Update on double differential charm σ at 7 TeV 2010

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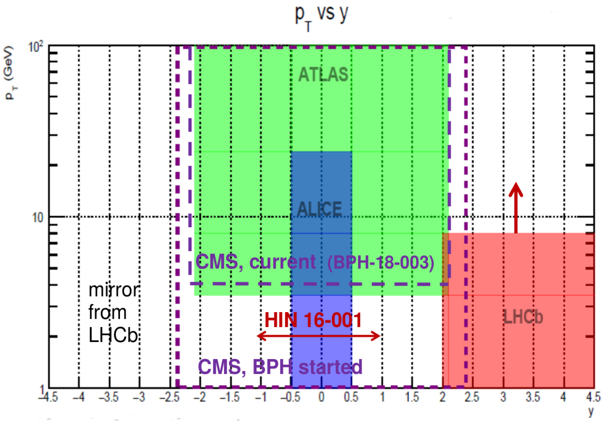
QCD meeting

Intro

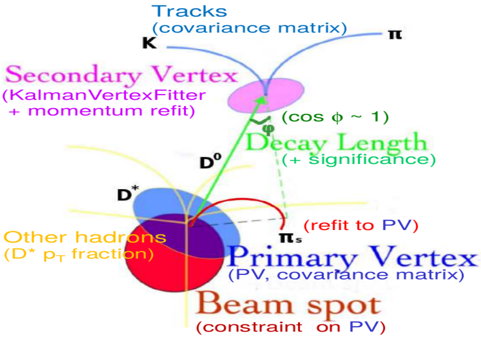
- Objective: To measure the total cross section of inclusive charm at different pp center of mass energies (0.9, 2.76, 5, 7, 8, 13 (from PU in BParking) TeV)
- Strategy: By covering full phase space and by using all PVs in the event. More details can be found in backup and AN-18-284
- What's new? with respect to [prev.]
  - Loosen $D^{*\pm}$ pre-selection
  - Added dEdx cut
  - Signal yield
  - Efficiency
  - σ as a function of p_T and y
  - Towards total cross section
  - Conclusion and outlook

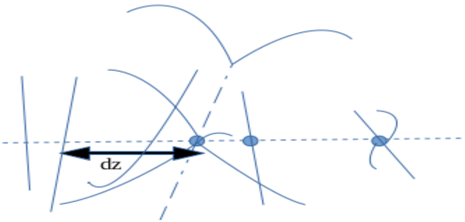


$D^{*\pm}$ selection

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

- Possible combination:
    - Right charge: $K^\mp\pi^\pm\pi_s^\pm$
    - Wrong charge: $K^\mp\pi^\mp\pi_s^\pm$ (combinatorial background)
- Optimized for low p_T charm
- Different cut at higher p_T (> 3.5 GeV) and lower p_T (< 3.5 GeV)*
- Track p_T cut only apply to pion, instead of kaon and pion; $p_T^\pi > 0.5$ GeV
- Cut on dEdx for kaon
    - discriminate K & π and K & p
- Cut on max. distance from tracks to PV
    - loosen dz cut at D* preselection (from 0.1 to 0.5 cm)
    - tighten (dz $\times$ sinθ) cut at analysis level*



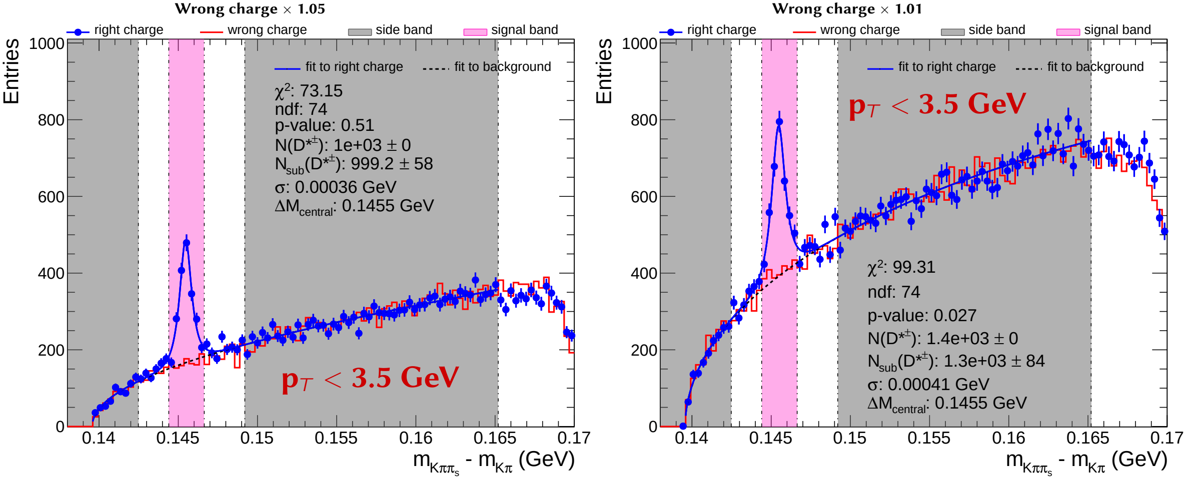


*See cuts in backup

Signal extraction

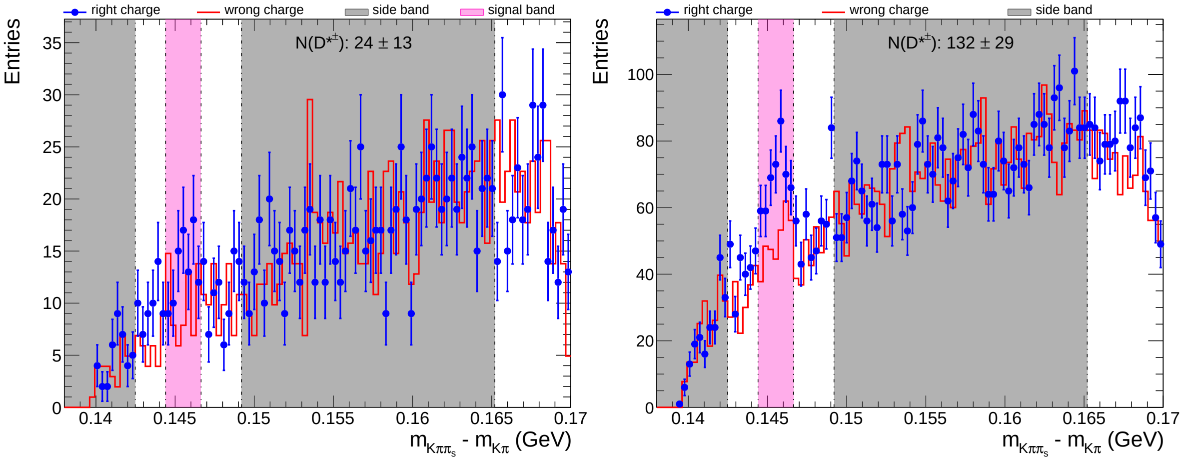
Signal extraction

- Using wrong charge background subtraction method



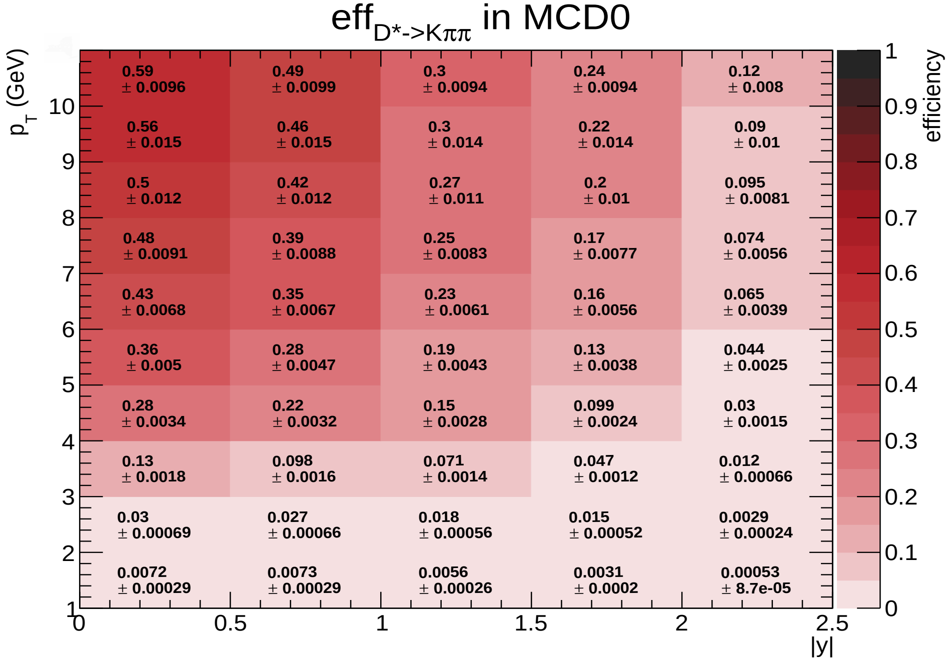
The plots show Nsignal at lower p_T. More signal are gain as well as the background. See backup for Nsignal at higher p_T and at different phase space (left: old, right:new)

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



One example of phase space where you can see clearly the improvement (right plot) with these latest selection cuts

Efficiency

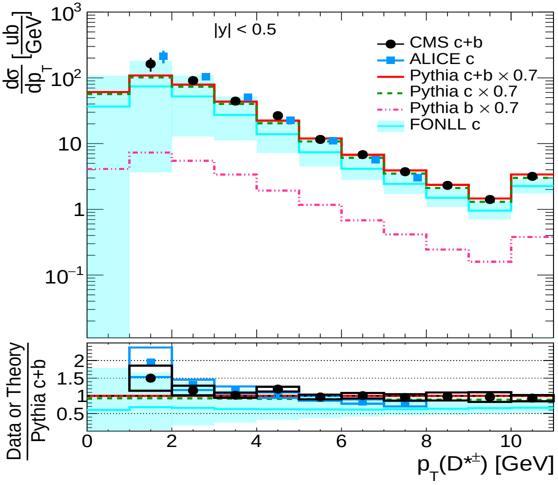


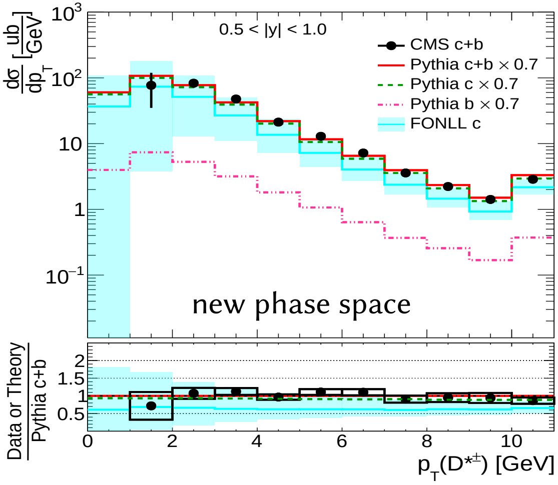
Efficiency improves at the region that we measure compared with the old ones (see backup)

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

after applied efficient

σ as a function of p_T in y bins

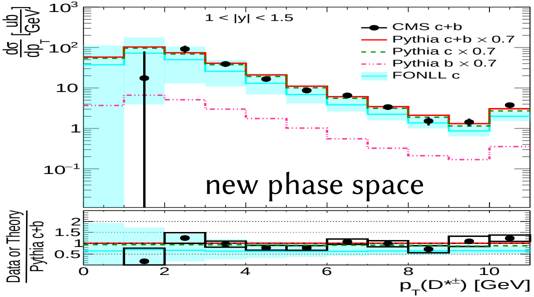


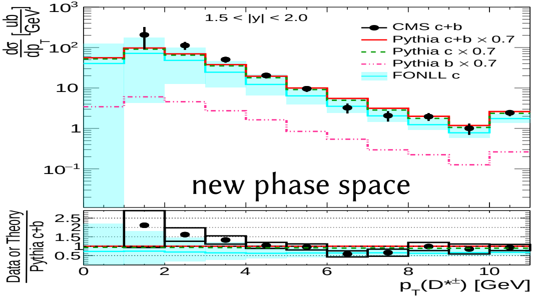


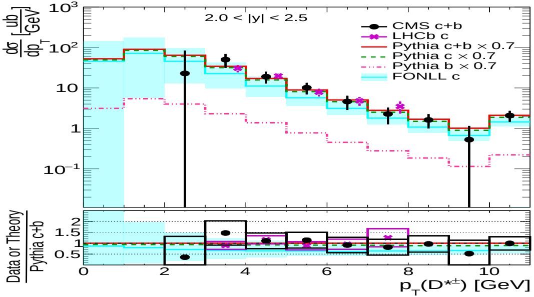
(Left) The cross section is comparable with ALICE

(Right) Region where cross sections have never been measured before

σ as a function of p_T in y bins

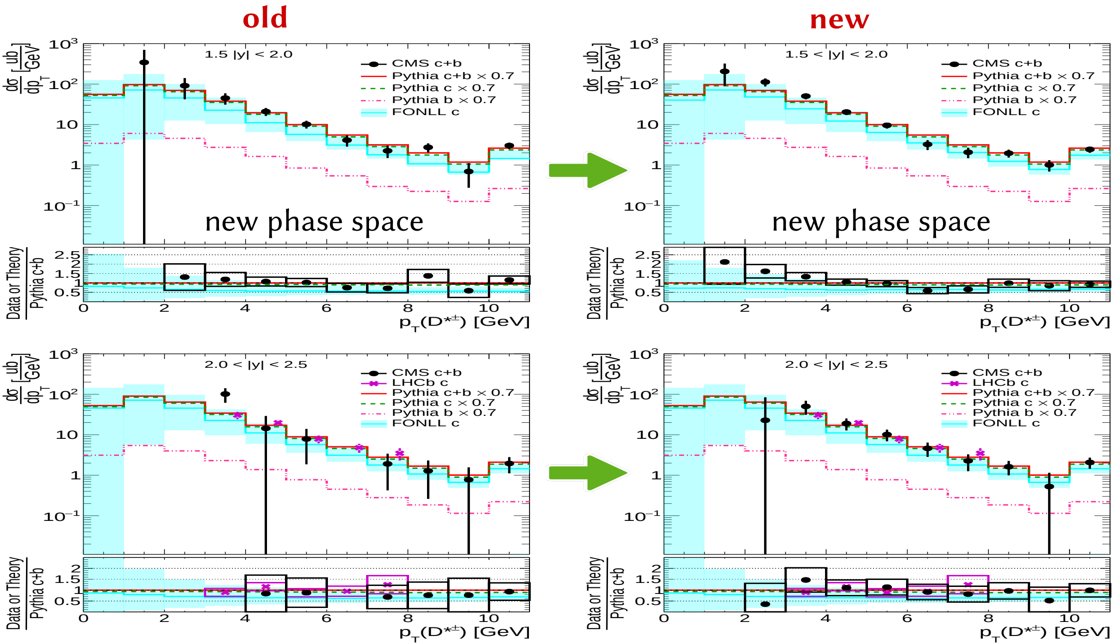




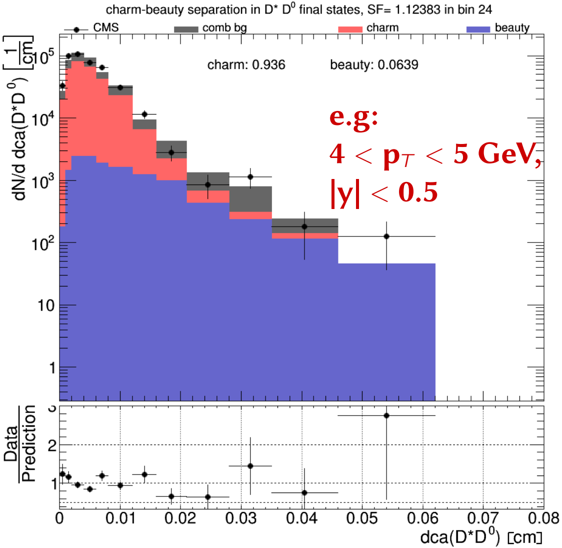


- Cross section is consistent with LHCb
- For |y| above 2.5, will use LHCb measurement

σ as a function of p_T in |y| bins: 1.5-2.0 & 2.0-2.5



Distance closest approach (dca) fit 7 TeV 2010



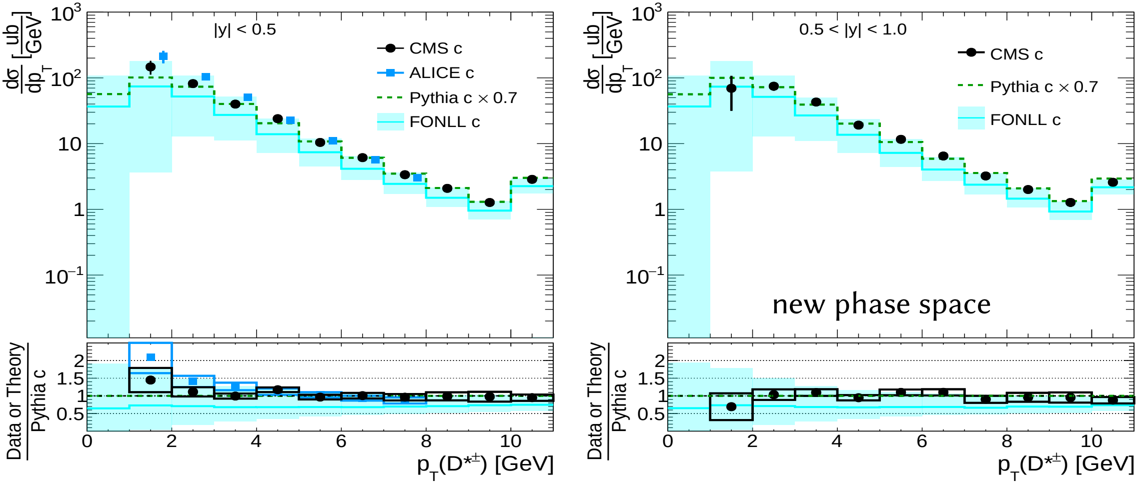
Measured and expected charm fraction $|y| < 0.5$		
P_T (GeV)	Data	Pythia
1 - 2	1.00 +- 0.09	0.875
2 - 3	0.71 +- 0.13	0.890
3 - 4	0.90 +- 0.04	0.894
4 - 5	0.94 +- 0.03	0.910
5 - 6	0.95 +- 0.06	0.892
6 - 7	0.85 +- 0.10	0.899
7 - 8	0.91 +- 0.06	0.904
8 - 9	0.89 +- 0.08	0.909
9 - 10	0.84 +- 0.16	0.909
> 10	1.00 +- 0.02	0.903
Linear ave. (charm frac.)	0.90 +- 0.5	0.90

Using linear ave. from Pythia for charm beauty separation, $\text{charm}_{frac} = 0.9$

- Pythia describes charm fraction well within very large data uncertainties

Cross section as a function of p_T & $|y|$ after $c+b \rightarrow c$ rescaling to 0.9 (statistical uncertainty only)

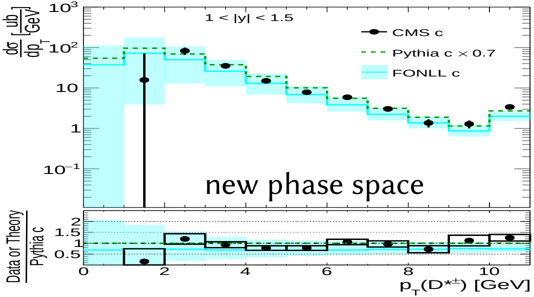
σ as a function of p_T in |y| bin

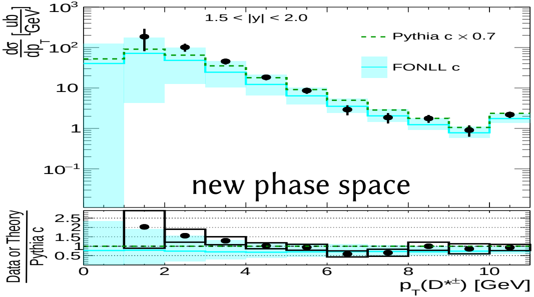


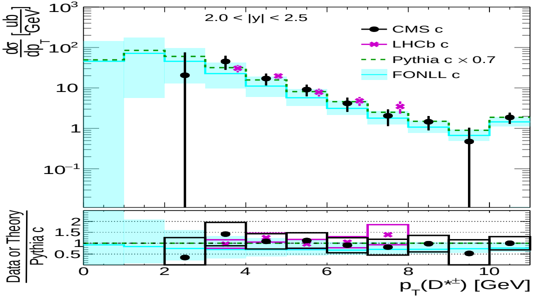
(Left) The cross section is comparable with ALICE

(Right) Region where cross sections have never been measured before

σ as a function of p_T in |y| bin

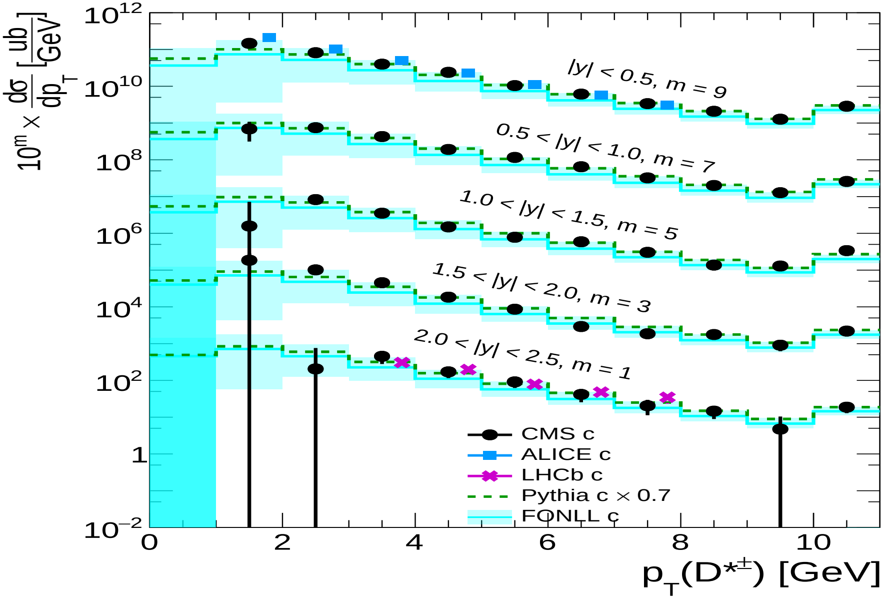






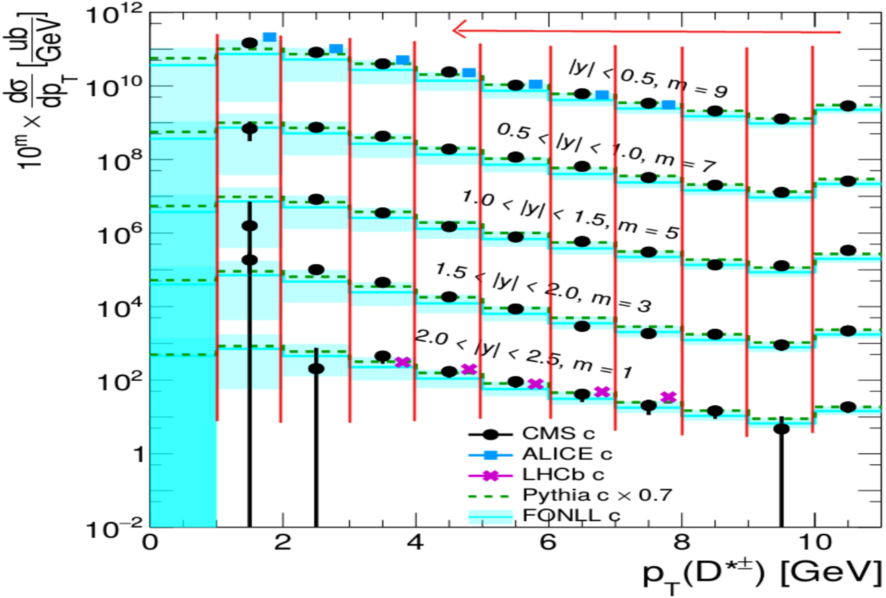
- Cross section is consistent with LHCb
- For |y| above 2.5, will use LHCb measurement

double differential σ as a function of p_T in |y| bins



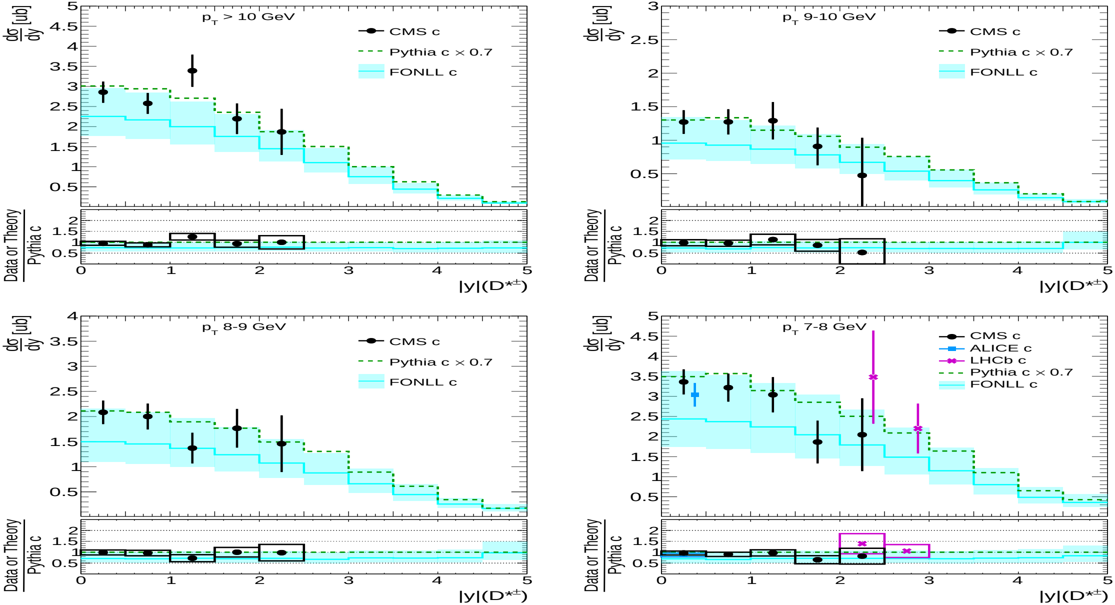
The upper band of FONLL is in agreement with data

double differential σ as a function of p_T in |y| bins

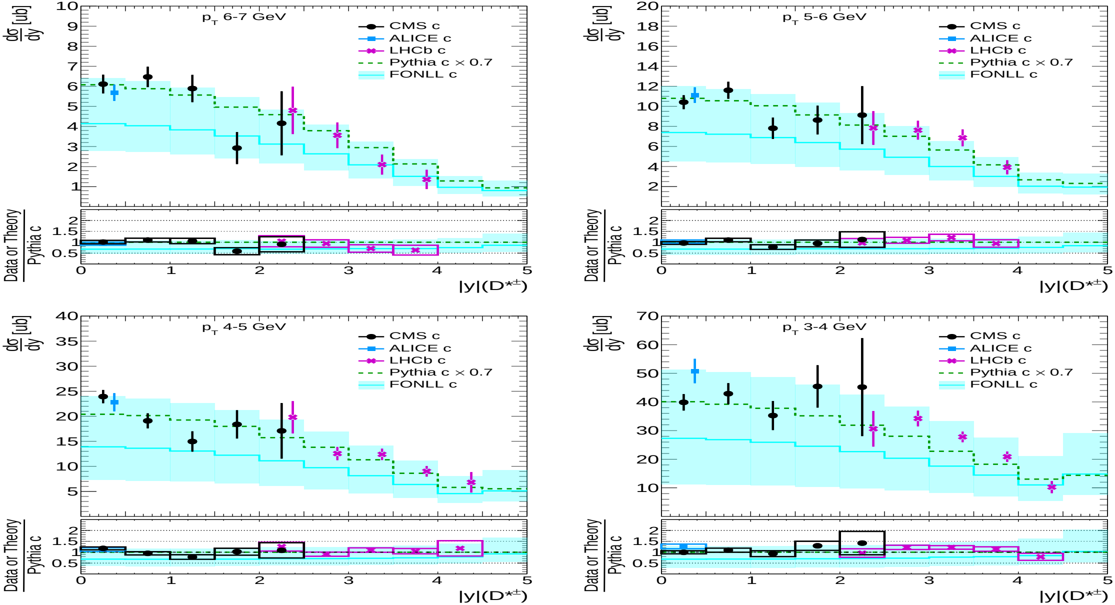


The columns between the red lines show the same D^* σ as a function of |y| (start from high p_T region)

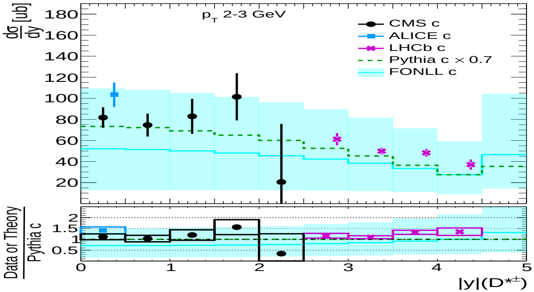
σ as a function of |y| in p_T bin

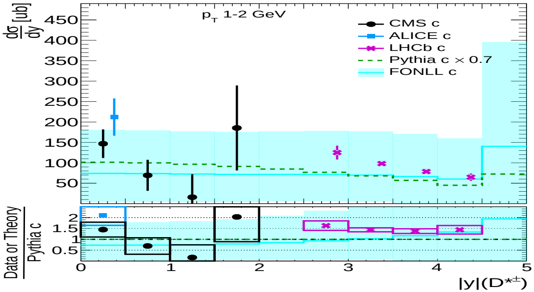


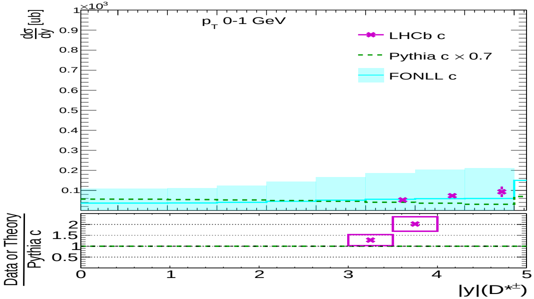
σ as a function of $|y|$ in p_T bin



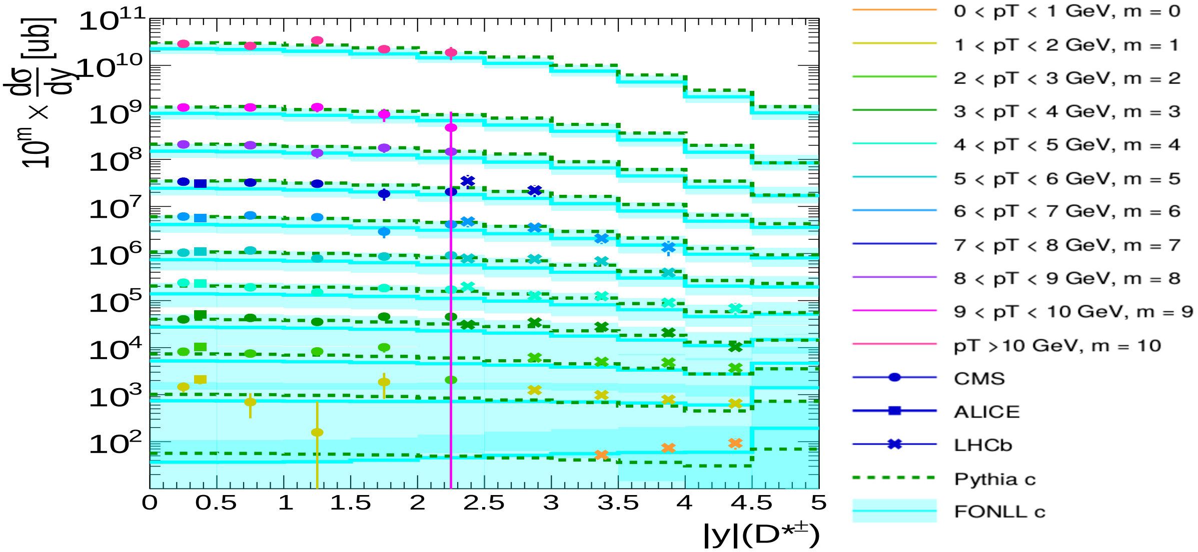
σ as a function of |y| in p_T bin







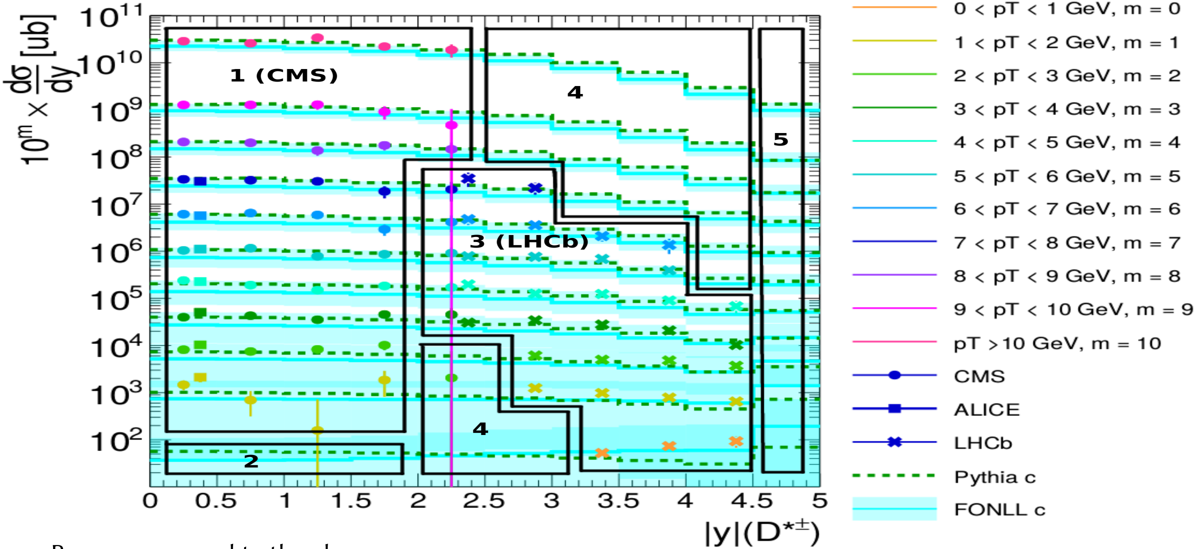
double differential σ as a function of |y| in p_T bins



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

Towards a total charm cross section
(very preliminary)

double differential σ as a function of $|y|$ in p_T bins



Boxes correspond to the phase space in calculating total charm σ from measurement and extrapolation

total $c\bar{c}$ σ: 8.3 $\pm$ 0.8 (stat.) $\pm$?? (sys.) mb

Towards a total charm cross section (very preliminary)

	Phase space	Integrated D^* cross section (μb)
1	CMS region measured: $\lvert y\rvert < 2$, $p_T > 1$	1096 $\pm$ 133 (stat.) $\pm$?? (sys.)
2	CMS region extrapolated (pt 0-1): (FONLL upper limit)	472 $\pm$ 57 (stat.) $\pm$?? (sys.) $\pm$?? (extrapolation)
3	LHCb region measured: $2 < \lvert y\rvert < 4.5$, $1 < p_T < 8$	1018 $\pm$ 40 (stat.) $\pm$ 120 (sys.)
4	LHCb region extrapolated:	344 $\pm$ 15 (stat.) $\pm$ 38 (sys.) $\pm$ 19 (extrapolation)
5	beyond LHCb extrapolated $\lvert y\rvert > 4.5$: (FONLL upper limit, except PDF)	1059 (tbc) $\pm$?? (stat.)
	Total	3989 $\pm$ 360 (stat.) $\pm$?? (sys.)

- fragmentation fraction: 0.239 / 2
- total ccbar cross section: 8.3 $\pm$ 0.8 (stat.) $\pm$?? (sys.) mb
- theory extrapolation factor: $\sim$1.9 (if confirmed): smallest extrapolation factor ever achieved at LHC (but still somewhat larger than hoped for)

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)
- charm fraction = 5.5%

Conclusion

- The analysis is performed using 7 TeV 2010 data (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
- The double differential D^* σ has been measured
- The upper edge of the FONLL theory band is an agreement with the data (as in all other existing measurements)
- The result for the charm 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
- First attempt in calculating the total $c\bar{c}$ σ = 8.3 mb

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
- Strategy: By using all PVs in the event & 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 $\sim$10 mb!

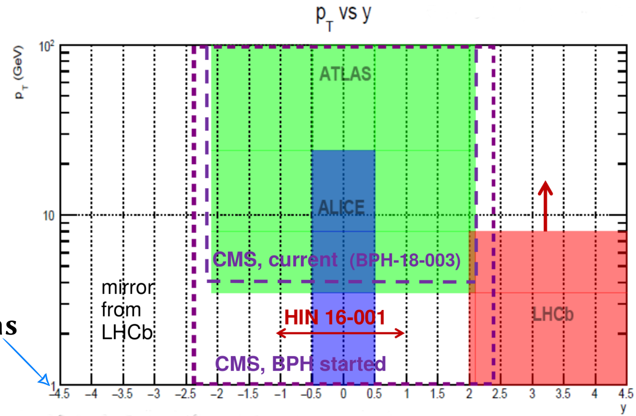
CMS (5 & 13 TeV)

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:1702.00766

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	5,729,356	0.110
/Electron/Run2010B-Apr21ReReco-v1/AOD	32,772,061	19,213,11x	0.369
/EGMonitor/Run2010A-Apr21ReReco-v1/AOD	67,929,392	126,022	0.00242
/EGMonitor/Run2010B-Apr21ReReco-v1/AOD	11,826,859	1,922,025	0.0369
Total	733,345,312	160,107,677	3.0 nb^{-1}

Table 2: JSON file 7 TeV 2010

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

All the datasets are available as **Open Data!** No need to stage on disk

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 nb^{-1}

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

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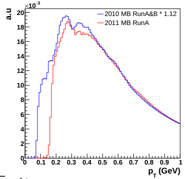
Total	733,345,312	160,107,677	3.0 nb^{-1}

Why 7 TeV 2010? (see backup)



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Cert_136033-149442_7TeV_Apr21ReReco_Collisions10_JSON_v2.txt

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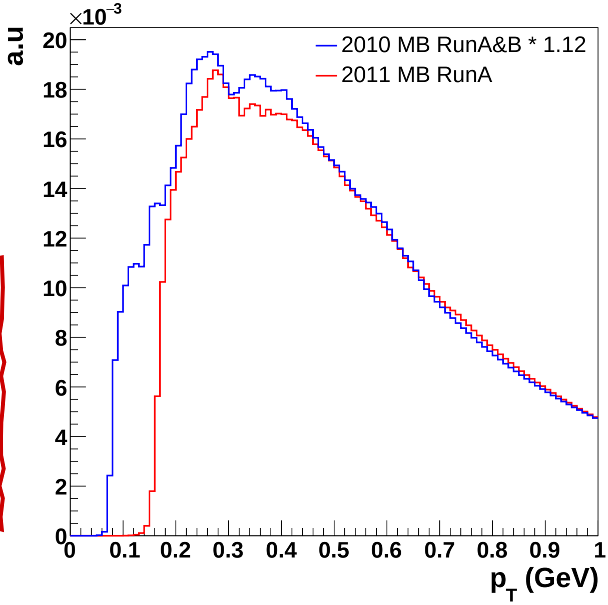
(more details in here or AN-18-284)

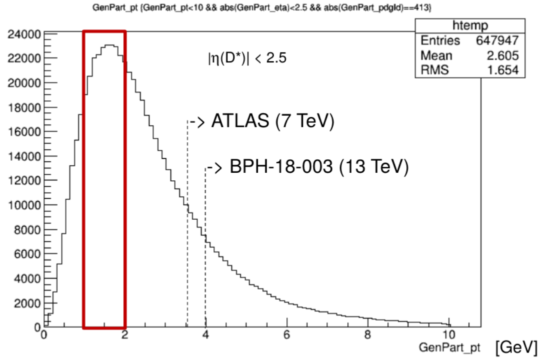
Low p_T tracks in 2010 vs 2011 MinimumBias data

- min. threshold p_T 2010 is lower than 2011
- able to access π_s from D^* decays with $p_T < 200$ MeV



D^* p_T distribution

D* p_T distribution at 7 TeV
2010 Minimum Bias MC



p_T bin 1-2 GeV (slow π p_T 70-150 MeV) crucial for total cross section (and 2-3 GeV)

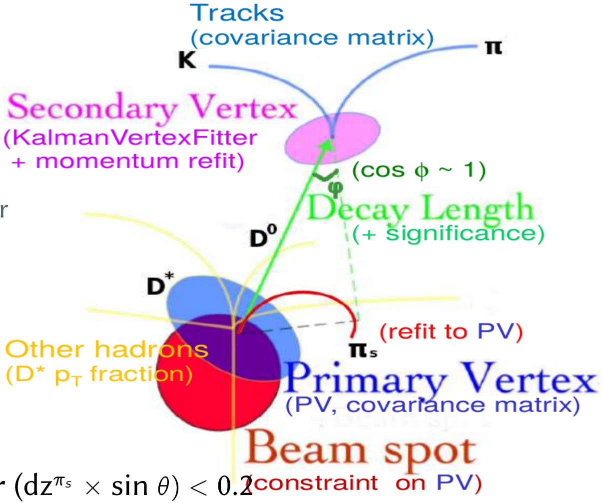
$D^{*\pm} \to D^0\pi^\pm \to K^\mp\pi^\pm\pi^\pm$ selection

optimized for low p_T charm

$$\boxed{p_{T\,frac} = \frac{p_T \text{ of D meson}}{\sum p_T \text{ of all tracks}_{\text{at respective PV}}}}$$

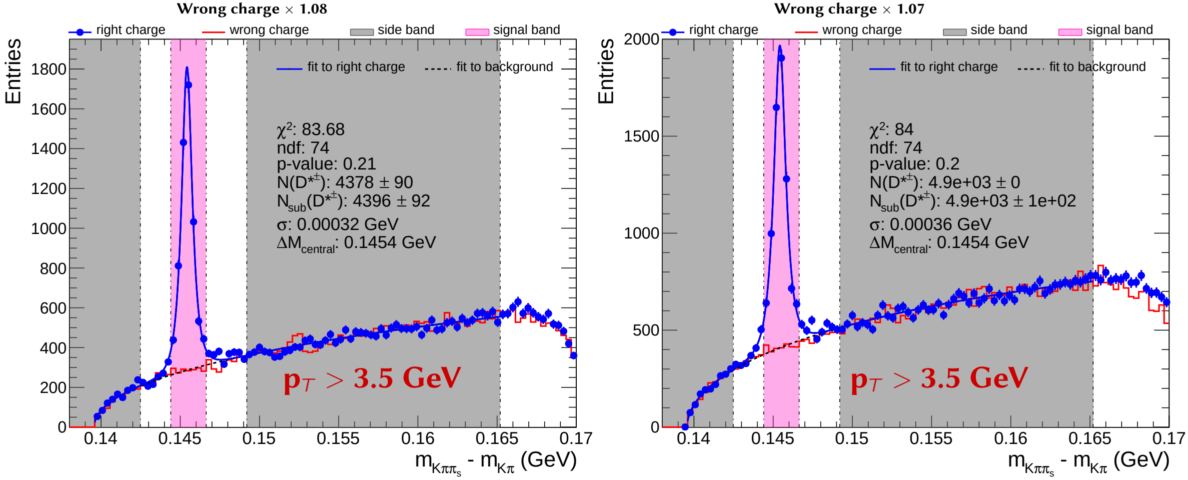
$$\boxed{dl^{D^0}_{Sig} = \frac{dl^{D^0}}{dl^{D^0}_{err}}}$$

- Possible combination:
  - Right charge: $K^\mp\pi^\pm\pi^\pm_s$
  - Wrong charge: $K^\mp\pi^\mp\pi^\pm_s$ (combinatorial background)
- For higher p_T ($p_T^{D^*} > 3.5$ GeV):
  - ($dl^{D^0}_{Sig} >$ -1 & $p^{D^*}_{T\,frac} > 0.15$ and $\cos\phi > 0.8$) or $dl^{D^0}_{Sig} > 2$
- For lower p_T ($p_T^{D^*} < 3.5$ GeV):
  - (($dl^{D^0}_{Sig} > 1.5$ & $p^{D^*}_{T\,frac} > 0.15$) or $dl^{D^0}_{Sig} > 3$ or ($dl^{D^0}_{Sig} > 2$ and $\cos\phi_{D^0} > 0.995$)) and $p^{D^0}_{T\,frac} > 0.1$ and $\cos\phi > 0.8$
- $dxy^K < 0.15$ **or** $dxy^\pi < 0.15$ **or** $dxy^{\pi_s} < 0.3$
- $(dz^K \times \sin\theta) < 0.1$ **or** $(dz^\pi \times \sin\theta) < 0.1$ **or** $(dz^{\pi_s} \times \sin\theta) < 0.2$



Signal extraction

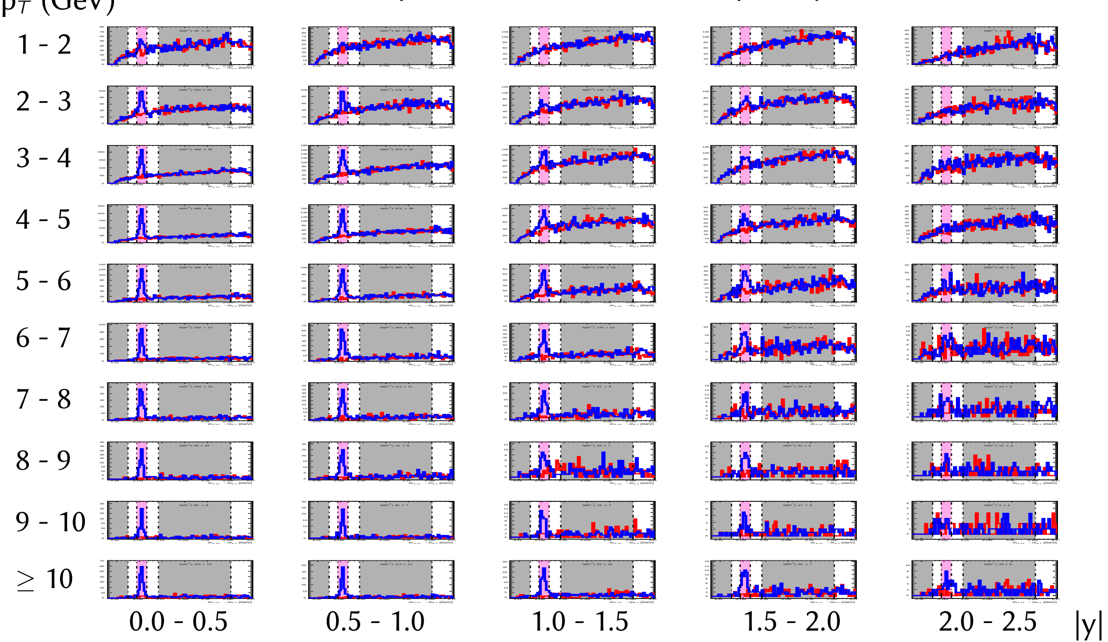
- Using wrong charge background subtraction method



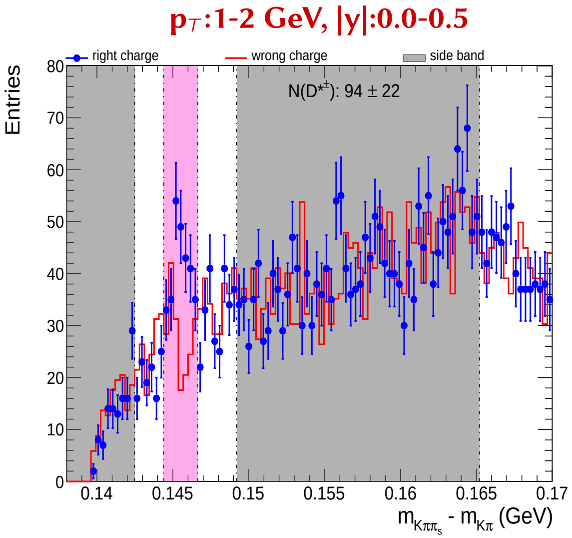
The plots show Nsignal at higher p_T. More signal are gain as well as the background..

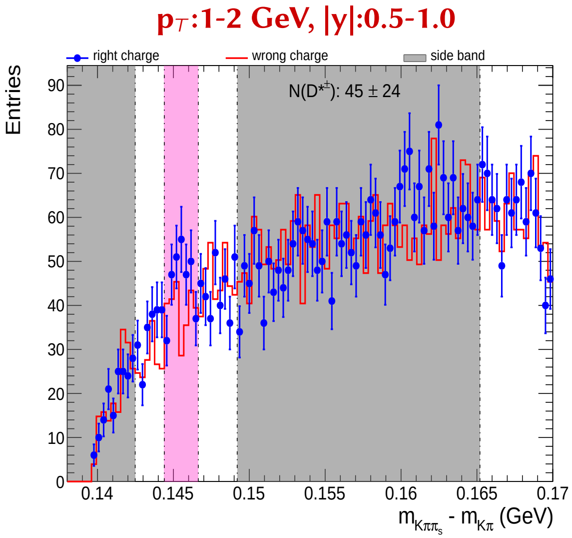
$\Delta m = m_{K\pi\pi_s} - m_{K\pi}$ in 50 bins

Δm peak can be seen in most of the phase space

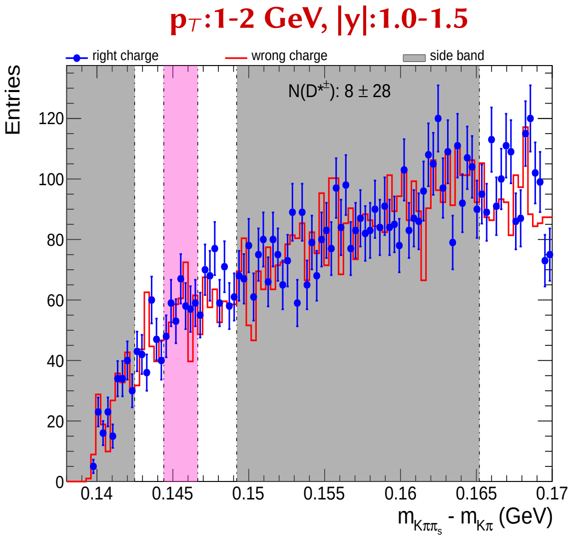


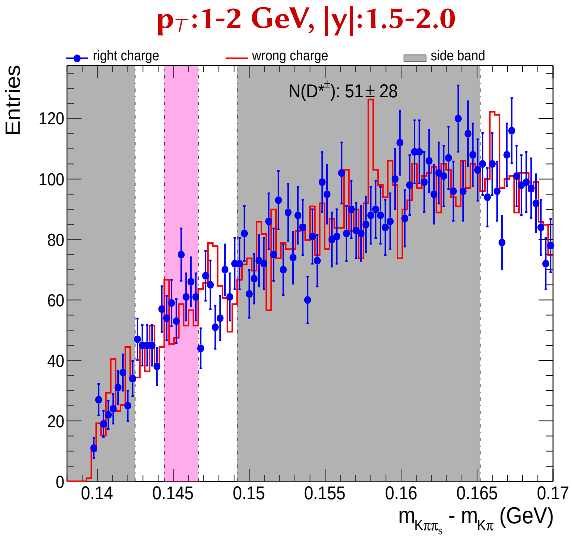
Nsignal at different phase space



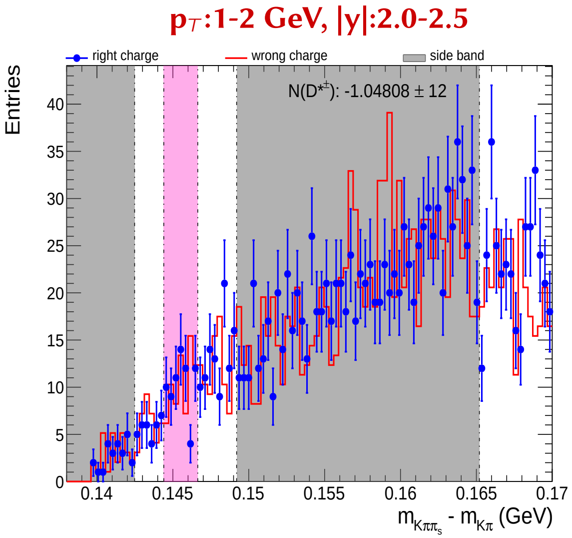


Nsignal using background substraction

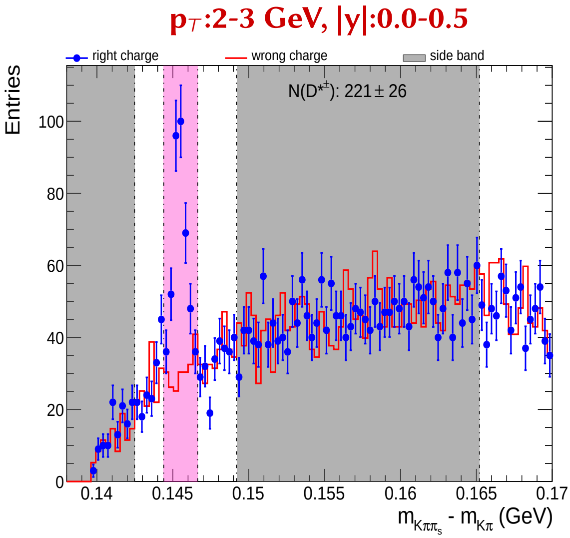


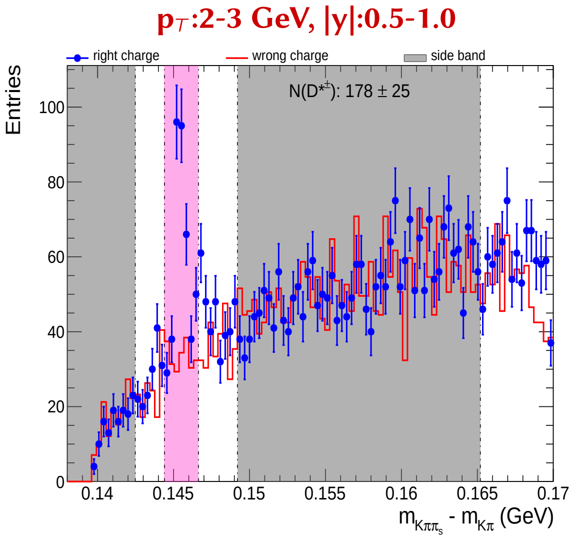


Nsignal using background substraction



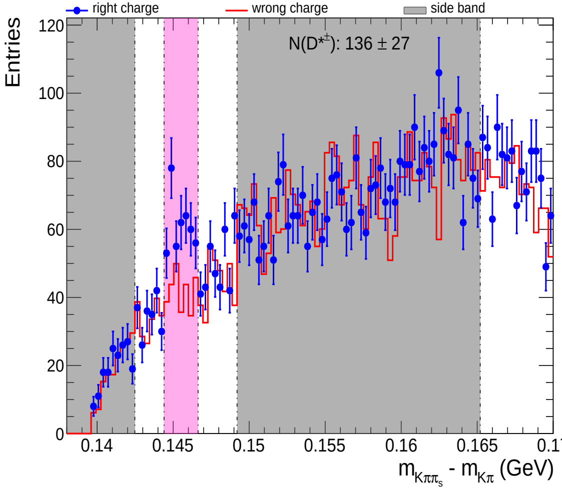
Nsignal using background substraction



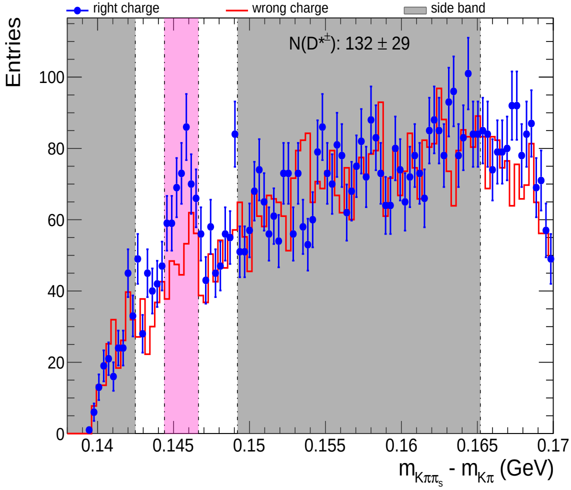


Nsignal using background substraction

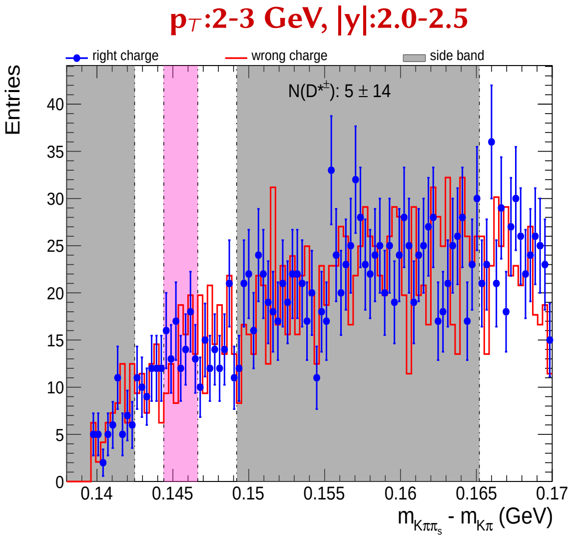
p_T:2-3 GeV, |y|:1.0-1.5



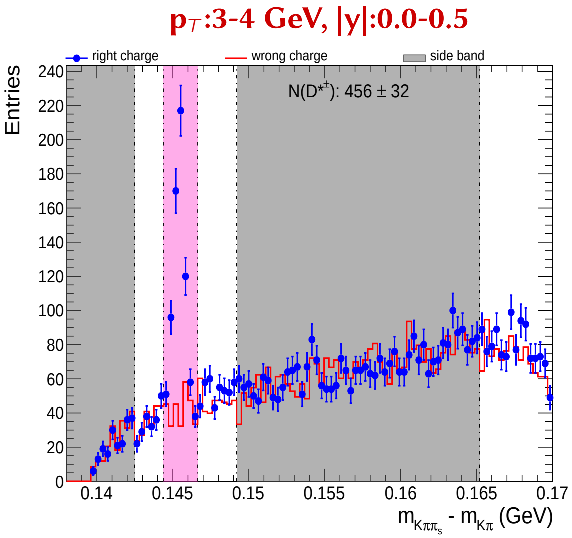
p_T:2-3 GeV, |y|:1.5-2.0

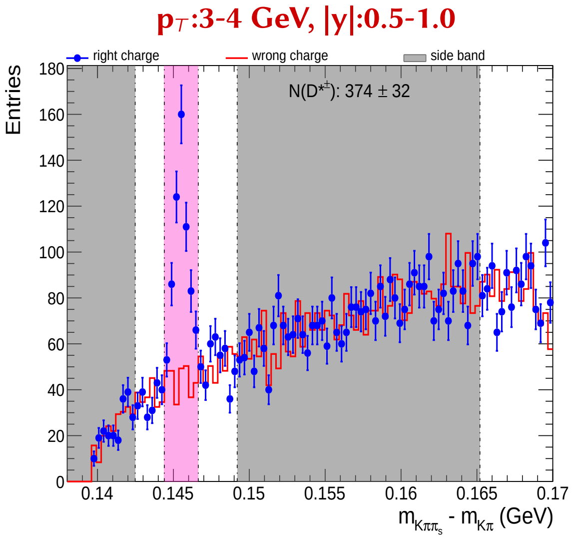


Nsignal using background substraction

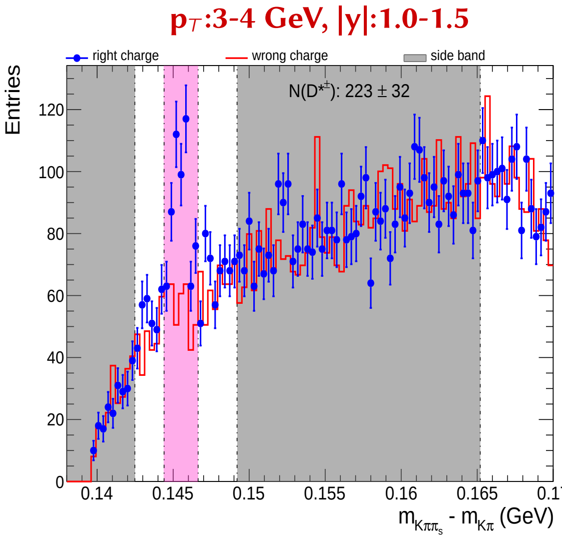


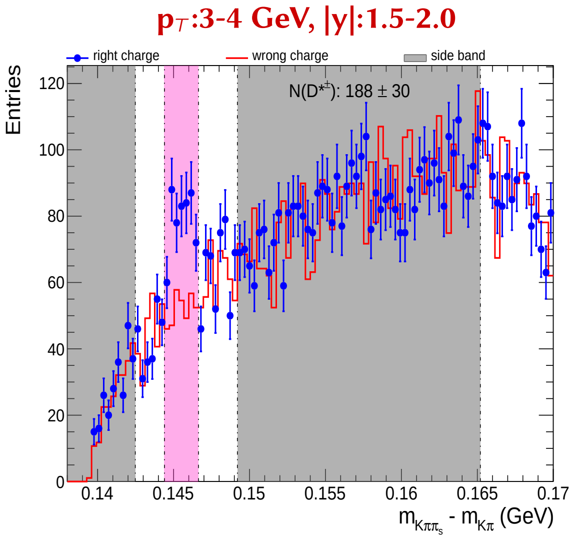
Nsignal using background substraction



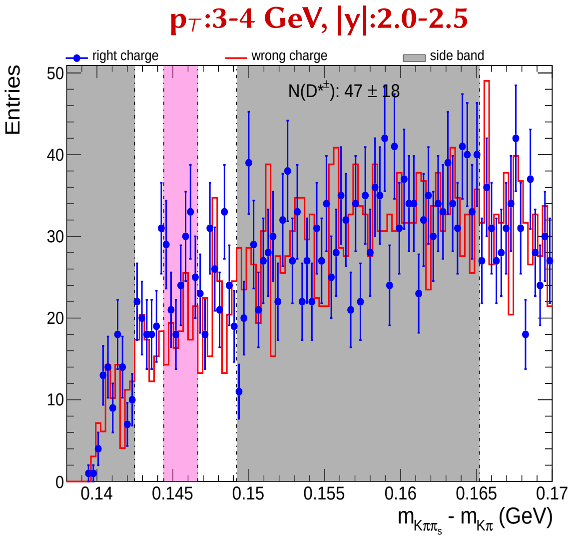


Nsignal using background substraction

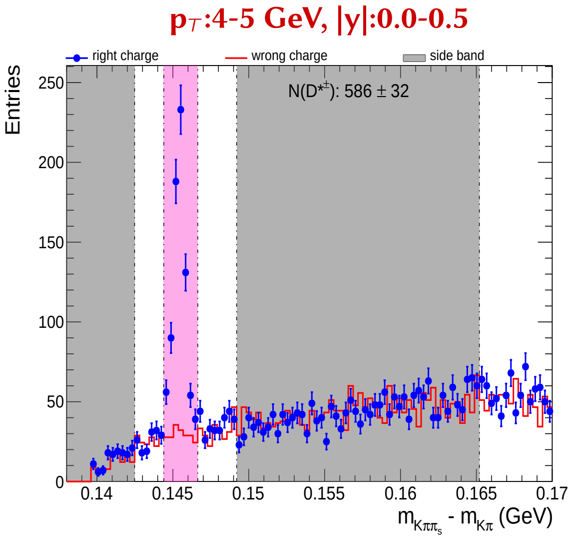


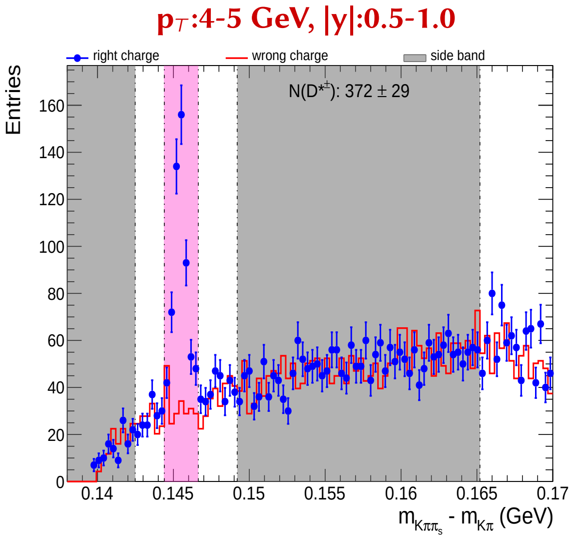


Nsignal using background substraction

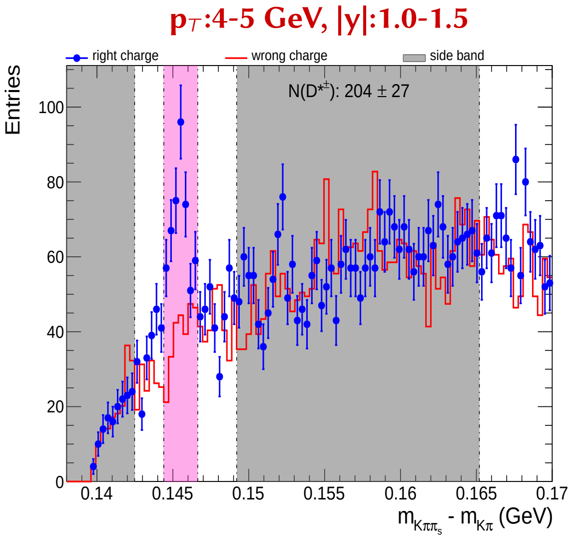


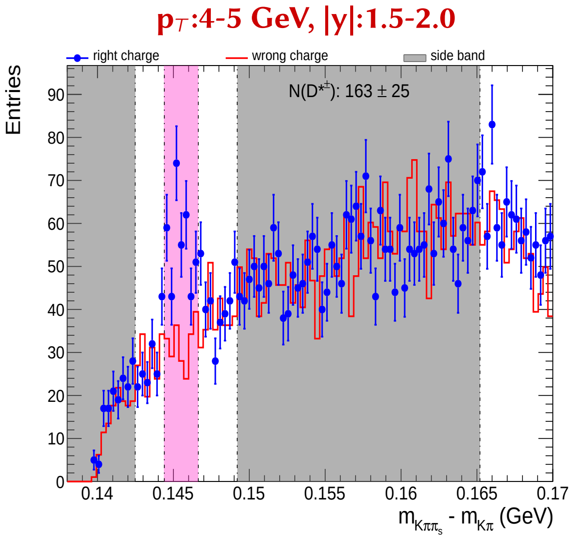
Nsignal using background substraction





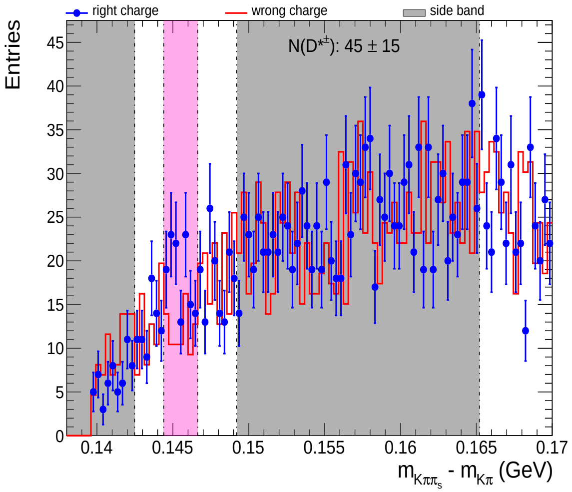
Nsignal using background substraction





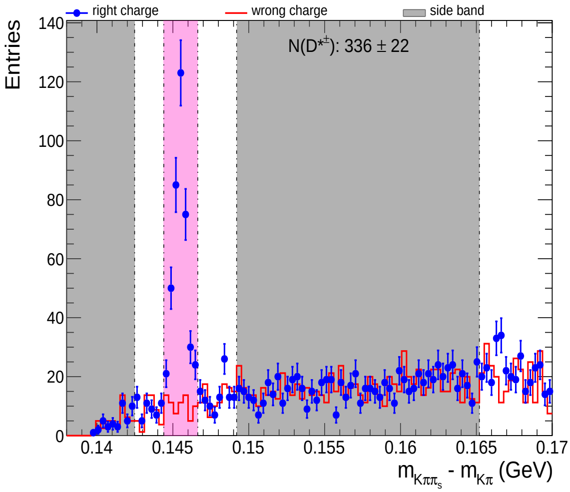
Nsignal using background substraction

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

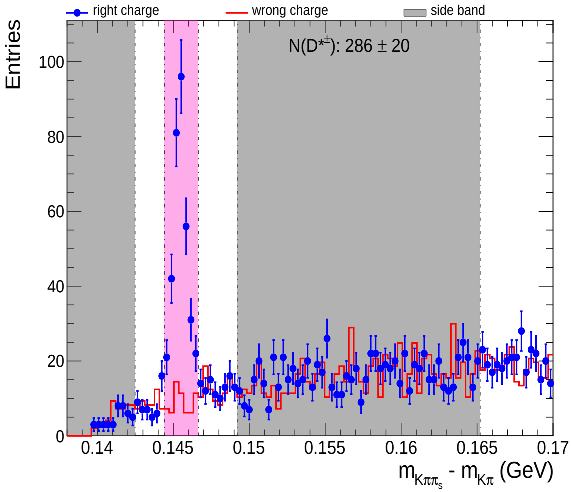


Nsignal using background substraction

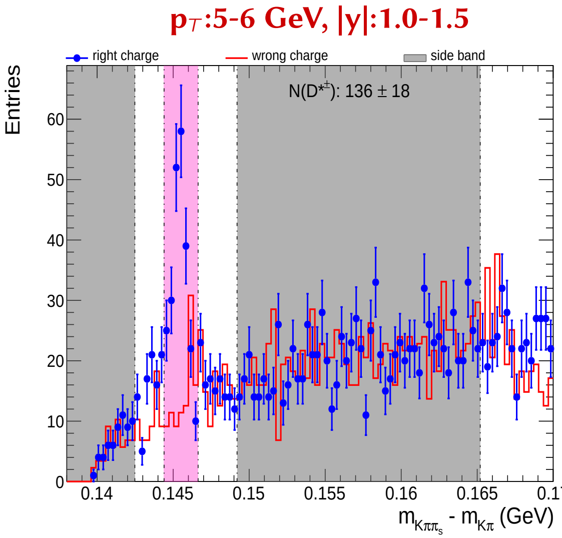
p_T:5-6 GeV, |y|:0.0-0.5

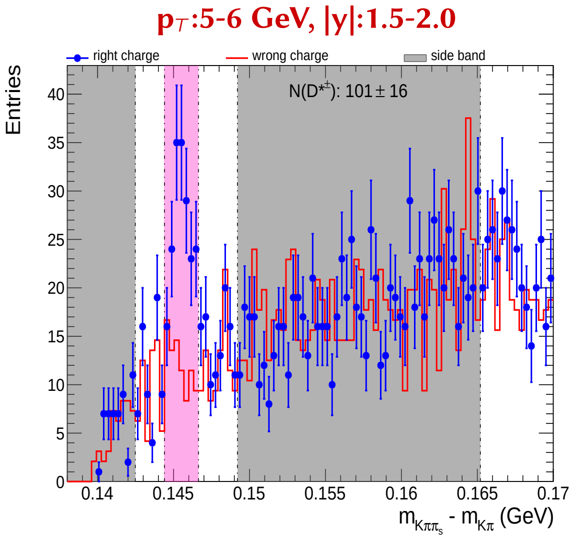


p_T:5-6 GeV, |y|:0.5-1.0

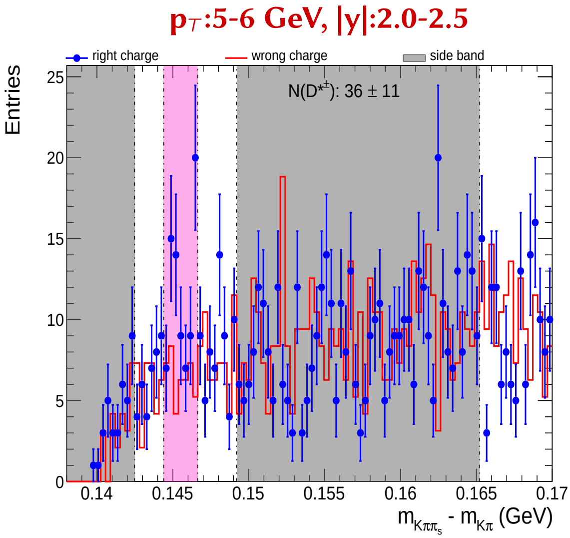


Nsignal using background substraction

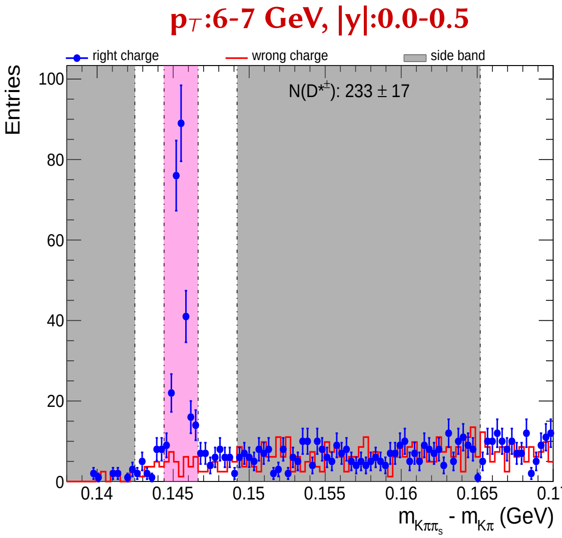


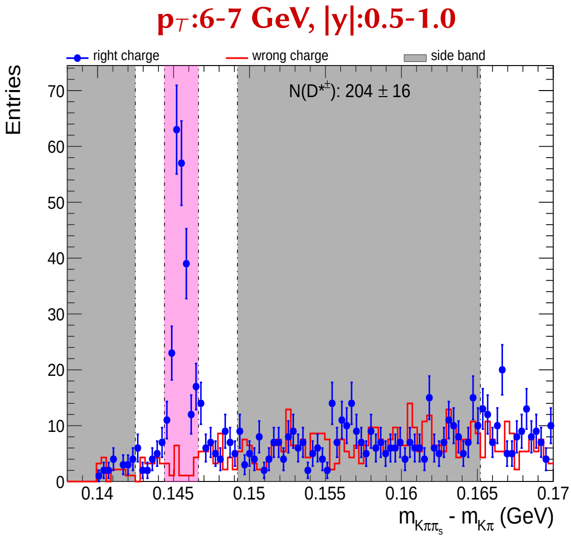


Nsignal using background substraction



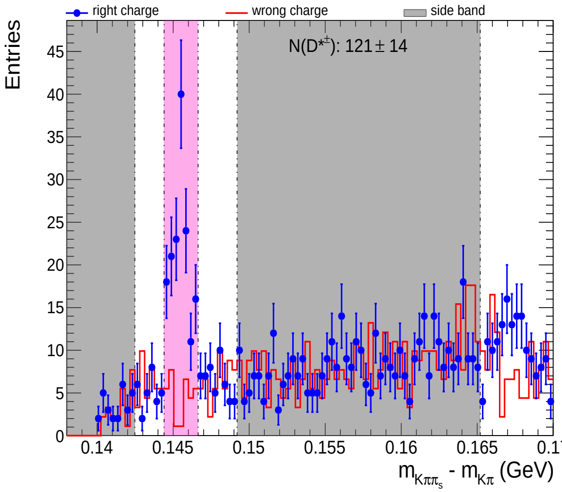
Nsignal using background substraction



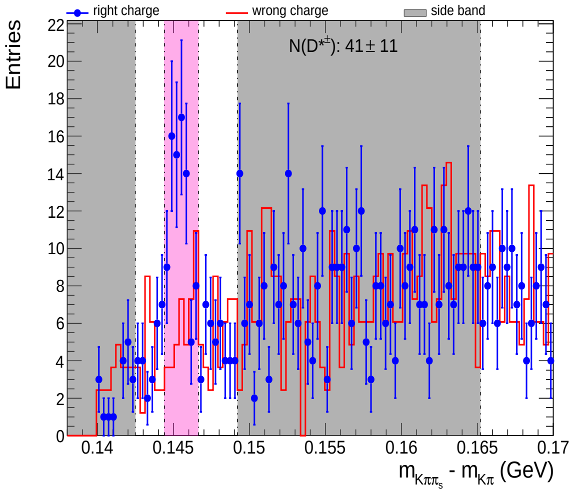


Nsignal using background substraction

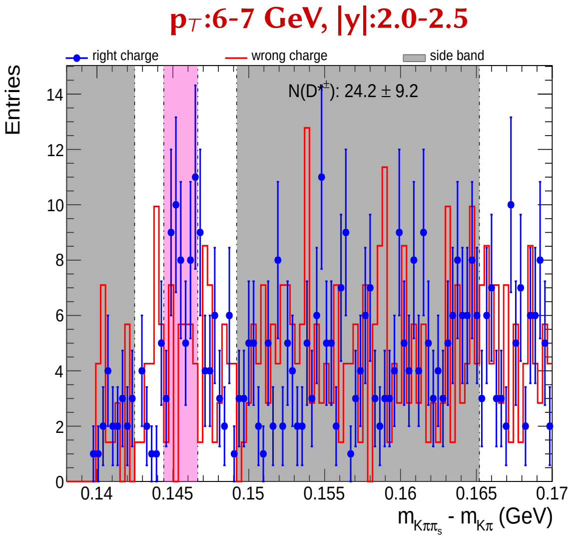
p_T:6-7 GeV, |y|:1.0-1.5



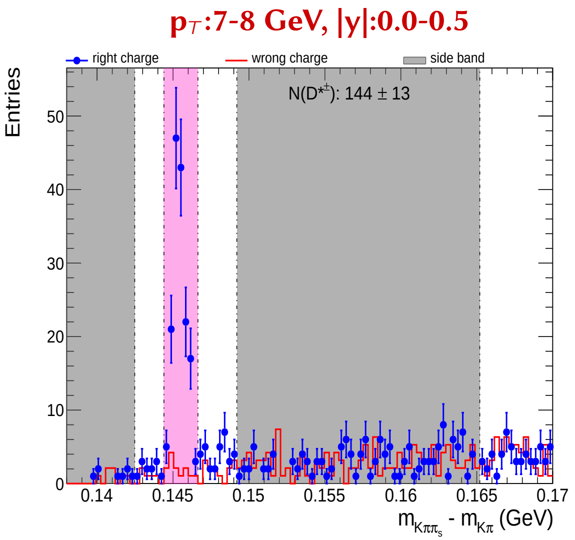
p_T:6-7 GeV, |y|:1.5-2.0

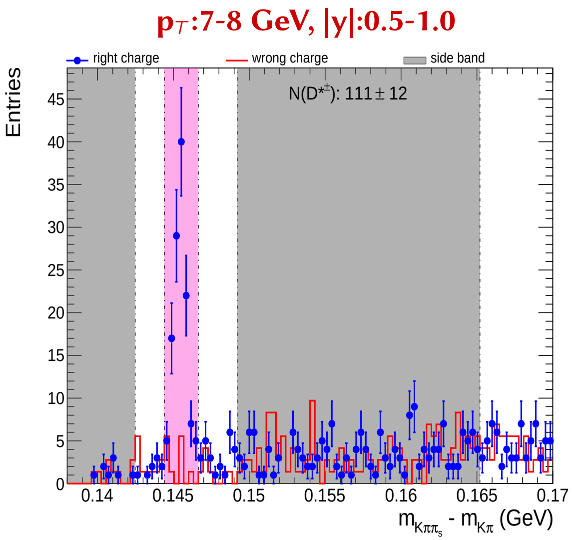


Nsignal using background substraction

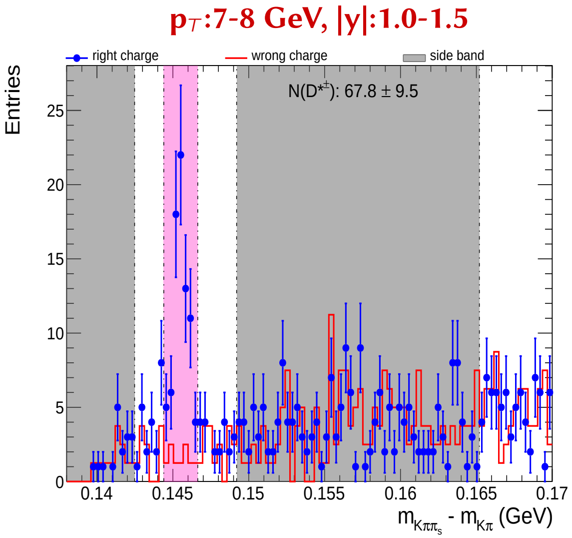


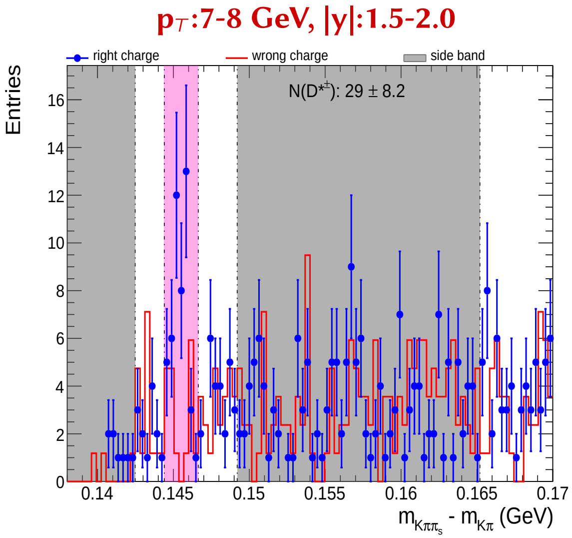
Nsignal using background substraction



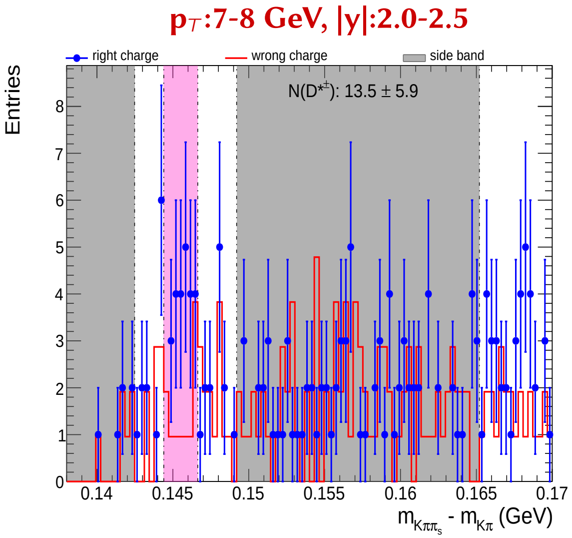


Nsignal using background substraction

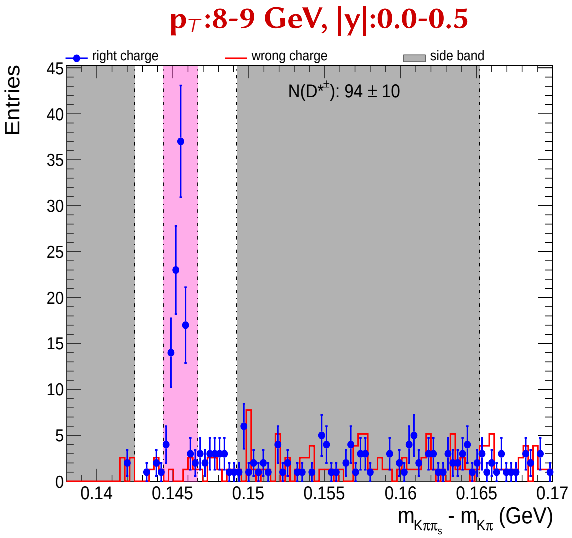


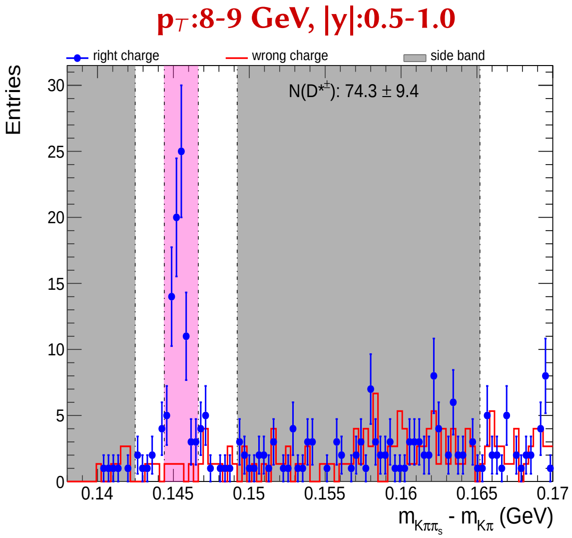


Nsignal using background substraction

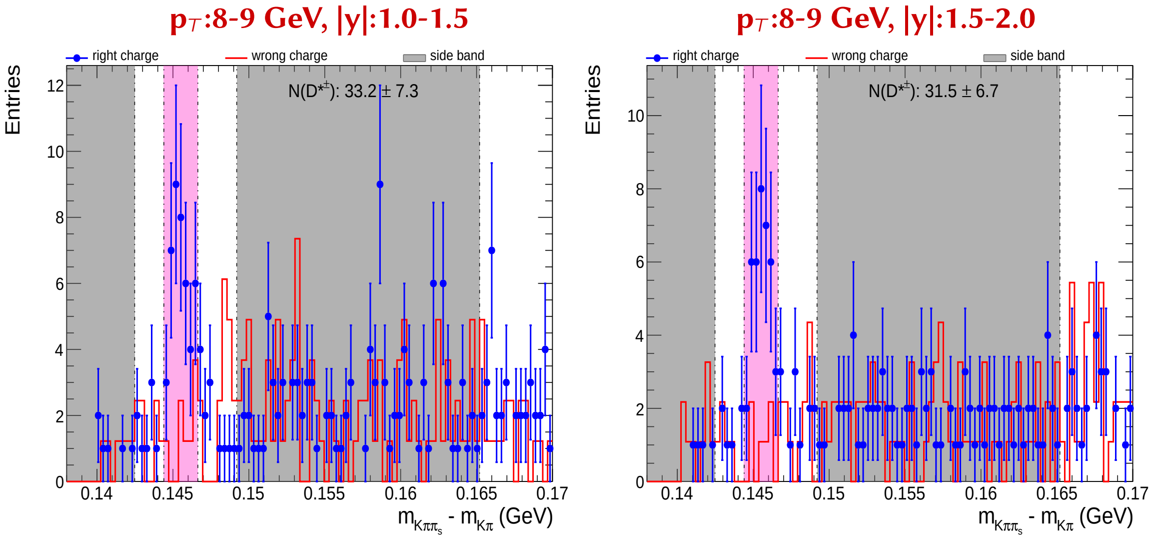


Nsignal using background substraction



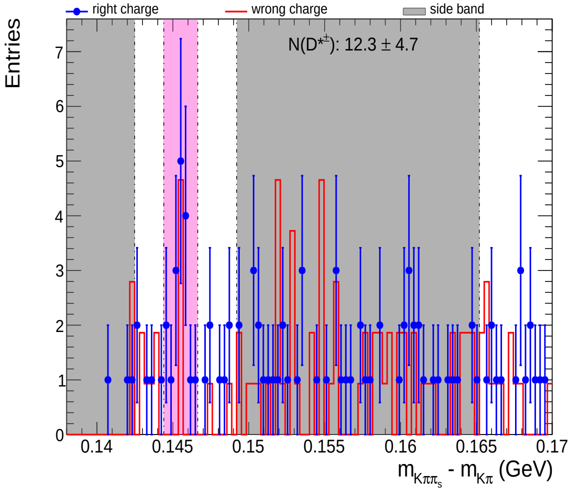


Nsignal using background substraction

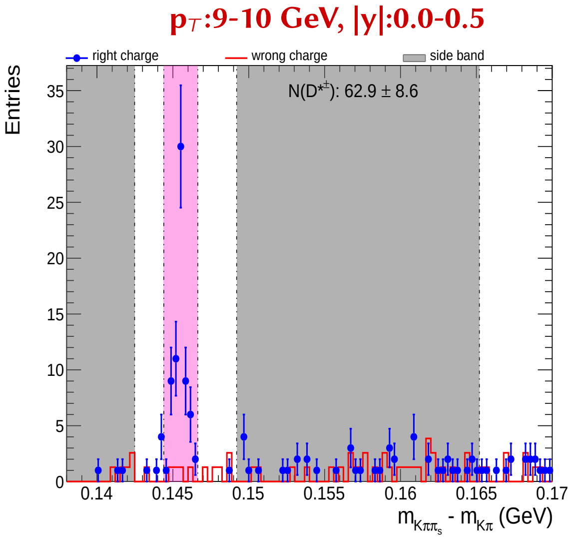


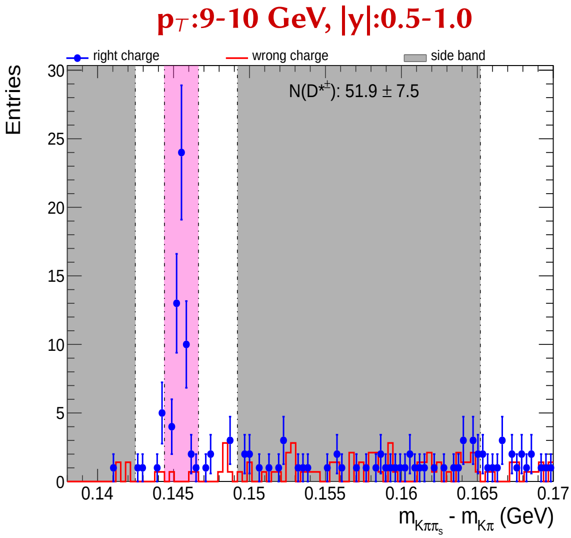
Nsignal using background substraction

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

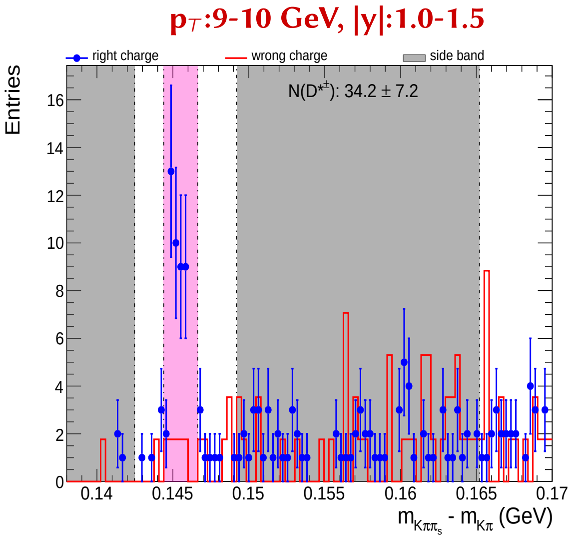


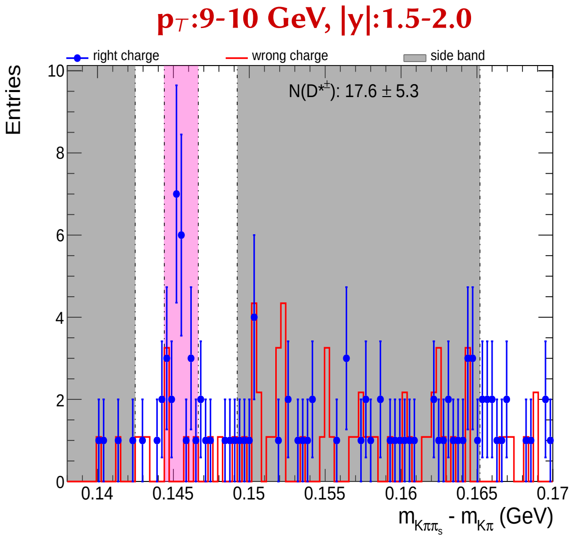
Nsignal using background substraction



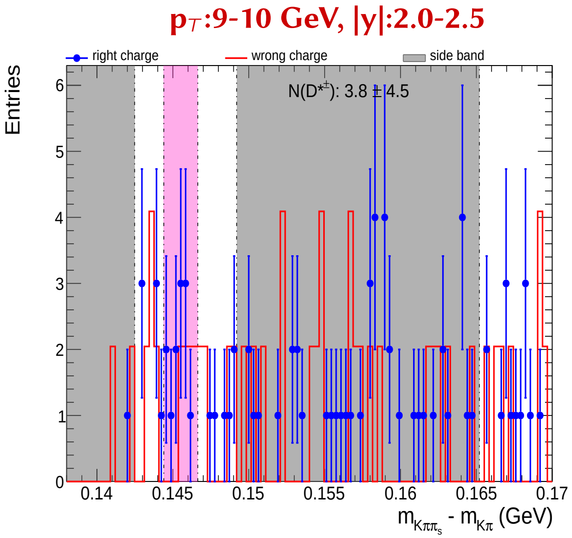


Nsignal using background substraction

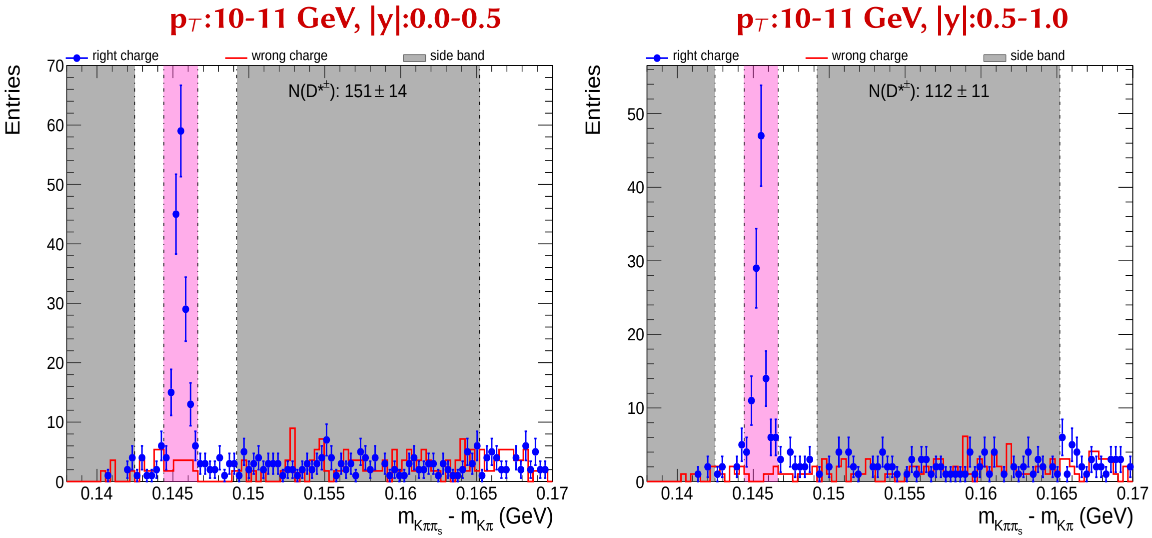




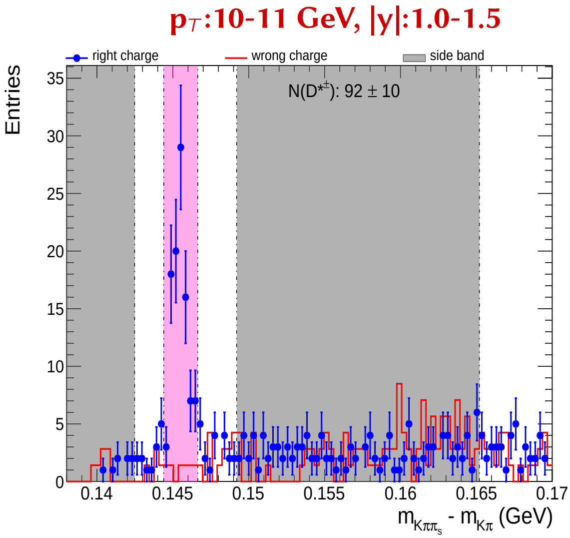
Nsignal using background substraction

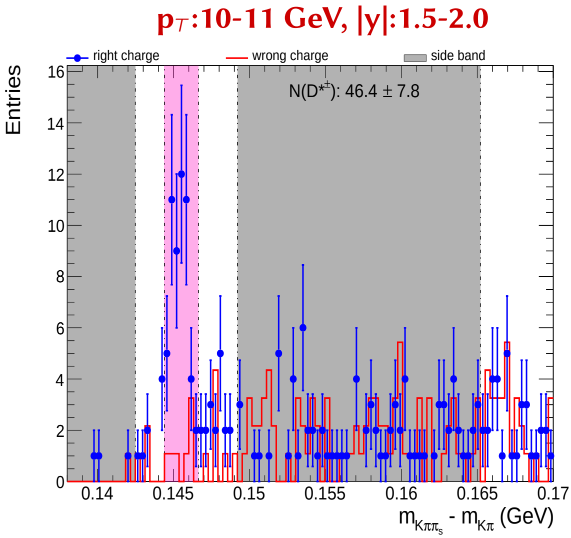


Nsignal using background substraction

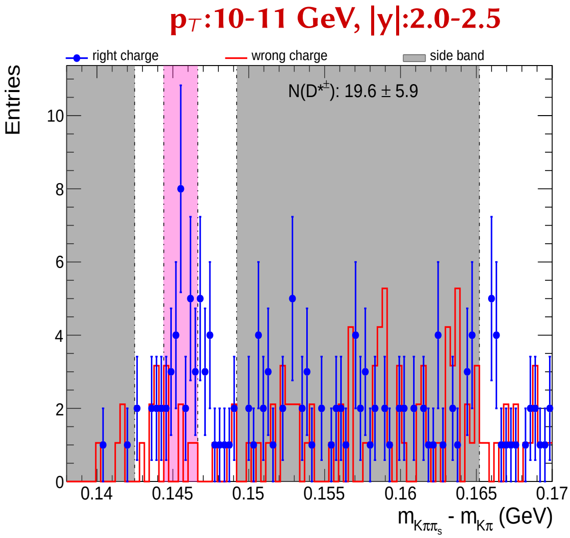


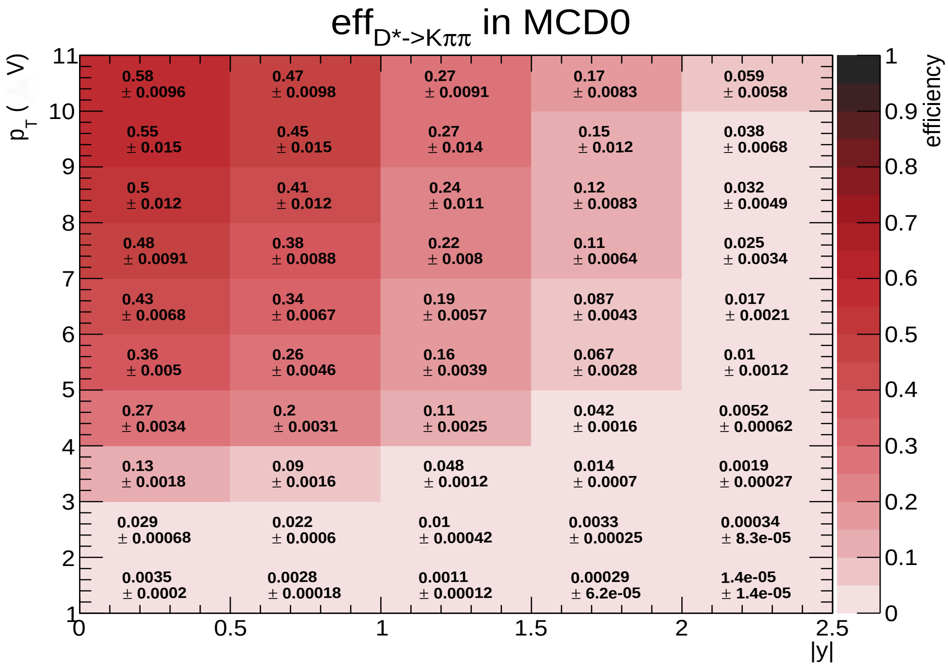
Nsignal using background substraction





Nsignal using background substraction





Efficiency from previous presentation

dca fit fot higher and lower p_T region

- dca fit has also been done at higher and lower p_T region to cover all phase space:

Measured and expected charm fraction (all rapidity)		
P_T (GeV)	Data	Pythia
< 3.5	0.95 +- 0.02	0.911
> 3.5	0.91 +- 0.07	0.884