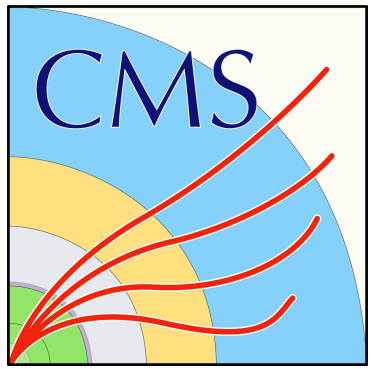
Update on double differential charm σ at 7 TeV 2010

N. Z. Jomhari, A. Geiser, J. Metwally

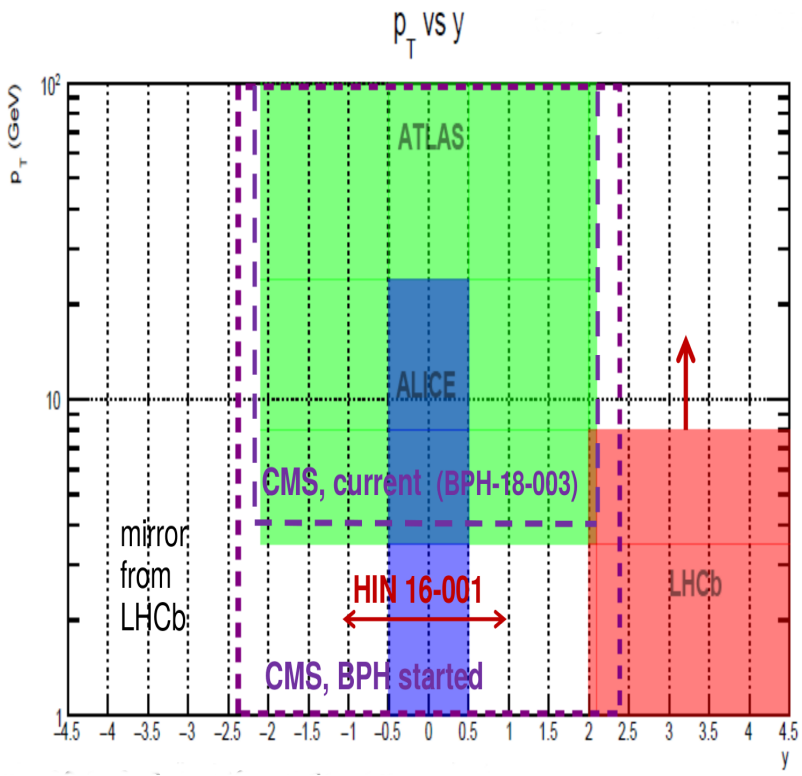
DESY Hamburg
QCD meeting

July 10, 2020



Intro

- Objective: To measure the total cross section of inclusive charm at different pp center of mass energies (0.9, 2.7, 5, 7, 8, 13 (from PU in BParking) TeV)
- Strategy: By covering full phase space and by using all PVs in the event. More details can be found in backup and AN-18-284
- Today (double differential $D^*\sigma$ 7 TeV):
  - Datasets and luminosity (new)
  - $D^{*\pm}$ selection
  - Signal yield
  - Refit of π_s (new)
  - Migration plot (new)
  - Efficiency and acceptance
  - FONLL prediction (new)
  - σ as a function of p_T and y
  - Partial systematics (new)
  - Conclusion and outlook



Datasets & luminosity

Table 1: Data 7 TeV 2010

Data	#Events	(N)MB	eff.lumi (nb^{-1})
/ZeroBias/Commissioning10-May19ReReco-v1/RECO	129,186,198	646,080	0.0124
/ZeroBias/Run2010A-Apr21ReReco-v1/AOD	34,923,622	9,884,247	0.190
/MinimumBias/Commissioning10-May19ReReco-v1/RECO	46,553,963	32,246,050	0.619
/MinimumBias/Run2010A-Apr21ReReco-v1/AOD	103,848,957	25,950,980	0.498
/MinimumBias/Run2010B-Apr21ReReco-v1/AOD	40,785,403	16,092,377	0.309
/MuOnia/Run2010A-Apr21ReReco-v1/AOD	33,021,472	4,258,204	0.0817
/MuOnia/Run2010B-Apr21ReReco-v1/AOD	26,685,576	20,388,79x	0.391
/Mu/Run2010A-Apr21ReReco-v1/AOD	51,802,592	6,039,449	0.116
/Mu/Run2010B-Apr21ReReco-v1/AOD	32,376,291	15,094,68x	0.290
/MuMonitor/Run2010A-Apr21ReReco-v1/AOD	55,740,719	717,184	0.0138
/MuMonitor/Run2010B-Apr21ReReco-v1/AOD	12,728,741	1,799,123	0.0345
/EG/Run2010A-Apr21ReReco-v1/AOD	53,163,466	5,034,667	0.097
/Electron/Run2010B-Apr21ReReco-v1/AOD	32,772,061	16,598,76x	0.319
/EGMonitor/Run2010A-Apr21ReReco-v1/AOD	67,929,392	3,315	0.000
/EGMonitor/Run2010B-Apr21ReReco-v1/AOD	11,826,859	1,457,837	0.028
Total	733,345,312	156,211,743	3.0

Table 2: JSON file 7 TeV 2010

JSON file
Run2010A, Run2010B:
Cert_136033-149442_7TeV_Apr21ReReco_Collisions10_JSON_v2.txt

Table 3: MC 7 TeV 2010

MC Sample	#Events	eff.lumi (nb^{-1})
/D0Kpi_pT0toInf_TuneZ2star_7TeV-pythia6-evtgen/ LowPU2010DR42-NoPU2010_DR42_START42_V17B-v2/AODSIM	5,801,549	20.37

(more details in here or AN-18-284)

Table 1: Data 7 TeV 2010

Data	#Events	(N)MB	eff.lumi (nb^{-1})
/ZeroBias/Commissioning10-May19ReReco-v1/RECO	129,186,198	646,080	0.0124
/ZeroBias/Run2010A-Apr21ReReco-v1/AOD	34,923,622	9,884,247	0.190
/MinimumBias/Commissioning10-May19ReReco-v1/RECO	46,553,963	32,246,050	0.619
/MinimumBias/Run2010A-Apr21ReReco-v1/AOD	103,848,957	25,950,980	0.498
/MinimumBias/Run2010B-Apr21ReReco-v1/AOD	40,785,403	16,092,377	0.309
/MuOnia/Run2010A-Apr21ReReco-v1/AOD	33,021,472	4,258,204	0.0817
/MuOnia/Run2010B-Apr21ReReco-v1/AOD	26,685,576	20,388,79x	0.391
/Mu/Run2010A-Apr21ReReco-v1/AOD	51,802,592	6,039,449	0.116
/Mu/Run2010B-Apr21ReReco-v1/AOD	32,376,291	15,094,68x	0.290
/MuMonitor/Run2010A-Apr21ReReco-v1/AOD	55,740,719	717,184	0.0138
/MuMonitor/Run2010B-Apr21ReReco-v1/AOD	12,728,741	1,799,123	0.0345
/EG/Run2010A-Apr21ReReco-v1/AOD	53,163,466	5,034,667	0.097
/Electron/Run2010B-Apr21ReReco-v1/AOD	32,772,061	16,598,76x	0.319
/EGMonitor/Run2010A-Apr21ReReco-v1/AOD	67,929,392	3,315	0.000
/EGMonitor/Run2010B-Apr21ReReco-v1/AOD	11,826,859	1,457,837	0.028
Total	733,345,312	156,211,743	3.0

Table 2: JSON file 7 TeV 2010

JSON file
Run2010A, Run2010B:
Cert_136033-149442_7TeV_Apr21ReReco_Collisions10_JSON_v2.txt

Table 3: MC 7 TeV 2010

MC Sample	#Events	eff.lumi (nb^{-1})
/D0Kpi_pT0toInf_TuneZ2star_7TeV-pythia6-evtgen/ LowPU2010DR42-NoPU2010_DR42_START42_V17B-v2/AODSIM	5,801,549	20.37

(more details in here or AN-18-284)

$D^{*\pm}$ selection

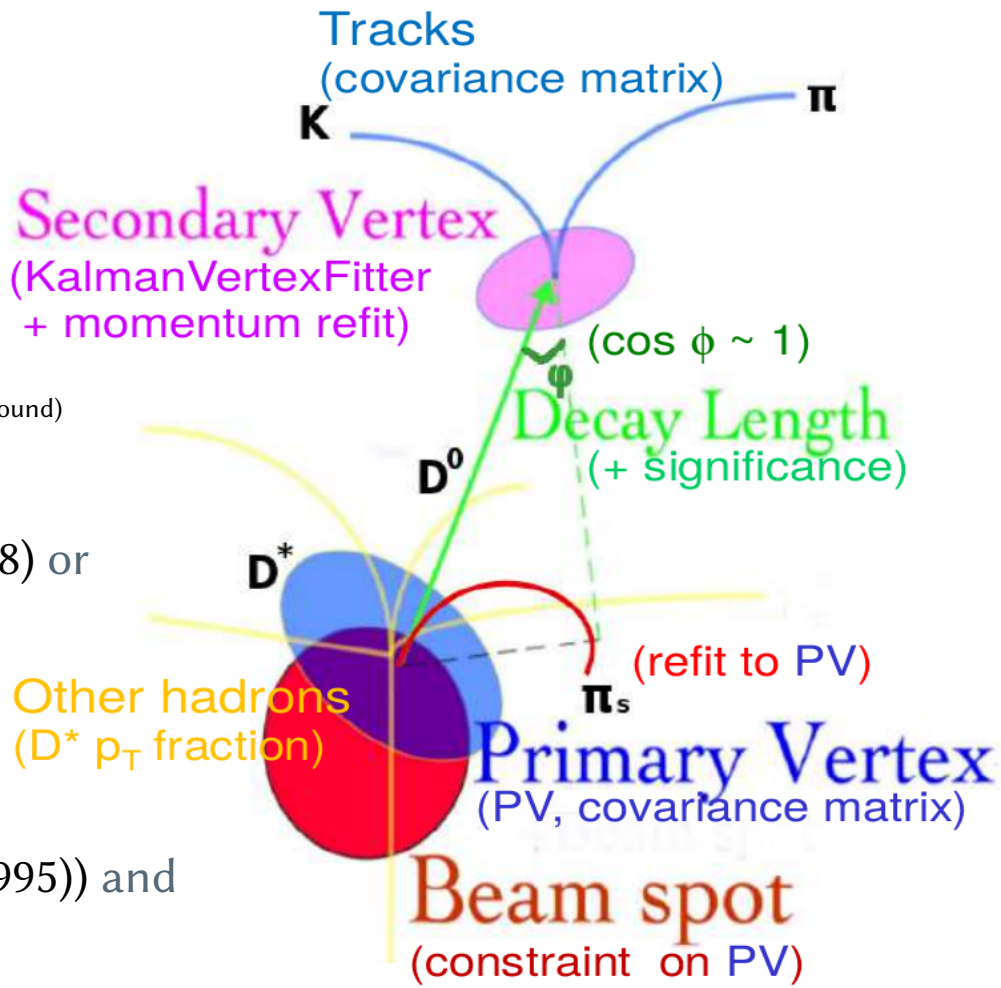
$D^{*\pm} \to D^0\pi^\pm \to K^\mp\pi^\pm\pi^\pm$ selection

optimized for low p_T charm

$$p_{Tfrac} = \frac{p_T \text{ of D meson}}{\sum p_T \text{ of all tracks}} \quad \text{at respective PV}$$

$$dl^{D^0}_{Sig} = \frac{dl^{D^0}}{dl^{D^0}_{err}}$$

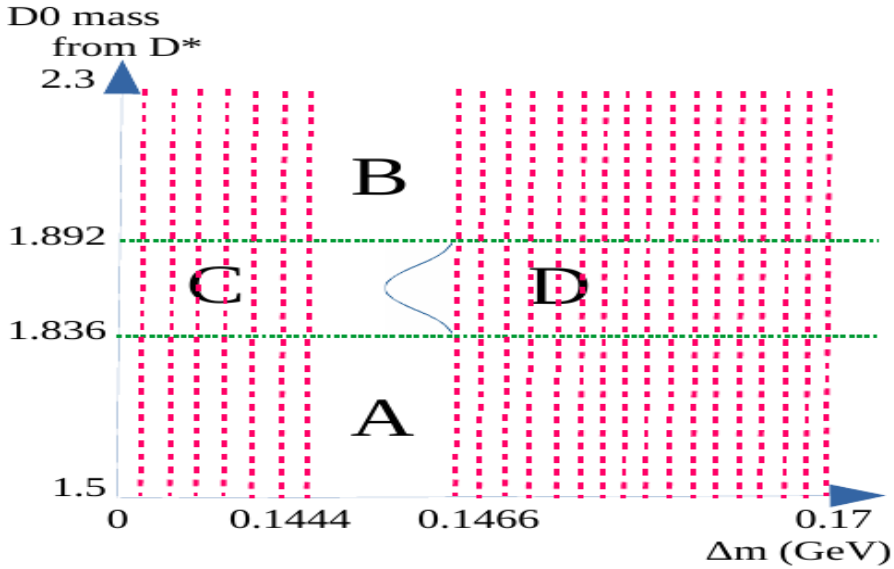
- Track p_T cut
  - $p_T^{K,\pi} > 0.5$ GeV, none for π_s
- D^0 mass cut (1.836-1.892) GeV
- Possible combination:
  - Right charge: $K^\mp\pi^\pm\pi_s^\pm$
  - Wrong charge: $K^\mp\pi^\mp\pi_s^\pm$ (combinatorial background)
- For higher p_T ($p_T^{D^*} > 3.5$ GeV):
  - $(dl^{D^0}_{Sig} > 0$ & $p^{D^*}_{Tfrac} > 0.15$ and $\cos\phi > 0.8)$ or $dl^{D^0}_{Sig} > 2$
- For lower p_T ($p_T^{D^*} < 3.5$ GeV):
  - $((dl^{D^0}_{Sig} > 1.5$ & $p^{D^*}_{Tfrac} > 0.15)$ or $dl^{D^0}_{Sig} > 3$ or $(dl^{D^0}_{Sig} > 2$ and $\cos\phi_{D^0} > 0.995))$ and $p^{D^0}_{Tfrac} > 0.1$ and $\cos\phi > 0.8$

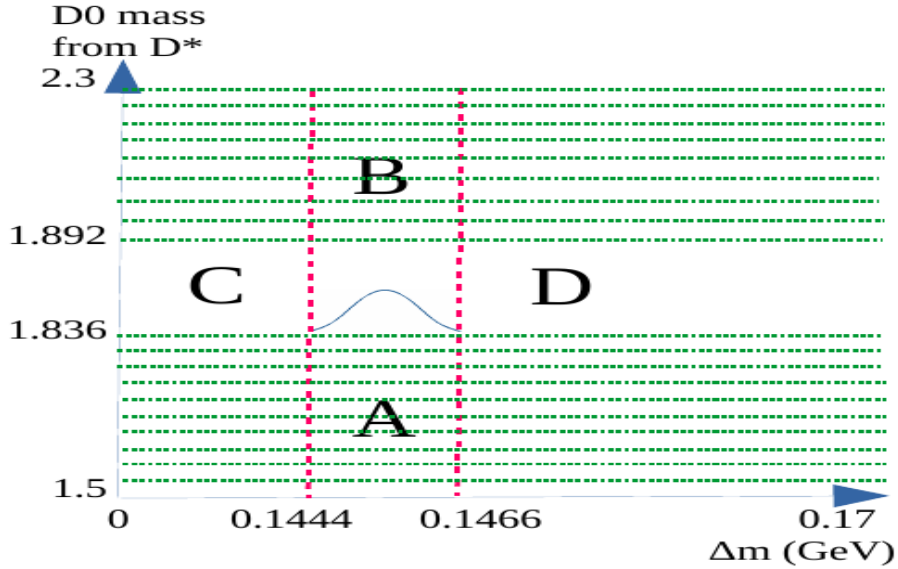


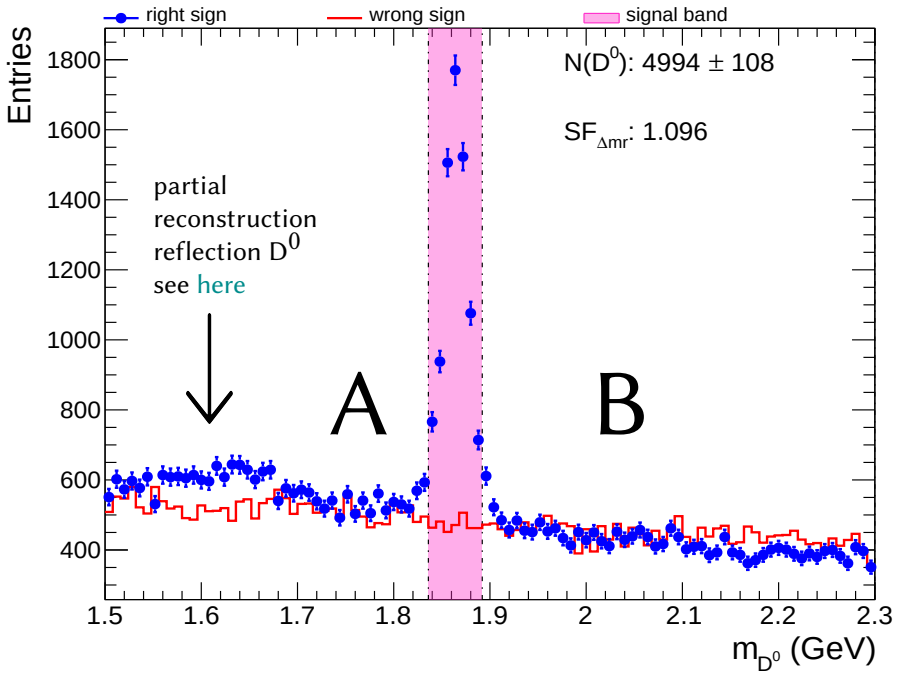
Signal yield

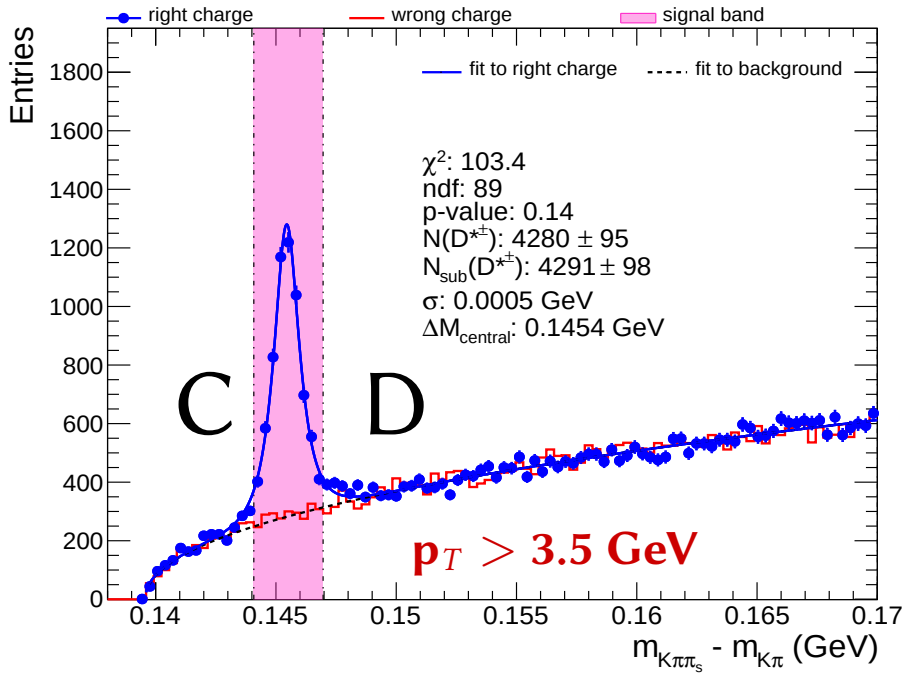
- binning slightly adjusted
- refit of slow pion

D^0 from D^* mass cut

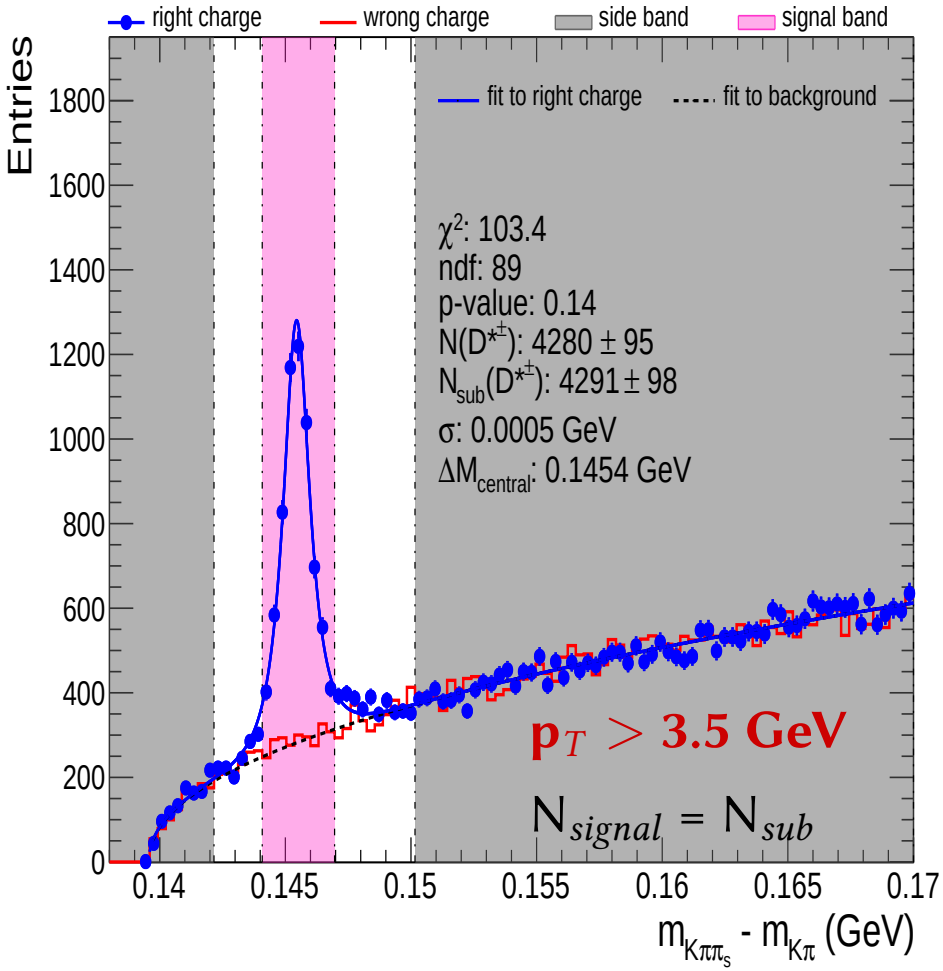








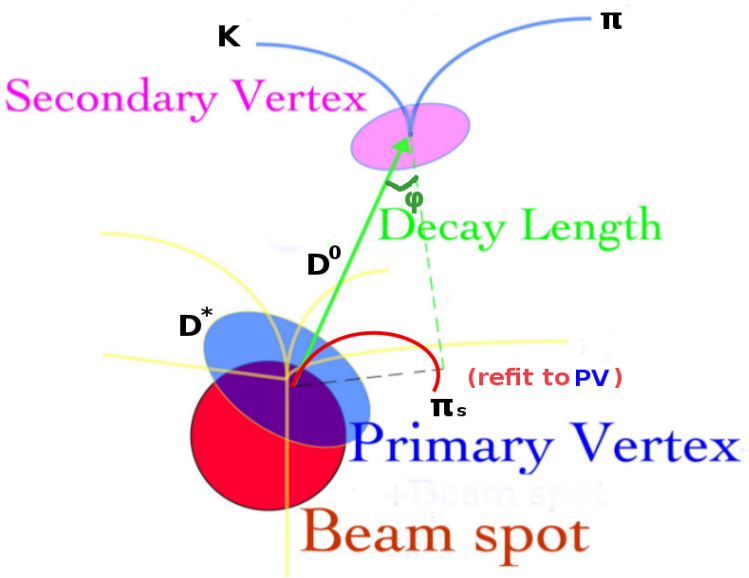
Signal extraction

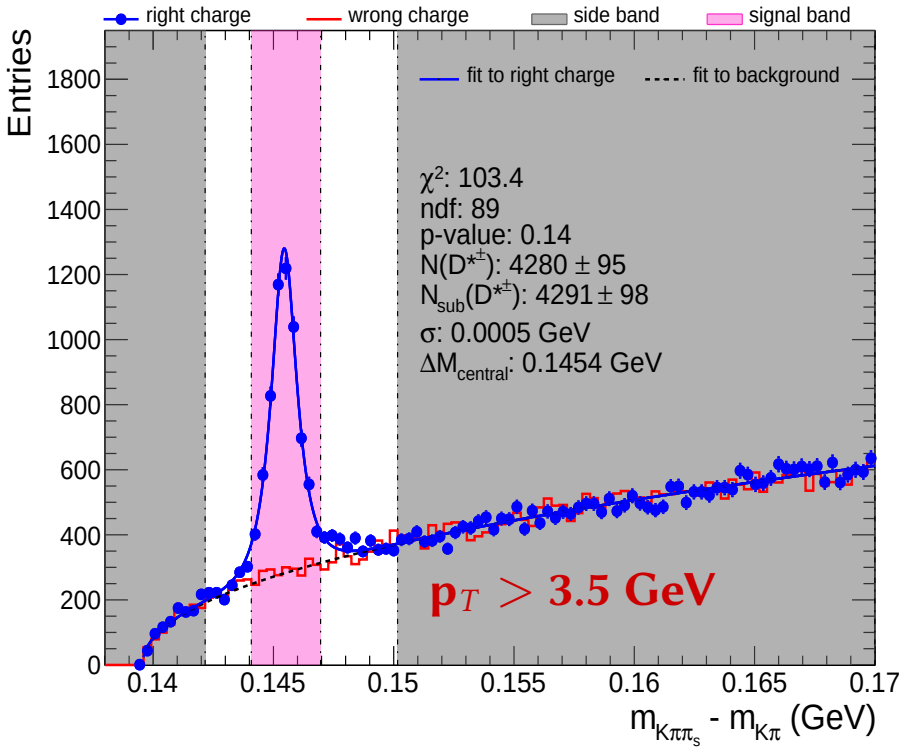


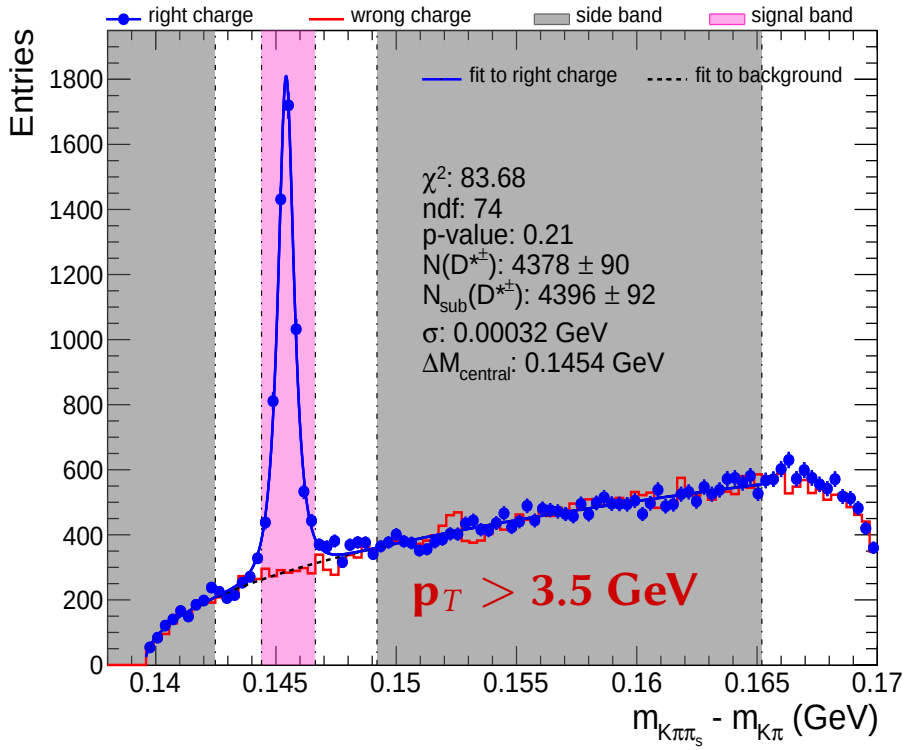
Background subtraction method (N_{sub})

- Normalize wrong charge (WC) sign to the right charge sign in the side bands to get the scale factor (SF = 1.096)
- Use the SF to normalize WC sign in signal band
- Substract right charge sign to the normalized wrong charge to get N*signal*

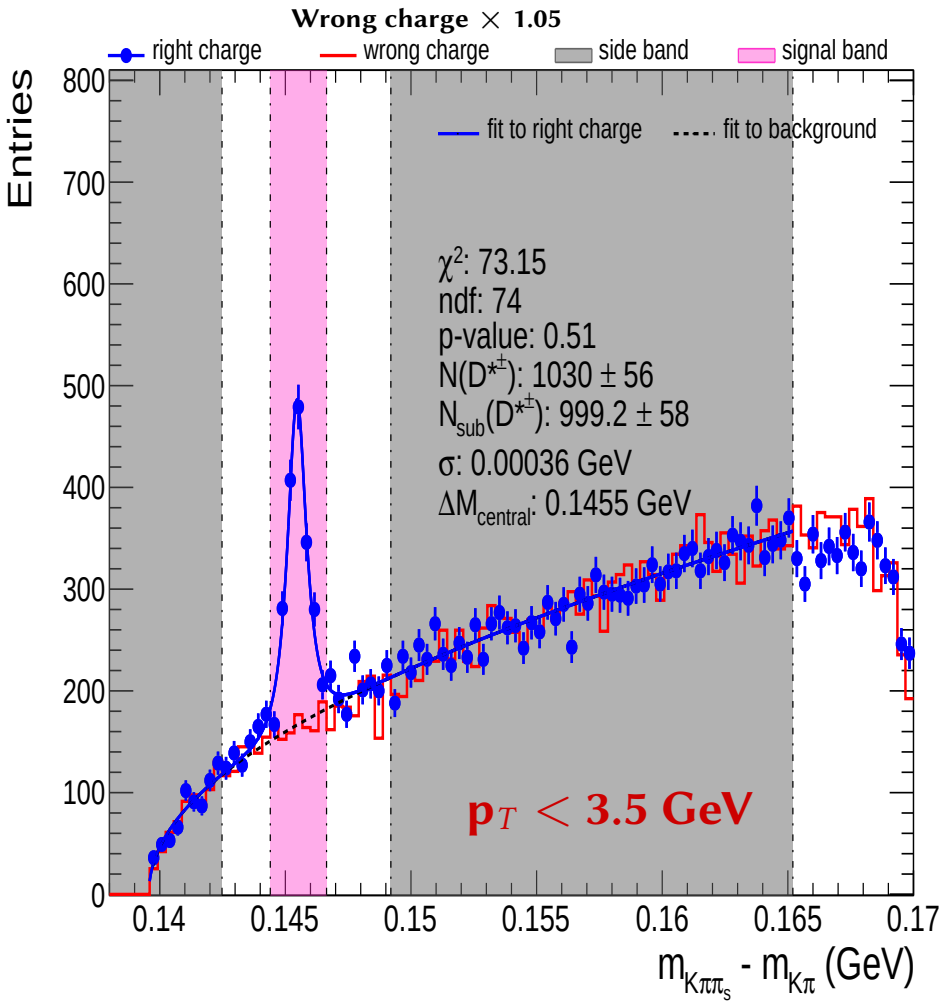
- **Refit of π_{slow} gives better signal to background ratio.**
- **Width is narrower**

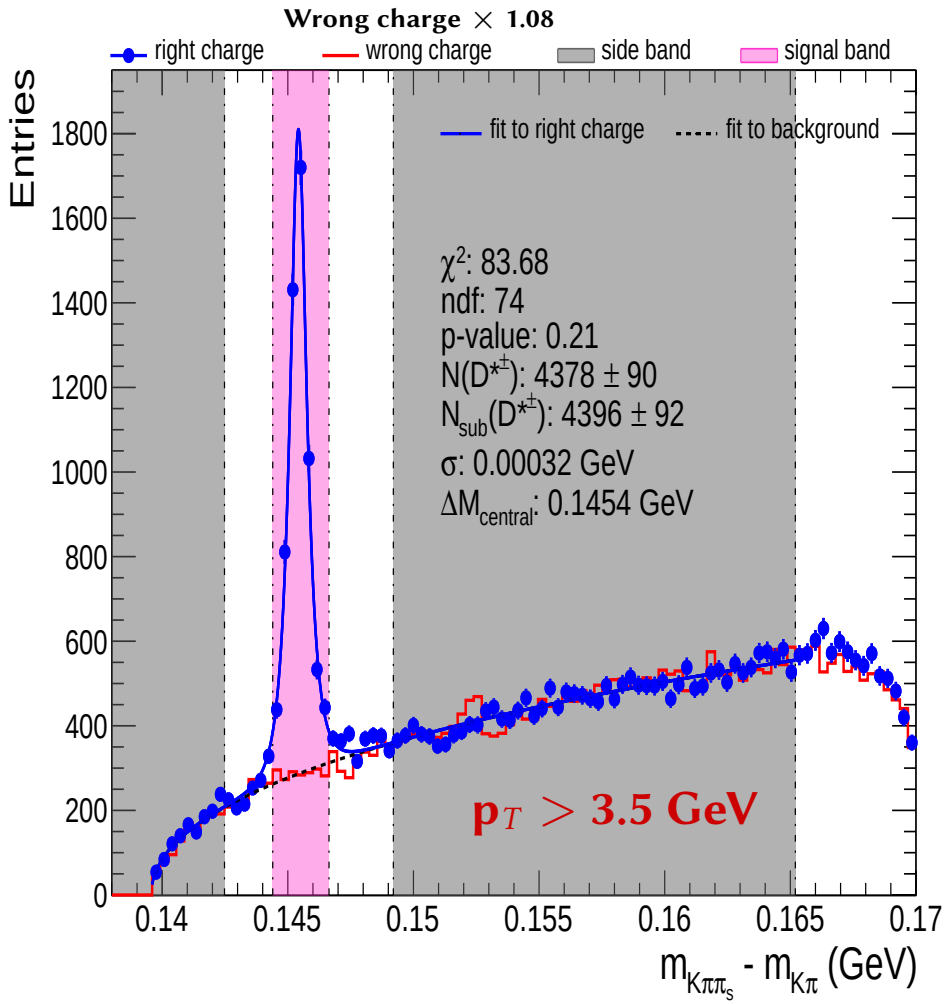






Δm_r at lower and higher p_T region

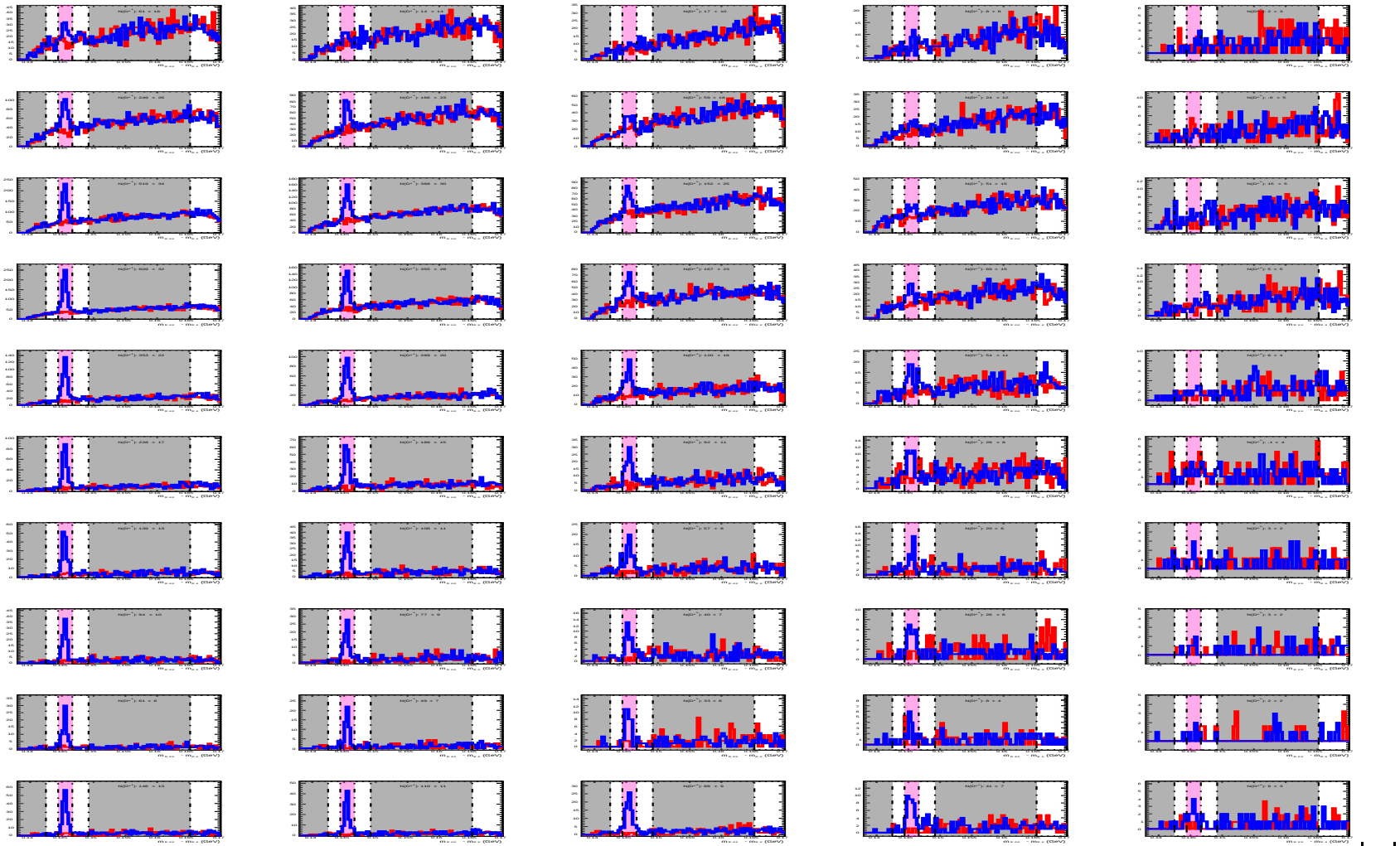




The number of signal is determined using background subtraction method

Δm_r in 50 bins

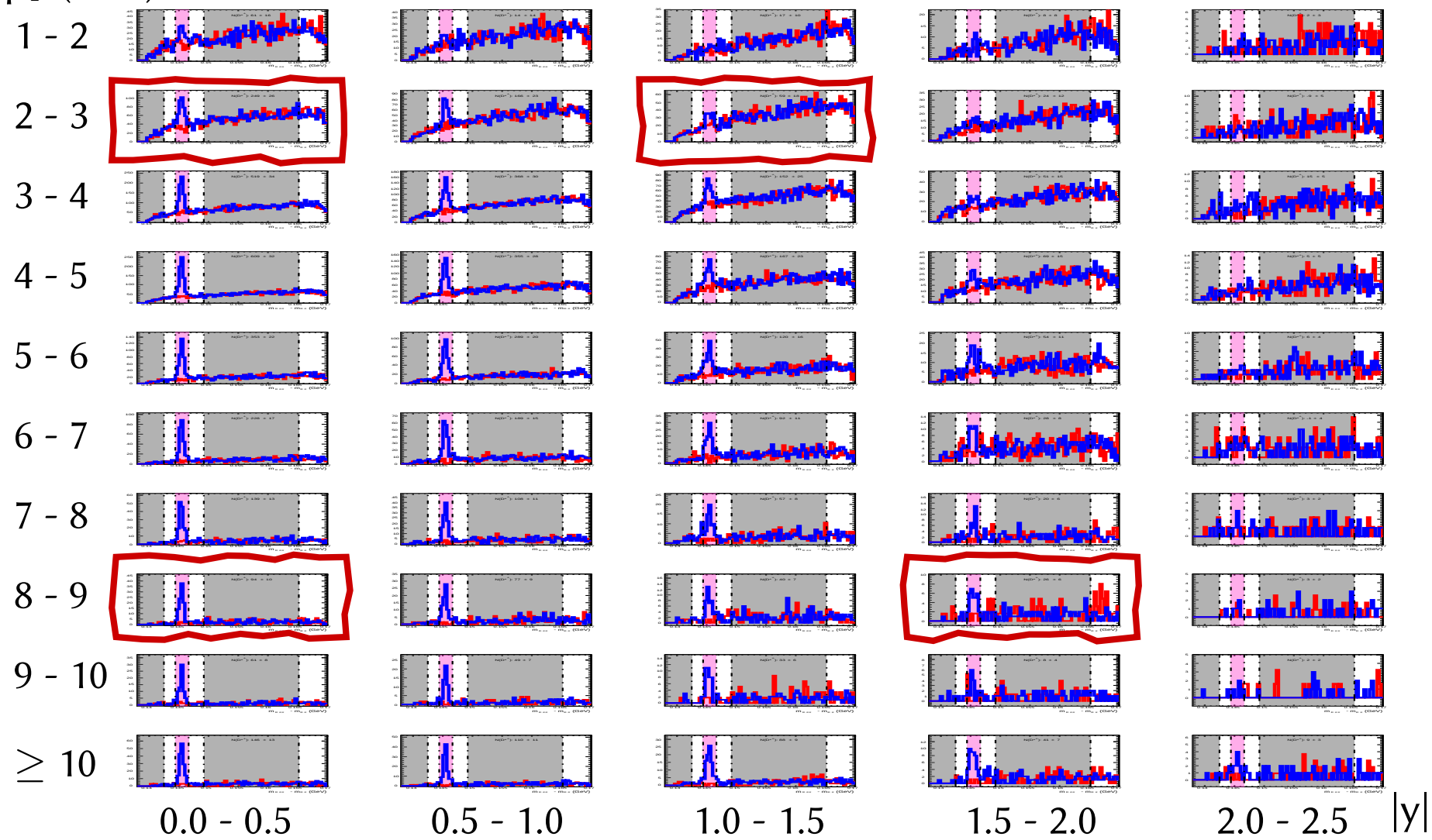
$2\times$ more statistics compared to results in previous status report



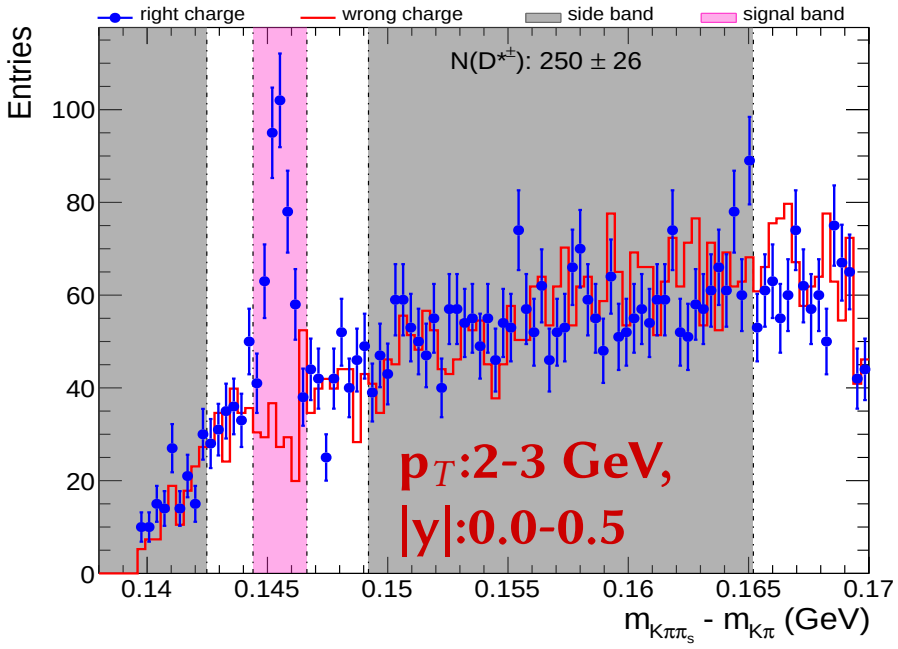
Δm_r peak can be seen in most of the phase space

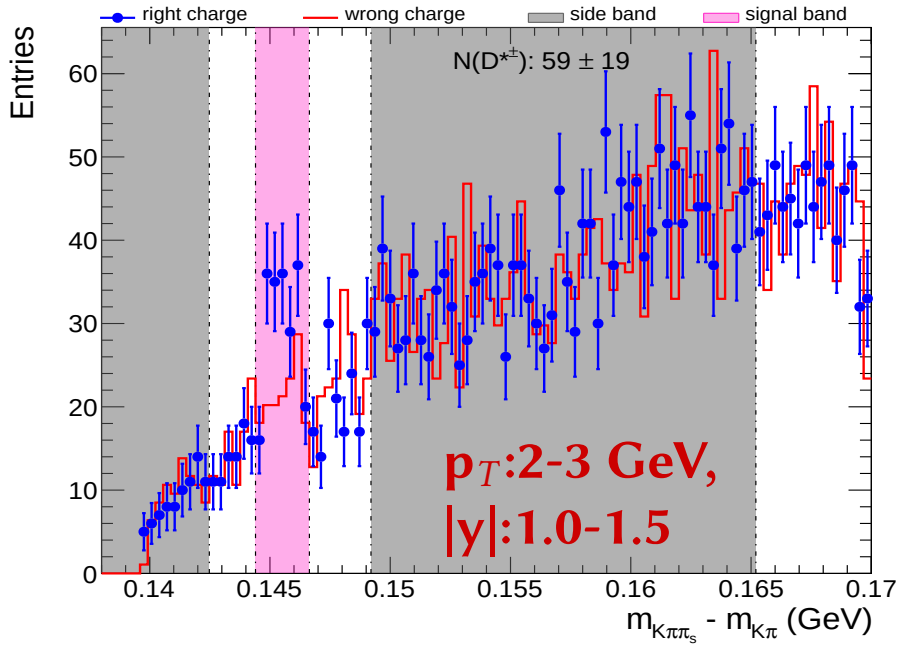
Δm_r in 50 bins

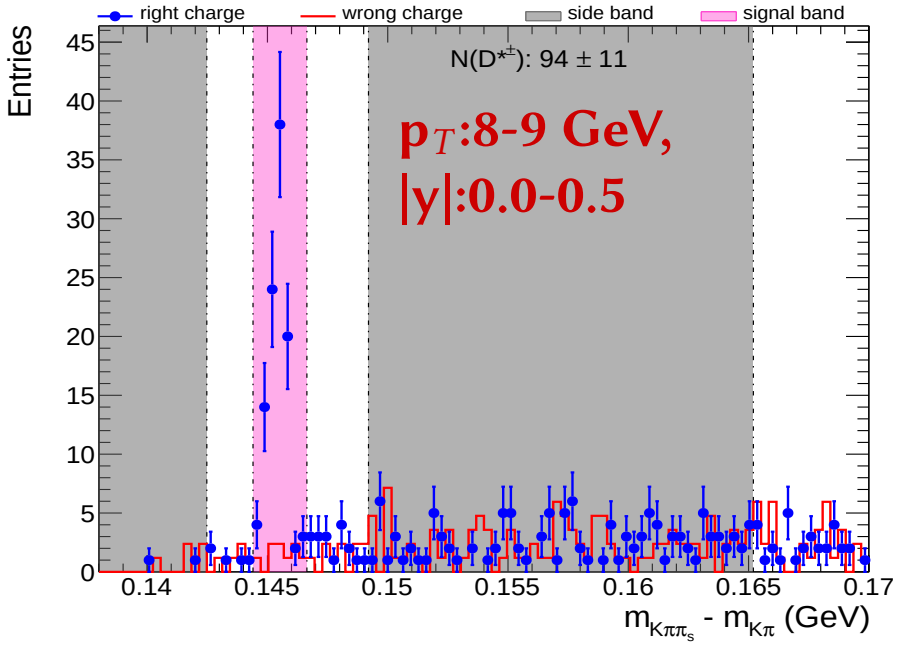
$2\times$ more statistics compared to results in previous status report

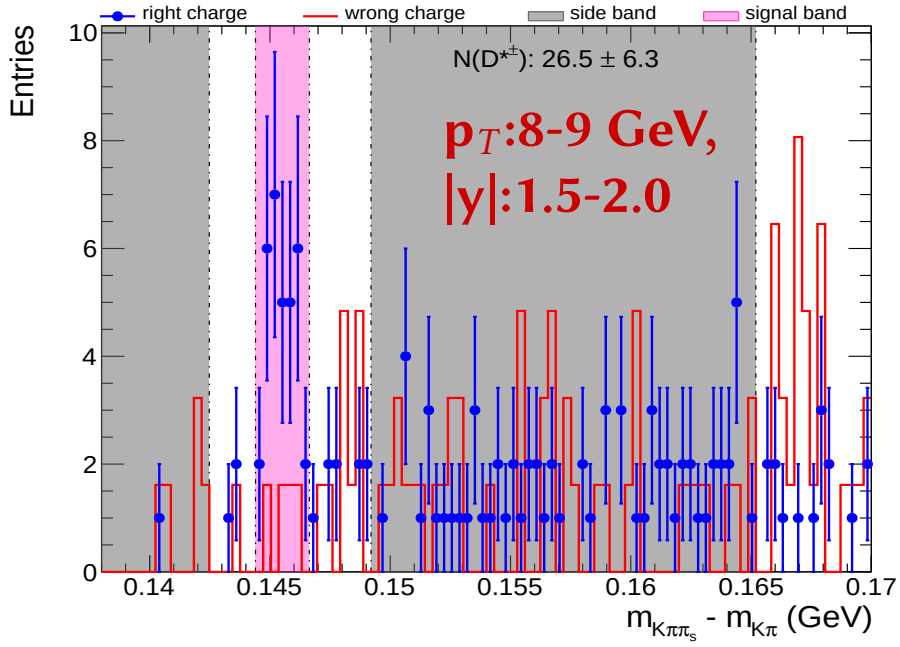


The red boxes pick examples shown on the next



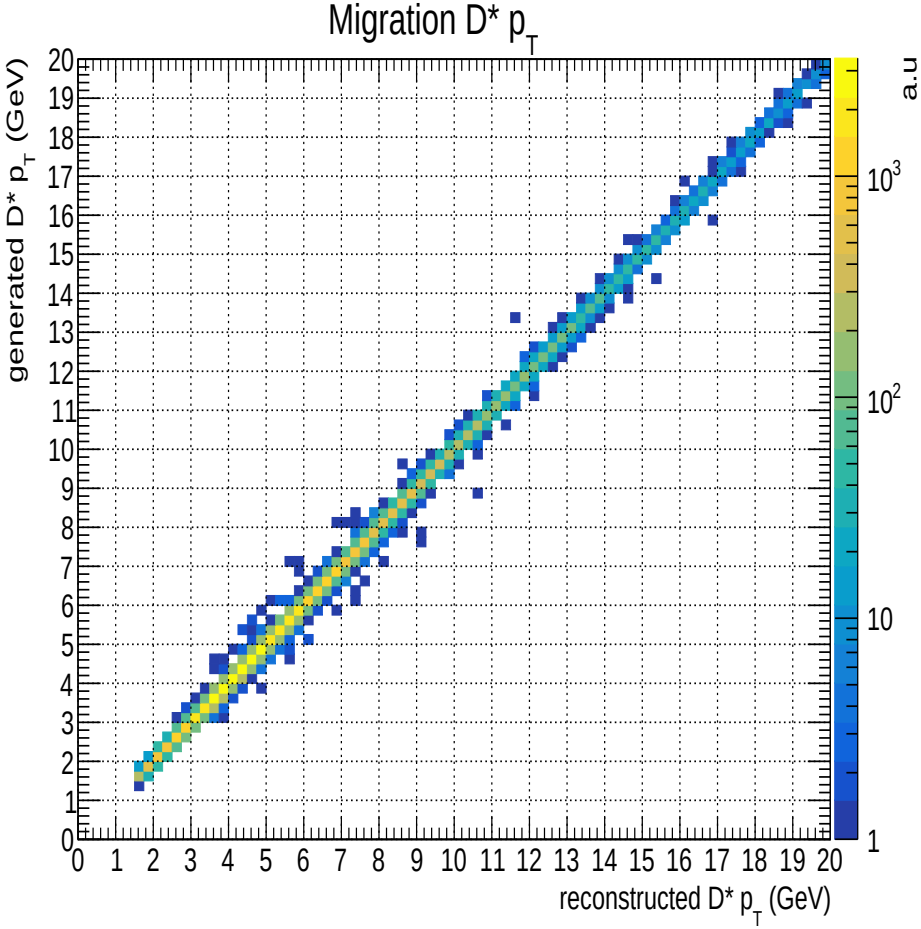


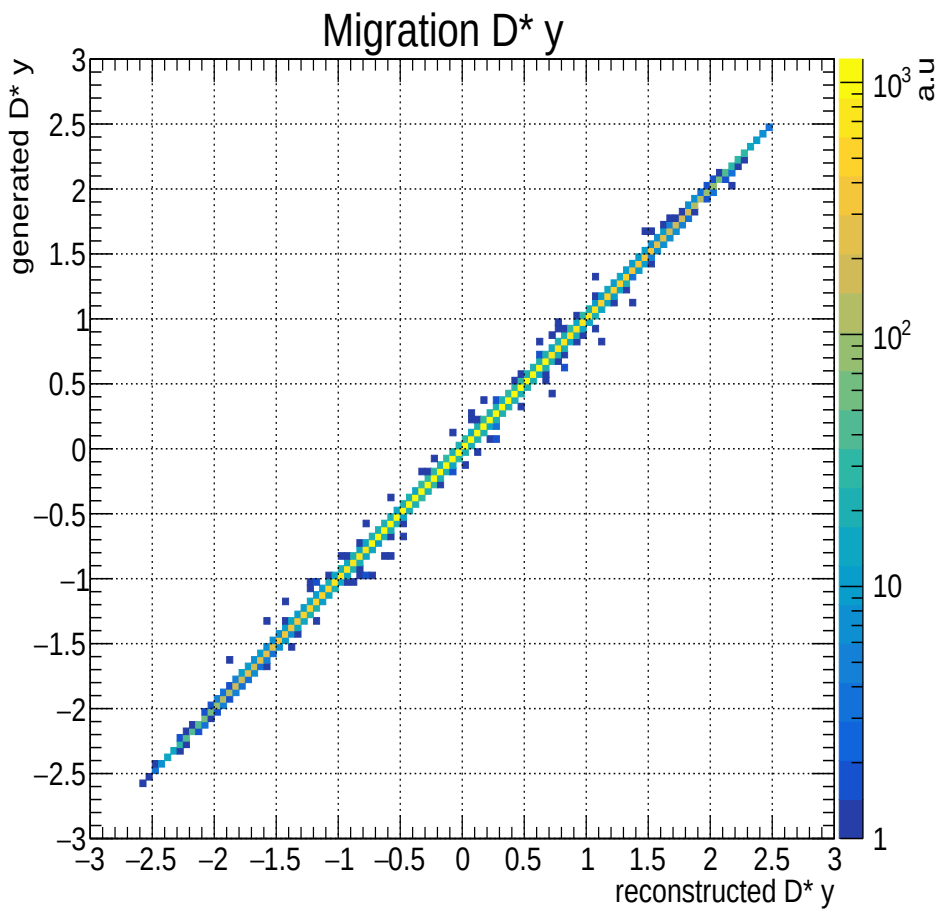




For all phase space, see backup

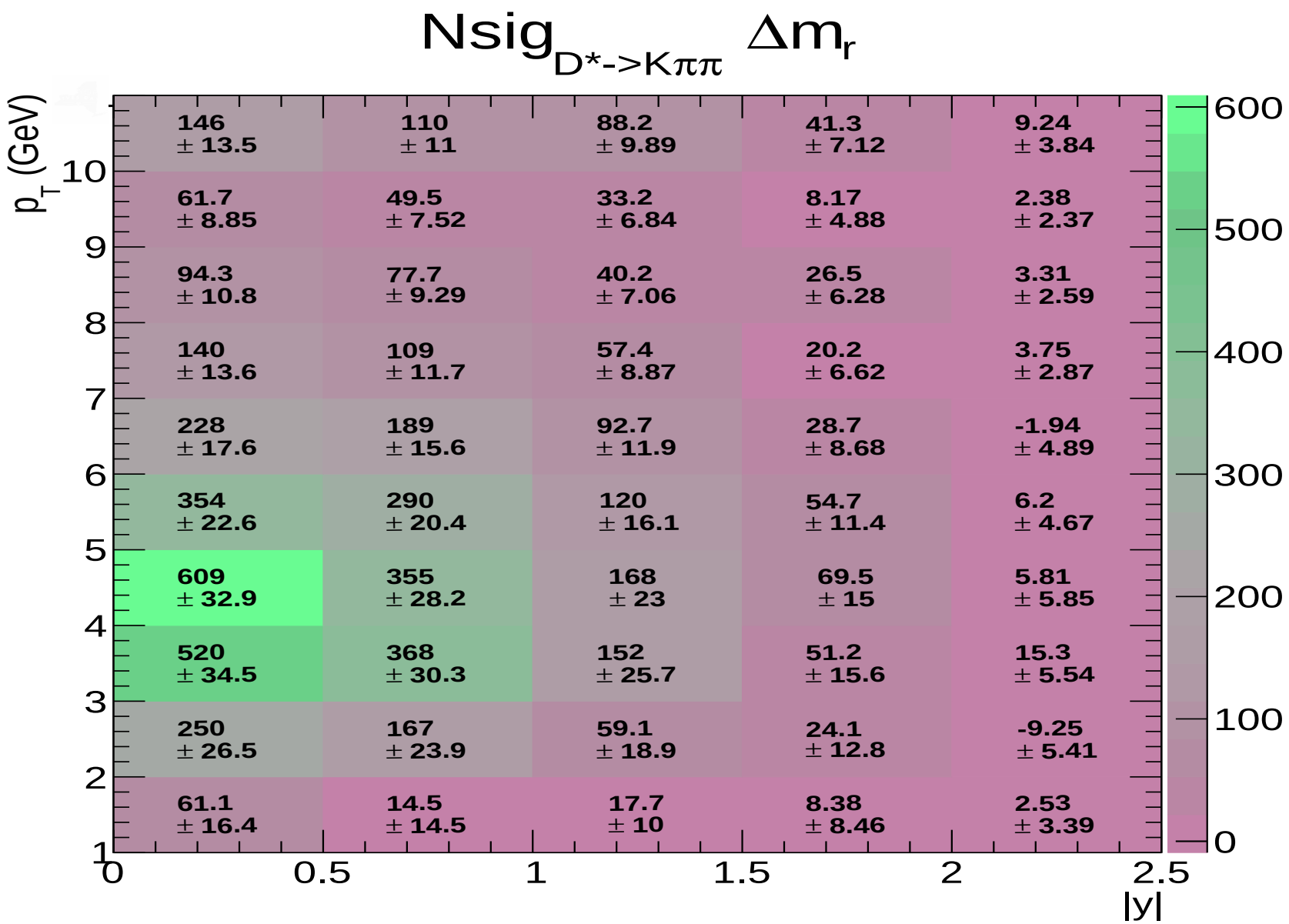
Migration plot for D* in $D^0 \rightarrow K\pi$ MC





The migration is small for every 1 GeV p_T bin and 0.5 |y|. Used bin-to-bin unfolding

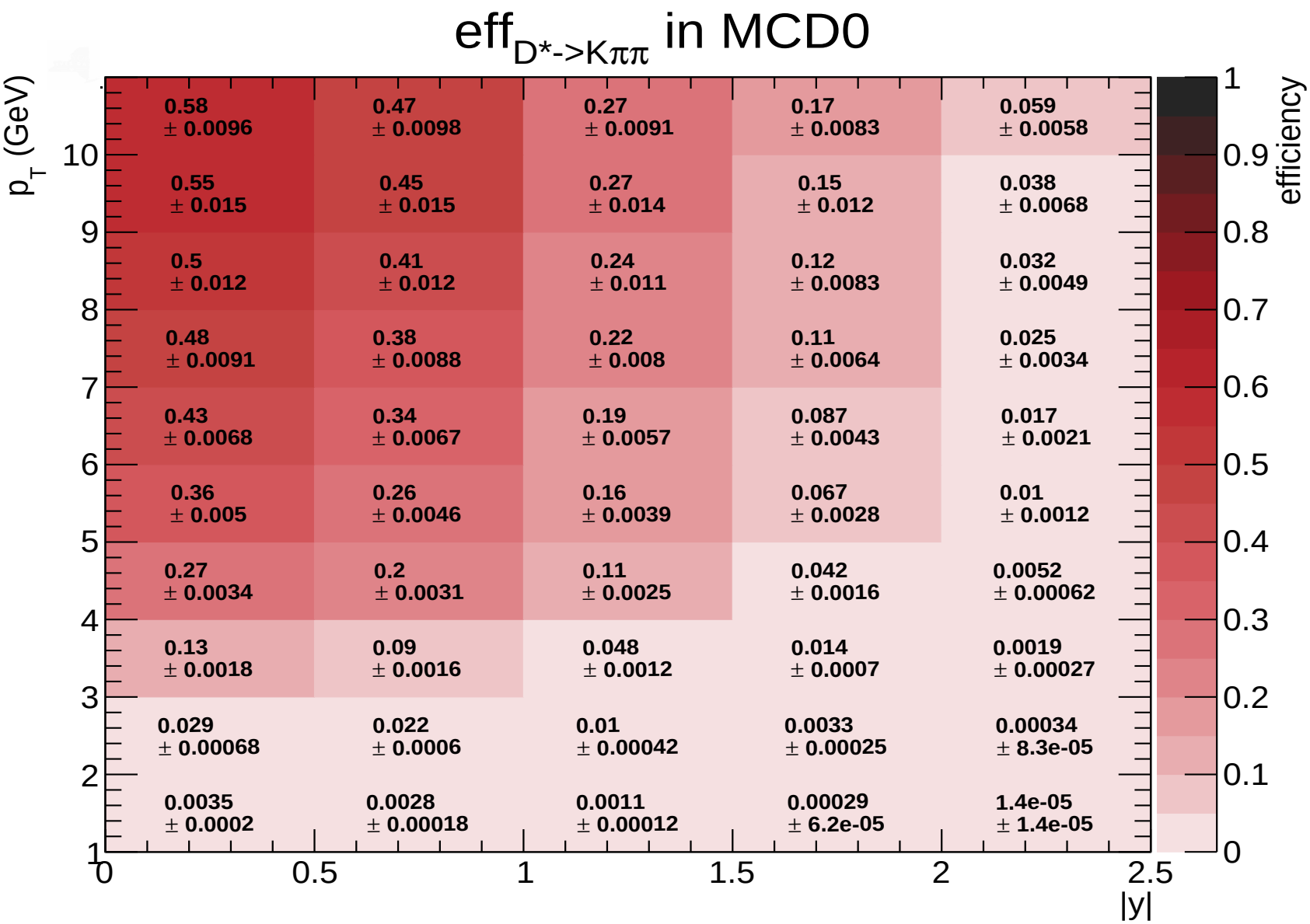
Nsignal table in data



Efficiency & acceptance

Efficiency & acceptance

- Branching ratio (BR) from PDG 2020:
  - $D^* \rightarrow D^0\pi = 0.677 \pm 0.005$
  - $D^0 \rightarrow K\pi = 0.0395 \pm 0.0003$
- Acceptance: 0.0267 ± 0.00028
  (BR $D^* \rightarrow D^0 K\pi$ * BR $D^0 \rightarrow K\pi$)
- Detector efficiency
  - $\frac{N_{reco\&true}}{N_{true}}$



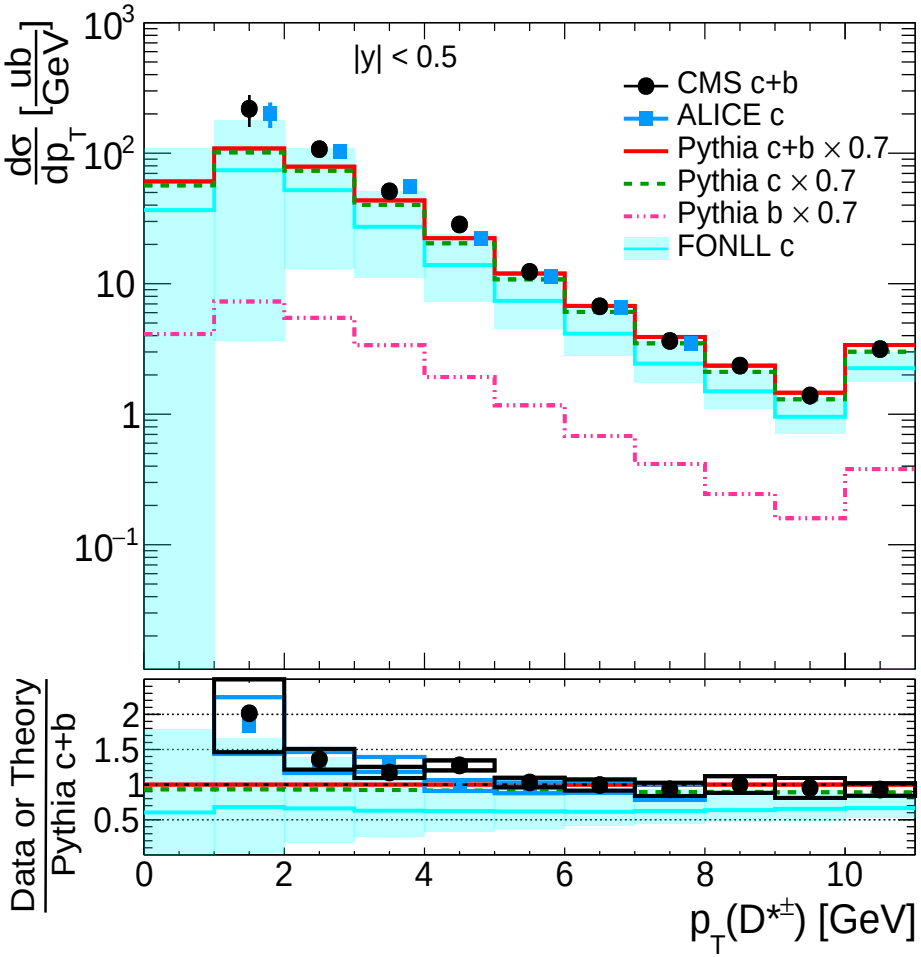
Efficiency decreases when rapidity go higher but increases as p_T go higher

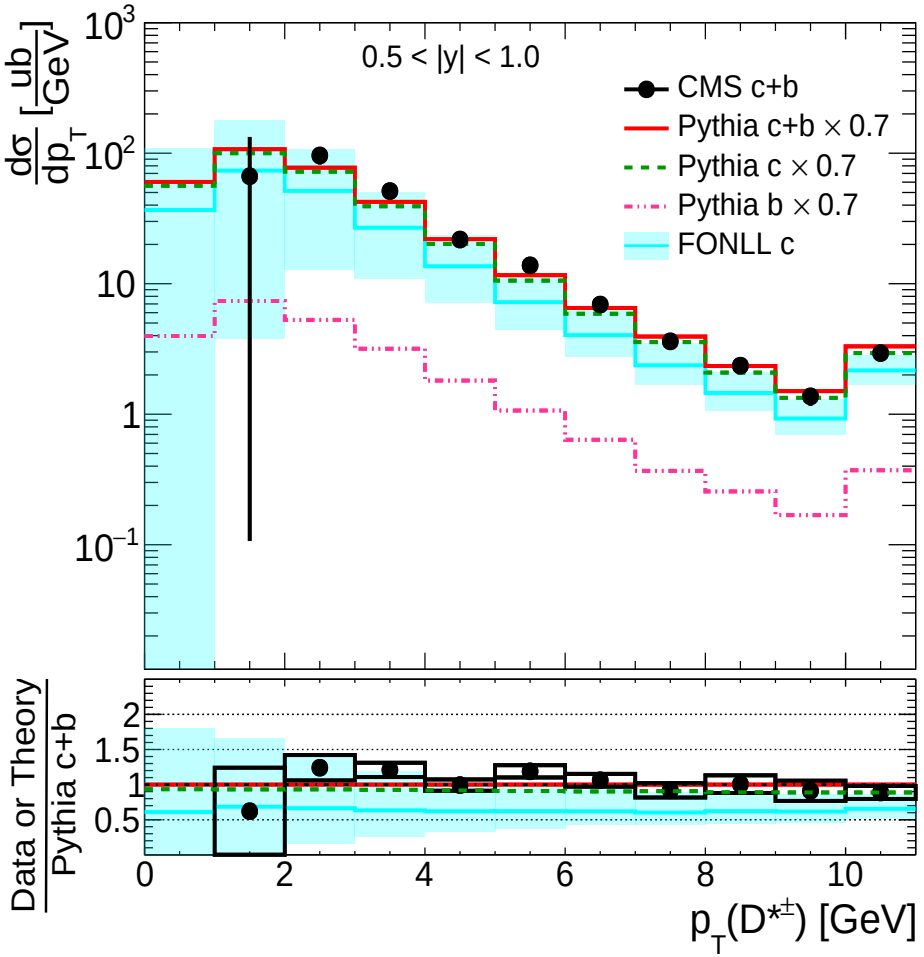
FONLL prediction for prompt D* (Josry)

- FONLL is a NLO+NLL theory prediction that calculates heavy quark production folded with fragmentation (charm)
- This prediction is used at pp collider 7 TeV with cuts every 1 GeV p_T and 0.5 |y|
- PDF used: NNPDF30_nlo_as_0118
- Charm fragmentation fraction:
  - f($c \rightarrow D^*$) = 0.236
- Uses relevant moment of fragmentation function extracted from LEP data

Cross section as a function of p_T & |y| (statistical uncertainty only)

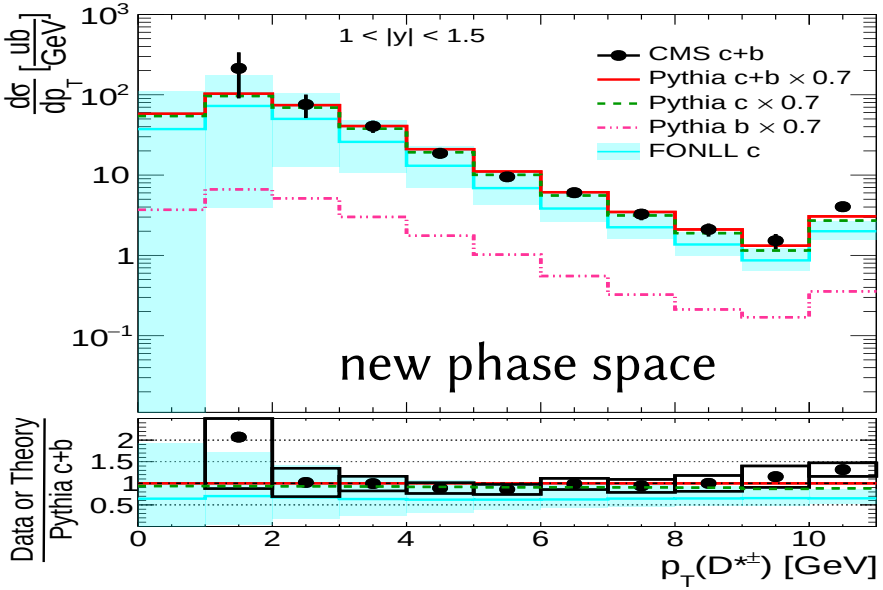
σ as a function of p_T

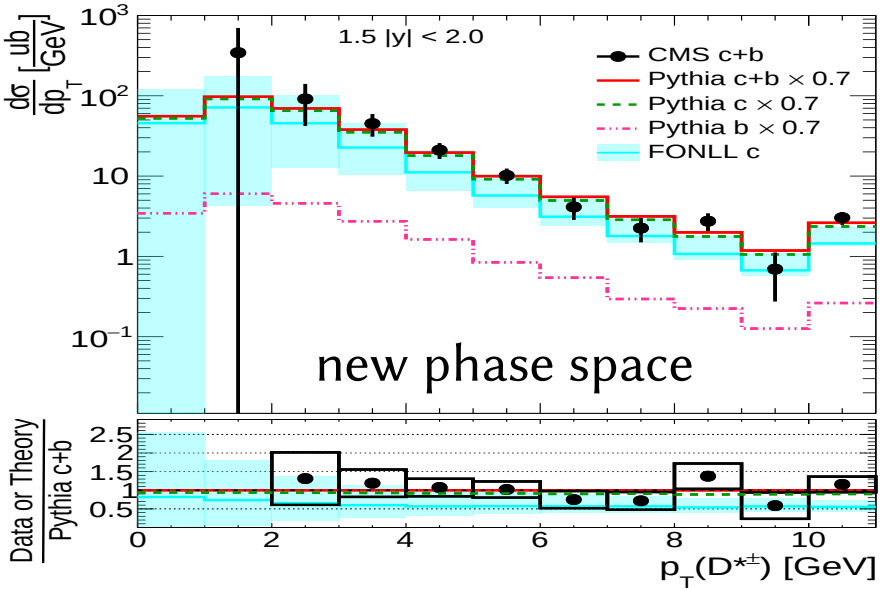


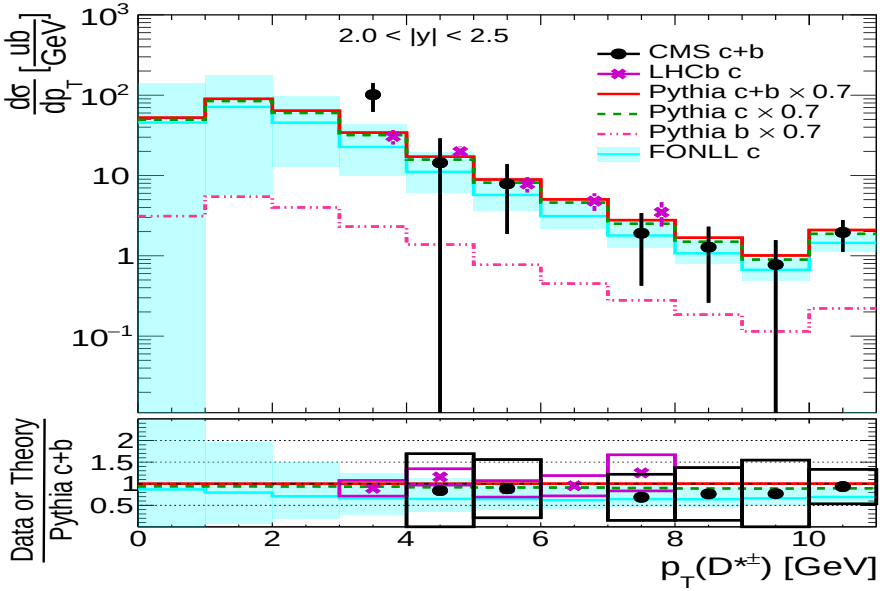


(Left) The cross section is comparable with ALICE
(Right) Region where cross sections have never been measured before

σ as a function of p_T

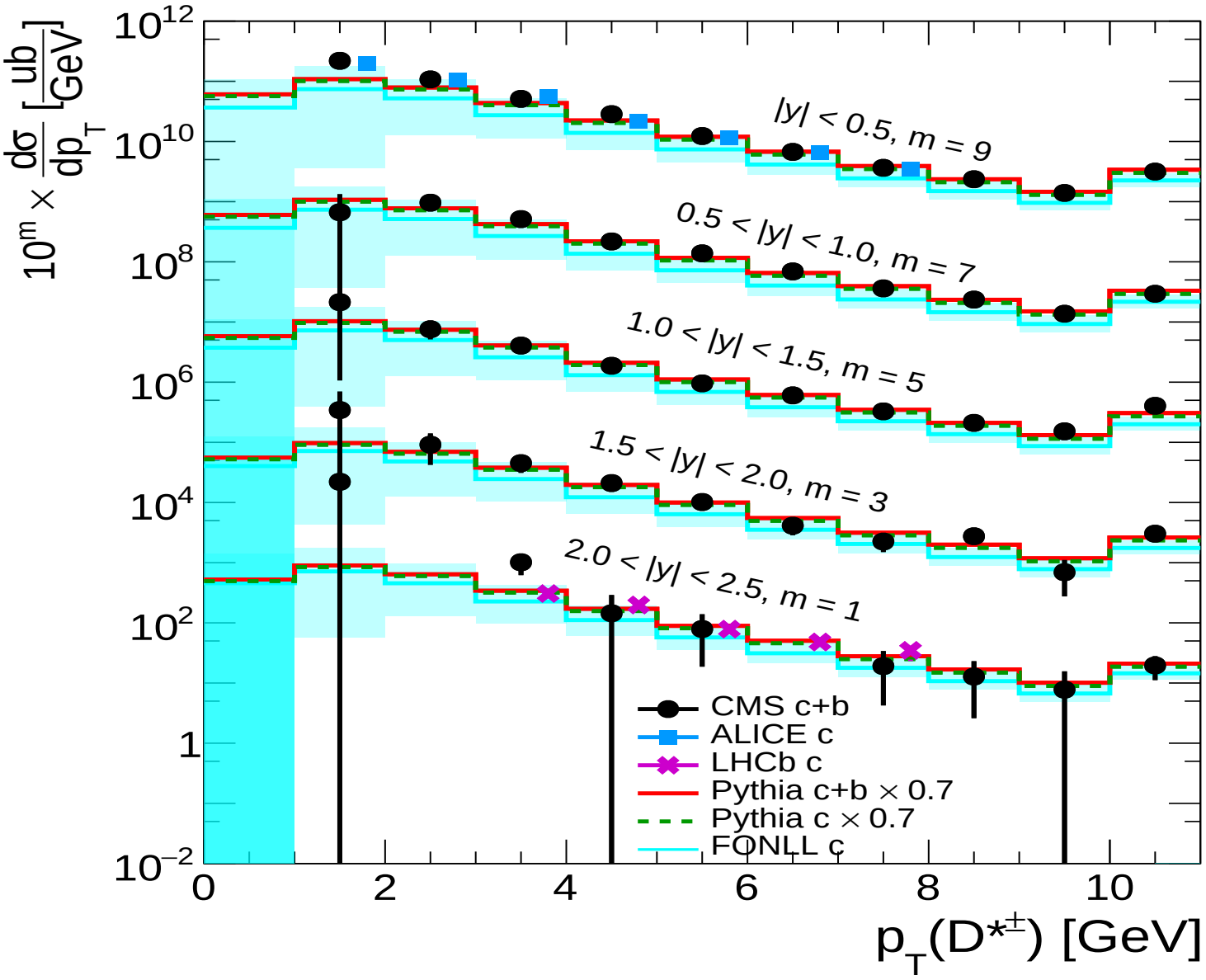




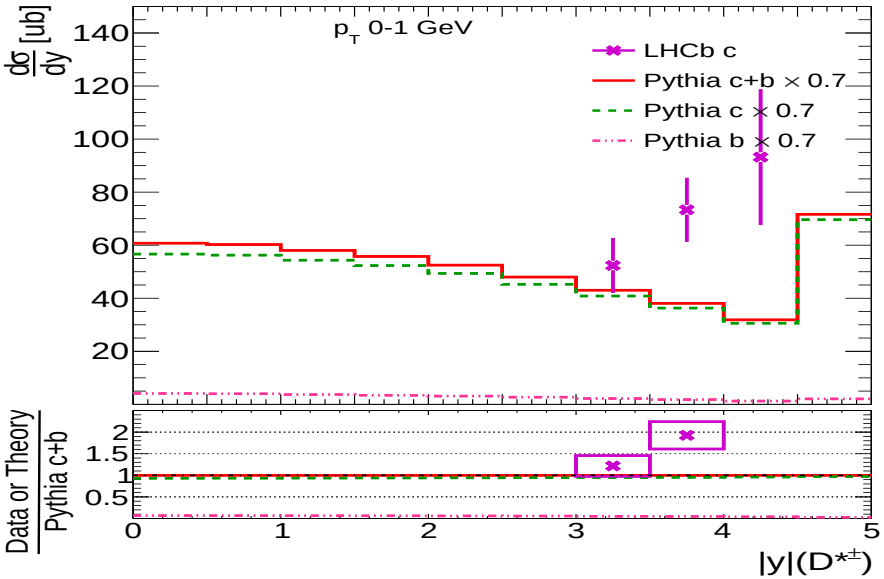


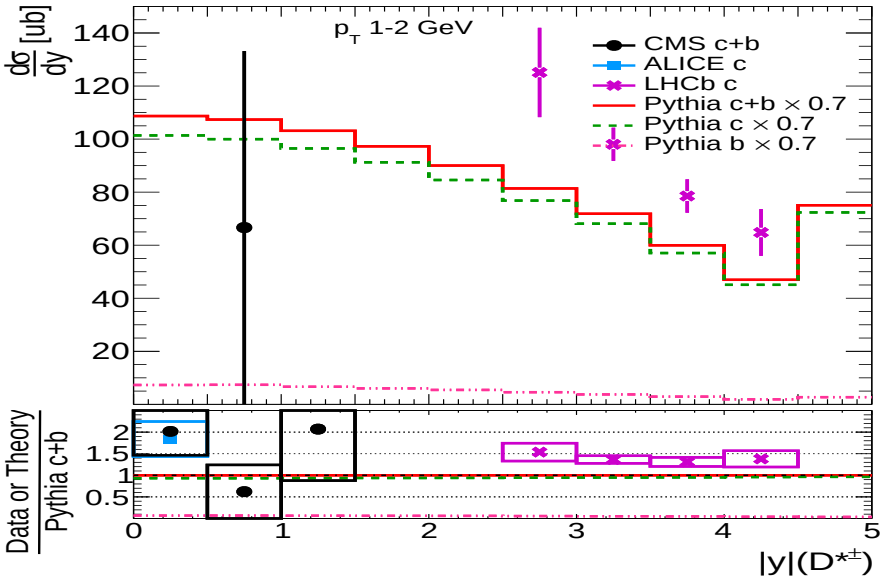
- Comparison with LHCb result, (LHCb have more precise measurement)
- will use LHCb measurement, also for |y| above 2.5)

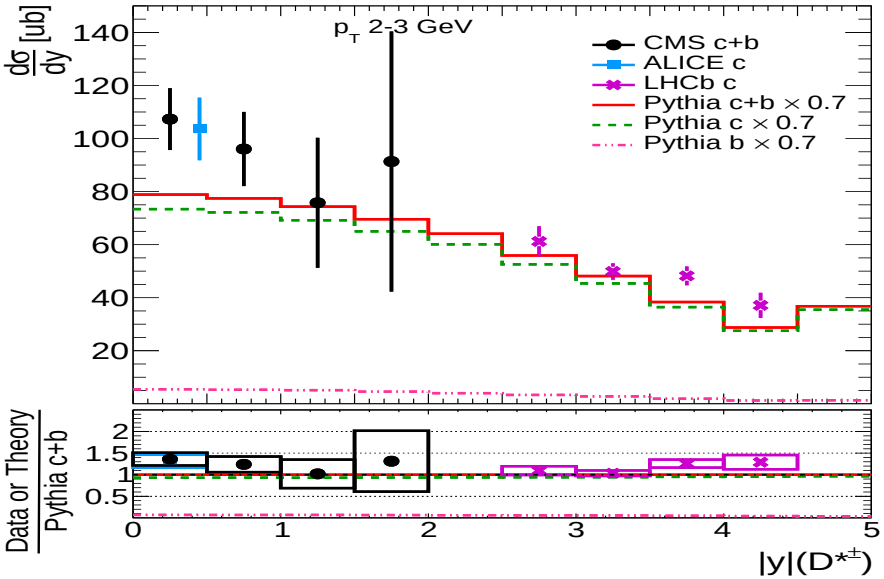
double differential σ as a function of p_T

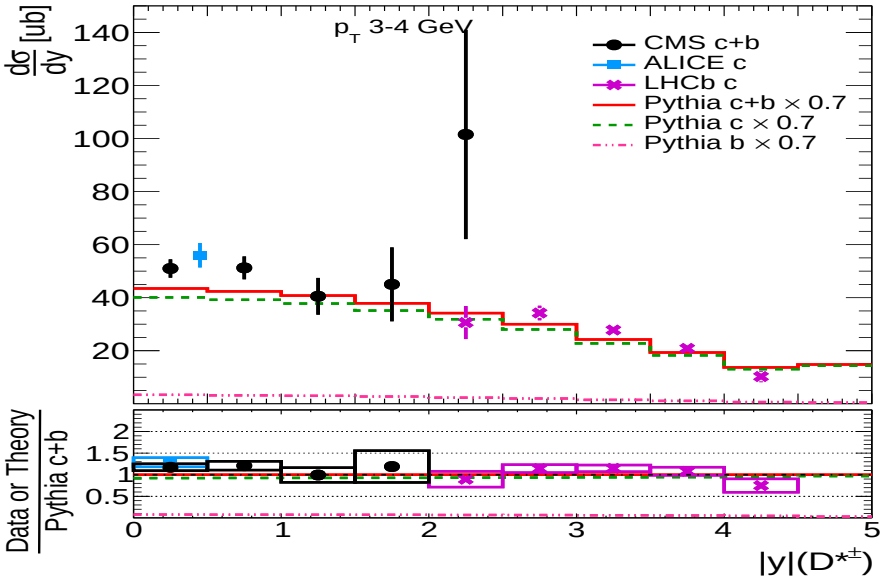


σ as a function of |y|

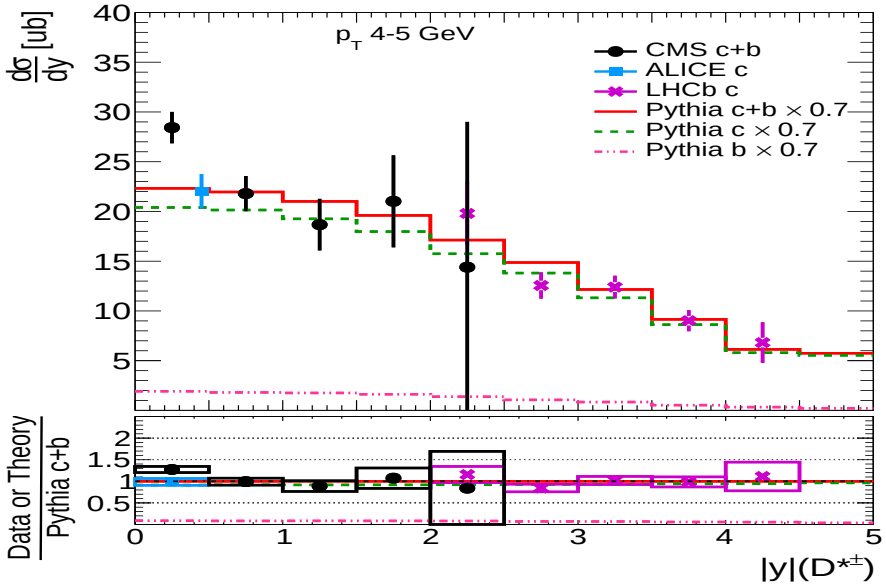


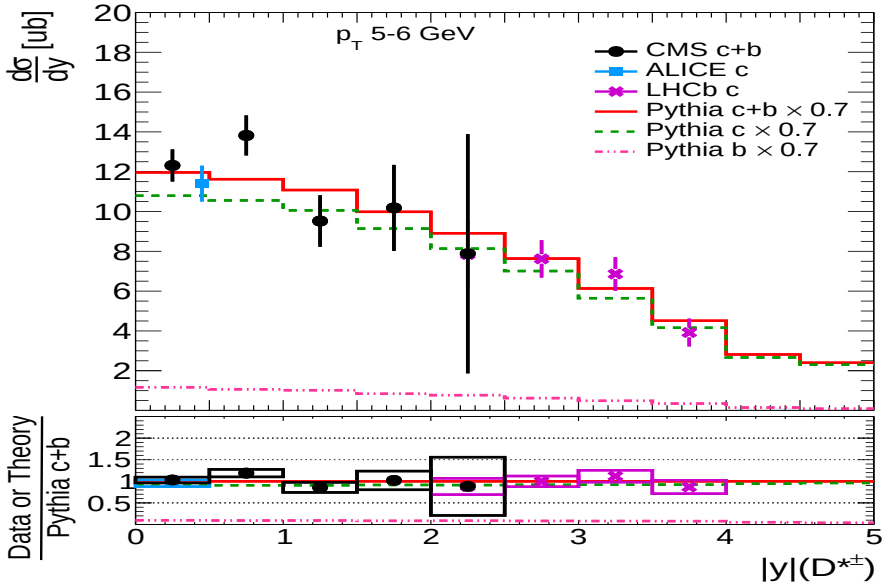


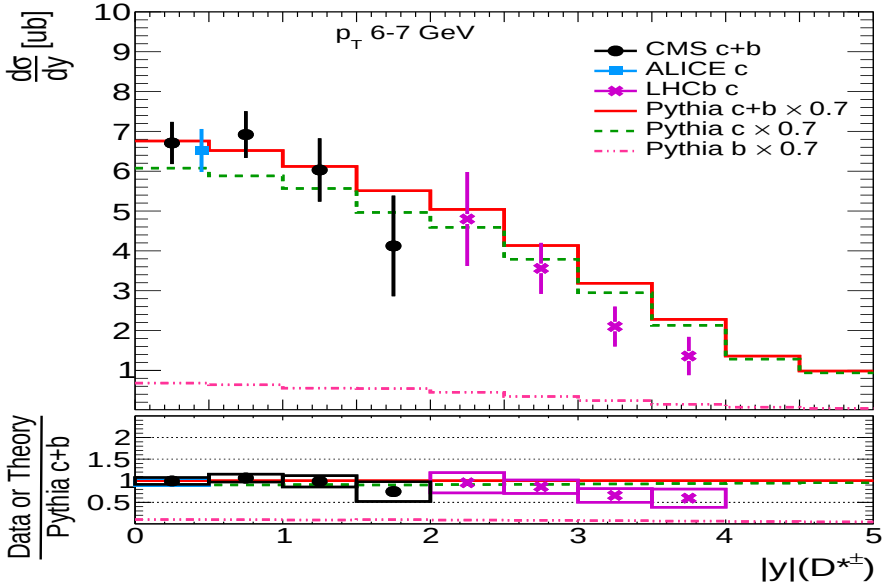


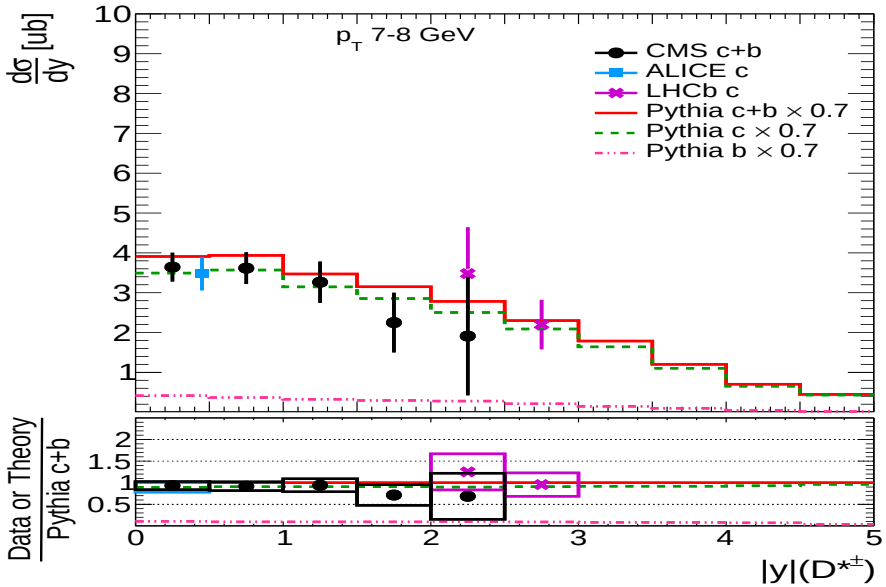


σ as a function of |y|

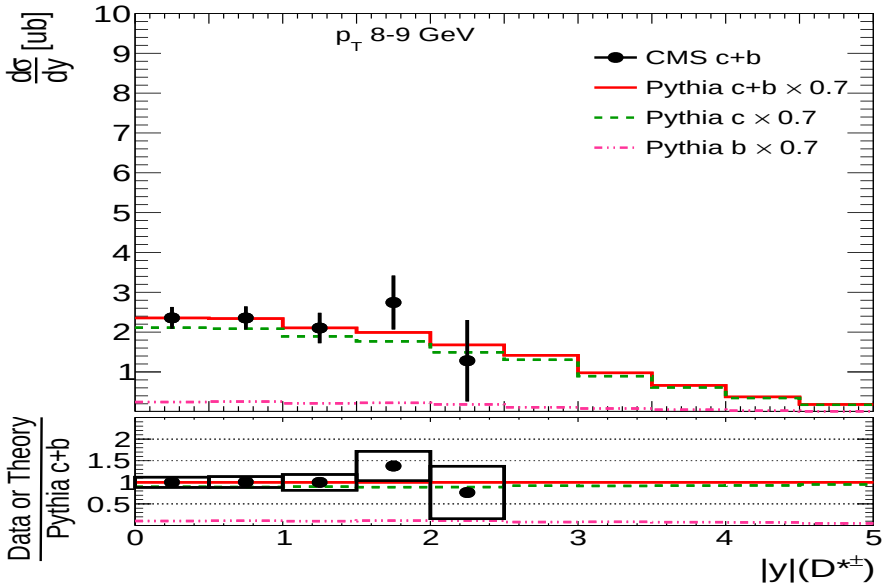


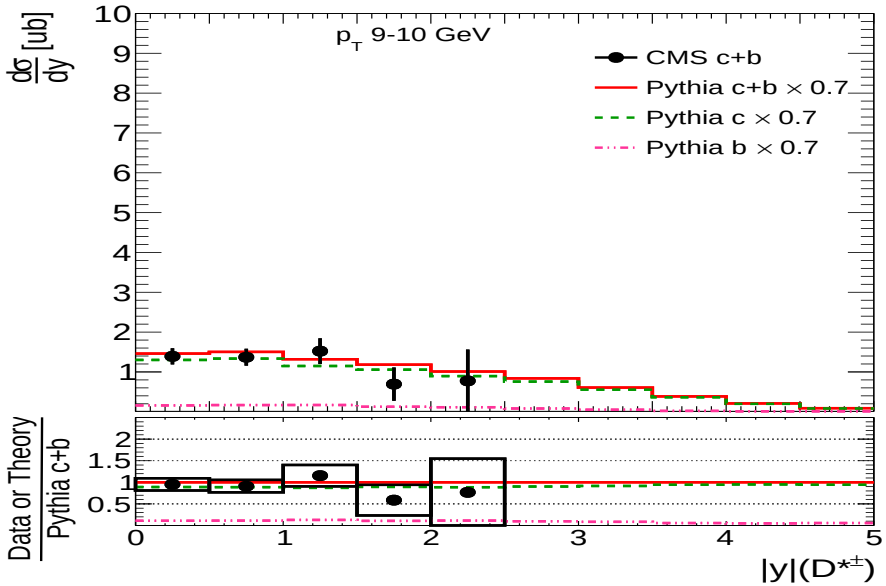


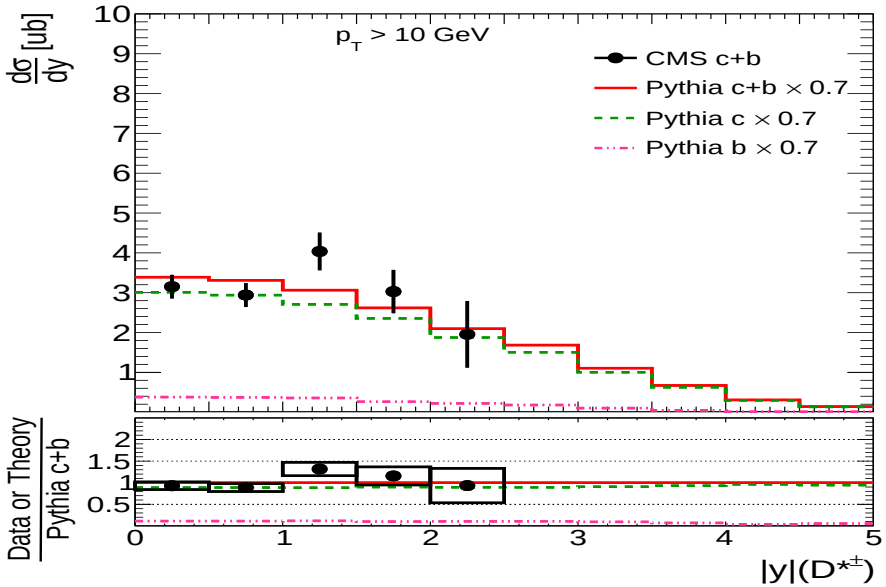




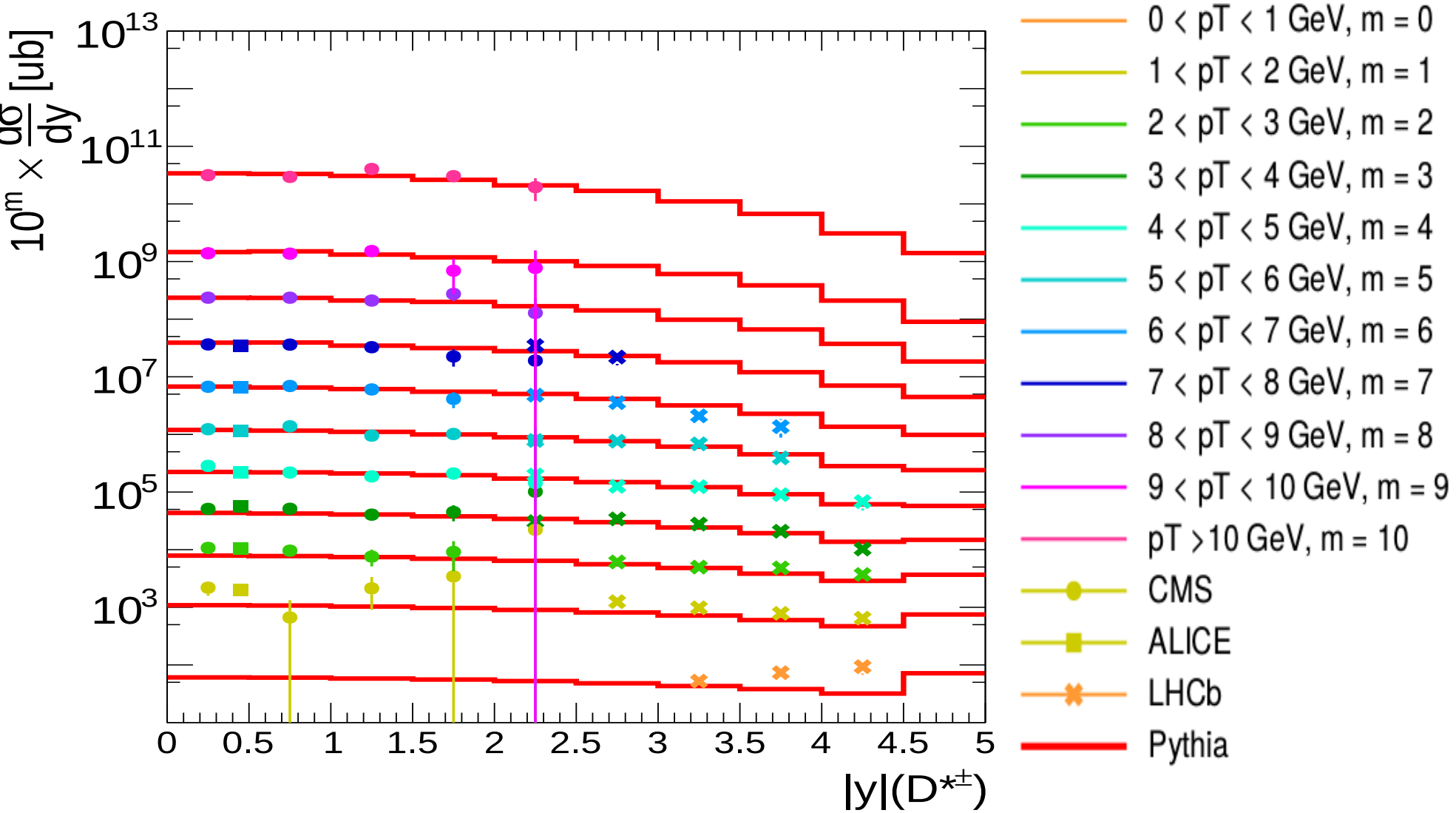
σ as a function of |y|







double differential σ as a function of |y|



The σ was compared with ALICE and LHCb result for each |y| bin

Systematic uncertainties (very preliminary)

Systematic uncertainties (very preliminary)

- Below are parts of the systematics that is ongoing and it is not a complete list yet
- These values are not yet applied to the current results
- PU = 5% (limited statistic of MinimumBias MC)
- lumi = 4% (from CMS DP-2011/002)
- tracking = 9.4% (from Valentina's PAS: BPH-18-003)
- BR = 1.1% (from PDG 2020)
- trigger = negligible (by definition)

Conclusion and outlook

- Conclusion
  - The analysis is performed using 7TeV 2010 datasets (special low p_T tracking)
  - Since statistics is a limiting factor for this analysis, using (in addition) pile-up vertices helps to get sizeable additional statistics
  - Refit of π_s gives better signal to background ratio
  - The detector efficiency to reconstruct $D^* \rightarrow K\pi\pi$ in $D^0 \rightarrow K\pi$ MC reaches ~60% at high p_T and low |y| and is non-zero down to $p_T > 1$ GeV
  - The upper edge of the FONLL theory band is an agreement with the data (as in all other existing measurements)
  - The result for the cross section is in agreement with ALICE at low |y|, with LHCb at high |y|, and covers the phase space in between that was never (fully) measured before
- Outlook
  - There is an ongoing further efficiency improvement especially at lower p_T and higher |y|. See backup
  - c/b separation ongoing
  - Calculation of total cross section from double differential cross section soon

Backup

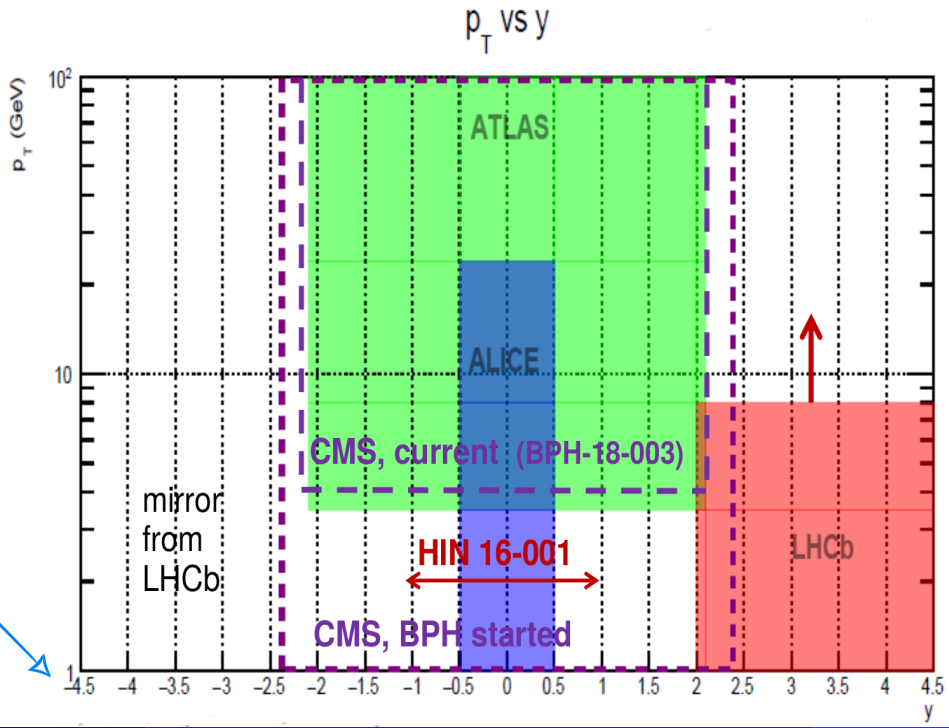
Introduction overview

- Objective: To measure the total cross section of inclusive charm at different pp center of mass energies (0.9, 2.7, 5, 7, 8, 13 (from PU in BParking) TeV)
- Why? Test NNLO QCD, constraints on PDFs, measurement of charm quark mass
- So far, only parts of phase space are measured at LHC
- CMS + LHCb together can cover essentially full phase space of $\sigma_{c\bar{c}}^{tot}$
- Challenge: Acceptance of D mesons at low p_T

$\sigma_{c\bar{c}}^{tot}$ expected to be ~10 mb!

CMS (5 & 13 TeV)
arXiv:1708.04962
BPH-18-003

Goal:
Measure D mesons down to p_T 1 GeV

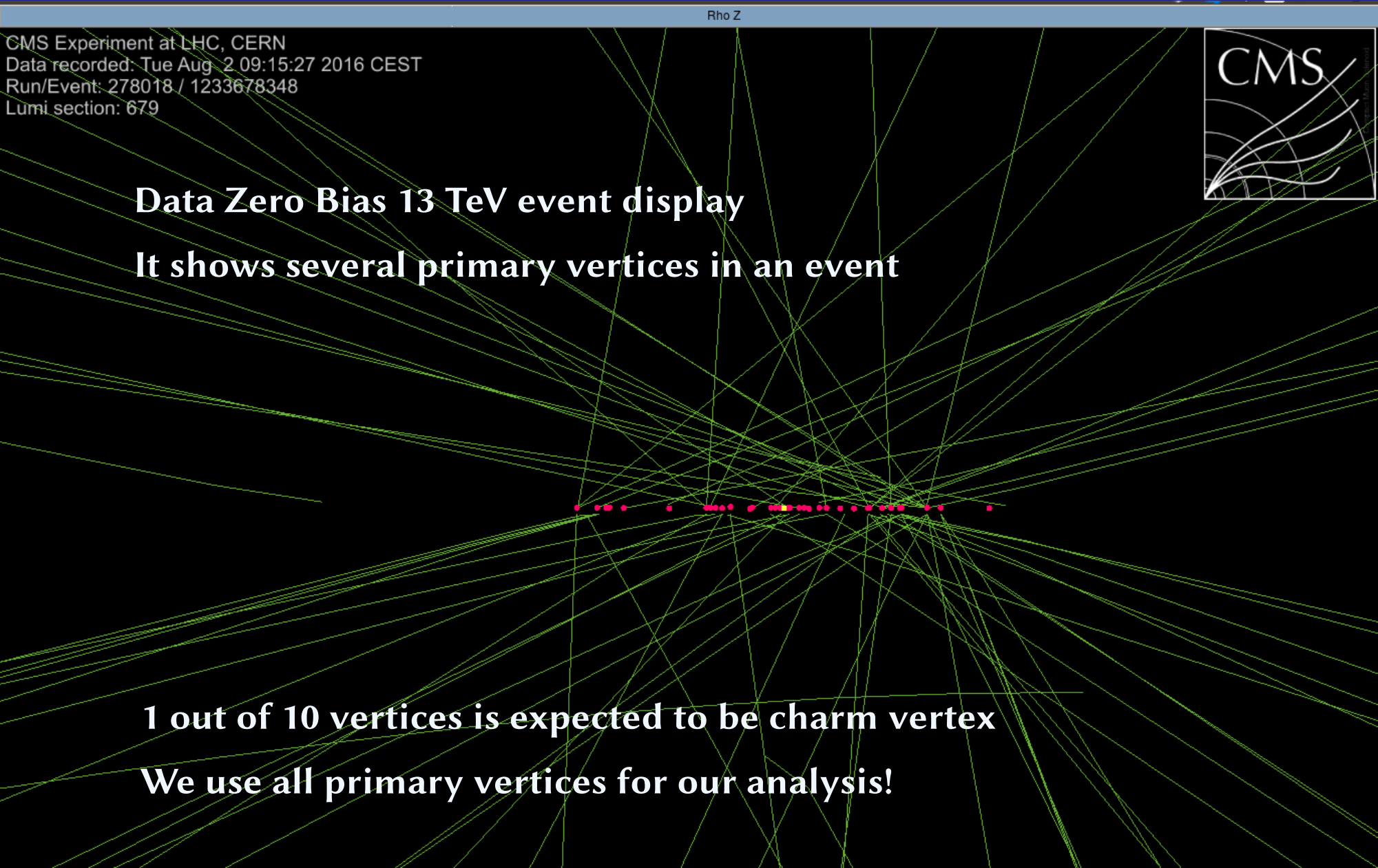


ATLAS (7 TeV)
arXiv:1512.02913v2

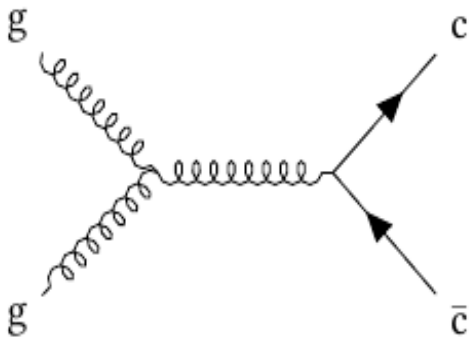
LHCb (5, 7 & 13 TeV)
arXiv:1610.02230v2
arXiv:1302.2864v1
arXiv:1510.01707v6

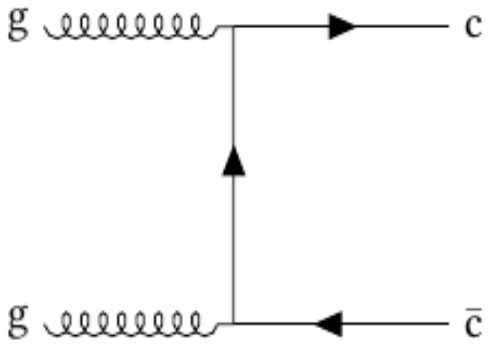
ALICE (2.76, 5 & 7 TeV)
arXiv:1205.4007v3
arXiv:1901.07979
arXiv:1111.1553v3

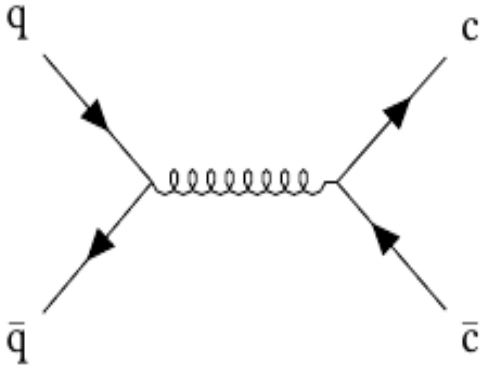
Analysis strategy in general



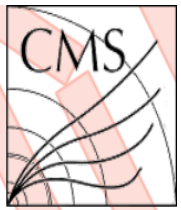
D meson reconstruction

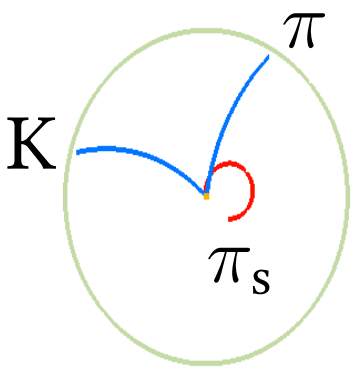




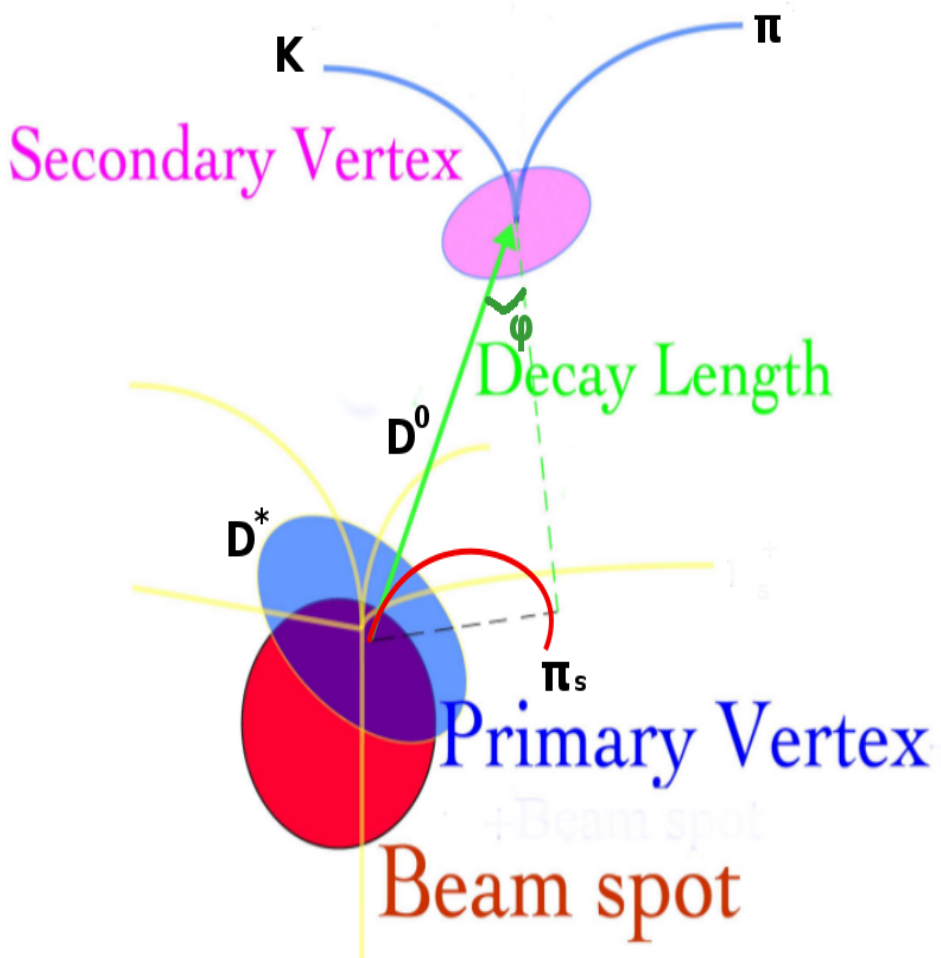


CMS Experiment at LHC, CERN
Data recorded: Sun Oct 17 06:06:53 2010 CEST
Run/Event: 148031 / 442976968
Lumi section: 554

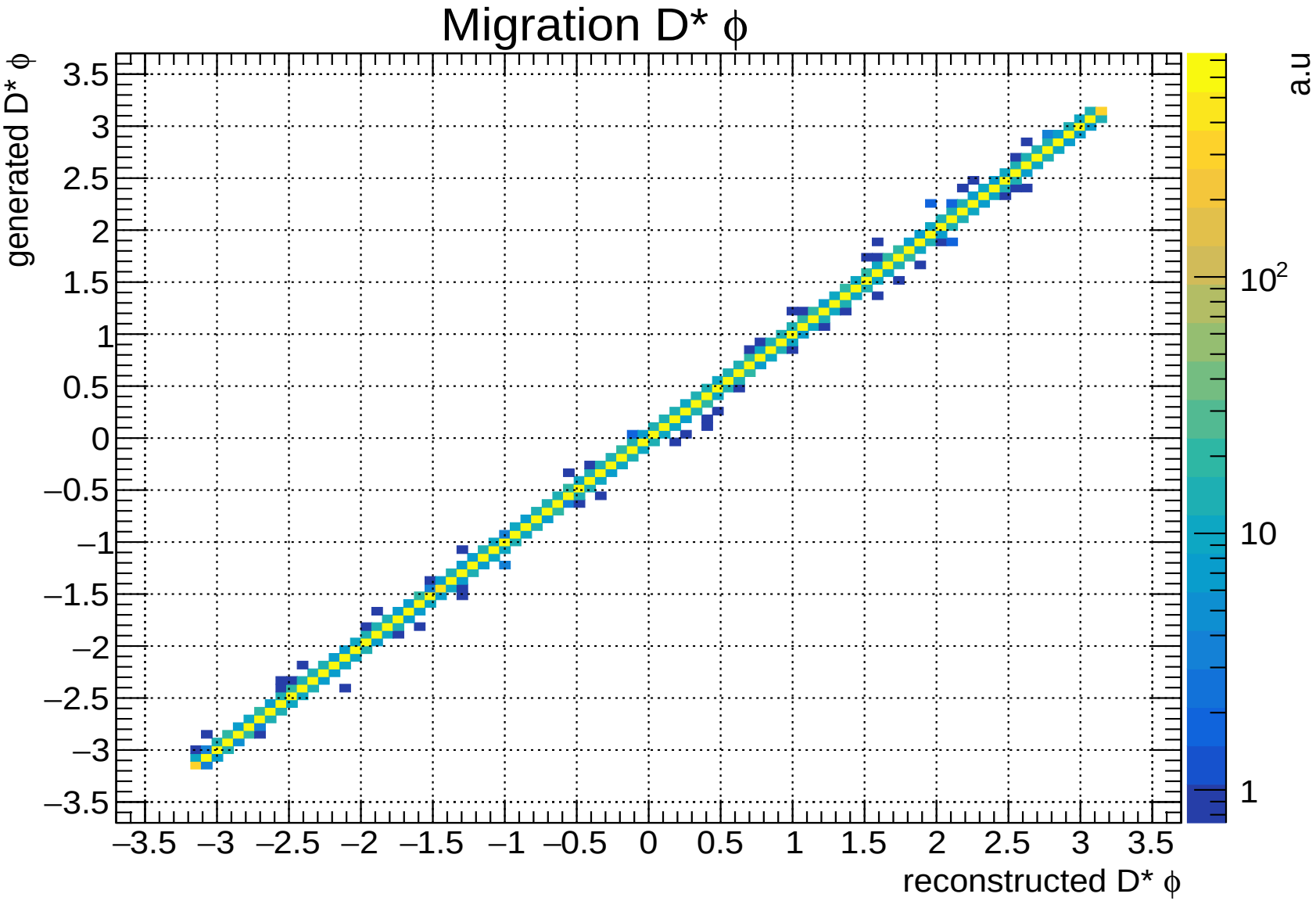




MB 2010 Data

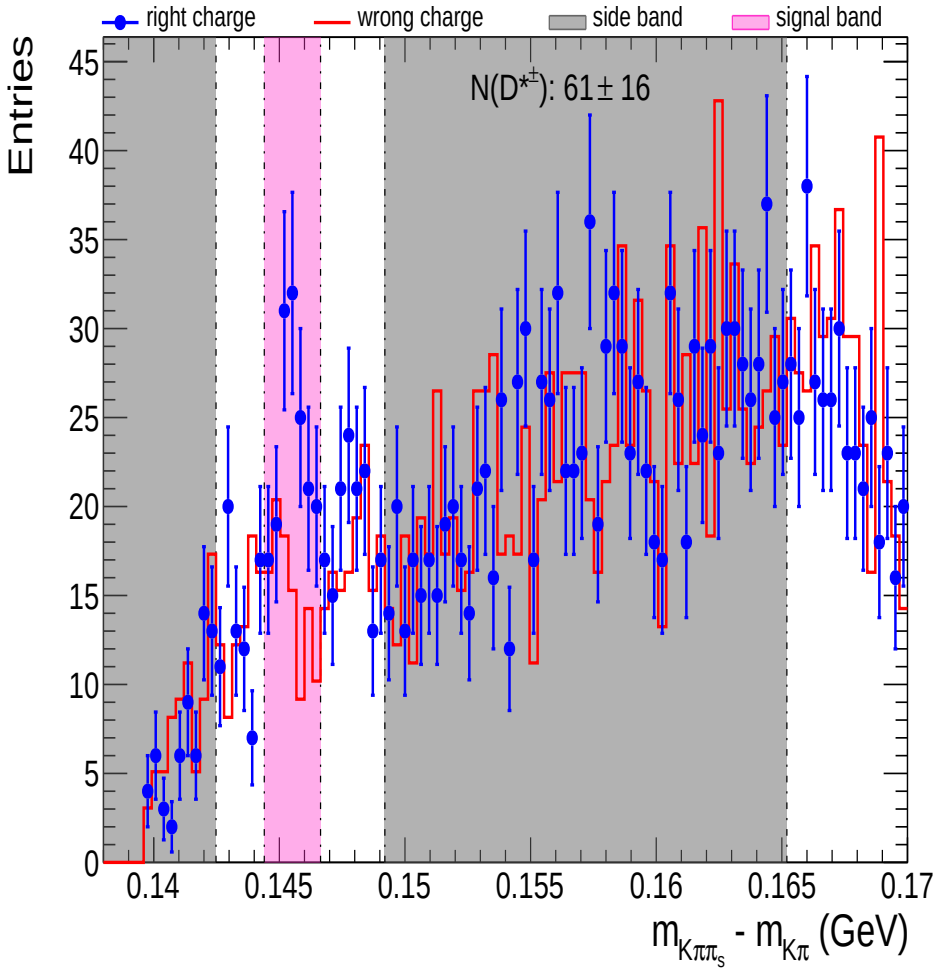


Migration plot for D* phi in $D^0 \rightarrow K\pi$ MC

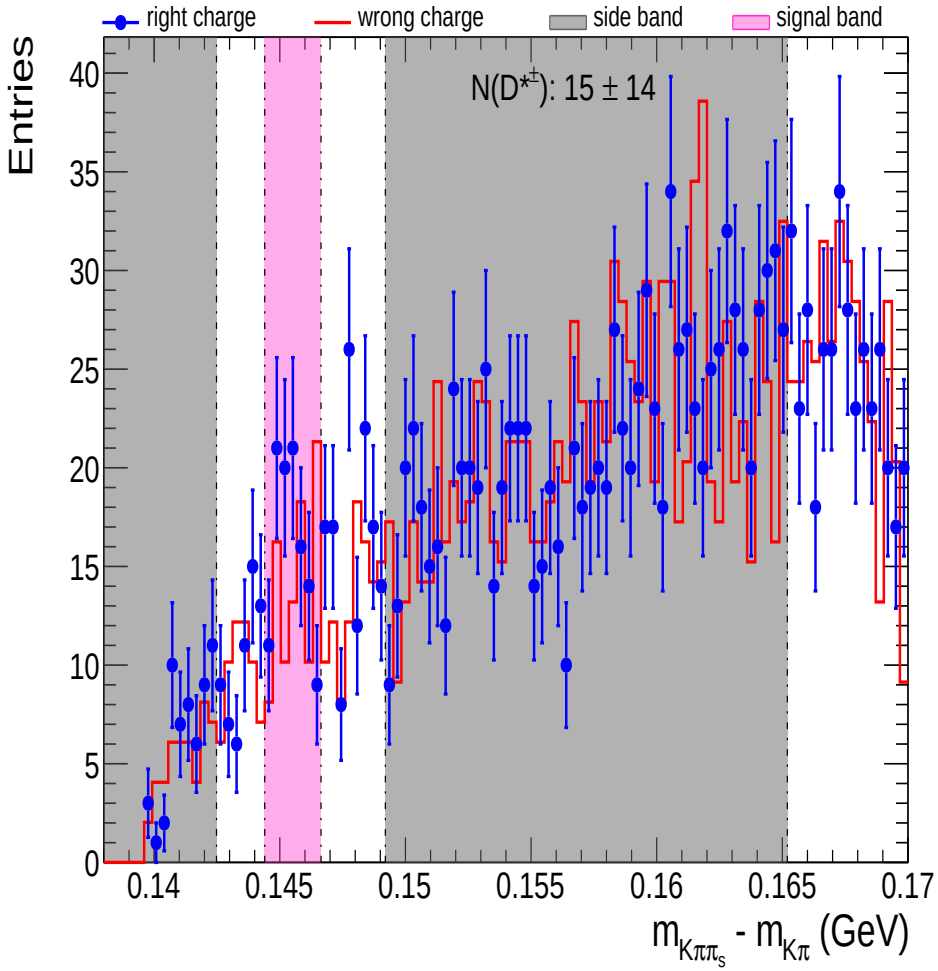


Δm_r at different phase space

p_T:1-2 GeV, |y|:0.0-0.5

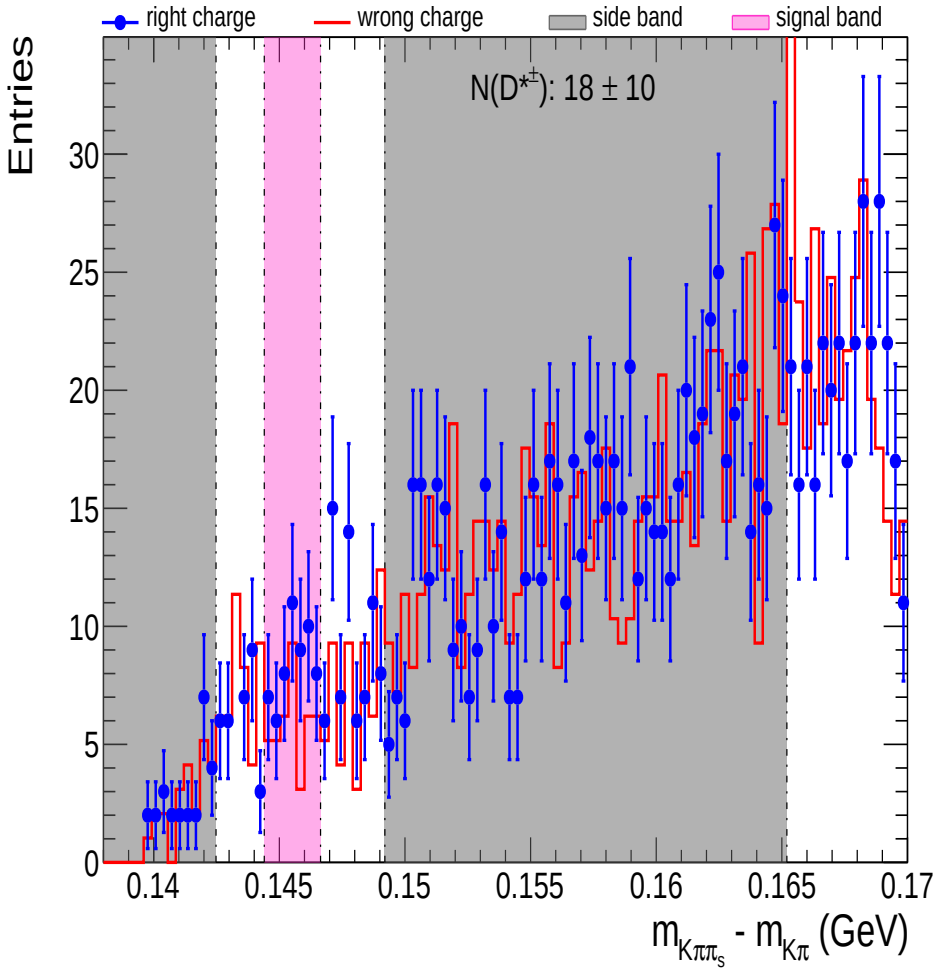


p_T:1-2 GeV, |y|:0.5-1.0

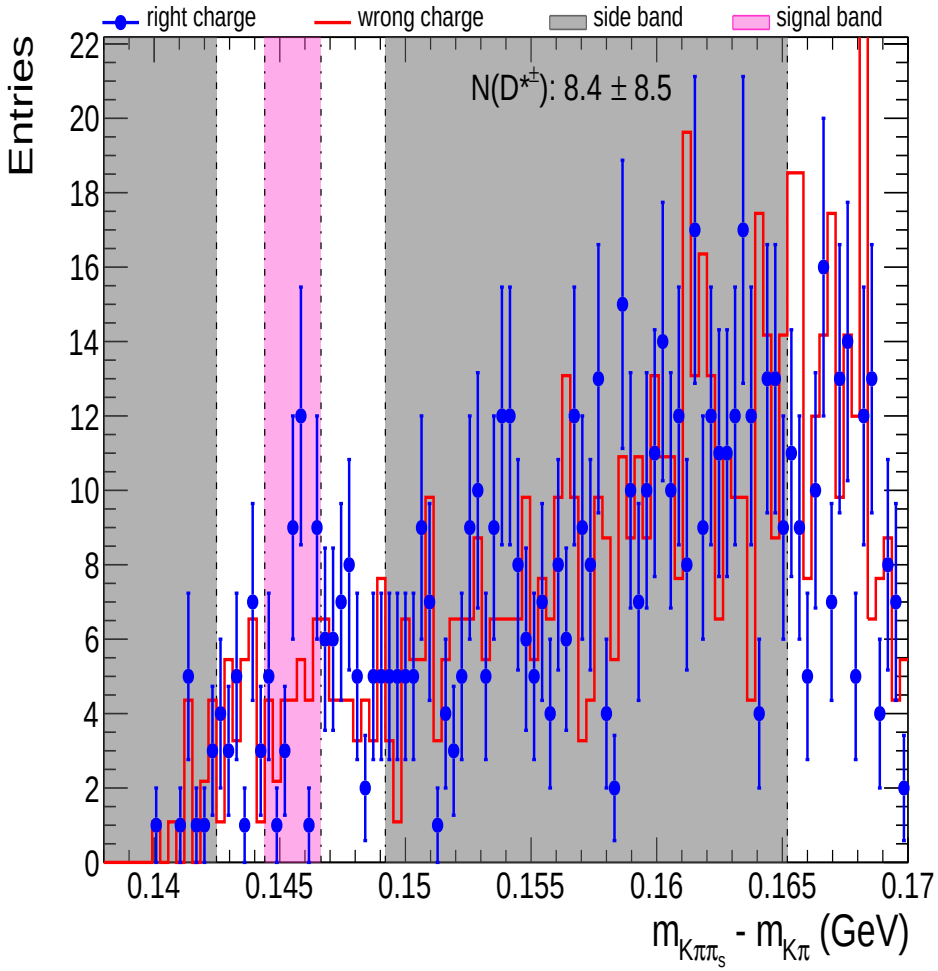


Δm_r at different phase space

p_T:1-2 GeV, |y|:1.0-1.5

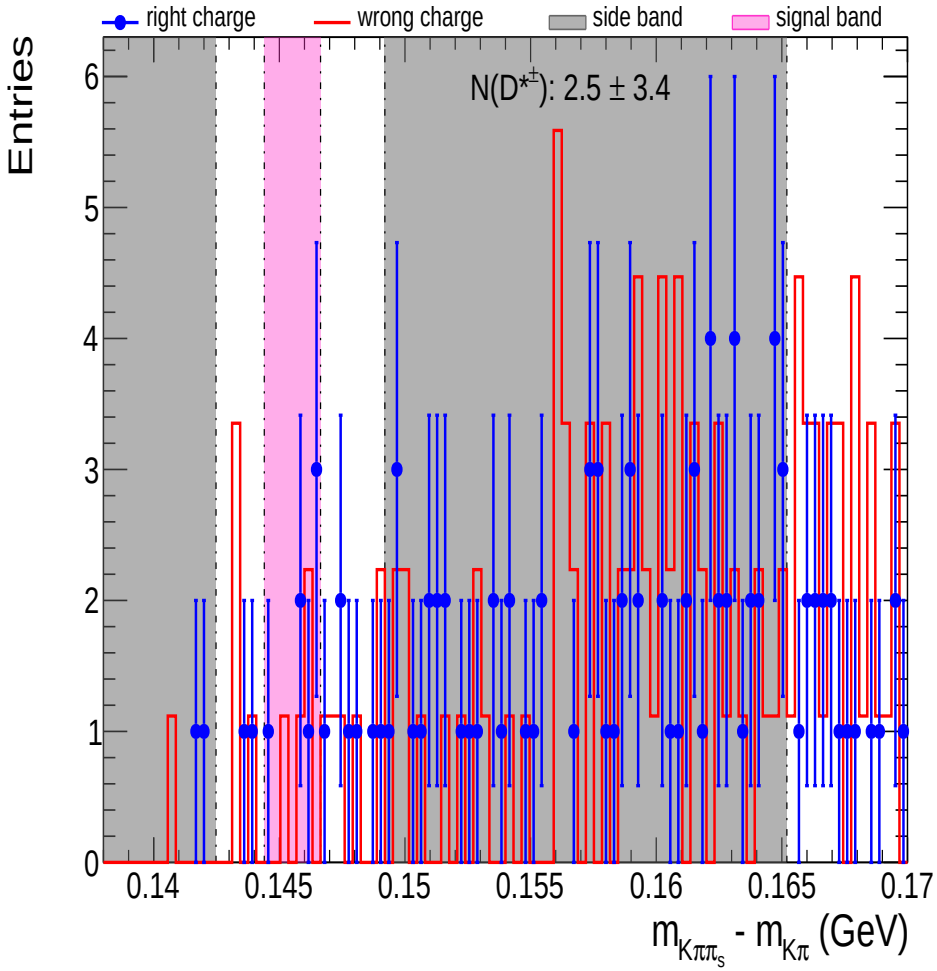


p_T:1-2 GeV, |y|:1.5-2.0



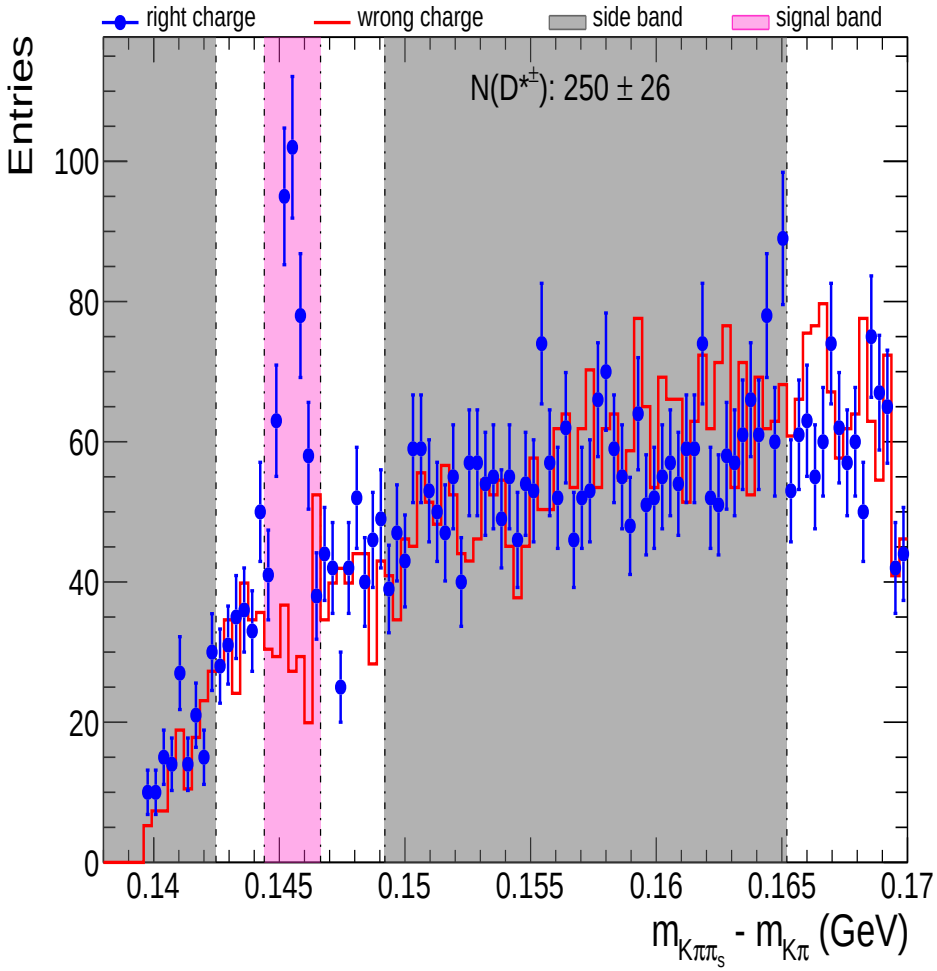
Δm_r at different phase space

p_T:1-2 GeV, |y|:2.0-2.5

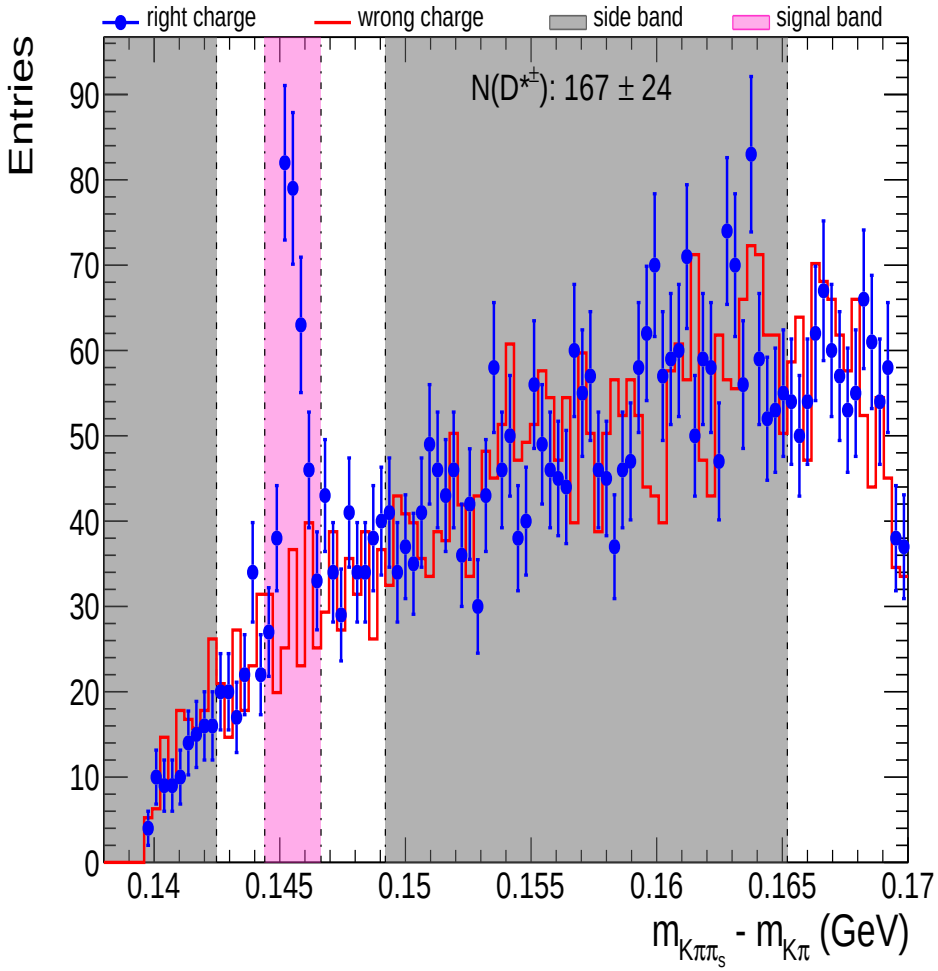


Δm_r at different phase space

p_T:2-3 GeV, |y|:0.0-0.5

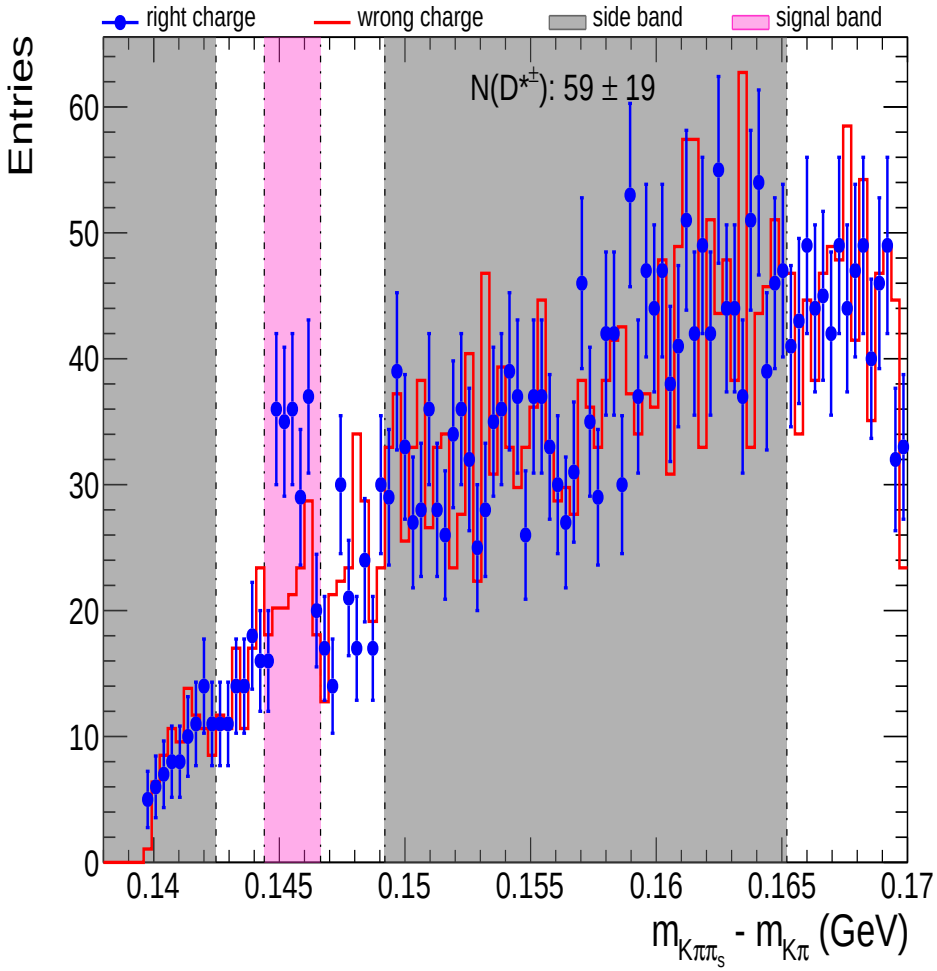


p_T:2-3 GeV, |y|:0.5-1.0

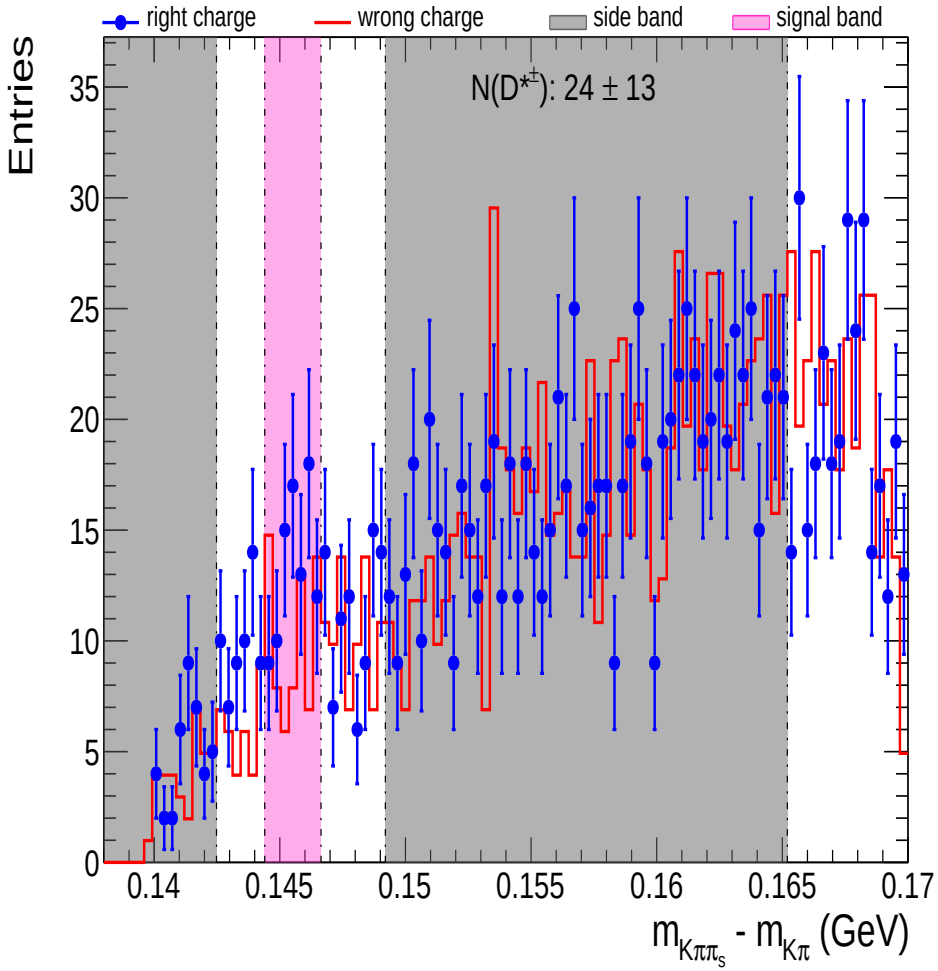


Δm_r at different phase space

p_T:2-3 GeV, |y|:1.0-1.5

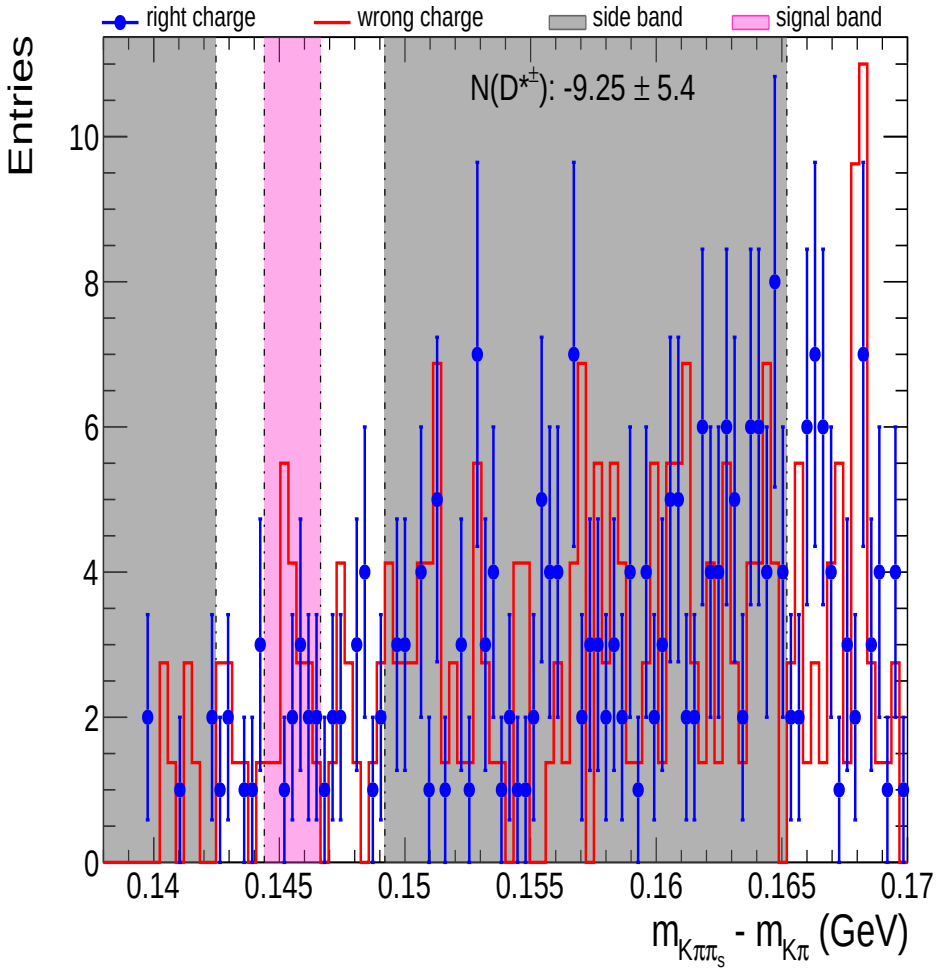


p_T:2-3 GeV, |y|:1.5-2.0



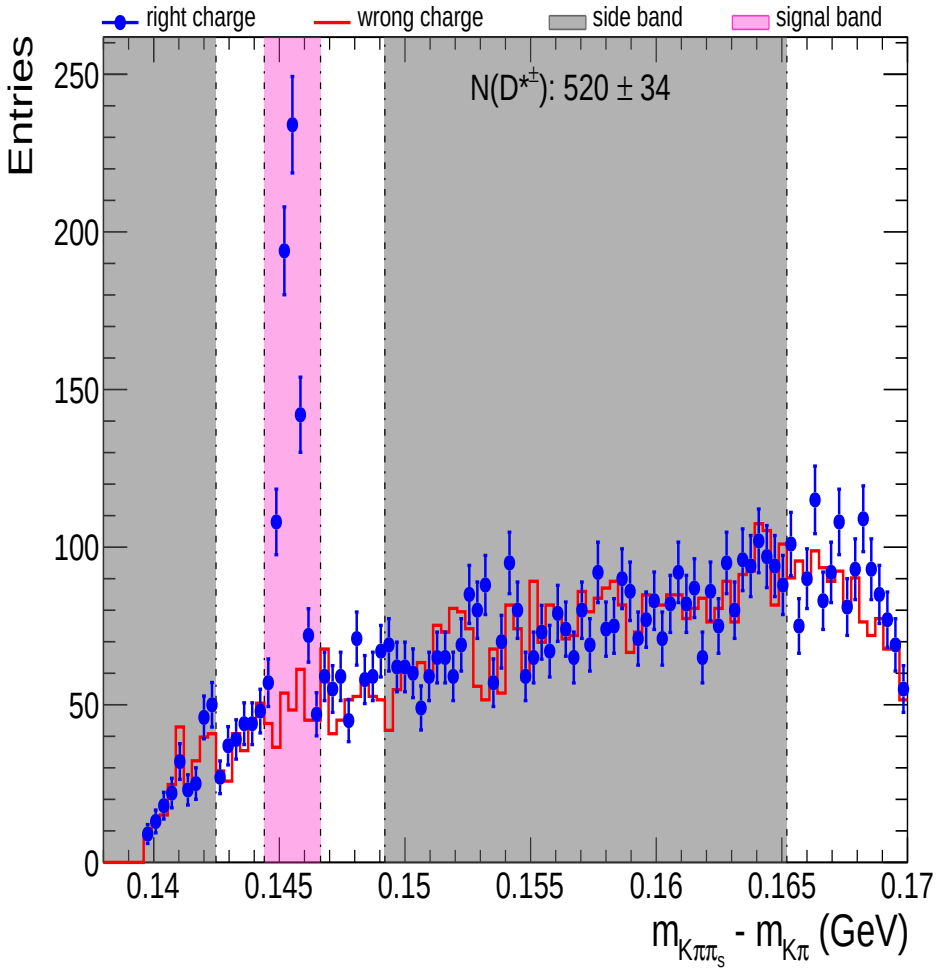
Δm_r at different phase space

p_T:2-3 GeV, |y|:2.0-2.5

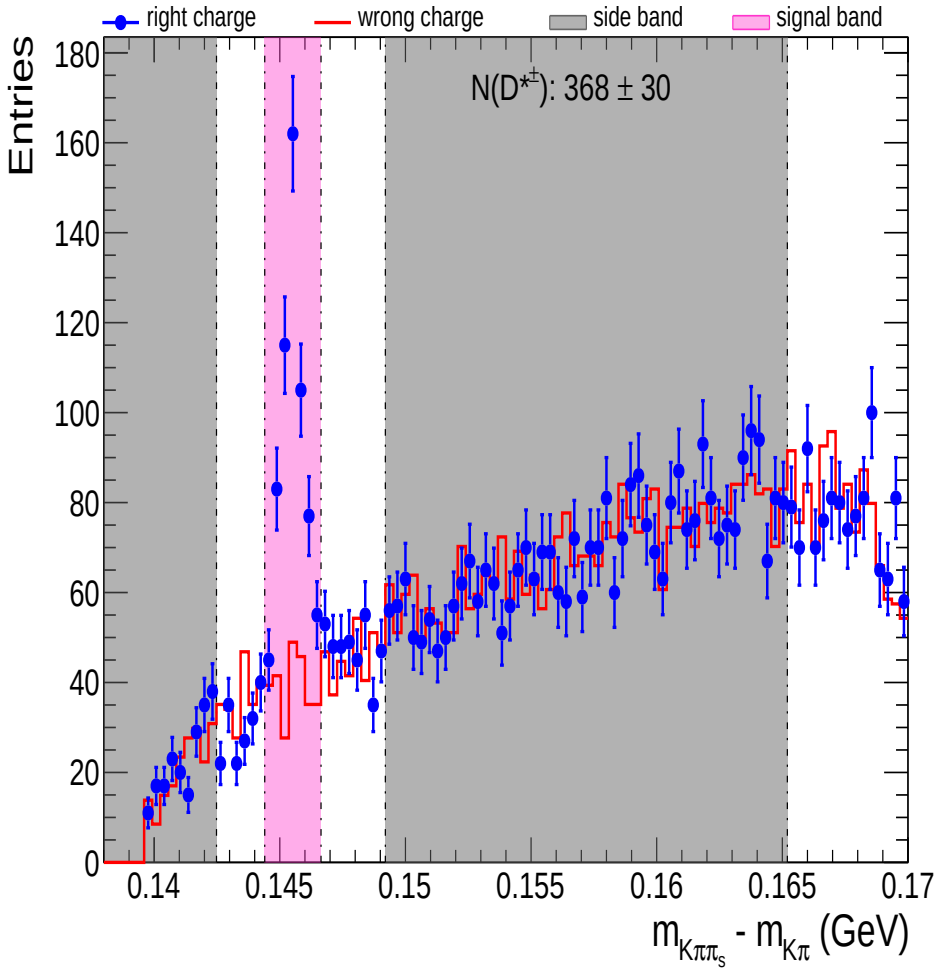


Δm_r at different phase space

p_T:3-4 GeV, |y|:0.0-0.5

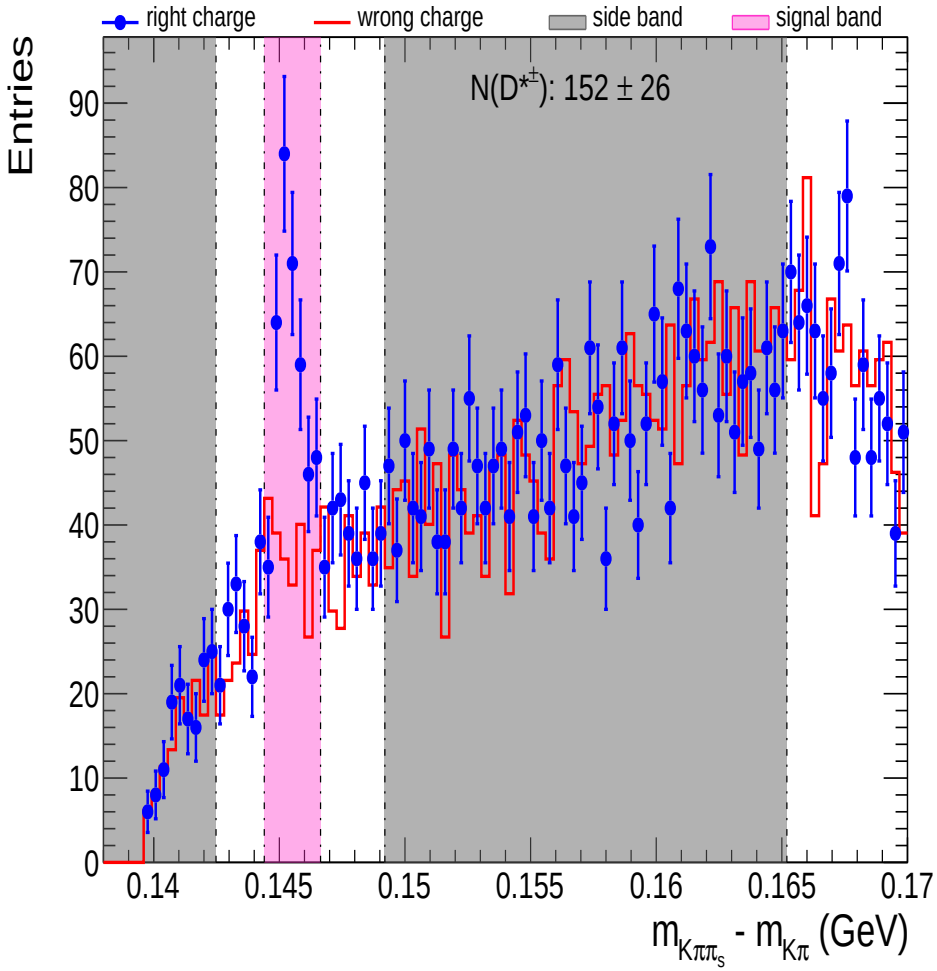


p_T:3-4 GeV, |y|:0.5-1.0

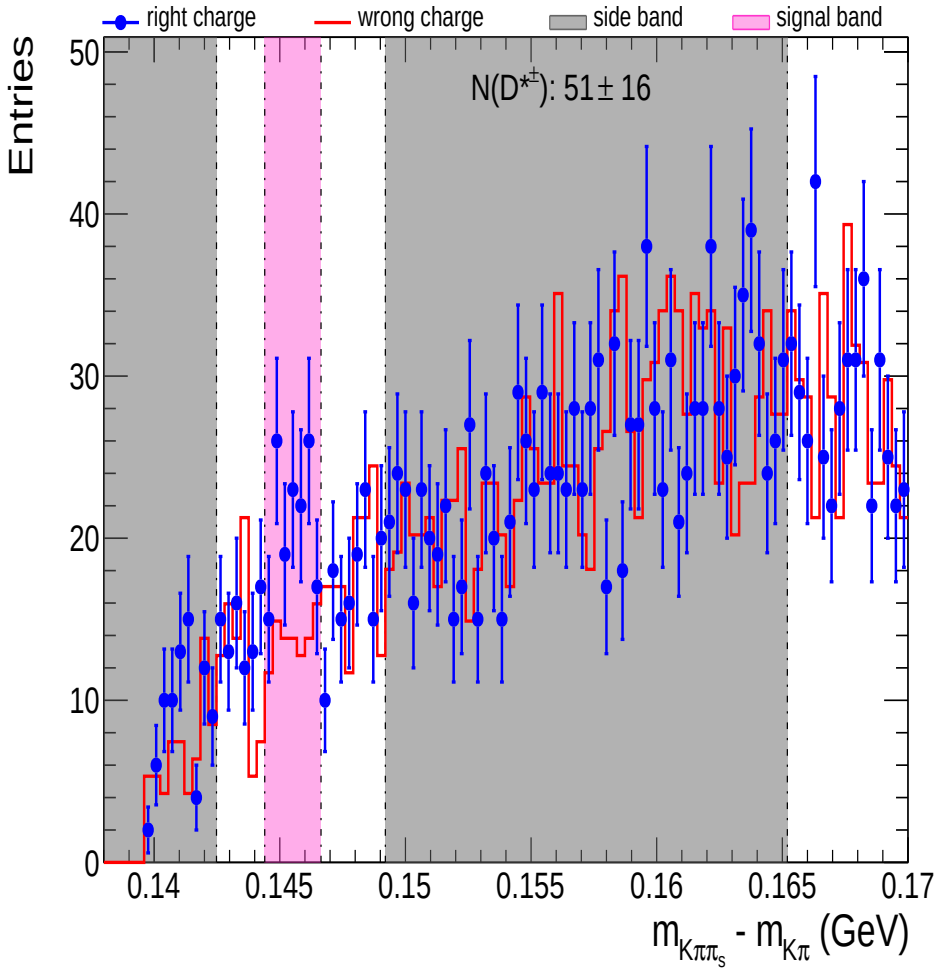


Δm_r at different phase space

p_T:3-4 GeV, |y|:1.0-1.5

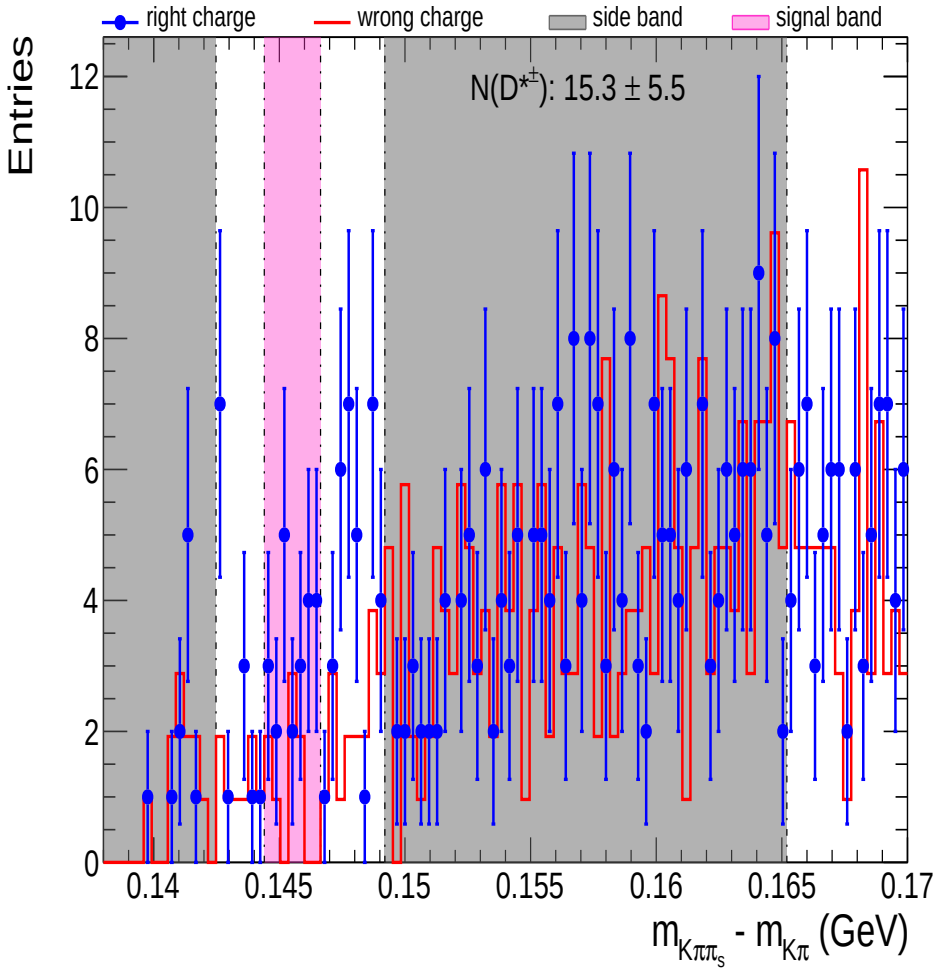


p_T:3-4 GeV, |y|:1.5-2.0



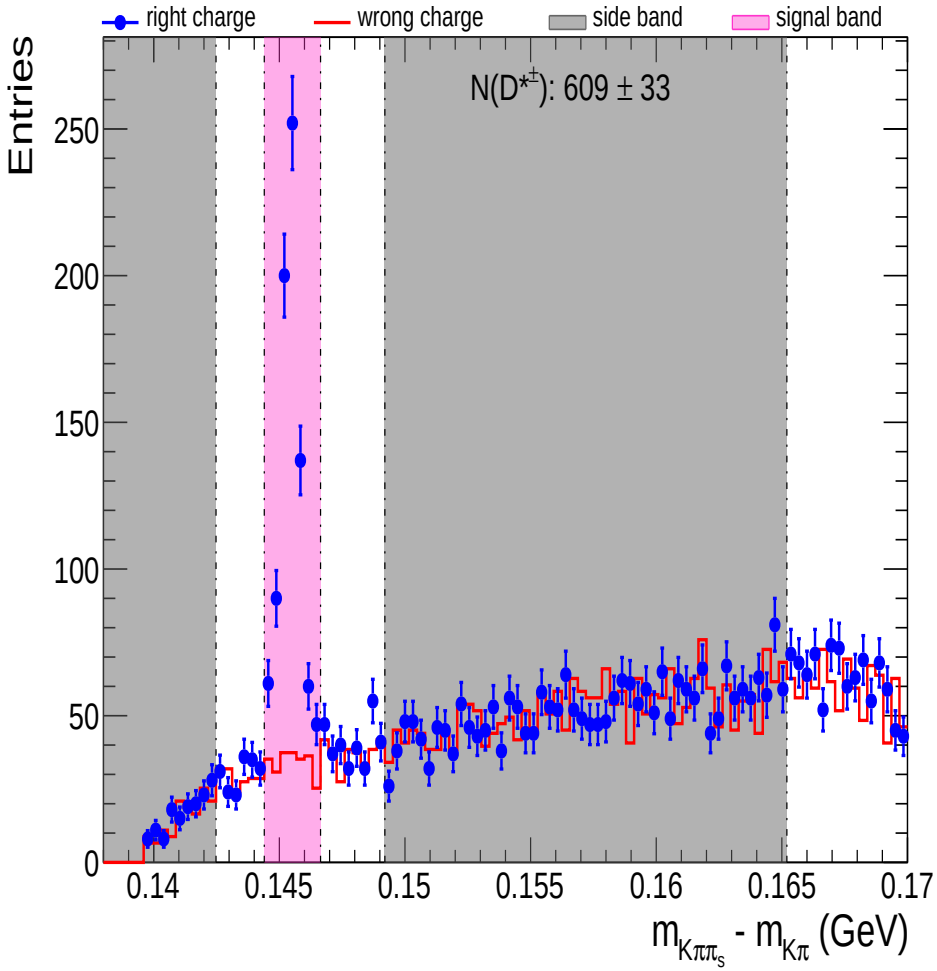
Δm_r at different phase space

p_T:3-4 GeV, |y|:2.0-2.5

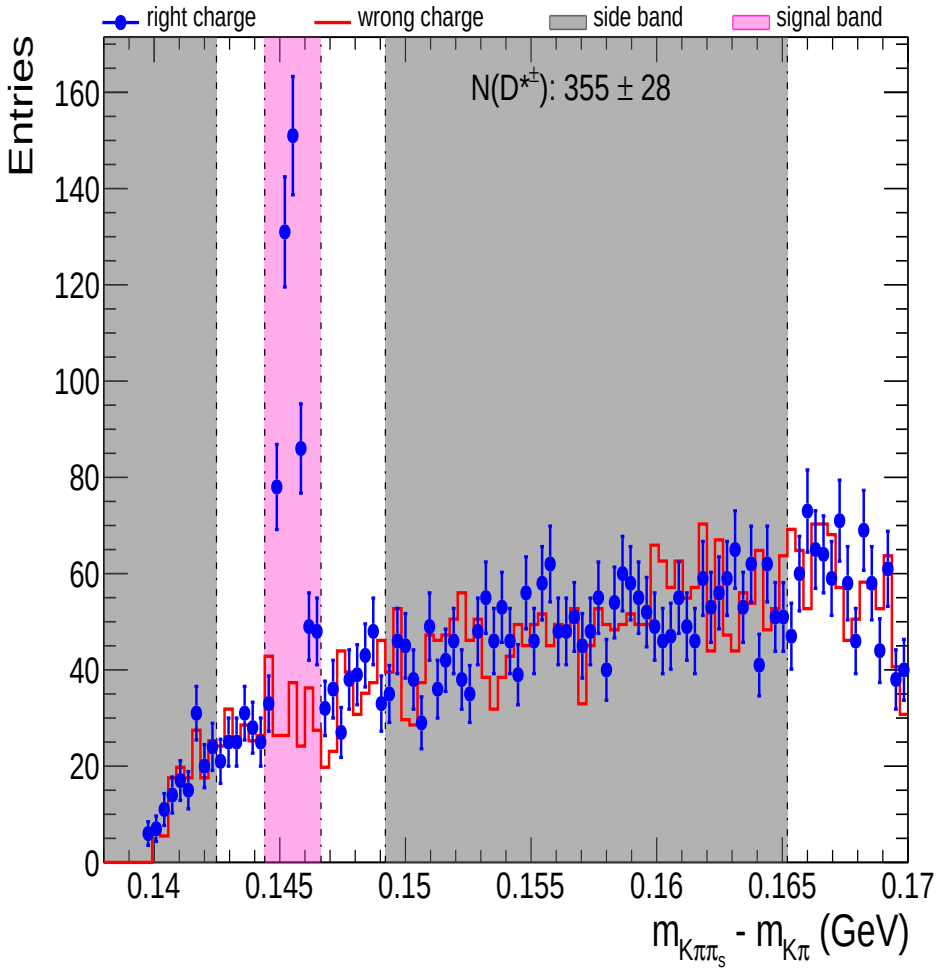


Δm_r at different phase space

p_T:4-5 GeV, |y|:0.0-0.5

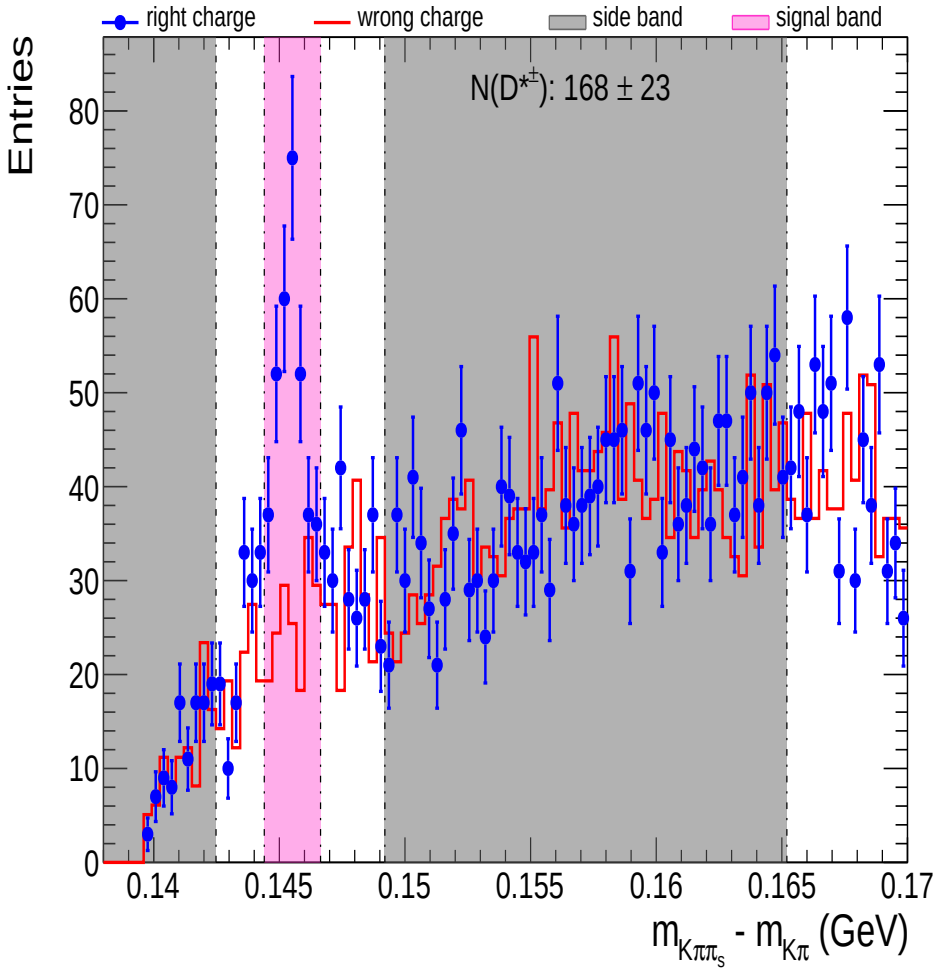


p_T:4-5 GeV, |y|:0.5-1.0

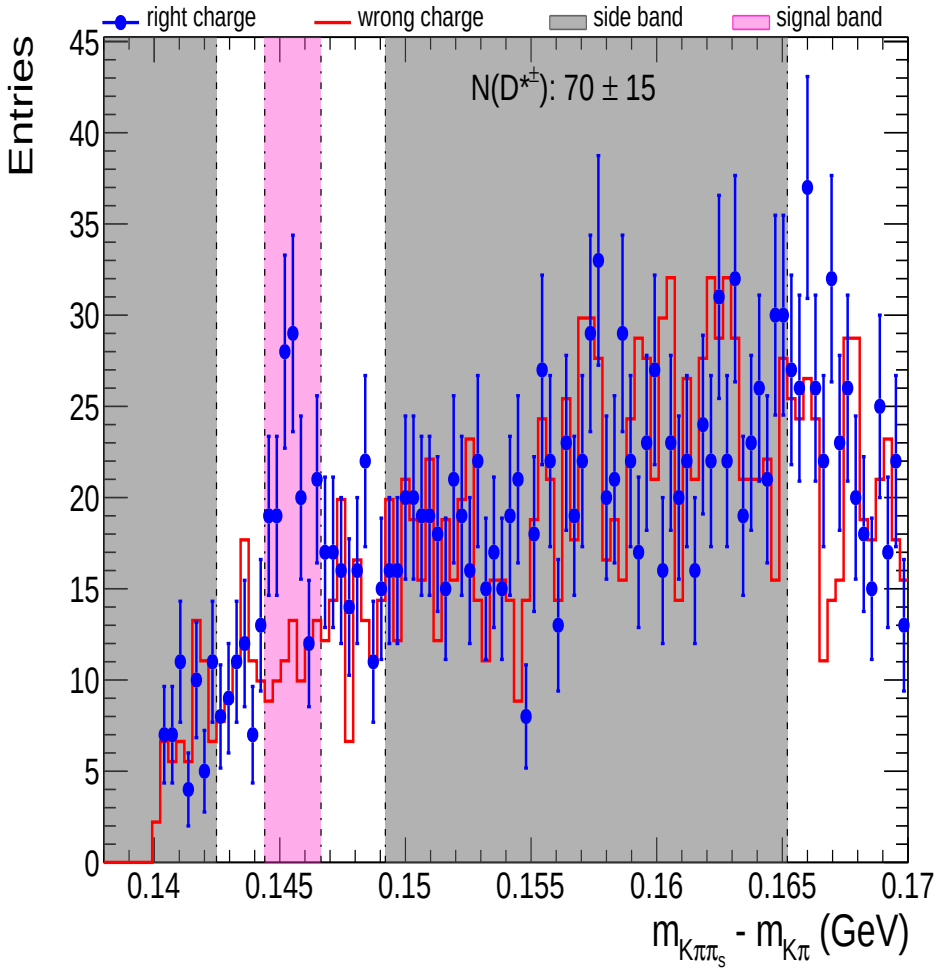


Δm_r at different phase space

p_T:4-5 GeV, |y|:1.0-1.5

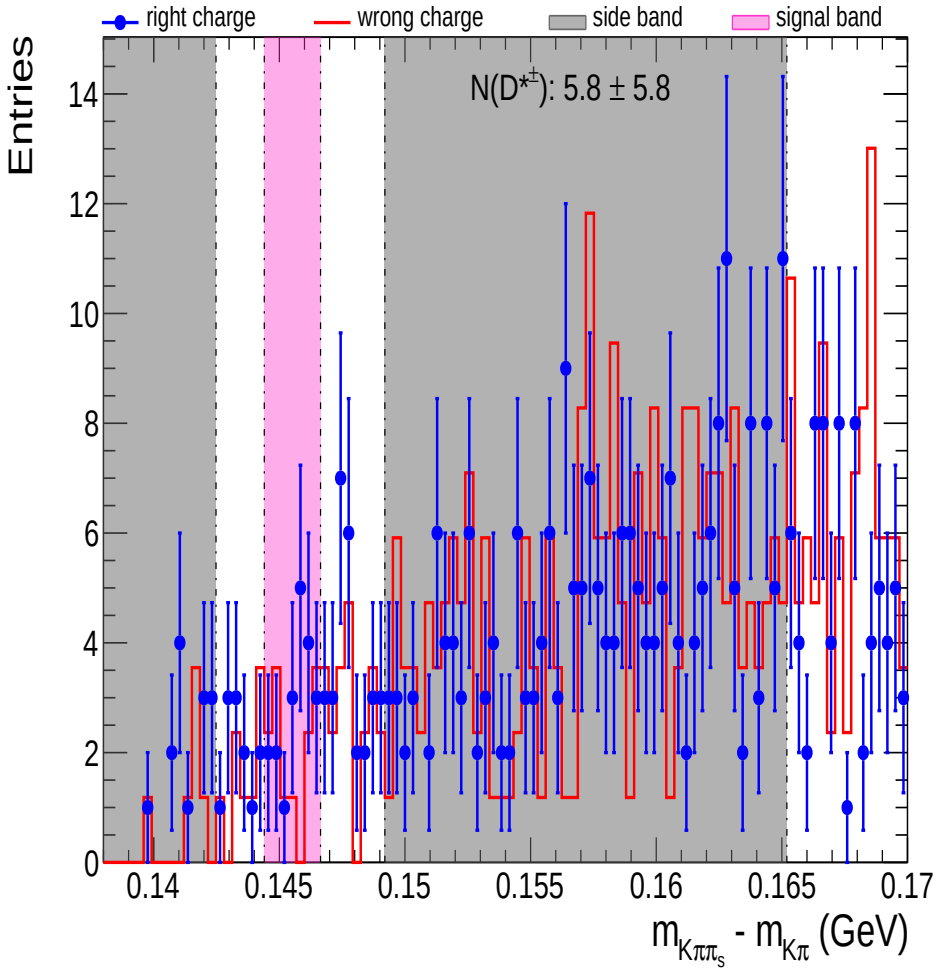


p_T:4-5 GeV, |y|:1.5-2.0



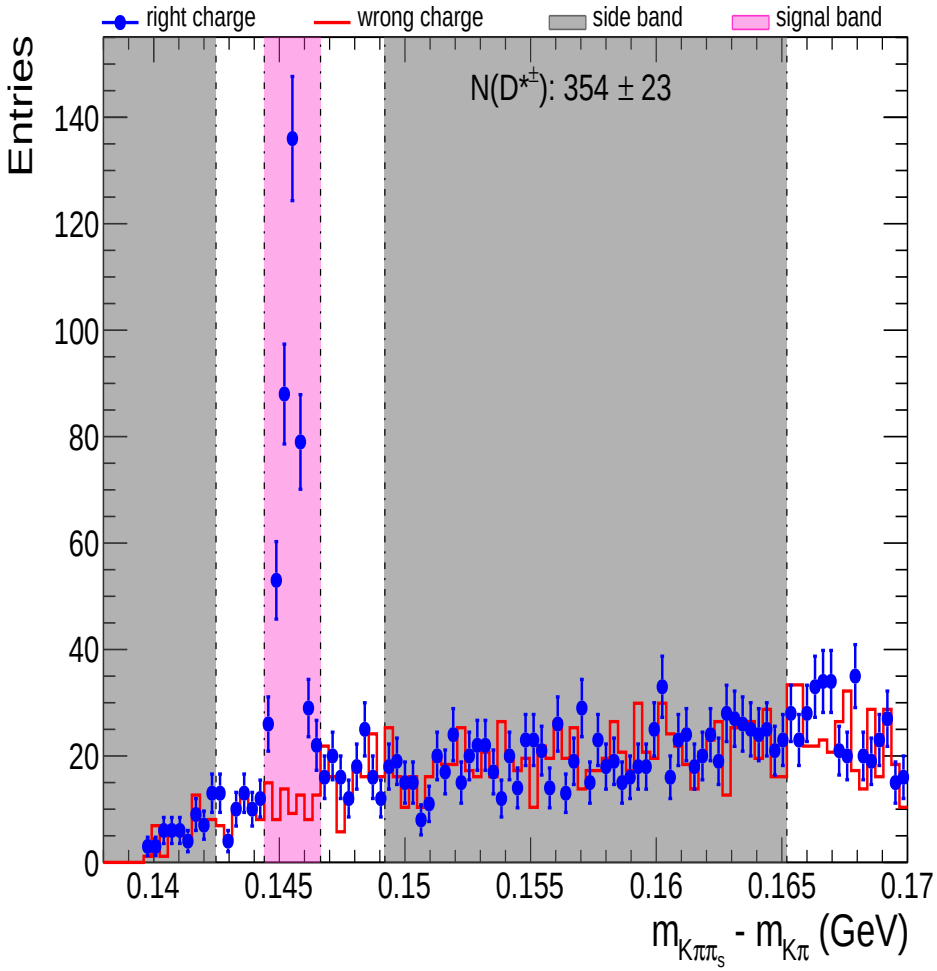
Δm_r at different phase space

p_T:4-5 GeV, |y|:2.0-2.5

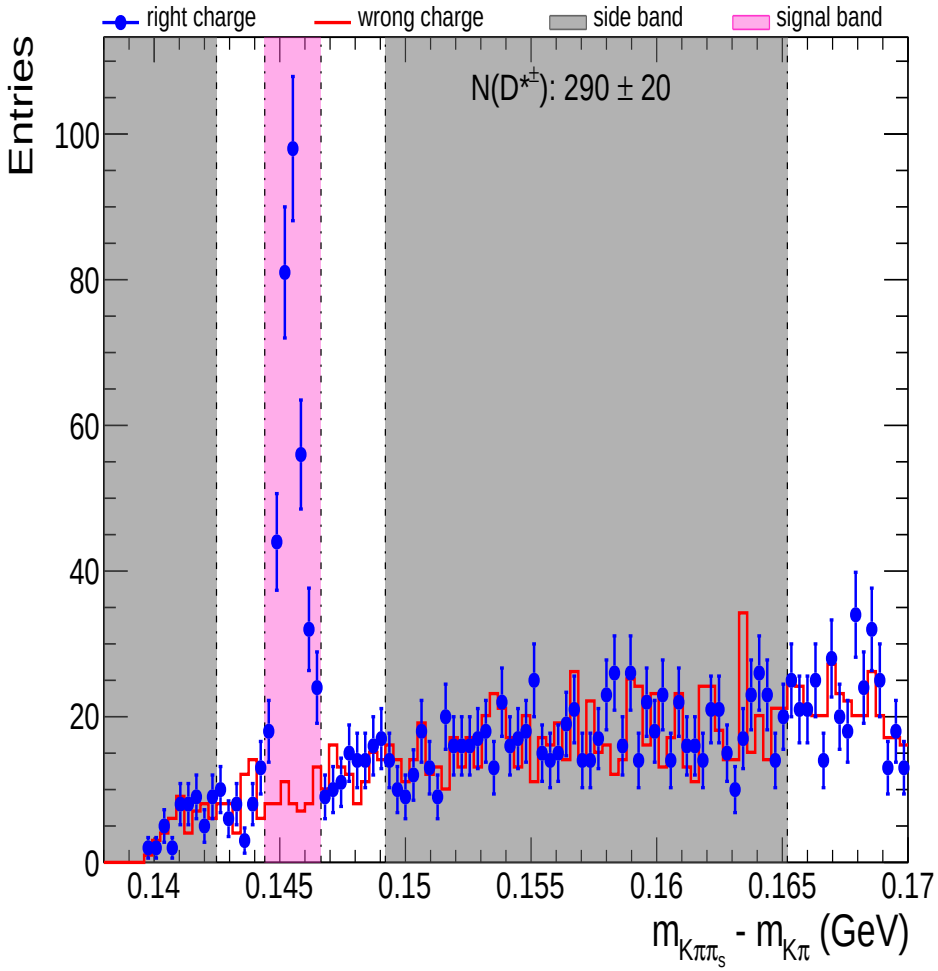


Δm_r at different phase space

p_T:5-6 GeV, |y|:0.0-0.5

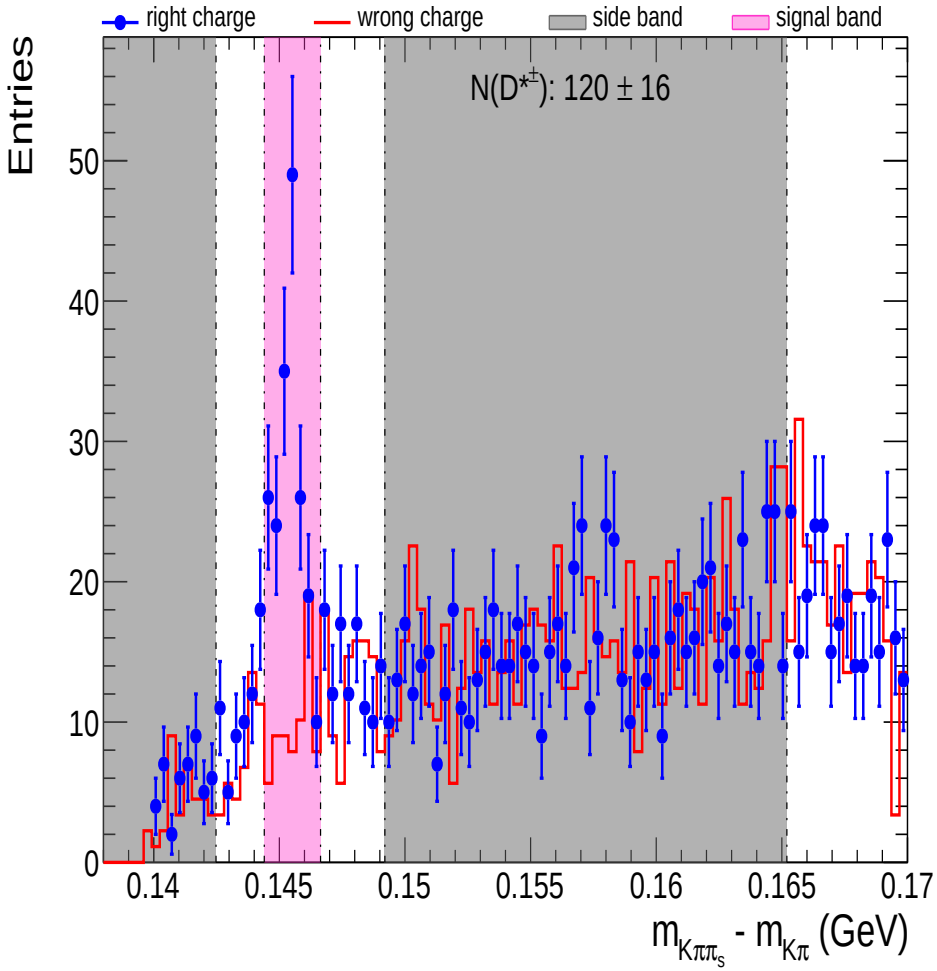


p_T:5-6 GeV, |y|:0.5-1.0

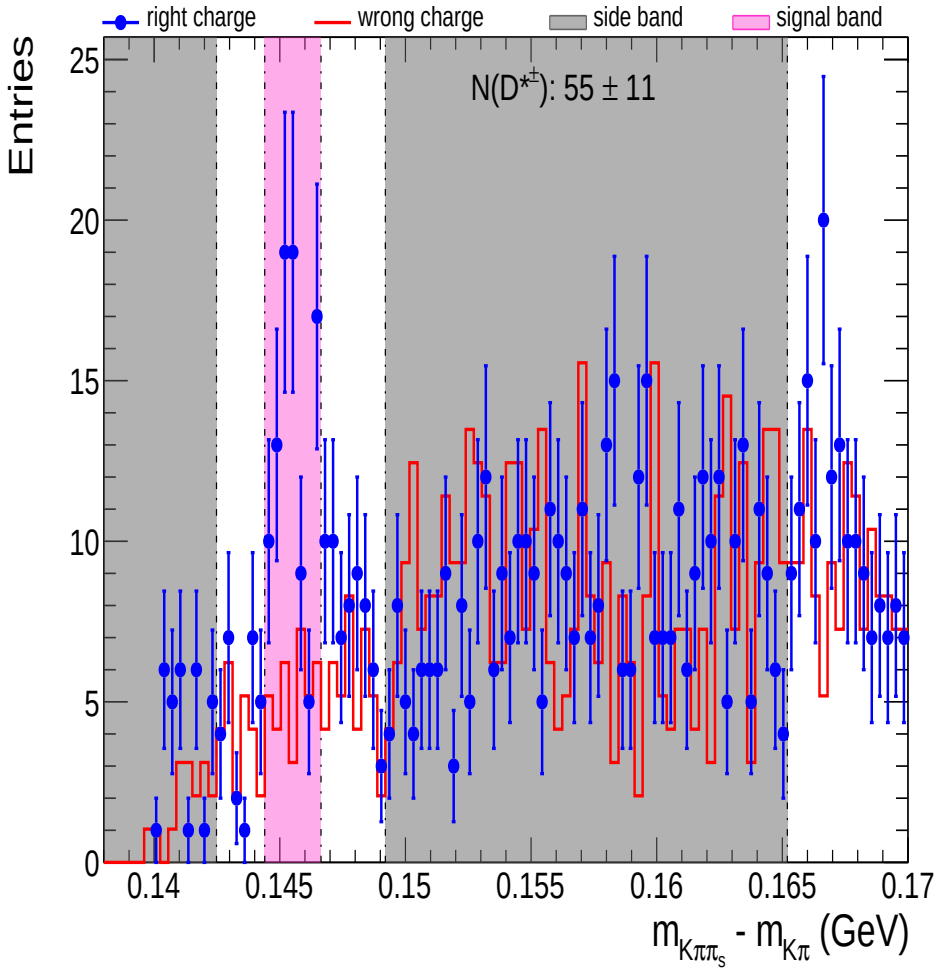


Δm_r at different phase space

p_T:5-6 GeV, |y|:1.0-1.5

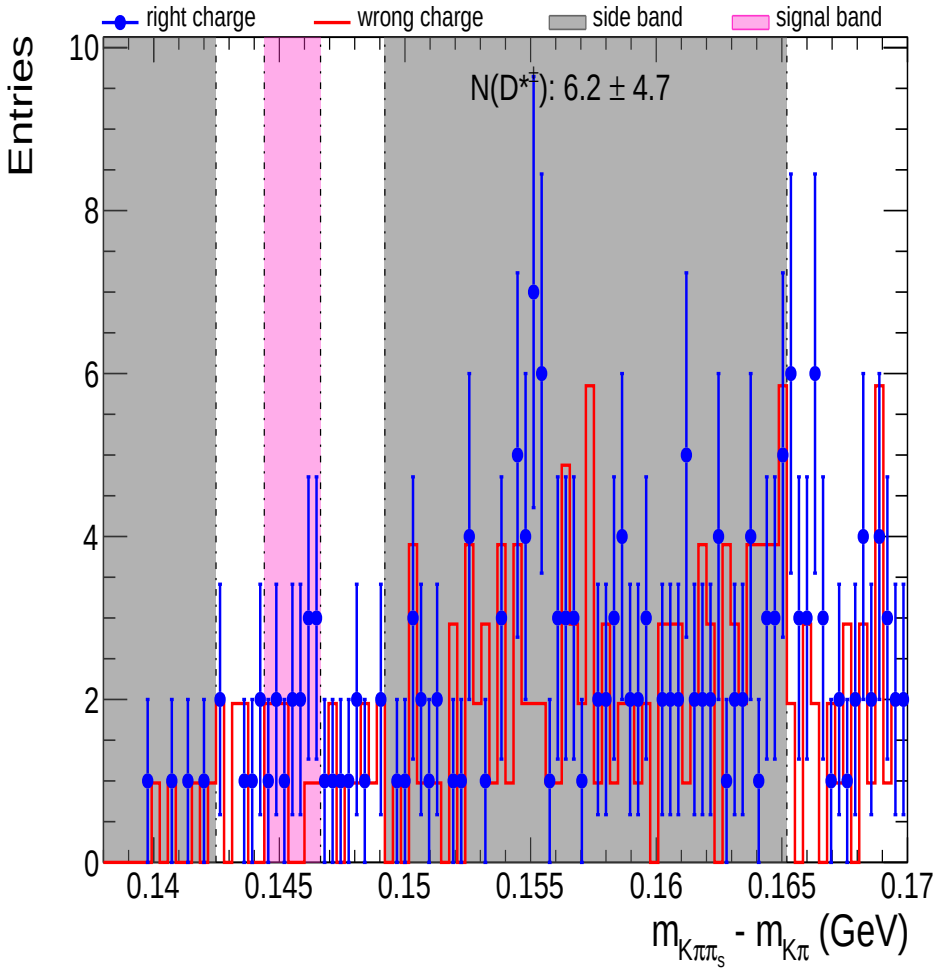


p_T:5-6 GeV, |y|:1.5-2.0



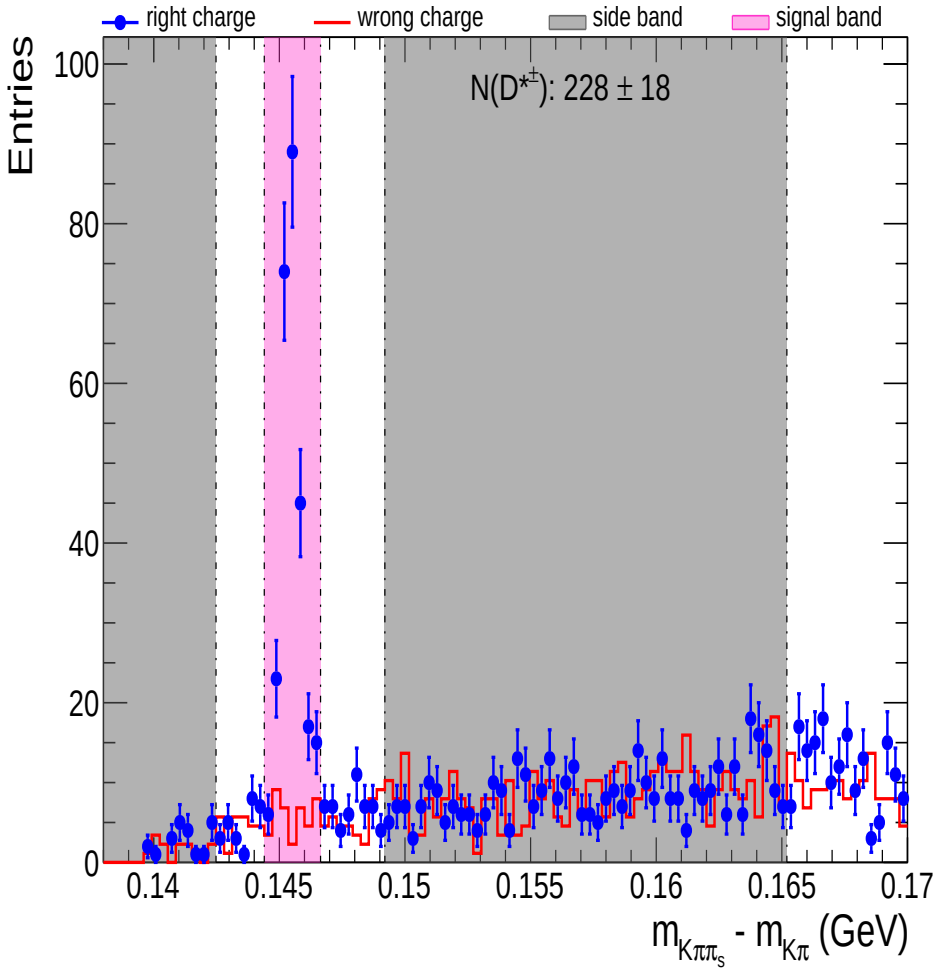
Δm_r at different phase space

p_T:5-6 GeV, |y|:2.0-2.5

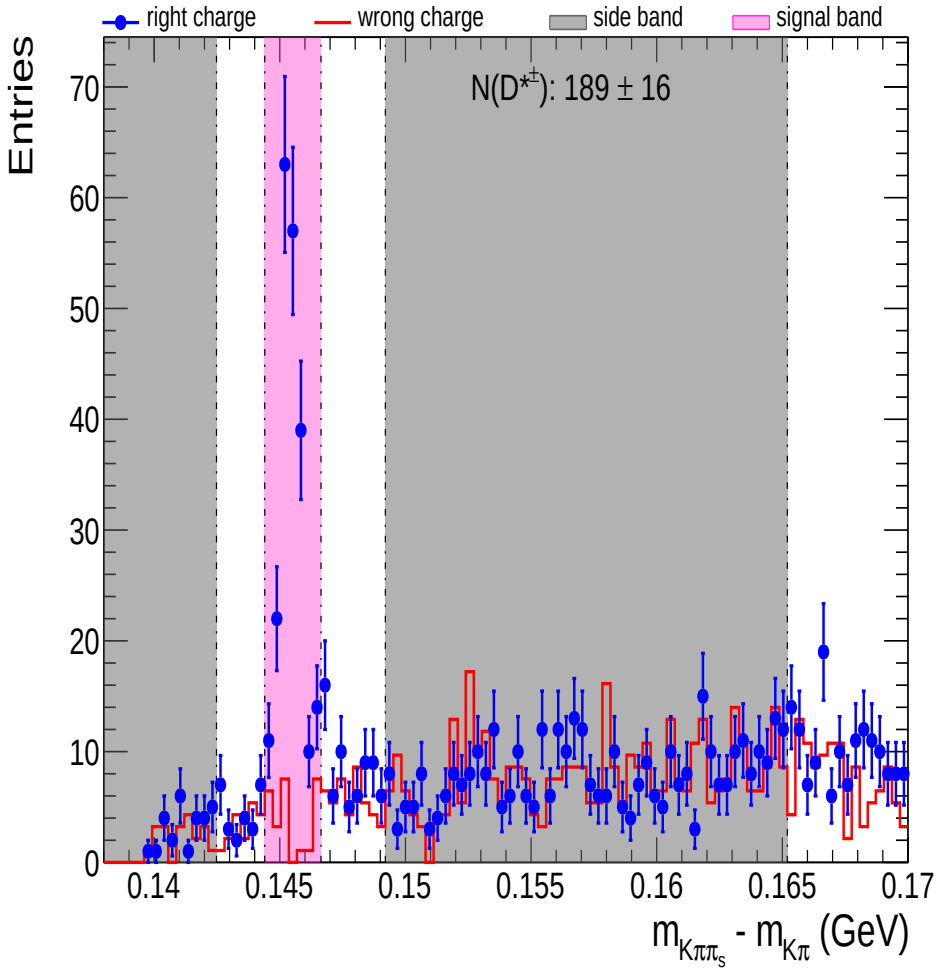


Δm_r at different phase space

p_T:6-7 GeV, |y|:0.0-0.5

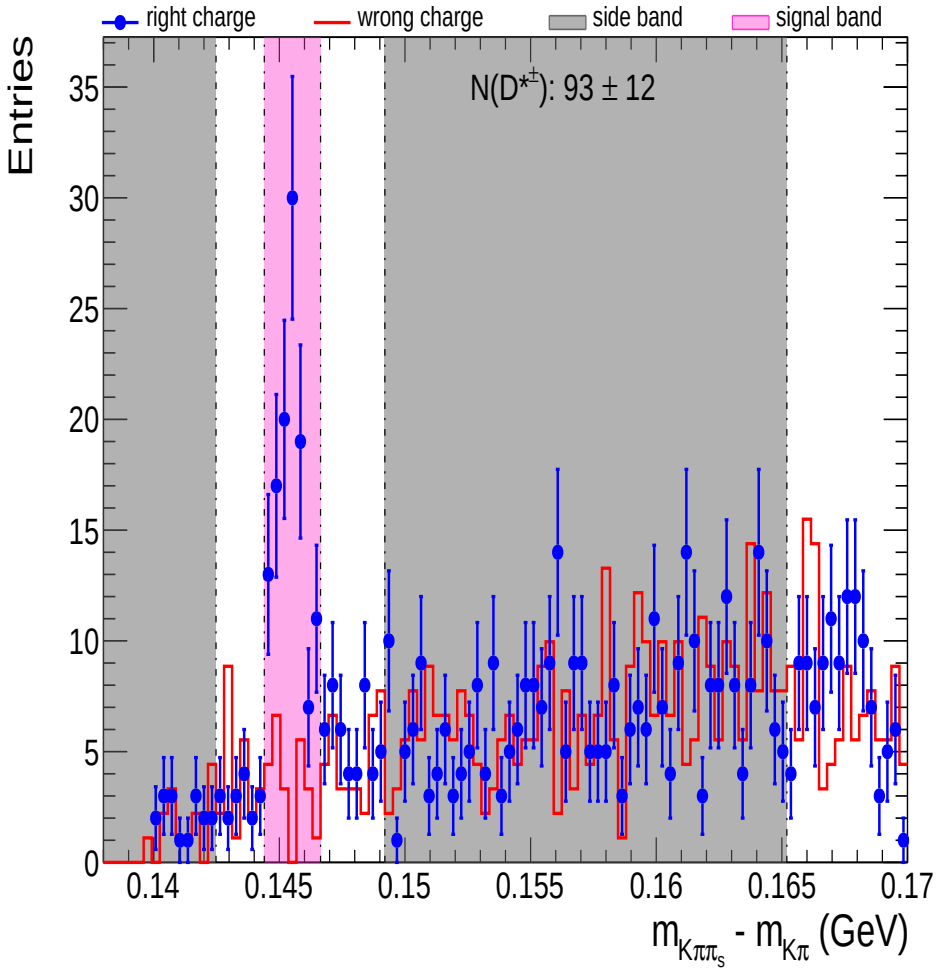


p_T:6-7 GeV, |y|:0.5-1.0

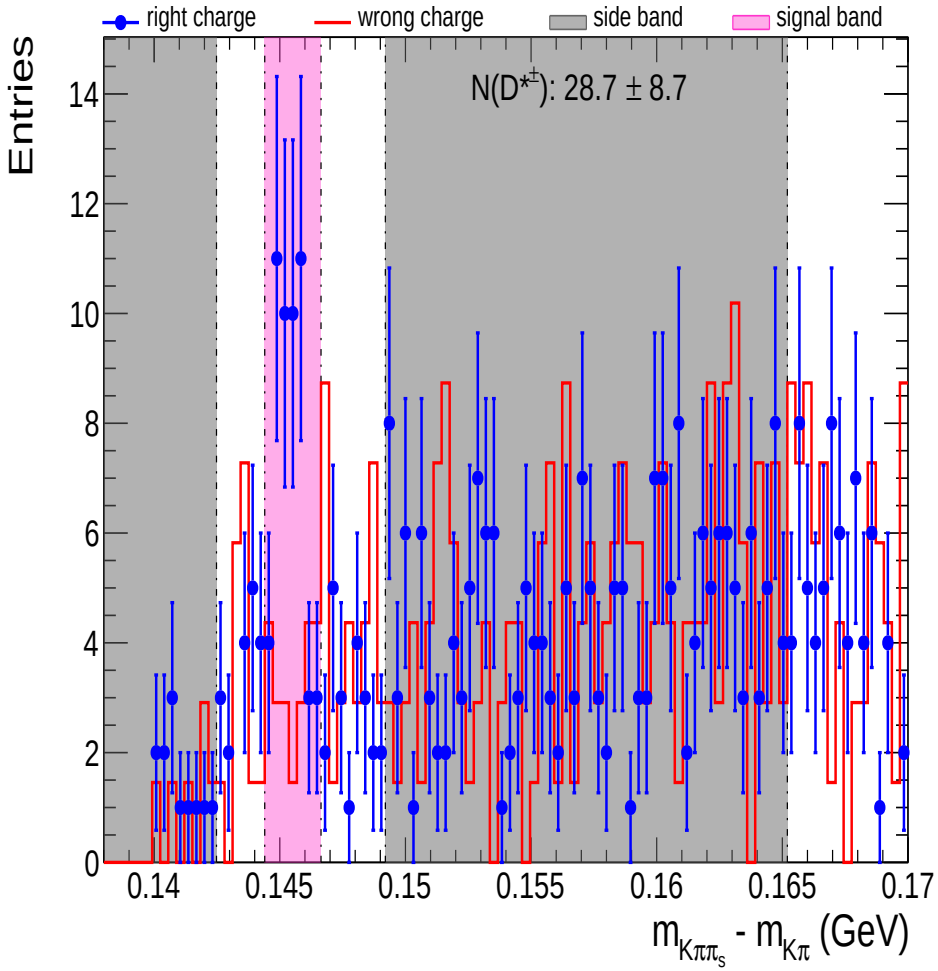


Δm_r at different phase space

p_T:6-7 GeV, |y|:1.0-1.5

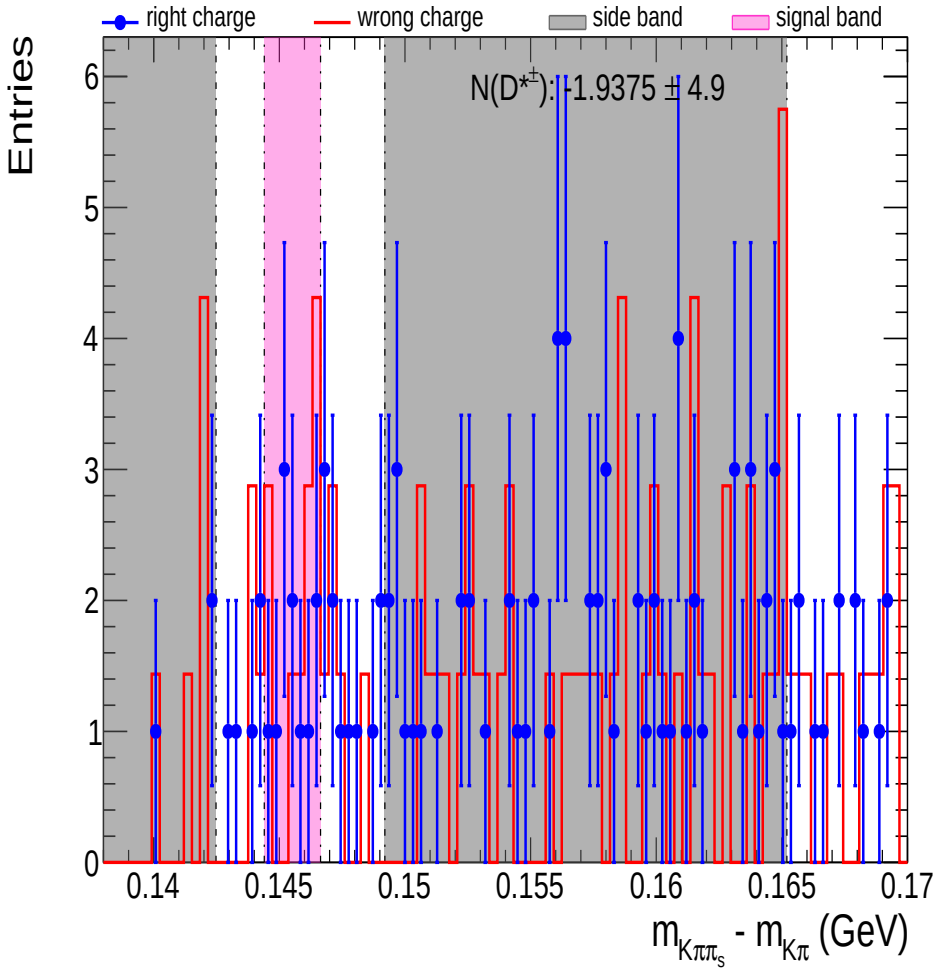


p_T:6-7 GeV, |y|:1.5-2.0



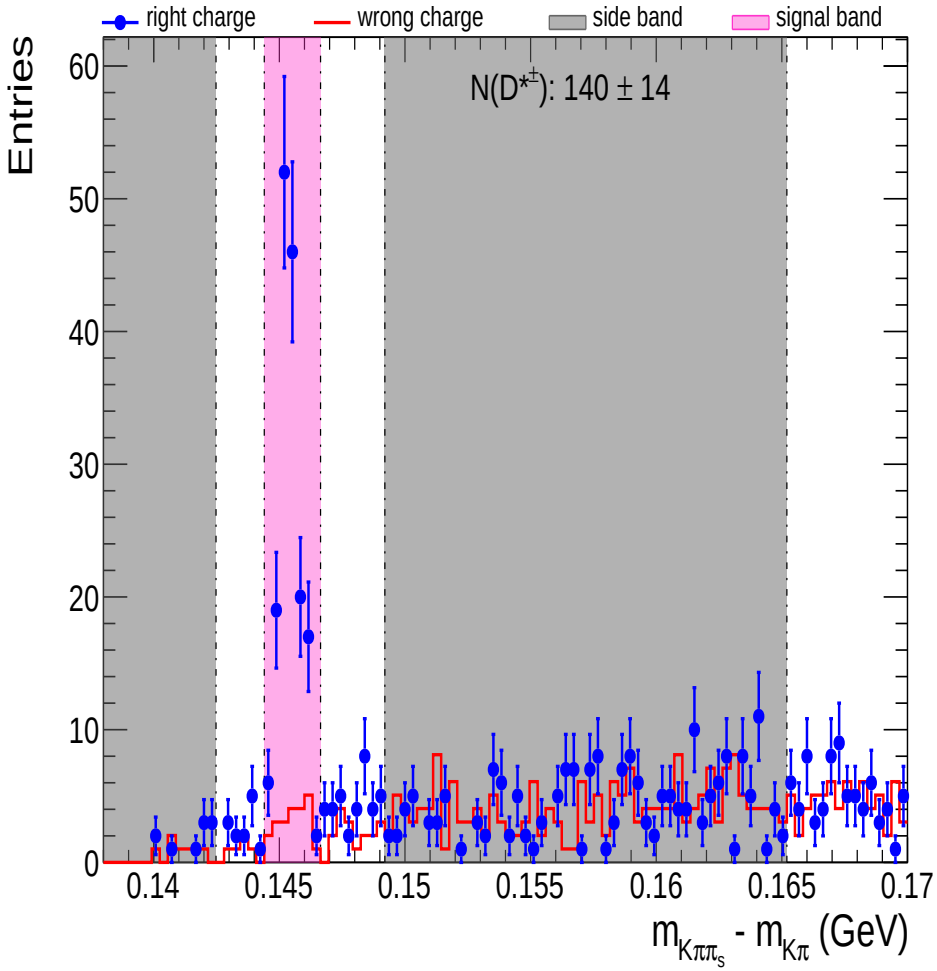
Δm_r at different phase space

p_T:6-7 GeV, |y|:2.0-2.5

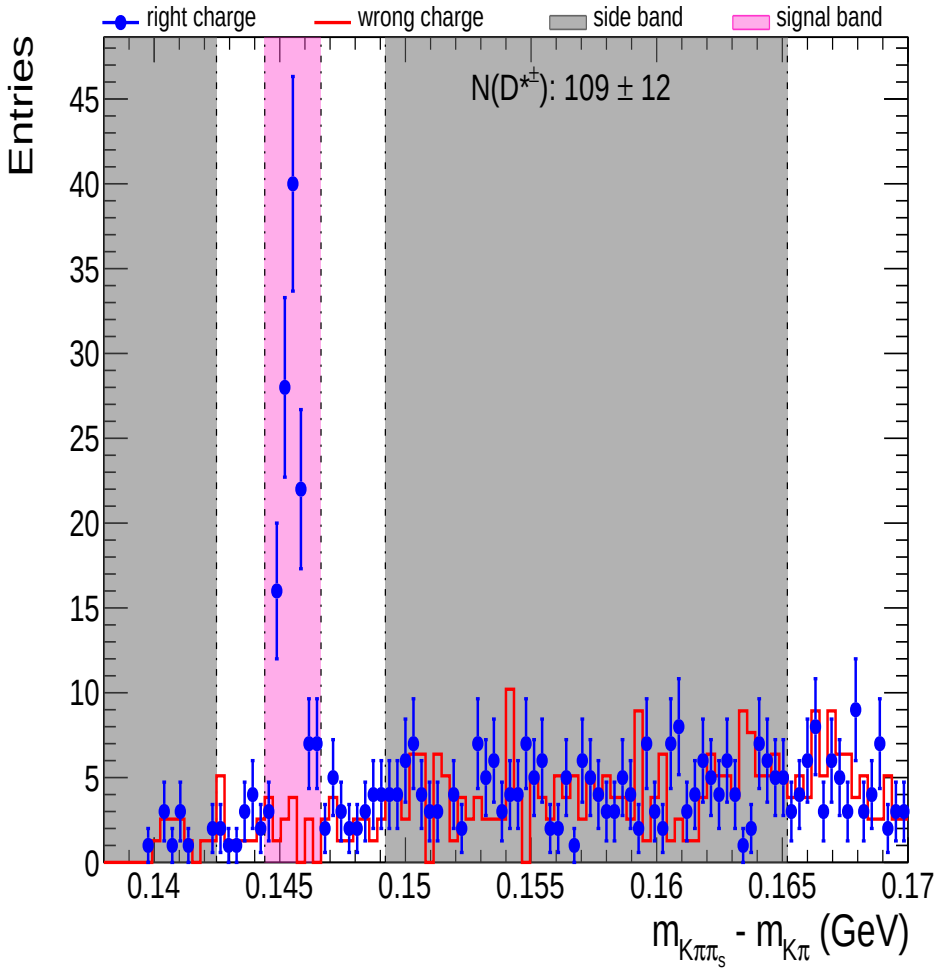


Δm_r at different phase space

p_T:7-8 GeV, |y|:0.0-0.5

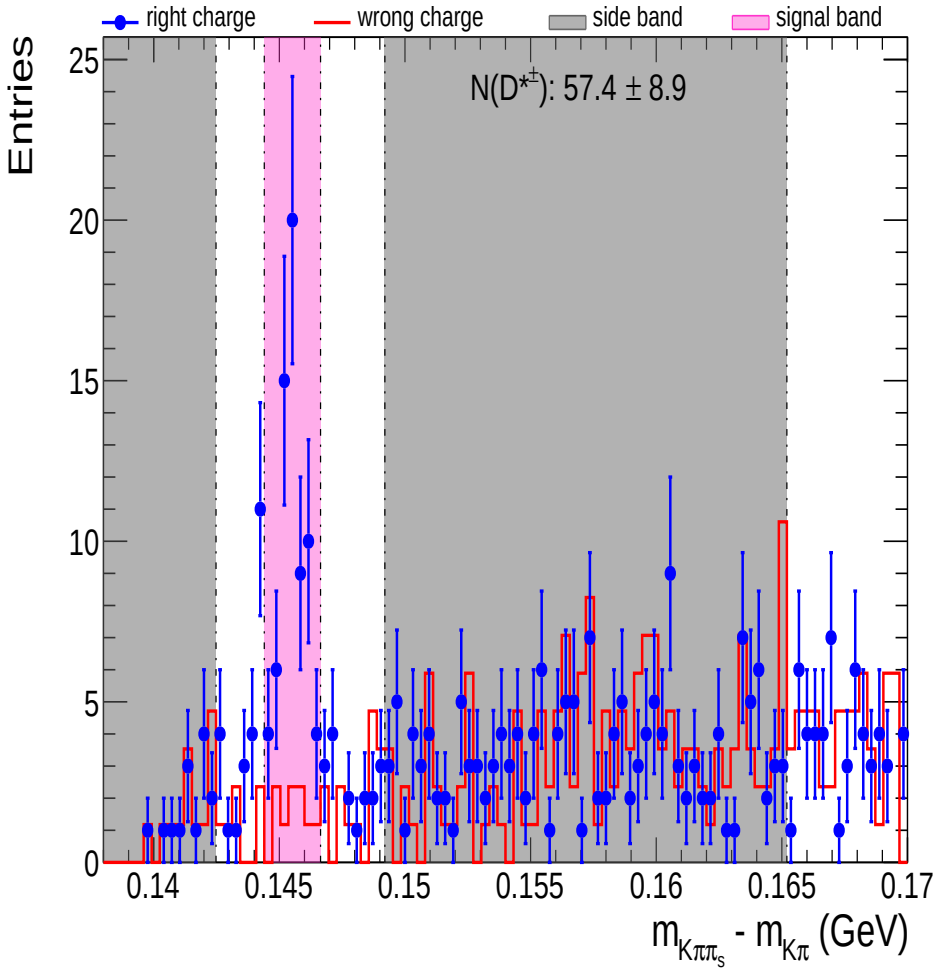


p_T:7-8 GeV, |y|:0.5-1.0

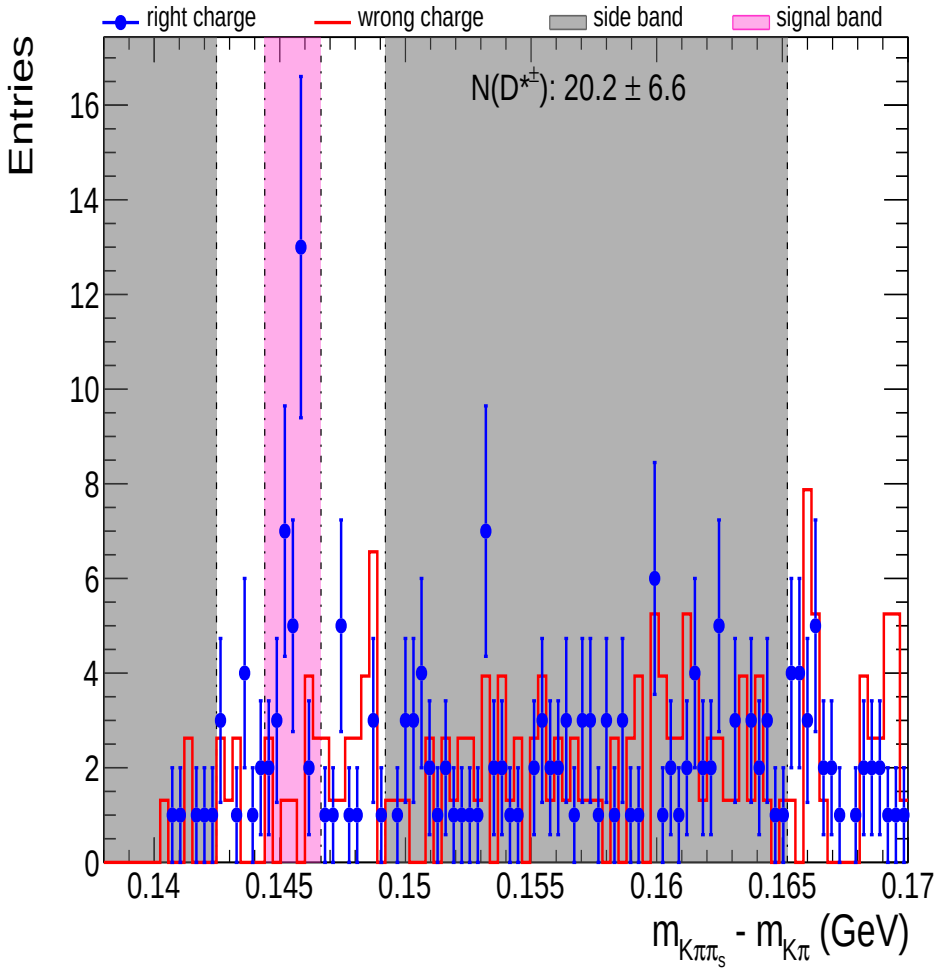


Δm_r at different phase space

p_T:7-8 GeV, |y|:1.0-1.5

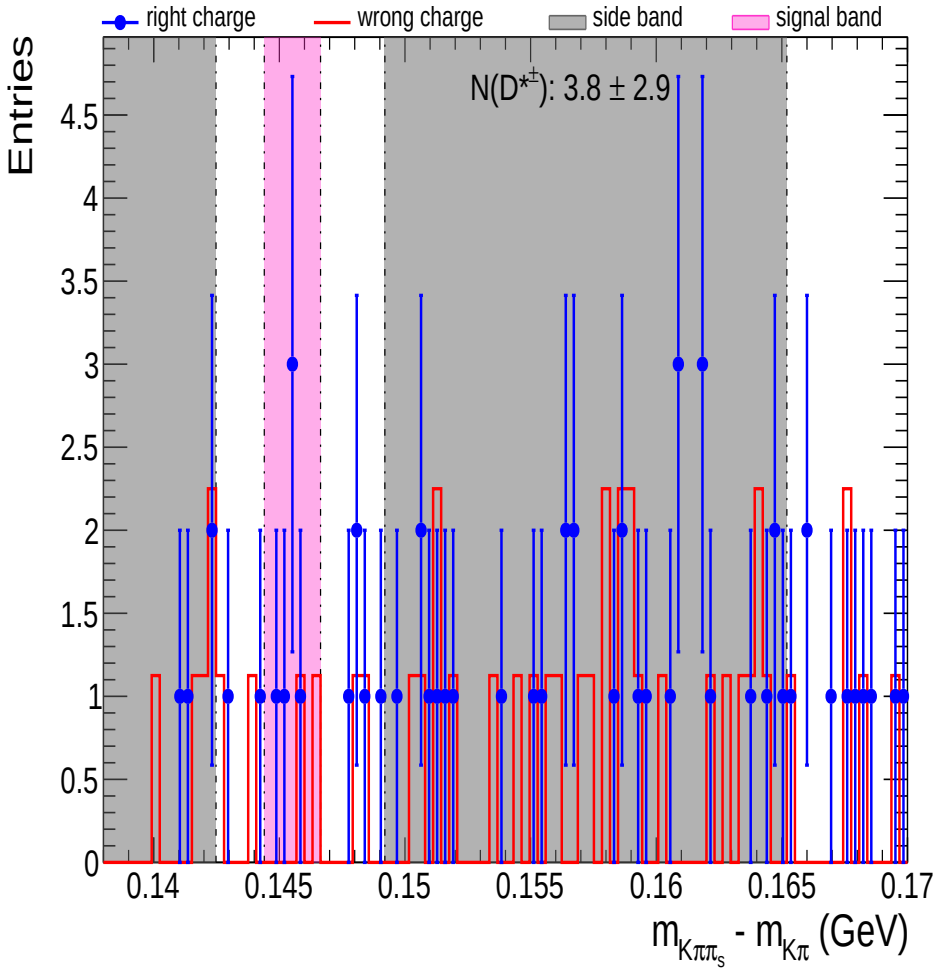


p_T:7-8 GeV, |y|:1.5-2.0



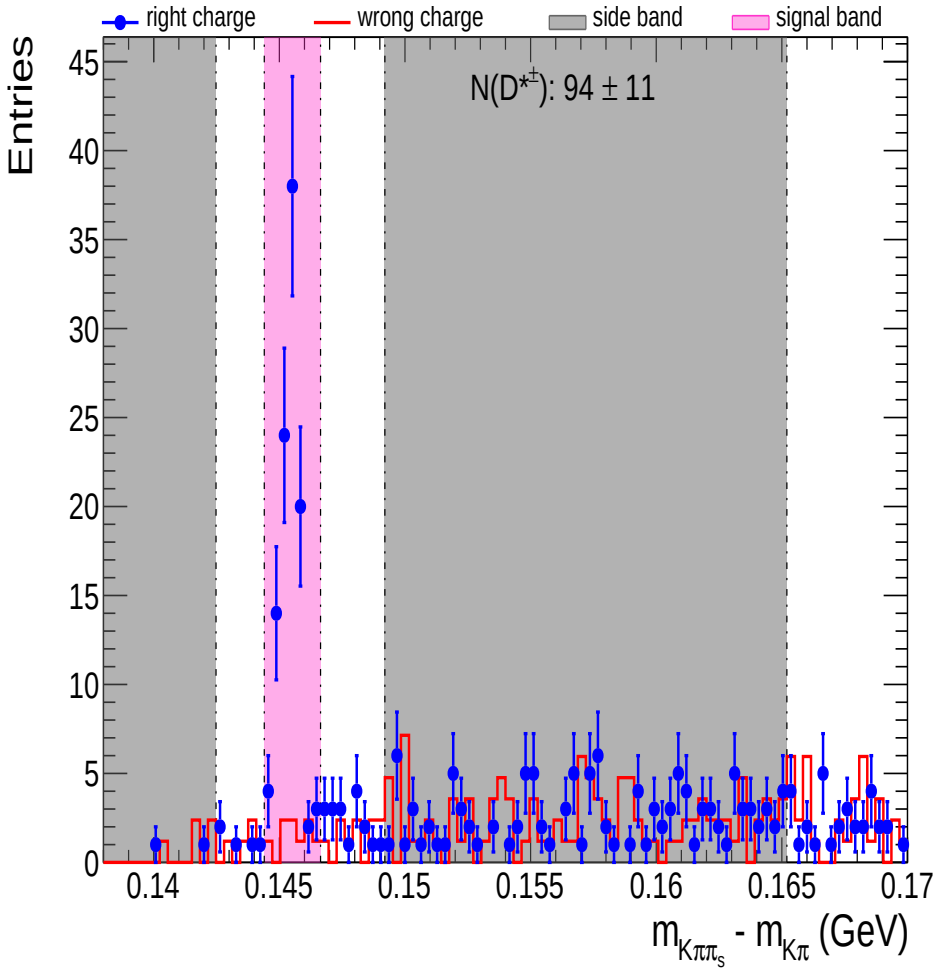
Δm_r at different phase space

p_T:7-8 GeV, |y|:2.0-2.5

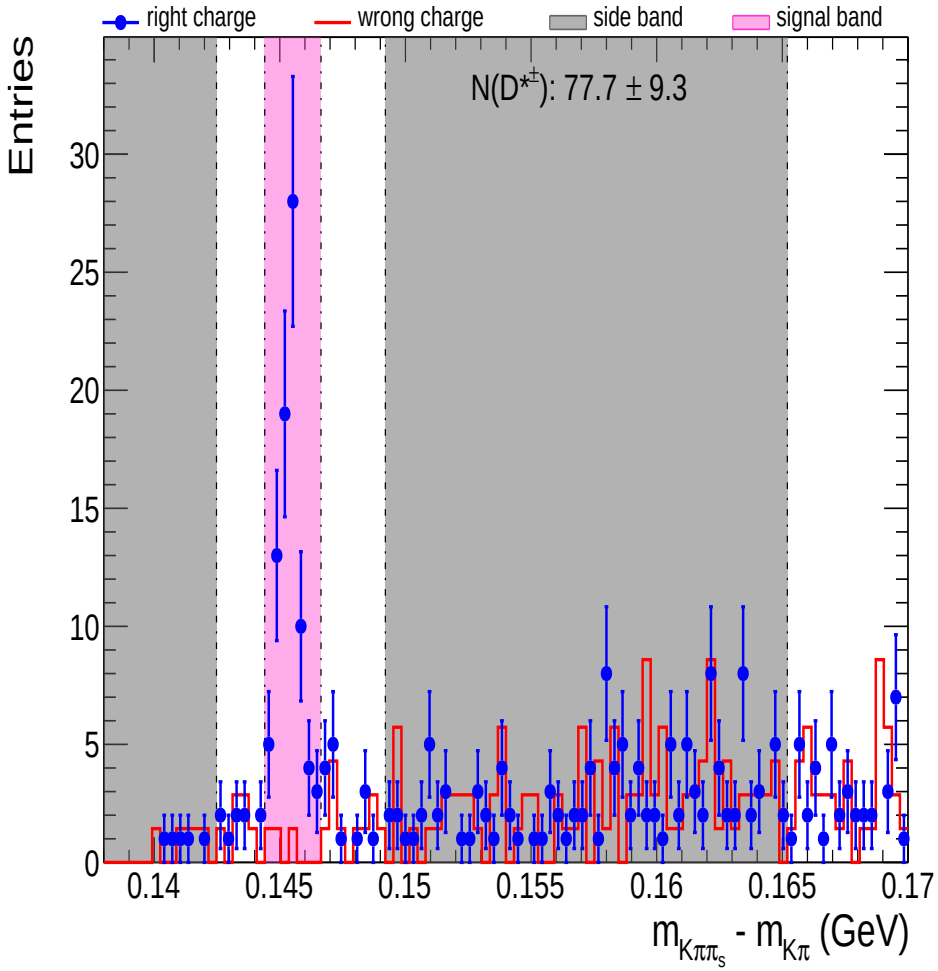


Δm_r at different phase space

p_T:8-9 GeV, |y|:0.0-0.5

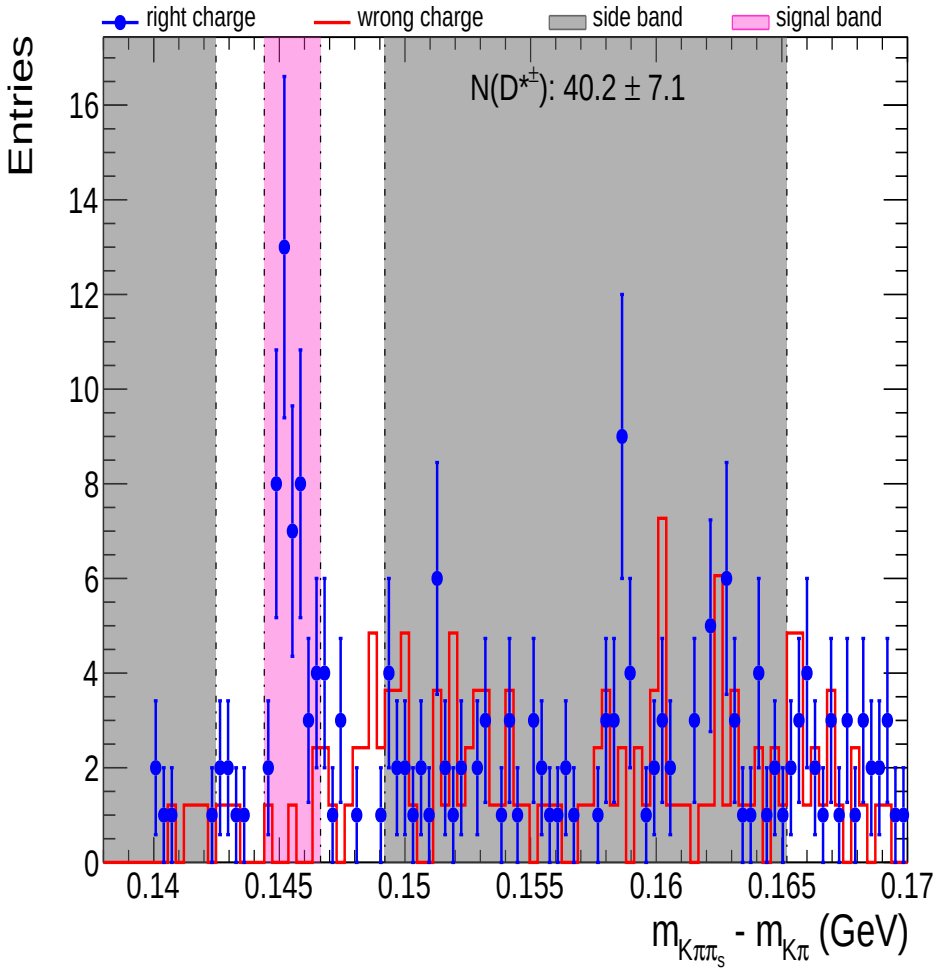


p_T:8-9 GeV, |y|:0.5-1.0

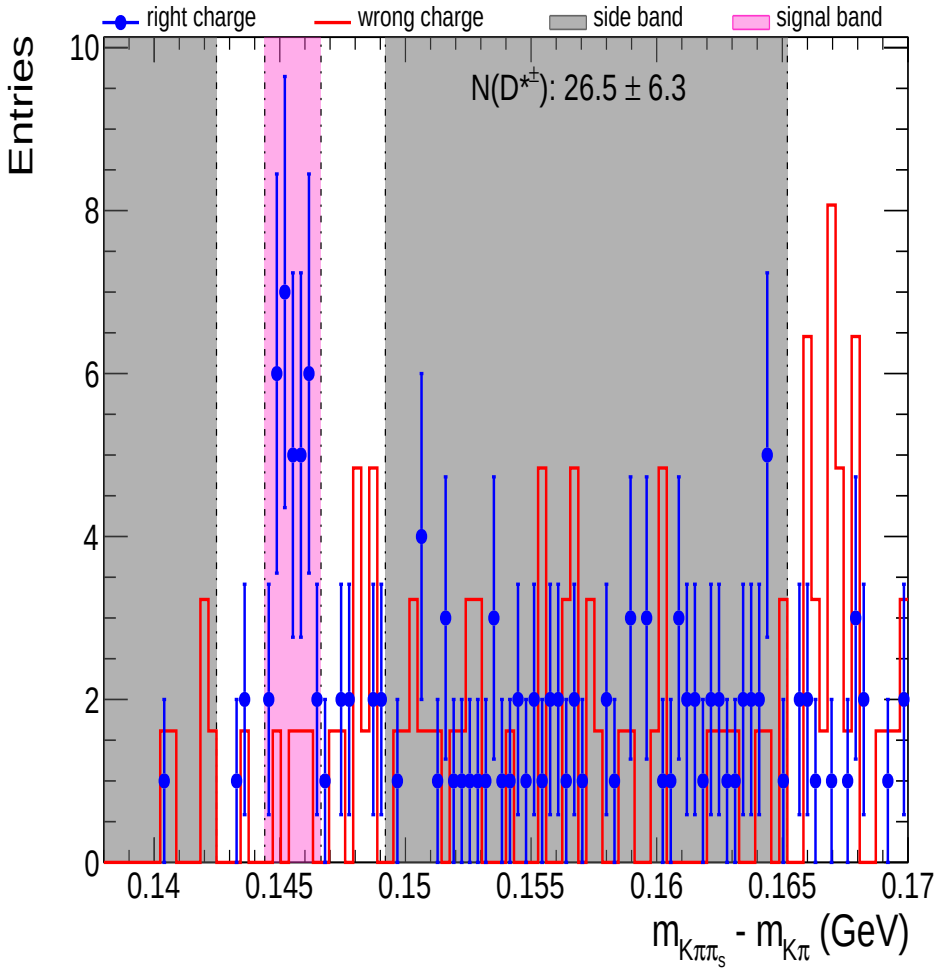


Δm_r at different phase space

p_T:8-9 GeV, |y|:1.0-1.5

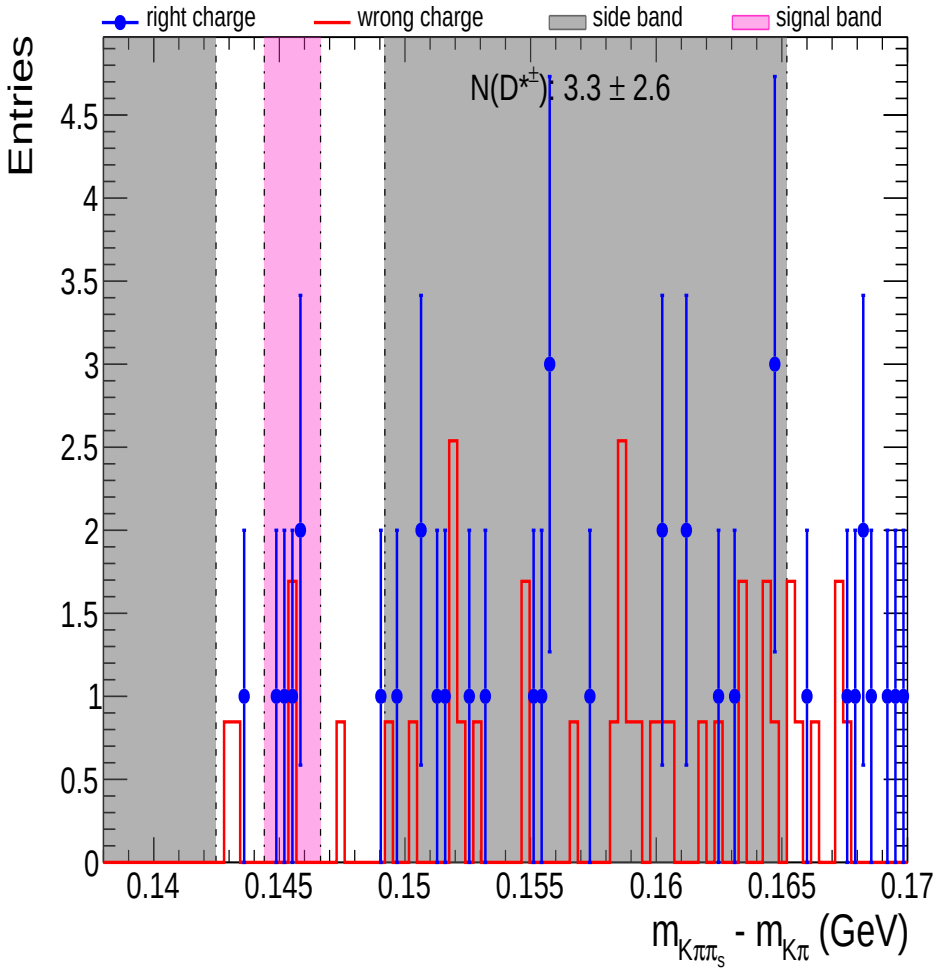


p_T:8-9 GeV, |y|:1.5-2.0



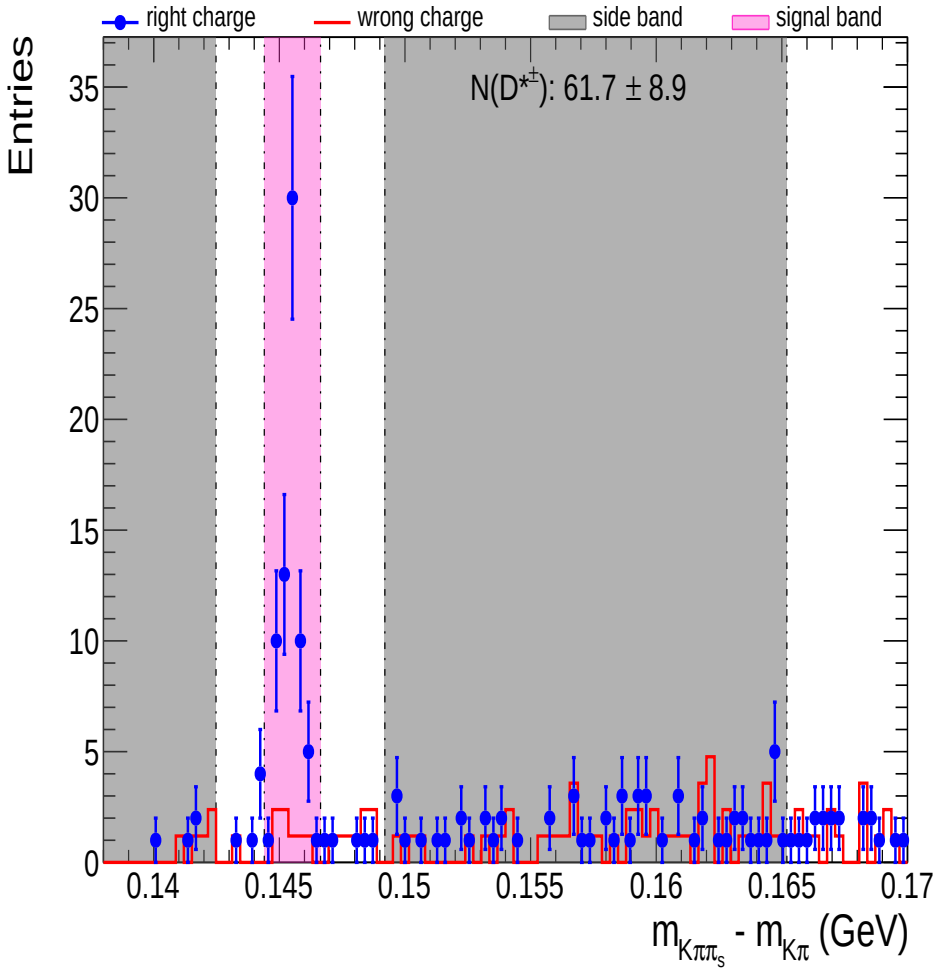
Δm_r at different phase space

p_T:8-9 GeV, |y|:2.0-2.5

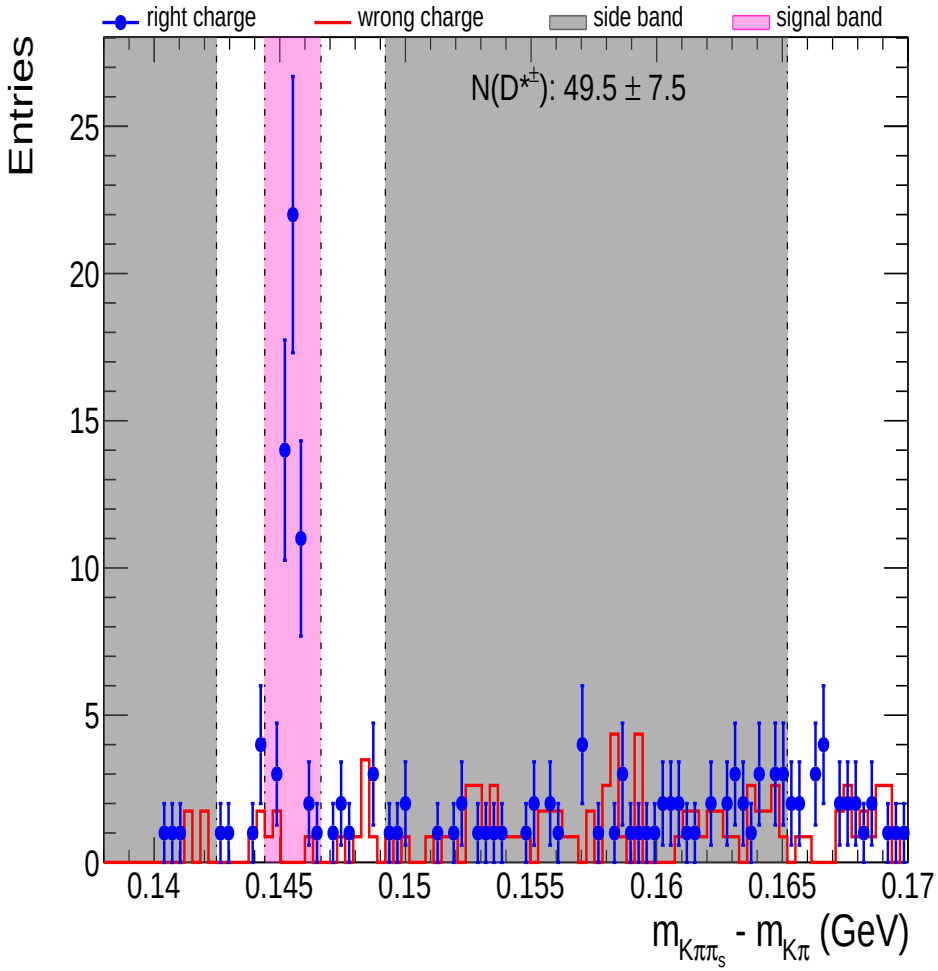


Δm_r at different phase space

p_T:9-10 GeV, |y|:0.0-0.5

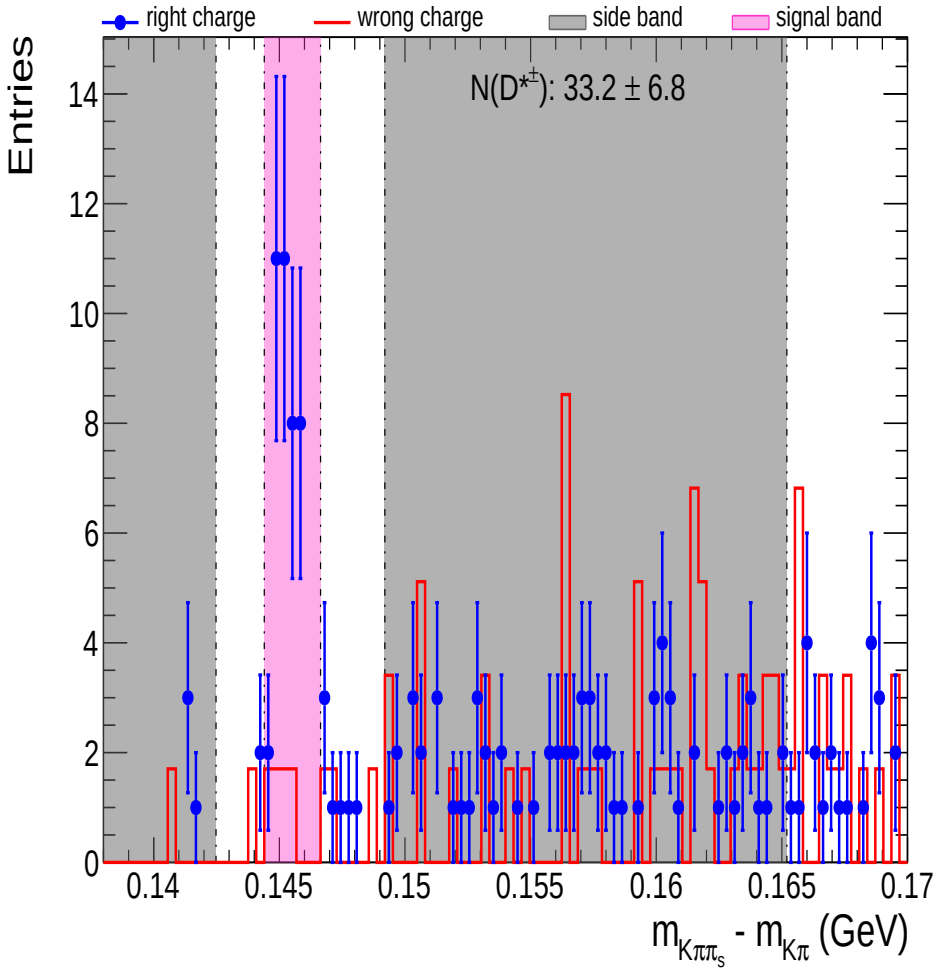


p_T:9-10 GeV, |y|:0.5-1.0

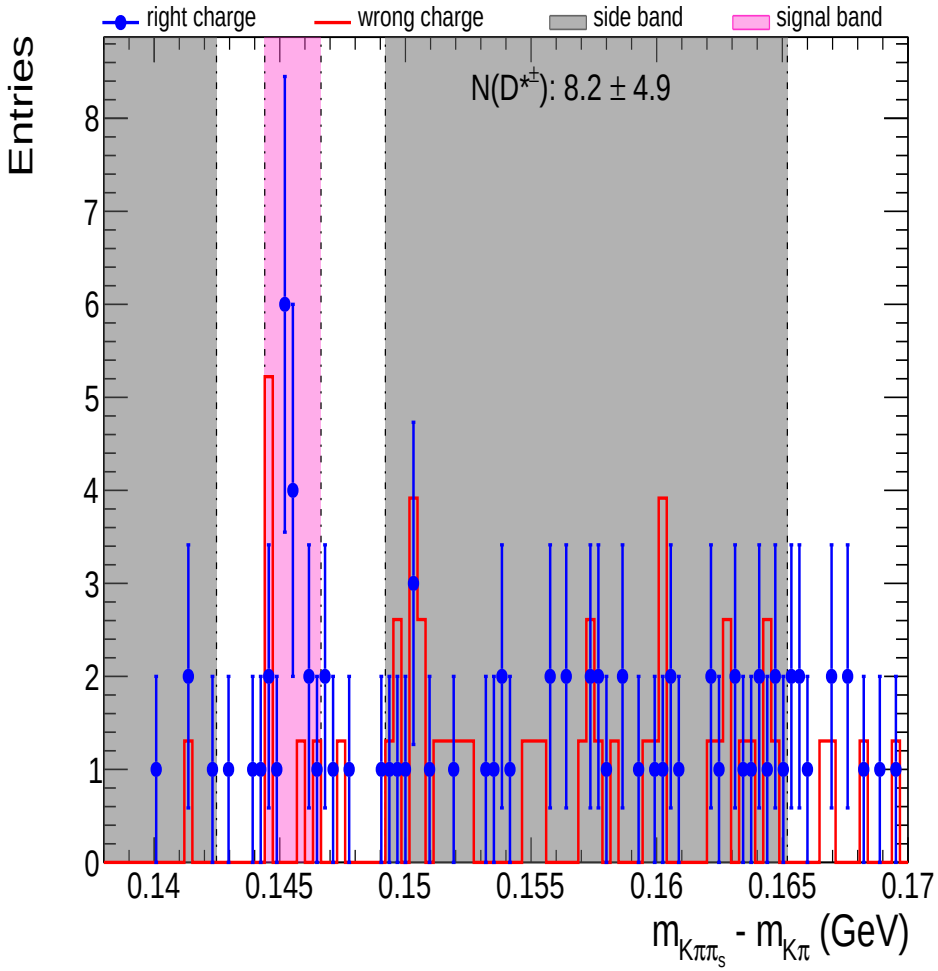


Δm_r at different phase space

p_T:9-10 GeV, |y|:1.0-1.5

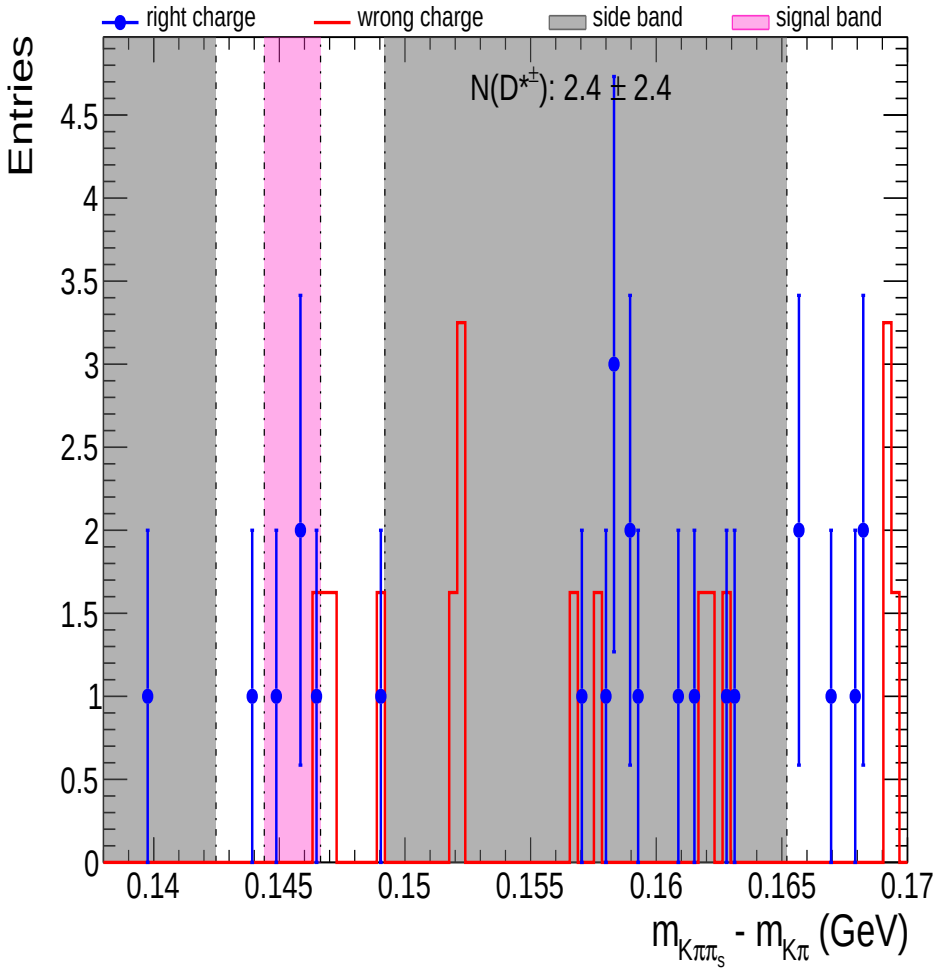


p_T:9-10 GeV, |y|:1.5-2.0



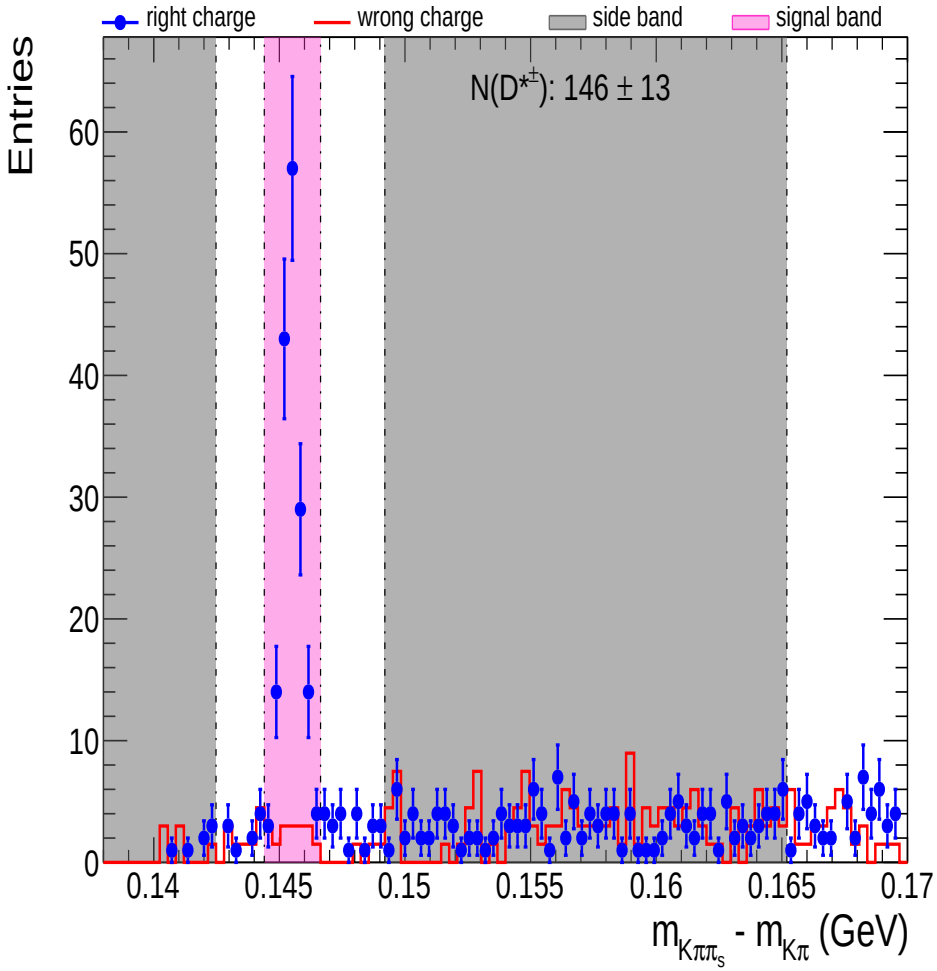
Δm_r at different phase space

p_T:9-10 GeV, |y|:2.0-2.5

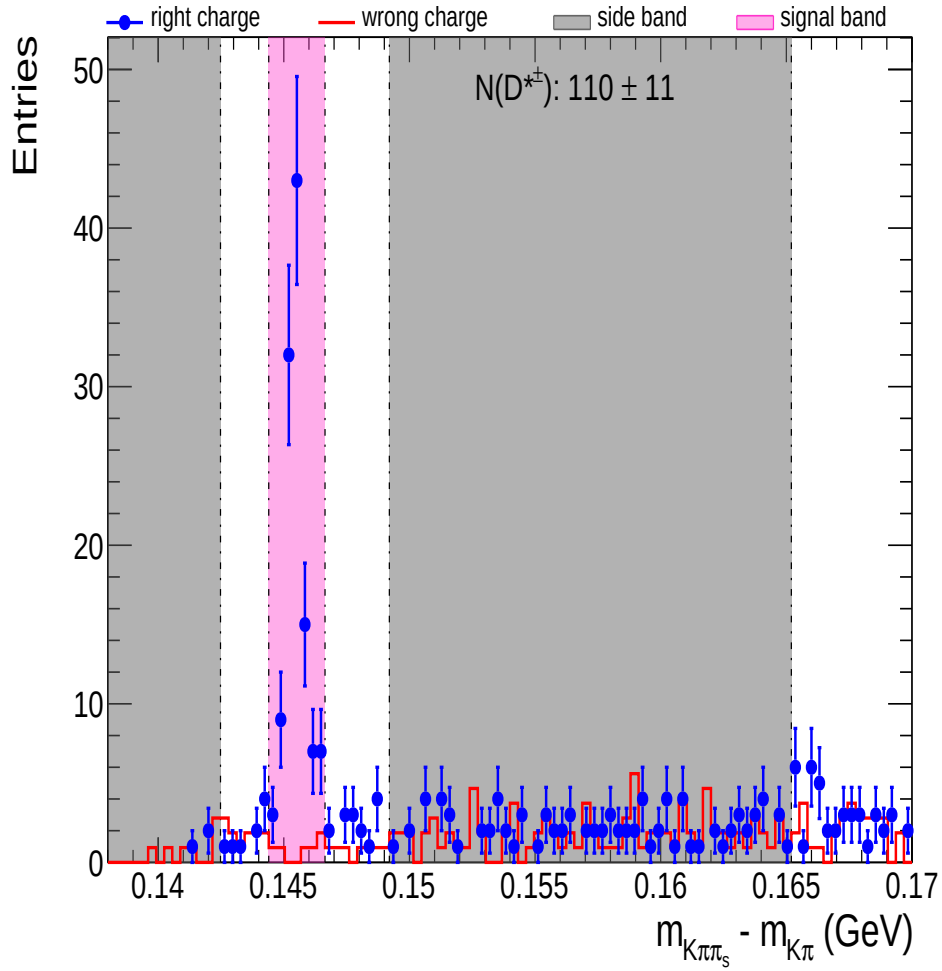


Δm_r at different phase space

p_T:10-11 GeV, |y|:0.0-0.5

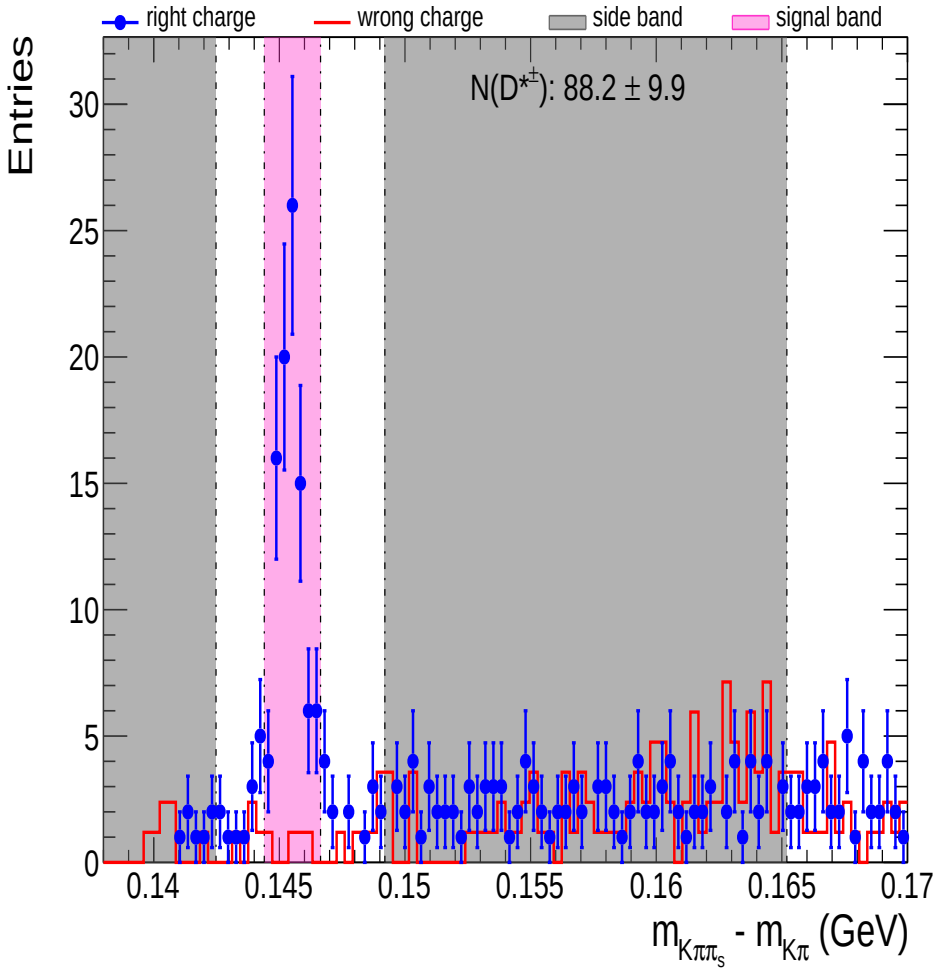


p_T:10-11 GeV, |y|:0.5-1.0

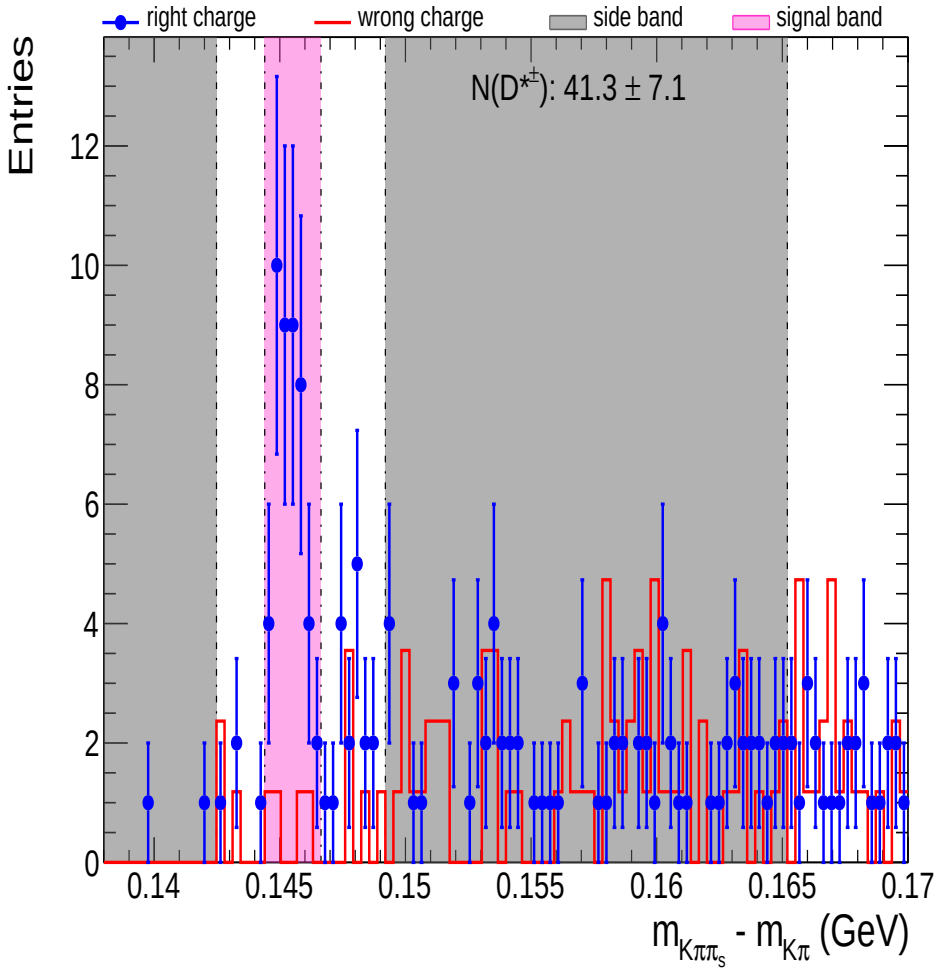


Δm_r at different phase space

p_T:10-11 GeV, |y|:1.0-1.5

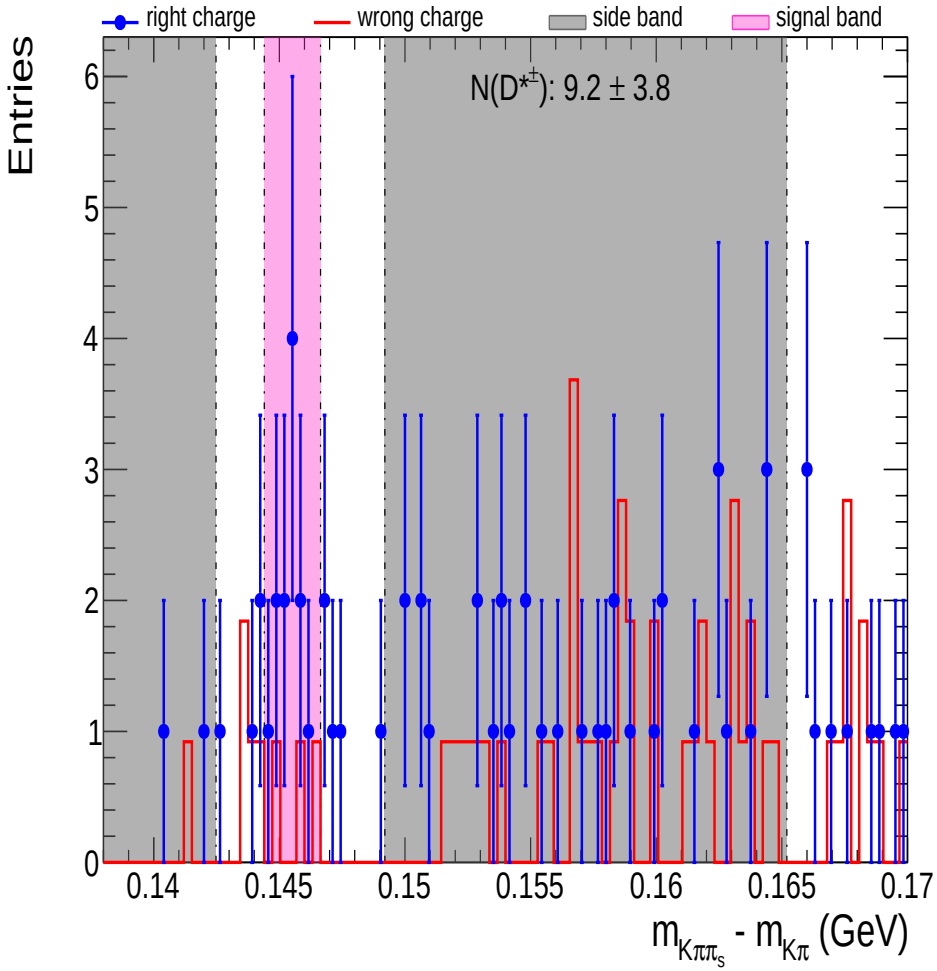


p_T:10-11 GeV, |y|:1.5-2.0

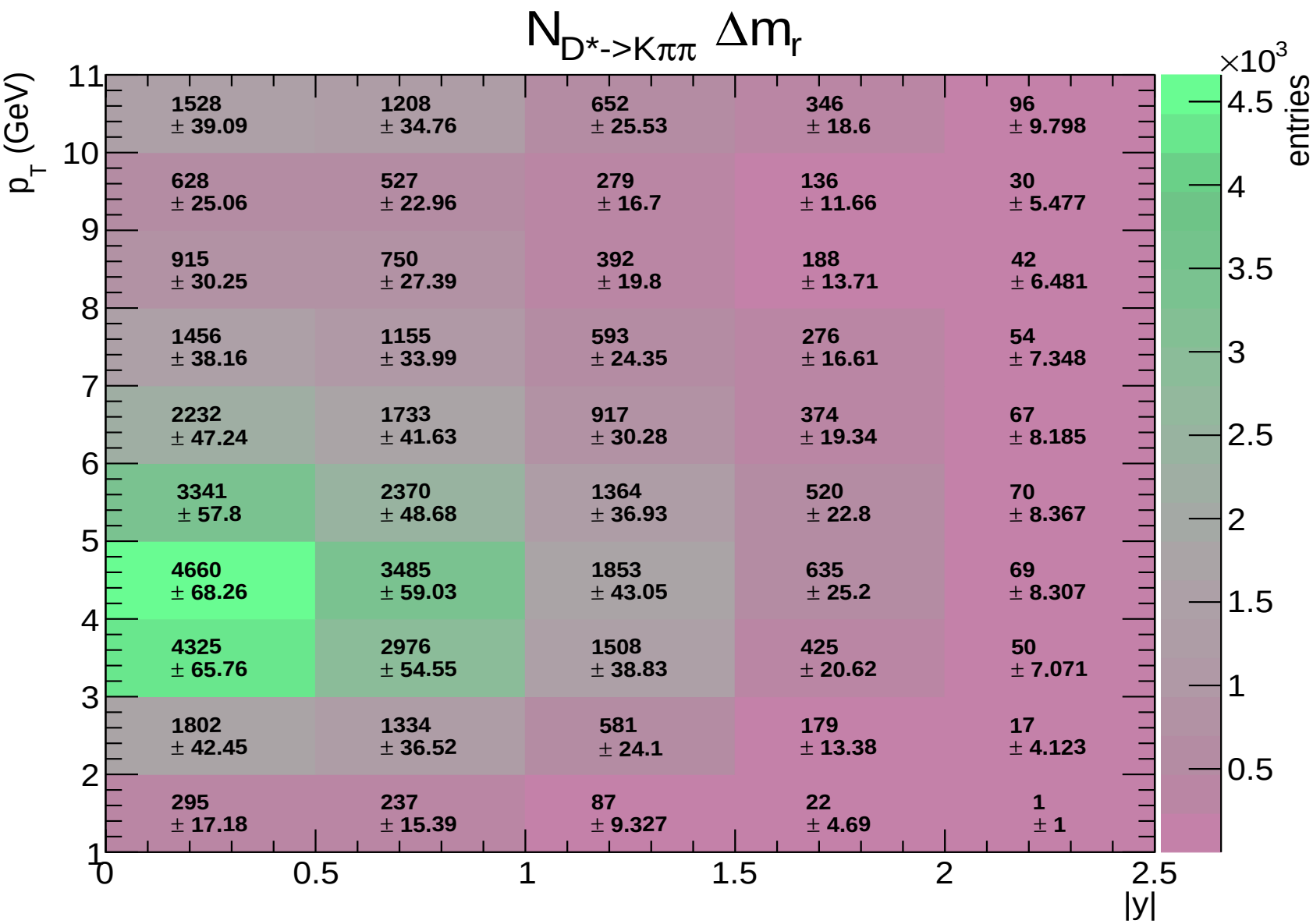


Δm_r at different phase space

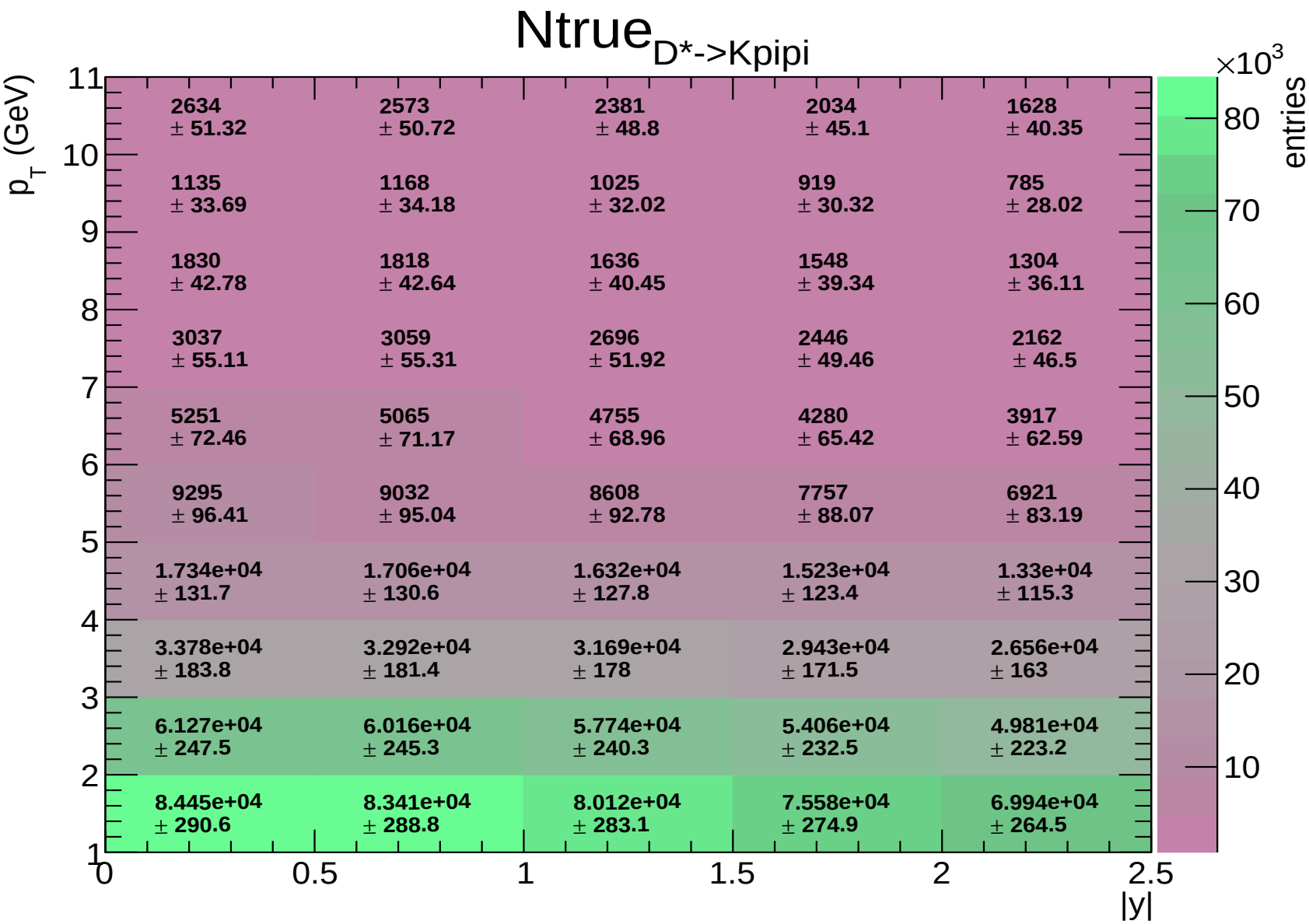
p_T:10-11 GeV, |y|:2.0-2.5



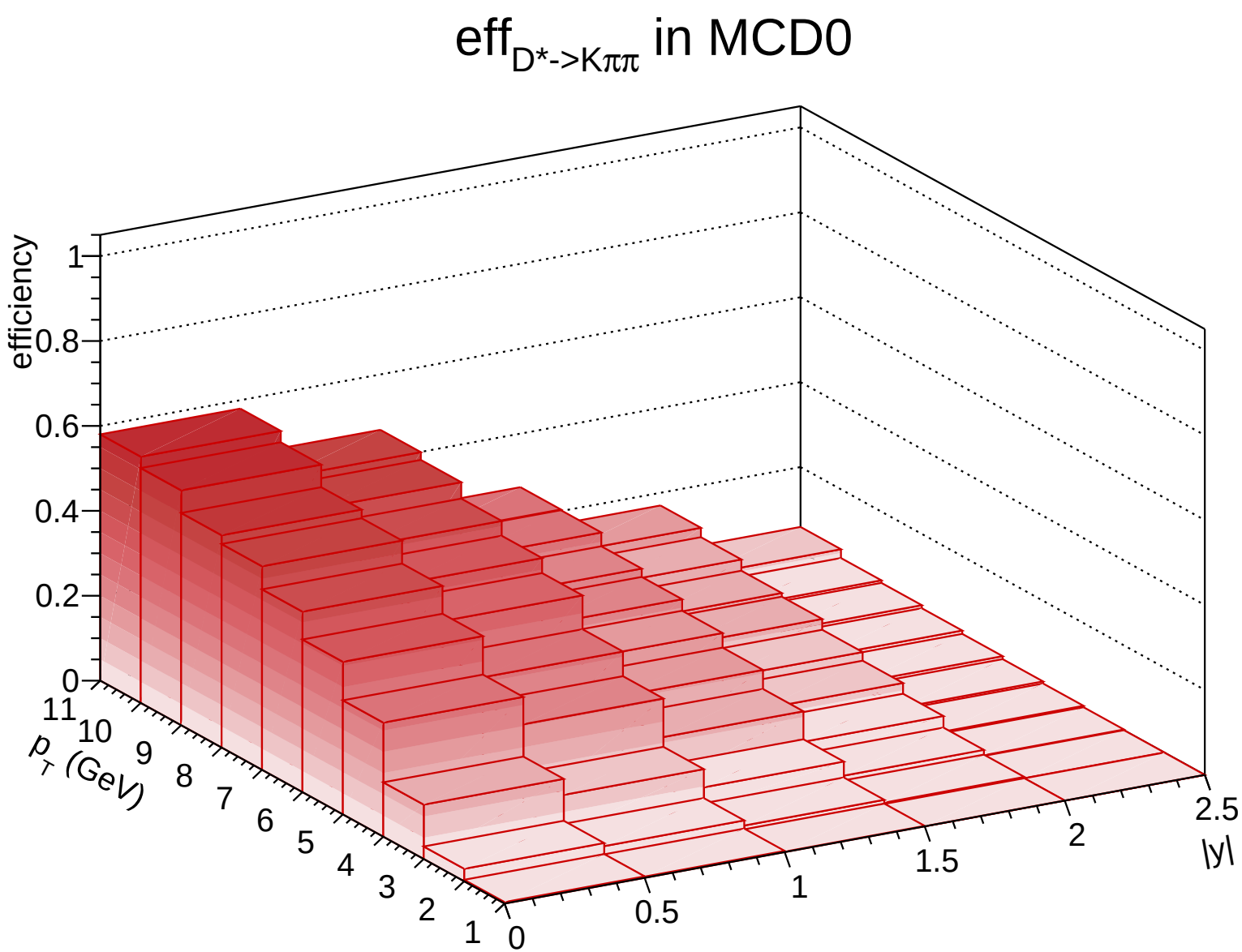
Nreco match true



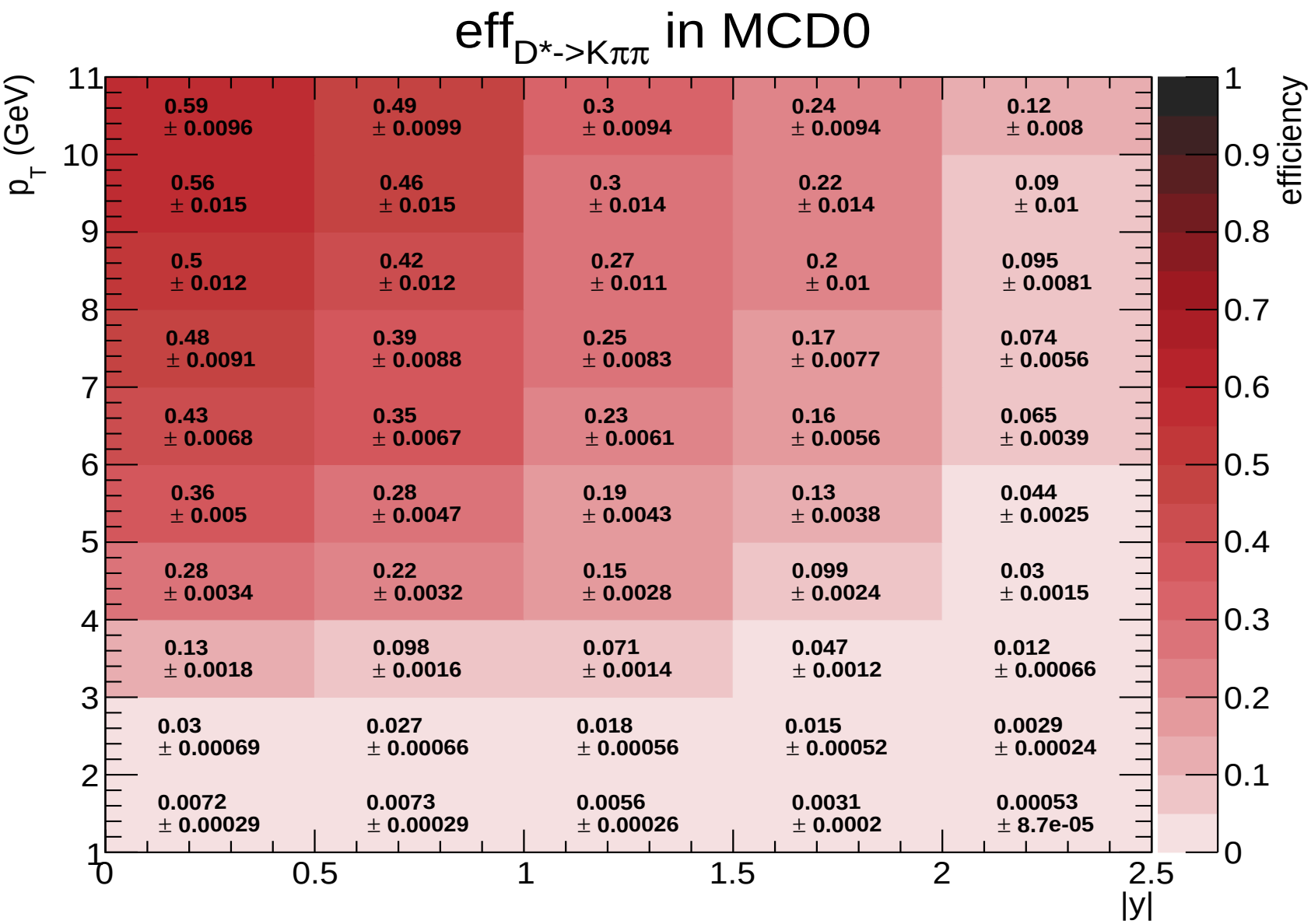
Ntrue


Ntrue D*->Kpipi
p_T (GeV)
|y|
entries
×10^3
11
10
9
8
7
6
5
4
3
2
1
0
0.5
1
1.5
2
2.5
10
20
30
40
50
60
70
80
2634 ± 51.32
2573 ± 50.72
2381 ± 48.8
2034 ± 45.1
1628 ± 40.35
1135 ± 33.69
1168 ± 34.18
1025 ± 32.02
919 ± 30.32
785 ± 28.02
1830 ± 42.78
1818 ± 42.64
1636 ± 40.45
1548 ± 39.34
1304 ± 36.11
3037 ± 55.11
3059 ± 55.31
2696 ± 51.92
2446 ± 49.46
2162 ± 46.5
5251 ± 72.46
5065 ± 71.17
4755 ± 68.96
4280 ± 65.42
3917 ± 62.59
9295 ± 96.41
9032 ± 95.04
8608 ± 92.78
7757 ± 88.07
6921 ± 83.19
1.734e+04 ± 131.7
1.706e+04 ± 130.6
1.632e+04 ± 127.8
1.523e+04 ± 123.4
1.33e+04 ± 115.3
3.378e+04 ± 183.8
3.292e+04 ± 181.4
3.169e+04 ± 178
2.943e+04 ± 171.5
2.656e+04 ± 163
6.127e+04 ± 247.5
6.016e+04 ± 245.3
5.774e+04 ± 240.3
5.406e+04 ± 232.5
4.981e+04 ± 223.2
8.445e+04 ± 290.6
8.341e+04 ± 288.8
8.012e+04 ± 283.1
7.558e+04 ± 274.9
6.994e+04 ± 264.5

Eff in 3D


eff D*->Kππ in MCD0
efficiency
1
0.8
0.6
0.4
0.2
0
11
10
9
8
7
6
5
4
3
2
1
0
p_T (GeV)
0
0.5
1
1.5
2
2.5
|y|

Improvement in the efficiency (ongoing work)



Migration plot for D* p_T in $D^0 \rightarrow K\pi$ MC (new selection cut)