BIC prototype test at CERN PS and plan for KEK

Jan 14th 2025

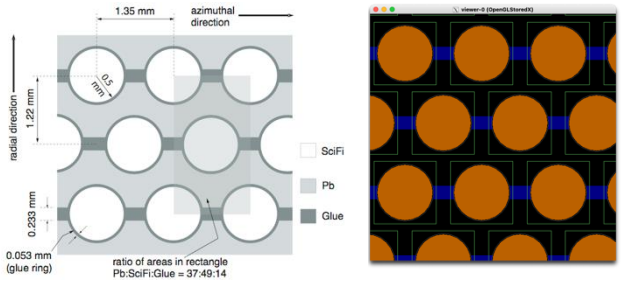
BIC System Testing Meeting

Jeongsu Bok (Pusan National University)

Outline

- Beam test at CERN PS in Aug. 2024
  - Production
  - Experimental Setup
  - Results
- Future beam test plan
  - At KEK in Mar. 2025
  - Future options

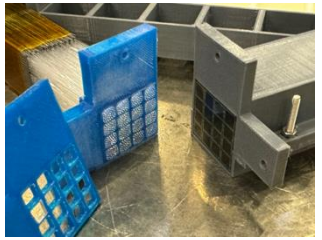
Prototype



Implemented geometry based on material composition of prototype

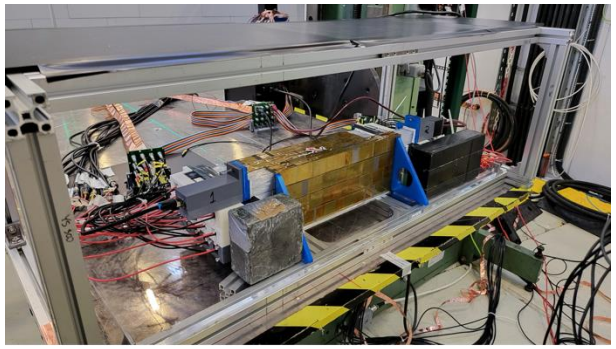
M11 0.22%	M12 0.84%	M13 1.55%	M14 1.64%	M15 1.17%
M6 8.98%	M7 29.10%	M8 27.71%	M9 16.07%	M10 7.46%
M1 0.21%	M2 0.81%	M3 1.50%	M4 1.58%	M5 1.16%

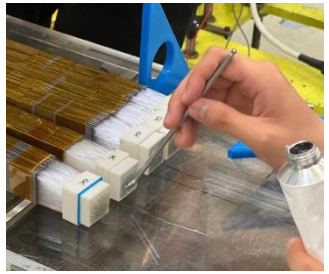
Previous Pb/SciFi - SiPM

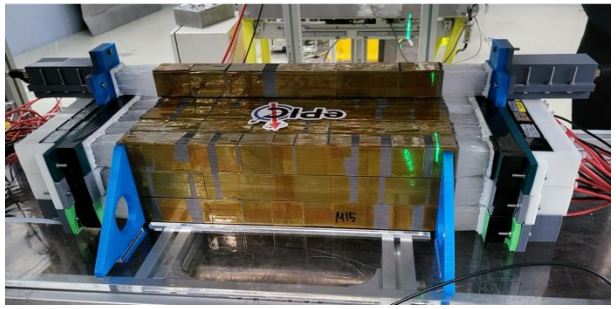


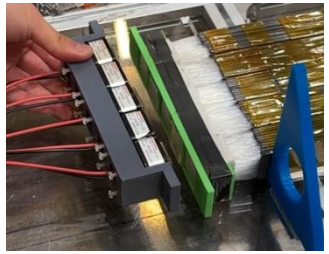
- 3x5 stacking of 32x3x3 cm^3 unit modules
  - 32x9x15cm^3
  - Fiber is bundled, glued, and polished
  - Connected to glass PMT
  - Power supply in additional board, connected to DAQ module and trigger board using USB and LAN
- Additional module with SiPM

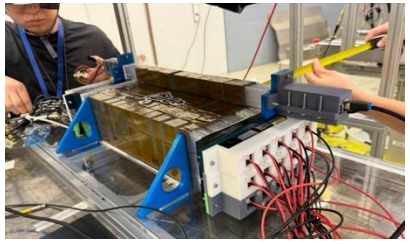
Beam Test Setup at CERN PS T10

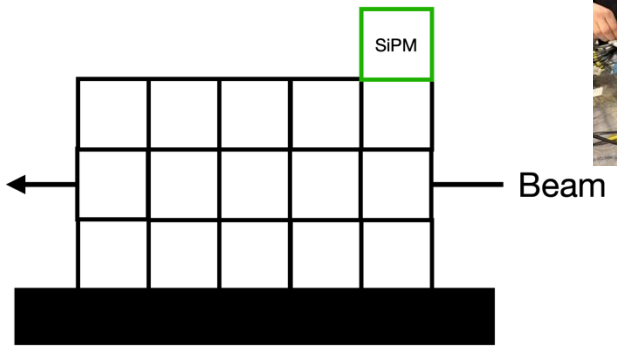


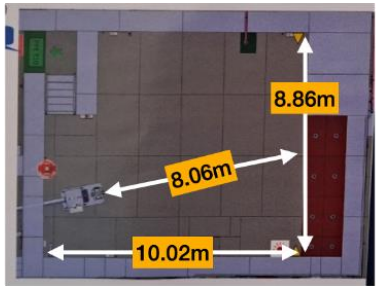


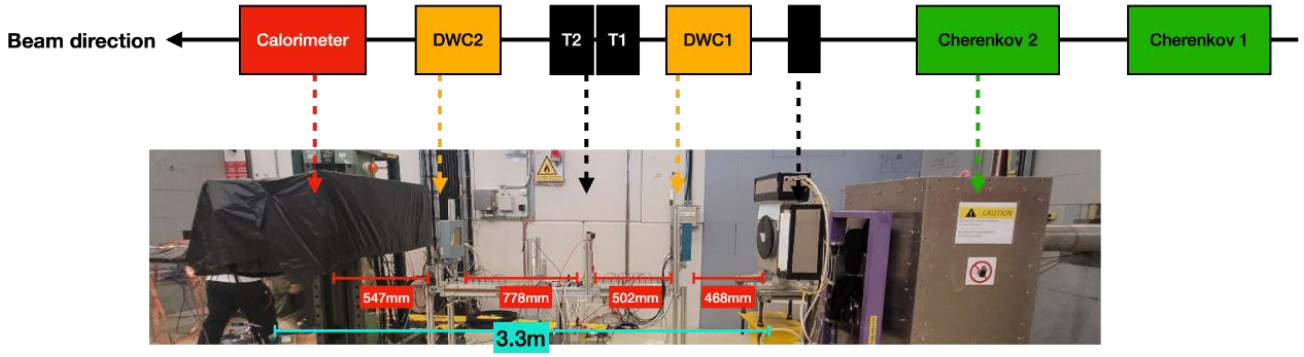




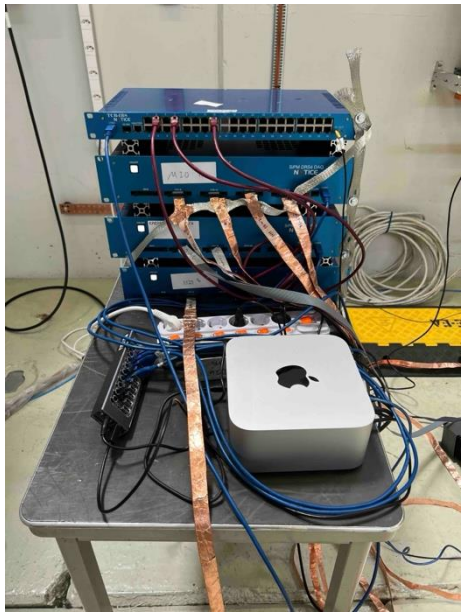


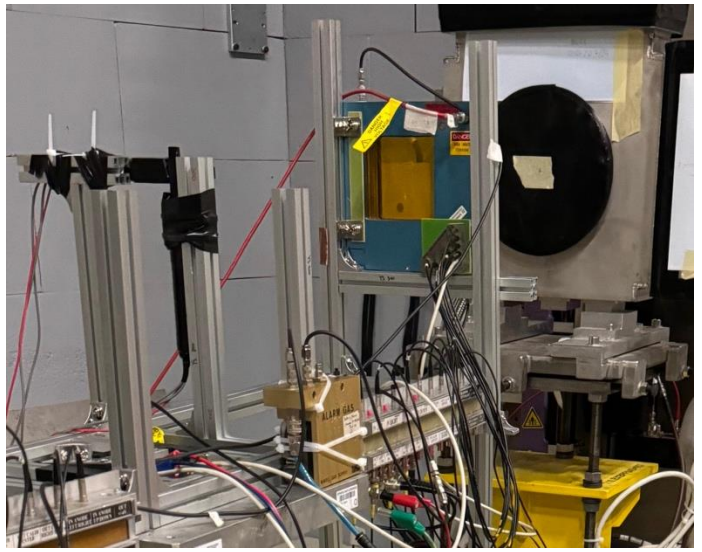






Beam Test Setup at CERN PS T10





DWC

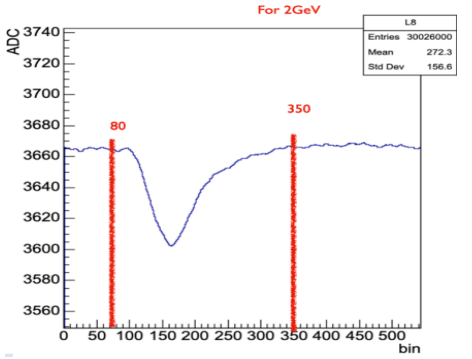
Trigger

DAQ: DRS4-DAQ 3x36ch from
- 30ch PMT(R11265-100)
- DWC
- Cherenkov
- Trigger scintillator

Pulse Height Adjustment and Calibration

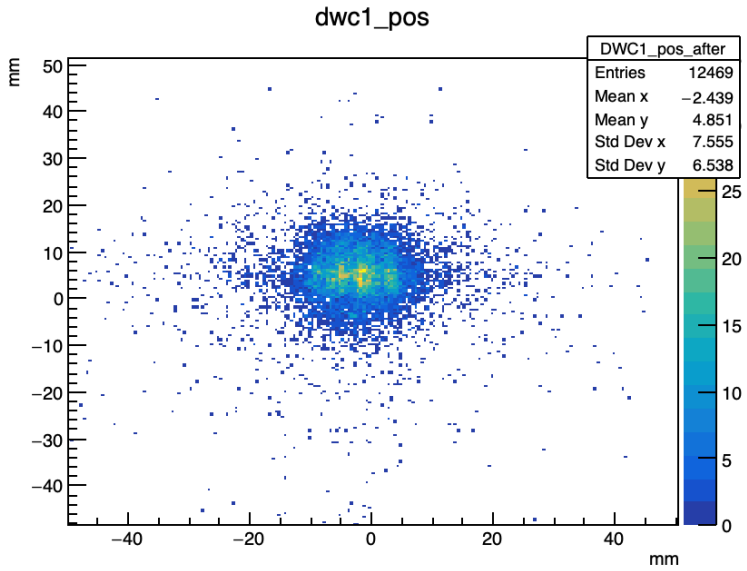
- Starting from beam position confirmation
  - Moving beam position (table) from end to end to confirm the beam position
  - Pulse height drops at the edge
- Pulse height adjustment
  - Based on energy deposit in GEANT4 simulation
  - Adjust PMT HV to make module response similar
  - Also to prevent saturation at 5 GeV/c
- Calibration
  - 2million events to center of prototype.
  - Compare integrated ADC and energy deposit in simulation for each module
  - After summing the signals from all modules, apply additional scale factor for the total energy deposit
- PID using Cherenkov Counter
- Beam position using Delay Wire Chamber

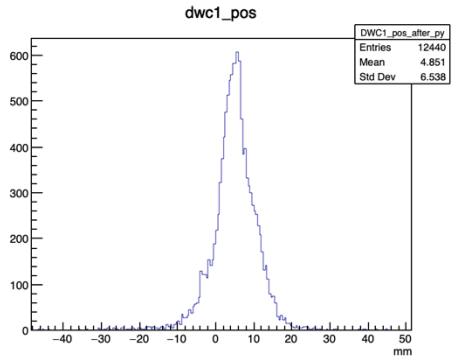
Electron selection using two Cherenkov counters

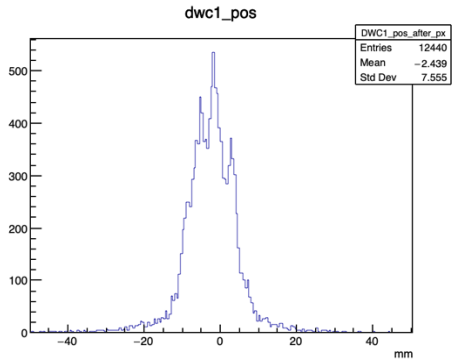


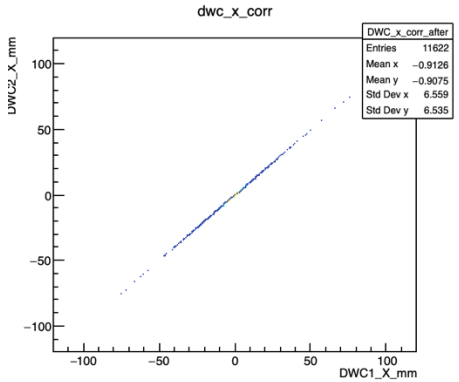
Determine integral range in time structure

Beam profile at T10

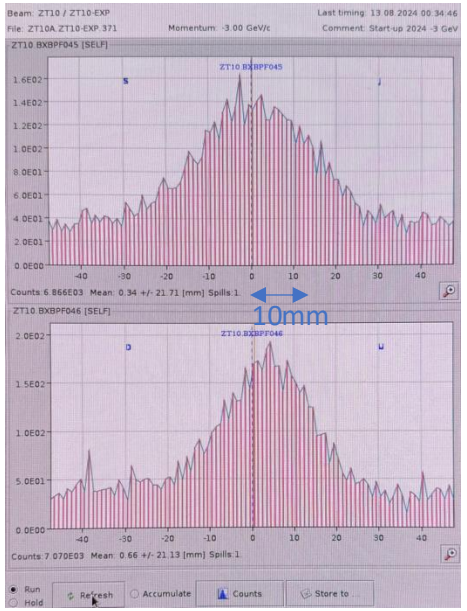








- After electron selection
- Position using Delay Wire Chamber
- Triggered area 10x10mm^2 smaller than beam size
- Almost straight, according to DWC1-2 correlation

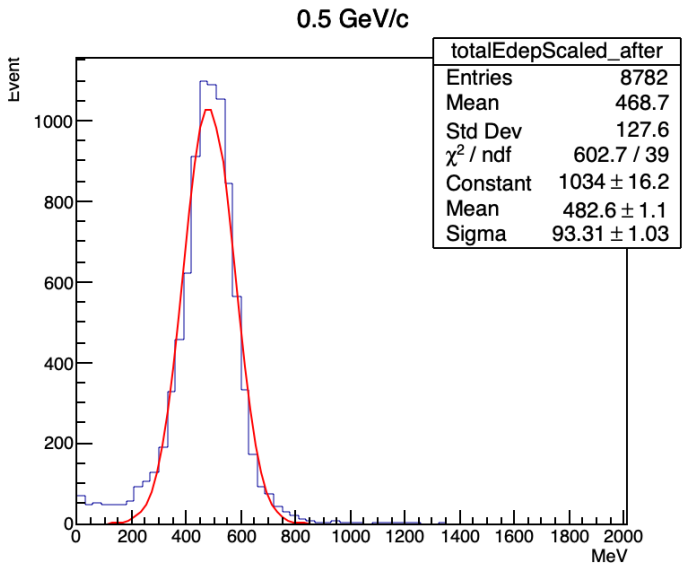


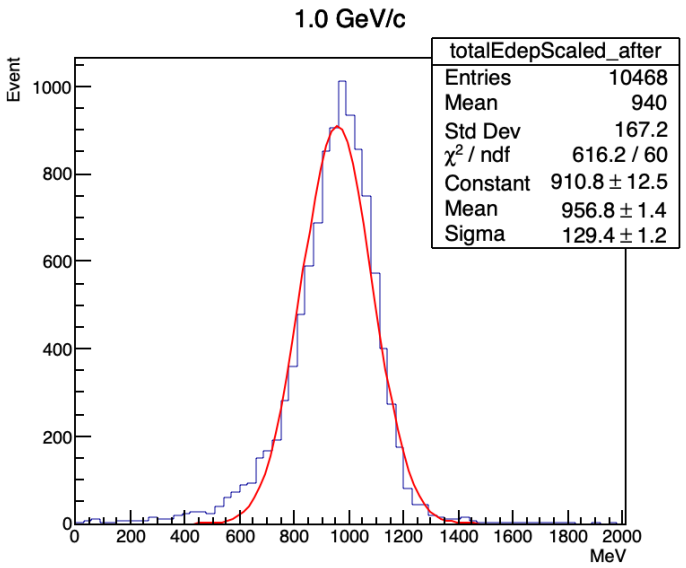
3 GeV/c
depends on collimator setup and beam energy

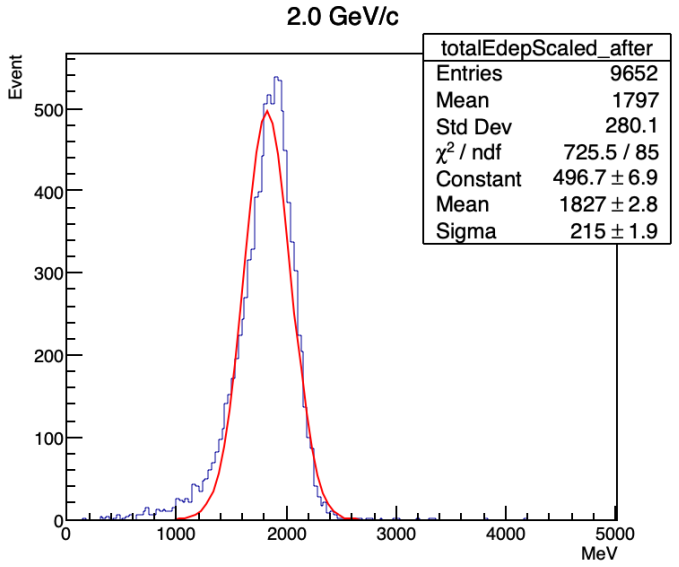
Experimental Program

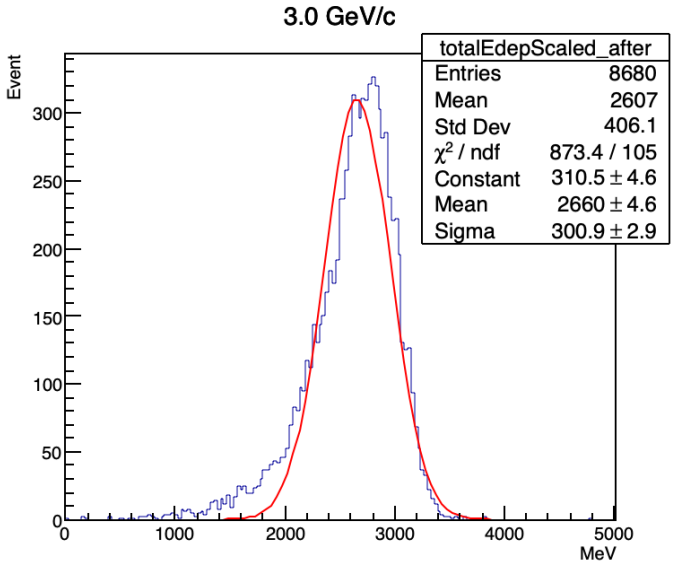
- Energy response using 0.5, 1, 2, 3 GeV/c electron beam
- Horizontal position scan for time resolution
- SiPM module
- Additional tests

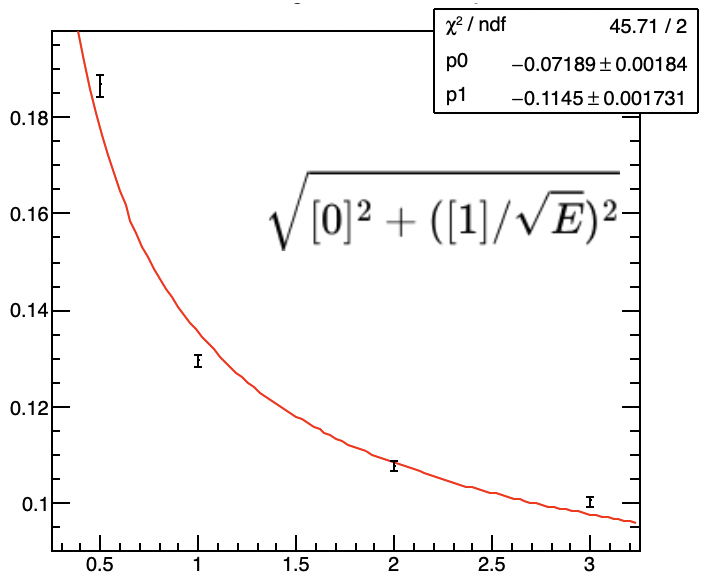
Result





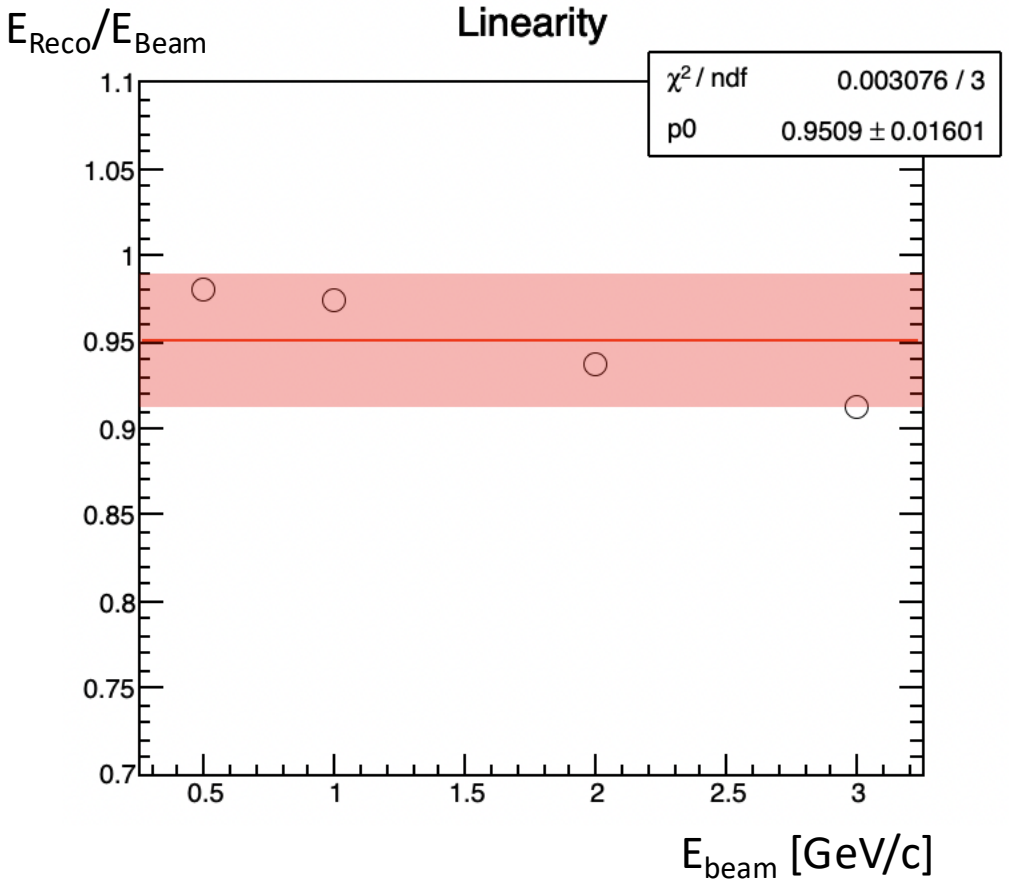






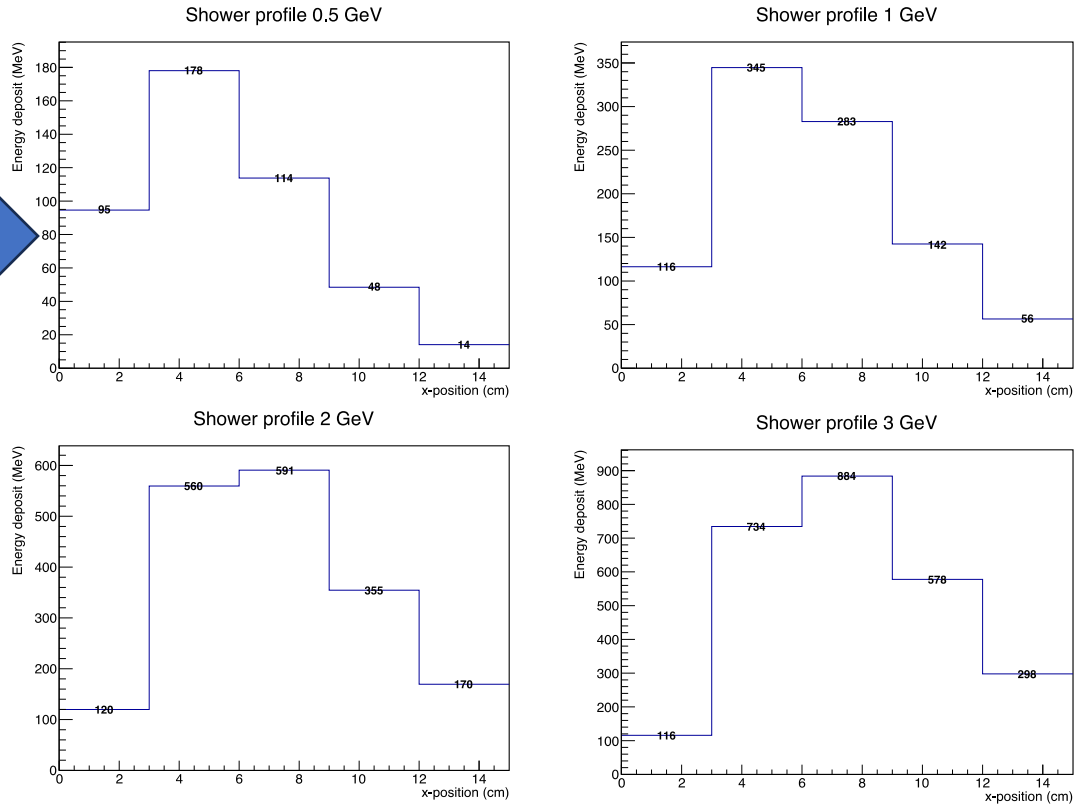
- Stochastic term: 11.5%
- Constant term: 7.2%

Result: Linearity

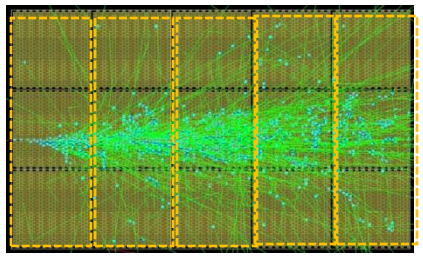


- The result is linear within 4%
  - Function: constant
  - Band: 4%
- However, little bit larger than energy deposit in simulation due to Gaussian fit.

Result: Longitudinal shower profile



Beam



Beam

3x5 각 모듈 별 Edep 비율 (0.5 ~ 5 GeV)

• 3x5 구조 결과

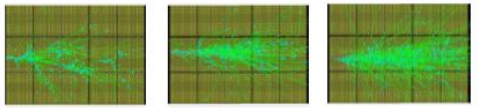
Energy Deposit [%]

E (GeV)	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M4	M15
0.5	0.44	1.39	1.80	1.40	0.81	23.39	35.22	18.76	8.00	3.15	0.44	1.35	1.72	1.35	0.78
1	0.34	1.14	1.73	1.52	0.95	16.26	34.05	23.08	10.98	4.48	0.33	1.11	1.68	1.44	0.91
2	0.25	0.94	1.61	1.59	1.10	11.18	31.29	26.27	14.13	6.29	0.25	0.90	1.57	1.54	1.07
3	0.21	0.81	1.50	1.58	1.16	8.98	29.10	27.71	16.07	7.46	0.22	0.84	1.55	1.64	1.17
4	0.19	0.77	1.50	1.64	1.23	7.66	27.50	28.50	17.41	8.39	0.19	0.74	1.44	1.61	1.21
5	0.18	0.72	1.45	1.65	1.28	6.75	26.19	28.92	18.6	9.16	0.17	0.70	1.40	1.61	1.25

(%)

• 모듈 배치도

11	12	13	14	15
6	7	8	9	10
1	2	3	4	5



1 GeV 2 GeV 3 GeV

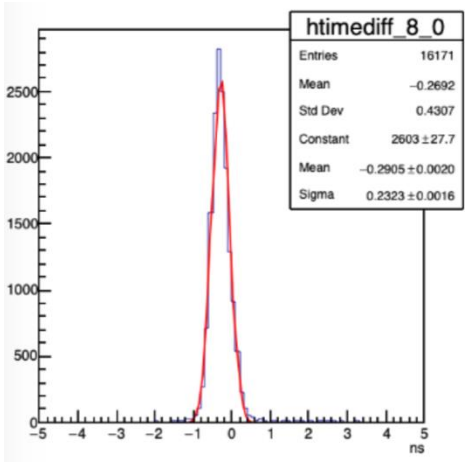
* 빔 에너지가 높을수록 샤워가 뒤에 모듈들까지 전달되어 모듈 별 energy deposit 비율이 달라지는 것으로 보인다.

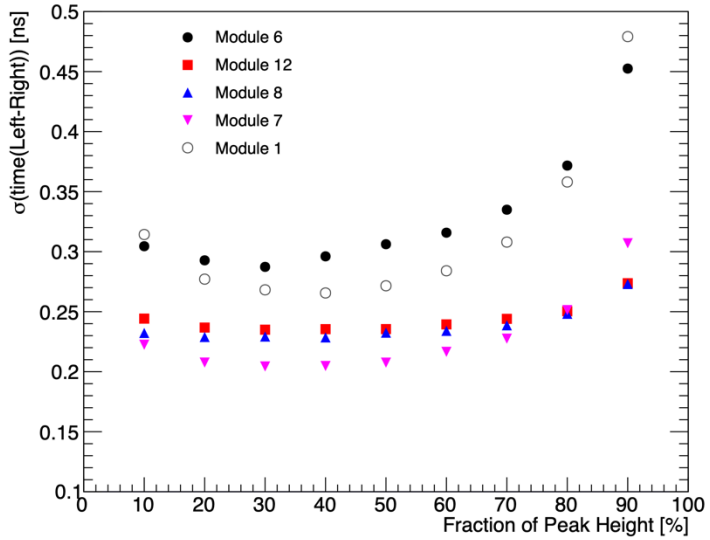
Energy deposit is maximum at

2nd module in 0.5,1 GeV/c

3rd module in 2,3 GeV/c

Result: Time resolution

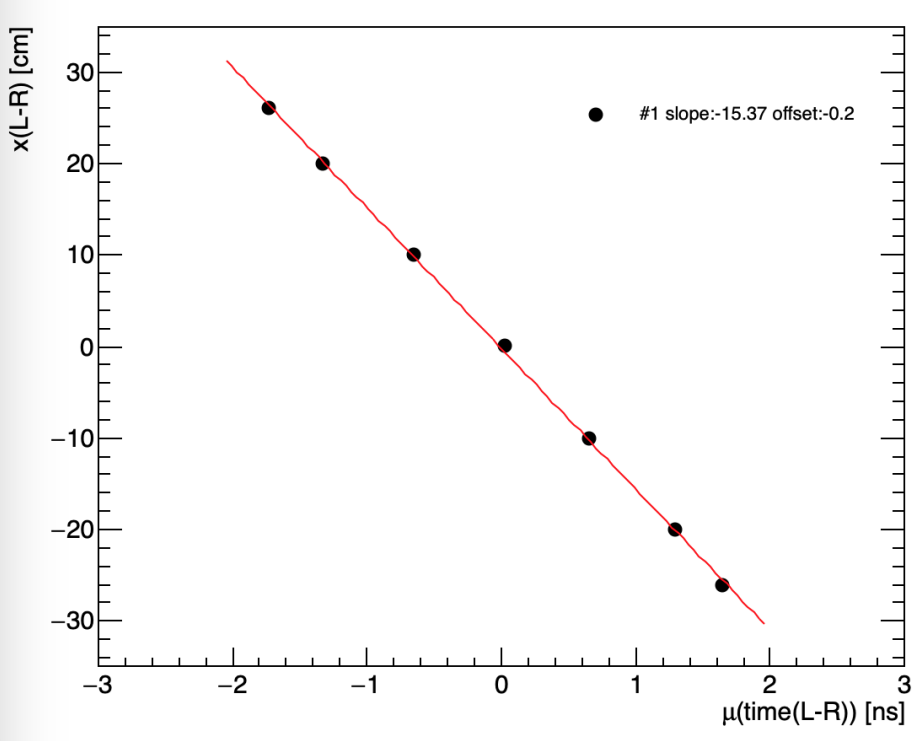




- σ of Time(Left-Right)
- Using constant fraction 30%
- Most upstream module σ ~ 280ns
  - Depends on module and light yield
  - More energy deposit in downstream

- SiPM module showed comparable performance in time resolution and energy resolution.

Result: Effective Speed



- -13,-10,-5,0,+5,+10,+13cm
- Then, horizontal length difference: +26,+20,+10,0,-10,-20,-26 cm
- Checked $\mu(t_{L-R})$
- Most upstream module
- Without reflection
  - n = 1.59(core) 1.49(clad)
  - v = c/n = 18.8 cm/ns
- Data: 15.4 cm/ns
- Checking simulation

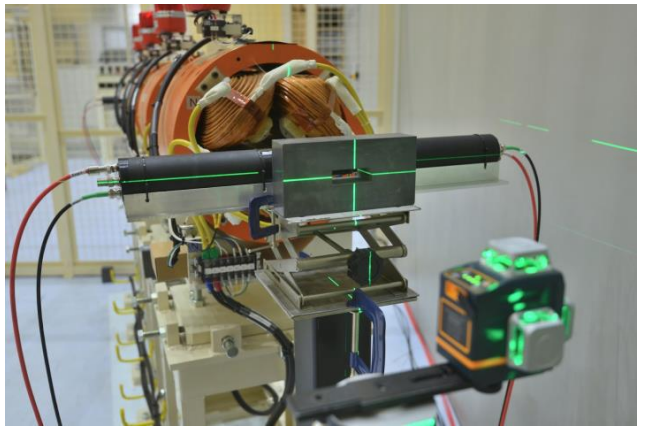
Future Testbeam Plan

Schedule

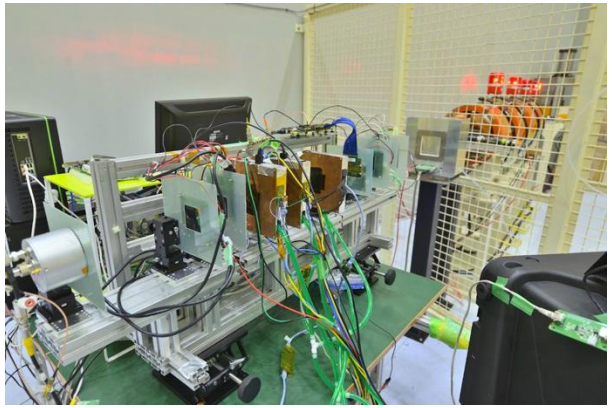
- KEK (1~5 GeV/c electron)
  - March 2025: proposal submitted on Jan. 8th
    - Beam period: March 6th ~ 24th
  - May-June 2025
  - Oct-Dec 2025
- CERN PS (0.5~5 GeV/c electron, muon, pion)
  - Submitted proposal on Oct. 21st, aiming August 2025
  - 0.5~5 GeV/c electron beam, muon possible
  - https://ps-sps-coordination.web.cern.ch/ps-sps-coordination/

KEK beam line

Trigger Counters

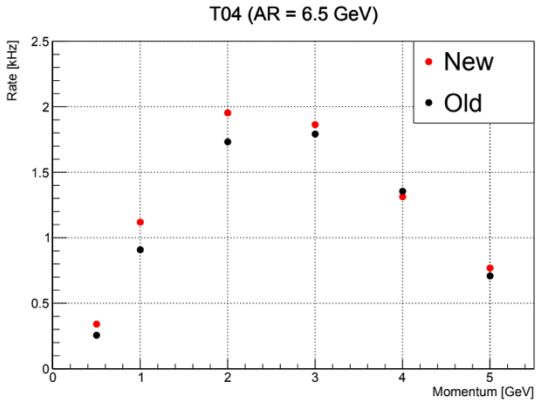


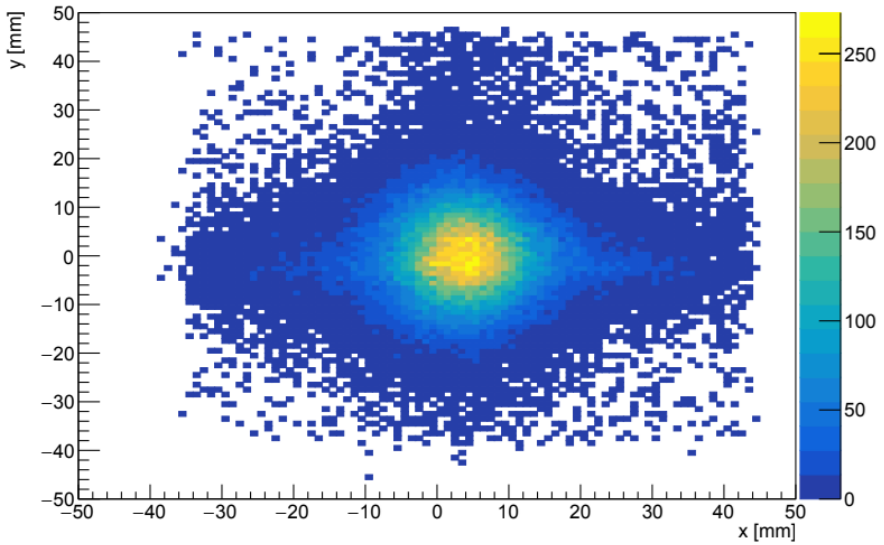
Counting Room

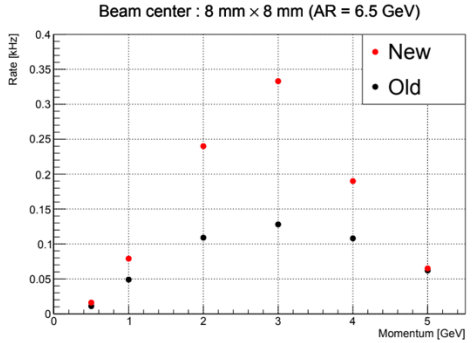


Beam Shutter

KEK beam rate and profile



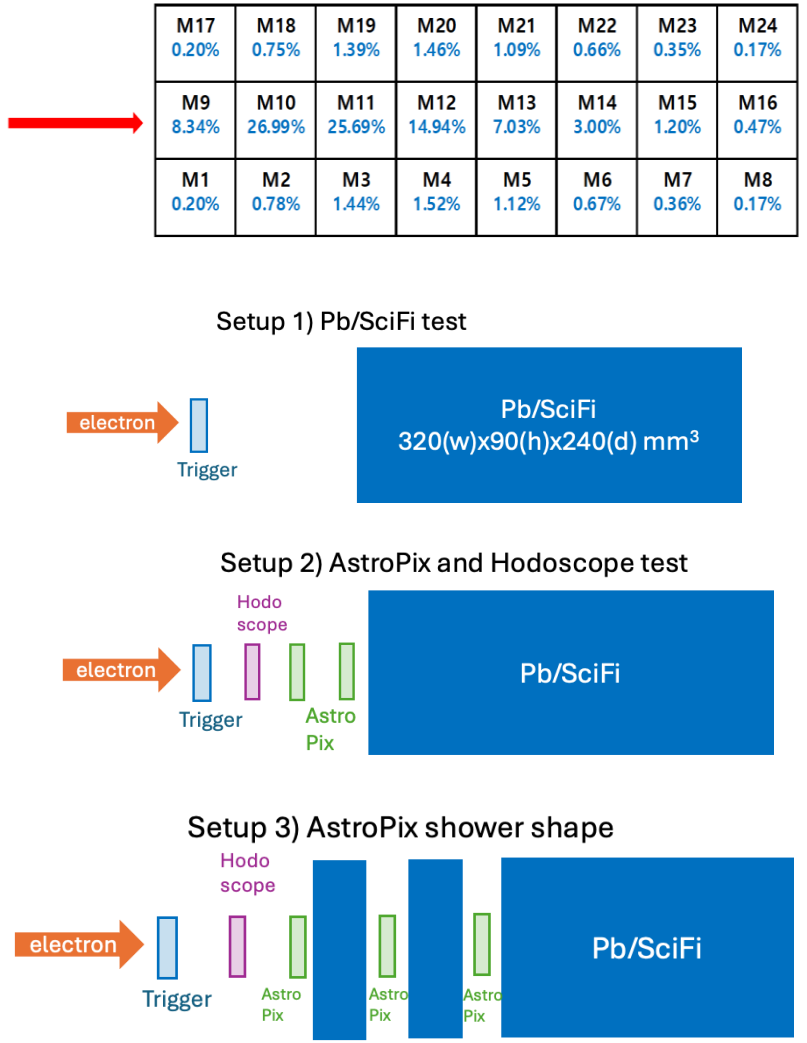




- Rate: Overall rate is 2~2.5 kHz, Highest rate ~ 3 GeV. Δp/p: 10%
- At 3 GeV, σ~4mm, wide in x-direction, Beam rate with 8mm x 8mm: 350 Hz
- Naive estimation for 8x8mm2 trigger area: 87,255,350,203,63 Hz at 1,2,3,4,5 GeV/c
- At CERN PS using 10x10mm2 trigger area (+DWC,Cherenkov)
  - 0.73, 2.9, 5.6, 6 Hz at 0.5,1,2,3 GeV/c

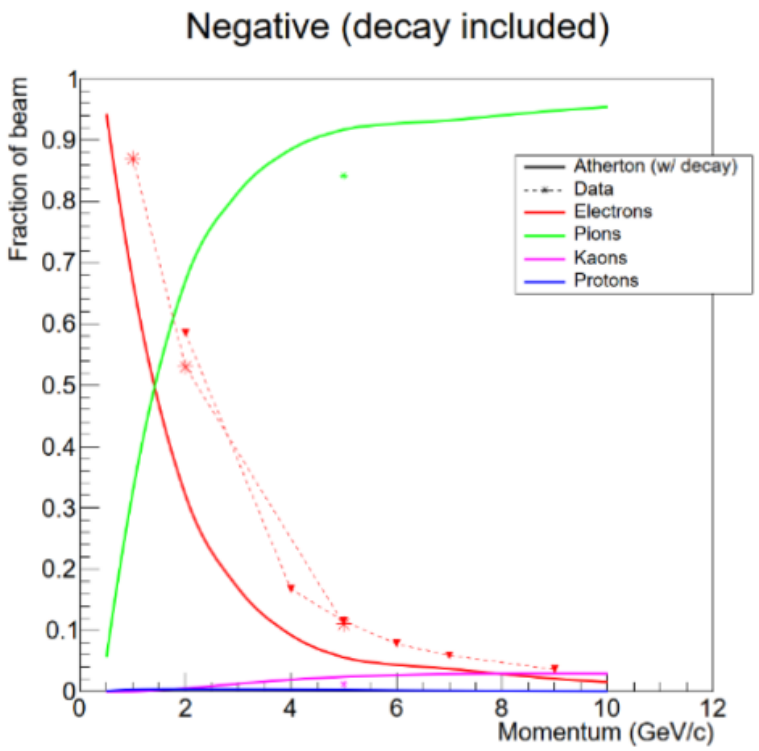
Plan for the KEK beamtest in March

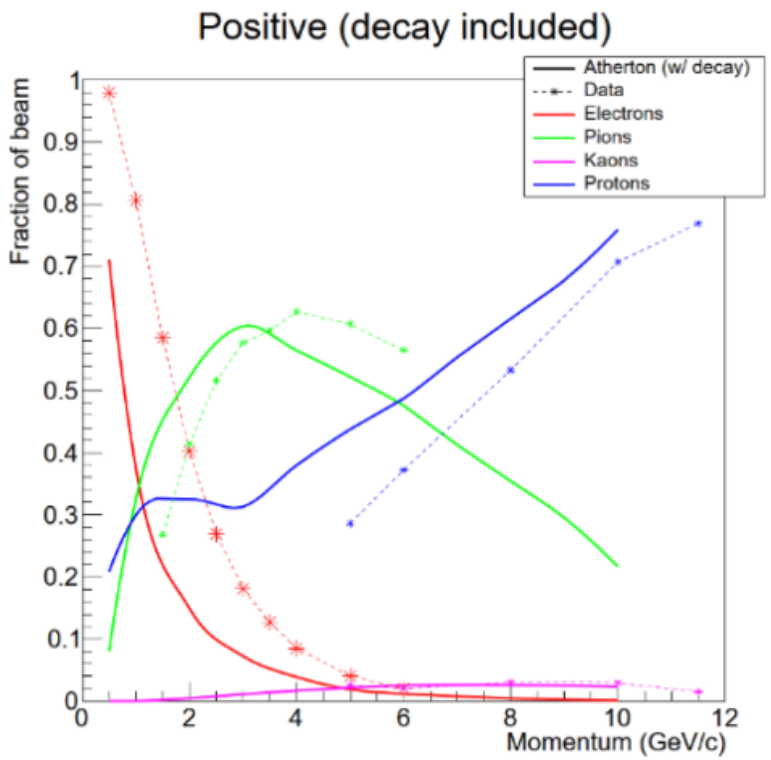
- If we get beam time, programs are
  - Energy scan for 3x8 or larger
    - 95% energy deposit for 3 GeV electrons
  - AstroPix test
  - Calibration of separated Pb/SciFi
  - Hodoscope operation
  - If possible, AstroPix shower shape
- Goals in intermediate term
  - PMT → SiPM comparison
  - Build a bulk sector (70cm)
  - AstroPix+ Pb/SciFi

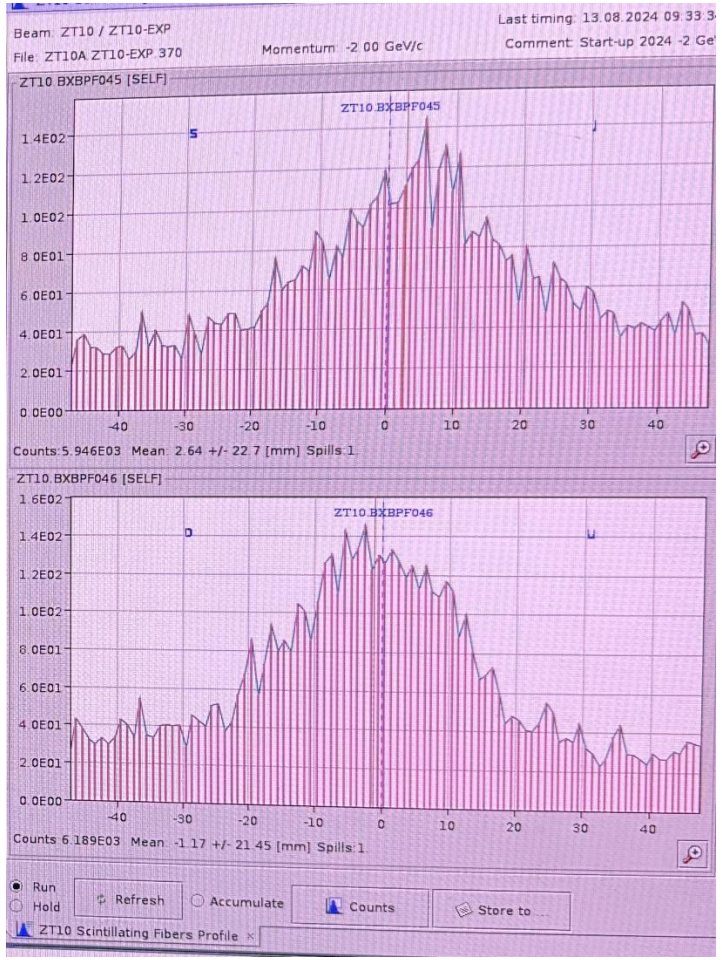


backup

CERN PS Beam info



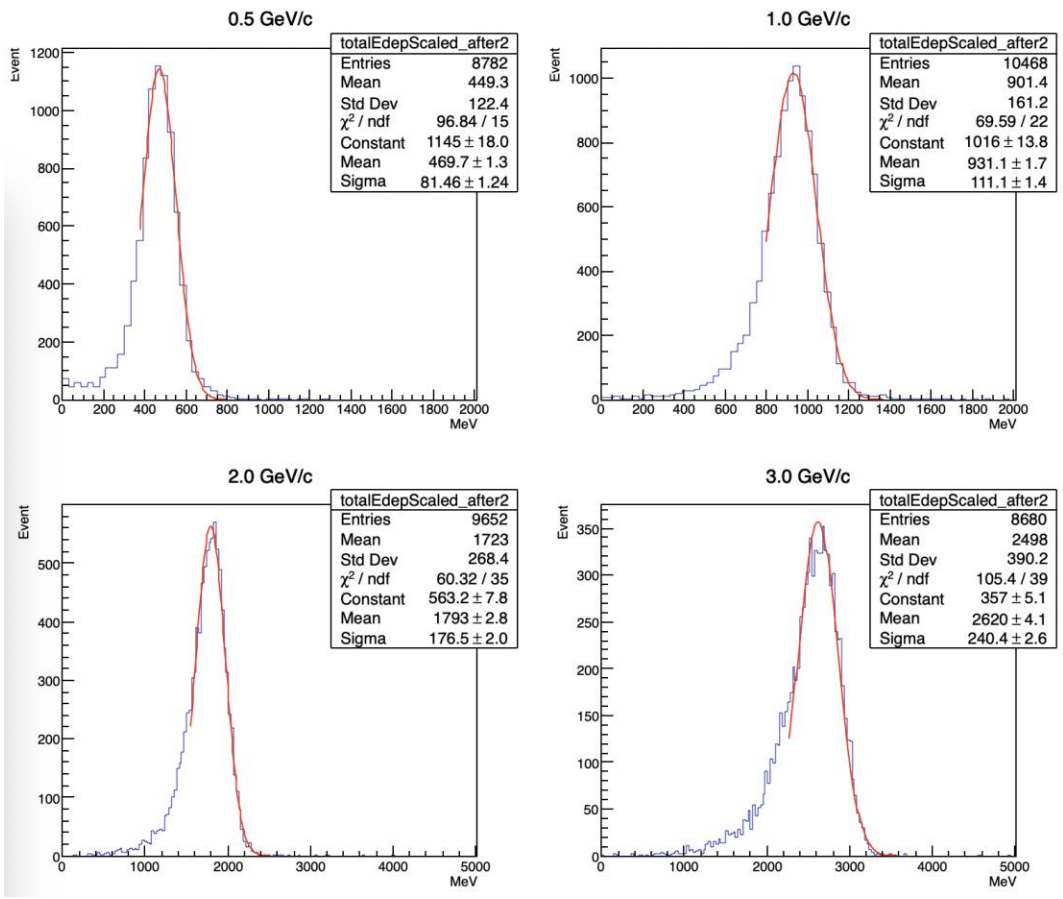


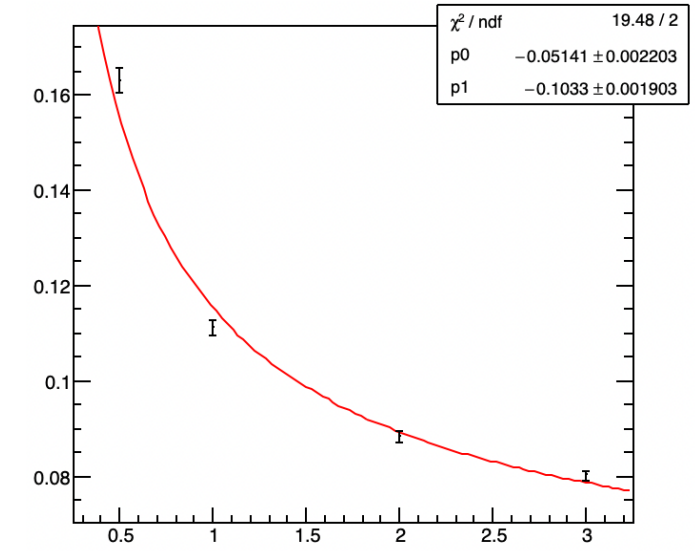


Characteristics of the beams

Parameter	T09	T10	T11
p_{max} of secondary beam in $^{GeV}/_{c}$	16	12	3.5
$\Delta p/p$ in %	± 0.7 to ± 15		
Maximum intensity/spill (hadrons/electrons)	10^6		
Available particle types	Pure electrons (T09 only) or mixed electrons (T10) or mixed/pure hadrons or pure muons		

Expected result in future measurements





- Future measurements with larger volume, tail due to leakage will shrink
  - If we narrow the fit range, it becomes 10.3%⊕5.1%

Backup: expected stochastic term

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus b$$

$$a_{\text{stoch}} = \sqrt{a_{\text{SF}}^2 + a_{\text{LY}}^2}$$

$$a_{\text{SF}} = 2.7\% \sqrt{\frac{d}{f}} \sim 8.9\%$$

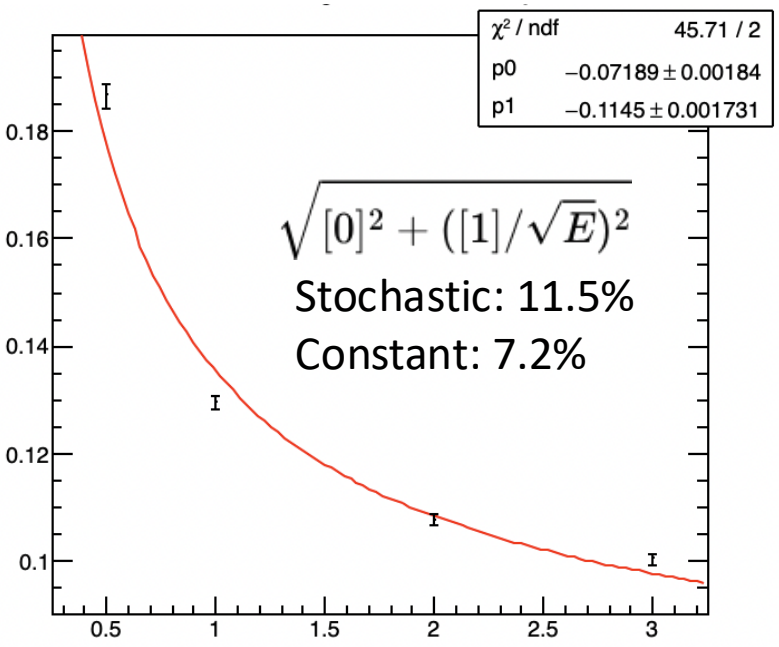
$$d = 1mm$$

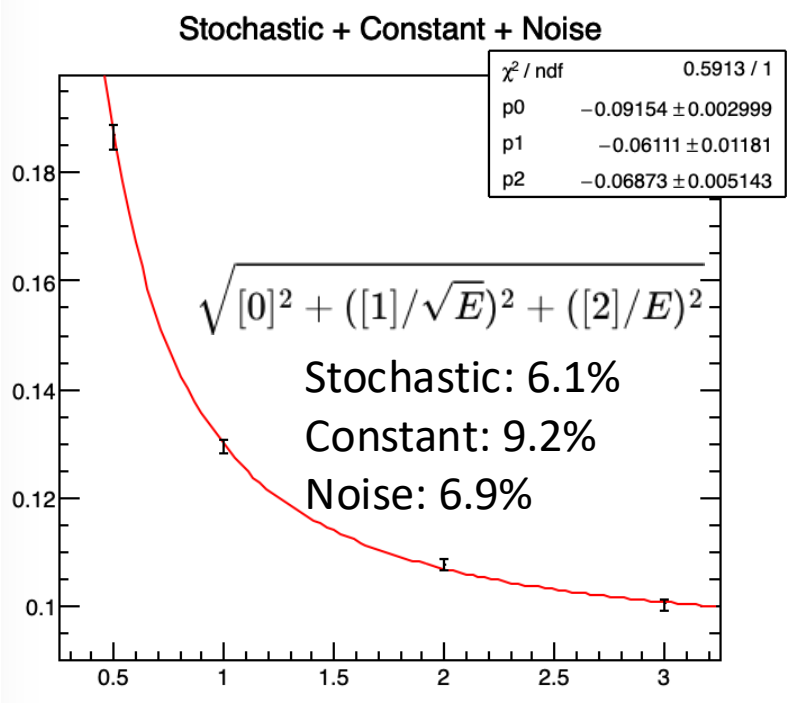
$$f = \frac{2MeV/cm \times V_{poly}}{dE/dx(Pb) \times V_{Pb} + 2MeV/cm \times V_{poly}}$$

$$\text{LY} \sim 1000 \text{ p. e. /GeV}$$

$$\Rightarrow a_{\text{stoch}} = \sqrt{0.089^2 + (1/\sqrt{1000})^2} = 0.09445$$

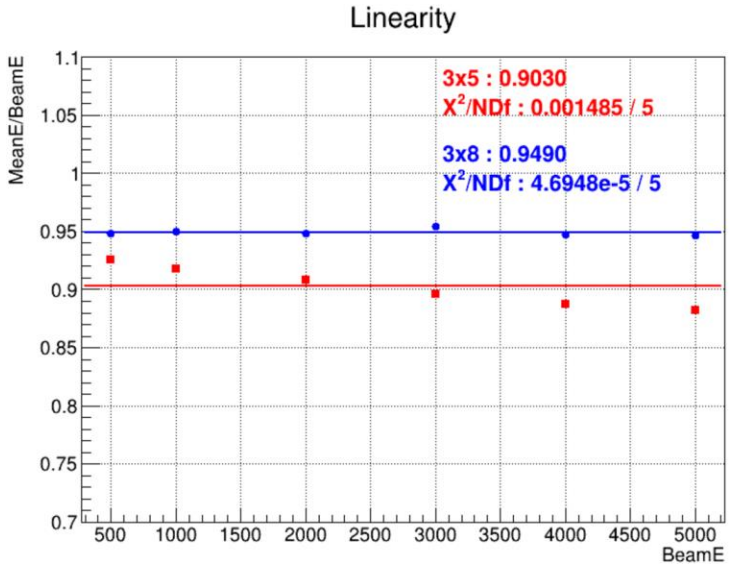
Backup: Fitting with Noise Term



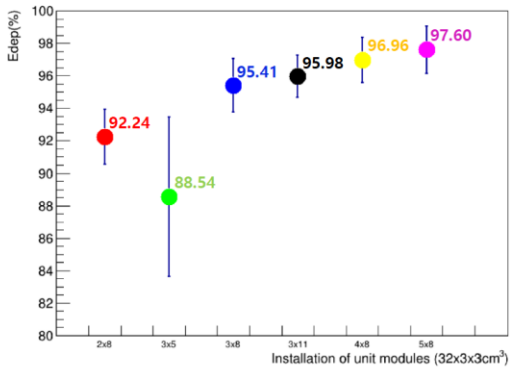


- In case of limited fitting range (not the official result)
- 3 parameters for 4 datapoints
- For the fit with 3 parameters, 6.1% of stochastic term does not make sense in this setup
- We will include more points in future testbeam

Backup: Simulation of prototype



<Energy deposit by electrons at 3 GeV/c>



- **Value** : Edep mean *100 / Beam E
- **Err** : Edep Std Dev *100 / Beam E

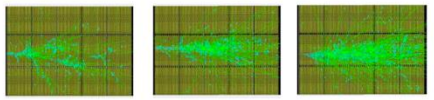
• **3x8 구조 결과**

E (GeV)	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11	M 12	M 13	M 14	M 15	M 16	M 17	M 18	M 19	M 20	M 21	M 22	M 23	M 24
0.5	0.5	1.7	2.0	1.5	0.8	0.4	0.2	0.1	22.5	33.3	17.7	7.6	3.0	1.2	0.4	0.2	0.5	1.6	1.9	1.4	0.8	0.4	0.2	0.1
1	0.4	1.4	1.9	1.6	1.0	0.5	0.3	0.1	15.6	32.3	21.3	10.0	4.2	1.7	0.6	0.3	0.4	1.3	1.9	1.5	0.9	0.5	0.2	0.1
2	0.3	1.1	1.8	1.7	1.1	0.6	0.3	0.1	10.5	29.0	24.0	13.0	5.8	2.4	0.9	0.4	0.3	1.1	1.7	1.6	1.1	0.6	0.3	0.1
3	0.2	0.8	1.4	1.5	1.1	0.7	0.4	0.2	8.3	27.0	25.7	14.9	7.0	3.0	1.2	0.5	0.2	0.8	1.4	1.5	1.1	0.7	0.4	0.2
4	0.2	0.9	1.7	1.7	1.3	0.8	0.4	0.2	7.0	24.9	25.6	15.6	7.6	3.3	1.4	0.5	0.2	0.8	1.6	1.7	1.2	0.7	0.4	0.2
5	0.2	0.8	1.6	1.7	1.3	0.8	0.4	0.2	6.2	23.7	25.9	16.5	8.2	3.6	1.5	0.6	0.2	0.8	1.5	1.7	1.3	0.8	0.4	0.2

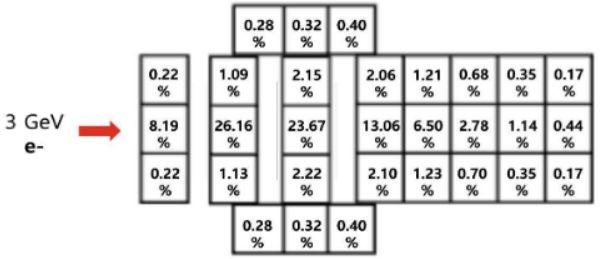
(%)

• **모듈 배치도**

	17	18	19	20	21	22	23	24
→	9	10	11	12	13	14	15	16
	1	2	3	4	5	6	7	8



Backup: simulation for various geometry

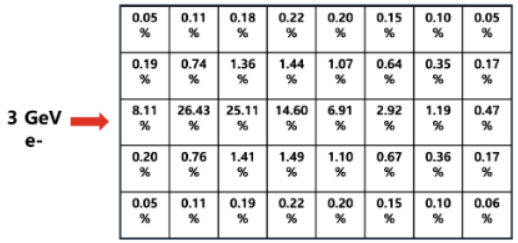


Total Energy Deposit : 2.85 GeV (94.98 %)

3x8+6 Modules

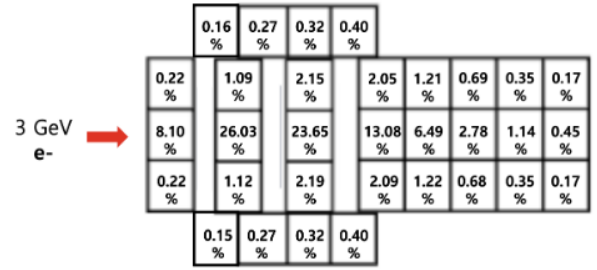
Total Energy Deposit : 2.79 GeV (92.95 %)

3x8+0 Modules



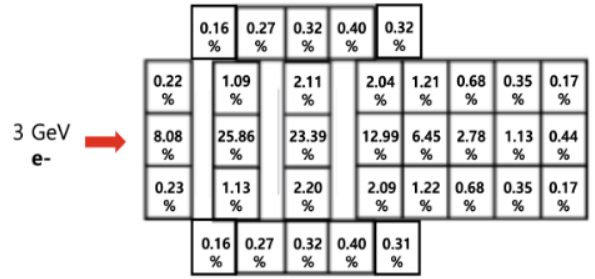
Total energy deposit : 2.93 GeV (97.60 %)

5x8 Modules



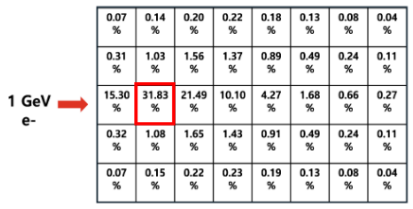
Total Energy Deposit : 2.86 GeV (95.30 %)

3x8+8 Modules



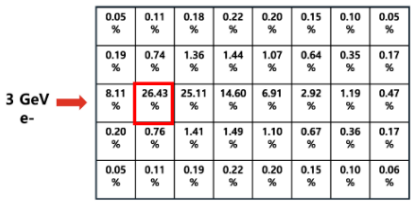
Total Energy Deposit : 2.88 GeV (95.92 %)

3x8+10 Modules



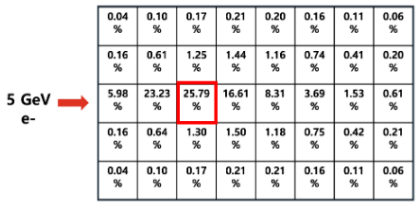
Total energy deposit : 0.97 GeV (97.49 %)

1 GeV beam



Total energy deposit : 2.93 GeV (97.60 %)

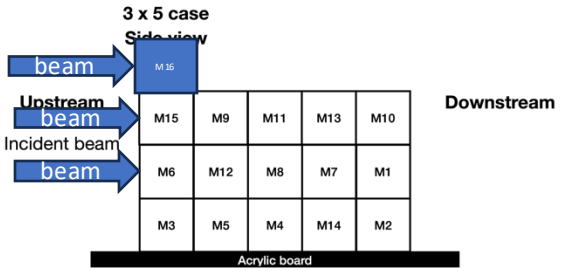
3 GeV beam

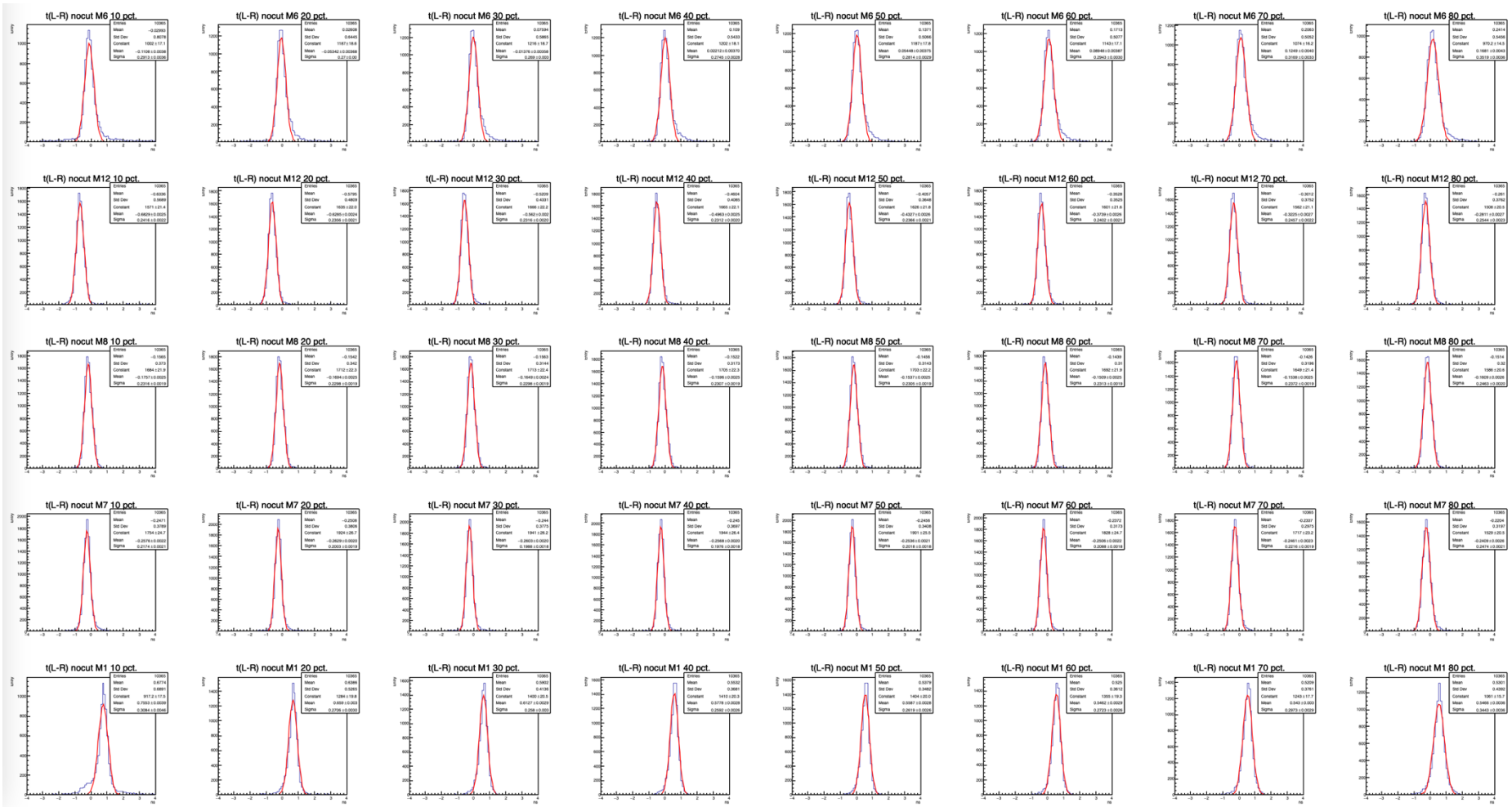


Total energy deposit : 4.89 GeV (97.76 %)

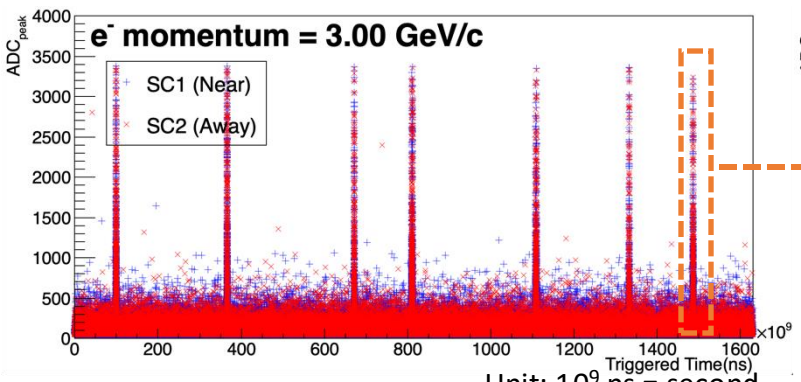
5 GeV beam

Backup: fit result for PMT

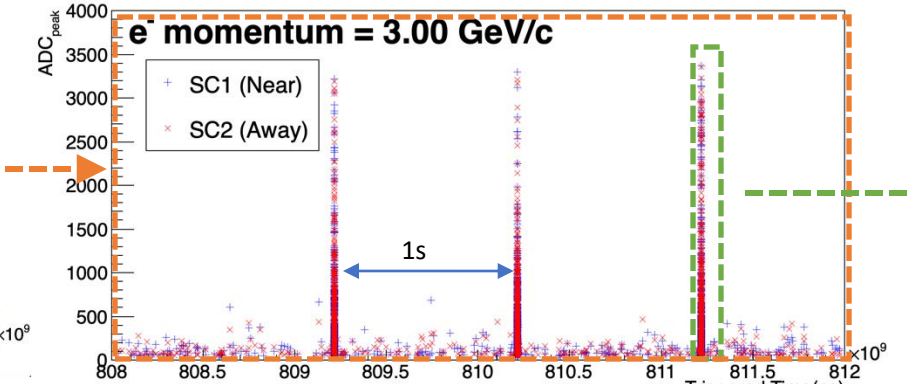




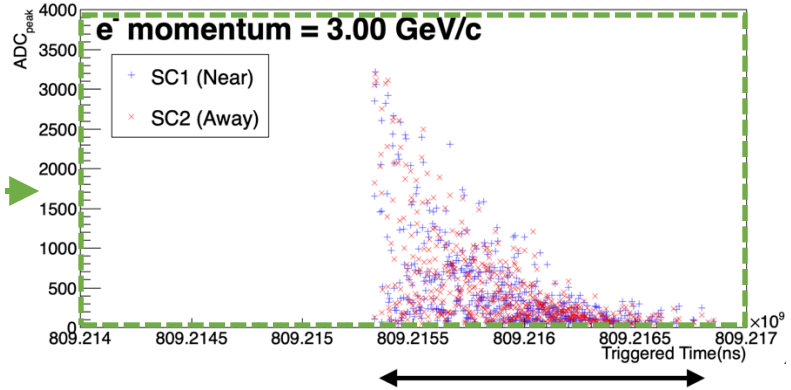
Backup: KEK Beam structure (2024 March)



▲Triggered time versus ADC(∝Deposited Energy)

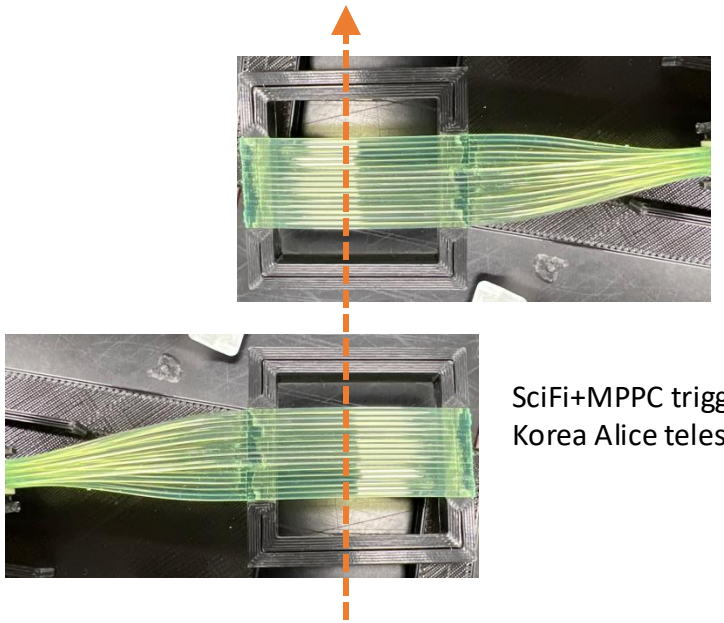


Unit: 10^9 ns = second



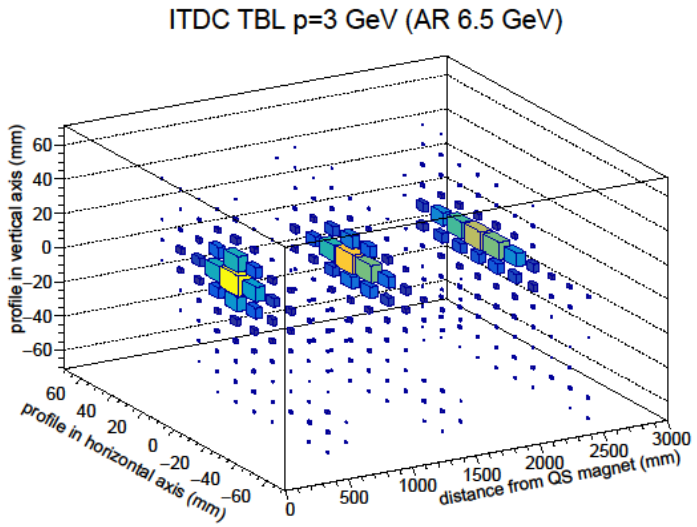
1.5 ms

- 2024 March setup using two triggers of SciFi-MPPC
- Additional injection ~ms in every ~100s
  - 3 peaks in an additional injection
  - VETO out is prepared in the control room.
    - need to consider how to include veto in our DAQ and reject signal
- Otherwise, rate seemed stable



SciFi+MPPC trigger for Korea Alice telescope

Backup: KEK Beam profile along beam axis



Momentum and AR operation Beam energy	Direction	Z = 0.65 m	Z= 1.50 m	Z=2.50 m
3 GeV @ AR 6,5 GeV	Horizontal	10.0 mm	12.9 mm	14.8 mm
3 GeV @ AR 5.0 GeV	Horizontal	10.2 mm	12.8 mm	----
3 GeV @ AR 6,5 GeV	Vertical	8.9 mm	7.1 mm	5.2 mm
3 GeV @ AR 5.0 GeV	Vertical;	8.9 mm	7.0 mm	-----

- Beam width in sigma (gaussian fit) in beam axis direction
- Z=0 is at the edge of the last quadrupole magnet.

Table

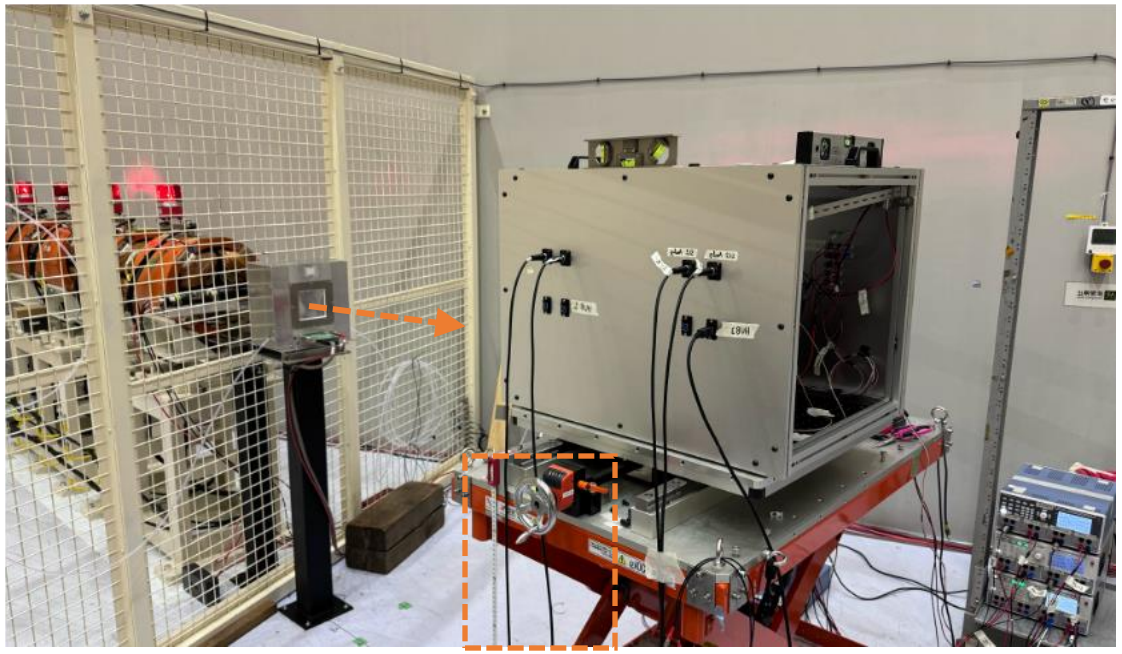
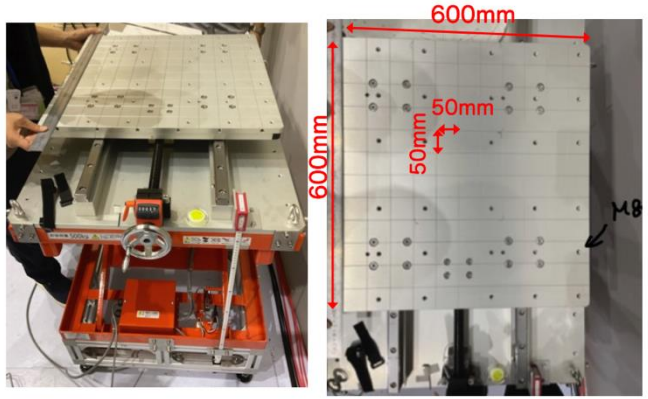


Table for the setup



- Table at test area
  - Height adjustable in 555-1275mm
  - Beam position: 1185mm
  - Movable horizontally too
  - See the attached drawing for more detailed geometry
- Laser for alignment available

- Movable stool on the table
  - Horizontal move: wheel counter
  - Vertical move: tape ruler
  - Table itself is movable
- Table dimension
  - Only one table: Aluminum profile should be prepared if we need more space.
  - Stool size match to the Telescope
    - 550(x)×550(y)×700(z) mm3
- A frame+stool, a desk for power supply and others.
- If we need more ancillary detectors out of table, we have to consider Aluminum profile.