MEG II 実験のための
陽電子タイミングカウンターの開発
PSIでのハイレートビーム試験

Development of Positron Timing Counter with SiPM for MEG-II Experiment
Beam Test Result in the high rate environment at PSI

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Physics Motivation

- Search for cLFV (charged lepton flavor violation), $\mu^+ \rightarrow e^+\gamma$ decay
  - Forbidden in the SM
  - Sizable branching ratio is expected by many bSMs
- Most stringent upper limit of the branching ration is set by the MEG experiment;

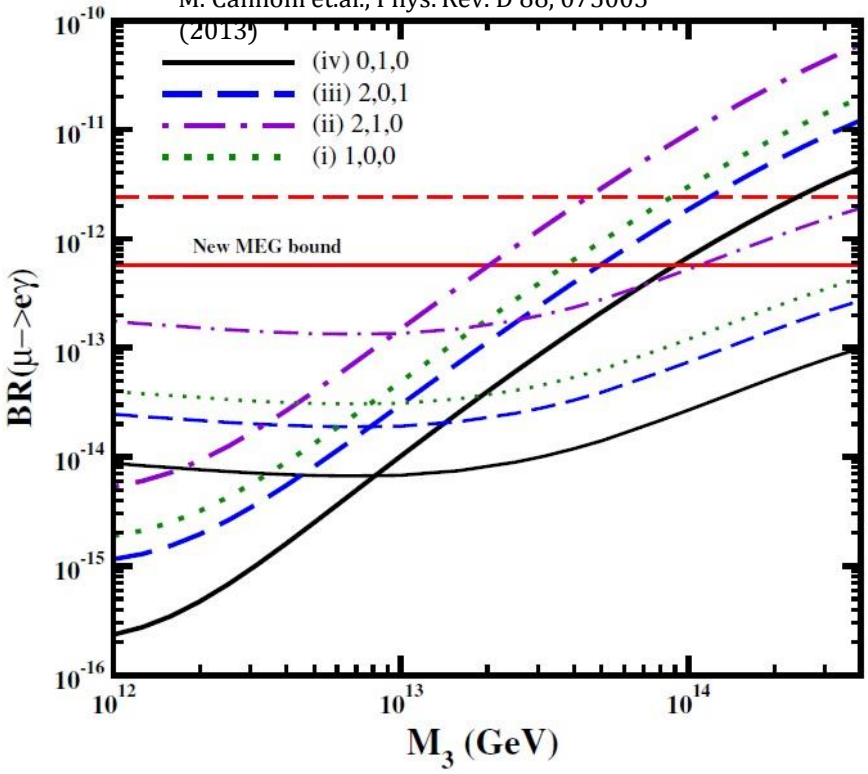
$$\mathbf{5.7 \times 10^{-13}}\ 90\%\ \text{C.L.}$$

(Phys. Rev. Lett. 110(2013) 201801)

Already started exploring bSM region!

An example, the expectation of the BR from SU(5) SUSY-GUT

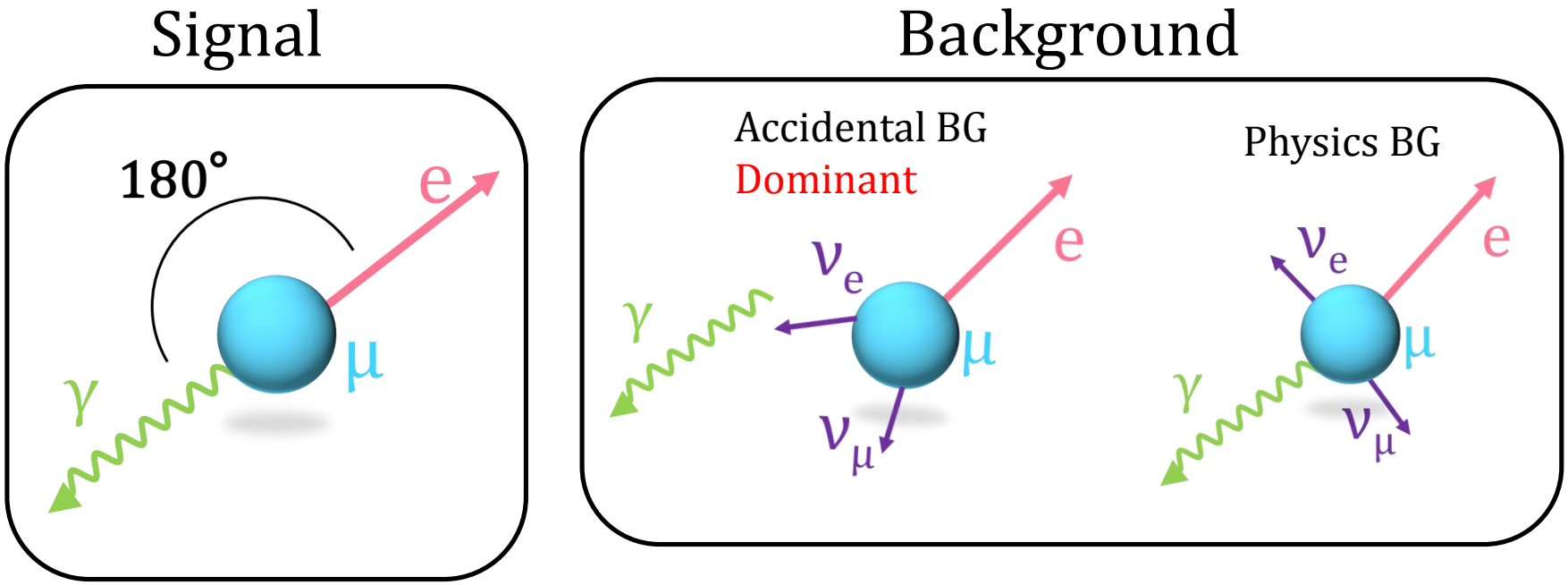
M. Cannoni et.al., Phys. Rev. D 88, 075005 (2013)



Mass of right handed neutrino

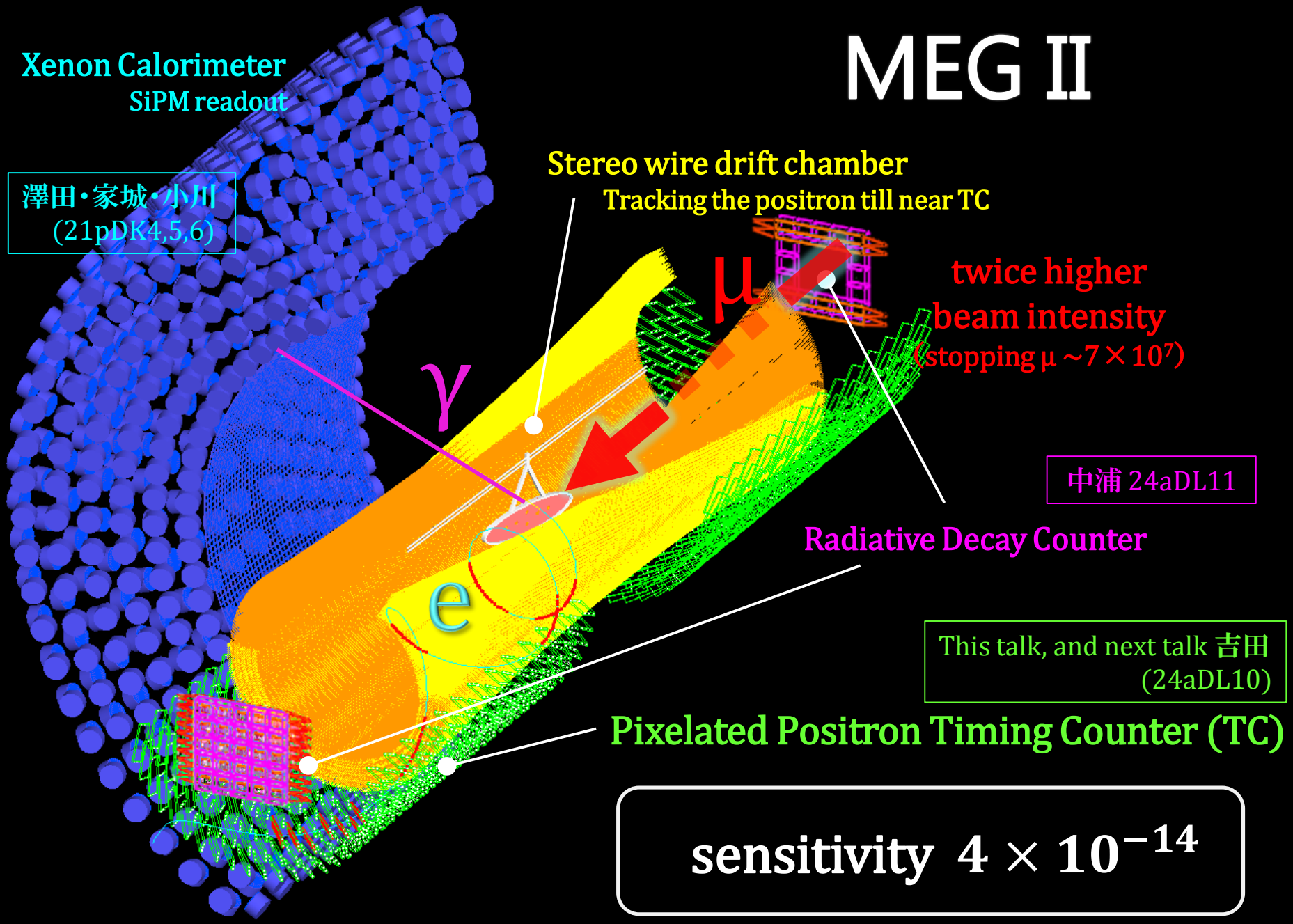
⇨ Upgrade MEG experiment (MEG II)

What should we measure?



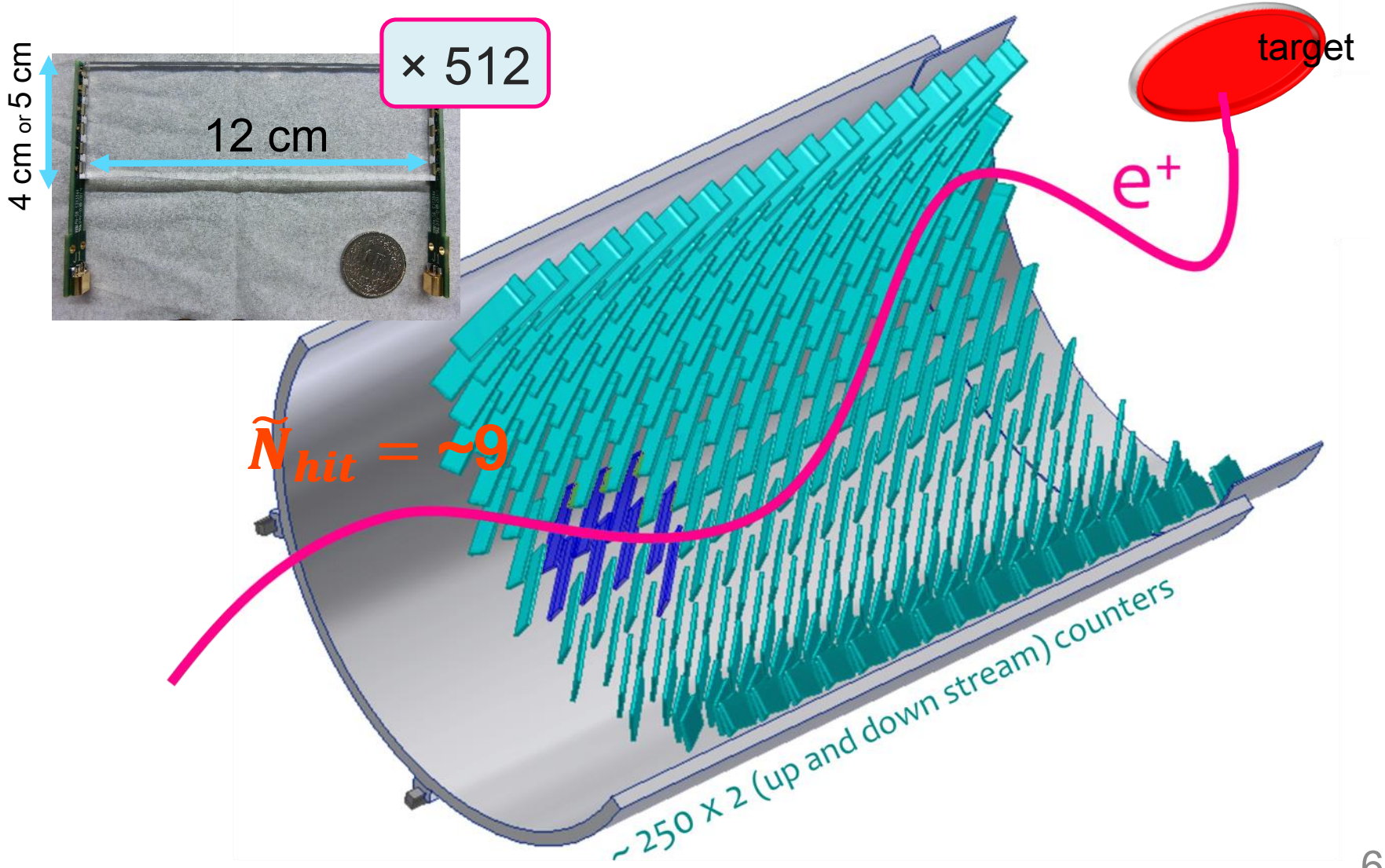
We should measure
Timing・ Position・ Momentum precisely.

MEG II

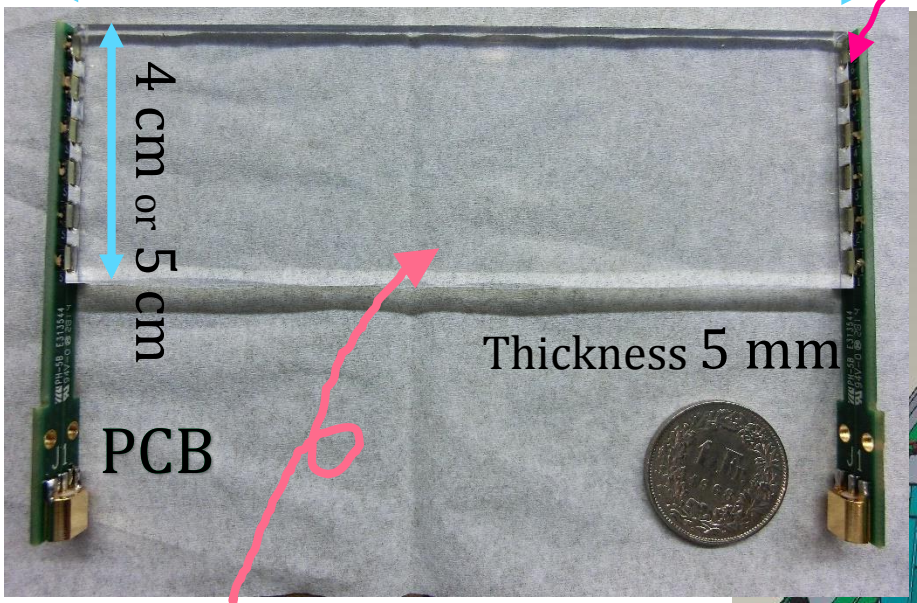


sensitivity 4×10^{-14}

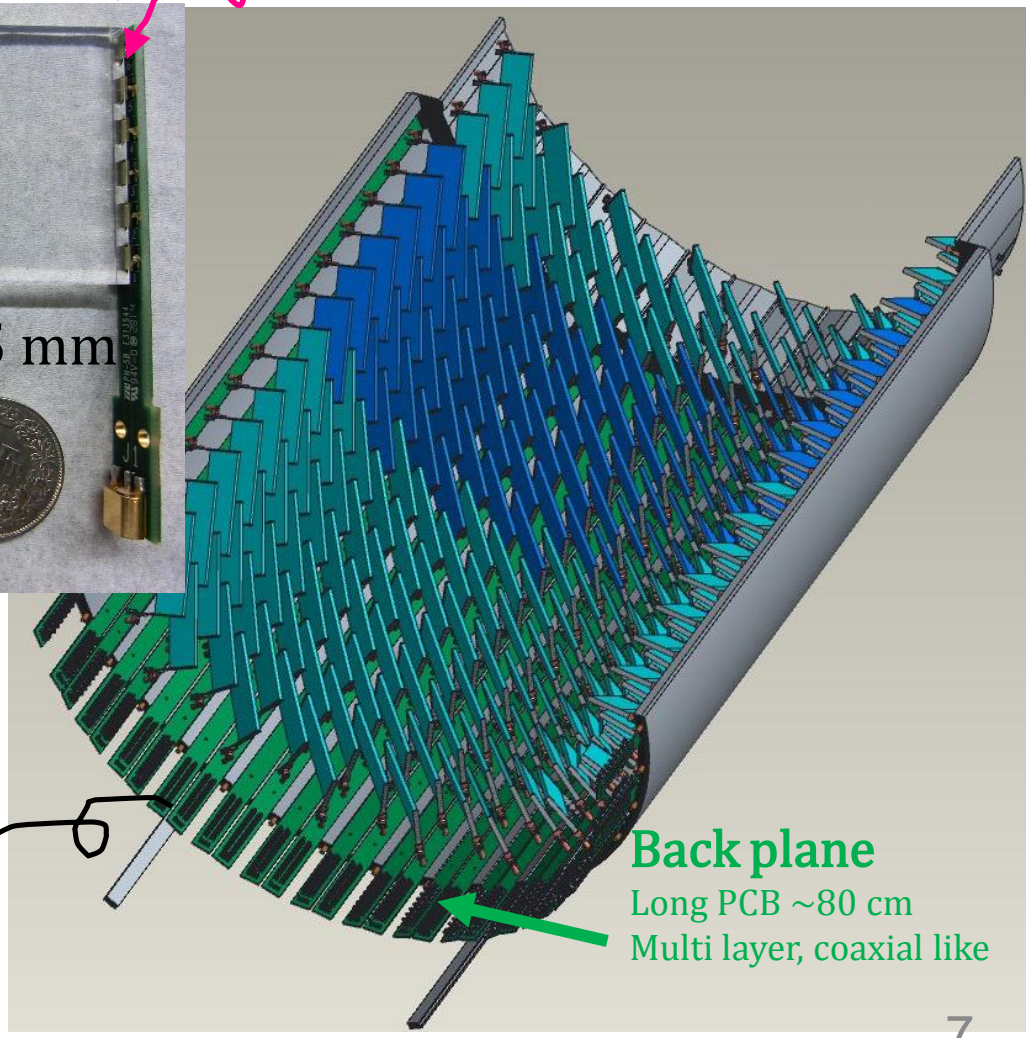
Pixelated Positron Timing Counter



Pixelated Positron Timing Counter



6 SiPMs in series at the both end
AdvanSiD (Italy) 3x3 mm^2, 50 um



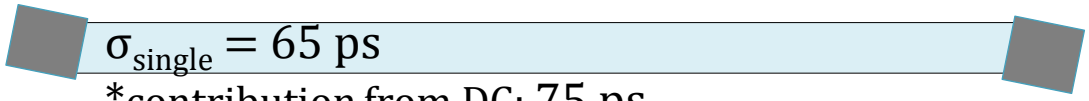
Fast Plastic Scintillator
BC422, rise time 0.35 ns
attenuation length 8 cm

Cable (RG178)
Non-magnetic

Back plane
Long PCB ~80 cm
Multi layer, coaxial like

Principle

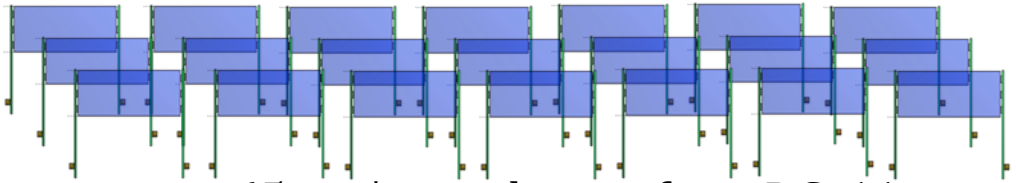
MEG I: 80 cm scintillator bar (with 2 PMTs) ×15



$\sigma_{single} = 65$ ps

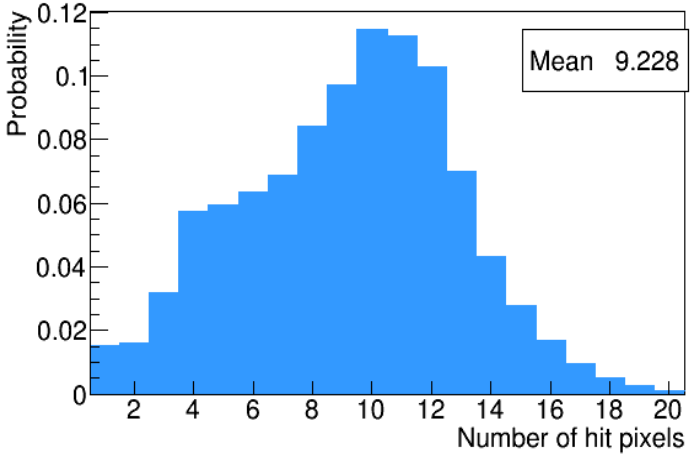
*contribution from DC; 75 ps

MEG II: 12 cm scintillator counter ×250



$\sigma_{single} = 65$ ps *contribution from DC; 11 ps

Number of hit counters (MC)

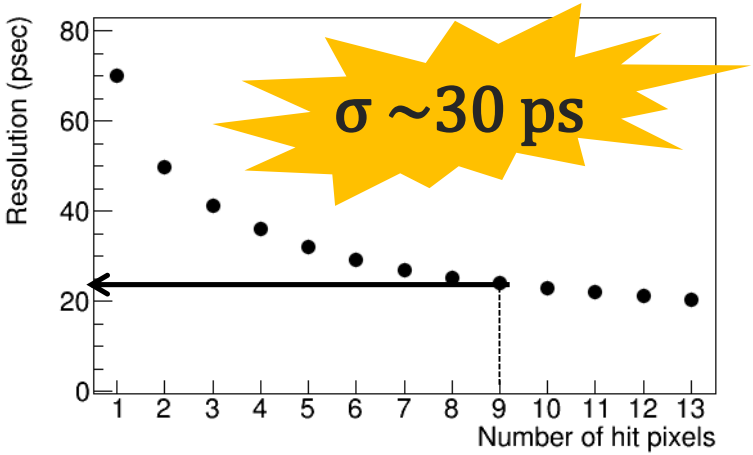


- Many hits
  - Averaging timing information, final TC resolution improve. (We already prove the principle in the other beam tests.)

$$\sigma^2_{total}(N_{hit}) = \frac{\sigma^2_{single}}{N_{hit}} + \frac{\sigma^2_{inter-counter}}{N_{hit}} + \sigma^2_{MS}(N_{hit})$$

~30 ps ~5 ps

Resolution vs. # of hit counters



- Pile Up Reduction
  - Beam intensity becomes higher in MEG II
- Able to track the positron

Status

- Prototype test
  - Good single counter performance was already demonstrated.
  - Multiple hit scheme was proved by beam tests in a quiet environment.
    - Positron beam at BTF in Italy
    - 50 Hz, 1-2 positrons in a bunch
- Calibration (next talk)
  - Laser
  - Michel positron
- Software development
  - Timing reconstruction method

BEAM TEST

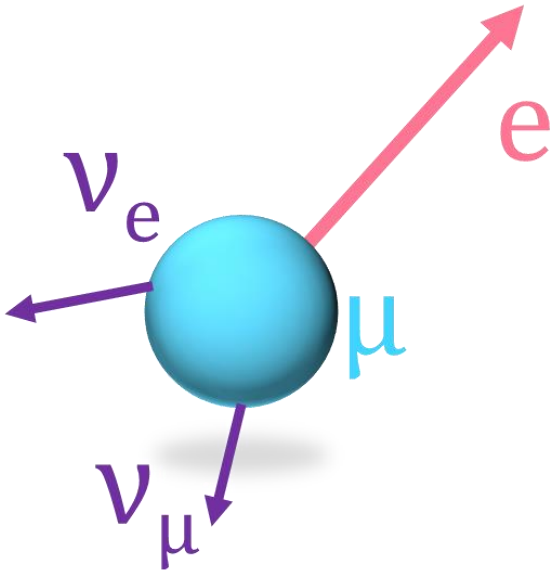
Motivation

- Previous beam test was conducted at low positron rate. (~50 Hz)

From MC study (height is 4 cm)

Length [cm]	Average Rate (kHz)	Highest Rate (kHz)
12	70.2	174

- However in MEG II , TC will suffer high rate positron backgrounds (> ~45MeV, < ~180kHz)



muon normal decay

Operate TC in this high rate environment.

Set up

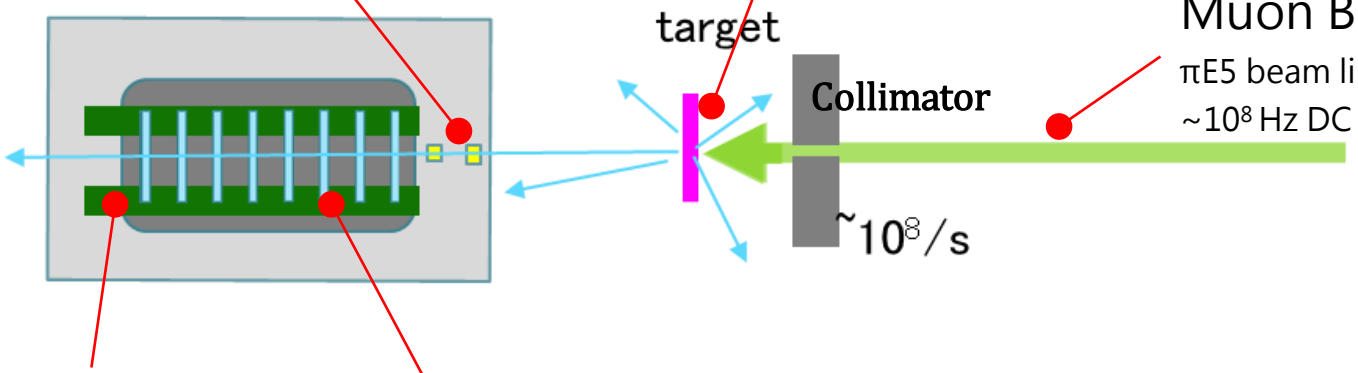
Coincident Trigger

2 small counters

5x5x5 mm^3, 1 MPPC
Teflon wrapping
Time Reference

Michel Positron

Normal decay from stopping muon
The same as real background
We can get time uniform background.



Muon Beam

πE5 beam line at PSI
~10^8 Hz DC beam

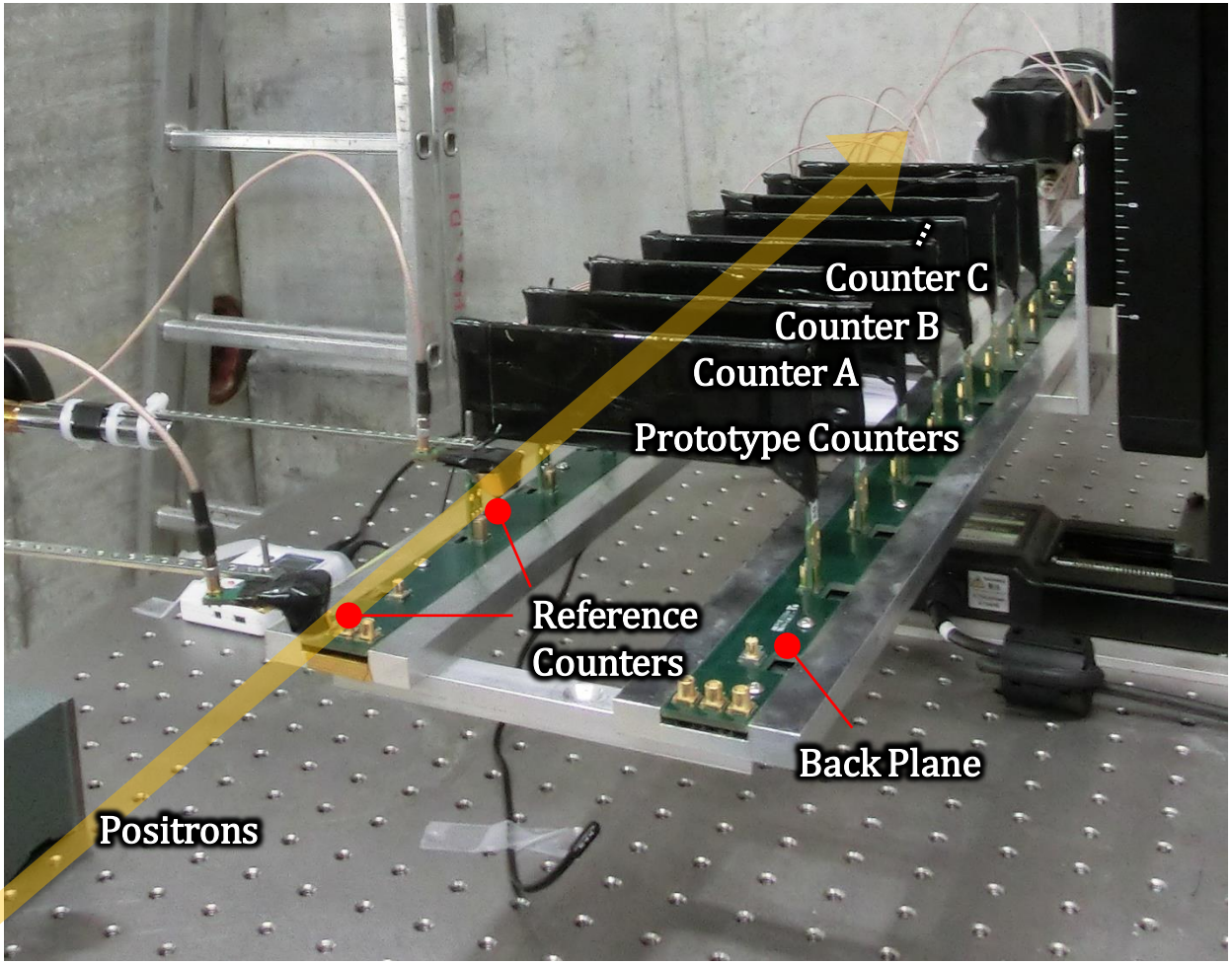
Back plane

8 Prototype Counters

6 for 120x40x5 mm^3, 2 for 120x50x5 mm^3
AdvanSiD w/o new technology -> w/ new technology
Scintillator BC422 -> EJ232
Reflector 3M Mylar film, light shielded

Digitizer (DRS)
1.6 GHz

We had to use scintillators and SiPMs of bad performance due to quality control issues of vendors.


Counter C
Counter B
Counter A
Prototype Counters
Reference
Counters
Back Plane
Positrons

Rate

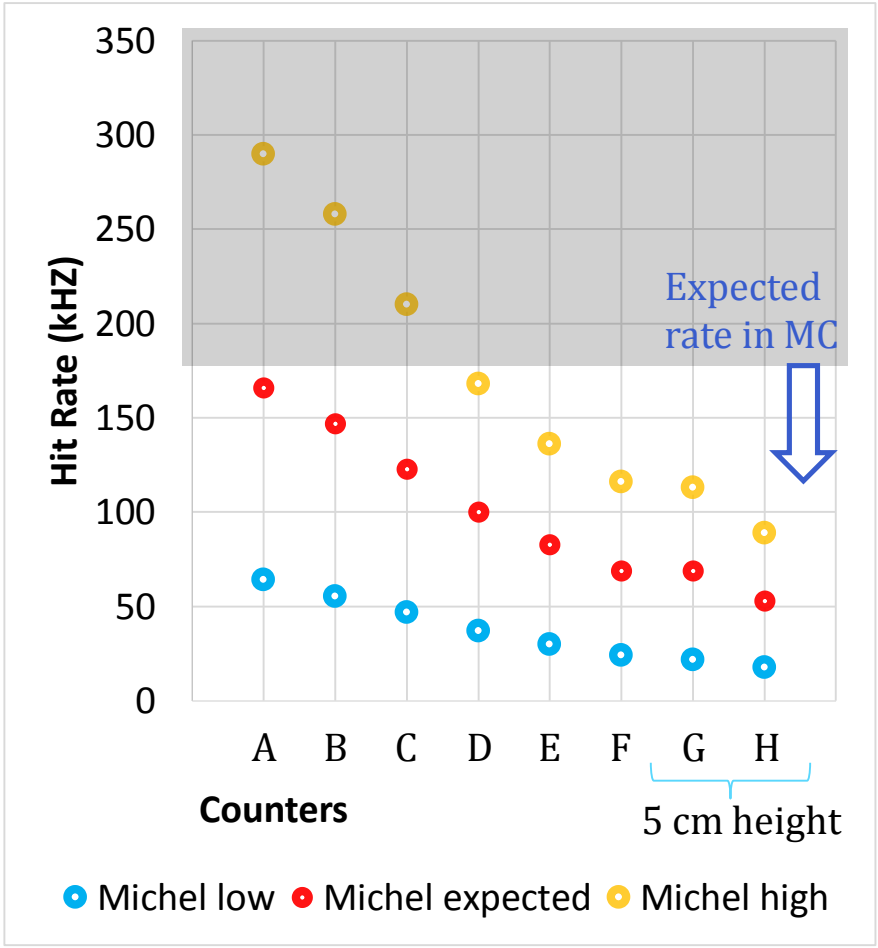
We adjusted the beam slit for rate scanning (3 points)

Three hit rate conditions

- Low rate; 17.8 – 64 kHz
- Expected rate; **53 – 166 kHz**
- High rate; 89 – 290 kHz

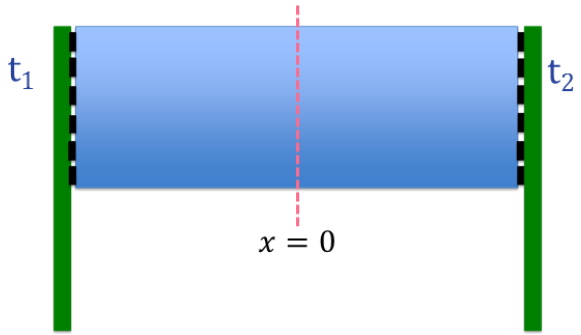
From MC study (height is 4 cm)

Length [cm]	Average Rate (kHz)	Highest Rate (kHz)
12	70.2	174

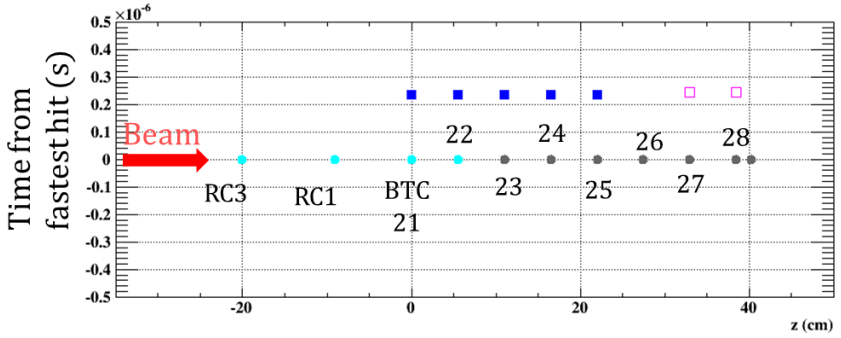


Analysis

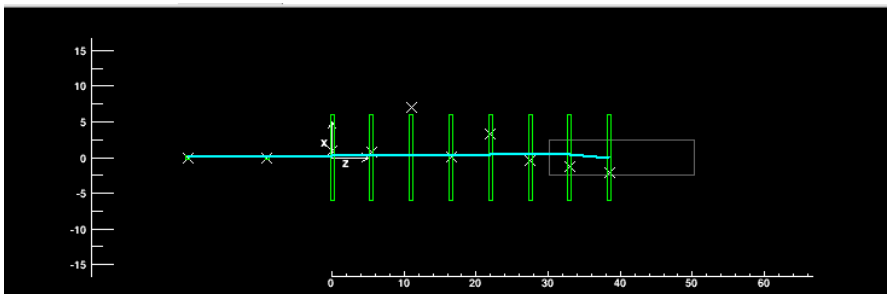
- Single Counter
  Timing $(t_1 + t_2)/2$
  Position $x = v_{eff}(t_1 - t_2)/2$



- Clustering
  - Clustering based on reconstructed time.
  - Cut the pile up hits

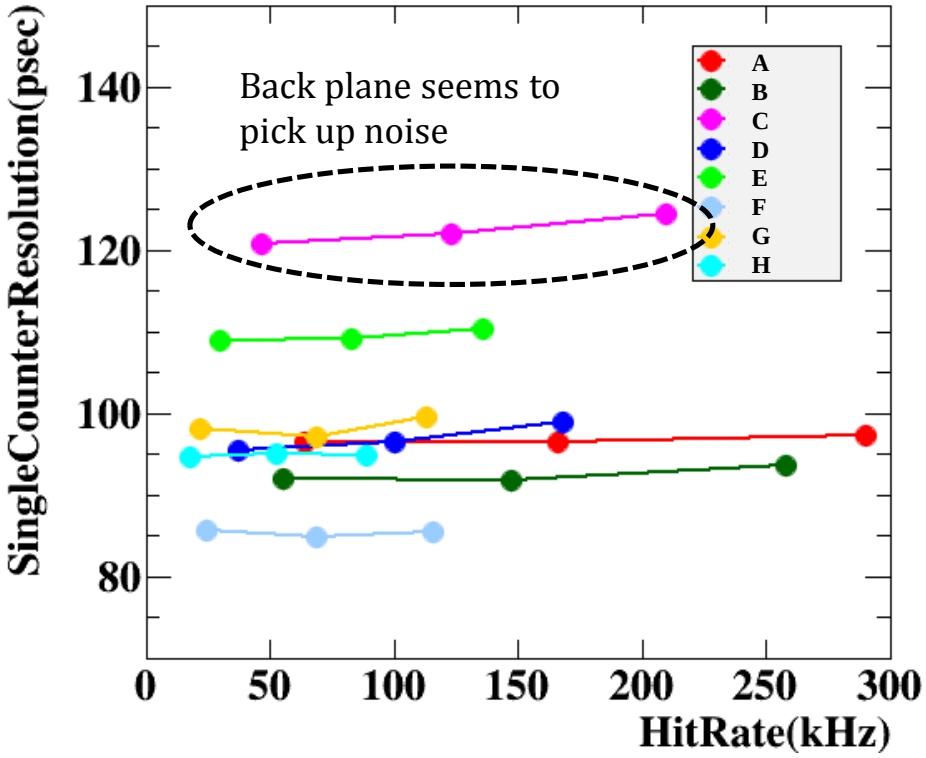


- Tracking
  - Using reconstructed position
  - Far hits from trajectory are removed.



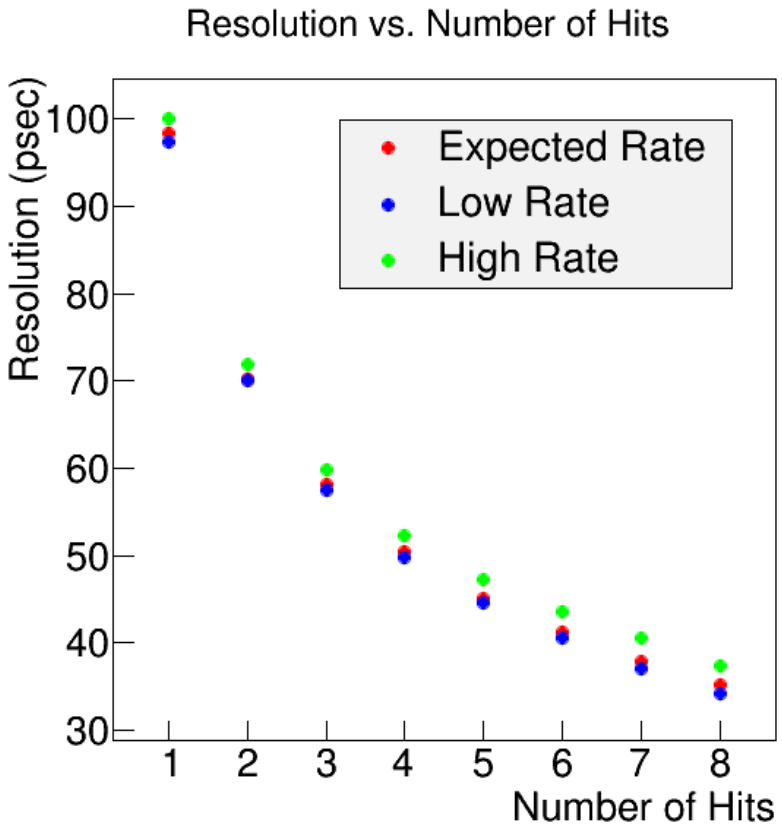
Notice: There is trade-off b/w strict cut and efficiency.
We should optimize the parameter for final analysis

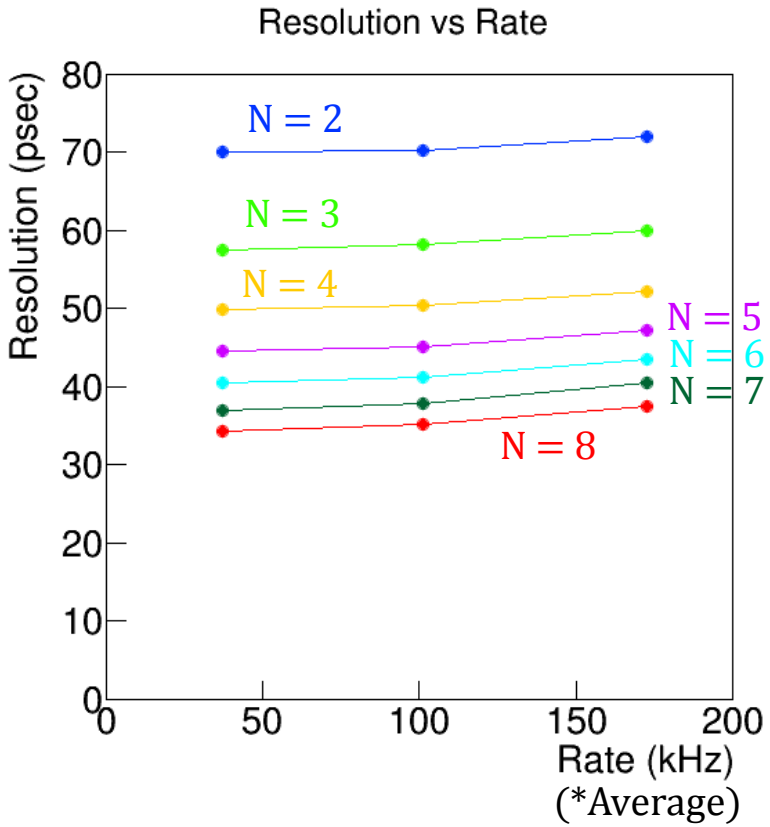
Single Counter Resolution



Small degradation of the resolutions from higher rate can be observed.

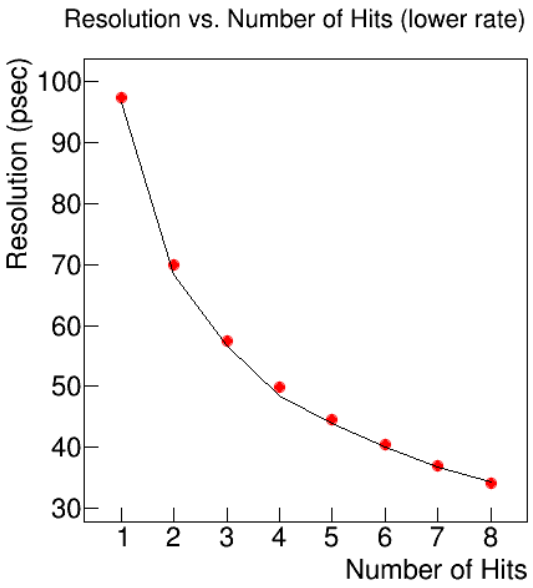
Overall Resolution

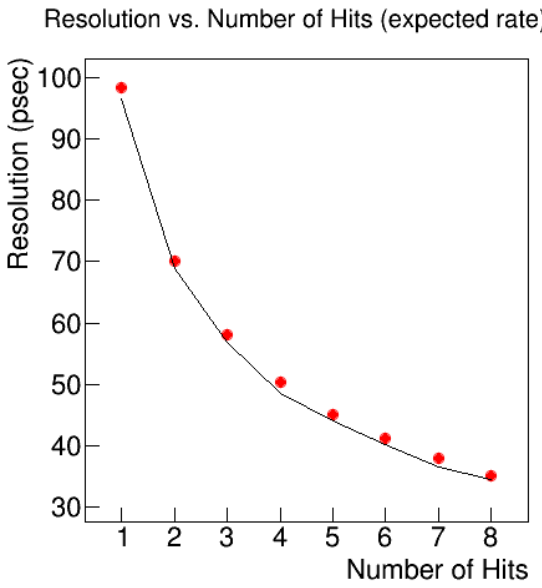


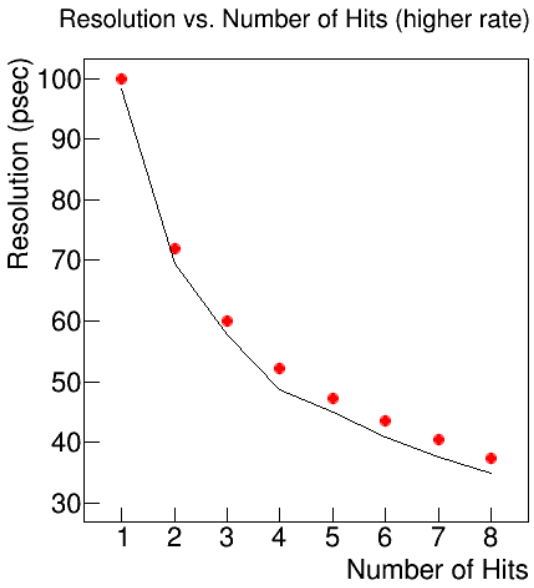


Only small degradation of the resolution up to the expected hit rate.

Overall Resolution







- The difference becomes larger in higher rate. However the difference is not so effective especially b/ lower rate and expected rate.
- At n = 8, the overall resolution is ~35 ps.
  - This number will improve with final counters because the single resolutions will improve from ~90 ps to ~65 ps.

Schedule & Status

In this beam test, we demonstrated good performance in high rate environment expected in the experiment.
It is time to construct and test the final detector.

- Construction
  - SiPMs were already delivered and tested.
  - Support structure is under construction.
  - SiPMs array will be tested soon.
  - Counter mass production and mass test

- TC DS engineering run is planned in Dec.
  - Down stream of TC will be installed and tested with the muon beam.
  - Number of readout electronics channels are limited. (Half of the DS TC channels can be readout at one time)

- Next spring TC US will be installed.
- Summer in 2016, the engineering run will start.
- Following the engineering run, physics run will start.

Summary

- The MEG II experiment will search for $\mu \to e\gamma$ decay at a unprecedented sensitivity of 4×10^{-14}.
- The Pixelated Positron Timing Counter of 30 ps resolution is in preparation.

- We conducted a beam test with prototype counters under the MEG II beam condition.
  - We obtained the excellent resolution of 35 ps with 8 counters.
  - The final performance of TC will be better by using better counters.

- Preparation for TC DS engineering run in Dec. is underway.

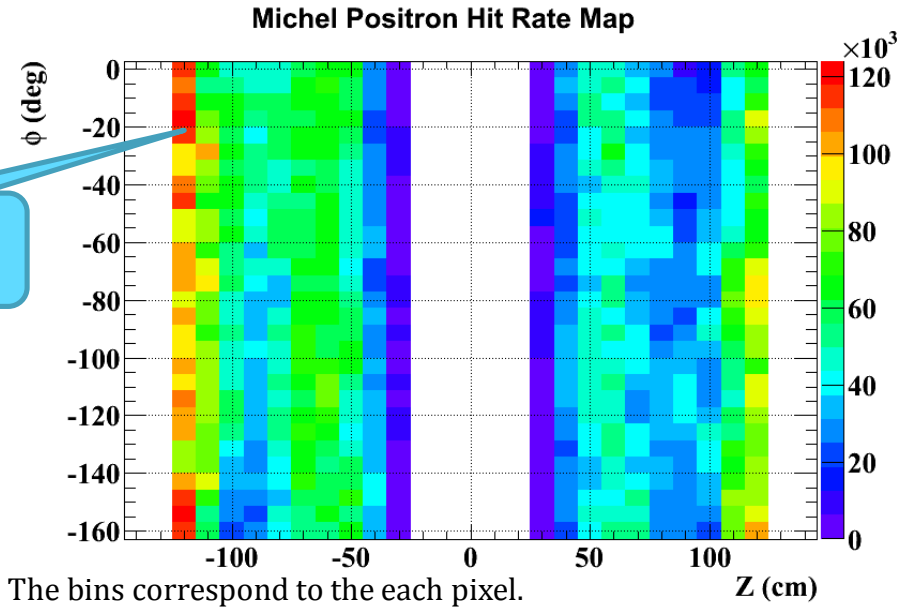
MEG
Mu-E-Gamma Collaboration

東京大学
THE UNIVERSITY OF TOKYO

BACK UP

Pileup Study

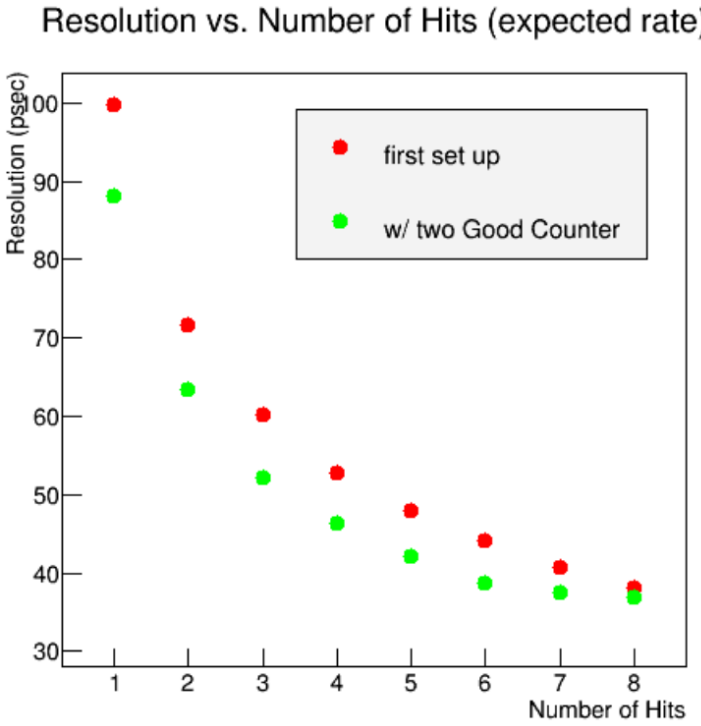
- Michel positron (4π, all momentum)
- Hit rate of Michel positron depends on position.



90x30x5 pixels

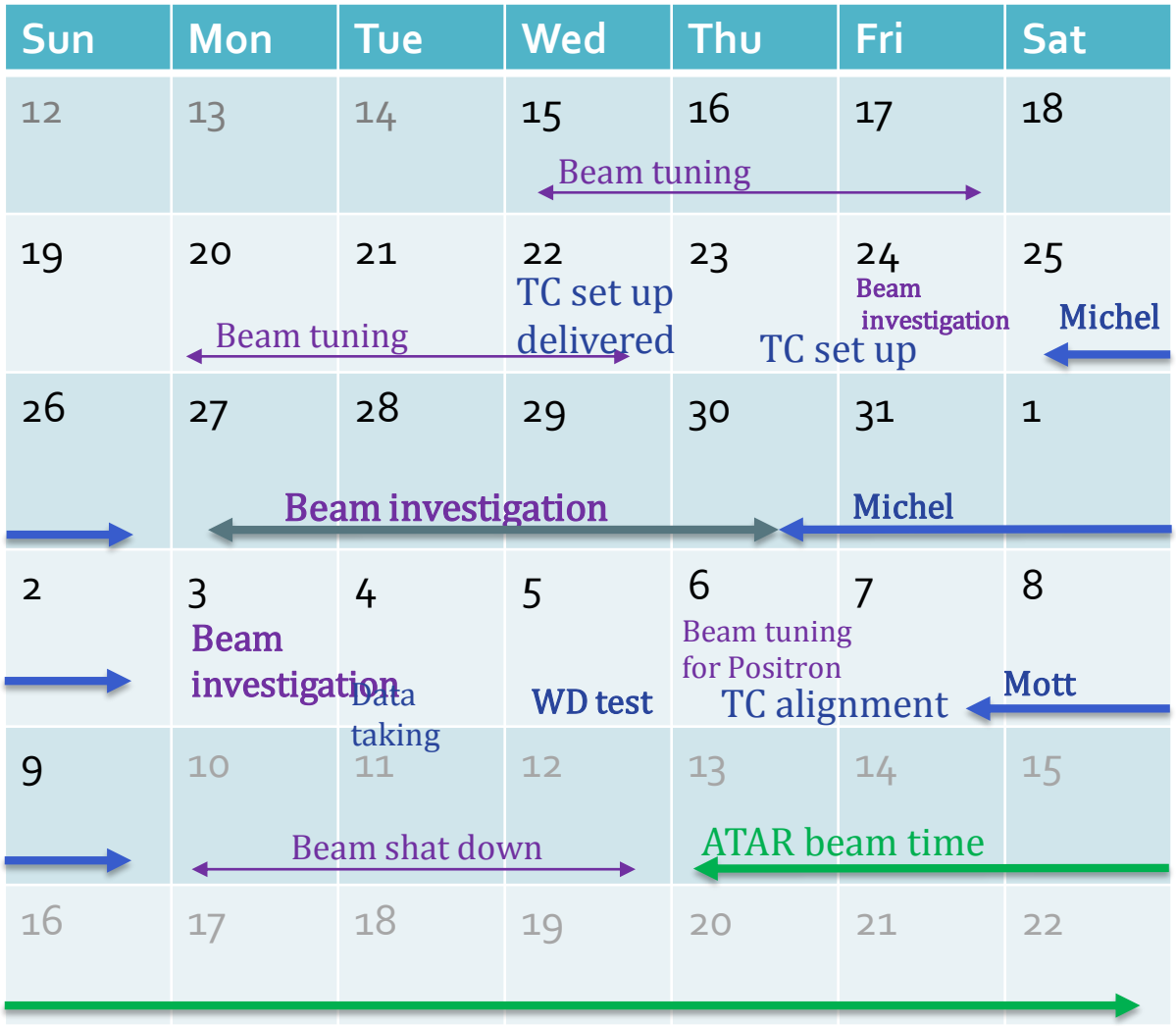
The bins correspond to the each pixel.

Final Performance



- We could measure the final prototype counters. (only two counters)
- The TC performance improved.
- In the final detector better performance is expected.

Time line



- Beam

  We lost ~6 days for the investigation.