$\mu^+ \rightarrow e^+\gamma$ 探索実験 MEG II の物理データ収集に向けた準備

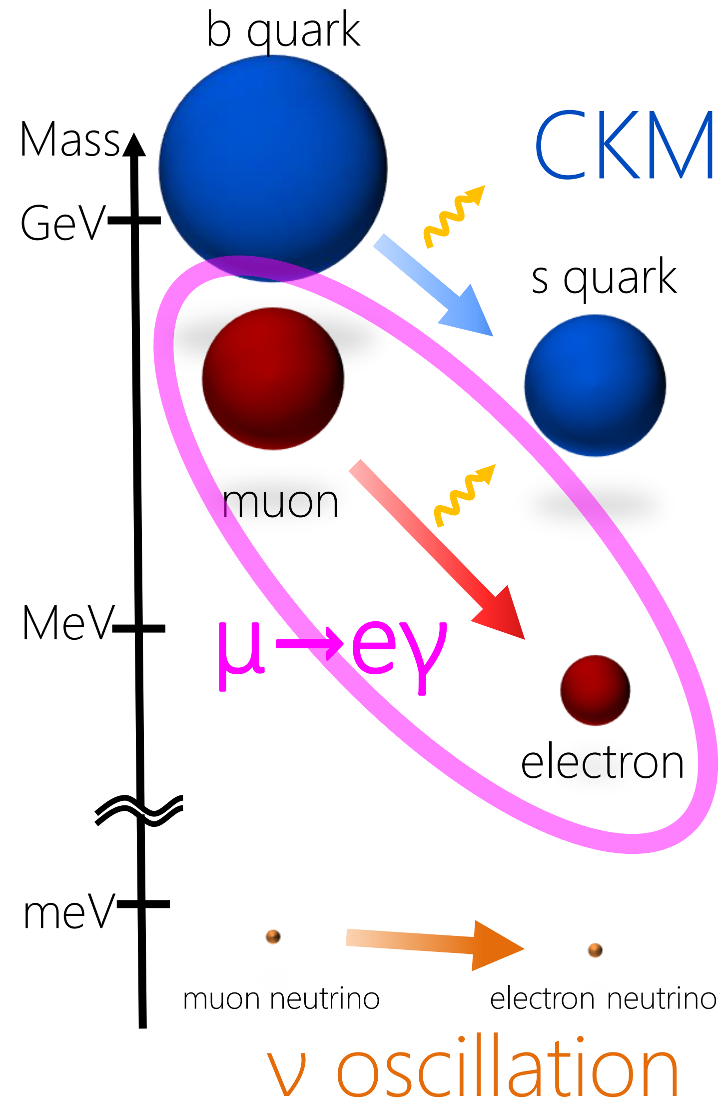
- Detector construction status
- Challenges in the data acquisition

- Y. Uchiyama (The University of Tokyo)
for the MEG II collaboration

- 日本物理学会2016年秋季大会
(21 Sep, 2016)

Physics of $\mu^+ \rightarrow e^+\gamma$

- Charged Lepton Flavor Violation
  - Never observed yet
  - Practically forbidden in SM
  - by tiny neutrino masses
- But, we know 'flavors' **are** violated in SM
- Why not in physics beyond SM?
  1. Generally no reason to be conserved.
  2. Even with some symmetry, contribution from the known FV is unavoidable via radiative corrections in the new physics.
- Why charged lepton?
  1. No SM contribution, no theoretical uncertainty.
  2. Probably, connected to the mystery of neutrino.
- Many theoretical predictions are within experimental reach



e.g. SUSY + heavy ν_R

- Right-handed Majorana neutrinos
- Additional Yukawa coupling
  - New source of flavor mixing
  - Would be sizable due to the seesaw mechanism

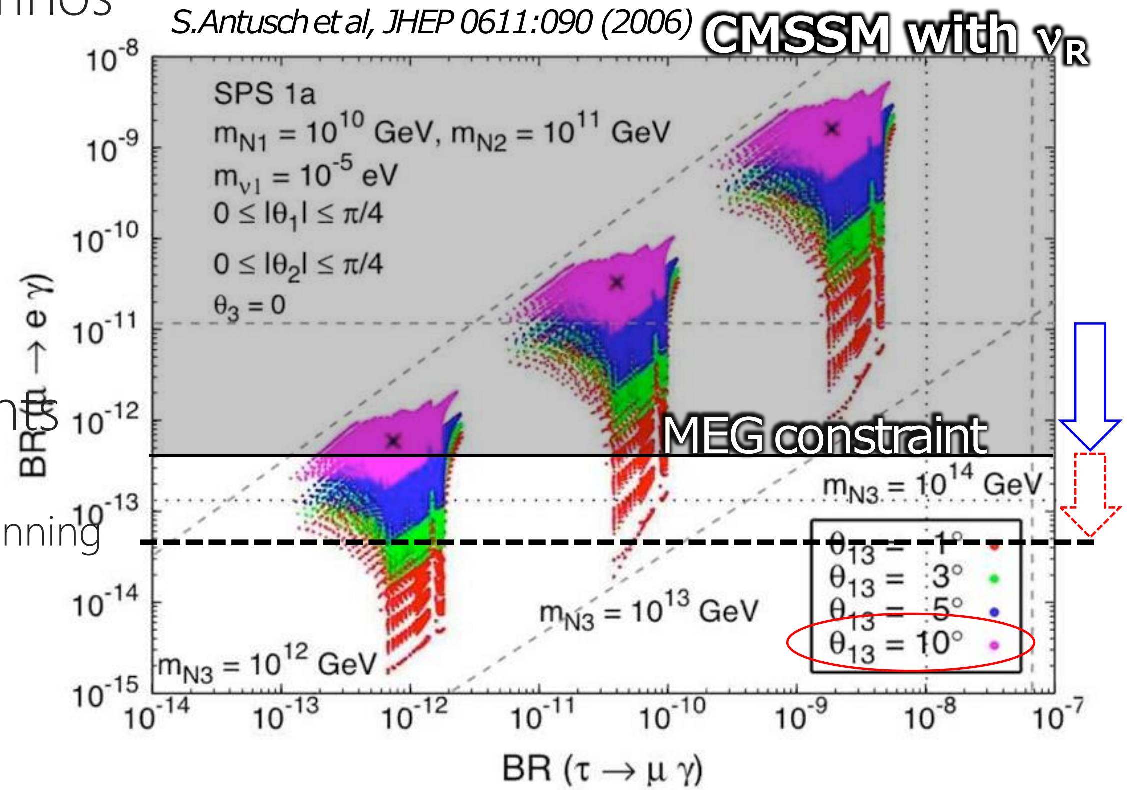
⇩

- Generate off-diagonal elements in SUSY soft mass term
  - Via renormalization group evolution running from GUT scale to weak scale

⇩

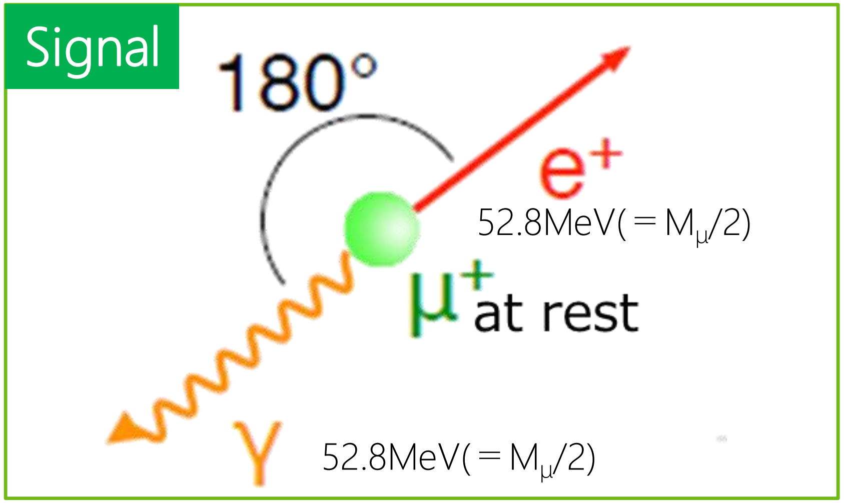
- Sizable $\mu^+ \to e^+\gamma$

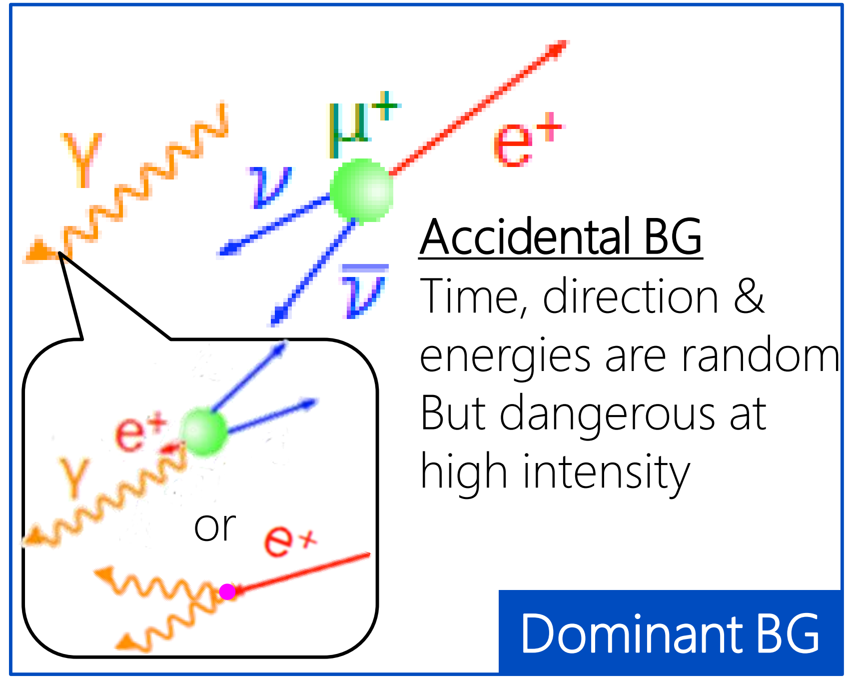
S.Antusch et al, JHEP 0611:090 (2006)



Caveat: $\Gamma \propto \Lambda^4$

Experimental requirements





$$R_{BG} \propto R_{\mu}^{2} \cdot \delta E_{e} \cdot (\delta E_{\gamma})^{2} \cdot \delta\omega/4\pi \cdot \delta t$$

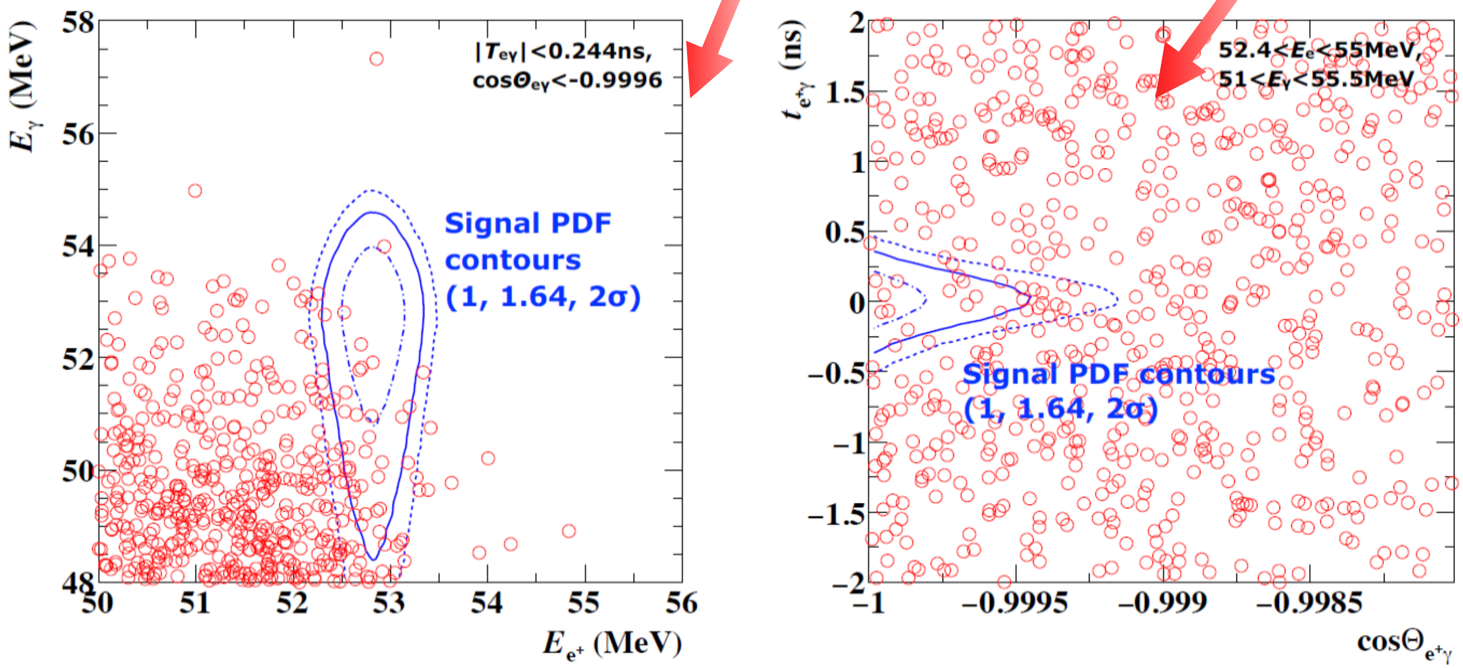
accidentally back-to-back | accidentally coincident

- High intensity DC μ^+ beam
- High resolution detector for energy, timing, and direction of γ & e^+.

Eur. Phys. J. C (2016) **76**:434

MEG final result

$$R_{BG} \propto R_\mu^{\,2} \cdot \delta E_e \cdot (\delta E_\gamma)^2 \cdot \delta\omega/4\pi \cdot \delta t$$



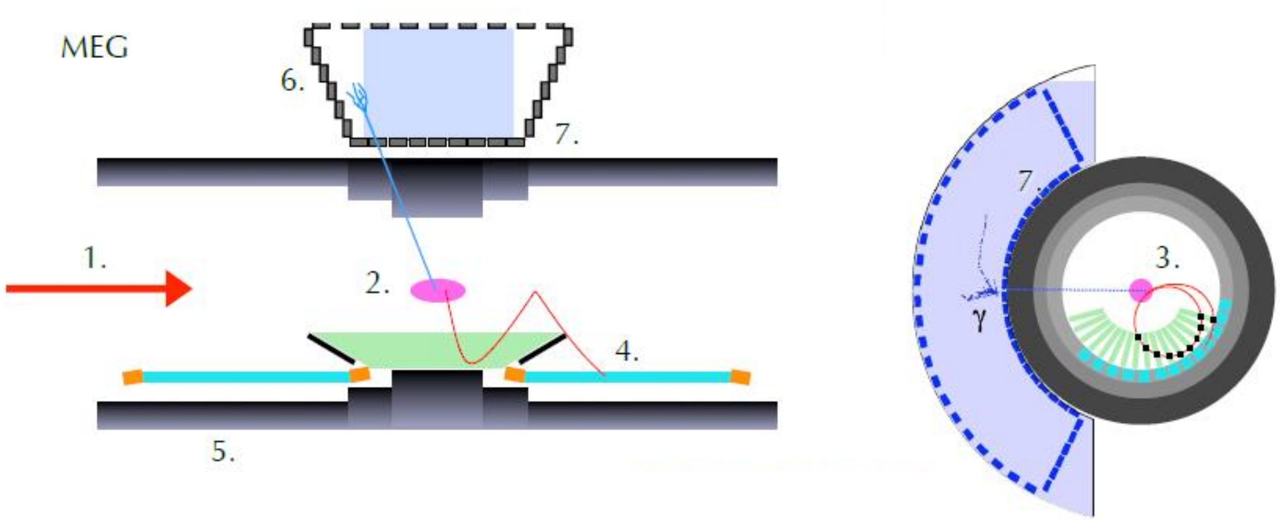
- Search for $\mu^+ \to e^+\gamma$ in 1.7×10^{13} muon decays
- No excess was found and new upper limit was set:

$$B(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13} \text{ (90\% C.L.)}$$

(while 5.3×10^{-13} expected)

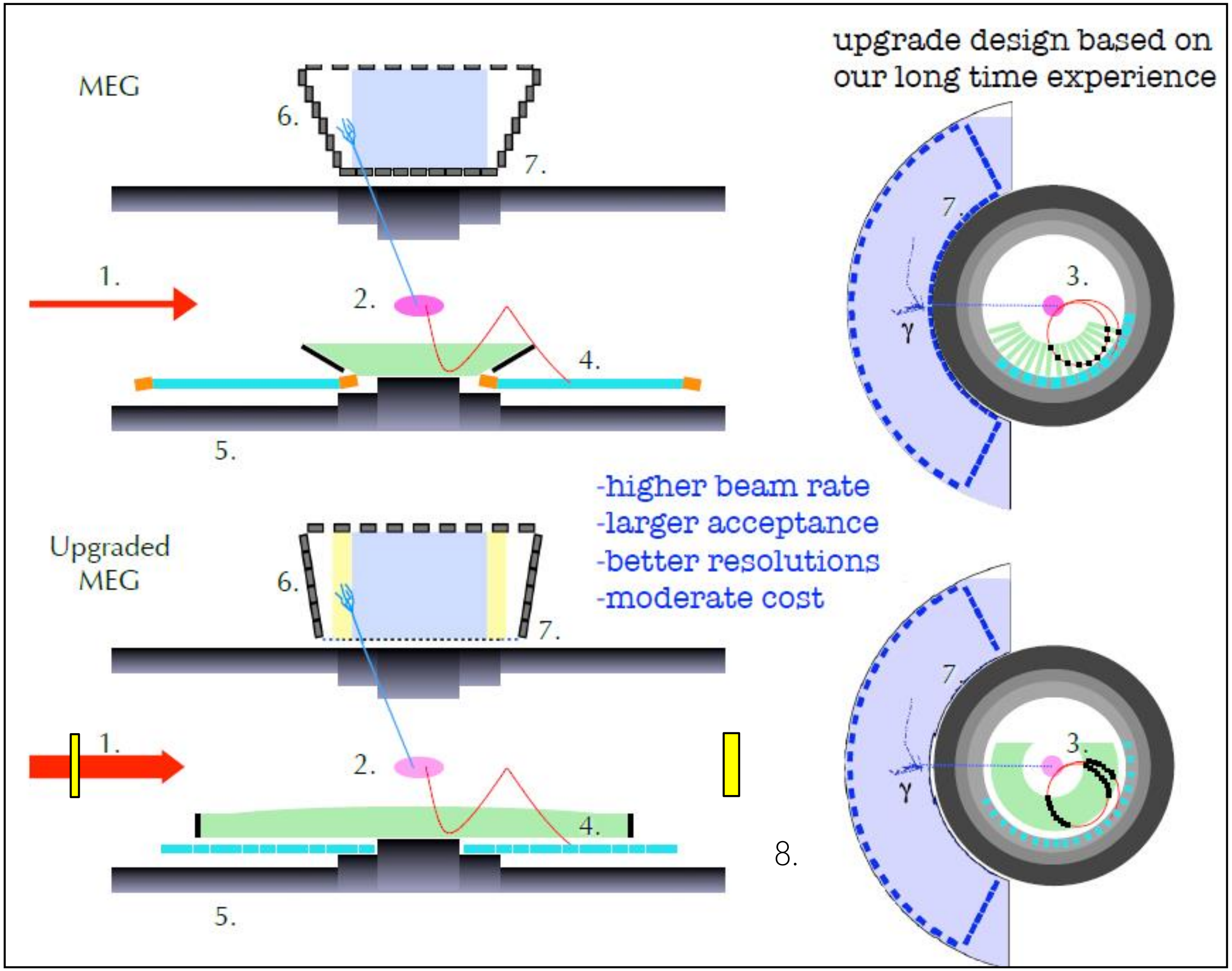
$\times 30$
improvement from the prev. experiment

MEG experiment



- μ^+: World's most intense DC muon beam @ PSI
- γ: Detect with liquid xenon scintillation detector
- e^+: Detect with gradient B-field spectrometer
  (drift chamber & timing counter inside)

MEG II: ×10 improvement



- > × 2 intensity muon beam
- New 2-m long single volume drift chamber
- New pixelated timing counter with SiPM
- Upgrade LXe g-ray detector with MPPC (incident wall)
- New BG-ID detector on the beam axis (RDC)

- All apparatus ready in 2017
- Search for $\mu^+ \rightarrow e^+\gamma$ down to

4×10^{-14}

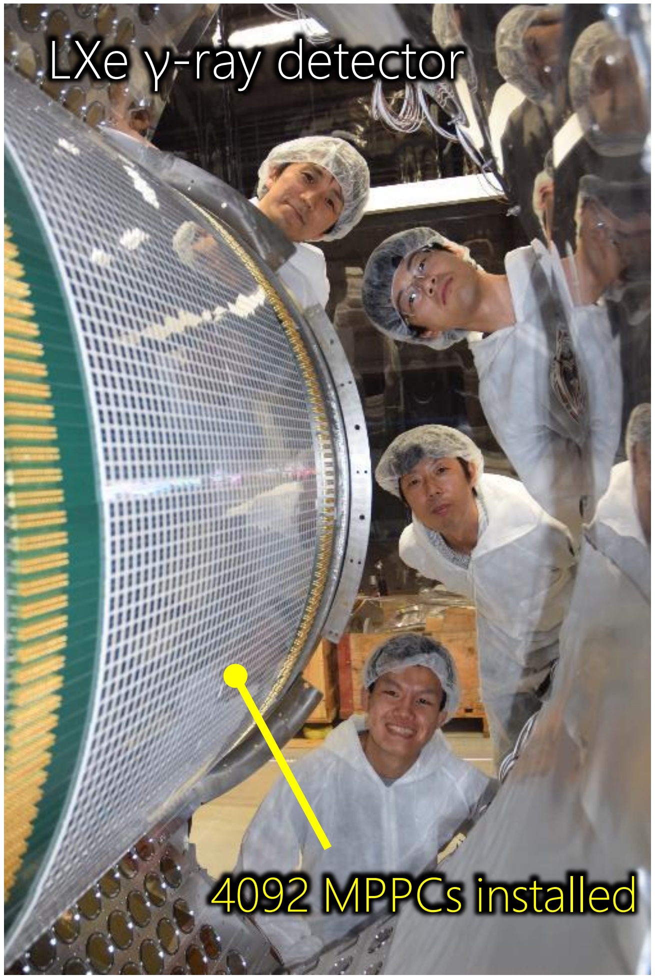
(90% C.L. sensitivity)

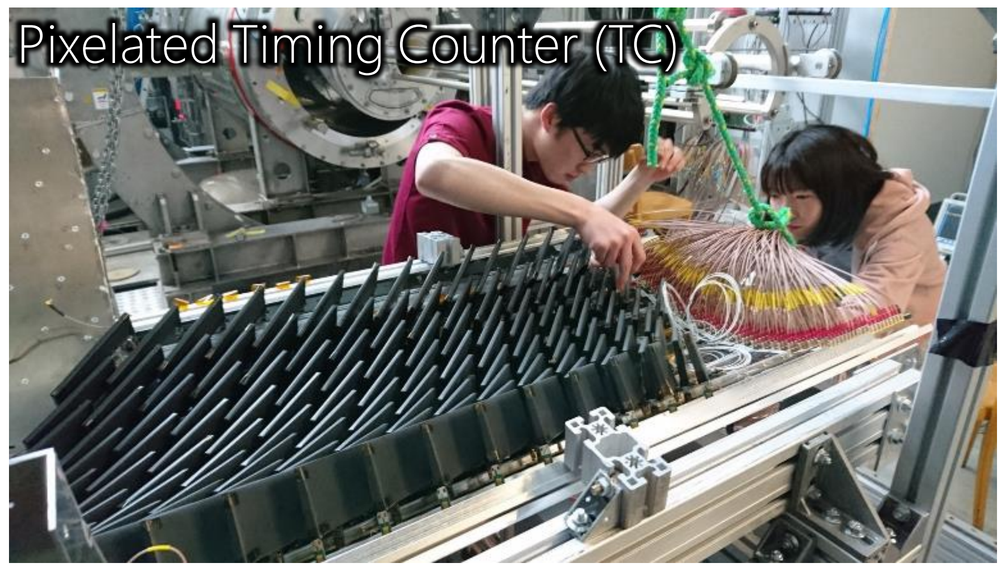
× 2 better resolutions everywhere

Status of detector construction

Construction status

- All detectors under construction





Construction status

- Construction of all the detectors progresses
- but with some schedule delays

LXe (Liquid Xenon γ-ray detector)

- Photo sensors assembly almost done, signal check & cabling ongoing 22aSF9
- Assembled detector goes to beamline in Nov followed by liquefaction, purification

CDC (Cylindrical Drift Chamber)

- Wiring has been stopped after the wire-break issue happened (discuss later).
- Delay of half year. Assembled detector delivered to PSI next spring.

TC (pixelated Timing Counter)

- All the counters produced & tested.
- One module assembled this autumn, the other in winter.

RDC (Radiative Decay (BG identify) Counter)

- Downstream detector assembled & tested in beam 21aSE6
- Upstream detector still in R&D 21aSE7

Tested in MEG II beam

Construction sta

- Construction of all the detectors
- but with some schedule delays

LXe (Liquid Xenon γ-ray detector)

- Photo sensors assembly almost
- Assembled detector goes to be

SF9

CDC (Cylindrical Drift Chamber)

- W … he w
- De … tec

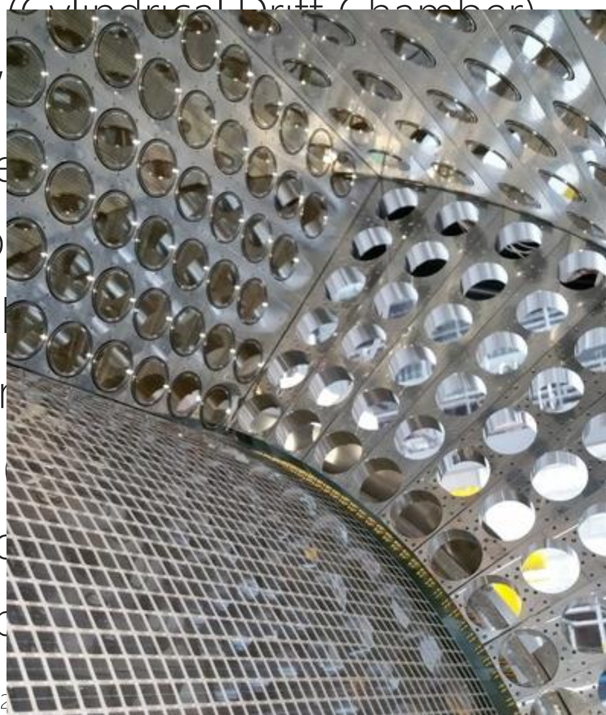
TC (p

- Al … ted.
- O … umm

RDC … Cou

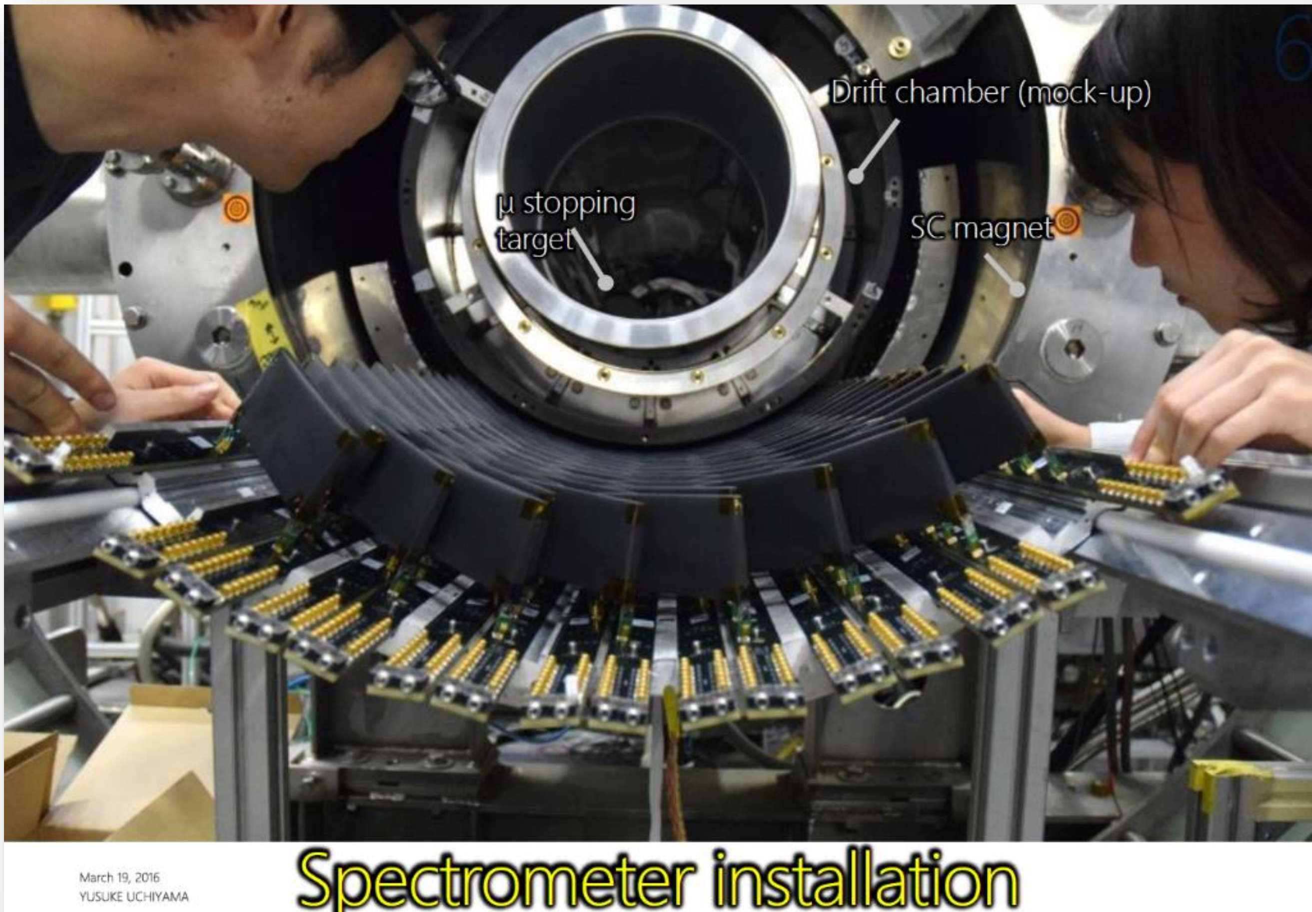
- D … d &
- Up

G II



Beamline & e^+ spectrometer commissioning

- Beamline & e^+ spectrometer were successfully tested for the installation
- And carried out 1st **MEG II pilot run** last Dec.



Last JPS

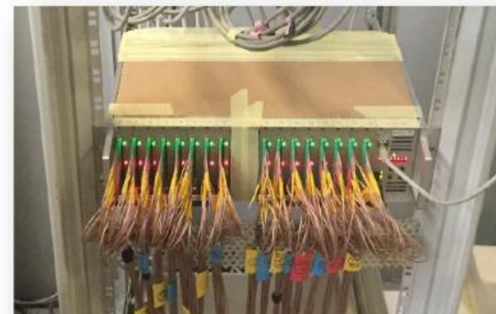
Pilot run 2

- Carried out 2nd pilot run in June – July with TC, RDC, and improved elec.
- Why?

Last JPS

Electronics problems

- WaveDAQ system
  - Multi-functional board
    Amplifier, shaper, waveform digitizing, first level trigger & SiPM biasing.
  - First test in the pilot run.
- Confirmed several functionalities
  - Biasing & triggering works well
  - Basic waveform sampling succeeded.
- Figure out several problems
  - FPGA programming bug, mis cabling on board, lack of synchronization, missing calibration, and noise.
- → consequences
  - Data quality of the pilot run is not good.
  - Need intensive work to solve these problems before mass production
- Carry out another pilot run with modified electronics in June



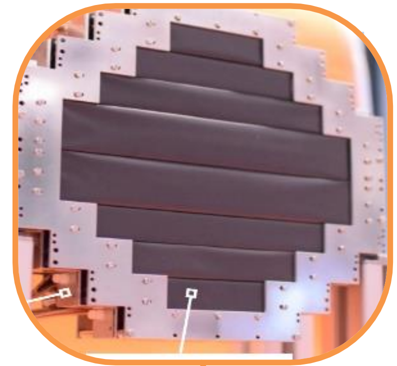
A 3U crate manages 256 channels

- Electronics development takes more than expected
- Before confirmation of all functionality, never order mass production.

Not possible full system to be ready in 2016

Pilot run 2

- Confirmed almost all problems are solved
  - ☐ Bugs are all fixed
  - ☐ Synchronization b/w boards works in 50 ps precision (should be improved further)
  - ☐ Still slightly higher but improved noise level
  - ■ Found another problem (non-linearity) thanks to new detector test
  - ☐ Next step: Produce & test 4 crates of electronics. → Used for LXe detector commissioning



- Test ¼ TC with positrons from muon decay (again)
- First & successful test of downstream RDC
  - ☐ Installation into the beam line
  - ☐ Operation in beam and detected radiative muon decays

- Good data were taken
  - ☐ See dedicated talks in this meeting

21aSE6 (RDC), 23pSG3,4 (TC)

Outstanding issues & delay

- Major delay

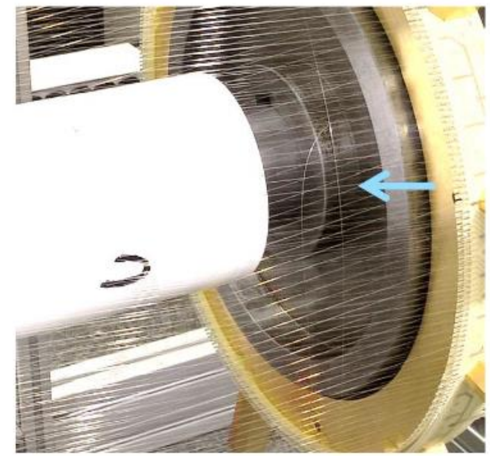
1. To solve the elec. problem.
2. To solve the CDC wire-break problem.
   - Prepare safe environment of wiring
   - Ensure rH < 60% all the time

- Other potential issues
  - SiPM detach from scintillator or PCB (TC & RDC)
    Several measures ongoing
  - SiPM radiation damage (TC)
    Tests done & planned → 23aSF9
  - MPPC PDE angular dependence (LXe)
    Measurement done → 22aSF10

16

Wire break

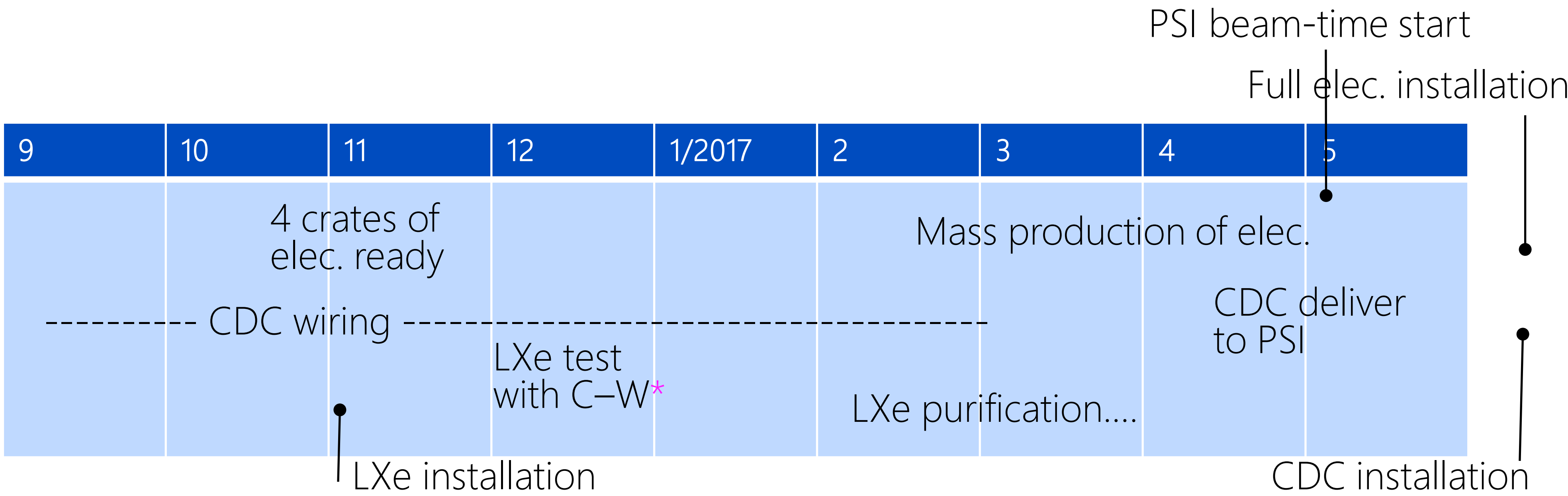
- On 8/Mar, during an elongation test (to nominal length)
- 13 50μm guard wires broke.
  - Later, other 4 guard wires + 1 cathode wire broke
- Deep investigation is on going
  - So far, no clear reasons found
  - From the geometrical viewpoint, it is not possible.
- Due to this incident, wiring is now stopped.



March 19, 2016
YUSUKE UCHIYAMA

Conclusion:
- Due to exposure to humid environment
- Control of the humidity in clean room was not good enough (@ Pisa University)
  ⇒Power cut & heater stop → T=13℃, rH=99%

Prospects



* C–W: Cockcroft-Walton accelerator to generate 17.6 MeV γ-ray from Li(p,γ)Be

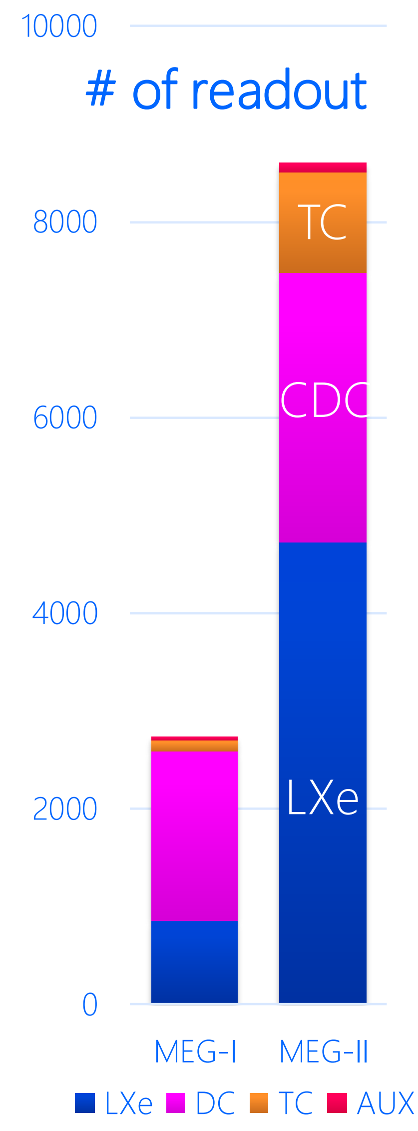
- Full apparatus will be ready by summer 2017
- Start engineering run → followed by physics run

Data acquisition and computing system

DAQ challenges

- ×3 of # of readouts from MEG
  - ~9000 chs of waveform data
- \> ×4 of BG rate
  - BG rate ∝ (beam rate)^2
- ×2 of detection efficiency
- How to suppress the total amount of data?

	MEG	MEG II (if just scale)
Trigger rate	11 Hz	90 Hz ?
Data rate	10 MB/s	240 MB/s ?
Disk	400 TB	9.6 PB ?
CPU	50 cores	1200 cores ?



Not feasible technically and in budgetary

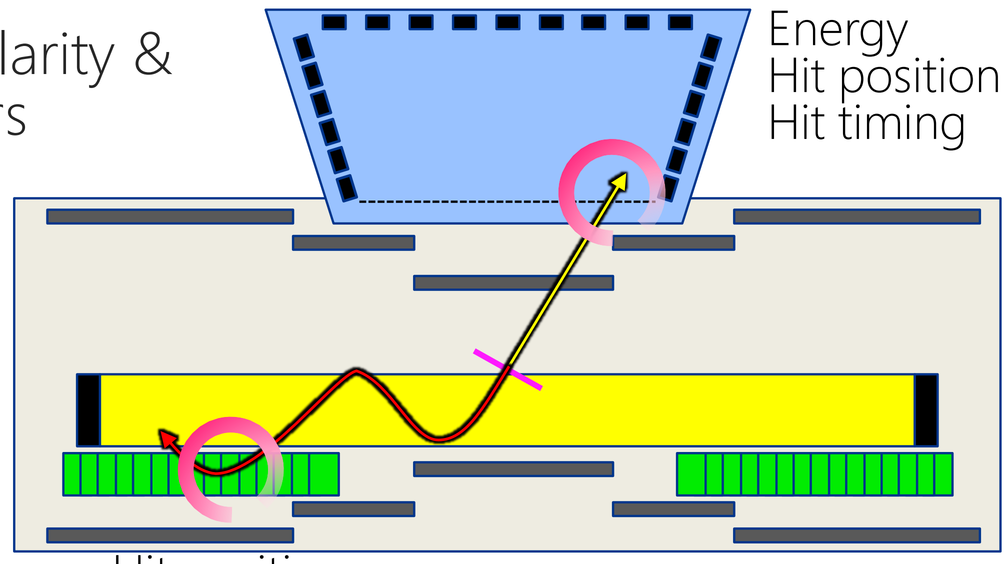
Trigger

- More efficient trigger is indispensable.

- Trigger logics (basically same as MEG)

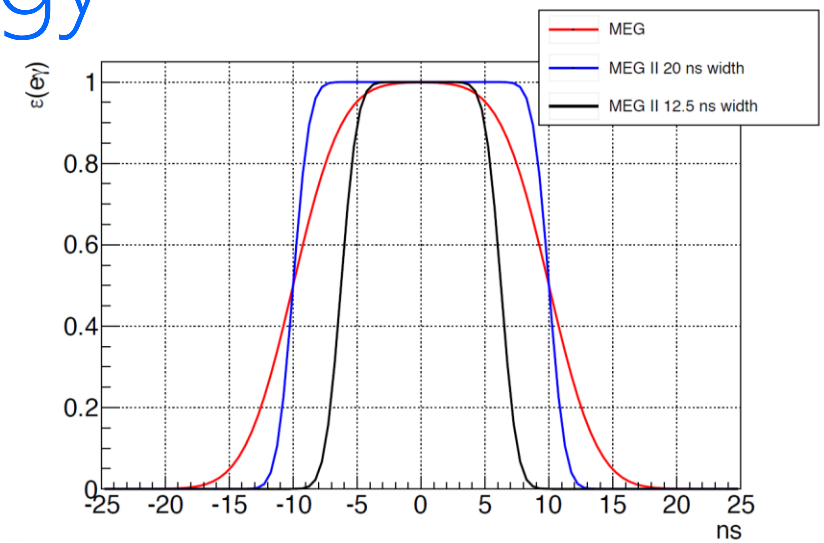
1. Gamma-ray energy threshold
2. Time coincidence
3. e–γ direction matching (close to 180°)

- Improve by use of higher granularity & better resolution of the detectors

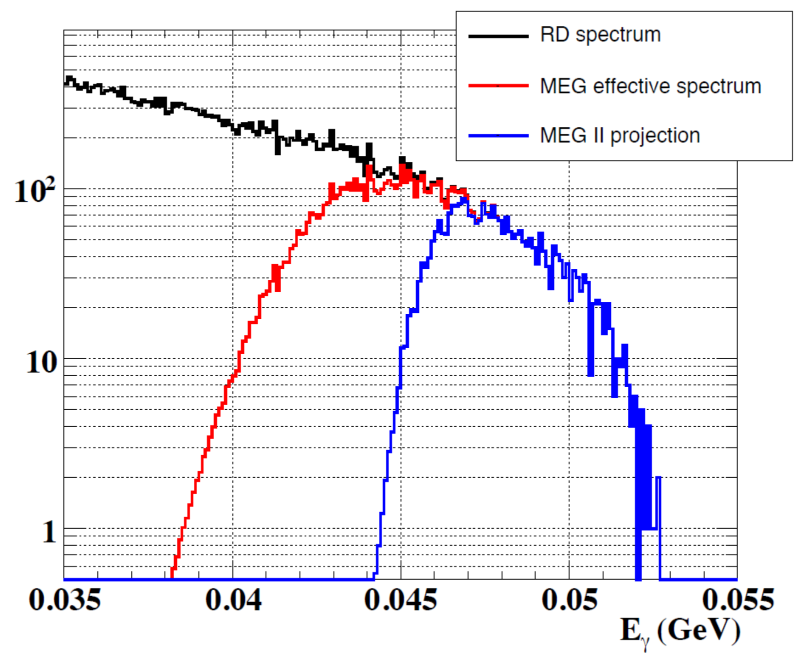


Trigger: Timing & Energy

- Online time resolution
  - Evaluated in the pilot runs.
  - Expected ~ 1 ns for $\mu^+ \to e^+\gamma$ trigger
    3 times improvement from MEG I
    Due to faster discriminator & faster FPGA
  - 30–50% trigger rate reduction expected

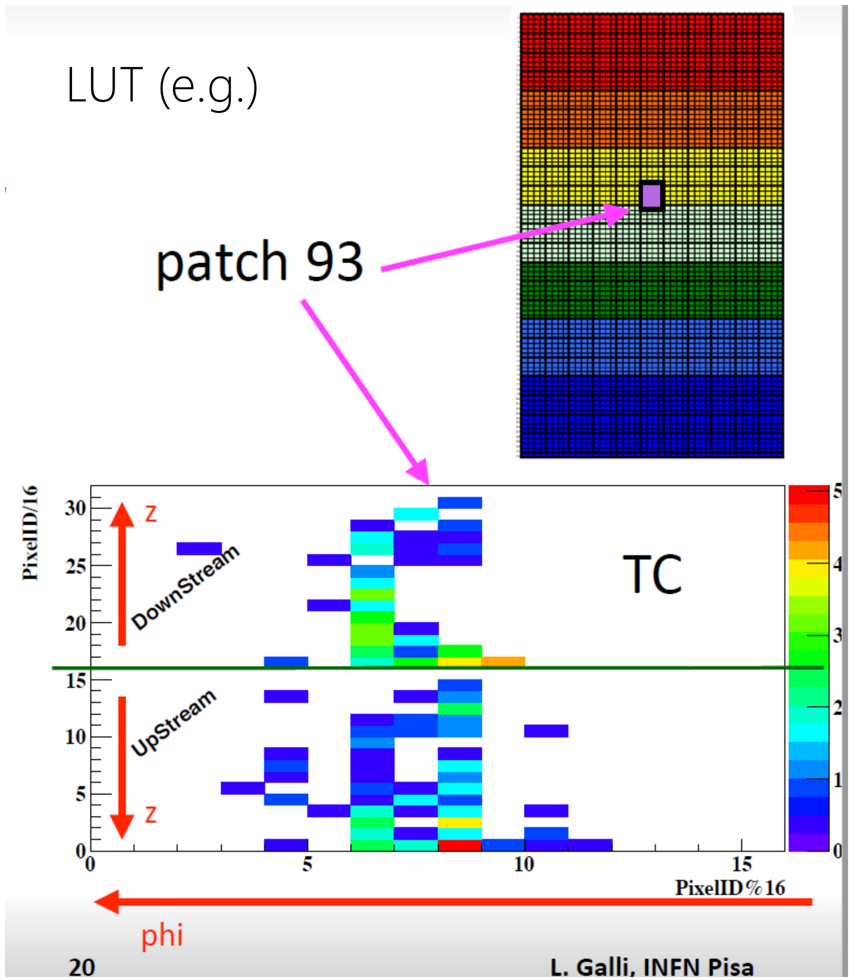


- Online γ energy resolution
  - Study with MC
  - 12 bit, 100 MSPS waveform for PMT & MPPC
  - 5 bit channel calibration
  - Sum in FPGA
  - Resolution expected to improve 3.5% → 1.5%
  - 60% trigger rate reduction expected
    retaining >99% efficiency @ 48 MeV
  - To be checked with calibration data this fall
    What's the effect of real calibration + noise?



Trigger: Direction match

- Direction match is judged using a Look up table prepared from MC
  - See max hit LXe-MPPC & first hit TC-counter
  - 16 LXe MPPCs are grouped → similar to 1 PMT
  - Improvement from new pixelated TC
  - 40% trigger rate reduction expected
    retaining 97% coverage



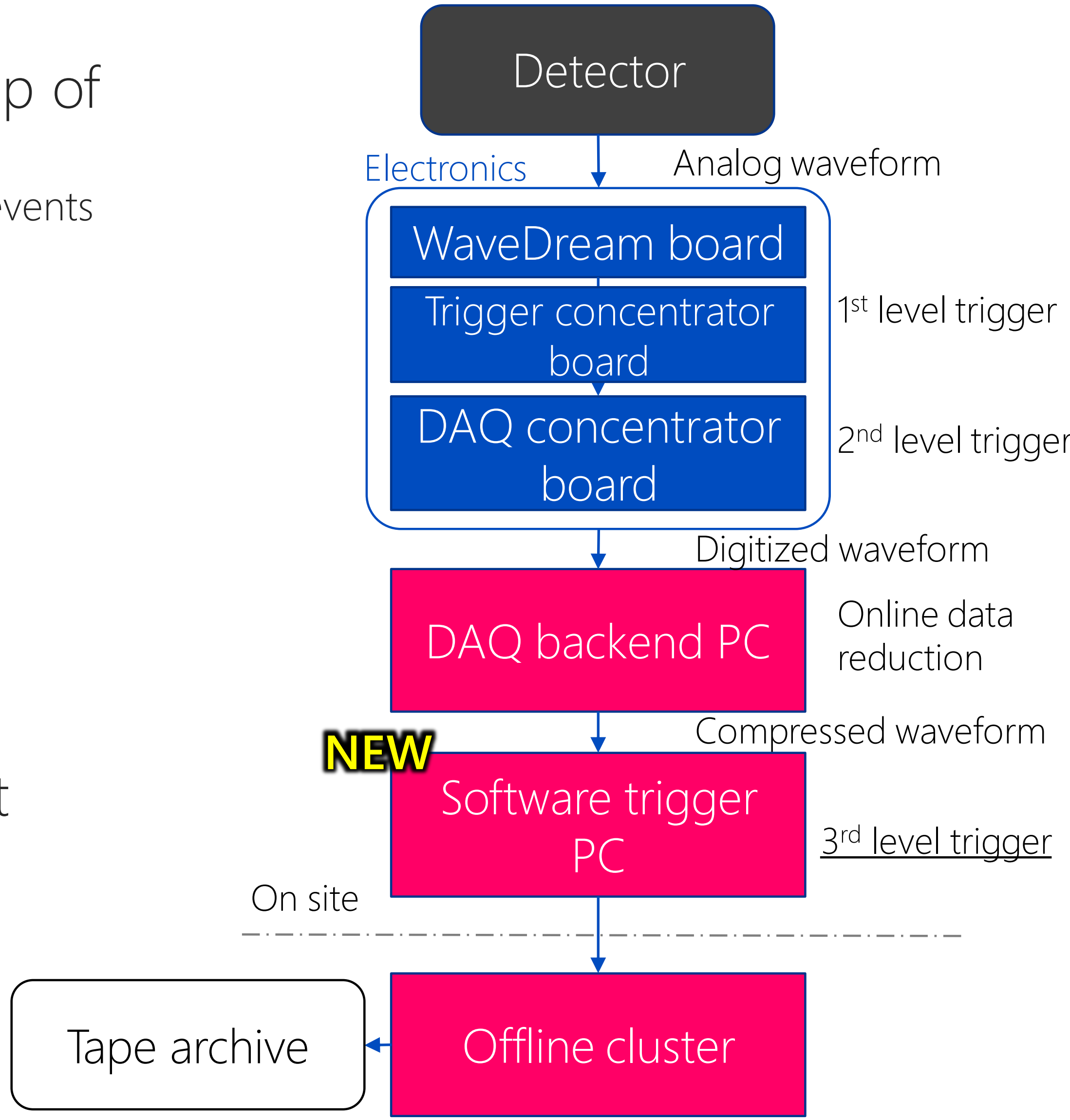
- In total, trigger rate is expected

  0.7 × 0.4 × 0.6 × 90 Hz = 15 Hz
  time energy direction (preliminary)

  manageable rate is feasible!

Software trigger

- Possibility of adding another step of trigger = Software trigger
  - Use offline reconstruction in PC to select events
- Enable use of track information
- Apply more complicated data reduction algorithms
  - Compression of waveform data
- Requirements
  - Fast reconstruction algorithm
  - Real time & reliable calibration
- Consideration of the system just started.

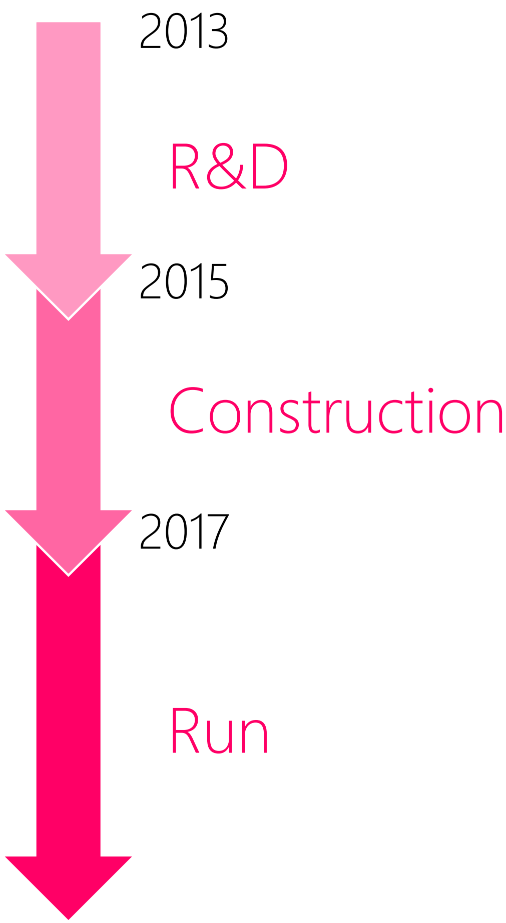


Computing resource

- Computing resource has to be completely renewed.
- New system built in PSI computing infrastructure
  - Discussion started.
  - Idea of joining in Tier3 at PSI
    Share the system, infrastructure, and administrators
  - Cost estimation underway
  - Test of system using existing Tier3 resource has been started
- Set up by next summer
  - With reduced amount
  - Expand the disk storage and CPUs on demand

	MEG	MEG II (if just scale)	MEG II goal
Trigger rate	11 Hz	90 Hz	~10 Hz
Data rate	10 MB/s	240 MB/s	25 MB/s
Disk	400 TB	9.6 PB	1 – 1.5 PB
CPU	50 cores	1200 cores	150 cores

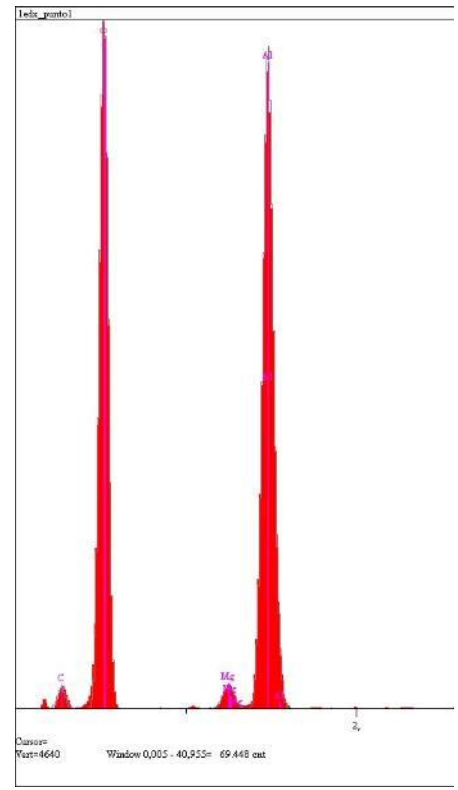
Conclusion

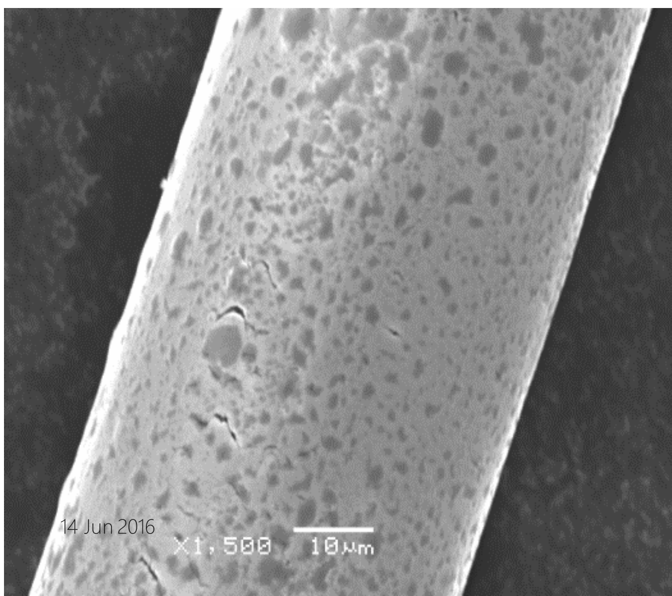


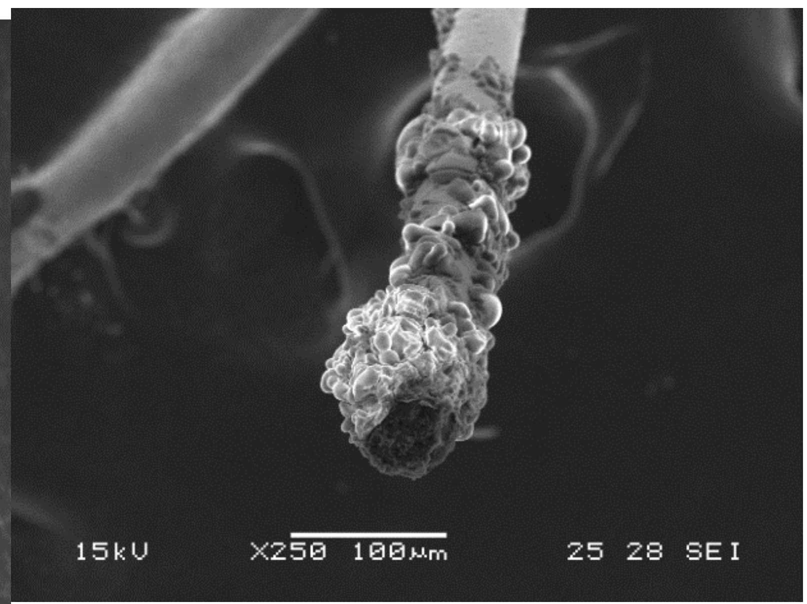
- Construction of MEG II is underway
- But, ~half year delay from last JPS point
  - Addressing issues found during construction & pilot run
  - Overall schedule is not changed so much;
    it was restricted by the electronics development.
- 2nd pilot run was successfully carried out in MEG II beam with part of assembled detectors and improved electronics
- DAQ of MEG II is also challenging
  - Online trigger being developed to keep manageable rate
  - New software trigger is under consideration
  - Computing resource will be also upgraded
- All the apparatus will be ready by summer 2017
- Start engineering run in autumn 2017

Humidity effect

- Test were performed in Lecce and in Pisa
  - Aluminium wires were immersed or sprayed with demineralized water and with 3% water solution of NaCl
  - In all cases wire breaking of the type observed on the chamber were induced.
- The salt near the wire edge contains Al and O: it could be aluminium oxide or aluminium hydroxide





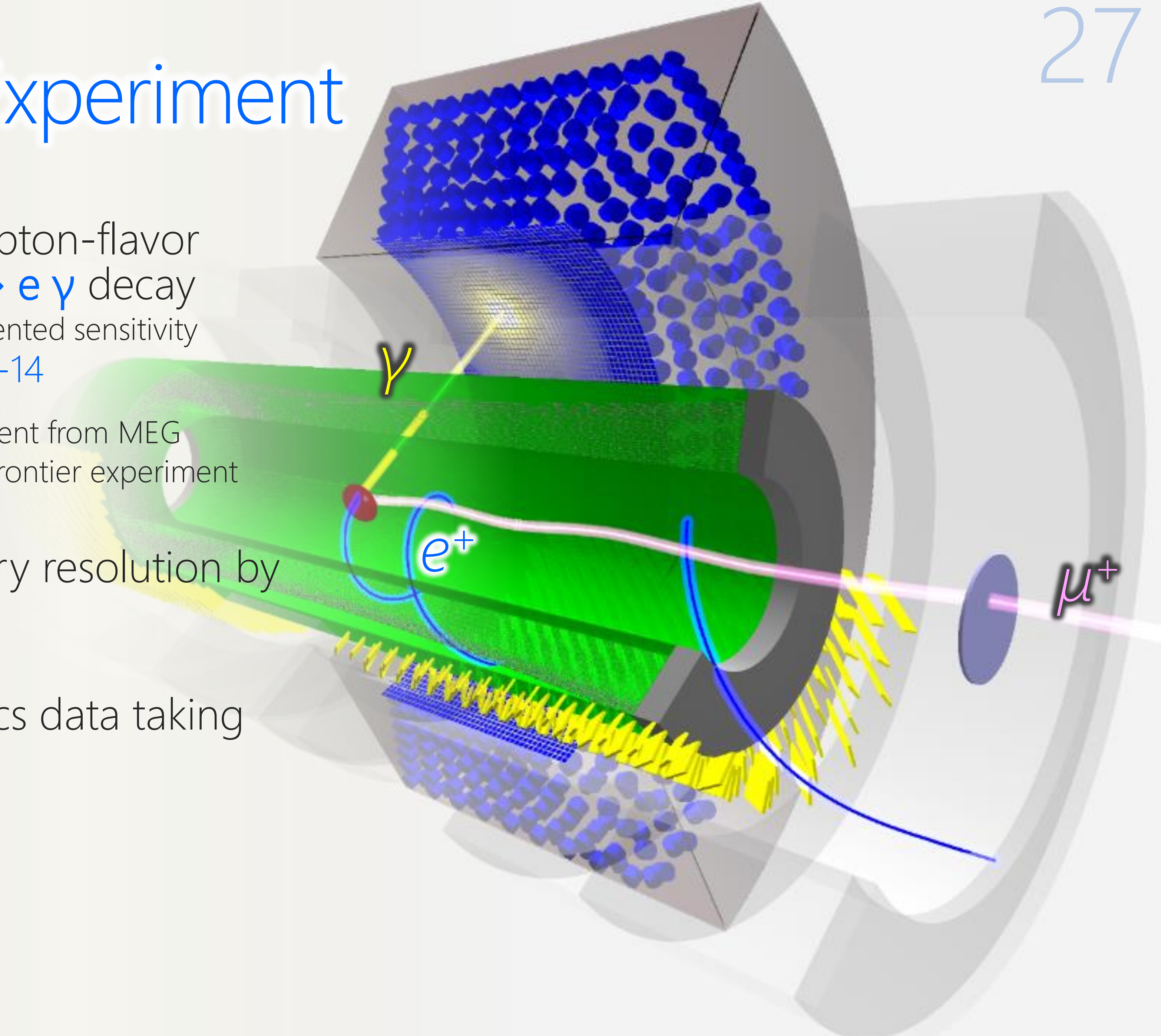


Past experience

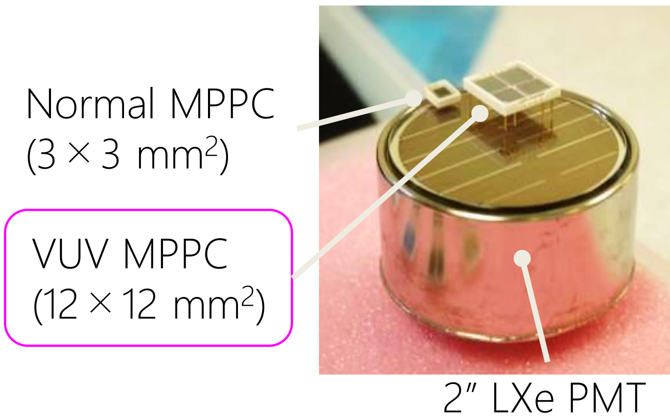
- The KLOE experiment used the same type of wire
  - Core of aluminium 5056 of 80 um
  - Layer of ~0,3 um of silver
- They wired the chamber in 50% rh environment to test with HV each wire layer before starting with the following one. The wiring went on for 9 months.
- The salt formation was never observed. They were not aware of the intrinsic fragility of this type of wire.
- The chamber is still operational 10 years after the production
- **The KLOE wire shows the same salt production of our wires if sprayed with water**

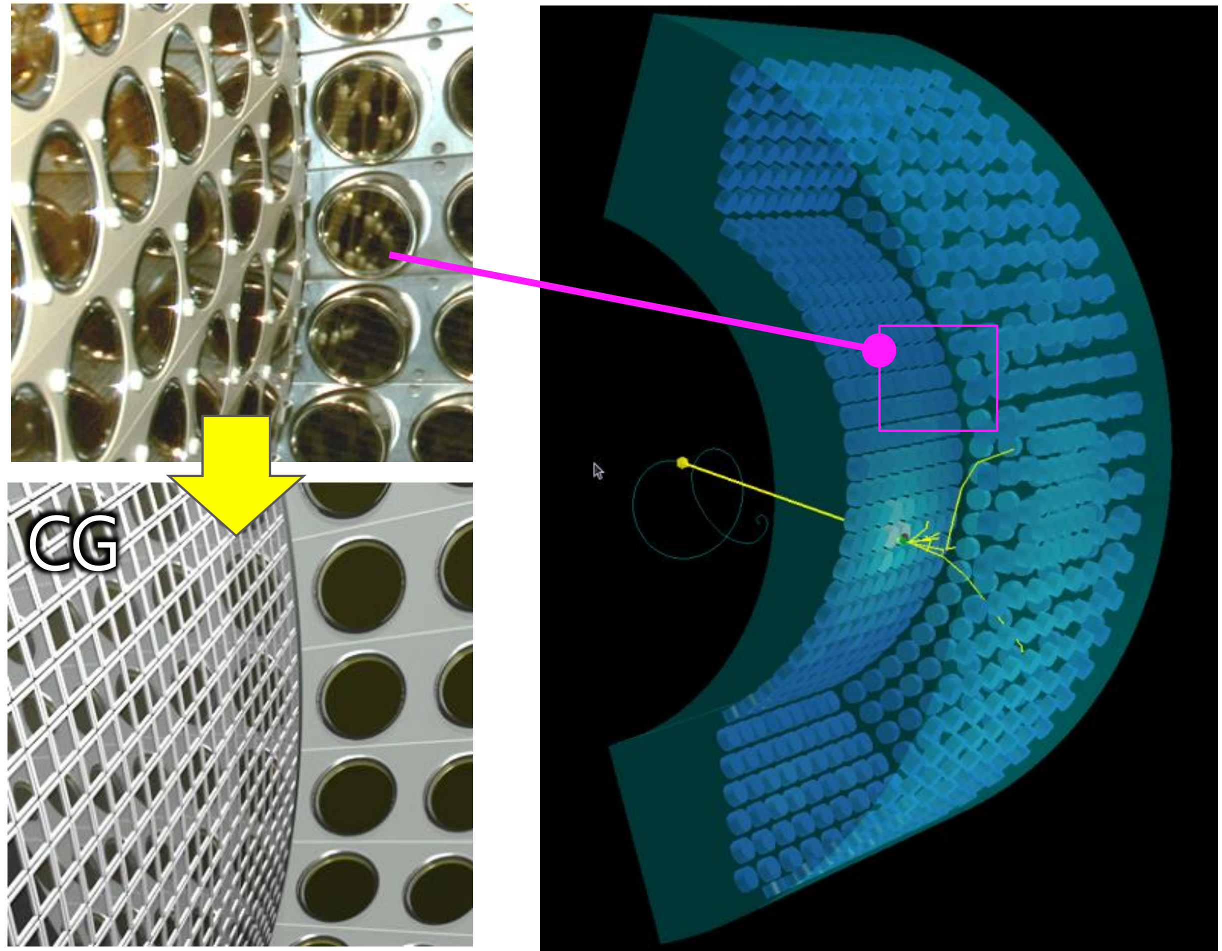
MEG II Experiment

- Search for lepton-flavor violating $\mu \to e\gamma$ decay
  - With unprecedented sensitivity
    4×10^{-14}
  - $\times$10 improvement from MEG
  - High-intensity frontier experiment
- Improve every resolution by factor 2
- Aim at physics data taking from 2017



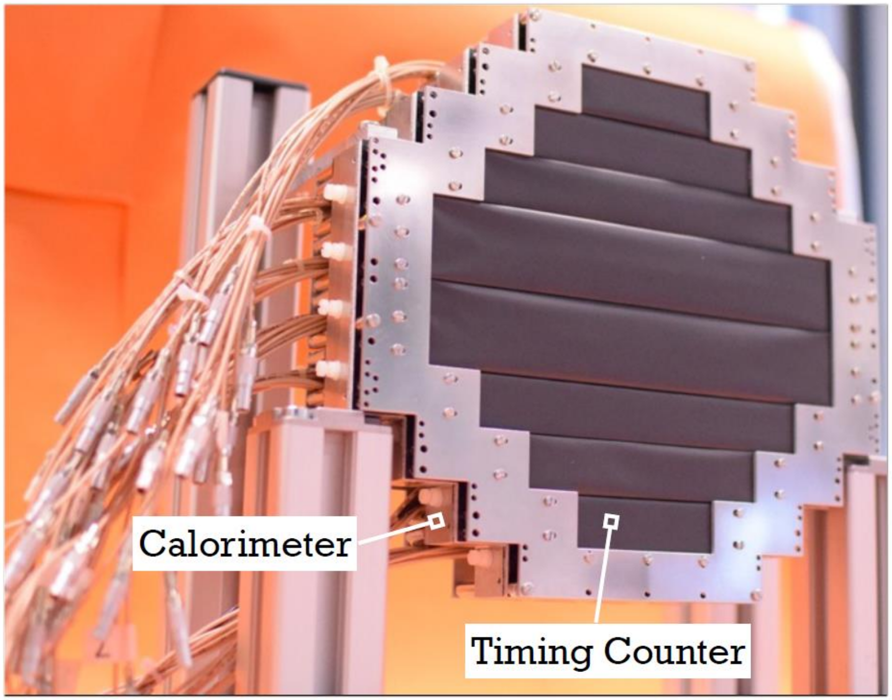
LXe photon detector





- 4092 MPPCs on 186 PCBs, ready for assembly.
- Assembled detector will be installed in the area in Jul.
- Test performance with 18-MeV γ line from Li(p,γ)Be (C–W accel.)

New BG-tagging detector (RDC)

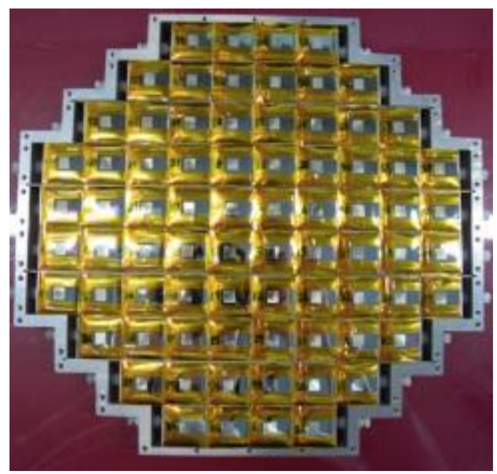


Put on the beam axis to detect low-momentum e^+ from

$\mu \rightarrow e\nu\nu\gamma$ to tag high-energy γ

Low momentum (e)

High energy → BG (γ)



- Downstream detector was constructed
- The functionality was tested with γ source (^{88}Y)
- Upstream detector (scintillating fiber) study pushed forward
  - Influence on beam was directly tested in the beam study period
  - Small impact → positive for the adoption