SCINTILLATION FIBER DETECTOR FOR DOSE VERIFICATION IN PROTON THERAPY

Suhyun Lee

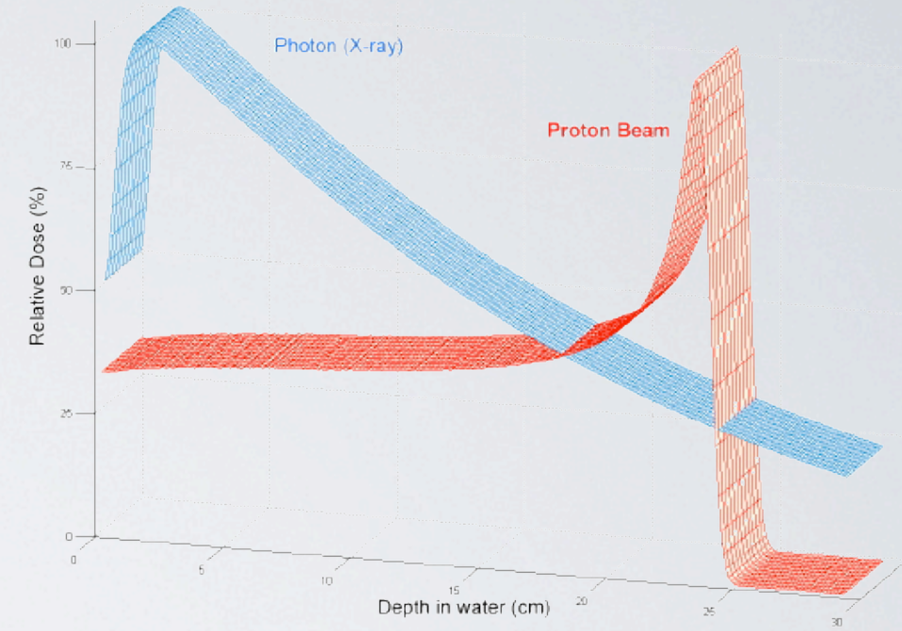
Nuclear Physics Lab.
Korea University

CONTENTS

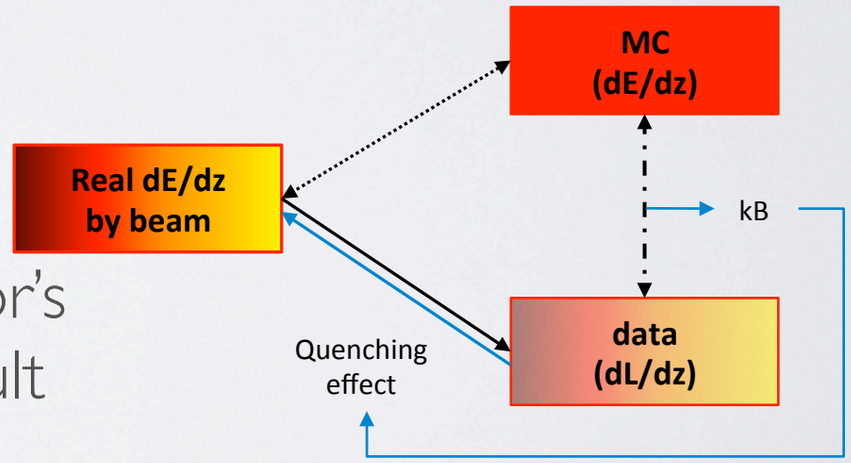
- Introduction
- Detector
  - Scintillation-fiber array
  - Electronics
- Beam Test
- Result
- Summary & Future

INTRODUCTION

- Motivation:
  - Development of dose verification detector for the therapeutic hadron beam
    (ex. several hundred MeV proton)



- Goal:
  - Two-dimensional beam measurement and fast response
  - Check the Bragg peak by using multi-layered absorber
  - Obtain Birks parameter kB and Quantify scintillator's quenching effect by comparing MC (GEANT4) result and data

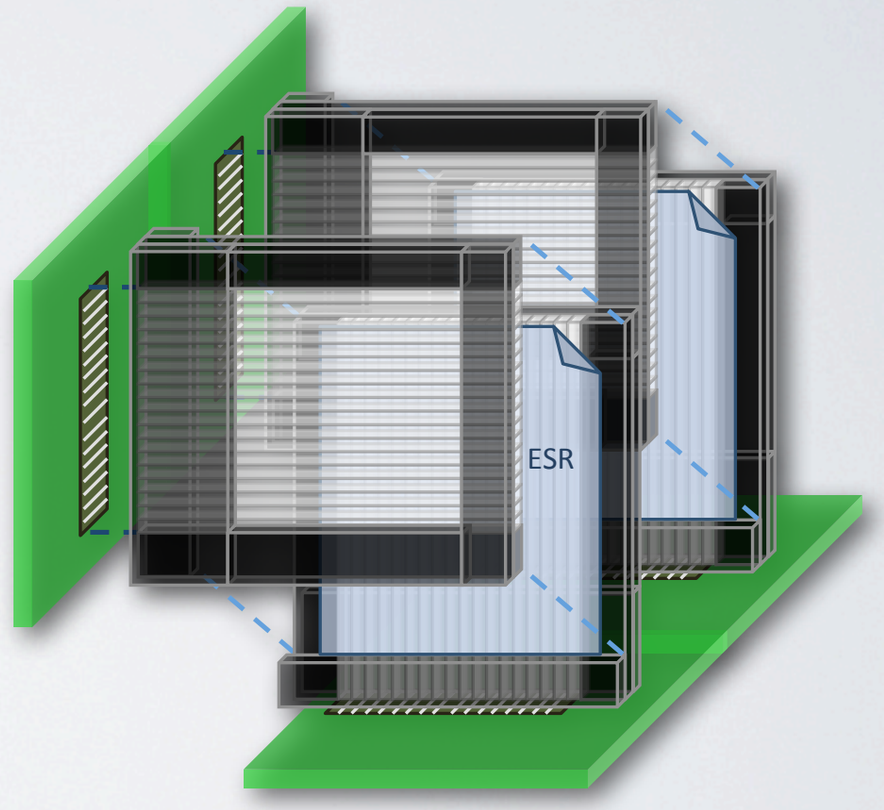


DETECTOR

- Two-dimensional array with 128×128 channels (2 array)

- double-clad scintillation fiber (Bicron BCF-60)
  - 0.8×0.8 mm^2, square-shaped
  - Light emission peak at 530 nm (green)
  - Small radiation-induced degradation

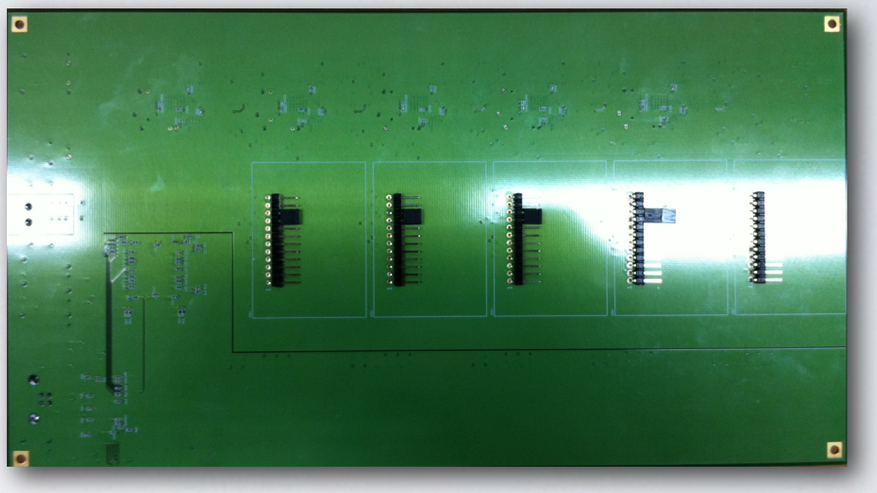
- The array was designed for the physical match to the readout photodiodes



DETECTOR

- 2 units of charge-integration mode DAQ

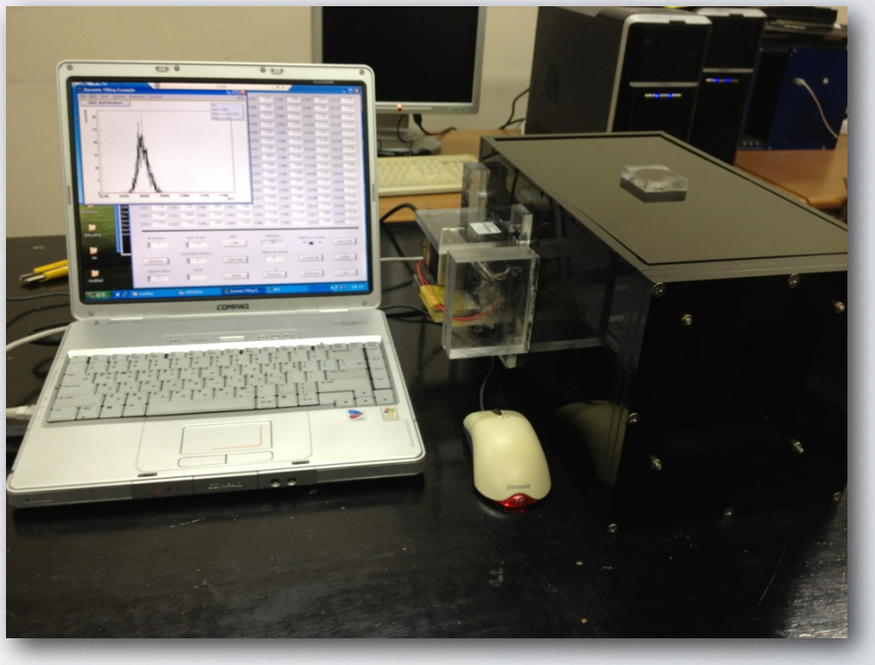
- Readout by using Si-Photodiodes (Hamamatsu S8866-128)
  - 4 pieces of 128 channel diodes for a unit of DAQ
  - Quantum efficiency at 530 nm: ~ 60 %



- Adjustable gain mode and charge-integration time

- Graphic user interface

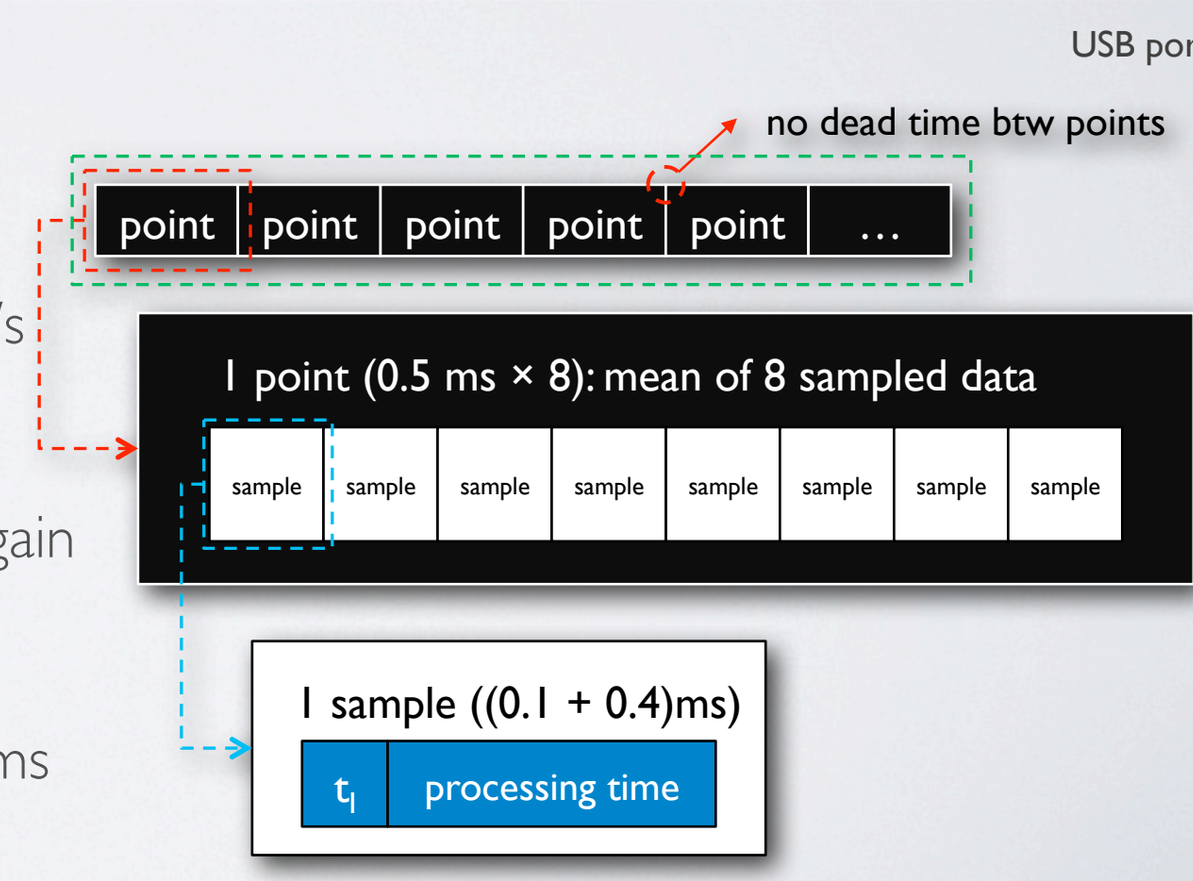
- Designed for the typical therapeutic hadron beam (~ 200 MeV, 0.1 ~ 10 nA)



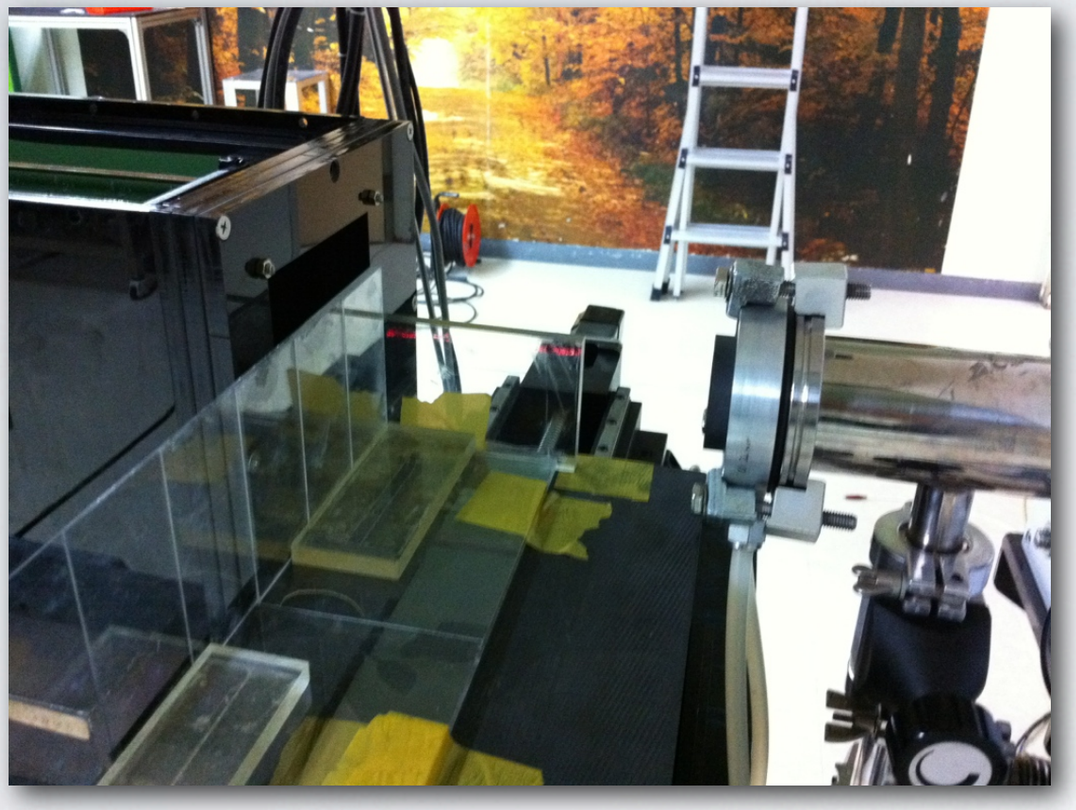
DAQ CHARACTERISTICS

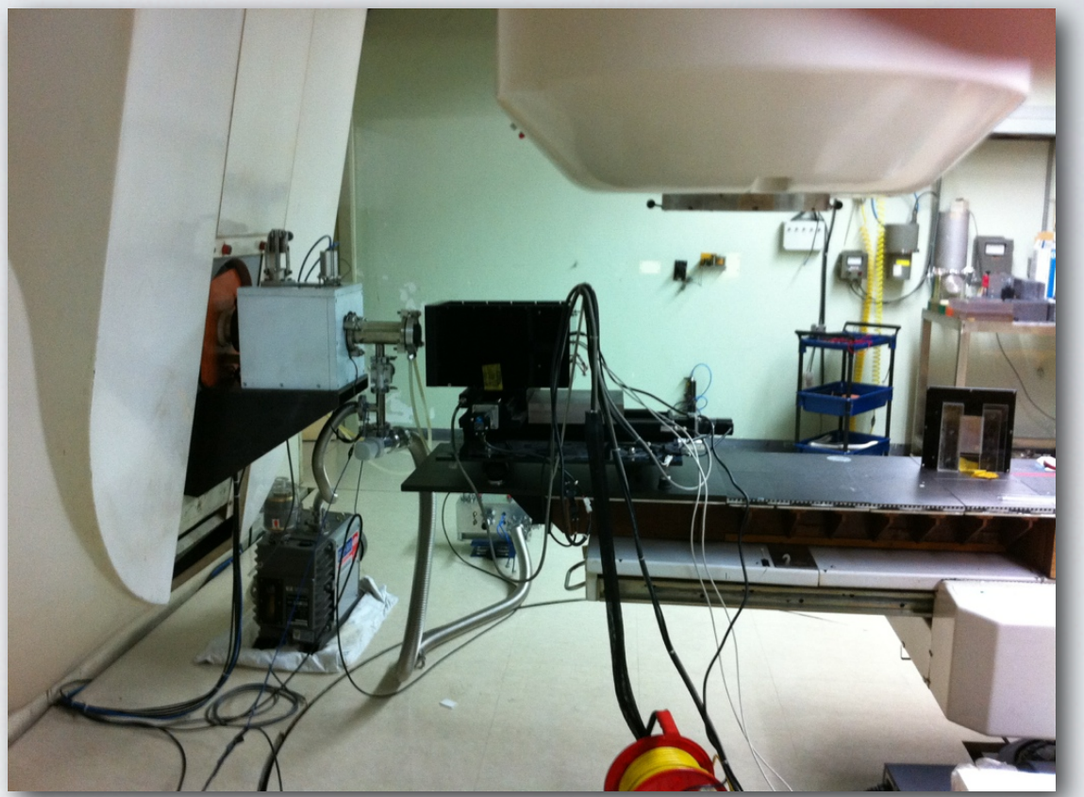
- Multi-layered DAQ
  - Total 5 × 2 × 128 channels
  - USB 2.0 based communication
    - Data transport
    - Remote control

- DAQ specification
  - Data acquisition in second (s) unit: 250 points/s
  - Data recorded in Binary codes
    → conversion to the ASCII codes is possible
  - Dynamic range: 3.5 and 1.75 pC for high/low gain
    → corresponding MAX. ADC: 218 (262,144)
  - Integration time: 0.1 ms for 1 point
  - Elapsed time for the 1 point measurement: 4 ms



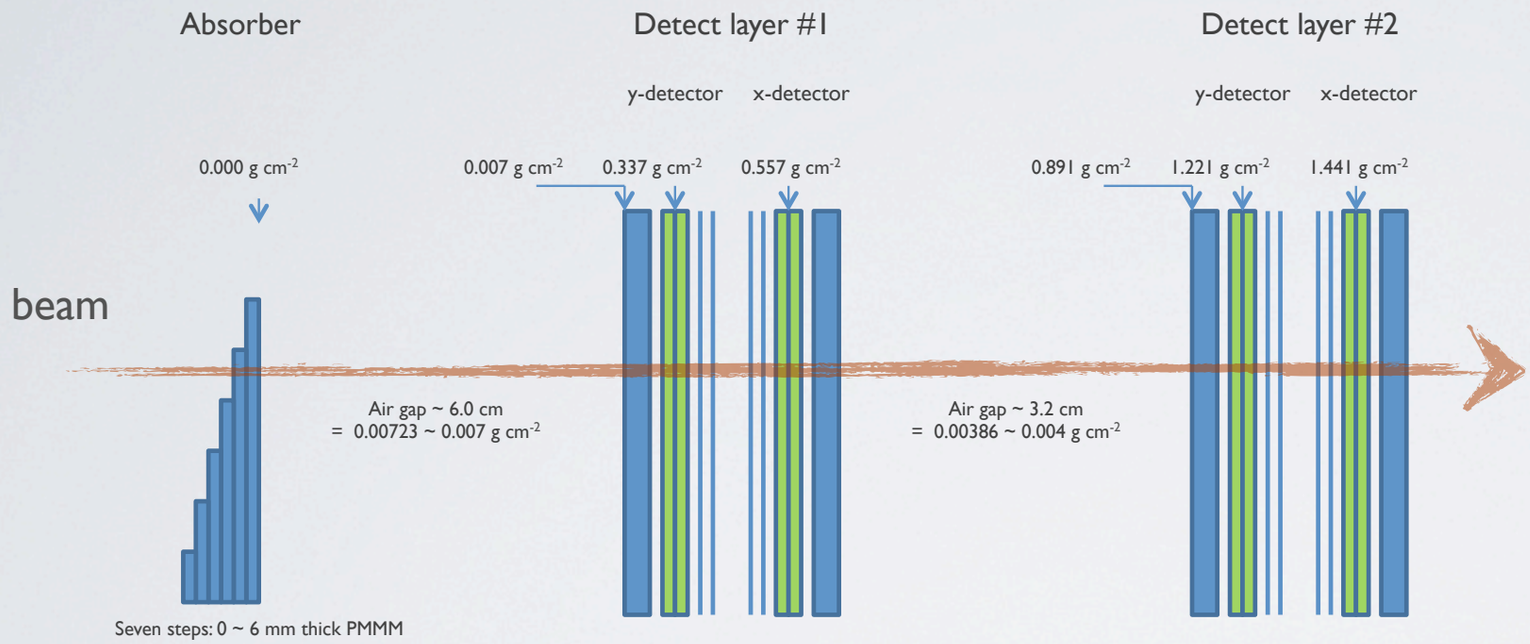
BEAM TEST





- Beam test by using MC50 cyclotron at KIRAMS (Feb. 1, 2012)
  45 MeV proton beam with several different beam current (0.5, 1, and 1.5 nA)
  Distance from beam exit to surface of Sc-fiber array: 17.5 + 5.5 cm
  Calibration by using own spread-out beam

BEAM TEST



Depth measured by y- detector #1 :
0.44472, 0.56372, 0.68272, 0.80172, 0.92072, 1.03972 g cm^{-2}

Depth measured by x- detector #1 :
0.68256, 0.80156, 0.92056, 1.03956, 1.15856, 1.27756 g cm^{-2}

Depth measured by y- detector #2 :
1.33400, 1.45300, 1.57200, 1.69100, 1.81000, 1.92900 g cm^{-2}

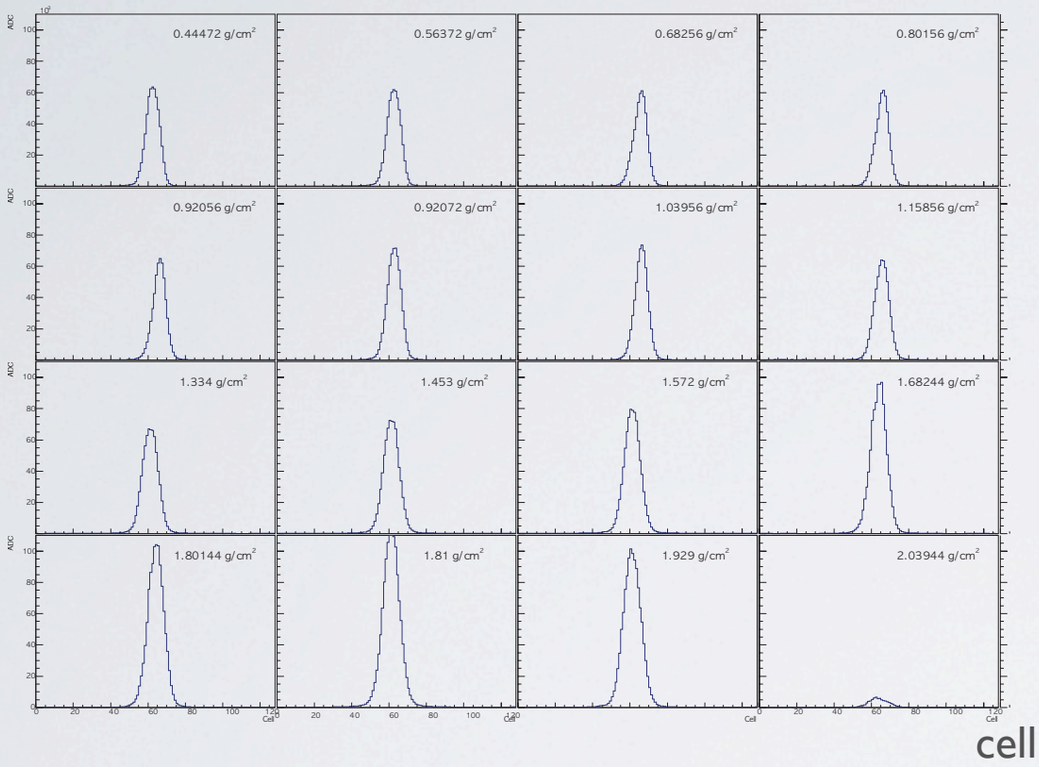
Depth measured by x- detector #2 :
1.56344, 1.68244, 1.80144, 1.92044, 2.03944, 2.15844 g cm^{-2}

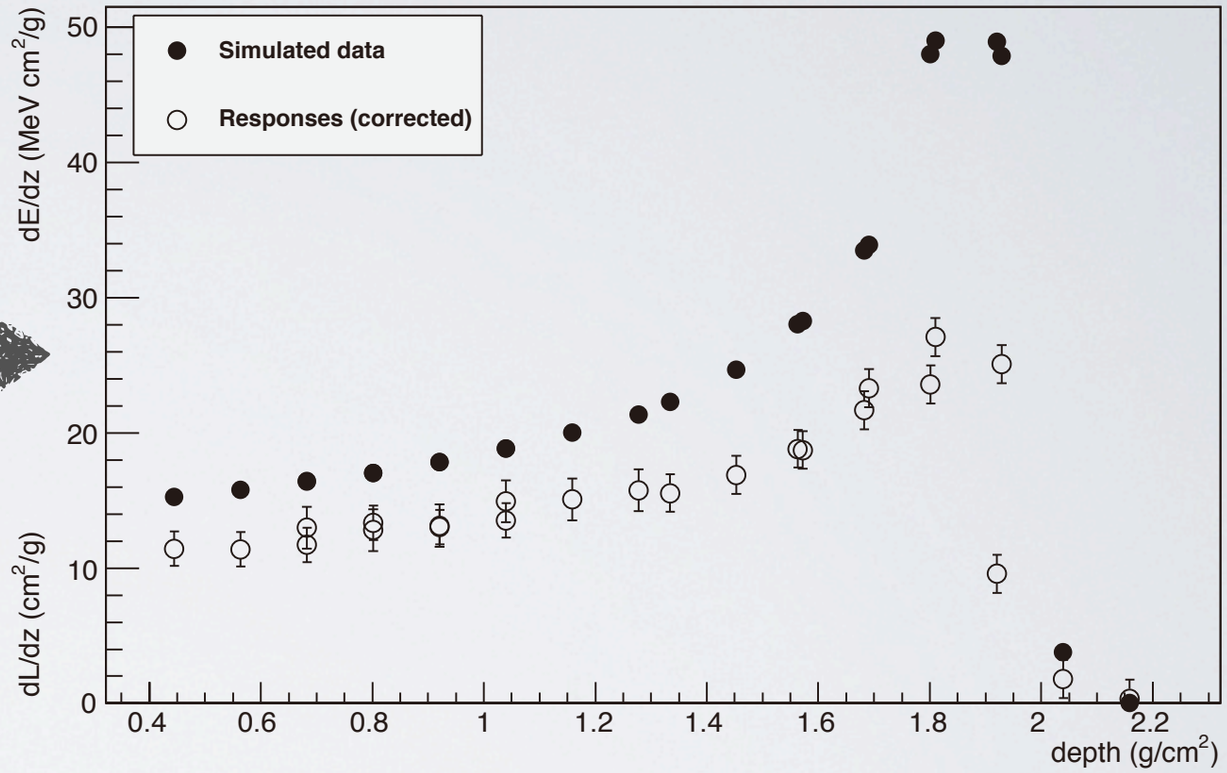
- Total 24 set of beam data was obtained by using multi-layered absorber
  2500 time bins (10 s) per a set of data

- absorber : multi-layered PMMA plate
  $\rho = 1.199 \pm 0.0085$ (g/cm^3)

RESULT

ADC

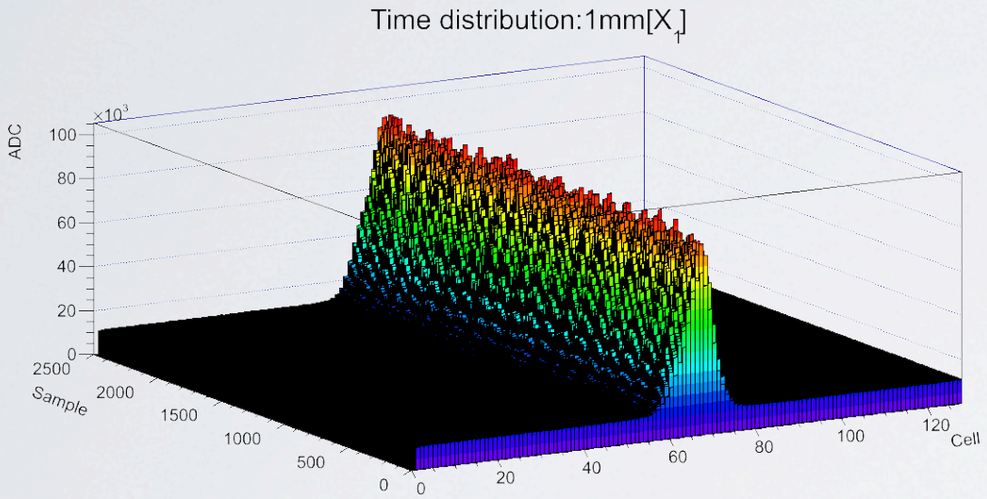


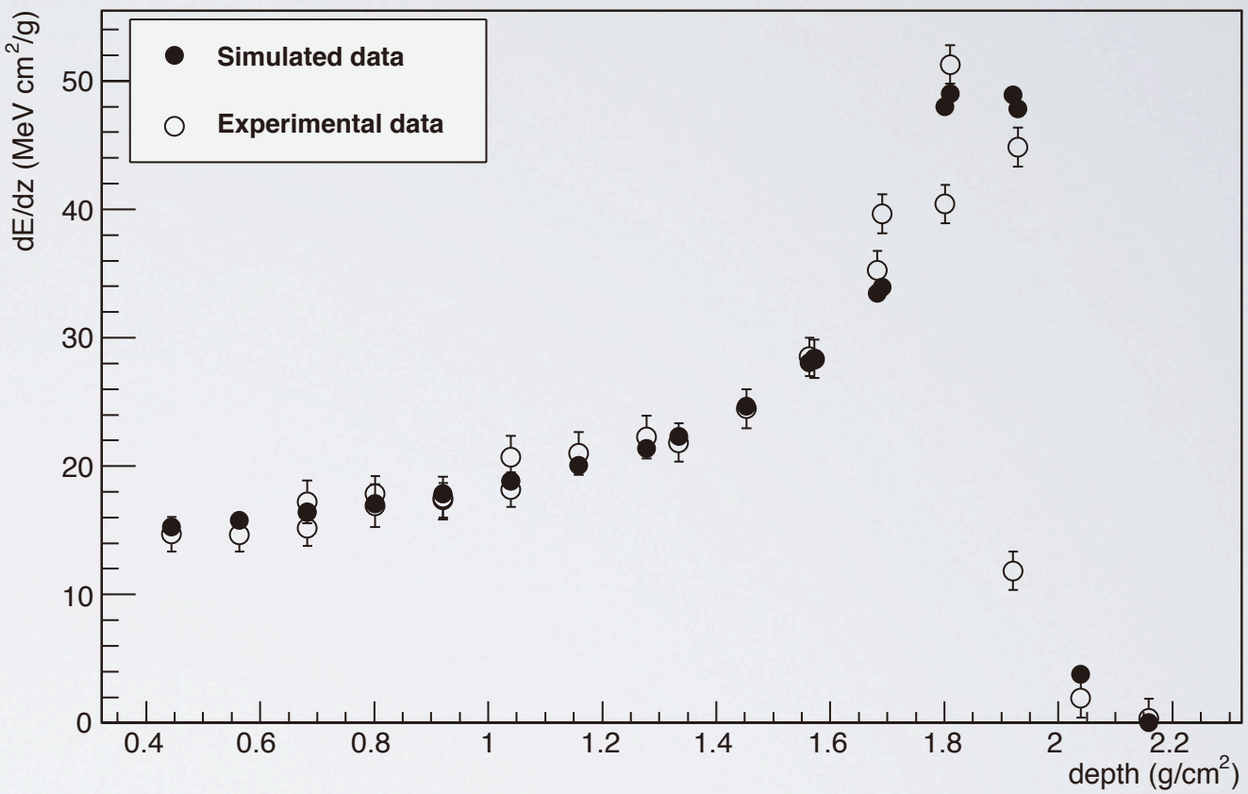


- The spatial responses of the detector measured at different absorber depths (*z*)
- Scintillation responses of the detector and the specific energy losses as a function of the depth in the absorber

RESULT

$$\frac{dL}{dz} = \frac{S\left(\frac{dE}{dz}\right)}{1 + kB\left(\frac{dE}{dz}\right) + \cdots}$$

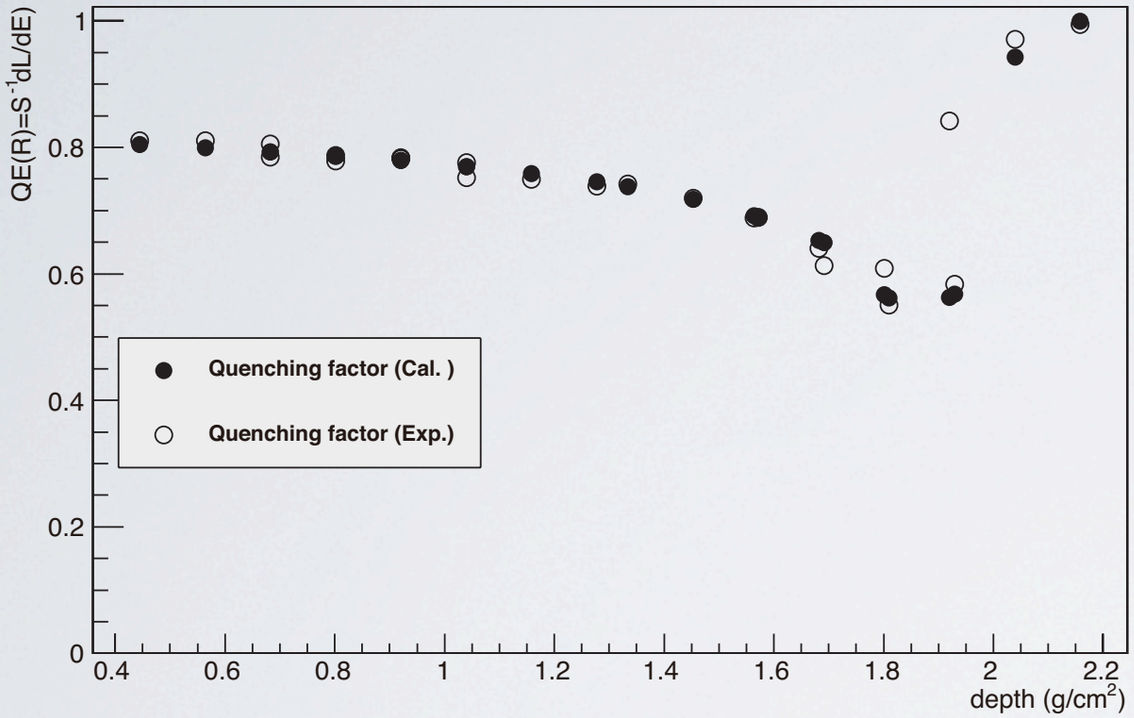


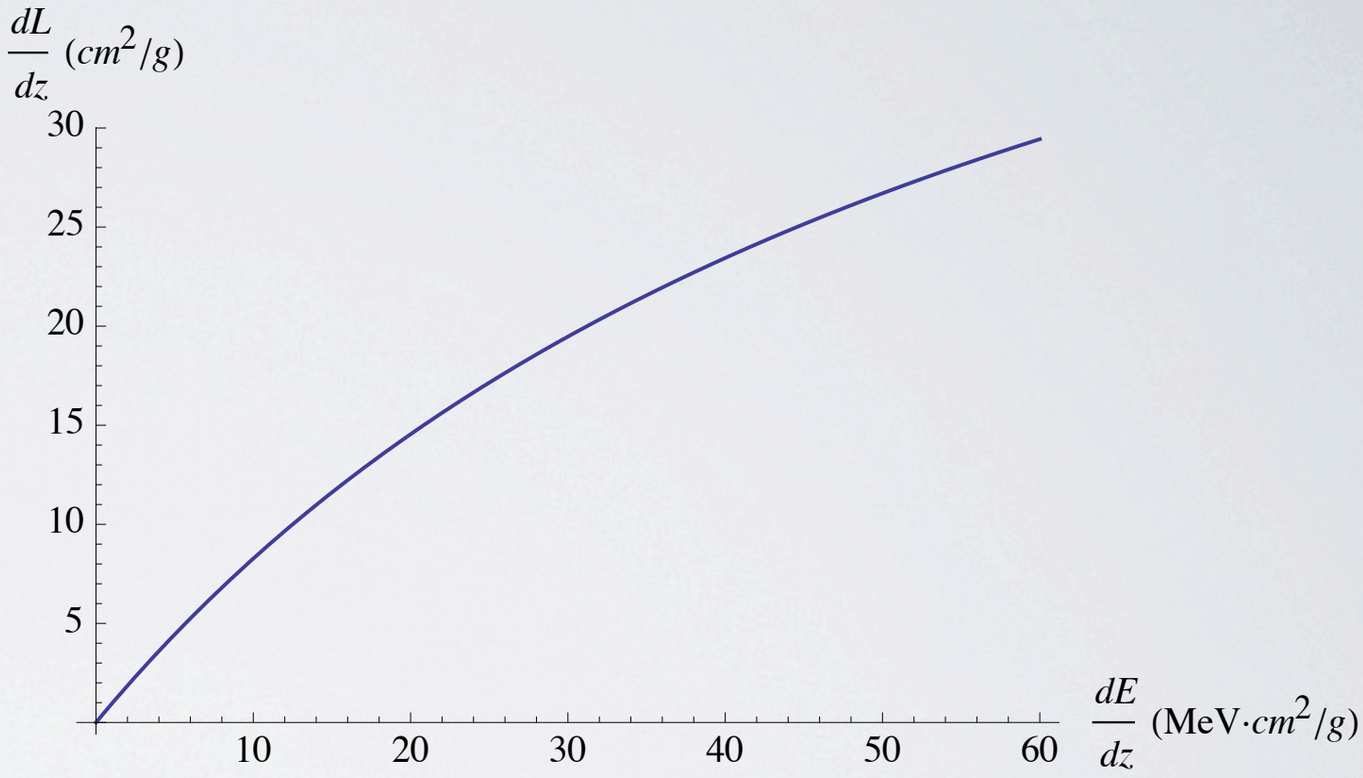


- Obtained S & kB from the fit processes
  - kB : 0.015906

- beam fluctuation

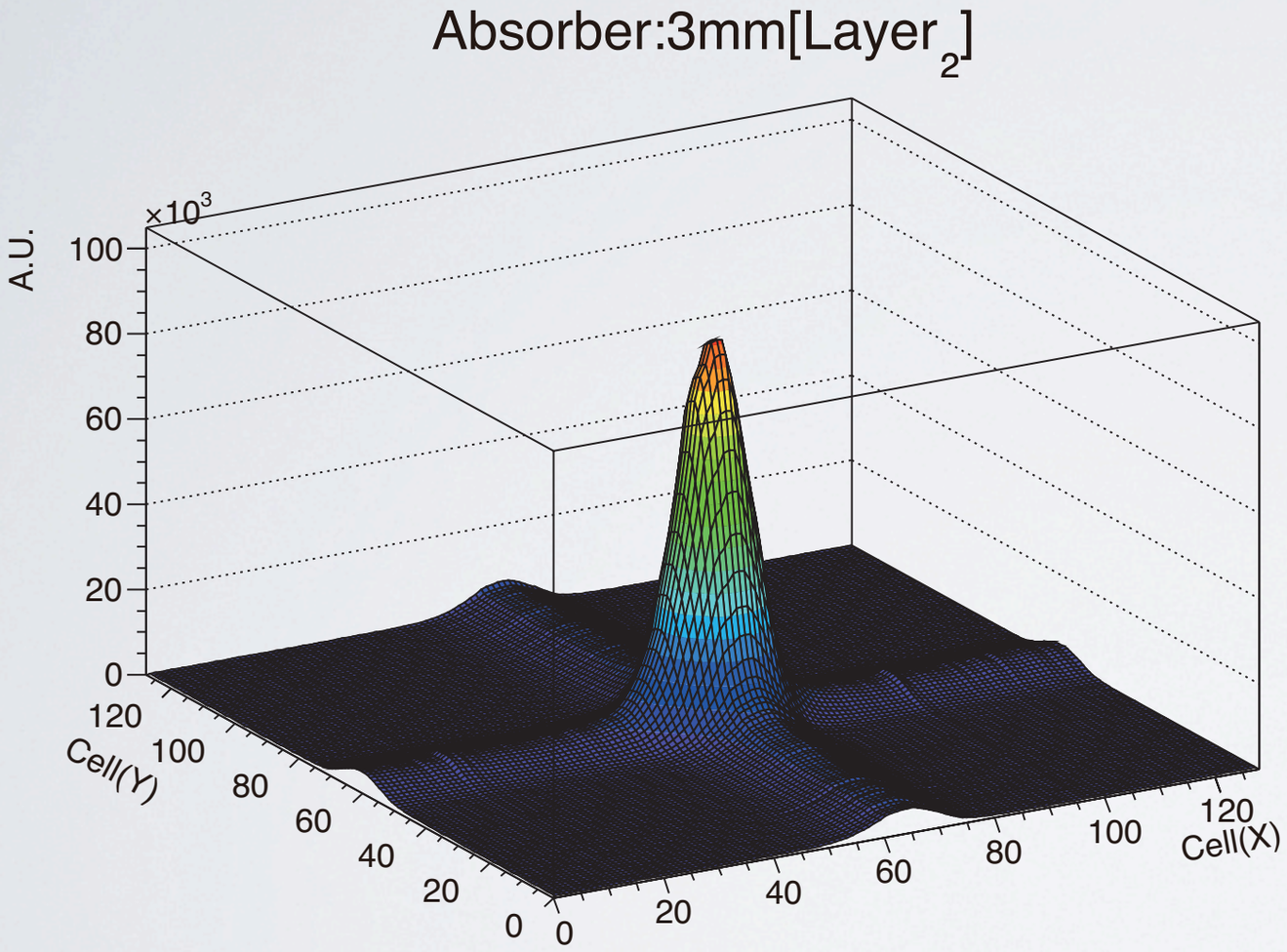
RESULT





- Measured quenching factors and the fitted data obtained by using the kB value
- We got the relation between ADC counts and specific energy losses

RESULT



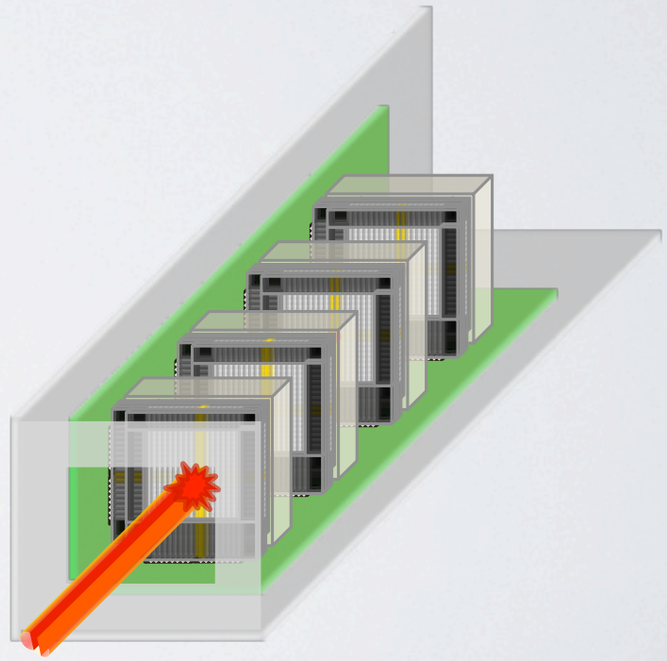
- 2-dimensional beam verification from *x* and *y* detector
- Quenching factor is not applied to beam verification yet

SUMMARY

- A detector for time-dependent dose verification was developed successfully
  - Detector characteristics:
    - 2D scintillation fiber array + charge-integration mode electronics
  - Beam test at KIRAMS (proton, 45 MeV, ≤ 1.5 nA):
    - Measured energy deposition in fiber array with 24 steps of absorber thickness

- Result:
  - Checked beam information by time
  - Checked Bragg peak
  - 1st - order Birks kB parameter Obtained
  - Quantified scintillator's quenching effect by comparing MC and data

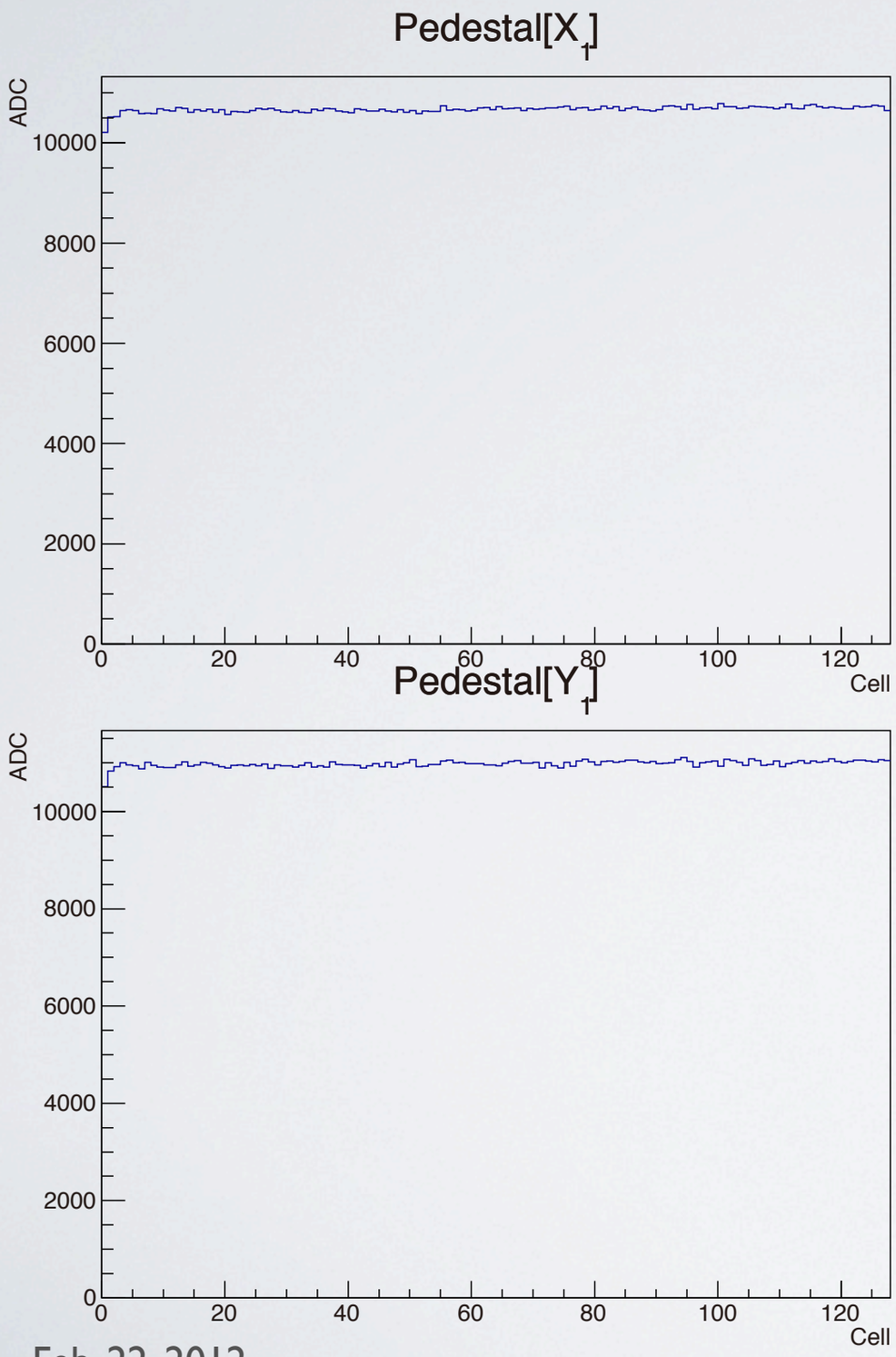
- Future
  - DAQ development is ongoing
  - Requires precise therapeutic beam for the test (200MeV proton beam)

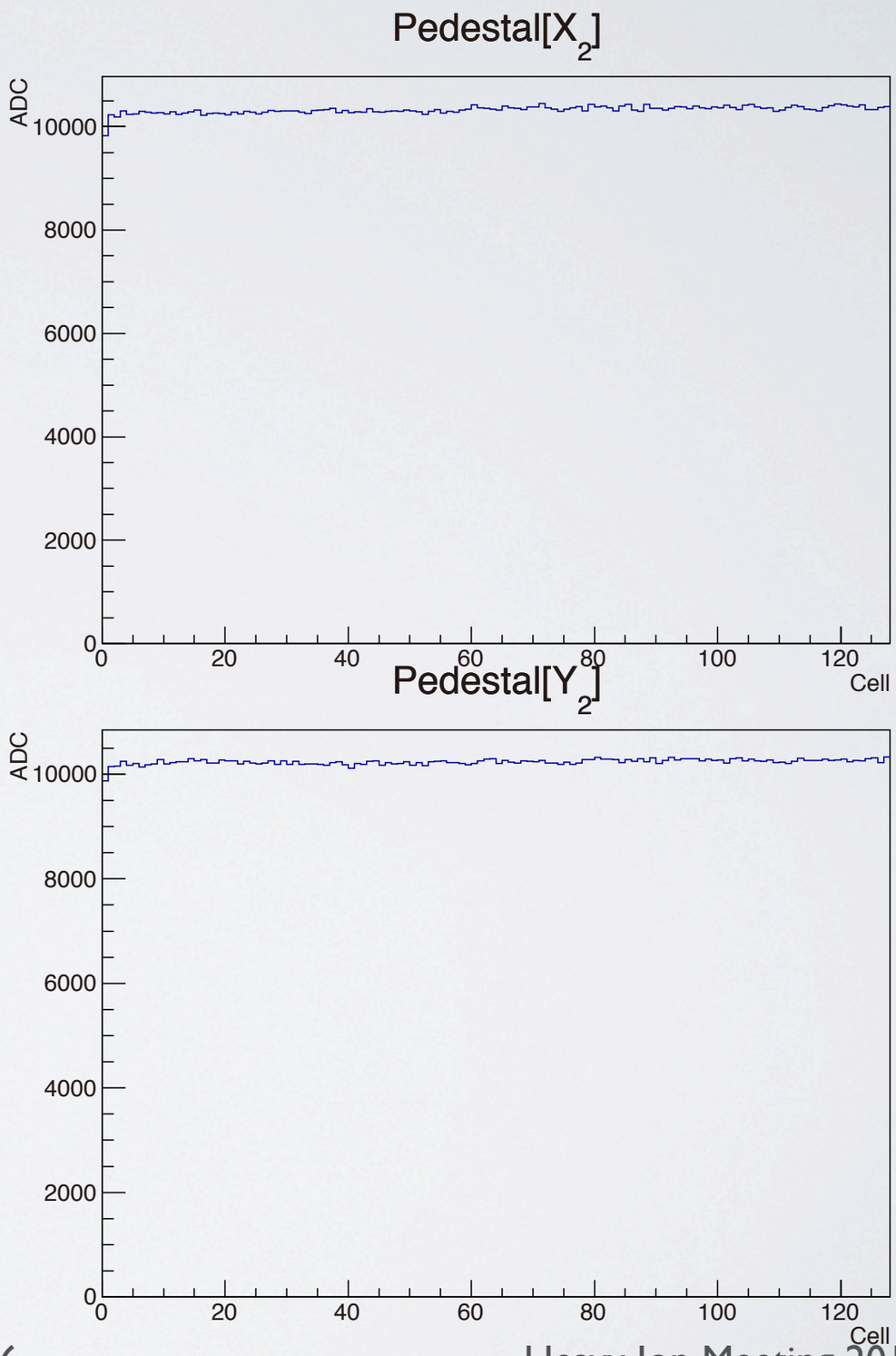


THANK YOU!!

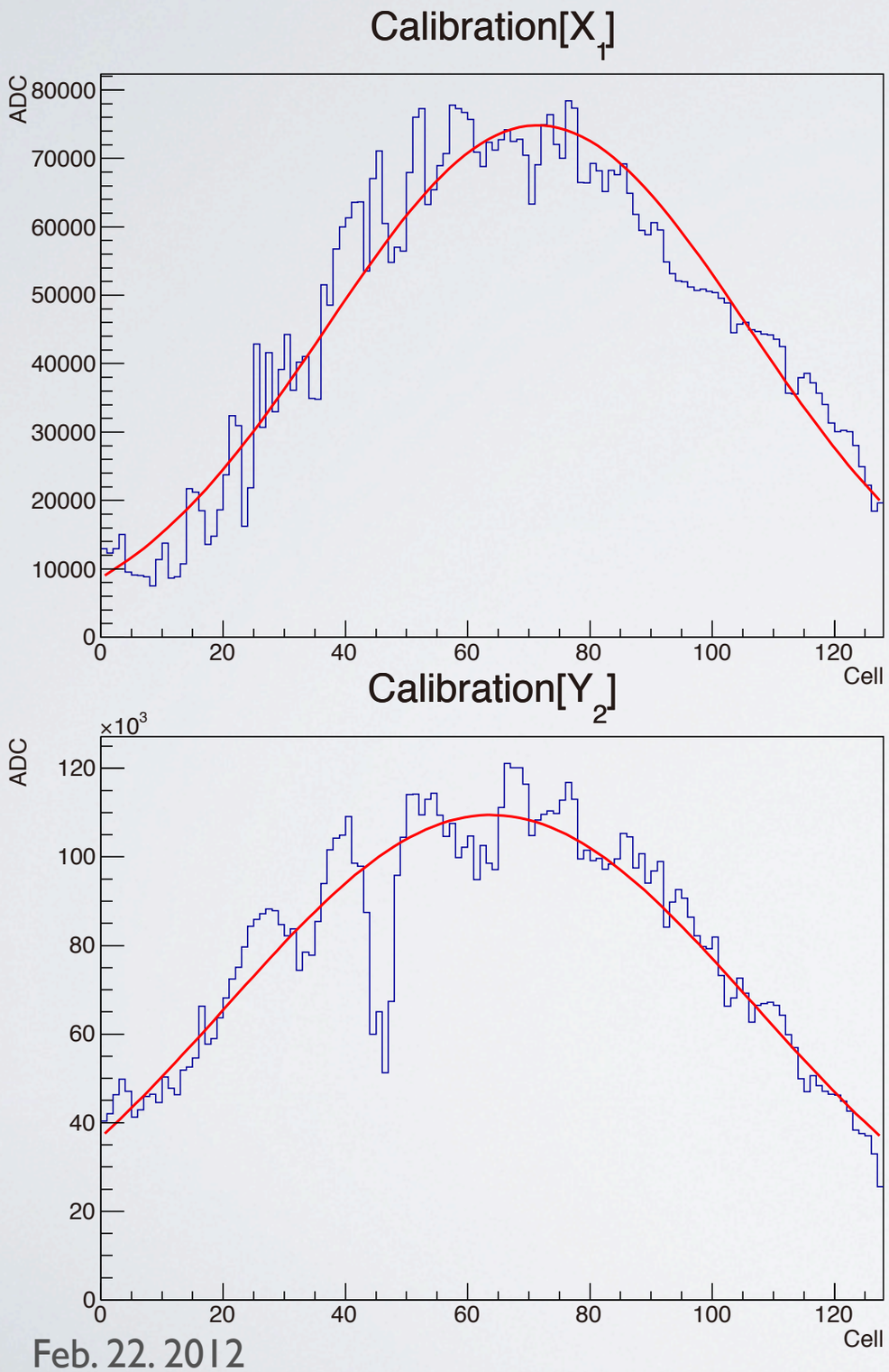
BACK UP

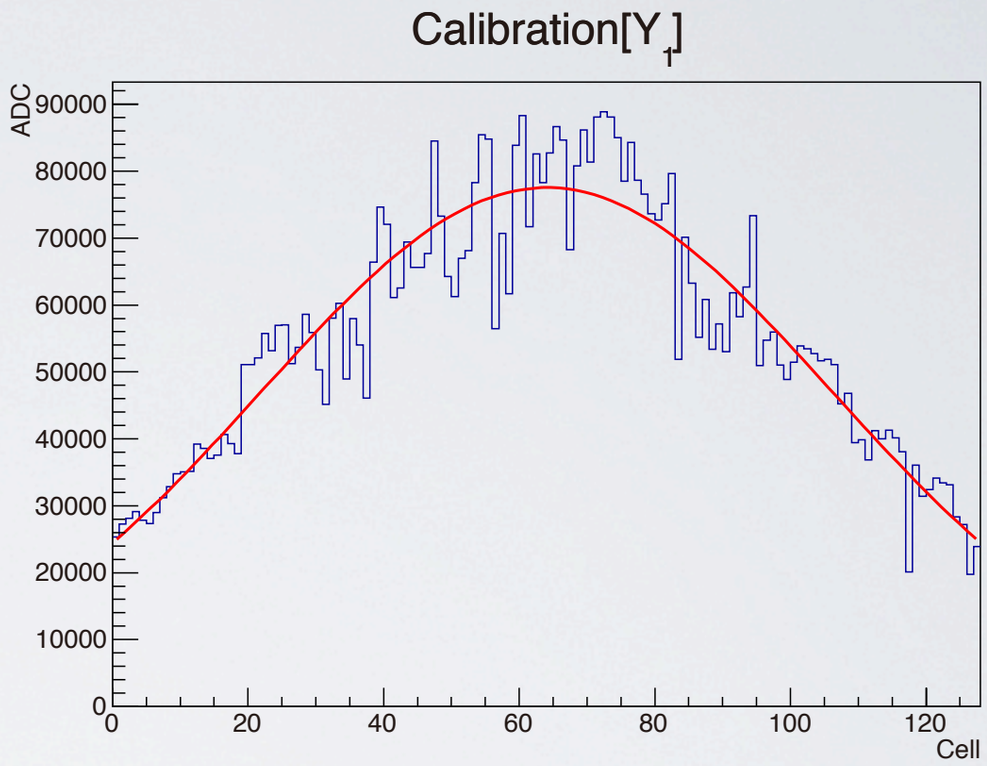
PEDESTAL LEVELS





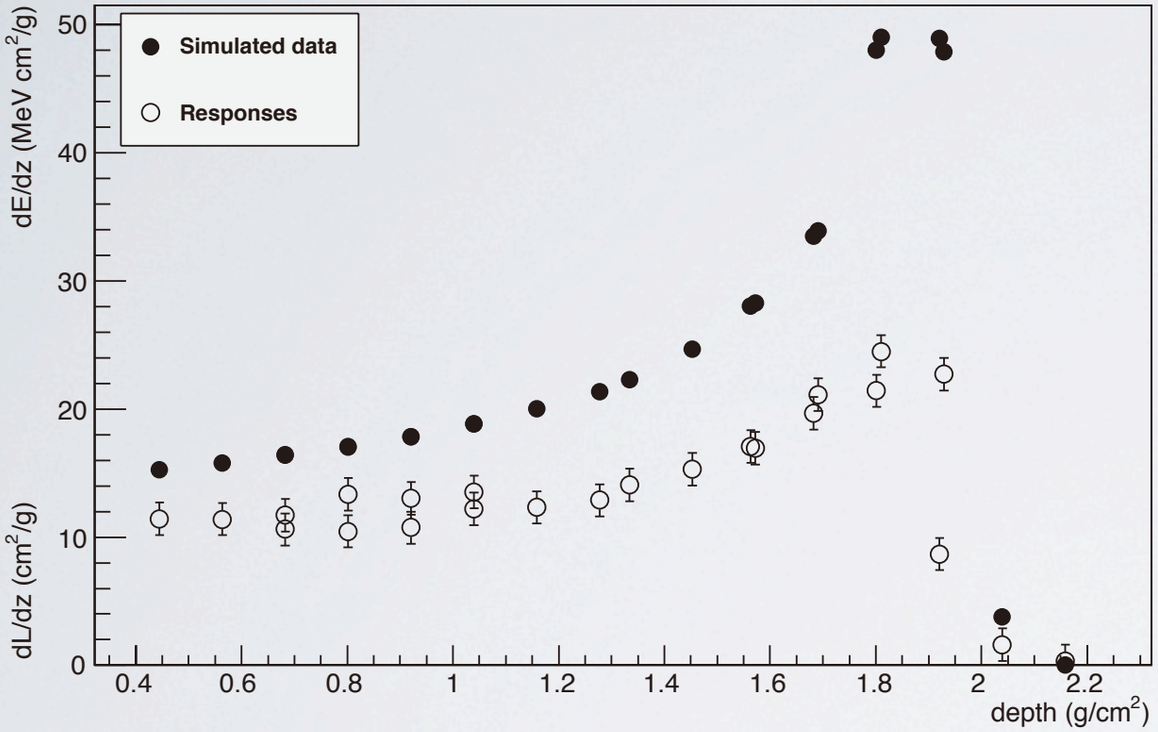
CALIBRATION

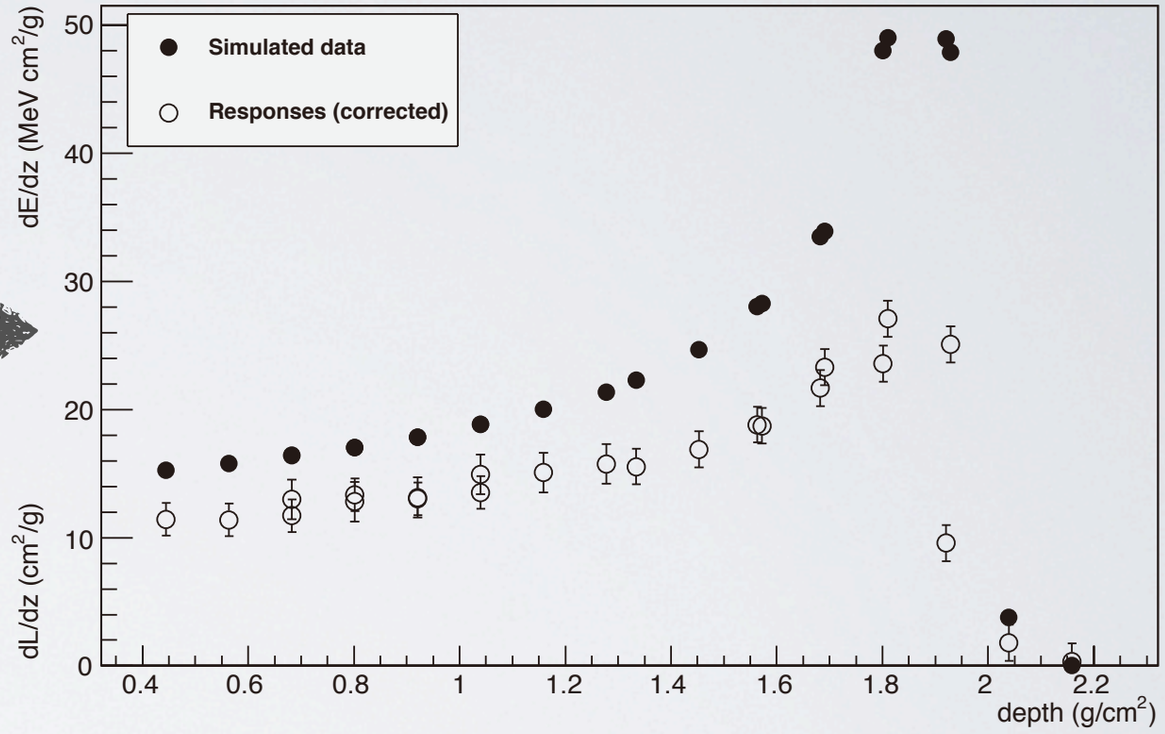




- Calibration factors
  - binned likelihood fit
  - $a_{cal} = \frac{fit\ \ value}{data\ \ point}$
  - some of the factors may be incorrect

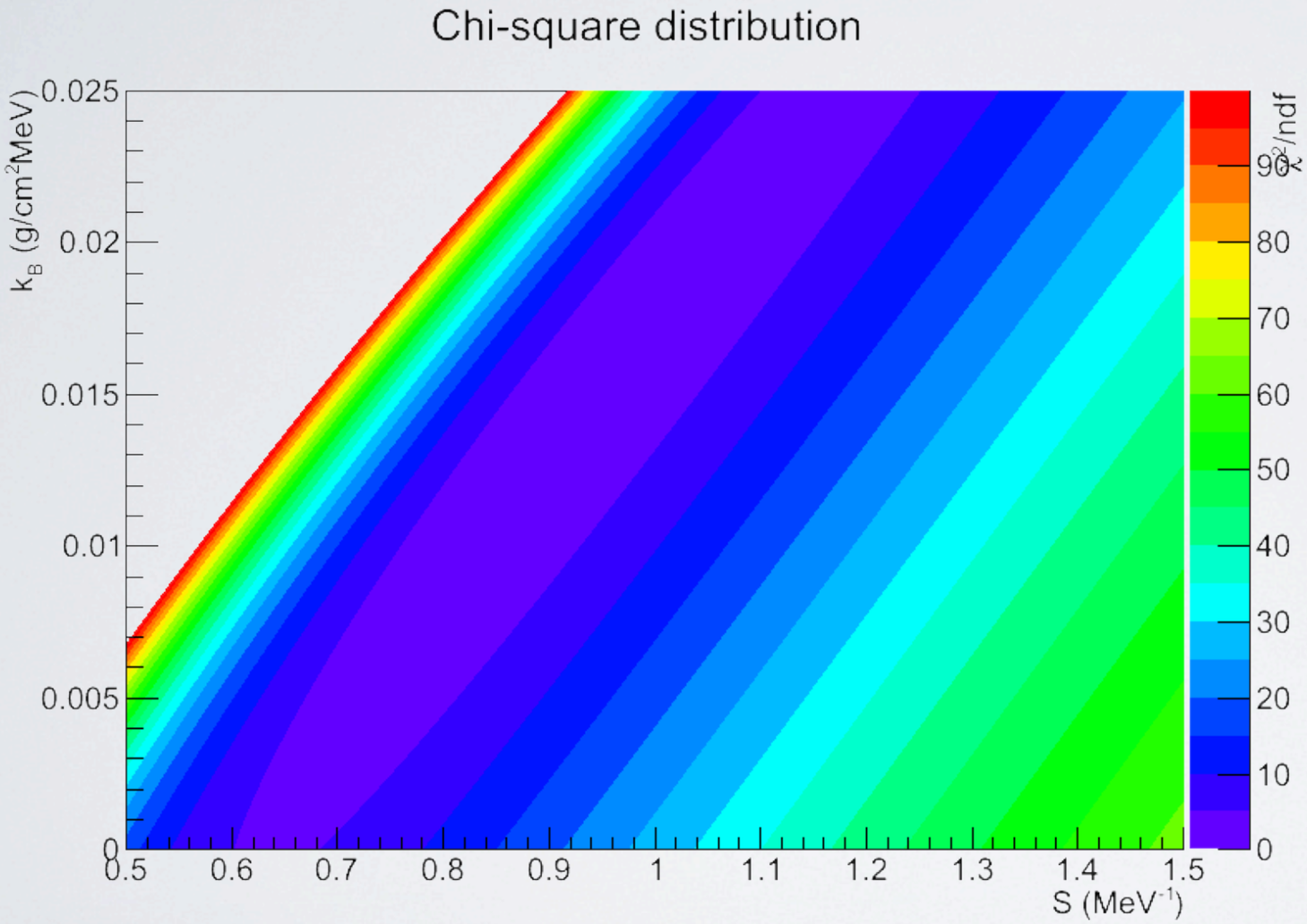
NORMALIZATION





- Y1 : 1 X1 : 1.22415
  Y2 : 1.1049 X2 : 1.10118

BIRK'S COEFFICIENT



- Parameter space
  - S & kB

- S : 0.9588
  kB : 0.015906

PHOTODIODE ARRAY

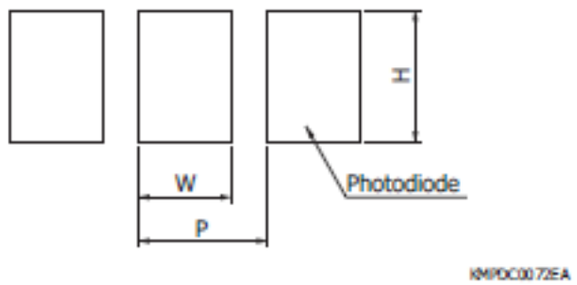
- Hamamatsu S8866-128
  - 128 ch photodiode array
  - ((0.1 + 0.7) × 0.8) mm2 (square-shaped) for a pixel
  - Two possible voltage offset (High & Low gain)

Specifications

Parameter	Symbol *1	S8866-64		S8866-128		Unit
Element pitch	P	1.6		0.8		mm
Element diffusion width	W	1.5		0.7		mm
Element height	H	1.6		0.8		mm
Number of elements	-	64		128		-
Active area length	-	102.4		102.4		mm
Line rate	-	7800		3900		lines/s

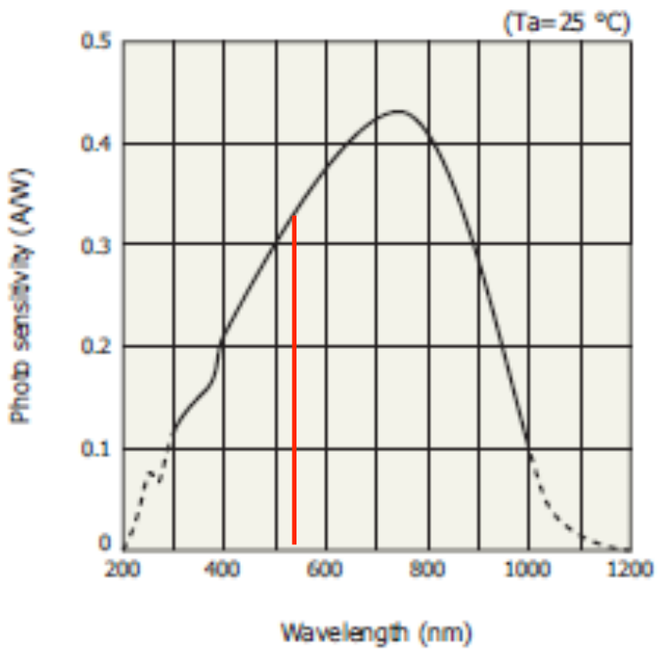
*1: Refer to following figure.

Enlarged view of active area

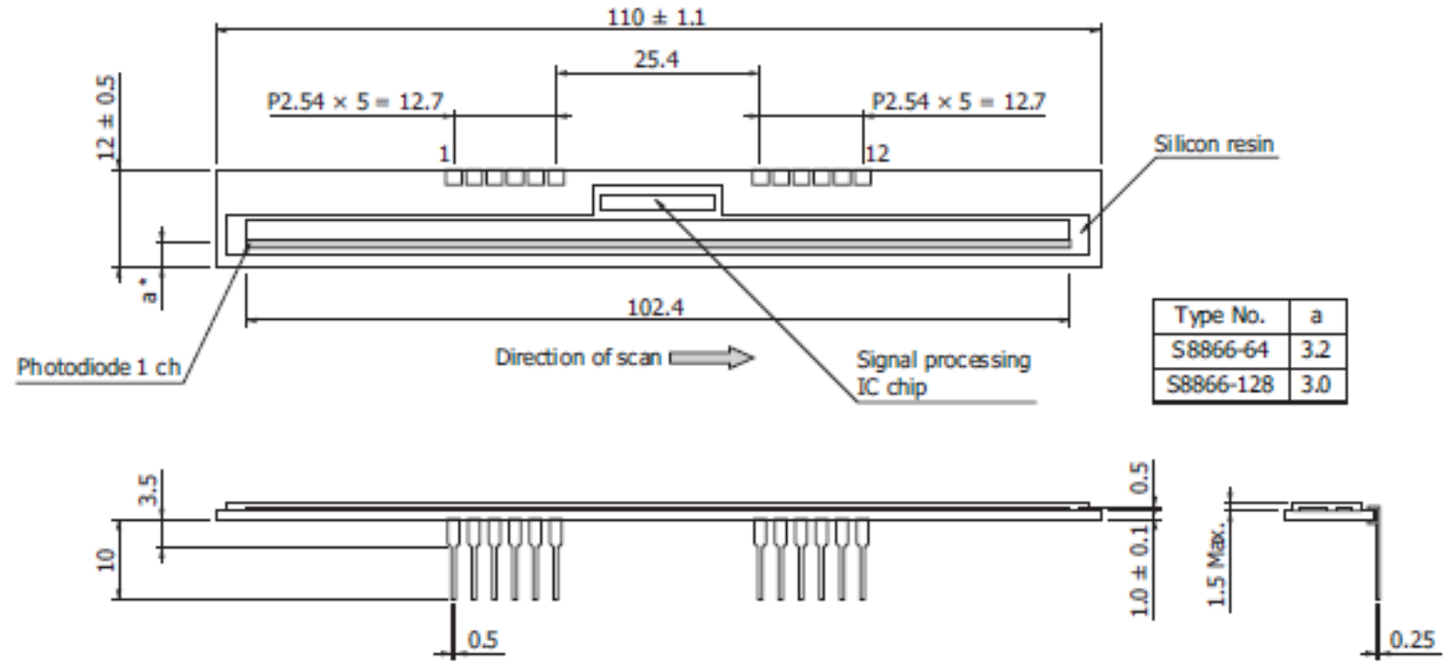


PHOTODIODE ARRAY

Spectral response (measurement example)



Dimensional outline (unit: mm)



Type No.	a
S8866-64	3.2
S8866-128	3.0

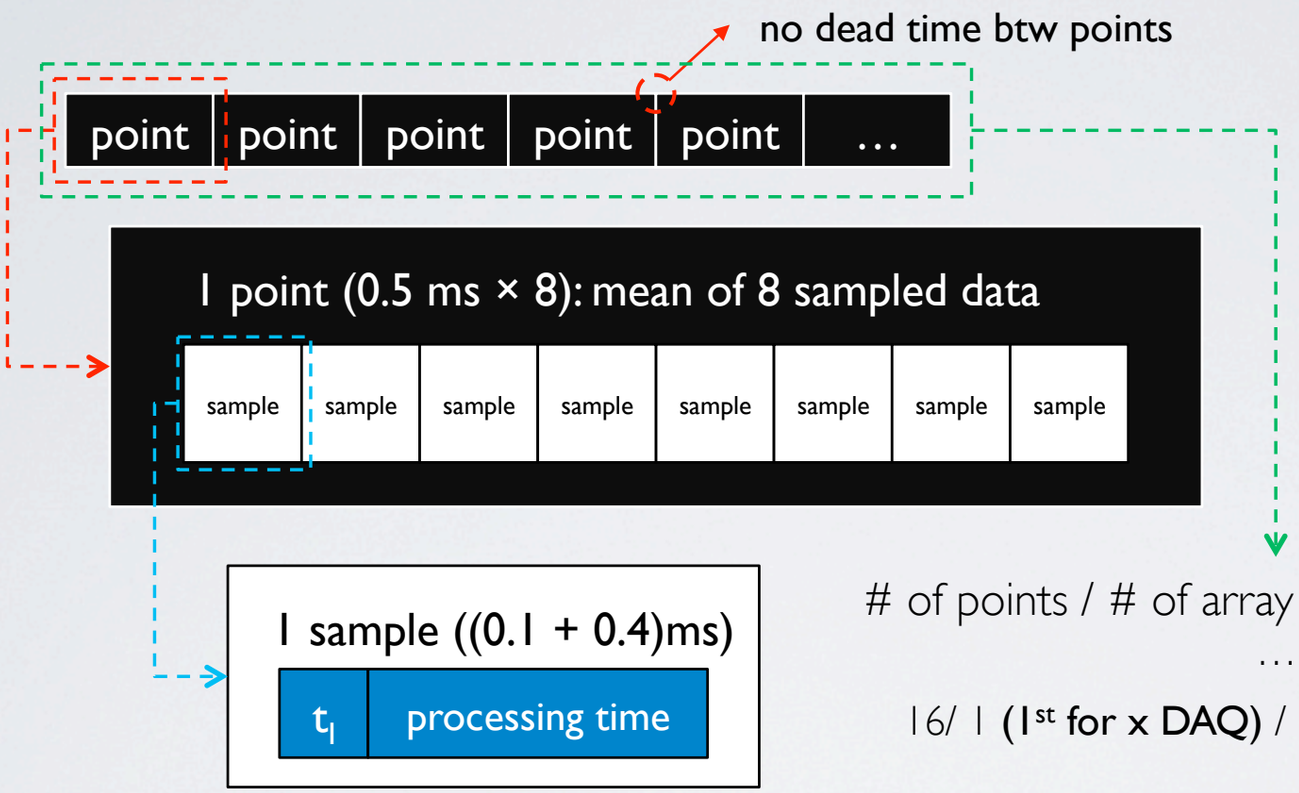
* Distance from the bottom of the board to the center of active area
Board: Ceramic

DAQ CHARACTERISTICS

- Multi-layered (5 array per board) DAQ
  - Total 5 × 2 × 128 channels
  - USB 2.0 based communication
    - Don't use cable longer than 3 m length!
    - Reomte control required for the experiment

- DAQ specification
  - Data acquisition in second (s) unit: 250 points/s
  - Data recorded in Binary codes
    → conversion to the ASCII codes is possible
  - Dynamic range: 3.5 and 1.75 pC for high / low gain
    → corresponding MAX. ADC: 218 (262,144)
  - Integration time: 0.1 ms for 1 point
  - Elapsed time for the 1 point measurement: 4 ms

DETECTOR



# of points / # of array / # of ch (cell) / data

…

16/ 1 **(1st for x DAQ)** / 128 (Max. ch) / 5,763

…

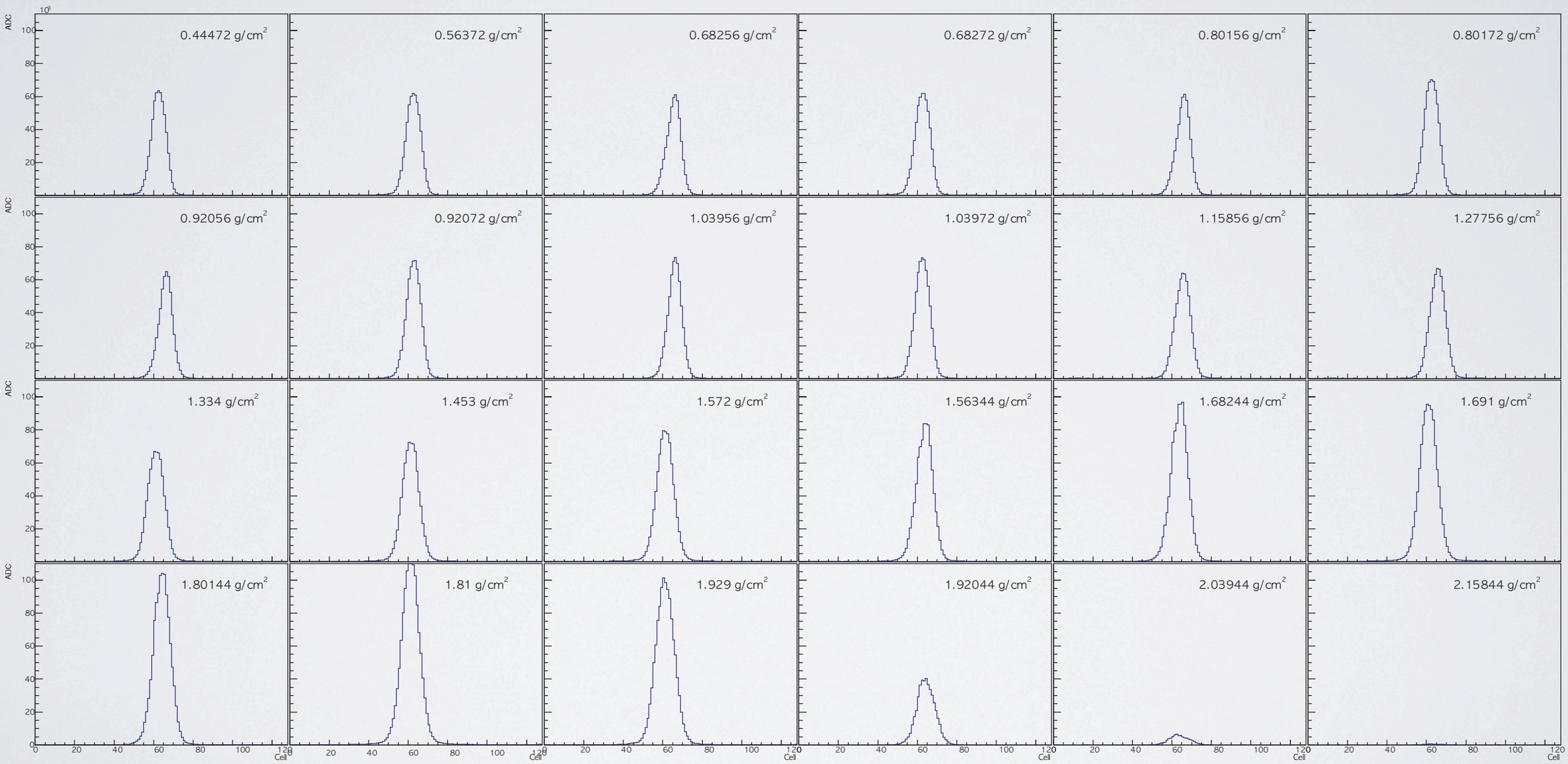
20 / 6 **(1st for y DAQ)** / 128 (Max. ch) / 6,725

…

- ADC ↔ charge relation:
  - $I_D = Q/t_I = (ADC / 262,144) \times DR/t_I$

  where
  - I_D = Measured current
  - Q = Accumulated charge during integration time (t_I)
  - DR = Dynamic range (3.5 and 1.75 pC)
  - t_I = Integration time (0.1 ms for 1 point)

ENERGY LOSS


0.44472 g/cm²
0.56372 g/cm²
0.68256 g/cm²
0.68272 g/cm²
0.80156 g/cm²
0.80172 g/cm²
0.92056 g/cm²
0.92072 g/cm²
1.03956 g/cm²
1.03972 g/cm²
1.15856 g/cm²
1.27756 g/cm²
1.334 g/cm²
1.453 g/cm²
1.572 g/cm²
1.56344 g/cm²
1.68244 g/cm²
1.691 g/cm²
1.80144 g/cm²
1.81 g/cm²
1.929 g/cm²
1.92044 g/cm²
2.03944 g/cm²
2.15844 g/cm²
ADC
Cell