MEG II実験開始に向けた検出器の建設状況とその展望

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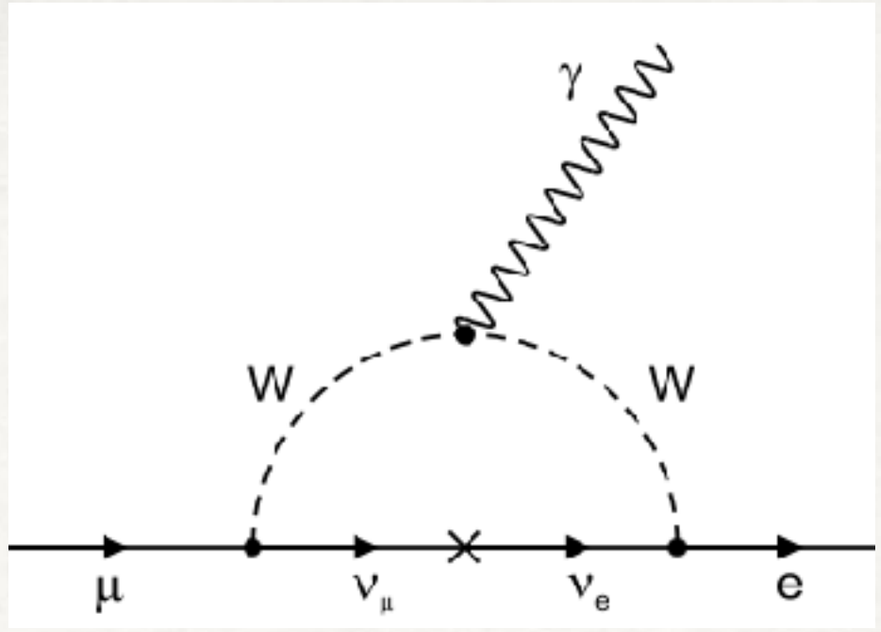
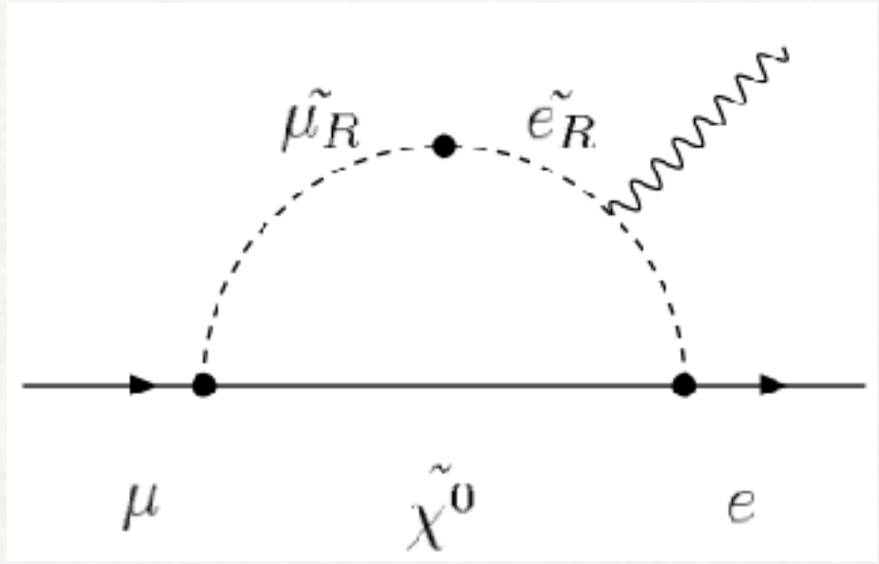
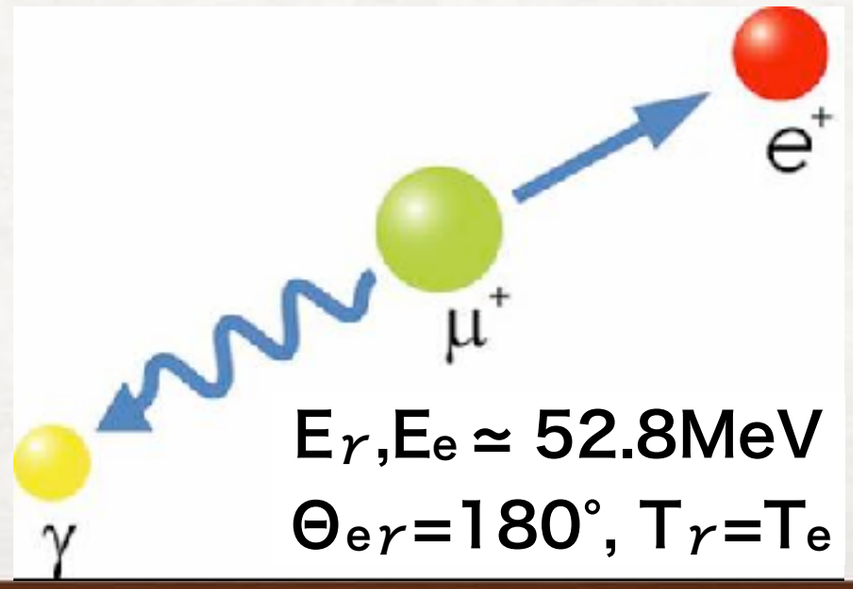
International Center for Elementary Particle Physics
The University of Tokyo

Charged lepton flavor violation

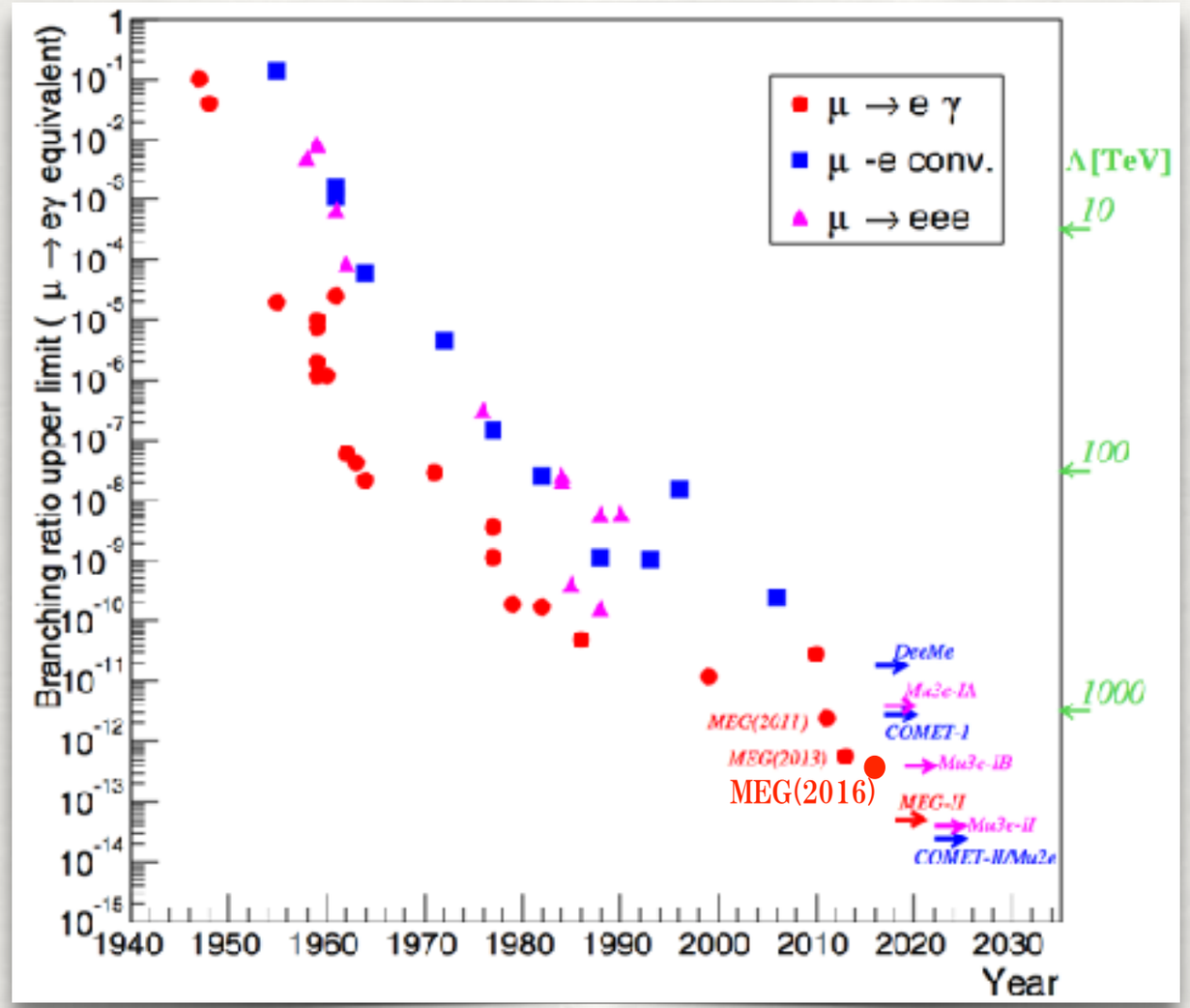
- Standard Model prediction
  - $BR(\mu^+ \rightarrow e^+\gamma) < 10^{-54}$
- Current experimental limit
  - $BR(\mu^+ \rightarrow e^+\gamma) < 4.2 \times 10^{-13}$ by MEG (Eur. Phys. J. C(2016)76:434)
- Many new physics models are already constrained, or predict just below the limit
- Signal would be clear sign of New Physics
- Intense muon beam available
- Clean experimental signature



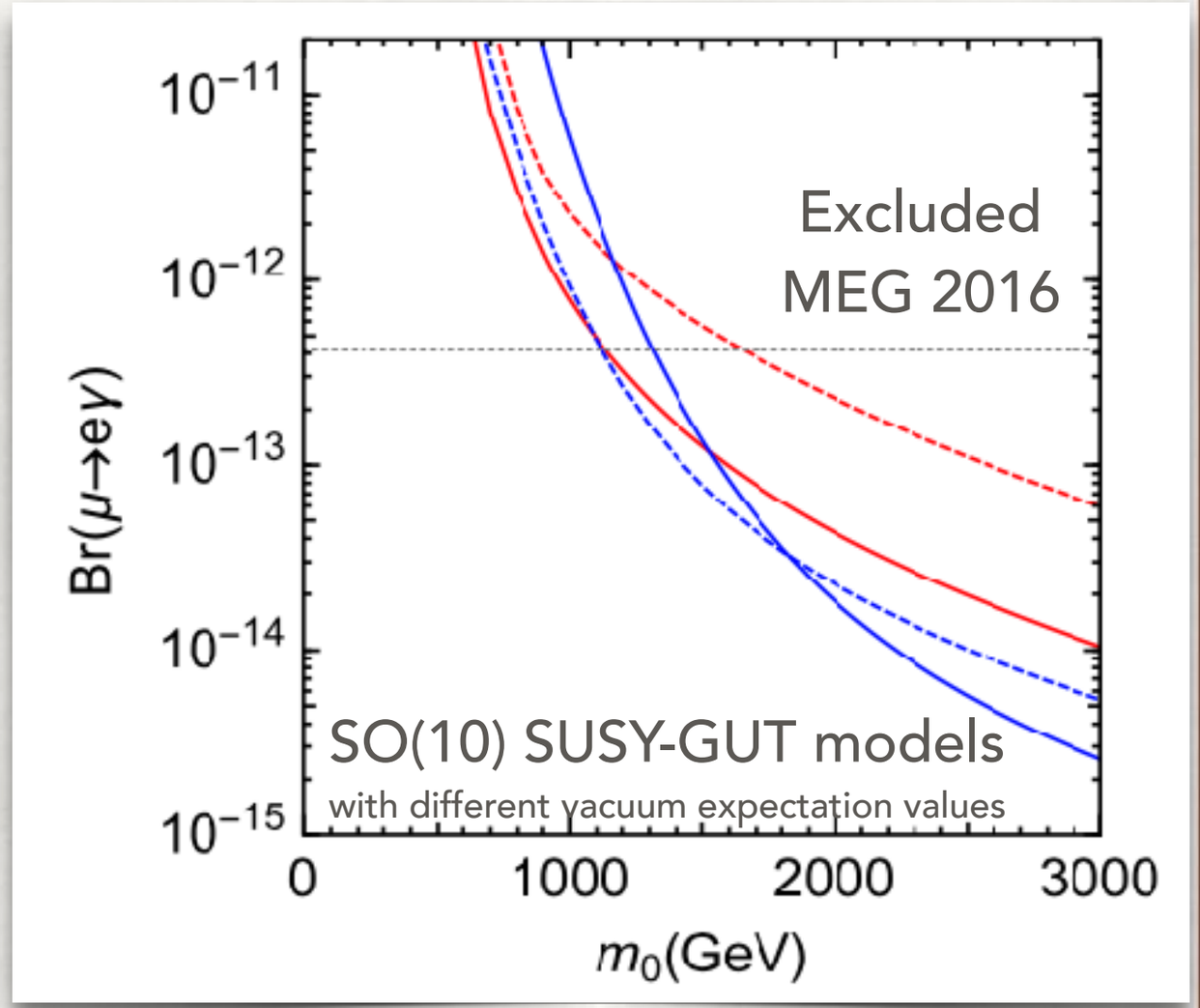




Experimental bound and theory prediction



T. Mori, W. Ootani. Prog. in PNP, 79 (2014) 57



T. Fukuyama et al. Phys. Rev. D 94(2016) 7, 075018

- DeeMe, COMET, Mu2e, Mu3e experiments will also start soon.
- Important to check all decay modes to distinguish theory models
- Many theories are already constrained
- Real chance to discover new physics

MEG II Experiment

~4×10-14 sensitivity

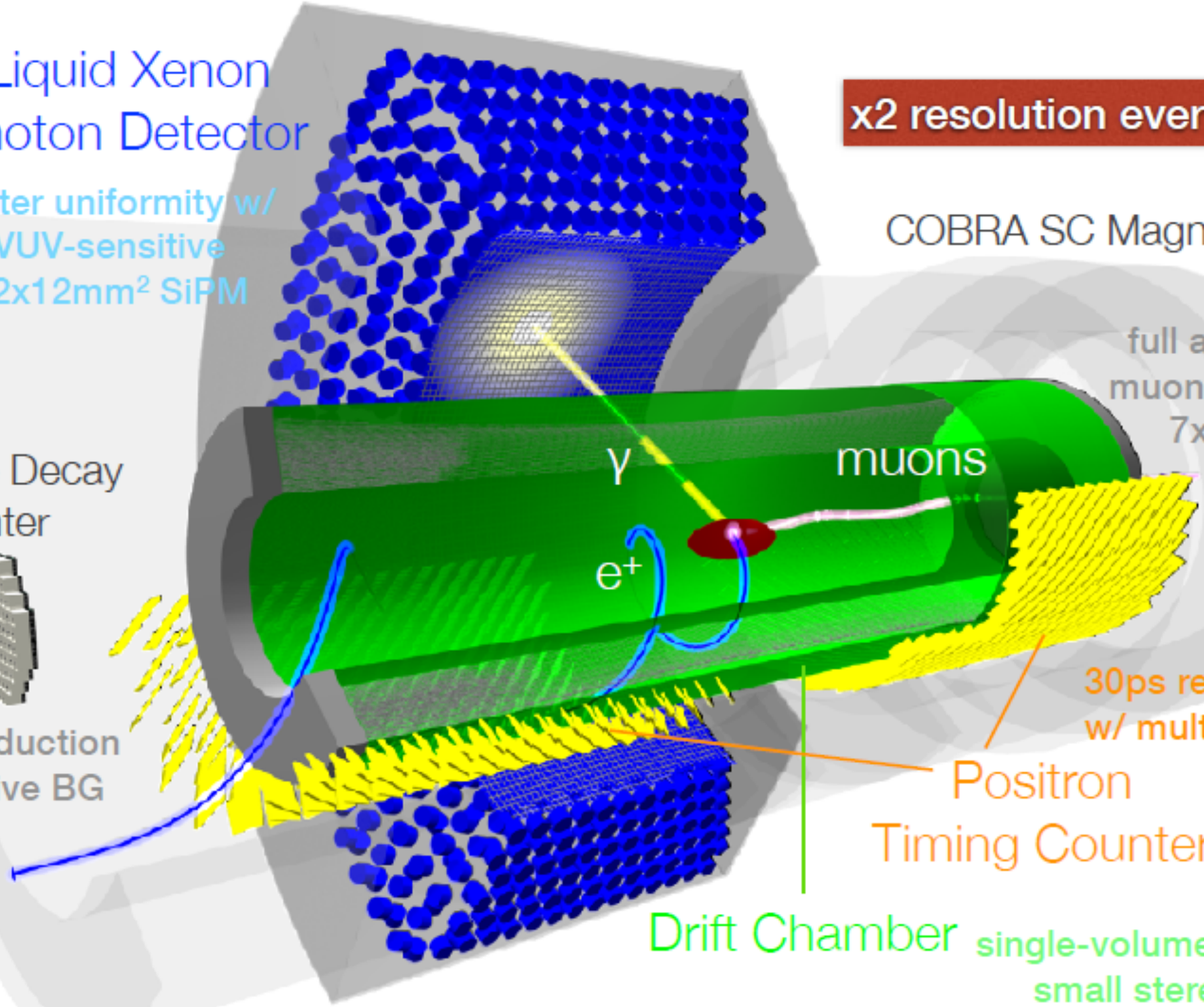
Liquid Xenon
Photon Detector

better uniformity w/
VUV-sensitive
12x12mm^2 SiPM

x2 resolution everywhere

COBRA SC Magnet

full available
muon intensity
7x10^7/s



Radiative Decay
Counter

further reduction
of radiative BG

30ps resolution
w/ multiple hits

Positron
Timing Counter

Drift Chamber single-volume He:iC$_4$H$_{10}$
small stereo cells

MEG II Detector Construction Progress from Last JPS Meeting

- **LXe detector (energy, position, and timing measurements of γ)**
  - All 4092 MPPC assembly, signal check & cabling done. PCB detachment problem(next page) happened, but it is solved now. LXe operation will start this spring.
- **Timing counter (timing measurement of e^+)**
  - All 512 pixelated counters are produced. One module (DS, 256 pixels) is assembled. SiPM detachment problem(later) from scintillator is investigated. Additional treatments are applied now, and two modules will be ready this summer.
- **Drift chamber (e^+ tracking)**
  - In March 2016, 18 wires / 700 wired wires broken due to humidity.
  - 4 more wires broken again in October(later). Due to some investigation, the schedule is delayed, and the construction will finish at the end of this year
- **Radiative Decay Counter (identification of low momentum e+ associated with high energy γ from)**
  - Downstream detector assembled & tested in beam. Upstream detector in R&D (**18aK33-6**).
- Engineering run & physics run planned in 2017, but now not possible due to the delays…

Sensor alignment method (**18aK33-5**)

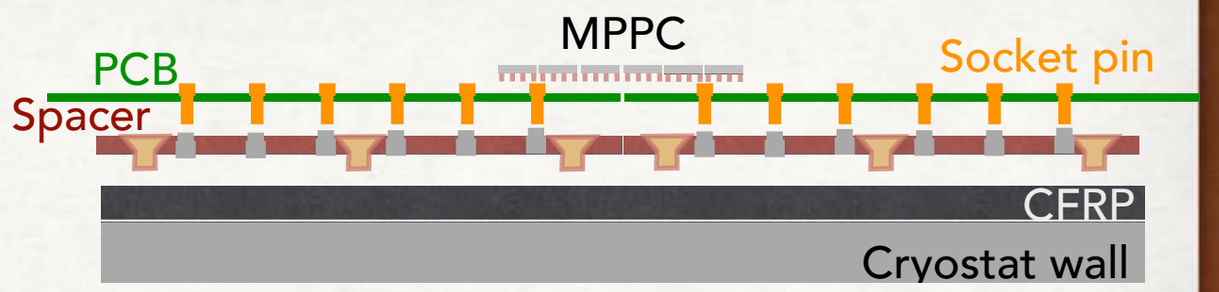
MPPC PDE angular dependence measurement (**19pK34-8**)

Online data reduction (**19pK34-9**)

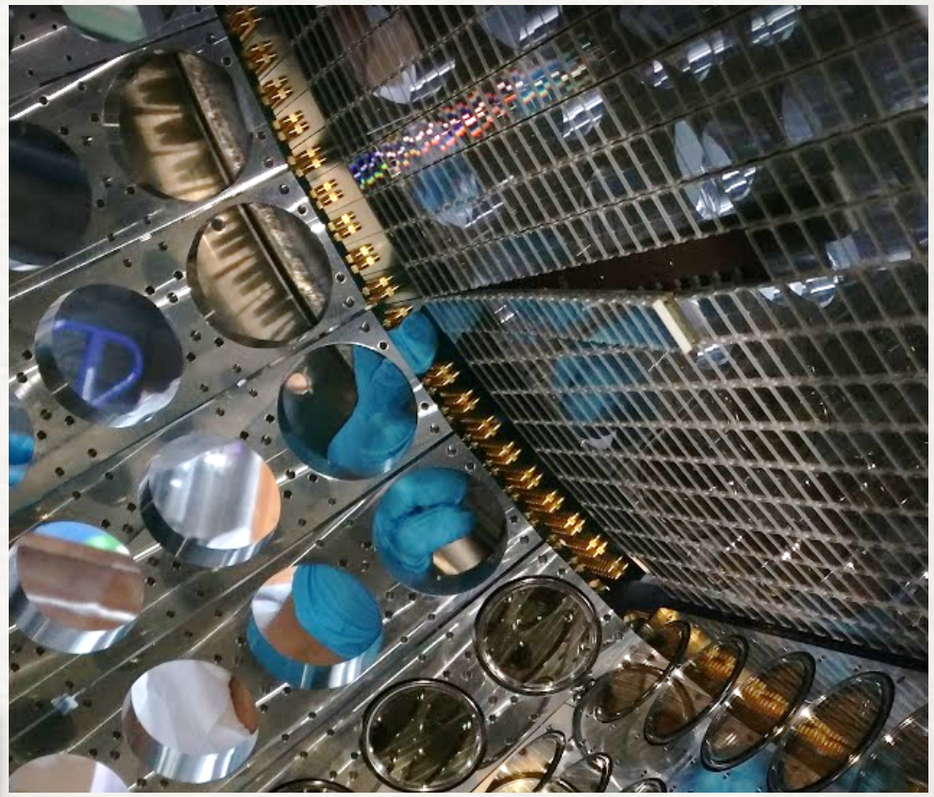
Positron reconstruction algorithm study(**17pK33-6**)

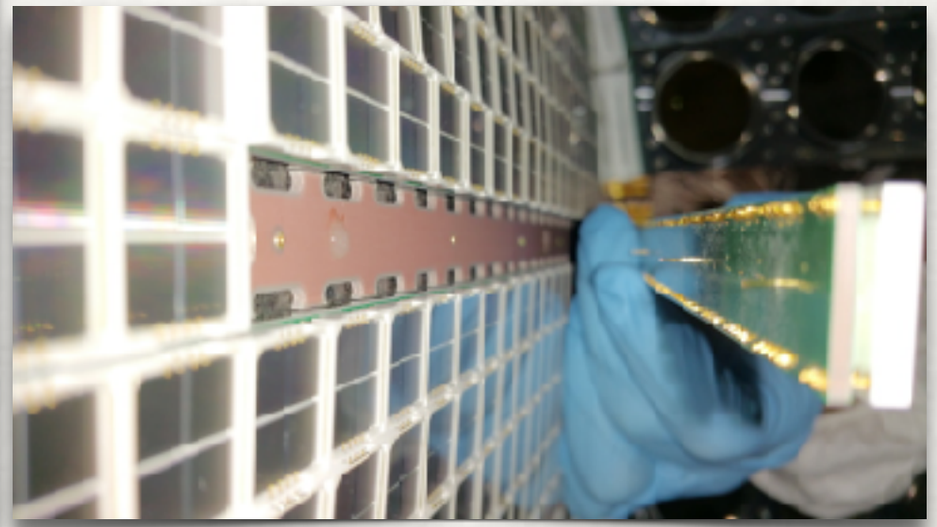
TC waveform simulation performance study(**20aA12-1**)

LXe PCB detach problem

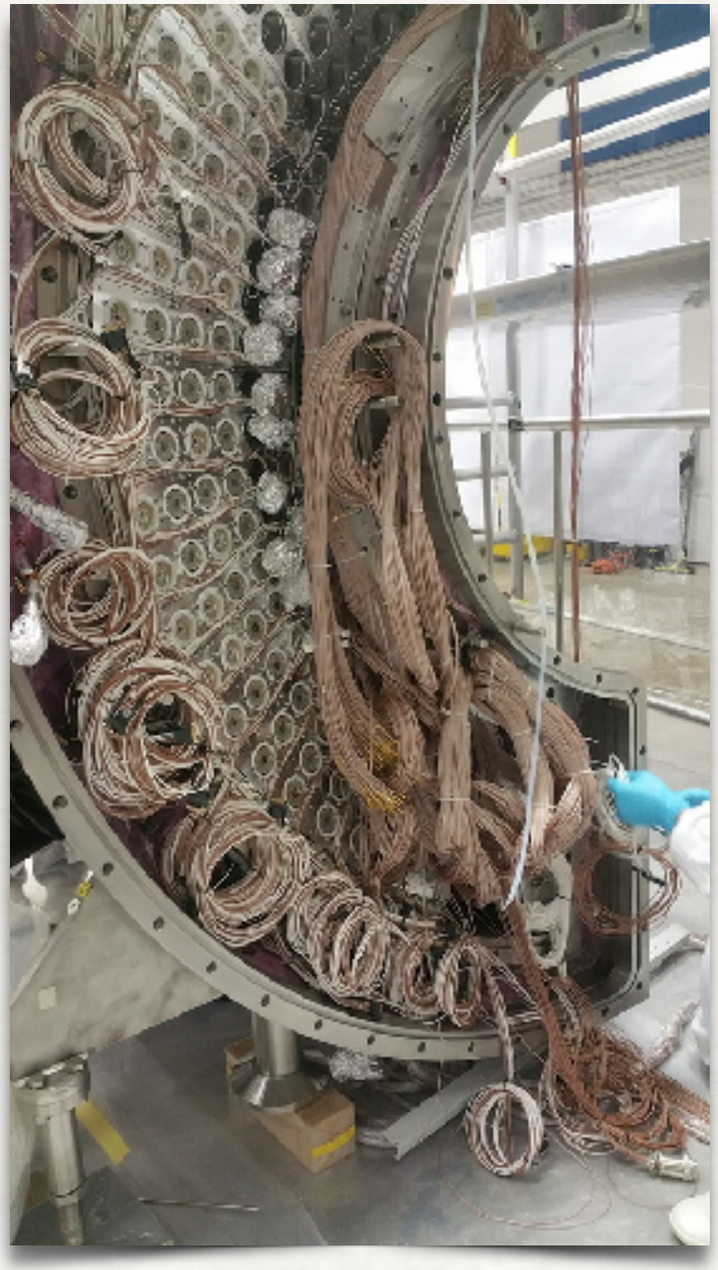


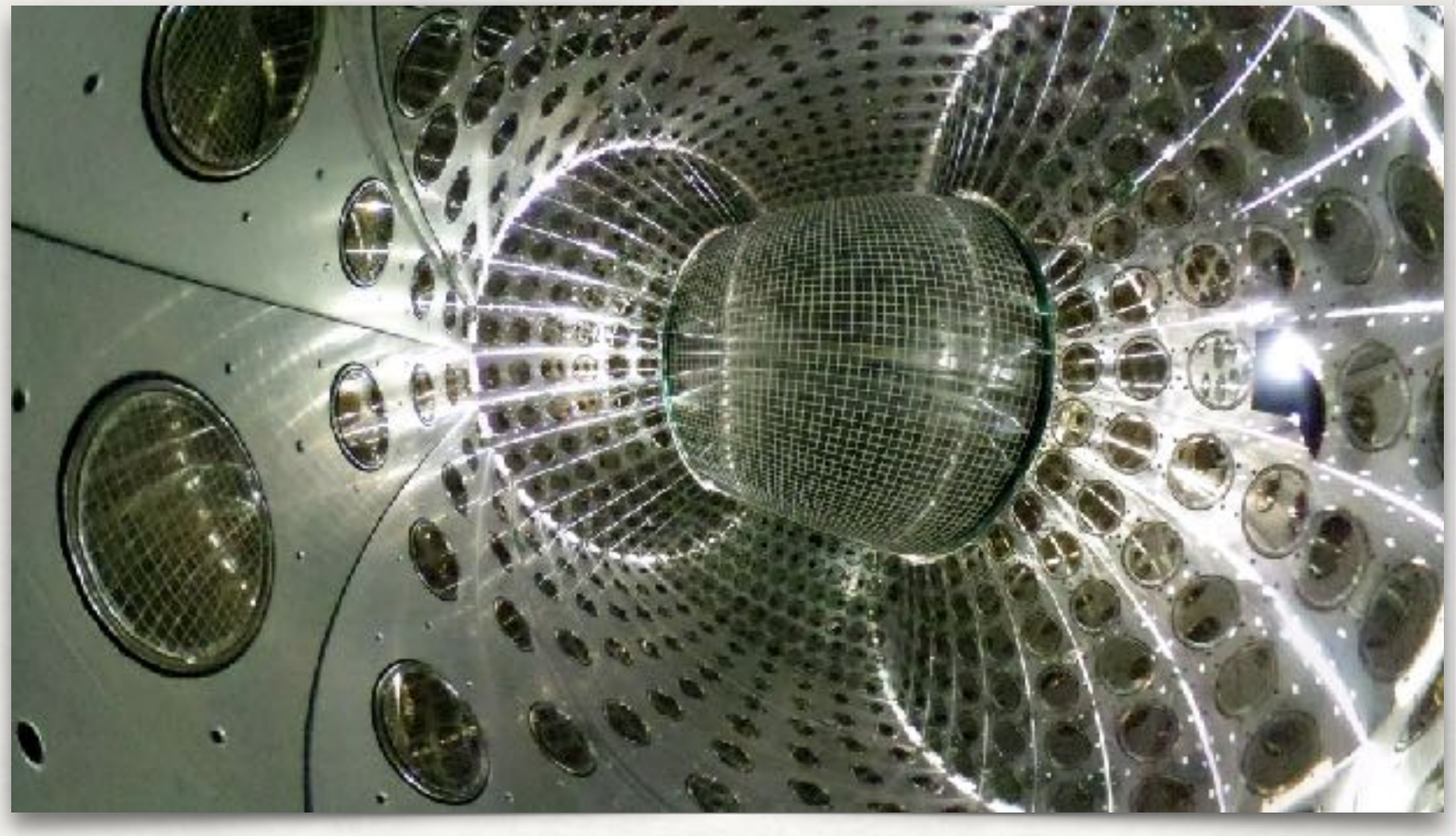
- Rather complicated MPPC mounting method
  - No screw from outside to reduce dead space
  - Minimize LXe in front of fiducial volume
- Problem
  - PCBs which support MPPC are attached with socket pins and a screw at one end, the other end rarely detached
- Solution
  - We decided to put Araldite between PCB and Spacer, successfully done!
- Confirmation
  - LifeCam HD-5000 web camera is installed
  - Used by ANKOK exp. (LAr)
  - Check inside even during liquid transfer

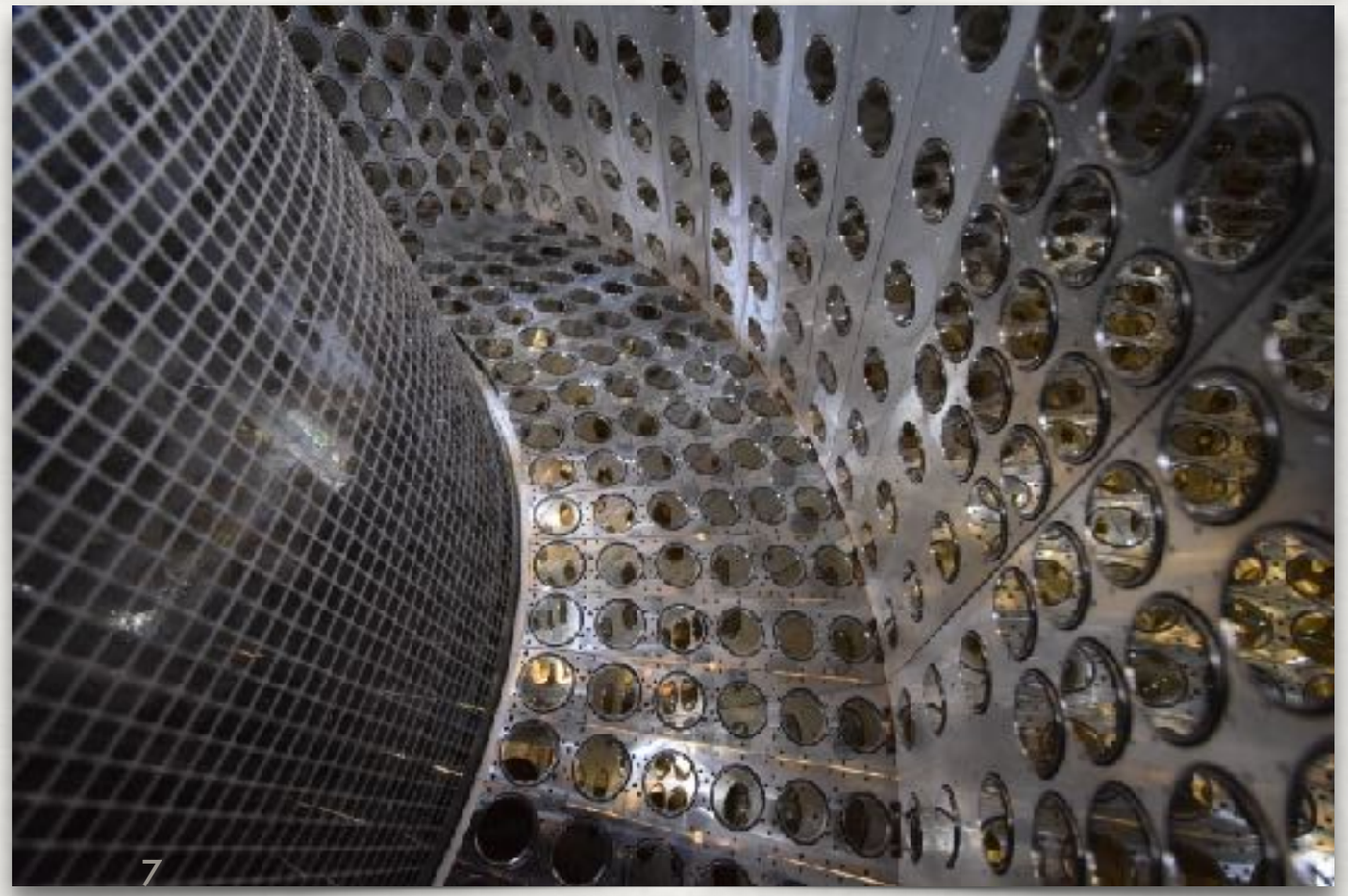




LXe Status

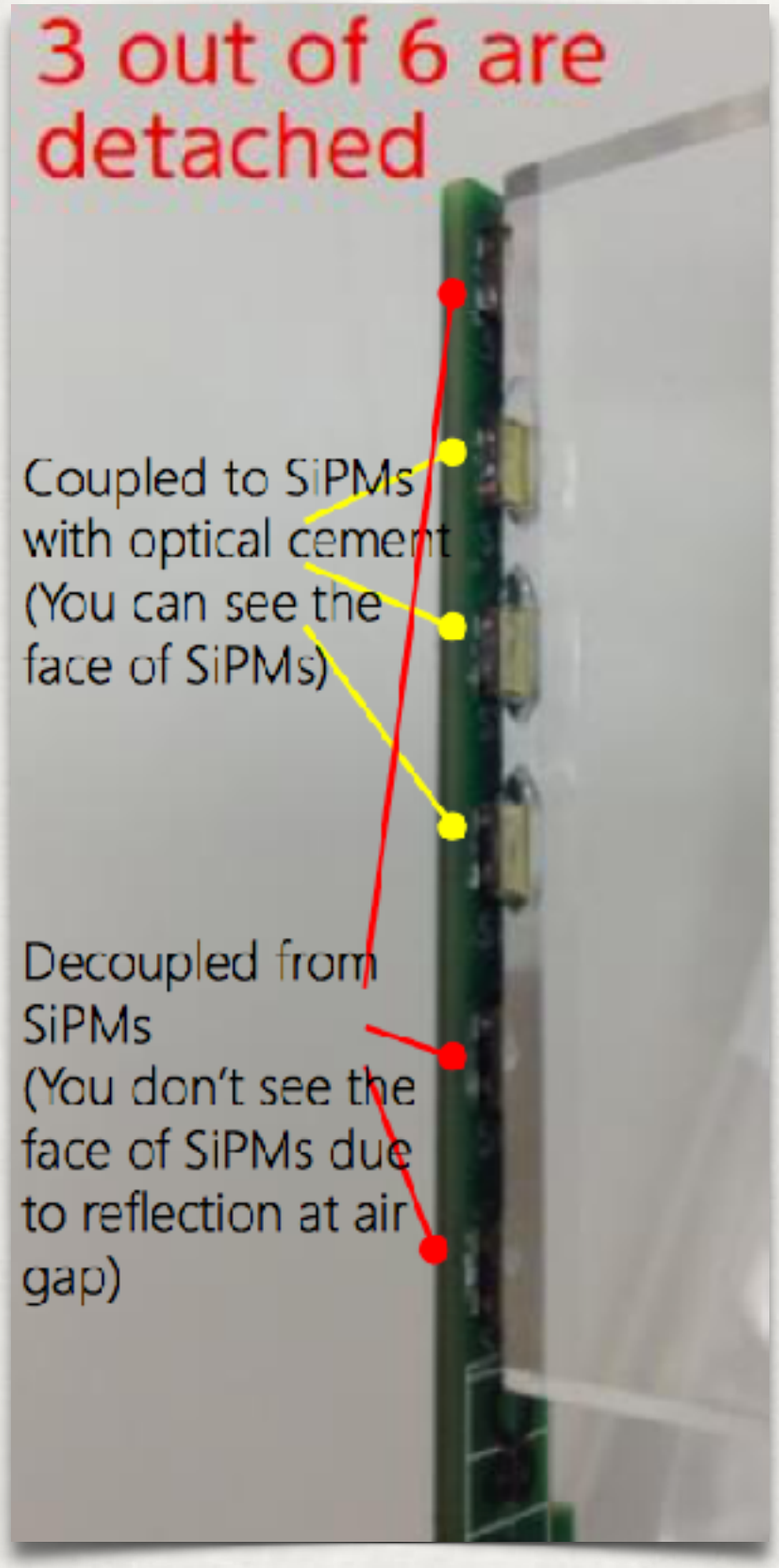




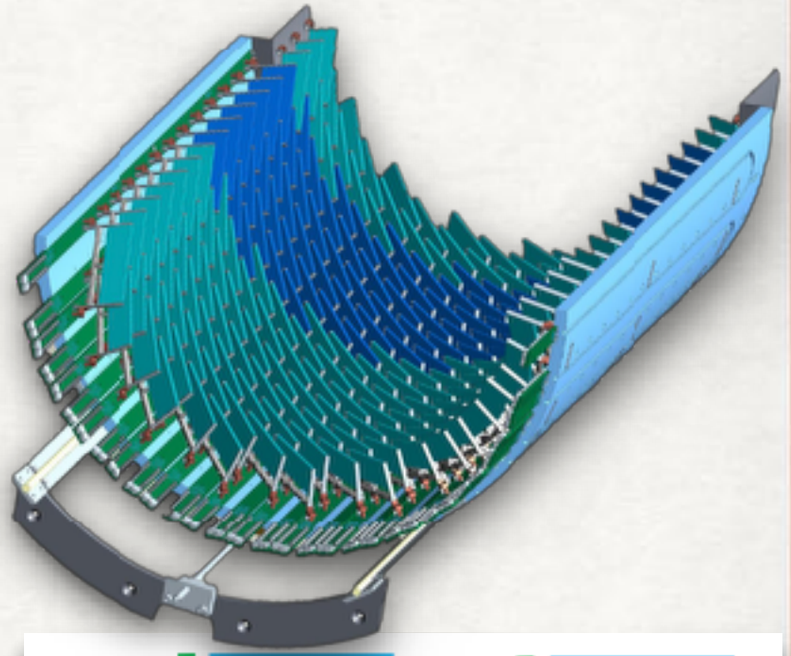


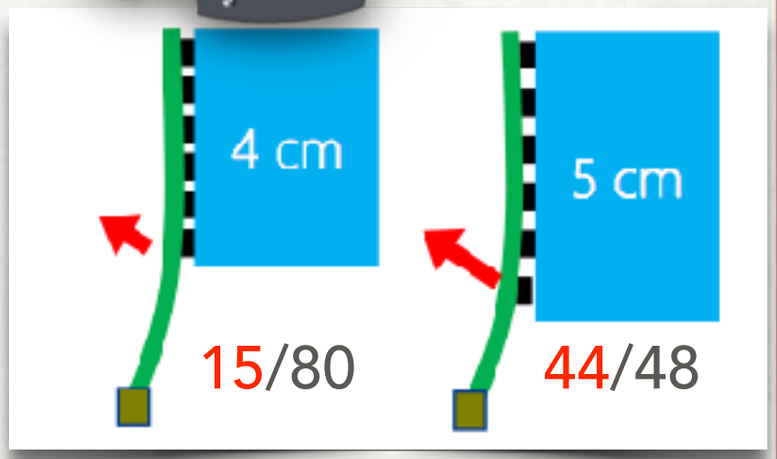
- Now cabling, waveform check are in progress.
- Start LXe transfer, purification & monitoring in spring - summer

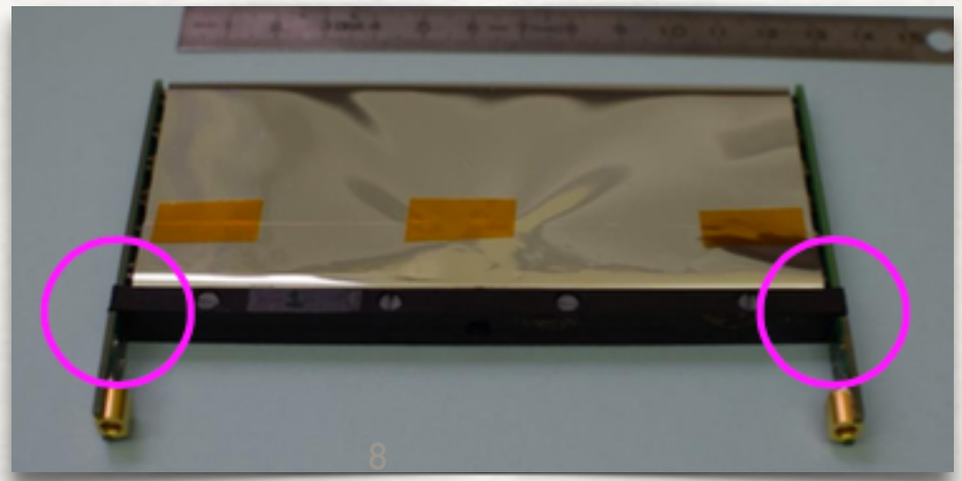
Timing counter SiPM detachment problem

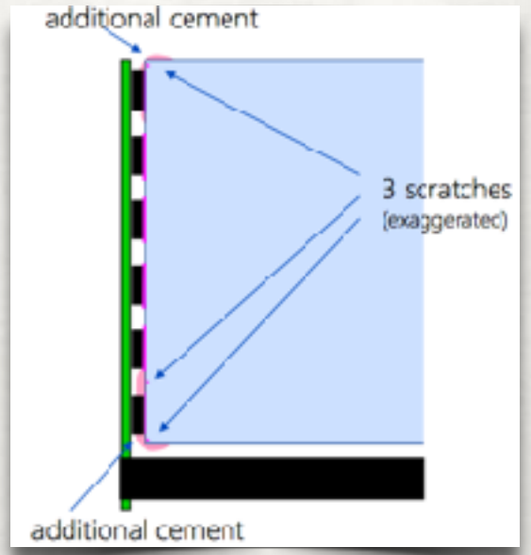


- Double side read-out
  - 6 SiPMs array coupled to scinti. and mounted in series on a PCB which act also as supporting structure.
- Problem
  - 128 counters mounted on 'old' structure, and about one half counters had SiPM detach problem
- Solution
  - Support structure with improved machining precision
  - Additional reinforcement
    - Fiber-support bars are fixed with Araldite
    - Additional cement with some scratches

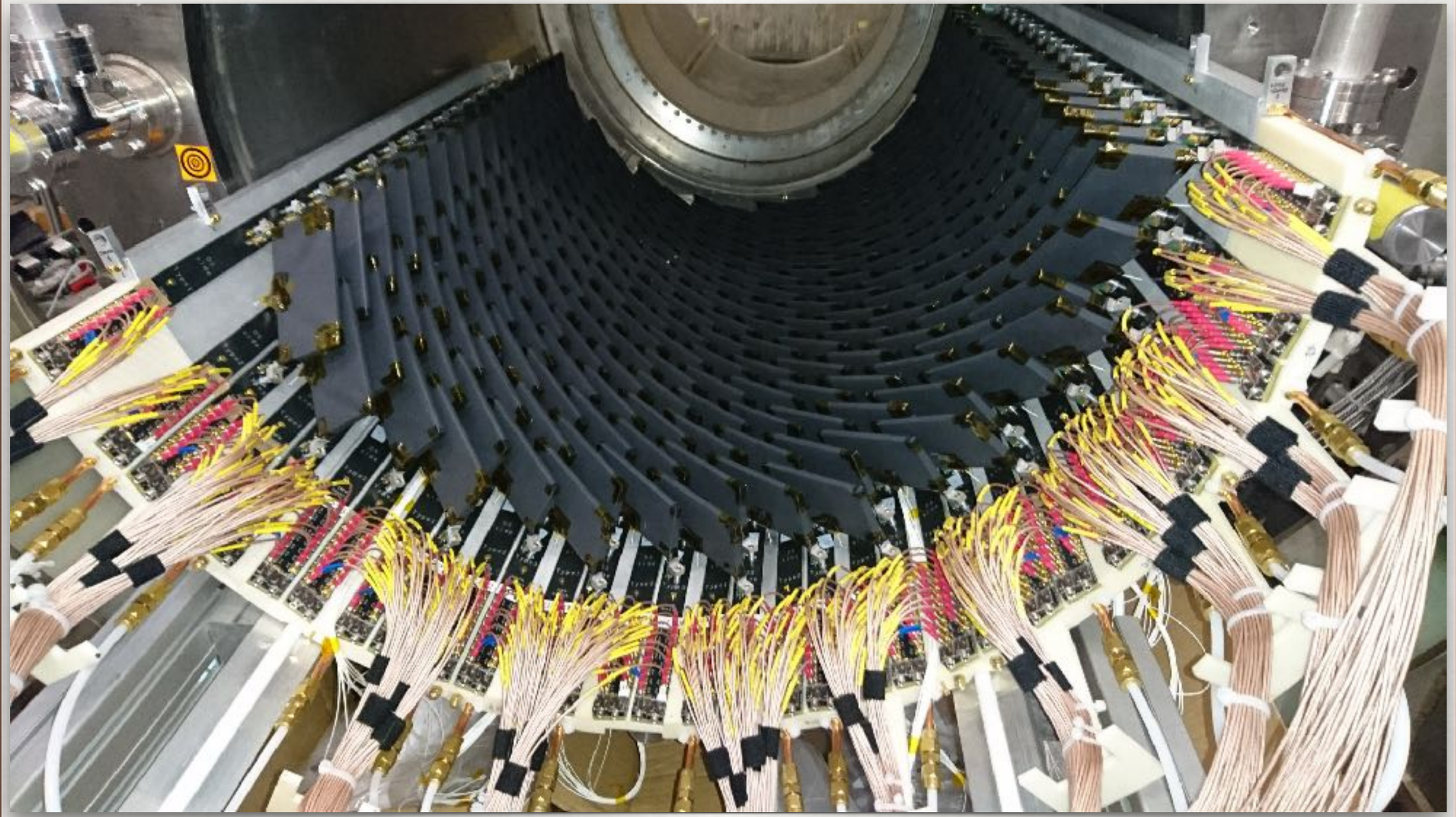








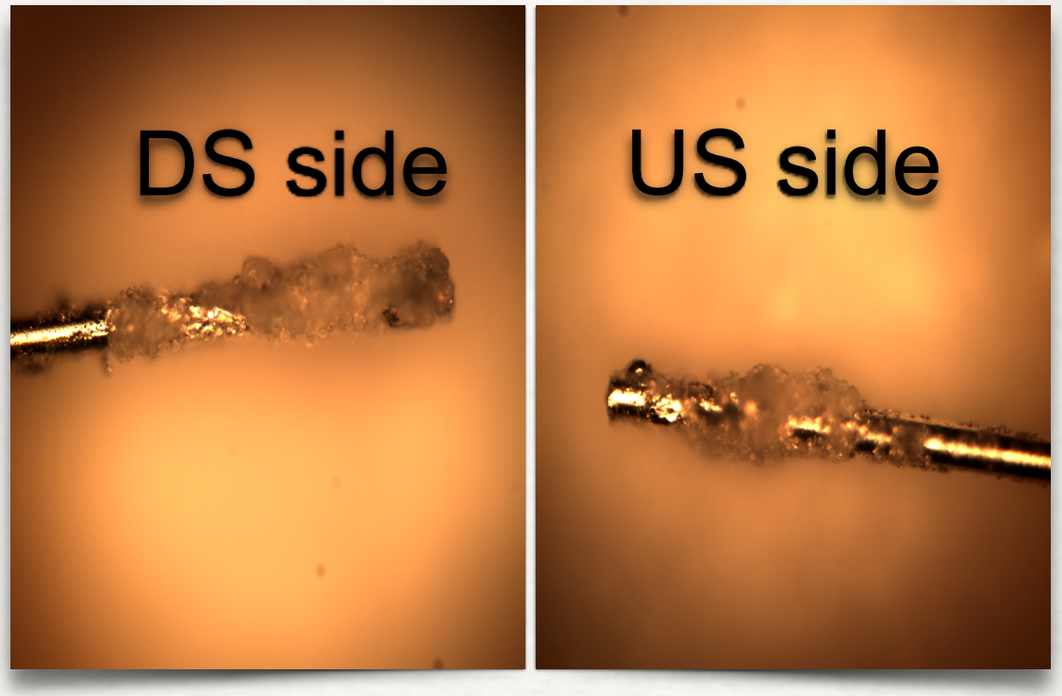
TC status

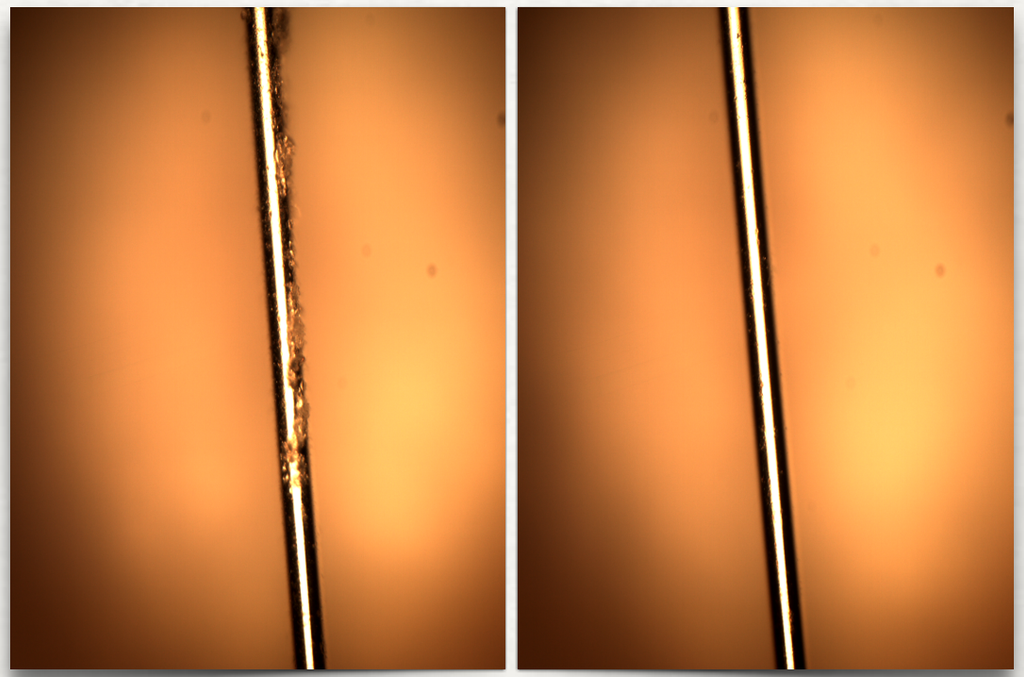


- One module (DS) is ready(the reinforcement treatment will be applied this summer), and the other will be ready by this summer

Drift chamber Problem

- First wire problem
  - 17 guard wires + 1 cathode wire / 700 wired wires broken due to humidity in March 2016
  - We thought we understand the problem, ensure the environmental relative humidity<50% in the clean room, and restart wiring in September.
- However, second wire problem happened!
  - 4 more wires broken in October.
  - All breaks within 30cm from DS side of the wire.
  - The damage is not diffuse but localized on a few mm spots.
  - Human saliva? Increased precautions (mask)





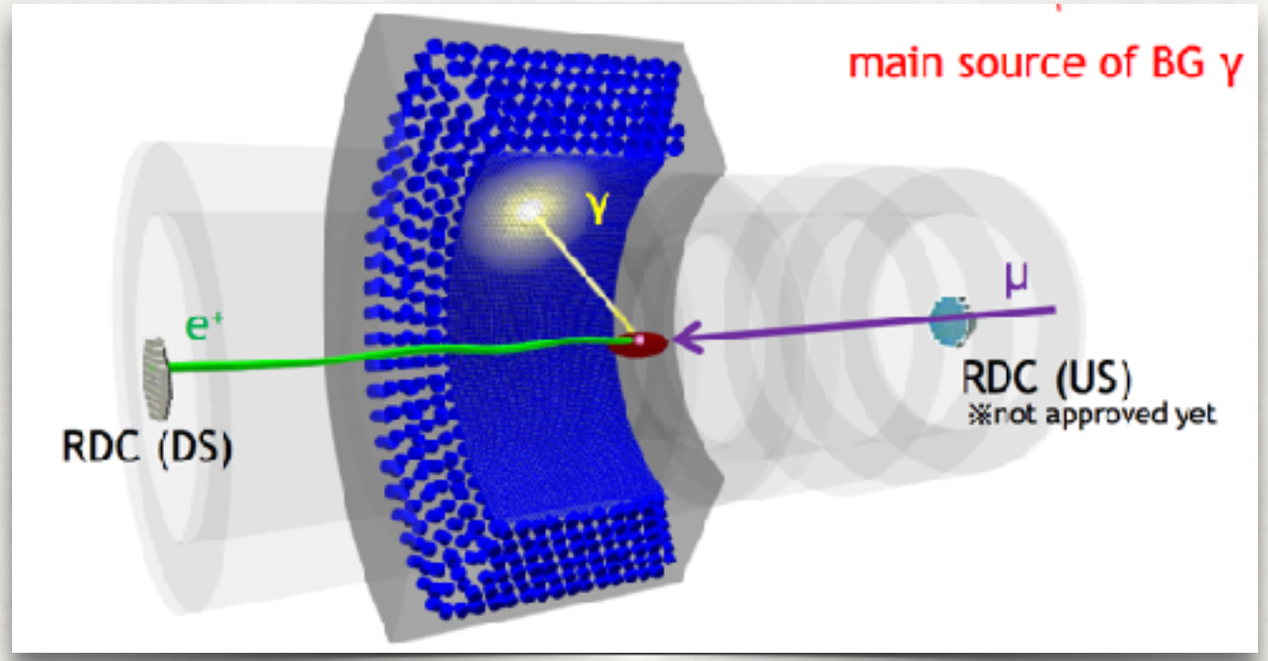
0.5 mm from the breakage

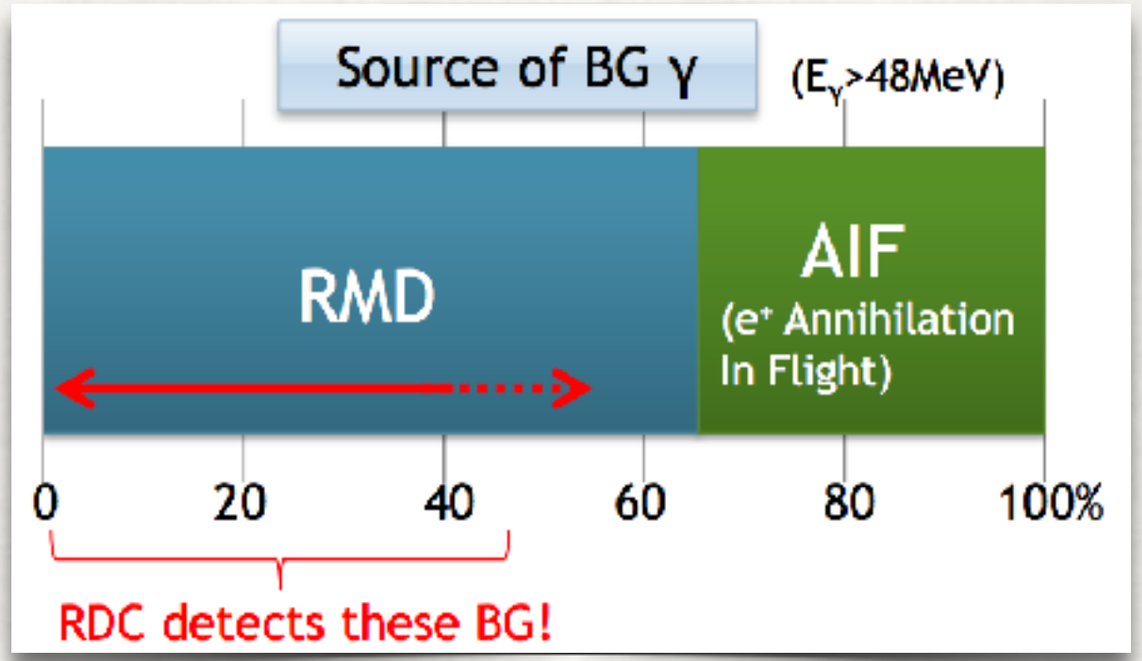
1 mm from the breakage

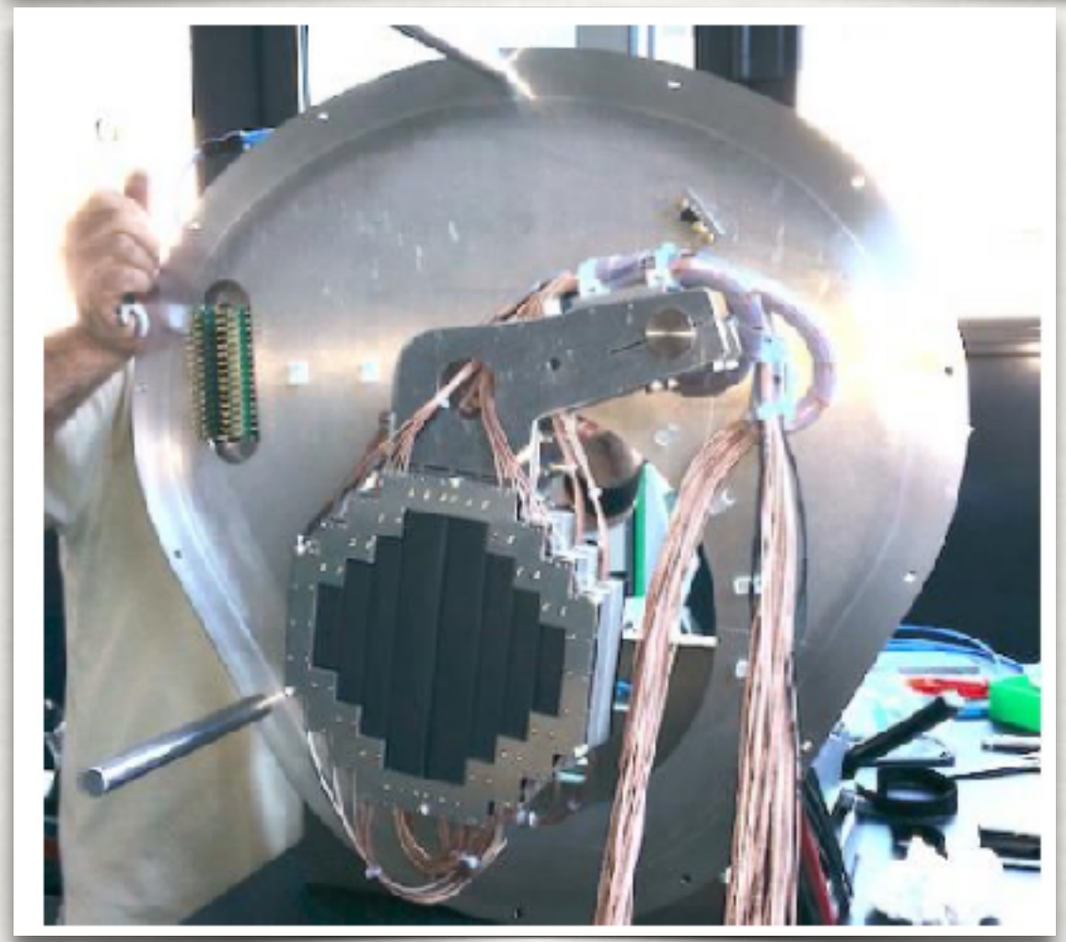
Present status of Drift chamber

- Restart wiring again. End of the wiring task : August 2017
- Chamber delivery at PSI : November 2017
- We decided not to install the drift chamber this year because we want to carry out LXe + TC + RDC + TDAQ muon beam data taking.

RDC status

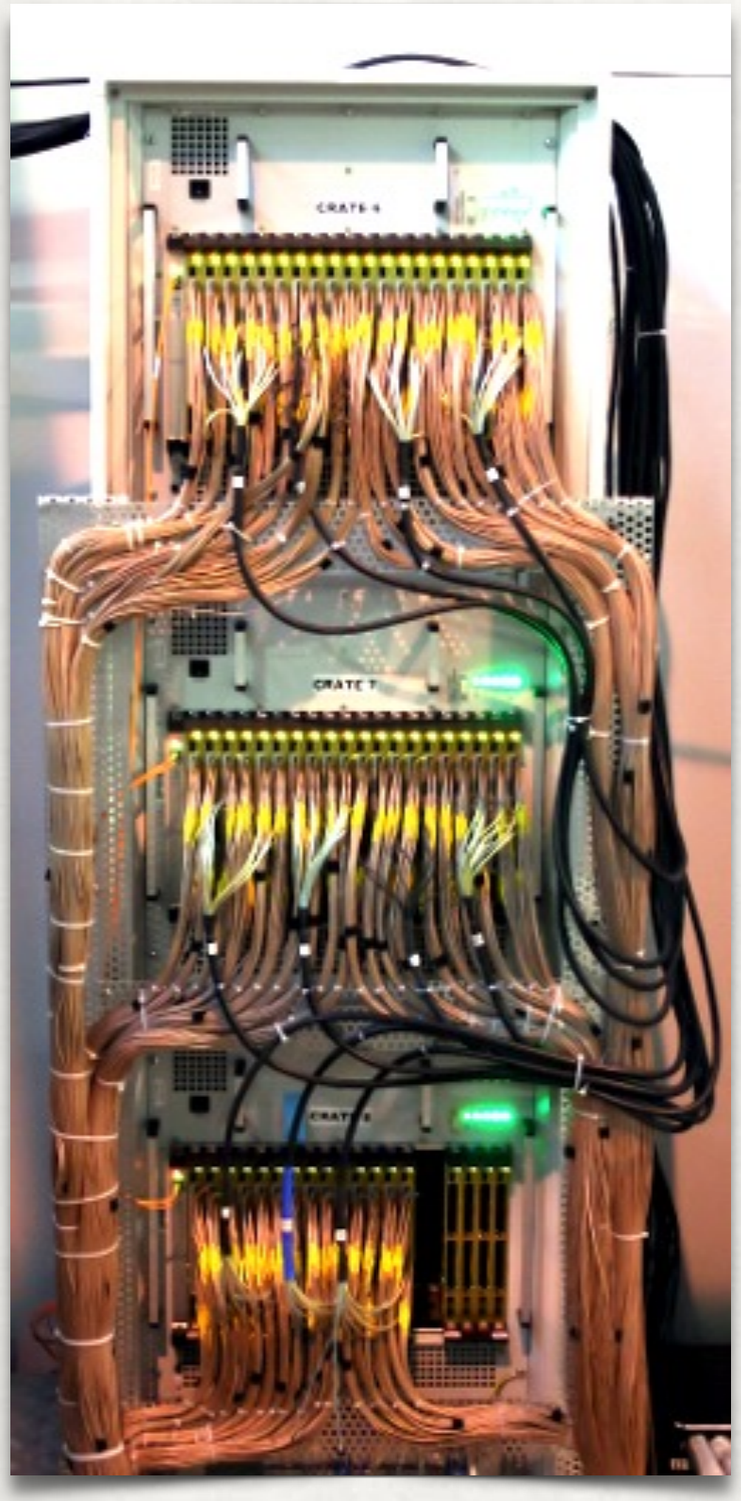






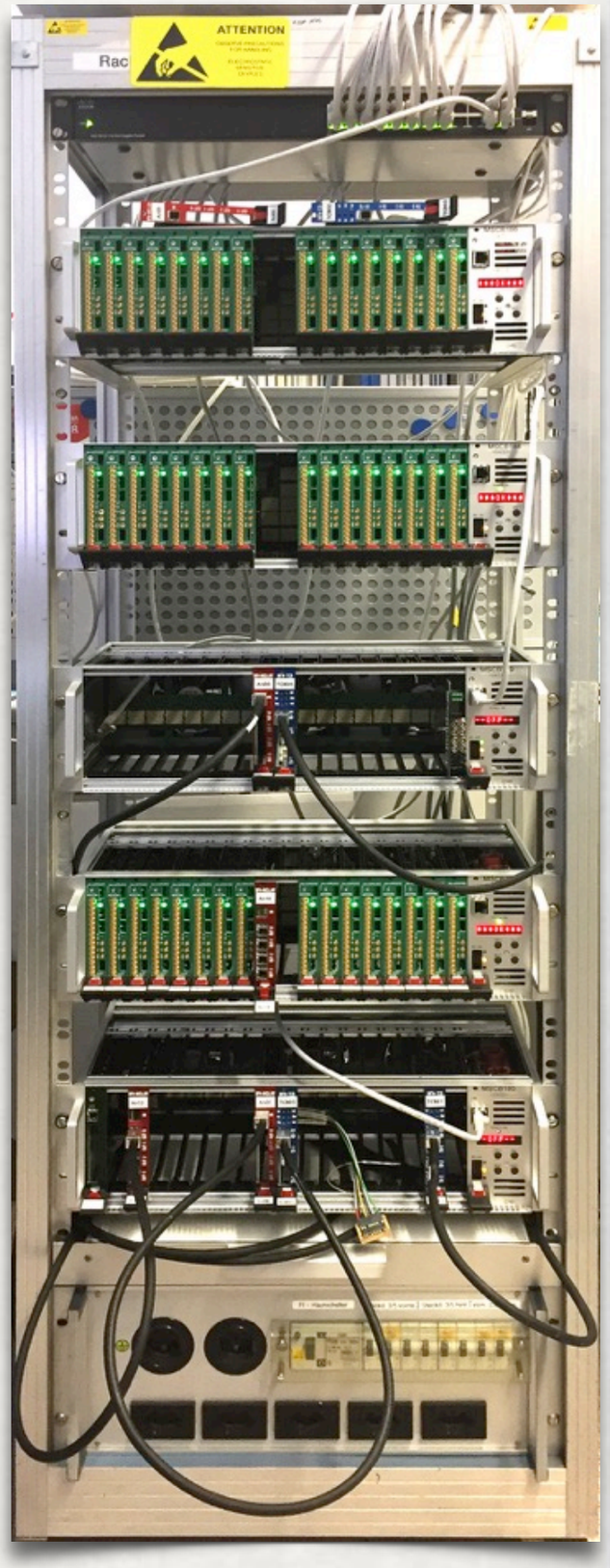
- DS RDC (Plastic scintillators + LYSO) are already made(small modification will be done), support structure has been constructed, and pilot run with muon beam performed
- US RDC (Scintillating fibers) Provisional design is made, influence for the muon beam, efficiency to detect RMD has been studied. Radiation damage of fibers are investigated, and early installation will be tried. **(18aK33-6)**

Readout electronics



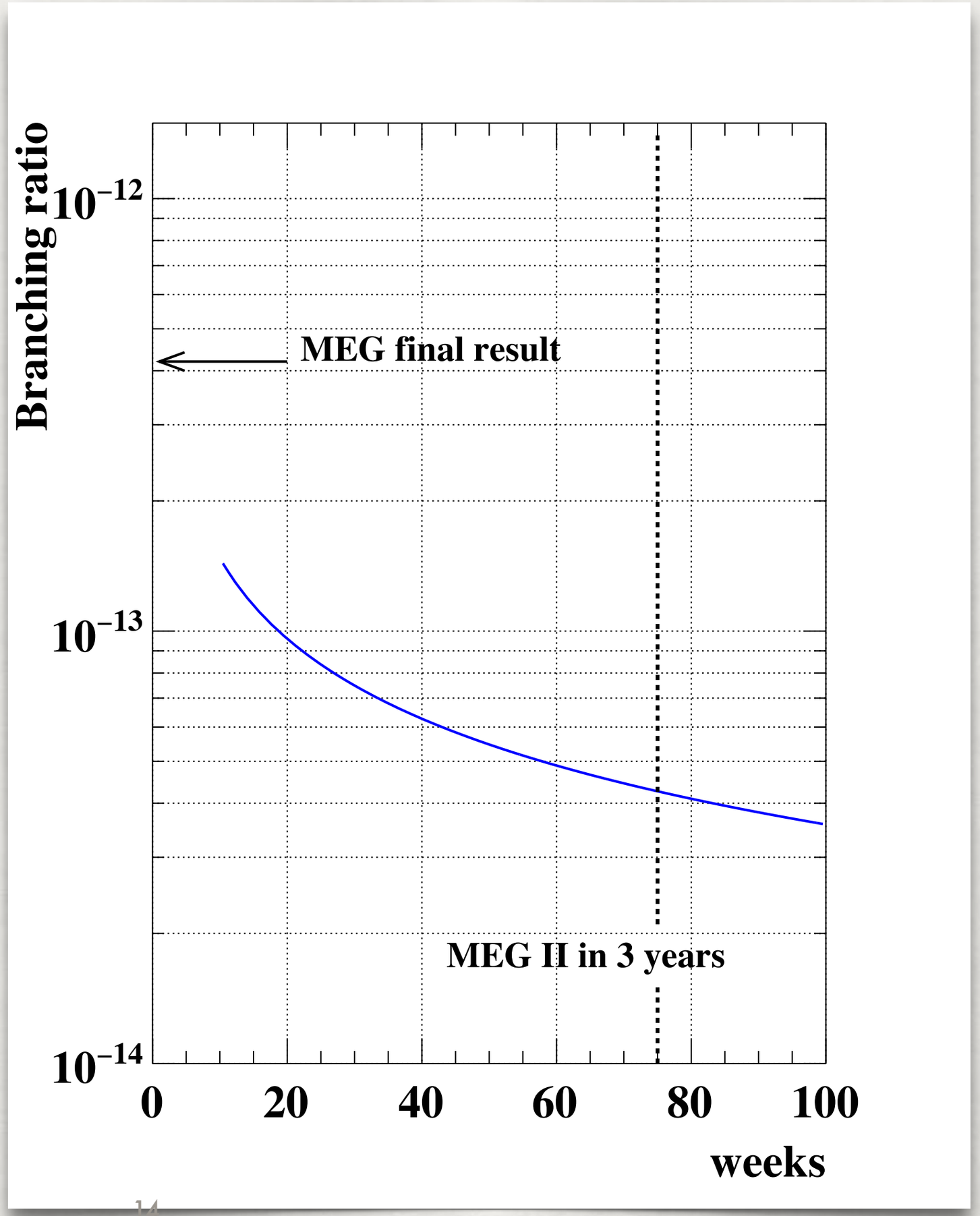
- MEG
- Separated DAQ&Trigger
- 3000 ch. DRS4 (0.8GSPS/ 1.6GSPS)
- 1000 ch. Trigger (100 MSPS)
- 5 Racks

- MEG II
- Combined DAQ&Trigger
- 9000 ch.
- Same rack space
- SiPM amplifier & Bias voltage supply integrated
- Four crates (1024 ch.) will be ready soon
- All Ch. for 2017 available in October



Updated plan for 2017 - 2018

- All detectors expected to be completed in 2017
  - However, drift chamber installation will continue into 2018
- Integrate LXe + TC + RDC + TDAQ & take data in November - December 2017
  - Michel run - TC timing resolution
  - RDC+LXe - RMD ID
  - LXe - energy, timing, position resolution with 17.6MeV CW p+ Li, online reduction study
- PSI beam time will be shorten in 2018 (start at July)
  - Aim at engineering run then, and start physic run
  - Once we start physics run, the sensitivity can reach the MEG final result within a few months

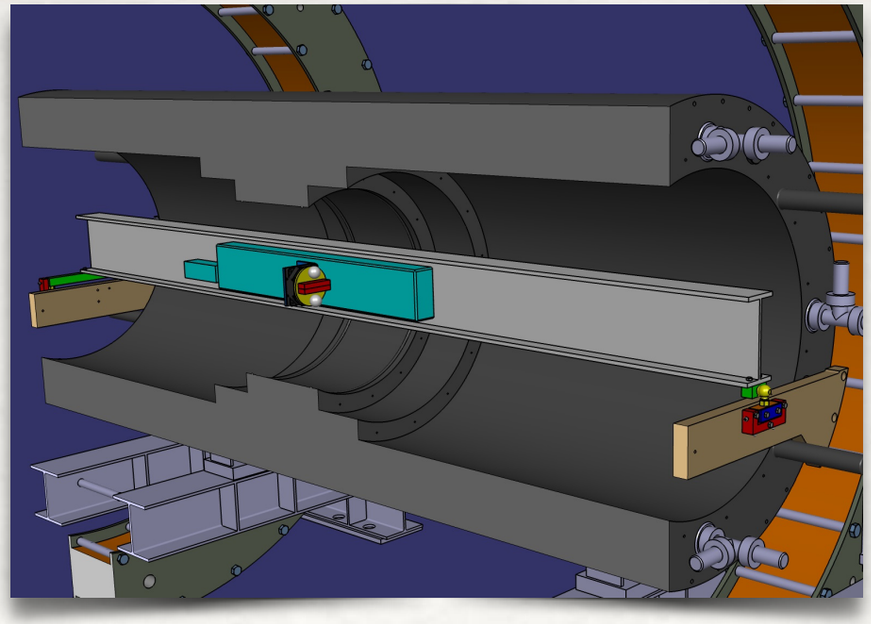


Summary

- Construction of MEG II detectors has been in progress.
- There were several issues and problems which have delayed our schedule, but this is a necessary step for the successful and stable MEG II experiment
- All detectors except for drift chamber to be completed in 2017, and at the end of 2017, data taking with muon beam with LXe + TC + RDC + TDAQ system is planned.
- Installation work will continue in 2018, and the engineering run will start in July followed by the physics run. A few months data taking will already give a better sensitivity than MEG.

What will be done in 2017?

- LXe X-ray alignment
- LXe energy, timing, position resolution study with 17.6MeV γ from Cockcroft-Walton accelerator plus Li target
- DC mockup installation into the beam line
- TC Michel run timing resolution study, laser calibration
- RDC + LXe Radiative muon decay identification
- TDAQ full electronics

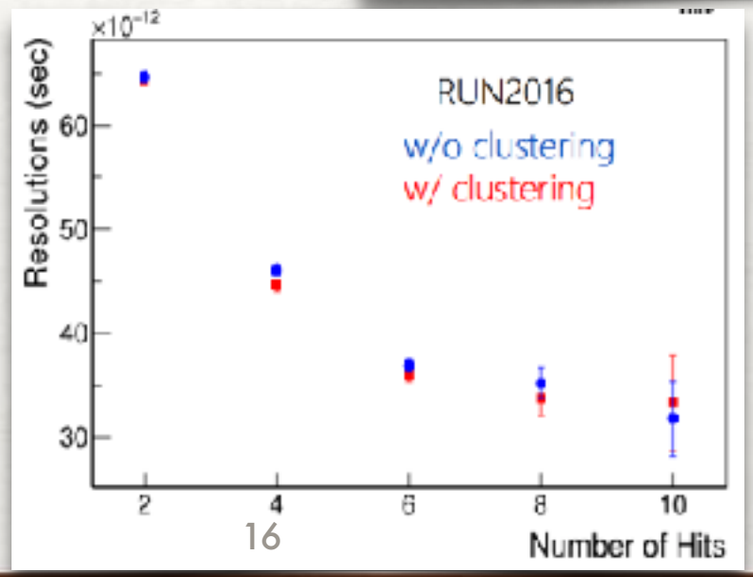


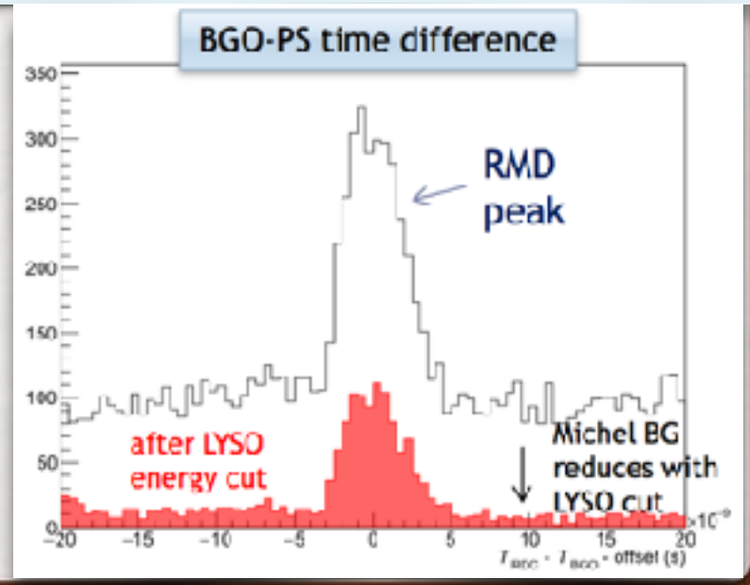
Timing, position resolution (MC)

MEG II (Simulation)	17.6 MeV γ readout: 1024 ch	17.6 MeV γ readout: all ch	52.8 MeV signal γ readout: all ch	
Position	2.1 mm	2.1 mm	1.9 mm	5-6mm
Timing	53 ps	52 ps	41 ps	67ps

Energy resolution (MC) (MEG)

MEG II (Simulation)	17.6 MeV γ readout: 1024 ch	17.6 MeV γ readout: all ch	52.8 MeV signal γ readout: all ch	
Energy (w<2cm)	1.6%	0.9%	0.7%	2.3%
Energy (w>2cm)	1.2%	0.7%	0.6%	1.6%



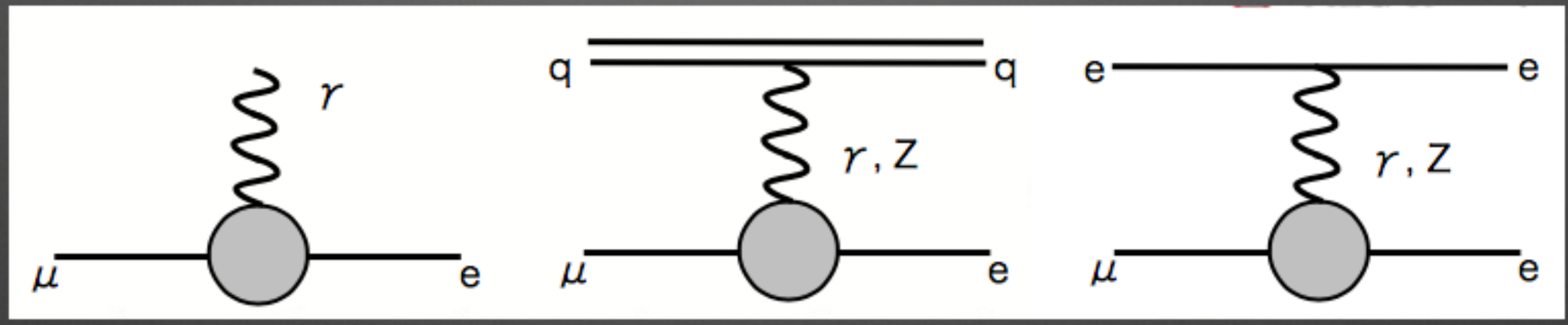


Muon cLFV Sensitivity comparisons

$\mu \to e\gamma$ $\mu N \to eN$ $\mu \to 3e$

"dipole" dominant

(SUSY etc)



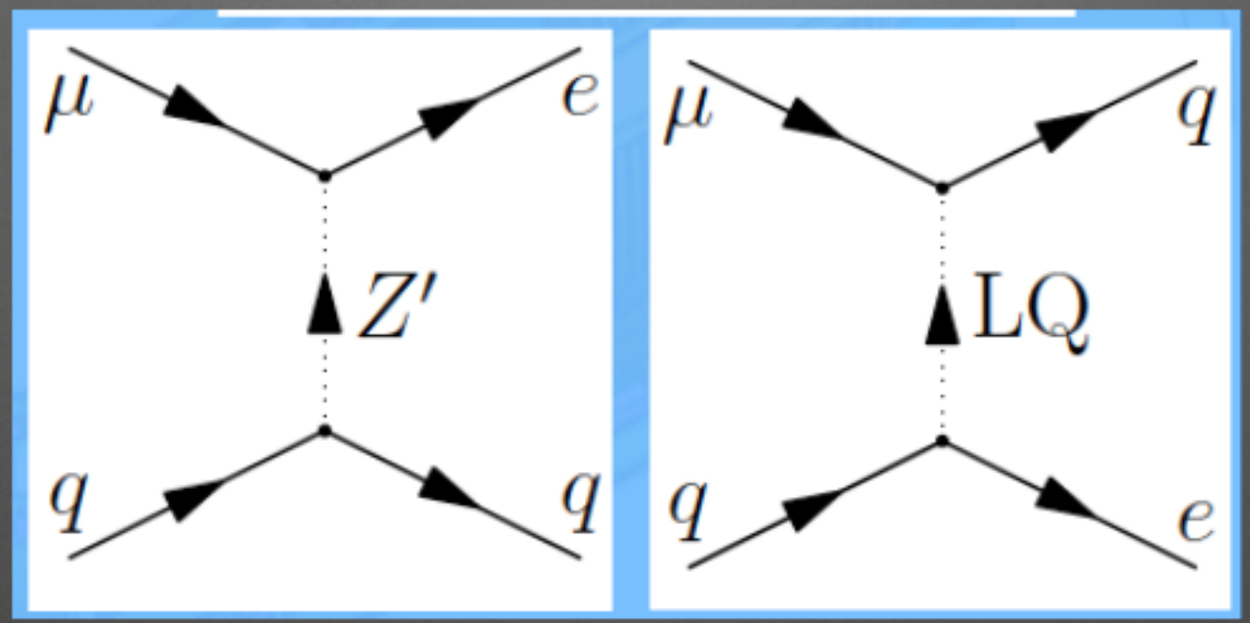
1 : 1/390 : 1/170

BR = 4×10^{-14} : 1×10^{-16} : 2×10^{-16}

~MEG II goal

for Al target

a caveat !

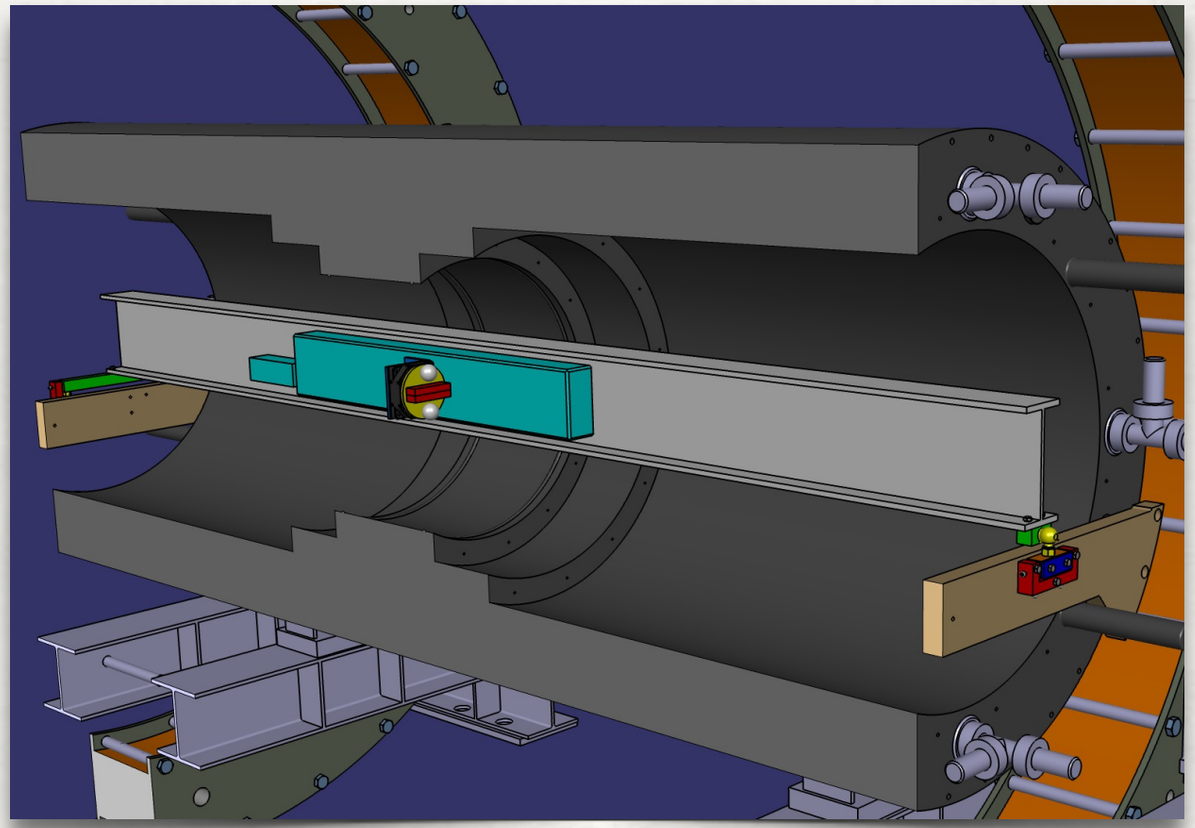


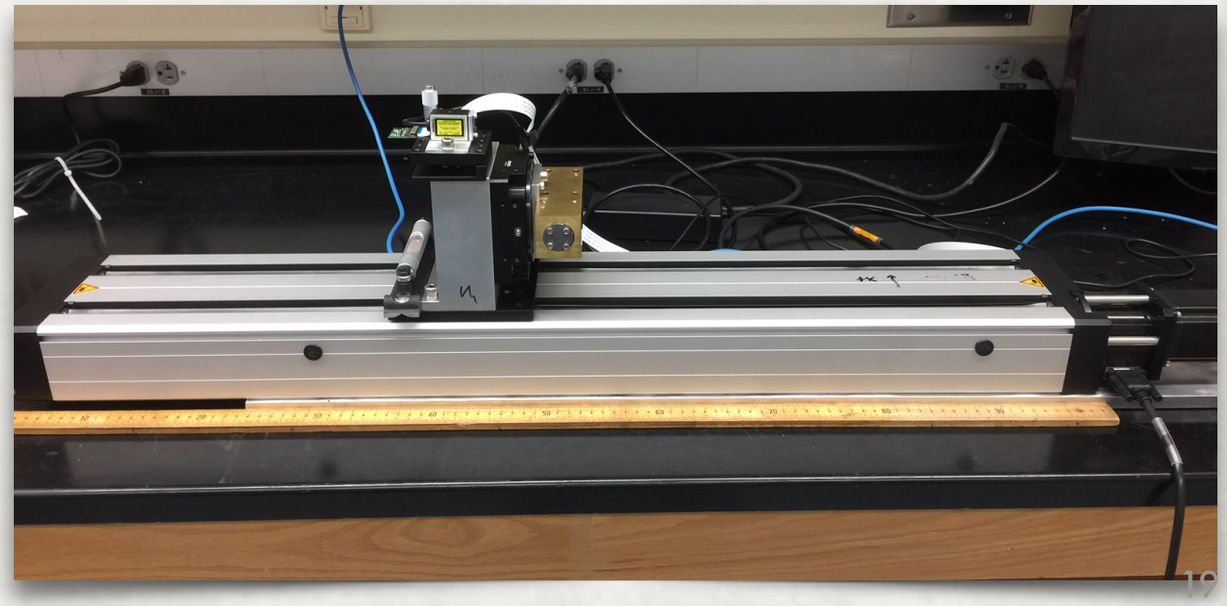
Some models have “four-fermion” *tree* terms which could strongly enhance

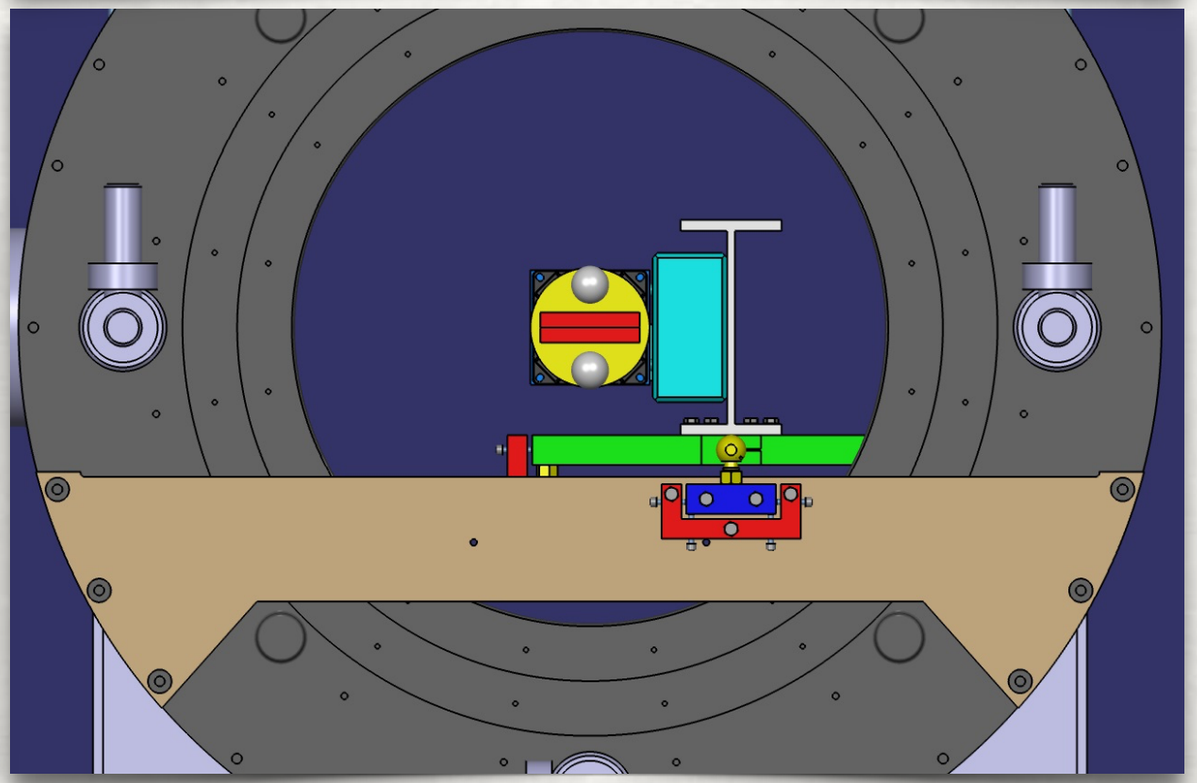
$$\mu N \to eN \qquad \mu \to 3e$$

MPPC ALIGNMENT WITH X-RAY

- Produce collimated X-ray beam of known position and orientation
  - 124 and 132keV from ^{57}Co
  - Brass 36x36x110mm^3, beam slit ~0.15x5mm^2 → spot size at LXe ~1.2x40mm^2
- Detect electrons from Compton scattering of photons immediately in front of MPPC



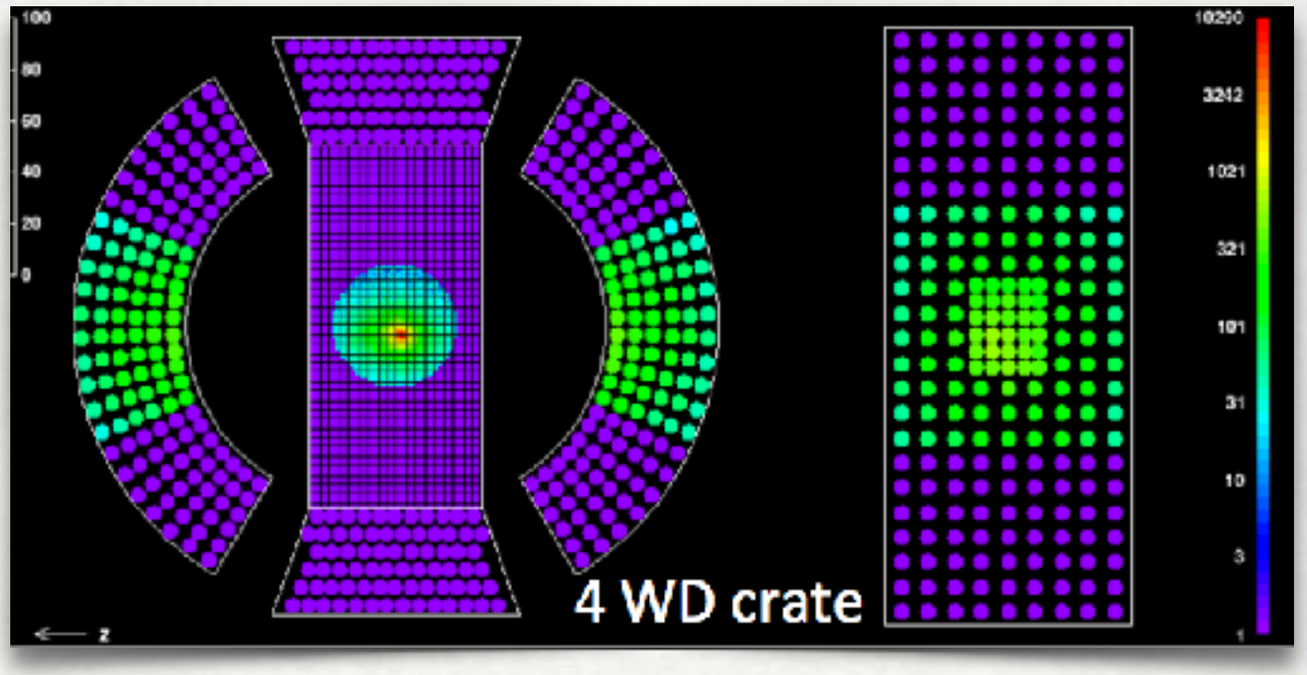




LXE CALIBRATION WITH CW

- Timing, position resolution
  - lower γ energy (p.e. statistics) have little effect
  - Even with limited #ch. electronics, we can check the improvements from MEG
- Energy resolution
  - limited # electronics cause worse resolution, but still good to check the improvements from MEG
  - 2.8% for 17.6MeV γ in MEG

Example of 1024 ch. readout



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(MEG)

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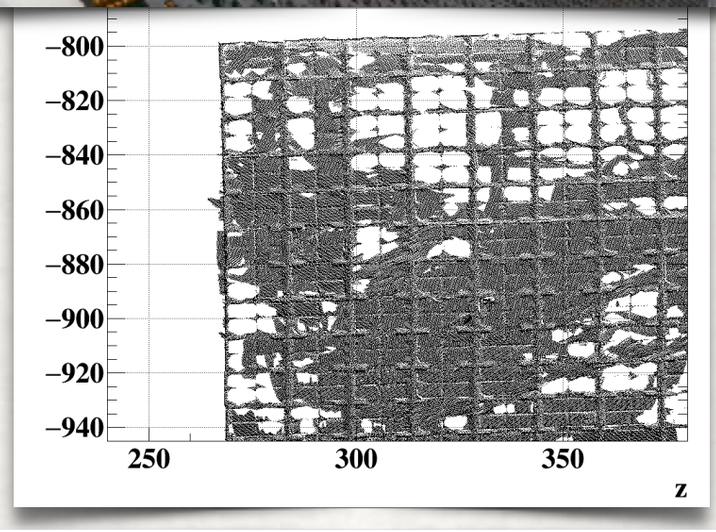
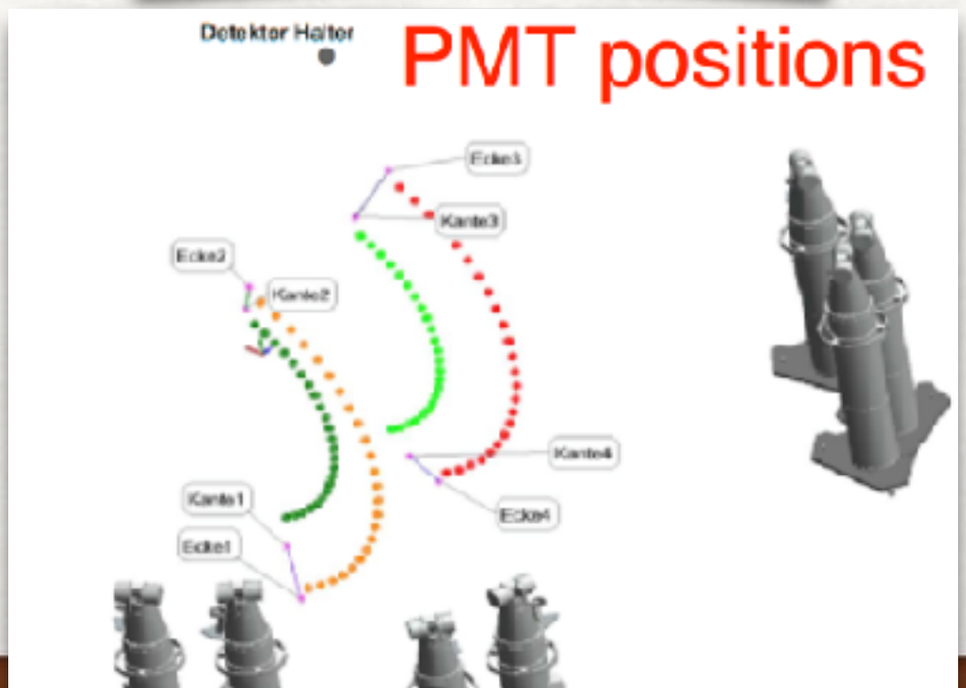
(MEG)

ALIGNMENT WORK

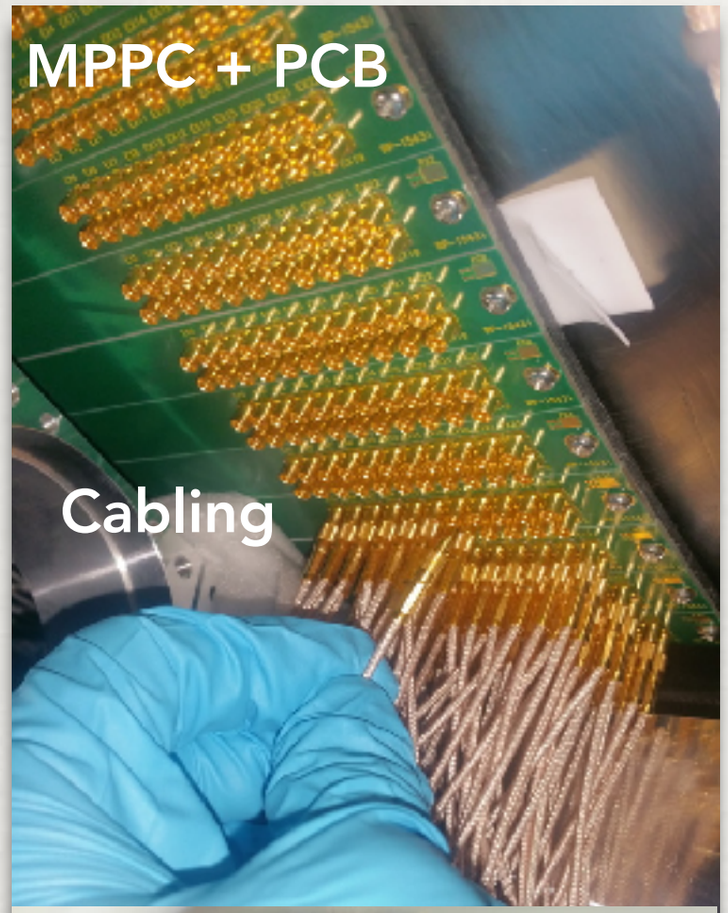
- Sensor position alignment at room temperature in COBRA coordinate < 0.5mm precision
  - All MPPC positions by 3D FARO arm scan
  - PMT lateral holder positions, top/ bottom holder edges by laser tracker
- At LXe temperature
  - Potentiometers in vacuum vessel to monitor the position of the inner cryostat
  - X-ray measurement (in 2017, later)

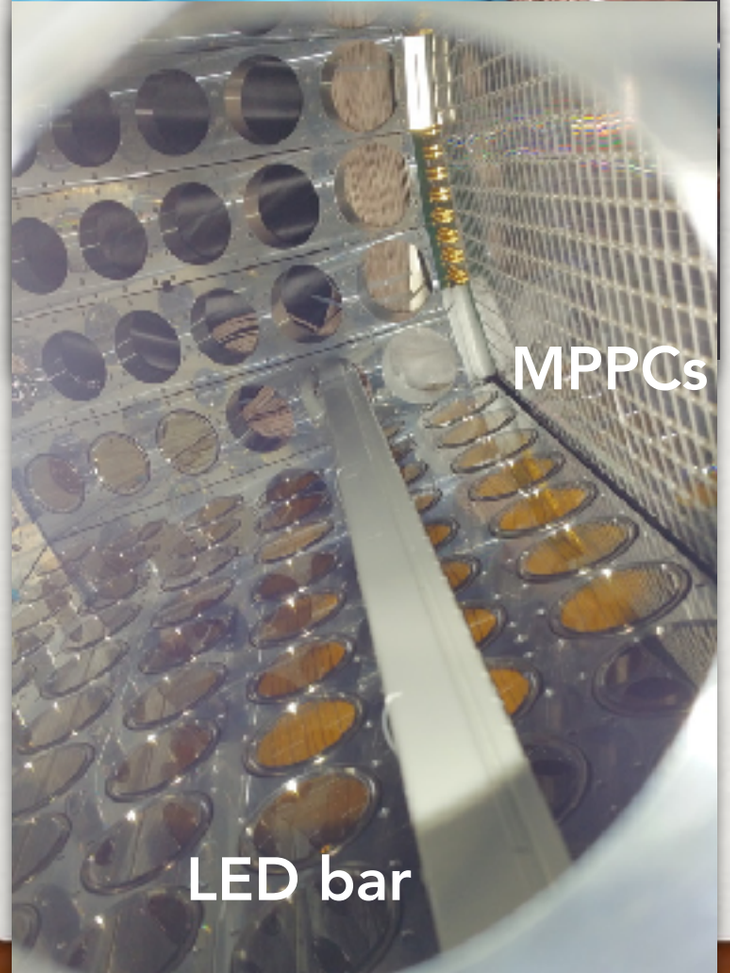


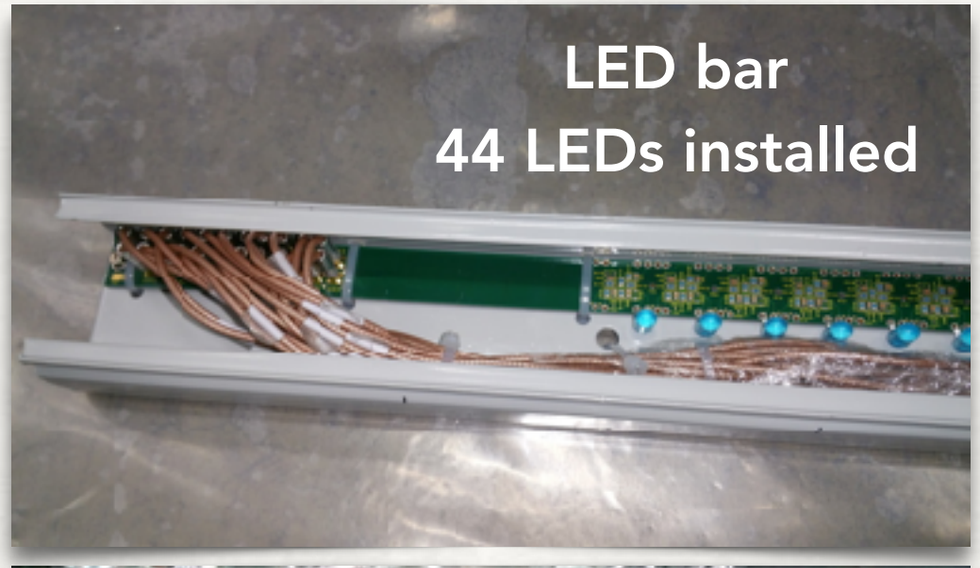


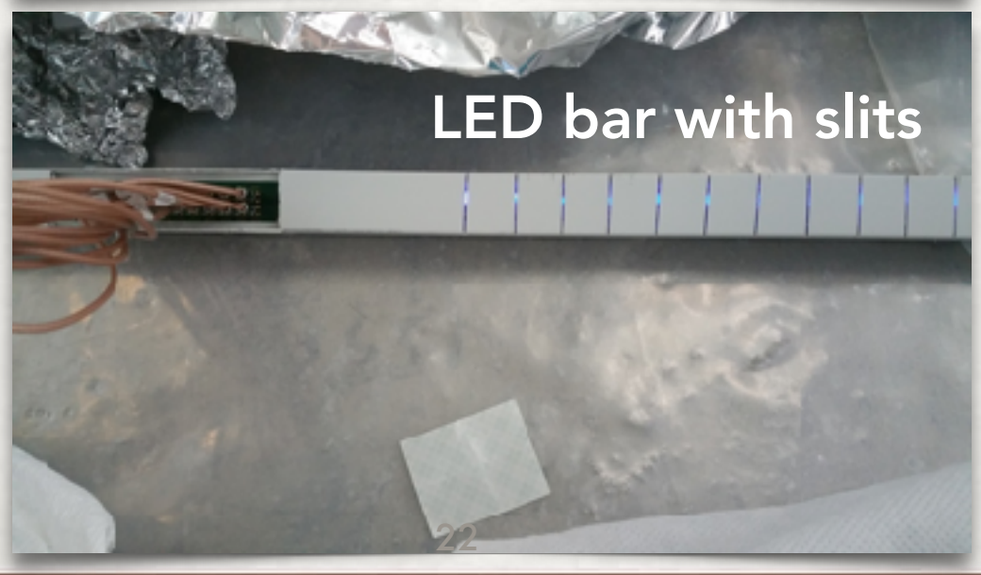
LXe calorimeter construction

- In order to check that cabling is correct, each MPPC is illuminated by one LED, and the current is read out
- Measurements done after each row cabling (44 MPPCs) x 93 rows



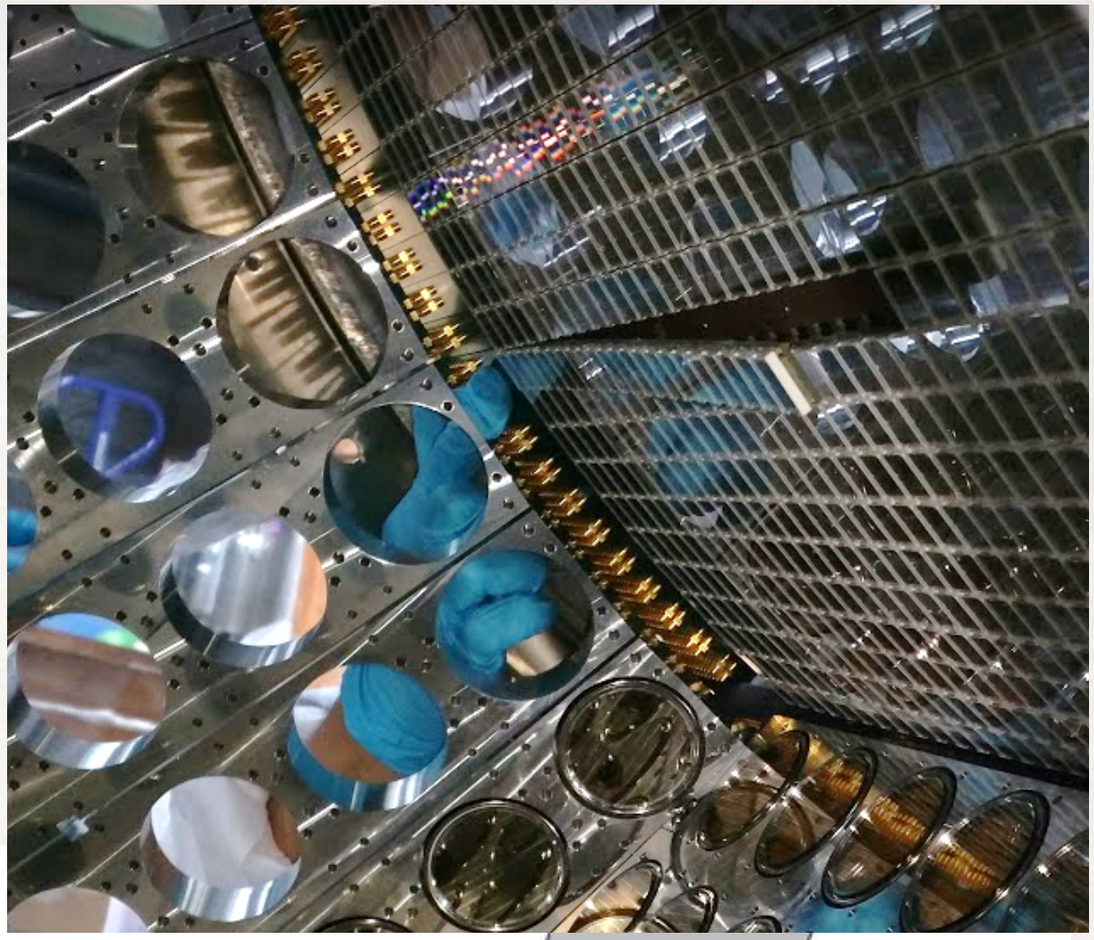


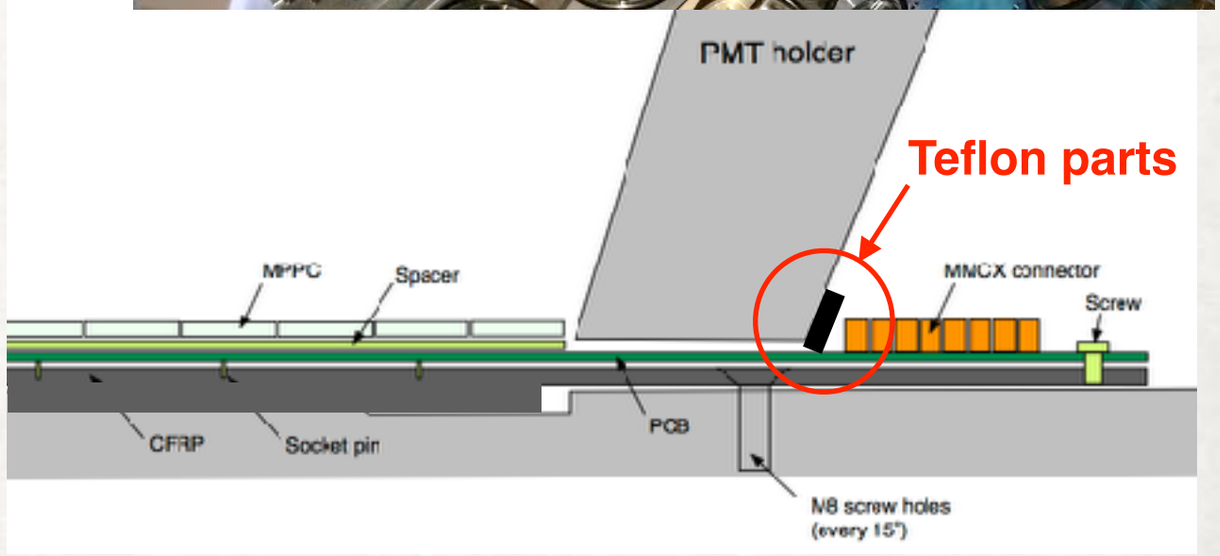


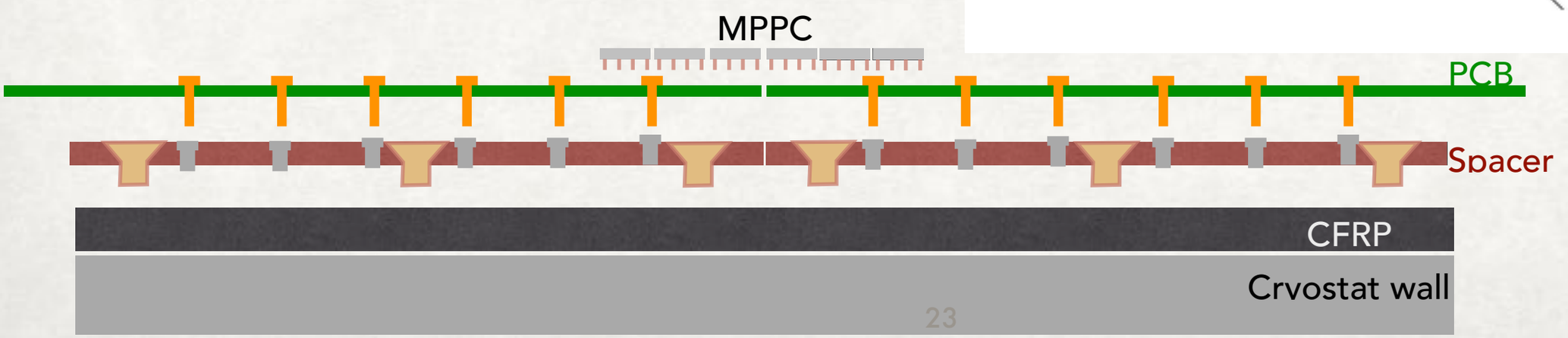


LXe PCB detach problem

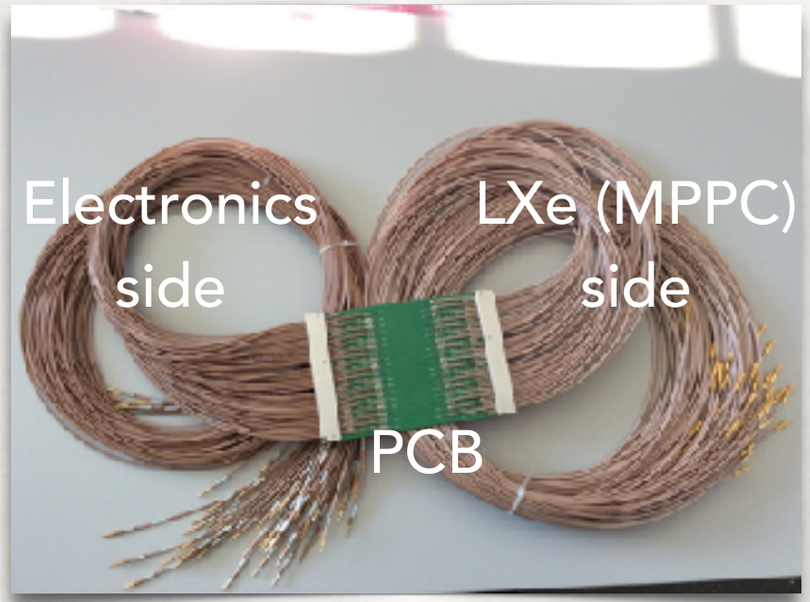
- PCBs which support MPPC are attached with socket pins and a screw at one end
- Once cables are connected to MMCX connectors, and the cables are pulled, the PCBs are detached from the spacer board
- We installed additional teflon parts to support PCBs



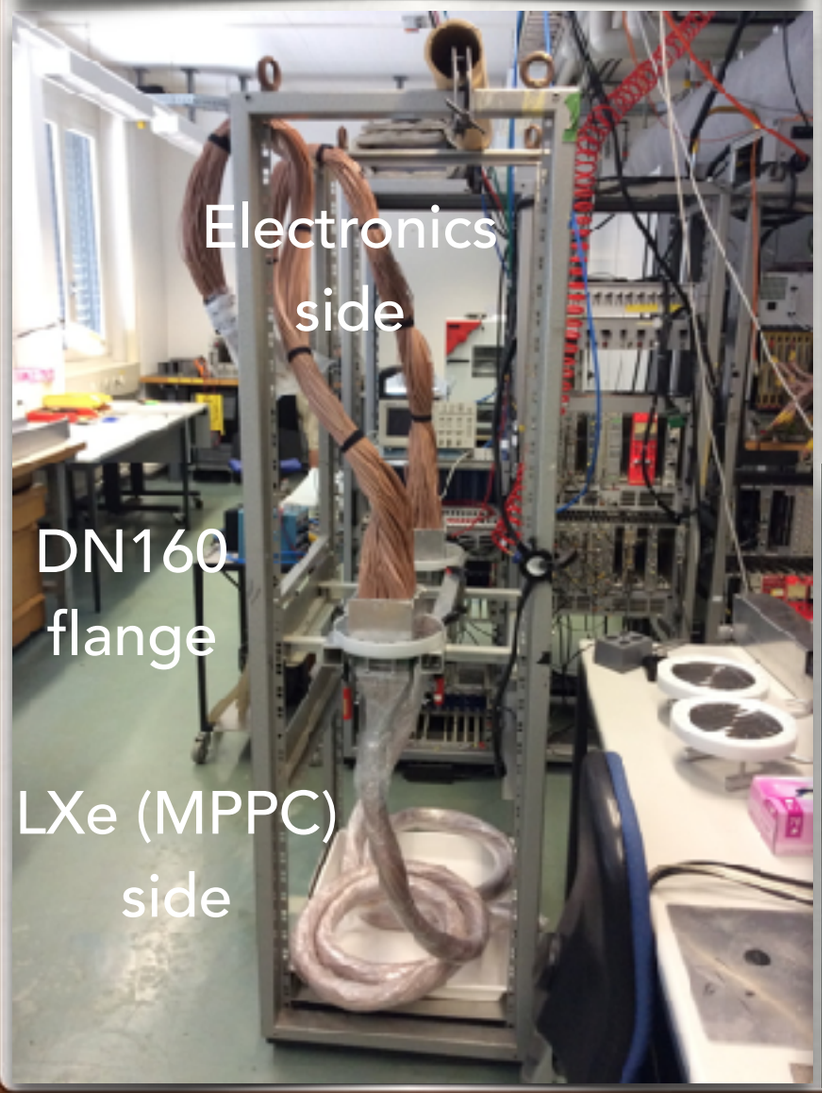




FEEDTHROUGH

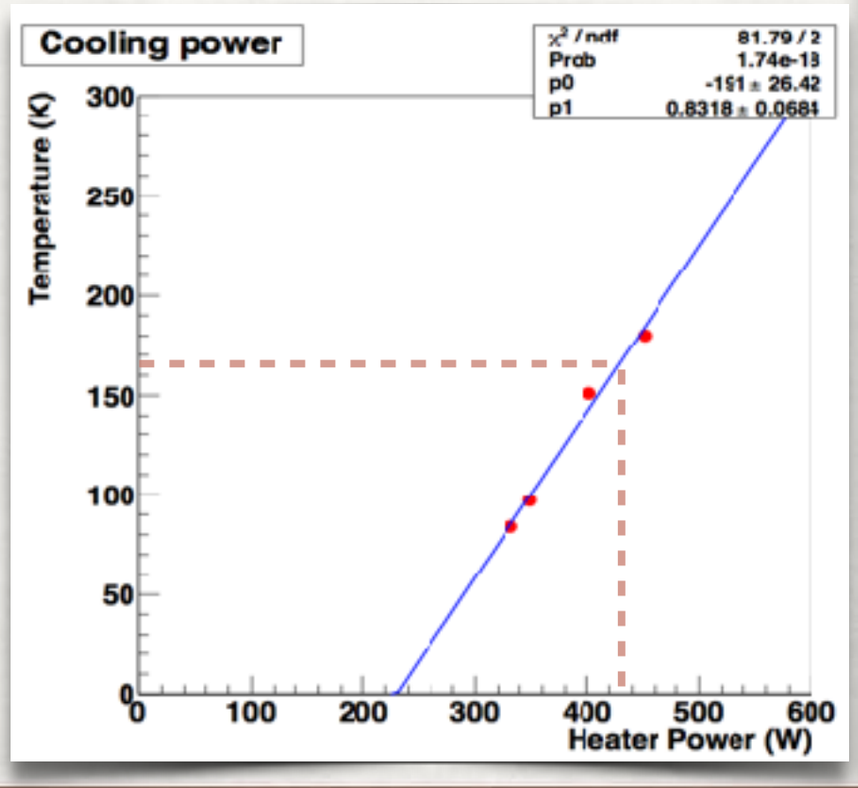


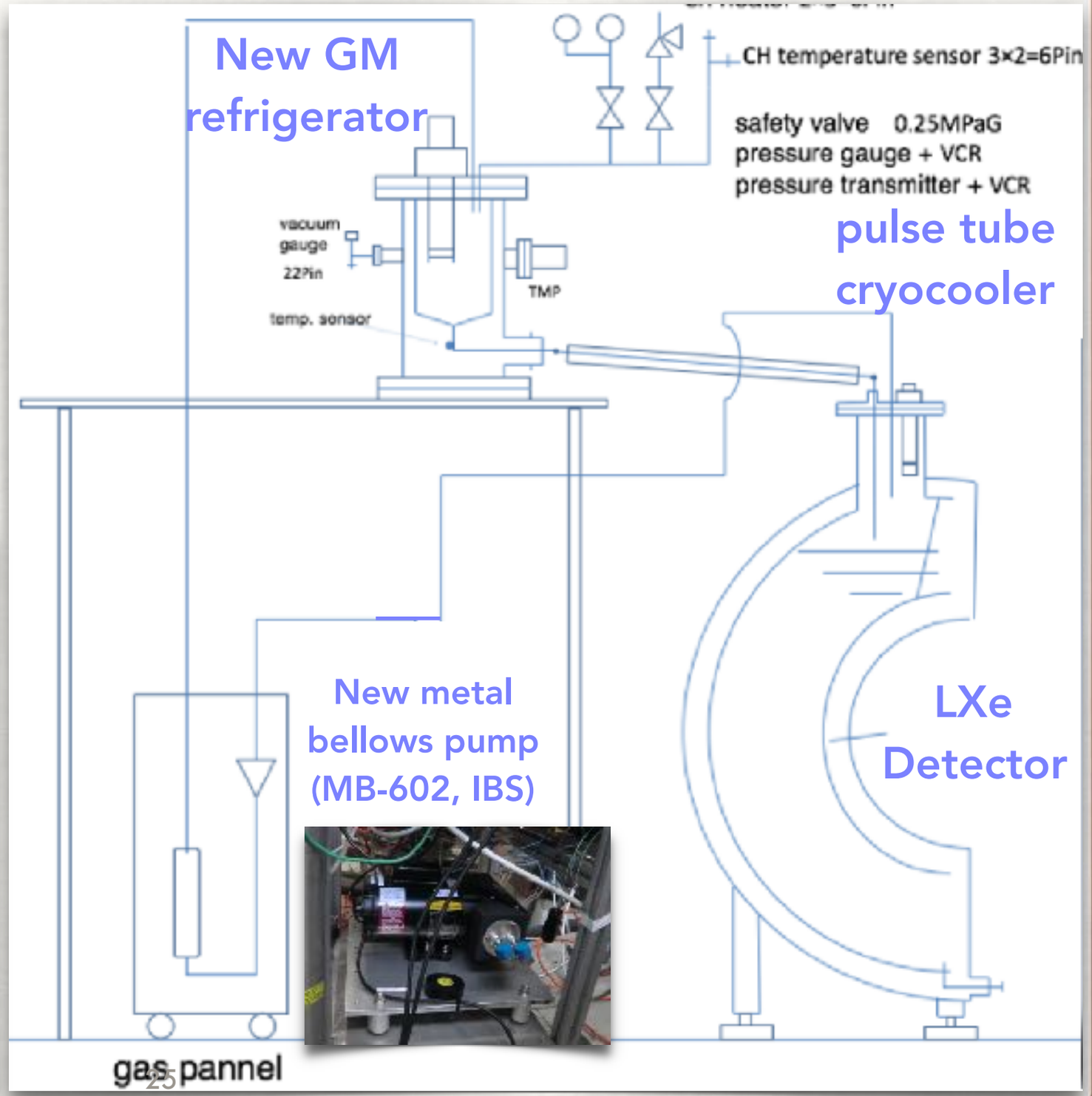
- Cable soldering on PCB by Elfab company
- Gluing (Stycast 2850FT + catalyst 24LV)
  6 PCBs on a DN160 flange by PSI detector group
- Leak test by PSI vacuum group
- 12 new feedthrough flanges are produced, and mounted



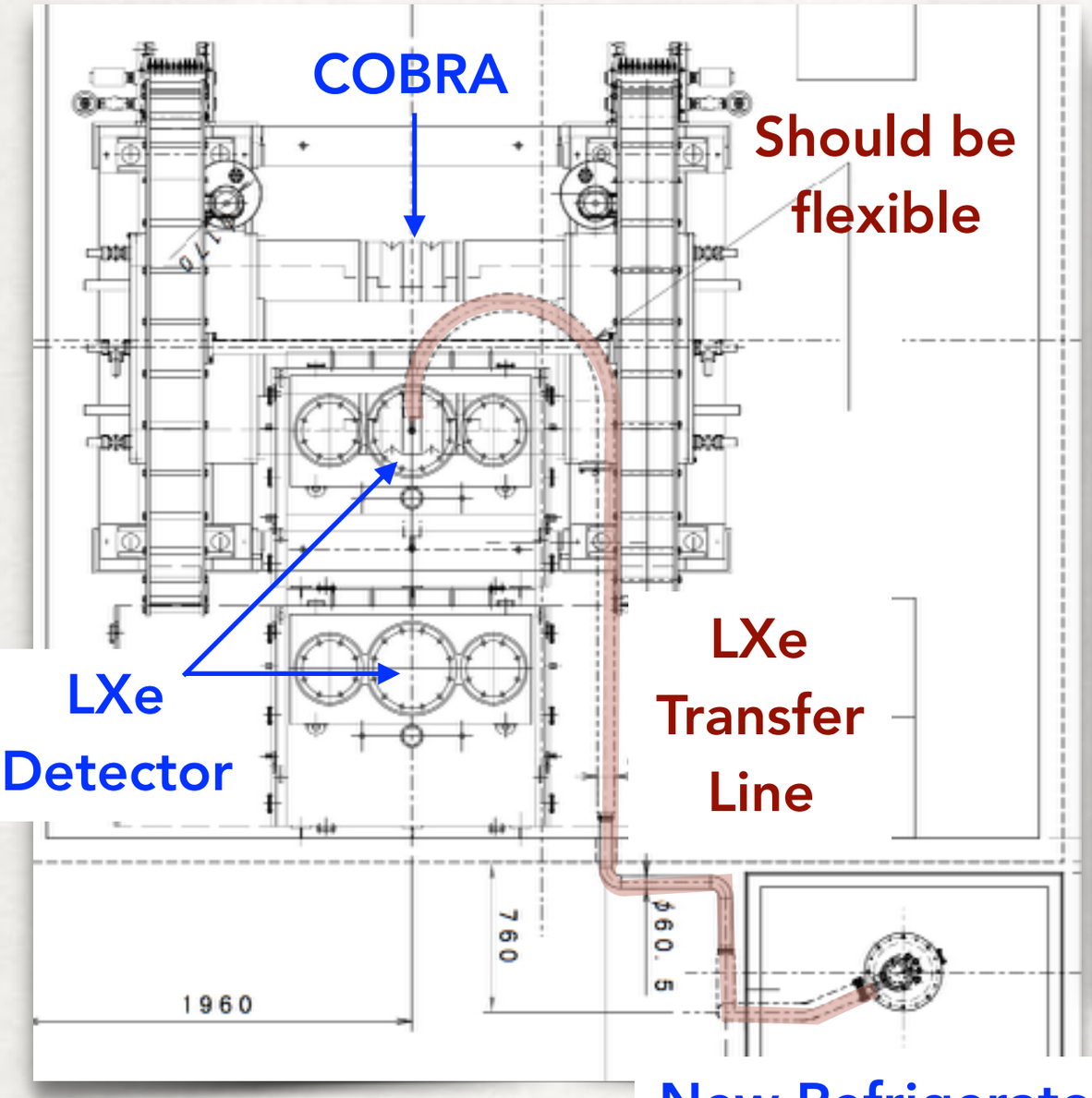
LXE DETECTOR CRYOGENICS

- Need to increase cooling power
  - A new GM refrigerator (AL300, CRYOMECH) + CP1010 compressor outside the cryostat in addition to the current pulse tube cryocooler
  - Cooling power is tested on site ~430W @ 165K
  - Now system integration before connecting LXe cryostat is in progress



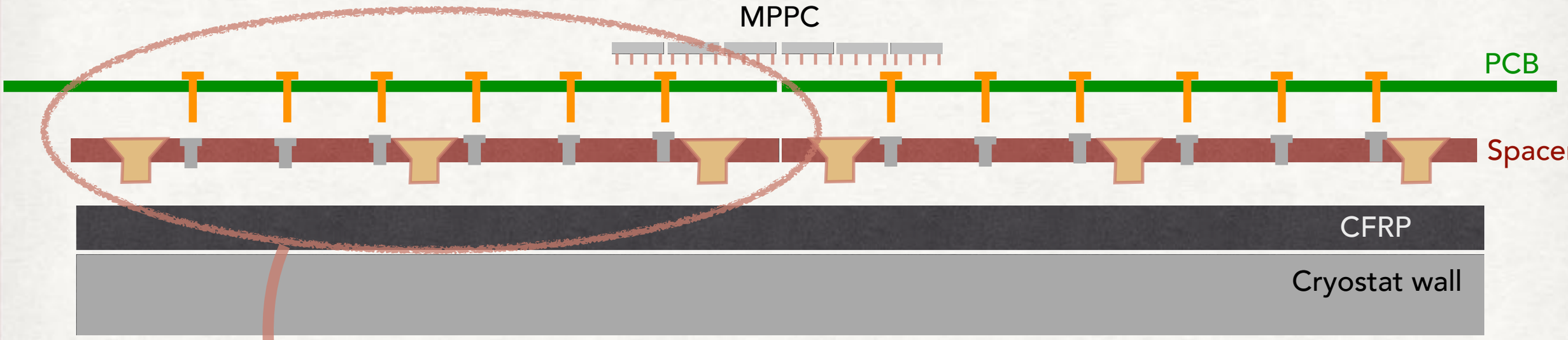


NEW GM REFRIGERATOR

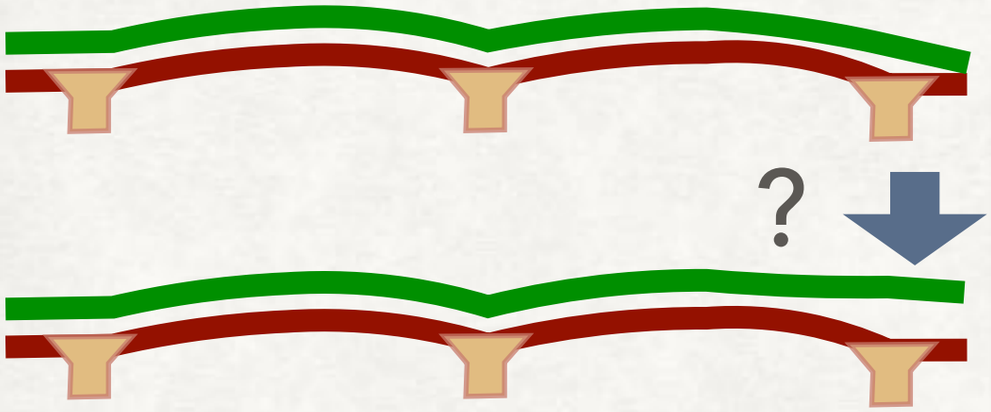


- New refrigerator, transfer line are ready.

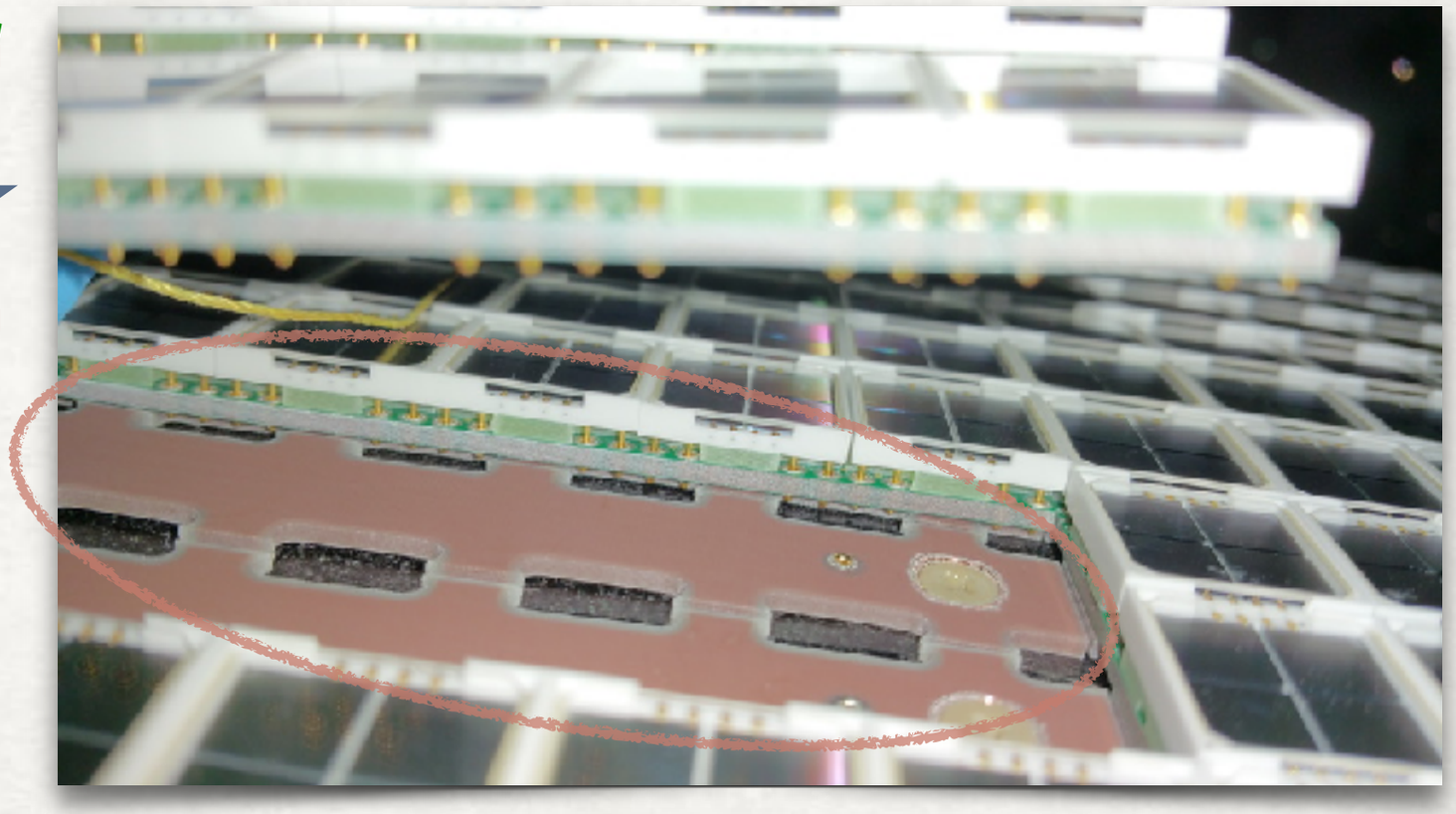
A POSSIBLE REASON?



Exaggerated



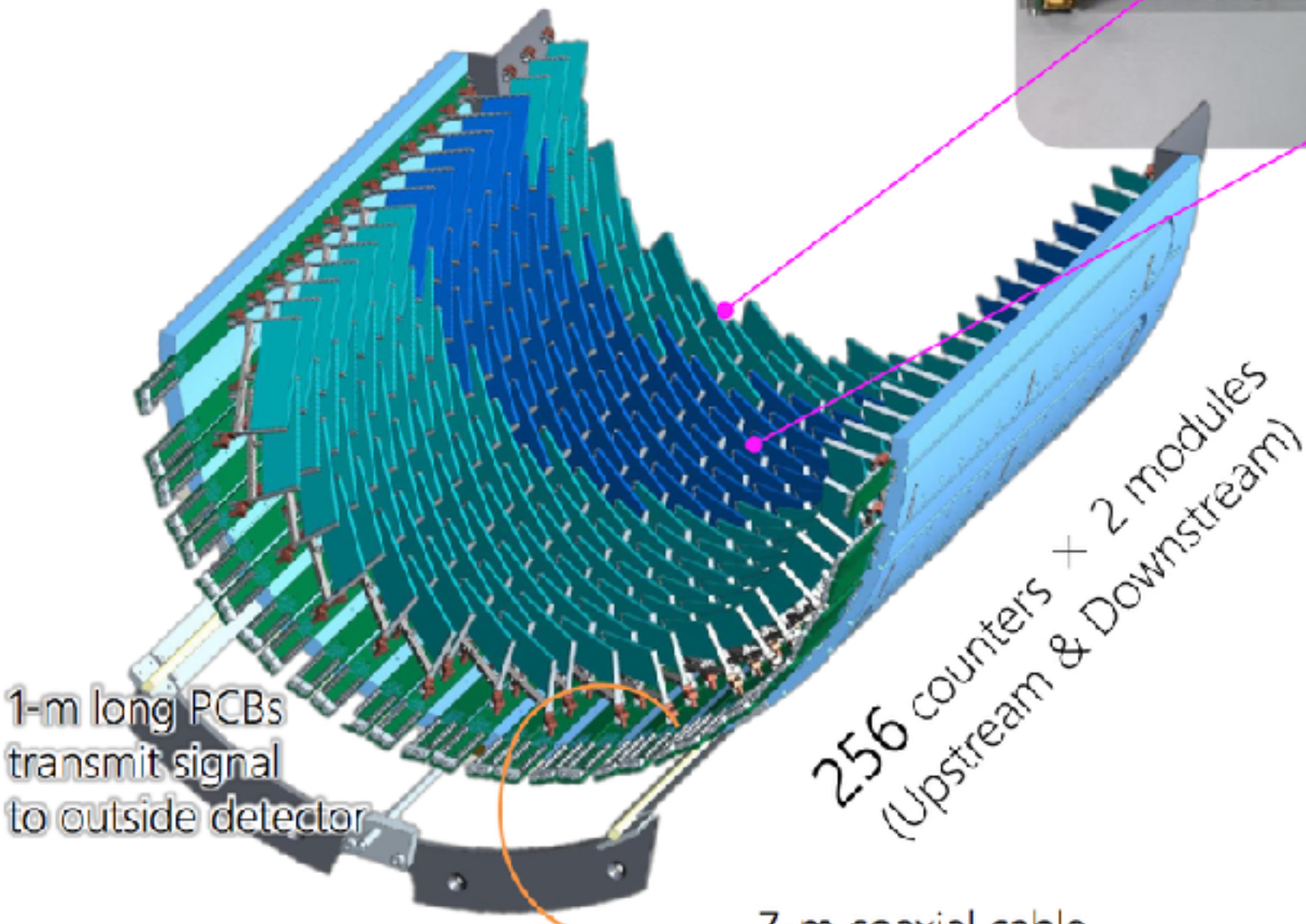
- Distance of Screw holes of CFRP and spacer may not be perfect?
- The last pin loosen by the stress?
- If this is the case, the gluing at the edge part should work because the other edge is fixed by screw.



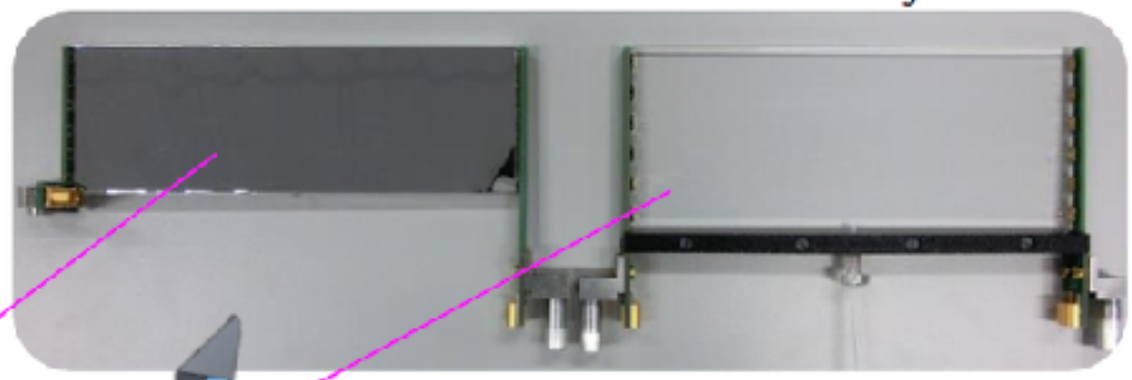
MEG II Timing Counter

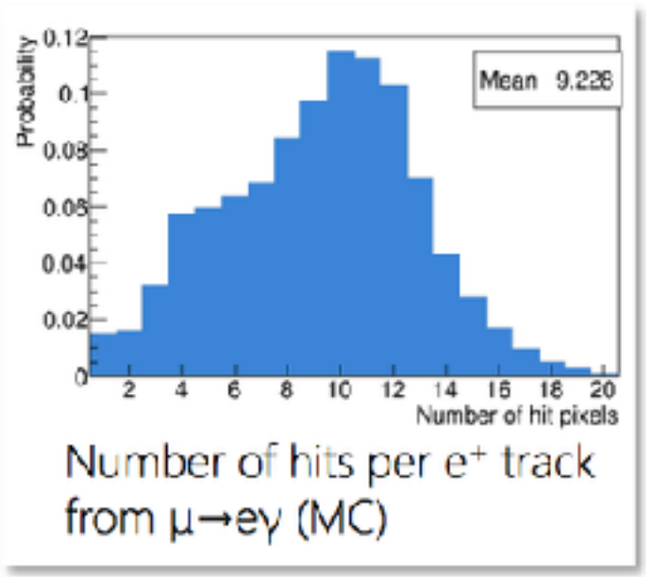
- New TC = **pixelated** TC

  with $\sigma(t_{e+})$ = **30–35** ps



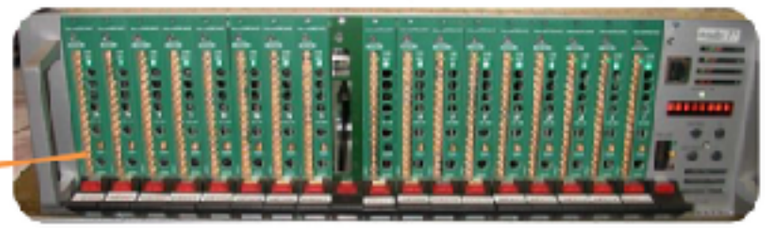
2 different sizes
to follow e⁺ trajectories





Number of hits per e⁺ track
from μ→eγ (MC)

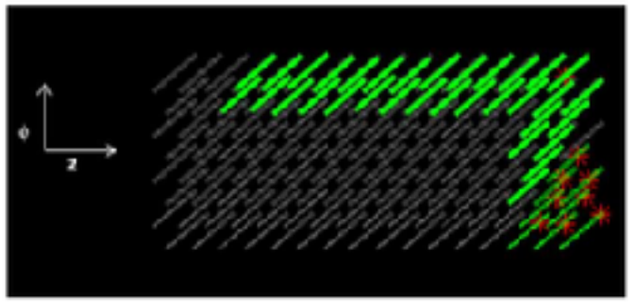
WaveDAQ crate (256 ch/crate)

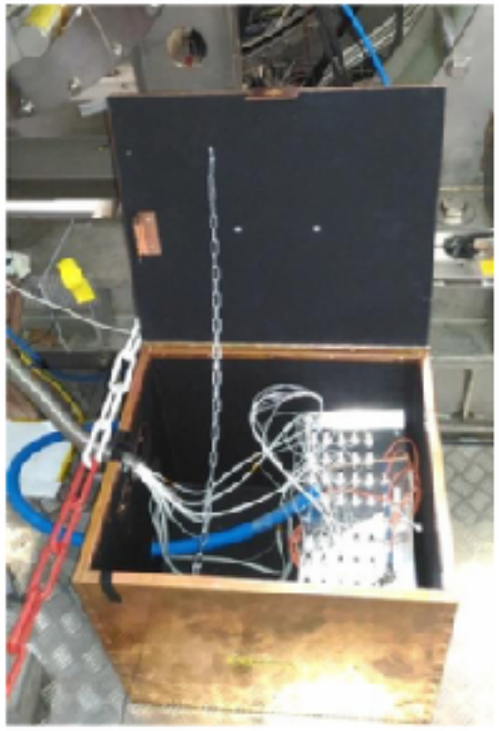


Time calibration

- Two independent methods were developed and tested in RUN2016

- Laser-based method
  - Laser pulse is injected to each counter
  - In RUN2016, injected to 40 counters
  - Optical length for each channel (fiber length etc.) was pre-calibrated
  - Expected precision (from R&D): σ_{Laser} = 25 ps





Optical splitters dividing a laser light

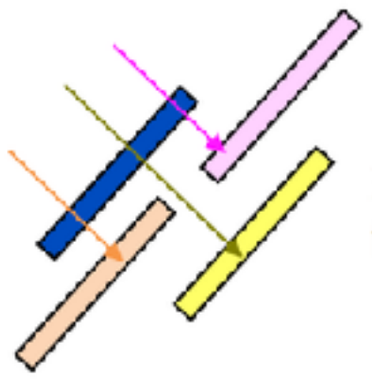
- Track-based (Michel) method
  - Using Michel e^+ passing several counters
  - Simultaneously minimize

Measured time　　Calculated time

$$\chi^2 = \sum_i^{N_{ev}} \sum_j^{N_{hit}} ((T_{ij} - (T_{0i} + TOF_{ij} + \Delta T_j)/\sigma))^2$$

Time offset of each counter
:What we want to know

  - For the ***TOF*** calculation, use CDC
  - But in RUN2016, TOF calculated from MC are used
    - A mean value for each counter combination
  - Expected precision (from MC): σ_{Mchie} = 10 ps
  - Subject to position-dependent bias

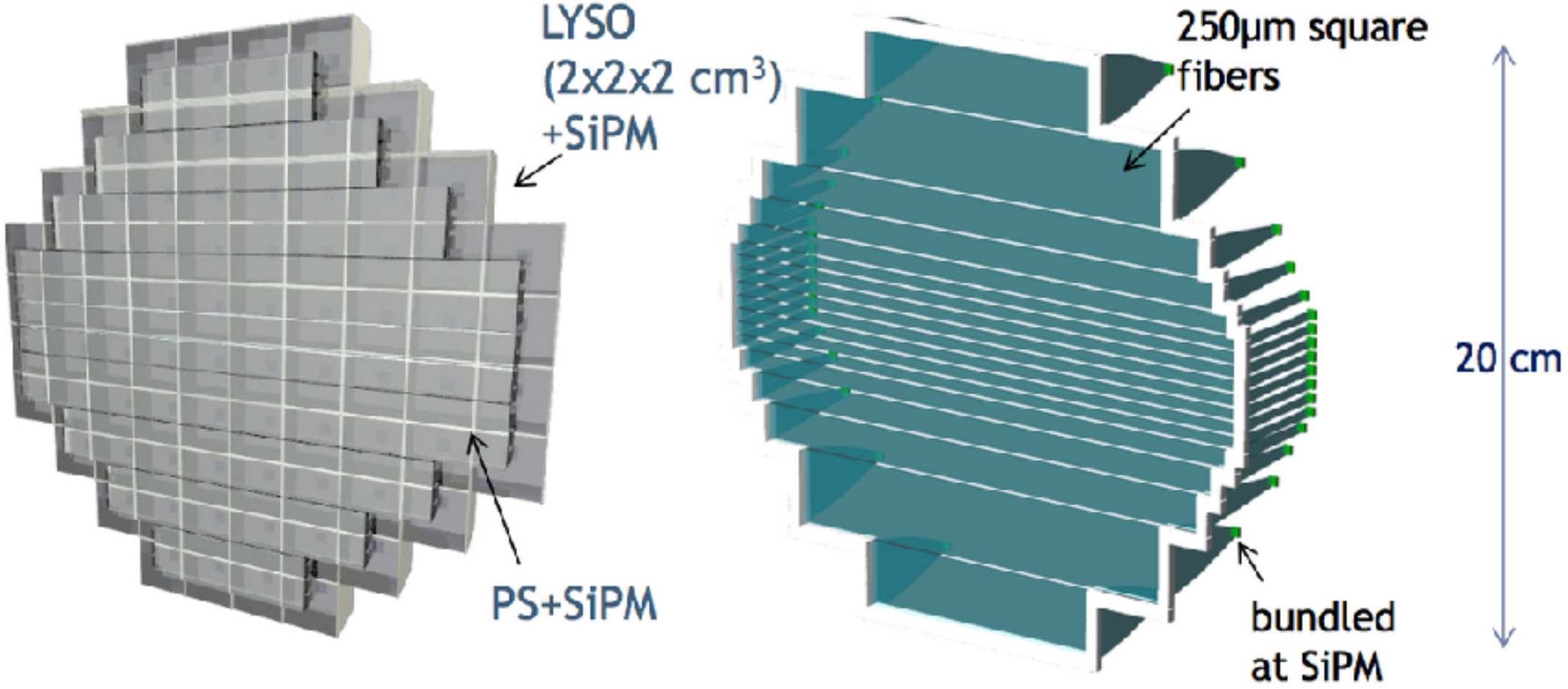


3 combinations for each counter

Detector design

DS RDC

US RDC



- Plastic Scintillators (PS) x 12
  → e^+ timing
- LYSO crystals x 76
  → e^+ energy
  (distinguish RMD e^+ from Michel e^+)

- Scintillating fibers
  → e^+ timing

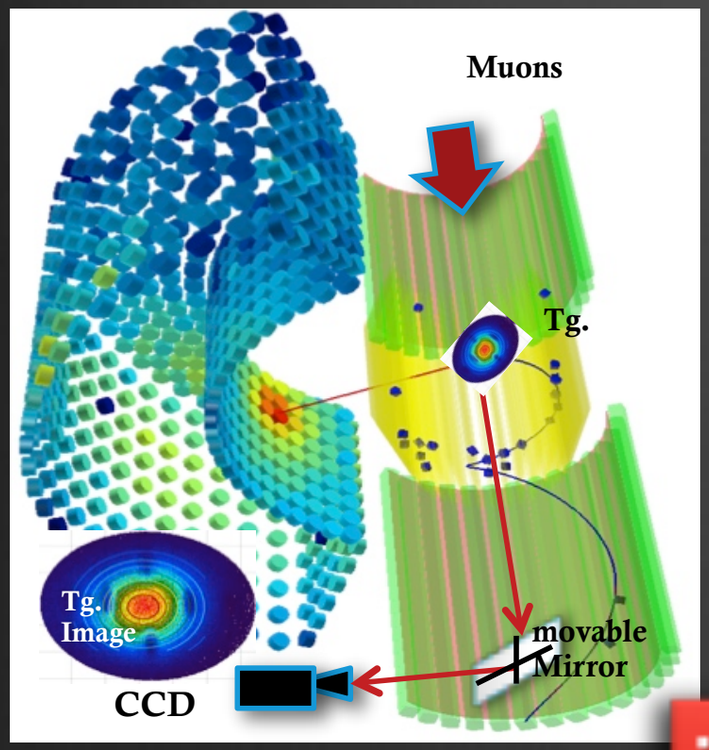
Trigger rate projection

- MEG trigger rate: 11.5 Hz
  - *we use the maximum value ever had*
- rescaling for the MEG II beam rate -> 50Hz
- then we apply the trigger rate reductions
  - *35% from timing*
    - from 3ns down to 1ns for online positron gamma coincidence
      - *improvement due to improved electronics: timing with onboard fast discriminators*
  - *60% from gamma energy*
  - *40% from direction match*
    - as a result the trigger rate is expected ~10 Hz

Further Beam Studies

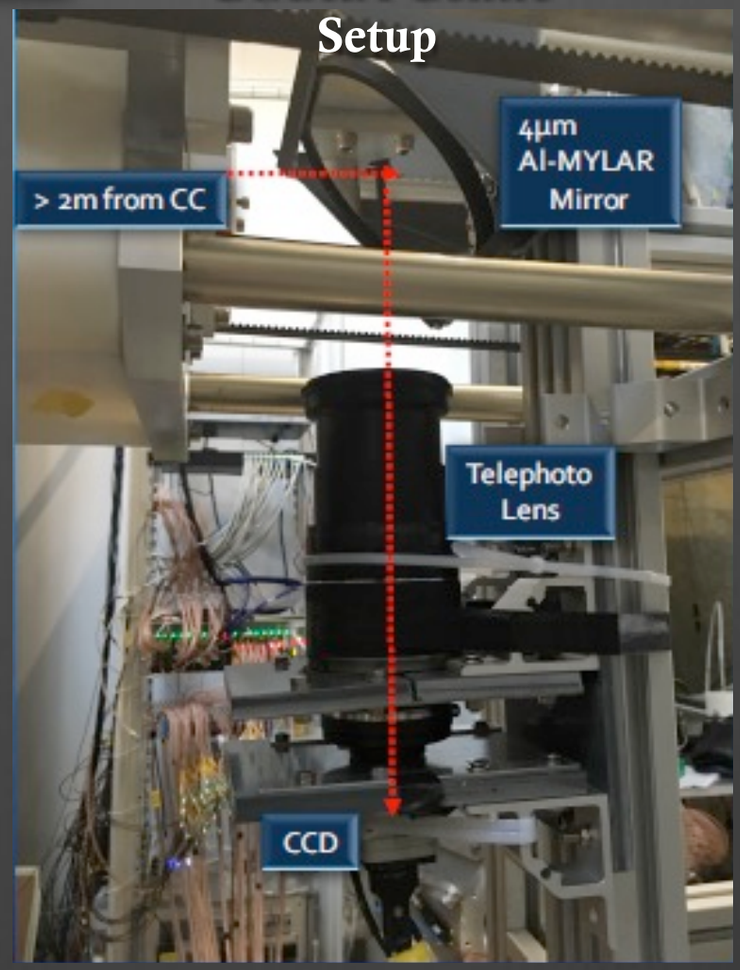
MEG II Scintillating Target Beam Monitor

- Use Scintillation Target for MEG II
- View with movable mirror system in RDC flange with fix CCD on flange side.



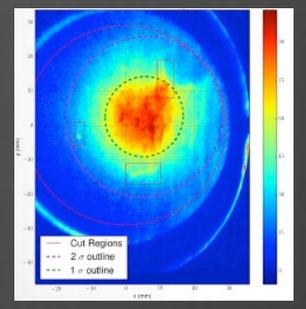
BC400B 150μm thick elliptical target @ 15° in 100% He atmosphere

COBRA Centre Setup



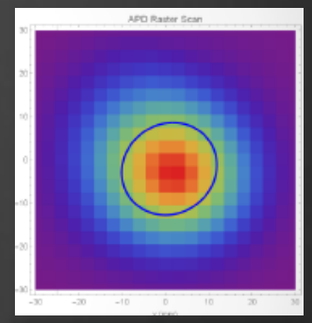
- Allows in situ. Target Muon beam monitoring: centring, profiles & intensity
- Tested up to 1T Bfield with CCD
- Exposure times 10 -100s
- 2-D fits consistent at 2% nominal intensity
- Radiation hardness tests started being analyzed
- Michel Run exposed to 50kGy ≡ 5 Mrad

2D-fit CCD Data



(σ_X = 11.3 mm, σ_Y =11.7 mm)

2D-fit Pill scan Data



(σ_X = 11 mm, σ_Y =10.7 mm)

Fits still consistent at 2% Nominal beam intensity