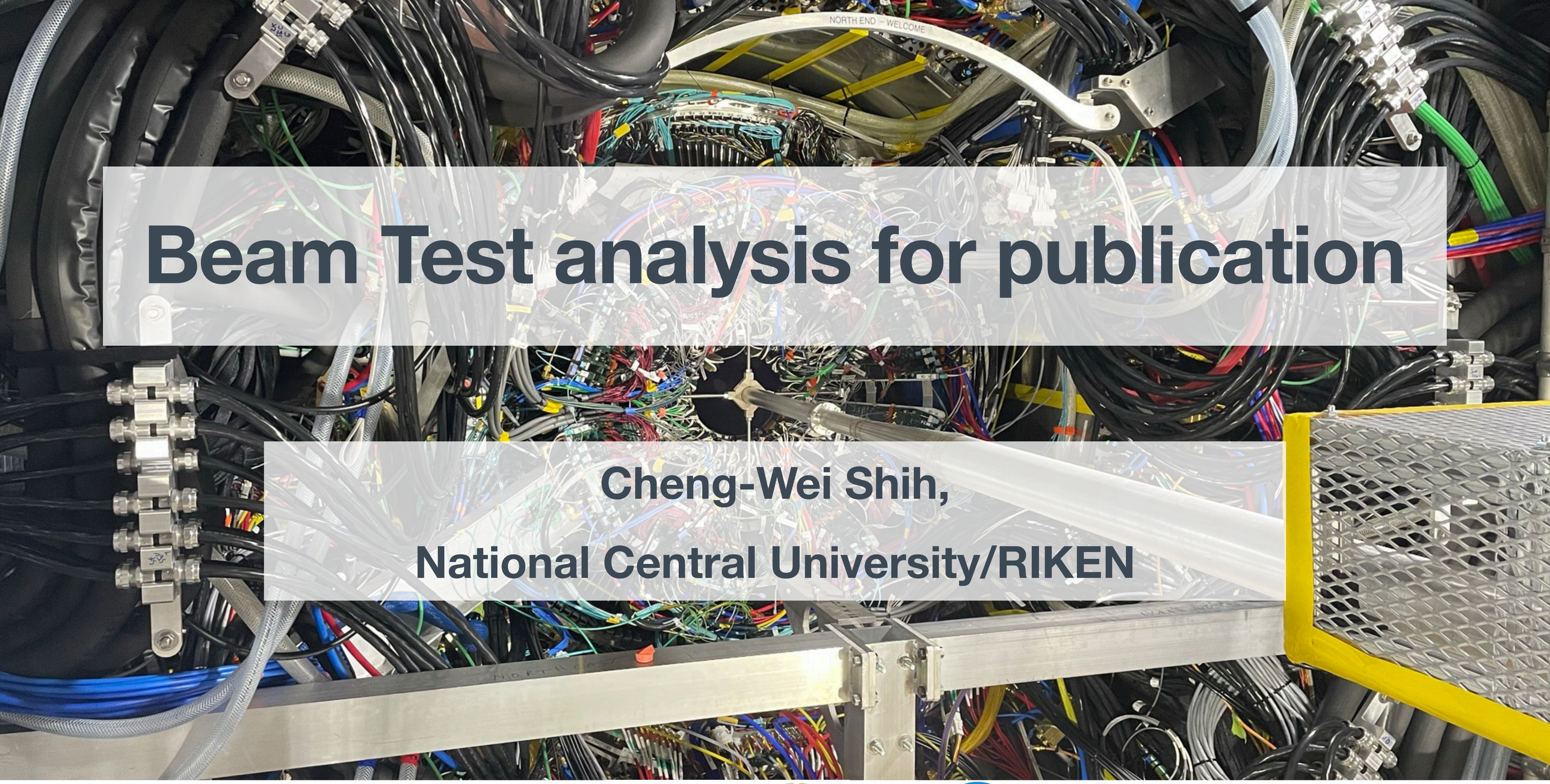

Beam Test analysis for publication

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National Central University/RIKEN

May 16th, 2025
INTT meeting

sPHENIX INTT sPHENIX 國立中央大學 National Central University RIKEN

Comments from the presentation last time

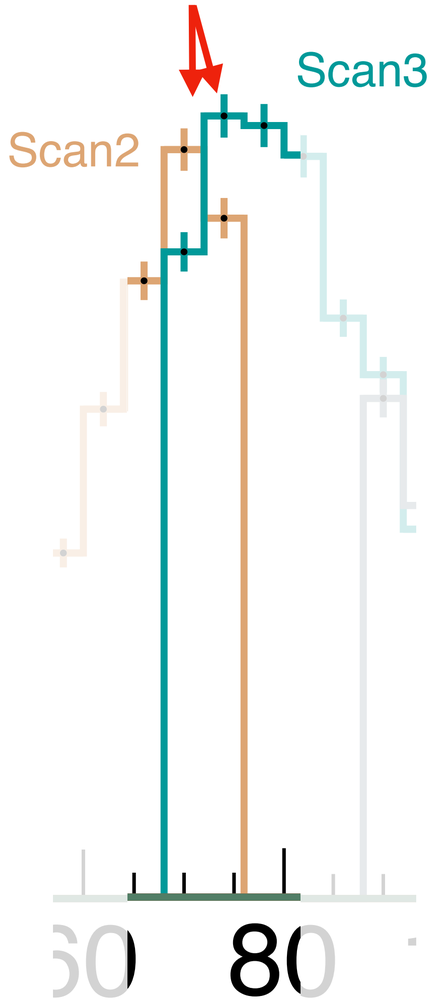
- Energy deposit distribution (DAC Scan)
  - Genki: are the distribution shapes of U9, U10, and U11 the same?
  - Takashi: what is the proper way to combine distributions?

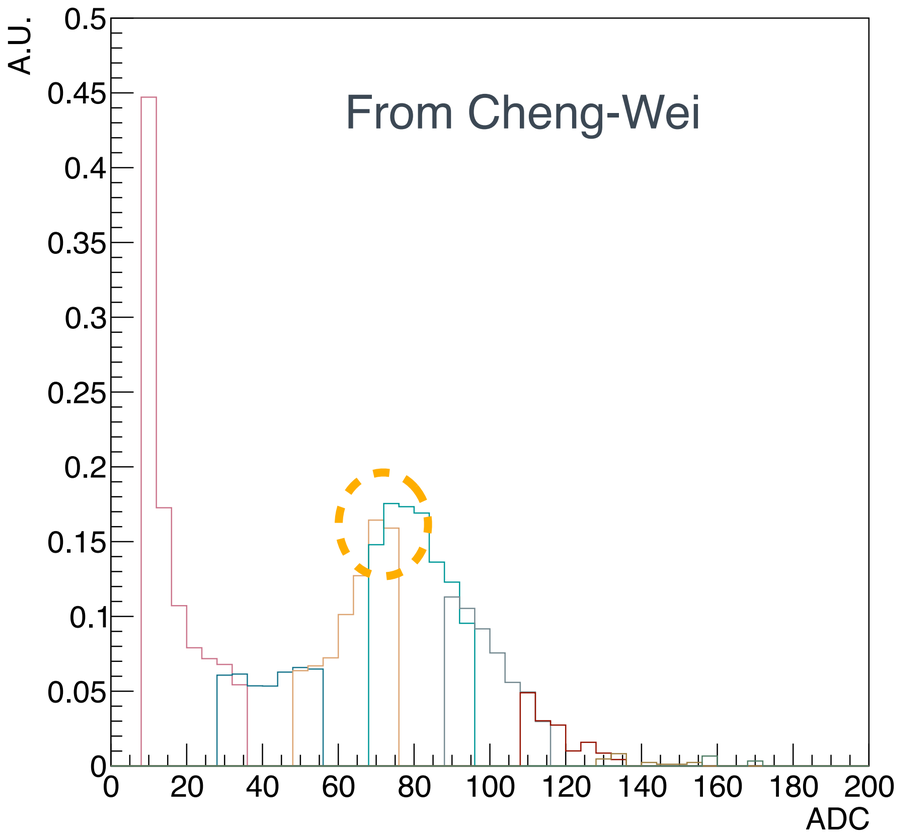
- Residual distribution
  - Genki: in L1L0 slope distributions, why there are dips in distributions?

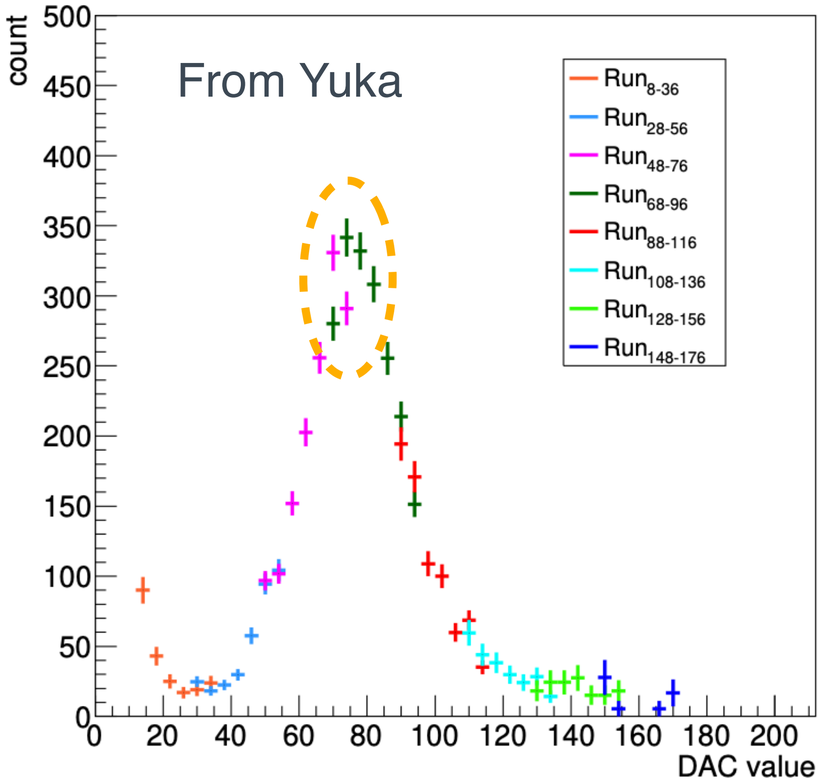
- Hit detection efficiency:
  - Itaru: the simulation should be used to determine the proper residual cut

Reminder, DAC Scan - in combining bins

The disagreement in the overlap bins between Scan2 and Scan3, observed in the past as well

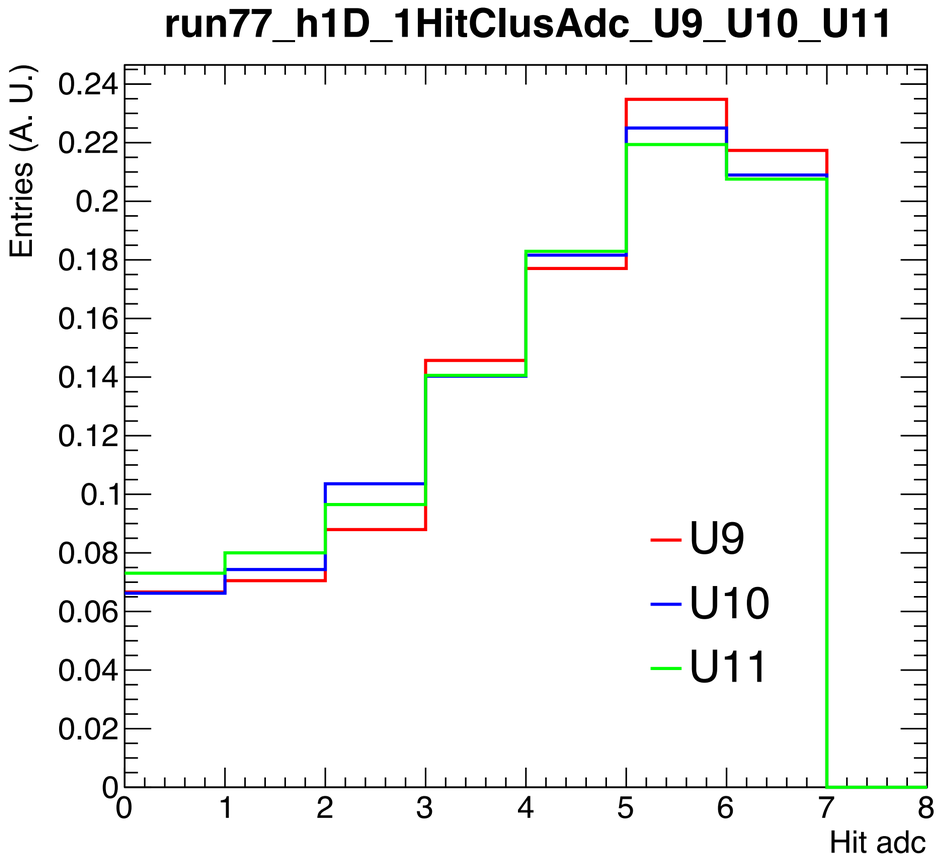






Energy deposit distribution (DAC Scan)

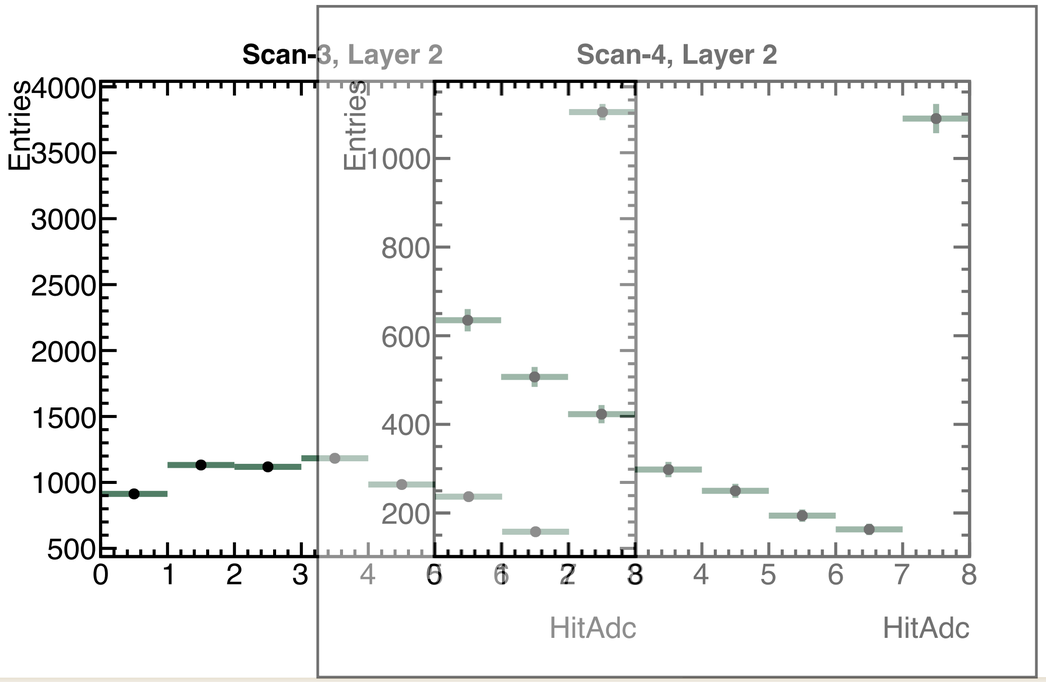
- Energy deposit distribution (DAC Scan)
  - Genki: are the distribution shapes of U9, U10, and U11 the same?



They all behavior similarly

Energy deposit distribution (DAC Scan)

- Takashi: what is the proper way to combine distributions?
  - Suggestion from Takashi: including overflow bin to do the distribution matching
- Trial:
  - Scan3 as reference, introducing scales to adjacent scans to match the distributions, sequentially
  - Example: scale applied on Scan4 = $(\mathrm{Size}_{\mathrm{bin}_{6\mathrm{th}}}^{\mathrm{Scan3}} + \mathrm{Size}_{\mathrm{bin}_{7\mathrm{th}}}^{\mathrm{Scan3}} + \mathrm{Size}_{\mathrm{bin}_{8\mathrm{th}}}^{\mathrm{Scan3}})/(\mathrm{Integral\ of\ Scan4})$
  - $(Size_{bin_{6th}}^{Scan3} + Size_{bin_{7th}}^{Scan3} + Size_{bin_{8th}}^{Scan3})$: everything above adc 88
  - $(\mathrm{Integral\ of\ Scan4})$: everything above adc 88

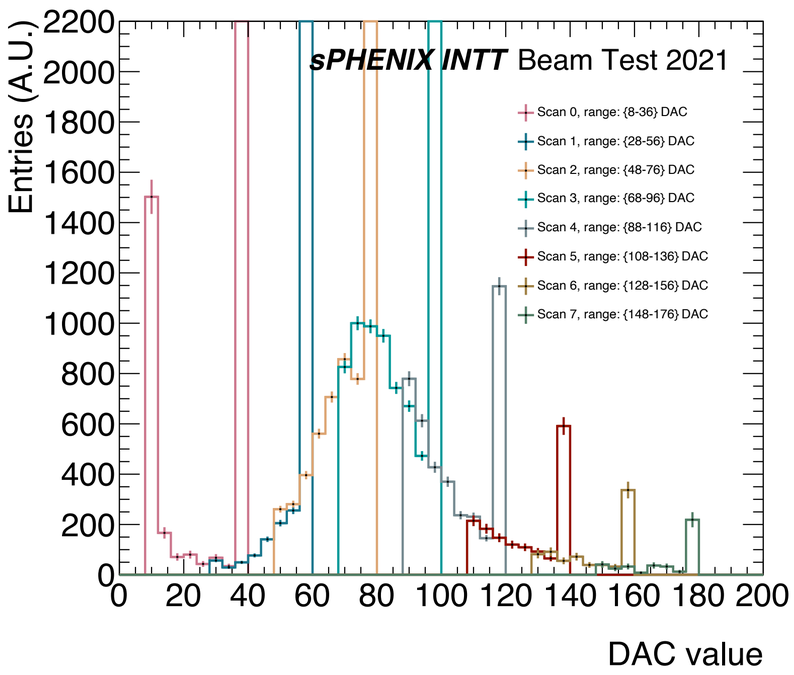


Energy deposit distribution (DAC Scan)

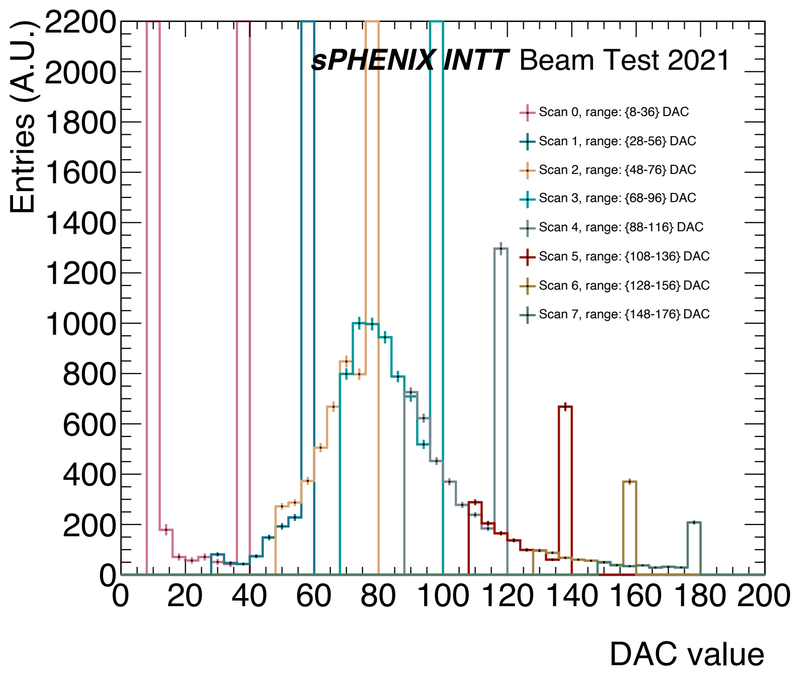
- Takashi: what is the proper way to combine distributions?
  - Suggestion from Takashi: including overflow bin to do the distribution matching

The overflow bins are included in calculating the scaling factors

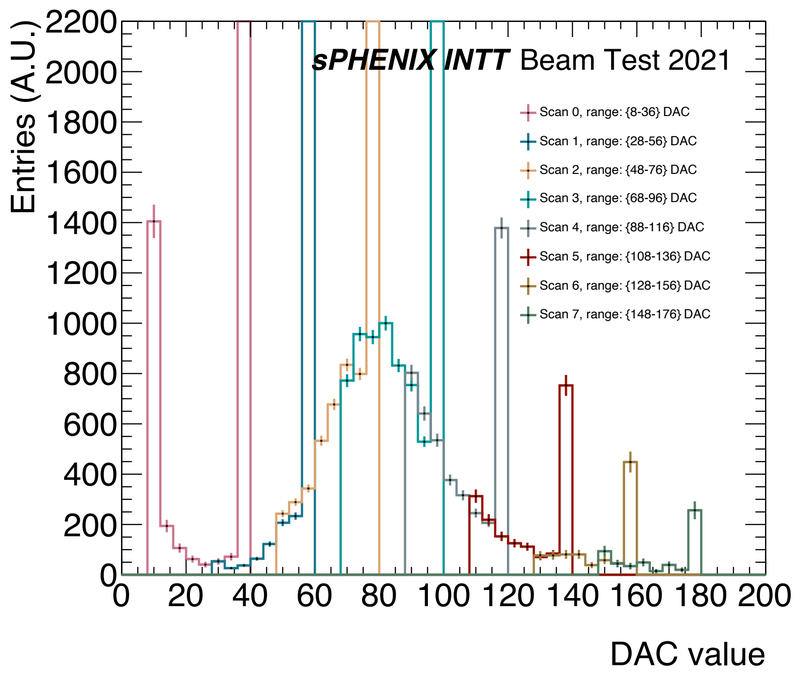
L0



L1



L2

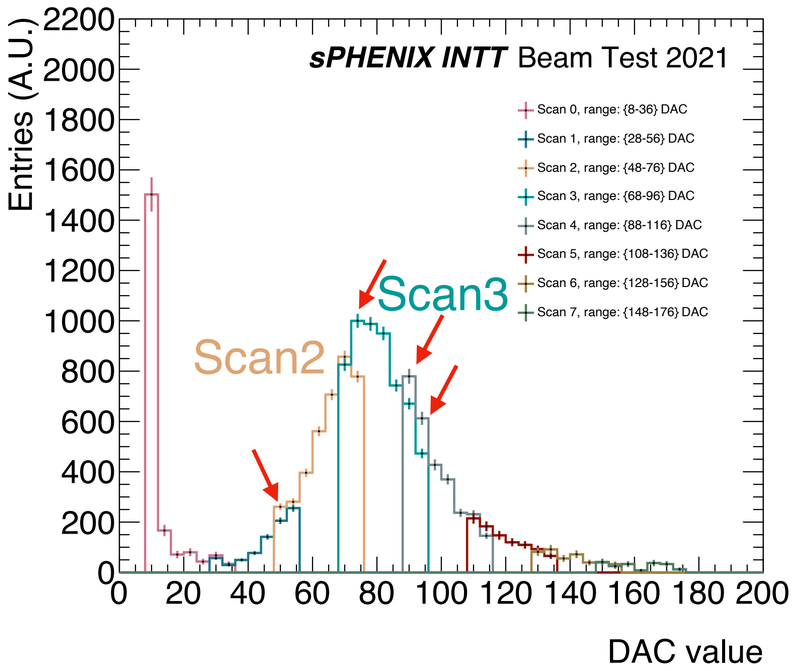


Energy deposit distribution (DAC Scan)

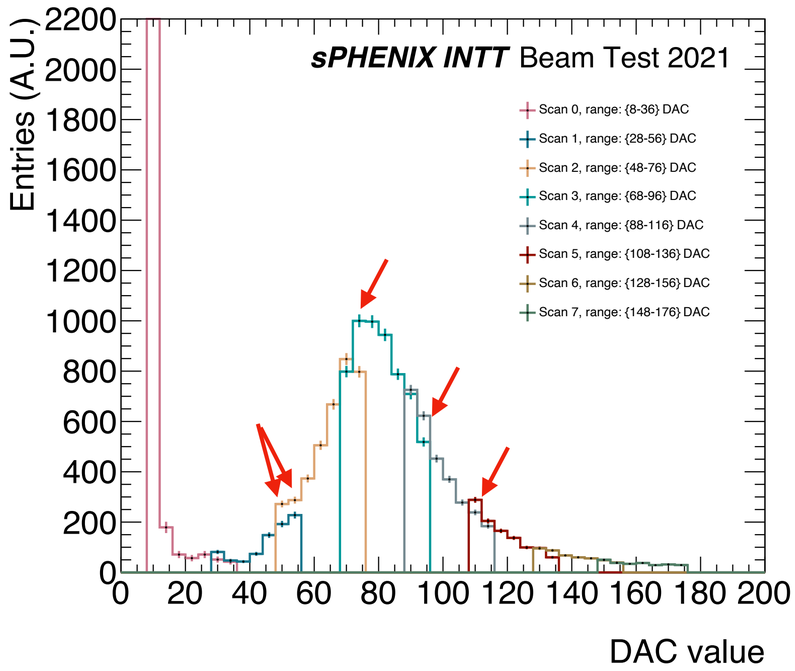
- Takashi: what is the proper way to combine distributions?
  - Suggestion from Takashi: including overflow bin to do the distribution matching

Remove 8th bins for better visibility

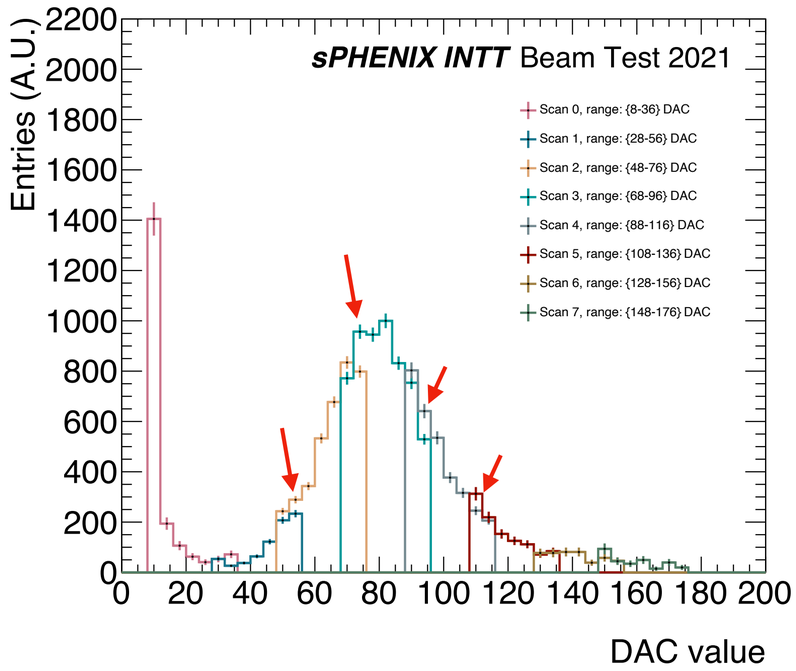
L0



L1



L2



Seems to have more bins with disagreements

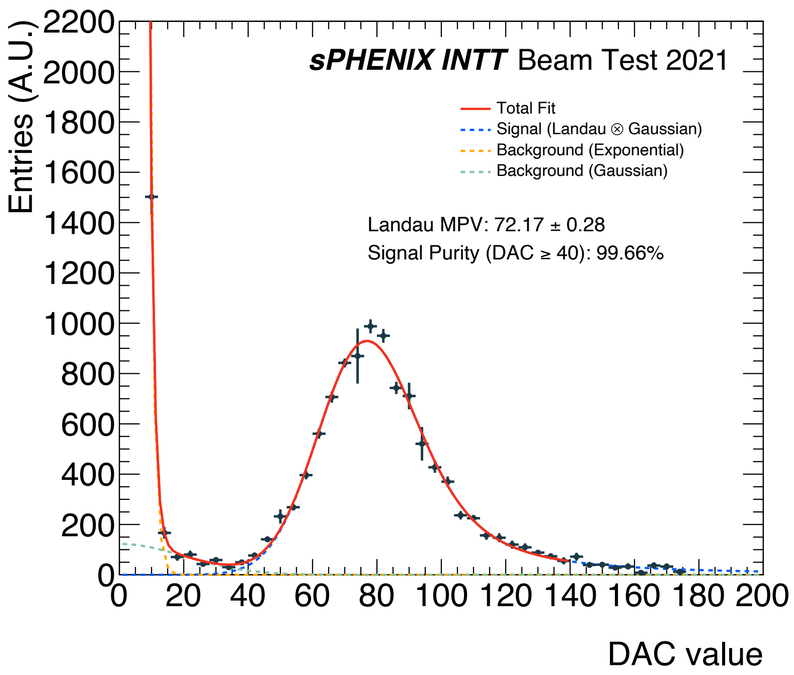
Between Scan2 and Scan3, the left overlapped bin agree within their statistical uncertainties → similar to just using left overlapped bins to do the mathcing

Energy deposit distribution (DAC Scan)

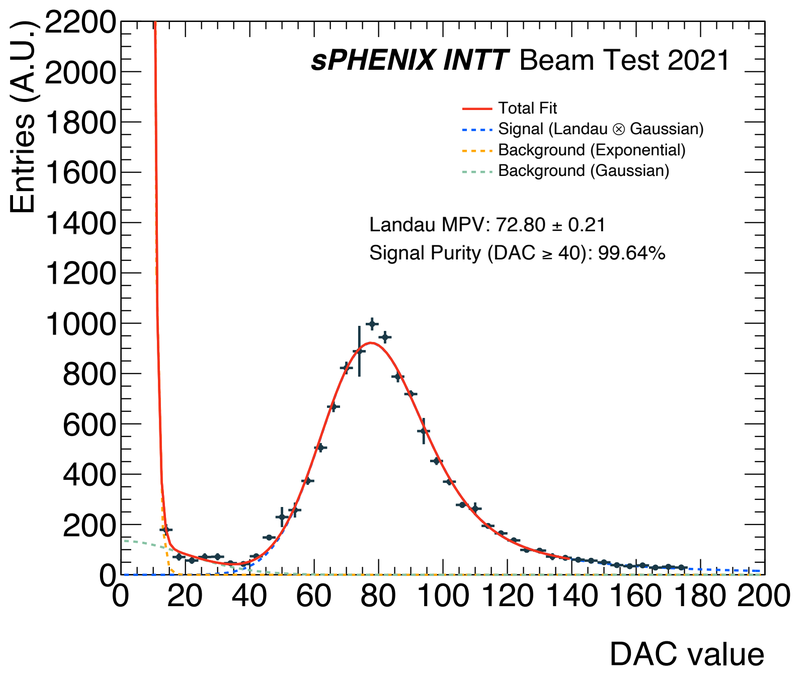
- Takashi: what is the proper way to combine distributions?
  - Suggestion from Takashi: including overflow bin to do the distribution matching

Using same way to combine overlapped bins (weighted average with systematic uncertainty inflation) and fitting

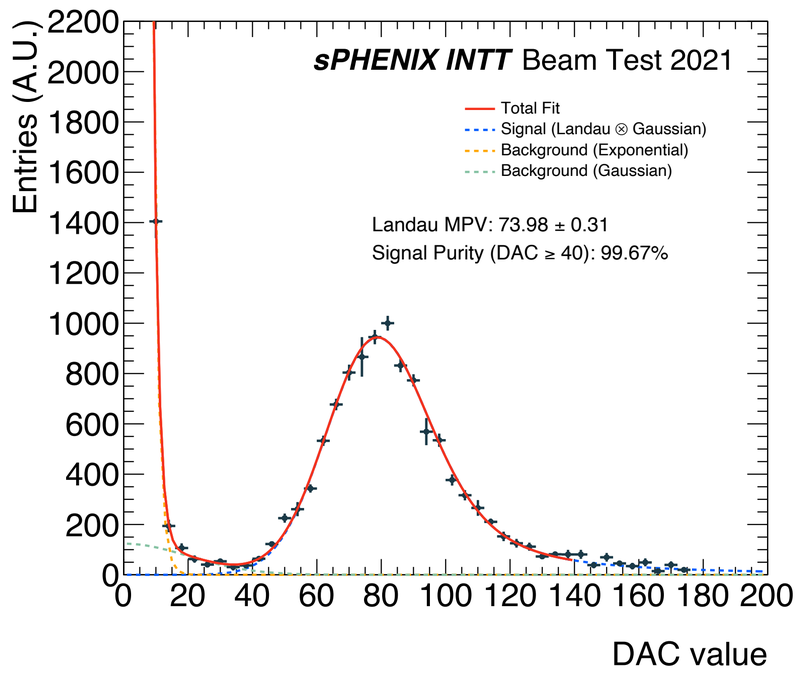
L0



L1



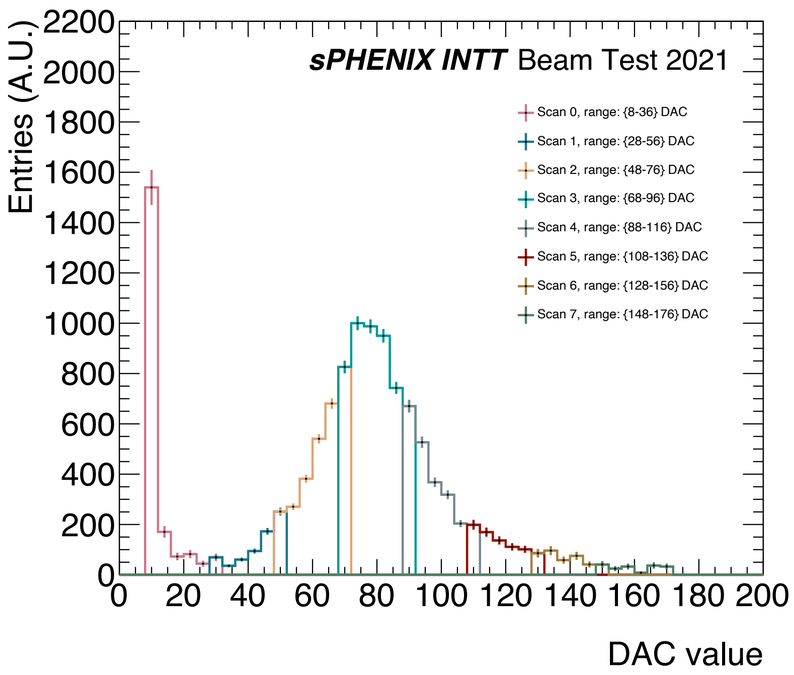
L2



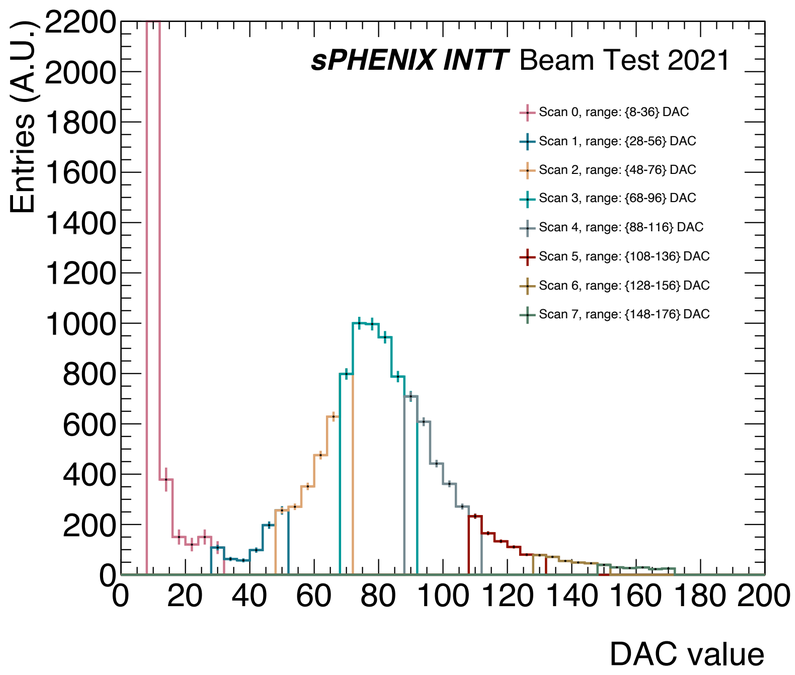
Energy deposit distribution (DAC Scan)

- Another approach:
  - Only use one bin for all distribution matchings
  - The overlapped bins are therefore on the top of each other

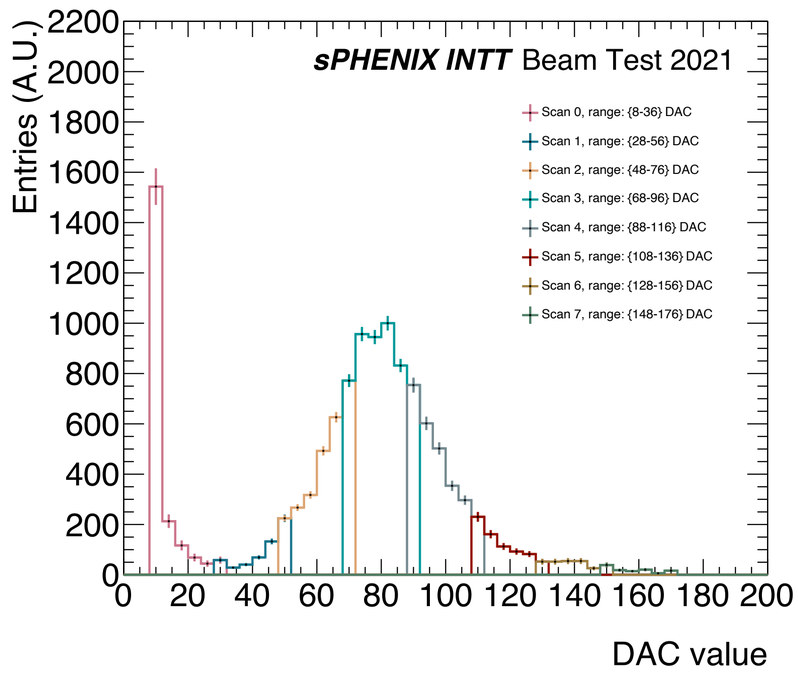
L0



L1

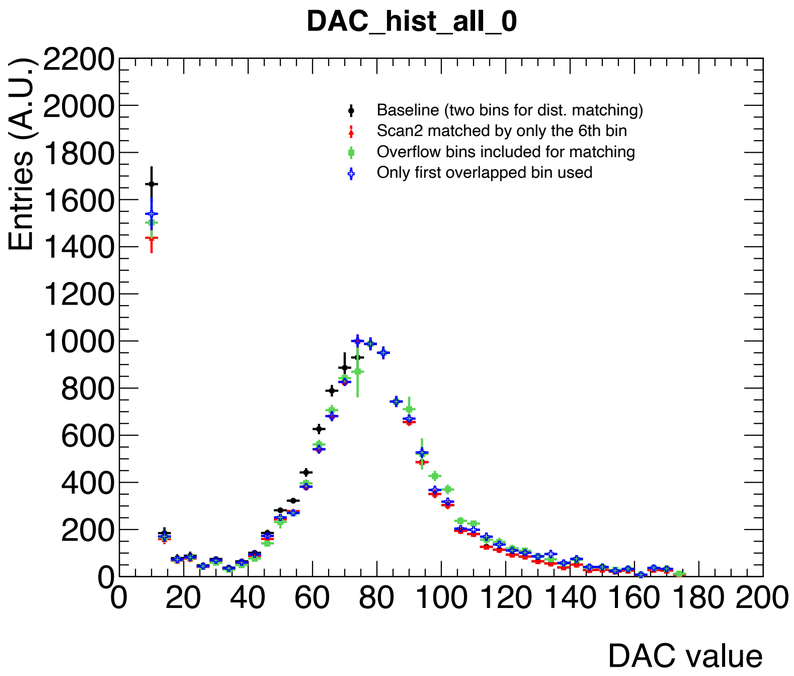


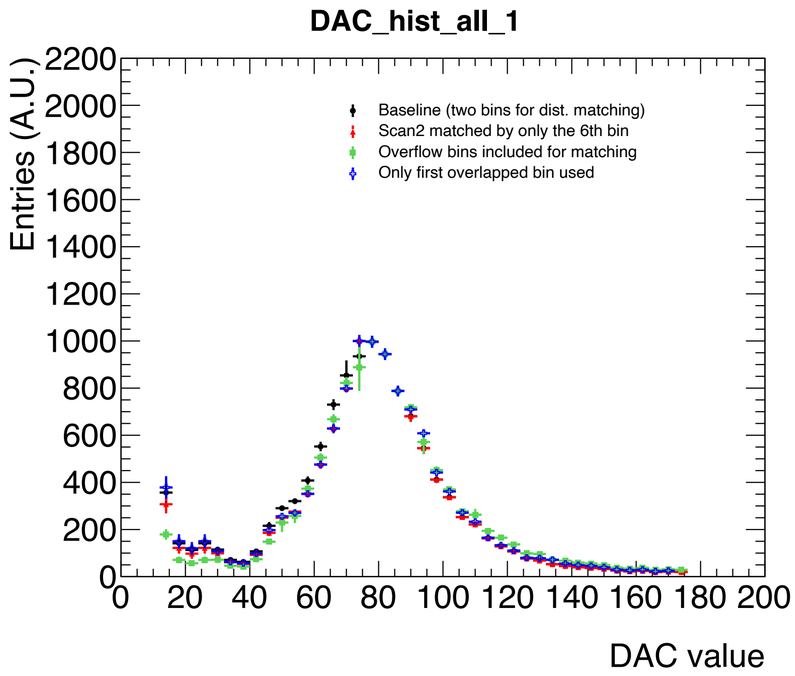
L2

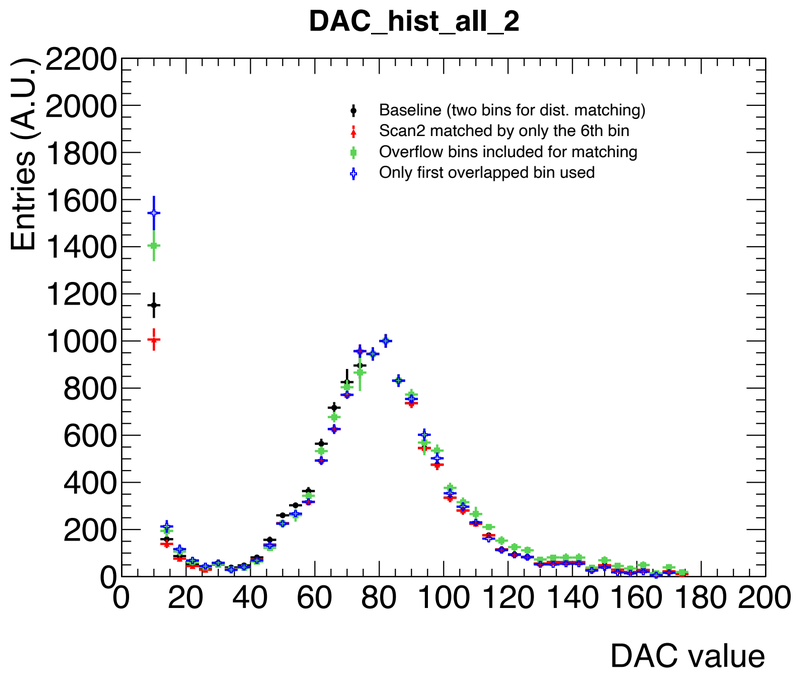


Energy deposit distribution (DAC Scan)

Comparing 4 matching methods





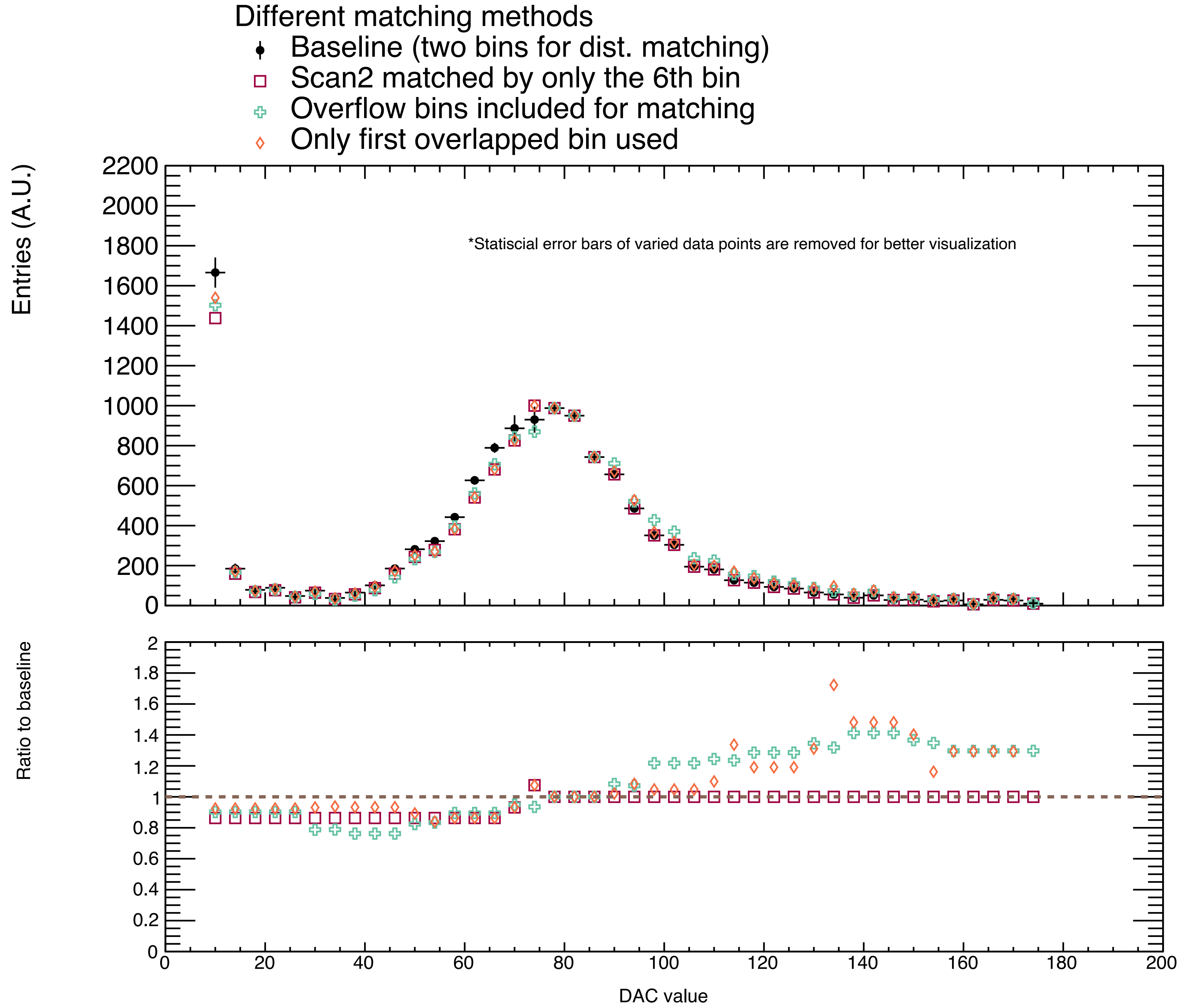


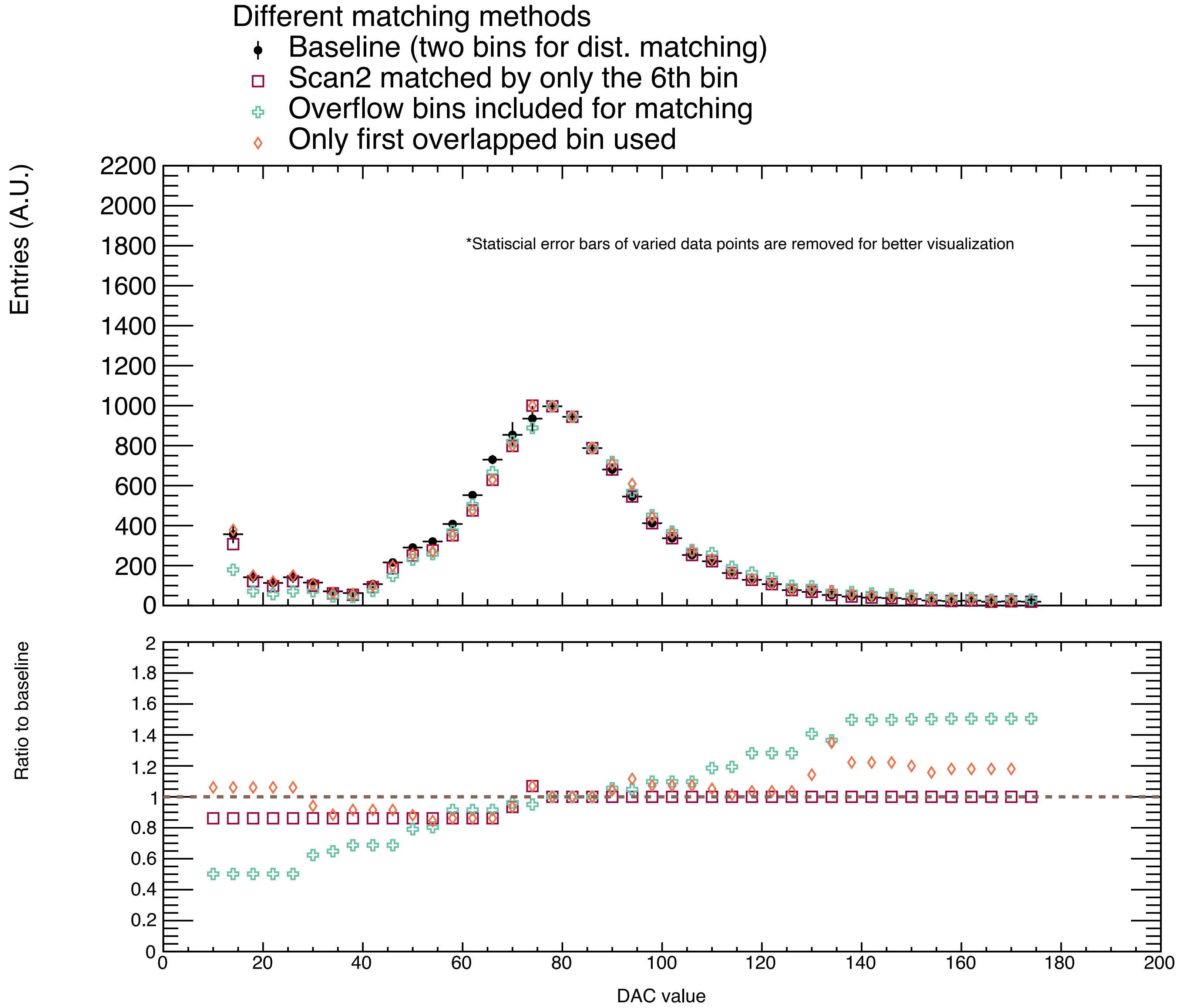
(personal opinion)

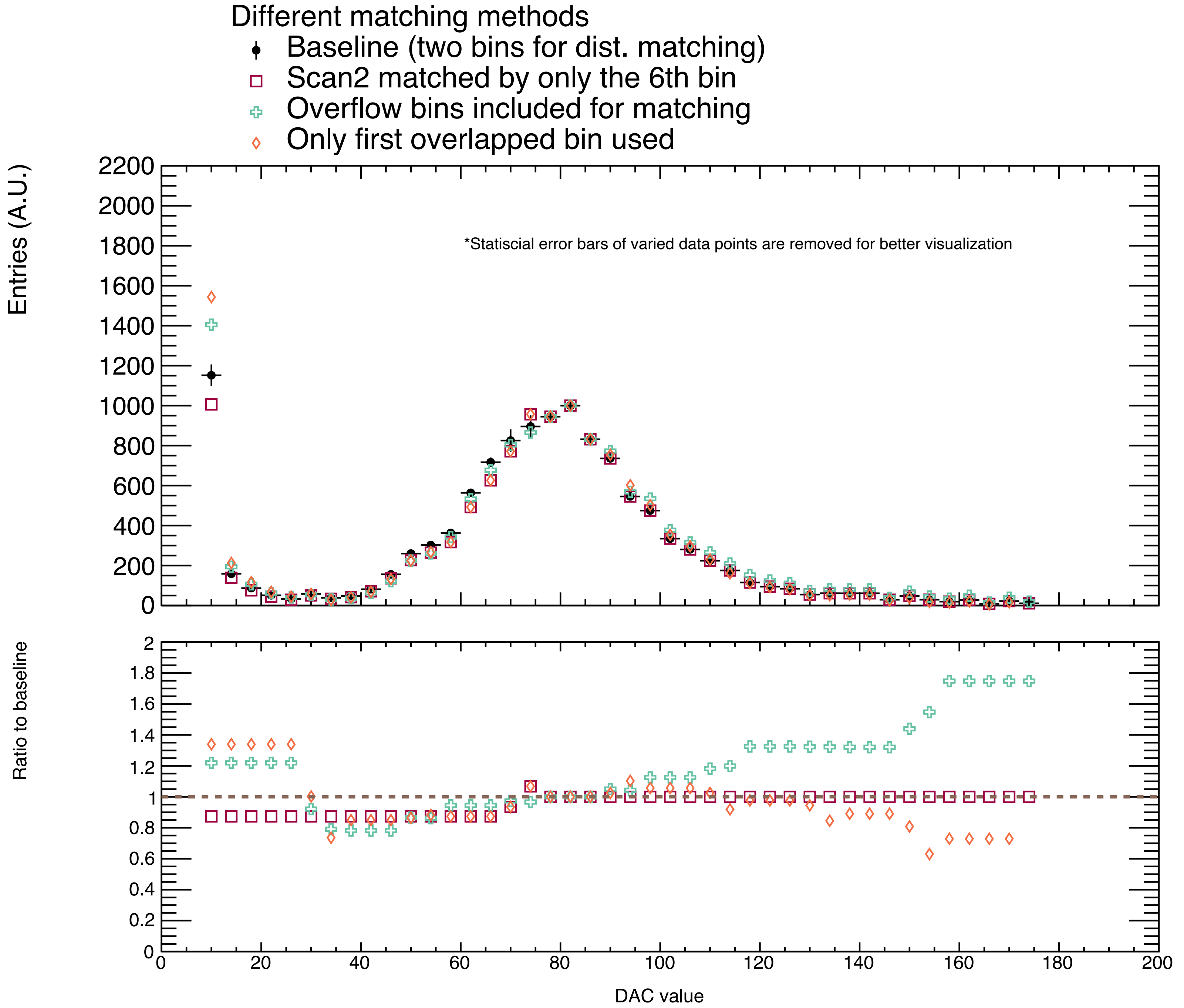
Different matching methods give slightly different shapes, which should be quoted as systematic uncertainty

Energy deposit distribution (DAC Scan)

Comparing 4 matching methods







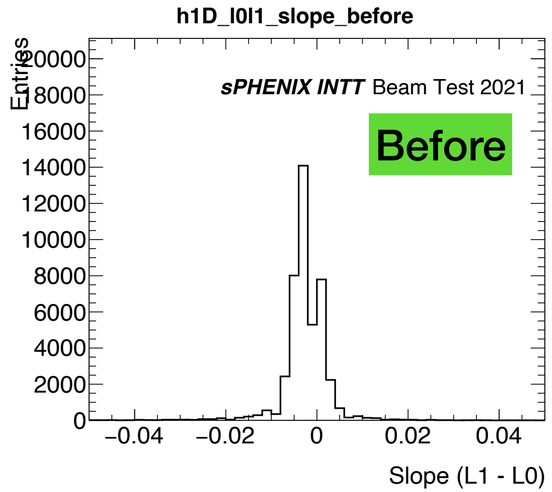
All matching method doesn’t change the shape of distribution significantly → Variation should be the systematic uncertainty

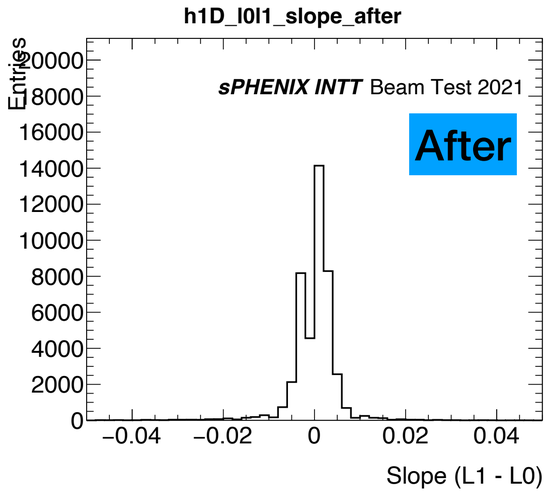
- What should we determine the final shape of the energy deposit distributions and fit the distributions?
  - Option1: Original method as baseline, the other three as the variation
  - Option2: Original method as baseline, <u>Scan2 matched by only the 6th bin</u> as variation (what shown last week)
  - Option3: Option 1, but remove <u>Overflow bins included for matching</u> from variation
  - Option4: Any thoughts?

Residual distribution

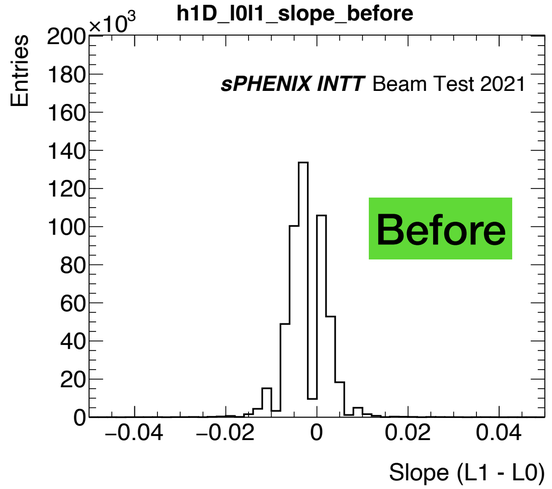
- Residual distribution
  - Genki: in L1L0 slope distributions, why there are dips in distributions ?

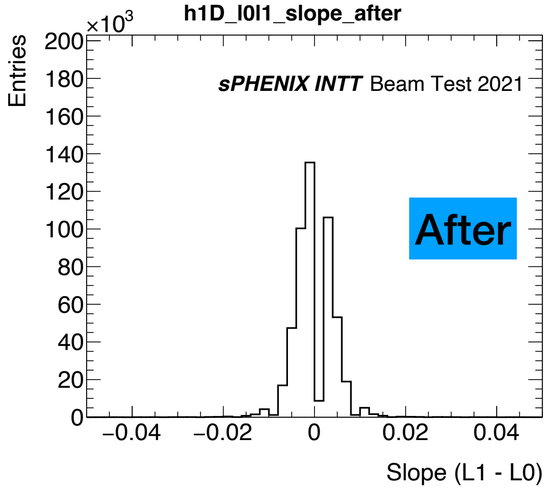
Data Run52, U8





MC

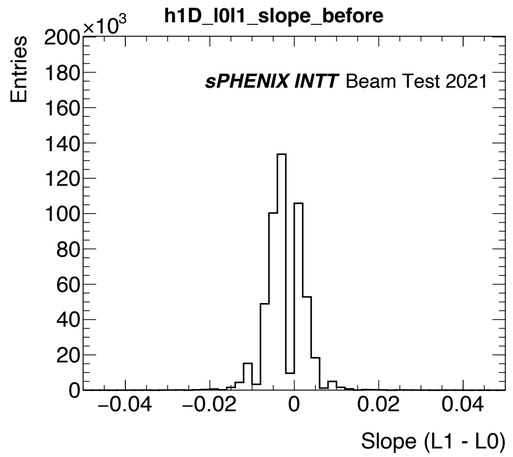




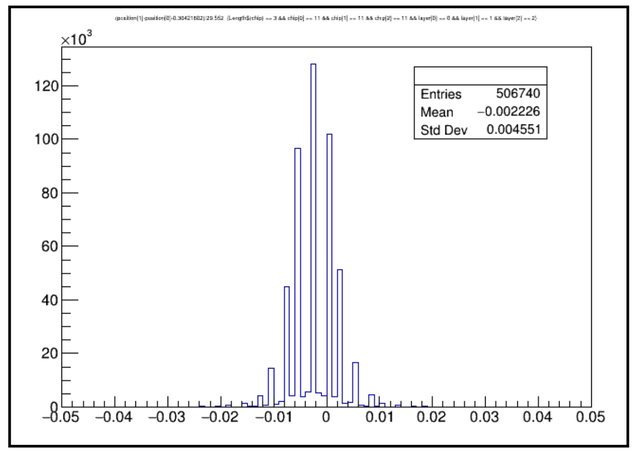
Residual distribution

- Residual distribution
  - Genki: in L1L0 slope distributions, why there are dips in distributions ?
- Ans:
  - Setting of the TH1Ds: (50,-0.05,0.05) → Bin width : 0.002
  - Minimal slope change, say L0 one layer with one channel movement
    - 0.078 mm (strip width) ÷ 29.552 mm (ladder distance in Z axis) = 0.002639… → <u>which is larger than one bin width</u>
  - In one event, if one cluster is with cluster size > 1, there is a chance to have minimal variation < 0.002639 → could have the entry in the dip

MC



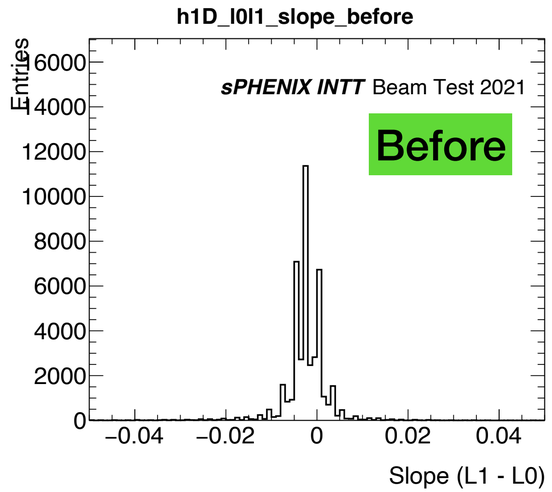
Change number of bins from 50 to 100

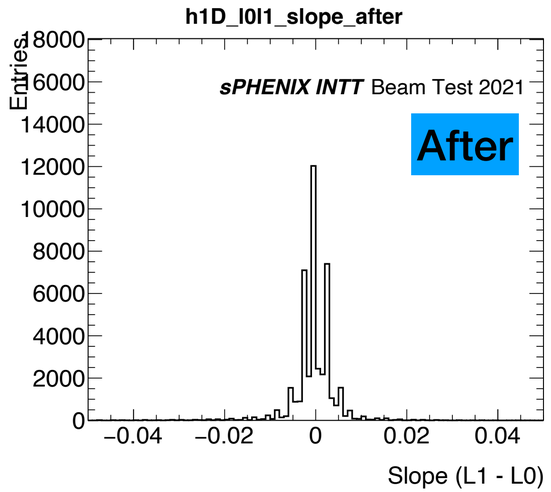


Residual distribution

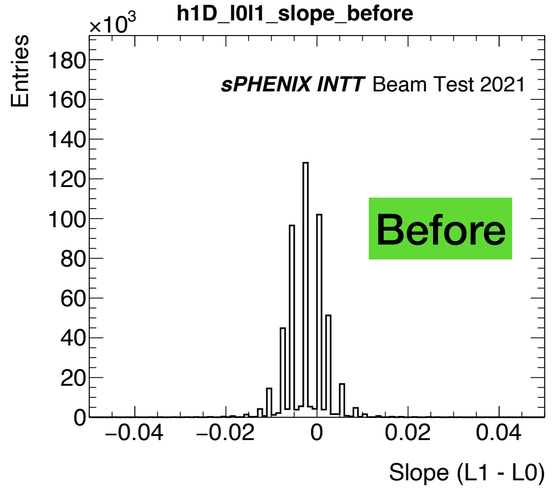
- Residual distribution:
  - Now change the bin width to 100

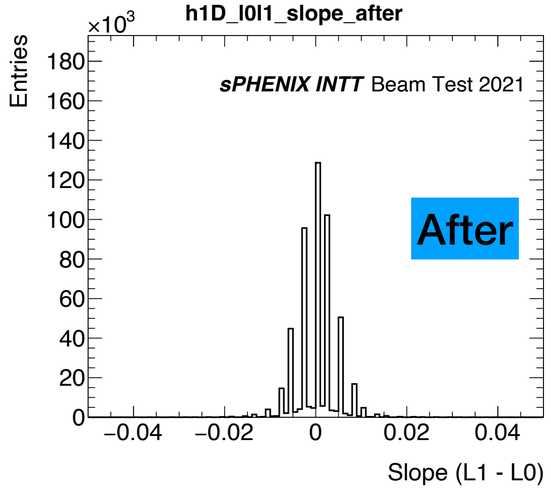
Data Run52, U8





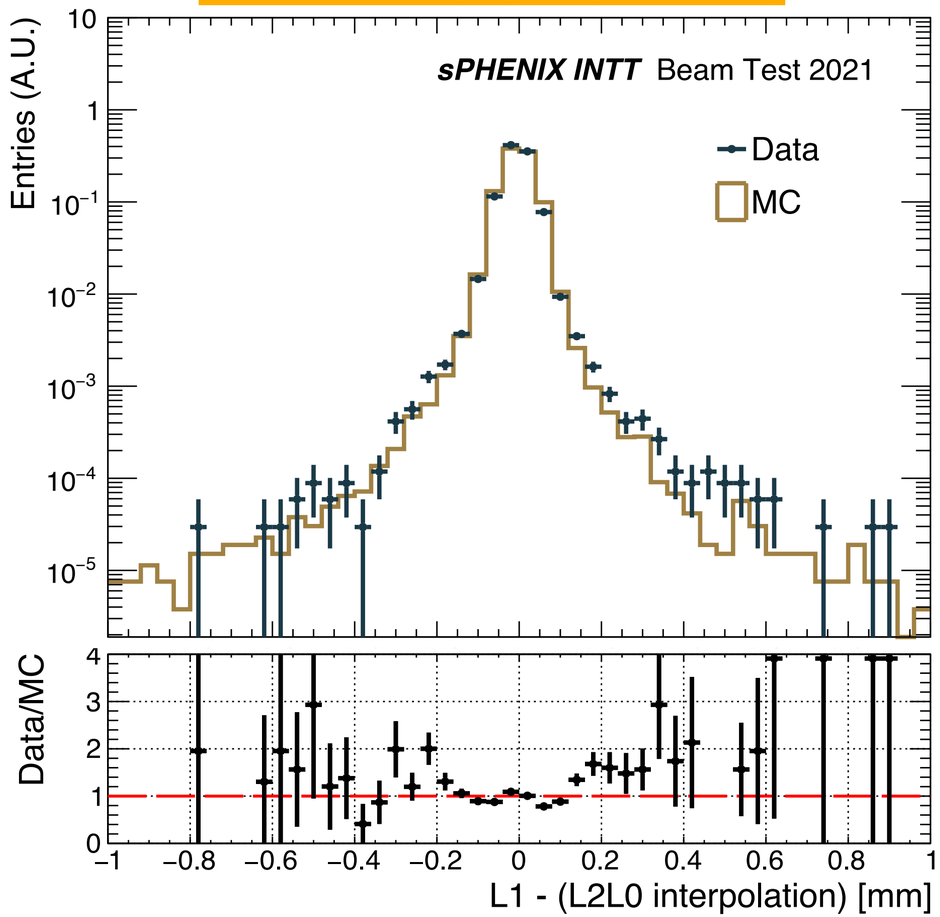
MC



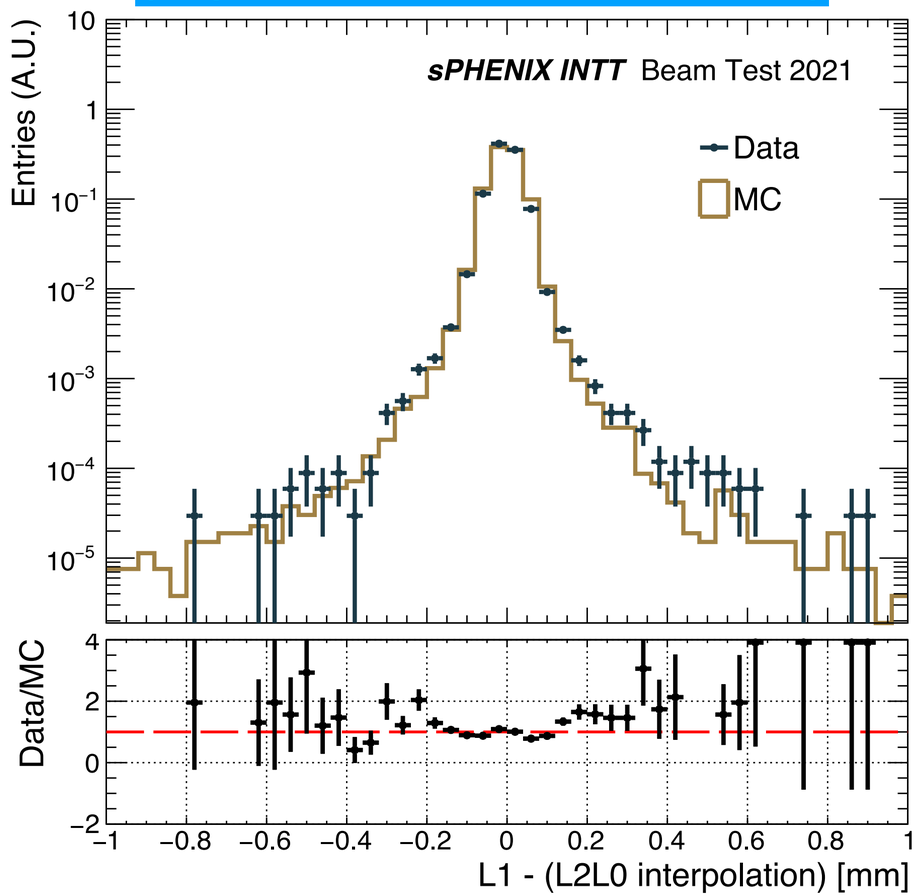


Residual distribution

New
Plot to be in paper (tentative)



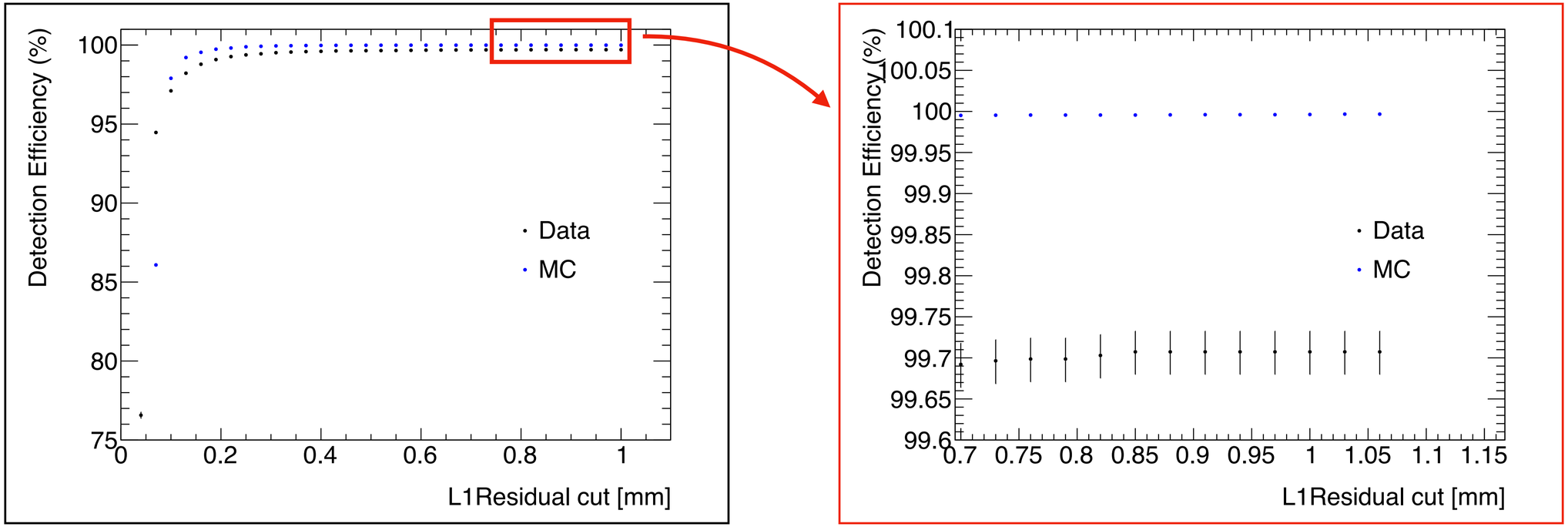
Original
(slope distribution bin width 0.002)



Result is consistent with what presented previously

Hit detection efficiency

- Hit detection efficiency:
  - Itaru: the simulation should be used to determine the proper residual cut
  - **Goal: we want the residual cut as small as possible, but also make sure no physics (signal hits) is artificially discarded**
- According to the simulation study, with the residual cut larger than 0.7 mm, the hit detection efficiency is measured to be > 99.995% (@0.7 mm, effi. = 99.9952%)
  - **Residual cut of 0.7 mm is applied to data**
  - No additional correction applied to data (Nearly 100% of hits are retained in MC)
  - Residual cut variation is removed from the systematic uncertainty sources (Differences of effi. with residual cut from 0.7 mm to 1.0 mm well within their stat. unc.)



Hit detection efficiency - systematic unc.

Sources considered for estimating the systematic uncertainty

Source	Variation	Run52			Run89		
		Numerator	Denominator	Efficiency(%)	Numerator	Denominator	Efficiency(%)
Baseline		42972	43099	99.705	50511	50746	99.537
(New) Column	U8 → U9 (Run52) U10 → U11(Run89)	44210	44301	99.795	37156	37338	99.513
Slope Cut	0.01 → 0.013	43658	43795	99.687	51384	51623	99.537
	0.01 → 0.007	41759	41877	99.718	48633	48856	99.544
Boundary Cut	8 ch → 11 ch	42972	43099	99.705	49397	49625	99.541
	8 ch → 5 ch	42972	43099	99.705	51629	51873	99.530

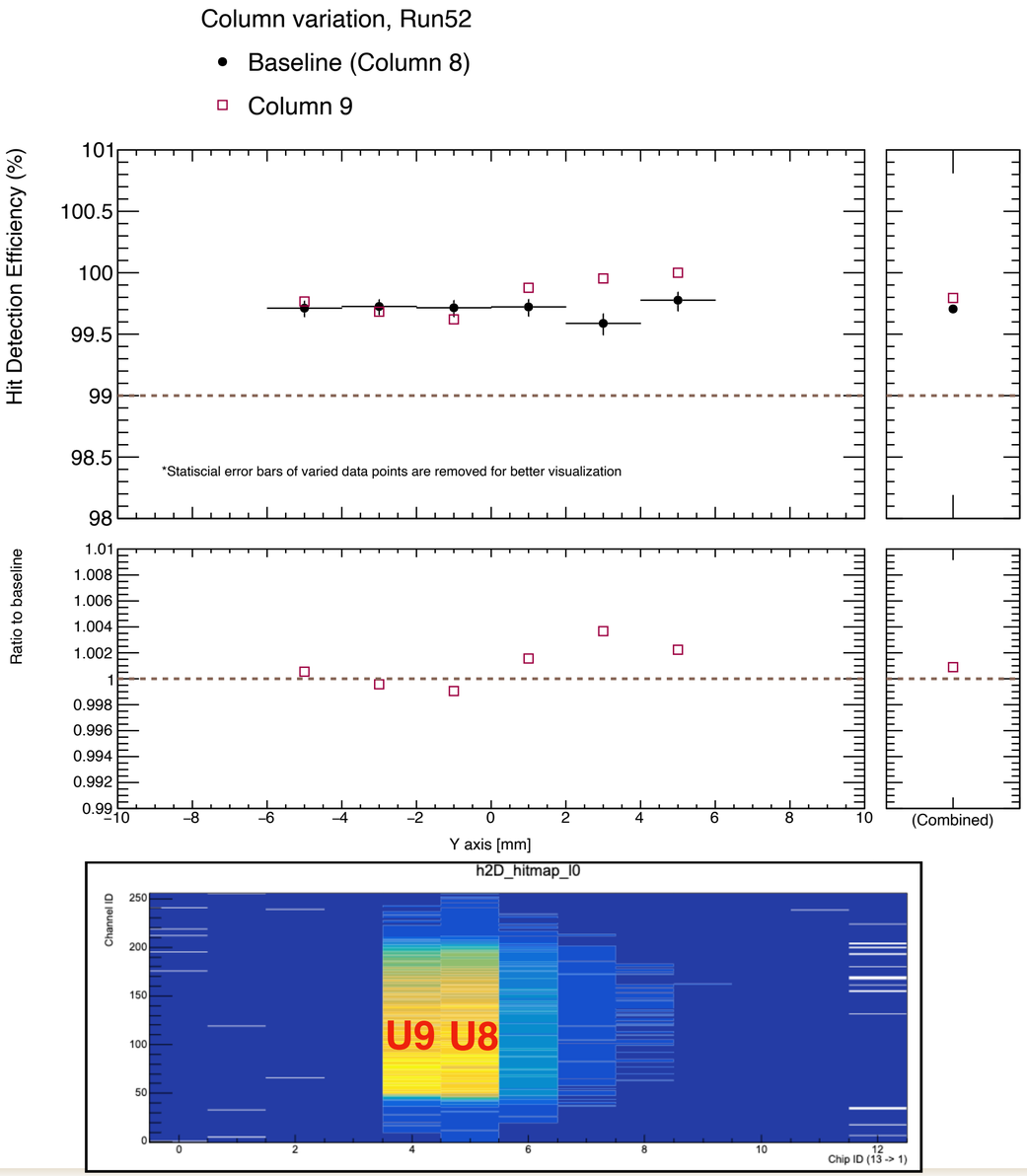
considered in the past

Residual cut is removed from the systematic uncertainty sources

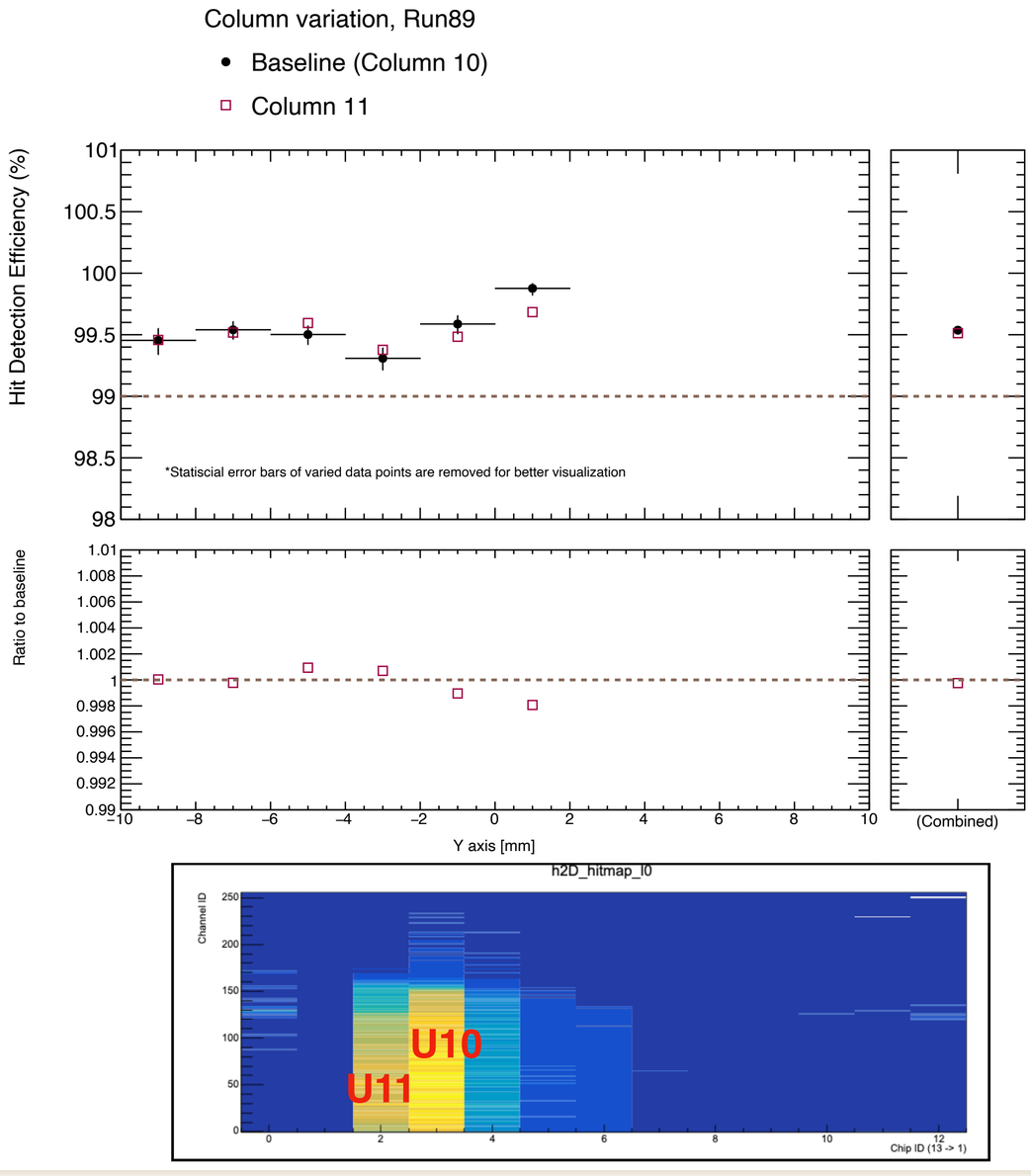
The numbers are statistically combined for estimating systematic uncertainty

Hit detection efficiency as a function of Y axis

Run52

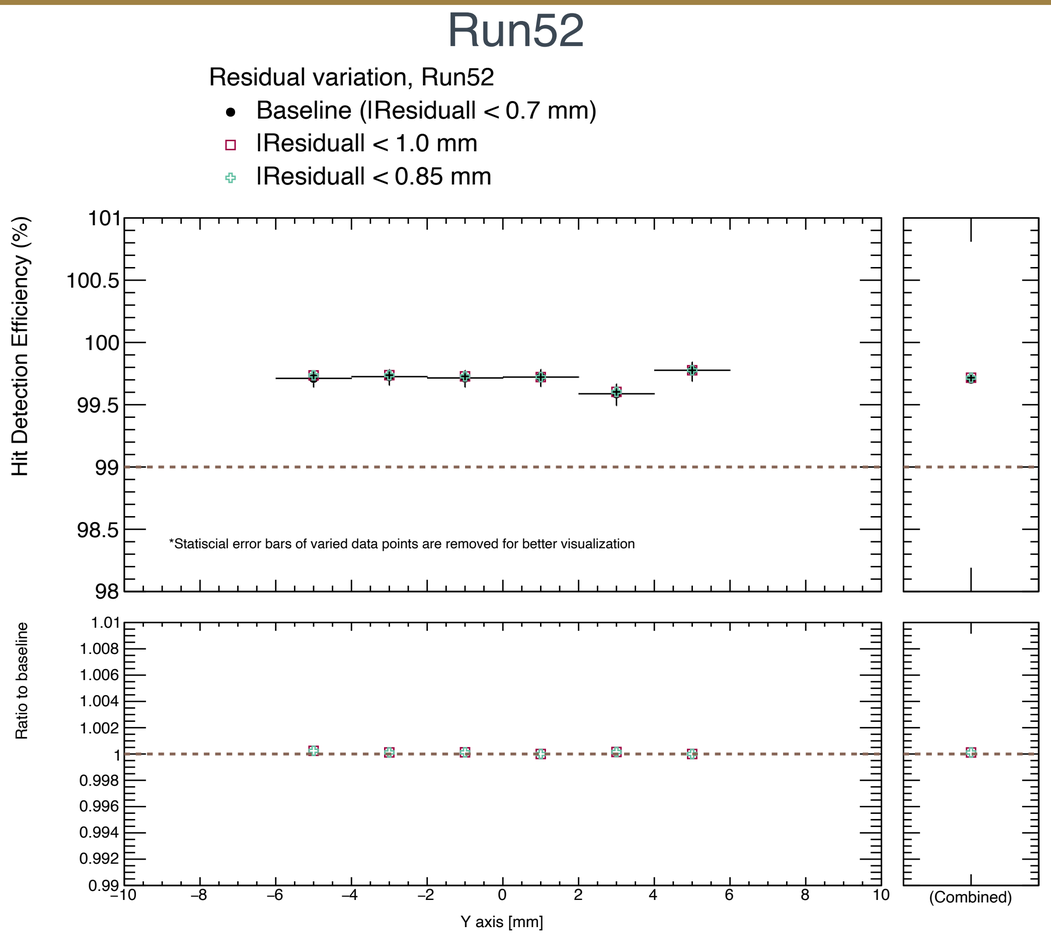


Run89

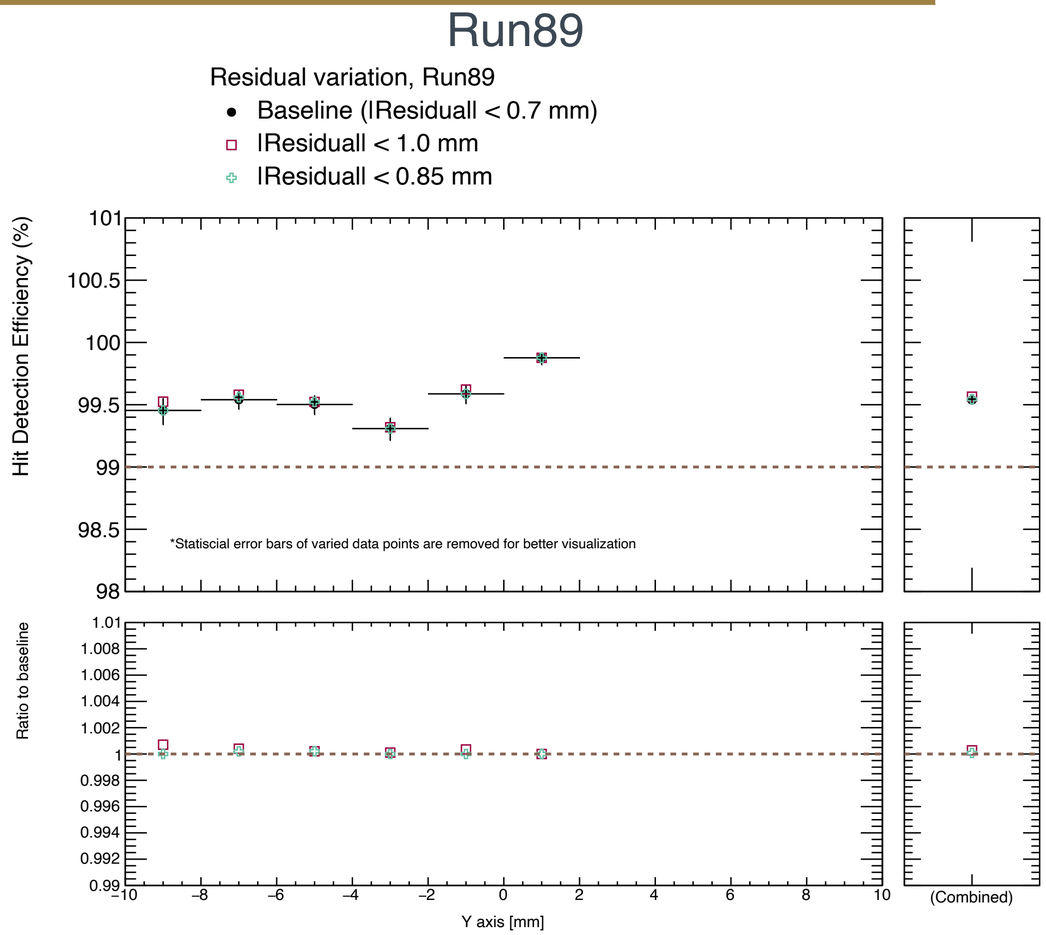


Hit detection efficiency as a function of Y axis

Run52



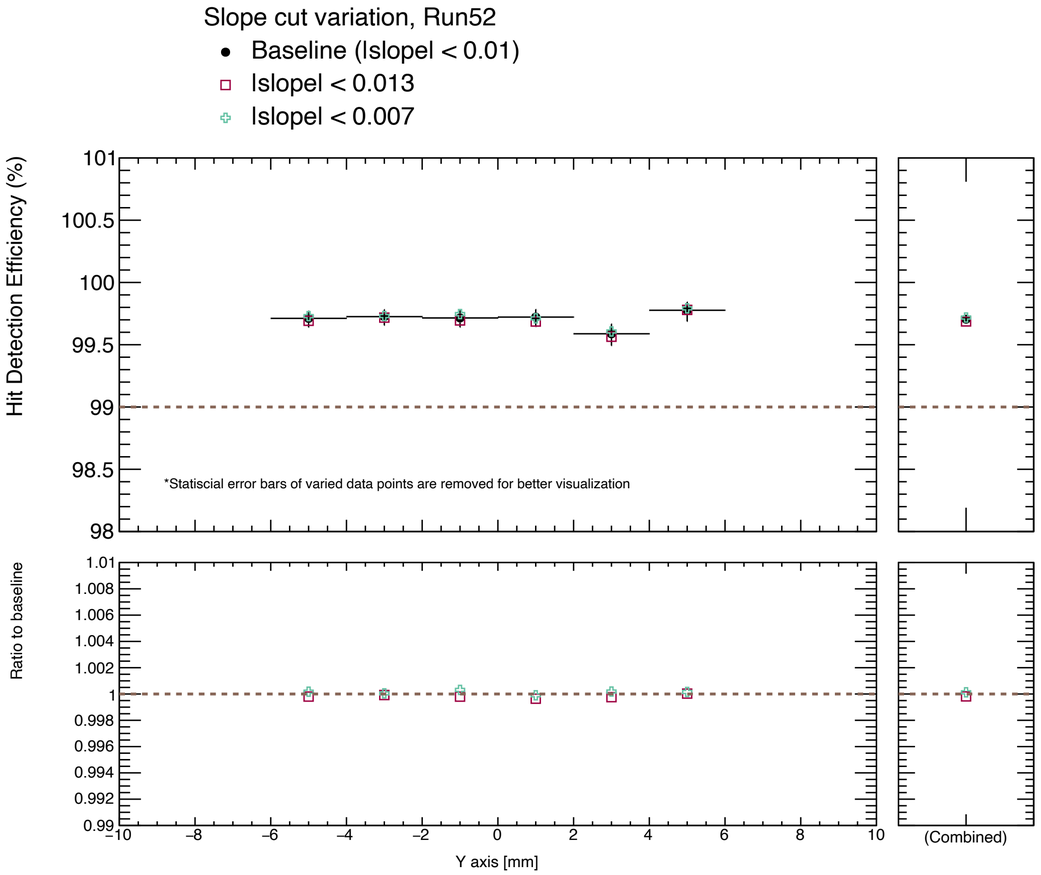
Run89



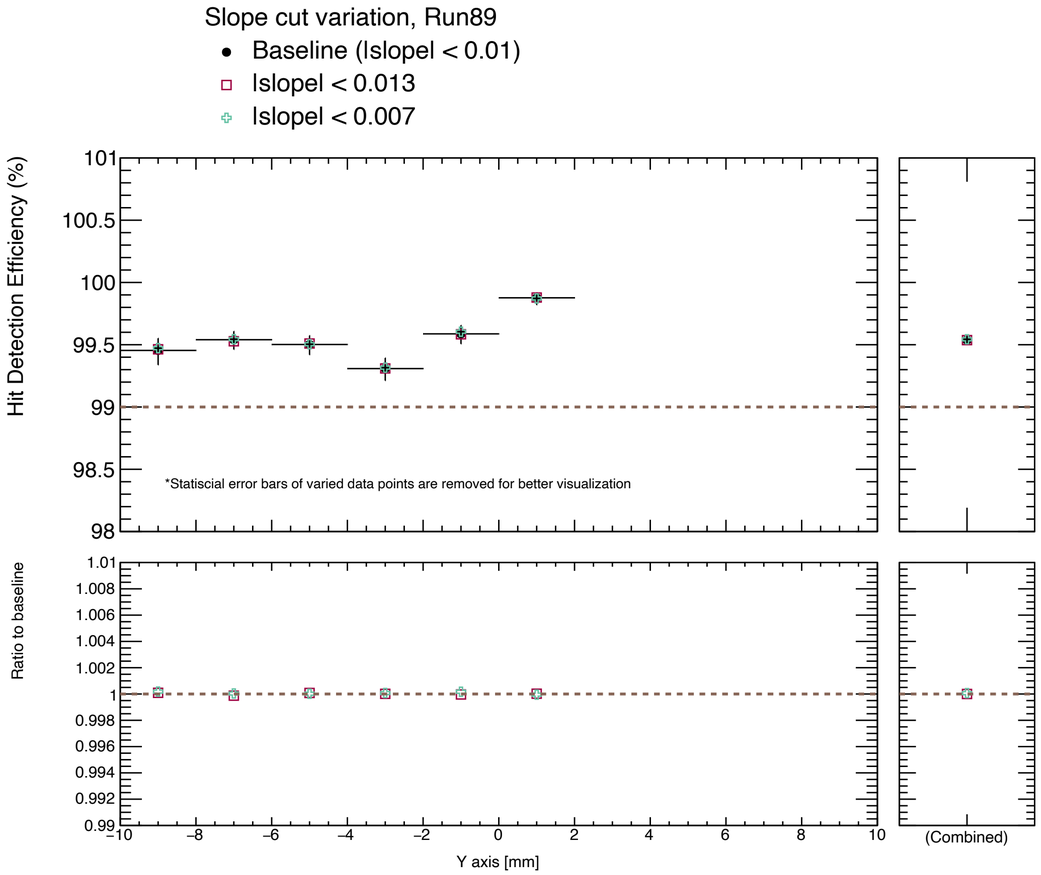
Just for your reference, not used in the systematic uncertainty estimation for the moment

Hit detection efficiency as a function of Y axis

Run52



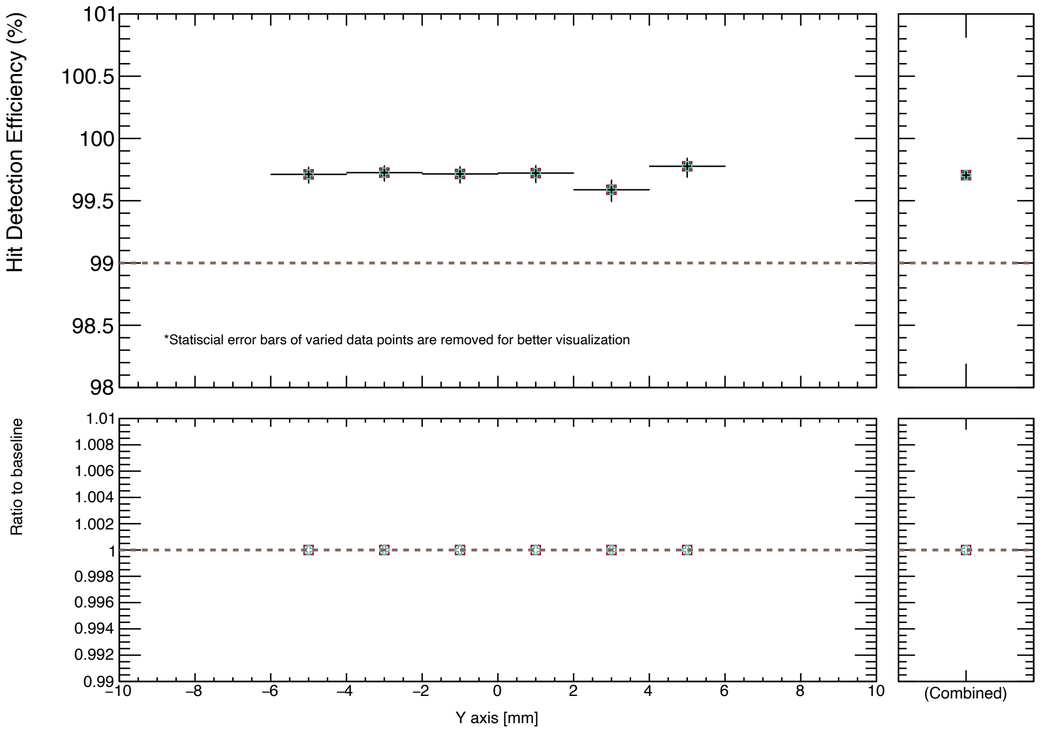
Run89



Hit detection efficiency as a function of Y axis

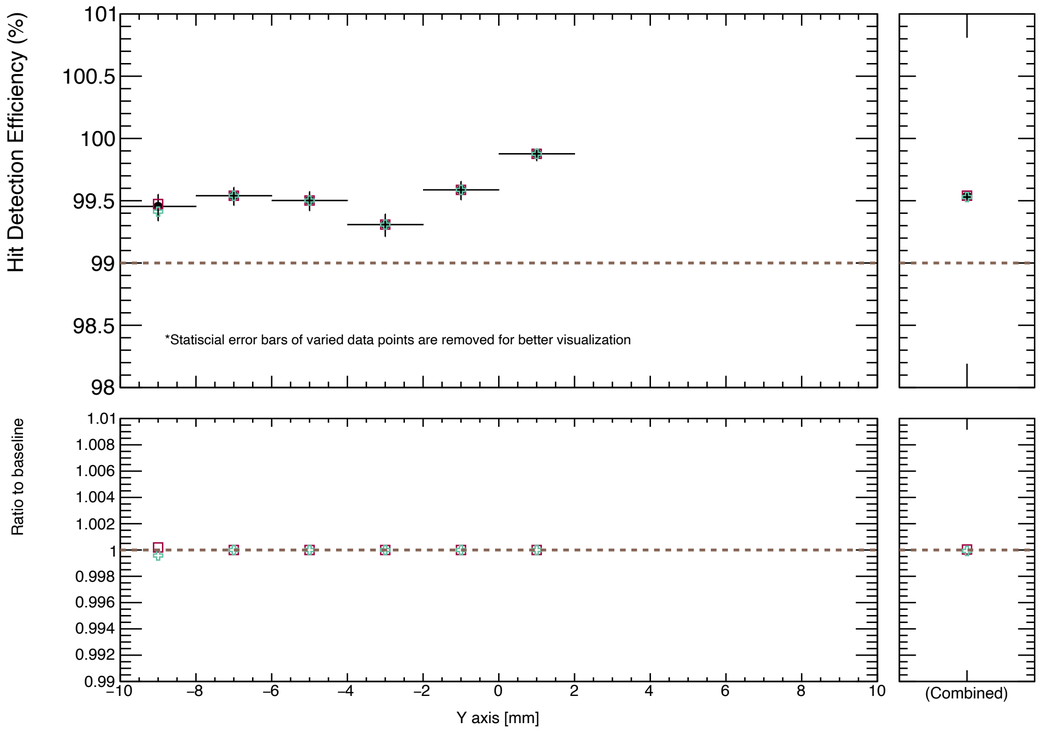
Run52

Boundary cut variation, Run52
- Baseline (Hits of L0 & L2 to edge < 8 channels)
- Hits of L0 & L2 to edge < 11 channels
- Hits of L0 & L2 to edge < 5 channels



Run89

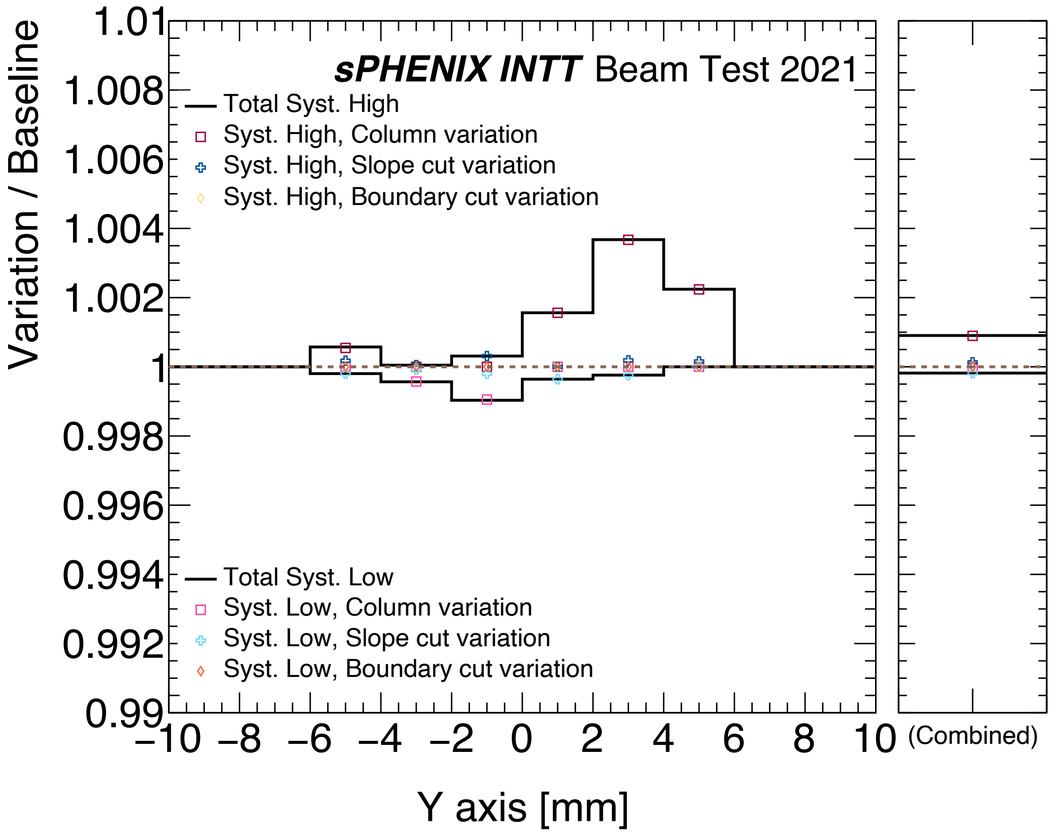
Boundary cut variation, Run89
- Baseline (Hits of L0 & L2 to edge < 8 channels)
- Hits of L0 & L2 to edge < 11 channels
- Hits of L0 & L2 to edge < 5 channels



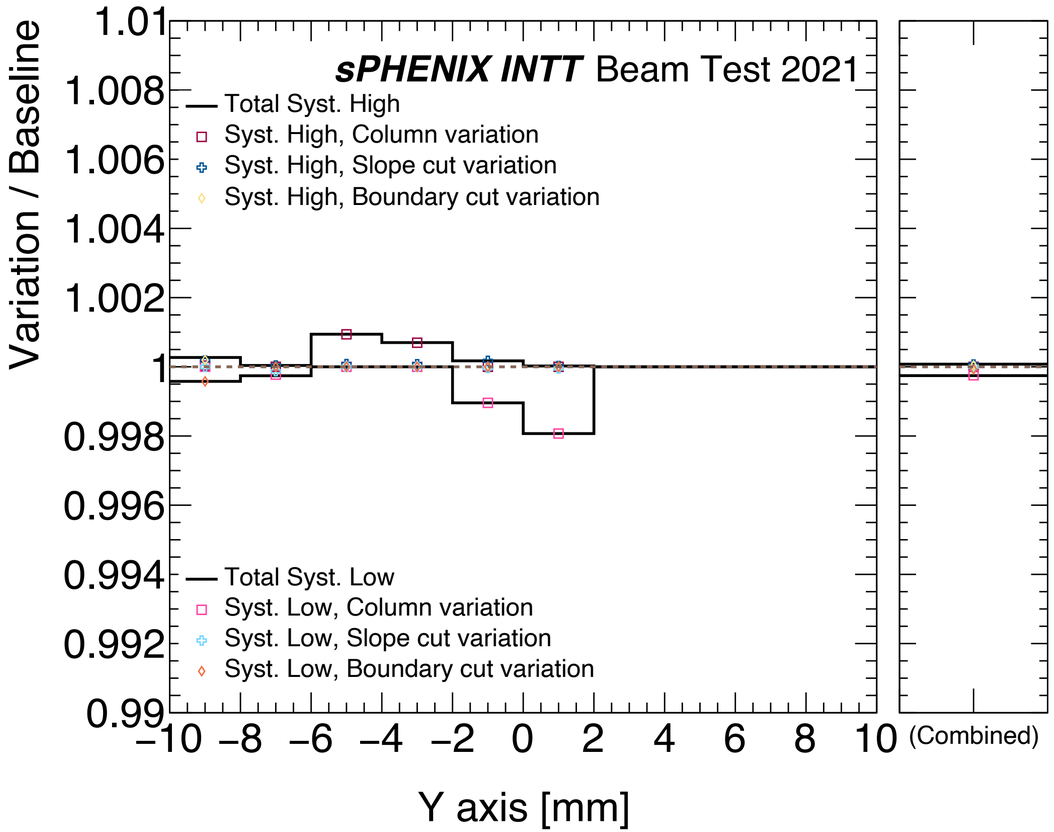
Hit detection efficiency as a function of Y axis

The total systematic uncertainty in each bin is obtained by summing all sources in quadrature

Run52



Run89



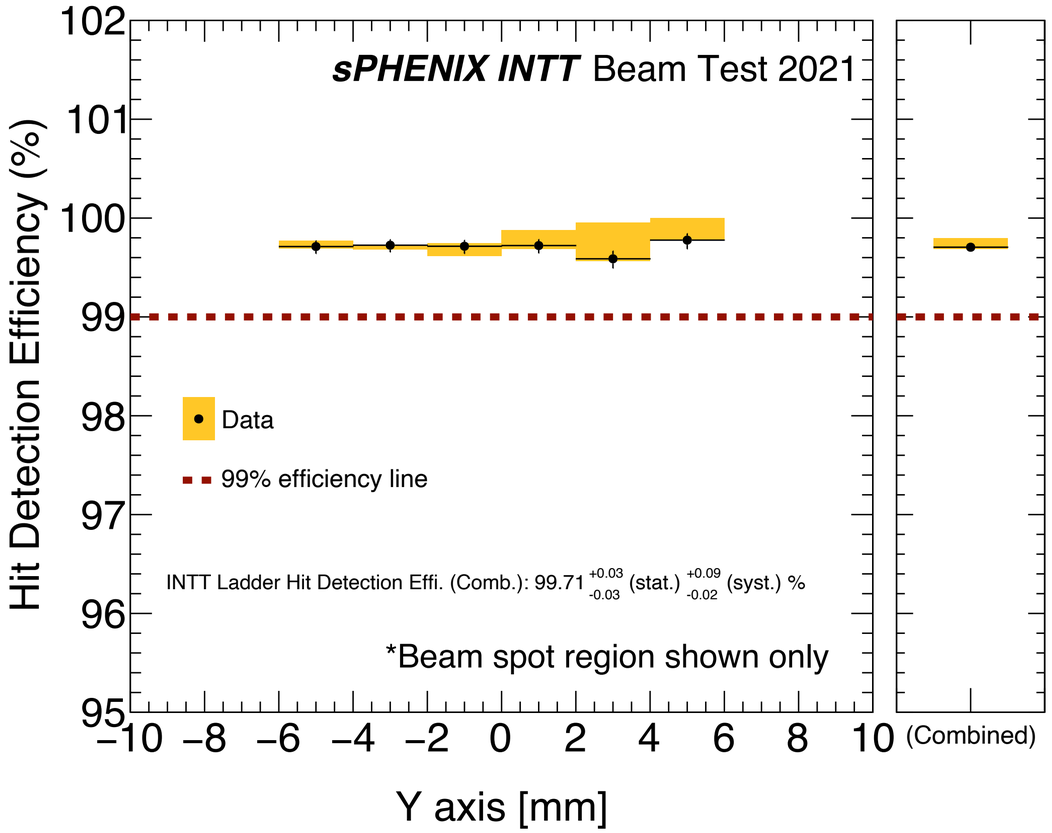
Hit detection efficiency as a function of Y axis

Run52

Hit detection efficiency (combined):

It was: $99.668\ ^{+0.028}_{-0.030}(stat.)\ ^{+0.109}_{-0.144}(syst.)\ \%$

It is : $99.705\ ^{+0.026}_{-0.028}(stat.)\ ^{+0.090}_{-0.018}(syst.)\ \%$

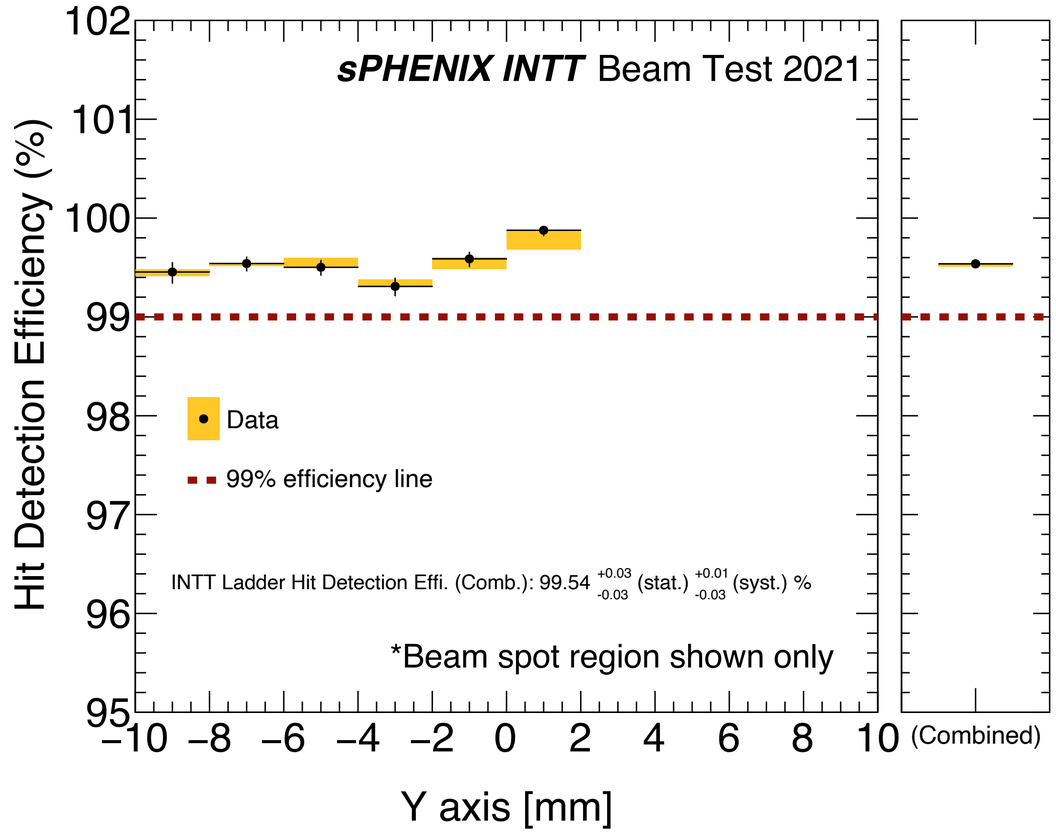


Run89

Hit detection efficiency (combined):

It was: $99.497\ ^{+0.031}_{-0.033}(stat.)\ ^{+0.046}_{-0.109}(syst.)\ \%$

It is : $99.537\ ^{+0.030}_{-0.032}(stat.)\ ^{+0.008}_{-0.025}(syst.)\ \%$



Recap - hit detection efficiency of L1

Debut of **fitting method** with effi. under control: 2022/Jan/07
Debut of **DUT method**: 2022/Dec/02

In ELPH report

Table 1. The sources of the systematic uncertainties affecting the detection efficiency calculation.

Sources	Scan range	Uncertainty (%)
Residual cut	0.164 mm–0.304 mm	0.063
Slope cut	0.0088–0.0112	3×10^{-3}
Edge effect	0 ch–10 ch	4×10^{-4}
Total		0.063

$$99.33 \pm 0.04(\mathrm{stat}) \pm 0.06(\mathrm{sys})\ \%$$

----------New----------

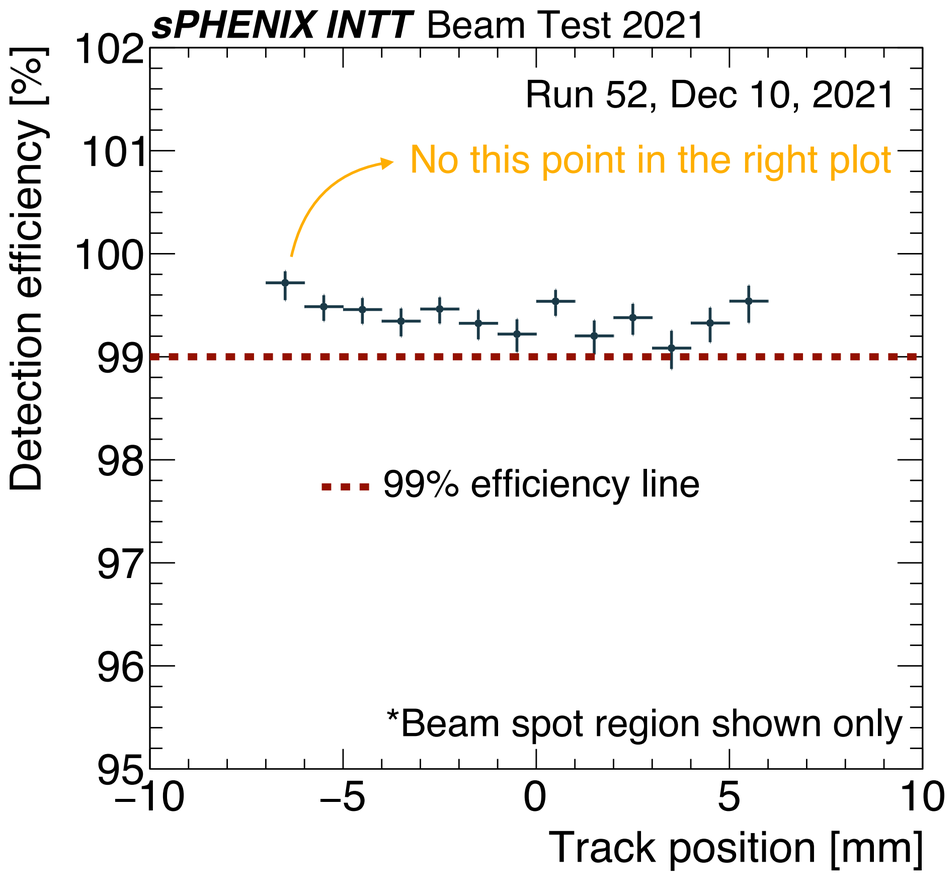
From Run52, hit detection efficiency (Combined): $99.705\ ^{+0.026}_{-0.028}(stat.)\ ^{+0.090}_{-0.018}(syst.)\ \%$

- In ELPH report, the average of variation is used as uncertainty (insensitive to the tested variations)
  - In new result: differences are summed up in quadrature (conventional way)
  - In new result: one more source considered: **column variation**
- 0.234 mm (0.7 mm) is used for Residual cut in ELPH (New results)
  - Good agreement with MC in residual distribution obtained, therefore loose the selection a bit

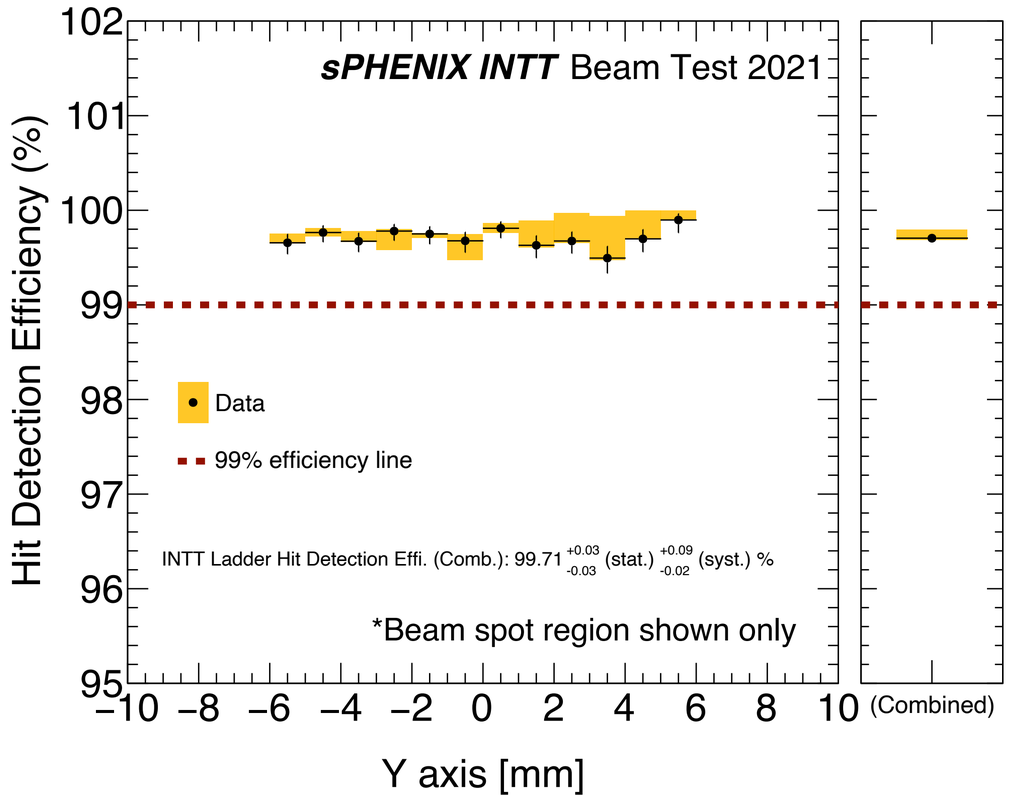
Recap - hit detection efficiency of L1

Debut of **fitting method** with effi. under control: 2022/Jan/07
Debut of **DUT method**: 2022/Dec/02

The previous plot (the one on ELPH report)



The new plot with same bin width for comparison



In comparing the baseline data points, basically same shape

Things that might affect detection efficiency

- The current measured hit detection efficiency in data: > 99.5% (w/ Residual cut 0.7 mm)

- Precision limit of physics model in GEANT in large angle
  - The used residual cut determined by MC is too narrow, efficiency goes down ↓

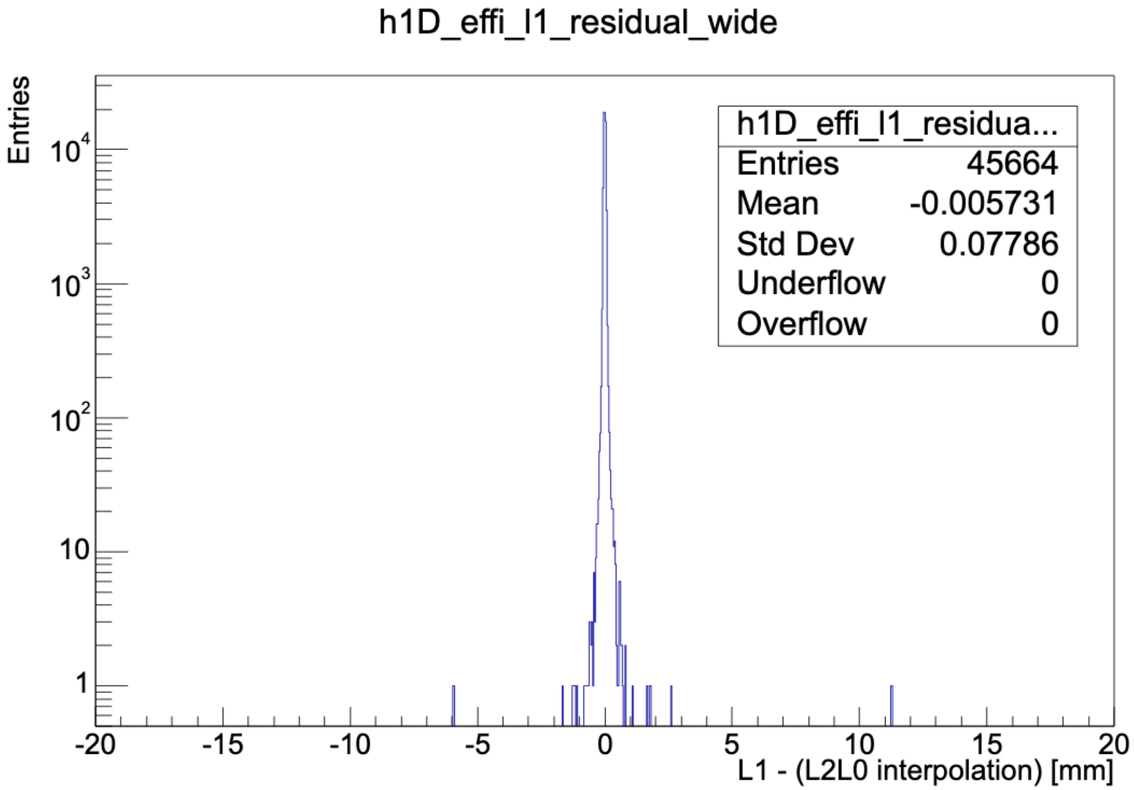
- Possible extra background/noise hit contamination in data
  - Extra hits that somewhat match to the reconstructed track, efficiency goes up ↑
  - What fraction of hits that are noise hits, but are treated as signal hits due to their small L1 residuals?

- INTT readout system (including silicon, signal transmission, processing, etc.)
  - Hits are somewhat dropped along the way from detection to data storage, efficiency goes down ↓

Things that might affect detection efficiency

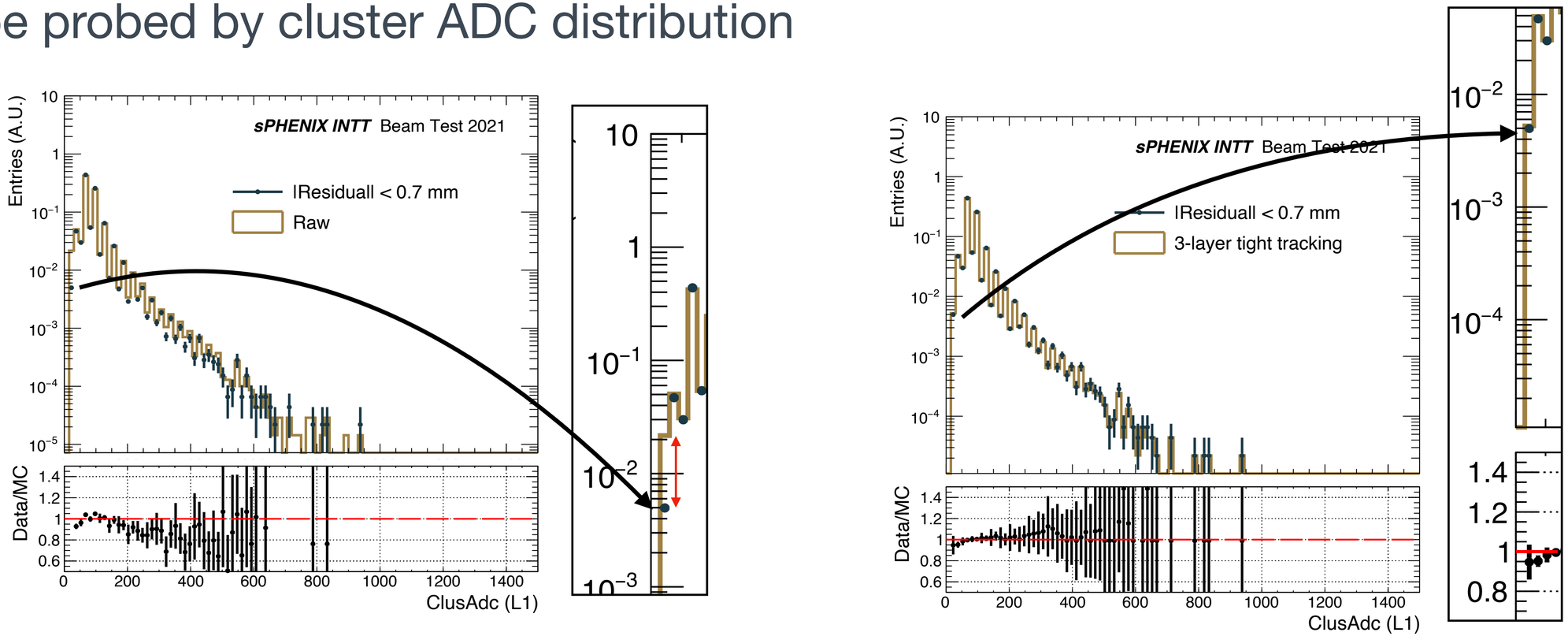
- Is the residual cut determined by MC too narrow that makes efficiency go down↓?
  - Even if we have no residual cut (set the residual cut to be 20 mm), the efficiency increases only 0.0393%
  - The ~0.5% (considering Run89) inefficiency might be due to electronics

Residual cut	numerator	Increment	denominator	efficiency
0.7 mm	45646	0	45787	99.6921
1.0 mm	45653	7	45787	99.7073
3 mm	45662	16	45787	99.7270
5 mm	45662	16	45787	99.7270
20 mm	45664	18	45787	99.7314



Things that might affect detection efficiency

- Noise hits been counted as good hits in detection efficiency measurement?
  - Can be probed by cluster ADC distribution



- (Left Figure) In the Raw distribution, more single-hit clusters with hit ADC = 0
  - The noise hits are reduced in the hit finding in the detection efficiency measurement
- (Right Figure) The 3-layer tight* tracking is the most powerful way to reject noise hits in the beam test configuration
  - Good agreement in the first bin → marginal noise contamination

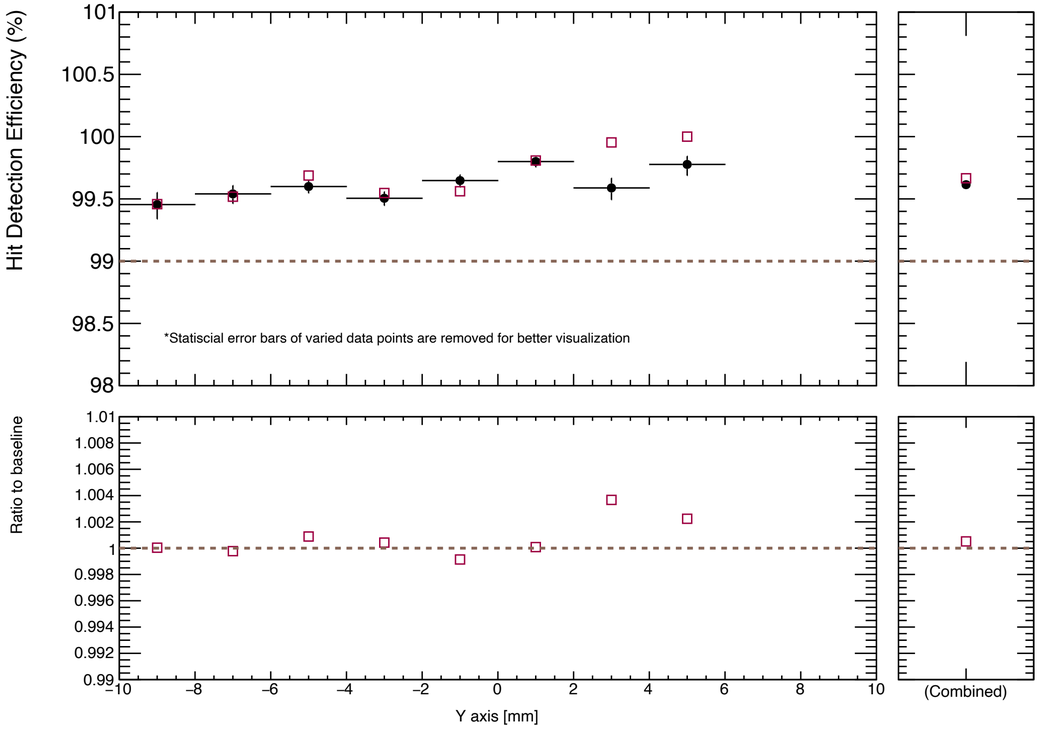
*tight: single cluster in each selected column, no cluster in adjacent columns, track slope < 0.01 and L1 residual < 0.7 mm

Final, Run52 & Run89 combined

Wider coverage in Y axis: -10 mm to 6 mm

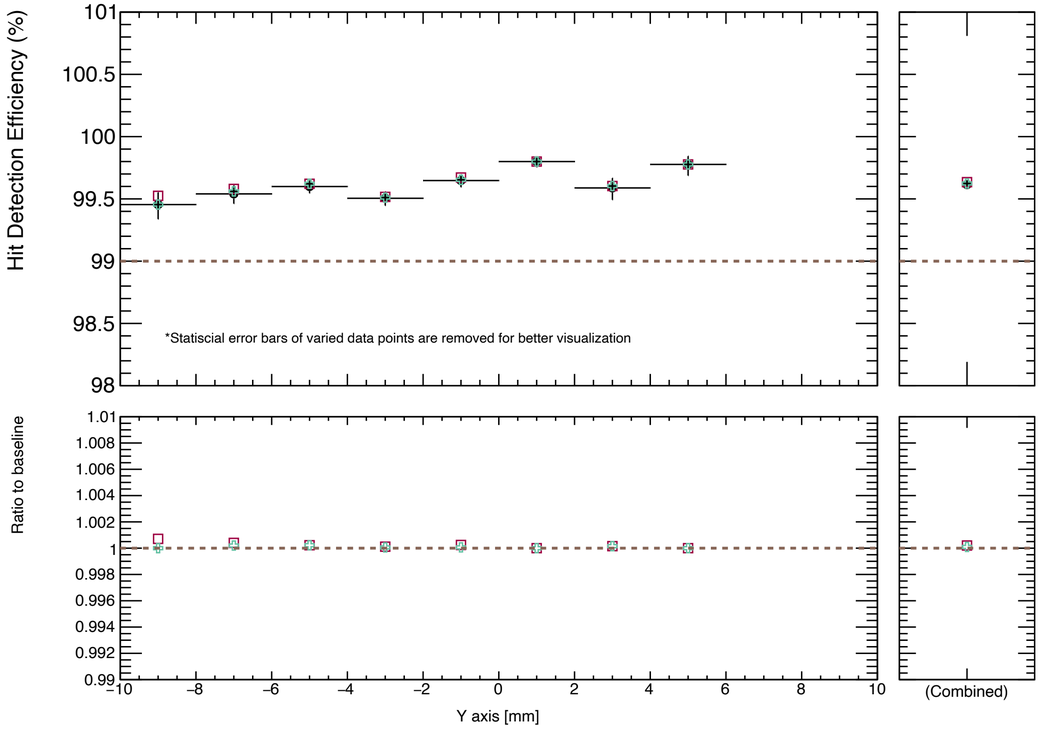
Column variation, Run52+Run89

- Baseline (Run52: Column 8, Run89: Column 10)
- Run52: Column 9, Run89: Column 11



Residual variation, Run52+Run89

- Baseline (|Residuall < 0.7 mm)
- |Residuall < 1.0 mm
- |Residuall < 0.85 mm

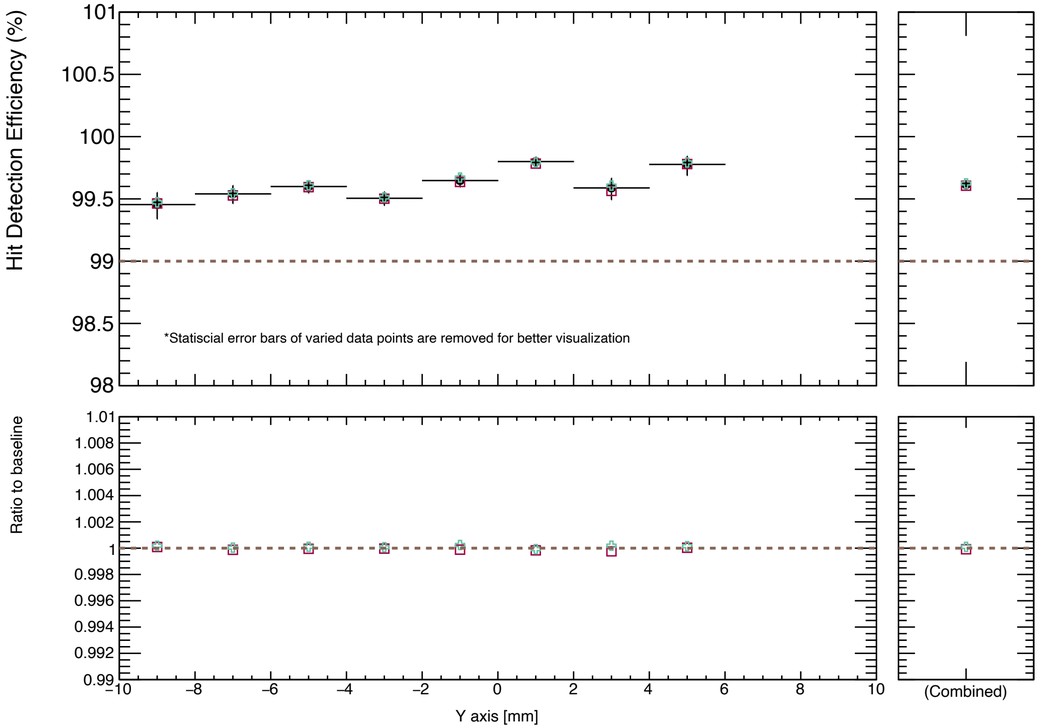


Just for your reference, not used in the systematic uncertainty estimation for the moment

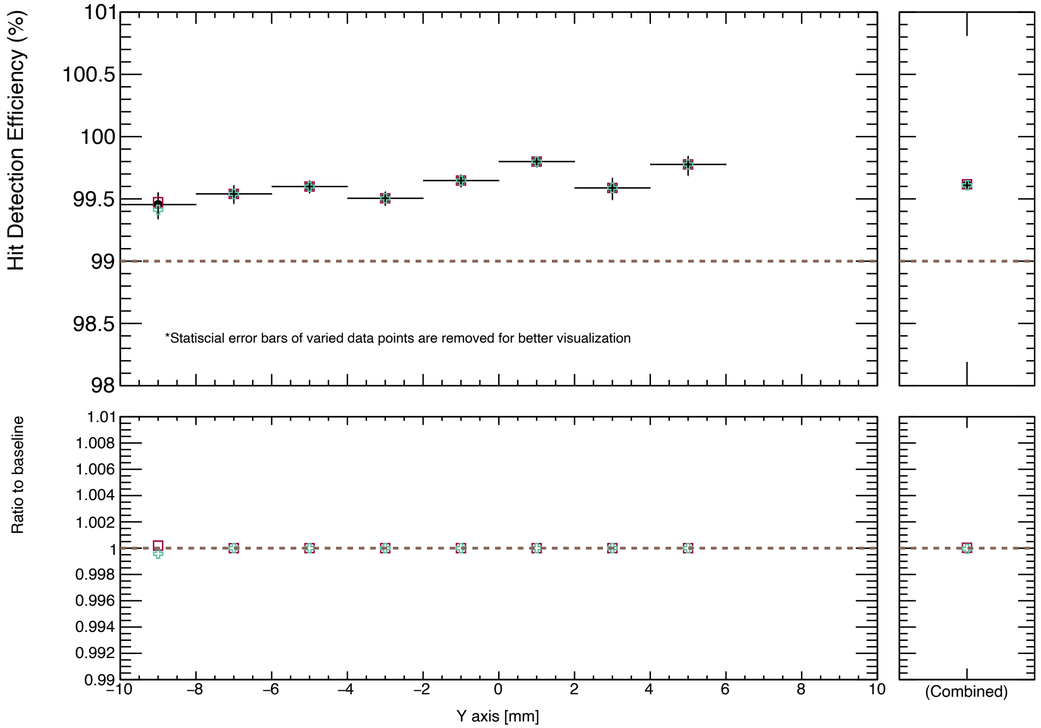
Final, Run52 & Run89 combined

Wider coverage in Y axis: -10 mm to 6 mm

Slope cut variation, Run52+Run89
- Baseline (Islopel < 0.01)
- Islopel < 0.013
- Islopel < 0.007



Boundary cut variation, Run52+Run89
- Baseline (Hits of L0 & L2 to edge < 8 channels)
- Hits of L0 & L2 to edge < 11 channels
- Hits of L0 & L2 to edge < 5 channels



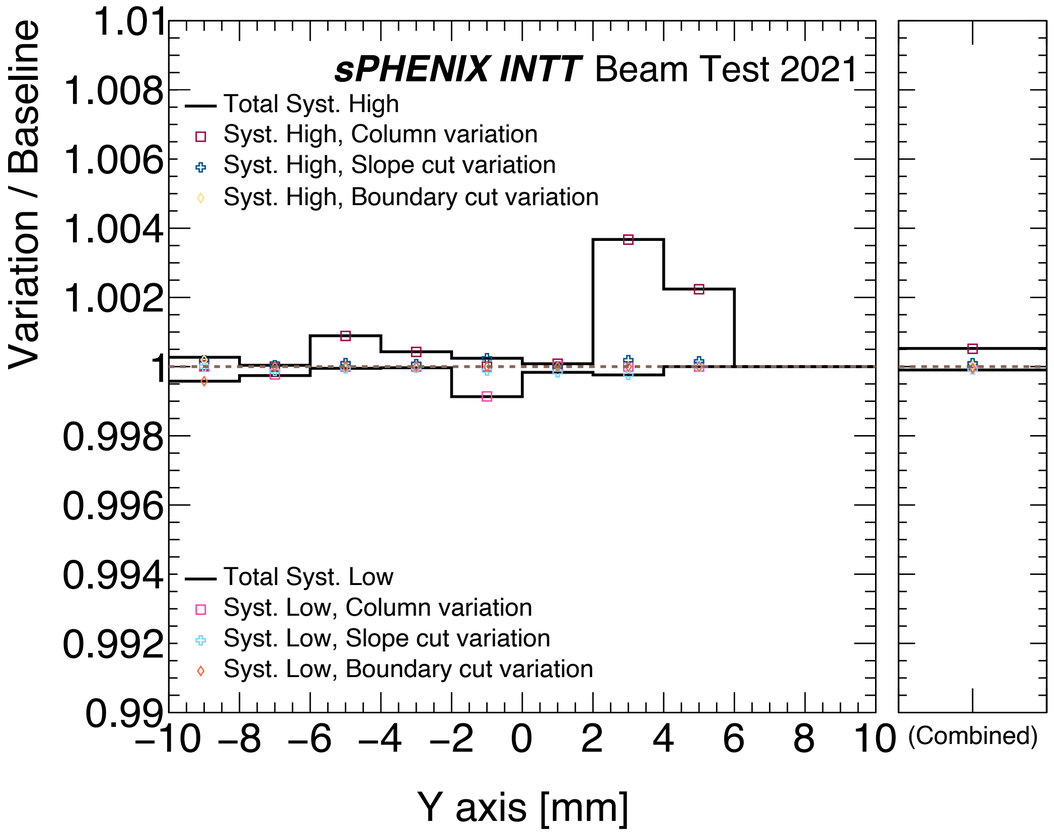
Final, Run52 & Run89 combined

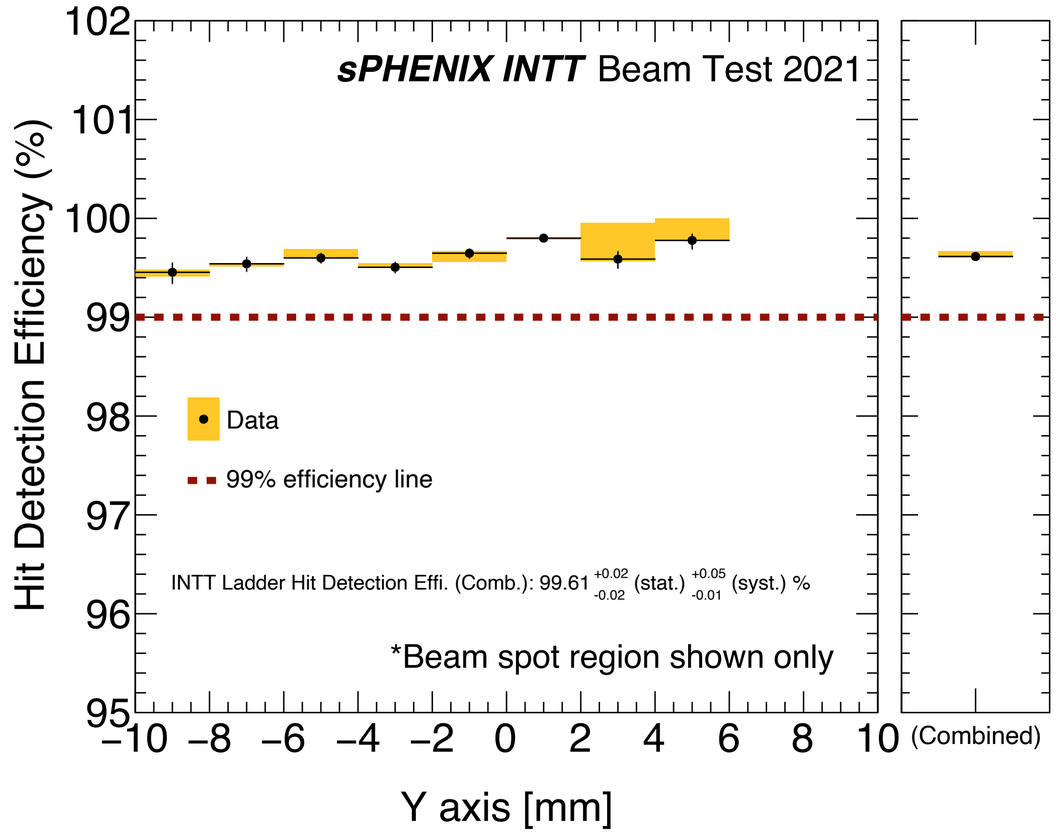
Hit detection efficiency (Combined)

It was: $99.576\ ^{+0.021}_{-0.022}(stat.)\ ^{+0.079}_{-0.125}(syst.)\ \%$

Numbers to be in paper (tentative)

It is : $99.61\ ^{+0.02}_{-0.02}(stat.)\ ^{+0.05}_{-0.01}(syst.)\ \%$



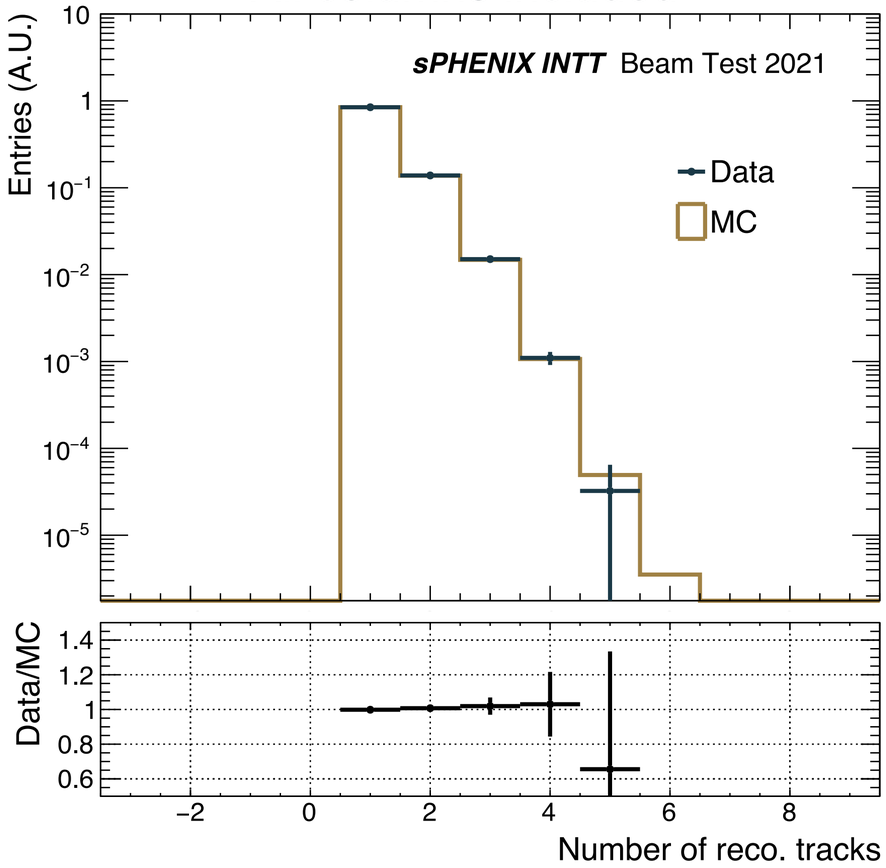


Plot to be in paper (tentative)

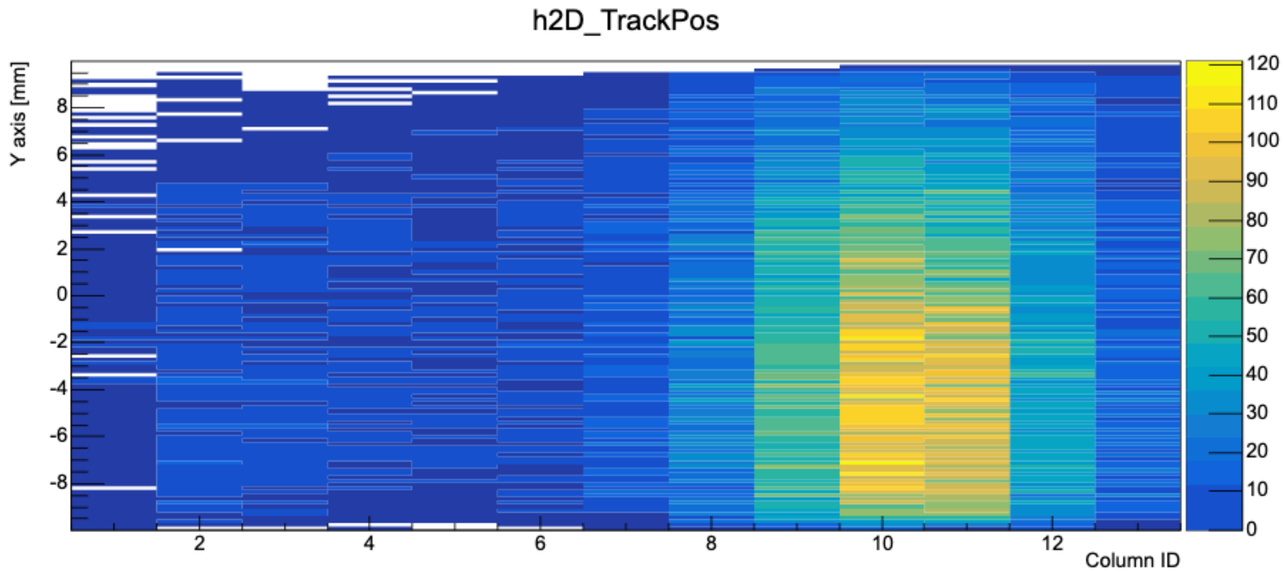
Number of reconstructed tracks

- Change the residual cut for track QA from 0.5 mm to 0.7 mm, to be in line with what used in hit detection efficiency

All columns included



Track position in data



Plot to be in paper (tentative)

Summary

- Energy deposit distribution (DAC Scan)
  - Genki: are the distribution shapes of U9, U10, and U11 the same? → **Yes**
  - Takashi: what is the proper way to combine distributions → **We need to conclude what combine methods should be included in systematic uncertainty**

- Residual distribution
  - Genki: in L1L0 slope distributions, why there are dips in distributions? → **As demonstrated, due to binning effect**

- Hit detection efficiency:
  - Itaru: the simulation should be a reference to determine the proper residual cut → **As demonstrated with simulation, > 99.995% of hits can be retained with a residual cut of 0.7 mm. Residual cut of 0.7 mm is then used in data**

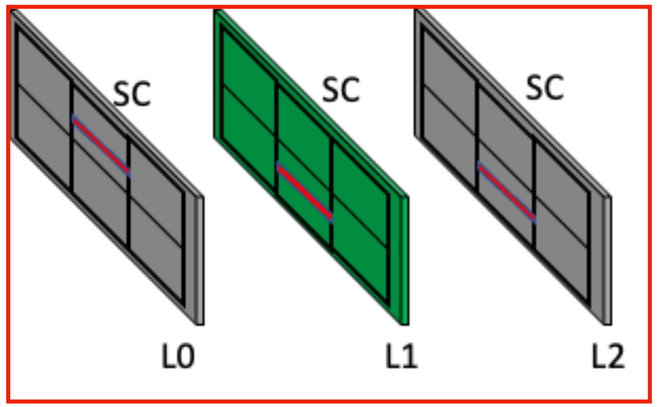
Back up

Scattering comparison with MC

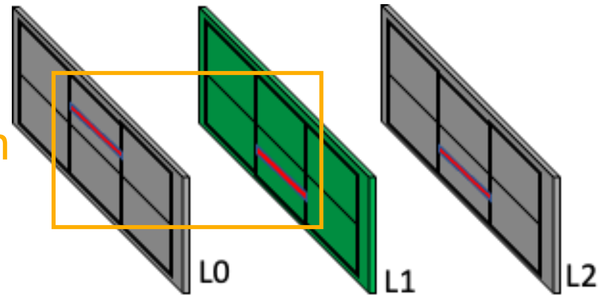
- Method: L0L1 are used for reconstructing proto-track (have constrain), set L2 free

- Data: Run52, column U8, events with clone hit are discarded
- MC: beam spot at center of ladder, U11 is used

- For both data and MC:
  - L1 alignment correction and L0L1 slope re-centering applied
  - Event selection:
    - Single hit in each layer
    - Hits should be at the Selected Column (SC)
    - |L0L1_slope| ≤ 0.01
    - |L0L1_avg_pos| ≤ 5 mm (Ladder coverage: ±10 mm)
  - Check residual: L1 - (L2L0 interpolation)
    - Quantity used in hit detection efficiency analysis



Constrain on proto-track



Hit detection efficiency

- Method: DUT approach (Detector Under Test)
  - Use L0 and L2 to reconstruct tracks. When good track is found, check clusters in L1
- Data: Run52 and Run89
- L1 alignment correction and L0L2 slope re-centering applied before event selection

Tracking	Events with clone hits found are discarded	
	Single cluster in Selected Column (SC) of L0 (abbr. SCL0) and L2 (abbr. SCL2) required	
	For three layers, require no cluster in adjacent columns (SC-1 & SC+1)	
Track QA	Edge exclusion	(ladder bottom edge + 8 ch) < Y-pos of SCL0 and SCL2 < (ladder top edge - 8 ch)
	Cluster ADC	Cluster Adc of SCL0 > adc0 && Cluster Adc of SCL2 > adc0
	Slope cut	fabs(slope of SCL2 - SCL0) < 0.01
	Track pos.	Focus on beam spot region (Run52: -6 to 6 mm, Run89: -10 to 2 mm)
Good track classification	Residual	Smallest |CL1 - CL2&CL0 interpolation| < 0.7 mm

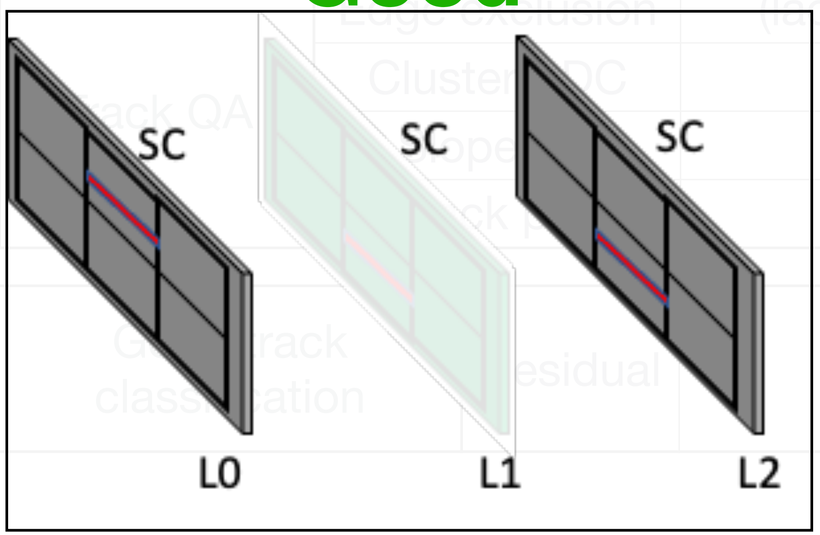
$$\text{Effi.} = \frac{\text{Good Events and L1 Good Cluster Found}}{\text{Good Events}} = \frac{N(L0 \bigcap L1 \bigcap L2)}{N(L0 \bigcap L2)}$$

Hit detection efficiency

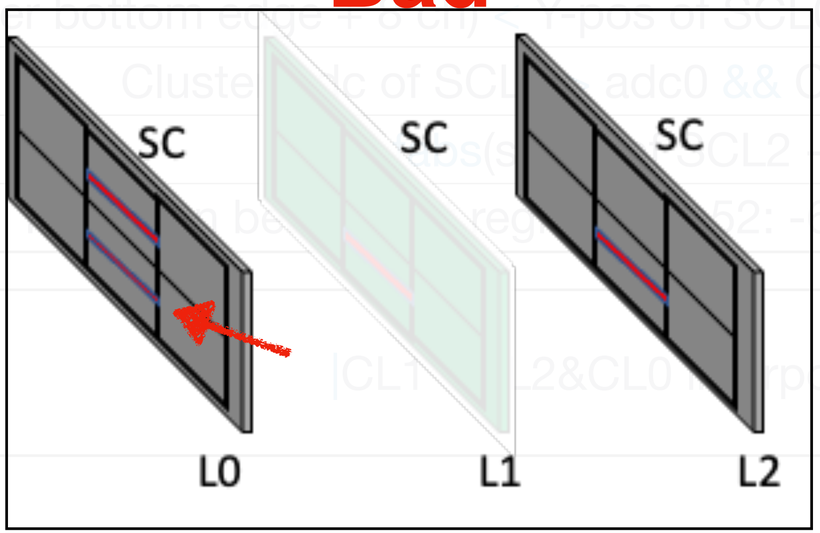
To minimize the ambiguity of track reconstruction
(Only two layers for track reco., to improve the purity, tight selection required)

Tracking	Single cluster in Selected Column (SC) of L0 (abbr. SCL0) and L2 (abbr. SCL2) required

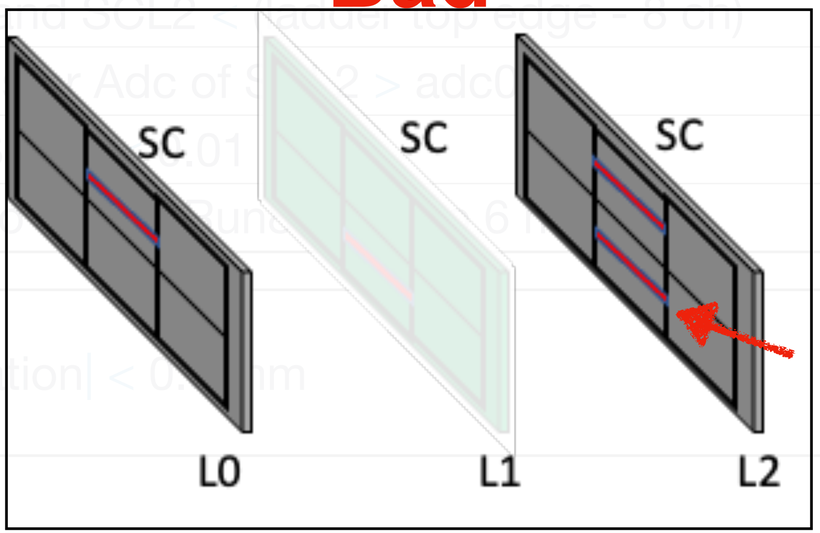
Good



Bad



Bad



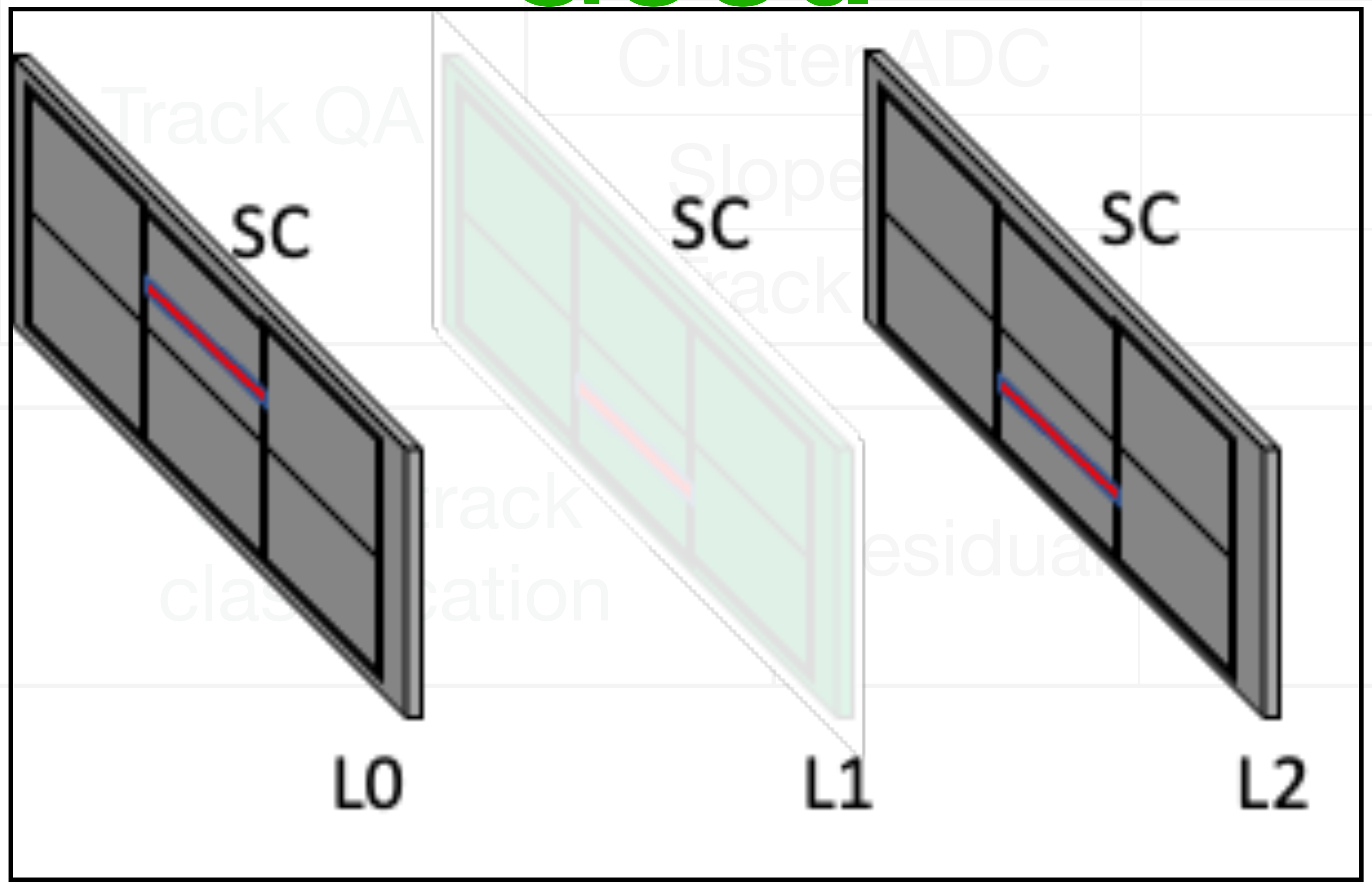
Hit detection efficiency

- Method: DUT approach (Detector Under Test)
  - Use L0 and L2 to reconstruct tracks. When good track is found, check L1
- Data: Run52, Column U8. Events with clone hit are discarded
- L1 mis-align

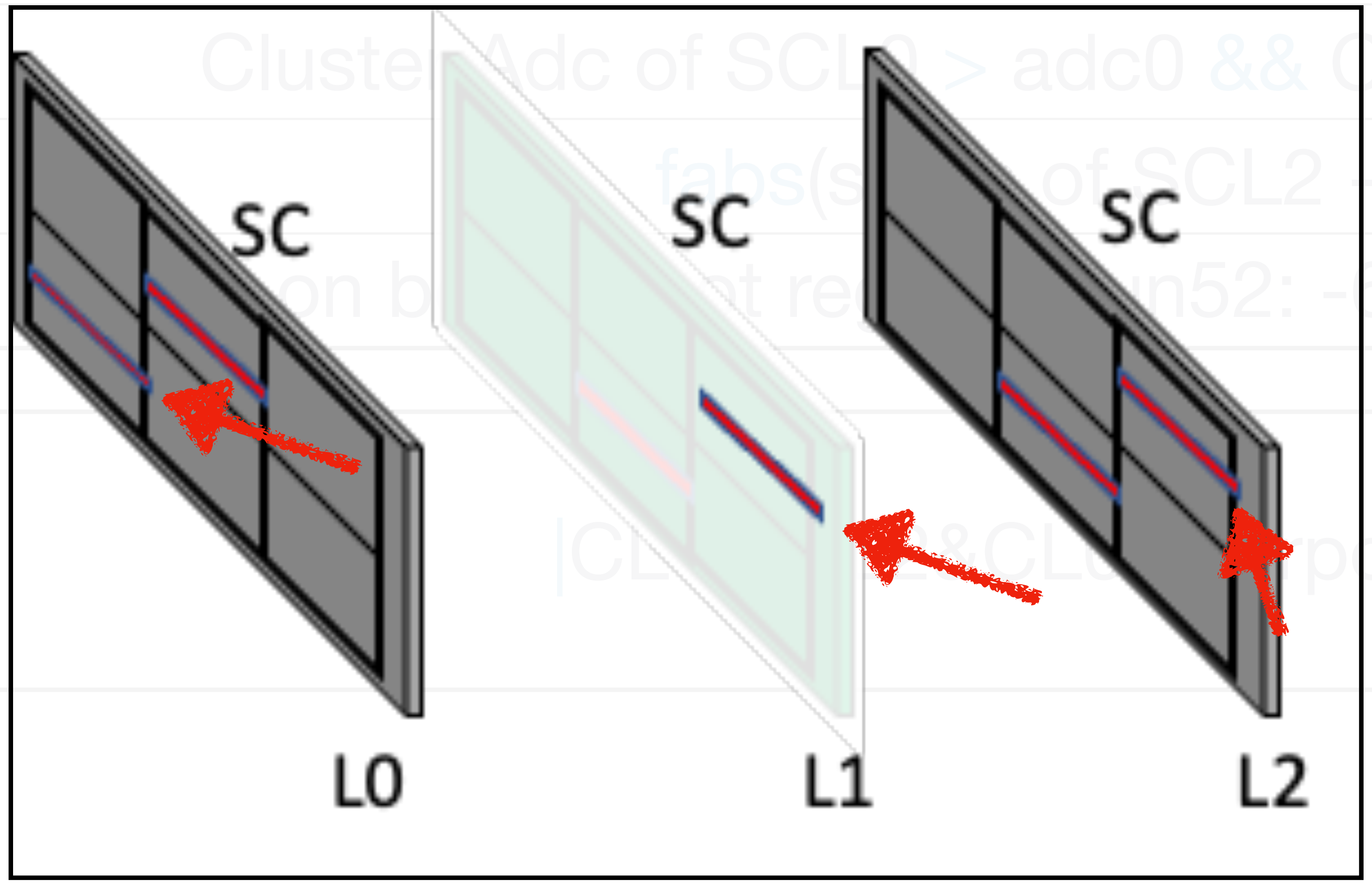
To account for the misalignment in the longitudinal axis (x axis)

Tracking	Events with clone hits found are discarded
	Single Cluster in Selected Column (SC) of L0 (abbr. SCL0) and L2 (abbr. SCL2) required
	For three layers, require no cluster in adjacent columns (SC-1 & SC+1)

Good



Bad



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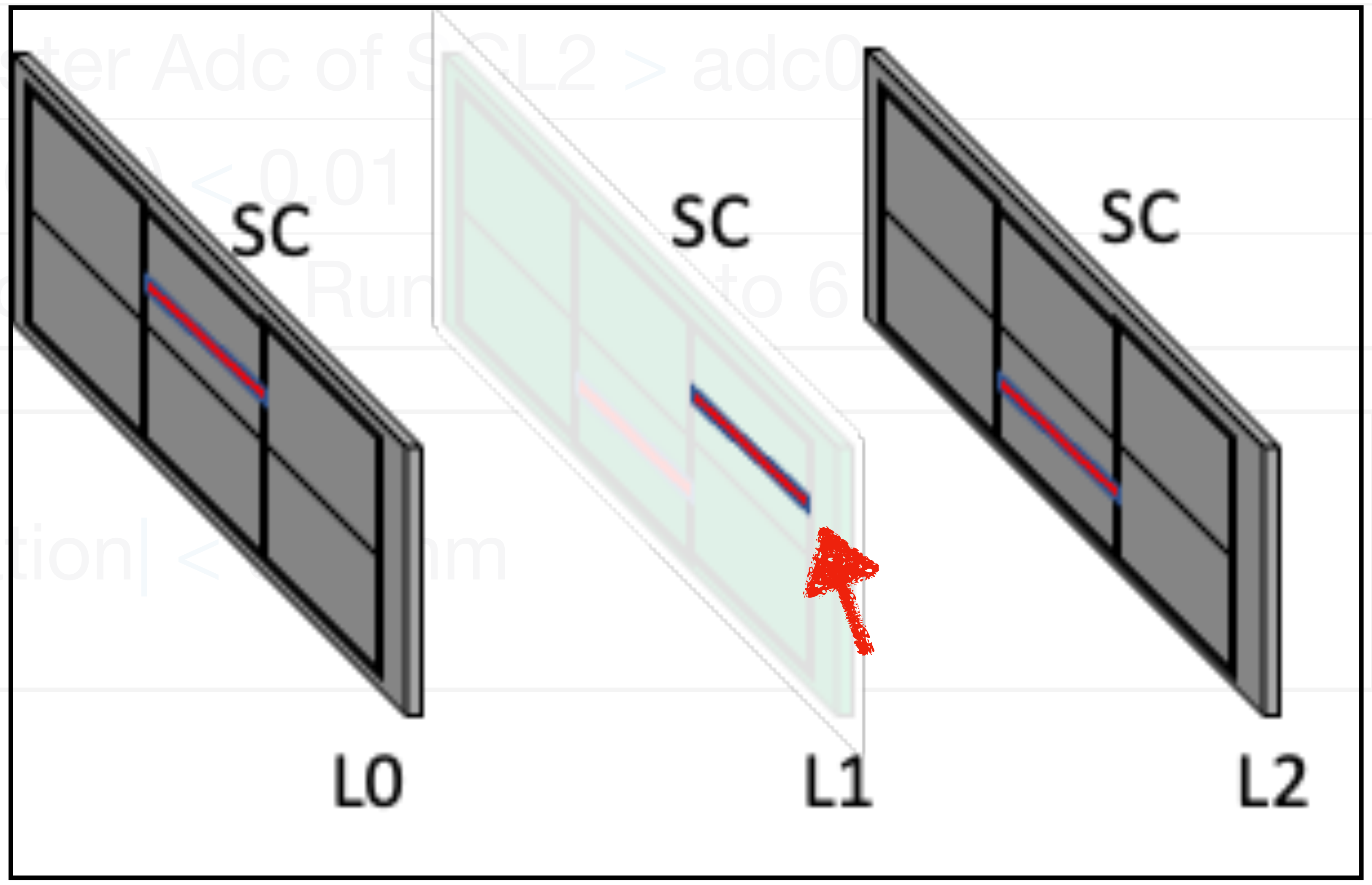
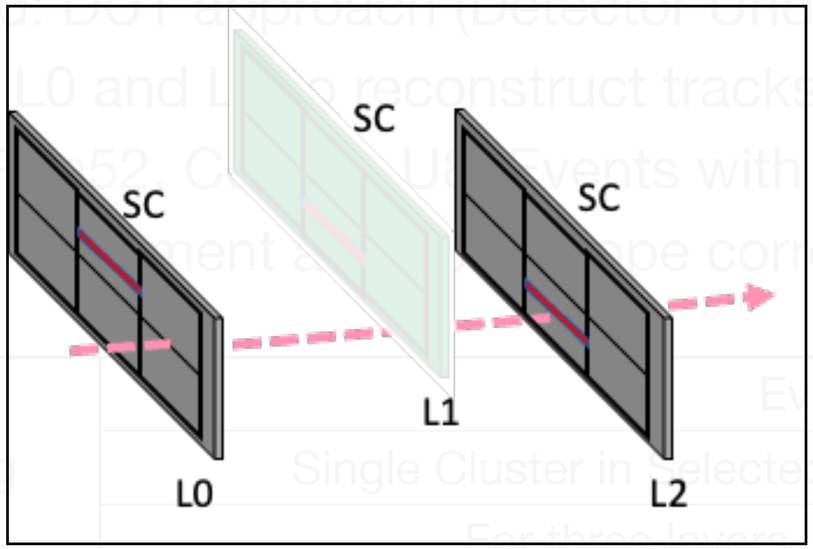
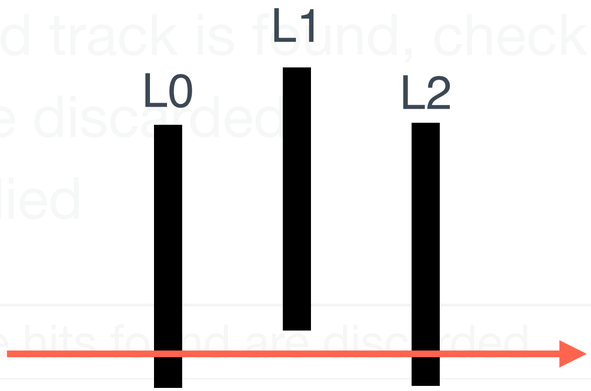


Hit detection efficiency





	Edge exclusion	(ladder bottom edge + 8 ch) < Y-pos of SCL0 and SCL2 < (ladder top edge - 8 ch)

To account for the misalignment in the transverse axis (y axis)

Hit detection efficiency

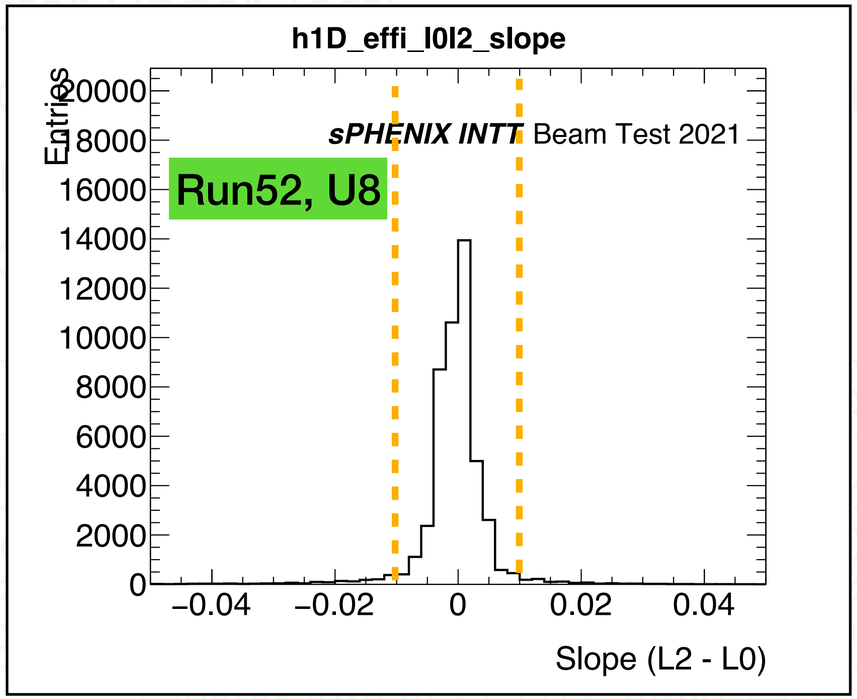
- Method: DUT approach (Detector Under Test)
  - Use L0 and L2 to reconstruct tracks. When good track is found, check L1
- Data: Run52, Column U8. Events with clone hit are discarded
- L1 mis-alignment and L0L2 slope corrections applied

To minimize tracks reconstructed by noise hits

(Only two layers for track reco., to improve the purity, tight selection required)

Tracking	Layer requirement	Single Cluster in Selected Column (SC) of L0 (abbr. SCL0) and L2 (abbr. SCL2) required
		For three layers, require no cluster in adjacent Columns (SC-1 & SC+1)
Track QA	Edge exclusion	(ladder bottom edge + 8 ch) < Y-pos of SCL0 and SCL2 < (ladder top edge - 8 ch)
	Cluster ADC	Cluster Adc of SCL0 > adc0 && Cluster Adc of SCL2 > adc0
	Slope cut	fabs(slope of SCL2 - SCL0) < 0.01
	Track pos	Focus on beam spot region (Run52: -6 to 6 mm, Run89: -10 to 6 mm)
Good track classification	Residual	|CL1 - CL2&CL0 interpolation| < 0.5 mm

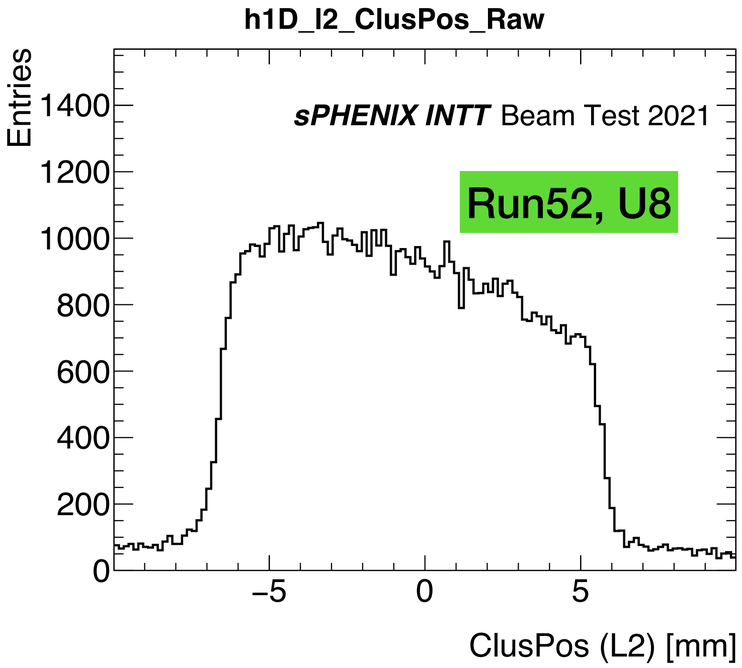
Hit detection efficiency

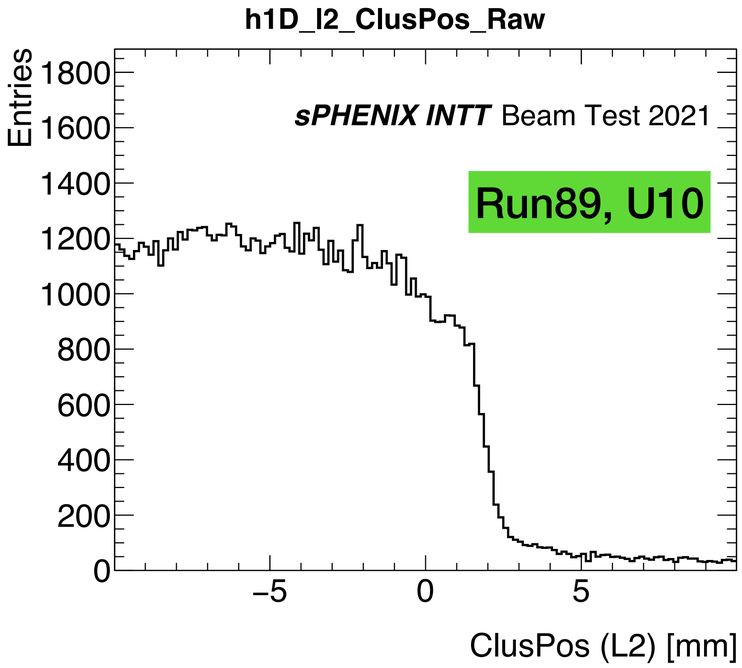


Track QA	Slope cut	fabs(slope of SCL2 - SCL0) < 0.01

To make sure that reco. tracks are coming from the beam

Hit detection efficiency





	Track pos.	Focus on beam spot region (Run52: -6 to 6 mm, Run89: -10 to 2 mm)

To make sure that reco. tracks are coming from the beam

The last criterion for the event selection

(Events that pass this one are then considered as Good Events, the denominator)

Hit detection efficiency

- Method: DUT approach (Detector Under Test)
  - Use L0 and L2 to reconstruct tracks. When good track is found, check L1
- Data: Run52, Column U8. Events with clone hit are discarded
- L1 mis-alignment and L0L2 slope corrections applied

Tracking	Events with clone hits found are discarded	
	Single Cluster in Selected Column (SC) of L0 (abbr. SCL0) and L2 (abbr. SCL2) required	
	For three layers, require no cluster in adjacent columns (SC-1 & SC+1)	
Track QA	Edge exclusion	(ladder bottom edge + 8 ch) < Y-pos of SCL0 and SCL2 < (ladder top edge - 8 ch)
	Cluster ADC	Cluster Adc of SCL0 > adc0 && Cluster Adc of SCL2 > adc0
	Slope cut	fabs(slope of SCL2 - SCL0) < 0.01
	Track pos	Focus on beam spot region (Run52: -6 to 6 mm, Run89: -10 to 6 mm)

When Good Event is found, then check clusters in L1

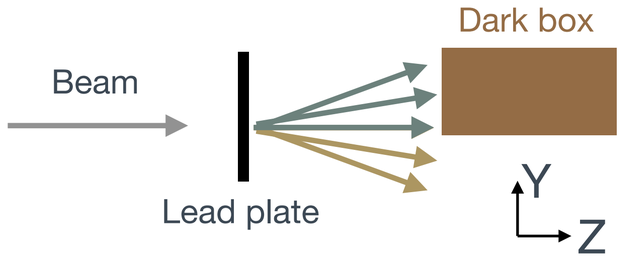
Good track classification	Residual	smallest |CL1 - CL2&CL0 interpolation| < 0.7 mm

$$\text{Effi.} = \frac{\text{Good Events and L1 Good Cluster Found}}{\text{Good Events}} = \frac{N(L0 \bigcap L1 \bigcap L2)}{N(L0 \bigcap L2)}$$

Number of reco. tracks compared to MC

- Data Run64 (thin lead plate in between beam and INTT telescope)

- Method:
  - Track reconstruction performed by looping over clusters of three layers in each column
  - The combination quality is evaluated by fitting the clusters with slope line. The combination with the smallest reduced chi-square is checked
  - **Good reco. track: Residual (L1 - L2L0 interpolation) < 0.7 mm**
  - One column could have more than one reconstructed track in one event
  - Single cluster can only be involved in one track
  - All 13 columns are checked



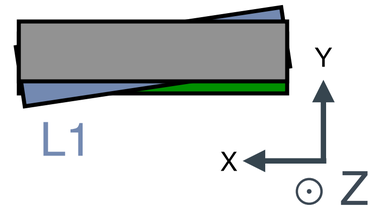
- Key correction: L1 alignment correction for all 13 columns

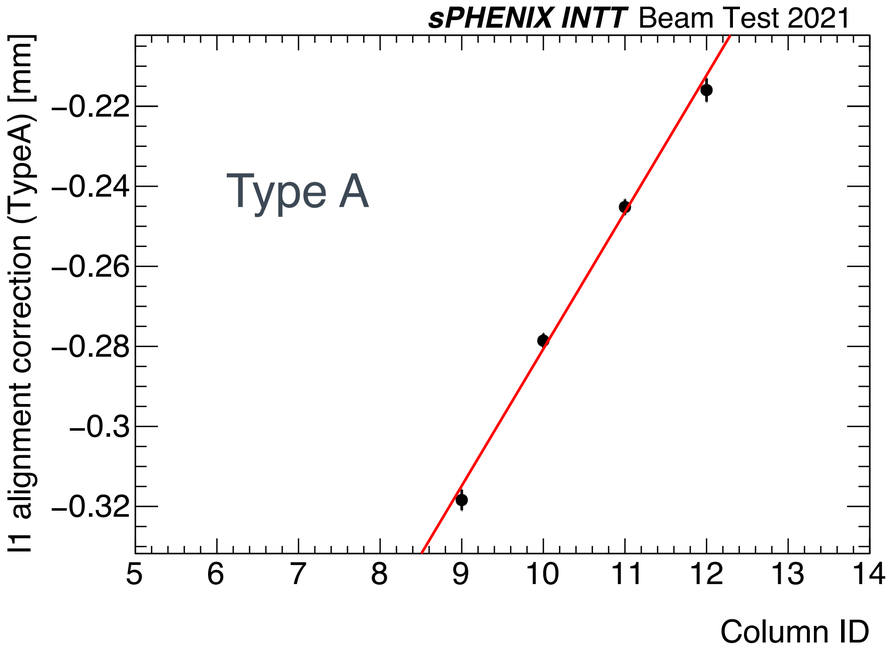
- In data, events with clone hit are discarded

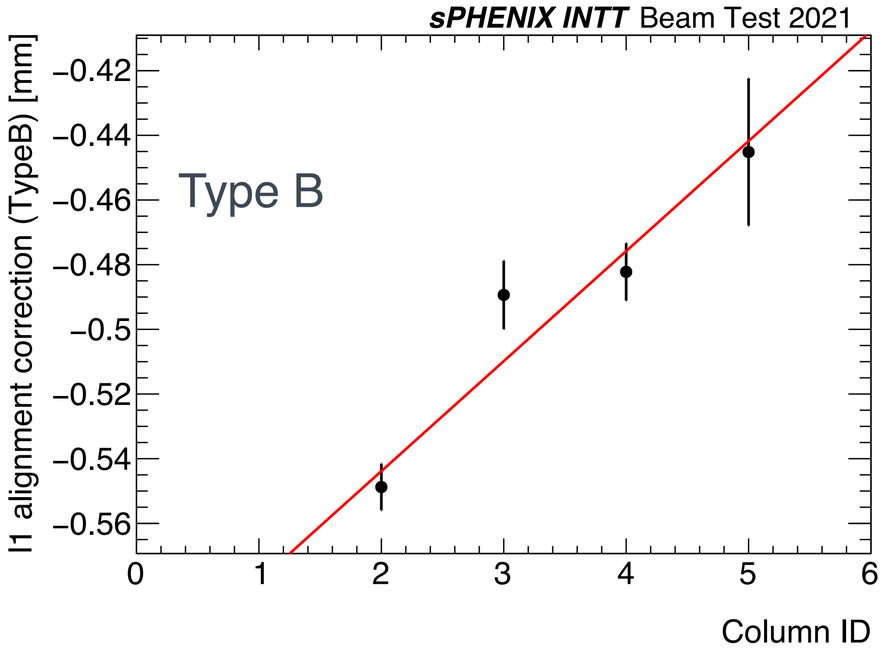
Number of reco. tracks compared to MC

- In **Data**: L1 alignment correction for all 13 columns
  - By fitting method (each column has different L1 alignment correction)
    - Beam spot not wide enough to coverage the whole ladder
  - The ladder L1 is slightly tilted in the Z axis with respect to L0&L2

*Not to scale





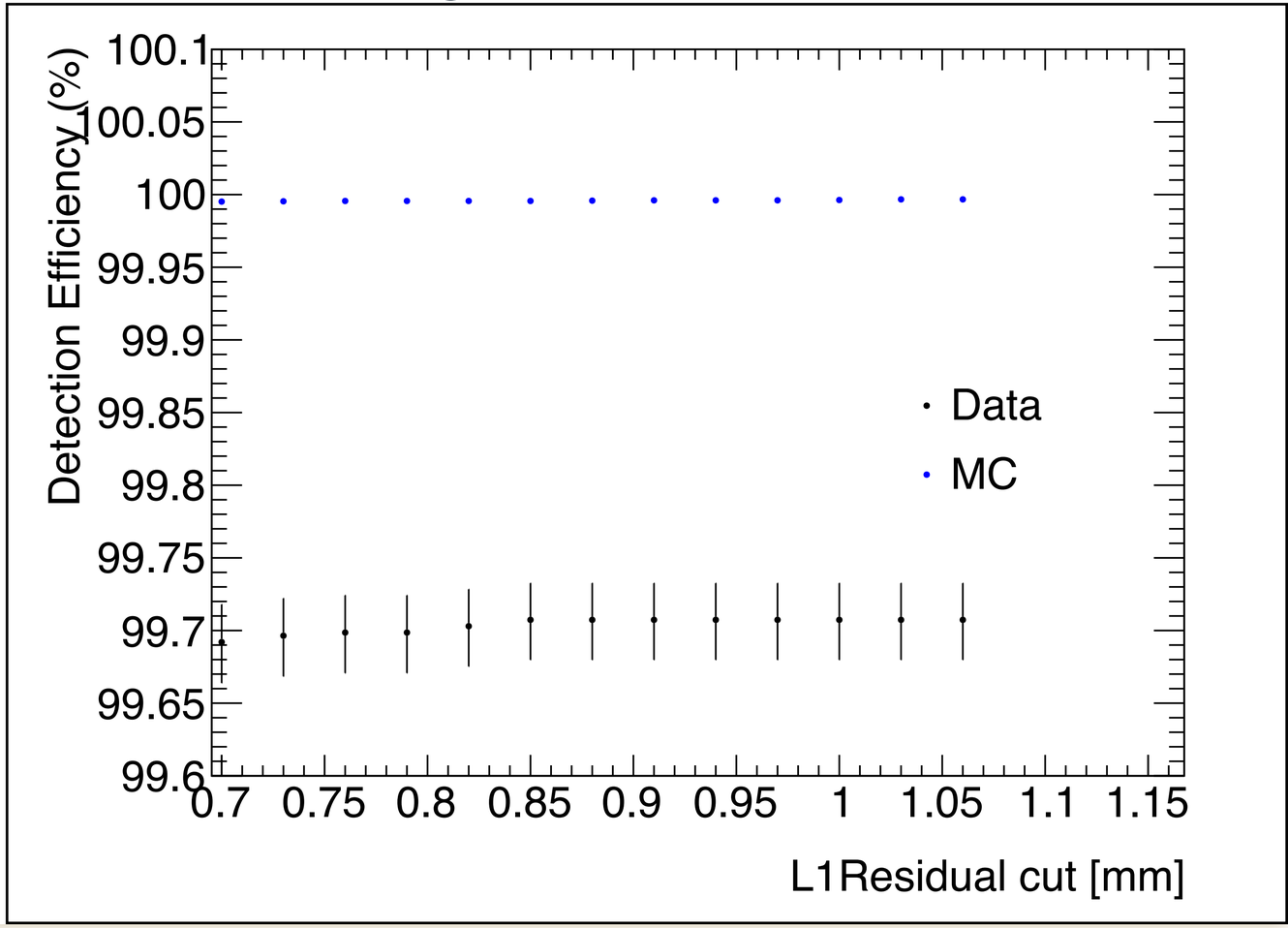


- In **Simulation**: No L1 rotation, correction for all columns given by average of L1 alignments measured by columns U9, U10 and U11 (beam spot region)

The update of the residual cut for hit detection efficiency

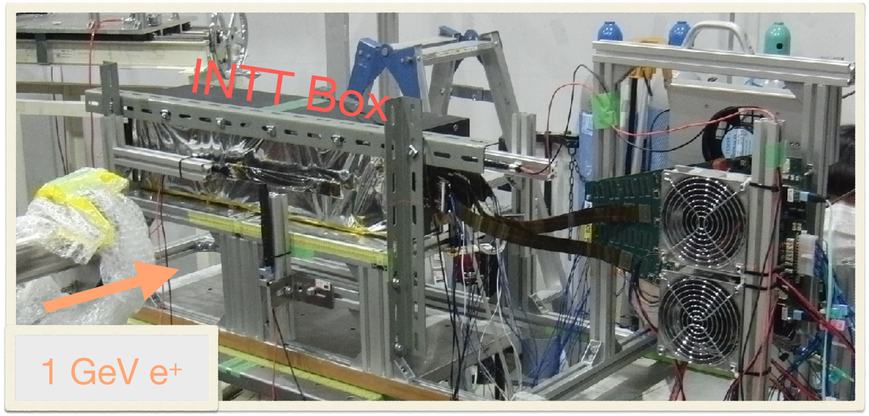
- All Simulation points (blue circles) are with the detection efficiencies above 99.995% in the given range (residual cut from 0.7 mm to 1.0 mm), and the statistical errors of blue circles are in the order of 0.001%, which are marginal
- I therefore conclude that the residual cut should be in the range of 0.7 mm to 1.0 mm

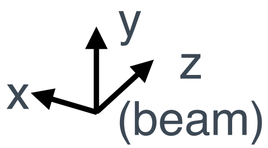
- Procedures:
  - In data, measure the detection effi. with L1 residual cut of 0.7, 0.85, 1.0 mm (to cover the control region)
  - Set the effi. value with residual cut of 0.85 to be the baseline
  - The variation of effi. values with residual cut of 0.7 and 1.0 mm comparing to baseline would be the systematic uncertainty (which would be very close to zero according to the black circles)
  - **No correction applied to data**
    - Since the Simulation shows over the 99.995% detection efficiency in the given region
    - (The Simulation is used to obtain the range of the proper residual cut)

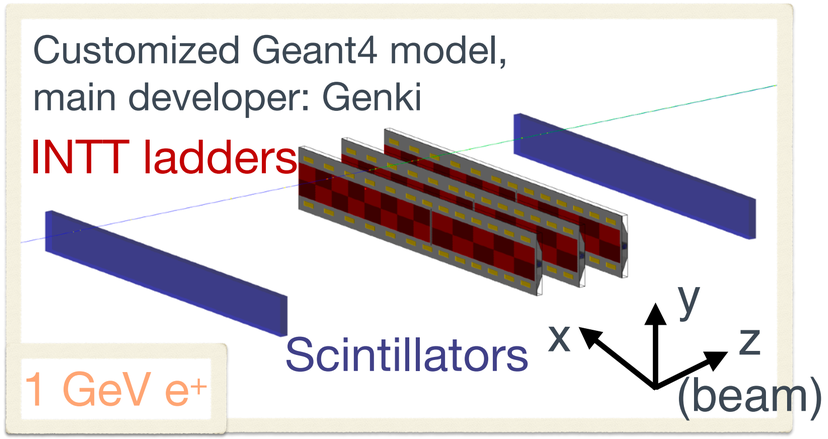


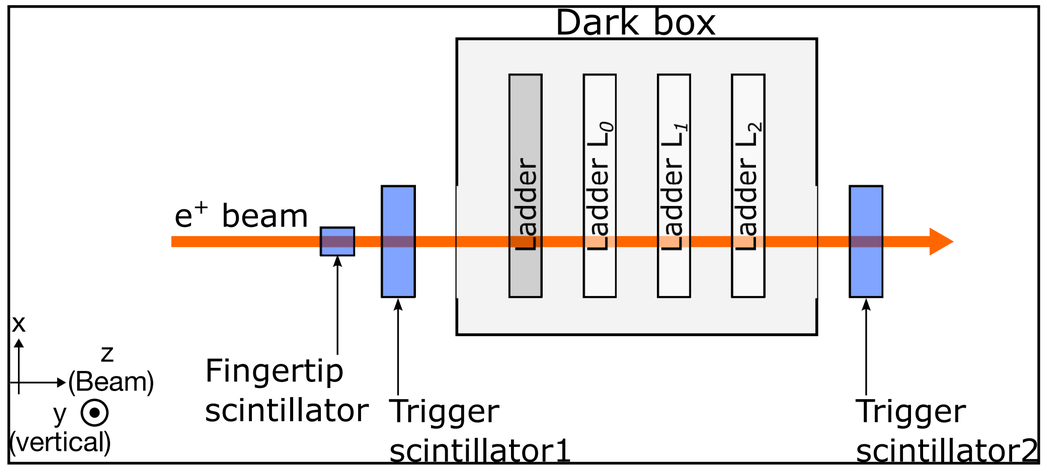
General information

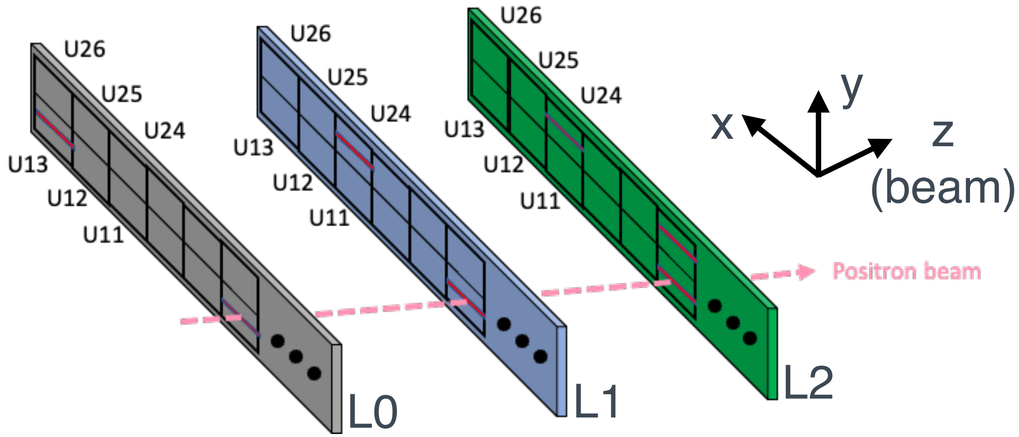
- A beam test experiment was performed at the end of 2021, ELPH, Japan
  - Four ladders were placed in the dark box
    - First ladder deactivated due to light leakage
  - Beam time: 2021/Dec/07 to 2021/Dec/10
- Positron beam with energy of 1000 MeV was used
- Main goal: ladder hit detection efficiency











Y axis in beam test corresponds to the ϕ axis at 1008-IR

Overview (obsolete)

- The analyses of the following topics are completed, improved and reproducible, and to be included in the paper
  - Energy deposit distribution (DAC Scan, Run71-Run78)
    - Systematic uncertainty accounts for different ways to match distributions
  - Scattering distribution compared with MC (Run52)
  - Hit detection efficiency (Run52 and Run89)
    - Re-estimate the systematic uncertainties
    - Two runs combined
  - Number of reconstructed tracks compared with MC (Run64)
    - With lead plate in between beam and the INTT telescope

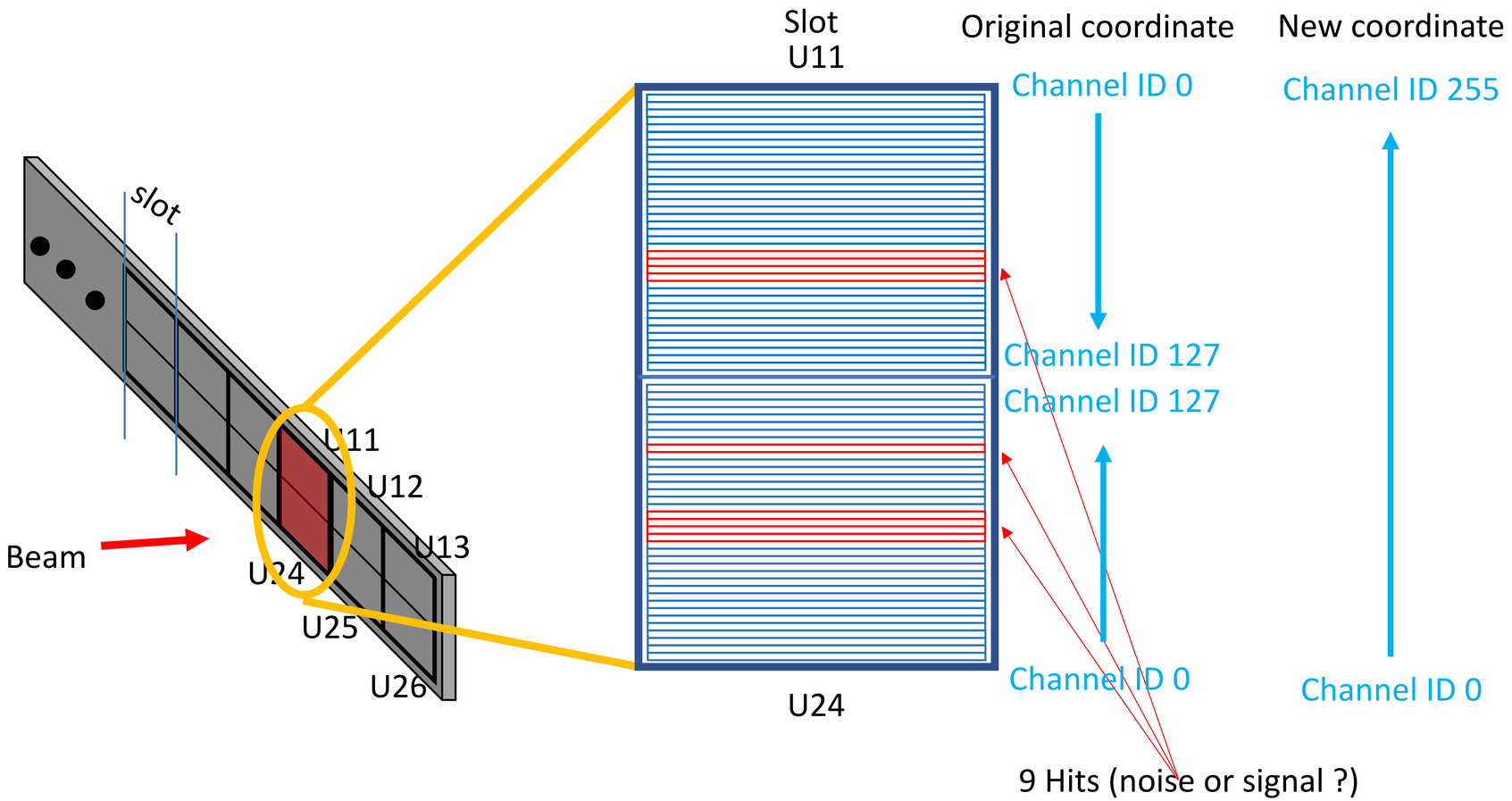
- The results are consistent with what presented in the past

- Analysis note:
  - **INTT_BeamTest_AN_v1.pdf:** https://indico.bnl.gov/event/28070/contributions/107263/attachments/61693/105917/INTT_BeamTest_AN_v1.pdf
  - **Overleaf project:** https://www.overleaf.com/read/ttchfvmcrppt#6156dc
- Analysis code: https://github.com/ChengWeiShih/Final_BeamTest2021_Publication
- Target Journal: Nuclear Instruments and Methods (NIM)

Clustering - 1

Clustering was performed column by column

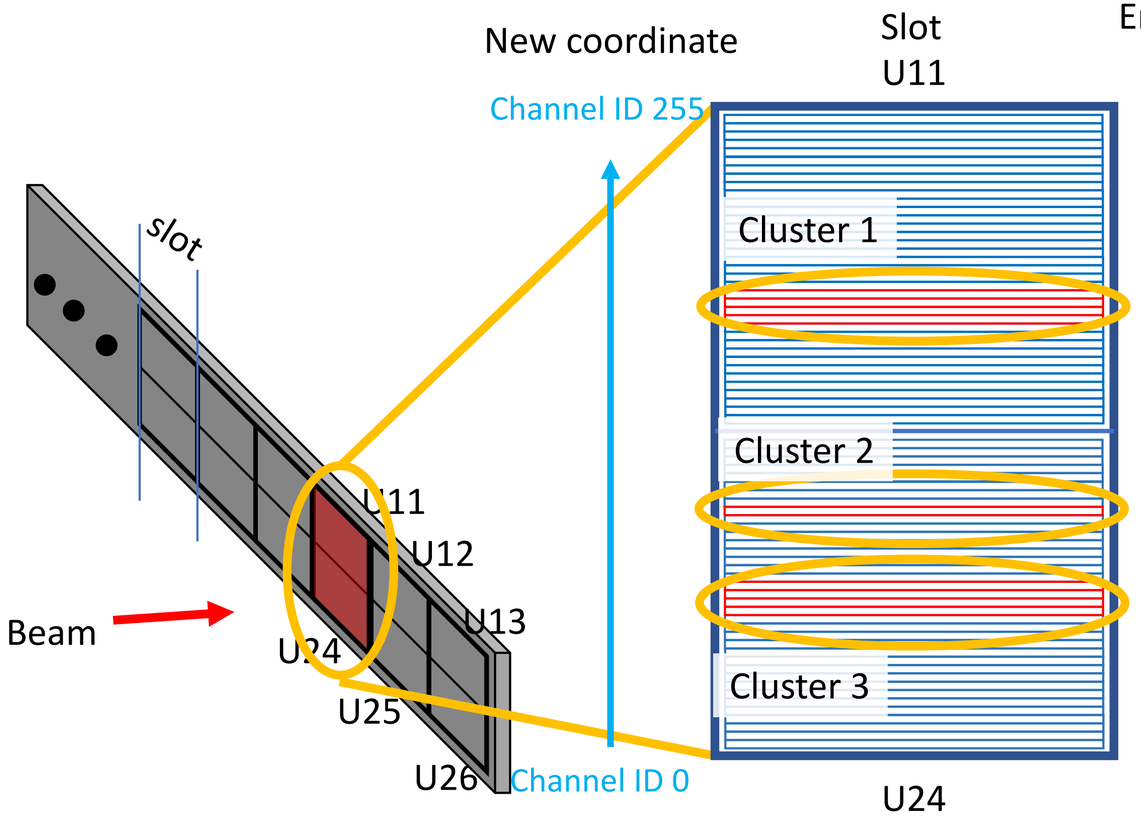
Tracking algorithm



Clustering - 2

Clustering was performed column by column

Tracking algorithm



Energy-weighted method is applied

$$P_j^l = \frac{\sum_n C_n E_n}{\sum_n E_n}$$

C_n : position (mm) in y-axis of channel n in cluster

E_n : energy deposit of channel n in cluster

P_j : final position in y-axis of cluster j

Cluster : the adjacent channels

	Cluster 1	Cluster 2
Chan_id :	3 4 5 6	8 9 10

reduce

9 fired-channels -> 3 positions

DAC Scan table

RunNumber	adc0	adc1	adc2	adc3	adc4	adc5	adc6	adc7
71	88	92	96	100	104	108	112	116
72	108	112	116	120	124	128	132	136
73	128	132	136	140	144	148	152	156
74	148	152	156	160	164	168	172	176
75	8	12	16	20	24	28	32	36
76	28	32	36	40	44	48	52	56
77	48	52	56	60	64	68	72	76
78	68	72	76	80	84	88	92	96

Table 1: The threshold settings used for the DCA-scan runs.