The Silicon Tracking System of the E16 experiment at J-PARC: commissioning and results from the test beam

12th Beam Telescopes and Test Beams Workshop

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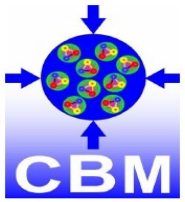
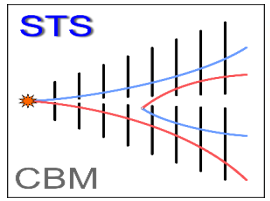
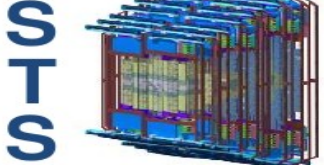
for the CBM and E16 collaboration







Outline

- E16 experiment at **J-PARC**
  - Physics motivation
  - Experimental setup
- E16-STS built with CBM-STS modules
  - Description
  - Testing results
- **KEK PF-AR** test beam line
- Commissioning at **KEK** in **PF-AR** facility
  - **ENC** and calibration performance
- Results from the test beam
- Summary

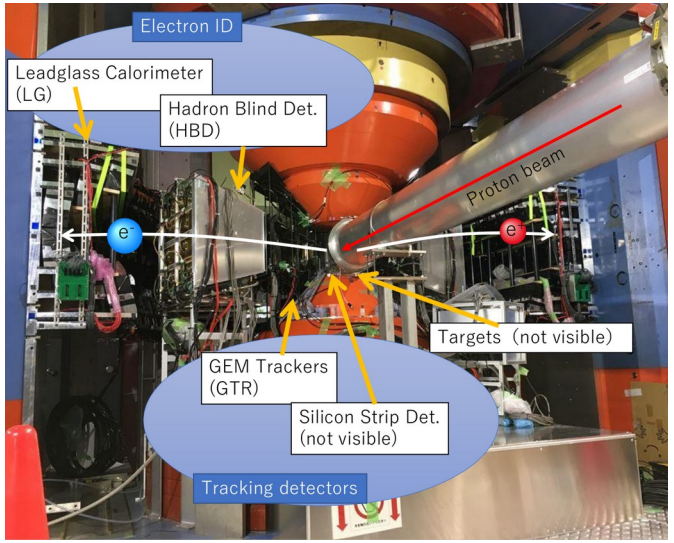
Physics motivation for E16 & experimental setup

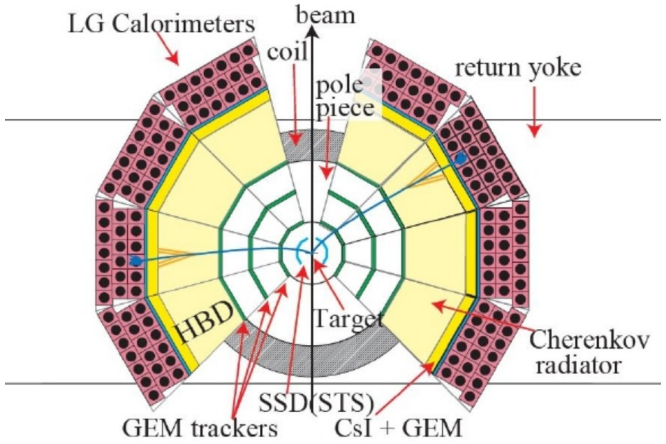
E16 intends to measure

- p + (C, Cu, Pb, CH_2) -> (ρ, ω, φ) + X
- p + A interaction rate: 10 MHz (10 times higher than **KEK E325**)
- Measuring vector mesons via e^+e^- decay
- 100 times higher statistics than **KEK E325** and better resolution σ = 5 MeV for φ
- **Setup**
  - Target chamber in the center
  - 30 GeV primary proton beam
- **Detectors**

  tracking:
  - Silicon Strip Detector
  - GEM tracker

  electron identification:
  - Hadron Blind (Cherenkov)
  - PbGl calorimeter





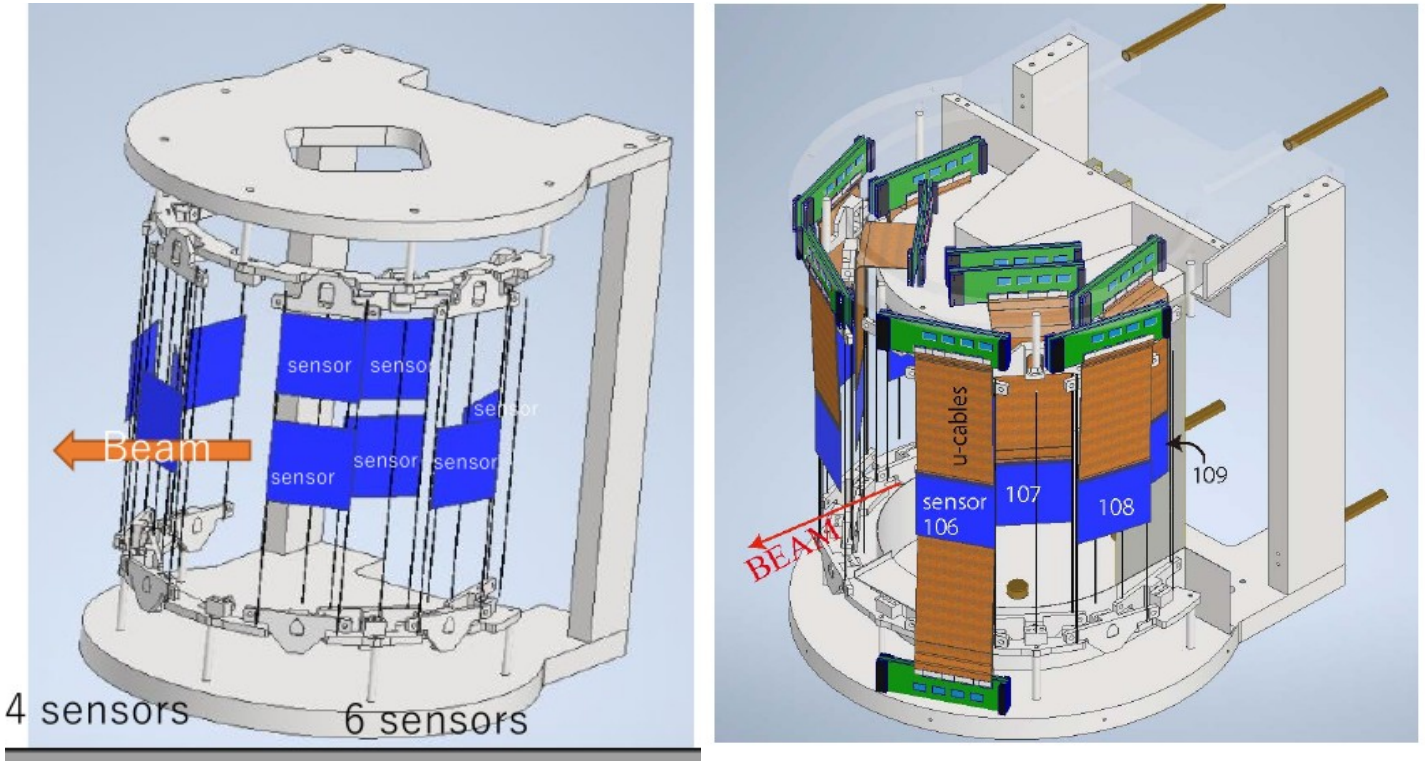
CBM Silicon Tracking System (STS) in the E16 experiment

STS modules features:

- Light weight
- High rate capability
- Fine segmentation
- Double-sided readout
- Position resolution 30 μm
- Time resolution 5 ns

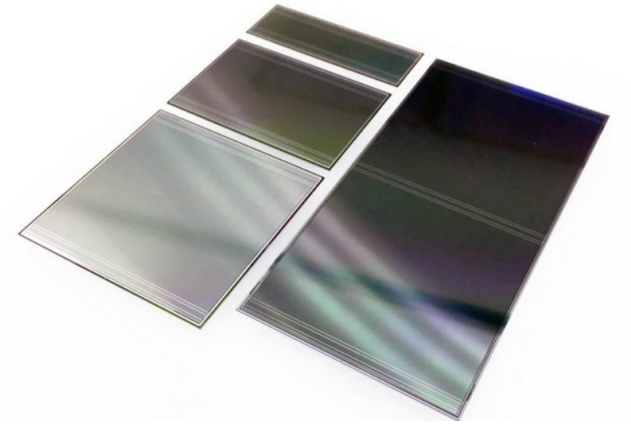
E16 tracker design is based on 10 STS modules built with:

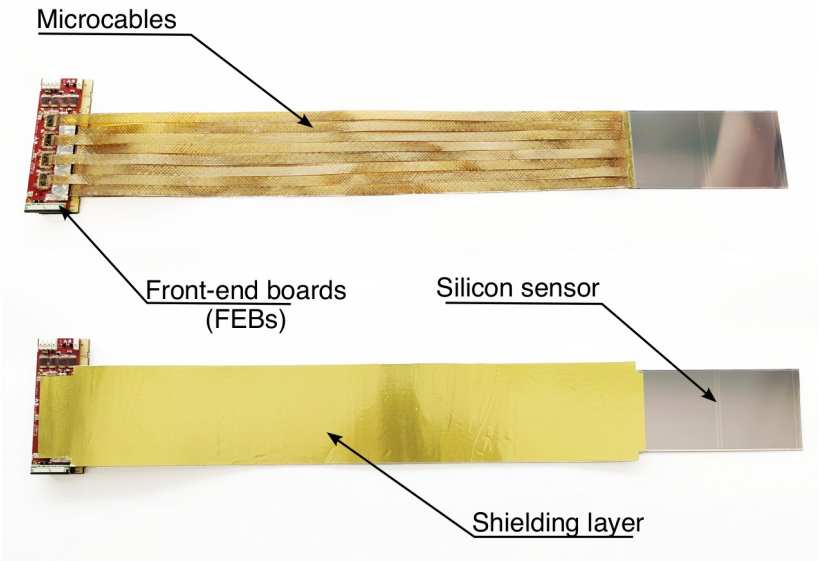
- 6.2 x 6.2 cm^2 sensors
- FEB8-v3 with 2 data uplinks/ASIC
- Carbon fiber ladders of 231 mm, capable to accommodate up to 3 sensors
- Cooling: 2 cooper pipes



Design of the Silicon Strip Detector in the E16 experiment

CBM Silicon Tracking System (STS) modules





- Building block of the STS
- Double-sided silicon sensor with different sensor sizes:
  - 2.2 x 6.2 cm^2, 4.2 x 6.2 cm^2, 6.2 x 6.2 cm^2, 12.4 x 6.2 cm^2
- Stack of low material budget polymide microcables
- Front-end boards
  - each FEBs carry 8 custom-designed ASICs
  - Self-triggered ASIC with 128 readout channels
  - Each channel has a double path architecture for signal processing:
    - FAST path for accurate timing (14 bits TDC)
    - SLOW path for amplitude measurement (5 bits FLASH ADC)

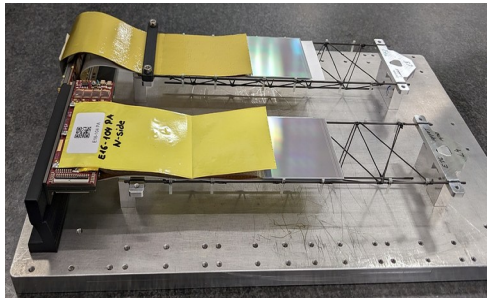
E16-STS Assembly and Testing

- 10 pre-series (FEB, microcables) modules were built, assembled and tested at GSI

Module Testing

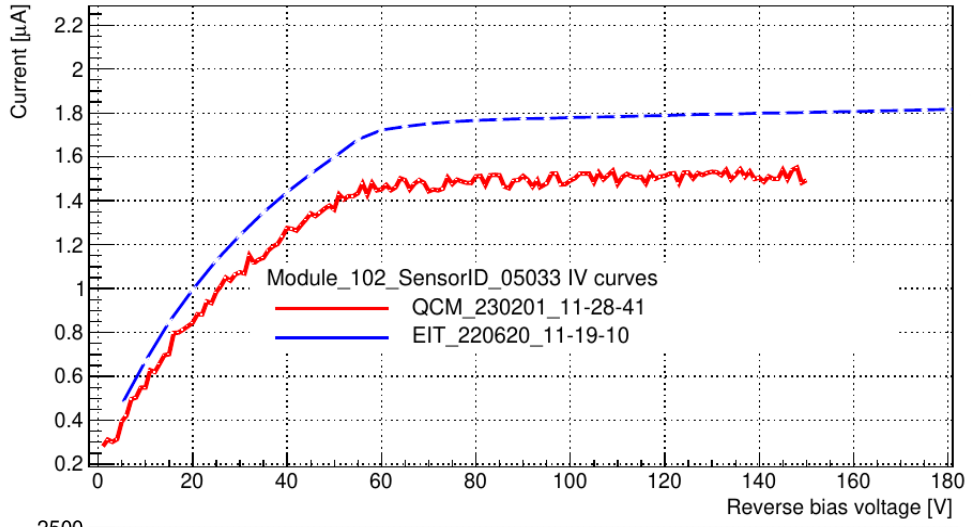
- To identify issues and try to solve them
- To calibrate the measuring circuits
- To ensure the quality of the produced object and to provide a reliable, full-working object to the next steps

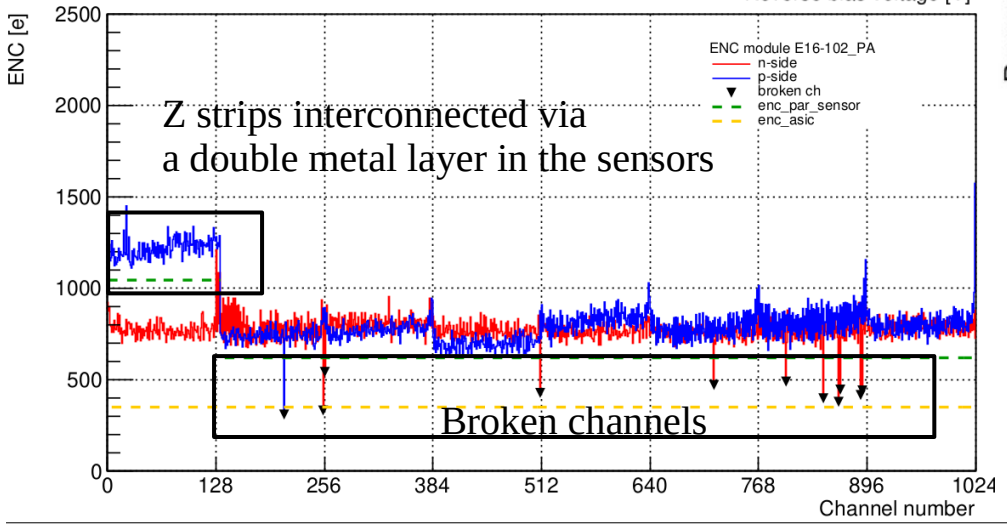
- ENC noise average of 800 e
- Fulfilled the target goal of 1.5% broken channels
- Modules were mounted onto a carbon fiber ladder and sent to Japan

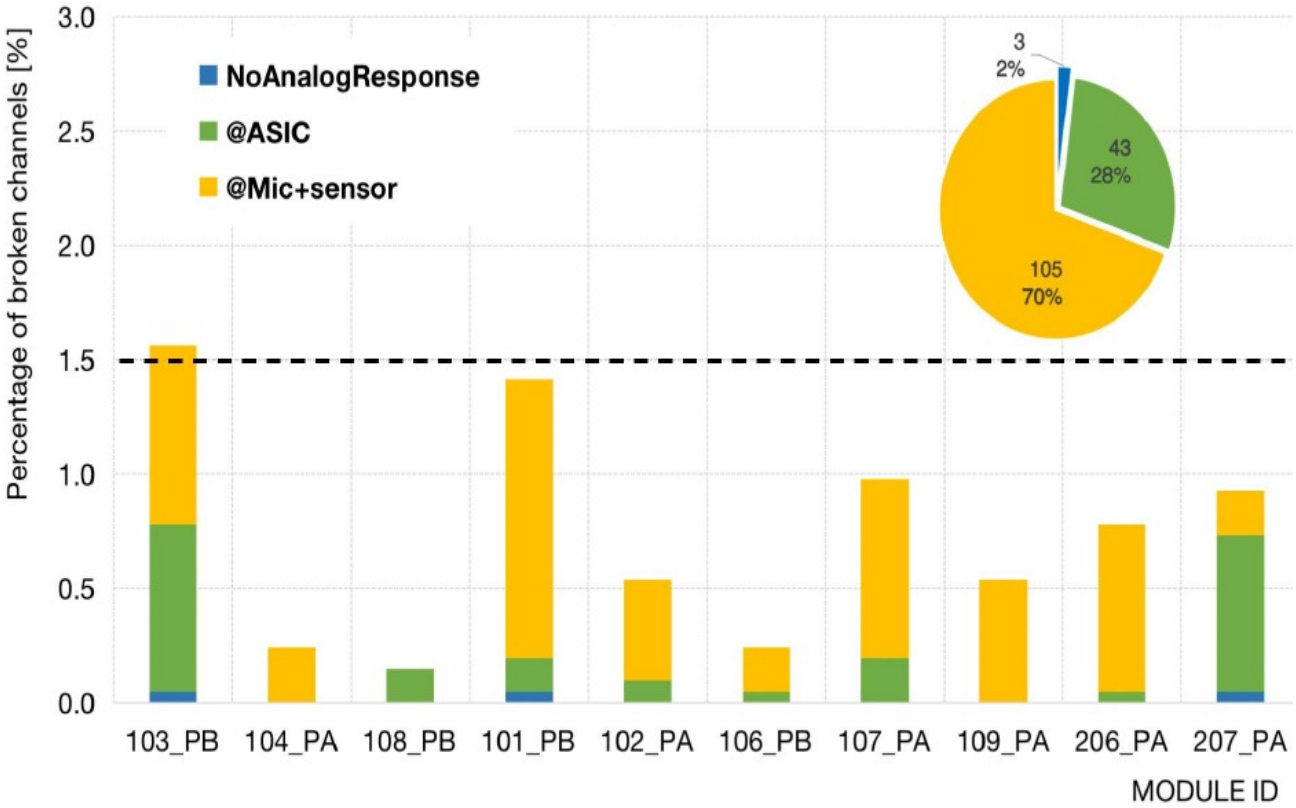


E16-STS chamber with 10 modules mounted onto ladder

E16-STS Testing Results

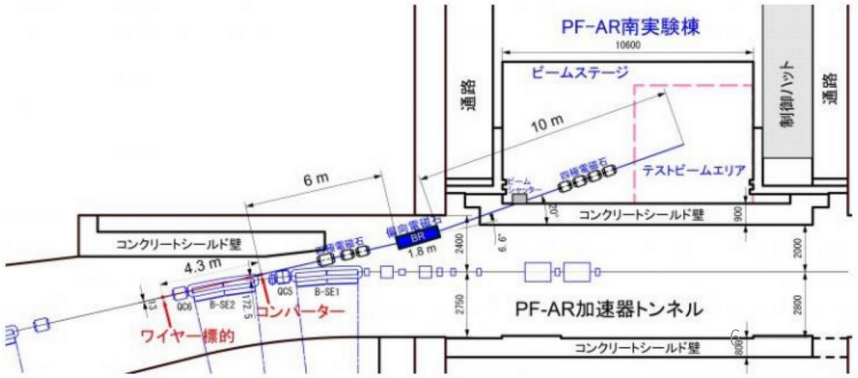




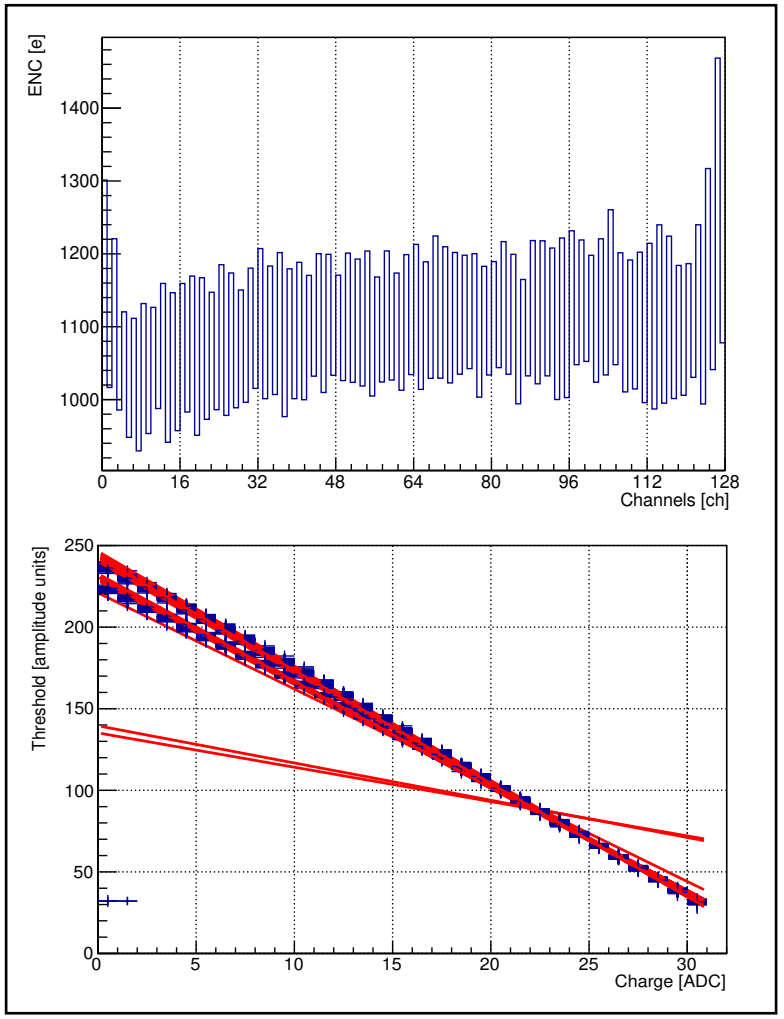


KEK PF-AR test beam line

- The beam line was recently constructed and became available at KEK Tsukuba Campus in 2022
- The **P**hoton **F**actory - **A**dvanced **R**ing
  - electron storage ring, 5 GeV or 6.5 GeV depending on the operation mode. A wire target is inserted inside the PF-AR ring. Extracted Gamma is converted to electrons / positrons by means of a converter
- The beamtime was conducted in November 2023



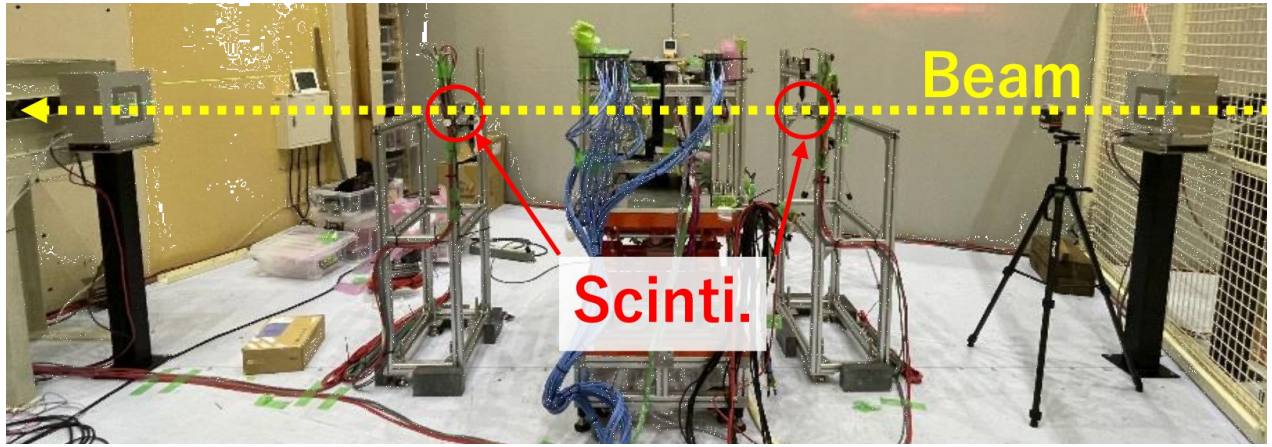
Commissioning at KEK in PF-AR facility



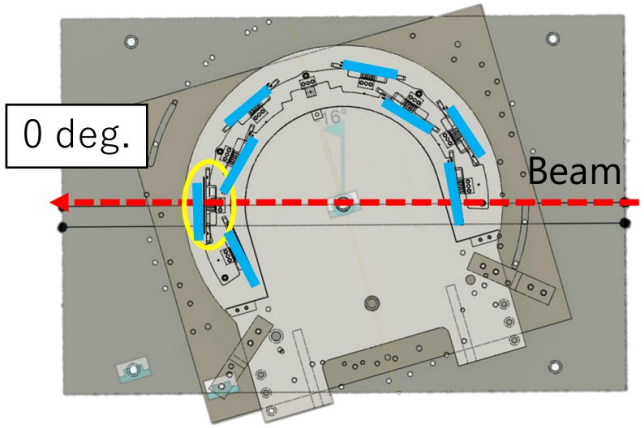
ENC and ADC gain measured on site for 1 ASIC of a tested module

- High odd-even difference in ENC
- Two differences ADC gain for odd and even channels
- Instability in the communication with the modules when increasing the biasing voltage
- Source of the problem identified: improved noise figure and system communication

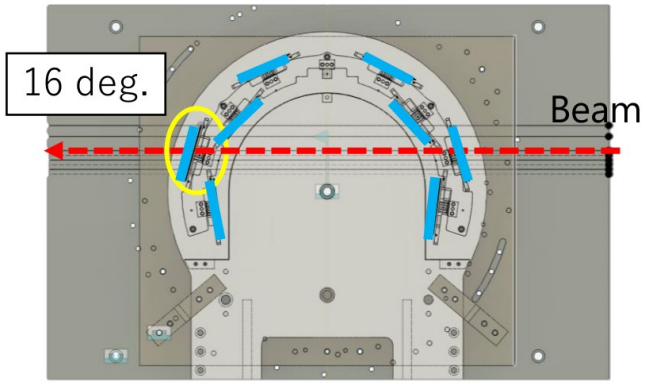
Test beam line Setup



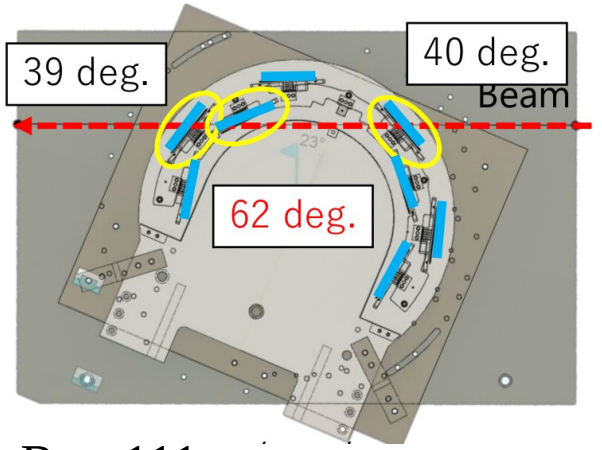
- Electron beam: 3 GeV/c
- Beam rate: ~20 Hz
- Setup
  - E16-STS chamber + 4 scintillators
  - 3 differents configurations



Run 91

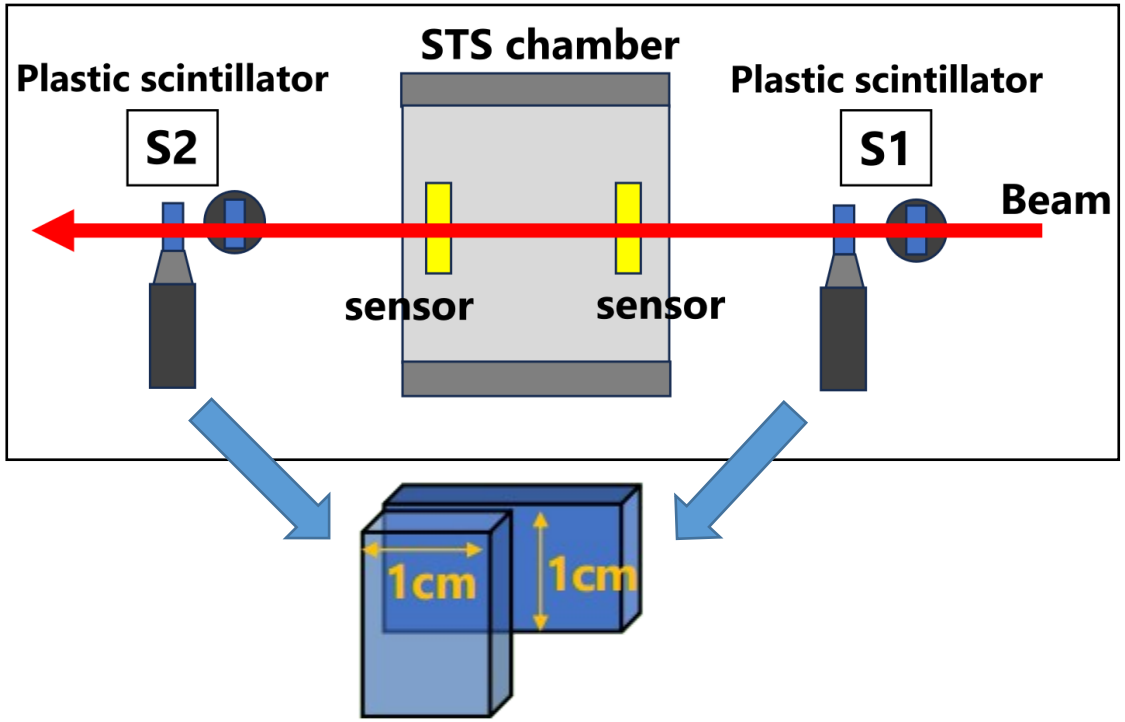


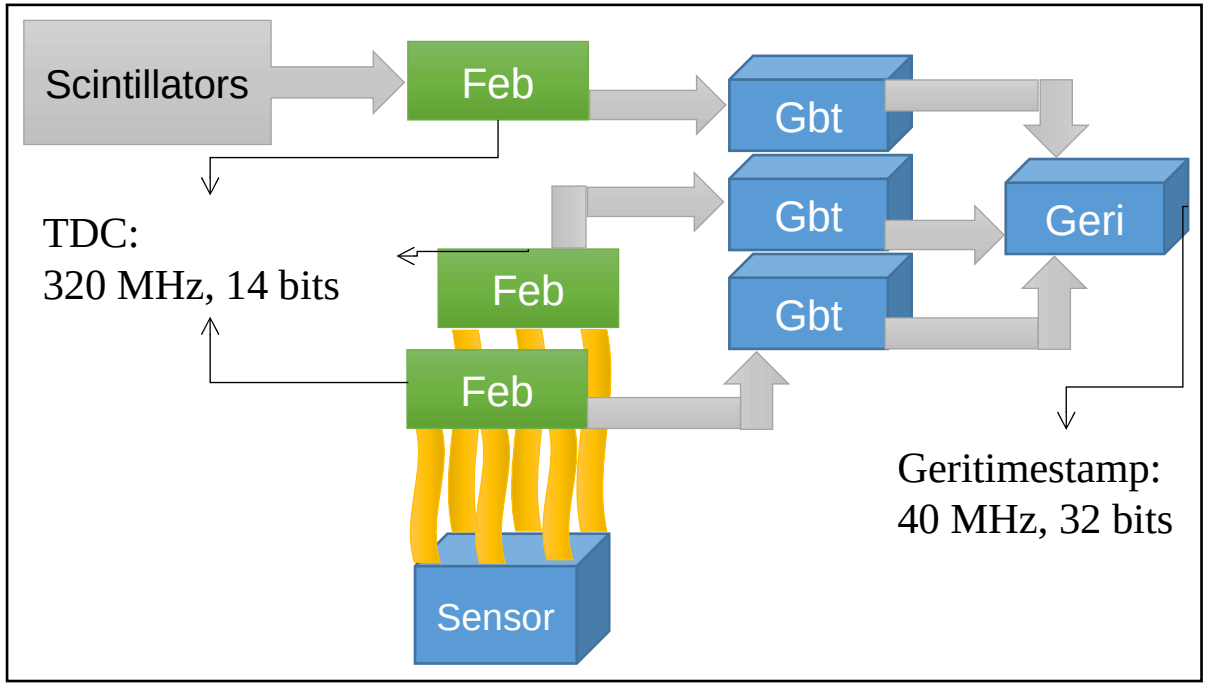
Run 81



Run 111

Test beam line Setup and Readout chain



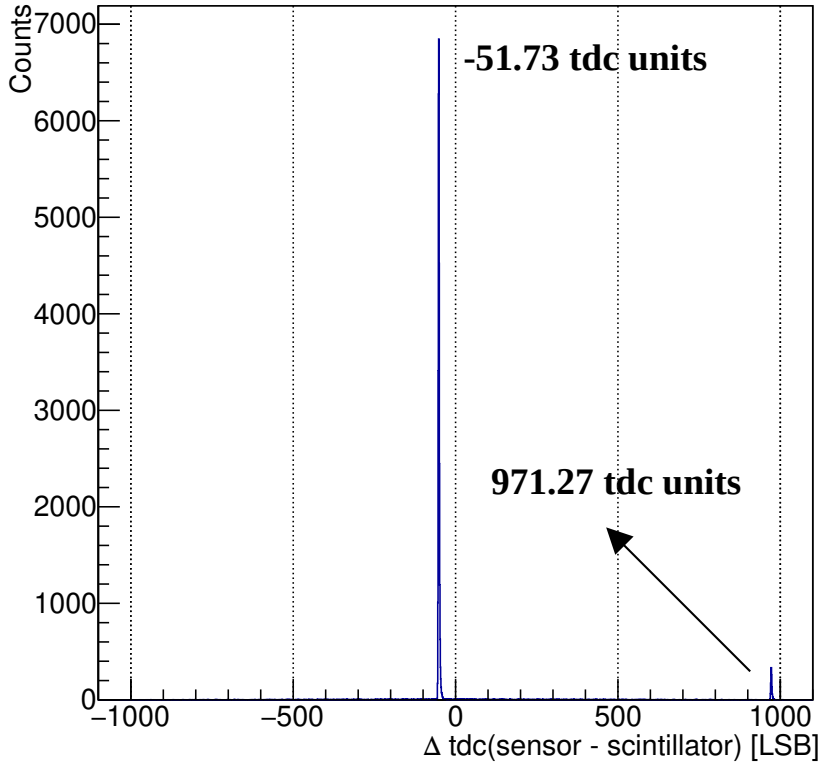


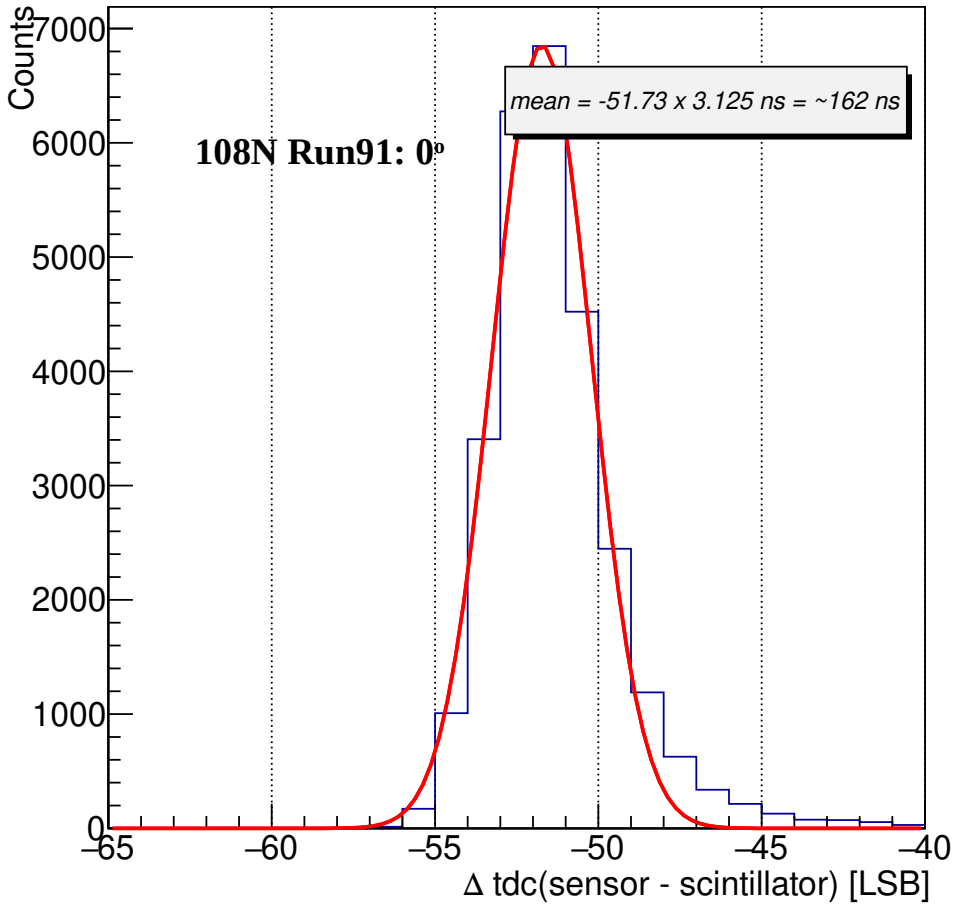
- Active area determined by scintillators S1 & S2: **1 cm²**
- the candidates hits are chosen in the GERI readout board: **scintillators and sensor's geritimestamp "close it"** (± 500 ns)

Results from the test beam Time Coincidence

First step:

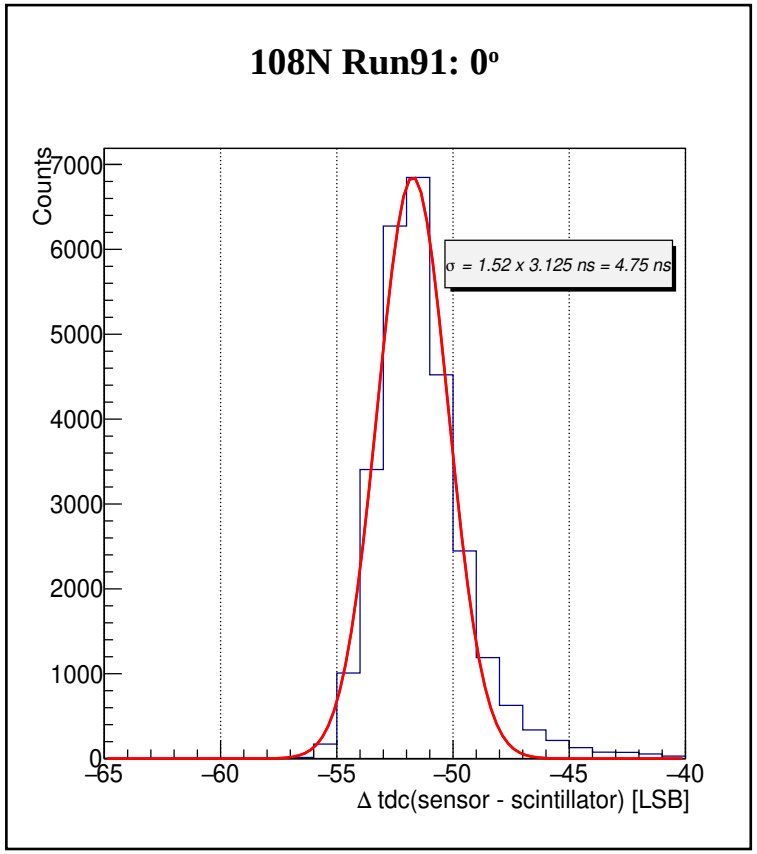
- Identification of coincidence hits between sensors and scintillators in a time window of ± 20 (500 ns)

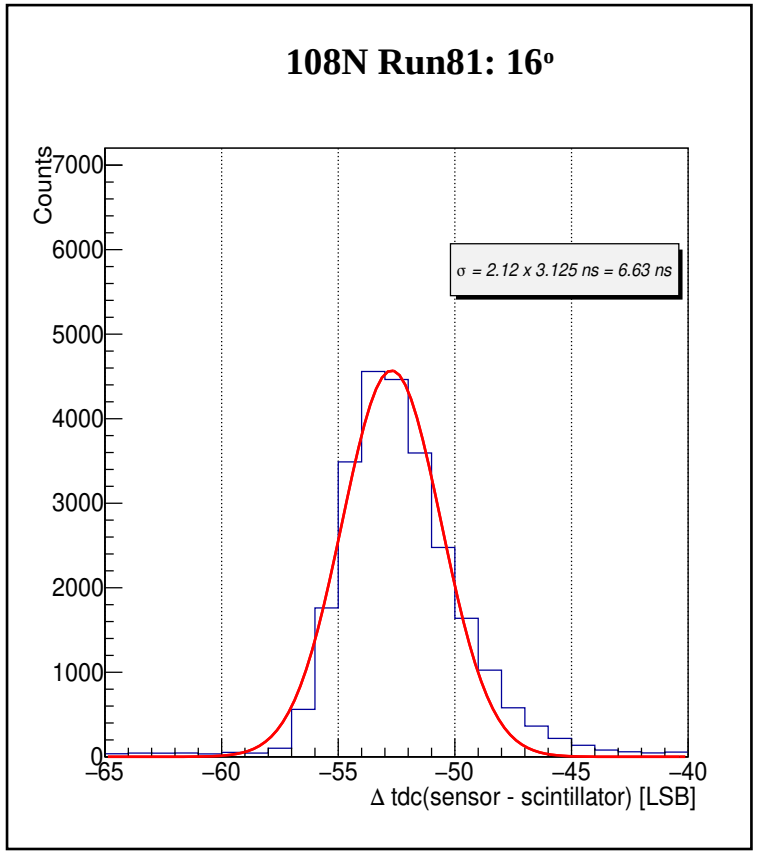


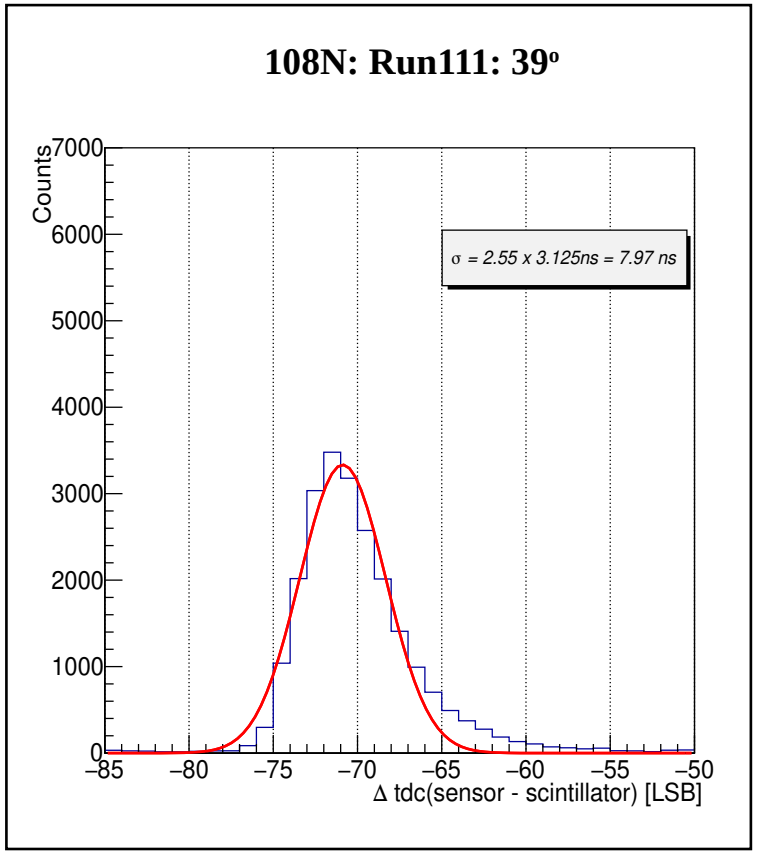


- Coincidence sensor - scintillators

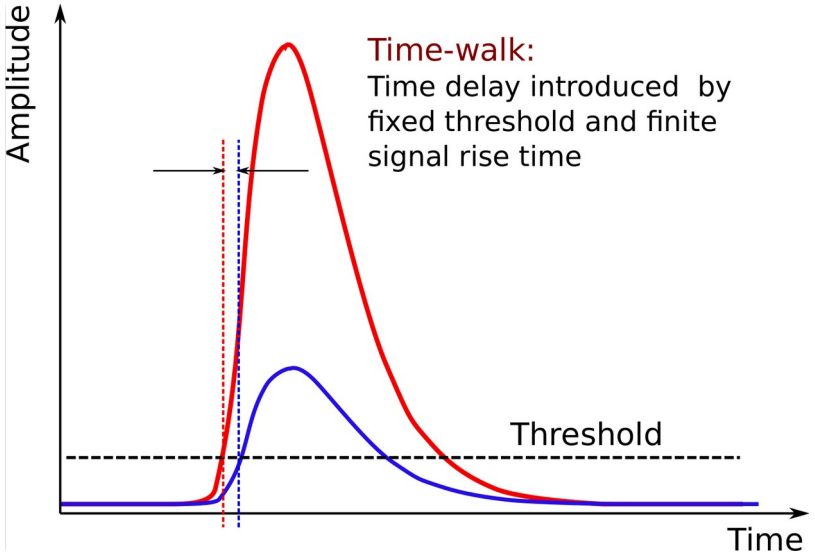
Results from the test beam Time Resolution

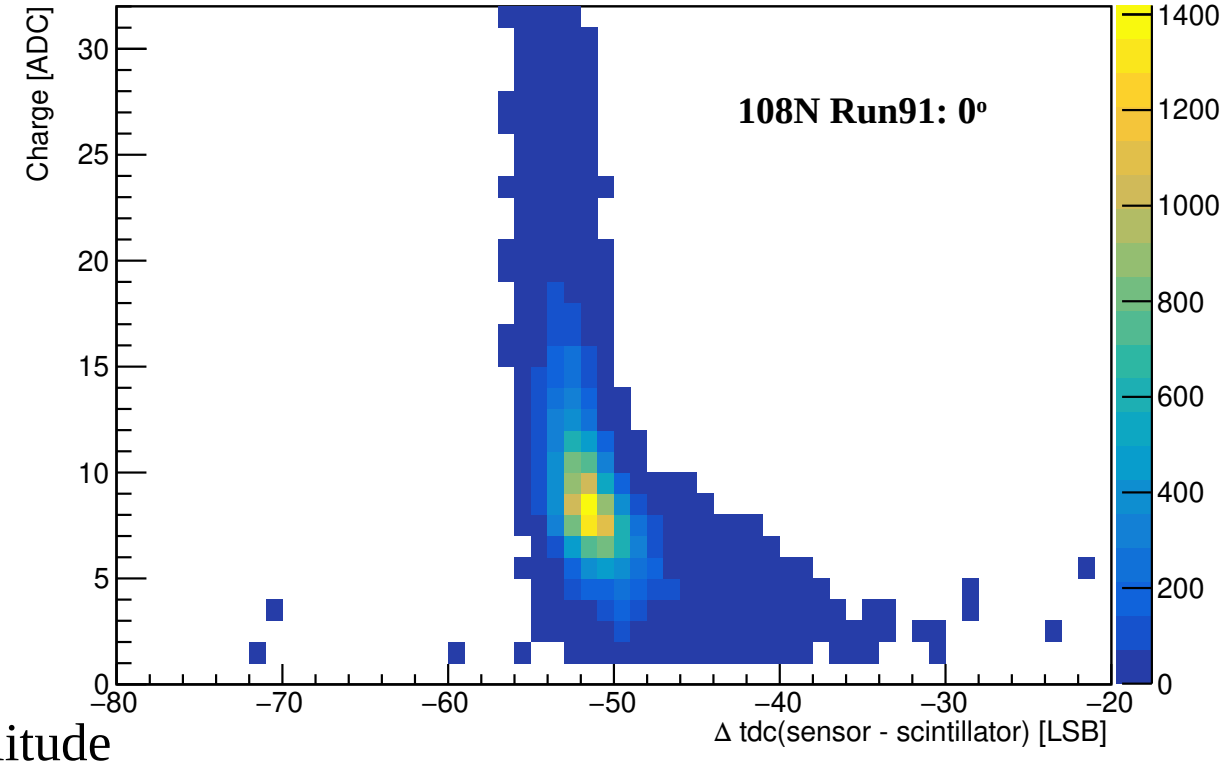






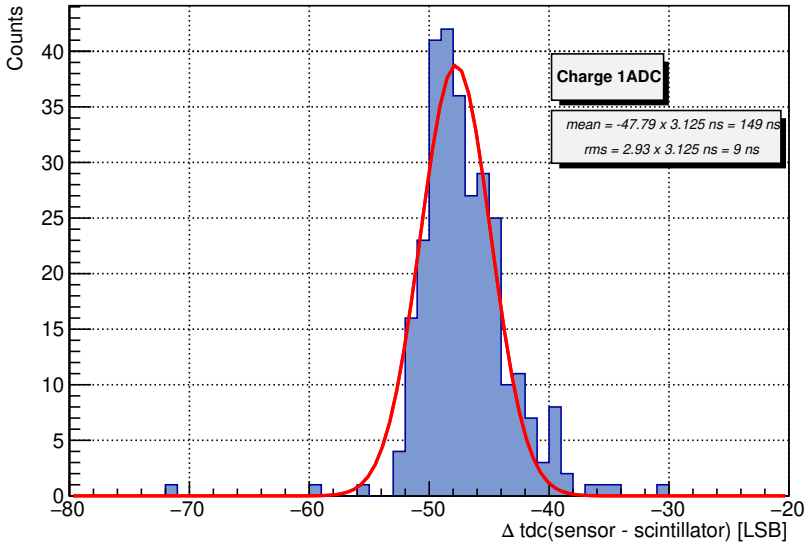
Results from the test beam Time Walk

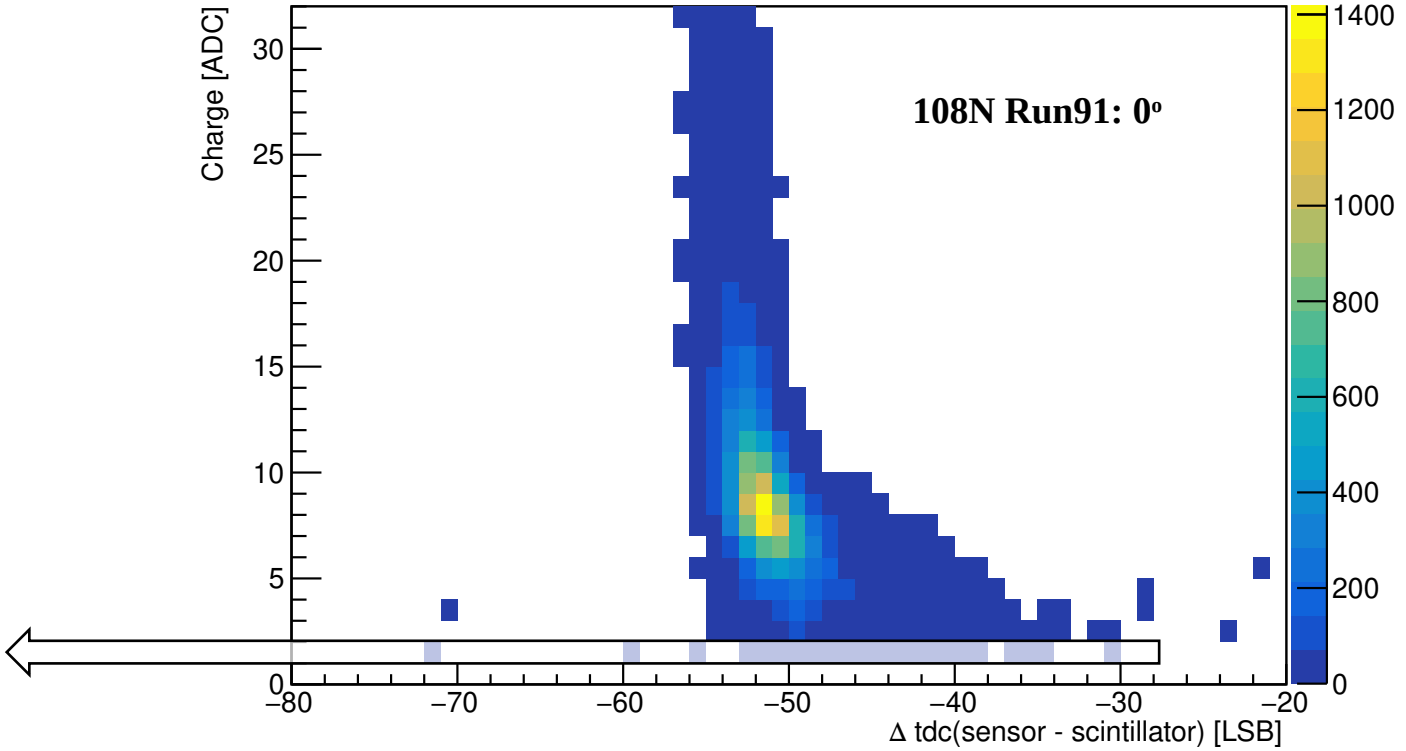




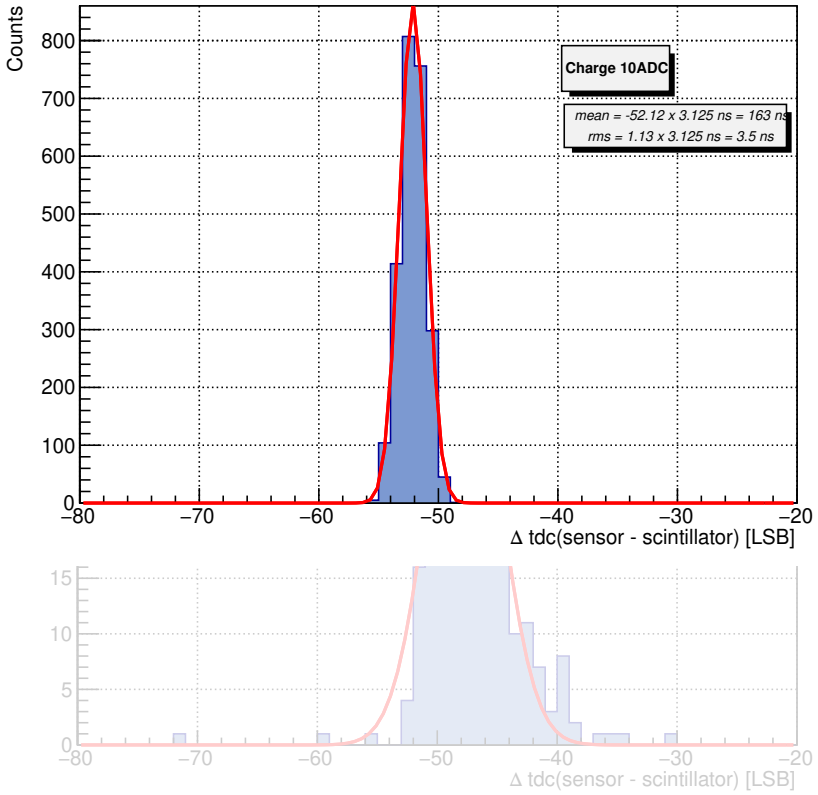
- Electronic effect
- Larger delay for the signals with lower amplitude
- Processed offline

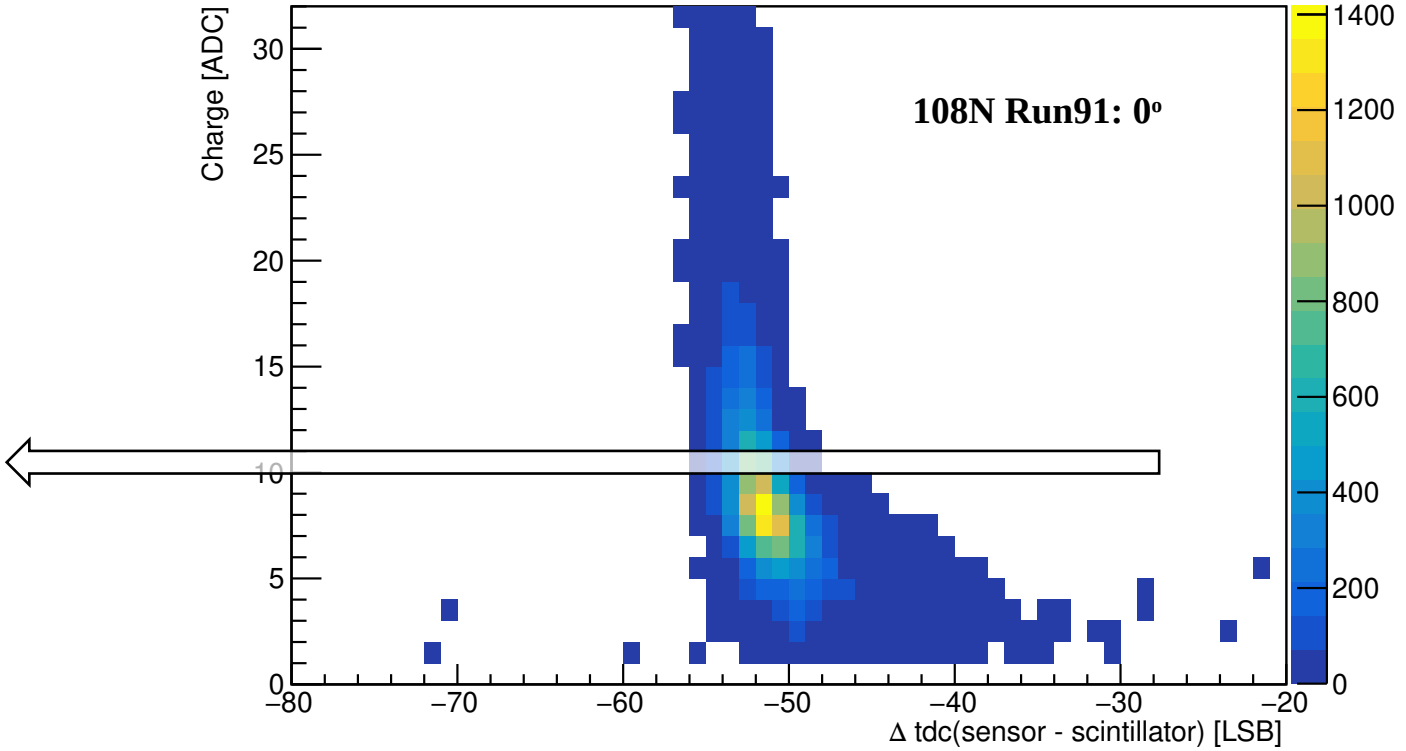
Results from the test beam Time Walk



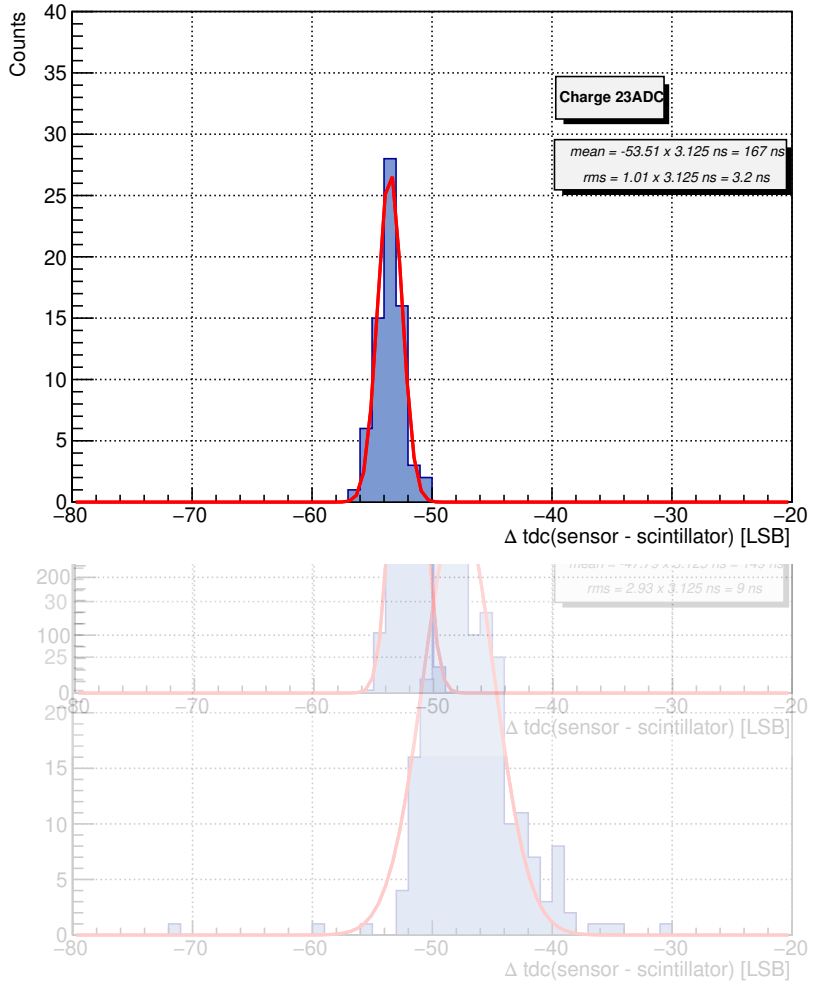


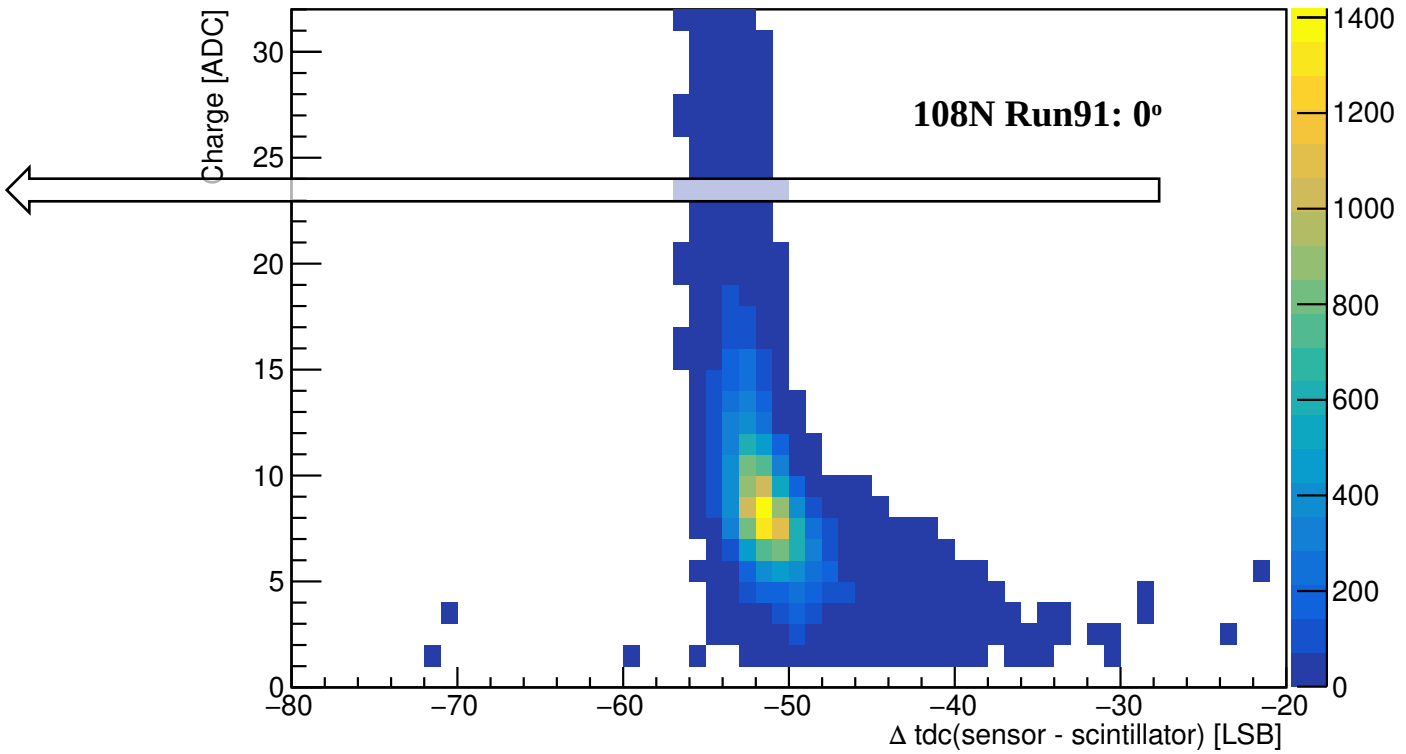
Results from the test beam Time Walk



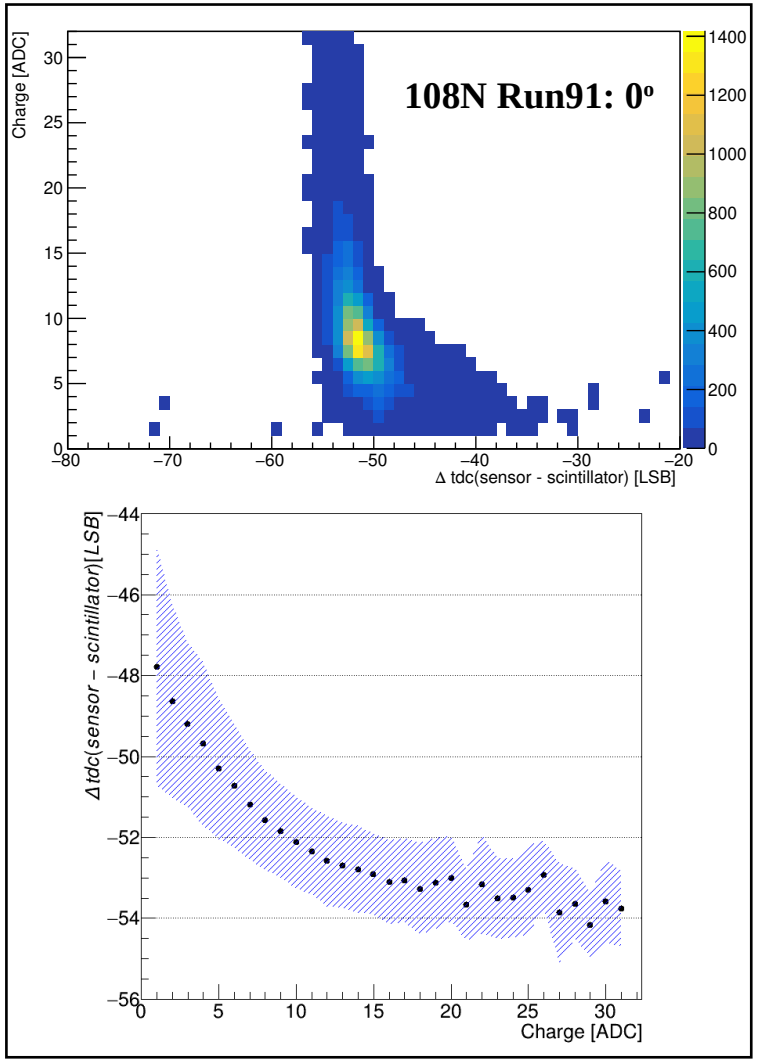


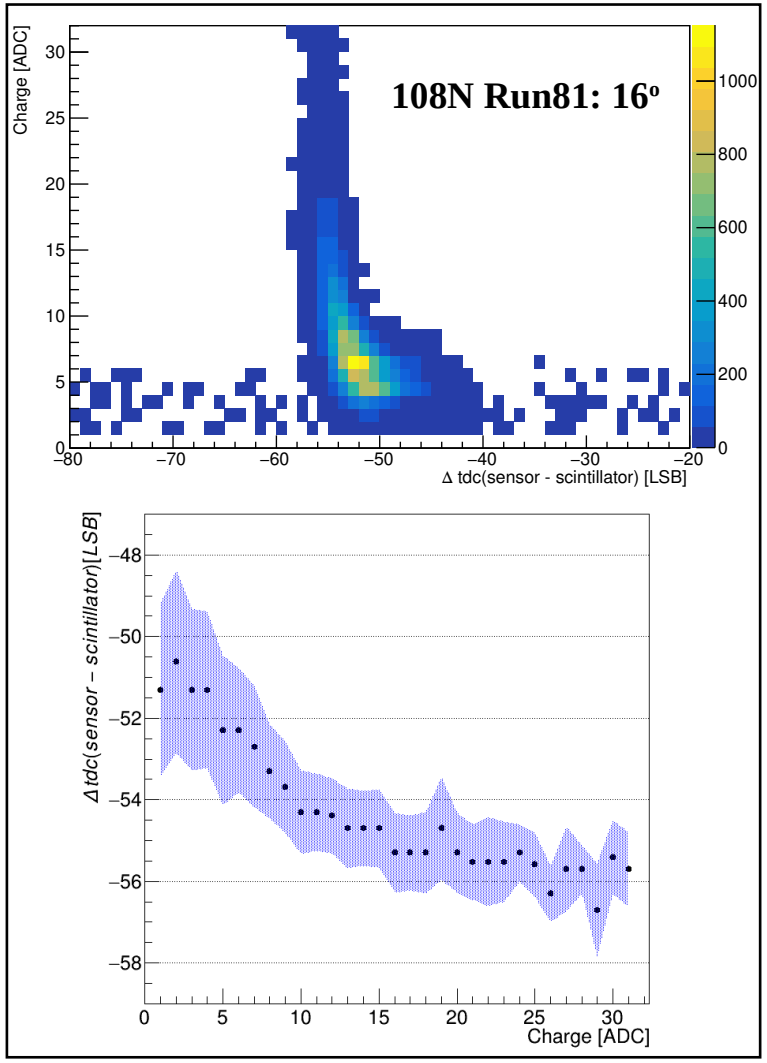
Results from the test beam Time Walk

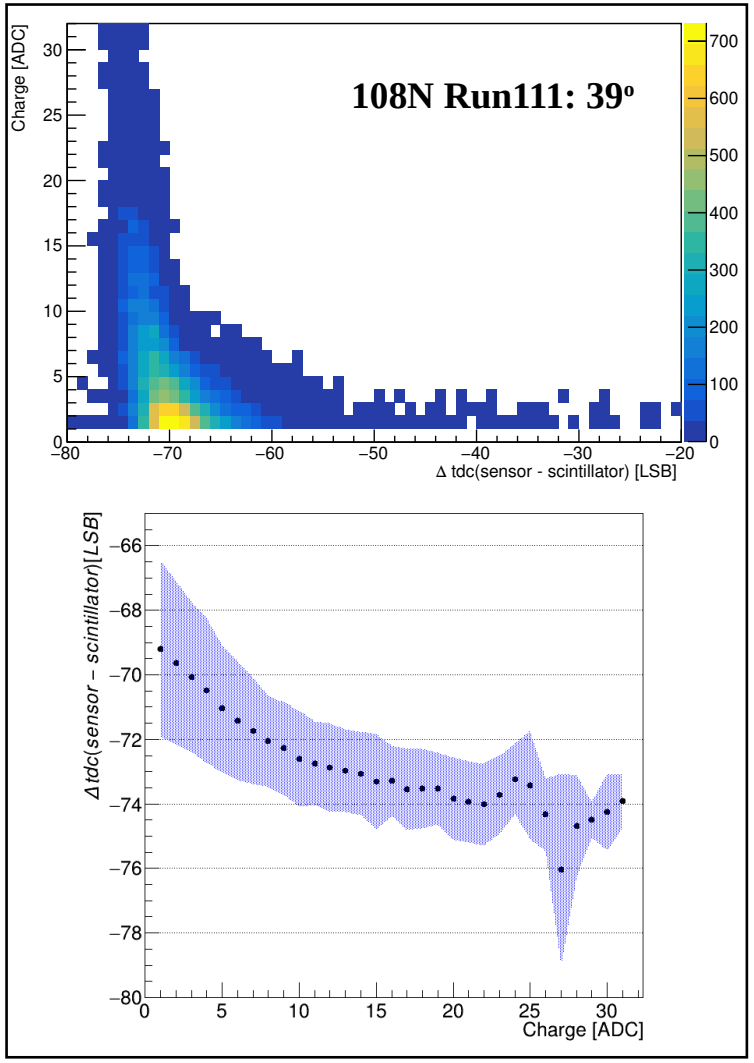




Results from the test beam Time Walk

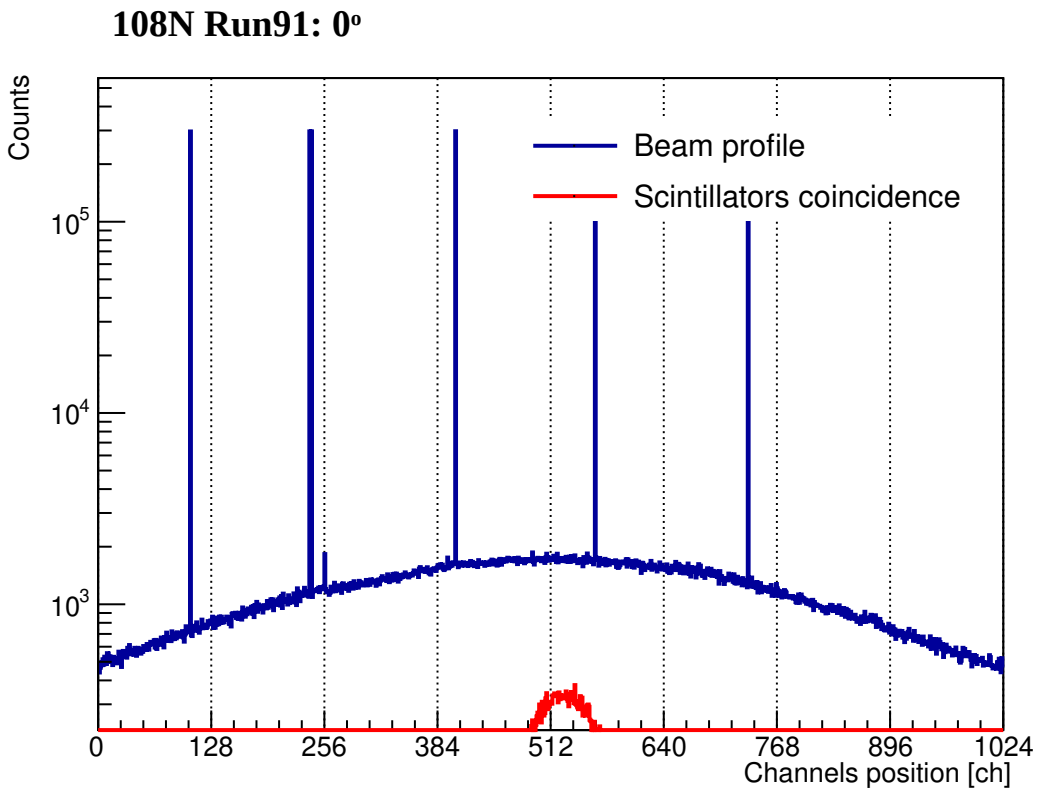


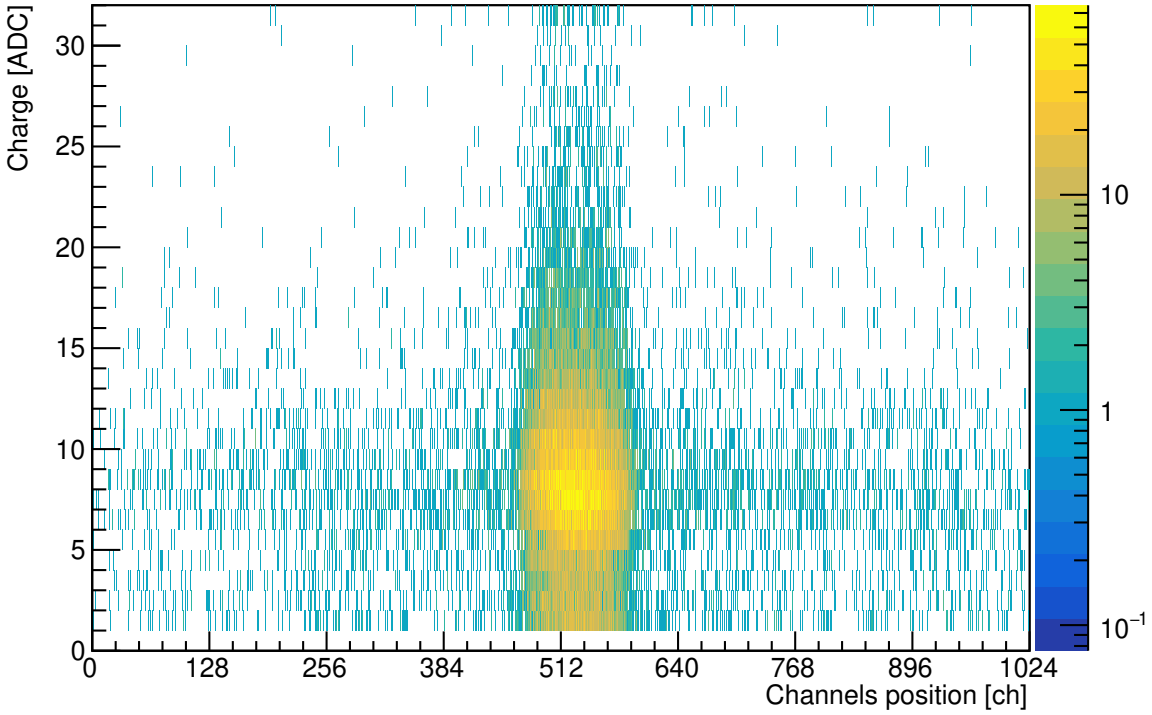




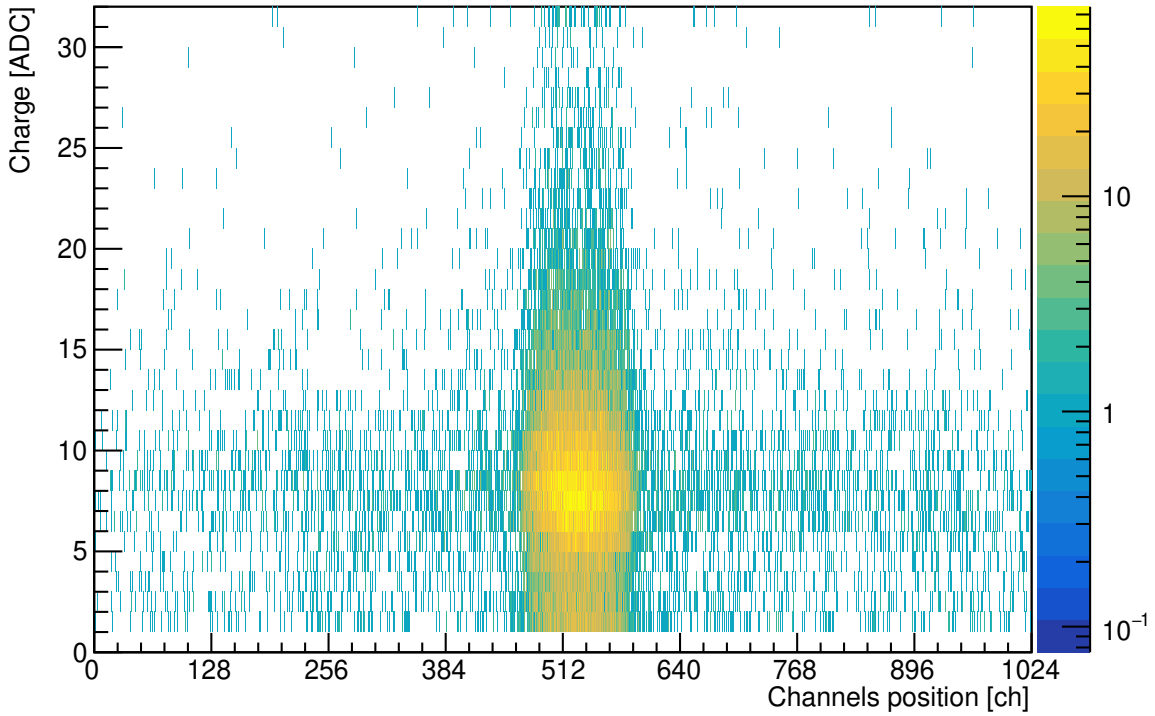
Results from the test beam Hit Profile & Charge

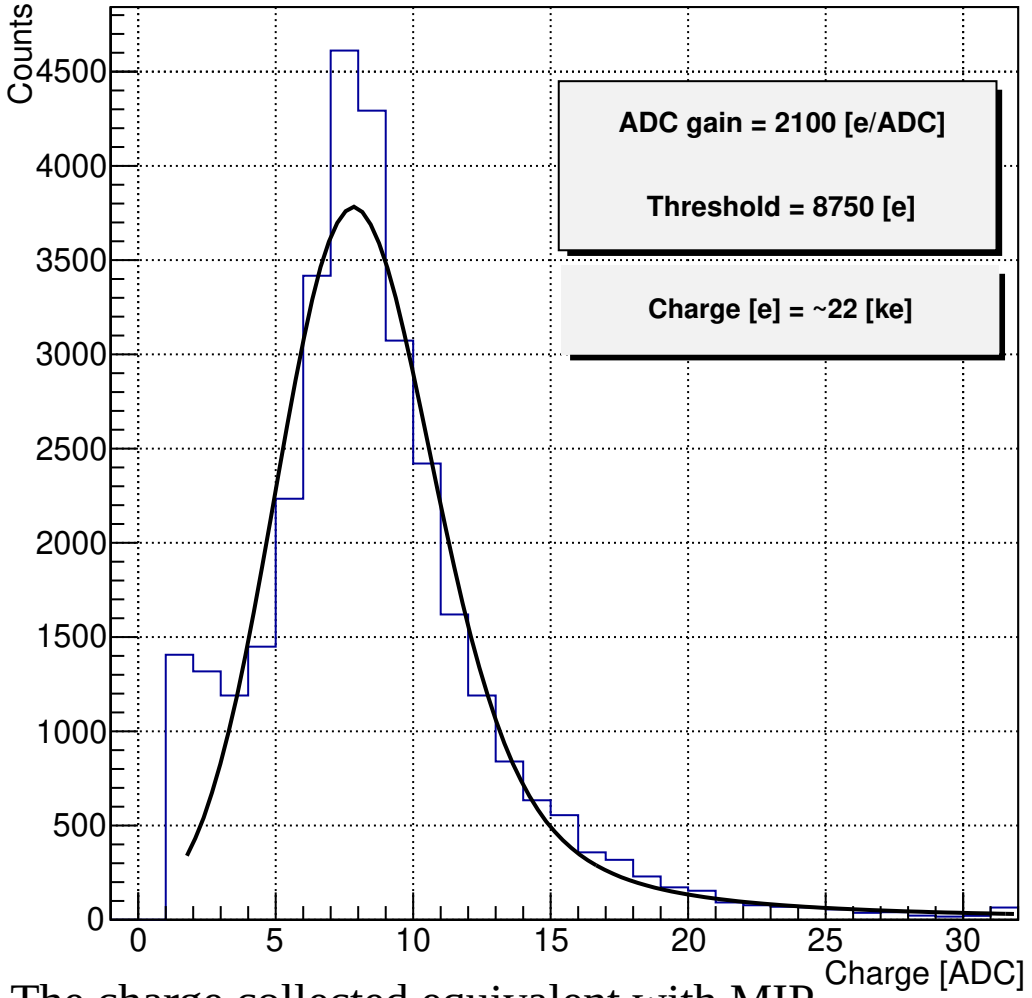
- Beam profile with some noisy channels (blue)





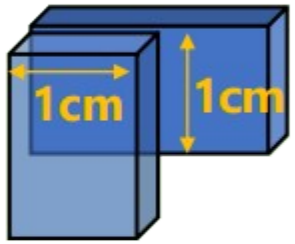
Results from the test beam Hit Profile & Charge





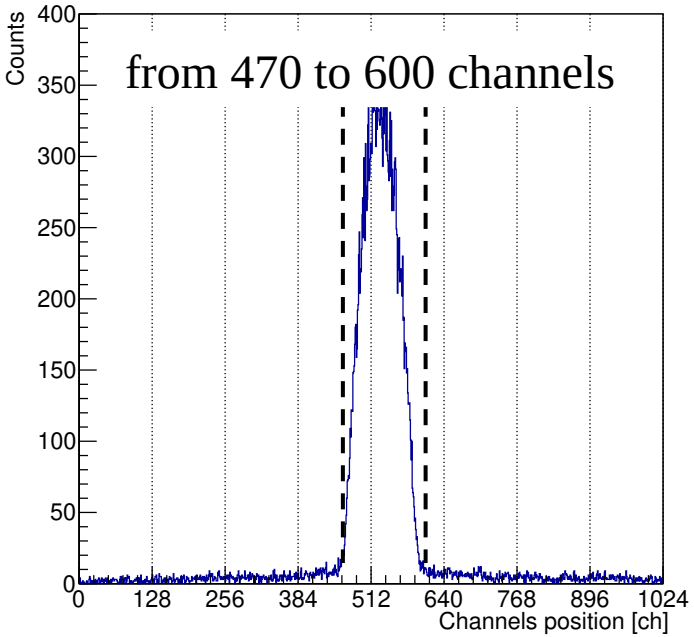
- The charge collected equivalent with MIP

Results from the test beam Cuts & Efficiency

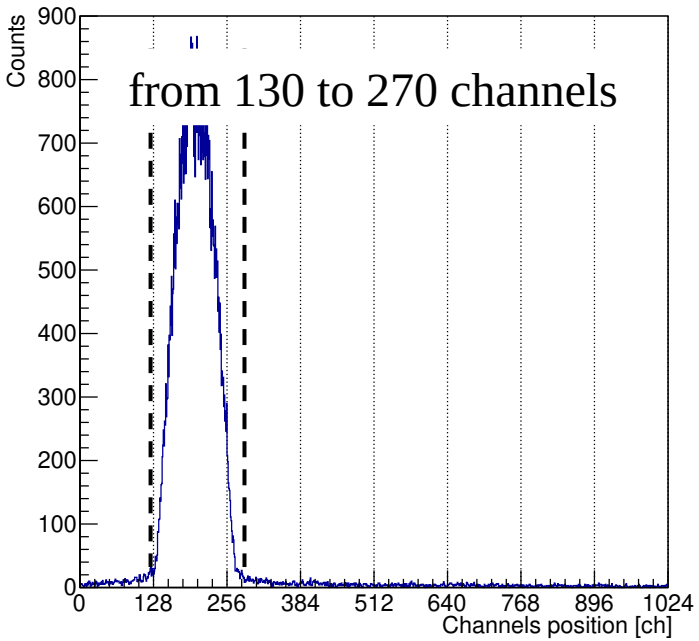


Reminder : area restricted by scintillators 1 cm^2

108N Run91: 0º



108N Run81: 16º



Time window:

- $-55 < \Delta_{peak}(\text{sensor - scintillator}) < -40$

Efficiency:

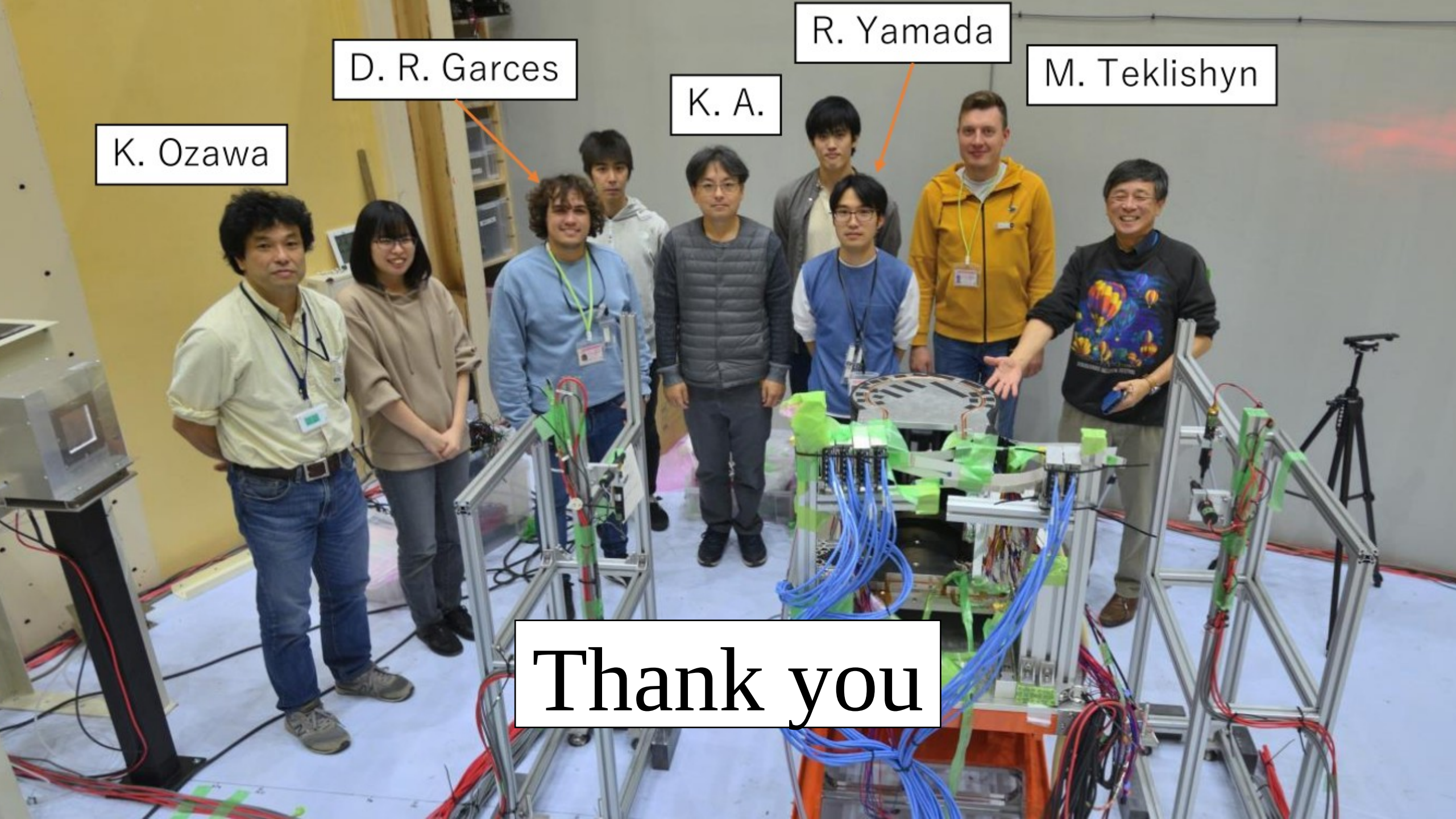
- **Run91: 98.84%**
- **Run81: 45.24%**

Summary

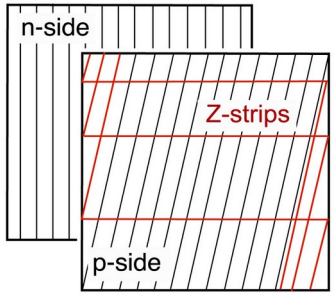
- Innermost tracking detector of **J-PARC E16** is E16-**STS**:
  - 10 modules in 8 ladders built and installed in 2023
- Beam test at **KEK PF-AR** in November 2023
- The selection using timestamp works, demonstrating successful operation of the system
- Efficiency was quite high ~99% for 0 degree of inclination, and low ~45% for inclined track of 16 degrees
- Great collaboration between GSI-STS group and E16 collaboration, and valuable feedback to CBM-STS where series production was started.

Outlook:

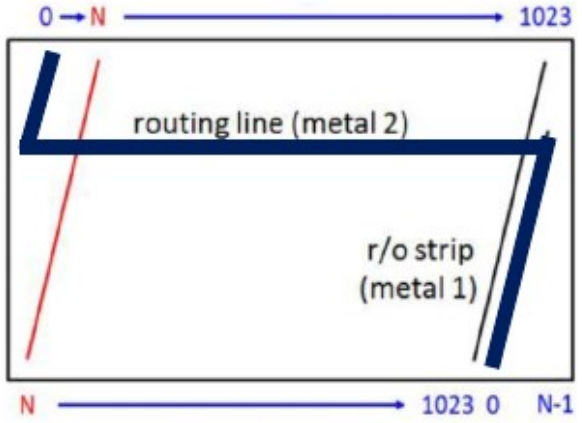
- Reinstall the chamber to the **J-PARC** experimental area for the next commissioning run planned in April 2024


K. Ozawa
D. R. Garces
K. A.
R. Yamada
M. Teklishyn
Thank you

Double-sided double-metal silicon microstrip sensor



Z channels interconnected via a double metal layer



$$ENC = \left[\underbrace{L_{\text{sensor}} \cdot 1.02 \frac{\text{pF}}{\text{cm}}}_{\text{sensor}} + \underbrace{L_{\text{cable}} \cdot 0.38 \frac{\text{pF}}{\text{cm}}}_{\text{microcable}} \right] \cdot 25 \frac{\text{e}}{\text{pF}} + \underbrace{350\ e}_{\text{ASIC}}$$

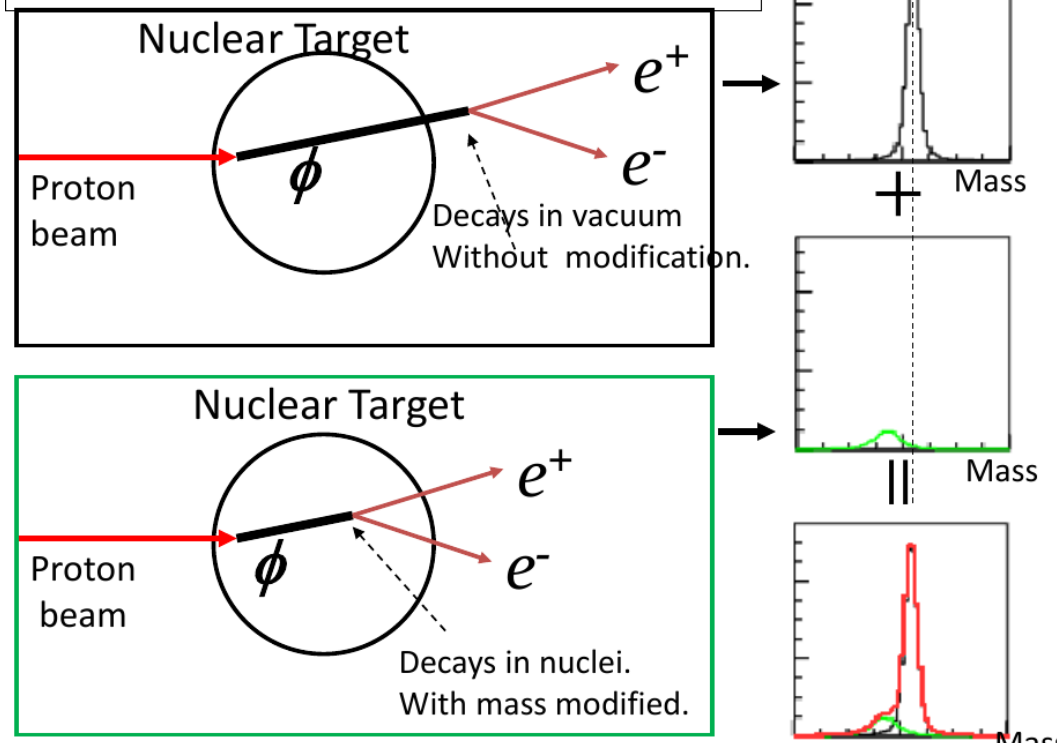
Z-strip: 17 pF extra for double metal routing
I. Panasenko, PhD thesis

4.3.1 Frame

Table. 3. Structure of the uplink frames.

Structure of the uplink frames (before 8b/10b encoding)																									
	BYTE<0> frame_bits<23:16> bits_8b10b<29:20>								BYTE<1> frame_bits<15:8> bits_8b10b<19:10>								BYTE<2> frame_bits<7:0> bits_8b10b<9:0>							
Type	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Dummy Hit	0	7-bit channel address = 0x00							5-bit ADC = 0x00					0x0		0x0 (SMX2.1: Timestamp<13:6> (actual state of counter) can be switched on by CONFIG register 192, 3) <2>								0
Hit	0	7-bit channel address							5-bit ADC > 0x00					TS<9:8> (overlap)		Timestamp<7:0>								EM
TS_MSB	1	1	Timestamp<13:8>						Timestamp<13:8>						Timestamp<13:8>						4-bit CRC poly 0x9 = $(x^4)+x+1$			
RDdata_ack ~~(implemented)~~	1	0	1	15-bit register content															3-bit sequence number (LSB)		3-bit CRC poly 0x5 = $(x^3)+x+1$			
Ack (SMX2)	1	0	0	ACK	4-bit sequence number			CP	4-bit status value						0x00 ~~or Timestamp<7:2> depending on CONFIG<1> register setting~~						4-bit CRC poly 0x9 = $(x^4)+x+1$			
Ack (SMX2.1)	1	0	0	ACK 0x1 Or NACK 0x2	4-bit sequence number			CP	4-bit status value						0x00 or Timestamp<13:8> Depending on the config register col=3 bit <1>.						4-bit CRC poly 0x9 = $(x^4)+x+1$			
ALERT_FRM (SMX2.1)	1	0	0	0x3	11-bit STATUS register content (not masked by Col=36 register!)																4-bit CRC poly 0x9 = $(x^4)+x+1$			
SEQ_ERR	1	0	0	0x0	TBU												TBU				TBU			

Example: p + A → ϕ + X



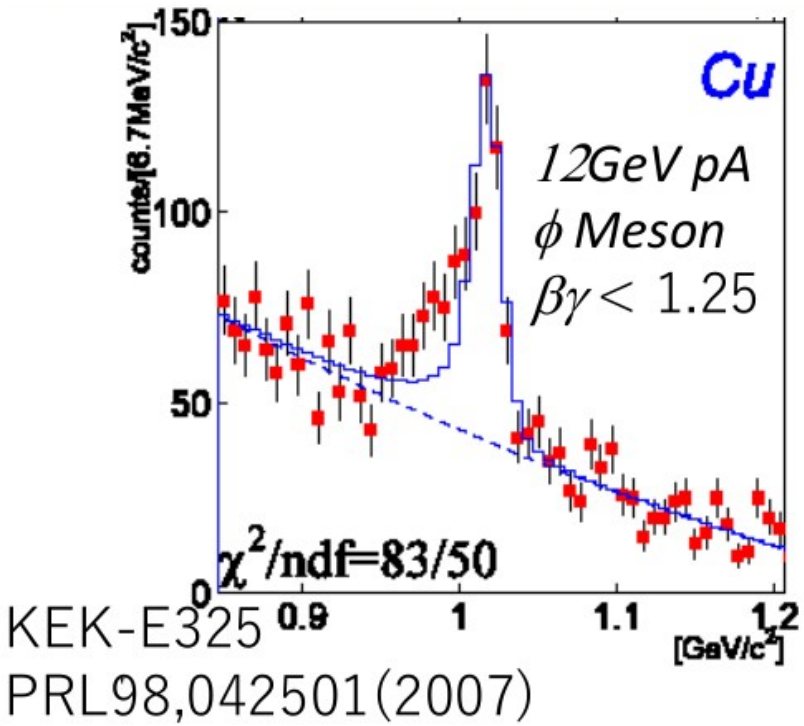
Well-known
Inv. mass
In vacuum

+

Modified mas
In nuclei.

||

Observed
invariant
mass.



KEK-E325
PRL98,042501(2007)

Lepton pair in the final state.
→ small final state interaction.

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