# Status of charm and beauty cross sections at 5 TeV

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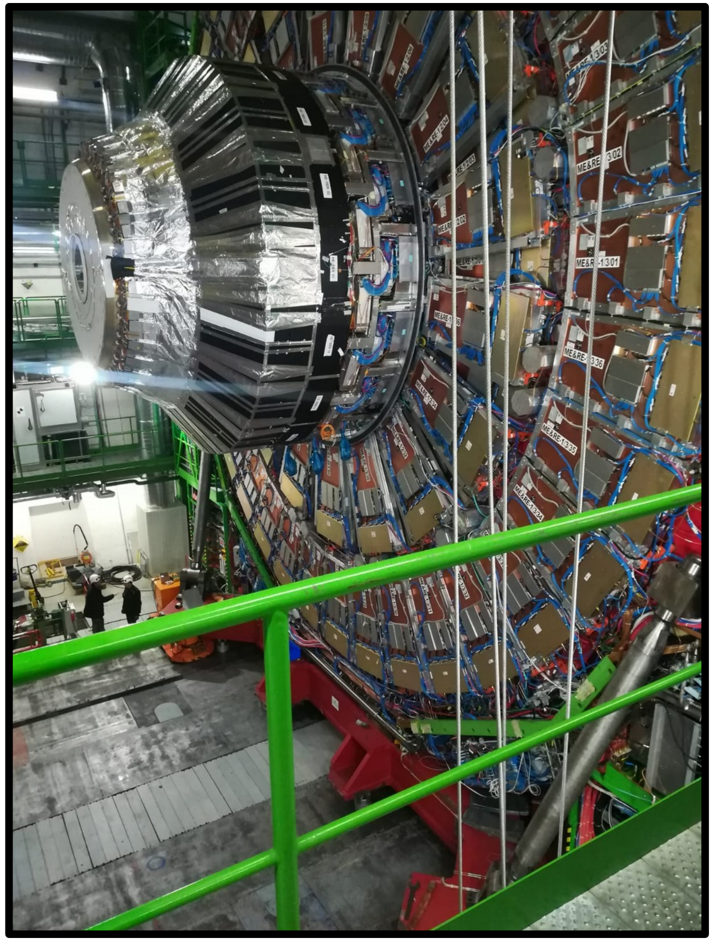
# My PhD project

- Measure total beauty cross sections at different center of mass energies 0.9, 2.76, 5, 7, 8, and 13 TeV, without theory extrapolation for the first time in $\longrightarrow$

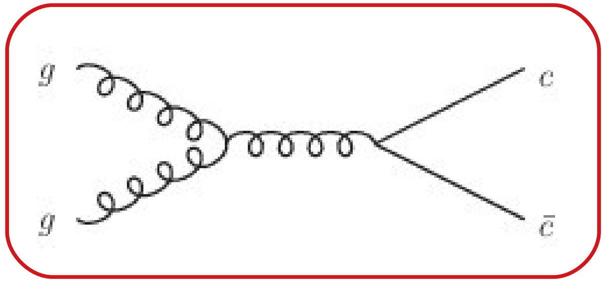


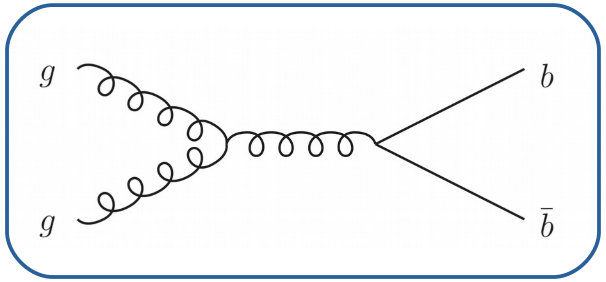
- Measure cross sections in full phase space of D mesons from b hadron decays in small bins in $p_T$ and |Y| and integrate
- Decays:

$$B \to D^* X \to D^0 \pi_s X \to K\pi\pi_s X$$

and

$$B \to D^0 X \to K\pi X$$

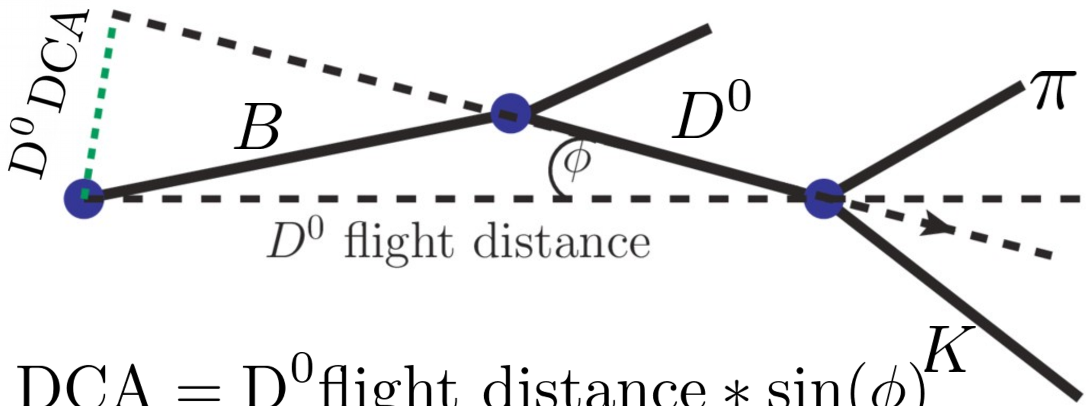


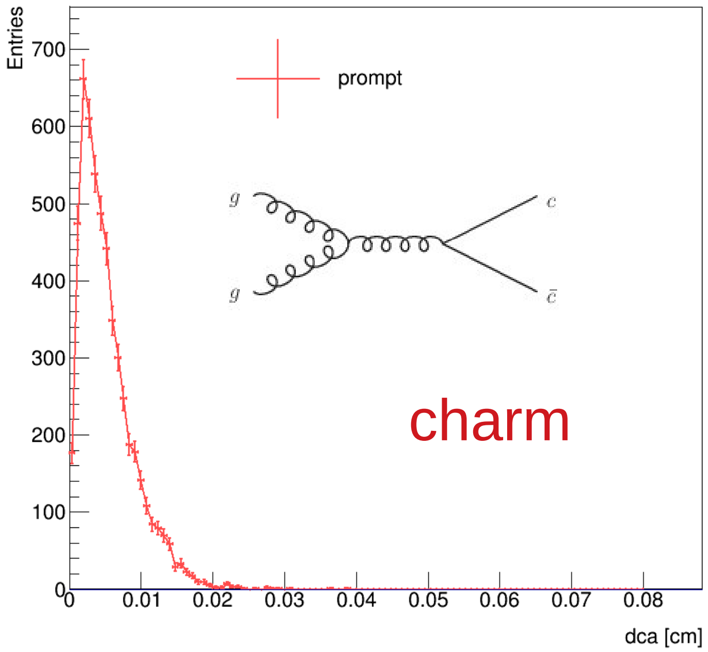

- **Challenge**: Separation of D mesons (prompt and from b hadrons decays) near the production threshold

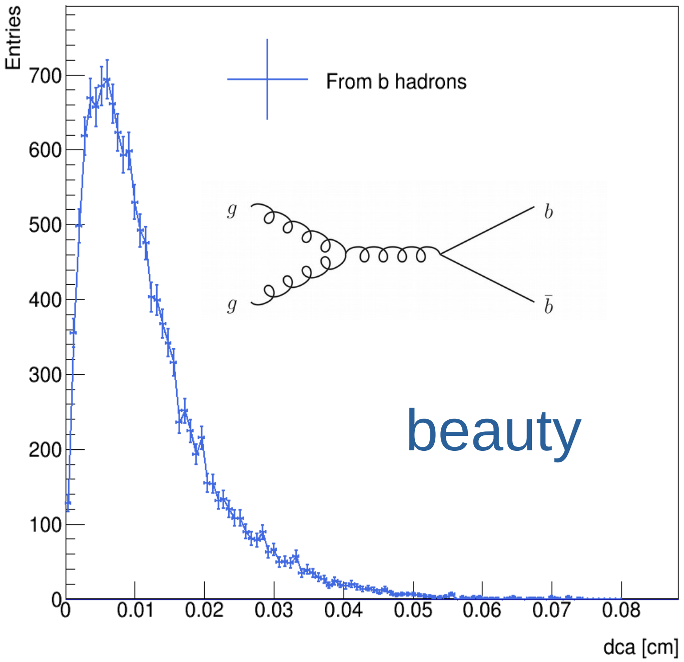
# Charm-Beauty Separation

- Trained with MC (prompt and non-prompt $D^0$) how to distinguish statistical between charm and beauty (talk can be found here)
- Distance of Closest Approach (DCA) distribution



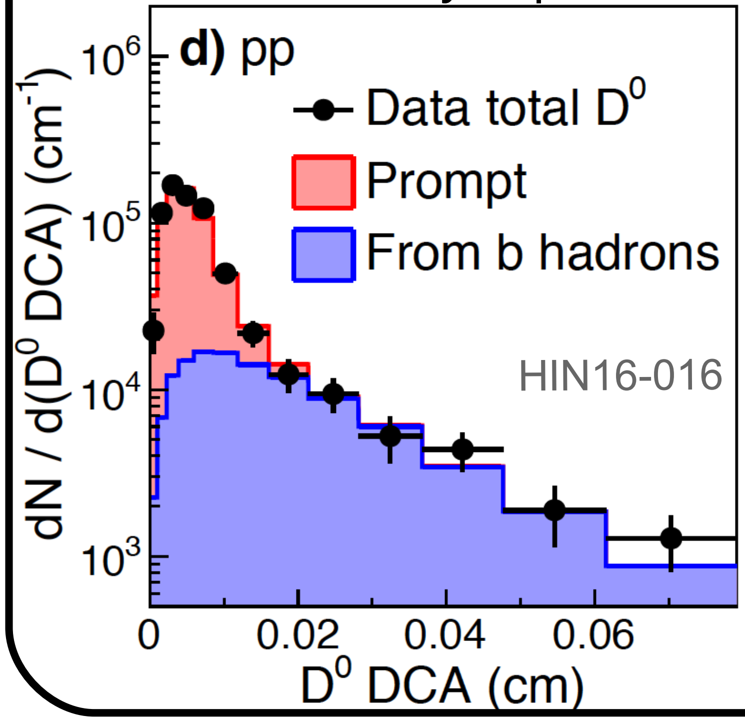

$$\mathrm{D^0\ DCA = D^0 flight\ distance} * \sin(\phi)$$




Shapes are different and can be used to fit

Method as in HIN16-016 is used for the charm-beauty separation




Amount of beauty ~ 10%

# Information about used data and MC for 2015 5 TeV

data

| Sample | #Events | w. JSONv2 | w. JSON | (N)MB |
|---|---|---|---|---|
| /MinimumBias1/Run2015E-PromptReco-v1/AOD | 126,809,757 | 73,368,897 | 111,413,194 | |
| /MinimumBias2/Run2015E-PromptReco-v1/AOD | 126,998,875 | 73,494,008 | 111,600,855 | |
| /MinimumBias3/Run2015E-PromptReco-v1/AOD | 126,853,017 | 73,379,825 | 111,502,472 | |
| /MinimumBias4/Run2015E-PromptReco-v1/AOD | 127,250,025 | 73,729,327 | 111,851,720 | |
| /MinimumBias5/Run2015E-PromptReco-v1/AOD | 127,169,537 | 73,649,847 | 111,772,459 | |
| /MinimumBias6/Run2015E-PromptReco-v1/AOD | 127,256,729 | 73,737,123 | 111,859,378 | |
| /MinimumBias7/Run2015E-PromptReco-v1/AOD | 127,256,692 | 73,736,801 | 111,858,963 | |
| /MinimumBias8/Run2015E-PromptReco-v1/AOD | 127,239,988 | 73,736,118 | 111,841,797 | |
| /MinimumBias9/Run2015E-PromptReco-v1/AOD | 127,222,974 | 73,736,847 | 111,826,347 | |
| /MinimumBias10/Run2015E-PromptReco-v1/AOD | 127,220,628 | 73,699,535 | 111,822,249 | |
| /MinimumBias11/Run2015E-PromptReco-v1/AOD | 126,325,160 | 73,749,761 | 111,857,169 | |
| /MinimumBias12/Run2015E-PromptReco-v1/AOD | 127,207,059 | 73,701,871 | 111,808,958 | |
| /MinimumBias13/Run2015E-PromptReco-v1/AOD | 125,206,184 | 71,915,856 | 109,958,587 | |
| /MinimumBias14/Run2015E-PromptReco-v1/AOD | 126,522,737 | 73,495,492 | 111,602,374 | |
| /MinimumBias15/Run2015E-PromptReco-v1/AOD | 126,753,153 | 73,494,707 | 111,602,223 | |
| /MinimumBias16/Run2015E-PromptReco-v1/AOD | 127,128,323 | 73,750,208 | 111,872,629 | |
| /MinimumBias17/Run2015E-PromptReco-v1/AOD | 126,280,043 | 72,982,926 | 111,105,435 | |
| /MinimumBias18/Run2015E-PromptReco-v1/AOD | 126,542,929 | 73,253,032 | 111,311,694 | |
| /MinimumBias19/Run2015E-PromptReco-v1/AOD | 126,373,548 | 73,123,502 | 111,214,484 | |
| /MinimumBias20/Run2015E-PromptReco-v1/AOD | 127,031,373 | 73,527,679 | 111,633,897 | |
| Total | 2,536,648,731 | 1,469,263,362 | 2,231,316,884 | 1,853,304,000 |
| effective luminosity (see section 5.2) | | 27.95 $nb^{-1}$ | 40.17 $nb^{-1}$ | 40.17 $nb^{-1}$ |

MC

| | | |
|---|---|---|
| /D0Kpi_pT0toInf_TuneCUEP8M1_5TeV_pythia8-evtgen/ HINppWinter16DR-75X_mcRun2_asymptotic_ppAt5TeV_v3-v3/AODSIM | 12,077,624 | 40.4 $nb^{-1}$ |

# Used cuts for selection of $D^{*\pm} \to D^0\pi_s^\pm \to K^\mp\pi^\pm\pi_s^\pm$

- Track $p_T$ cut: $p_T^{K,\pi} > 0.5\ GeV$ none for slow pion $\pi_s$
- $D^0$ mass cut: $1.836 < m_{D^0} < 1.892\ GeV$
- We define our cuts in two $p_T$ regions differently:

  - in the **higher** $p_T$ region $p_T^{D^*} > 3.5\ GeV$

$$\left(dl_{sig}^{D^0} > 0\ \ \&\ \ pt_{T frac}^{D^*} > 0.15\ \ \&\ \ \cos(\phi) > 0.8\right)\ or\ dl_{sig}^{D^0} > 2$$

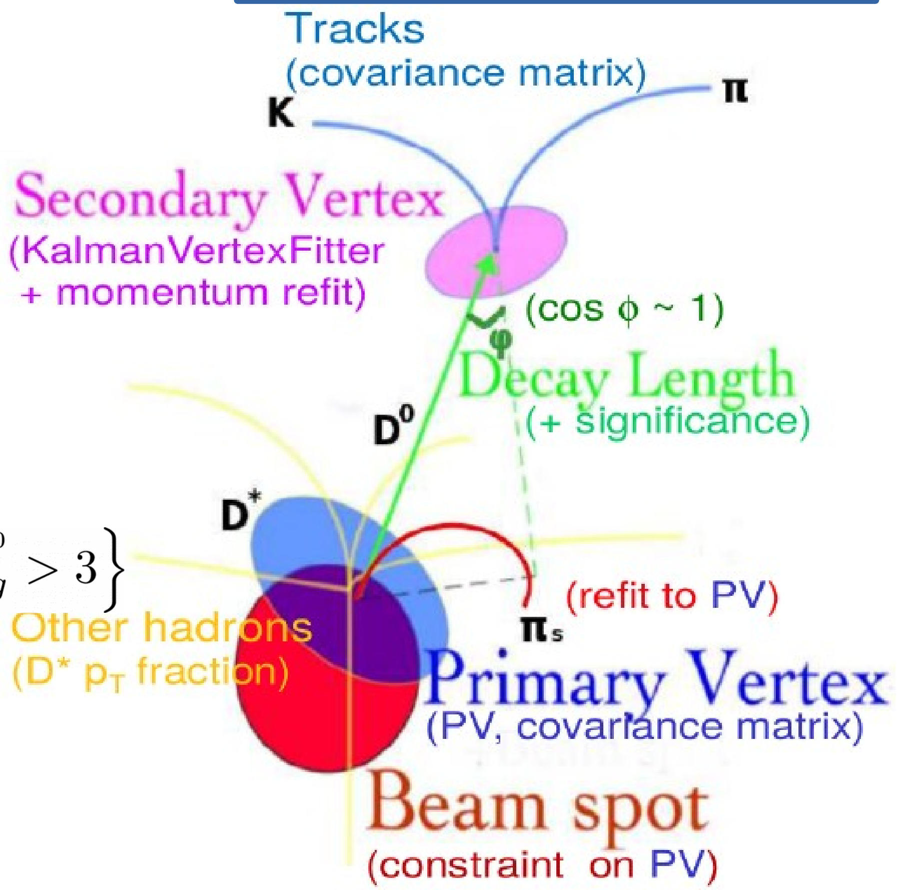
  - in the **lower** $p_T$ region $p_T^{D^*} < 3.5\ GeV$

$$\mathrm{pt}_{T frac}^{D^0} > 0.1\ \ \&\ \ \cos(\phi) > 0.8\ \ \&$$

$$\left\{\left(dl_{sig}^{D^0} > 1.5\ \&\ pt_{T frac}^{D^*} > 0.15\right)\ or\ \left(dl_{sig}^{D^0} > 2\ \&\ \cos(\phi_{D^0}) > 0.995\right)\ or\ dl_{sig}^{D^0} > 3\right\}$$

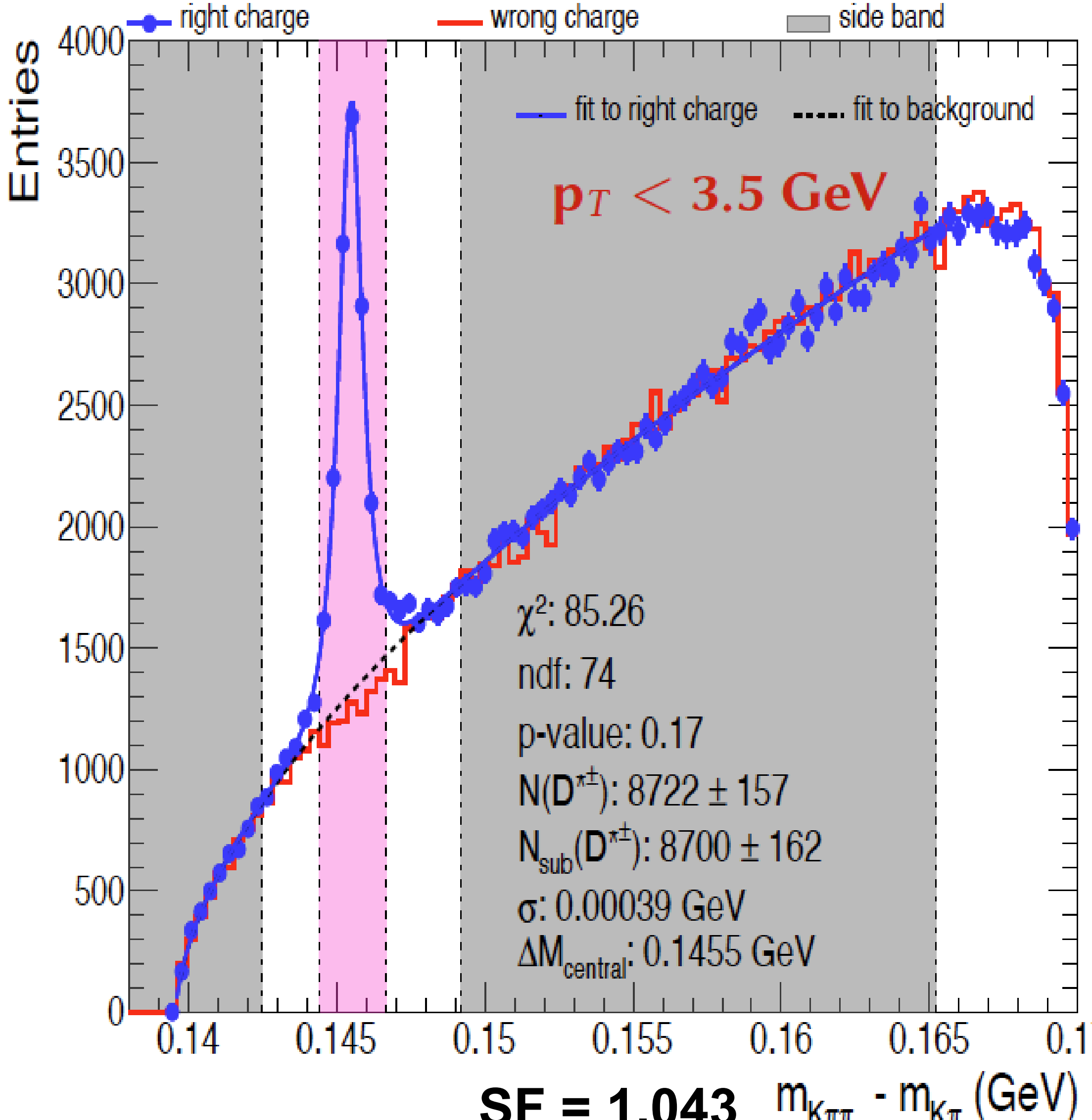
- With $p_{T frac} = \dfrac{p_T\ of\ D\ meson}{p_T\ of \sum^{\text{all tracks}}_{\text{at respective PV}}}$ and $dl_{sig}^{D^0} = \dfrac{dl^{D^0}}{dl_{err}^{D^0}}$

| the $D^*$ system | |
|---|---|
| right charge $K^\mp\pi^\pm\pi_s^\pm$ with a real $D^0$ | wrong charge $K^\mp\pi^\mp\pi_s^\pm$ comb bg |
| use both to extract a very clear signal | |

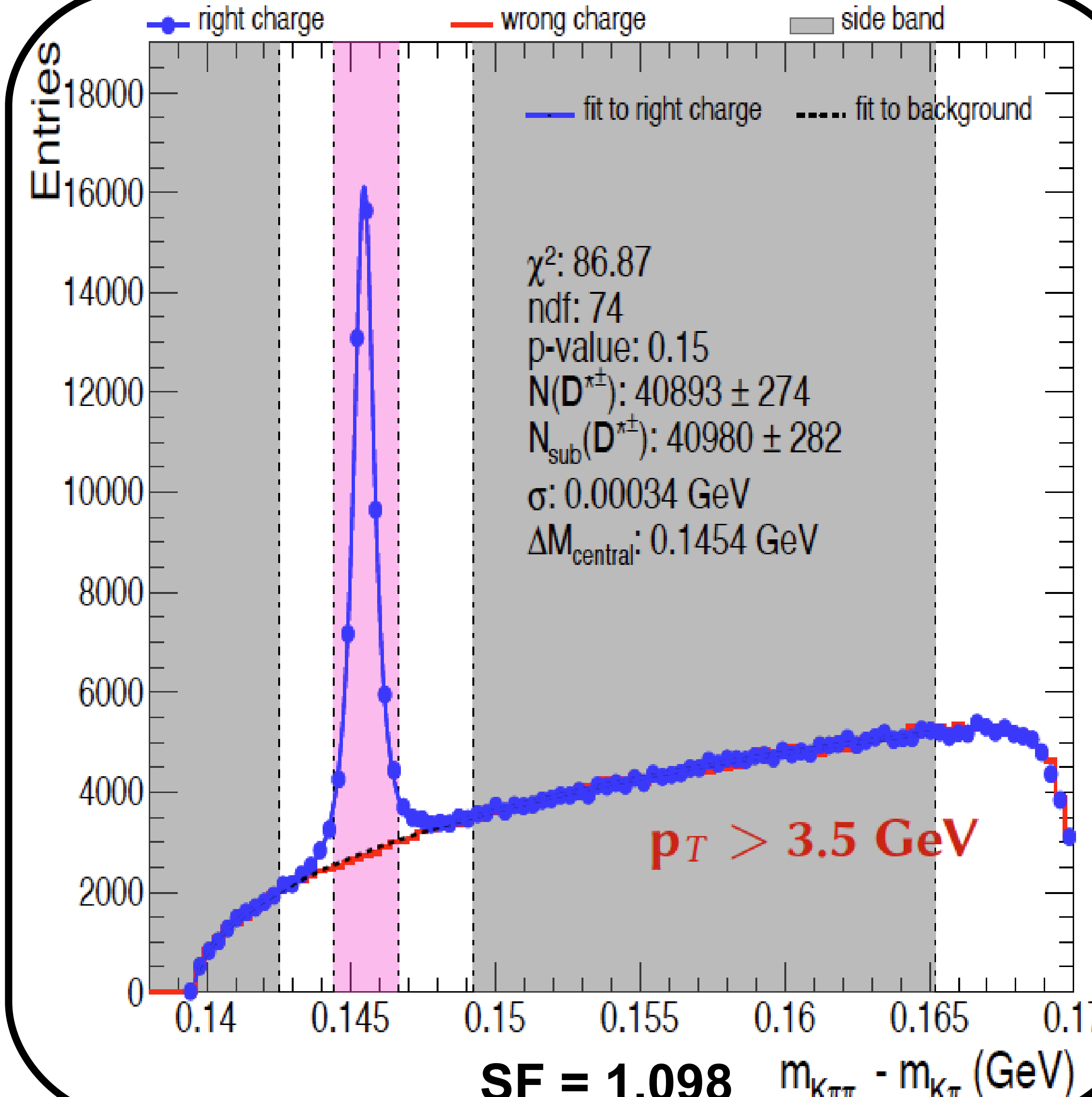


# Signal extraction on 5 TeV 2015 data

- We measure $D^{*\pm} \to D^0\pi_s^\pm \to K^\mp\pi^\pm\pi_s^\pm$ and need to subtract the background in the signal region




**SF = 1.043**




**SF = 1.098**

**next slide**

# Fitting to data

- Used the Higgs combine tool for fitting the MC templates to the data
  - $N_c^{signal} = 38346.7^{+377.8}_{-377.7}$
  - $N_b^{signal} = 2665.7^{+280.8}_{-271.6}$
- Partial total cross section in phase space:

$$p_T > 3.5\,GeV \quad |Y| < 2.5$$

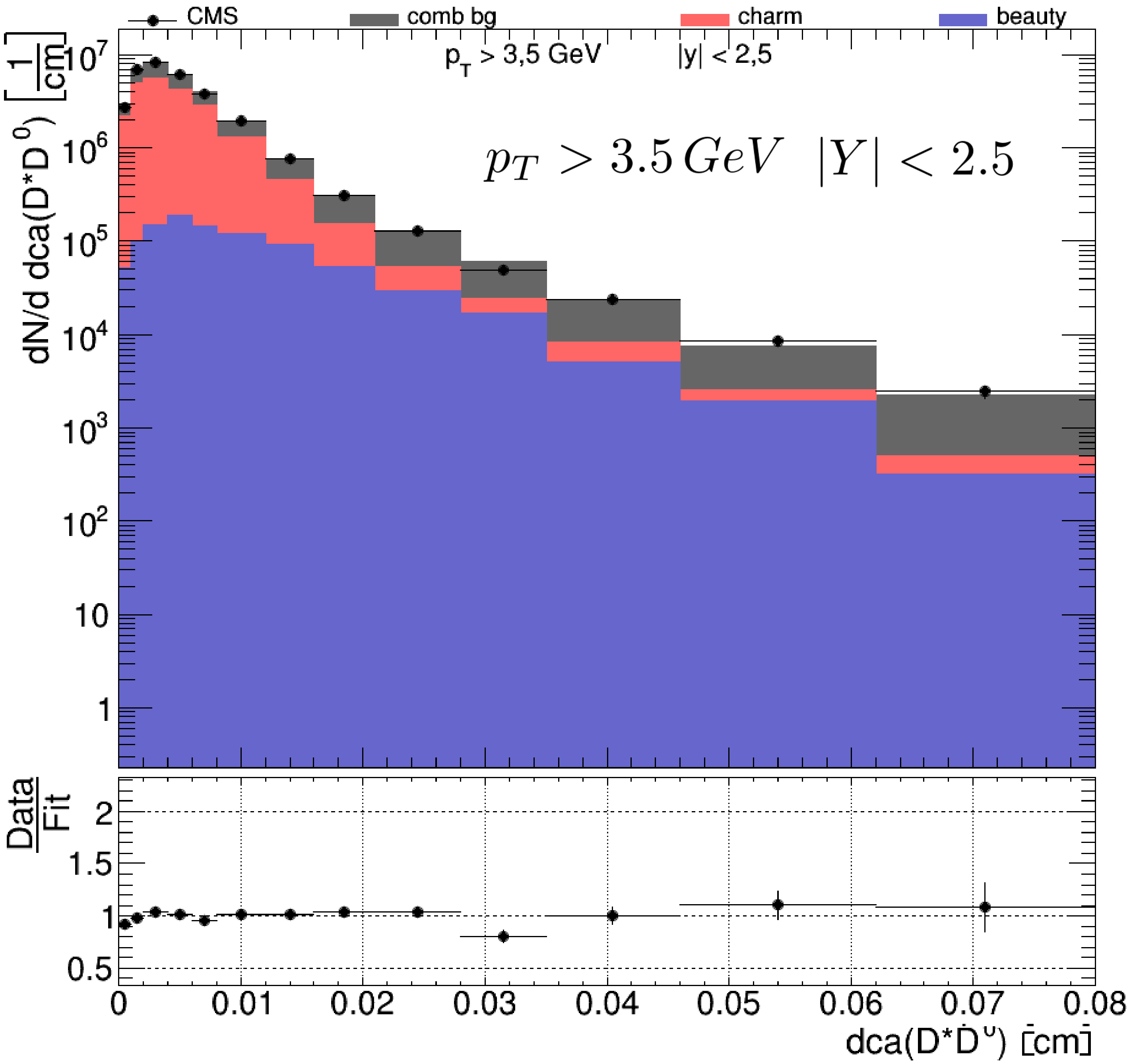
$$\sigma_{pp \to D^*_{prompt}} = 246.06^{+2.42}_{-2.42}\,\mu b$$

PYTHIA:$301.08\mu b$

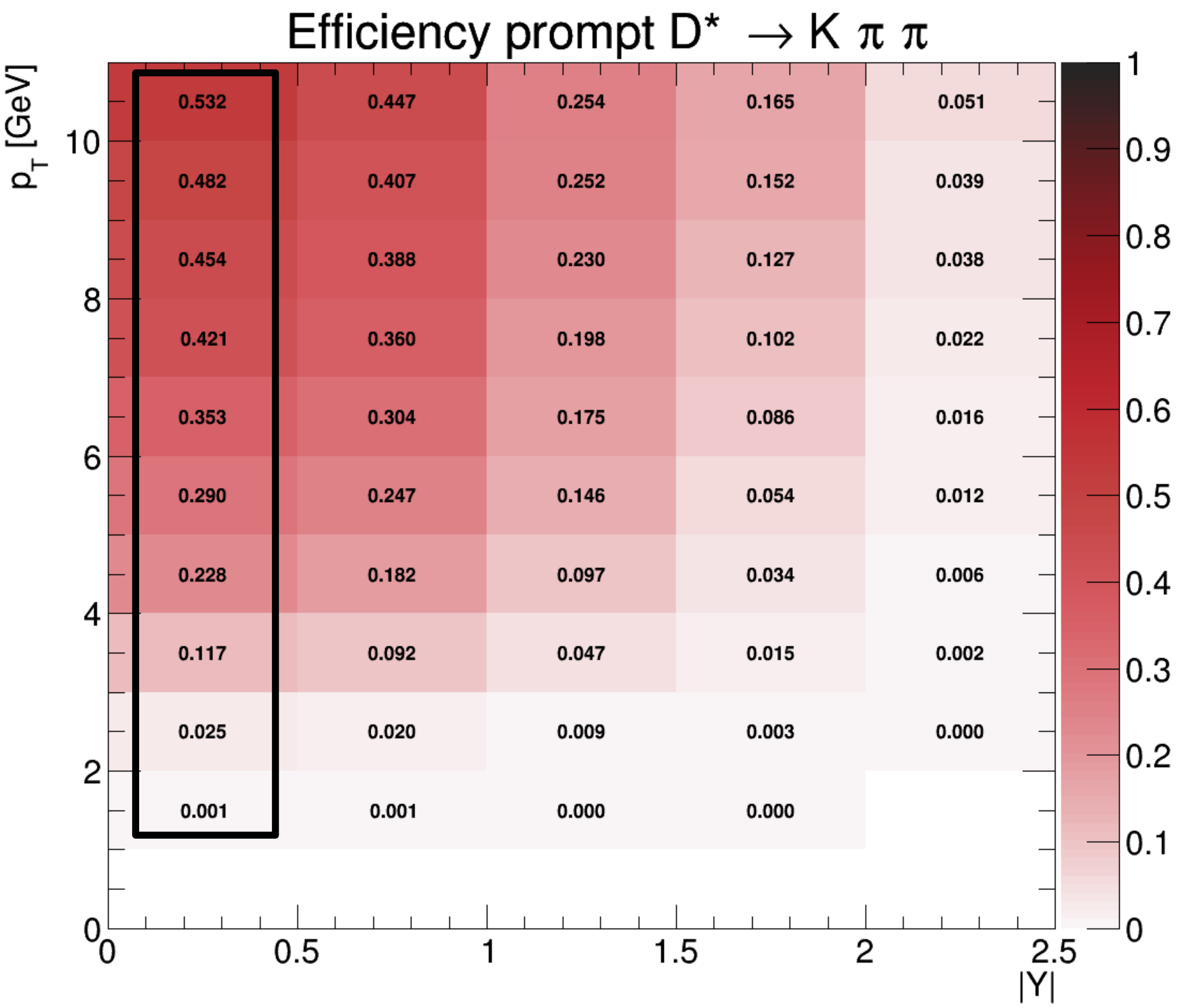
$$\sigma_{pp \to D^*_{nonprompt}} = 17.94^{+1.89}_{-1.83}\,\mu b$$

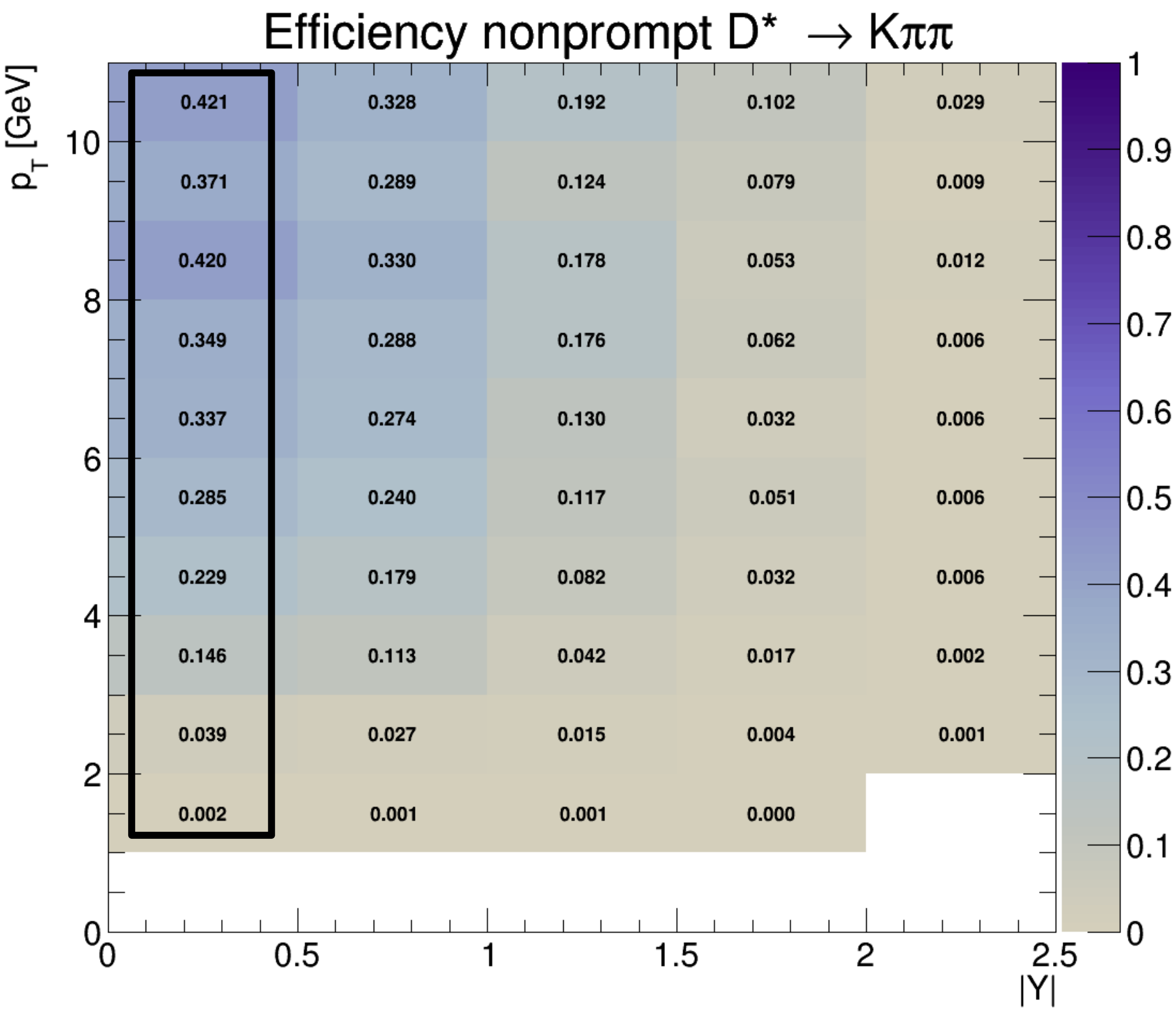
PYTHIA: $30.77\mu b$

**only statistical uncertainties**



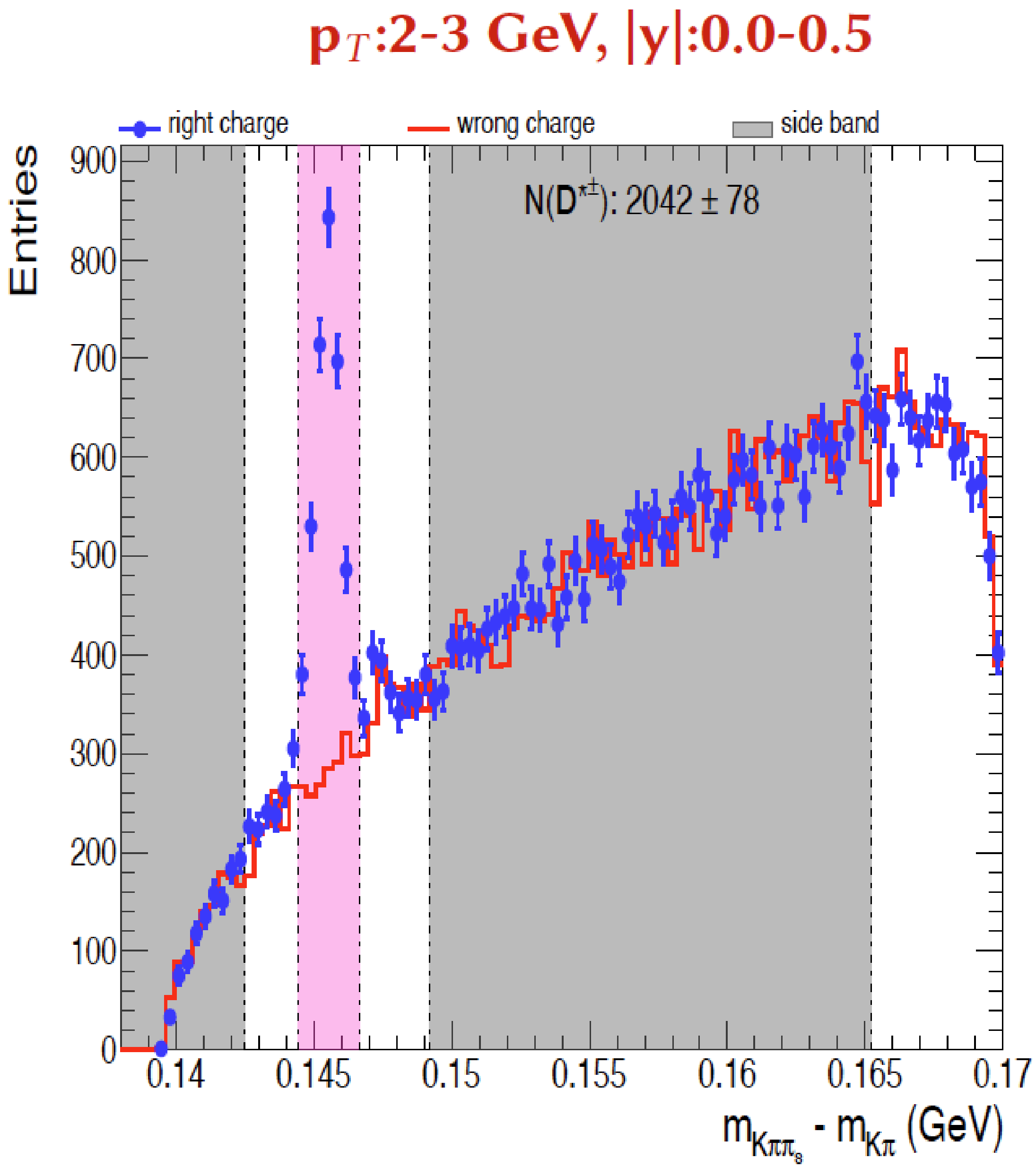
# Double differential efficiency table for (non)prompt D*

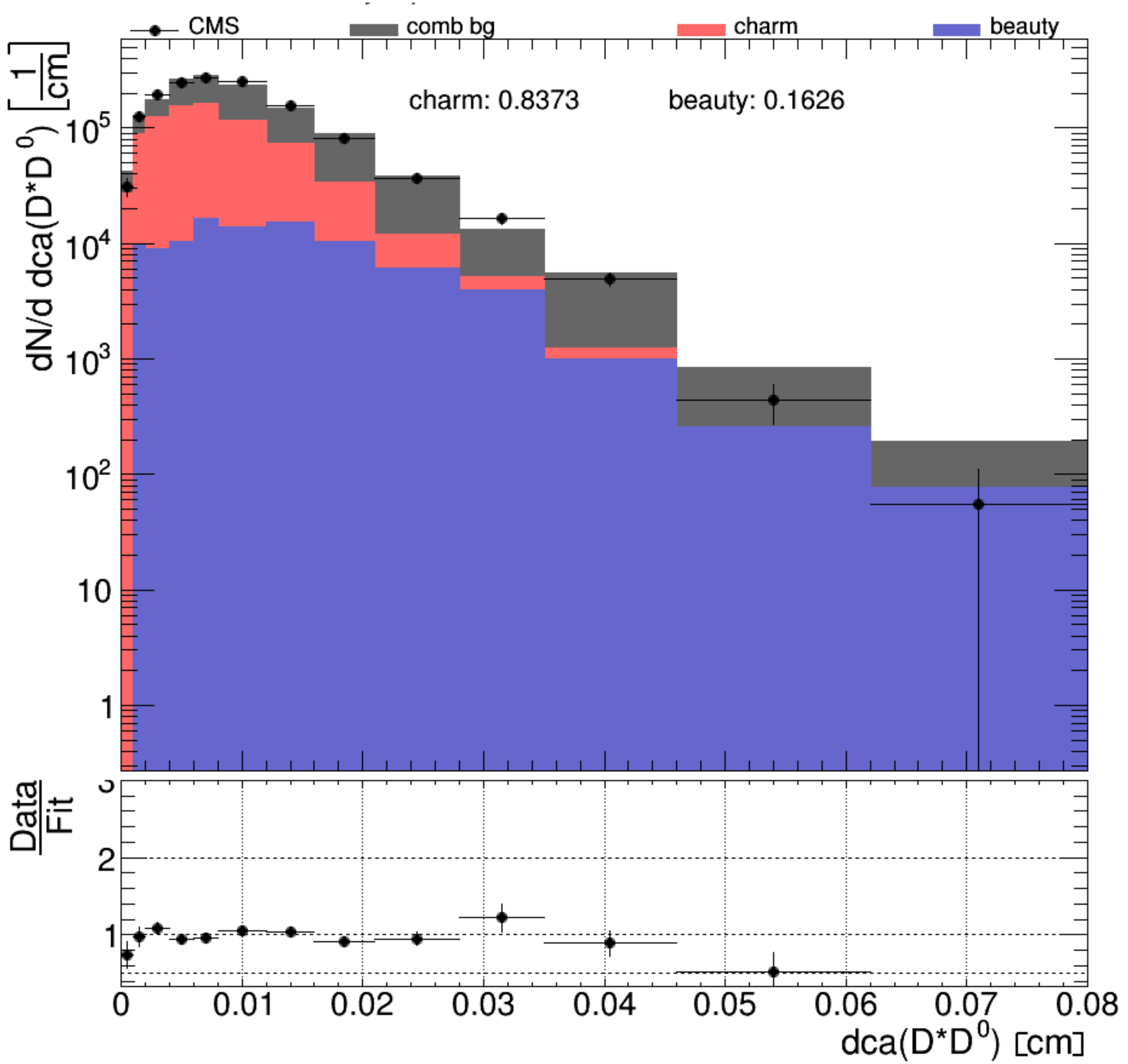



- Focus on phase space region |Y| < 0.5

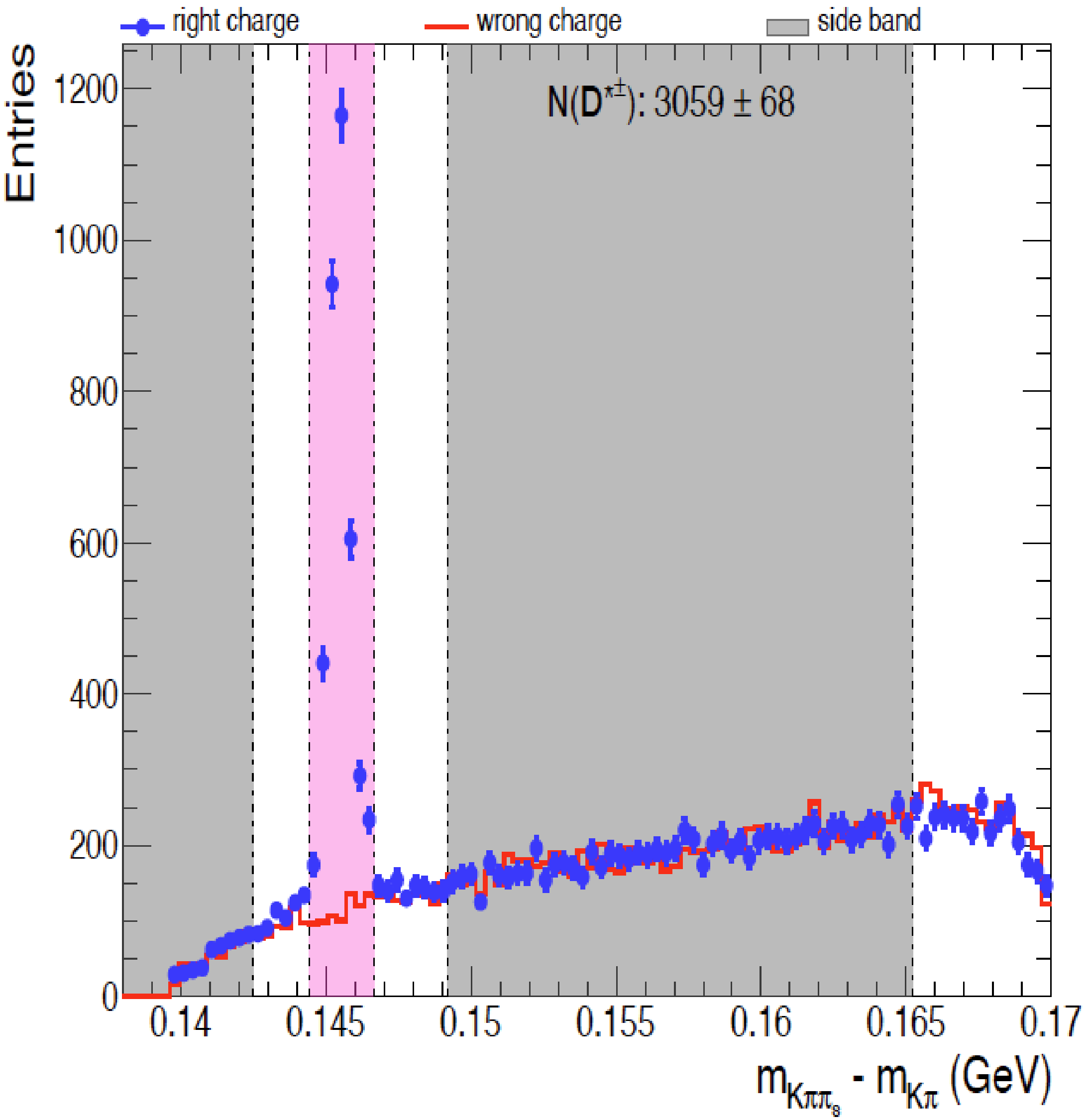
# Charm-Beauty Separation example

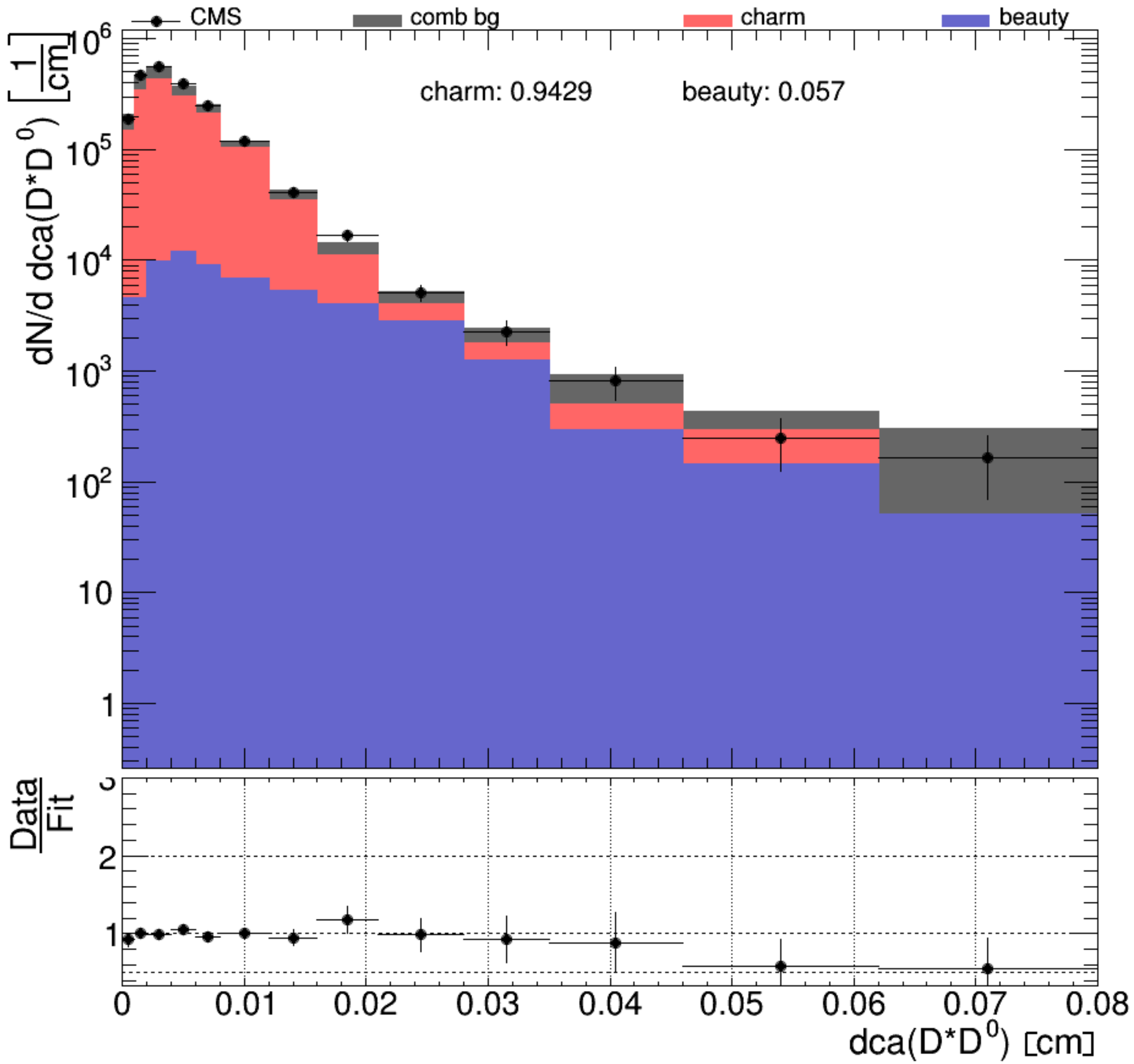


# Charm-Beauty Separation example

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

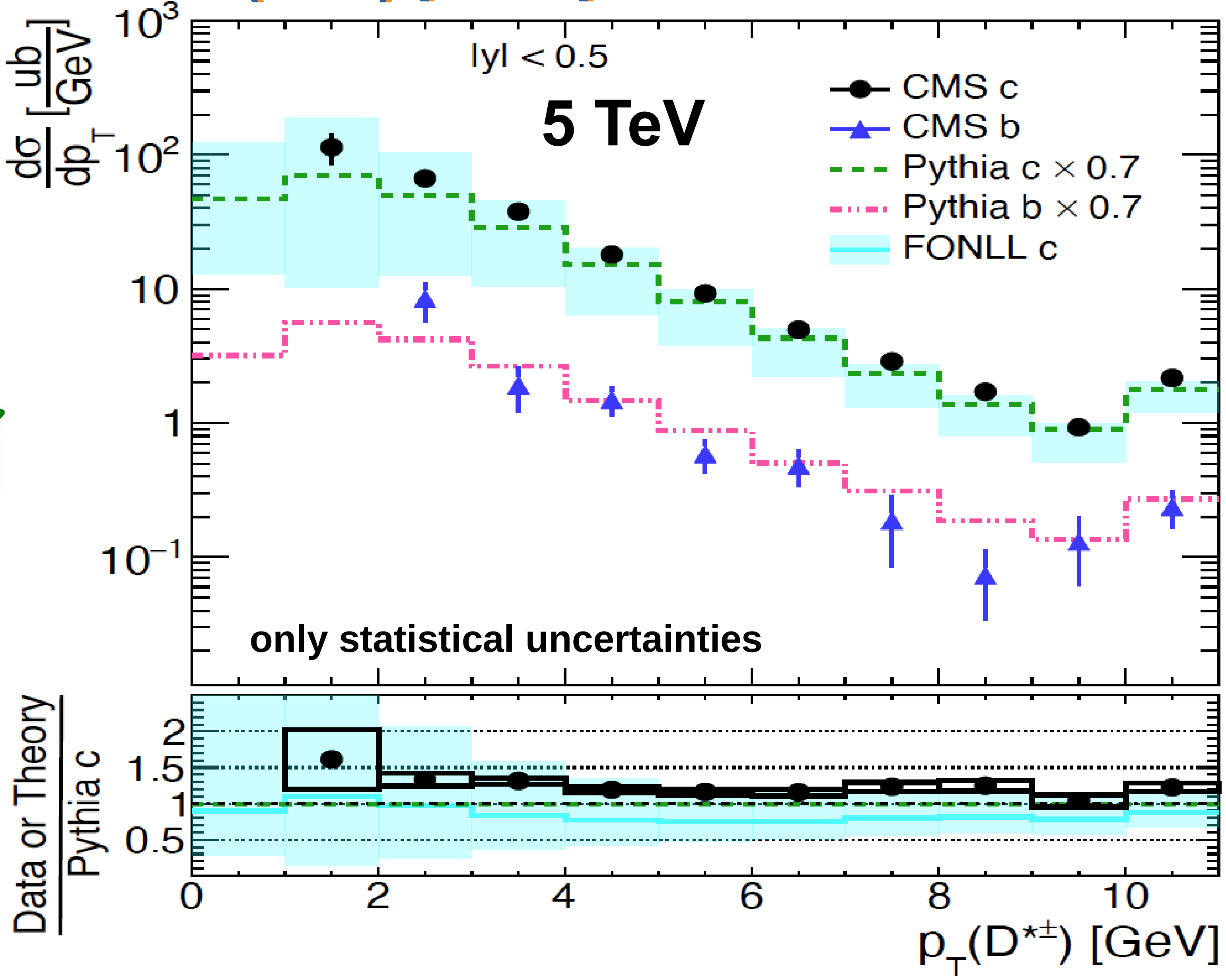


# Differential cross section for (non) prompt D*

First measurement of D* from charm and beauty in this phase space in CMS

- Agreement with predictions ✓
- Remainder of phase space & comparison to other measurements in progress



# Summary

- Measured D mesons $D^{*\pm} \to D^0 \pi_s^{\pm} \to K^{\mp} \pi^{\pm} \pi_s^{\pm}$
- Separation of D mesons (prompt and from b hadrons decays) near the production threshold
- First measurement of D* cross sections from charm and beauty at 5TeV in CMS
- More detailed information in other presentations

# Backup

# Backup

- Trained with a MC ( prompt and non-prompt $D^0$ ) how to distinguish statistical between charm and beauty and created Distance of Closest Approach (DCA) distribution (HIN16-016) , Used:
  - MC15_PrmtD0pT0: /PrmtD0_pThat-0_pT-0_pp_5p02-Pythia8/HINppWinter16DR-75X_mcRun2_asymptotic_ppAt5TeV_v3-v1/AODSIM, 1347186 events
  - MC15_NonPrD0pT0: /NonPrD0_pThat-0_pT-0_pp_5p02-Pythia8/HINppWinter16DR-75X_mcRun2_asymptotic_ppAt5TeV_v3-v1/AODSIM, 1942712 events
  - **MC15_D0Kp**i: /D0Kpi_pT0toInf_TuneCUEP8M1_5TeV_pythia8-evtgen/HINppWinter16DR-75X_mcRun2_asymptotic_ppAt5TeV_v3-v3/AODSIM, "pdmv_evts_in_DAS": 12077624

# Fixed Order Next to Leading Log

- We used FONLL for the prediction of heavy quark production and chose D* as hadronic final state
- We used the following set of parameters for charm production
  - the fragmentation factor for charm $f_c = 0.236$
  - the PDF set CTEQ6.6 (PDF uncertainty summed in quadrature to mass und scale uncertainty)
  - central value for mass $m_c = 1.5$ GeV (mass uncertainty $m_c = 1.3$, $1.7$ GeV summed in quadrature to scales uncertainties)
  - central value $\mu_R = \mu_F = \mu_0 = \mathrm{sqrt}(m^2 + p_T^2)$
  - scale uncertainties: $\mu_0/2 < \mu_R$ and $\mu_F < 2\mu_0$ with $1/2 < \mu_R/\mu_F < 2$
- We variate the mass, PDF, renormalisation and factorization scale and got and uncertainty band by the lower and upper values of this variation

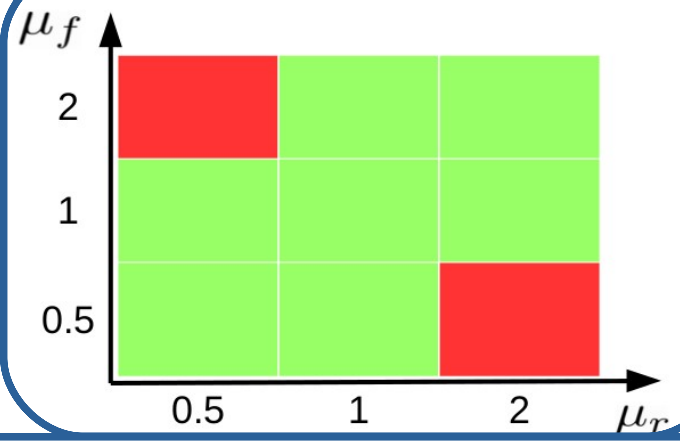



Illustration of the seven combinations of the variation of the renormalisation scale $\mu_r$ and factorization scale $\mu_f$

# Cross section calculation in higher pt bin

$$N_{c+b} = (c \pm \delta_c) \bullet N_c + (b \pm \delta_b) \bullet N_b = (0.812^{0.008}_{-0.008} \pm 0.008) \bullet 47225 + (0.579^{0.061}_{-0.059} \pm 0.06) \bullet 4604$$

$$= \boxed{(38346.7^{377.8}_{-377.8} \pm 377.8)} + \boxed{(2665.72^{280.844}_{-271.636} \pm 276.24)} = 41012.4 \pm 468.019$$

Branching ratios:

$D^* \rightarrow D^0 \pi = 0.667 \pm 0.005$

$D^0 \rightarrow K \pi = 0.0395 \pm 0.0003$

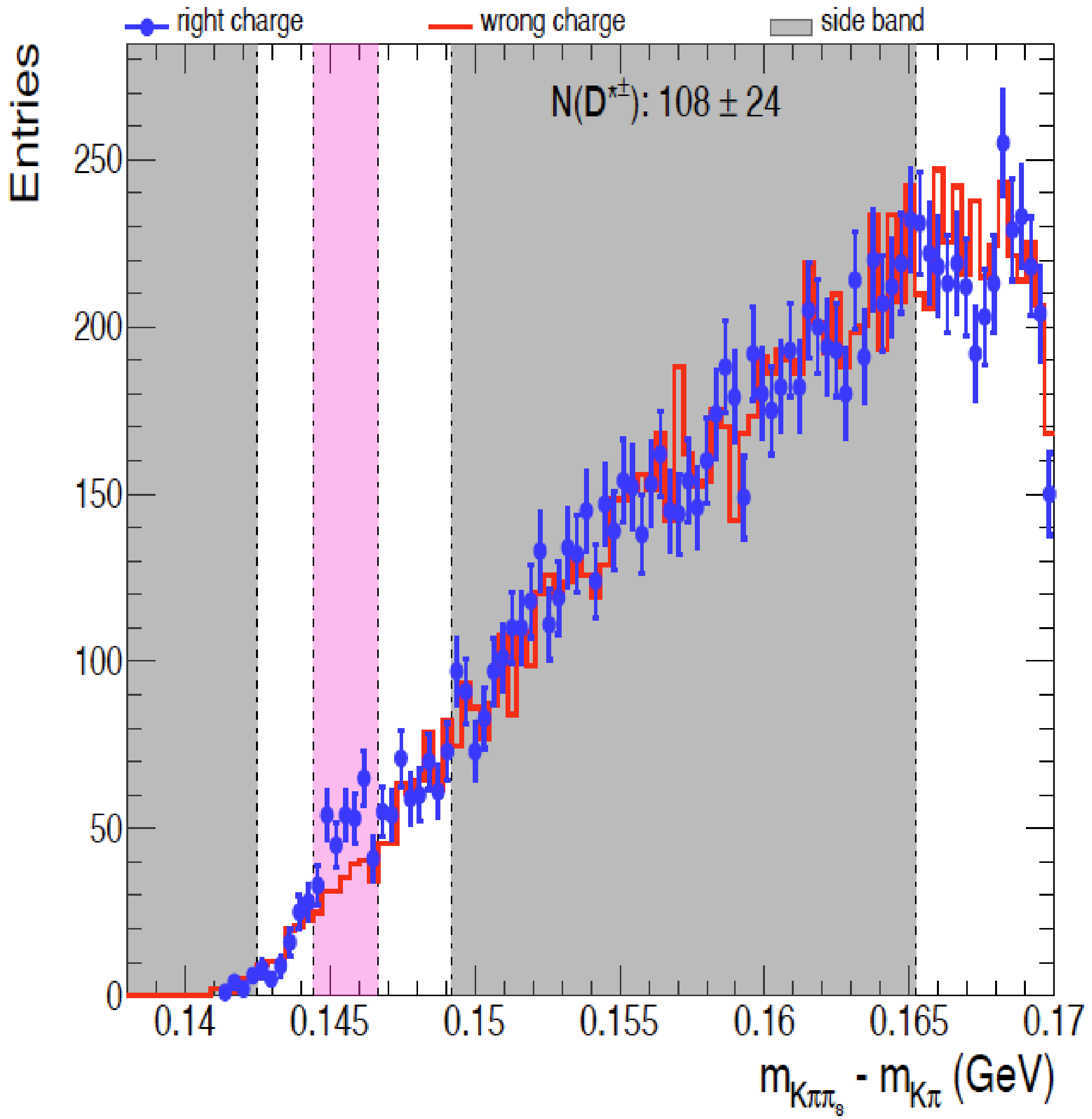
for 2015 Data 5TeV $L_{int} = 40.17$ :

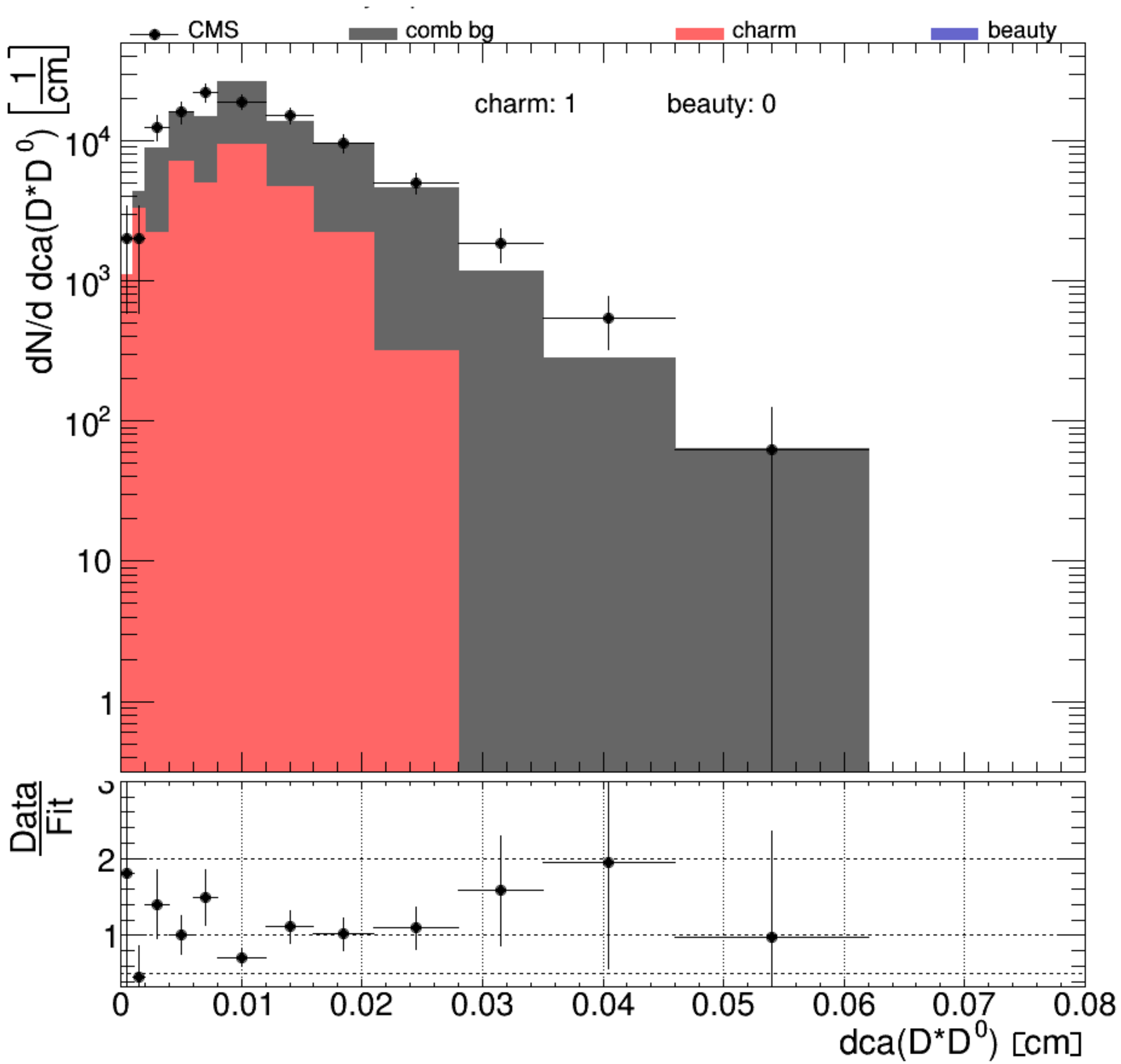
$$\sigma_{pp \rightarrow D^*_{nonprompt} \rightarrow D^0 \pi \rightarrow K \pi \pi} = \frac{N_{signal}}{L_{int} \bullet \epsilon_b} = \frac{2665.72}{40.17 \bullet 0.140439} = 472.526 \text{ nb} \quad , \quad \boxed{\sigma_{pp \rightarrow D^*_{nonprompt}} = 17935^{1889.53}_{-1827.58} \text{ nb}}$$

$$\sigma_{pp \rightarrow D^*_{prompt} \rightarrow D^0 \pi \rightarrow K \pi \pi} = \frac{N_{signal}}{L_{int} \bullet \epsilon_c} = \frac{38346.7}{40.17 \bullet 0.147249} = 6482.96 \text{ nb} \quad , \quad \boxed{\sigma_{pp \rightarrow D^*_{prompt}} = 246065^{2424.29}_{-2424.29} \text{ nb}}$$

# Charm-Beauty Separation example

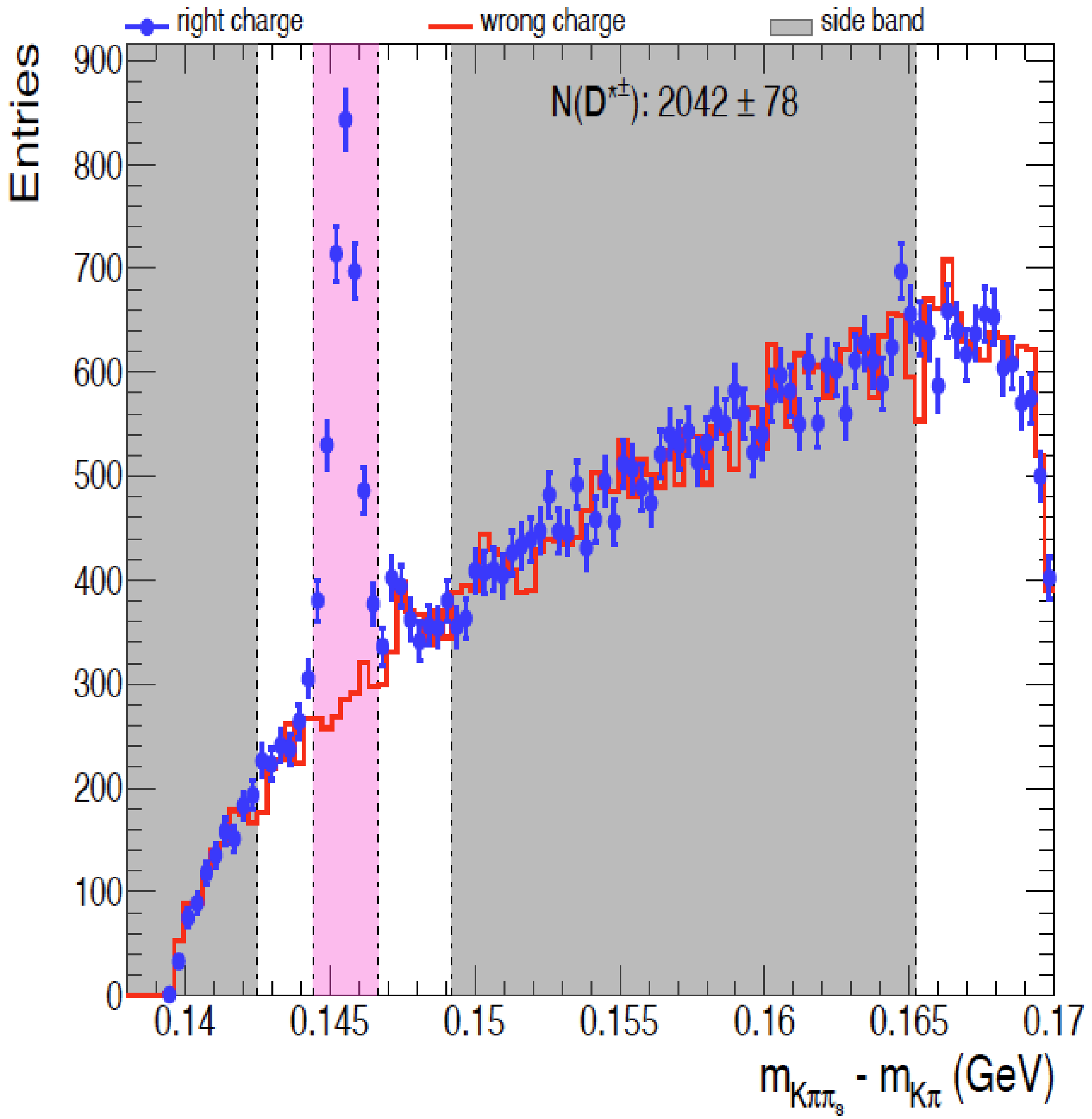
$p_T$:1-2 GeV, |y|:0.0-0.5

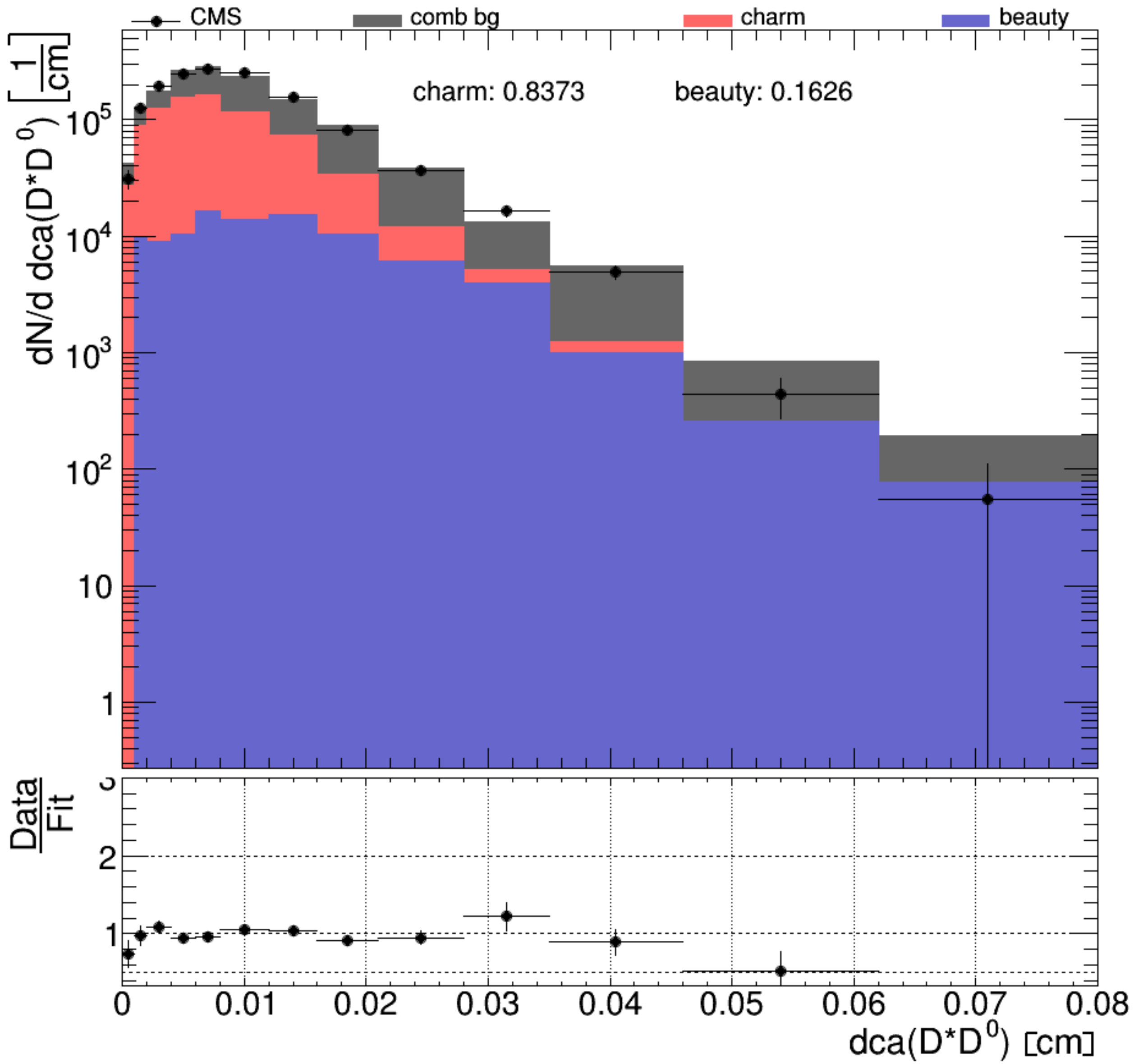


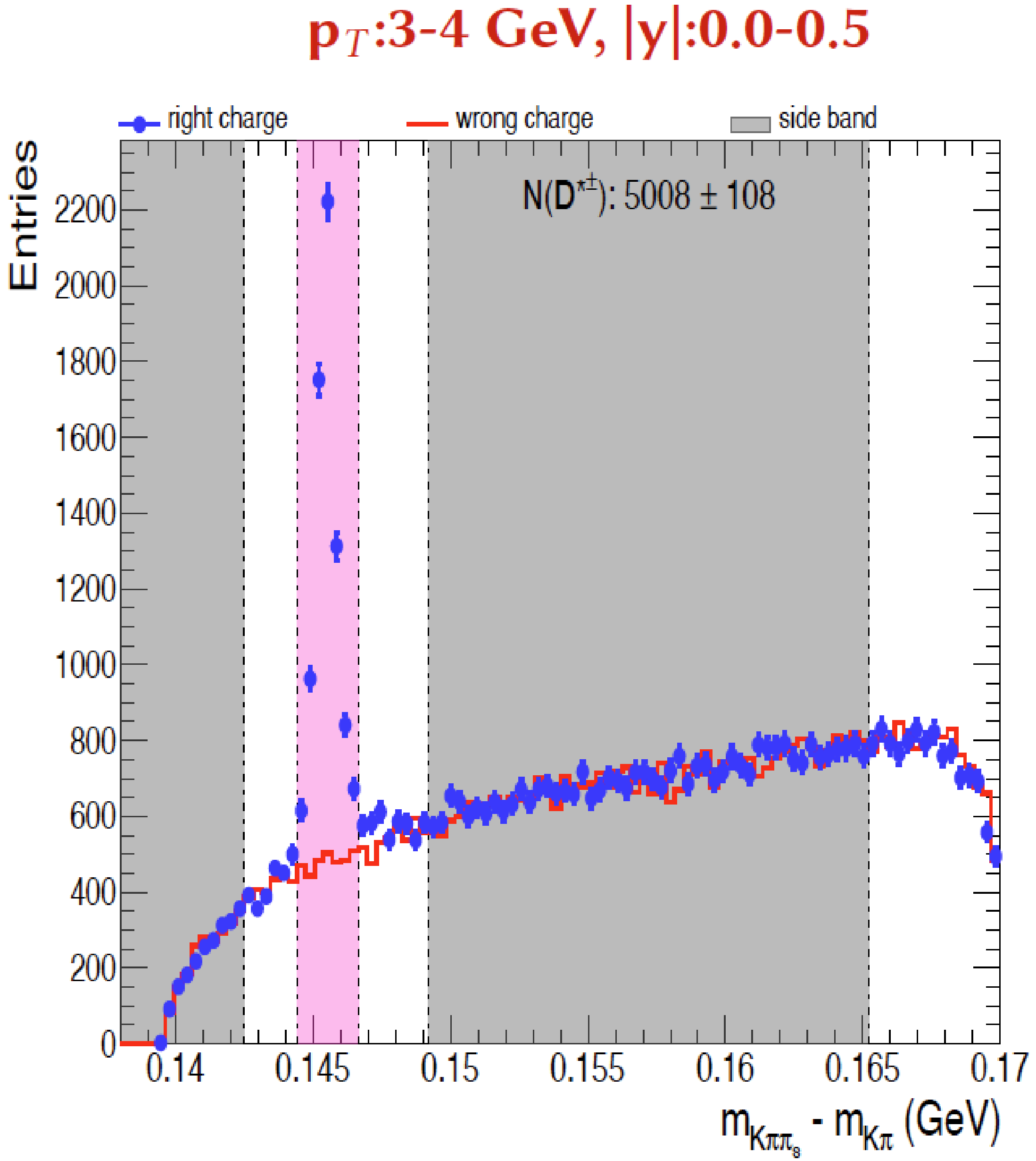
# Charm-Beauty Separation example

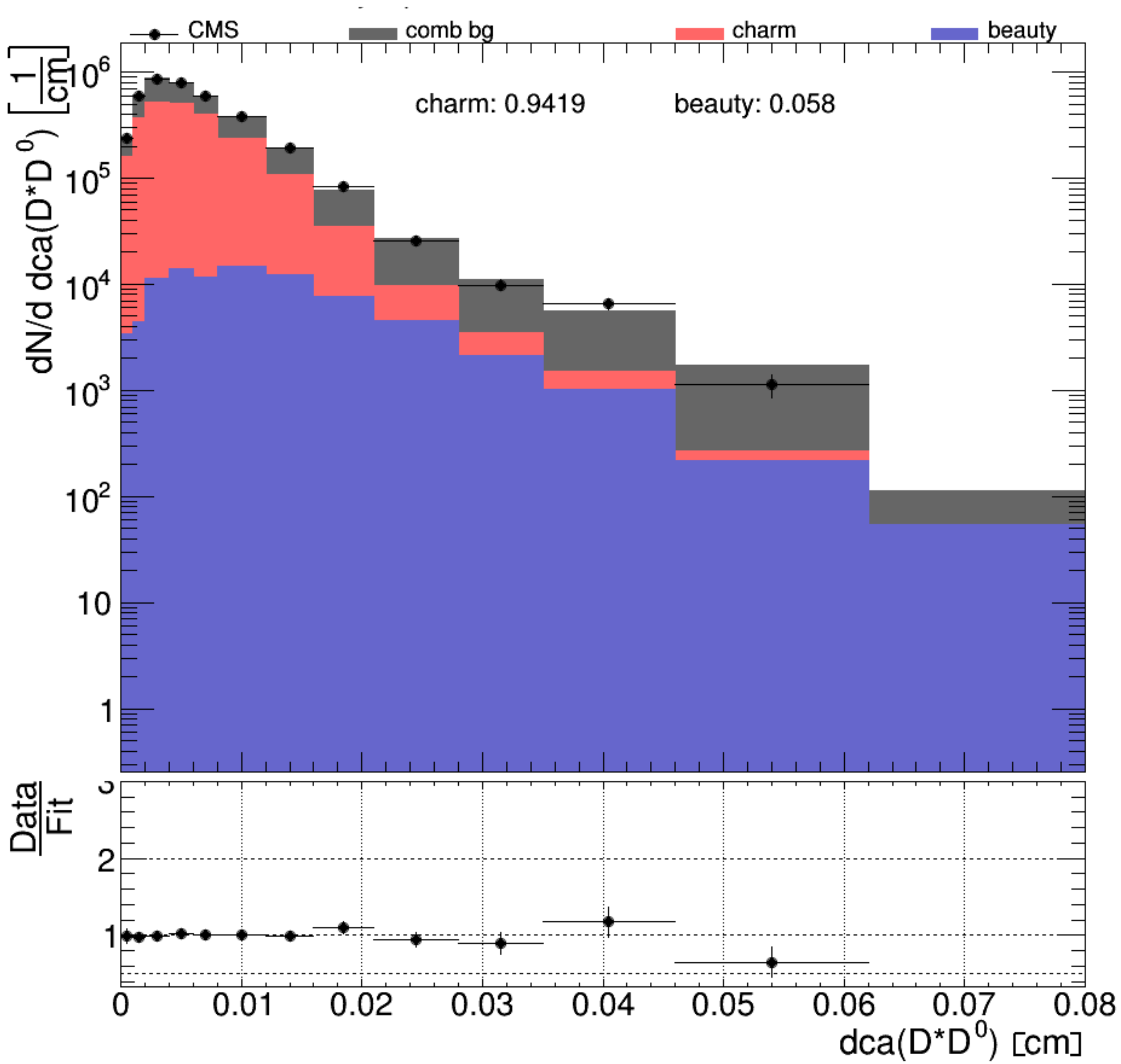
$p_T$:2-3 GeV, |y|:0.0-0.5



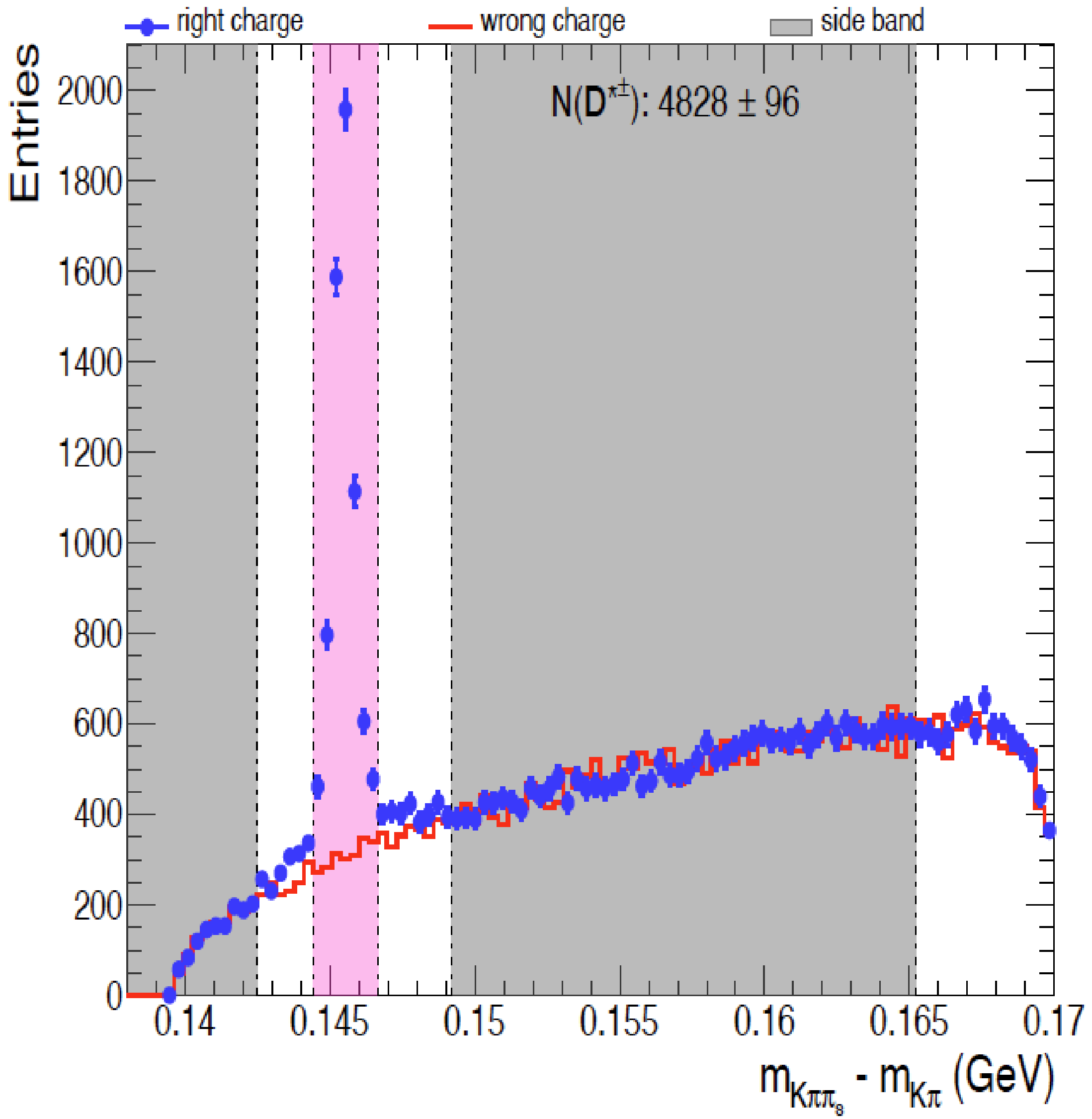
# Charm-Beauty Separation example

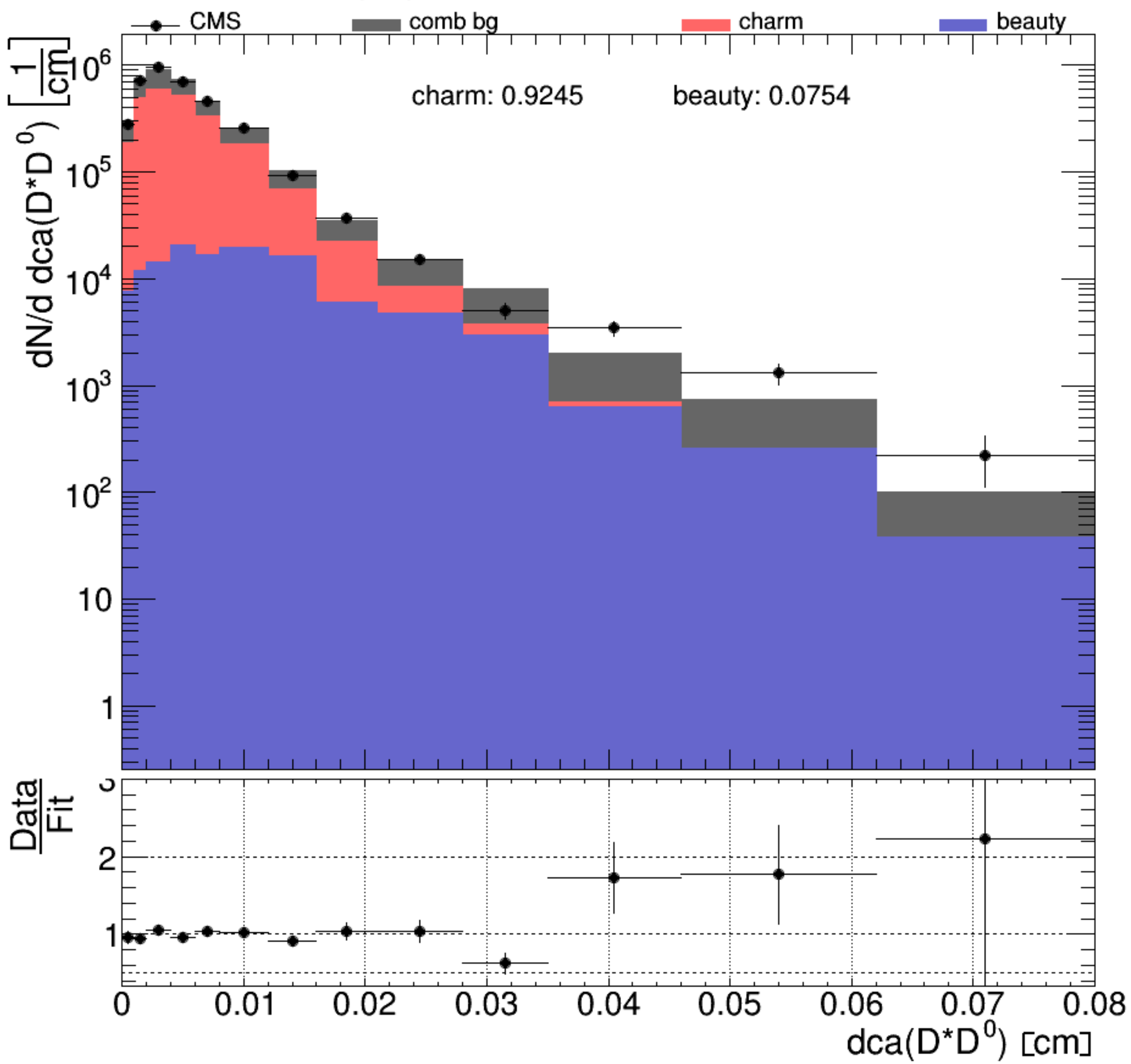


# Charm-Beauty Separation example

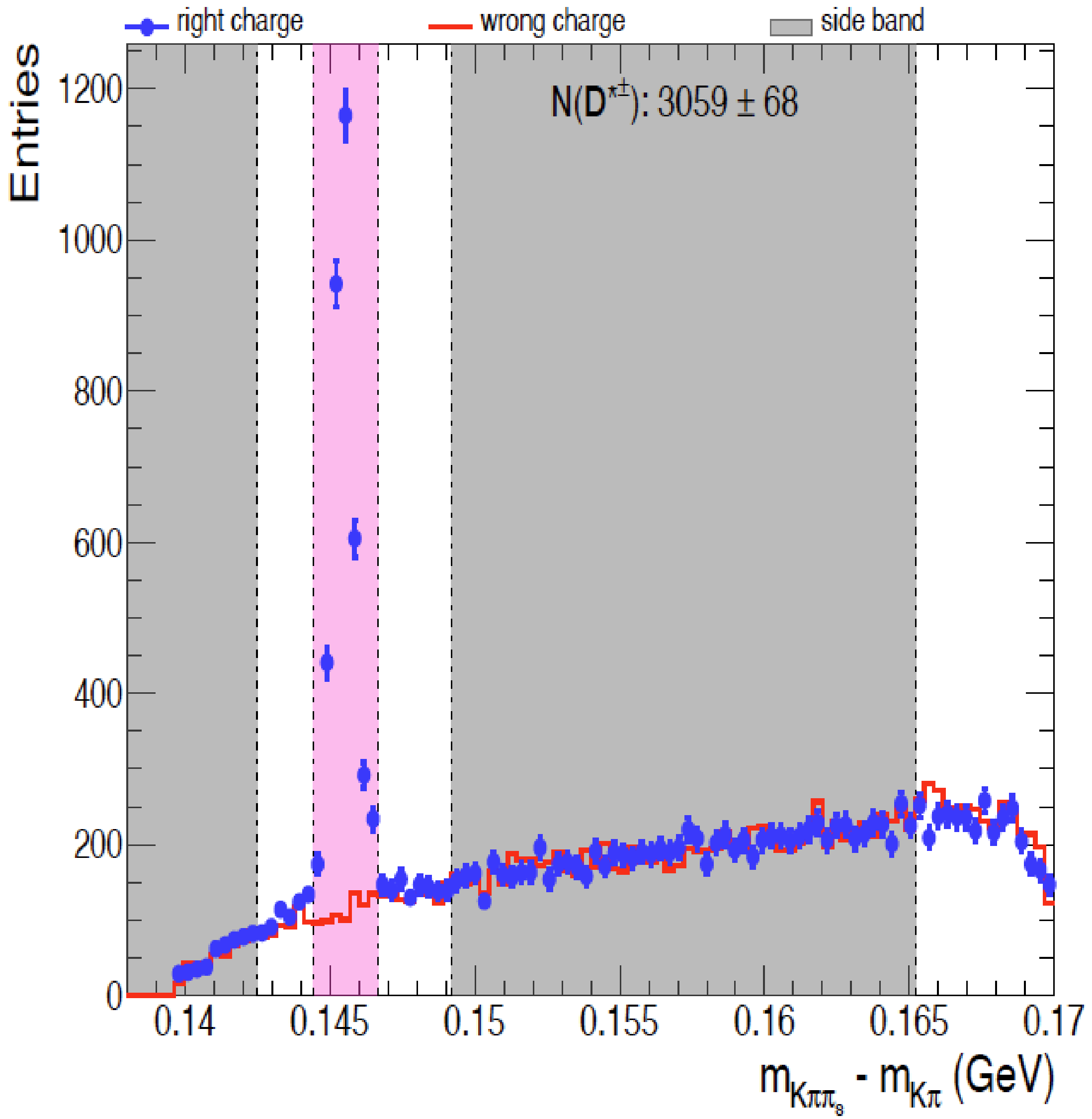
$p_T$:4-5 GeV, |y|:0.0-0.5

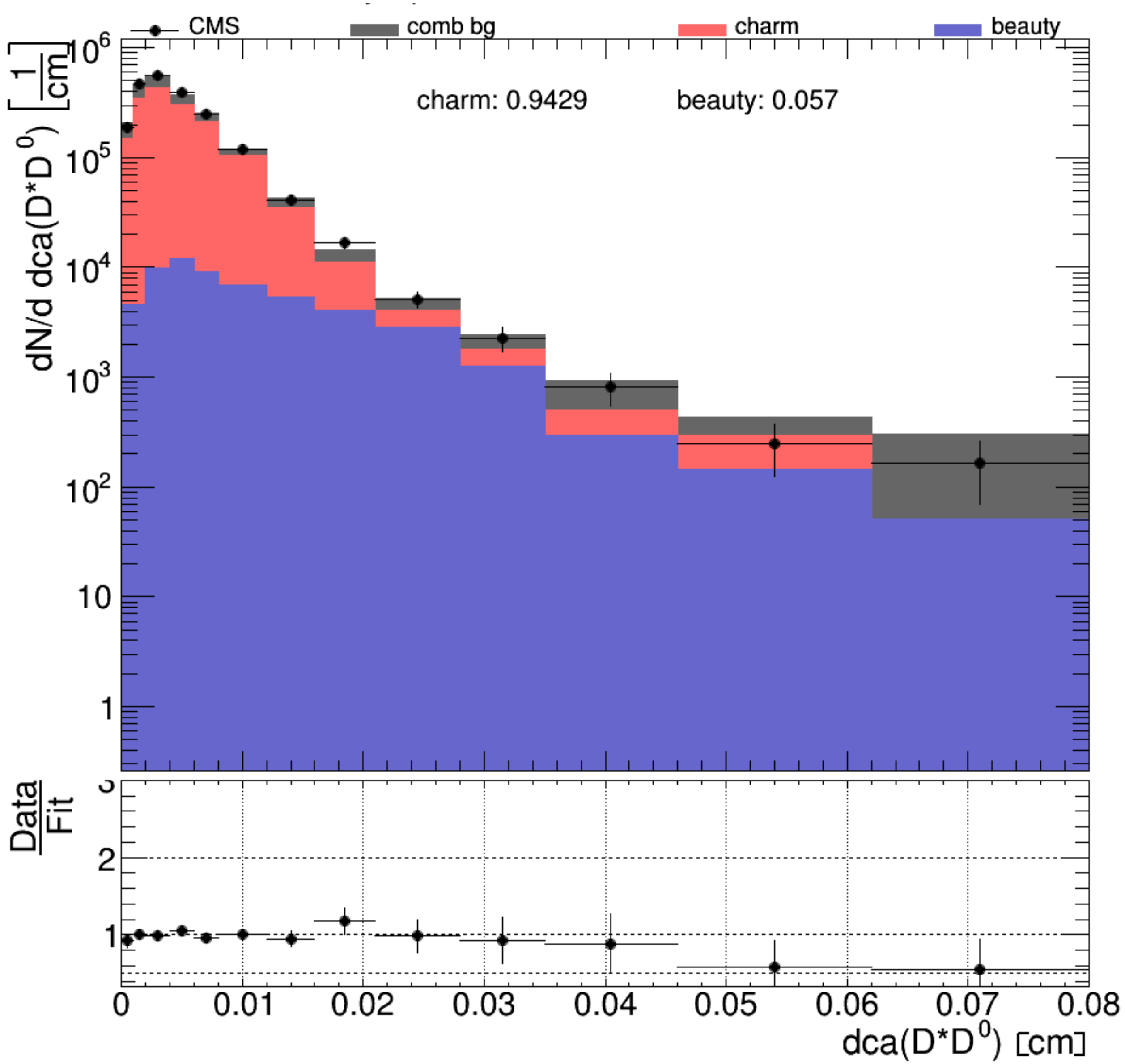


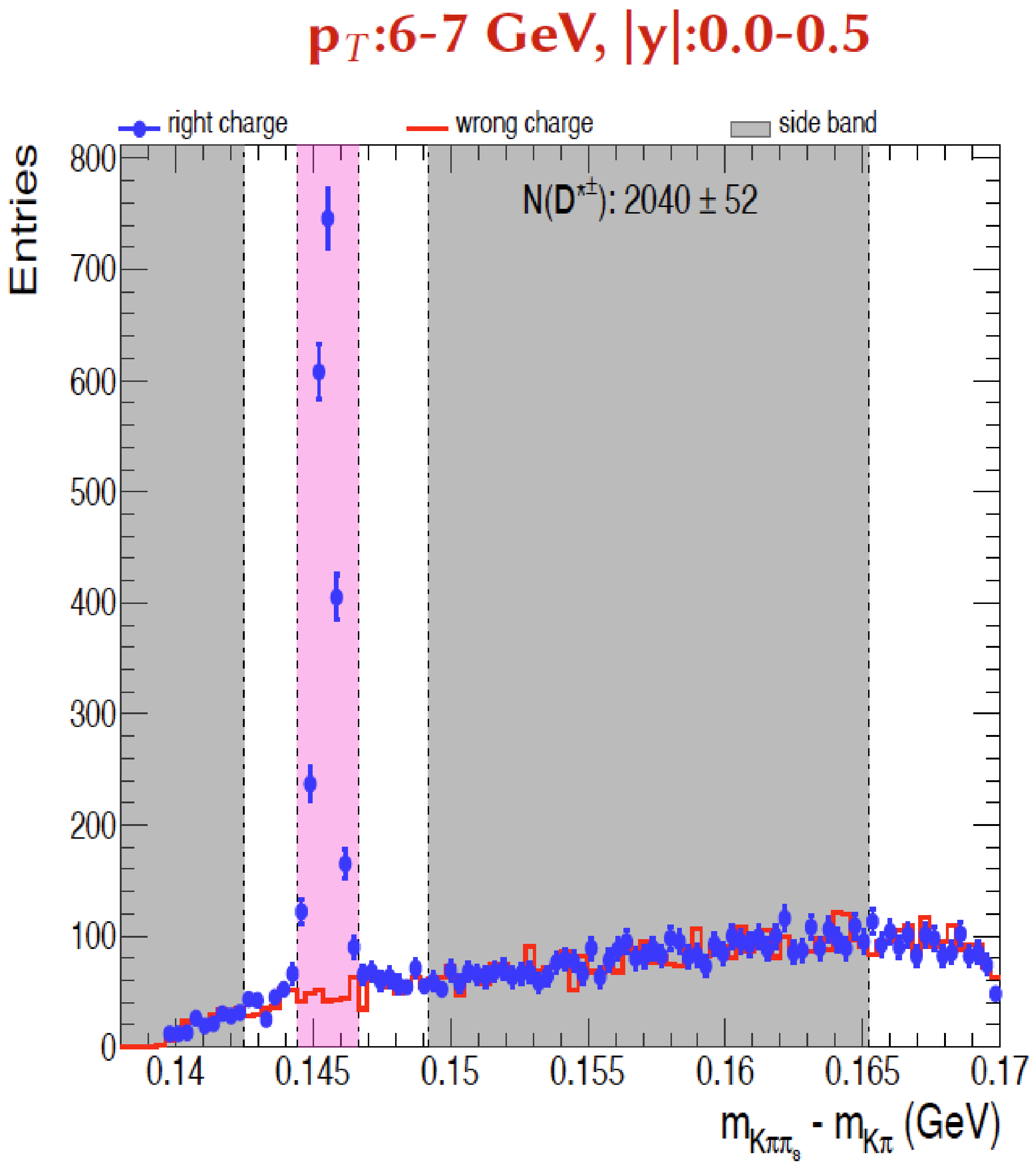
# Charm-Beauty Separation example

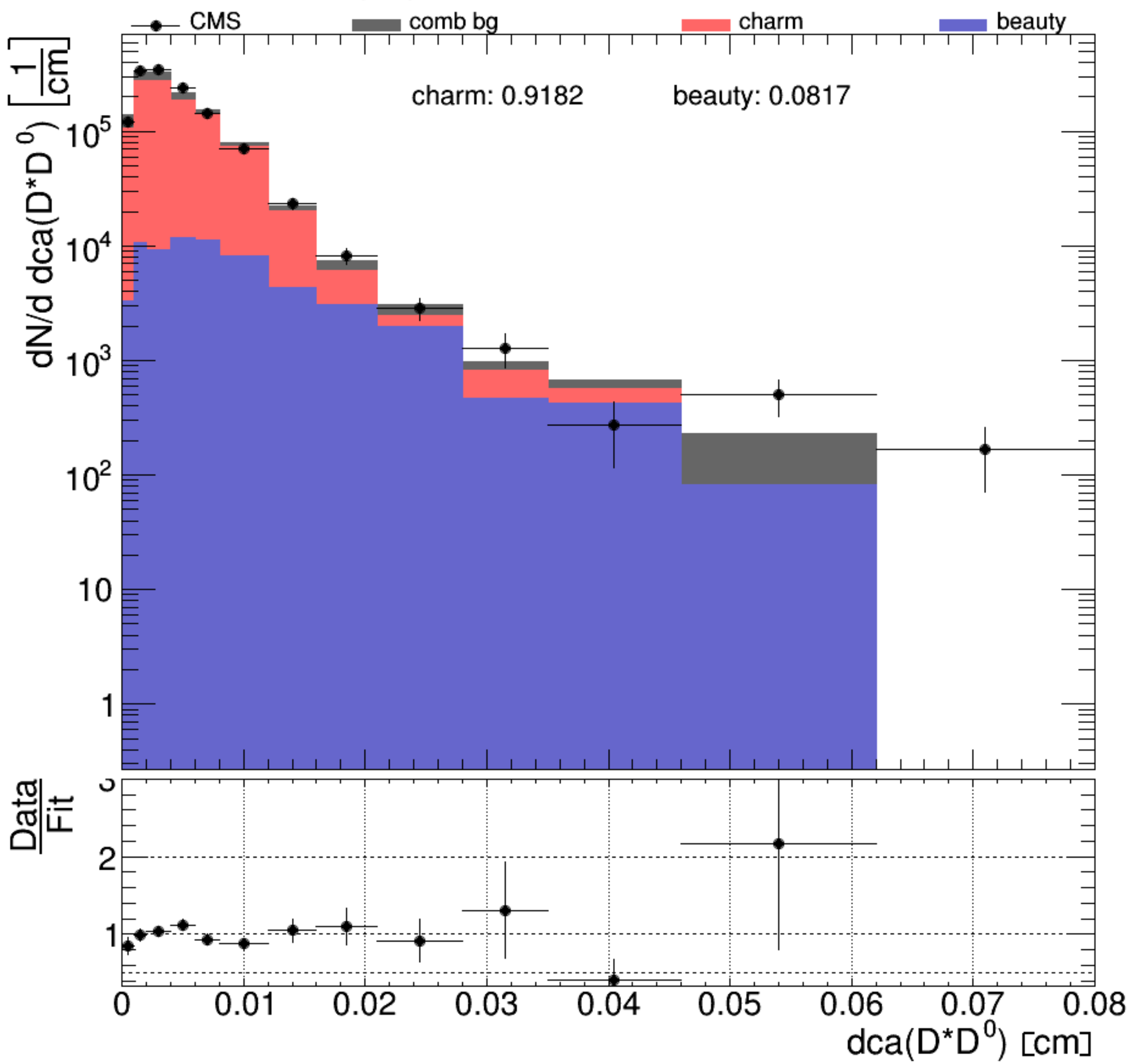
$p_T$:5-6 GeV, |y|:0.0-0.5



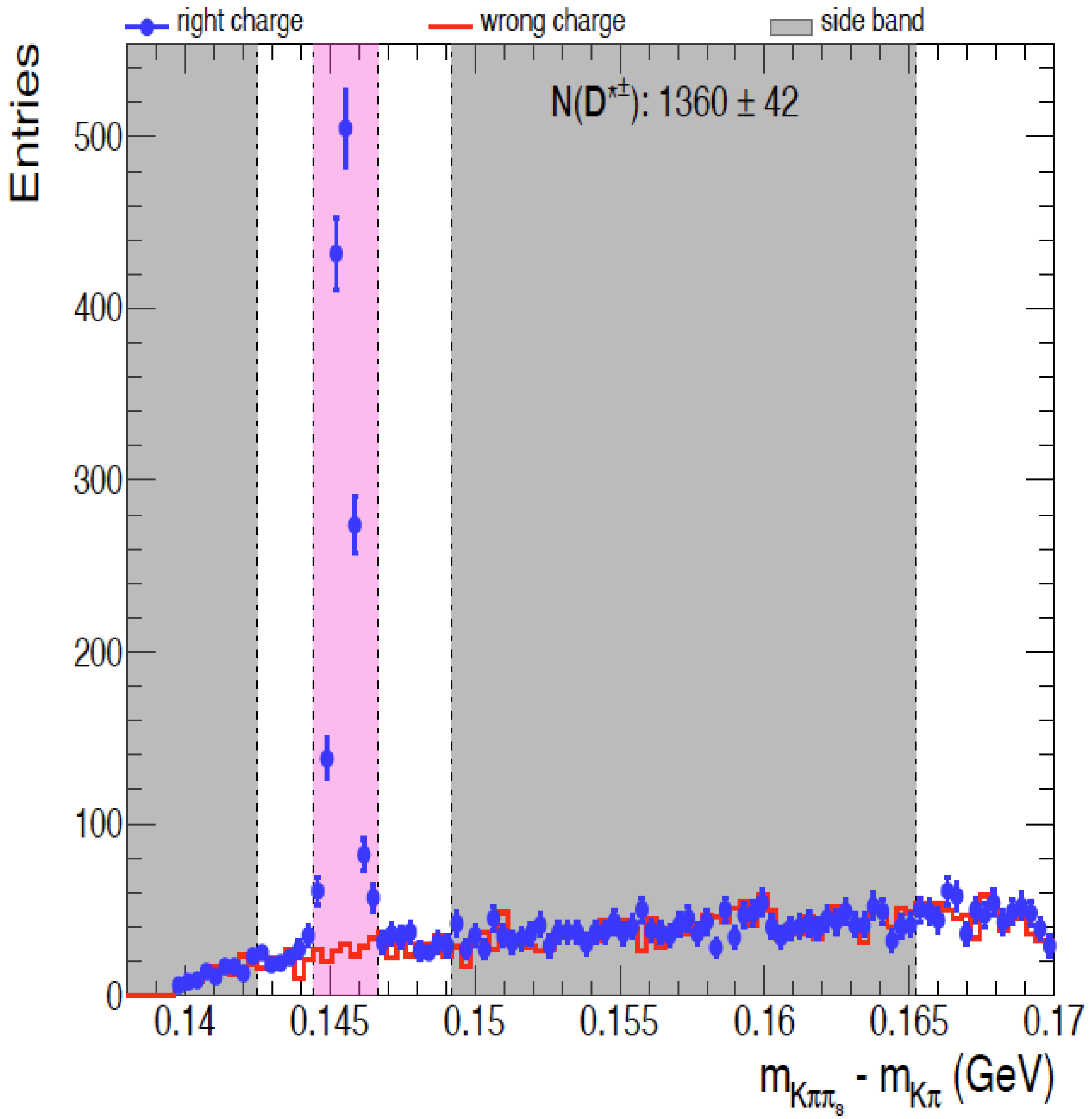
# Charm-Beauty Separation example

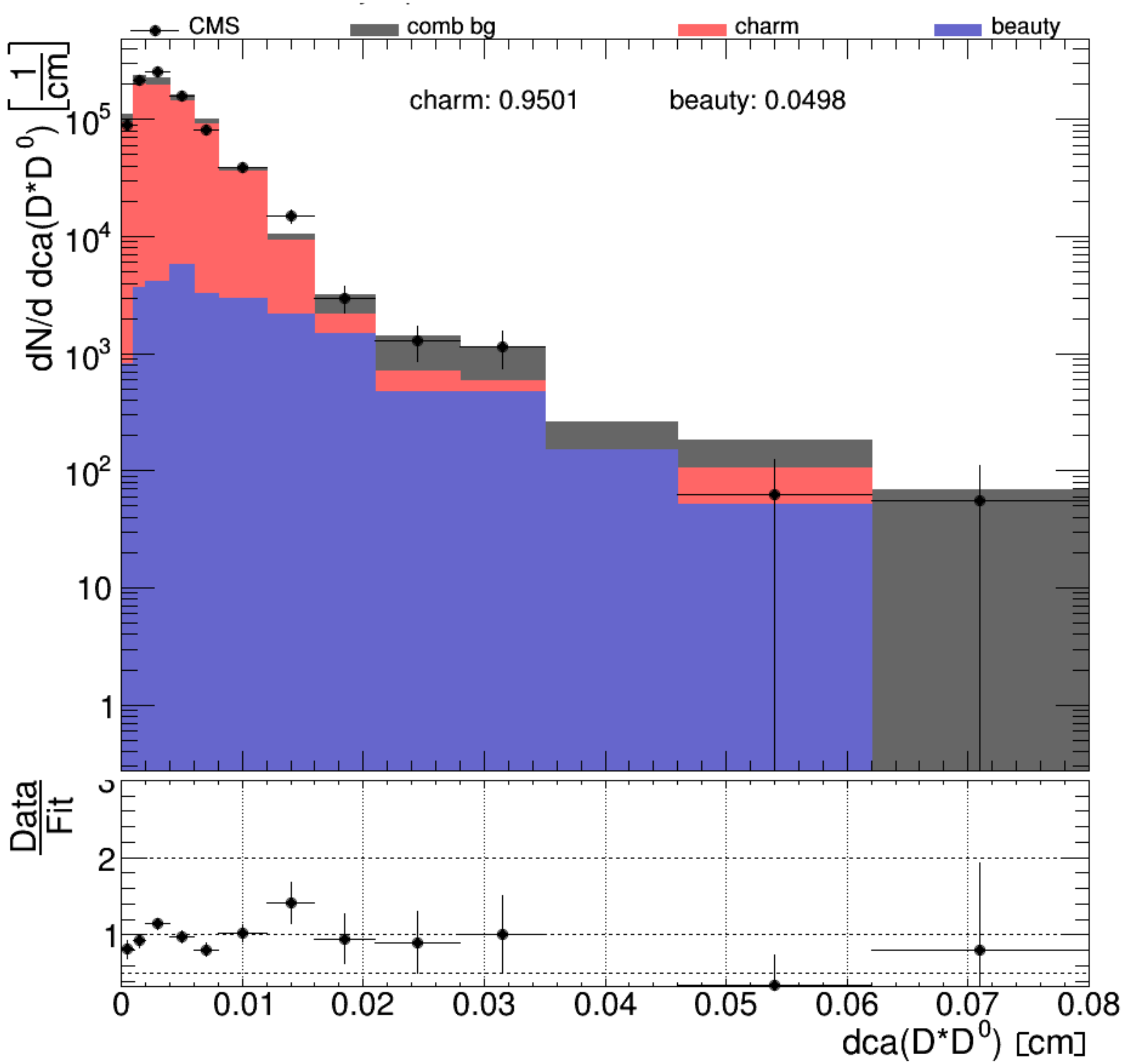


# Charm-Beauty Separation example

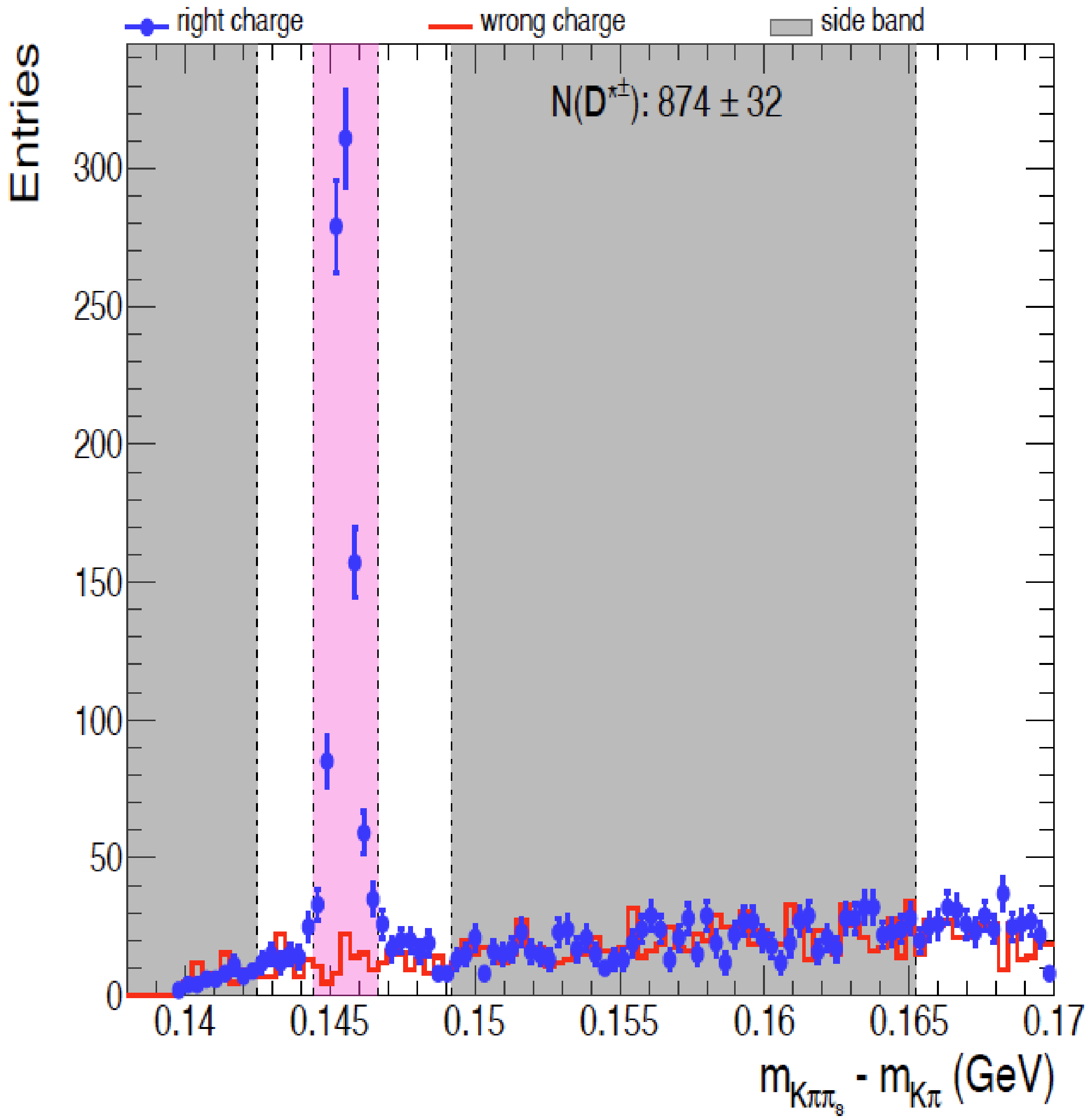
$p_T$:7-8 GeV, $|y|$:0.0-0.5

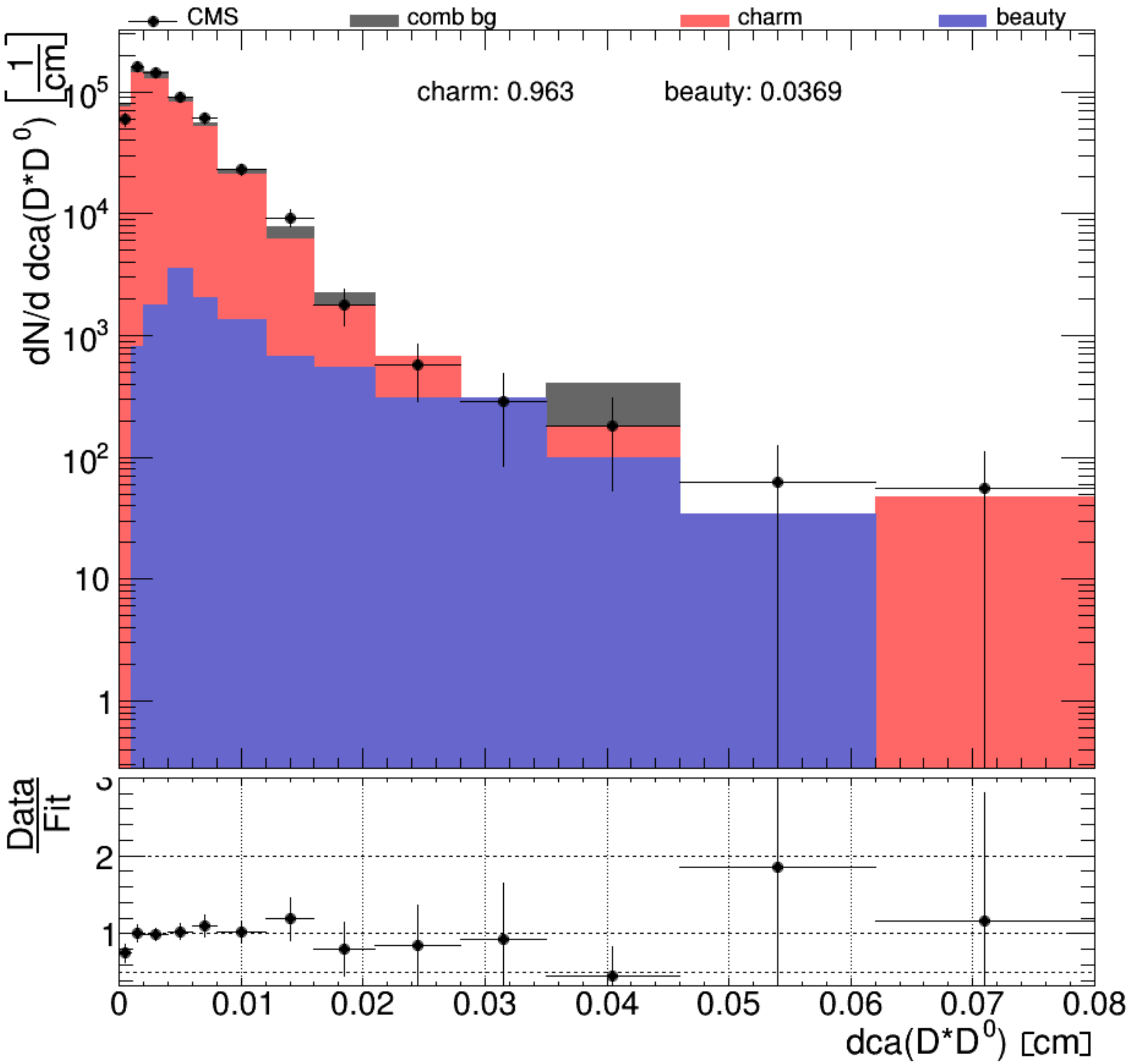


# Charm-Beauty Separation example

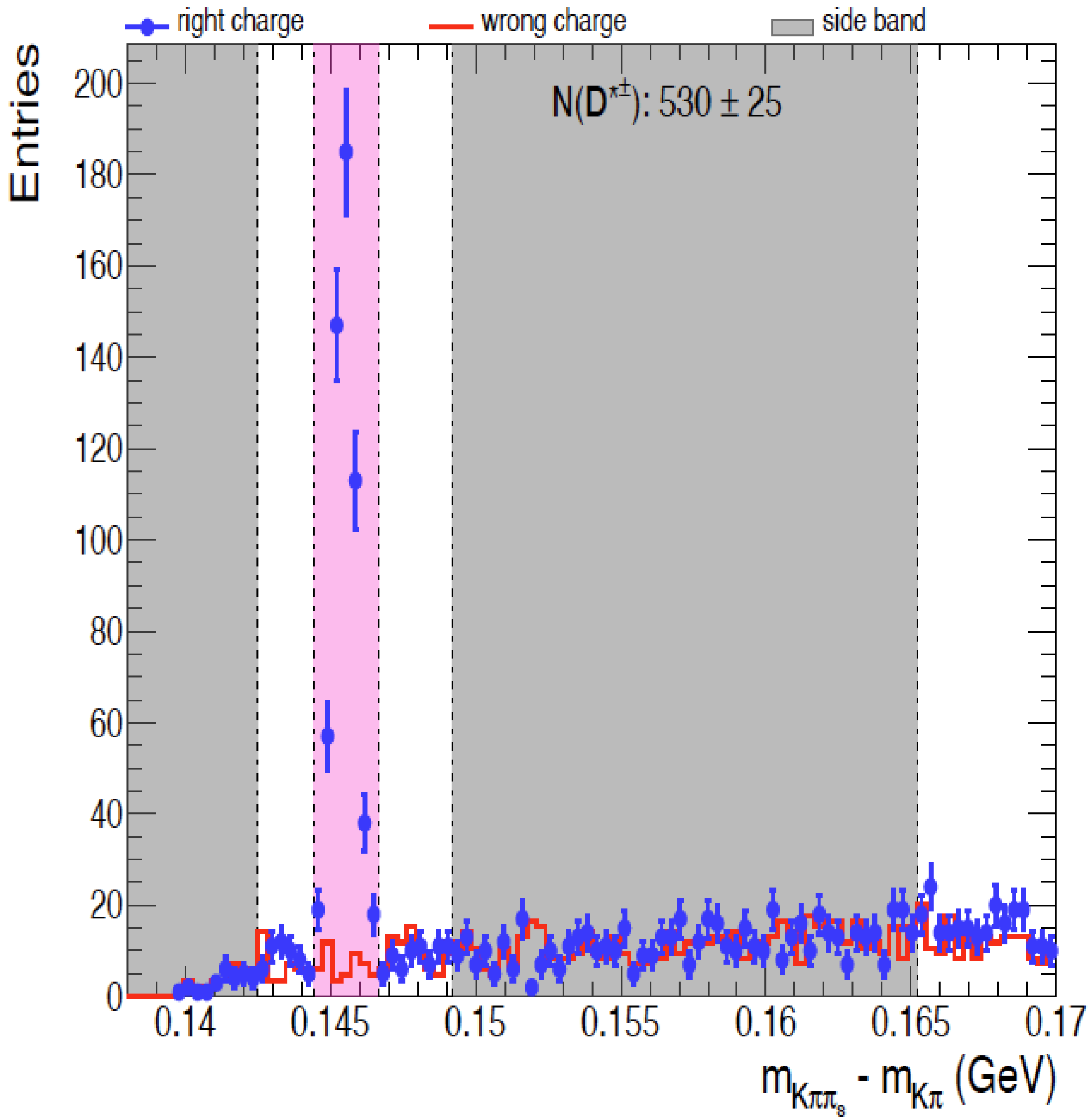
$p_T$:8-9 GeV, |y|:0.0-0.5

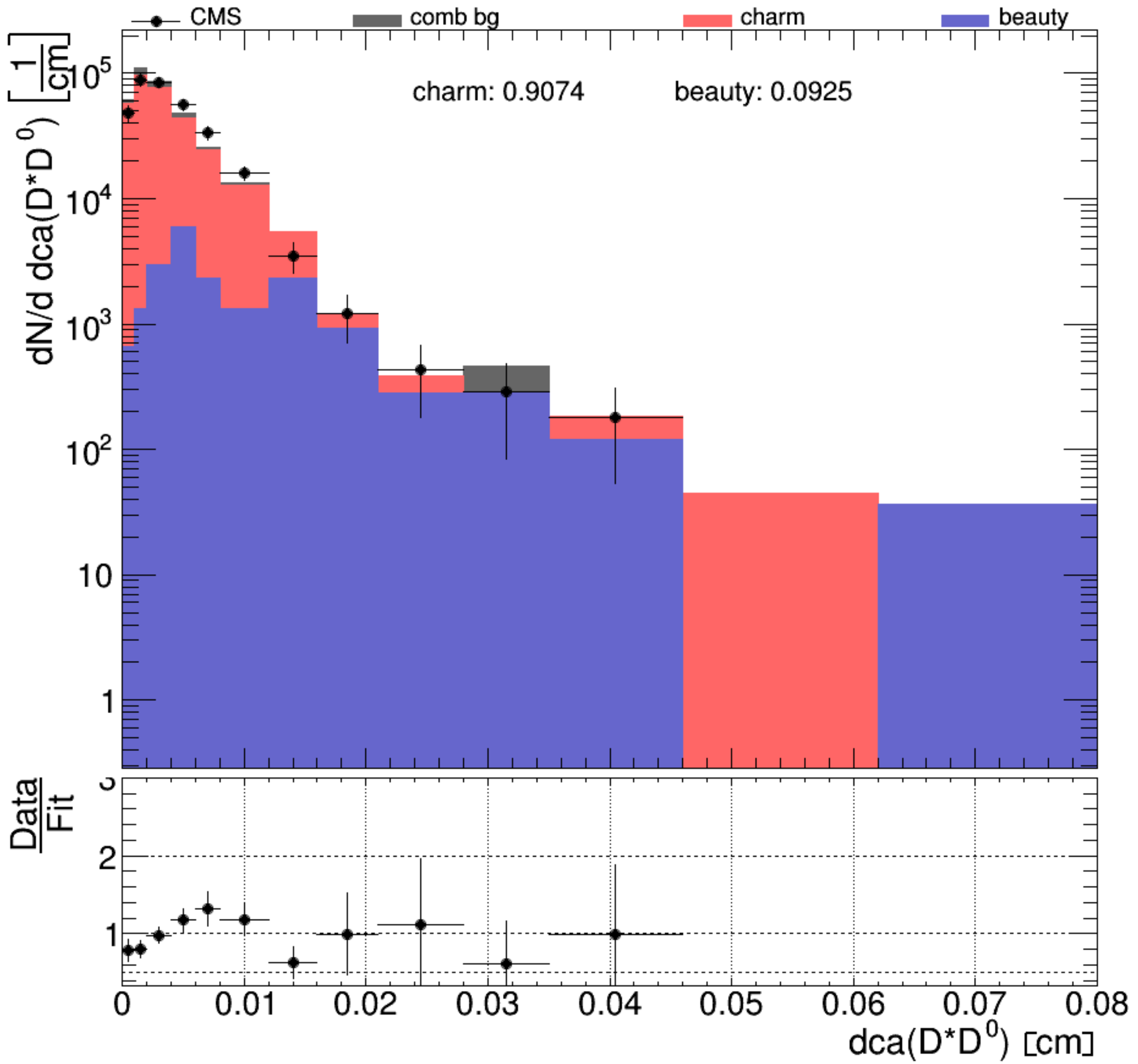


# Charm-Beauty Separation example

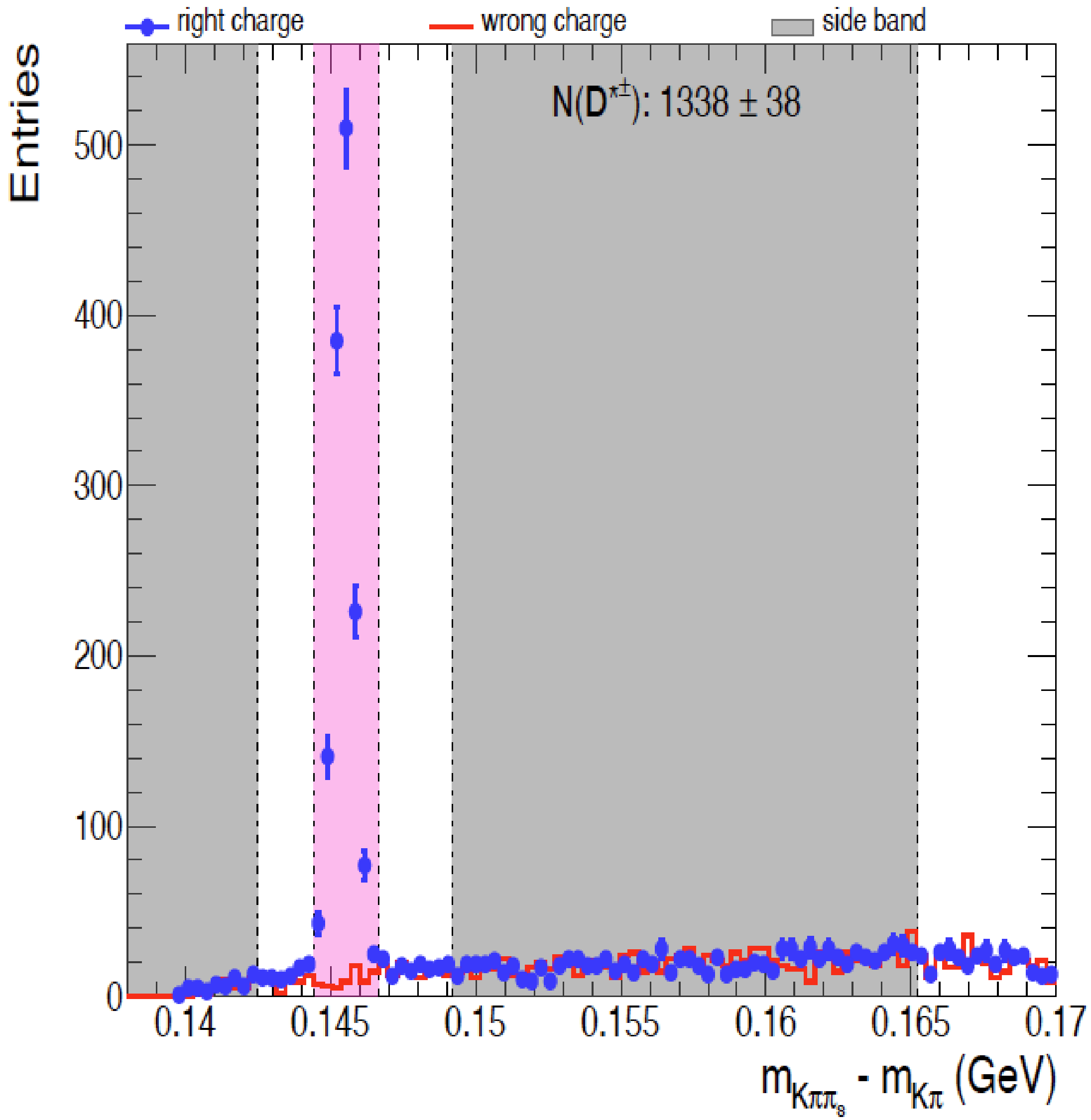
$p_T$:9-10 GeV, |y|:0.0-0.5

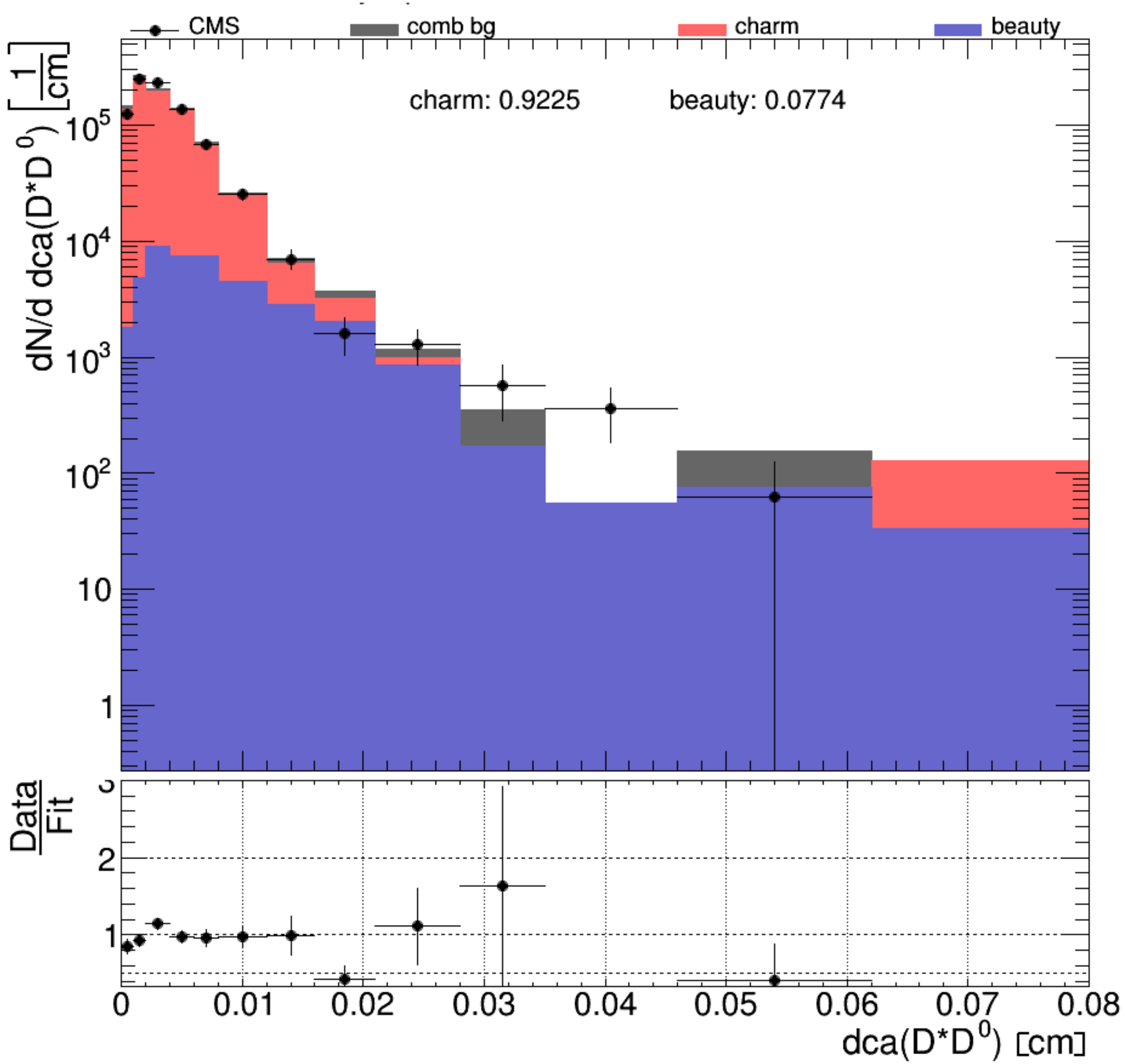


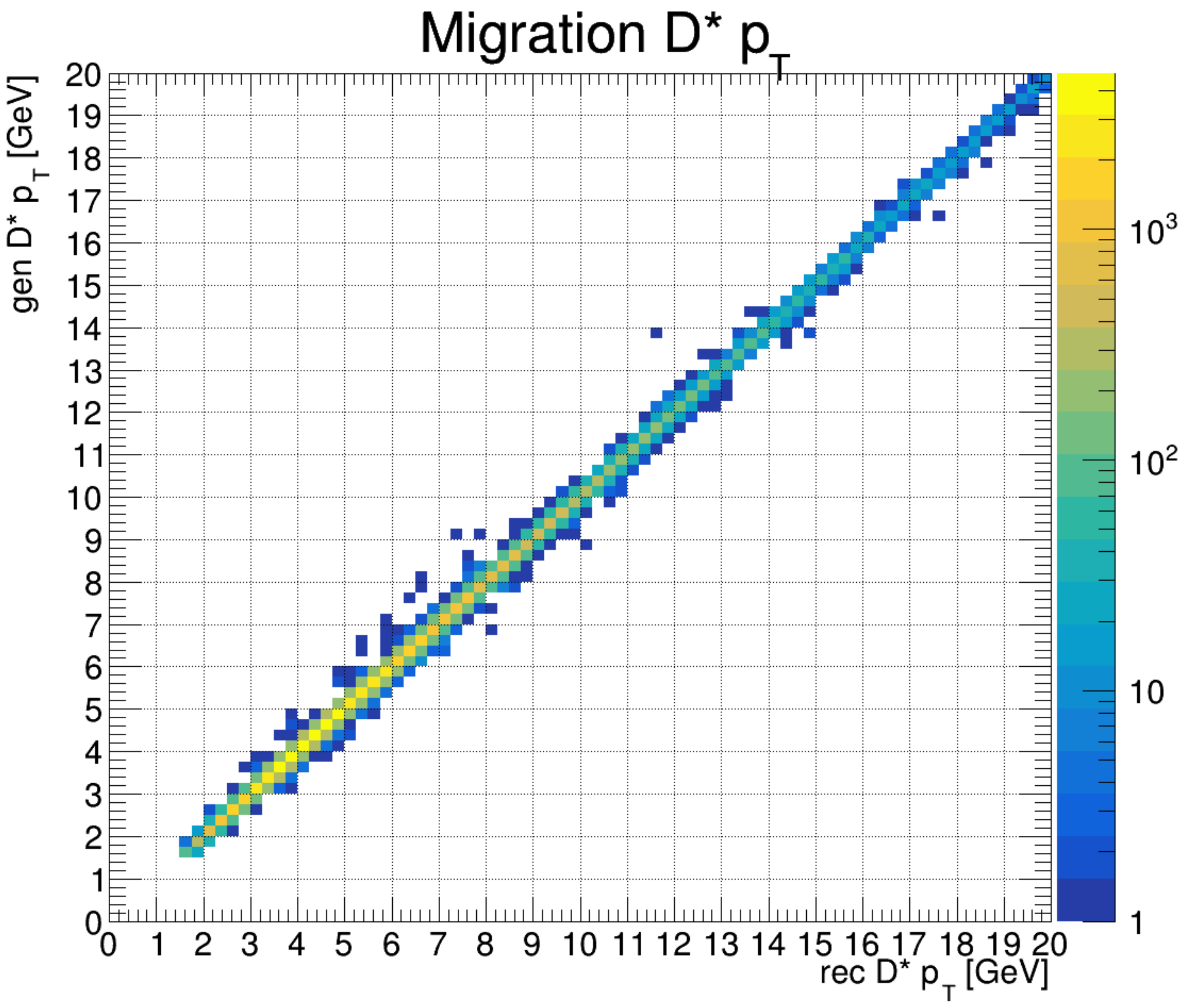
# Charm-Beauty Separation example

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



# Migration plot



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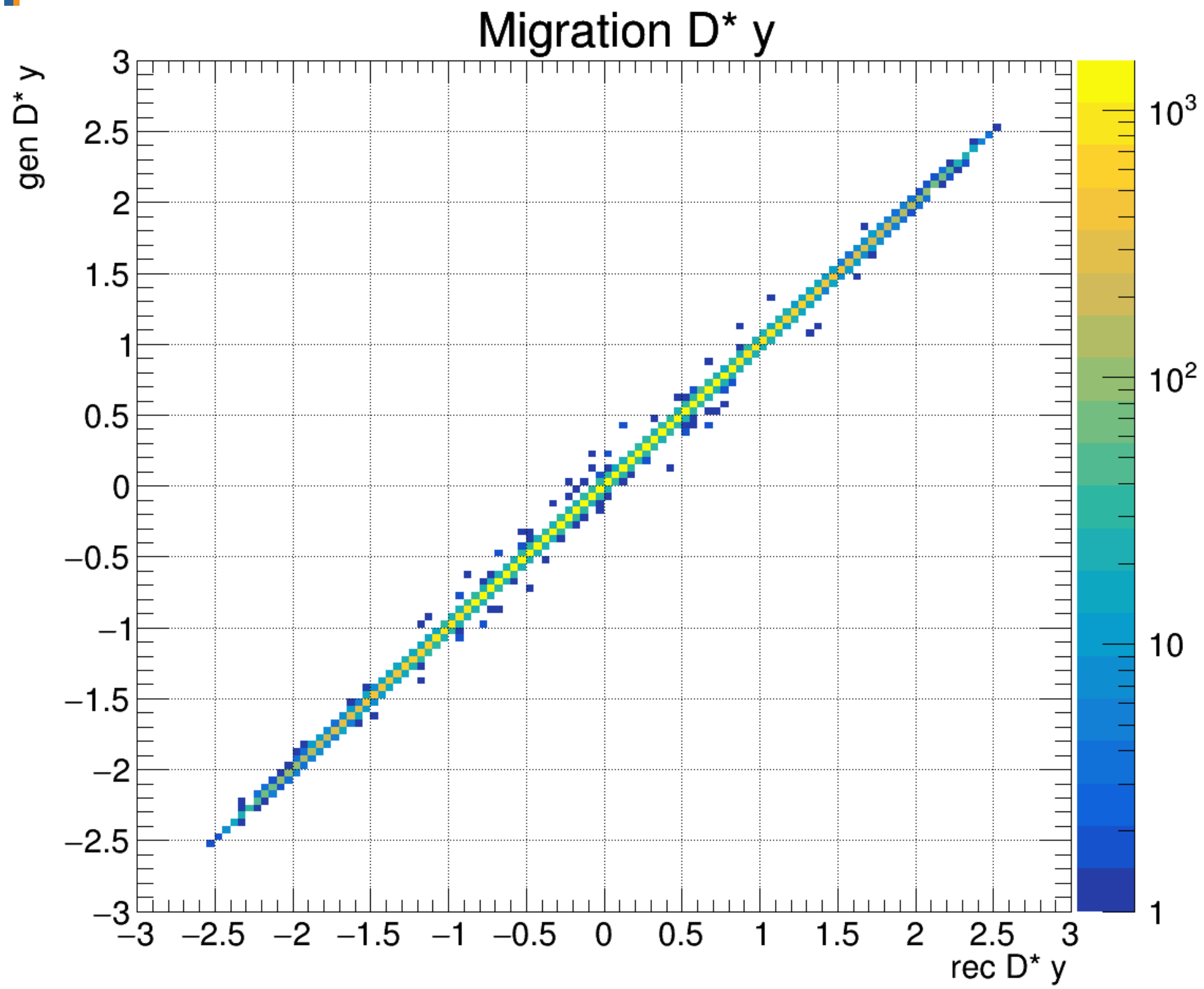

# Migration plot