ALICE

GSI

CLHCP 2023

Central China Normal University

Measurement of branching-fraction ratio $BR(\Omega_c^0 \to \Omega^- e^+ \nu_e)/BR(\Omega_c^0 \to \Omega^- \pi^+)$ at ALICE

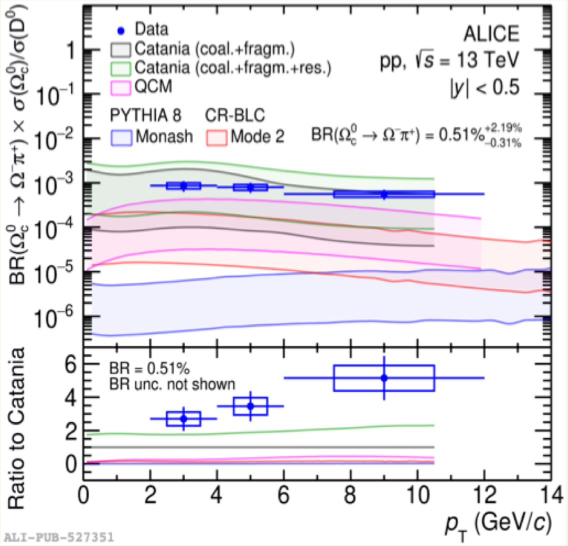
Tiantian Cheng (CCNU & GSI), Zhongbao Yin (supervisor)
tiantian.cheng@cern.ch

November 17th 2023

Motivation

- Result $\Omega_c^0 \rightarrow \Omega^- \pi^+$ in pp 13 TeV
  - The p_T trend of the baryon-to-meson ratio is similar as other baryons (Λ_c^+, $\Xi_c^{0,+}$, $\Sigma_c^{0,++}$)
  - The value of BR($\Omega_c^0 \rightarrow \Omega^- \pi^+$) from theoretical calculation limits the possibility of drawing stronger conclusions
    - $BR(\Omega_c^0 \rightarrow \Omega^- \pi^+) = (0.51 \pm 0.07)\%$

	$BR(\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e) / BR(\Omega_c^0 \rightarrow \Omega^- \pi^+)$
CLEO Collaboration	2.4 ± 1.2(stat.) ± 0.2(syst.) (paper_link)
BELLE Collaboration	1.98 ± 0.13(stat.) ± 0.08(syst.) (paper_link)
Theory	0.71 (paper_link)
	1.1 ± 0.2 (paper_link)



- Goal: **provide our measurement of $BR(\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e)/BR(\Omega_c^0 \rightarrow \Omega^- \pi^+)$**

Analysis strategy

- The KFParticle package is used
  - Only used for the reconstruction of cascade
- Boosted Decision Trees are used
  - XGboost and hipe4ml package
  - Optimisation of hyperparameters with Optuna
- Raw yield extraction
- MC p_T re-weight
- Unfolding technique
- Efficiency correction
- Systematic study

Cuts vairbales	cuts
AOD Filter Bit	4(Standard cuts with very loose DCA)
Number of CrossedRows	>70
CrossedRows Over Findable Cluster	>0.8
Number of TPC PID clusters	>50
Number of ITS cluster	>3
ITS/TPC refit	TRUE
p_T^e(GeV/c)	>0.5
η	< 0.8
SPD hit	kBoth (suppress photon conversion)
prefilter cut	$m_{e^+e^-}$ <0.05 GeV/c^2

Table 2: Tracking cuts for e applied in this analysis.

Cuts variables	cuts
Number of CrossedRows	>70
CrossedRows Over Findable Cluster	>0.8
Number of TPC PID clusters	>50

Table 4: The tracking cuts for Ω daughters applied in this analysis.

Cuts variables	$2 < p_T$ (GeV/c) < 4	$4 < p_T$ (GeV/c) < 6	$6 < p_T$ (GeV/c) < 12
$n\sigma_{TOF}(K \leftarrow \Omega)$	-999 or(-5, 5)	-999 or(-5, 5)	-999 or(-5, 5)
$n\sigma_{TOF}$(e)	(-5, 5)	(-5, 5)	(-5, 5)
$n\sigma_{TPC}$(e)	(-4, 4)	(-4, 4)	(-4, 4)
CosOA	>0	>0.25	>0.5
χ^2_{topo}(Ω to PV)	>0	>0	>0

Table 5: The further pre-selections applied in this analysis.

Candidates for training:
Signal (S): pure MC signal
Background (B):
Same event wrong sign (SE(WS))

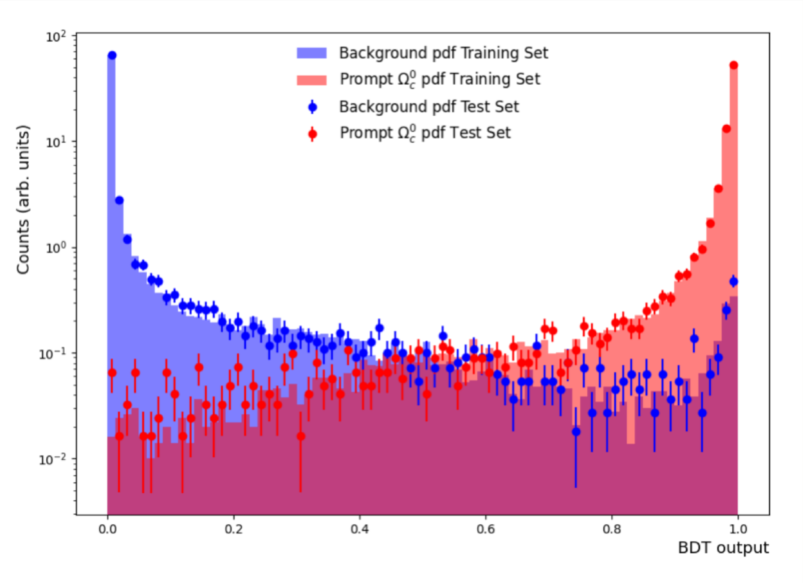
p_T (GeV/c)	2-4	4-6	6-12
Prompt	**49705**	**54126**	**41341**
Background	**43832**	**24402**	**9366**

Note: Electron-candidate tracks without TOF PID information are **not** included in this analysis, as it will bring huge contamination from other hadrons

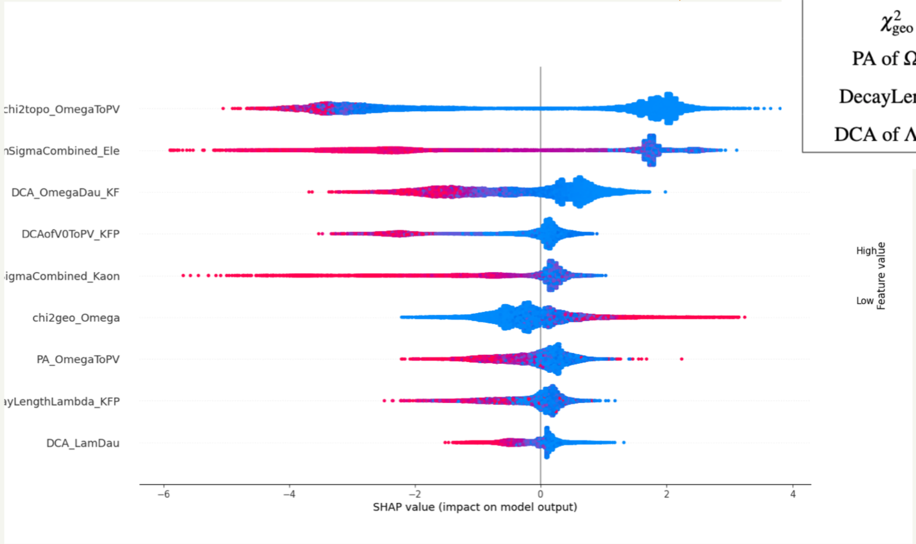
BDT output ($2 < p_{\mathrm{T}}\,(\mathrm{GeV}/c) < 4$)

Training variables (Ranking of importance)
$\chi^2_{\mathrm{topo}}(\Omega$ to PV)
$n\sigma_{\mathrm{e}}^{\mathrm{combined}}$
DCA of Ω daughter
DCA of V0 To PV
$n\sigma_{\mathrm{K}}^{\mathrm{combined}}$
$\chi^2_{\mathrm{geo}}\,(\Omega)$
PA of Ω To PV
DecayLength of Λ
DCA of Λ daughter

Probability distribution



Feature importance



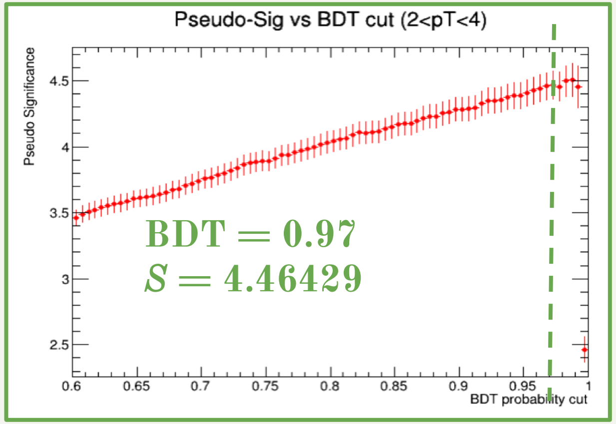
- The plots for other p_{T} bins can be seen here

Working point determination

- **Expected signal (s):** obtained from hadronic result (HEPData)
  - The result is BR * $d\sigma/dp_T dy$
  - Assumption: same ratio as Ξ_c^0 BR_Semi/BR_Hadr : 1.38 ± 0.14 (stat.) ± 0.22 (syst)(paper_link)

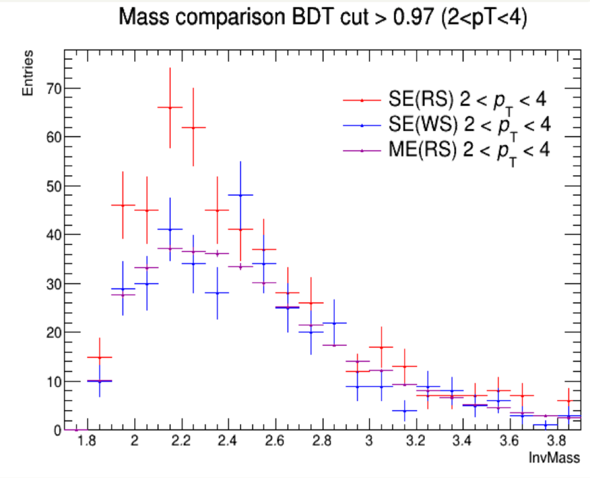
$$N_{\Omega_c^0} = 2 \cdot (\frac{d\sigma}{dp_T dy}) \cdot \Delta y \cdot \Delta p_T \cdot (Acc \times \varepsilon) \cdot L_{int} \cdot BR_{semi} = 2 \cdot (\frac{d\sigma}{dp_T dy} \cdot BR_{hadr}) \cdot \Delta y \cdot \Delta p_T \cdot (Acc \times \varepsilon) \cdot L_{int} \cdot \frac{BR_{semi}}{BR_{hadr}}$$

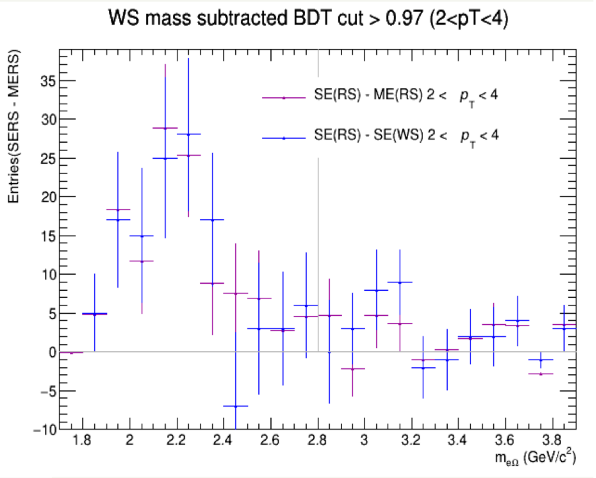
- **Background (b):** Wrong-Sign (WS) in Same-Event
- **Efficiency:** $\varepsilon = Acc \times \varepsilon_{preselection} \times \varepsilon_{BDT}$:
  - Preselection efficiency: $Acc \times \varepsilon_{preselection} = MC(Reco)/MC(Gen)$
    - $|y| < 0.8$
  - BDT efficiency: $\varepsilon_{BDT} = MC(Reco)_{w/\ BDT\ cut}/MC(Reco)_{w/o\ BDT\ cut}$
- **Pseudo-significance:** $S = s/\sqrt{(s+b)}$
  - Estimation of the significance expected in data
  - It is used to find the working point
    - Helps to reduce the bias on the BDT cut tuning
  - The distribution for other p_T bins seen here

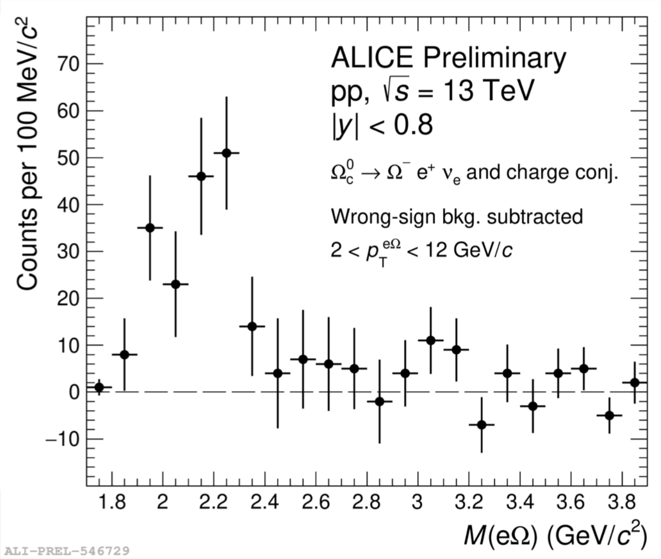


Comparison mass distribution

SE(WS): Same event wrong sign ($e^{\pm}\Omega^{\pm}$)
SE(RS): Same event right sign ($e^{\pm}\Omega^{\mp}$)
ME(RS): Mixed event right sign ($e^{\pm}\Omega^{\mp}$)





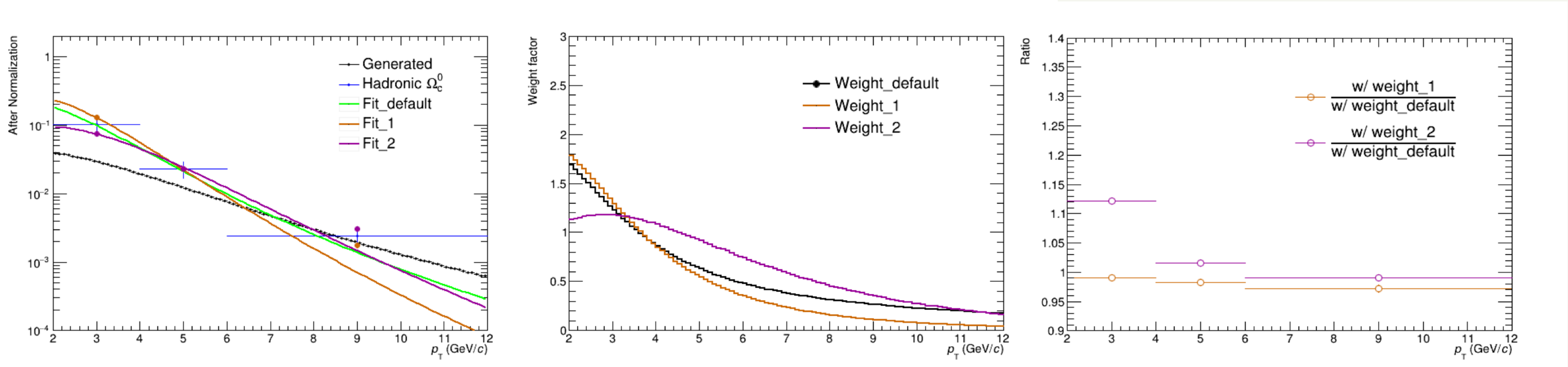


Other two p_{T} bins can be seen here

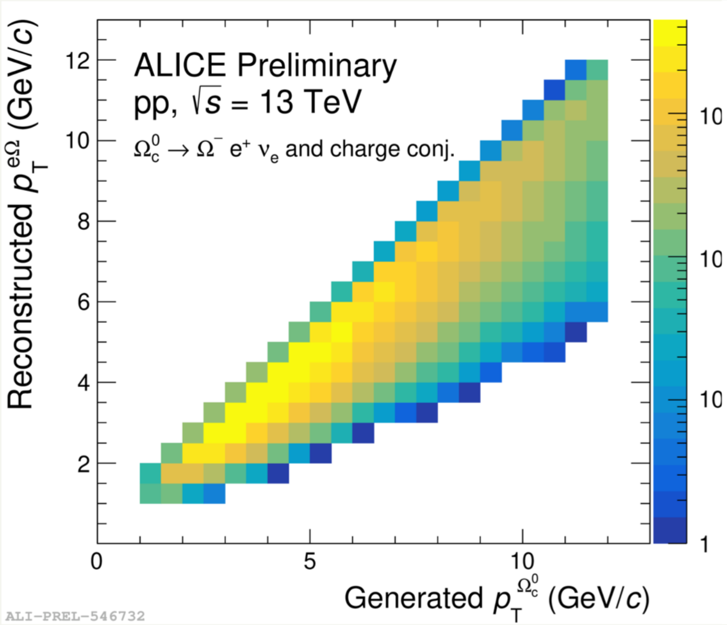
- The idea of mixed event is to create pairs of tracks to mimic uncorrelated background
  - The tracks of pairs (e and Ω) should be from different events with similar mult. and z_{vtx} position
- The distributions from Mixed-Event (ME), are compatible with SE(WS)
- The SE(WS) is used for the background subtraction in this analysis

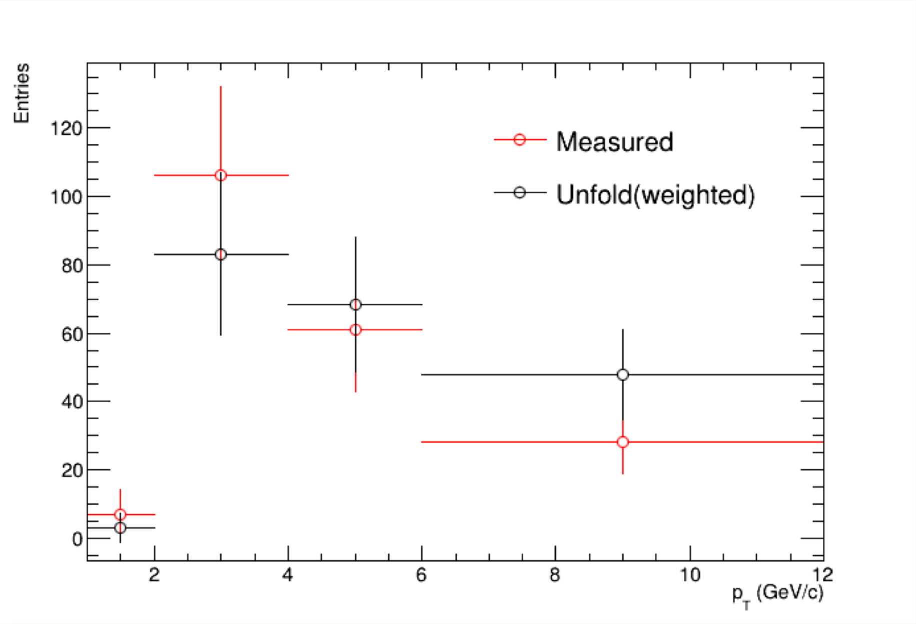
MC p_T re-weight

- The **PYTHIA** Ω_c^0 p_T spectrum poorly describes the measured p_T spectrum of the **hadronic** decay channel
  - Reweighting the MC p_T spectrum is needed to better match nature
- Weight factor is obtained using a Tsallis fit to the hadronic Ω_c^0 spectrum
  - **Green** one is chosen for the central weighting strategy
  - Other two fits are used to assign systematic uncertainty



Unfolding procedure



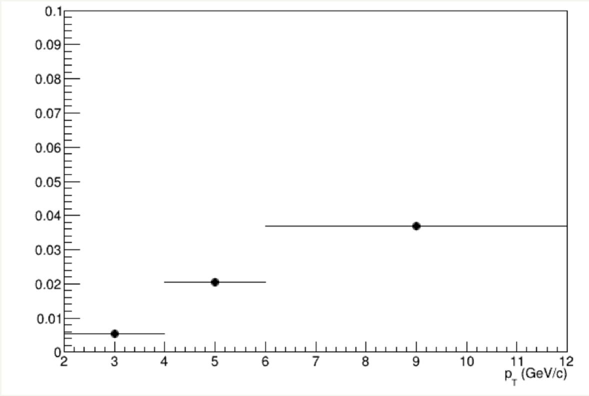


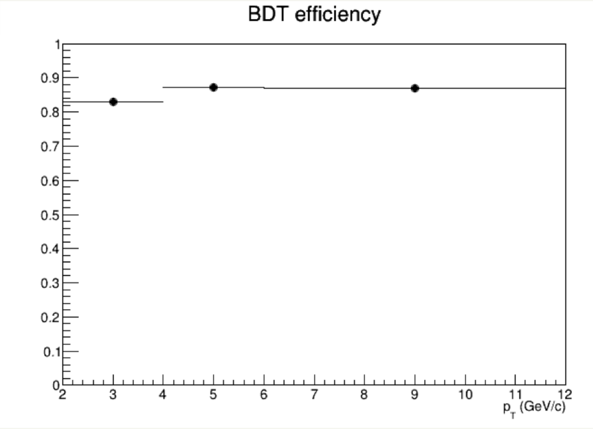
- The correction for the missing momentum of the neutrino performed by the **Bayesian unfolding technique**
  - The response matrix represents the correlation between the p_T of the Ω_c^0 baryon and that of the reconstructed eΩ pair
- **The p_T weight is applied to the response matrix**
- The refold procedure is done to check the stability of the unfolding procedure
- The **weighted unfolded yield of Ω_c^0** (black color) is used to correct for acceptance-times-efficiency

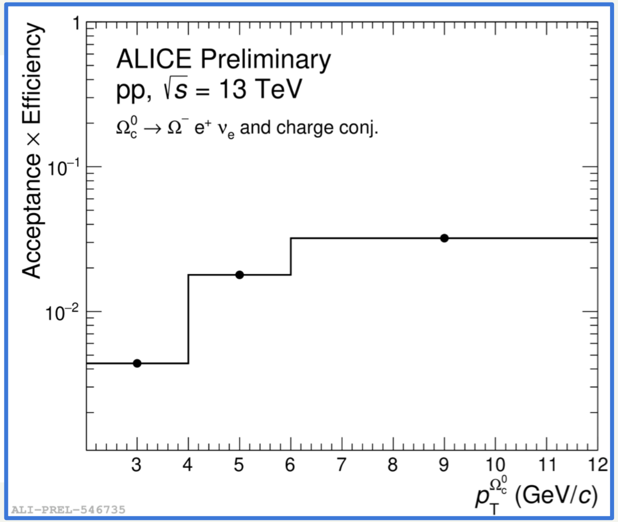
Reconstruction efficiency

- The p_{T} weight is applied
- **Reconstruction efficiency**: $\varepsilon = \mathrm{Acc} \times \varepsilon_{\mathrm{preselection}} \times \varepsilon_{\mathrm{BDT}}$:
  - Preselection efficiency: $\mathrm{Acc} \times \varepsilon_{\mathrm{preselection}} = \mathrm{MC(Reco)/MC(Gen)}$
    - $|y| < 0.8$
  - BDT efficiency: $\varepsilon_{\mathrm{BDT}} = \mathrm{MC(Reco)}_{\mathrm{w/\ BDT\ cut}} / \mathrm{MC(Reco)}_{\mathrm{w/o\ BDT\ cut}}$

Acc x $\varepsilon_{\mathrm{preselection}}$







Systematic uncertainty estimation

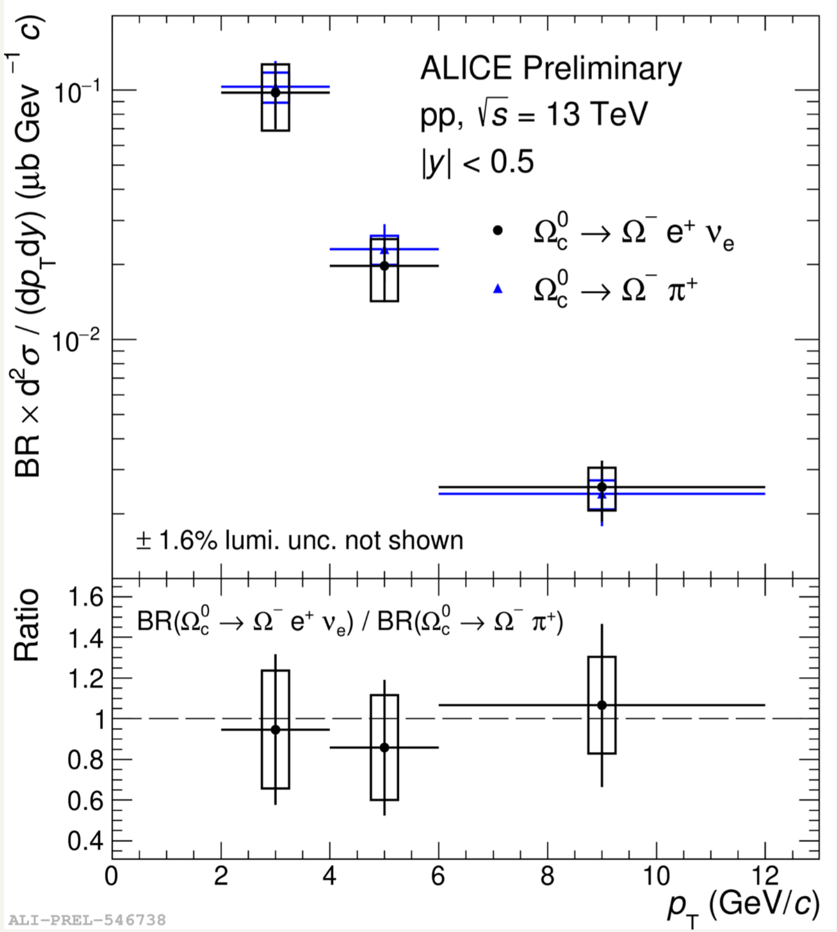
- The various contributions of systematic uncertainties are summed in quadrature
  - **Yield extraction: eΩ Mass cut**
  - **ITS-TPC matching**
  - **Track quality selection**
  - **Unfolding procedure**
    - **Bayesian-unfolding iterations**
    - **Unfolding method**
    - **Unfolding p_T binning**
  - **BDT cut variations**
  - **MC p_T shape**

p_T (GeV/c)	2–4	4–6	6–12
$e\Omega$ pair mass	10%	10%	10%
ITS-TPC matching	2%	2%	2%
Track quality selection	4%	4%	4%
Bayesian-unfolding iterations	4%	4%	4%
Unfolding method	4%	4%	4%
Response-matrix p_T range and binning	20%	20%	–
BDT cut variation	15%	15%	15%
MC p_T shape	10%	2%	1%
Total systematic uncertainty	± 30%	± 28%	± 19%
Luminosity	1.6%		

Table 14: The Summary of the systematic uncertainties in this analysis.

Final result comparison

- First comparison of two different decay channels at ALICE
  - Correlated systematics between the two analysis
    - ITS-TPC matching
    - Track quality selection
    - MC p_{T} shape
  - Lumi. uncertainties fully cancel in the ratio
- The measurement of branching-fraction $\mathrm{BR}(\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e) / \mathrm{BR}(\Omega_c^0 \rightarrow \Omega^- \pi^+)$ is obtained



Weighted average of the 3 p_T intervals

- The ratio of the two measurements was averaged over p_T using the inverse uncorrelated relative uncertainties as **weights** (link)
  - The weights were defined as the sum in quadrature of the relative statistical and the p_T-uncorrelated part of the syst. unc.

Weights: $\frac{1}{w_i^2}$

$$w_i = \sqrt{\left(\frac{\sigma_i^{stat}}{R_i}\right)^2 + \left(\frac{\sigma_i^{pTuncorr}}{Y_i}\right)^2}$$

$$\langle R\rangle_{pT} = \frac{\Sigma_i\left(R_i \cdot \frac{1}{w_i^2}\right)}{\Sigma_i\left(\frac{1}{w_i^2}\right)}$$

$$\langle\sigma_{stat}\rangle_{pT} = \frac{\sqrt{\Sigma_i\left(\sigma_i^{stat} \cdot \frac{1}{w_i^2}\right)^2}}{\Sigma_i\left(\frac{1}{w_i^2}\right)}$$

$$\left\langle\sigma_{syst}^{pTuncorr}\right\rangle_{pT} = \frac{\sqrt{\Sigma_i\left(\sigma_i^{pTuncorr} \cdot \frac{1}{w_i^2}\right)^2}}{\Sigma_i\left(\frac{1}{w_i^2}\right)}$$

$$\left\langle\sigma_{syst}^{pTcorr\_up}\right\rangle_{pT} = \langle R\rangle_{pT} \cdot \sqrt{\left(\frac{\langle R^{pTcorr\_down;hadro}\rangle_{pT}}{\langle R\rangle_{pT}} - 1\right)^2 + \left(\frac{\langle R^{pTcorr\_up;semi}\rangle_{pT}}{\langle R\rangle_{pT}} - 1\right)^2}$$

$$\left\langle\sigma_{syst}^{pTcorr\_down}\right\rangle_{pT} = \langle R\rangle_{pT} \cdot \sqrt{\left(\frac{\langle R^{pTcorr\_up;hadro}\rangle_{pT}}{\langle R\rangle_{pT}} - 1\right)^2 + \left(\frac{\langle R^{pTcorr\_down;semi}\rangle_{pT}}{\langle R\rangle_{pT}} - 1\right)^2}$$

$$\left\langle\sigma_{syst}^{pTcorr}\right\rangle_{pT} = \max\left[\left\langle\sigma_{syst}^{pTcorr\_up}\right\rangle_{pT}, \left\langle\sigma_{syst}^{pTcorr\_down}\right\rangle_{pT}\right]$$

The p_T-correlated syst. unc. were propagated by recomputing the ratio after shifting up and down the ratios with the corresponding p_T-correlated syst. unc.

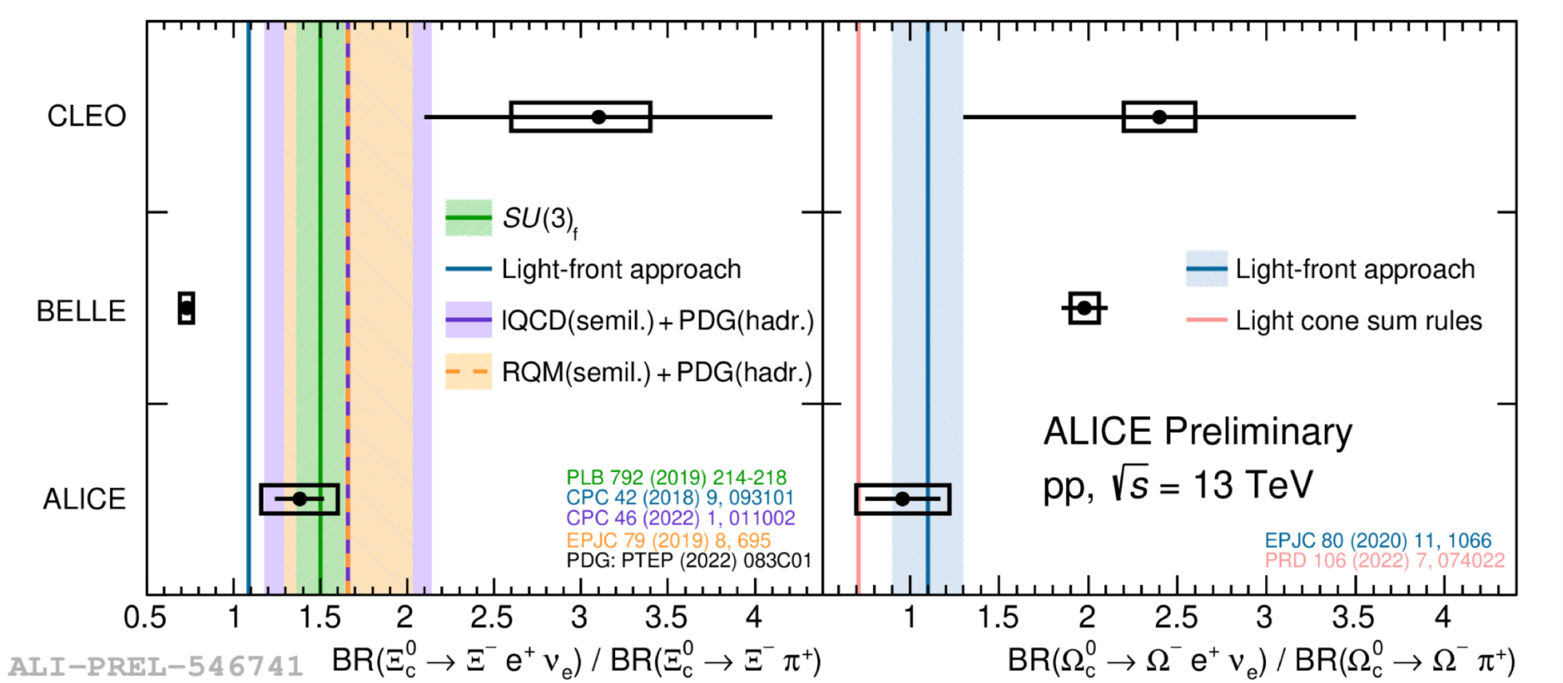
Same procedure was performed Ξ_c^0 paper, (slides)

Semileptonic:
All the systematic sources are considered as p_T correlated

Hadronic:
MC p_T shape, BDT cut variation, track quality selection and ITS-TPC matching (all except raw-yield extraction) are considered as p_T correlated

BR ratios comparison:

- $n\sigma$ difference between ALICE and BELLE:
  - For Ξ_c^0 : 2.5σ
  - For Ω_c^0 : 2.7σ



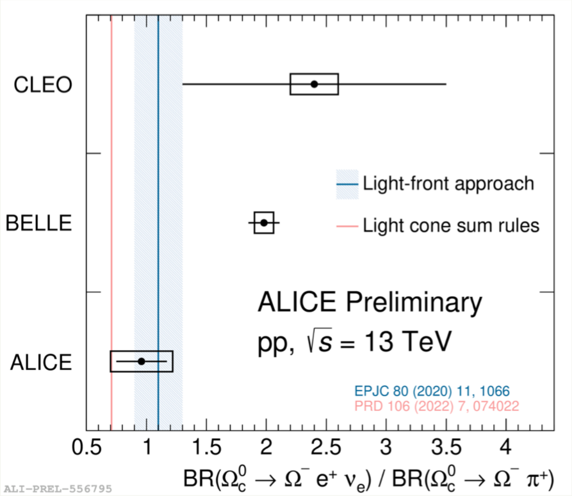
→ **ALICE: 0.96 ± 0.21(stat.) ± 0.28(syst.)**

→ Belle: 1.98 ± 0.13 (stat.) ± 0.08(syst.)

Summary

This result is shown in QM ALICE highlight talk

- The production of the charm-strange baryon Ω_c^0 in its semileptonic decay channel ($\Omega_c^0 \to \Omega^- e^+ \nu_e$) is measured for its first time in ALICE
- The ratio of $BR(\Omega_c^0 \to \Omega^- e^+ \nu_e) / BR(\Omega_c^0 \to \Omega^- \pi^+)$ is measured in ALICE
  - There is about 2.7σ tension compared with the one from BELLE collaboration
  - Our result is fully compatible with the theory results



- ➢ After preliminary, the ME used as bkg
  - ➢ Effects of 10% on the raw yield extraction
  - ➢ **Improve** the relative statistical error about **20-25%**
- ➢ Paper proposal was on 15th Nov.(link)

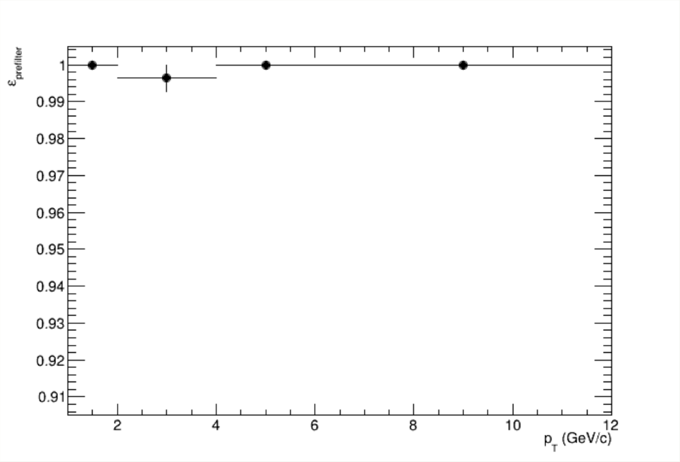
Thanks for your attention

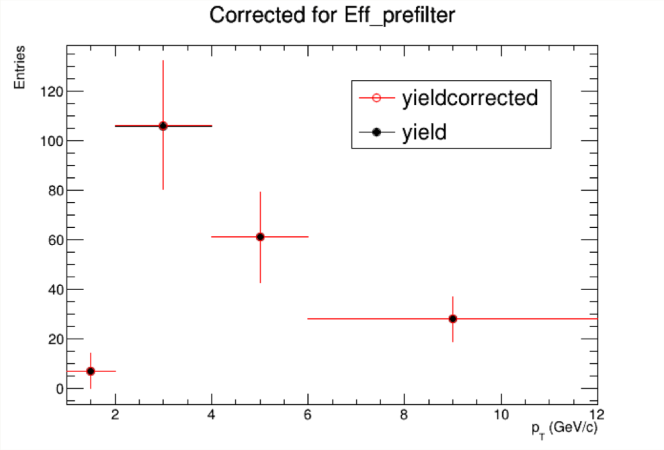
ADDITIONAL SLIDES

Prefilter correction

- Non-HF electrons are mainly from γ conversion or Dalitz decays, which can be removed by using electron pair mass cut (called 'prefilter')
  - There is a probability of wrongly tagging an electron as photonic
- The prefilter efficiency is calculated using real data, to correct for the 'missing' electrons:
  - It is a very minimal effect

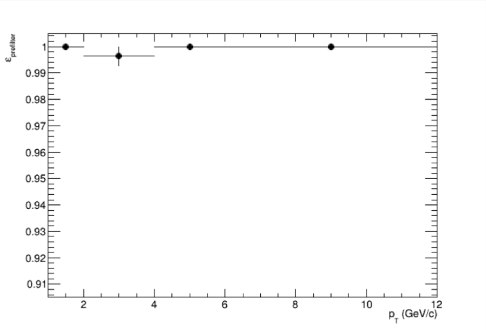
$$\varepsilon_{\text{prefilter}} = \frac{N_{e\Omega}(\text{same sign prefilter on})}{N_{e\Omega}(\text{ prefilter off})}$$

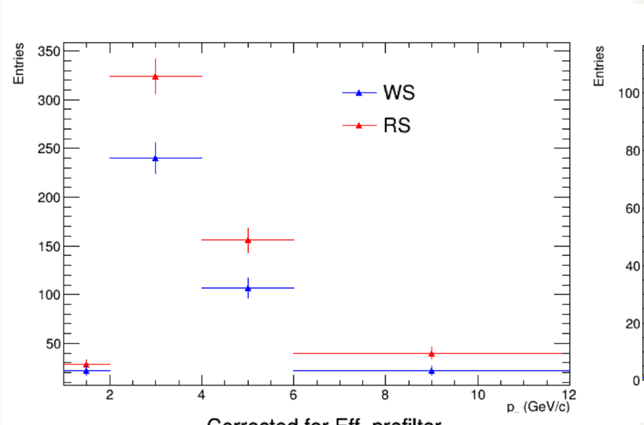


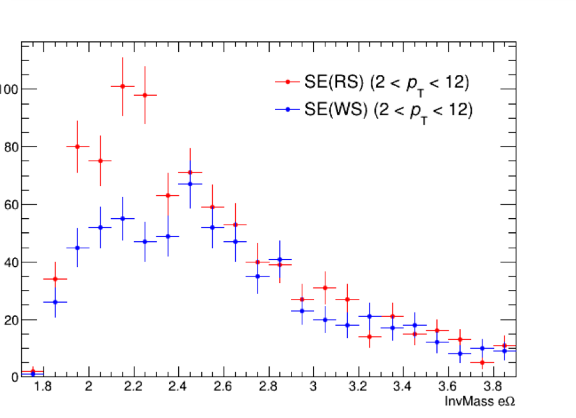


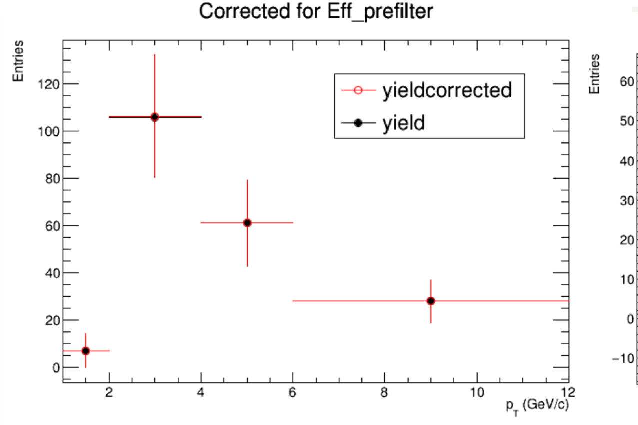
Yield and mass distribution

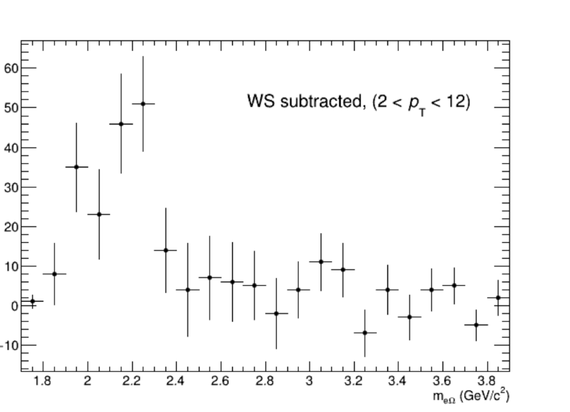
To correct the wrong tagging for ele





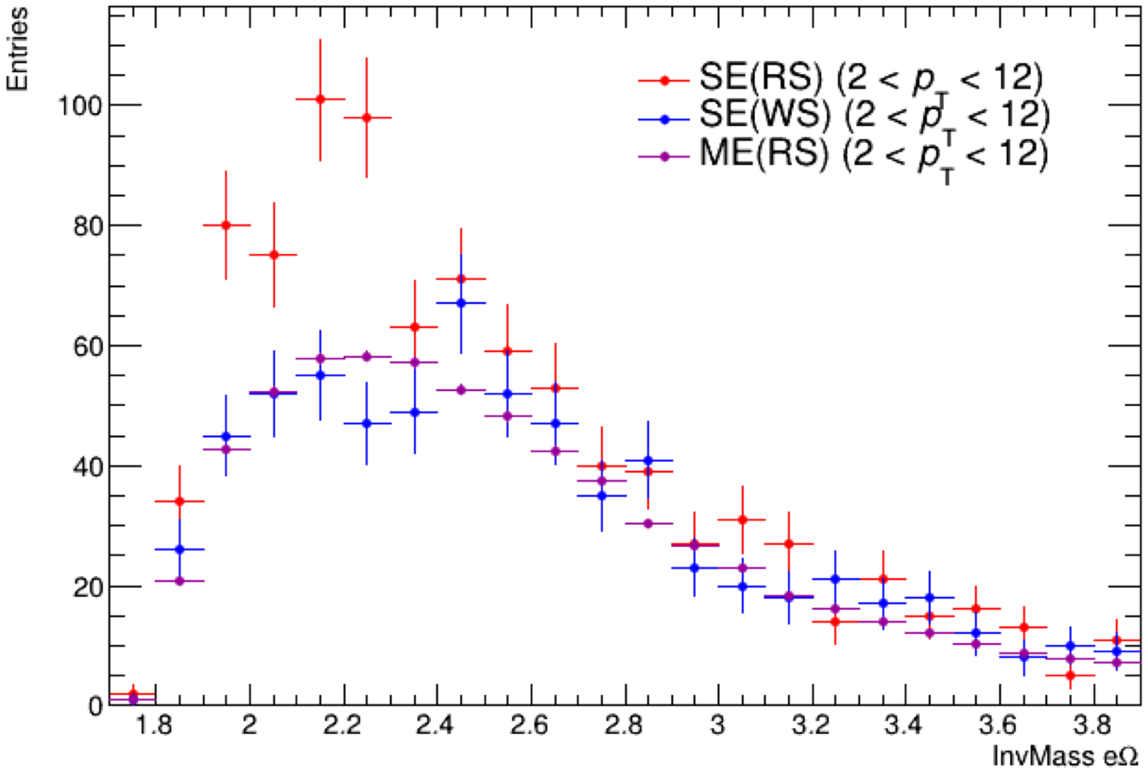






- Top left: The p_T distributions of WS and RS eΩ pairs
- Top right: The invariant mass distribution of RS and WS eΩ pairs
- Bottom left: The yield distribution of $p_T^{e\Omega}$
- Bottom right: The invariant mass distribution of WS eΩ subtracted

Mass distribution comparison



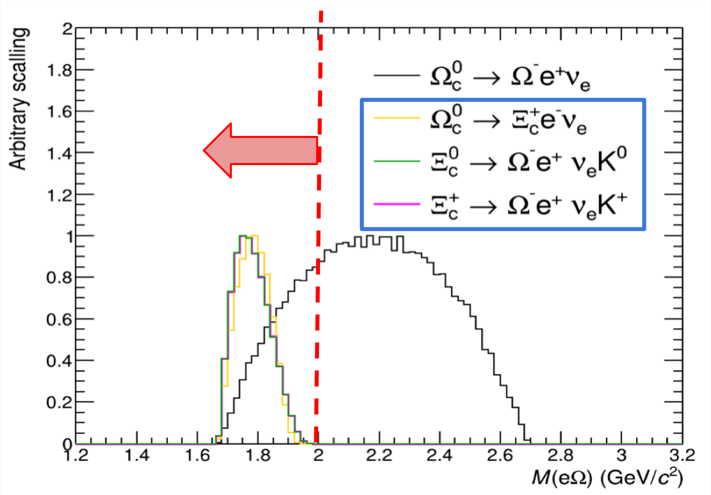
Systematic study 1): PYTHIA 8 study

Thanks to Luuk and Sanghoon

- Investigate possible contaminations to RS eΩ pairs from other decays
  - There are no guidelines from PDG about possible 'contaminating' decay channels
  - We consider the following three decay channels as contamination [1, 2]

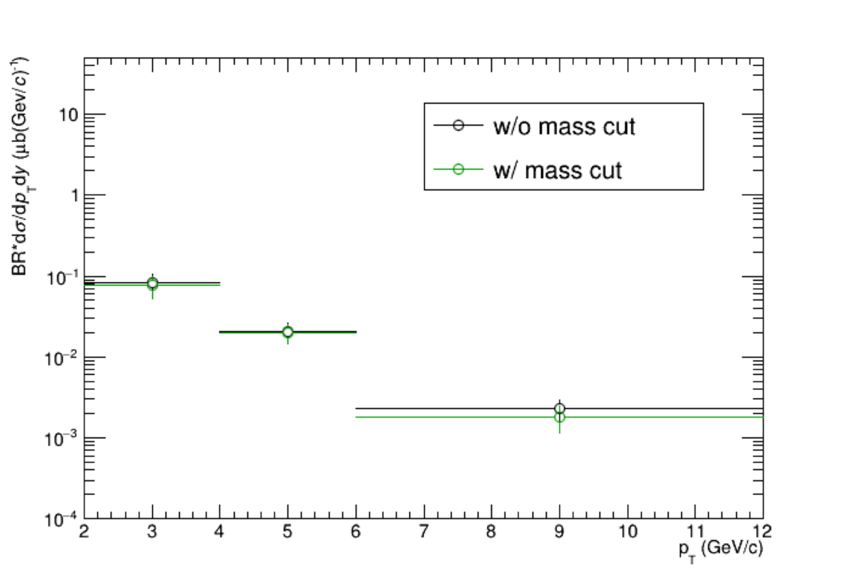
- It shows that there will be clean signal region if the mass cut > 2 is applied
  - **Application of mass cut is reported in the next slide**

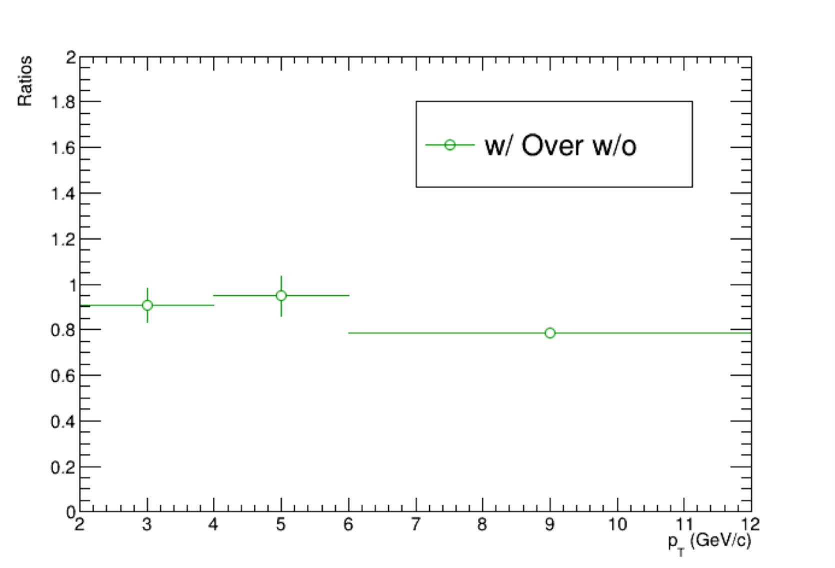
! Belle and CLEO do not perform a correction/apply a selection regarding contaminating decays



[1] N R Soni*, Proceedings on Nucl. Phys. 60 (2015)
[2] R.Ammar, et al, CLEO Collaboration, PRL 89.171803

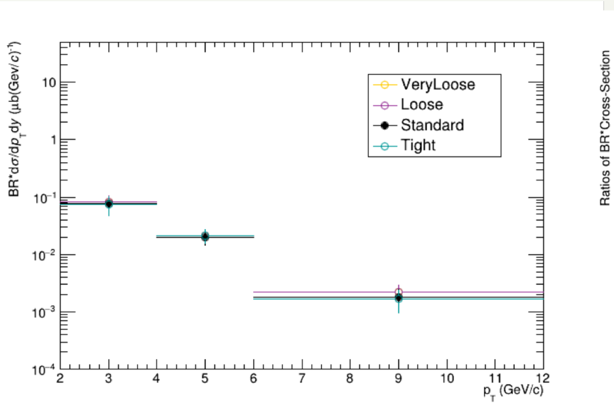
Systematic study 1): Mass cut check: BR x dσ/dp_Tdy

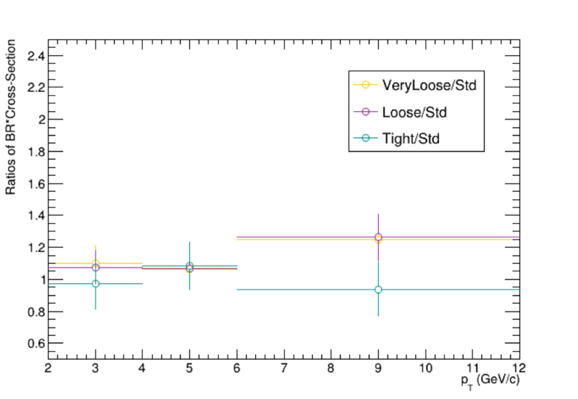




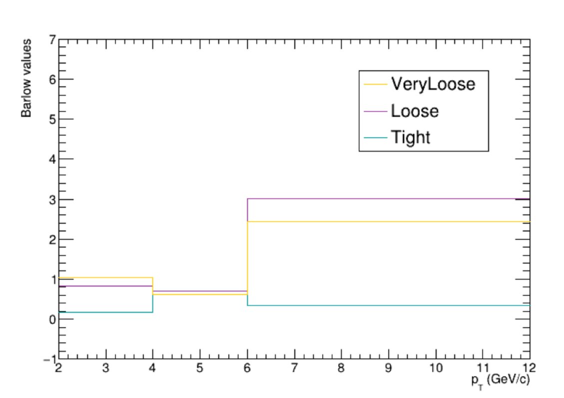
- The application of a mass cut at 2 GeV/c^2 gives about 10% effect (assigned as systematic)
- There is a big fluctuation at last p_T bin due to lack of statistics
- Study effect of varying the mass cut can be seen in the next slide

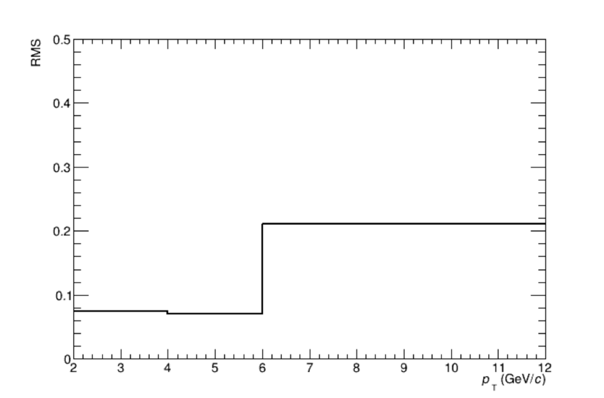
Systematic study 1): eΩ mass mass cut





Cut variable	VeryLoose	Loose	Standard	Tight
$M_{e\Omega}$ (GeV/c^2)	1.8	1.9	2	2.1





- Together with the mass cut check (above slide), 10% is assigned for the systematic

10% for Syst.