

# Digital DAQ System at RIBF for Beta-Decay Studies

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RIKEN Nishina Center

Active stoppers for decay experiments

Valencia, March 25<sup>th</sup> 2025

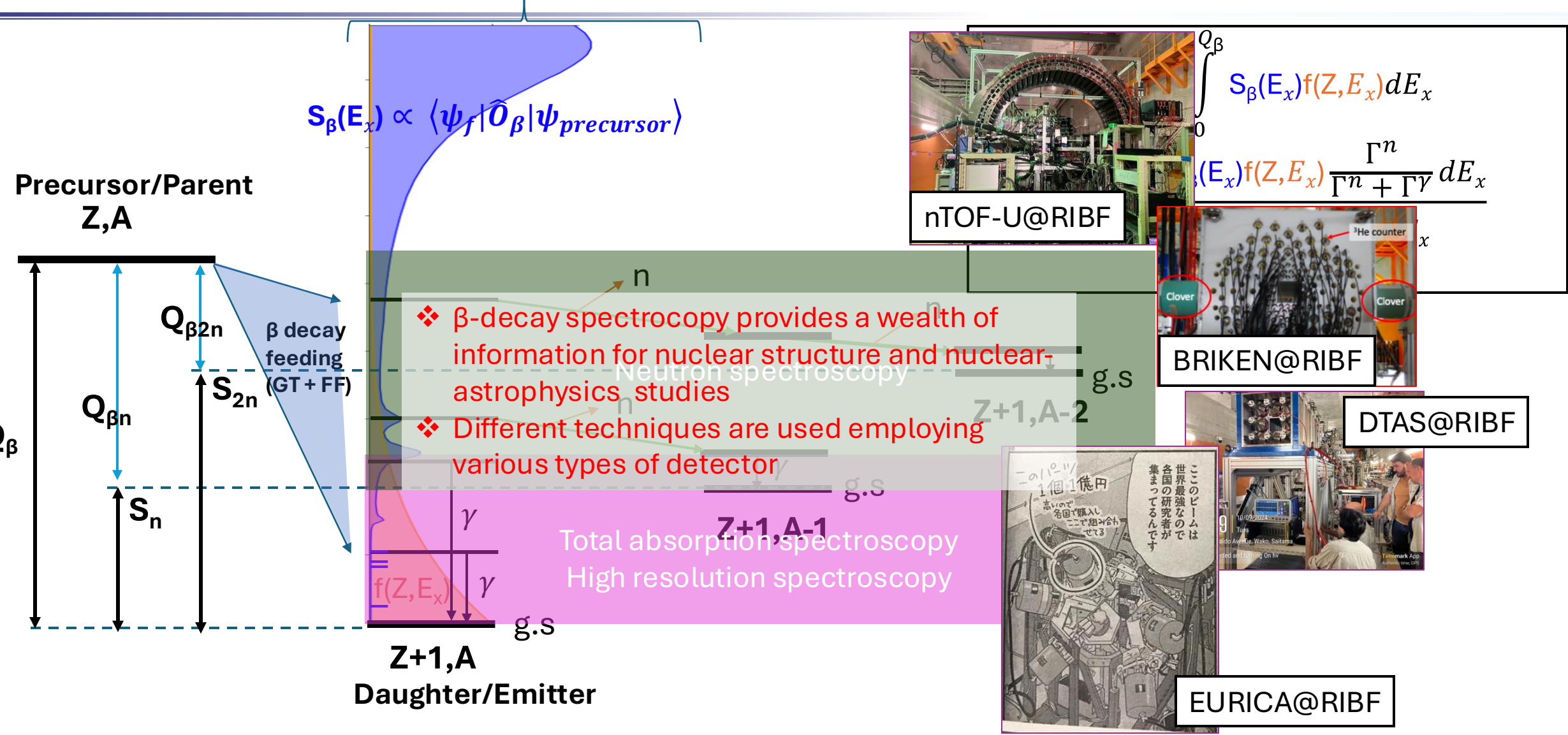


理化学研究所  
仁科加速器科学研究センター



- Motivation: why we need a Digital DAQ system?
- Harwares and softwares
- Implementation and some selected results

# Motivation: (beta)decay spectroscopy studies at RIBF



# Requirements

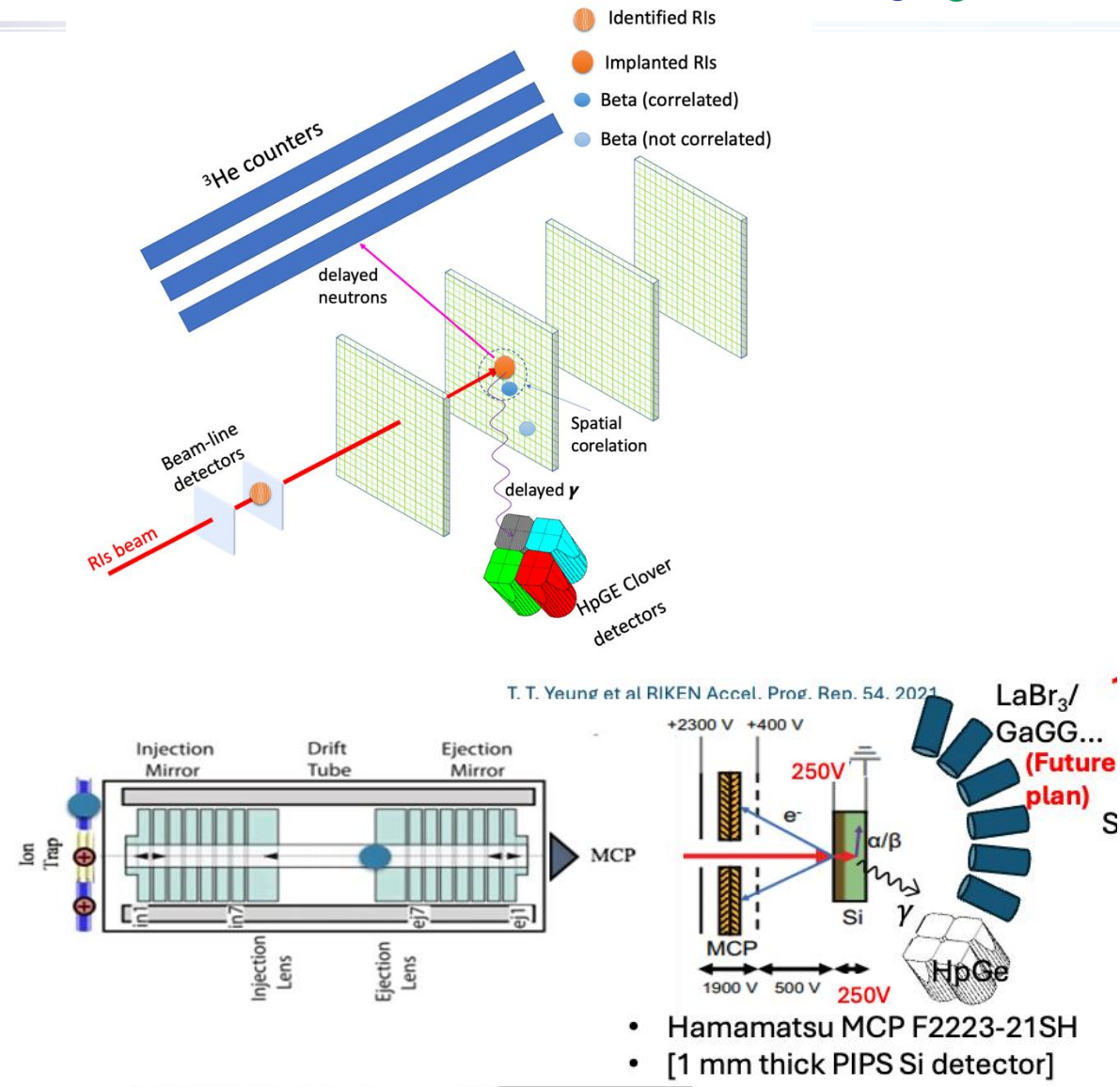
## Scale of a decay spectroscopy experiment at RIBF

- 3-50~ collaborators
- 1-2 weeks beam time
- Variety of detector type: semiconductor, gaseous, MCP, scintillation
- Number of channels: few 100s

## Requirements

- RI identification (BigRIPS/MRTOF)
- Coincidence/correlation with different time-ranges:
  - Prompt ( $ns \sim \mu s$ ) coincidence between in-flight RI, implantation and  $\gamma$ -rays/neutron signals
  - Delayed ( $ms \sim s$ ) coincidence between beta-implantation
- For isomeric decay spectroscopy: high rates tolerance

=> Traditional triggered system (A/QDC, TDC) with common busy global trigger scheme is no longer an ideal solution

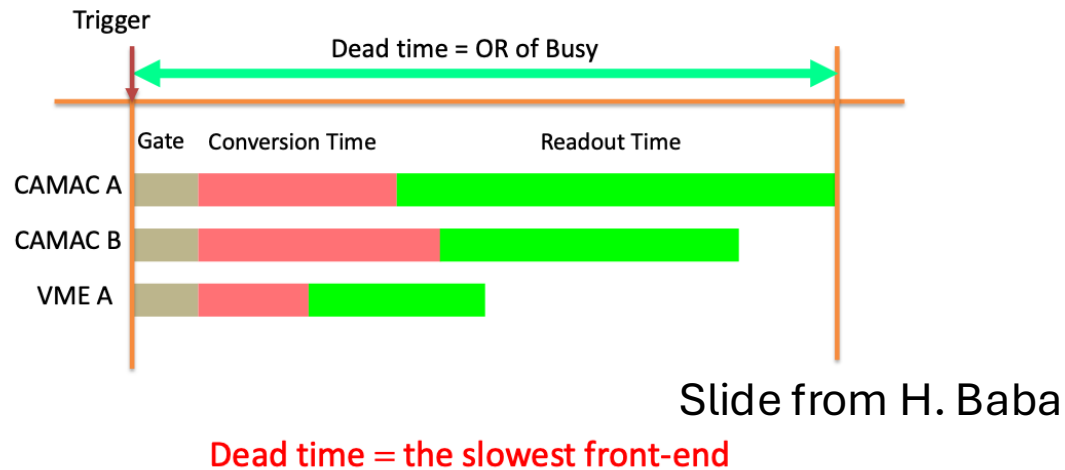


# Why digital DAQ system?

## - Common triggered DAQ:

Hardware: Q/ADC, (multi-hit) TDC

Dead time in Common trigger DAQ



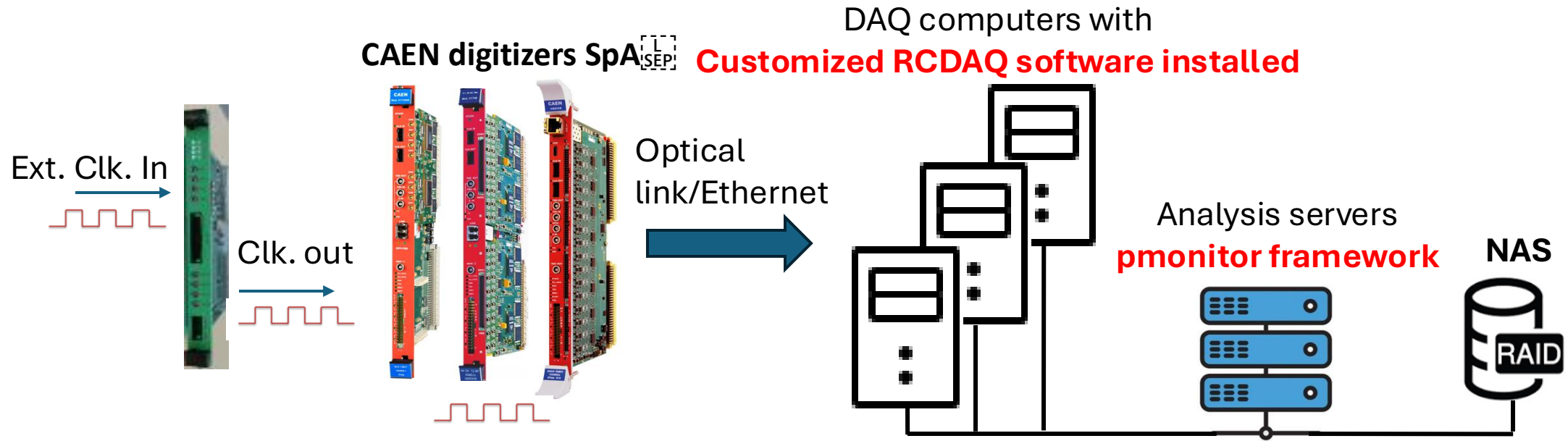
## Digital DAQ:

Hardware: Waveform digitizer (flash-ADC) + FPGA

- Continuous acquisition from per-channel on-board memory in parallel with readout
- No need for EOB management

Feature	Triggered DAQ	Digital DAQ
<b>Data Recording</b>	Event-driven	Continuous
<b>Event Selection and Time Correlation</b>	Hardware-based, fixed	Software-based, flexible
<b>Data Volume</b>	Lower	Higher
<b>Processing Requirements</b>	Lower	Higher
<b>Risk of Missing Events</b>	Higher	Lower
<b>Data handling</b>	Time and energy data are separated (TDC-Q/ADC)	Together
<b>Time synchronization</b>	Less important	More important

# Infrastructure of the Digital DAQ system



- LUPO timestamping modules **x2**
- V1730 **x8 = 128 channels**  
14 bits, 500 MS/S with full FPGA firmwares (DPP-PSD, DPP-PHA...)
- V2745 **x1 = 64 channels**  
16 bits, 125 MS/S, digitizer 2.0 with DPP-PSD, DPP-PHA firmwares
- V1740(D) **x 8 = 512 channels**  
12 bits, 82.5 MS/S, waveform recording firmware
- V1741 **x 4 = 256 channels**  
16 bits peak sensing ADC firmware

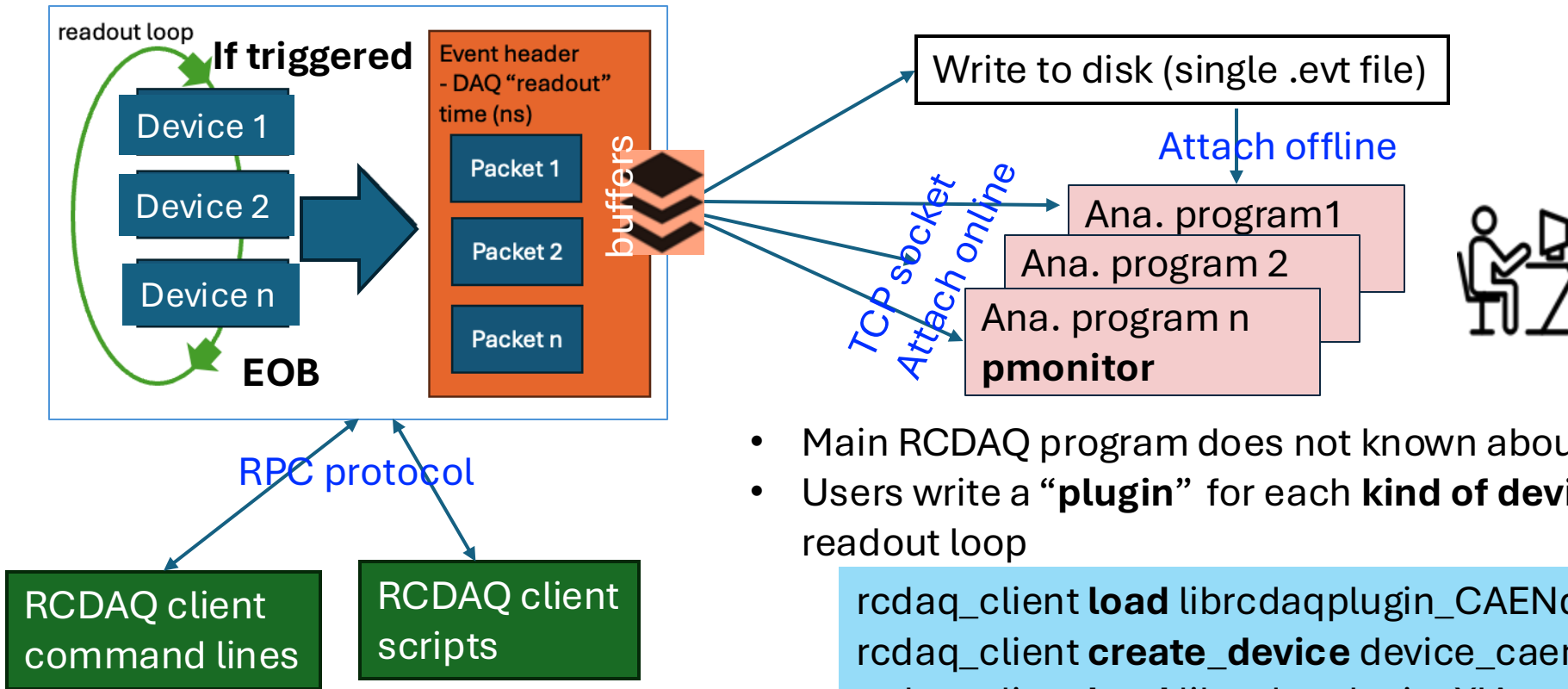
⇒ **Record waveform and FPGA-processed data**

- Based on **the RCDAQ software** developed by **Dr. Martin L. Purschke** for the sPHENIX experiment at RHIC, BNL (My PhD time summer-school teacher)

- Modularity
- Data integrity, robustness and resilience
- No exposure of analysis code to internals
- Binary payload format agnostic
- No preferred endianness
- Support for data compression
- Different event types
- Set of tools to inspect / display / manipulate files
- Online monitoring support
- Electronic Logbook support
- OS integration
- Interface to community analysis tools ( these days: root and 3rd-party frameworks)

M. Purschke slide, International School in Real Time Systems 2016, Ho Chi Minh City, Vietnam

# RCDAQ is originally designed for triggered system



- Main RCDAQ program does not know about any hardware
- Users write a “**plugin**” for each **kind of device** and add to the readout loop

```
rcdaq_client load librcdaqplugin_CAENdrs2.so
rcdaq_client create_device device_caen_v1740zsp 1 50 0 0
rcdaq_client load librcdaqplugin_XIA.so
rcdaq_client create_device device_xia_pixie16 1 60 0 1
rcdaq_client daq_begin #start the run
rcdaq_client daq_end #end the run
```

=> **Highly customizable**, one can readout any hardware given a library or a sample code



# RCDAQ plugins for digitizers

- RCDAQ plugins for all available CAEN digitizers have been developed
- **Text format** configuration file for the V1740 => Compatible with input of the **wavedump** program developed by CAEN
- **Excel format** configuration file for V1730 and V2745 => Easy to modify, clones and optimize parameters.
- For V1740 modules: **software zero-suppression mode** has been implemented to discard data below threshold

```

1 # *****
2 # WaveDump Configuration File
3 # *****
4
5 # NOTE:
6 # The lines between the commands @OFF and @ON will be skipped.
7 # This can be used to exclude parts of the file.
8
9 # -----
10 # Settings common to all channels
11 # -----
12 [COMMON]
13
14 # OPEN: open the digitizer
15 # options: USB 0 0      Desktop/NIM digitizer through USB
16 #           USB 0 BA    VME digitizer through USB-V1718 (BA = BaseAddress of the VME board, 32 bit hex)
17 #           PCI 0 0 0    Desktop/NIM/VME through CONET (optical link)
18 #           PCI 0 0 BA   VME digitizer through V2718 (BA = BaseAddress of the VME board, 32 bit hex)
19 #OPEN USB 0 0
20 #OPEN USB 0 32100000
21 OPEN PCI 2 0 0
22 #OPEN PCI 0 0 32100000

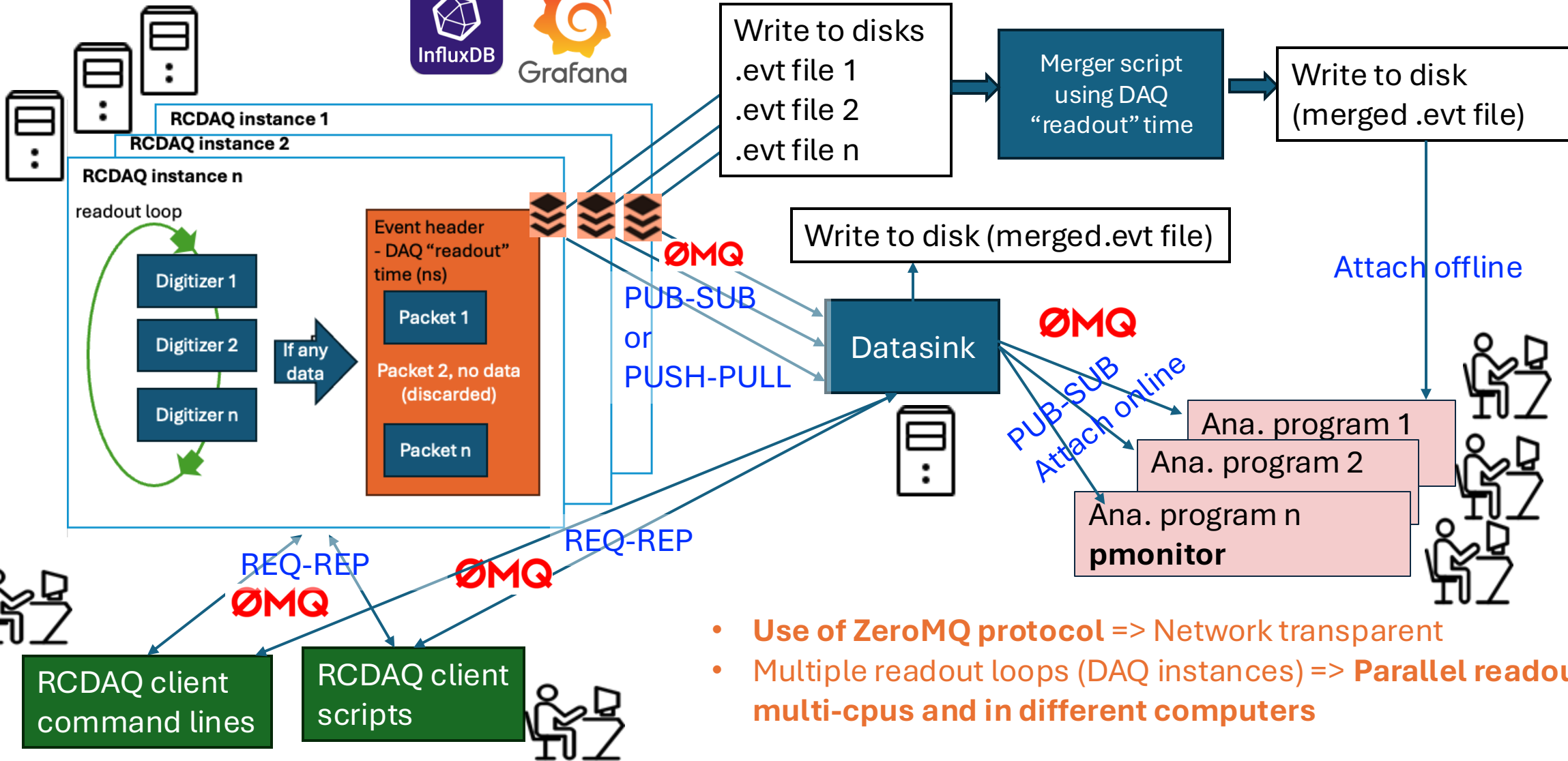
```

caendpconfig.xlsx - LibreOffice Calc

ID	Name	Input dynamic	Self trigger	Threshold	Trigger holdoff	Fast Discriminator	Input rise time	Rise Time Vth	Trap rise time	Trap flat top	Trap pole zero	Peaking time
1	Note:	0-1: 2 Vpp, 0.5 Vpp	0	Equal to twice th	In unit of 8 ns	Options: 1; 2; 4;	In ns	In sample; pile In ns	In ns	In ns	In ns	Float (0-100 % of Tr
2	0 CH0	0	1	24	100	4	104	40	5100	1600	46500	80
3	1 CH1	0	1	24	100	4	104	40	5100	1600	49500	80
4	2 CH2	0	1	24	100	4	104	40	5100	1600	53000	80
5	3 CH3	0	1	50	100	4	104	40	5100	1600	52000	80
6	4 CH4	0	1	50	100	4	104	40	5100	1600	52000	80
7	5 CH5	0	1	50	100	4	104	40	5100	1600	52000	80
8	6 CH6	0	1	50	100	4	104	40	5100	1600	52000	80
9	7 CH7	0	1	50	100	4	104	40	5100	1600	52000	80
10	8 CH8	0	1	50	100	4	104	40	5100	1600	52000	80
11	9 CH9	0	1	50	100	4	104	40	5100	1600	52000	80
12	10 CH10	0	1	50	100	4	104	40	5100	1600	52000	80
13	11 CH11	0	1	50	100	4	104	40	5100	1600	52000	80
14	12 CH12	0	1	50	100	4	104	40	5100	1600	52000	80
15	13 CH13	0	1	50	100	4	104	40	5100	1600	52000	80
16	14 CH14	0	1	50	100	4	104	40	5100	1600	52000	80
17	15 CH15	0	1	50	100	4	104	40	5100	1600	52000	80
18	16 CH16	0	1	50	100	4	104	40	5100	1600	52000	80
19	17 CH17	0	1	50	100	4	104	40	5100	1600	52000	80
20	18 CH18	0	1	50	100	4	104	40	5100	1600	52000	80
21	19 CH19	0	1	50	100	4	104	40	5100	1600	52000	80
22	20 CH20	0	1	50	100	4	104	40	5100	1600	52000	80
23	21 CH21	0	1	50	100	4	104	40	5100	1600	52000	80
24	22 CH22	0	1	50	100	4	104	40	5100	1600	52000	80
25	23 CH23	0	1	50	100	4	104	40	5100	1600	52000	80
26	24 CH24	0	1	50	100	4	104	40	5100	1600	52000	80
27	25 CH25	0	1	50	100	4	104	40	5100	1600	52000	80
28	26 CH26	0	1	50	100	4	104	40	5100	1600	52000	80
29	27 CH27	0	1	50	100	4	104	40	5100	1600	52000	80
30	28 CH28	0	1	50	100	4	104	40	5100	1600	52000	80
31												

Read configuration parameters in excel file

# Customized RCDAQ



- Use of ZeroMQ protocol => Network transparent
- Multiple readout loops (DAQ instances) => **Parallel readout in multi-cpus and in different computers**



- User analysis program built within the **sPHENIX Event Libraries and pmonitor Package**
- We provide a comprehensive template for making a data analysis program:

- **Declare histograms, variables outside of callable methods**
- **Init()** => Initialize histograms objects and parameters
- **OpenFile()** => Initialize file and trees
- **ProcessCorrelatedEvent(CorrelatedDataStructure\*)** => Event reconstruction with  $\mu s$  correlation time  
=> Fill histograms, trees after event building
- **ProcessHit(SingleHitDataStructure\* )**  
=> Fill histograms, trees before event building, **fill std::mmap object for correlations**
- **DoUpdate()** => Automatically call every fix period for monitoring purpose
- **CloseMe()** => Actions when data stream close (finish reading)

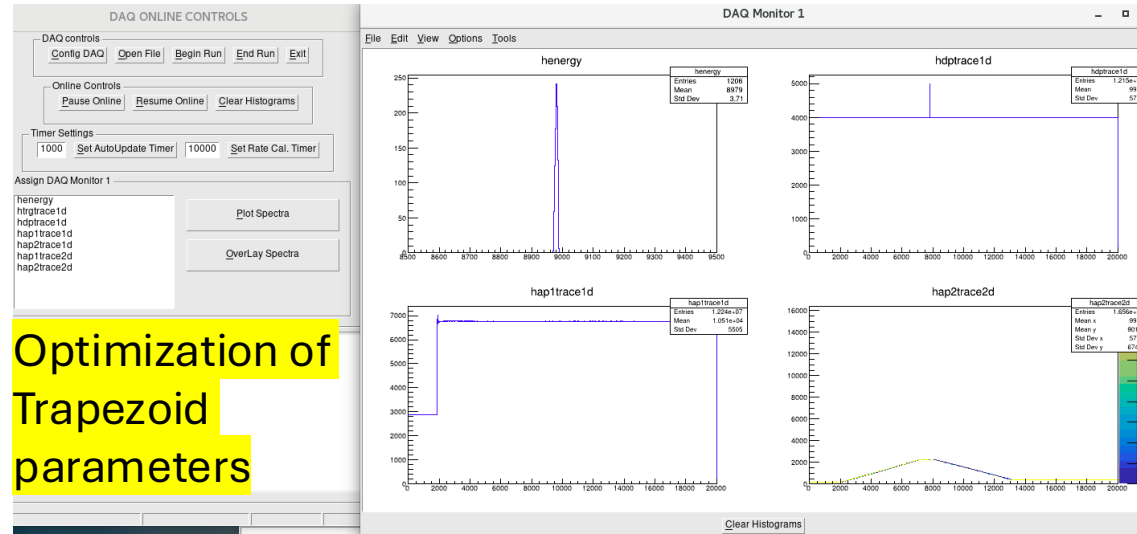
-----  
**Decoder** functions

**Event building** functions using timestamp (TThread functions run in background)



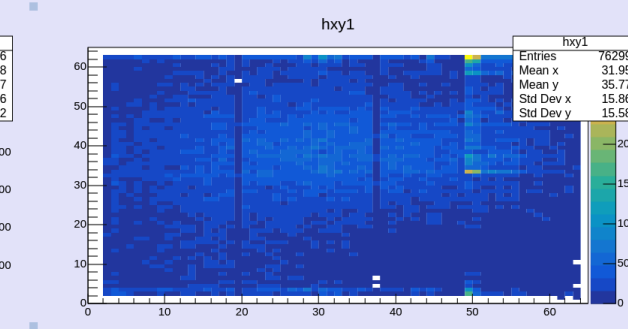
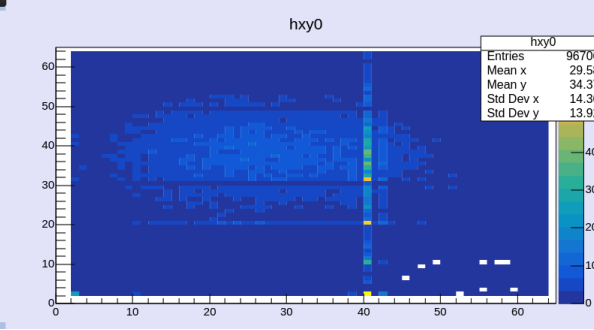
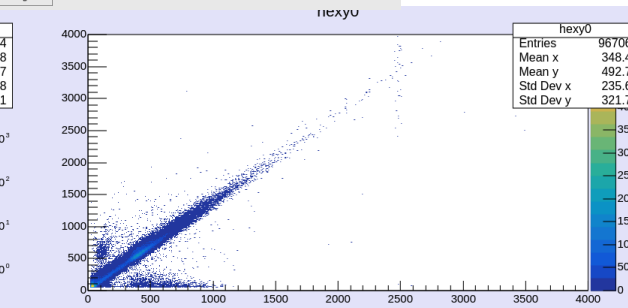
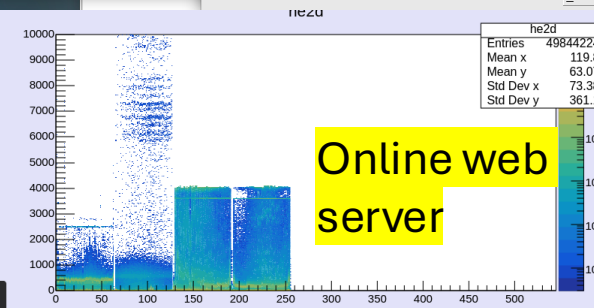
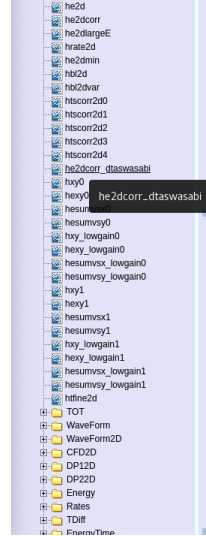
# GUI support for online monitoring and Digitizer parameters configuration

- GUI and web-browser based online monitoring can be made from the user analysis template



ROOT online server

JSROOT version 6.3.x 31/10/2023  
Hierarchy in json and xml format  
 Monitoring grid 2x2  
[open all](#) | [close all](#) | [reload](#) | [clear](#)





# Interactive session (CUI) for online/offline analysis

`./ana => Attach online stream`

`./ana rawdatafile.evt => Attach offline data`

`./ana rawdatafile.evt output_rootfile.root => Make root file`

```

pmonitor [0] help
-- pmonitor commands

pstatus()           gives a brief status of pmonitor
pfileopen("filename") opens a PRDF file
plistopen("filename") opens a file with a list of prdfs
ptestopen()         opens a test input stream
pclose()             closes the open stream
pstart(nevt)         starts event loop for nevt events in background (nevt=0 -> all events)
prun(nevt)           run nevt events (nevt=0 -> all events)

pidentify()          identify the next event read from the data stream
pidentify(5)         identify the next 5 events read from the data stream
pidentify(0)         identify all events read from the data stream (lots of output!)
pclearidentify()     resets pidentify(0)

pupdate(TCanvas *c1, int seconds) starts periodic updates of Canvas c1
pendupdate(TCanvas *c1) stop updating Canvas c1
pendupdate()         stop updating all Canvases that are updating

--
-- Additional commands

ls      list of directories/histos
cd      change directory
zone no_of_columns no_of_rows create a canvas
lc      list of canvases
cc canvas_num pad_num change canvas
ht histo_id option draw histo
hn pad_num(or) option draw next histo
hnn pad_num(or) option draw next histo with new color
htt histo_id option draw histo with new color
ft      Fit TH1 and TH2 histogram within range with gaussian function
ftt     Fit TH1 histogram interactively with gaussian function + linear background
fttm peakposition1 peakposition2 peakposition... fwhm Fit TH1 histogram interactively with

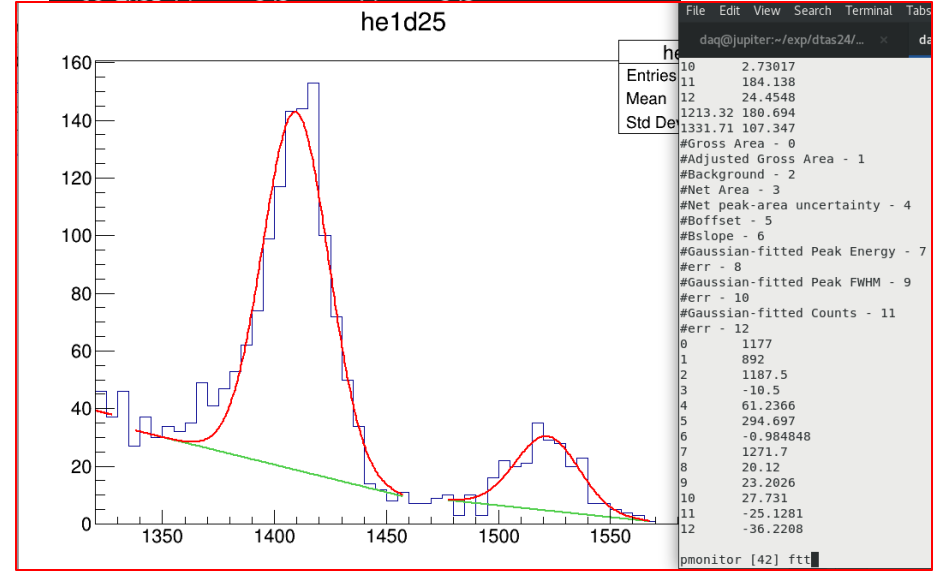
```

**paw-like commands** for manipulating histograms, including functions for peak fitting

```

myonline.root
> 0 TTree mtreehighgain0 mtreehighgain0
  1 TTree mtreehighgain1 mtreehighgain1
  2 TTree mtreelowgain mtreelowgain
  3 TTree treeaida treeaida
  4 TH2F hpid hpid
  5 TH2F hpid0 hpid0
  6 TH2F hpid1 hpid1
  7 TH2F hpidout hpidout
  8 TH1I hz hz
  9 TH2F he2d he2d
 10 TH2F he2dcorr he2dcorr
 11 TH2F he2dlargeE he2dlargeE
 12 TH2F hrate2d hrate2d
 13 TH2F he2dmin he2dmin
 14 TH2F hbl2d hbl2d
 15 TH2F hbl2dvar hbl2d Variation
 16 TH2I htscorr2d0 htscorr2d0
 17 TH2I htscorr2d1 htscorr2d1
 18 TH2I htscorr2d2 htscorr2d2

```

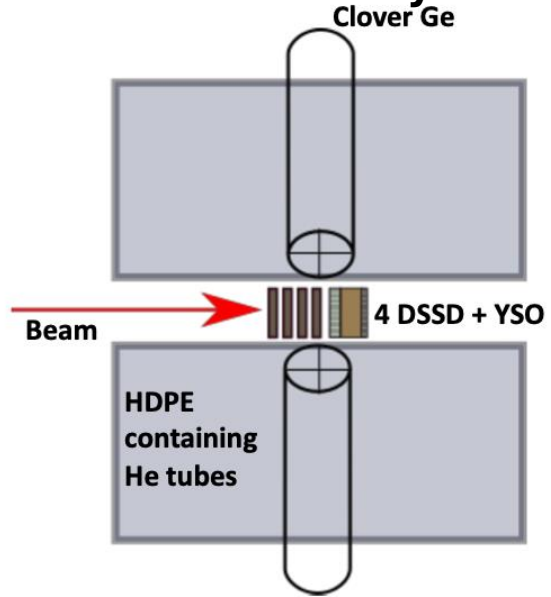




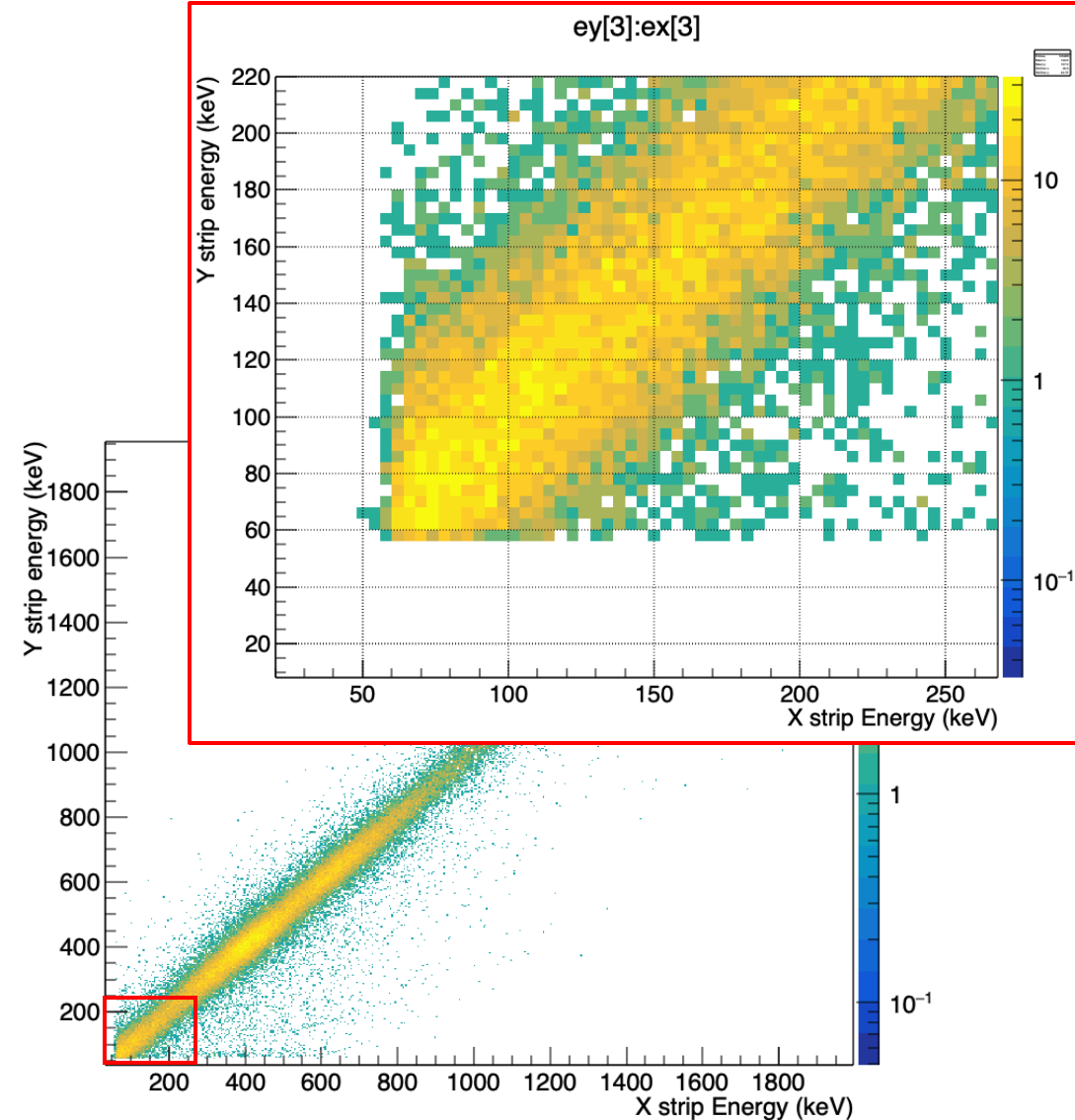
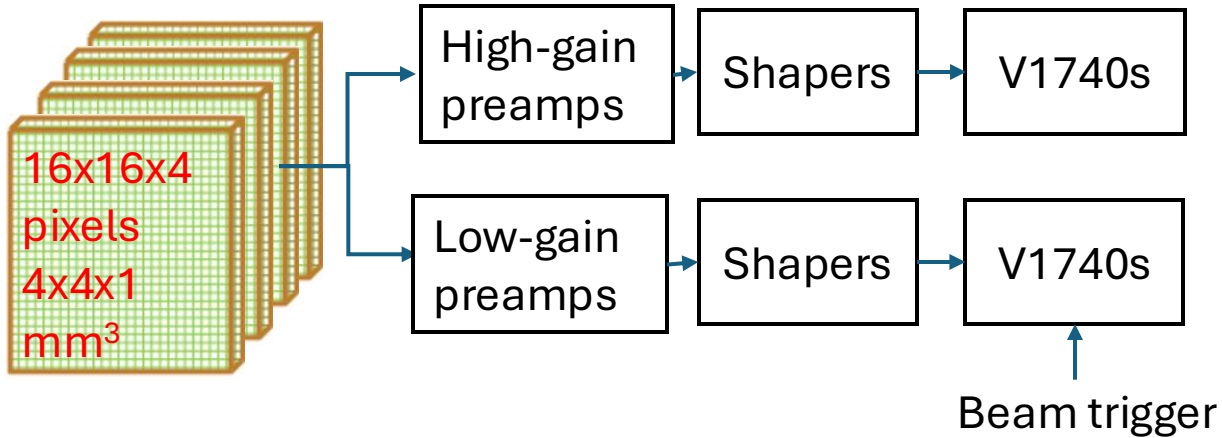
- **Fall 2017:** BRIKEN experiment around  $^{78}\text{Ni}$  and mid-shell region  $A\sim 100$  (~2 weeks beamtime)
- **Spring 2021:** BRIKEN experiment around Rare-Earth and  $N=126$  region (~3 weeks)
- **Fall 2021:** ZD-MRTOF mass measurement experiments with Zerodegree PID (~1 week)
- **Spring 2024:** Parasitic experiments with ZD-MRTOF, decay station and Zerodegree PID (~1 months)
- **Fall 2024:** DTAS experiment  $N>126$ , Decay station, ZD-MRTOF, Zerodegree PID (~ 3 weeks)

# BRIKEN 2017 experimental campaign

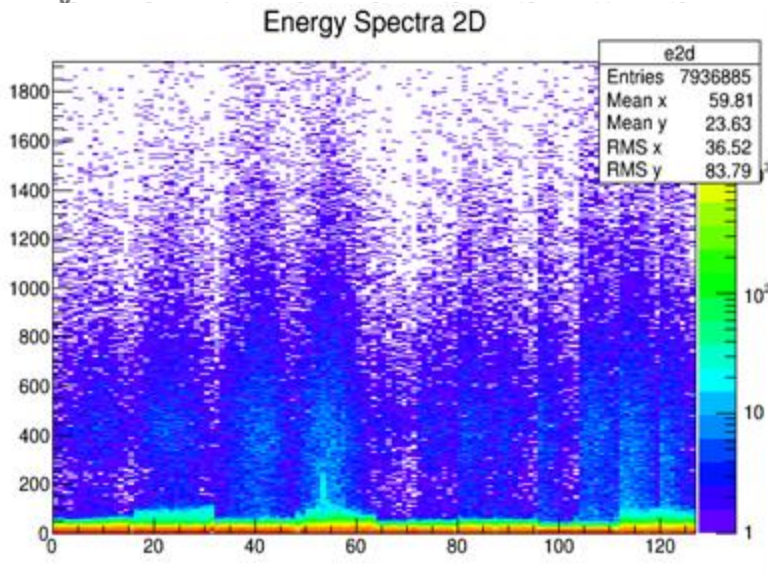
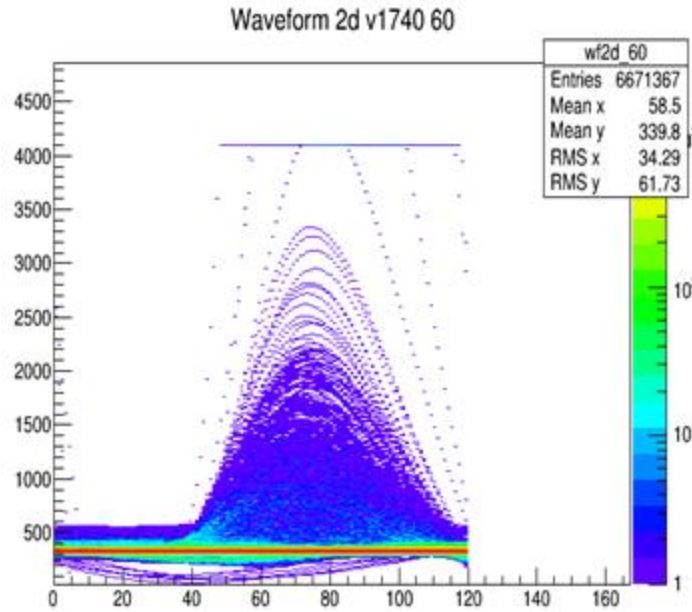
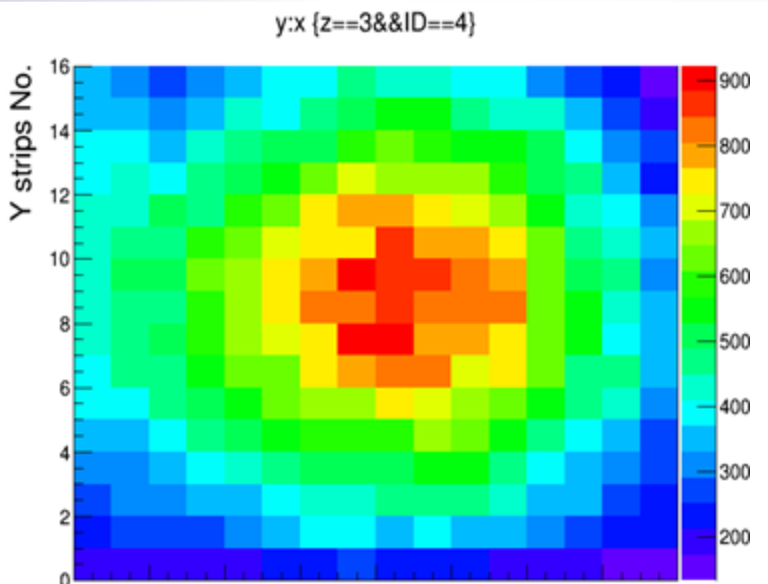
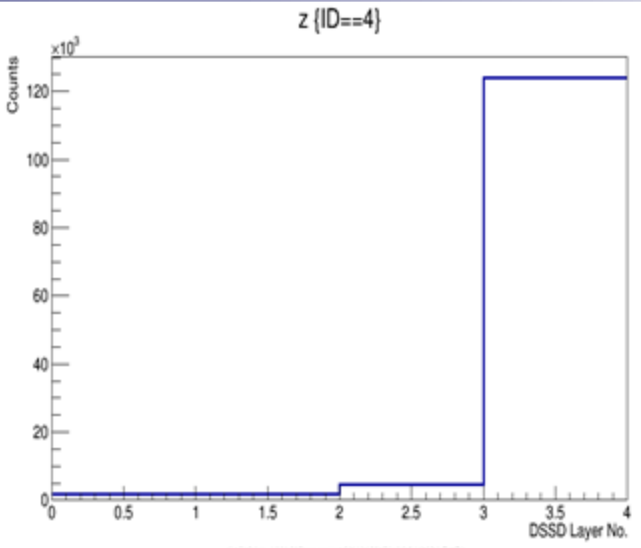
## BRIKEN: Beta-delayed neutron emission at RIKEN



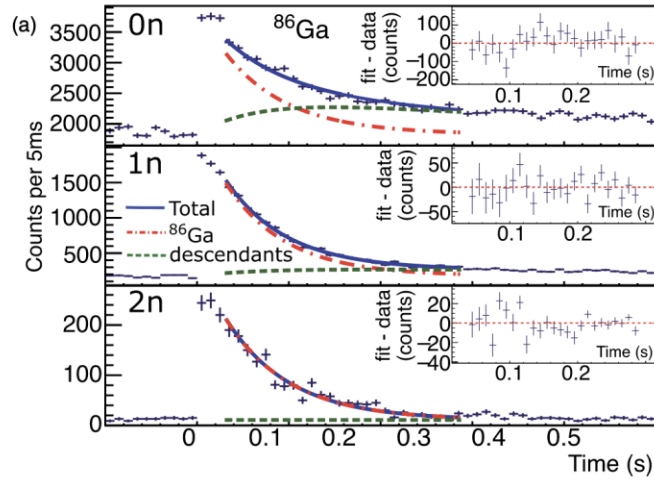
- WAS3ABi readout electronics was simplified: No need to prepare CAMAC discriminators and trigger circuit
- Low thresholds of  $\sim 60$  keV
- Deadtime-free



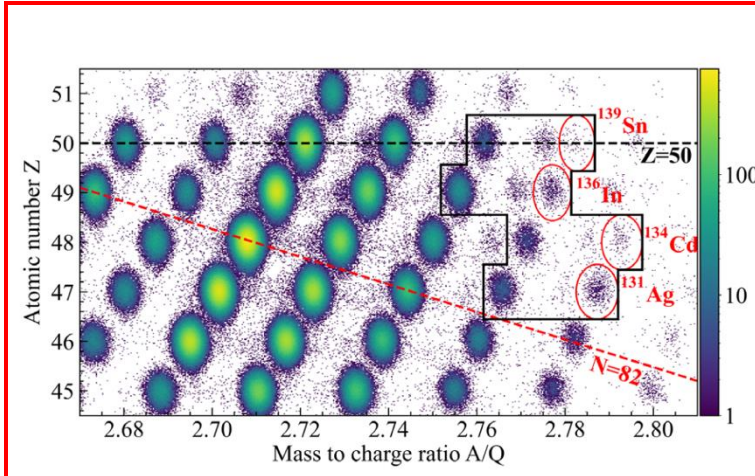
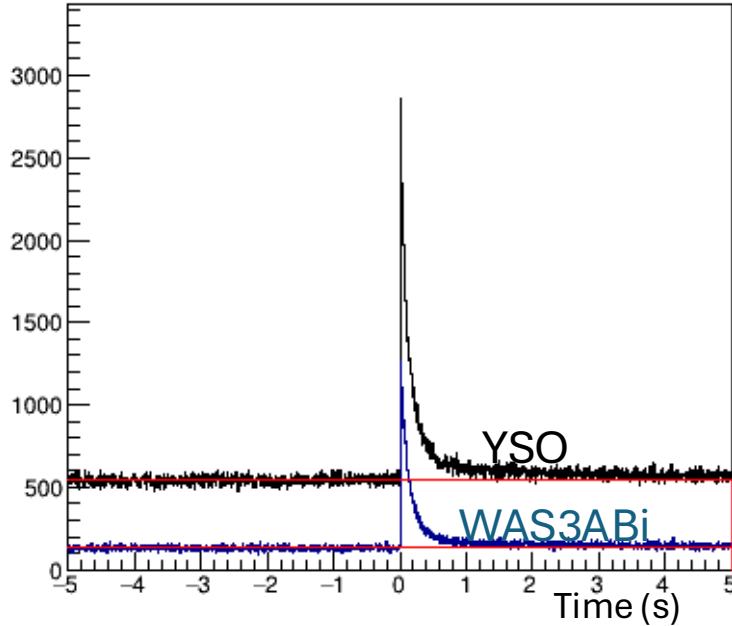
# Some online plots



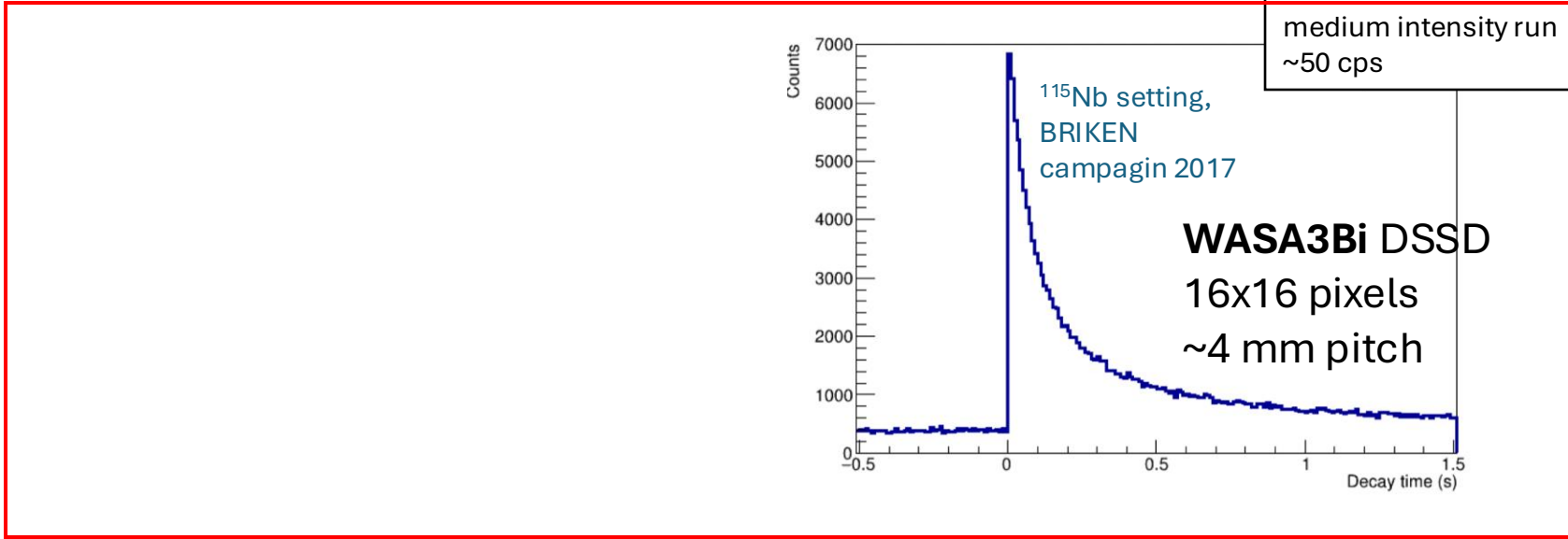
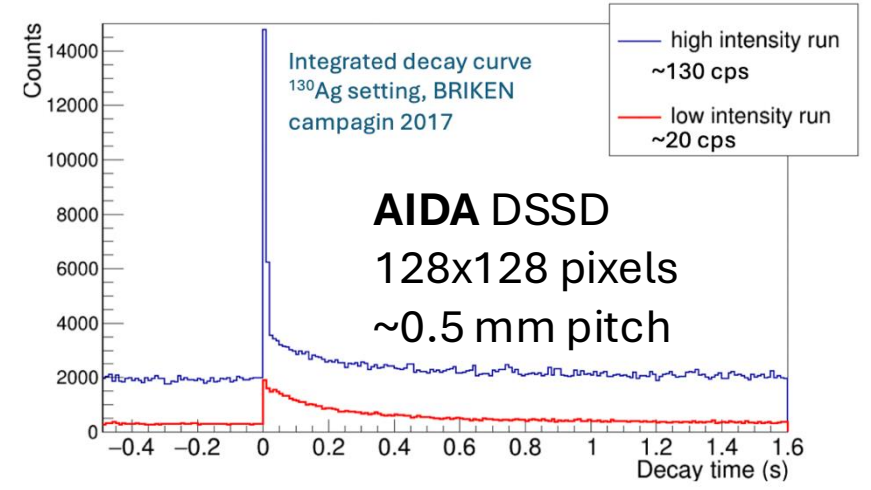
# Selected results in comparison with AIDA



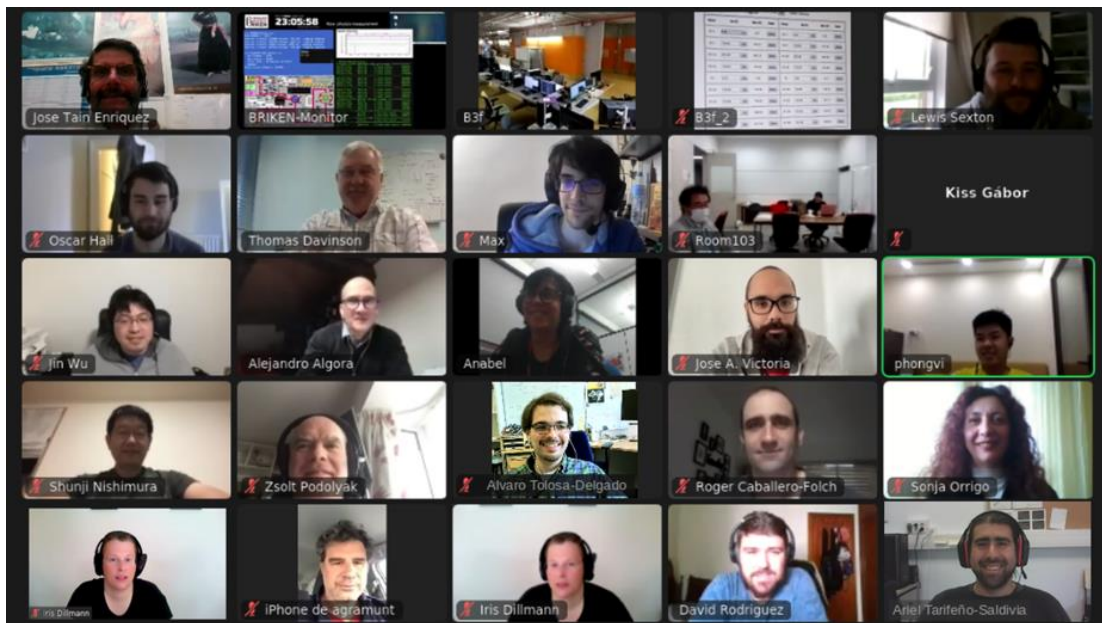
R. Yokoyama, Phys. Rev. C 100, 031302(R) (2019)



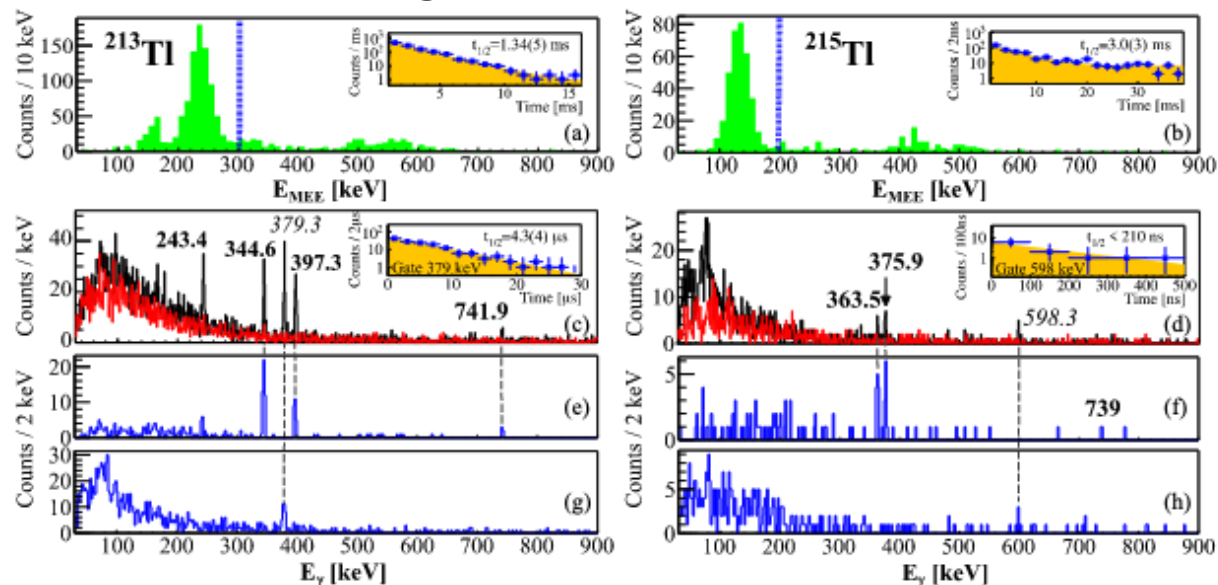
V. H. P. et al., PRL 129, 172701 (2022)



# BRIKEN 2021 experimental campaign



- Local team: hardware preparation
- Remote collaborative works to prepare online/offline analysis codes (task sharing)
  - O. Hall, Phong => WAS3ABi
  - M. Pallas, A. Tolosa Delgado => He<sub>3</sub>, HpGE
  - Other online participants => Start and stop run, monitor histograms, check offline data



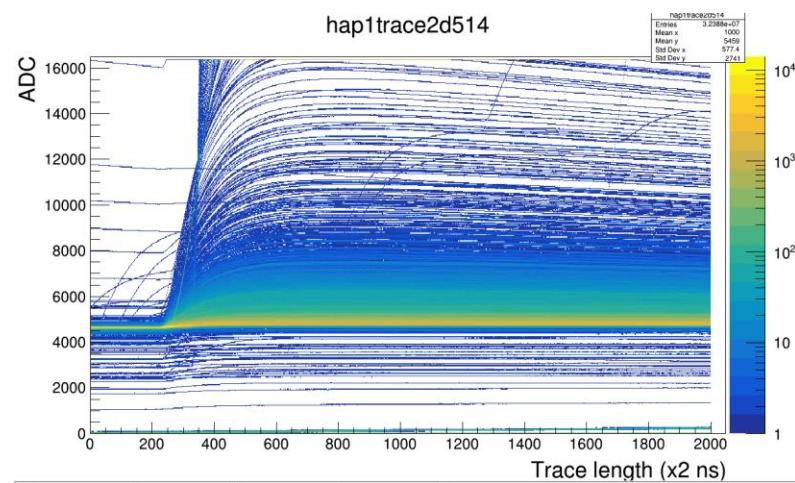
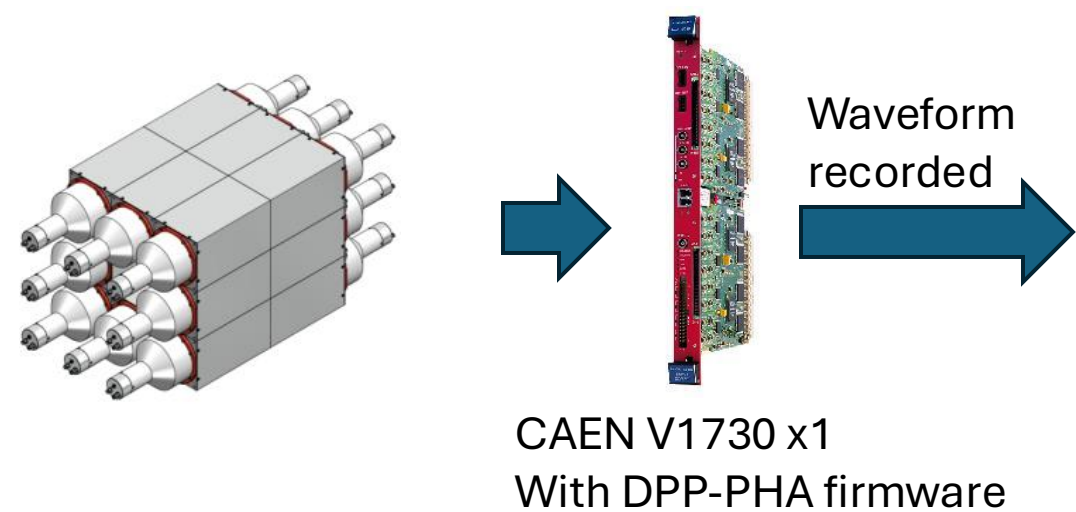
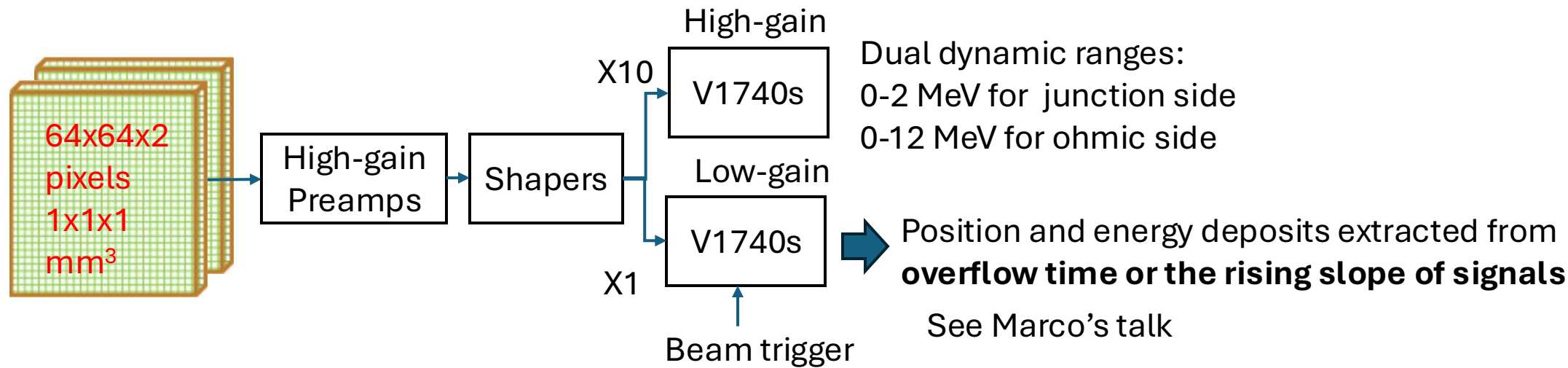
Data: WAS3ABi and only one HPGe clover

T. T. Yeung, A. I. Morales, et. al. PRL 133, 072501 (2024)

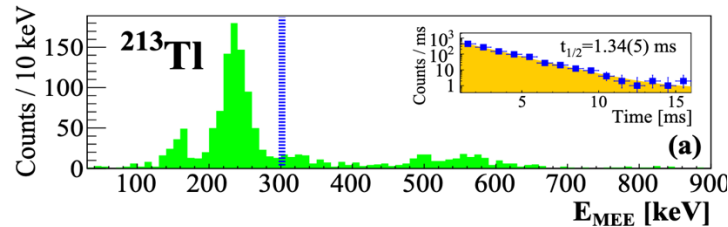
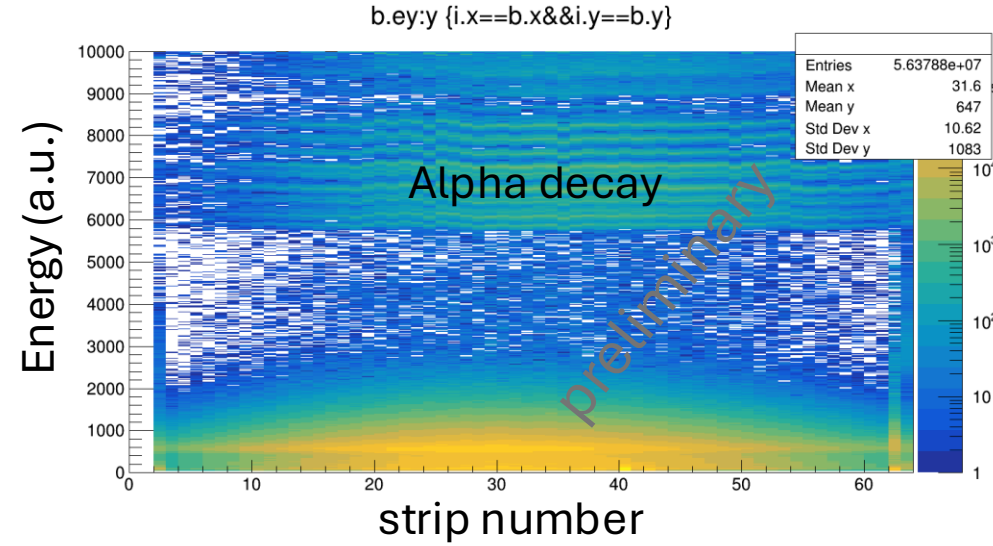
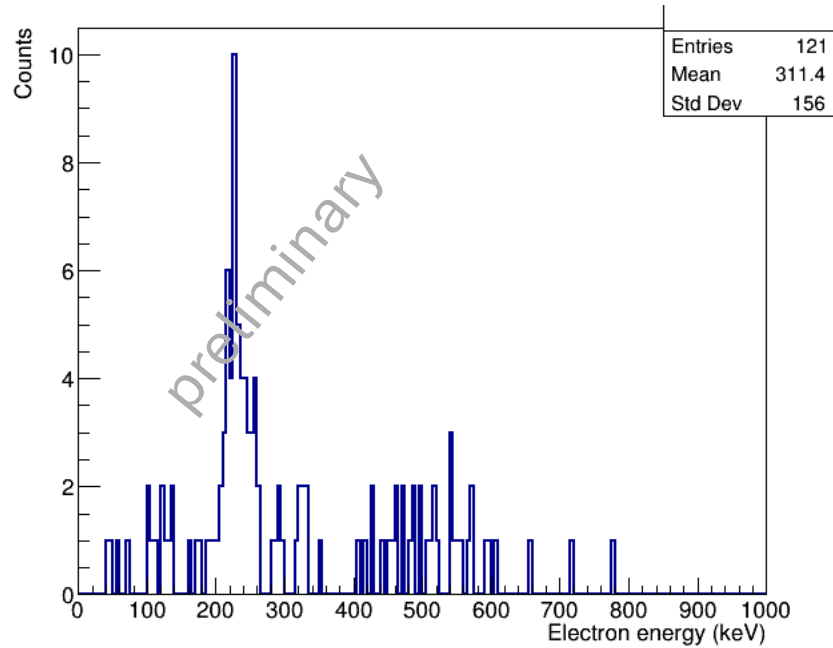
T. T. Yeung's talk



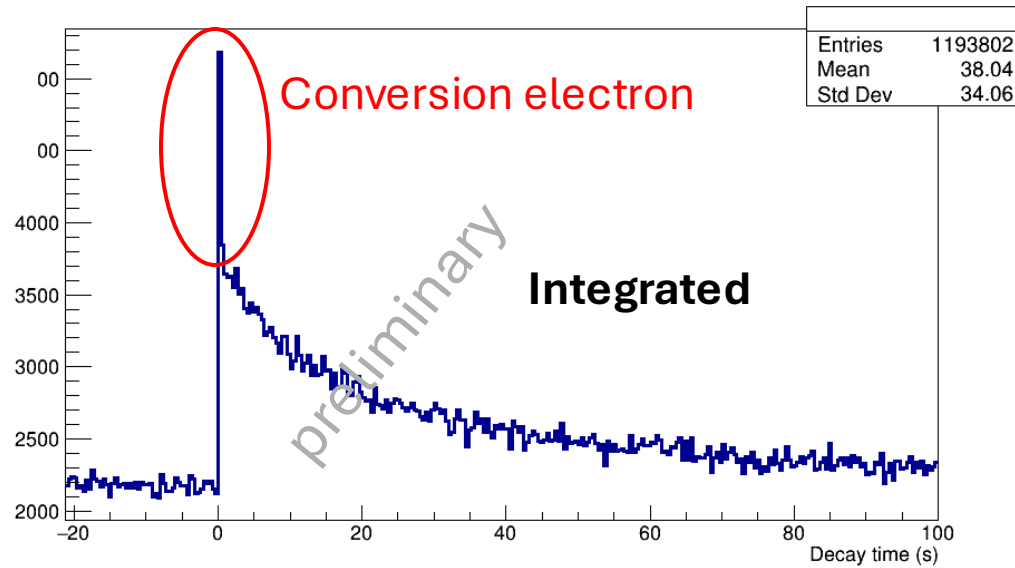
# DTAS experiment 2024 (N>126 region)



# Some plots from nearline analysis



T. T. Yeung, A. I. Morales, et. al. PRL 133, 072501 (2024)

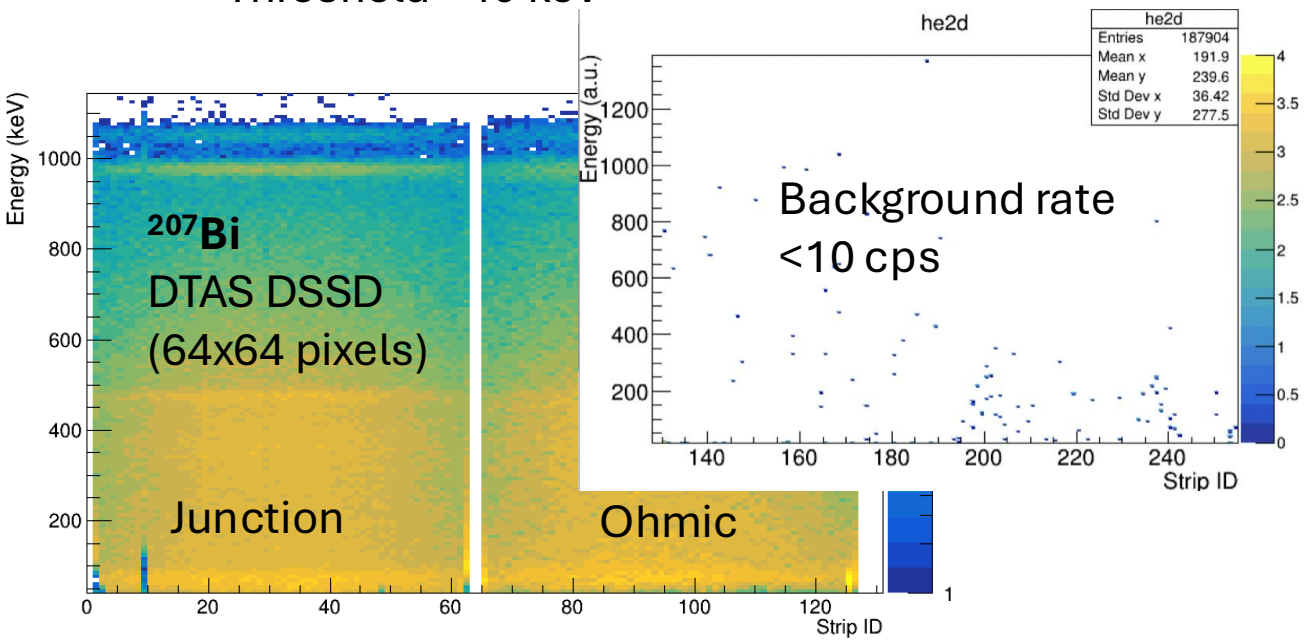
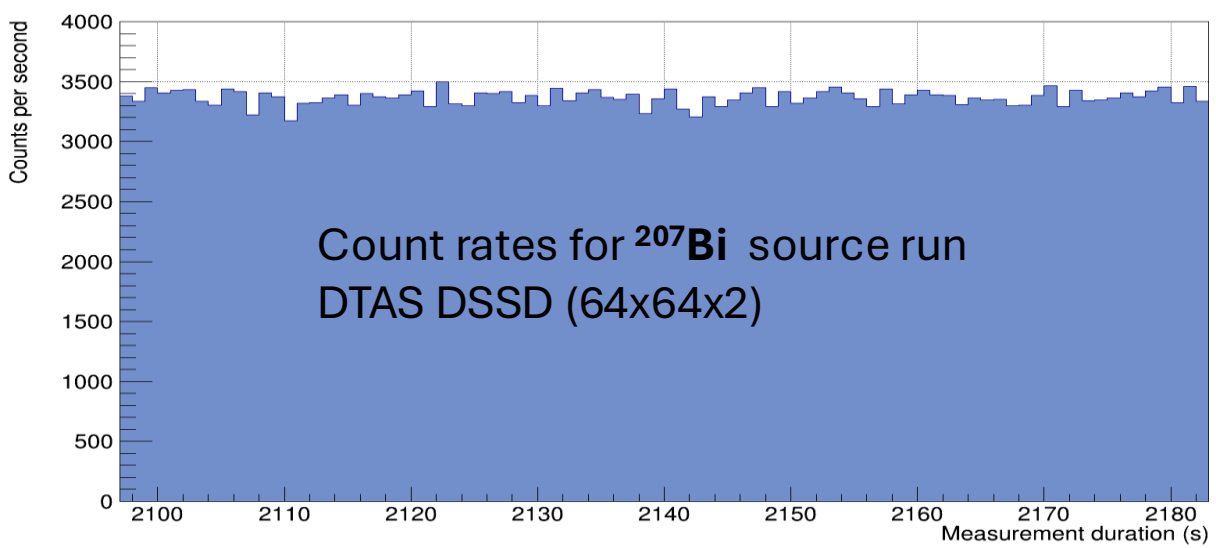
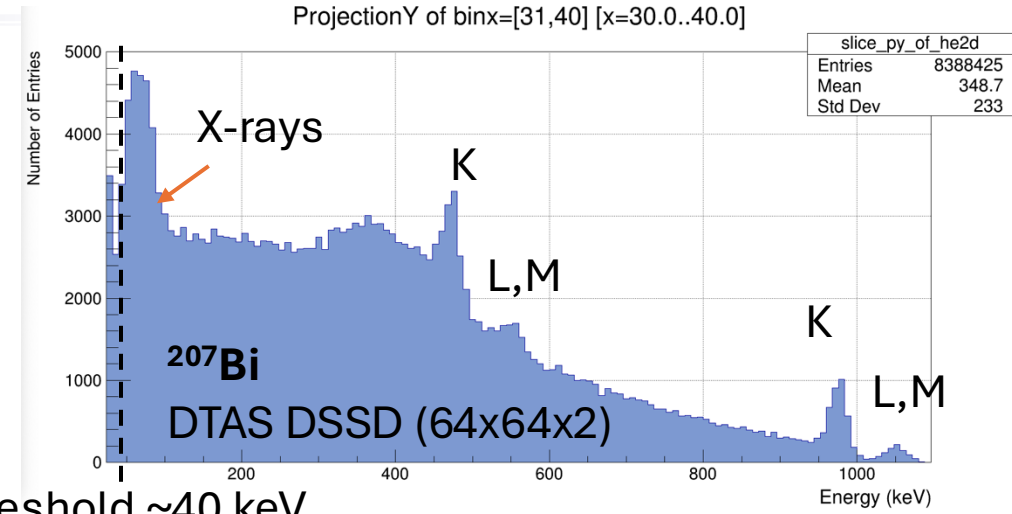




# Performance of WAS3ABi with digital DAQ

## - DAQ rates

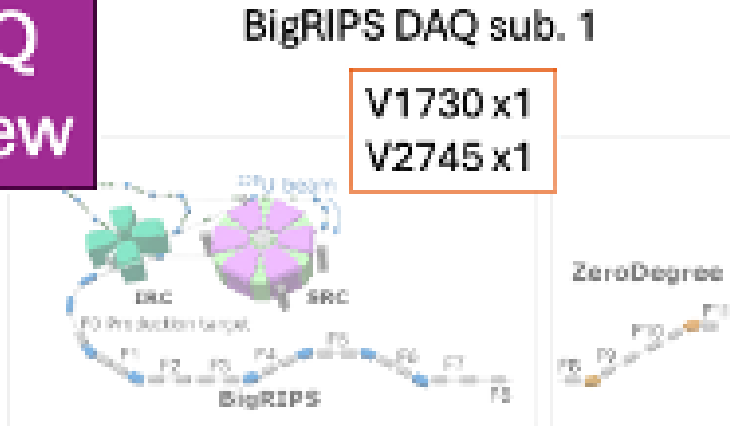
- BRIKEN2017: (16x16x4) => 50 cps (78Ni, 100Br region)
- BRIKEN2021: (32x32x2) => 100 cps (Rare earth, N~126 region)
- DTAS2024: (64x64x2) => 150 cps (N>126 region)
- **Maximum DAQ rates**, assuming 1 implantation ~ 6 beta decay ( $^{100}\text{Br}$  region):
  - 3000 cps beta => **500 cps implantation rate**
  - The maximum DAQ rate **does not depend** on number of readout channels



# Decay station with neutron-TOF detector array

## fRCDAQ Overview

\*Fully self-trigger DAQ system



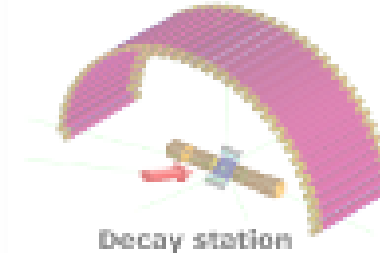
ZDMRTOF DAQ sub. 2

(V1730 x1)



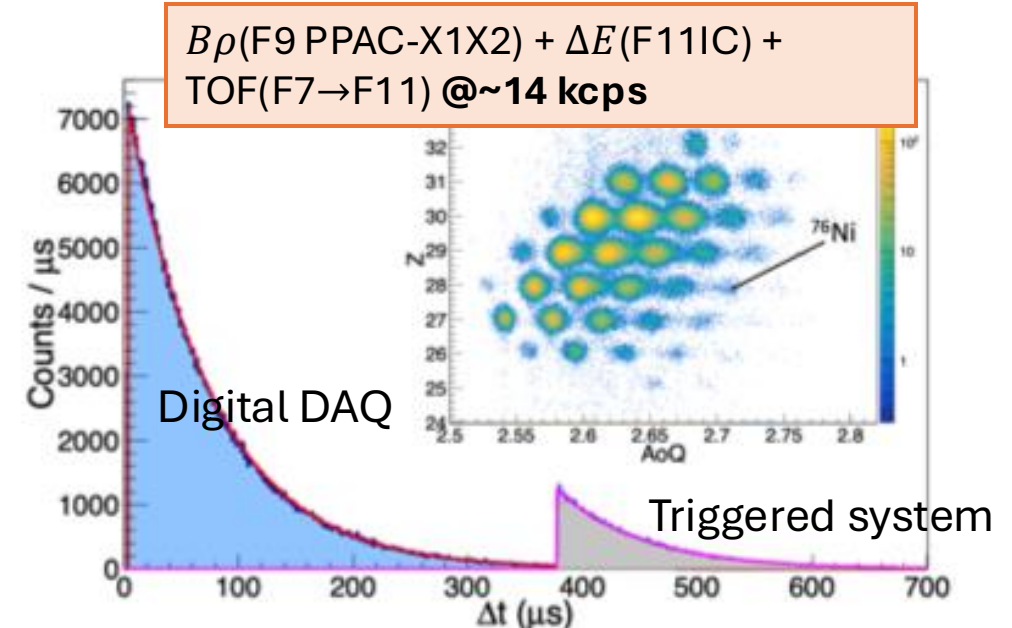
Advanced Decay Station ADS DAQ sub. 3

V1730 x8  
V1741 x2  
V1740 x2



Parasitic beamtime with

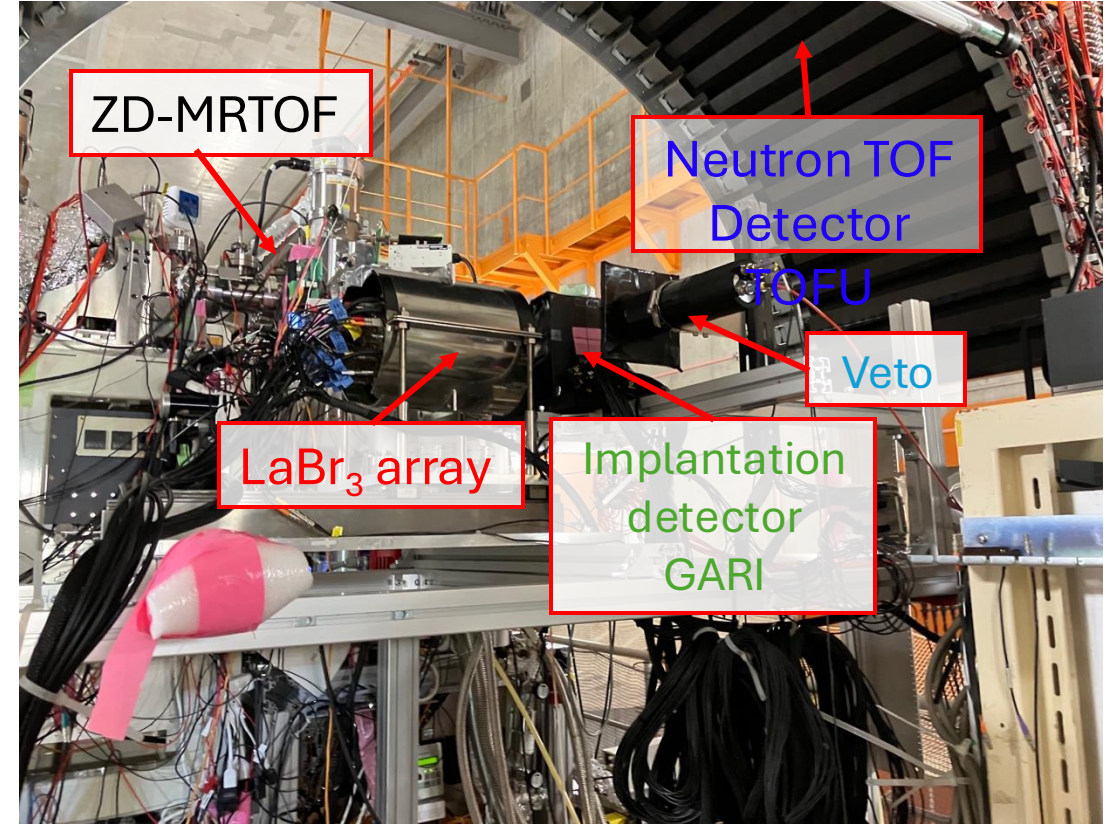
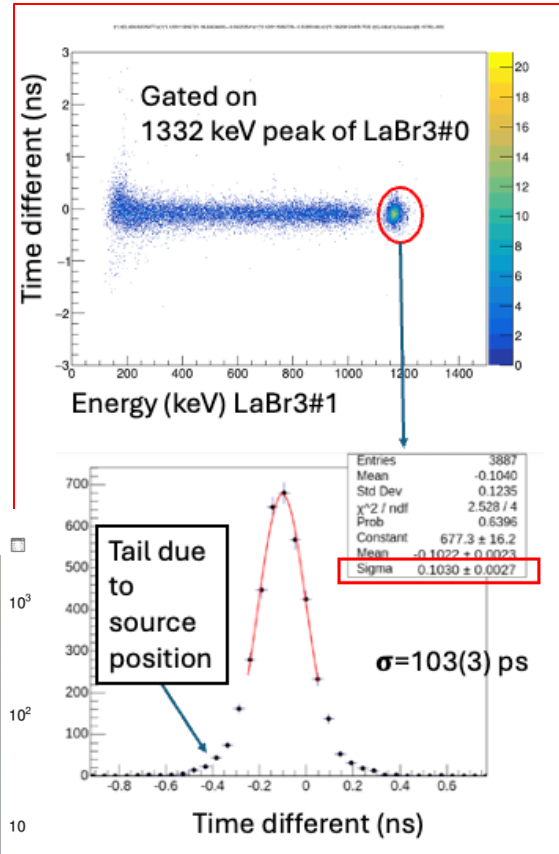
- In-beam and transmission cross-section measurement experiments
  - Mass measurement experiments with ZDMRTOF setup
- ⇒ PID with beam rate up to **30 kcps**



V.H.P., et. al. RIKEN Accel. Prog. Report 56

# Decay station with neutron-TOF detector array

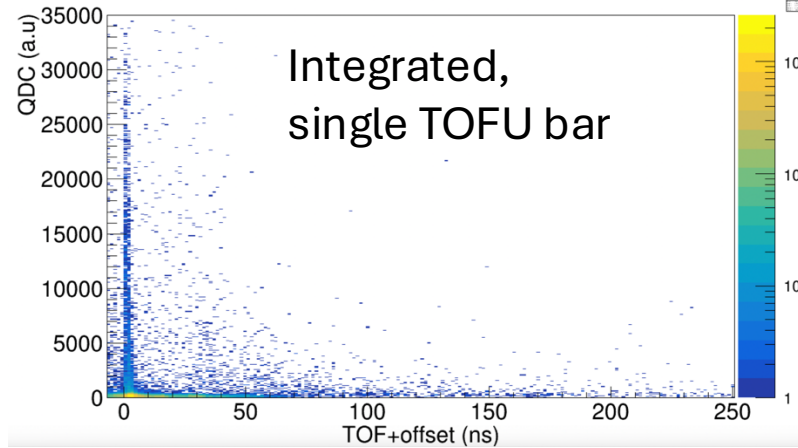
LaBr<sub>3</sub>



Information about GARi Active stopper: Quanbo's talk

hTOFU\_EvsT12

Integrated, single TOFU bar







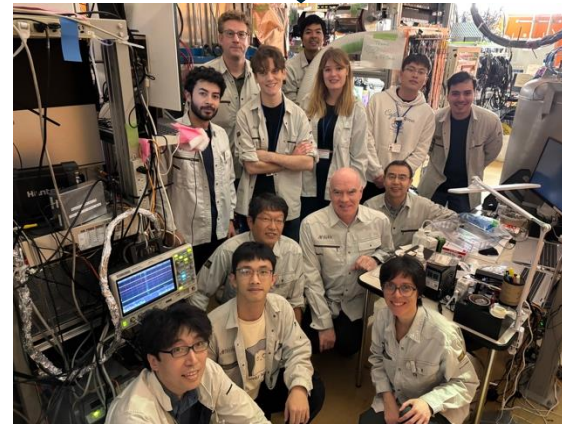
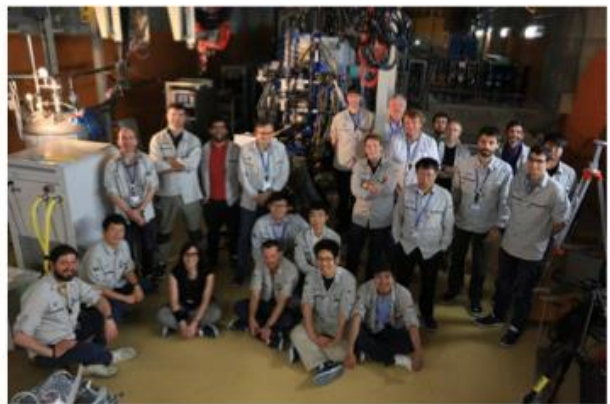
- ❖ Digital DAQ system with waveform digitizer has been developed since 8 years for beta-decay studies at RIBF
- ❖ Customized RCDAQ software framework with many “**R**eally **C**ool” features
- ❖ **Versatile, scalable** and **easy-to-understand** framework for setting up DAQ and data analysis
- ❖ Successful implementation in various experiments
  - ❖ Performance of digital DAQ for 3 active stopper systems: WAS3ABi, GARi and MCP-Si, has been demonstrated
- ❖ For future experiments, **our collaborators can help** writing DAQ plugins for their devices and analysis codes based on templates provided

# Thank you for your attention!

```
$ ddump -t 9 -p 940  
beamrun_daq0-00187-0000.evt  
> collaboration_photo.jpg
```



BRIKEN collaboration



DTAS collaboration (Fall 2024)

ZD-MRTOF  $\beta$ -decay collaboration

