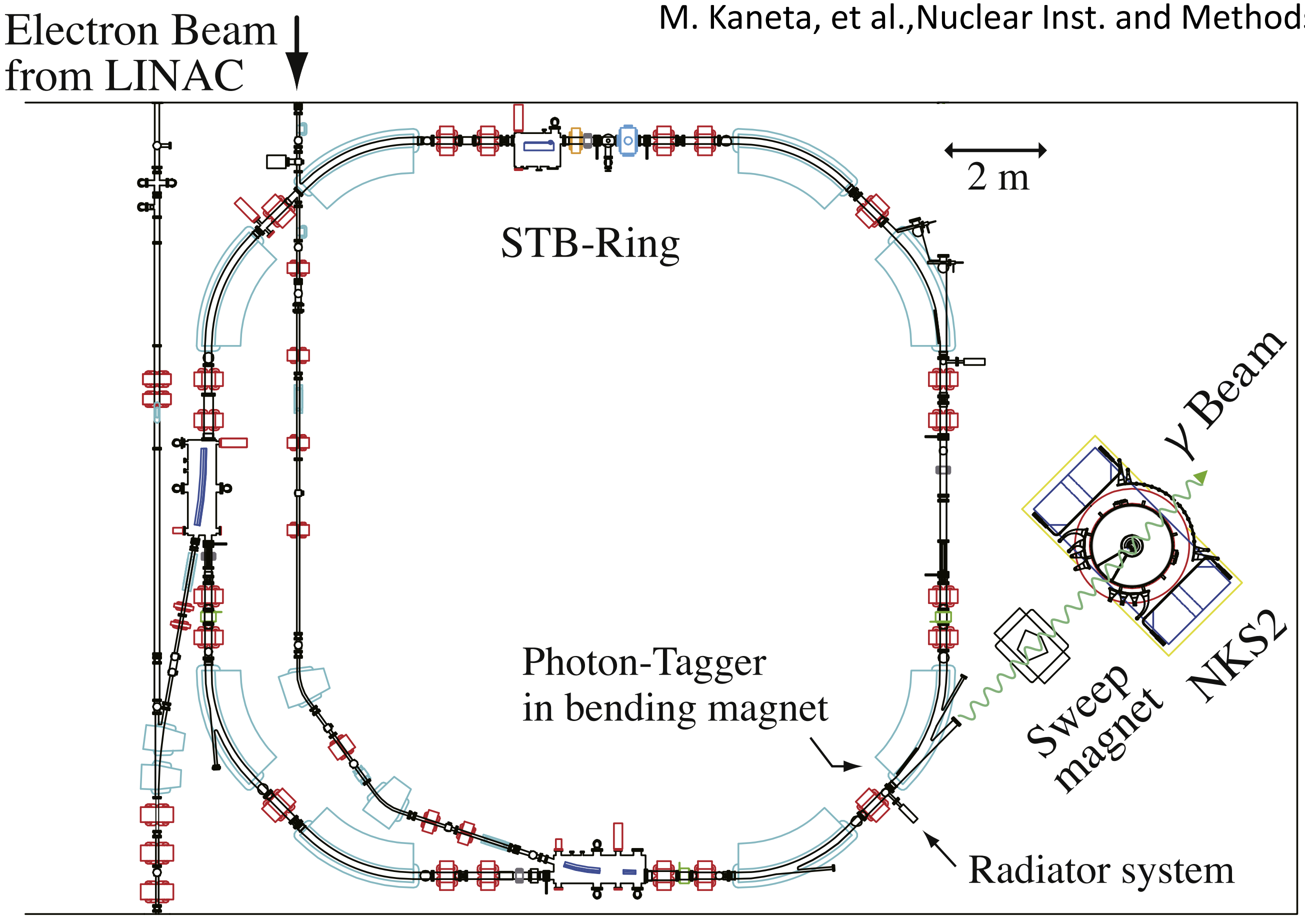
- **Photon Beam Position Monitor (BPM)**
  - Basic design: Plastic scintillation fiber (kuraray SCSF-78)
    Hamamatsu Photonics SiPM (MPPC S13360-1350PE, S13360-3050PE)
  - Readout: TOT circuit based on Op-Amp (AD8000) and comparator (LTC6754)
  - DAQ: Streaming TDC (FPGA module (HUL))

- **Test experiment using tagged photon beam at ELPH in March 2022**
  - Beam profiling can be done with position accuracy:
    $\Delta\mu \leq 10\ \mu$m, $\Delta\ \sigma \leq 10\ \mu$m for 1 second measurement

Back Up

Booster STorage Ring at ELPH

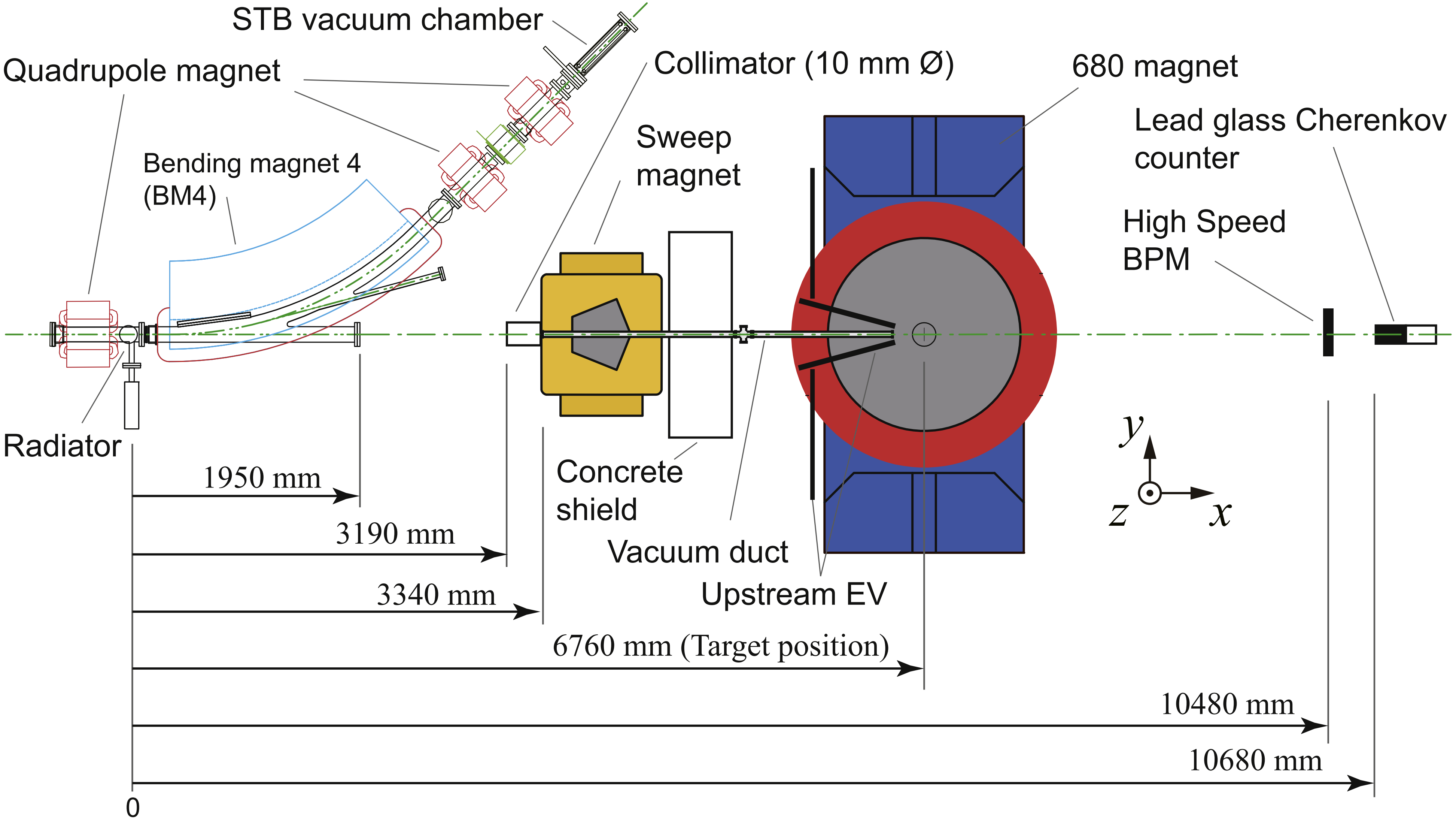
M. Kaneta, et al.,Nuclear Inst. and Methods in Physics Research, A 886 (2018) 88–103



Injection Beam Energy	Injection Repetition	Ring Top Energy	Storage Beam Current
90 MeV	~0.05 Hz (typ.)	0.8~1.3 GeV	~30 mA

Scaling of BM4 Beam Line and NKS2

M. Kaneta, et al.,Nuclear Inst. and Methods in Physics Research, A 886 (2018) 88–103



Plastic scintillation fibers kuraray SCSF-78

- Luminous
  - color: blue
  - peak: 450 nm

- Absorption peak: 2.8 nm

- Attenuation length: > 4.0 m

- Feature
  - High emission
  - High damping length

MPPC

	pixel pitch (μm)	Effective light receiving surface size (mm)	Aperture ratio (%)
S13360-1350PE	25	1.3 × 1.3	47
S13360-3050PE	50	3.0 × 3.0	74

MPPC

Hamamatsu Photonics K.K.

電気的および光学的特性 (指定のない場合はTyp. Ta=25 °C)

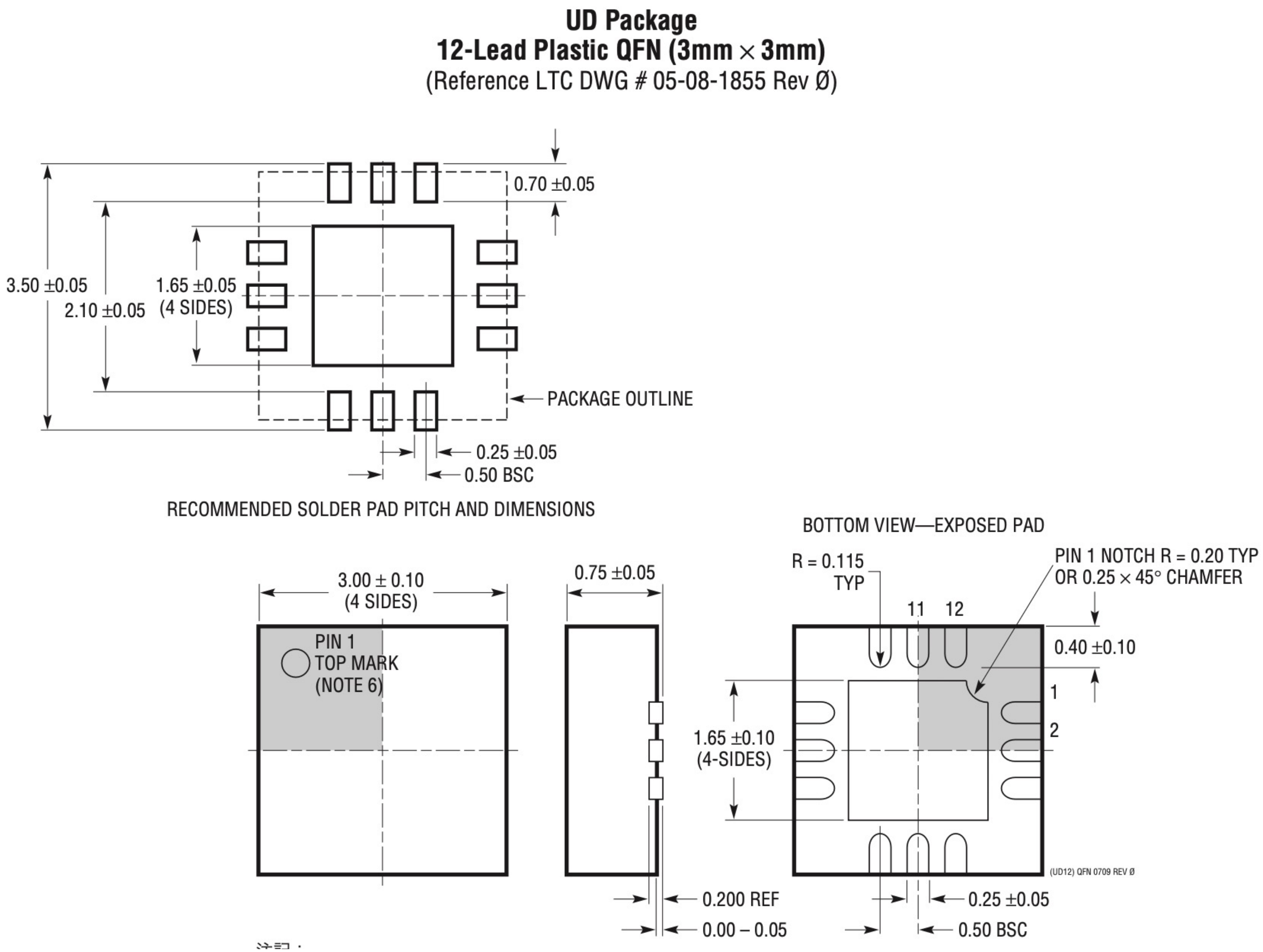
型名	測定条件	感度波長範囲 λ (nm)	最大感度波長 λp (nm)	検出効率 PDE*4 λ=λp (%)	ダークカウント*5 Typ. (kcps)	ダークカウント*5 Max. (kcps)	端子間容量 Ct (pF)	増倍率 M	降伏電圧 VBR (V)	クロストーク確率 (%)	推奨動作電圧 Vop (V)	推奨動作電圧の温度係数 ΔTVop (mV/°C)
S13360-1325CS	Vover =5 V	270 ~ 900	450	25	70	210	60	7.0×10^5	53 ± 5	1	VBR + 5	54
S13360-1325PE		320 ~ 900										
S13360-3025CS		270 ~ 900			400	1200	320					
S13360-3025PE		320 ~ 900										
S13360-6025CS		270 ~ 900			1600	5000	1280					
S13360-6025PE		320 ~ 900										
S13360-1350CS	Vover =3 V	270 ~ 900		40	90	270	60	1.7×10^6		3	VBR + 3	
S13360-1350PE		320 ~ 900										
S13360-3050CS		270 ~ 900			500	1500	320					
S13360-3050PE		320 ~ 900										
S13360-6050CS		270 ~ 900			2000	6000	1280					
S13360-6050PE		320 ~ 900										
S13360-1375CS	Vover =3 V	270 ~ 900		50	90	270	60	4.0×10^6		7	VBR + 3	
S13360-1375PE		320 ~ 900										
S13360-3075CS		270 ~ 900			500	1500	320					
S13360-3075PE		320 ~ 900										
S13360-6075CS		270 ~ 900			2000	6000	1280					
S13360-6075PE		320 ~ 900										

*4: 検出効率は、クロストークとアフターパルスを含んでいません。

*5: 閾値=0.5 p.e.

注) 上記の特性値は、表中の増倍率が得られる動作電圧における値です (製品に添付されるデータを参照してください)。

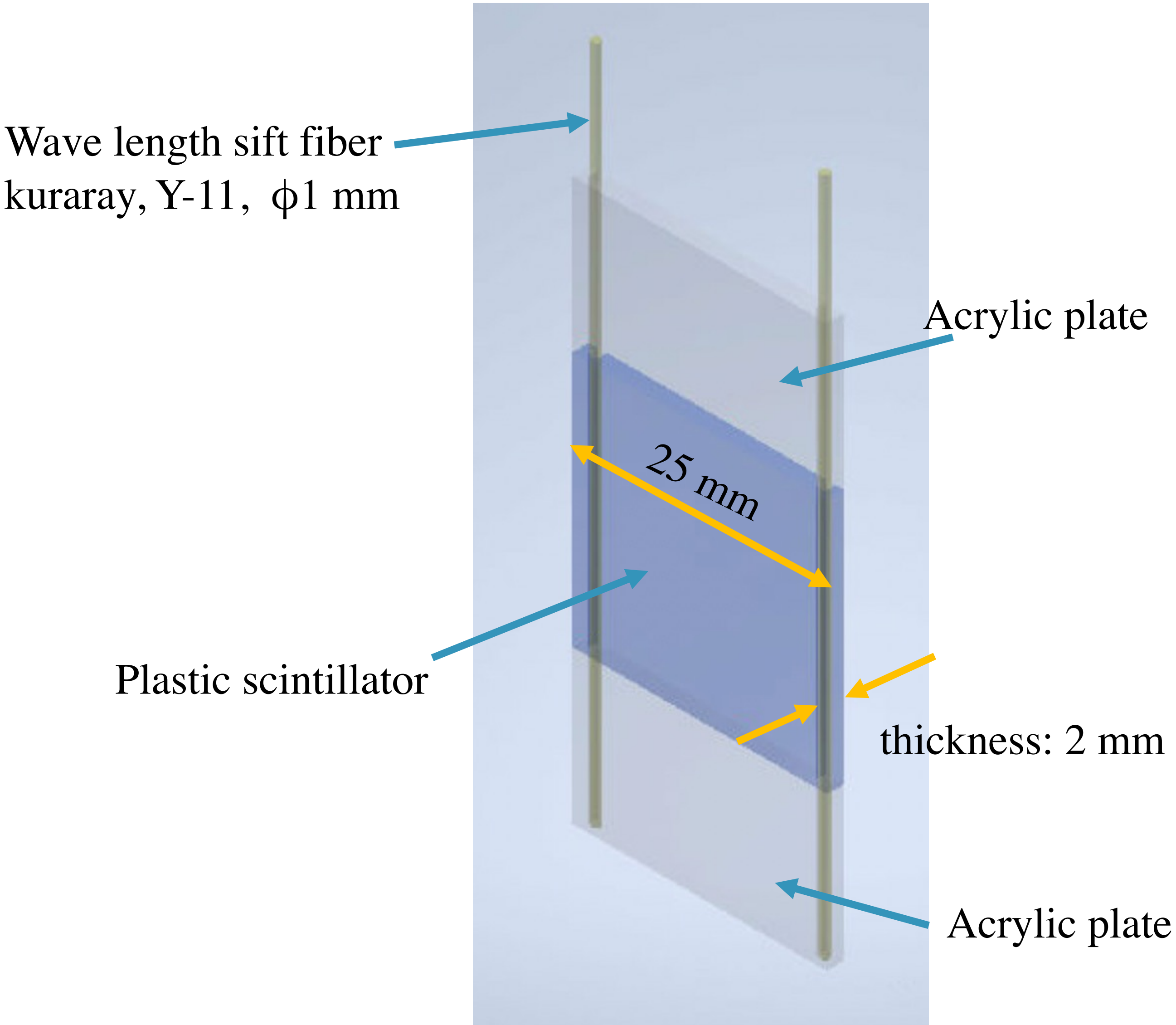
LTC6754



- 短い伝播遅延時間:**1.8n**(s標準)
- 低い オーバードライブ分散:**1n**(s標準)
  (オーバードライブは **10mV ~ 125mV**)
- 切り替え速度が高速:**890Mbp**(s標準)
- **LVDS** 互換の出力段
- レール・トゥ・レール入力を両方のレールを超えて拡張
- 低静止電流:13.4mA
- 電源電圧範囲:2.4V ~ 5.25V
- LTC6754ファミリ共通の特長:
- 入力電源と出力電源が別個
- 消費電力低減のためのシャットダウン・ピン
- 出力ラッチと調整可能なヒステリシス
- SC70パッケージおよび3mm×3mm QFNパッケージ

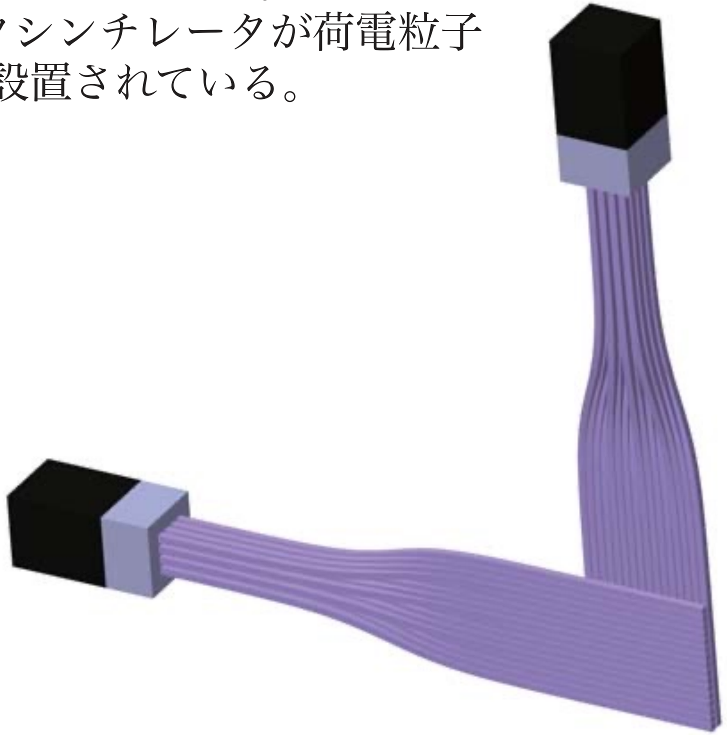
LINEAR Technology

Trigger counter



BPM3 [4][5][9]

GeV-γ ビームラインの最下流、標的から2,230 mの距離に設置.
隙間無く並べられた3 mm角のシンチレーションファイバー15本が水平方向と垂直方向の 2層に重ねられたものである。
BPMの上流には 5 mm厚のプラスチックシンチレータが荷電粒子除去用に 1 枚とトリガ゛ー生成用に2枚設置されている。



[4] M. Nanao, T. Ishikawa, H. Shimizu, Research Report of LNS-Tohoku 36, 2003, p. 56.
[5] T. Ishikawa, et al., Nucl. Instrum. Methods Phys. Res. A 622 (2010) 1.
[9] 大串 尚永　修士論文 (平成 21 年)

BPM3 [4][5][9]

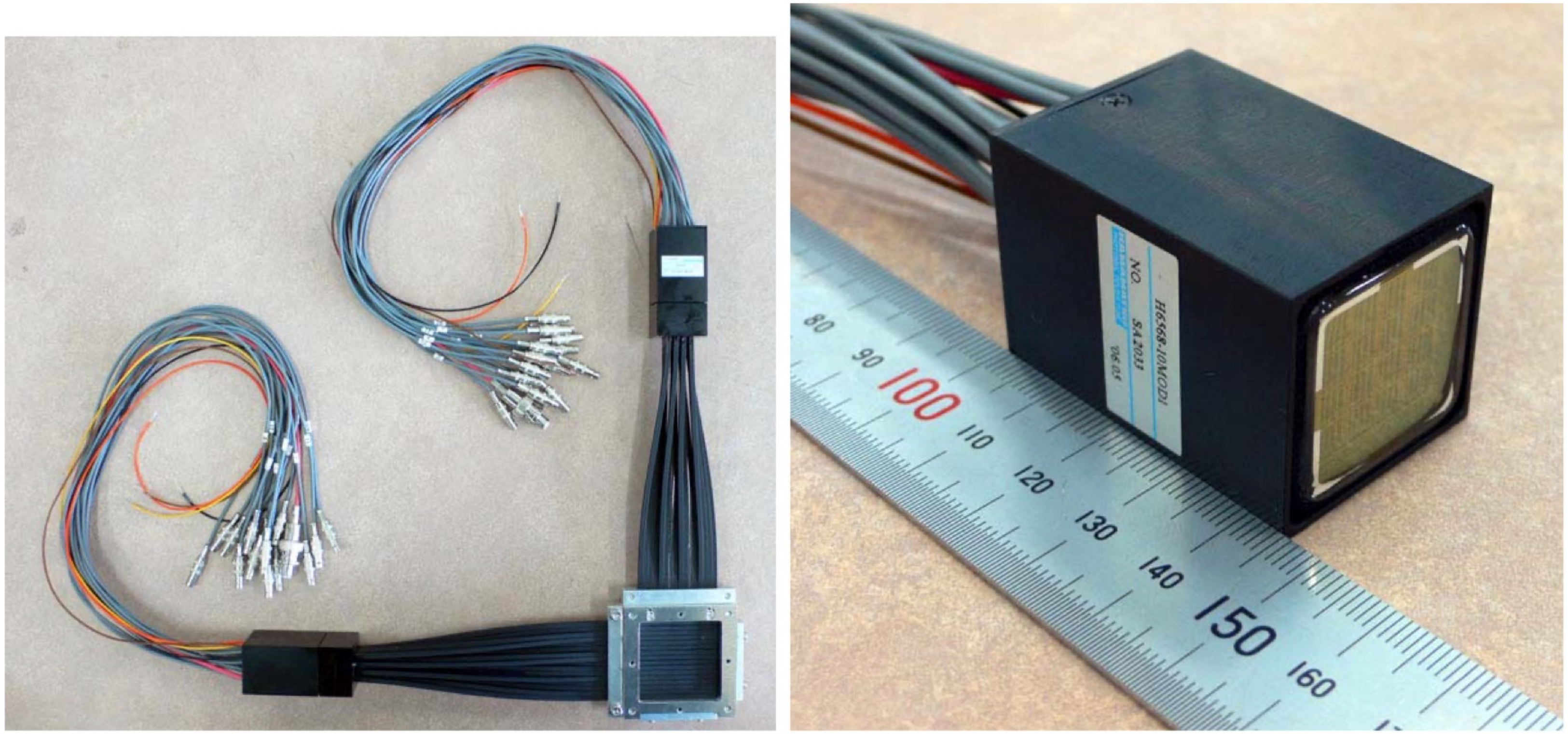


図 2.4: 使用したシンチレーティングファイバーと光電子増倍管。右は シンチレーティングファイバー 16 本 2 層を直角に組んだ様子である。左は 4 × 4 マルチアノード光電子増倍管 H6558-10MOD であり、1 層に 1 つずつ接続されている。

[4] M. Nanao, T. Ishikawa, H. Shimizu, Research Report of LNS-Tohoku 36, 2003, p. 56.
[5] T. Ishikawa, et al., Nucl. Instrum. Methods Phys. Res. A 622 (2010) 1.
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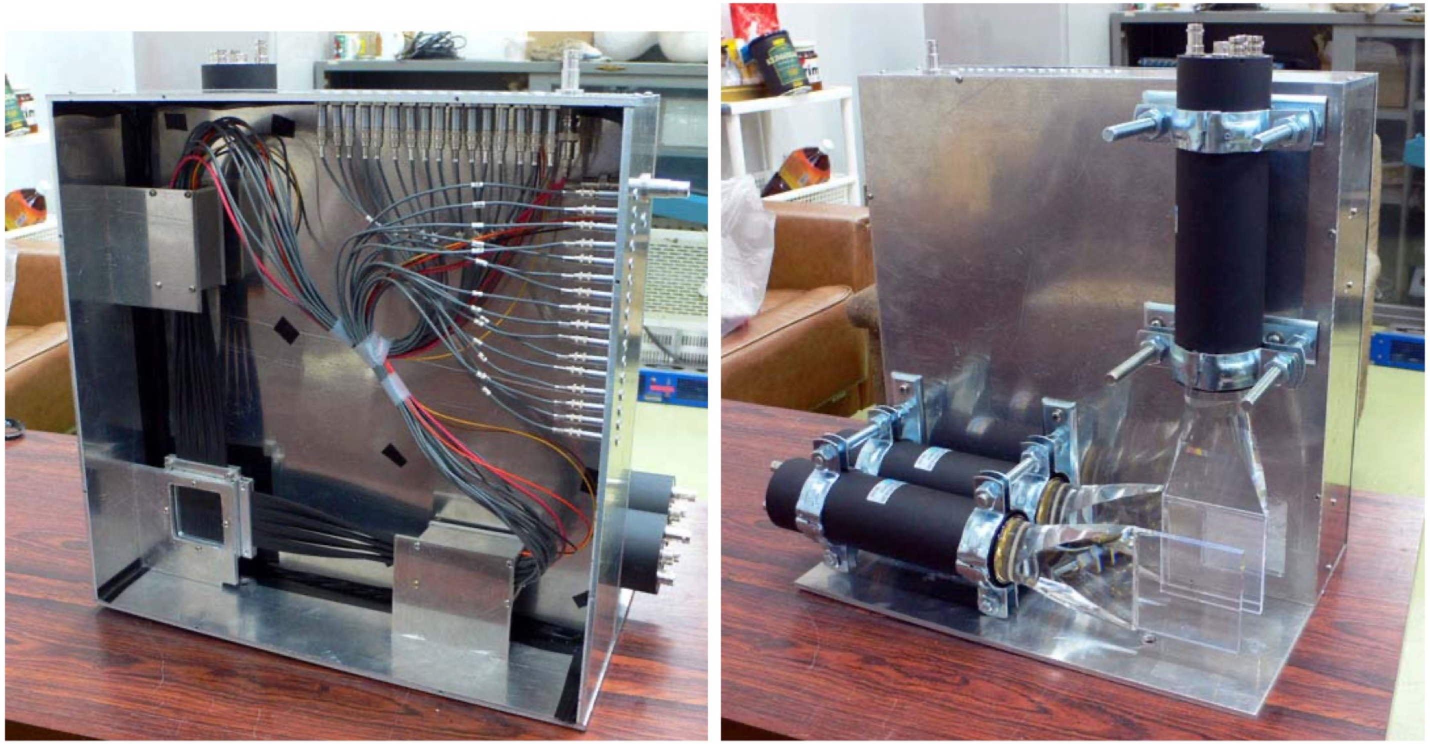
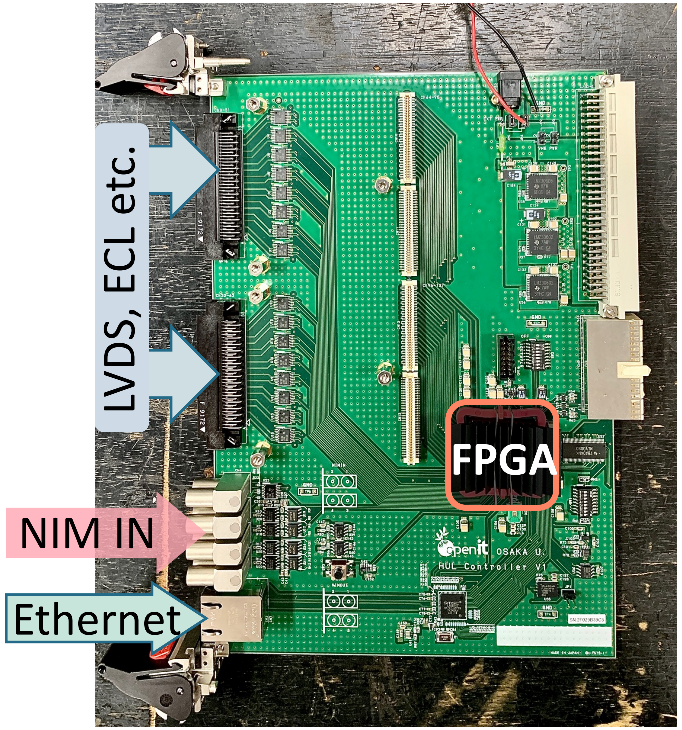


図 2.5: BPM 筐体の外観。右はビーム下流側から、左はビーム上流側から見た図である。BPM の上流側にはトリガー用にプラスチックシンチレータが設置されており、上流から VETO, UP, DOWN と称する。VETO と DOWN は横置き、UP は縦置きであり、3 枚とも光電子増倍管 H7195MOD で読み出しを行っている。

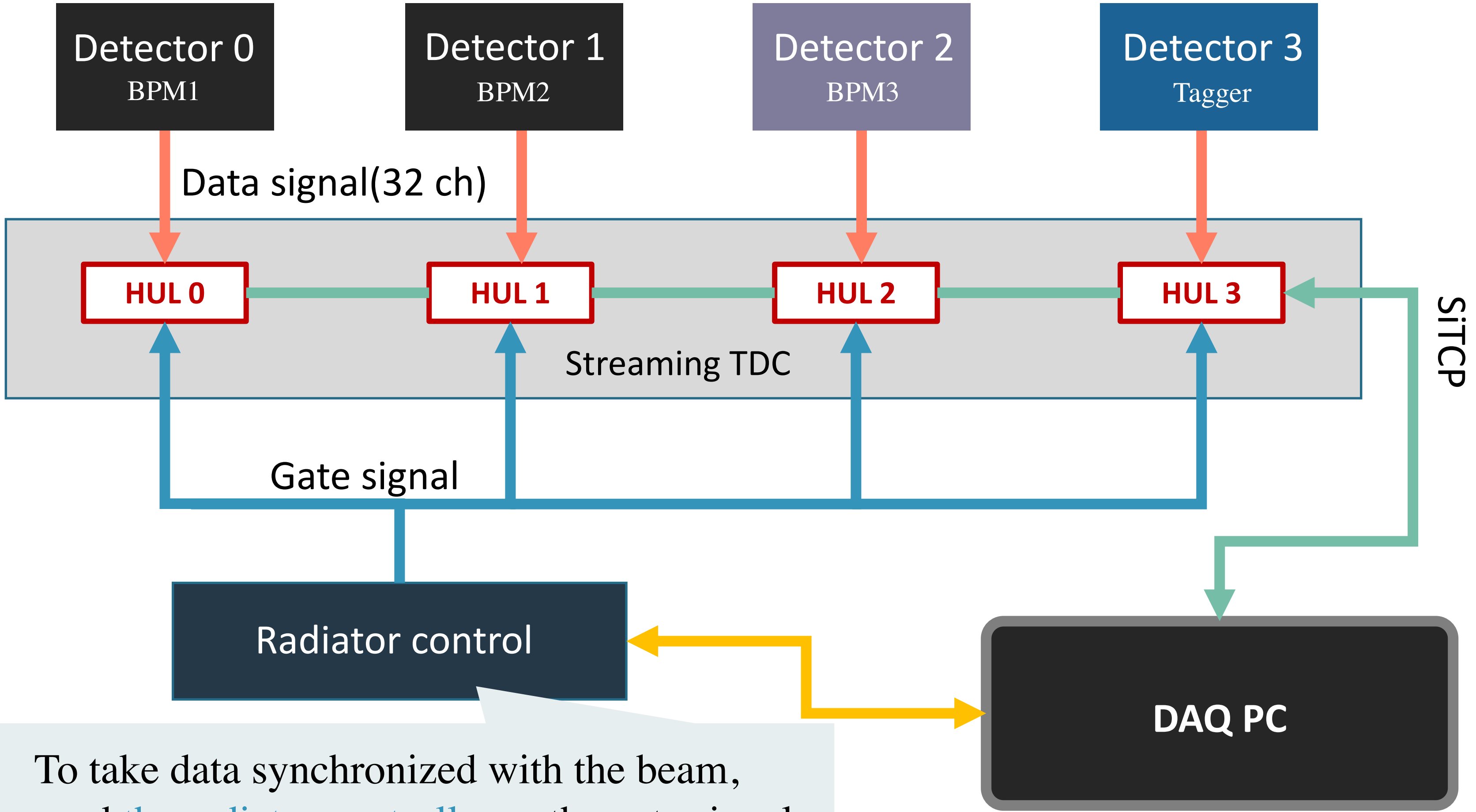
[4] M. Nanao, T. Ishikawa, H. Shimizu, Research Report of LNS-Tohoku 36, 2003, p. 56.
[5] T. Ishikawa, et al., Nucl. Instrum. Methods Phys. Res. A 622 (2010) 1.
[9] 大串 尚永　修士論文 (平成 21 年)

Data acquisition system

Hadron **U**niversal **L**ogic
firmware: streaming TDC [3]



- Trigger less
- Deadtime less

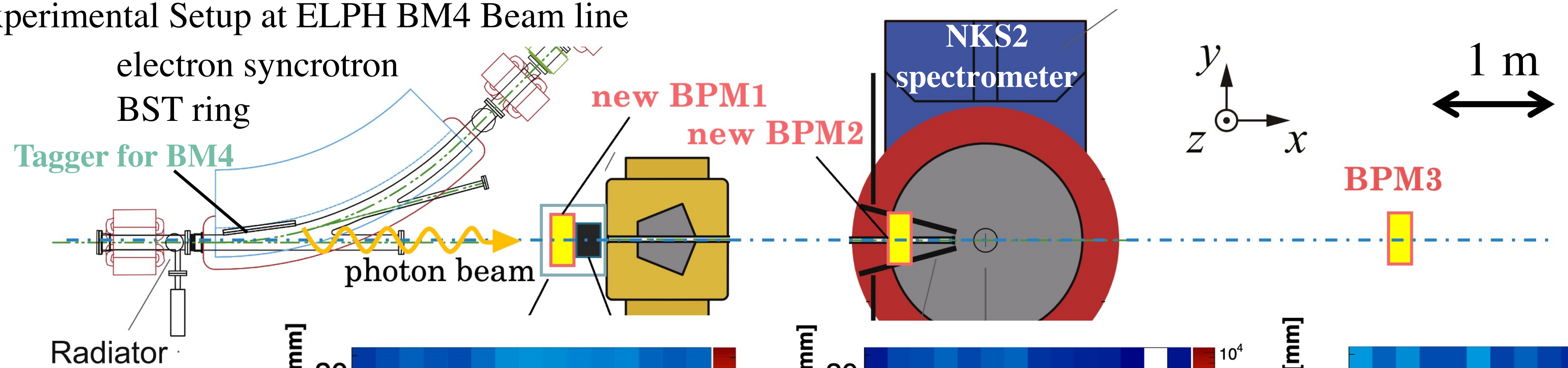


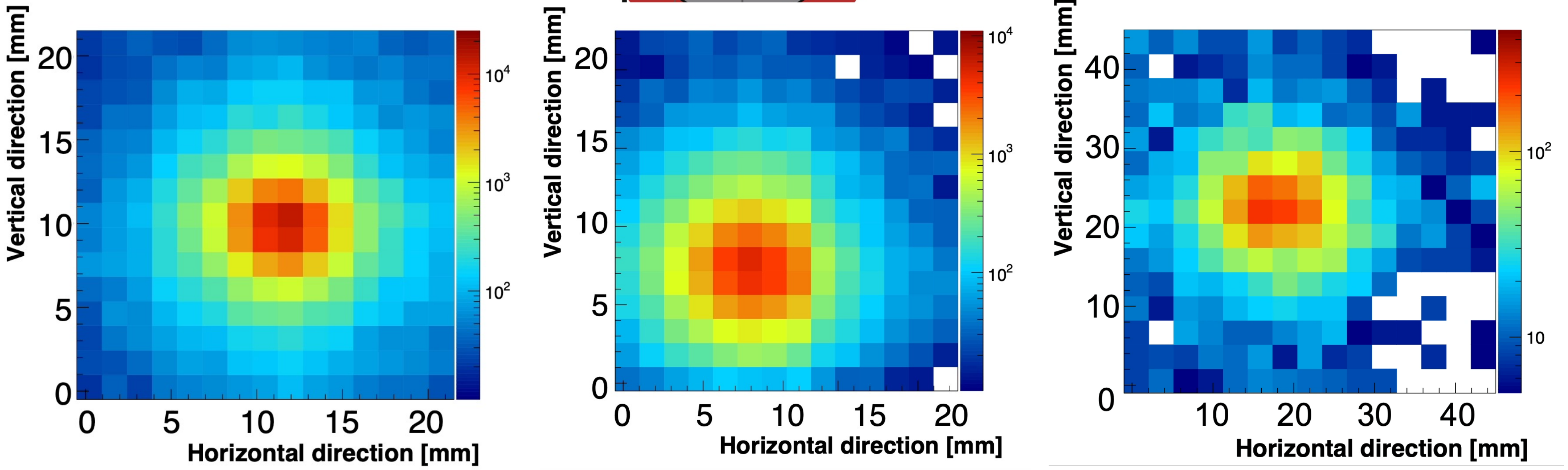
To take data synchronized with the beam, used the radiator controller as the gate signal.

[3]R. Honda et al., Prog. Theor. Exp. Phys., Issue 12 (2021) 123H01.

Operation check at ELPH BM4 beam line

Experimental Setup at ELPH BM4 Beam line





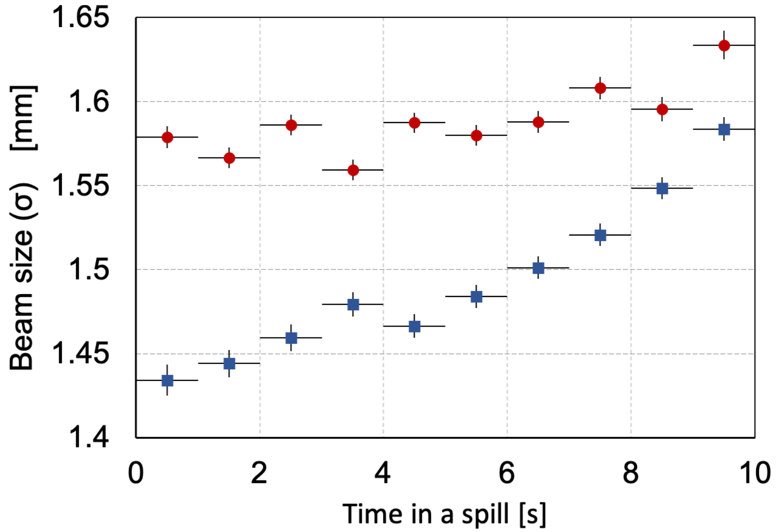
It was confirmed that

- Stable operatio
- Separation of a
- Beam fluctuati
  - ➢ Sampling rate
  - ➢ Total count rate: ~ MHz

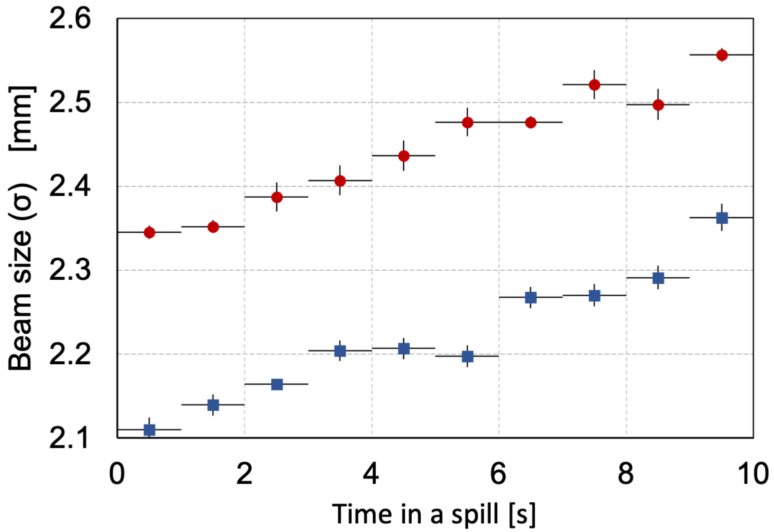
Time dependence of the beam size

● Gravity direction
■ Horizontal direction

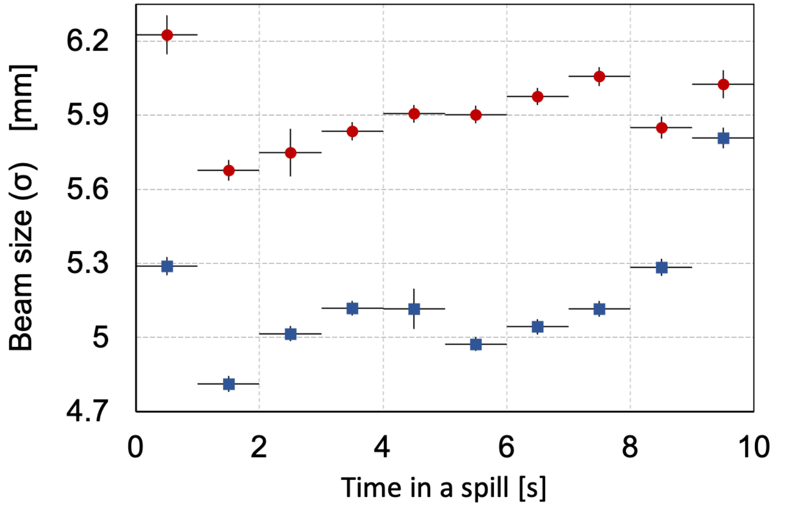
BPM1 (direction from radiator: 3 m)



BPM2 (direction from radiator: 5.9 m)



BPM3 (direction from radiator: 10.5 m)



- Beam size increases significantly within a spill.

  due to the characteristics of Coulomb scattering of the radiator and electron beam[8]

- Beam size (avg):

  Gravity direction σ = 1.70 mm

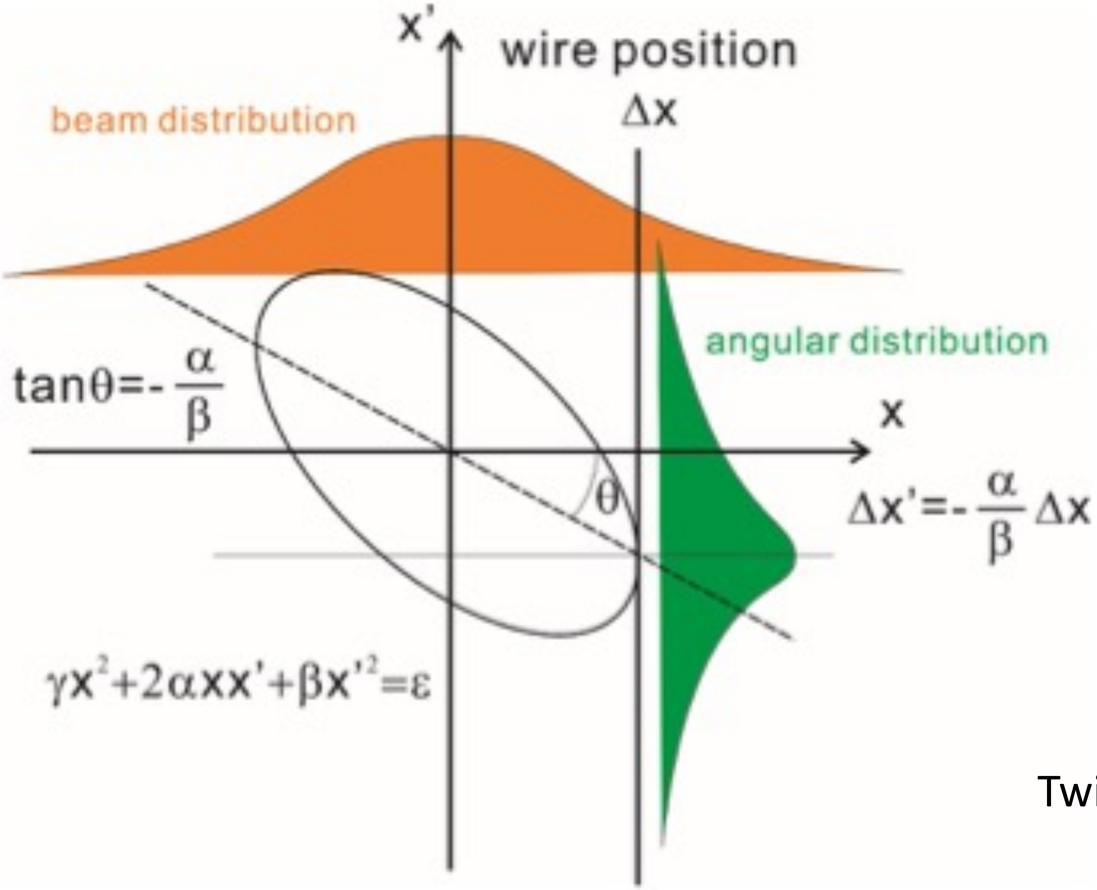
  Horizontal direction σ = 1.56 mm

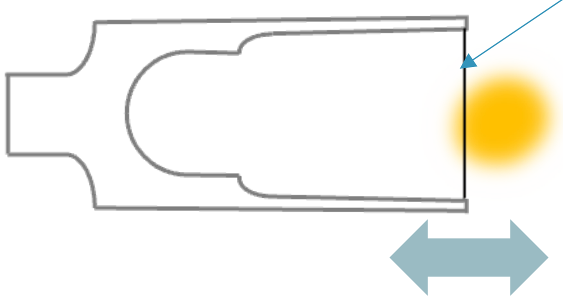
Beam size increases significantly within a spill.

[8] T. Muto, PASJ2015 WEP003

Radiator and phase space of the beam

x – x' phase space





Electron beam distribution
= Photon intensity at wire position

Photon beam direction: $\Delta x' = -\frac{\alpha}{\beta}\Delta x$

determined by ring parameters

Twiss Parameter @Radiator: $(\alpha, \beta) = (3.69, 1.59\,) \Rightarrow \frac{\alpha}{\beta} = 0.43$

[2] F. Hinode, et al., in: Proc. of 2005 PAC 2458;

About the Photon Beam Size

Photon beam size
Ring-specific emittance is not determined, once or many times
Coulomb Depends on the nature of scattered electrons.

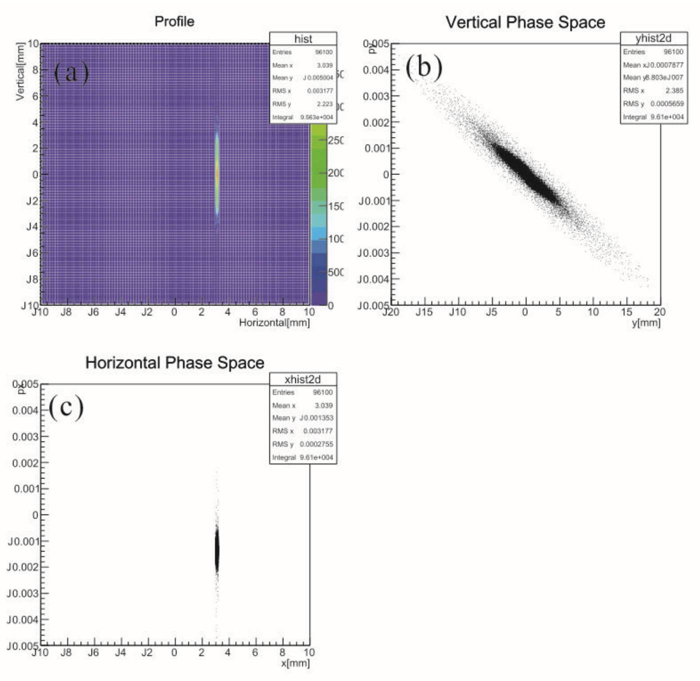
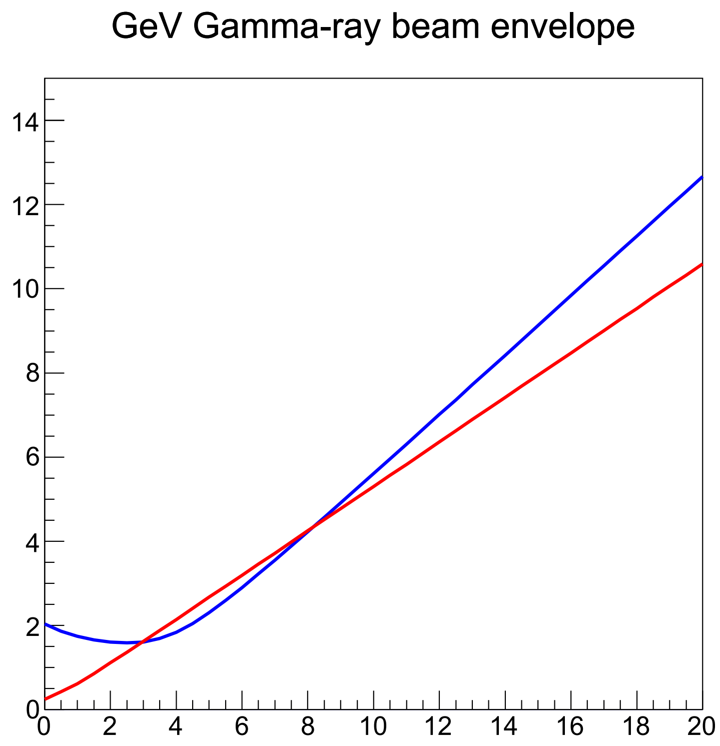


Figure 4: Profile and phase spaces of recirculating electron at the radiator position after Coulomb scattering. (a) profile, (b) vertical phase space, (c) horizontal phase space.

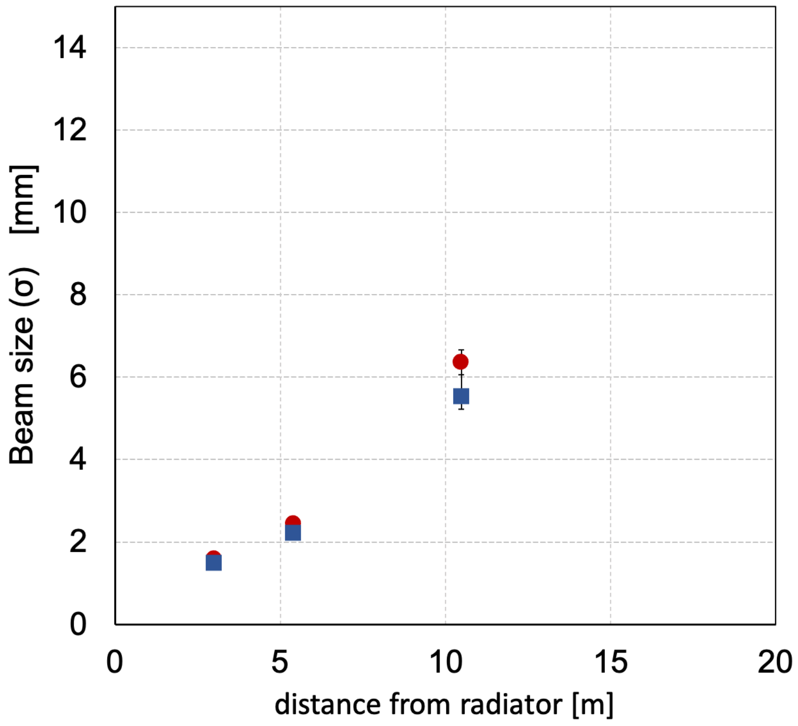


Gamma ray beam envelope after radiator. The red: horizontal size, the blue: vertical size.

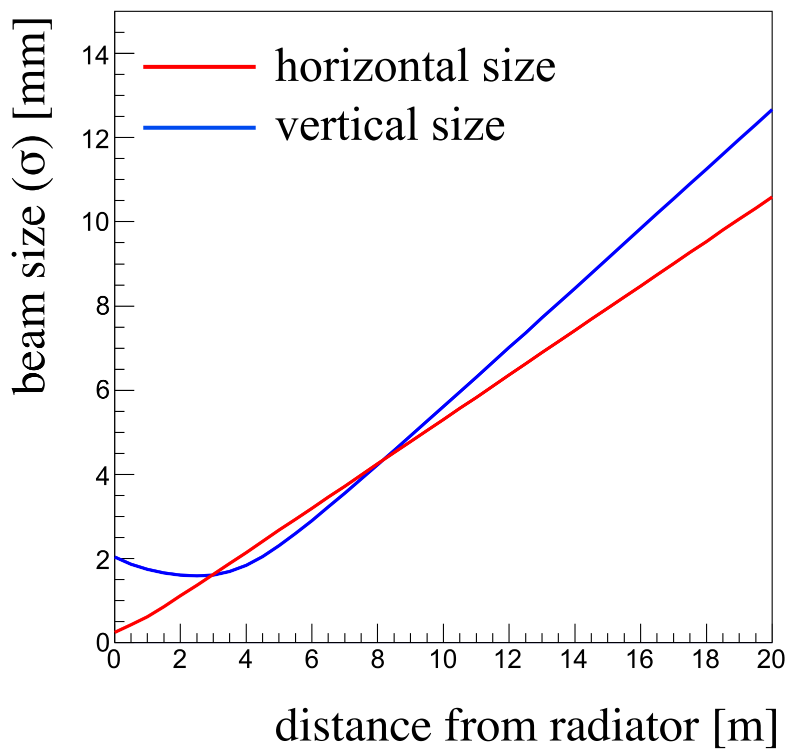
[3]T. Muto, PASJ2015 WEP003

Beam size measurement

■ Gravity direction
● Horizontal direction



GeV gamma ray beam envelope[6]

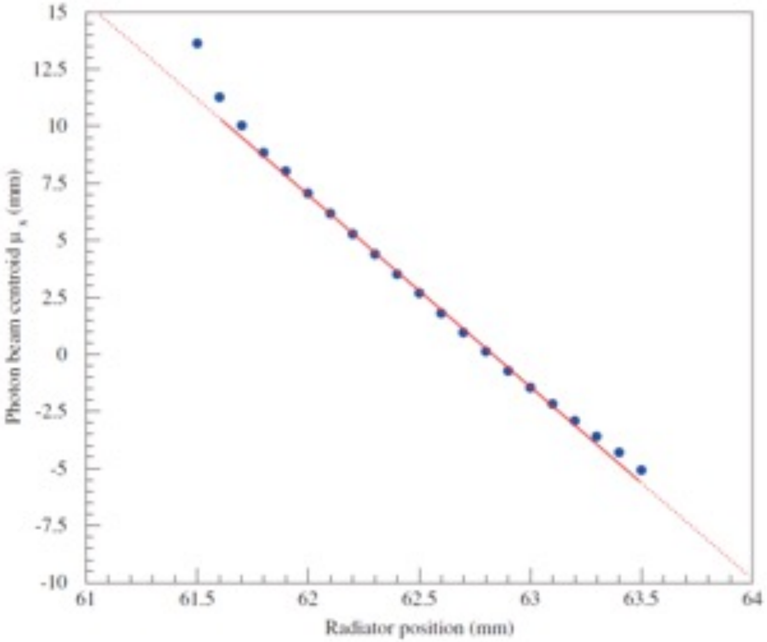


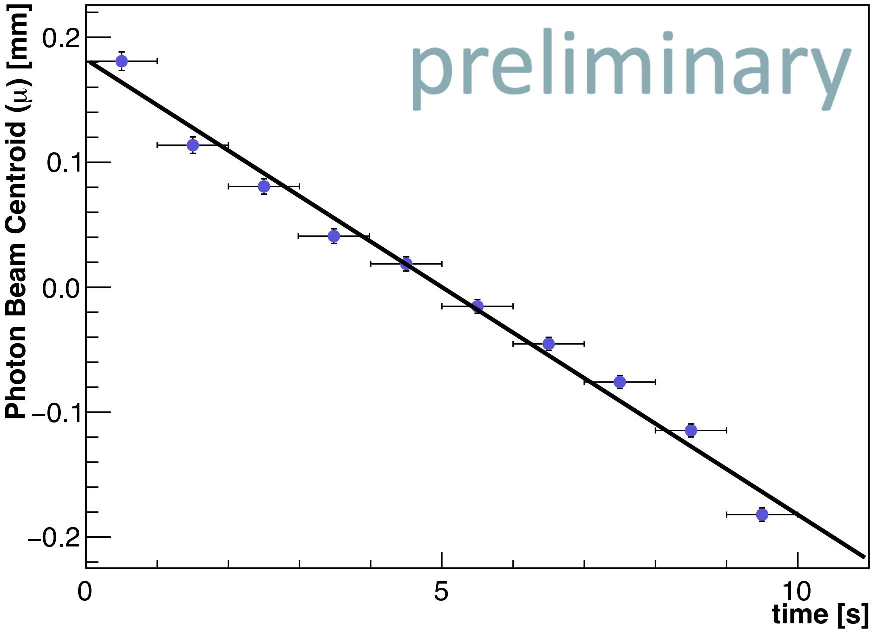
- ➢ Consistent with the theoretical beam size [8] predicted
- ➢ time dependence was also measured

[8] T. Muto, PASJ2015 WEP003

Radiator and phase space of the beam

Photon beam direction[4]





$$\Delta x' = -\frac{\alpha}{\beta}\Delta x = -0.41\Delta x$$

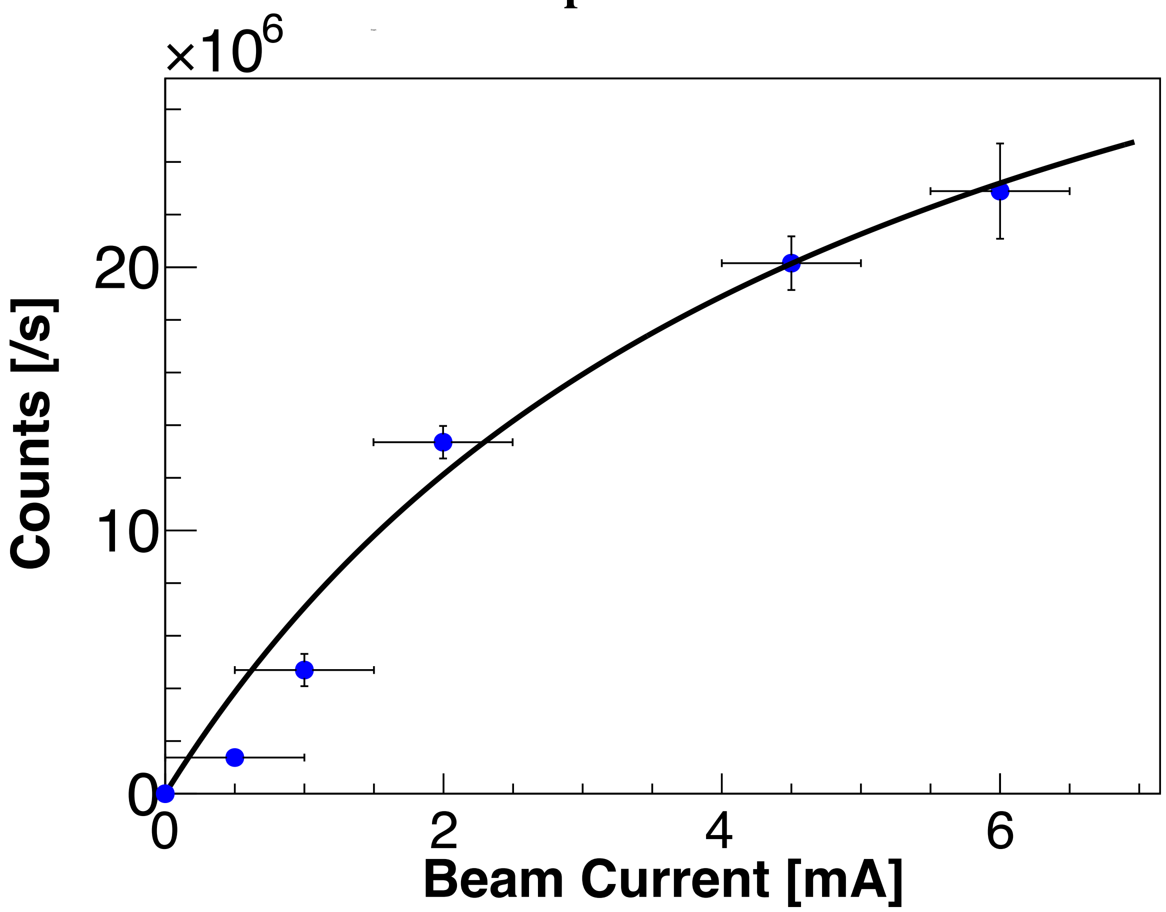
$$\Delta x' = -\frac{\alpha}{\beta}\Delta x = -(0.37 \pm 0.02)\Delta x$$

(Converted to radiator position [mm] assuming that the horizontal axis is the radiator speed of 0.1 mm/s)

[4]T. Ishikawa, et al., ELPH Experiment : #2815 Annual Report 2015

Rate Study

The fitting of the non-paralyzed counting correction function was performed in consideration of the dead time.



MPPC bias voltage：56 V

Fit function：$y = \frac{p_0 x}{1 - p_0 p_1 x}$

Fit parameter： $p_0 = (8.5 \pm 3.0) \times 10^6$
$p_1 = (2.4 \pm 0.9) \times 10^{-8}$
(χ^2/NDF = 0.48)

(※MPPC operation voltage = 54.4 V)

- Rate at beam current 6 mA: ~ 23 MHz
- Saturation is visible in the beam current region above 4 mA, however, beam profiling is possible.

Now, designing the new BPM…
→ Plan to reduce the material thickness and reduce the rate