MEG II実験用液体キセノン検出器の開発

Development of MEG II liquid xenon detector

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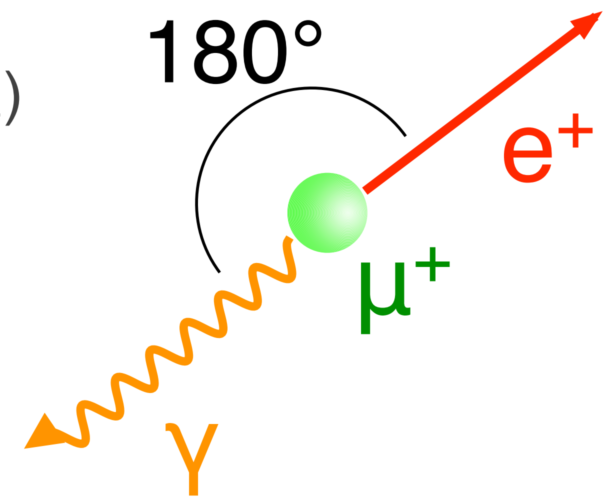
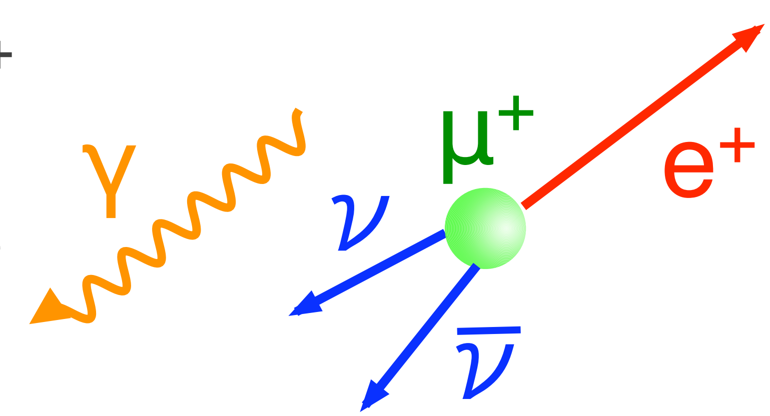
MEG II — Introduction

- MEG experiment to search for **LFV muon decay** $\mu^+ \to e^+ \gamma$ with the highest sensitivity **~5×10^{-13}**, finished the data taking in 2013
  - The new result with the full statistics will be in this summer. Kaneko, 21aDF3
- An **upgraded** experiment MEG II with **10 times higher sensitivity** is prepared for starting in 2016. Uchiyama, 21aDF4
  - Pre-engeering run in this year.
    - Beam tuning
    - Mechanical integrity check
    - DAQ with beam and a part of detector.

- Signal
  - μ^+ decay at rest
  - 52.8MeV (half of M_μ) (E_γ,E_e)
  - Back-to-back ($\theta_{e\gamma}$,$\varphi_{e\gamma}$)
  - Timing coincidence ($T_{e\gamma}$)

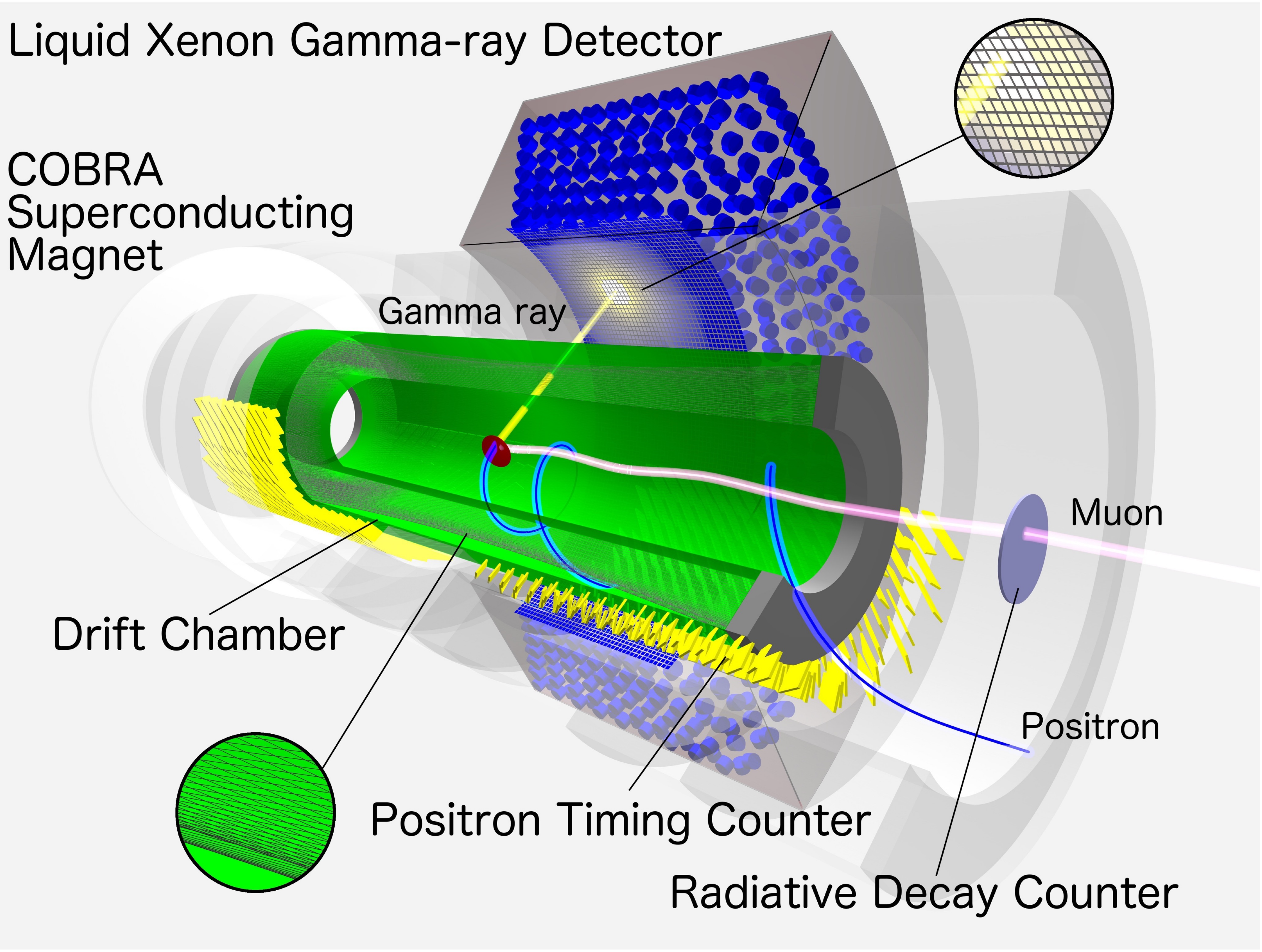


- Accidental background
  - Michel decay e^+ + random γ
  - Flat timing, angle
  - E < 52.8 MeV



MEG II — apparatus

MEG II detector



- Muon beam
  - >2 times intense beam
- LXe detector
  - PMT → SiPM
- Drift chamber
  - Single volume
- e^+ timing counter
  - Higher granularity

    Nishimura, 24aDL9

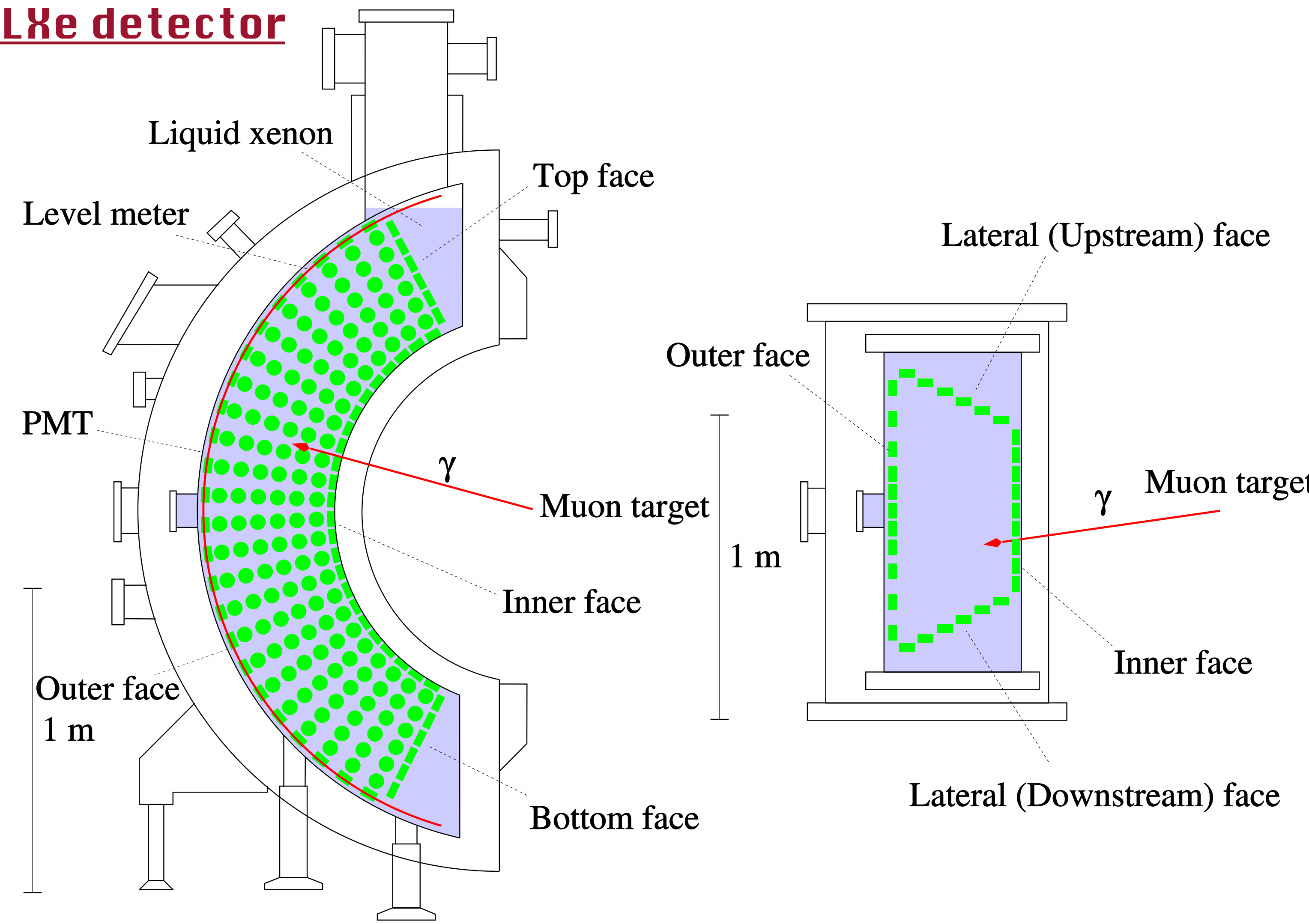
    Yoshida, 24aDL10
- Radiative decay counter
  - Active BG identification

    Nakaura, 24aDL11

Liquid Xenon Detector

- The largest (**900 litters**) LXe detector
- **846** VUV sensitive PMTs directly detect scintillation photons (Q.E × C.E. ~ **16%** for 175nm photons)
- Excellent energy, position and time resolutions
- Pileup-identification capable

MEG LXe detector



MEG PMT for LXe

	NaI	BGO	GSO	LSO	LXe
Effective atomic number	50	73	58	65	54
Density (g/cm^3)	3.7	7.1	6.7	7.4	3
Relative light output (%)	100	15	20-40	45-70	80
Decay time (nsec)	230	300	60	40	4.2, 22, 45

Upgrade Concept

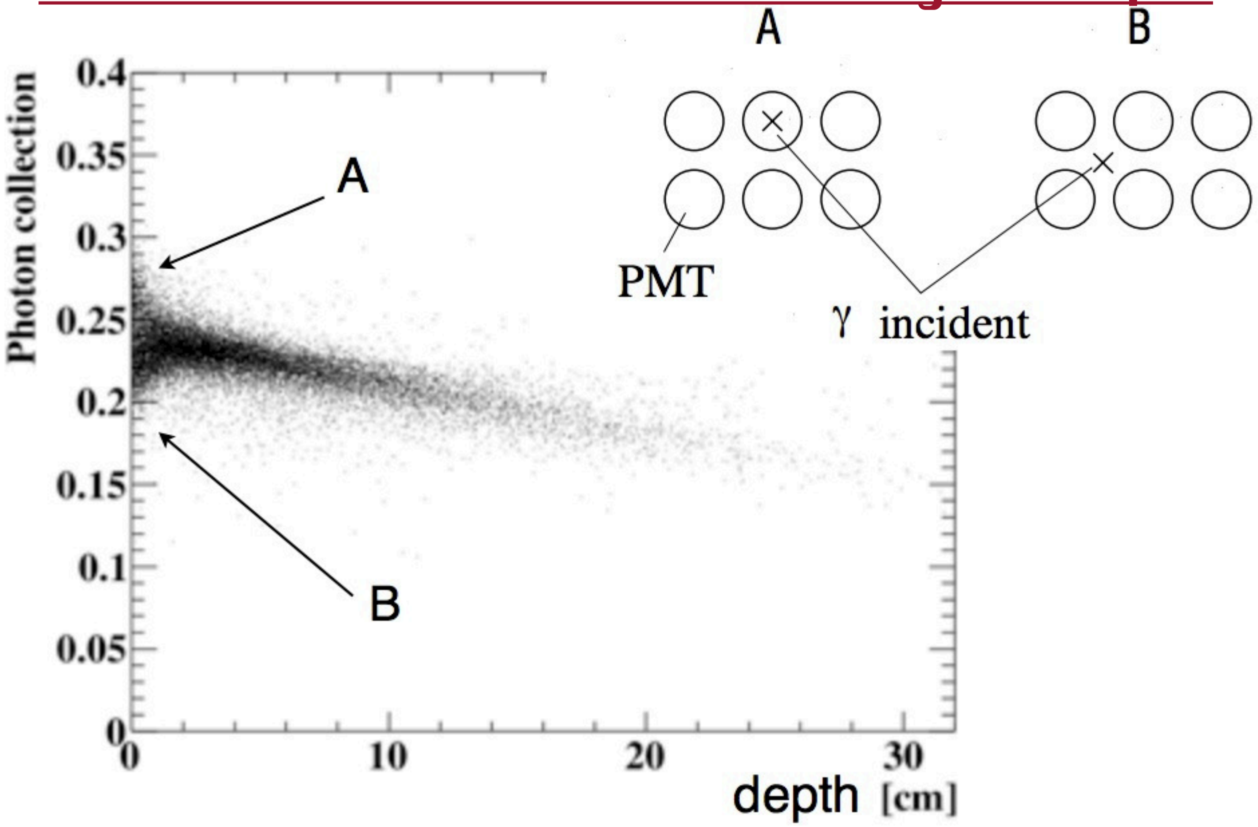
Resolution of shallow events (~40%) is worse because of **large fluctuation of photon-collection efficiency**. Higher granularity and less dead space for uniform response

Lower energy tail due to **energy loss** of γ rays before entering LXe, and **energy leaks** from the inner or lateral faces.

Thinner photo-sensor

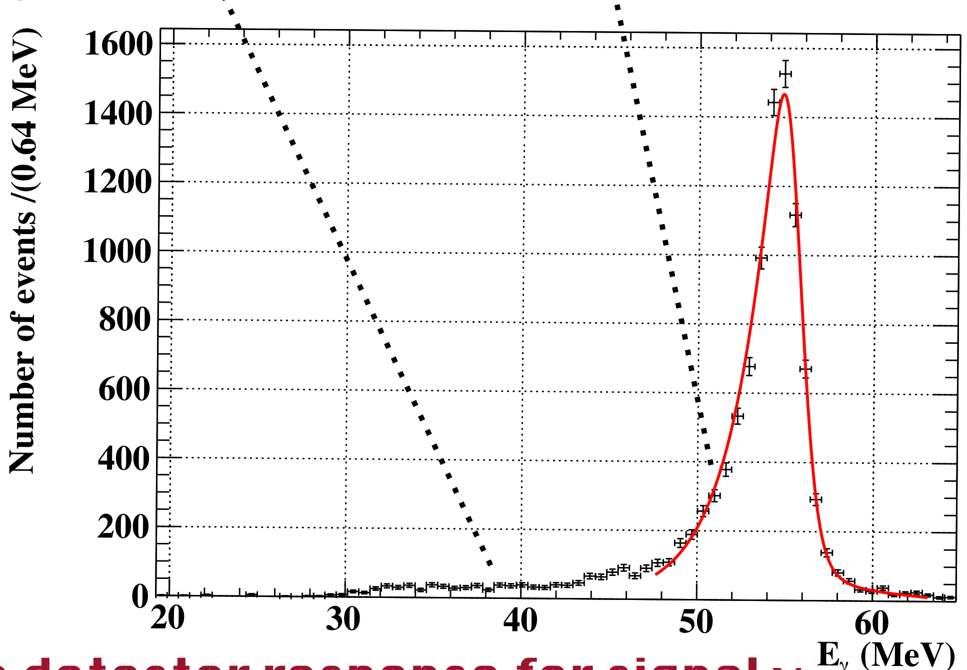
Wider LXe volume

Photoelection collection efficiency v.s. depth

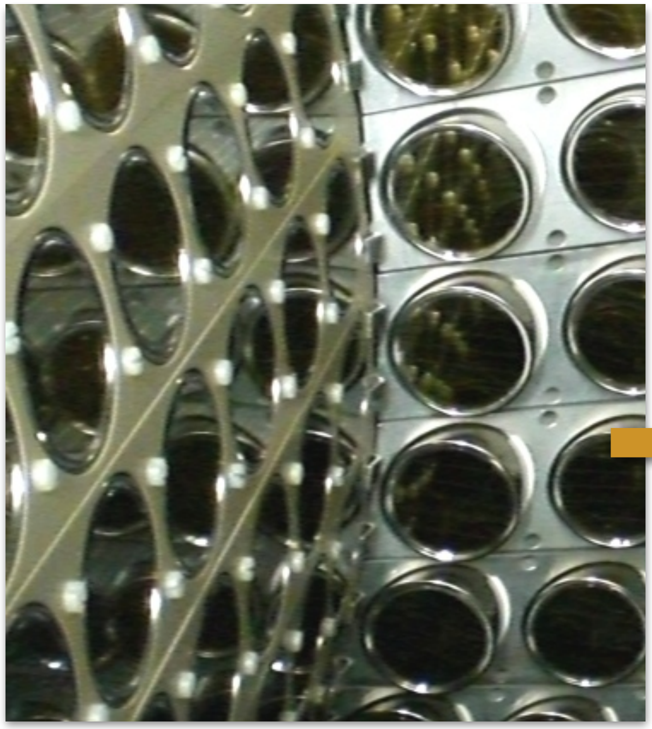


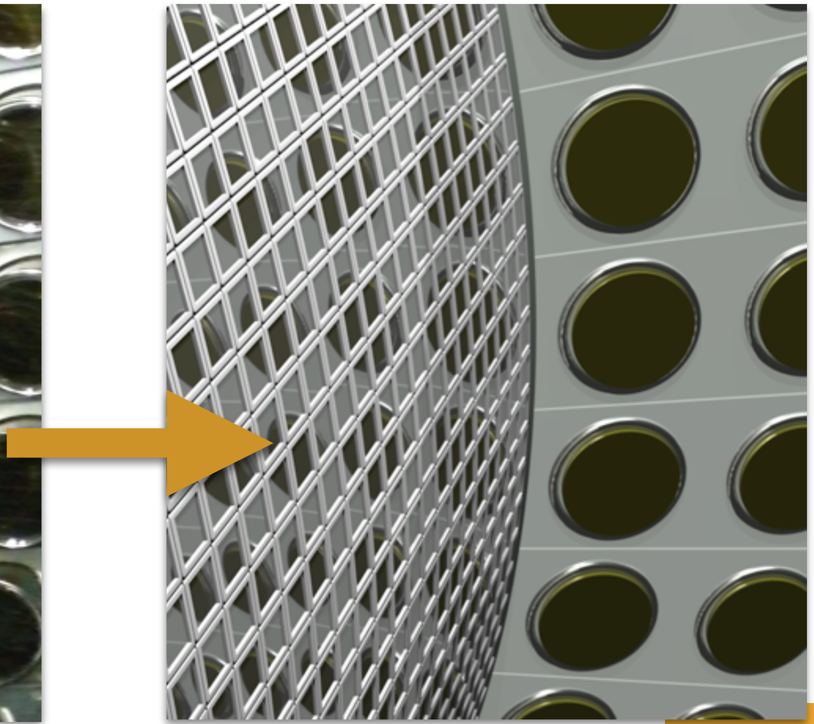
Energy leaks from LXe

Energy loss before LXe



LXe detector response for signal γ





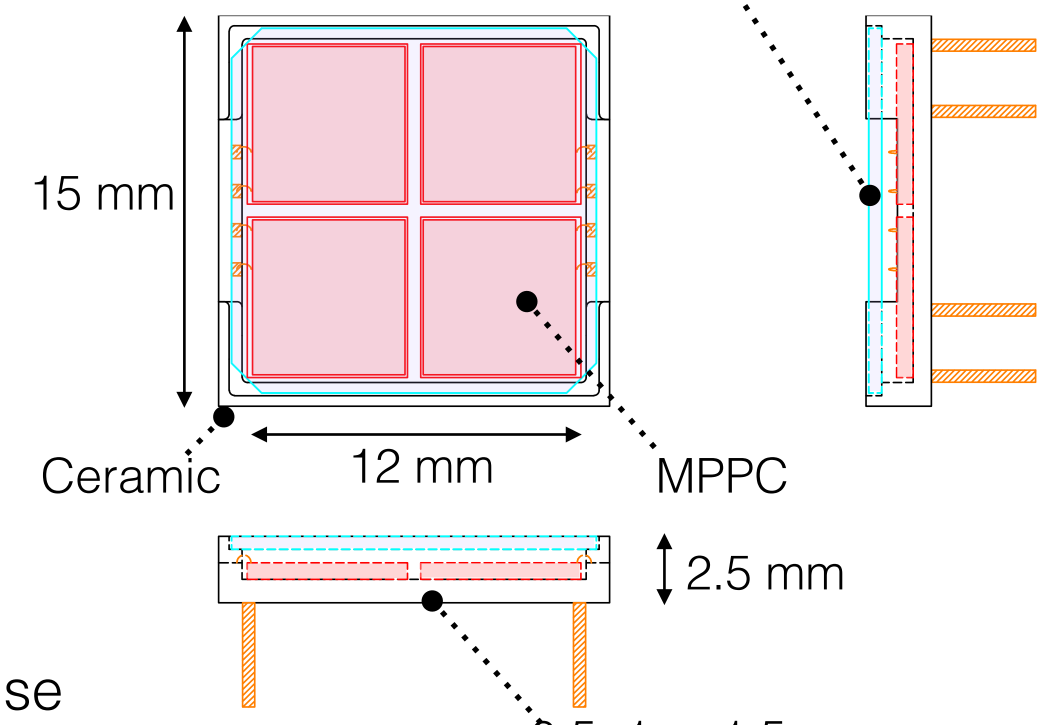
Expected performance : 1% energy resolution, ~2mm position resolution

VUV MPPC

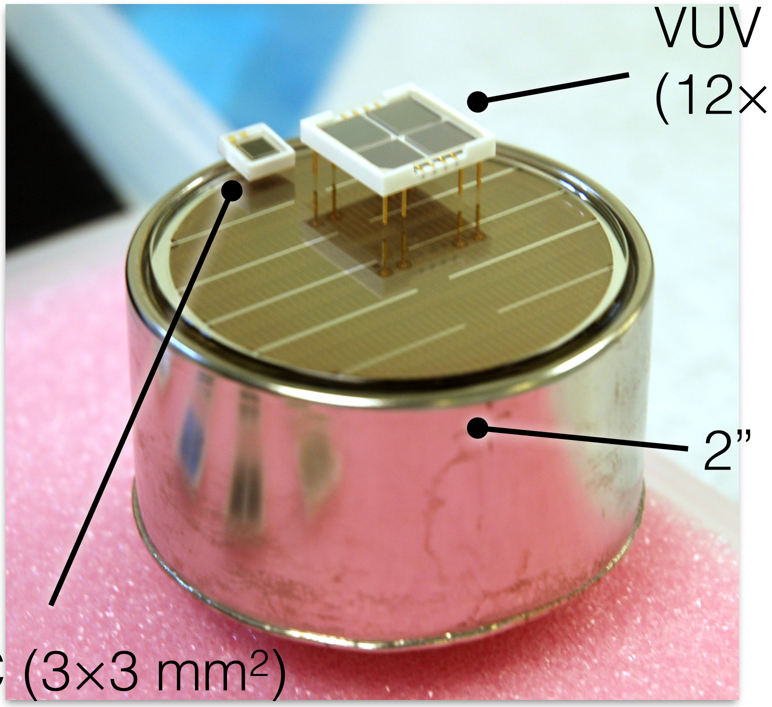
We developed **VUV-sensitive MPPC** with Hamamatsu
model : S10943-3186(X)

- **Sensitive to LXe scintillation light**, λ~175 nm
  - No protection layer, thinner insensitive layer
  - Optimized optical property of the surface
- **Large sensitive area, 12×12 mm²**
- **50 µm** pixel pitch : ~**47–56k pixels** in each package
- Metal quench resister suitable for the low temperature use
- **Four segments** in each package
  - Possible to read each segment separately or to connect them outside of the package
- Thin **quartz window** for protection
  - Open space between the window and MPPCs to allow LXe enter the space
- Different gaps (0.5, 1 or 1.5 mm) to test possibility of discharge due to some conductive dusts floating in LXe.

VUV MPPC structure



LXe photosensors



Development history and status

2012

- **Detector concept with VUV-SiPM**, rough estimation of the performance improvement
- First test of **VUV MPPC confirmed ~10% PDE** for LXe scintillation

2013

- **First large (12×12 mm^2) sample** confirmed **~17% PDE**.
- **Slow pulse** (~200 ns fall time) was observed
  - The problem was **solved by introducing the series connection** of sub-divided sensors (→ 30–60 ns fall time).
- **A new technology to suppress afterpulse**.
  - Wider operation voltage rage (**1.5 → 3 V**)
  - But the **PDE of this model was low**.

2014

- The **PDE recovered (~17%)** with a new sample.
- Confirmed that the high rate background gamma is not an issue for the MPPC operation.
- Detailed study of the energy resolution (up to ~1000 p.e.) shows **clear worsening by the crosstalk**.
- **600 samples** (for mass test in LXe) were produced and tested at room temperature.

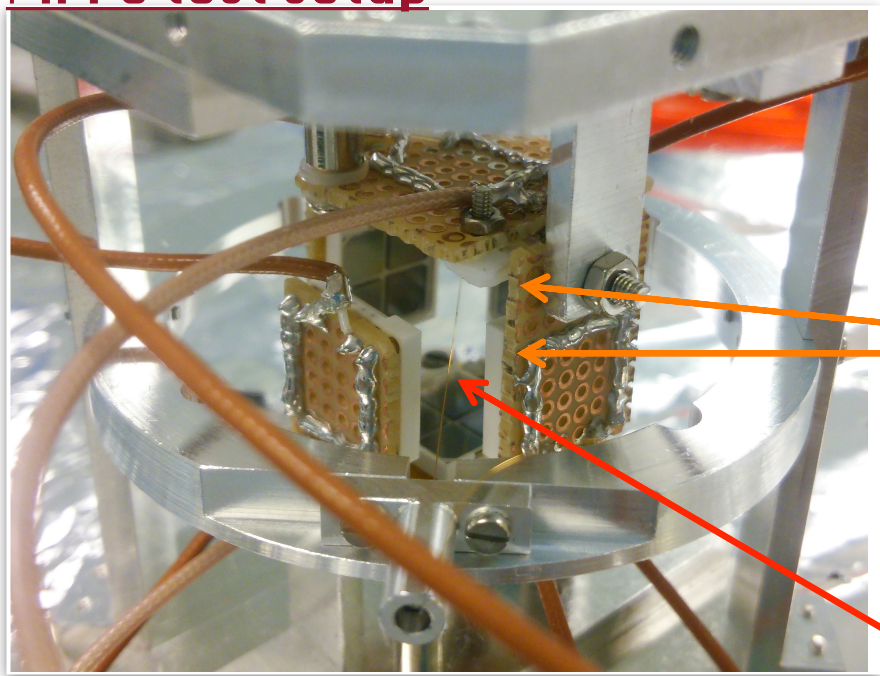
2015 (up to now)

- Resolution test with a crosstalk suppressed model and higher p.e. statistics. This talk
- Mass test in LXe detector. Ieki, 21pDK5
- Development of the reconstruction algorithms and detailed simulation studies of the performance. Ogawa, 21pDK6

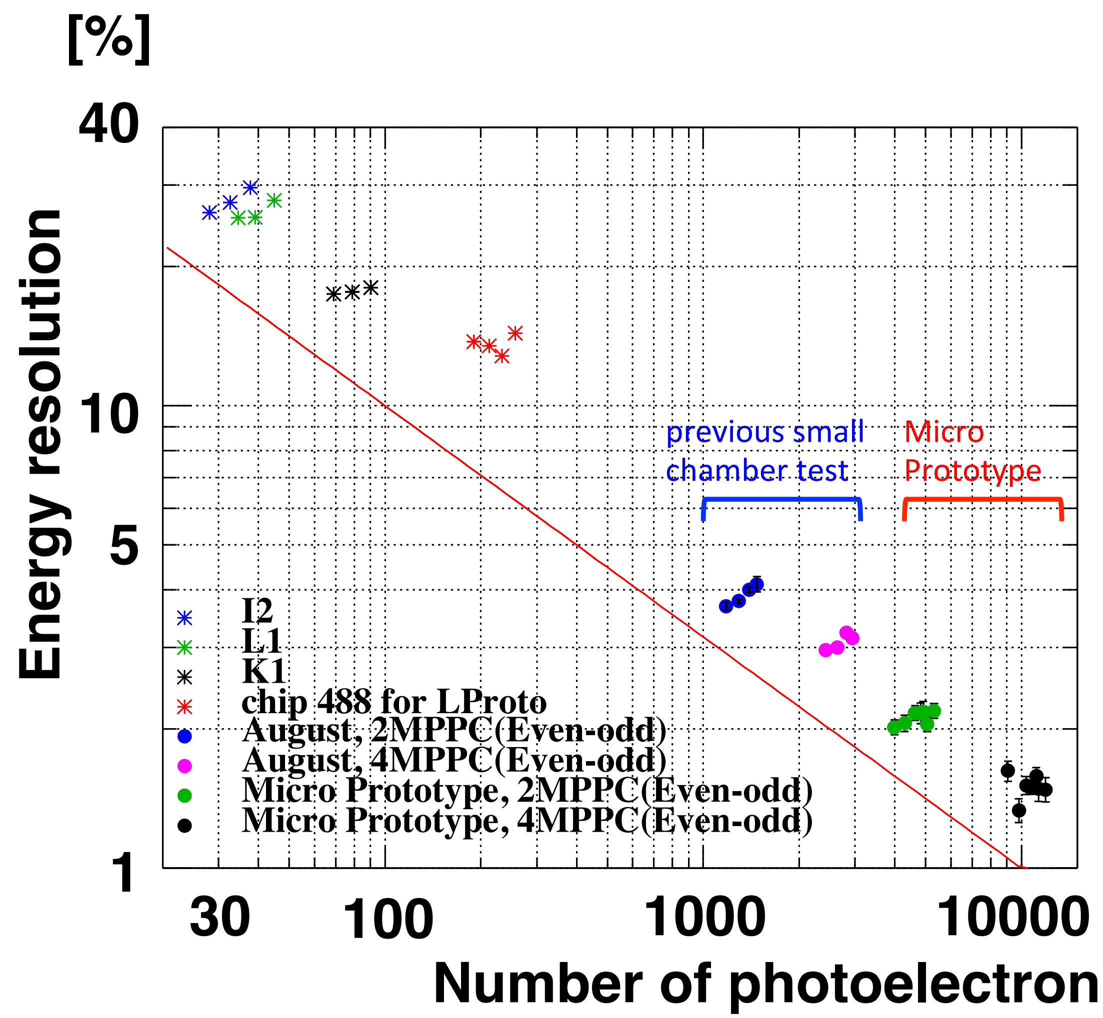
In parallel, developments of the detector technologies (feedthrough, design of holder, electronics etc.)

MPPC test in LXe with high p.e. statistics

MPPC test setup



- **6 MPPCs** surrounding an **Am source** (~5 MeV alpha source) attached on a tungsten wire
- The setup is submerged **in LXe**.
- Total acceptance is **~34%**
- Expected number of **p.e. ~2.7 k per MPPC** (assuming 20% PDE)



Analysis and results

- Energy resolution is calculated from the difference of observed number of photons of one or two MPPCs.
- The improvement of the resolution continues down to **1.4% @ ~10k p.e.**
  - The resolution is 1.6 times worse than the statistical term.

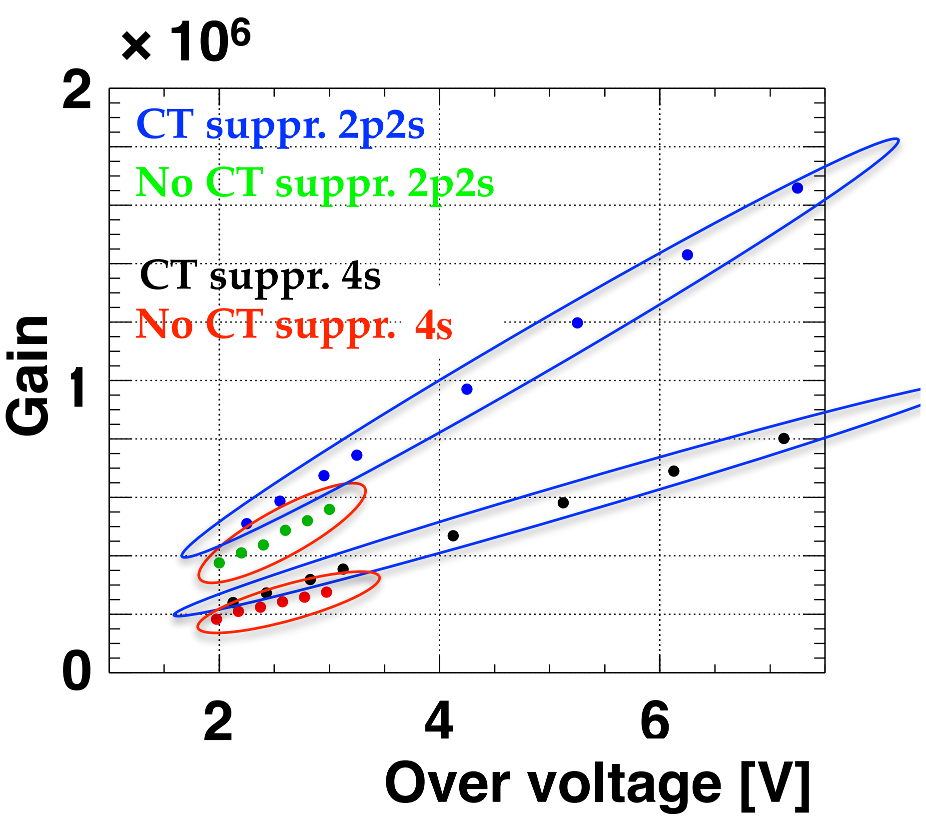
If the tendency continue up to the expected number of p.e. of 1.8×10^5, **the statistic term does not limit the energy resolution**.

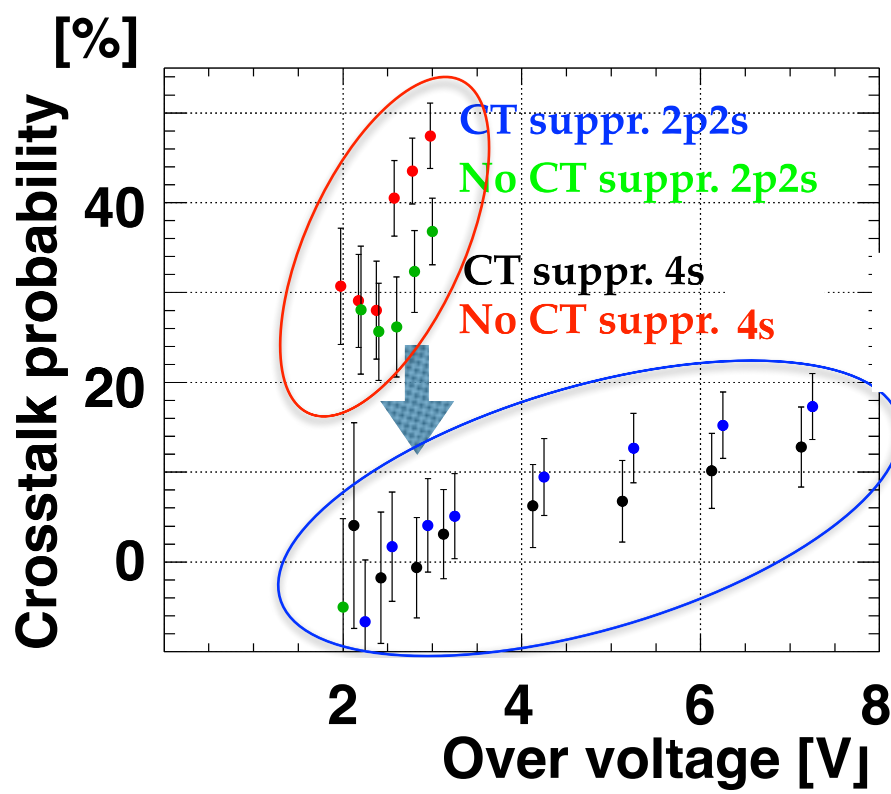
Crosstalk suppressed model

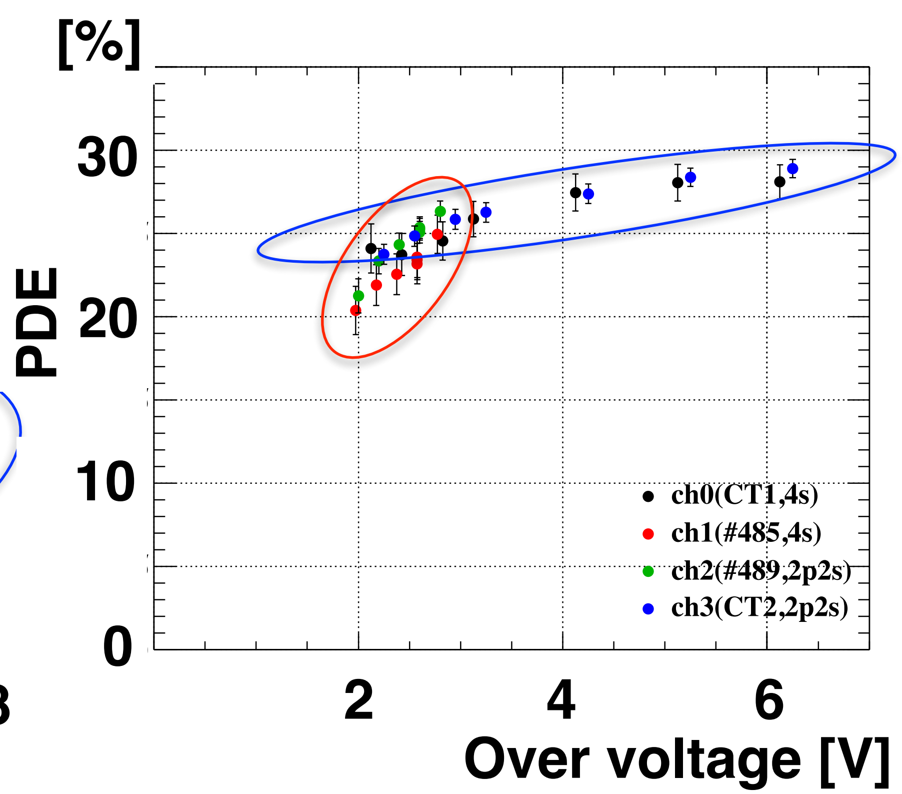
- New samples with cross-talk suppression were tested (this model will be used for the final detector).
  - Wider overvoltage range (3 → 7 V)
  - Lower breakdown voltage by 12 V

Results
- Larger gain (x 1.2)
- Much smaller crosstalk
- Almost same PDE as the previous model with the same voltage
  - Higher voltage with the higher voltage.

W/o crosstalk sup.
With crosstalk sup.







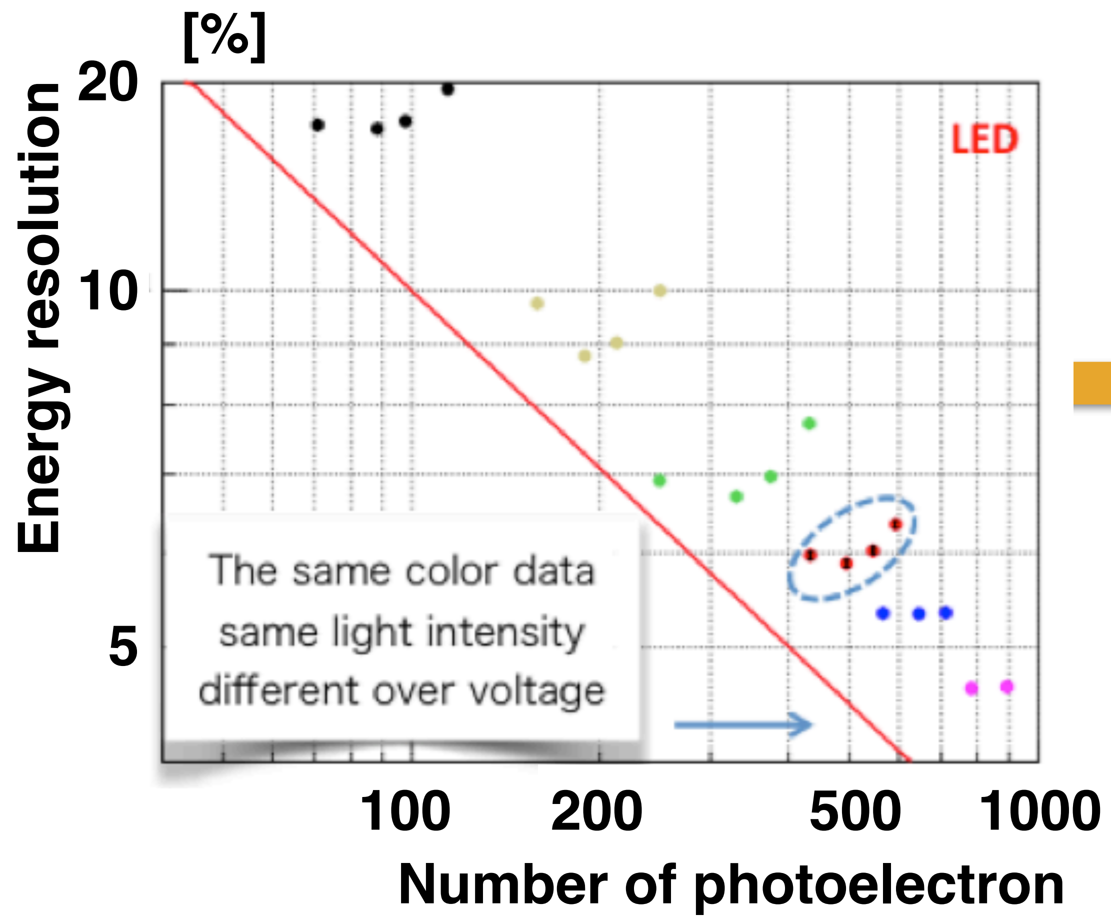
2p2s, 4s : different ways for connecting 4 MPPCs on a package (briefly explained in P13)

Resolution with Crosstalk suppressed model

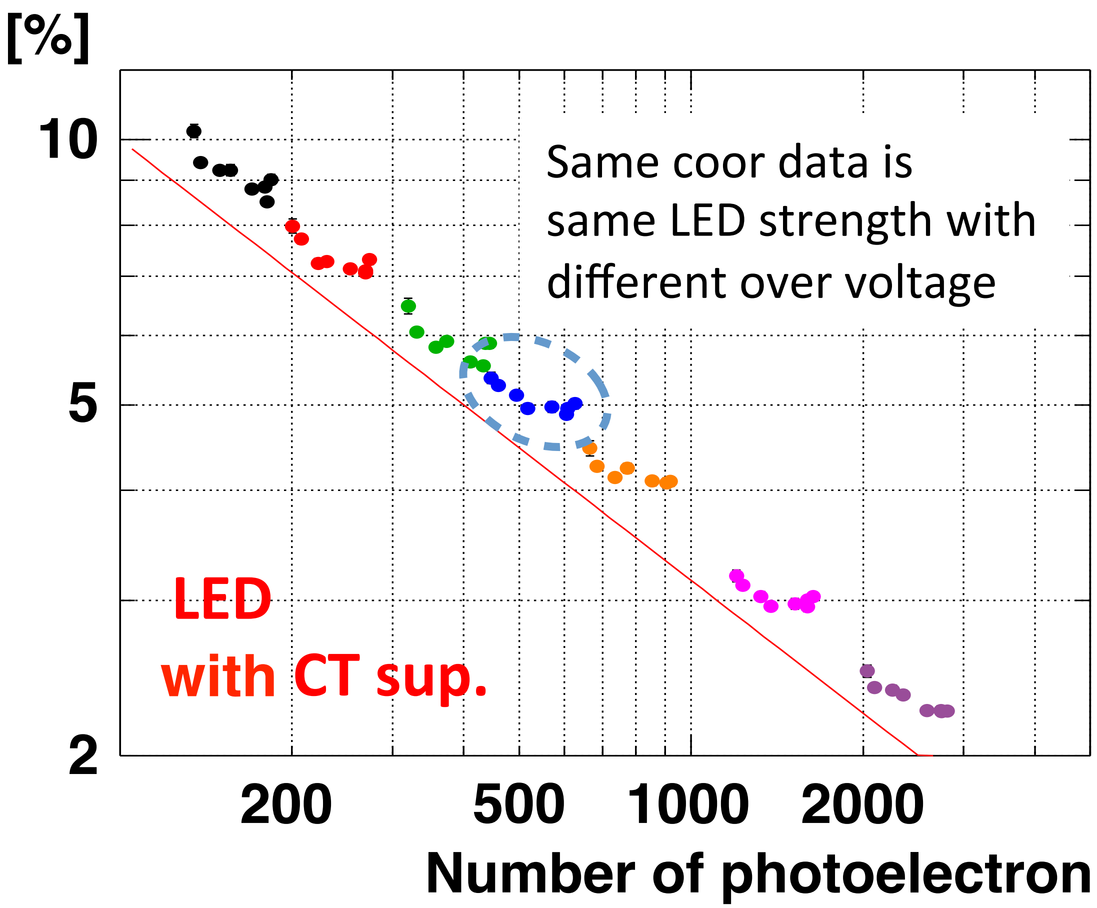
The resolution is checked with using LEDs

Energy resolution v.s. phoelectron statistics

w/o crosstalk sup.



with crosstalk sup.

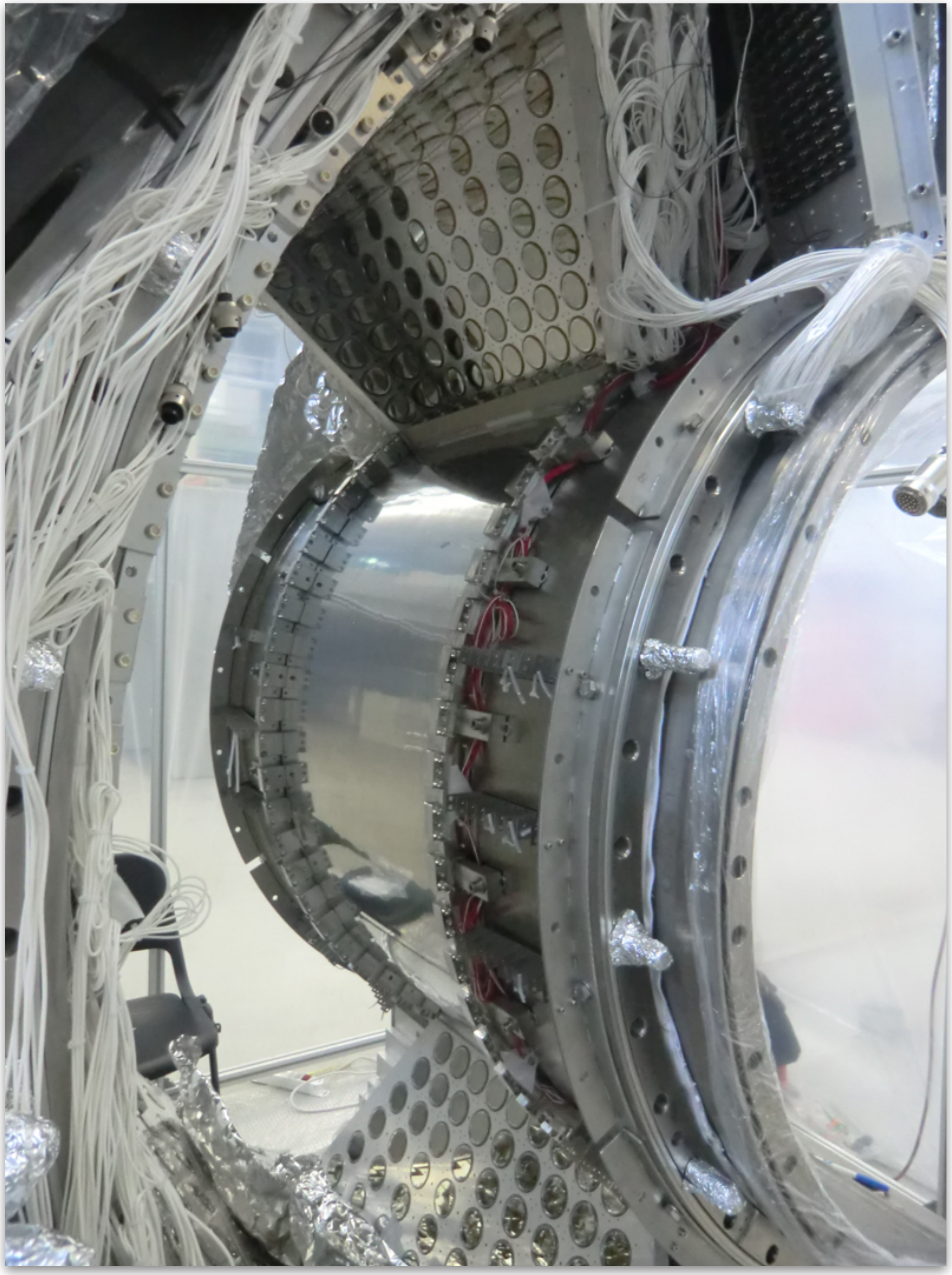


The raise of the resolution as the bias voltage increase almost disappear with the crosstalk suppressed mode.

Detector preparation status

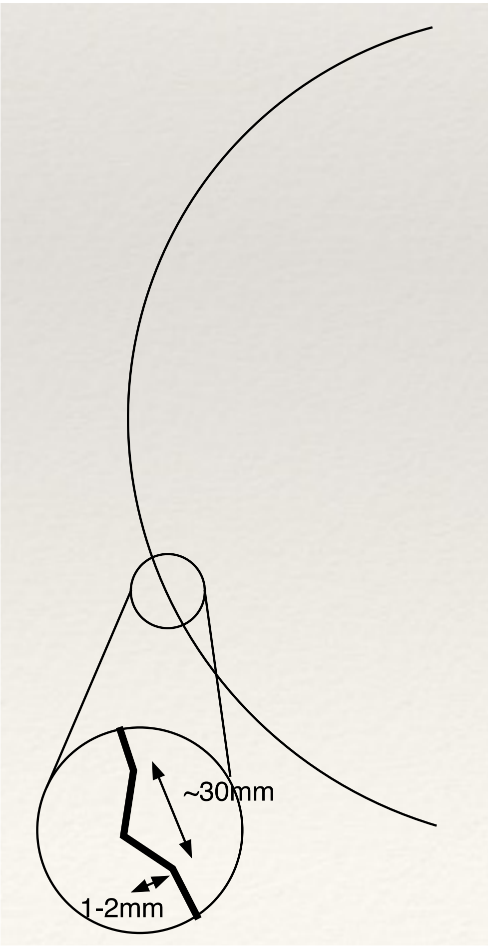
- The LXe detector is out from the beam area
- Most of inner and lateral PMTs were removed.
- The mass production of the final version of MPPC was started.
    - We will start the test of them at room-temperature soon.
- MPPC support structure will be prepared, then we will put MPPCs.
- Design and production of various parts are done in parallel
    - Holders of the inner MPPCs and the lateral PMTs
    - Additional LXe refrigeratorImprovement of the design of feedthrough
    - Monitoring tools of the cryostat position
    - …

LXe detecotor, present status

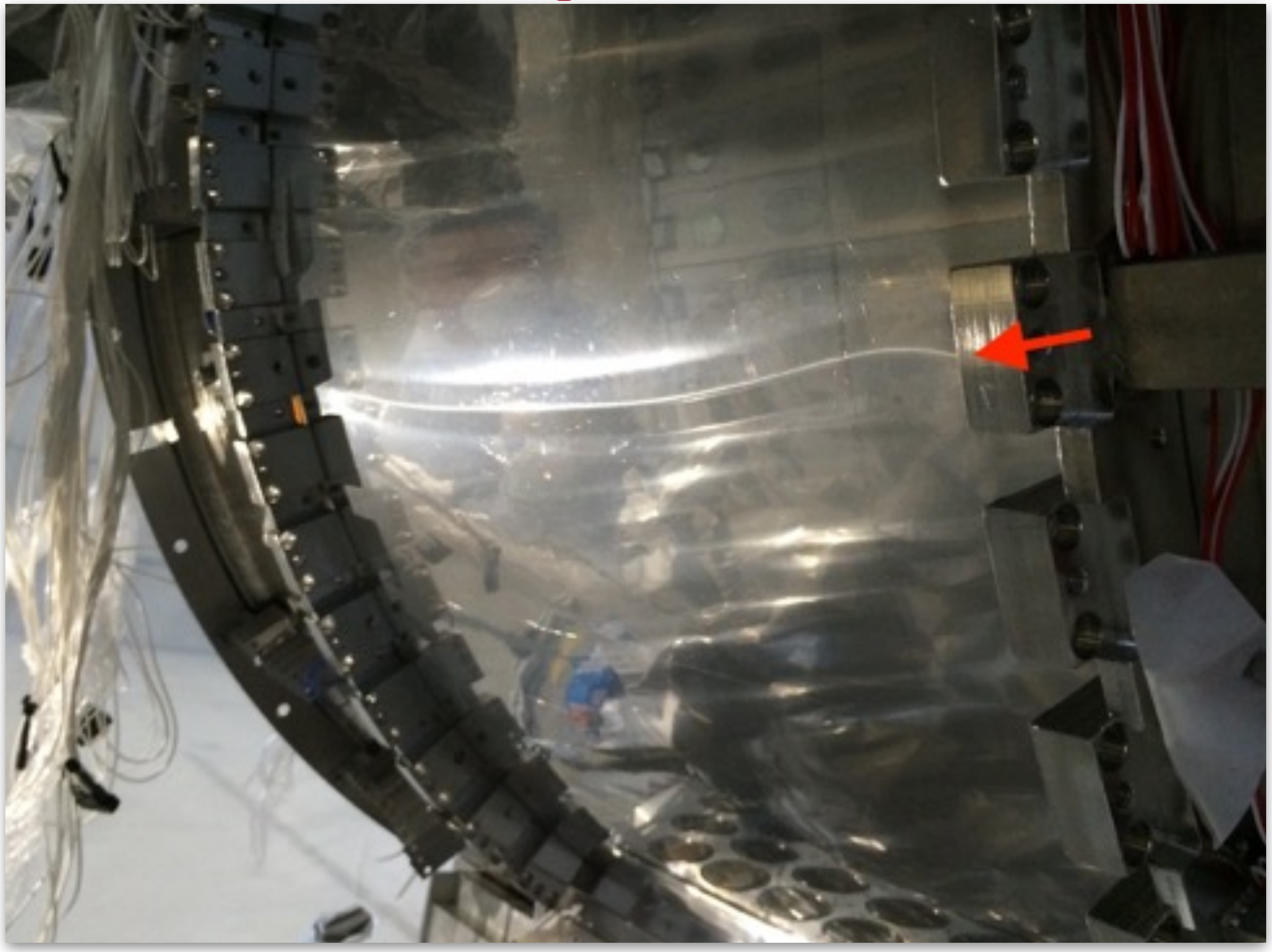


Deformation of Cryostat

Deformation of a thin window of the cryostat was found.



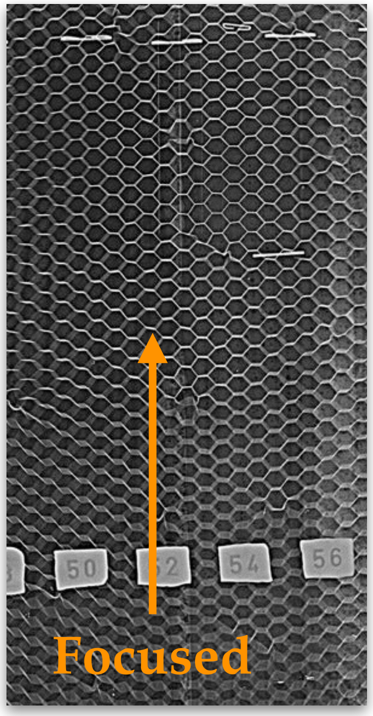
Deformation of the cryostat



Fiber scope and its image

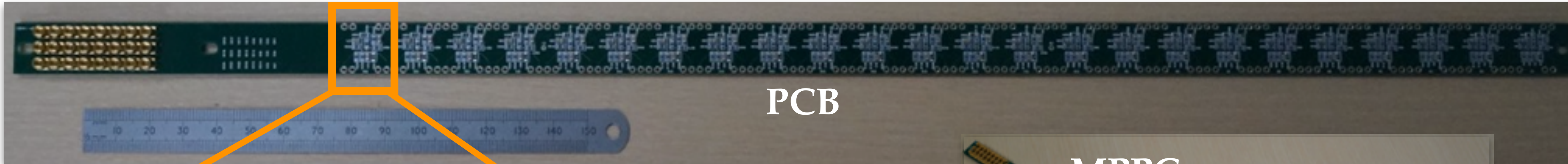
From a visual check with a fiber scope and a non-destructive check with X-ray, **the structure does not seem broken**.
We will performa a pressure test to check the cryostat stay in a elastic region.

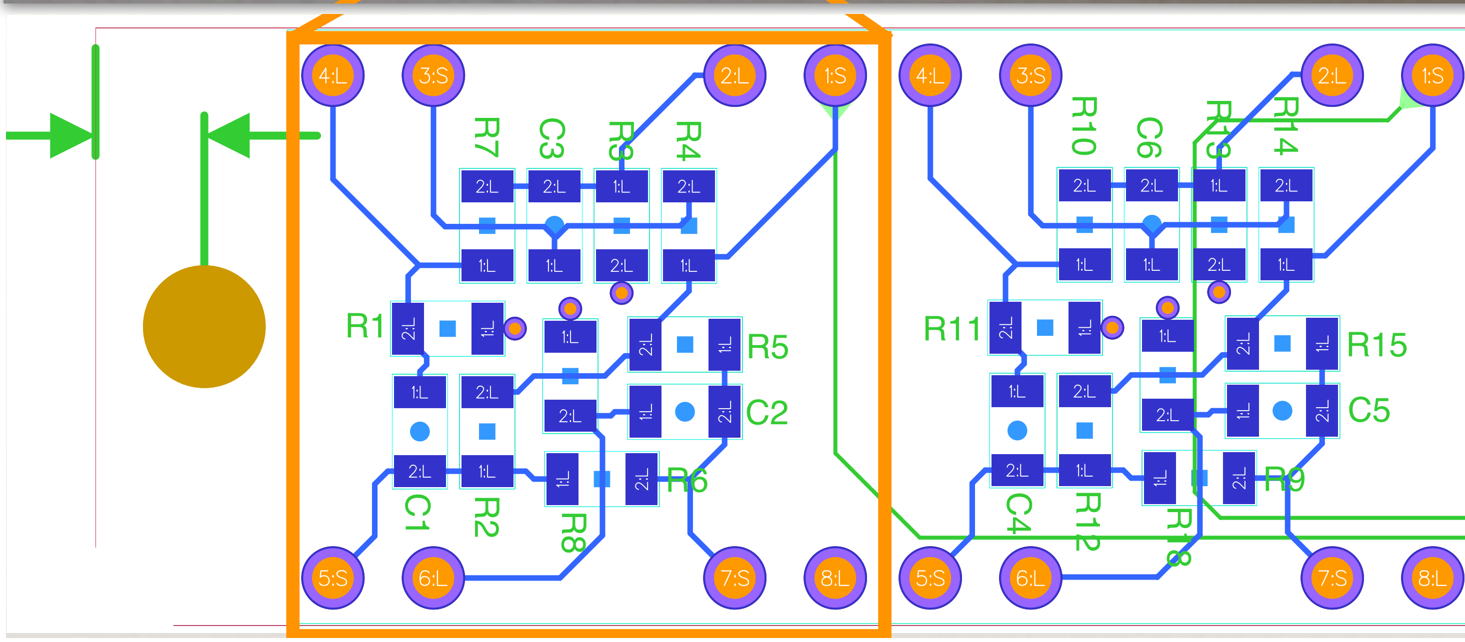
Honeycombe image taken with X-ray

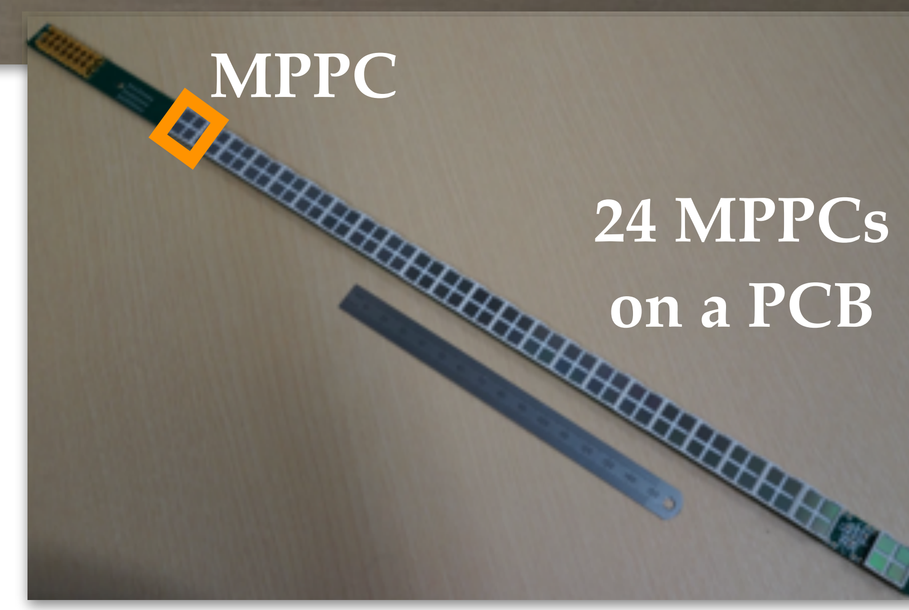


Assembly PCB

Assembly PCB (before putting MPPCs)

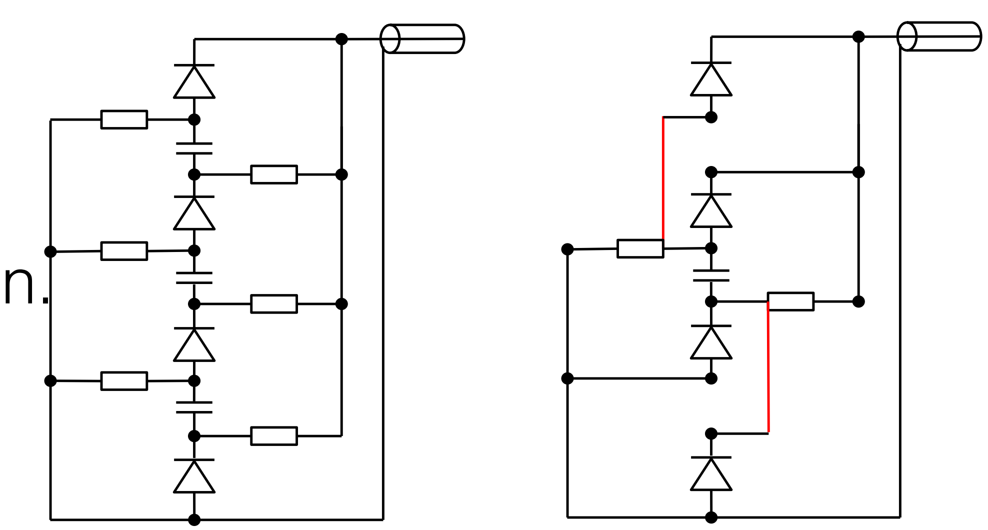






Assembly PCB (after putting MPPCs)

- Co-axial structure implemented in PCB
- 24 MPPCs on a PCB (for prototype tests)
- Switchable “4-seg” or “2-seg” “hybrid” connection.
  - Different falling time constant, with common bias voltage



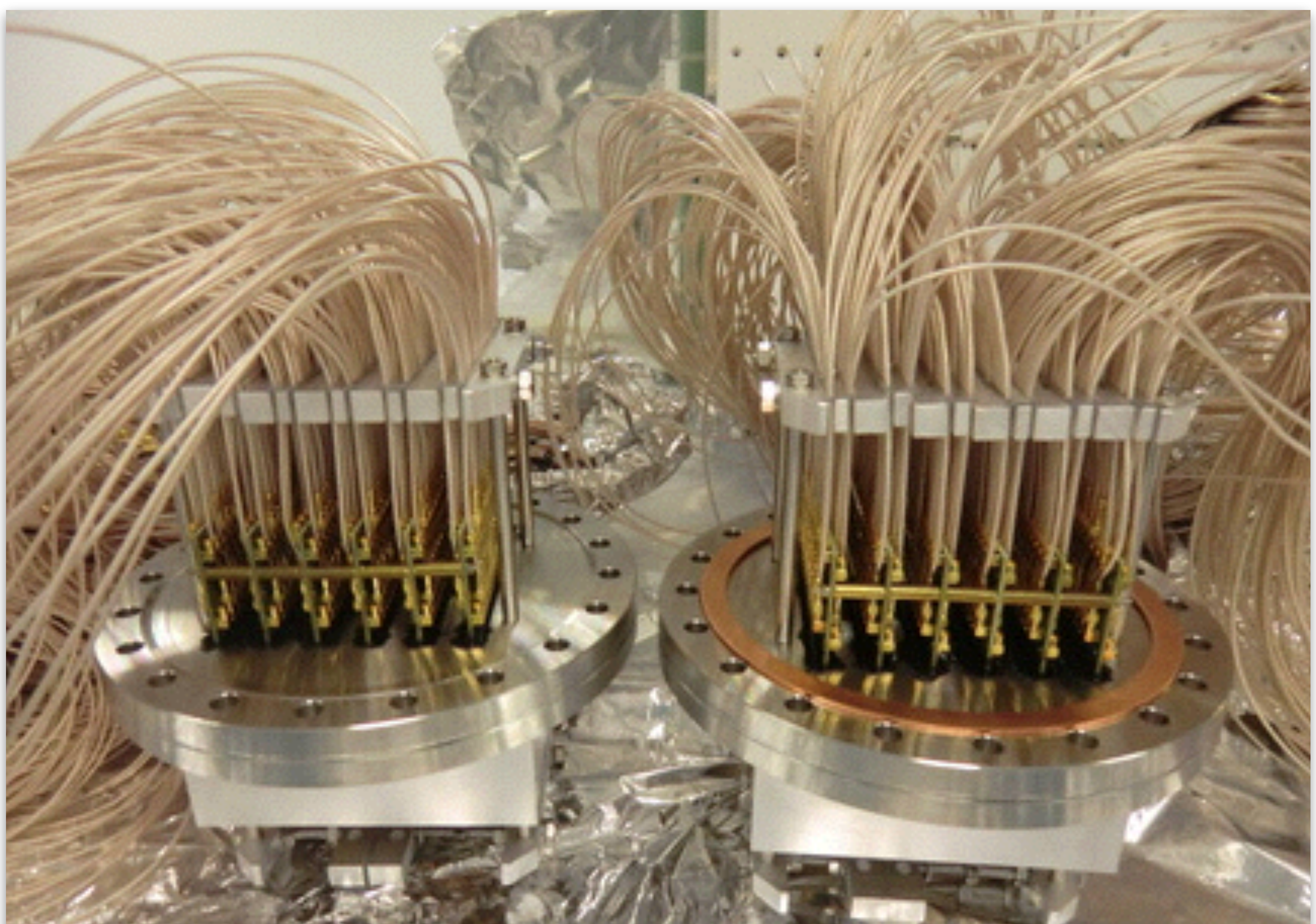
MPPC connection schemes

PCB Feedthrough

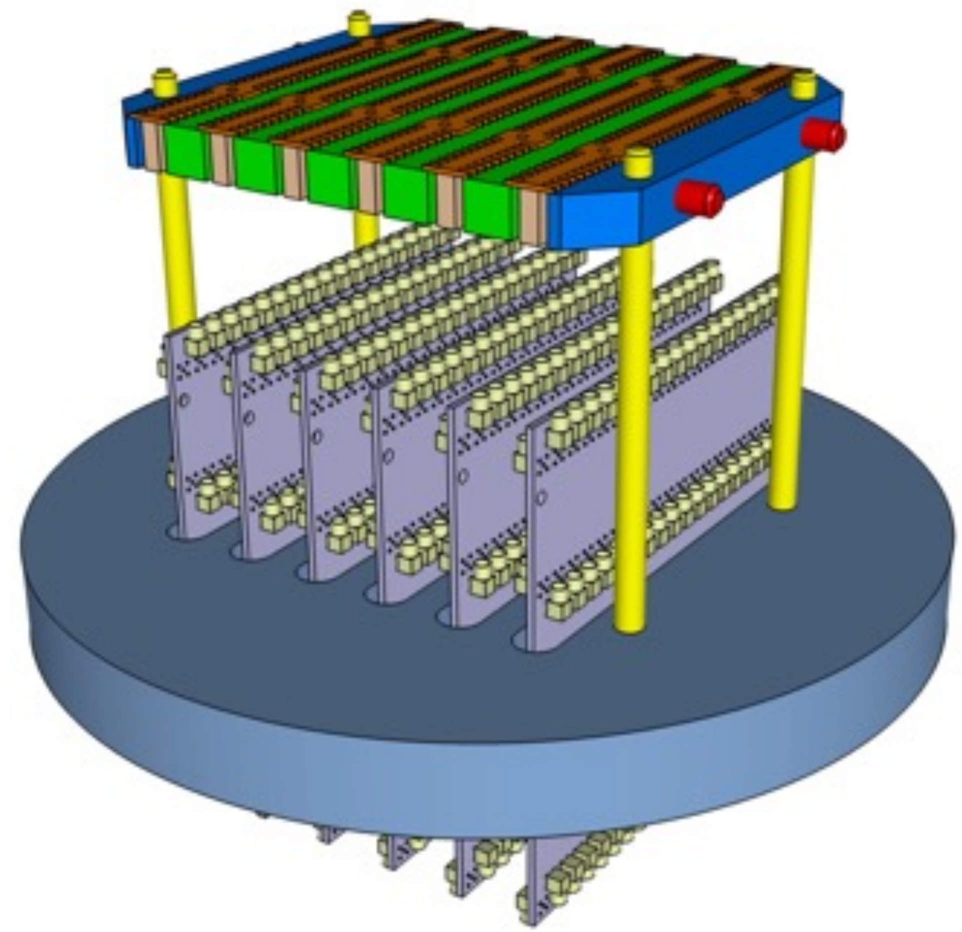
High density co-axial like feedthrough

- Six PCBs glues in slits on a flange
- Co-axial like structure in the PCB
- 72 ch per PCB
- Wires are connected with MPPC connectors or directly soldered

PCB feedthrough for MPPC low-temperature tests



PCB feedthrough and cable support



Tested in the low-temperature MPPC mass-test

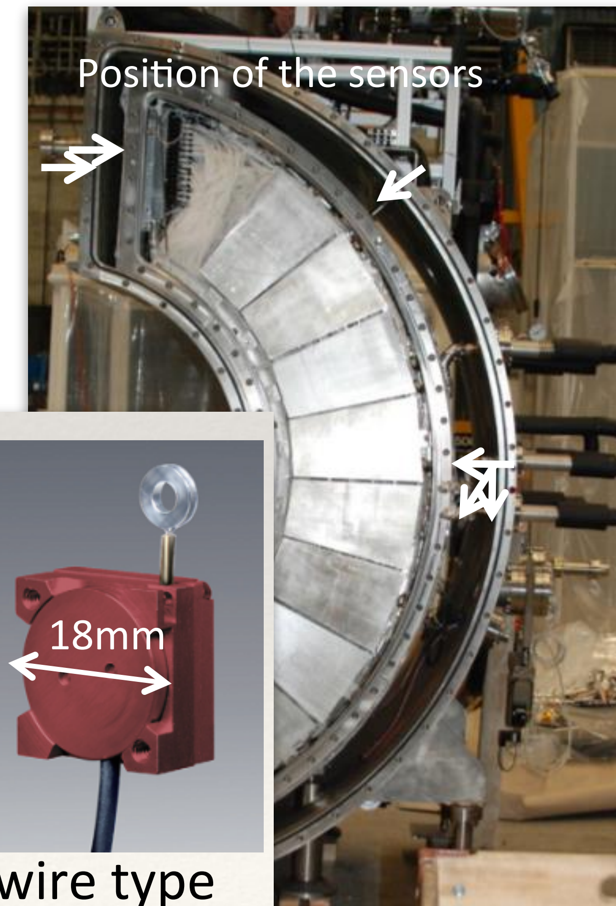
Detector Alignment

Measurement and monitoring of the detector position.

- Investigating feasibility of installing tools for monitoring deformation of the cryostat due to the weight of LXe (~3 tons) and low temperature (~165 K)

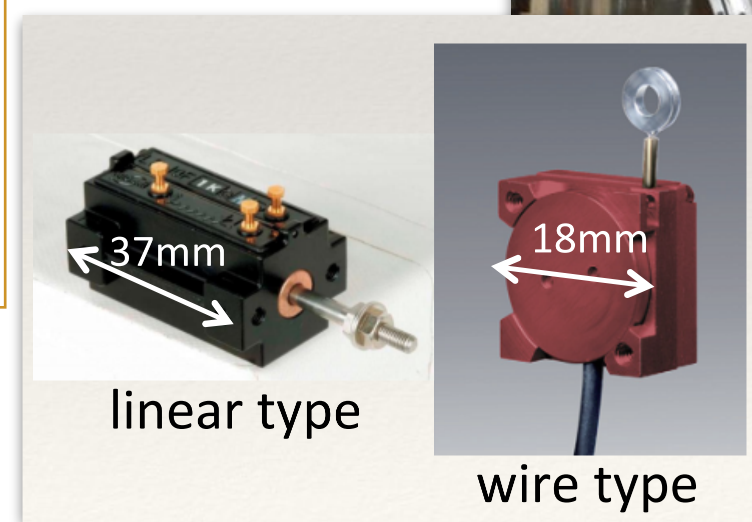
Between LXe outer cryostat and the rest of MEG II detector.

- Laser tracker
- Put a marker on the cryostat.
- The measurement can be done any time (when beam is off).



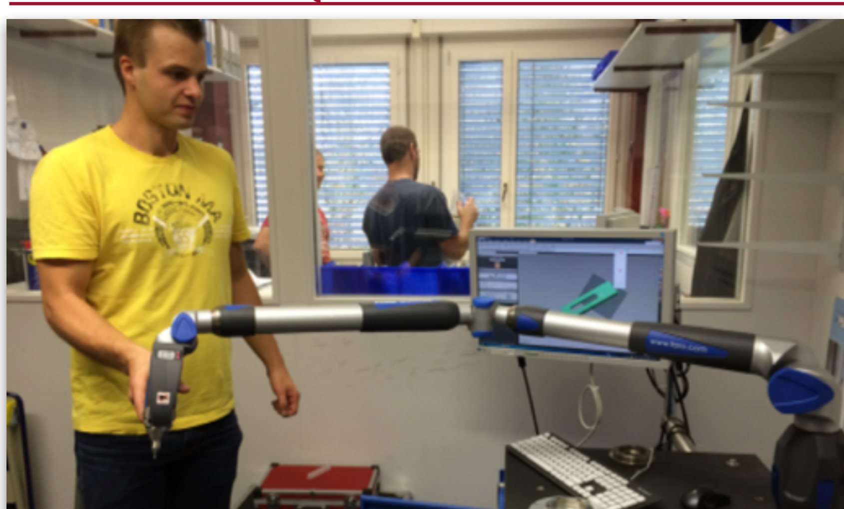
Between LXe inner cryostat and Photon sensors

- 3D Scanner
- Can be measured only before installation
- Supporting structure is rigid



Potentiometers

3D scanner (demonstrated in PSI)



Between LXe inner cryostat and outer cryostat

- Potentiometers can be used probably.
- Online permanent monitoring

Summary and schedule

- The development of the VUV MPPC for LXe is finished.
  - Mass test of the (almost) final model is done (next talk).
  - The final model (with crosstalk suppression) was tested.
    - The energy resolution is improved because of the low crosstalk
    - Due to the wider operation voltage rage, the PDE becomes even higher (up to 27%)
- Various detector components are designed and tested.
- Schedule
  - 2015
    - Mass test of the MPPCs for the final detector at room temperature
    - The final detector will be built
    - Test of a prototype electronics (256ch)
  - 2016
    - Purification of LXe
    - DAQ test with the full electronics
    - Calibration with Am, LED, pi0 decays and so on.
    - To be ready for MEG II run