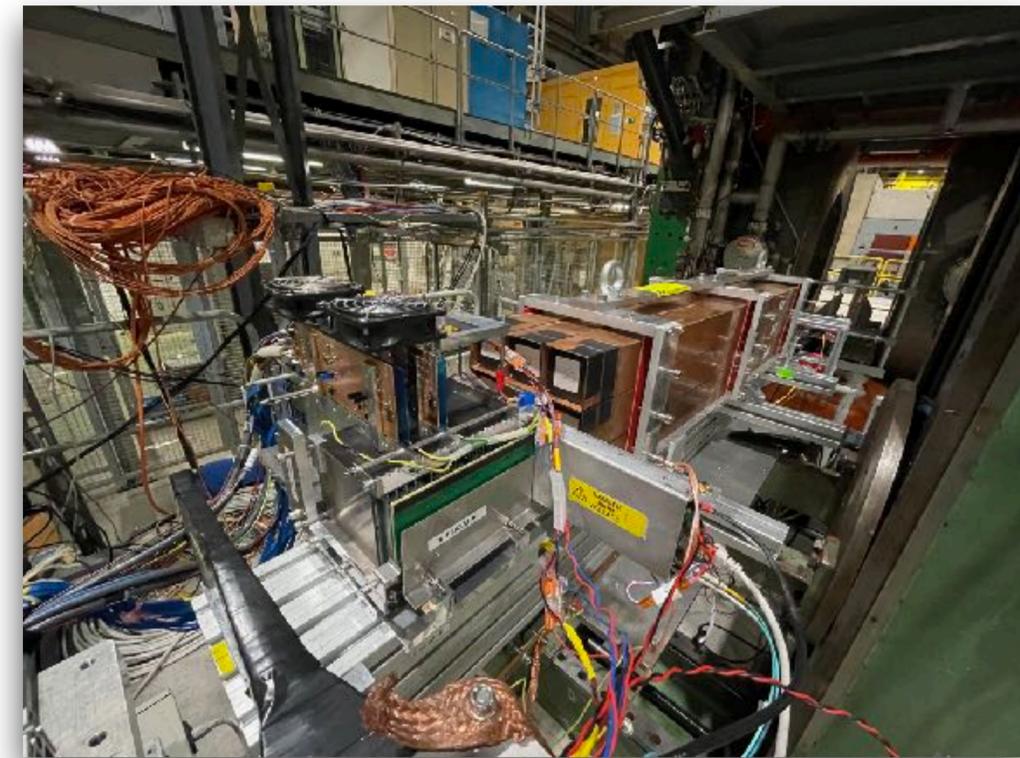


# ALICE FoCal-E application for ZDC



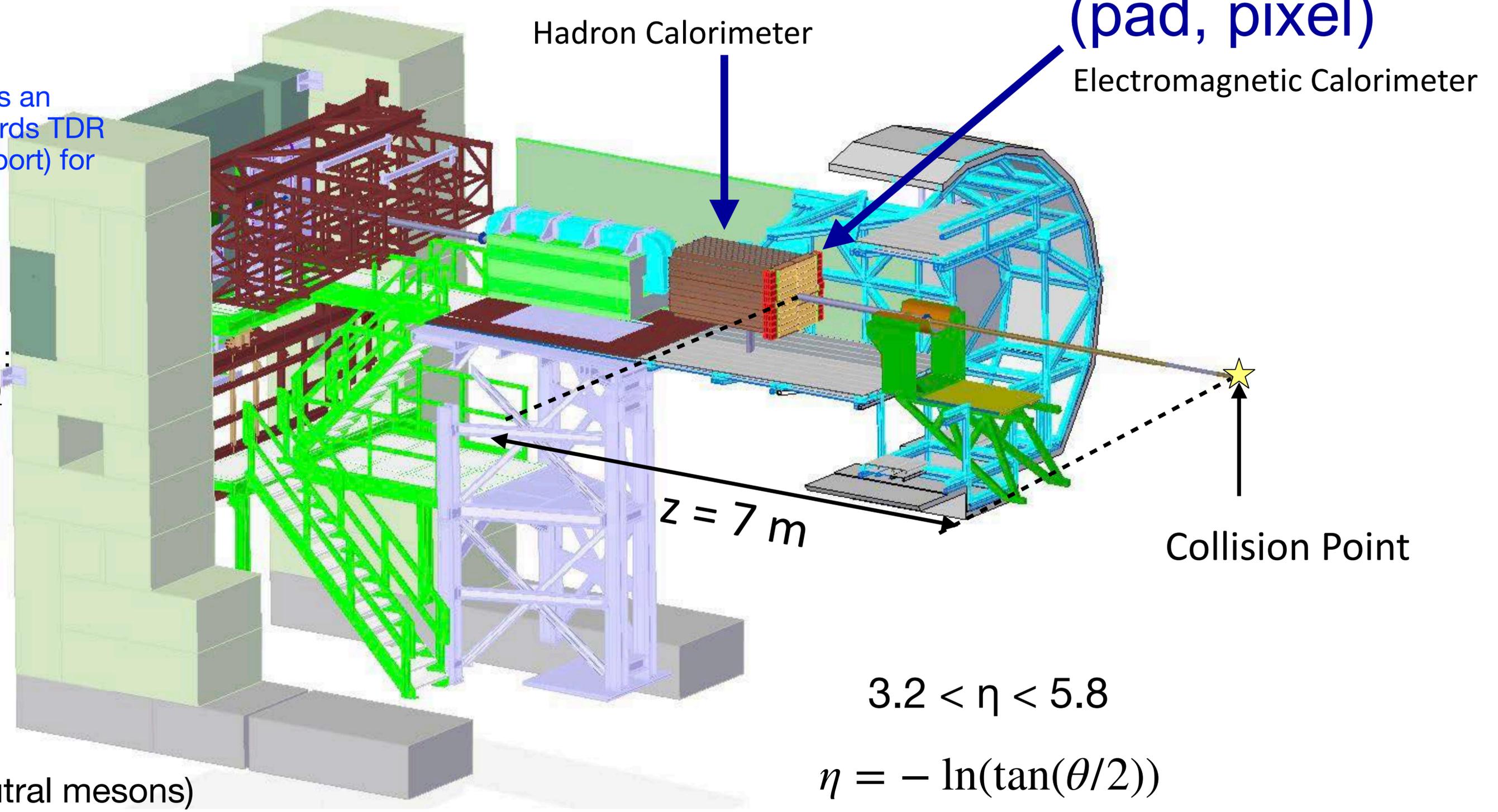
Tatsuya Chujo  
(University of Tsukuba)



# The FoCal project

- **Forward Calorimeter**
- Endorsed by LHCC as an upgrade project towards TDR (Technical Design Report) for LHC Run-4 (2029-)
- TDR in 2023 summer

FoCal Public Note (LoI) :  
[CERN-LHCC-2020-009](https://cds.cern.ch/record/2781143/files/CERN-LHCC-2020-009.pdf)



## Observables:

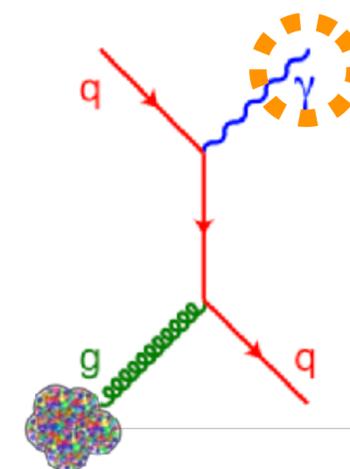
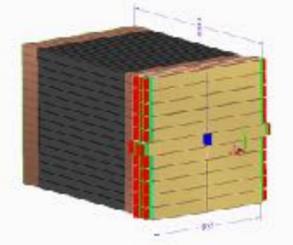
- $\pi^0$  (and other neutral mesons)
- Isolated (direct) photons
- Jets (and di-jets)
- J/psi, UPC

FoCal Project Leaders:

C. Loizides (ORNL), I. Bearden (Niels Bohr Inst.), T. Chujo (U. Tsukuba)

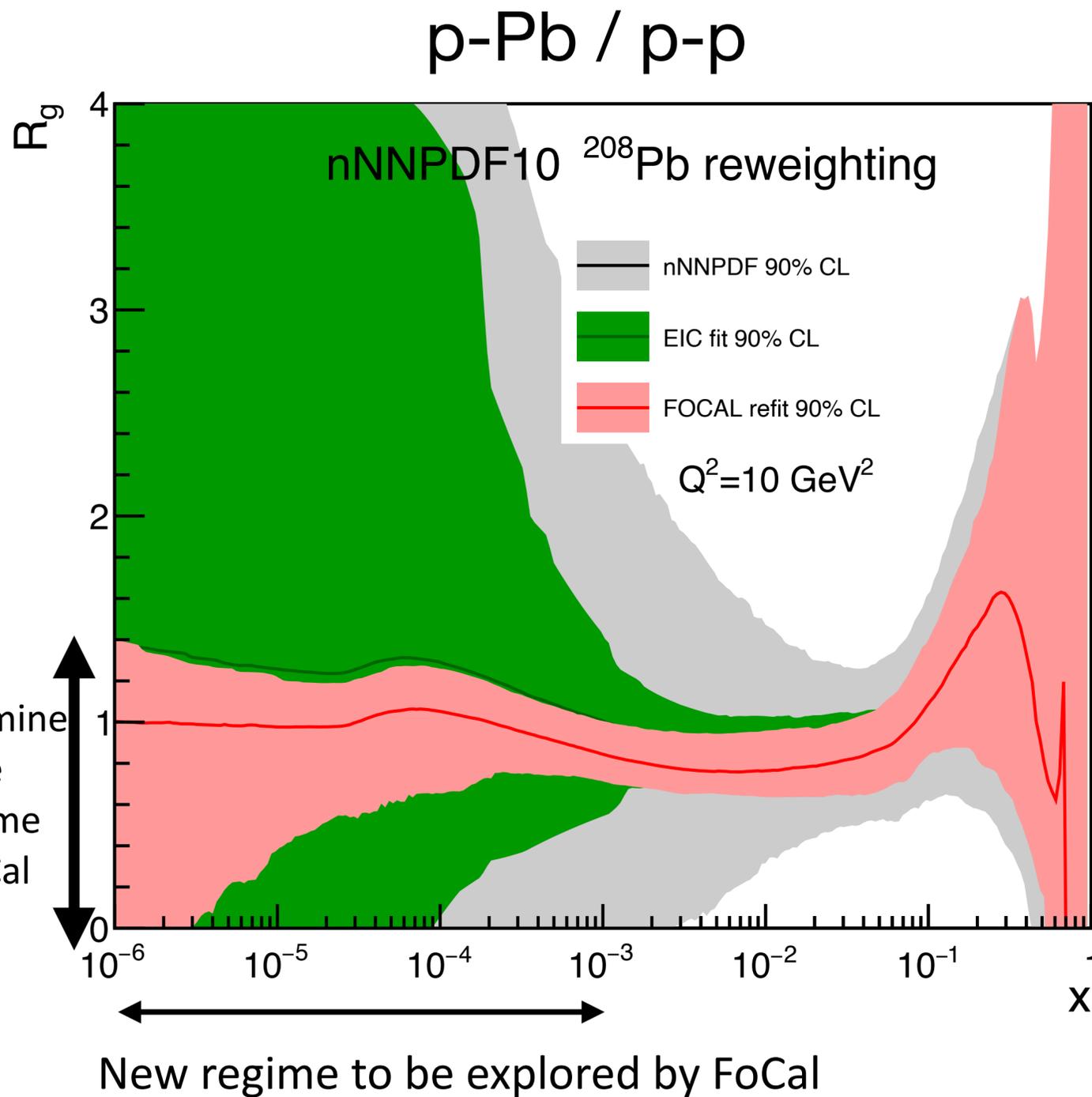
# Determination of gluon distribution in Pb nucleus by FoCal

## - Isolated photon measurement -



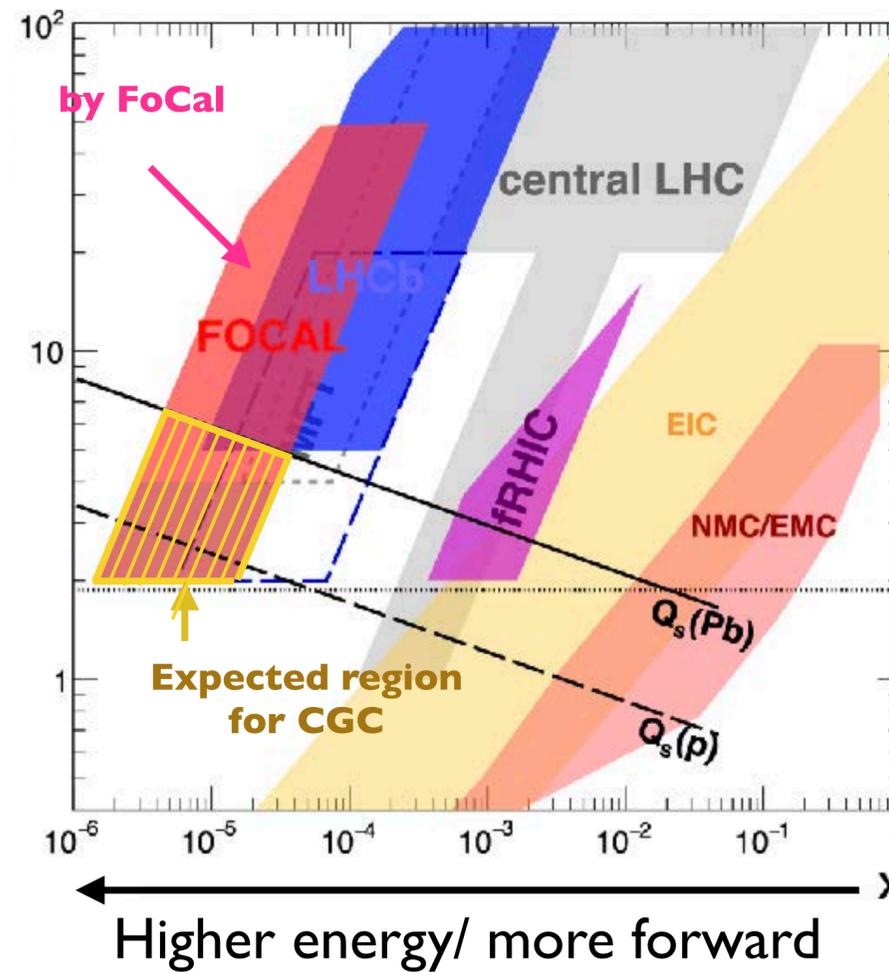
Current  
Uncertainty

Determine  
for the  
first time  
by FoCal



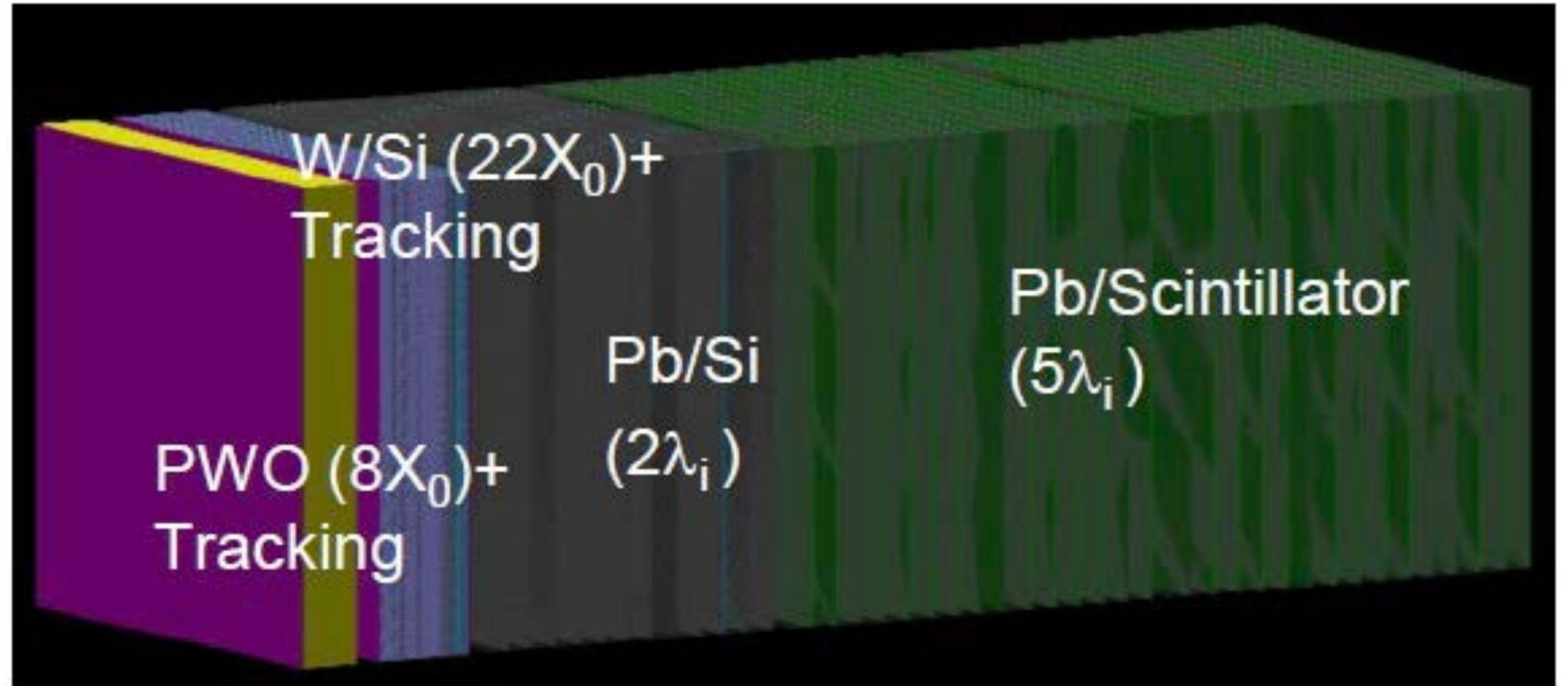
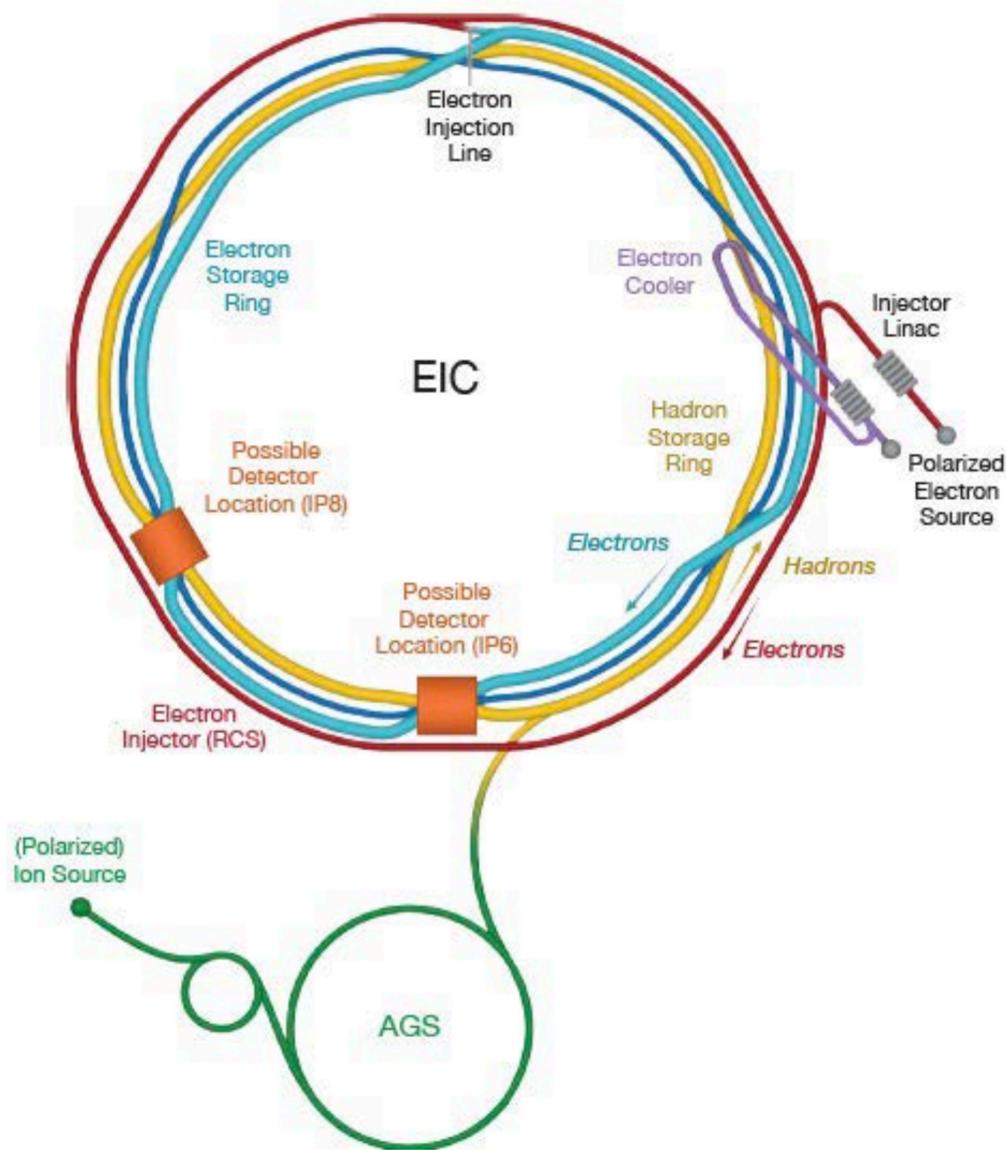
$Q \sim p_T$  (Transverse Momentum) (GeV)

New regime to be explored



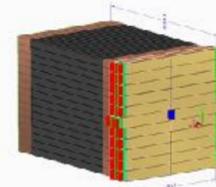
$$x \approx \frac{2p_T}{\sqrt{s}} \exp^{-\eta}$$

# FoCal technology in EIC ZDC



↑  
**this part**

A ZDC design for EIC



# FoCal Japan Group

## University of Tsukuba

- ◆ FoCal-E pad
- ◆ T. Chujo, (new AP), Y. Miake, A. Ghimouz, S. Sakai, T. Kumaoka (D3), Y. Asatani (M2), T. Kawaguchi (M1), K. Sato (M1), T. Inukai (B4), T. Yokoo (B4)

## Tsukuba University of Technology

- ◆ FoCal-E pad electronics, IV/CV, probe station, module assembly
- ◆ M. Inaba

## Hiroshima University

- ◆ Integration
- ◆ T. Sugitate

## Nara Women's University

- ◆ Test beam, IV/CV temp dep.
- ◆ M. Shimomura, T. Hachiya, Y. Sasaki (B4)

## 7 institutes and 23 members



## RIKEN

- ◆ Irradiation test, trigger, test beam
- ◆ Y. Goto, I. Nakagawa, R. Seidl, M. Kim(PD), (T. Kumaoka, JRA D2)

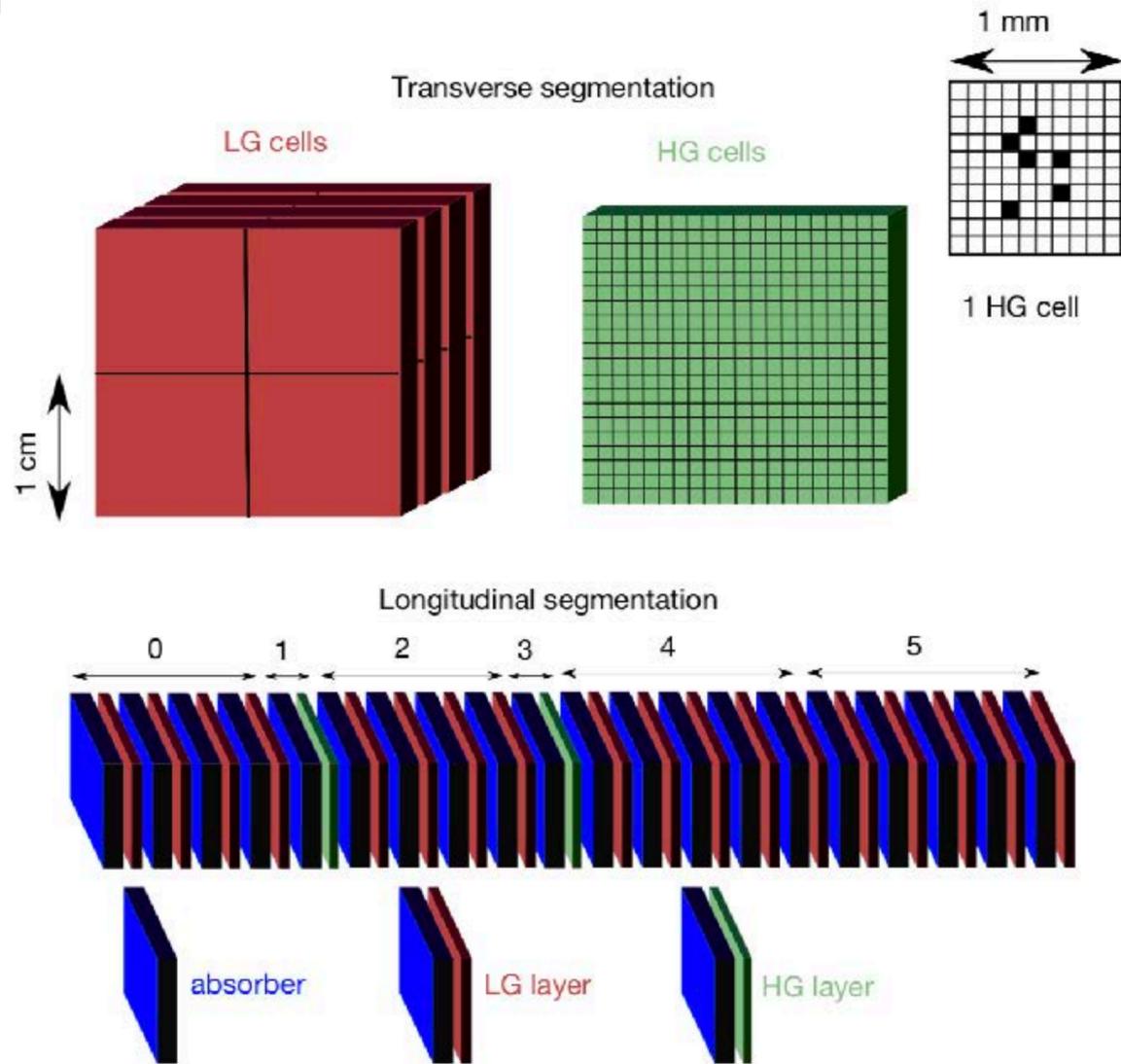
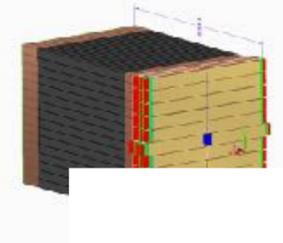
## Nagasaki Institute of Applied Science

- ◆ PAD readout, CRU, trigger
- ◆ K. Oyama

## Saga University

- ◆ CRU, trigger
- ◆ T. Fusayasu, T. Ishida (M2)

# Detector design



## FoCal-E

20 layers of W(3.5 mm  $\approx 1X_0$ ) + silicon sensors:

Two types: **Pad (LG)** and **Pixel (HG)**

- Pad: shower profile and total energy
- Pixel: position resolution to resolve overlapping showers

### Separate $\gamma/\pi^0$ at high energy

Two photon separation from  $\pi^0$  decay ( $p_T=10$  GeV,  $\eta=4.5$ )  $\sim 5$ mm

- Requires small Molière radius and high granularity readout
- Si-W calorimeter with effective granularity  $\approx 1$ mm<sup>2</sup>

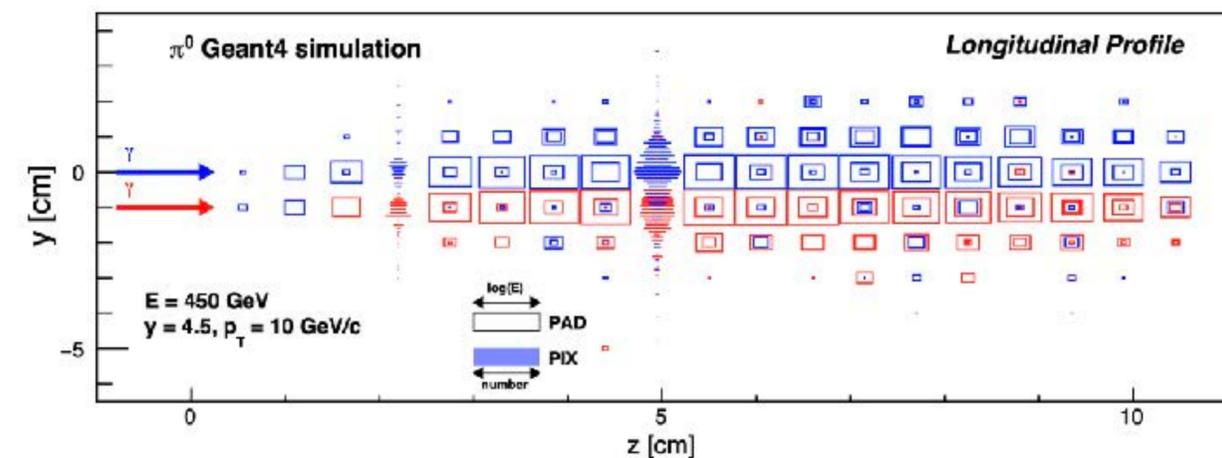
## FoCal-H

Conventional metal-scintillator design

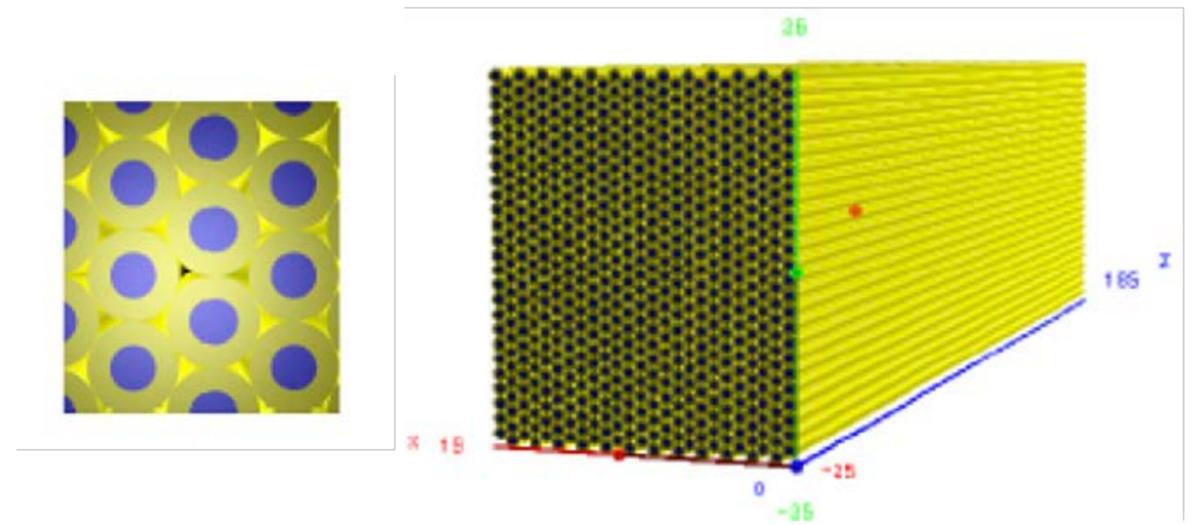
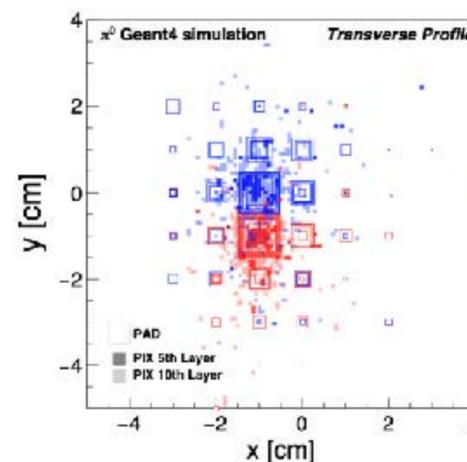
Sampling / tower structure not yet defined

No longitudinal readout required

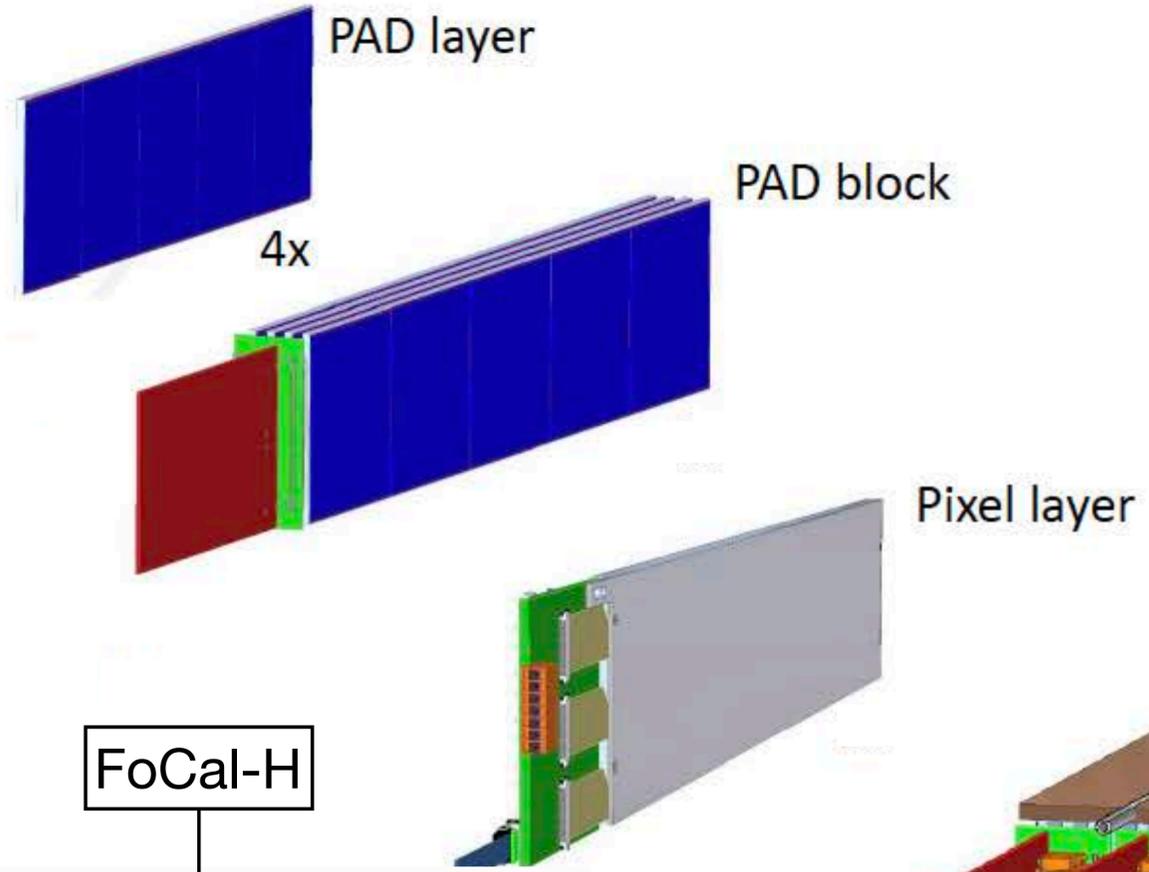
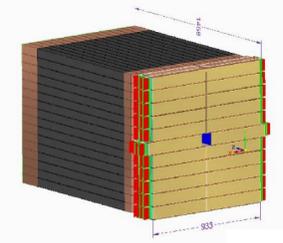
Longitudinal profile (2 $\gamma$  showers)



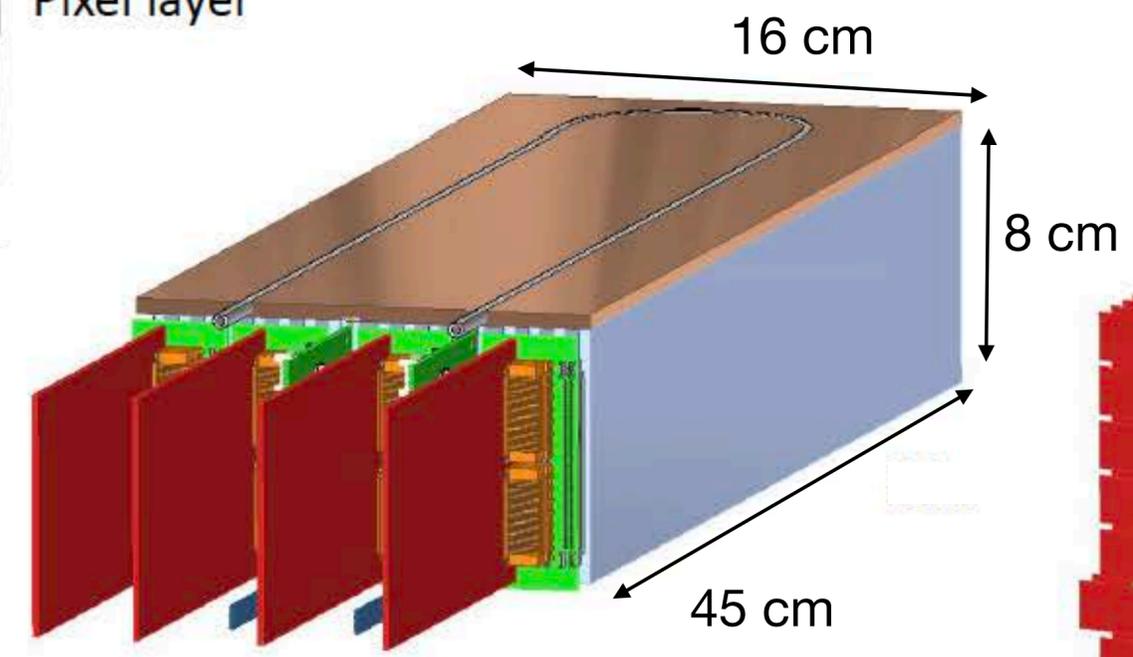
Trans. profile



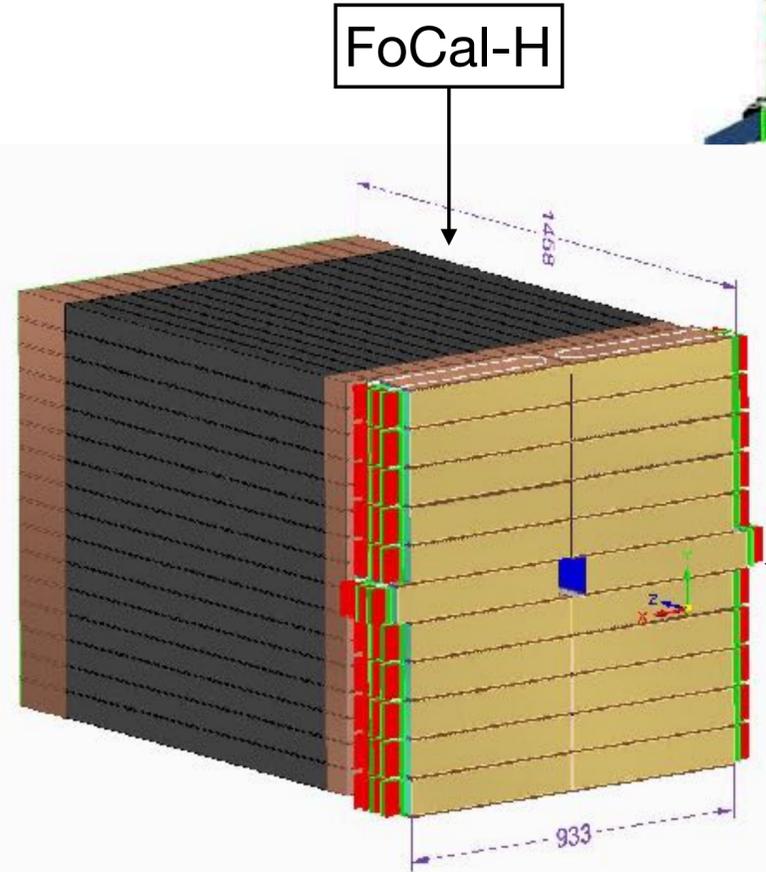
# FoCal integration



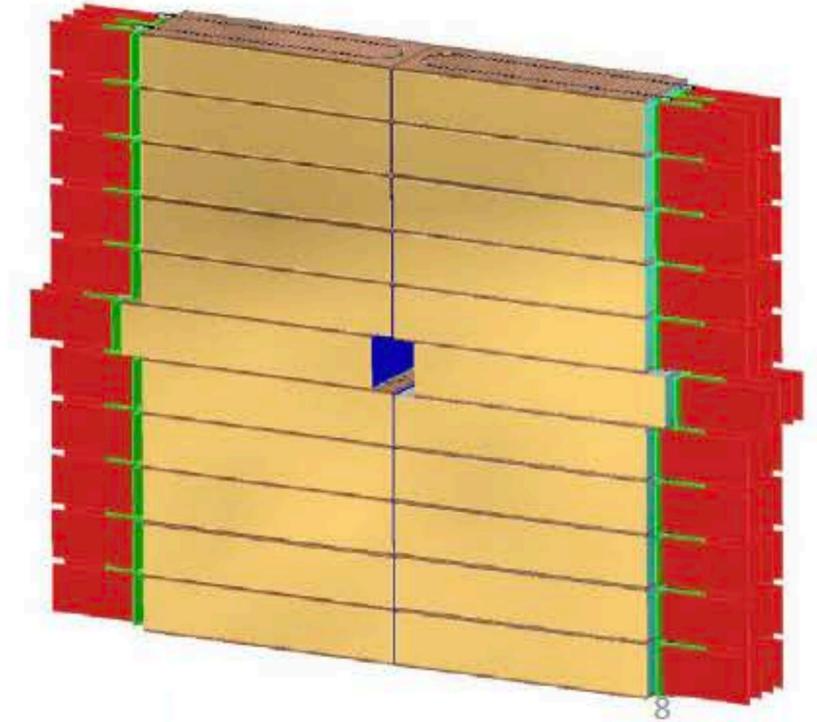
**Module:**  
**18 PAD layers + 2 PIXEL layers**



**FoCal-E: 22 modules**

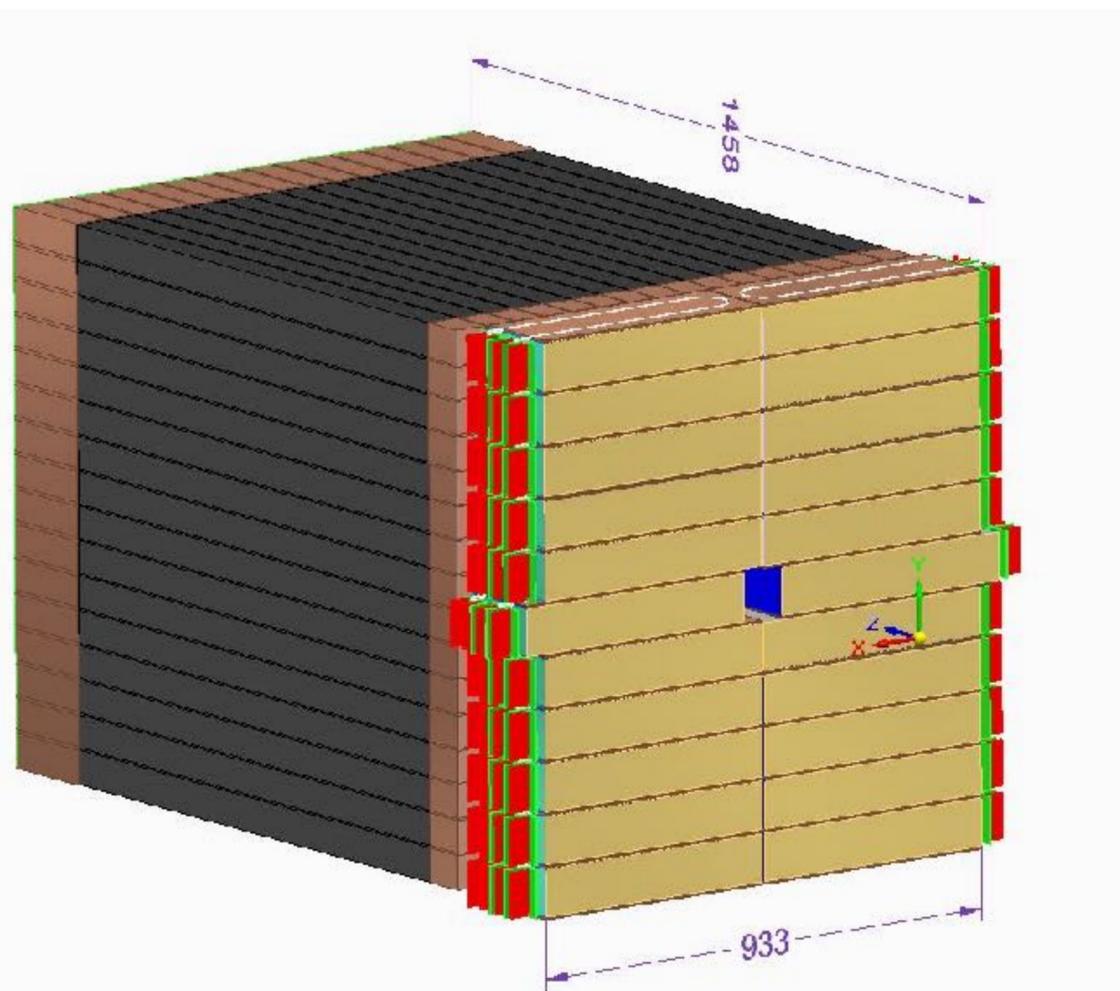


FoCal-E



# FoCal R&D status

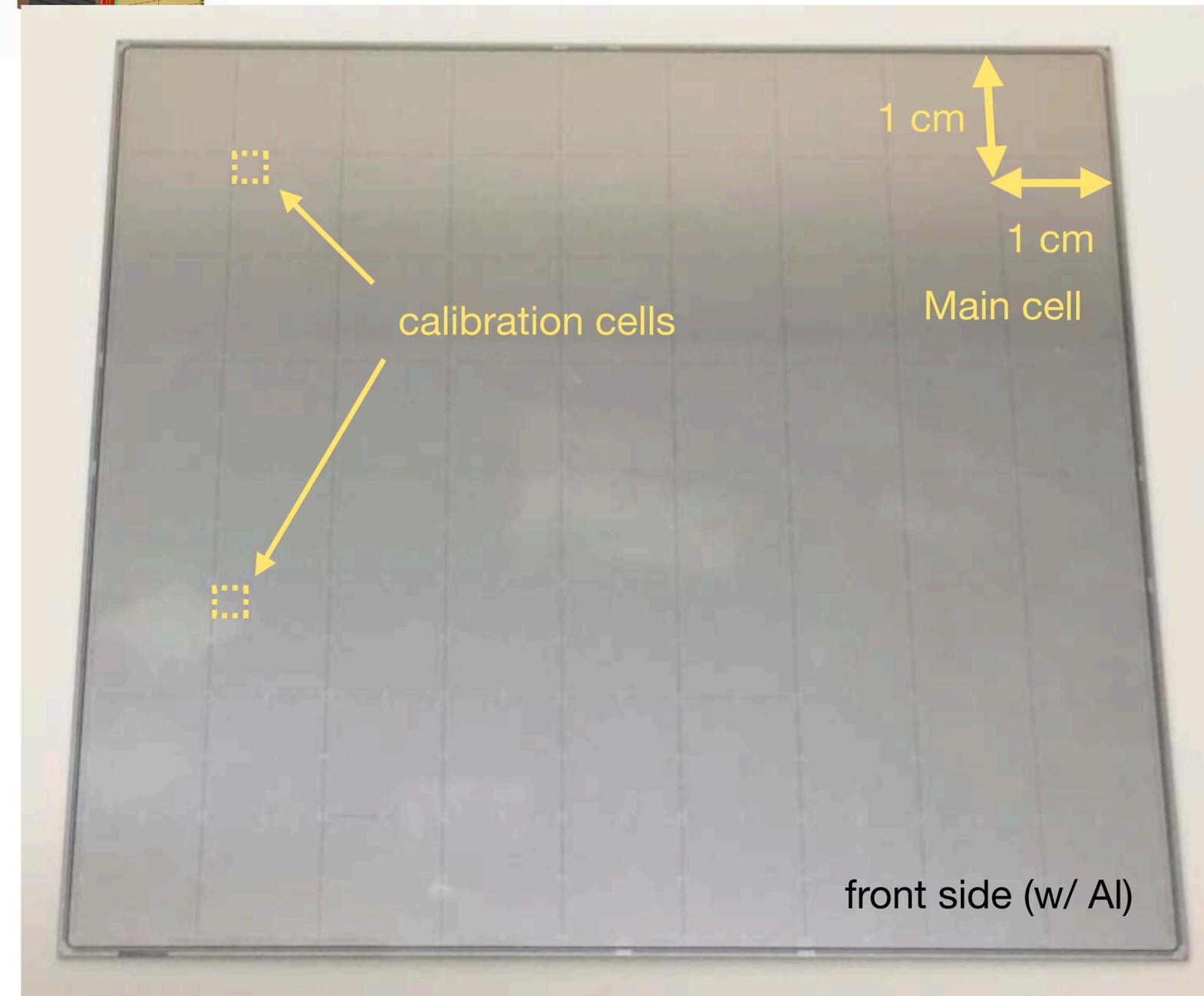
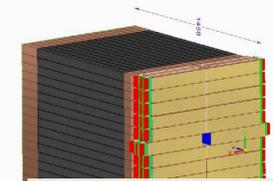
1. FoCal-E PAD
2. FoCal-E PIXEL
3. FoCal-H



CERN EP Newsletter (March, 2022) on FoCal test beam in 2021:

<https://ep-news.web.cern.ch/content/towards-focal-alice-experiment>

# FoCal-E PAD sensor

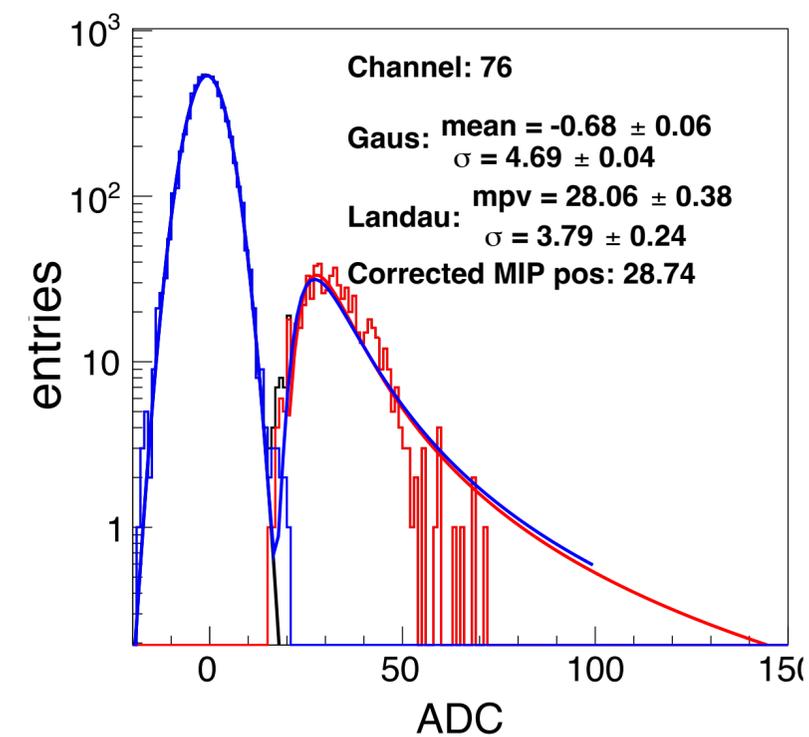


back side (Au)

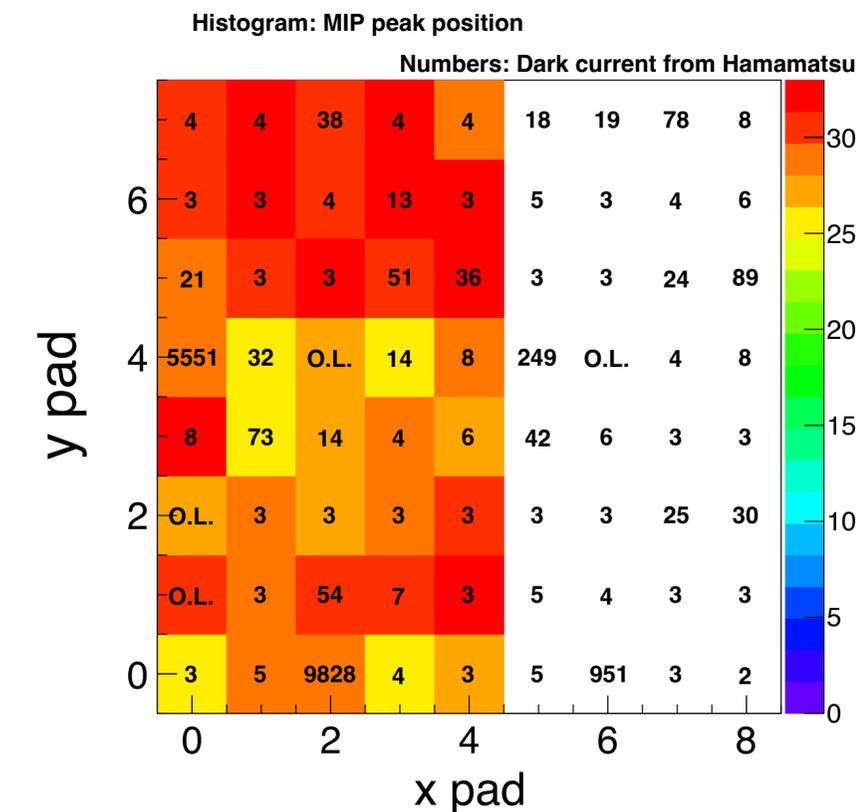
Hamamatsu S16211-0813  
p-sub, 320  $\mu\text{m}$ , w/ Al,  
1  $\text{cm}^2$  pad cell size

## First time use of p-type for FoCal (2021, Feb., ELPL)

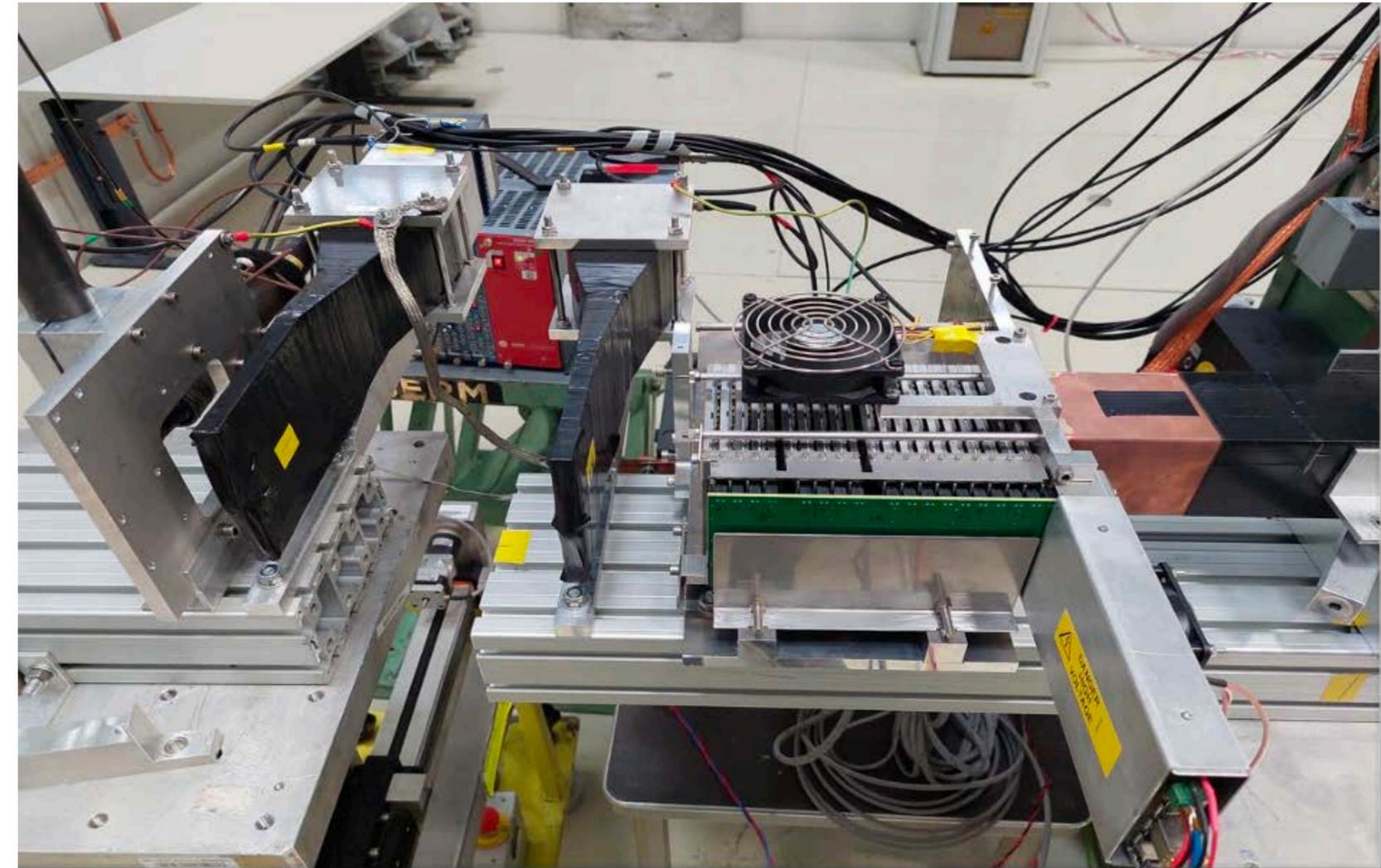
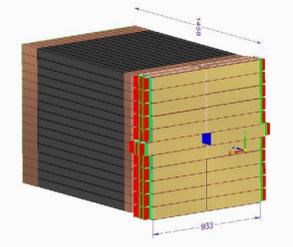
- 8x9 cells + calibration cells (w/Al), produced 30.
- More rad. hard than n-type.
- used APV25 hybrid board, compatible with HGCROC (readout ASIC for final detector) in 2021, and used HGCROC v2 in 2022
- Seen clear MIP signal (cosmic etc.), 25-33 ADC counts (APV), 10-15% variation.



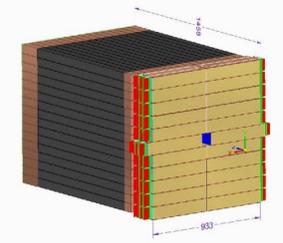
ELPH (Tohoku U.) test beam 2021



# PS test beam, T9 line (2022.06)

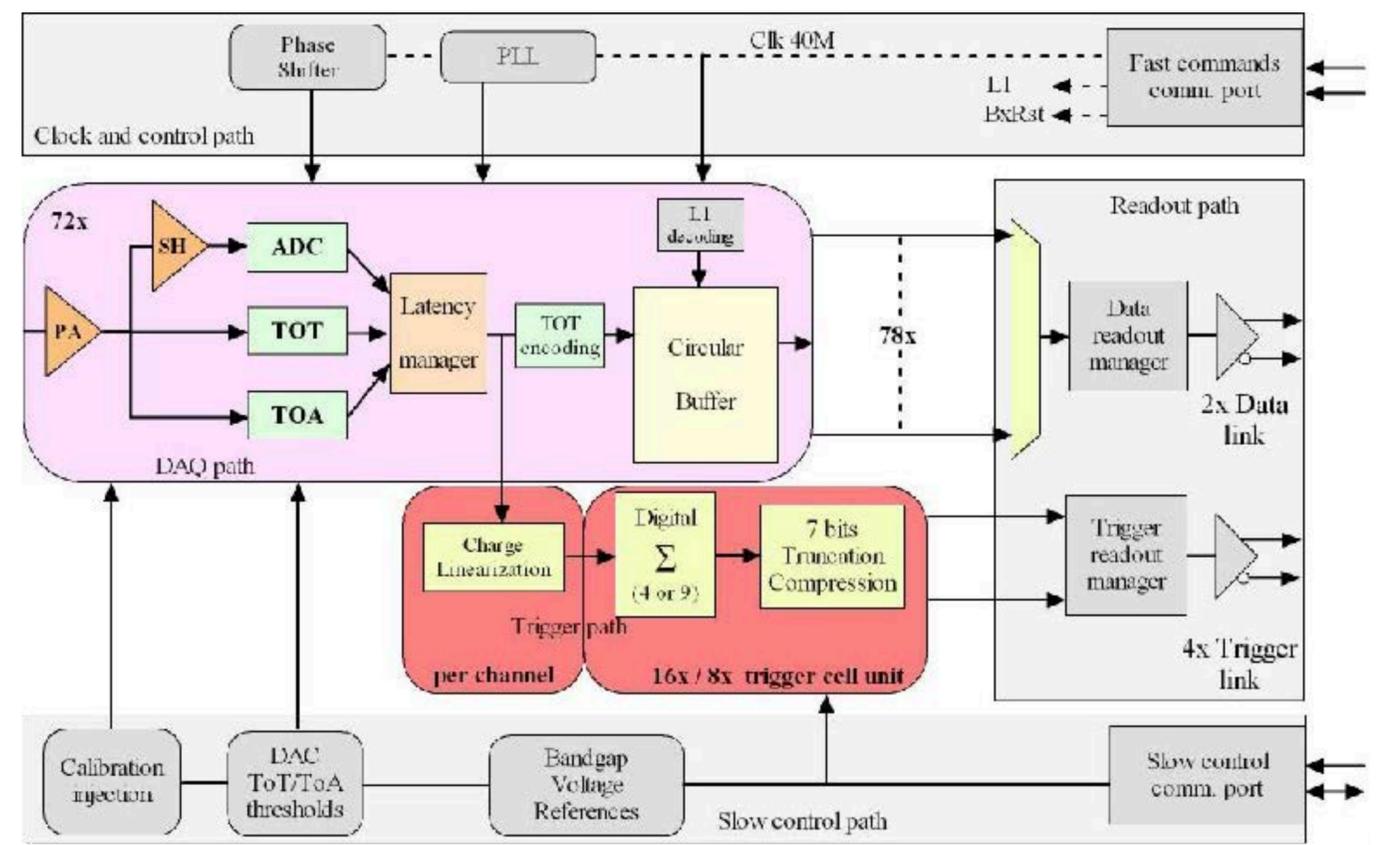


# HGCROC for FoCal-E PAD readout

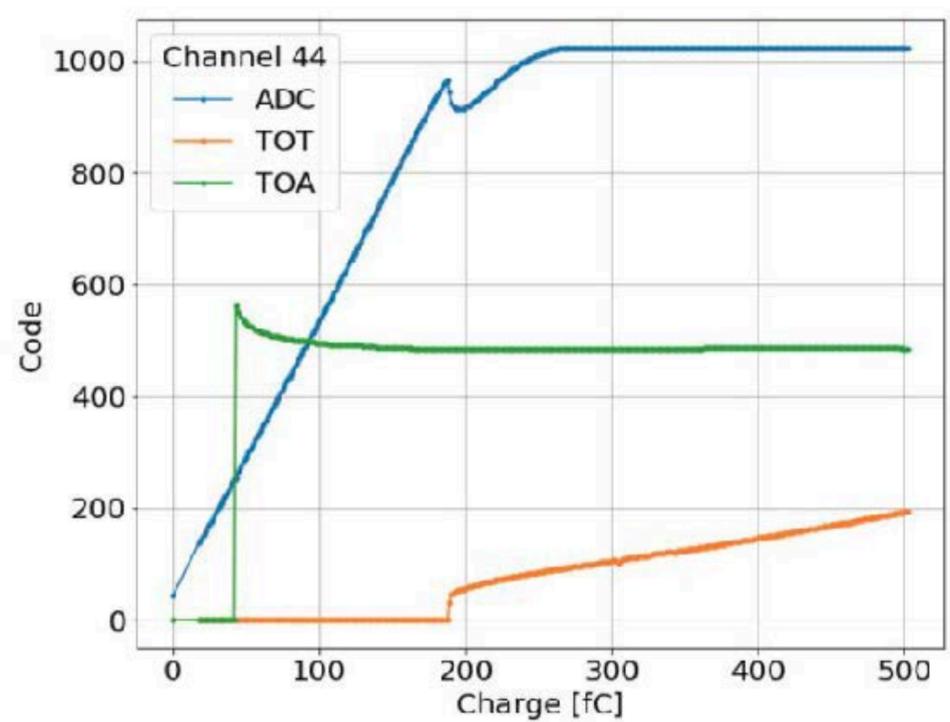


## Readout ASIC: HGCROC (CMS HGCAL)

- 72 channels (+4 for CMN +2 for calib. cell) per chip: ADC (10 bits) + ToT (12 bits).
- Dynamic range: 0.2 fC to 10 pC (MIP to 1 TeV shower).
- Readout samples all channels @ 40 MHz.
- **Successful data taking by HGCROC (ADC/ToT) + KCU105 w/ charge injection (Grenoble/ Tsukuba).**



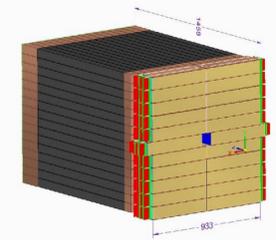
ADC+ToT by charge injection (Grenoble)



HGCROC test board

XILINX FPGA KCU105

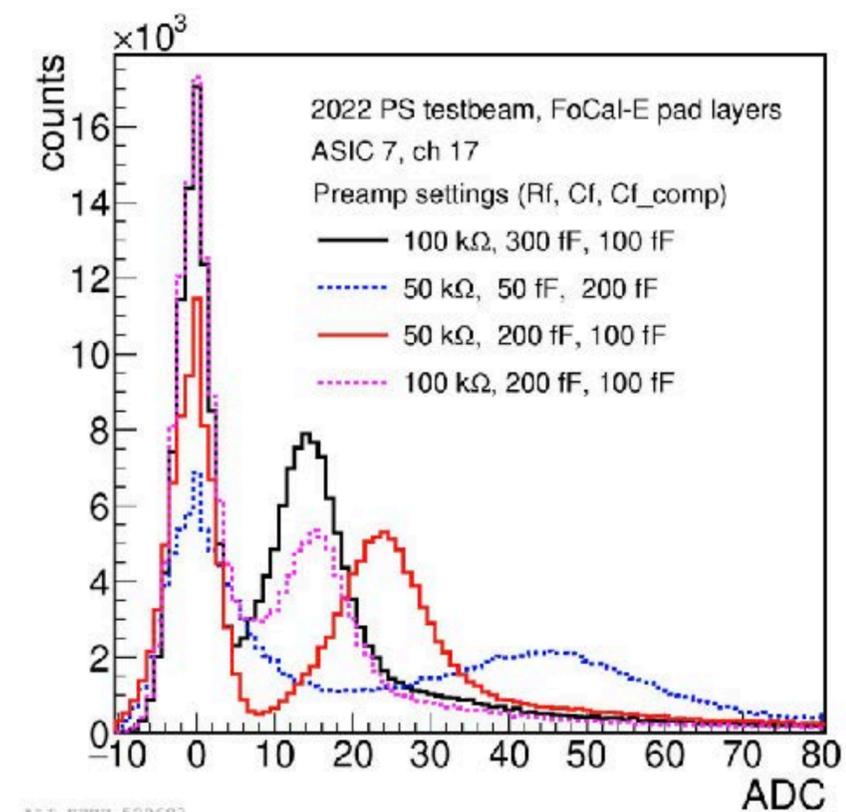
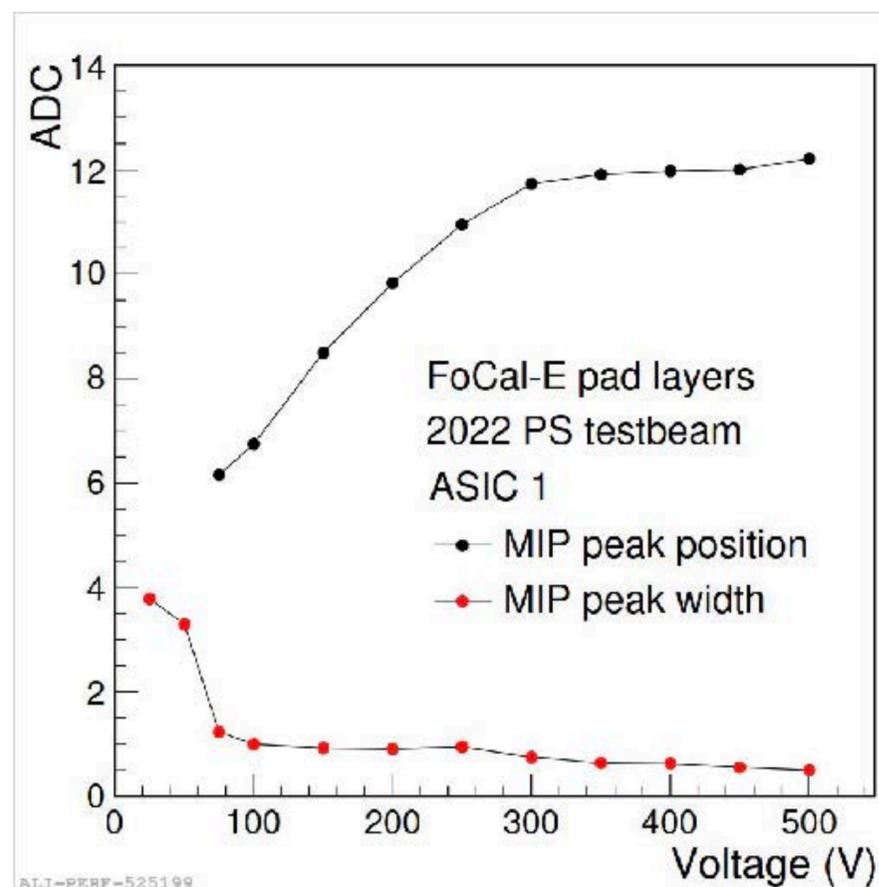
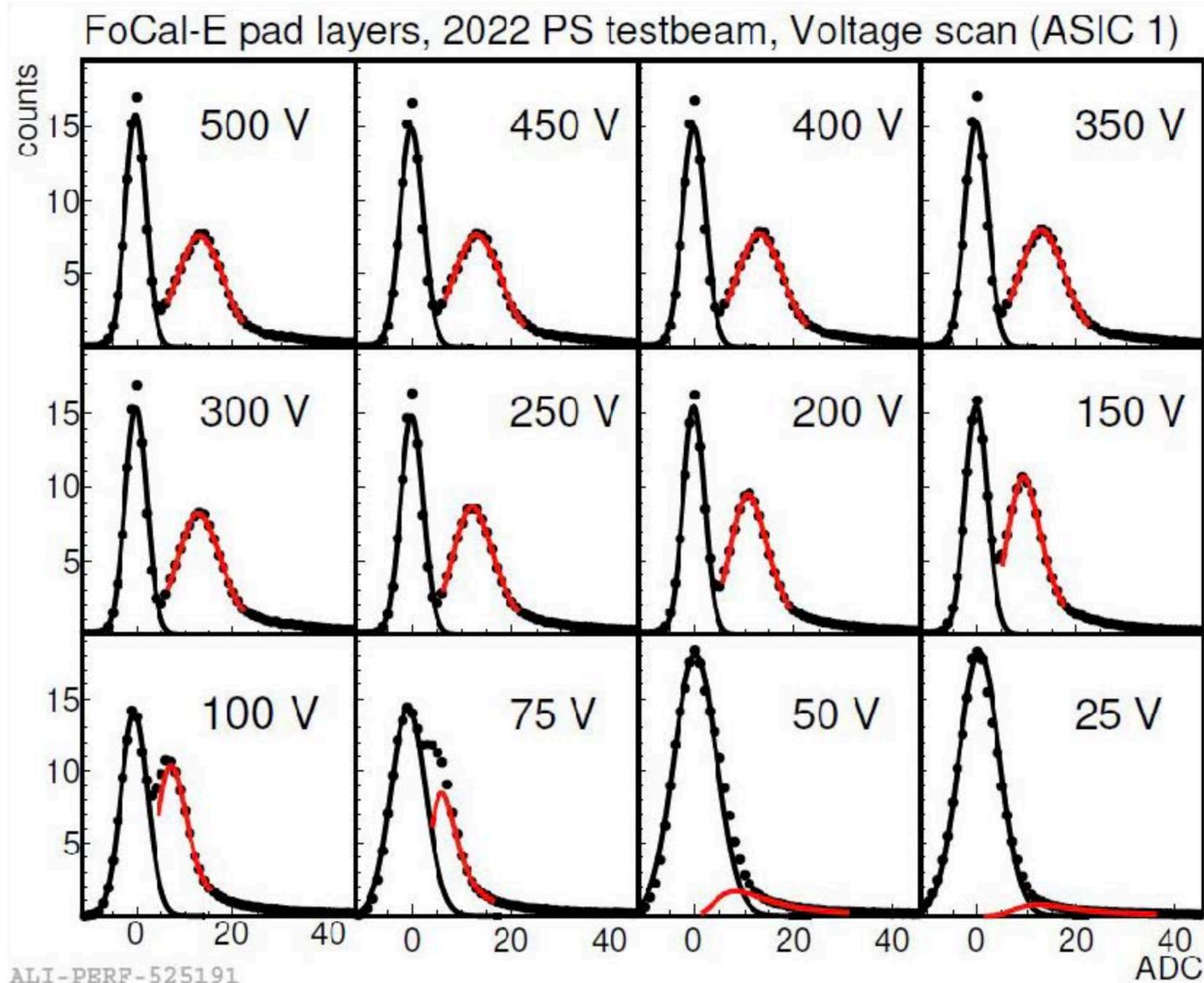
# FoCal-E PAD : Results



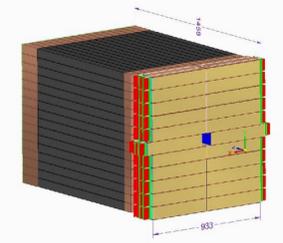
**Bias voltage scan by hadron beams (15 GeV/c)**

**Clear MIP peaks have been observed**

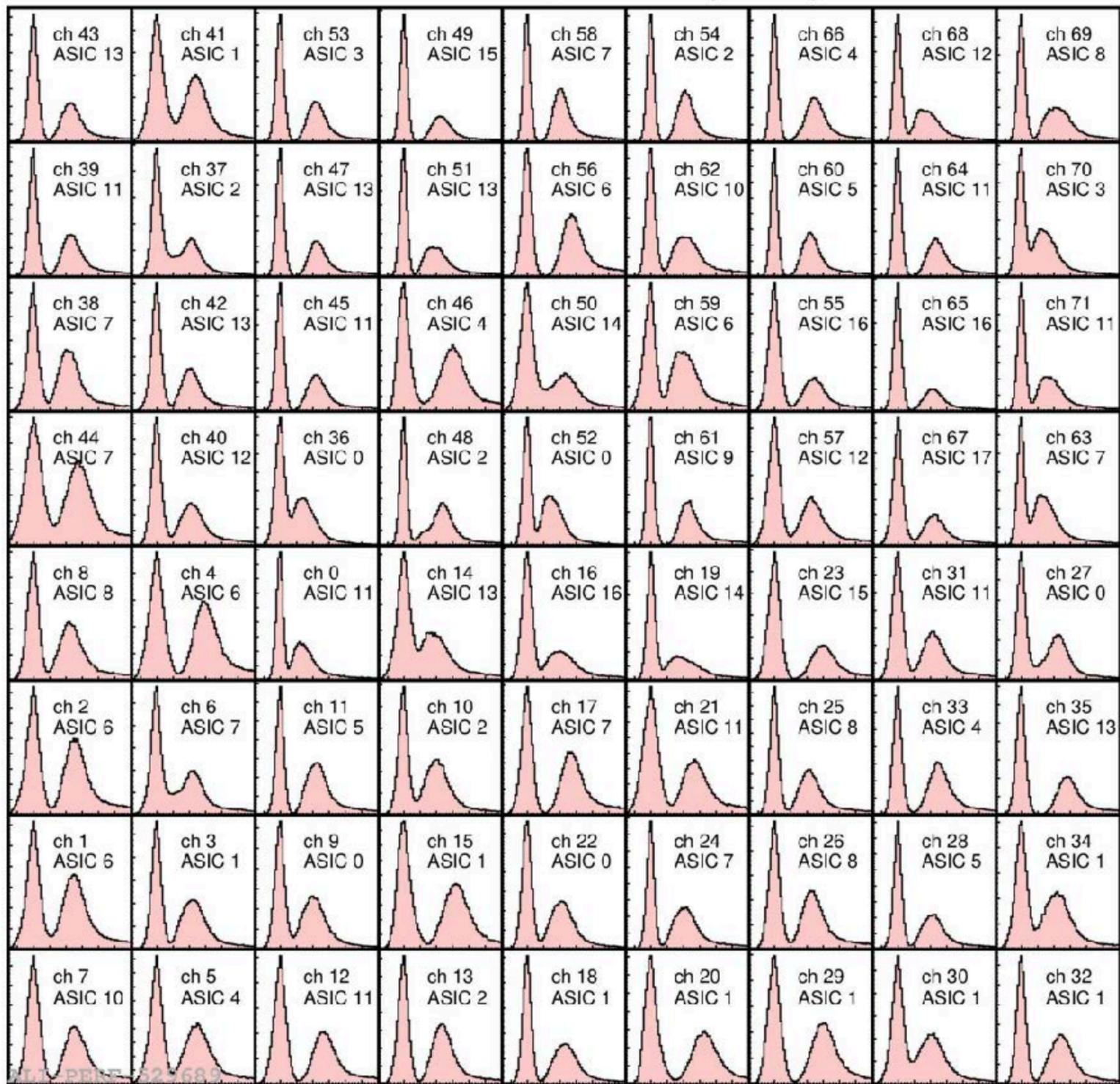
- **Preamplifier setting scan to choose best setting for MIP**
- **Reaching full depletion voltage ~300 V**



# FoCal-E PAD : Results



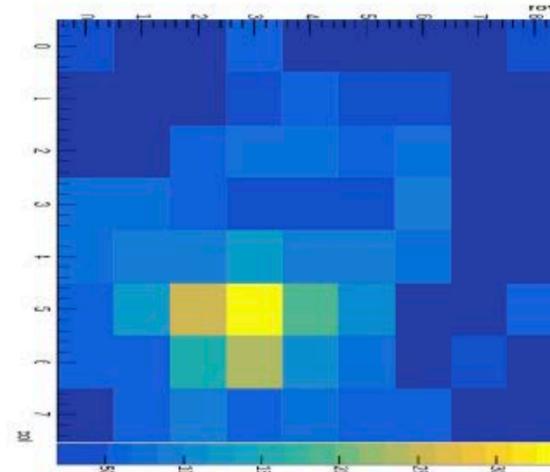
Position scan, 2022 PS testbeam, FoCal-E pad layers



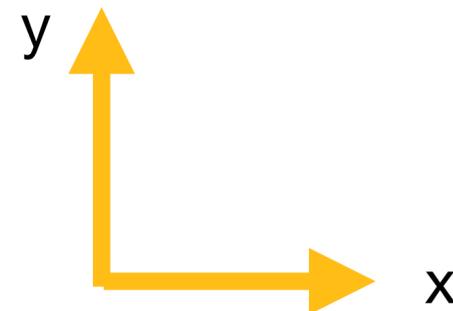
**Position scan by hadron beams (15 GeV/c)**

**Clear MIP peaks have been observed for (almost all) channels layers**

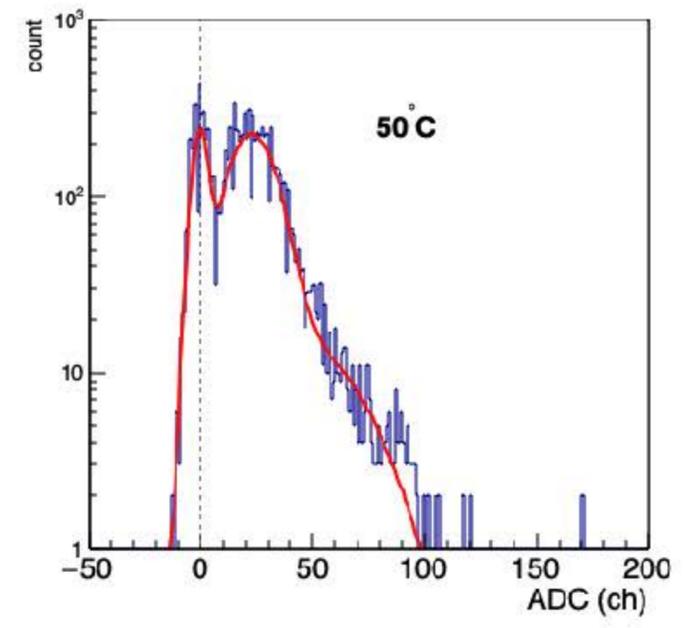
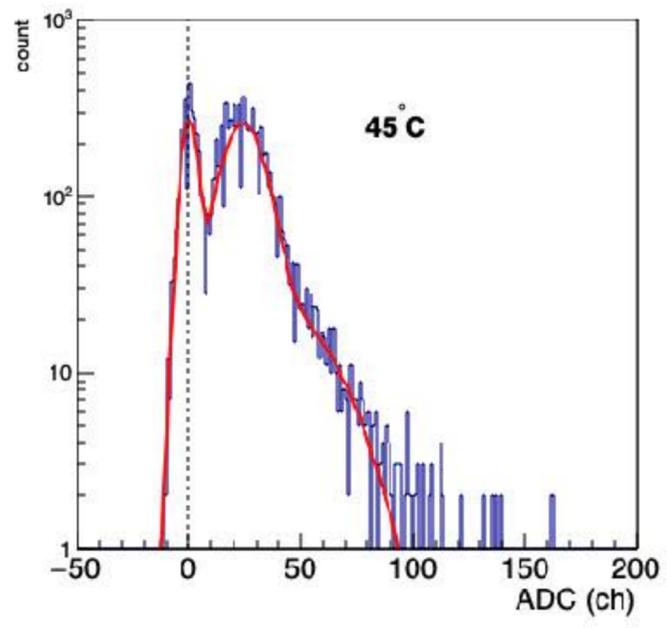
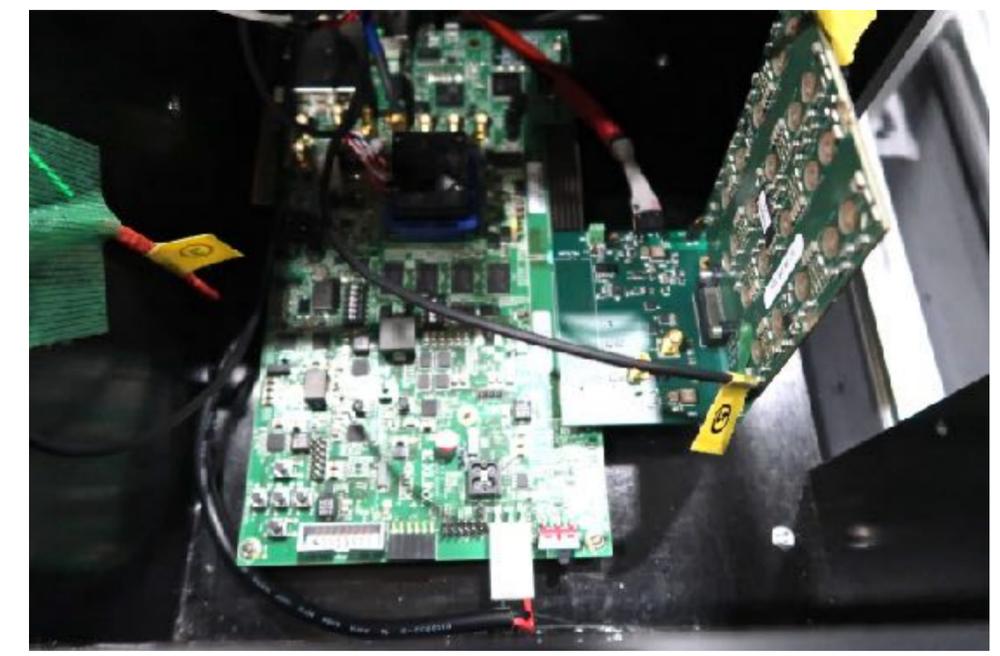
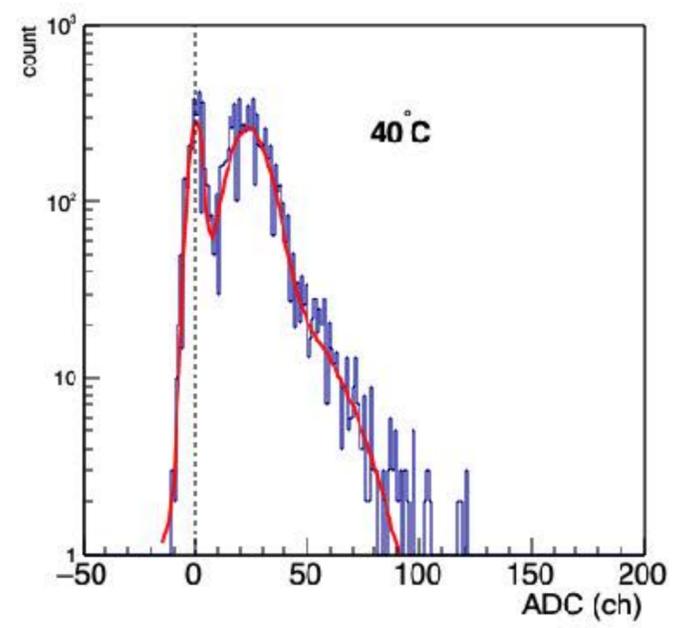
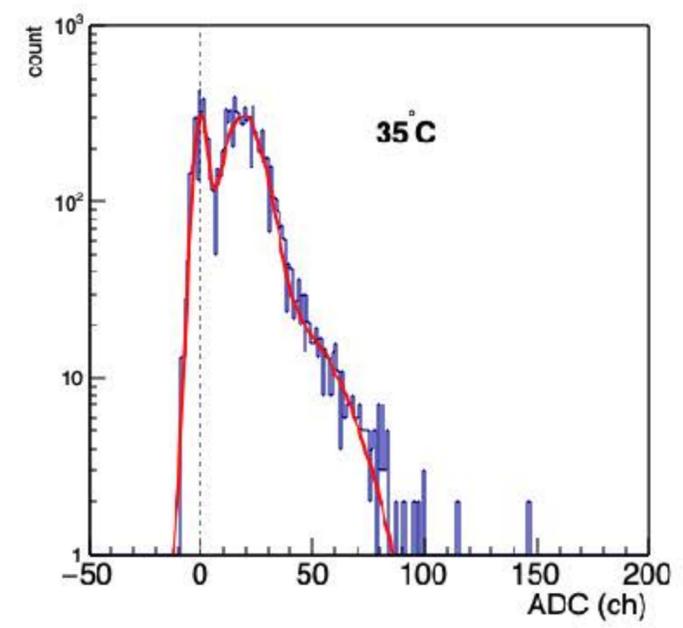
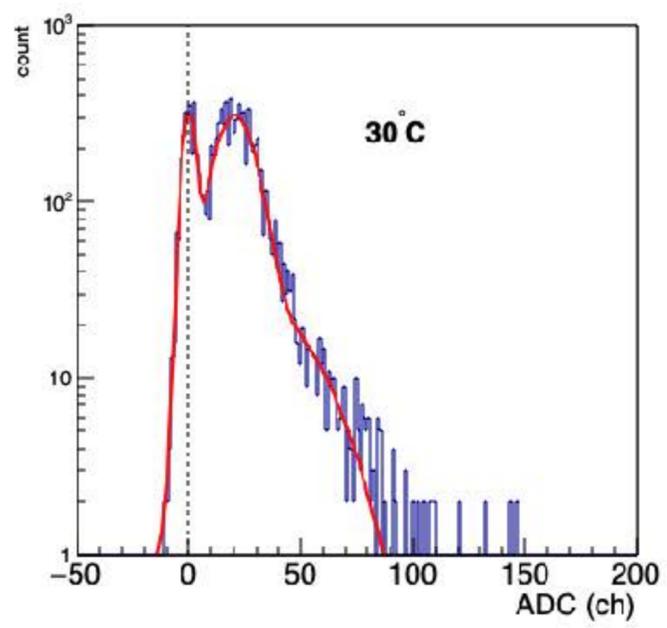
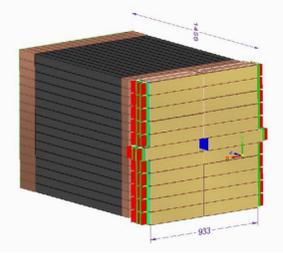
Position scan performed with 100 GeV hadrons



43	41	53	49	58	54	66	68	69
39	37	47	51	56	62	60	64	70
38	42	45	46	50	59	55	65	71
44	40	35	48	52	61	57	67	63
8	4	0	14	16	10	23	31	27
7	6	11	10	17	21	25	33	35
1	3	0	15	22	24	26	28	34
7	5	12	13	18	20	24	30	32

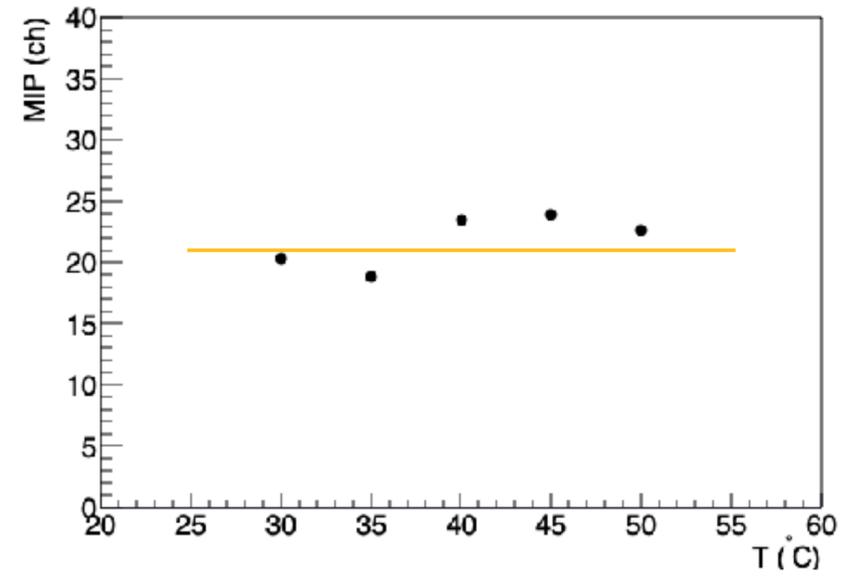


# Temperature dependence of MIP peaks for p-type 8x9 main sensor (ELPH 2023, Feb)

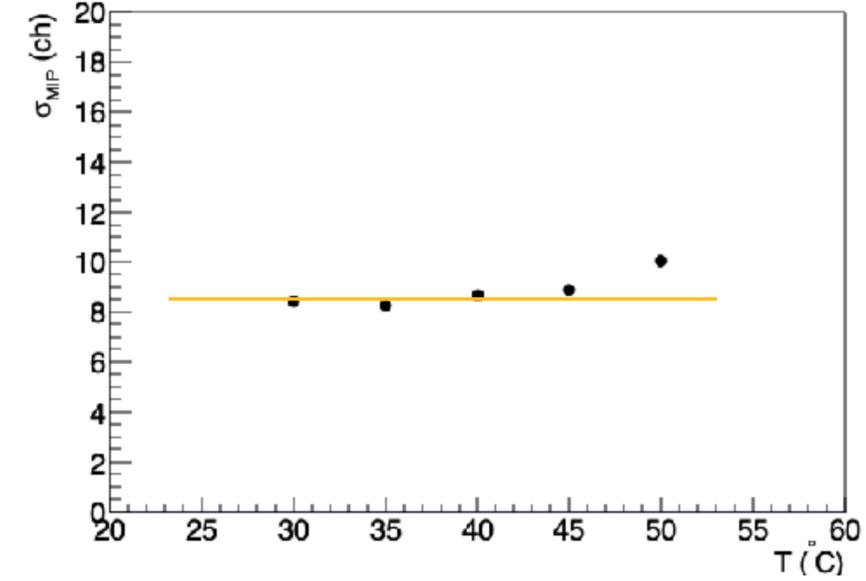


**Small change from 30 to 50 °C**

MIP vs. Temp.

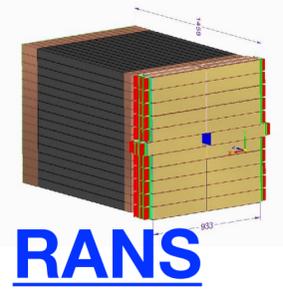


MIP width vs. Temp.

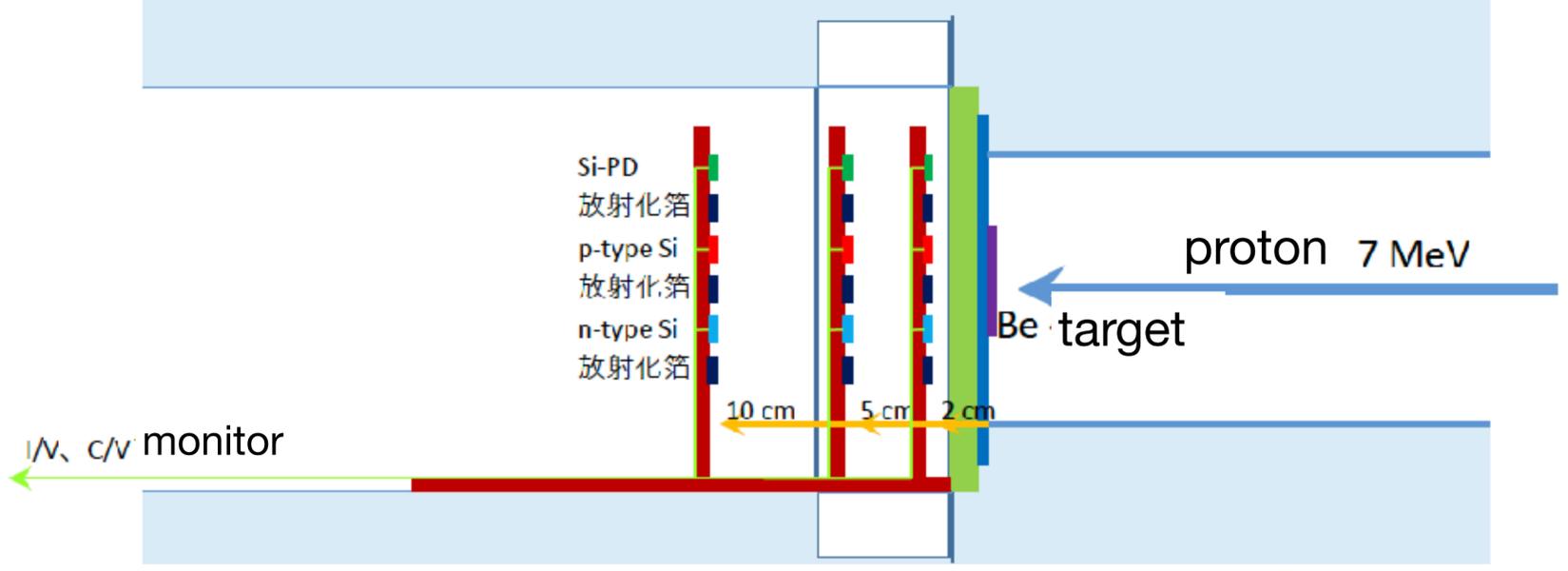


# Neutron Irradiation test in Japan

(RIKEN, Tsukuba Tech, Tsukuba, Nara)

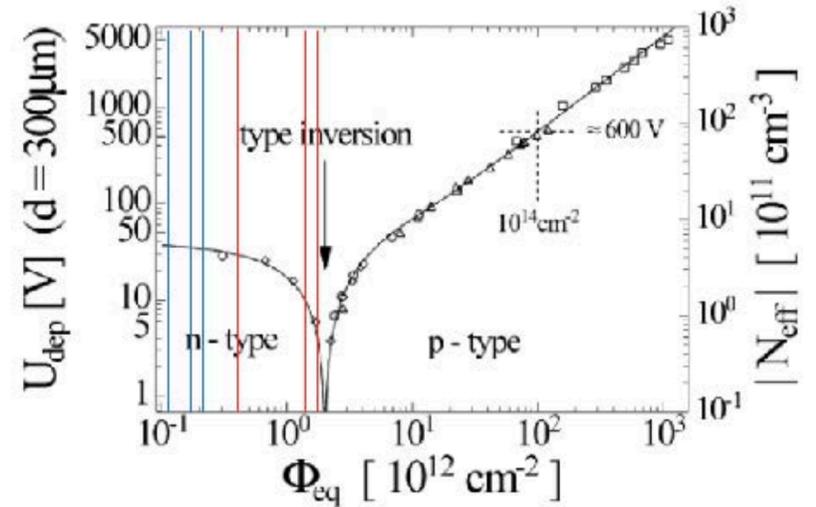


**(RIKEN Accelerator-driven compact Neutron Source)**



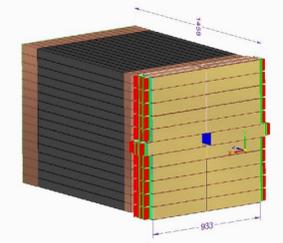
(Yuji Goto)

	1hour	2hour	3hour	4hour	5hour	
2cm	3600	7200	10800	14400	18000	$\times 10^8$
5cm	576	1152	1728	2304	2880	$n_{eq}/cm^2$
10cm	144	288	432	576	720	



- First irradiation test for both p and n type Si with neutrons was done on March 3-4, 2022
- 2nd test: March 7-8 ,2023
- After irradiation, IV / CV remeasured

# RANS irradiation test



March 3-4, 2022, RANS at RIKEN



国立大学法人  
筑波技術大学  
National University Corporation  
Tsukuba University of Technology



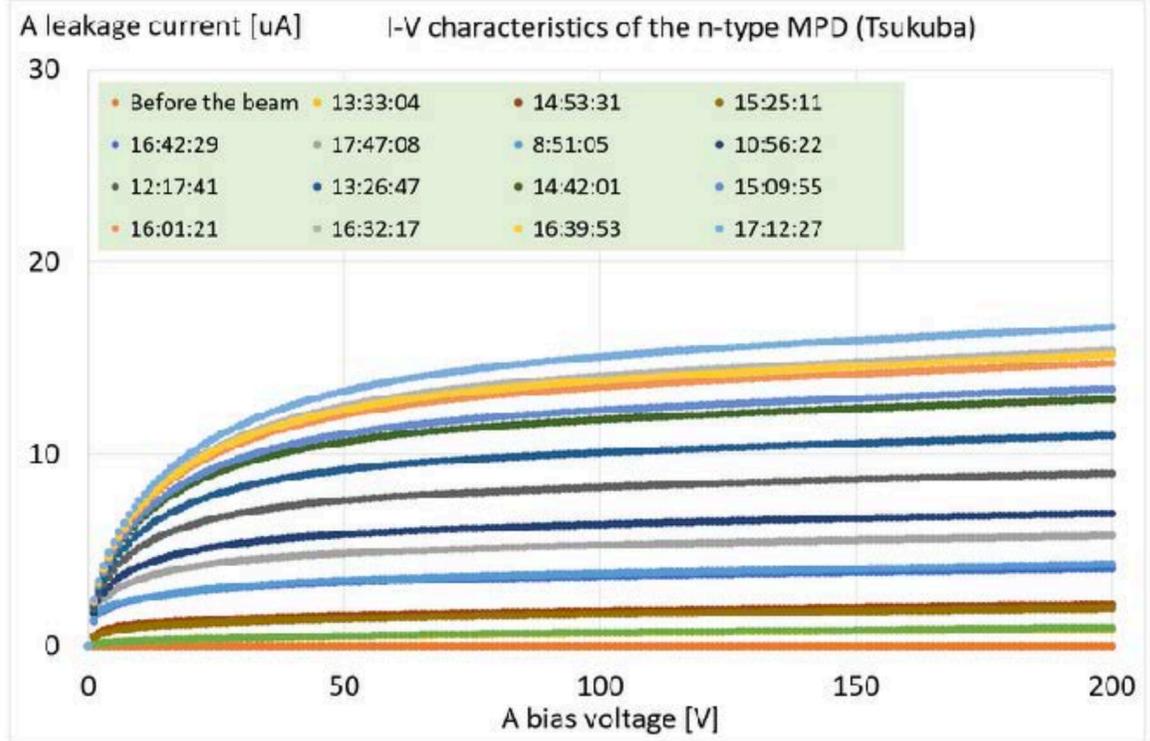
## 2022 data (first test)

- Monitor PD, baby chips were used
- irradiated  $\sim 10^{14}$  neutron /cm<sup>2</sup> in two days

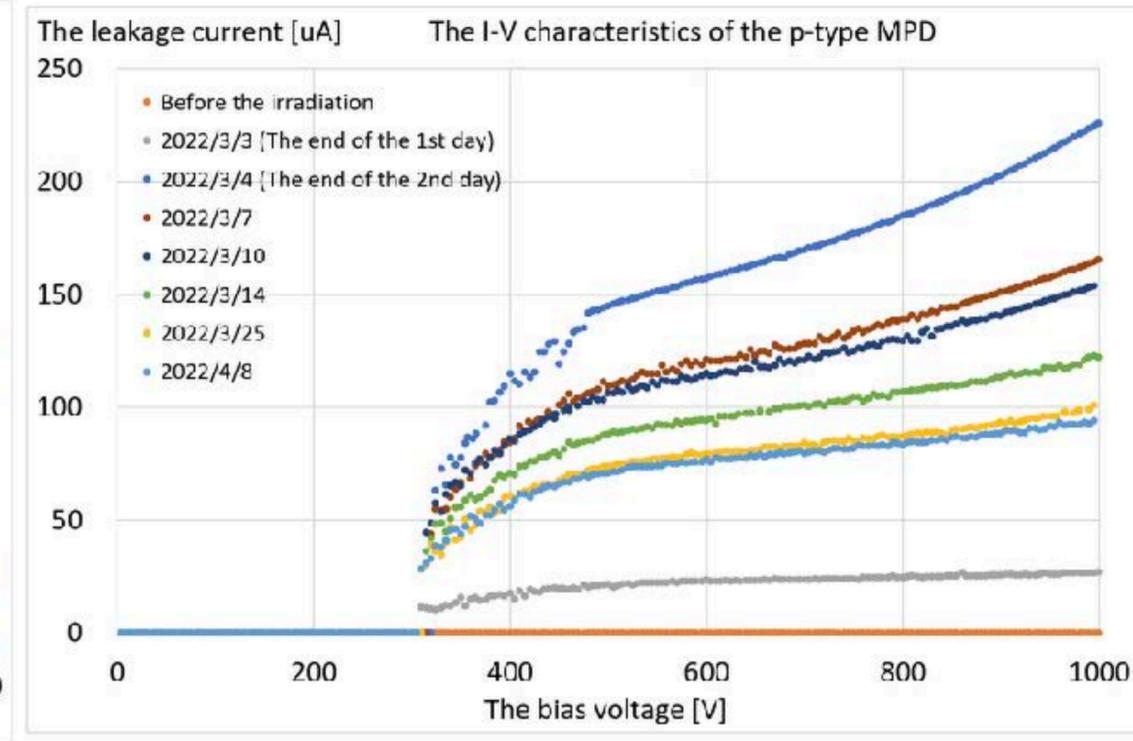


PCBs with sensors

## n-type



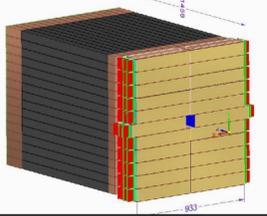
## p-type



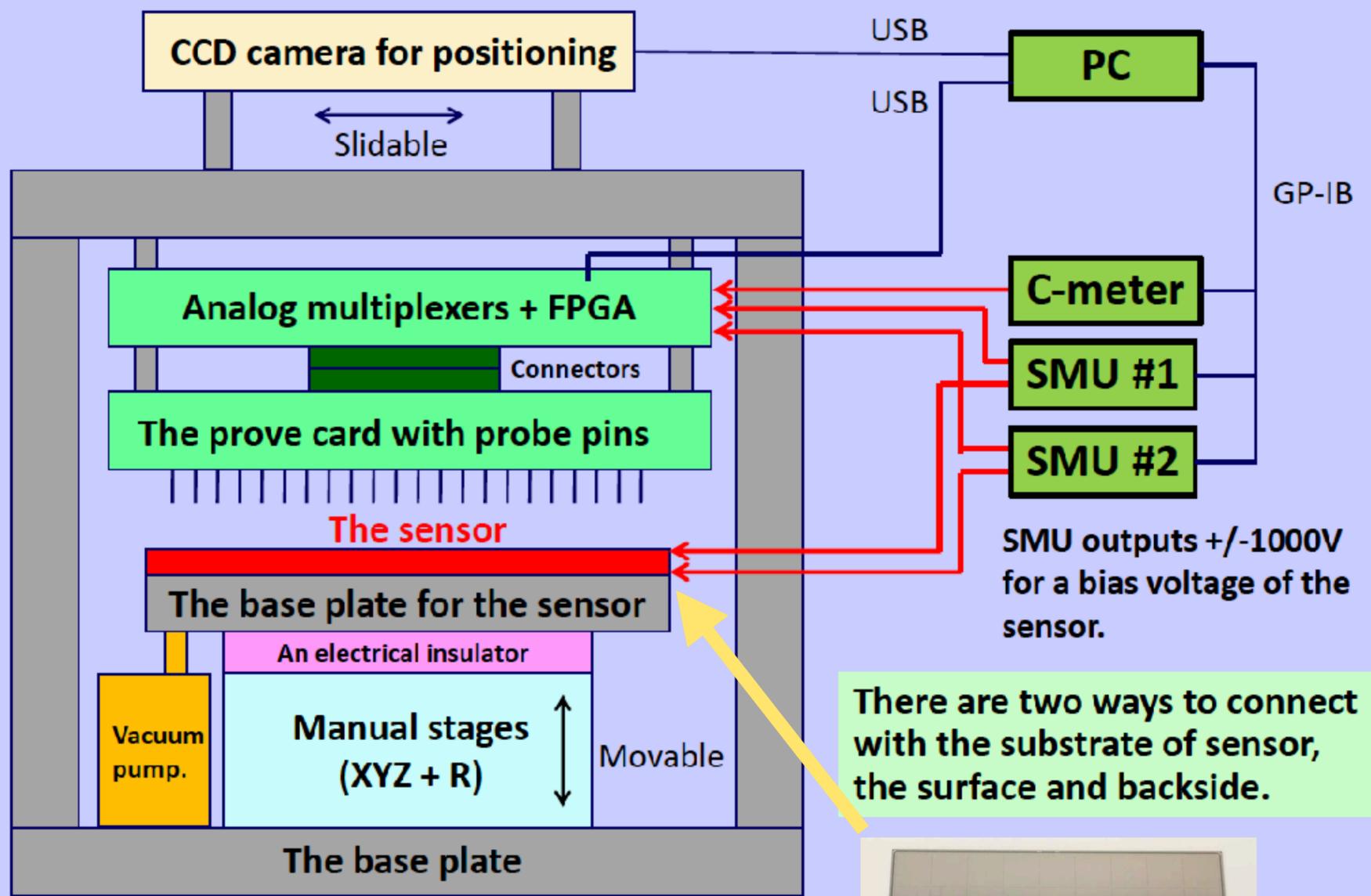
(M. Inaba)

# Probe station for large sensors

(M. Inaba)



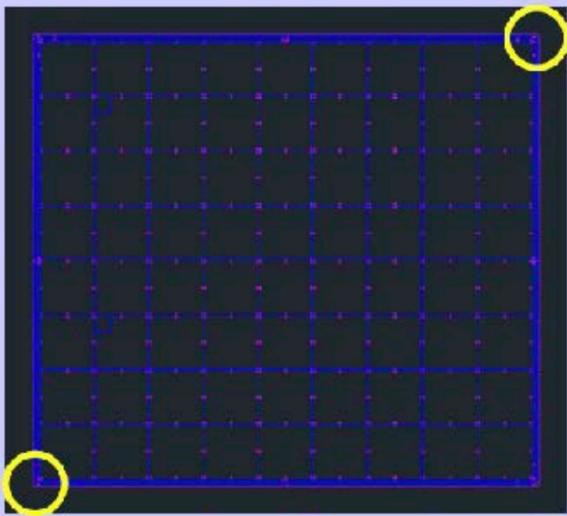
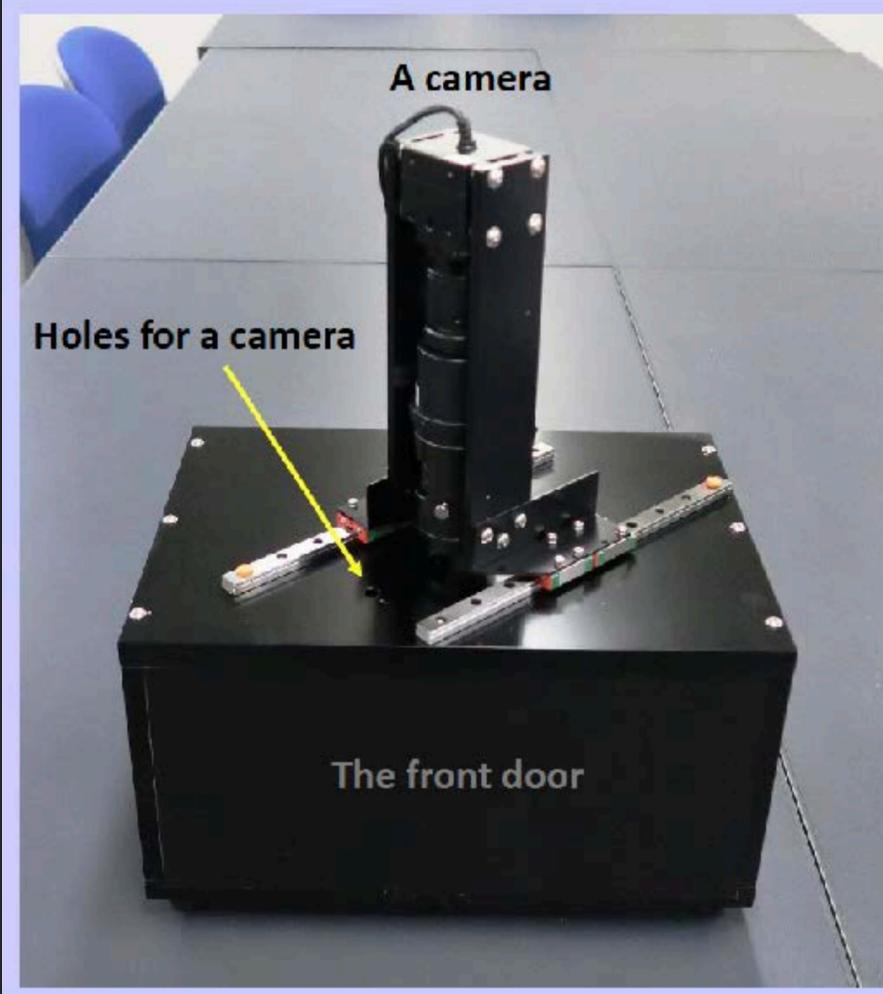
## An idea of a new probe station



There are two ways to connect with the substrate of sensor, the surface and backside.



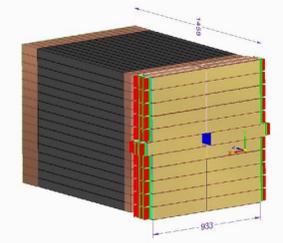
## The outside of a new probe station



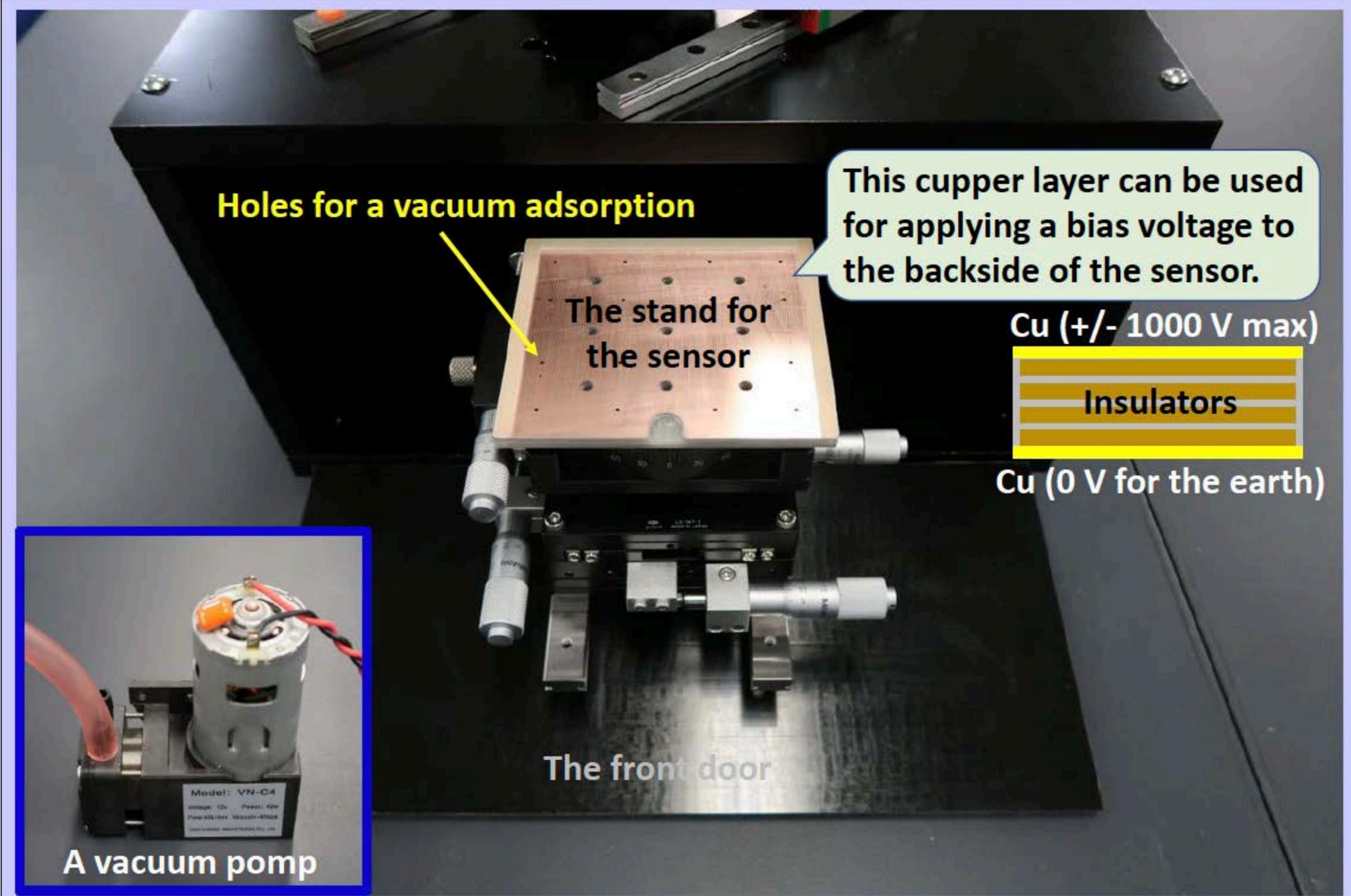
The sensor has alignment marks at the corners.

Width: 350 mm,  
Length: 250 mm,  
Height: 455 mm  
(the box only: 180 mm).

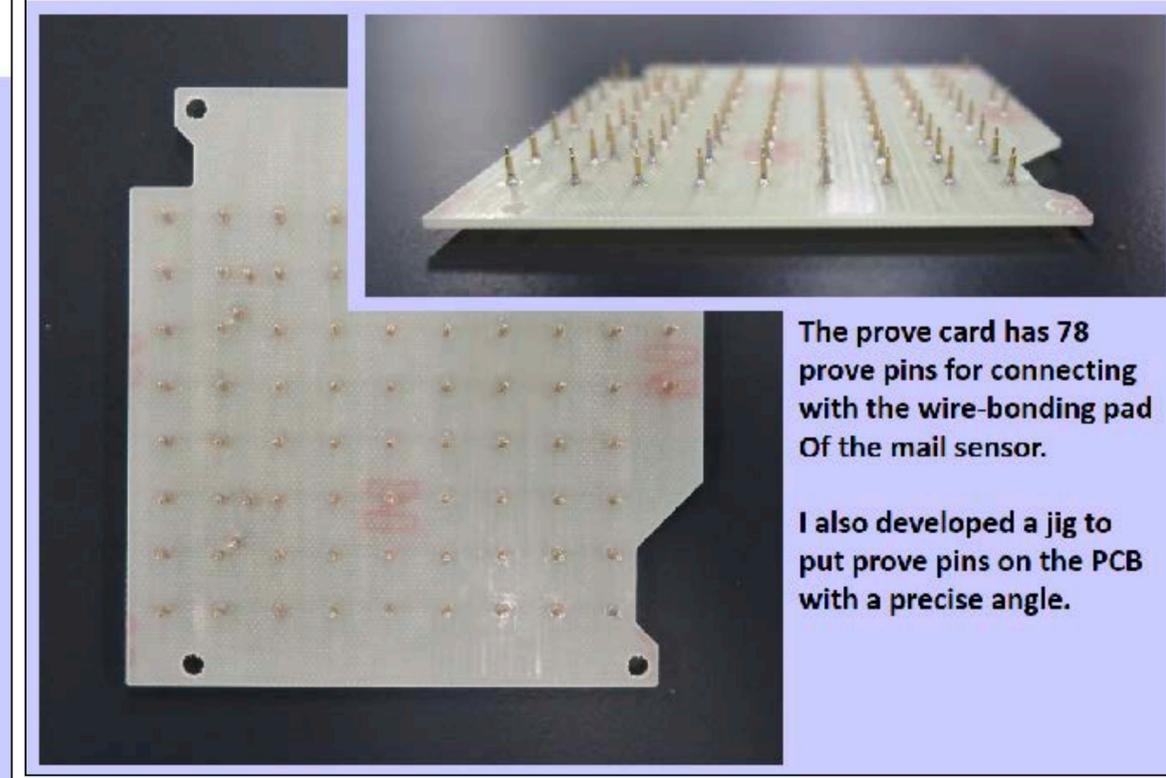
# Probe station for large sensors



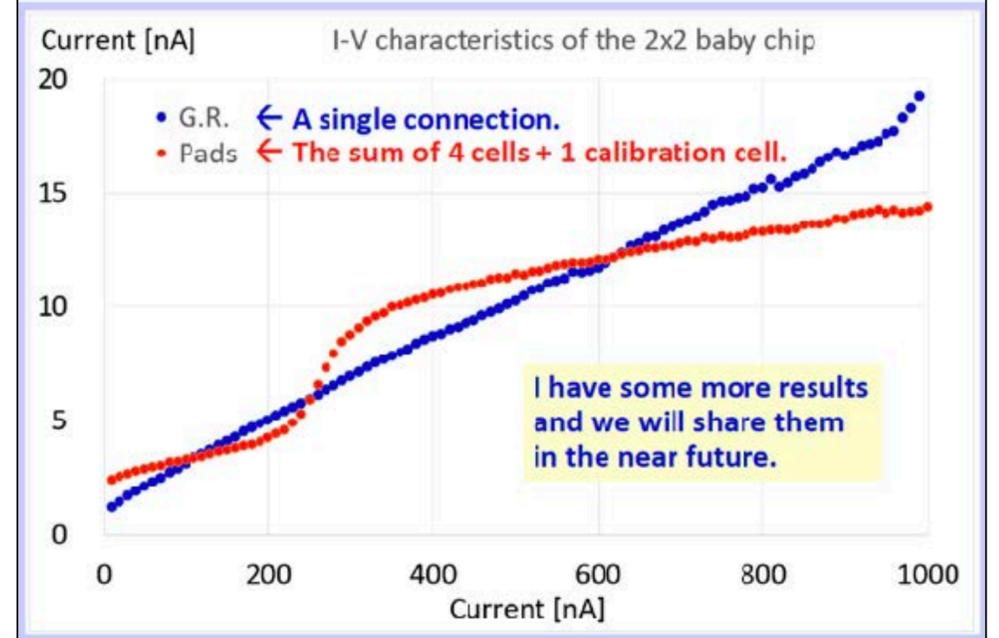
## A drawer for easy exchanging of sensors



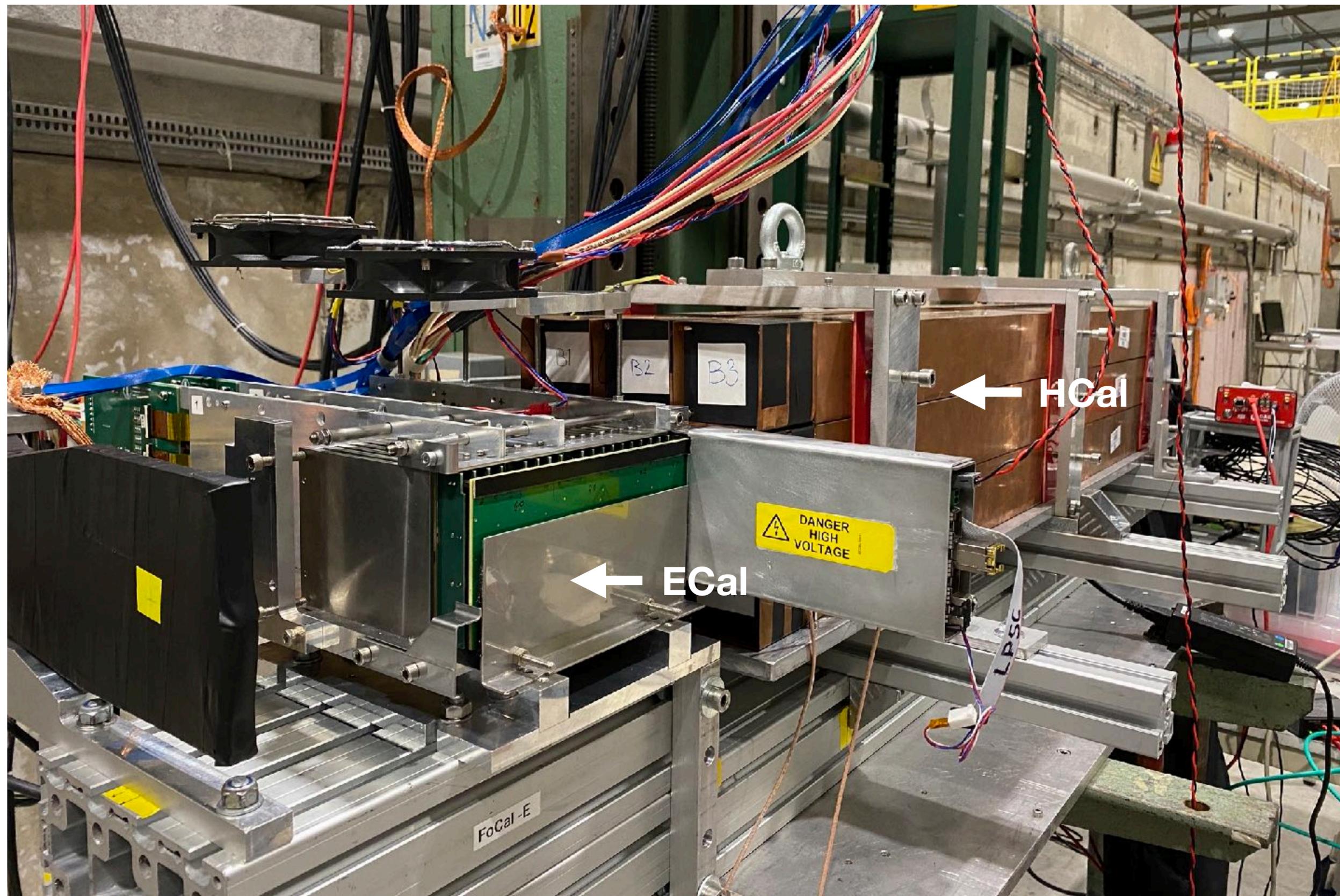
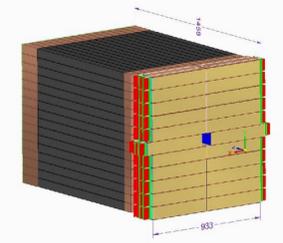
## The probe card



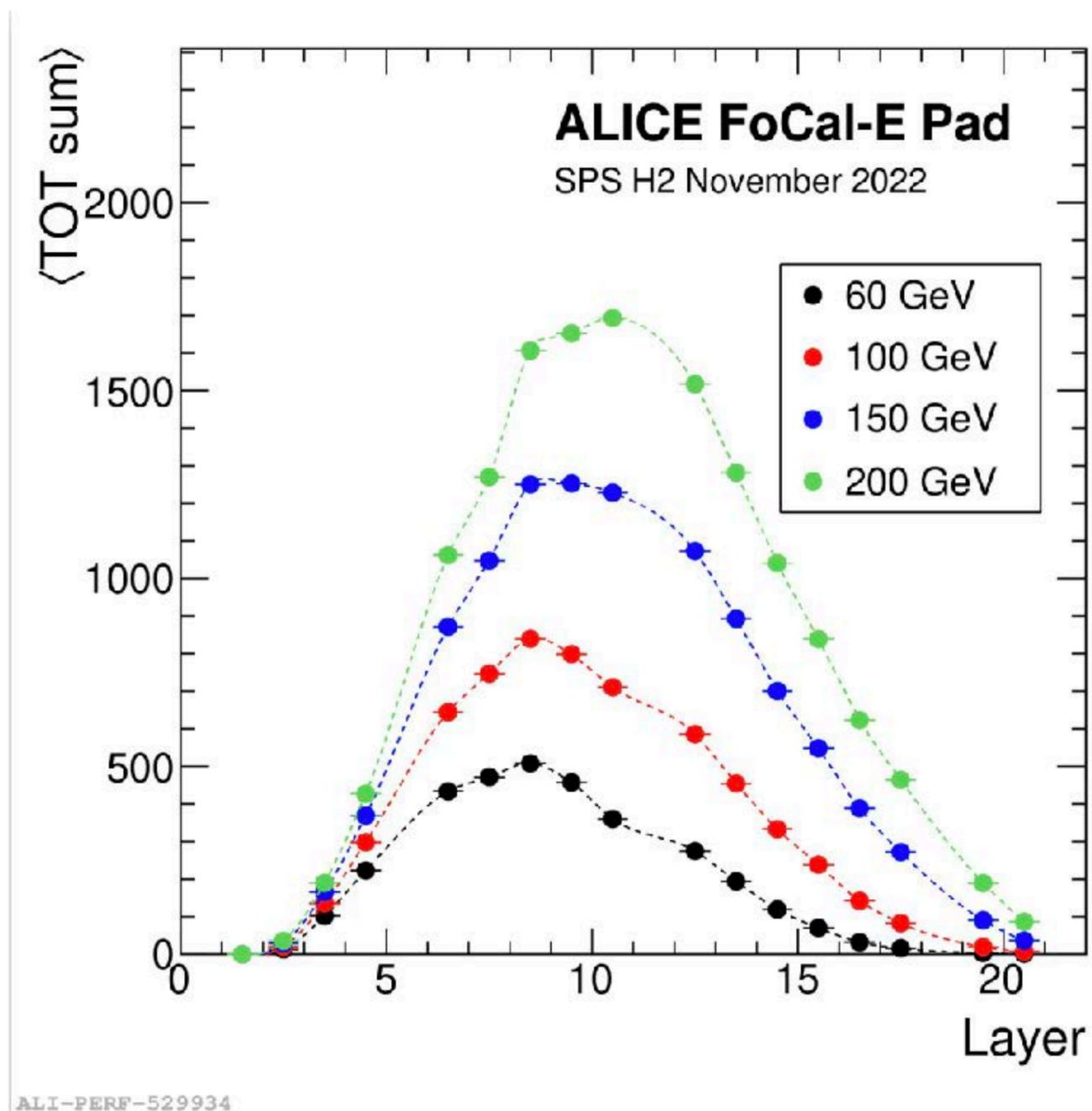
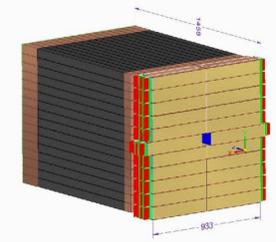
## A test result



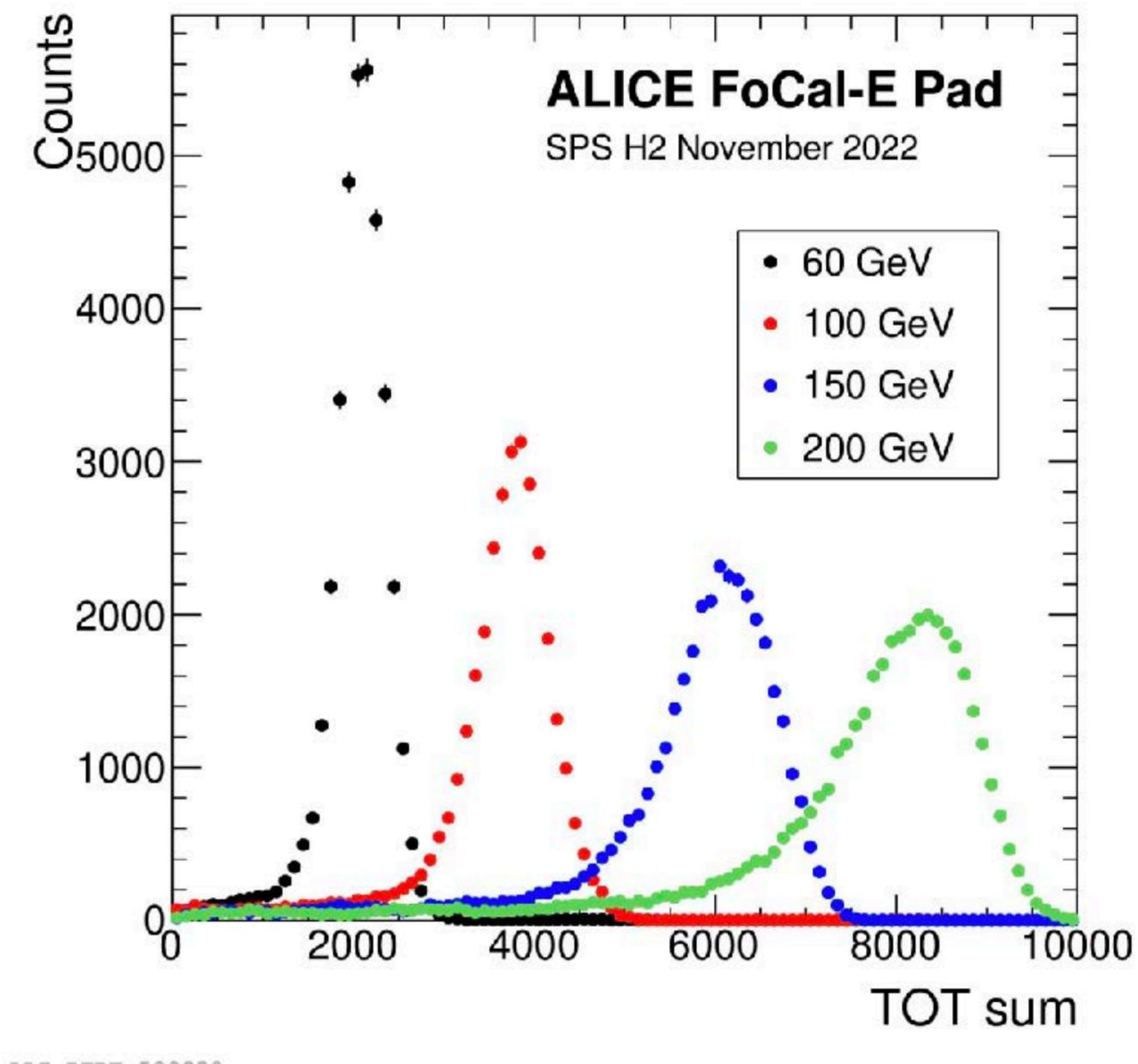
# SPS test beam, H6 / H2 line (2022.09/11)



# FoCal-E pad longitudinal shower profile

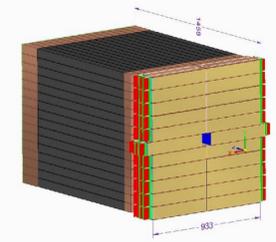


**Longitudinal shower profiles**



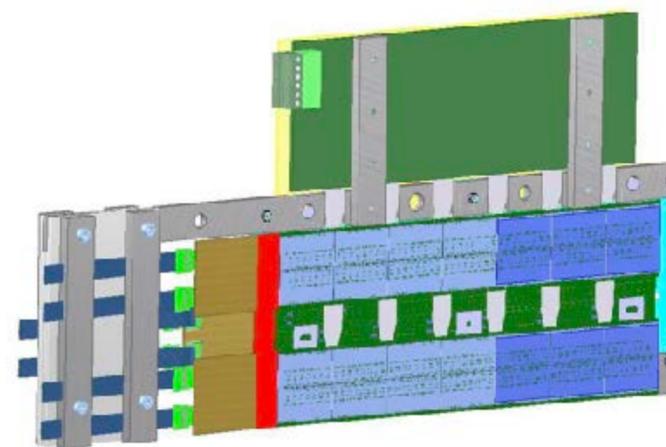
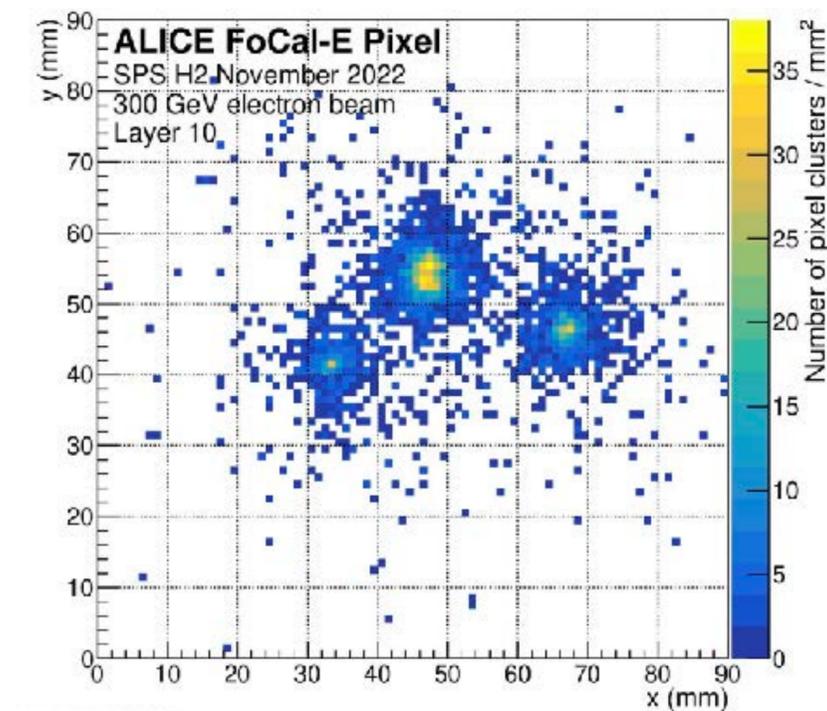
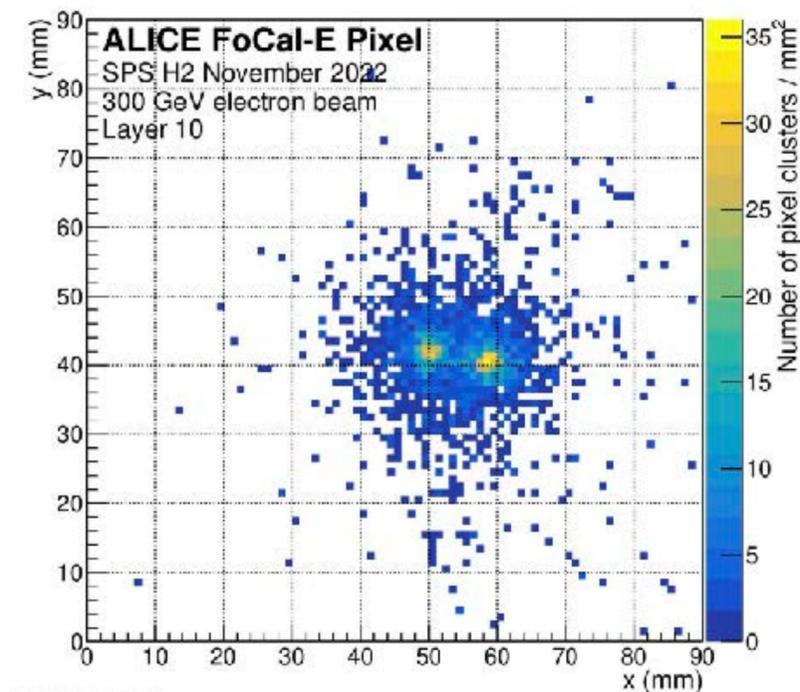
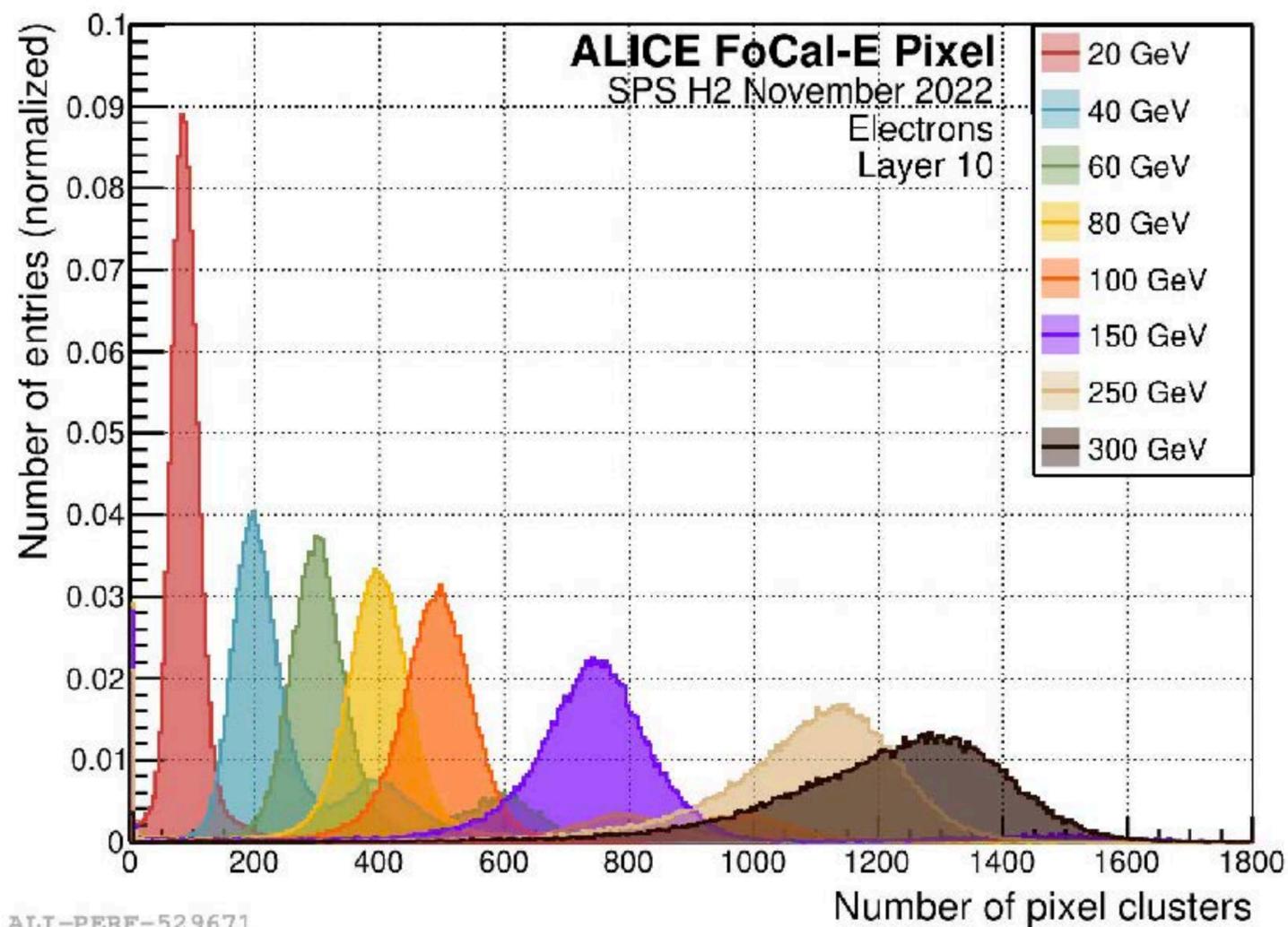
**TOT sum distributions**  
~ energy deposit

# FoCal-E PIXEL @ SPS test beam in 2022

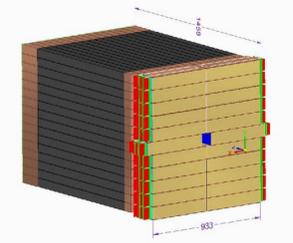


- Successful commissioning of the HICs (ALPIDE)
- Double and triple electron signature identified in preliminary analysis

2022 preliminary results [HICs layers] - Layer 10

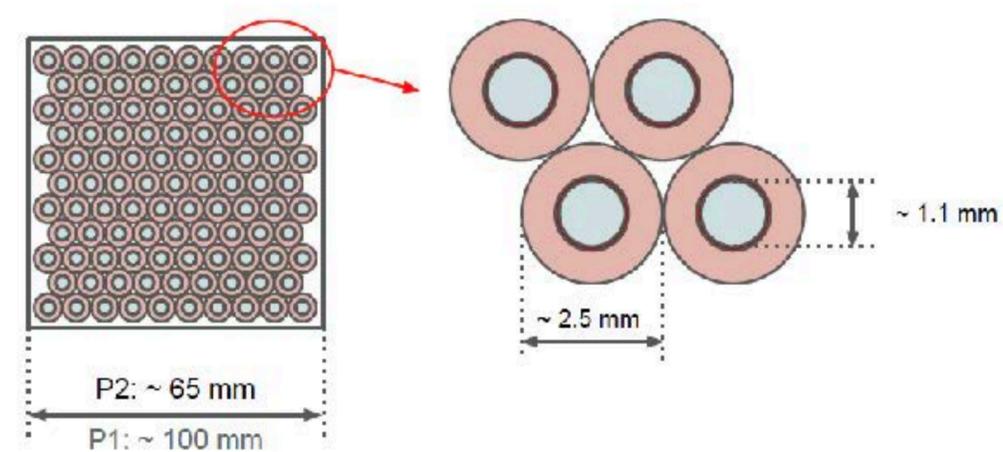
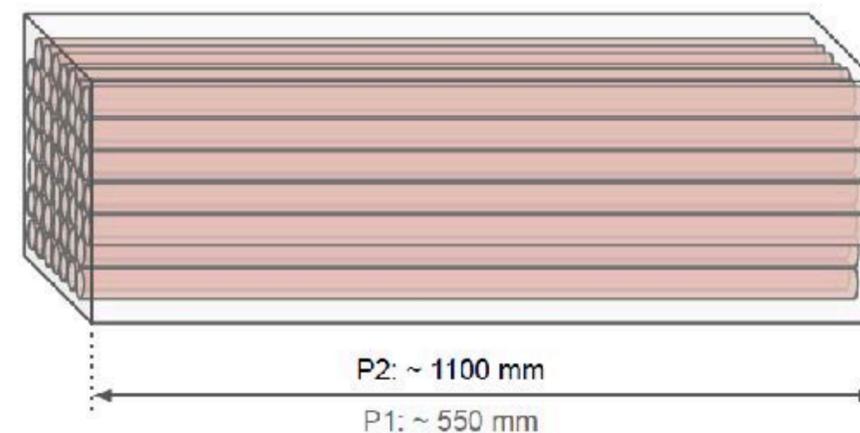


# FoCal-H

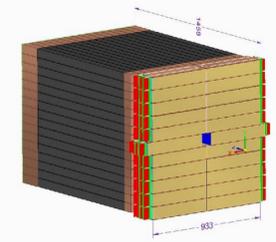


## Prototype 2 (used during 2022 tests)

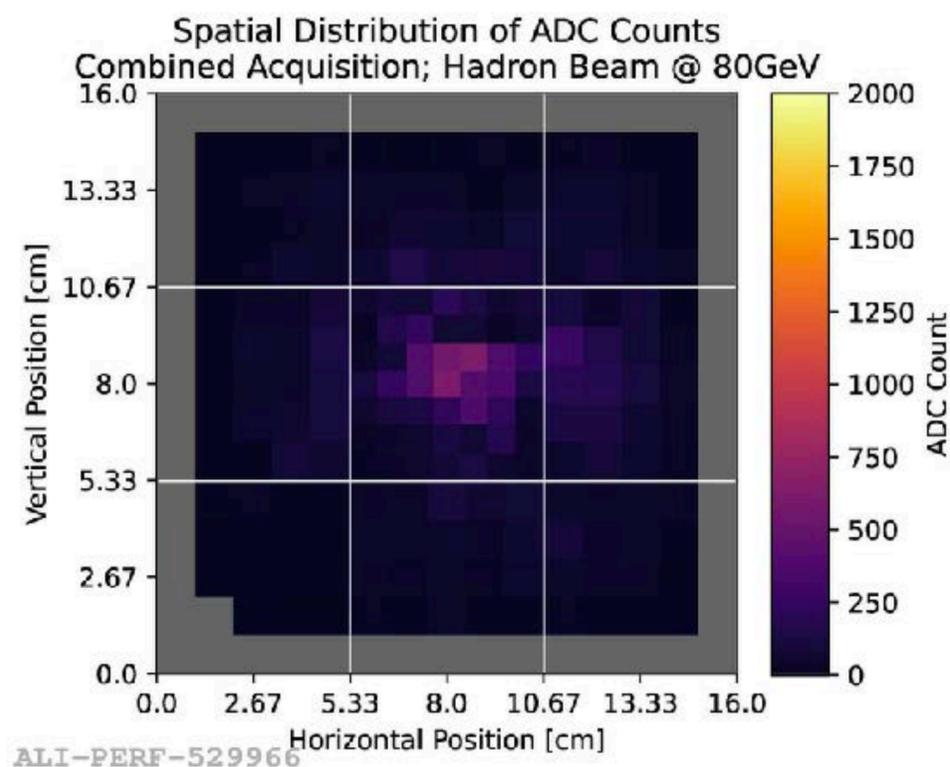
- Cu capillary-tubes enclosing BCF scintillating fibers
- 6.5 cm x 6.5 cm x 110 cm
- 1 mm BCF12 scintillating fiber
- SiPM: 9 (central), 25 (sides) Hamamatsu: S13360-6025PE
- Readout (1) : 2/3 CAEN DT5202 boards (2xCitiroc-1A chips)
- Readout (2) : Alternative custom VMM-based readout (with SRS system)



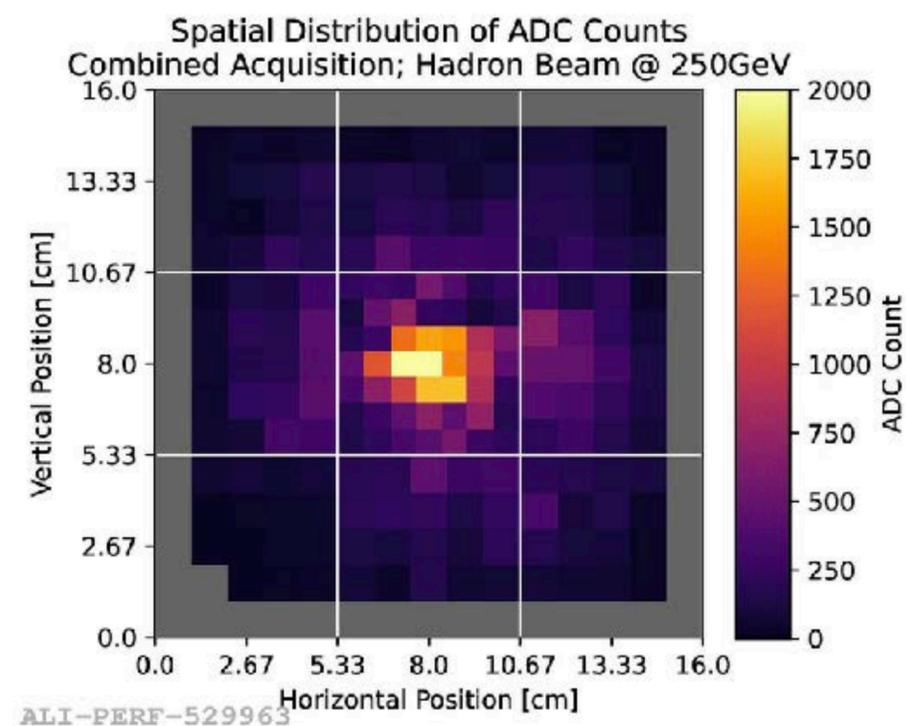
# FoCal-H



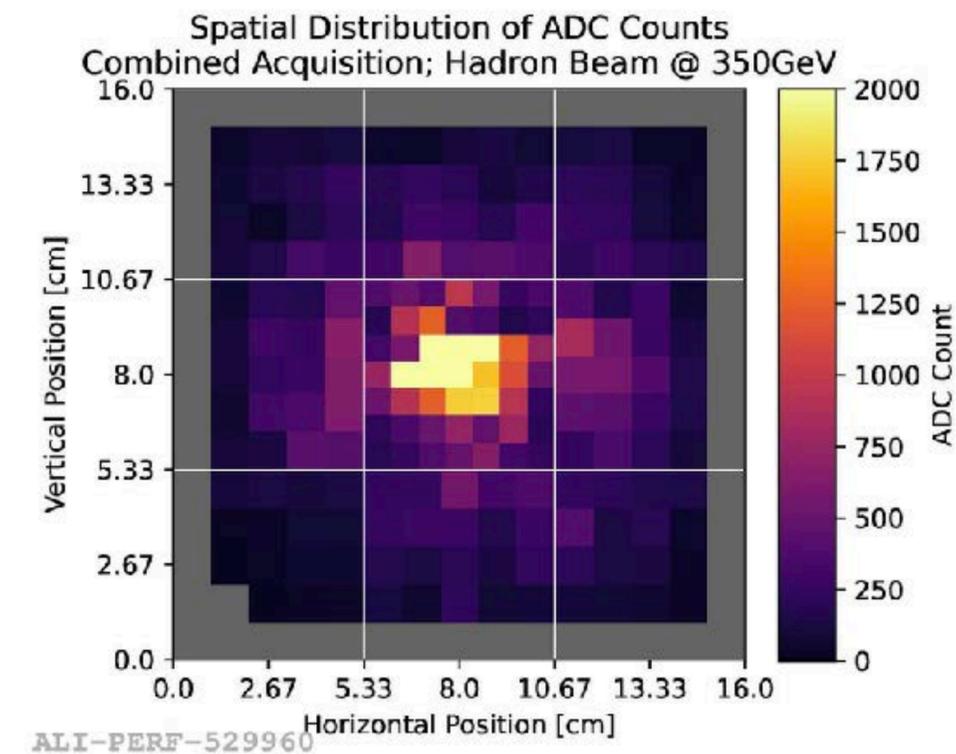
FoCal-H (9 modules) 2D hit maps with hadron beam @ different energies



80 GeV Hadron



250 GeV Hadron



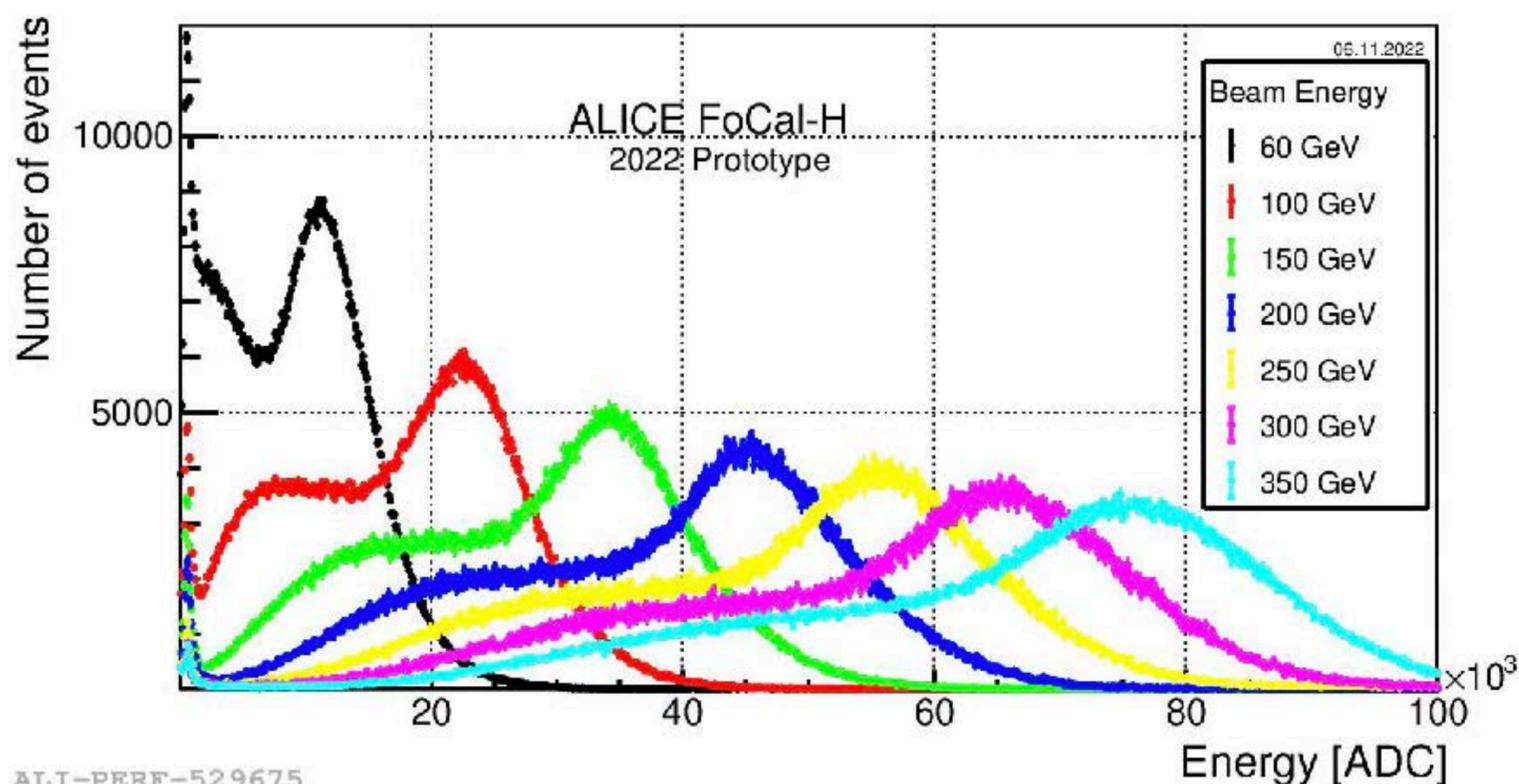
350 GeV Hadron

- Energy deposited increasing with the beam energy
- Grey bands → Non instrumented SiPMs (3 CAEN DT5202 boards used)
- 49 (central) + 25x8 (sides) SiPMs, photosensitive area: 6x6 mm, pixel size: 25  $\mu m$

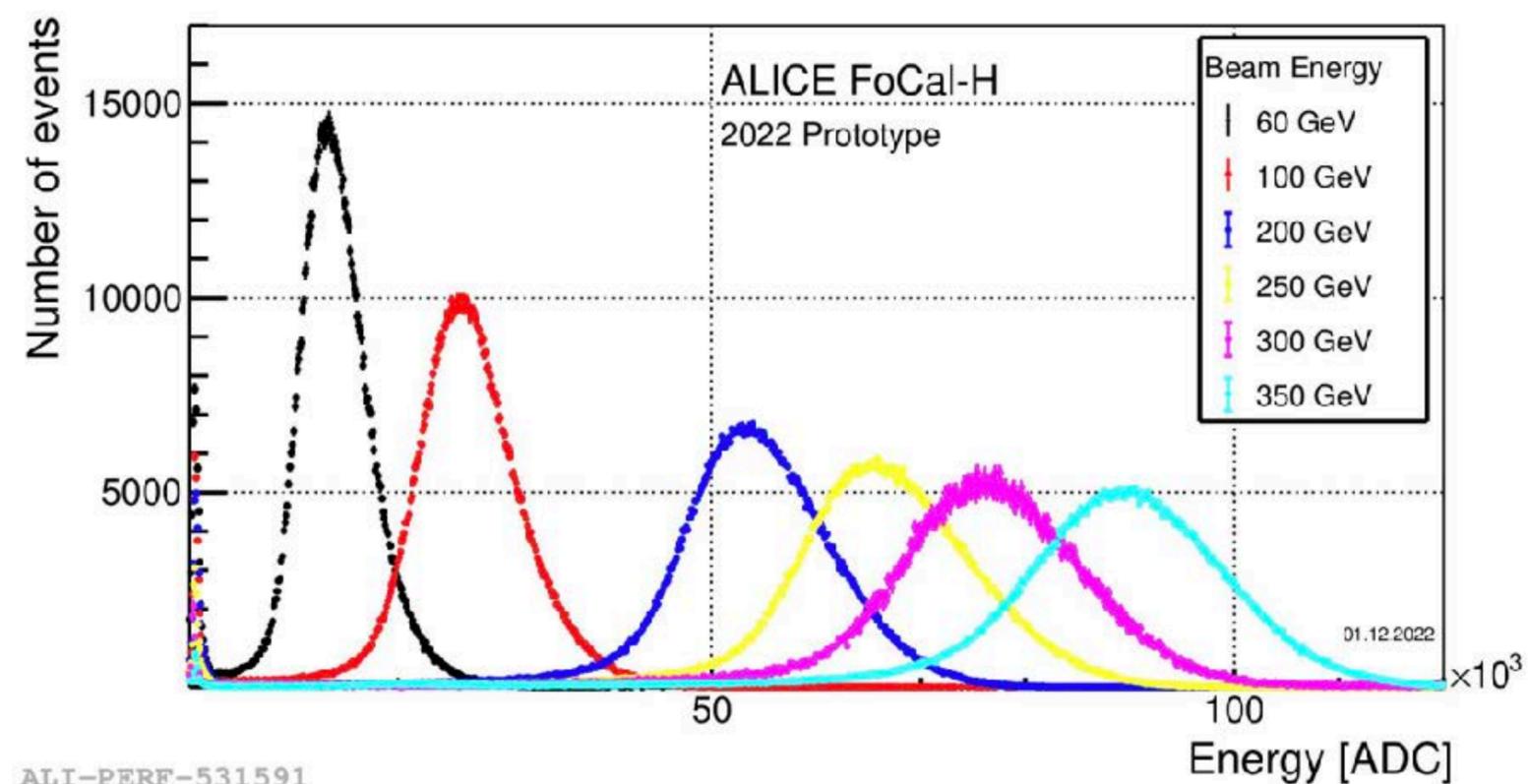
# FoCal-H

- Reconstructed charge in the FoCal-H prototype [ADC counts/energy]
- SPS positive hadron beam, energies (60 - 350 GeV)

w/ FoCal-E in front

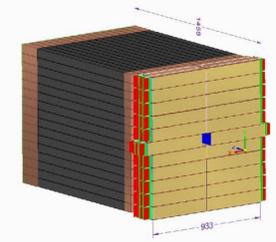


w/o FoCal-E in front



- Distributions qualitatively follow the expected trends
- MIP peak (centered around 0) is at the same position for each beam energy
- The position of the second peak move according to the beam energy
- The tails at lower energy deposit disappear (conversion in Focal - E)

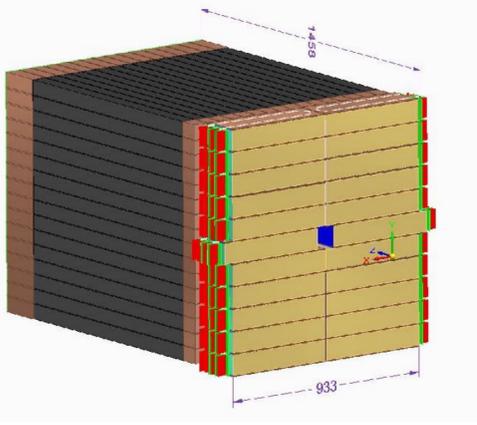
# Timeline



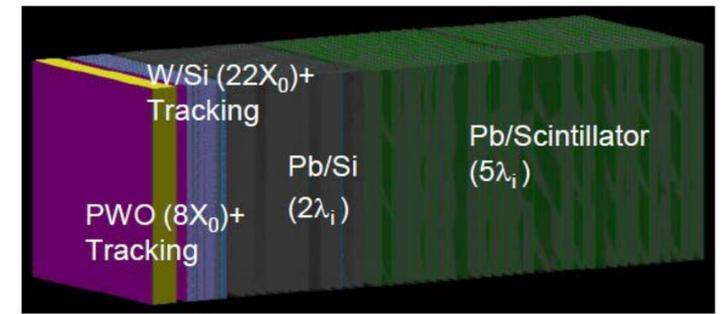
	19	2020				2021				2022				2023				2024				2025				2026				2027				2028				2029			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4																
LHC		LS2								Run-3												LS3												Run-4							
Lol		Red																																							
R&D		Orange																																							
Test beams (SPS, DESY, KEK)						Green				Green				Green																											
TDR										Green				Green																											
Final design														Red				Red																							
Production, construction, test of module																		Blue				Blue				Blue				Blue				Blue							
Pre-assembly, calibration with test beam (KEK)																						Dark Blue																			
Installation and commissioning																										Blue				Blue				Blue							
Contingency																														Grey				Grey							
Global commissioning and physics data taking																																		Purple				Purple			

**Final R&D in 2022 towards Technical Design Report in 2023**

Production in 2024-2026, Installation in 2027, Physics data taking in 2029-2032 (LHC Run-4)

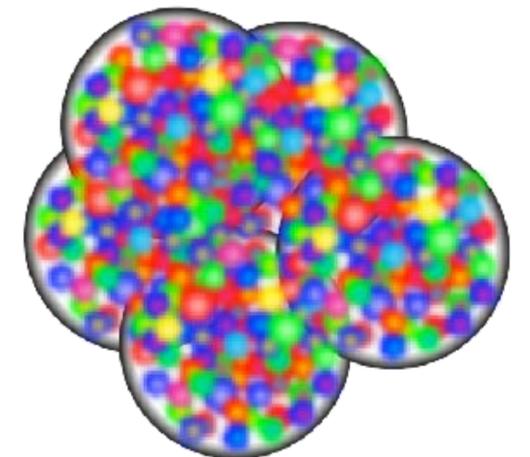


# Summary



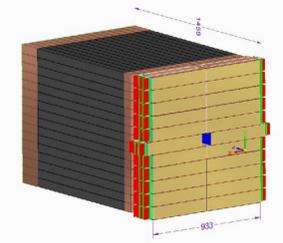
- For EIC ZDC, there is a proposal to use a FoCal technology
- FoCal in ALICE;
  - Final design and performance evaluation towards Technical Design Report (TDR) in 2023
  - Production in 2024-2026, Installation in 2027, Physics data taking in 2029-2032 (LHC Run-4)
  - Good synergy with EIC both detector wise and physics wise
- Progressing well towards the final design

*Thank you for your attentions !*

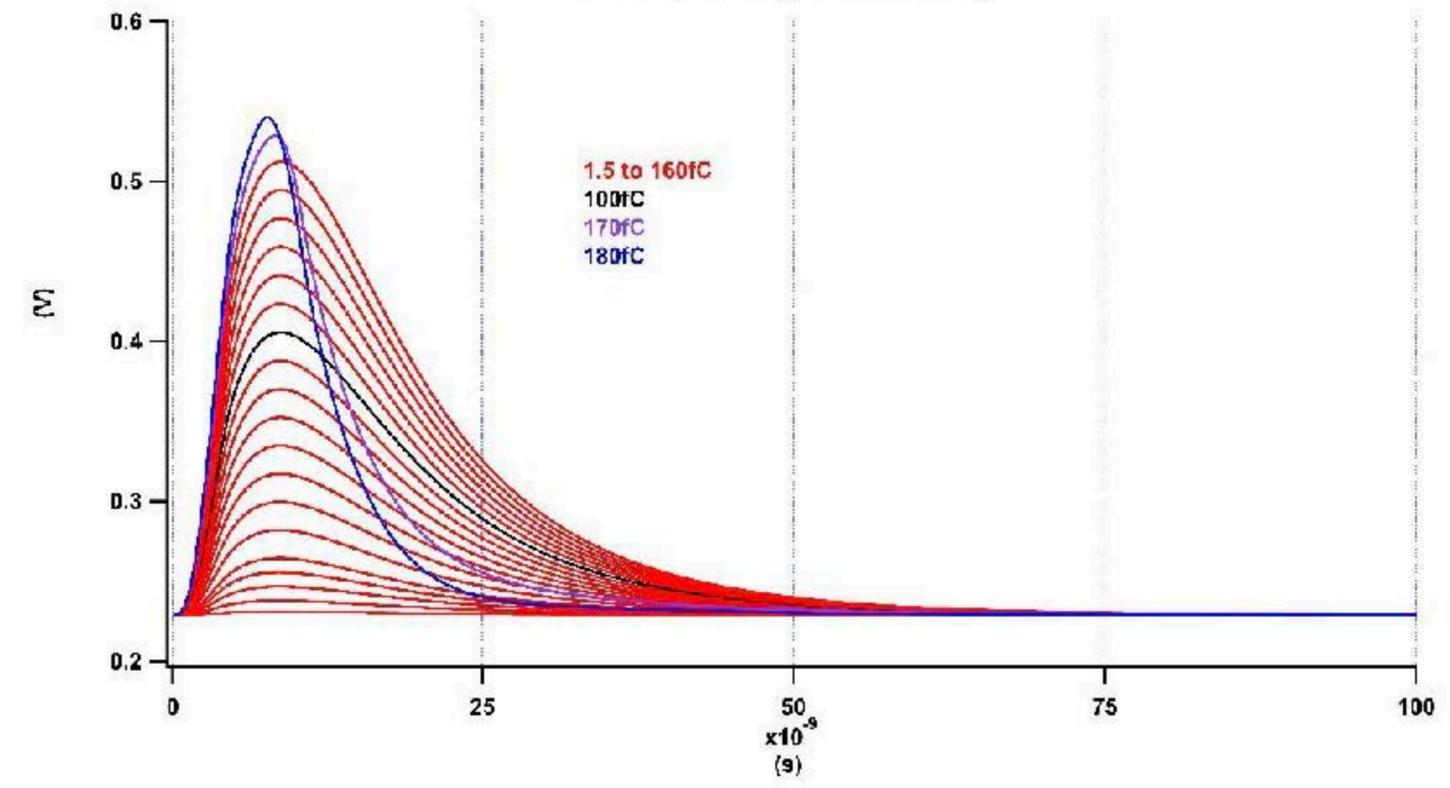


**Backup**

# HGCROC (shaping time and noise)

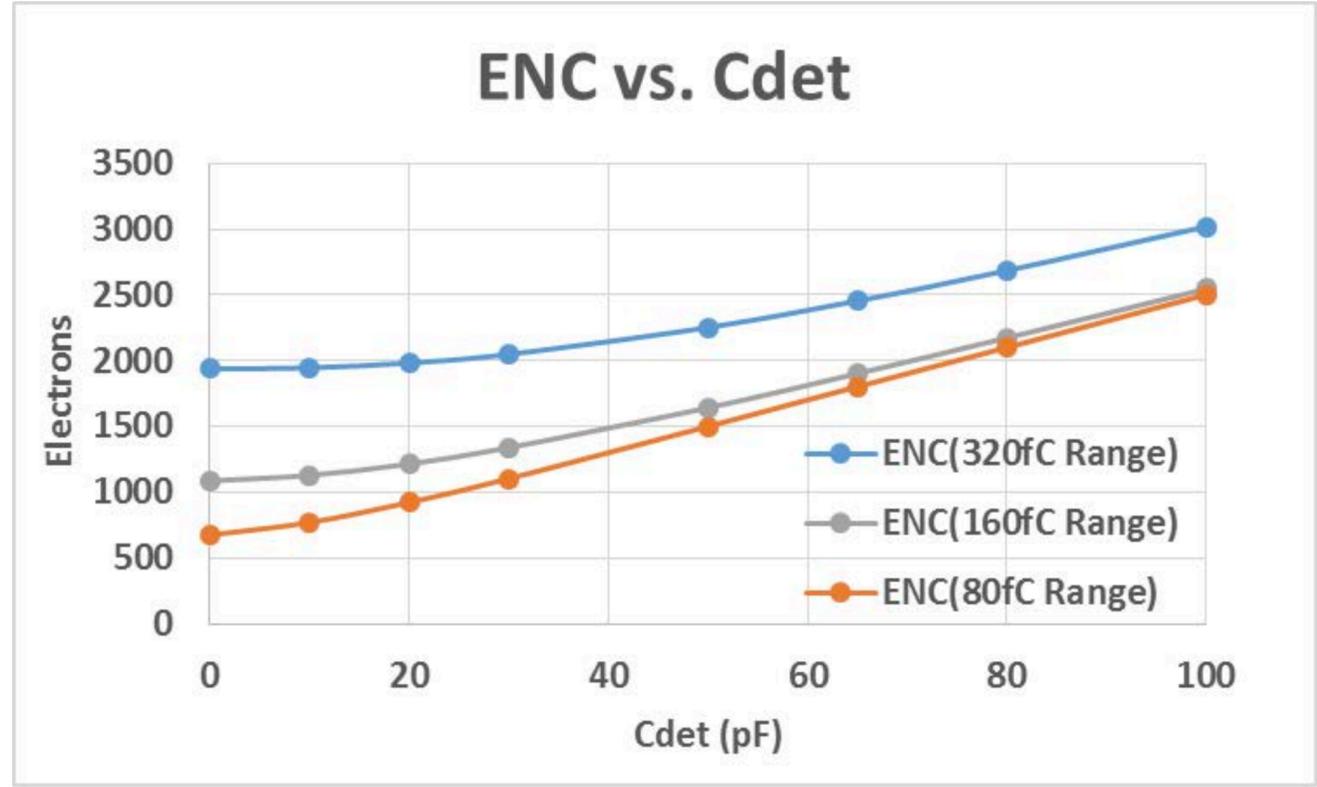


**Preamplifier waveforms**  
Default preamp gain: 160fC range

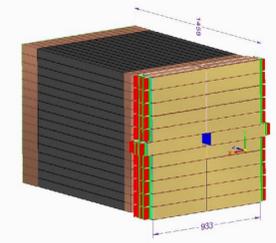


HGCROC shaping time < 25 ns

**ENC vs. Cdet**



Equivalent Noise Charge (ENC) as a function of the detector capacitance



# List of institutes participating in FoCal (LoI, 2020)

ALICE-FoCal collaboration  
34 institutes, 12 countries



BARC	Bhaba Atomic Research Centre, Mumbai, India	V.B. Chandratre
Berkeley	Lawrence Berkeley National Laboratory, Berkeley, USA	M. Ploskon
Bhubaneswar	Institute of Physics, Bhubaneswar, India	P. K. Sahu
Bergen	University of Bergen, Bergen, Norway	D. Roehrich
Bose	Bose Institute, Kolkata, India	S. Das
CCNU	Central China Normal University	D. Zhou
Detroit	Wayne State University, Detroit, USA	J. Putschke
Gauhati	Gauhati University, India	B. Bhattacharjee
Grenoble	LPCS Grenoble, France	R. Guernane
Hiroshima	Hiroshima University, Hiroshima, Japan	T. Sugitate
Houston	University of Houston, Houston, USA	R. Bellwied
HVL	Western Norway University of Applied Sciences, Bergen Norway	H. Helstrup
IITB	Indian Institute of Technology Bombay, Mumbai, India	R. Varma
Indore	Indian Institute of Technology Indore, Indore, India	R. Sahoo
INR RAS	Inst. f. Nuclear Research Russian Acad. of Science, Moscow, Russia	T. Karavicheva
Jammu	Jammu University, Jammu, India	A. Bhasin
Jyväskylä	University of Jyväskylä, Jyväskylä, Finland	S. Räsänen
Knoxville	University of Tennessee, Knoxville, USA	K. Read
Nara	Nara Women's University, Nara, Japan	M. Shimomura
NBI	Niels Bohr Institute, Copenhagen, Denmark	I. Bearden
MEPhI	National Research Nuclear University, Moscow, Russia	A. Bolozdyny
NISER	National Institute of Science Education and Research (NISER)	B. Mohanty
Oak Ridge	Oak Ridge National Laboratory (ORNL), Oak Ridge, USA	C. Loizides
Oslo	University of Oslo, Oslo, Norway	T. Tveter
Panjab	Panjab University, Chandigarh, India	L. Kumar
RIKEN	Institute of Physical and Chemical Research, Toky, Japan	Y. Goto
Sao Paulo	Universidade de Sao Paulo (USP), Sao Paulo, Brazil	M. Munhoz
Tsukuba	University of Tsukuba	T. Chujo
Tsukuba Tech	Tsukuba University of Technology	M. Inaba
UFRGS	Universidade Federal Do Rio Grande Do Sul	M.B. Gay Ducati
UU/Nikhef	Utrecht University, Utrecht, and Nikhef, Amsterdam, Netherlands	T. Peitzmann
VECC	Variable Energy Cyclotron Centre, Kolkata, India	S. Chattopadhyay
USN	University of South-Eastern Norway, Kongsberg, Norway	J. Lien
Yonsei	Yonsei University, Seoul, Korea	Y. Kwon

