MEG実験アップグレードに向けたSiPMを用いた新しい時間測定器の研究

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日本物理学会　2013年春季大会
広島大学

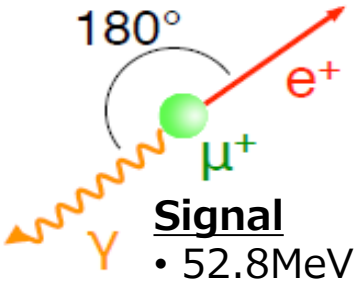
MEG
Mu-E-Gamma Collaboration

MEG

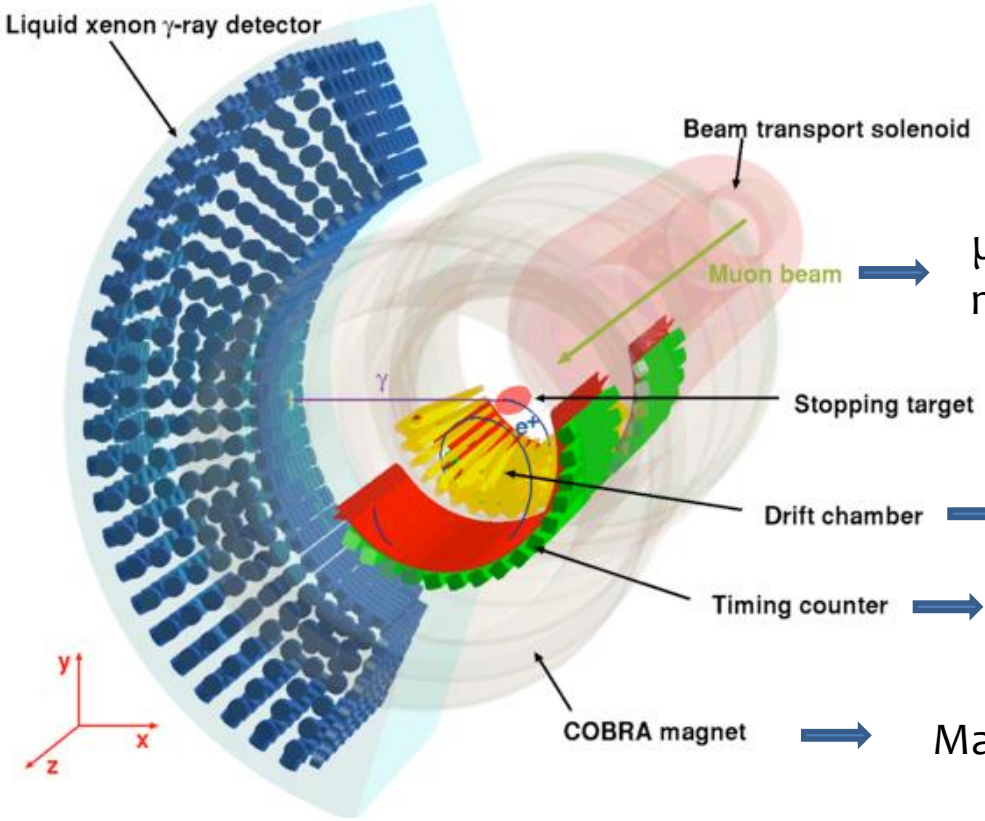
26pRC03:内山

東京大学
THE UNIVERSITY OF TOKYO

- Search for charged lepton flavor violation (cLFV), **μ → eγ**
  - Forbidden in the SM
  - Some models predict large branching ratios



Signal
- 52.8MeV
- Back-to-back
- Time coincidence



μ beam at PSI (Paul Scherrer Institute)
muon stopping rate; 3×10^7Hz

Momentum, decay vertex,
emission angle and track length

Impact time

Make gradient magnetic field

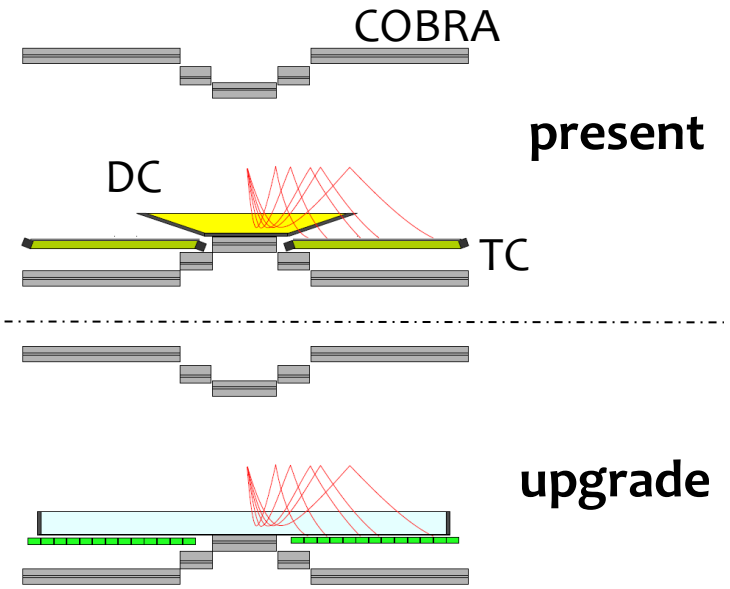
Most stringent upper limit of 5.7×10^{-13} 90% C.L. in this March.
(arXiv:1303.0754)

29pRC02:藤井

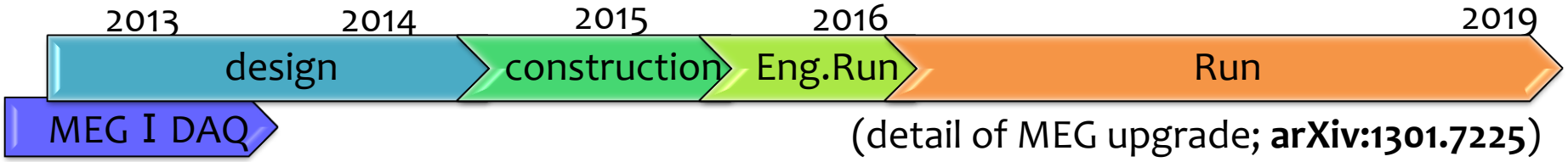
Upgrade

- sensitivity goal -> 5×10^{-14}
  - improve detection efficiency twice
  - improve resolutions half
- μ beam
  - twice higher beam intensity
- Xenon Calorimeter
  - Smaller photo-sensor
- Positron spectrometer
  - Positron tracker
    - Stereo wire drift chamber
    - ✓ efficiency
      ->minimize material along the positrons path to the timing counter
    - ✓ Resolution
      ->increase measurement points
  - **Timing counter**
    - **Pixelated Timing Counter**

28pRF03:金子

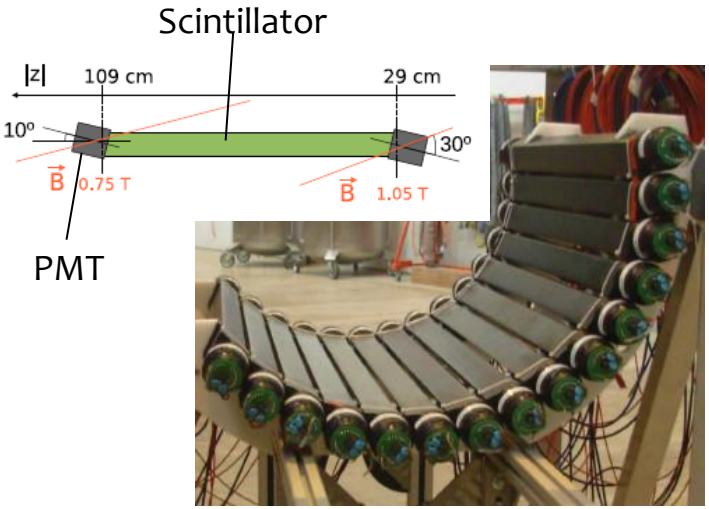


Upgrade proposal is approved by PSI committee.

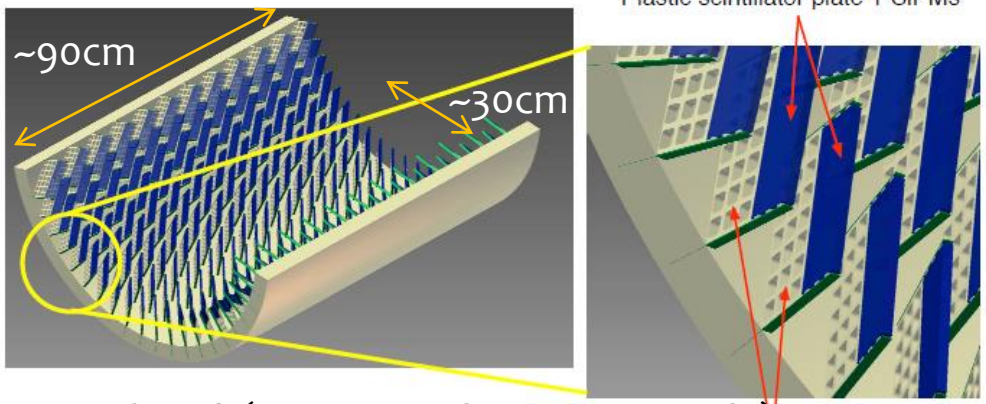


(detail of MEG upgrade; **arXiv:1301.7225**)

Pixelated Timing Counter

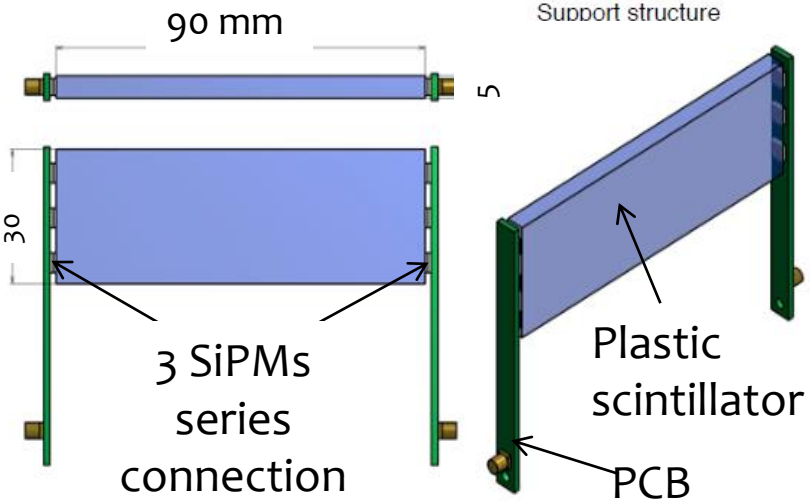


present



upgrade

For getting good time resolution…



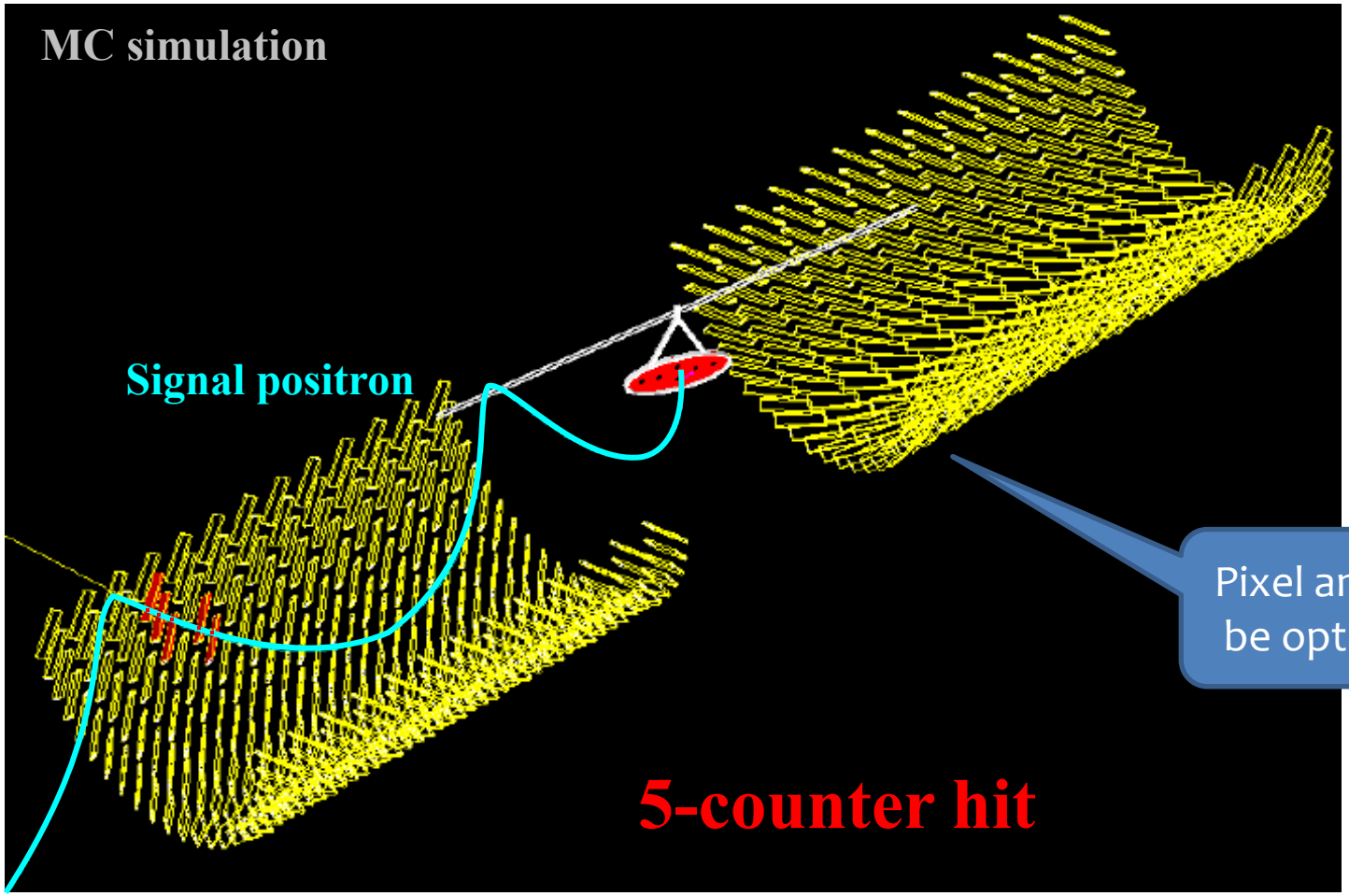
Present problem

- Sensitivity to the magnetic field
- Large ambiguity along Z direction
- high single event rate

upgrade

- magnetic field insensitive photo-sensors
- a higher level of segmentation

Multi-counter hit



Multiple hit scheme

Total timing counter resolution is

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

30-40 ps

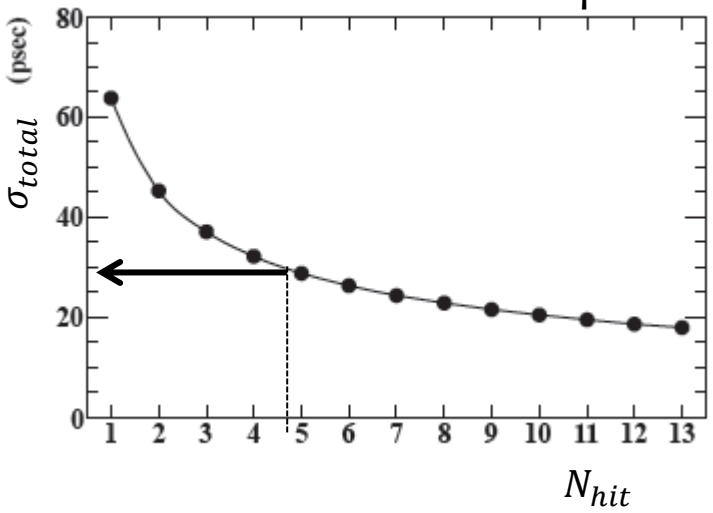
~5ps

~50 ps

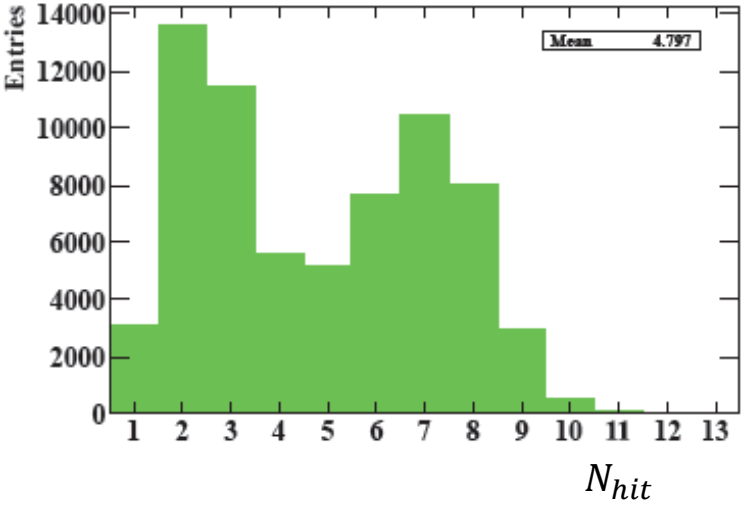
⇒ **the average time resolution :**

30-35 ps (current ~76 ps)

Resolution vs. # of hit pixels



Number of hit pixels (MC)

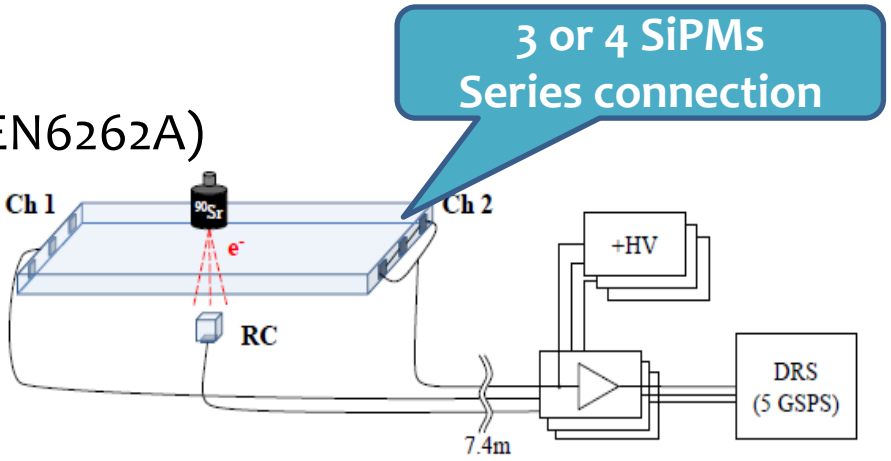


Requirement

- Good single pixel resolution
  - Single pixel R&D
- Hit many pixels
  - Layout study with MC

Single Pixel Study

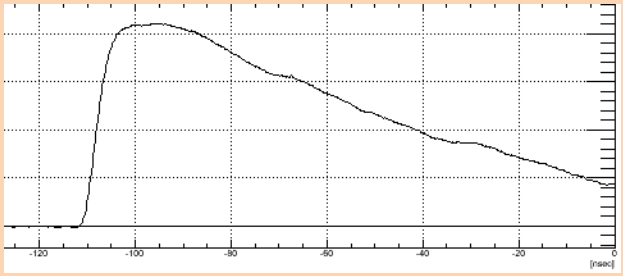
- Test Counter
  - SiPM
    - HAMAMATSU MPPC (S10362-33-050C, 3x3 mm2, 50μm-3600 pixels)
  - Fast plastic scintillator
    - 90x30x5mm, BC422
  - glued with optical grease (OKEN6262A)
- Source Sr90 (<2.28MeV, β-ray)
- Reference counter
  - 5×5×5 mm scintillator BC422
  - Readout by a MPPC
  - Trigger, Collimate

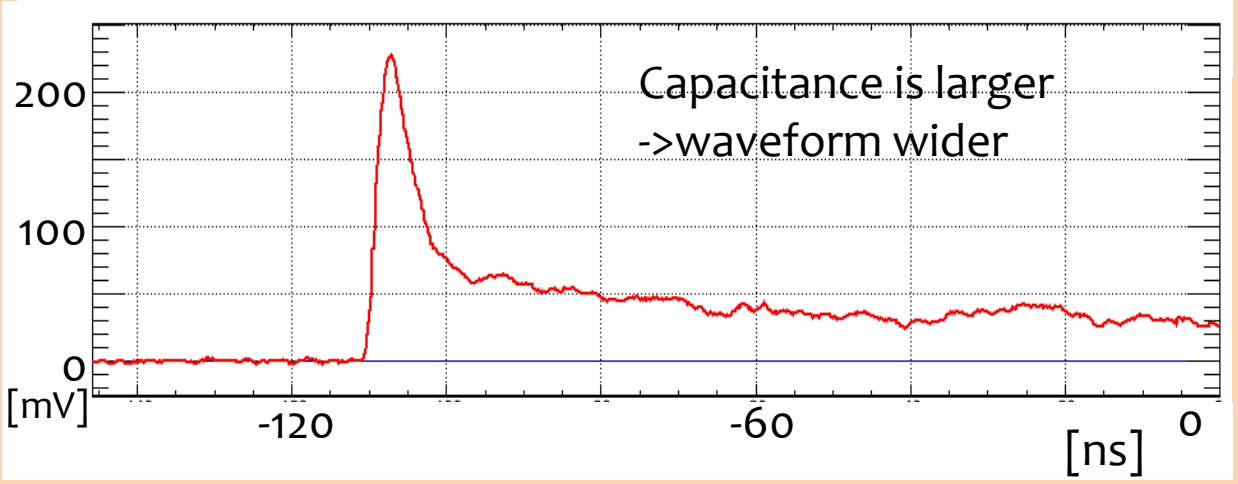


- Waveform digitizer sampling (DRS developed at PSI) @5GSPS
- Voltage amplifier developed by PSI (Gain~20, 600 MHz bandwidth)
- Shaping with high-pass filter & pole-zero cancellation
- Long cable (7.4m) before amplifier
- KEITHLEY Pico ammeter for MPPC bias (HV), Bias 218V~222V (for series connection)

waveform

Parallel connection

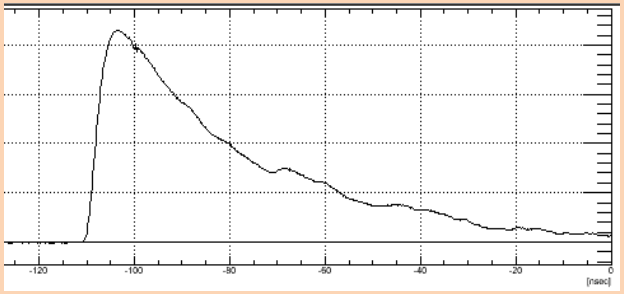


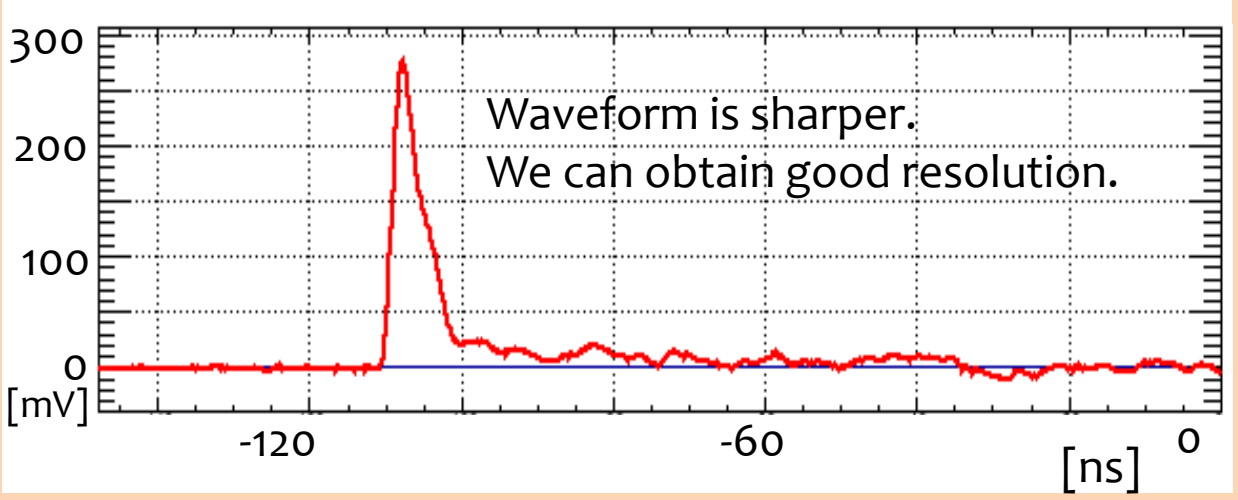


Before shaping

After shaping

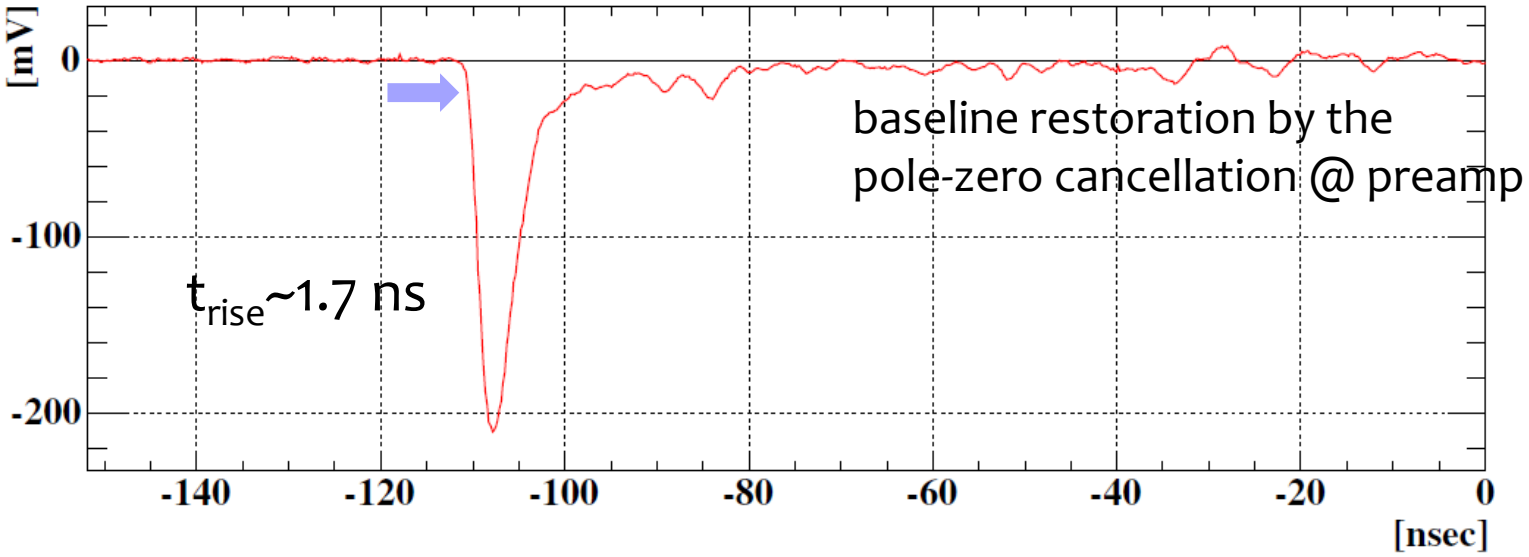
Series connection





Analysis

- Signal time is picked-off by Constant-Fraction method (~10%)
  - very leading-edge is relevant to precise timing
- *e* hit time is reconstructed by the average of times measured at the both ends
- Resolution of test counter is evaluated from $(t_0 + t_1)/2 - t_{ref}$
- Reconstruct hit position by $v \times (t_1 - t_0)/2$ (v ; scintillation light speed)



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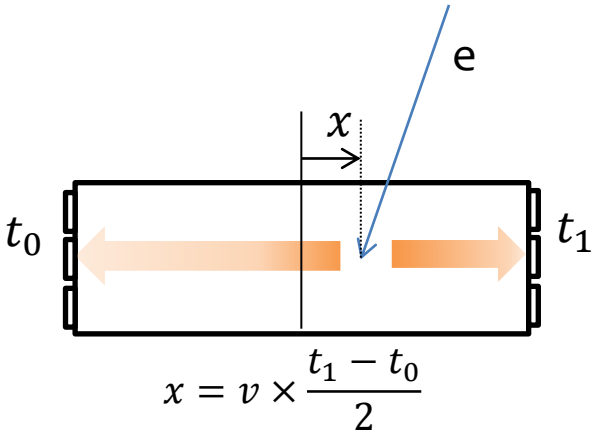
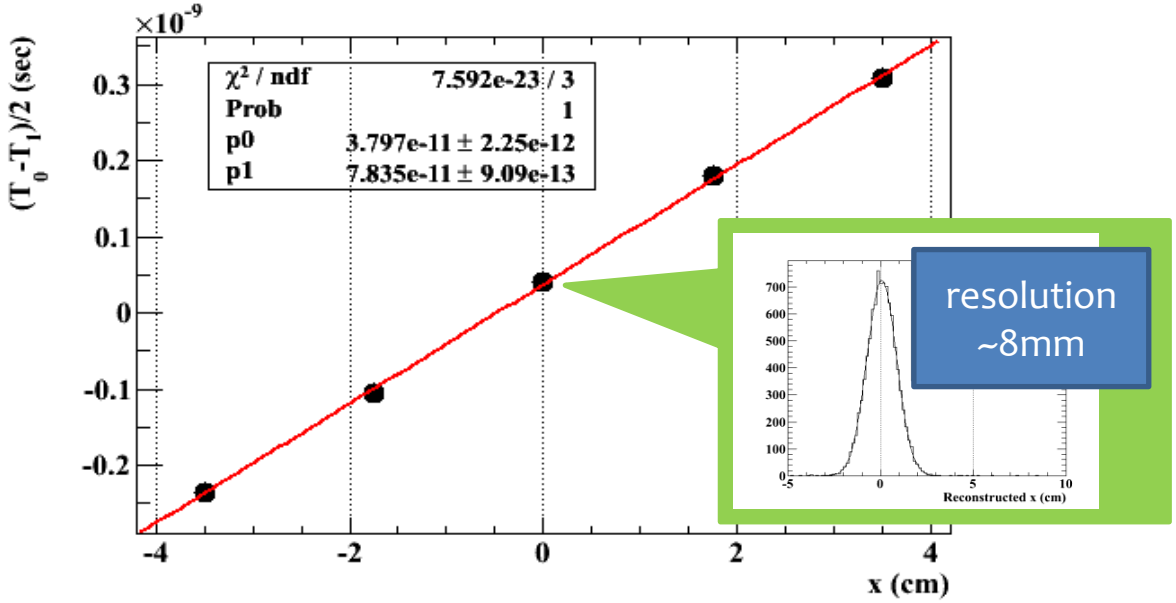
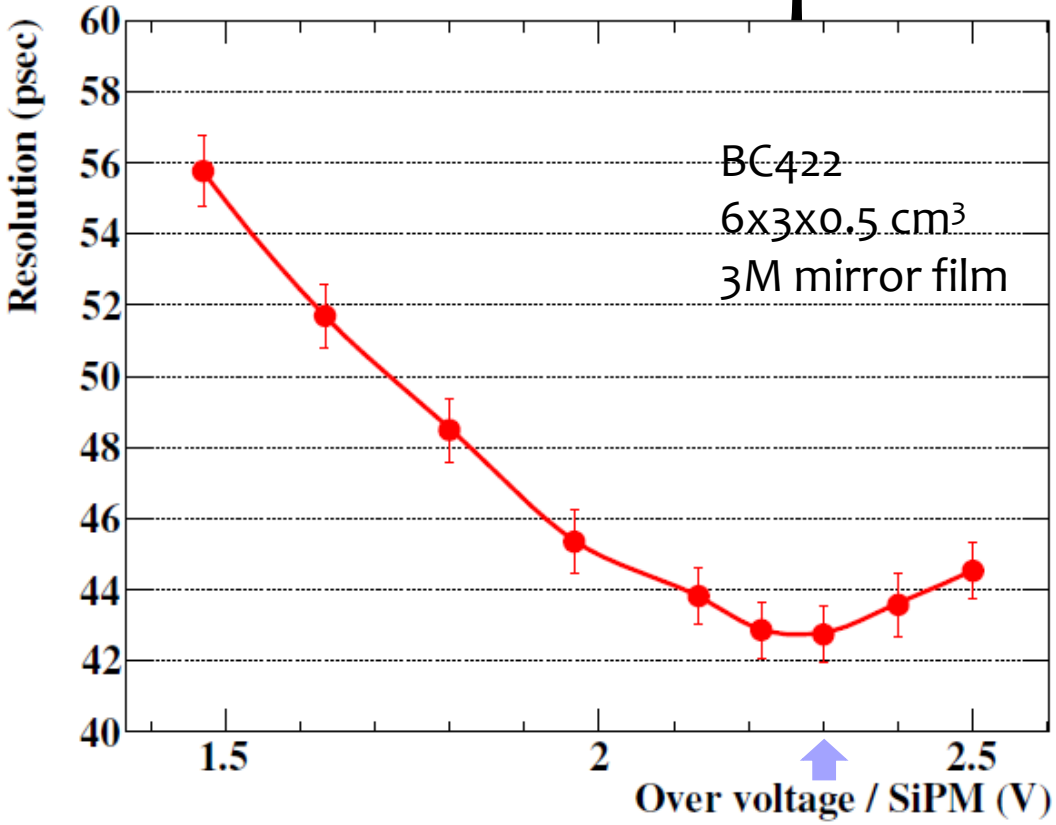
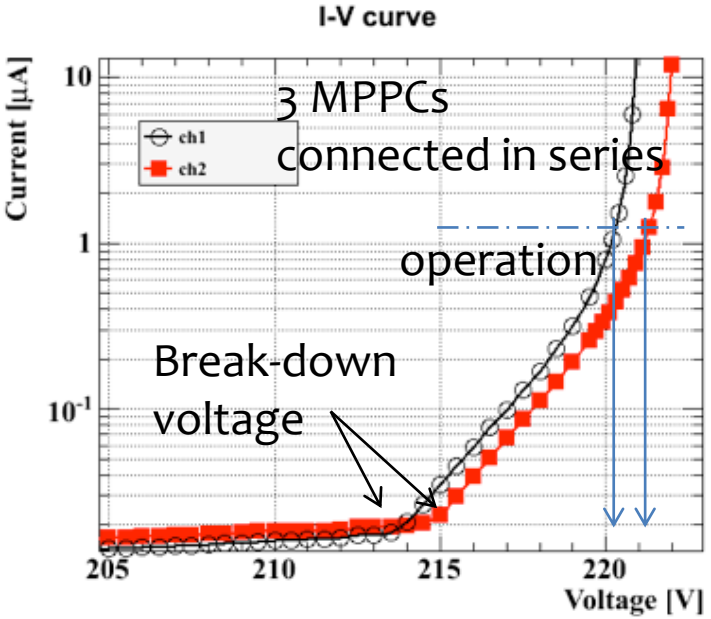




Bias dependence





Good time resolution of 43 ps is obtained.

- Resolution improves with higher over-voltage
- then degraded because of higher dark noise
- Following test done at over-voltage =2.3 V/SiPMs

Other tests

- Position scan
- Optimization
  - Size
    - length(60-120mm), width(3.5-5 mm), height(30, 40 mm)
  - Scintillators
    - BC422, BC420, BC418
  - Manufacture of SiPM
    - HAMAMATSU, KETEK, AdvanSiD
  - Reflector
    - Aluminized Mylar, Teflon tape, 3M radiant mirror

Single Pixel R&D with source is almost done!!
We could obtain the satisfying result about single pixel.

Other tests

- Position scan
- Optimization
  - Size
    - length(60-120mm), width(3.5-5 mm), height(30-40 m
  - Manufacture of SiPM
    - HAMAMATSU, KETEK, AdvanSiD
  - Reflector
    - Aluminized Mylar, Teflon tape, 3M radiant mirror

Next stage is to test with beam.

Single Pixel R&D with source is almost done!!
We could obtain the satisfying result about single pixel.

Beam test in PSI

Motivation

- Check the response to MIP
- Check if we can obtain consistent time resolution in the area
- Check the noise in the area
- Obtain data where the positrons penetrate two counters
- Pre-test for planned beam test with prototype detector.

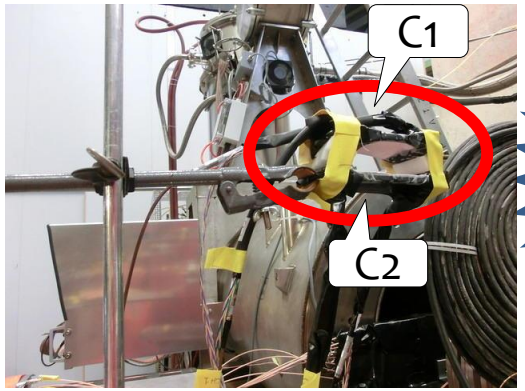
Setup

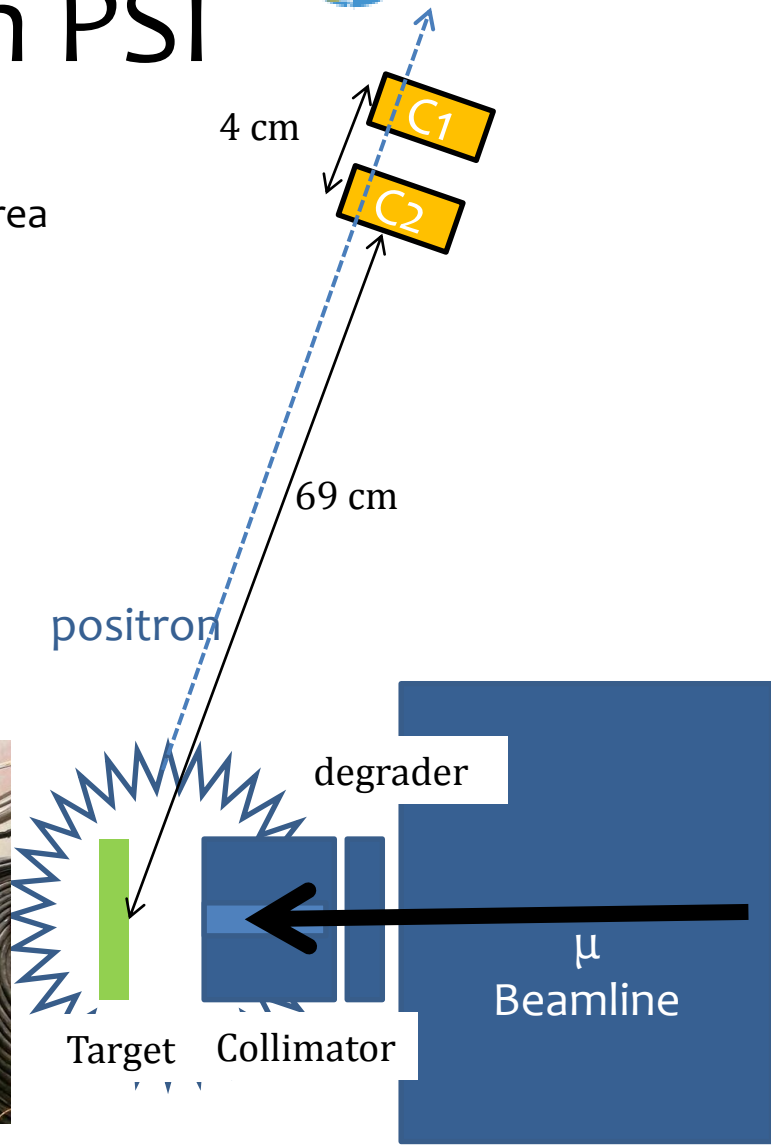
Mu beam

Counter 1 (C1): BC422 60x30x5mm, 3M wrapping

Counter 2 (C2): BC422 90x30x5mm, 3M wrapping

Light tight shielding with black tape.

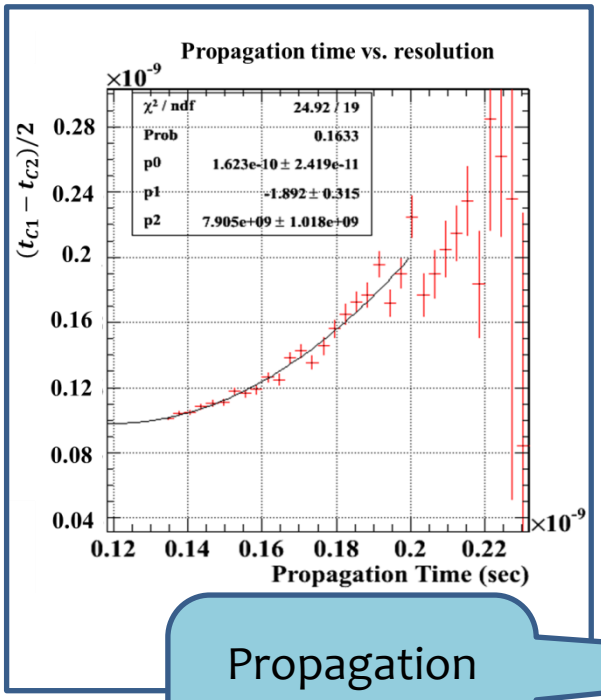




Expected resolution from lab data is

~33ps (C1 43.6 ps , C2 49.9 ps) no inter-counter jitter

Resolution

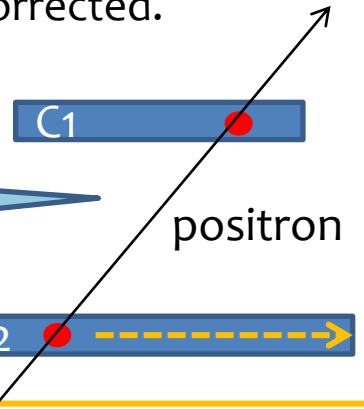


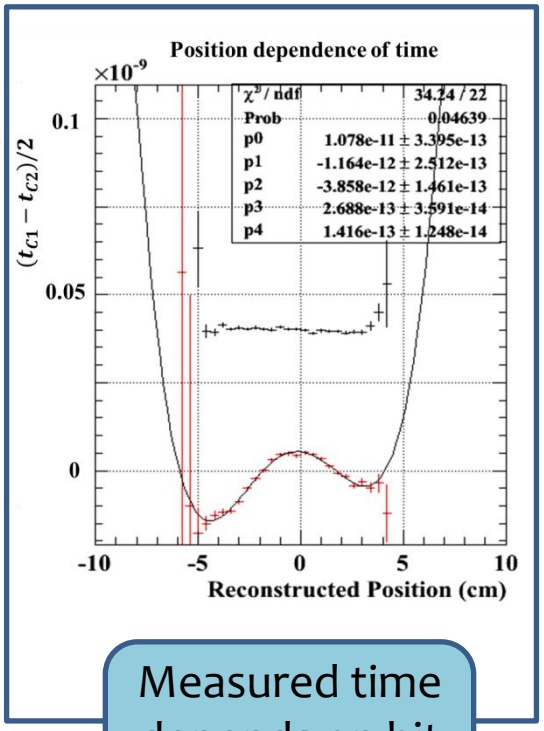
Propagation time depends on path length

Analysis

Resolution is evaluated from $(t_{C1} - t_{C2})/2$

- Propagation time which may depends on incident angle is corrected.
- Position dependence of mean is also corrected.





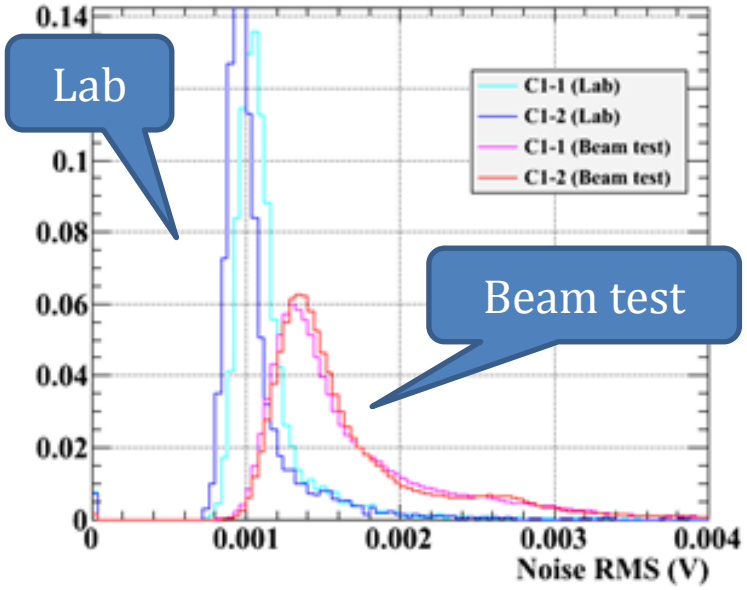
Measured time depends on hit position

The combined resolution with position cut is 35 ps.

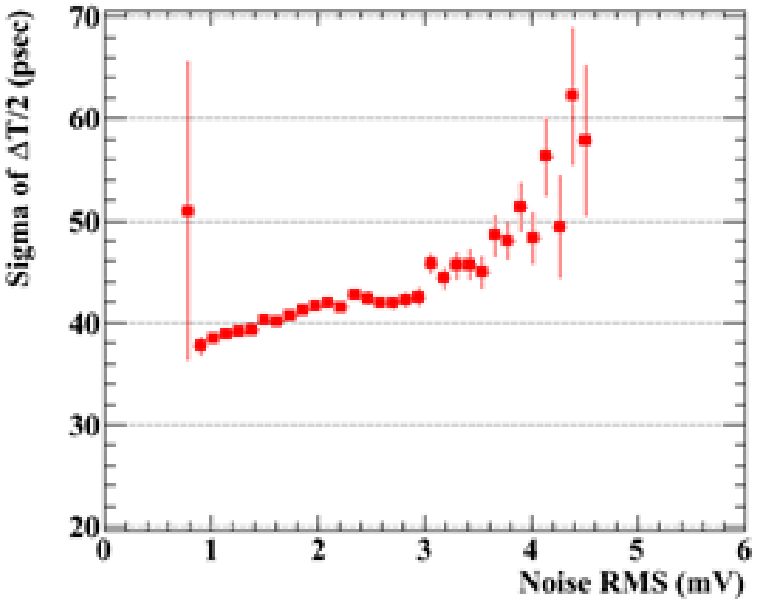
- The consistent resolution with lab data. (expected ~33ps)
- We can obtain better resolution by multiple hits. (single ~ 50 ps)

*inter-counter jitter effect is not included

Noise



Resolution

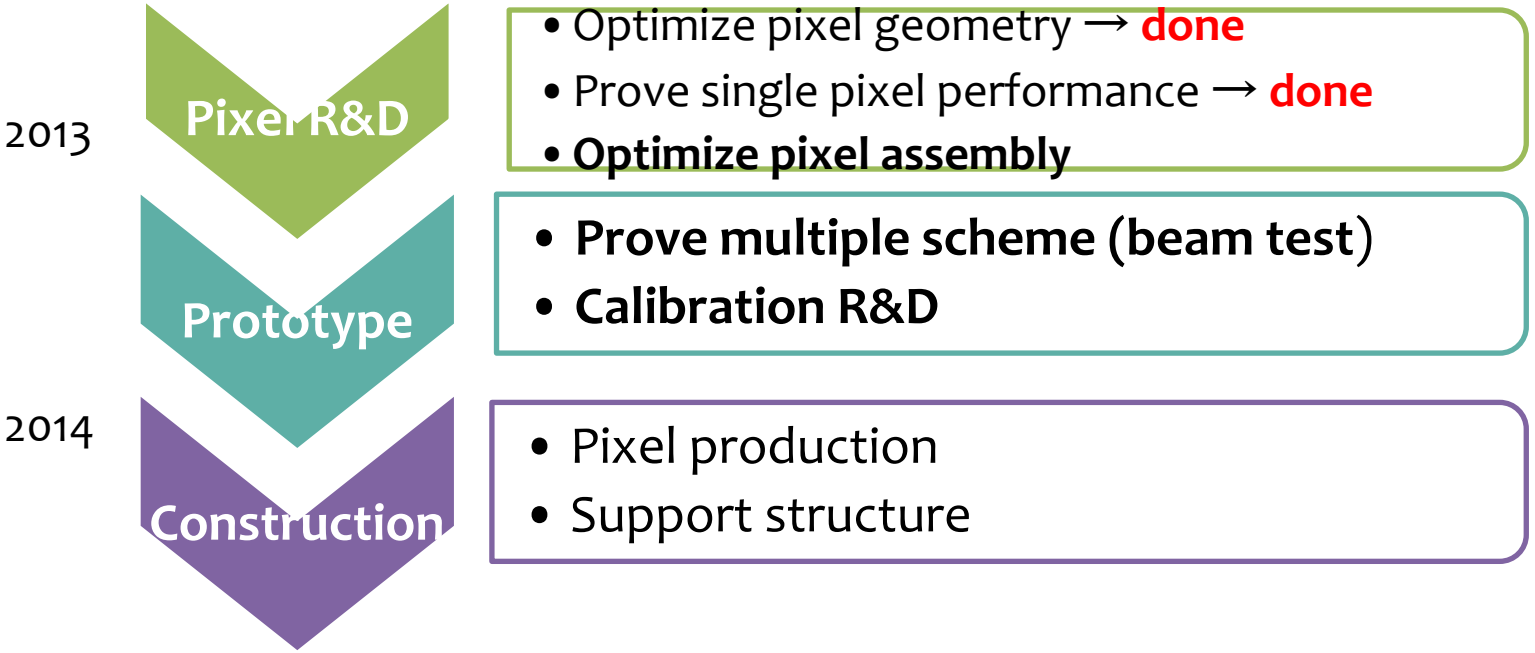


- Noise increased by ~40%.
- Resolution depends on noise. (~ 2-3 ps/ mV)

  → Noise effect is not crucial.

Summary and Prospects

- Pixelated timing counter with an improved timing resolution is under development for MEG upgrade.
  - Pixel with SiPM and fast plastic scintillator
- About single counter, good time resolution of 40-45 ps was obtained.
- Beam test
  - Though noise increase good resolution can be obtained.
  - Though jitter is not included, better resolution can be obtained by multiple hit.



MEG
Mu-E-Gamma Collaboration

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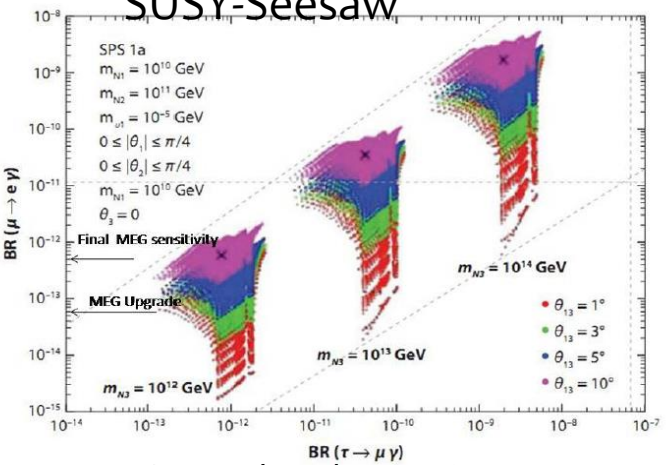
BACK UP

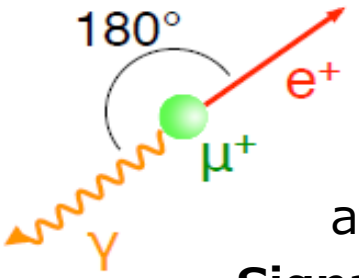
μ → eγ

- Search for charged lepton flavor violation (cLFV), μ → eγ
  - Forbidden in the SM
  - Some models predict large branching ratios
- Requirement
  - high intensity DC μ^+ beam
  - high rate tolerable positron detector
  - high performance gamma-ray detector
- Current best upper limit set by MEG:
  5.7×10^{-13} (Phys. Rev. Lett. 107 (2011) 171801)

SUSY-Seesaw

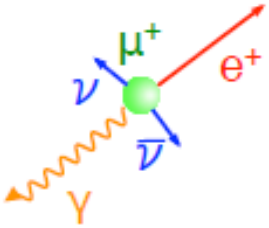


S.Antusch et al, JHEP 0611:090 (2006)

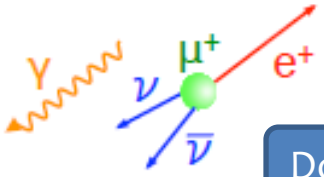


at rest

Signal
- 52.8MeV
- Back-to-back
- Time coincidence



Physics BG
(radiative muon decay)
- <52.8MeV
- Any angle
- Time coincidence

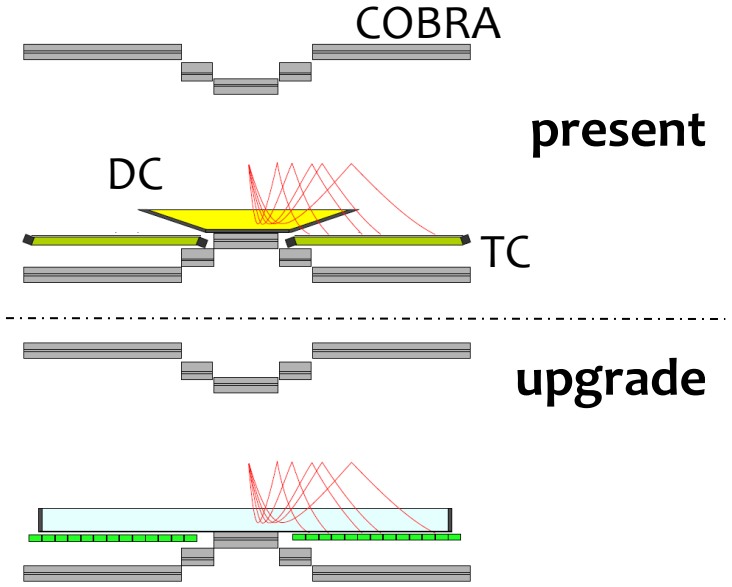


Dominant

Accidental BG
- <52.8MeV
- Any angle
- Random

$t_{e\gamma}$ resolution

track length: 75 ps→ 11 ps
gamma side: 67 ps →76 ps
Timing counter: 76ps → 30-35ps

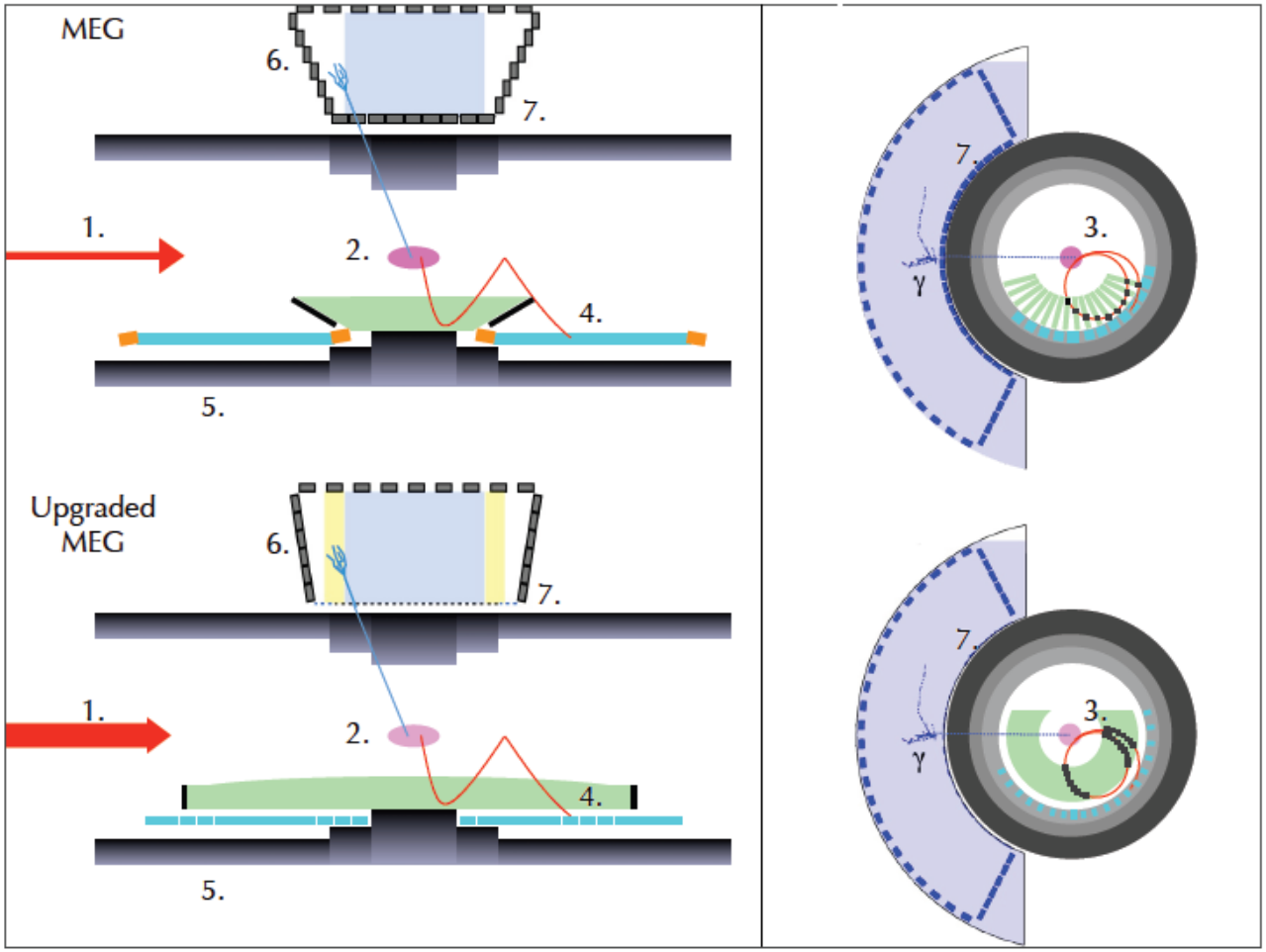


$\sigma_{e\gamma}$ = 130 ps → 84 ps (35% ↓)

Resolution and efficiencies for MEG upgrade

PDF parameters	Present MEG	Upgrade scenario
e^+ energy (keV)	320	110-140
e^+ θ (mrad)	11	5-7
e^+ ϕ (mrad)	7.2	5-7
e^+ vertex Z/Y(core) (mm)	2.0/1.1	1.5/1.0
γ enegy (%) ($w > 2$ cm)	1.9	1.0
γ position (u, v, w) (mm)	5(u, v), 6(w)	2
γ-e^+ timing (ps)	122	75-90
Efficiency (%)		
trigger	$\approx$ 99	$\approx$ 99
γ reconstruction	59	59
e^+ reconstruction	40	85-90
event selection	80	85

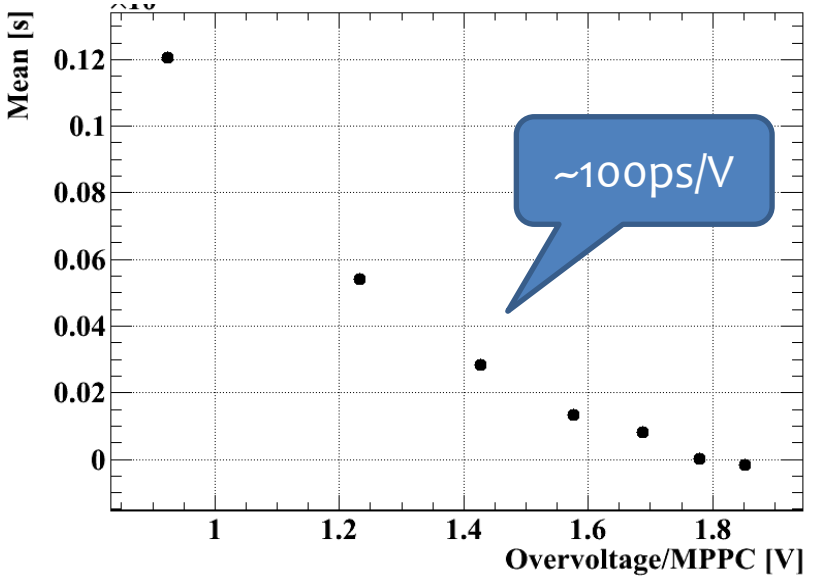
Upgrade summary



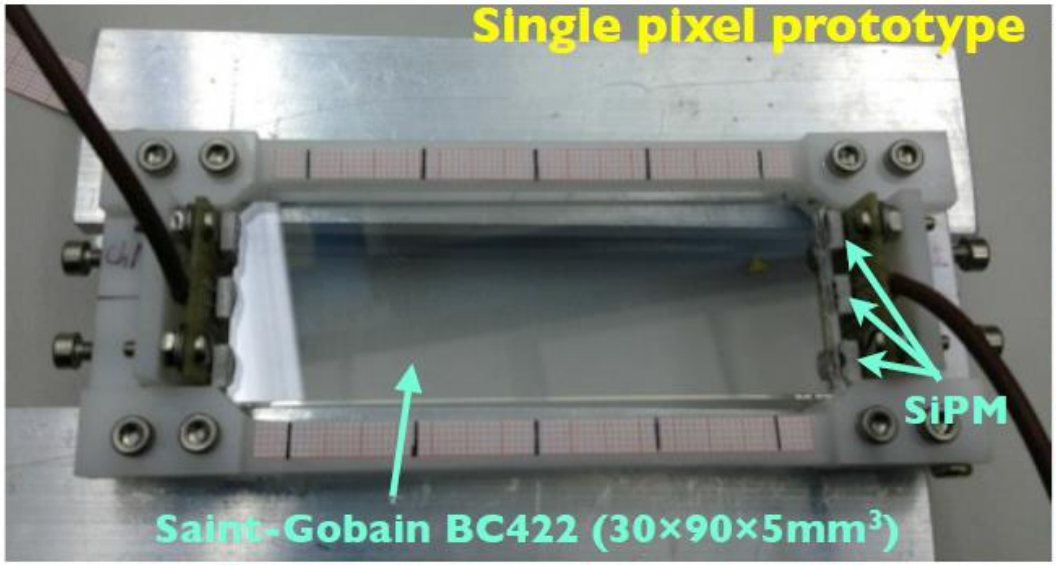
Temperature dependence

- Relatively large temperature coeff. of break-down voltage for MPPC (56mV/℃) might be an issue
  - Temp. variation in COBRA is a few ℃
  - Time shift due to this is expected to be ~15 ps
    - doesn't seem a big issue
  - Possible solutions
    - Improve detector temp. stabilization
    - KETEK SiPM with lower temp. coeff. (<1%/℃)

Measured time shift vs over voltage



Pixel prototype



Series vs. parallel connection

- Parallel

  We can't apply bias voltage to each MPPC. We should choose MPPCs which have the same characteristic.

  Capacitance ↑

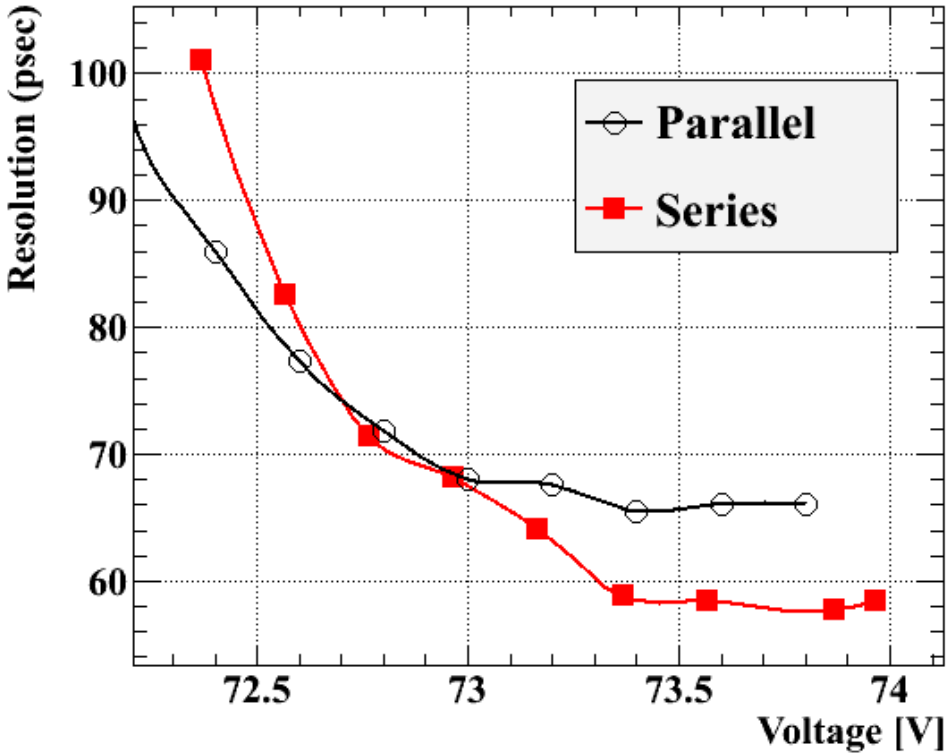
  -> waveform wider

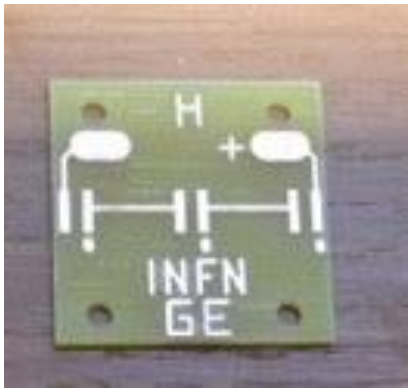
- Series

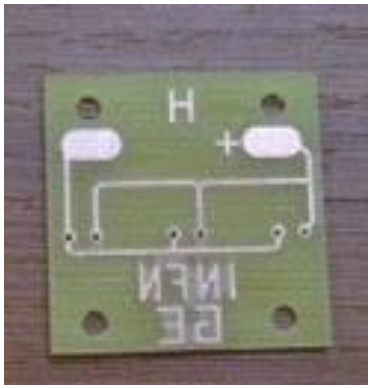
  Automatically bias voltage is adjusted.

  Waveform is sharper.

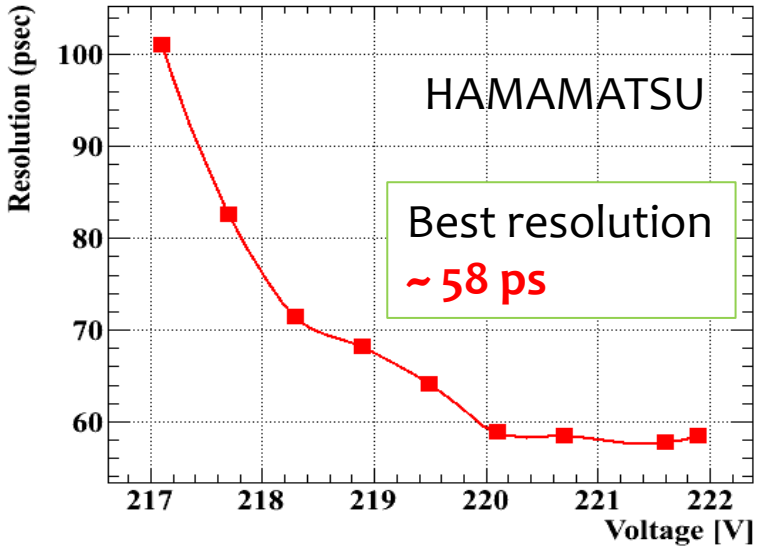
Series connection gives us better results.

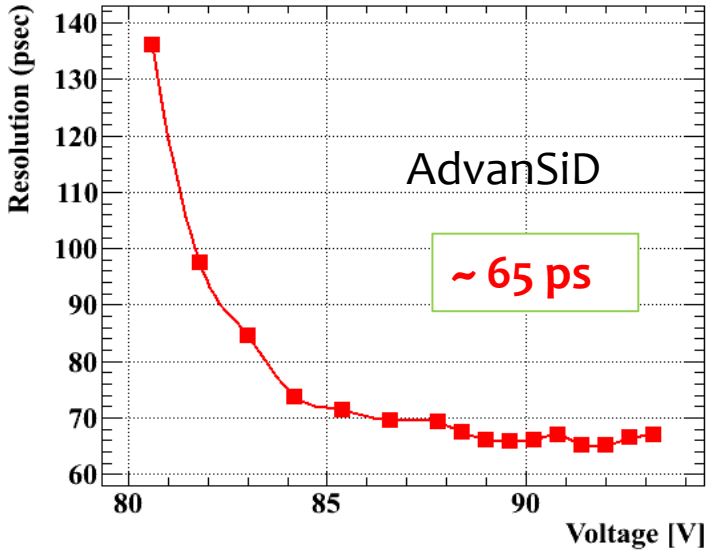


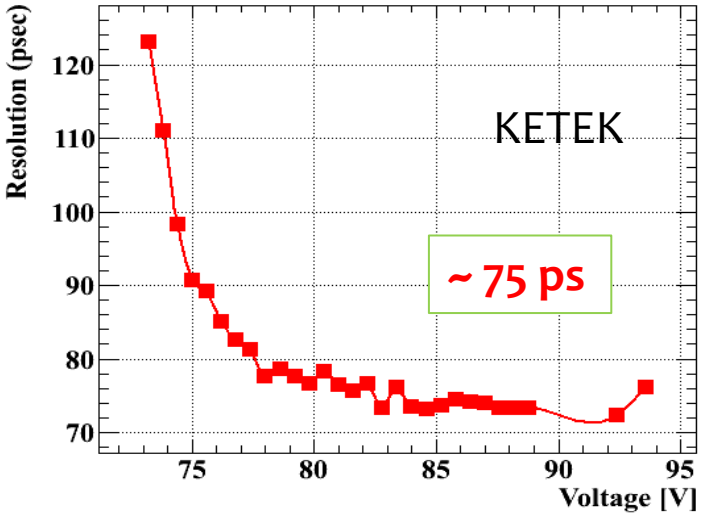




Manufacture of SiPM (Preliminary)

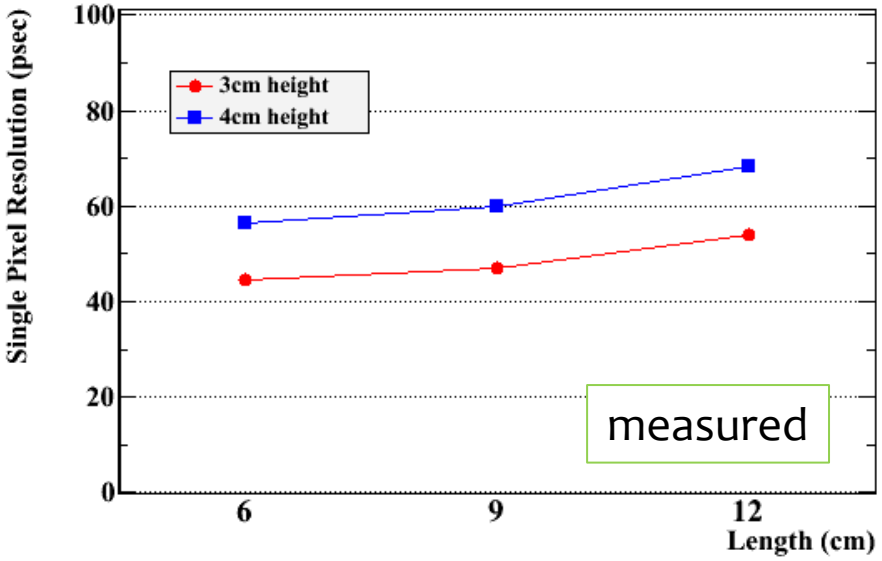


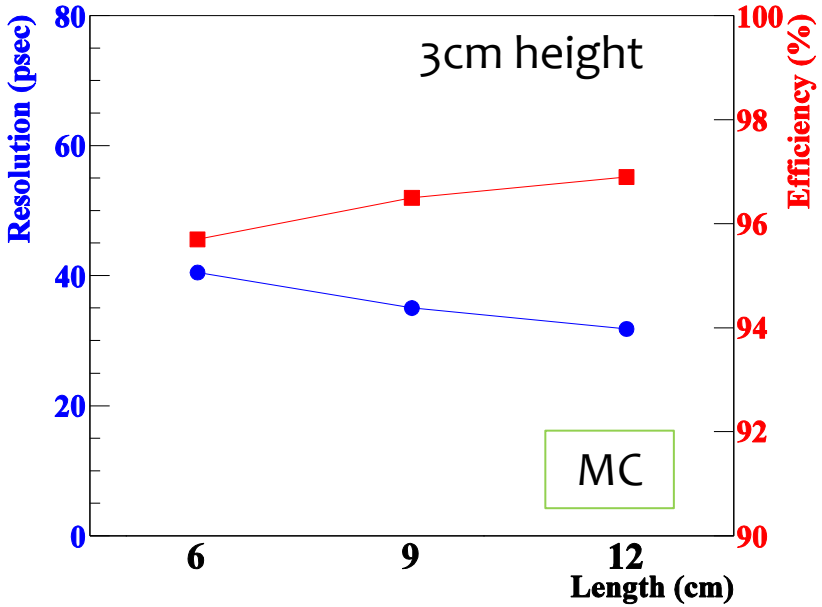




- HAMAMATSU SiPMs give us the best resolution.

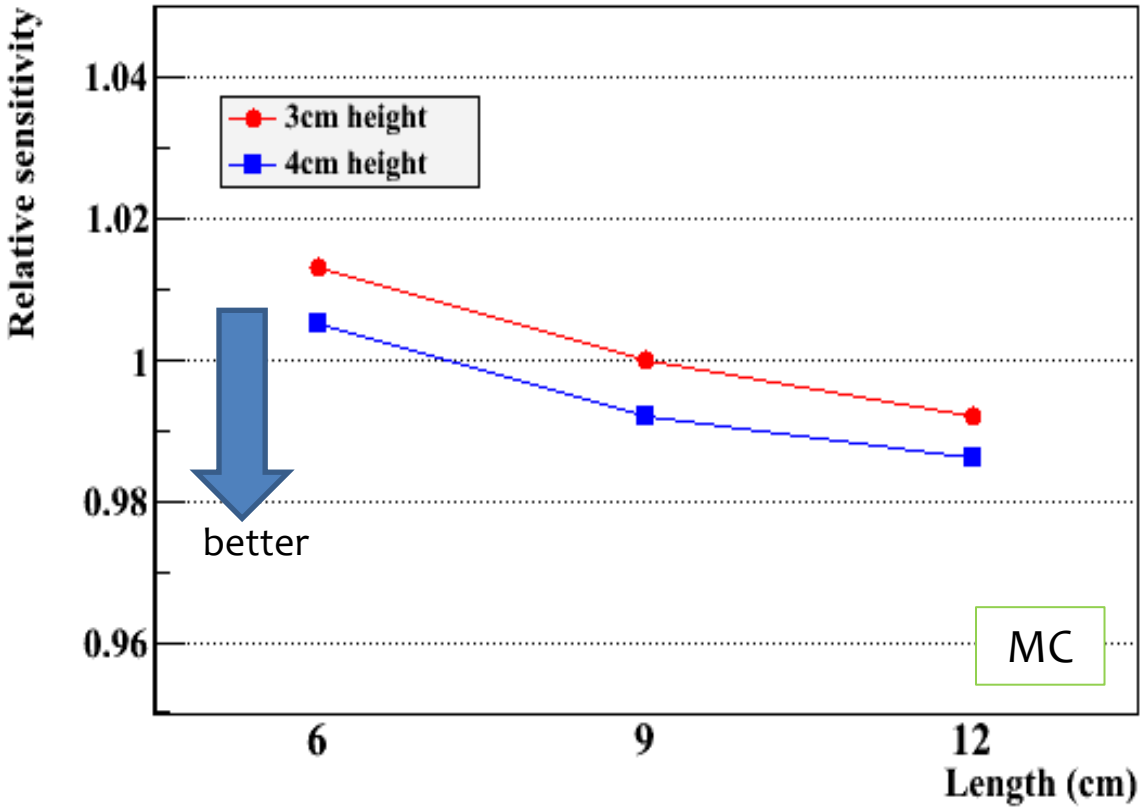
Size Optimization





- Single resolution is worse with larger pixel.
- However # of hit pixel increases with larger pixels.

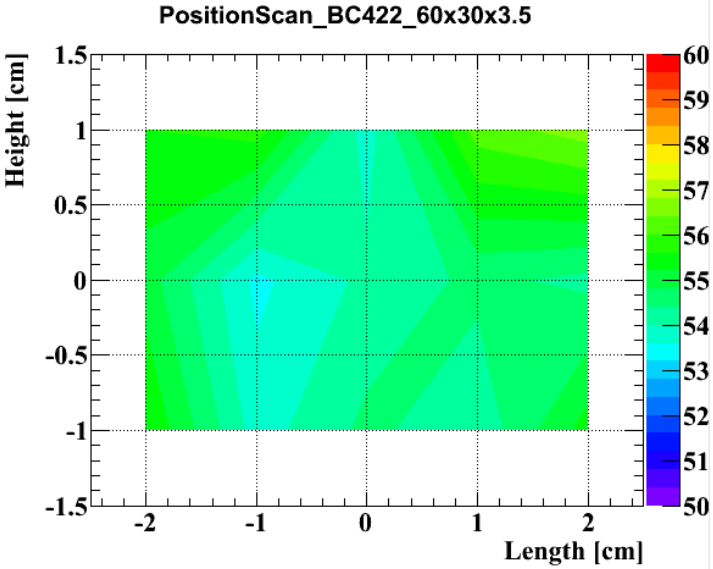
Result of size optimization

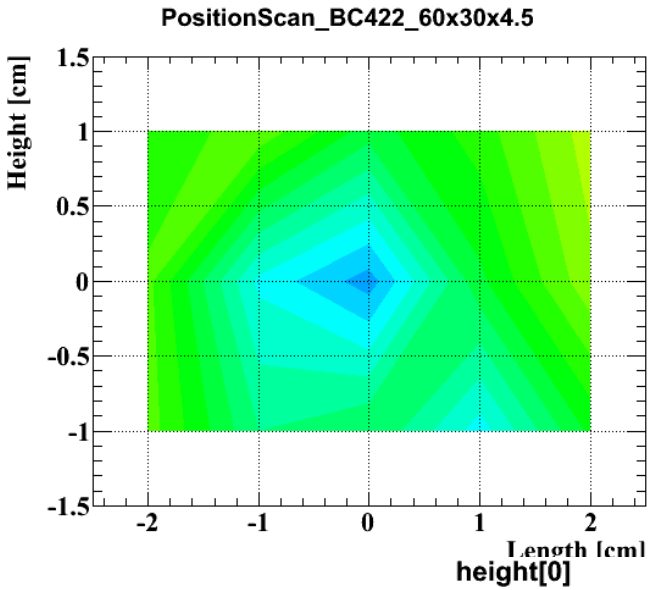


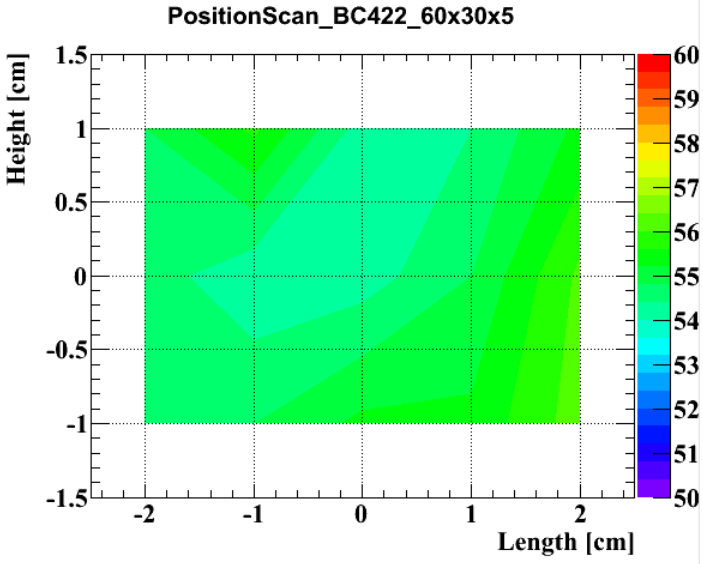
Larger pixel is better.

(Effect of high rate is not included.)

Several Thickness Test

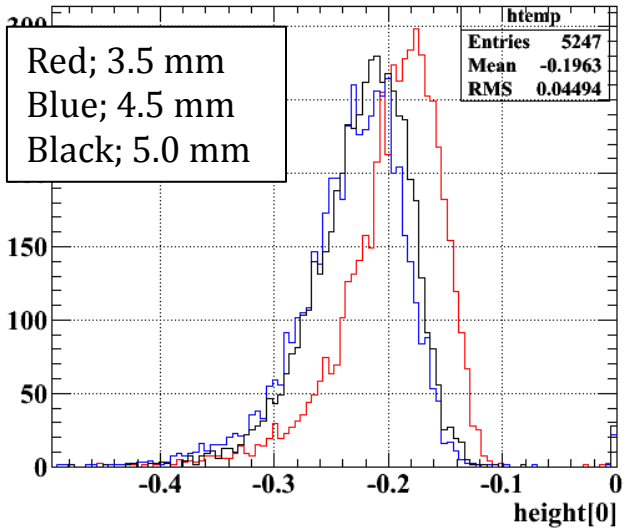






Resolution don't depend on thickness so much?

3.5mm scintillator mounting may be not good??



Scintillator Type

- Test BC418, 420, and 422 which is 90x40x5mm with 4MPPCs

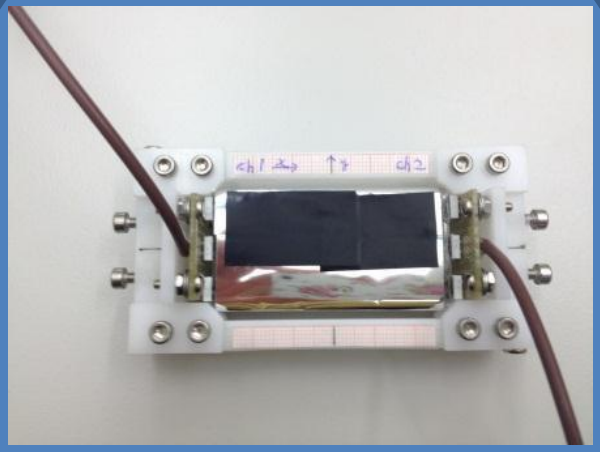
Properties	BC-418	BC-420	BC-422
Light Output [% Anthracene]	67	64	55
Rise Time [ns]	0.5	0.5	0.35
Decay Time [ns]	1.4	1.5	1.6
Wavelength of Max. Emission [nm]	391	391	370
Bulk Light Attenuation Length [cm]	100	110	8

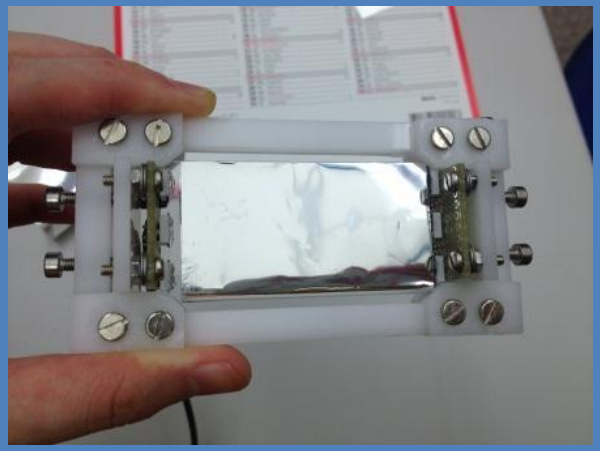
Properties of ultra-fast plastic scintillators from Saint-Gobain

Scintillator Type	Single Resolution (ps)
BC422	51.2
BC420	57.7
BC418	55.8

Wrapping Test

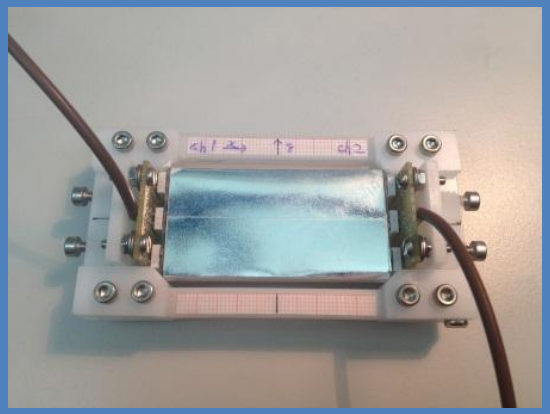
Aluminized Mylar, Teflon tape, 3M radiant mirror film





Al Mylar

Teflon

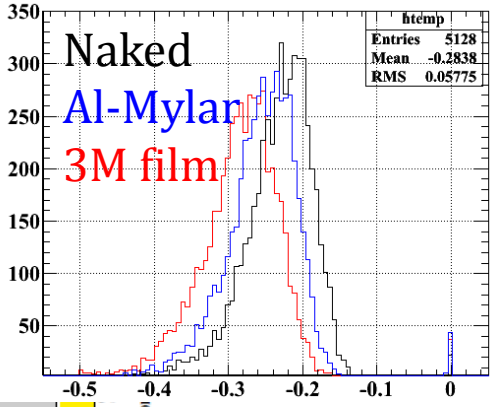


3M

Setup
BC422, 60x30x4.5 mm3
3 MPPCs in series each side
32 ns LEMO cable before preamp
Amplifier 1 kOhm
RC: 71.5 V, 2.23 uA

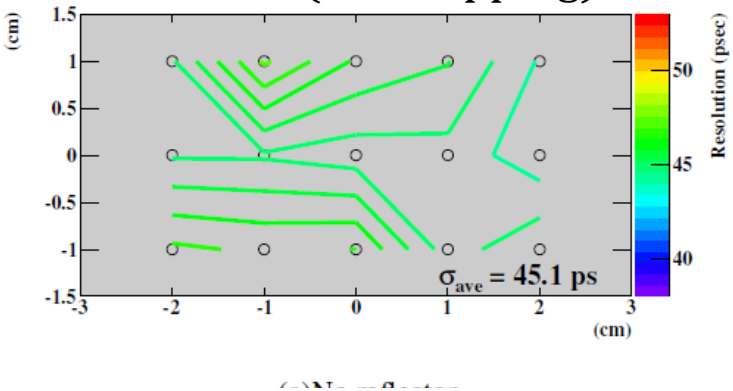
About all, position scanning was done.

Wrapping Test

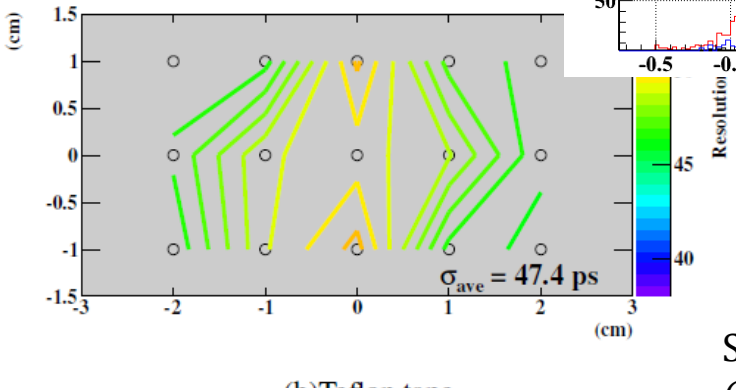


- Resolution maps

naked (no wrapping)

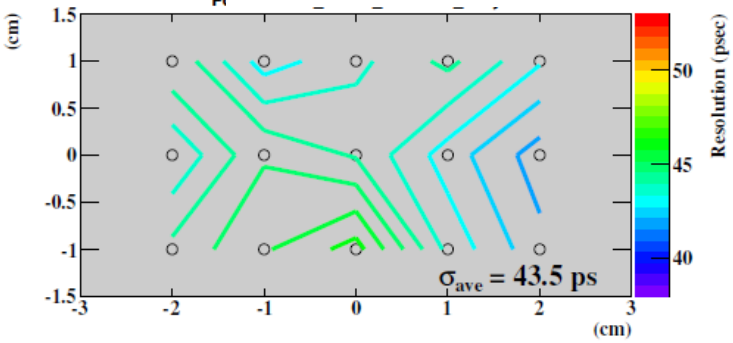


Teflon



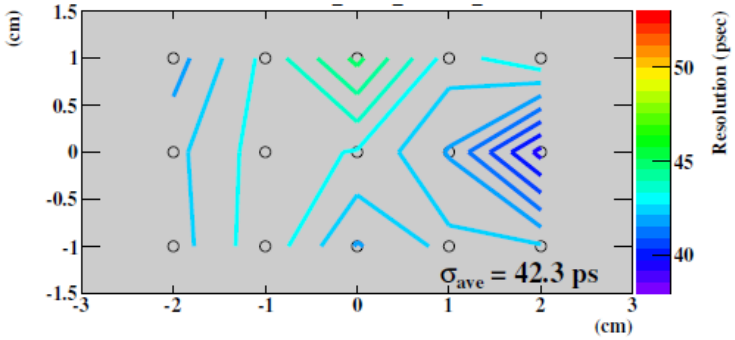
Scan 15 points
(1cm interval in X,Y)

Al-Mylar



(c)Aluminized mylar

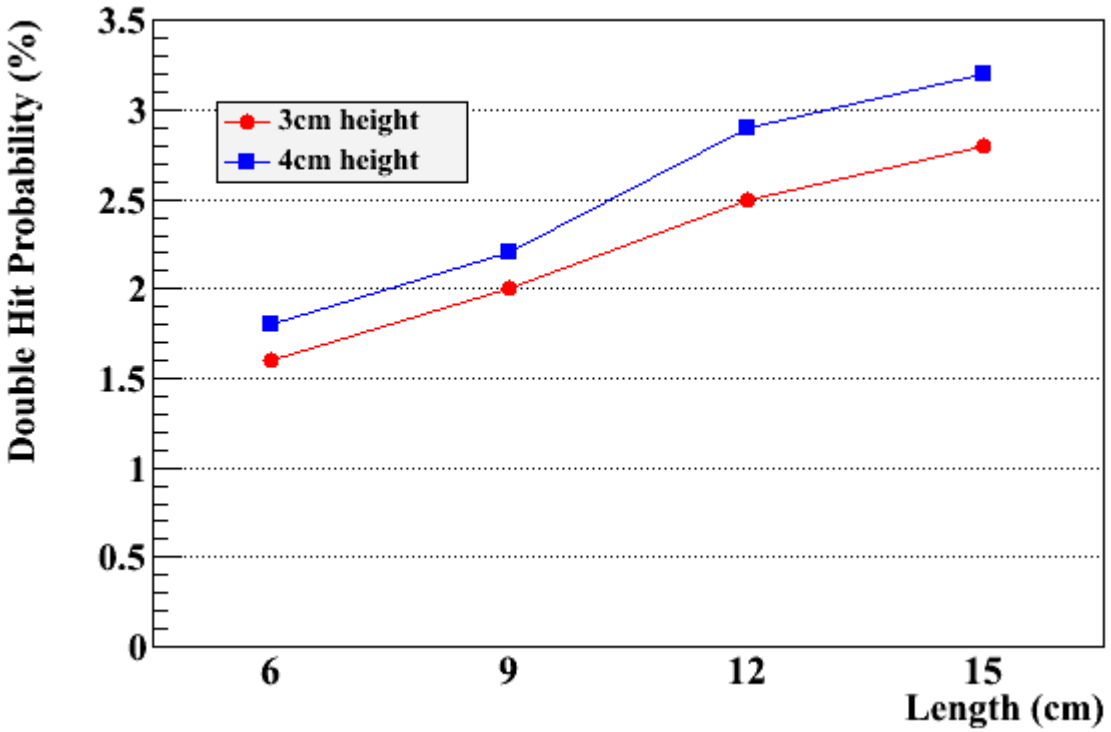
3M mirror film



(d)3M radiant mirror film

3M-film is the best for time resolution.

Double Hit



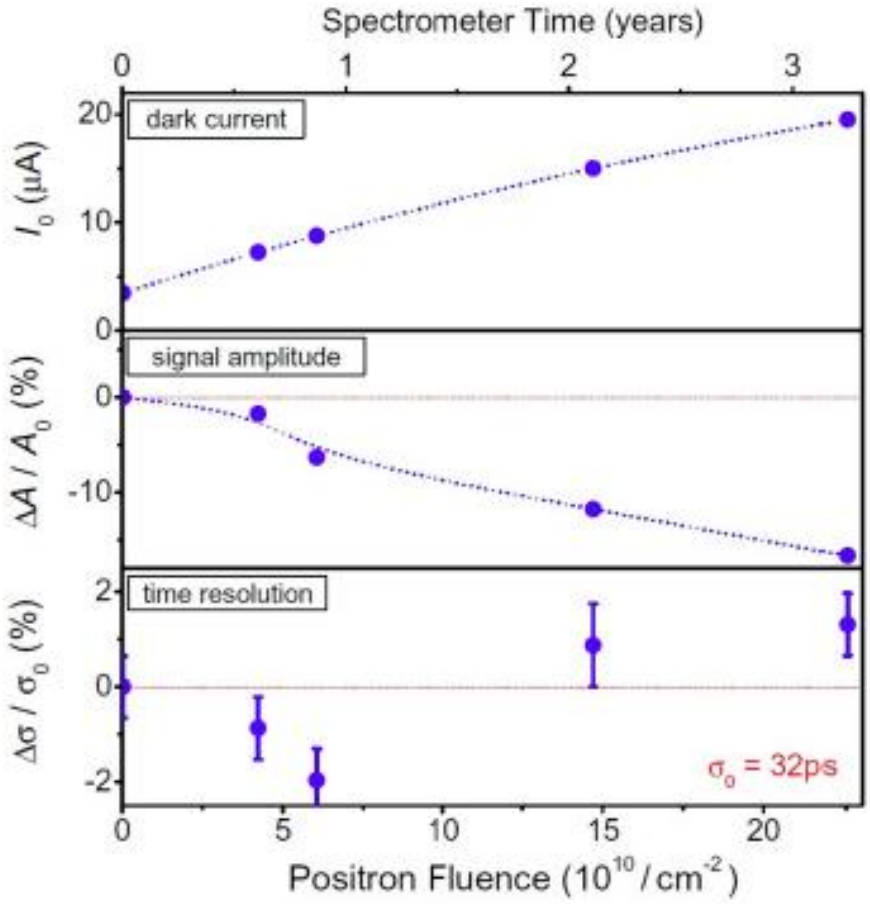
Can be ignored

Cost

Item	Cost (k€)
SiPMT-MPPC	68
Scintillator	10
Support structurer	20
Digitizers, HV	62
Cables	47
PCB	2
Connectors	17
Laser for calibration	20
Opgtical fibers	21
Reflectors	1
Total	**267**

Cost estimate for the new pixelated timing counter

Radial hardness

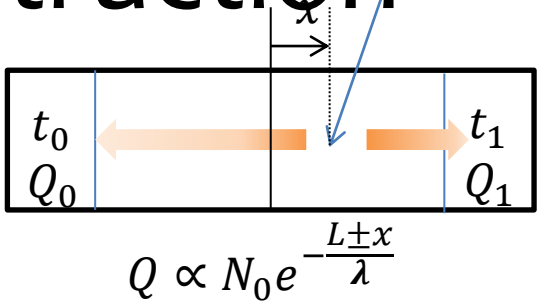


Results from the irradiation tests of Hamamatsu MPPC (S10362-33-050C) performed by the PSI SR group. Significant increase of dark current (top) and 15% gain degrease (middle) are observed, while the timing resolution is unchanged (bottom).

Courtesy of Dr. A. Stoykov of Paul Scherrer Institut.

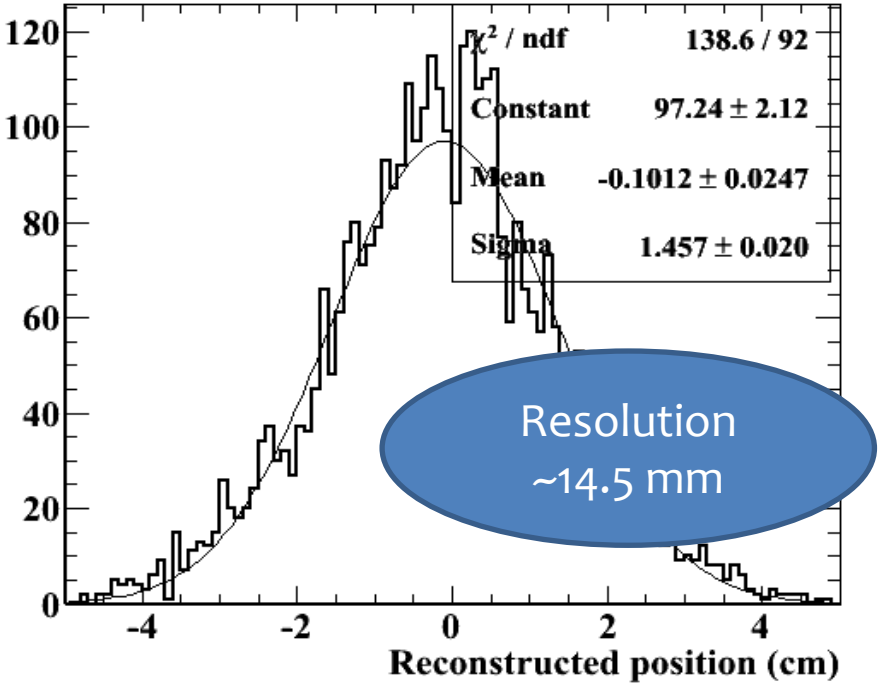
Another position reconstruction

- $x = 0.5 \times \lambda \log \frac{Q_1}{Q_0}$ -> attenuation length



$$Q \propto N_0 e^{-\frac{L \pm x}{\lambda}}$$

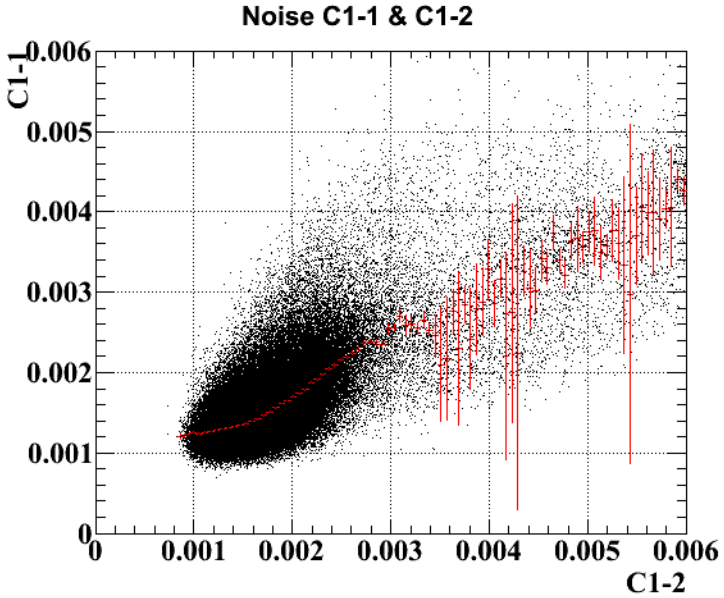
BC422

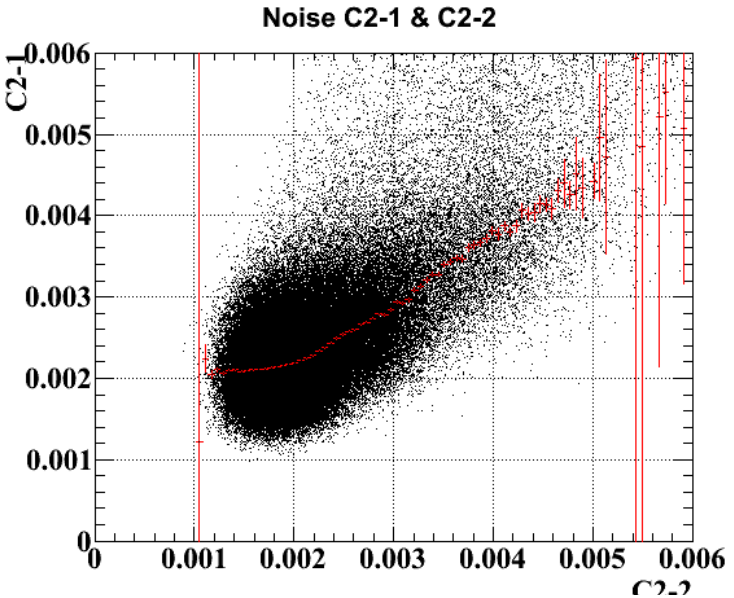


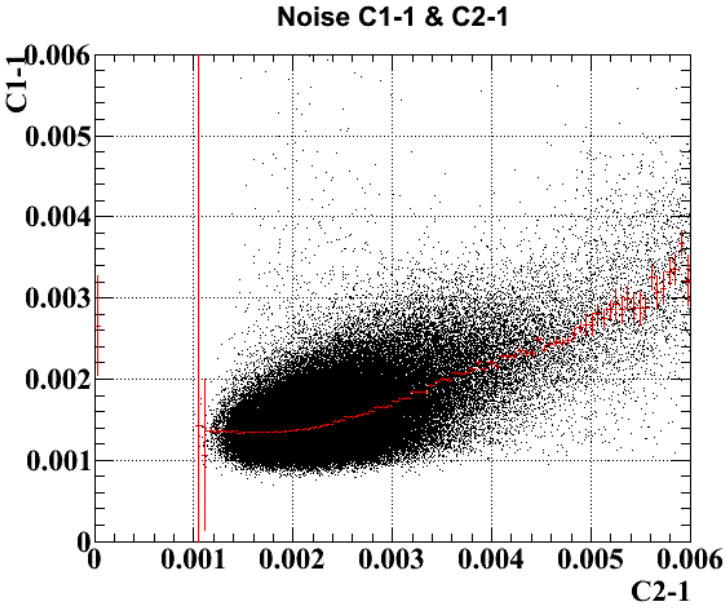
Beam test time line

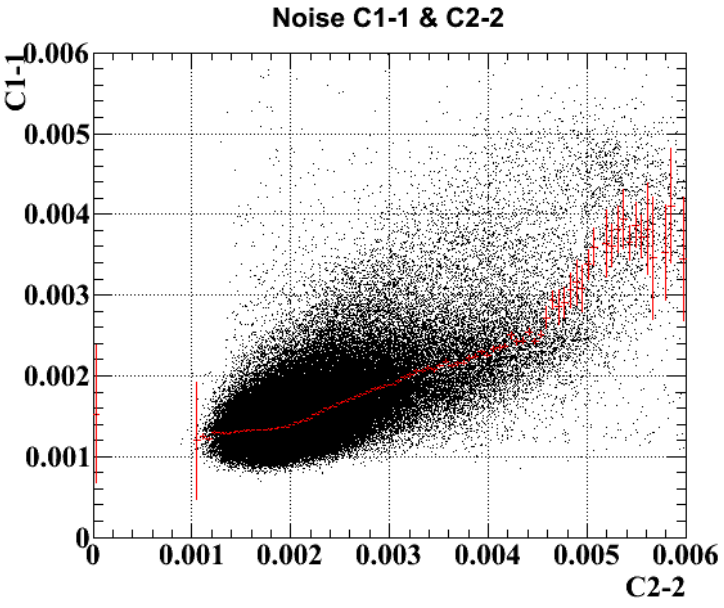
Dec. 12	Dec. 13	Dec. 14	Dec. 15	Dec. 16
Decide beam test		Counter test in lab	Counter test in lab	
Dec. 17	Dec. 18	Dec. 19 Beam Test	Dec. 20 Beam Test	Dec. 21 Beam Test
Counter Setup (light shielding and set on stands so on)	Setup in area Check if counters work with cosmic.	Setup at beam line 18:40- Beam test start parallel configuration	parallel configuration -4:00 15:50-16:15 parallel configuration 17:25-19:00 cross configuration	2:50-3:40 with one reference 4:40-5:00 staggered configuration 5:10-6:30 (beam shutdown) with two references

Noise Correlation

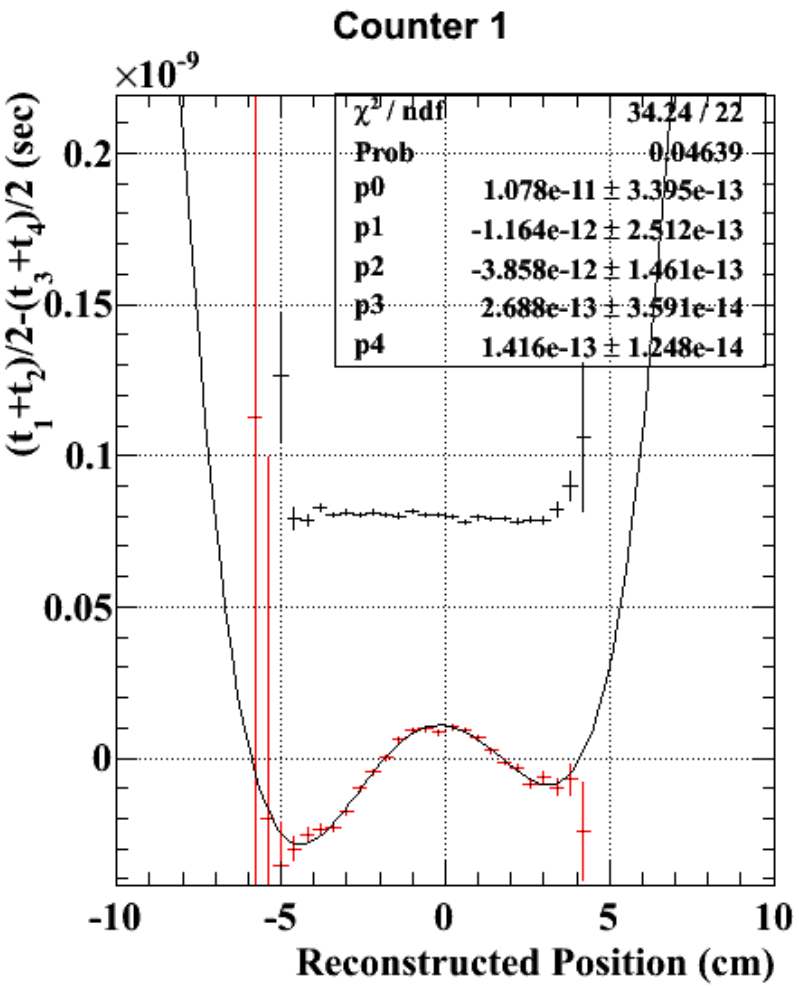


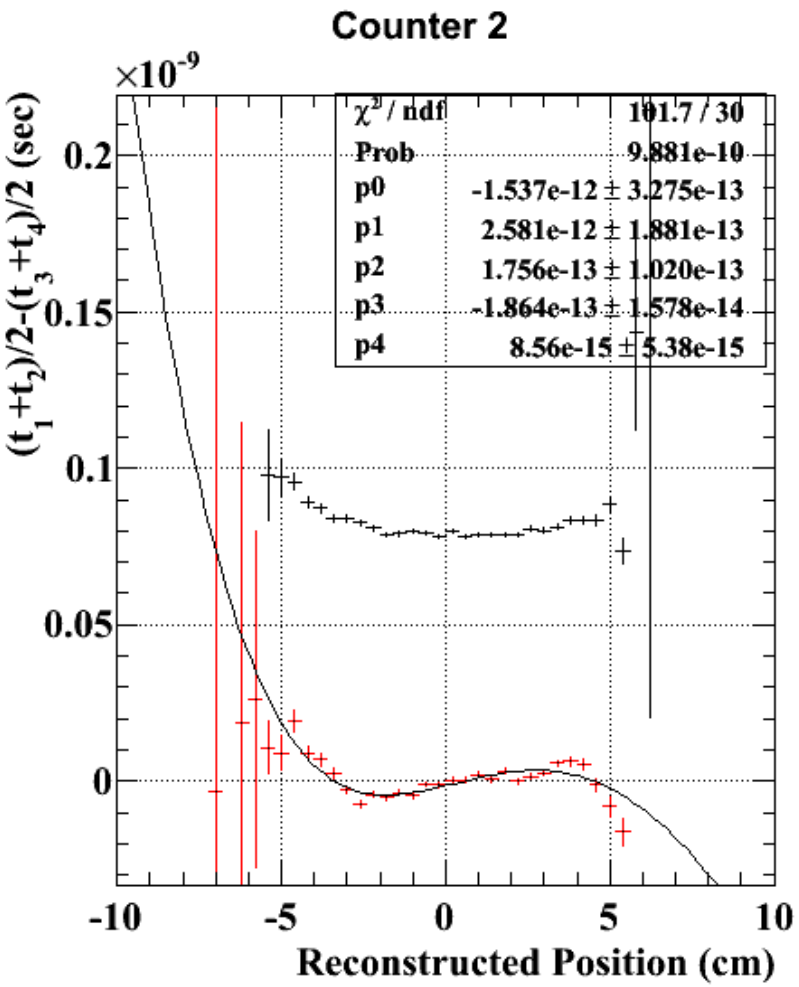




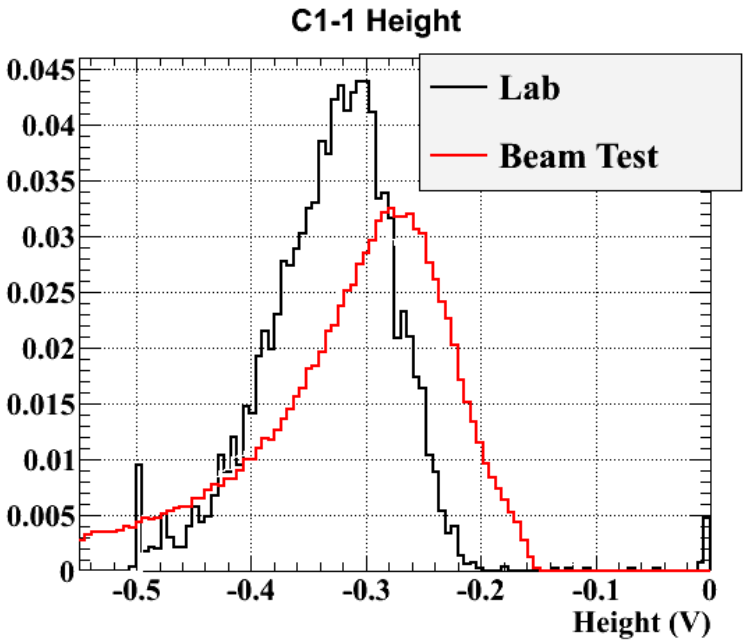


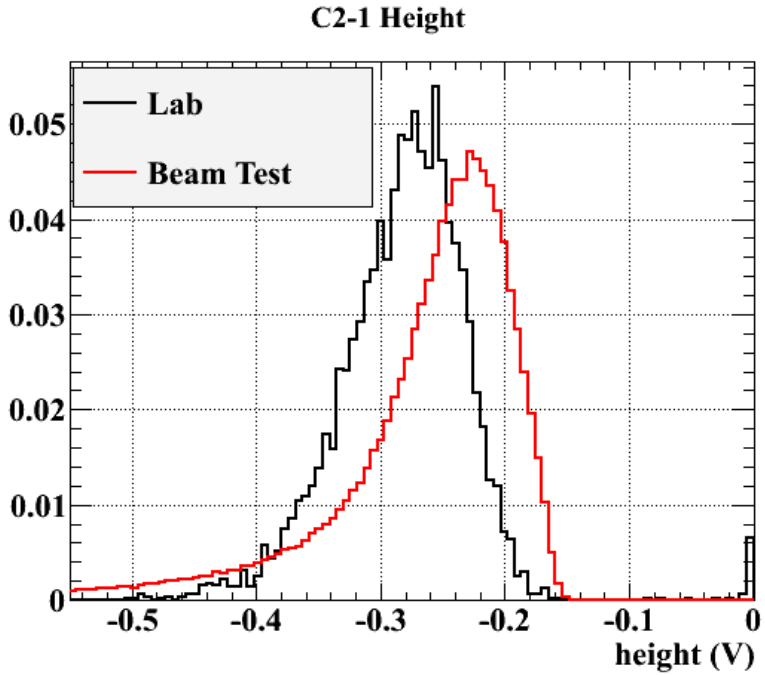
Mean Correction (Position)





Pulse height at beam test





Pulse height decreases by 13% (C1-1) and 21% (C2-1)
Expected decreasing is 10 – 20 %
(Lab: <2MeV beta from Sr90, Beam test: MIP)