Beam Test analysis for publication (Approval presentation)

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INTT meeting

sPHENIX INTT

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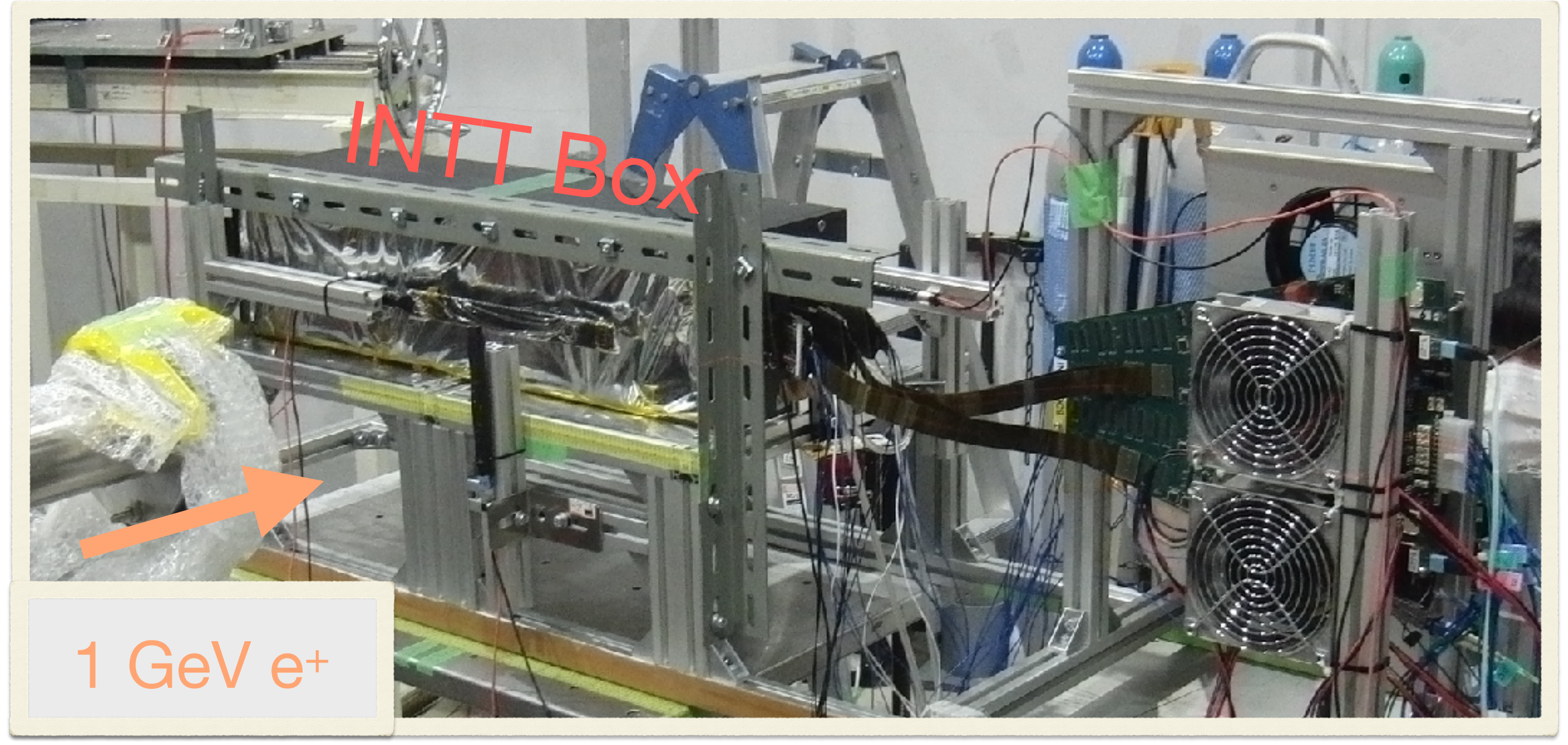
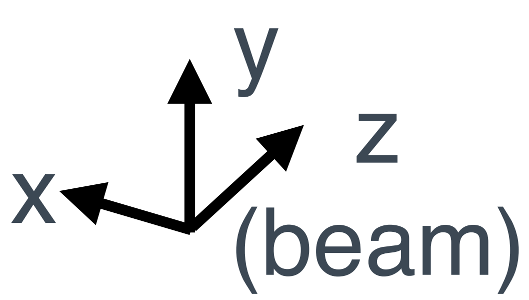
National Central University

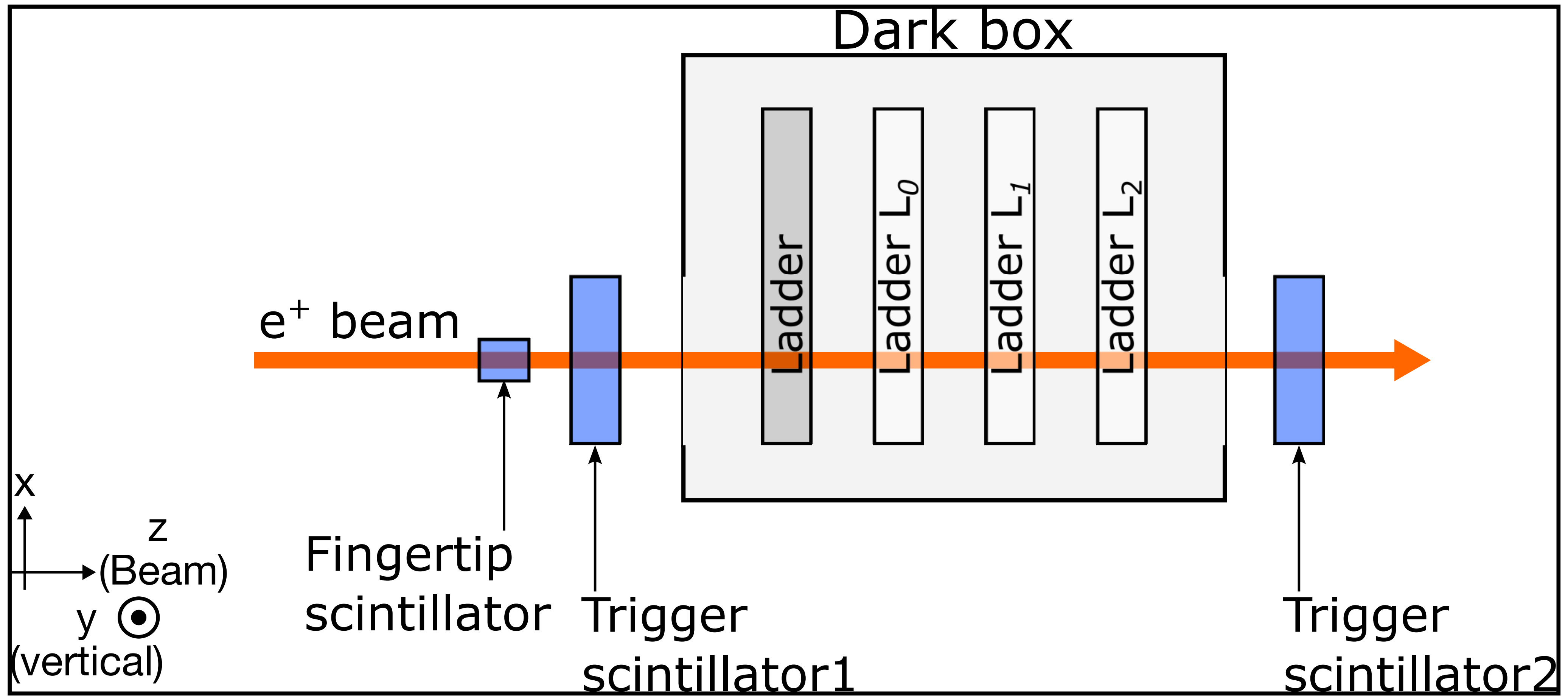
RIKEN

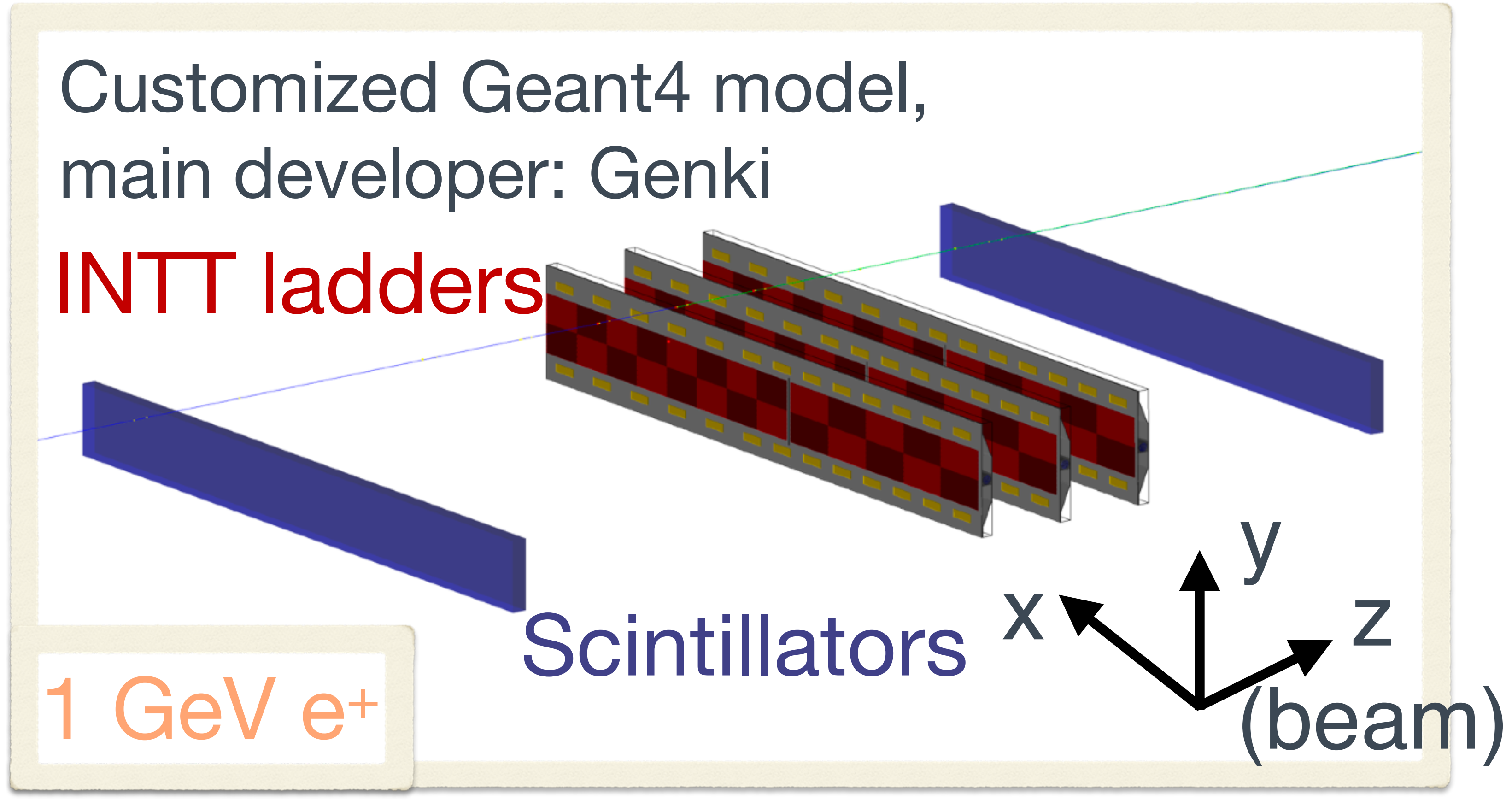
General information

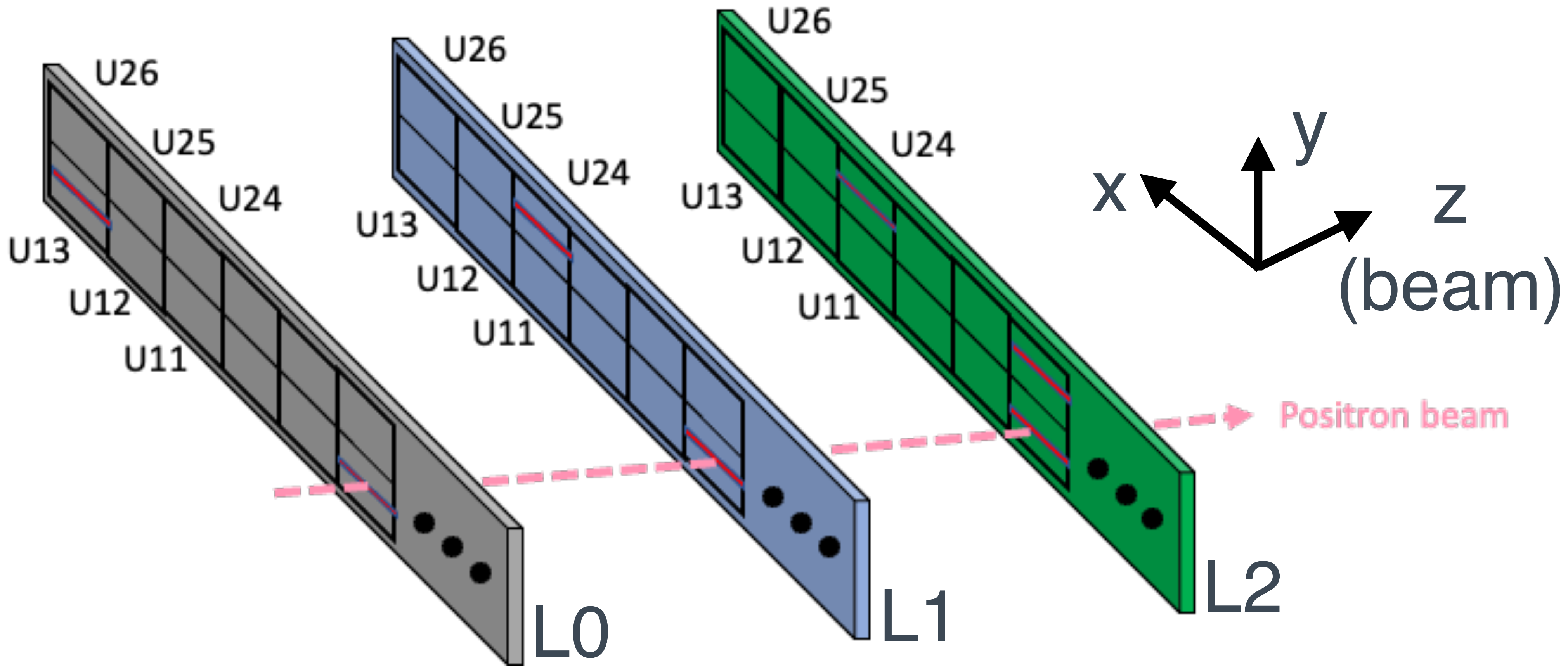
- A beam test experiment was performed at the end of 2021, ELPH, Japan
  - Four ladders were placed in the dark box
    - First ladder deactivated due to light leakage
  - Beam time: 2021/Dec/07 to 2021/Dec/10
- Positron beam with energy of 800 MeV was used*
- Main goal: ladder hit detection efficiency











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

*Beam energy has been confirmed with the ePIC ZDC beam test TW team

Overview

- 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

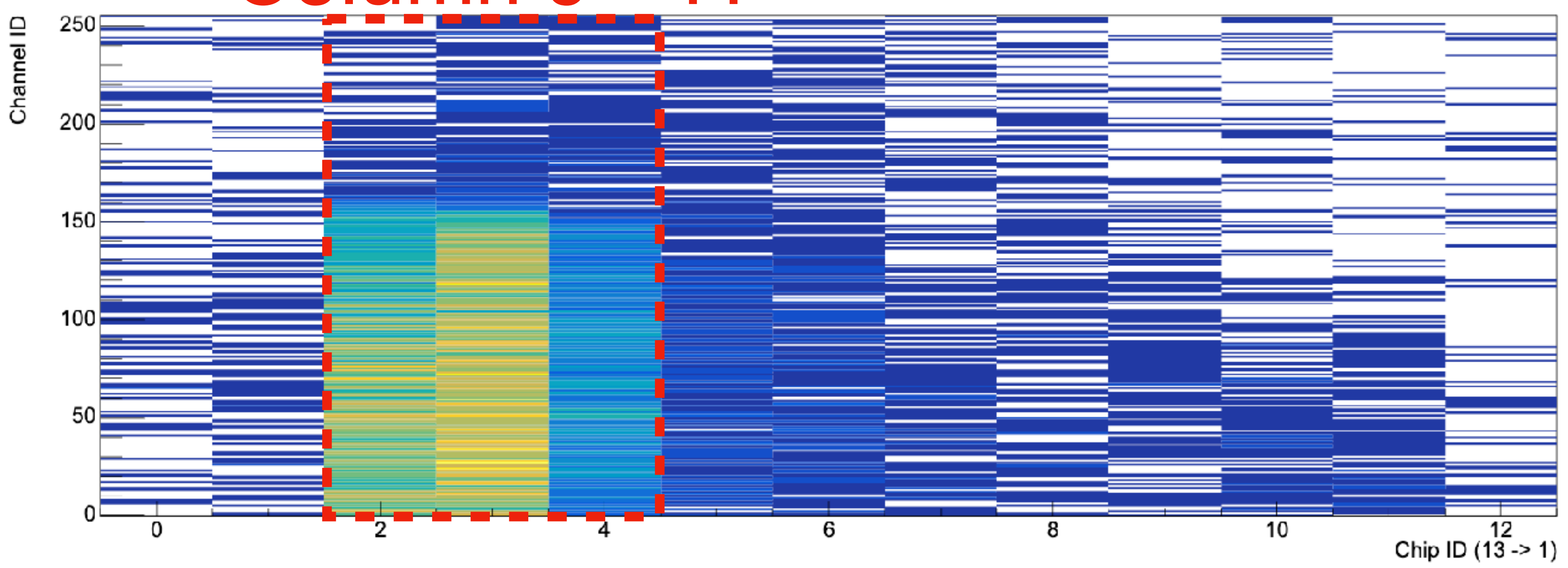
- The results are consistent with what presented in the past

- 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)

DAC Scan - the matrices

- Run 71 - 78 (total coverage: 8 to 176 with the span of 4 adc)
- Requiring single cluster or no cluster in each layer (inclusive to location, and cluster size)
- Clone-hit events removed
- Columns within beam-spot region selected (Column9, 10, 11)
- Single-hit clusters selected
- Overflow bin (bin 8th) removed in each scan

Column 9 - 11

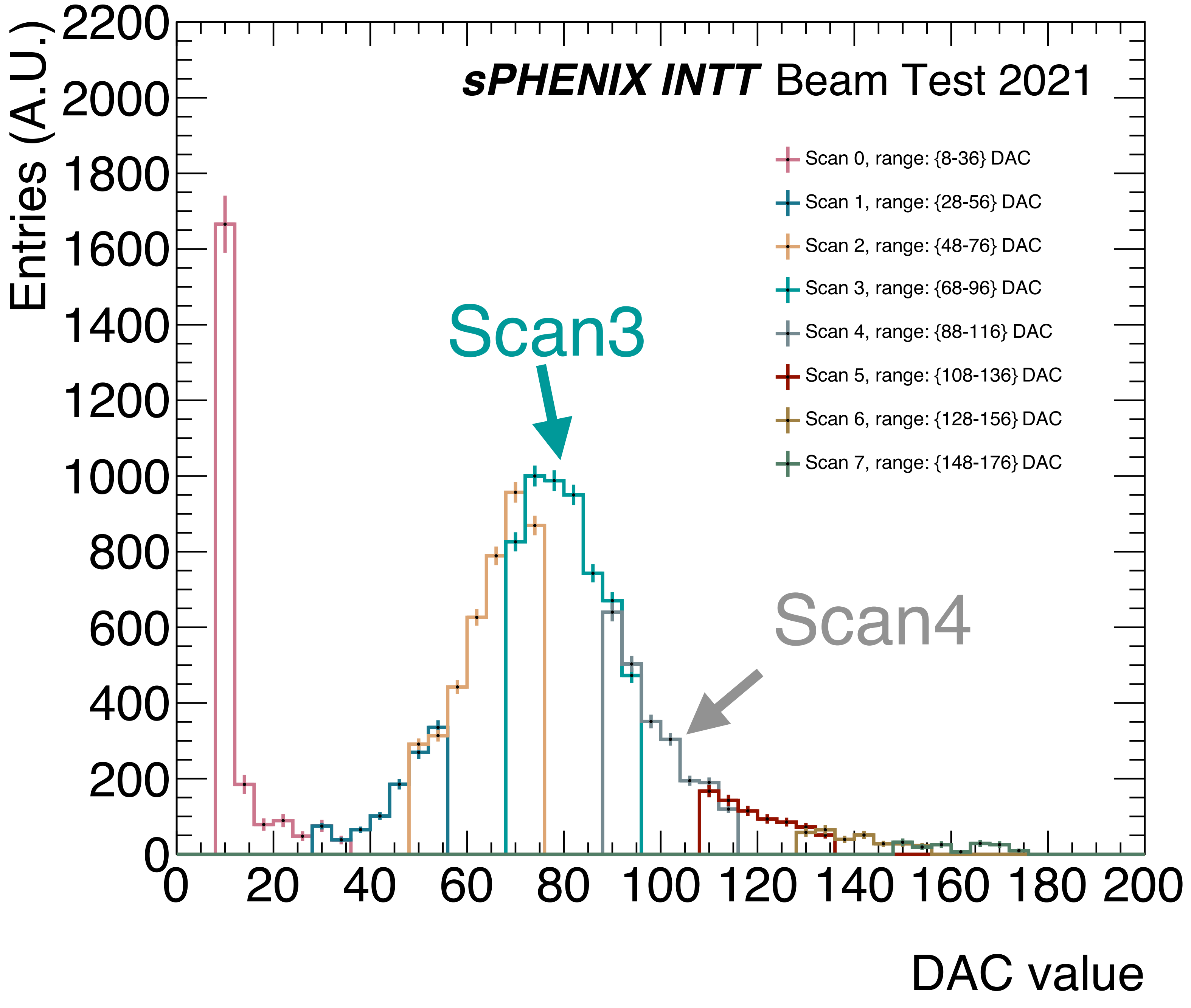


L0 L1 L2

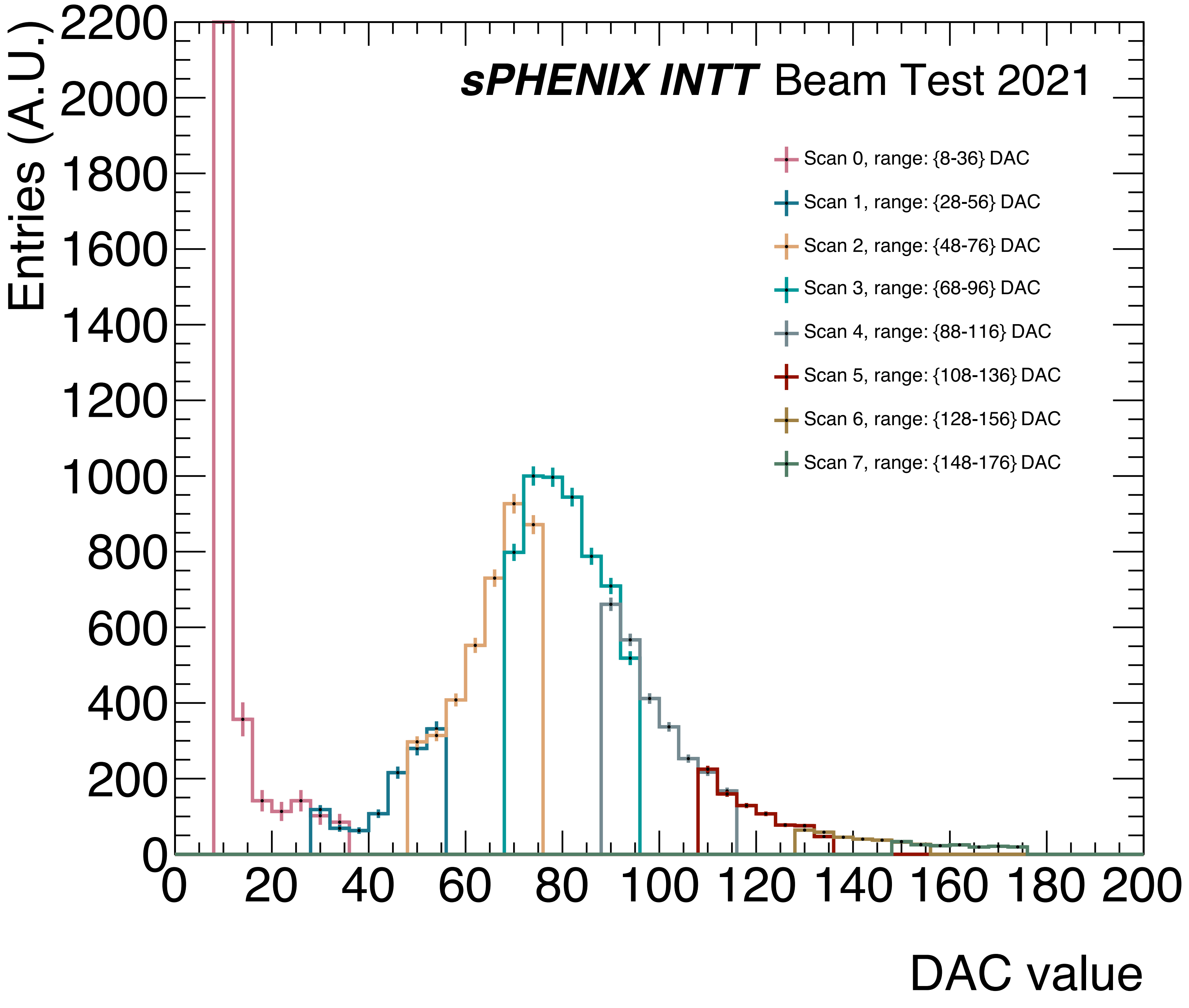
DAC Scan - matching b/w scans

- In each scan, two bins overlapped with its following scan, which are used for matching
- Scan3 as reference, introducing scales to adjacent scans to match the distributions, sequentially
- Example: scale applied on Scan4 = $(Size^{Scan3}_{bin_6} + Size^{Scan3}_{bin_7})/(Size^{Scan4}_{bin_0} + Size^{Scan4}_{bin_1})$
- (Same method used previously)

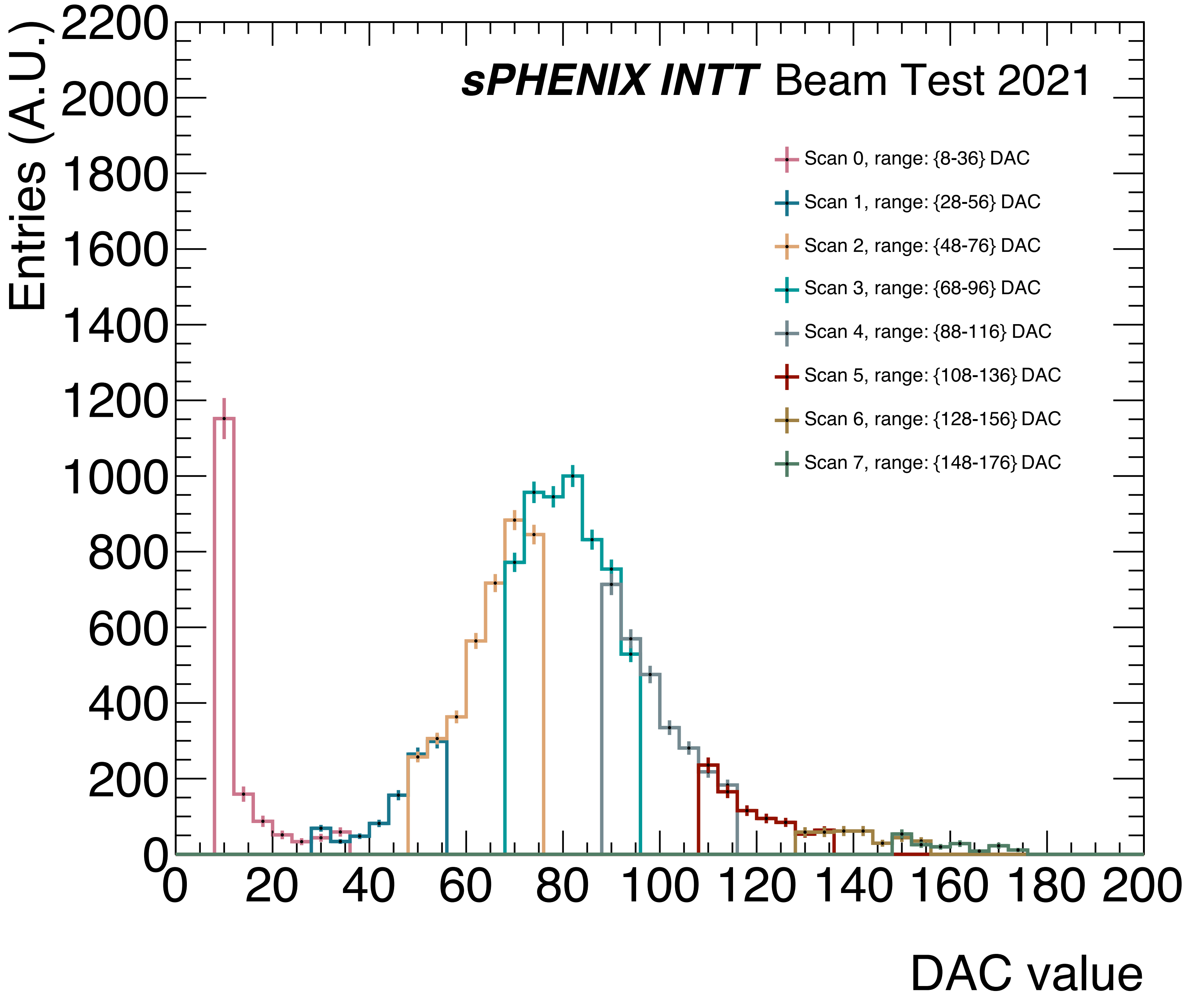
L0



L1

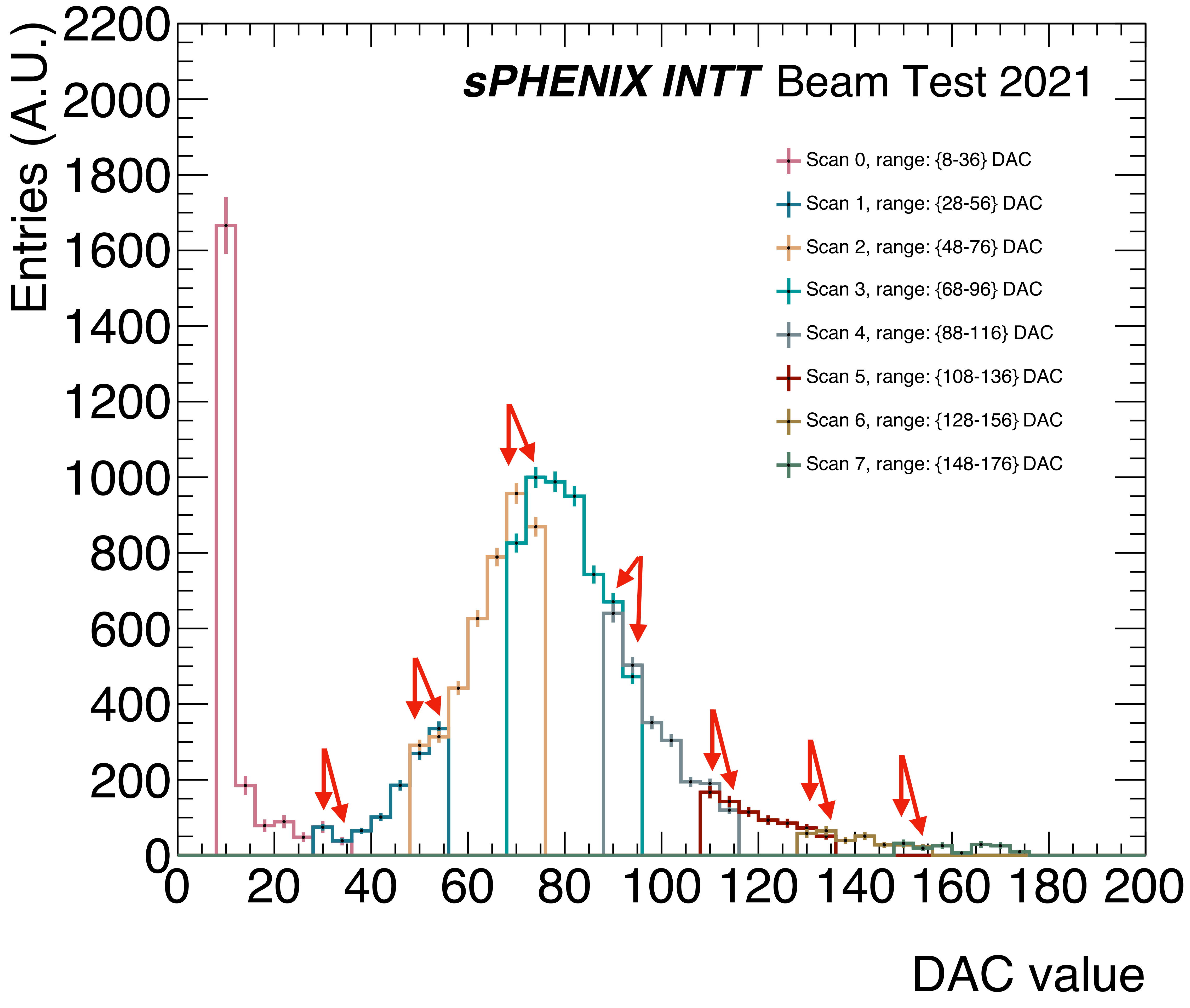


L2



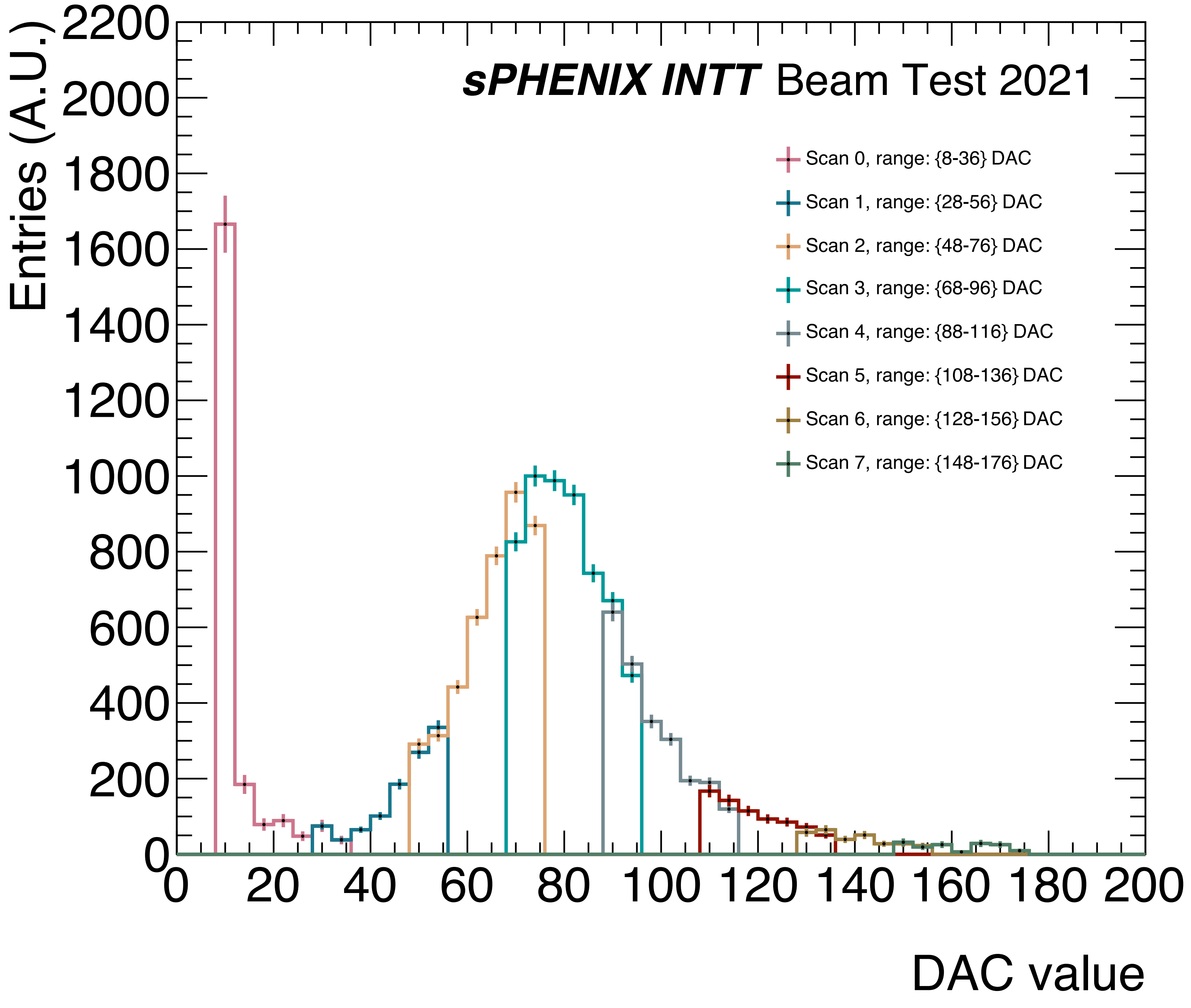
DAC Scan - Combine bins

- The overlap bins are statistically combined
- $$\bar{X} \pm \sigma_X = \frac{A \cdot w_A + B \cdot w_B}{w_A + w_B} \pm \sqrt{\frac{1}{w_A + w_B}}$$
- A: bin content of the bin1
- w_A : 1 / [(statistical error of bin1)²]
- B: bin content of the bin2
- w_B : 1 / [(statistical error of bin2)²]
- If reduced $\chi^2 > 1$, $\sigma_X \rightarrow \sigma_X \cdot \sqrt{\chi^2/NDF}$
  - Method introduced by PDG
  - NDF: 2 -1 = 1

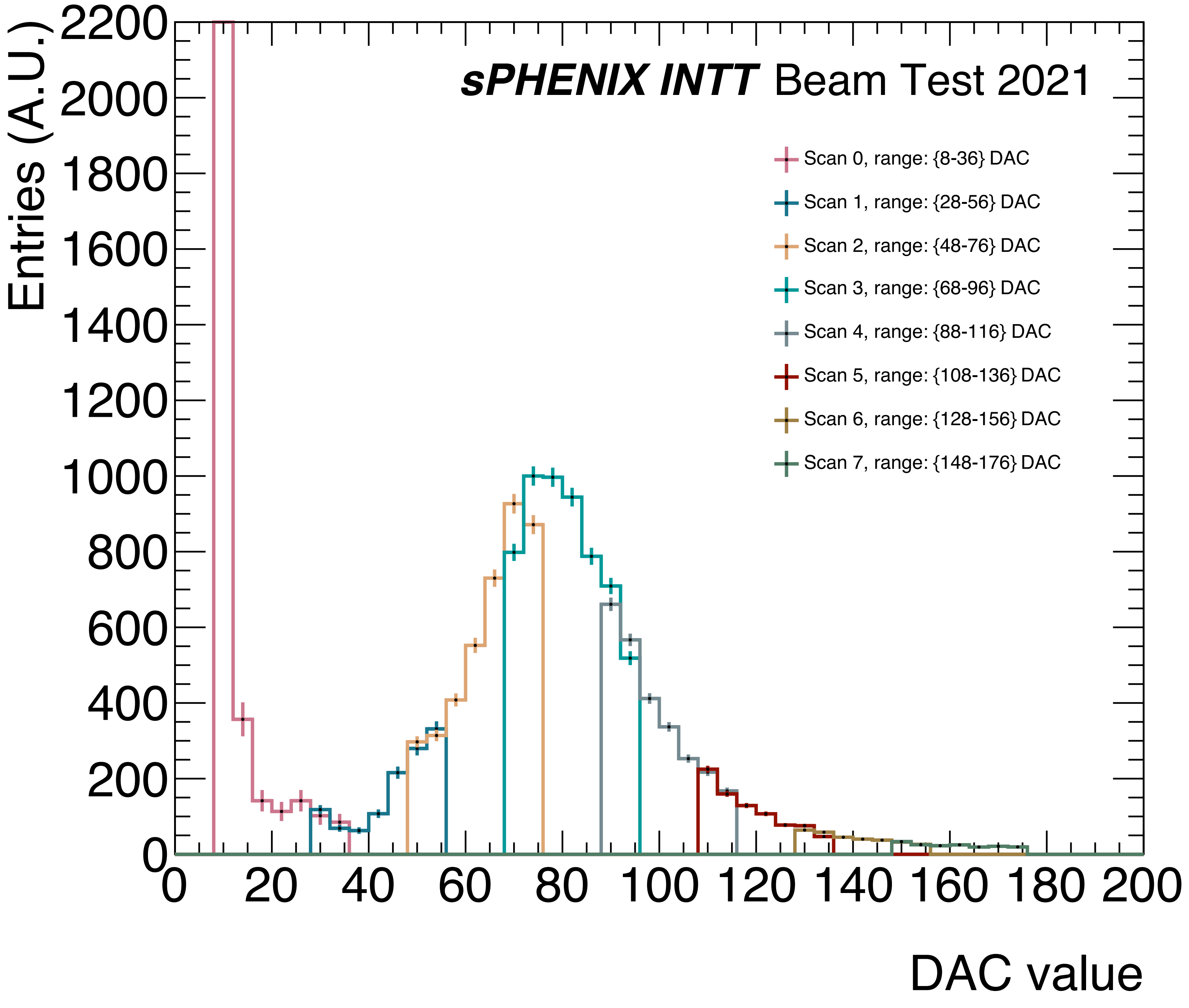


DAC Scan - matching b/w scans

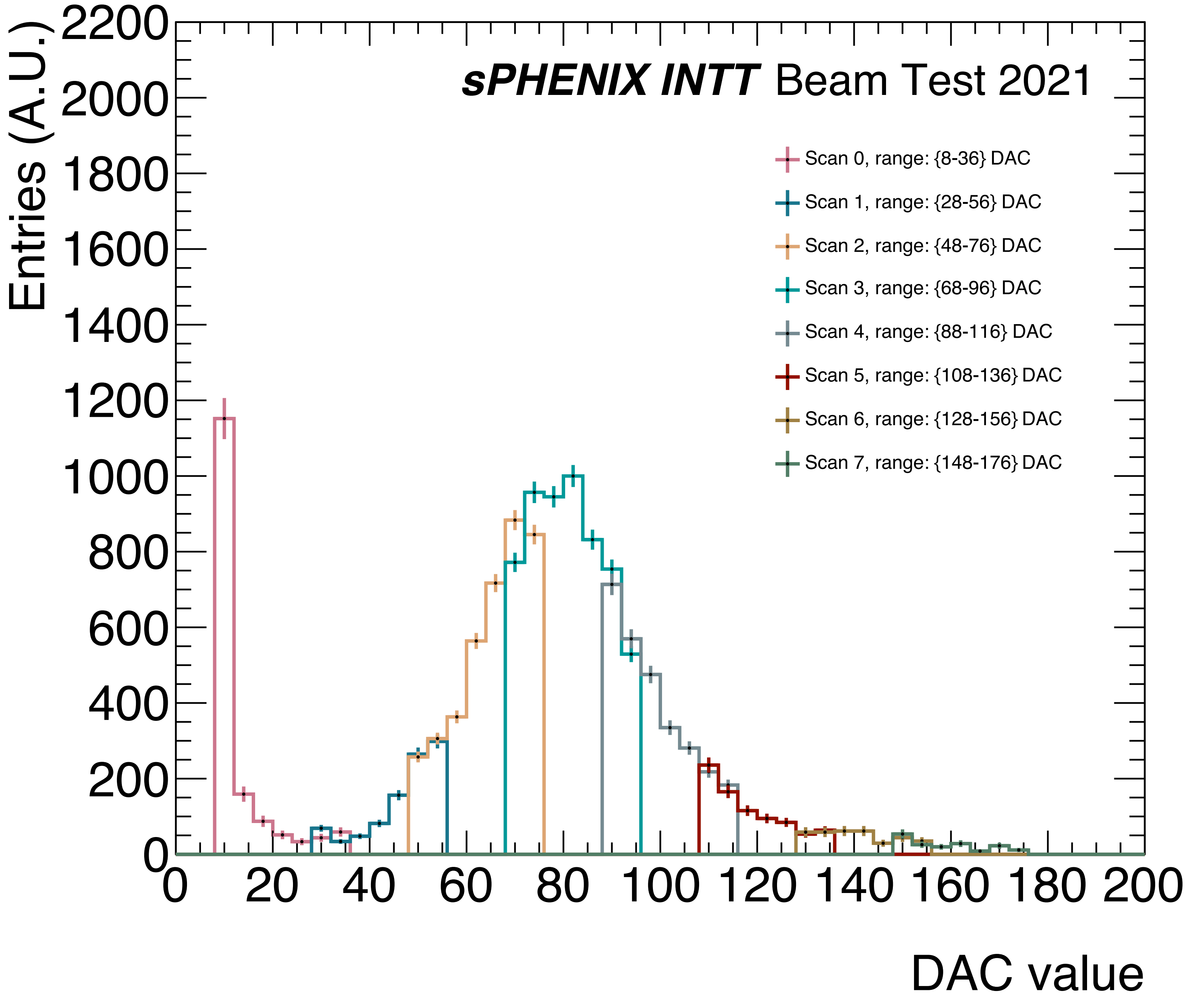
L0



L1



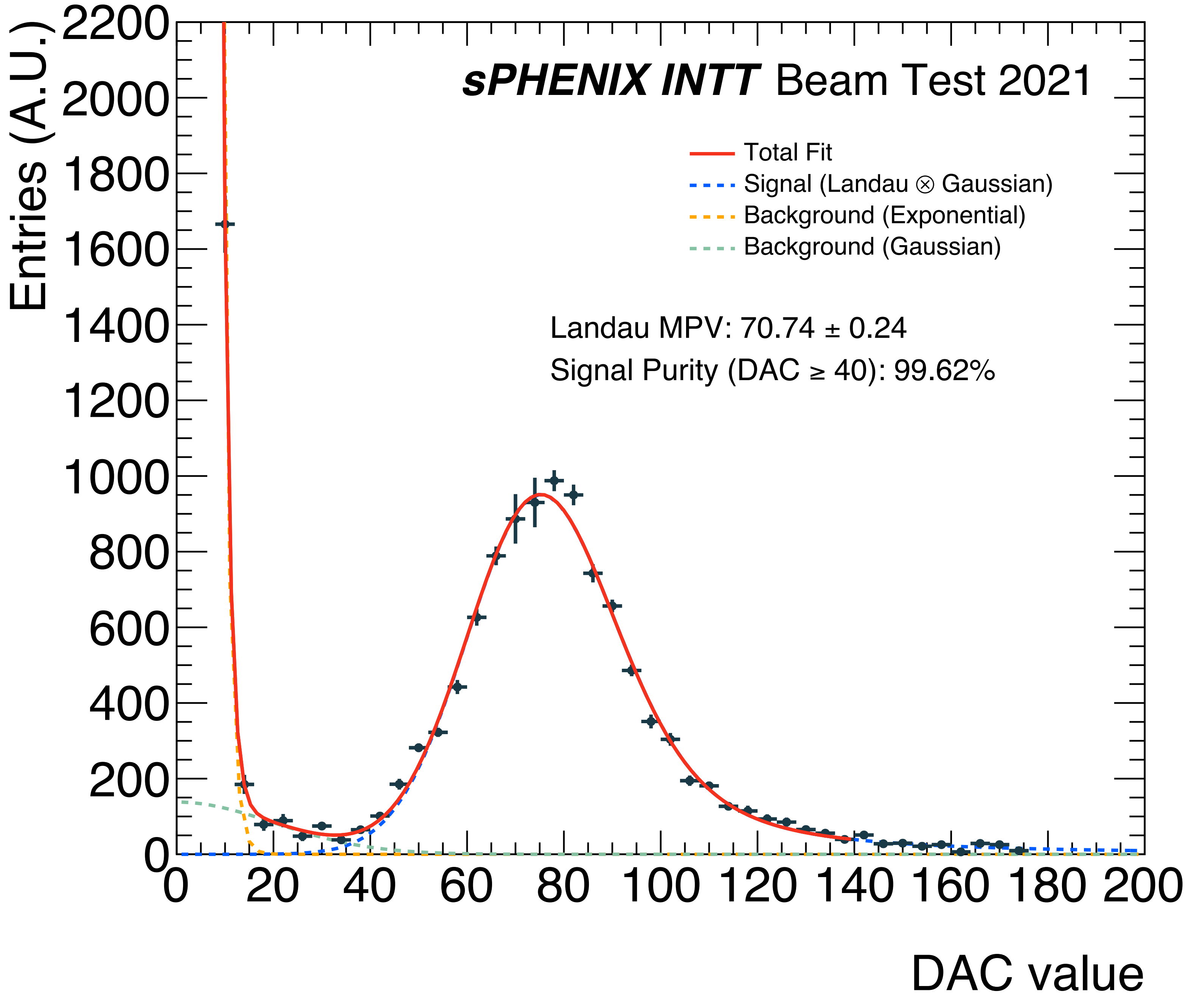
L2



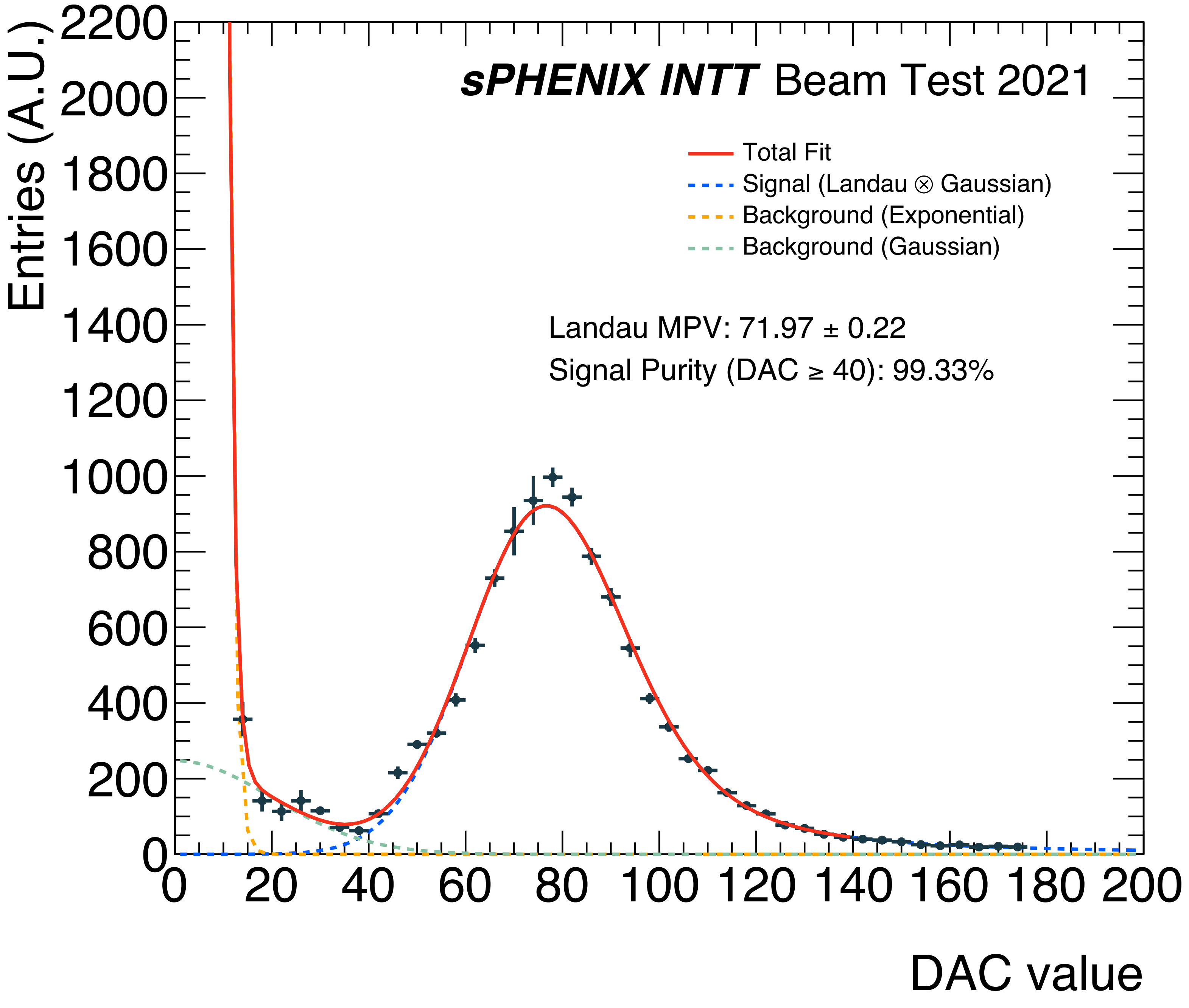
DAC Scan - bins combined with fit

- Signal component: Landau-Gaussian convolution
- Background: Exponential + Gaussian
- Fit range: 8 to 140 DAC
- Signal Purity {DAC ≧ 40}: > 99.3%

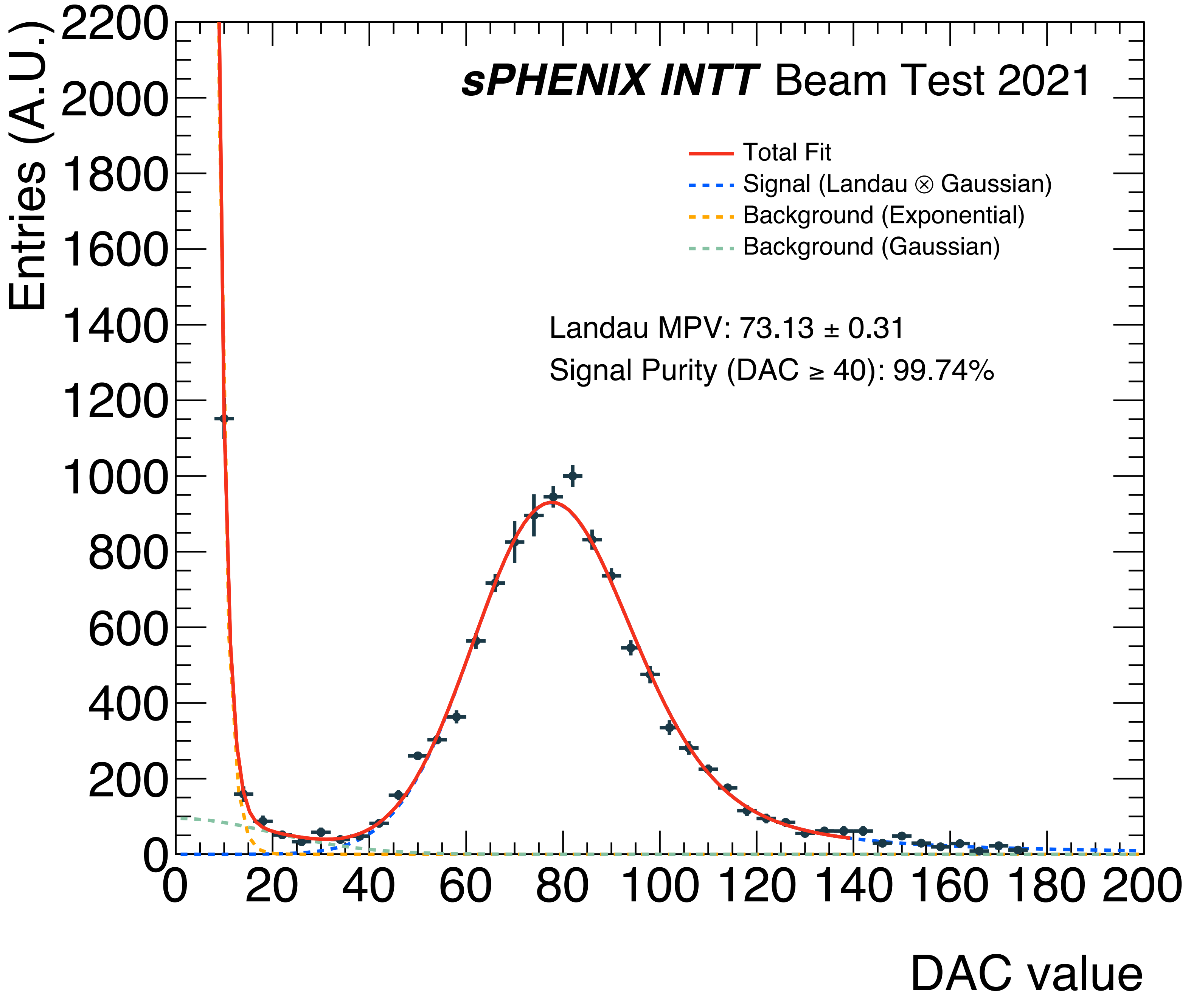
L0



L1

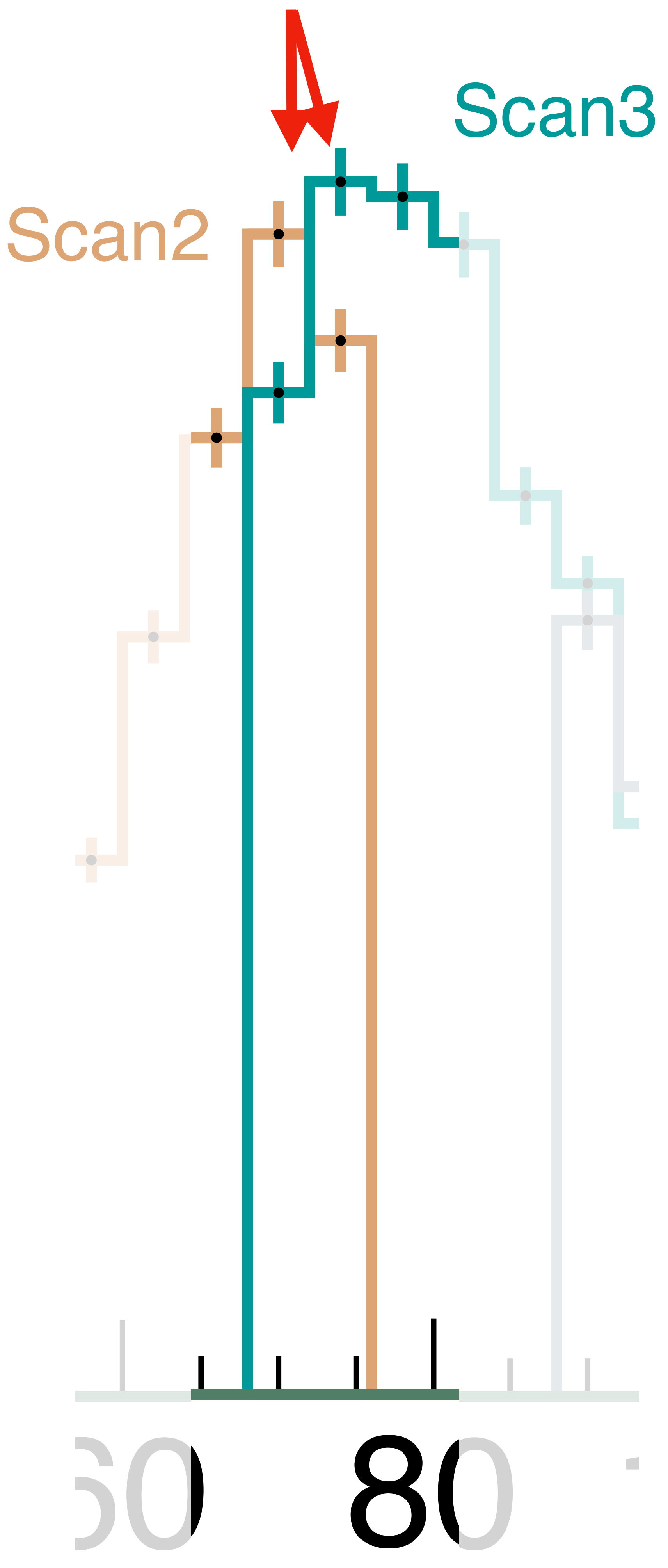


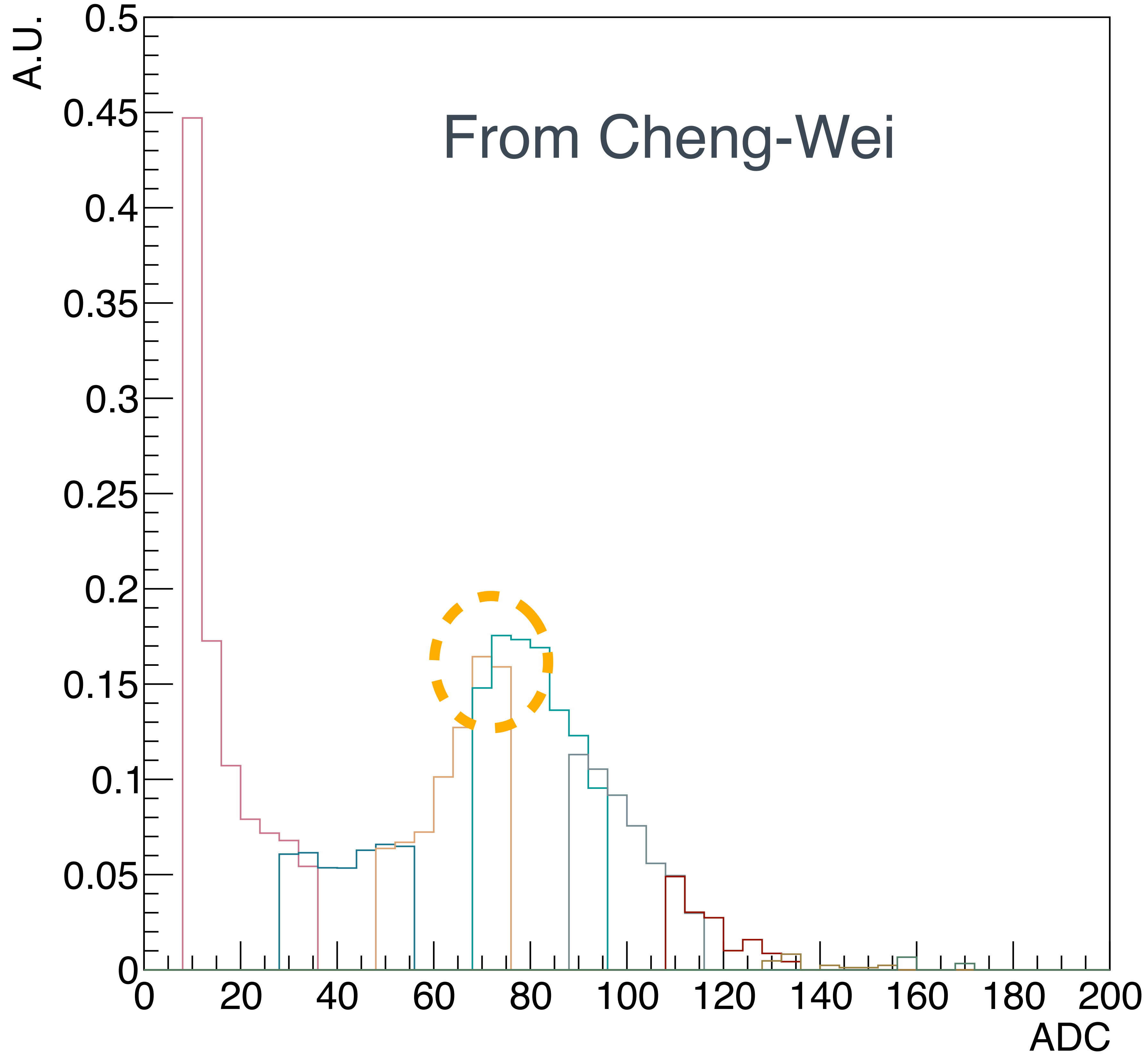
L2

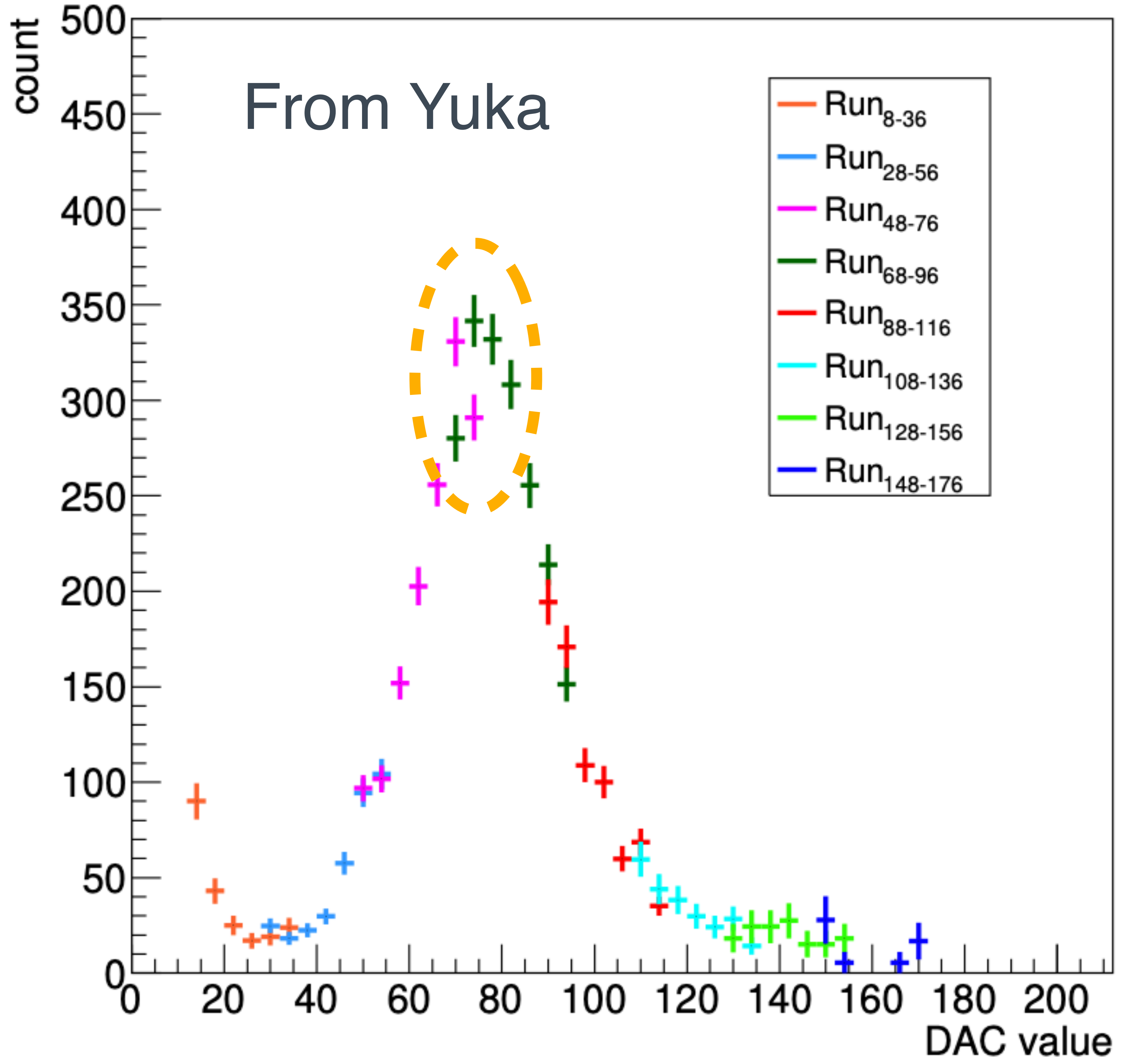


DAC Scan - in combining bins

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

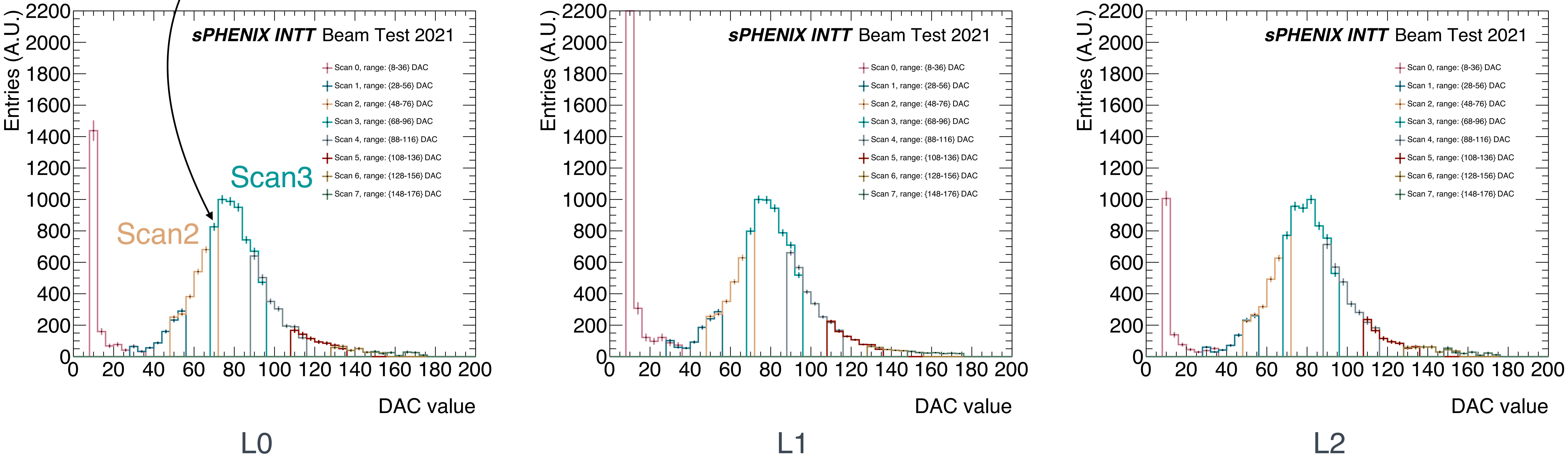




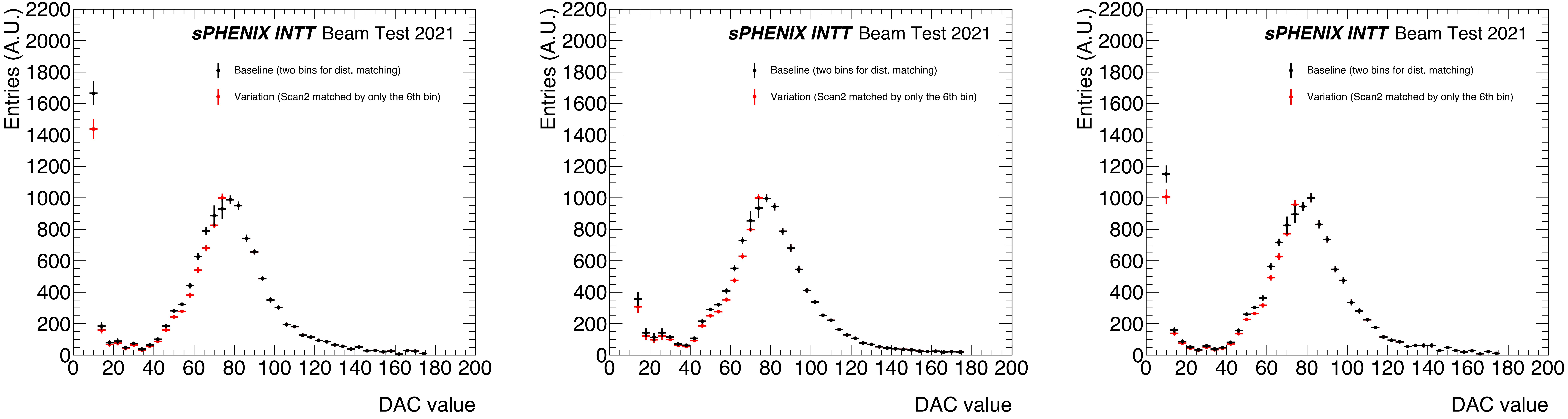


Matching Scan2 and Scan3 in different way

Here the matching of Scan2 to Scan3 is only by Bin6th of Scan2 and Bin1st of Scan3
(Bin6th of Scan2 and Bin1st of Scan3 are therefore on the top of each other)



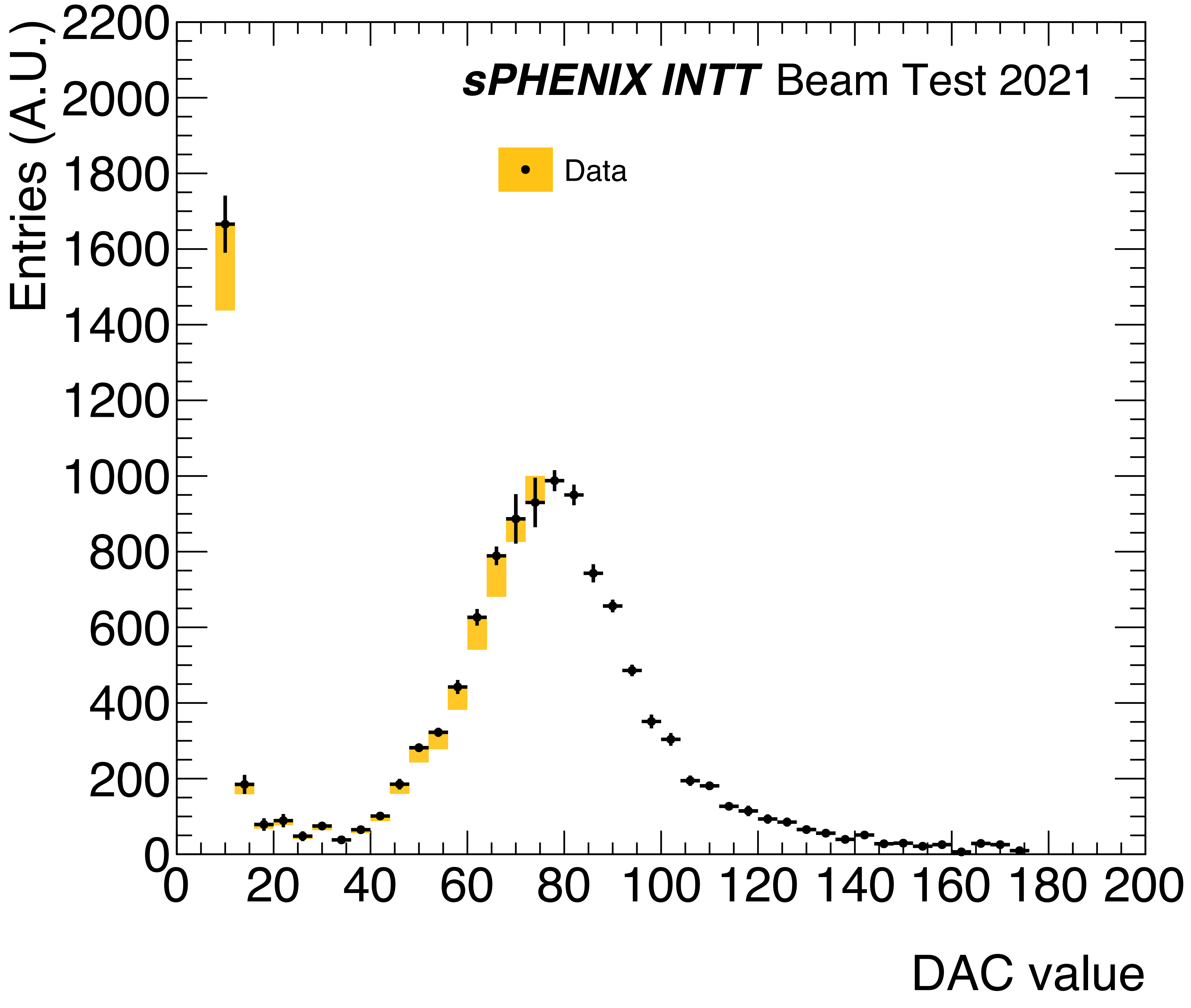
Comparison b/w two ways of matching Scan2 and Scan3



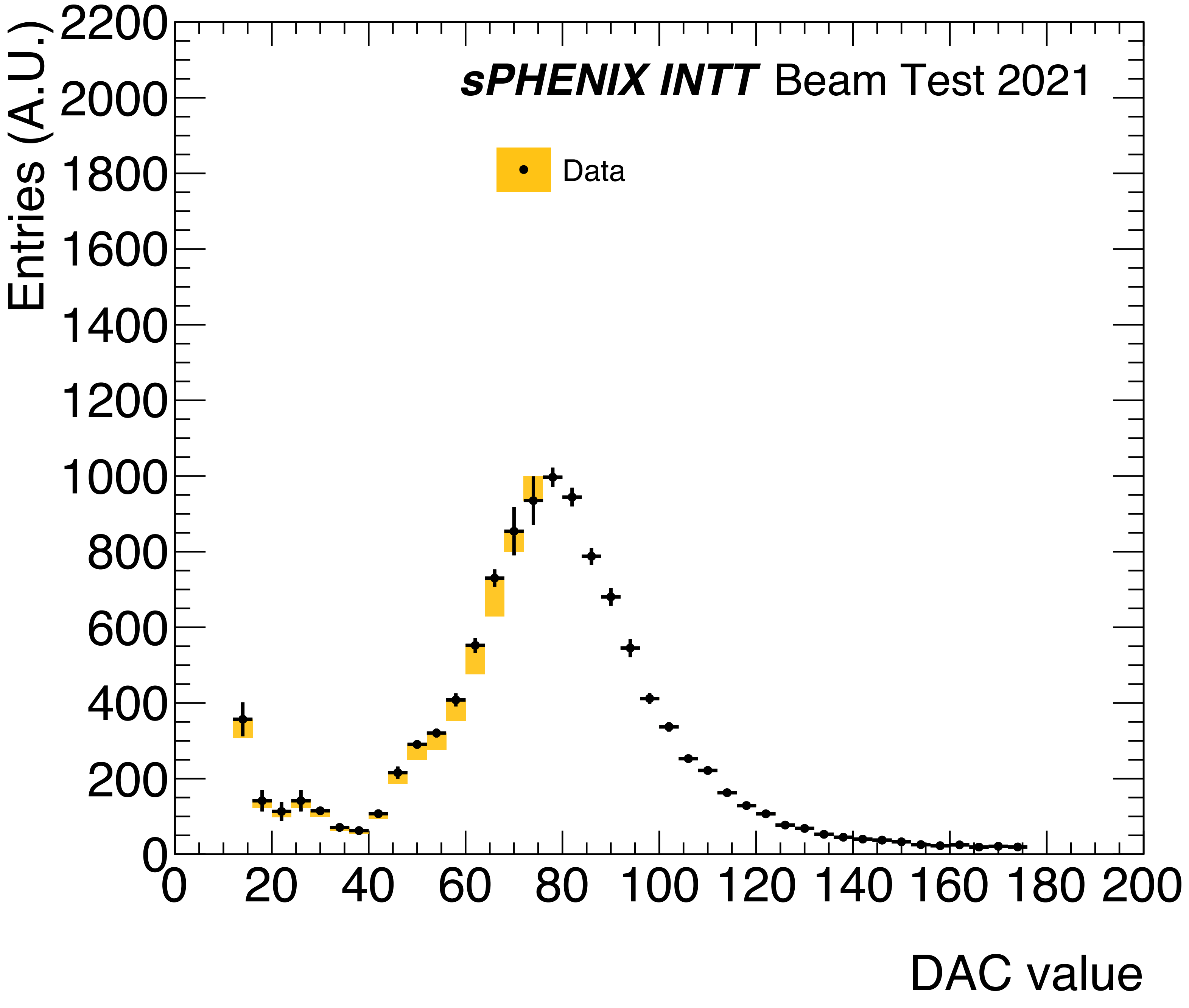
L0 L1 L2

Systematic uncertainty

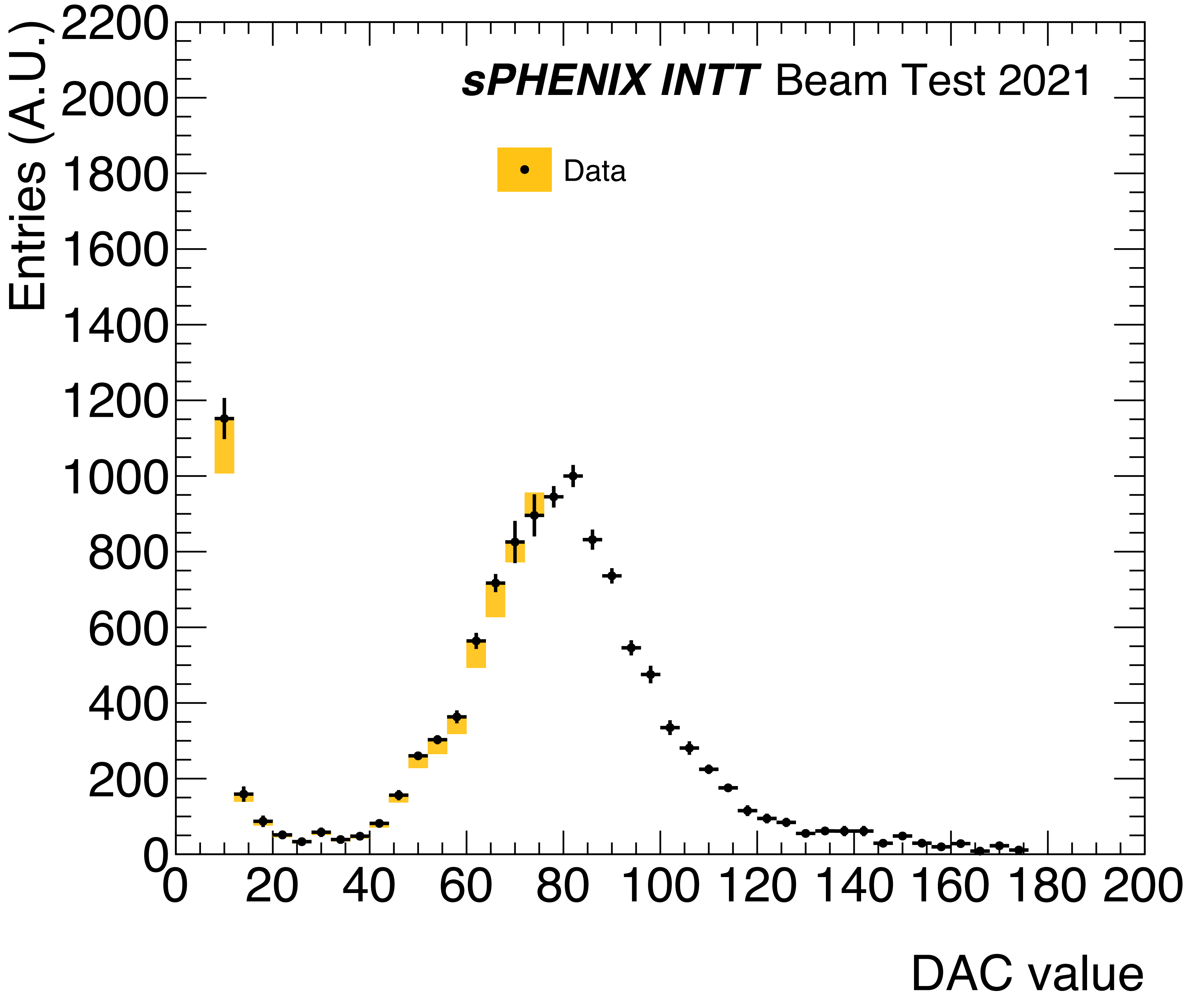
The differences are quoted as the systematic uncertainties



L0



L1

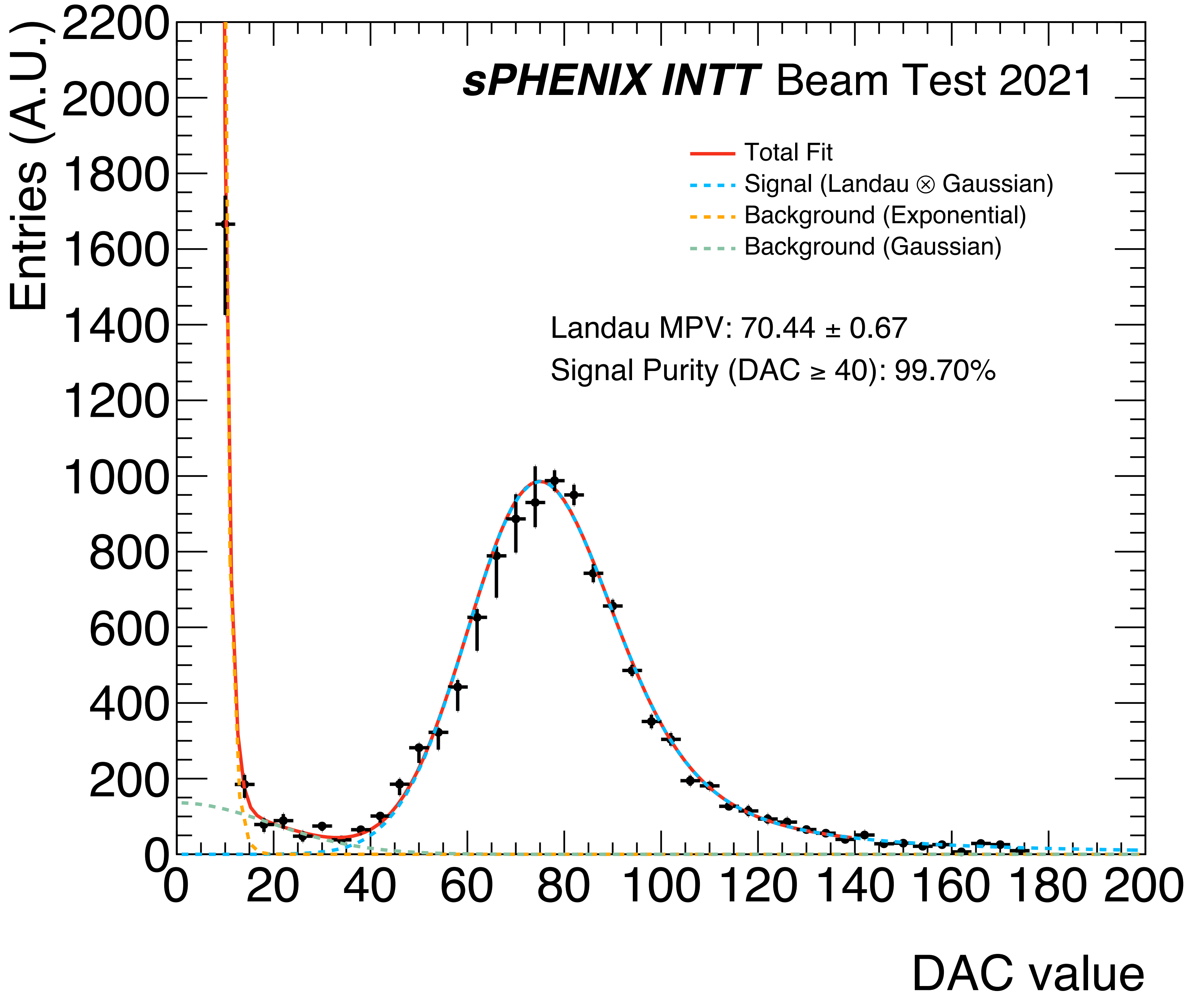


L2

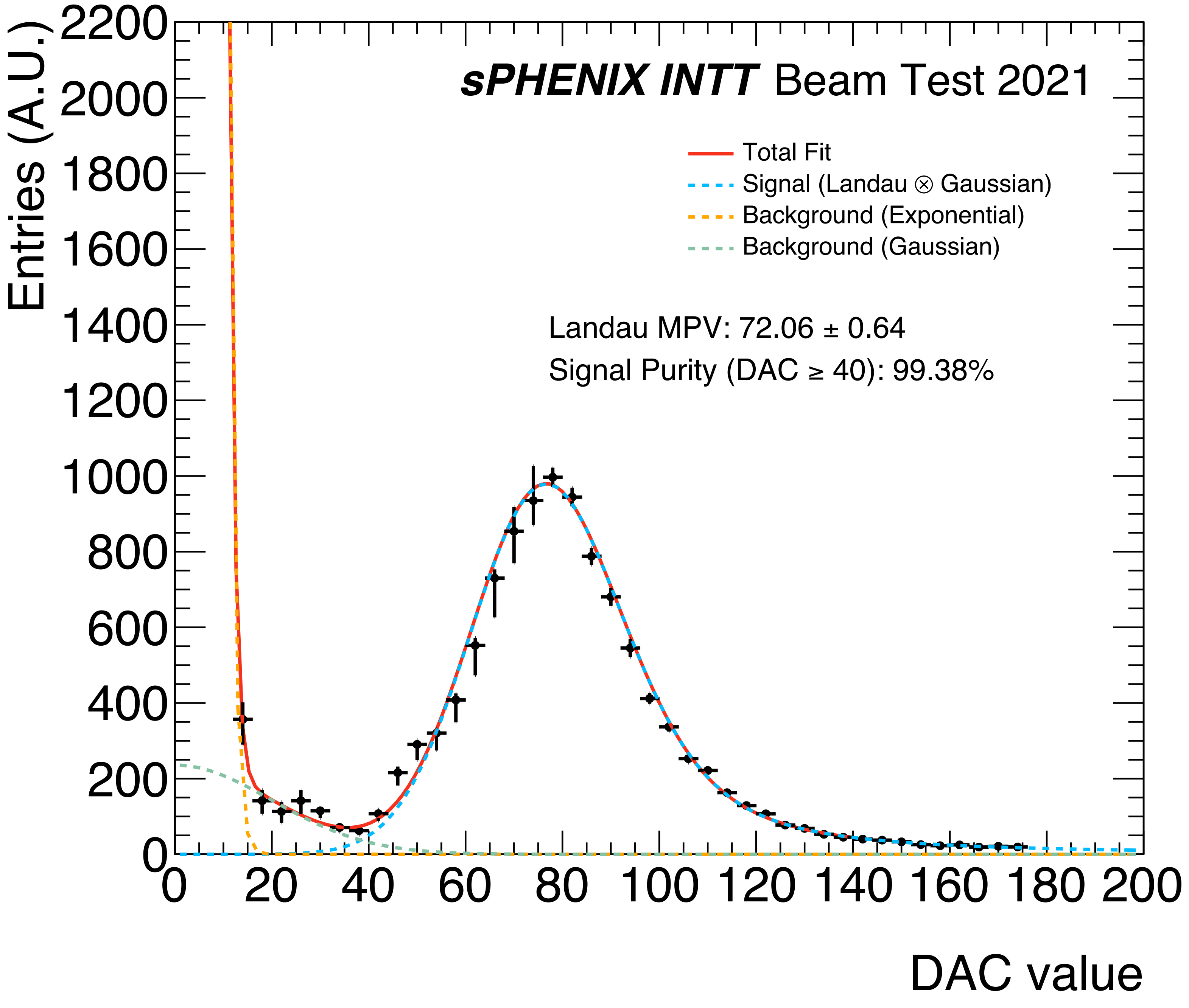
Final distributions

In each bin, the systematic uncertainty and statistical uncertainty are summed up in quadrature
Distributions are fitted the same way as introduced
Physics message doesn't change, signal purity > 99% in region ≧ 40

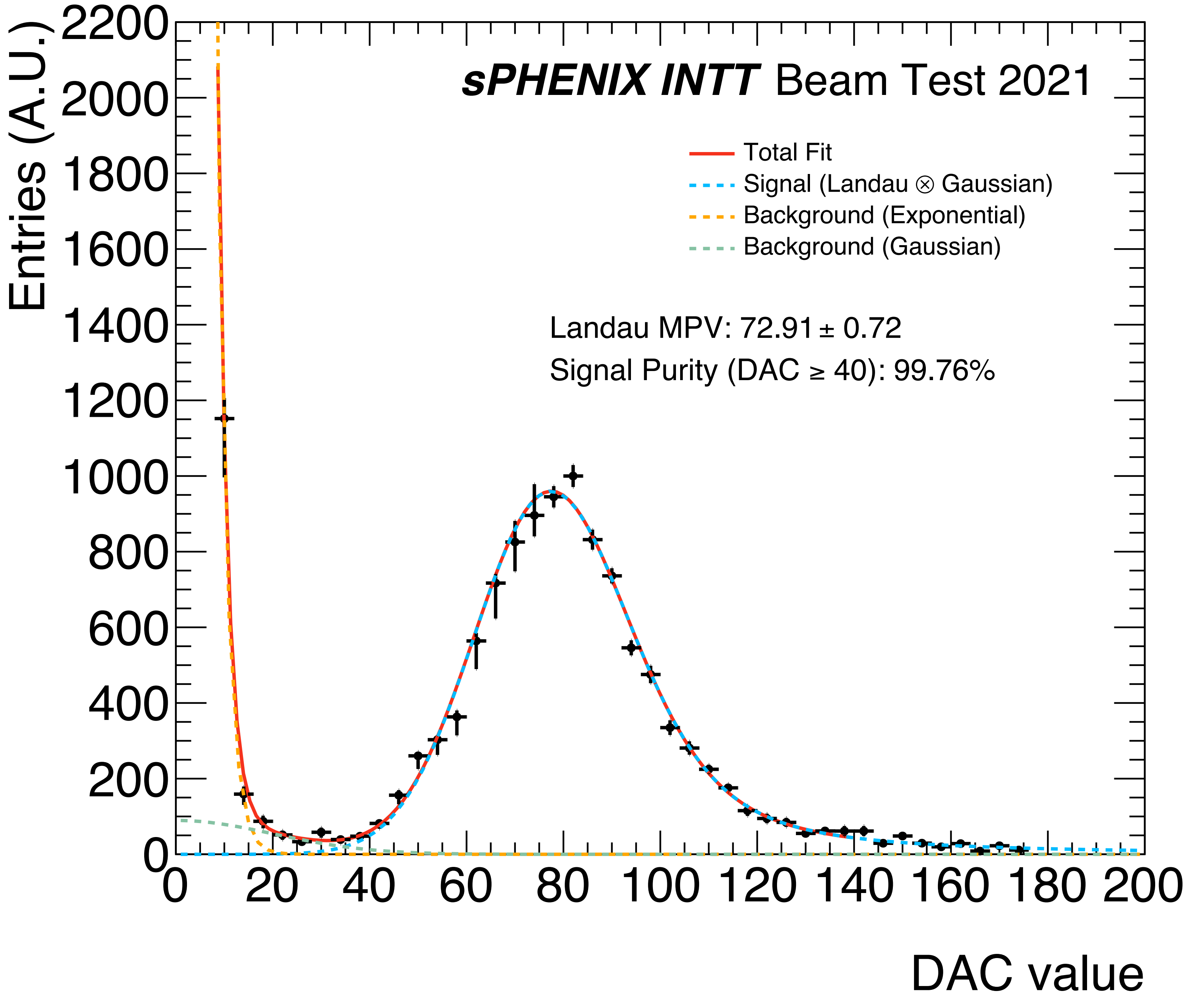
Plot to be in paper (tentative)



L0



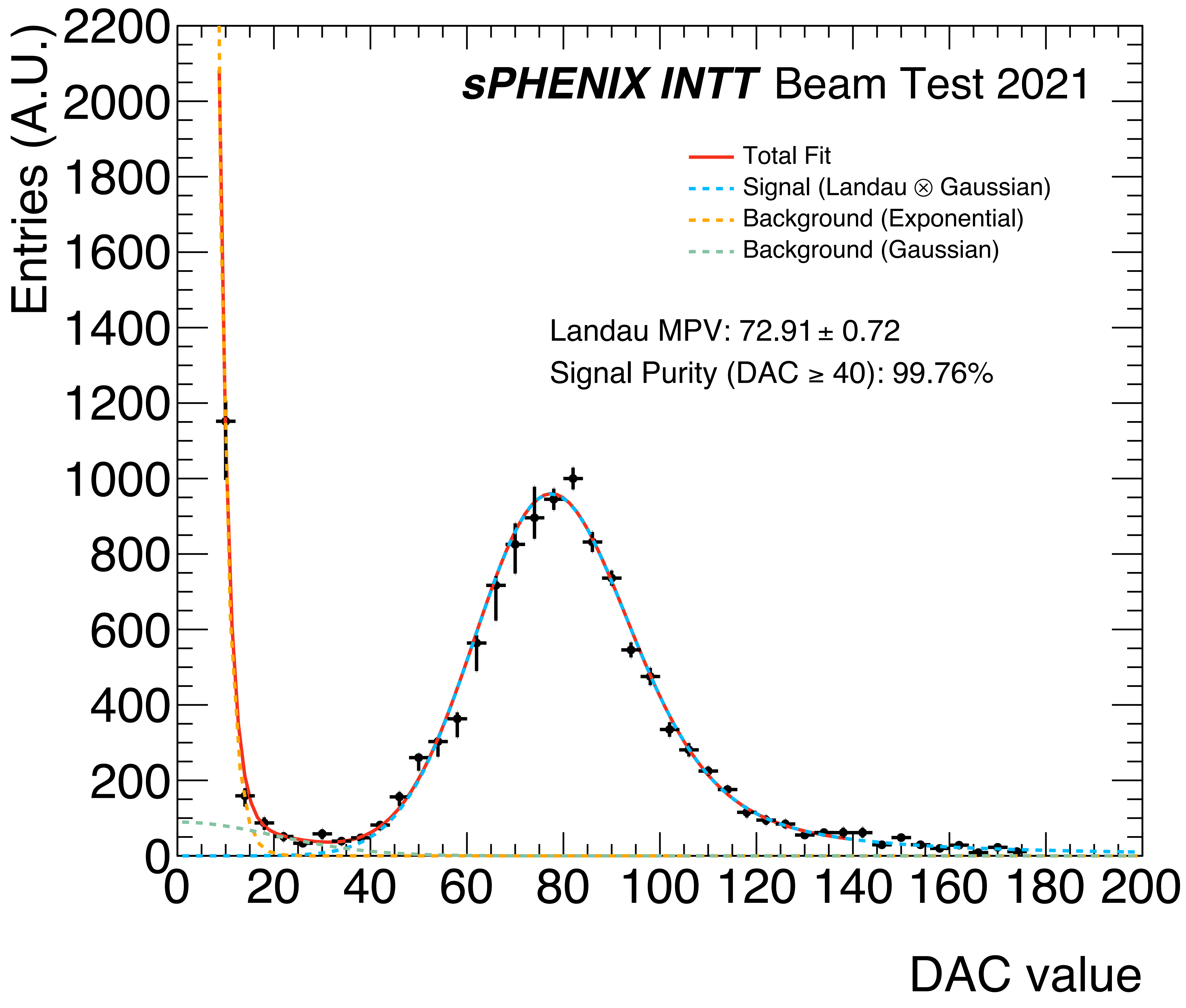
L1



L2

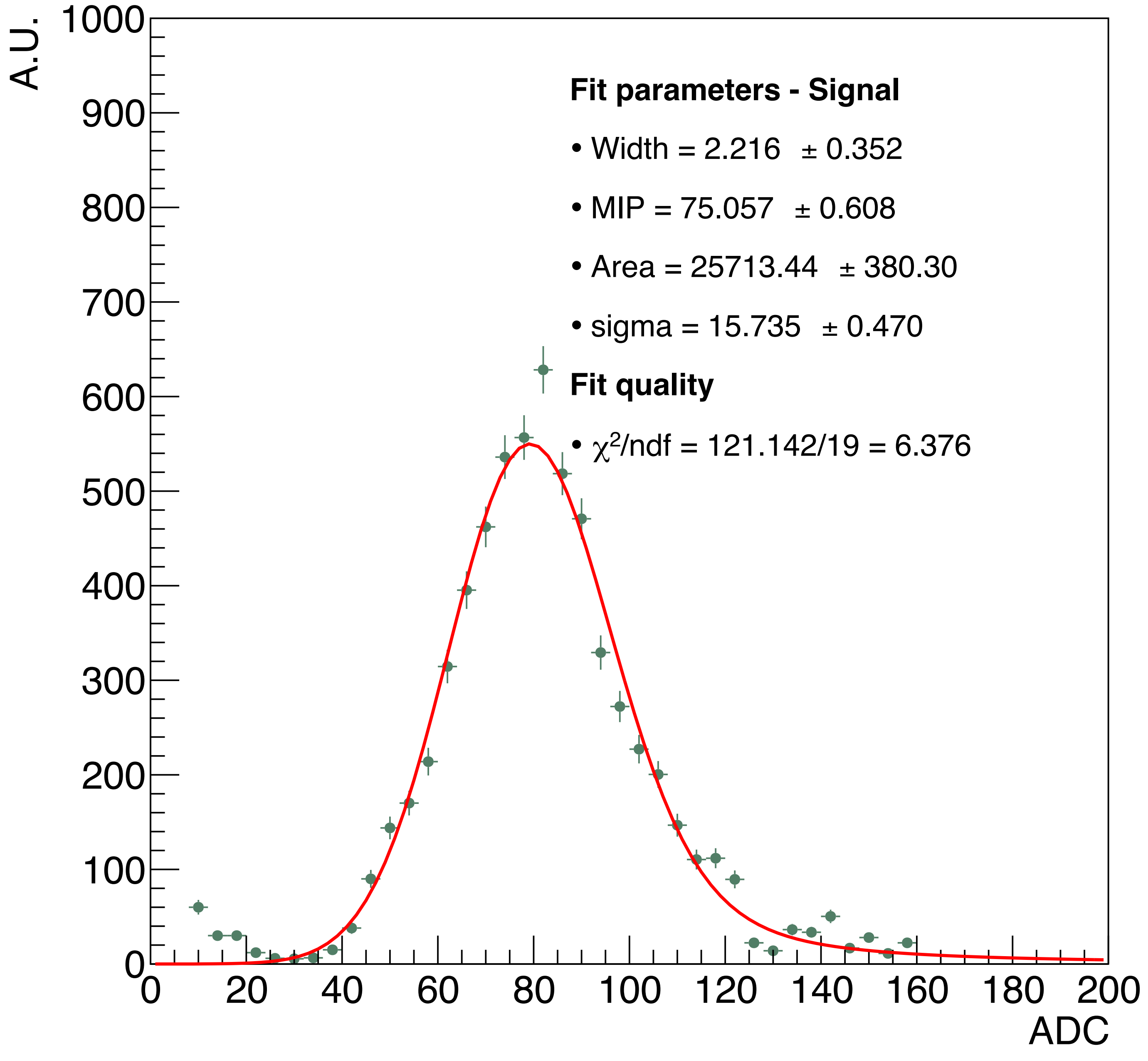
Recap - energy deposit distribution, L2

The new plot

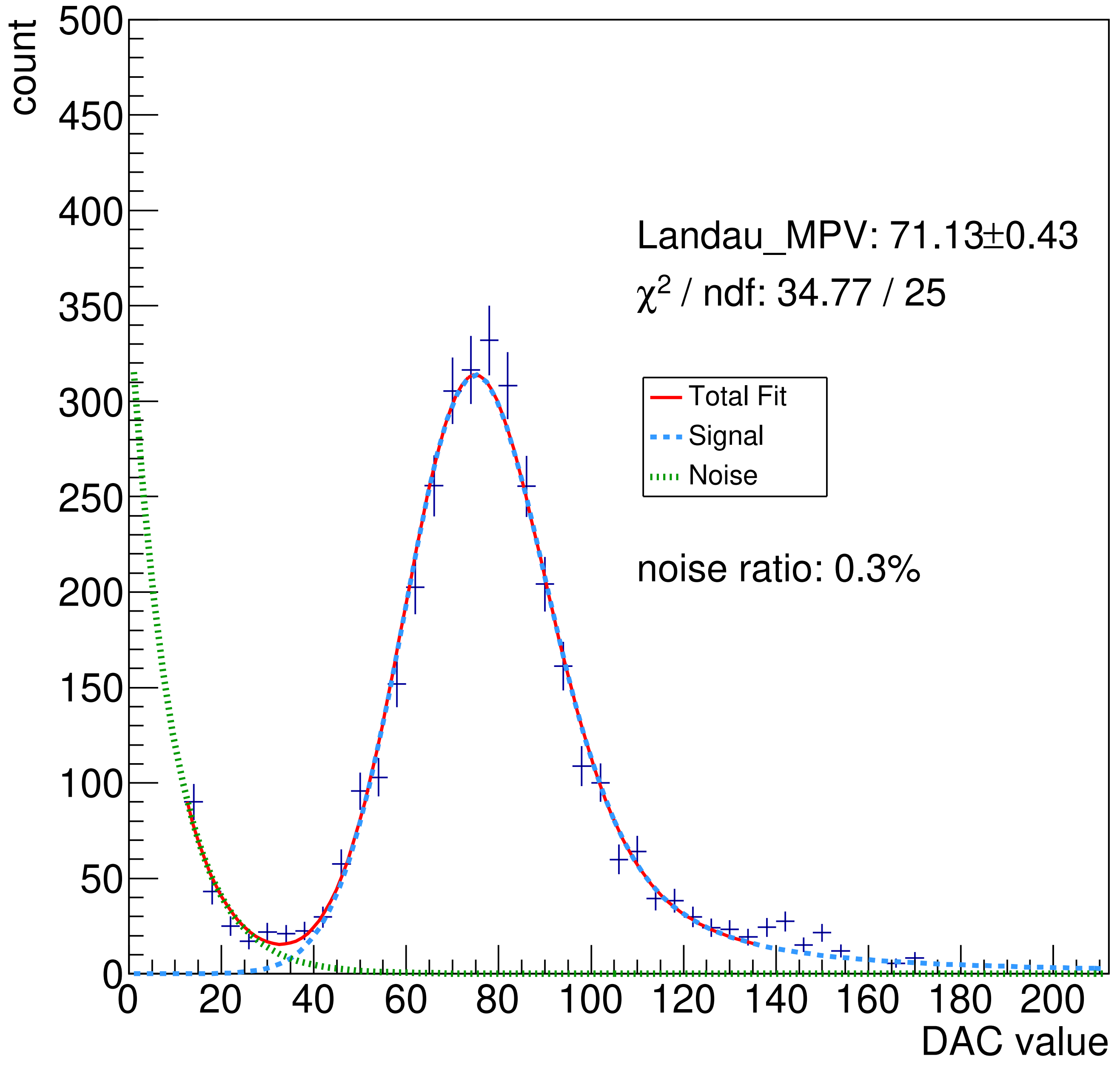


Plot to be in paper (tentative)

By Cheng-Wei
Debut: 2022/Jan/23



By Yuka
Debut: 2022/Dec/09
Plot used in ELPH report 2021

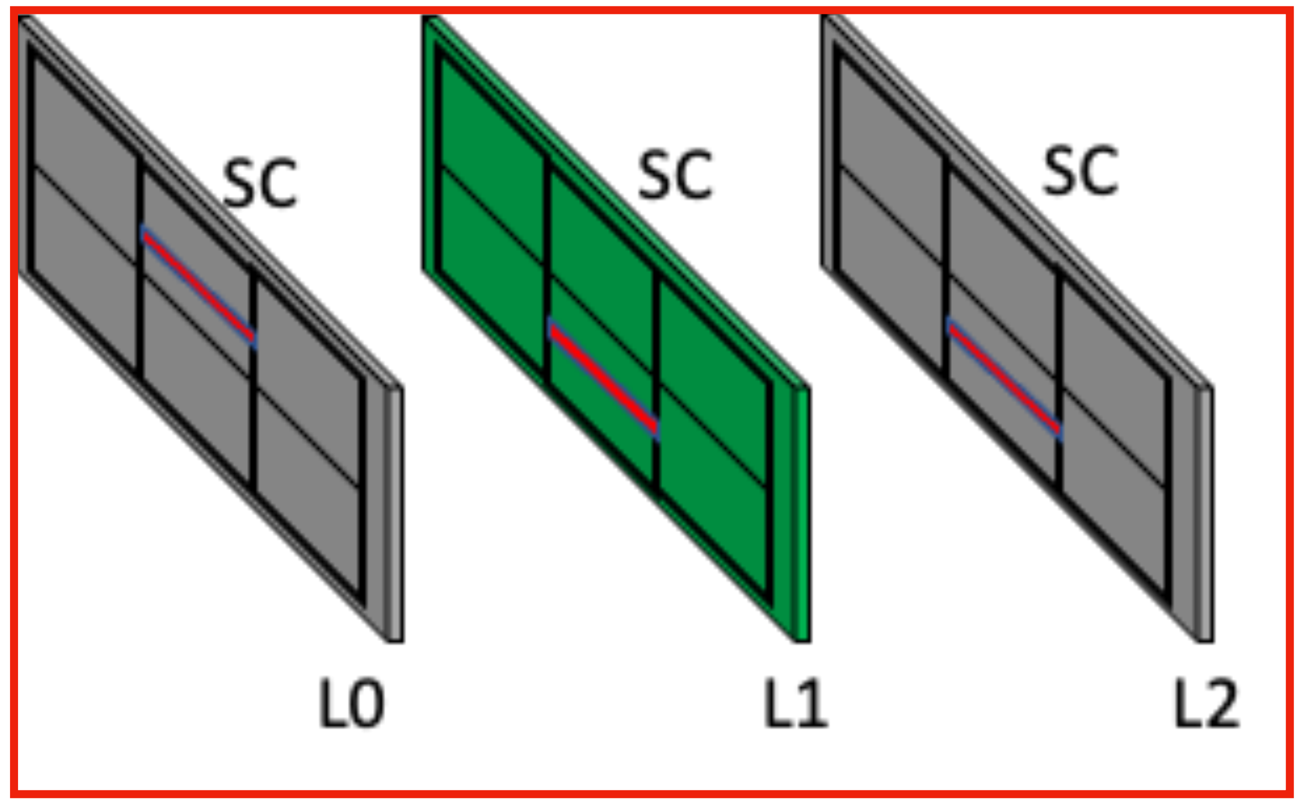


Scattering comparison with MC

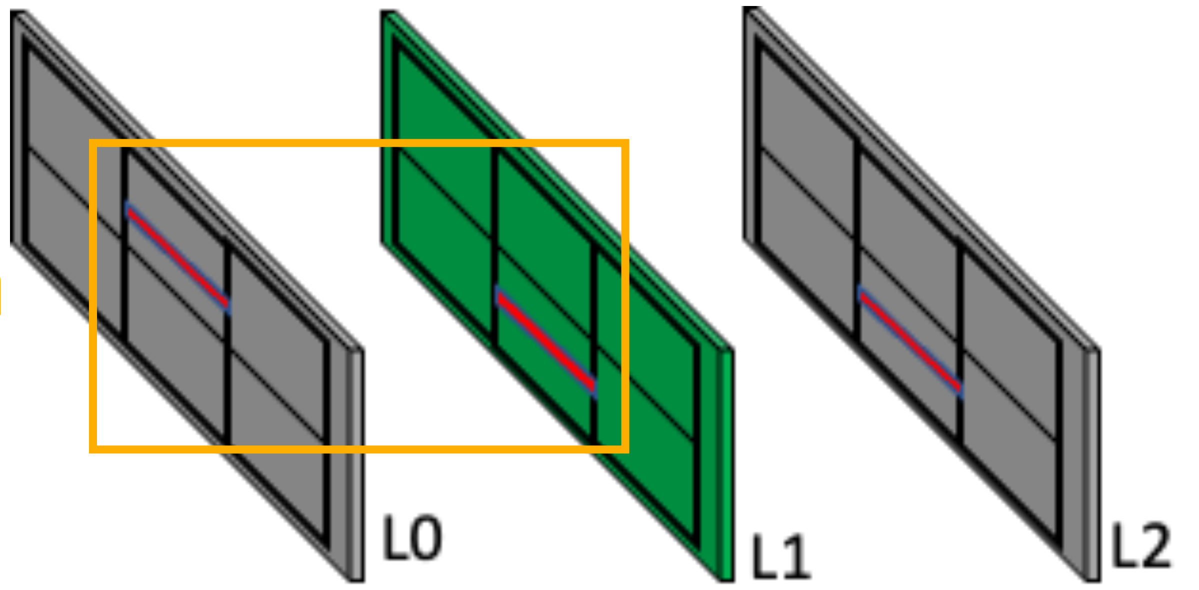
- Method: L0L1 are used for reconstructing proto-track (have constrain), set L2 free

- 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)
    - $|L0L1\_slope| \leq 0.01$
    - $|L0L1\_avg\_pos| \leq 5$ mm (Ladder coverage: ±10 mm)
  - Check residual: L1 - (L2L0 interpolation)
    - Quantity used in hit detection efficiency analysis



Constrain on
proto-track

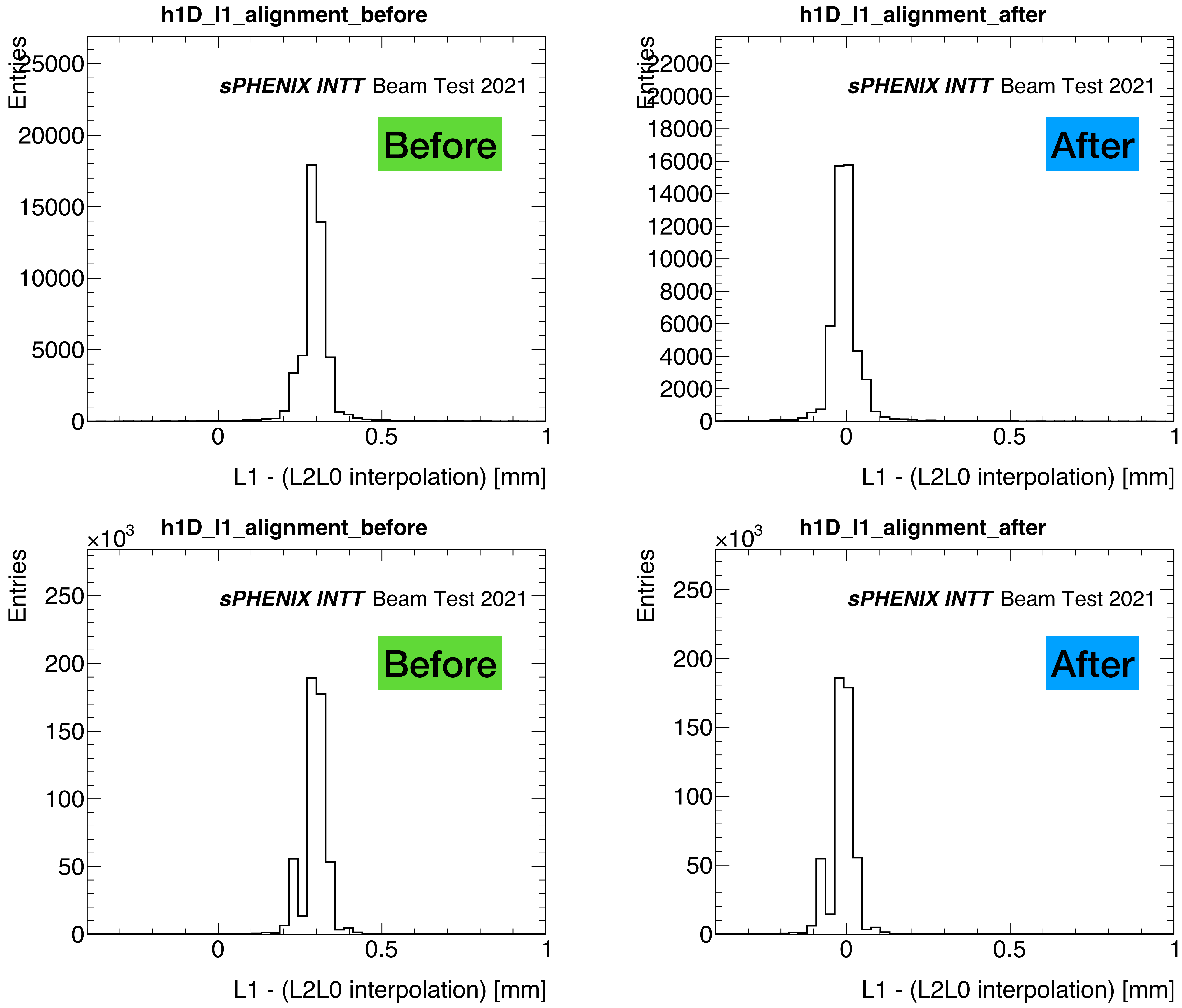


Scattering comparison with MC

Layer-1 alignment correction

Data Run52, U8

MC

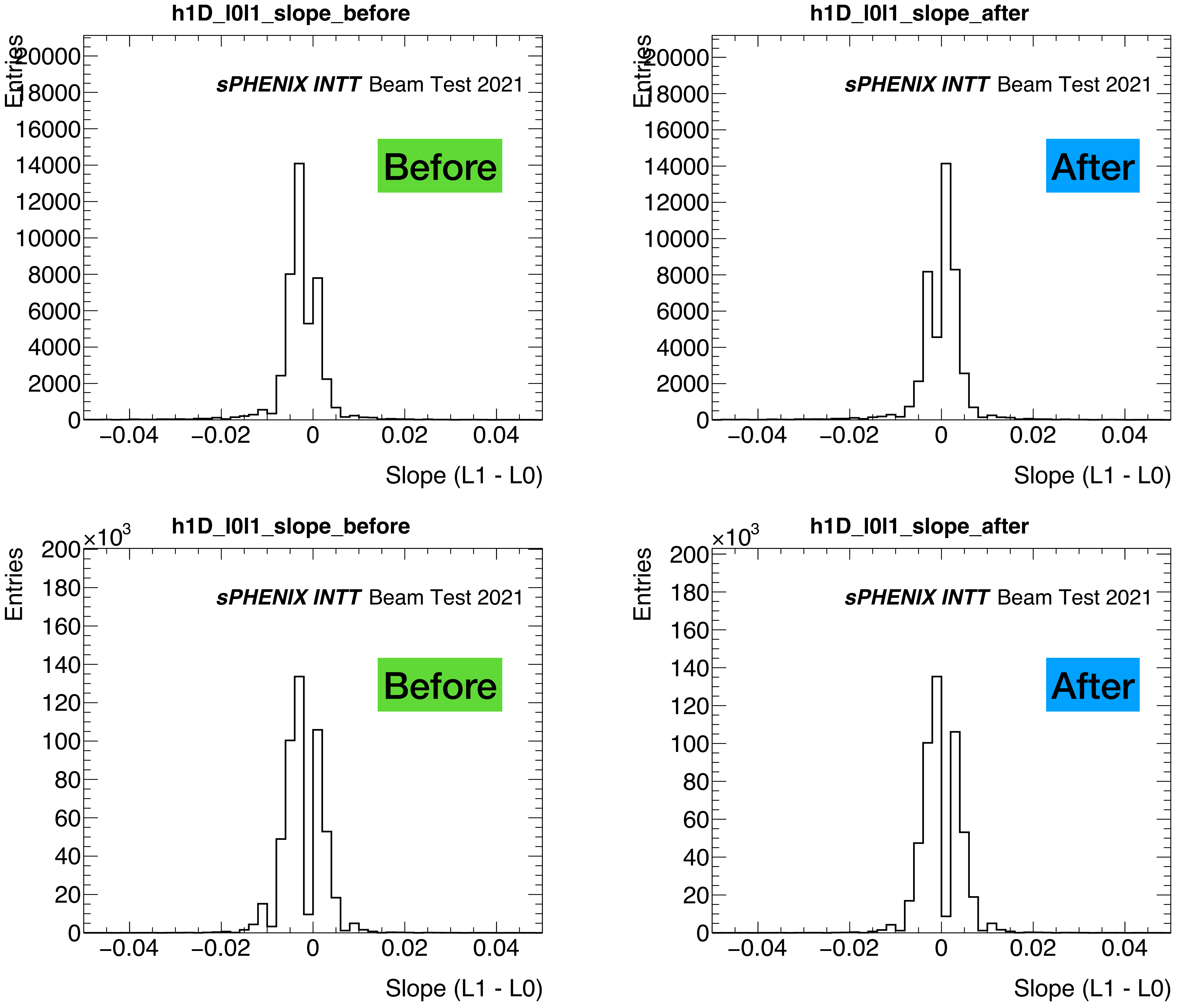


Scattering comparison with MC

L0L1 slope re-centering

Data Run52, U8

MC

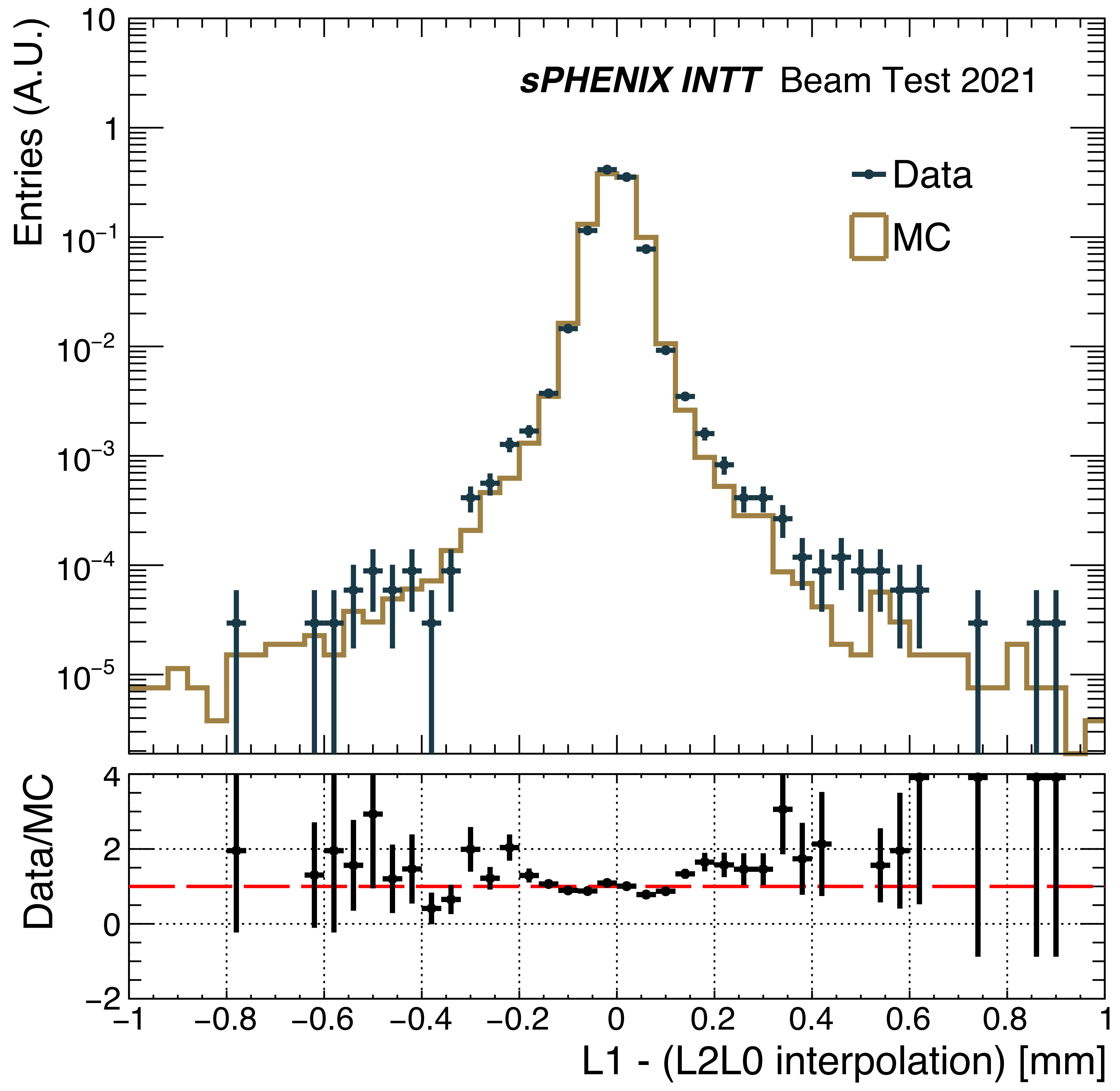


Re-centering: It's not a correction. It's just to make the distribution peak close to zero for applying symmetric slope cut

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 study

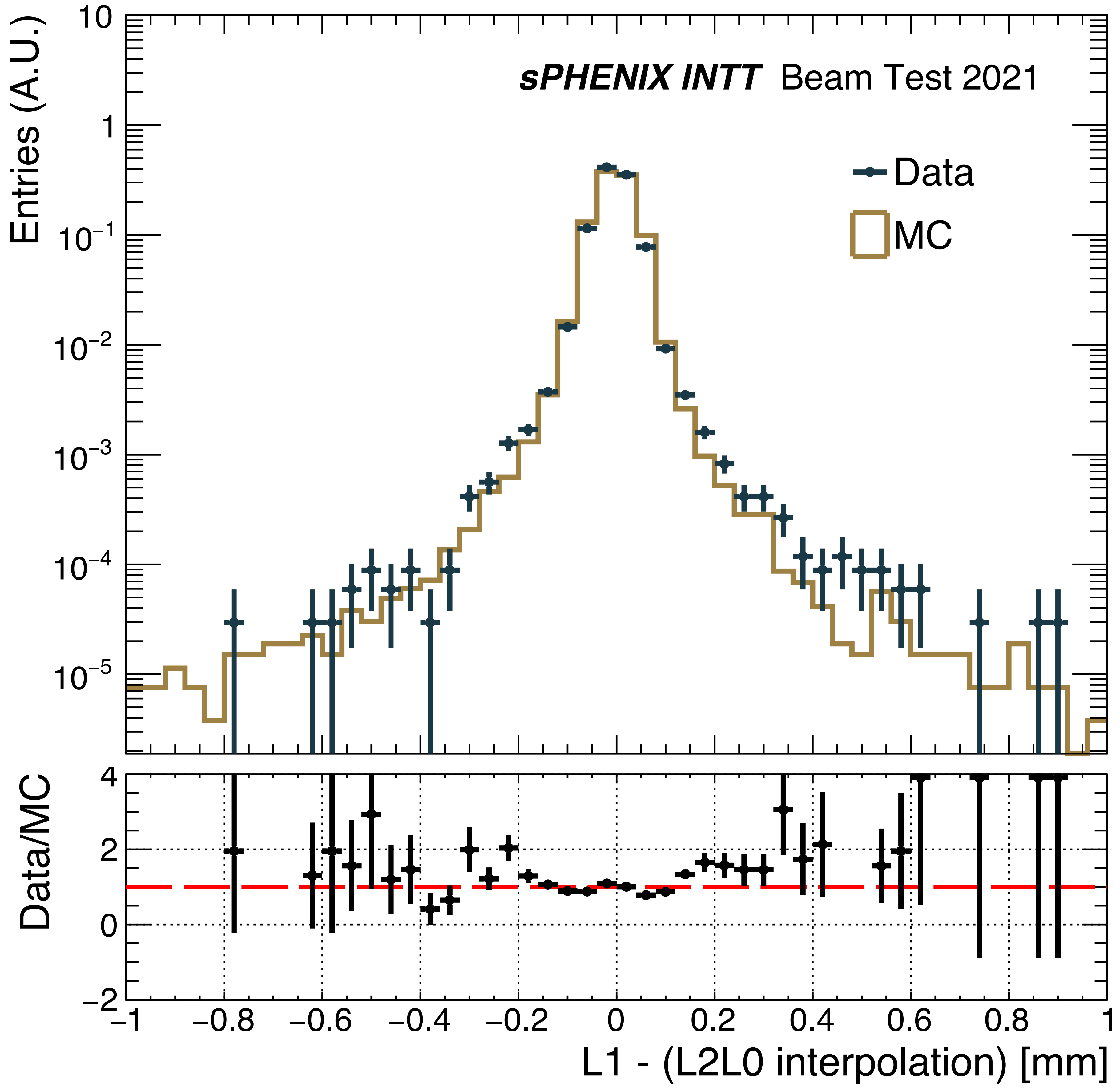
Plot to be in paper (tentative)



Agreement between data and MC is reasonably well

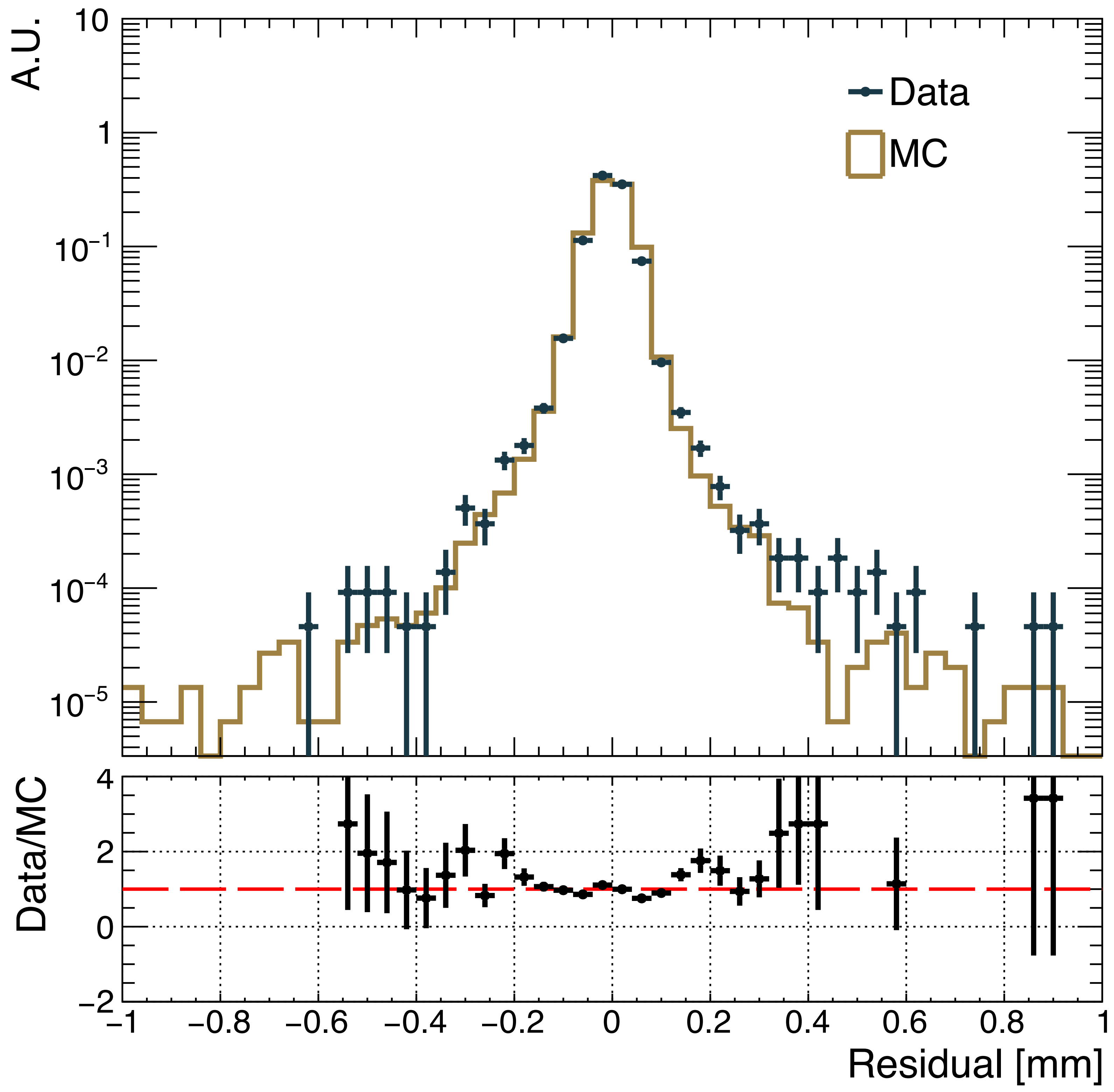
Recap - Scattering comparison

The new plot



Plot to be in paper (tentative)

Debut: 2023/July/20



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| < 0.5 mm

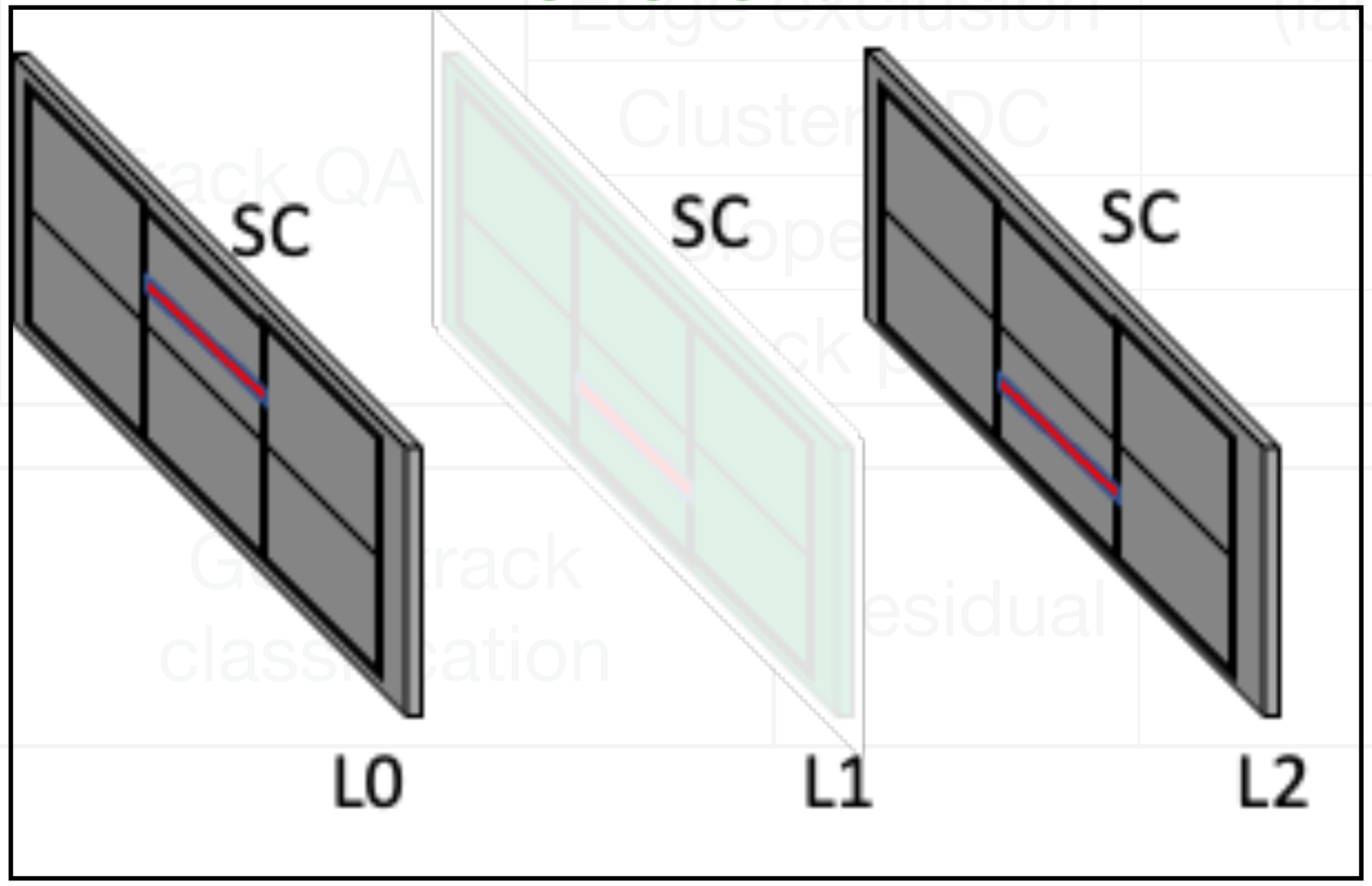
$$\text{Effi.} = \frac{\text{Good Events and L1 Good Cluster Found}}{\text{Good Events}} = \frac{N(L0 \cap L1 \cap L2)}{N(L0 \cap L2)}$$

Hit detection efficiency

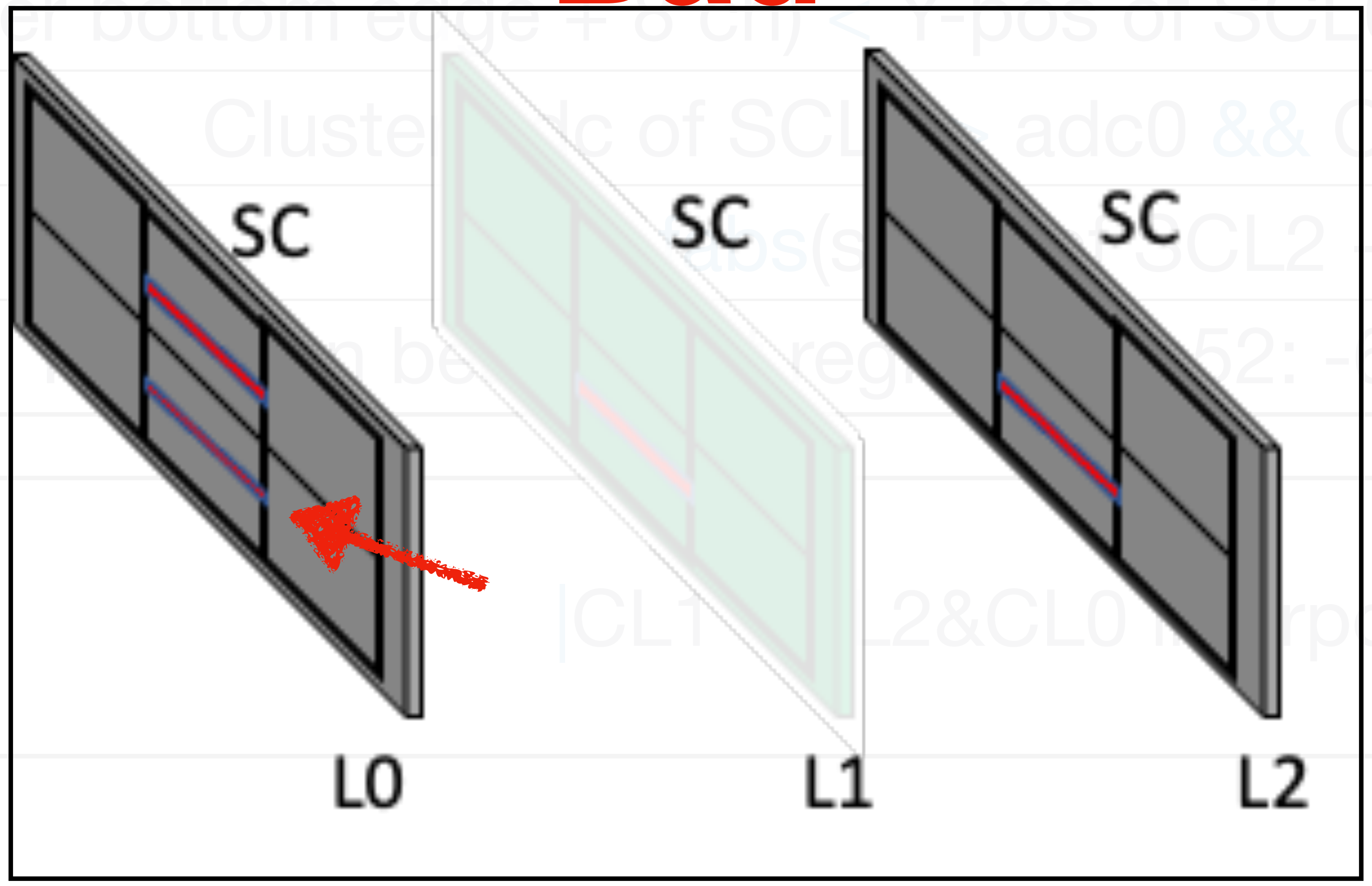
To minimize the ambiguity of track reconstruction
(Only two layers for track reco., to improve the purity, tight selection required)

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

Good



Bad



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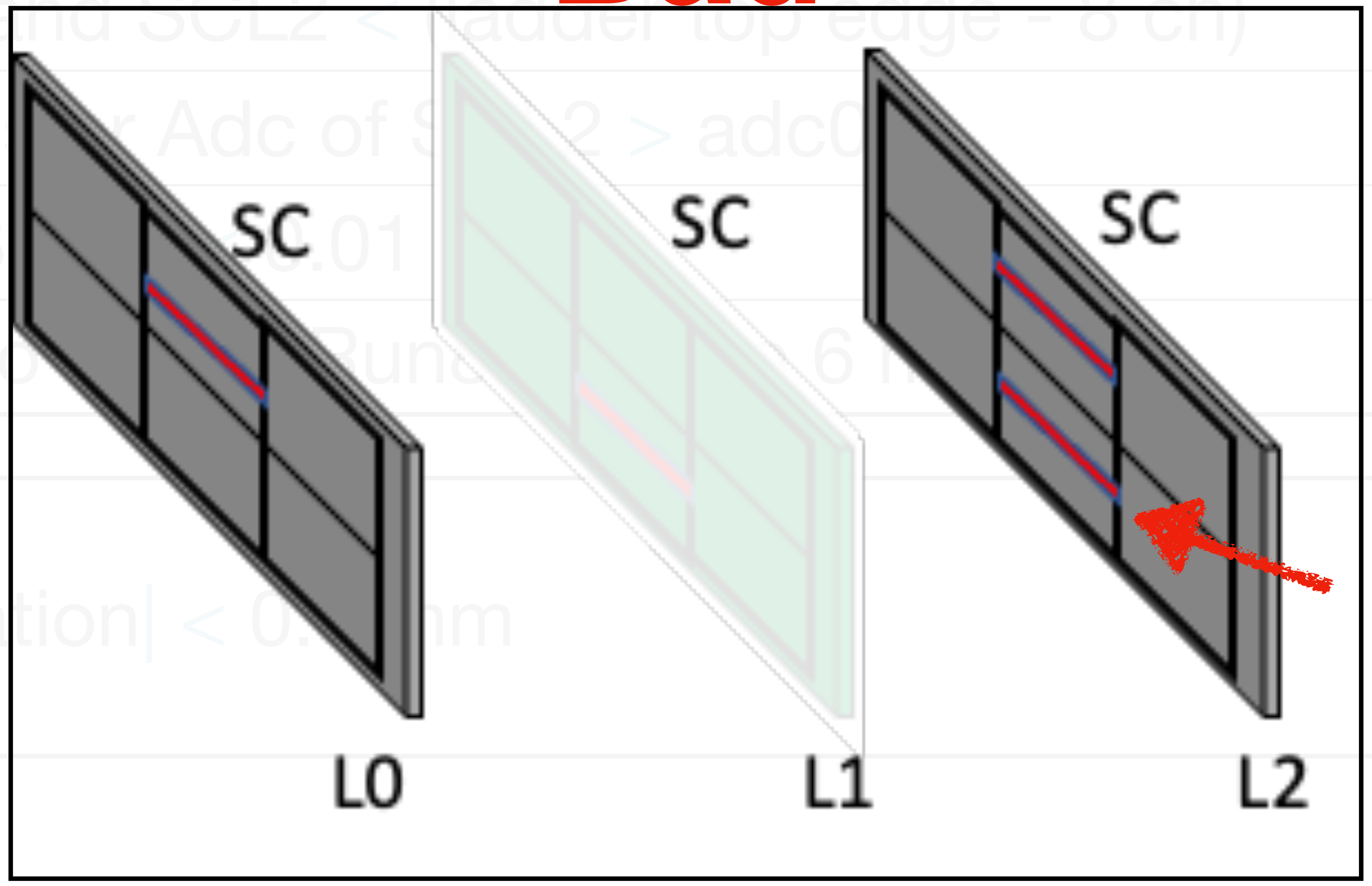


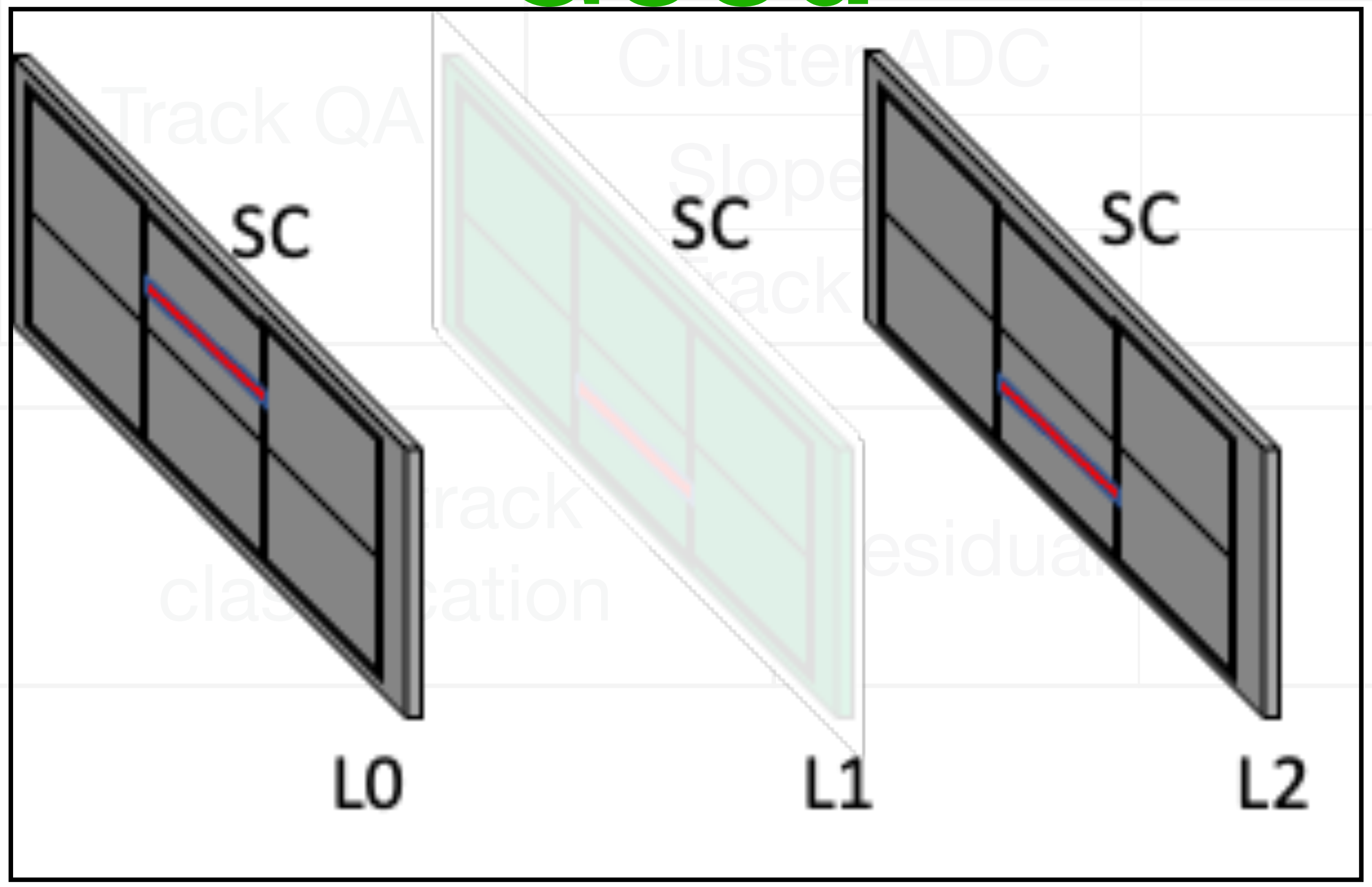
Hit detection efficiency

- 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



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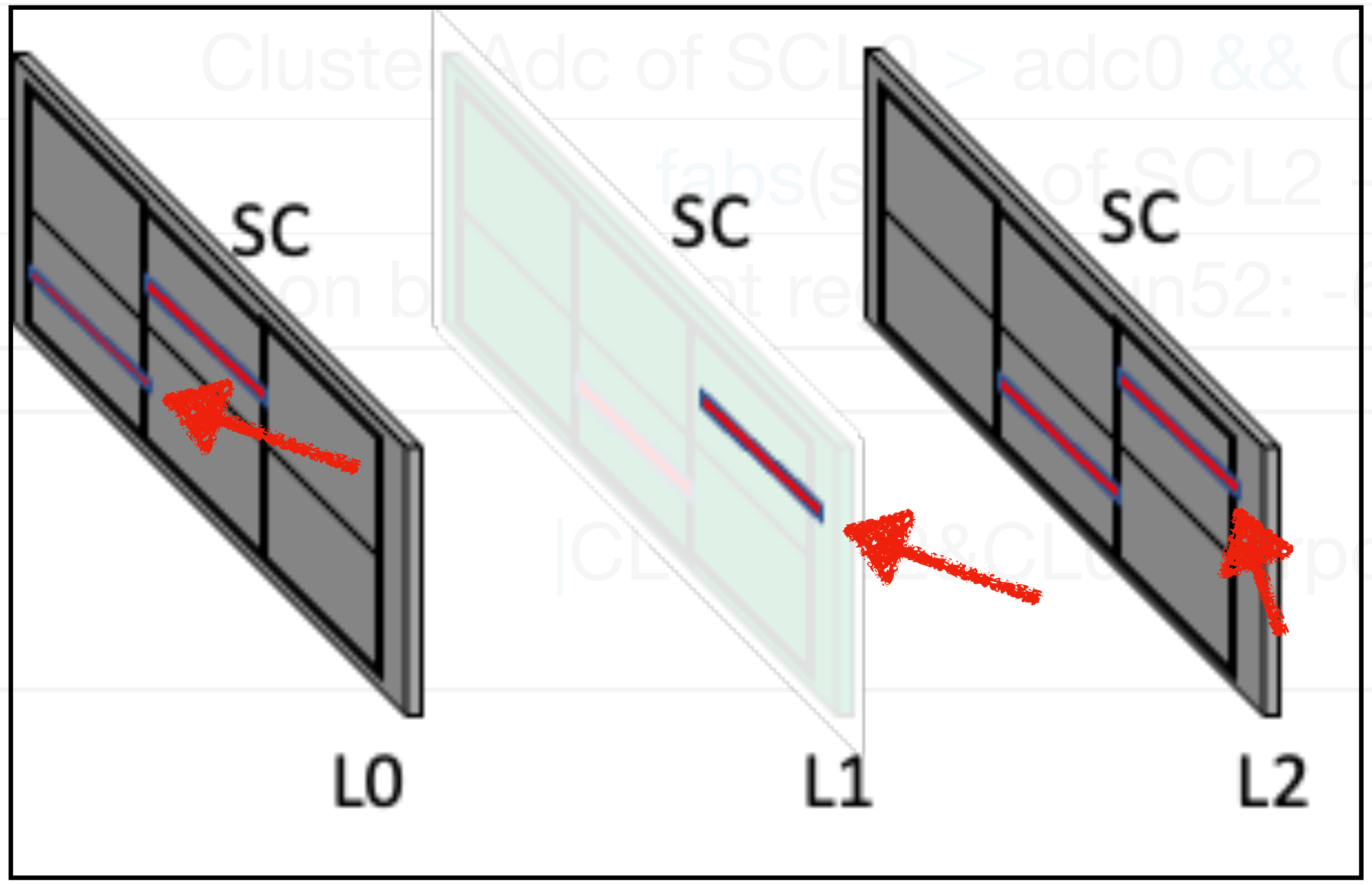

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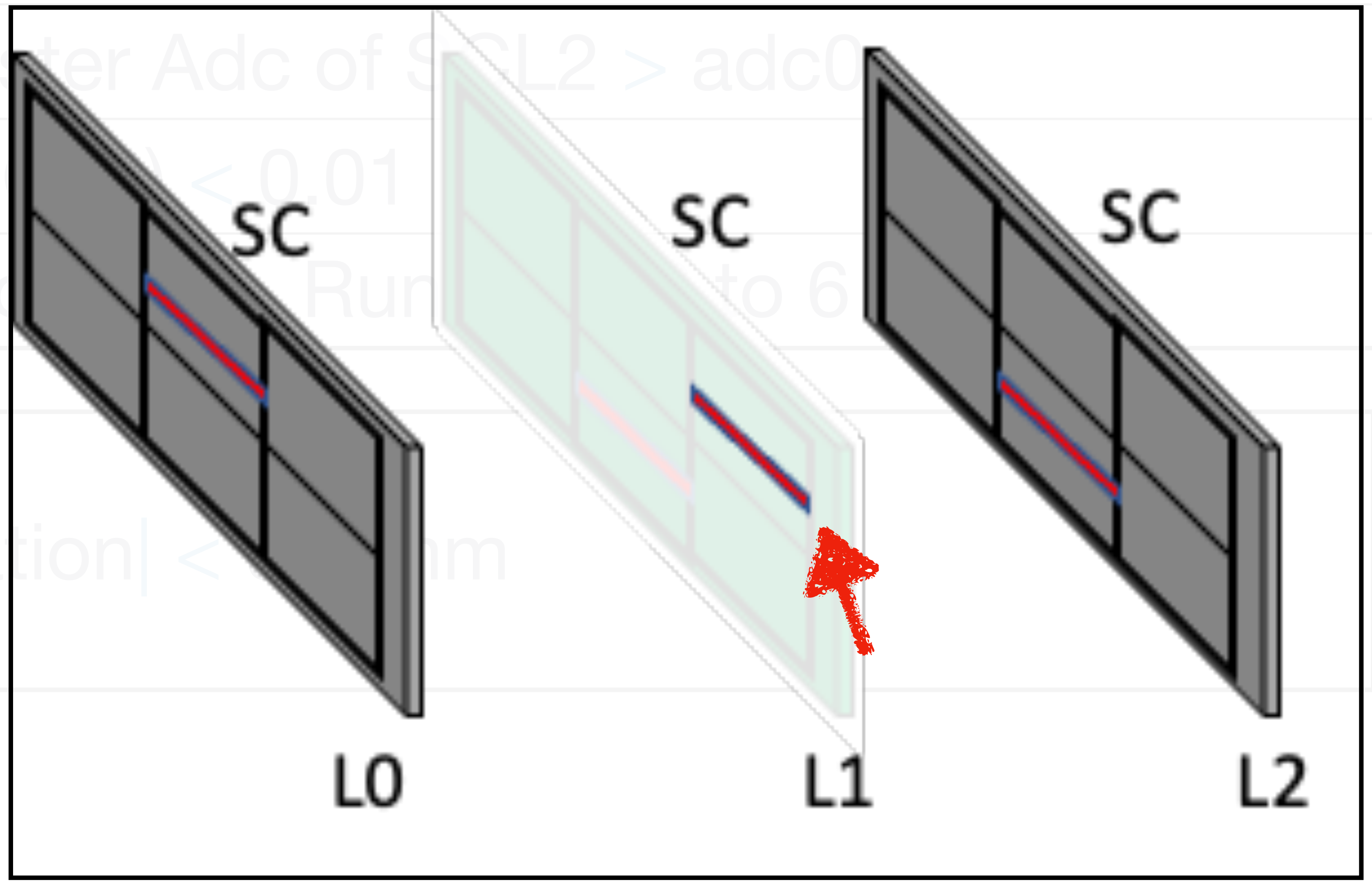
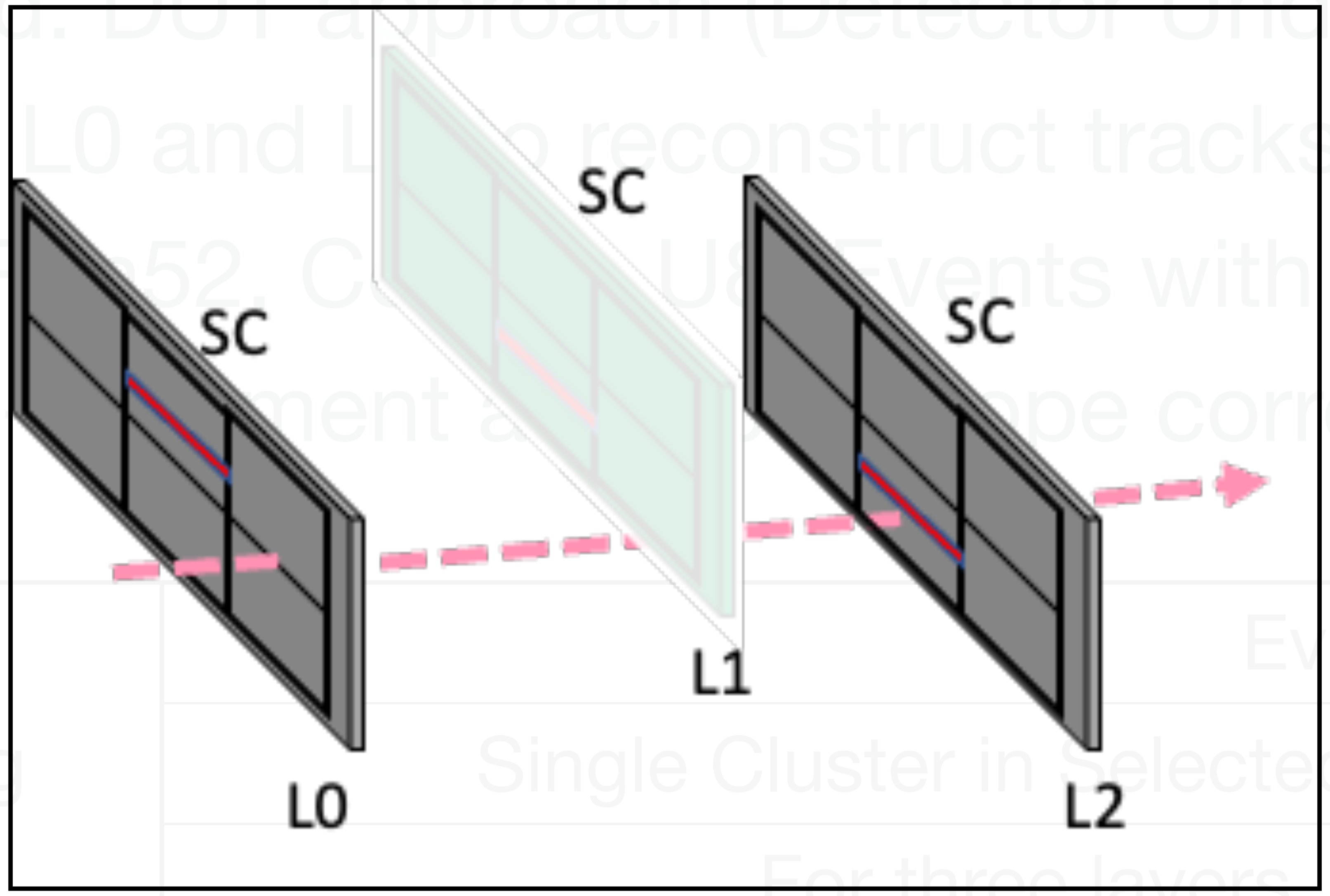
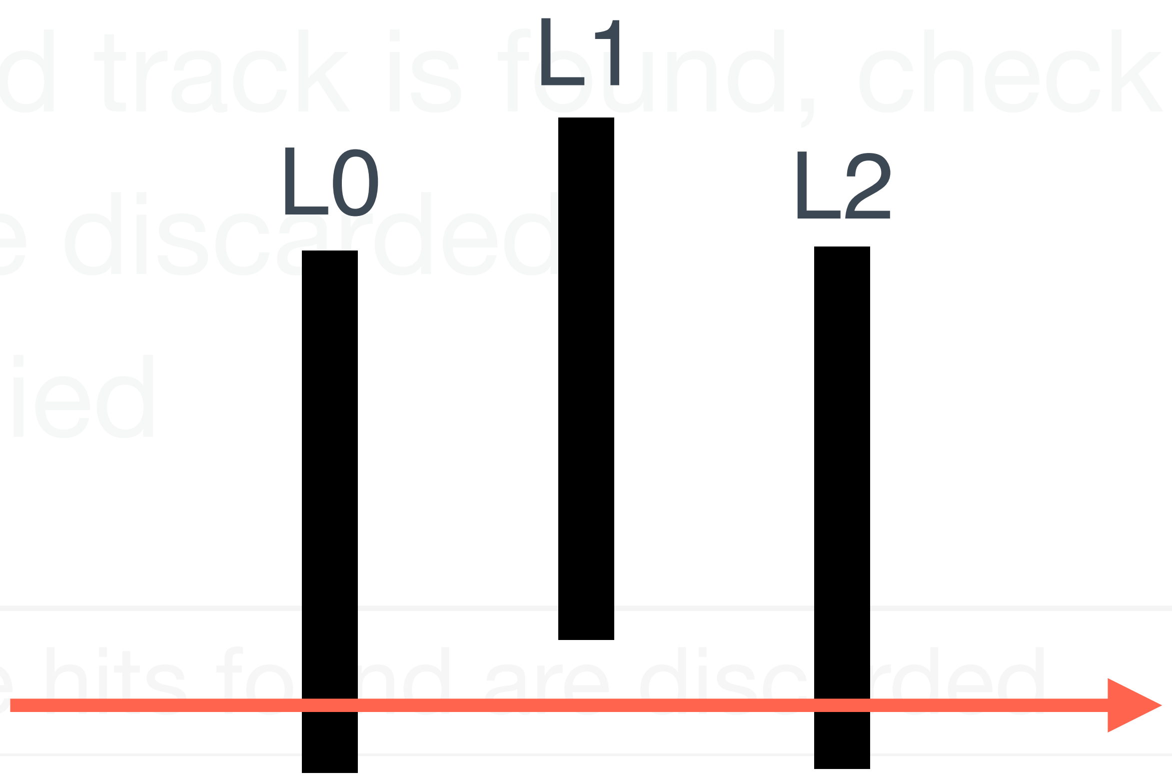


Hit detection efficiency





	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

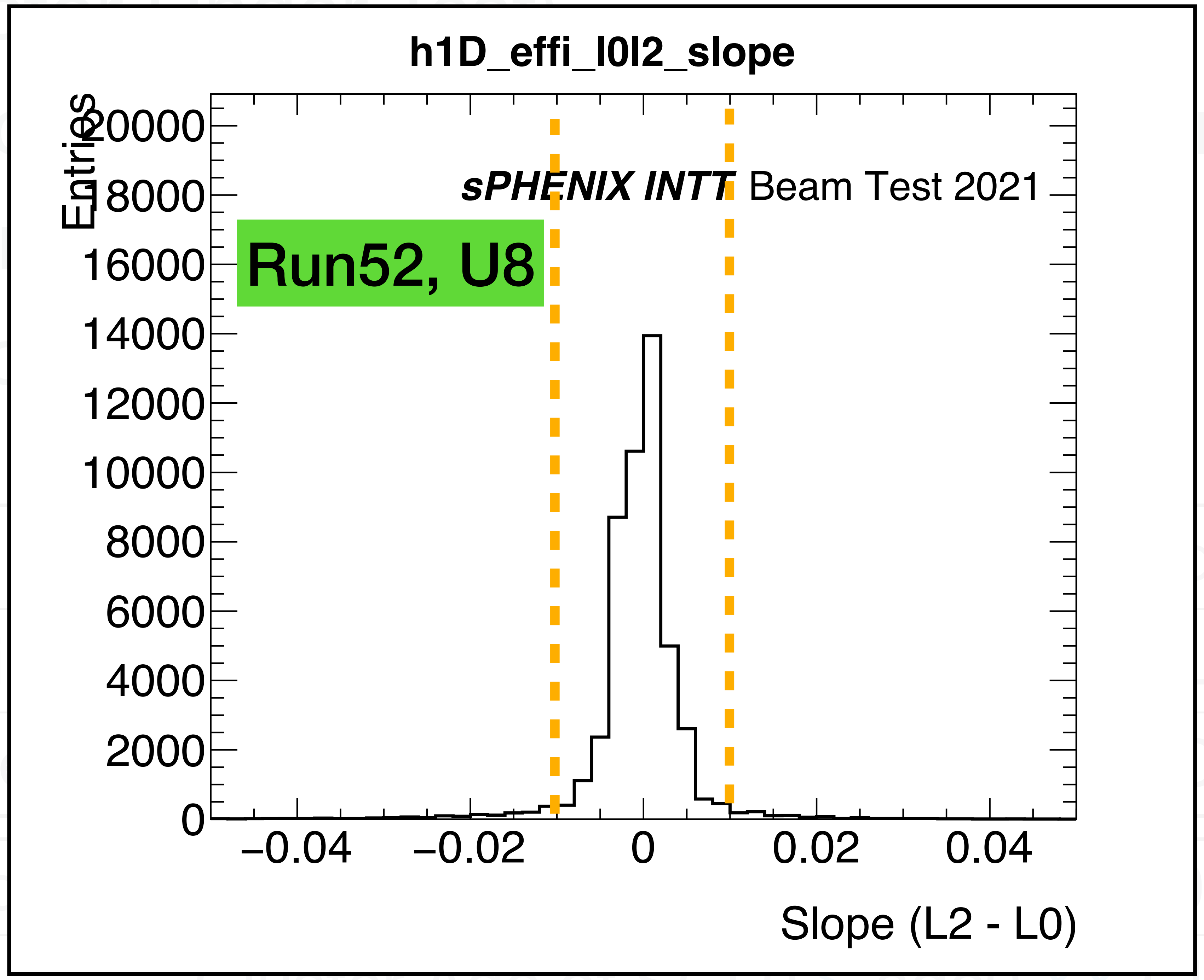
To minimize tracks reconstructed by noise hits
(Only two layers for track reco., to improve the purity, tight selection required)

Tracking	[illegible]
	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

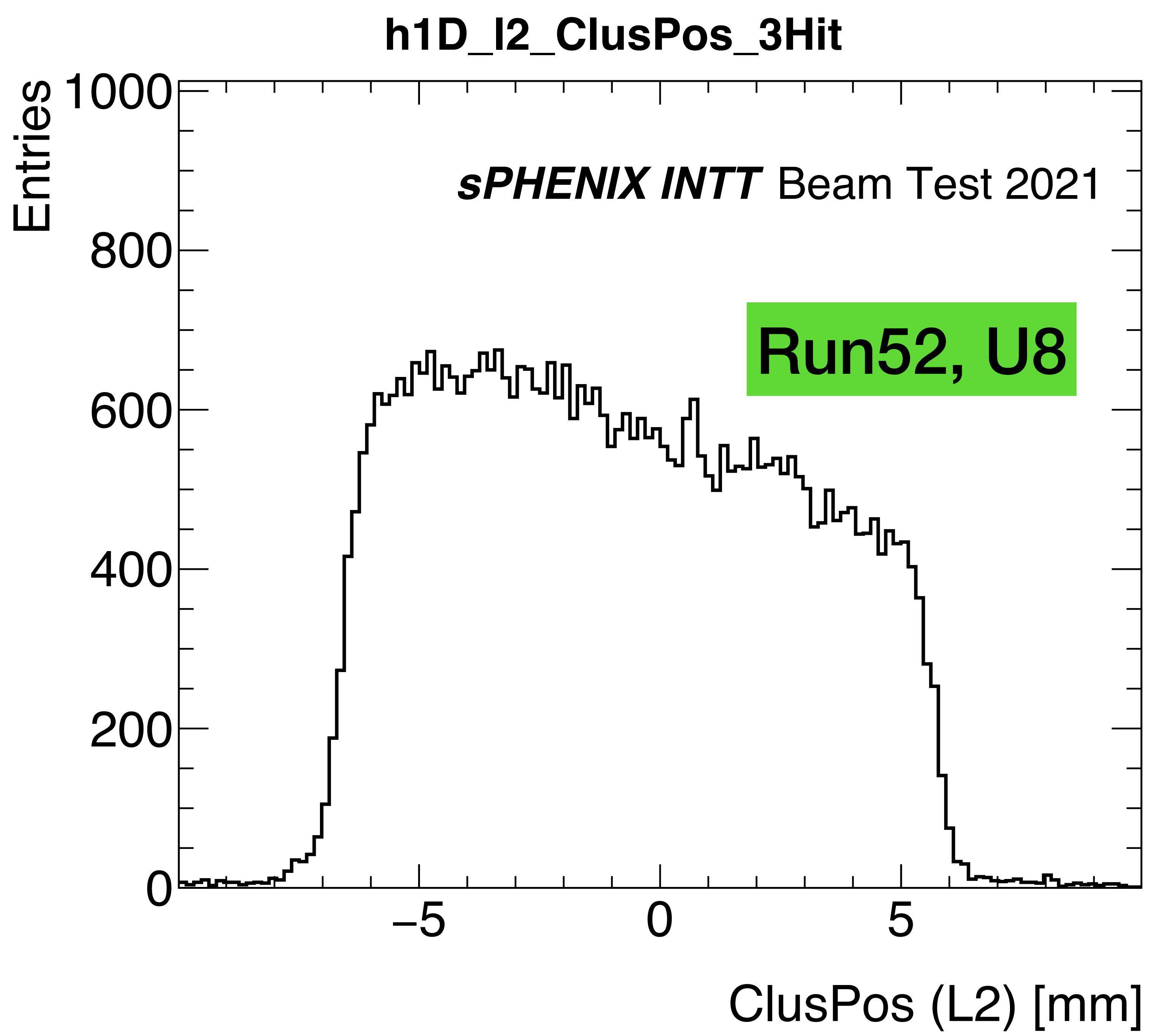
Hit detection efficiency

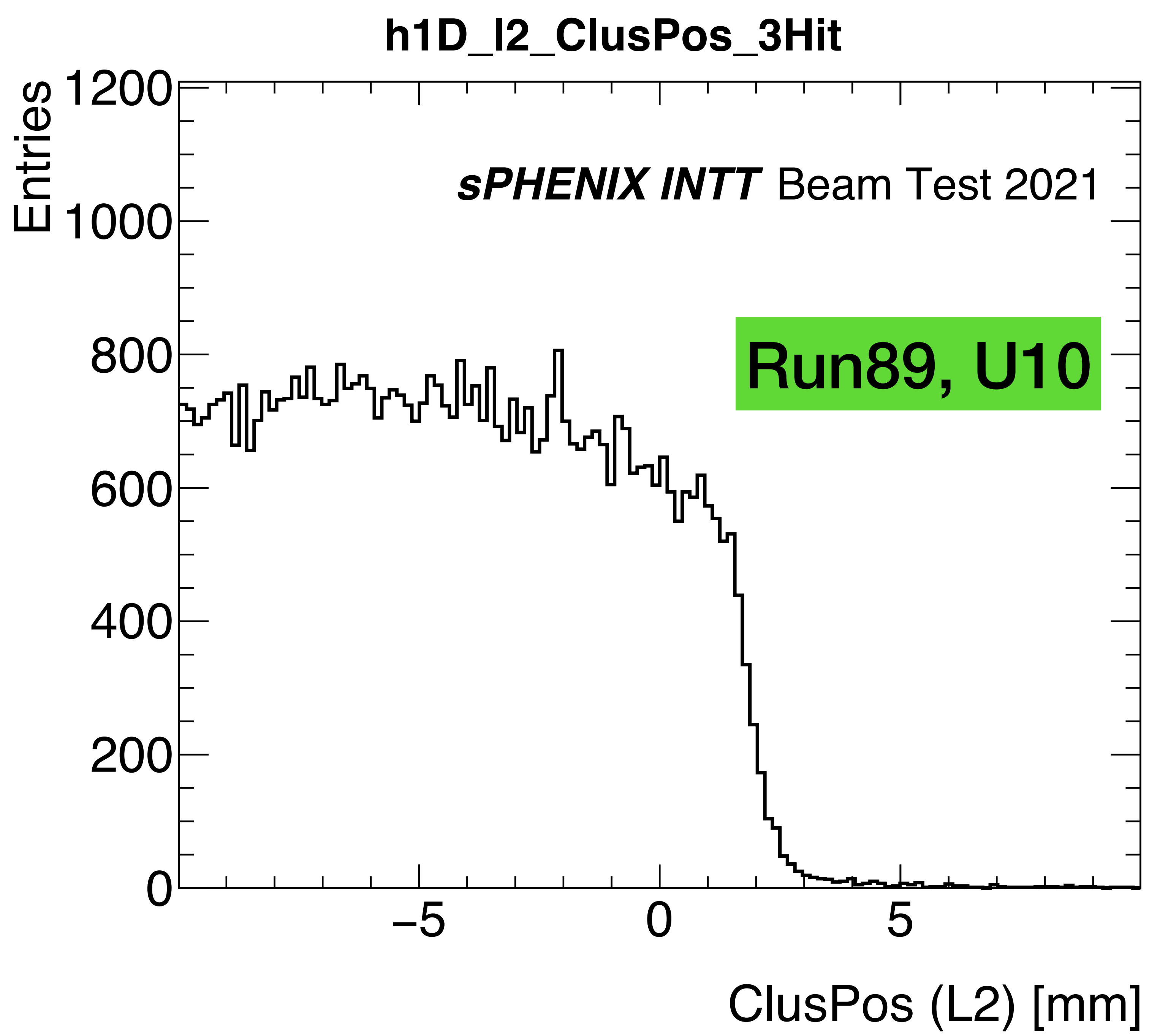


Track QA	Slope cut	fabs(slope of SCL2 - SCL0) < 0.01

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

Hit detection efficiency





Track QA	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)

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

Good track classification	Residual	|CL1 - CL2&CL0 interpolation| < 0.5 mm

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)

When Good Event is found, then check clusters in L1

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	smallest |CL1 - CL2&CL0 interpolation| < 0.5 mm

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

Hit detection efficiency - systematic unc.

Sources considered for estimating the systematic uncertainty

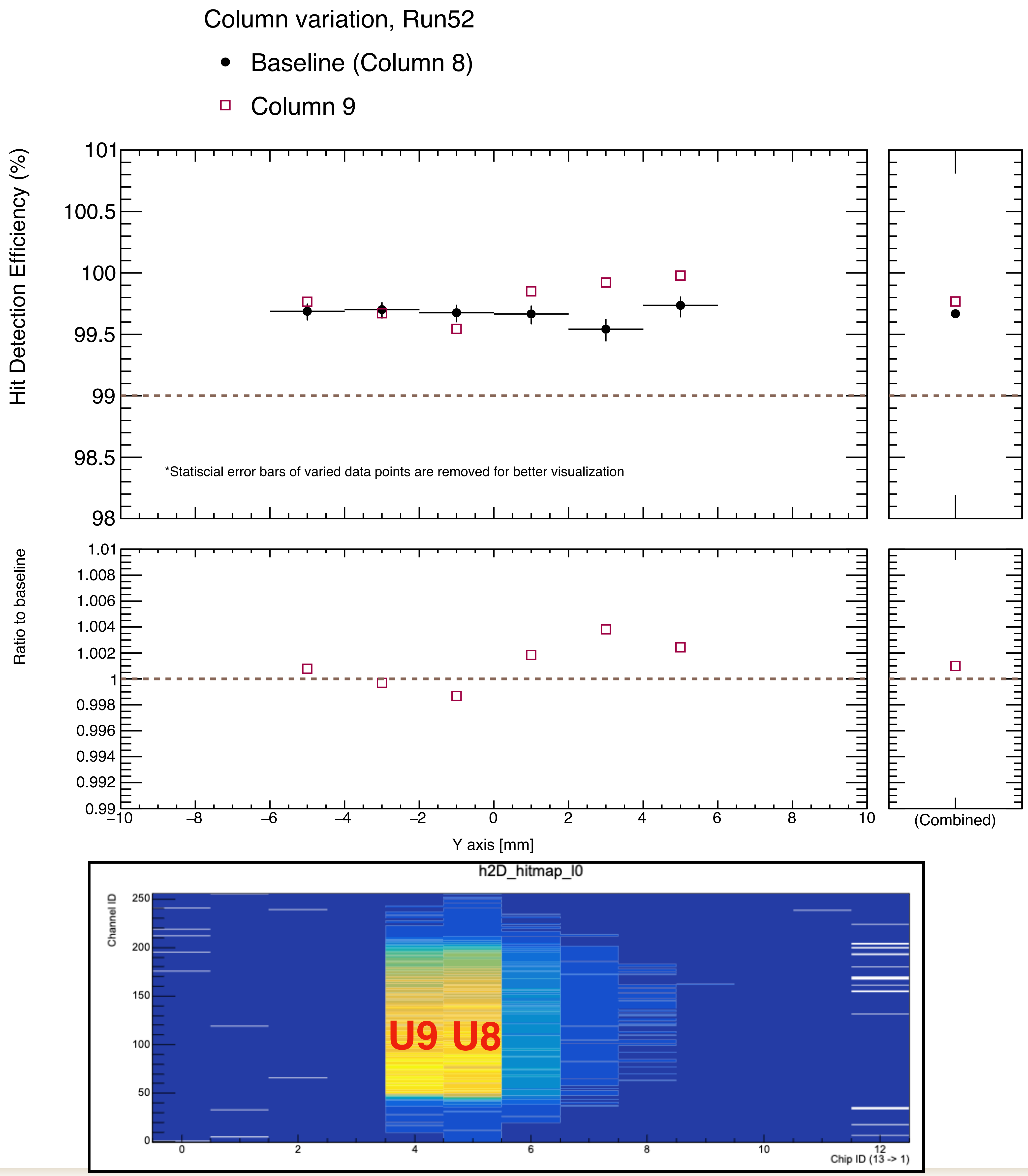
Source	Variation	Run52			Run89		
		Numerator	Denominator	Efficiency(%)	Numerator	Denominator	Efficiency(%)
Baseline		42956	43099	**99.668**	50491	50746	**99.497**
(New) Column	U8 → U9 (Run52) U10 → U11(Run89)	44198	44301	**99.768**	37148	37338	**99.491**
Residual Cut	0.5 mm → 0.7 mm	42972	43099	**99.705**	50511	50746	**99.537**
	0.5 mm → 0.3 mm	42895	43099	**99.527**	50436	50746	**99.389**
Slope Cut	0.01 → 0.013	43638	43795	**99.642**	51359	51623	**99.489**
	0.01 → 0.007	41748	41877	**99.692**	48622	48856	**99.521**
Boundary Cut	8 ch → 11 ch	42956	43099	**99.668**	49378	49625	**99.502**
	8 ch → 5 ch	42956	43099	**99.668**	51609	51873	**99.491**

considered in the past

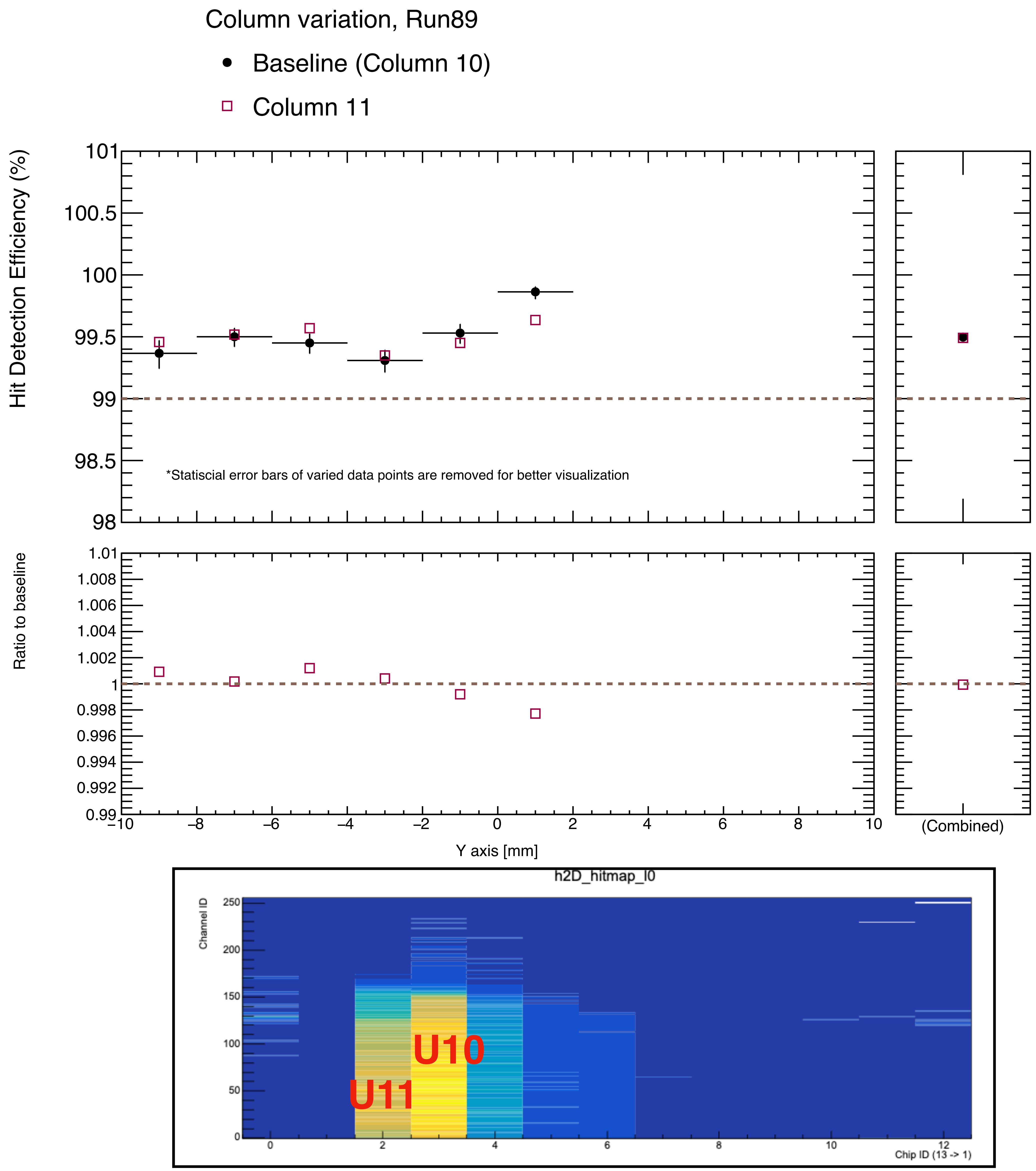
The numbers are statistically combined for estimating systematic uncertainty

Hit detection efficiency as a function of Y axis

Run52

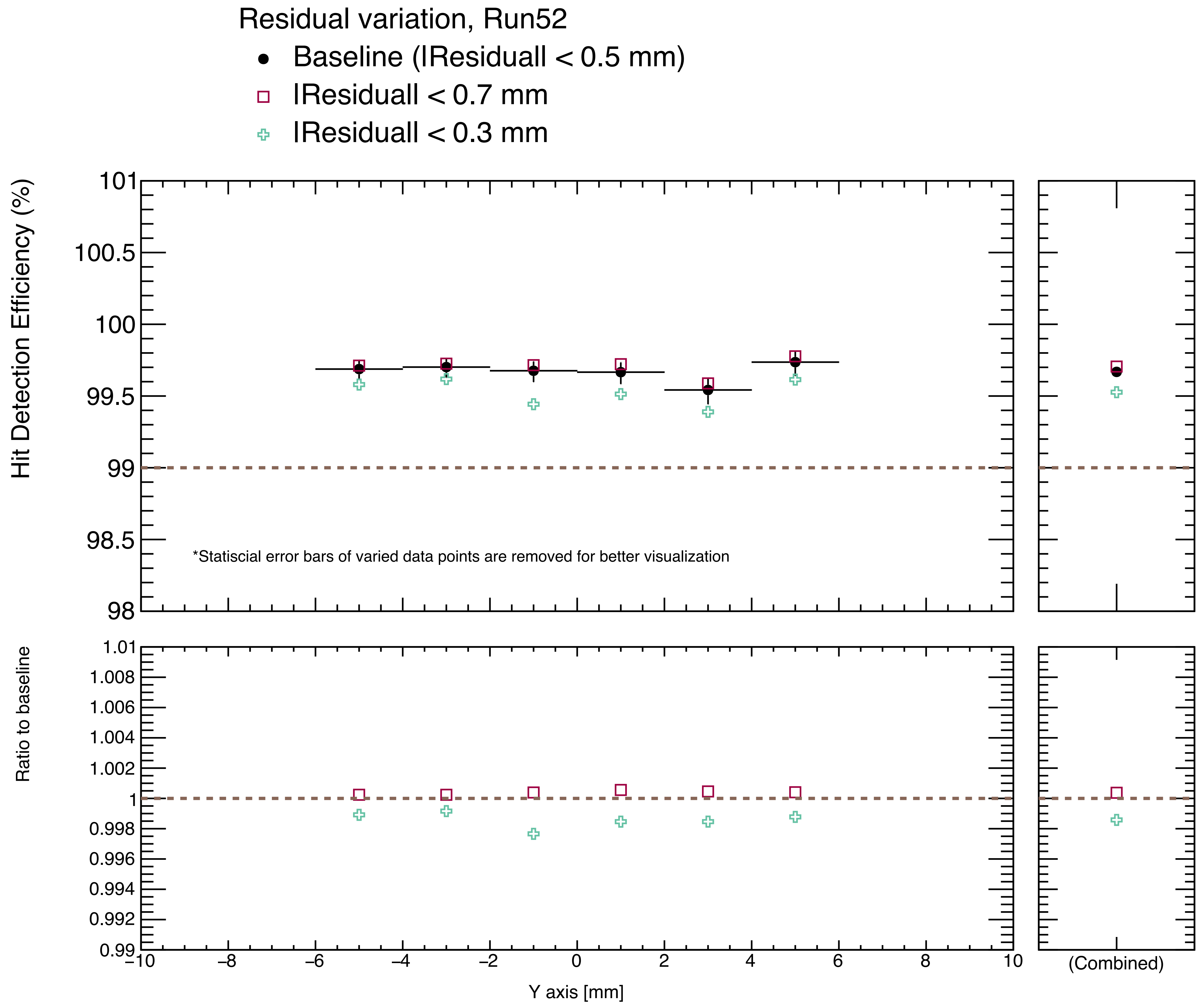


Run89

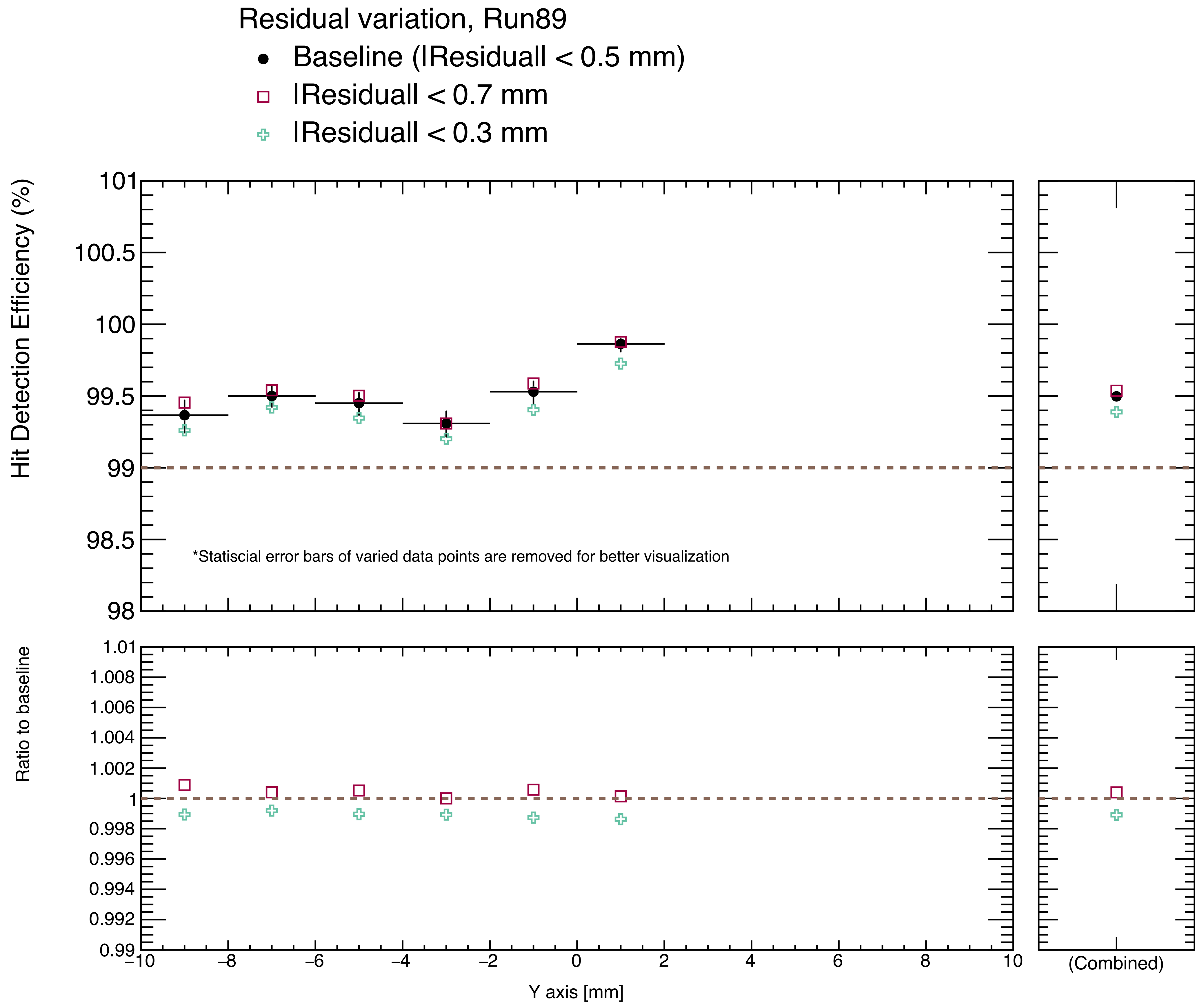


Hit detection efficiency as a function of Y axis

Run52

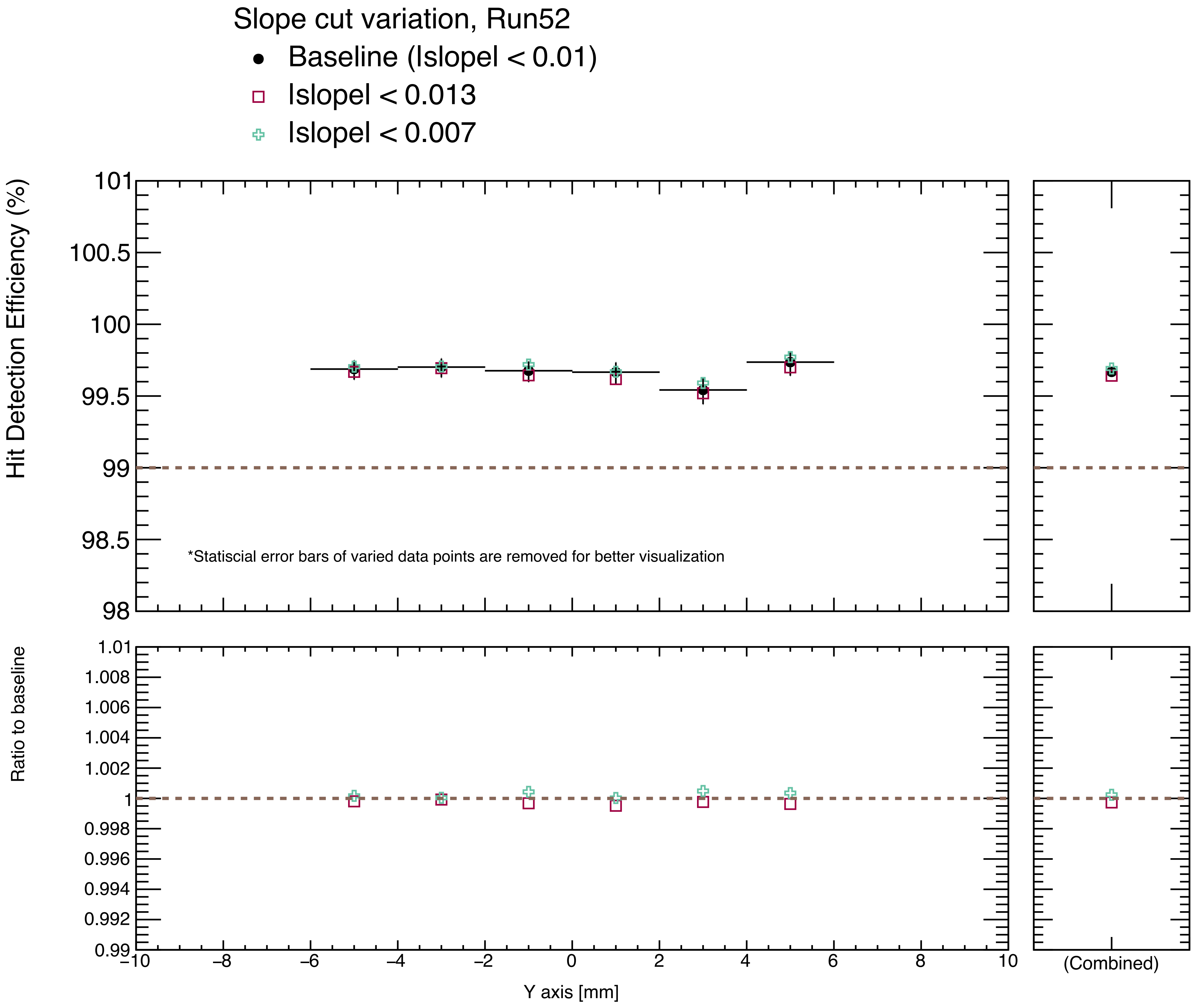


Run89

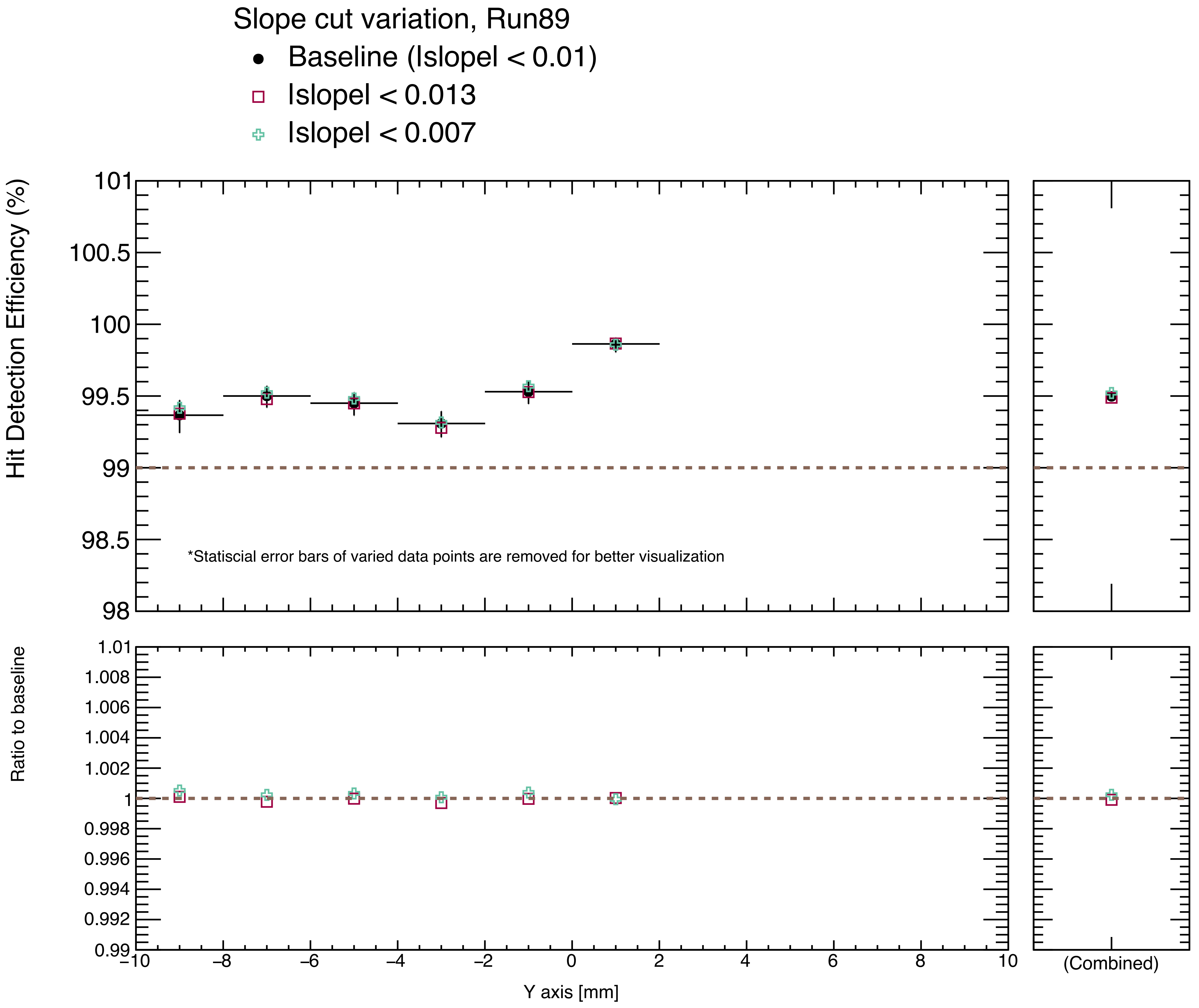


Hit detection efficiency as a function of Y axis

Run52

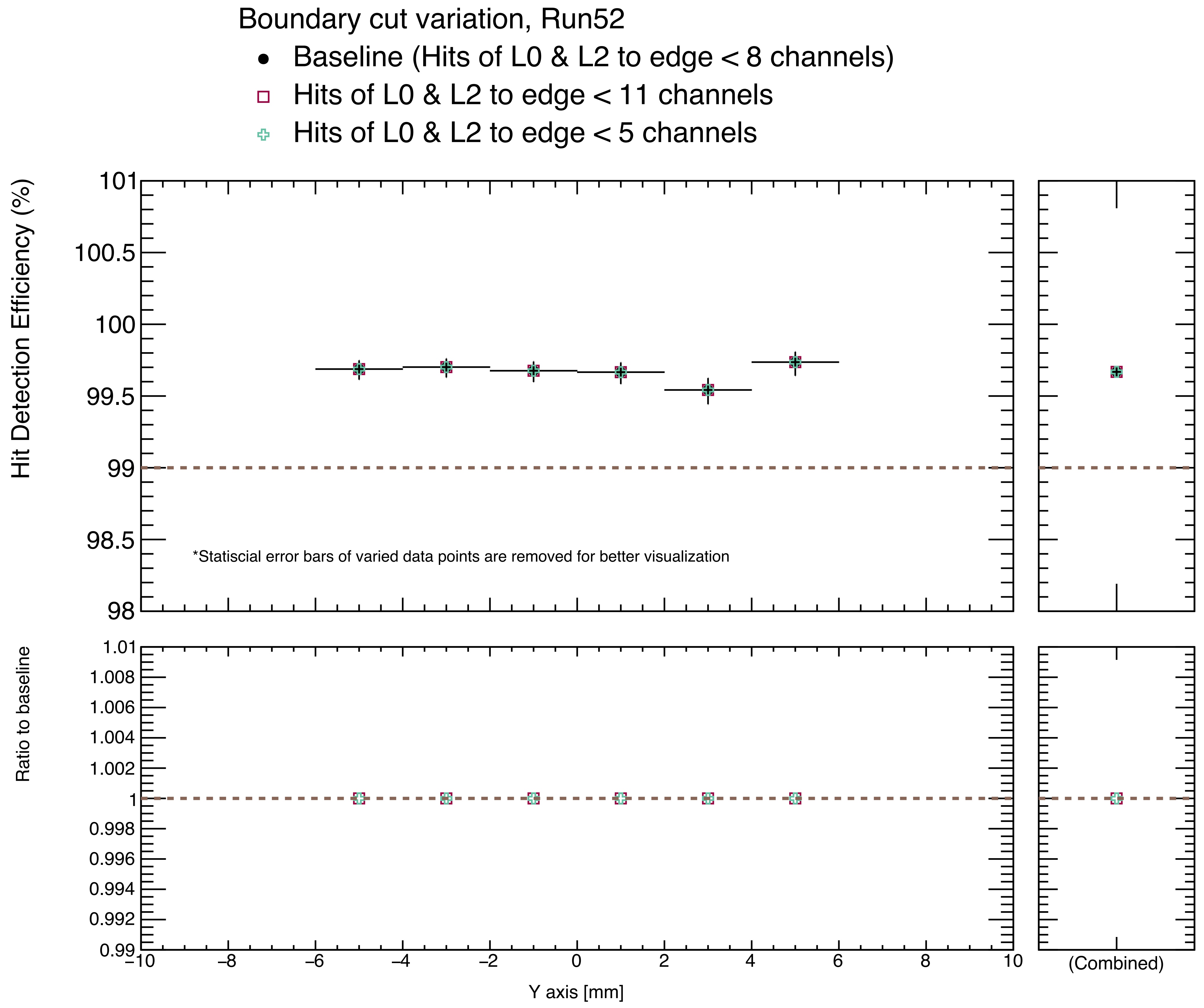


Run89

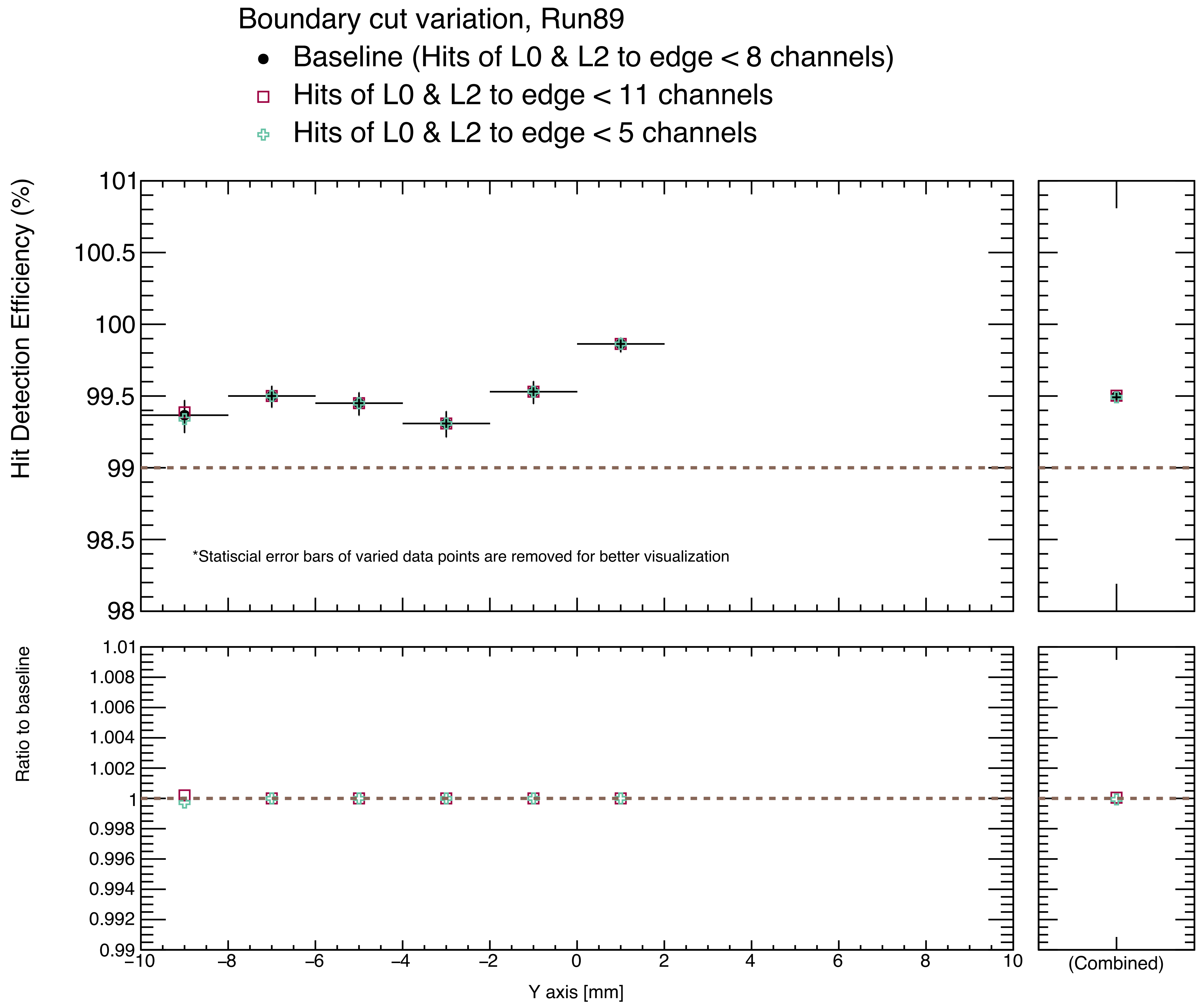


Hit detection efficiency as a function of Y axis

Run52



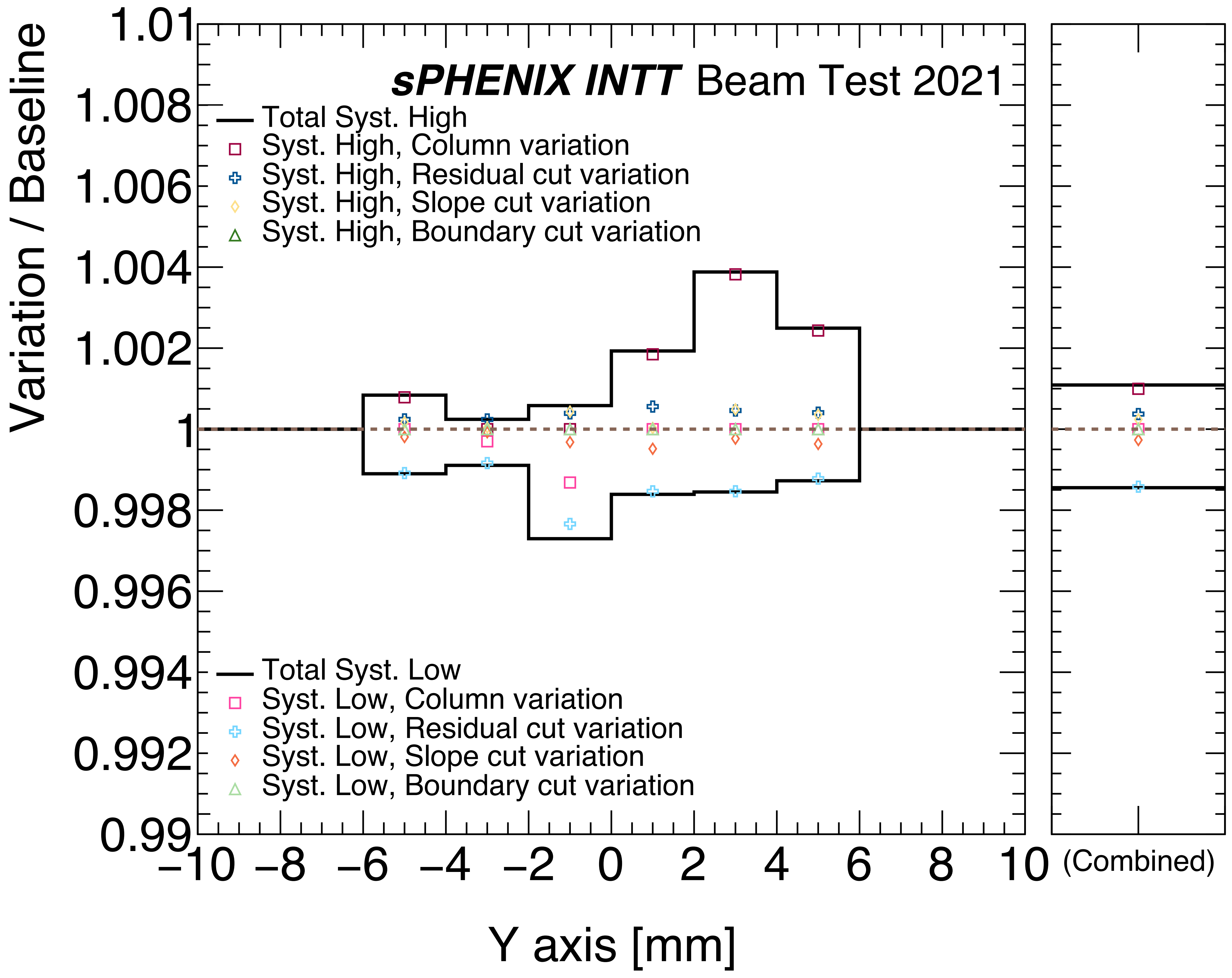
Run89



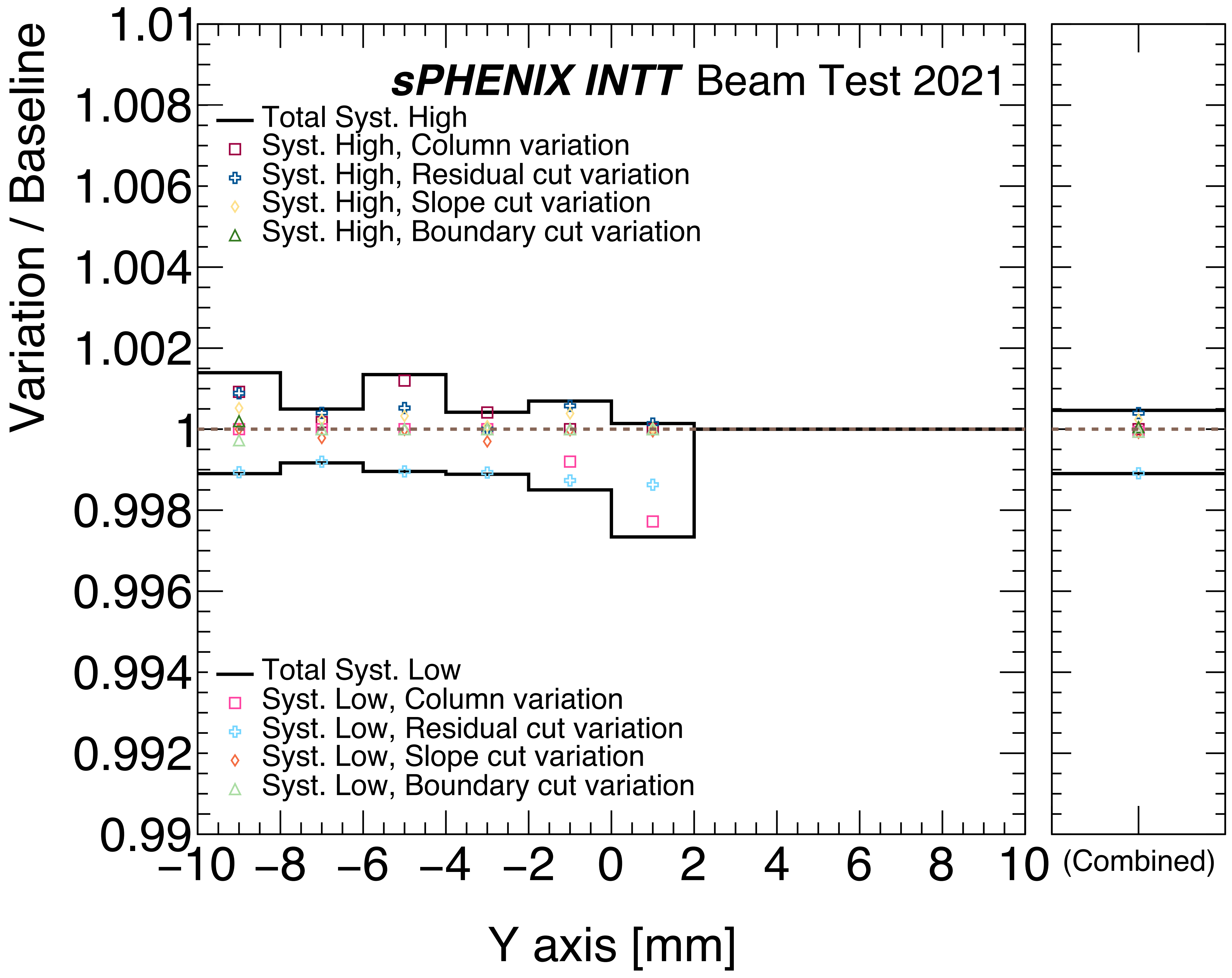
Hit detection efficiency as a function of Y axis

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

Run52



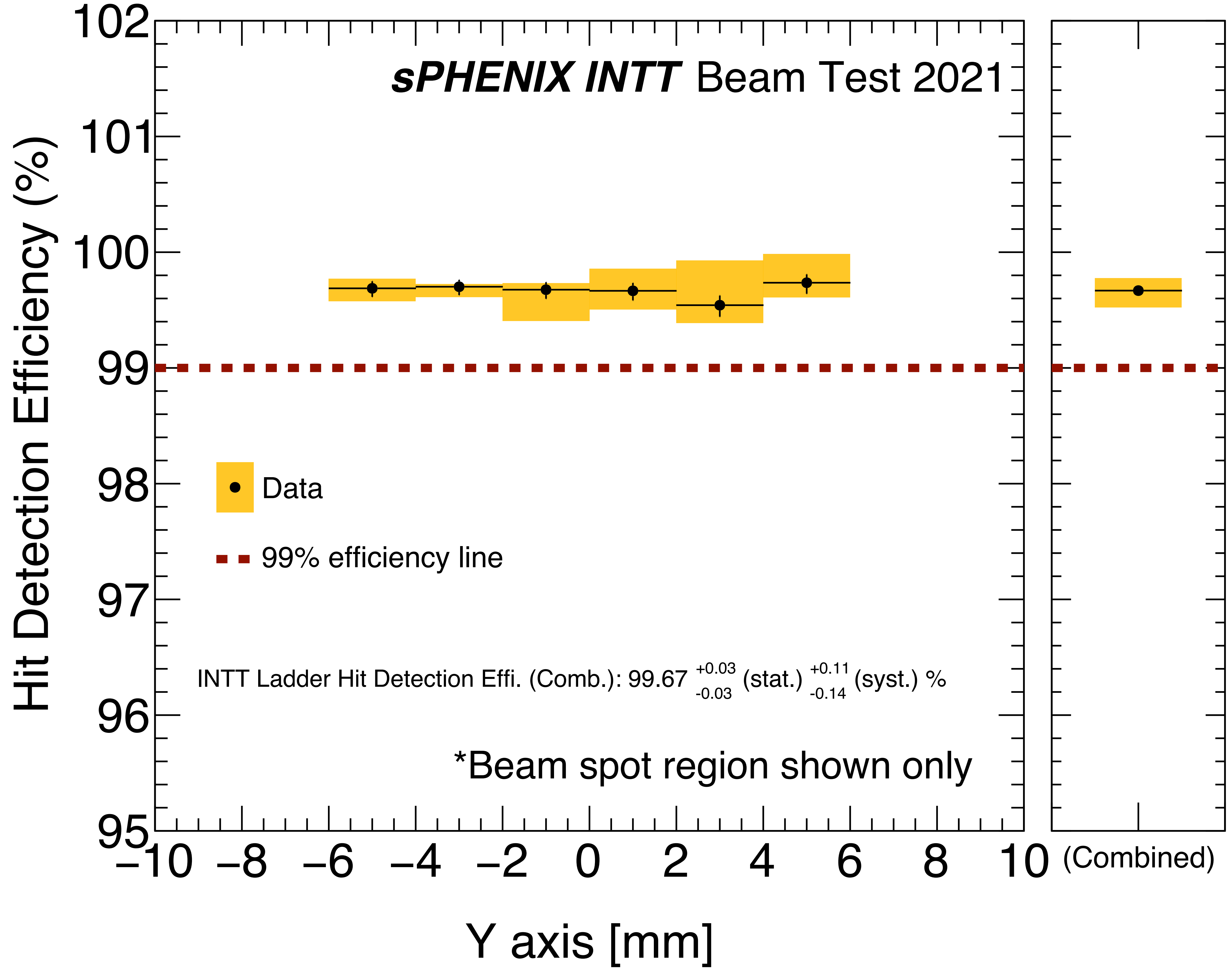
Run89



Hit detection efficiency as a function of Y axis

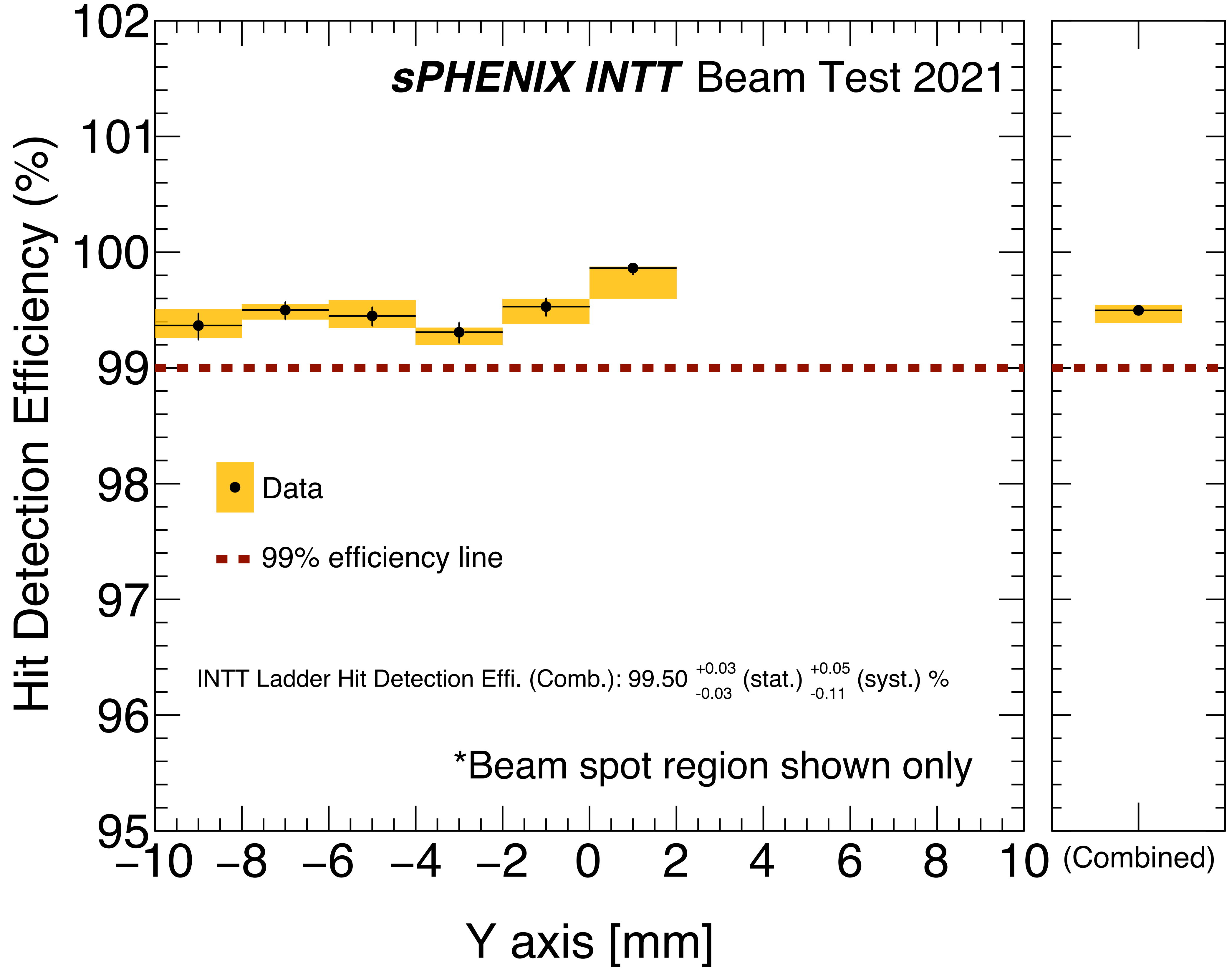
Run52

Hit detection efficiency (combined):
$$99.668\,^{+0.028}_{-0.030}(stat.)\,^{+0.109}_{-0.144}(syst.)\,\%$$



Run89

Hit detection efficiency (combined):
$$99.497\,^{+0.031}_{-0.033}(stat.)\,^{+0.046}_{-0.109}(syst.)\,\%$$



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––––––––––––

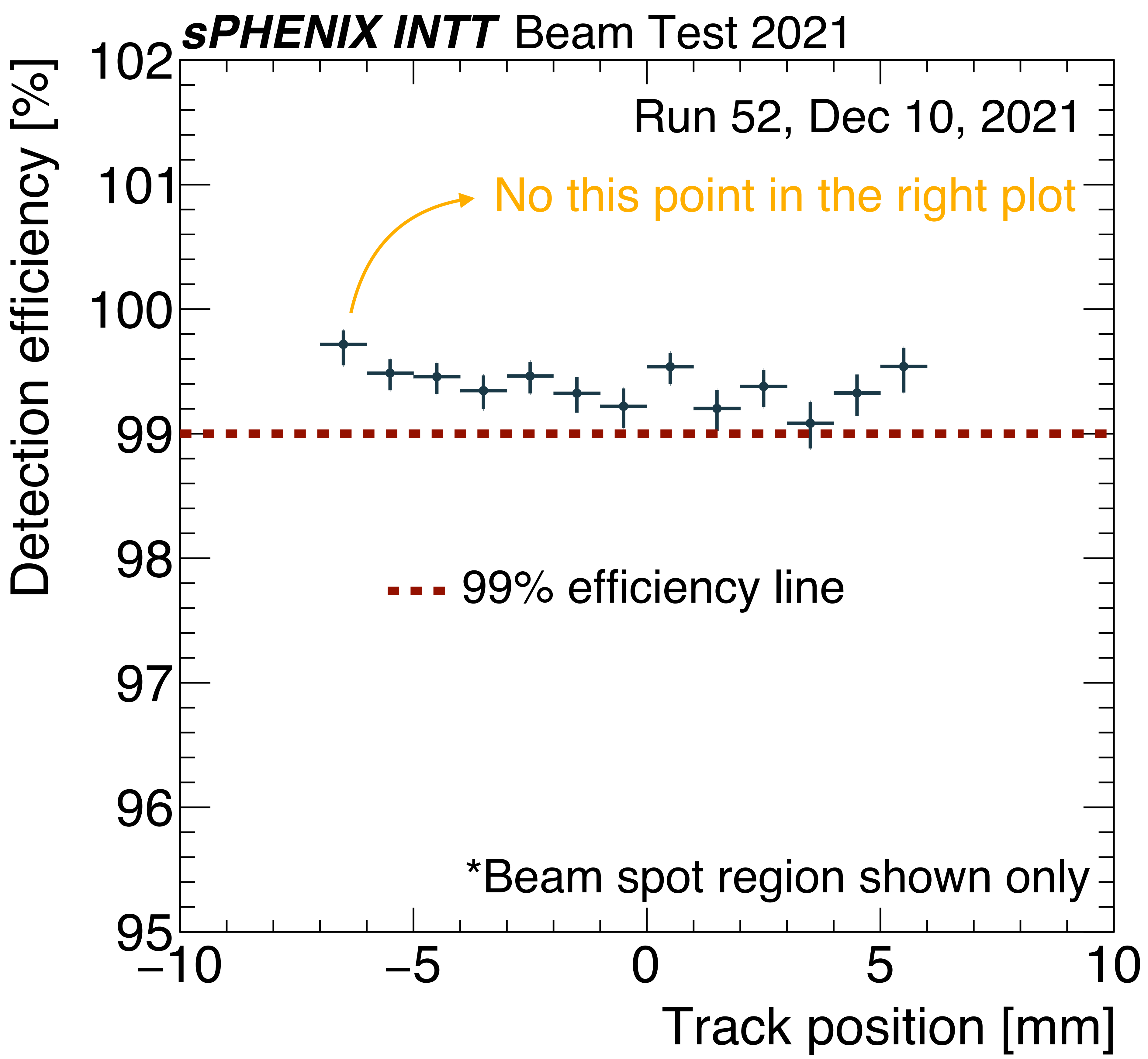
From Run52, hit detection efficiency (Combined): $99.668\ ^{+0.028}_{-0.030}(stat.)\ ^{+0.109}_{-0.144}(syst.)\ \%$

- 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 (0.5 mm) is used for Residual cut in ELPH (New results)
  - Good agreement with MC in residual distribution obtained, therefore loose the selection a bit

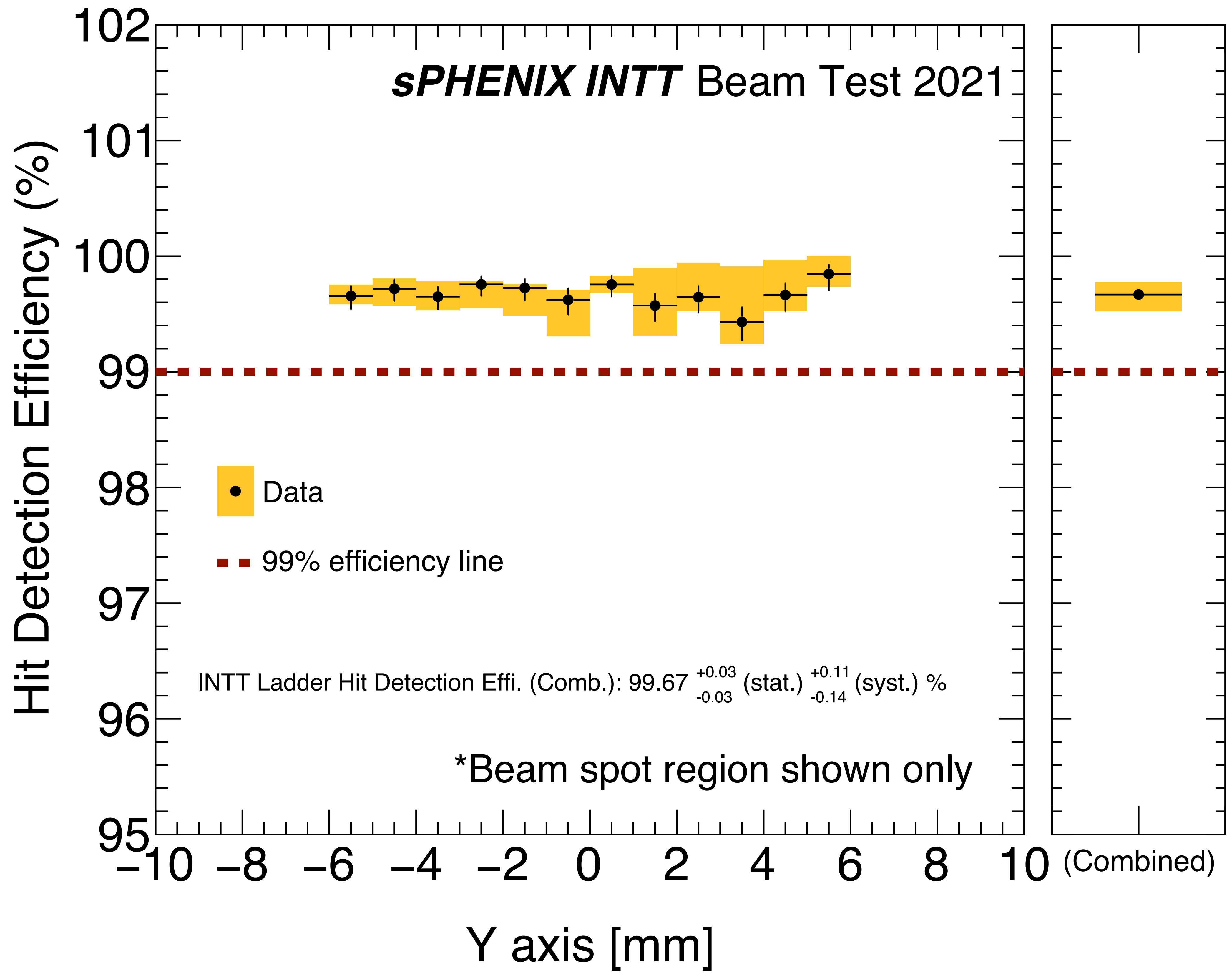
Recap - hit detection efficiency of L1

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)



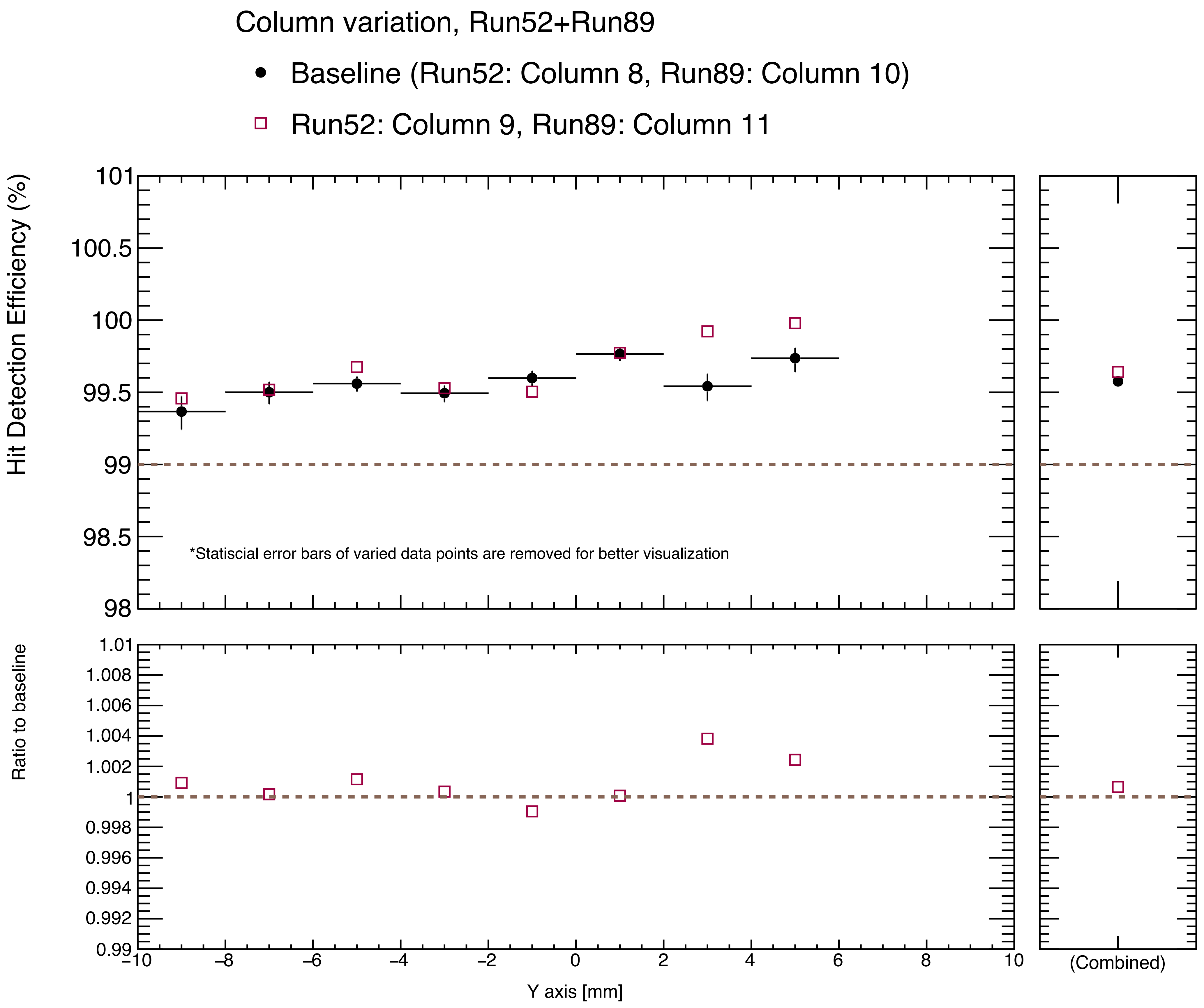
The new plot with same bin width for comparison

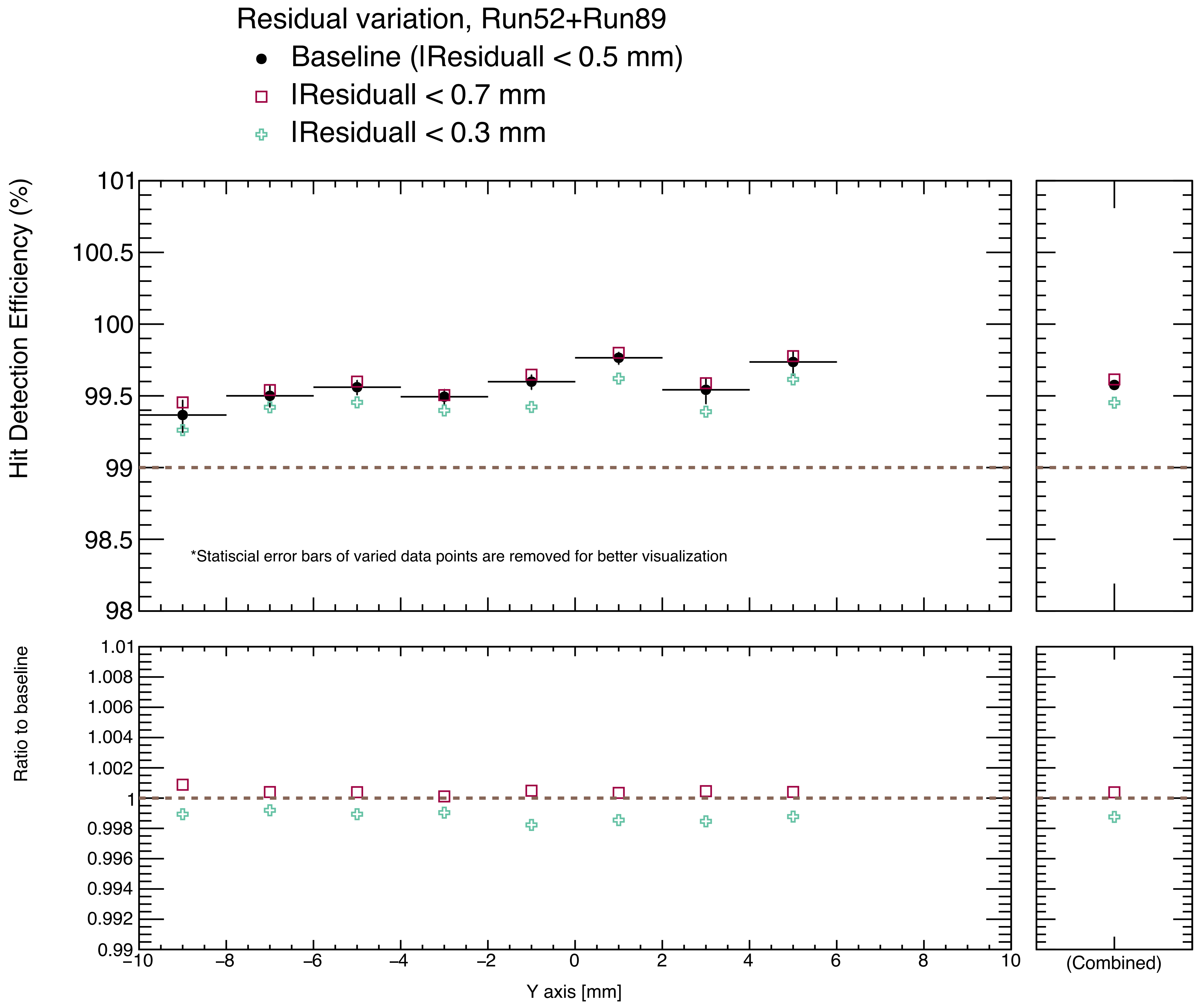


In comparing the baseline data points, basically same shape

Final, Run52 & Run89 combined

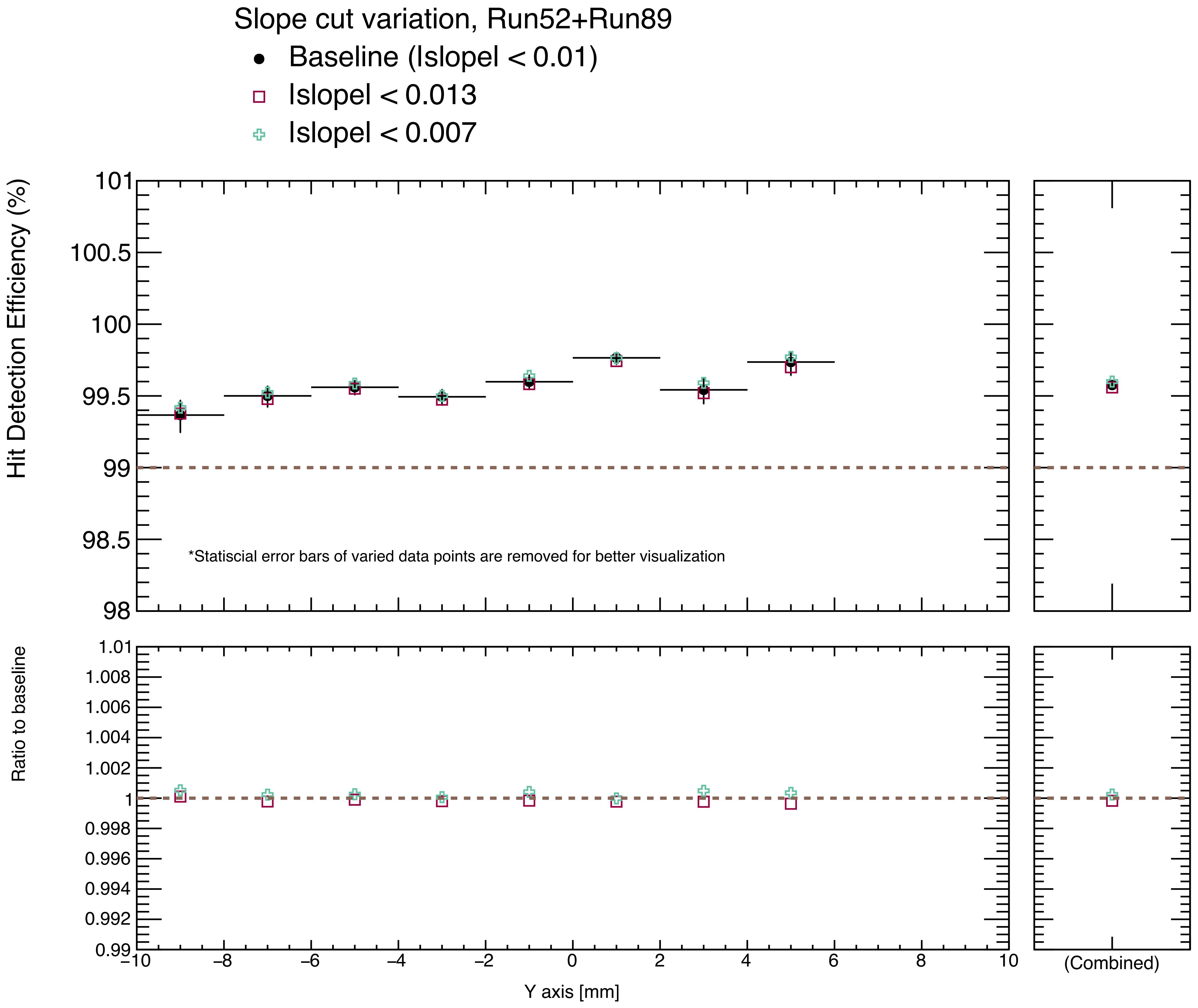
Wider coverage in Y axis: -10 mm to 6 mm

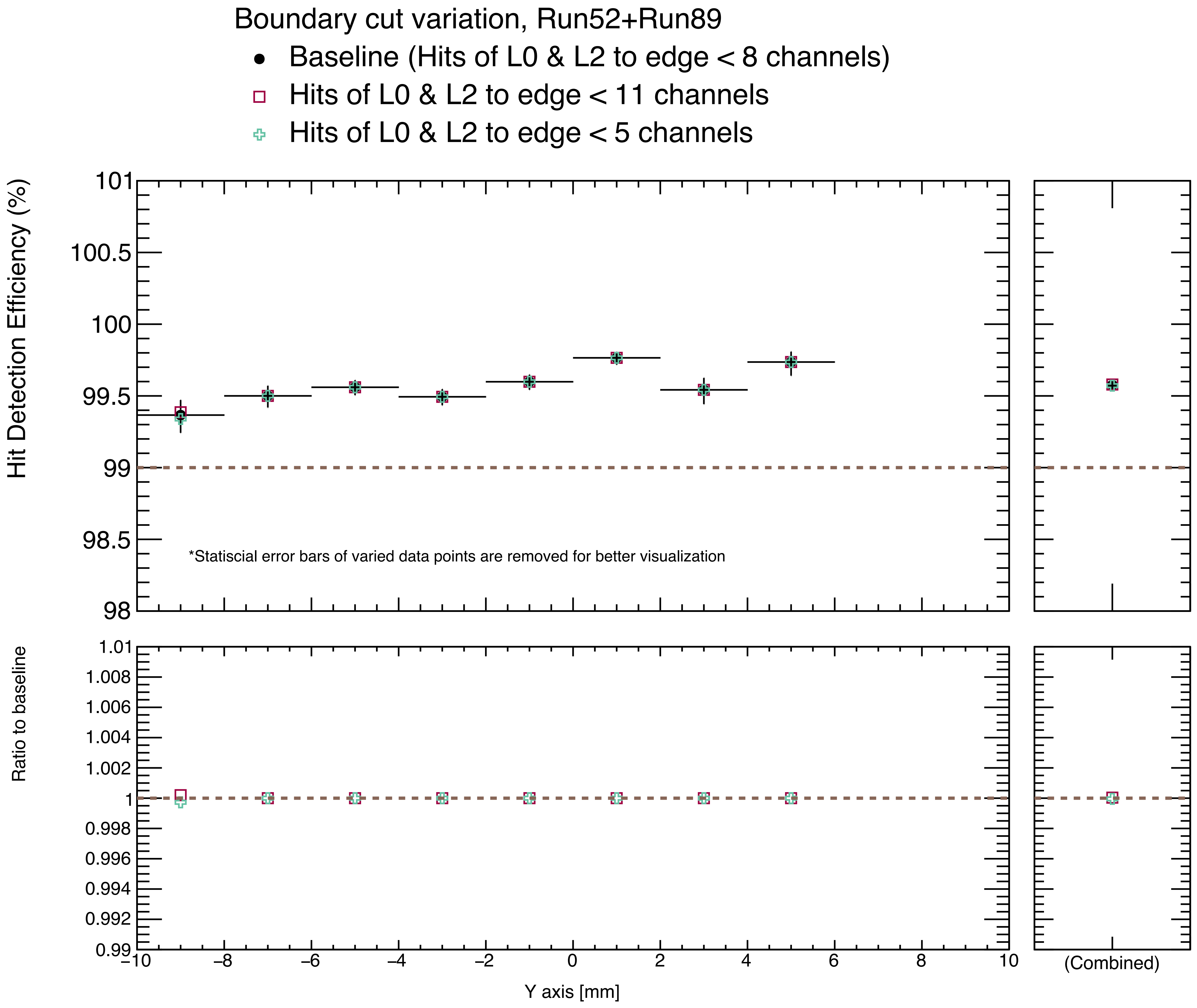




Final, Run52 & Run89 combined

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

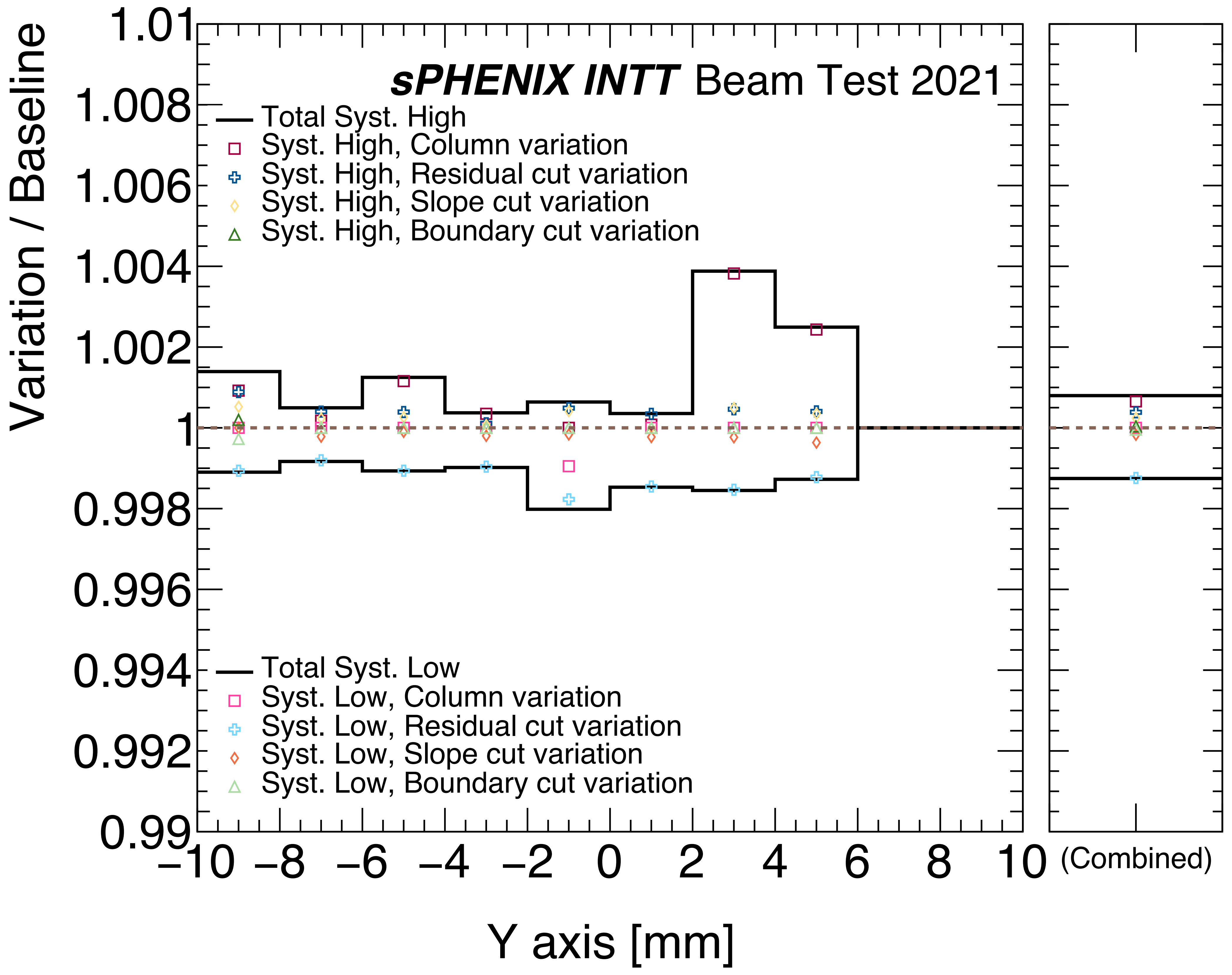


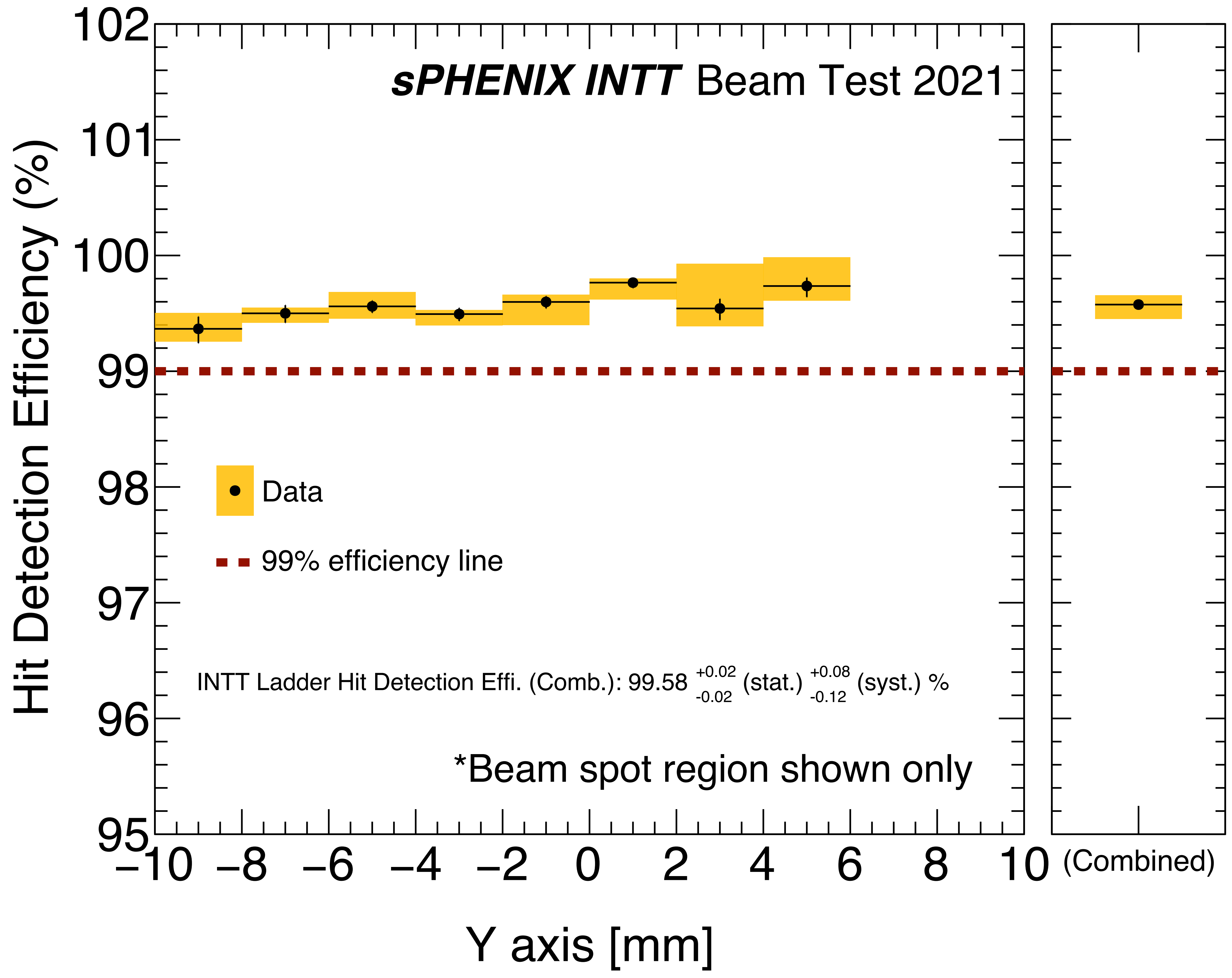


Final, Run52 & Run89 combined

Numbers to be in paper (tentative)

Hit detection efficiency (Combined): $99.576\ ^{+0.021}_{-0.022}(stat.)\ ^{+0.079}_{-0.125}(syst.)\ \%$



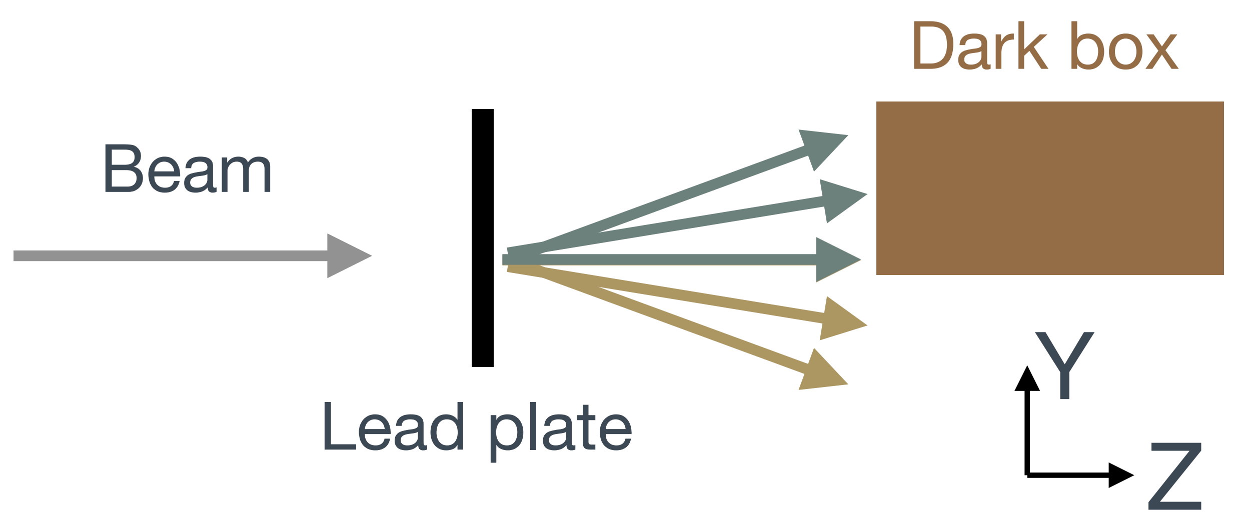


Plot to be in paper (tentative)

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) < 0.5 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



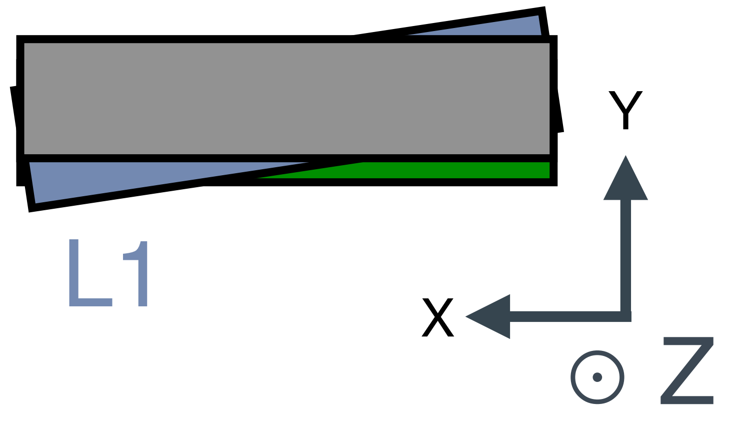
- Key correction: L1 alignment correction for all 13 columns

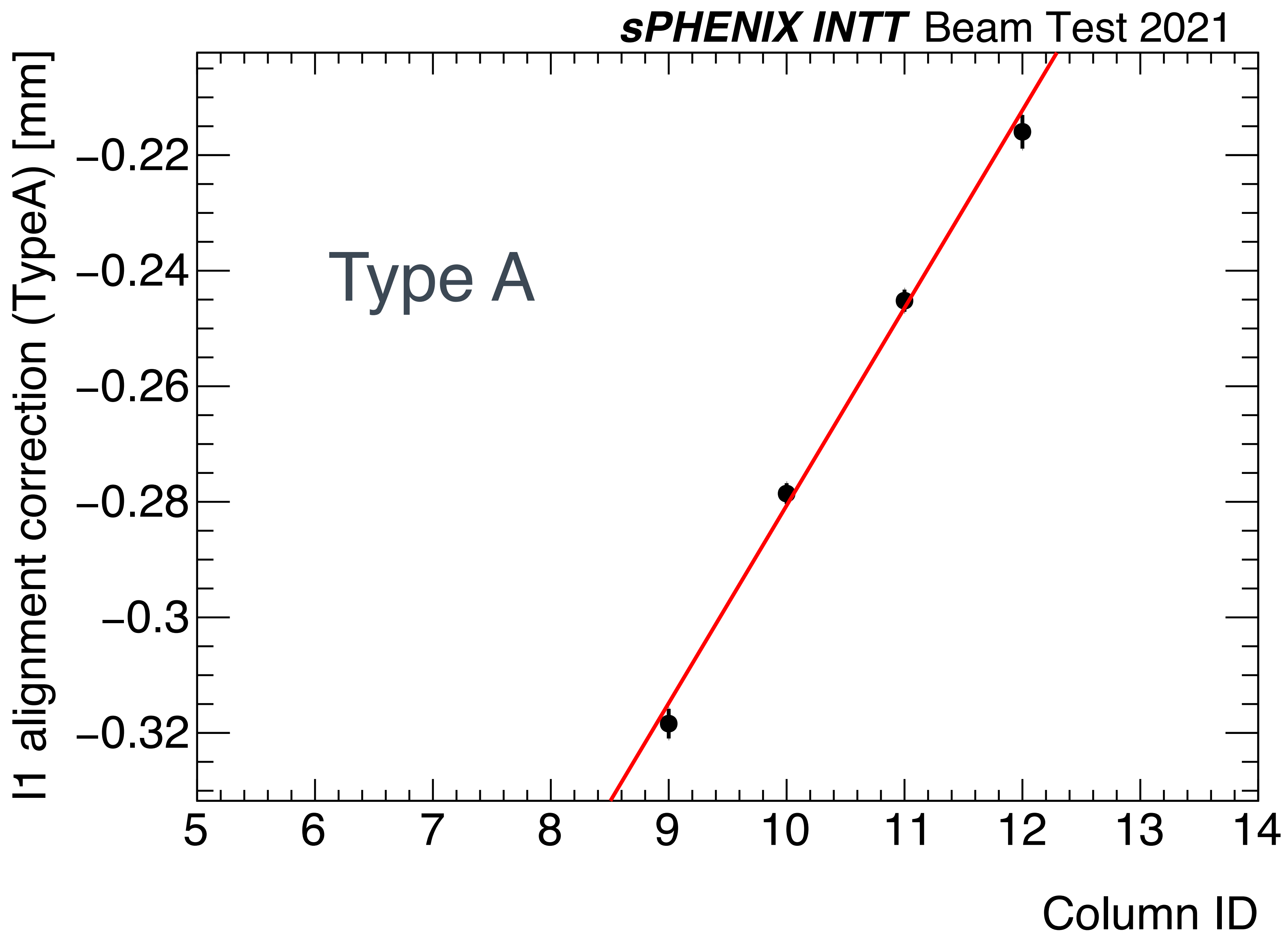
- In data, events with clone hit are discarded

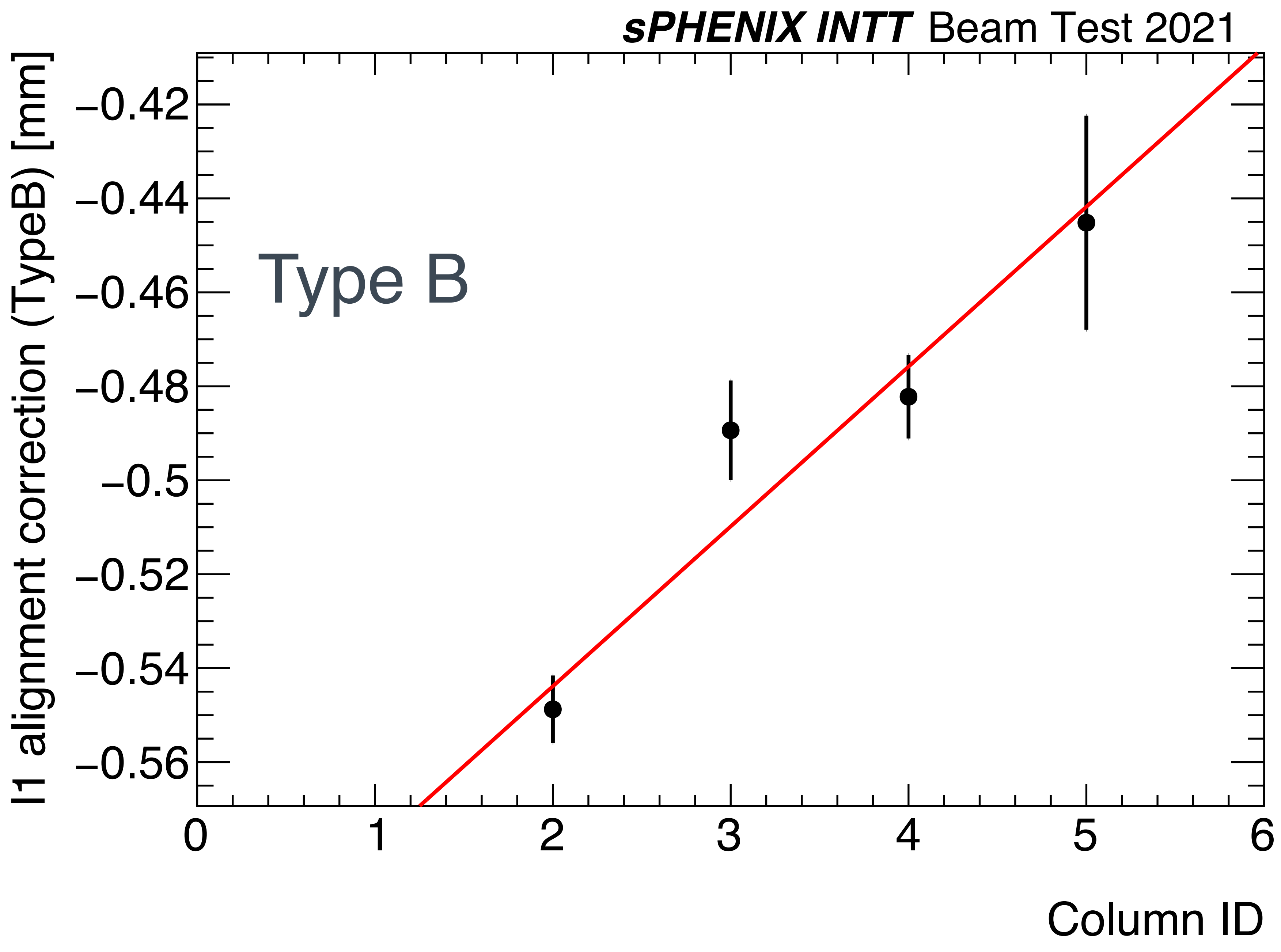
Number of reco. tracks compared to MC

- In **<u>Data</u>**: 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





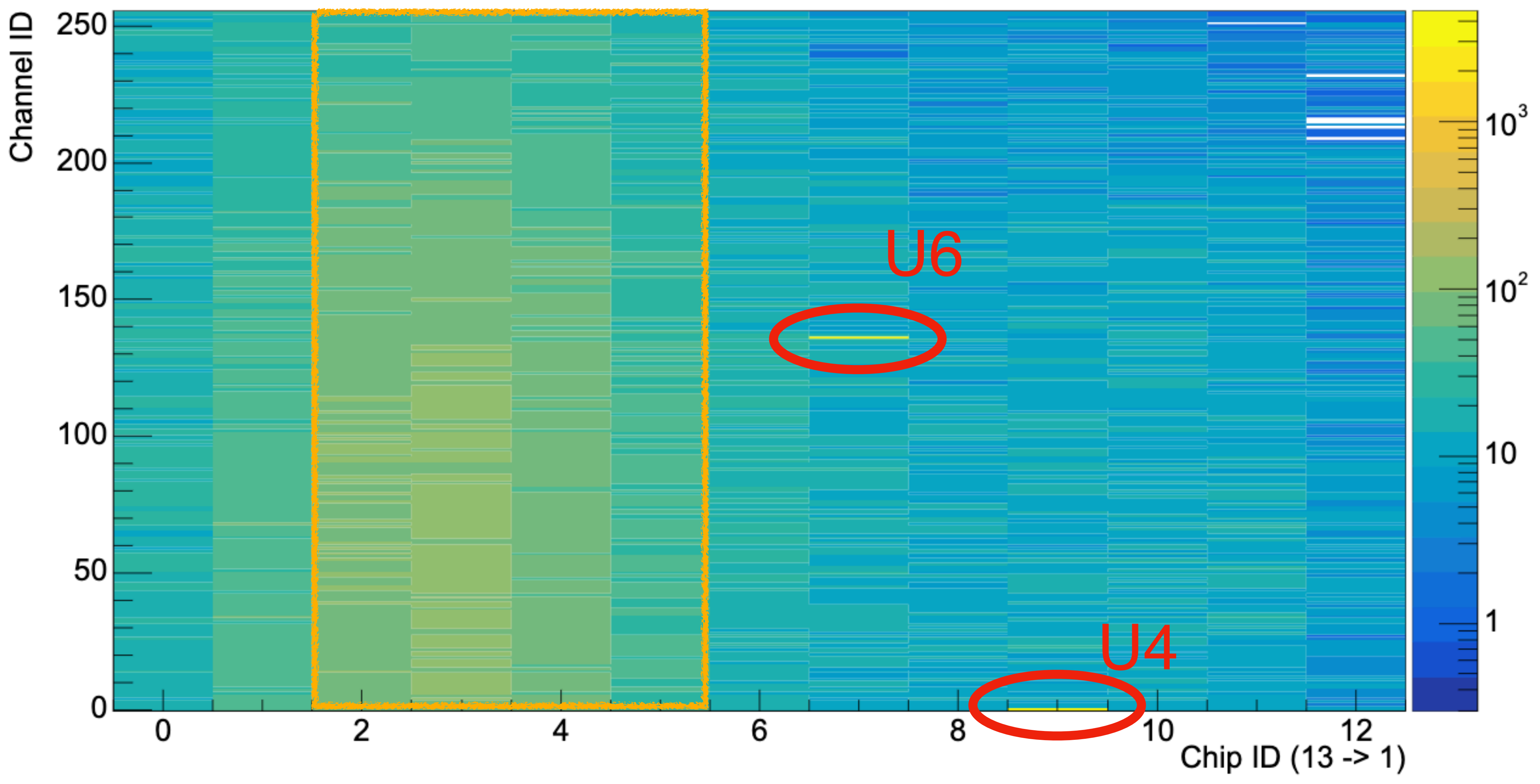


- In **<u>Simulation</u>**: No L1 rotation, correction for all columns given by average of L1 alignments measured by columns U9, U10 and U11 (beam spot region)

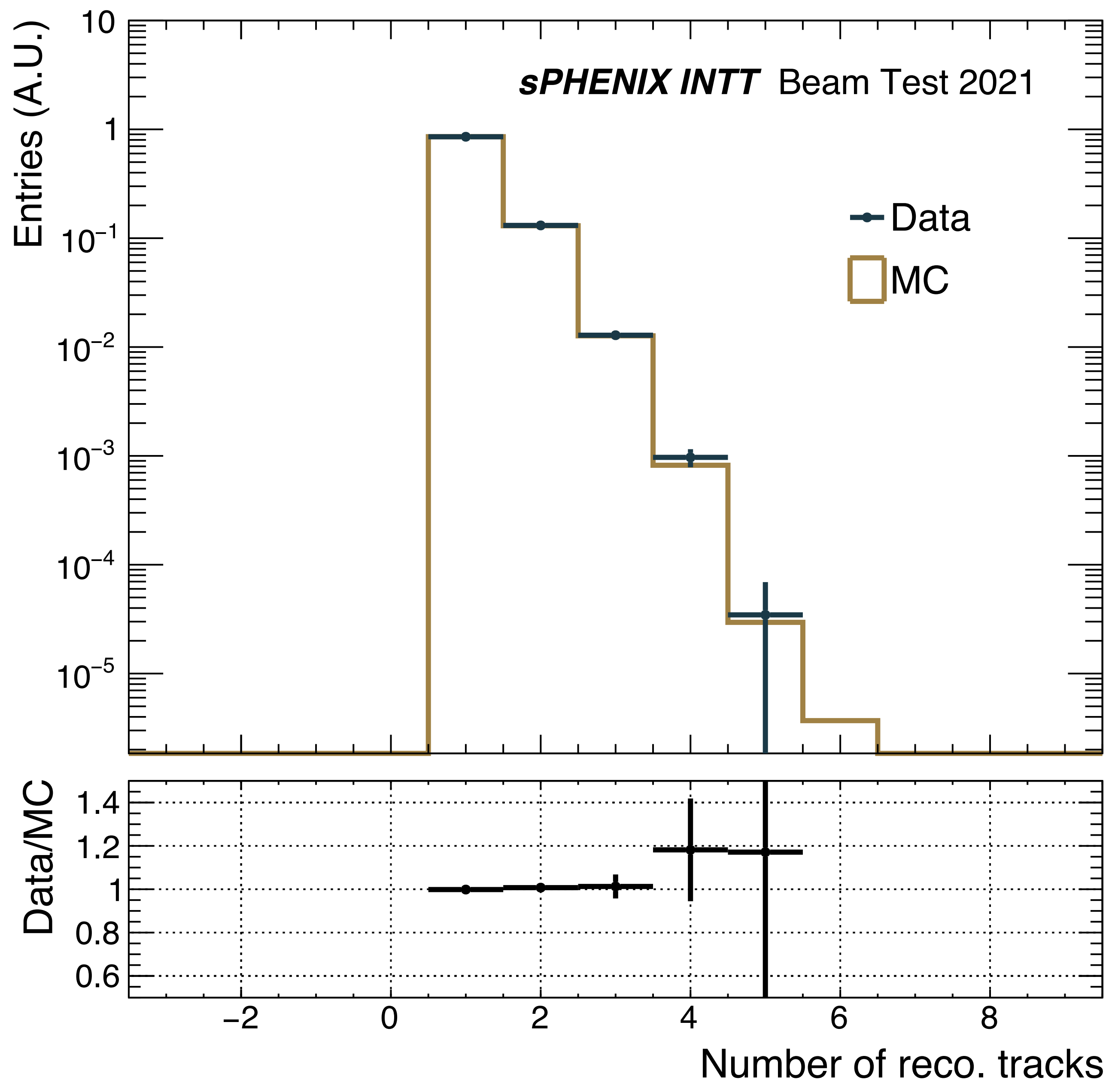
Number of reco. tracks compared to MC

In L2 of Run64, two hot channels found in column 4 and column 6

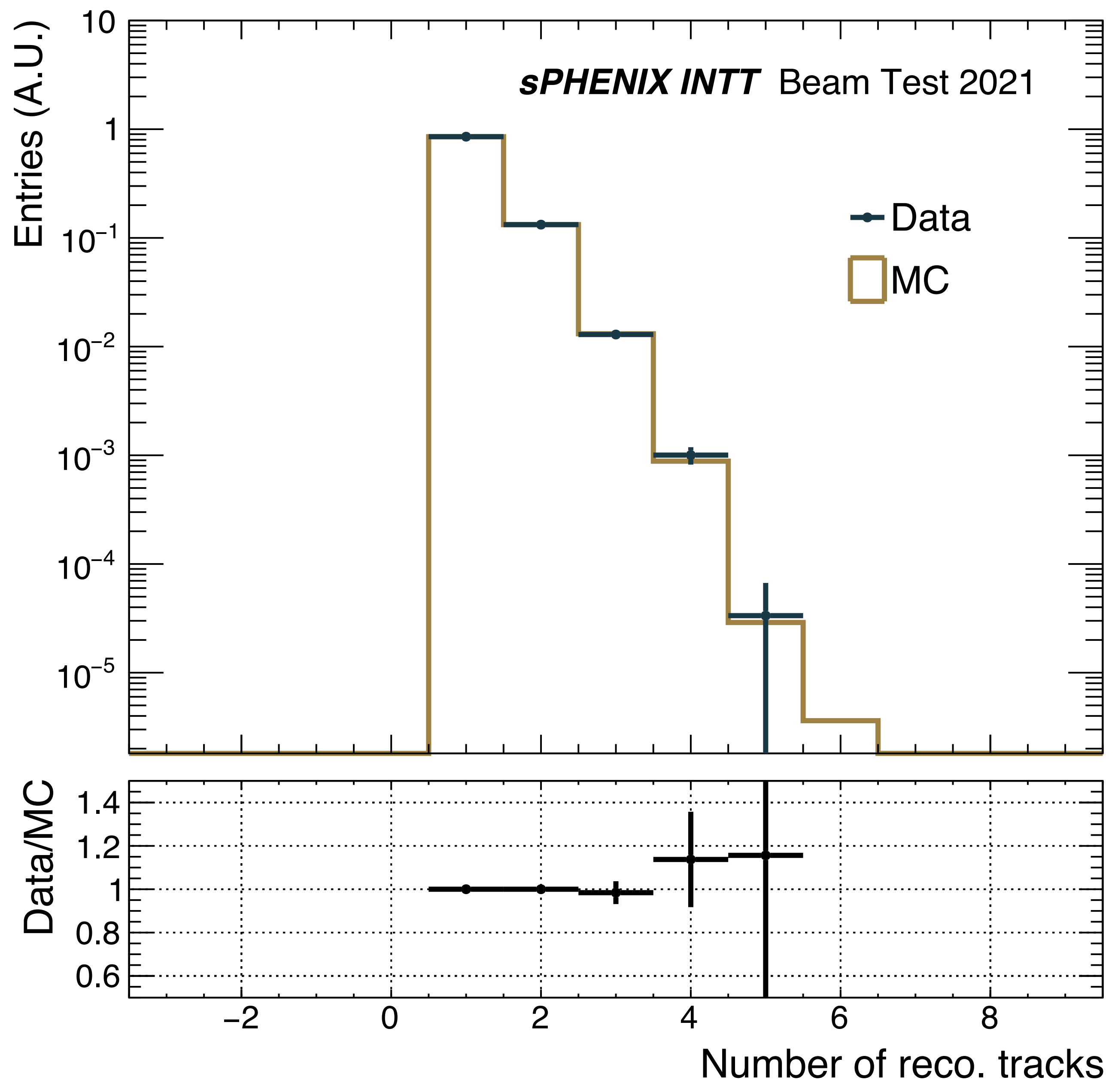
Beam spot region



Columns U4 & U6 rejected



All columns included

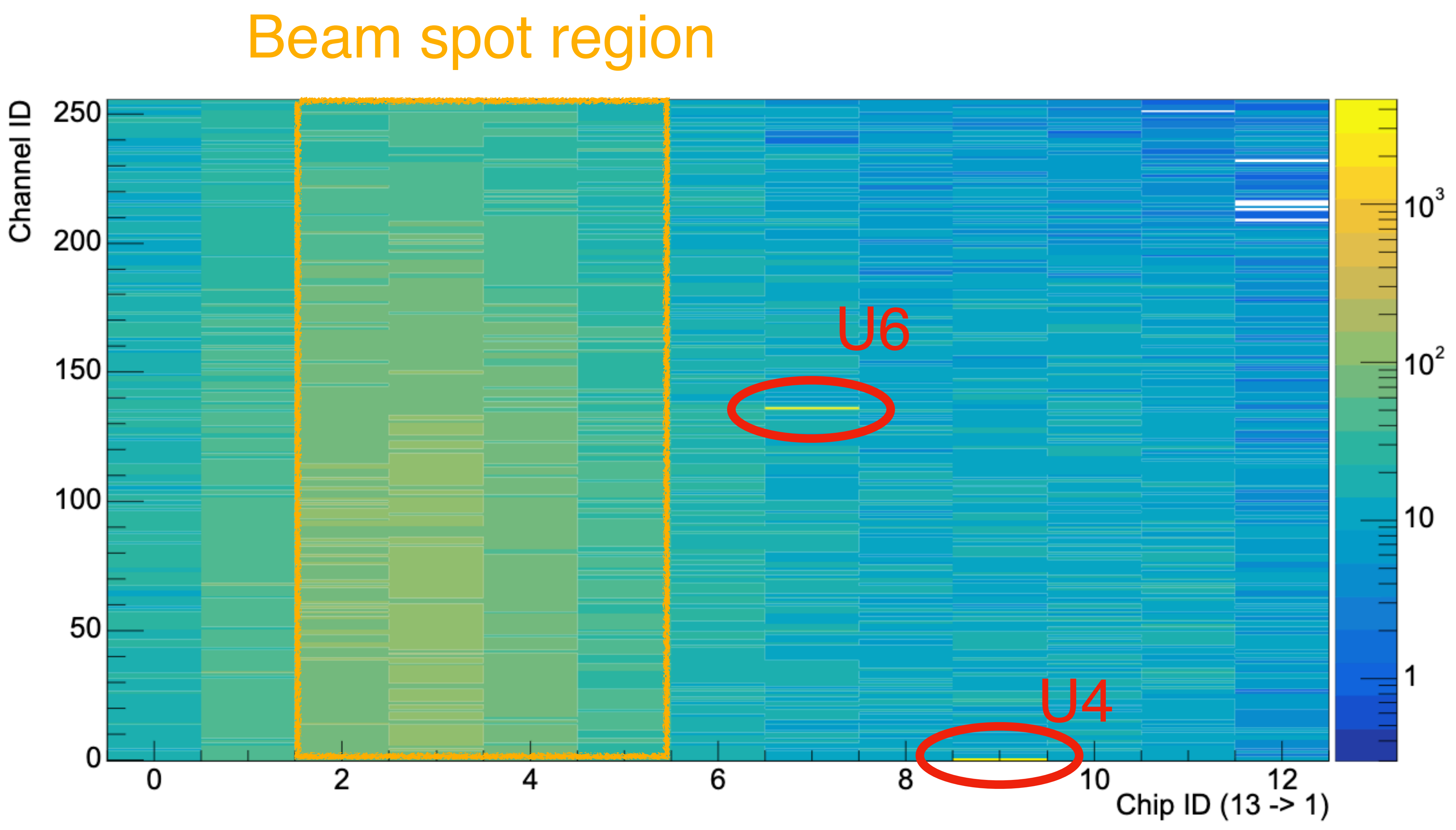


Good agreement b/w data and MC regardless whether columns U4 and U6 are discarded or not

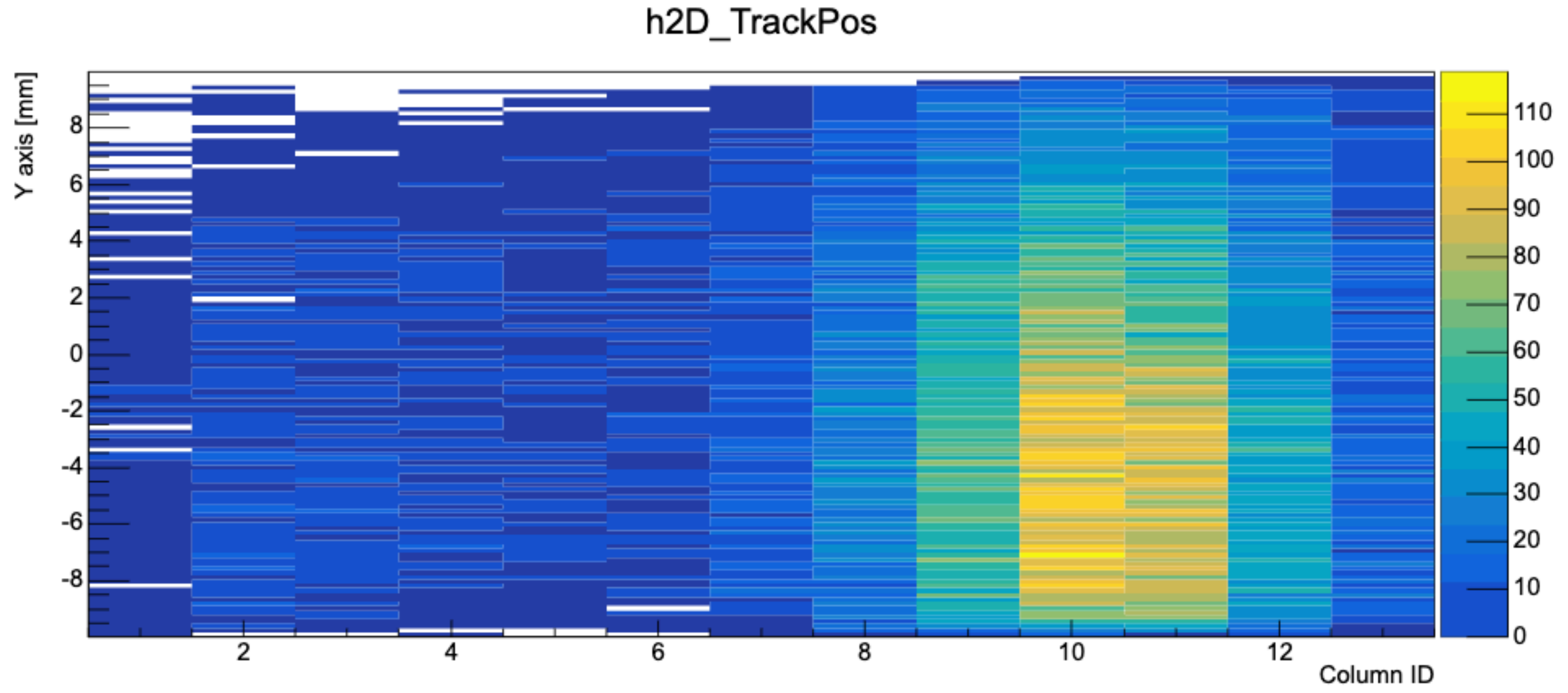
Very good noise hit rejection by the 3-hit tracking

Number of reco. tracks compared to MC

In L2 of Run64, two hot channels
in column 4 and column 6



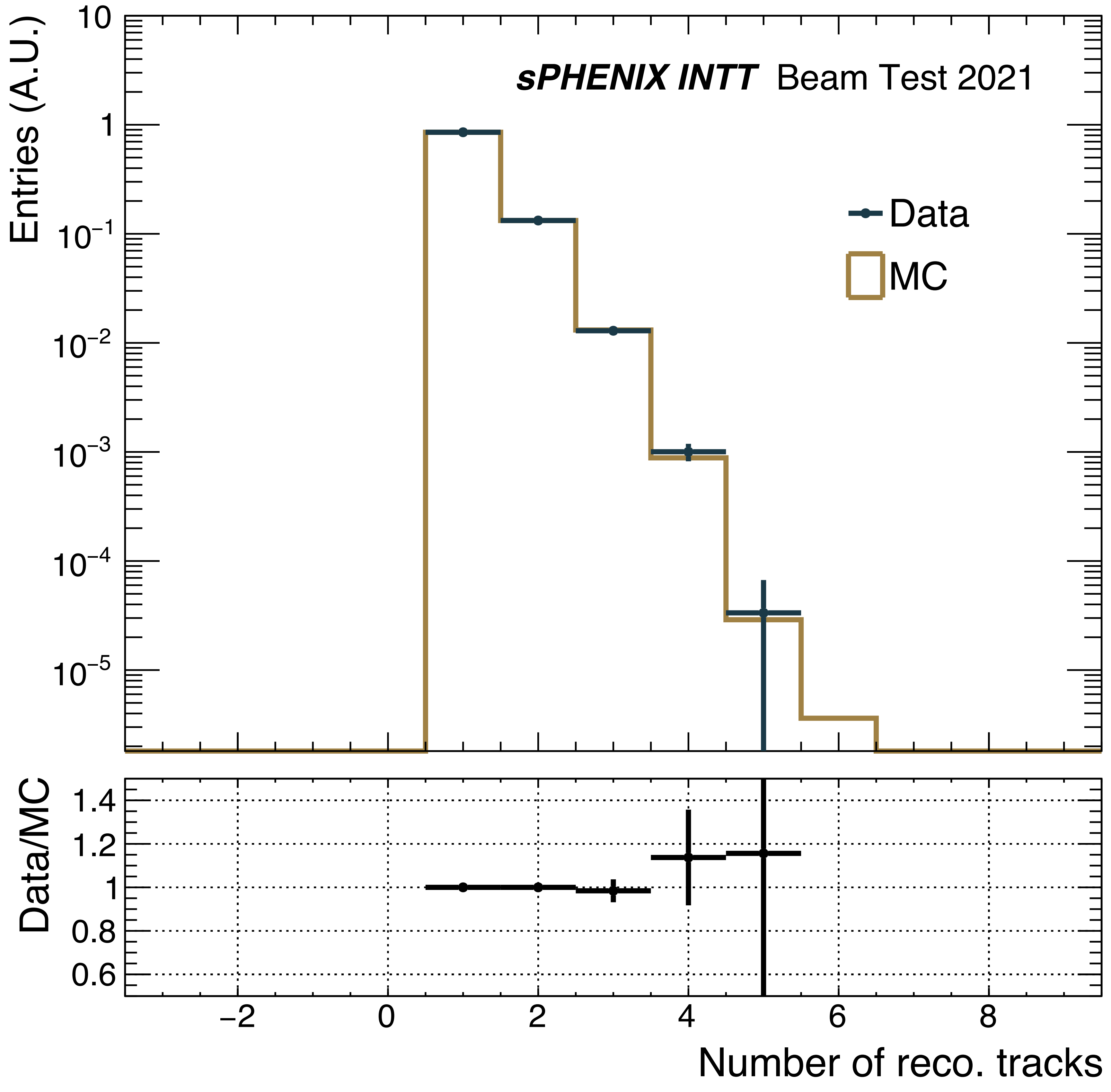
Reco. good track positions
(All column included)
(X axis coordination opposite)



Good agreement b/w data and MC regardless whether columns U4 and U6 are discarded or not
Very good noise hit rejection by the 3-hit tracking

Recap - Number of reco. tracks compared to MC

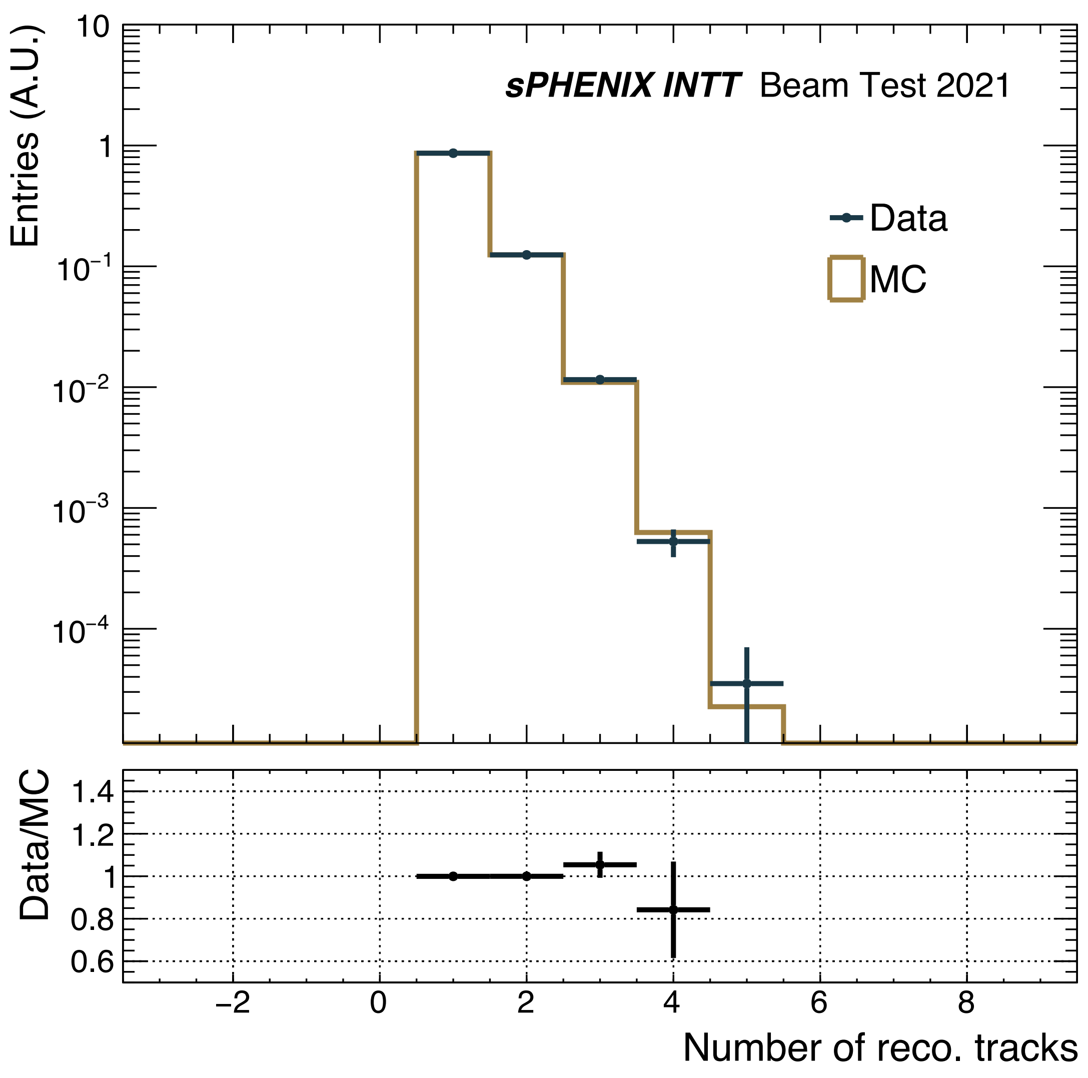
New plot
(All column included)
(Clus-Fit deviation requirement: 0.5 mm)



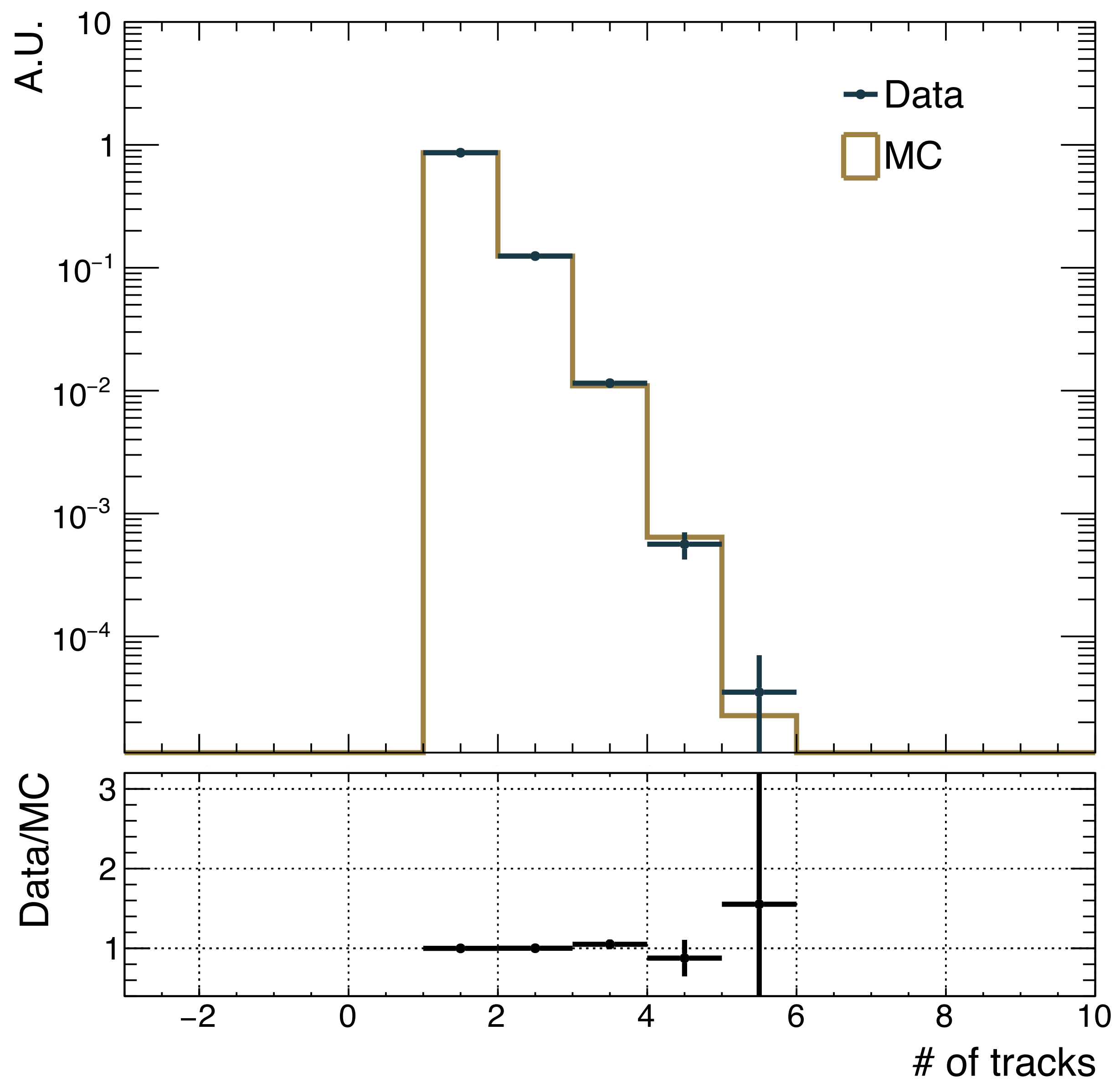
Plot to be in paper (tentative)

(All column included)
(Clus-Fit deviation requirement: 0.234 mm)

New plot



Debut: 2023/Feb/17



Summary

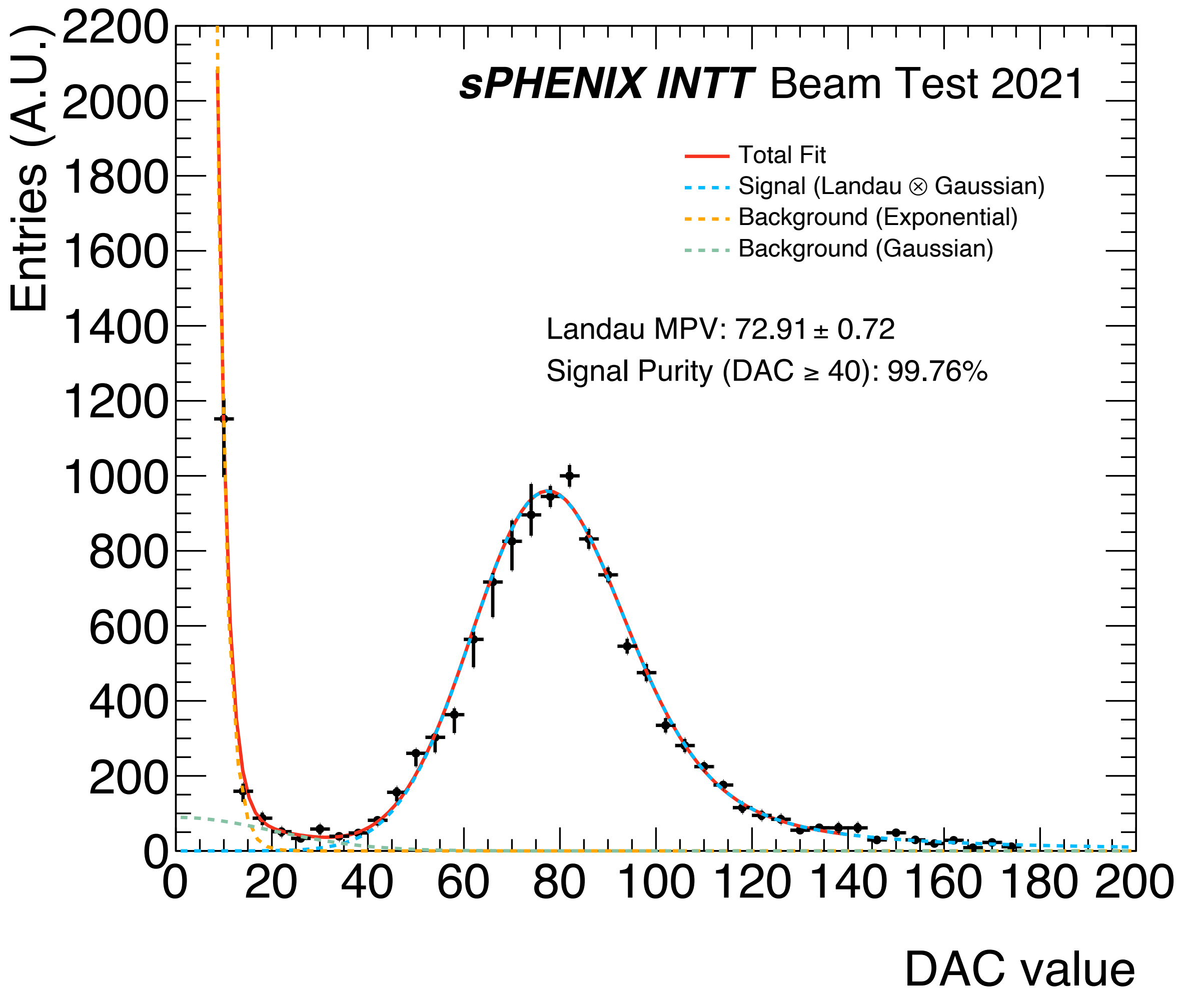
- I would like to request the approval for following plots for publication
  - Energy deposit distribution
  - Residual distribution comparison with MC
  - Hit detection efficiency (the values and plots)
  - Number of reconstructed tracks compared with MC

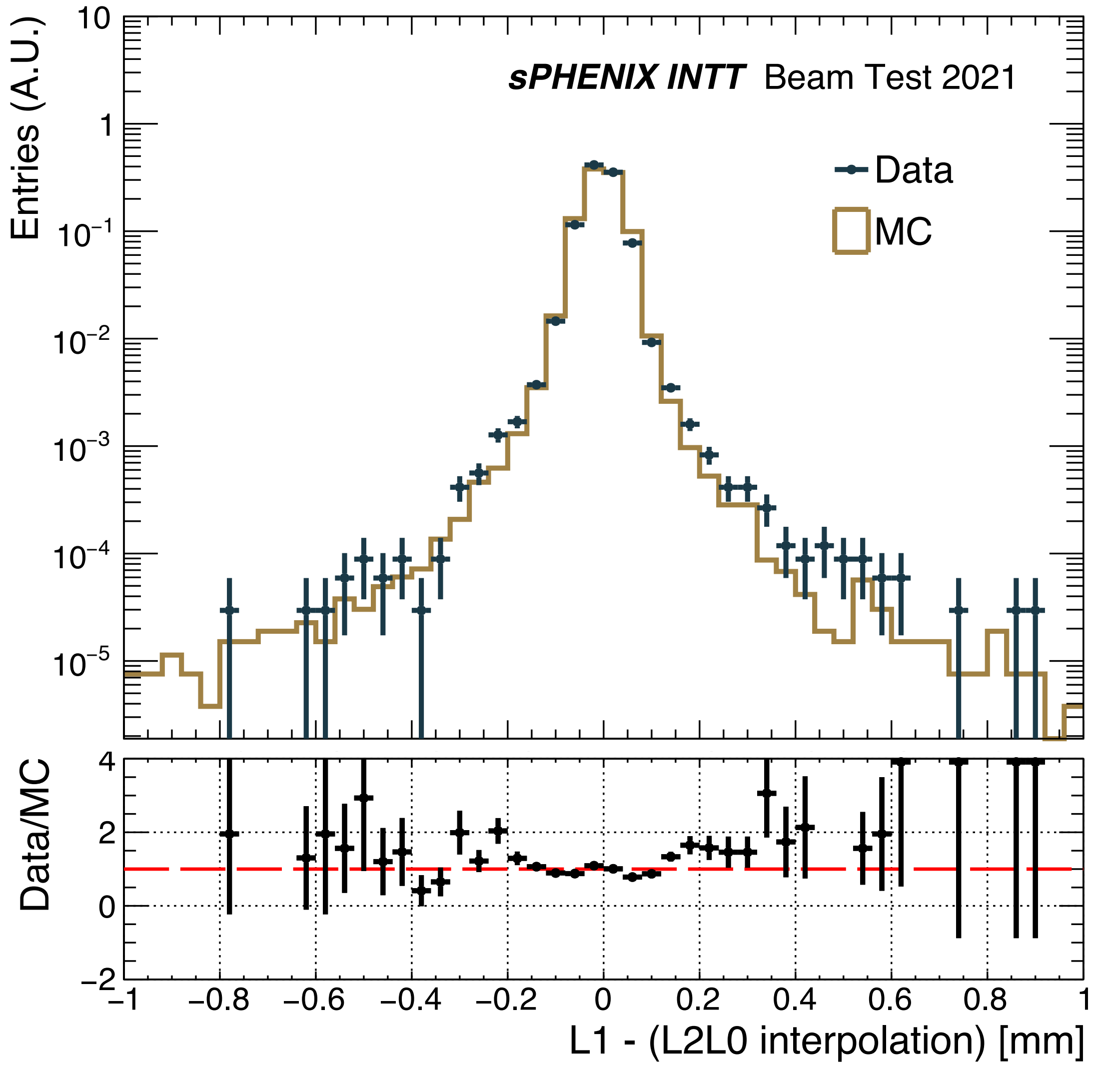
- The analyses of the introduced topics are completed, improved and reproducible, and to be included in the paper
- <u>The results are consistent with what presented in the past</u>

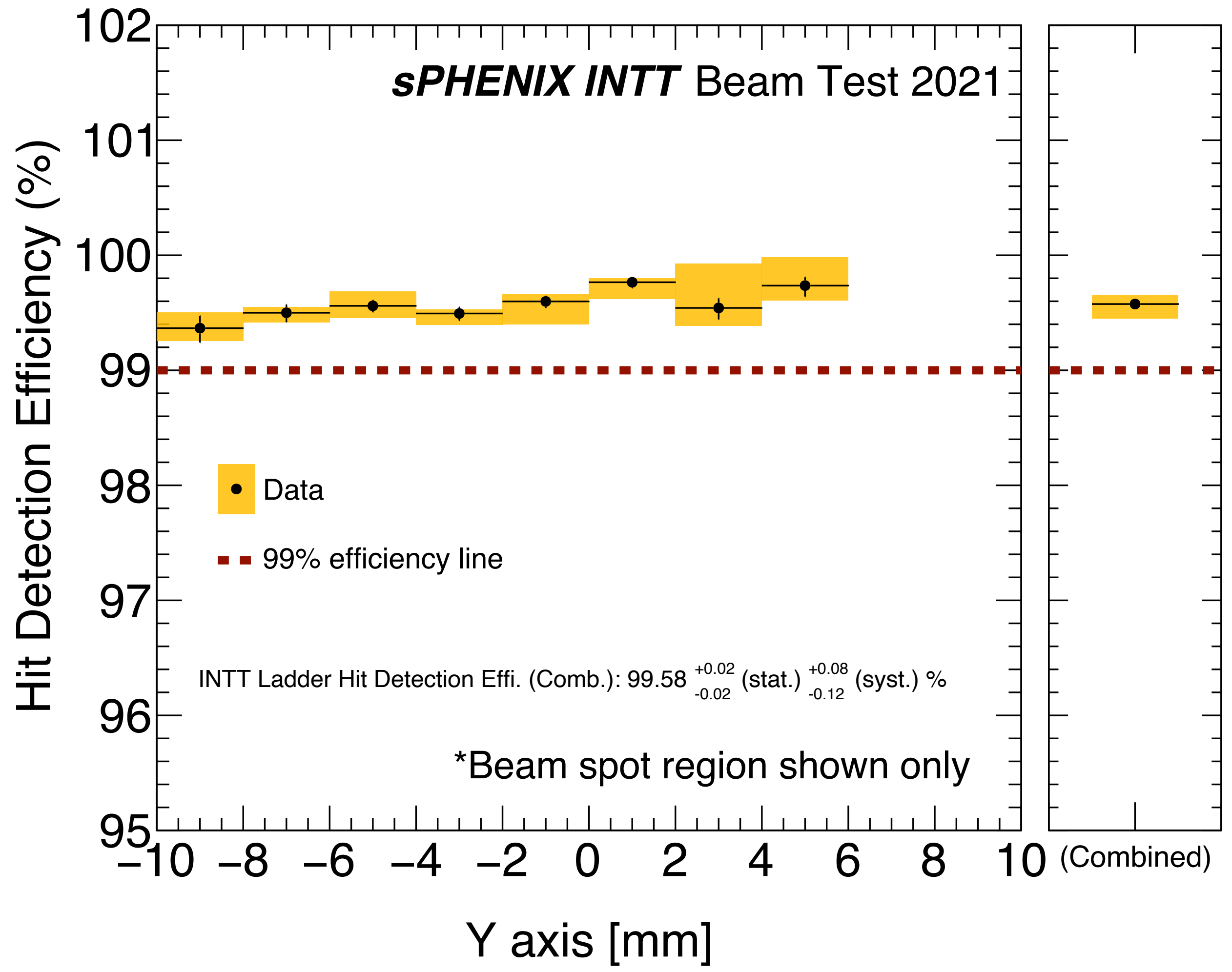
- Please raise hand if you have any questions and comments

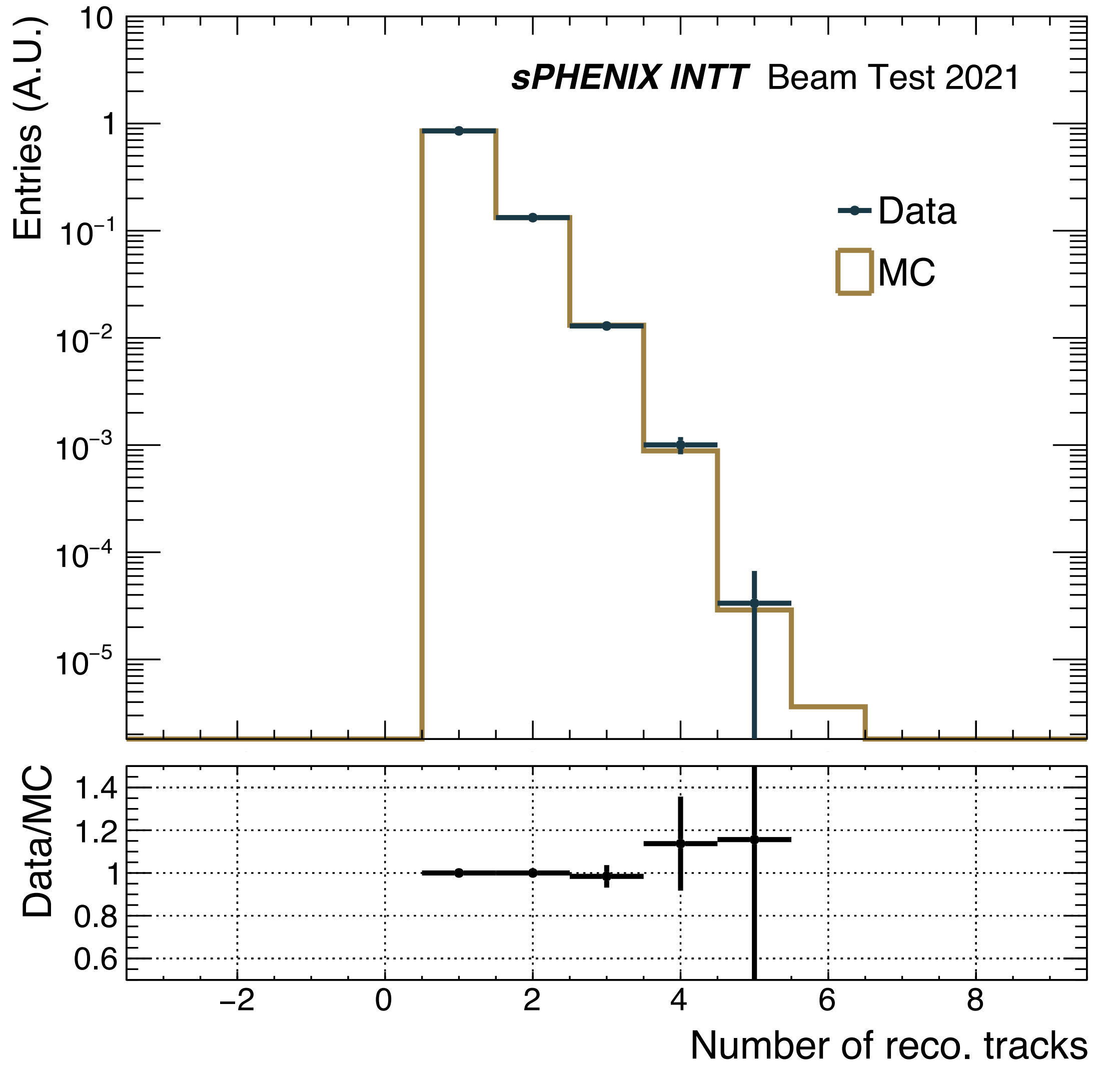
- I will be moving on preparing the paper draft if no major update in analysis method required

Plots and numbers request to be approved







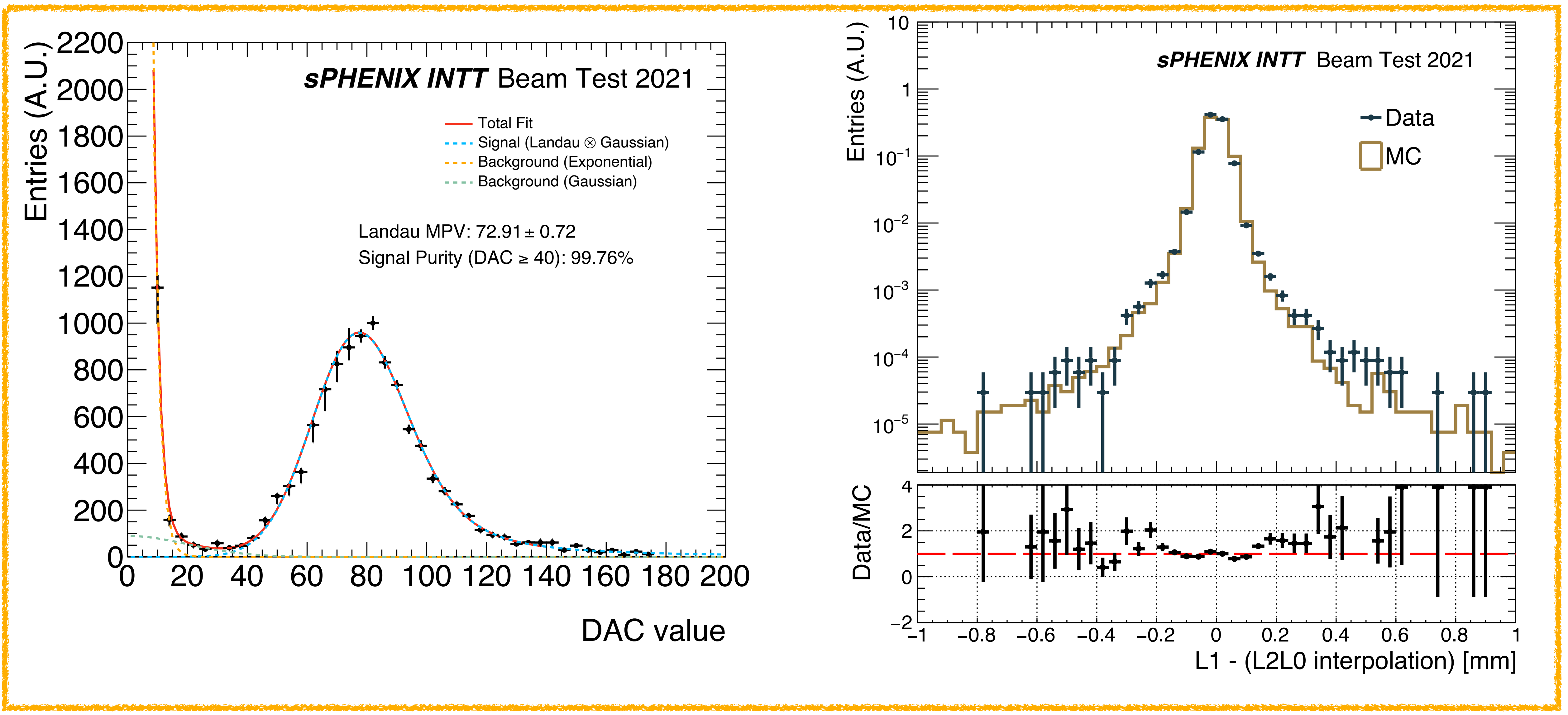


Hit detection efficiency (Combined): $99.576\ ^{+0.021}_{-0.022}(stat.)\ ^{+0.079}_{-0.125}(syst.)\ \%$

Structure of paper (tentative)

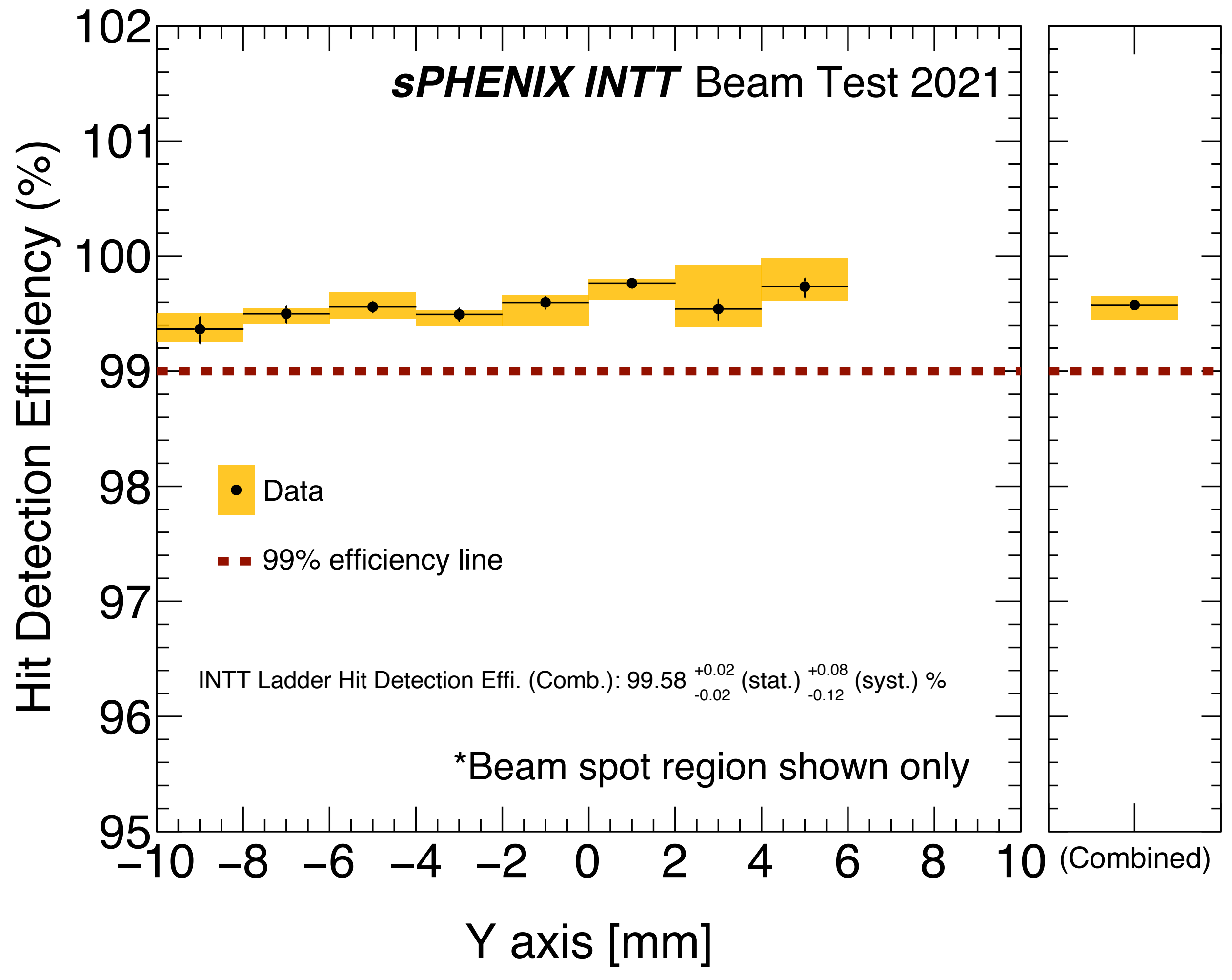
A

- Understand the basic detector performance
- High signal purity
- Good agreement with MC



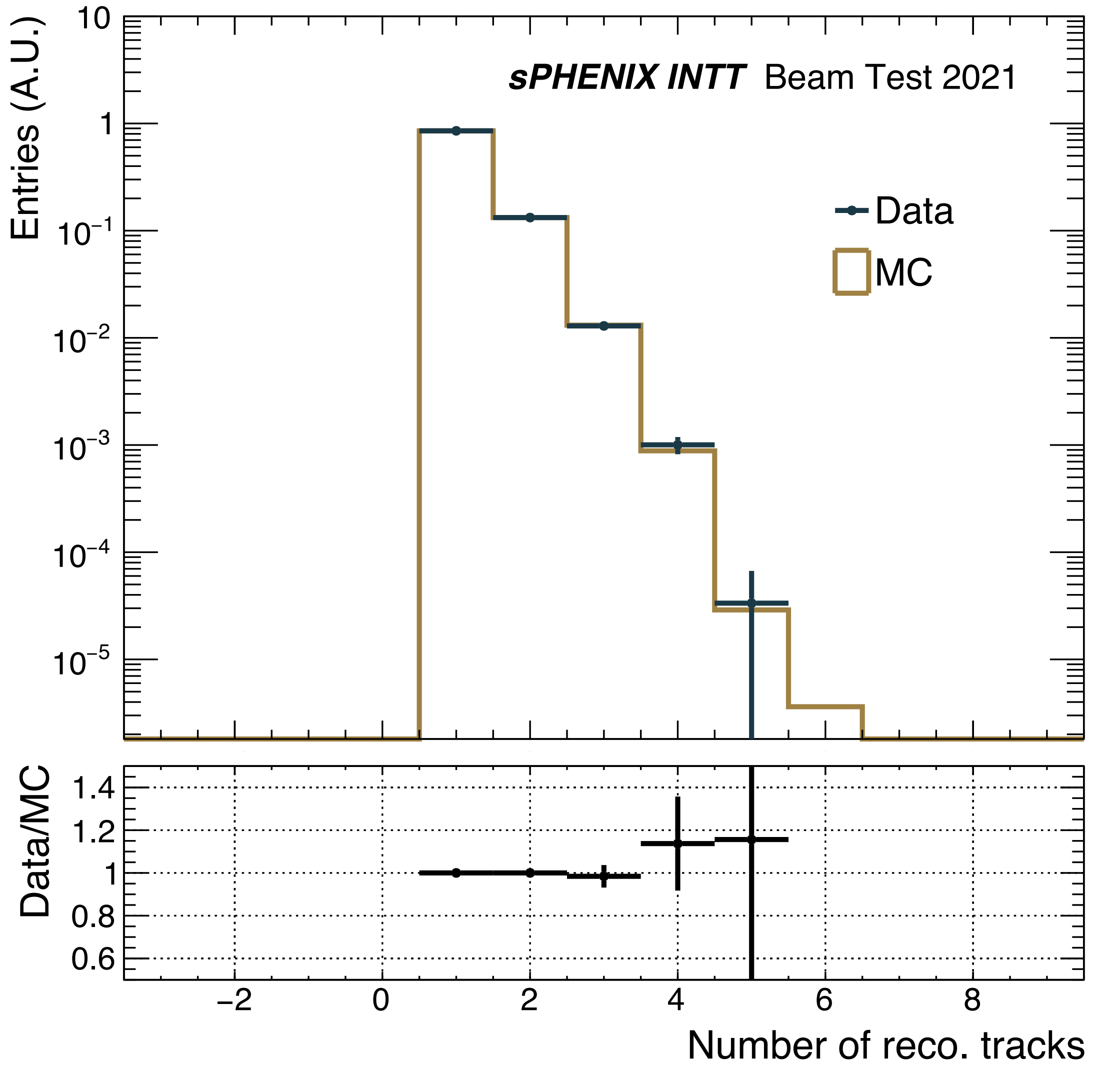
B

Hit detection effi. > 99%



C

Therefore performing tracking. Result shows good agreement with MC

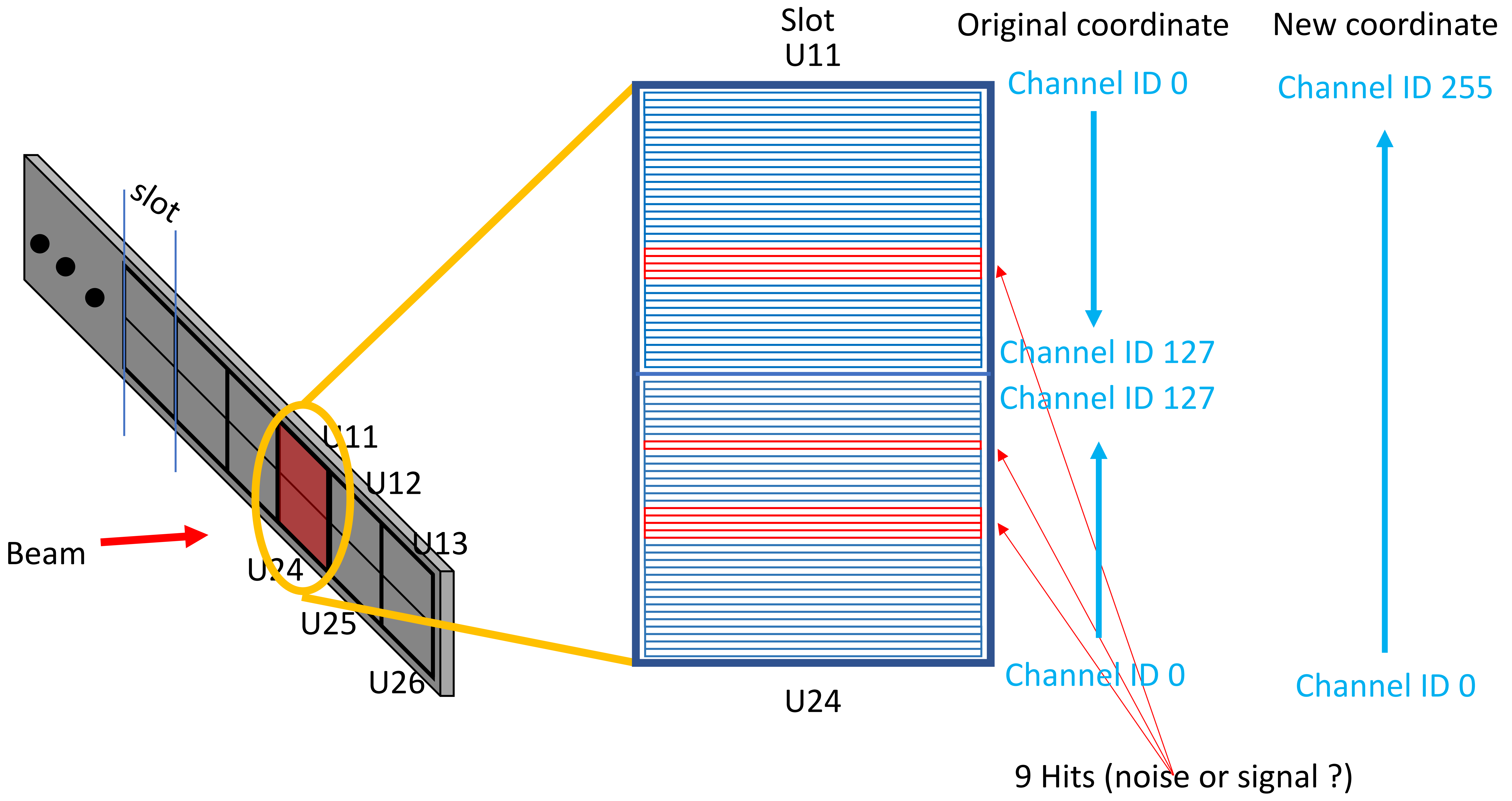


Back up

Clustering - 1

Clustering was performed column by column

Tracking algorithm



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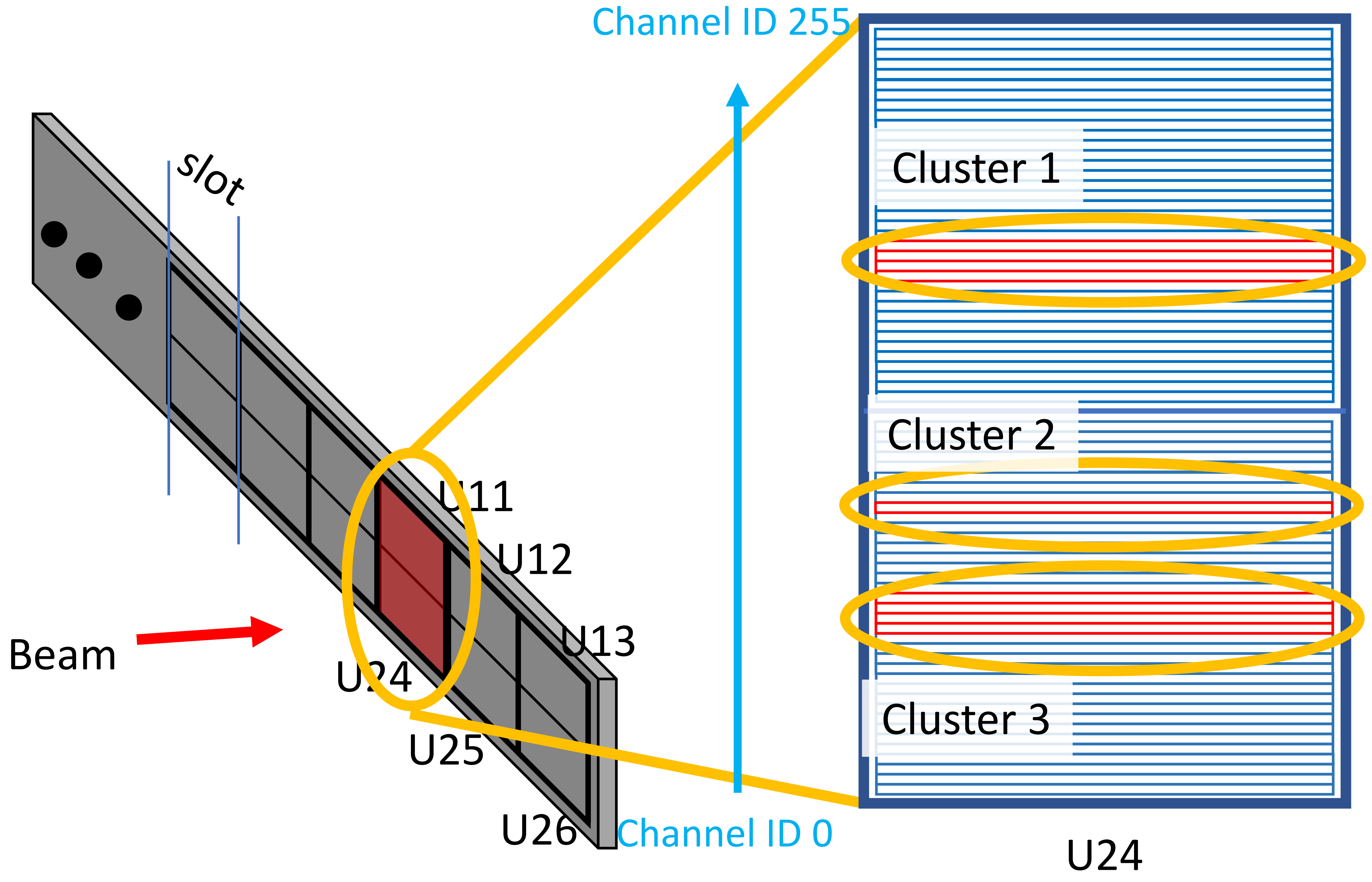
Clustering - 2

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

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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.