MEG II実験
陽電子タイミングカウンターの
放射線損傷状況の定量的評価と改修計画

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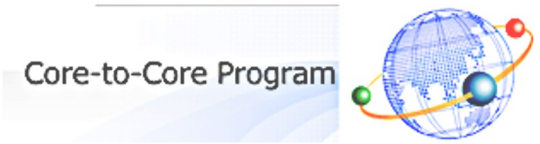
2023年9月19日(火) 日本物理学会第78回年次大会

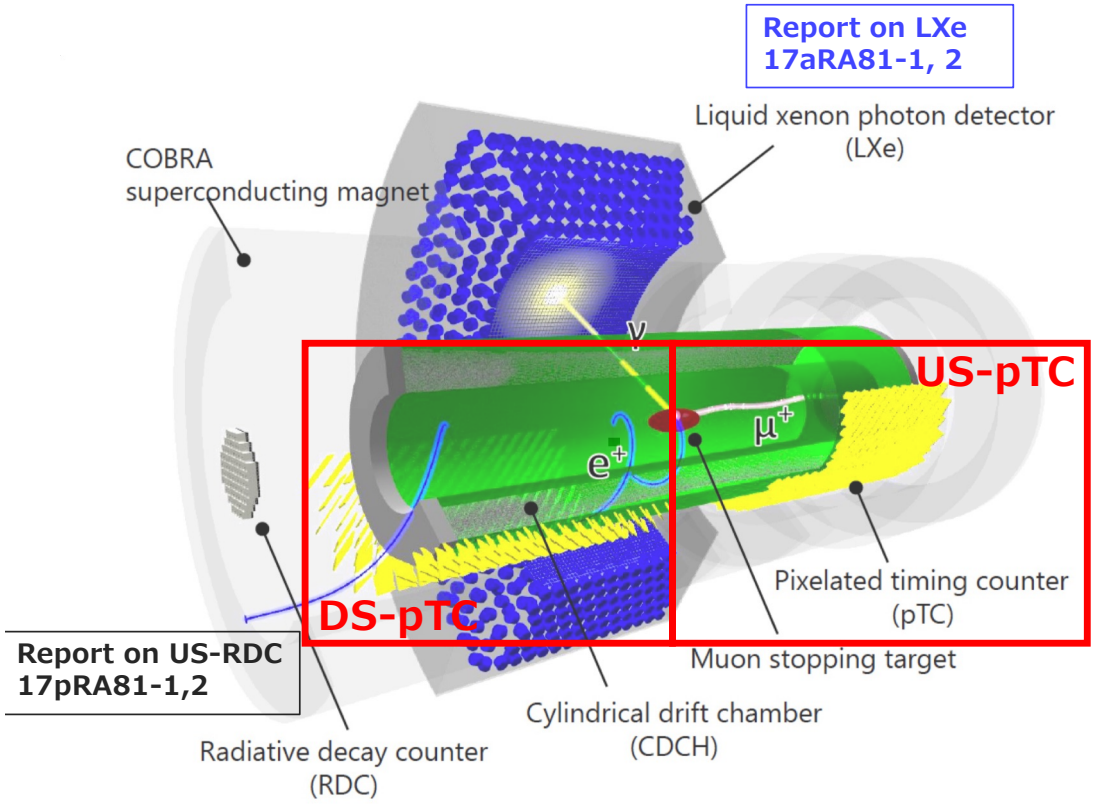
19aRC21-11



Topics

- Introduction
  - MEG II experiment
  - pixelated / positron Timing Counter (pTC)
    - pixels, performance so far
- pTC performance in physics run
  - Dark current history in 2021
  - Development on analysis side
  - Pixel refurbishment plan
- Conclusion

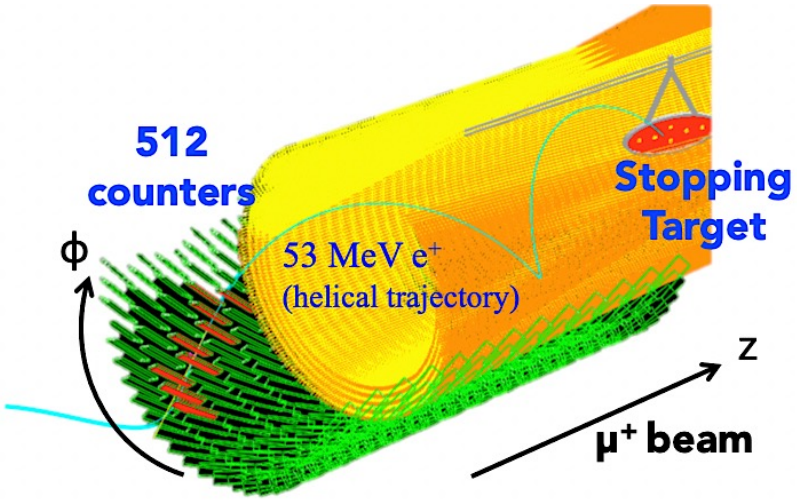
MEG II experiment

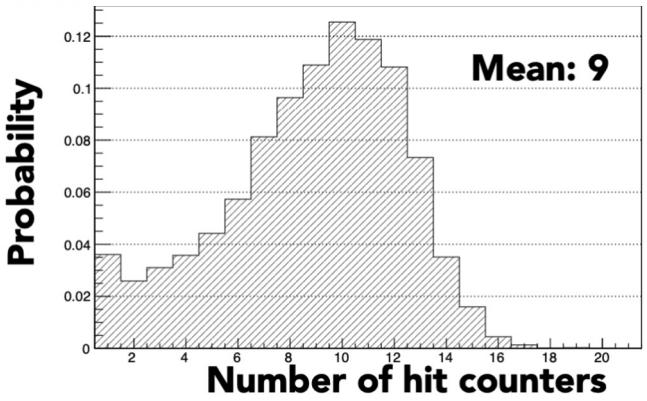


"The design of the MEG II experiment"
EPJ-C 78 (2018) 380

- Search for **cLFV** ($\mu \to e\,\gamma$) with aimed sensitivity: **6 x 10^{-14}**
- An order better from the MEG result (2016) : $\mathcal{B}(\mu \to e\,\gamma) < 4.2 \times 10^{-13}$
- The physics data acquisition
  - General report: 18aRD11-5
  - 2021 analysis: 18pRA34-7, 8
  - 2022: finalizing calibrations
  - 2023: DAQ going well

pixelated Timing Counter (pTC)

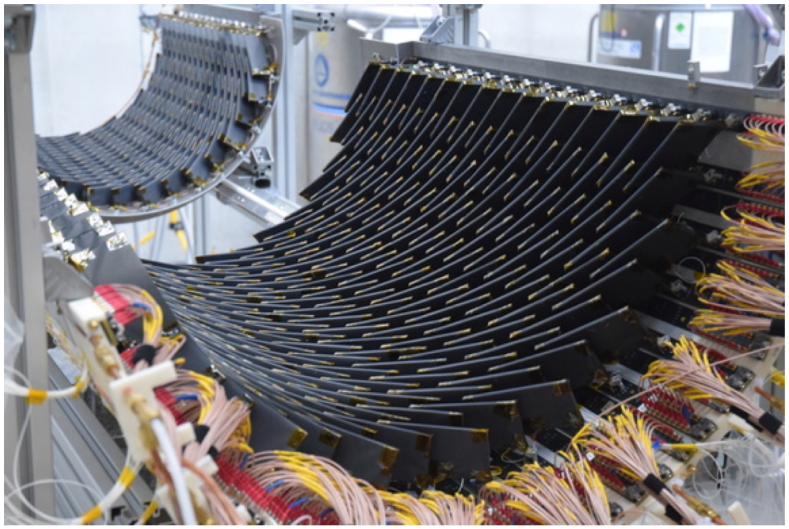


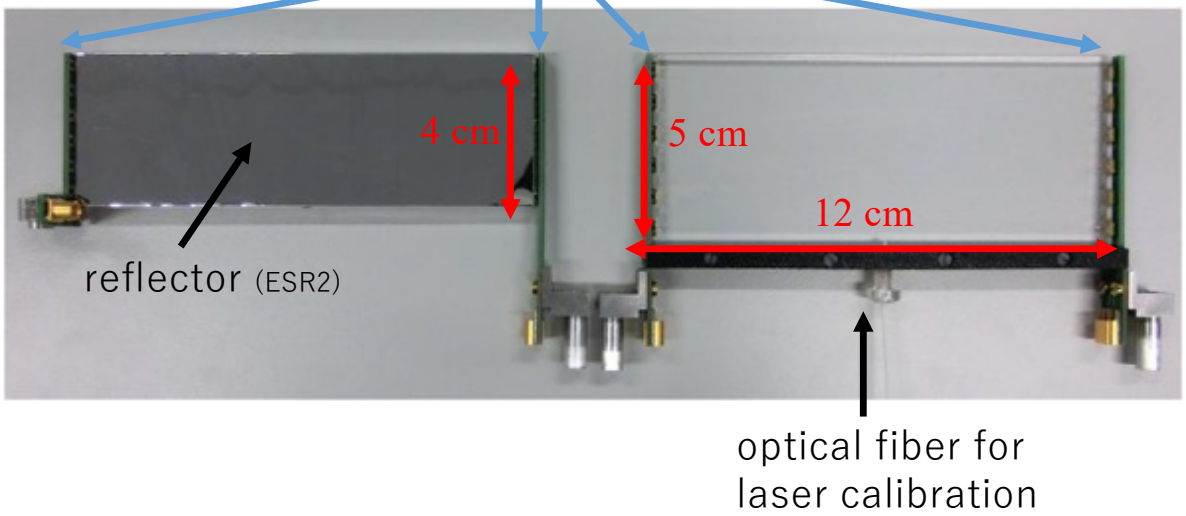


Concept

- **Improve e^+ time resolution by multiple-pixel-hit scheme.**
- Upstream 256 + Downstream 256 = **512 pixels**
- Mean ~ **9 hits** (MC, signal e^+)

pTC: pixels



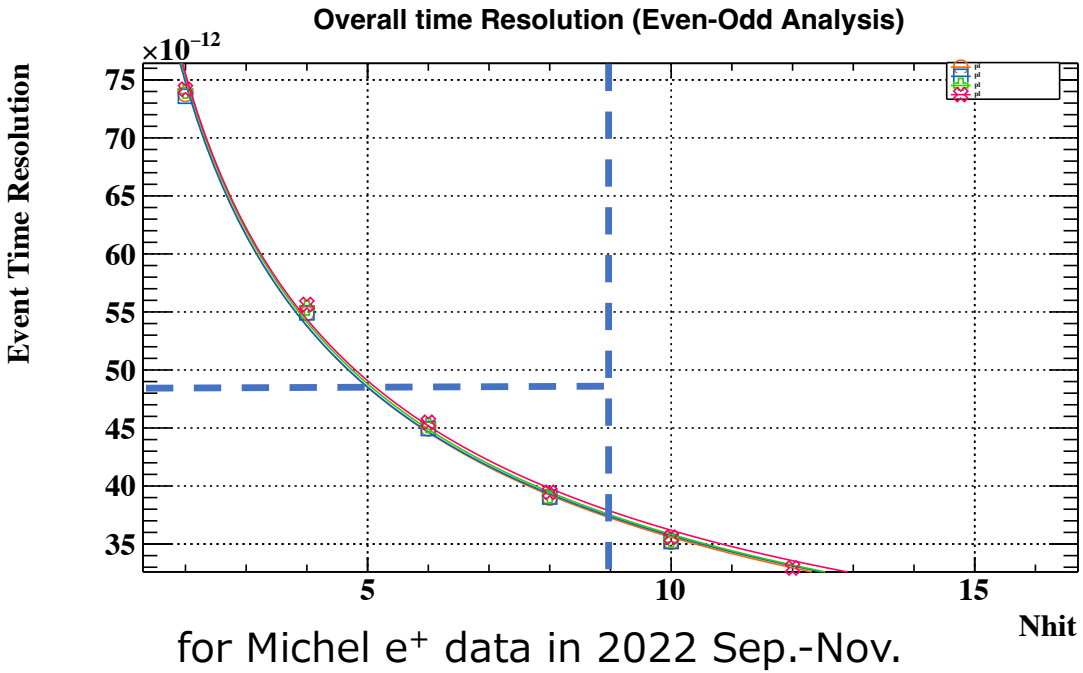


- **Upstream 256 + Downstream 256 = 512 pixels**
- **12 cm × 5 cm (4 cm) × 5 mm** plastic scintillator (BC422).
- Read by series connection of **6 SiPMs** on both side.

(AdvanSiD, ASD-NUV3S-P High-Gain, 3 x 3 mm^2, 50 x 50 μm^2, $V_{breakdown}$ ~ 24 V).

pTC: performance so far

$$\sigma_{\mathrm{pTC}}(N_{\mathrm{hit}}) = \sqrt{\frac{\sigma^2_{\mathrm{intrinsic}} + \sigma^2_{\mathrm{inter-pixel}}}{N_{\mathrm{hit}}}} + \mathrm{const.}$$



for Michel e⁺ data in 2022 Sep.-Nov.

- The estimated time resolution at 9 hits is **37 ps**.
- $\sqrt{\sigma^2_{\mathrm{intrinsic}} + \sigma^2_{\mathrm{inter-pixel}}}$ **~ 110 ps**

precision of the timing calibration

Period	t_{e^+} resolution for 9 hits
2022 Sep.	37.2 ps
2022 Oct.	37.4 ps
2022 beg. Nov.	37.5 ps
2022 mid. Nov.	37.8 ps

Dark current history in 2021

- 93 Days in 2021 + 1 Day ref. in 2023
  - To follow in the same HV config.
  - After 171 Days under muon beam.
    (108 in 2022 + 63 in 2023)

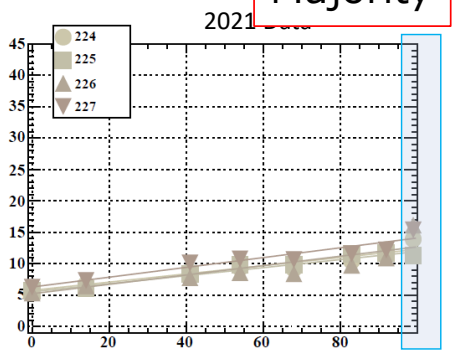
- Almost all the pixels show the similar increment.
  - **By +5 - 10 μA for 264 Days.**

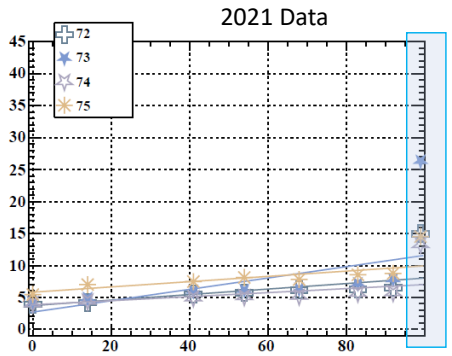
- Prediction (converted from 宇佐見@'17秋季大会)
  - +5 - 7.5 μA
  - 2 x 10^{10} ~50-MeV-positrons /cm^2 ~ 6 Gy
  - eff. NIEL -> 10^9 1-MeV-neutrons /cm^2

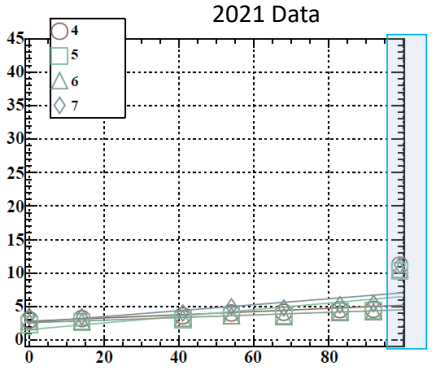
2021 Current + 2023 Current at 2021 HV conf.

from 16 Aug. to 17 Nov. (2021) + on 9 Aug. (2023)

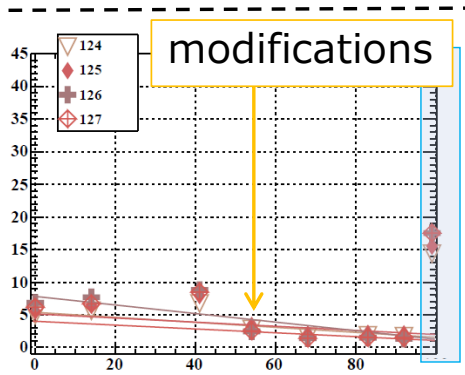
Majority





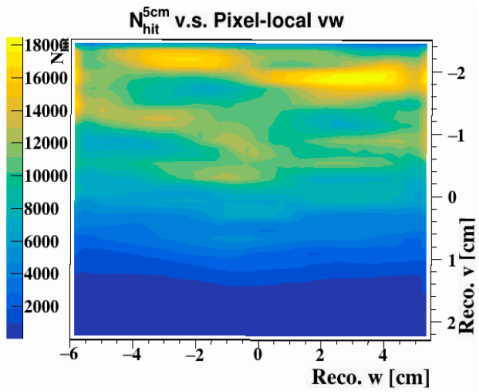


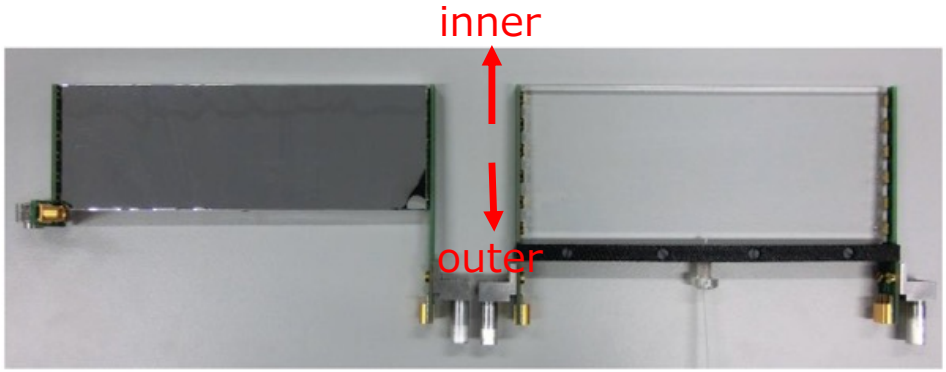
modifications



Development in analysis side

- Radiation damage accumulates more on the inner side of SiPMs.





- It causes a difference of the response of pixel, on the hit position of a passing particle.
  - Regard as time offsets depending on the hit position.
  - Offset correction resolves the problem.

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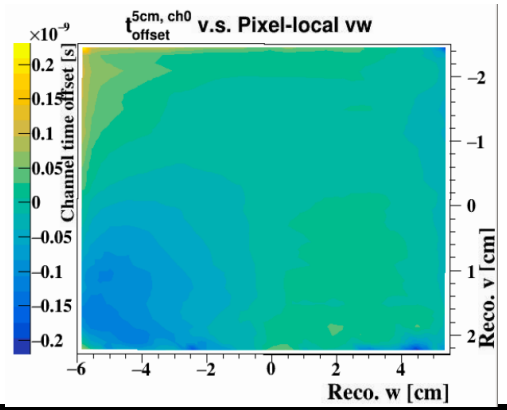
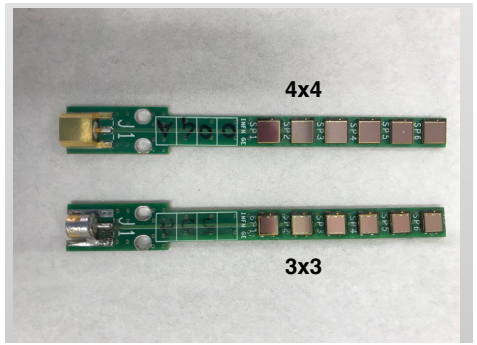
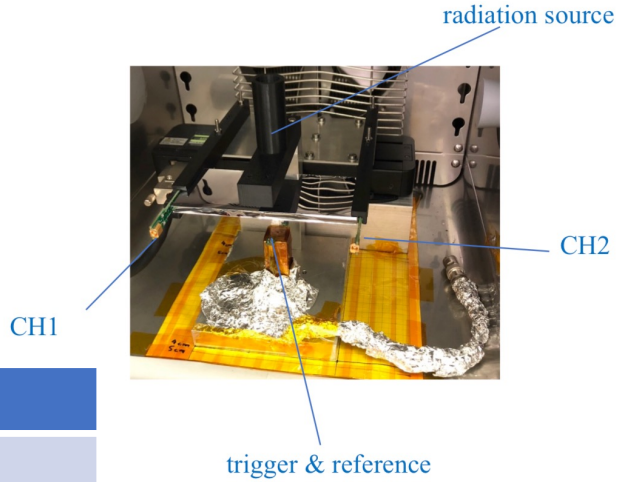


Pixel refurbishment plan

- SiPM: ASD-NUV3S-P (**3x3 mm²**) -> ASD-NUV4S-P (**4x4 mm²**)



- Performance of pixels



Lots (model)	Lab. test	in operation
2017 (ASD-NUV3S-P)	80 – 90 ps	90 – 100 ps
2018, 2021 (ASD-NUV3S-P)	70 ps	80 ps
2022, 2023 (ASD-NUV4S-P)	70 ps	80 ps ? (expected)

- About 100 pixels to be exchanged.
  - Priority on the most damaged pixels.
  - After SiPM delivery, probably on maintenance at the beg. of 2024

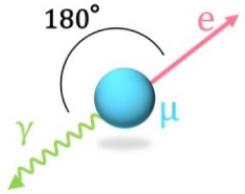
Conclusion

- MEG II timing counter has been on long-term operation.
  - Dark current increment (~10 uA) shows its radiation damage.

- Analysis improvement and pixel refurbishment will resolve them for coming years of MEG II run.
  - Position dependence of radiation damage can be corrected as position-dependent time walk.
  - A new lot of 1000 SiPMs (~100 pixels) are being prepared for the refurbishment.

Back up

MuEGamma Decay



- One of charged lepton flavor violating (cLFV) decays, which is forbidden in the Standard Model.

- Many of the new physics beyond the Standard Model (BSM) predict that the branching ratio is $\mathcal{O}$ (10^{-13}) – $\mathcal{O}(10^{-14}$) where an undiscovered particle in $\mathcal{O}(10)$ TeV mediates the process.

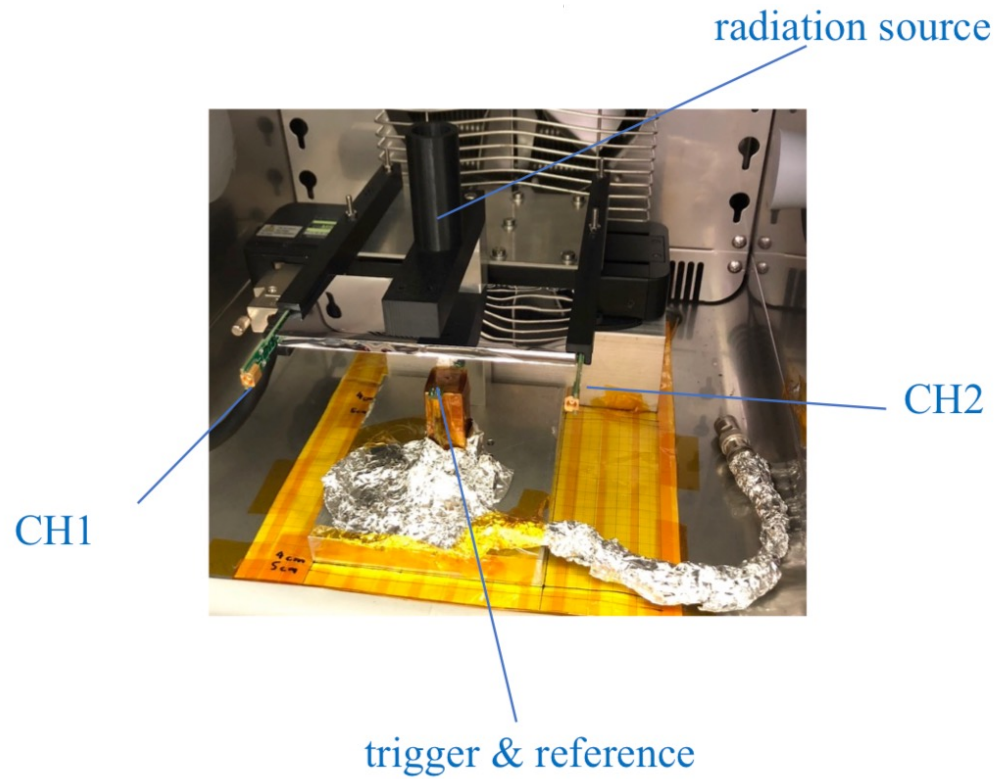
- Upper limit on the branching ratio was obtained by the MEG experiment: $\mathcal{B}(\mu \to e\,\gamma) < 4.2 \times 10^{-13}$ (90% C.L.)

Resolution Lab. test

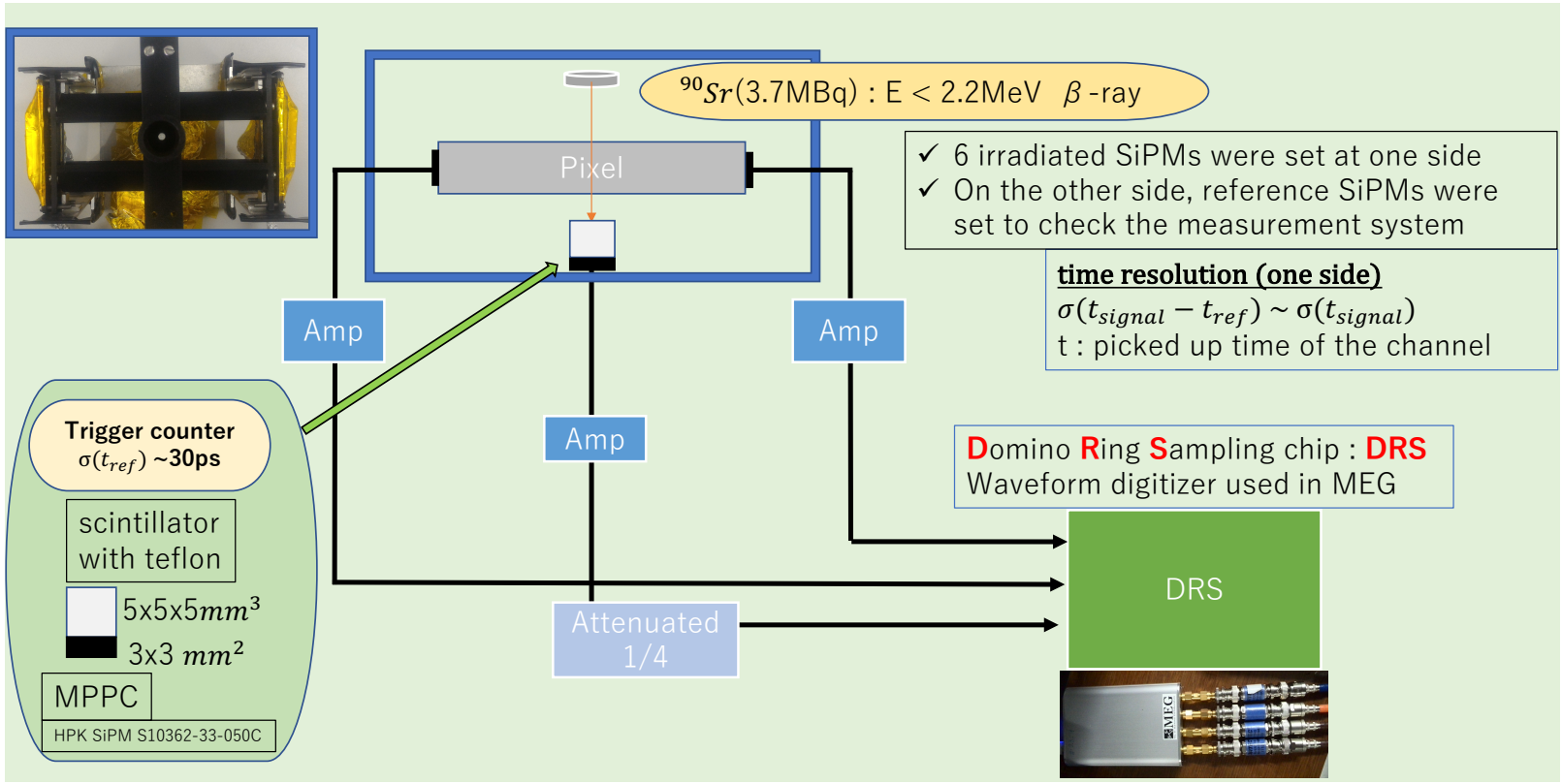
- Set a pixel to the moving stage in a thermal chamber (~30 degC).
- Apply V_{bd} + 24 V to each PCB.
- Triggered with β-ray source (Sr^{90}) and reference counter, to obtain time resolution for

$$t = (t_1 + t_2)/2 - t_{ref}$$

at three positions.



Resolution Lab. test



Time resolution evaluation

- $t_{\mathrm{ave}} := \frac{1}{n_{\mathrm{hit}}} \sum (t_i^{\mathrm{reco}} - t_0^{\mathrm{reco}} - TOF_{i,0})$

(single pixel / channel)

- $t_{\mathrm{even}} := \frac{1}{n_{\mathrm{hit}/2}} \sum (t_{2i}^{\mathrm{reco}} - t_0^{\mathrm{reco}} - TOF_{2i,0})$

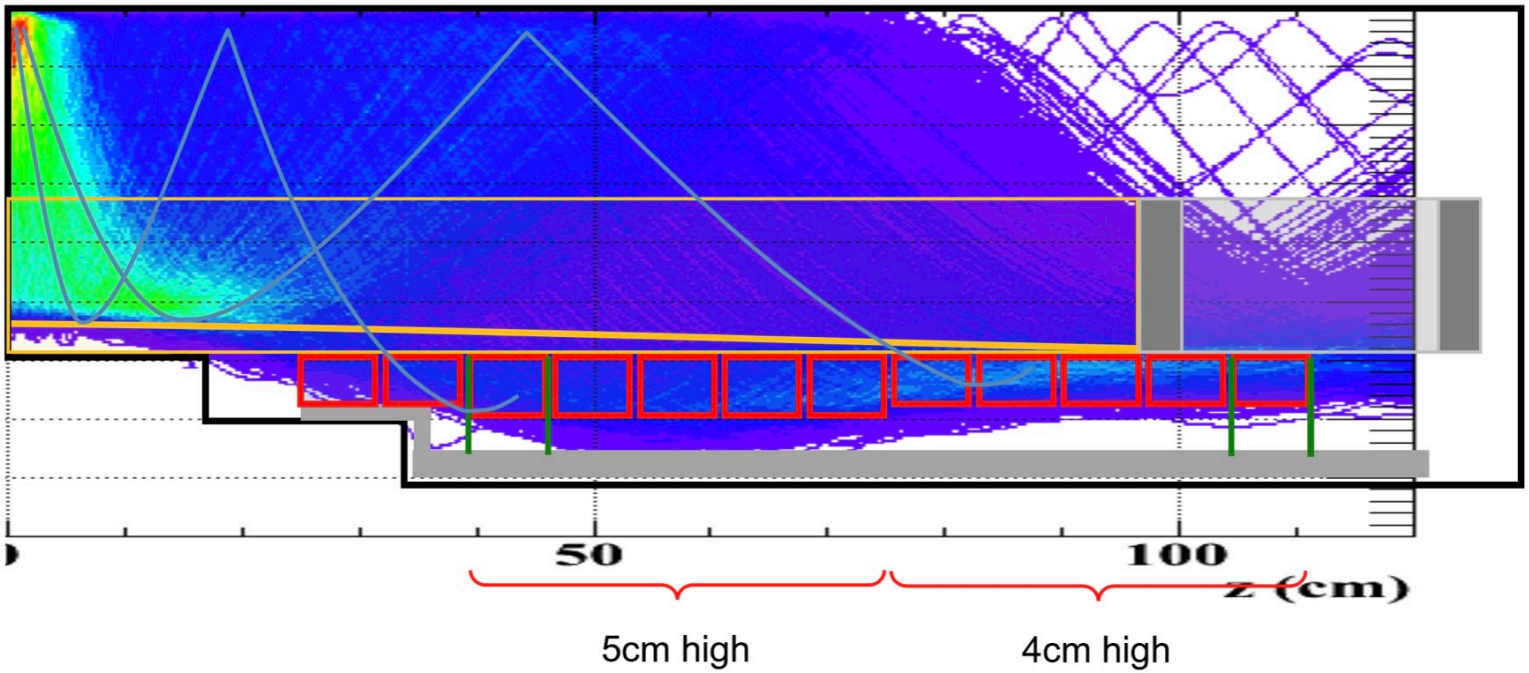
$t_{\mathrm{odd}} := \frac{1}{n_{\mathrm{hit}/2}} \sum (t_{2i+1}^{\mathrm{reco}} - t_0^{\mathrm{reco}} - TOF_{2i+1,0})$

$\sigma(N_{\mathrm{hit}}) = \sigma(t_{\mathrm{even}} - t_{\mathrm{odd}})$ **(even-odd)**

- 2 complemental methods.
  - Single counter resolution evaluation, depends on the tave from nearby counters.
  - Even-odd analysis is not sensitive to 1st order of i-th systematics on the tracking.

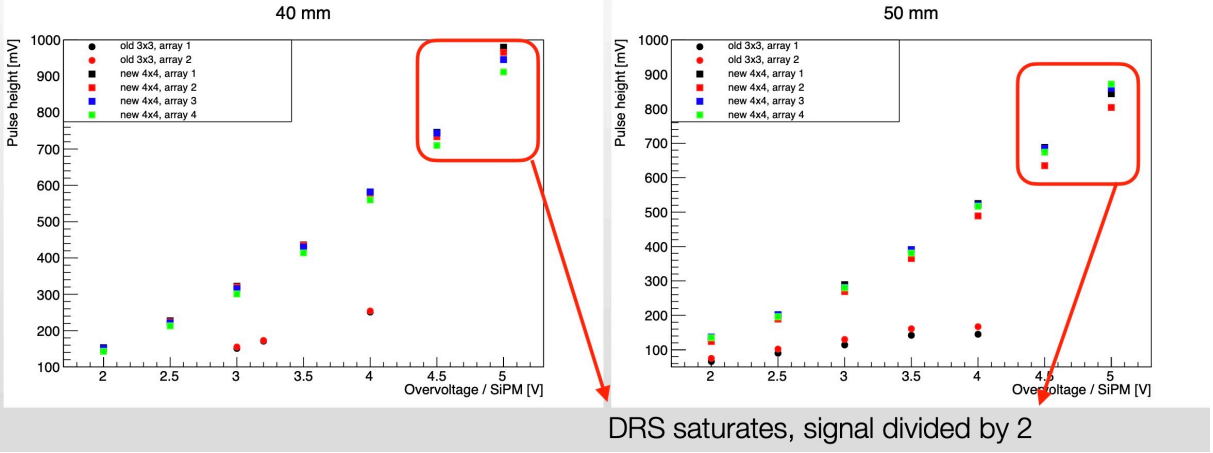
Pixels

- 4cm, 5cm

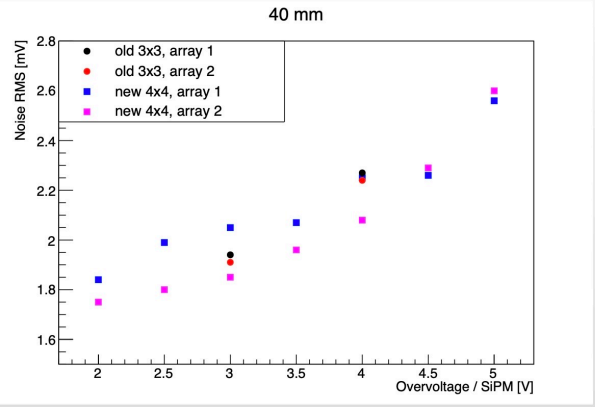


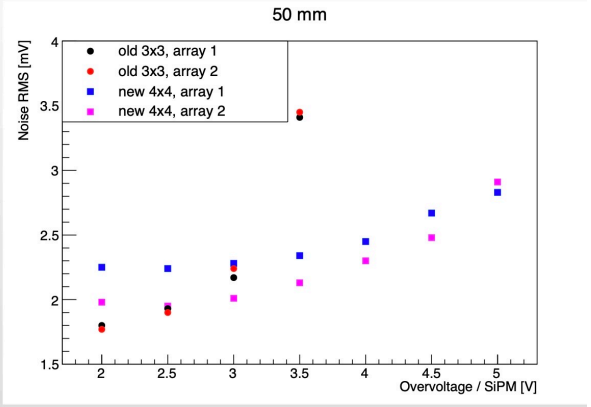
New Pixels

- 4cm, 5cm



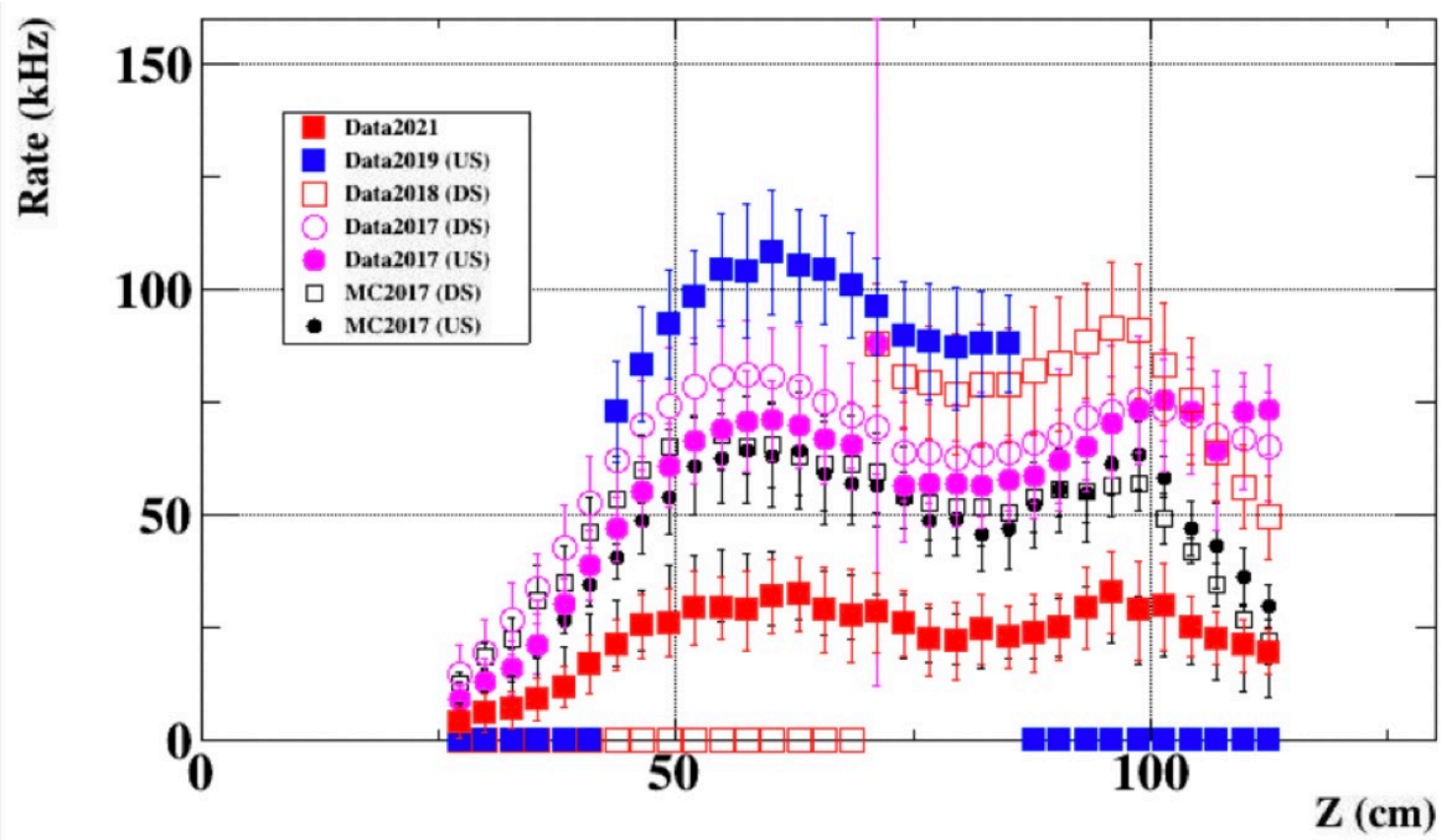
DRS saturates, signal divided by 2





Hit rate

- 2017 – 2021 ~ generally halved



Presumed increment

- Muon beam
  - 2021: 93 Days (16 Aug – 17 Nov)
  - 2022: 108 Days (1 Aug – 17 Nov)
  - 2023: 63 Days (7 Jun - 9 Aug)

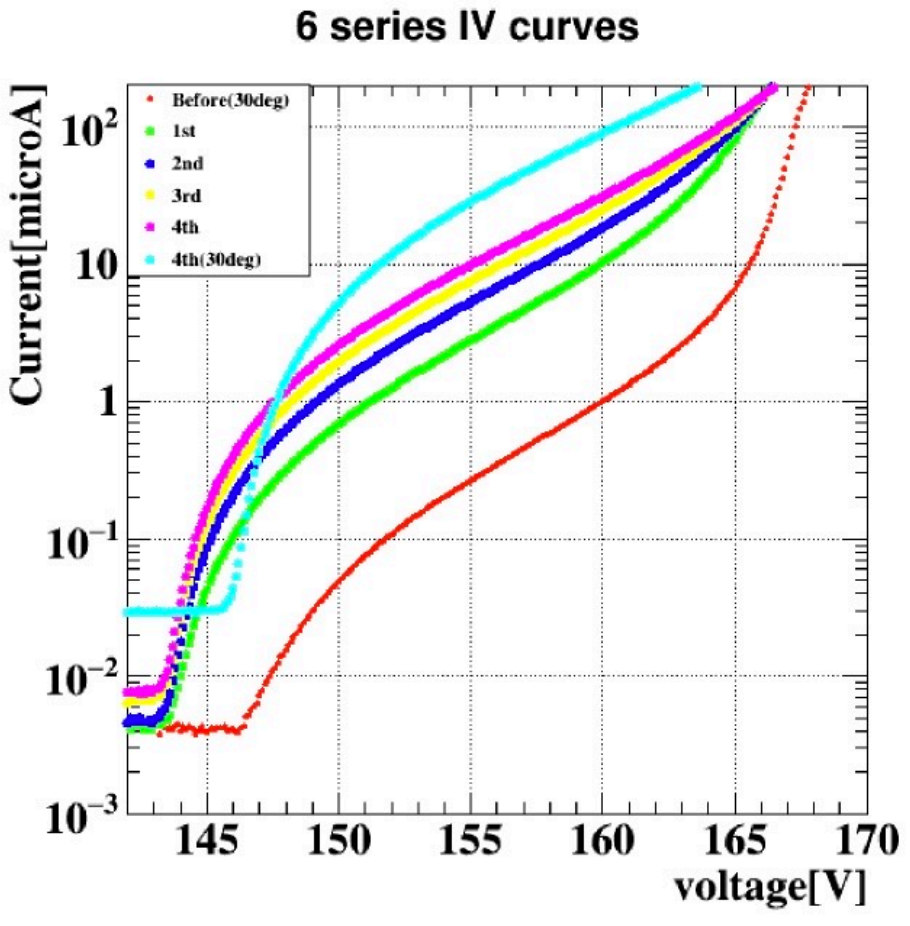
- Presumed increment
  - ~100 uA (from 2017 commissioning)
  - 525 days, 30 degC

$$0.2346\ \mu A \times \frac{24\ \text{hours}}{31\ \text{hours} + 55\ \text{min}} \times 7\ \text{days} \times (25 \times 3)\ \text{weeks} \sim 93 \mu A \qquad (5.1)$$

Irradiation test (‘16-’17)

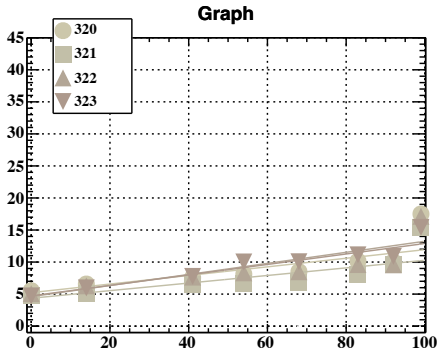
- equivalent to
  +100 uA increment for 160V

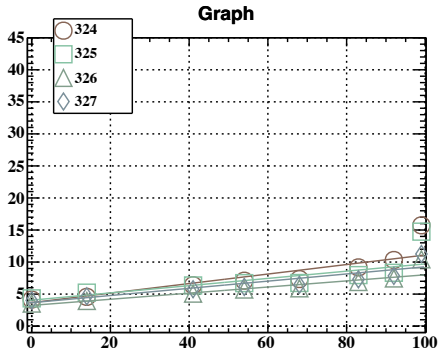
  -> +30 uA @ 10 degC

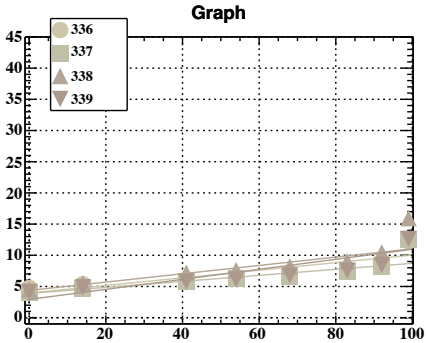


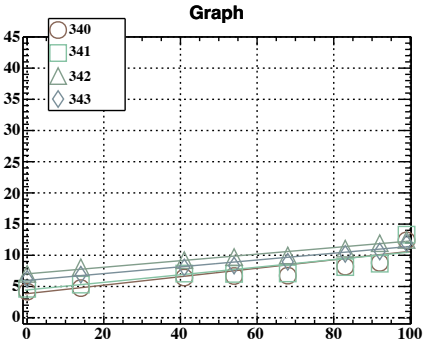
Examples (1, DS-pTC)

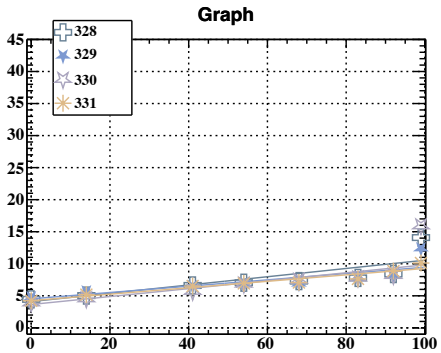
- Number = channel No.
  (e.g. pixel 0 contains ch0-1, pixel 1 contains ch2-3)

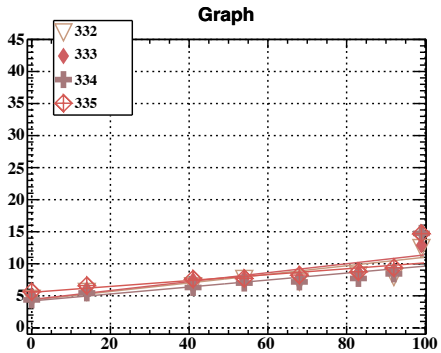


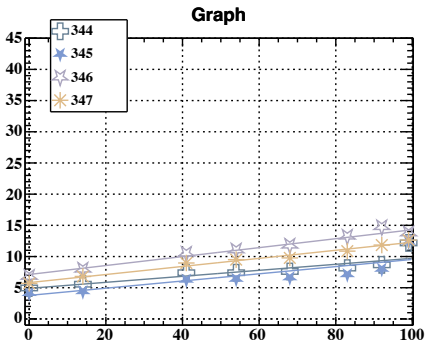


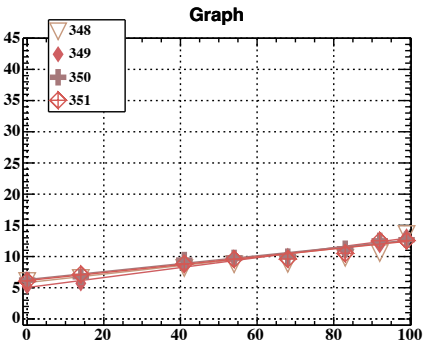






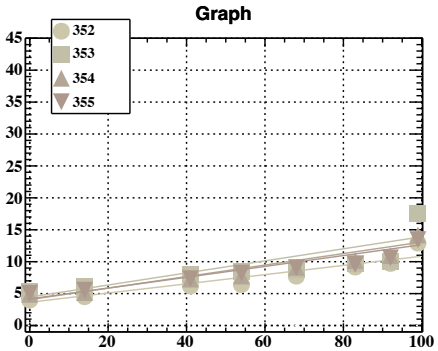


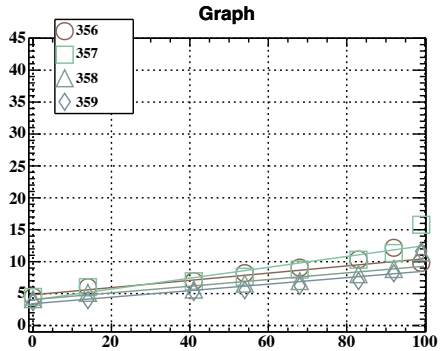


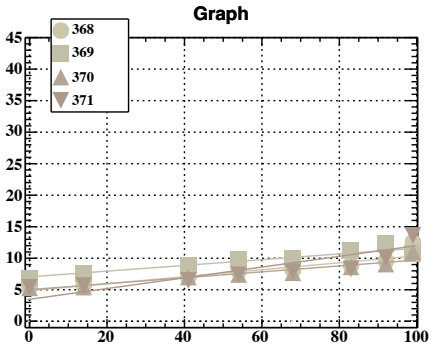


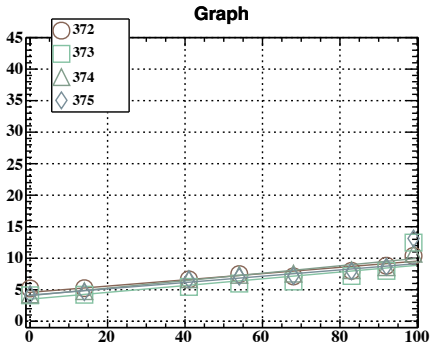
Examples (2, DS-pTC)

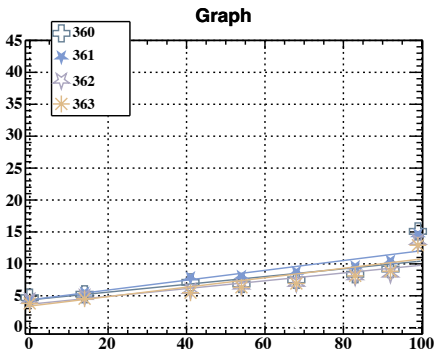
- Number = channel No.
  (e.g. pixel 0 contains ch0-1, pixel 1 contains ch2-3)

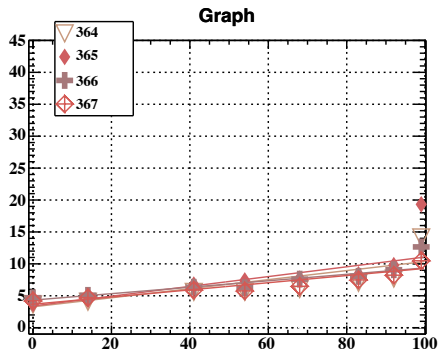


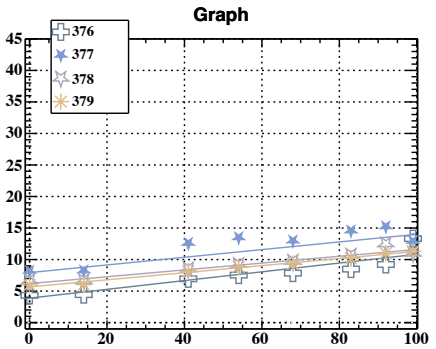


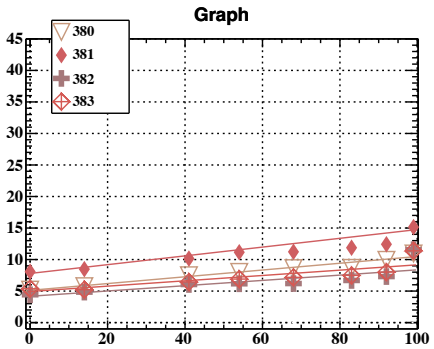






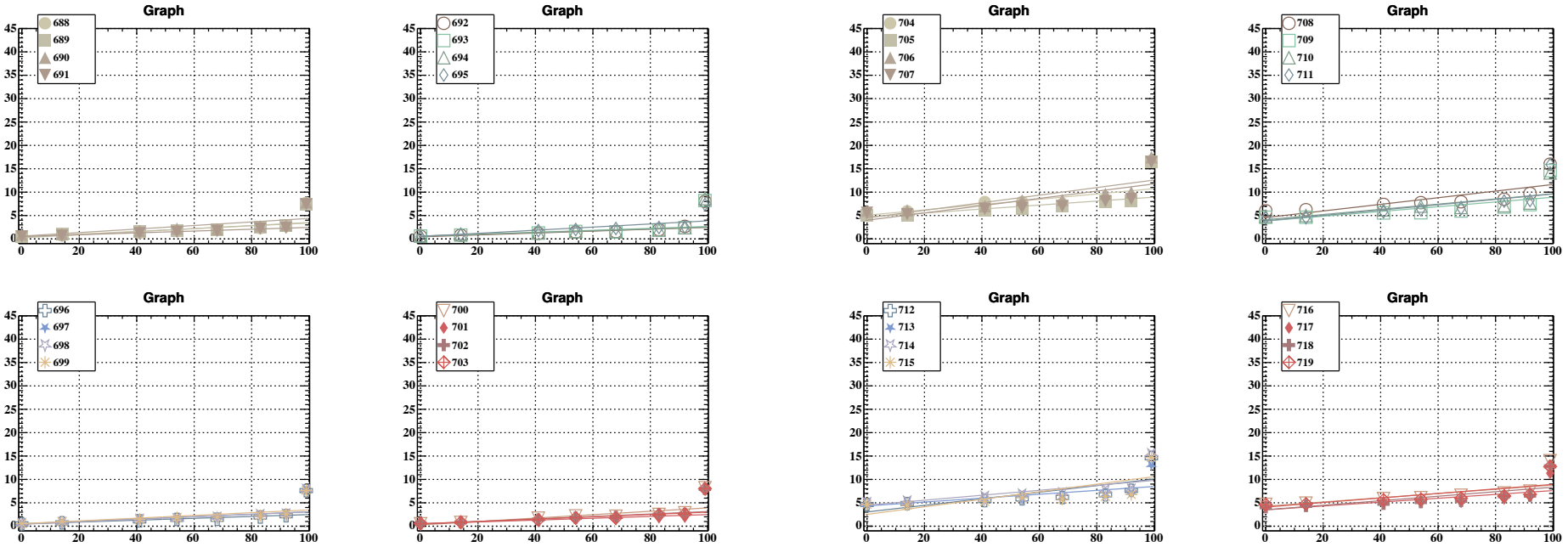






Examples (3, US-pTC)

- Number = channel No.
  (e.g. pixel 0 contains ch0-1, pixel 1 contains ch2-3)



Examples (2)

- Number = channel No.
  (e.g. pixel 0 contains ch0-1, pixel 1 contains ch2-3)