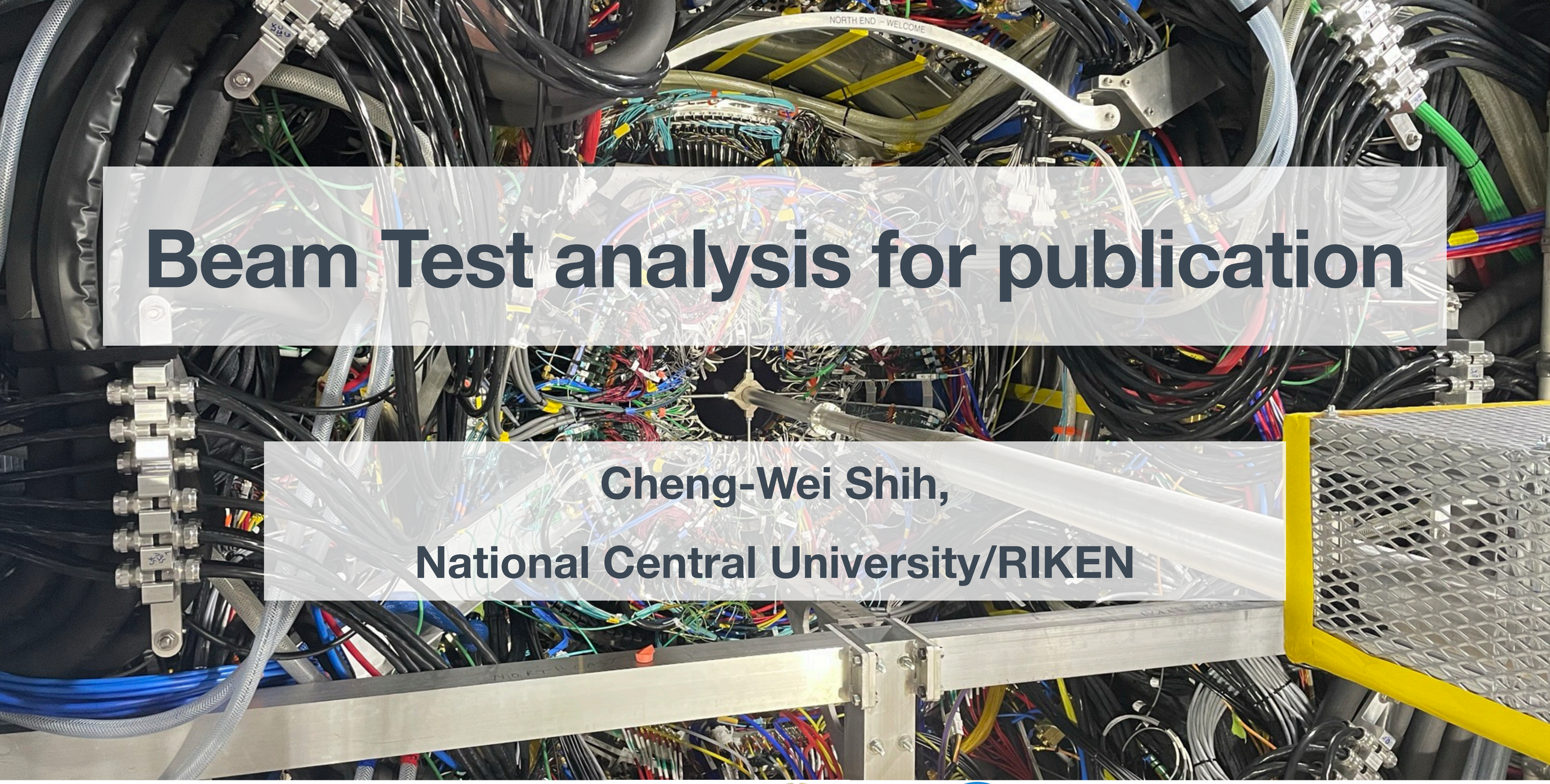


Beam Test analysis for publication

Cheng-Wei Shih,

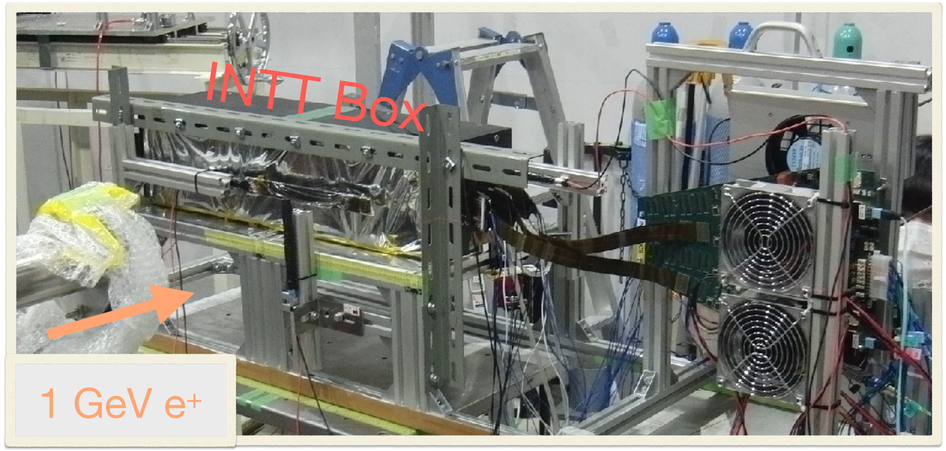
National Central University/RIKEN

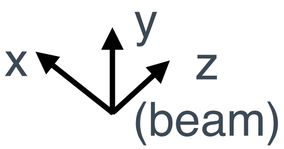
May 9th, 2025
INTT meeting

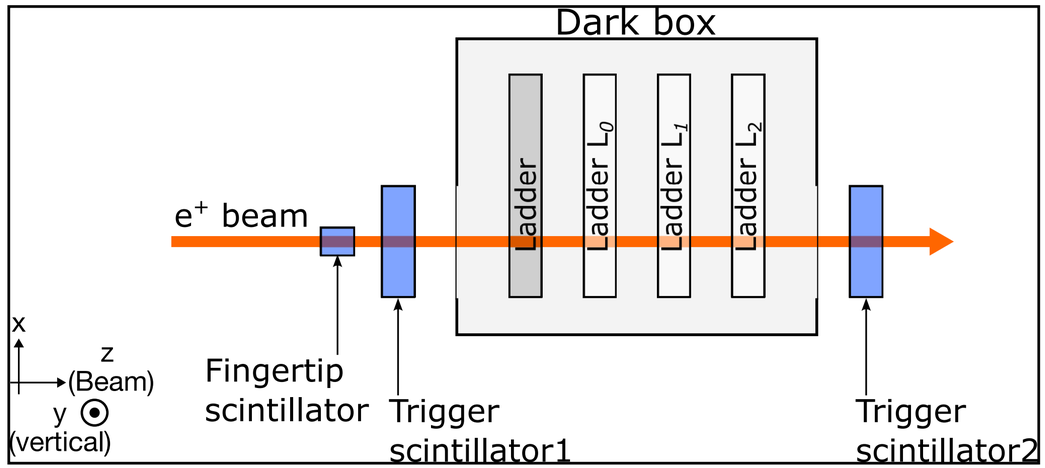
sPHENIX INTT sPHENIX 國立中央大學 National Central University RIKEN

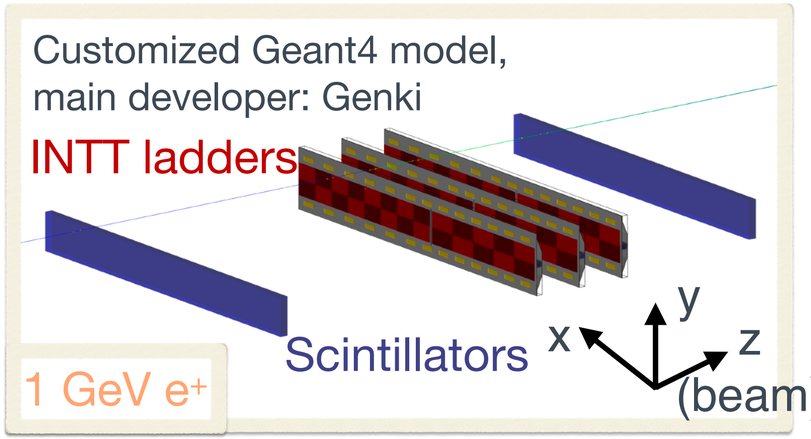
General information

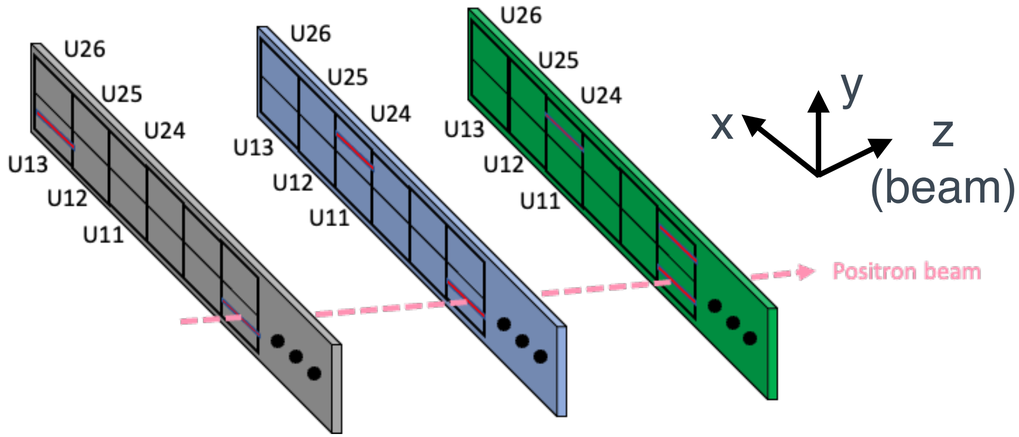
- A beam test experiment was performed at the end of 2021, ELPH, Japan
  - Four ladders were placed in the dark box
  - Beam time: 2021/Dec/07 to 2021/Dec/10
- Positron beam with energy of 800 MeV was used*
- Main goal: ladder hit detection efficiency











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

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

Analysis overview

- The analyses of the following topics are completed, improved and reproducible, and to be included in the paper
  - Analysis note: https://www.overleaf.com/read/ttchfvmcrppt#6156dc
  - Analysis code: https://github.com/ChengWeiShih/Final_BeamTest2021_Publication
  - Target Journal: NIM-A

- Energy deposit distribution (DAC Scan)
  - Systematic uncertainty accounts for different way to matching distributions

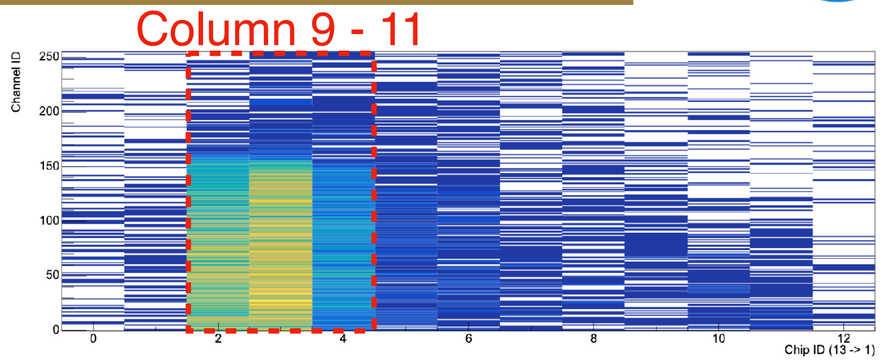
- Scattering relevant distribution compared with MC

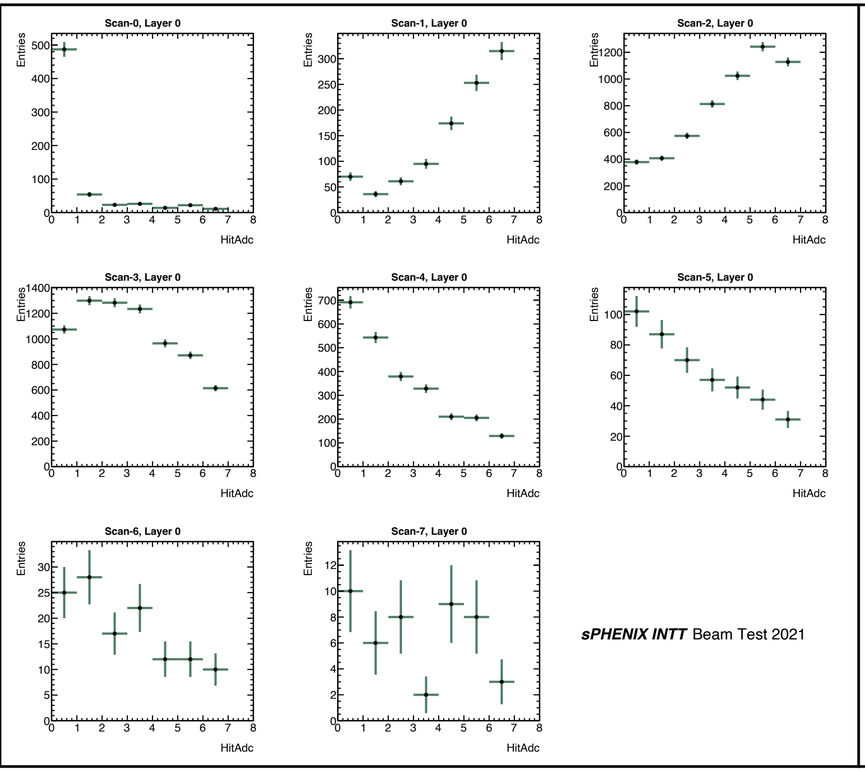
- Hit detection efficiency
  - Re-estimate the systematic uncertainties
  - Run52 and Run89 combined

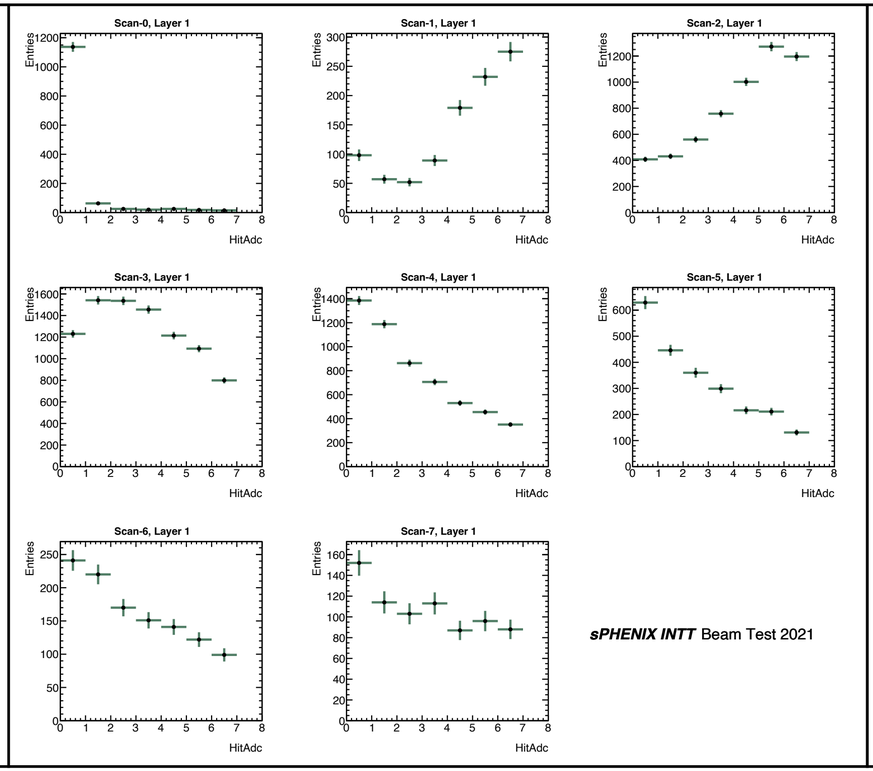
- Number of reconstructed tracks compared with MC

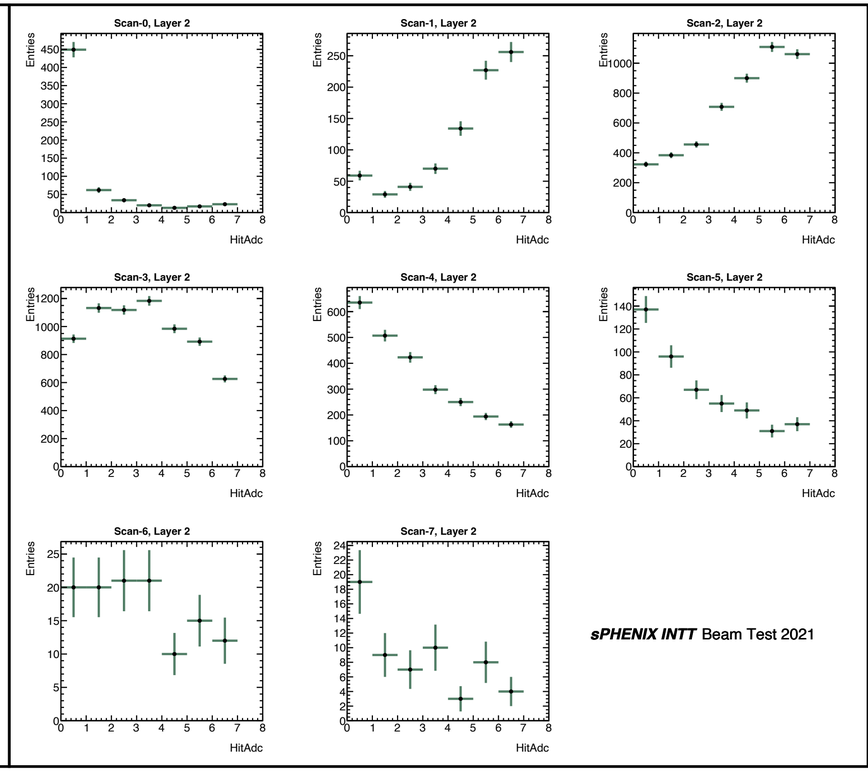
DAC Scan - the matrices

- 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 selected (Column9, 10, 11)
- Single-hit clusters selected
- Overflow bin (bin 8th) removed in each scan





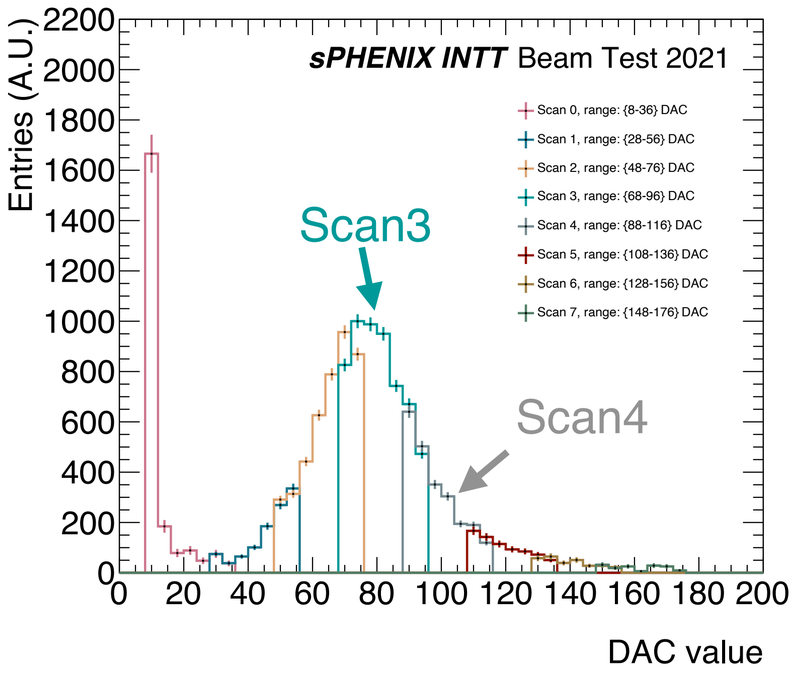




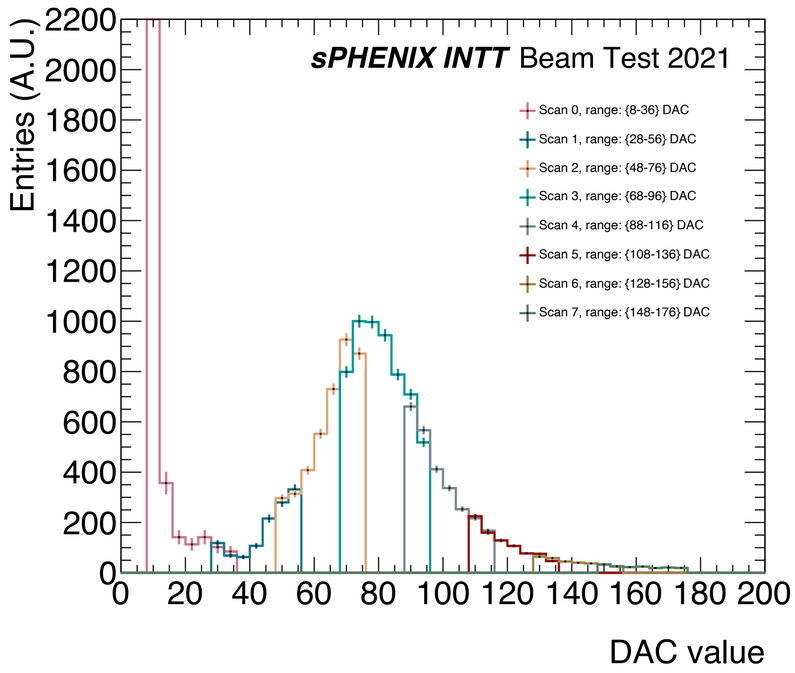
L0 L1 L2

DAC Scan - matching b/w scans

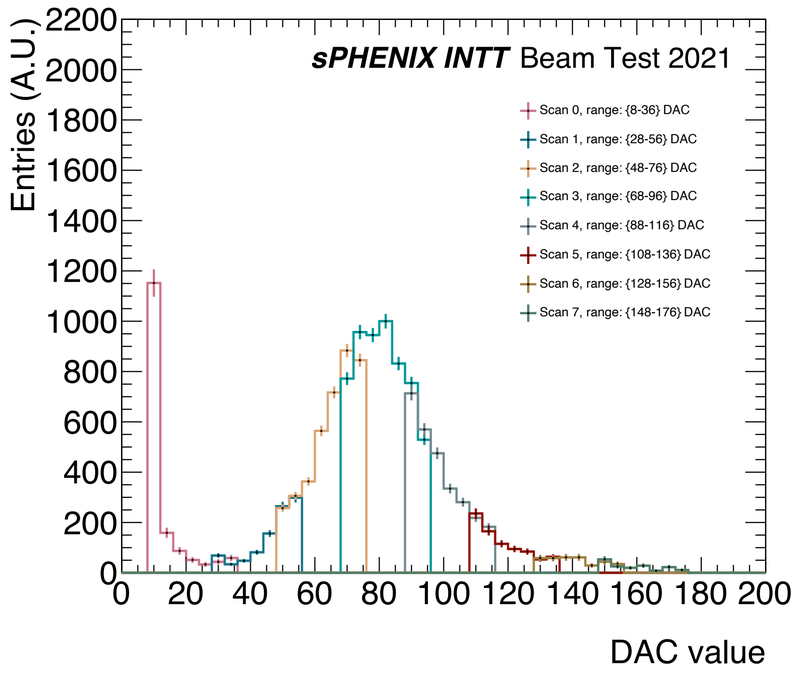
- In each scan, two bins overlapped with its following scan, which are used for matching
- Scan3 as reference, introducing scales to the adjacent scans to match the distributions, sequentially
- Example: scale applied on scan4 = $(Size_{bin_6}^{scan3} + Size_{bin_7}^{scan3})/(Size_{bin_0}^{scan4} + Size_{bin_1}^{scan4})$
- (Same method used previously)



L0



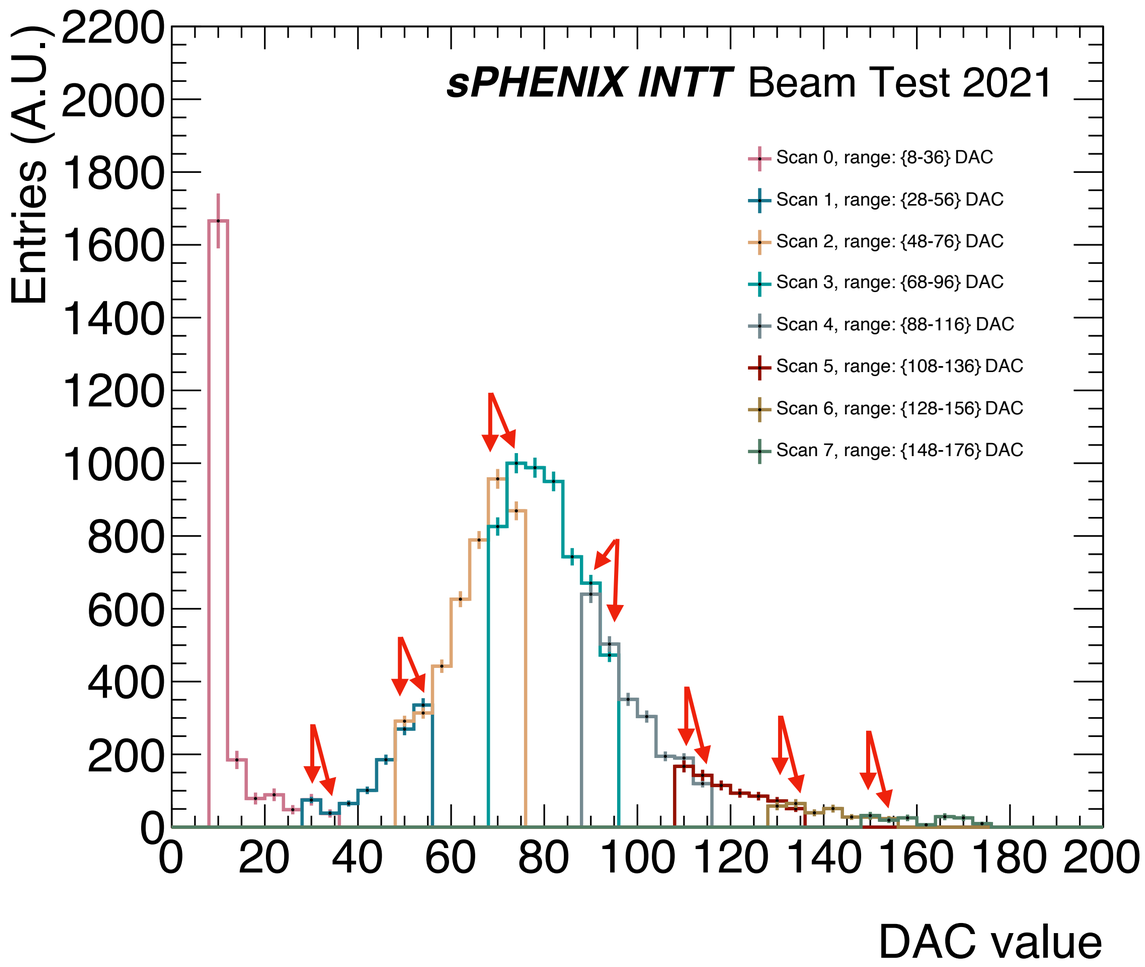
L1



L2

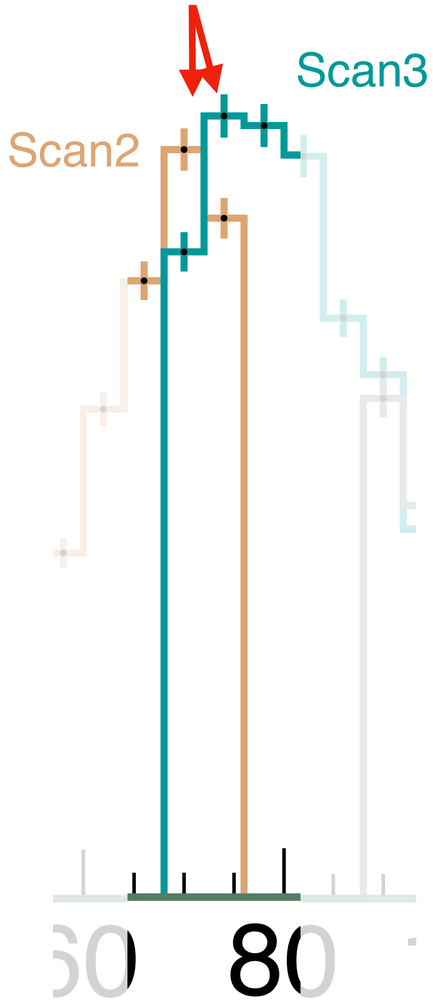
DAC Scan - Combine bins

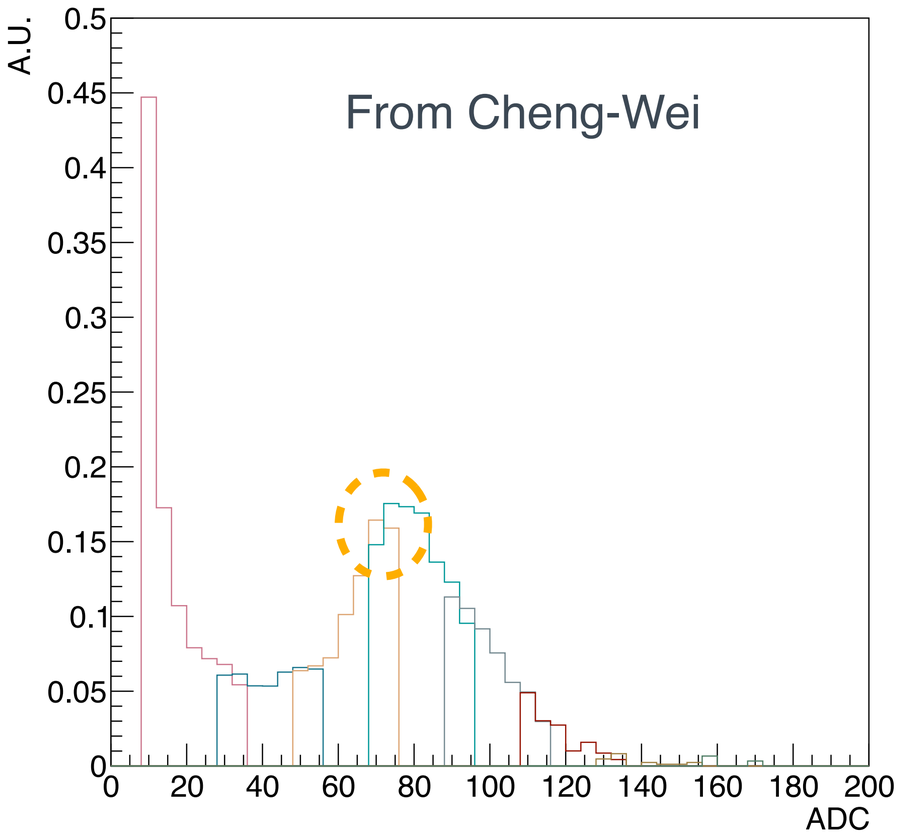
- The overlap bins are statistically combined
- $$\bar{X} \pm \sigma_X = \frac{A \cdot w_A + B \cdot w_B}{w_A + w_B} \pm \sqrt{\frac{1}{w_A + w_B}}$$
- *A*: bin content of the bin1
- w_A : 1 / [(statistical error of bin1)^2]
- *B*: bin content of the bin2
- w_B : 1 / [(statistical error of bin2)^2]
-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

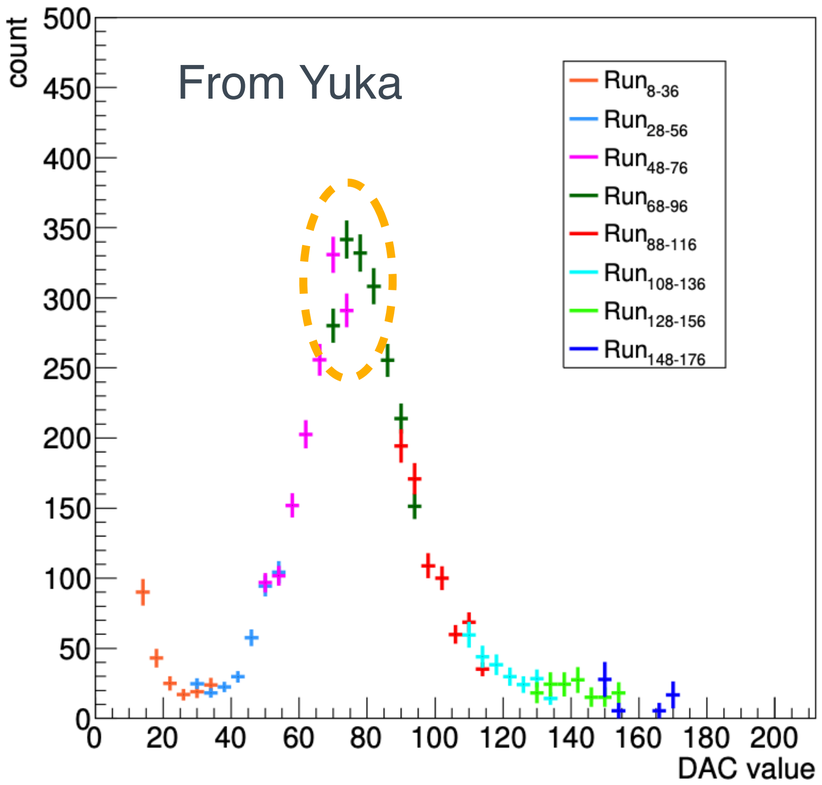


DAC Scan - Combine bins

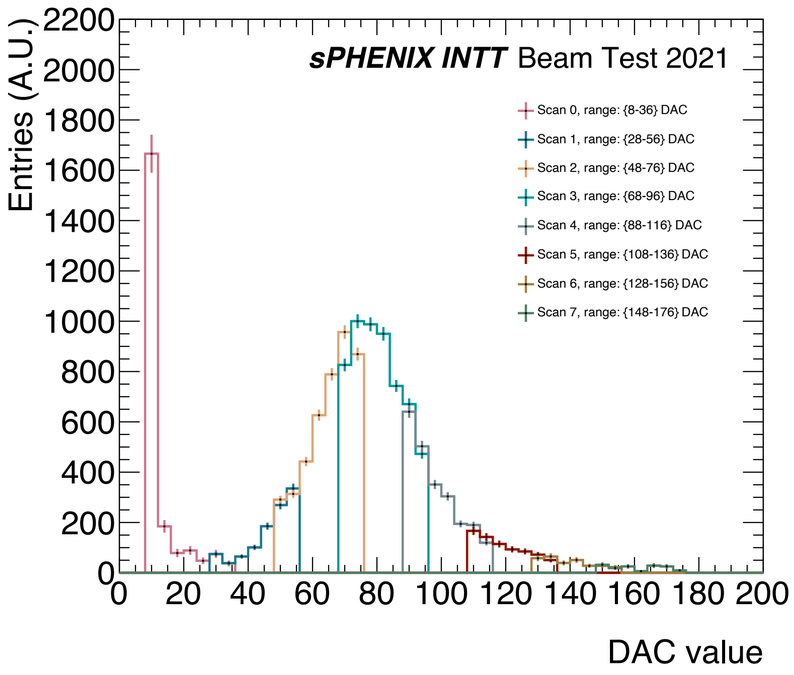
The disagreement in the overlap bins between scan2 and scan3, observed multiple times



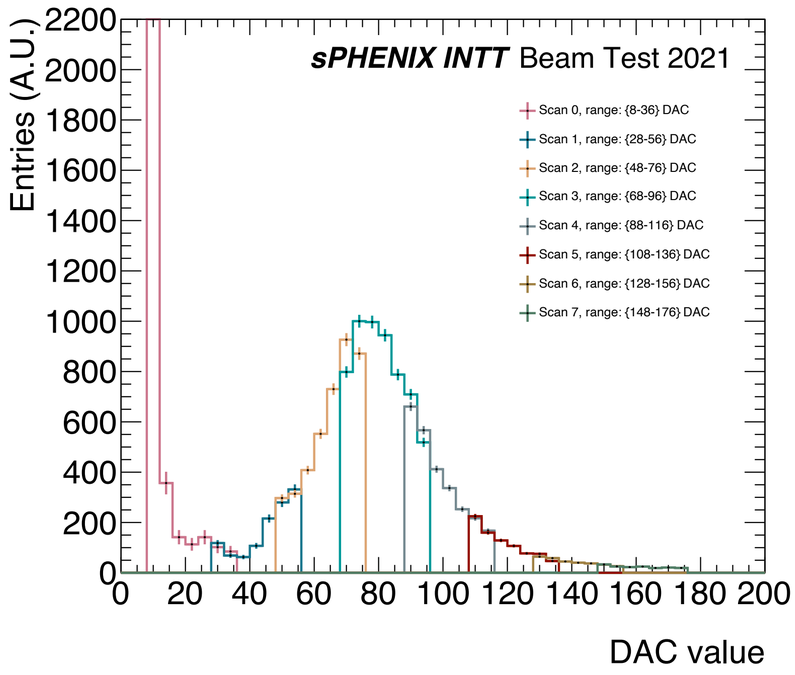




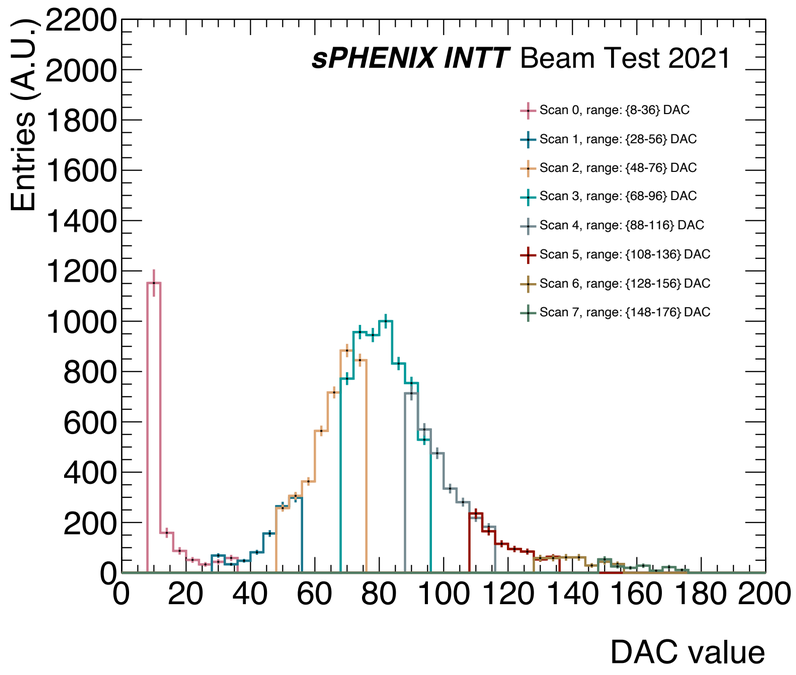
DAC Scan - matching b/w scans



L0



L1

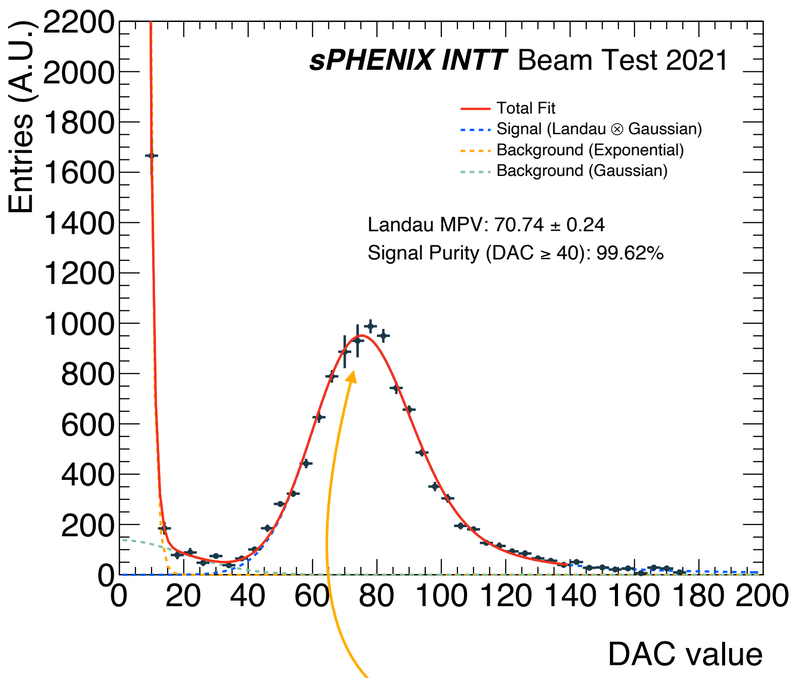


L2

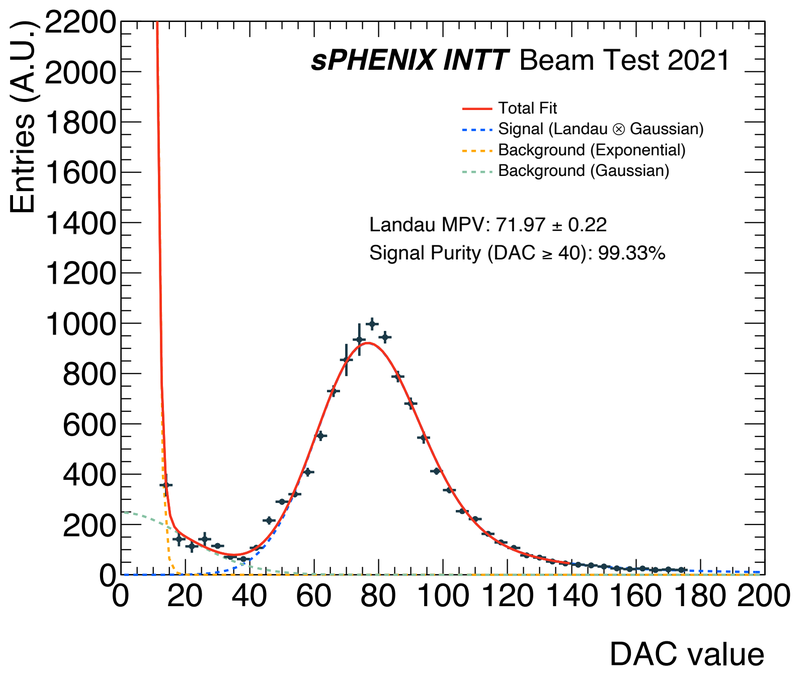
DAC Scan - final with fit

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

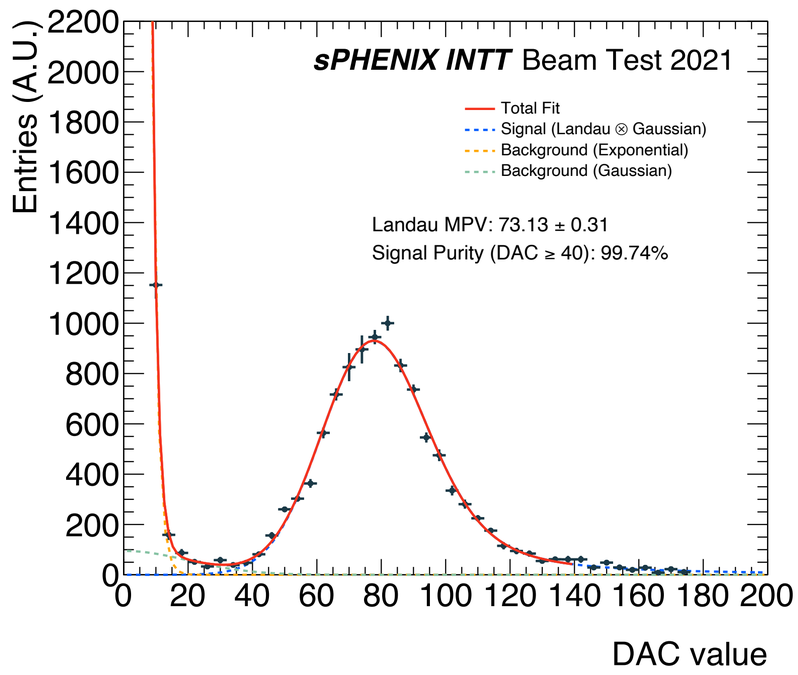
L0



L1



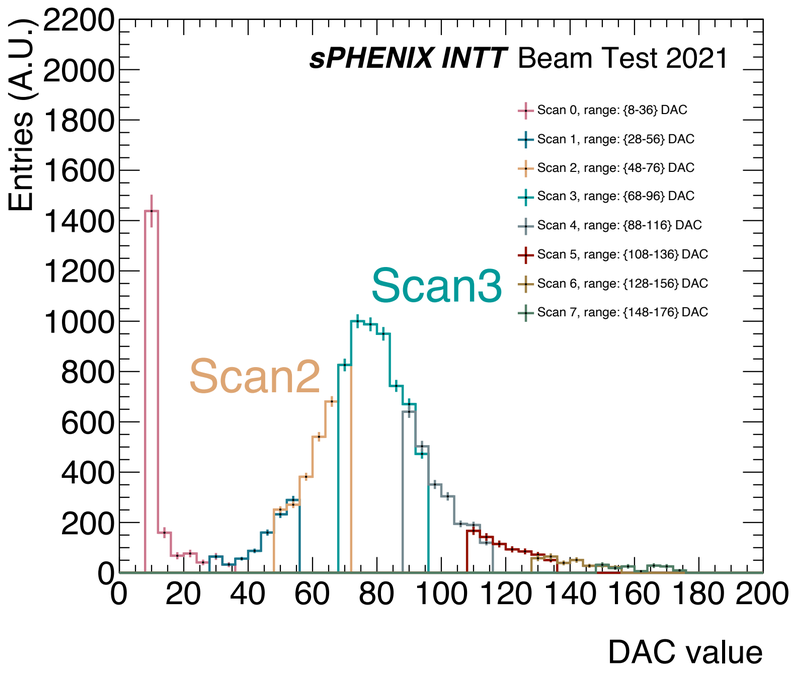
L2



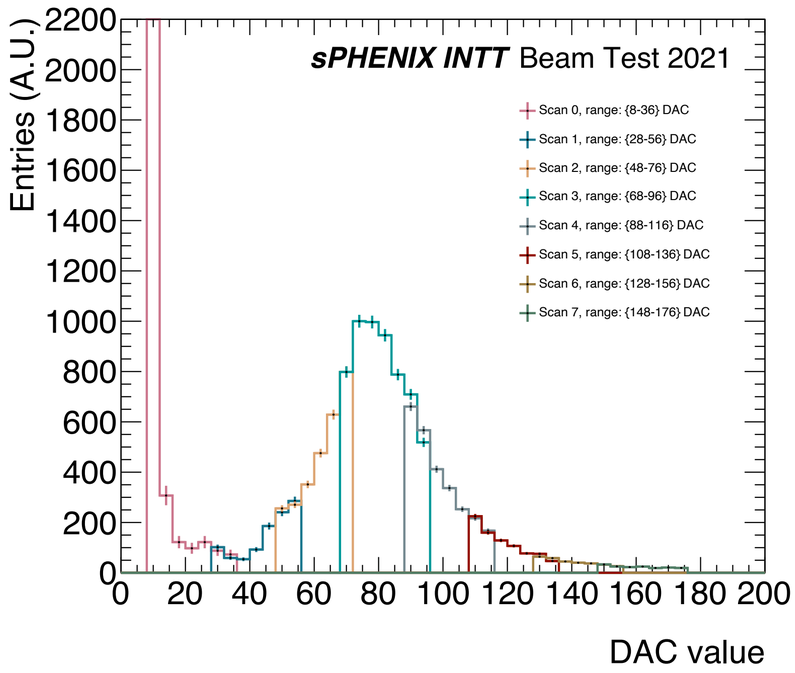
Relatively larger error bars due to the disagreements

Matching Scan2 and Scan3 in different way

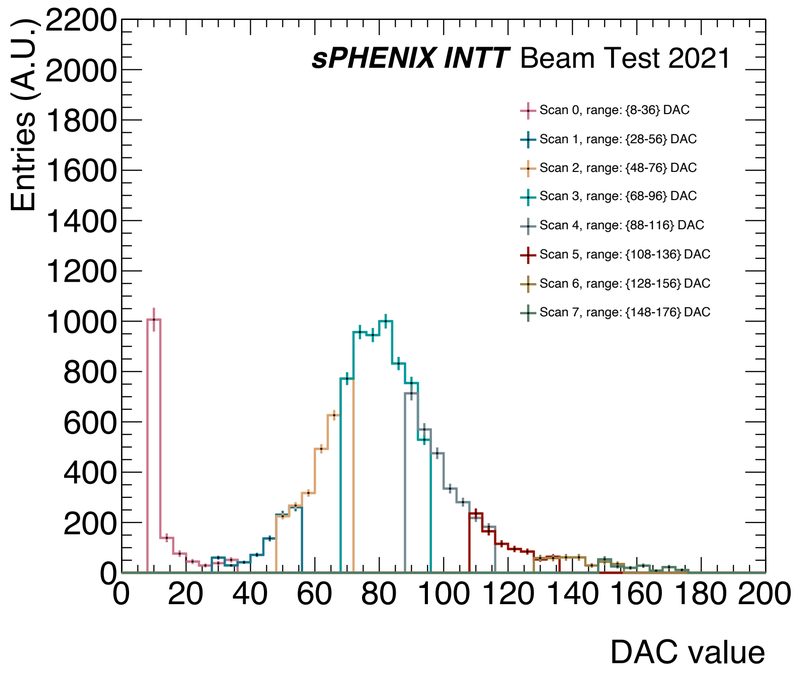
Here the matching of Scan2 to Scan3 is only by Bin6th of Scan2 and Bin1st of Scan3



L0

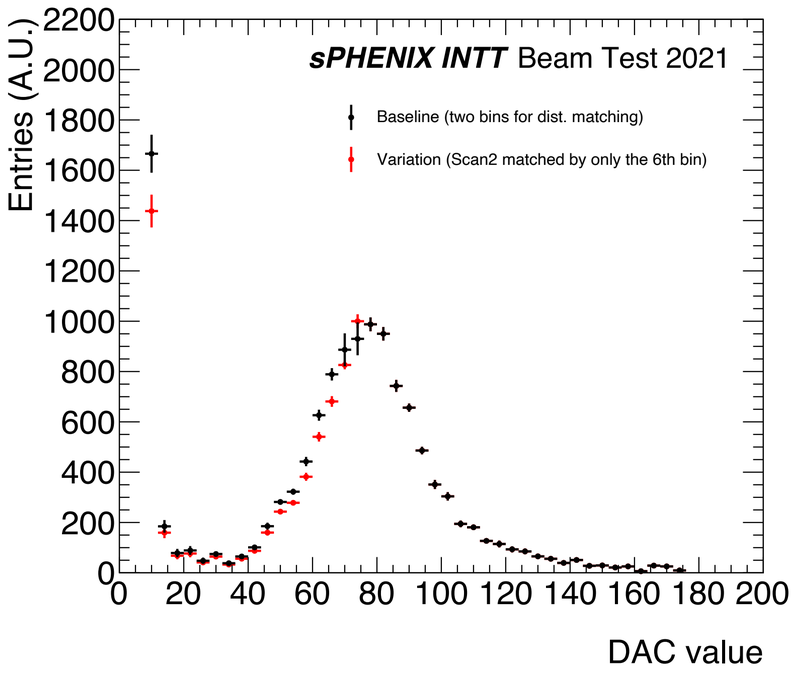


L1

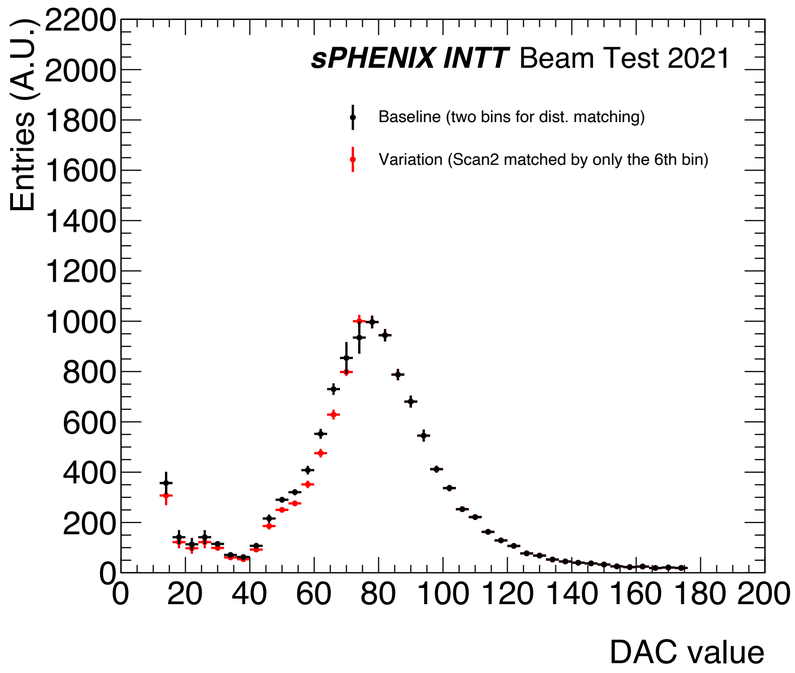


L2

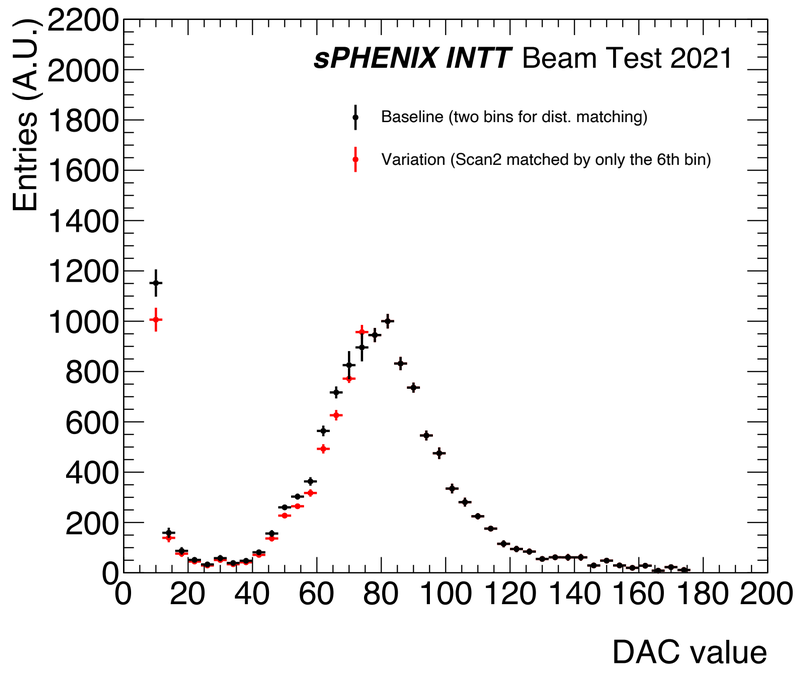
Comparison



L0



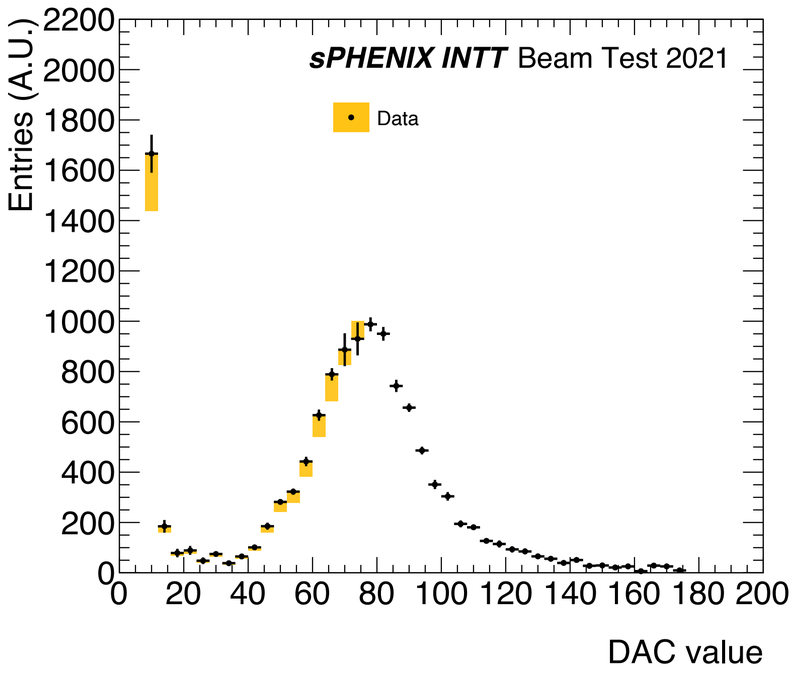
L1



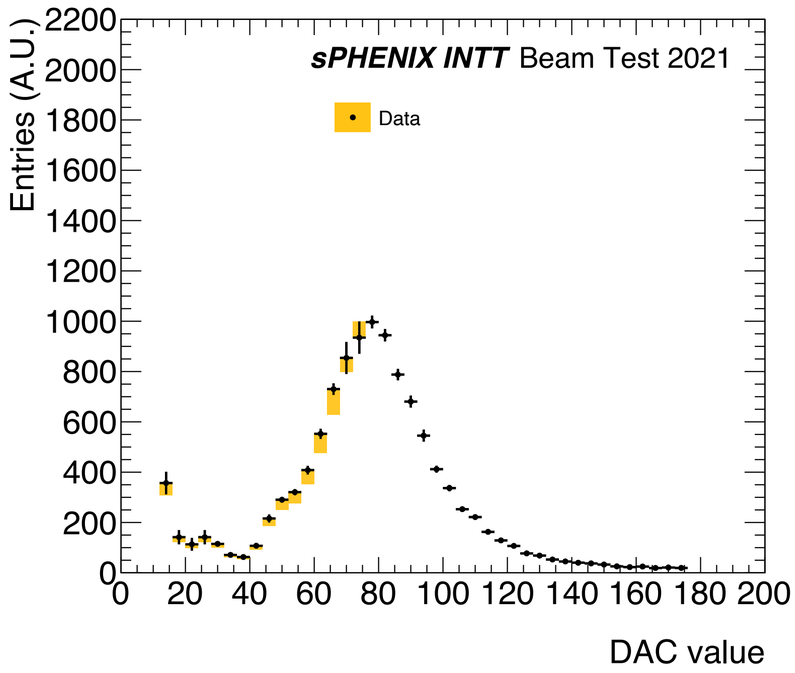
L2

Systematic uncertainty

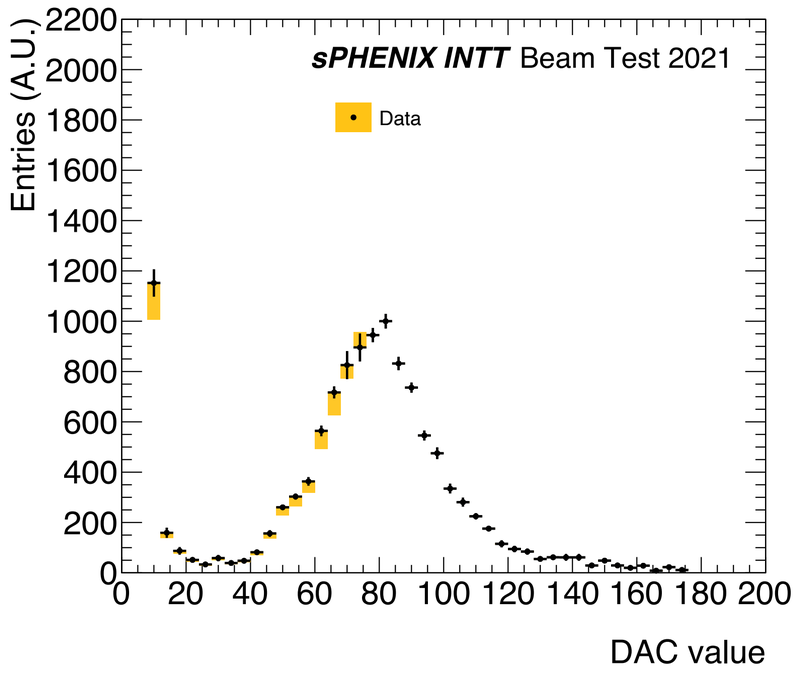
The differences are quoted as the systematic uncertainties



L0



L1

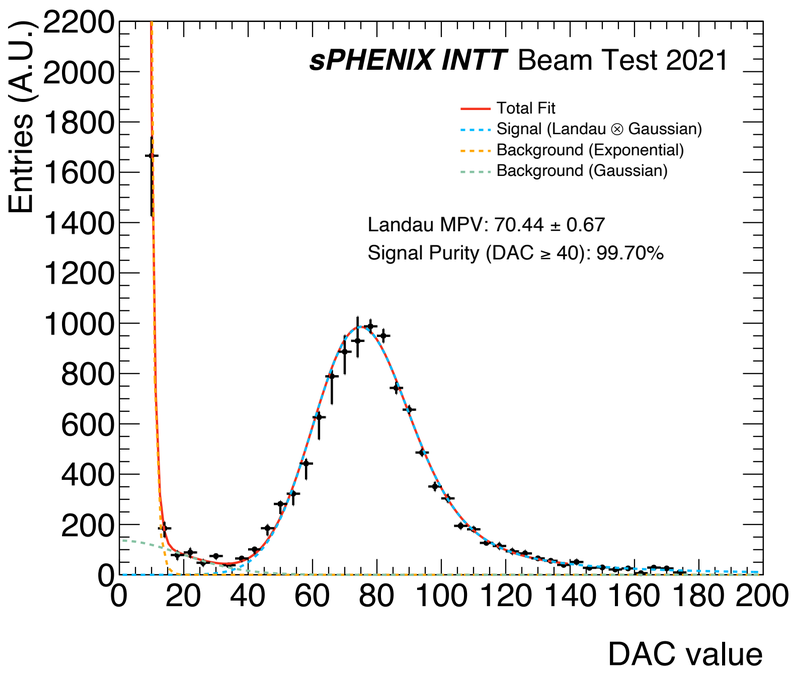


L2

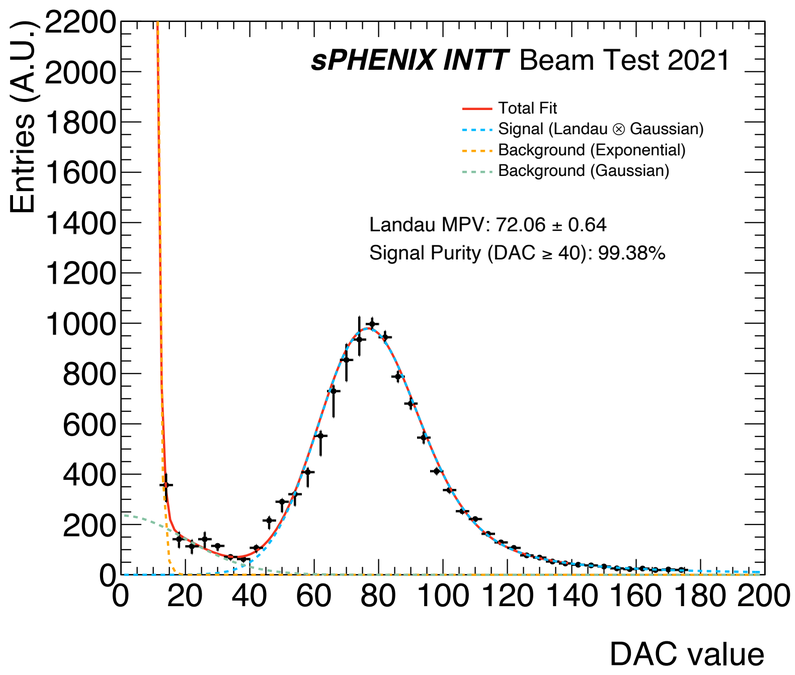
Final distributions

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

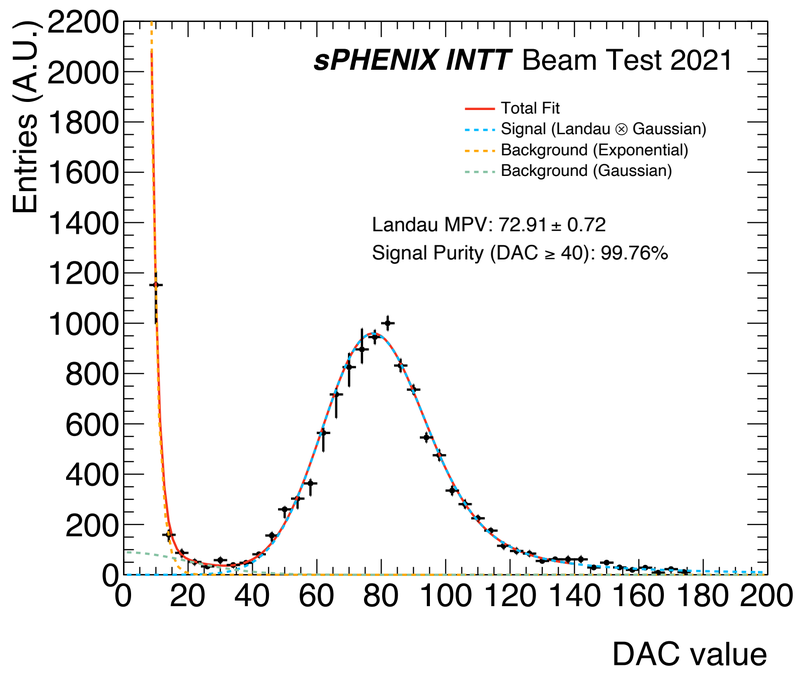
Plot to be in paper (tentative)



L0



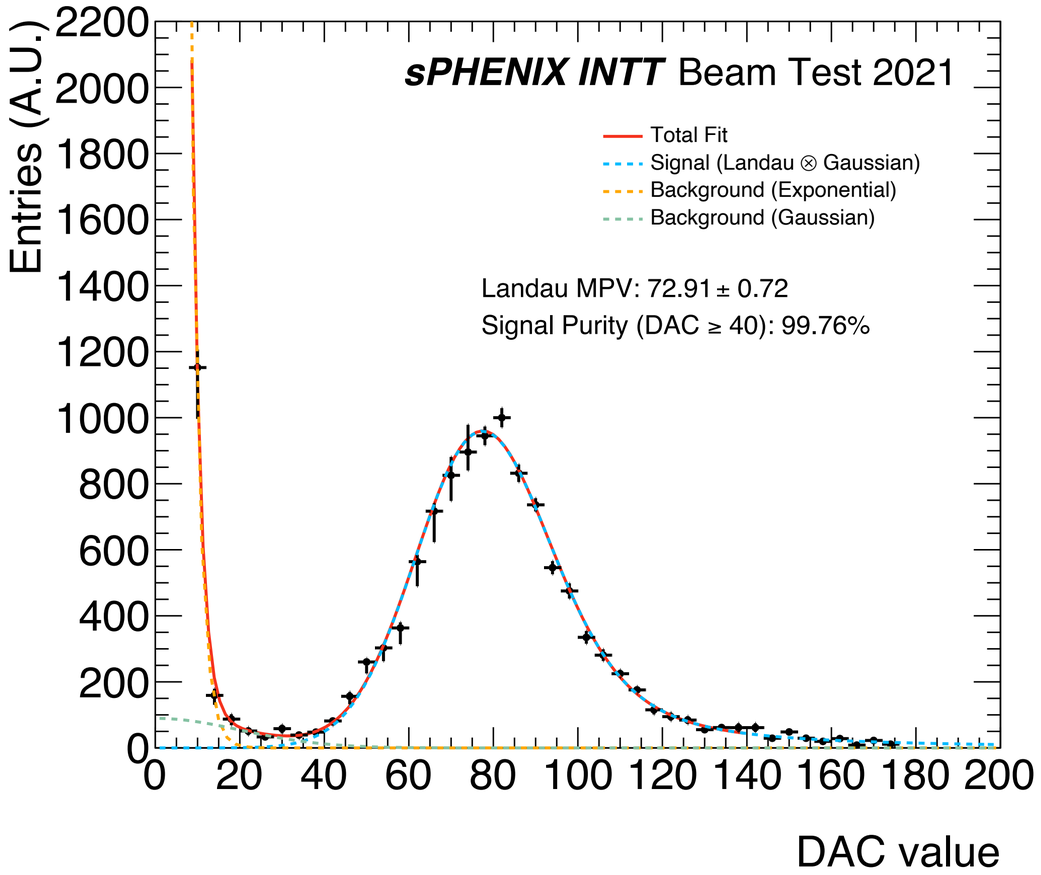
L1



L2

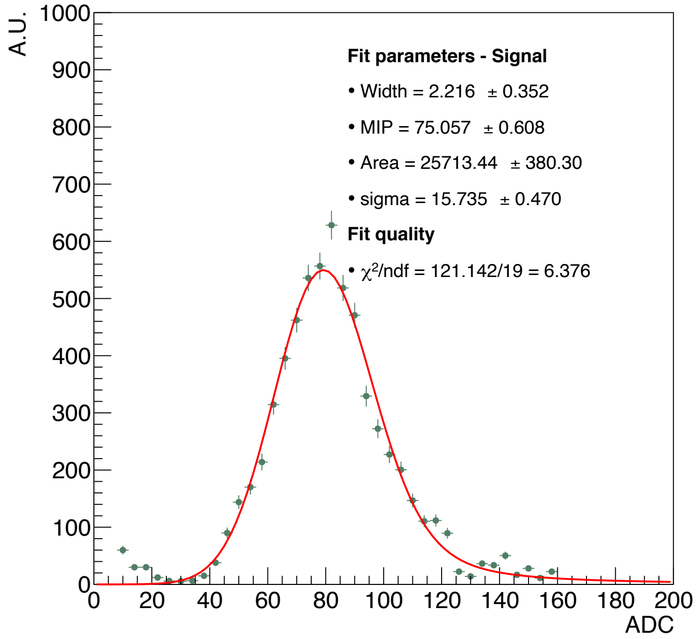
Recap - energy deposit distribution, L2

The new plot

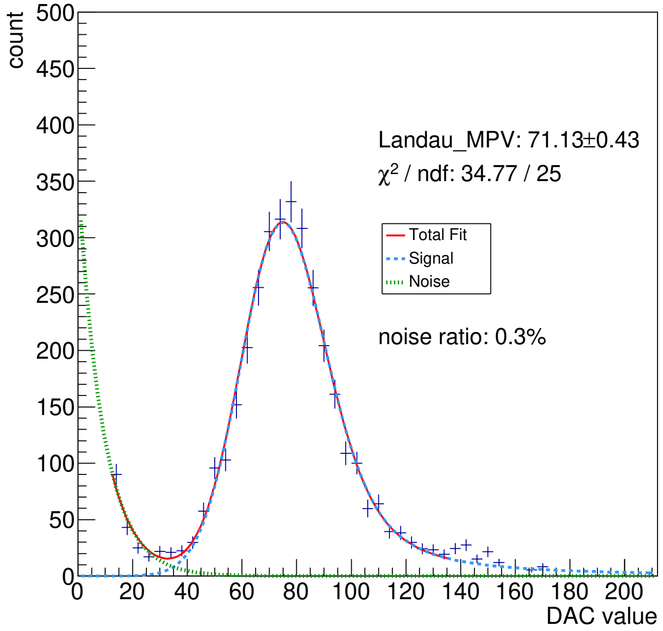


Plot to be in paper (tentative)

By Cheng-Wei
Debut: 2022/Jan/23



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

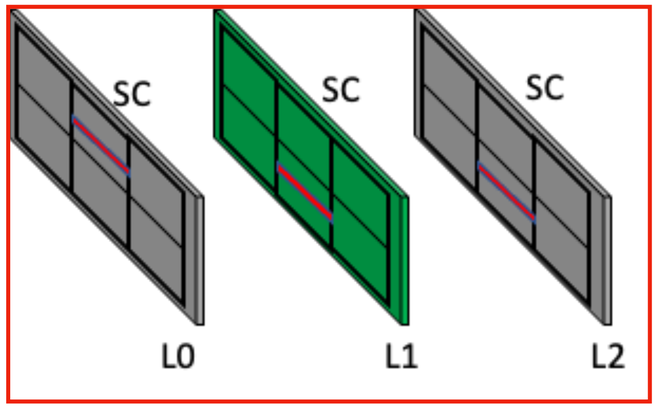


Scattering comparison with MC

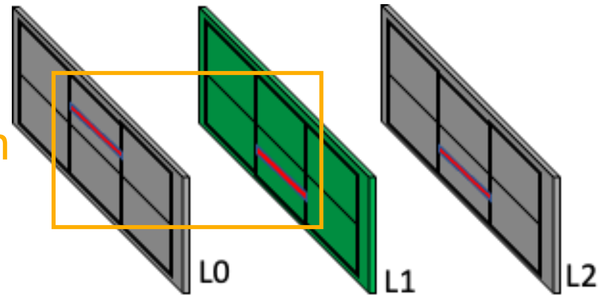
- Method: L0L1 are used for reconstructing proto-track (have constrain), set L2 free

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



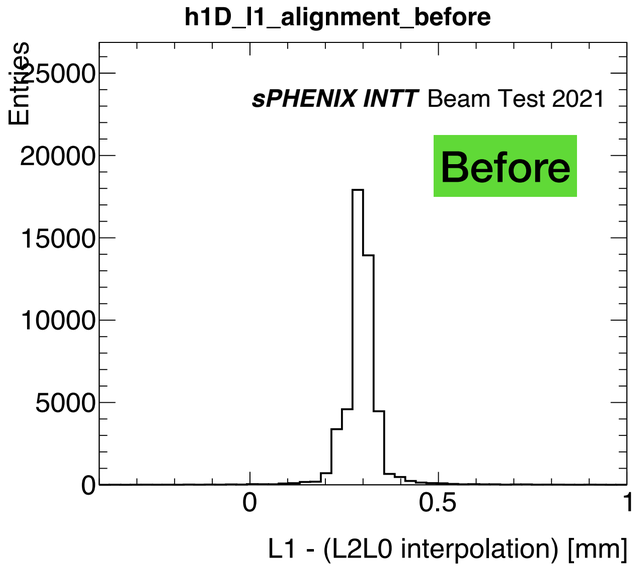
Constrain on proto-track

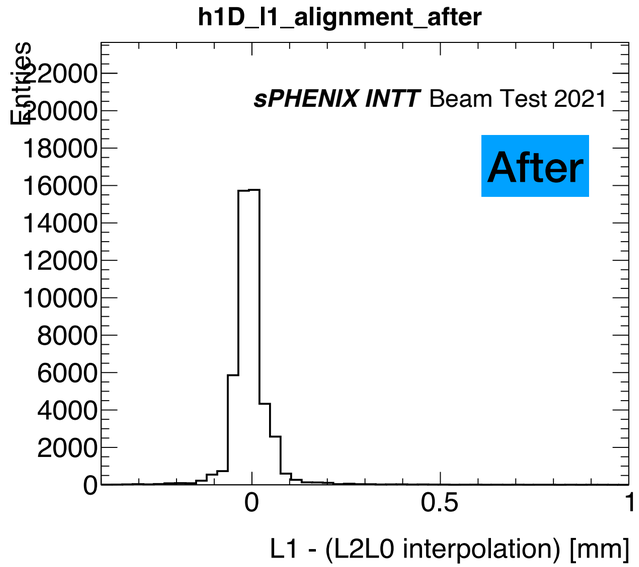


Scattering comparison with MC

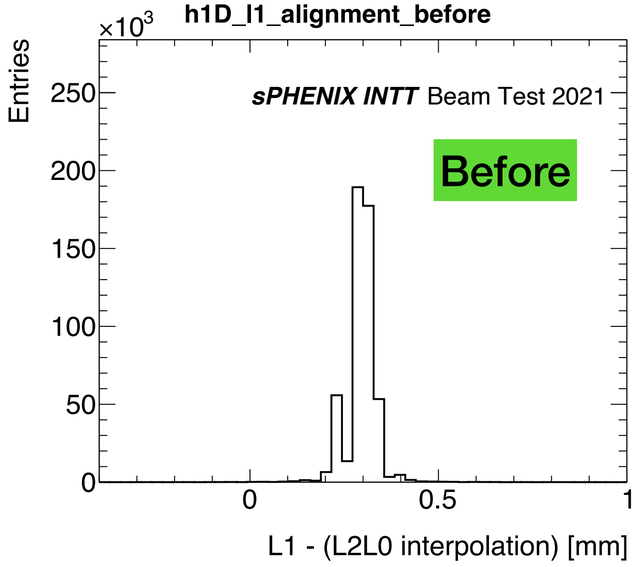
Layer-1 alignment correction

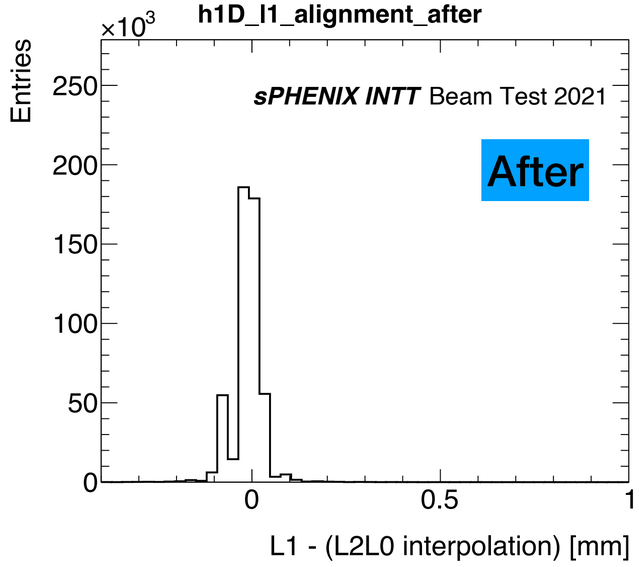
Data Run52, U8





MC

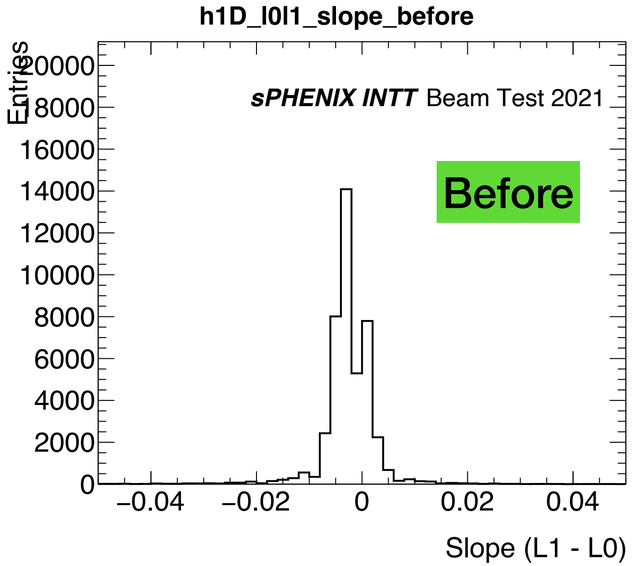


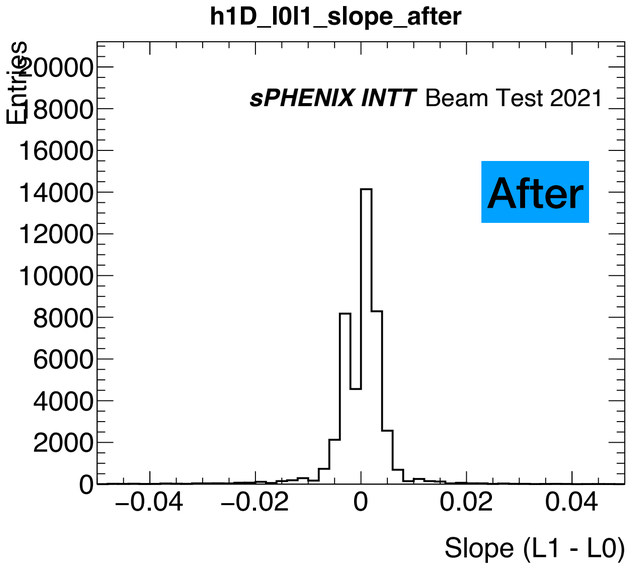


Scattering comparison with MC

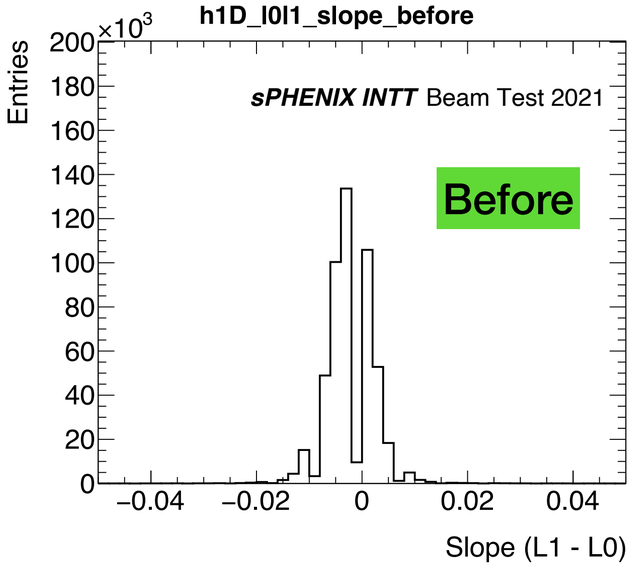
L0L1 slope re-centering

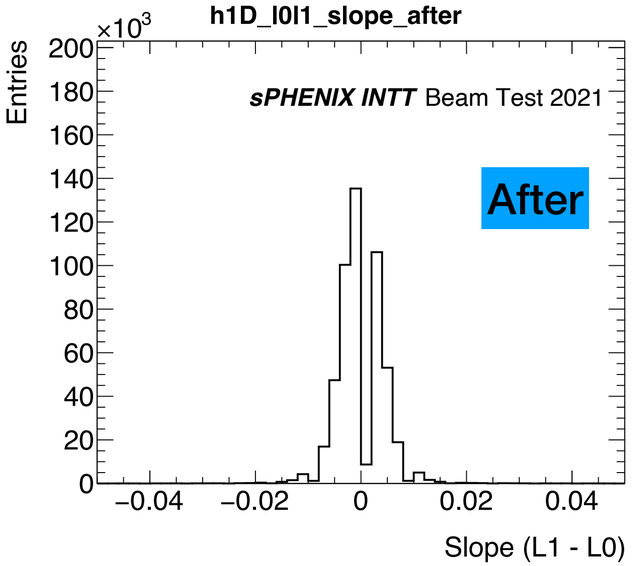
Data Run52, U8





MC





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

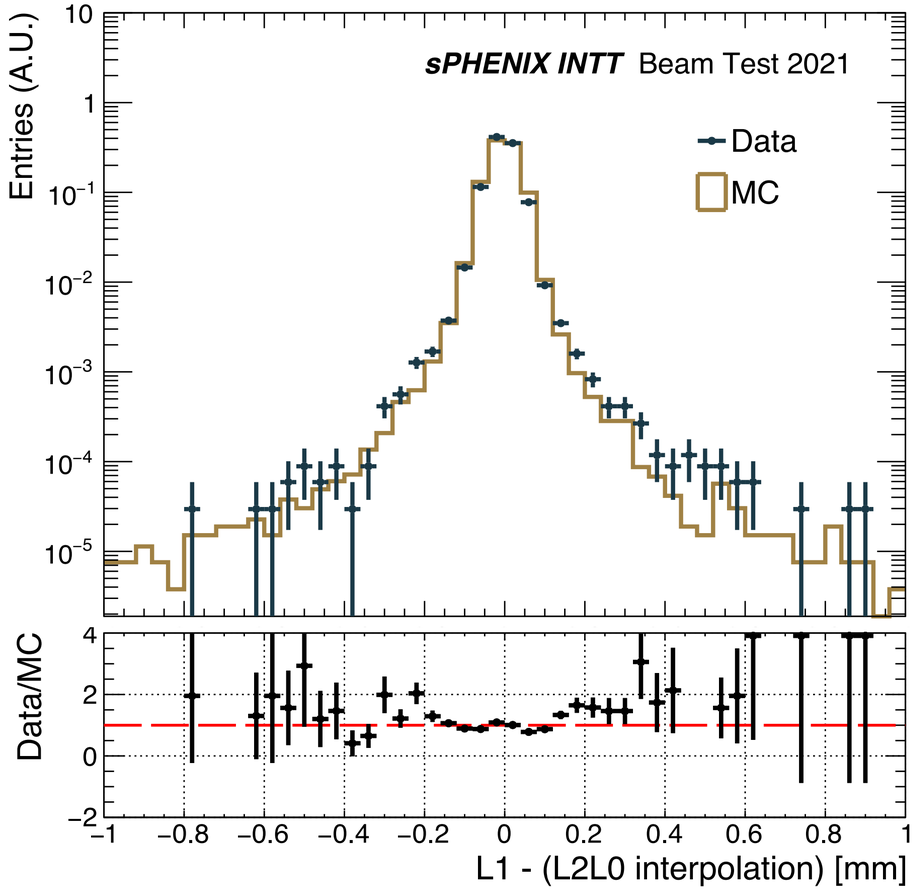
Scattering comparison with MC

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

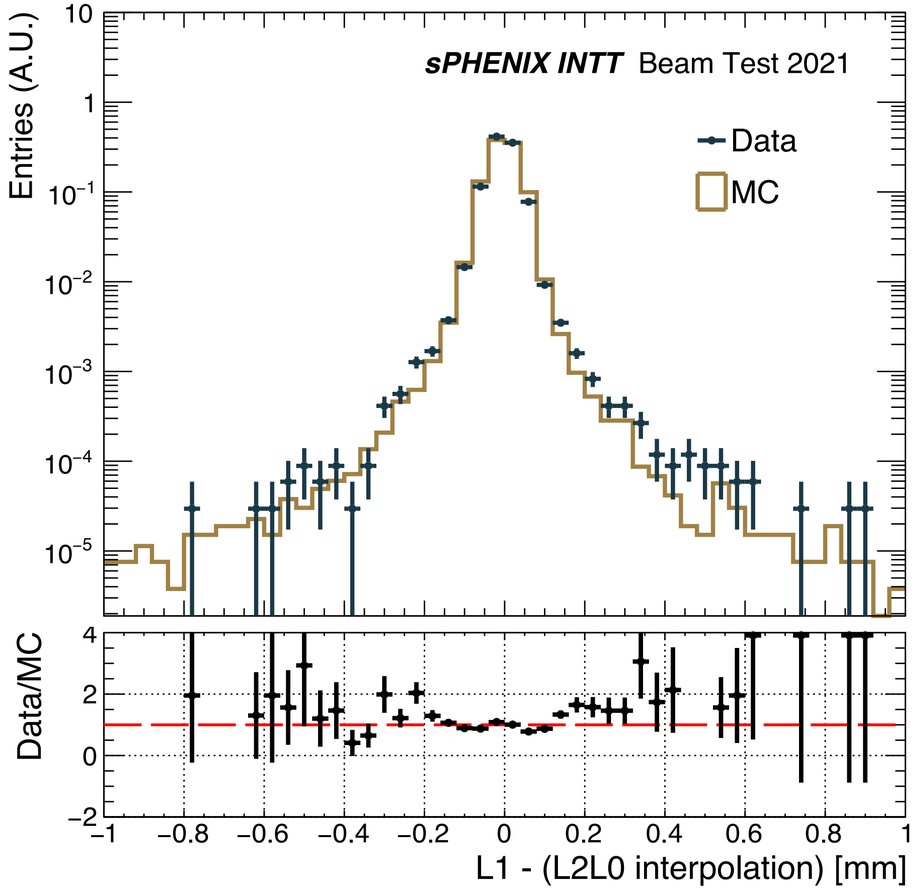
Plot to be in paper (tentative)



Agreement between data and MC is reasonable well

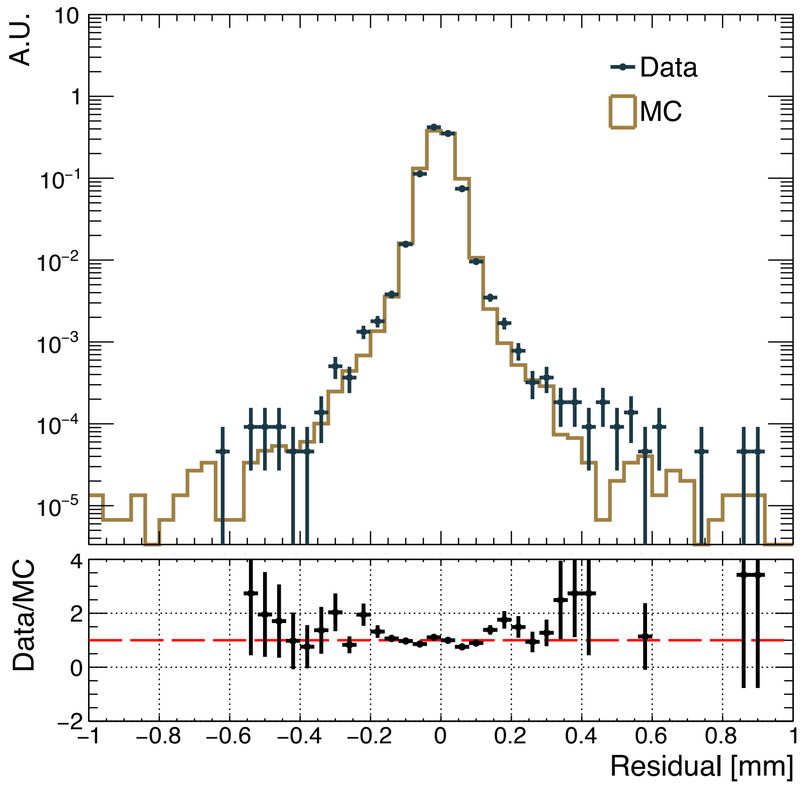
Recap - Scattering comparison

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 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)

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

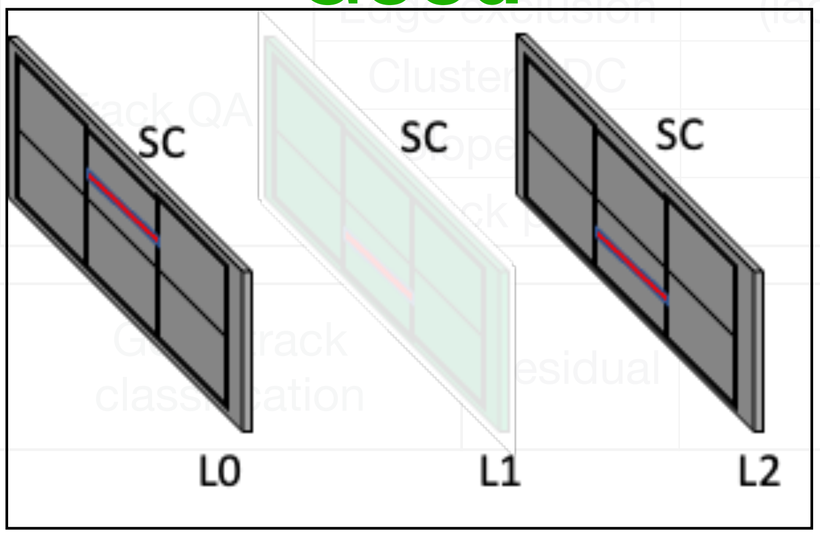
$$Effi. = \frac{Good\ Events\ and\ L1\ Good\ Hit\ Found}{Good\ Events} = \frac{L0 \bigcap L1 \bigcap L2}{L0 \bigcap L2}$$

Hit detection efficiency

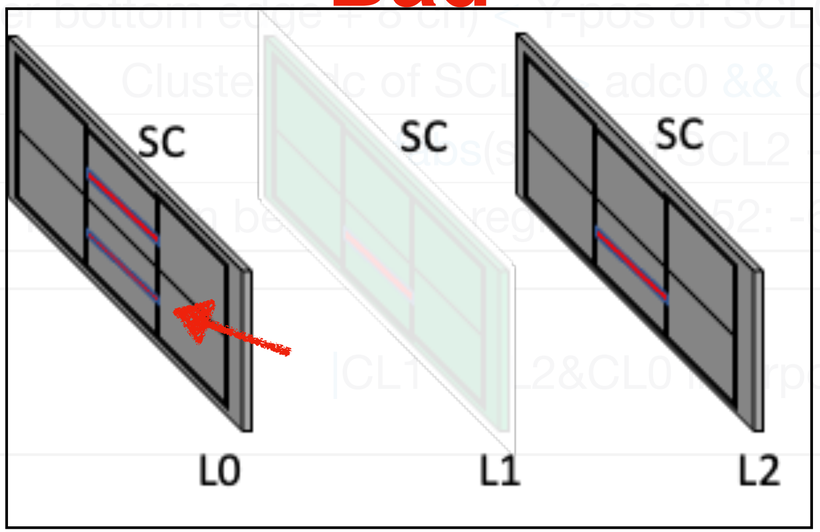
To minimize the ambiguity of track reconstruction
(Only two layers for track reco., to improve the purity, tight selection required)

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

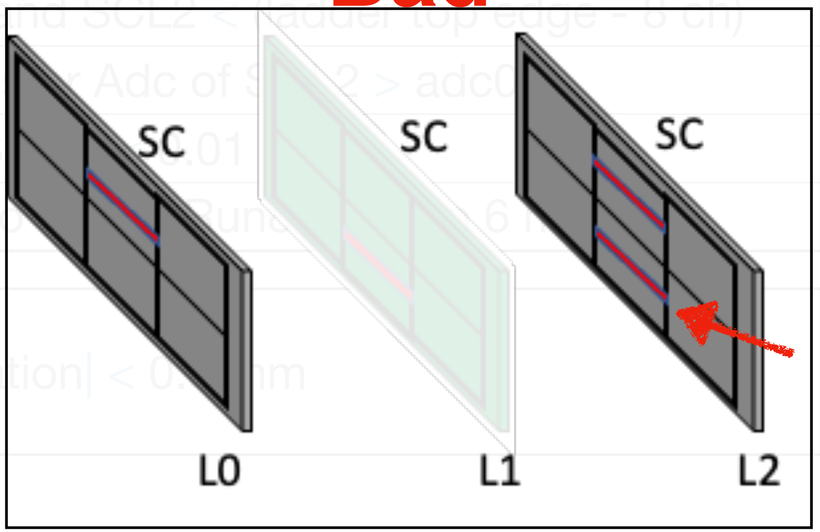
Good



Bad



Bad

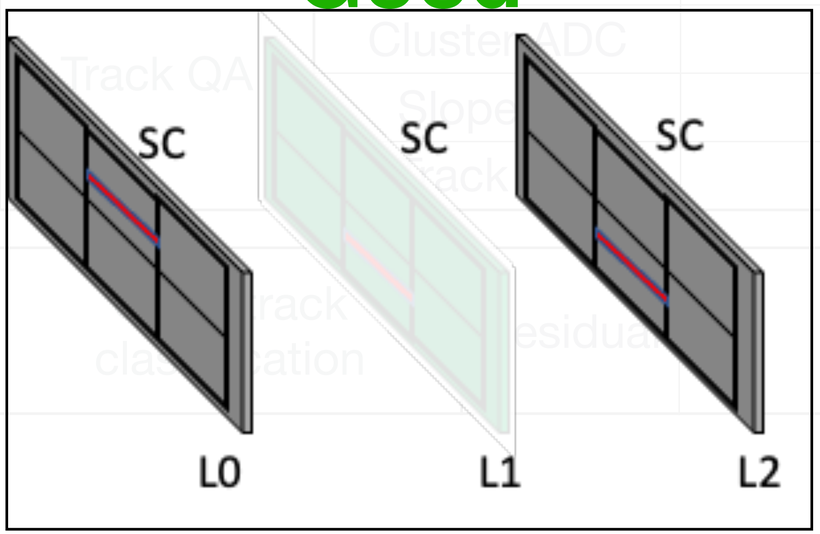


Hit detection efficiency

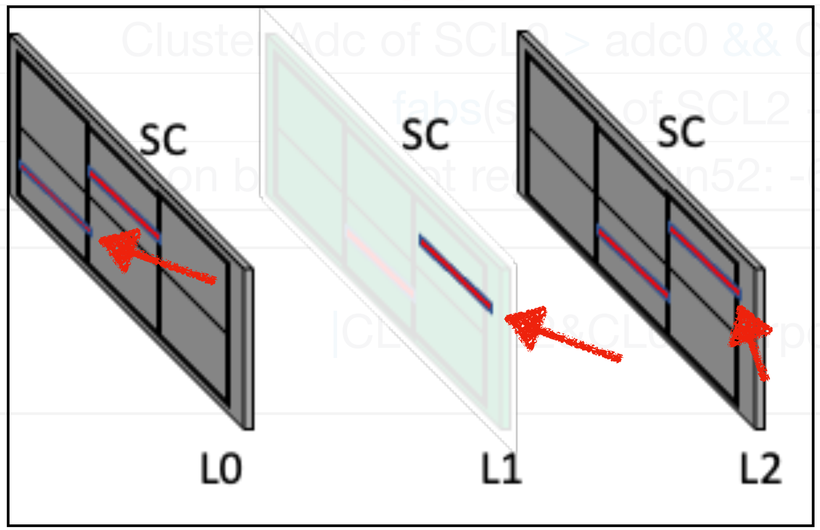
To account for the misalignment in the longitudinal axis (x axis)

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)

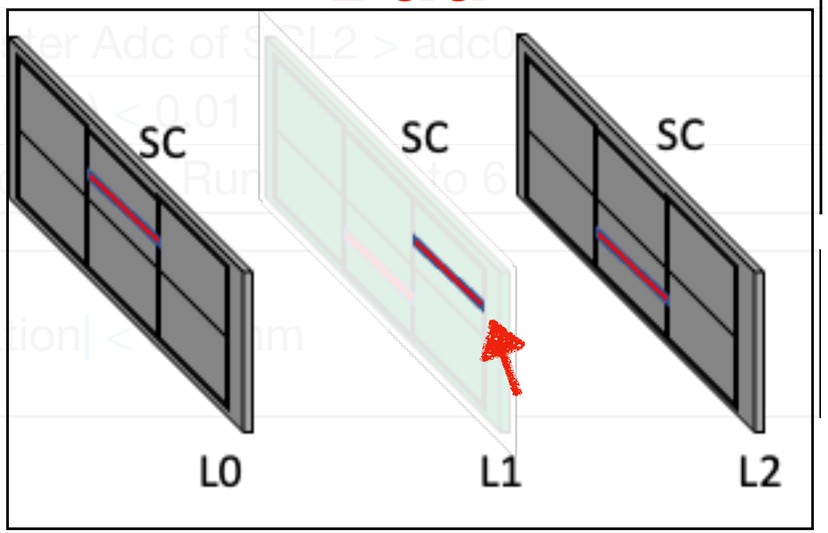
Good



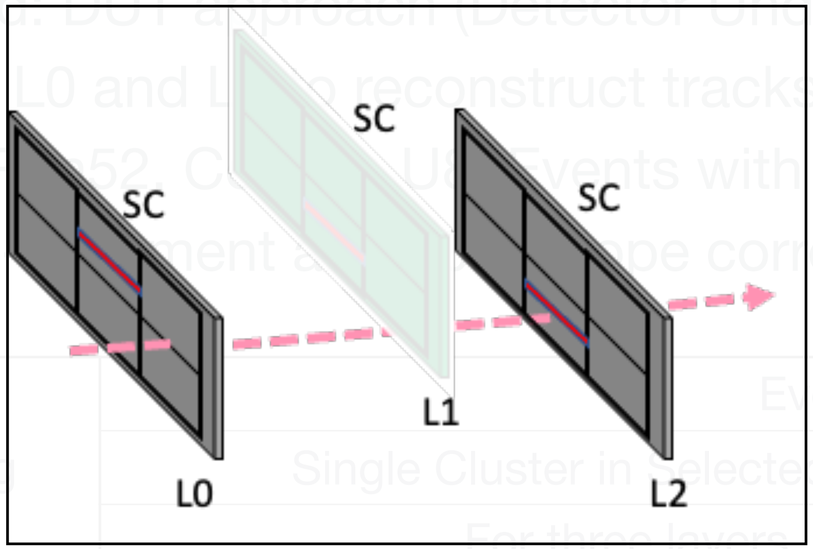
Bad

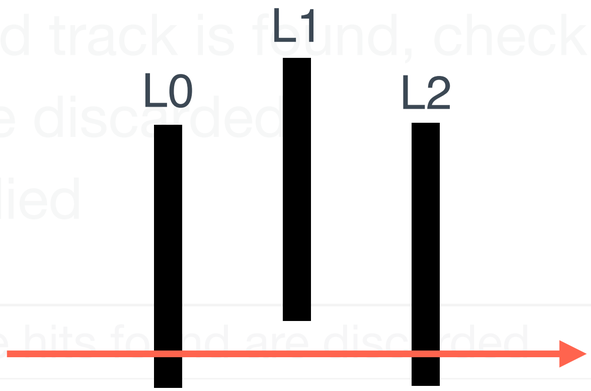


Bad



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

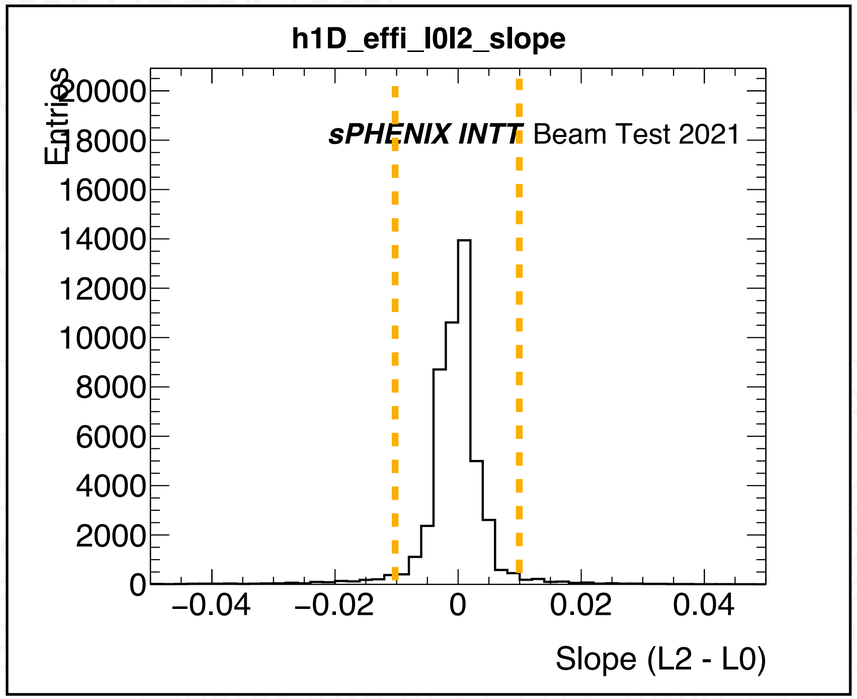
- Method: DUT approach (Detector Under Test)
  - Use L0 and L2 to reconstruct tracks. When good track is found, check L1
- Data: Run52, Column U8. Events with clone hit are discarded
- L1 mis-alignment and L0L2 slope corrections applied

To minimize tracks reconstructed by noise hits

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

Tracking	Layer requirement	Hits in all four layers required
		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

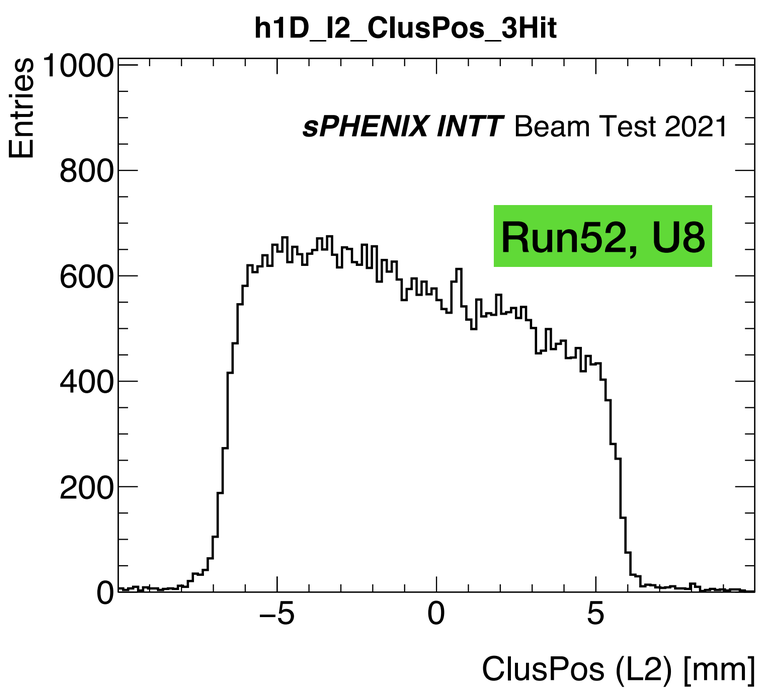
Hit detection efficiency

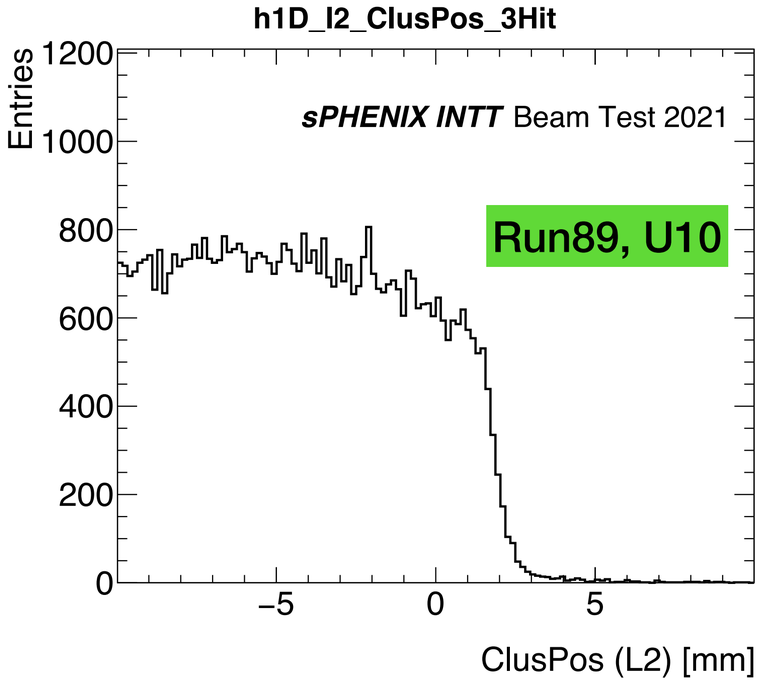


Track QA	Slope cut	fabs(slope of SCL2 - SCL0) < 0.01

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

Hit detection efficiency





Track QA	Track pos	Focus on beam spot region (Run52: -6 to 6 mm, Run89: -10 to 6 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	|CL1 - CL2&CL0 interpolation| < 0.5 mm

$$Effi. = \frac{Good\ Events\ and\ L1\ Good\ Hit\ Found}{Good\ Events} = \frac{L0 \bigcap L1 \bigcap L2}{L0 \bigcap L2}$$

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**
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**

All above 99%

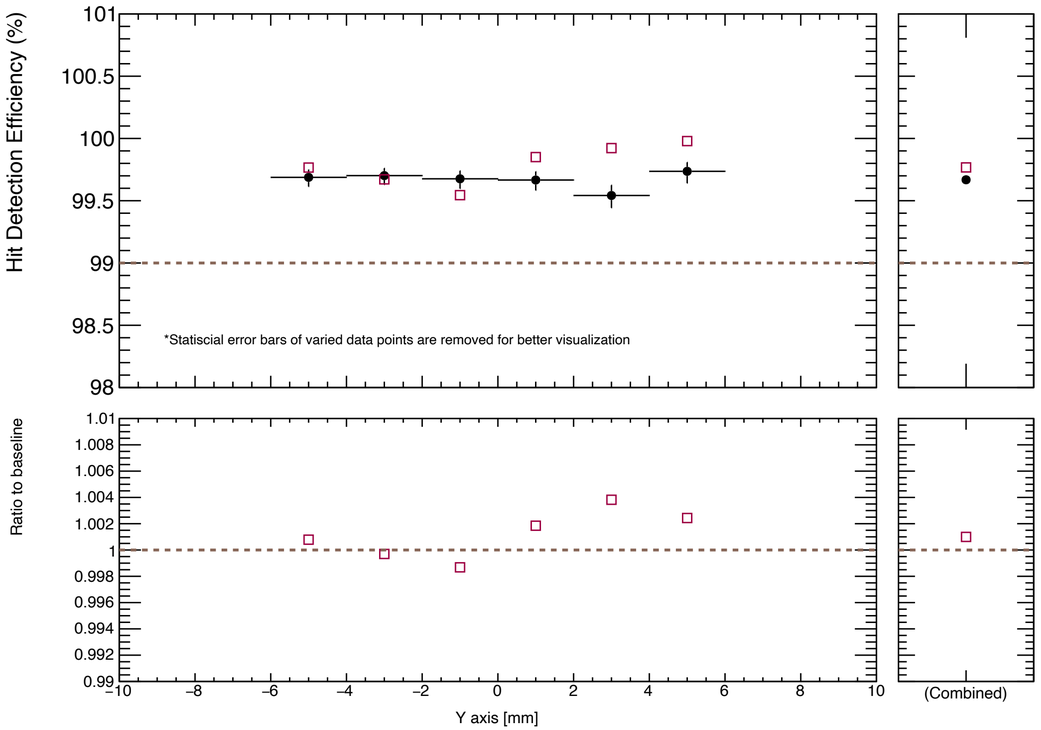
The numbers are statistically combined for estimating systematic uncertainty

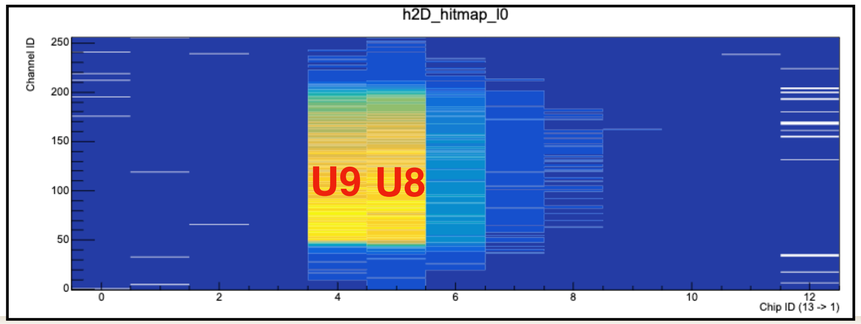
Hit detection efficiency as a function of Y axis

Run52

Column variation, Run52

- Baseline (Column 8)
- Column 9

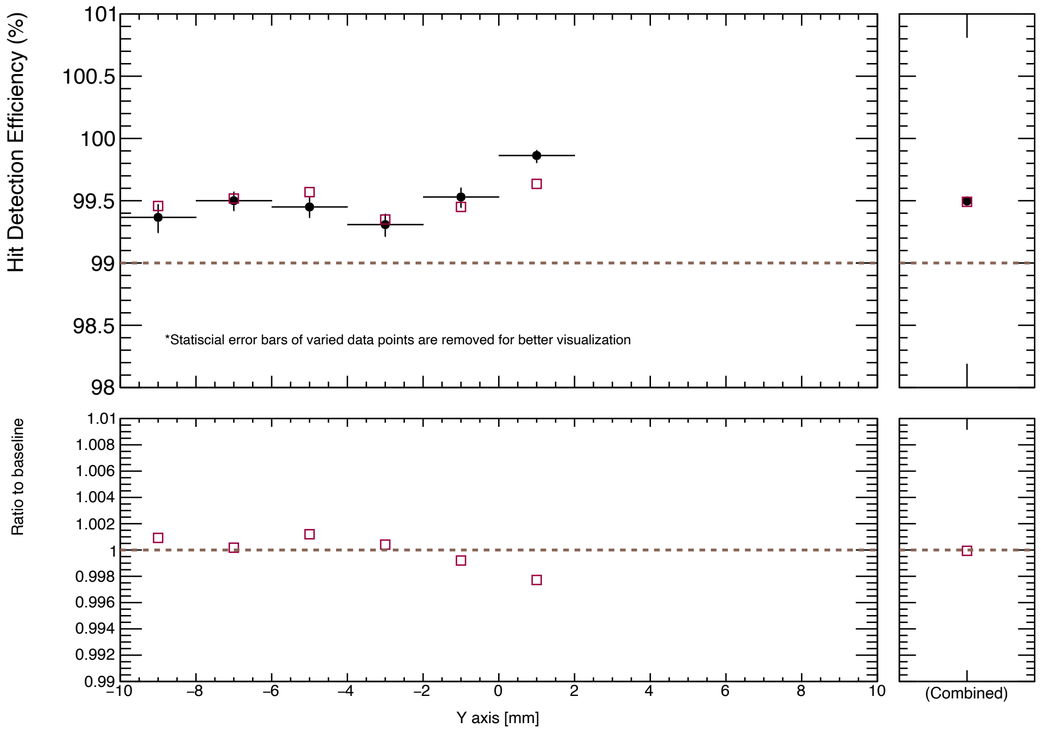


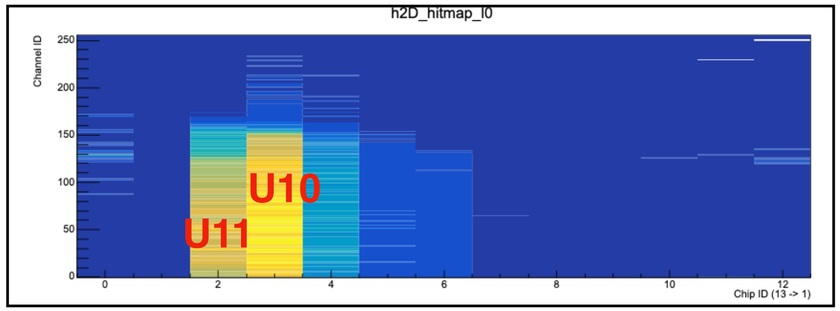


Run89

Column variation, Run89

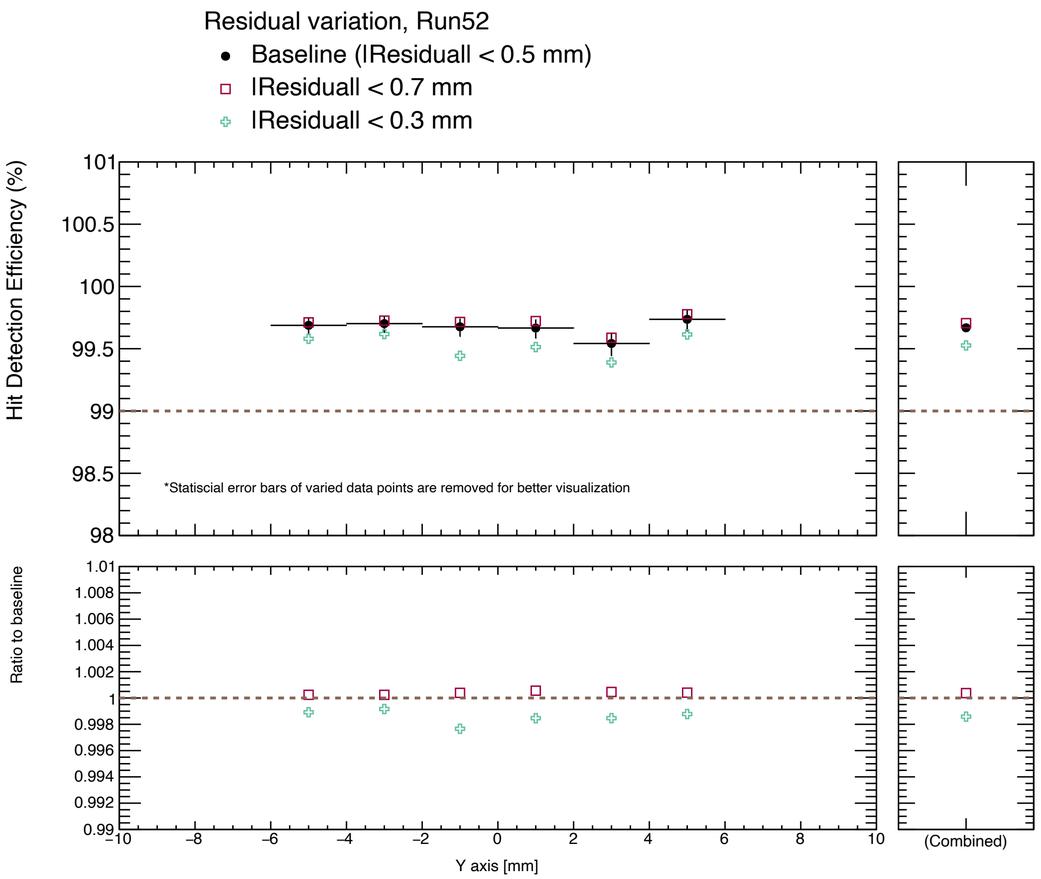
- Baseline (Column 10)
- Column 11



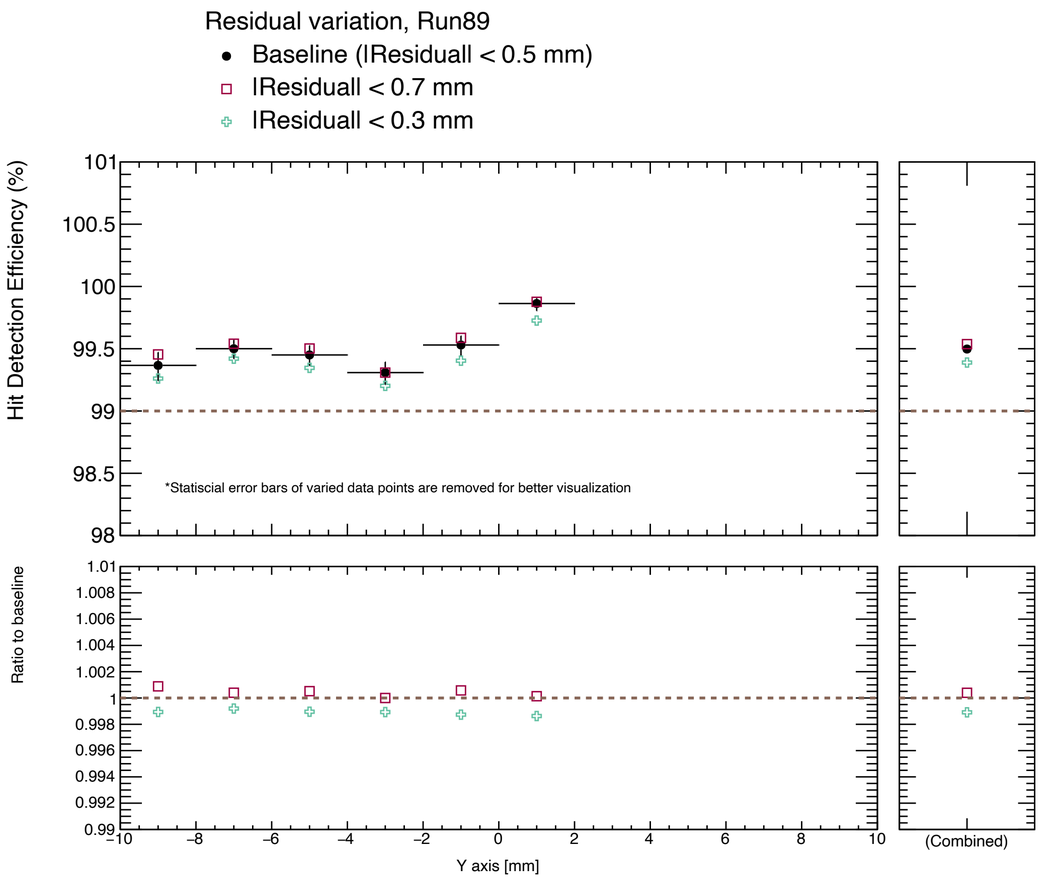


Hit detection efficiency as a function of Y axis

Run52

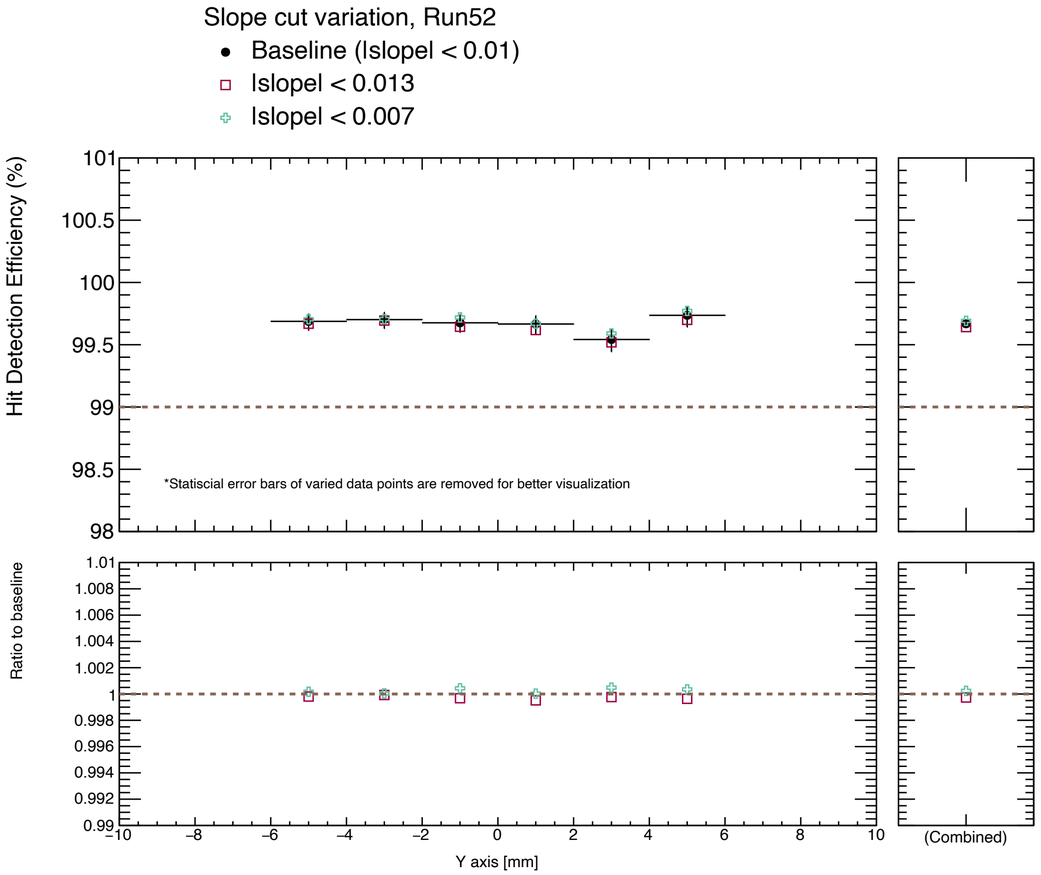


Run89

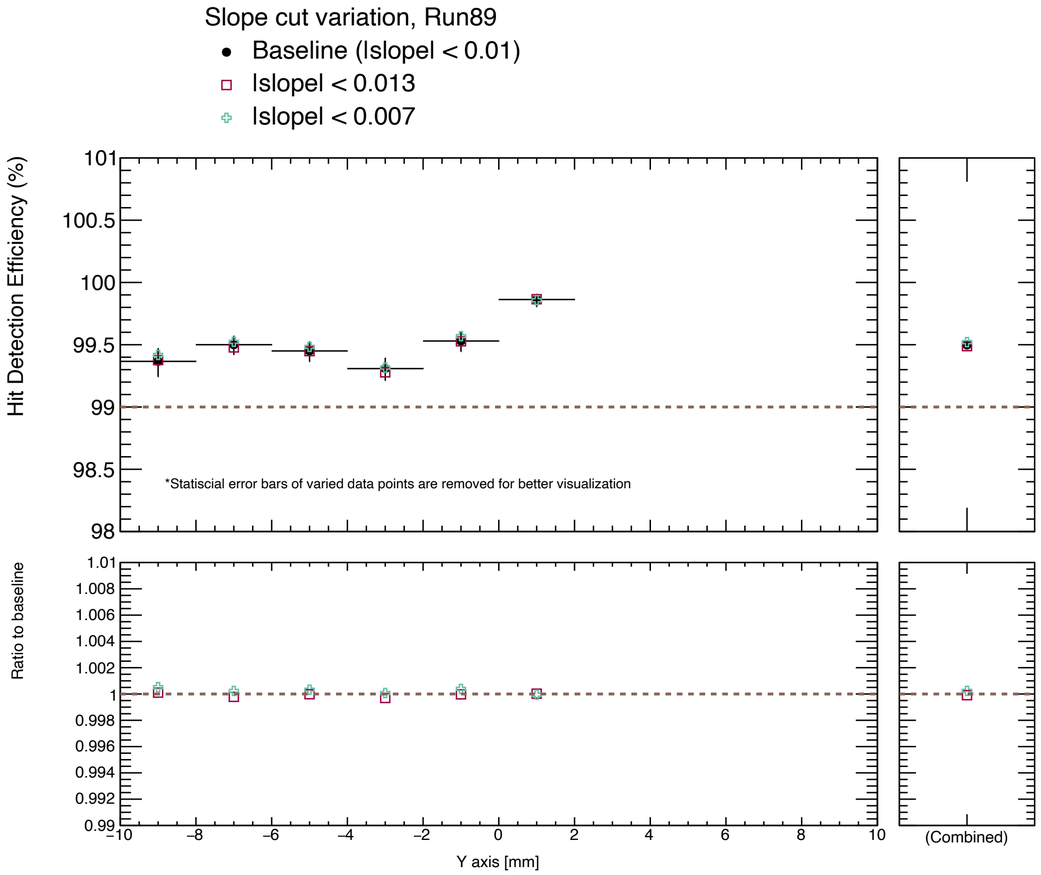


Hit detection efficiency as a function of Y axis

Run52



Run89

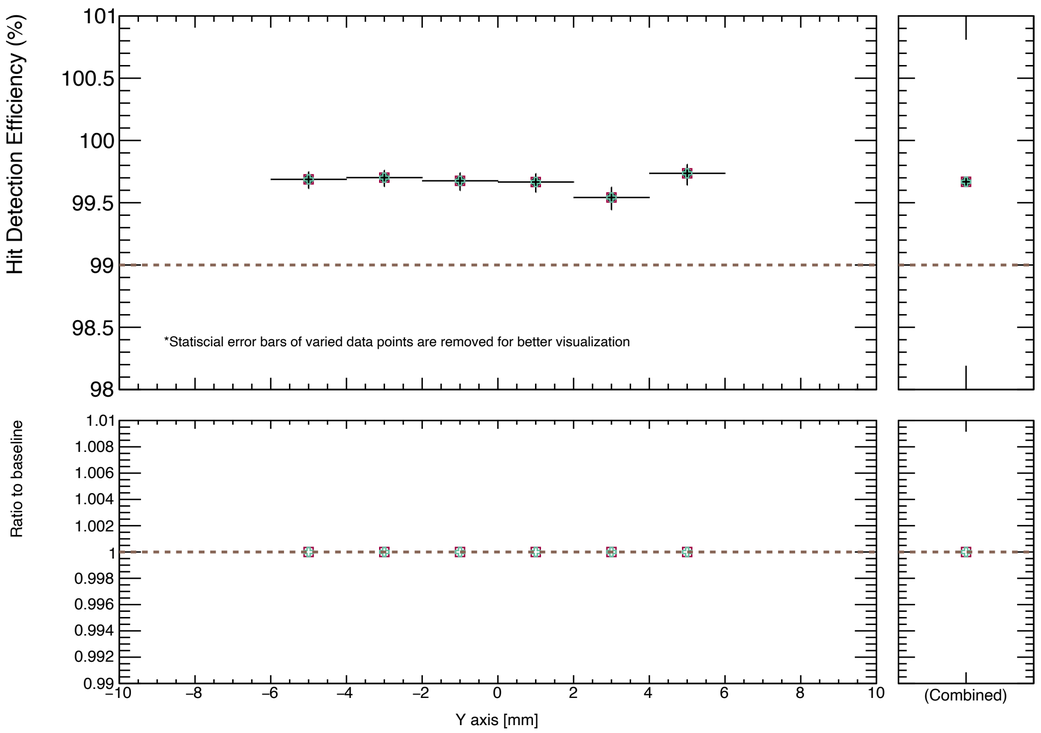


Hit detection efficiency as a function of Y axis

Run52

Boundary cut variation, Run52

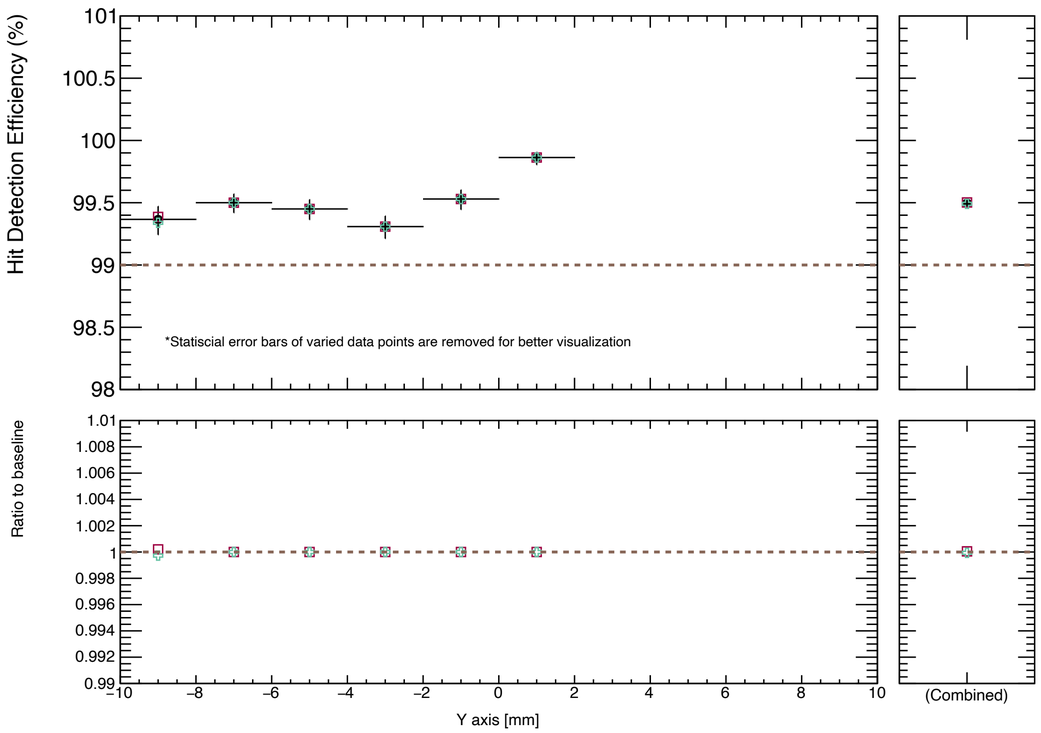
- Baseline (Hits of L0 & L2 to edge < 8 channels)
- Hits of L0 & L2 to edge < 11 channels
- Hits of L0 & L2 to edge < 5 channels



Run89

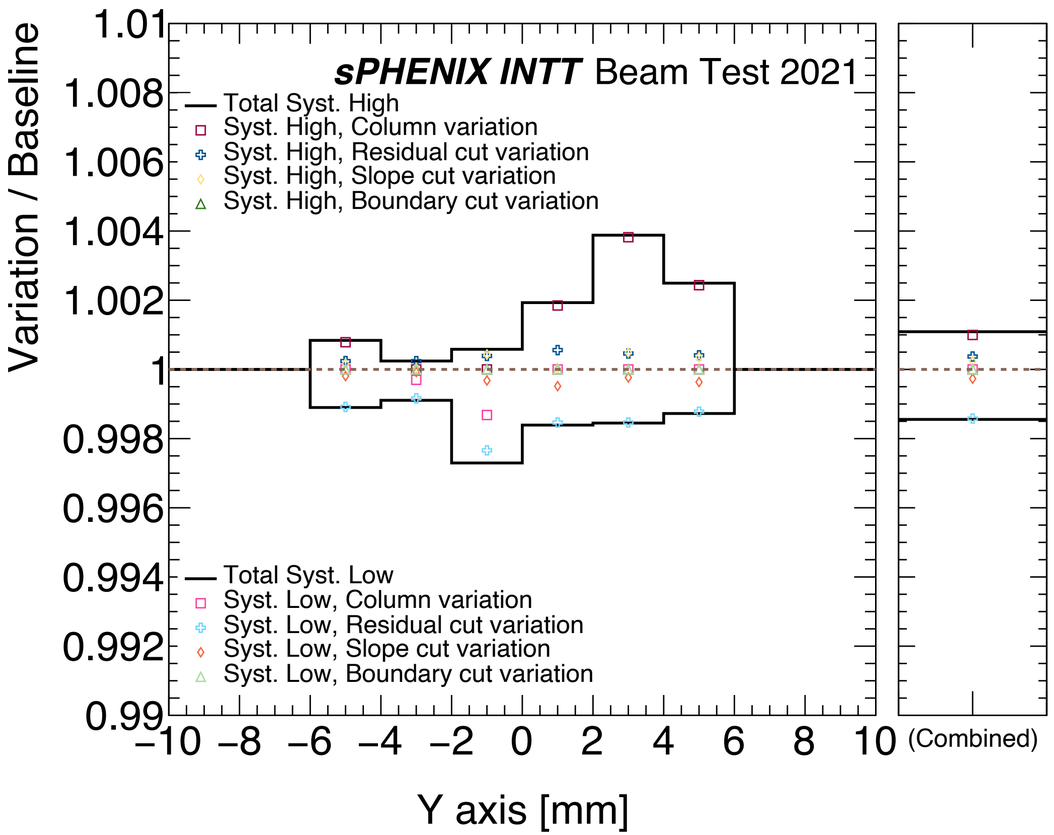
Boundary cut variation, Run89

- 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

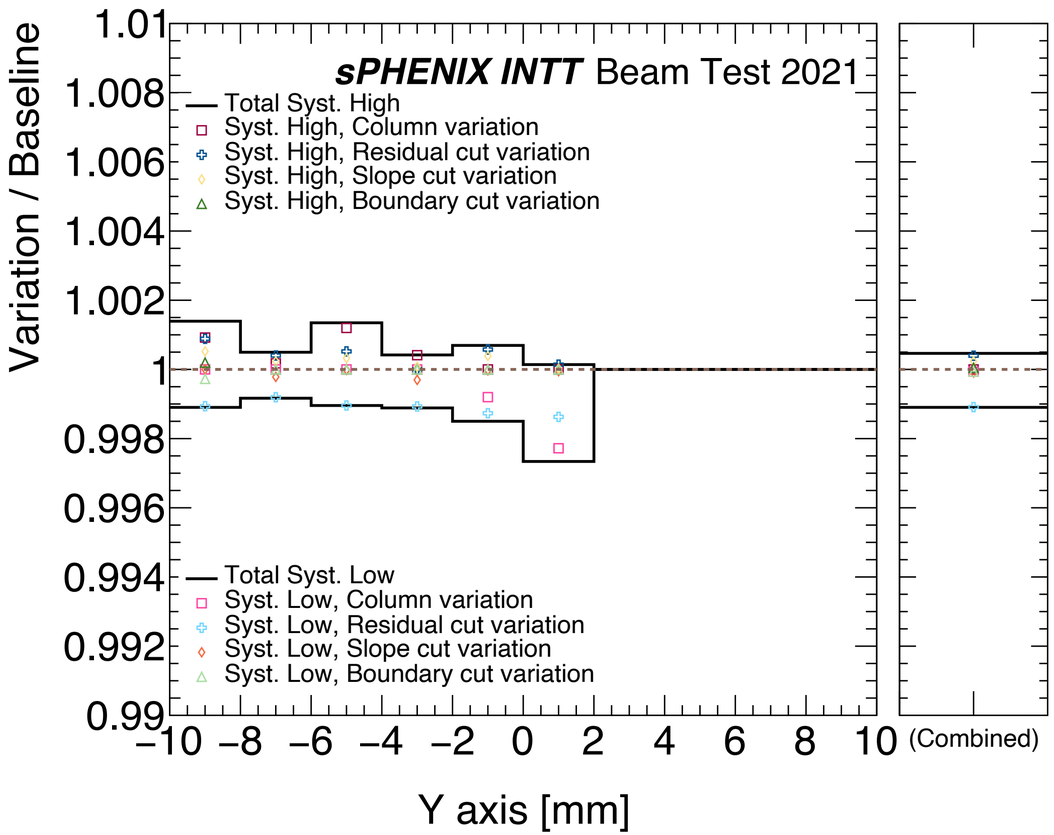


Hit detection efficiency as a function of Y axis

Run52



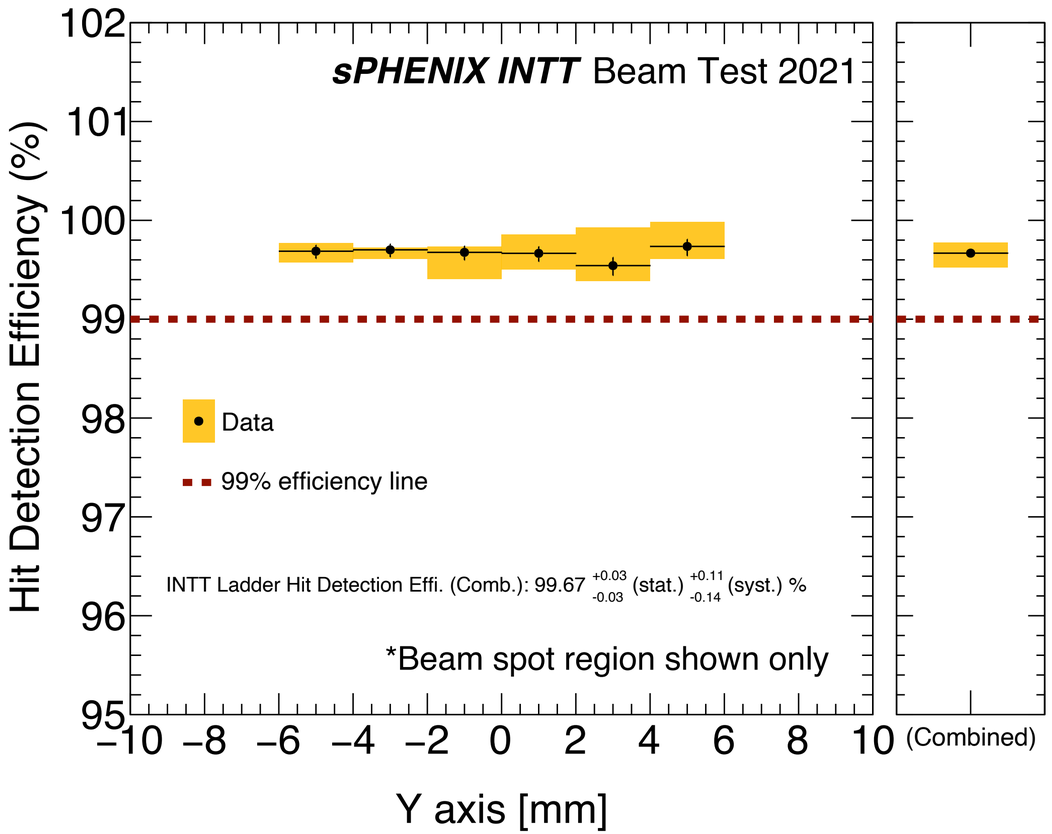
Run89



Hit detection efficiency as a function of Y axis

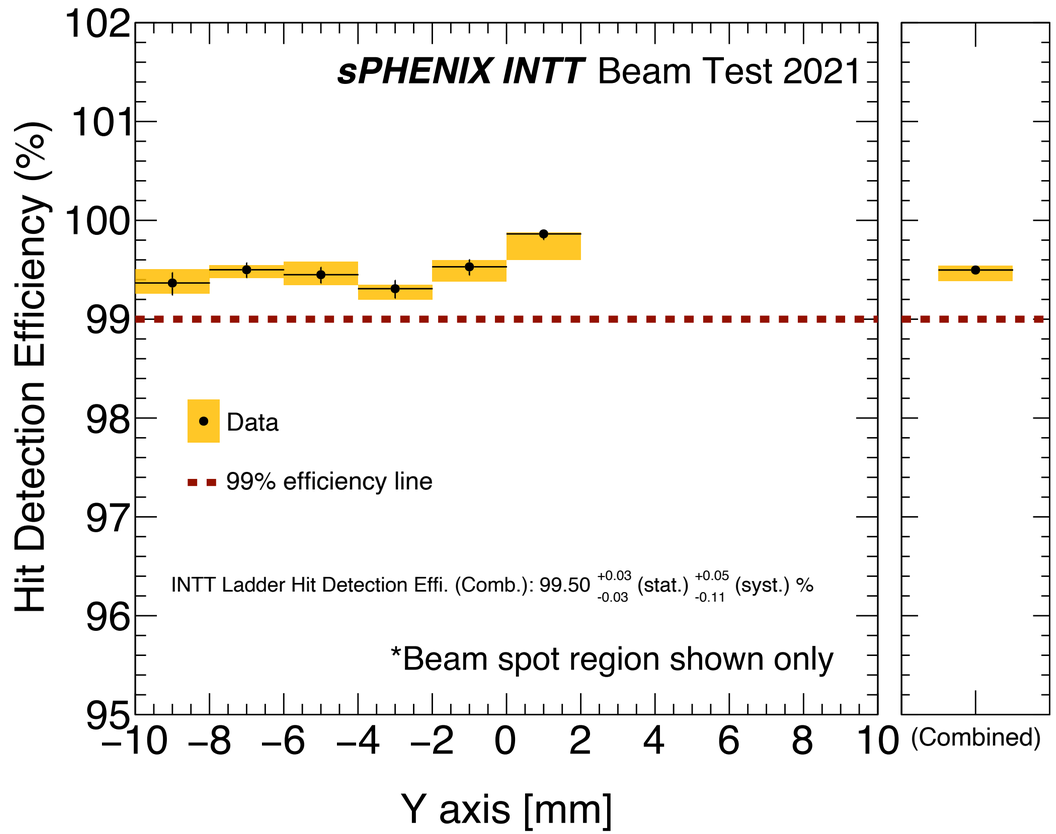
Run52

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 L0

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

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

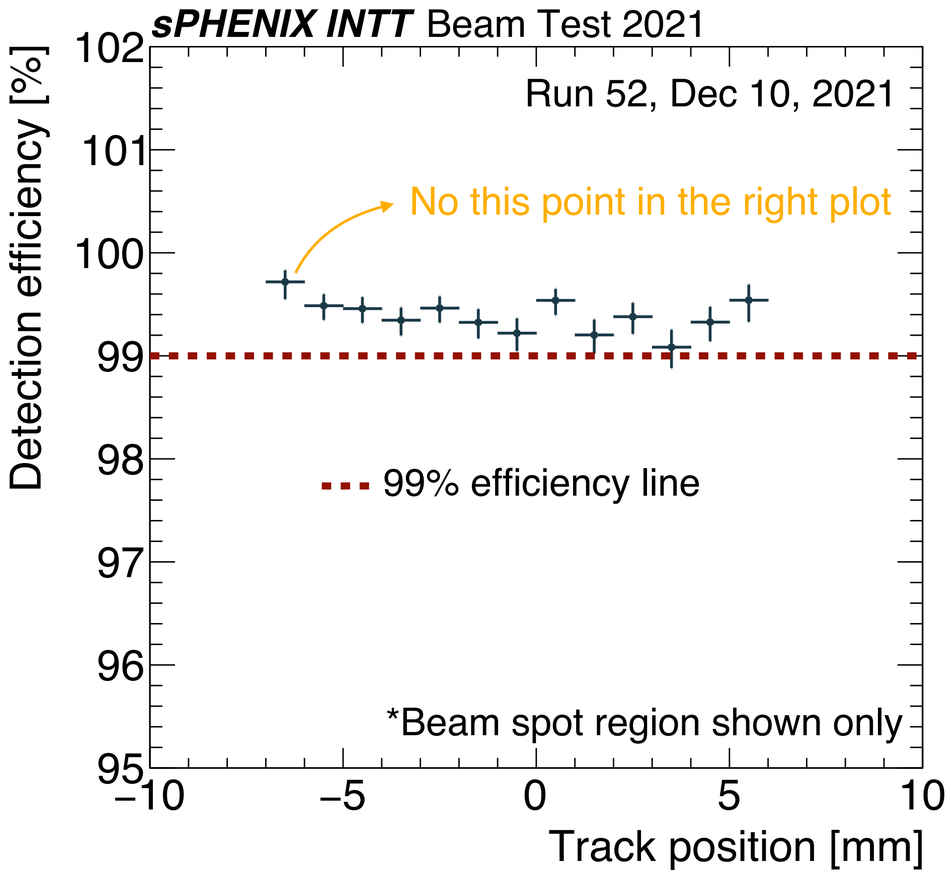
----------New----------

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

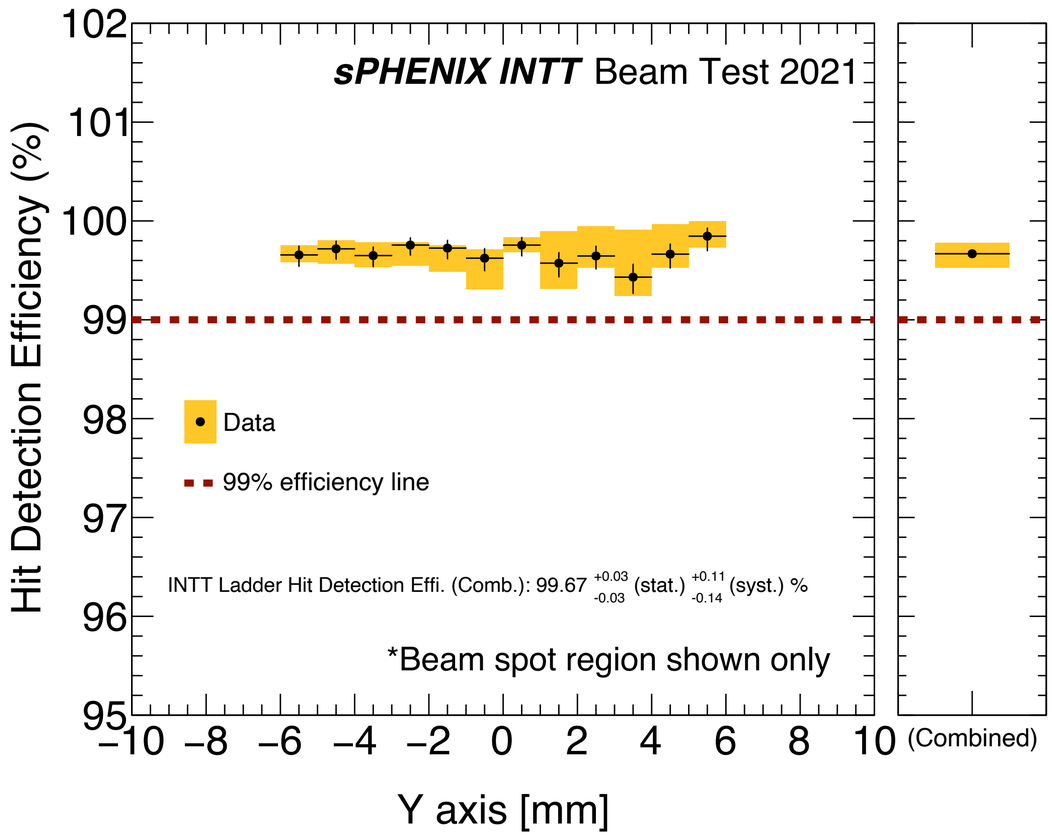
- In ELPH, the average of variation is used as uncertainty (Insensitive to the tested variations)
  - In new result: Direct differences are summed up in quadrature (conventional way)
  - In new result: One more source considered: Column
- 0.234 mm (0.5 mm) is used for Residual cut in ELPH (New results)
  - Have the good agreement with MC, therefore loose the selection a bit

Recap, detection effi. as a function of Y axis

The previous plot (the one on ELPH report)



The new plot with finer bin for comparison

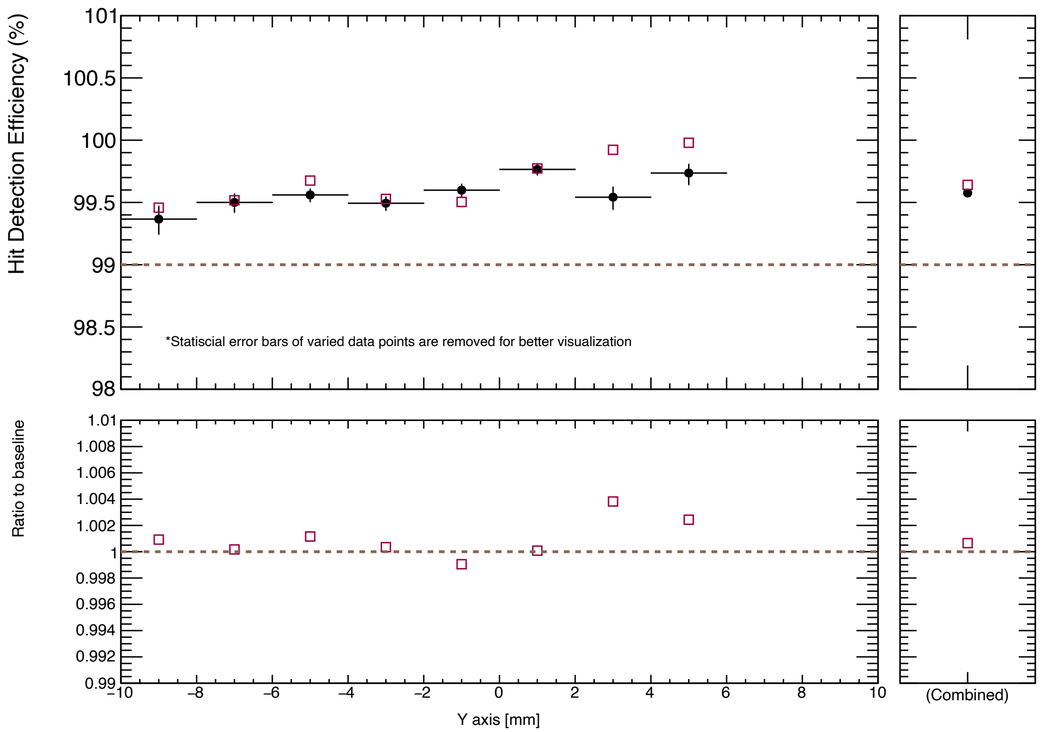


In comparing the baseline data points, basically same shape

Final, Run52 & Run89 combined

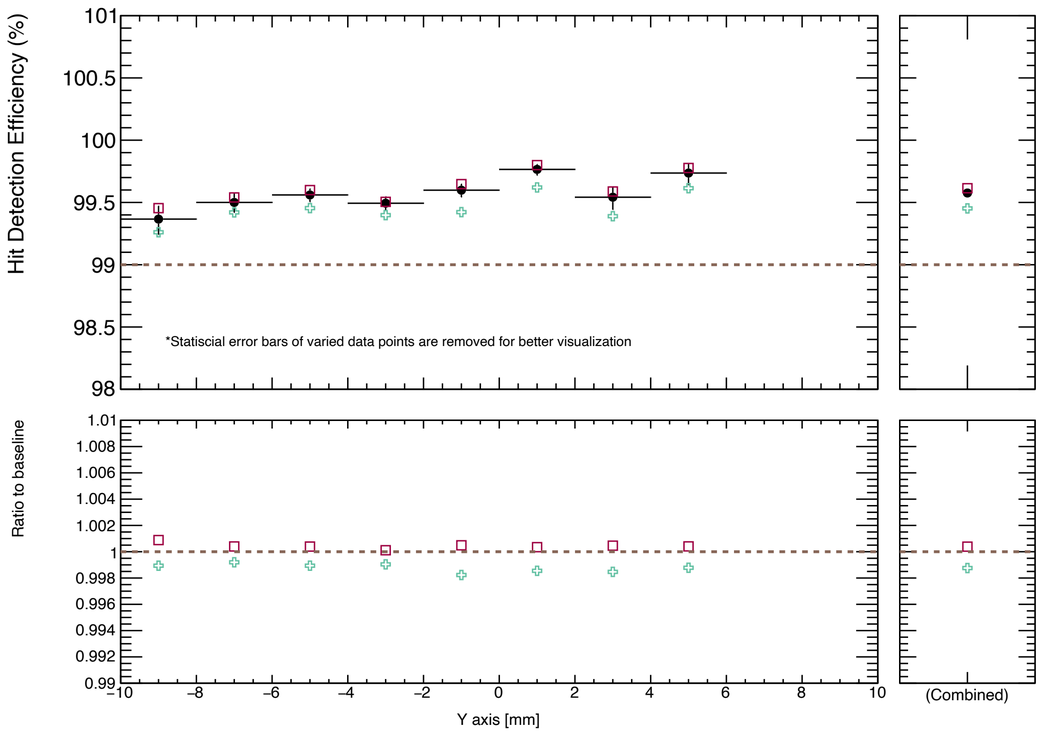
Column variation, Run52+Run89

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



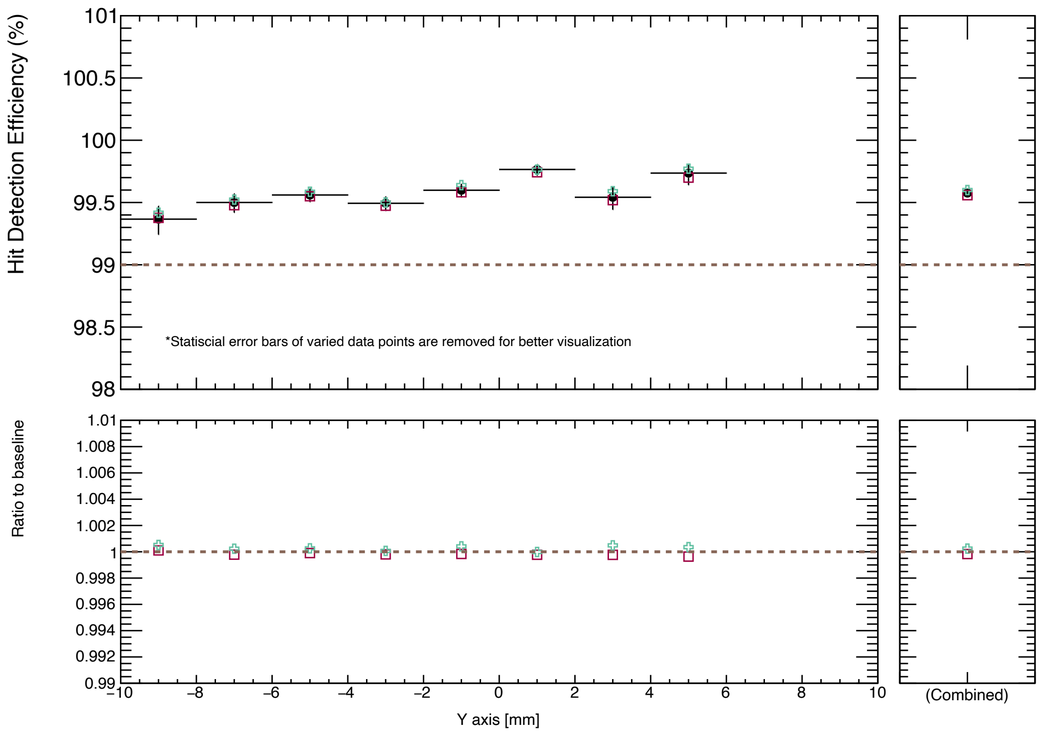
Residual variation, Run52+Run89

- Baseline (IResiduall < 0.5 mm)
- IResiduall < 0.7 mm
- IResiduall < 0.3 mm

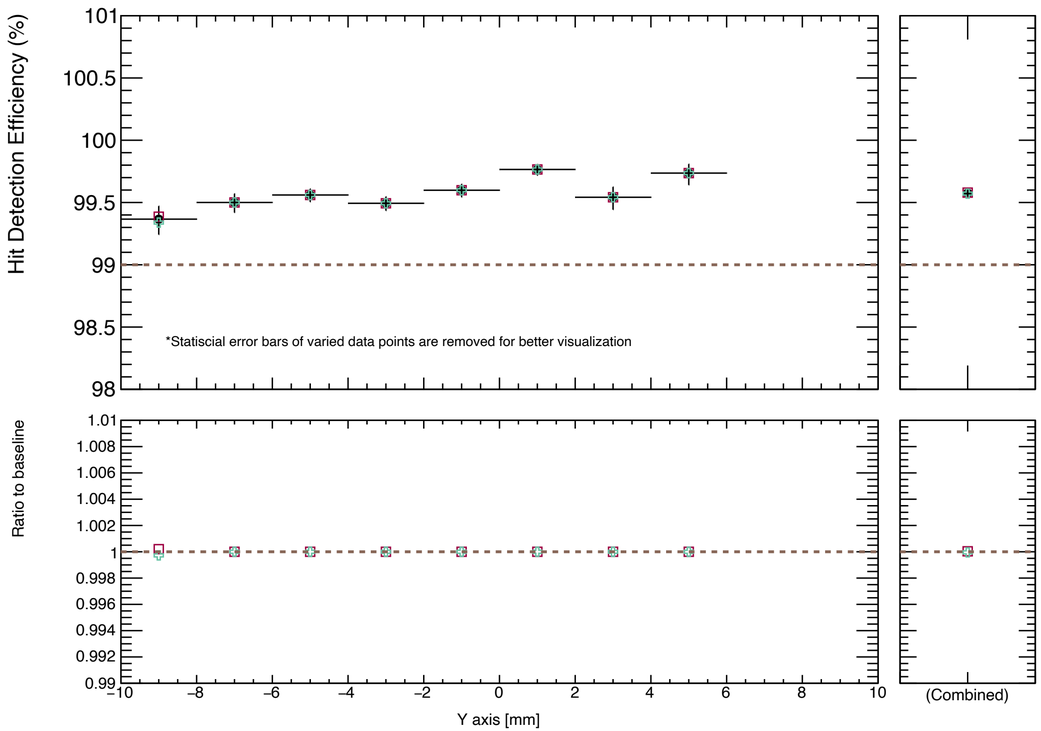


Final, Run52 & Run89 combined

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



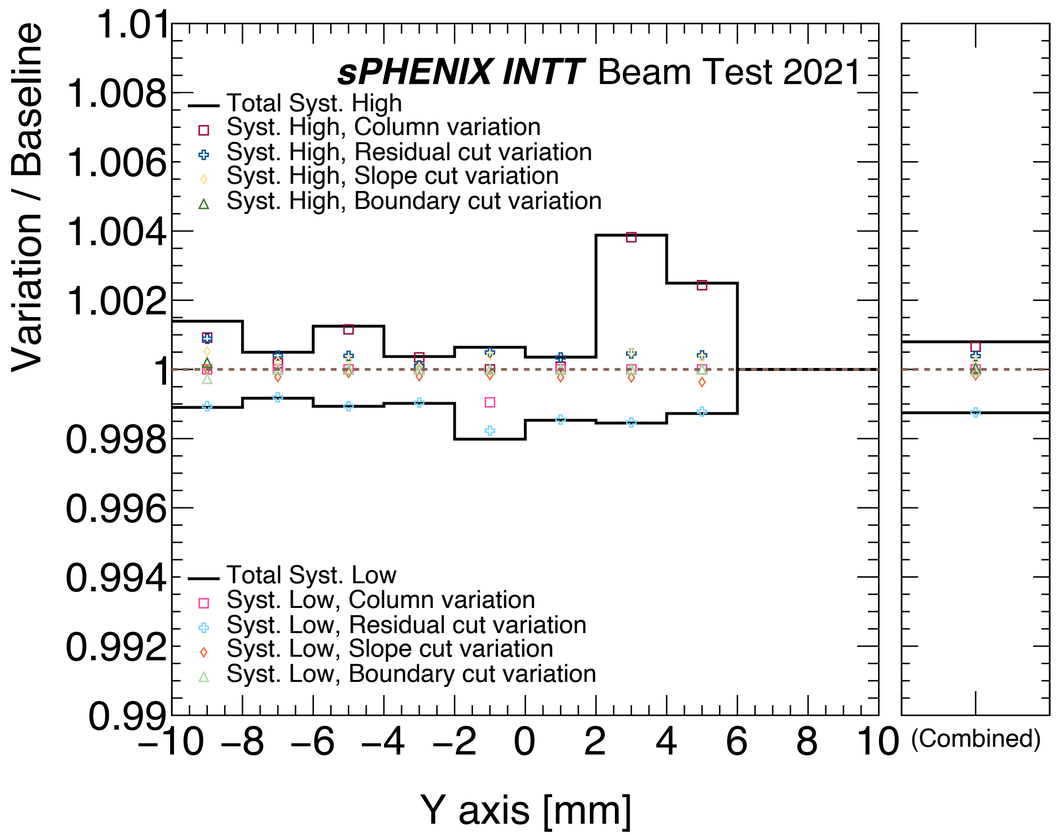
Boundary cut variation, Run52+Run89
- Baseline (Hits of L0 & L2 to edge < 8 channels)
- Hits of L0 & L2 to edge < 11 channels
- Hits of L0 & L2 to edge < 5 channels

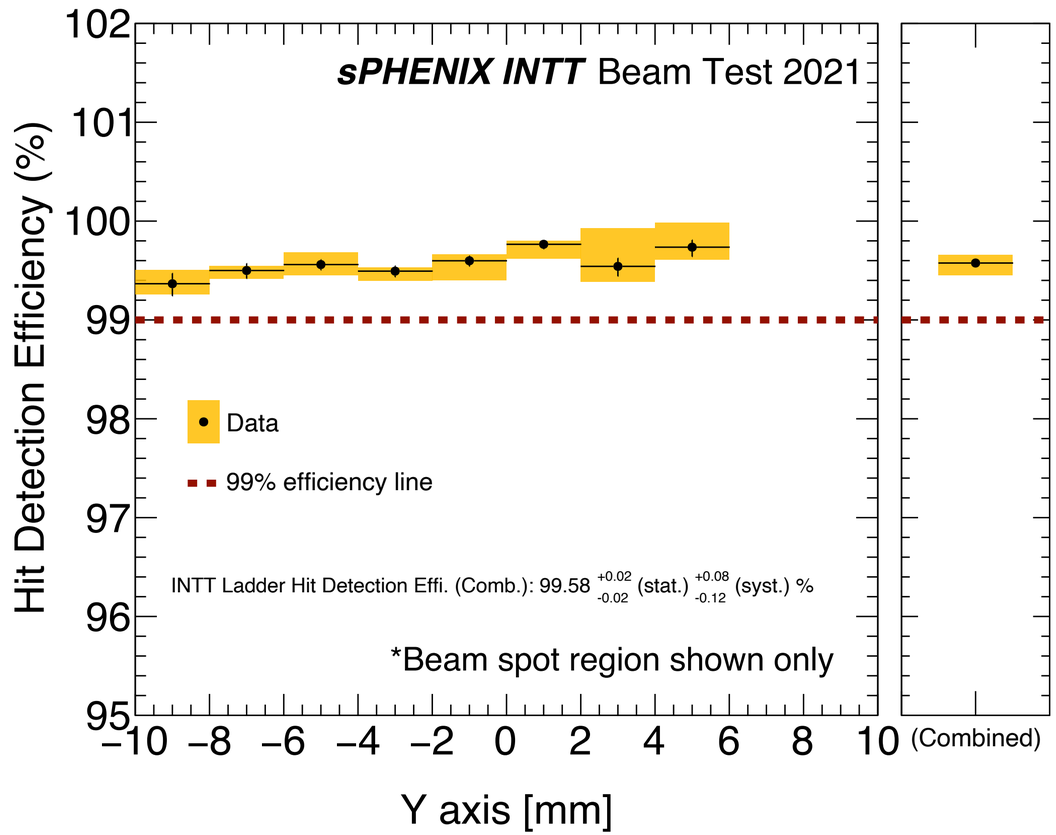


Final, Run52 & Run89 combined

Numbers to be in paper (tentative)

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

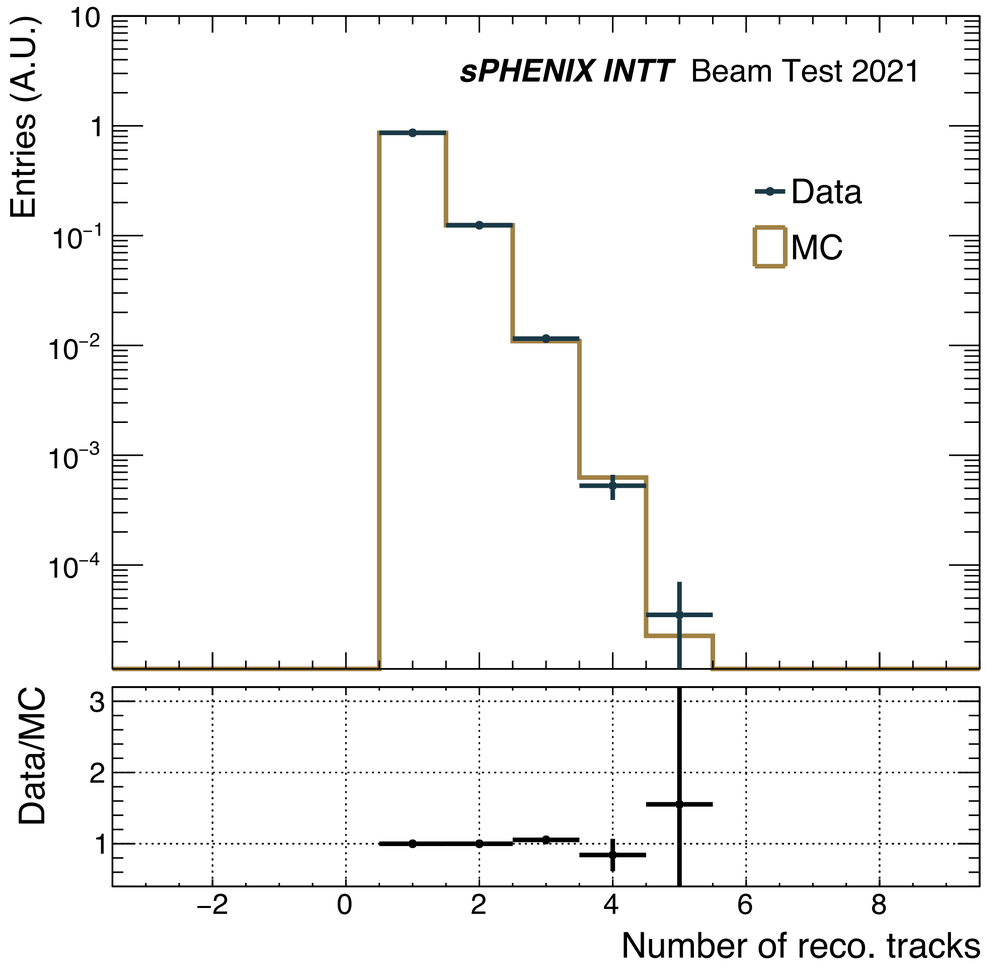




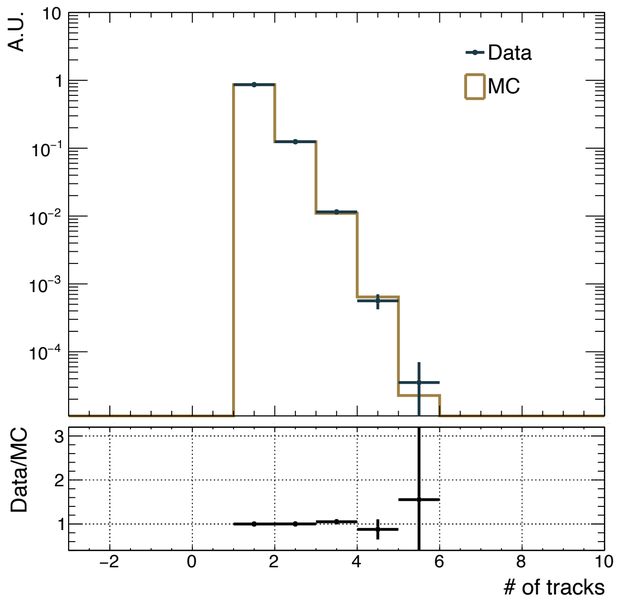
Plot to be in paper (tentative)

Number of reco. tracks compared to MC

Number of reco. tracks compared to MC



Debut: 2023/Feb/17



Plot to be in paper (tentative)

Summary

- The analyses of the introduced topics are completed, improved and reproducible, and to be included in the paper

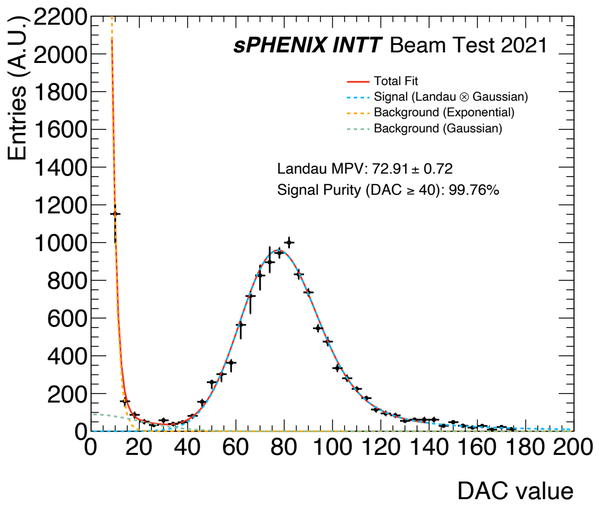
- I would like to request the approvals for plots of
  - Energy deposit distribution
  - Residual distribution comparison with MC
  - Hit detection efficiency (the values and plots)
  - Number of reconstructed tracks compared with MC

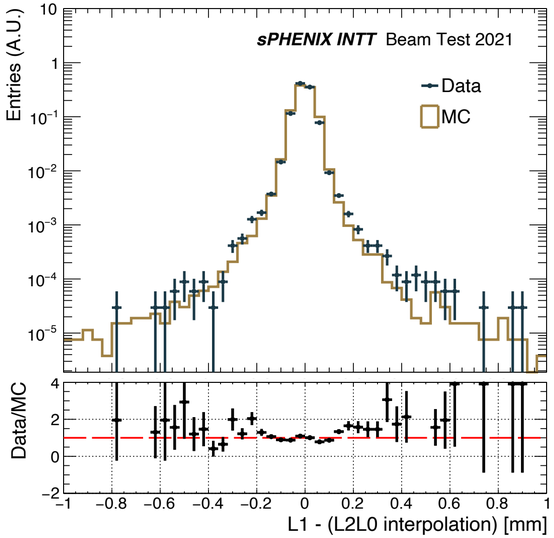
- Please raise hand if you have any questions and comments

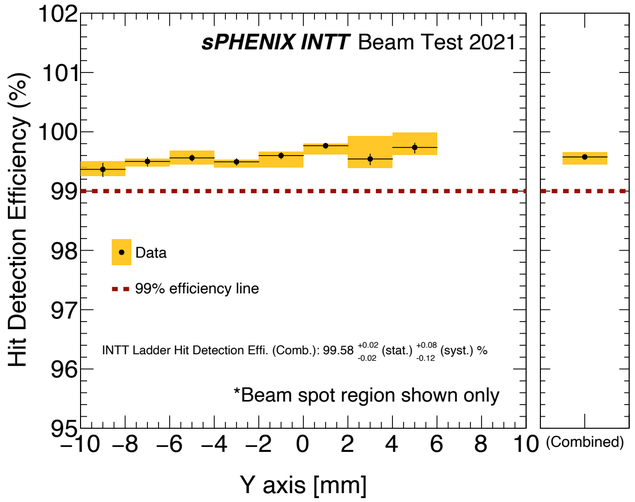
- I will be moving on preparing the paper draft if no major update in analysis method require
  - The draft will be largely based on our ELPH annual report

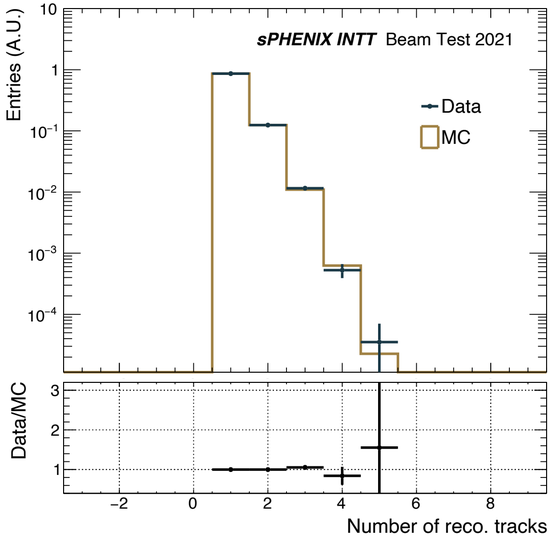
Plots and numbers request to be approved

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





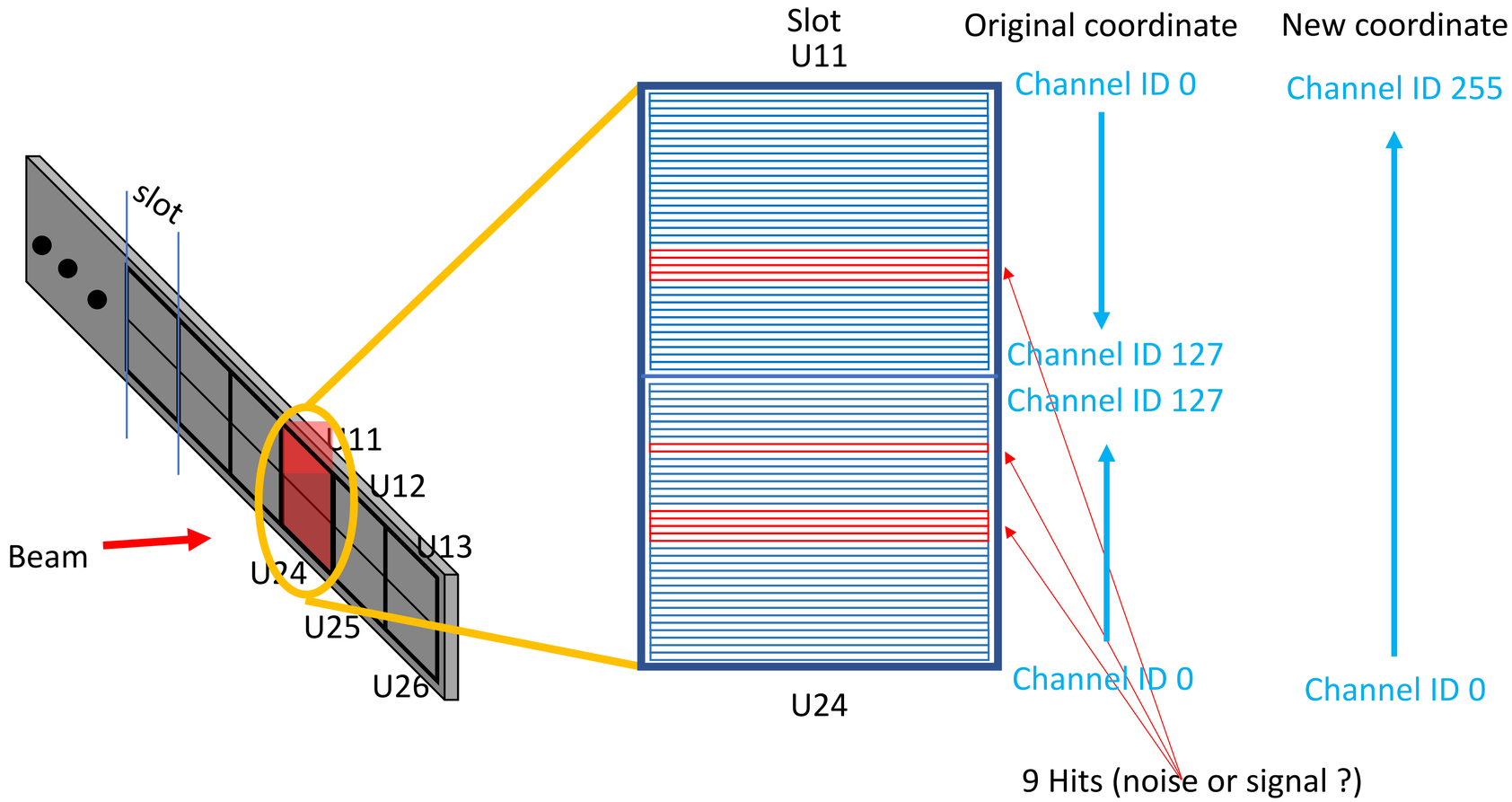




Back up

Clustering - 1

Tracking algorithm



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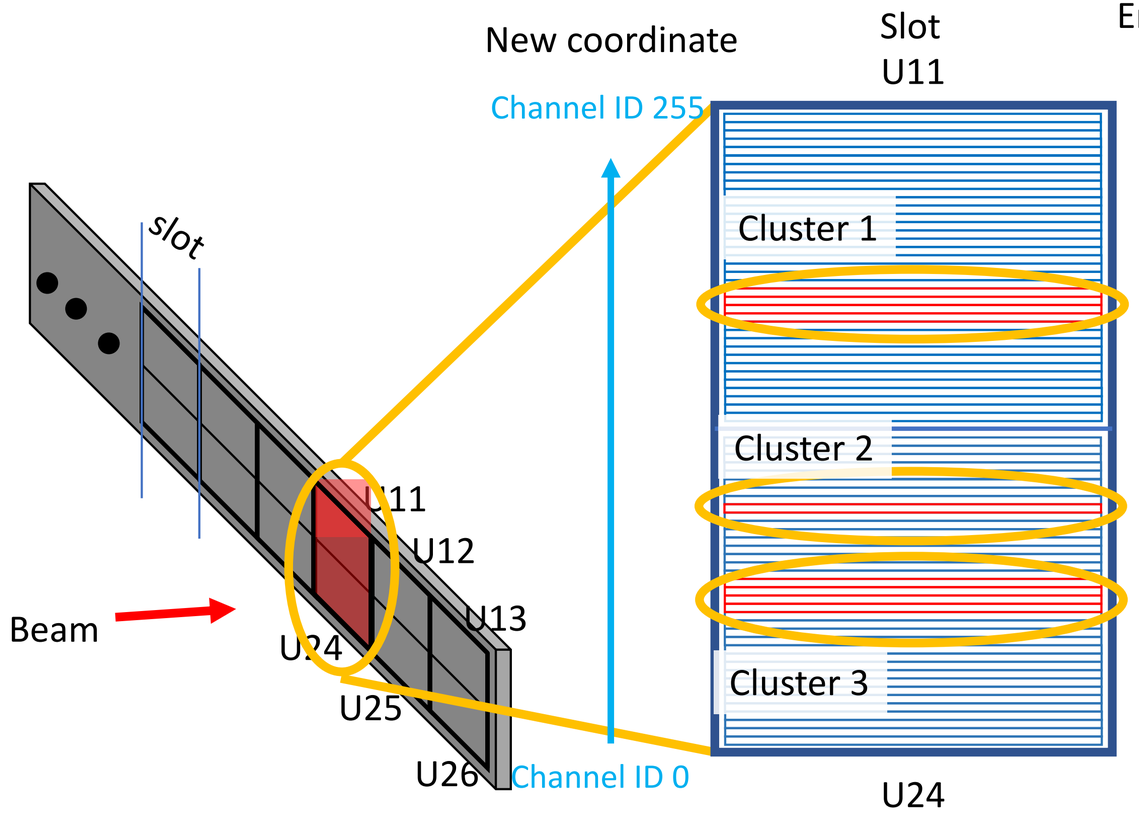
Clustering - 2

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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