D^{*+} Production at in pp collisions at $\sqrt{s} = 13.6$ TeV with Machine Learning Approach

ALICE-STAR-India
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Deependra Sharma (IITB)

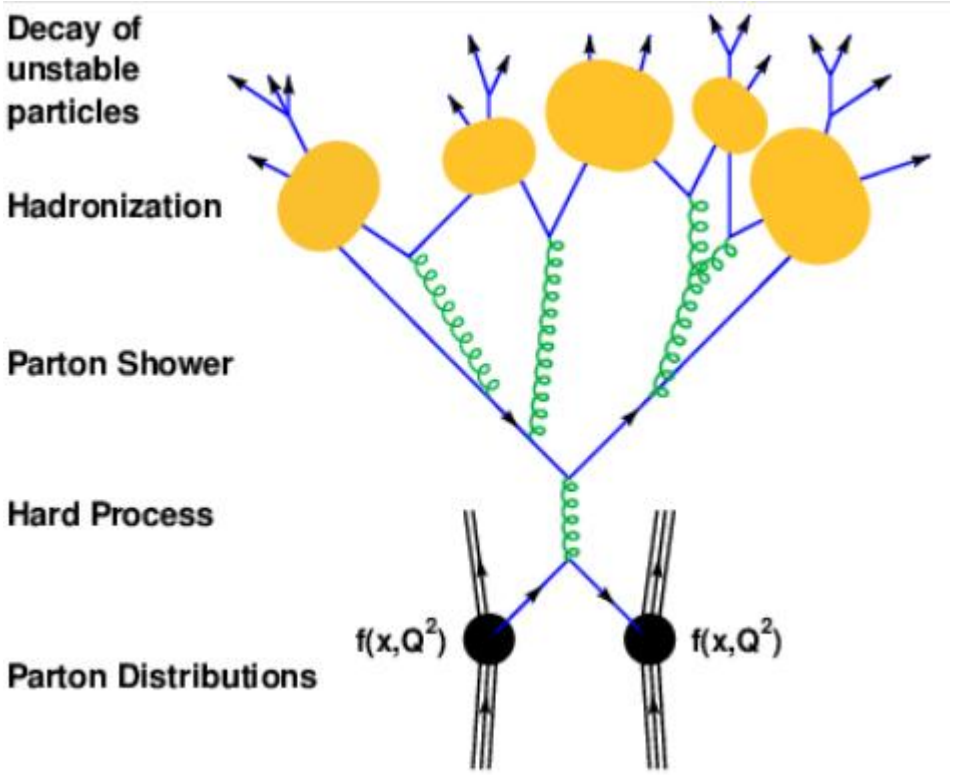
Prof. Sadhana Dash (IITB)

Outline

- Physics Motivation
- Previous Results
- ML Approach – XGBoost (Gradient Boosting Algorithm)
- Analysis Details
- Signal Extraction
- Spectra Calculation
- Systematics

Introduction (Primer to QCD)

- The measurement of production cross-section of D^{*+} meson in hadron collisions stands as an excellent laboratory for understanding QCD and hadronization mechanisms
- D^{*+} being a resonance candidate with extremely small lifetime hints towards production of very short lived massive resonance
- Monte Carlo studies to explain the experimentally measured spectra would help us put significant constraints on hadronization mechanisms



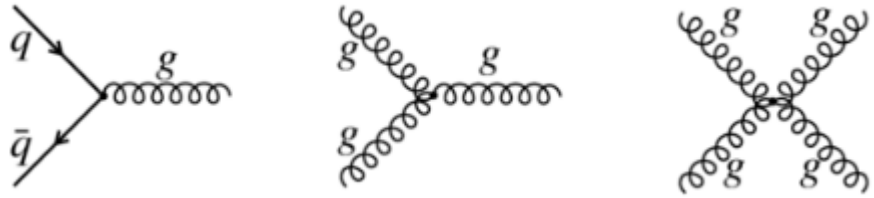
Production cross-section (QCD)

$$\sigma_{pp\to D^{*+}X} = \int dz\, f_1 \times f_2 \times \sigma_{Born} \times D_{q\to h}(z\, Q^2)$$

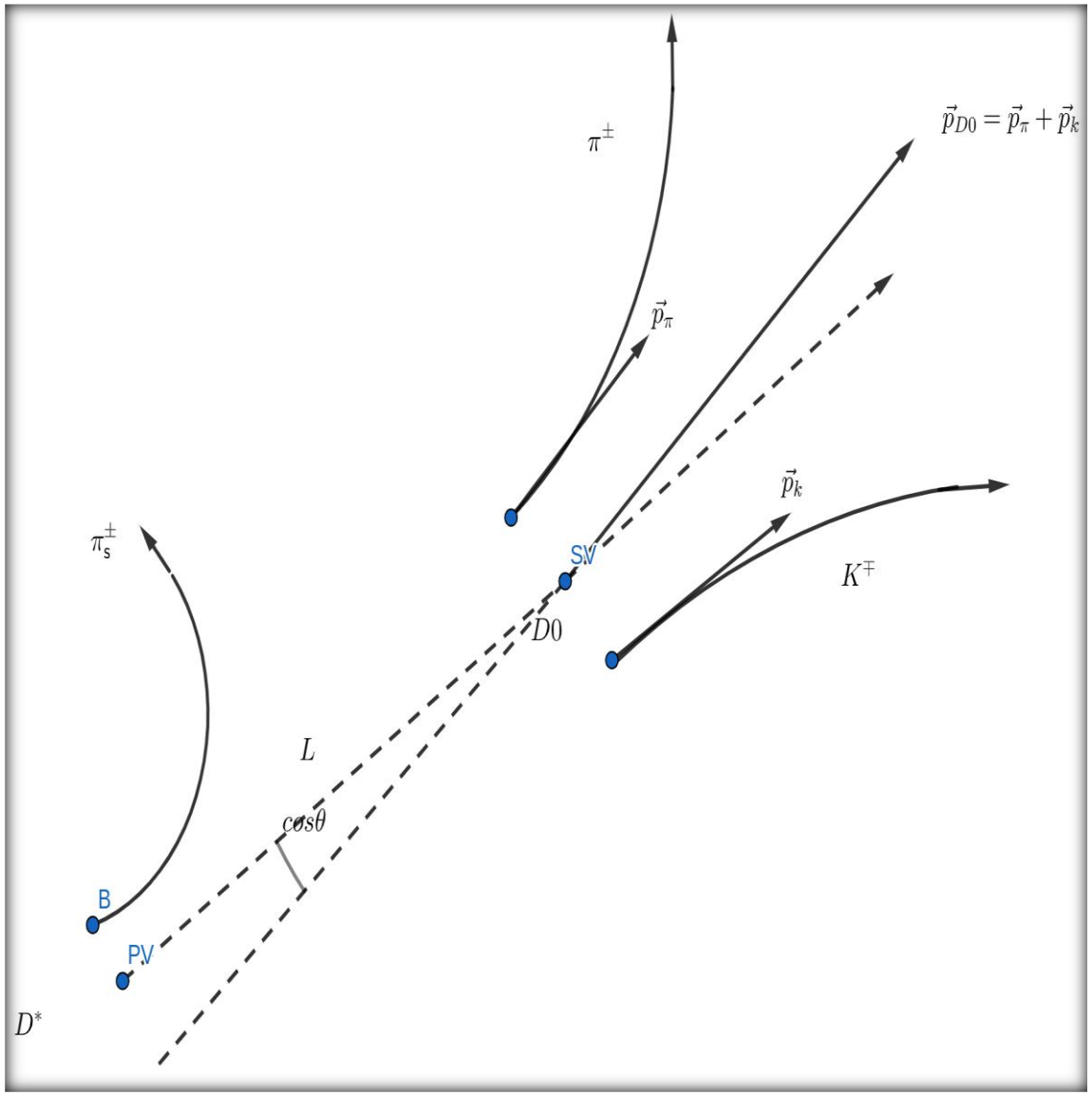
$$q\bar{q} \to c\bar{c}$$

$$gg \to c\bar{c}$$

Leading order process for production of charm quark



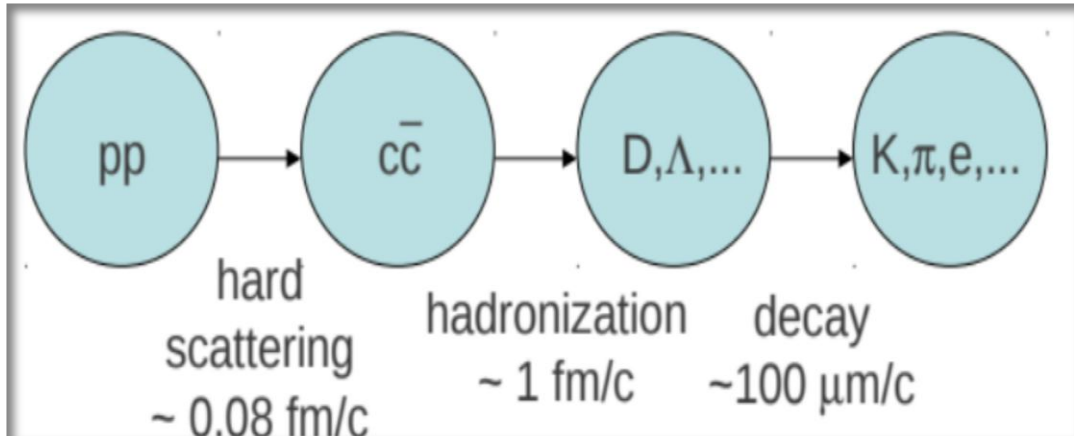
Decay Topology



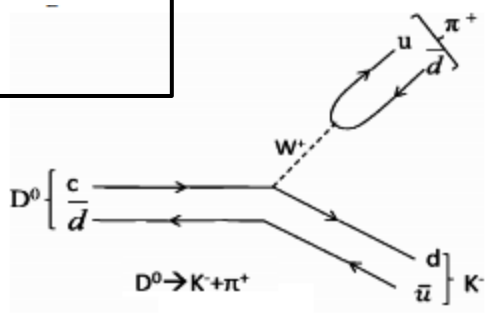
- $D^{*\pm} \rightarrow D^0 + \pi^{\pm}$
- $D^*(2.01\ GeV/c^2)$ & $D^0(1.86\ GeV/c^2)$

- **Motivation**
  - Open charm mesons are produced in earlier stage of collision, they carry the initial state information
  - They see full evolution of QGP, hence have equilibrium information of QGP.
  - Their production study with higher statistics, will give better model constraints.
  - Multiplicity dependence study will help in understanding the interplay between hard and soft physics.
- **Why in run 3?**
  - Improvement of the precision, with access to a much larger data sample
  - Aim to provide better constraints for model predictions

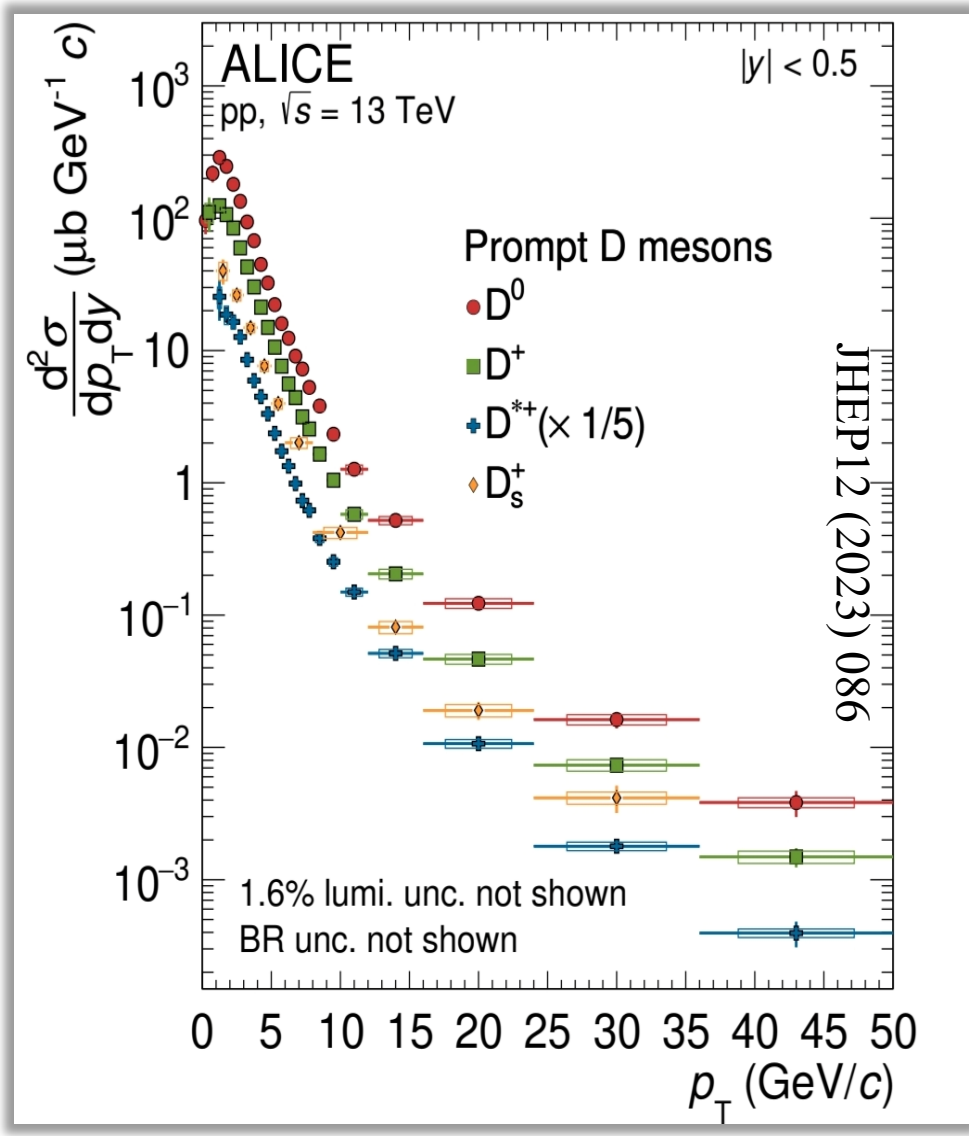
Some Previous Results



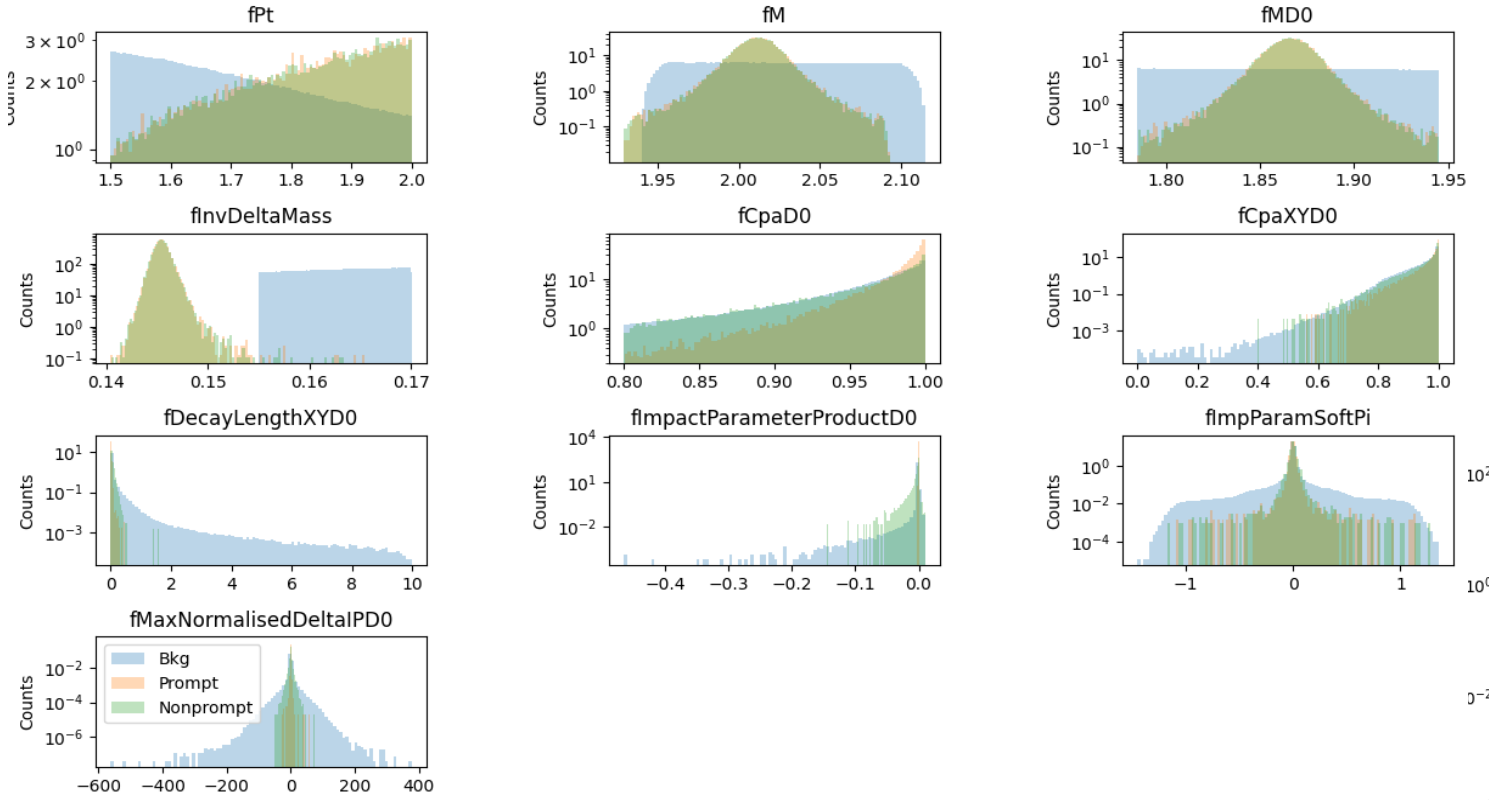
$m_{D^{*\pm}} - m_{D^0} = 145.4258 \pm 0.0017$ MeV
D*: $\Gamma = 83.4 \pm 1.8$ KeV , $c\tau \approx 2.368\ \mu m$
$D^0 : \Gamma = 1.605 \times 10^{-6}$ keV, $c\tau = 123.01\ \mu m$

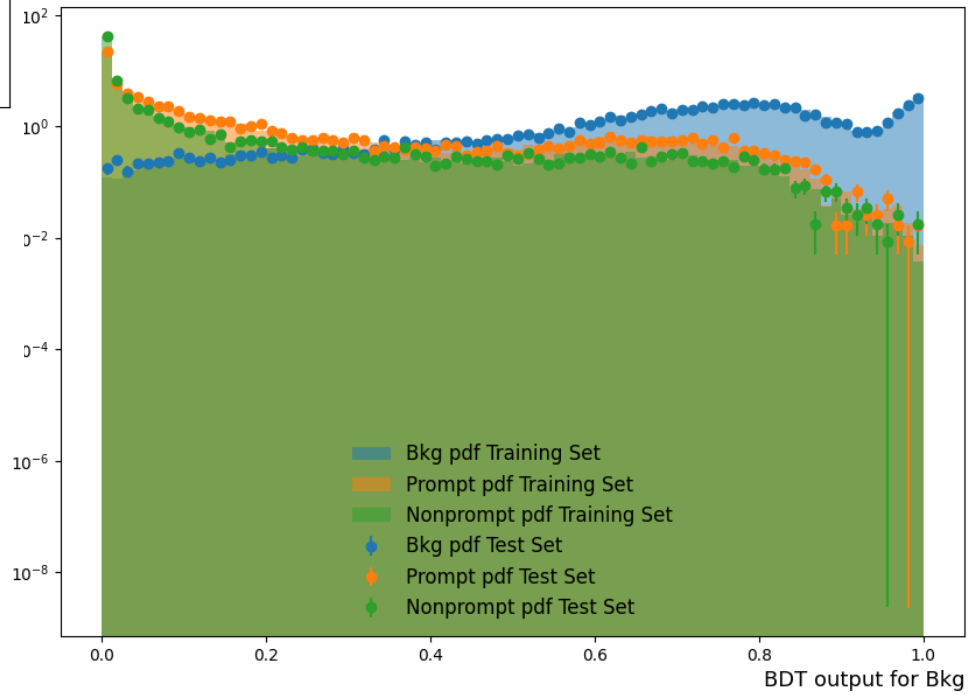


Decay Channel	BR (%)	Daughter Decay	$BR_{daughter}$ (%)
$D^{*\pm} \rightarrow D^0 + \pi_s^{\pm}$	67.7 ± 0.5	$D^0 \rightarrow K^- + \pi^+$	3.947 ± 0.030



D*+ meson selection- ML approach





Multi-class classification with XGBoost:

- Decay topology is used for training
- Invariant mass and p_T are not included in the training
- Prompt and non-prompt signals are taken from MC, combinatorial background is taken from sidebands in data

Analysis Details

- Data set for analysis: HF_LHC22o_pass7_minBias_2P3PDstar
- Model Training: HF_LHC24d3a
- Efficiency Calculation: HF_LHC24e3_All

- Event selection: $|V_z| < 10.0$ cm and sel8
- Selected events for analysis: 50B

- $p_T^{min} = 0.3$ GeV/c for all prongs except π_s
- $p_T^{min} = 0.1$ GeV/c for π_s
- $|\eta| < 0.8$
- PID cuts on D0 daughters

  for(0.15 GeV/$c < p_T < 5.0$ GeV/c)

  if($N\sigma_{TPC} < 3$ OR $N\sigma_{TOF} < 3$) Accepted;

  elseif($N\sigma_{TPC} < 5$ AND $N\sigma_{TOF} < 5$) Accepted;

Candidate selection Criteria

Parameter	D0 Candidates	Dstar Candidates
Product of daughter impact parameters (cm^2)	< 0.01	-
Cosine of pointing angle	> 0.8	-
Cosine of pointing angle in XY plane	> 0	-
Normalized decay length in XY plane	> 0	-
Chi2PCA of secondary vertex reconstruction	< 300	-
Impact parameter in XY plane (cm)	< 100	-
Normalized impact parameter of prongs	> 0	-
Decay length (cm)	$0.01 <$ decay length < 10	-
Decay length in XY plane (cm)	< 10	-
Impact parameter of soft pion (cm)	-	< 100
Normalized impact parameter of soft pion	-	< 1000
Transverse momentum of soft pion (GeV/c)	-	$0.1 < p_T < 100$
Invariant mass difference Δm (MeV/c^2)	-	within 100

Sample before BDT training

Input Feature	Range
Cosine of Pointing angle of D0	> 0.8
Cosine of Pointing angle in XY plane of D0	> 0.0
Decay length in XY plane of D0	> 0.0
Impact parameter product of D0	> 0.0
Impact parameter of soft pion	> 0.0
Normalized impact parameter of D0	> 0.0

Signal Extraction

$$f(x;\mu,\sigma,\alpha_L,n_L,\alpha_R,n_R) = \begin{cases} A_L \cdot (B_L - \frac{x-\mu}{\sigma})^{-n_L}, & \text{for } \frac{x-\mu}{\sigma} < -\alpha_L \\ \exp(-\frac{(x-\mu)^2}{2\sigma^2}), & \text{for } -\alpha_L \leqslant \frac{x-\mu}{\sigma} \leqslant \alpha_R \\ A_R \cdot (B_R + \frac{x-\mu}{\sigma})^{-n_R}, & \text{for } \frac{x-\mu}{\sigma} > \alpha_R \end{cases}$$

with

$$A_{L/R} = \left(\frac{n_{L/R}}{|\alpha_{L/R}|}\right)^{n}_{L/R} \cdot \exp\left(-\frac{|\alpha_{L/R}|^2}{2}\right)$$

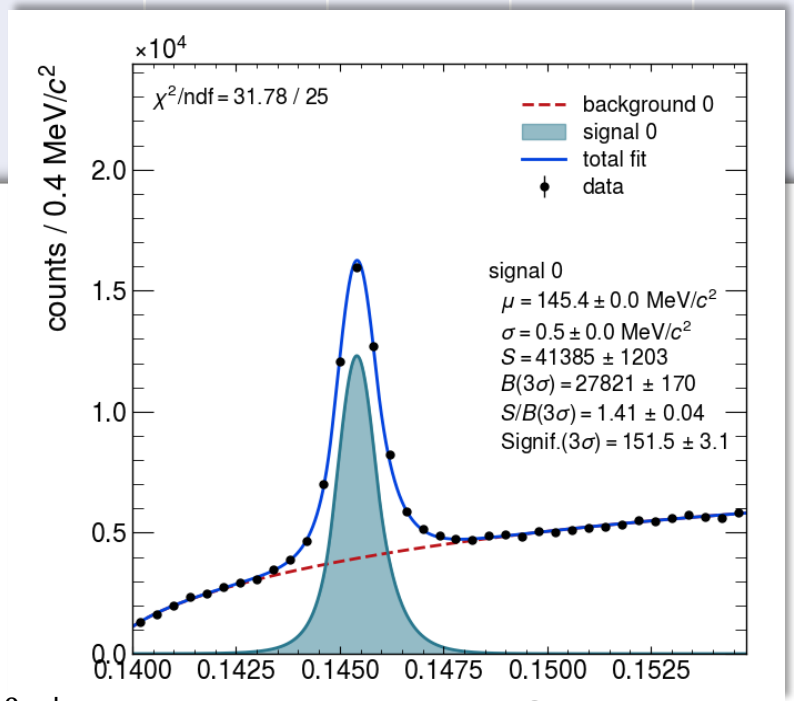
$$B_{L/R} = \frac{n_{L/R}}{|\alpha_{L/R}|} - |\alpha_{L/R}|$$

Fixed Selection cut for Background score for different p_T bins after optimization of working point

SR	1	2	3	4	5	6
p_T (GeV/c)	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	> 4.0
BDT cut on Background	0.02	0.2	0.2	0.2	0.2	0.4

$$f_{\text{background}}(x) = N_{\text{background}} \times \text{Exp}(x,\lambda)$$

$$\text{Exp}(x,\lambda) = \begin{cases} (x-M_\pi)^m \exp(c_1(x-M_\pi) + c_2(x-M_\pi)^2 + c_3(x-M_\pi)^3) & \text{for } p_T < 10.0 \text{ GeV/c} \\ (x-M_\pi)^m \exp(\lambda(x-M_\pi)) & \text{for } p_T > 10.0 \text{ GeV/c} \end{cases}$$



$\Delta M_{inv}^{D^0\pi^+}$ GeV/c² (5.5 GeV/c< p_T < 6.0 GeV/c)

Spectra Calculation

$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{2} f_{prompt}(p_T) . \frac{N_{raw}^{D^{*\pm}}(p_T)}{(Acc\ X\ \epsilon)_{prompt}(p_T)} . \frac{1}{\Delta p_T . BR . L_{int} 2y_{fid}(p_T)}$$

From invariant mass fit

$L_{int} = 844941\ \mu b^{-1}$

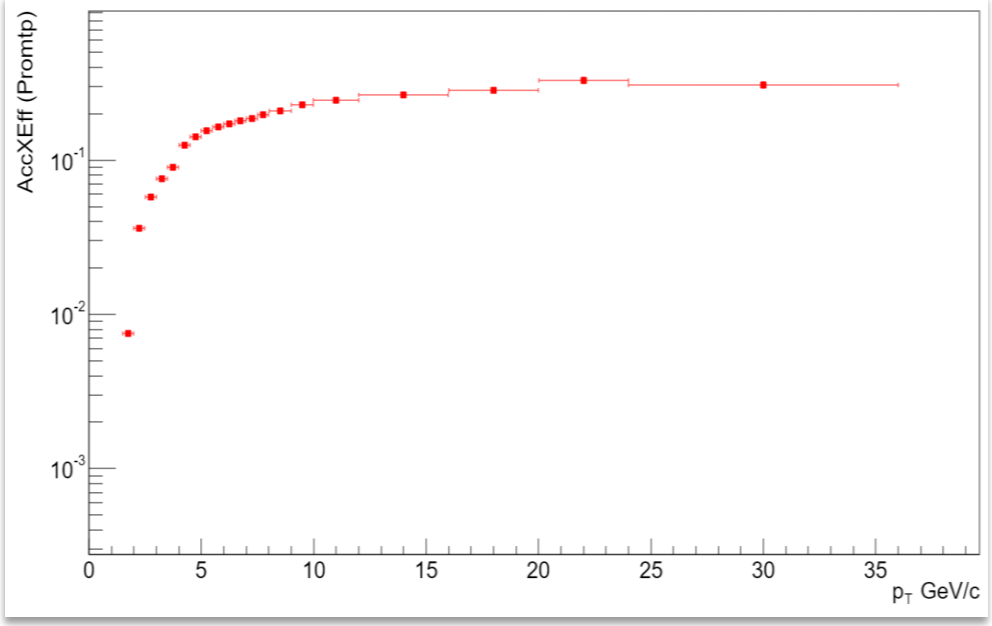
From cut variation method

Reco(MC)/Gen(MC)

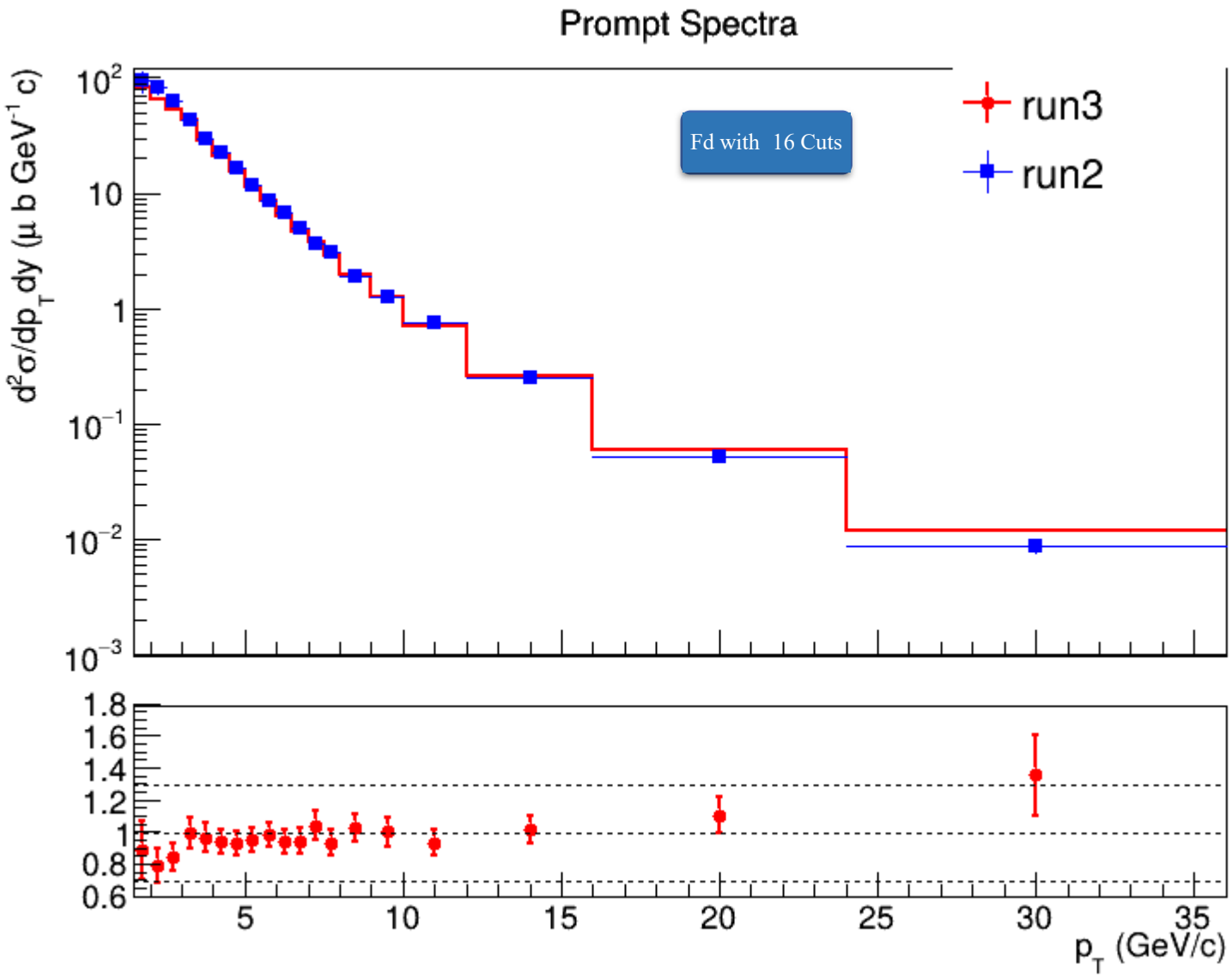
Decay Channel	BR (%)	Daughter Decay	$BR_{daughter}$ (%)
$D^{*\pm} \rightarrow D^0 + \pi_s^{\pm}$	67.7 ± 0.5	$D^0 \rightarrow K^- + \pi^+$	3.947 ± 0.030

- with 17 sets of cuts on non-prompt BDT score

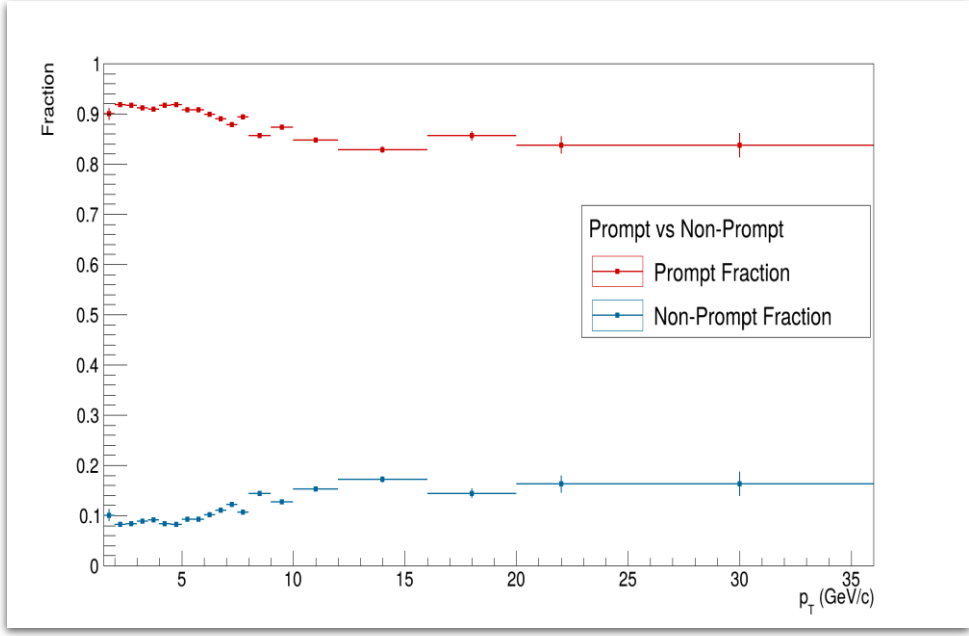
[0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9]



Prompt Spectra of D*+



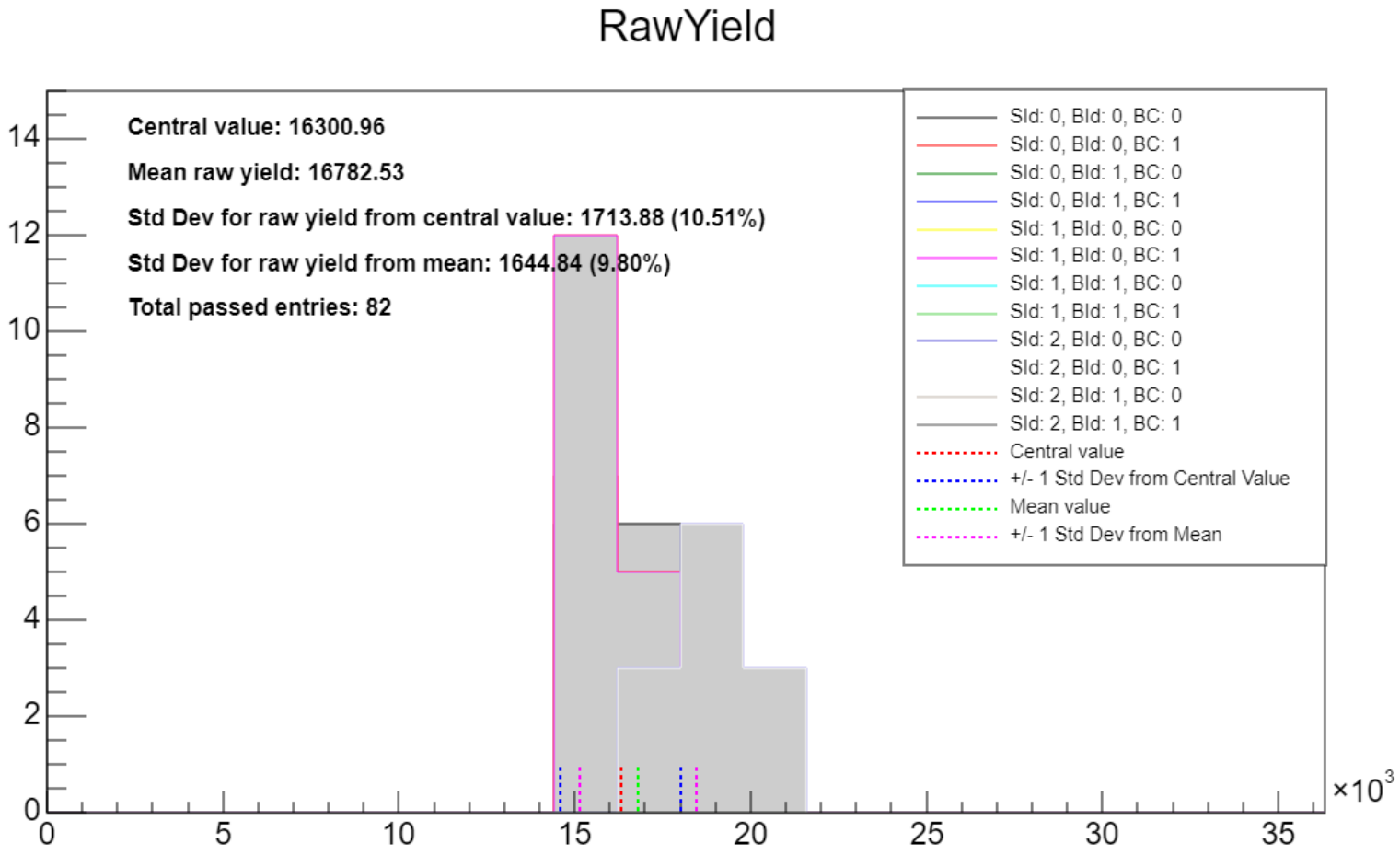
1. Minimum bias prompt spectra of D^{*+} in run-3 is nearly equal to that in run-2. Ratio is flat and unity up to mid p_T region.
2. Systematics corrections are in progress.



Run2 spectra -https://www.hepdata.net/record/ins2697877

Systematic on Raw Yield-3

$1.5 < p_T < 2.0$ GeV/c

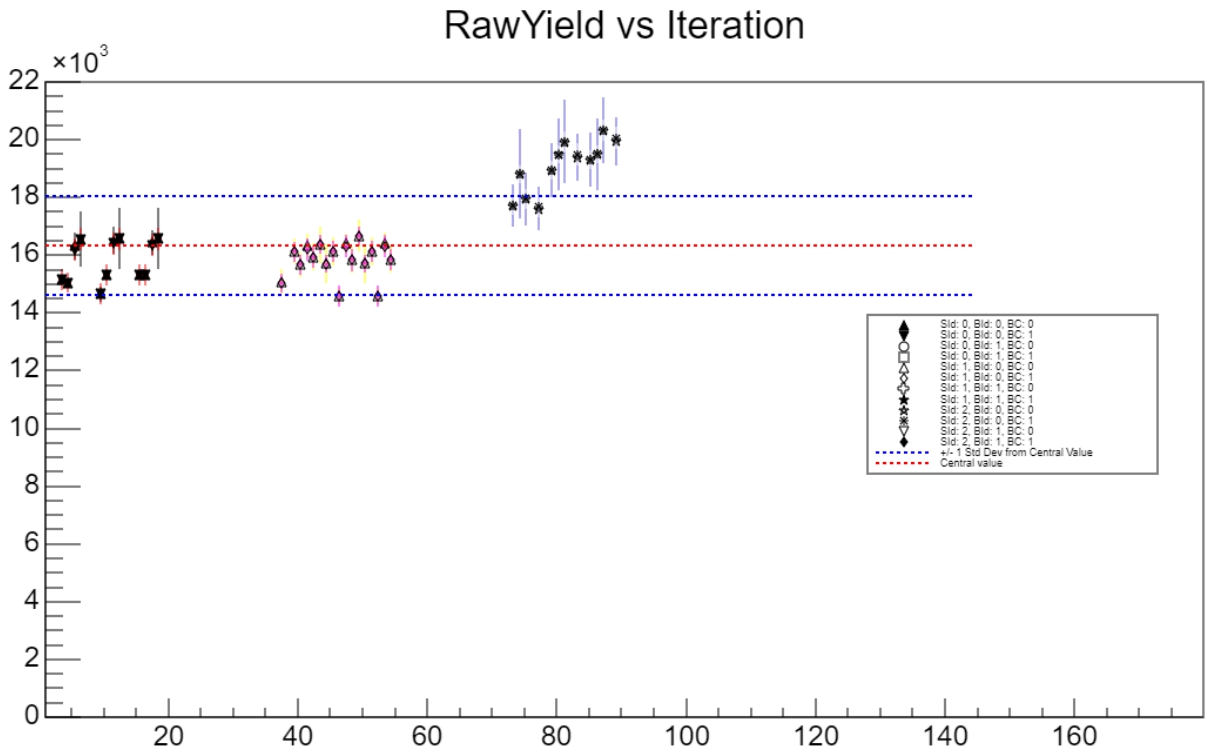


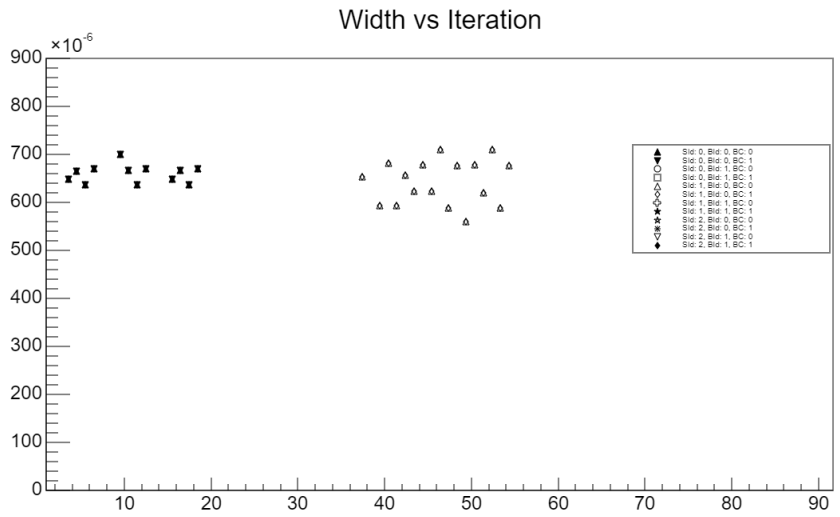
- Signal
  - Double Side Crystal Ball - 0
  - Generalized Gaussian with exponential tail - 1
  - Double Gaussian - 2
- Background
  - PowExpExt (m, c_1, c_2, c_3)
  - PowExp $(m = 0.5, c_2 = 0, . c_3 = 0.)$
- Rebin factor : 1,2
- Bin Counting On and OFF
- Different set of fit ranges

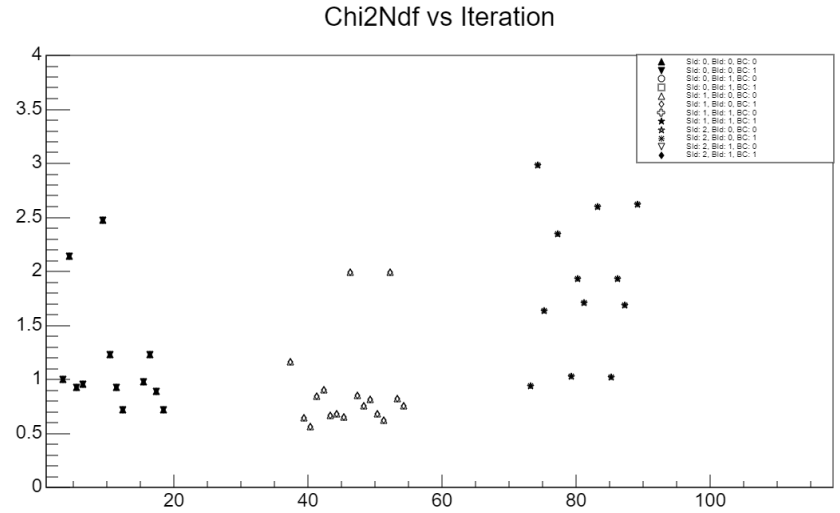
- $\chi^2/\text{ndf} < 3.0$
- All parameters are left free

Systematic on Raw Yield-3

$1.5 < p_T < 2.0$ GeV/c





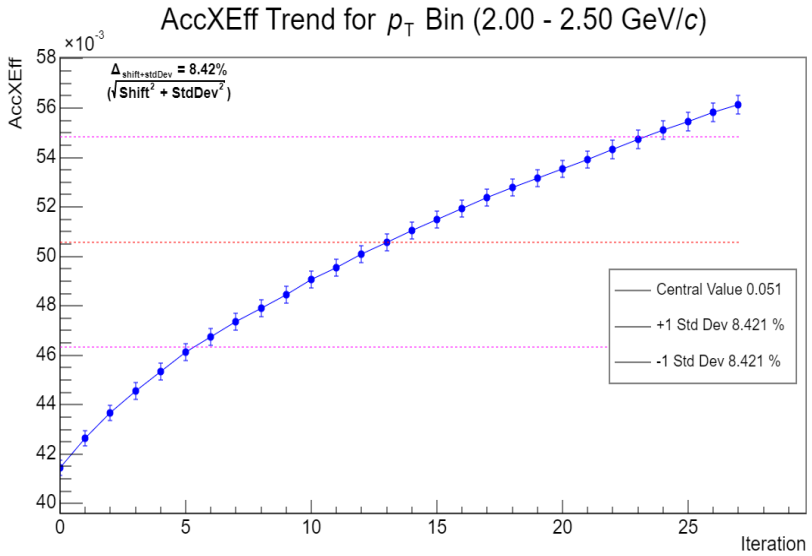


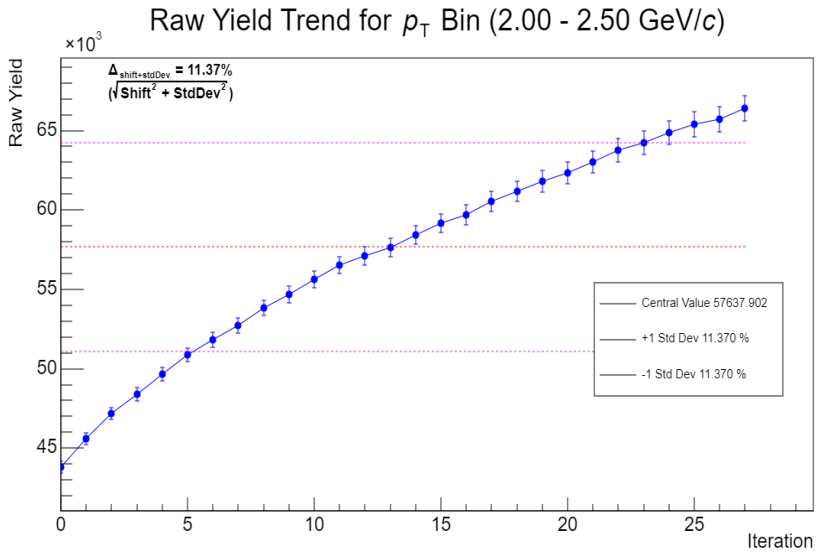
Systematic on Raw Yield-Table

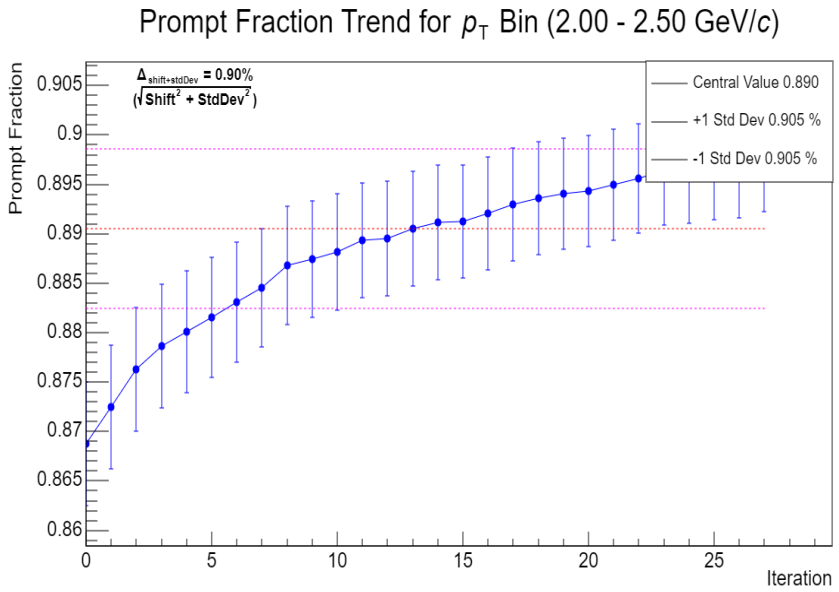
p_T Bin (GeV/ c)	Measured Systematics (%)	Assigned Systematics (%)
1.5 - 2.0	10.73	10
2.0 - 2.5	7.13	7
2.5 - 3.0	3.70	6
3.0 - 3.5	6.60	5
3.5 – 4.0	1.59	3
4.0 – 4.5	2.47	3
4.5 – 5.0	1.66	3
5.0 – 5.5	2.29	3
5.5 - 6.0	2.17	3
6.0 – 6.5	1.80	3

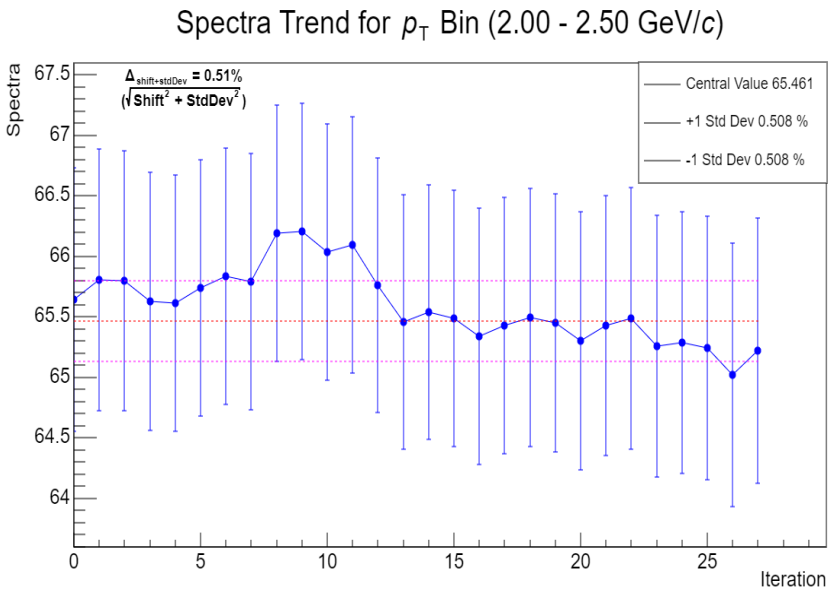
p_T Bin (GeV/ c)	Measured Systematics (%)	Assigned Systematics (%)
6.5 – 7.0	2.72	3
7.0 - 7.5	2.57	3
7.5 - 8.0	4.24	3
8.0 – 9.0	2.58	3
9.0 - 10.0	3.06	3
10.0 – 12.0	1.69	3
12.0 – 16.0	2.70	3
16.0 – 20.0	5.41	6
20.0 – 24.0	10.18	10
24.0 – 36.0	12.56	13

Systematic on BDT Selection -4









Background BDT Score cuts

- **Central value**: 0.2,
- **Bin width of THnSparse**: 0.01,
- **BDT_variation step size**: 0.01
- [0.07, 0.08, 0.09, 0.1,… , 0.34]
- Signal Parameters were fixed to central values

Systematic on BDT Selection - Table

p_T Bin (GeV/ c)	Measured Systematics (%)	Assigned Systematics (%)
1.5 - 2.0	1.58	1
2.0 - 2.5	0.51	1
2.5 - 3.0	0.55	1
3.0 - 3.5	13.21	1
3.5 – 4.0	1.88	1
4.0 – 4.5	1.24	1
4.5 – 5.0	0.39	1
5.0 – 5.5	0.29	1
5.5 - 6.0	0.53	1
6.0 – 6.5	0.76	1

Problematic, need to revisit the procedure (Backup)

p_T Bin (GeV/ c)	Measured Systematics (%)	Assigned Systematics (%)
6.5 – 7.0	0.95	1
7.0 - 7.5	1.00	1
7.5 - 8.0	0.36	1
8.0 – 9.0	0.35	1
9.0 - 10.0	1.19	1
10.0 – 12.0	1.20	1
12.0 – 16.0	0.94	1
16.0 – 20.0	0.89	1
20.0 – 24.0	2.00	1
24.0 – 36.0	7.18	1

Systematic on Tracking (from $D_{s1}^{+} \rightarrow$ Analysis)

	2-3	3-4	4–5	5-6	6-8	8-12	12-24
Raw yield extraction	3	3	3	3	3	3	3
BDT cut	12	12	12	12	12	12	12
Single track selections	12	12	7	7	5	3	2
Scaled with 3/4	**9**	**9**	**5.2**	**5.2**	**3.8**	**2.2**	**1.5**

Assigned

1.5 - 2.0	**2.0 - 2.5**	**2.5 - 3.0**	**3.0 - 3.5**	**3.5 – 4.0**	**4.0 – 4.5**	**4.5 – 5.0**	**5.0 – 5.5**	**5.5 - 6.0**	**6.0 – 6.5**
9	9	9	9	9	5	5	5	5	4
6.5 - 7.0	**7.0 - 7.5**	**7.5 - 8.0**	**8.0 – 9.0**	**9.0 – 10.0**	**10.0 – 12.0**	**12.0 – 16.0**	**16.0 – 20.0**	**20.0 - 24.0**	**24.0 – 36.0**
4	4	4	2	2	2	2	1	1	1

Systematic on prompt fraction

- with 9 sets of cuts [0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9] for all p_T bins
  - Uniform, Step Size: 0.1
  - Min: 0.1 & Max: 0.9

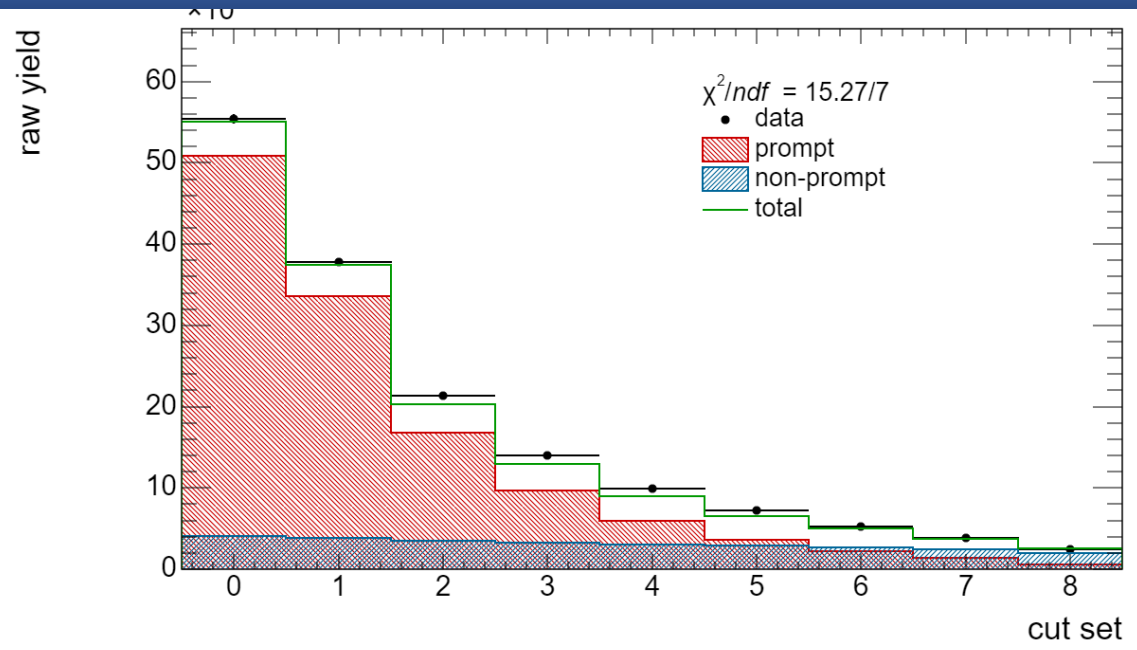
- with 20 sets of cuts [0.40, 0.42, 0.44, 0.46, 0.48, 0.50, 0.52 ,0.54, 0.56, 0.58, 0.60, 0.62, 0.64, 0.68, 0.70, 0.72, 0.74, 0.76, 0.78, 0.80] for all p_T bins
  - Uniform, Step Size: 0.02
  - Min: 0.40 & Max: 0.80

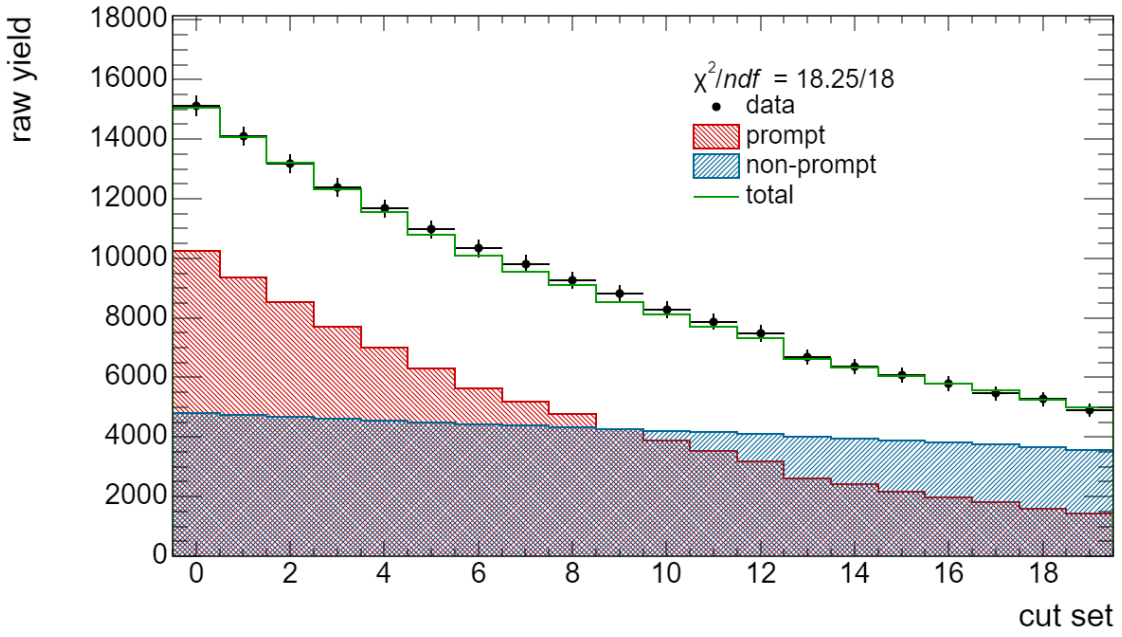
- with 17 sets of cuts [0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9] for all p_T bins
  - Uniform, Step Size: 0.05 Default
  - Min : 0.1 & Max: 0.9

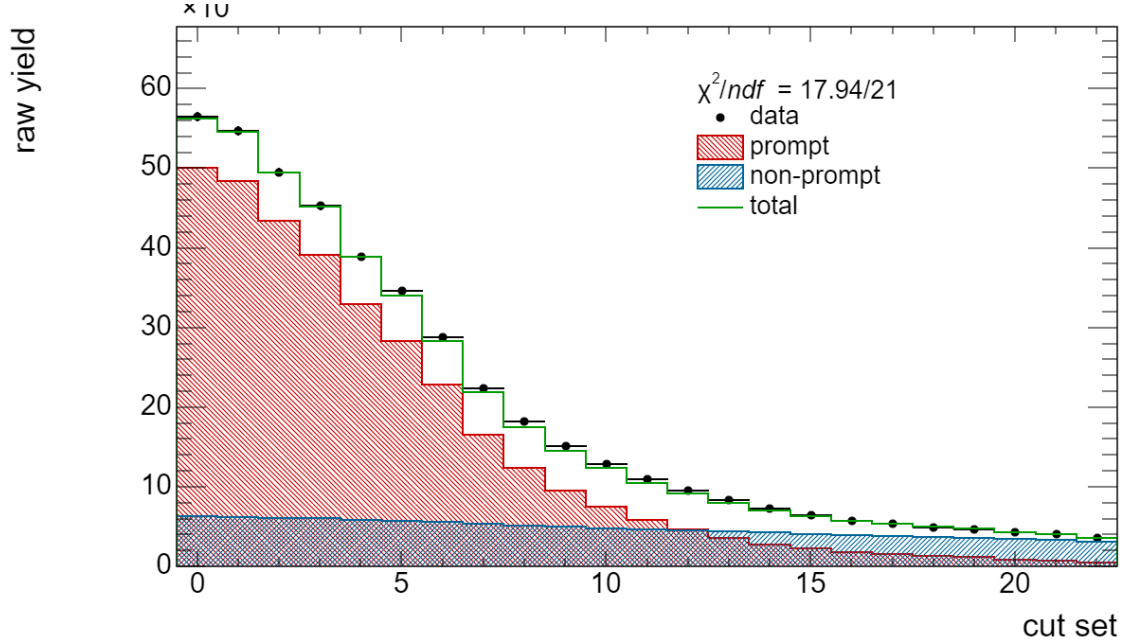
- With 23 sets of cuts [0.1, 0.12, 0.15, 0.17, 0.2, 0.22, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.77, 0.8, 0.82, 0.85,0.87, 0.9] for all p_T bins
  - More looser & tighter cuts

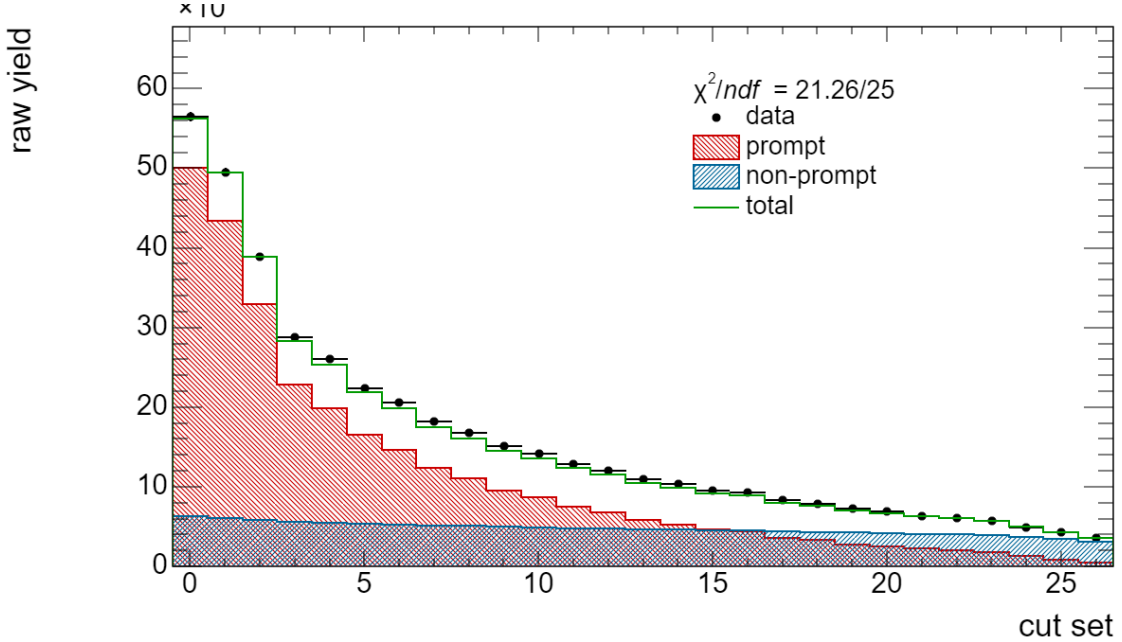
- With 27 sets of cuts [0.1, 0.15, 0.2, 0.25,0.27, 0.3,0.32, 0.35,0.37, 0.4,0.42, 0.45, 0.47,0.5, 0.52,0.55, 0.57, 0.6, 0.62, 0.65,0.67, 0.7,0.72, 0.75, 0.8, 0.85, 0.9] for all p_T bins
  - More medium cuts

Systematic on prompt fraction

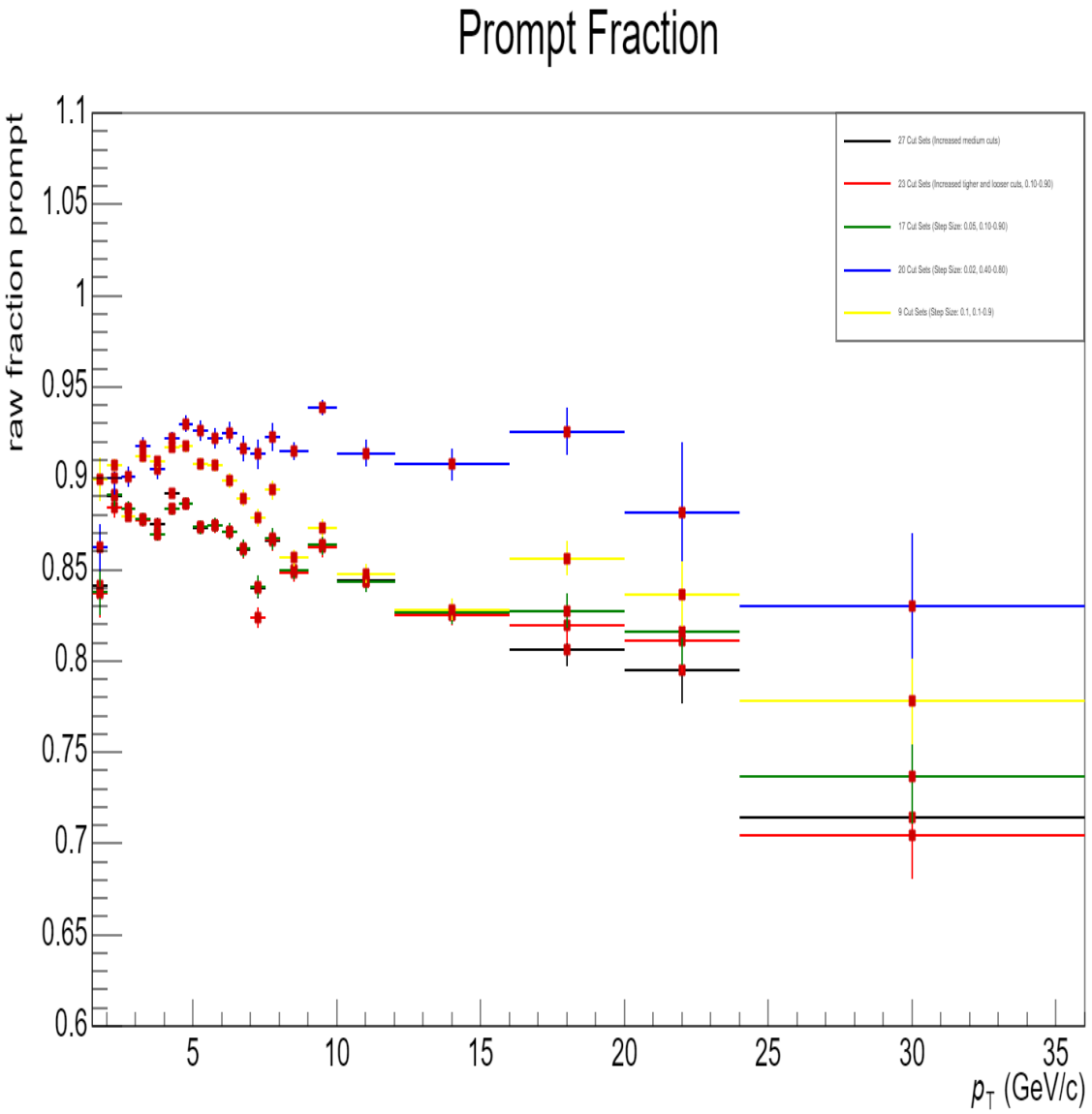


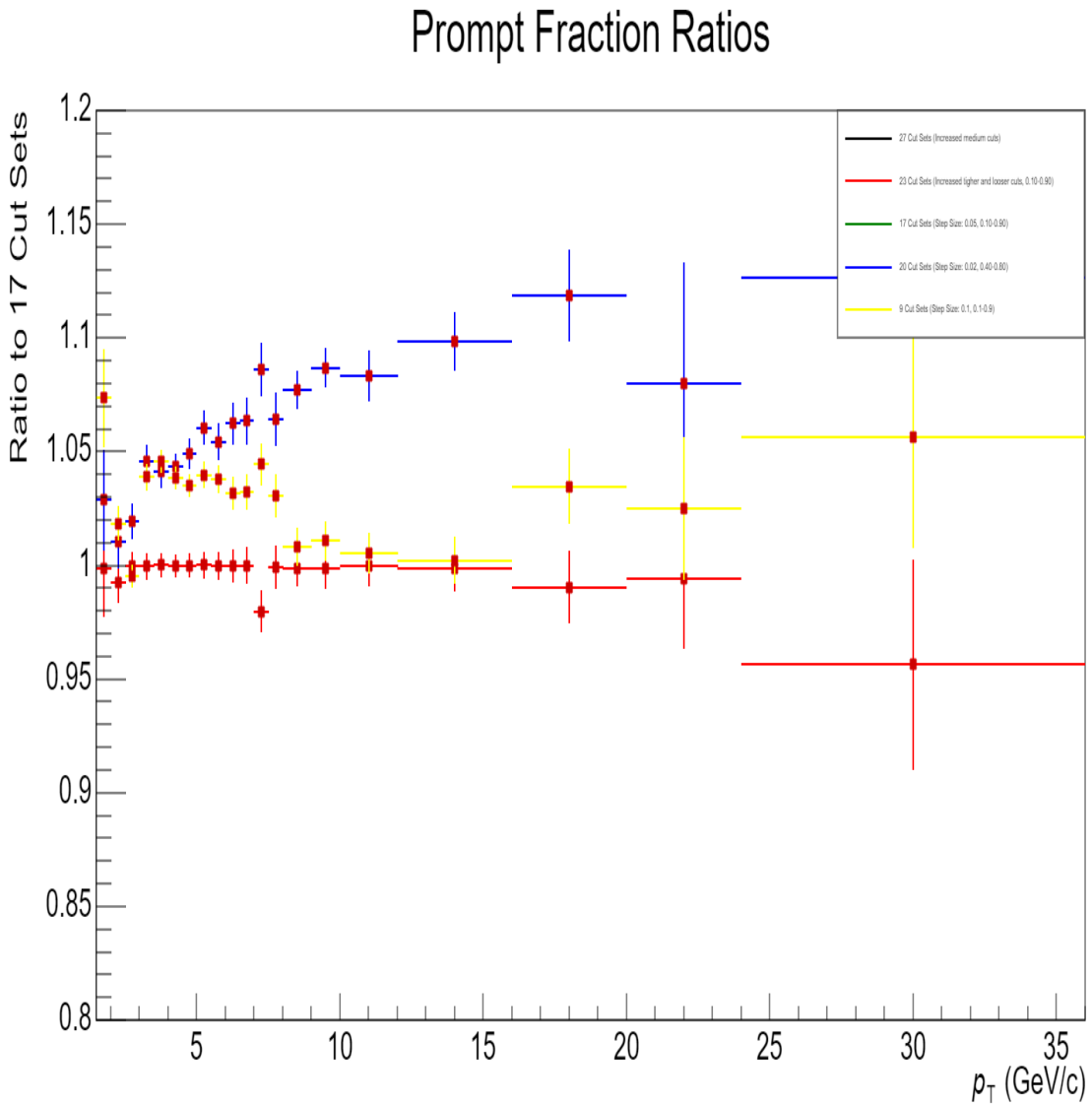






Systematic on prompt fraction

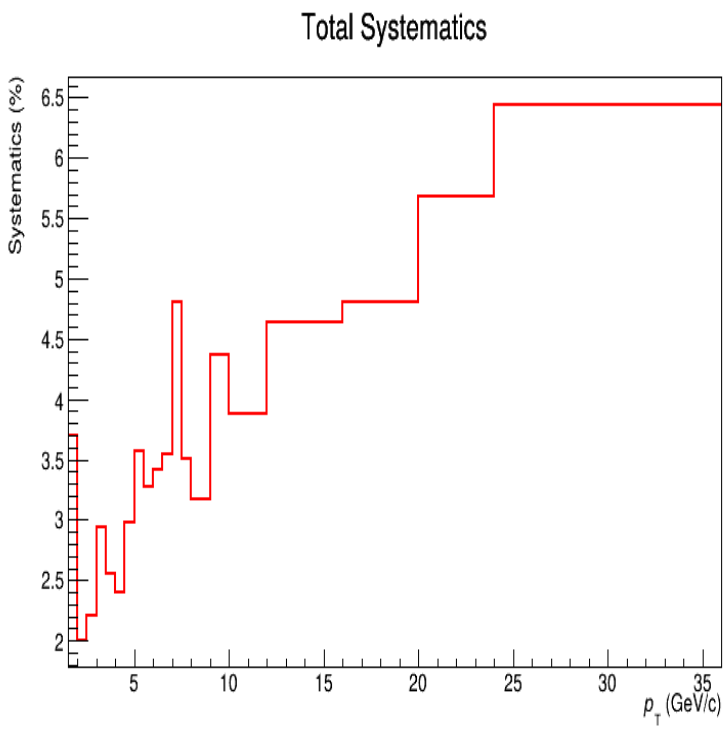




Systematic on prompt fraction

p_T Bin (GeV/ c)	Total Systematics (%) $\sqrt{(\text{Shift})^2 + (\text{StdDev})^2}$	Assigned Systematics (%)
1.5 - 2.0	3.70	3
2.0 - 2.5	2.00	3
2.5 - 3.0	2.21	3
3.0 - 3.5	2.94	3
3.5 – 4.0	2.55	3
4.0 – 4.5	2.40	3
4.5 – 5.0	2.97	3
5.0 – 5.5	3.57	3
5.5 - 6.0	3.27	3
6.0 – 6.5	3.41	3

p_T Bin (GeV/ c)	Total Systematics (%)	Assigned Systematics (%) $\sqrt{(\text{Shift})^2 + (\text{StdDev})^2}$
6.5 – 7.0	3.54	4
7.0 – 7.5	4.80	4
7.5 – 8.0	3.51	4
8.0 – 9.0	3.17	4
9.0 – 10.0	4.36	4
10.0 – 12.0	3.88	4
12.0 – 16.0	4.64	5
16.0 – 20.0	4.80	5
20.0 – 24.0	5.68	5
24.0 – 36.0	6.44	6



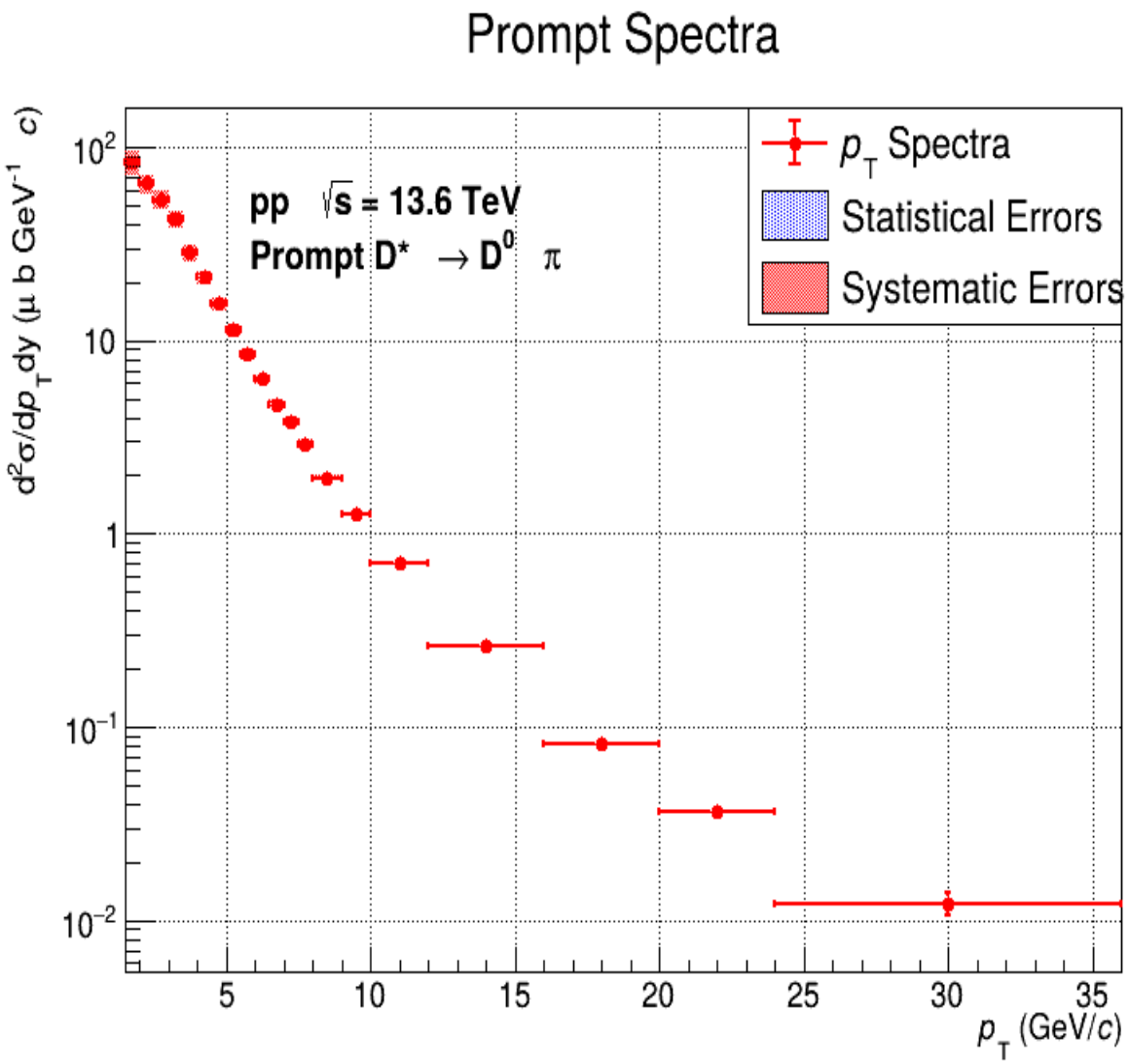
Systematic uncertainties summary

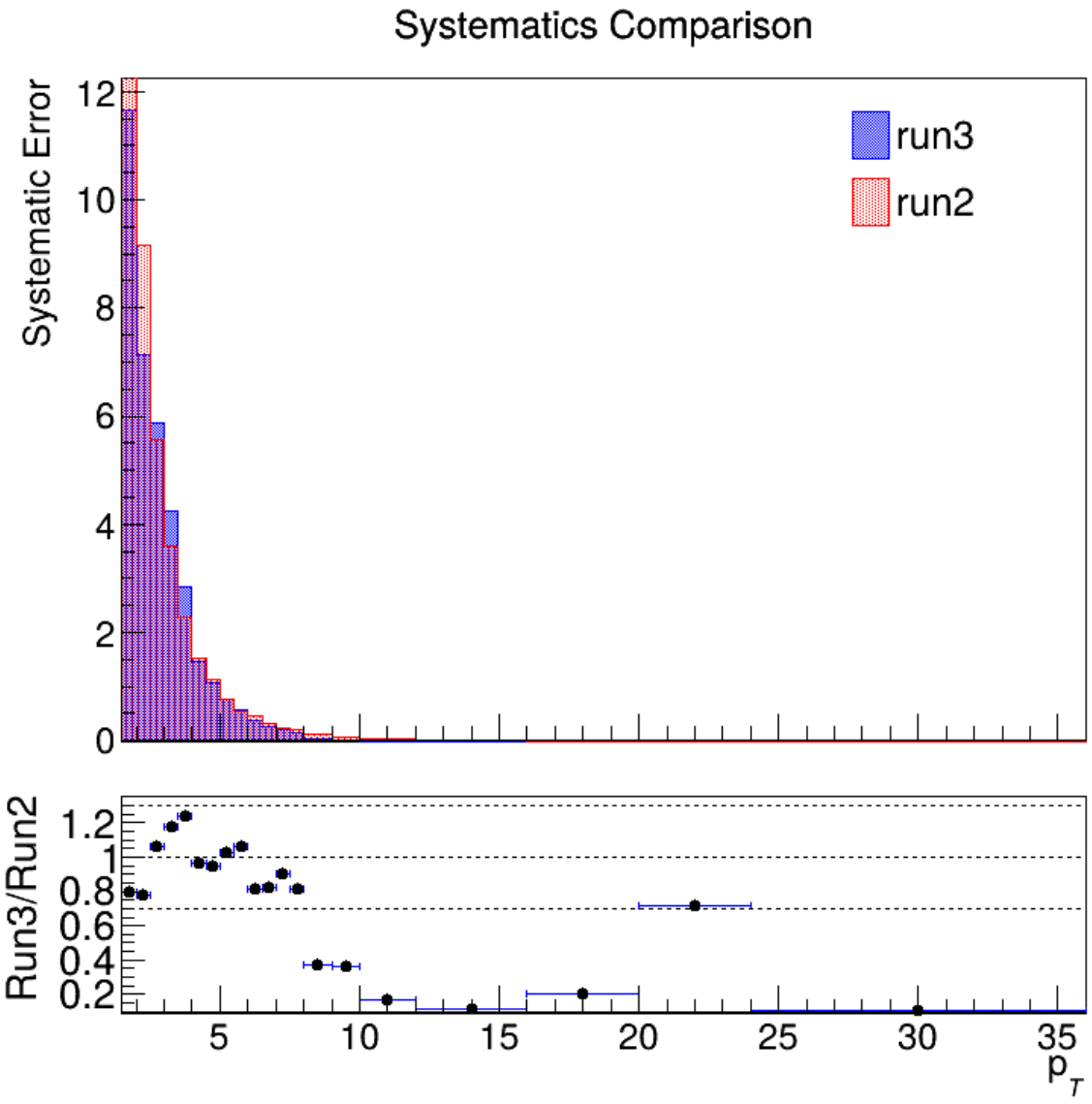
	1.5 - 2.0	2.0 - 2.5	2.5 - 3.0	3.0 - 3.5	3.5 – 4.0	4.0 – 4.5	4.5 – 5.0	5.0 – 5.5	5.5 - 6.0	6.0 – 6.5
Raw yield extraction	10	7	6	5	3	3	3	3	3	3
BDT Selection	1	1	1	1	1	1	1	1	1	1
Prompt Fraction	3	3	3	3	3	3	3	3	3	3
Single Track Selection	9	9	9	9	9	5	5	5	5	4
Luminosity	10	10	10	10	10	10	10	10	10	10
BR $D^0 \rightarrow K^- + \pi^+$	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
BR $D^{*\pm} \rightarrow D^0 + \pi_s^{\pm}$	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Total (wo L,BR)	14	11	11	10	10	7	7	7	7	6
Total	17	16	15	15	14	12	12	12	12	12

Systematic uncertainties summary

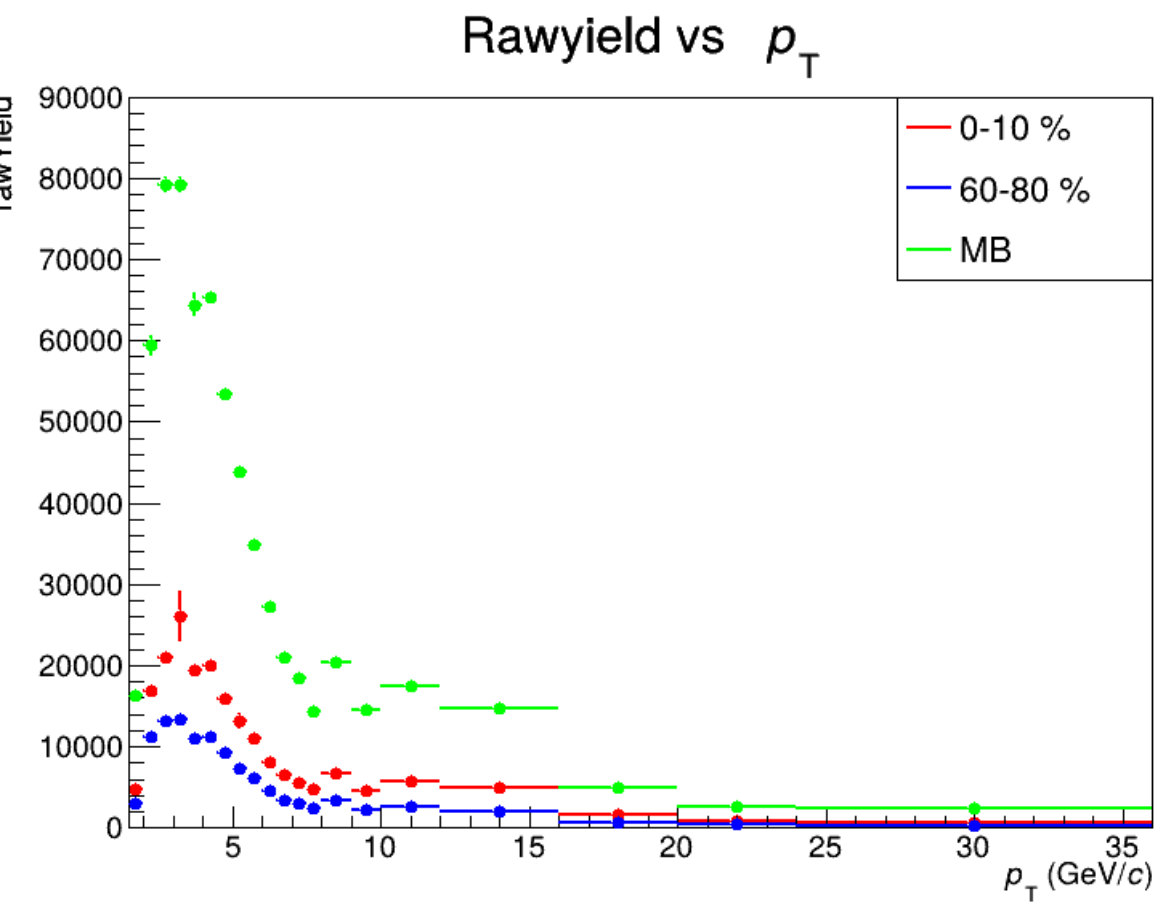
	6.5 - 7.0	7.0 - 7.5	7.5 - 8.0	8.0 – 9.0	9.0 – 10.0	10.0 – 12.0	12.0 – 16.0	16.0 – 20.0	20.0 - 24.0	24.0 – 36.0
Raw yield extraction	3	3	3	3	3	3	3	6	10	13
BDT Selection	1	1	1	1	1	1	1	1	1	1
Prompt Fraction	4	4	4	4	4	4	5	5	5	6
Single Track Selection	4	4	4	2	2	2	2	1	1	1
Luminosity	10	10	10	10	10	10	10	10	10	10
BR $D^0 \rightarrow K^- + \pi^+$	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
BR $D^{*\pm} \rightarrow D^0 + \pi_s^{\pm}$	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Total (wo L,BR)	6	6	6	5	5	5	6	8	11	14
Total	12	12	12	11	11	11	12	13	15	18

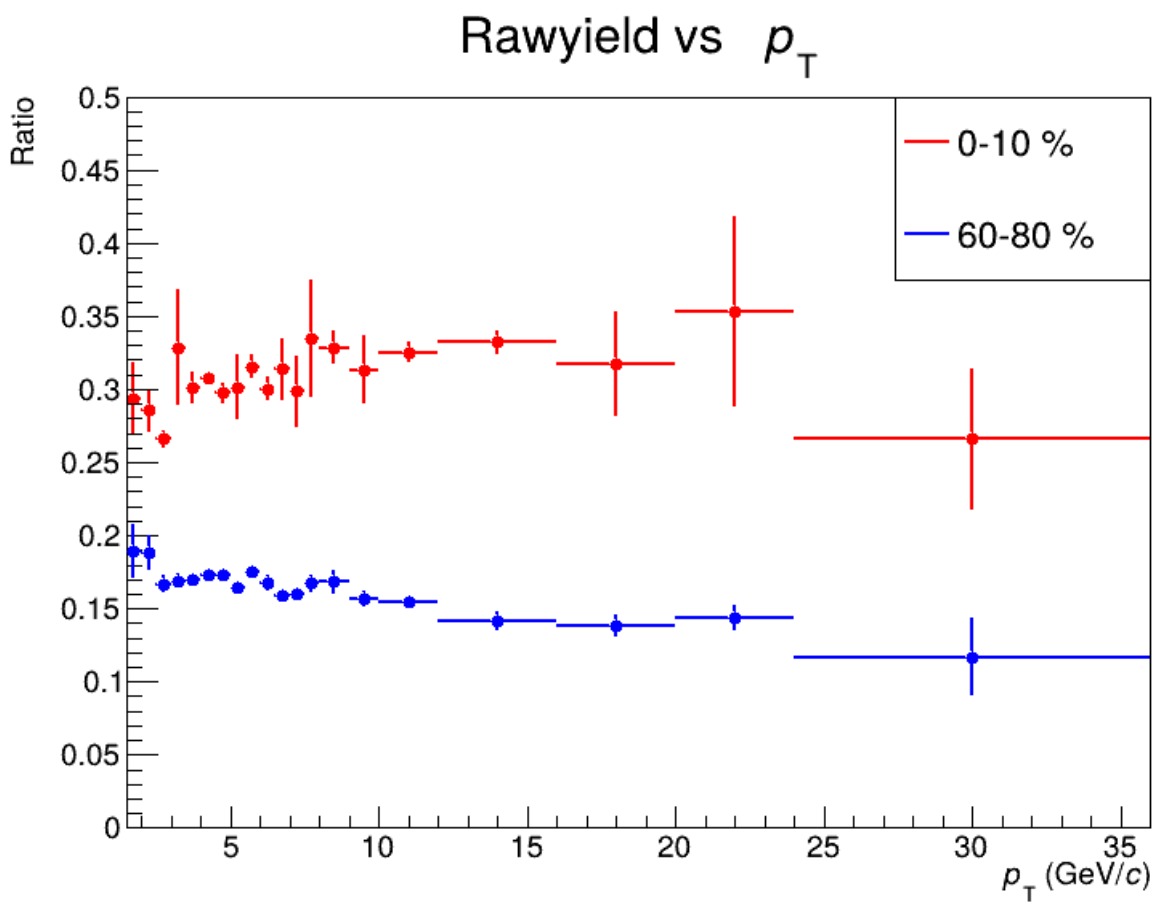
Systematic uncertainties summary





Multiplicity Dependent Rawyield





Current Status and Outlook

- Refining fit, some cuts and Re-evaluating systematics due to BDT selection to stabiles the results.
- Working on efficiency correction in multiplicity dependent analysis.

- Repeating same analysis for different multiplicity bins.
- Looking for if we could partially or fully understand interplay between hard and soft physics.

Acknowledgement:
I appreciate the effort by Jessica Ghatak to do a comparative study using rectangular cut helping better understanding and robustness of the framework.
I thank IITB for providing higher computing facility and funding.

Thankyou

Backup

Systematic Doubts

- I realized that back ground function

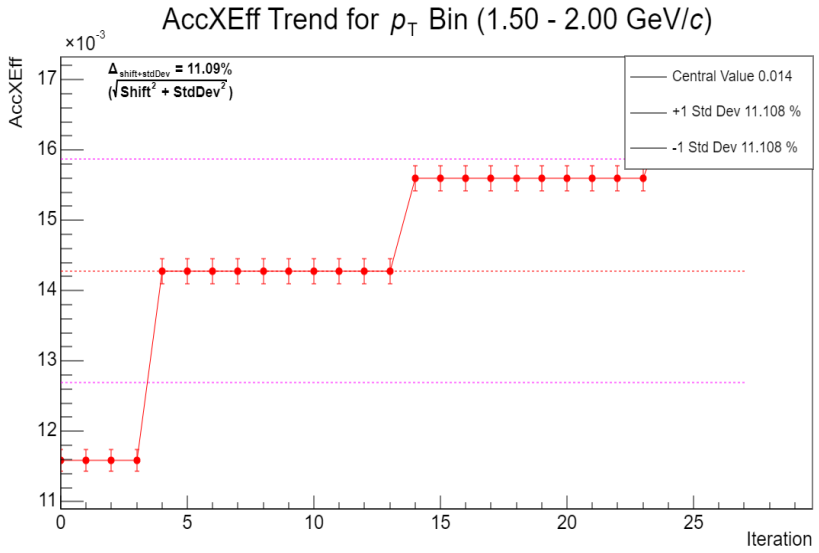
$$\boldsymbol{B(x) = (x - x_0)^m e^{-\lambda x}}$$

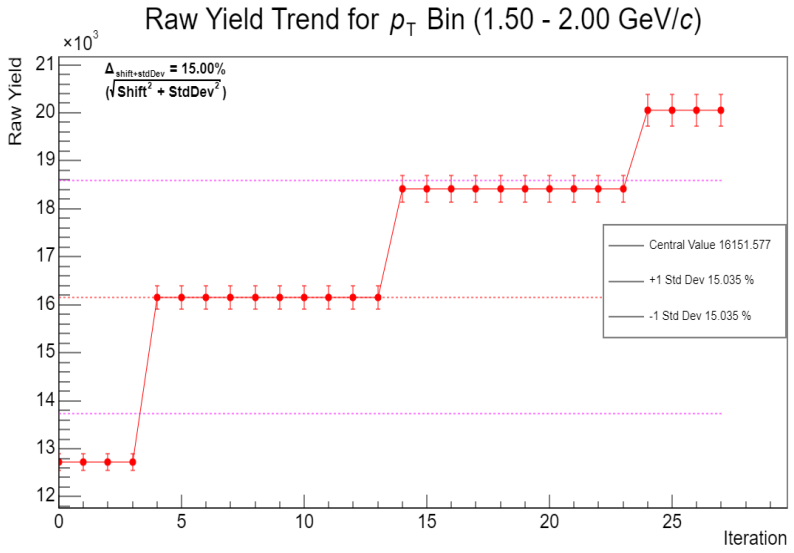
is not fitting well in lower and higher p_T bins, so should I try another back ground function

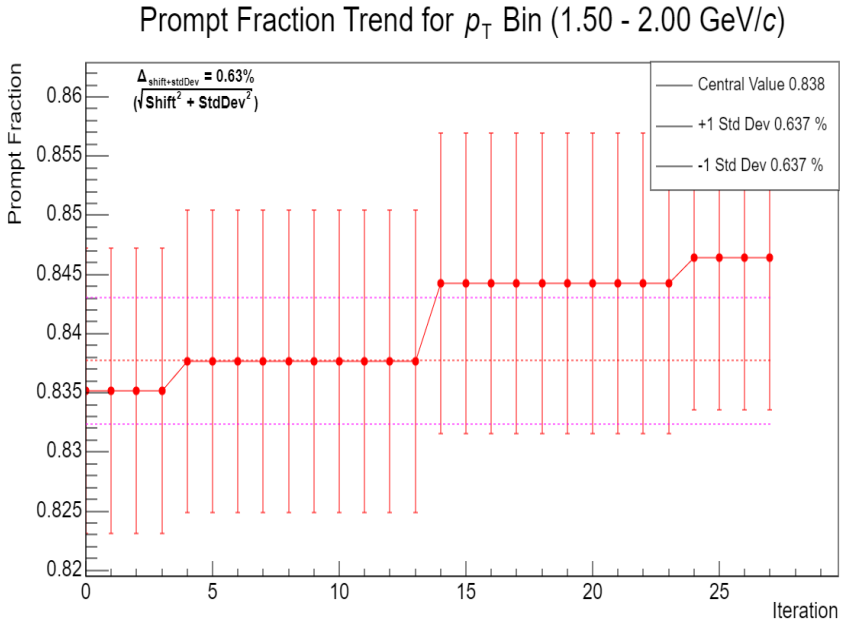
$$\boldsymbol{B'(x) = (x - x_0)^m e^{-\lambda x^n}}$$

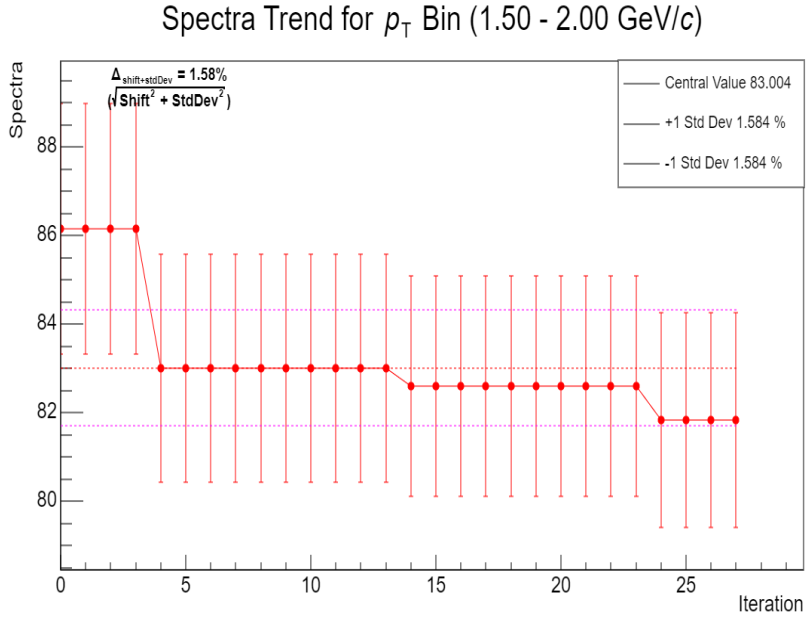
for systematic purpose? This may result to good systematic in lower p_T bins.

Systematic on BDT Selection -3









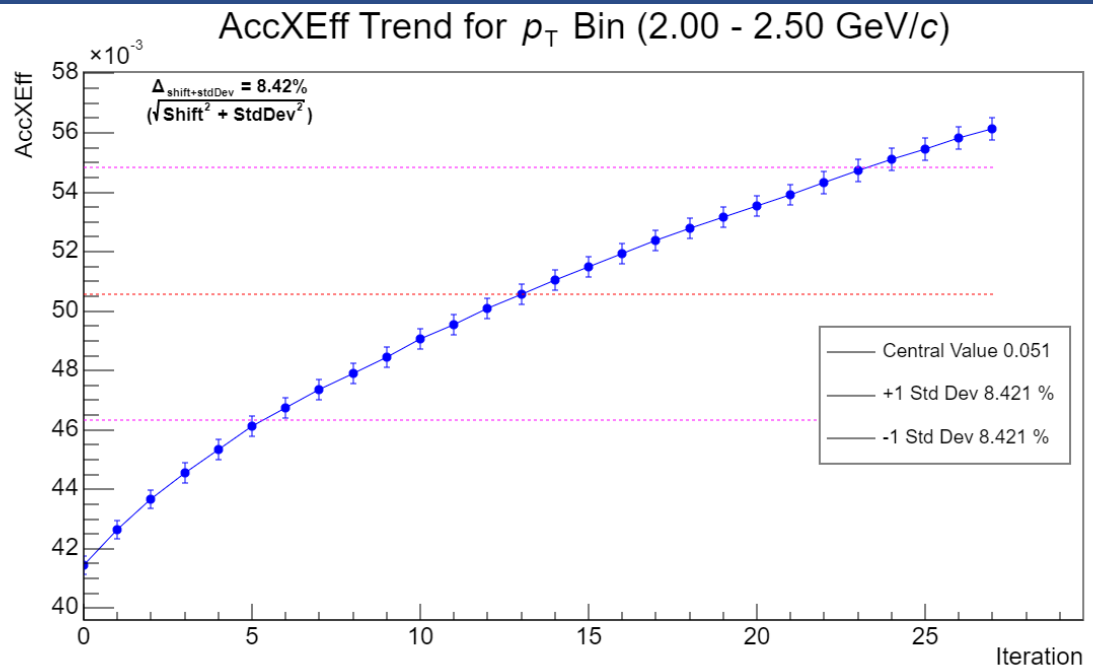
Background BDT Score cuts

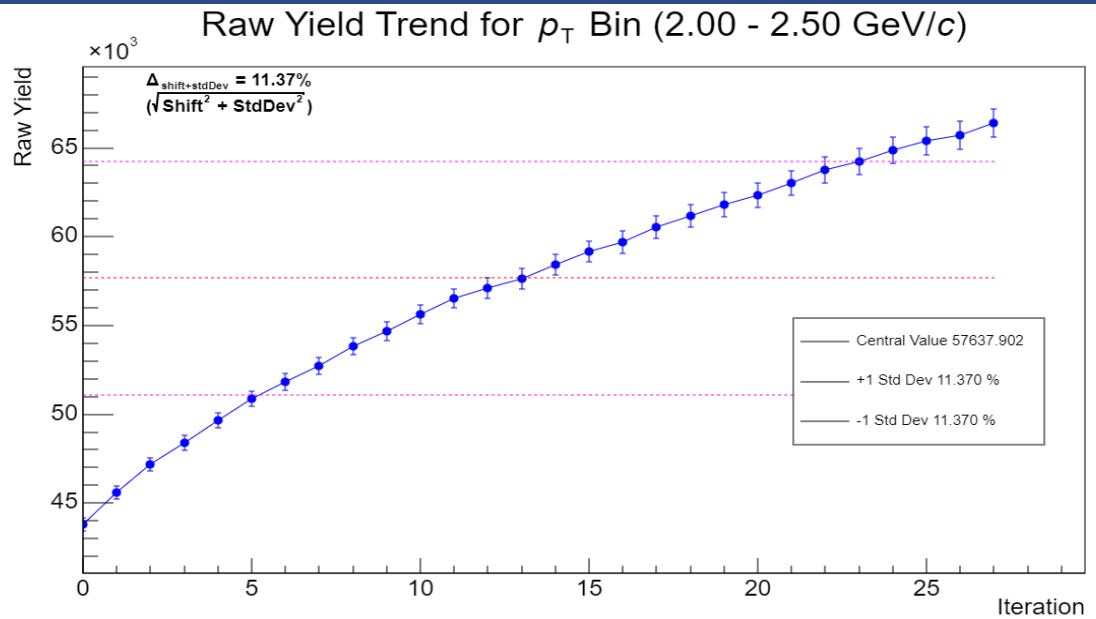
- **Central value**: 0.02,
- **Bin width of THnSparse**: 0.01,
- **BDT_variation step size**: 0.001

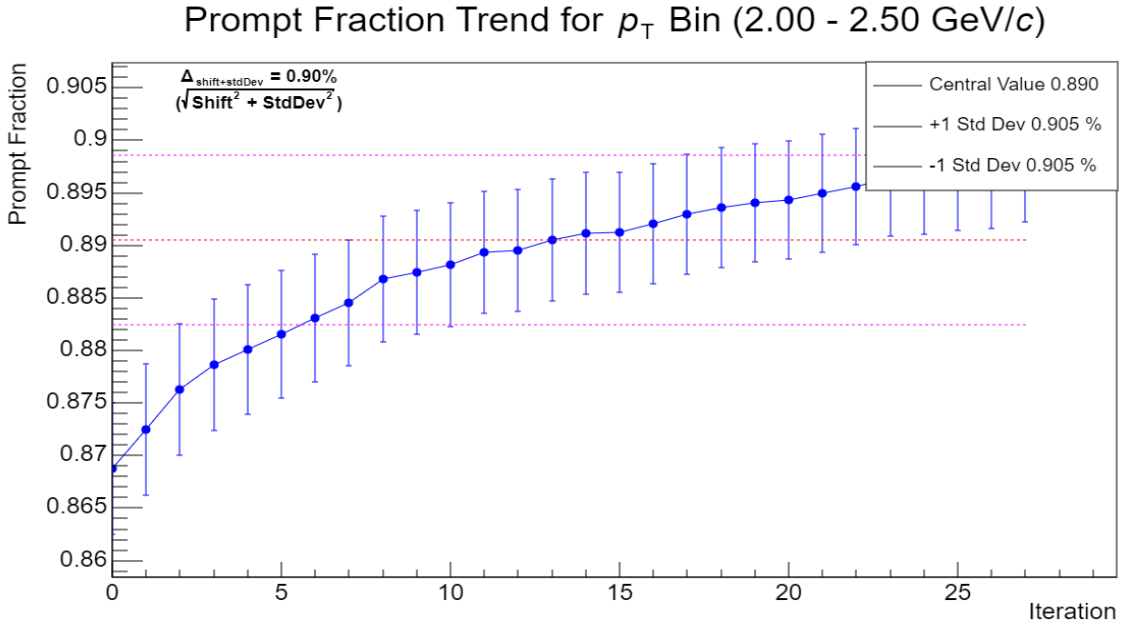
- [0.007, 0.008, 0.009, 0.01,… , 0.034]

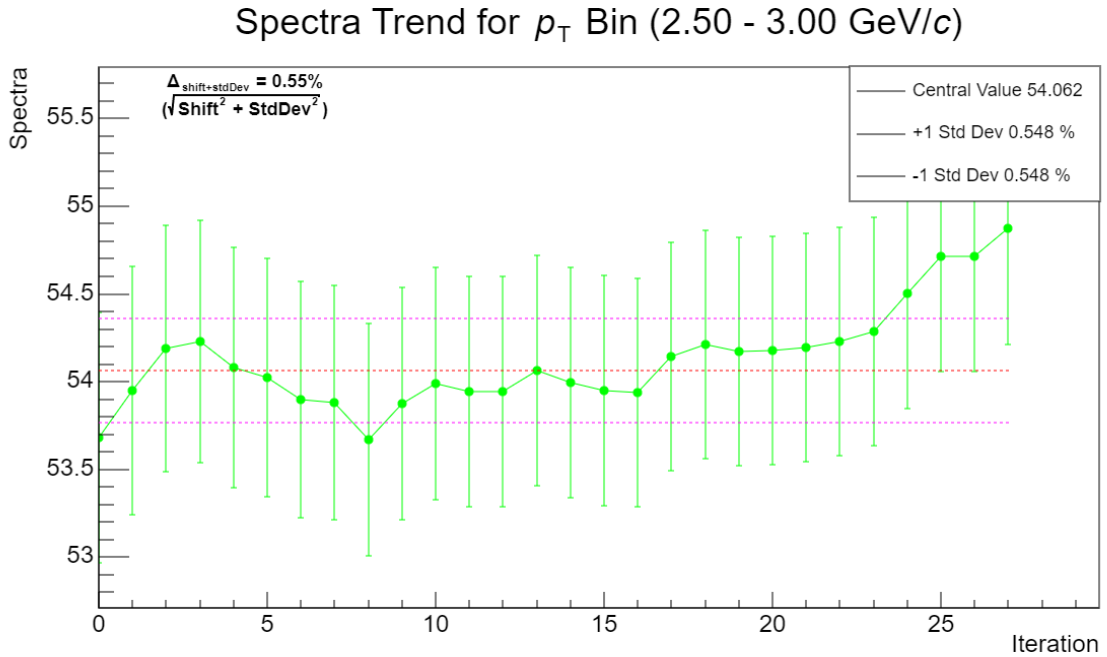
- Signal Parameters were fixed to central values

Systematic on BDT Selection -5

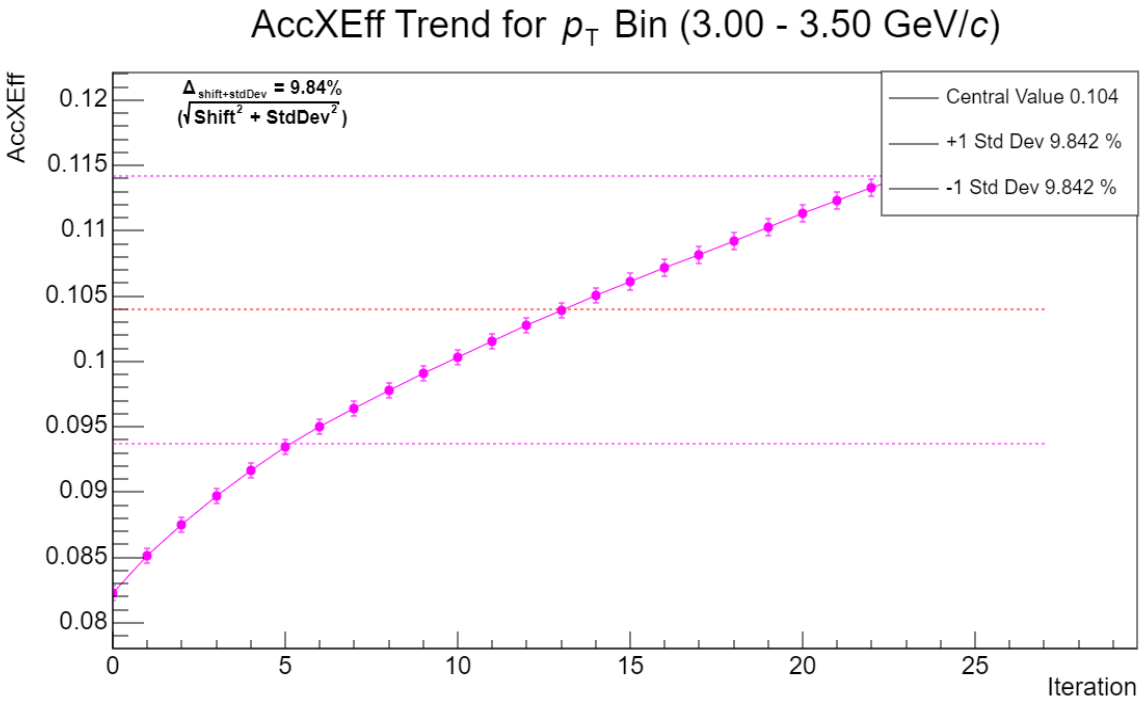


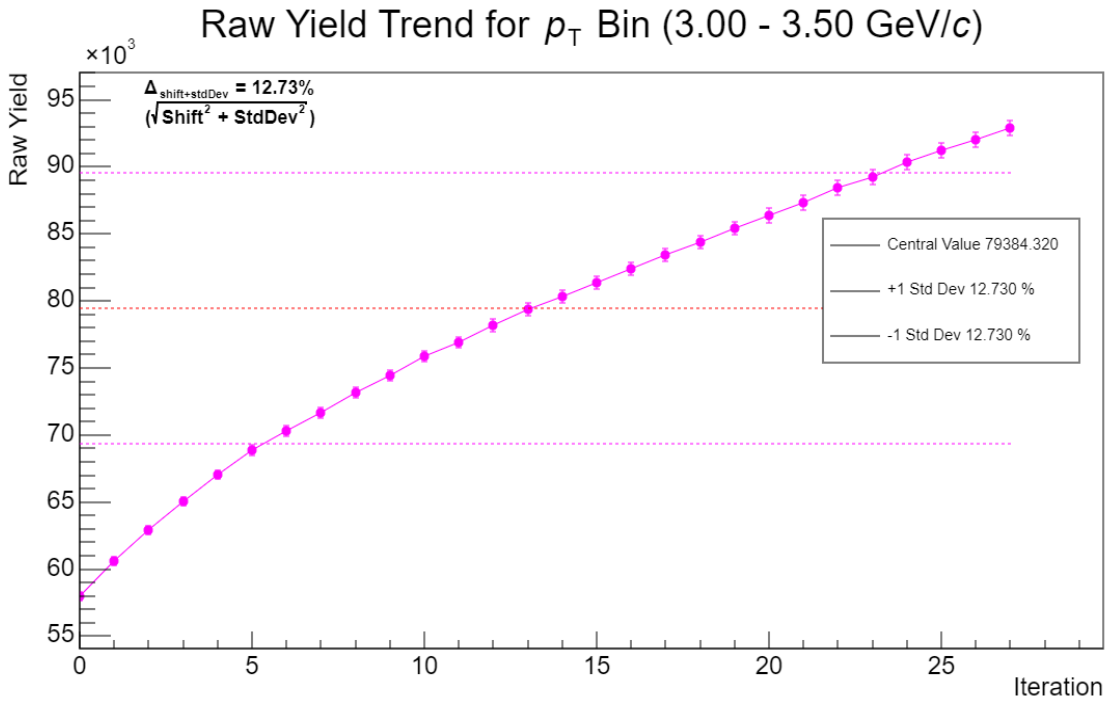


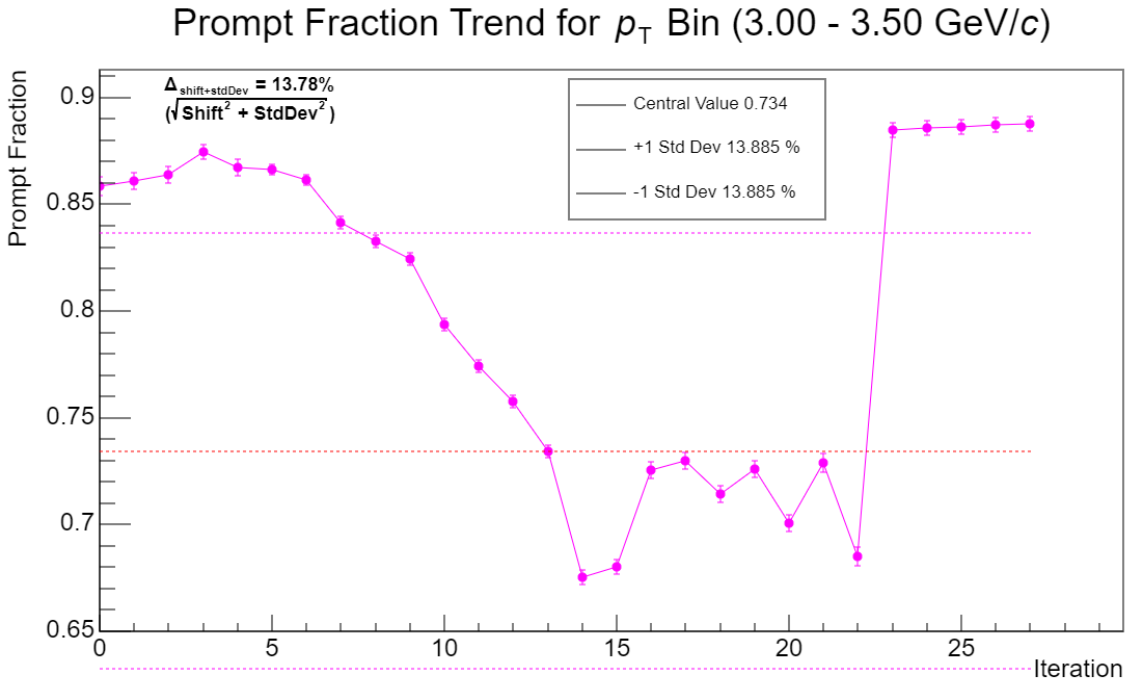


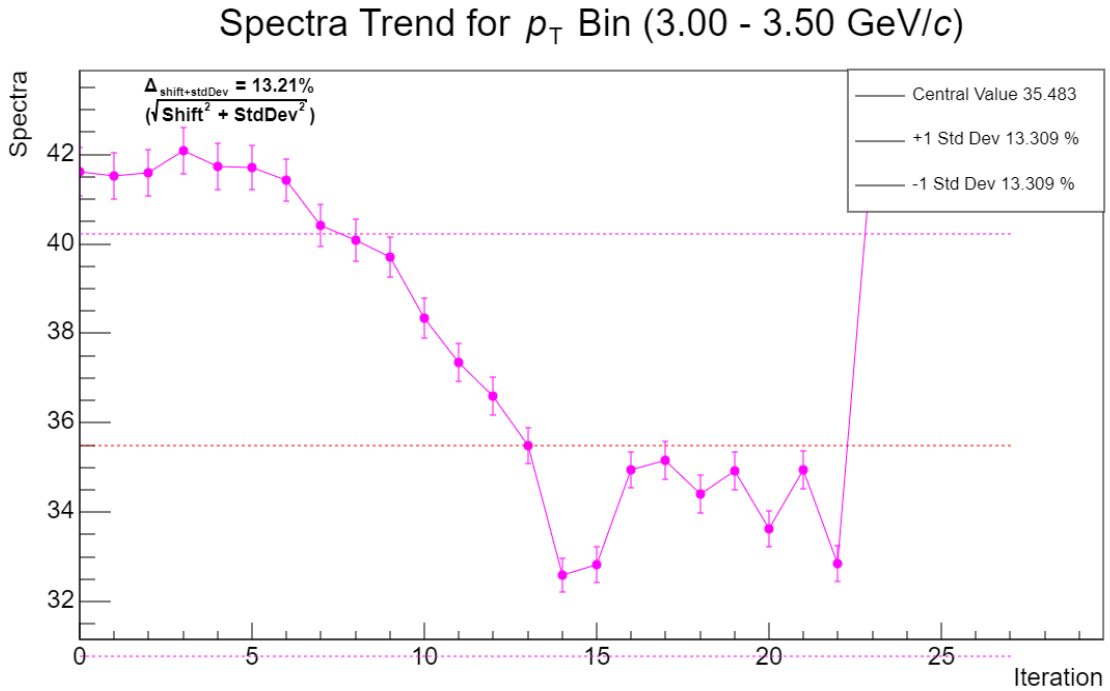


dia N

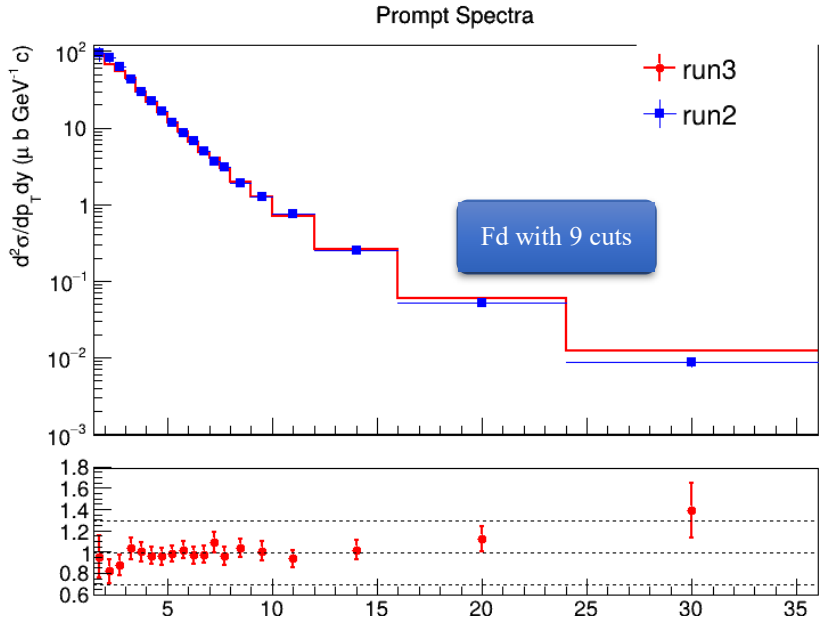

AccXEff Trend for p_T Bin (3.00 - 3.50 GeV/c)
$\Delta_{shift+stdDev}$ = 9.84%
($\sqrt{Shift^2 + StdDev^2}$)
Central Value 0.104
+1 Std Dev 9.842 %
-1 Std Dev 9.842 %
AccXEff
Iteration

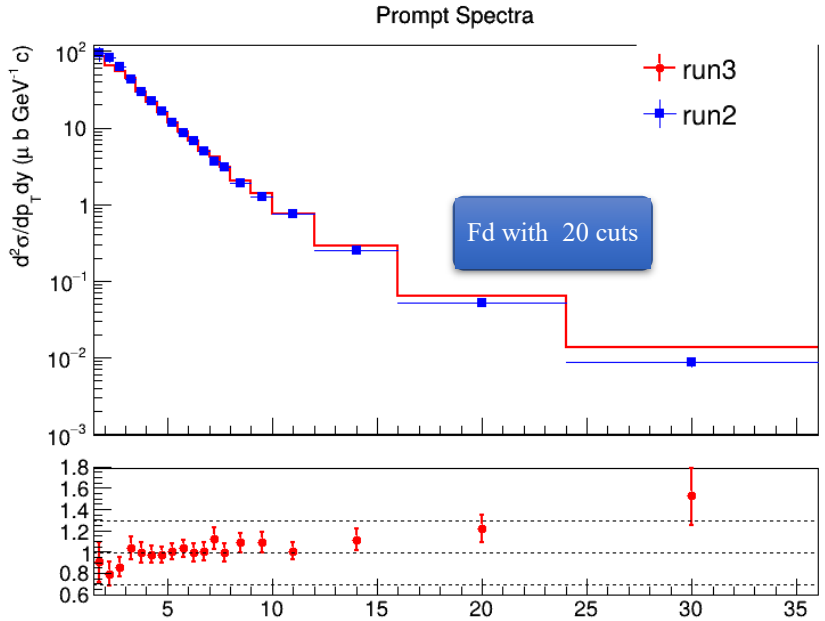

Raw Yield Trend for p_T Bin (3.00 - 3.50 GeV/c)
$\times 10^3$
$\Delta_{shift+stdDev}$ = 12.73%
($\sqrt{Shift^2 + StdDev^2}$)
Central Value 79384.320
+1 Std Dev 12.730 %
-1 Std Dev 12.730 %
Raw Yield
Iteration

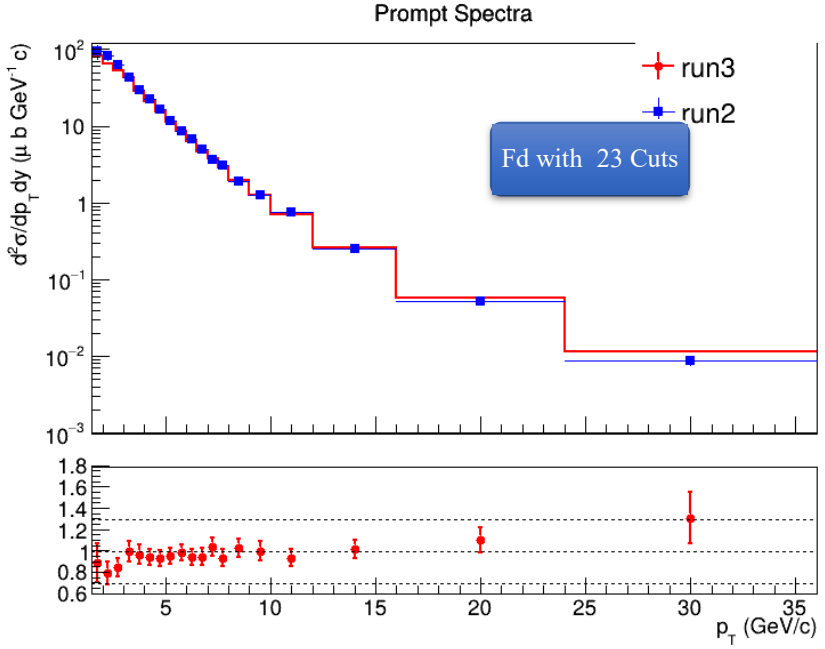

Prompt Fraction Trend for p_T Bin (3.00 - 3.50 GeV/c)
$\Delta_{shift+stdDev}$ = 13.78%
($\sqrt{Shift^2 + StdDev^2}$)
Central Value 0.734
+1 Std Dev 13.885 %
-1 Std Dev 13.885 %
Prompt Fraction
Iteration

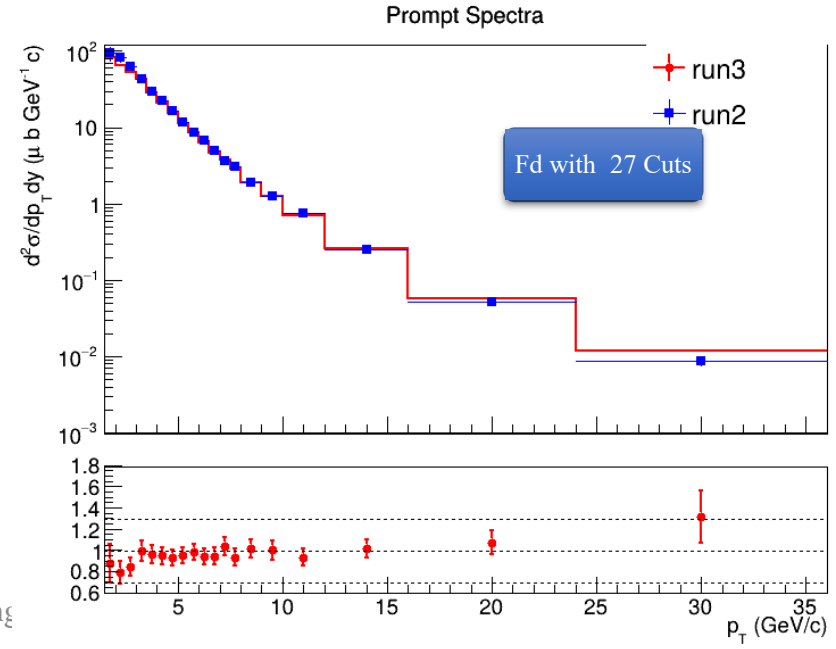

Spectra Trend for p_T Bin (3.00 - 3.50 GeV/c)
$\Delta_{shift+stdDev}$ = 13.21%
($\sqrt{Shift^2 + StdDev^2}$)
Central Value 35.483
+1 Std Dev 13.309 %
-1 Std Dev 13.309 %
Spectra
Iteration

Prompt Spectra of D*+

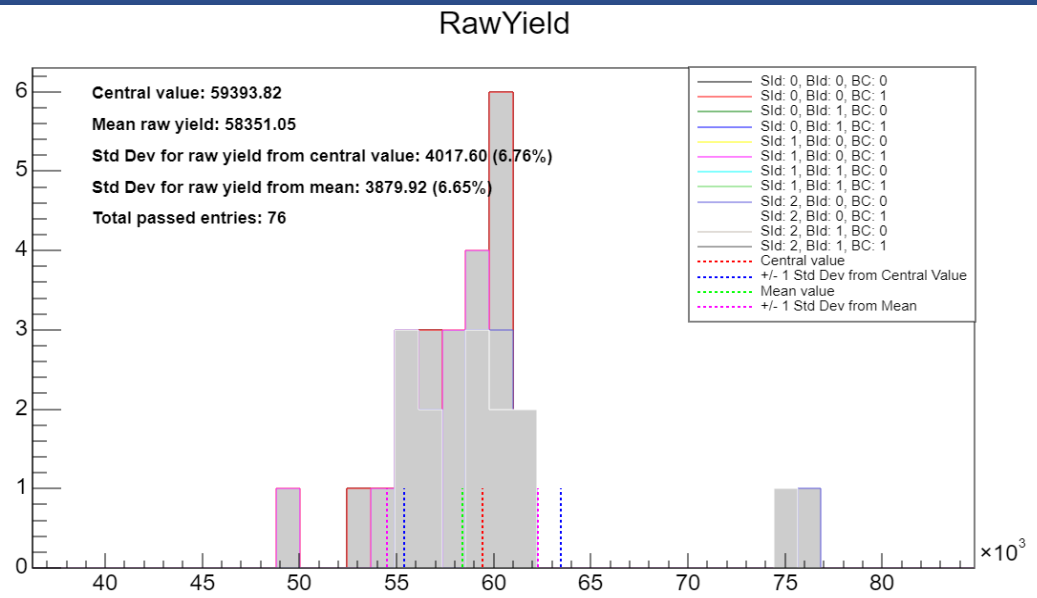


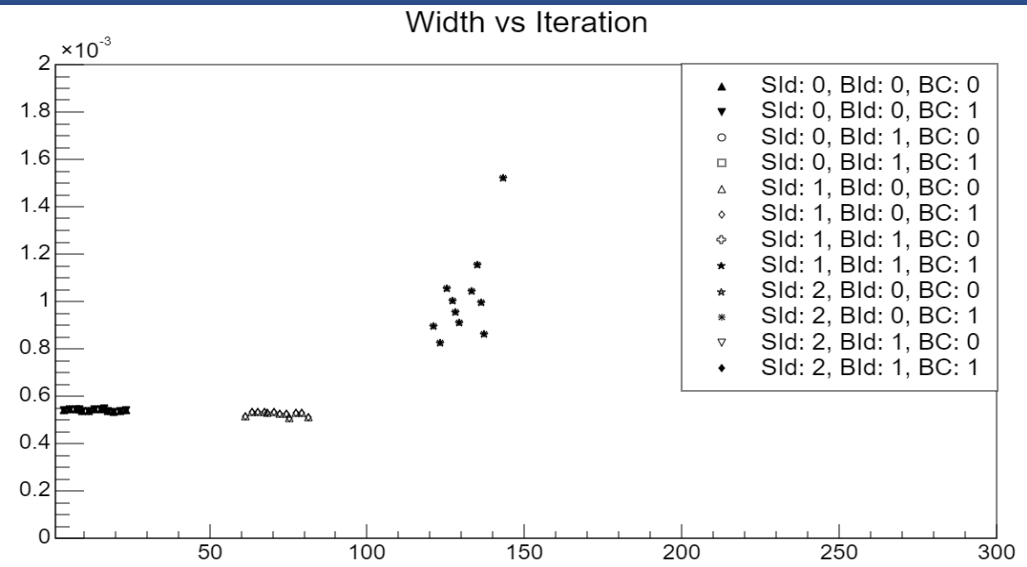




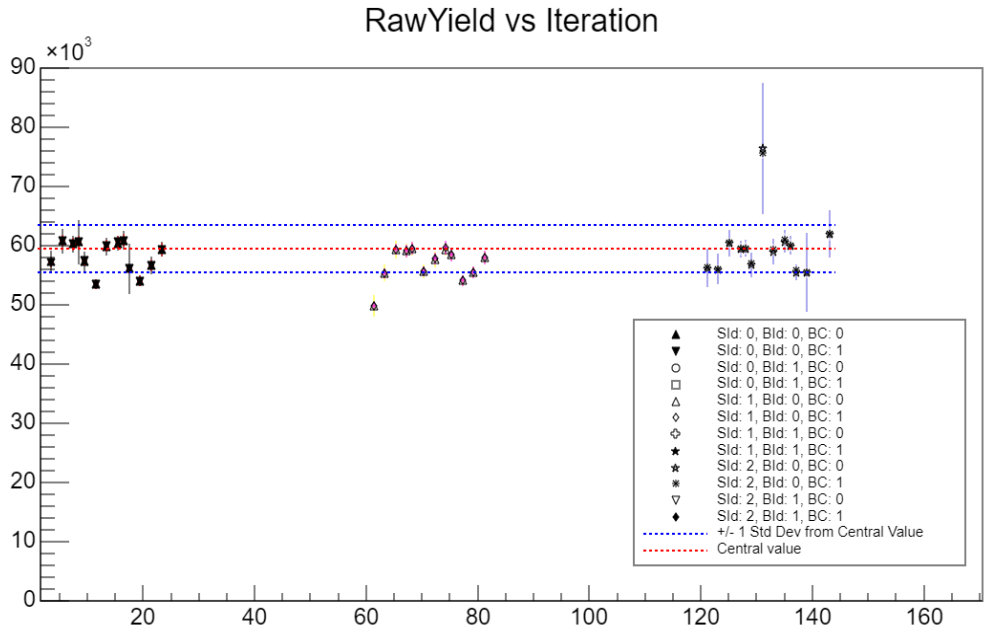


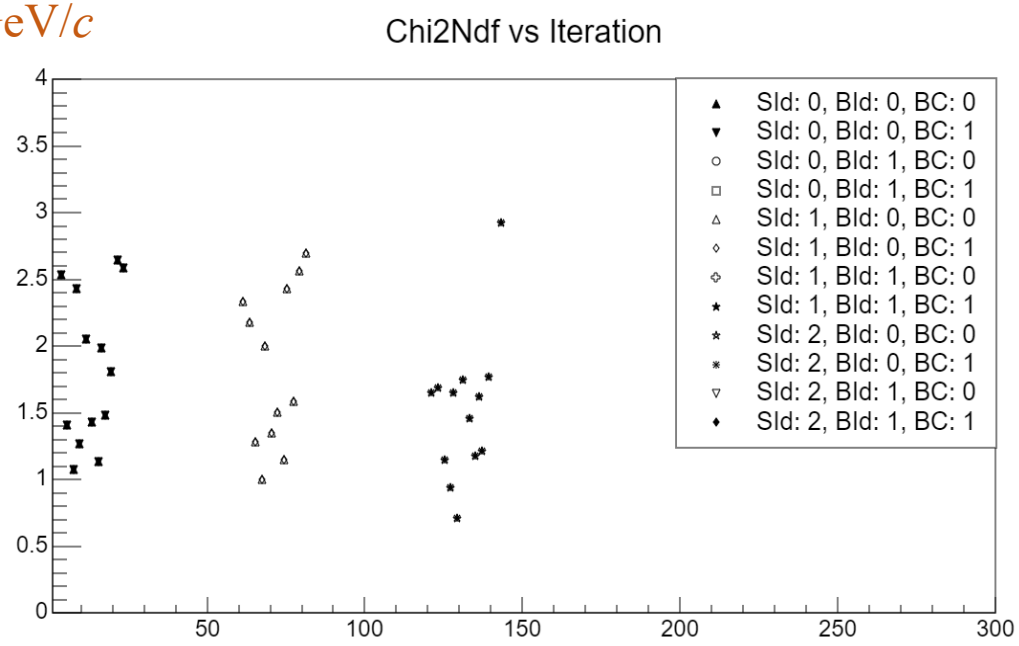
Systematic on Raw Yield-4



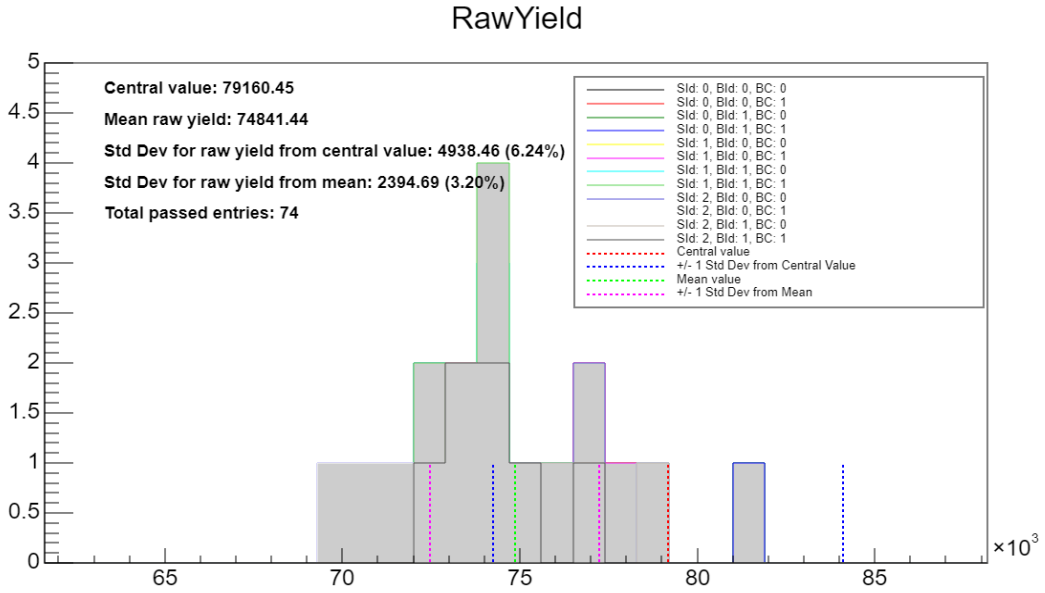


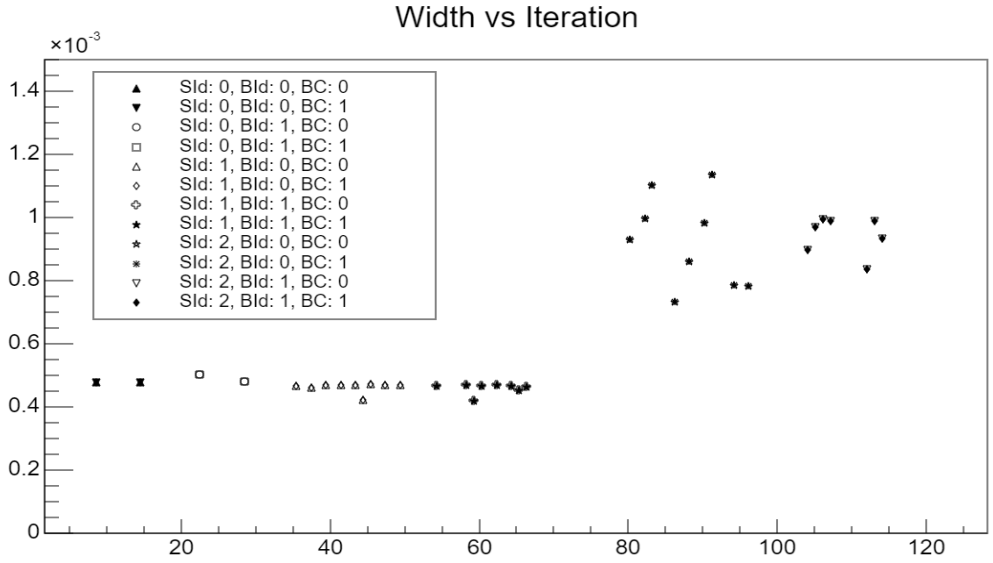
$2.0 < p_T < 2.5$ GeV/c



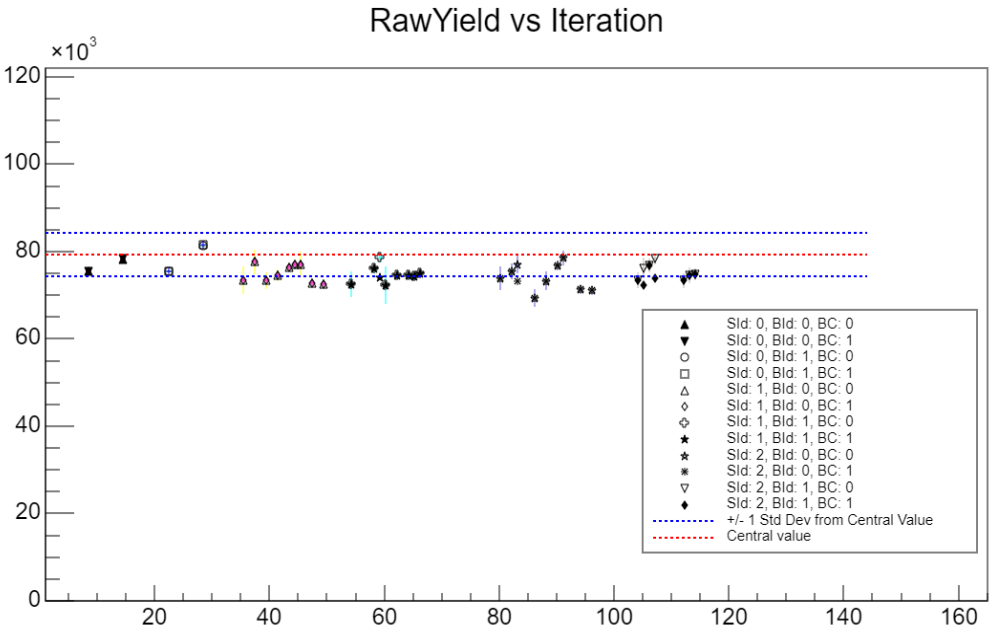


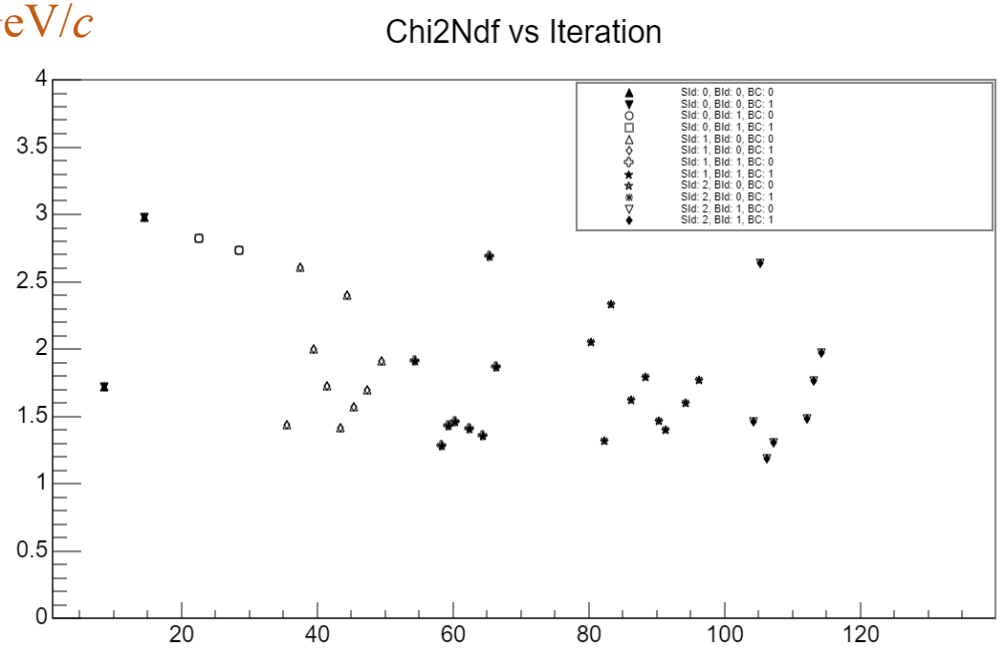
Systematic on Raw Yield-5



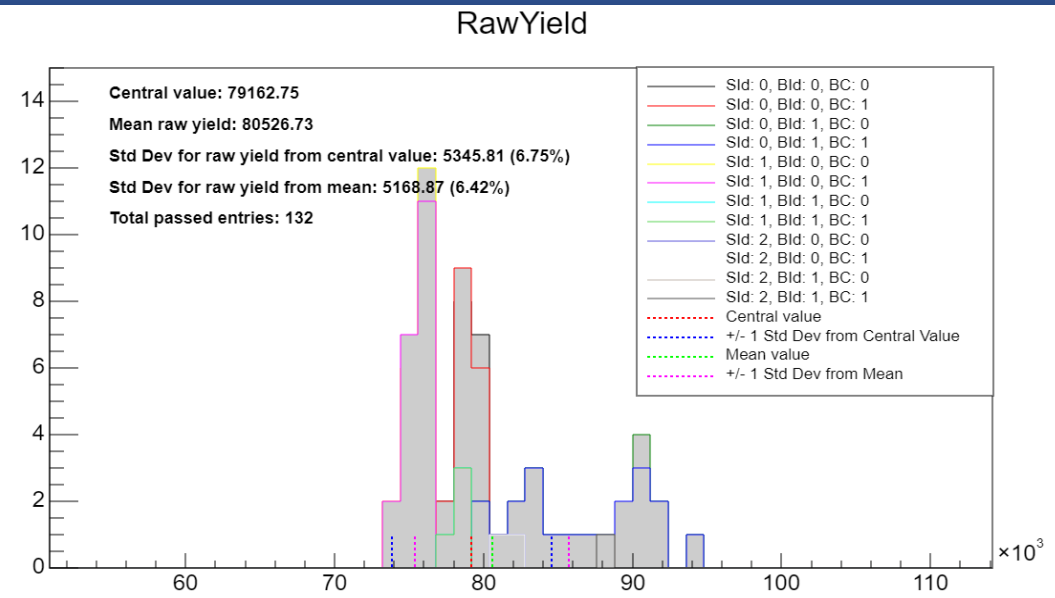


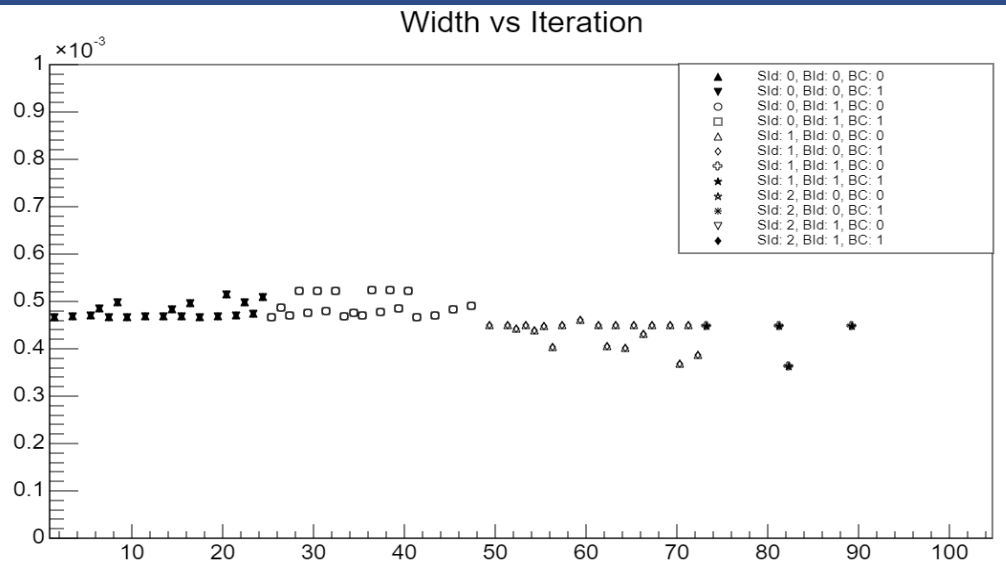
$2.5 < p_T < 3.0$ GeV/c



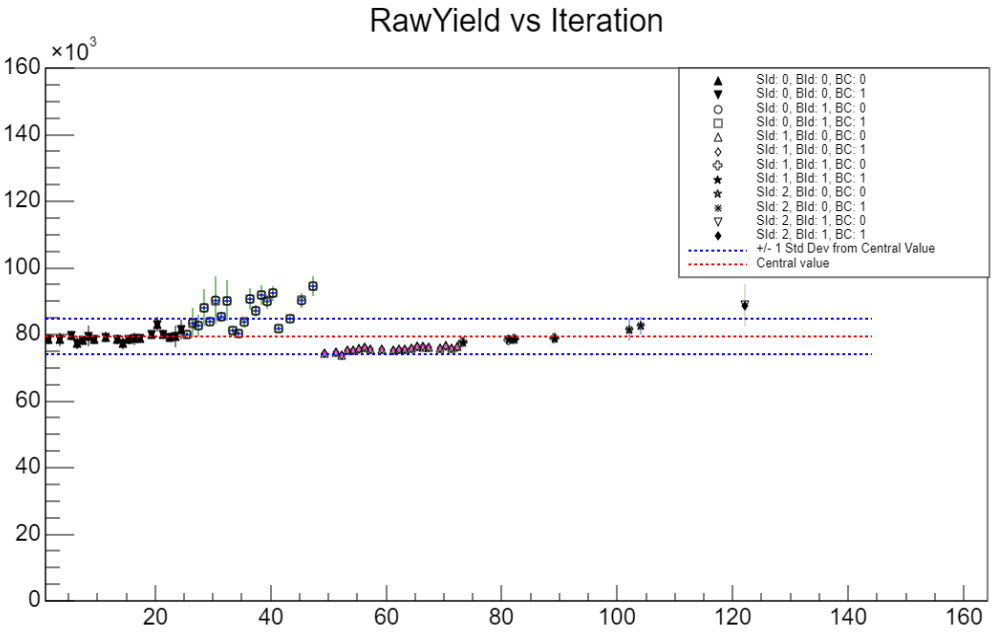


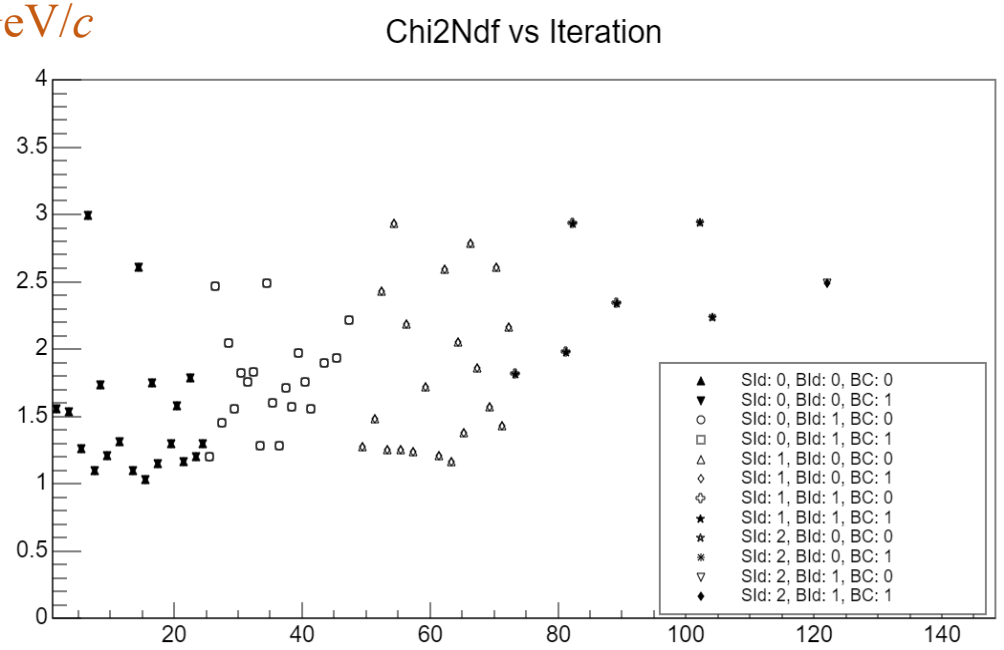
Systematic on Raw Yield-6



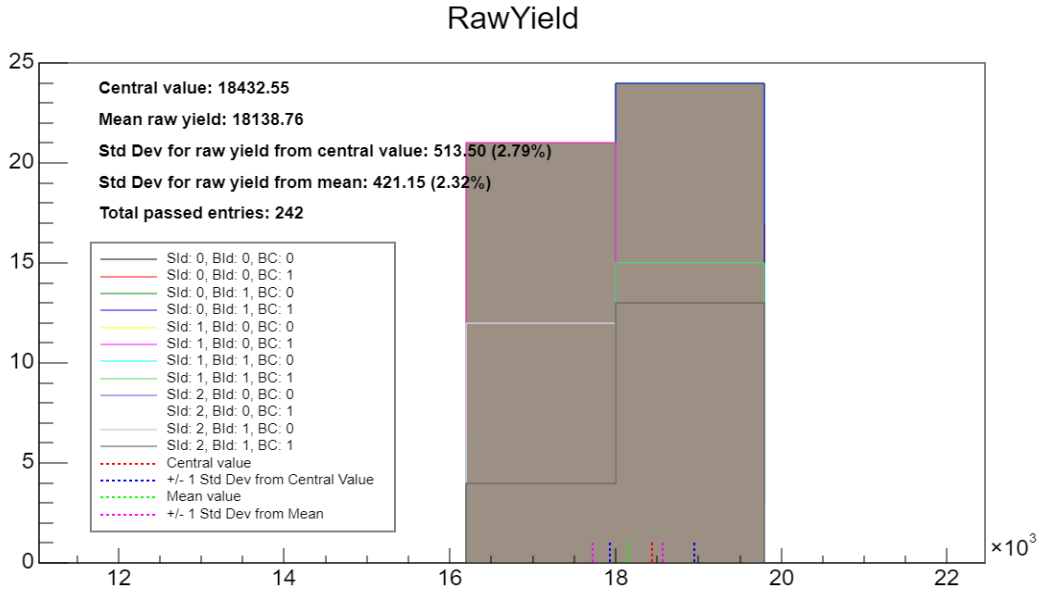


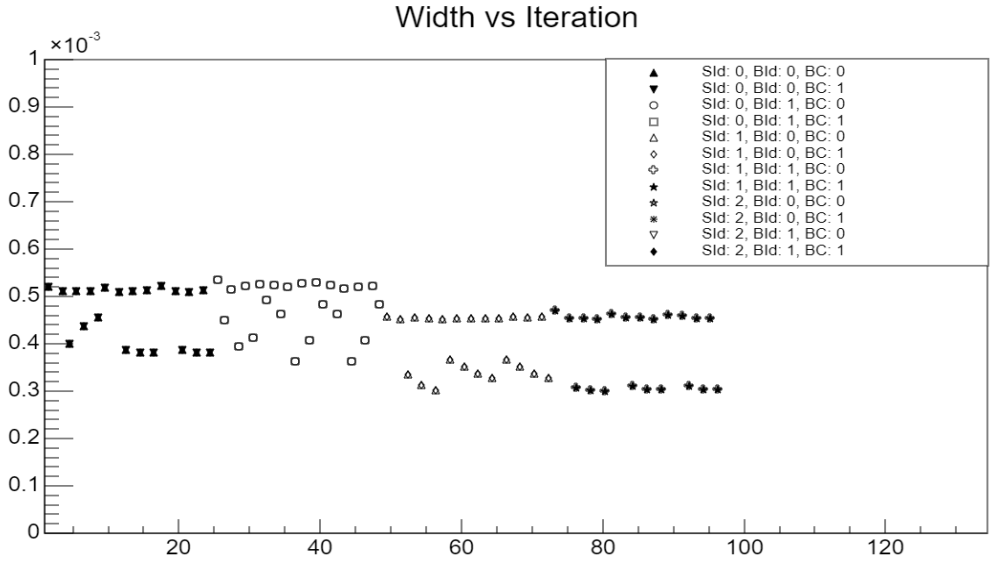
$3.0 < p_T < 3.5$ GeV/c



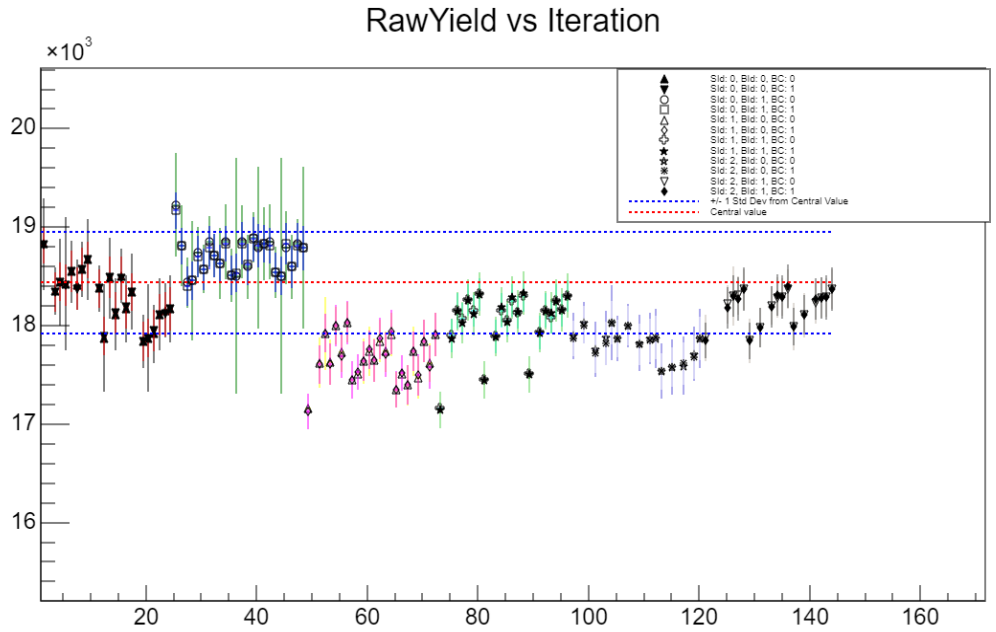


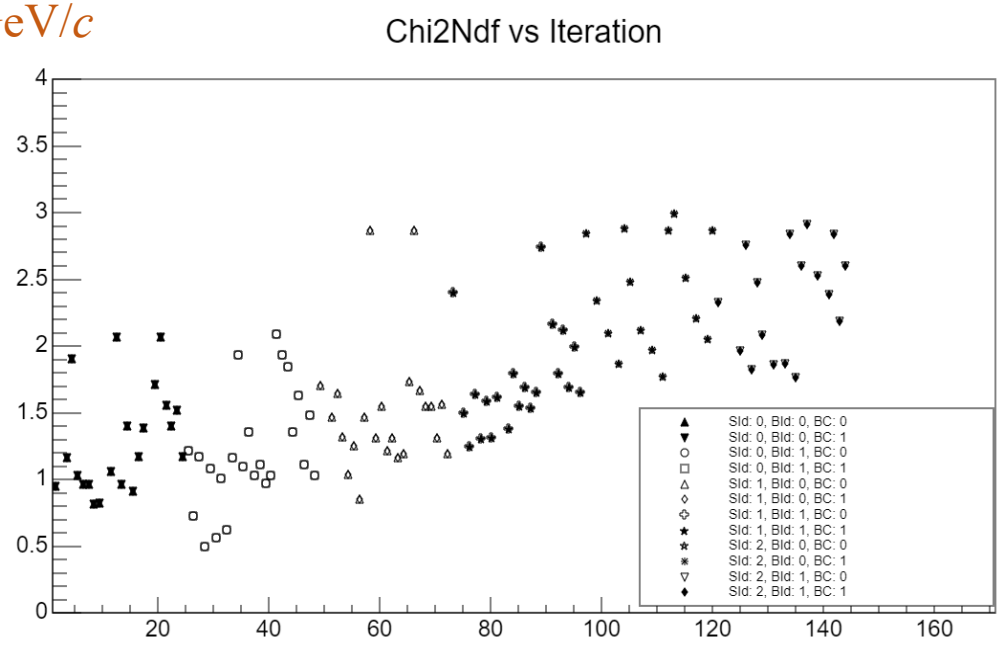
Systematic on Raw Yield-14



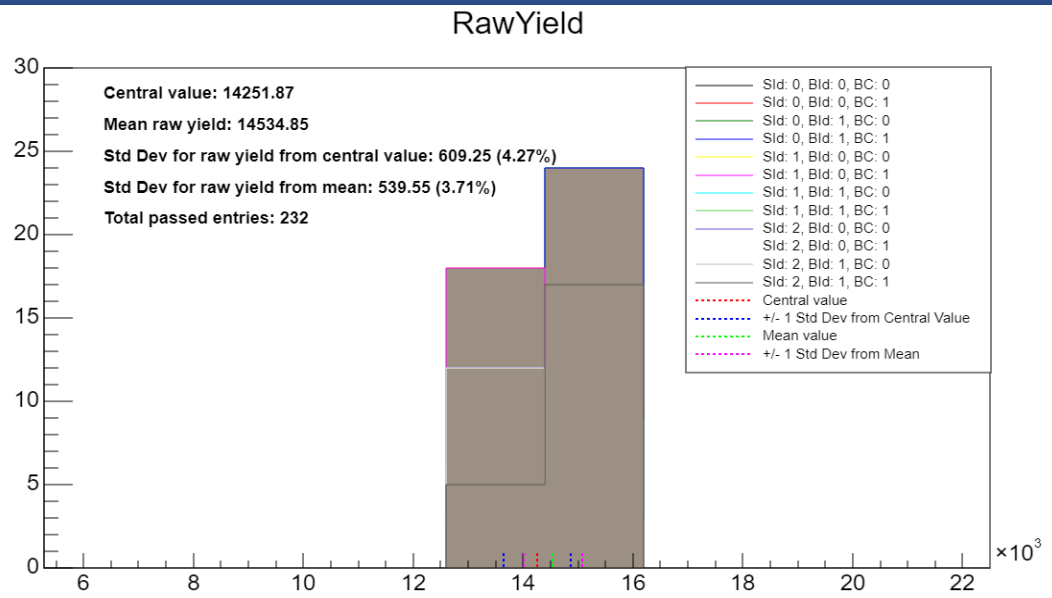


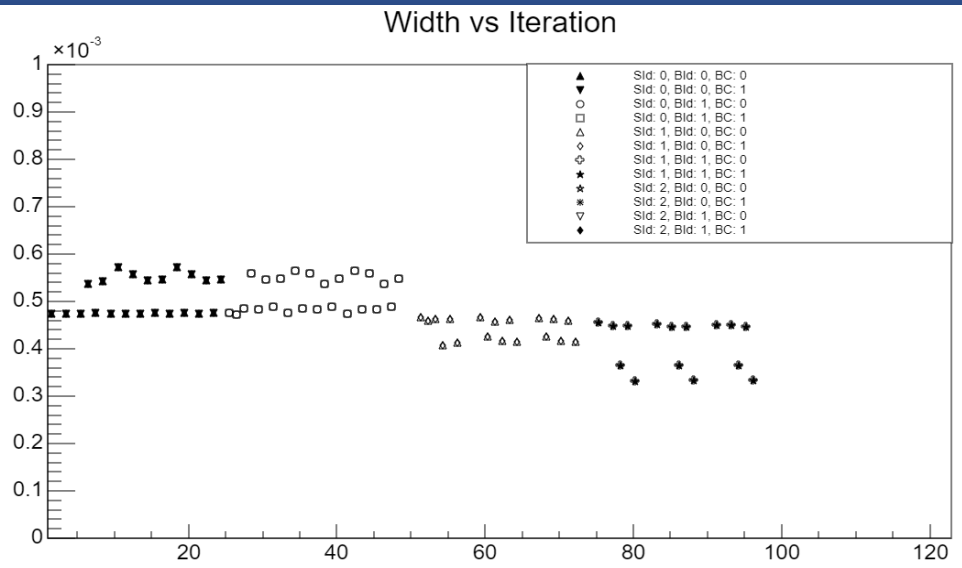
$7.0 < p_T < 7.5$ GeV/c



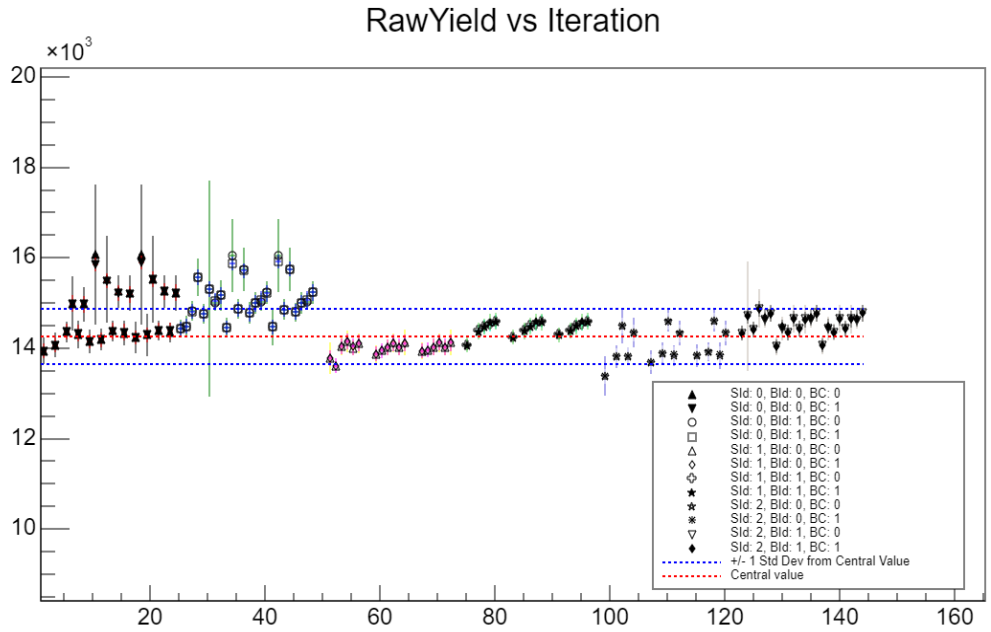


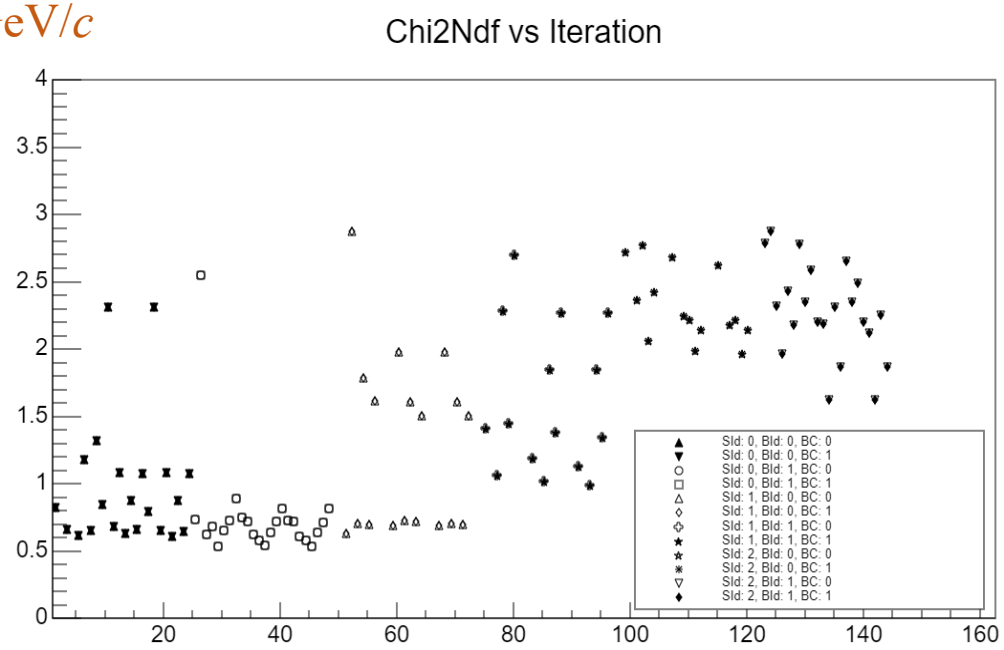
Systematic on Raw Yield-15



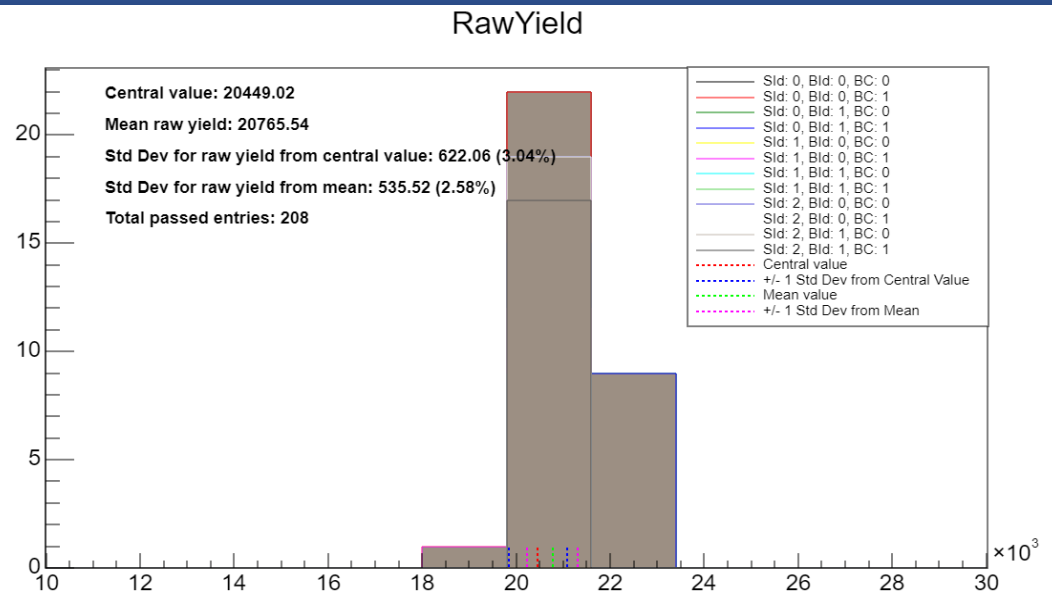


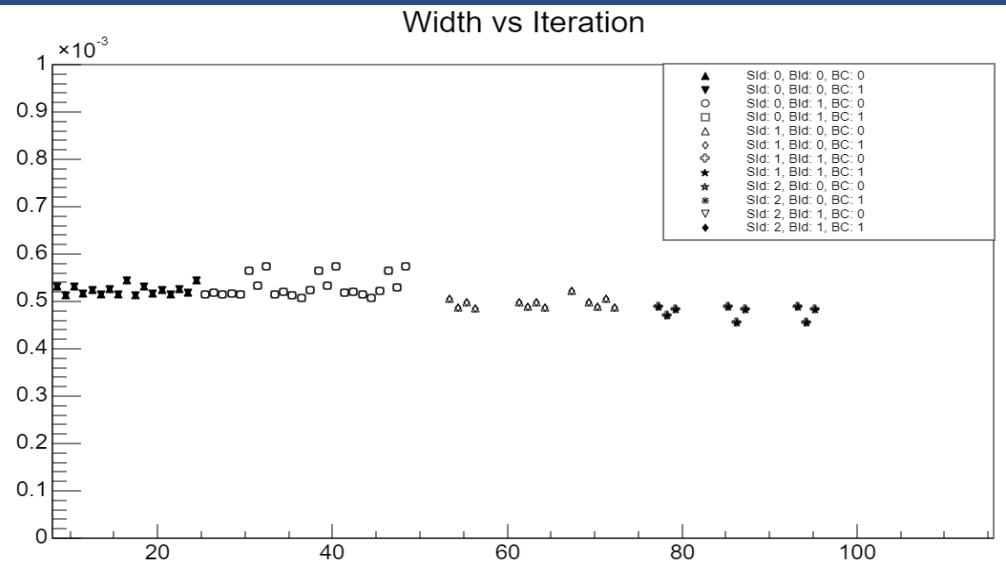
$7.5 < p_T < 8.0$ GeV/c



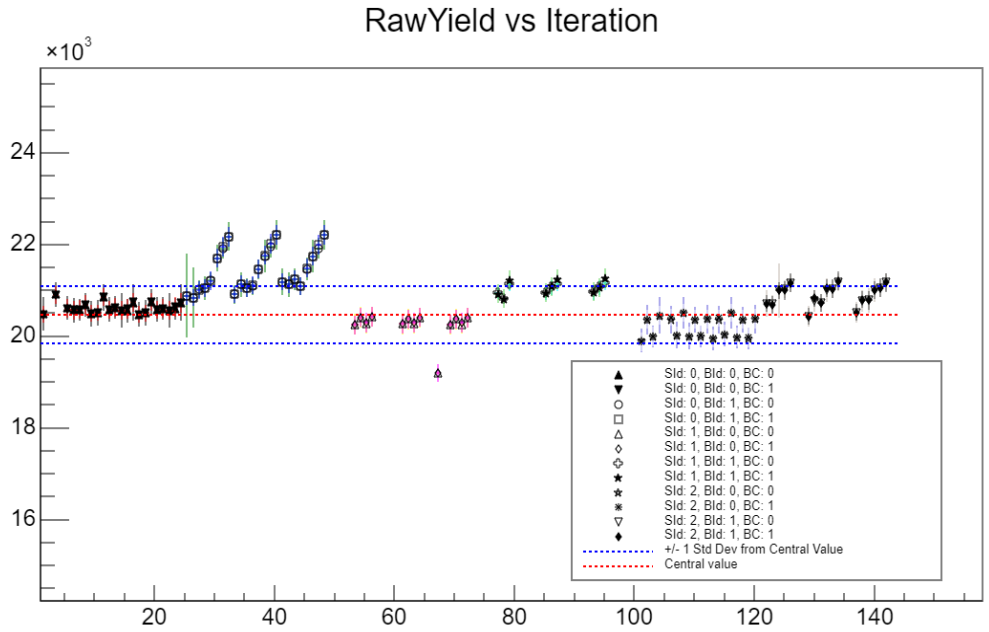


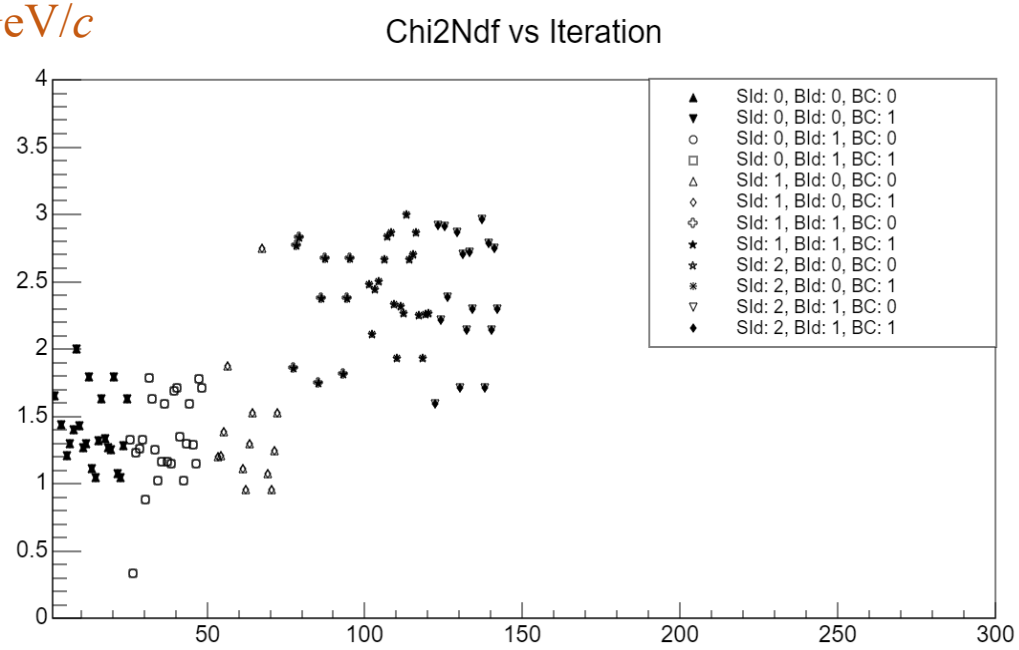
Systematic on Raw Yield-16



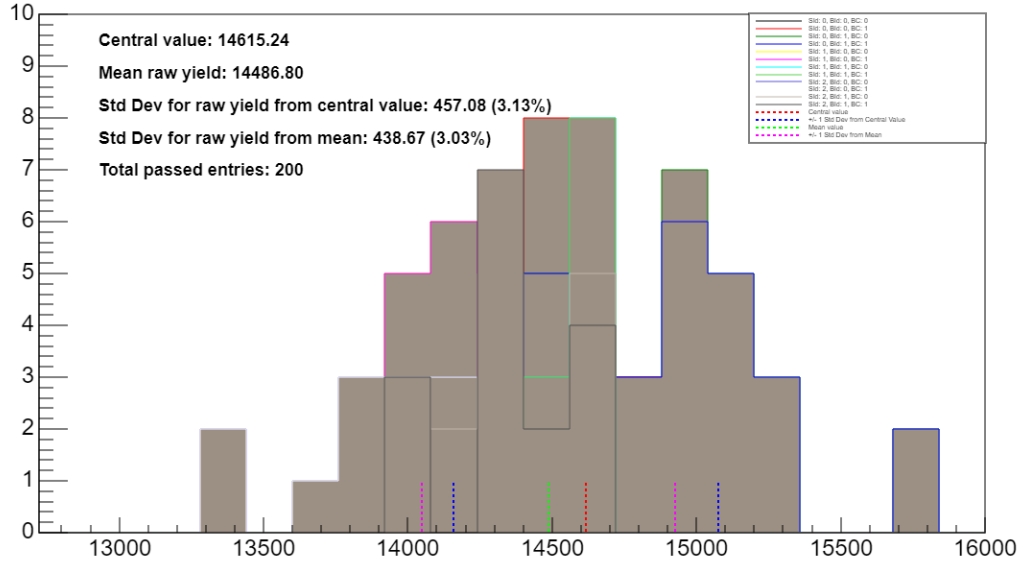


$8.0 < p_T < 9.0$ GeV/c

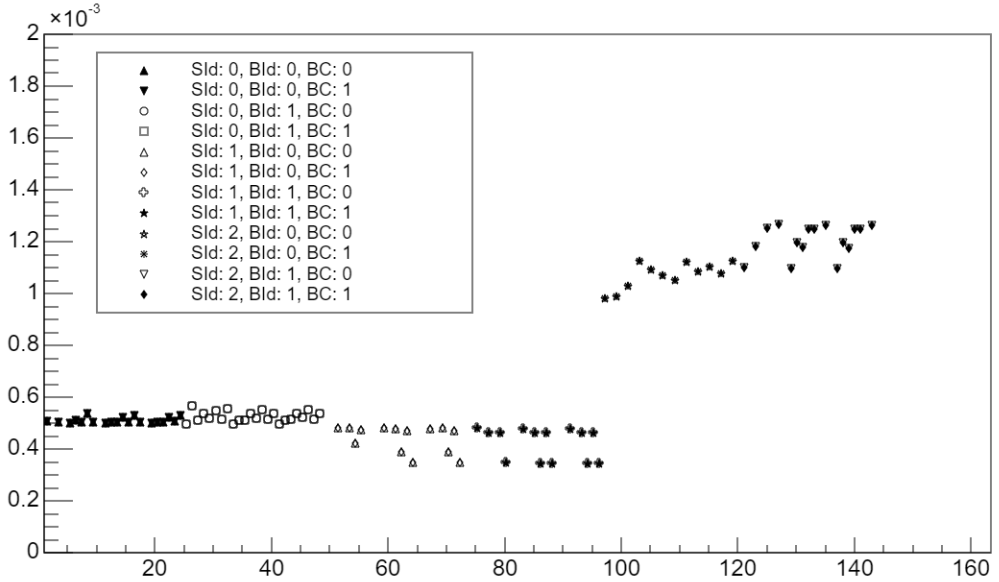




RawYield

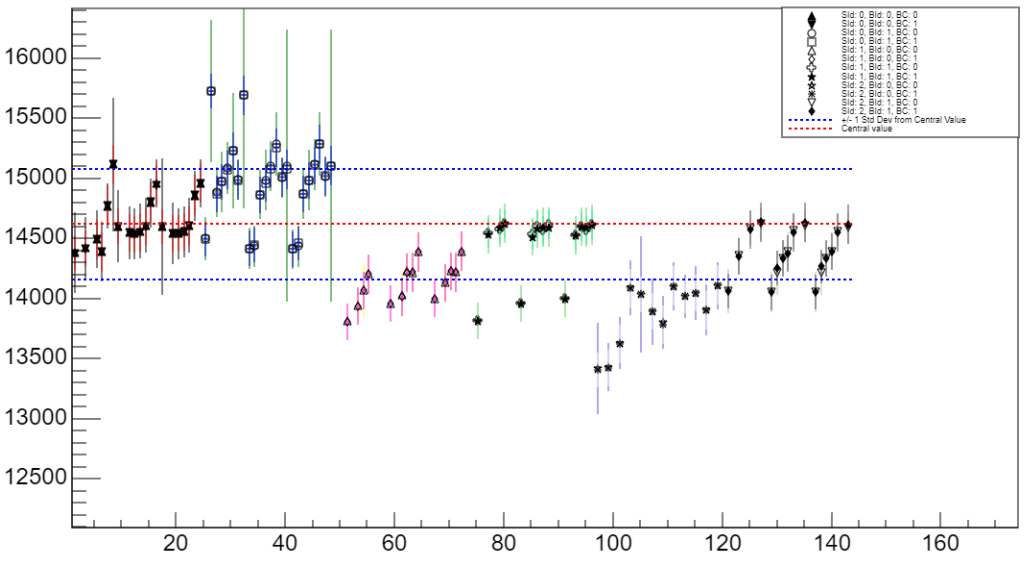


Width vs Iteration

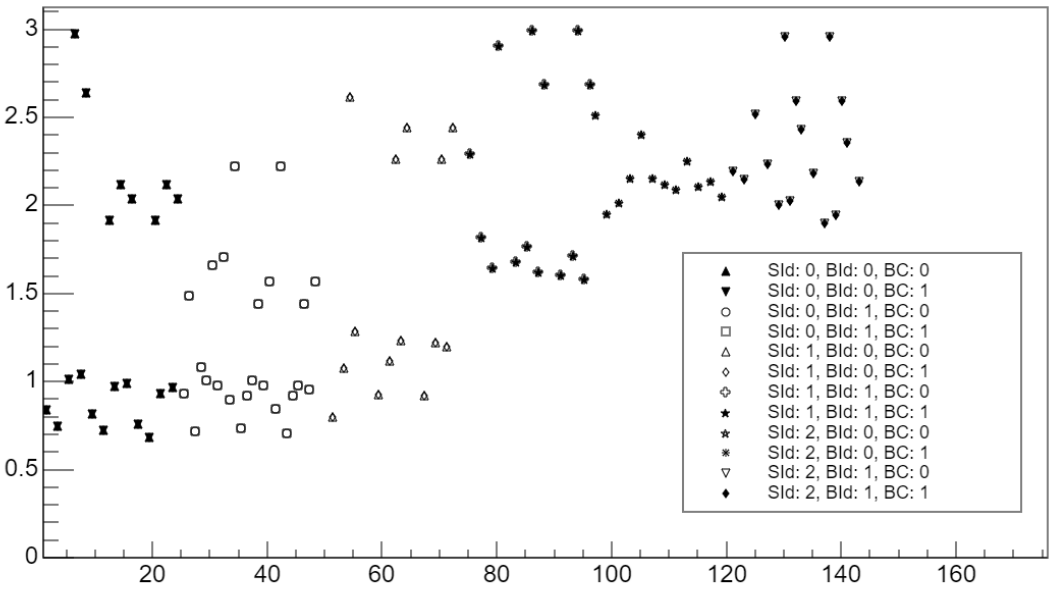


$9.0 < p_T < 10.0$ GeV/c

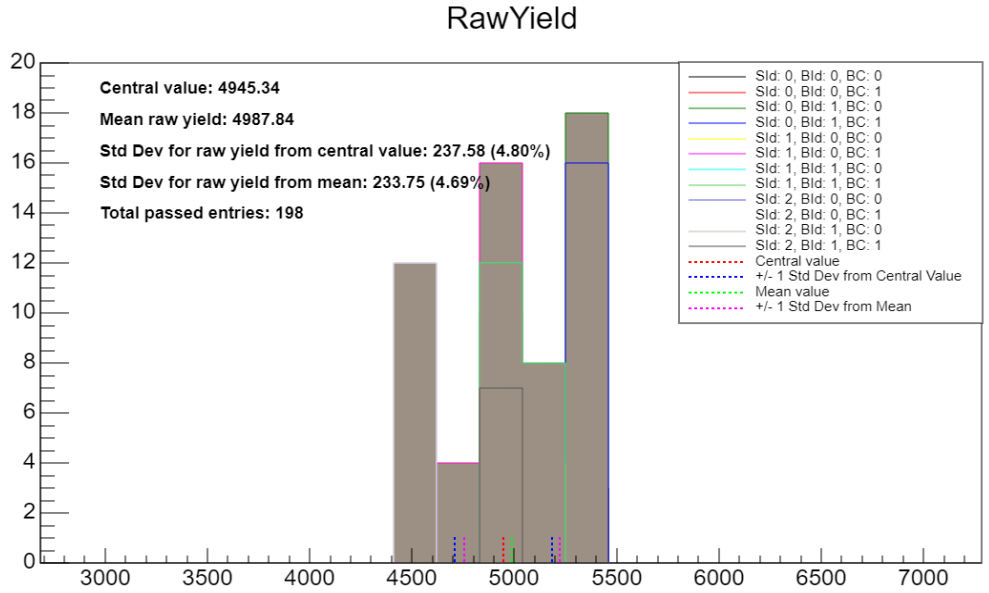
RawYield vs Iteration

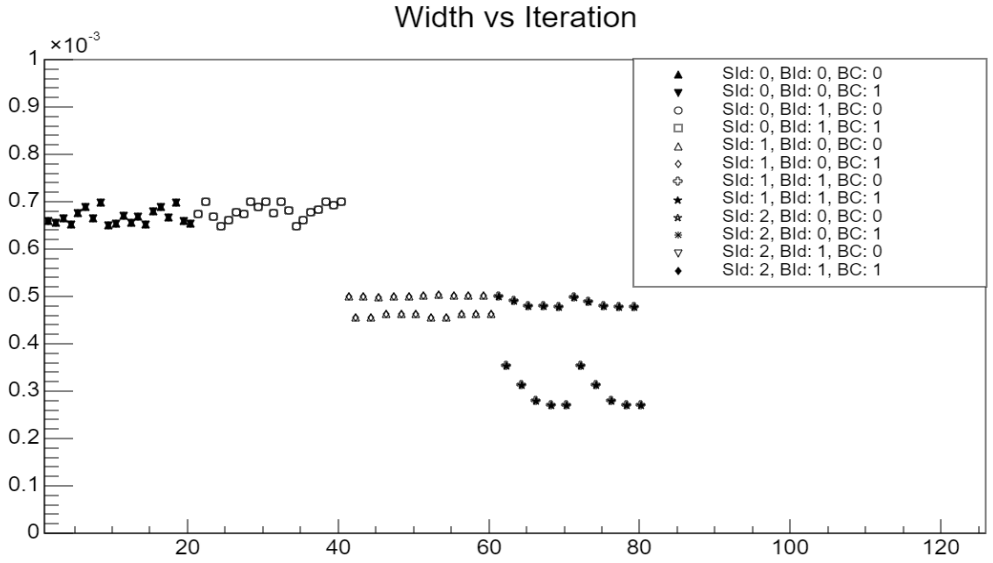


Chi2Ndf vs Iteration

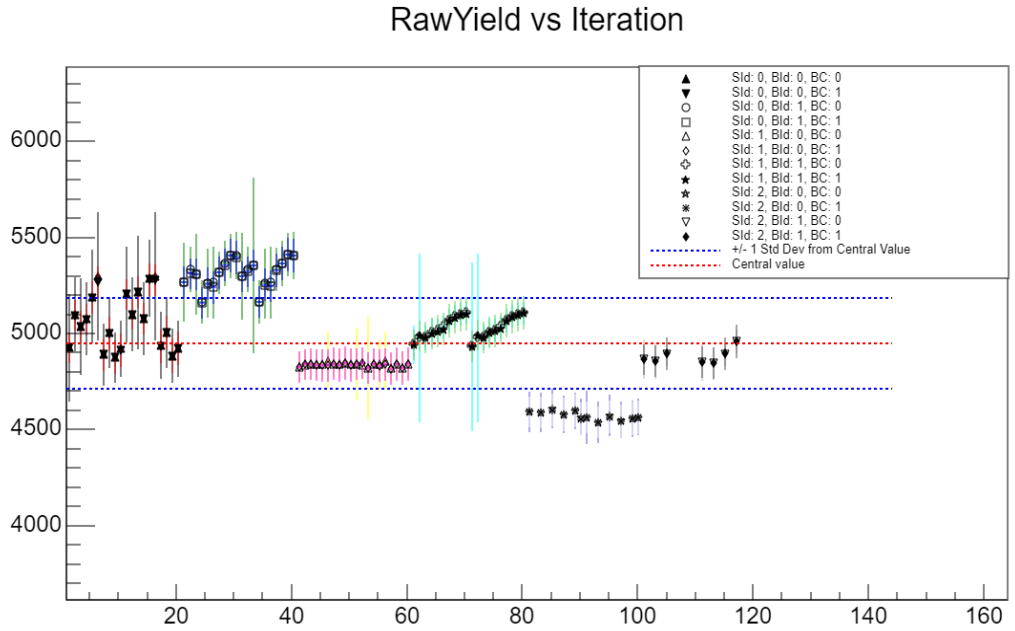


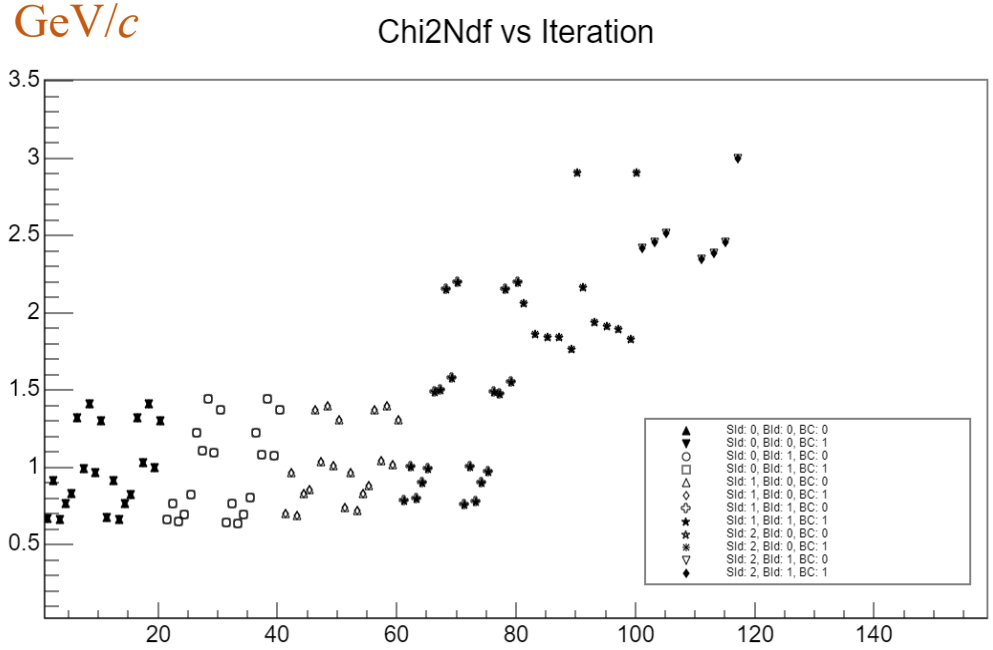
Systematic on Raw Yield-20



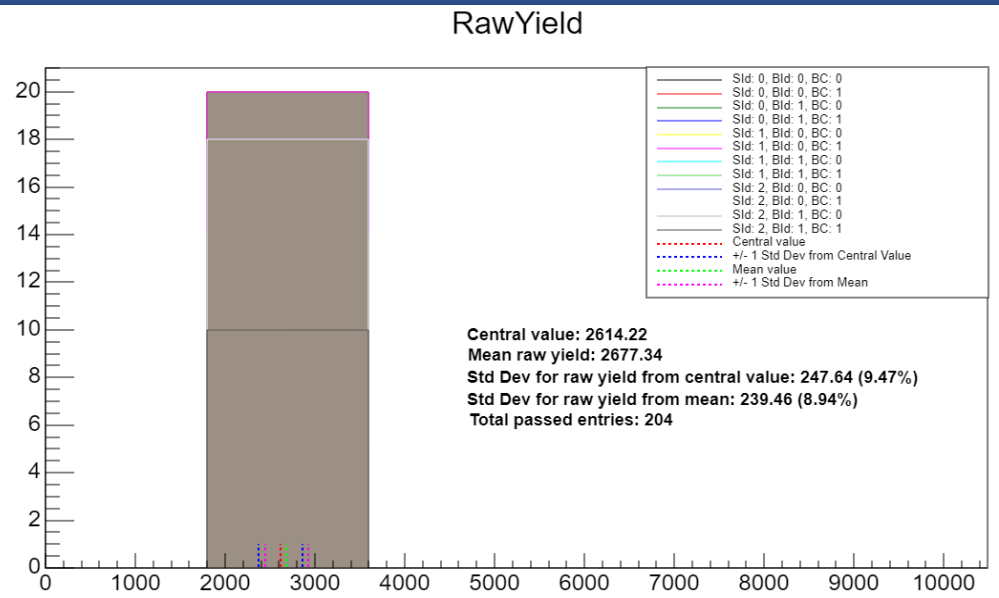


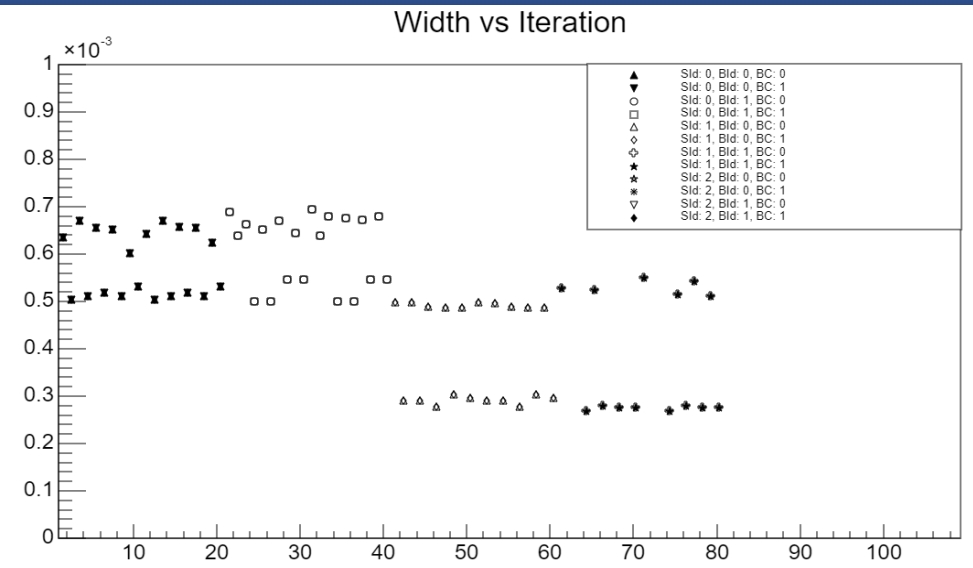
$16.0 < p_T < 20.0$ GeV/c



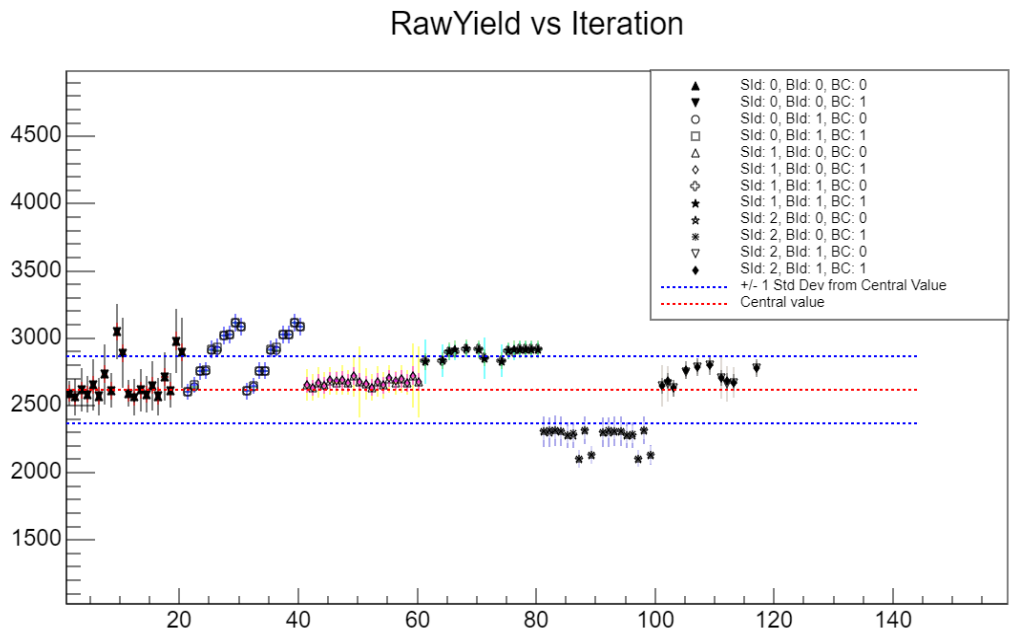


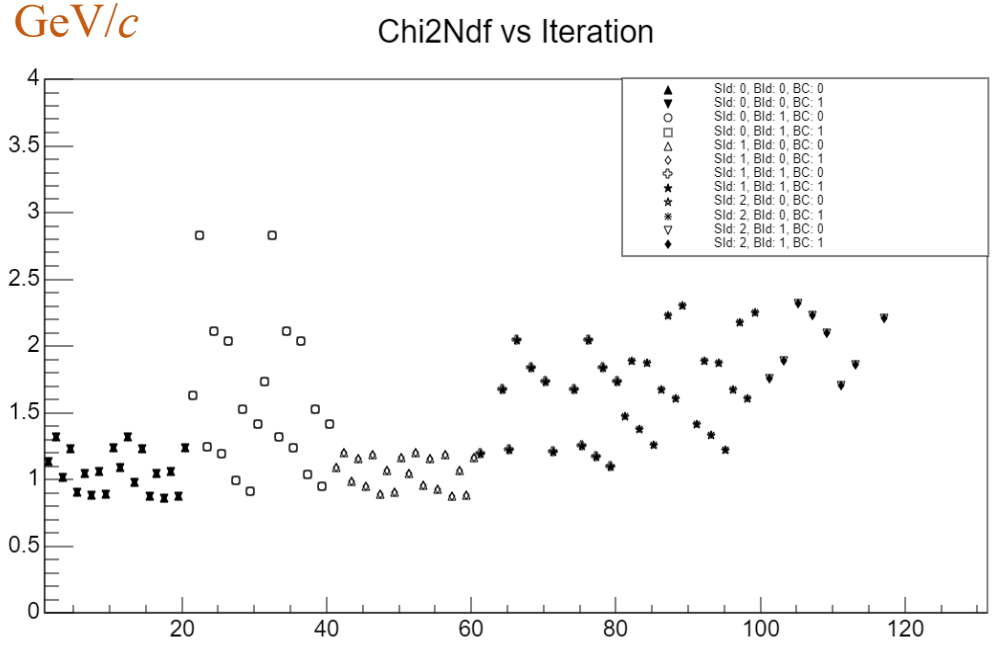
Systematic on Raw Yield-21



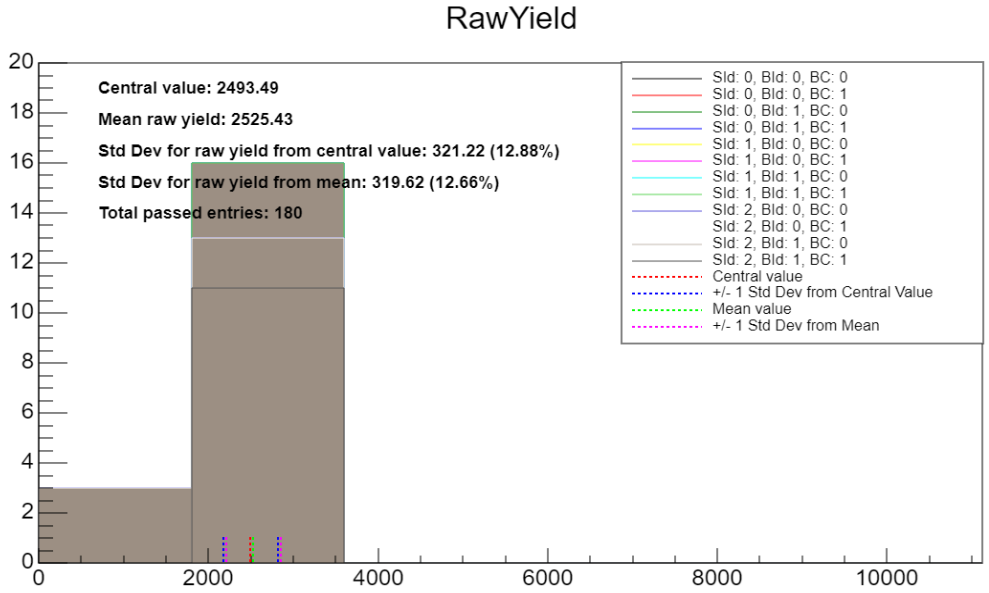


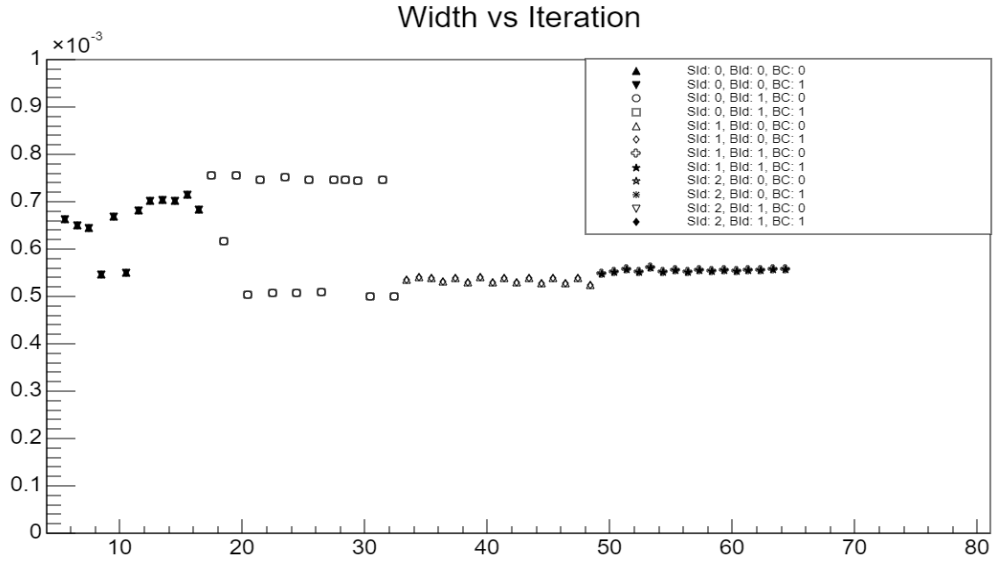
$20.0 < p_T < 24.0$ GeV/c



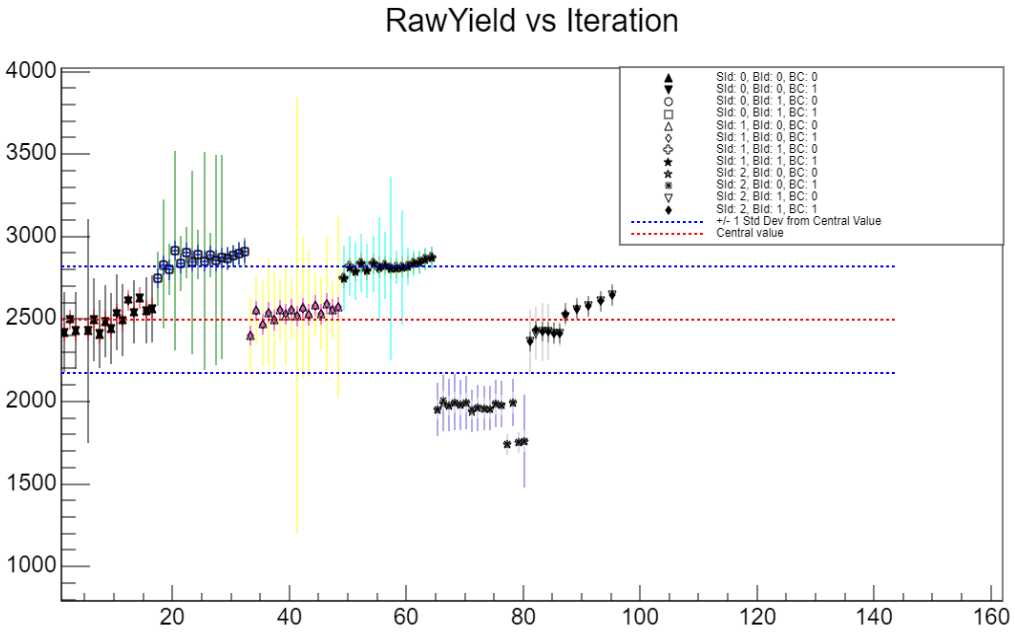


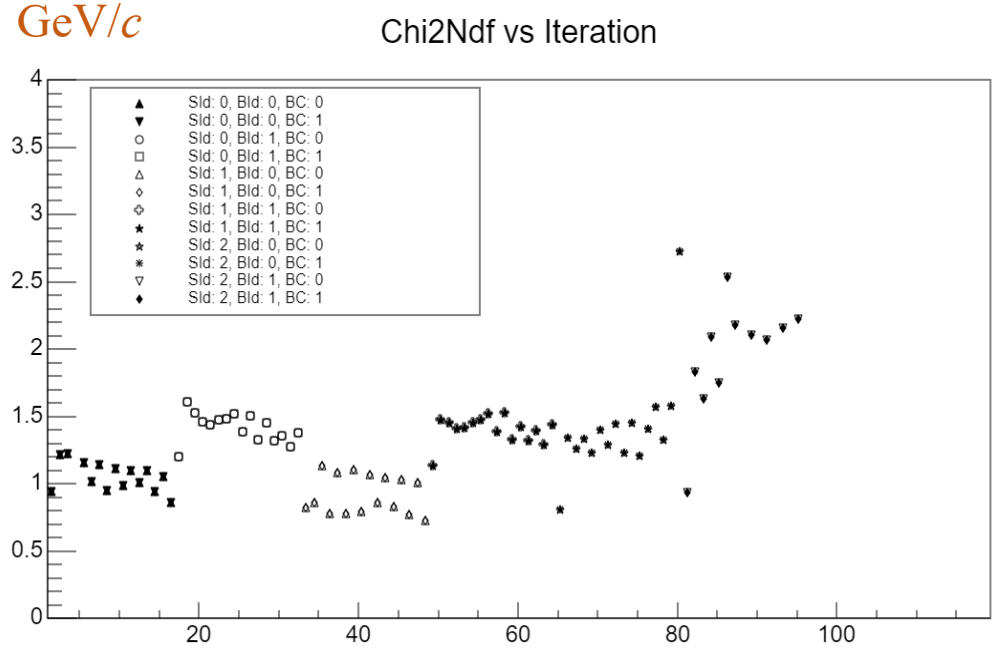
Systematic on Raw Yield-22

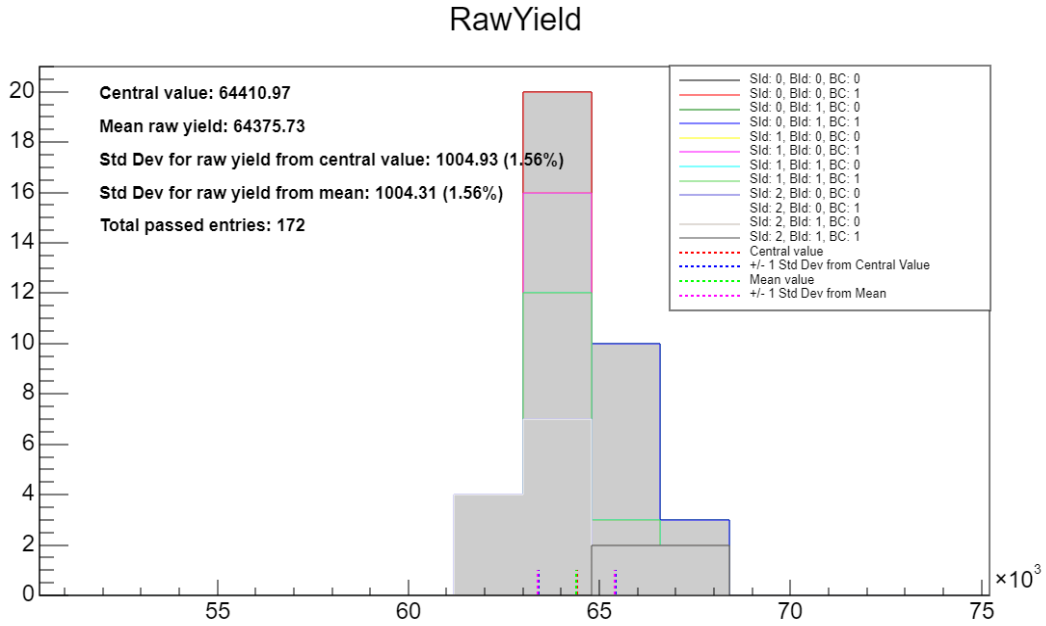


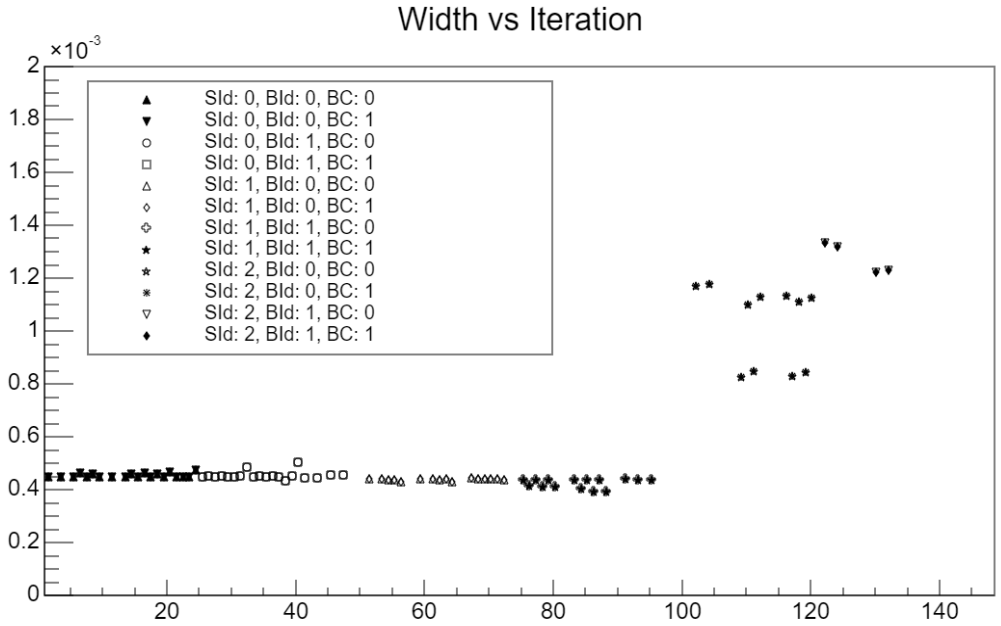


$24.0 < p_T < 36.0$ GeV/c

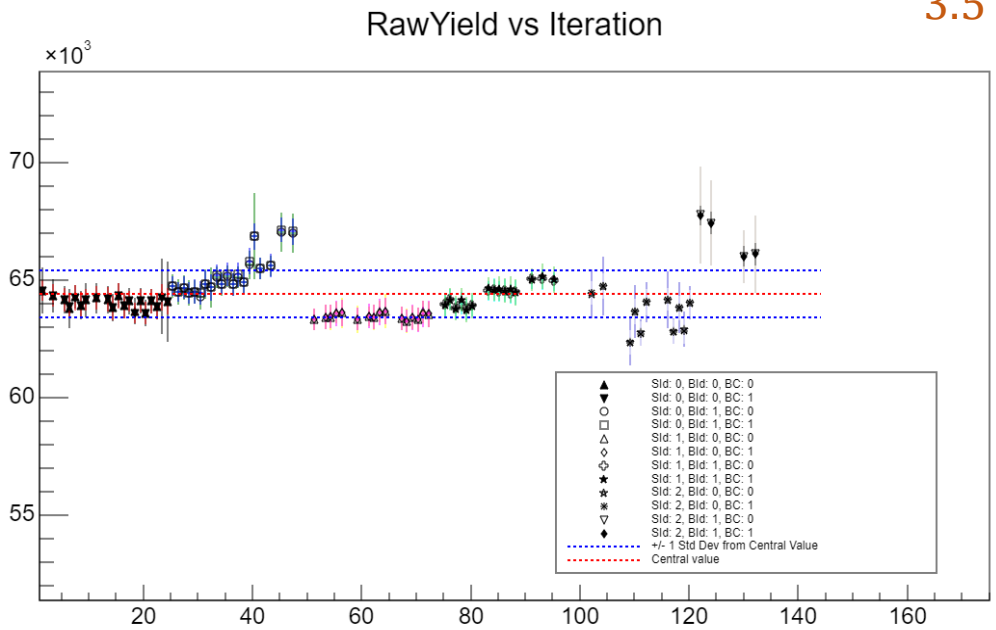


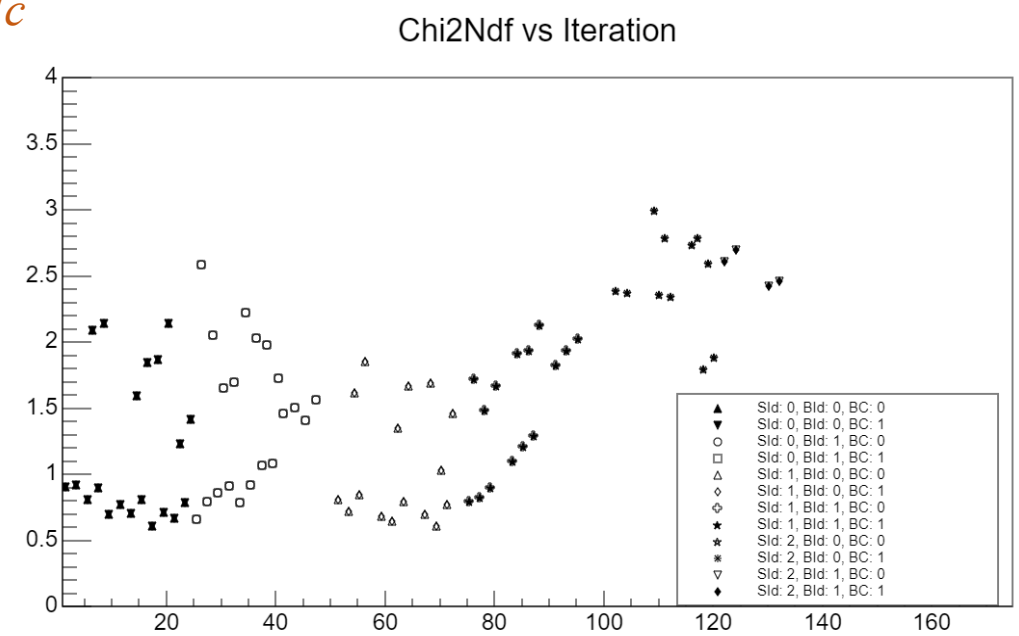


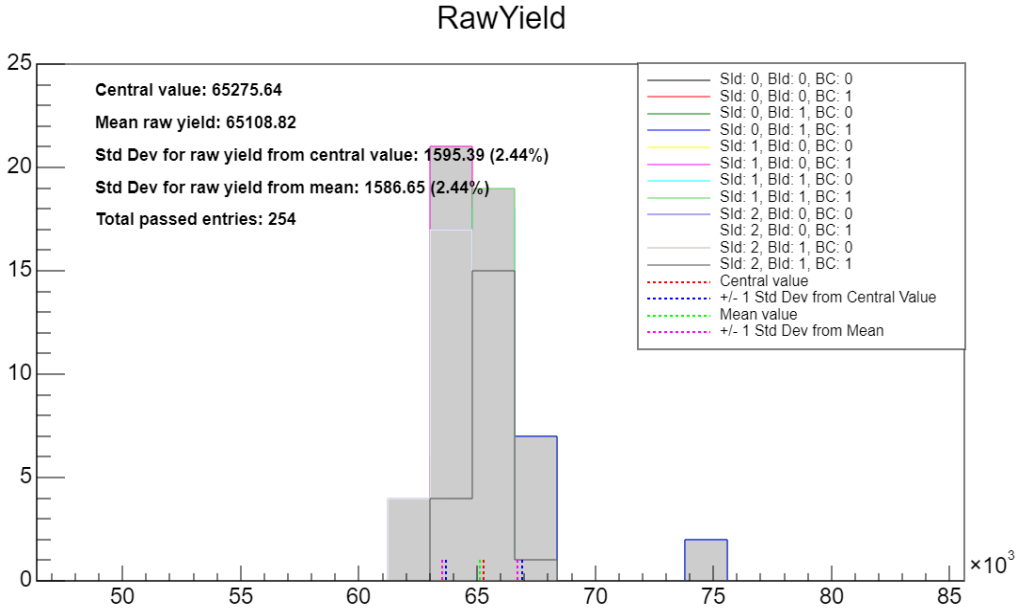

RawYield
Central value: 64410.97
Mean raw yield: 64375.73
Std Dev for raw yield from central value: 1004.93 (1.56%)
Std Dev for raw yield from mean: 1004.31 (1.56%)
Total passed entries: 172
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
Central value
+/- 1 Std Dev from Central Value
Mean value
+/- 1 Std Dev from Mean
×10^3

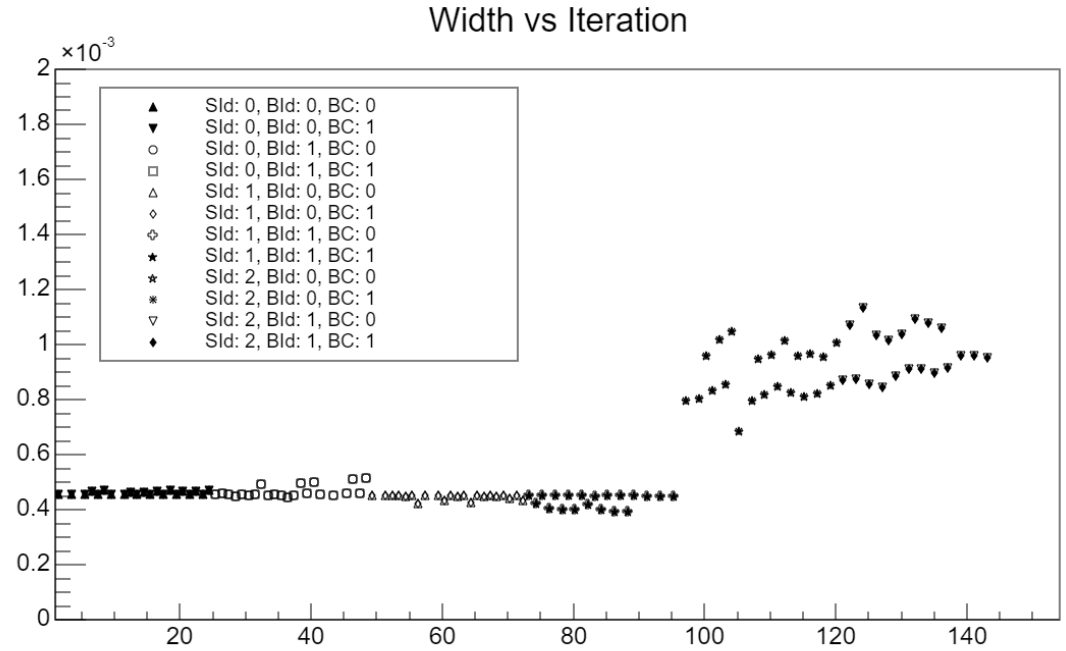

Width vs Iteration
×10^-3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

$3.5 < p_T < 4.0$ GeV/c

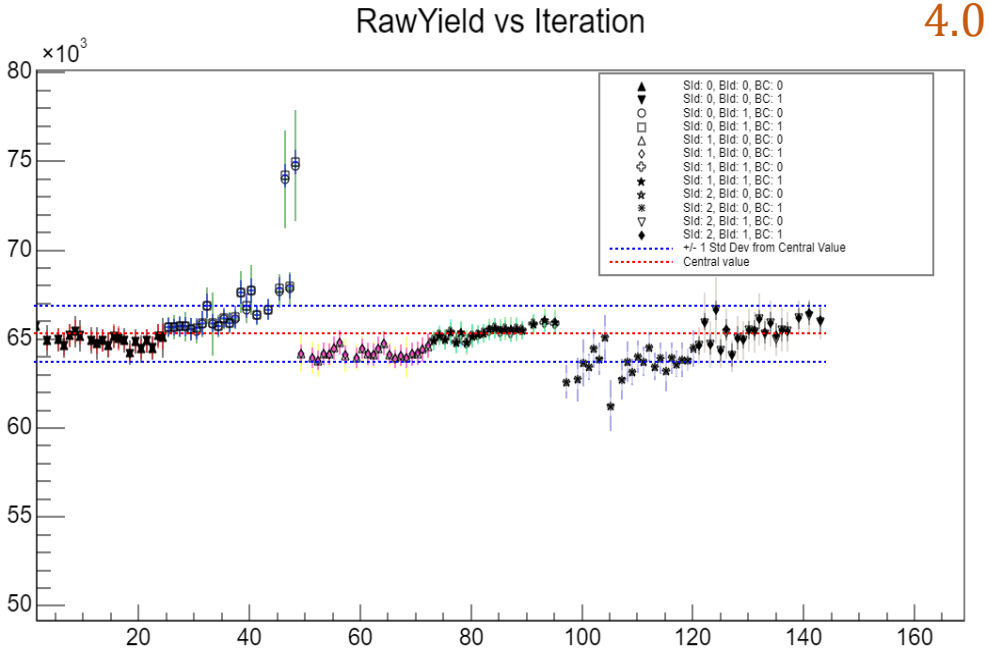

RawYield vs Iteration
×10^3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
+/- 1 Std Dev from Central Value
Central value

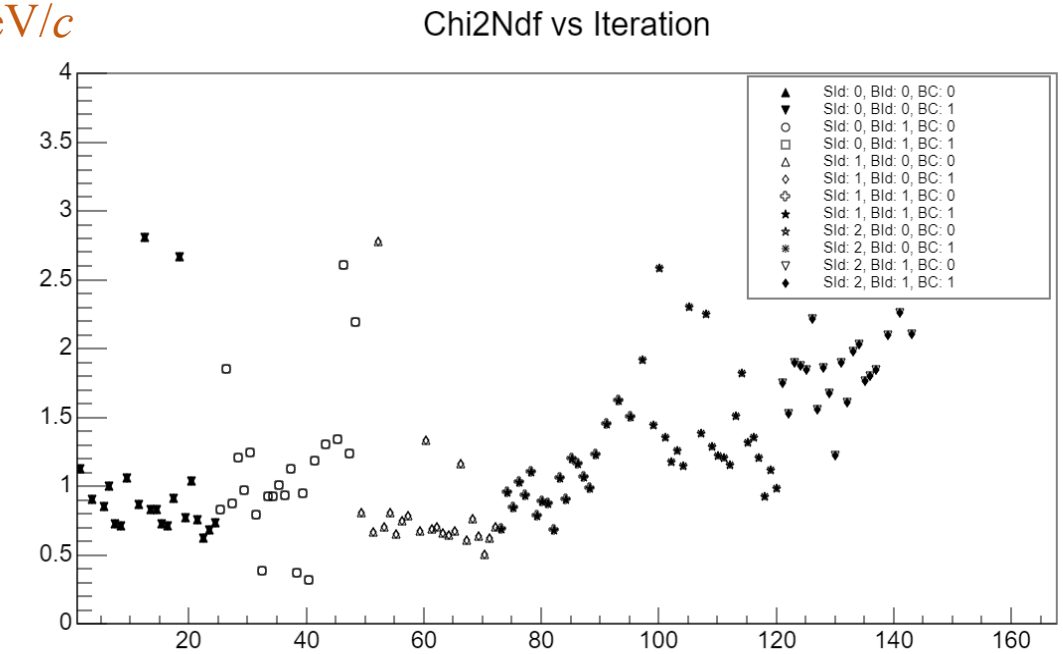

Chi2Ndf vs Iteration
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

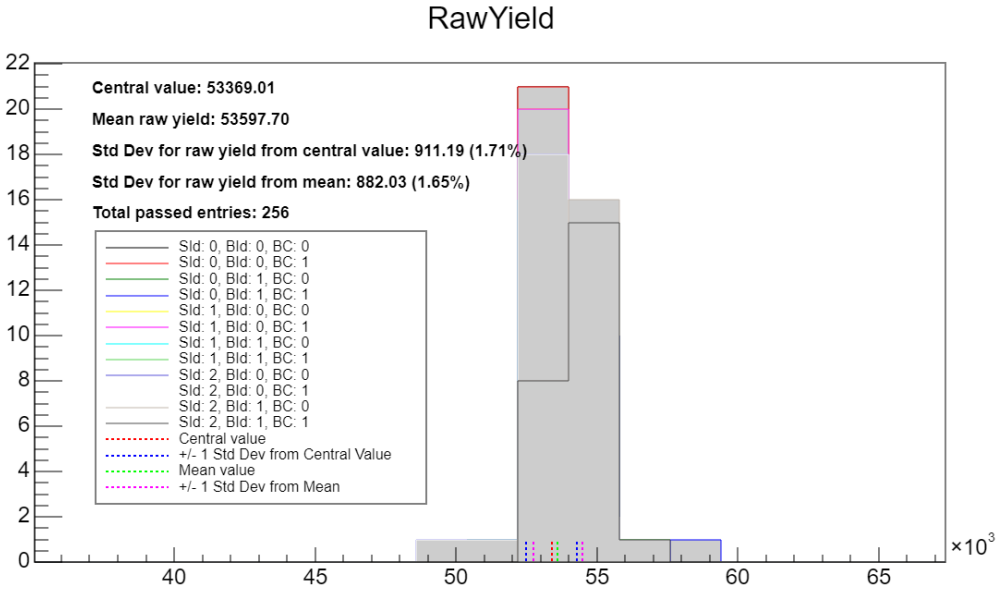

RawYield
Central value: 65275.64
Mean raw yield: 65108.82
Std Dev for raw yield from central value: 1595.39 (2.44%)
Std Dev for raw yield from mean: 1586.65 (2.44%)
Total passed entries: 254
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
Central value
+/- 1 Std Dev from Central Value
Mean value
+/- 1 Std Dev from Mean
×10^3

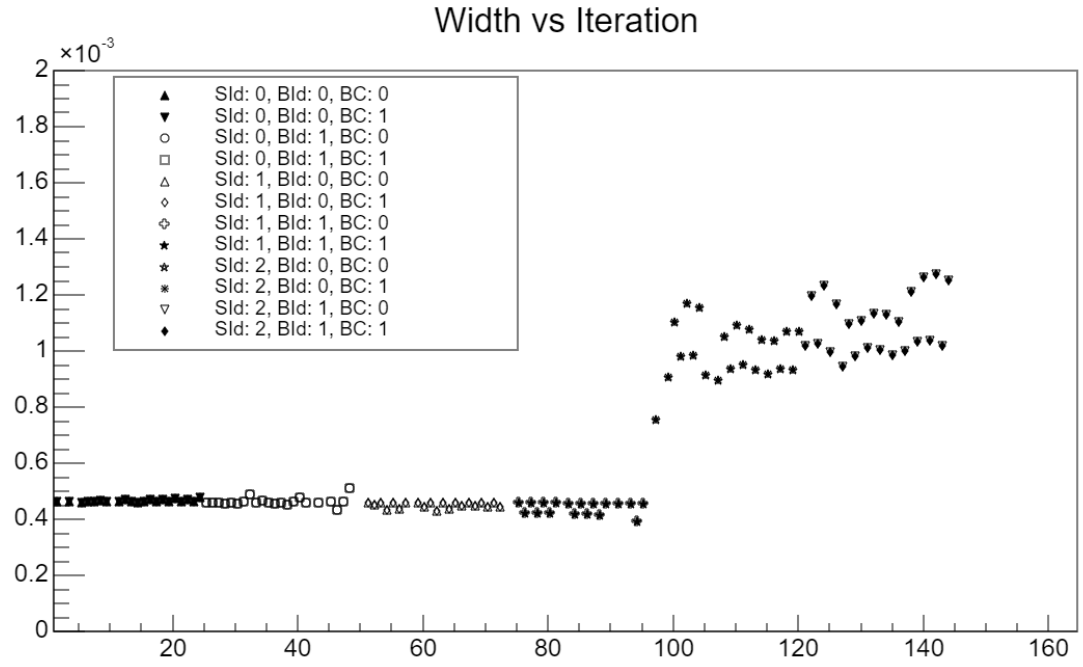

Width vs Iteration
×10^-3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

$4.0 < p_T < 4.5$ GeV/c

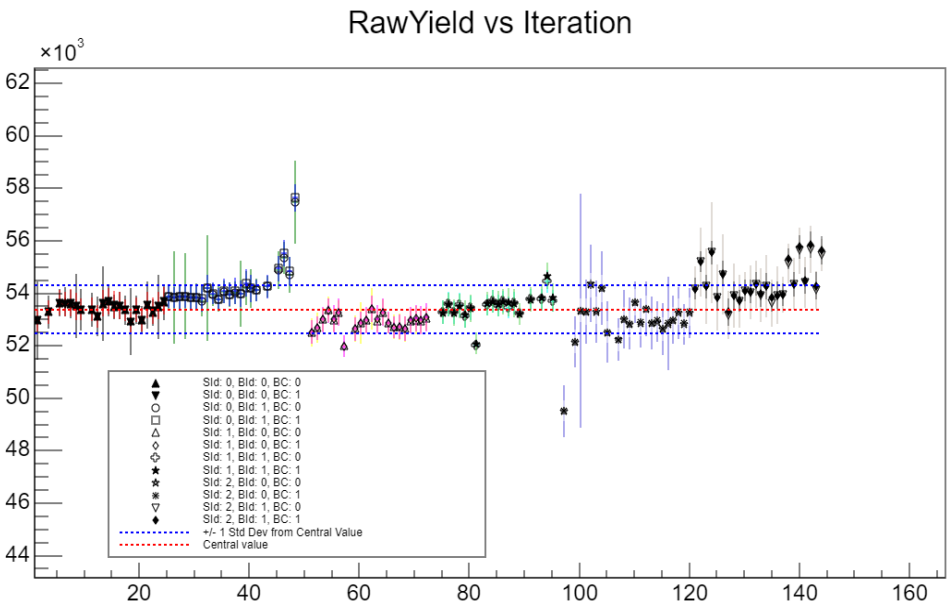

RawYield vs Iteration
×10^3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
+/- 1 Std Dev from Central Value
Central value

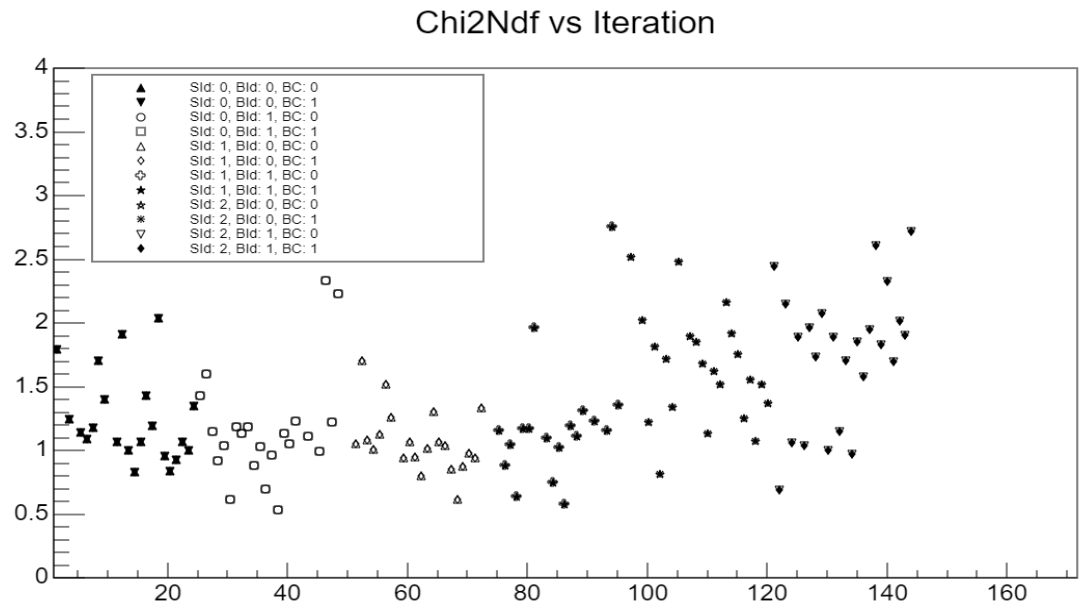

Chi2Ndf vs Iteration
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1


RawYield
Central value: 53369.01
Mean raw yield: 53597.70
Std Dev for raw yield from central value: 911.19 (1.71%)
Std Dev for raw yield from mean: 882.03 (1.65%)
Total passed entries: 256
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
Central value
+/- 1 Std Dev from Central Value
Mean value
+/- 1 Std Dev from Mean
×10^3

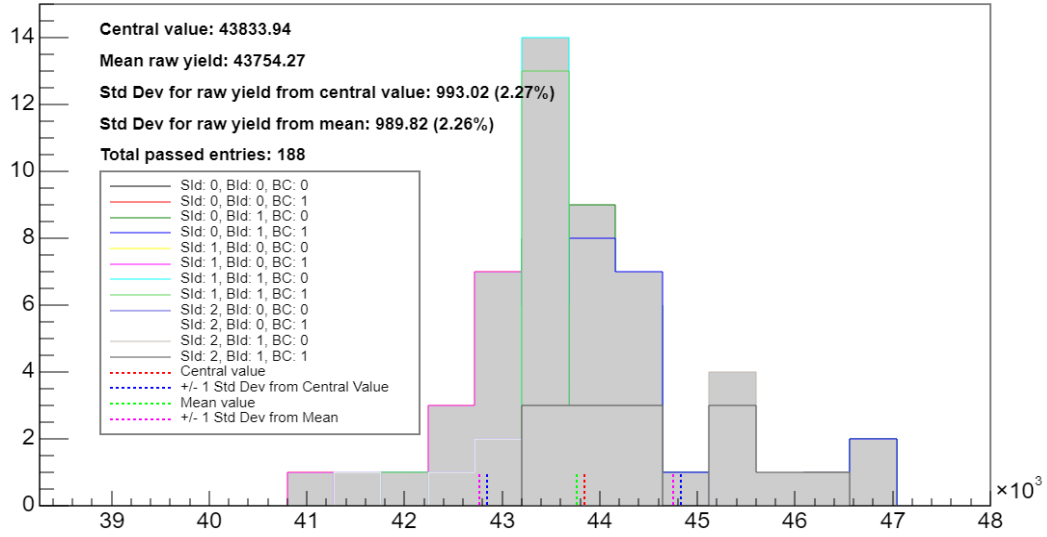

Width vs Iteration
×10^-3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

$4.5 < p_T < 5.0$ GeV/c

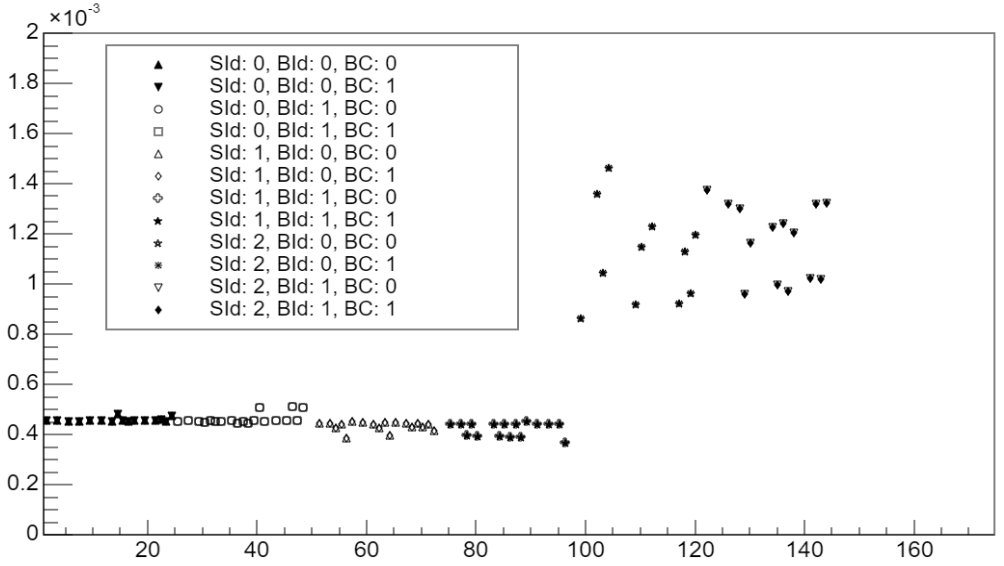

RawYield vs Iteration
×10^3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
+/- 1 Std Dev from Central Value
Central value


Chi2Ndf vs Iteration
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

RawYield

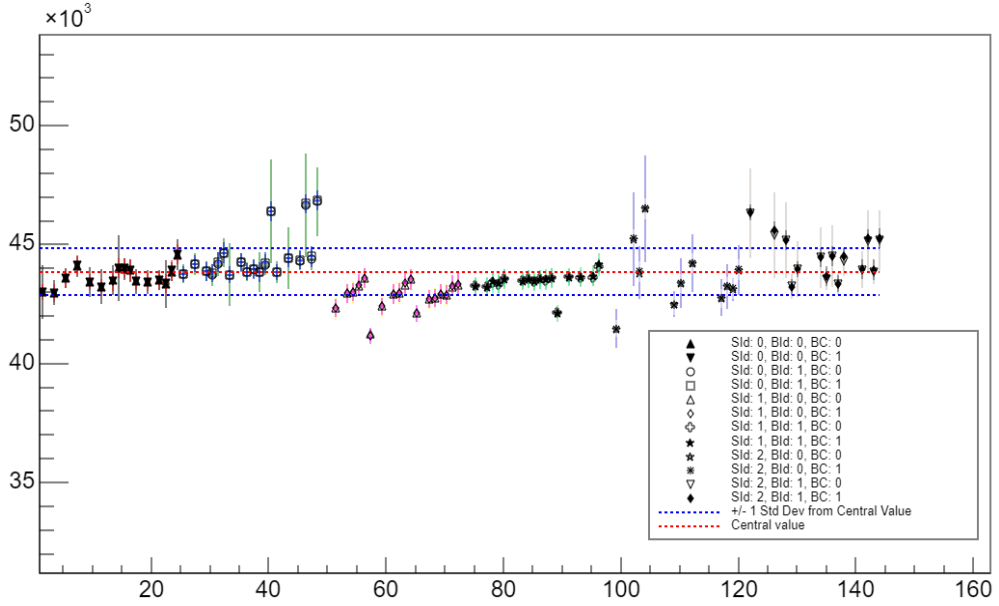


Width vs Iteration

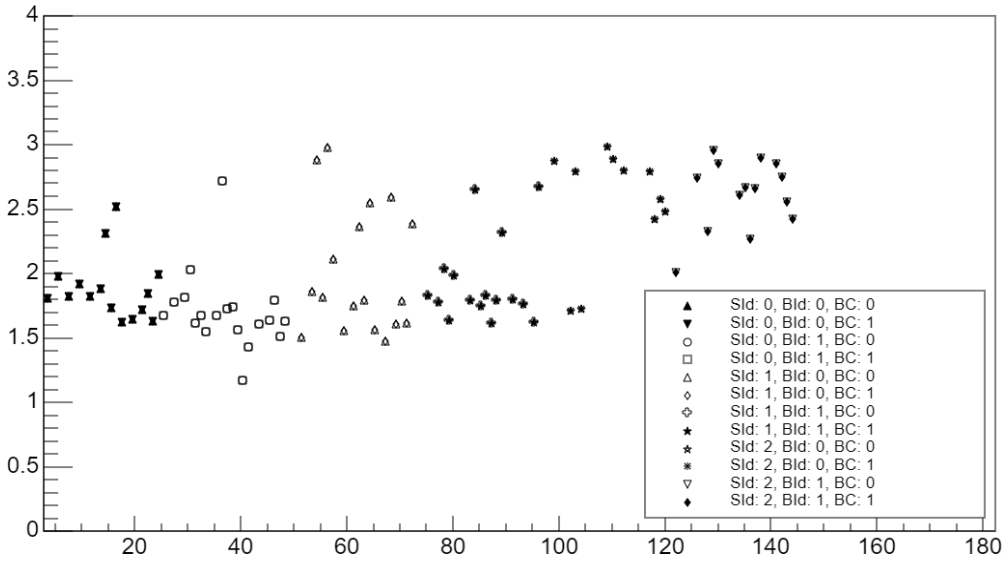


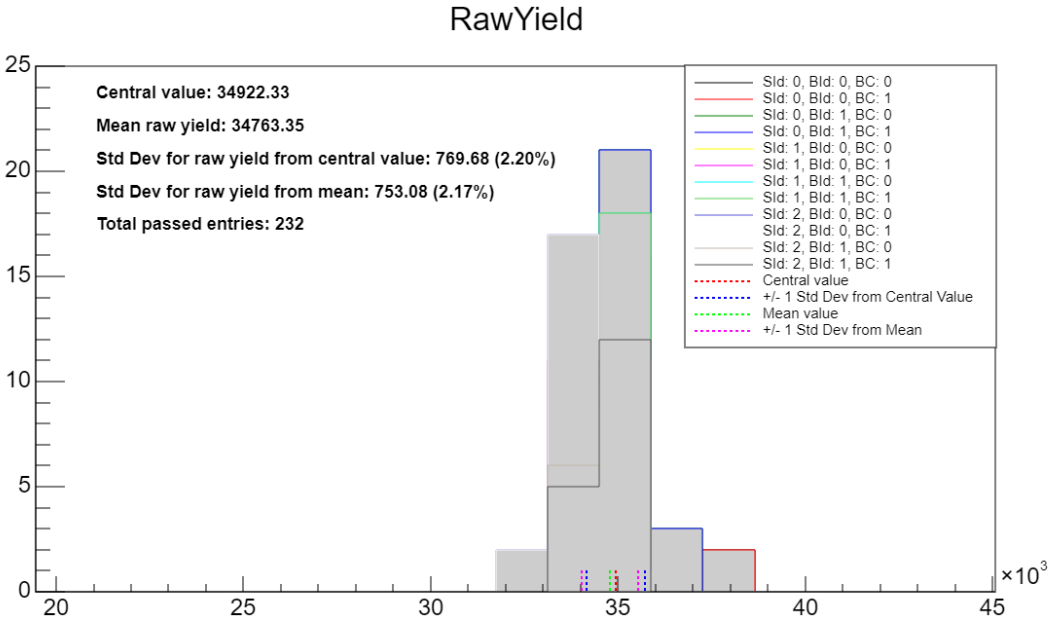
$5.0 < p_T < 5.5$ GeV/c

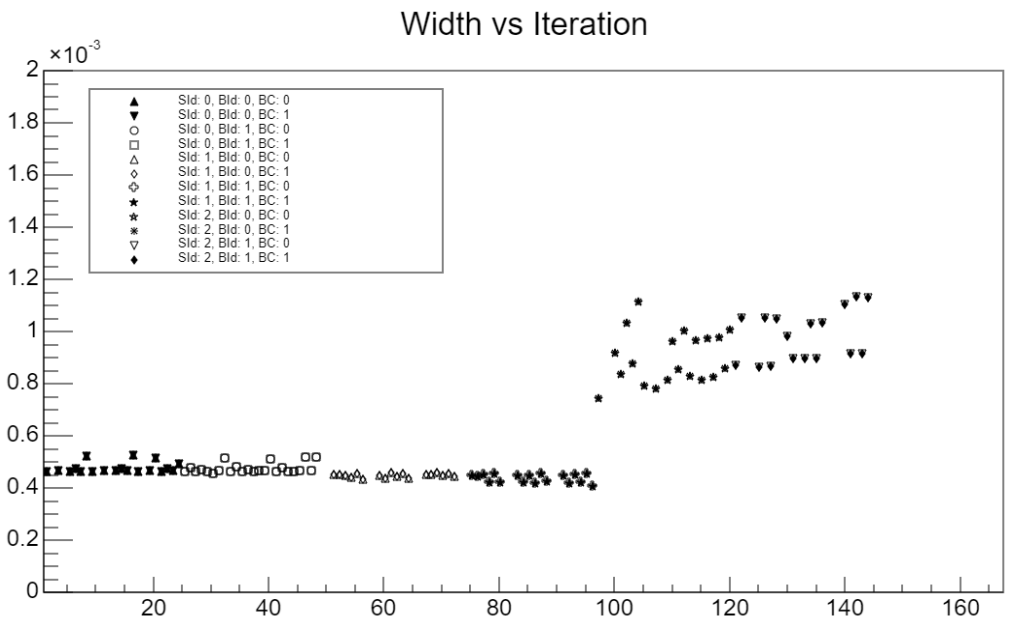
RawYield vs Iteration



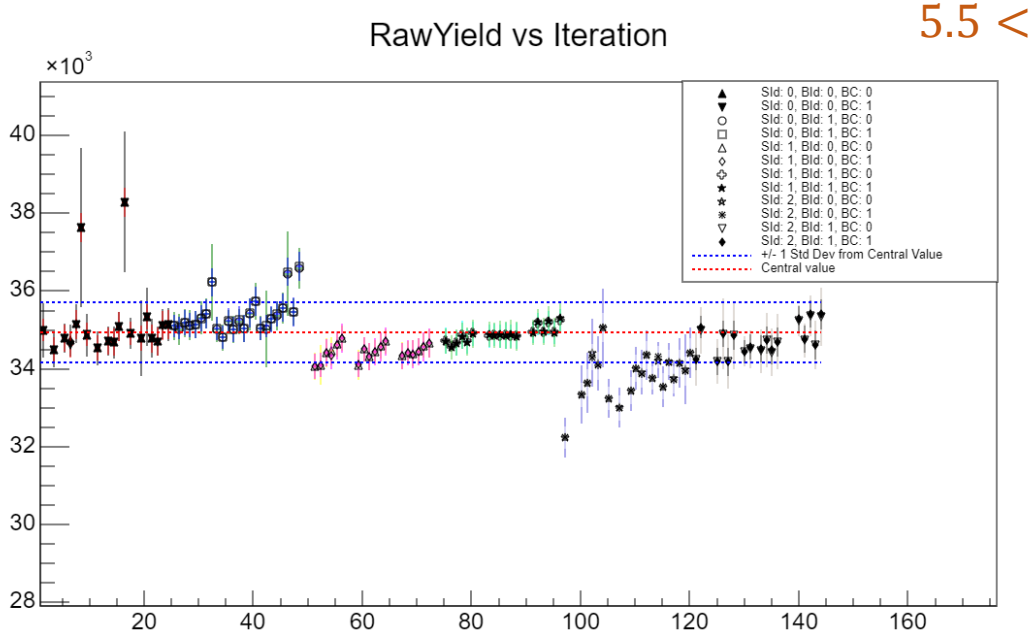
Chi2Ndf vs Iteration

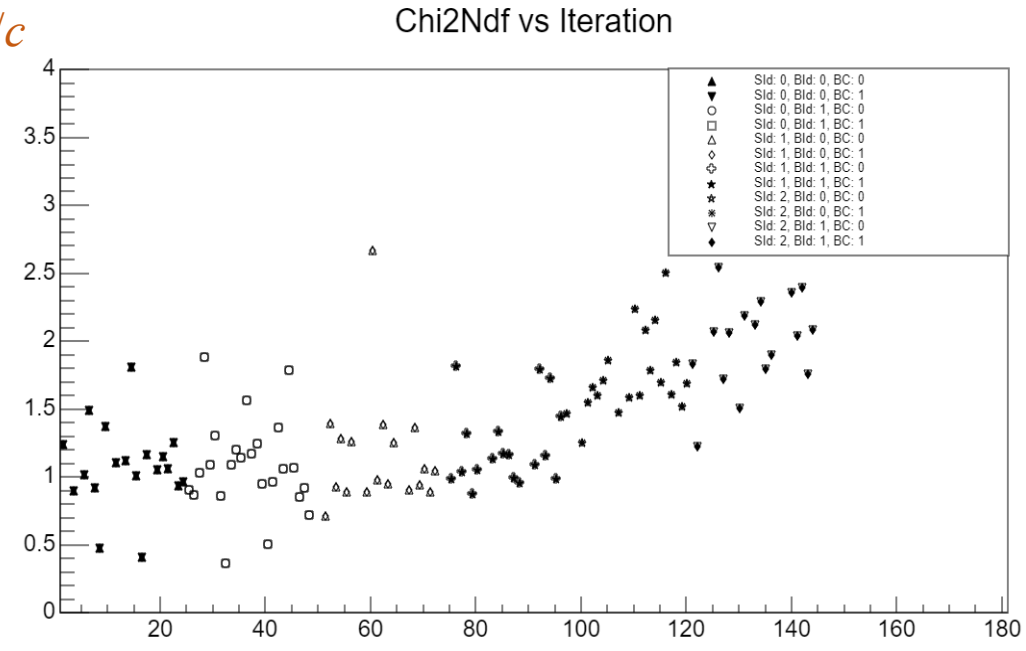


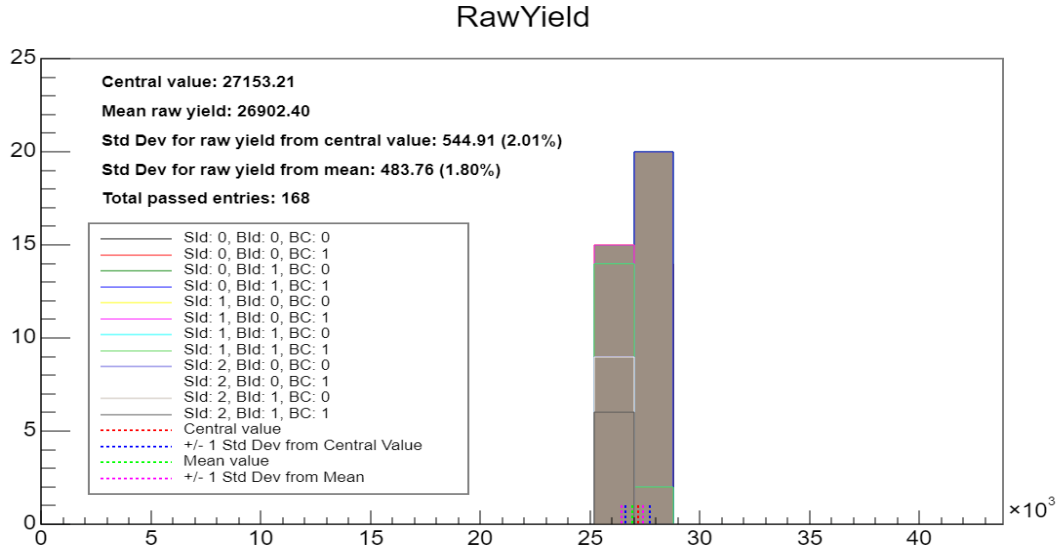

RawYield
Central value: 34922.33
Mean raw yield: 34763.35
Std Dev for raw yield from central value: 769.68 (2.20%)
Std Dev for raw yield from mean: 753.08 (2.17%)
Total passed entries: 232
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
Central value
+/- 1 Std Dev from Central Value
Mean value
+/- 1 Std Dev from Mean
×10^3

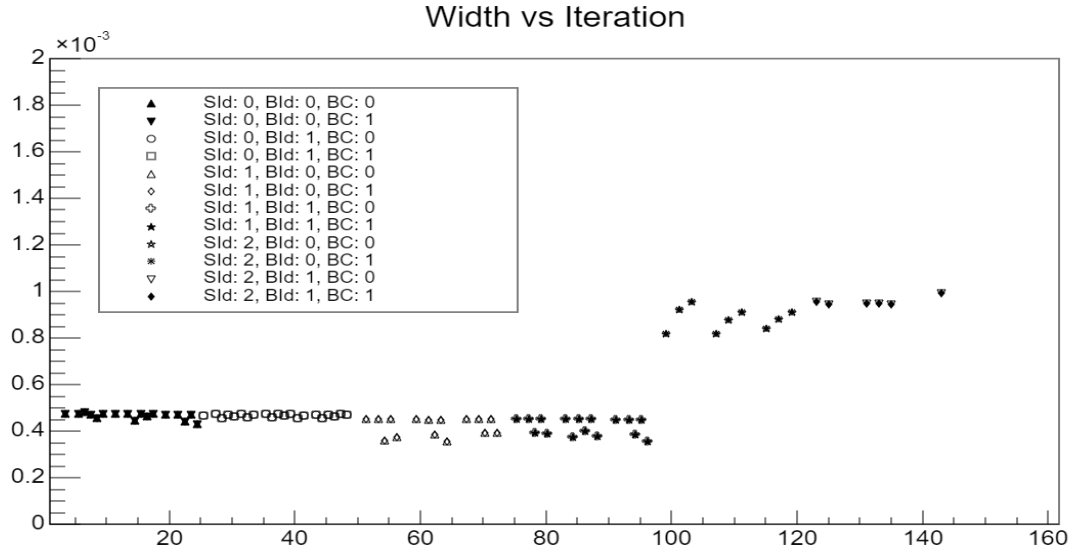

Width vs Iteration
×10^-3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

$5.5 < p_T < 6.0$ GeV/c

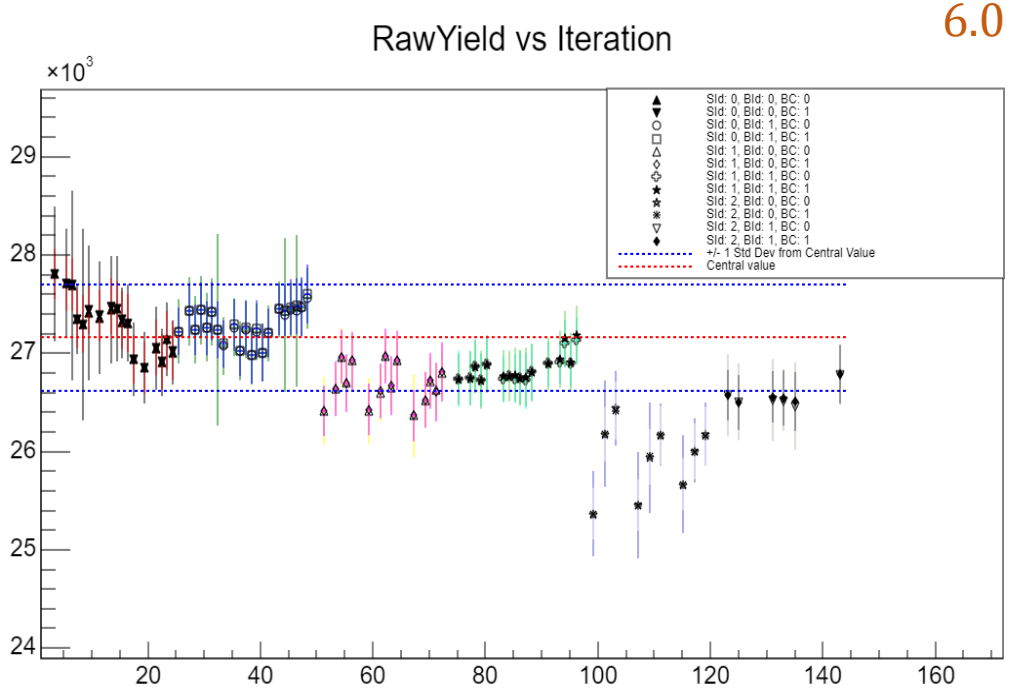

RawYield vs Iteration
×10^3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
+/- 1 Std Dev from Central Value
Central value

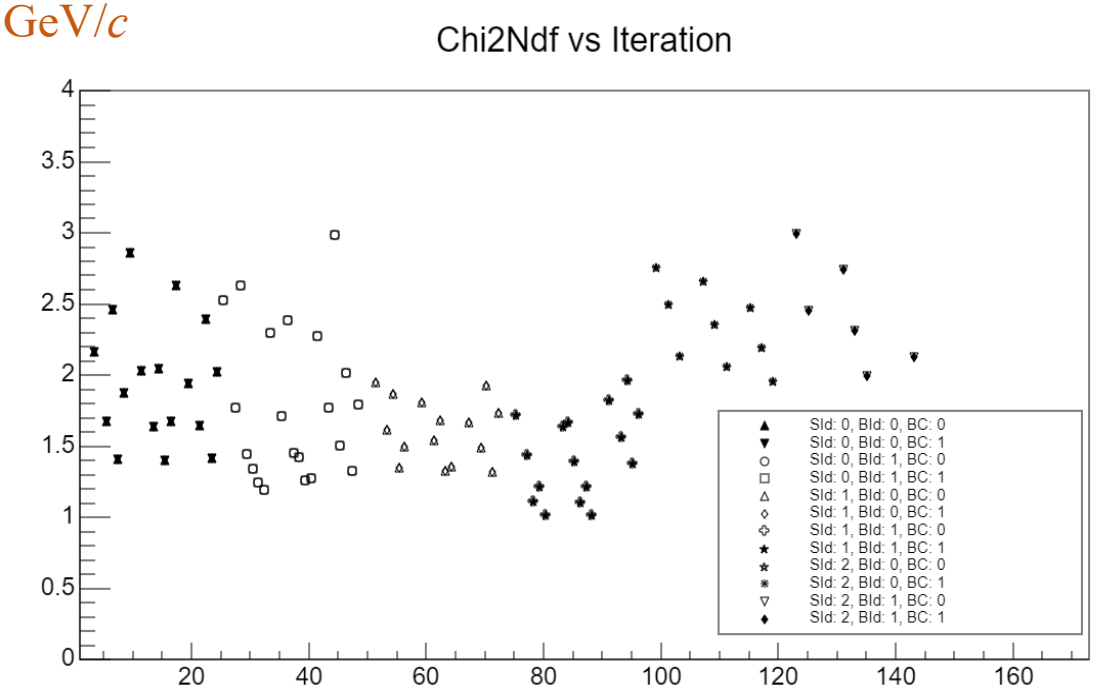

Chi2Ndf vs Iteration
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

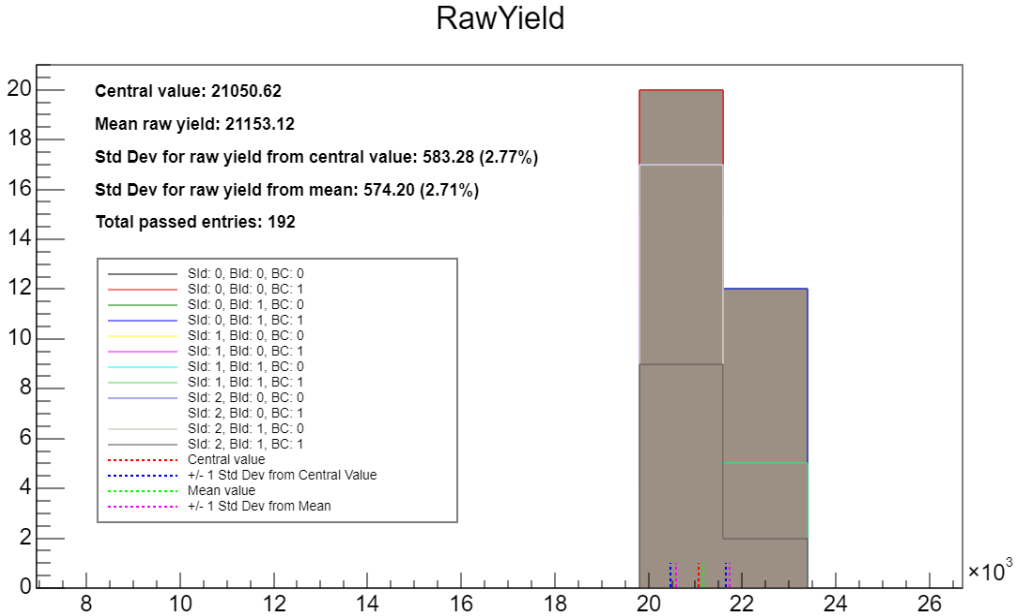

RawYield
Central value: 27153.21
Mean raw yield: 26902.40
Std Dev for raw yield from central value: 544.91 (2.01%)
Std Dev for raw yield from mean: 483.76 (1.80%)
Total passed entries: 168
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
Central value
+/- 1 Std Dev from Central Value
Mean value
+/- 1 Std Dev from Mean
×10^3

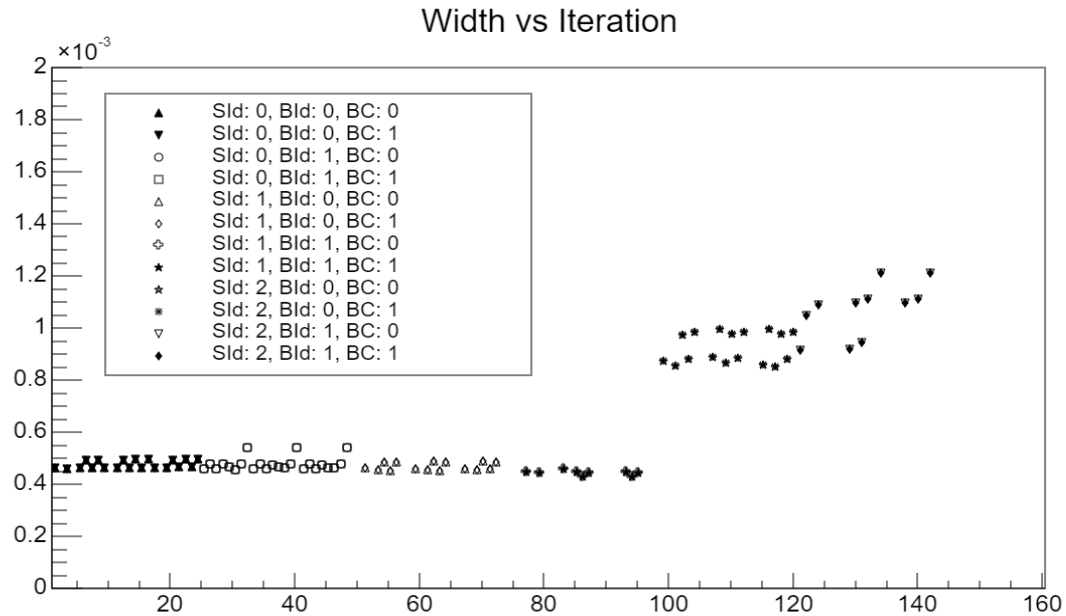

Width vs Iteration
×10^-3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

$6.0 < p_T < 6.5$ GeV/c

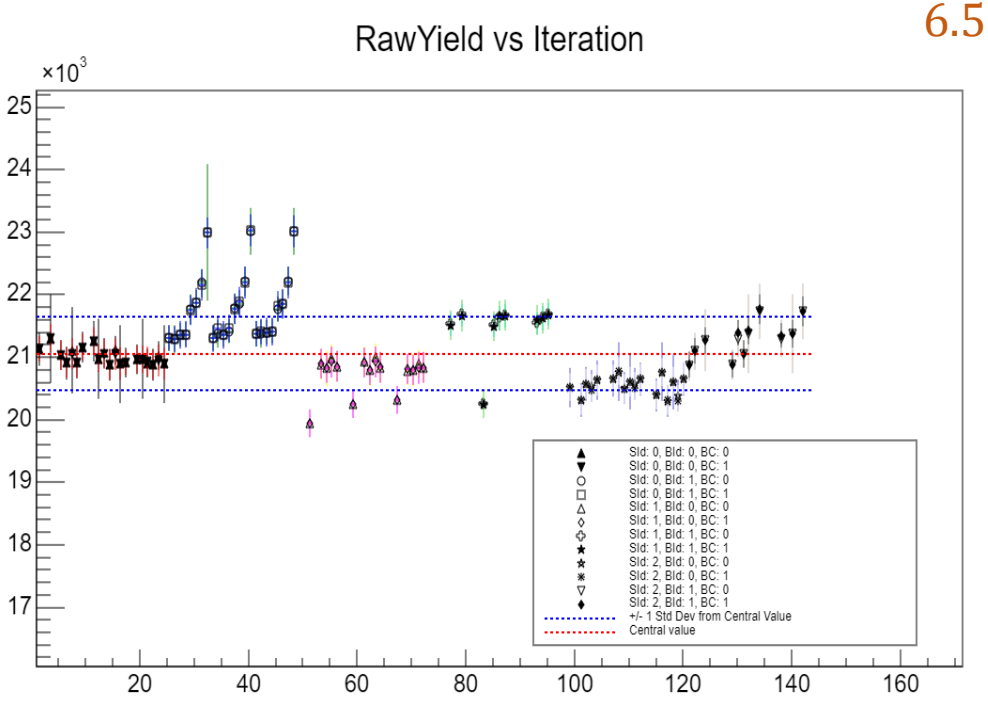

RawYield vs Iteration
×10^3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
+/- 1 Std Dev from Central Value
Central value

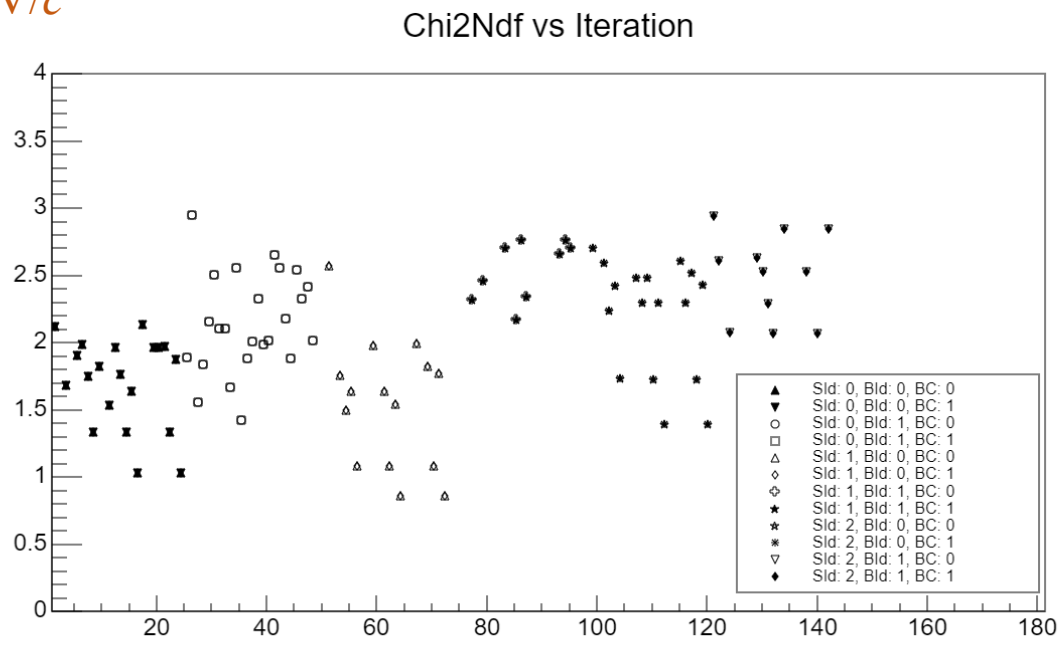

Chi2Ndf vs Iteration
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1


RawYield
Central value: 21050.62
Mean raw yield: 21153.12
Std Dev for raw yield from central value: 583.28 (2.77%)
Std Dev for raw yield from mean: 574.20 (2.71%)
Total passed entries: 192
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
Central value
+/- 1 Std Dev from Central Value
Mean value
+/- 1 Std Dev from Mean
×10^3

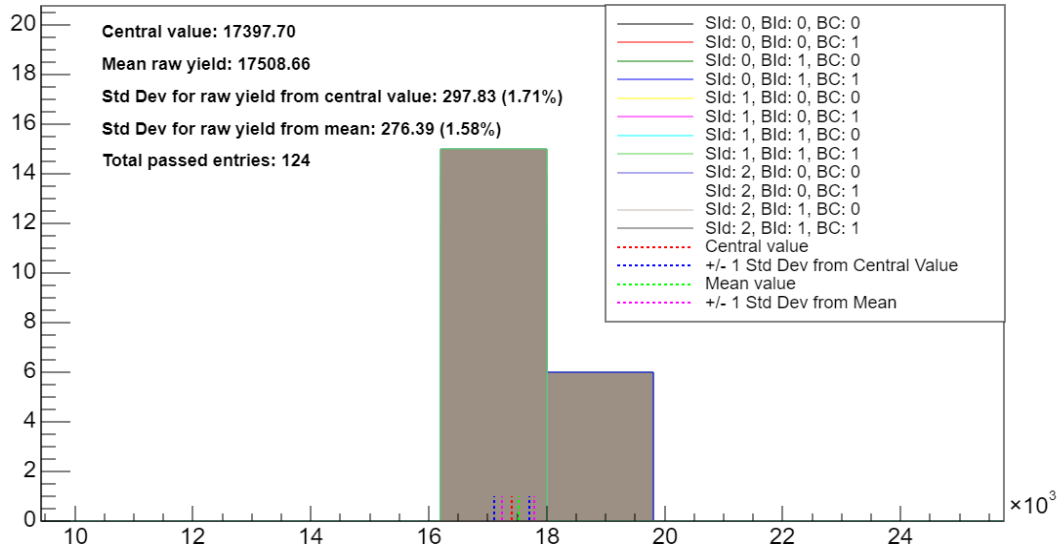

Width vs Iteration
×10^-3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

$6.5 < p_T < 7.0$ GeV/c

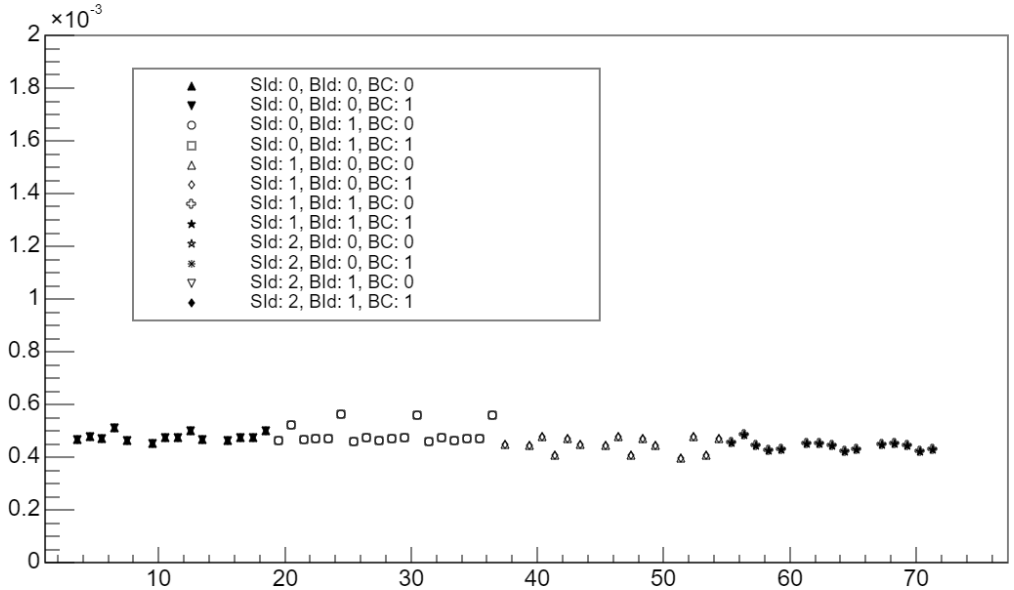

RawYield vs Iteration
×10^3
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1
+/- 1 Std Dev from Central Value
Central value


Chi2Ndf vs Iteration
SId: 0, BId: 0, BC: 0
SId: 0, BId: 0, BC: 1
SId: 0, BId: 1, BC: 0
SId: 0, BId: 1, BC: 1
SId: 1, BId: 0, BC: 0
SId: 1, BId: 0, BC: 1
SId: 1, BId: 1, BC: 0
SId: 1, BId: 1, BC: 1
SId: 2, BId: 0, BC: 0
SId: 2, BId: 0, BC: 1
SId: 2, BId: 1, BC: 0
SId: 2, BId: 1, BC: 1

RawYield

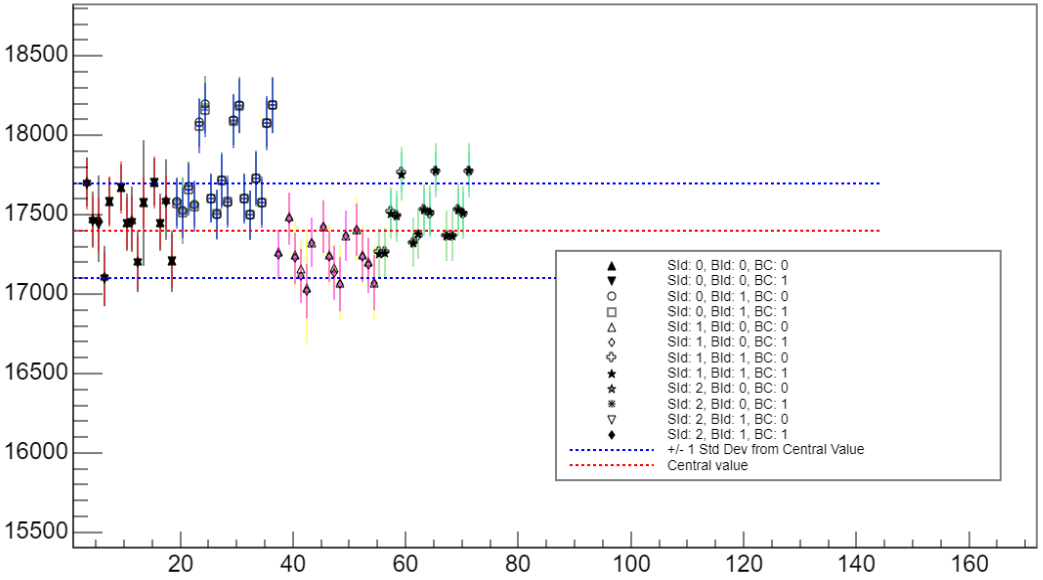


Width vs Iteration

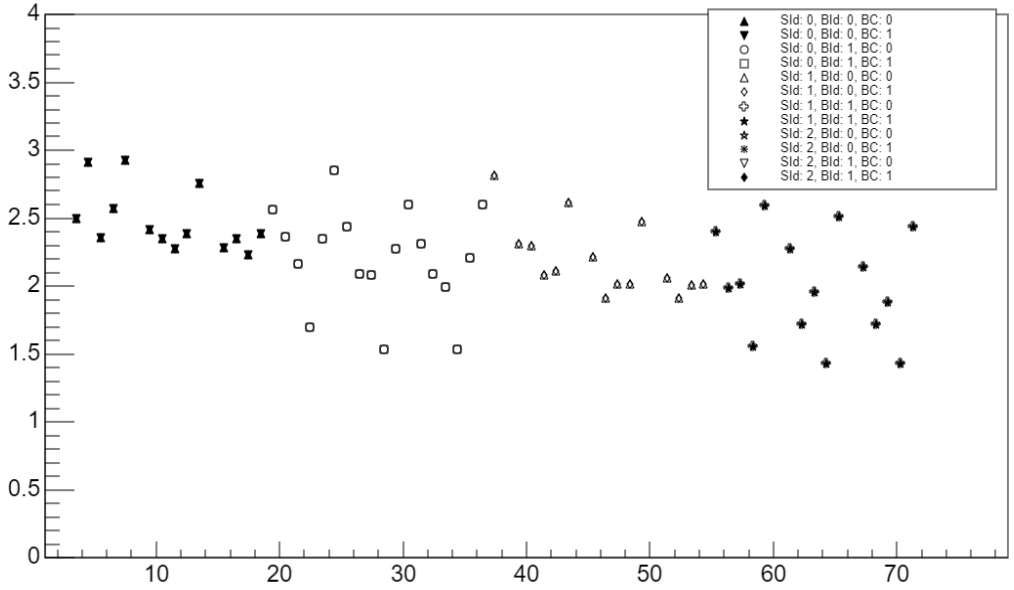


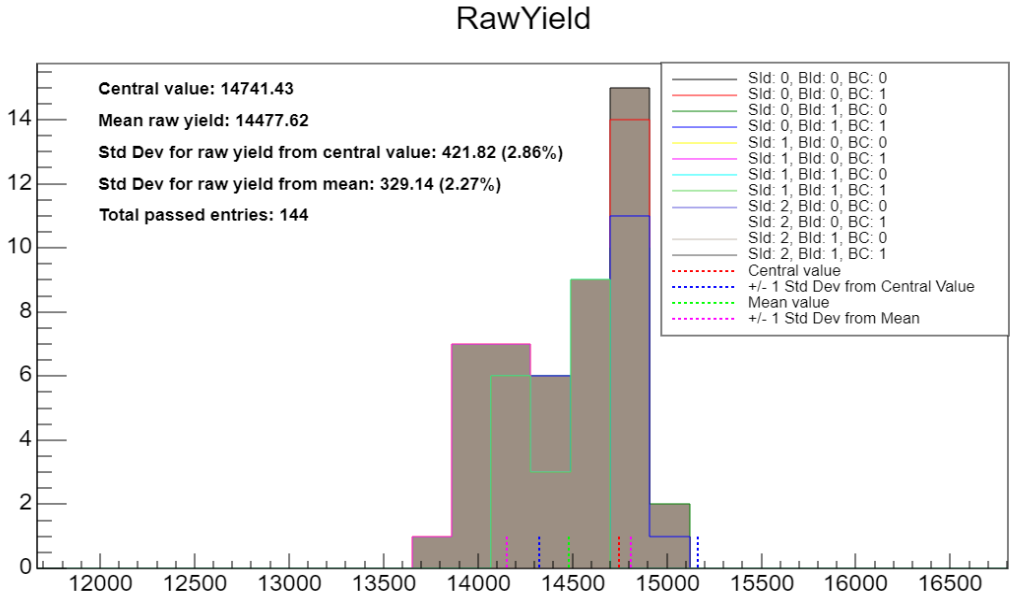
RawYield vs Iteration

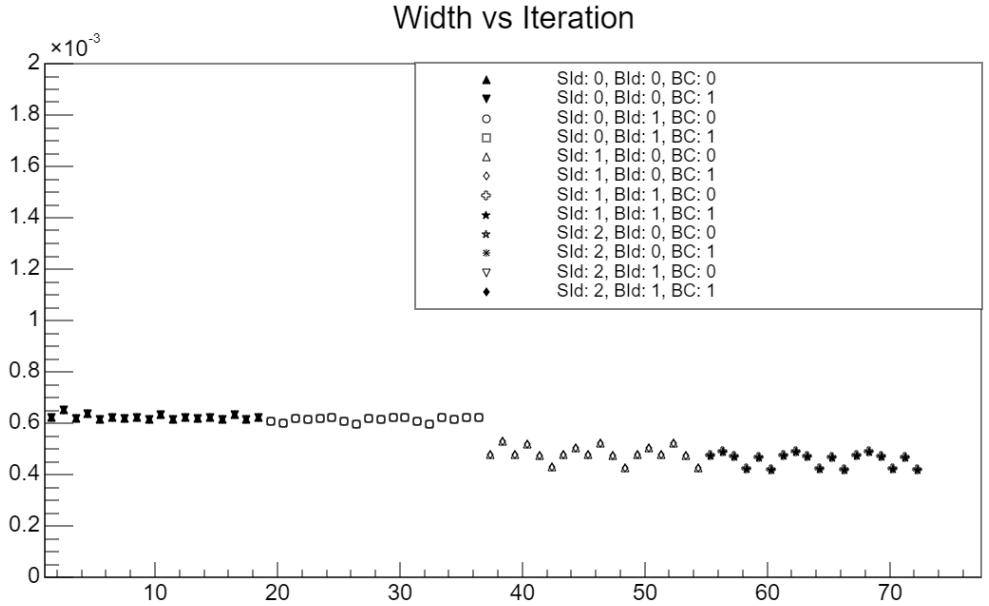
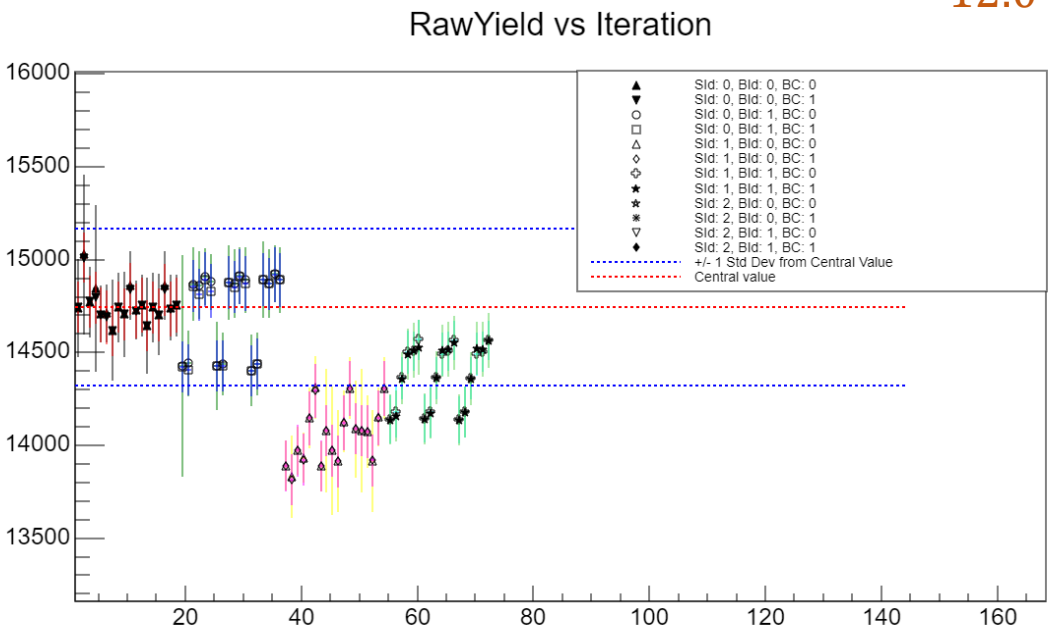
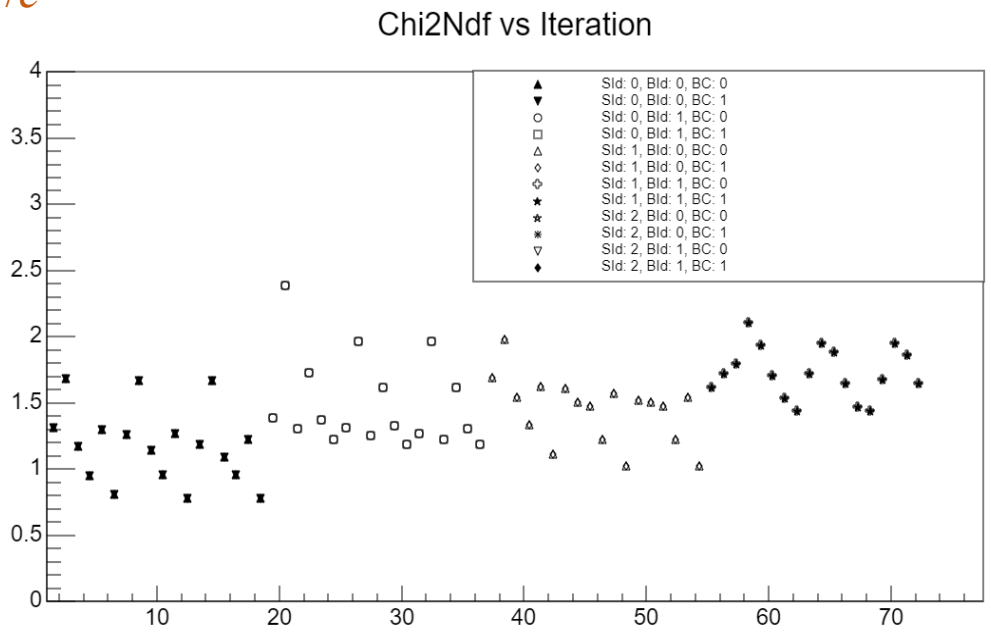
$10.0 < p_T < 12.0$ GeV/c



Chi2Ndf vs Iteration







$12.0 < p_T < 16.0$ GeV/c