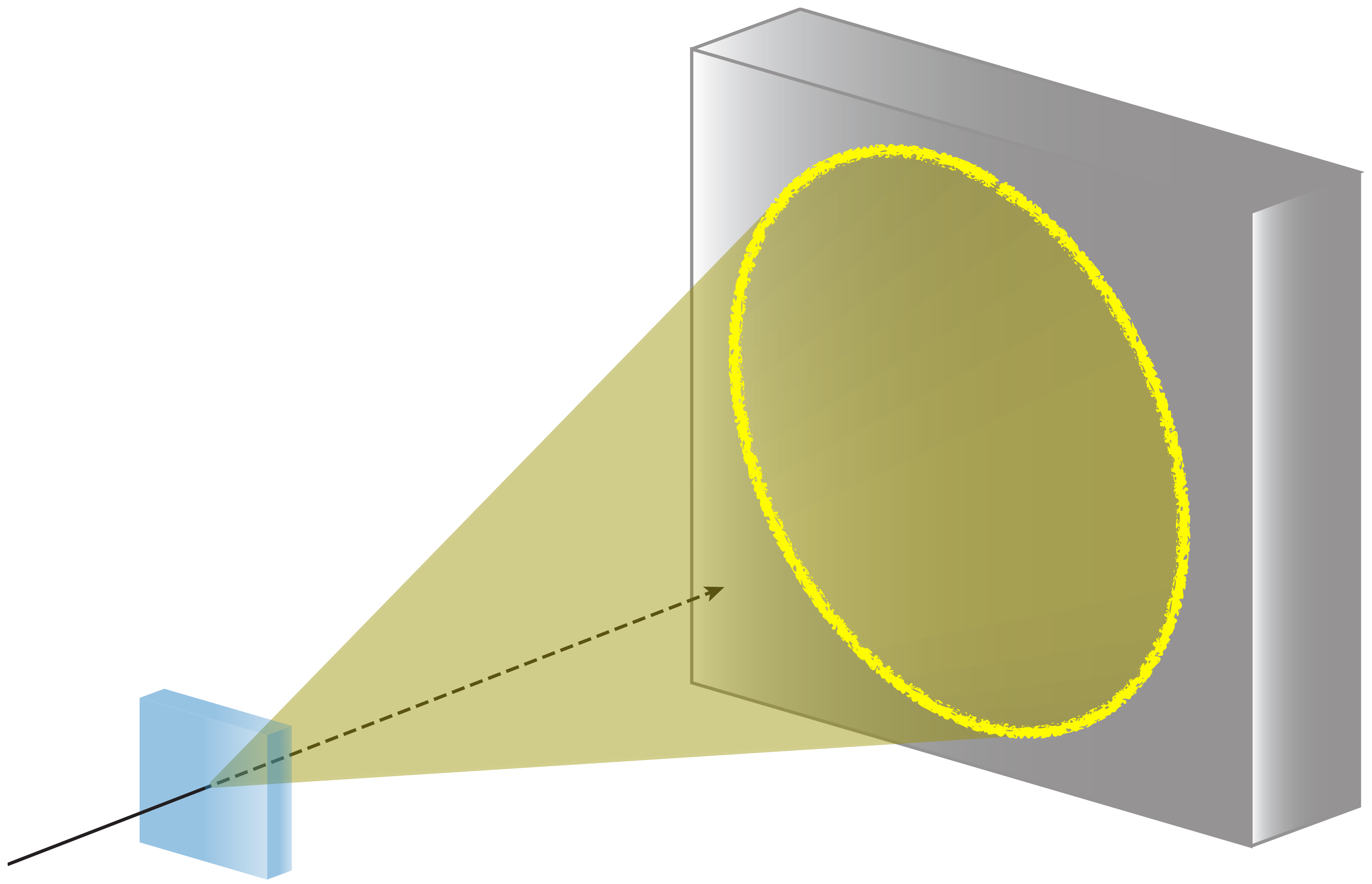
Development of Ring-Imaging Cherenkov Counter for Heavy Ions



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New Facilities and Instrumentation

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Contents

Introduction

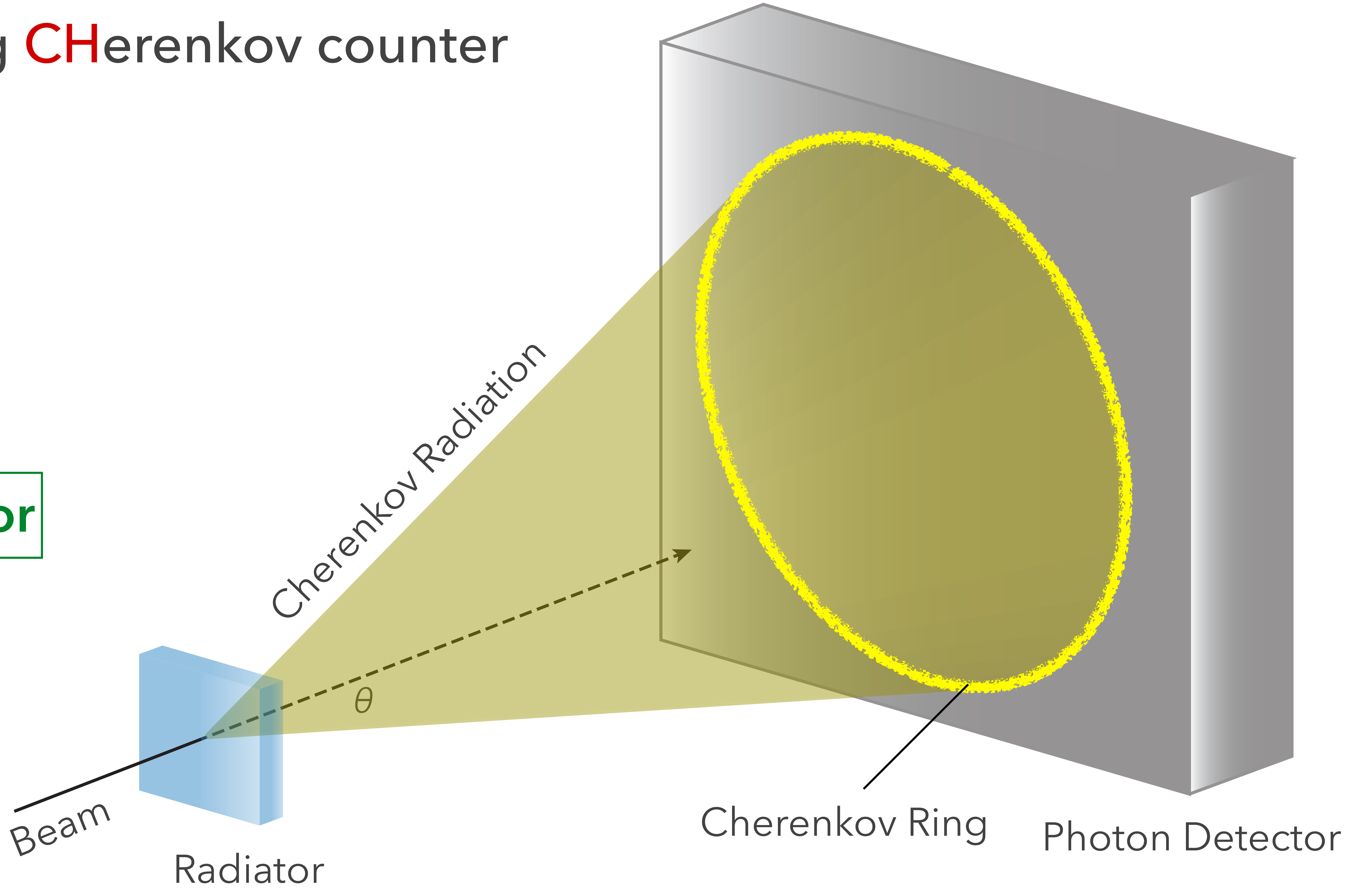
What is a RICH?

RICH: Ring-Imaging CHerenkov counter

$$\boxed{\cos\theta = \frac{1}{n\beta}}$$

n: Refractive index

Velocity detector



Background of RICHes

RICHes have been mainly used for particle physics experiments.

Examples

- **The First RICH tested at CERN**

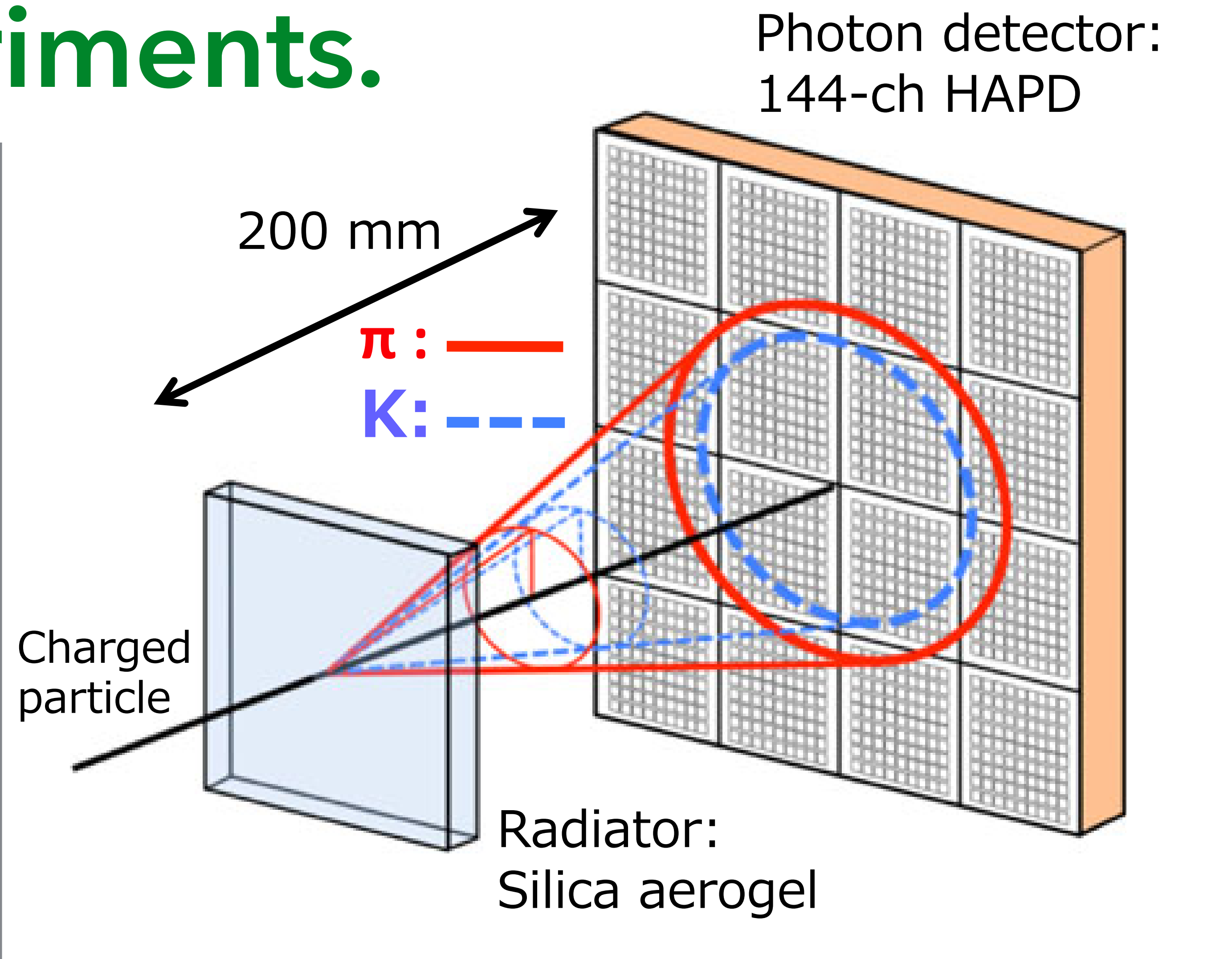
  Performed with the photo-ionization process

  (J. Séguinot and T. Ypsilantis, NIM 142, 377 (1977).)

- **The Aerogel RICH Counter in the KEK Belle II experiment**

  To separate **K** from **π** and to provide discrimination between **π**, **μ** and **e⁻**

  (S. Iwata, et al., PTEP 033H01 (2016).)



Aerogel RICH Counter

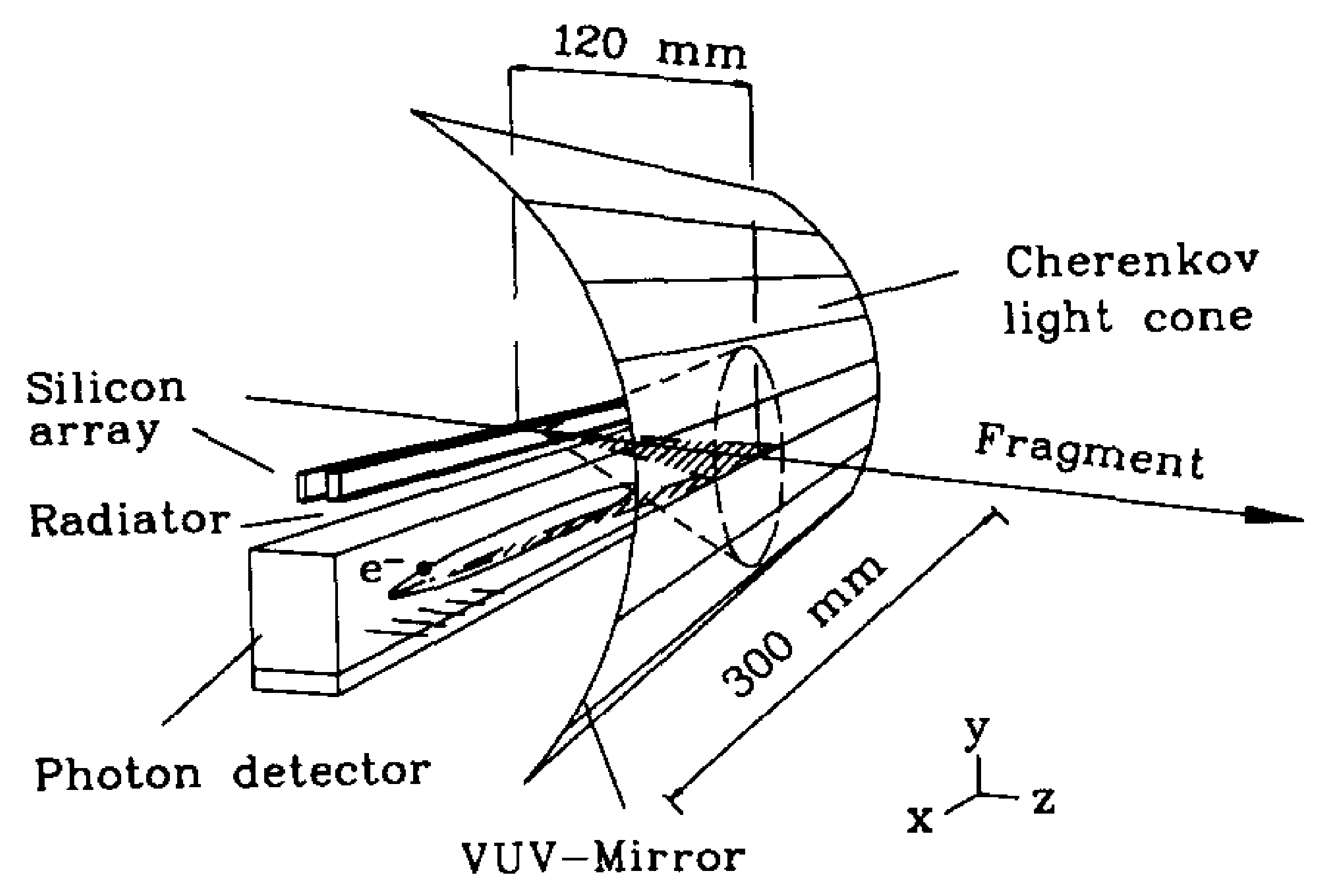
GSI developed a RICH for heavy ions in 1993.

Radiator: Liquid C_6F_{14}

Photon detector: Gas detector with TMAE (tetrakis ethylene)

$\Delta\beta(\sigma)/\beta$ **= 0.077%** with $\beta = 0.8269$ (^{129}Xe) was achieved.

(K. Zeitelhack, et al., NIM A 333, 458 (1993).)



RICH of GSI (1993)

Motivation and Advantages of a RICH for Heavy ions

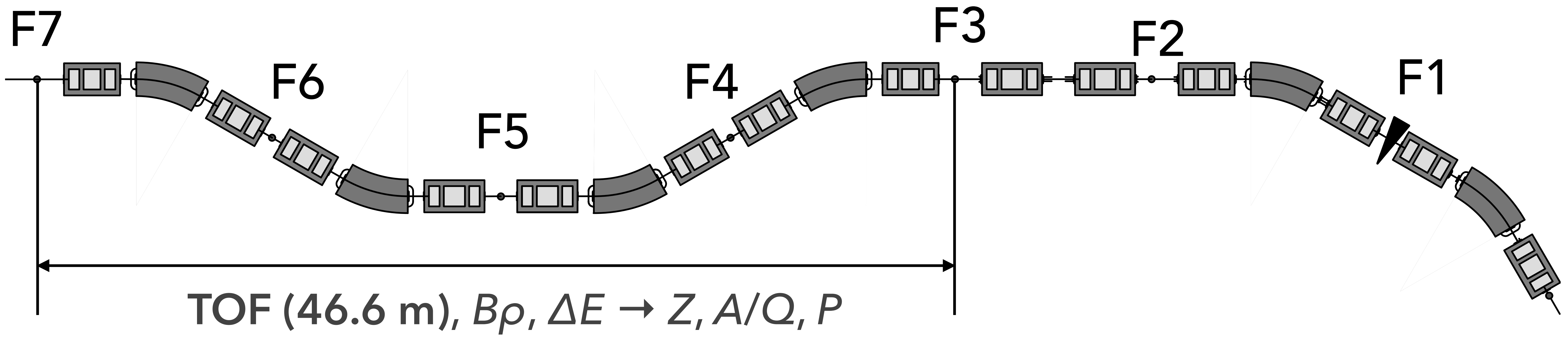
The conventional method: Time-of-flight (TOF) measurement

but

TOF measurement with high accuracy requires very long flight paths.

It requires **30 m** to obtain velocity resolution for **5.0σ** separation of mass number **A = 100** with detectors of σ = 100 ps. (with $\boldsymbol{\beta}$ **= 0.7**)

Our RICH for Heavy ions (HI-RICH) → **High precision, compact** and **low-cost detector**



A schematic view of BIgRIPS beam line at RIKEN

(T. Tubo, et al., NIM B 204, 97 (2003).)

Aims of the experiment

1. To develop HI-RICH which has sufficient performance for "particle identification" of the secondary beam

2. To understand tendencies of velocity resolution and detection efficiency

5.0σ separation of mass number A = 132

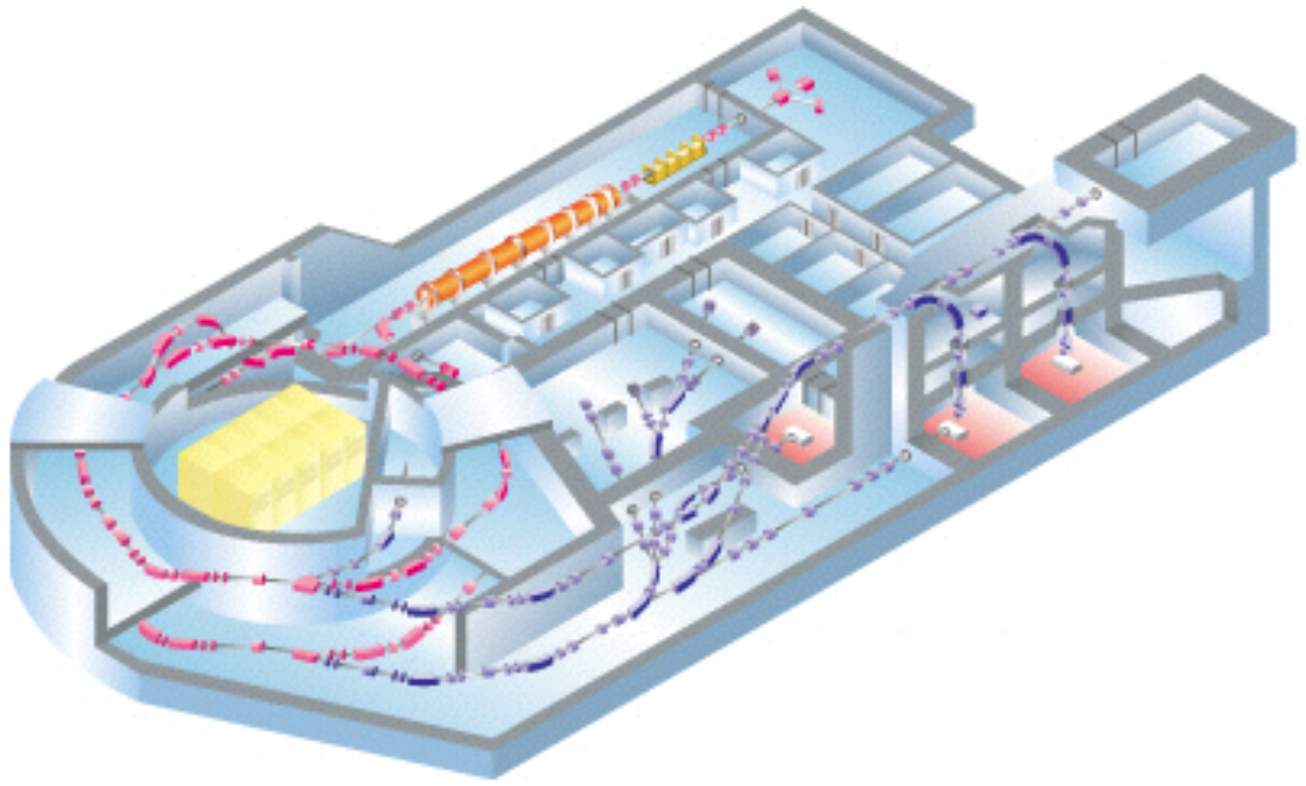
||

Velocity resolution **$\Delta\beta(\sigma)/\beta$ = 0.075%** with β = 0.71

Experimental Methods

Accelerator and Beam Line

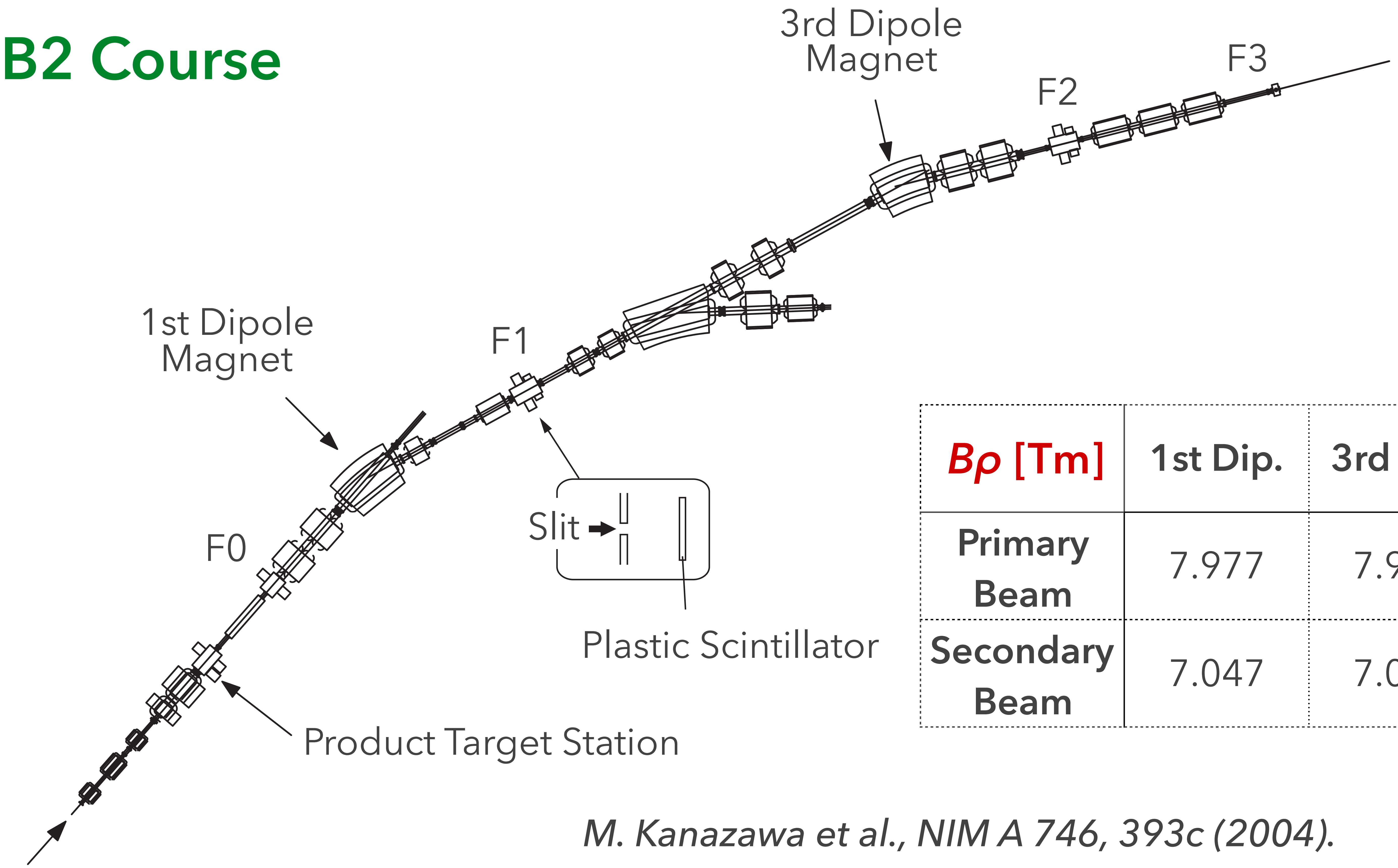
National Institute of Radiological Sciences



HIMAC (Accelerator)

- Accelerator for Heavy ions
- Synchrotron
- 800 MeV/u (Max.)

SB2 Course



Bρ [Tm]	1st Dip.	3rd Dip.
Primary Beam	7.977	7.938
Secondary Beam	7.047	7.008

M. Kanazawa et al., NIM A 746, 393c (2004).

S. Yamaki et al., NIM B 317, 774 (2013).

Primary Beam: $^{132}Xe^{54+}$ 420 MeV/u

Secondary Beam: $^{113}Sn^{50+}$ 390 MeV/u (typical nuclide)

Experimental Setup (Unit: mm)

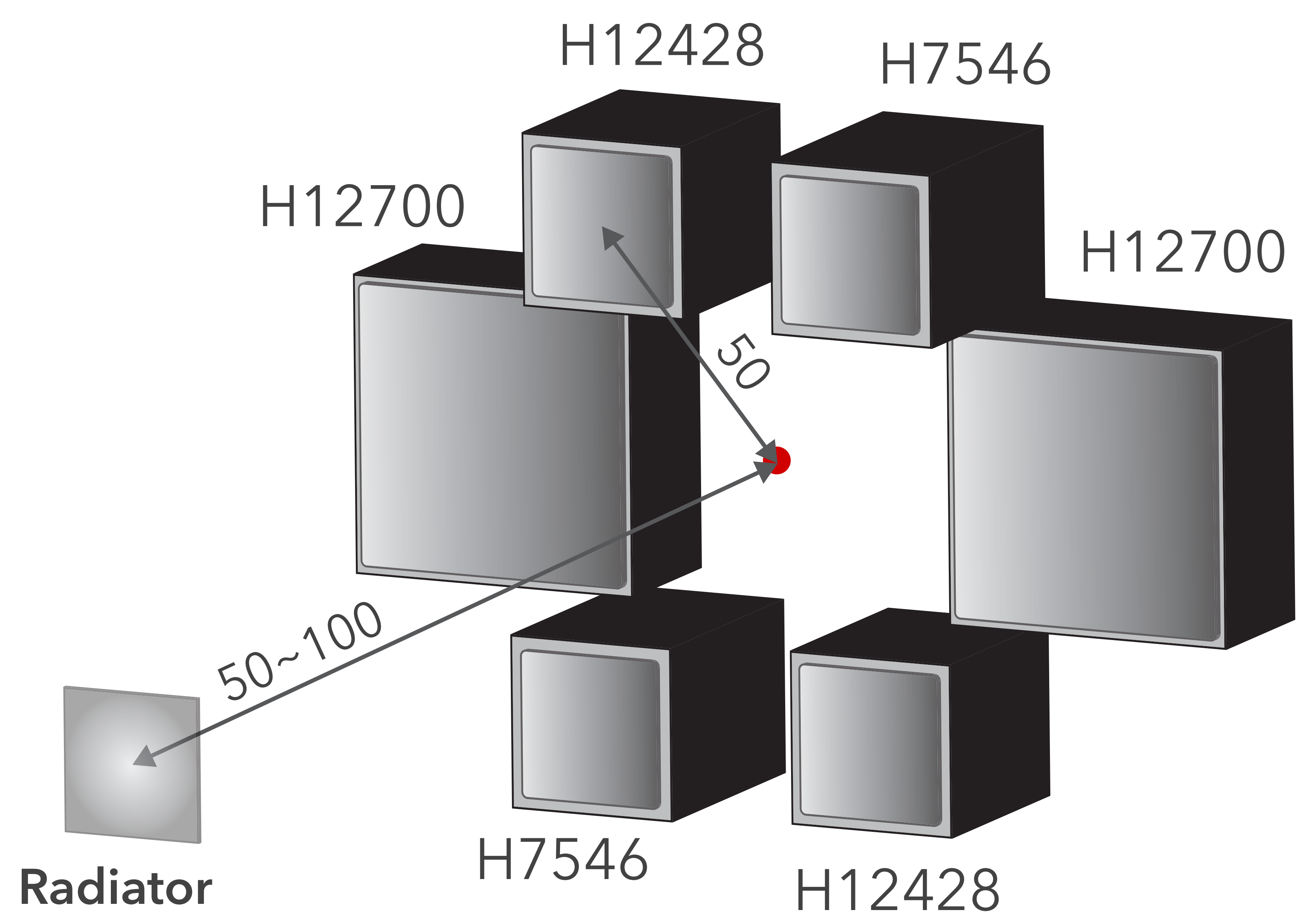
HI-RICH

8×8 Multi-anode PMT × 6 → **384 channels**
(manufactured by **HAMAMATSU**)

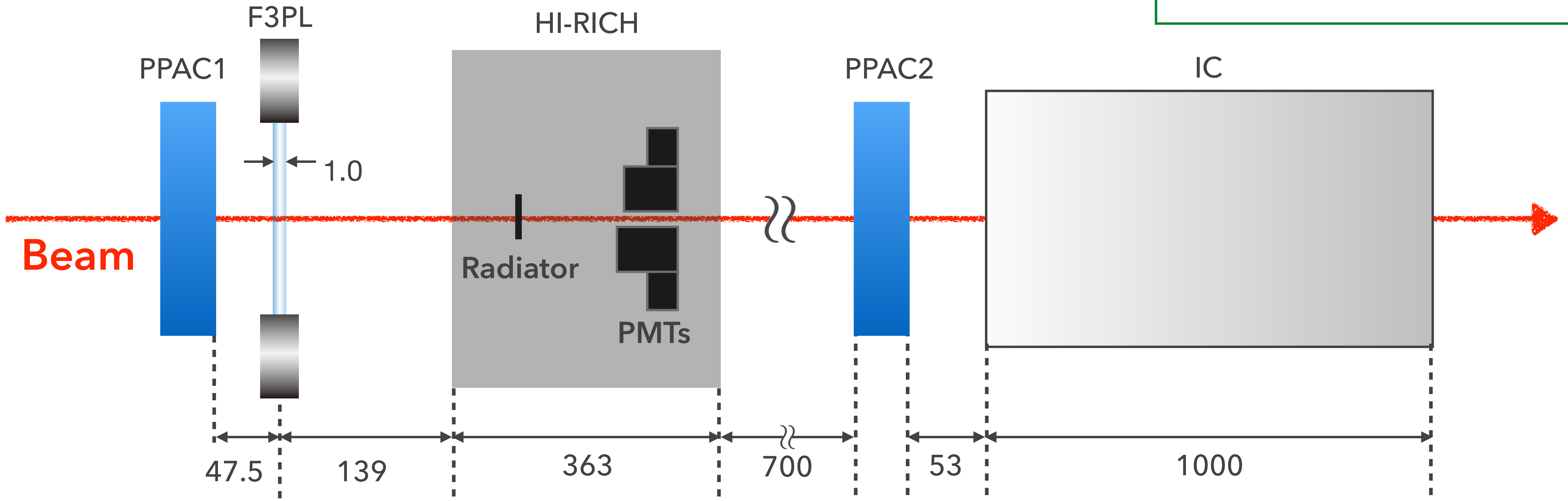
F3PL: Plastic Scintillator (**common trigger**)

IC: Ion Chamber (**Δ*E* detector**)

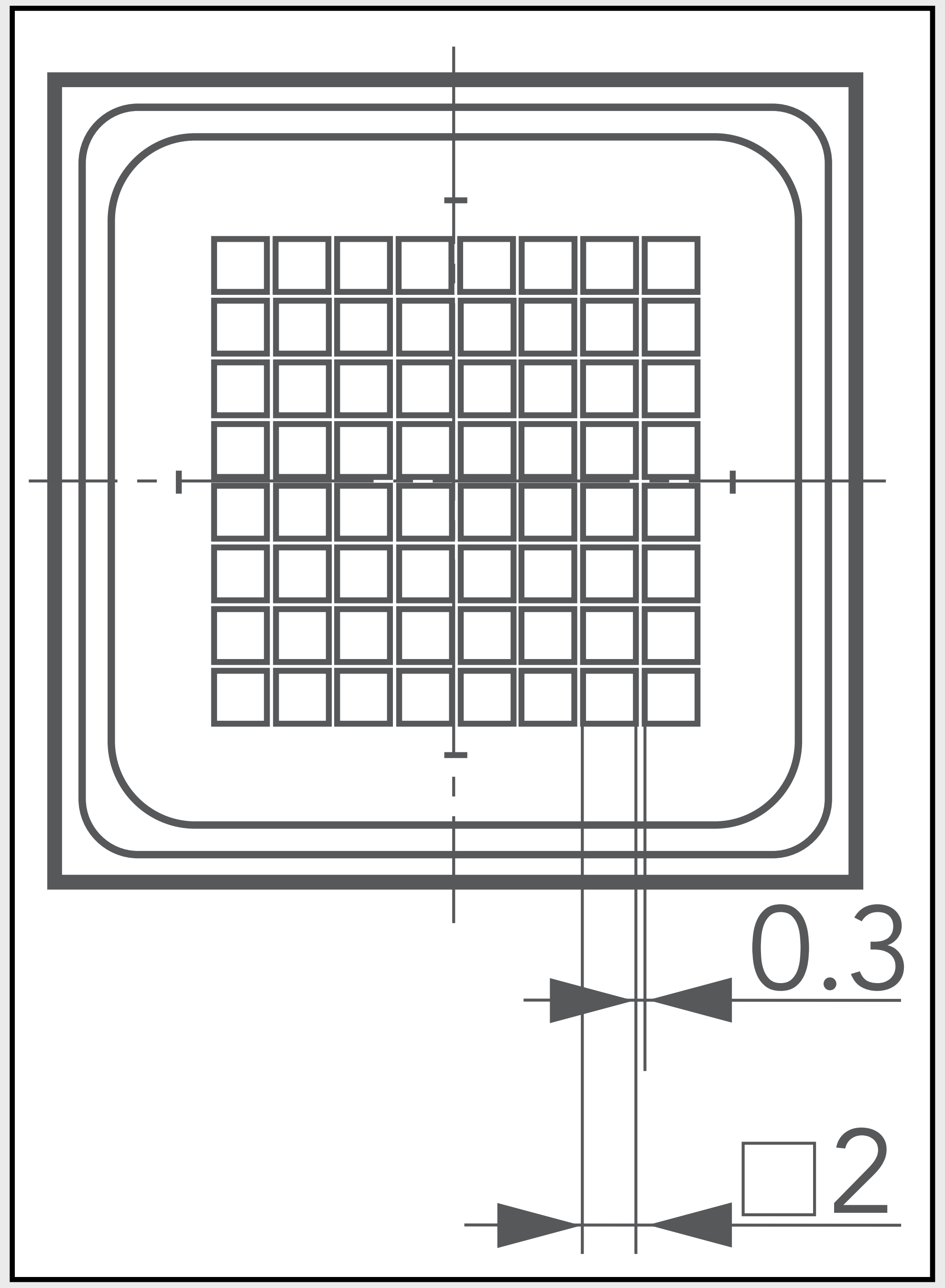
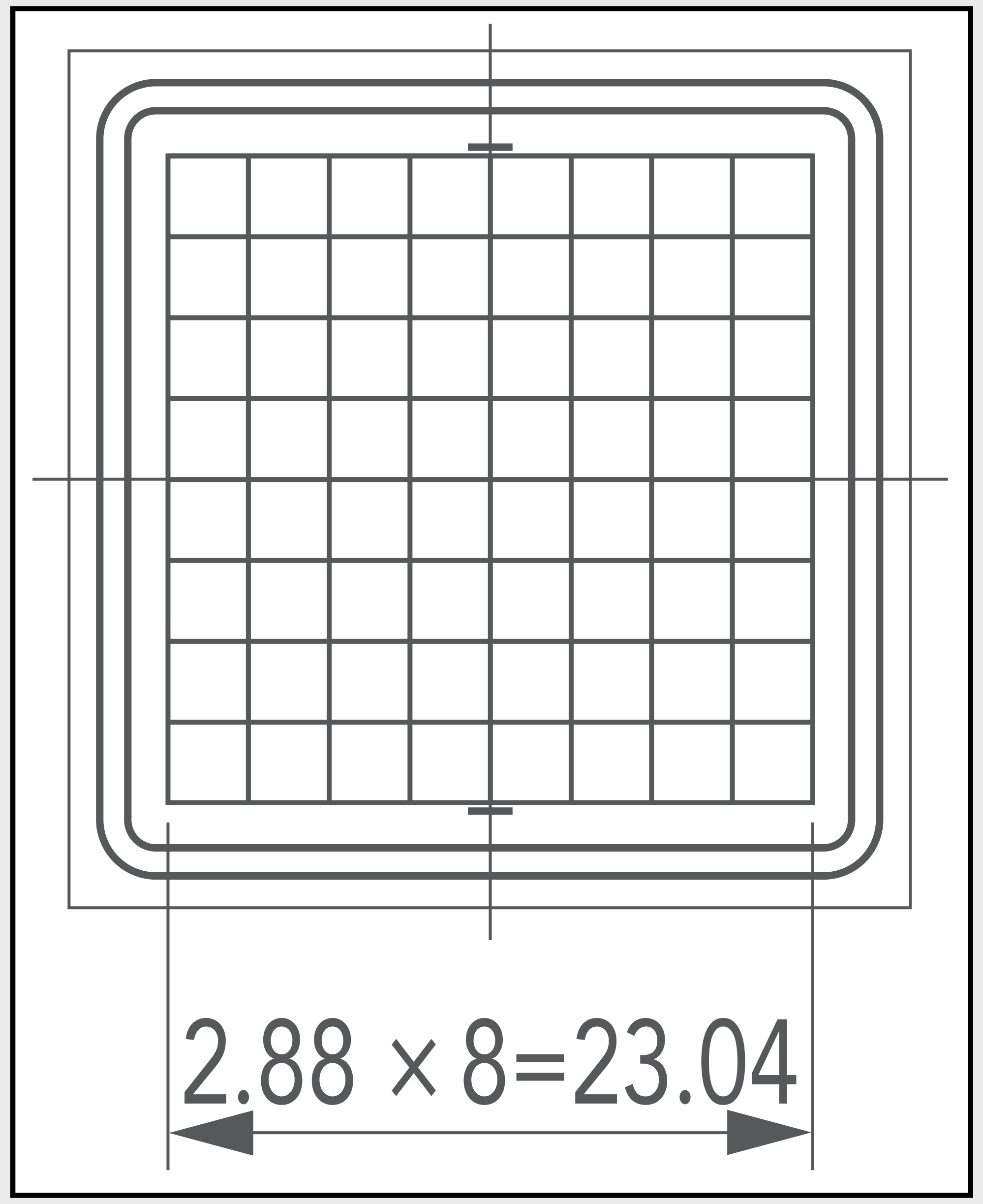
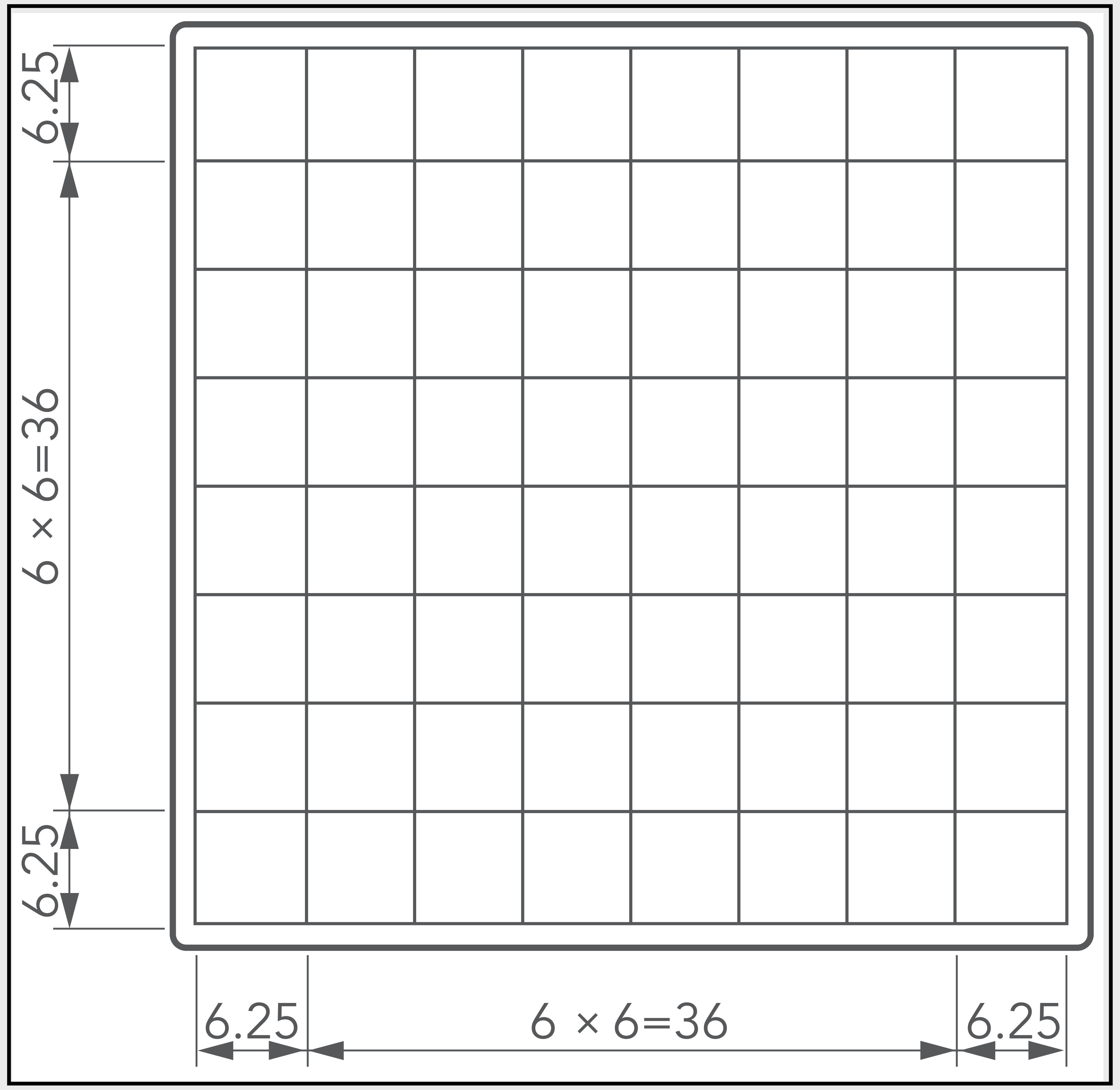
PPAC: Parallel Plate Avalanche Counter (**position detector**)



A schematic view of HI-RICH



PMTs' Pixels and Quantum Efficiency (QE)

<table>
<tr><th></th><th>H7546A-203</th><th>H12428A-203</th><th>H12700A</th></tr>
<tr><td>Max. QE
(@ Peak Wavelength)</td><td>43% (@ 350 nm)</td><td>43% (@ 350 nm)</td><td>33% (@ 350nm)</td></tr>
<tr><td>Pixels
(Unit: mm)</td><td>
</td><td>
</td><td>
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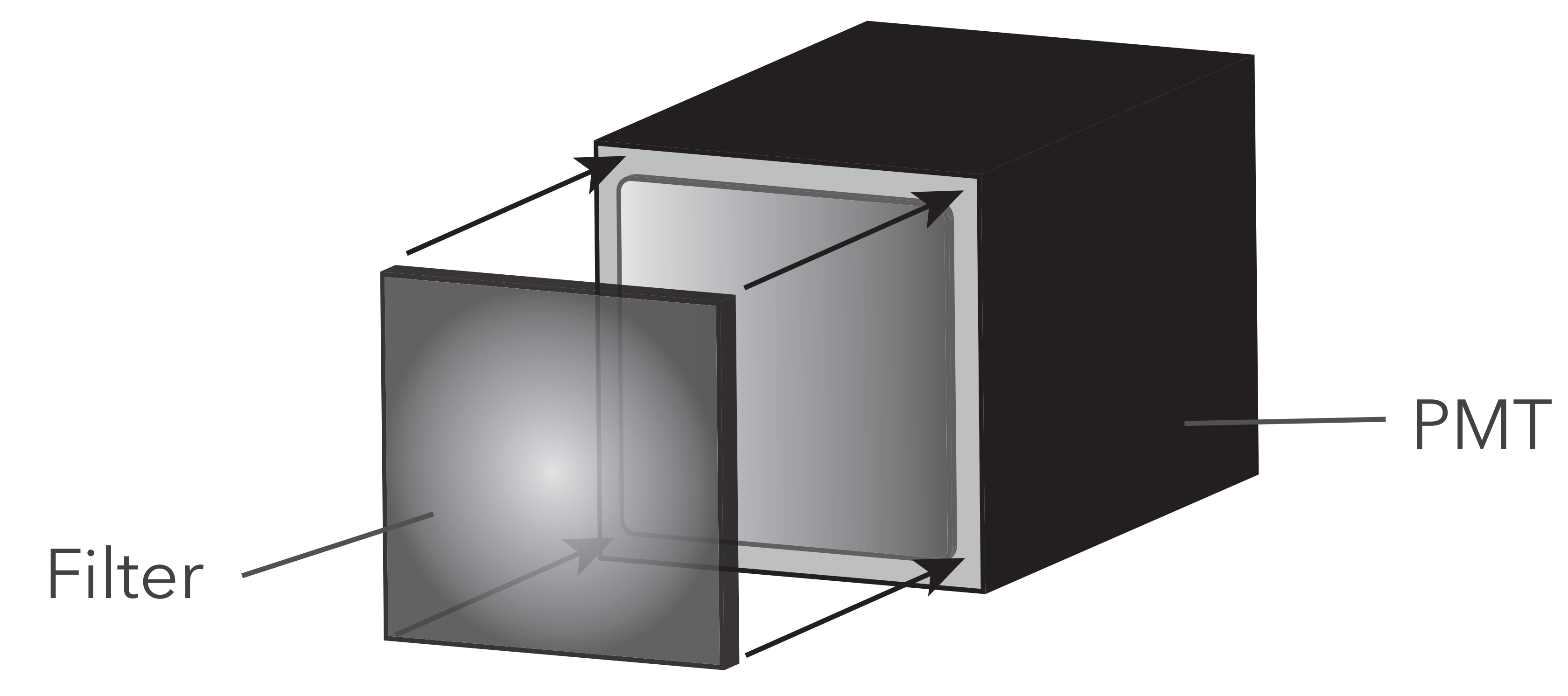
Radiators, Filters and Circuits of HI-RICH

Radiators

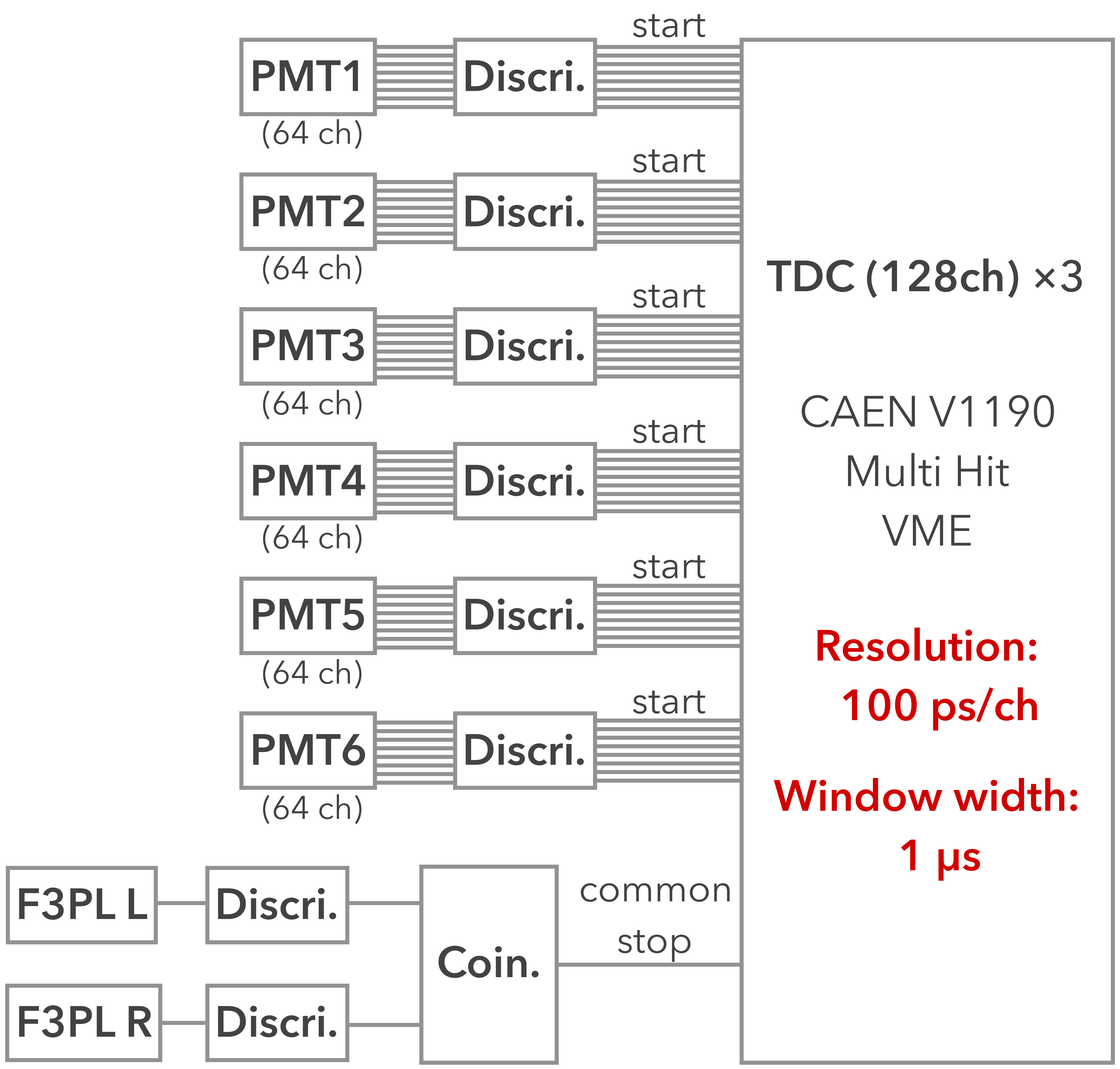
- Synthetic quartz (SiO_2) (n = 1.48)
  - 25 mm × 25 mm × 0.48 mmt
  - 25 mm × 25 mm × 0.95 mmt
- BK7 (n = 1.54)
  - 20 mm × 20 mm × 1.06 mmt

Filters (Edmund UV U-360)

- U360 Band Pass Filter
  - The center of wavelength: 360 nm
  - Peak transmission: 70%
  - Thickness: 2.5 mmt



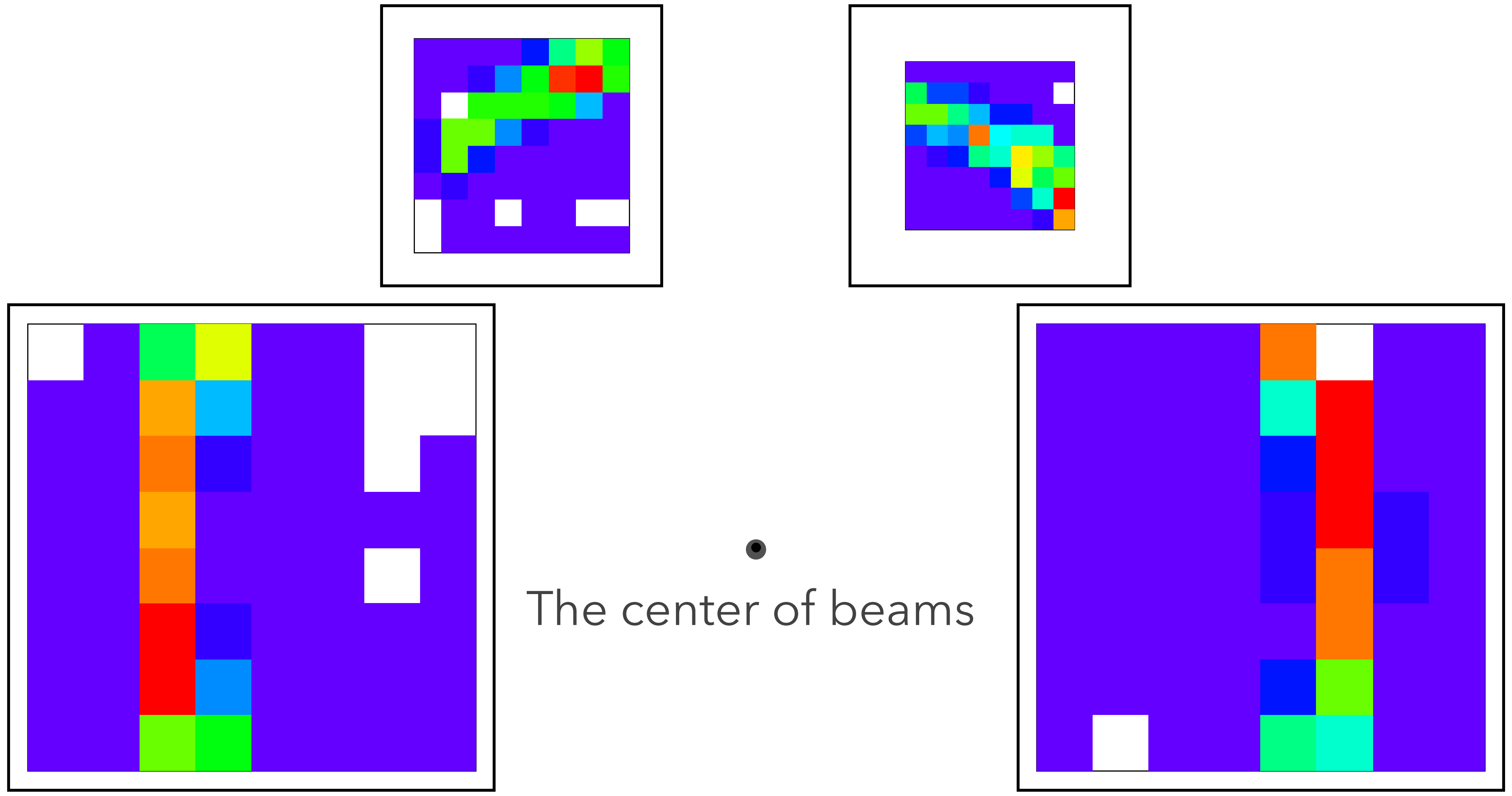
Circuit Diagram



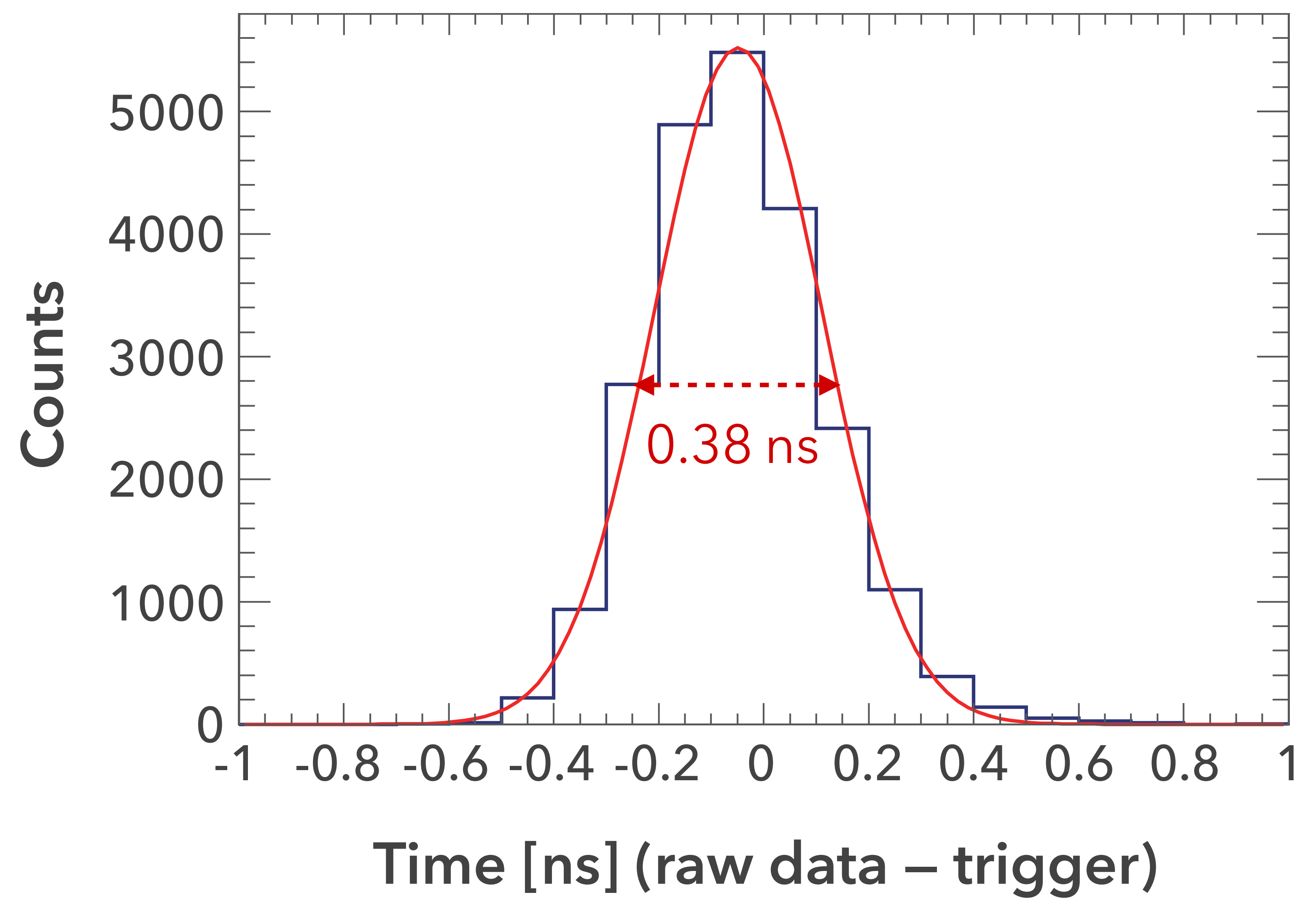
Results & Discussion

Results

Results of the **primary beam** with a radiator (**SiO_2**) thickness of **0.48 mmt** are shown below as an example.



Detected Cherenkov photons (all events)



Time spectrum of a channel (all events)

T.T.S. (FWHM) = 0.35 ns (catalog value)

(T.T.S.: Transit Time Spread of PMTs)

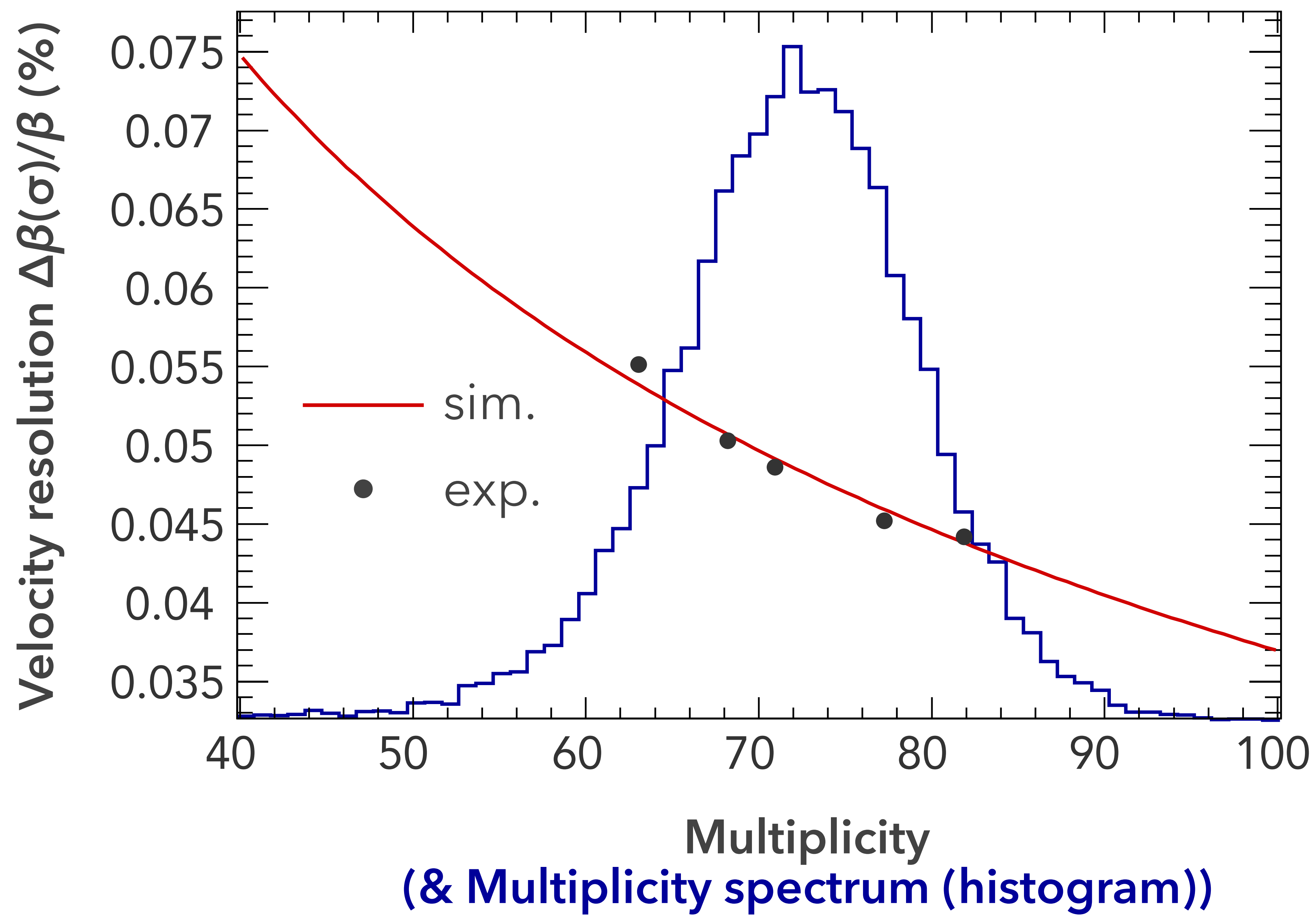
Simulation

Considered fluctuation:

1. Energy loss of beams in a radiator
2. Angles of emitted photons by dispersion of wavelength
3. Positions of emitted photons in a radiator

The number of photoelectrons were considered as Poisson distribution.

If a photoelectron reached a position of a PMT channel, the channel was considered to be hit. This process was repeated with all photoelectrons.



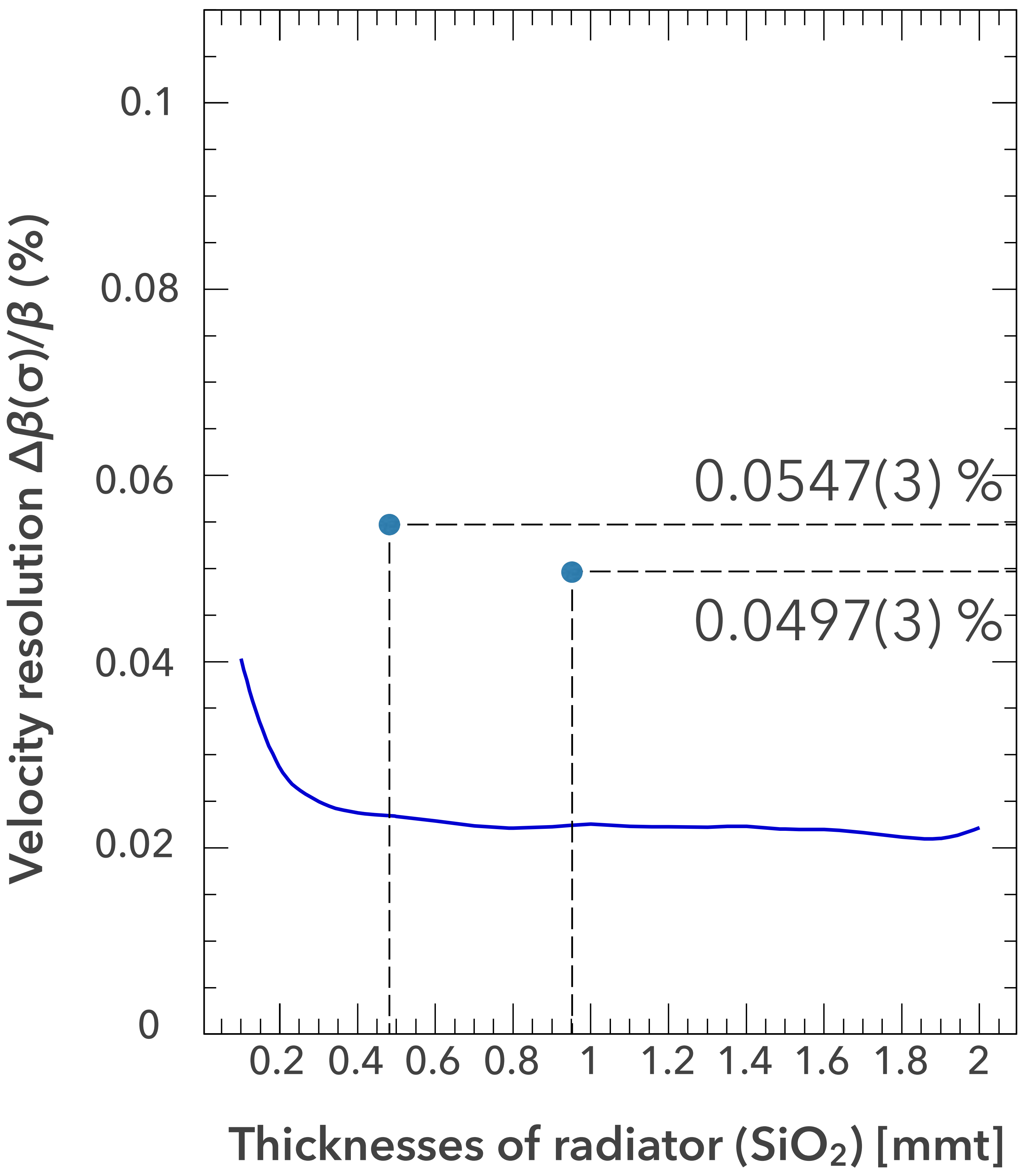
Multiplicity

= The number of hit channels in an event.

A comparison of multiplicity dependence of velocity resolution between sim. and exp. of the primary beam.

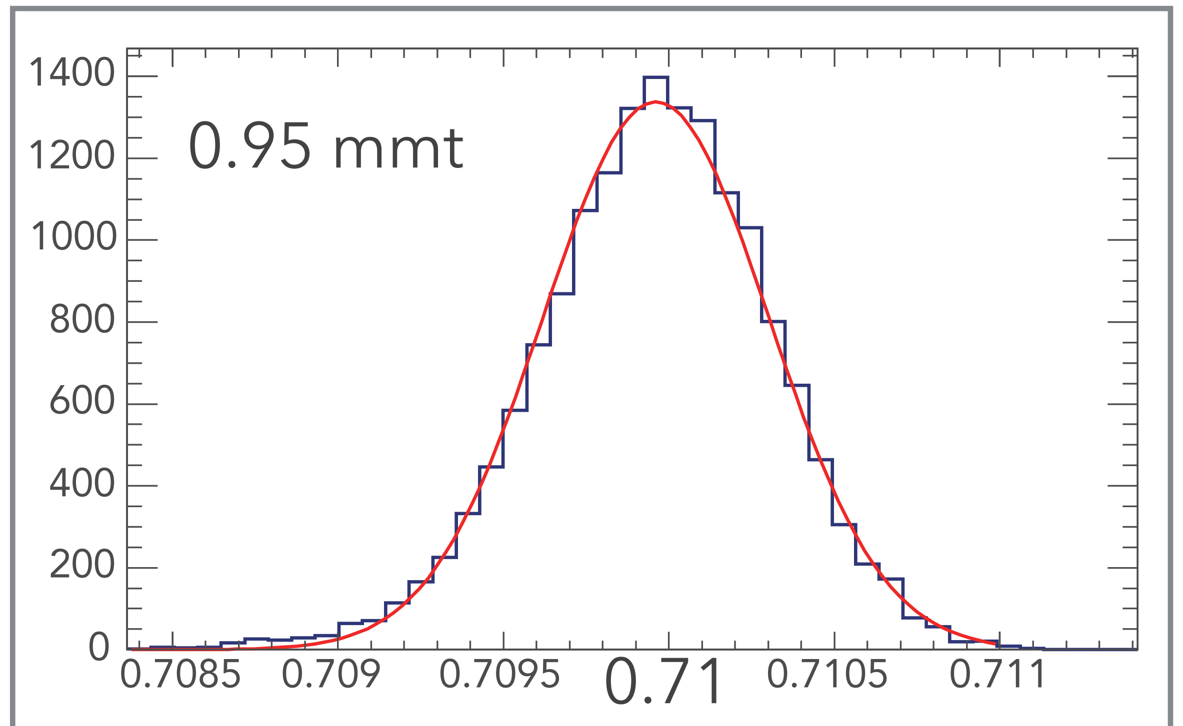
Some events were selected by each multiplicity gate.

Primary Beam ($^{132}Xe^{54+}$ 420 MeV/u)



(Simulated Detection efficiency ε = 100%)

	0.48 mmt	0.95 mmt
$\Delta\beta(\sigma)/\beta$ (%)	0.0547(3)	**0.0497(3)**
ε (%)	99.39(6)	99.86(3)



The spectrum of β

- **Experiment**
- **Simulation**

($N_{p.e.}$ (with 0.95 mmt) = 1400 ←theory)

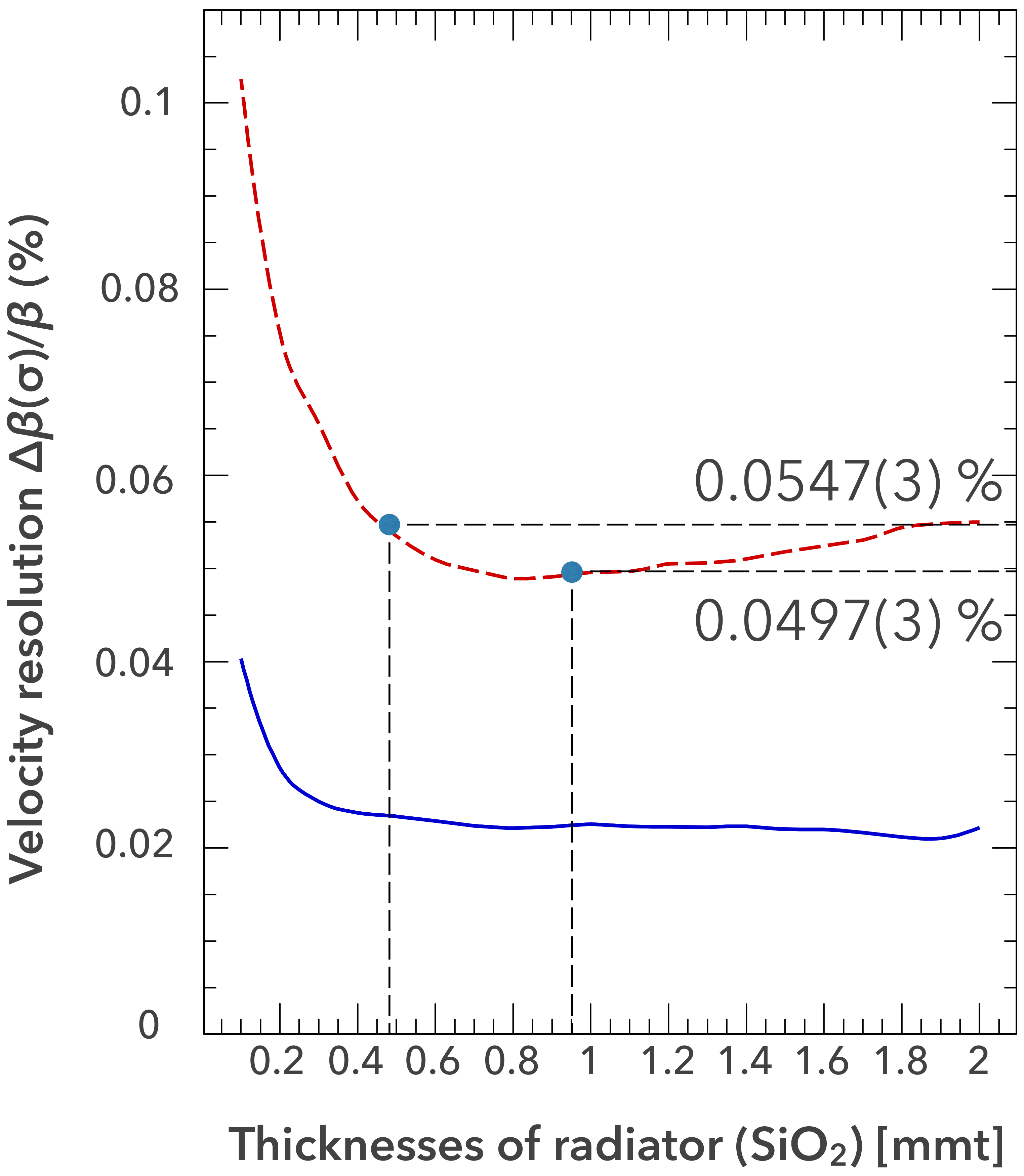
$$N_{p.e.} = N_{photon} \times \varepsilon_{filter} \times QE$$

$N_{p.e.}$ = the number of photoelectrons
N_{photon} = the number of photons
ε_{filter} = transmission of the filter
QE = quantum efficiency

$$\frac{dN_{photon}}{d\lambda dx} \propto \frac{Z^2 \sin^2\theta_C}{\lambda^2}$$

Z = atomic number
θ_C = radiation angle

Primary Beam ($^{132}Xe^{54+}$ 420 MeV/u)



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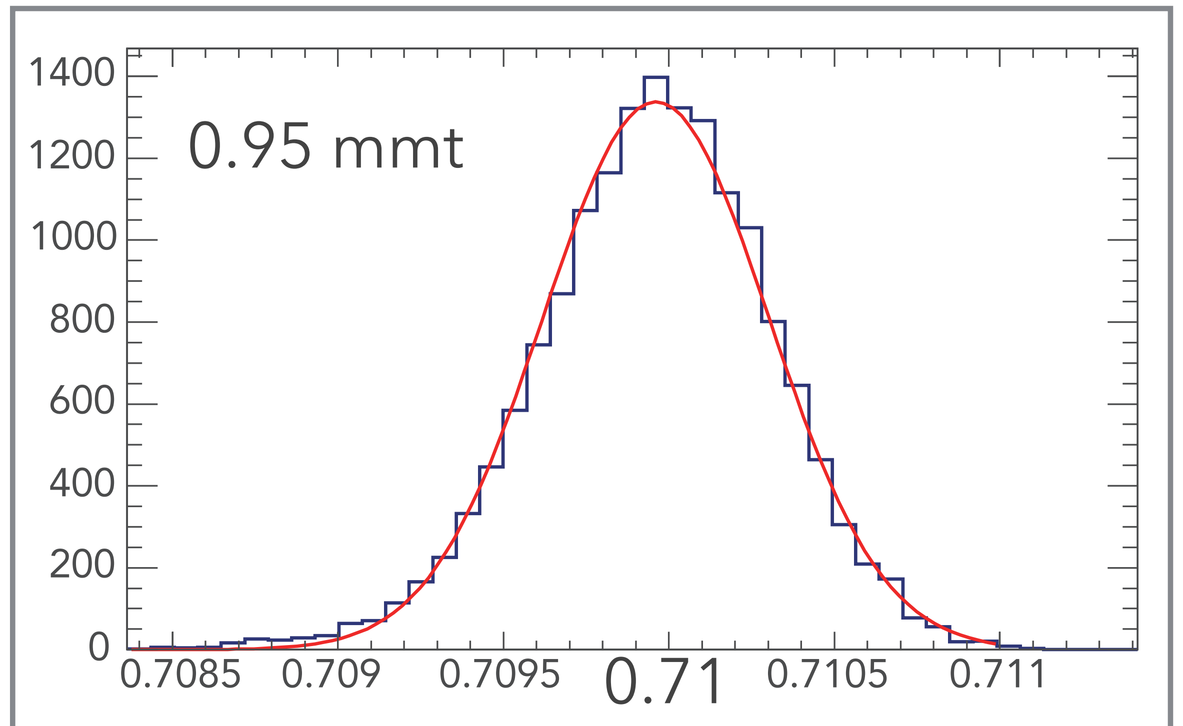

The spectrum of β

- **Experiment**
- **Simulation** ($N_{p.e.}$ (with 0.95 mmt) = 1400 ←theory)
- **Simulation** ($N_{p.e.}$ (with 0.95 mmt) = 230 ←real)

$$N_{p.e.} = N_{photon} \times \varepsilon_{filter} \times QE$$

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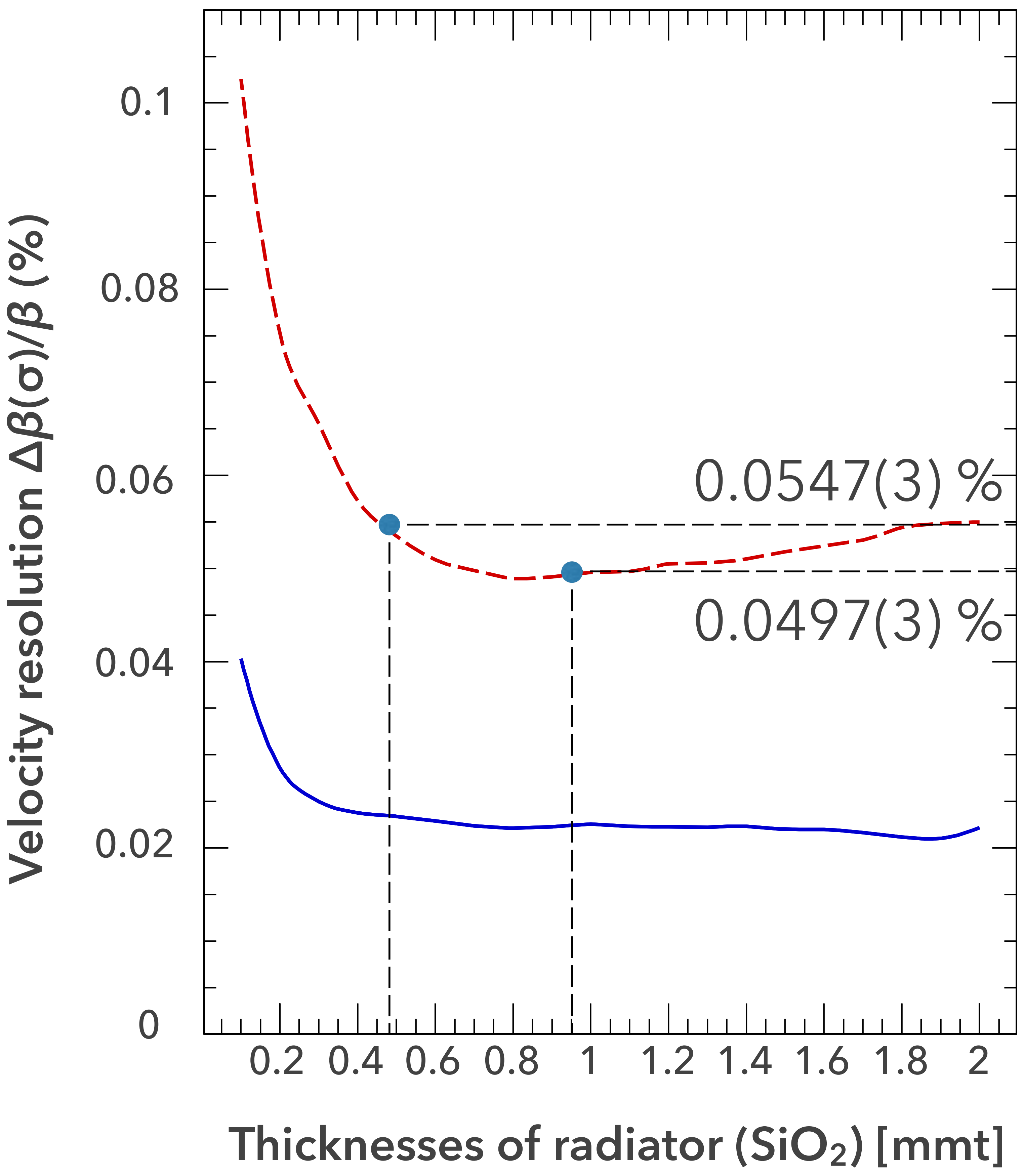

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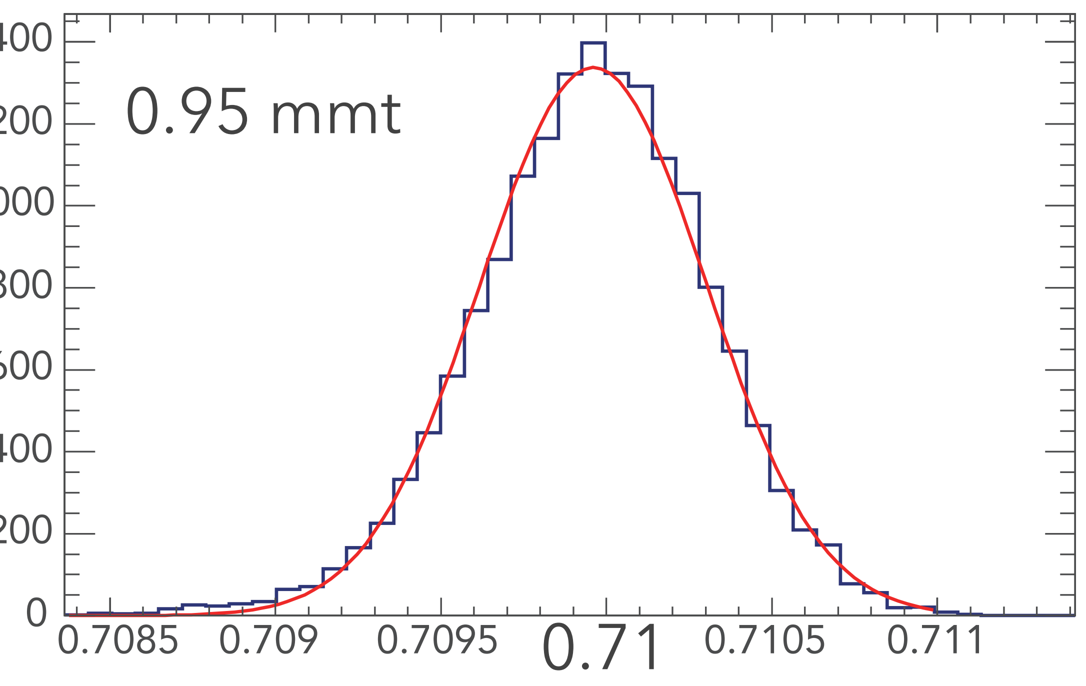

The spectrum of β

- **Experiment**
- **Simulation** ($N_{p.e.}$ (with 0.95 mmt) = 1400 ←theory)
- **Simulation** ($N_{p.e.}$ (with 0.95 mmt) = 230 ←real)

$$N_{p.e.} = N_{photon} \times \varepsilon_{filter} \times QE$$

$N_{p.e.}$ = the number of photoelectrons
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ε_{filter} = transmission of the filter
QE = quantum efficiency

$$\frac{dN_{photon}}{d\lambda dx} \propto \frac{Z^2 \sin^2 \theta_C}{\lambda^2}$$

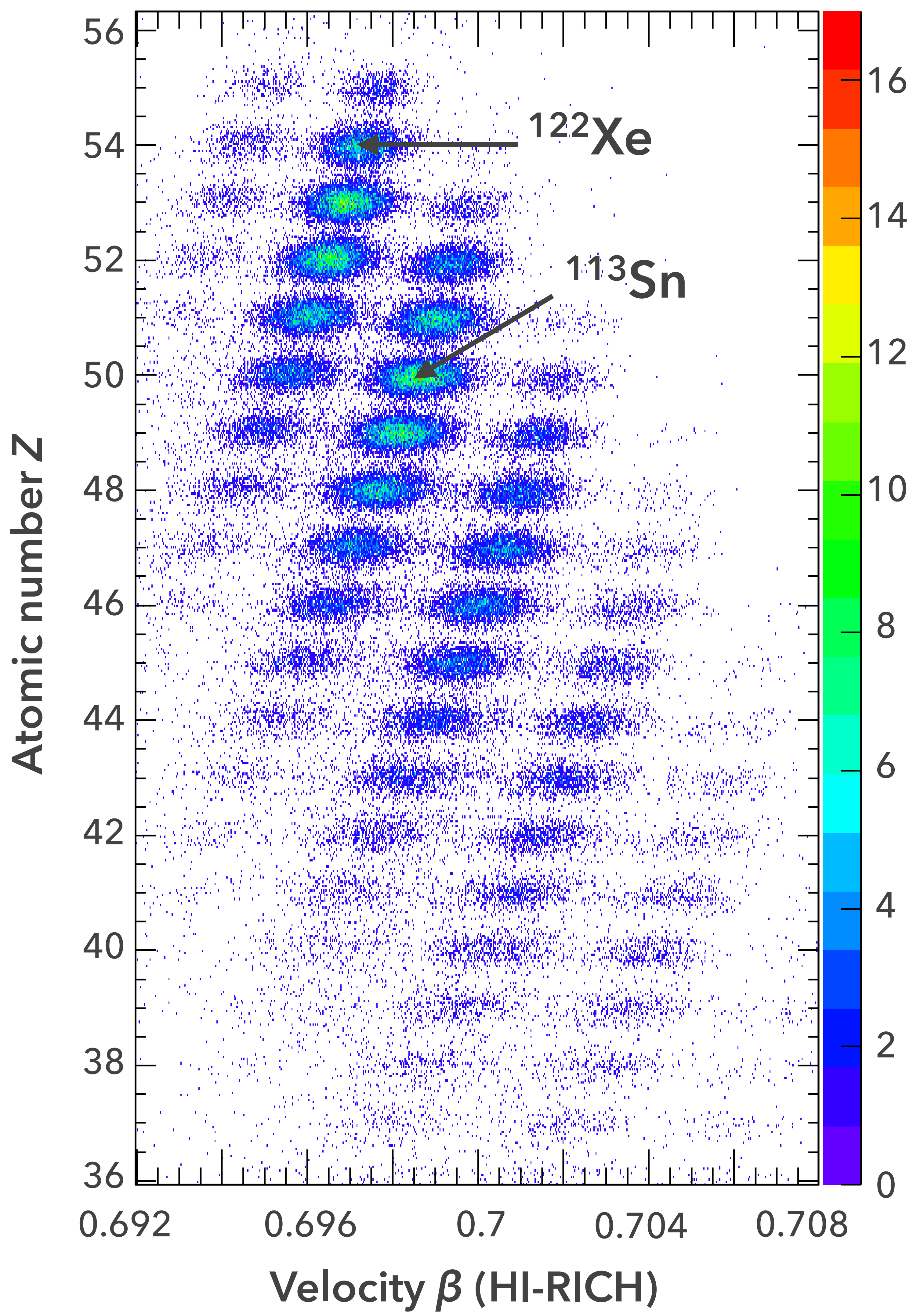
Z = atomic number
θ_C = radiation angle

$\Delta\beta(\sigma)/\beta$ = 0.050% is achieved! (β = 0.71)

|| **equivalent**

60 meters TOF with σ = 100 ps

Secondary Beam ($^{132}Xe^{54+}$ 420 MeV/u + Be target 2mm)



PID with the HI-RICH and Ion Chamber

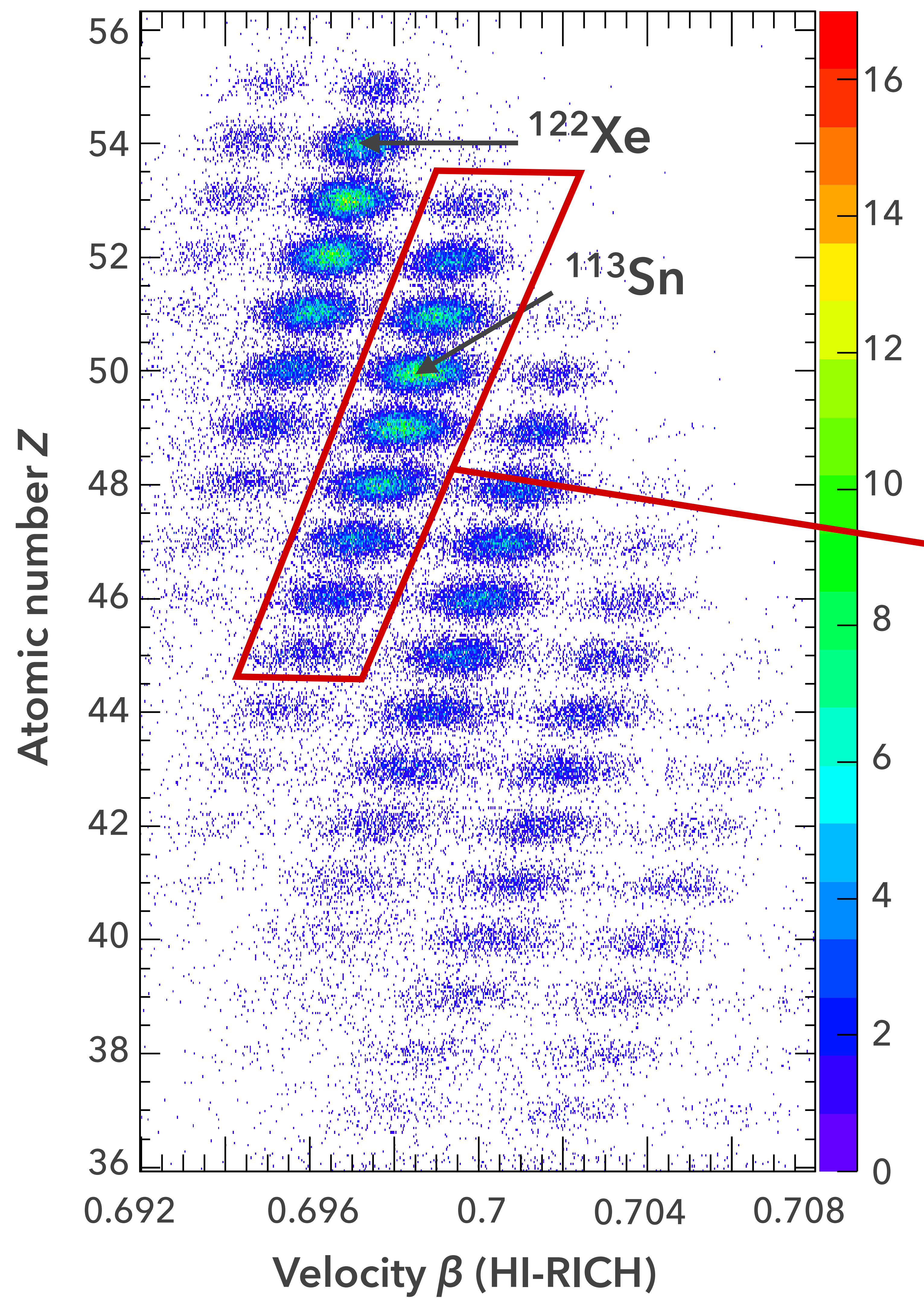
Radiator: BK7 1.06 mmt

^{113}Sn: $\Delta\beta(\sigma)/\beta$ = 0.086(1)%

||

5.3σ separation of mass number A = 113

Secondary Beam ($^{132}Xe^{54+}$ 420 MeV/u + Be target 2mm)



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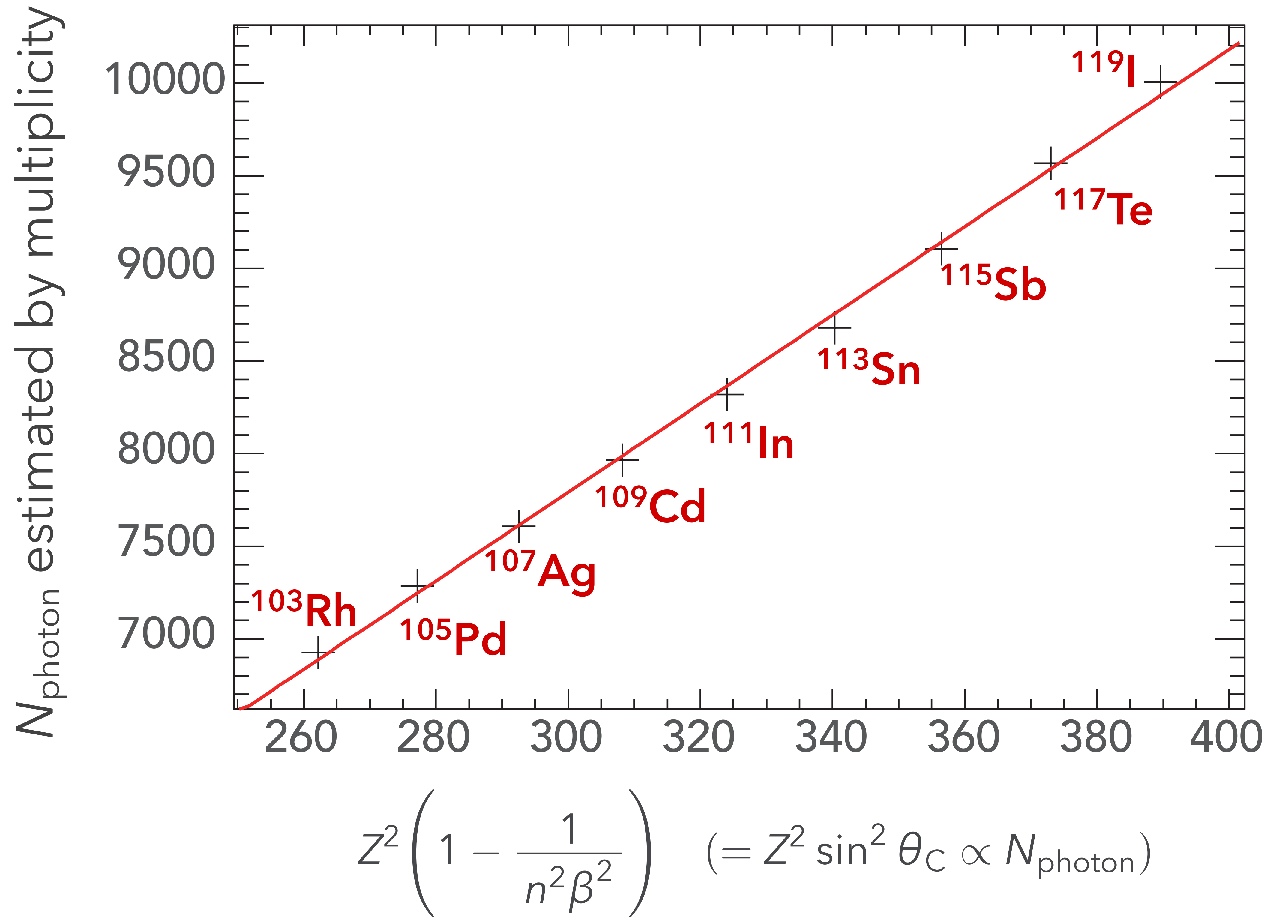

Summary

Experiment

- The experiment was Performed at **NIRS.**
- Primary beam was **420 MeV/u $^{132}Xe^{54+}$** beam.
- In the secondary beam, the target of material was 2 mm-thick Be.

Results and Discussion

- Multiplicity dependence of velocity resolution is well reproduced by the simulation.
- In the primary beam, **$\Delta\beta(\sigma)/\beta$ = 0.050%** and **ε = 99.9%** are achieved with $\beta = 0.71$ for primary beam.
- In the secondary beam, particle identification was successfully performed with HI-RICH and Ion Chamber.