MEG実験用ガンマ線検出器アップグレードと液体キセノン用PPDの開発

東大素粒子センター 澤田龍

他MEGコラボレーション

- Outline
  - Upgrade of LXe detector for MEG
  - Status of the development of MPPC for LXe detectors

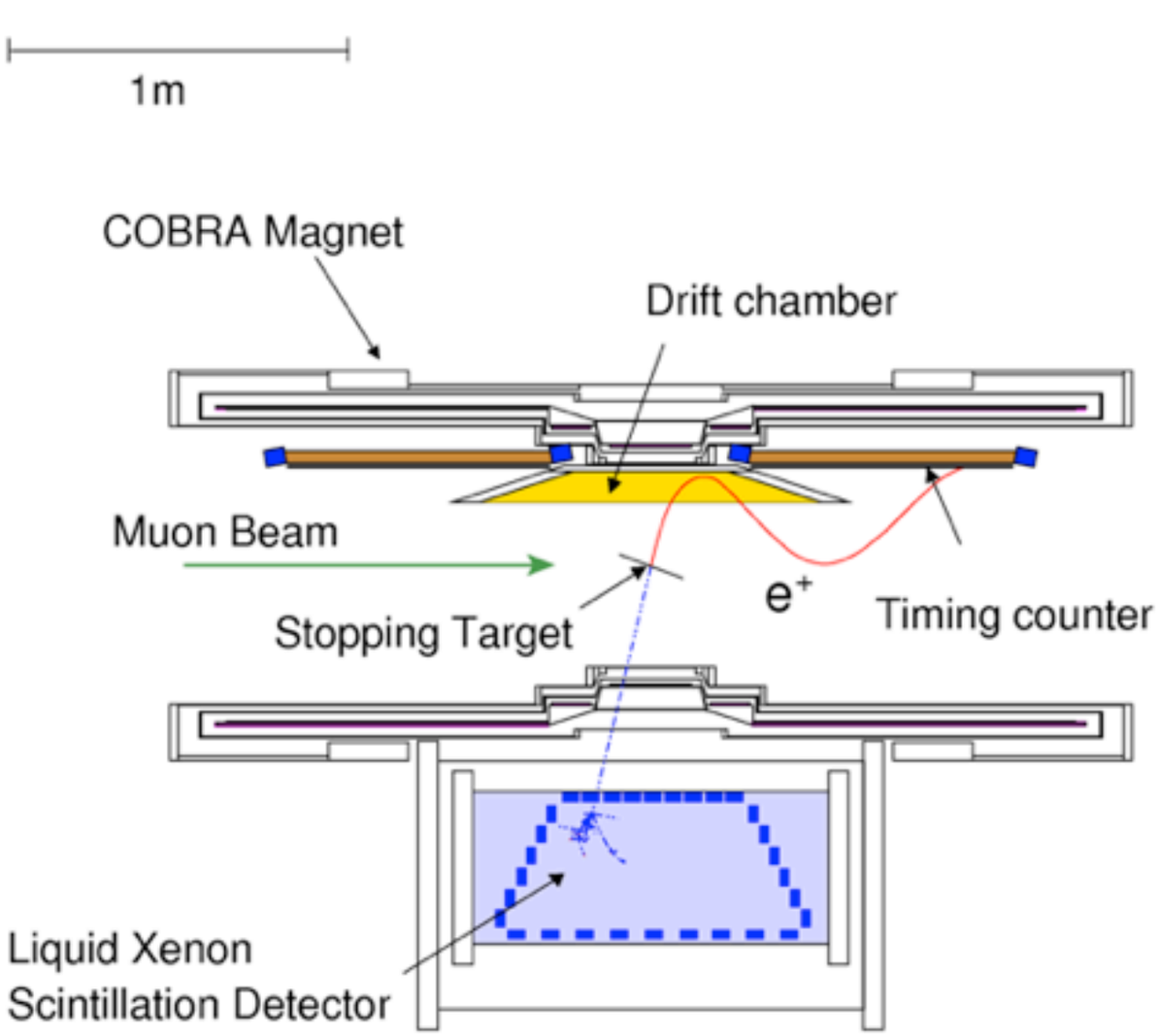
日本物理学会2012年秋季大会 京都産業大学

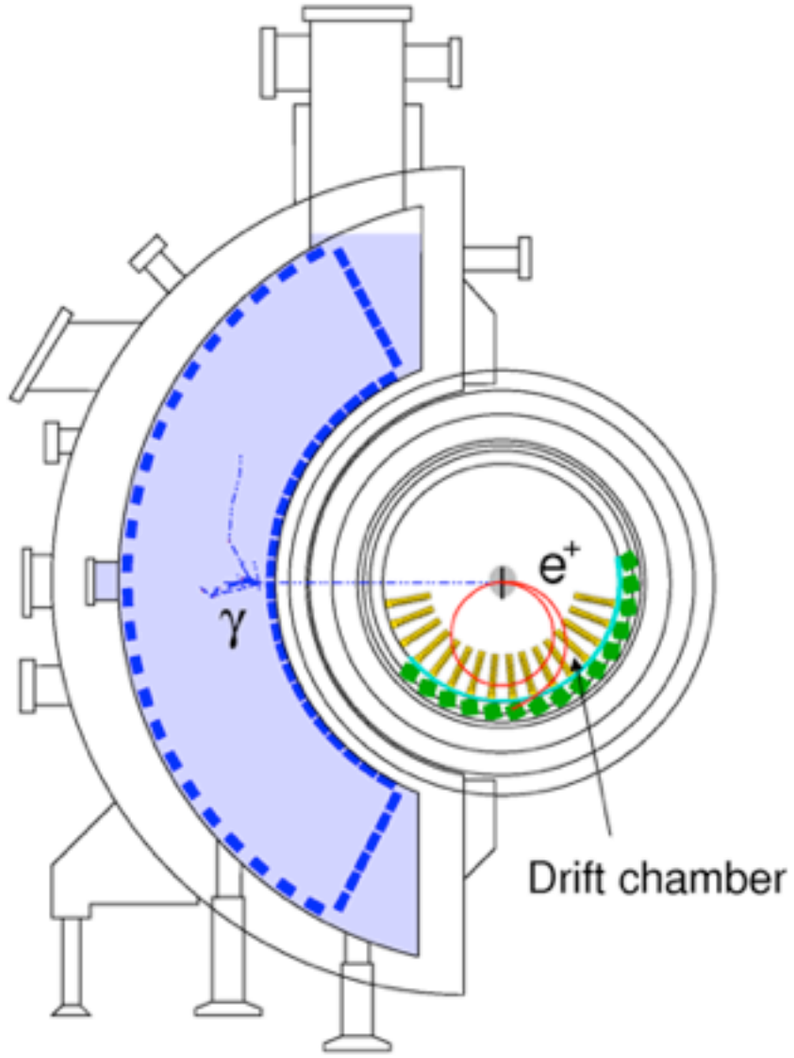
MEG experiment

Searching for LFV decay $\mu \rightarrow e\gamma$

The latest result (2009+2010 data) : $\mathcal{B} < 2.4 \times 10^{-12}$ *[PRL 107.171801(2011)]*

Sensitivity goal of MEG (until 2013) : $\mathcal{B} \sim 6 \times 10^{-13}$



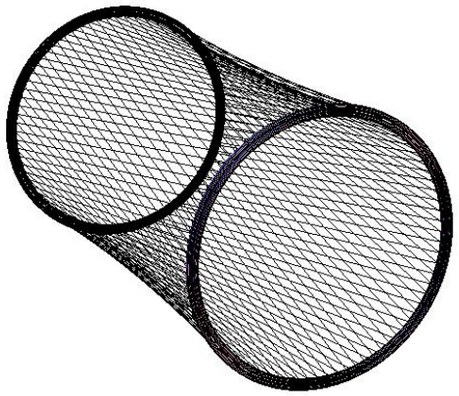


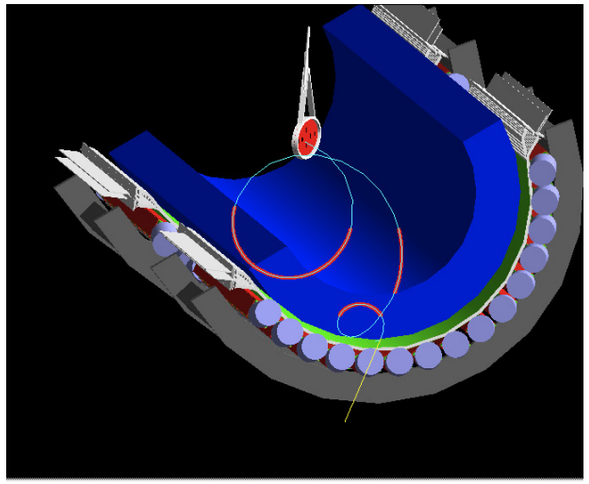
Upgrade 14aSK-6：岩本

Several studies are ongoing for the upgrade of MEG to improve the sensitivity by one order of magnitude, $\mathcal{O}(10^{-14})$.

- 2-3 times higher beam intensity
- LXe γ detector upgrade with MPPC
- Unique volume gas chamber
- Active target / SVT / Pixelated e^+ timing counter...

Large volume tricker
- TPC
- Cylindrical drift chamber

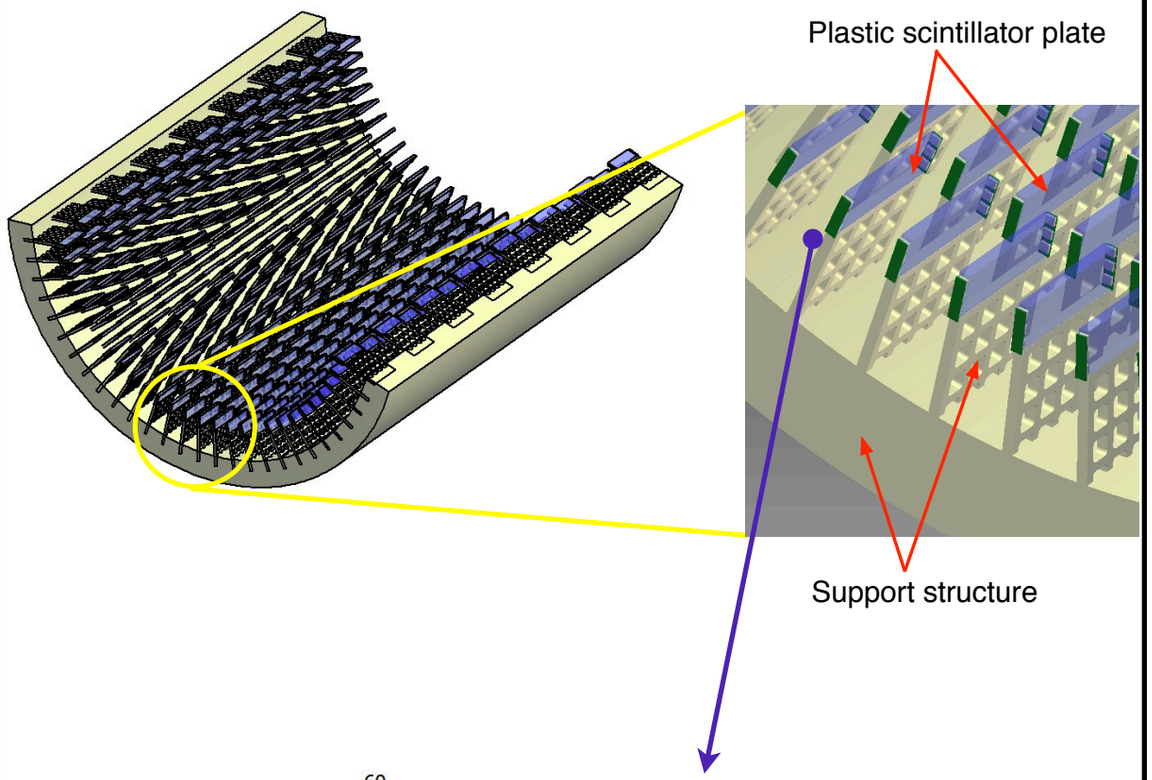


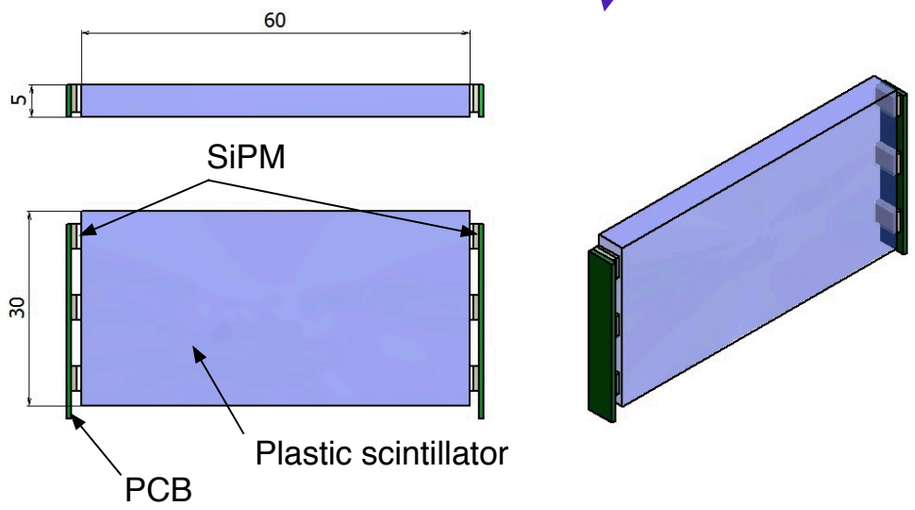


13pSG-9：藤井

Pixelated plastic timing counter

14pSK-4：西村





LXe detector : new configuration

Inner face,
2” PMT → Smaller device

- Better uniformity
- Precise position
- Higher detection efficiency

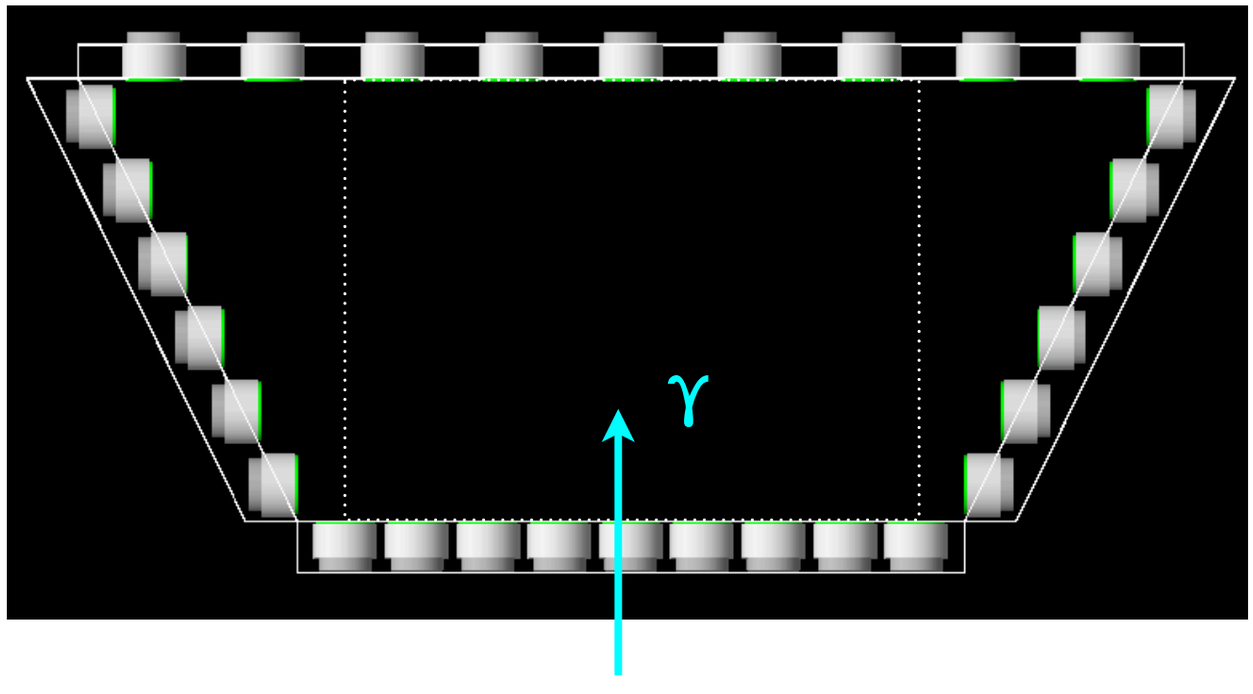
Slant angle of lateral PMT

- Better uniformity

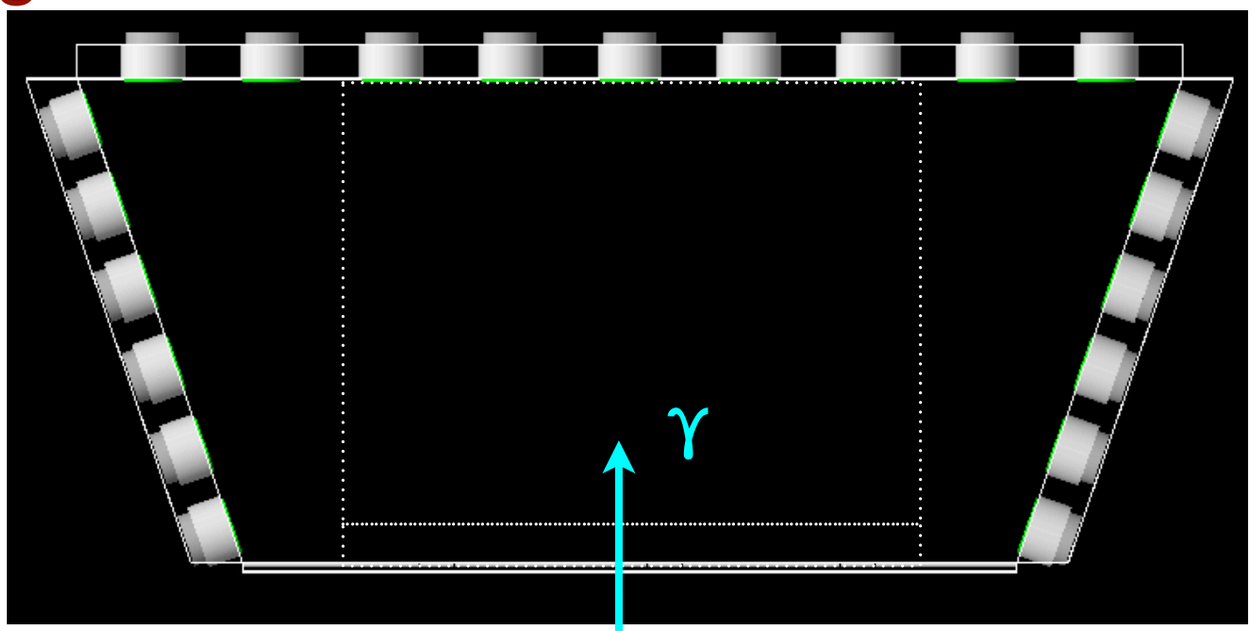
Wider inner face

- Reduce energy leakage

Present



Upgraded

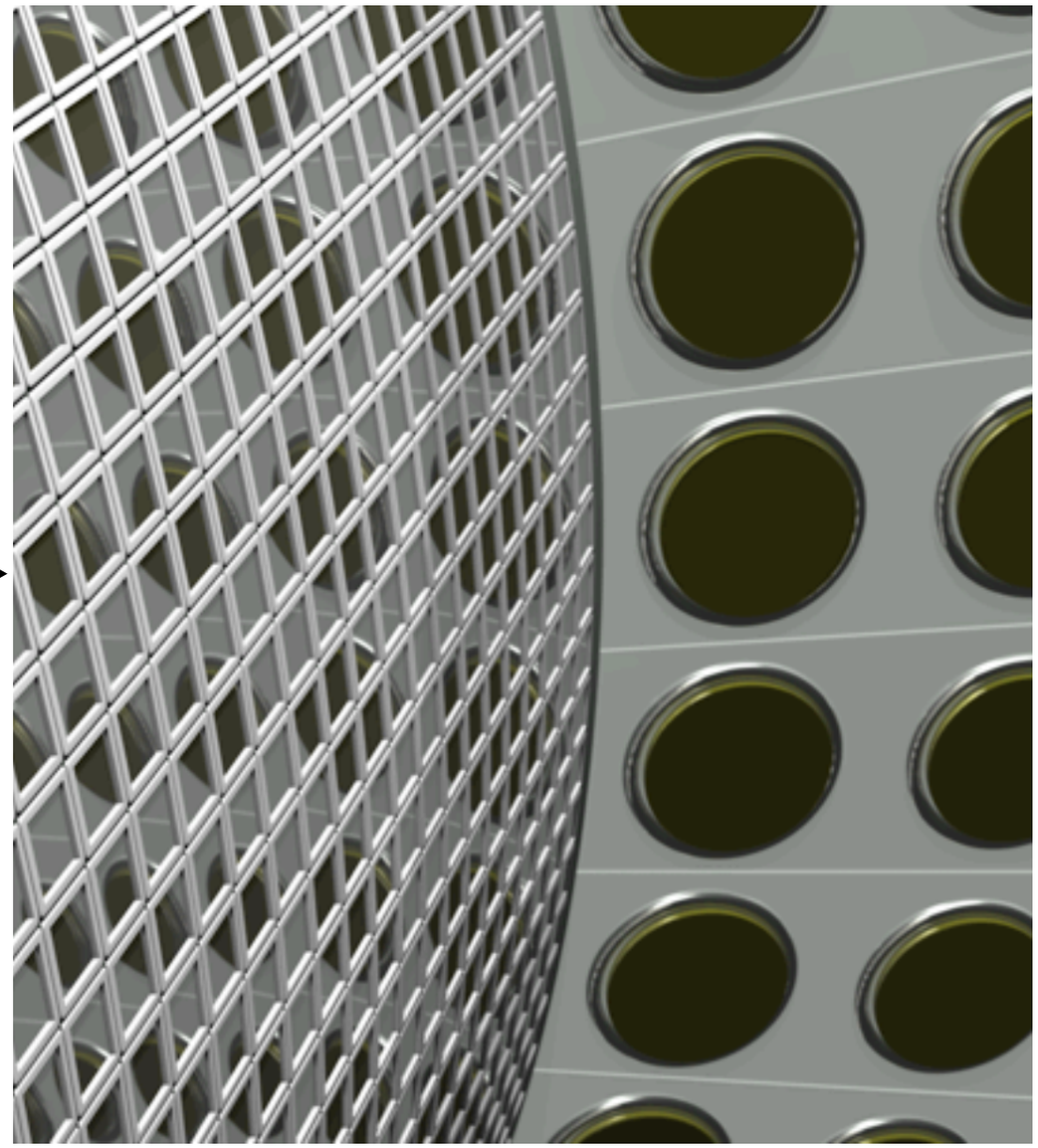


LXe detector : new configuration

Present

2 inch PMT
216 ch

Upgraded

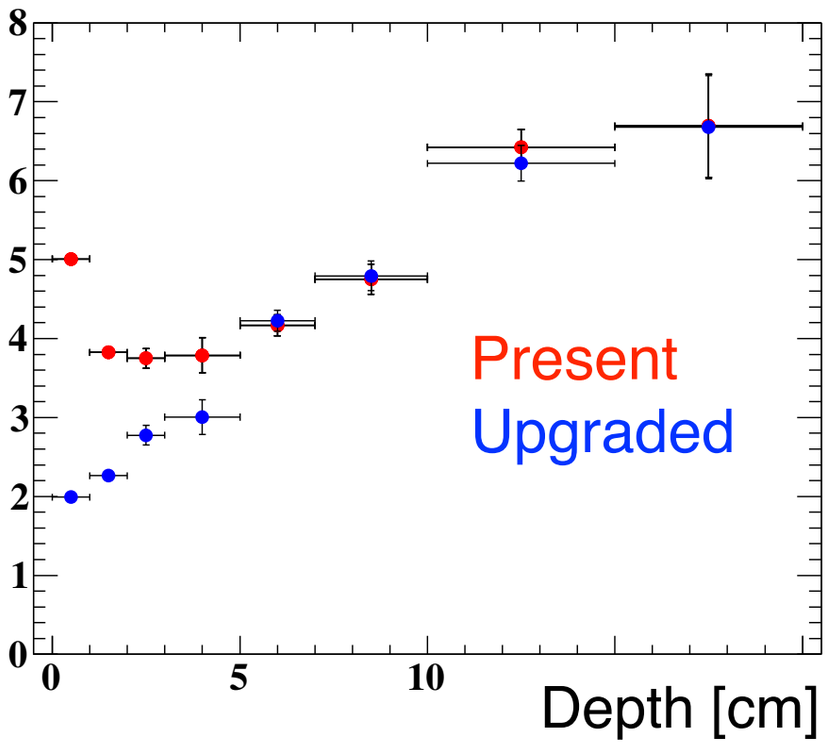


computer graphics

12×12 mm^2 MPPC
~ 4000 ch

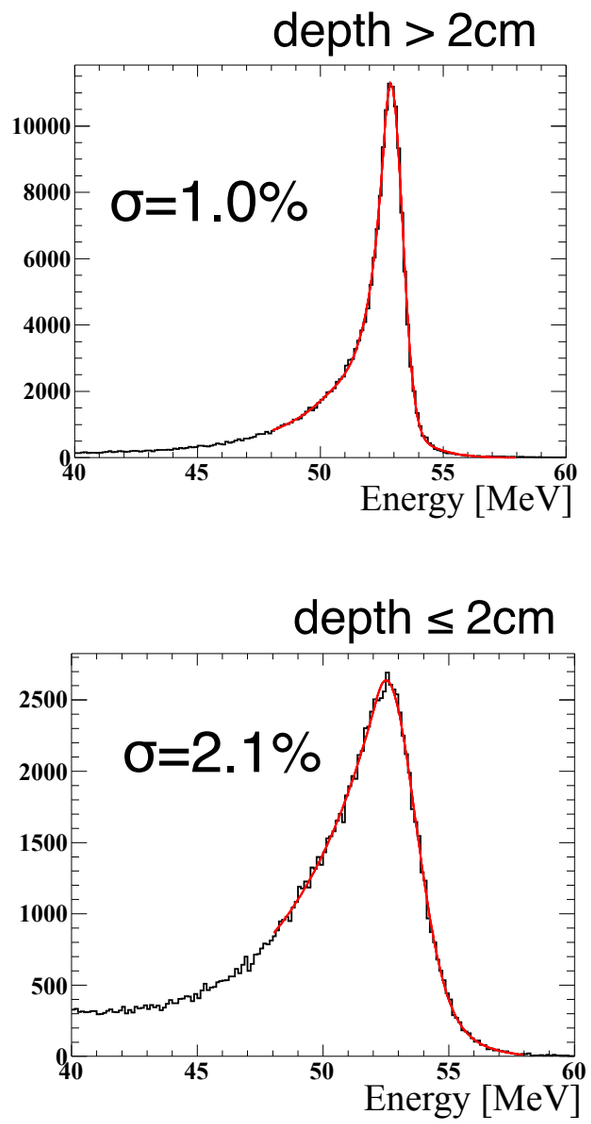
Possible improvements

MC position resolution

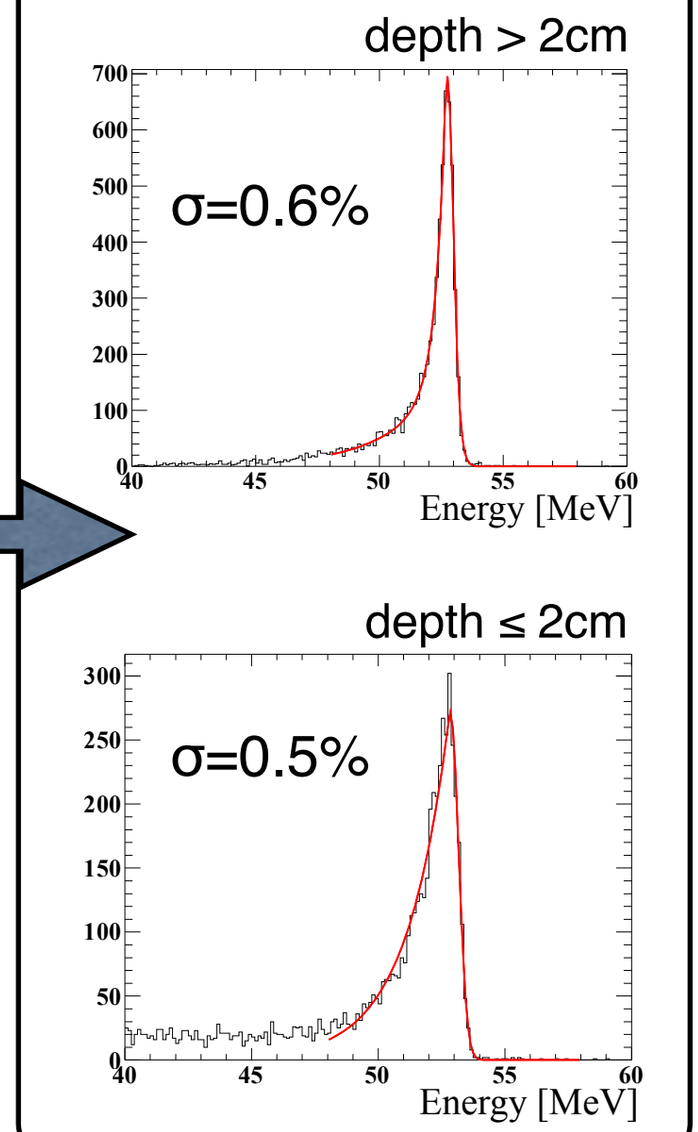


10% higher detection efficiency (MC)

MC, Energy
Present



MC, Energy
Upgraded



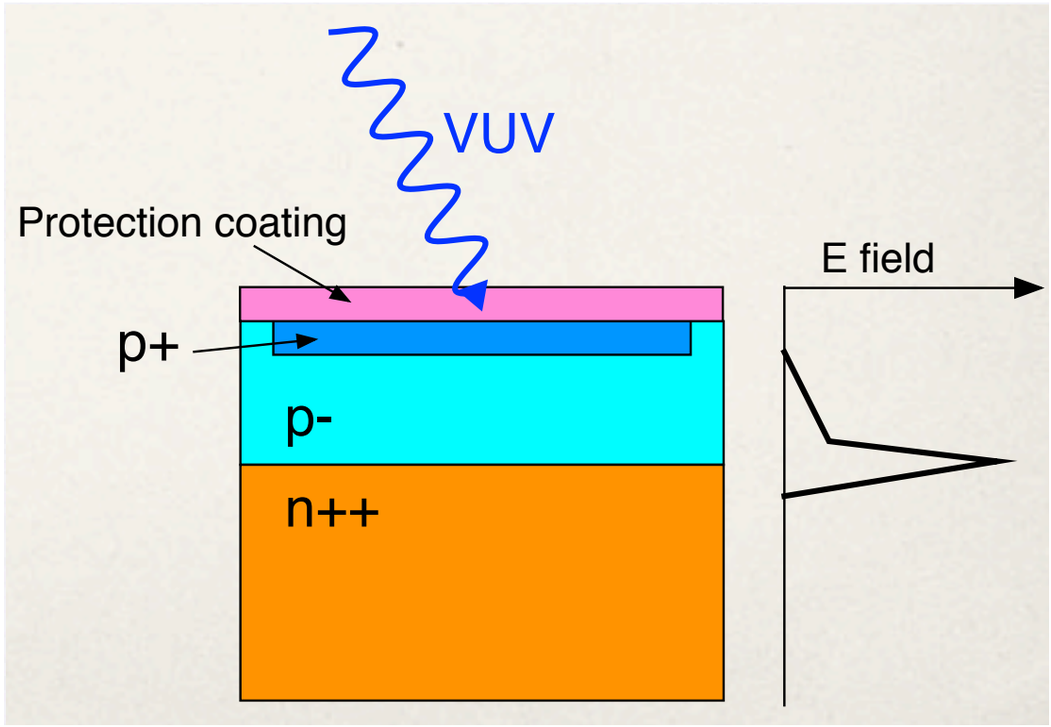
Actual resolution could be worse than MC.

Studies on energy resolution :12pSH-8 : 金子

Development of new MPPC for LXe

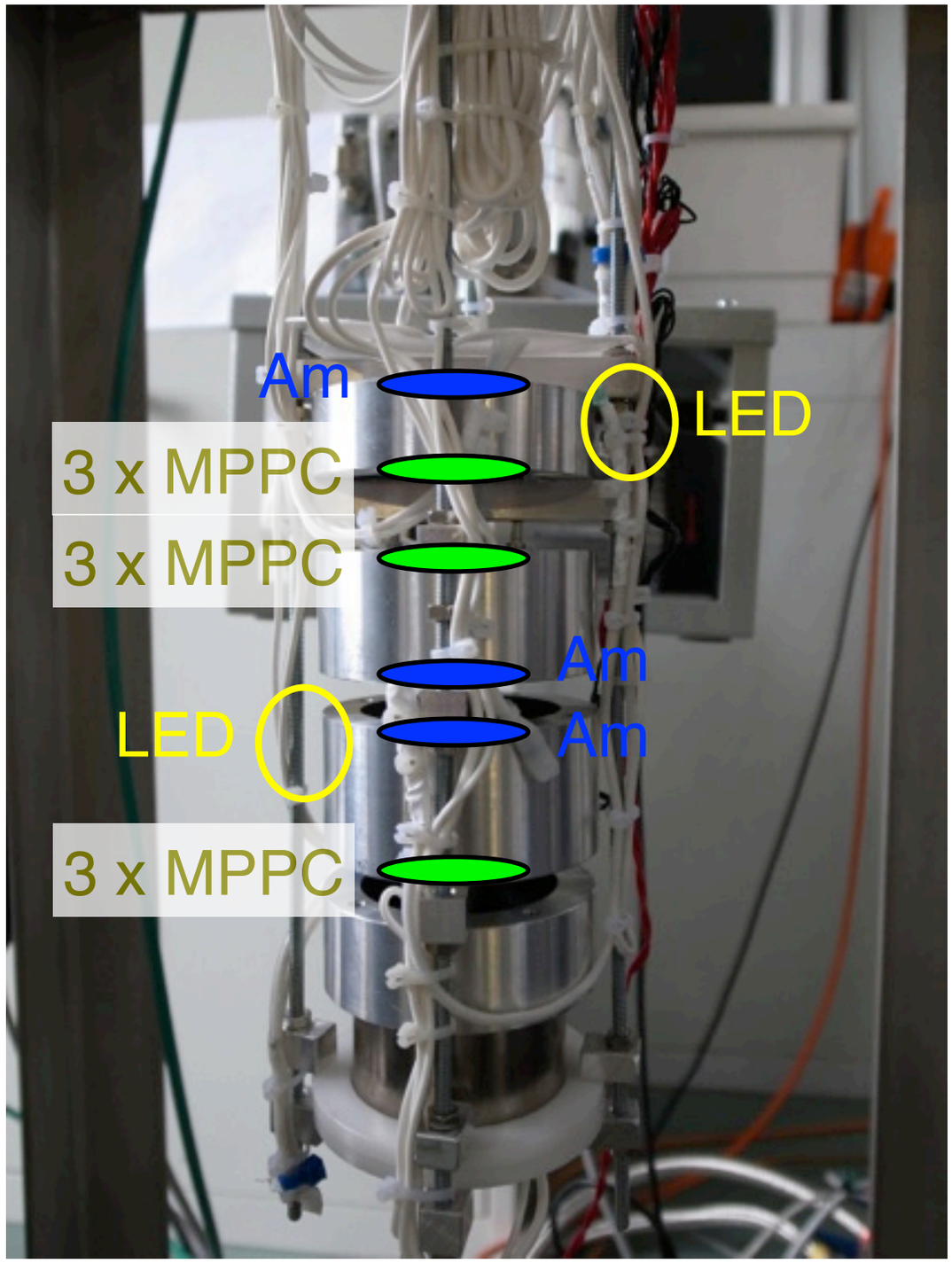
Collaboration with HAMAMATSU Photonics

- Detection of VUV light (~178 nm), PDE of commercial produce is nearly zero
  - Remove the protection coating
  - Anti-reflection coating
  - Thinner p+ layer
- Operation in LXe
  - Matching of refractive index
  - Quenching resistance at low temperature
  - Package design



Test setup

- Test facility at PSI
  - 2ℓ-LXe in small cryostat
  - 9 MPPC samples are installed
  - Alpha source (^{241}Am)
    - O(100) p.e. on 3×3mm^2 MPPC
    - PDE measurement
    - Time resolution measurement
- Pre-amplifiers are located outside of the chamber
- Digitization of waveforms using domino-ring sample (DRS) at 0.7 or 1.6 GHz sampling rate



Summary of the previous JPS meeting

- Tests of special MPPC samples in a small LXe chamber
- Confirmed that the samples work in LXe
  - Gain : $>10^6$
  - PDE ~ 10% (correction for cross-talk and after-pulsing was not done)
  - Dark rate is suppressed by $\mathcal{O}(10^5)$ at LXe temperature
  - 1 p.e. peak is visible with 4x4 monolithic array (connected in parallel)

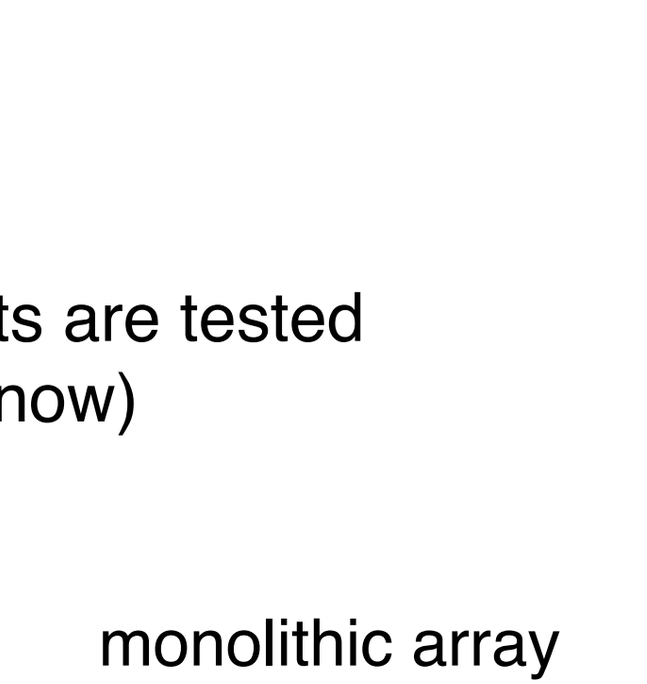
Tested samples

7 new types (A,B,C,D,E,F,G,H) of MPPCs and their variants are tested
But we can't show details of parameters. (Even we don't know)

- 1×1 mm^2 , 3×3 mm^2 and 4x4 monolithic array (12×12mm^2)
- 25, 50 or 100 μm pitch
- Options of the structure
  - Protection layer is removed (A-H)
  - Thinner p+ layer (AD, BE, CF)
  - Anti-reflection coating (A-C,D-F)
  - Refractive index matching for LXe (G,H)

3x3 mm^2 single

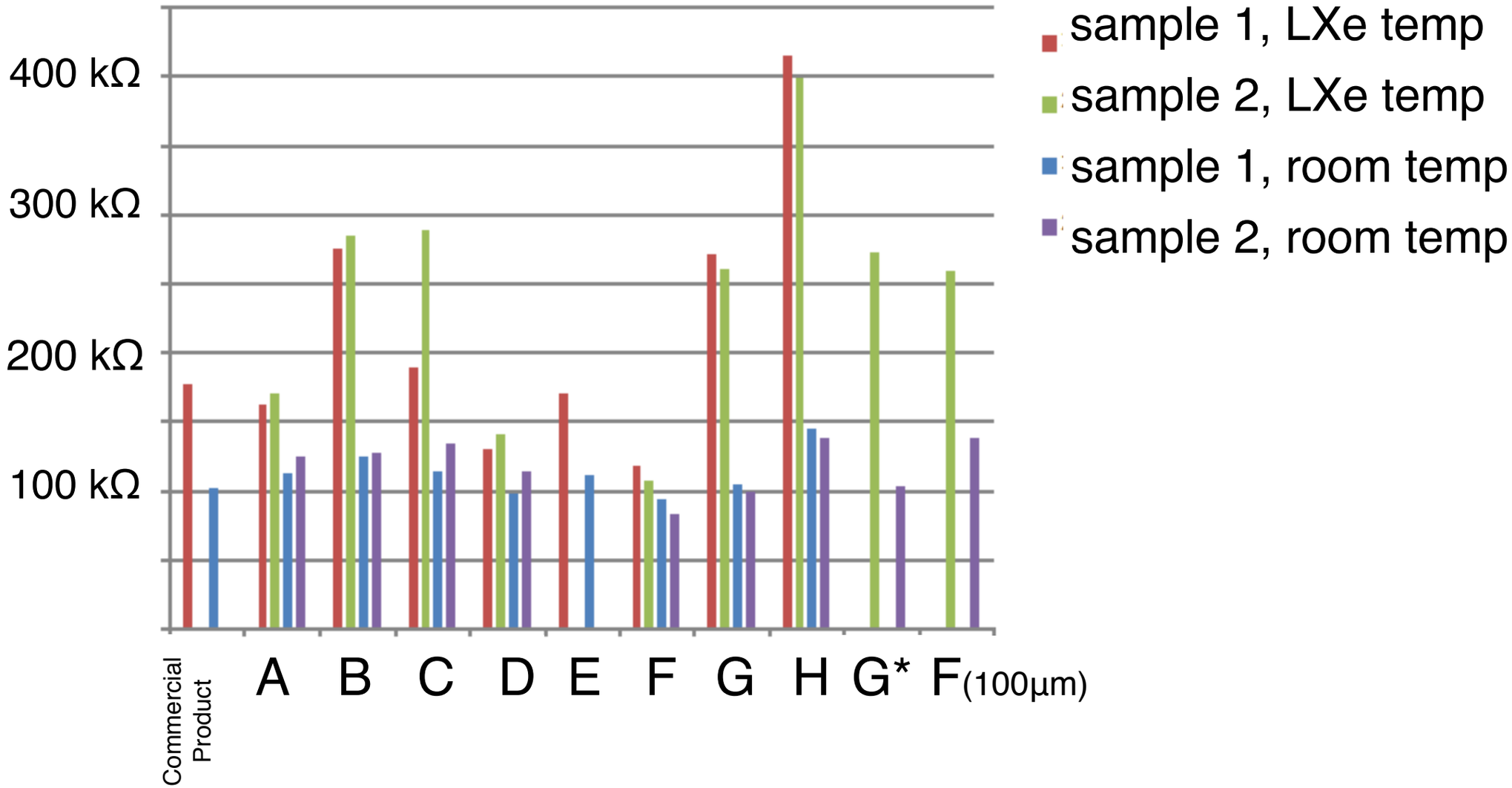
monolithic array
(We need this size)



1x1 mm^2 single

Quenching resistance

Poly-silicon quenching register : higher resistance at low temperature



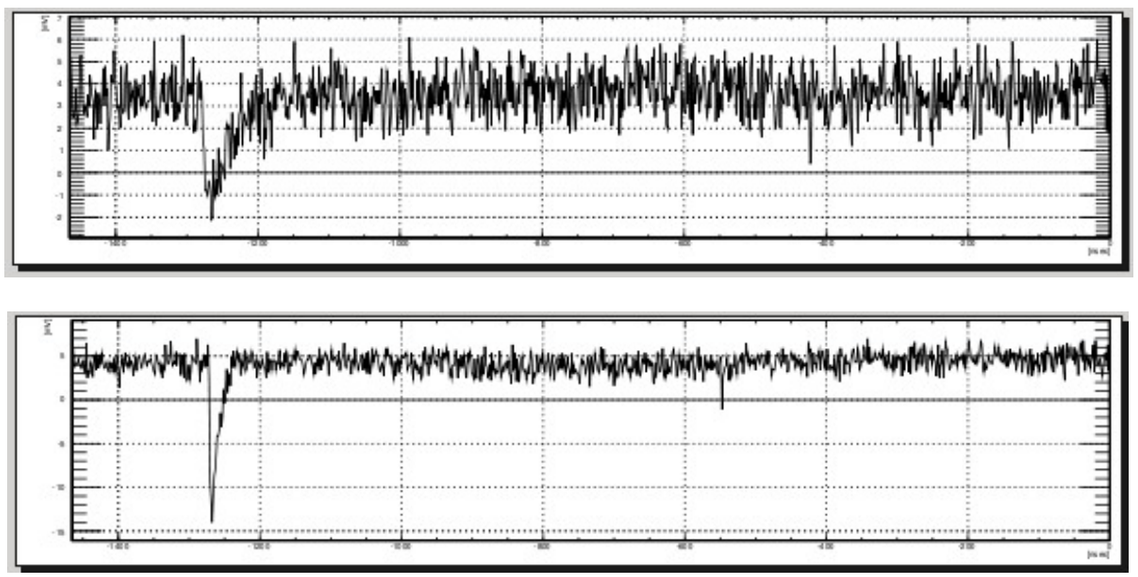
At room temperature : resistance of all samples ~100 kΩ

At LXe temperature : resistance become larger
by same amount for the same type

* second measurement of the same G sample to check reproducibility

Waveform

- We see narrow or wide 1 p.e. pulses (charge is same)
- Present at room temperature and at LXe temperature
- Only samples A-F (Related to the thinner p+ layer ?)
- The fraction depends on types
- The reason is unknown so far



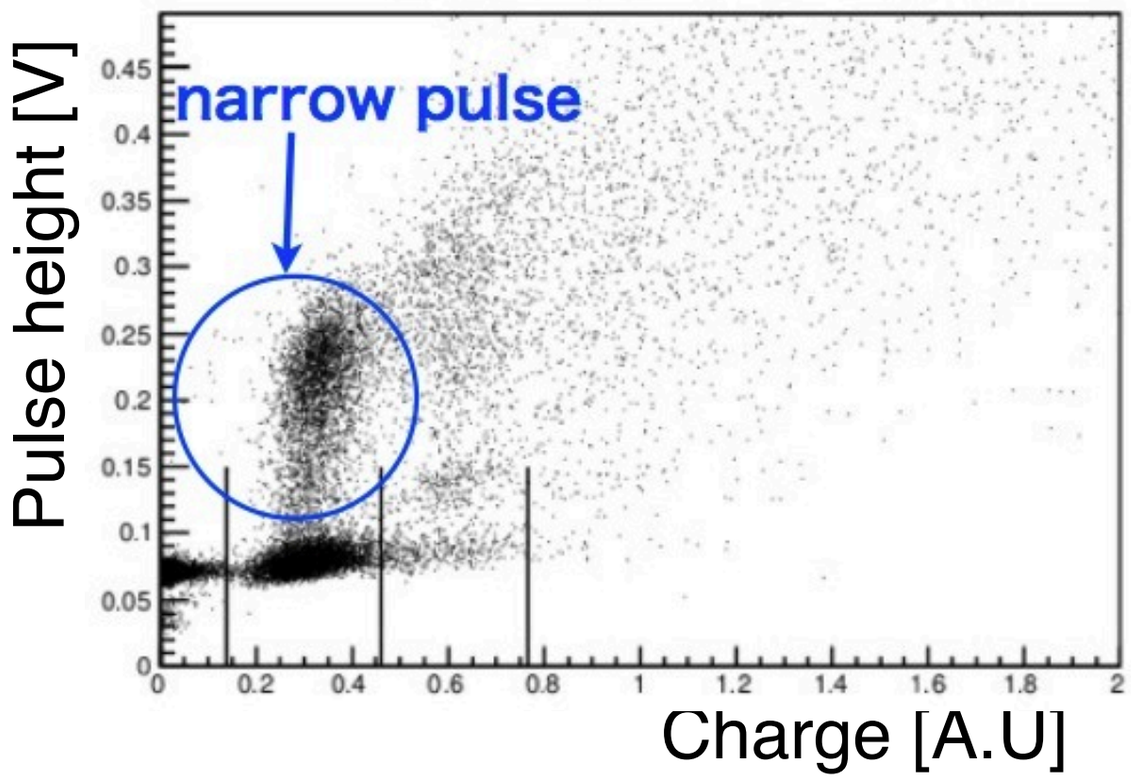


Photo-crosstalk (CT) and afterpulsing (AP)

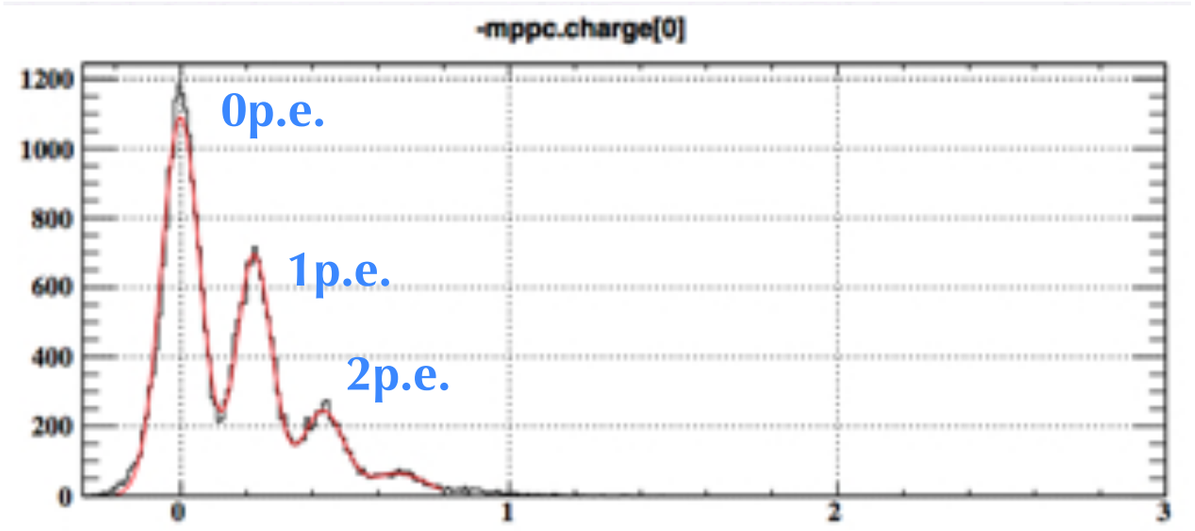
Method :
estimating CT+AP probability using the deviation from Poisson statistics

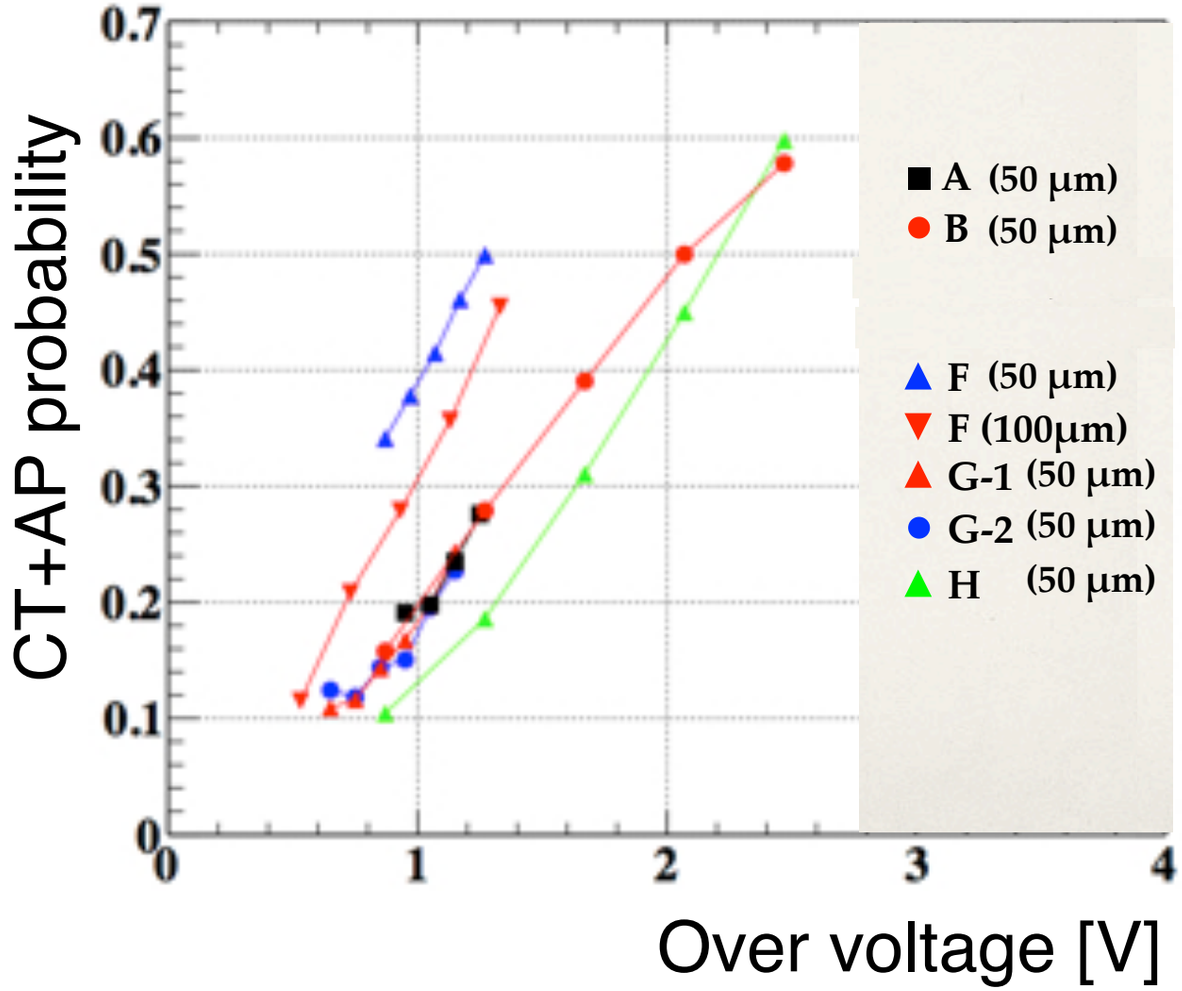
- LED data with triggering by LED and readout with a common clock
- Expecting probability of 1 p.e. from measured 0 p.e. probability

  Poisson mean = -Log($P_{0pe,meas}$)

- Deviation from Poisson statistics

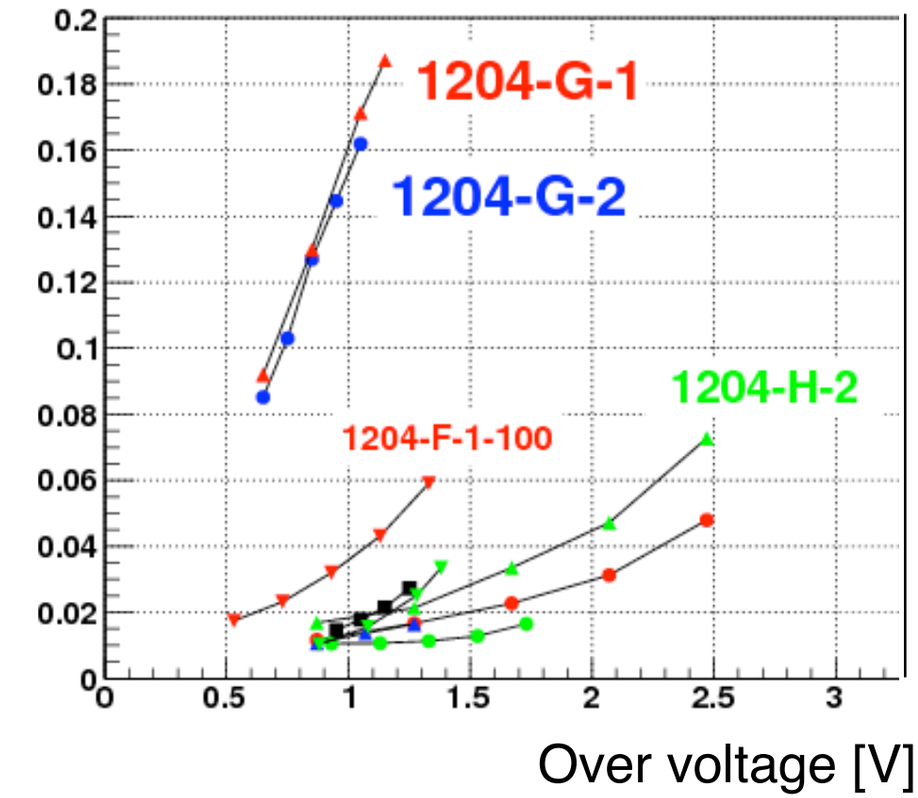
  $P_{CT+AF} = (P_{1pe,exp} - P_{1pe,meas}) / P_{1pe,exp}$





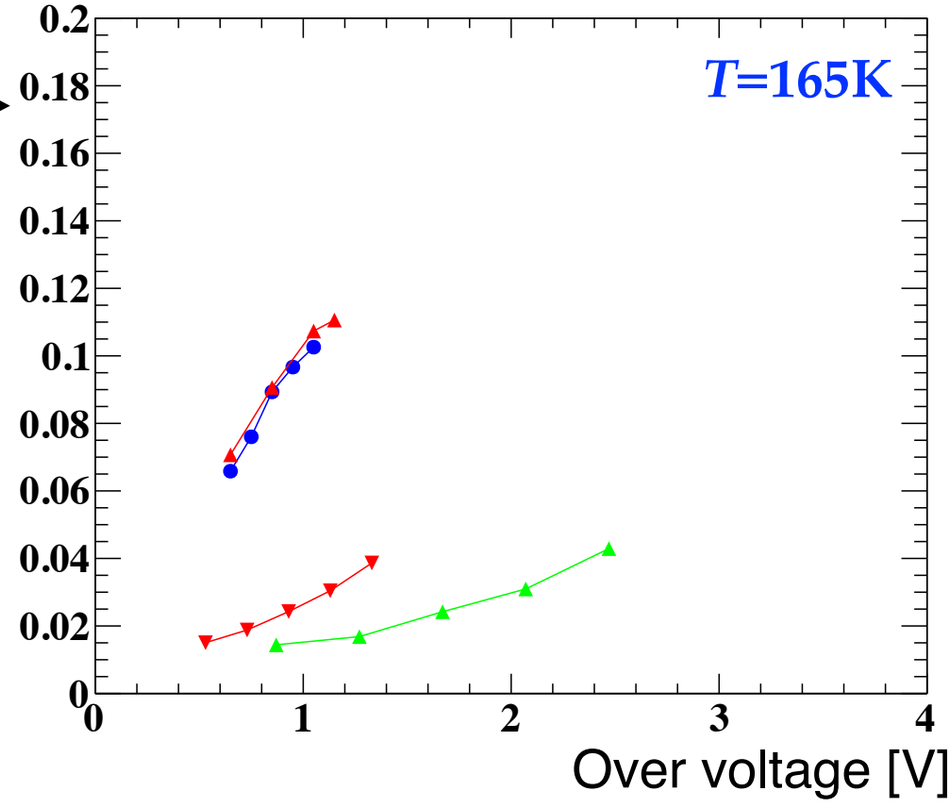
PDE

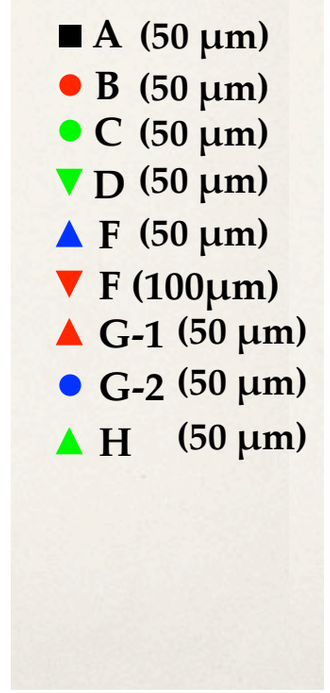
Raw PDE



Correction for CT+AP

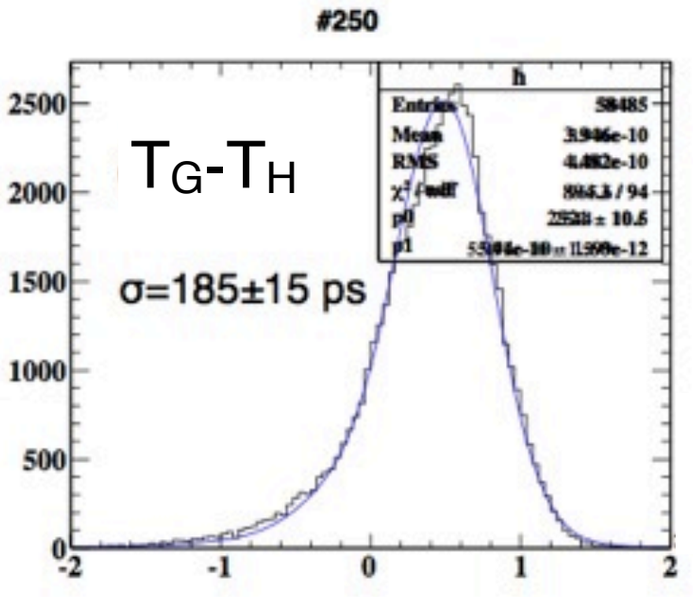
Corrected PDE

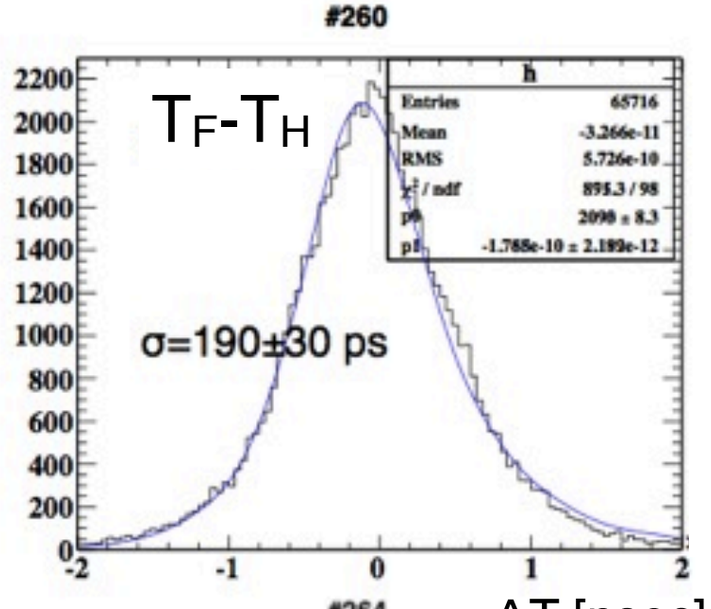


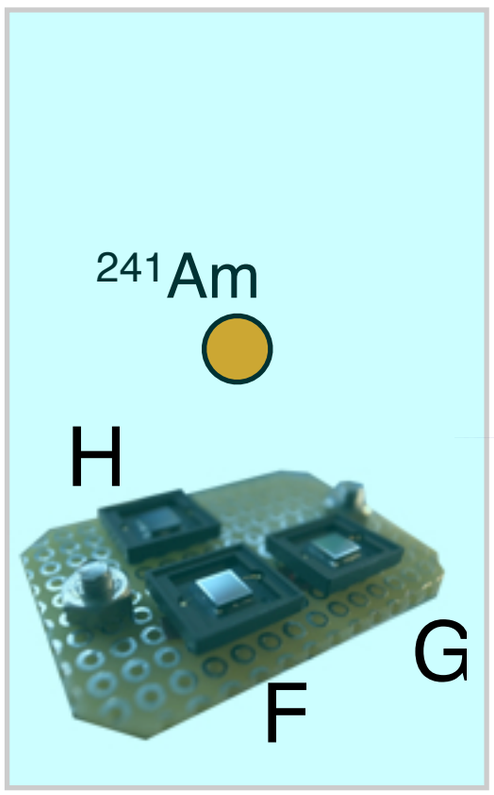


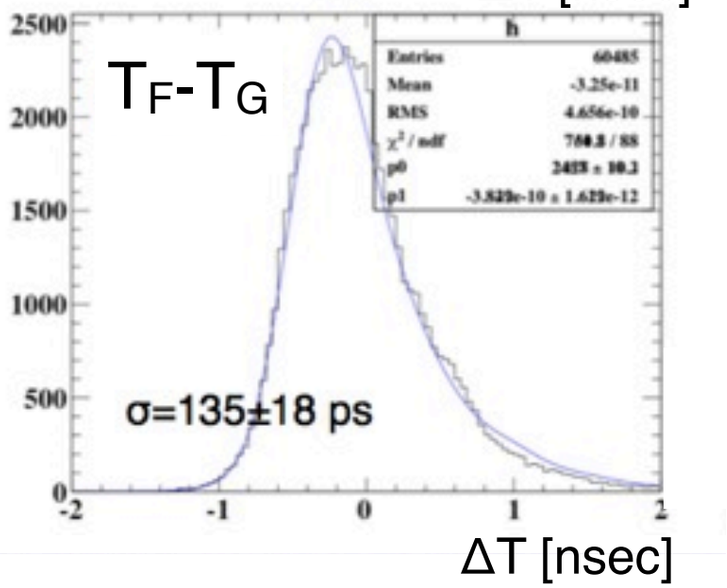
- Higher “Raw PDE” than reported in previous JPS meeting. Improvement of production.
- Corrected PDE of type G is 10% for LXe scintillation, and two samples show almost same behavior.
- The total number of p.e. observed with LXe detector using 11% PDE MPPC is same as the present detector because of higher light collection efficiency

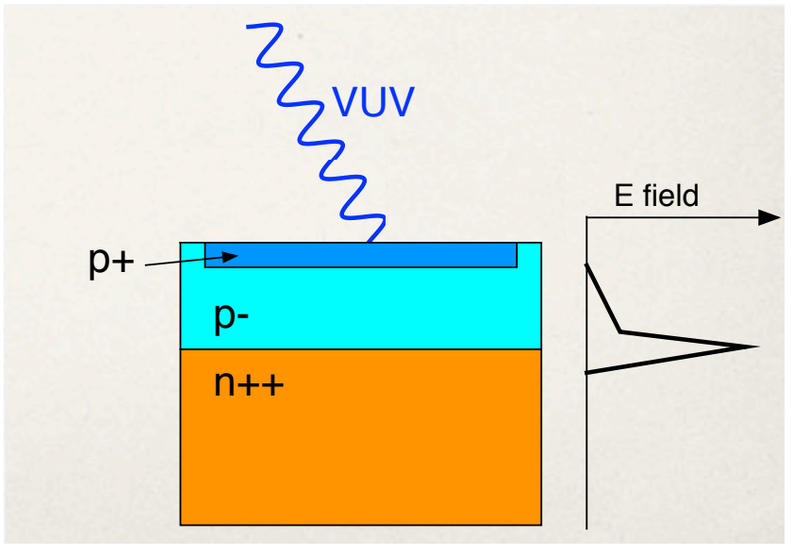
Time resolution









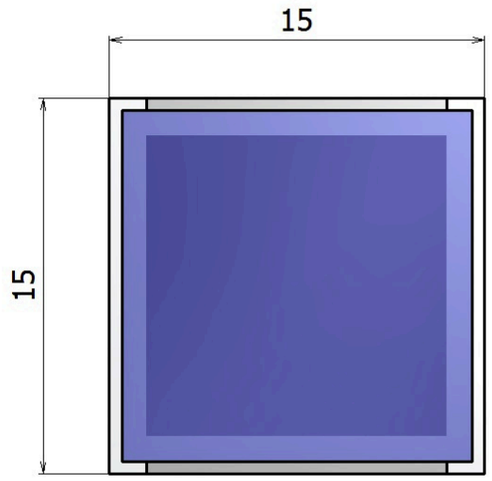


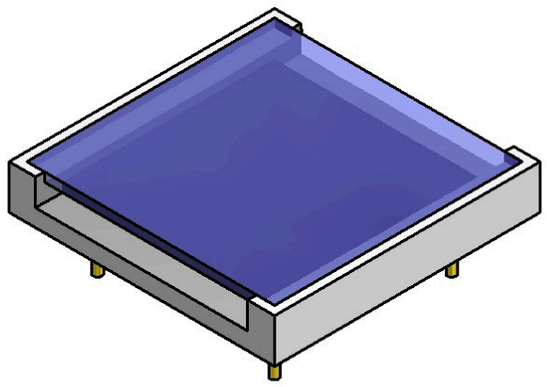
Result :

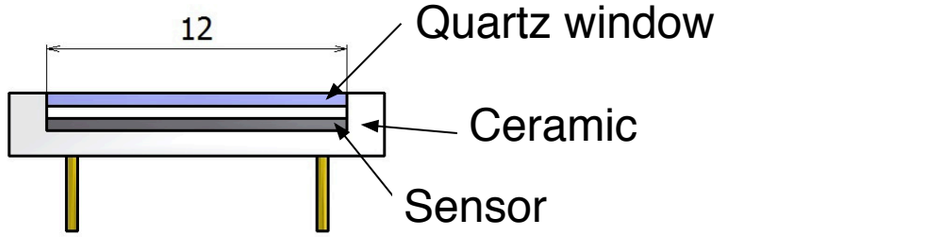
σ_{1pe} ~ 100-160 ps

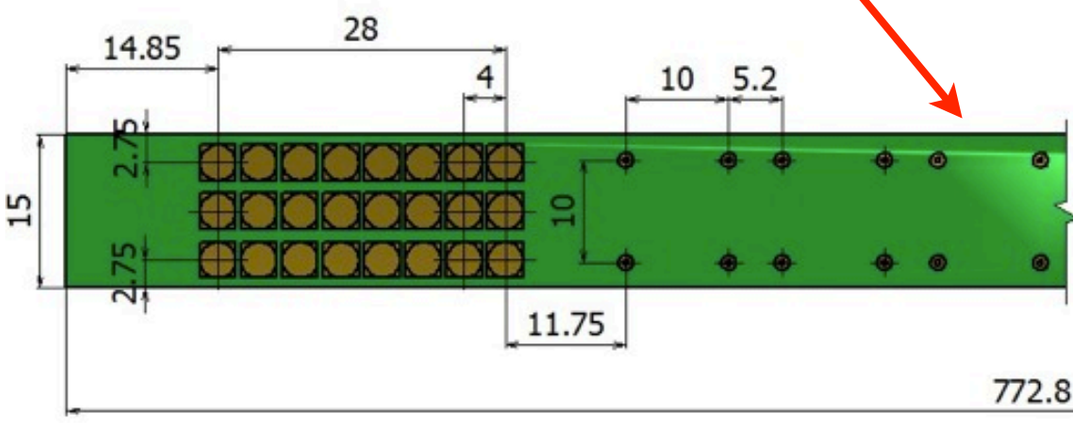
- Time resolution is measured using 5 MeV α from ^{241}Am in LXe
- Contribution of scintillation statistics is de-convolved

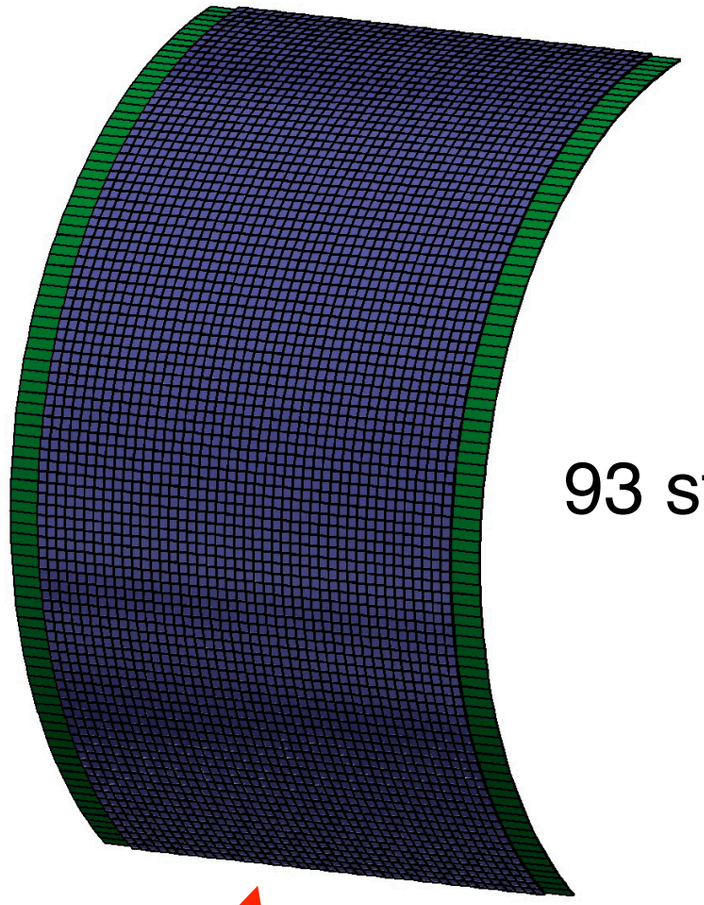
Package design



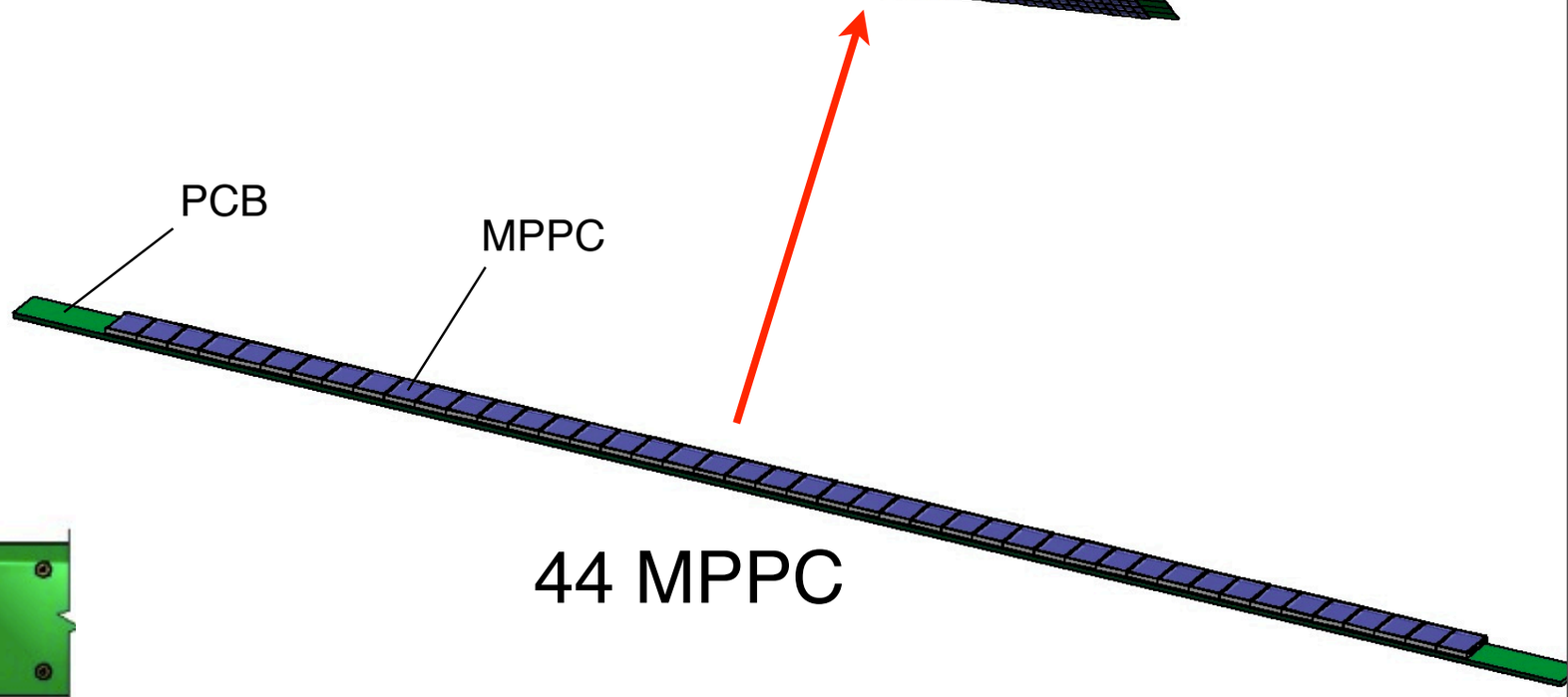








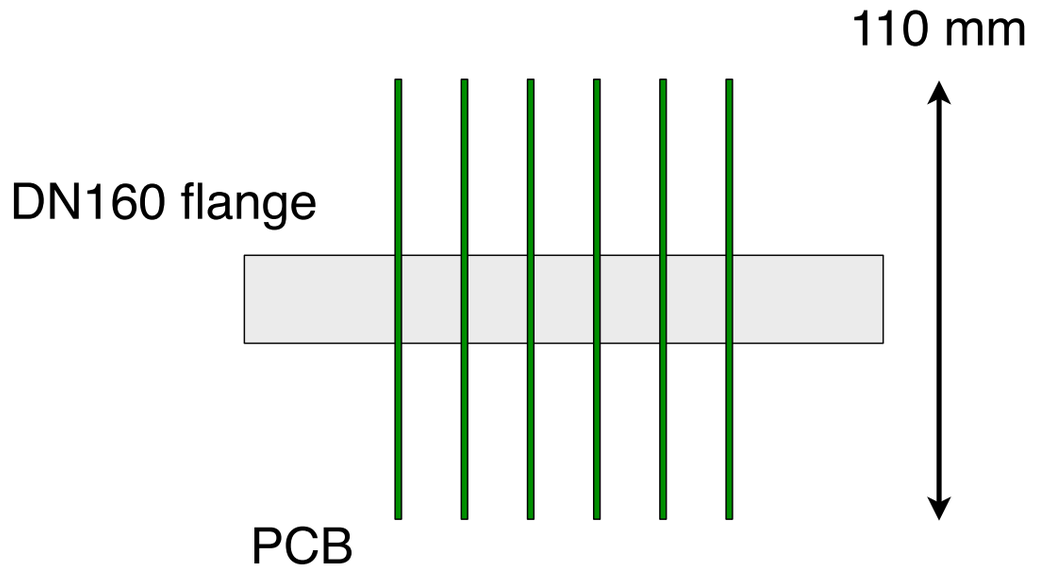
93 strips



44 MPPC

Feedthrough

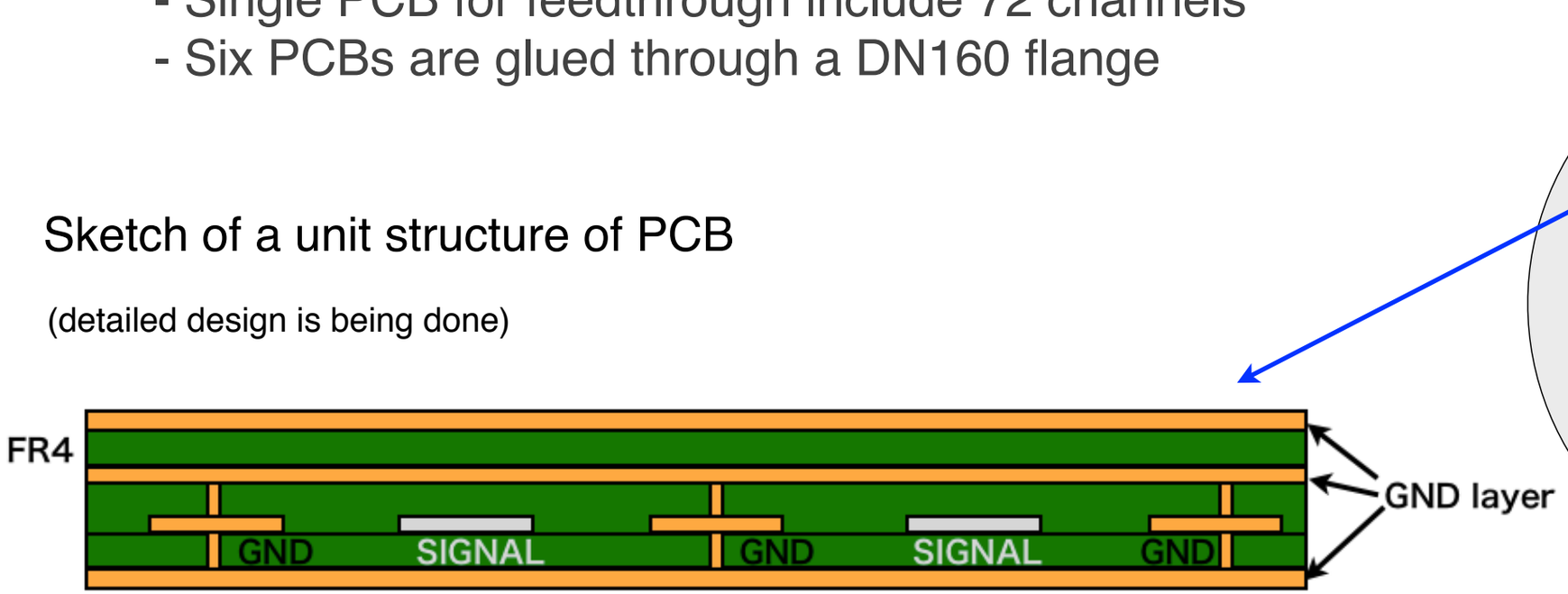
- Readout ~4000 ch with preventing too much attenuation
- High density feedthrough
- Avoid pickup noise at feedthrough



PSI electronics group is designing PCB to mount MPPCs and for feedthroughs
- Impedance : 50 Ω
- Multilayer PCB
- Single PCB for feedthrough include 72 channels
- Six PCBs are glued through a DN160 flange

Sketch of a unit structure of PCB

(detailed design is being done)



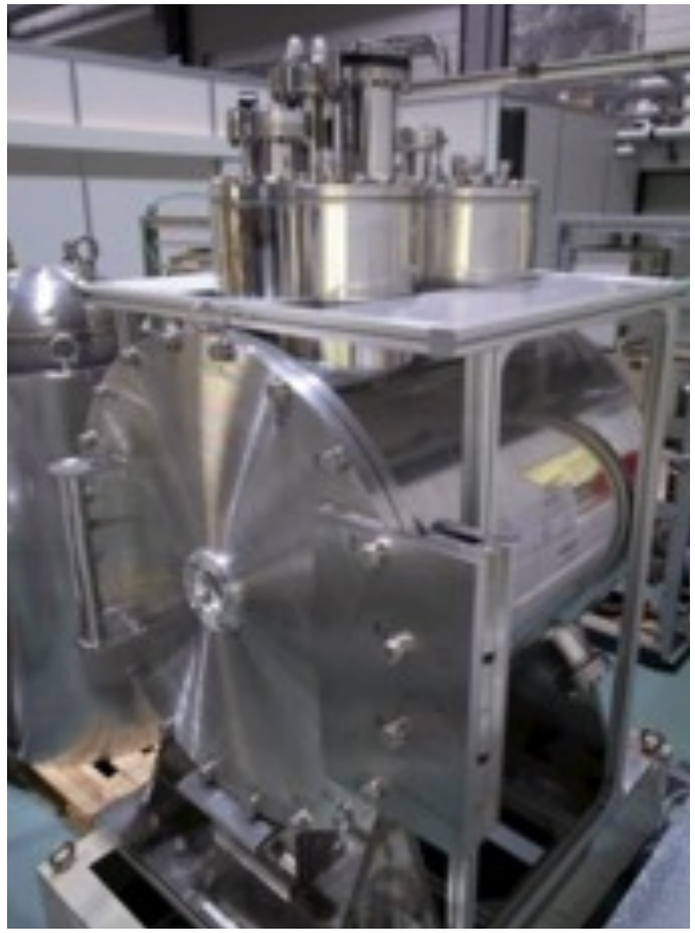
Plan

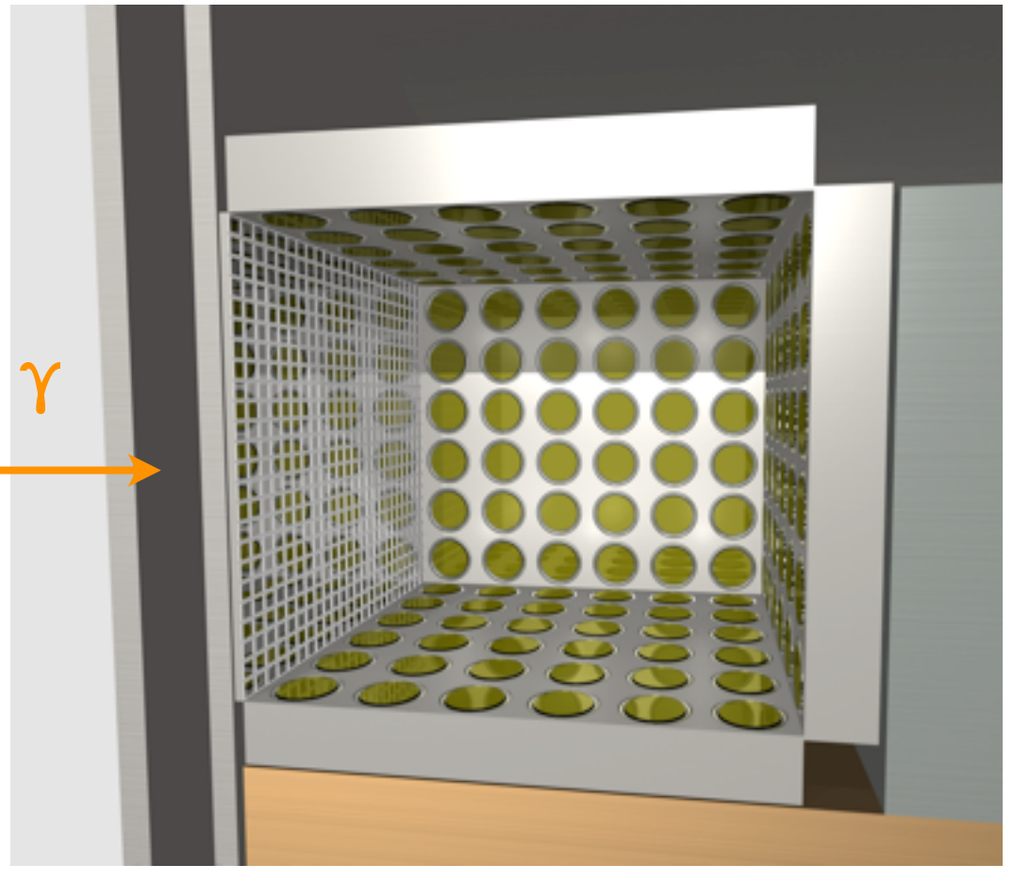
- By this Nov. (R&D)
  - R&D of UV MPPC
  - PCB feedthrough test
  - Readout technologies

- In 2013
  - MPPC/feedthrough/cable/connector production
  - Electronics
  - Prototype assembly & beam test

- By autumn 2014
  - Detector construction

Prototype cryostat





Prototype (CG)

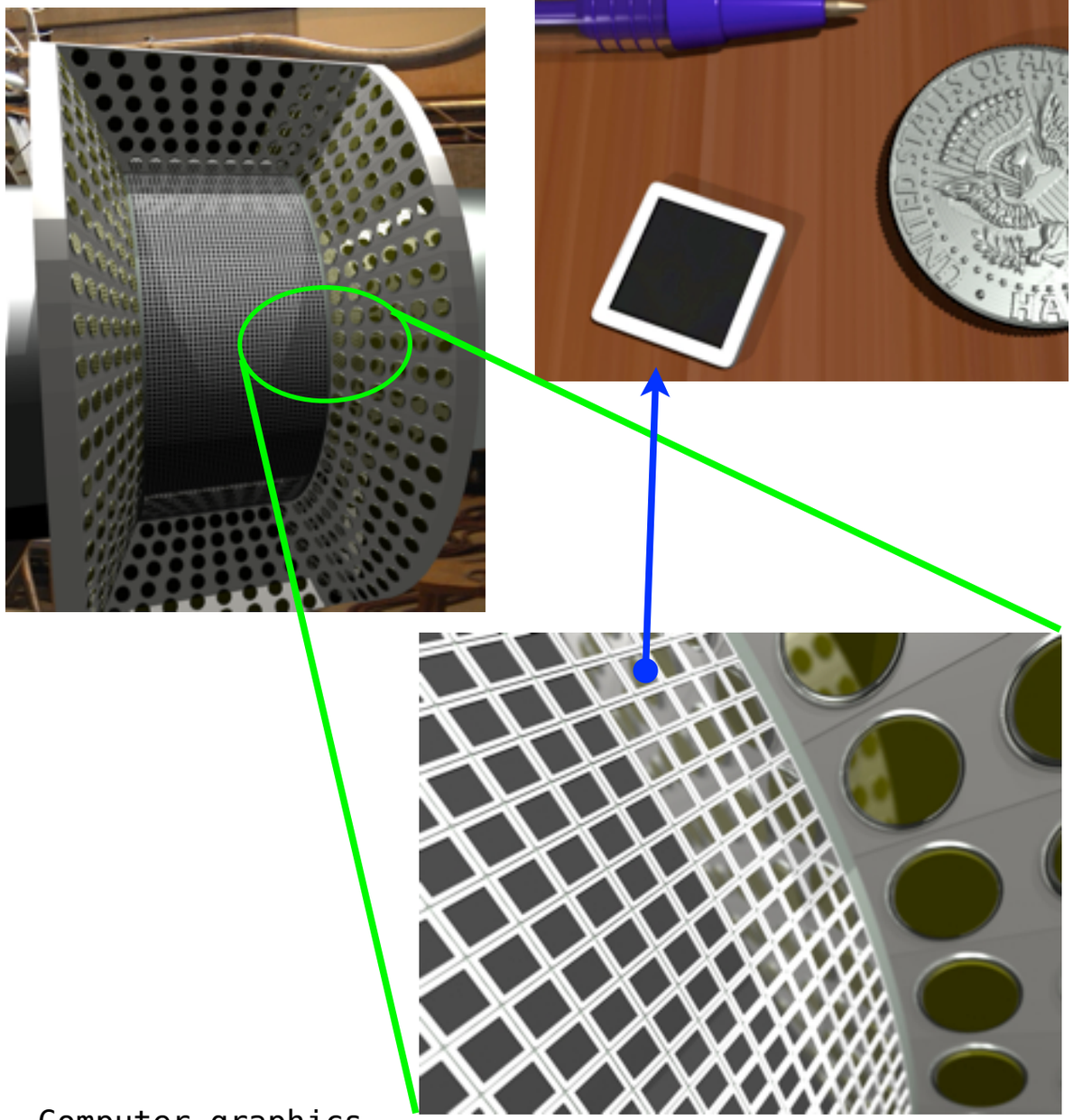
Summary

- MPPC studies for MEG LXe detector upgrade
  - Test with a small LXe cryostat
    - Gain > 10^6, PDE ~10%
      - Best result with G type (refractive index matching for LXe)
        - Time resolution for 1 p.e. : ~100-160 psec
  - Tests with larger MPPCs to be done
- Design of mounting PCB and feedthrough are on-going
- Prototype test will be done in the next year
- Construction of the upgraded detector in 2014

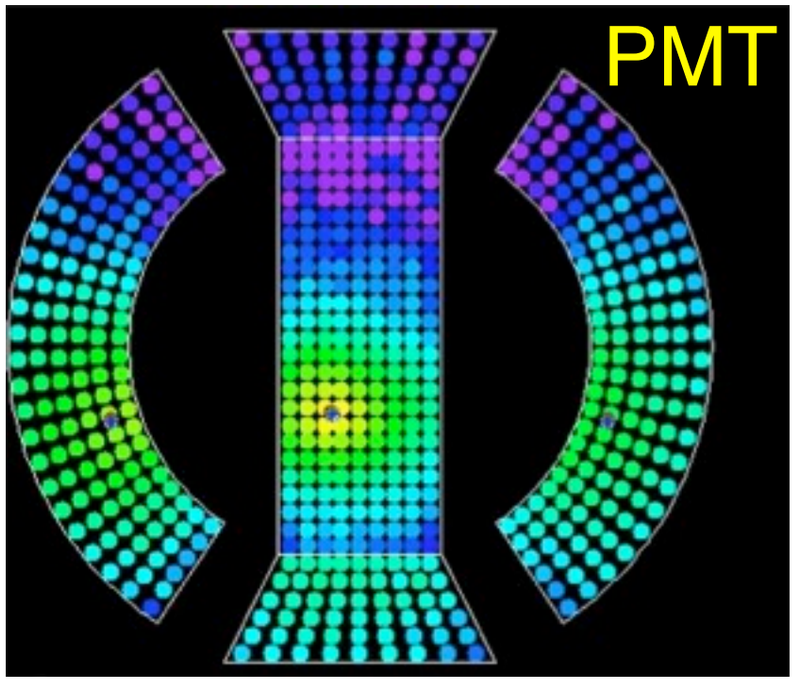
Backup

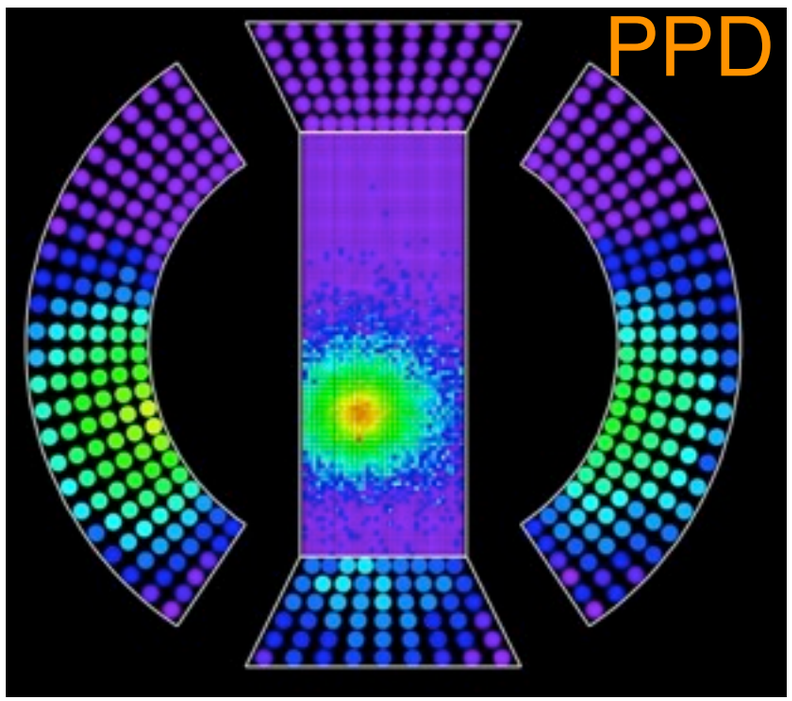
How an event looks like

~4000 MPPCs (15 x 15 mm) on the γ ray entrance face
Development of new large MPPC for LXe

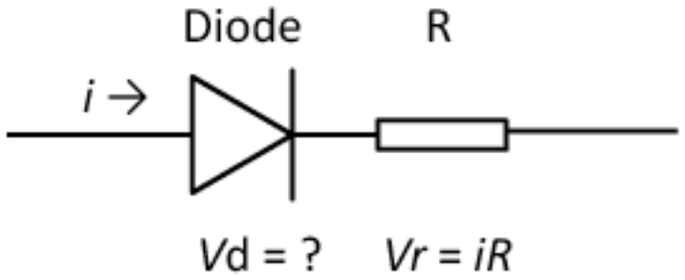


Computer graphics





Simple model of one MPPC pixel

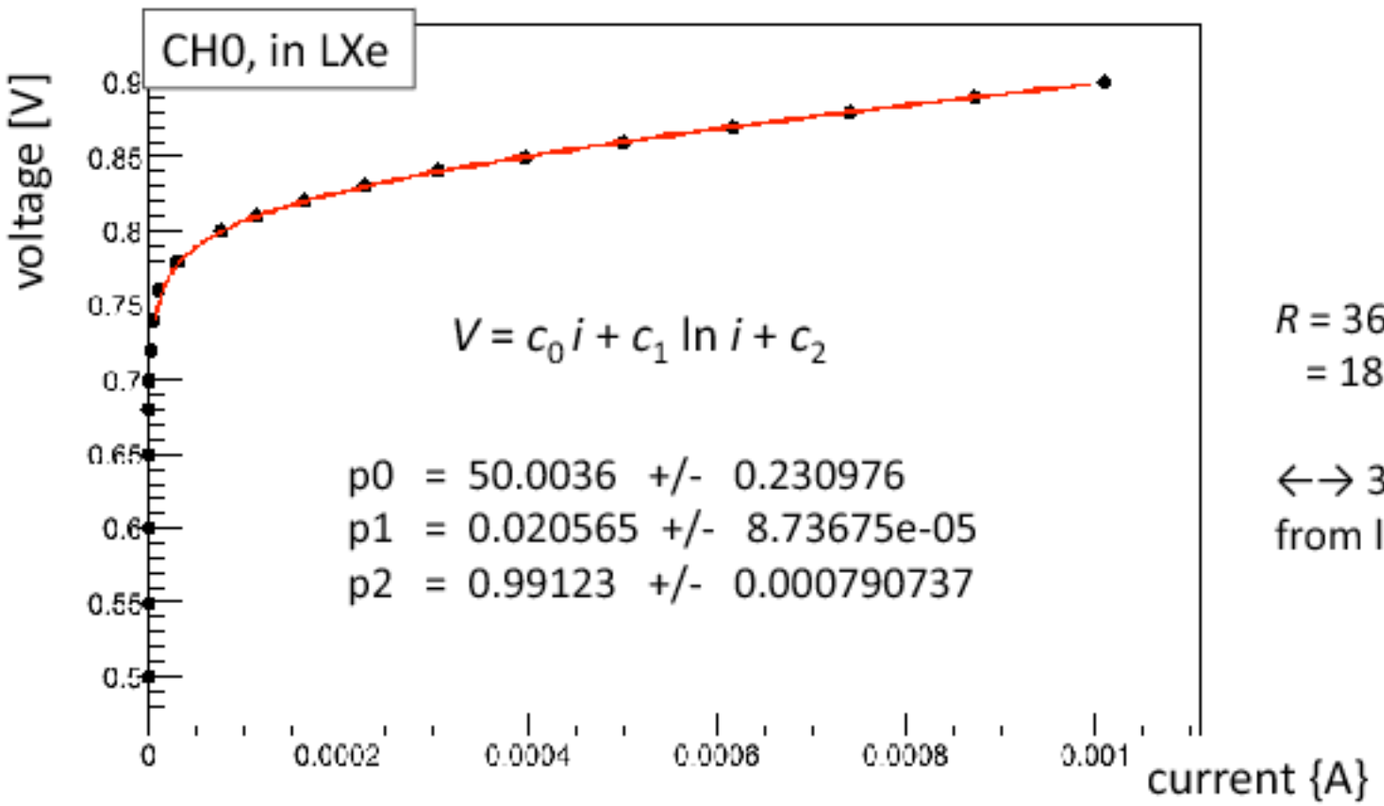


Approximated Characteristic of Diode

$I = I_0 \exp(kV\text{-}1)$

↓

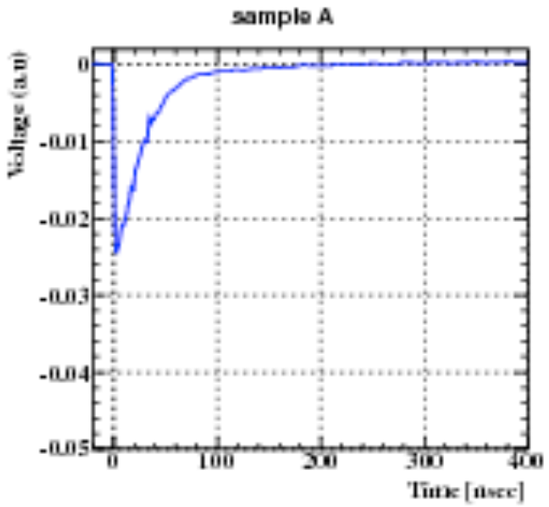
$V = c_1 \ln I + c_2$

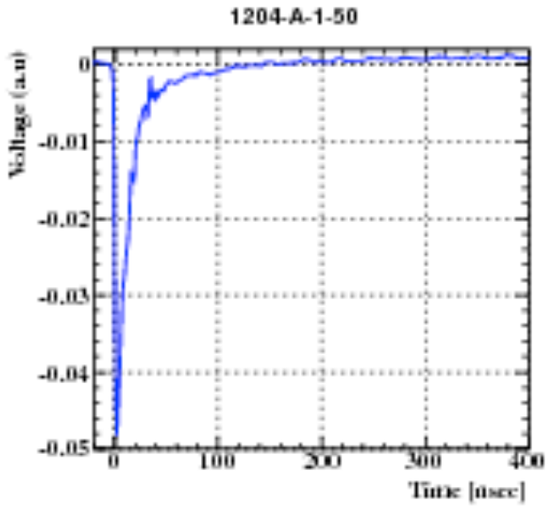


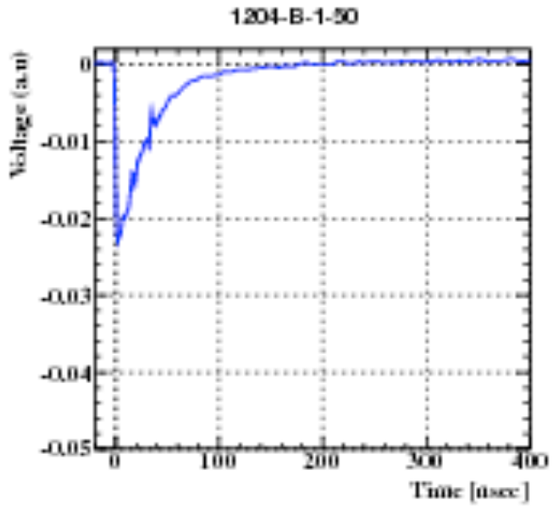
$R = 3600 \times c_0$
$= 180\ \text{k}\Omega$

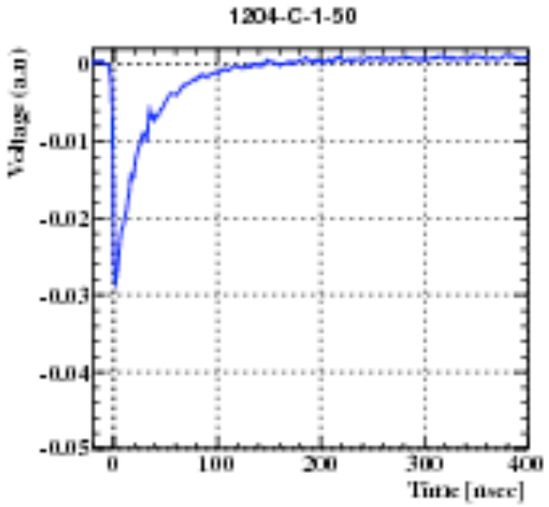
←→ 300 kΩ
from linear fitting

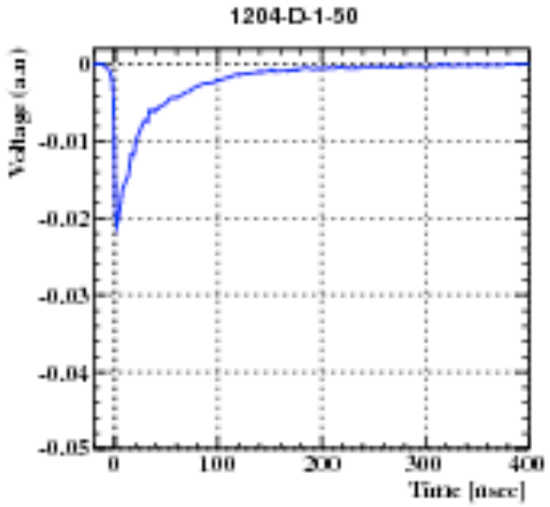
Waveforms

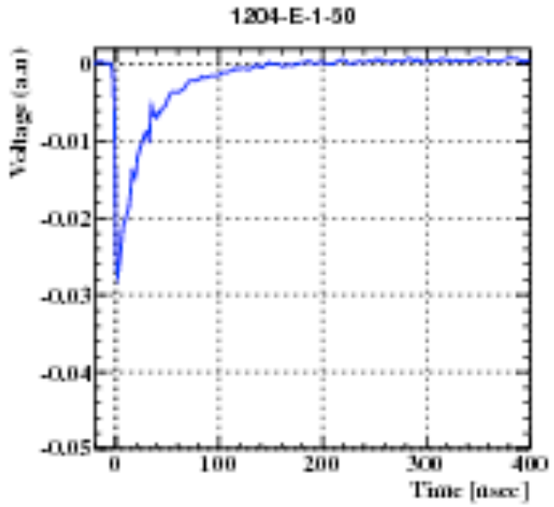

sample A
Voltage (a.u)
Time [nsec]

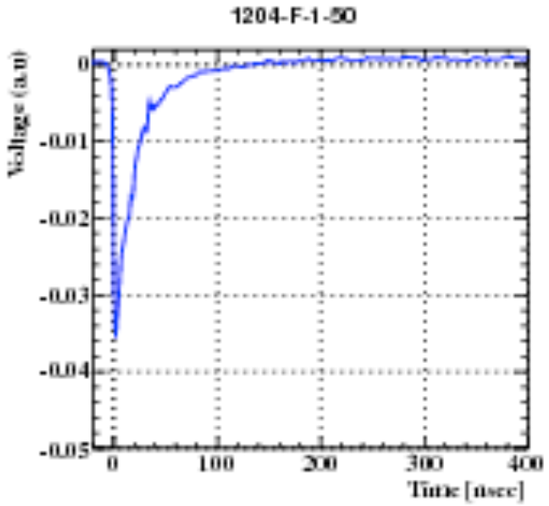

1204-A-1-50
Voltage (a.u)
Time [nsec]

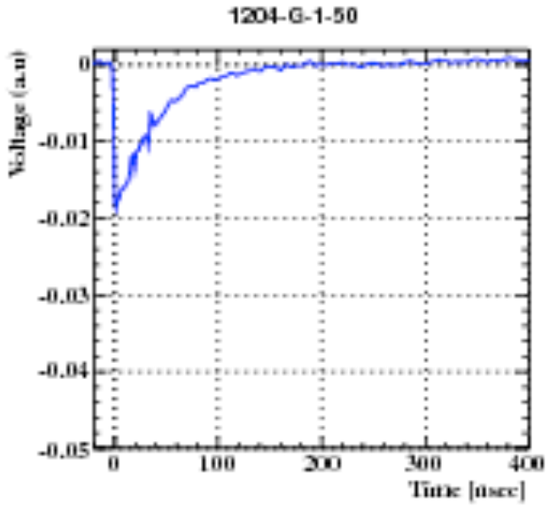

1204-B-1-50
Voltage (a.u)
Time [nsec]

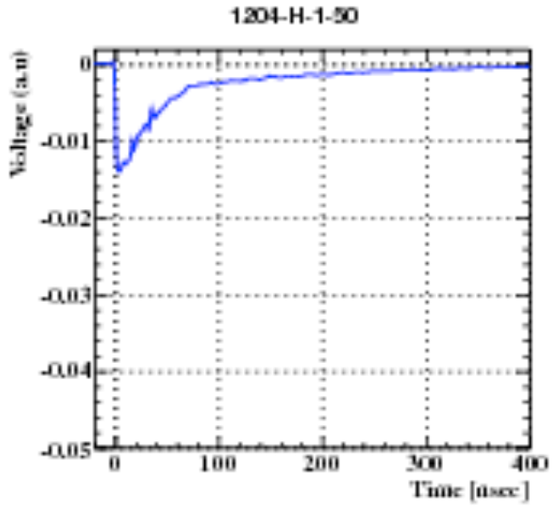

1204-C-1-50
Voltage (a.u)
Time [nsec]


1204-D-1-50
Voltage (a.u)
Time [nsec]

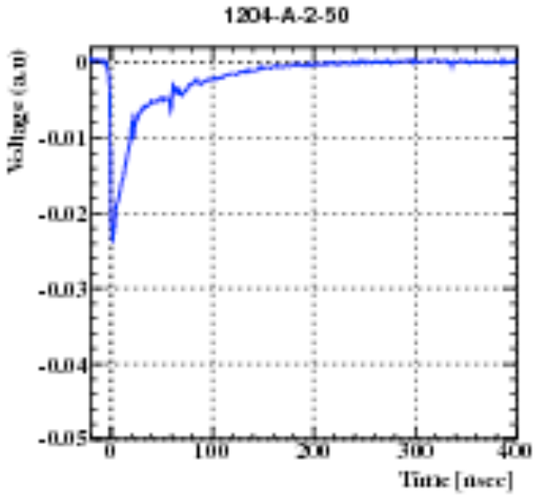

1204-E-1-50
Voltage (a.u)
Time [nsec]

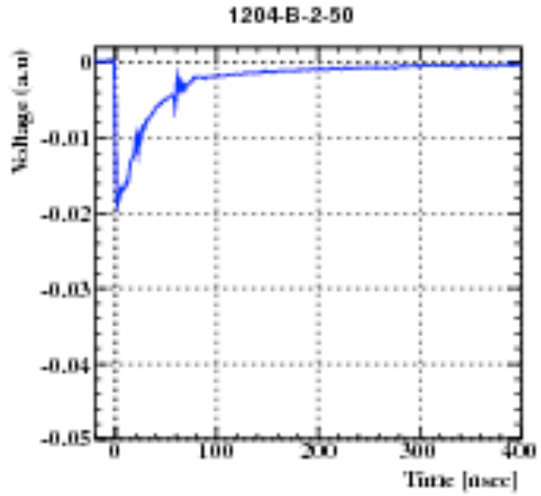

1204-F-1-50
Voltage (a.u)
Time [nsec]

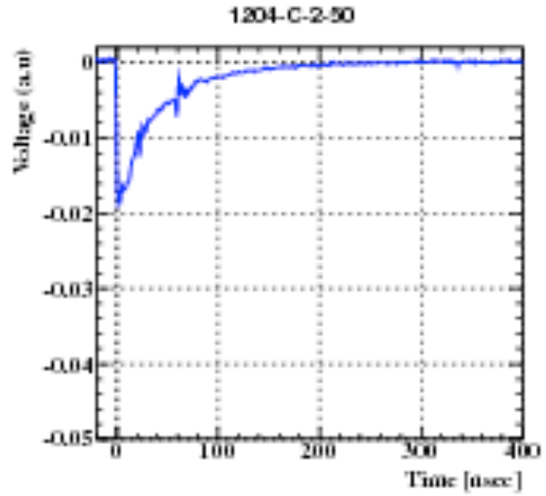

1204-G-1-50
Voltage (a.u)
Time [nsec]

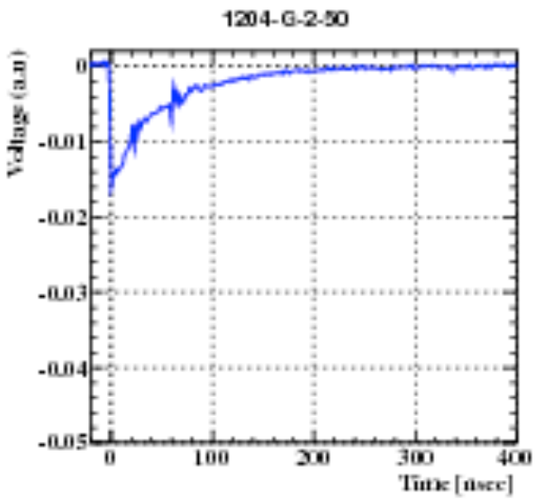

1204-H-1-50
Voltage (a.u)
Time [nsec]

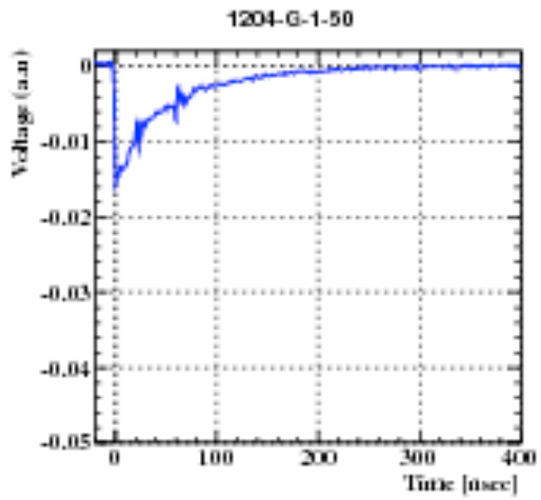
Waveforms

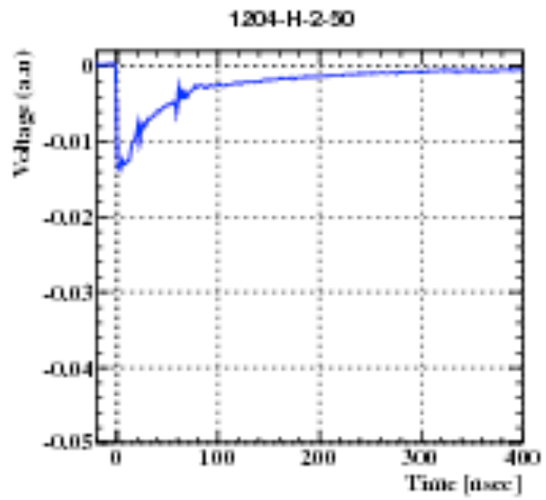

1204-A-2-50
Voltage (a.u)
Time [nsec]

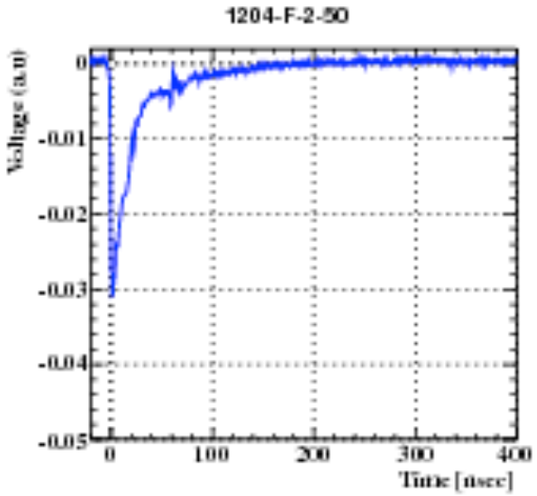

1204-B-2-50
Voltage (a.u)
Time [nsec]

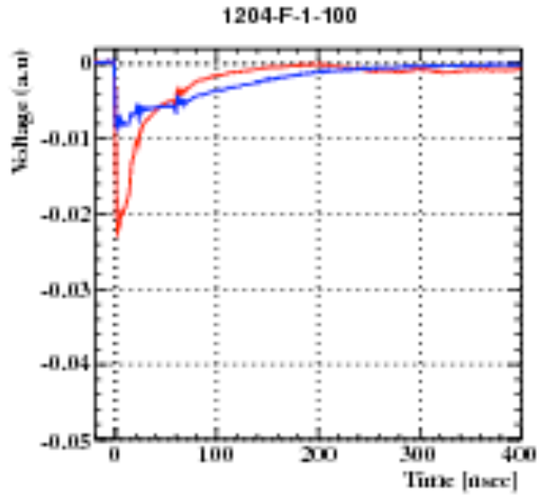

1204-C-2-50
Voltage (a.u)
Time [nsec]

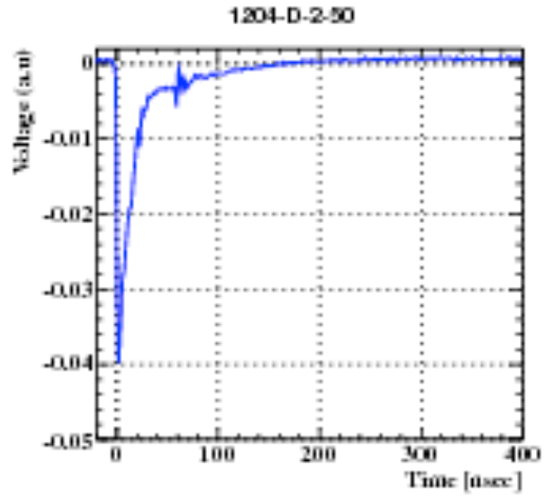

1204-G-2-50
Voltage (a.u)
Time [nsec]


1204-G-1-50
Voltage (a.u)
Time [nsec]

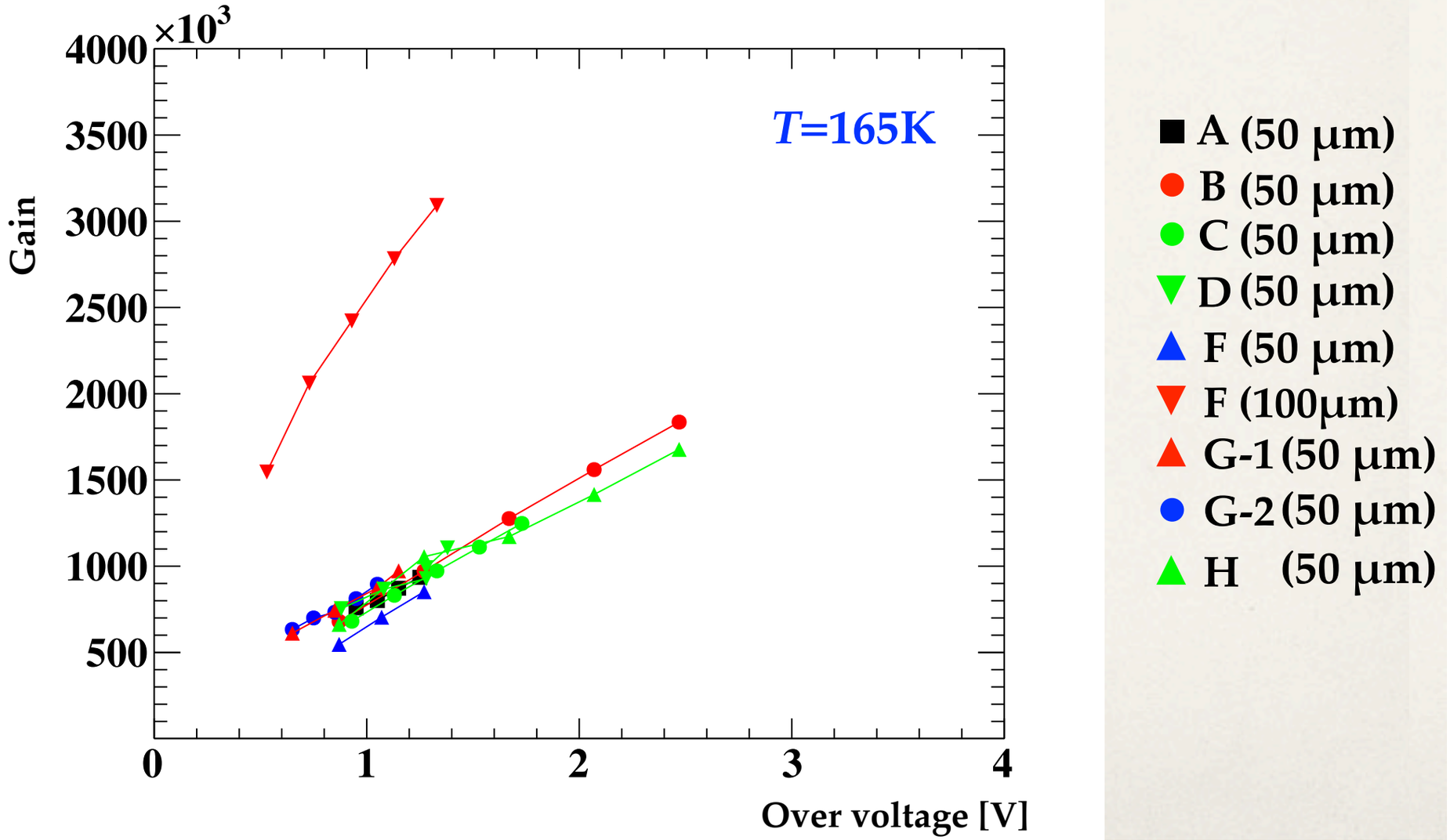

1204-H-2-50
Voltage (a.u)
Time [nsec]


1204-F-2-50
Voltage (a.u)
Time [nsec]


1204-F-1-100
Voltage (a.u)
Time [nsec]


1204-D-2-50
Voltage (a.u)
Time [nsec]

Gain


×10^3
4000
3500
3000
2500
2000
1500
1000
500
Gain
T=165K
0
1
2
3
4
Over voltage [V]
A (50 μm)
B (50 μm)
C (50 μm)
D (50 μm)
F (50 μm)
F (100μm)
G-1 (50 μm)
G-2 (50 μm)
H (50 μm)