Ξ^0_c production via semi-leptonic decay in pp collisions at $\sqrt{s}$ =13TeV

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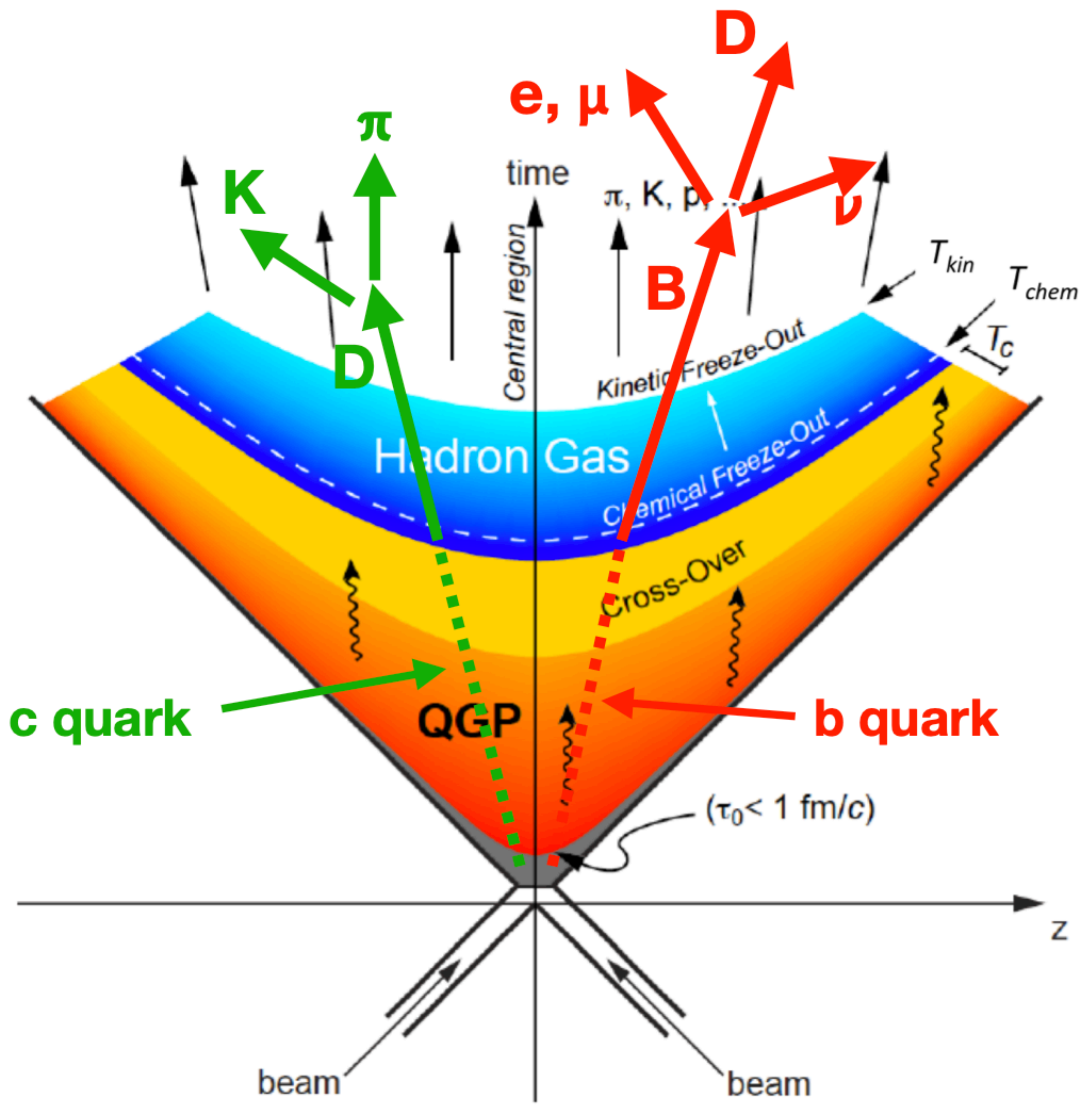
CENum Workshop

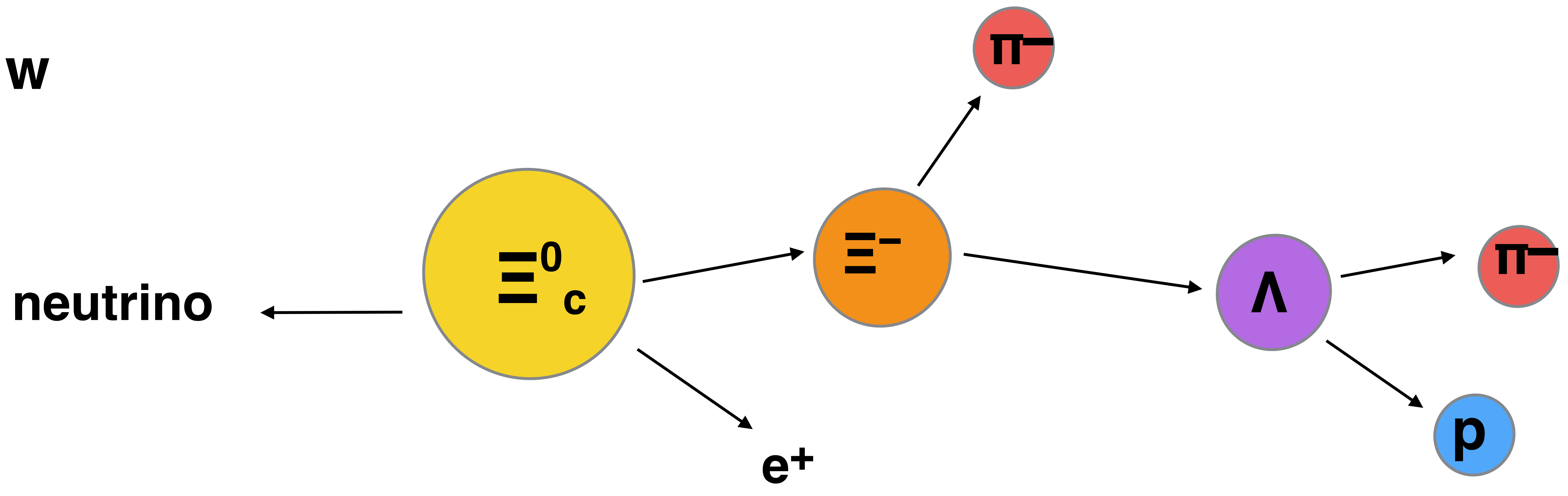
- Motivation

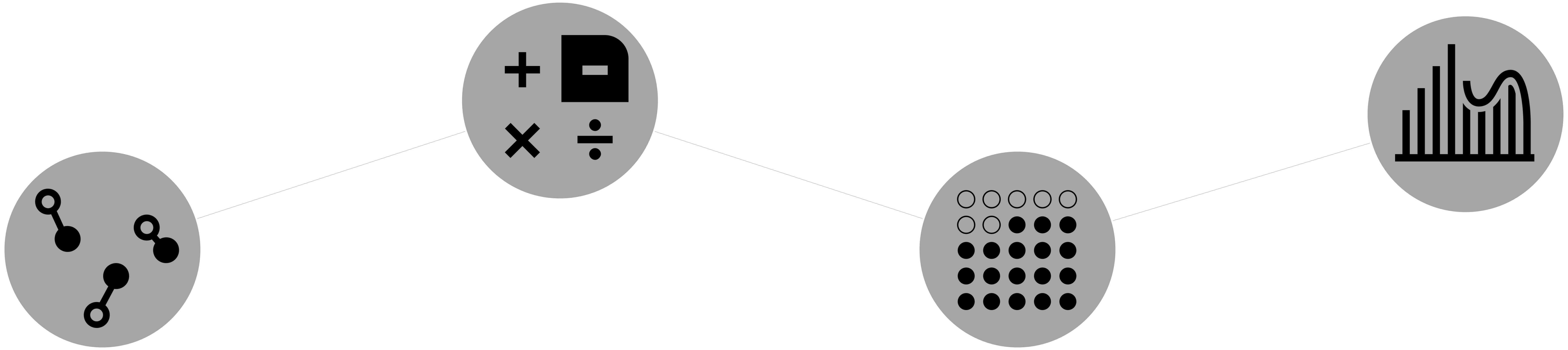
- **QGP probe with Heavy quarks**
  - Charm and beauty quarks are produced in initial hard-scattering processes with high Q^2, transported through the full medium created in the collisions.
  - Charm hadronization mechanisms can be studied using meson and baryon ratio such as D, Λ_c, Ξ_c,…
  - Provide new constraints on fragmentation function of charm quarks.
  - Provide the severe consequences of an enhanced production of baryons relative to mesons for the total charm cross-section.



- **pp collisions**
  - Reference for p-Pb and Pb-Pb collisions.
  - Testing ground for perturbative QCD calculations.

- Analysis flow





STEP. 1

Select e and Ξ and Make pair of Right Sign and Wrong Sign

STEP. 2

Subtract the Wrong Sign from Right Sign

STEP. 3

Using Unfolding technique to correct missing neutrino momentum

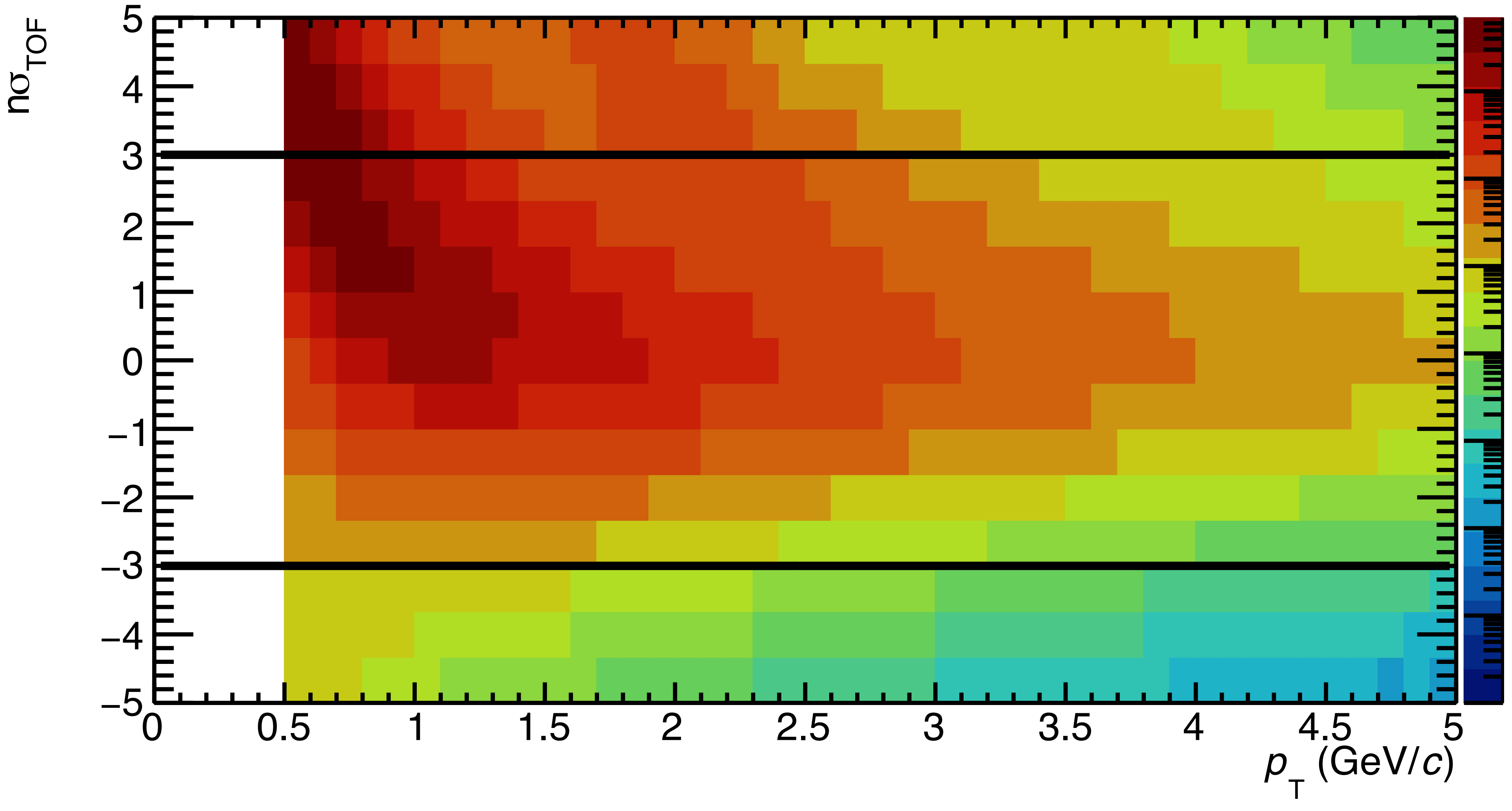
STEP. 4

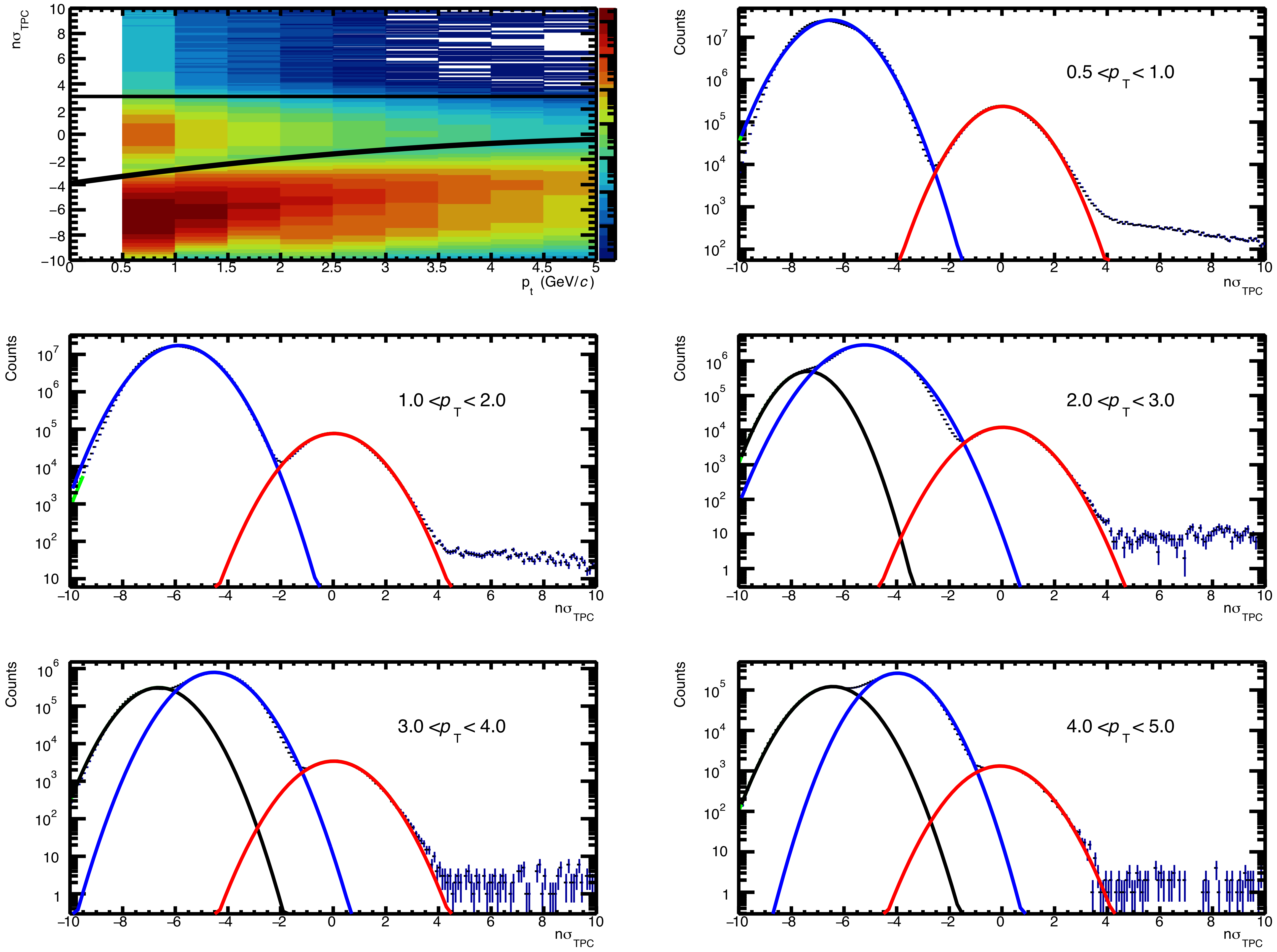
Efficiency correction and event normalization

- e selection

- **Detector**
  - Time Of Flight(TOF) and Time Projection Chamber(TPC) are used to identify electron.
- **nσ distribution**
  - e PID cuts applied in this analysis

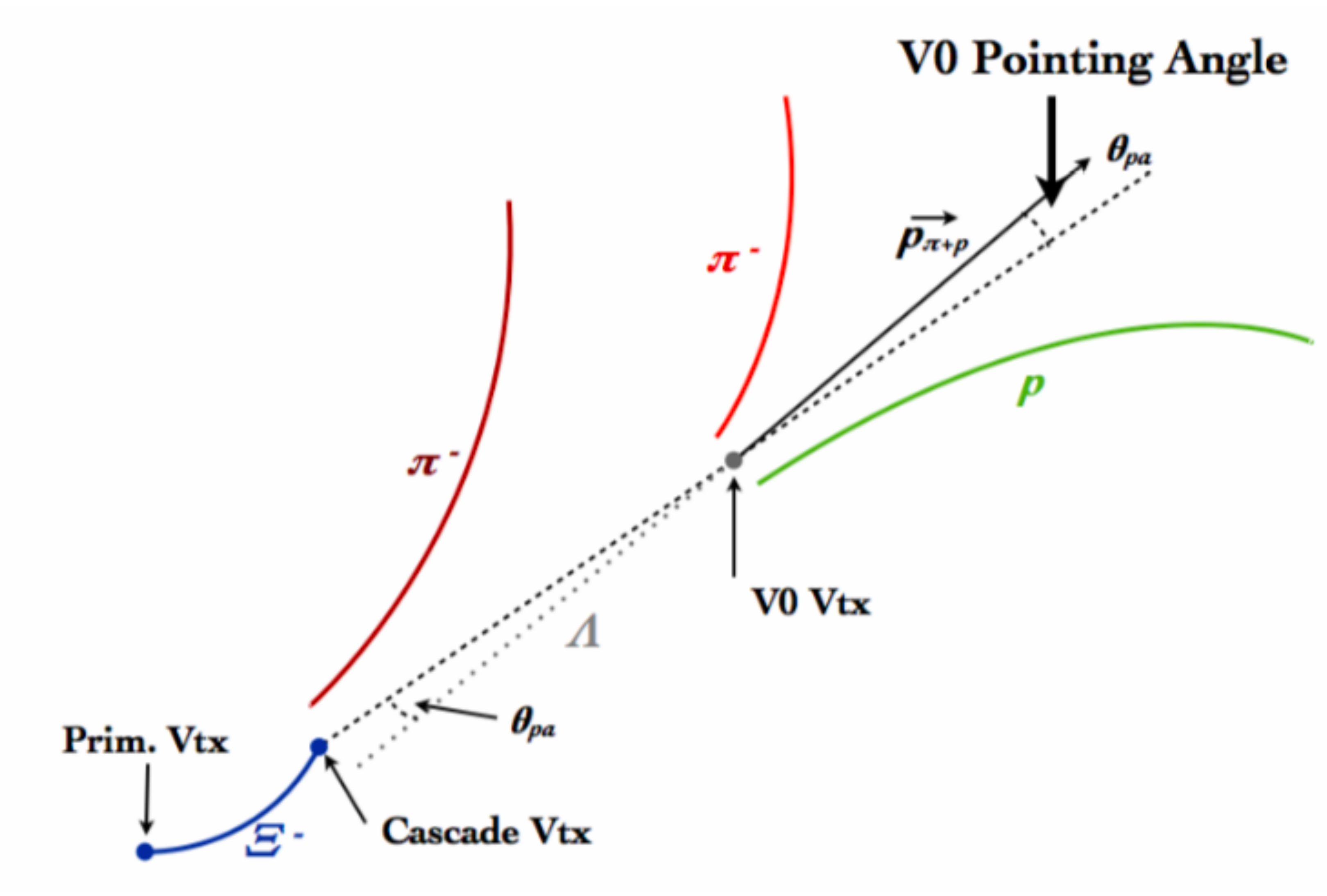
    ➡|TOF nσ|<3, $-3.9+1.17P_T-0.094P_T^2$ <TPC nσ<3

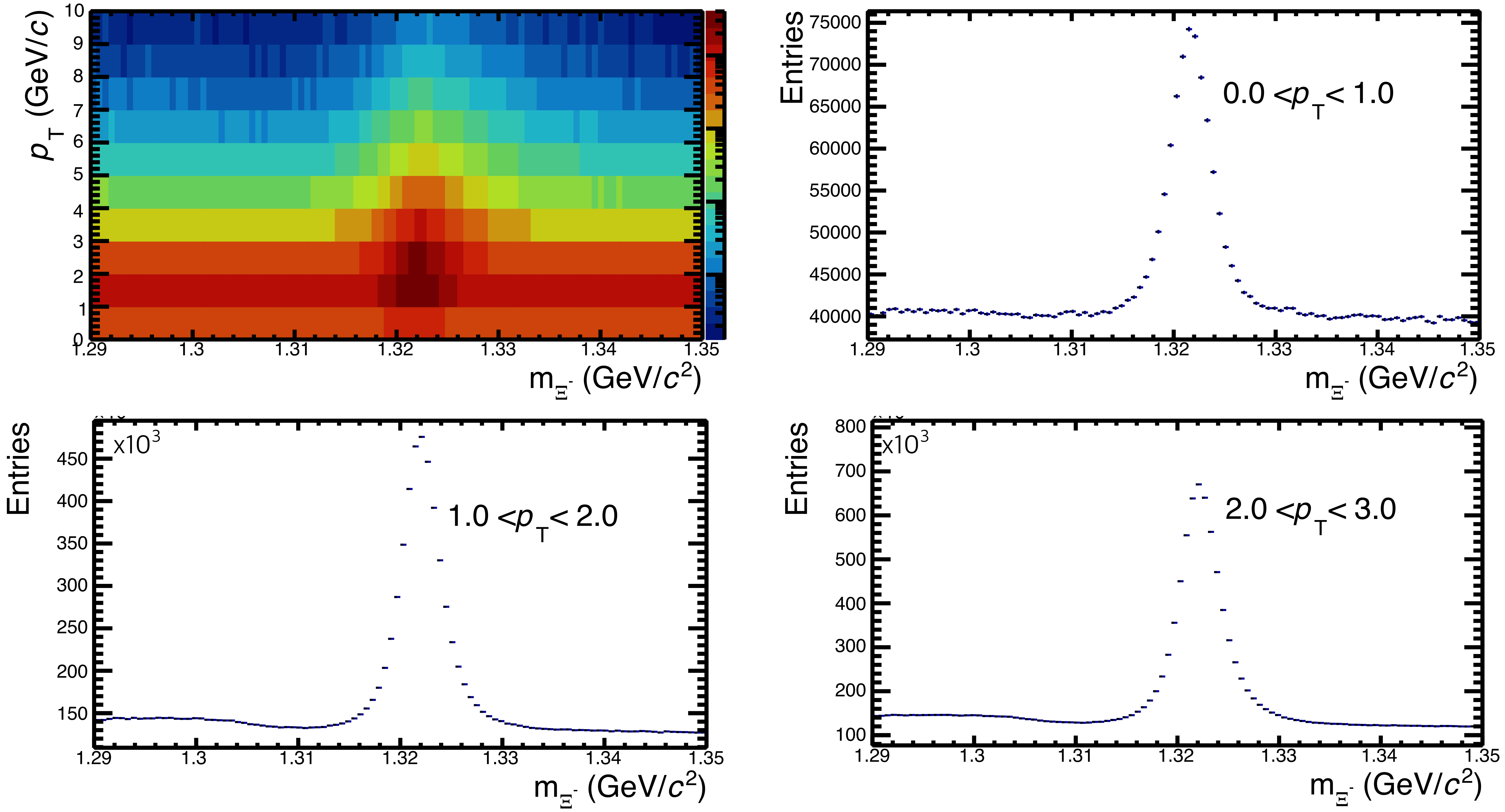




- Ξ selection

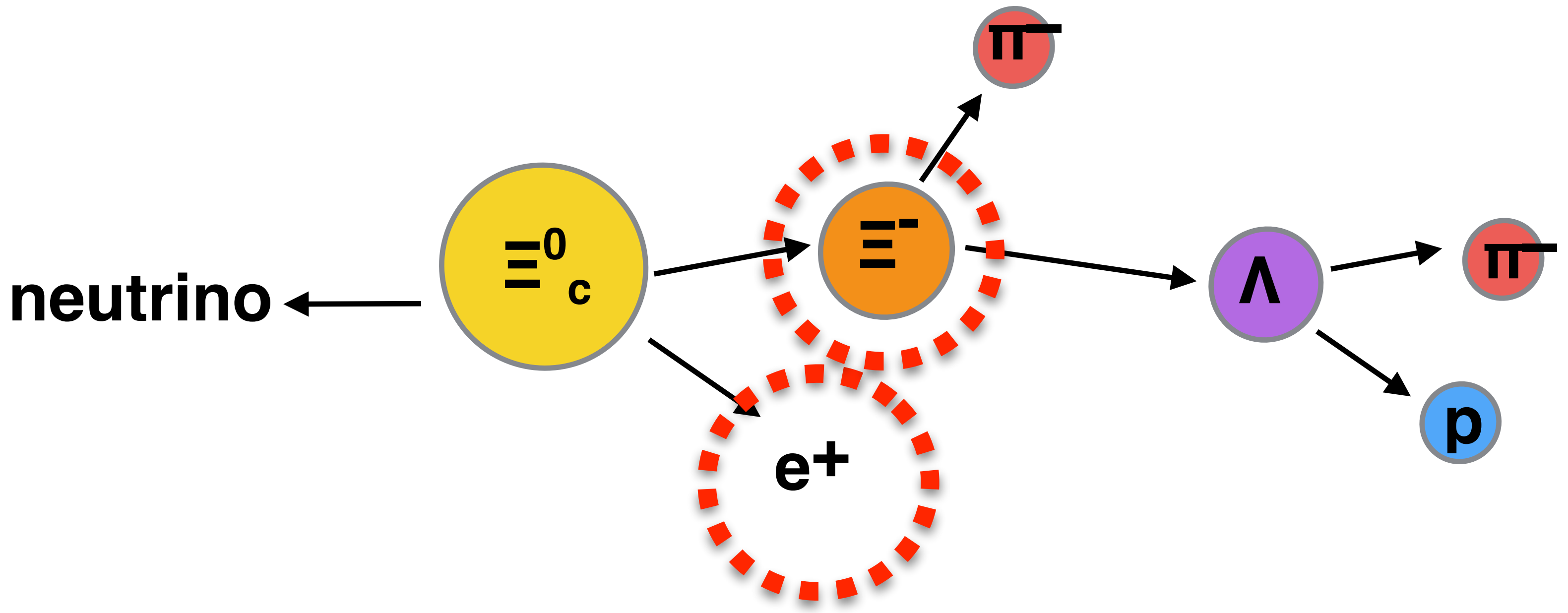
- **Ξ reconstruction**
  - Ξbaryons are reconstructed using the decay chain Ξ→ πΛ, followed by Λ → pπ.
  - Pion produced from Ξ⁻and Λ can be preferentially selected using mother particle's lifetimes. ($c\tau$ ~4.91 cm and 7.89 cm)
  - Ξ topology cuts are applied to remove the backgrounds.

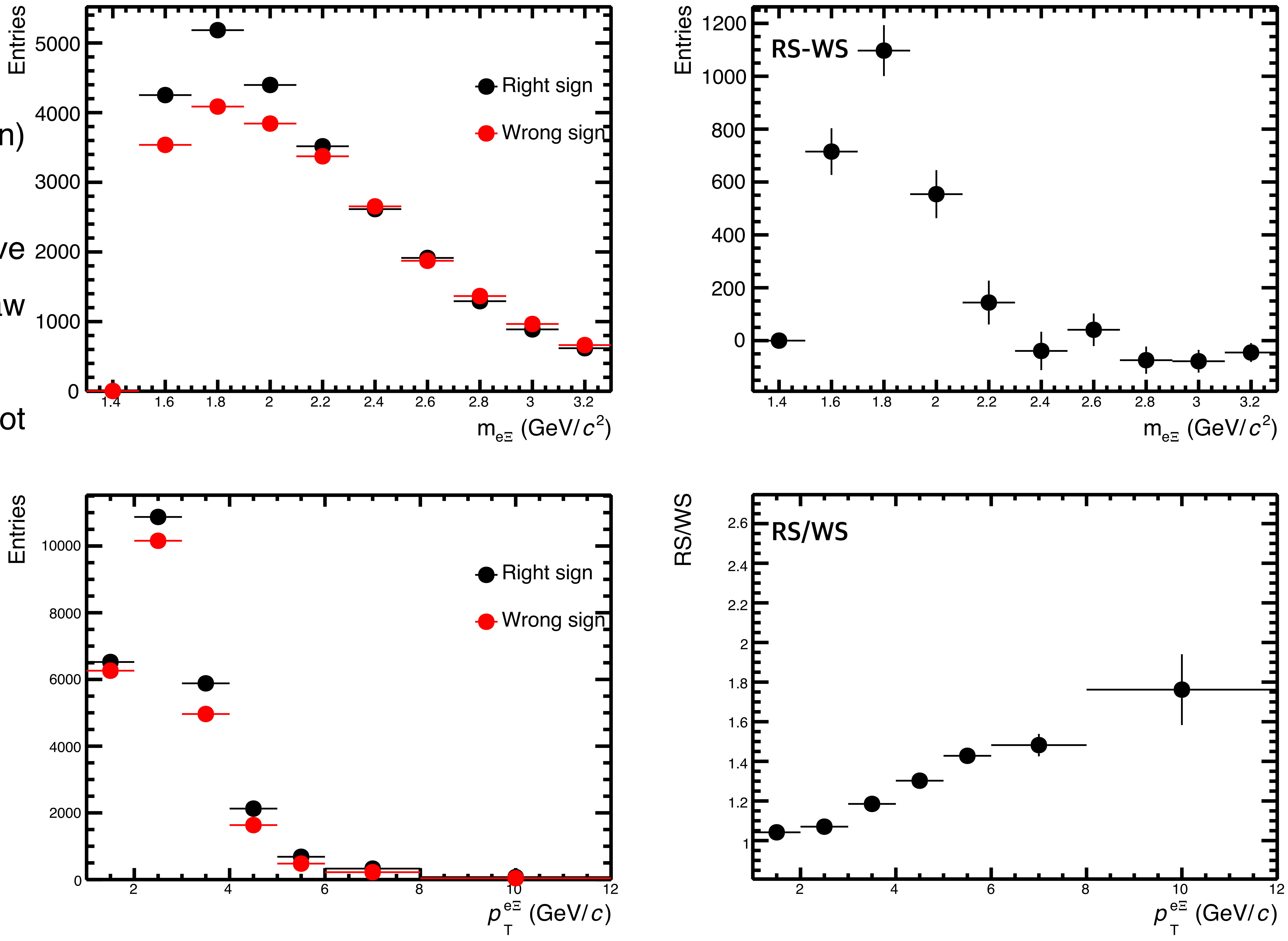




- Raw yield of Ξ^0_c

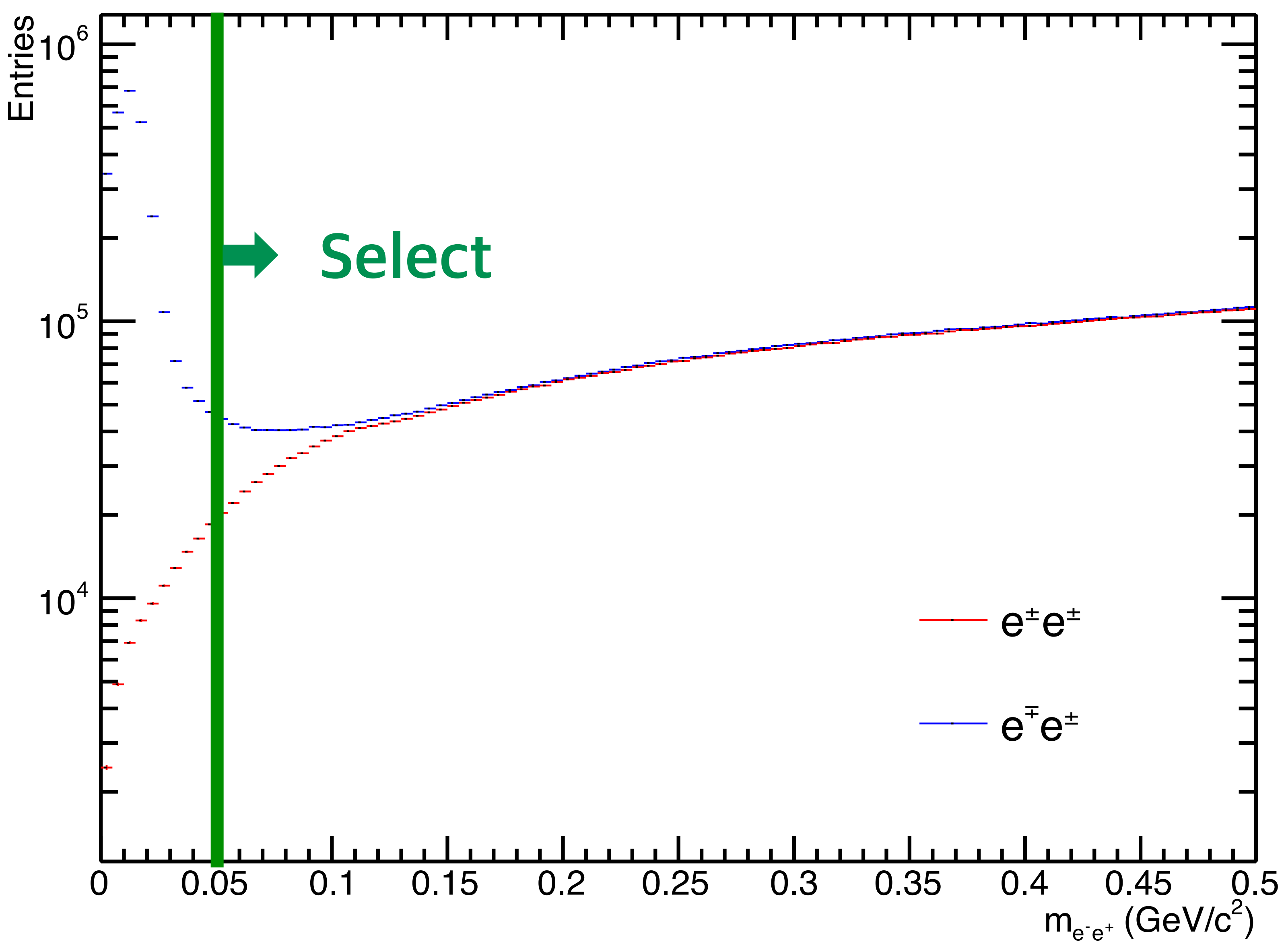
- **Make eXi pair**
  - RS(Right Sign) and WS(Wrong Sign) are made.
  - WS is subtracted from RS to remove combinatorial background and get raw yield.
  - In mass distribution, mass peak is not shown due to missing neutrino.

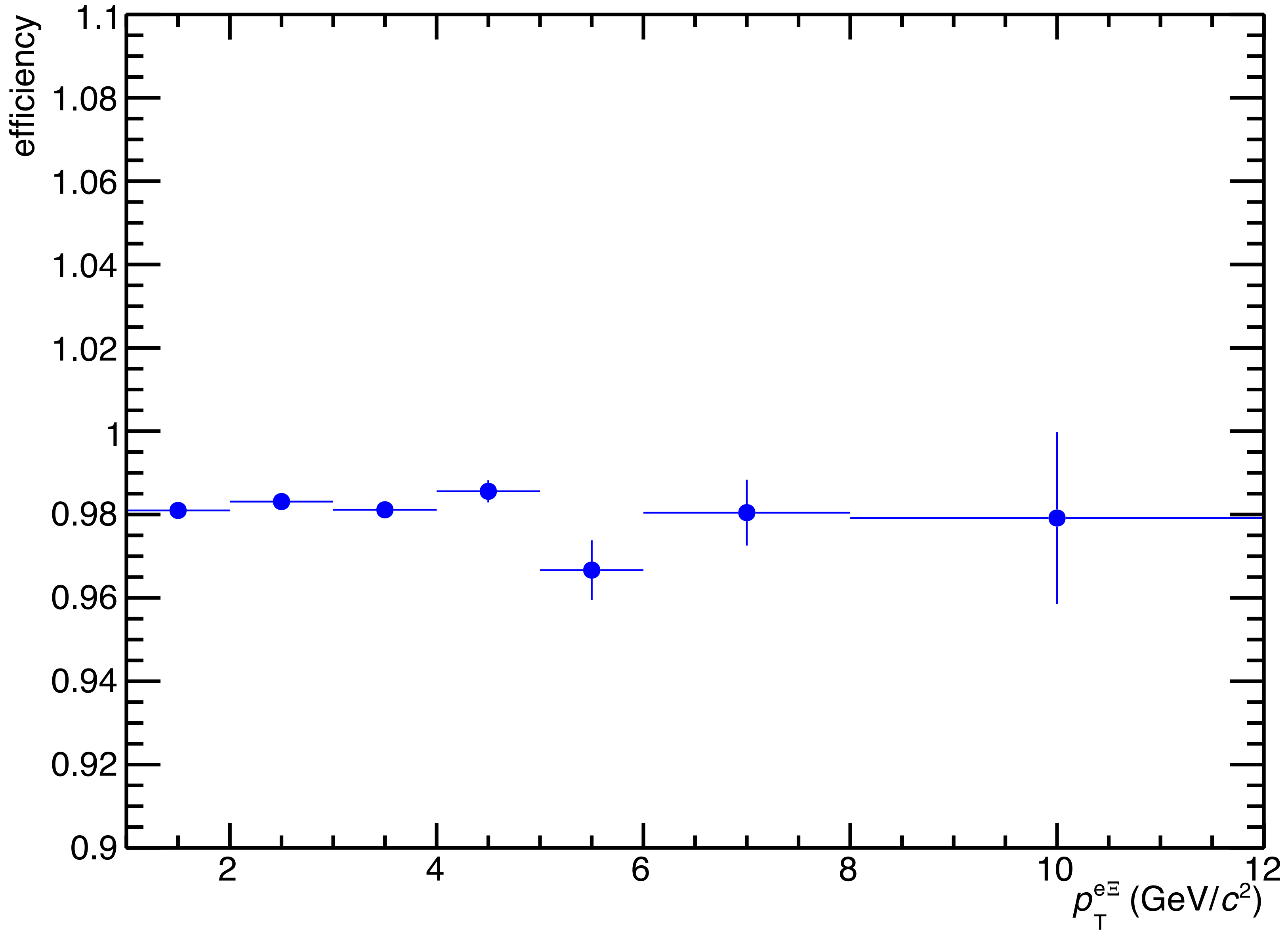


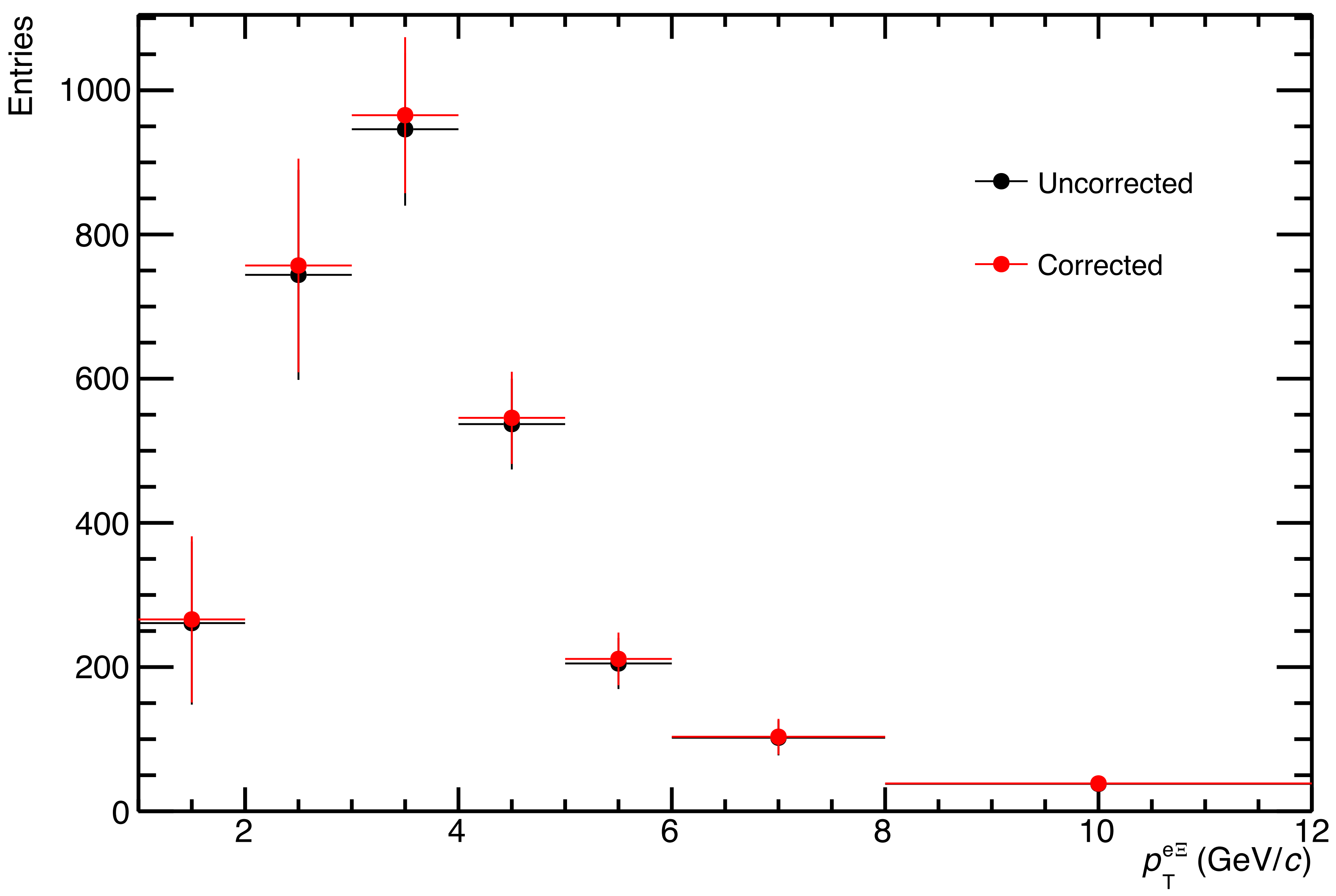


- Remove background electron

- **Background electron**
  - Background electrons from Dalitz decay and gamma conversions can be removed using electron pair mass information.
  - The invariant mass distribution of electron pairs has a peak around 0 GeV/c^2, which corresponds to the contributions from photonics electrons.
  - The efficiency $\varepsilon_{prefilter}$ is calculated using real data as $\epsilon_{Prefilter} = \frac{N_{e\Xi}(same\ sign\ mass\ cut\ on)}{N_{e\Xi}(mass\ cut\ off)}$

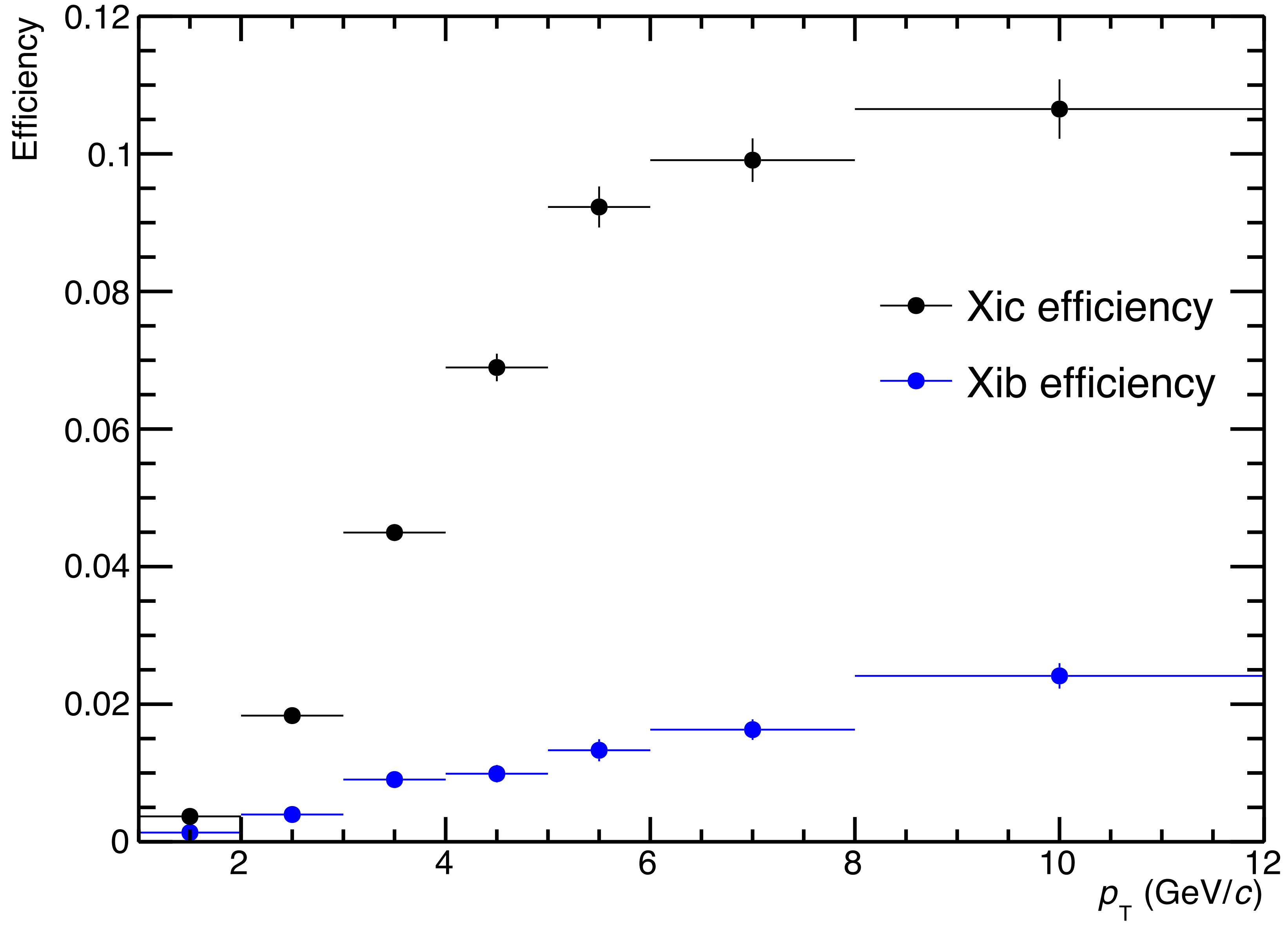


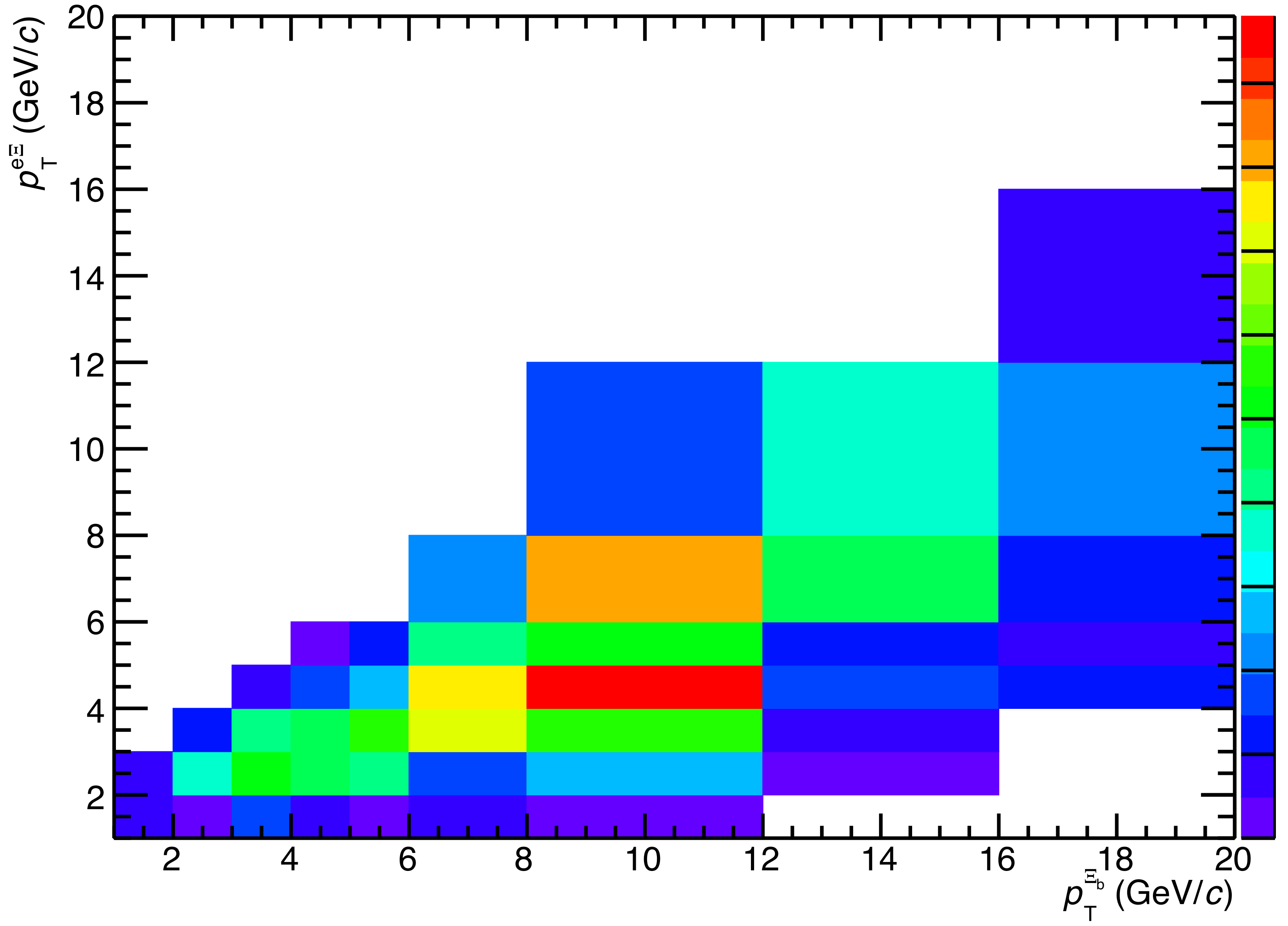


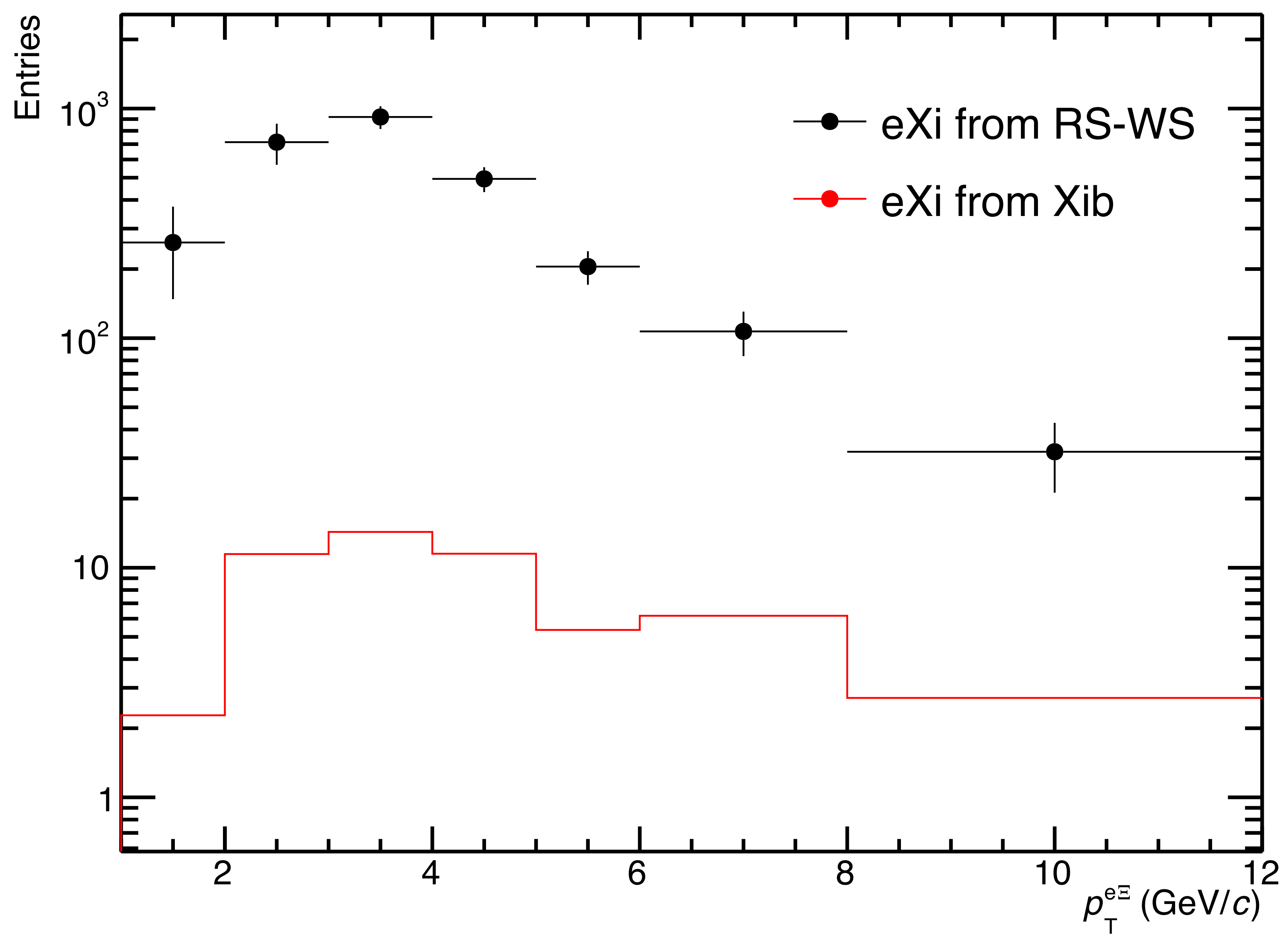


- Remove bottom baryon contribution

- **Bottom baryon contribution in WS**
  - In the WS spectra, there are contributions from bottom baryons, such as $\Xi_b \rightarrow e\Xi\nu$
  - The shape of the transverse momentum distribution of the Ξ_b baryon is assumed to be the same as Λ_b.
  - To scale 7TeV Λ_b to 13TeV Λ_b, it its assumed that baryon and meson energy dependence of fragmentation function are same.
  - The Ξ_b spectrum is further processed to take into account the detector acceptance, efficiency.
  - eΞ pair from Ξ_b is added to eΞ pair from RS-WS.





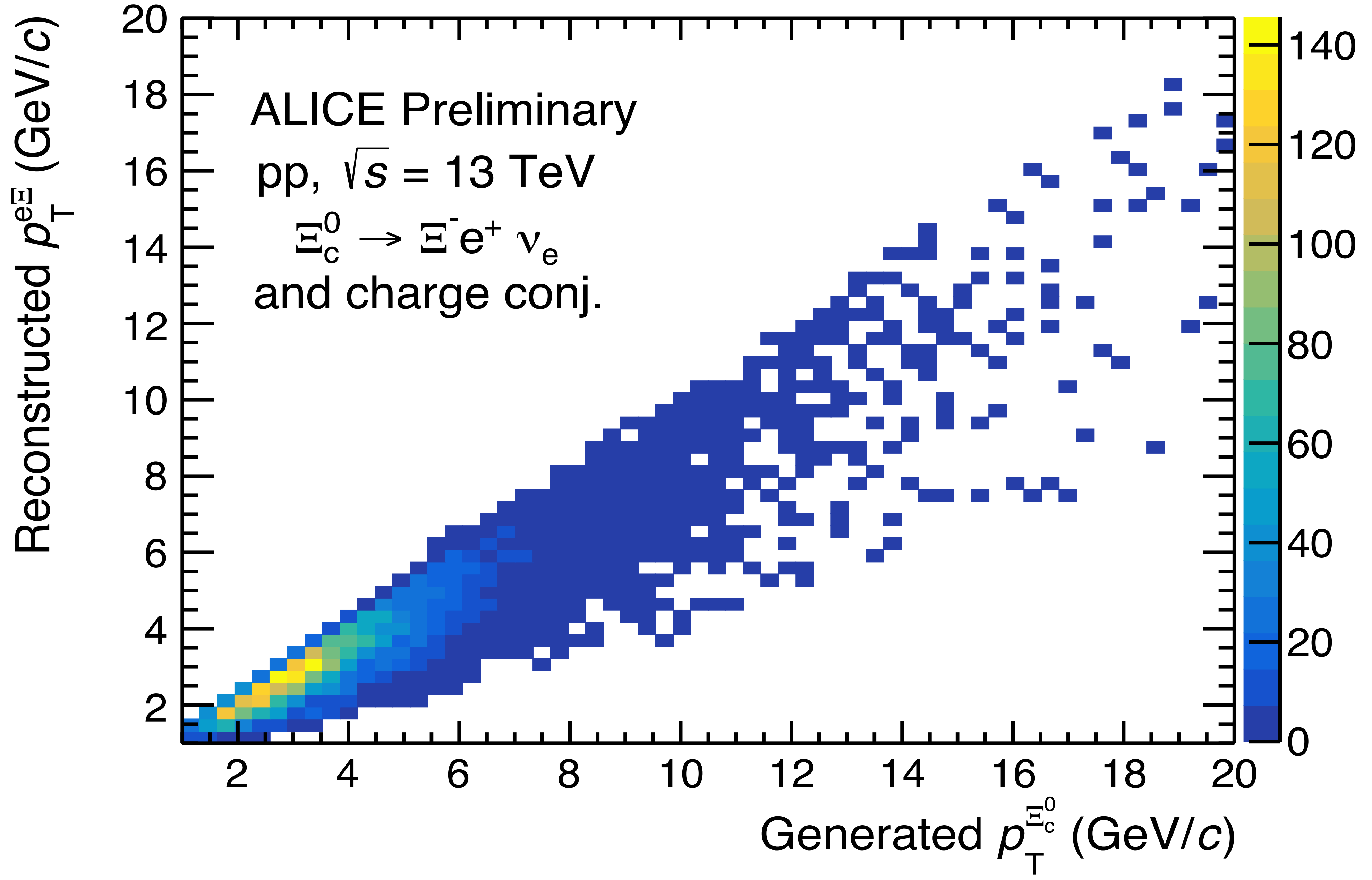


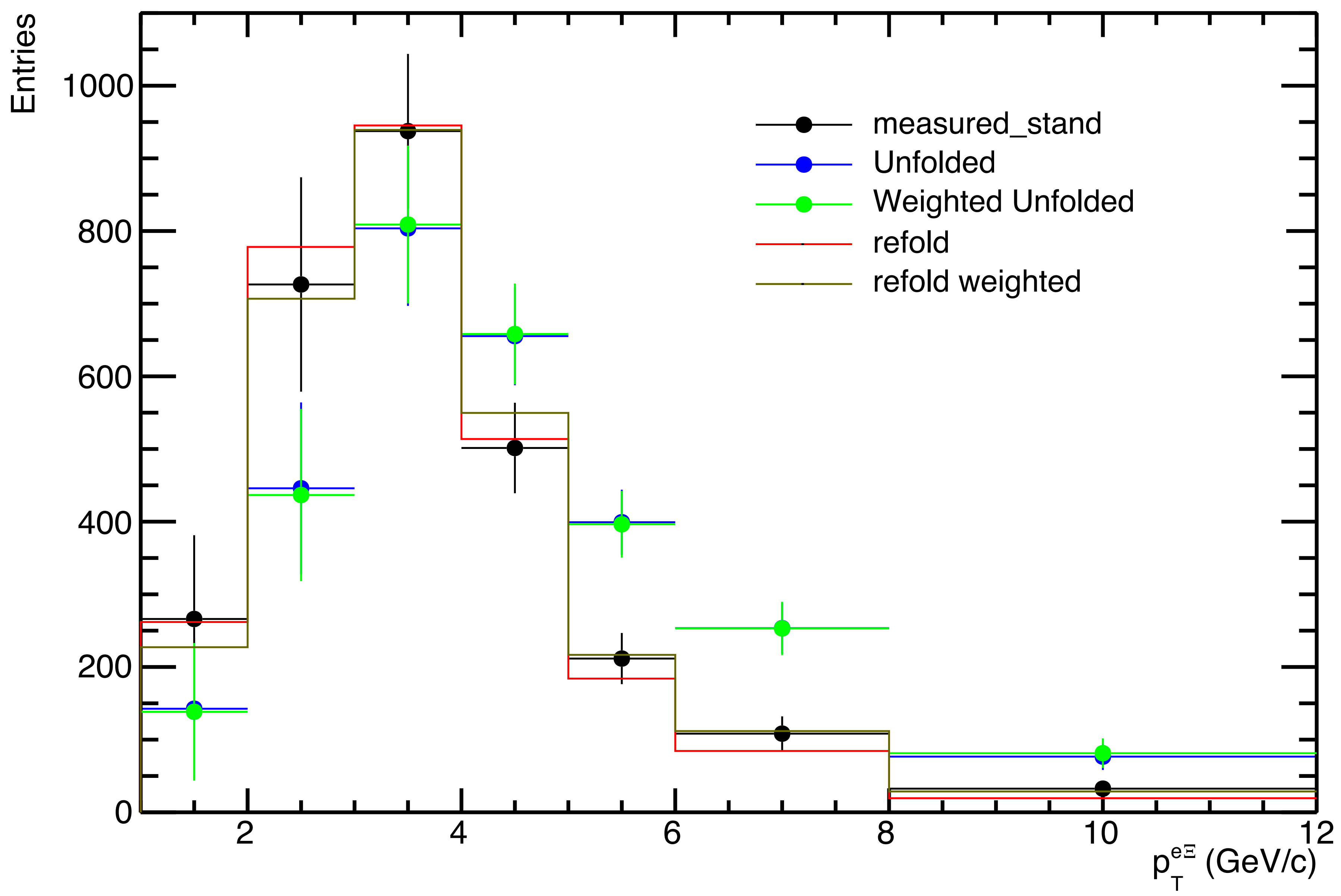
- Unfolding

- **Response matrix**
  - The response matrix is prepared in two steps

    1) The response matrix is obtained using the Ξ^0_c p_T distribution generated with MC.

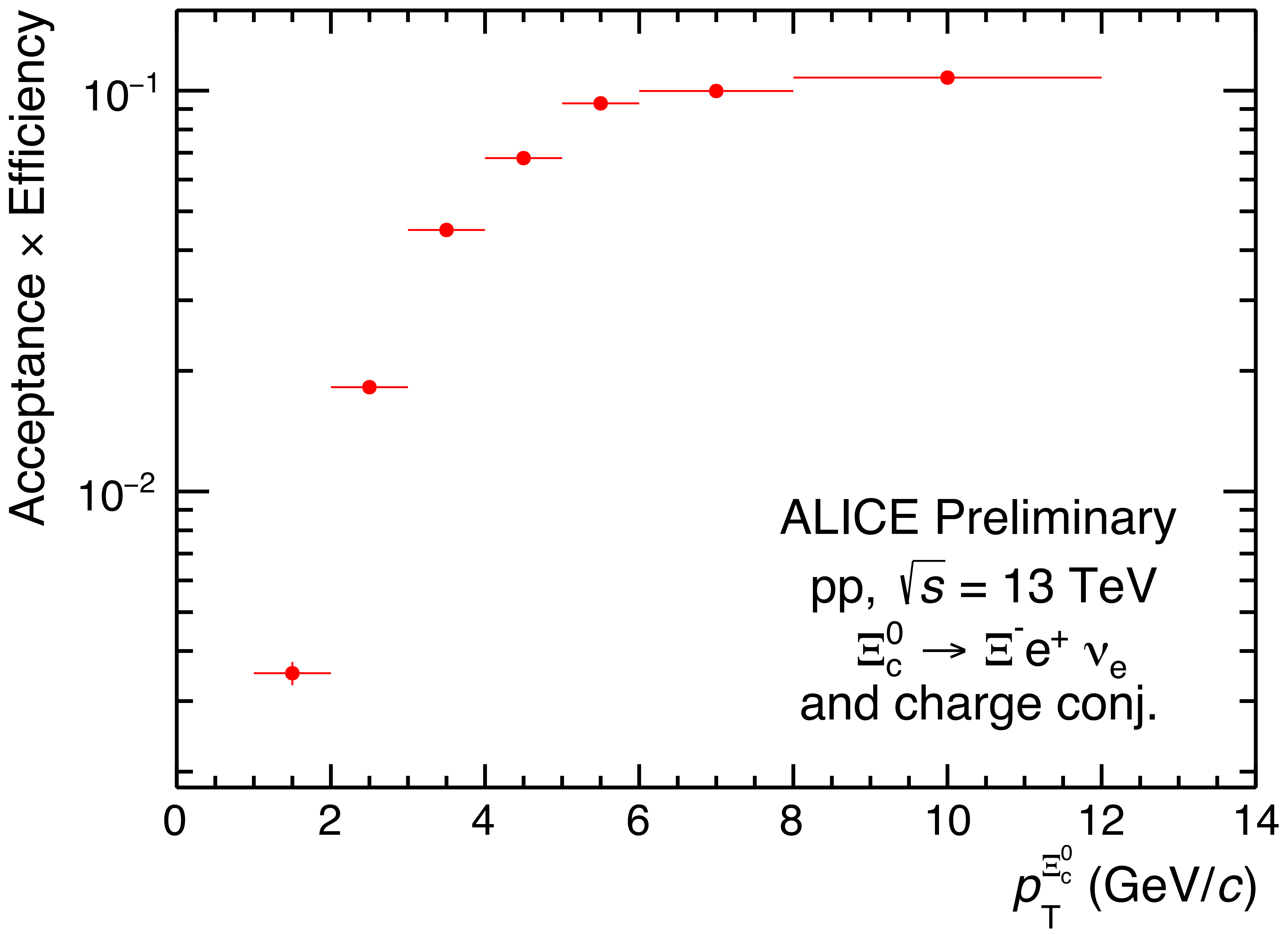
    2) The resulting Ξ^0_c distribution is used, to produce the response matrix, for the second iteration. .
- **Unfolding**
  - The transverse momentum distribution of eΞ pairs is corrected for the missing momentum of the neutrino using unfolding techniques.
  - Convergence of the Bayesian unfolding is achieved after three iterations.
  - Refolding procedure is performed to check the unfolding stability.





- Efficiency correction

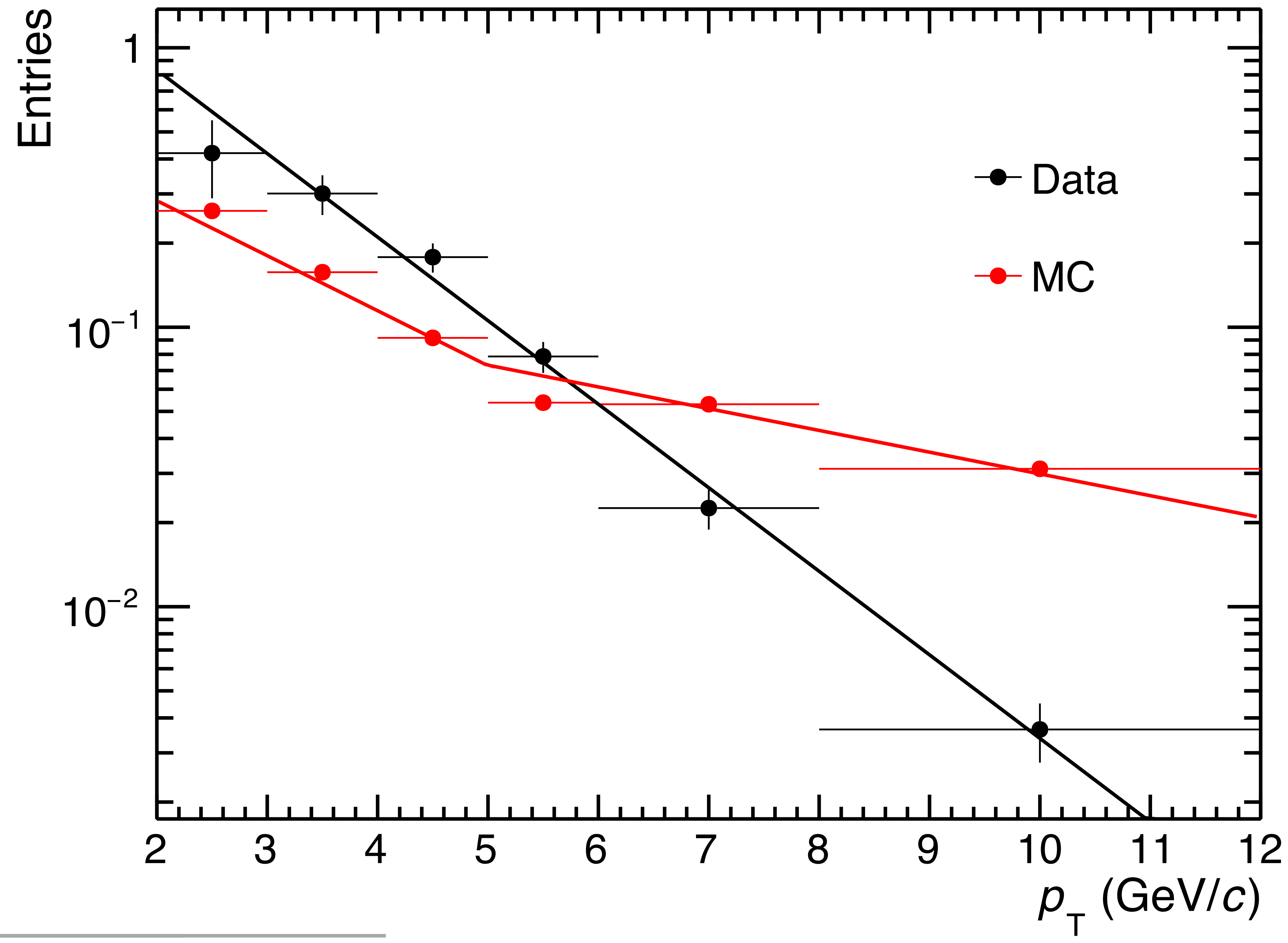
- **Efficiency**
  - To obtain the corrected spectra from the raw counts, the acceptance and efficiency correction factors as a function of p_T is calculated.
  - The inclusive efficiency ε_{total} is calculated as $Acc * \epsilon * \epsilon_{\Xi tag} = \left. \frac{N_{\Xi_c^0}(MC, Reco)}{N_{\Xi_c^0}(MC, Gen)} \right|_{|y|<0.5}$

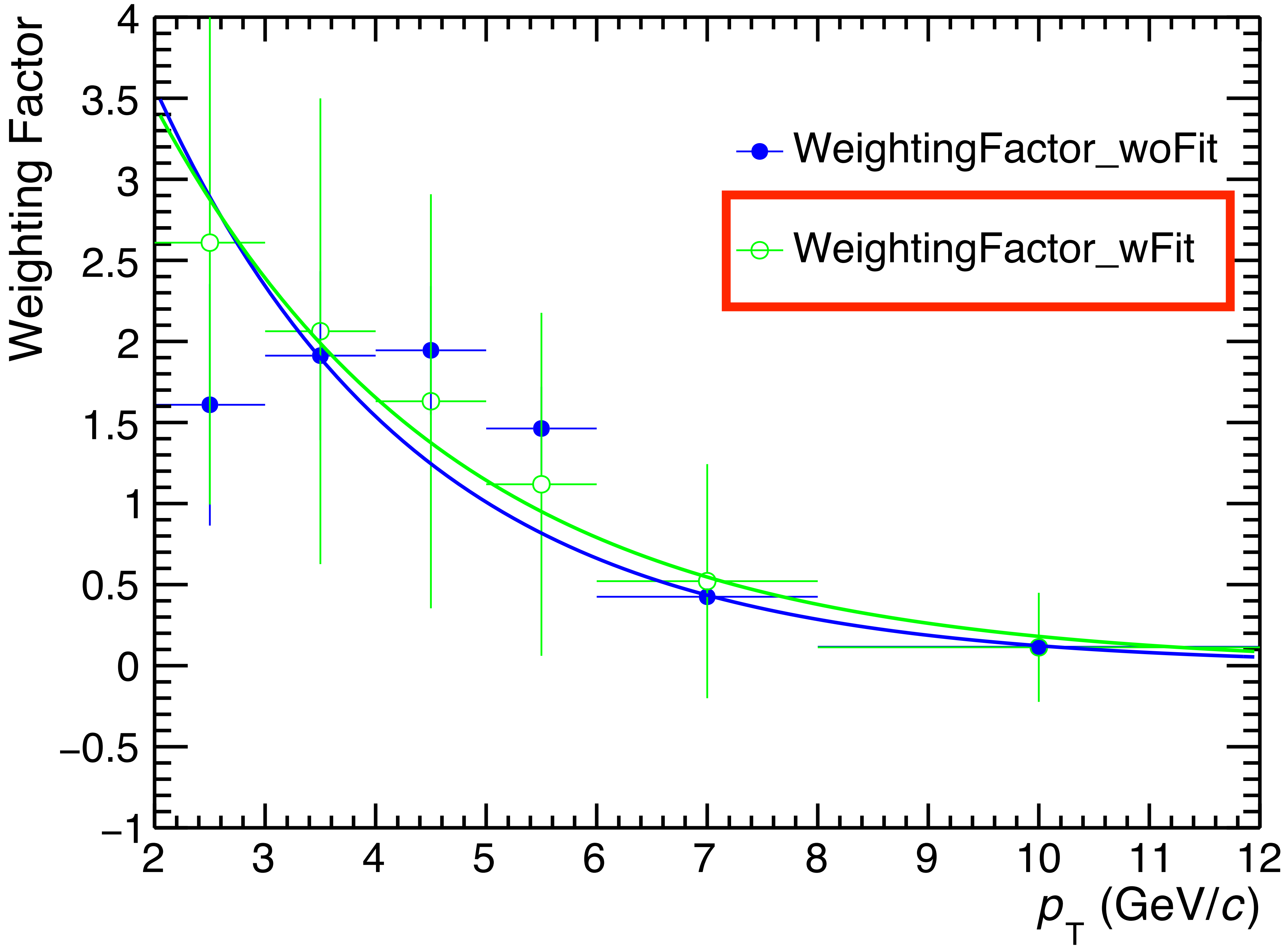


- Weighting procedure

$$Weighting\ factor = \frac{N_{\Xi_c^0}(Data)}{N_{\Xi_c^0}(MC)}$$

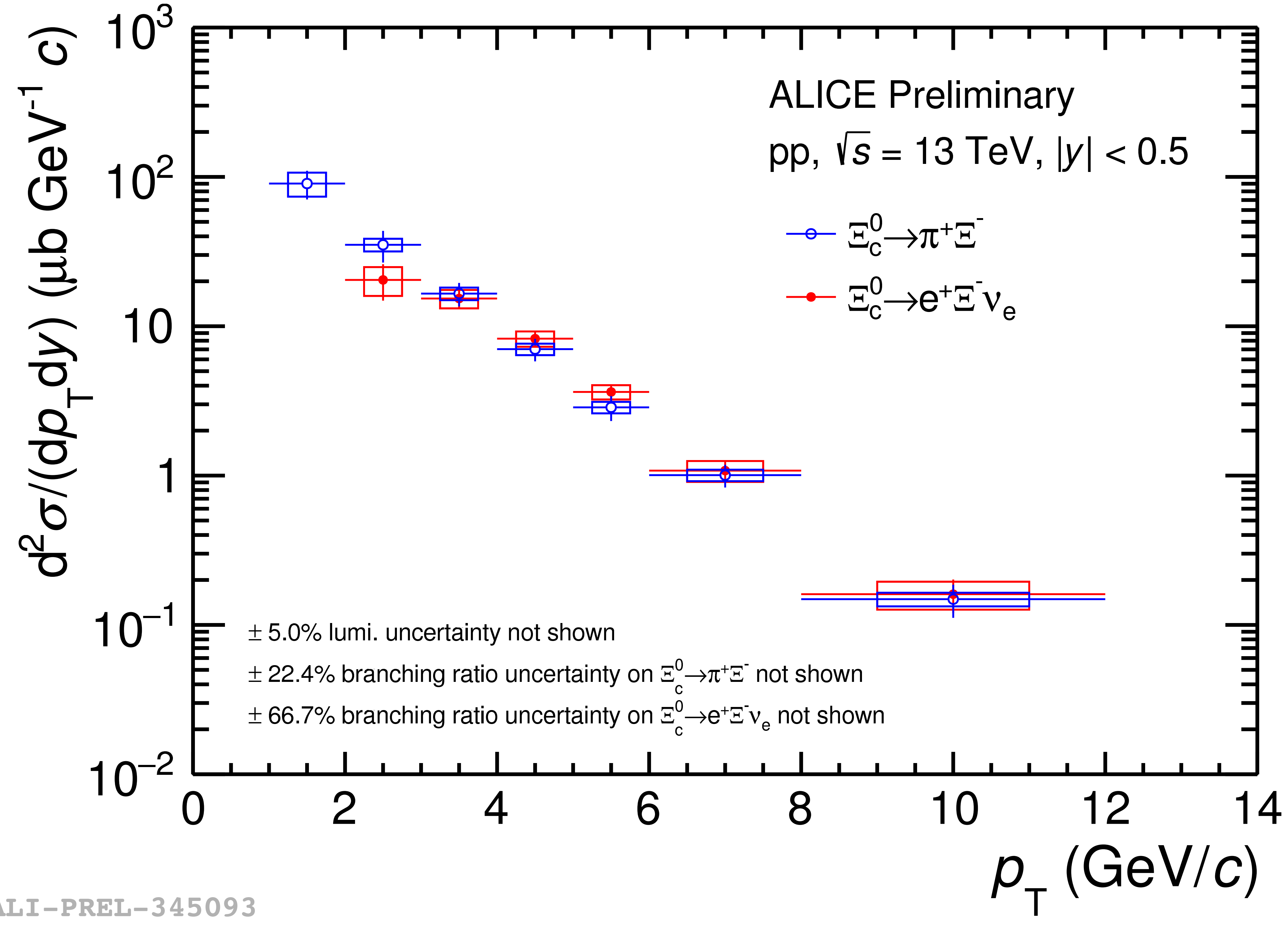
- **Weighting**
  - Weighting procedure is needed since p_T distributions of the MC Ξ^0_c and real data are different.
  - Data spectrum is taken after computing the corrected p_T spectrum with unweighted efficiency.
  - Exponential function is used to fit p_T spectrum and weighting factor.
  - Weighting factor is used for unfolding and efficiency to correct the p_T spectra.

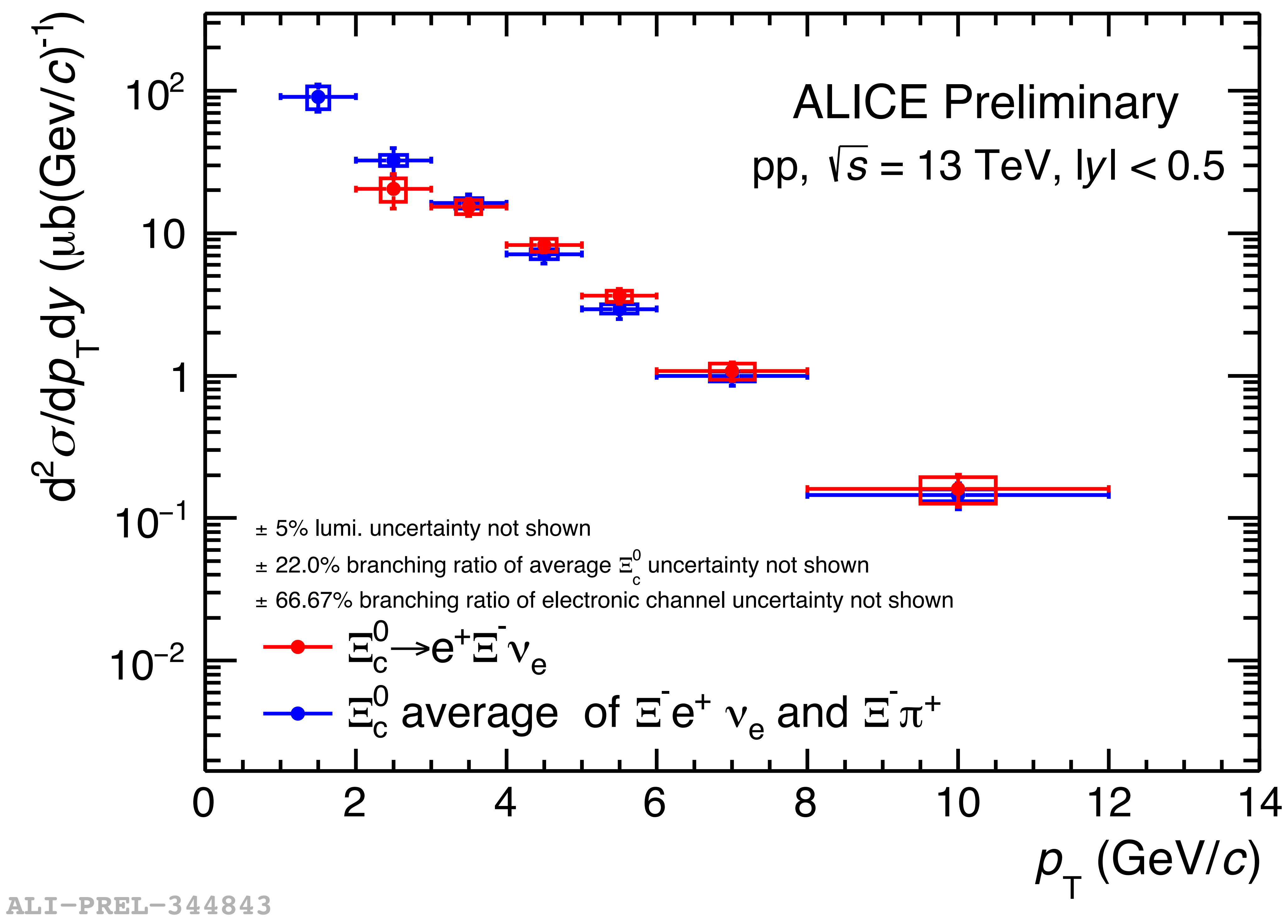




- Average of cross sections

- **Cross section**
  - The p_T differential cross sections of Ξ^0_c is calculated as
$$Br \frac{d\sigma^{\Xi_c^0}}{dp_T dy} = \frac{N^{raw}_{\Xi_c^0}}{2 \cdot \Delta p_T \Delta y \cdot (Acc \times \epsilon \times \epsilon_{\Xi_{tag}}) \cdot L_{int}}$$
  - The Ξ^0_c cross section via semi-leptonic channel and hadronic channel are averaged.
  - The measurements of Ξ^0_c via semi-leptonic and average of two decay channels are compatible.

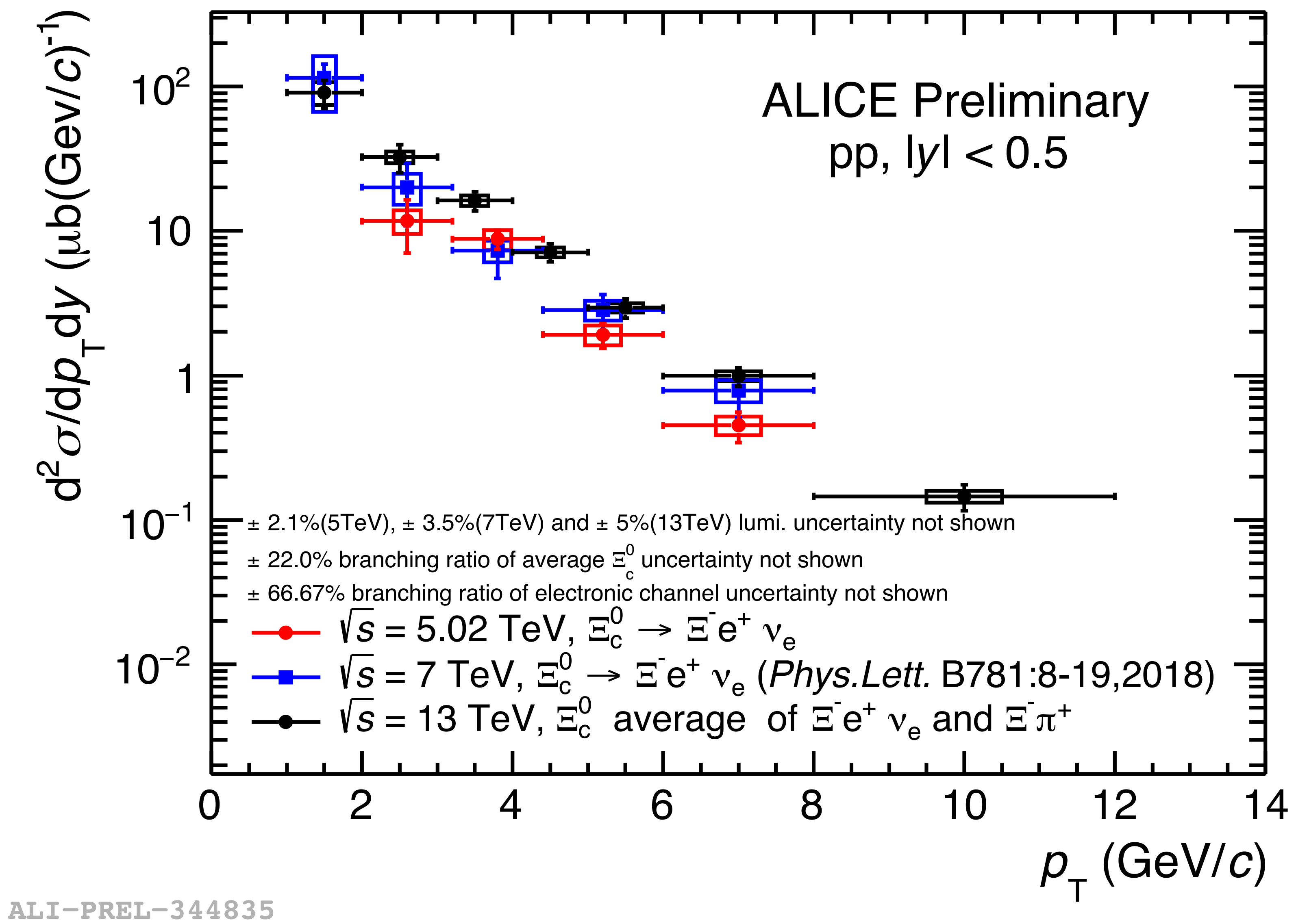




Result

- Ξ^0_c production in pp at 13TeV

- **Energy dependency**
  - Energy dependences are shown(5,7 and 13 TeV).
- **Constraint branching ratio**
  - Branching ratio fraction is calculated using Ξ^0_c measurements.
- **Measurement comparison**
  - Ξ^0_c measurement is compared with D^0 and Λ_c^+.
- **Model comparison**
  - The measurement ratio is compared with model.
  - The measurement provides constraints on model calculations.



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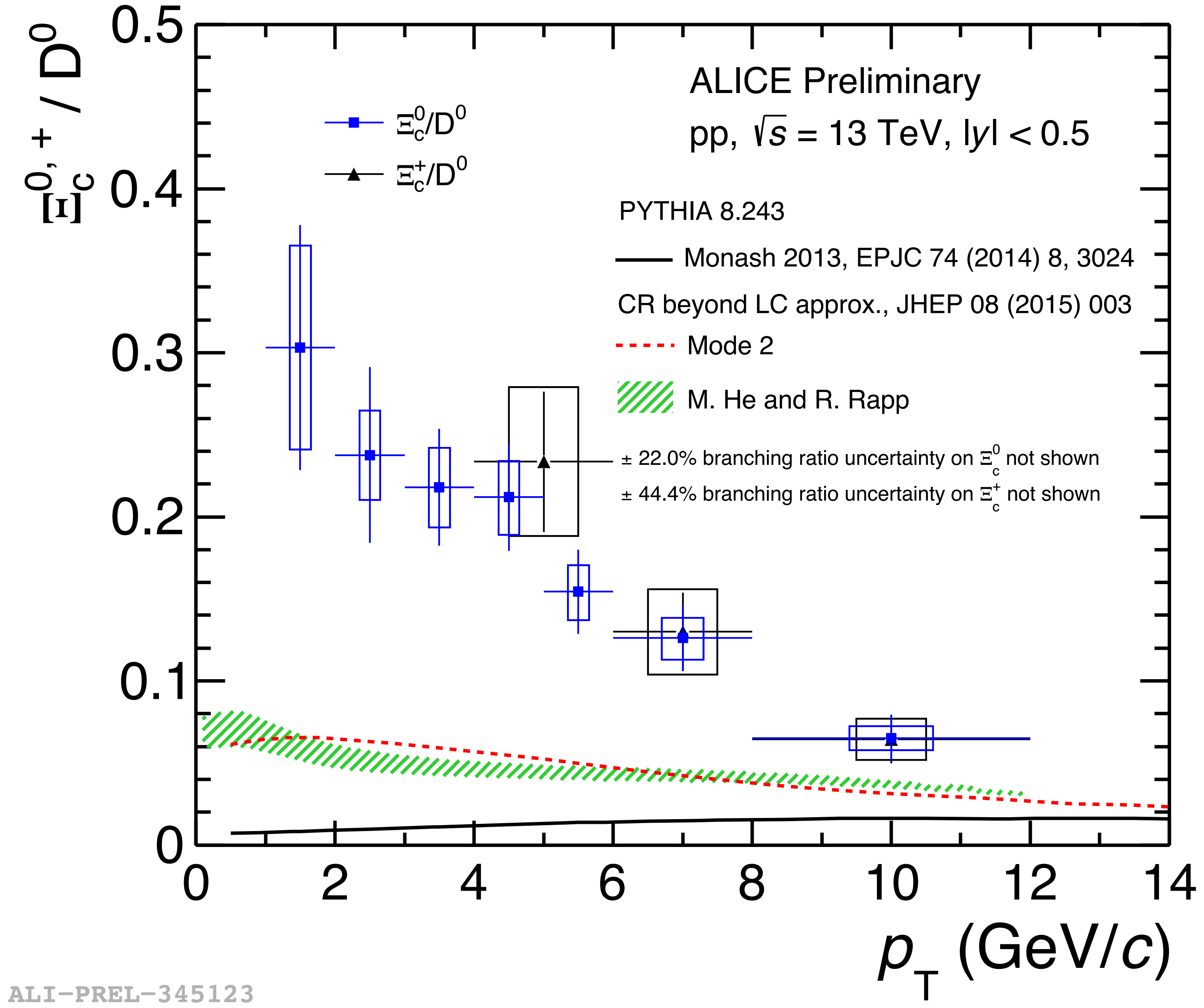

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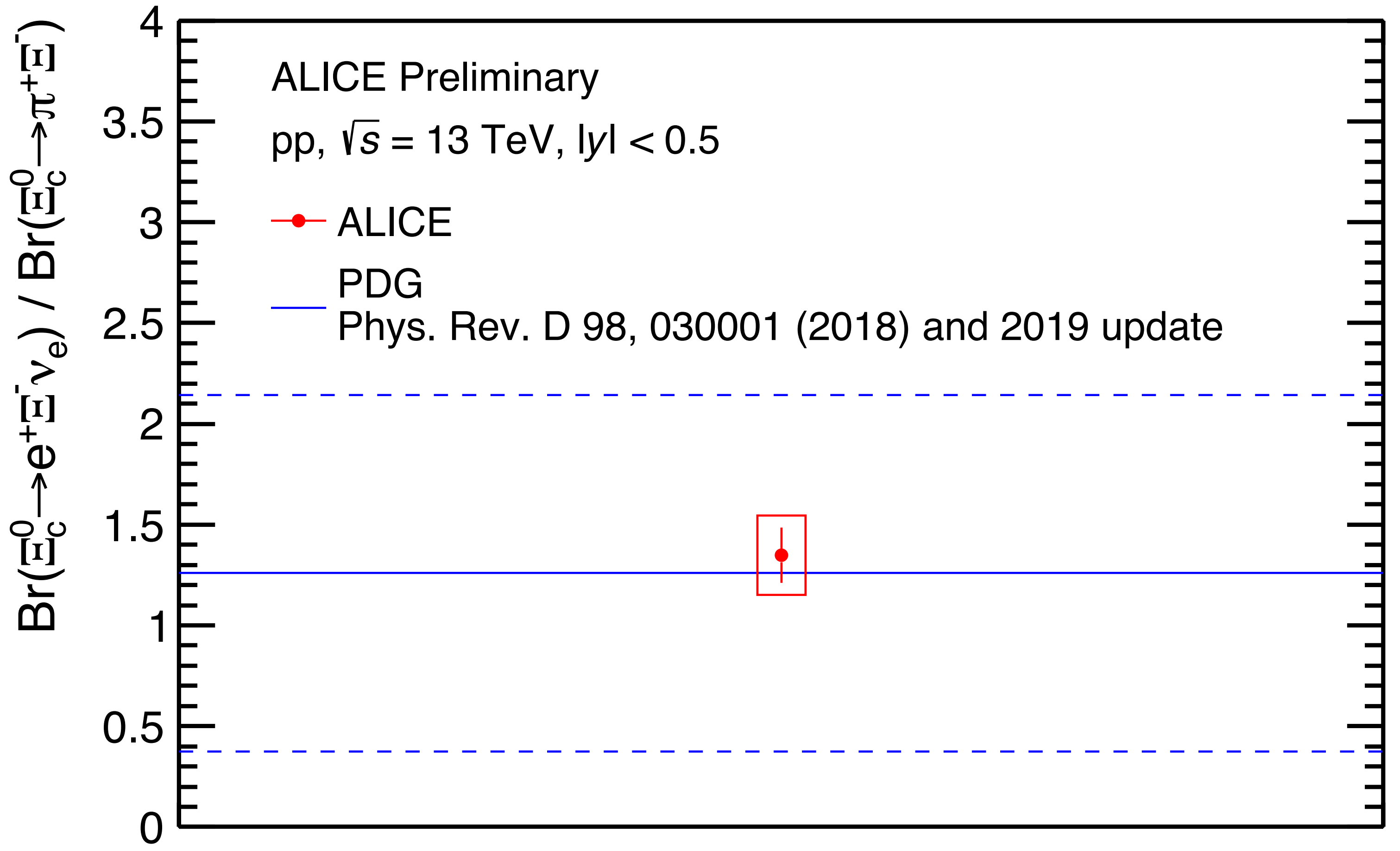

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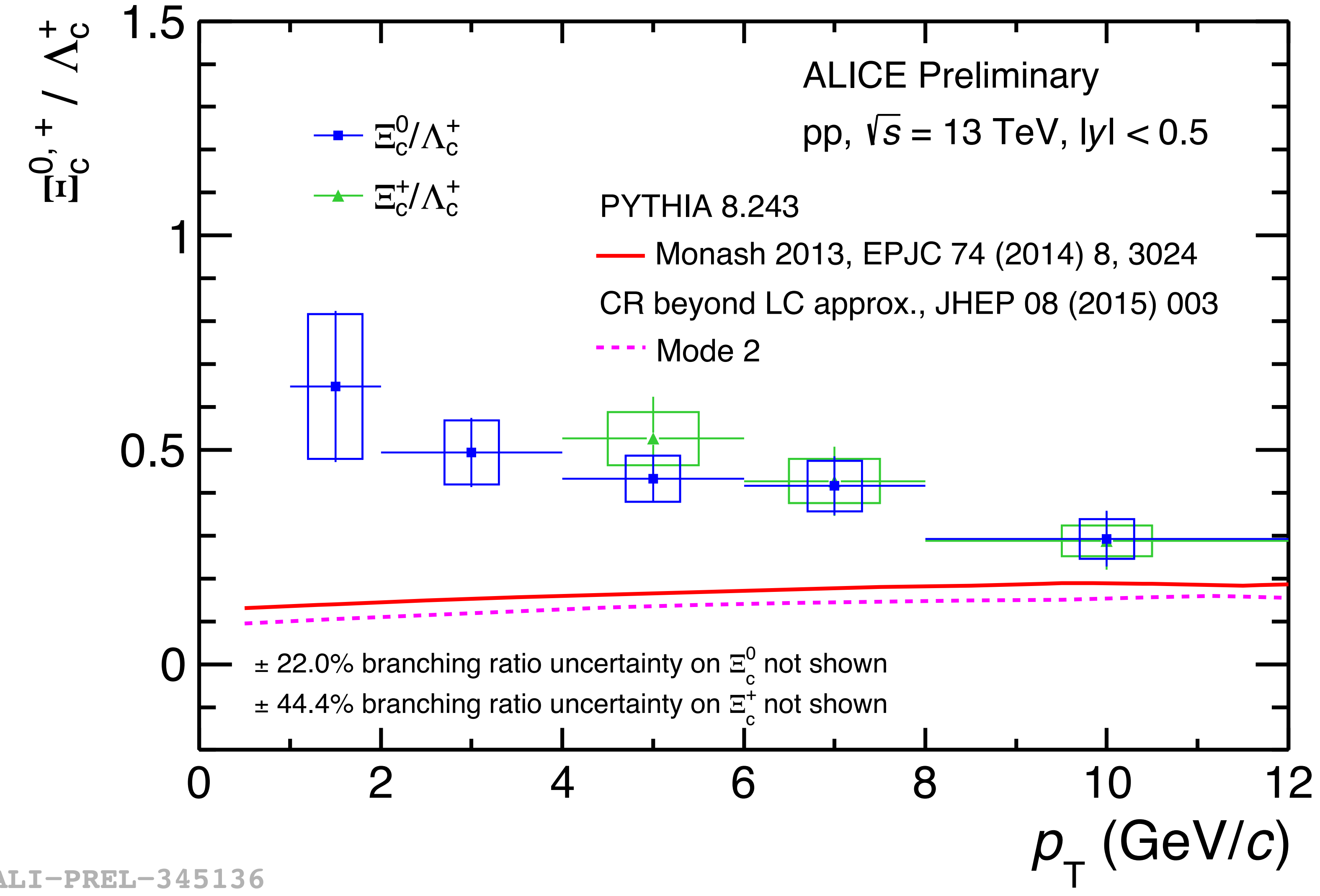

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- Summary and Plan

- **Summary**
  - Ξ^0_c production is being studied via semi-leptonic decay in pp collision at 13 TeV.
  - Electrons are selected using PID cuts and electron pair mass information, Ξ candidates are selected using PID cuts.
  - The electron loss caused by the misidentification of photonic electrons is confirmed via cut efficiency.
  - The eΞ pair subtraction method is used to remove the background and get raw yield.
  - The unfolding is used to corrected missing momentum of neutrino.
  - Because p_T distributions of the MC Ξ^0_c and real data are different, weighting procedure is performed.
  - The cross section is calculated using weighted spectra, weighted efficiency.
  - The Ξ^0_c production via semi-leptonic channel and hadronic channel are averaged and average one shows energy dependence.
  - The Ξ^0_c measurement is compared with D^0 and Λ_c^+, and provides constraints on model calculations and branching ratio fraction.

- **Plan**
  - Feeddown correction will be done.

Back up

- Cut list

Event cut variables	Cuts
Physics selection	AliVEvent::kINT7
Primary vertex	Within 10cm
Pile up	Rejection

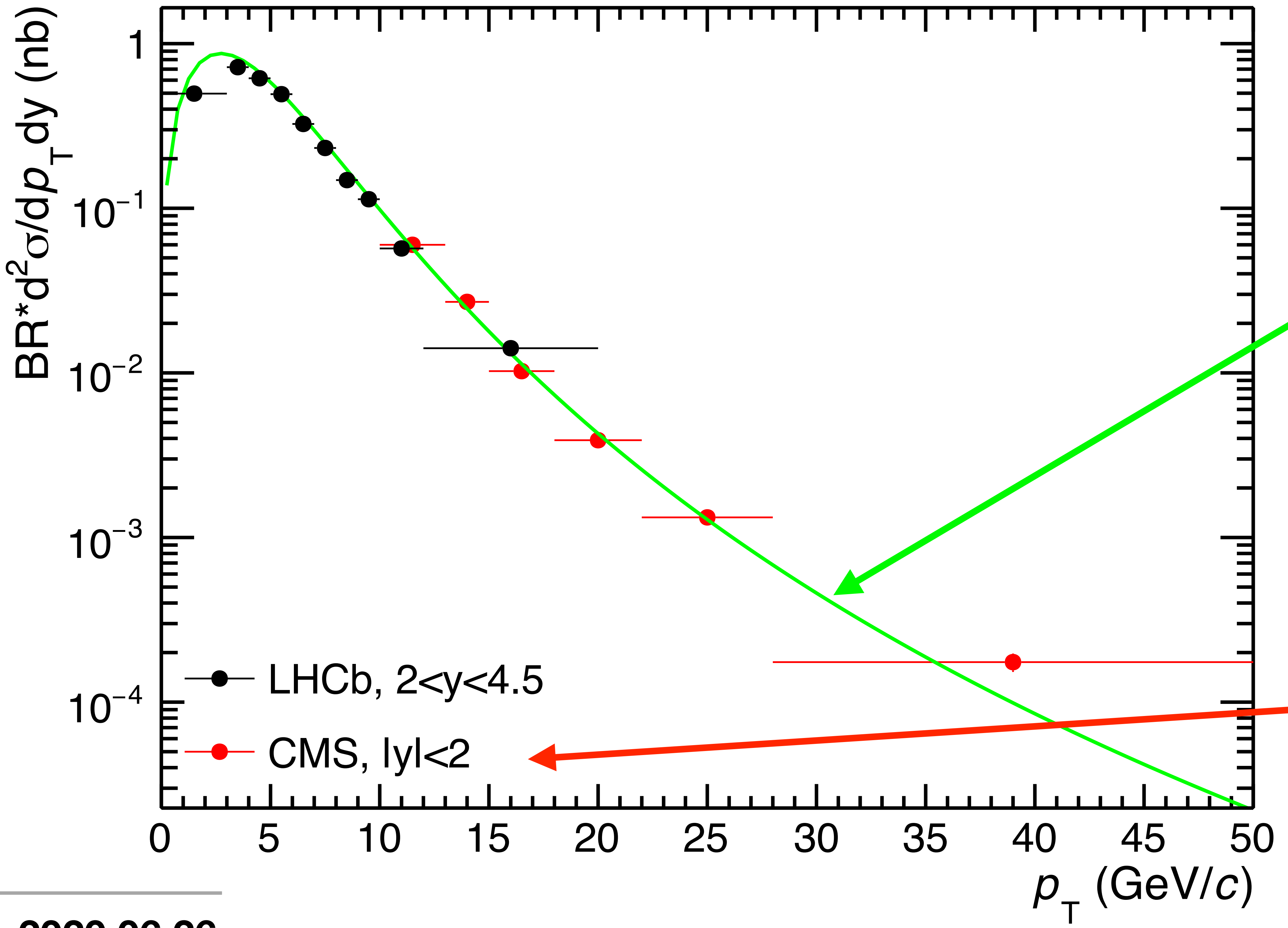
Track cut variables	Cuts
Track Filter bit	kTrkGlobalNoDCA
Number of CrossedRows	>70
CrossedRows over findable clusters	>0.8
Number of TPC PID clusters	>50
Ratio to findable cluster	>0.6
ITS/TPC refit	TRUE
Number of ITS cluster	>=3
pt	>0.5
|η|	<0.8
SPD hit	Both
|TOF nσ|	<3
TPC nσ	$f(P_T)$ ~ 3

$f(P_T) = -3.9+1.17P_T-0.094P_T^2$

Xi cut variables	Cuts
Number of CrossedRows	>70
CrossedRows over findable clusters	>0.77
Λ Mass tolerance (MeV/c2)	7.5
Ξ Mass tolerance (MeV/c2)	8
DCAof V0 to PV(cm)	>0.03
DCA f V0 daughters PV (cm)	>0.073
V0 cosine pointing angle to Ξ vertex	>0.983
DCA of bachelor track to PV (cm)	>0.0204
V0 decay length (cm)	>2.67
Ξ decay length (cm)	>0.38
TPC nσ (proton)	<4
TPC nσ (pion)	<4

- Correction of oversubtraction caused by bottom baryon

- **Fit Λ_b 7TeV measurement using Tsallis function**
  - The Ξ_b baryons are not measured at LHC energies. → **Assumption : Ξ_b p_T shape is same as Λ_b**
  - Λ_b was measured by CMS and LHCb at 7TeV.
    - CMS measurement is used to fit the spectrum down to 0GeV pT. (*Phys. Lett.*, B714:136–157, 2012)
    - LHCb measurement is not used due to the difference in the rapidity coverage from ALICE.



$$C \cdot p_T \left[1 + \frac{\sqrt{p_T^2+m^2}-m}{nT}\right]^{-n}$$

CMS: $n = 7.6 \pm 0.4$, $T = 1.10$ GeV

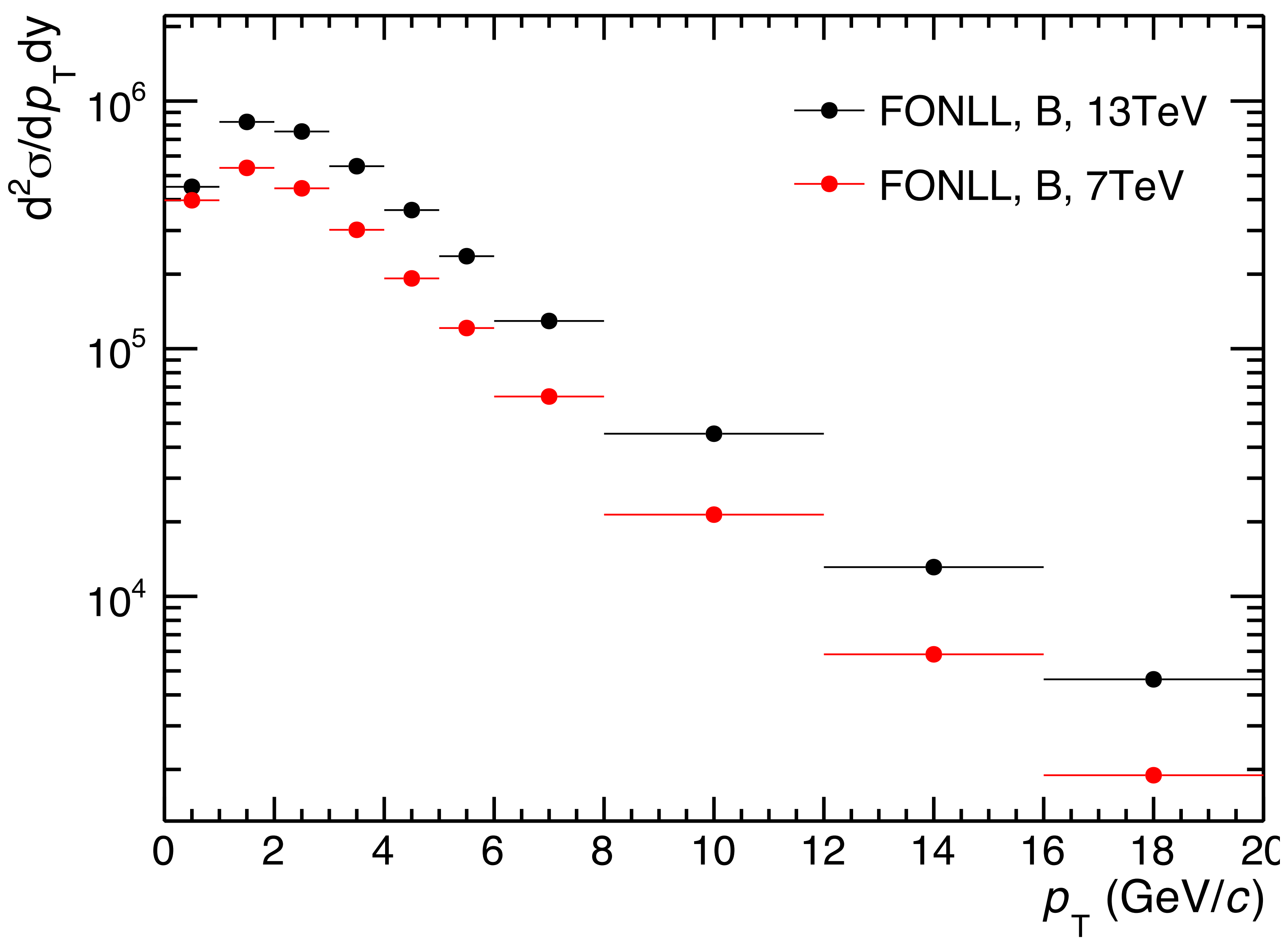
$$\frac{d\sigma(pp \to \Lambda_b X)}{dp_T^{\Lambda_b}} \times \mathcal{B}(\Lambda_b \to J/\psi\,\Lambda) = \frac{n_{sig}}{2 \cdot \epsilon \cdot \mathcal{B} \cdot \mathcal{L} \cdot \Delta p_T^{\Lambda_b}},$$

- Correction of oversubtraction caused by bottom baryon

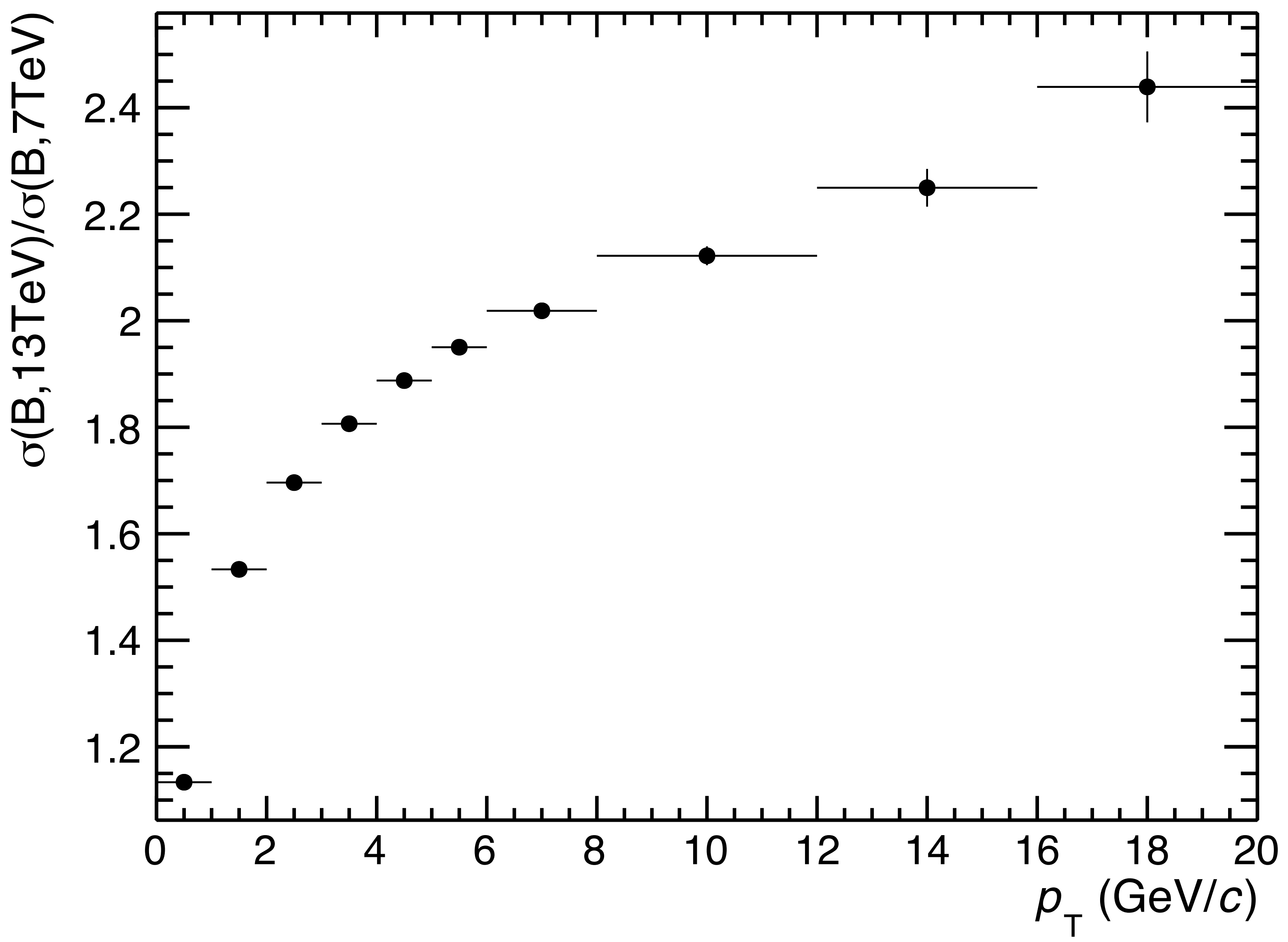
- **Λ_b 7TeV measurement is scaled to 13TeV by FONLL**
  - Since Λ_b was measured at 7TeV, energy scaling is needed using FONLL.
  - There is no Λ_b 13TeV spectrum in FONLL but there is B meson spectrum.

    ➡ **Assumption : B ratio (13TeV/7TeV) is same as Λ_b ratio (13TeV/7TeV)**

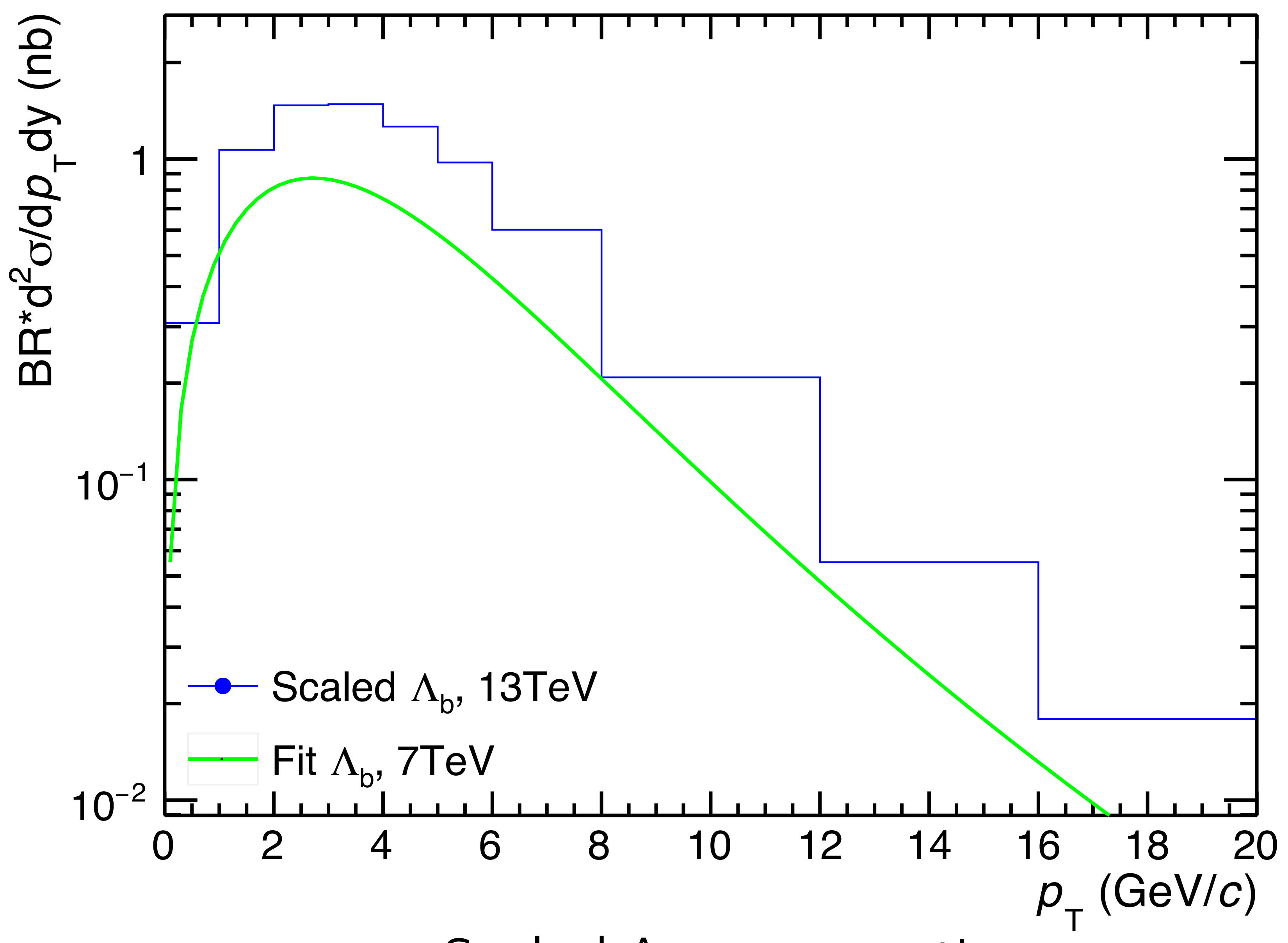
    → **Baryon and meson energy dependence of fragmentation function are same.**
  - 7TeV Λ_b cross section is scaled to 13TeV Λ_b by scale factor obtained B meson ratio.



B meson cross section



B meson cross section ratio (13TeV/7TeV)
Scale factor



Scaled Λ_b cross section

- Correction of oversubtraction caused by bottom baryon

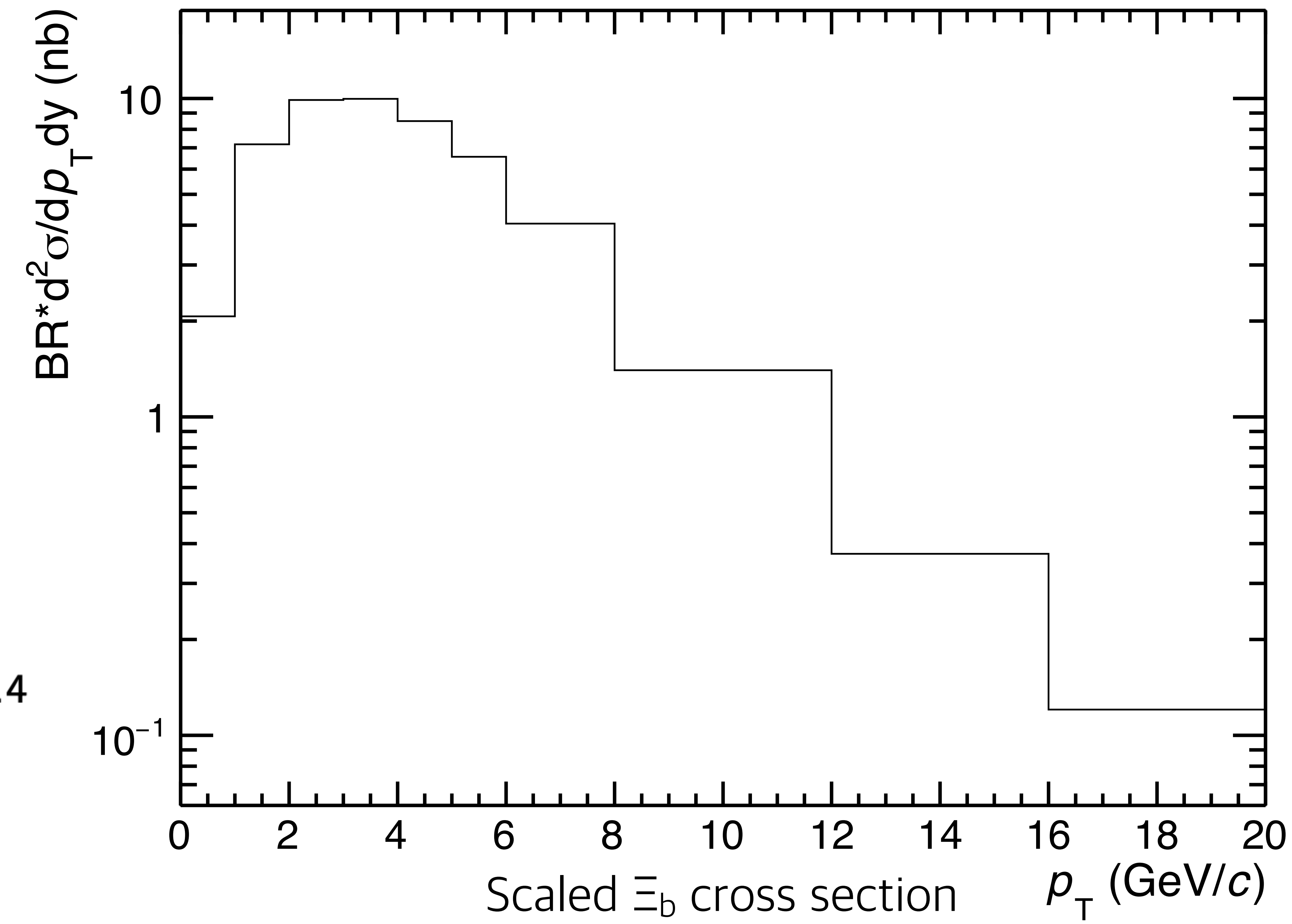
- **Multiply branching ratio fraction**
  - CMS measurement contains branching ratio Λ_b to J/ψΛ.

$$\frac{d\sigma(pp \to \Lambda_b X)}{dp_T^{\Lambda_b}} \times \mathcal{B}(\Lambda_b \to J/\psi\,\Lambda) = \frac{n_{sig}}{2 \cdot \epsilon \cdot \mathcal{B} \cdot \mathcal{L} \cdot \Delta p_T^{\Lambda_b}},$$

  - Branching ratio fraction is multiplied to 13TeV Λ_b cross section to get a Ξ_b cross section.
    - Branching ratio is obtained at PDG

$$\frac{BR(b \to \Xi_b)BR(\Xi_b \to e\Xi\nu)}{BR(b \to \Lambda_b)BR(\Lambda_b \to J/\Psi\Lambda)} = \frac{3.9 \times 10^{-4}}{5.8 \times 10^{-5}}$$

Γ_1	$\Xi^- \ell^- \overline{\nu}_\ell X \times$ B($\overline{b} \to \Xi_b$)	$(3.9 \pm 1.2) \times 10^{-4}$	S=1.4
Γ_1	$J/\psi(1S)\Lambda \times$ B($b \to \Lambda_b^0$)	$(5.8 \pm 0.8) \times 10^{-5}$	



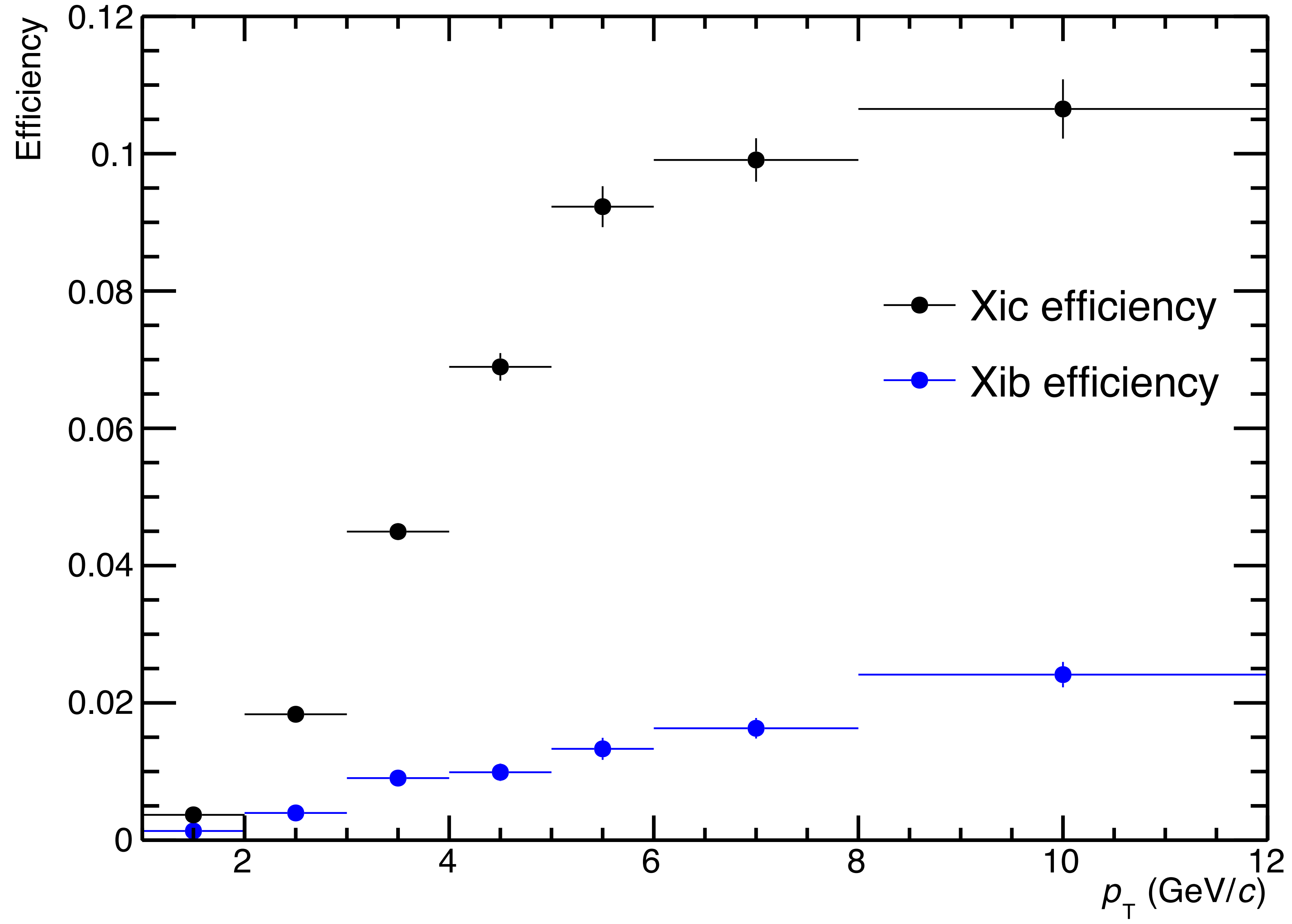
Scaled Ξ_b cross section

- Correction of oversubtraction caused by bottom baryon

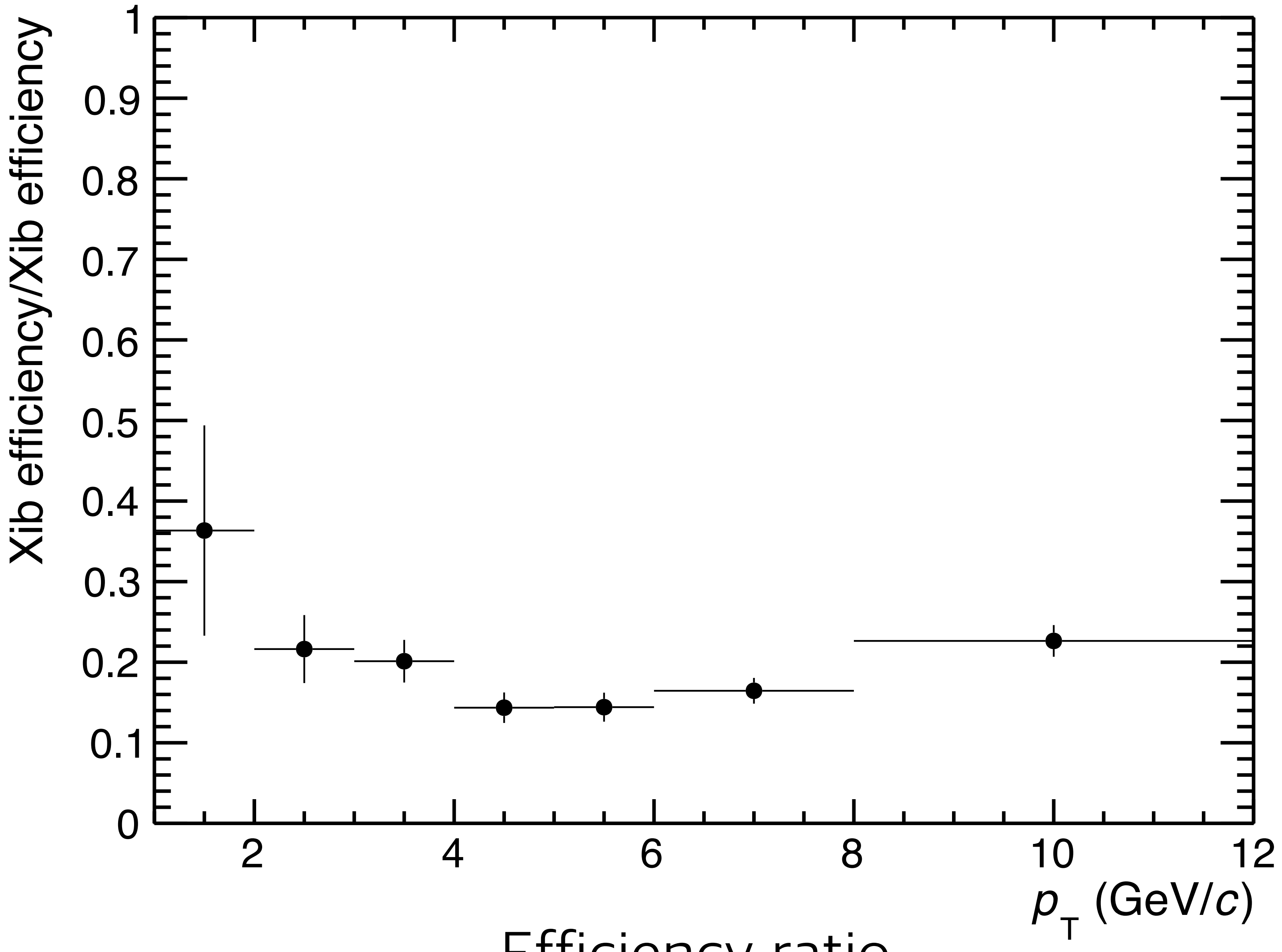
- **Multiply Ξ_b efficiency**
  - To get a Ξ_b yield in pp collisions at 13TeV, efficiency and some factors are multiplied.

$$N^{raw}_{\Xi_b} = Br\frac{d\sigma^{\Xi_b}}{dp_{\mathrm{T}}dy}2\Delta p_{\mathrm{T}}\Delta y \cdot \epsilon \cdot L_{int} \qquad \epsilon = \frac{\Xi_b(Reco, WS)}{\Xi_b(Gen)_{|y|<0.5}}$$

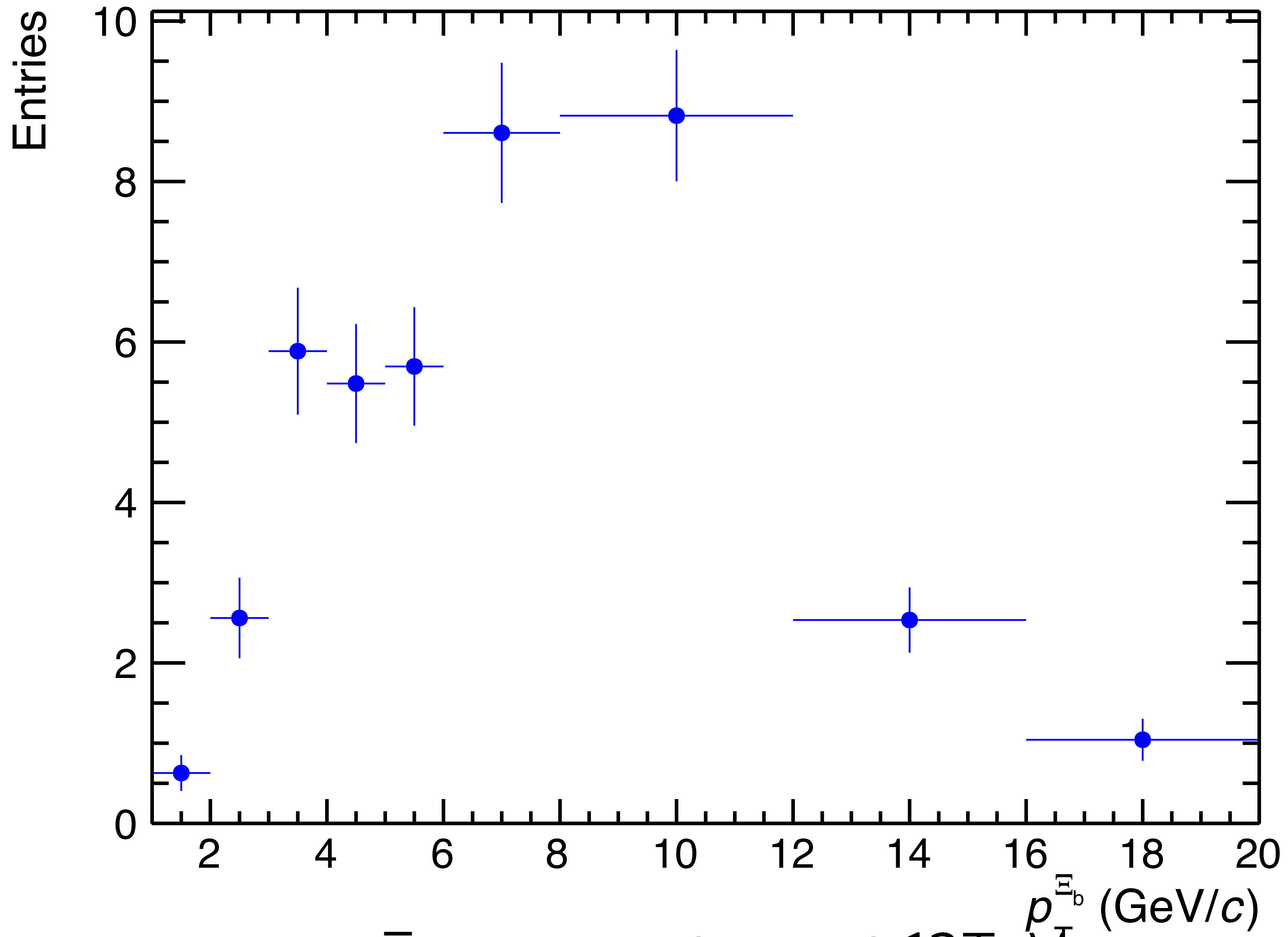
  - L_{int} is calculated same as 13TeV Ξ_c analysis.
  - Cuts are applied which same as Ξ_c analysis (track cut, Xi topology cut, pair cut …)



Efficiency of Xic and Xib



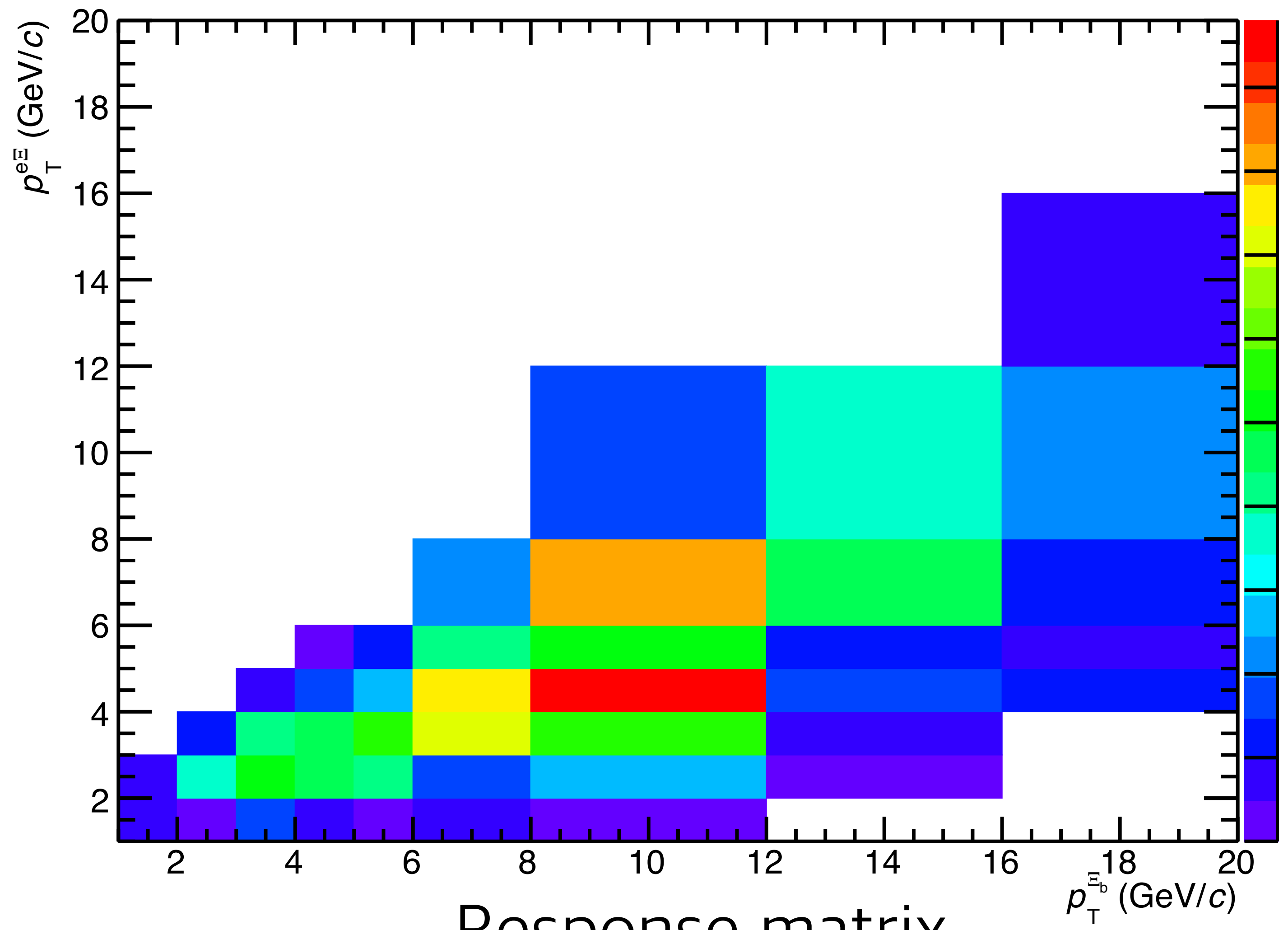
Efficiency ratio



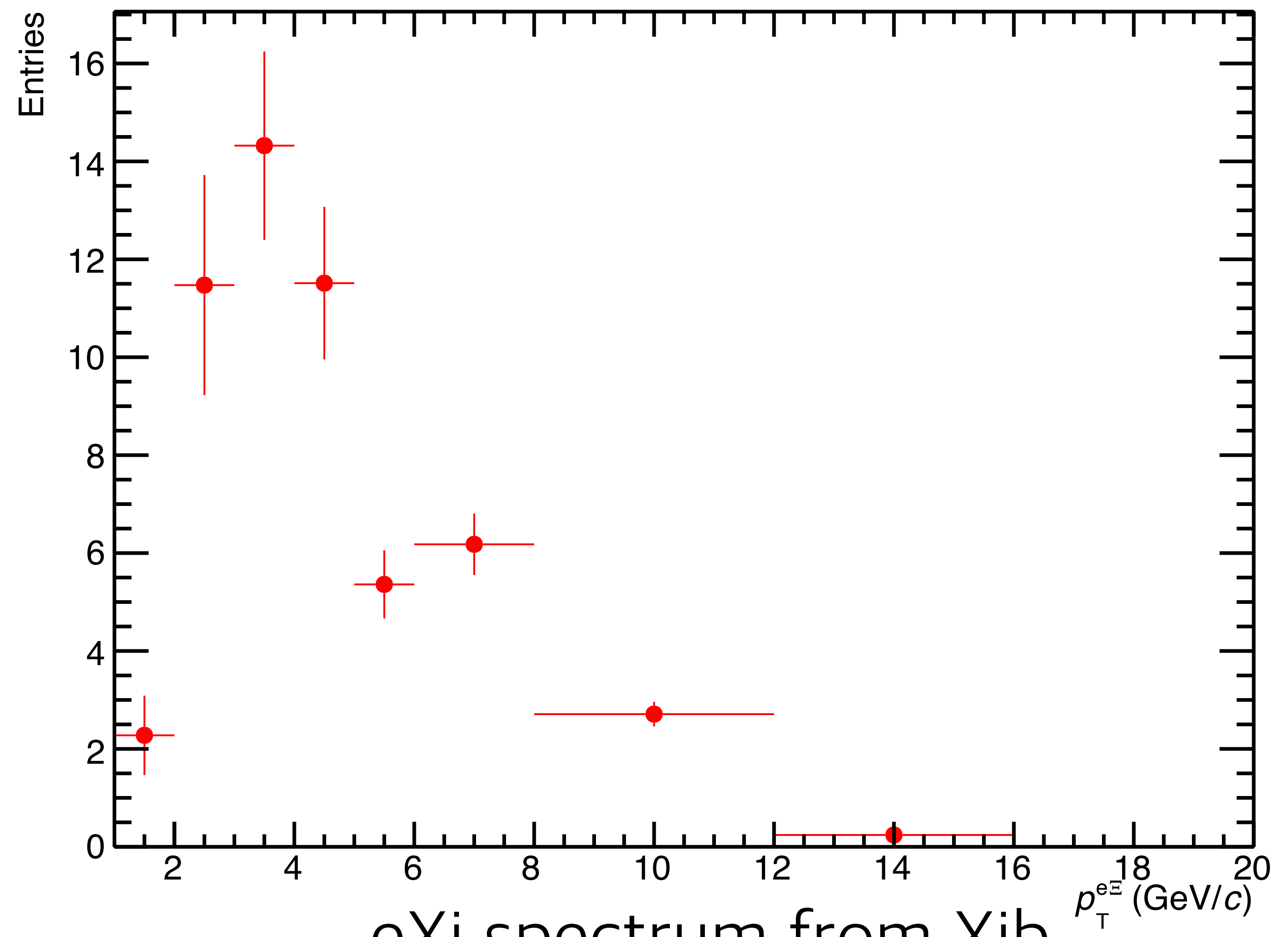
Ξ_b raw spectrum at 13TeV

- Correction of oversubtraction caused by bottom baryon

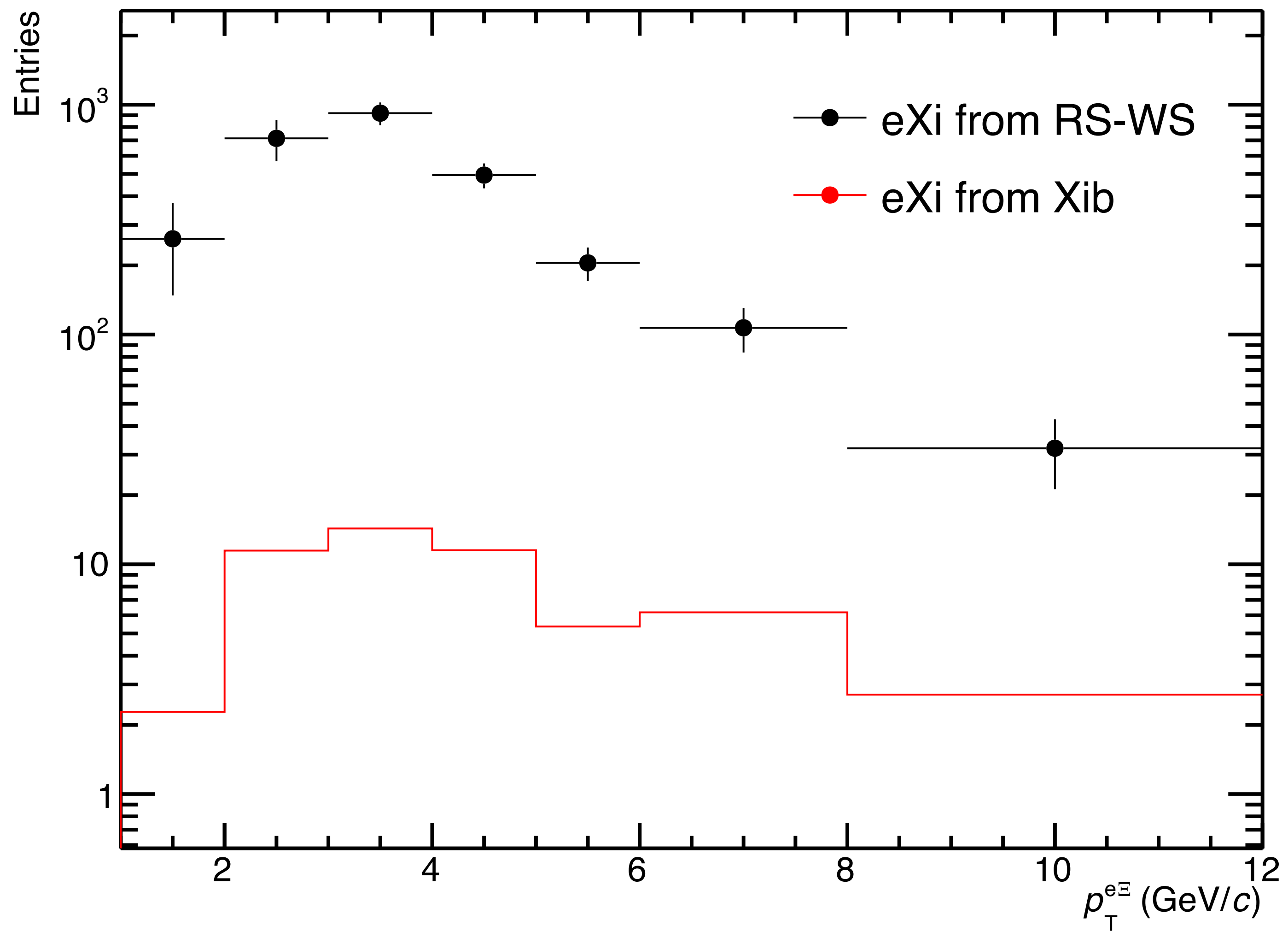
- **Convert Ξ_b p_T to eΞ p_T using response matrix**
  - Ξ_b spectrum is folded to eΞ spectrum using response matrix
    - Bin by Bin folding is done.
  - Ξ_b contribution in WS is 2% at low p_T region, and 10% at high p_T region.
    - At high p_T, b production increases.



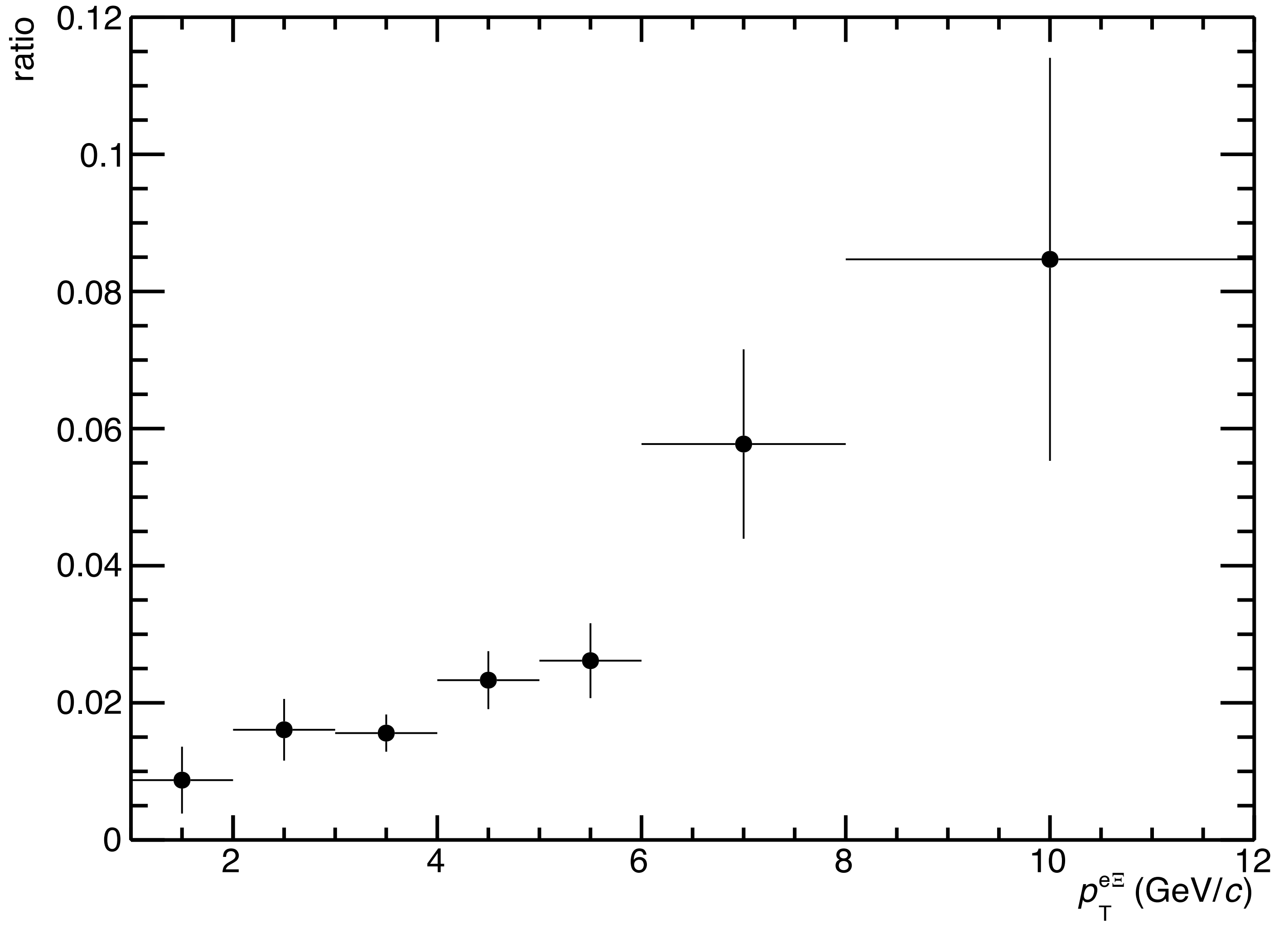
Response matrix



eXi spectrum from Xib



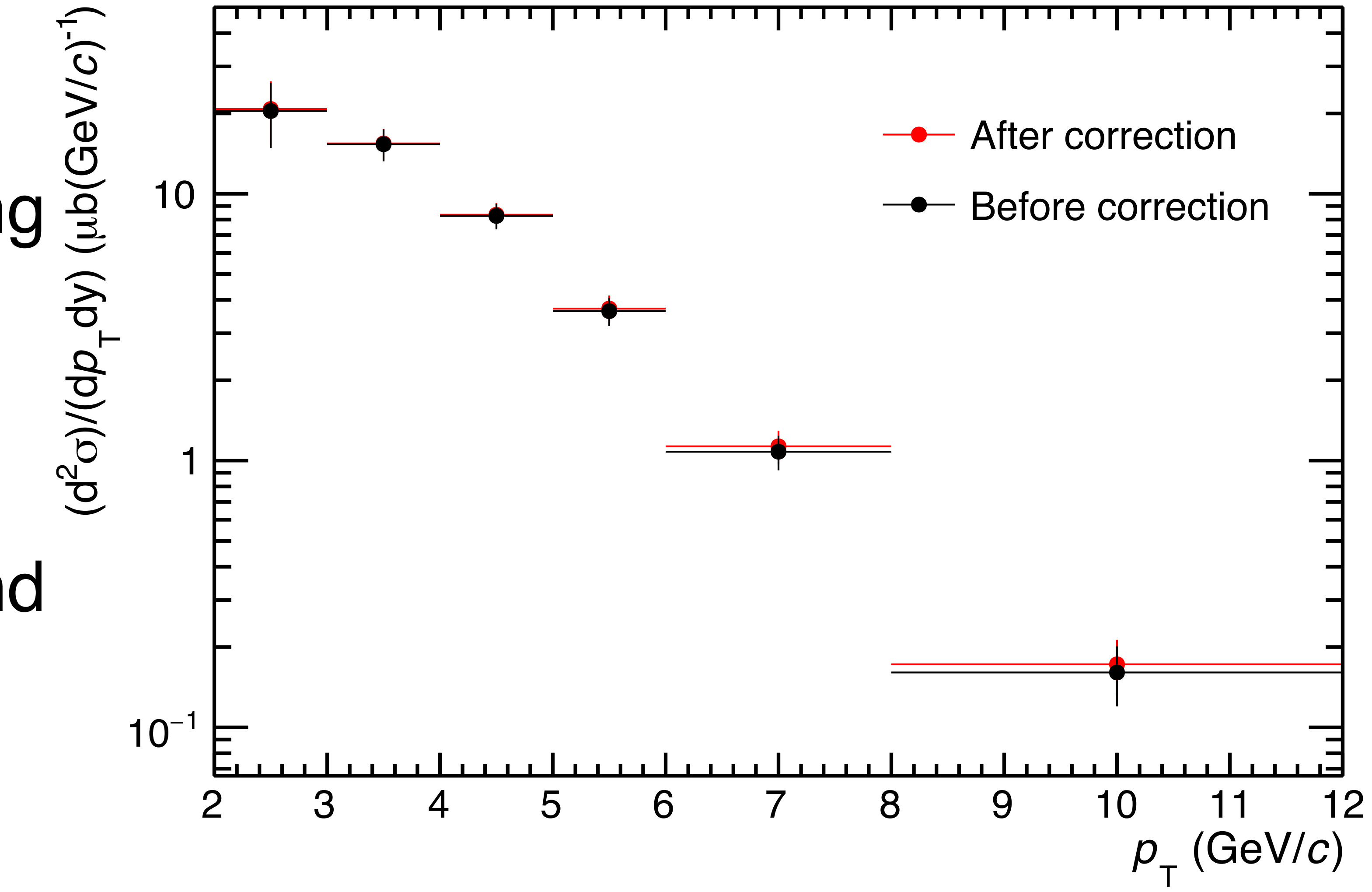
eXi pair spectrum



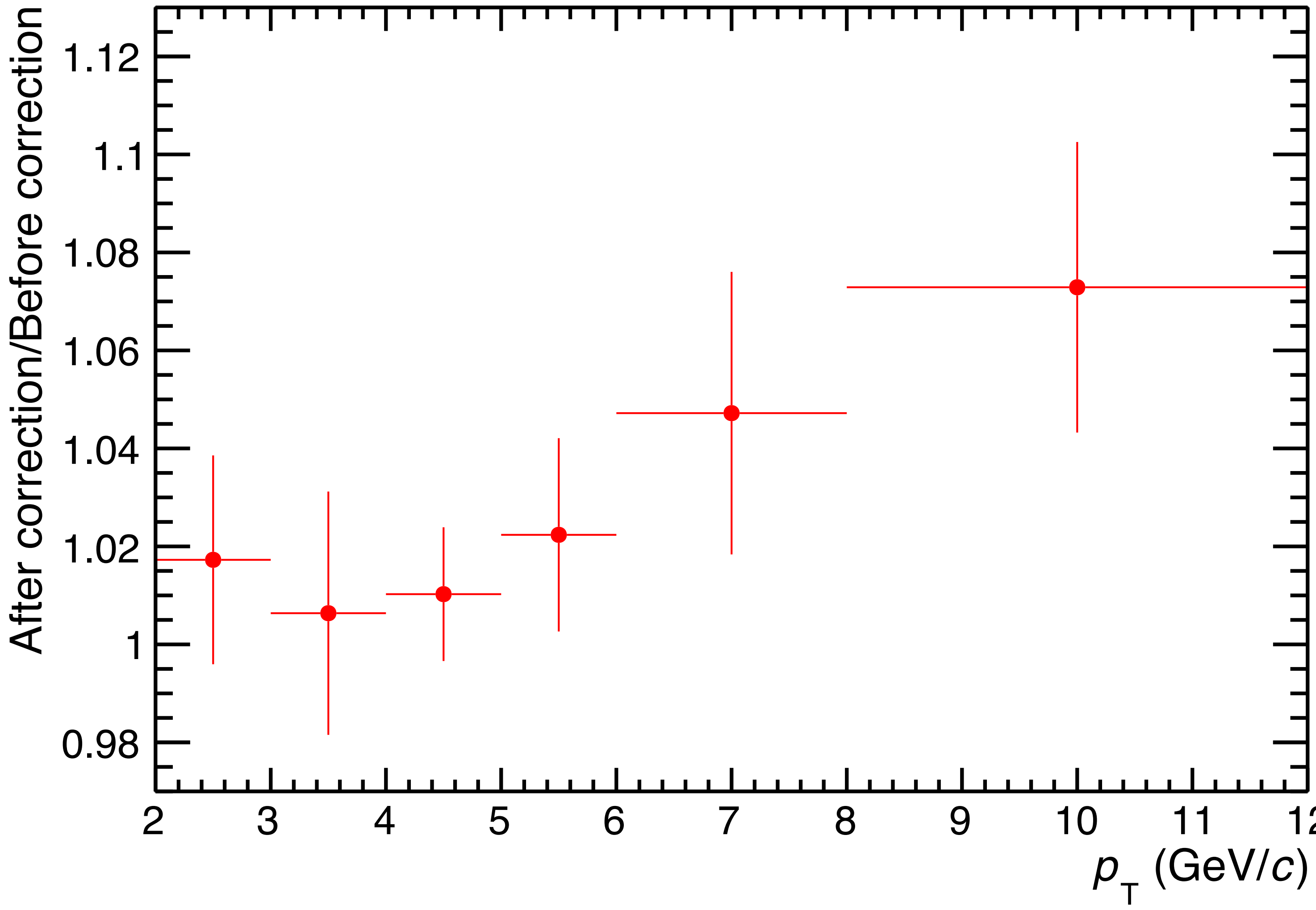
eXi pair ratio

- Correction of oversubtraction caused by bottom baryon

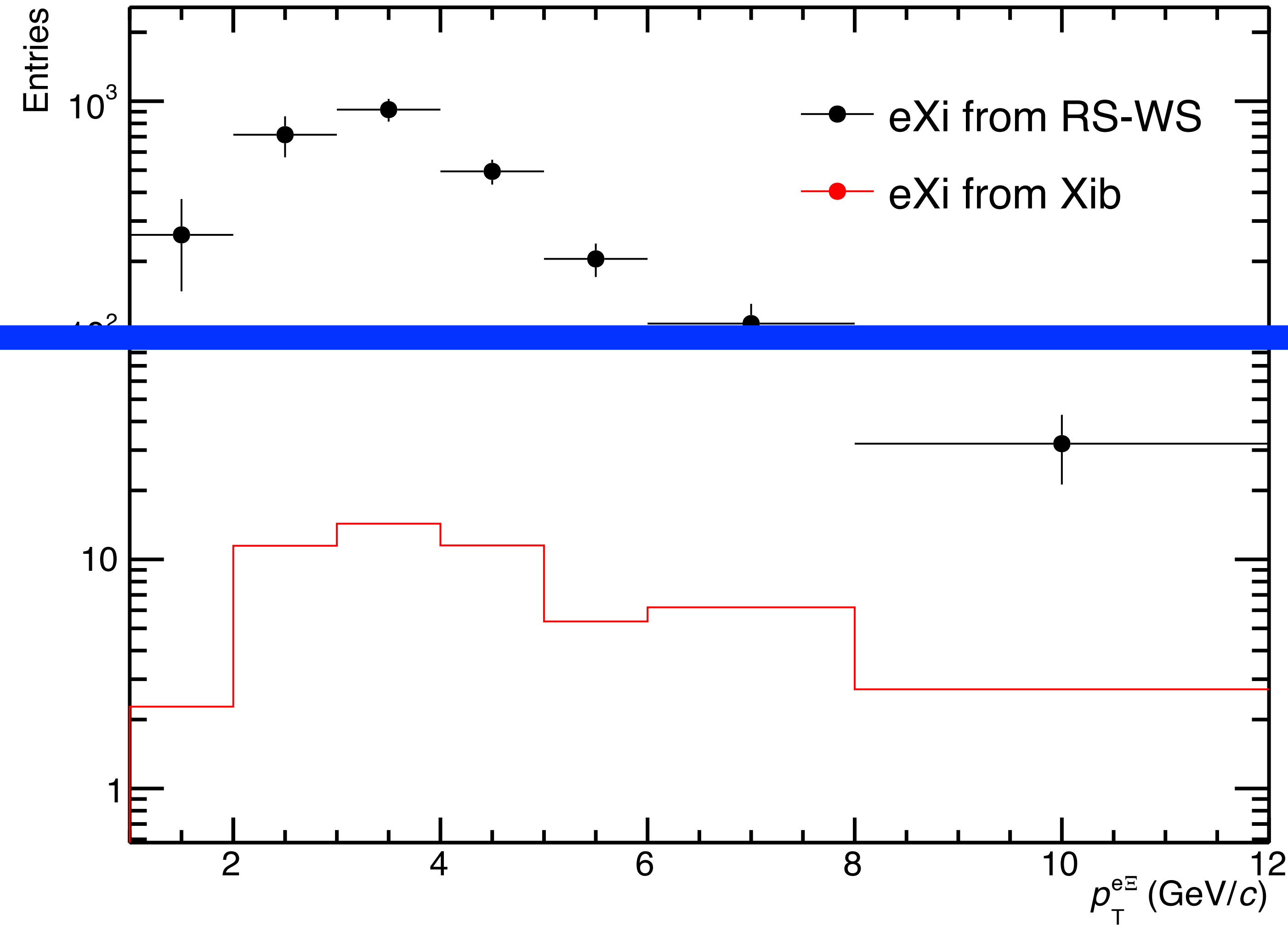
- **Convert Ξ_b p_T to eΞ p_T using response matrix**
  - Ξ_b spectrum is folded to eΞ spectrum using response matrix
    - Bin by Bin folding is done.
  - Ξ_b contribution in WS is 2% at low p_T region, and 10% at high p_T region.
    - At high p_T, b production increases.
  - eΞ pair from bottom baryon is added to eΞ pair from RS-WS.
  - Bottom baryon contribution increases the cross section 1~7%.



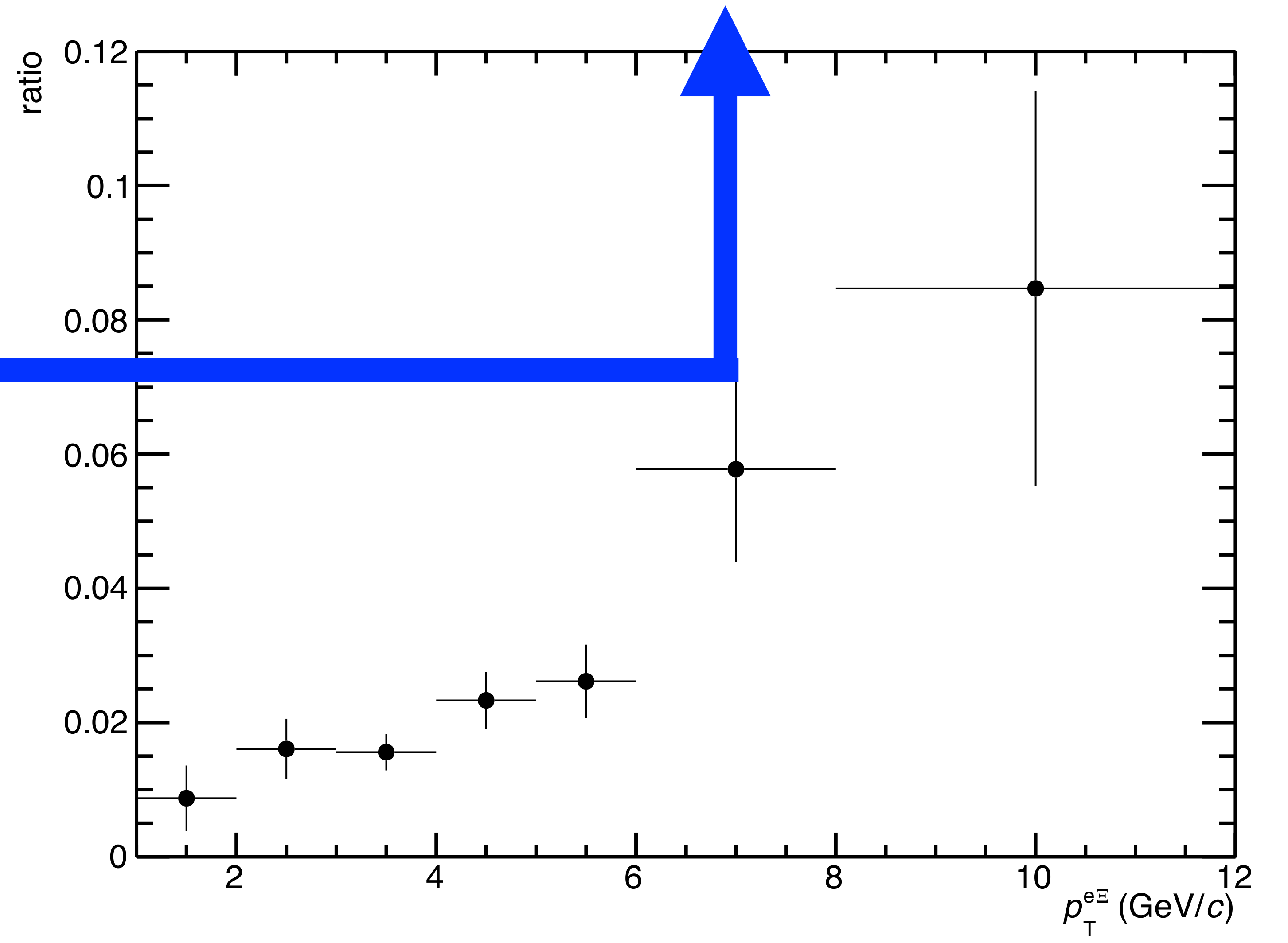
Cross sections



Cross section ratio

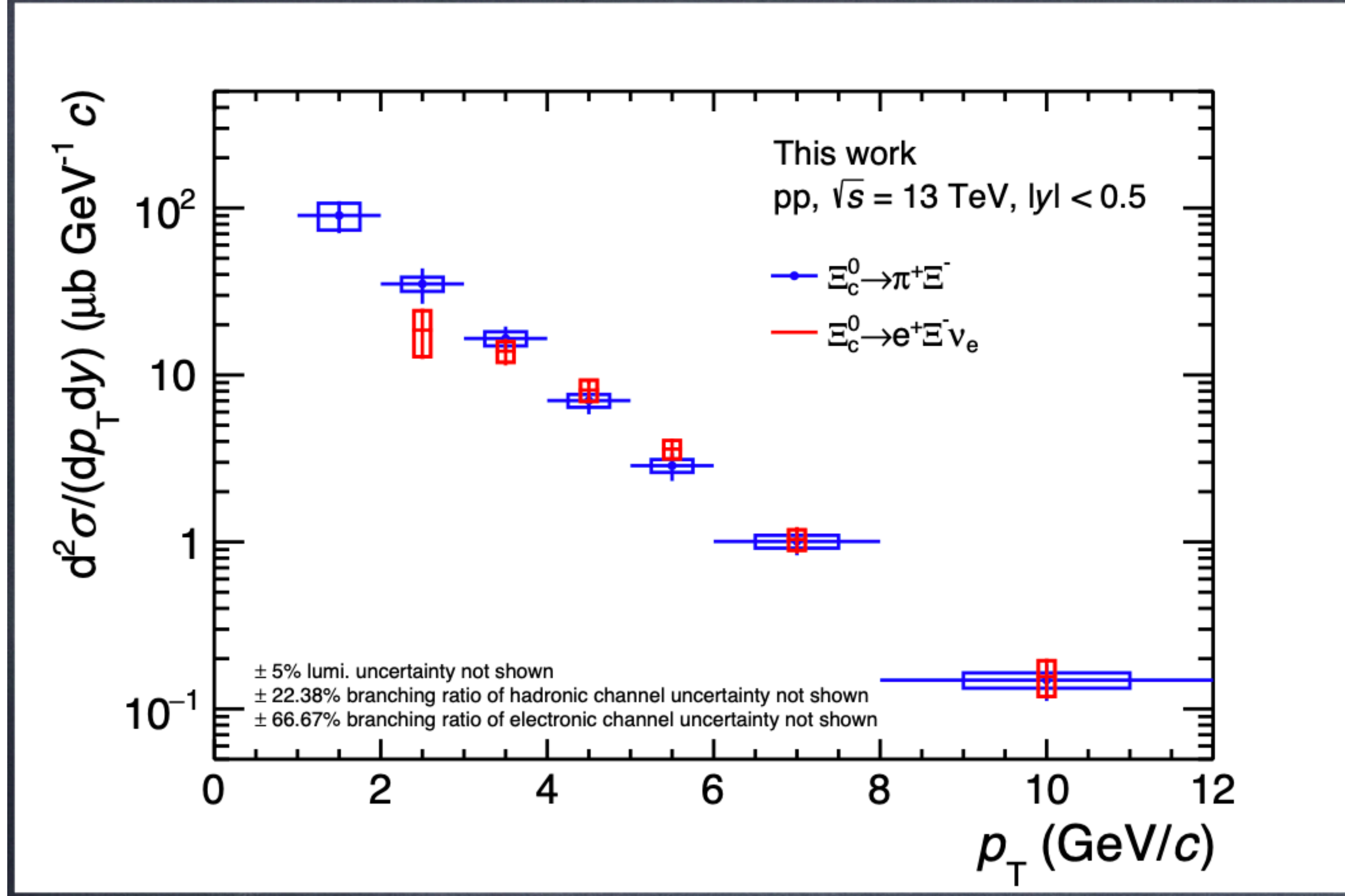


eXi pair spectrum



eXi pair ratio

Merged cross section



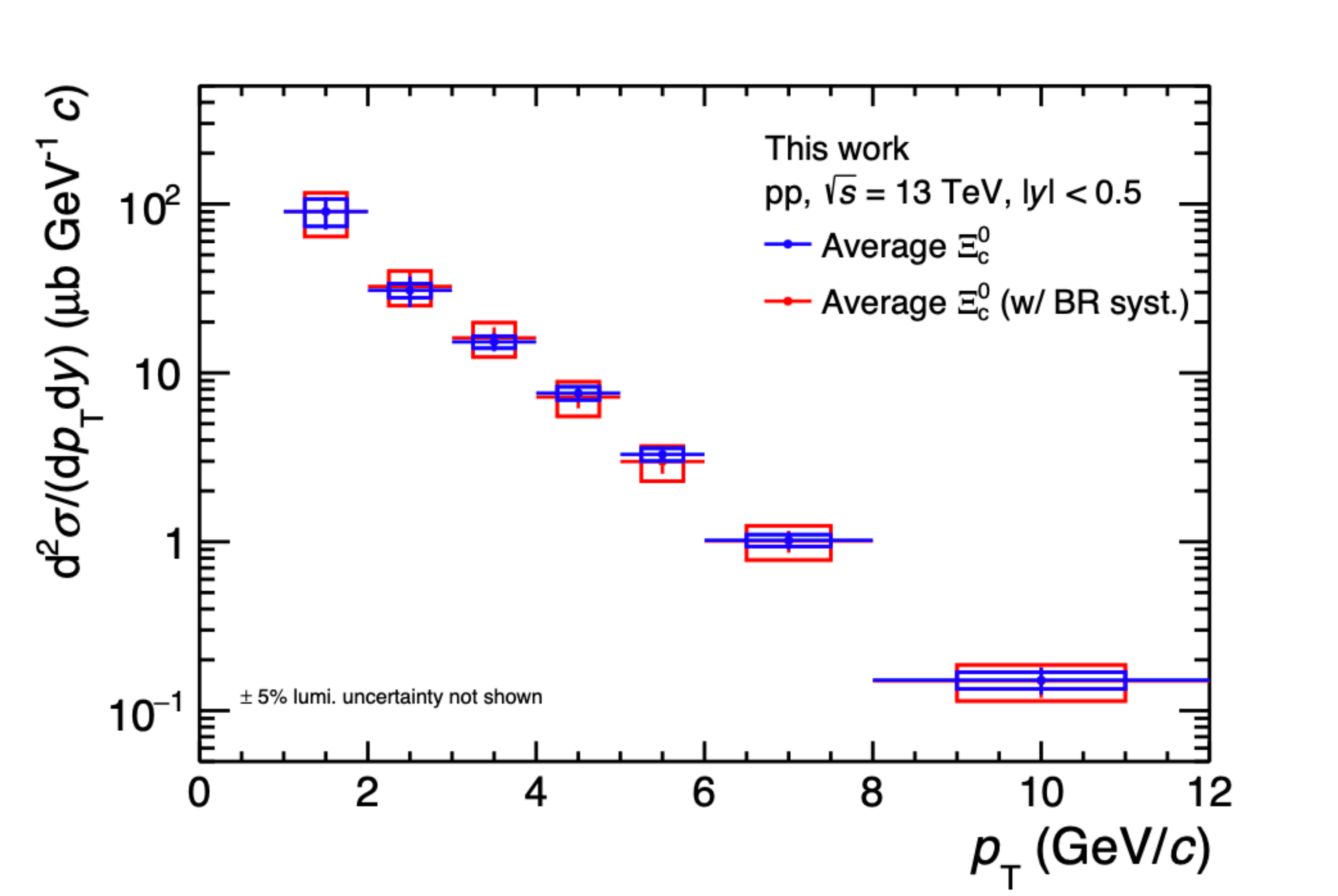
$$w_i^{uncorr} = \sqrt{(\frac{\sigma_i^{stat}}{N_i})^2 + (\frac{\sigma_i^{syst}}{N_i})^2}$$

$$< N > = \frac{N_h * \frac{1}{w_h^2} + N_e * \frac{1}{w_e^2}}{\frac{1}{w_h^2} + \frac{1}{w_e^2}}$$

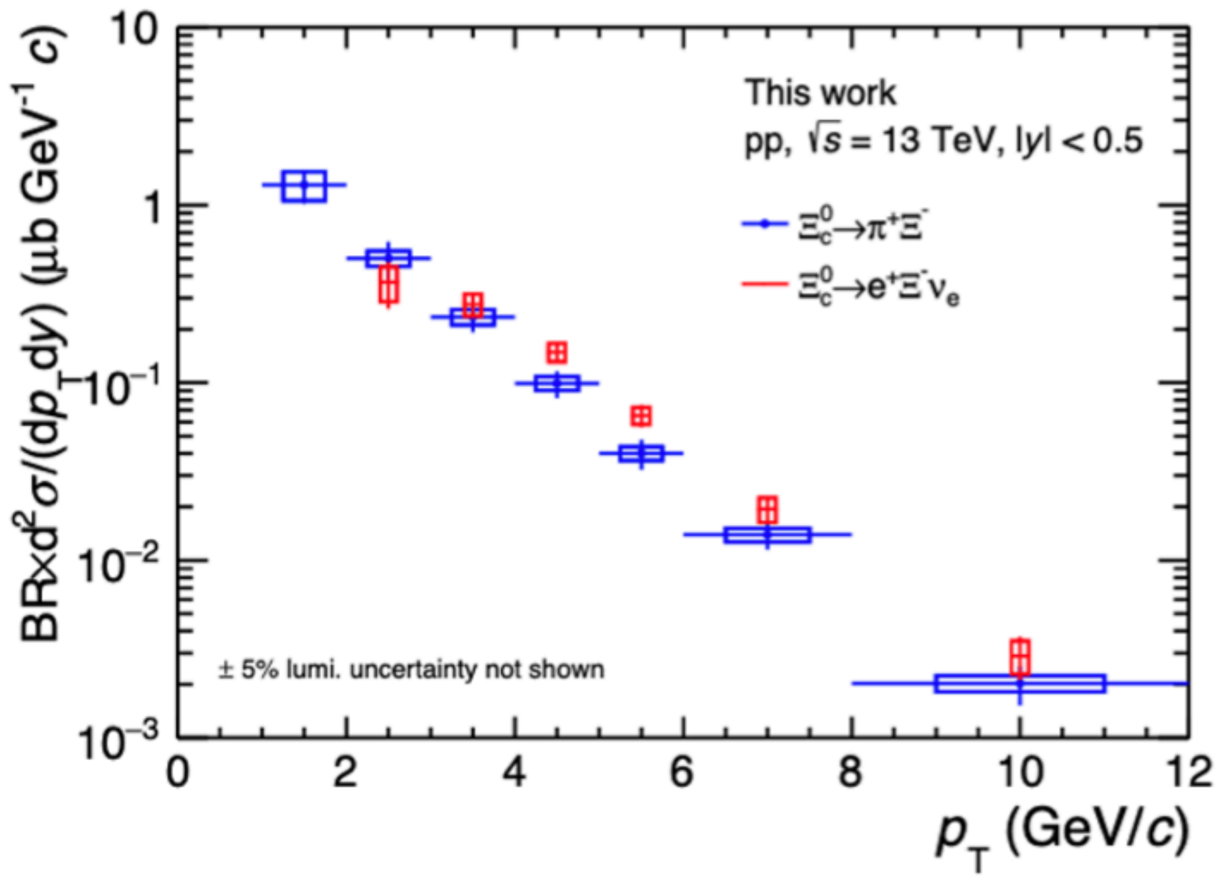
$$< \sigma_{stat} > = \frac{\sqrt{(\sigma_h^{stat} * \frac{1}{w_h^2})^2 + (\sigma_e^{stat} * \frac{1}{w_e^2})^2}}{\frac{1}{w_h^2} + \frac{1}{w_e^2}}$$

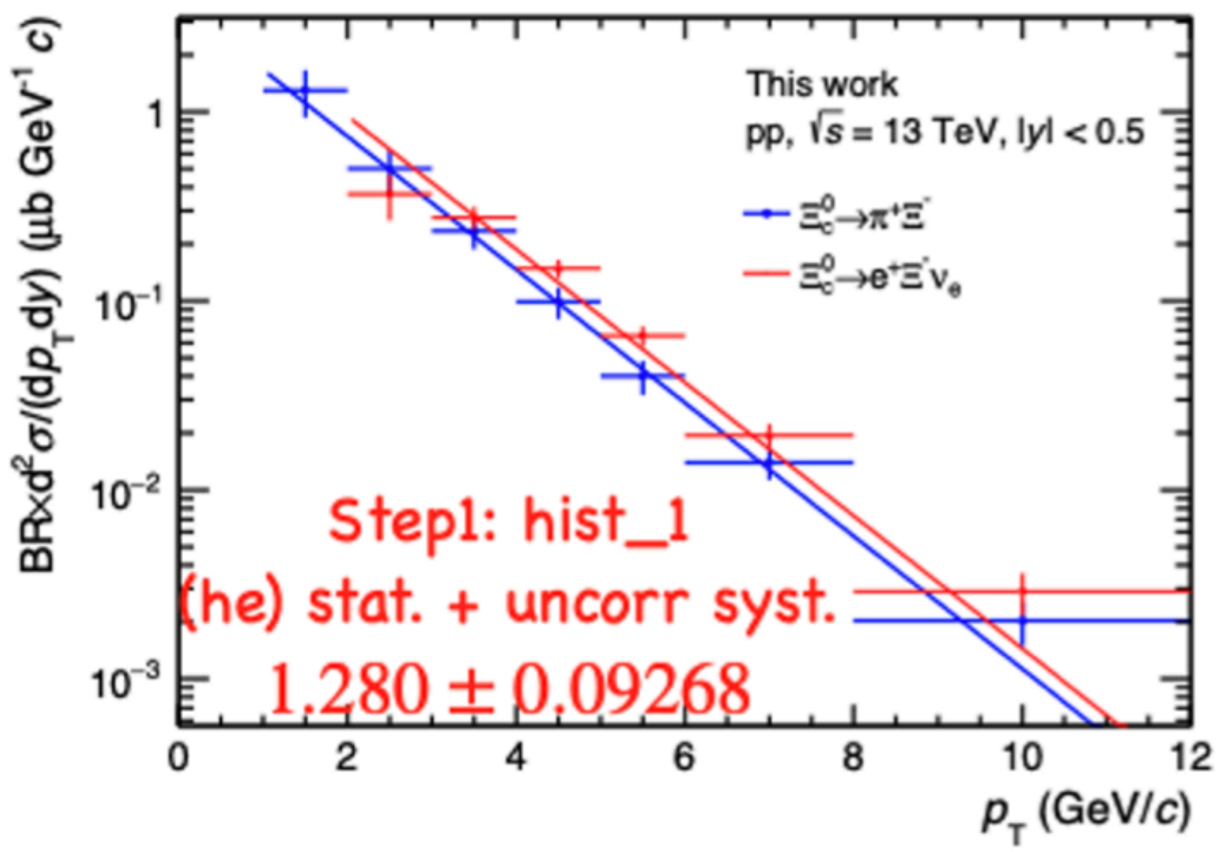
$$< \sigma_{syst} > = \frac{\sqrt{(\sigma_h^{syst} * \frac{1}{w_h^2})^2 + (\sigma_e^{syst} * \frac{1}{w_e^2})^2}}{\frac{1}{w_h^2} + \frac{1}{w_e^2}}$$

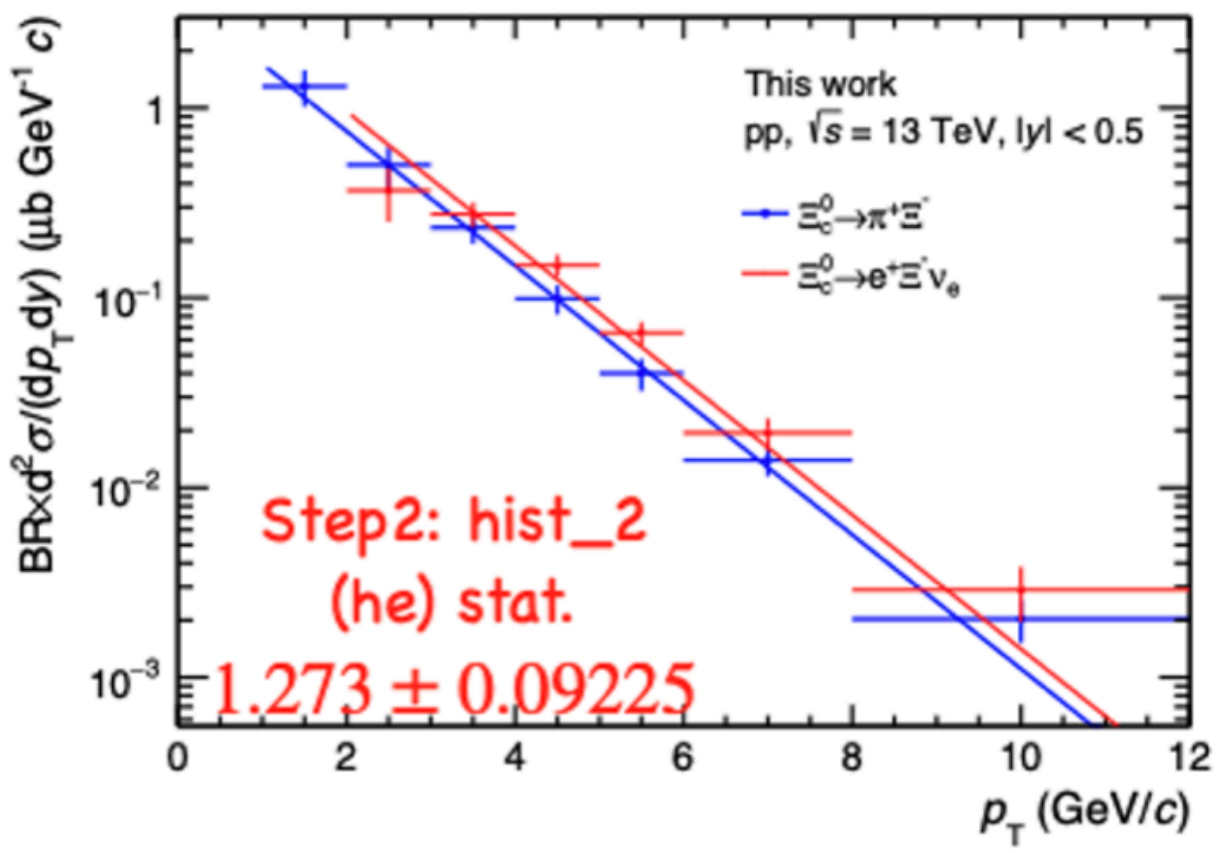
- Merge measurement by hadronic decay and by electronic decay
  - ➡ Not include systematic of BR
  - ➡ Include systematic of BR



Results: constrain on decay branching ratio (default)



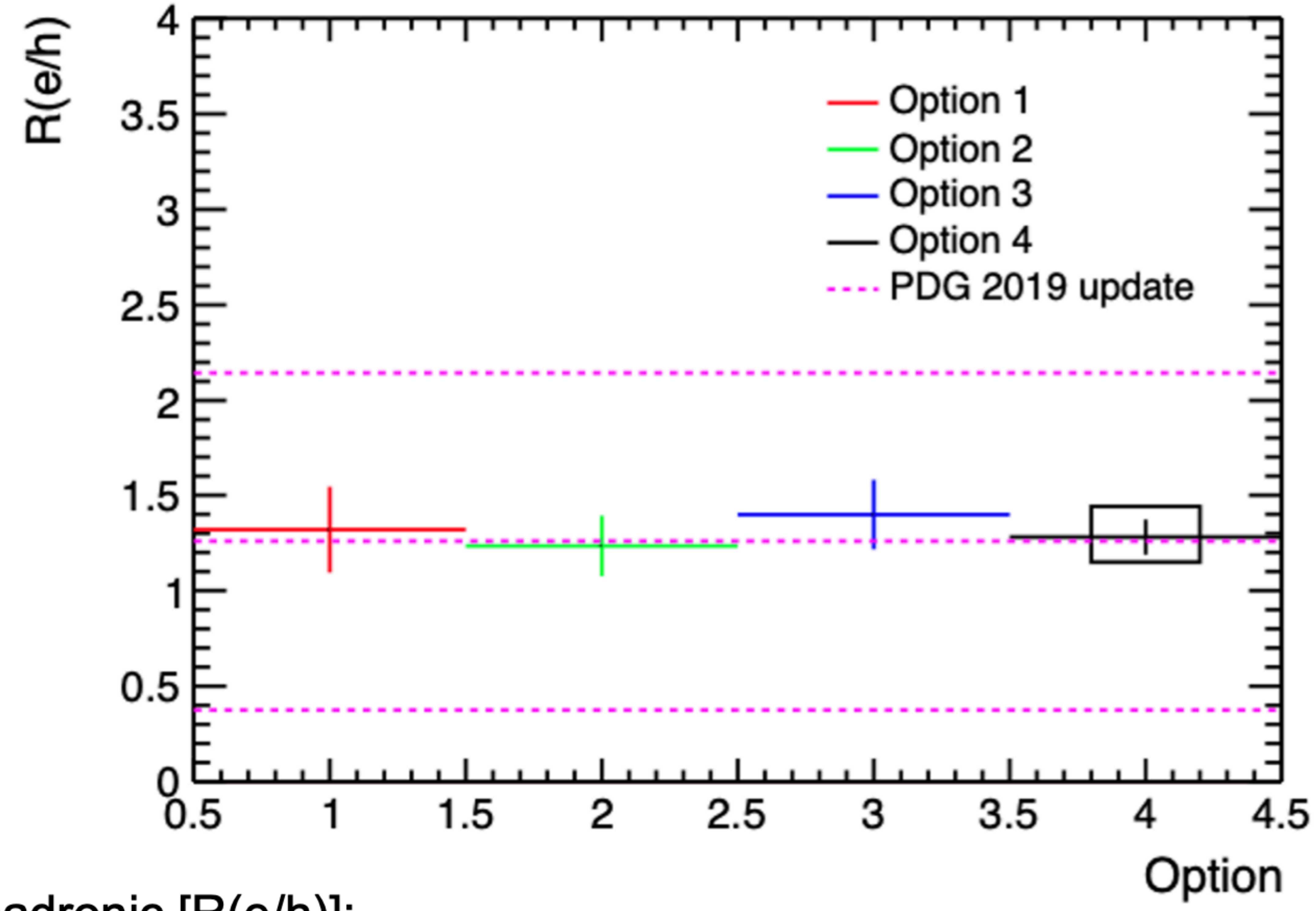




Fit hadronic decay from 1 GeV/c , then fit electronic decay by fixing the shape obtained from hadronic decay:

1) In both hadronic and electronic decay, considering stat. and uncorrelated syst., fit to extract central value 1.280 and stat. + uncorr syst. 0.09268
2) In both hadronic and electronic decay, considering only stat., fit to extract stat. uncertainty 0.09225
3) Move points up and down according to pt correlated syst. uncertainties in hadronic decay and fix central points in electronic decay, the contribution from hadronic decay to correlated syst. uncertainties can be obtained
4) The same way as step 3), just change the hadronic decay to electronic decay, the contribution from electronic decay to correlated syst. uncertainties can be obtained
5) Sum in quadrature step 3) and 4) to combine hadronic and electronic decay contribution to correlated syst. uncertainty for upper limit and lower limit separately
6) Extract uncorrelated syst. from step 1) according to step 2)
7) Final BR (electronic/hadronic): $R(e/h) = 1.280 \pm 0.092^{+0.161}_{-0.131}$

Results: different options to estimate R(e/h)



BR(hadronic, PDG) = (1.43±0.32)%
BR(electronic, PDG) = (1.8±1.2)%

- BR electronic/hadronic [R(e/h)]:
  - PDG 2018: 3.1 ± 1.1
  - PDG 2019 update: 1.259 ± 0.885
- Cross section not corrected by decay branching ratio
  - Is it possible to use two measurements to constrain the decay branching ratio ?

1) Integral from 3 GeV/c: $R(e/h) = 1.319 \pm 0.225$
2) Fit ratio from 2 GeV/c: $R(e/h) = 1.234 \pm 0.158$
3) Fit ratio from 3 GeV/c: $R(e/h) = 1.398 \pm 0.182$
4) (Default) shown in slide 11: $R(e/h) = 1.280 \pm 0.092^{+0.161}_{-0.131}$