

# Hodoscope/TOF Commissioning HKS HES ENGE

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# HODOSCOPE basic concept

## HKS & HES HODOSCOPE /ETOF, KTOF

-  $T_{RefDetector}^{HKS}$ ,  $T_{RD}^{HES}$

→ HKS-HES @target,  $T_{coin}$

→ Trigger timing determination

- **TOF( $\beta$ )**

→ PID by mass  $m^2 = p^2 \left( \frac{1}{\beta^2} - 1 \right)$

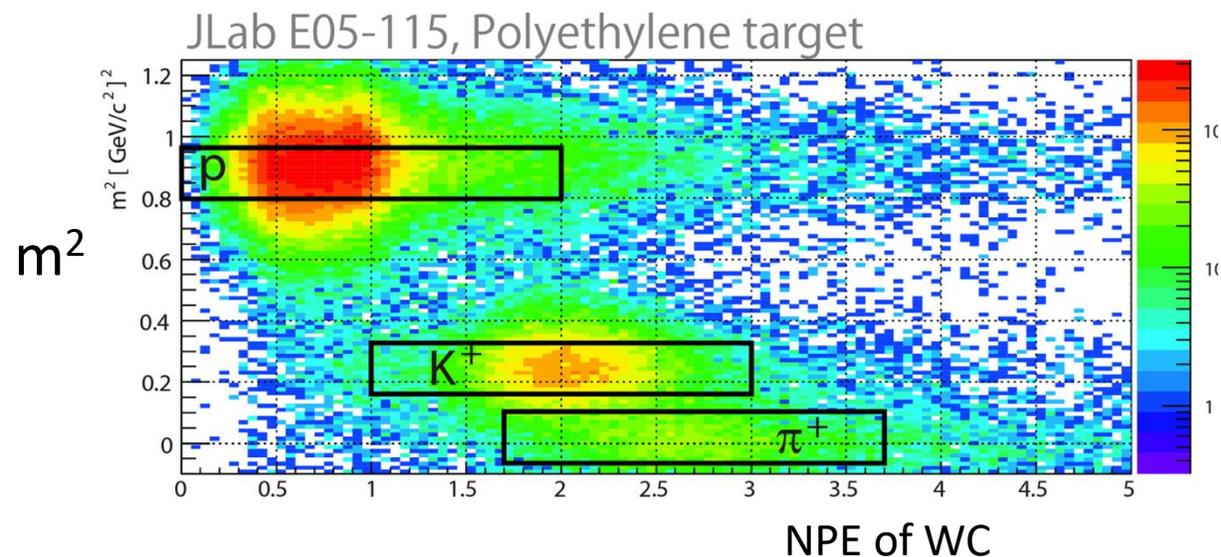
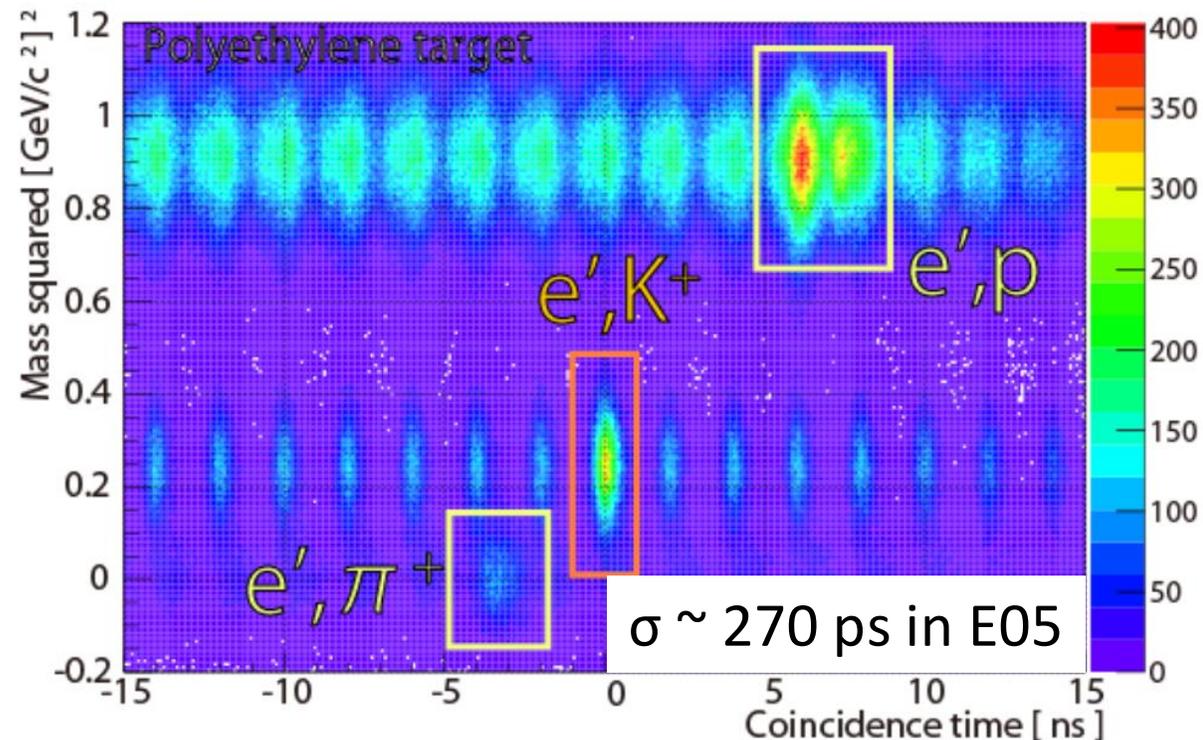
## ENGE HODOSCOPE /PiTOF

- **TOF( $\beta$ )**,  $T_{RD}^{ENGE}$  measurement

→ HKS-ENGE @target,  $T_{coin}$

→ Lifetime measurement

## HKS-HES Coincidence result from E05



# Coincidence time

Times of particle at target

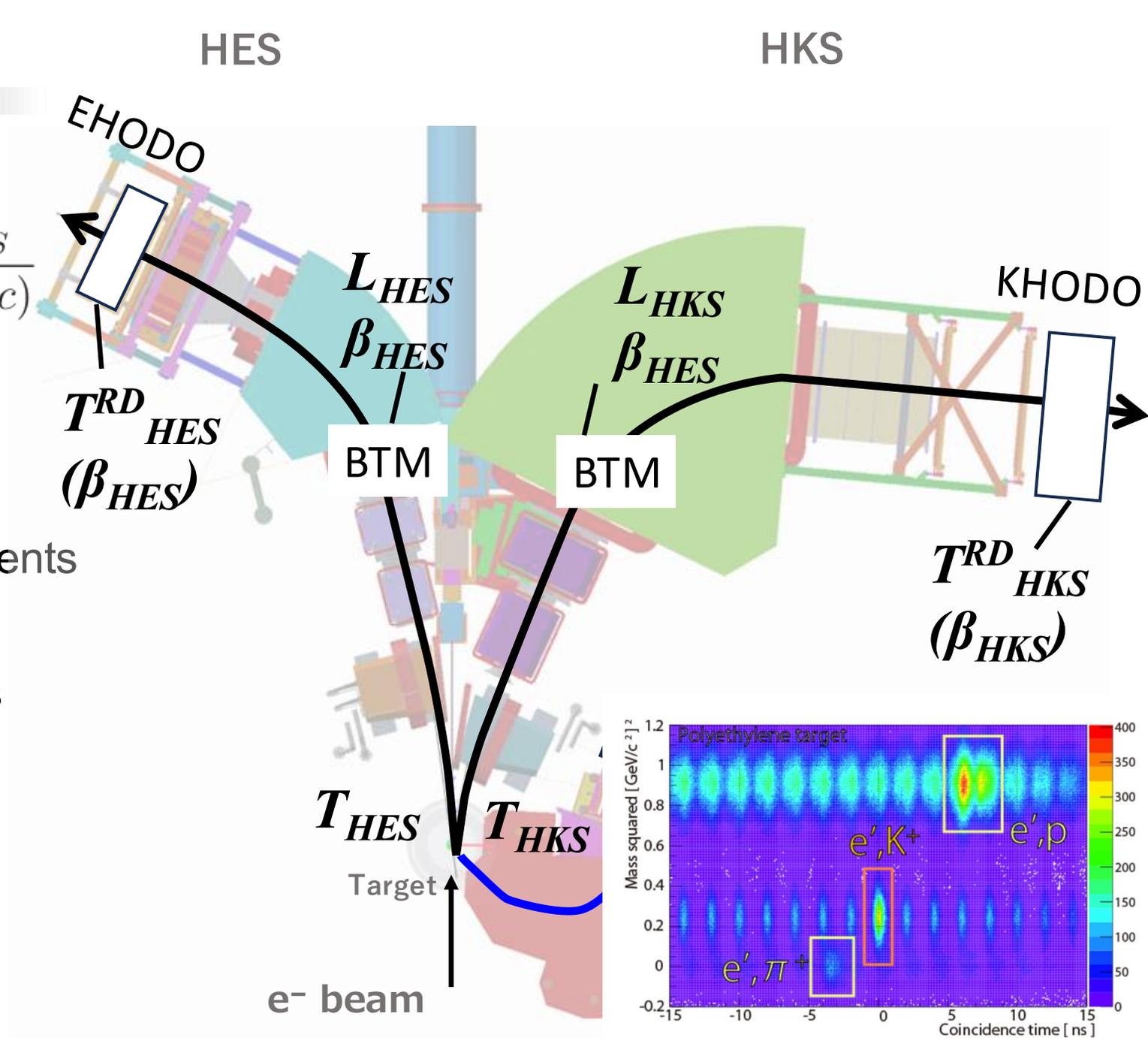
$$T_{HES,HKS} = T_{HES,HKS}^{RD} - \frac{L_{HES,HKS}}{(\beta_{HES,HKS}c)}$$

Coincidence time is defined as

$$T_{COIN} = T_{HKS} - T_{HES}$$

$|T_{COIN}| < 1$  ns is selected as  $e'K^+$  events

In E05,  $T_{COIN}$  resolution :  $\sigma = 270$  ps  
good separation of  $e'K^+$

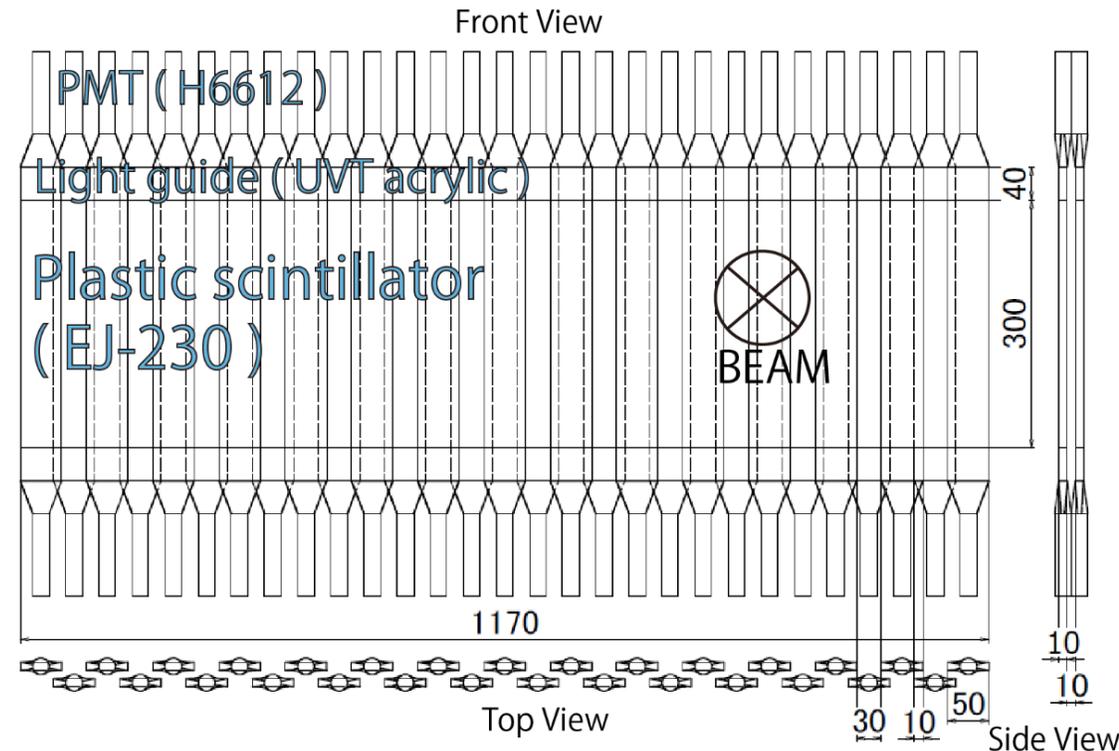
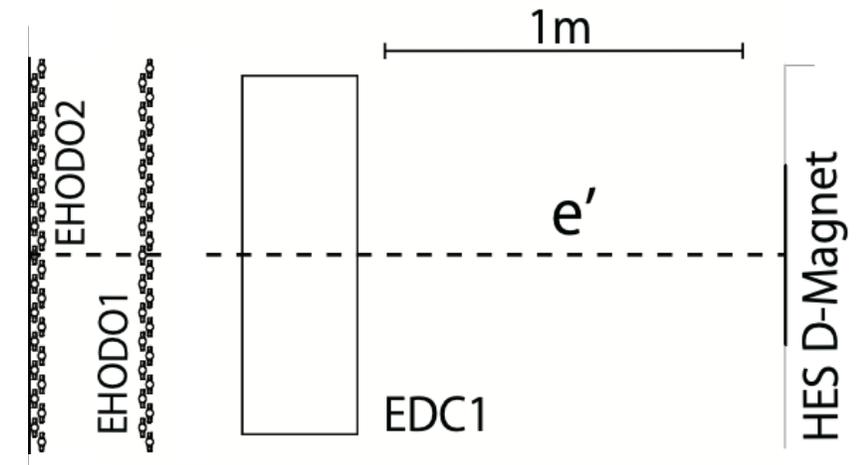


# EHODO/ETOF specification

Developed for E05 (> 15 yo)

Effective area	117 <sup>W</sup> cm x 30 <sup>H</sup> cm x 1 <sup>T</sup> cm
Segments	29 segments
Layer	2 (EHODO1 & EHODO2)
PMT	Hamamatsu H6612 (1 inch)
Scintillator	EJ-230
Time resolution	~ 90 ps w/cosmic in E05

Same hardware as E05, but **DAQ changed**  
116 ch for both FADC, vTDC



# EHODO/ETOF status

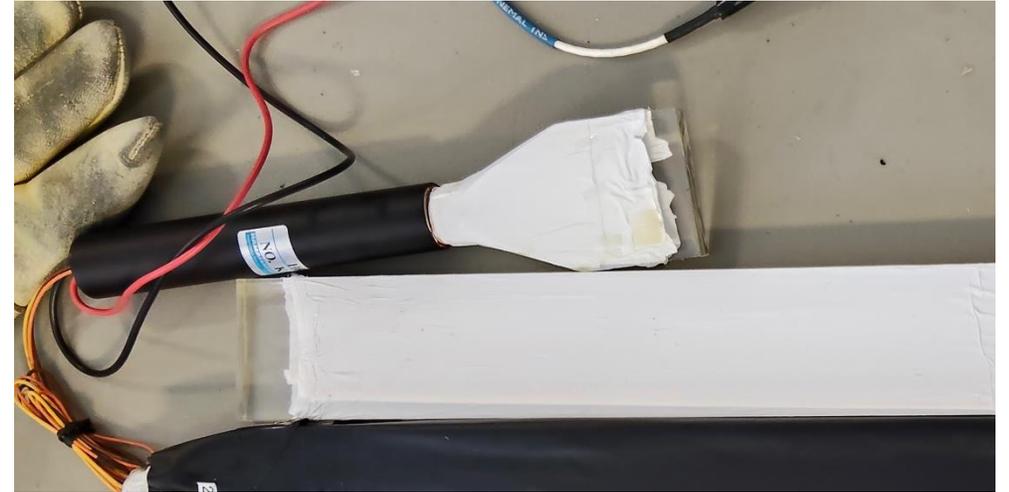
## Status :

- 8 paddles are broken (optical connection)
- Other paddles and Frame are stored in ESB

## Commisioning Plan :

- Repairment of optical connection
  - Bill is preparing epoxy and ePAS
- PMT output check (light leak, vaccum, noise)
- PMT gain test
- Timing resolution & TOF resolution study

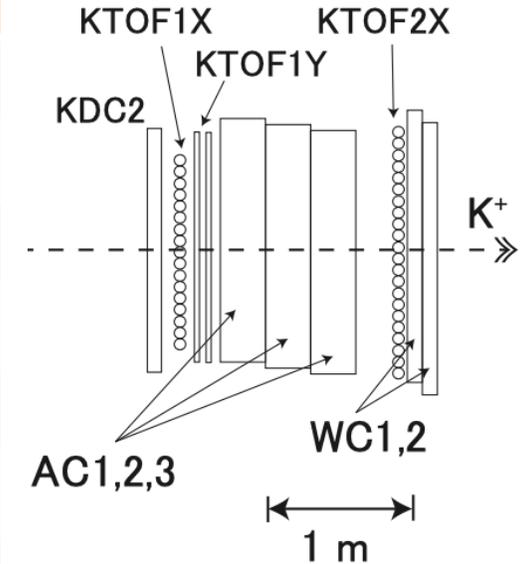
Main point to check: Time resolution with new DAQ system (shared issue with HKS)



# KHODO/KTOF specification

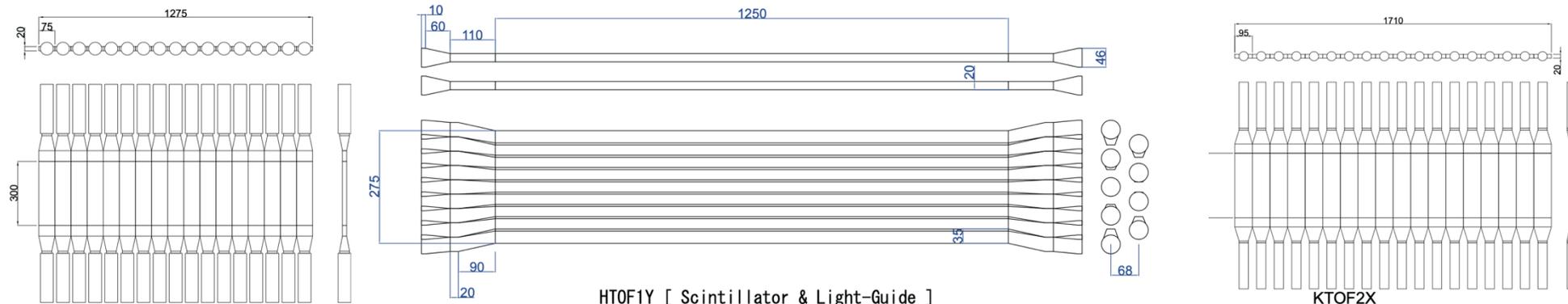
Developed for E01 (> 20 yo)

	1X	1Y	2X
Effective area	$127.5^W \times 30^H \times 2^T \text{ cm}^3$	$125^W \times 27.5^H \times 2^T \text{ cm}^3$	$171^W \times 35^H \times 2^T \text{ cm}^3$
Eff. area of seg	$7.5^W \times 30^H \times 2^T \text{ cm}^3$	$125^W \times 3.5^H \times 2^T \text{ cm}^3$	$9.5^W \times 35^H \times 2^T \text{ cm}^3$
Segments	17	9 (5 + 4)	18
PMT	H1949-50		
Scntillator	BC-408		
Timing resolution w/ cosmic	~ 60 ps in E05	~ 70 ps in E05	~ 60 ps in E05
	require < 100 ps		



116 ch for both FADC, vTDC

5/



# KHODO/KTOF Status

## Status :

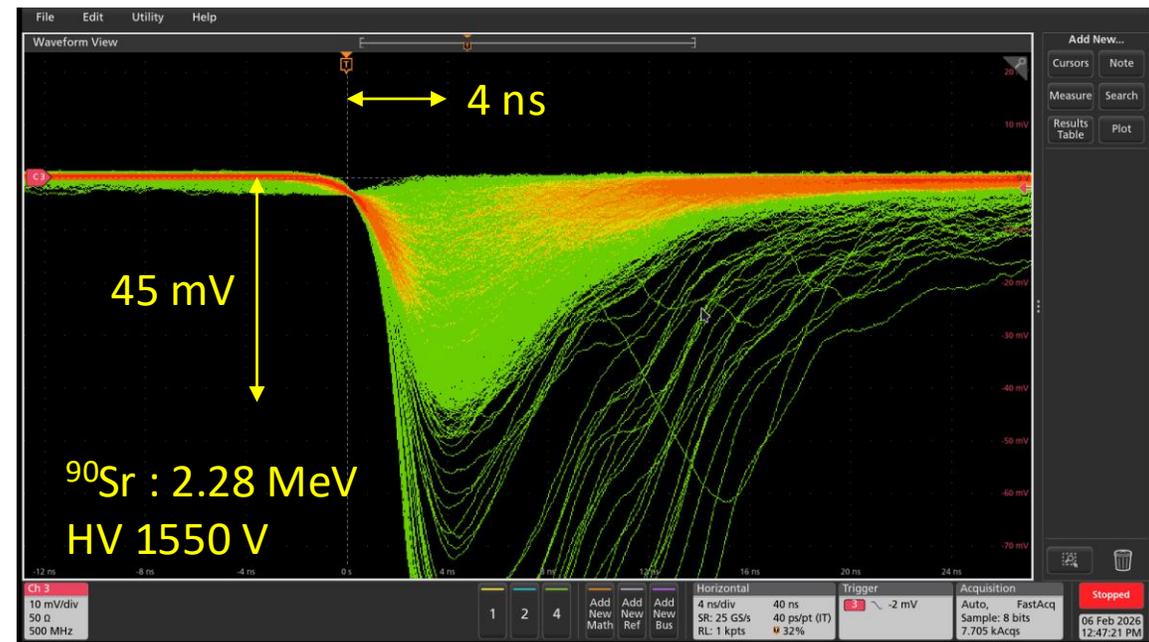
- stored in ESB
- cheking light leak [Log in 2017 \(Tohoku internal\)](#)
- All PMTs are alive

## Commisioning Plan :

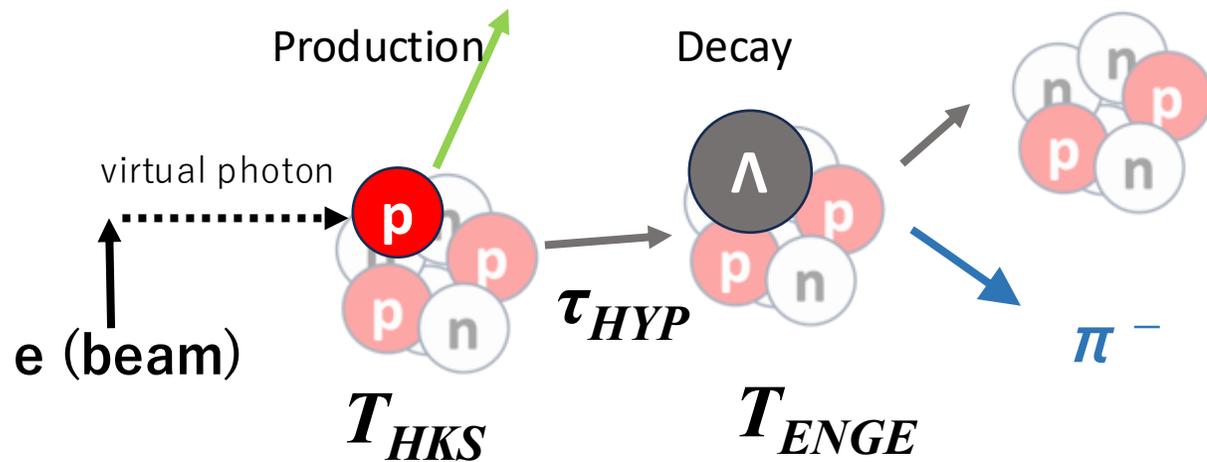
- PMT gain test w/  $\beta$ -ray in ESB
- Timing resolution & TOF resolution study

## Main point to check:

- Time resolution with new DAQ system (shared issue with HES)



# Lifetime measurement



Time of decay is derived as,

$$T_{ENGE} = T_{ENGE}^{RD} - \frac{L_{ENGE}}{(\beta_{ENGE}c)}$$

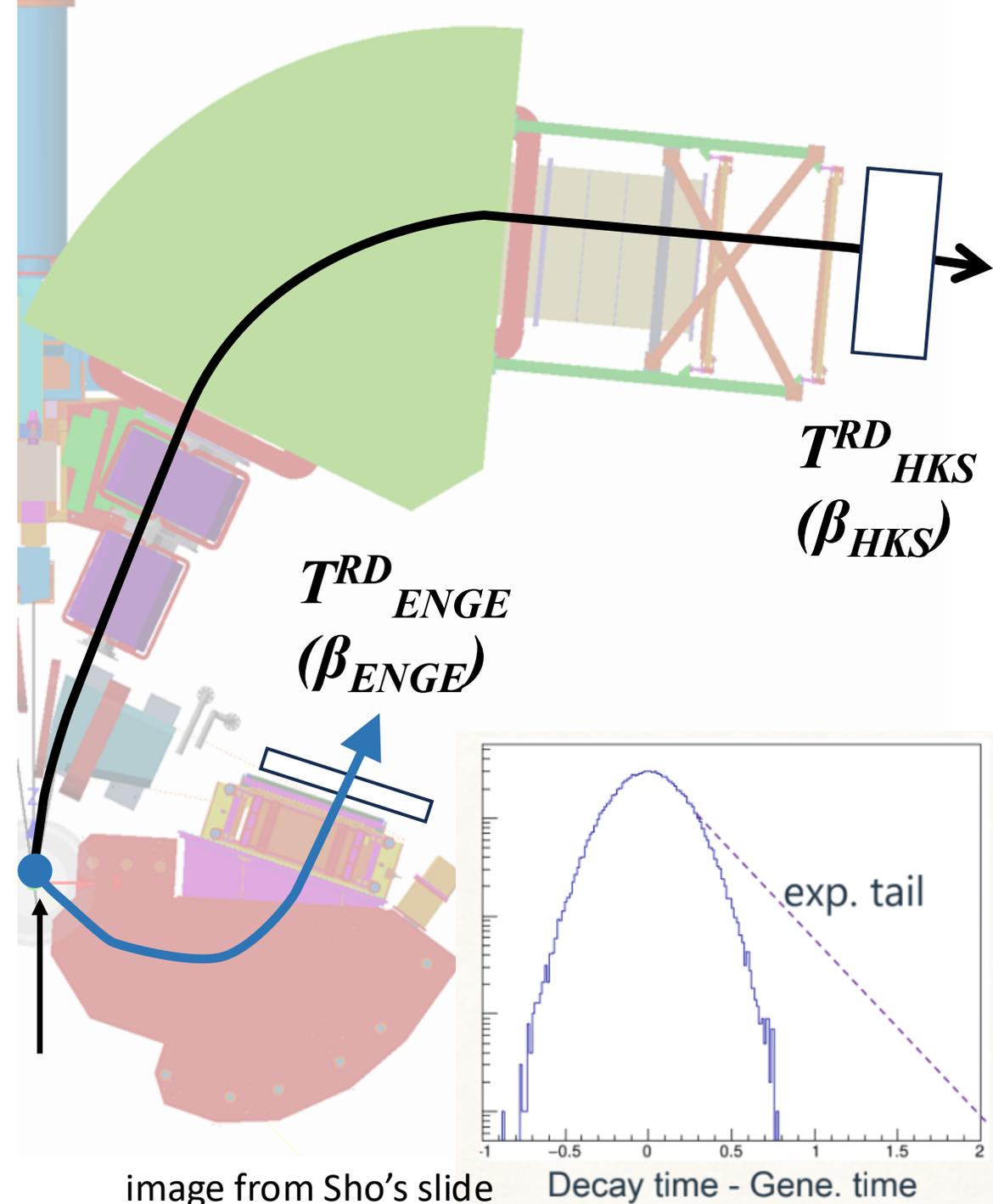
Time of production is defined as  $T_{HKS}$

Lifetime of hypernuclei is,

$$\tau_{HYP} = T_{ENGE} - T_{HKS} \sim 200 \text{ ps}$$

$\tau_{HYP}$  is short enough to suppress accidental BG

**100 ps** timing resolution is helpful

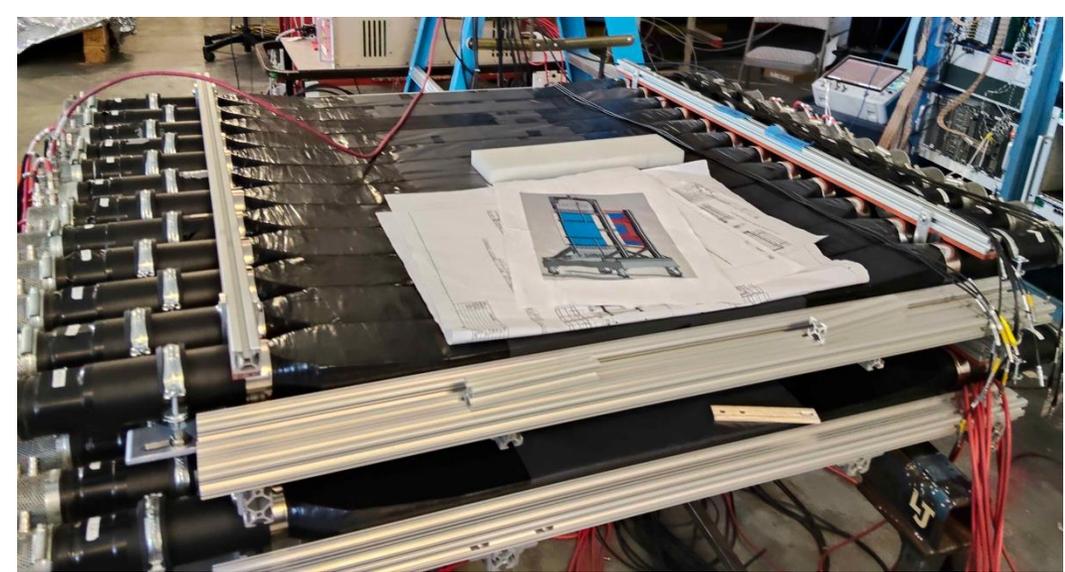


# ENGEHODO/PiTOF

Originally developed for Bigbite, modified for ENGE  
2-layers of 12 segments each

Status :

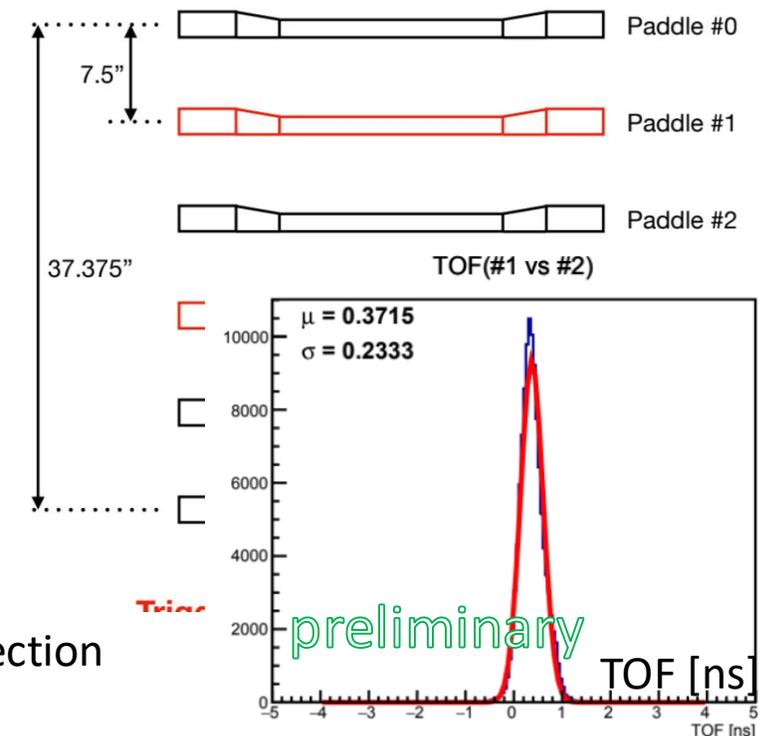
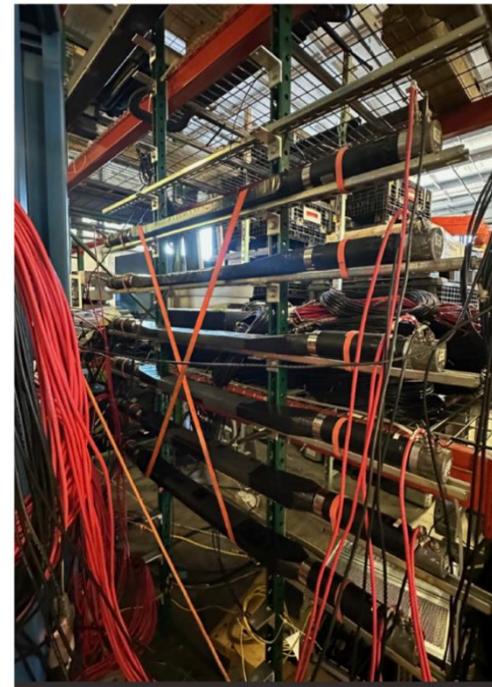
- PMT Gain adjustment is done by Bill
- Time resolution test is ongoing



ENGE HODO + test bench DAQ

TOF resolution  $\sim 230$  ps ( $\sigma$ )

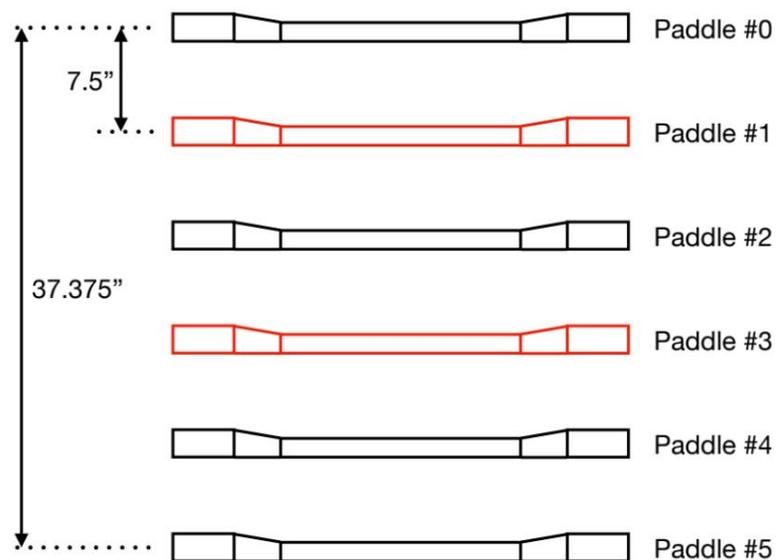
→ Updating test bench DAQ  
to same condition as beamtime



after timewalk correction

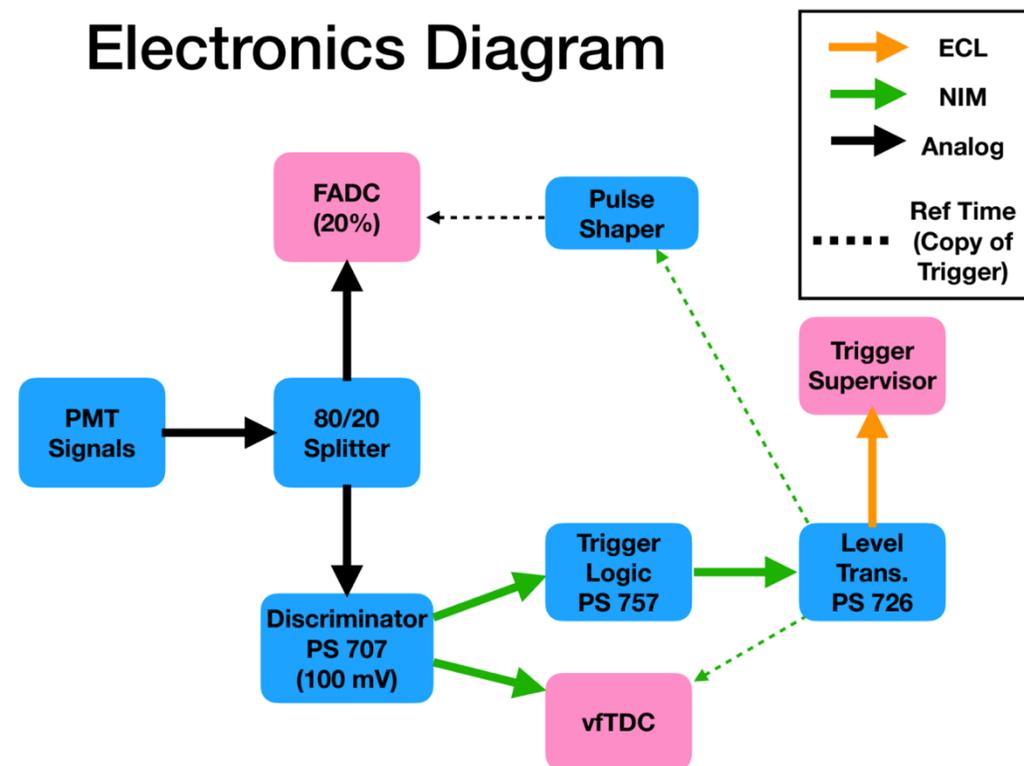
# ENGE HODO – TOF resolution evaluation

Setup & measurement by Bill in ESB



Trigger: Paddle 1L & Paddle 1R

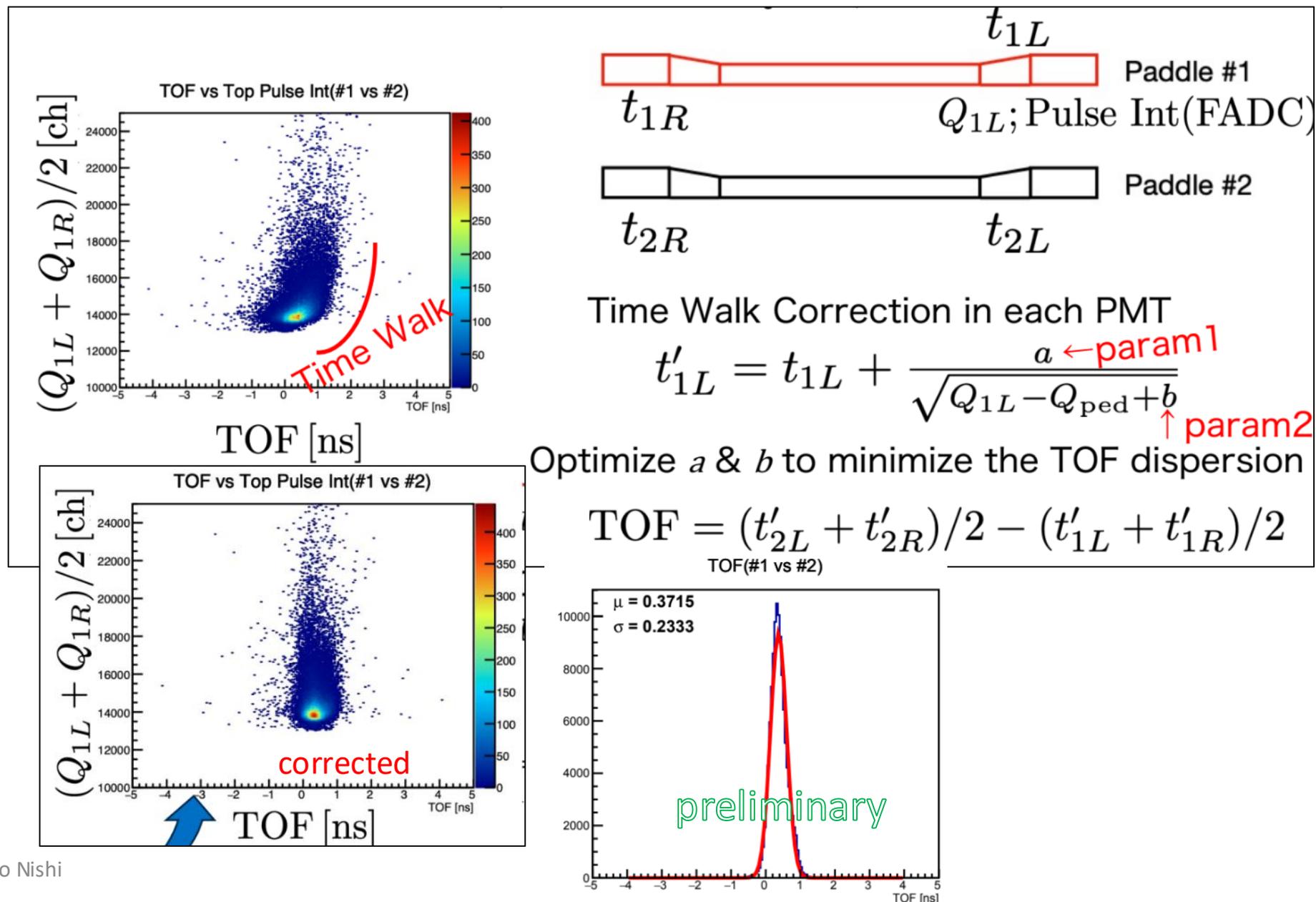
## Electronics Diagram



# ENGE HODO – TOF resolution analysis

Analysis by Jin

Current time resolution  
230 ps ( $\sigma$ )



# ENGE HODO – idea of improvement

Substructure in ADC-TOF hist

- trigger timing problem ?

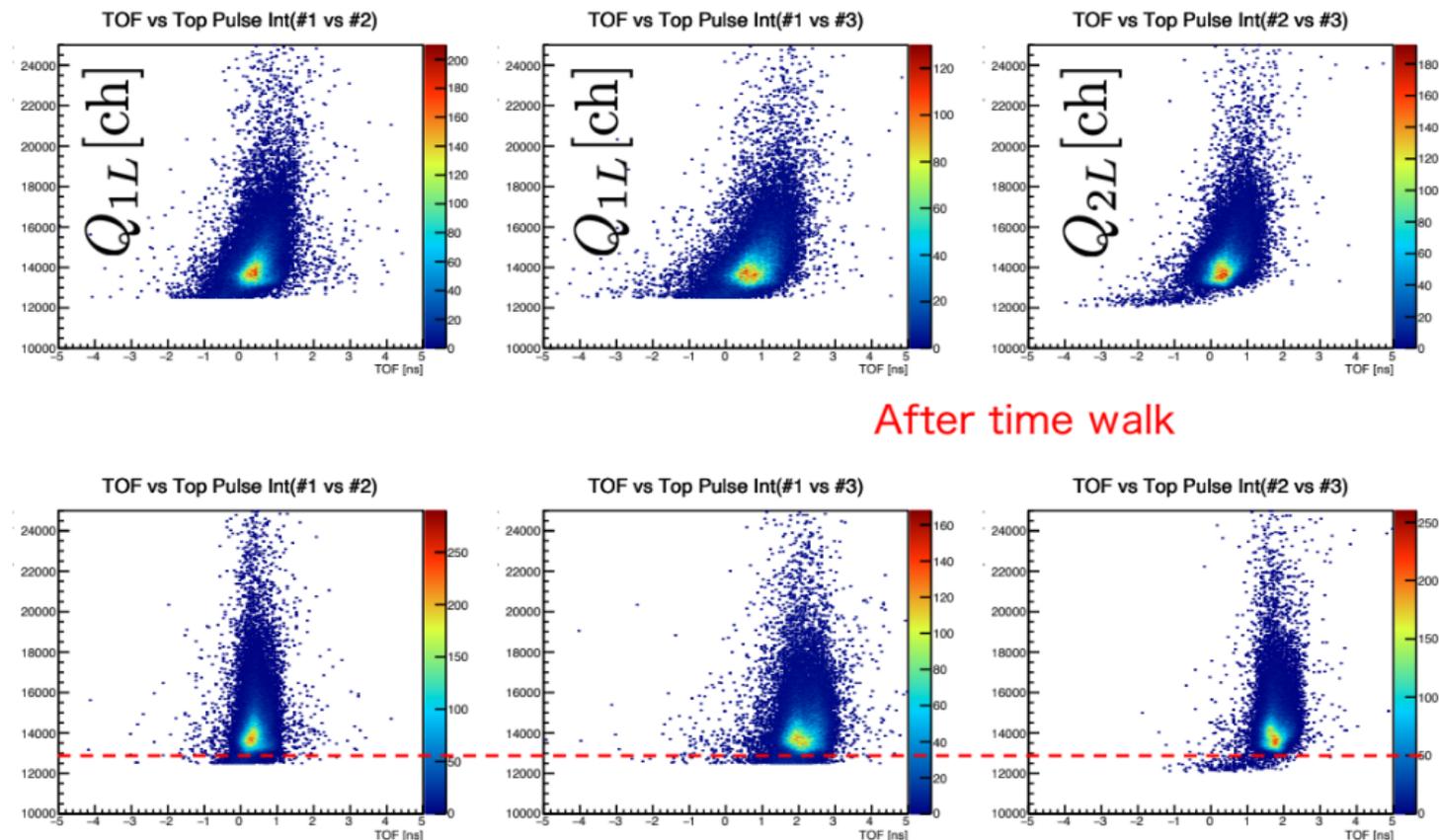
PMT Gain is not adjusted

- adjust in measurement or analysis

Hit position correction

- installation of third vertical layer
- analysis including ADC, TDC difference

## 2DHist TOF



Analysis by Jin

# Tasks & Timeline

	HKS	HES	ENGE
<b>HODO Status</b>	need light sheilding	need to repair (8)	ready
<b>PMT Signal Output</b>	To be checked	To be checked	Done
<b>PMT Gain Study</b>	Ongoing	To be checked	Done
<b>Time Resolution evaluation</b>	Under consideration	Under consideraton	~ 230 ps to be updated
<b>Spare Status</b>	0, to be prepared	0, to be prepared	A lot

~ Mar, 2026      EHODO repairment, KHODO light shielding  
 ENGE time resolution evaluation w/ new DAQ(fADC, vfTDC, VTP)  
*by Toshi, Kei, Kotaro, Jin, Sho, Ken, Ravin*

~ May, 2026      Time resolution evaluation of HKS, HES  
 Gain study of all HODO's in ESB environment *by Ken, Ravin*

in 2026            HKS, HES spare production in Japan

After installation    Gain study in magnetic filed (5 gauss)

# Summary

- Time resolution of KHODO & EHODO is crucial for PID, accidental BG suppression
- Time resolution of ENGEHODO is crucial for lifetime measurement

## Status

- in E05, KHODO & EHODO timing resolution is good enough, less than 100 ps
- Long interval since E05 → repairment & operation check is required
  
- No conclusive information on ENGEHODO time resolution

## Tasks in near future

- EHODO repairment
- KHODO gain test
- ENGE HODO time resolution measurement & analysis

# Appendix

# HKS PMT & Scintillator

(Unit: mm)

HKS

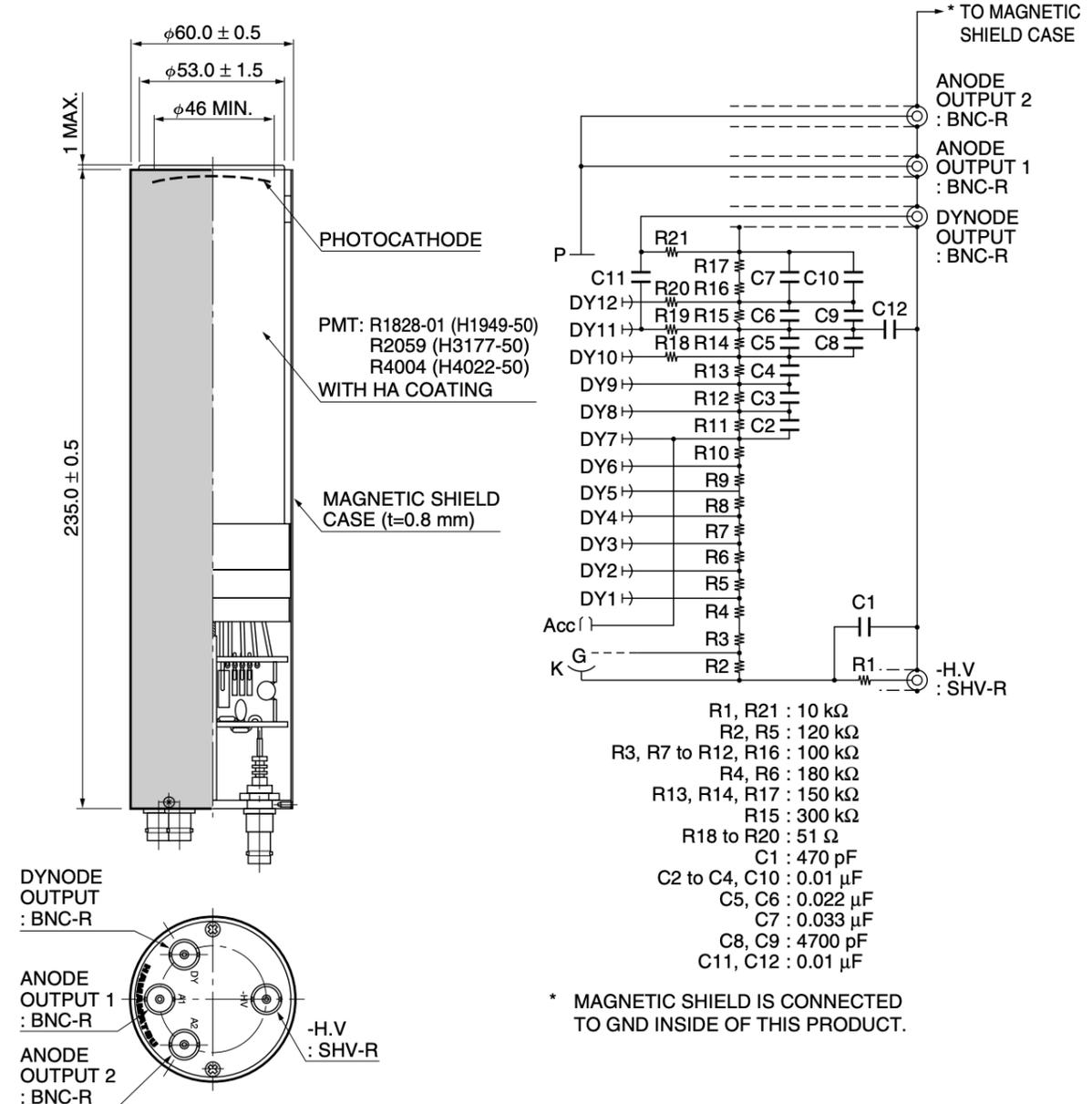
## [Hamamatsu H1949](#) (H1949-51)

[Anode] Gain Typ.	$2.0 \times 10^7$
[Time Response] Rise Time Typ	1.3 ns
[Time Response] Transit Time Typ.	28 ns
[Time Response] Transit Time Spread Typ.	0.55 ns

## Scintillator [BC-408](#)

Light Output, %	64
Rise Time (ns)	0.9
Decay Time (ns)	2.1
Pulse Width (FWHM) (ns)	~2.5
Wavelength of Max. Emission, (nm)	425
Light Attenuation Length (cm*)	210
Bulk Light Attenuation Length (cm)	380

## 18 H1949-50



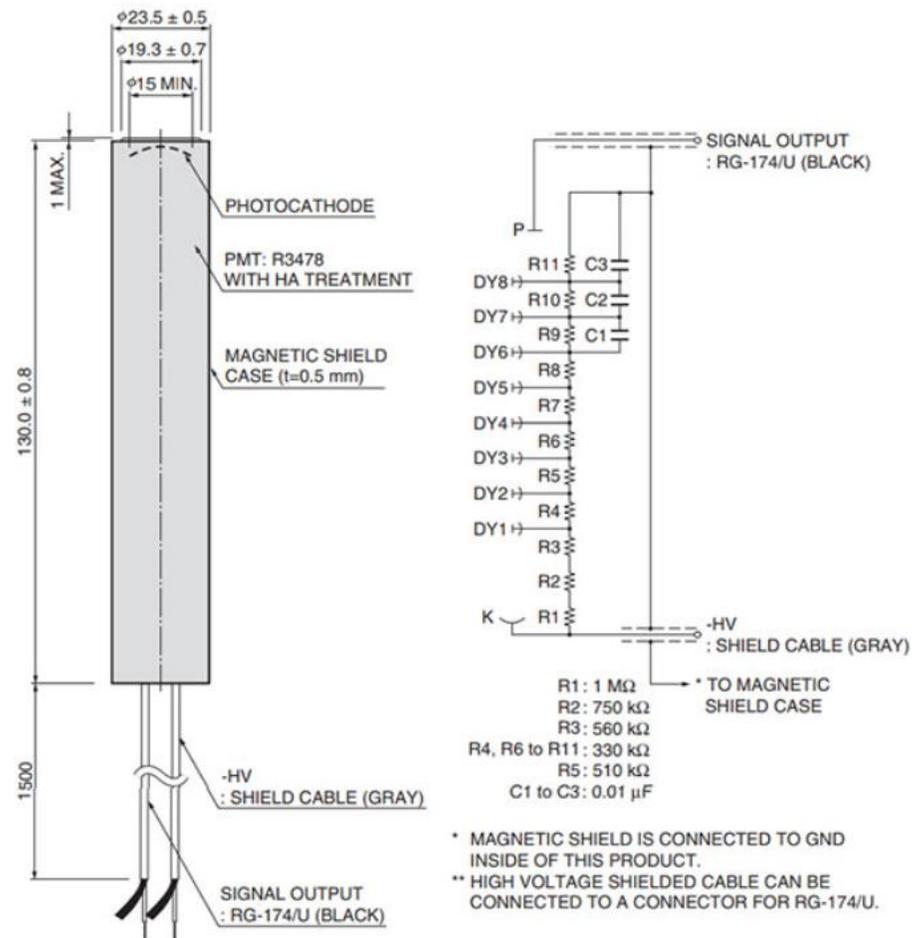
# HES PMT & Scinillator

## [Hamamatsu H6612](#)

[Anode] Gain Typ.	$1.7 \times 10^6$
[Time Response] Rise Time Typ	1.3 ns
[Time Response] Transit Time Typ.	14 ns
[Time Response] Transit Time Spread Typ.	0.36 ns

## Scintillator [EJ-230](#)

Light Output (% Anthracene)	64
Scintillation Efficiency (photons/1 MeV e <sup>-</sup> )	9,700
Wavelength of Maximum Emission (nm)	391
Light Attenuation Length (cm)	120
Rise Time (ns)	0.5
Decay Time (ns)	1.5
Pulse Width, FWHM (ns)	1.3



# Trigger & Rate summary in E05

Segment rate is less than 1 MHz

EHODO1 rate is up to 15 MHz

$\text{HES}_{\text{trigger}} = \text{EHODO1} \otimes \text{EHODO2}$

$$\text{EHODO1} = \sum_{j=1}^{29} \text{EHODO1}^j,$$

$$\text{EHODO2} = \sum_{j=1}^{29} \text{EHODO2}^j.$$

( $j$  : segment number)

Target	Target thickness [mg/cm <sup>2</sup> ]	Beam current [ $\mu\text{A}$ ]	Rate [MHz]			
			EDC1	EDC2	EHODO1	EHODO2
CH <sub>2</sub>	450.8	2.0	3.0	3.4	2.8	2.9
H <sub>2</sub> O	500.0	2.8	5.3	6.0	5.5	5.6
<sup>7</sup> Li	208.0	35	9.4	11	9.8	9.7
<sup>9</sup> Be	188.1	40	12	15	13	12
<sup>10</sup> B	56.1	40	5.0	5.9	5.1	5.1
<sup>12</sup> C	112.5	10	1.9	2.3	2.1	2.1
		35	12	13	13	13
<sup>52</sup> Cr	134.0	8.0	6.7	7.8	7.3	7.3

# E01 KTOF test reportt

<https://hallcweb.jlab.org/experiments/hks/manual/hkstechnote12.pdf>

typical operation ~1500 V

2 cm thick scintillator

→ MIP deposit ~ 4.2 MeV

pulse height direct / delayed

E01 @1500 V

50 mV of the 1 MeV deposit ( $^{60}\text{Co}$ )

2026 @ 1550 V

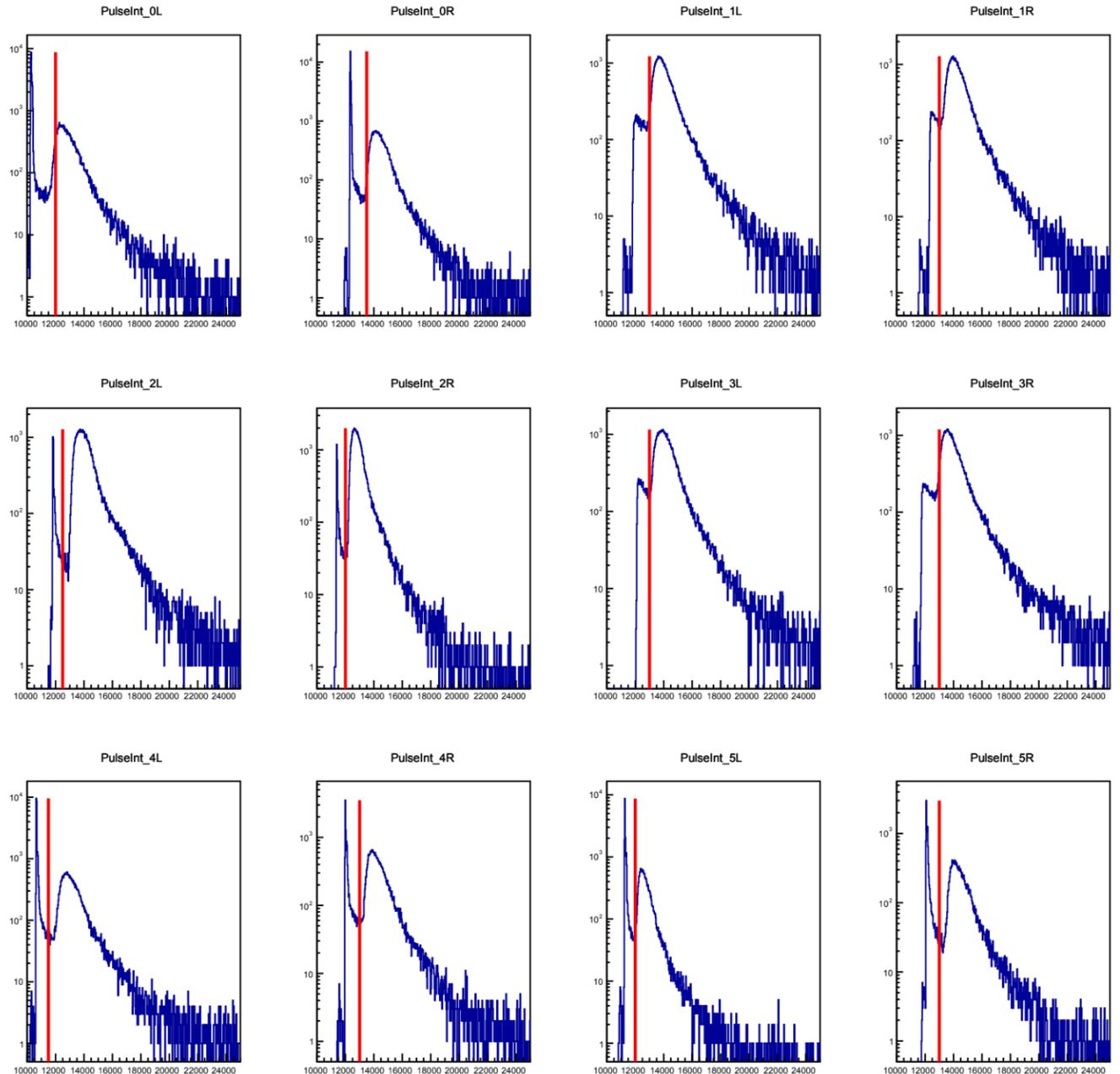
45 mV of 2.2 MeV deposit ( $^{90}\text{Sr}$ )

Counter Number	LEFT END		Mid. pos. P.h./ Decay Time	High volt.	RIGHT END		Mid. pos. P.h./ Decay time	High volt.	Counter Number
	P.h.dir / Decay time	P.h.del / Decay time			P.h.dir / Decay time	P.h.del / Decay time			
1X1L	50/40	10/220	45/40	1550	55/40	10/200	50/40	1540	1X1R
1X2L	50/40	10/220	45/40	1480	50/40	10/200	45/40	1410	1X2R
1X3L	50/40	10/200	45/40	1480	55/40	10/200	45/40	1480	1X3R
1X4L	50/40	10/220	45/40	1500	50/40	10/200	45/40	1490	1X4R
1X5L	50/40	10/200	45/40	1490	50/40	10/200	45/40	1440	1X5R
1X6L	50/40	10/200	45/40	1440	50/40	10/200	45/40	1440	1X6R
1X7L	50/40	10/200	45/40	1490	50/40	10/200	45/40	1410	1X7R
1X8L	50/40	10/200	45/40	1500	50/40	10/200	45/40	1530	1X8R
1X9L	50/40	10/200	45/40	1470	50/40	10/200	45/40	1410	1X9R
1X10L	50/40	10/200	45/40	1490	50/40	10/200	45/40	1440	1X10R
1X11L	50/40	10/200	45/40	1520	50/40	10/200	45/40	1360	1X11R
1X12L	50/40	10/200	45/40	1430	50/40	10/200	45/40	1490	1X12R
1X13L	50/40	10/200	45/40	1490	50/40	10/200	45/40	1440	1X13R
1X14L	50/40	10/200	45/40	1510	50/40	10/200	45/40	1470	1X14R
1X15L	50/40	10/200	45/40	1470	50/40	10/200	45/40	1490	1X15R
1X16L	50/40	10/200	45/40	1500	50/40	10/200	45/40	1450	1X16R
1X17L	50/40	10/200	45/40	1540	50/40	10/200	45/40	1450	1X17R

**THRESHOLD DETERMINATION:**  $^{60}\text{Co}$  deposits of around 1 MeV<sub>ee</sub> in the thickness of 2 cm of the plastic scintillator. Therefore, 50 mV of the  $^{60}\text{Co}$  (~ 1 MeV<sub>ee</sub>) is the threshold. High voltage in accord with it may be regarded as the minimal (conservative) voltage applied to the PMTs. Minimum ionizing particles (pions, kaons, muons) should deposit around  $\Delta E = 2.1 \text{ MeV/cm} \times 2 \text{ cm} = 4.2 \text{ MeV}$ .

# EHODO evaluation Gain matching

Gain matching of all channels  
on setup / analysis



## Fit of the waveforms

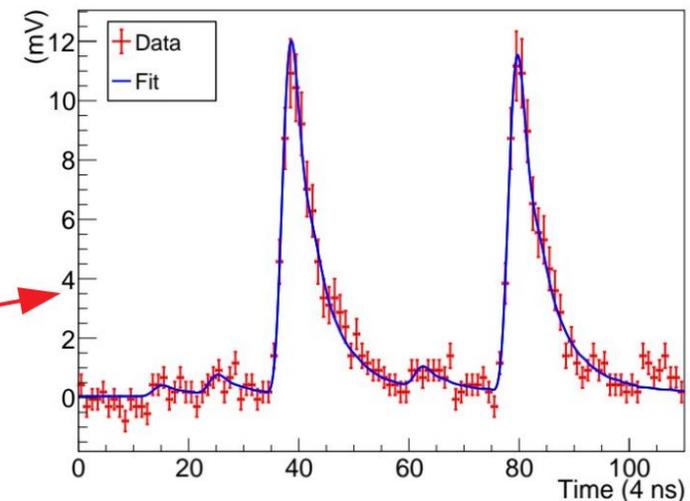
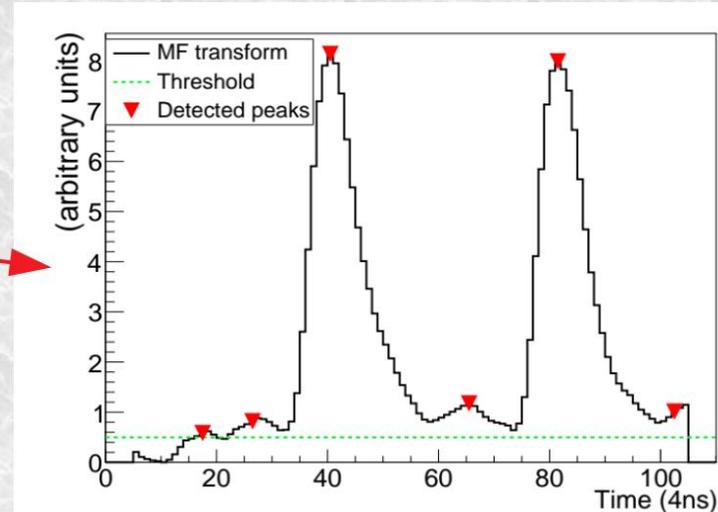
- **Matched filter** scheme to determine the **number** of pulses and the approximate **time** and **amplitude**

- The **fit** function:

$$F(t) = B + \sum_{i=1}^{N_{pulses}} A_i f(t - t_i)$$

Baseline      Amplitude      Time of pulse #i (4\*ns) relatively to the ref wf time

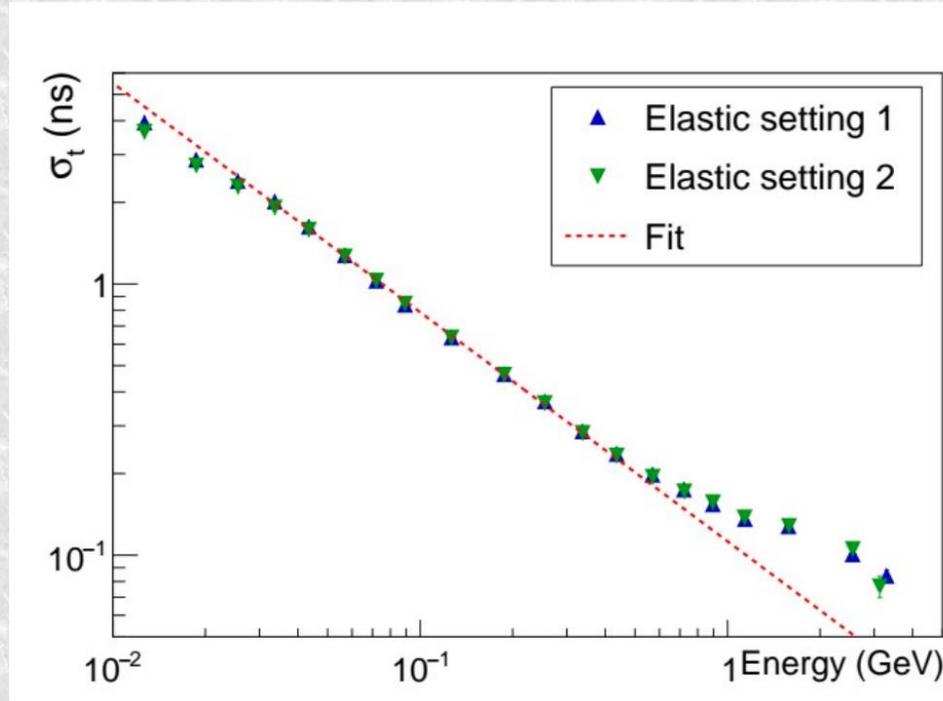
- **Fit** of the production data waveforms and retrieval of the **time** and **amplitude**



## Time Resolution

- These are the **intrinsic** time resolution results
- The **sigma** values obtained from the **fit** of the time distributions are divided by the **square root of 2**
- The resolution obeys the following **power law**:

$$\sigma_t(E) = (0.112 \text{ ns})[E/(1 \text{ GeV})]^{-0.845}$$



- An **intrinsic** timing resolution **better** than **200 ps** for energies above **500 MeV**