Non-prompt $\Lambda_c \rightarrow pK\pi$ production in p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV with ALICE

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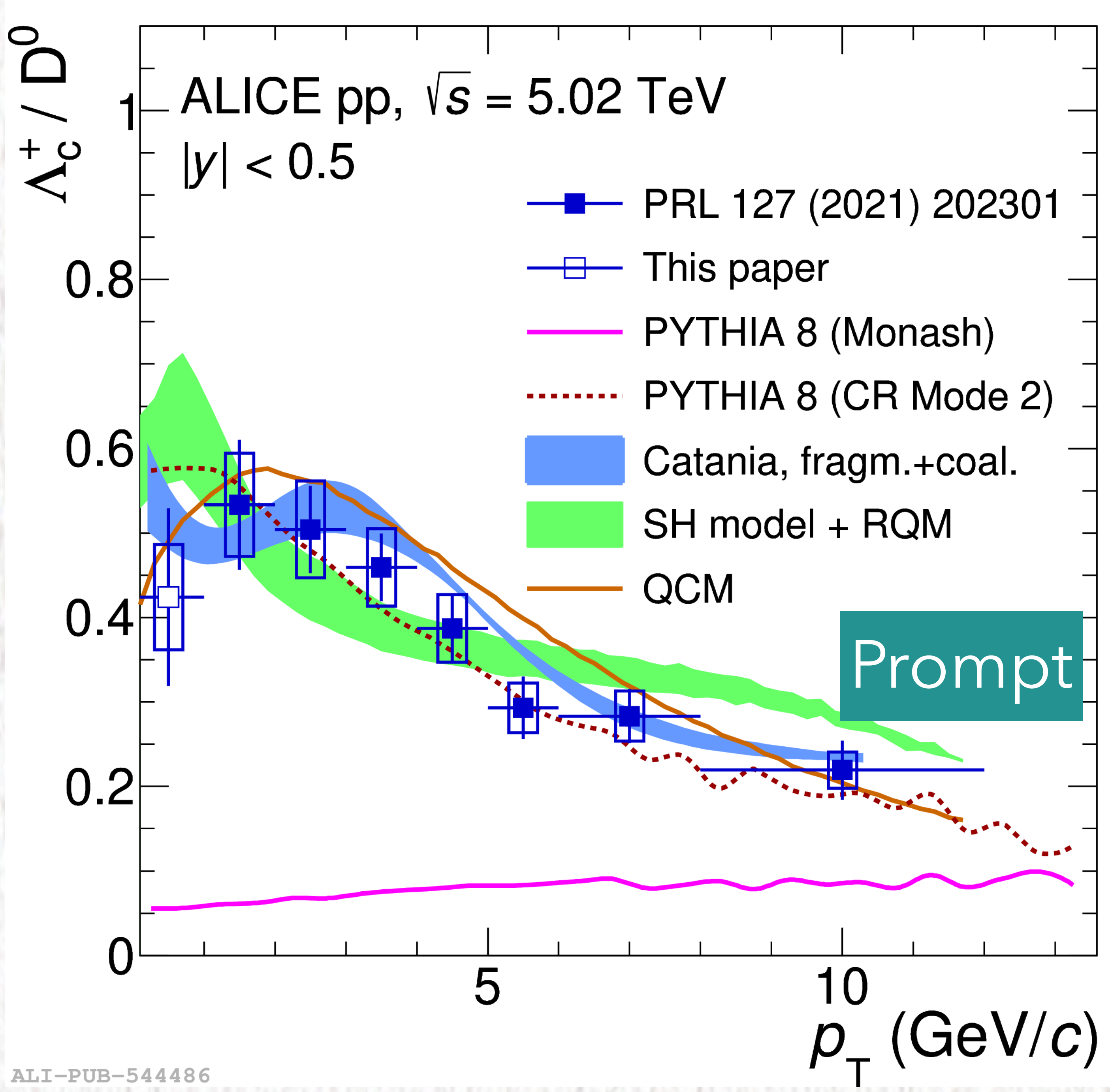
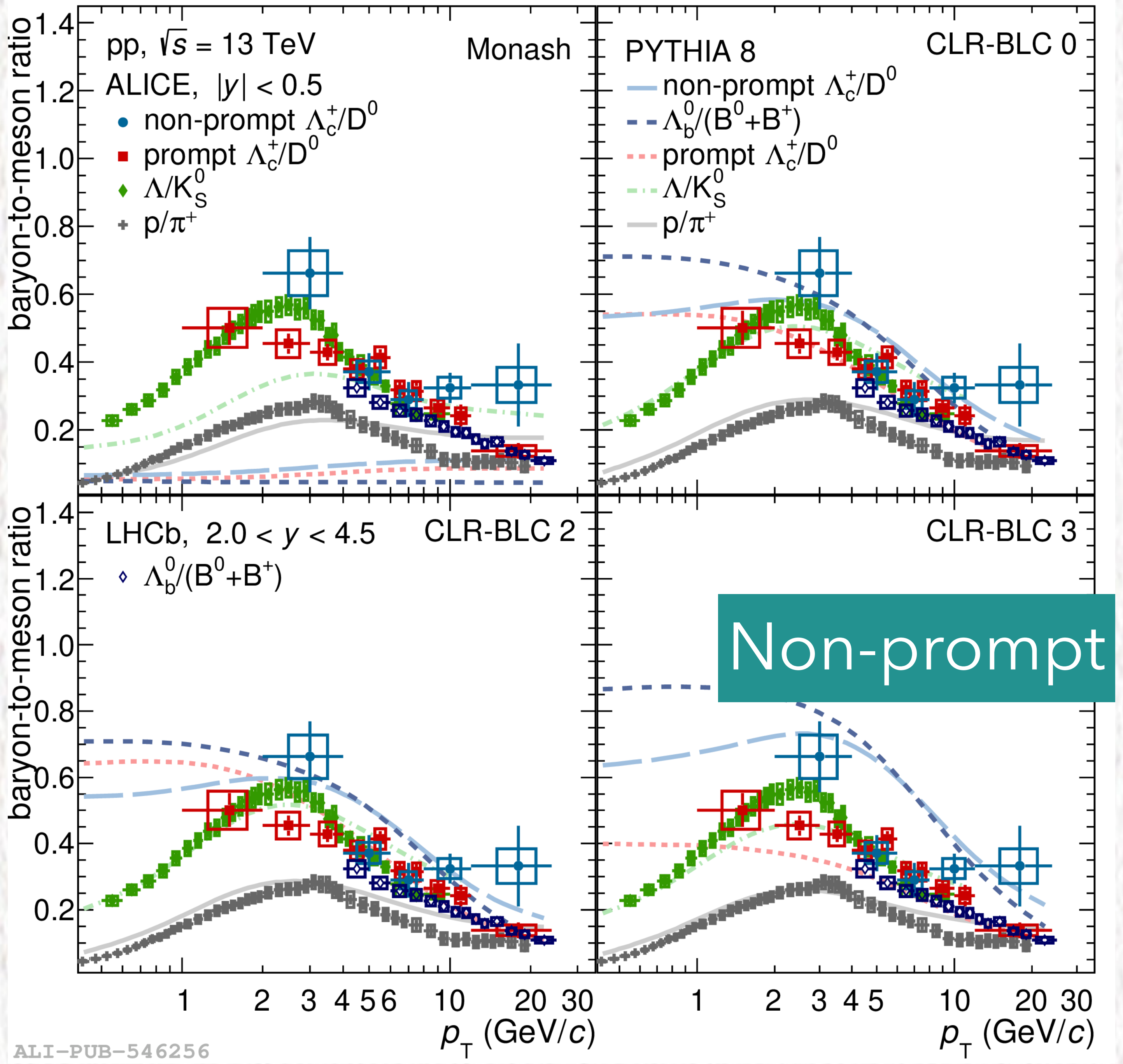
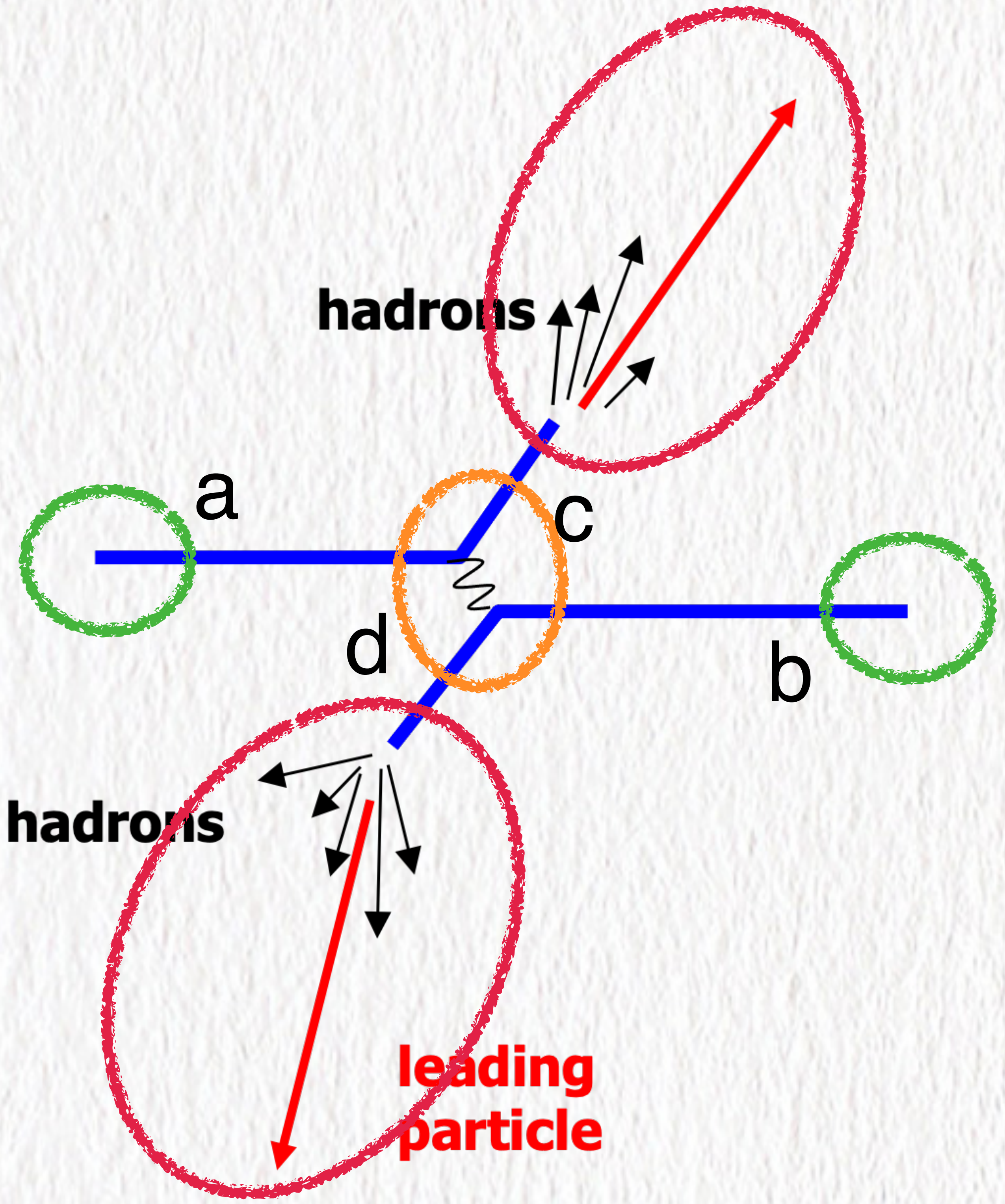
Prompt and non-prompt Λ_c^+ studies in pp collisions

$$\frac{d\sigma^h_{pp}}{dy\,d^2p_T} = K \sum_{abcd} \int dx_a dx_b \overbrace{f_a\left(x_a, Q^2\right) f_b\left(x_b, Q^2\right)}^{\text{PDF}} \overbrace{\frac{d\sigma}{d\hat{t}}(ab \to cd)}^{\text{pQCD}} \overbrace{\frac{D^0_{h/c}}{\pi z_c}}^{\text{FF}}$$

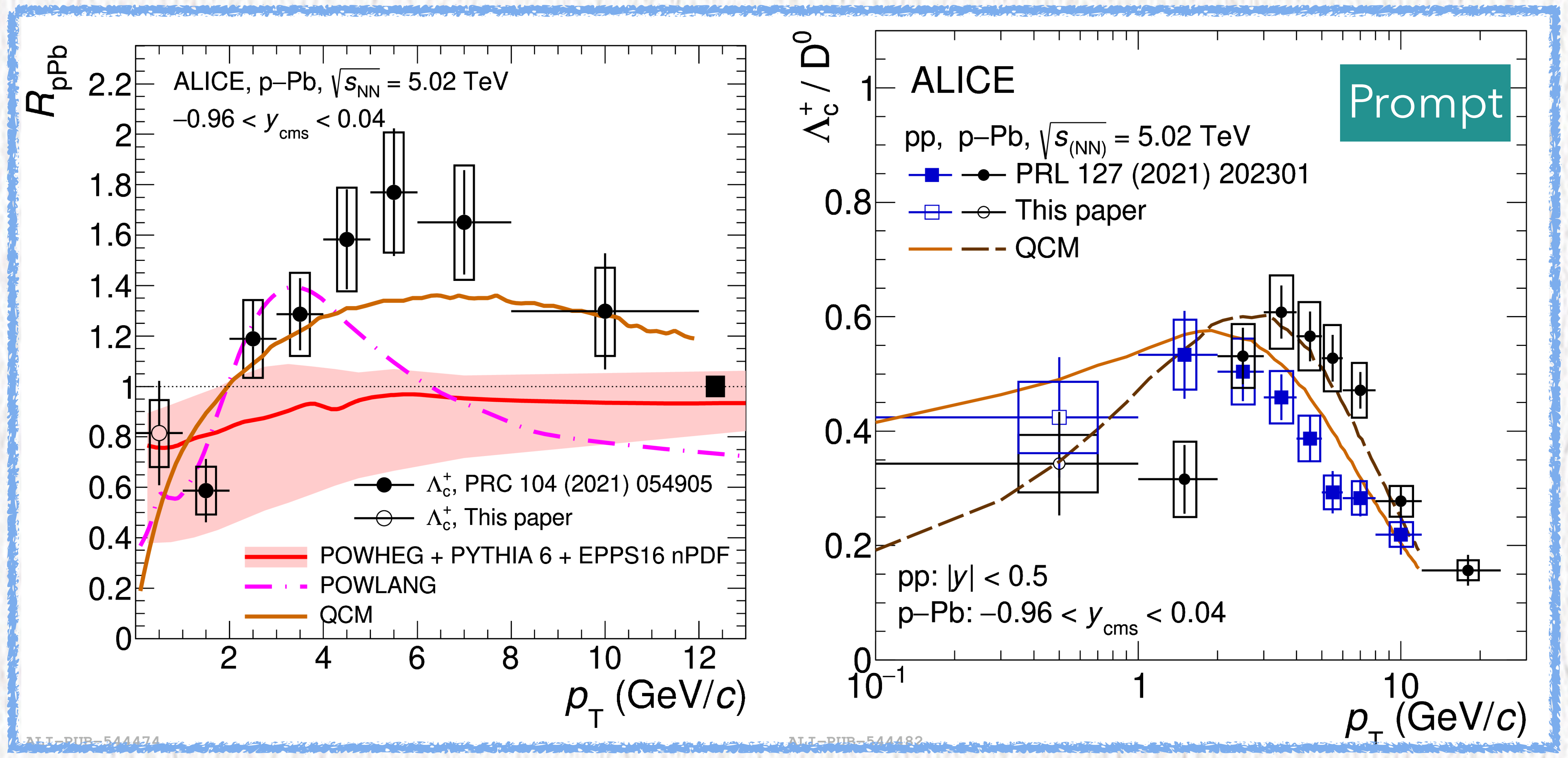


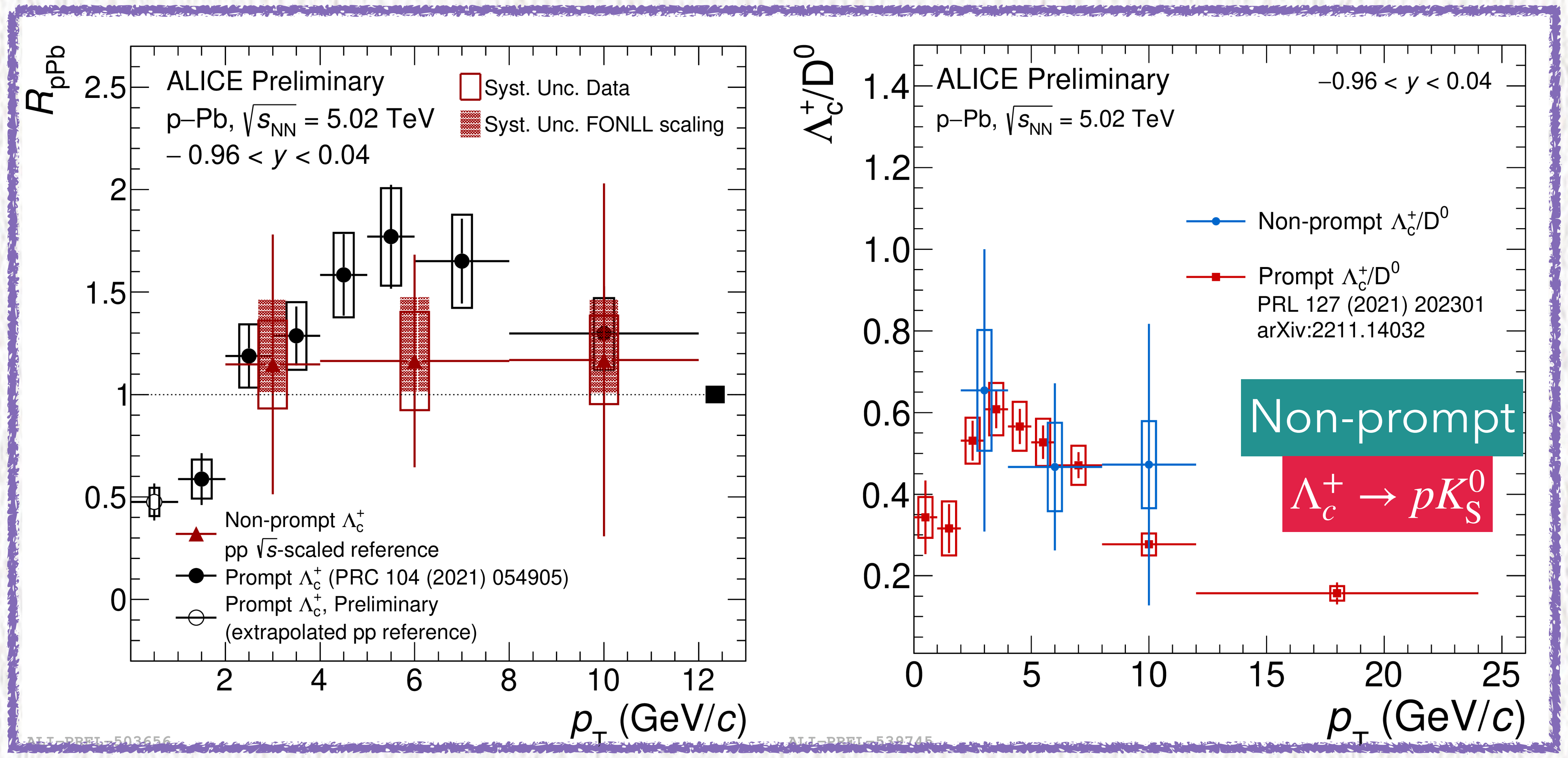




- Heavy hadrons ratios are sensitive to the hadronization process
- Λ_c^+ is the lightest charm baryon, which will give most abundant statistics
- Non-universal hadronization mechanisms among collision systems? Which are not fully understood

Previous prompt and non-prompt Λ_c^+ studies in p–Pb collisions

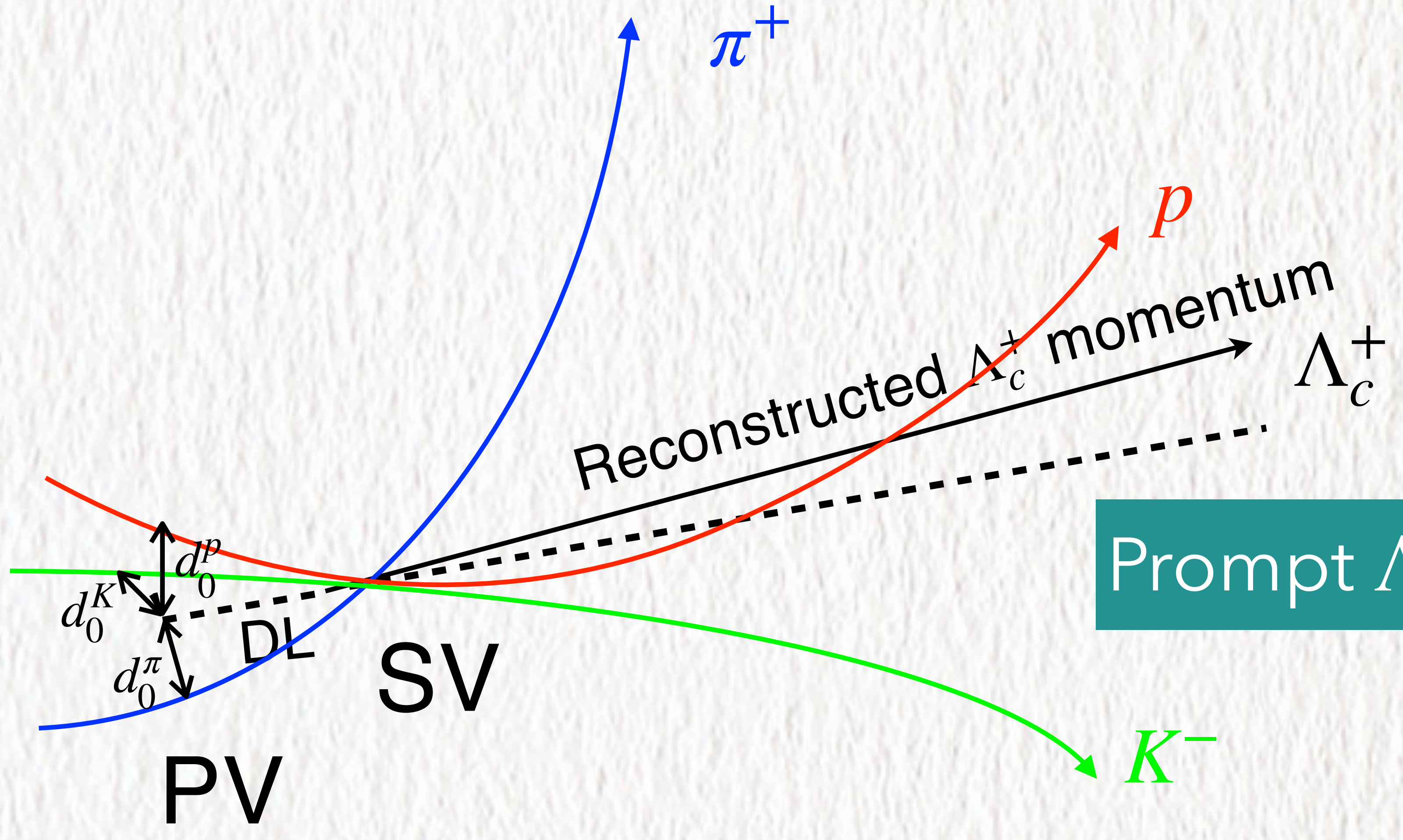




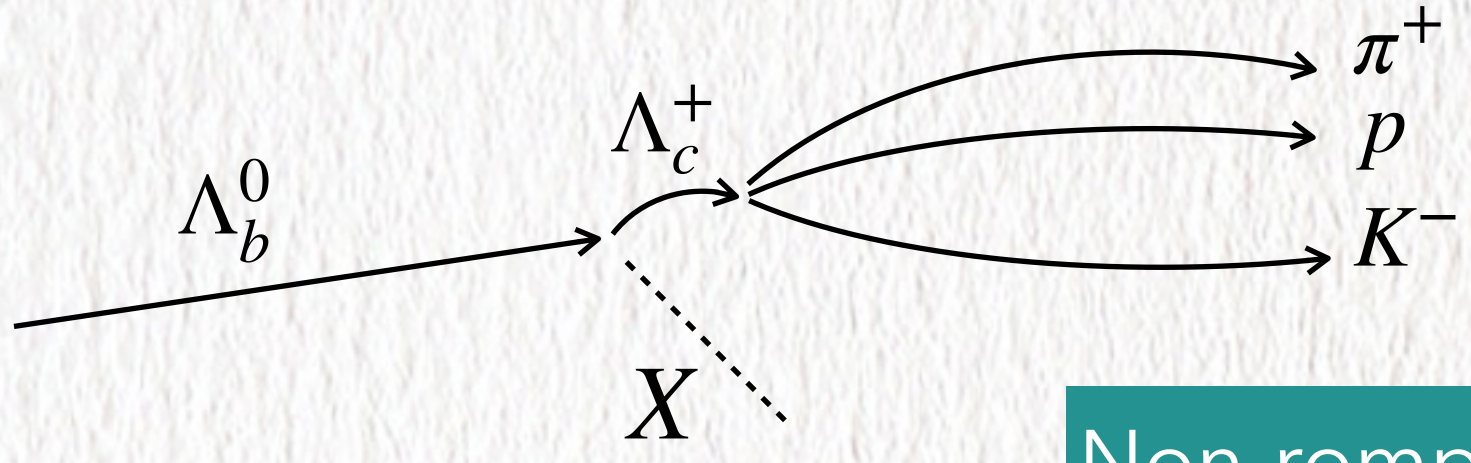
- Prompt Λ_c^+ down to $p_T = 0$ in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV
- Mean p_T shift of prompt Λ_c^+/D^0 in p–Pb w.r.t pp collisions, radial flow effect? Similar shift of non-prompt?
- Large uncertainties of the current non-prompt Λ_c^+ reconstruction, need to improve measurement precision

Λ_c^+ reconstruction

Decay channel: $\Lambda_c^+ \to pK^-\pi^+$

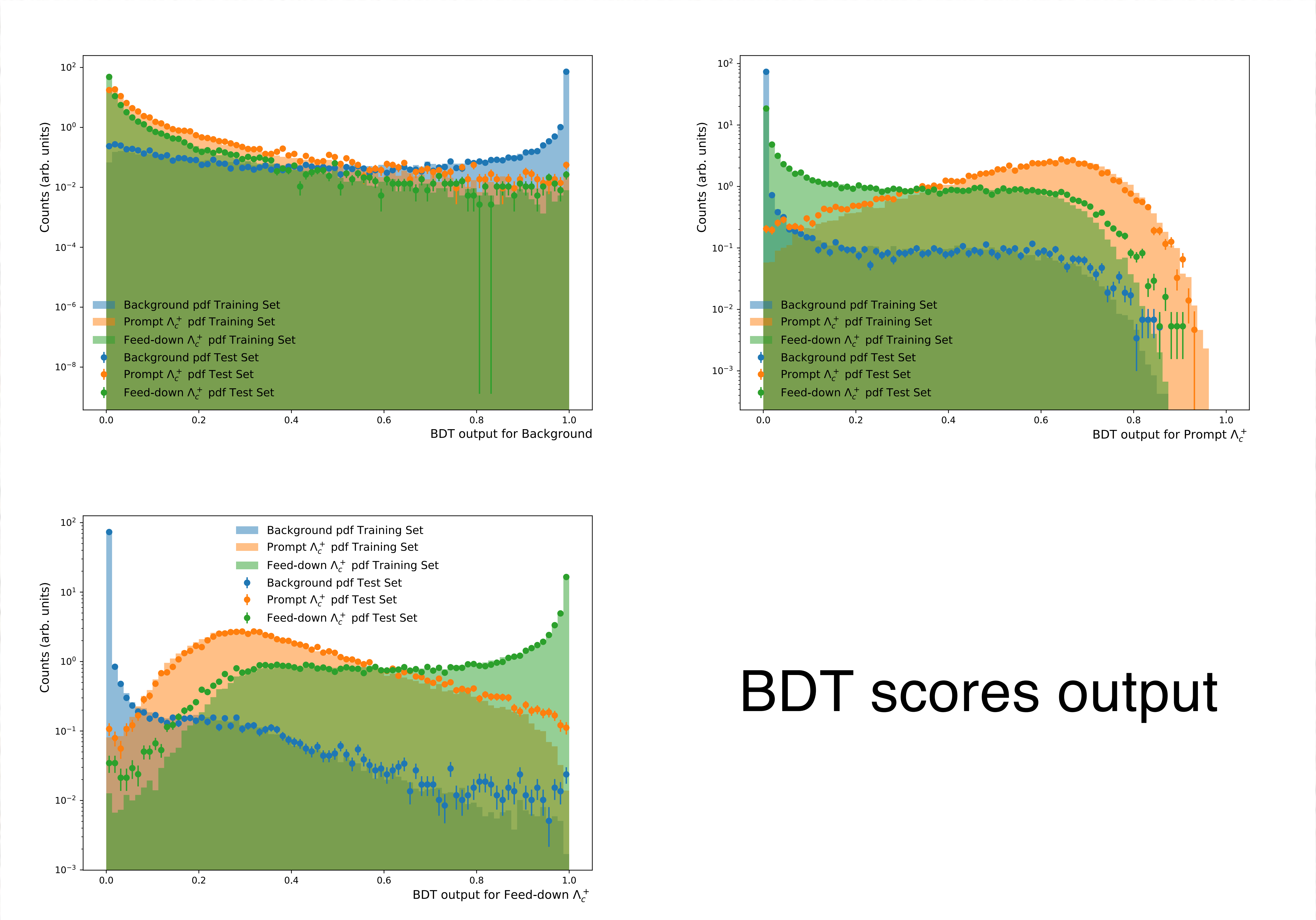


Prompt Λ_c^+



Non-rompt Λ_c^+

Topological variables can be used to separate prompt and non-prompt

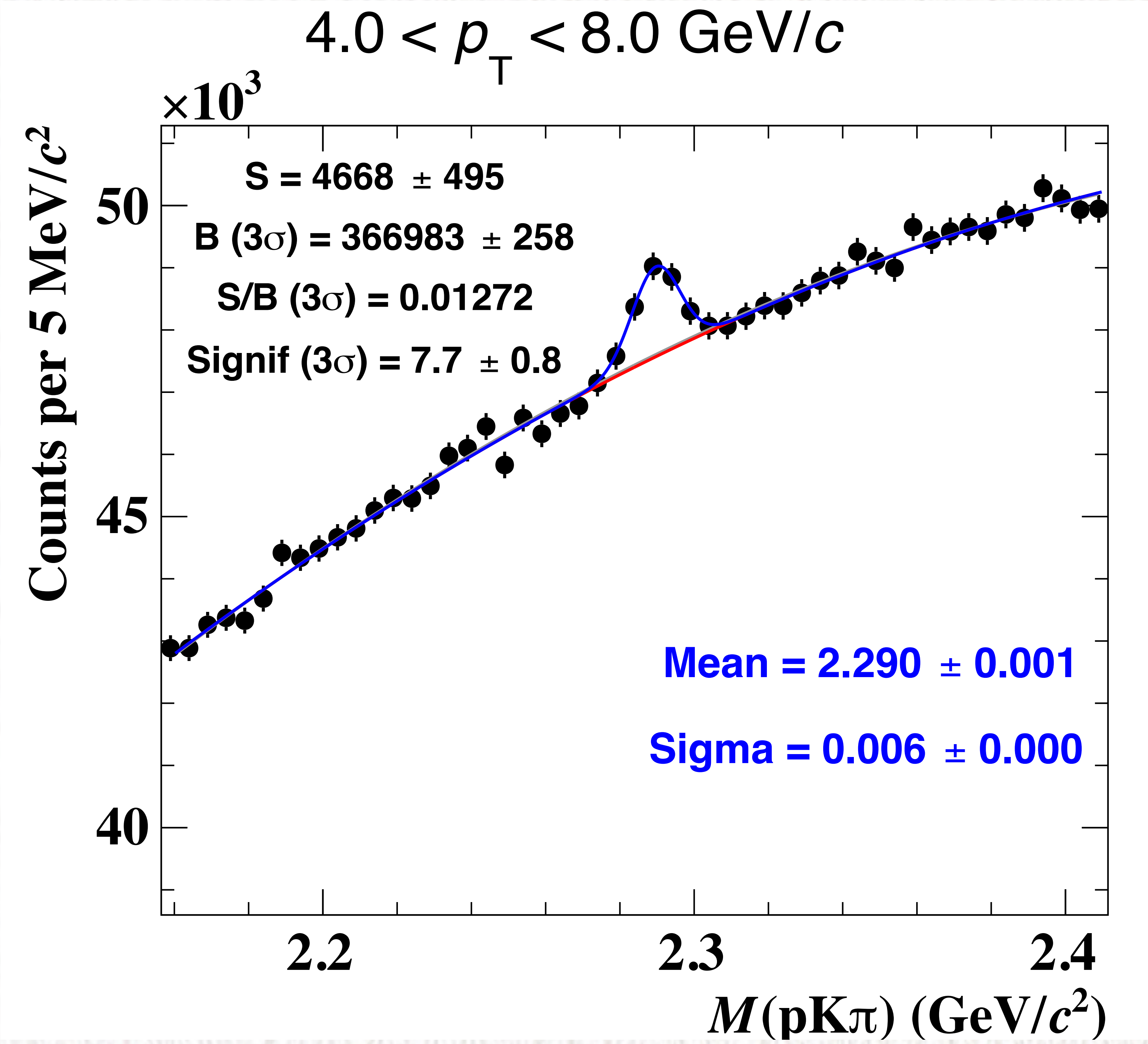


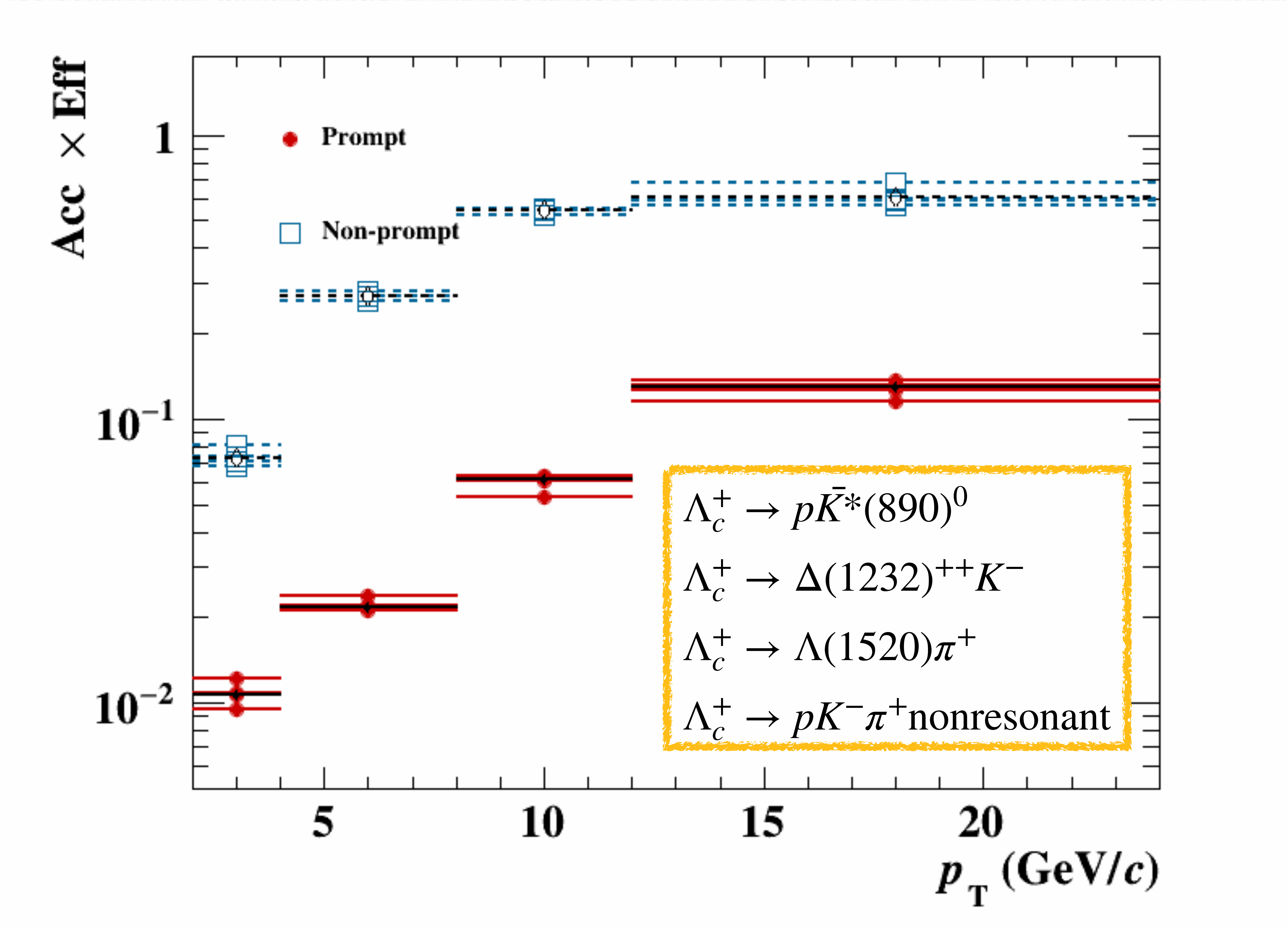
BDT scores output

- Three classification: 3 times binary classification
- BDT_Bkg < cut1 (to improve s/b) && BDT_Np > cut2 (no-prompt enhanced)

Raw yields and average acc×eff at the working point

BDT \ p_T	4 – 8
BDT_{Bkg} (<)	0.20
BDT_{FD} (>)	0.70





Use gaussian (signal) plus polynomial (background) to fit
The σ of gaussian were fixed to the prompt enhanced

Applied weights to the MC p_T spectra
Weight efficiencies according to the BRs

Data-driven method to estimate feed-down fraction

$$\varepsilon_i^{\mathrm{p}} \cdot N_{\mathrm{p}} + \varepsilon_i^{\mathrm{np}} \cdot N_{\mathrm{np}} = Y_i \longrightarrow \begin{cases} \varepsilon_1^{p} \cdot N_p + \varepsilon_1^{np} \cdot N_{np} = Y^1 \\ \cdots \\ \cdots \\ \varepsilon_n^{p} \cdot N_p + \varepsilon_n^{np} \cdot N_{np} = Y^n \end{cases} \longrightarrow \begin{pmatrix} \varepsilon_1^{\mathrm{p}} & \varepsilon_1^{\mathrm{np}} \\ \vdots & \vdots \\ \varepsilon_n^{\mathrm{p}} & \varepsilon_n^{\mathrm{np}} \end{pmatrix} \times \begin{pmatrix} N_{\mathrm{p}} \\ N_{\mathrm{np}} \end{pmatrix} - \begin{pmatrix} Y_1 \\ \vdots \\ Y_n \end{pmatrix} = \begin{pmatrix} \delta_2 \\ \vdots \\ \delta_n \end{pmatrix}$$

$$\chi^2 = \delta^T C^{-1} \delta$$

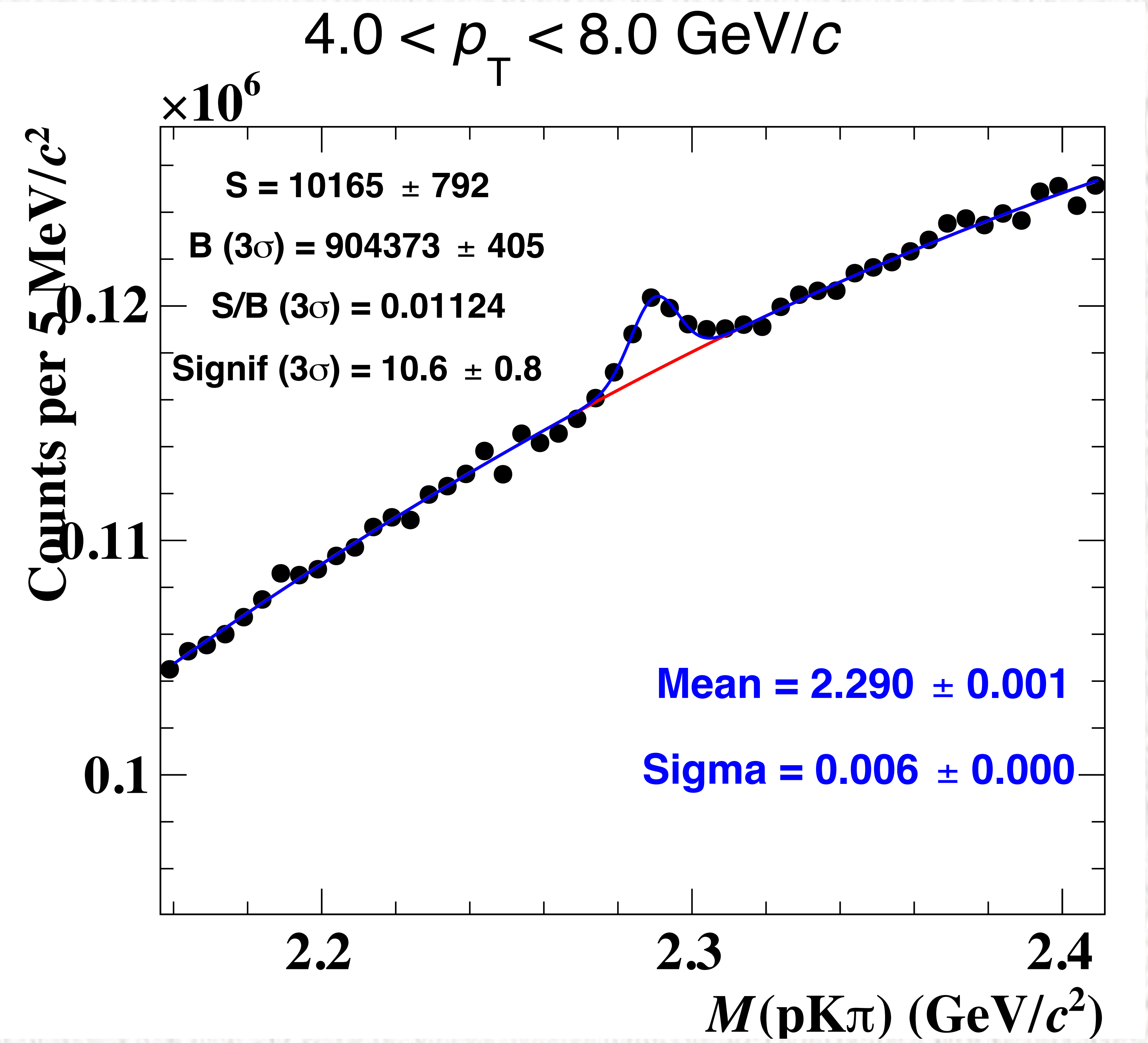
$$N = \mathrm{Cov}(N) \varepsilon^T C^{-1} Y$$

$$\mathrm{Cov}(N) = \left(\varepsilon^T C^{-1} \varepsilon\right)^{-1}$$

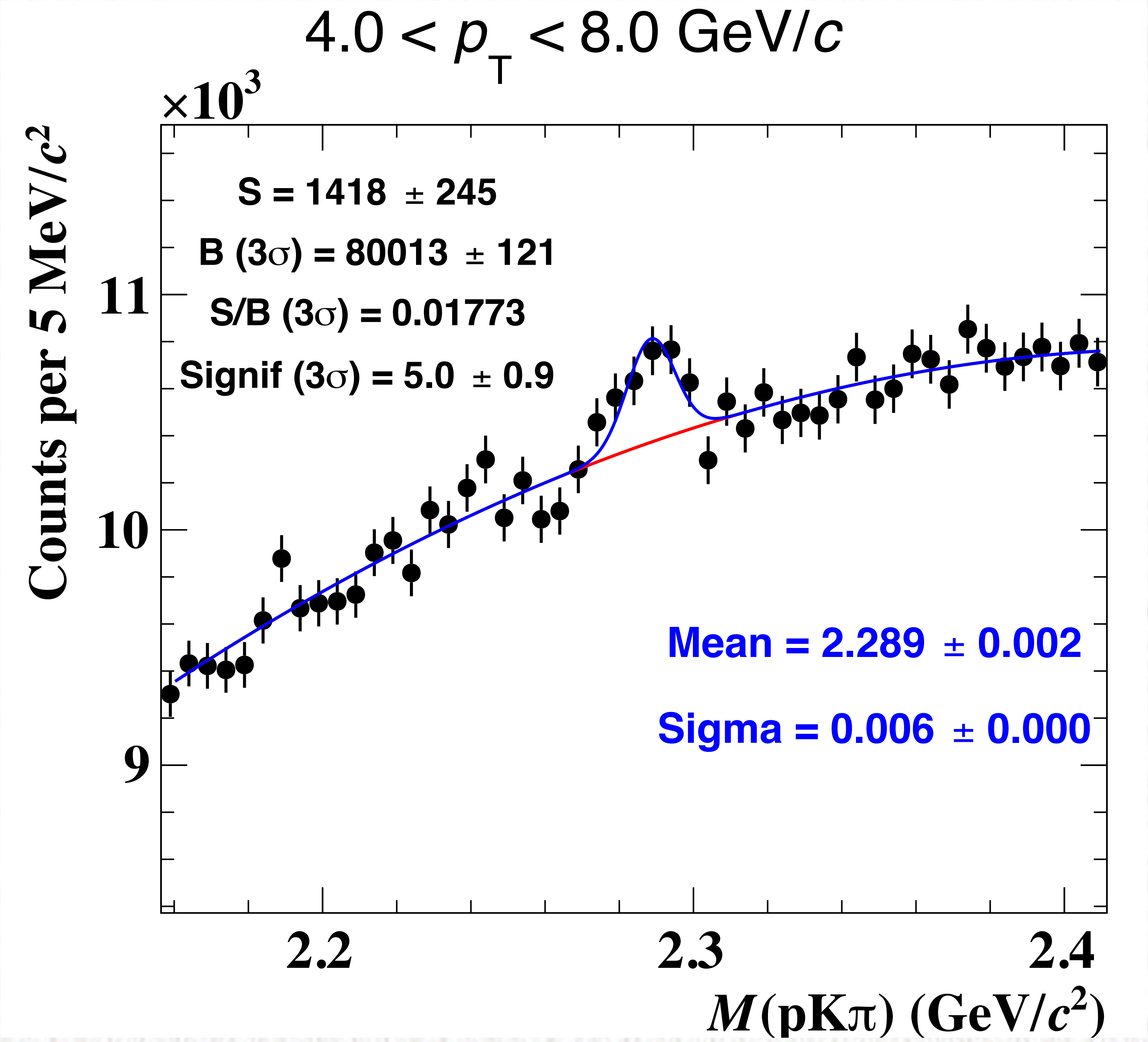
$$f_{FD} = \frac{\varepsilon_{FD} \cdot N_{FD}}{\varepsilon_{prompt} \cdot N_{prompt} + \varepsilon_{FD} \cdot N_{FD}}$$

- Achieve sets of raw yields and efficiencies at different BDT selections
- Require the subsequent set to be the strict subset of the previous one to treat uncertainties fully correlated
- Minimize the χ^2 to optimal estimation of prompt and non-prompt fractions

Signal extraction in different sets ($4 < p_T < 8$ GeV/c)

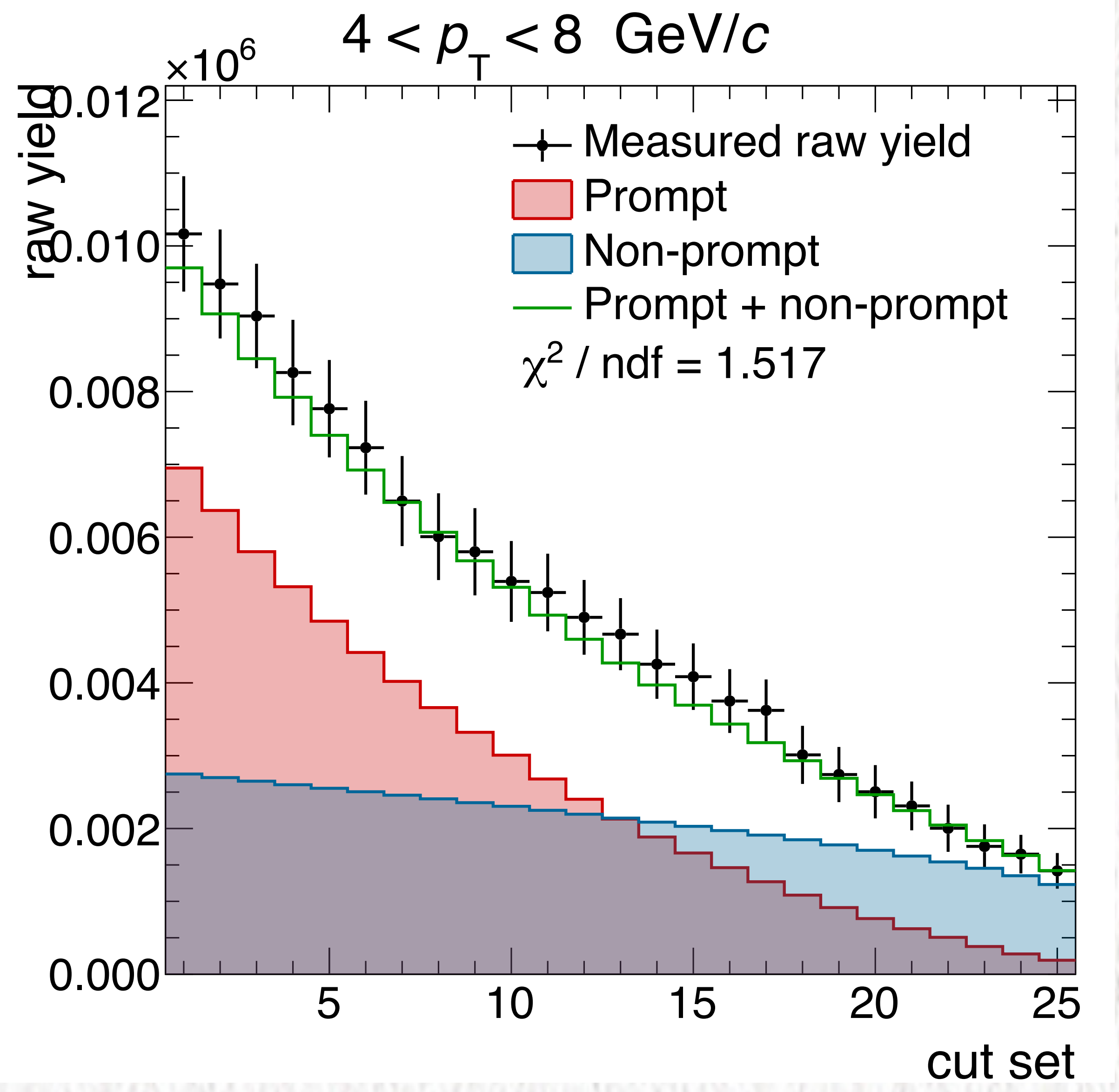


More and more stringent cutting ...

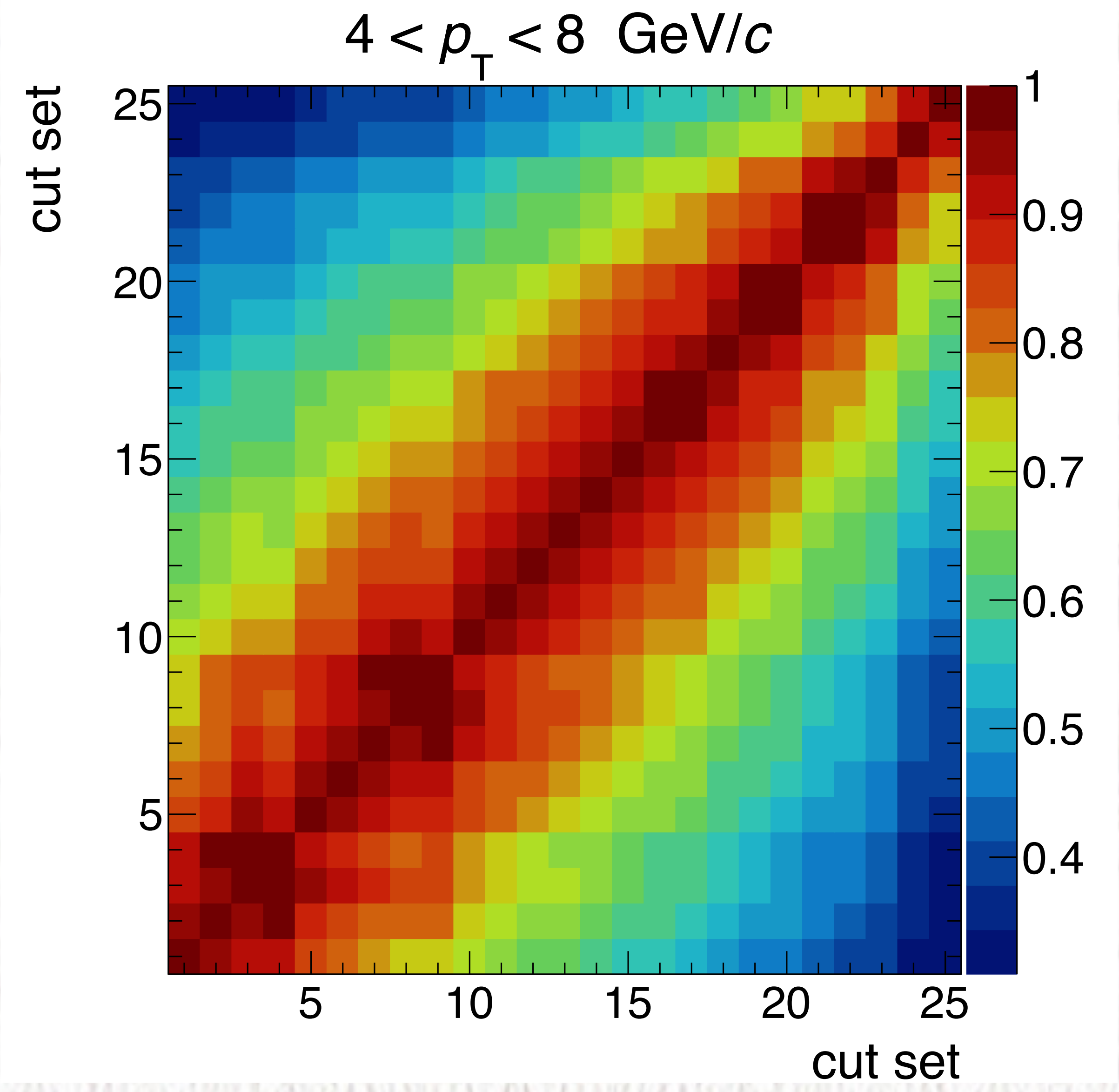


Cuts variation ($4 < p_T < 8$ GeV/c)

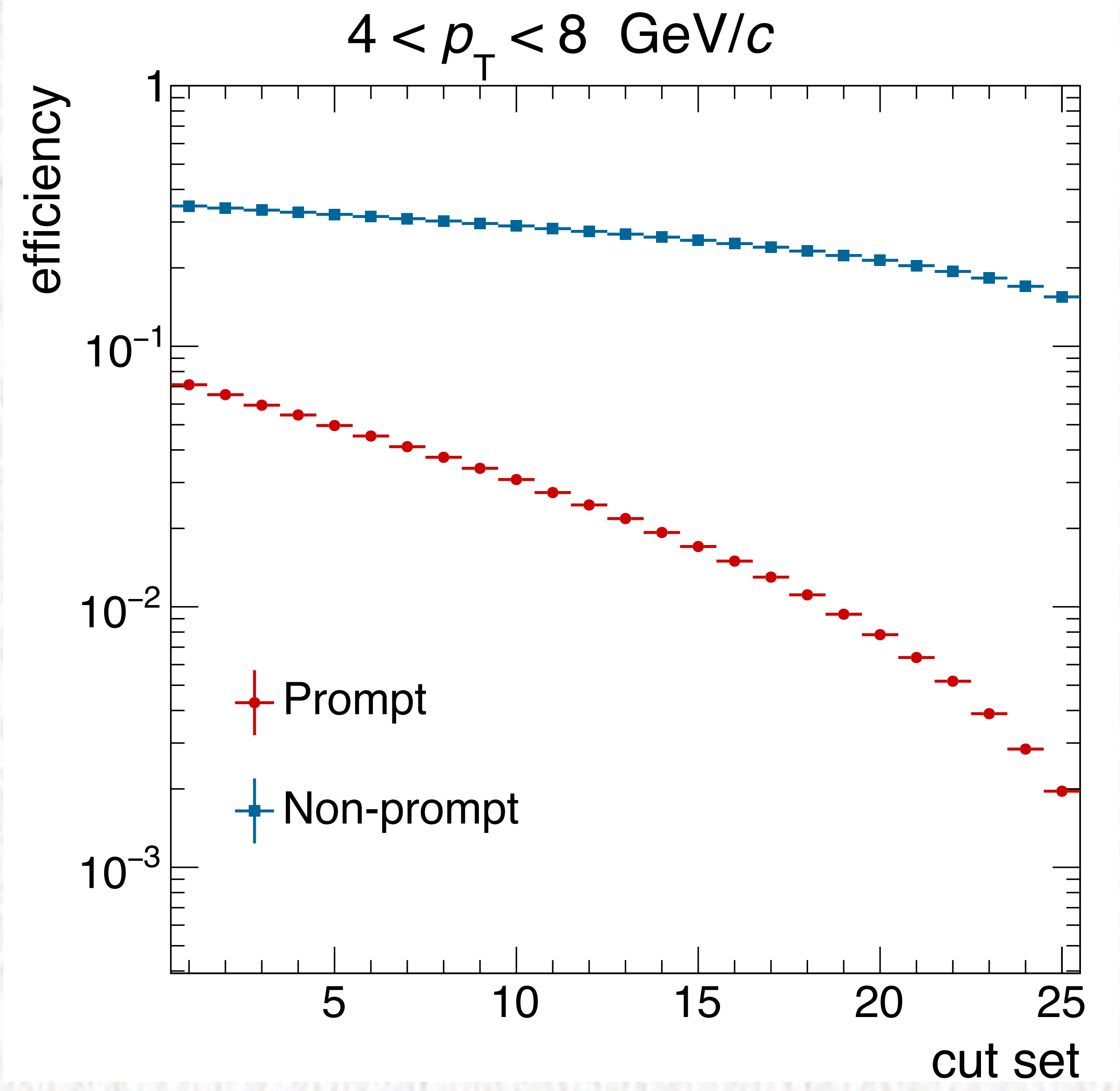
Raw yields vs. Cut set



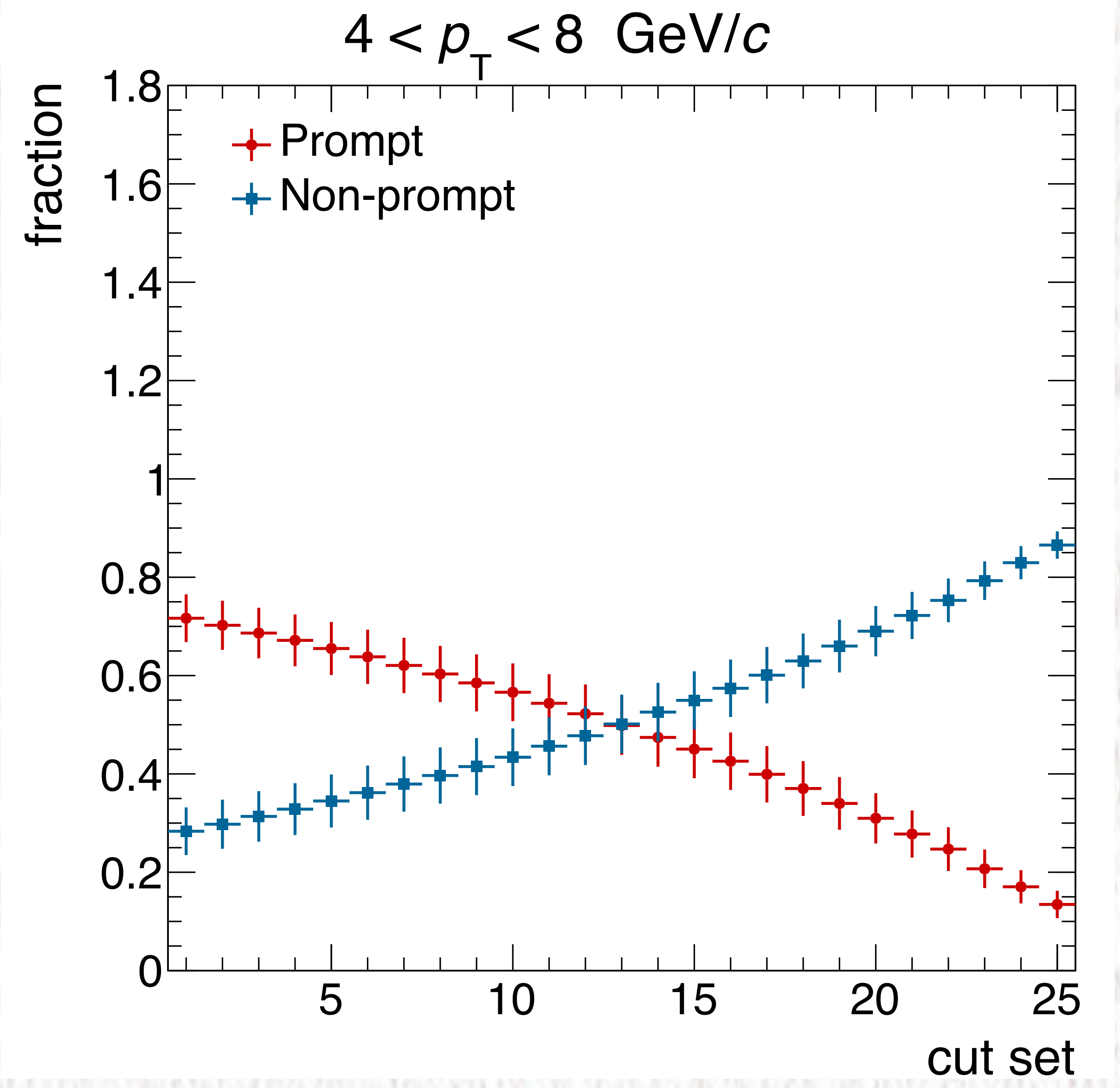
Covariance matrix correlation



Efficiencies vs. Cut set

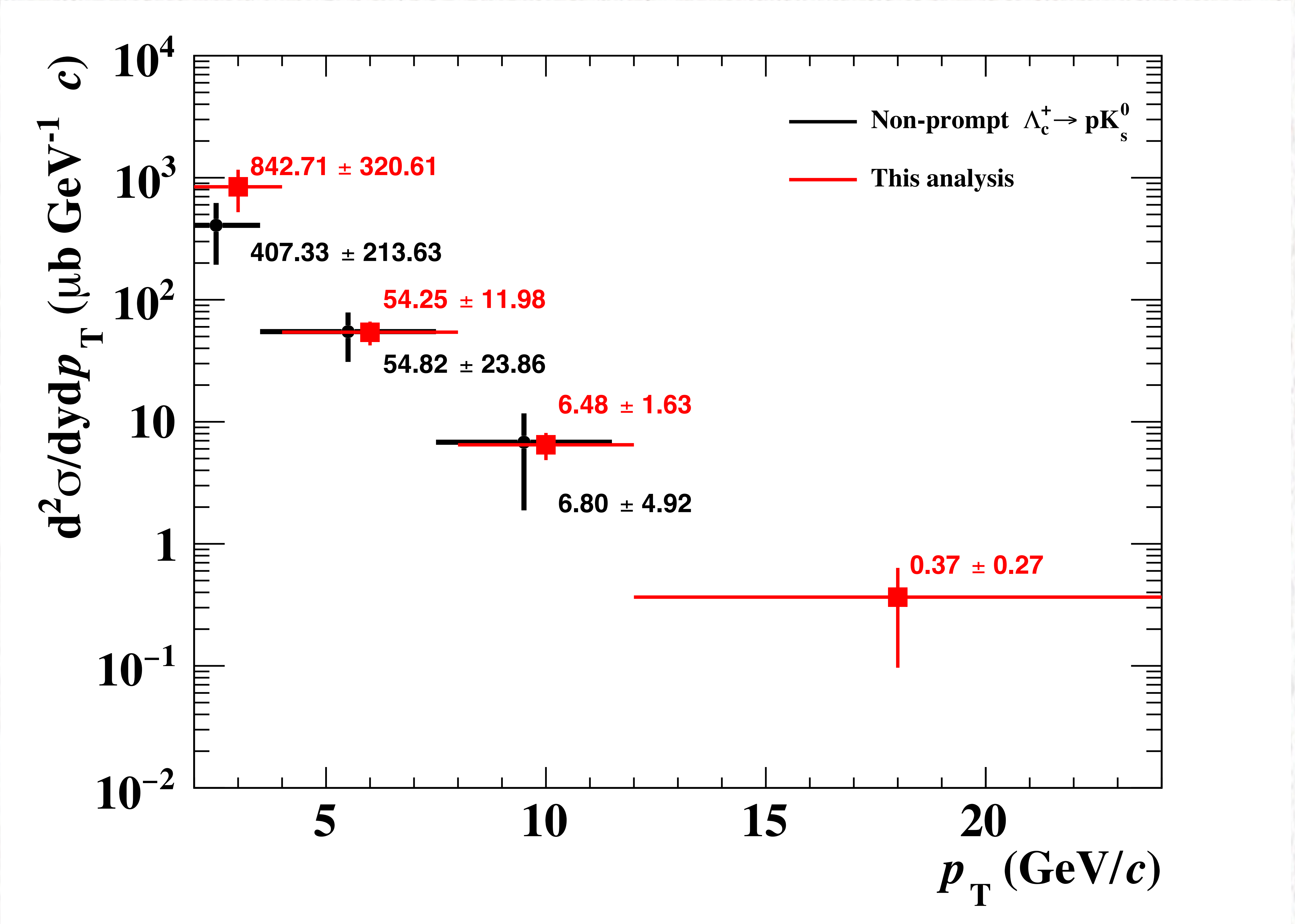


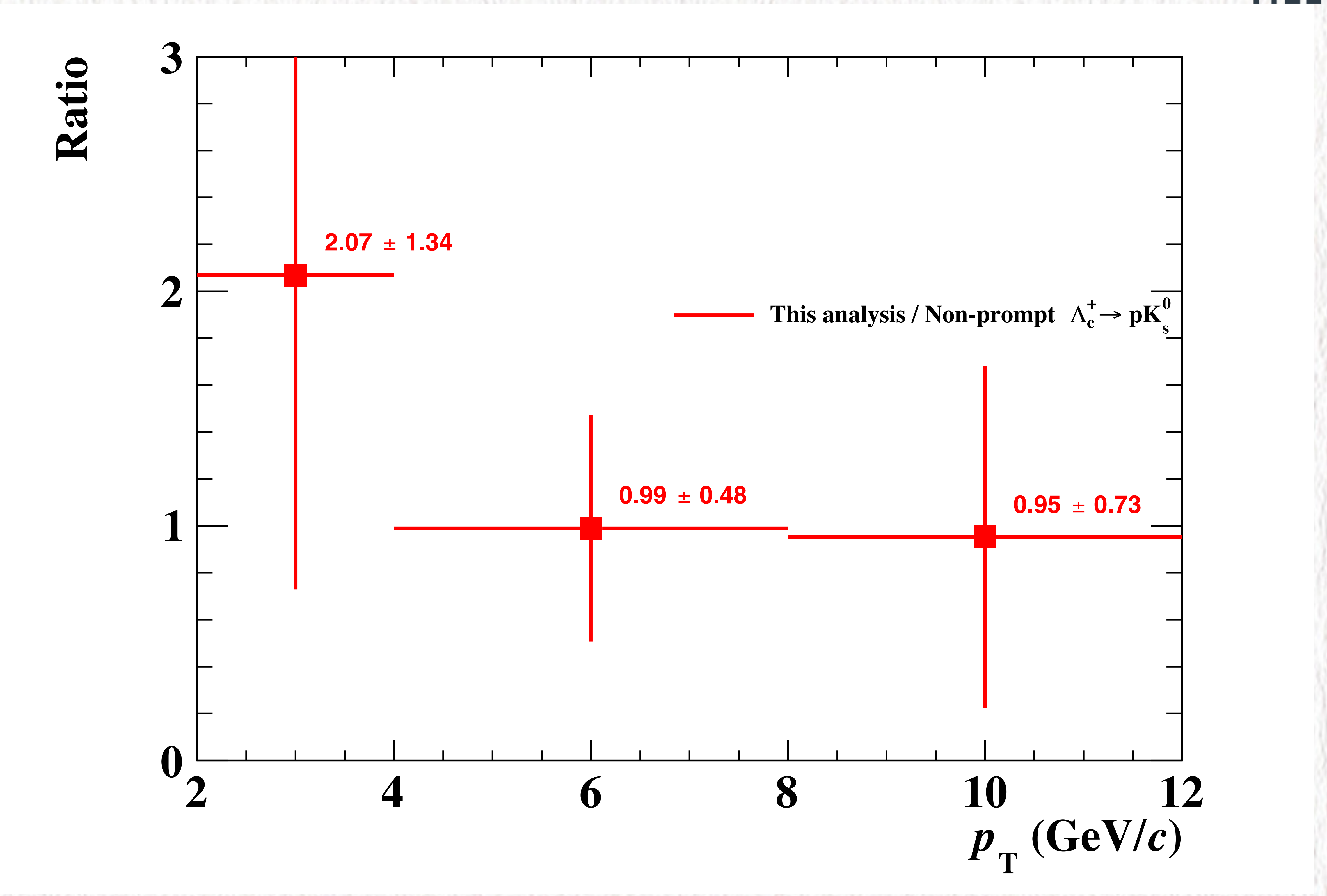
Fractions vs. Cut set



- Template fit the raw yields shape as a function of the cut set
- Avoid cut sets with issued covariance matrix
- Achieve non-prompt enhance samples, variate from 30%–85%

Non-prompt Λ_c^+ cross section comparison





- Some tension for the $2 < p_T < 4$ GeV/c, however compatible within the large uncertainties
- Consistent with the $\Lambda_c^+ \to pK_s^0$ for the $4 < p_T < 12$ GeV/c, additional cross section for $12 < p_T < 24$ GeV/c
- Significant smaller statistic uncertainties from this analysis
- No clear issue observed, will merge the two measurements

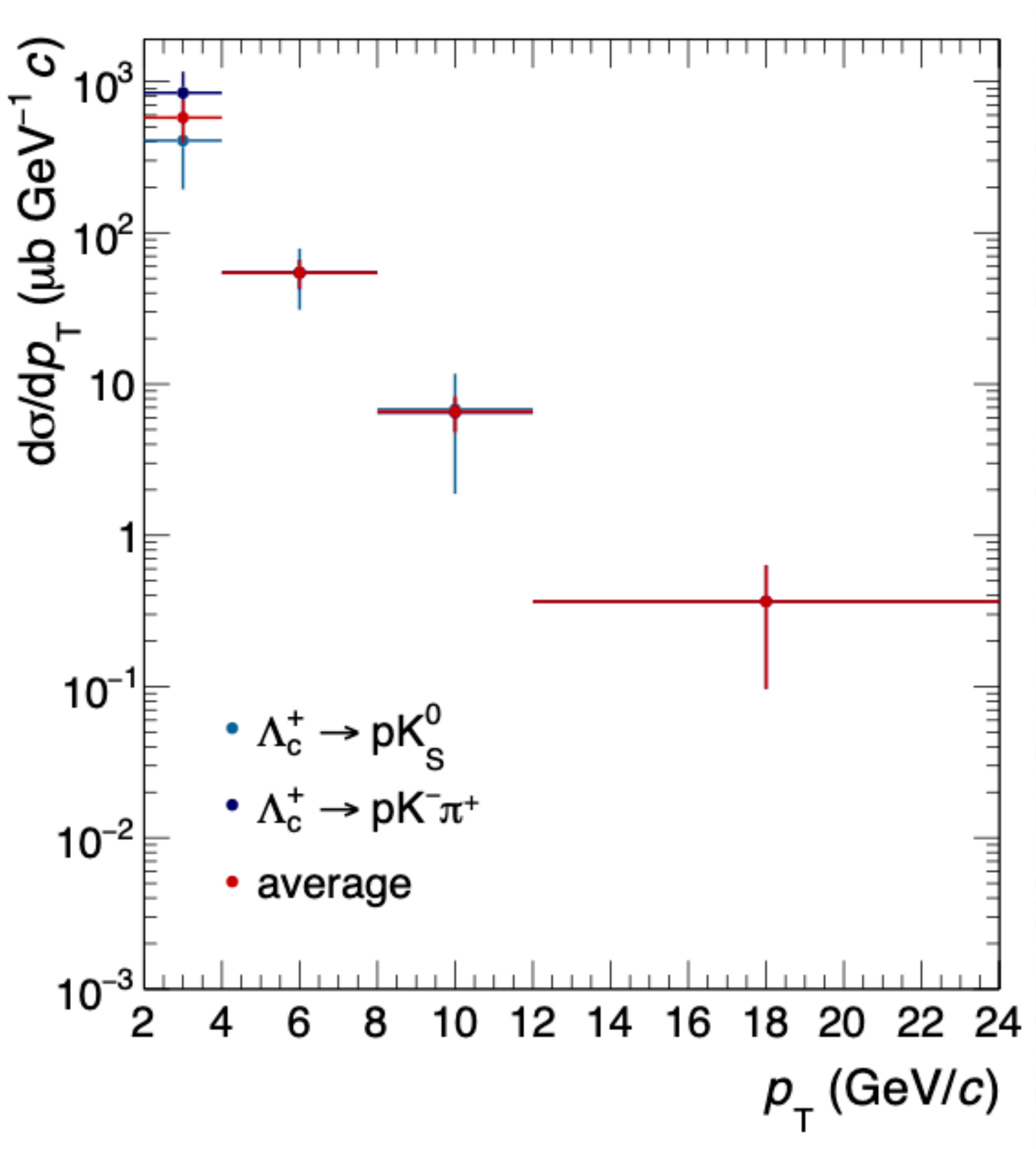
Averaged Non-prompt Λ_c^+ Cross-section

- The weighted average non-prompt Λ_c^+cross section was computed considering uncorrelated, correlated and partly correlated uncertainties:
- tracking efficiency —> fully correlated
- BR —> partly correlated
- Other syst. unc. —> uncorrelated

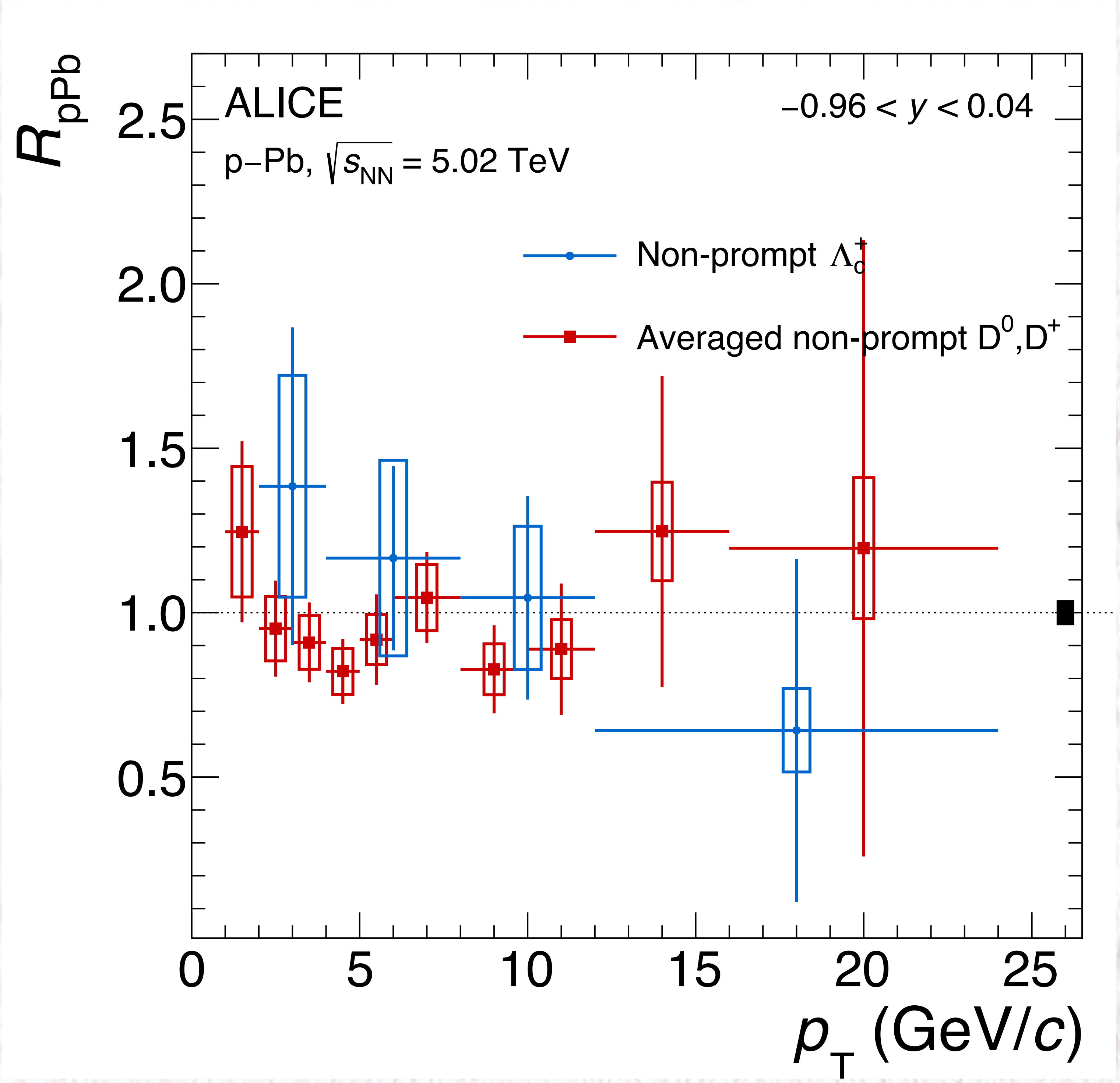
$$\langle \sigma \rangle = \sum_i w_i \cdot \sigma_i$$

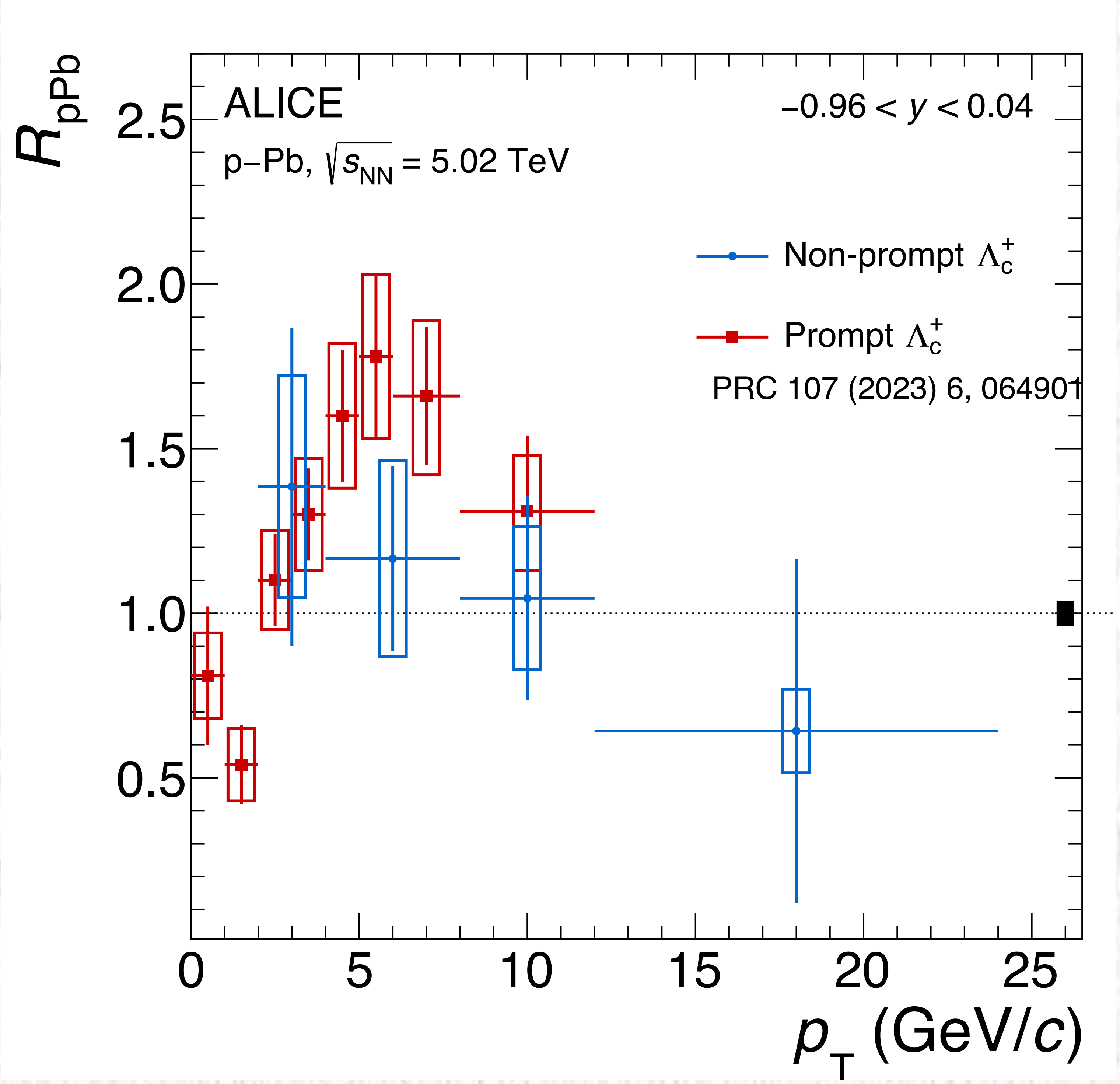
$$w_i = \frac{\sum_k (V_x)^{-1}_{ik}}{\sum_{j,k} (V_x)^{-1}_{jk}}$$

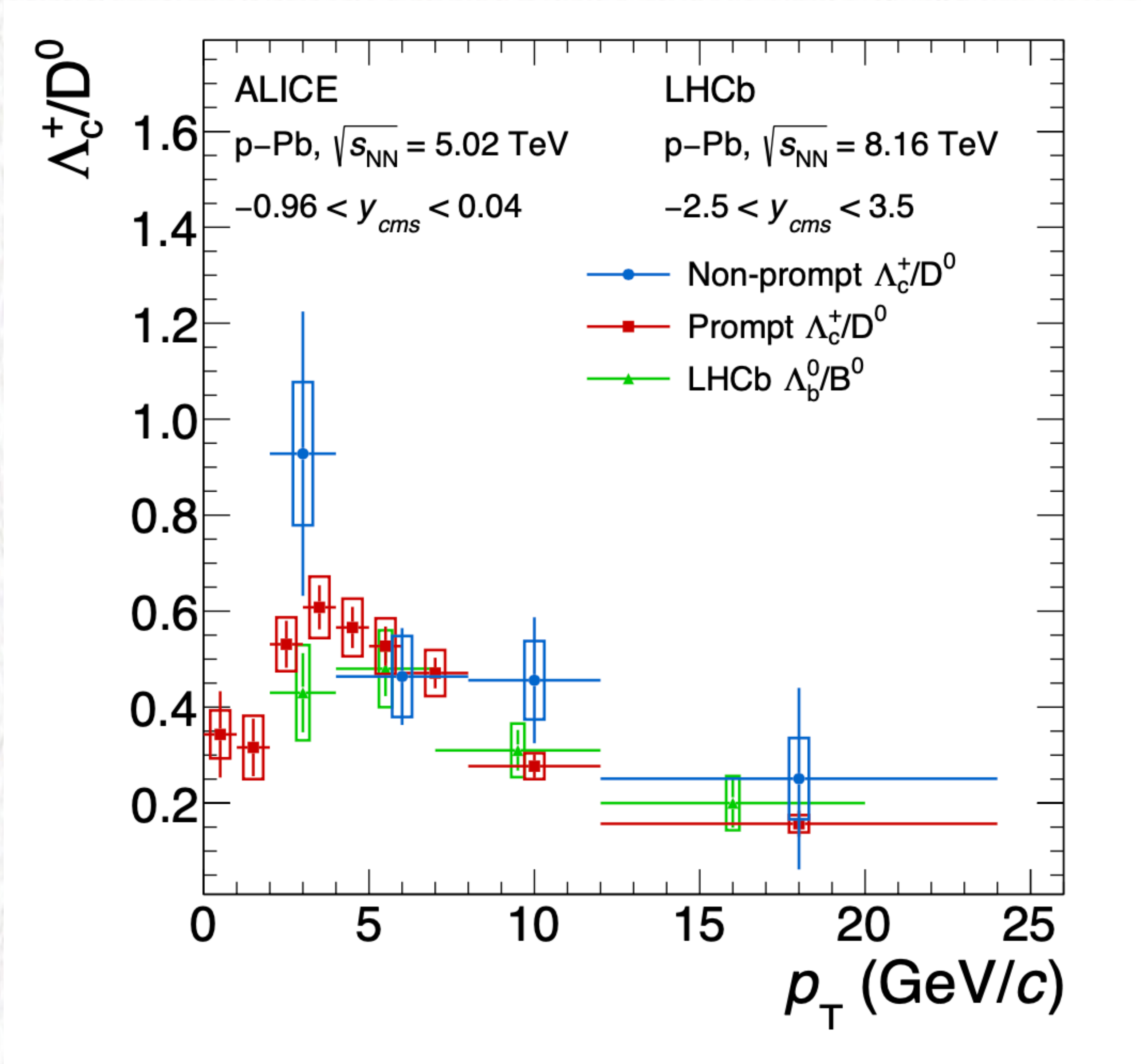
$$\begin{pmatrix} \mathrm{sys}^2_{\mathrm{pK}\pi} + \mathrm{stat}^2_{\mathrm{pK}\pi} & \rho(\mathrm{pK}\pi, \mathrm{pK^0_S}) \cdot \sigma^{\mathrm{BR}}_{pK\pi} \cdot \sigma^{\mathrm{BR}}_{pK^0_S} \\ \rho(\mathrm{pK}\pi, \mathrm{pK^0_S}) \cdot \sigma^{\mathrm{BR}}_{pK\pi} \cdot \sigma^{\mathrm{BR}}_{pK^0_S} & \mathrm{sys}^2_{\mathrm{pK^0_S}} + \mathrm{stat}^2_{\mathrm{pK^0_S}} \end{pmatrix}$$



Non-prompt Λ_c^+ R_{pPb} and Λ_c^+/D^0







- Non-prompt Λ_c^+ R_{pPb} is comparable to unity within uncertainties
- Non-prompt Λ_c^+/D^0 is compatible with prompt and Λ_b^0/B^0 within the uncertainties

Summary

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- Non-prompt Λ_c^+ production in p–Pb via machine learning method
- Cross-section from $\Lambda_c^+ \rightarrow pK\pi$ is comparable to $\Lambda_c^+ \rightarrow pK_S^0$ with significant smaller uncertainties
- Final cross-section is combined from the two decay channels
- Non-prompt Λ_c^+ R_{pPb} is comparable to unity within the uncertainties
- Non-prompt Λ_c^+/D^0 is compatible with prompt and Λ_b^0/B^0 within the uncertainties
- More precise measurements will benefit to better understanding

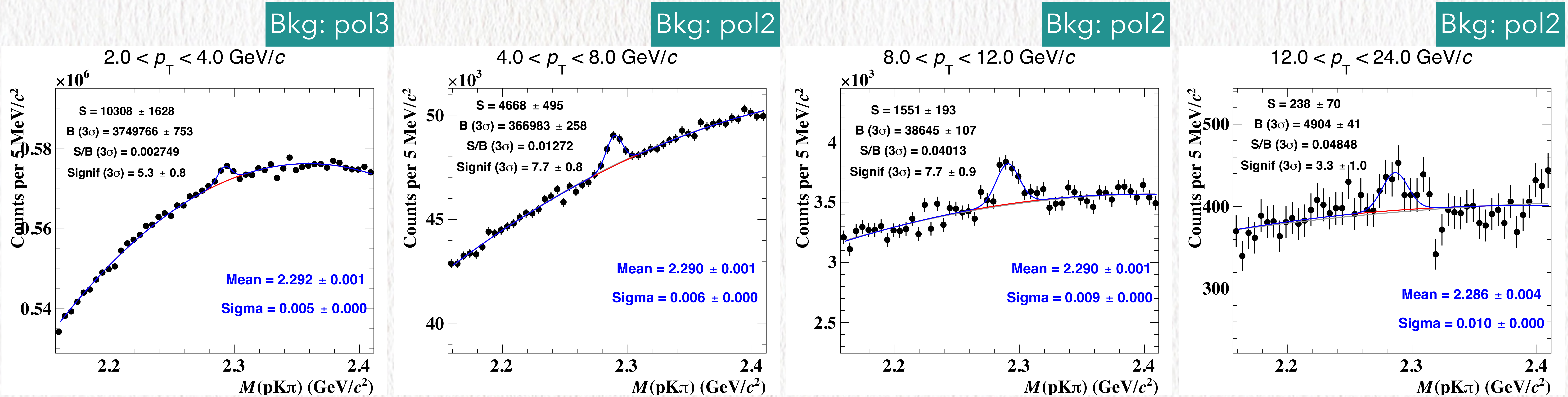
Thank you!

Additional slides

Raw yields and at the working point

BDT selections at working point

BDT \ p_T	2 – 4	4 – 8	8 – 12	12 – 24
BDT_{Bkg} (<)	0.18	0.20	0.15	0.15
BDT_{FD} (>)	0.60	0.70	0.65	0.55



- Use gaussian (signal) plus polynomial (background) to fit the inv. mass
- The σ of gaussian were fixed to the prompt enhanced fitting

Raw yields at the working point

BDT selections at working point

BDT \ p_T	2 – 4	4 – 8	8 – 12	12 – 24
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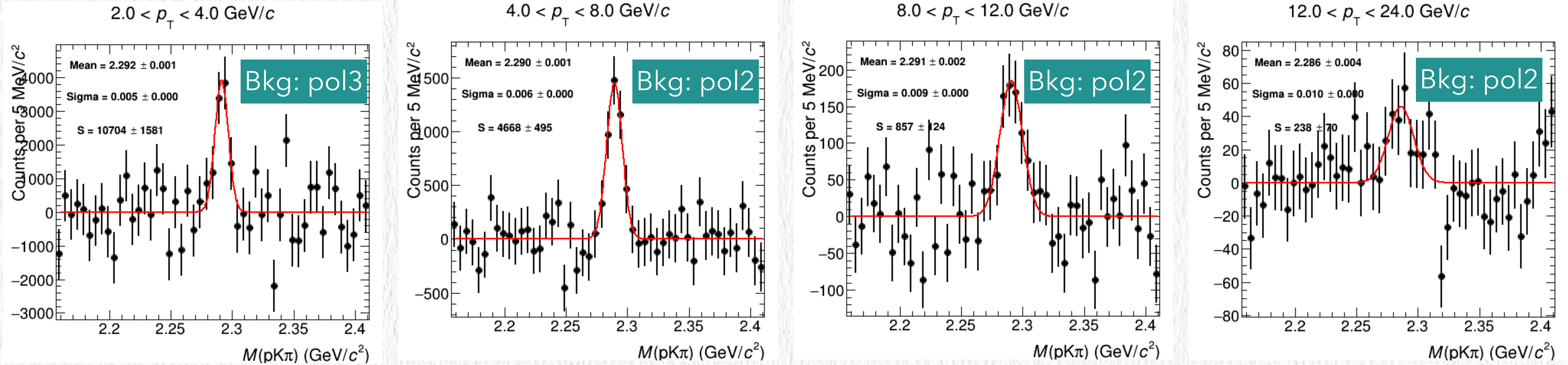
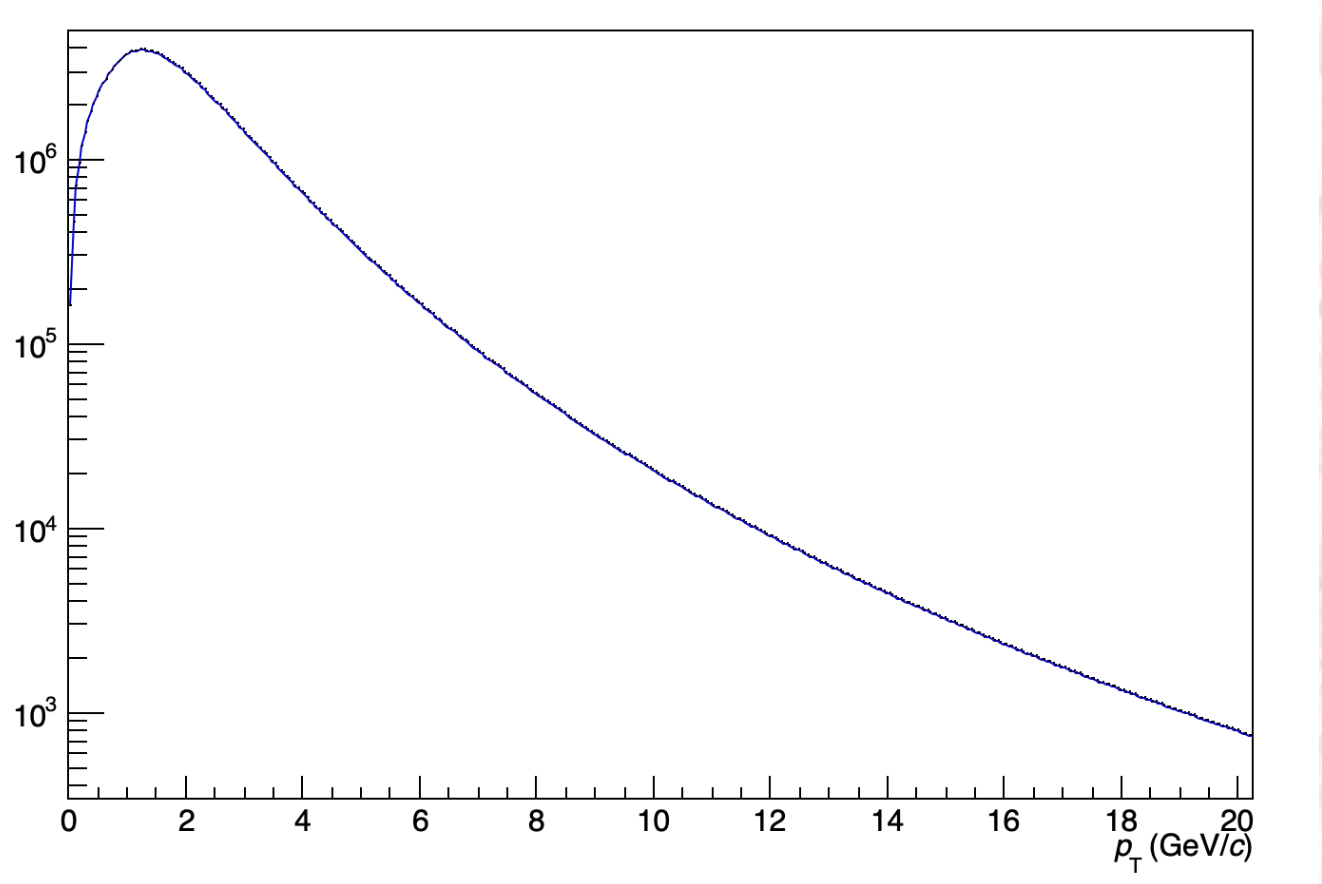


- Use gaussian (signal) plus polynomial (background) to fit the inv. mass
- The σ of gaussian were fixed to the prompt enhanced fitting

MC p_T weight — prompt

p_T^D from FONLL



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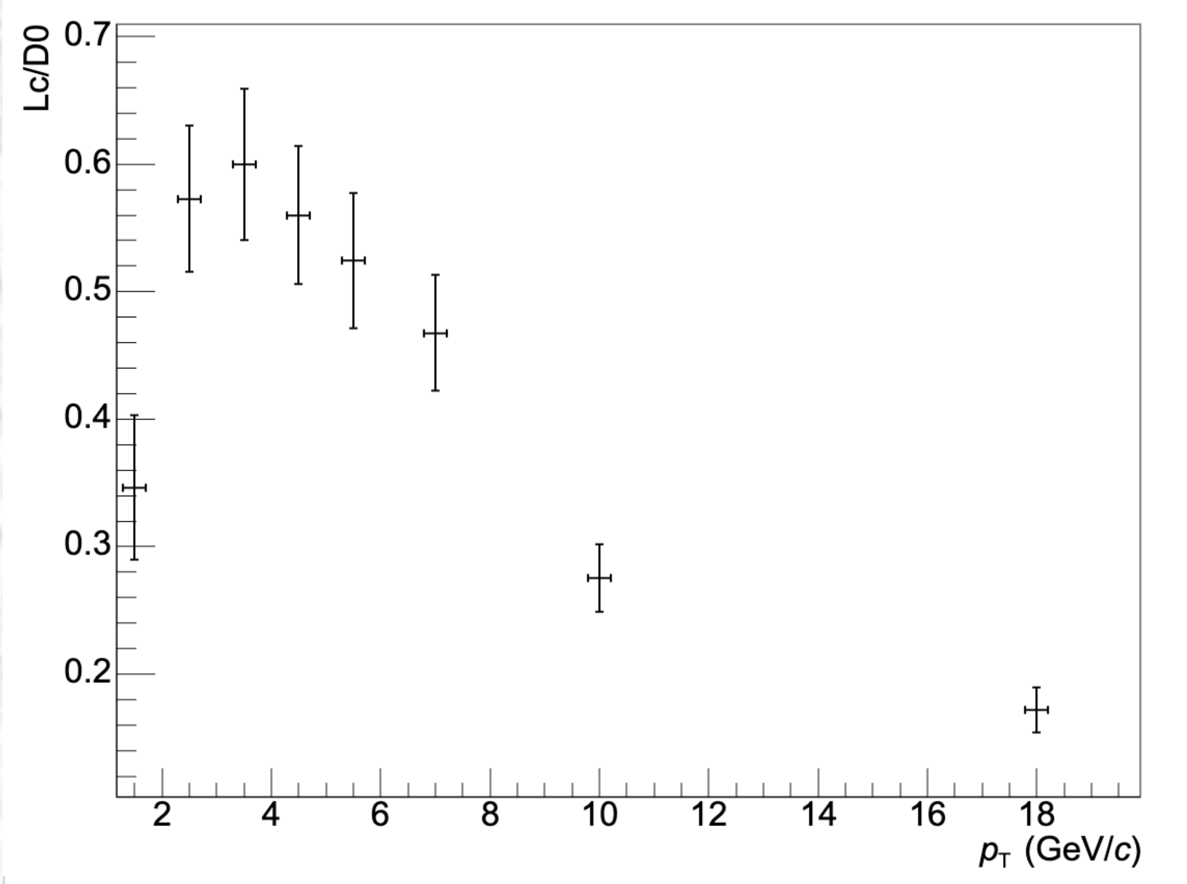
Prompt $\frac{\Lambda_c}{D^0}$ in pp



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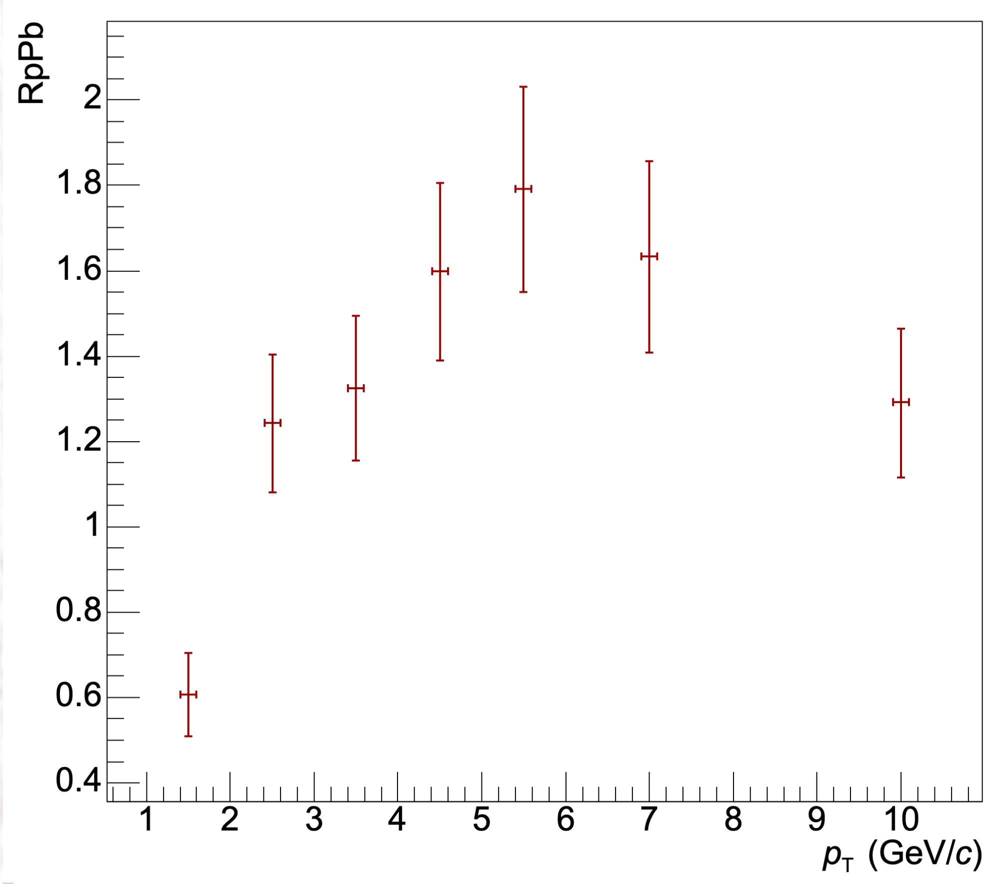
Prompt $R_{pA}^{\Lambda_c^+}$



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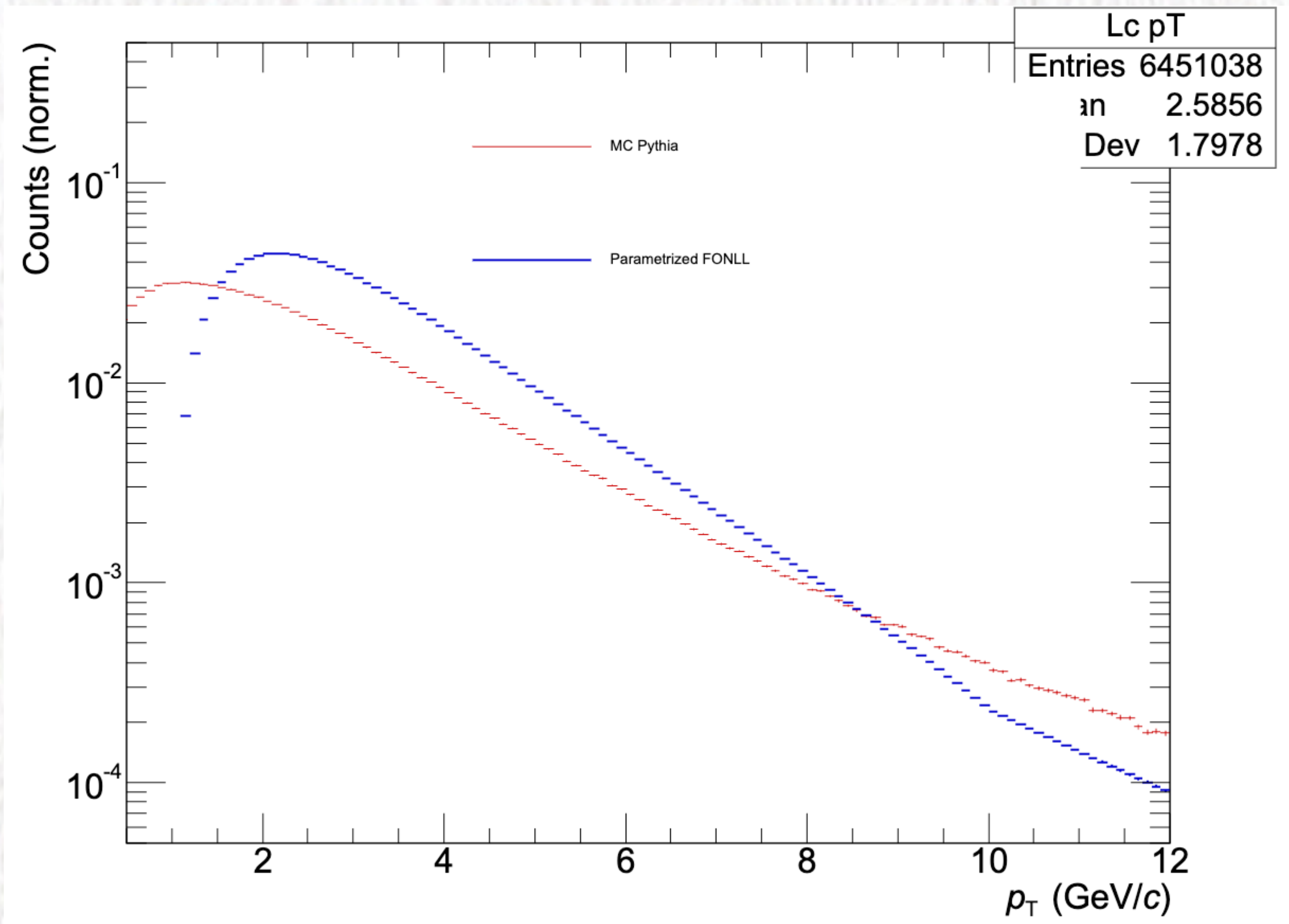

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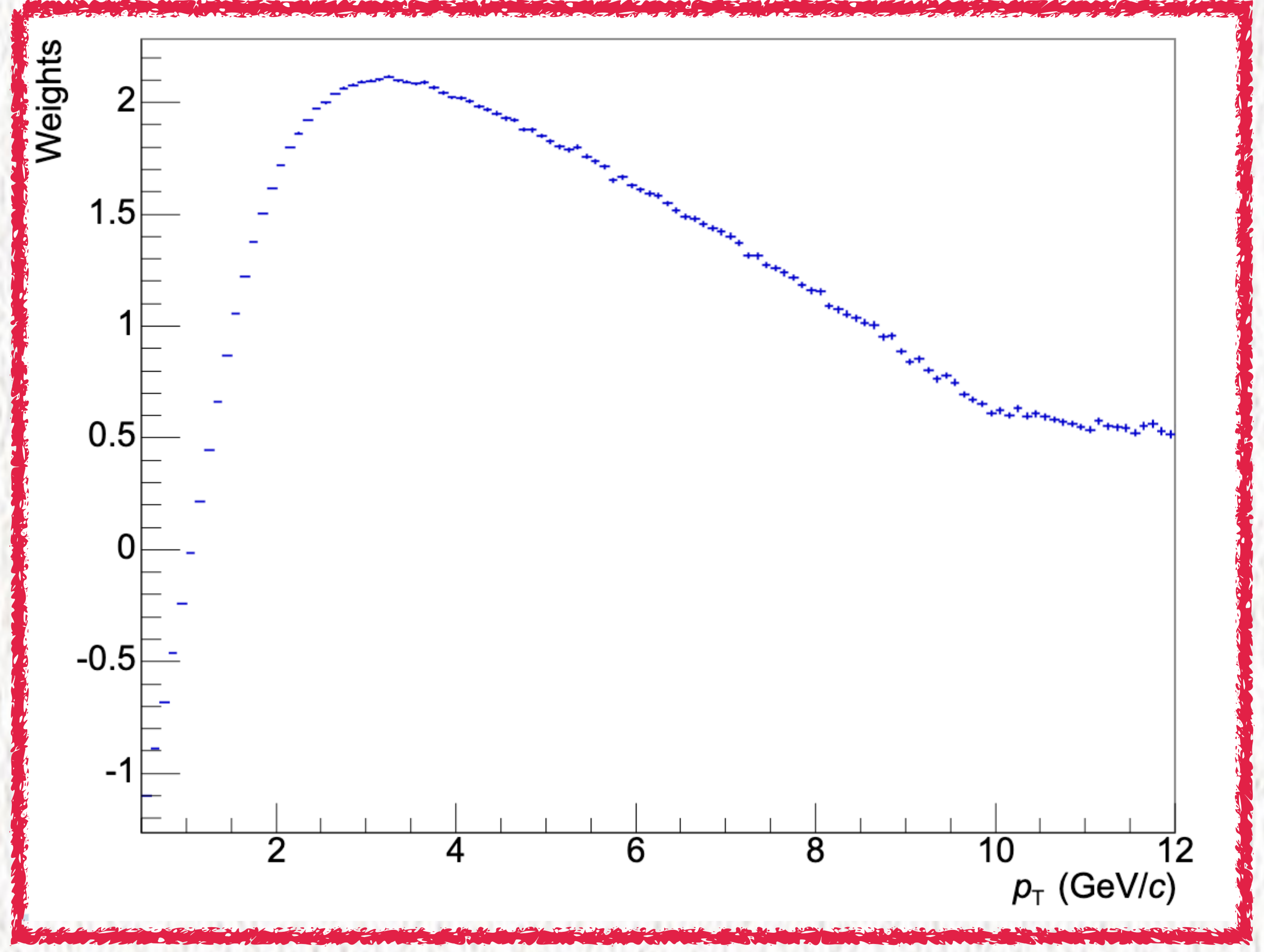
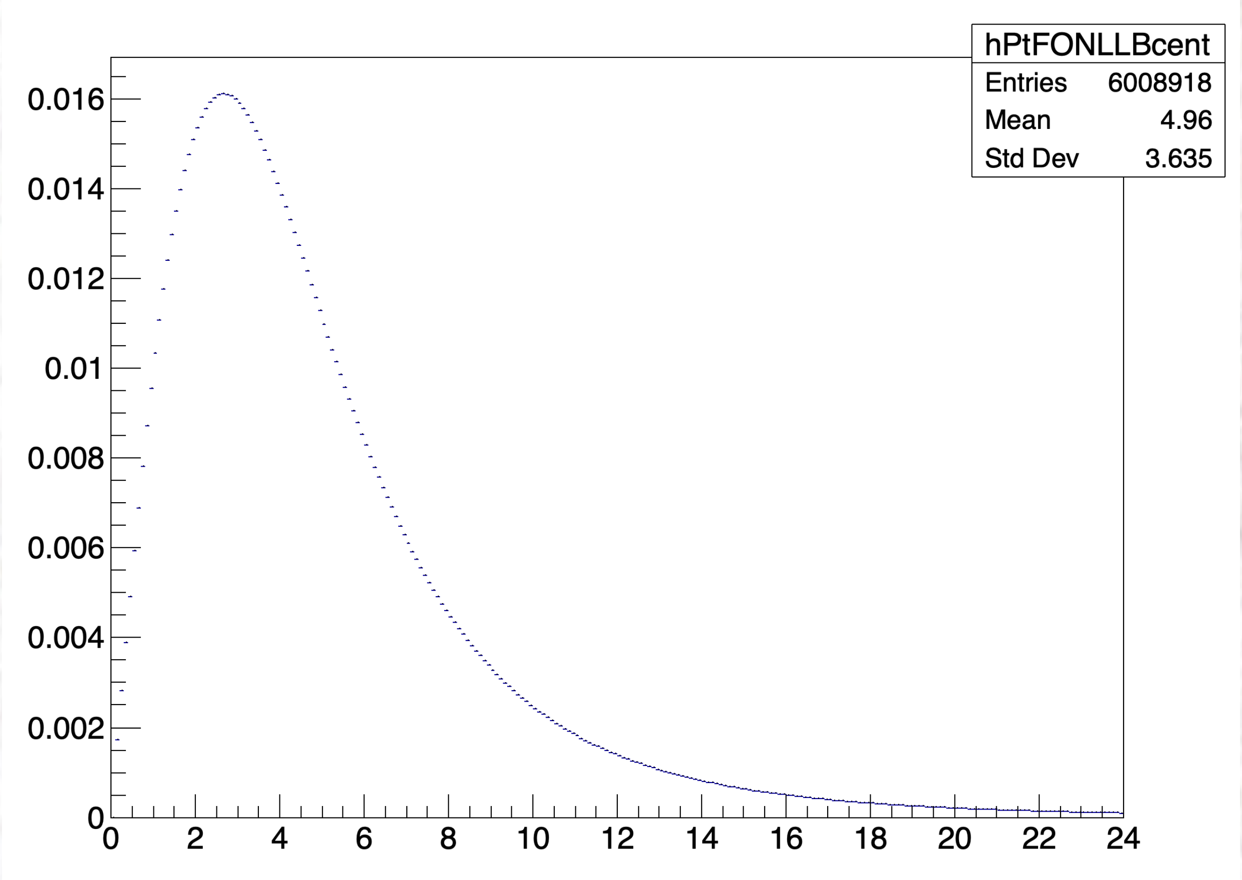
Weight of prompt $p_T^{\Lambda_c^+}$



Add weights to prompt Λ_c^+

MC p_T weight — non-prompt

$p_T^{H_B}$ from FONLL



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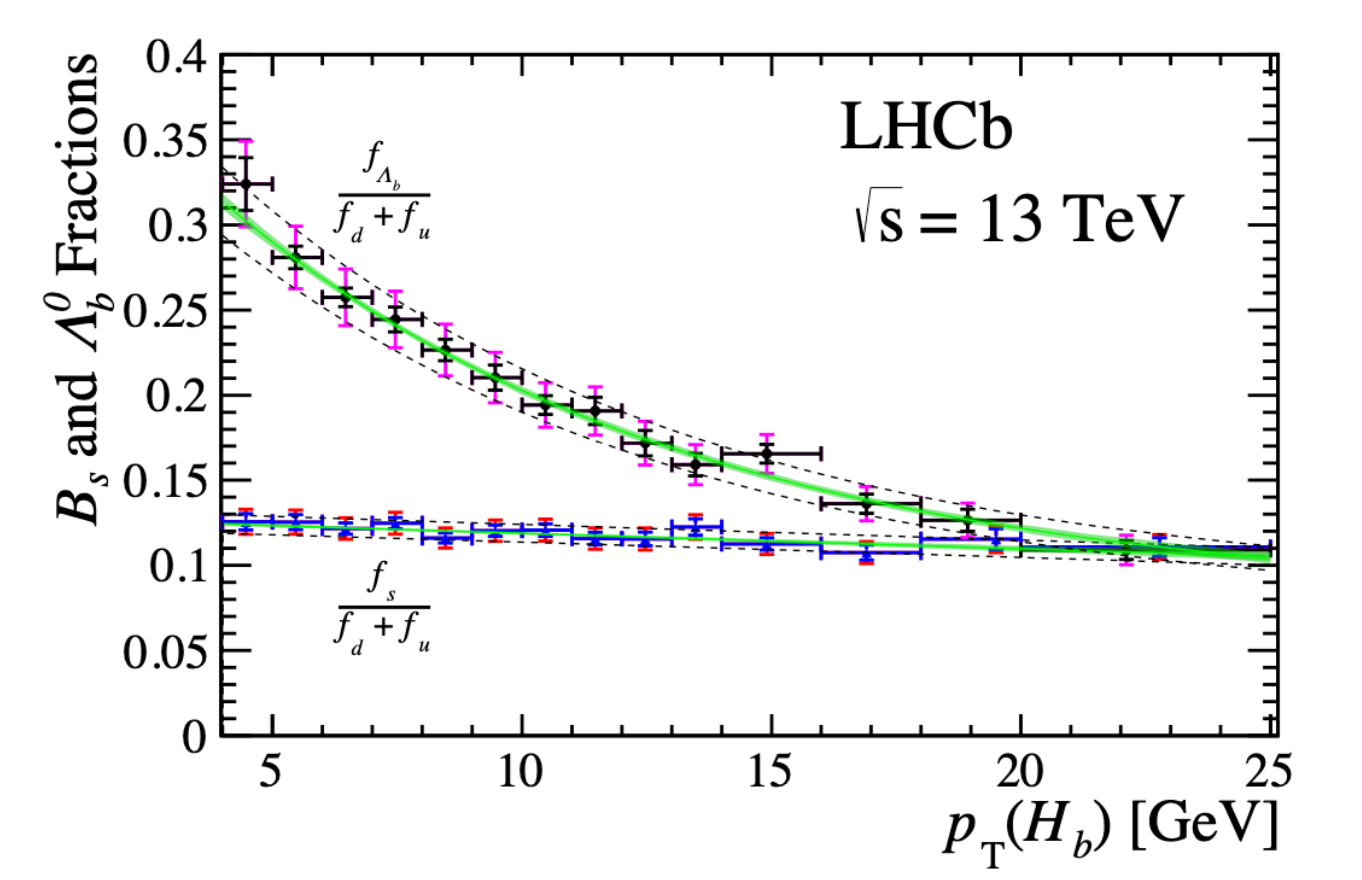
$\frac{\Lambda_b^0}{B^0 + B^+}$ in pp



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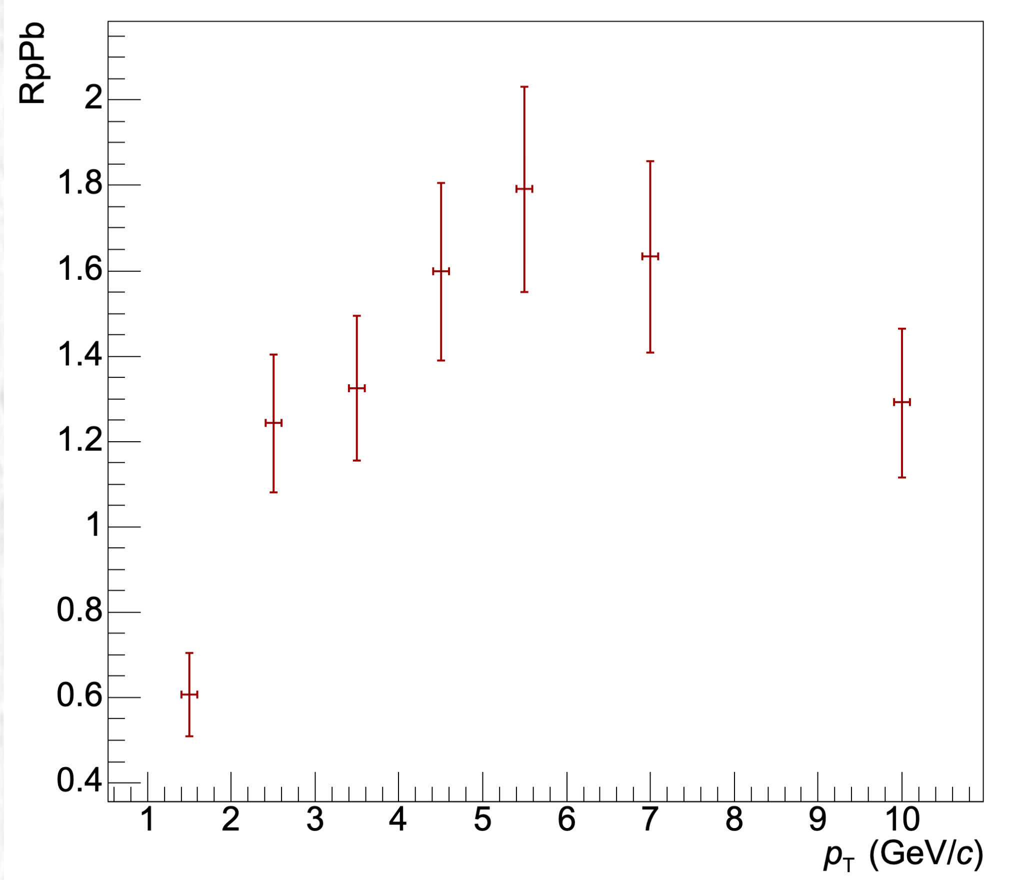
Prompt $R_{pA}^{\Lambda_c^+}$



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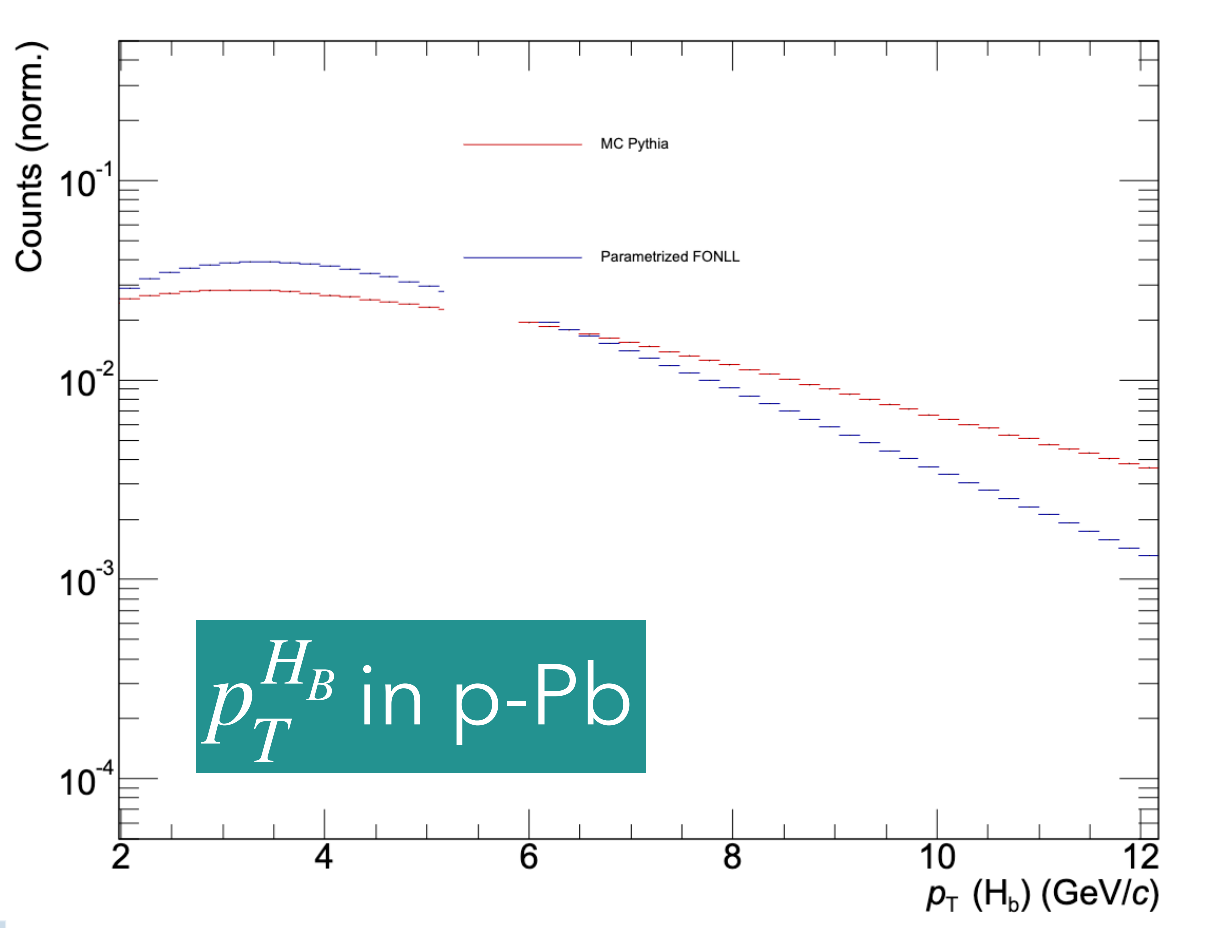
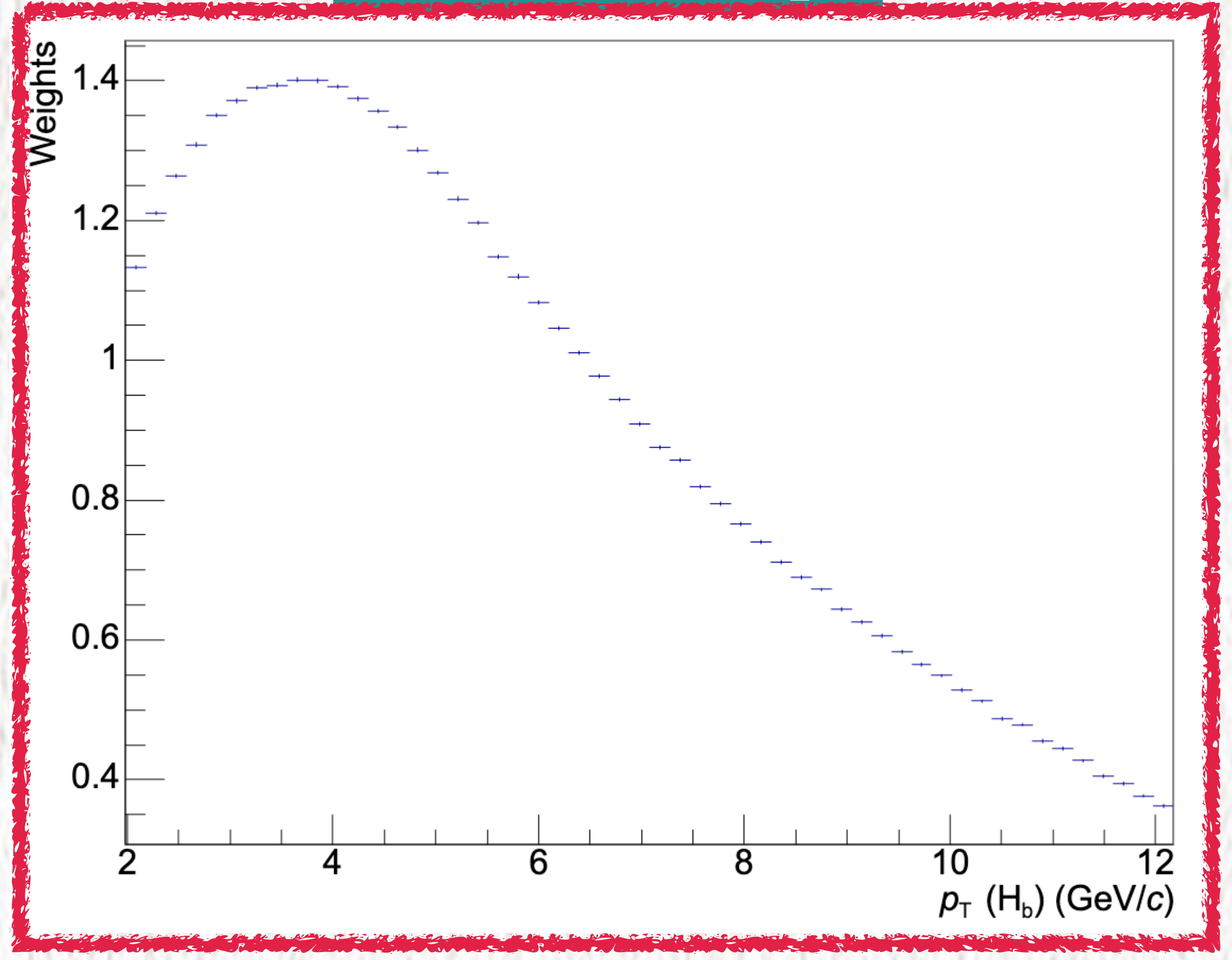


$p_T^{H_B}$ in p-Pb

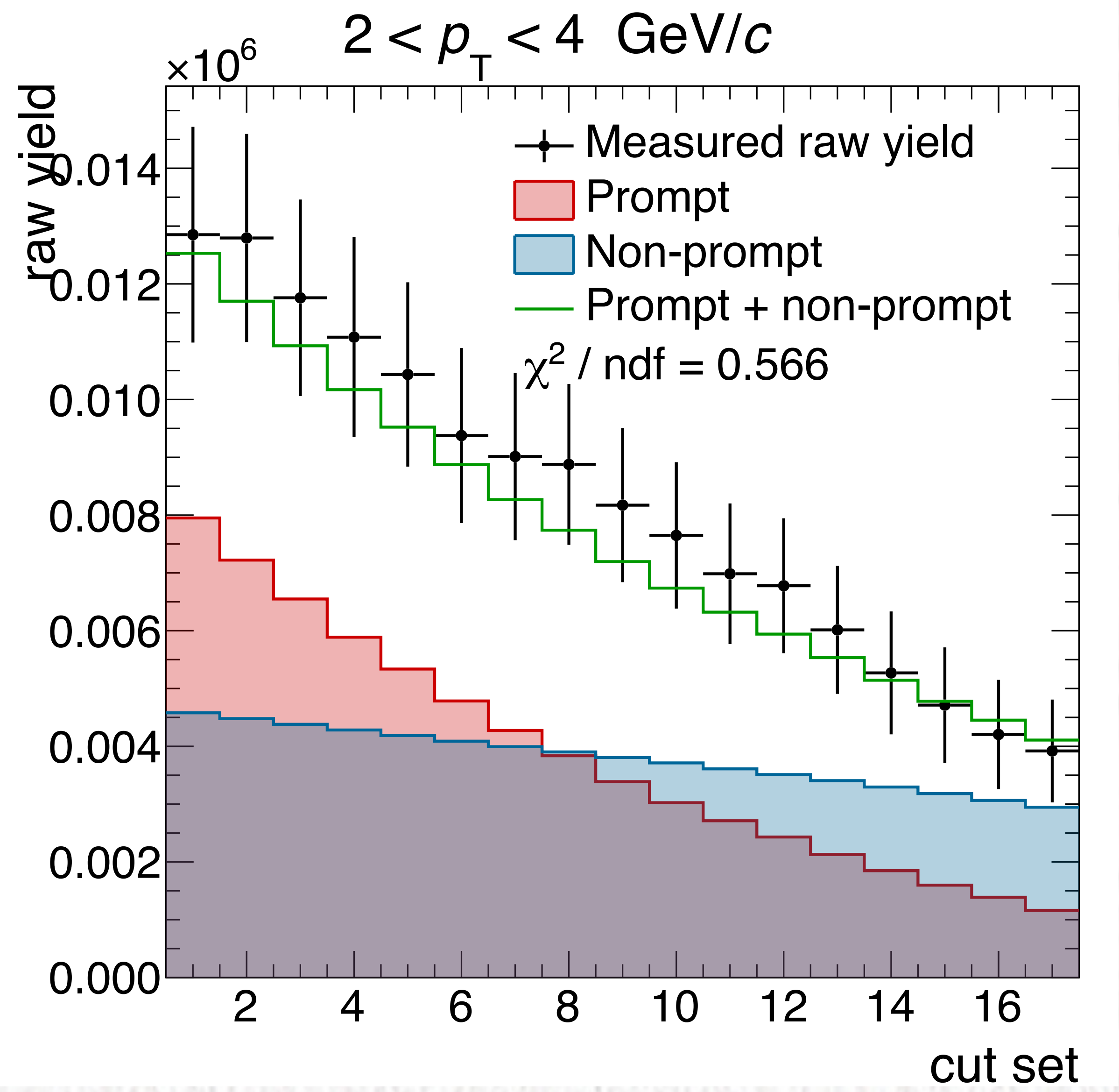
Weight of $p_T^{H_B}$



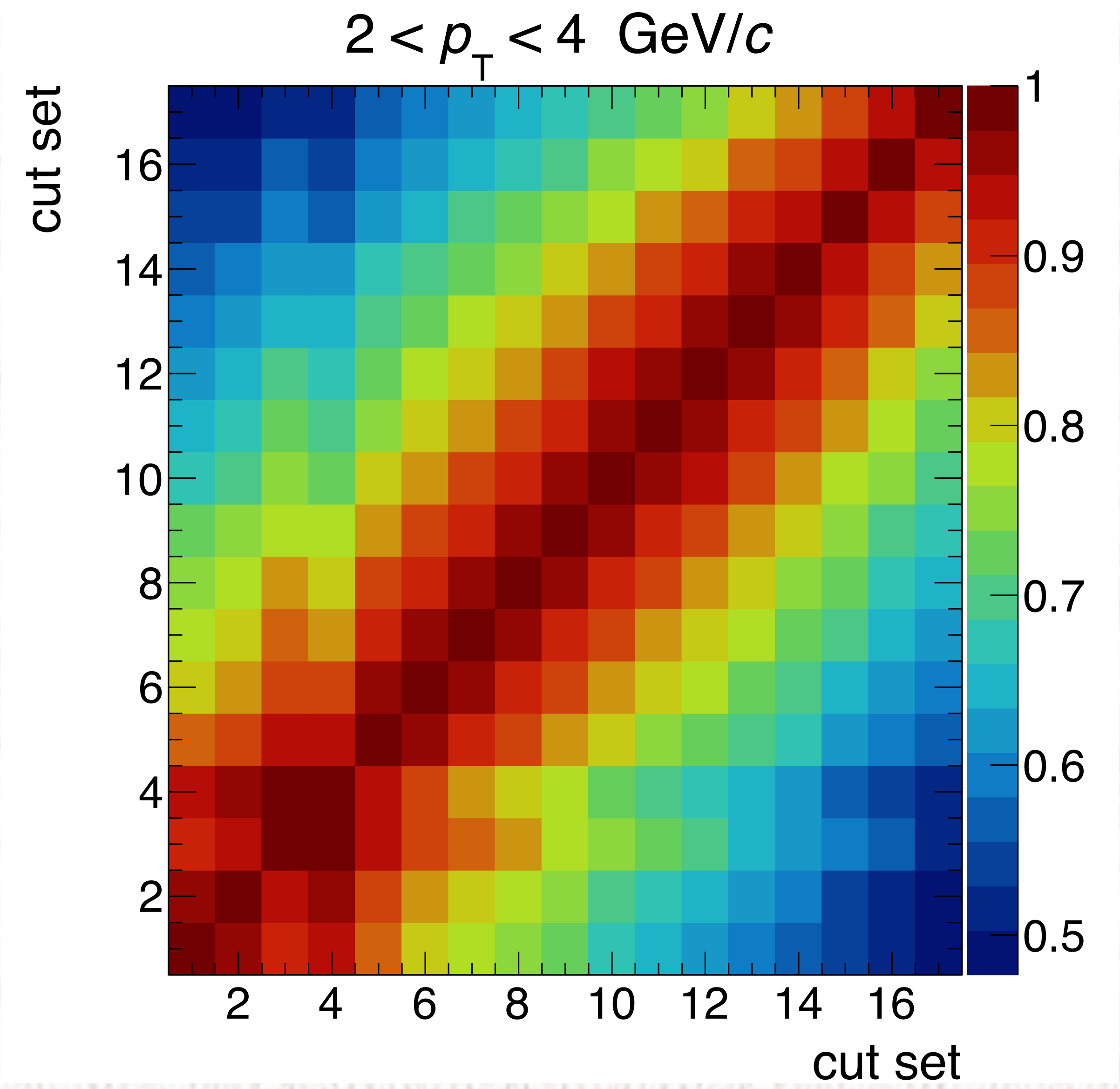
Add weights to H_B

Cuts variation ($2 < p_T < 4$ GeV/c)

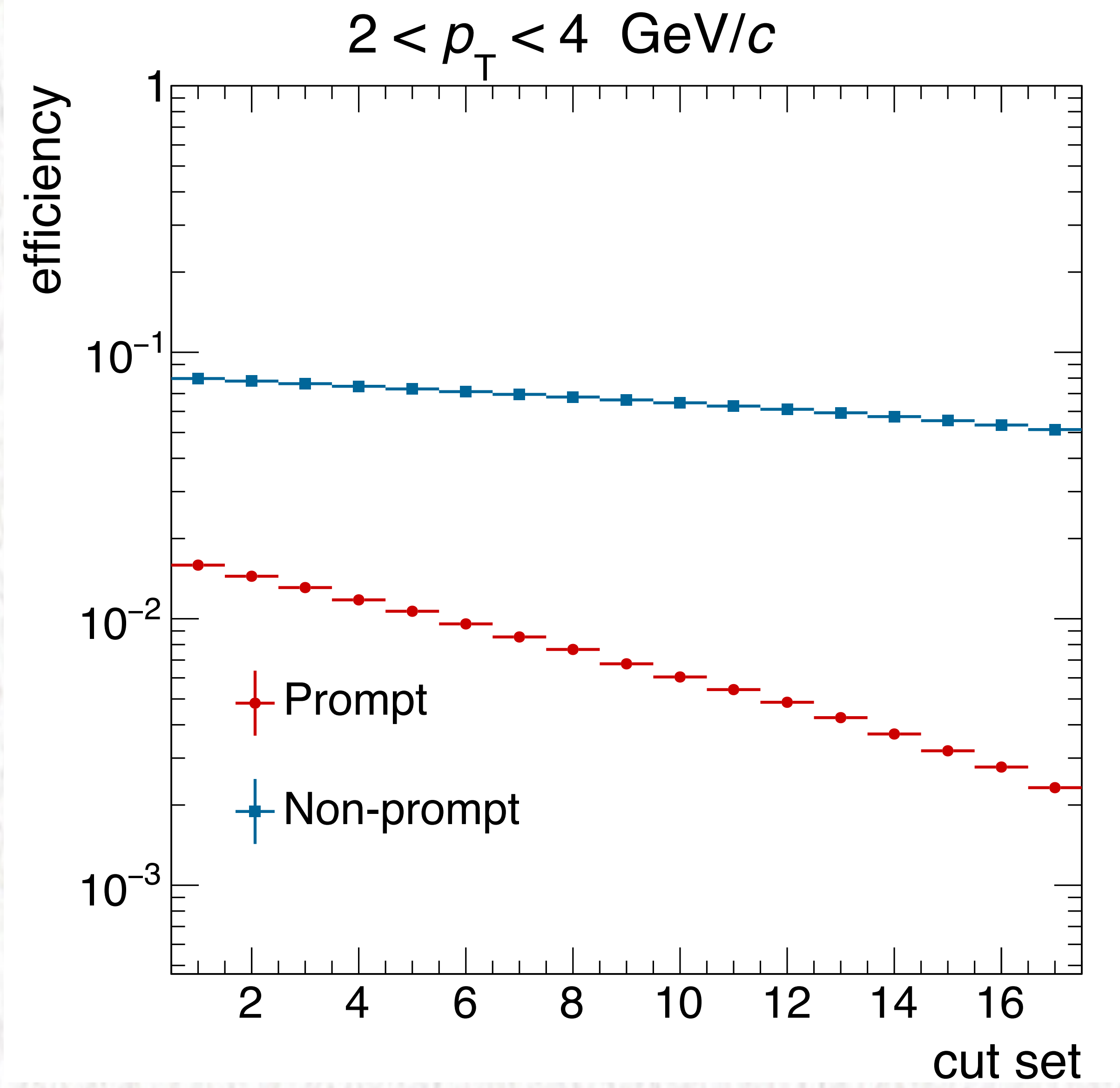
Raw yields vs. Cut set



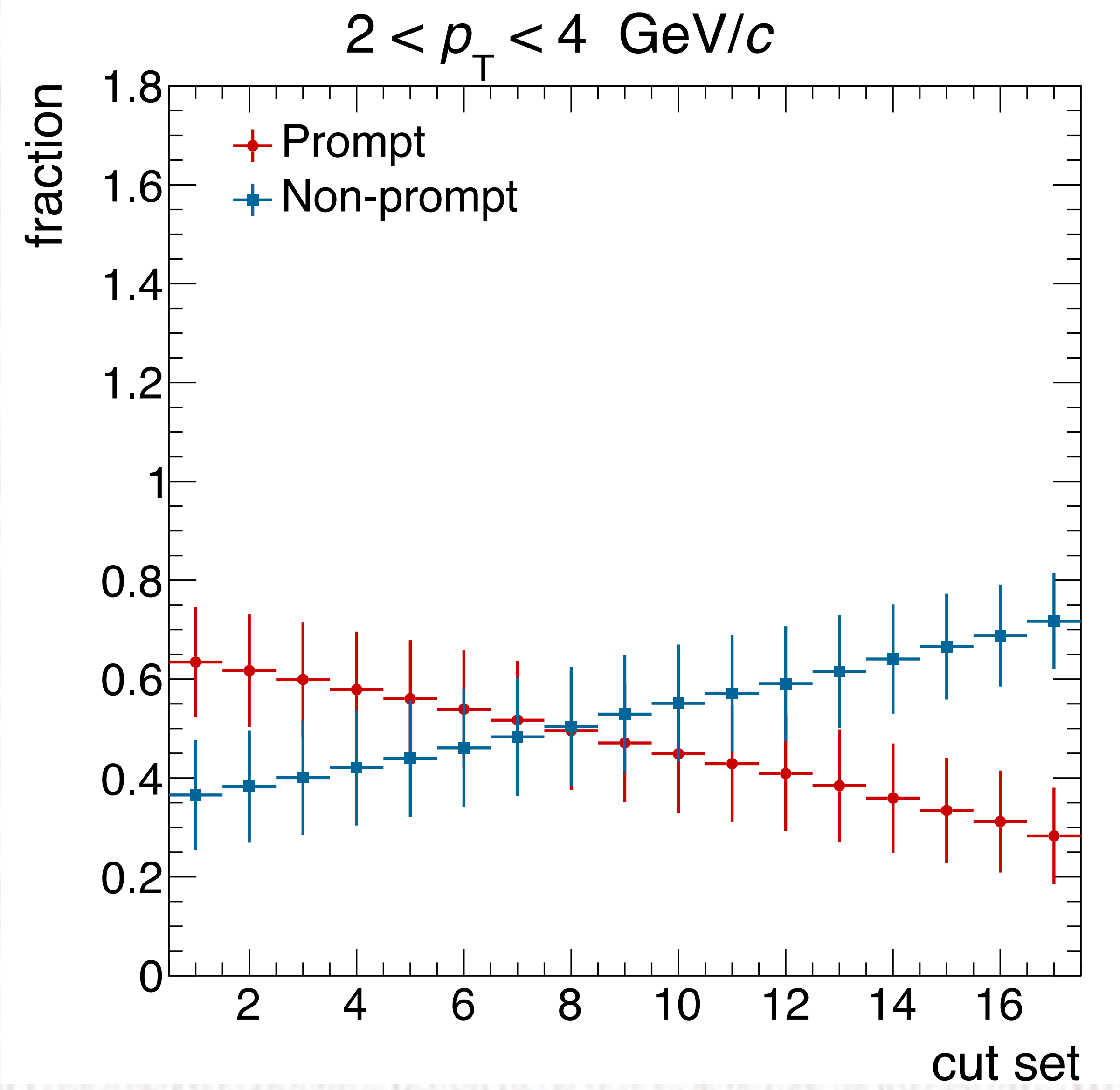
Covariance matrix correlation



Efficiencies vs. Cut set



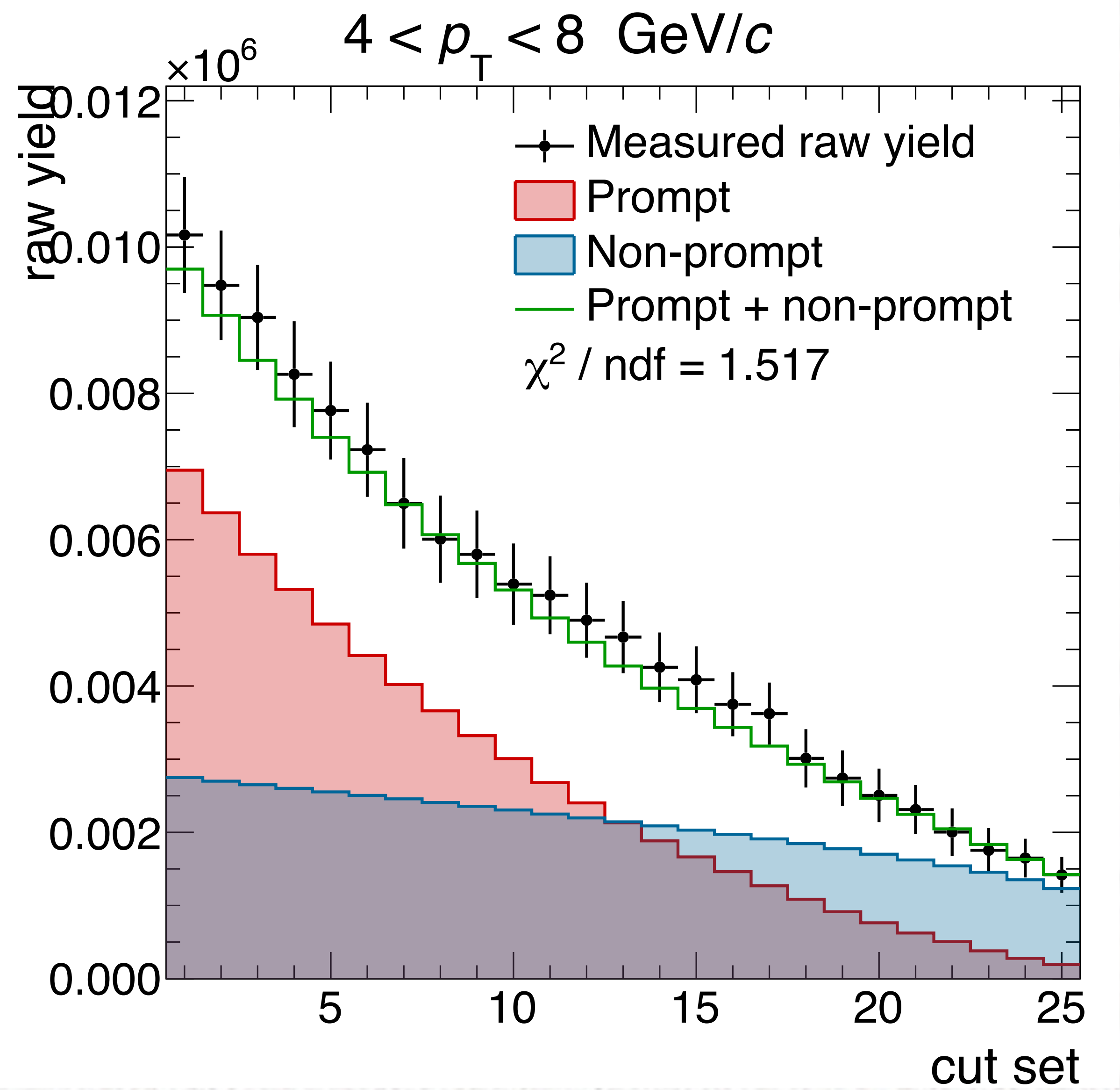
Fractions vs. Cut set



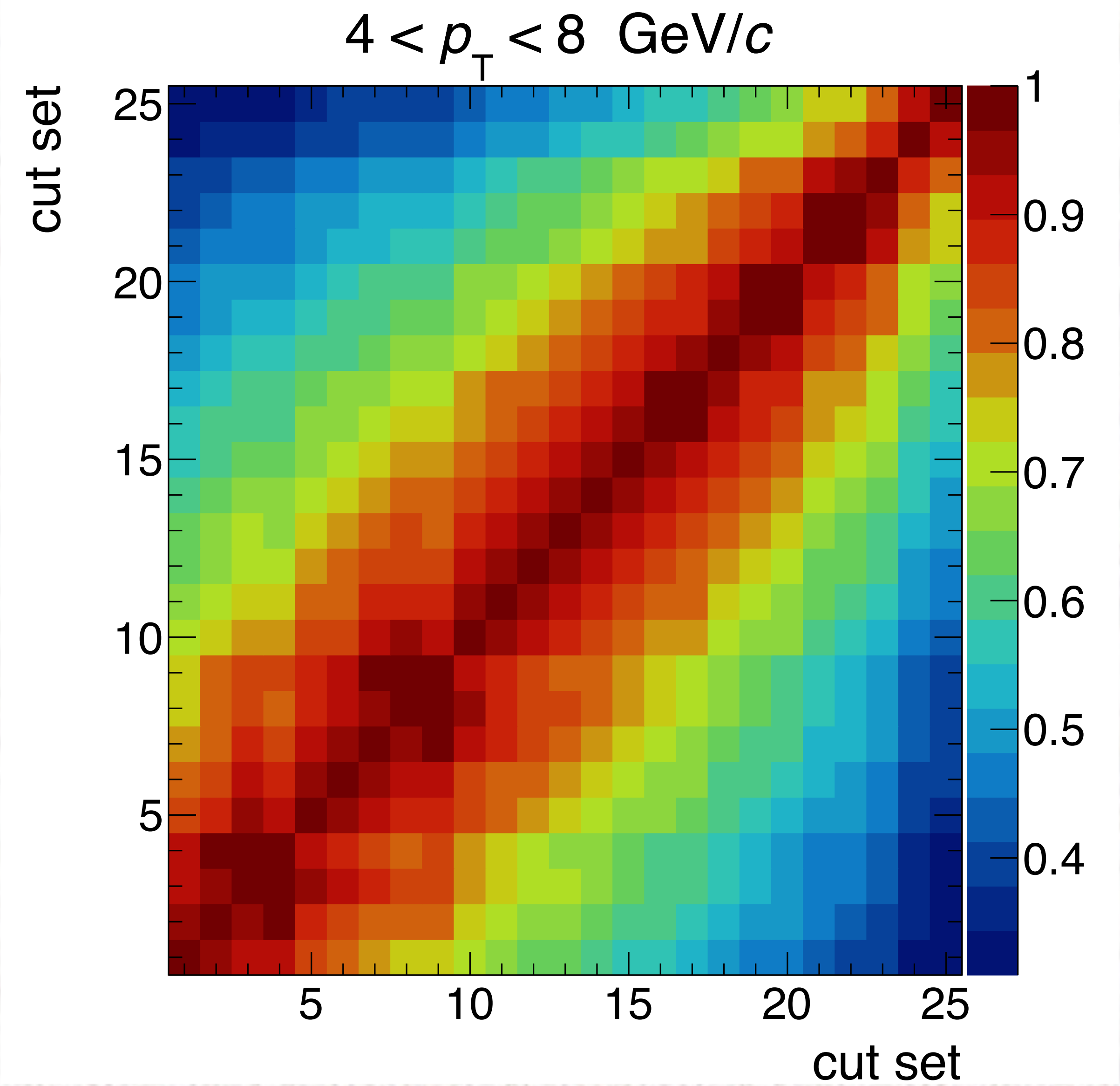
- Template fit the raw yields shape as a function of the cut set
- Avoid cut sets with issued covariance matrix
- Achieve non-prompt enhance samples, variate from 40%–70%

Cuts variation ($4 < p_T < 8$ GeV/c)

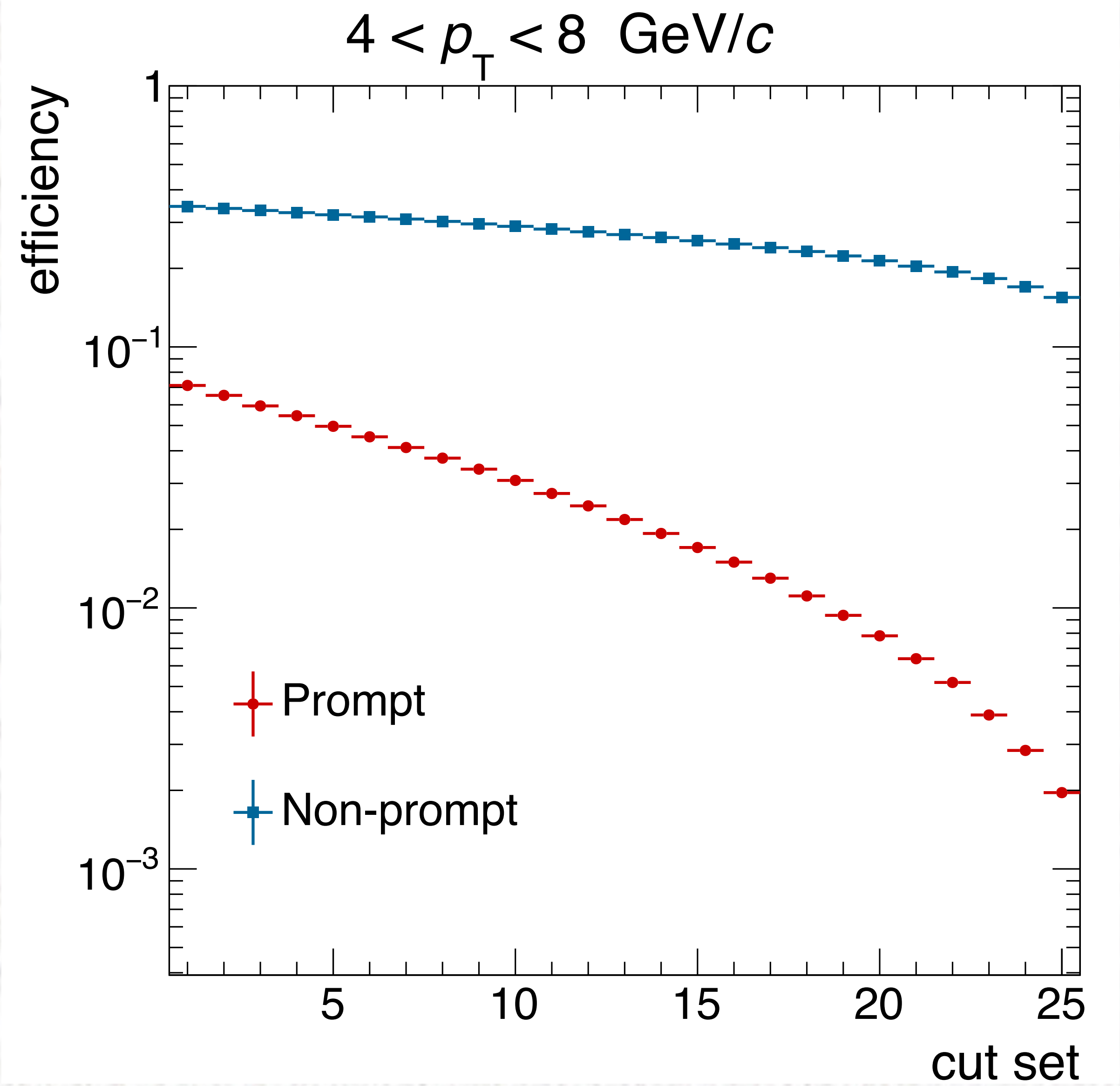
Raw yields vs. Cut set



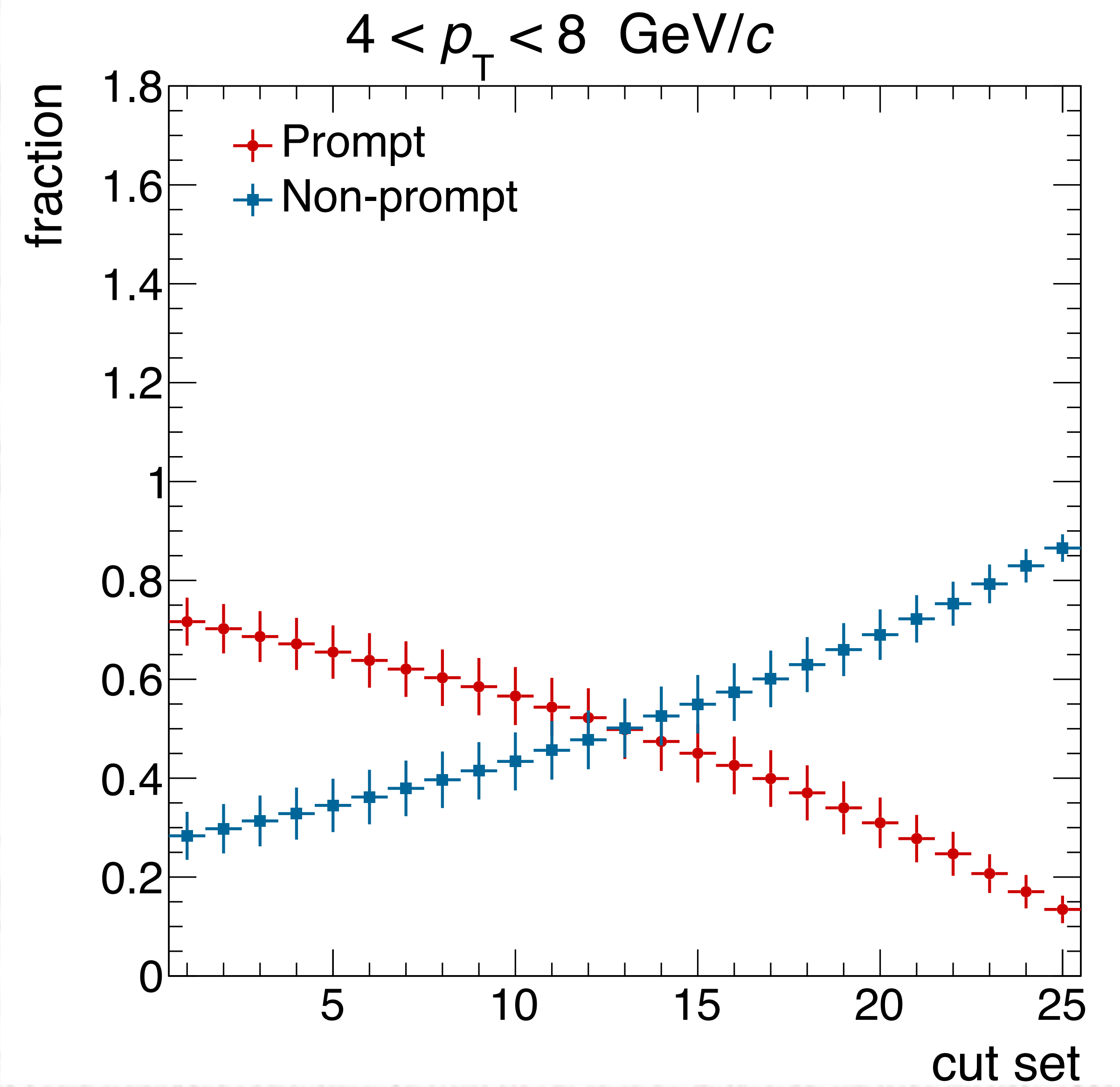
Covariance matrix correlation



Efficiencies vs. Cut set



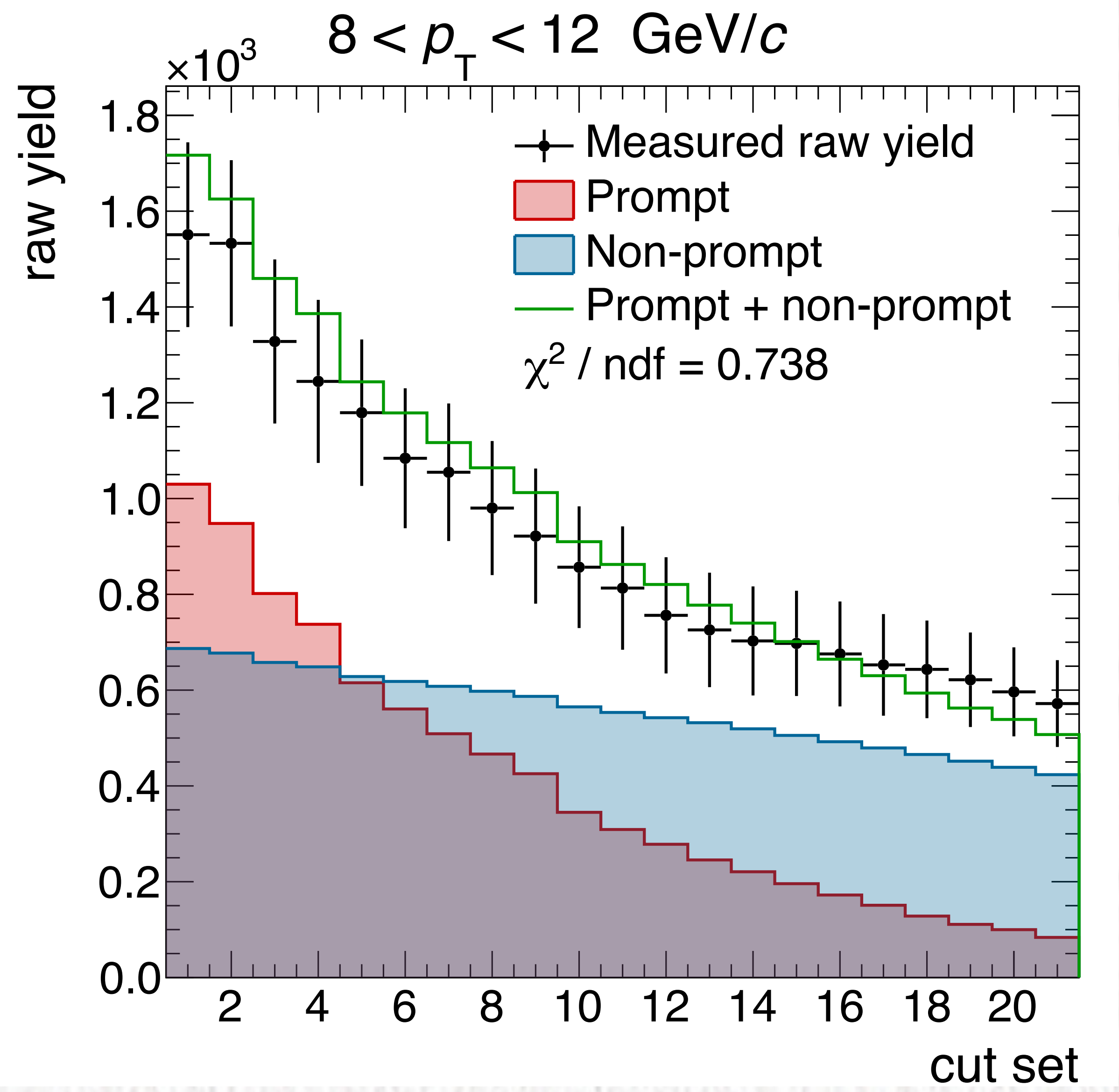
Fractions vs. Cut set



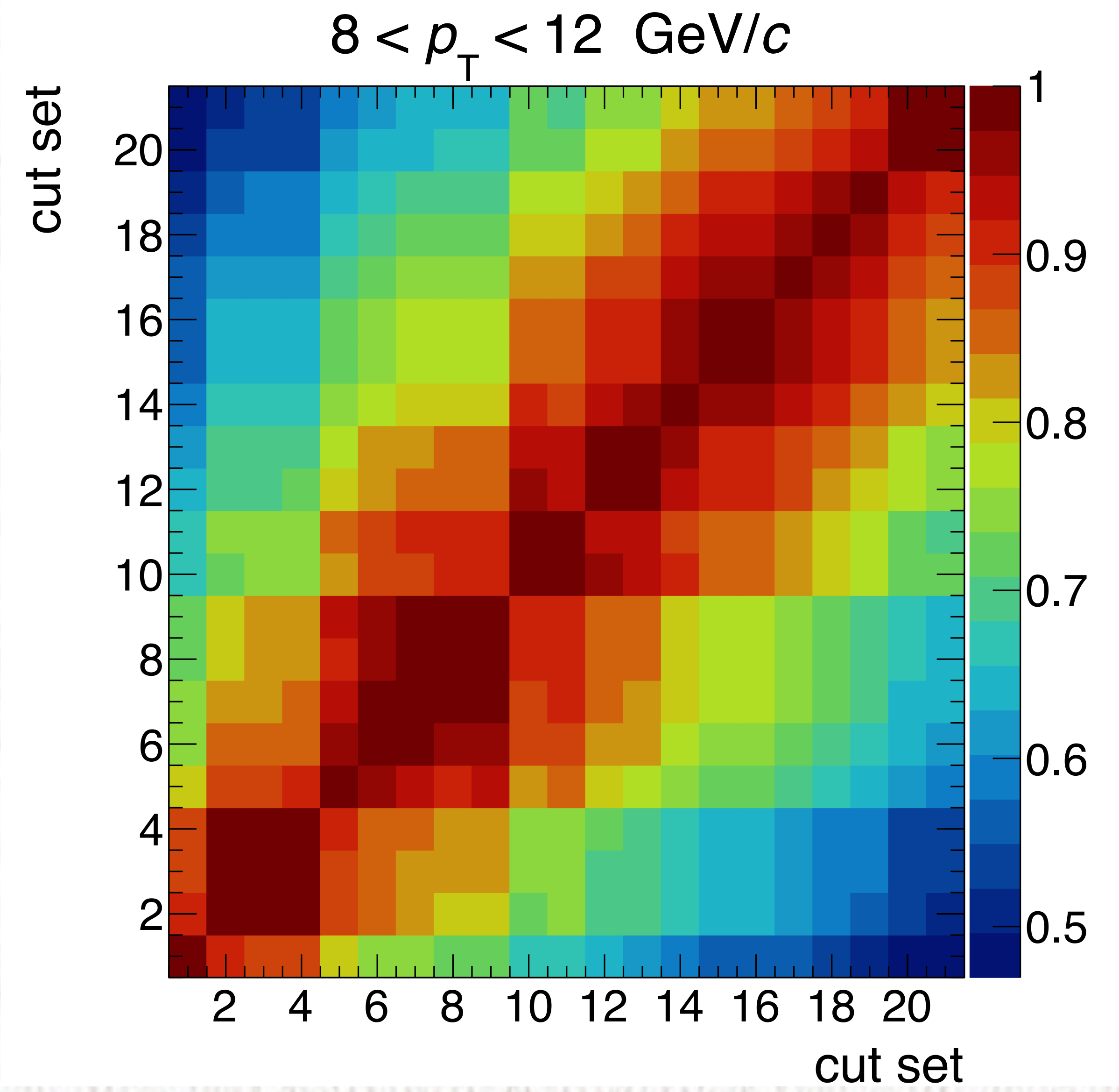
- Template fit the raw yields shape as a function of the cut set
- Avoid cut sets with issued covariance matrix
- Achieve non-prompt enhance samples, variate from 30%–85%

Cuts variation ($8 < p_T < 12$ GeV/c)

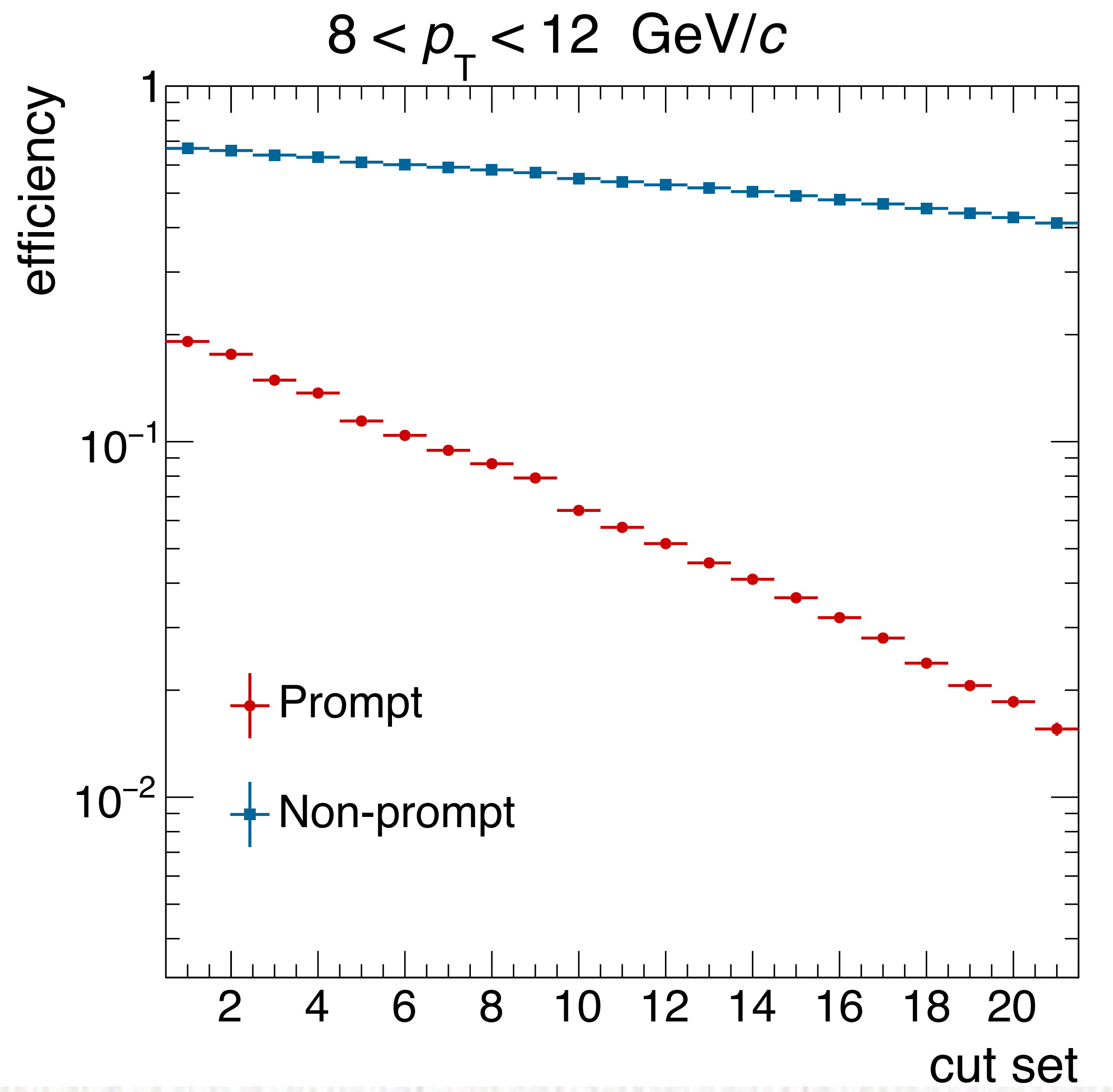
Raw yields vs. Cut set



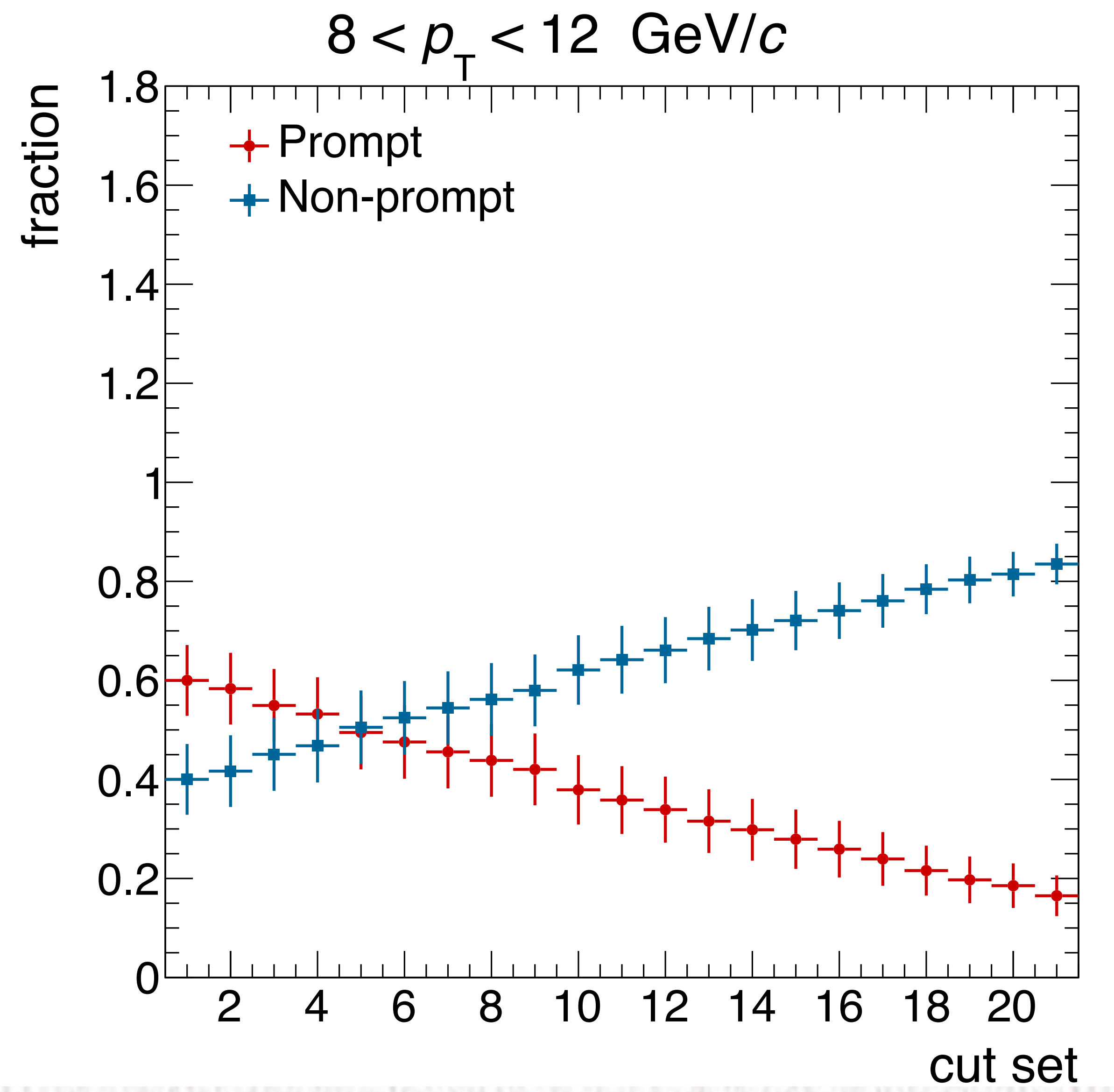
Covariance matrix correlation



Efficiencies vs. Cut set



Fractions vs. Cut set

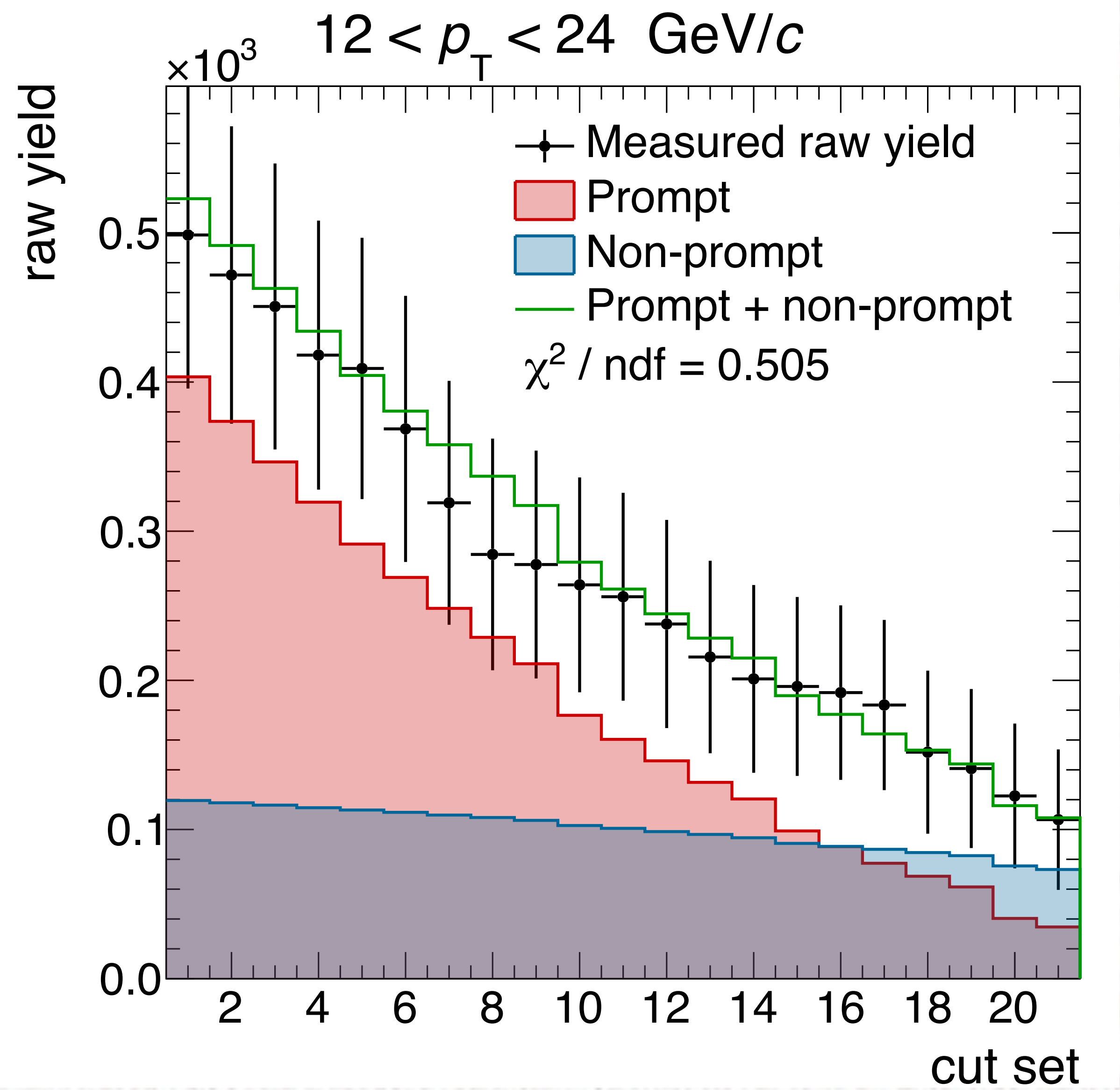


- Template fit the raw yields shape as a function of the cut set
- Avoid cut sets with issued covariance matrix
- Achieve non-prompt enhance samples, variate from 40%–80%

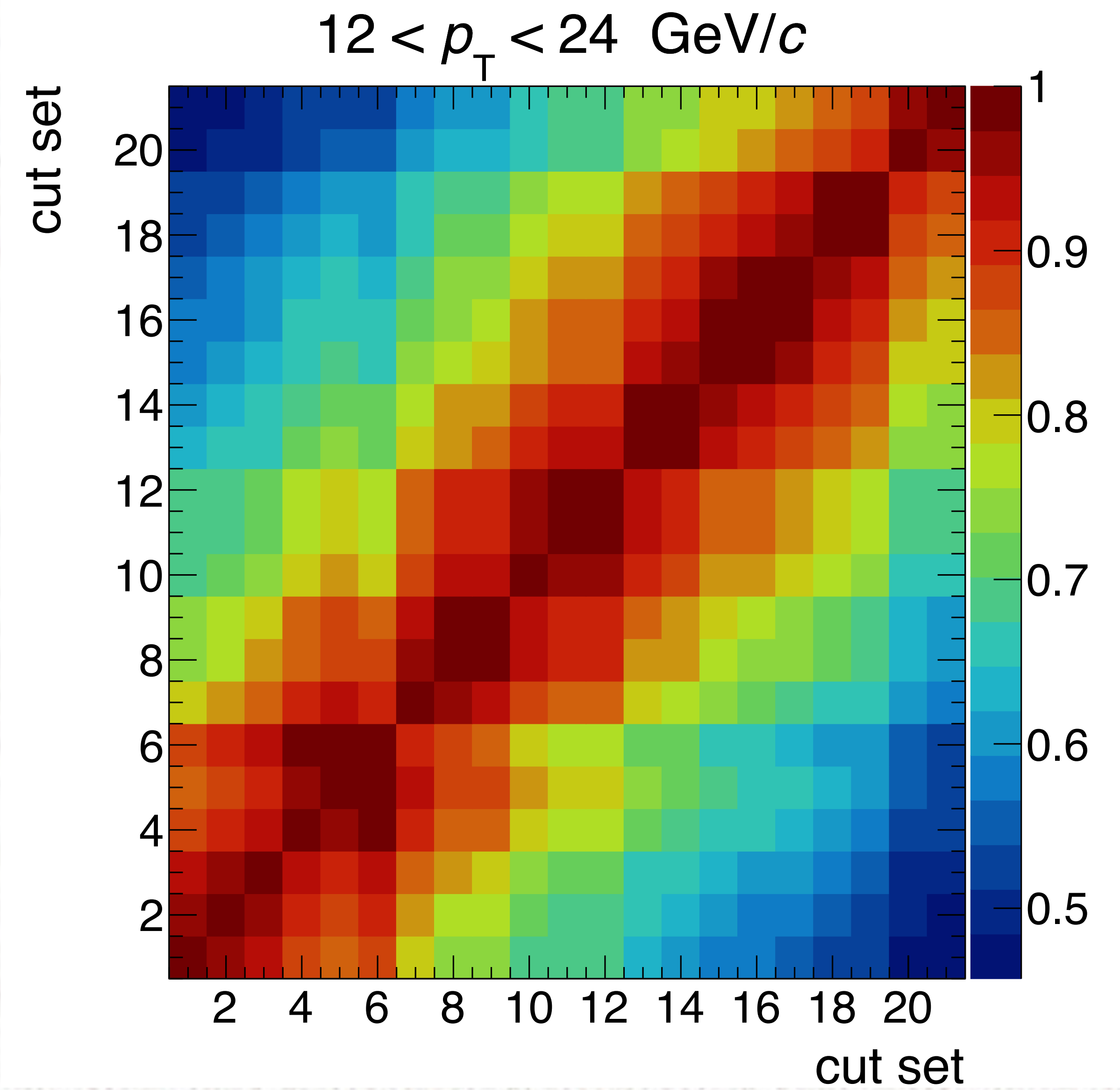
Cuts variation ($12 < p_T < 24$ GeV/c)

ALICE

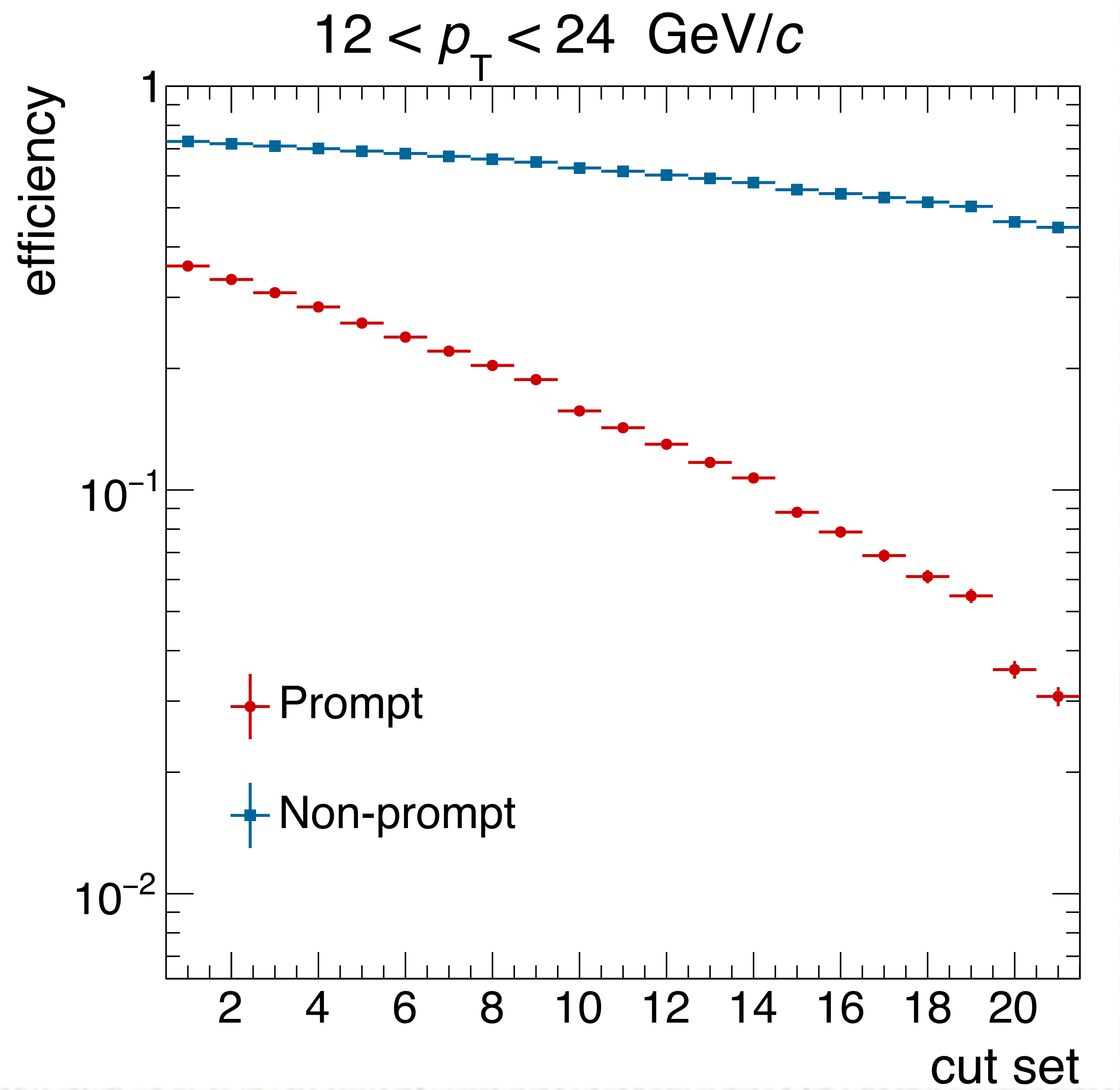
Raw yields vs. Cut set



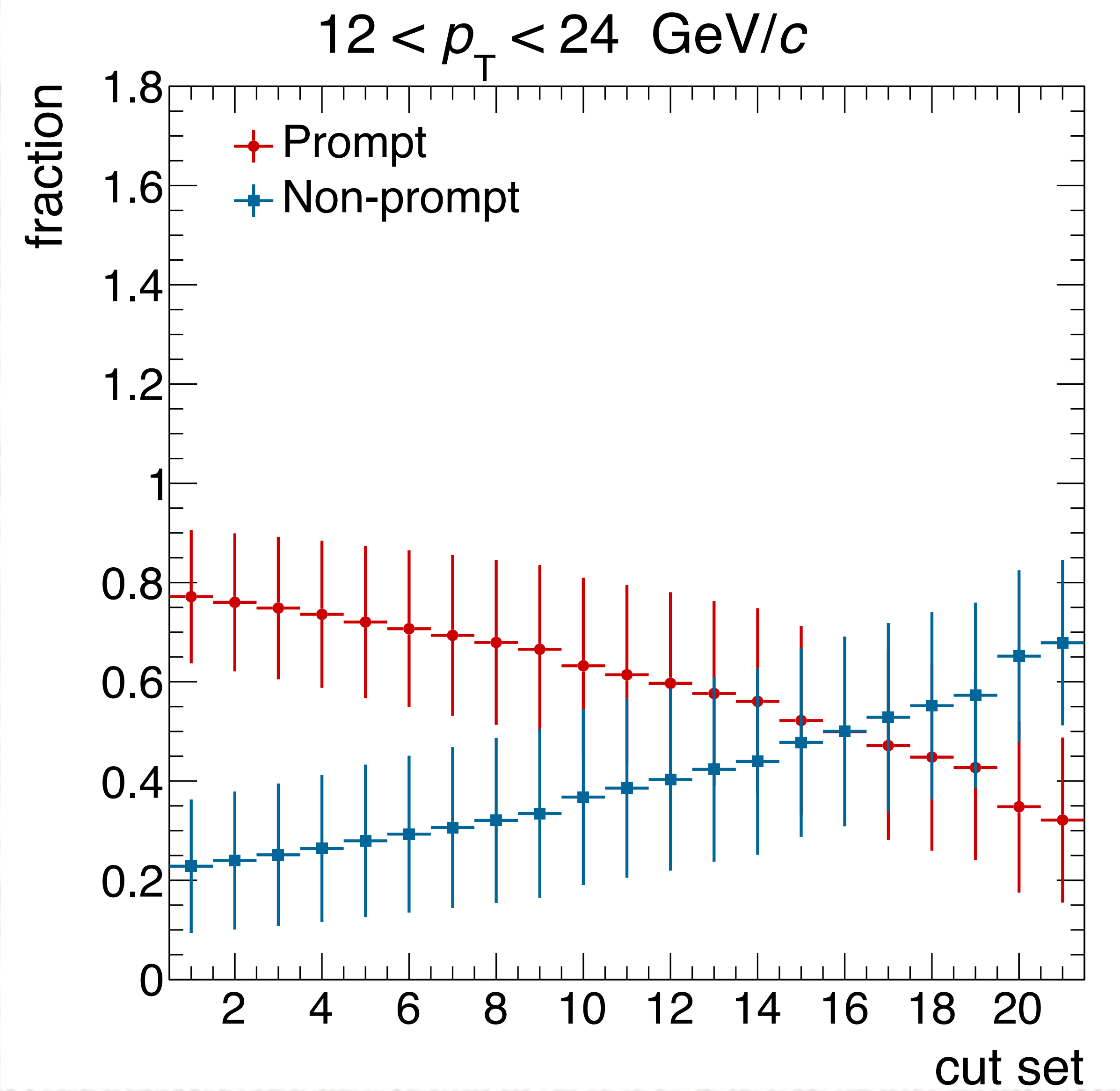
Covariance matrix correlation



Efficiencies vs. Cut set

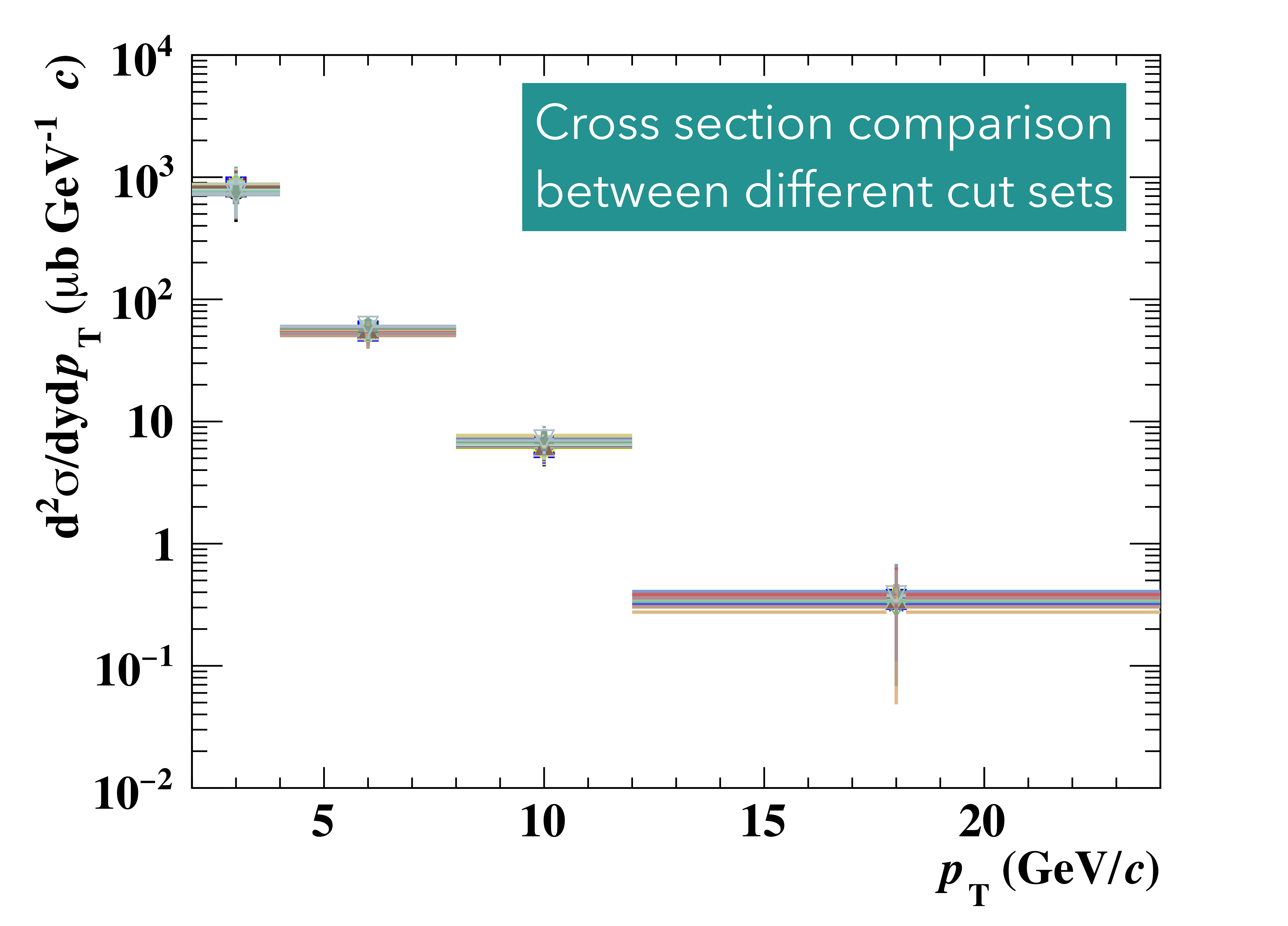


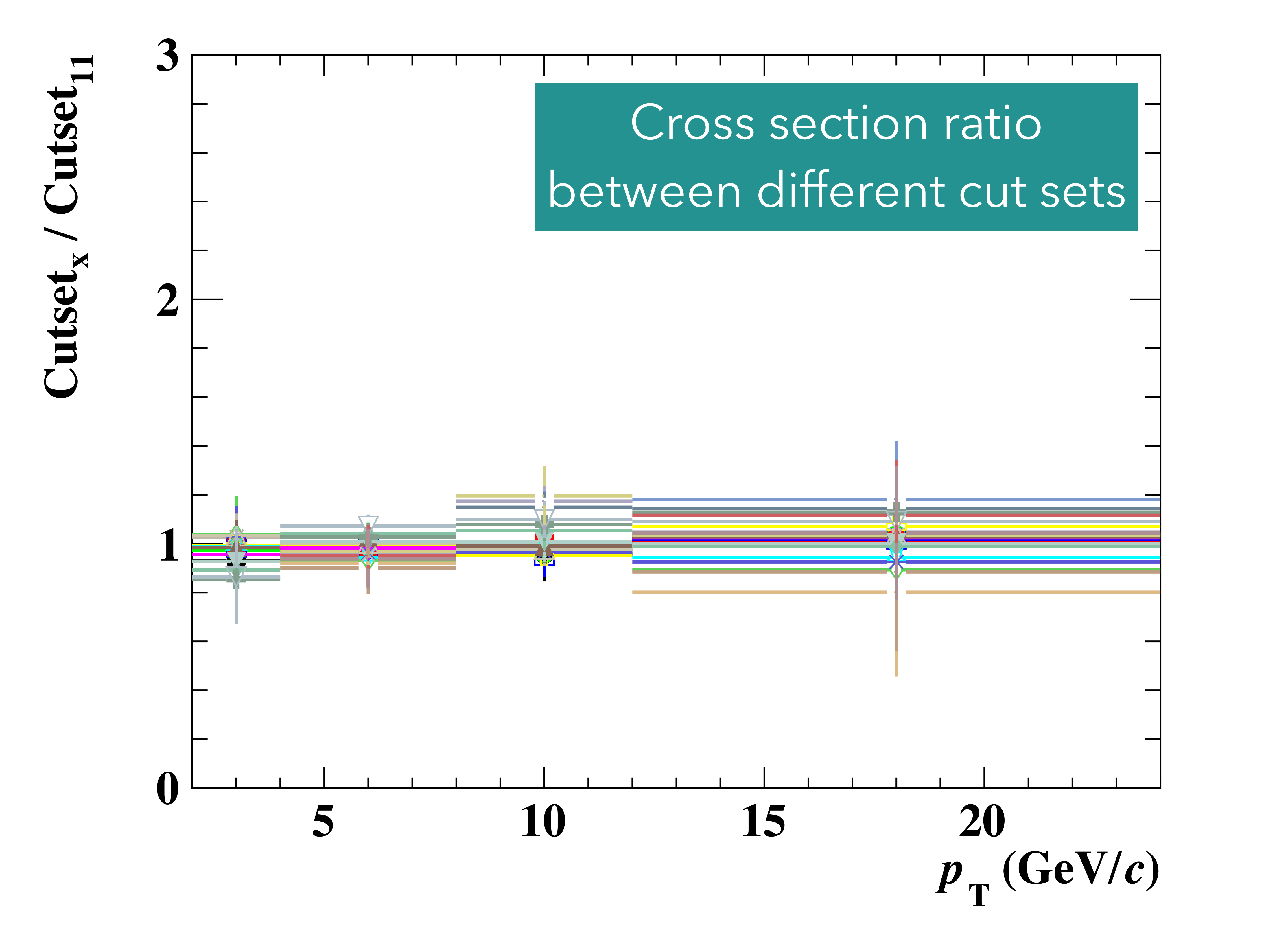
Fractions vs. Cut set



- Template fit the raw yields shape as a function of the cut set
- Avoid cut sets with issued covariance matrix
- Achieve non-prompt enhance samples, variate from 20%–70%

Non-prompt Λ_c^+ cross section comparison

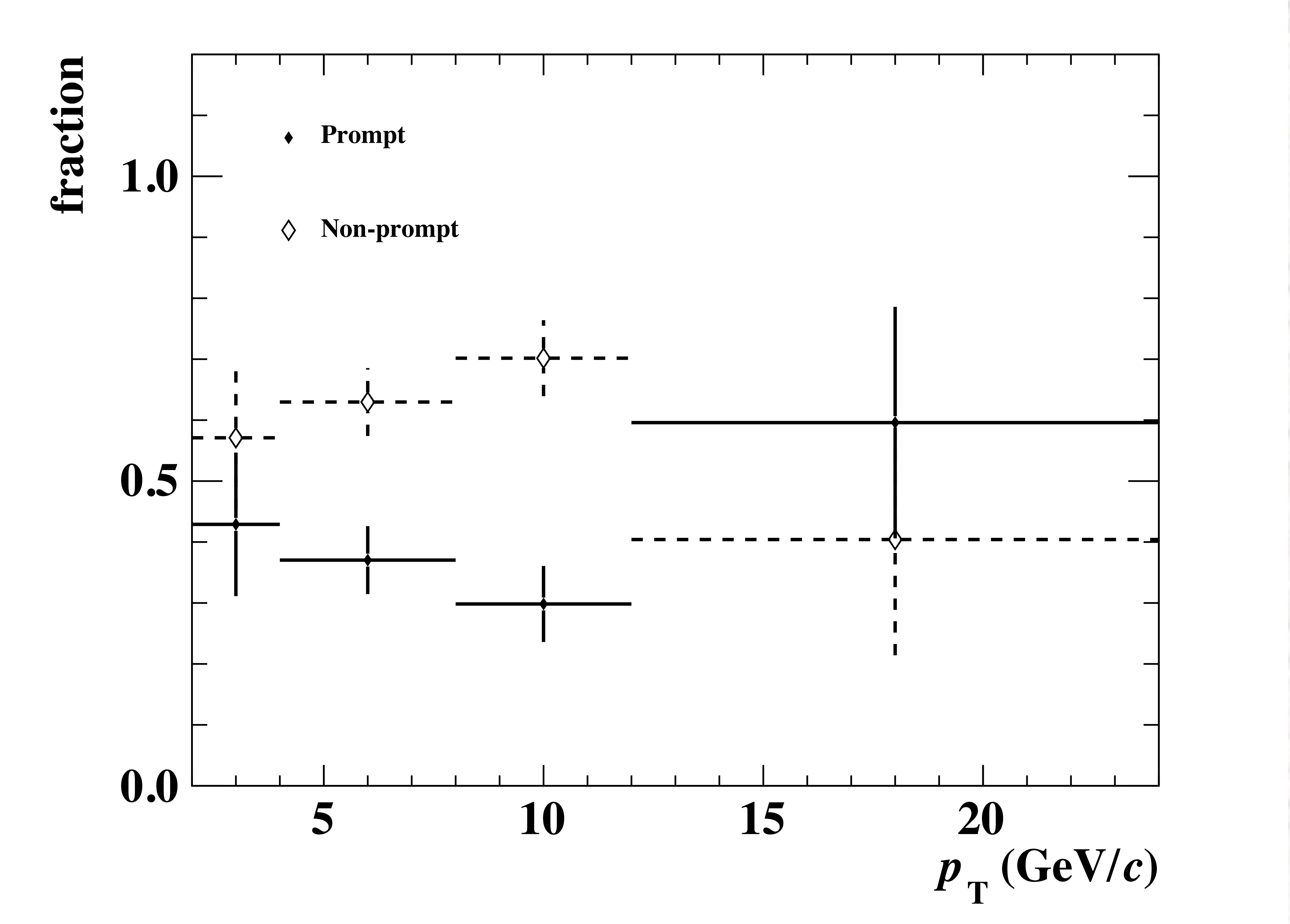




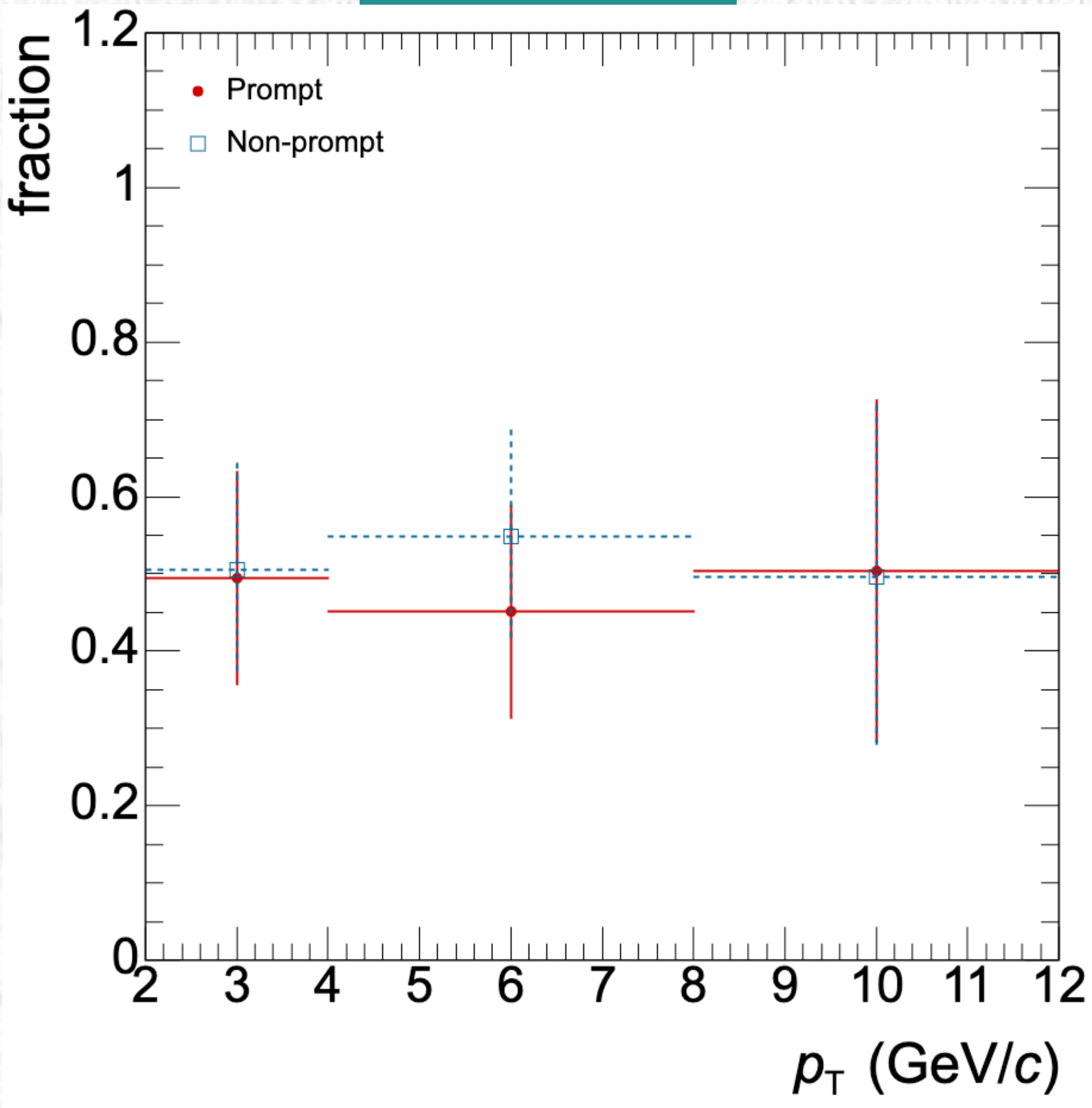
The calculated cross section among most of the cut sets have less than 10% deviation

Raw non-prompt fraction of the default cut set

$\Lambda_c^+ \to pK^-\pi^+$



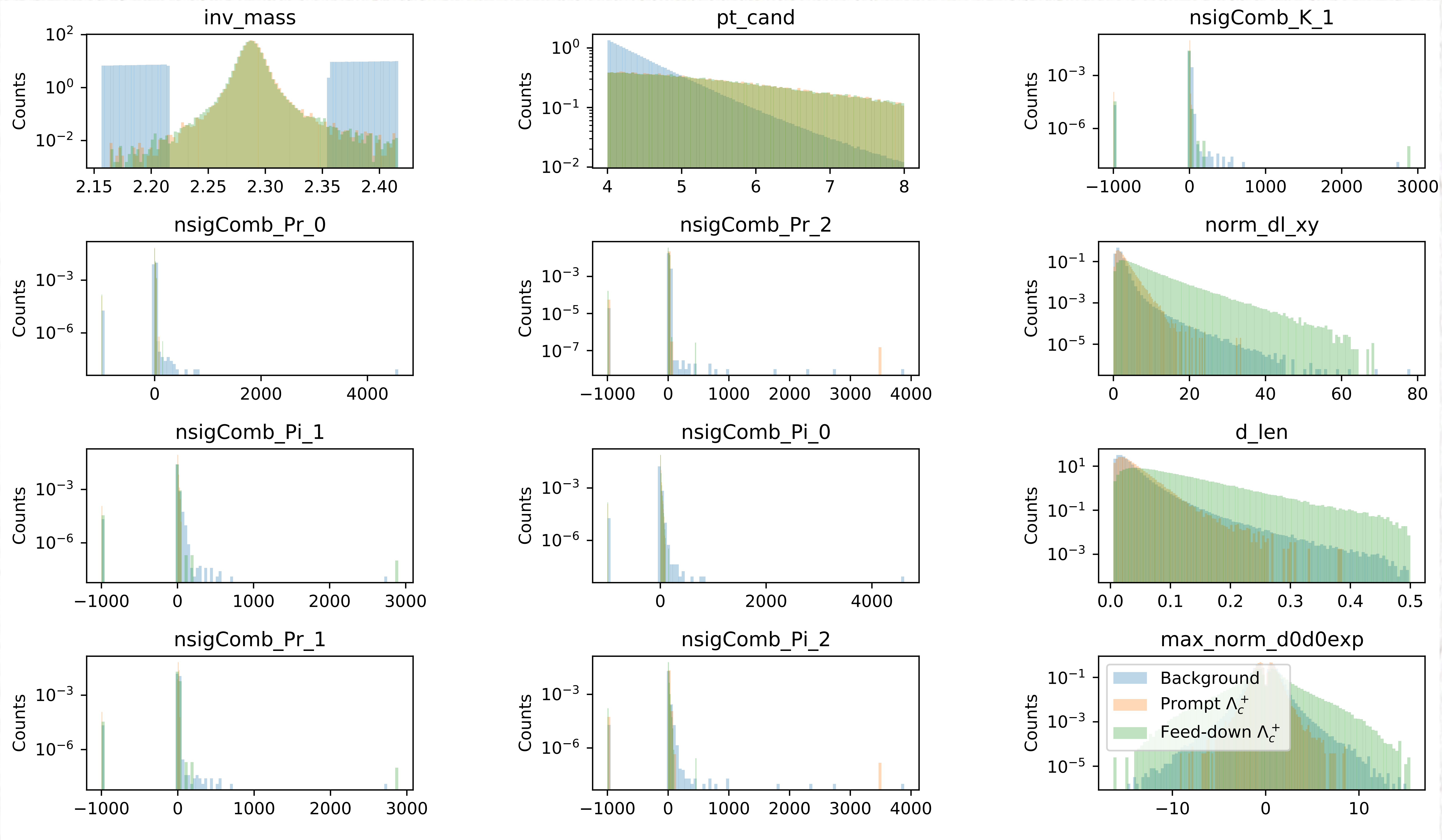
$\Lambda_c^+ \to pK_s^0$



- Non-prompt fraction ranges: 57%—70% (this analysis) vs. 50%—55% ($\Lambda_c^+ \to pK_s^0$) for $2 < p_T < 12$ GeV/c
- Additional cross section for $12 < p_T < 24$ GeV/c, non-prompt fraction is 40%

Pre-selections and variables QA

$4 < p_T < 8$ GeV/c

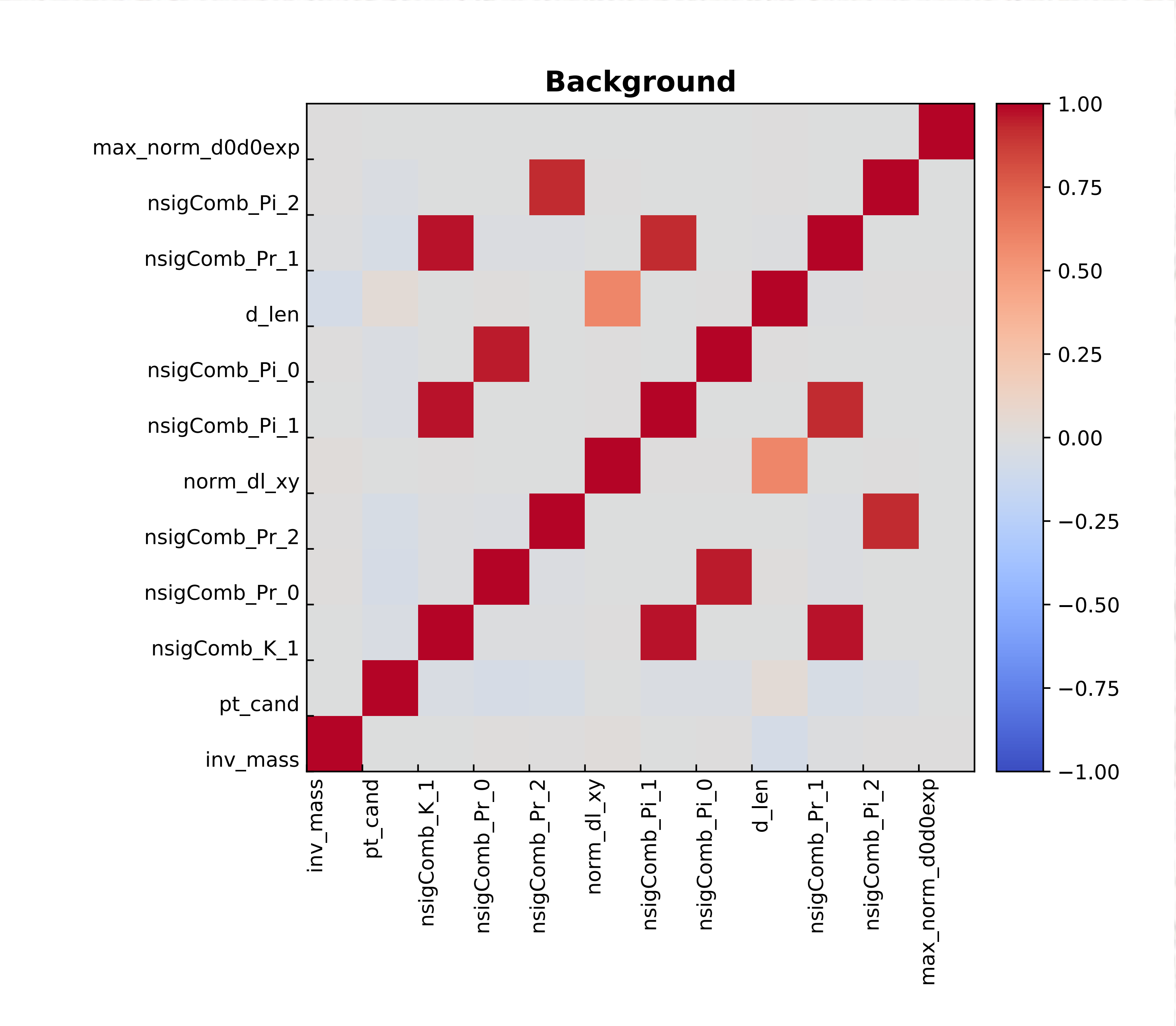


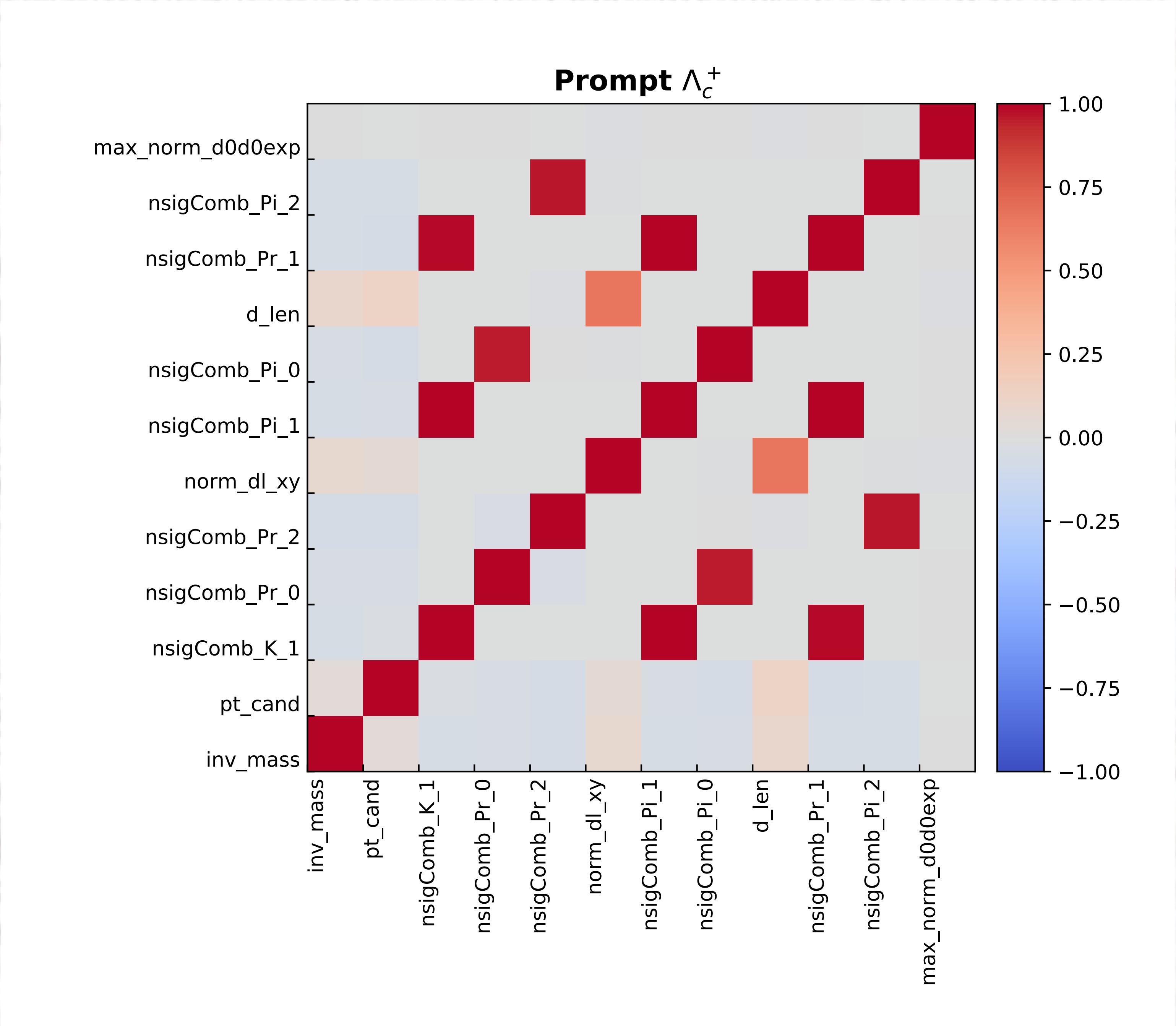
Pre-selections:

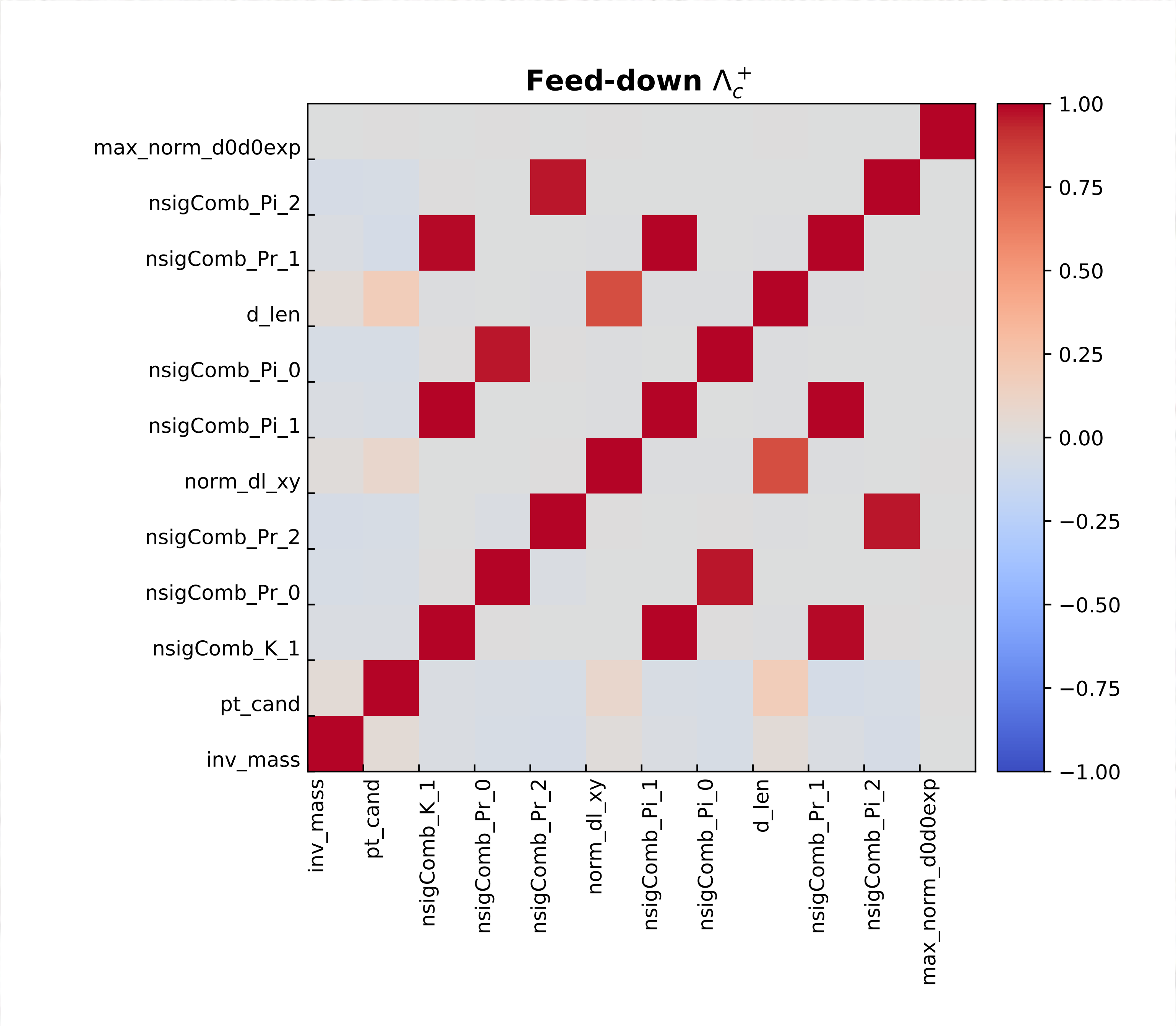
- DCA < 0.05 cm
- d_len > 0.005 cm
- cosPA > 0.8
- sigma_vertex < 0.04 cm
- $p_T^{prong_x}$ > 0.3 GeV/c

Variable correlation

$4 < p_T < 8$ GeV/c



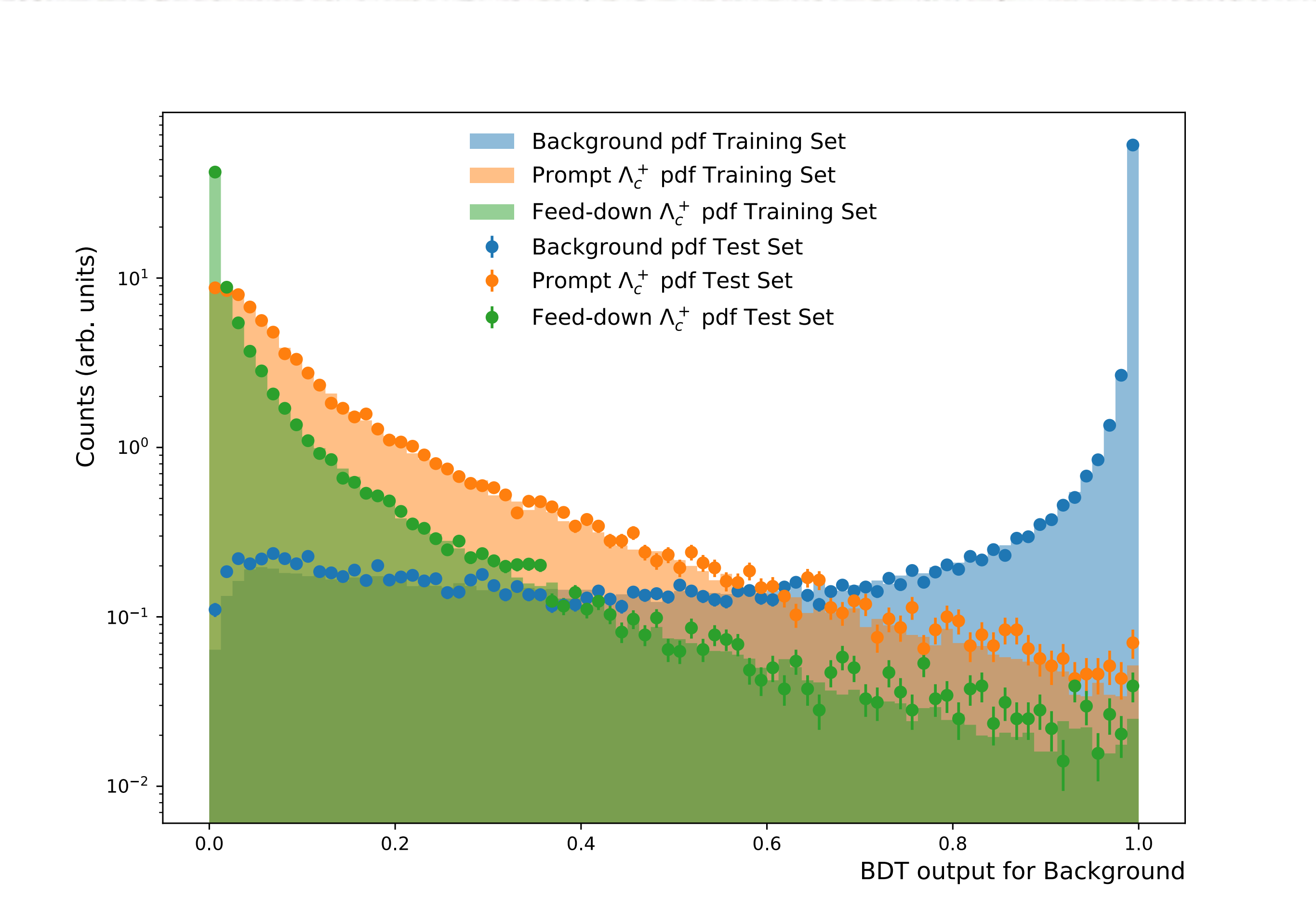


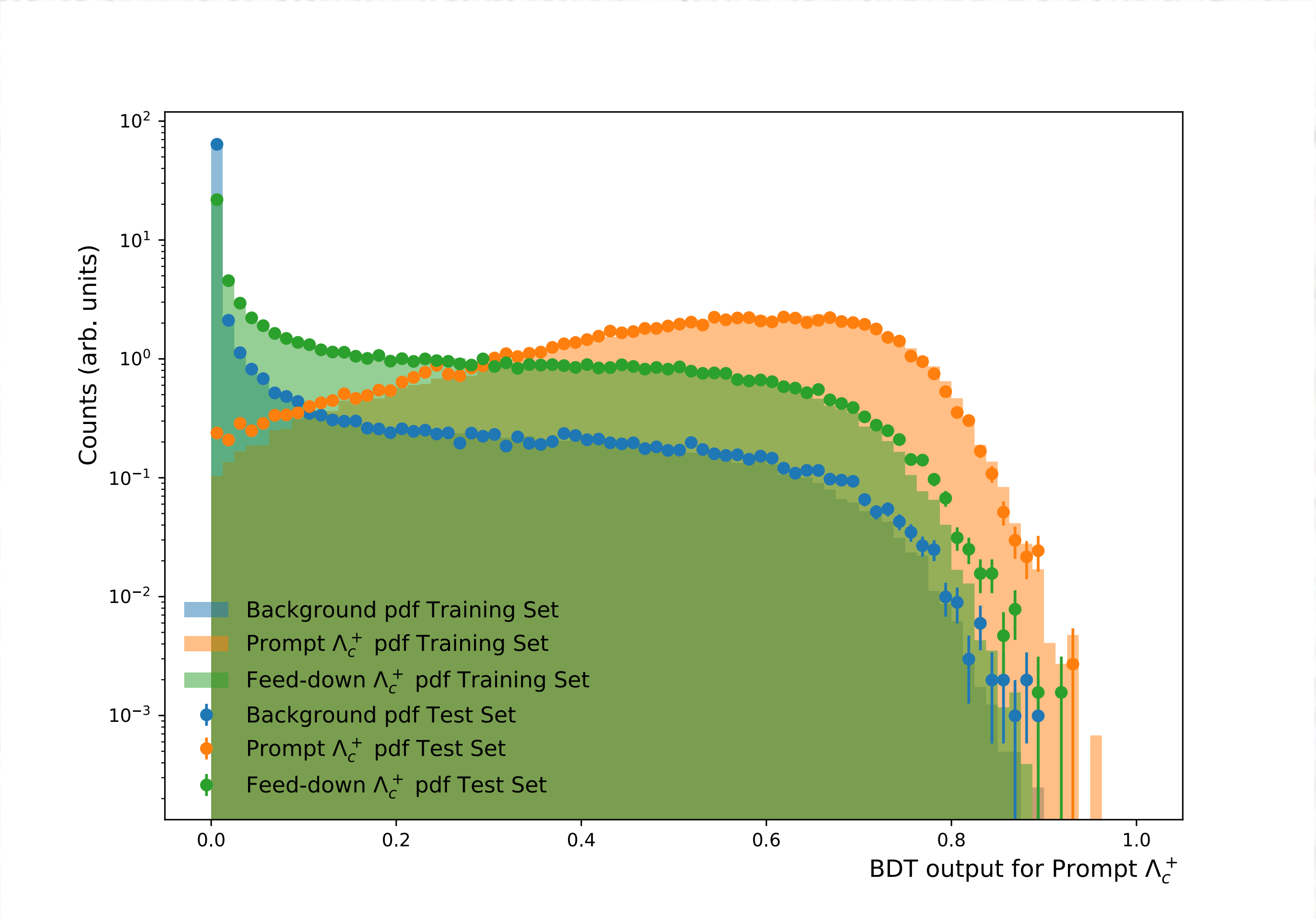


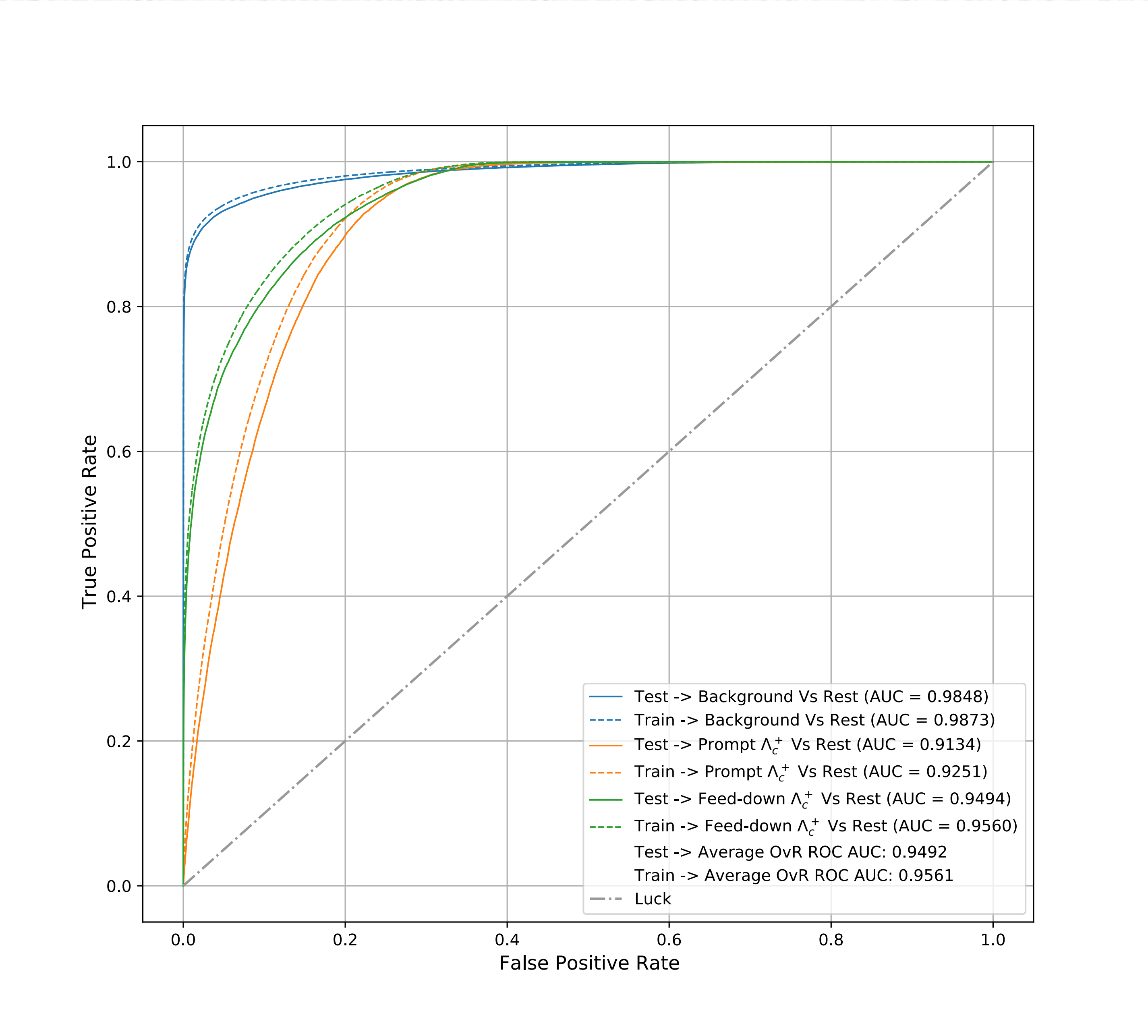
The distributions of the other two p_T intervals are in the backup

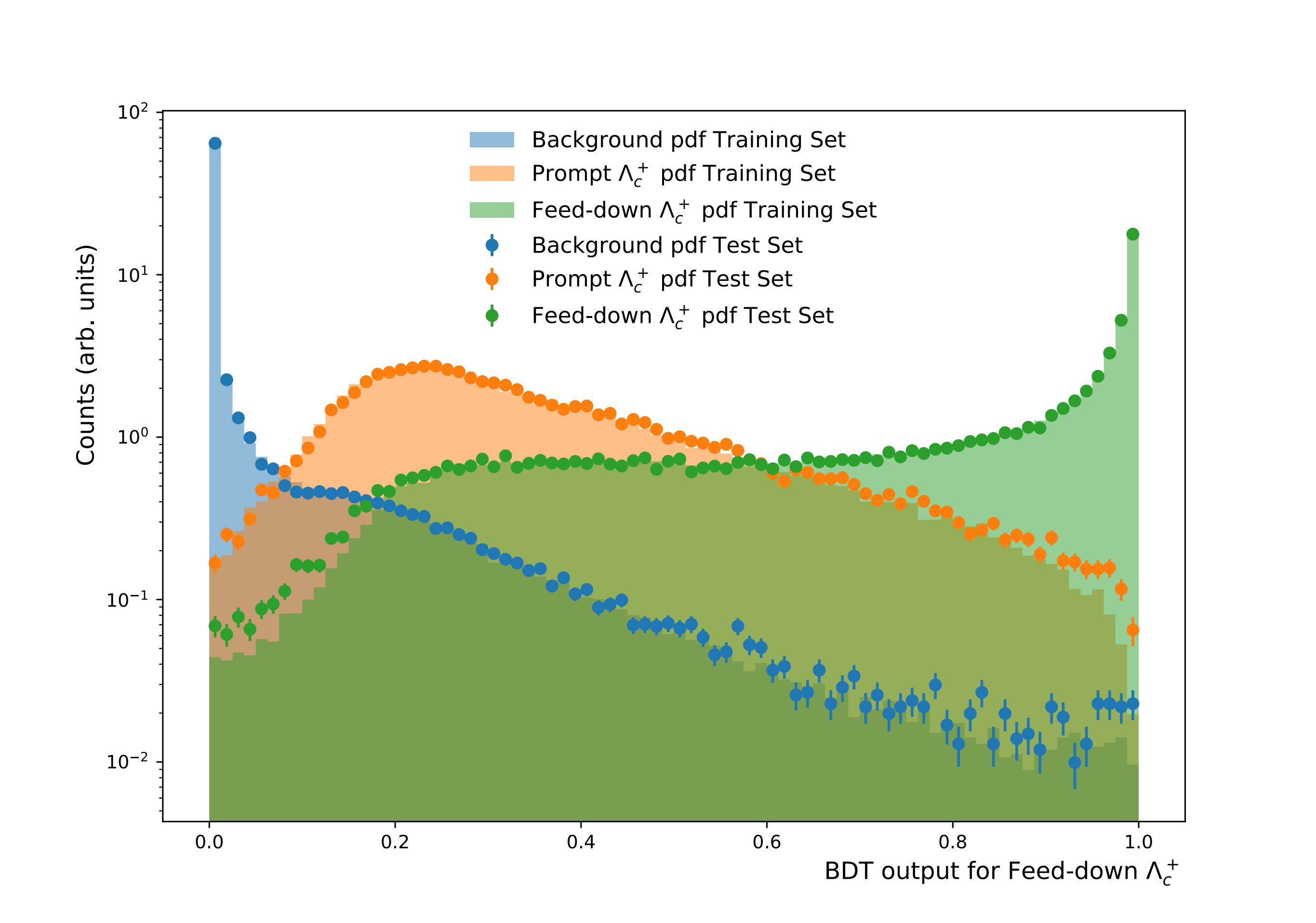
ML model training and testing

$4 < p_T < 8$ GeV/c





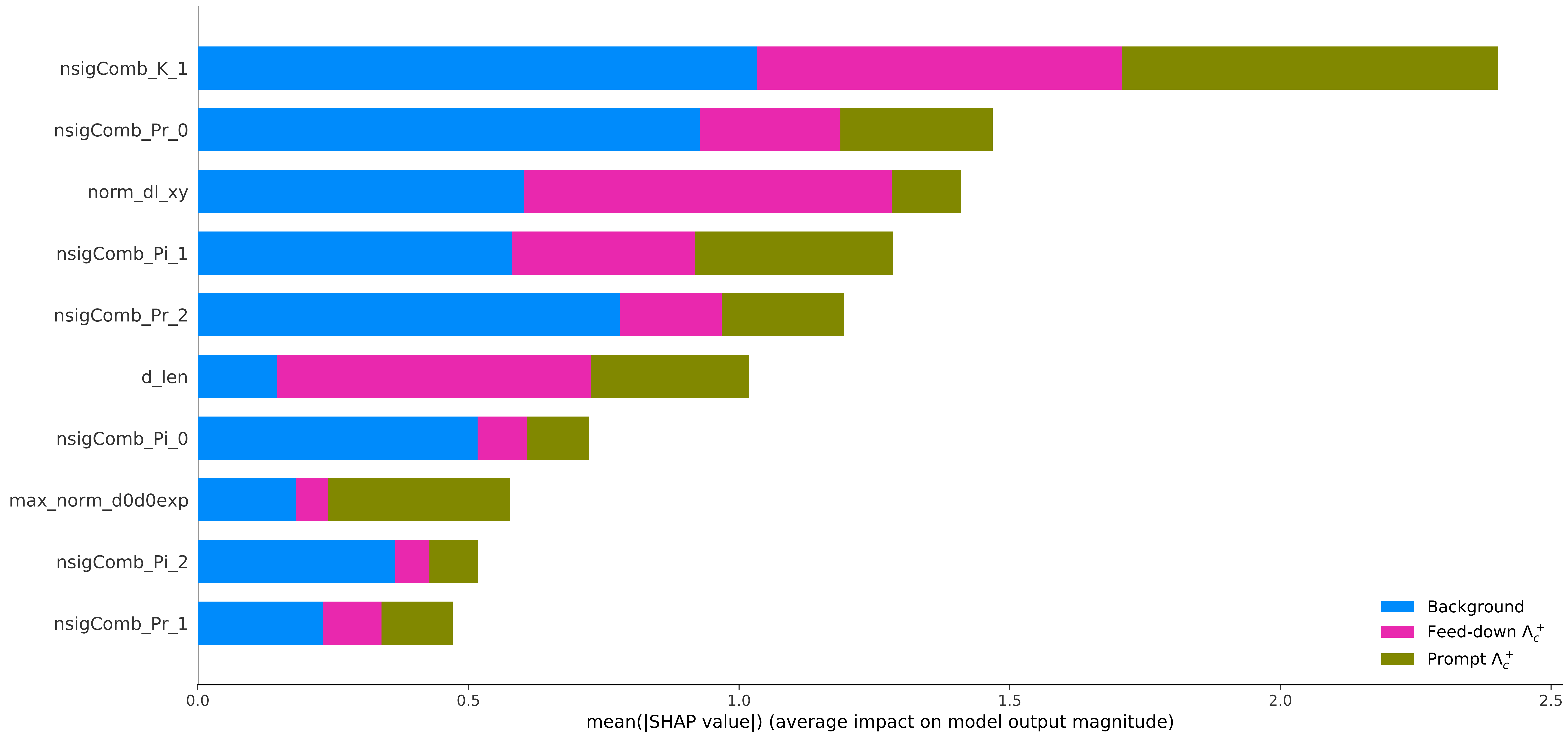




Feature importance

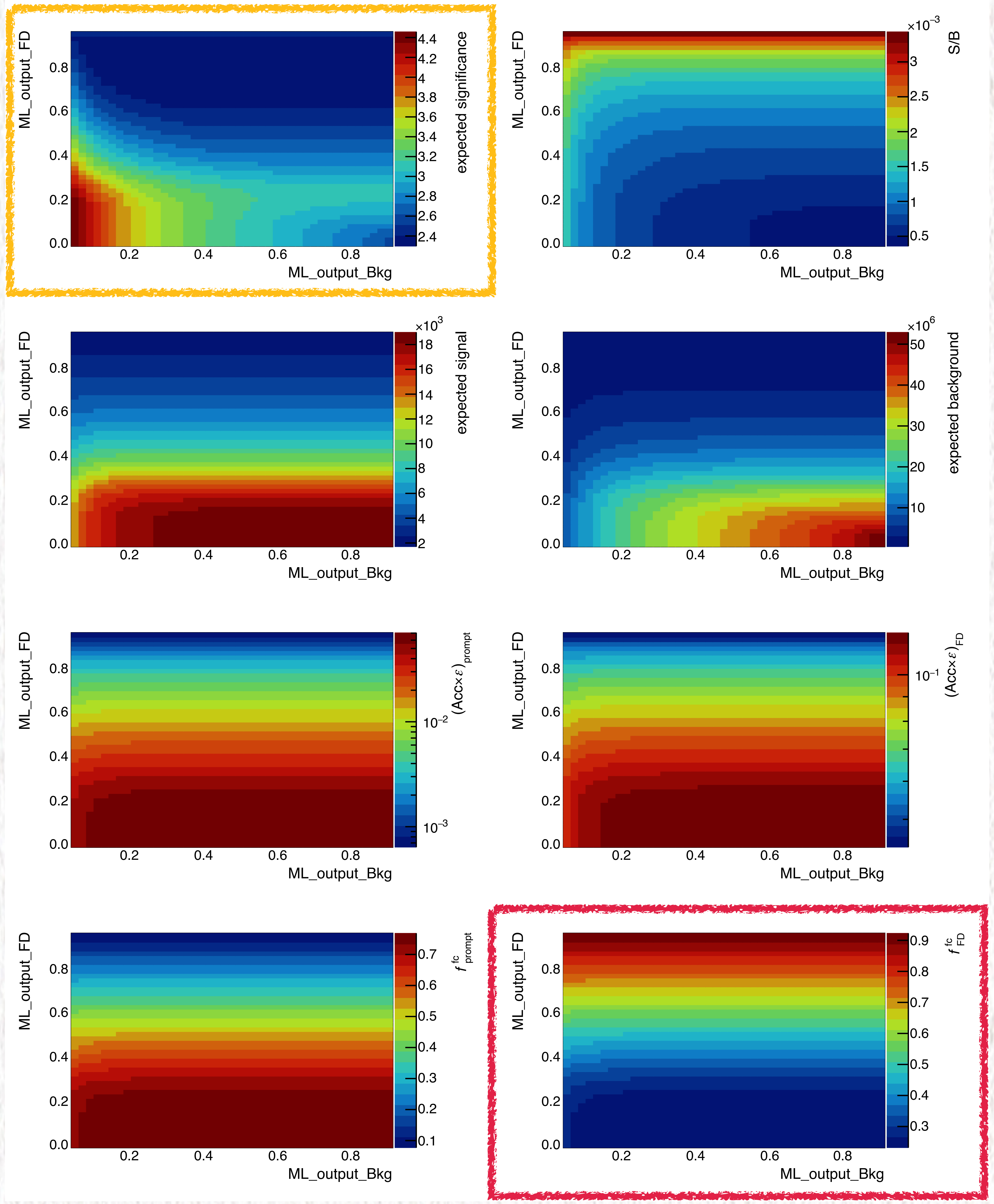
$4 < p_T < 8$ GeV/c

ALICE



Estimate working point

$2 < p_T < 4$ GeV/c



Maximize the pseudo-significance and the raw feed-down fraction:

$$S_{\mathrm{exp}} = 2 \cdot \left(\frac{\mathrm{d}\sigma}{\mathrm{d}p_{\mathrm{T}}}\right)^{\mathrm{FONLL}}_{\mathrm{prompt}} \cdot (\mathrm{Acc} \times \varepsilon)_{\mathrm{prompt}} \cdot c_{\Delta y} \cdot \Delta p_{\mathrm{T}} \cdot \mathrm{BR} \cdot \mathscr{L}_{\mathrm{int}} / f_{\mathrm{prompt}}$$

$$f_{\mathrm{prompt}} = \left(1 + \frac{(\mathrm{Acc} \times \varepsilon)_{\mathrm{non-prompt}} \cdot (\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}})^{\mathrm{FONLL}}_{\mathrm{non-prompt}}}{(\mathrm{Acc} \times \varepsilon)_{\mathrm{prompt}} \cdot (\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}})^{\mathrm{FONLL}}_{\mathrm{prompt}}}\right)^{-1}$$

$$f_{\mathrm{non-prompt}} = 1 - f_{\mathrm{prompt}}$$

BDT_Bkg < cut_bkg and BDT_FD > cut_FD

Averaged Non-prompt Λ_c^+ Cross-section

Uncorrelated uncertainties:

- Statistic uncertainties
- Raw yields
- BDT efficiencies
- Branch ratio

$$w_{uncorr} = \sqrt{\sum w_i^2}$$

$$weights = 1.0 / w_{uncorr}^2$$

Non-prompt Λ_c^+ cross-section compare to FONLL with Phyia8 decayer