S022 experiment Beam analysis

version.01

Masanori KANEKO

Abstract

- This is the analysis note for the beam line detectors in S022 experiment. We had used several kind of detectors(PPAC, Plastic, IC, BDC) in combination, that allows us to identify the charge, mass to charge ratio for beam isotope, and also beam spot profile at the reaction target.
- Babirl data acquisition software of RIBF was used to accumulate data from those detectors with ridf format, and ANAROOT library is used to analyze taken data. In basically, optimization of the calibration, correction and gate parameter is only needed because there are conventional beam reconstruction methods implemented in ANAROOT.

Information

- List of detectors and modules used

Detector	FocalPlane	Module	motivation
PPAC	F3, F5, F7	V1190	Tracking at focal plane
Plastic	F3, F7, F13	MQDC32, MTDC32	TOF and beam trigger
IC	F7	MADC32	Energy deposit
BDC	F13	AMTTDC	Beam tracking

- Analysis macros and modified source code of ANAROOT is uploaded in the GitHub repository.
    - https://github.com/SpiRIT-Collaboration/BeamAnalysis_S22
    - The macros there need the modified source code of ANAROOT.
- ANAROOT library should be available.
- Original working place that contains macros is
    - s015@ribfana02.riken.jp:/home/s015/exp/exp1605_s015/anaroot/users/S22_experiment/
        - Please type “anarootlogin S22_analysis” in the ribfana02 analysis server.

PID principle

- In the BigRIPS, there are several kind of magnet and slit, degrader, detectors in order to identify the beam particles by using a Bρ-ΔE-TOF method.
  - $B\rho = p/q$ ← dipole magnet & PPAC tracking
  - $\Delta E = f(\beta, q)$: Bethe-Bloch's formula ← Ion Chamber
  - $TOF = cL_{TOF}/\beta$ ← F3 and F7 plastic timing difference

PTEP **2012**, 03C003 T. Kubo et al.

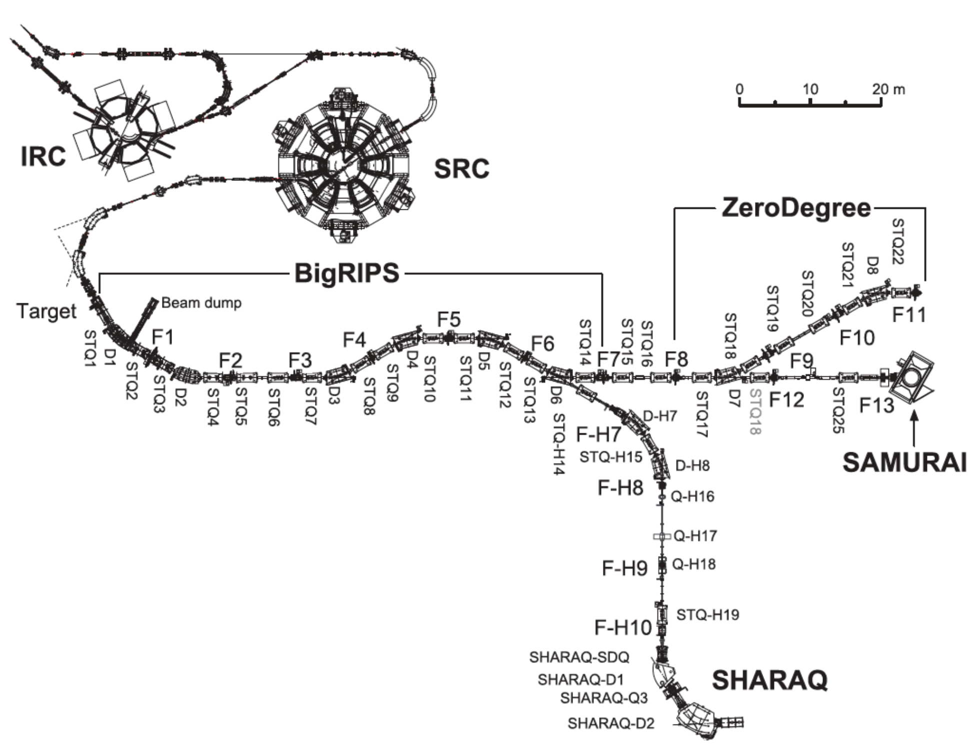


Fig. 1. Schematic layout of the RI Beam Factory (RIBF) at RIKEN Nishina Center.

PTEP **2012**, 03C003 T. Kubo et al.

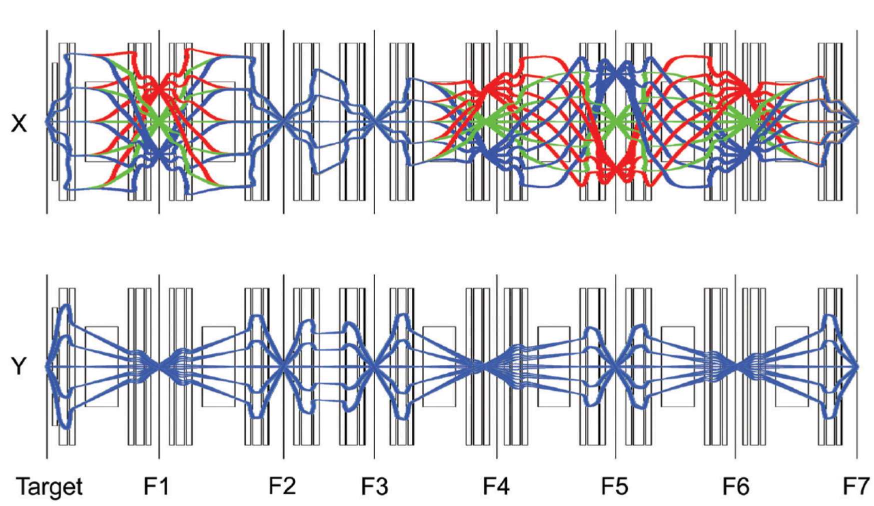


Fig. 2. Standard first-order ion optics of the BigRIPS separator calculated by the COSY INFINITY code: horizontal (upper) and vertical (lower) planes. The foci are denoted by F1–F7.

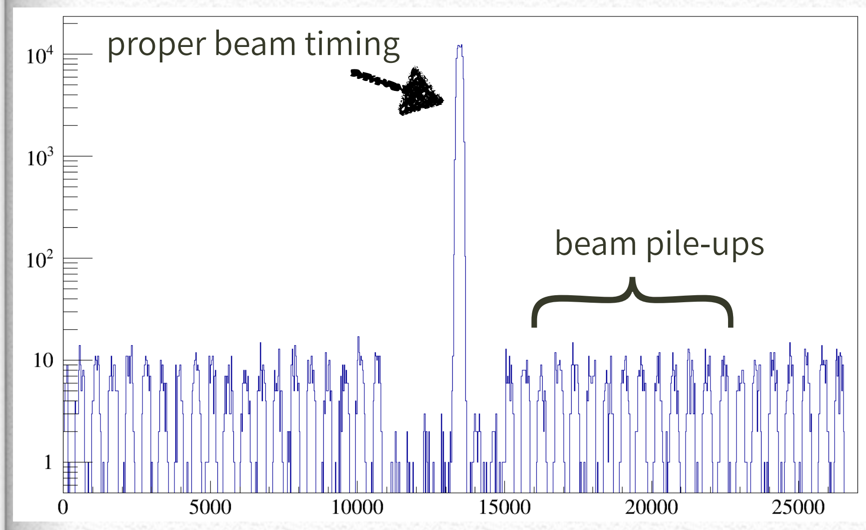
Issue list & answer

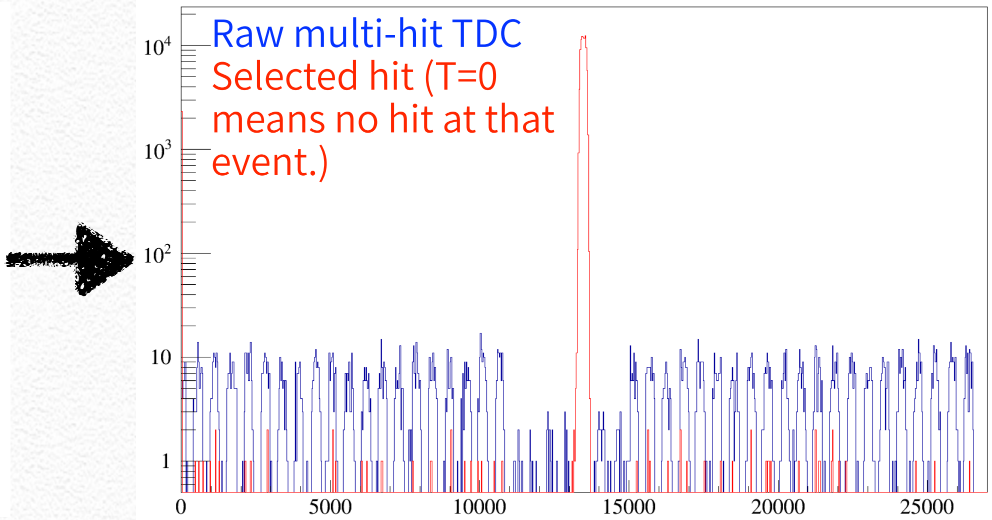
- PPAC
  - Low efficiency caused by trip.
    - Recovery for missing signal which uses average TSum parameter is implemented. It recovers about 5~10 % of total event.
  - F3 PPAC efficiency sudden drop (~20%) happened.
    - Beta reconstruction without low efficiency focal plane tracking is implemented. It is able to supplement missing reconstruction without large difference of the beta and A/Q.
- Plastic
  - TOF gradually changes because of radiation damage.
    - Slew correction is implemented. TOF resolution improves from ~200 ps to ~140 ps with the correction.
  - PMT gain drastically changed not because of damage.
    - Slew parameter is obtained for each group of run.
- Ion Chamber
  - Gains for half of anodes change
    - Channel by channel calibration

Multi-hit TDC: hit selection

- Because the data container of PPAC and plastic can hold one hit information, hit should be selected when MHTDC is used. In S022 experiment, V1190 for PPAC and MTDC32 for plastic are used. So at first, MHTDC data is analyzed like below,
  - Get proper beam timing from raw MHTDC histogram.
  - Adopt the closest hit from proper timing when the event has multi-hit in MHTDC.
  - This procedure is implemented in source codes which are TArtCalibPPAC.cc and TArtCalibPlastic.cc, and modified parameter class is described in TArtBigRIPSParameter.cc. The parameter of proper beam timing in PPAC is called “tx1mean” for example. (“tlmean” for plastic.)
  - Macros to find parameters can be found in GitHub, macros_1/anaPPACTMean.C for PPAC, or macros_1/anaPlasticTMean.C for plastic.

ex) F3-2A PPAC TX1 MHTDC histogram





PPAC TSum gate

- PPAC detector uses delay-line readout in order to measure the position where the beam particle passes through. The sum of delay time for each end is useful to distinguish weather the event is good or not. If one beam particle generates a signal in one cathode wire, sum of delay should have a constant value independent of position of incident beam in principle. So, the event with sum of delay far from that constant will be considered as a bad event like multiple hit or delta-rays event.
- TSum is defined in the ANAROOT as,
    - TSumX = TX1 + TX2 - 2*TA
    - It can cancel the beam-intrinsic time fluctuation like beta difference of the isotopes or jitter of TDC.
- Macros to decide TSum gate for each PPAC is uploaded in GitHub: macros_2/anaPPACTSumGate.C
    - This does fitting TSum histograms by gaussian function and make a gate as gaussian mean value $\pm$ 5 sigma.

PPAC TSum gate from paper

Figures from PPAC paper: NIMB 317 (2013) 717.

- TSum histogram for Z~50 particle at above and Z~30 at below.
- The δ-ray effect is enhanced in above figure because of high Z beam passing.
- (Typically TSum has smaller value than proper constant value when δ-ray is mixed.)

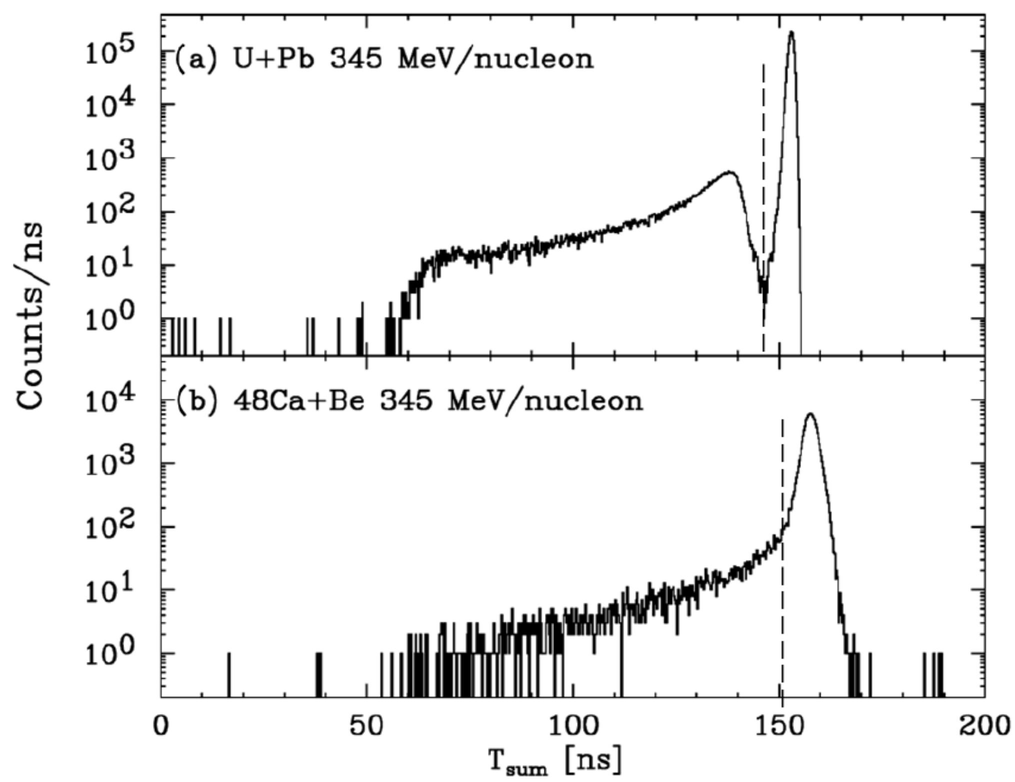
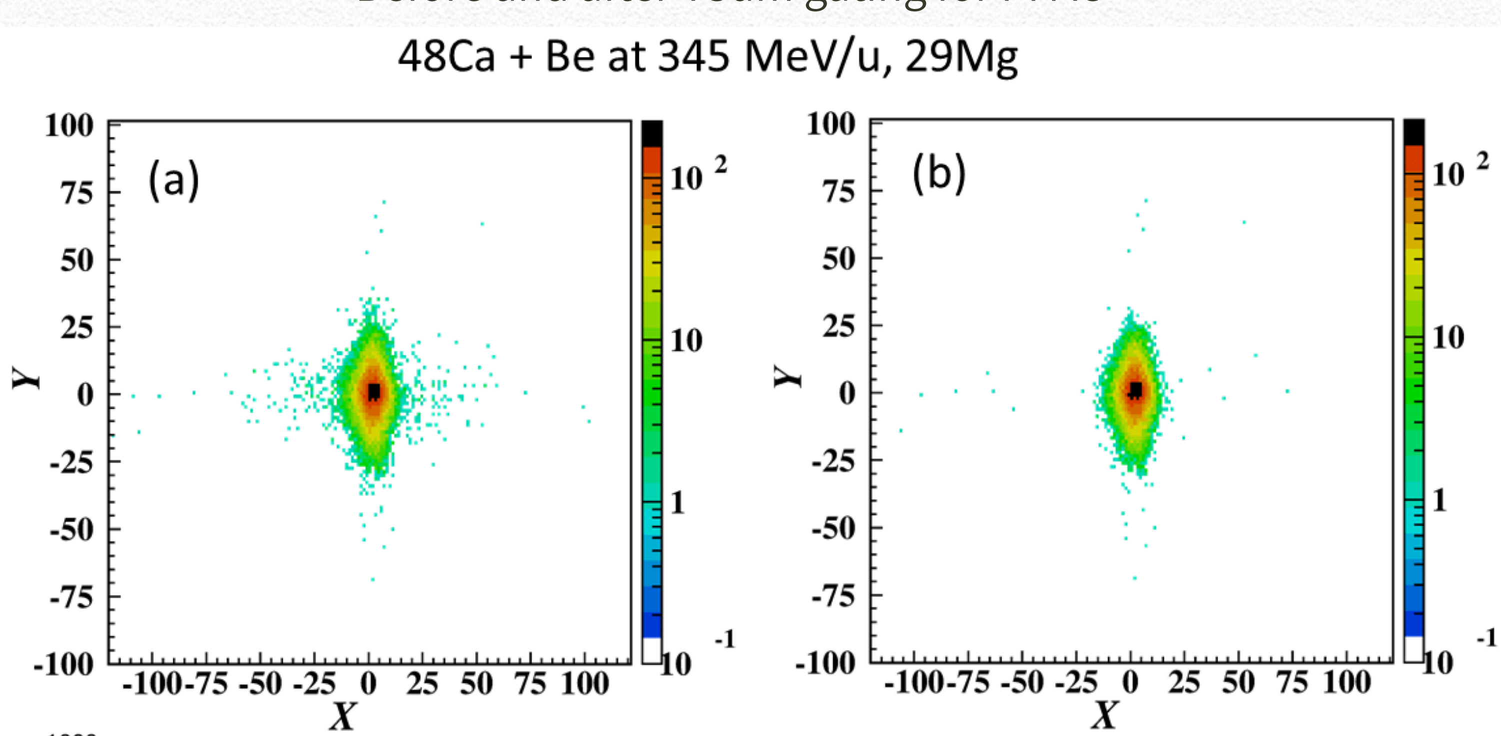


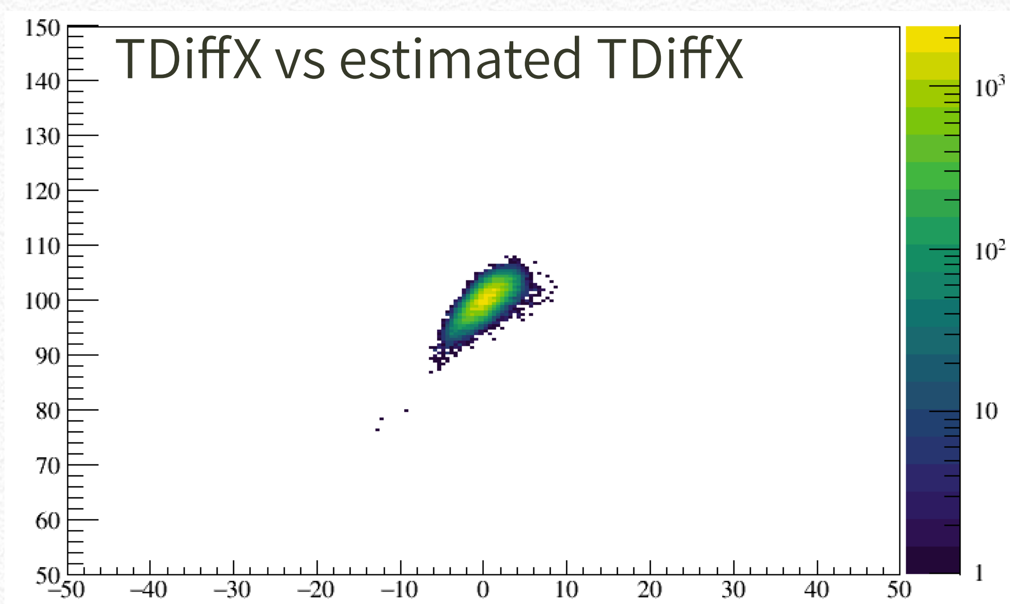
Fig. 15. T_{sum} spectrum of (a) fission fragments with Z~50 produced from the ^{238}U + Pb reaction at 345 MeV/nucleon and (b) light projectile fragments around ^{29}Mg produced from the ^{48}Ca + Be reaction at 345 MeV/nucleon. Dashed lines indicate the threshold to cut the events affected by δ rays. For the ^{48}Ca + Be reaction, the threshold is set where the tail of the spectrum starts since good separation between the true events and the events affected by δ rays is not demonstrated.

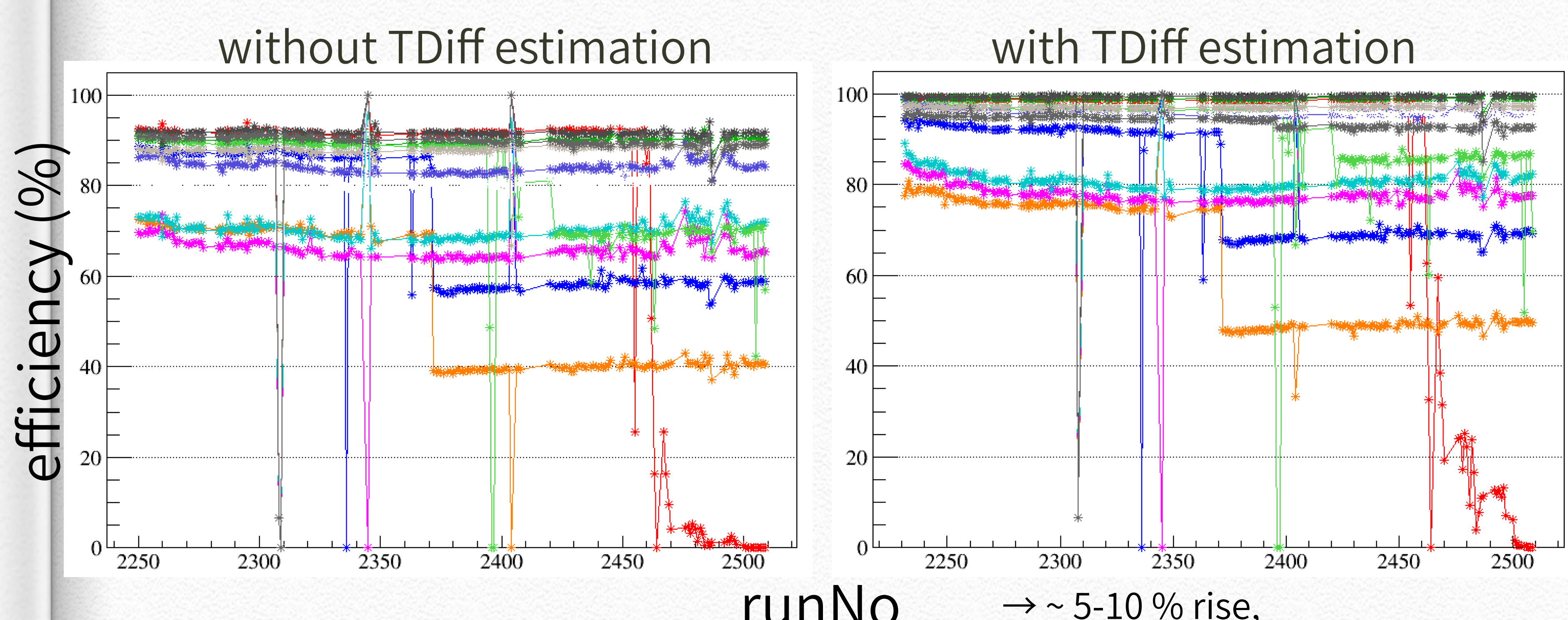
Before and after TSum gating for PPAC



PPAC missing signal recovery

- Time difference between two readout of delay-line is necessary to reconstruct position: X = C1*TDiffX + C2
  - TDiffX = TX1 - TX2
  - estimated TDiffX = TSumX - 2*TX2 +2*TA
    = -TSumX + 2*TX1 - 2*TA
  - where TSumX is provided by average of TSumX gate parameter of minimum and maximum,
    - TSumX = 0.5*(TSumXmin + TSumXmax)

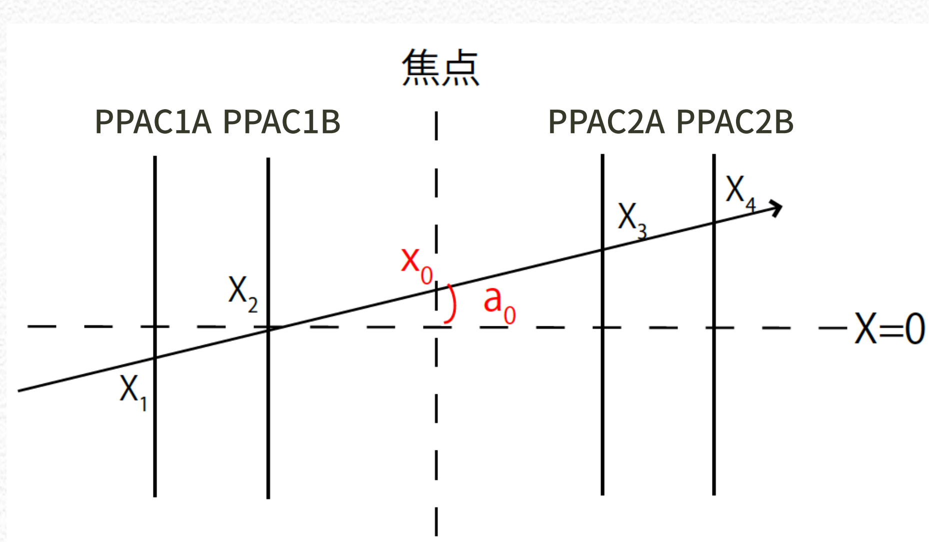




→ ~ 5-10 % rise,
but still efficiency drop on F3-2A/2B.

Focal plane tracking

- In order to calculate the $B\rho = B\rho_0(1+\delta)$ of beam particle at F3~F5 and F5~F7, where ρ0 is a curvature of the beam optical axis and δ is a fluctuation from the center-orbital rigidity, PPACs at each focal plane are used.
- In S022 experiment, two double-PPACs are used at F3, F5, F7. So basically there are four X and Y position information for each focal planes. In ANAROOT library, beam track is reconstructed by using least square method. In the case of low PPAC efficiency, the algorithm requires at least one position reconstructed in one double-PPAC.
    - So tracking works if 1A_X and 2B_X are available, but doesn't if only 1A_X and 1B_X are available for example.
- Schematics for a double-PPAC and least square method are described below.



さらに簡単な例として、モデル関数を1次関数とし、

$$f(x) = ax + b$$

とおくと、a と b は次式で求められる。

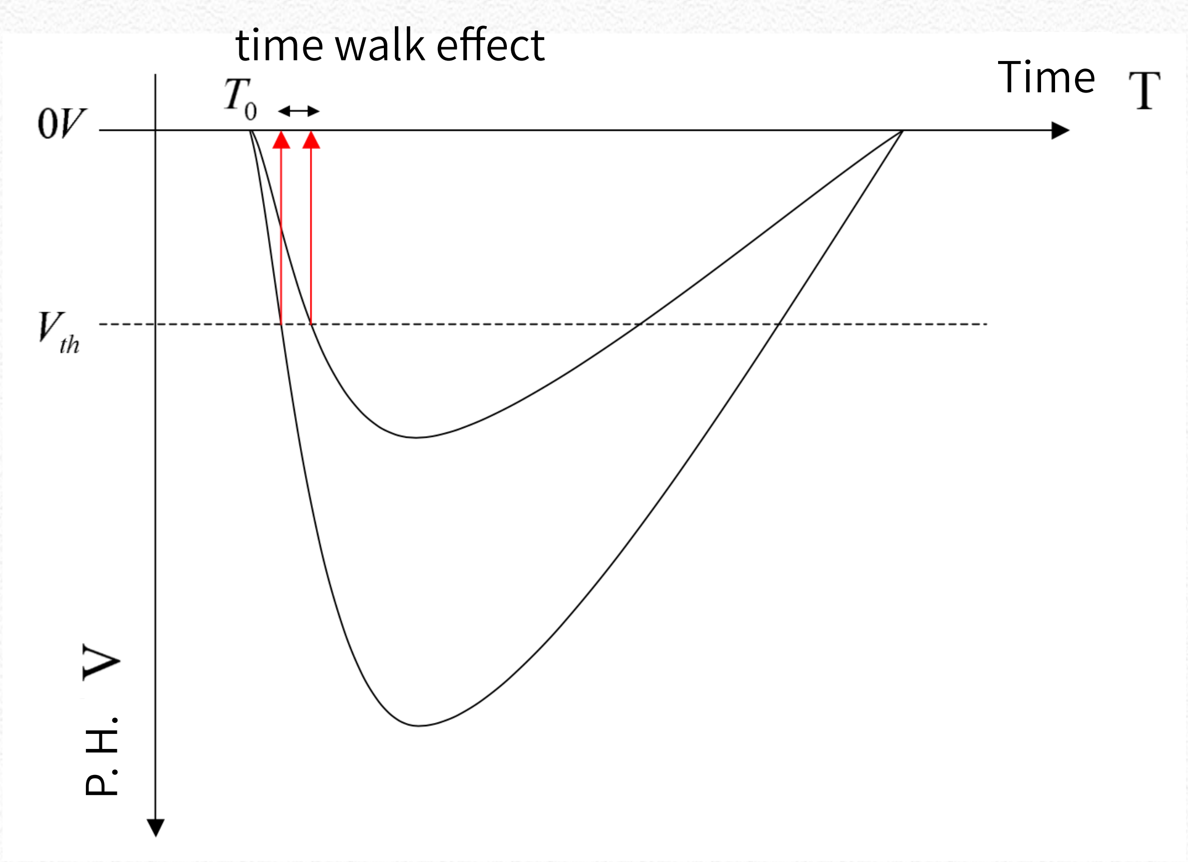
$$a = \frac{n\sum_{k=1}^{n} x_k y_k - \sum_{k=1}^{n} x_k \sum_{k=1}^{n} y_k}{n\sum_{k=1}^{n} x_k^2 - \left(\sum_{k=1}^{n} x_k\right)^2}$$

$$b = \frac{\sum_{k=1}^{n} x_k^2 \sum_{k=1}^{n} y_k - \sum_{k=1}^{n} x_k y_k \sum_{k=1}^{n} x_k}{n\sum_{k=1}^{n} x_k^2 - \left(\sum_{k=1}^{n} x_k\right)^2}$$

Plastic slew correction

- Because of high-Z beam passing through during the experiment, detector material is damaged by continuing to hit beams. Generally the case of a plastic, the damage will bring a deterioration of scintillation light, resulting the lower pulse height of the signal. This effect will cause a small delay of time measuring, as it is called “time walk effect”.
- The slewing correction is to subtract the pulse height dependence of the measured time from data. The correction often assume the dependence to be proportional to inverse squared root like
    - $T = a/\sqrt{QDC} + b$
    - and corrected time $T' = T - a/\sqrt{QDC}$

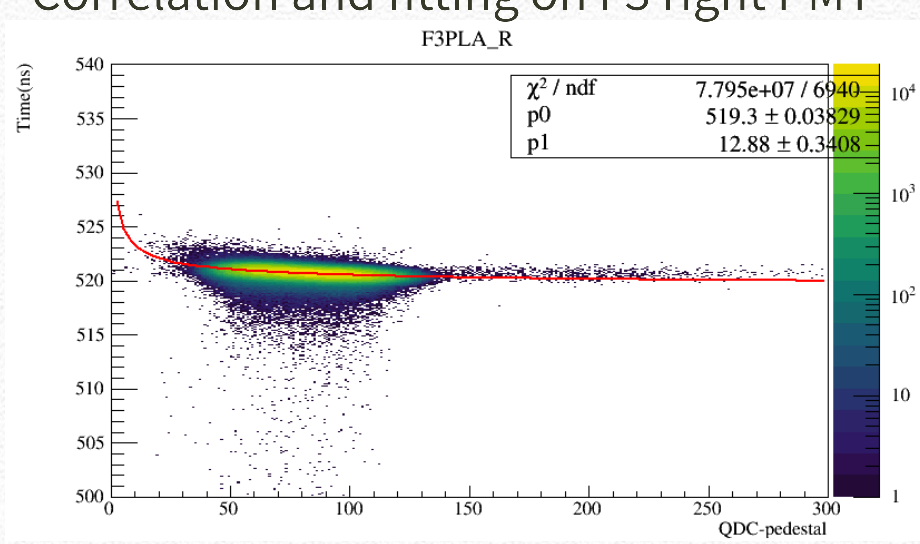
rough description of time walk effect.



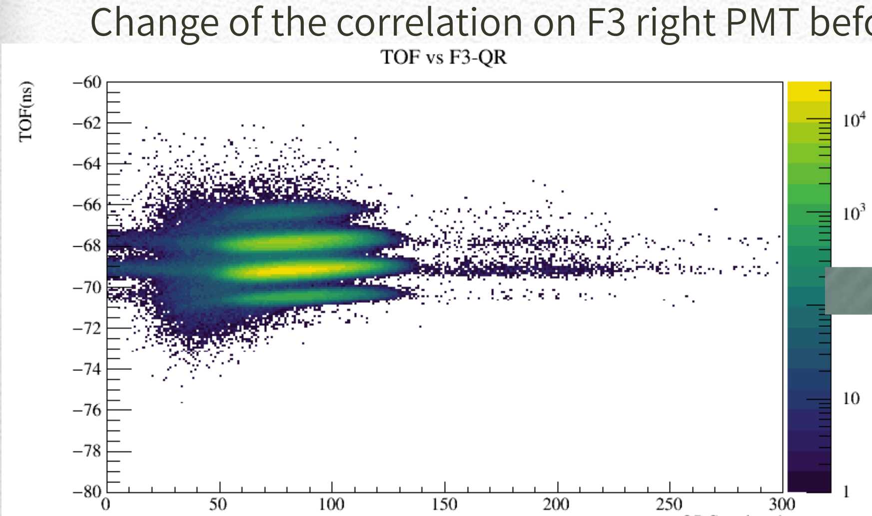
Plastic slew correction

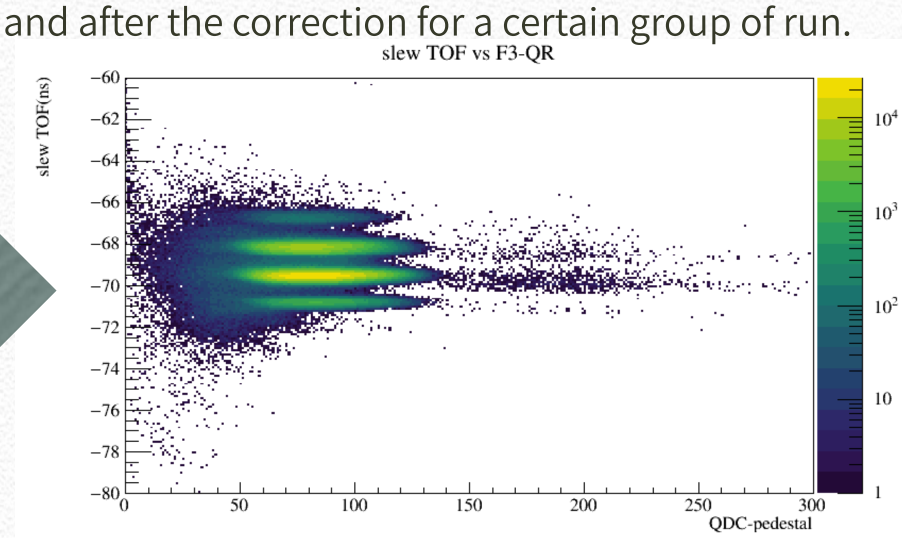
- To find correction parameter, macros_2/anaPlasticSlewing.C is used. This macro works as follows,
  - Make ADC - TDC correlation for each PMT with event selection on isotope of interest by selecting IC sum and TOF.
  - Fit the correlation plot by inverse squared root function.
    - Note that the plastic PMT gain has changed during the experiment because of some reasons other than a radiation damage, which were change of cabling or noise problem on PMT. So in the macro, the correction parameter is calculated for each grouped runs.
  - Check how correlation and TOF are changes after using the correction.

Correlation and fitting on F3 right PMT

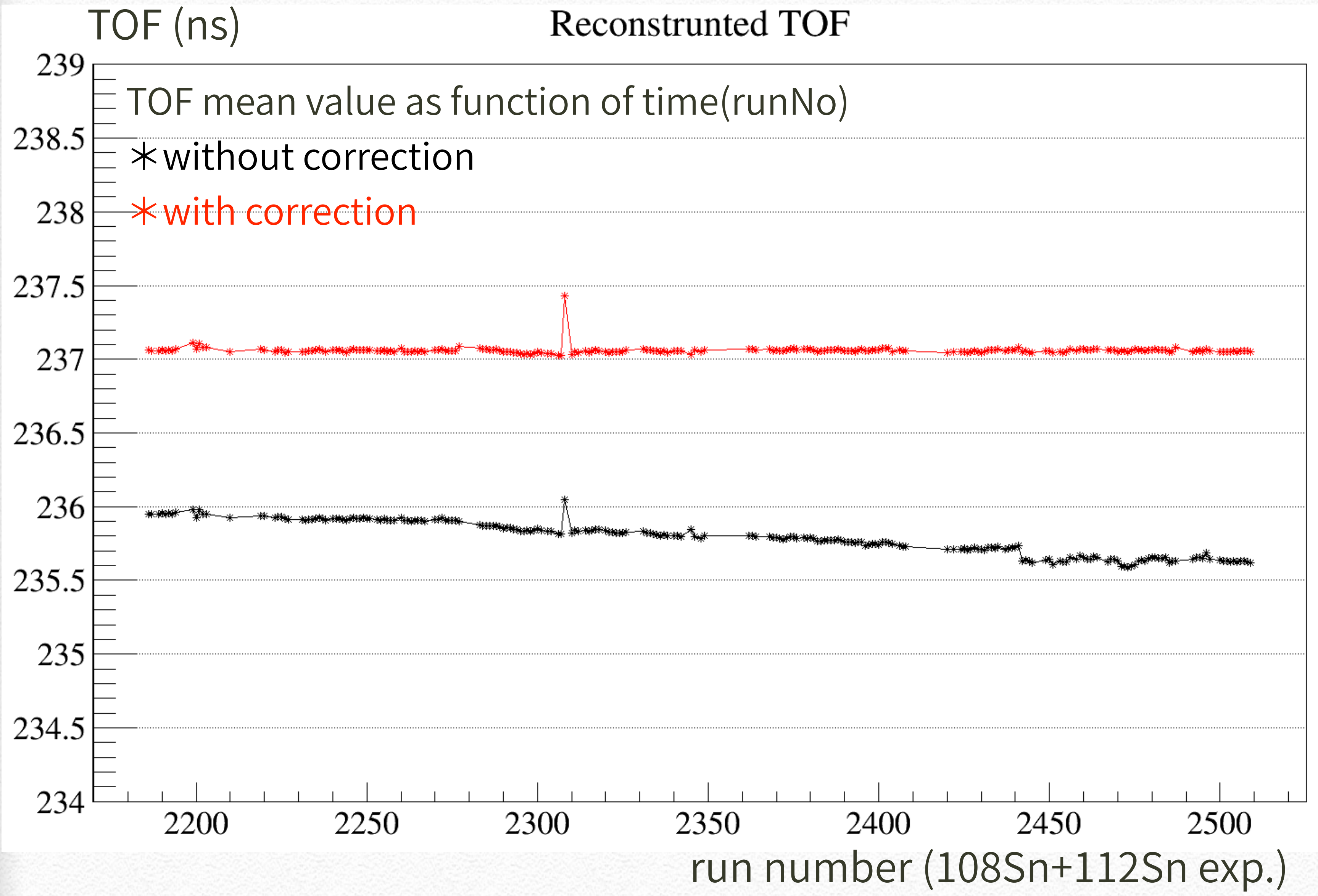


Change of the correlation on F3 right PMT before and after the correction for a certain group of run.

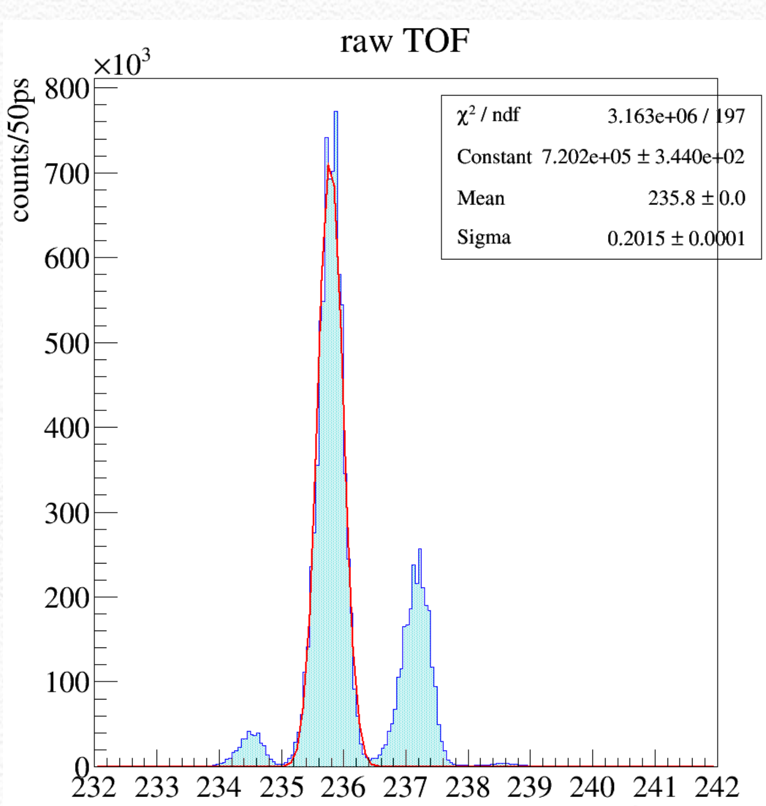


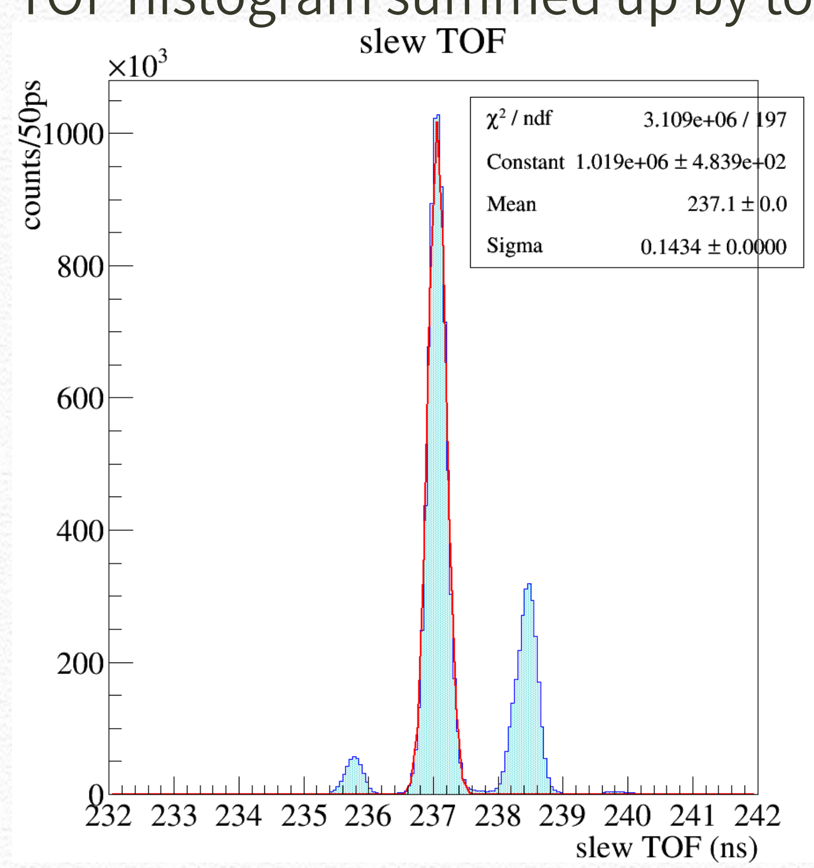


Plastic slew correction



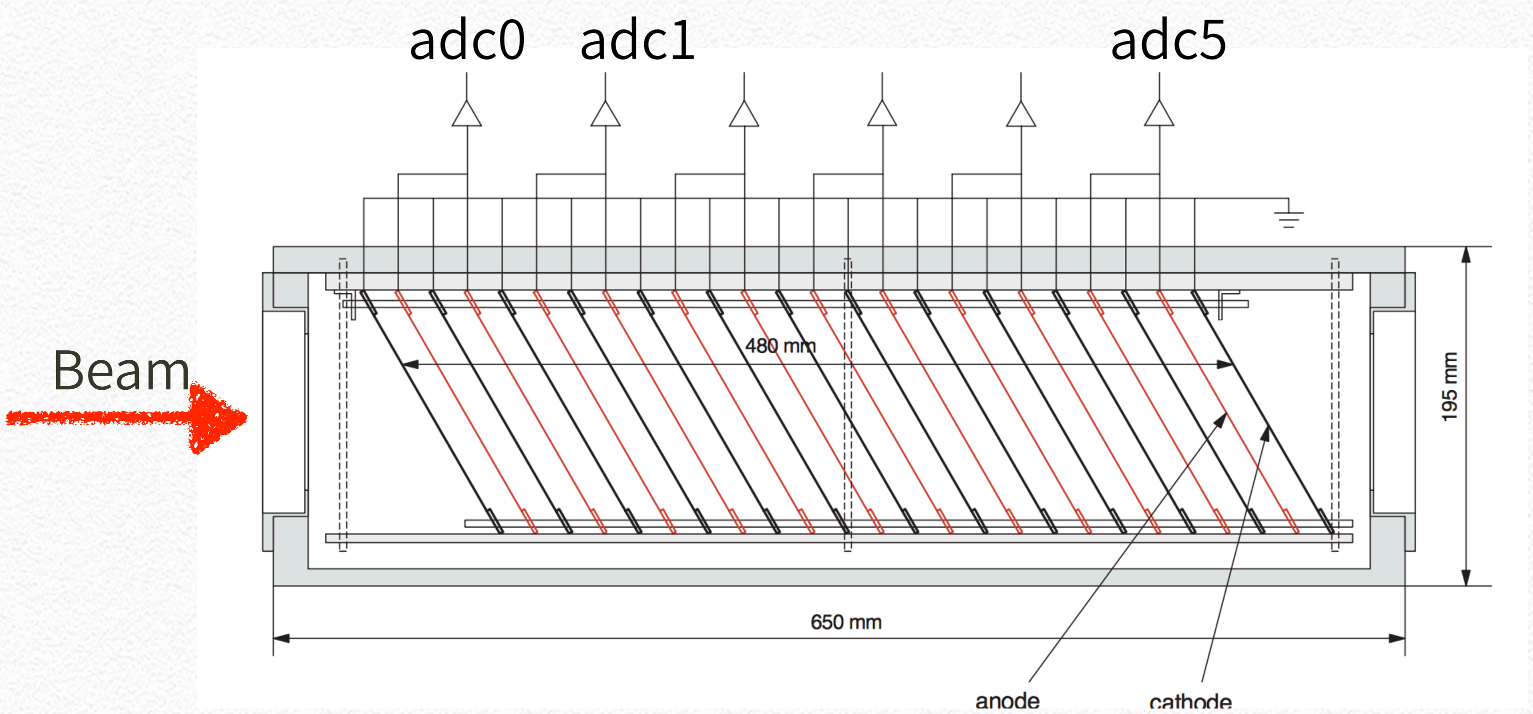
TOF histogram summed up by total run





Ion chamber calibration

- macros_2/anaICcalibration.C is used to calibrate each channel.
  - By using LISE++, energy deposit in each anode plane for each isotope is calculated, which is listed below.



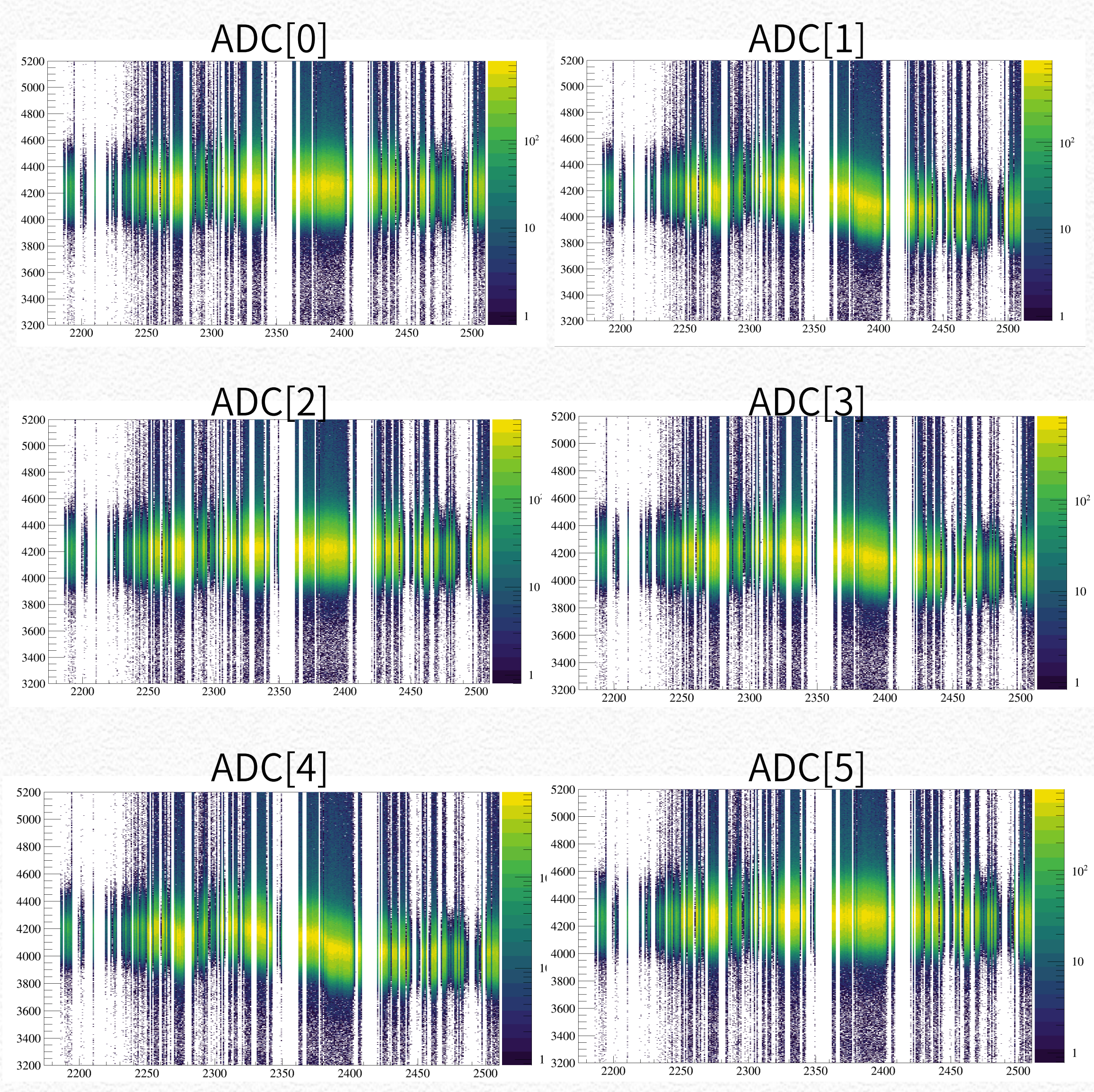
	ADC0	ADC1	ADC2	ADC3	ADC4	ADC5
108Sn	68.89	68.99	69.08	69.18	69.28	69.37
109Sn	69.48	69.58	69.65	69.75	69.84	69.93
107Sn	68.34	68.42	68.5	68.59	68.68	68.77
107In	66.78	66.86	66.96	67.05	67.12	67.22
106In	66.2	66.29	66.38	66.48	66.56	66.68
110Sb	71.61	71.72	71.81	71.92	72.02	72.12
109Sb	71.07	71.16	71.24	71.33	71.43	71.52

	ADC0	ADC1	ADC2	ADC3	ADC4	ADC5
112Sn	68.72	68.82	68.91	69	69.09	69.18
111Sn	68.2	68.28	68.36	68.45	68.52	68.6
110In	66.08	66.16	66.26	66.34	66.43	66.52
111In	66.65	66.74	66.82	66.89	66.98	67.05
113Sb	70.88	70.98	71.07	71.16	71.24	71.32
114Sb	71.44	71.51	71.6	71.7	71.8	71.9

Ion chamber calibration

- During the S022 experiment, anode plane gain of a half channels of ion chamber had been changing drastically run by run, whose reason is unclear.
- Problem is…
  - average for 6 channels varies by run and cannot be used to get isotope gate which is necessary for calibration of energy deposit.
    - Isotope cut condition needs to be set for individual runs.
    - For statistics, run will divided for several group by its gain.
  - behavior for 6 channels are individually different.
    - Grouping is necessary for each channel as well.

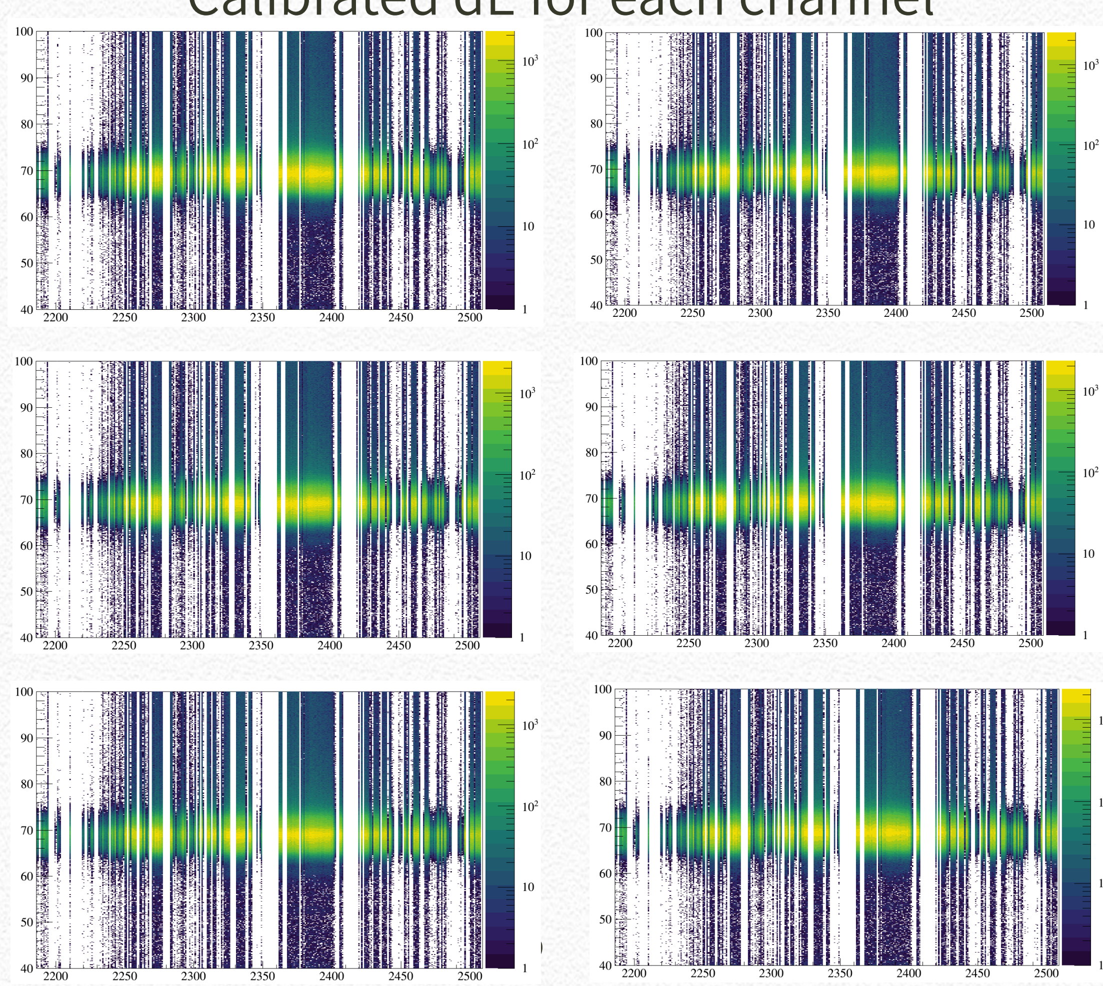
Raw data of IC ADC vs. run number



Ion chamber calibration

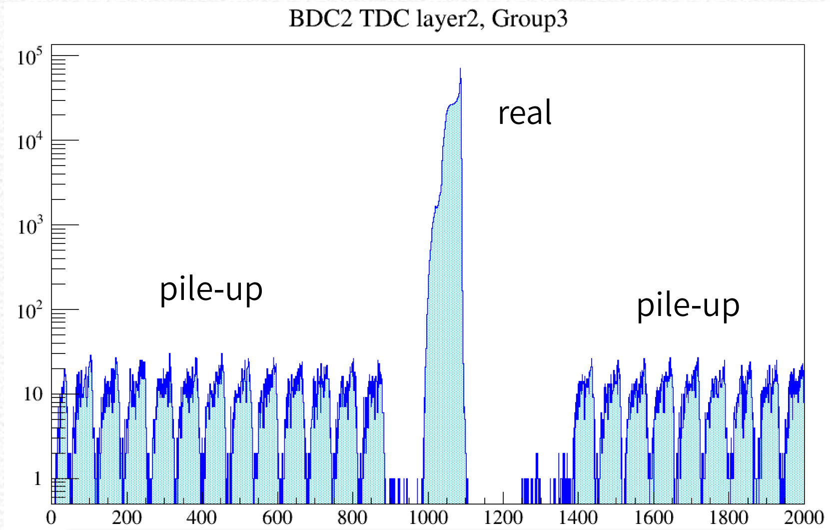
- macros_2/anaICcalibration.C works as following.
  - Make isotope gate by fZ(sqsum, beta) and A/Q, where fZ(sqsum, beta) is proportional to Z which is obtained from Bethe-Bloch formula:
  - Z = a*fZ(sqsum,beta) + b
  - and sqsum is a geometrical mean of 6 ADCs of IC.
    - Note that fZ will change by run because ADC varied. So, at first runs are divided by their sqsum gains and make run groups whose gains are close. After grouping, create isotope gates for each run group.
  - Each 6 channels have different behaviors by run, so another run grouping for each channel by their gains is also performed.
    - That grouping is for the sufficient statistics for the calibration.
  - For each channel, make ADC histograms for each isotope by using corresponding gate condition, which are being used for the comparison between ADC vs LISE++ calculated energy deposit.

Calibrated dE for each channel

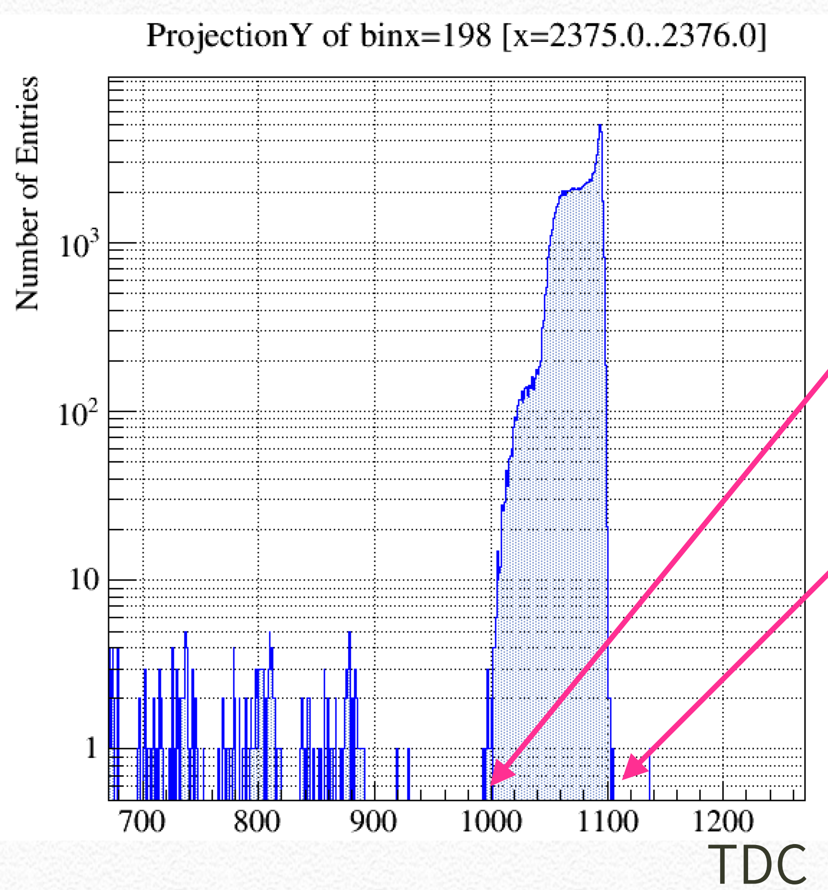


BDC

- In BDC analysis, ANAROOT needs TDC histogram of BDC and proper TDC range to calibrate TDC into drift length. Those are written in TArtCalibDCTrack.cc source code.



raw TDC histogram



minimum drift length

maximum drift length
= 2.5 mm (half of wire pitch)

The calibration factor is calculated in
TArtCalibDCTrack::SetTDCDistribution(h_tdc,layer) and,
TArtCalibDCTrack::SetTDCWindow(window_start, end) like…

$$\text{tdc2mm(tdc\_bin)} = \text{pitch}*0.5*\frac{\text{h\_tdc->Integral(window\_start, tdc\_bin)}}{\text{h\_tdc->Integral(window\_start, window\_end)}}$$

: calibration factor

window_start, window_stop: user set

Z and A/Q reconstruction

- Calculation of A/Q and Z from TOF37, tracking F3/F5/F7, F7IC.
- A/Q
  - By using measured position at focal plane, δ can be calculated.

$$x_{\mathrm{F7}} = (x|x)x_{\mathrm{F5}} + (x|a)a_{\mathrm{F5}} + (x|\delta)\delta_{57},$$

x_{F7}, x_{F5}, a_{F5}: From tracking information
(x|x), (x|a), (x|δ): Matrix element by COSY INFINITY

  - δ value and $B\rho_0$ from NMR probe, rigidity can be calculated.

$$B\rho_{57} = \left(1 + \frac{x_{\mathrm{F7}} - (x|x)x_{\mathrm{F5}} - (x|a)a_{\mathrm{F5}}}{(x|\delta)}\right) B\rho_{0;57}.$$

  - Using $B\rho_{35}$ and $B\rho_{57}$, and the assumption that charge state of beam doesn't change at F5, which is $(A/Q)_{35} = (A/Q)_{57}$, one A/Q value and β_{35}, β_{57} can be calculated.

$$\left.\begin{aligned} \mathrm{TOF} &= \frac{L_{35}}{\beta_{35}c} + \frac{L_{57}}{\beta_{57}c}, \\ \left(\frac{A}{Q}\right)_{35} &= \frac{B\rho_{35}}{\beta_{35}\gamma_{35}}\frac{c}{m_u}, \\ \left(\frac{A}{Q}\right)_{57} &= \frac{B\rho_{57}}{\beta_{57}\gamma_{57}}\frac{c}{m_u}, \end{aligned}\right\} \quad \frac{\beta_{35}\gamma_{35}}{\beta_{57}\gamma_{57}} = \frac{B\rho_{35}}{B\rho_{57}}.$$

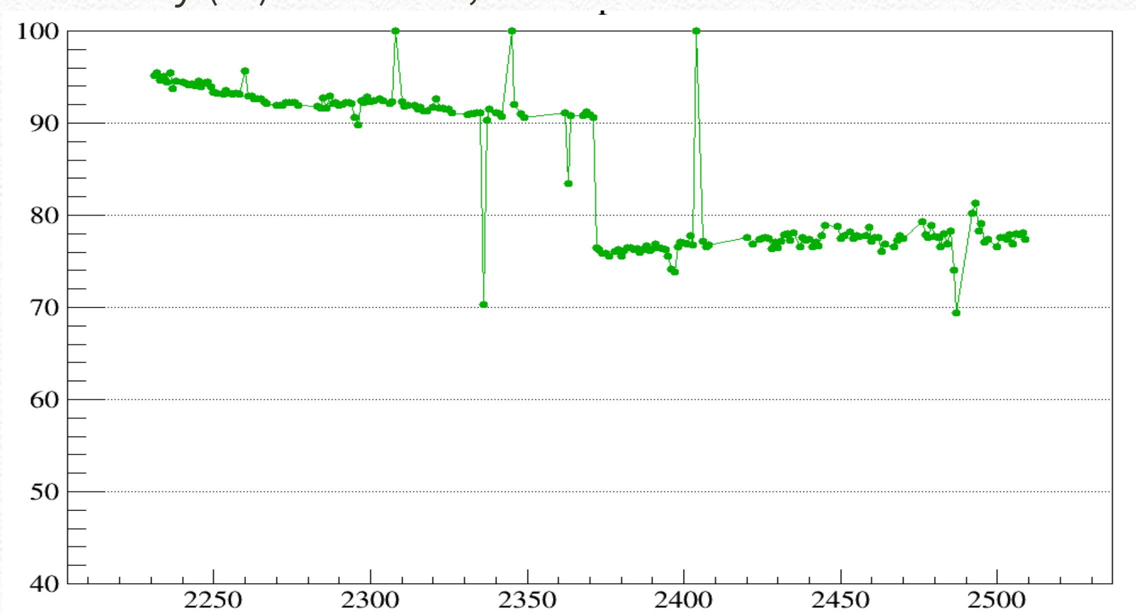
TOF37: measured   L35, L57: constant   Bρ35, Bρ57: calculated above
→ simultaneous equation for β35 and β57

- Z
  - By using calculated β57 and ΔE at F7IC together with Bethe-Bloch's empirical formula, Z can be calculated.

Beam reconstruction with limited information of focal plane tracking

- Because of drop of tracking efficiency in a certain focal plane, efficiency on conventional reconstruction method got large influence of about 15 % drop.

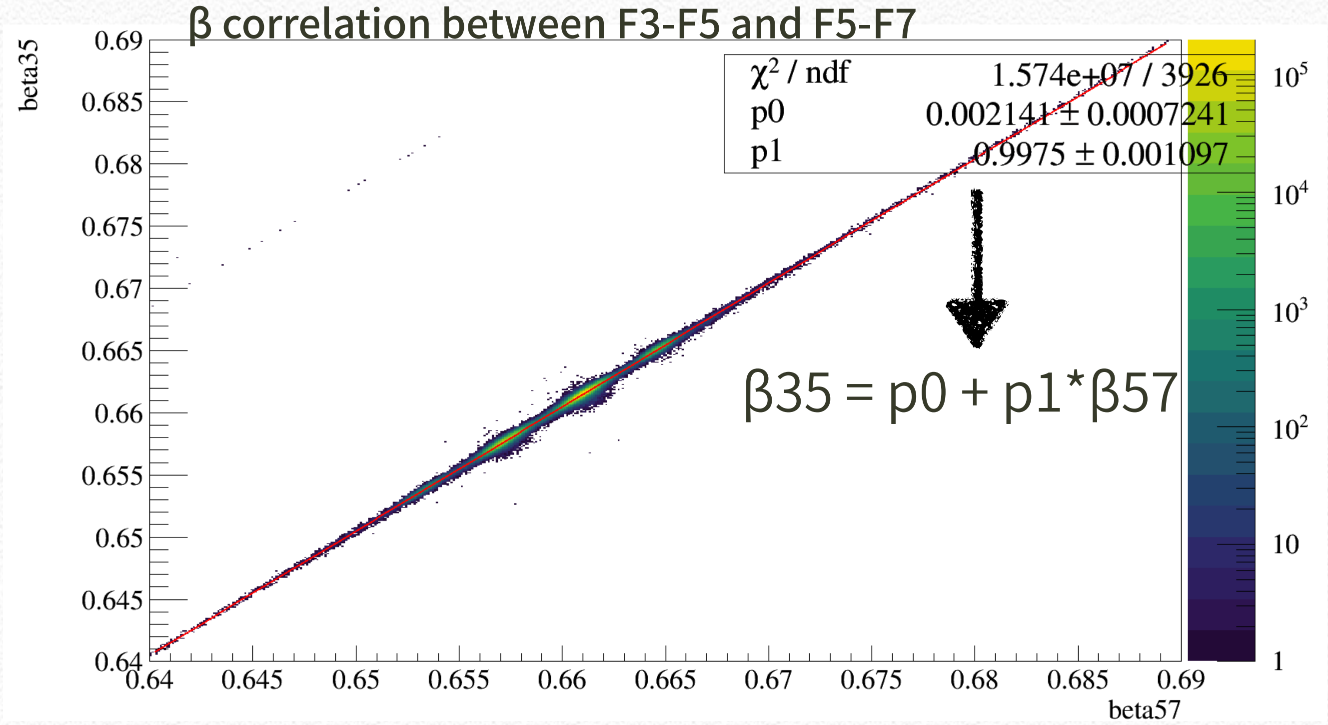
efficiency (%) vs. runNo, with conventional reconstruction



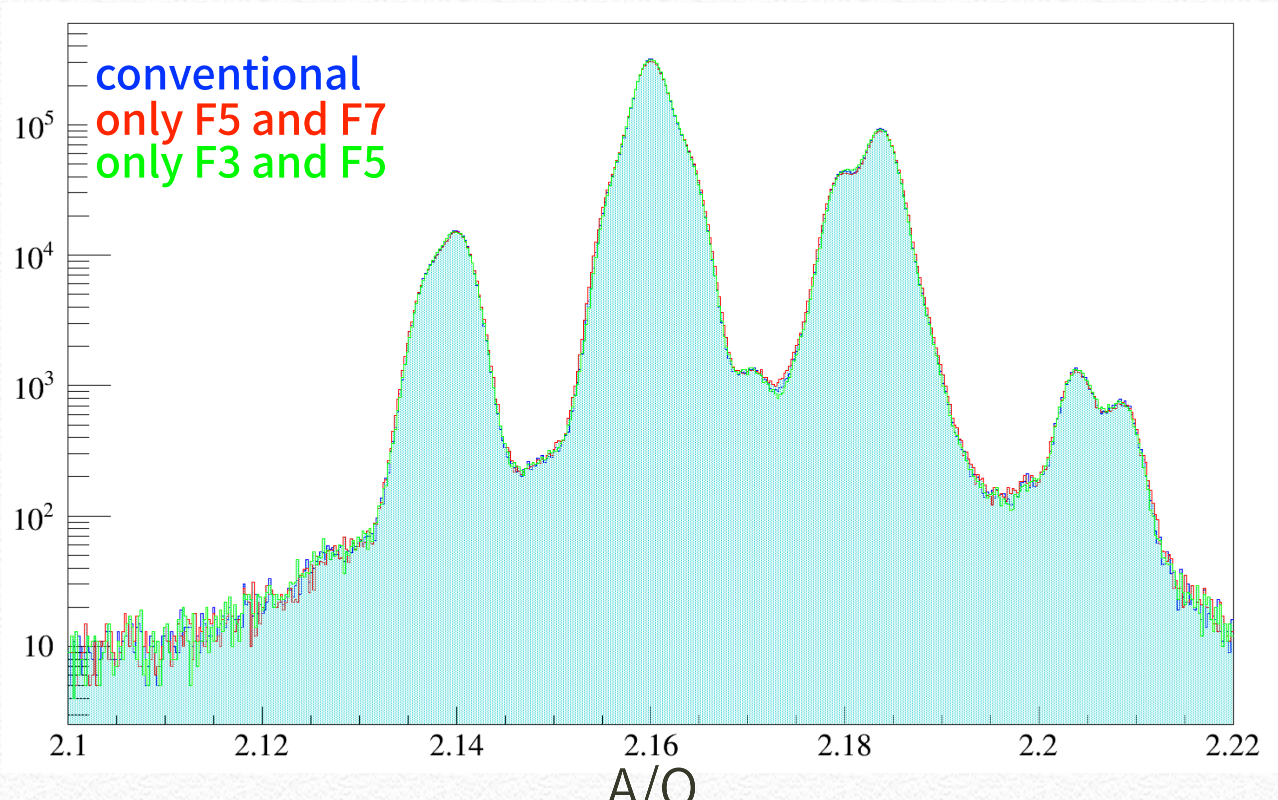
- In case of F3 tracking failure, reconstruction without that information is tried. In this case, Bρ35 cannot be obtained.
  - TOF37 = L35/β35c + L57/β57c
  - Here, as material at F5 is small, that is only PPACs, β35 is assumed not to change so much and to be proportional to β57.
  - With this assumption, β35 = a*β57 +b, we can calculate β57 and A/Q as well with one focal plane combination.
    - TOF37 = L35/(a*β57+b)c + L57/β57c
  - So, calibration factor for β35 is necessary in this procedure.
- The same procedure using F3 and F5 tracking information when F7 PPAC dead is tried too, which looks to be unavailable.
  - Please see two page next.

Beam reconstruction with limited information of focal plane tracking

- Correlation between β35 and β57 using "good" data, which is the three focal planes tracking are alive.



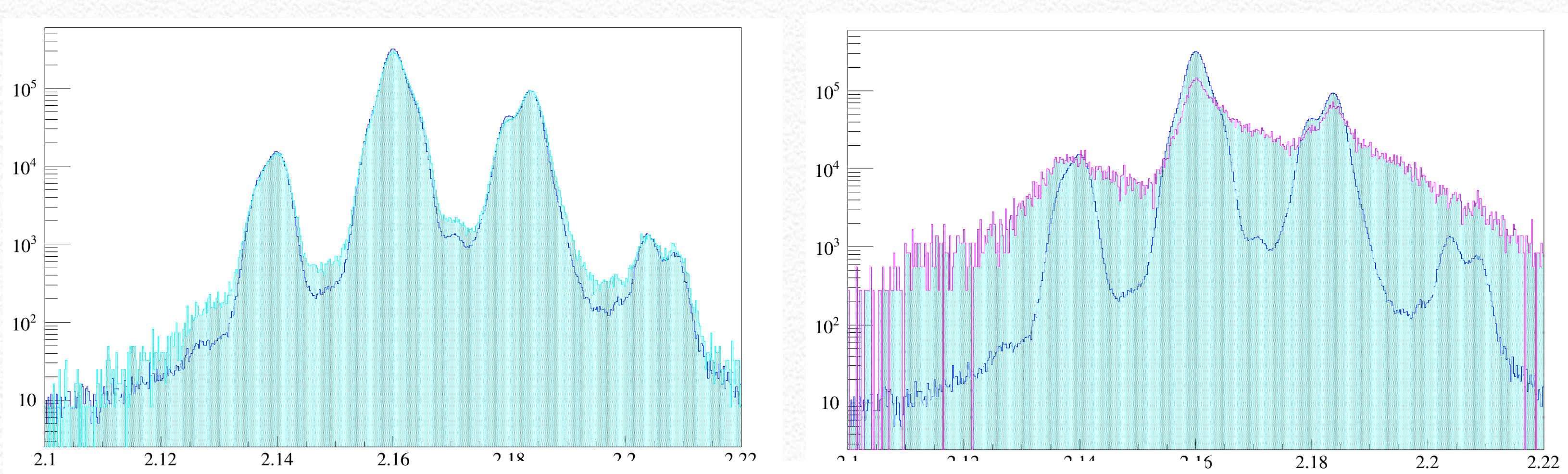
- By using the same data set (three focal plane tracking is available), correlation of three kinds of A/Q, one is obtained from conventional reconstruction method and the others are obtained by using F5 and F7 tracking with assumed beta35(=p0+p1*β57) or using F3 and F5 with assumed β57, is also checked.



The another A/Q reconstruction using only one focal planes combination and calibrated beta looks to be fine if the "good" data is used.

Beam reconstruction with limited information of focal plane tracking

- Previous figure is made by using good data whose three focal plane tracking was successful to see how much difference on beta or A/Q appears by different beta calculation procedure.
- How about data which actually lost one focal plane tracking information ?
  - Below two figures compare A/Q distributions obtained from conventional reconstruction method and that from one combination of focal planes(F5, F7) with calibrated beta35 or beta57(with F3, F5) respectively.
  - Histograms are normalized by its number of events.



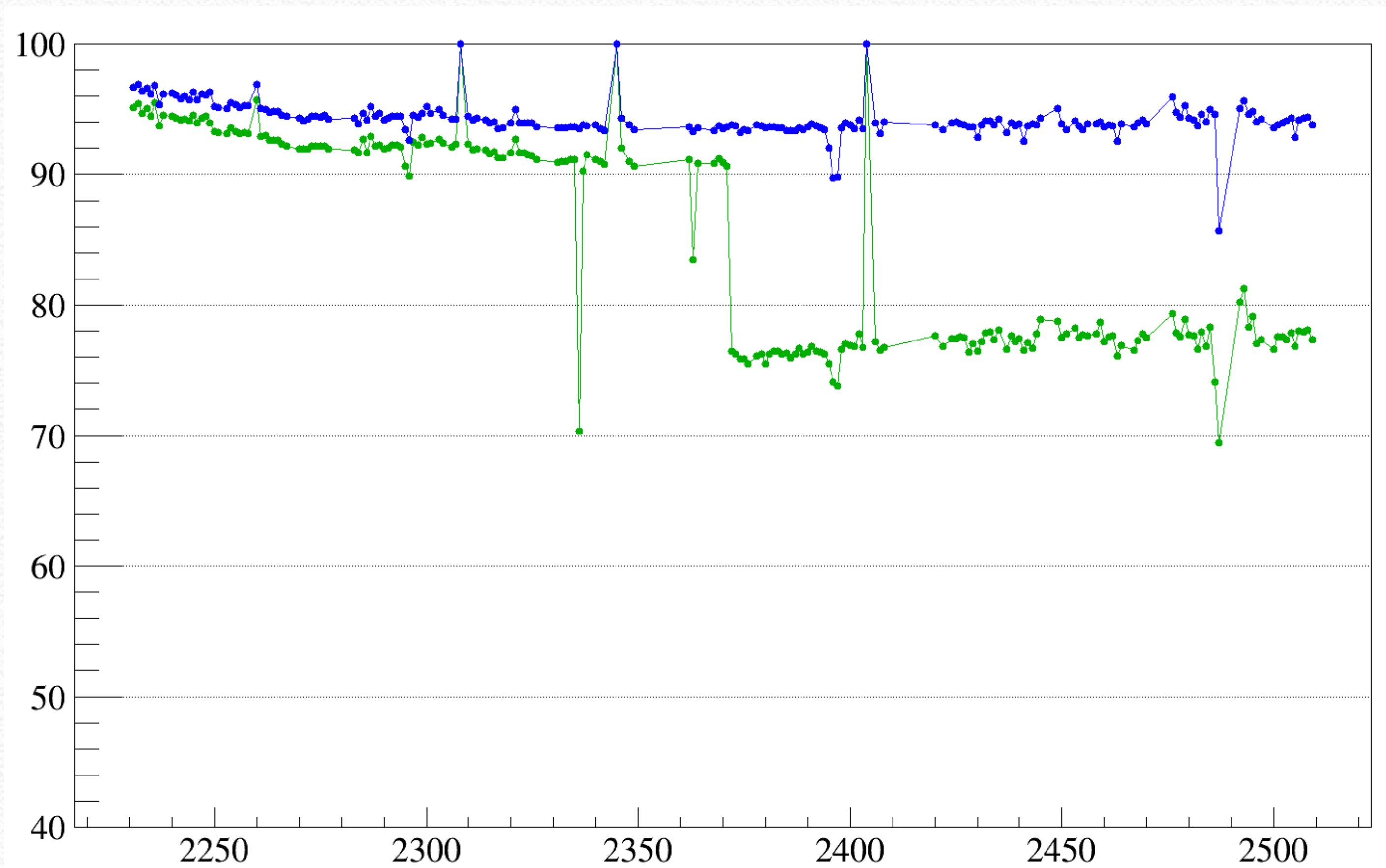
conventional
only F5 and F7 used when F3 was dead (normalized by event)
only F3 and F5 used when F7 was dead (normalized by event)

- Reco. from F3 and F5(magenta) looks to have a problem compared to conventional one, weak peak structure…
- So this method is used only when F3 is dead and the other two focal plane are available.

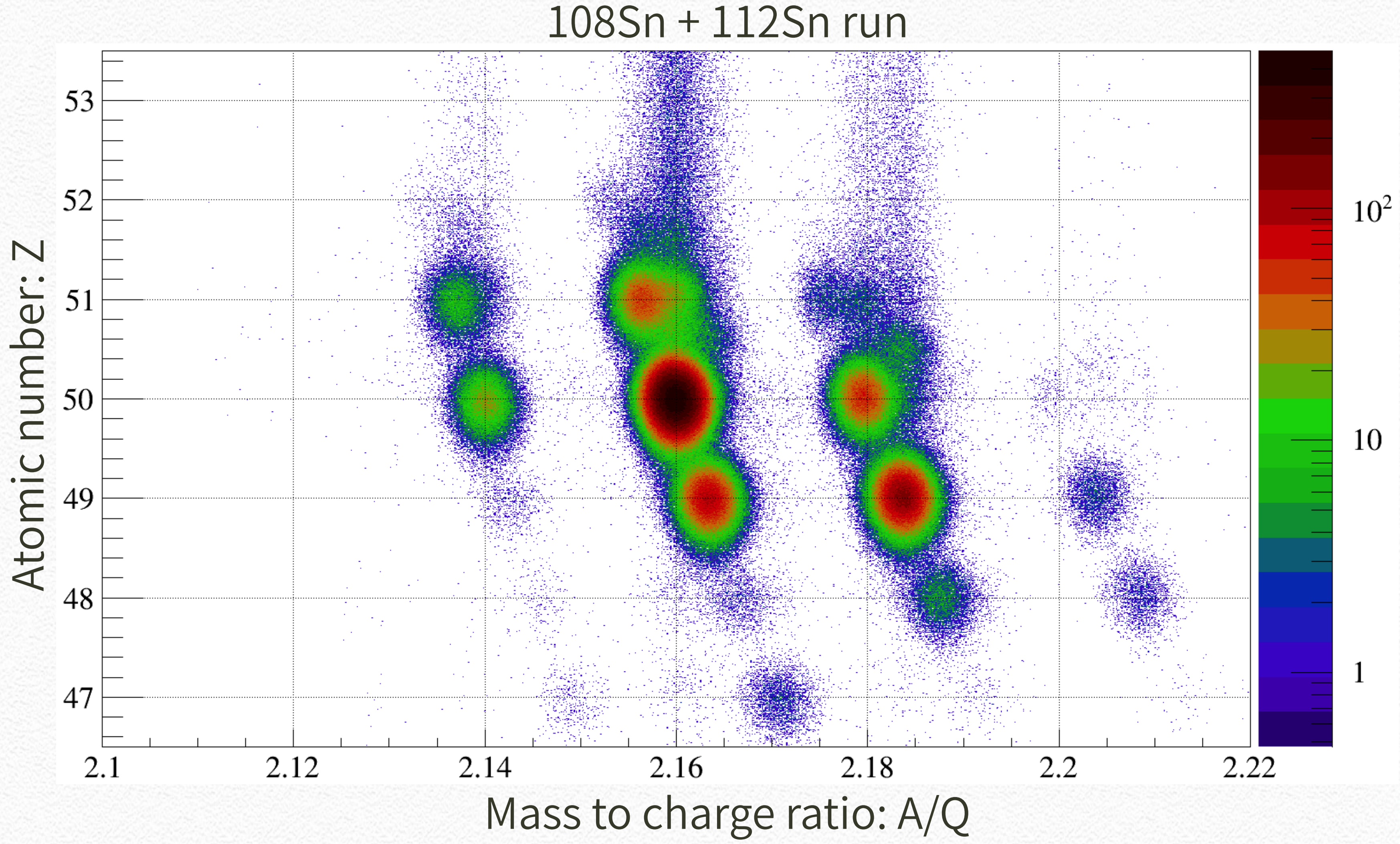
Beam reconstruction with limited information of focal plane tracking

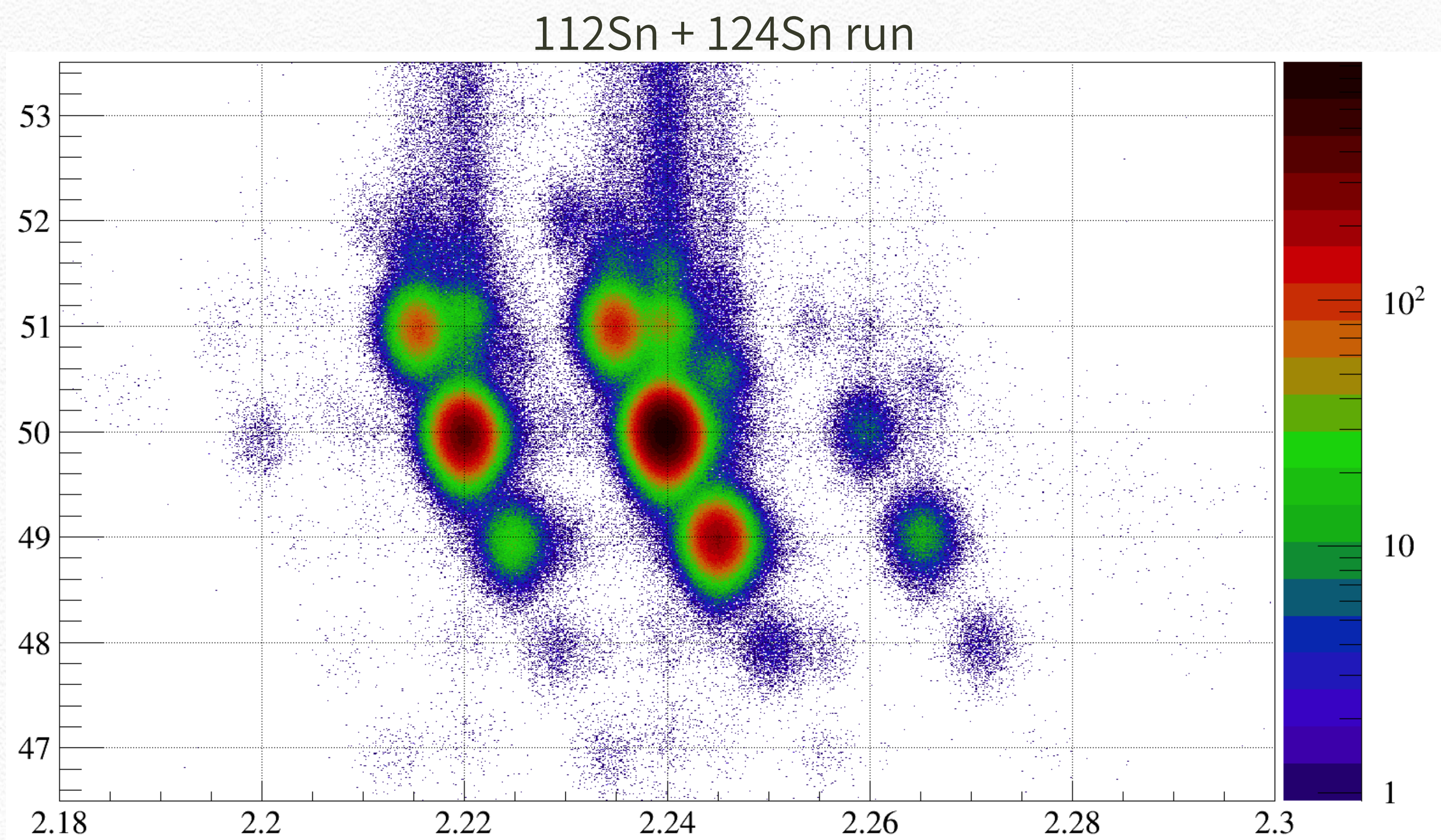
- After implementing the beam recovery procedure that works only when F3 tracking information cannot be used and F5 and F7 are available…

efficiency (%) vs. runNo, with conventional(F3F5F7)
and additional method(F3F5F7+F5F7) of reconstruction



PID plot


108Sn + 112Sn run
Atomic number: Z
Mass to charge ratio: A/Q
53
52
51
50
49
48
47
2.1
2.12
2.14
2.16
2.18
2.2
2.22
10^2
10
1


112Sn + 124Sn run
53
52
51
50
49
48
47
2.18
2.2
2.22
2.24
2.26
2.28
2.3
10^2
10
1

Background

- pile-up from PPAC MHTDC
- plastic correlation: hit position from QDC and TDC
- IC anode correlation: reaction in-between anodes.
- F13 plastic QDC correlation: reaction at F13-1 plastic.