

# $\Omega_c^0$ lifetime measurement

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$\Omega_c^0$  *lifetime measurement meeting*

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## 1. Prompt yield extraction

- Strategy to extract prompt yields
- Fit to MC samples of signal, normalization and control modes
- Sanity checks
- Fit to  $D^0$  data

## 2. Efficiency estimation

- Comparison of Dalitz distributions for MC and data of  $D^0$  mode
- Comparison of kinematic distributions for MC and data of  $D^0$  mode
- Comparison of topological distributions for MC and data of  $D^0$  mode
- Comparison of samples with different L0 trigger
- Comparison of event multiplicity
- Corrections to MC by weighting
- Decay time distribution with MC corrections

## 3. Efficiency studies of L0 Hadron TOS sample

# Section 1

## Prompt yield extraction

# Strategy to extract prompt yields

- Contamination from  $b$ -hadron decays is evident in large decay time bins
- Use  $\log_{10}(\chi^2_{\text{IP}})$  as discriminating variable
- Model the prompt and secondary components with the Bukin function

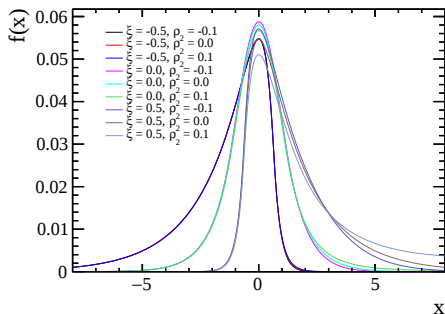
$$\mathcal{P}(x; \mu, \sigma, \xi, \rho_1, \rho_2) = \begin{cases} \exp \left\{ \frac{(x-x_1)\xi \sqrt{\xi^2+1} \sqrt{2 \ln 2}}{\sigma \left( \sqrt{\xi^2+1}-\xi \right)^2 \ln \left( \sqrt{\xi^2+1}+\xi \right)} + \rho_1 \left( \frac{x-x_1}{\mu-x_1} \right)^2 - \ln 2 \right\} & x \leq x_1, \\ \exp \left\{ - \left[ \frac{\ln \left( 1+2\xi \sqrt{\xi^2+1} \frac{x-\mu}{\sigma \sqrt{2 \ln 2}} \right)}{\ln \left( 1+2\xi^2-2\xi \sqrt{\xi^2+1} \right)} \right]^2 \times \ln 2 \right\} & x_1 < x < x_2, \\ \exp \left\{ \frac{(x-x_2)\xi \sqrt{\xi^2+1} \sqrt{2 \ln 2}}{\sigma \left( \sqrt{\xi^2+1}-\xi \right)^2 \ln \left( \sqrt{\xi^2+1}+\xi \right)} + \rho_2 \left( \frac{x-x_2}{\mu-x_2} \right)^2 - \ln 2 \right\} & x \geq x_2. \end{cases}$$

where

$$x_1 = \mu + \sigma \sqrt{2 \ln 2} \left( \frac{\xi}{\sqrt{\xi^2+1}} - 1 \right)$$

# Illustration of the Bukin functions

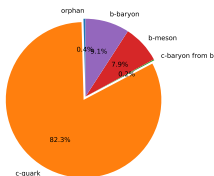
- Bukin functions with various asymmetry and tail parameters with  $\mu = 0, \sigma = 1, \rho_1 = 0$



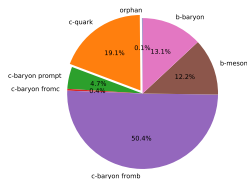
# Prompt and secondary MC samples

- Prompt and secondary MC samples of  $\Omega_c^0$ ,  $\Xi_c^0$  and  $D^0$ : acquired by apply MC\_MOTHER\_ID requirements to inclusive MC samples
- Components after all selections

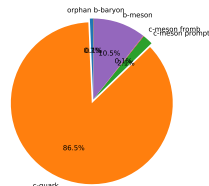
| Components         | orphan | c-quark | c-meson   | c-baryon    | b-meson   | b-baryon    |
|--------------------|--------|---------|-----------|-------------|-----------|-------------|
| abs (MC_MOTHER_ID) | 0      | 4       | (400,500) | (4000,5000) | (500,600) | (5000,6000) |



$\Omega_c^0$



$\Xi_c^0$



$D^0$

- Validation needed with  $b$ -decay MC samples

# The definition of the decay time

- Decay time  $t$  is defined as

$$t \equiv \frac{\vec{p} \cdot \vec{r}}{p^2} \times m$$

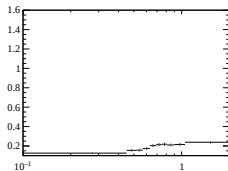
where  $\vec{p}$  is the momentum vector,  $\vec{r}$  the vector pointing from PV to decay vertex, and  $m$  the invariant mass of the charm hadron

# Fit with all parameters free in all decay time bins

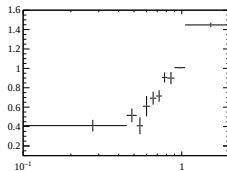
- All fits converge with accurate error matrix
- $\mu$ : dependent on  $t$  with clear pattern for prompt and secondary
- $\sigma$ : vary with  $t$  for prompt and secondary
- $\xi$ : vary with  $t$  for prompt and secondary
- $\rho_1, \rho_2$ : vary with  $t$  for prompt and secondary

# Fit results in decay-time bins: $\mu$

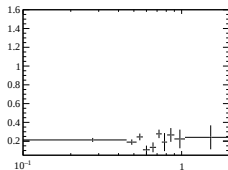
Prompt  
 $\Omega_c^0$



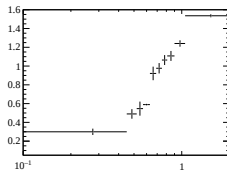
Secondary  
 $\Omega_c^0$



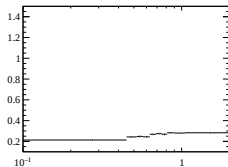
Prompt  
 $\Xi_c^0$



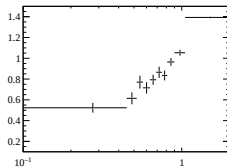
Secondary  
 $\Xi_c^0$



Prompt  
 $D^0$

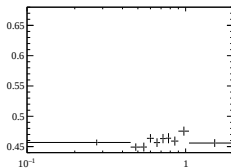


Secondary  
 $D^0$

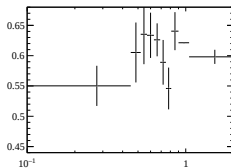


# Fit results in decay-time bins: $\sigma$

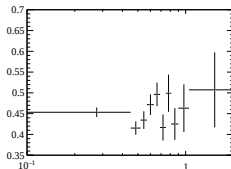
Prompt  
 $\Omega_c^0$



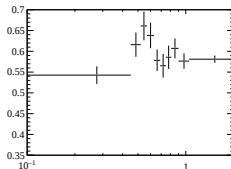
Secondary  
 $\Omega_c^0$



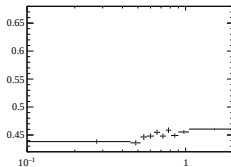
Prompt  
 $\Xi_c^0$



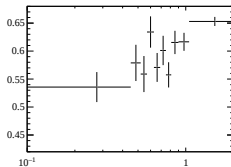
Secondary  
 $\Xi_c^0$



Prompt  
 $D^0$

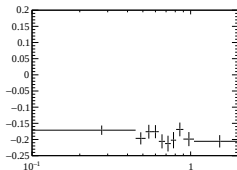


Secondary  
 $D^0$

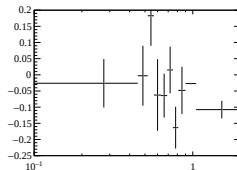


# Fit results in decay-time bins: $\xi$

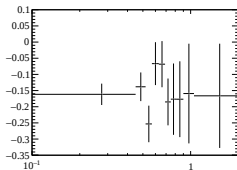
Prompt  
 $\Omega_c^0$



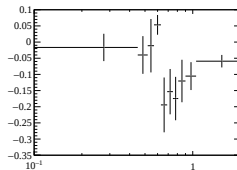
Secondary  
 $\Omega_c^0$



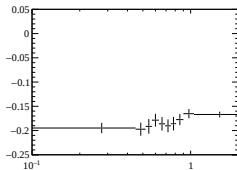
Prompt  
 $\Xi_c^0$



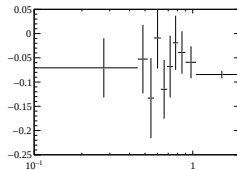
Secondary  
 $\Xi_c^0$



Prompt  
 $D^0$

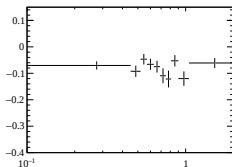


Secondary  
 $D^0$

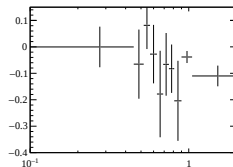


# Fit results in decay-time bins: $\rho_1$

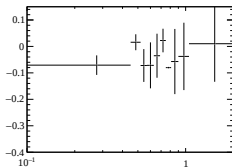
Prompt  
 $\Omega_c^0$



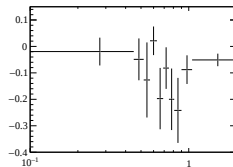
Secondary  
 $\Omega_c^0$



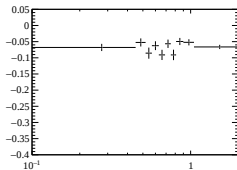
Prompt  
 $\Xi_c^0$



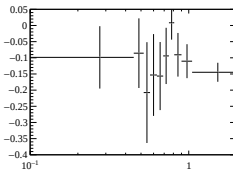
Secondary  
 $\Xi_c^0$



Prompt  
 $D^0$

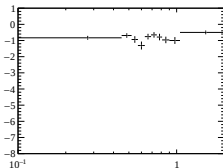


Secondary  
 $D^0$

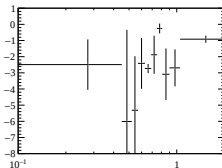


# Fit results in decay-time bins: $\rho_2$

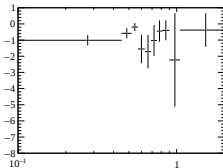
Prompt  
 $\Omega_c^0$



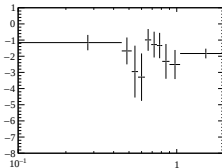
Secondary  
 $\Omega_c^0$



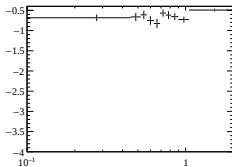
Prompt  
 $\Xi_c^0$



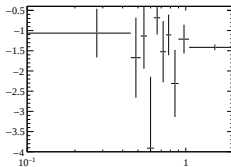
Secondary  
 $\Xi_c^0$



Prompt  
 $D^0$



Secondary  
 $D^0$

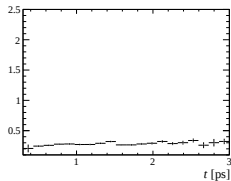


## Fit $D^0$ MC in even decay time bins

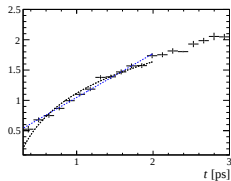
- Fit with all parameters free in equally-sized 20 decay time bins between 0.3 ps and 3 ps

# $D^0$ results in even decay-time bins: $\mu$

Prompt  
 $D^0$

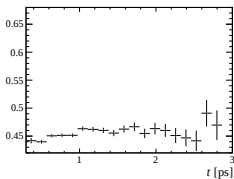


Secondary  
 $D^0$

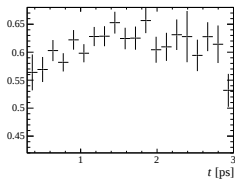


# $D^0$ results in even decay-time bins: $\sigma$

Prompt  
 $D^0$

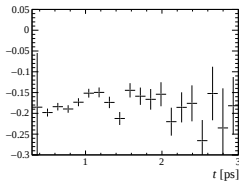


Secondary  
 $D^0$

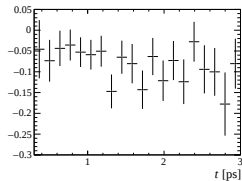


# $D^0$ results in even decay-time bins: $\xi$

Prompt  
 $D^0$

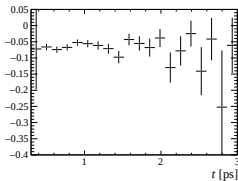


Secondary  
 $D^0$

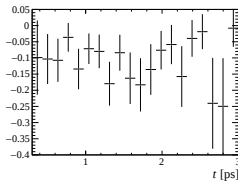


# $D^0$ results in even decay-time bins: $\rho_1$

Prompt  
 $D^0$

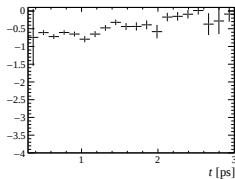


Secondary  
 $D^0$

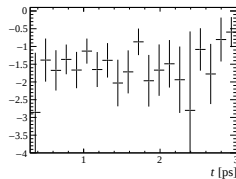


# $D^0$ results in even decay-time bins: $\rho_2$

Prompt  
 $D^0$



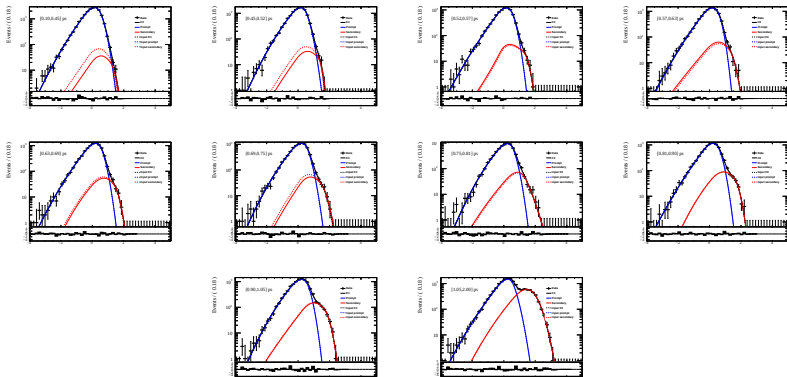
Secondary  
 $D^0$



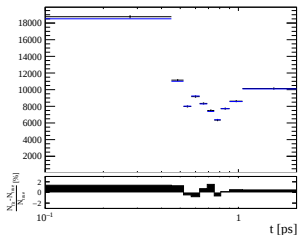
# Sanity check: fit combined MC samples

- Check whether the fit can re-produce the input prompt fraction with MC samples
- Fit the combined (prompt+secondary) MC with free  $\mu_{\text{prompt}}$  and  $\mu_{\text{secondary}}$ , while fixing other parameters to values of separate fits

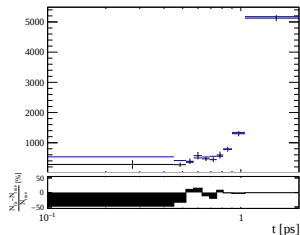
# Fit results of combined MC samples: $\Omega_c^0$



# Comparison of input and extracted yield: $\Omega_c^0$



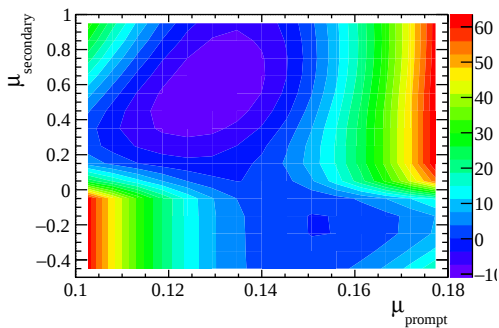
Prompt



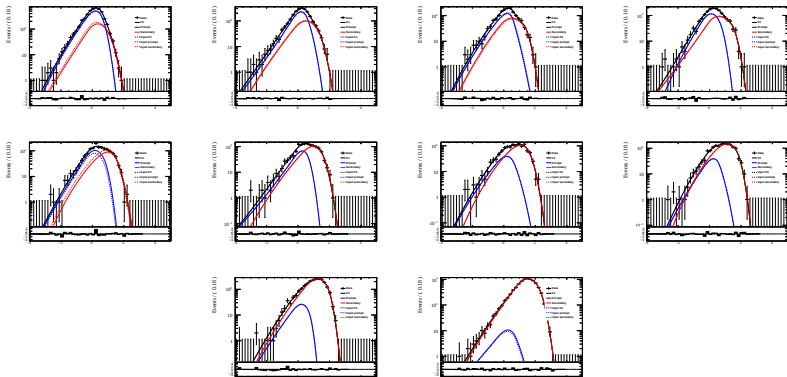
Secondary

# Likelihood scan of $\mu_{\text{prompt}}$ and $\mu_{\text{secondary}}$

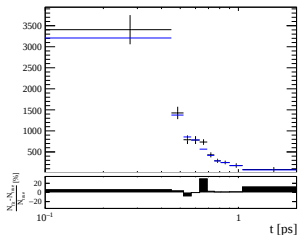
■  $\Omega_c^0$  bin 0



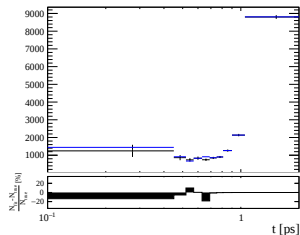
# Fit results of combined MC samples: $\Xi_c^0$



# Comparison of input and extracted yield: $\Xi_c^0$



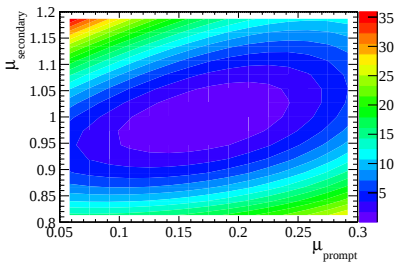
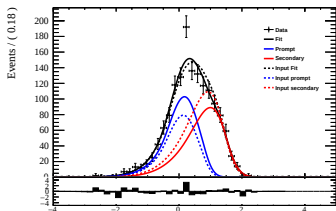
Prompt



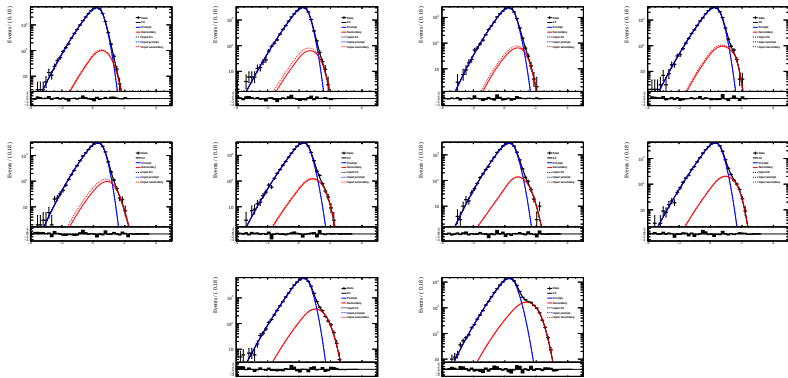
Secondary

# Likelihood scan of $\mu_{\text{prompt}}$ and $\mu_{\text{secondary}}$

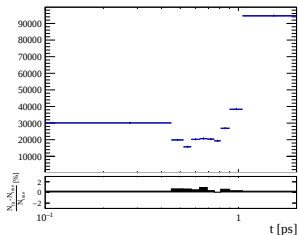
## ■ $\Xi_c^0$ bin 4



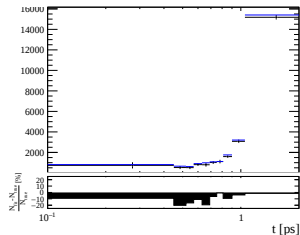
# Fit results of combined MC samples: $D^0$



# Comparison of input and extracted yield: $D^0$



Prompt

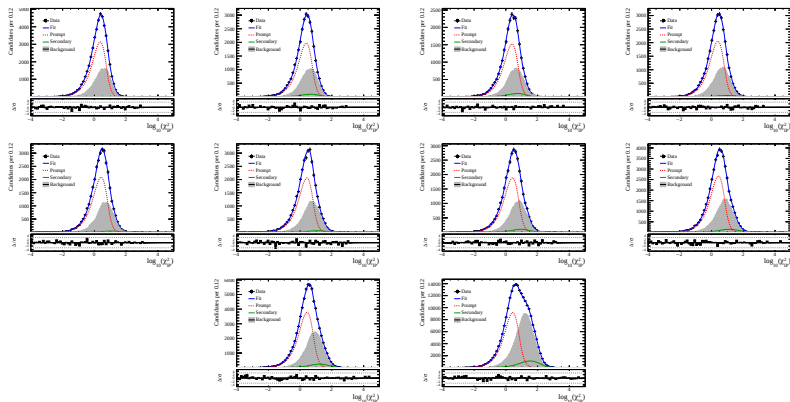


Secondary

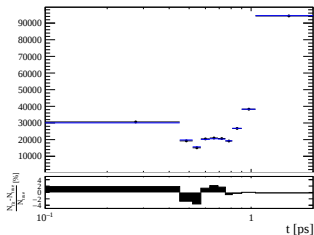
# Sanity check: fit background-injected combined MC

- Check whether the fit can re-produce the input prompt fraction
- Fit the combination of prompt MC, secondary MC and background from data
  - Background sample is generated from the RooKeysPdf of mass-sideband data
  - Background sample size is determined from the signal/background ratio in data
  - logIPCHI2 of MC sample is shifted by 0.15 to match the data
- Fit configuration
  - $\mu_{\text{prompt}}$  and  $\mu_{\text{secondary}}$  free to float
  - Other parameters fixed to separately-fit results
  - Number of background fixed to the input value

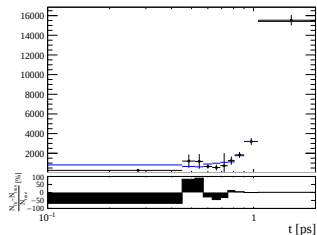
# Fit results of background-injected combined MC



# Comparison of input and extracted yield: $D^0$



Prompt



Secondary

# Fit to $D^{*+} \rightarrow \pi^+ D^0 (\rightarrow K^- K^+ \pi^- \pi^+)$ data

## ■ Mass fit

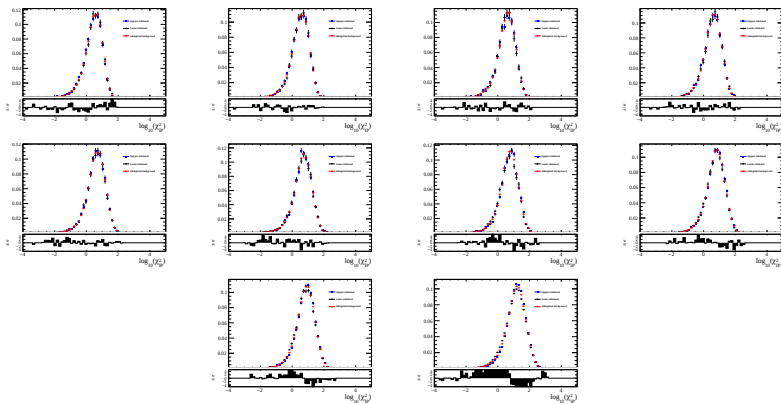
- In  $1865 \pm 45 \text{ MeV}/c^2$  mass region
- Gaussian + 2<sup>nd</sup>-order Chebychev

## ■ IPCHI2 fit

- In  $1865 \pm 2.5 \times 5.65 \text{ MeV}/c^2$  signal region
- Prompt and secondary signal components:  $\mu_{\text{prompt}}$  and  $\mu_{\text{secondary}}$  free and other parameters fixed to MC
- Background: kernel estimation with mass-sideband data  
Lower sideband:  $[1820, 1830] \text{ MeV}/c^2$   
Upper sideband:  $[1900, 1910] \text{ MeV}/c^2$
- The total number of backgrounds fixed to values from mass fit
- Binning scheme: the same as the signal mode

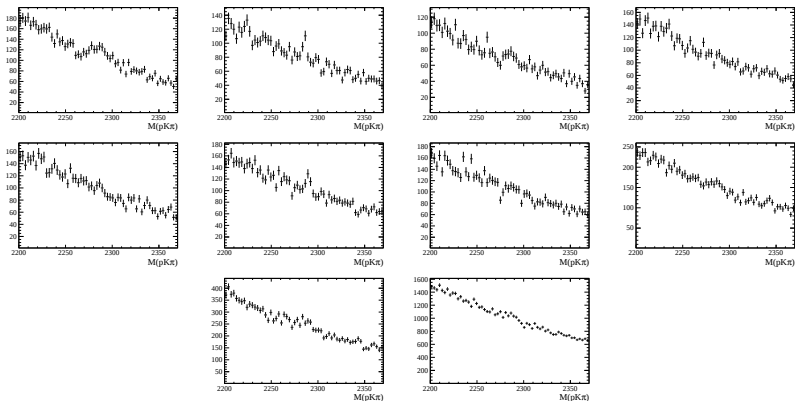
# Comparison of background logIPCHI2

- MC cannot provide a large combinatorial background sample
- Real data is necessary for background studies



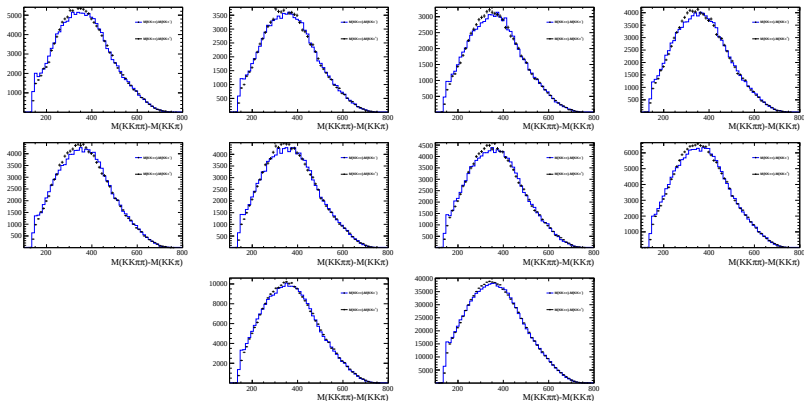
# Physics backgrounds in $D^{*+} \rightarrow \pi^+ D^0 (\rightarrow K^- K^+ \pi^- \pi^+)$

- $\Lambda_c^+$  background:  $p$  mis-identified as  $K^-$
- Suppressed by tight PID cuts



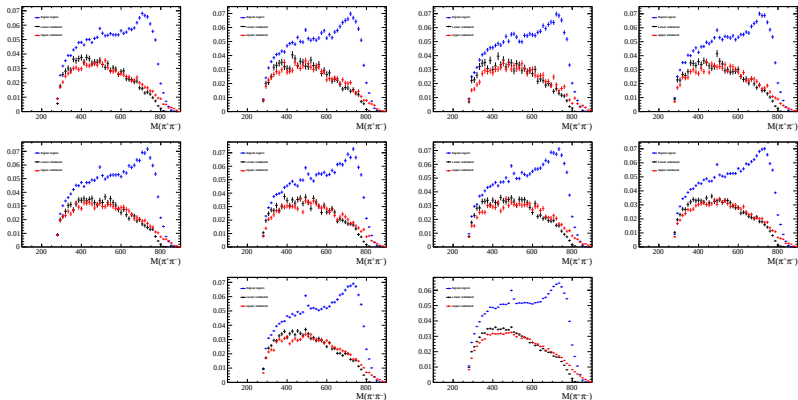
# Physics backgrounds in $D^{*+} \rightarrow \pi^+ D^0 (\rightarrow K^- K^+ \pi^- \pi^+)$

- $\pi$  swap:  $D^{*+} \rightarrow \pi^+ D^0 (\rightarrow K^- K^+ \pi^- \pi^+)$
- Not significant due to tight  $\chi^2_{\text{IP}}$  cuts

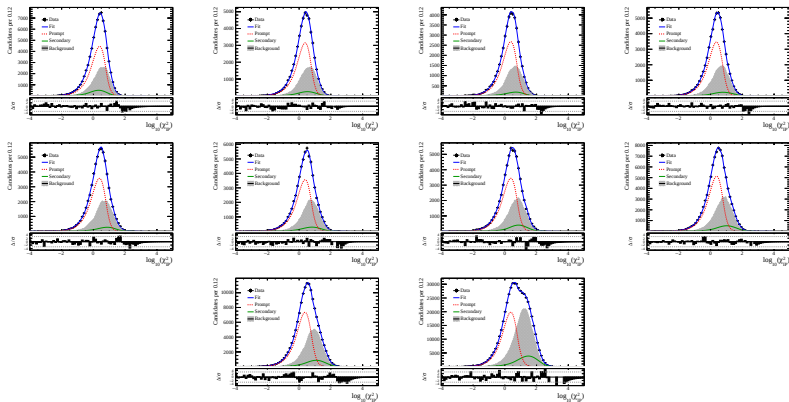


# Physics backgrounds in $D^{*+} \rightarrow \pi^+ D^0 (\rightarrow K^- K^+ \pi^- \pi^+)$

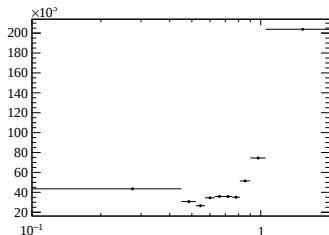
- $K_S^0$  background:  $D^0 \rightarrow K^- K^+ K_S^0 (\rightarrow \pi^+ \pi^-)$
- Exist but not significant in the signal region



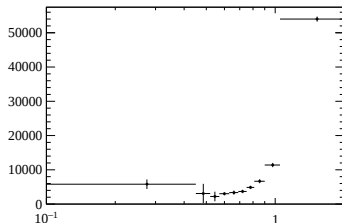
# Fit results of $D^0$ data



# Fit results of yields

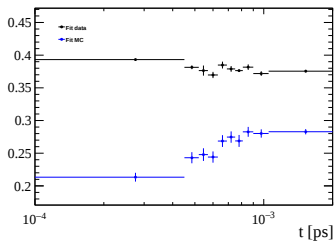


Prompt

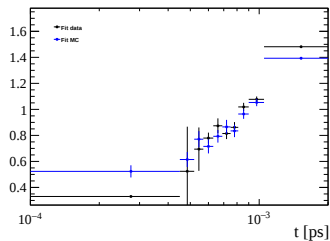


Secondary

# Fit results of $\mu$

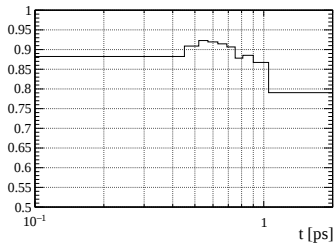


Prompt

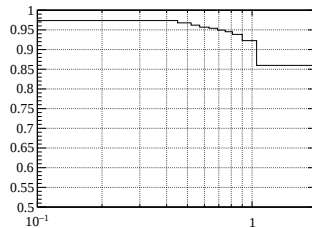


Secondary

# Comparison of data and MC: prompt fraction

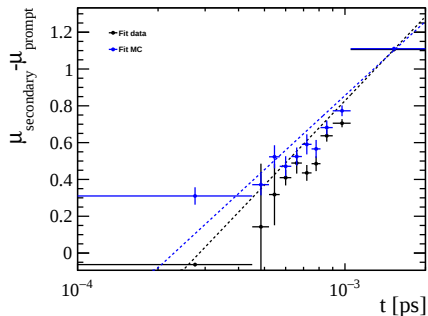


Data

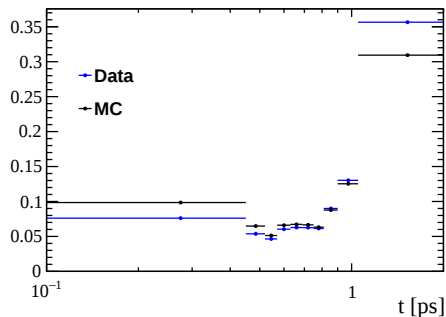


MC

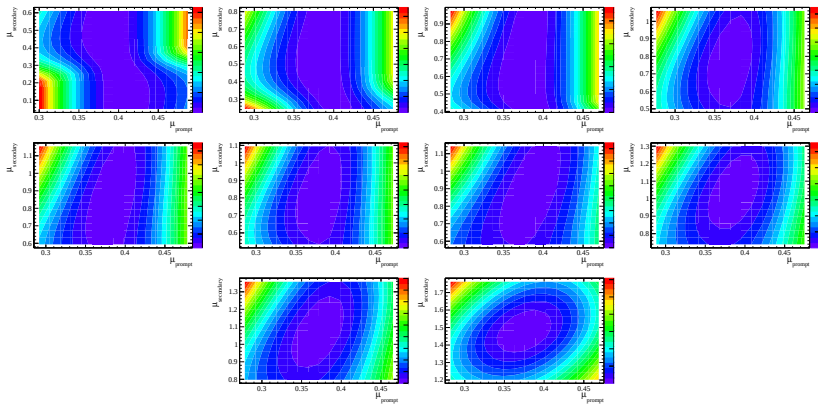
# Comparison of data and MC: $\mu_{\text{prompt}} - \mu_{\text{secondary}}$



# Comparison of data and MC: prompt yield

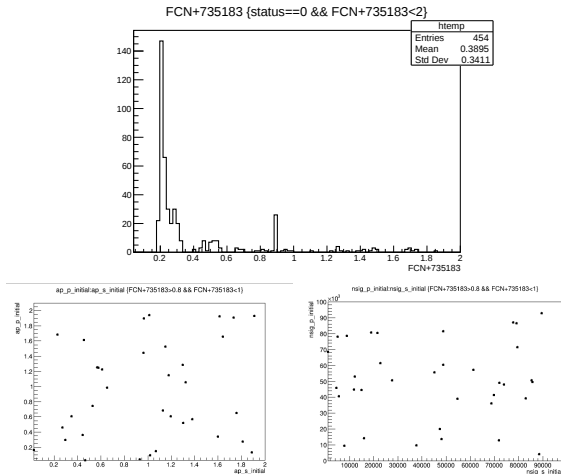


# Likelihood scan of $\mu_{\text{prompt}}$ and $\mu_{\text{secondary}}$



# Effect of initial values

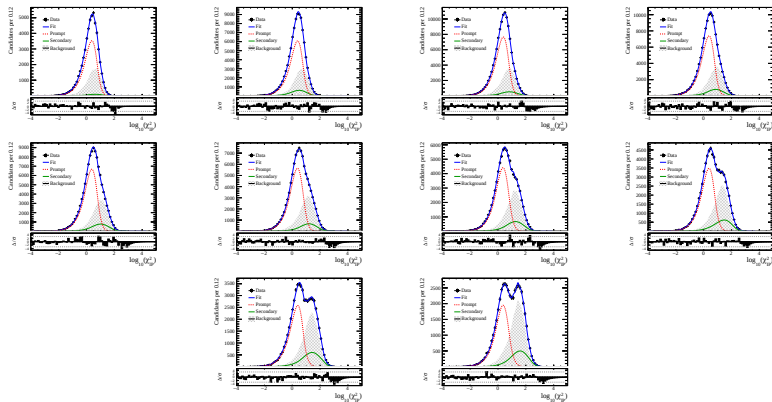
- Repeat the fit (bin 0) with random initial values in parameter space ( $\mu_{\text{prompt}}$ ,  $\mu_{\text{secondary}}$ ,  $N_{\text{prompt}}$ ,  $N_{\text{secondary}}$ )



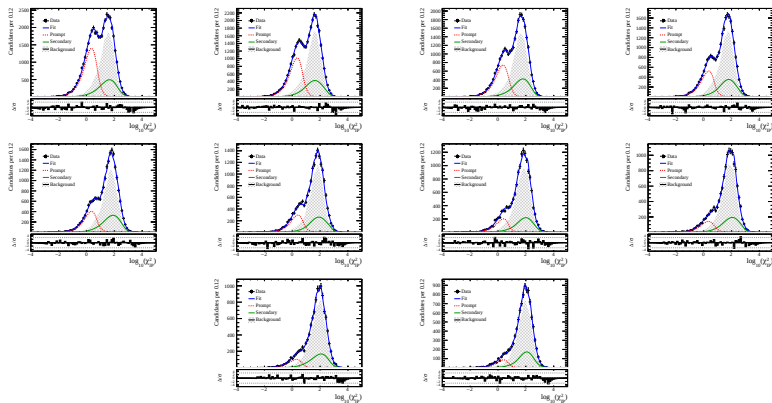
# Fit $D^0$ data in even decay time bins

- Study the effect of unequal binning scheme
- Fit data in equally-sized 20 decay time bins between 0.3 ps and 3 ps

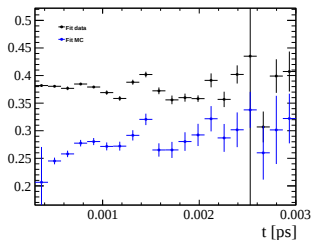
# Fit results of $D^0$ data in even bins: bin 0-9



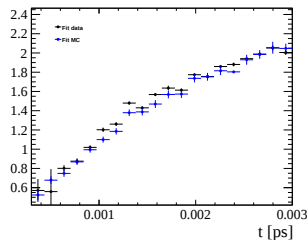
# Fit results of $D^0$ data in even bins: 10-19



# Fit results of $\mu$ in even bins

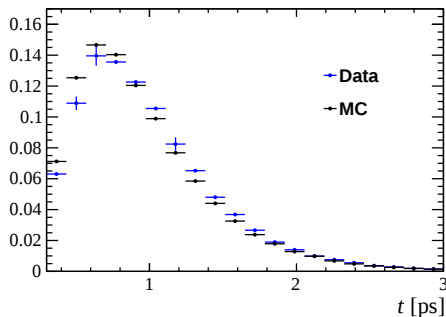


Prompt



Secondary

# Comparison of prompt yield in even decay-time bins



## Section 2

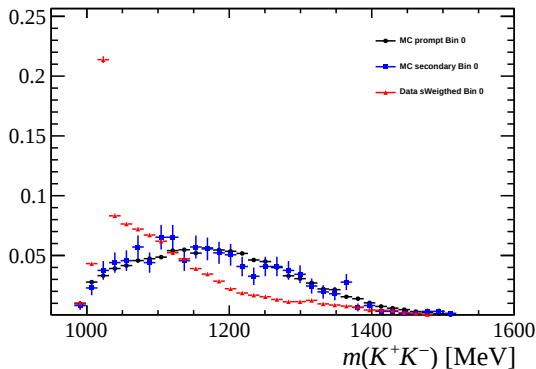
### Efficiency estimation

# Comparison of Dalitz distributions for MC and data of $D^0$ mode

- Five variables are needed to describe the  $D^0 \rightarrow K^+ K^- \pi^+ \pi^-$  decay
- Choose Cabibbo-Maksymowicz (CM) variables
  - $m(K^+ K^-)$
  - $m(\pi^+ \pi^-)$
  - $\cos(\theta_{K^+ K^-}^{K^+ K^-})$ : the cosine of the angle between the direction of the  $D^0$  and that of one of the kaons in the rest frame of the two kaons
  - $\cos(\theta_{\pi^+ \pi^-}^{\pi^+ \pi^-})$ : the cosine of the angle between the direction of the  $D^0$  and that of one of the pions in the rest frame of the two pions
  - $\cos(\phi)$ : the cosine of the angle in the  $D^0$  rest frame between the plane defined by the directions of the two kaons and the plane defined by the directions of the two pions
- Data sWeights are calculated from **mass fit**
- Decay time binning scheme: equally-sized 20 decay time bins between 0.3 ps and 3 ps

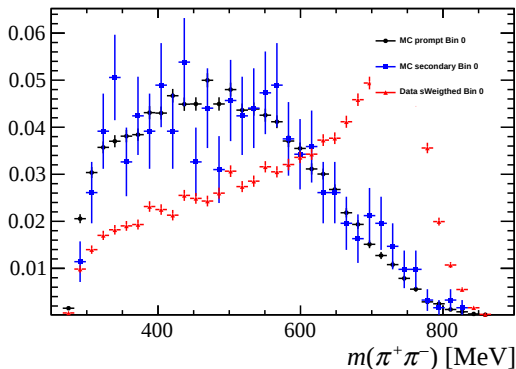
# Comparison of $m(K^+K^-)$ in Bin 0

- No  $\phi$  resonance in phase-space MC
- Prompt and secondary MC agree well



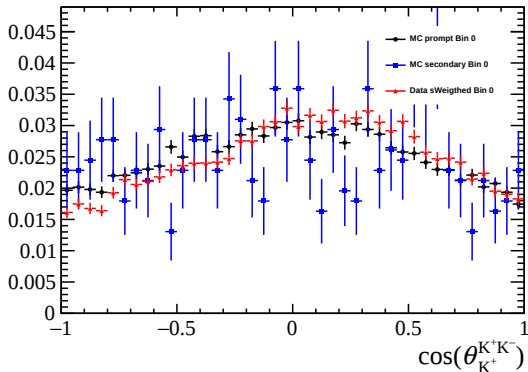
# Comparison of $m(\pi^+\pi^-)$ in Bin 0

- No  $\rho$  resonance in phase-space MC
- Prompt and secondary MC agree well



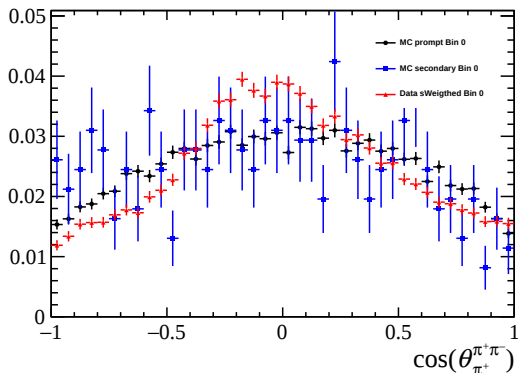
# Comparison of $\cos(\theta_{K^+K^-}^{K^+K^-})$ in Bin 0

- Data-MC discrepancy is small
- Data is not symmetric w.r.t. 0
- Prompt and secondary MC agree well



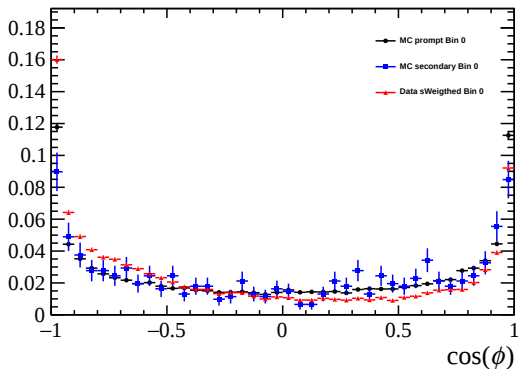
# Comparison of $\cos(\theta_{\pi^+\pi^-}^{\pi^+\pi^-})$ in Bin 0

- Data is not symmetric w.r.t. 0
- Prompt and secondary MC agree well



# Comparison of $\cos(\phi)$ in Bin 0

- Data is not symmetric w.r.t. 0
- Prompt and secondary MC agree well

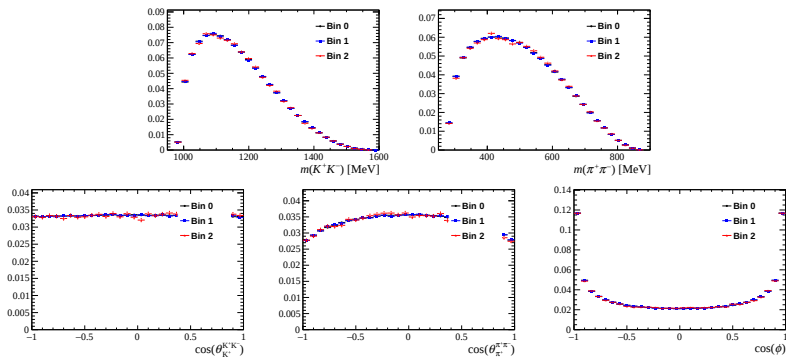


# Decay time dependence of CM variables

- Only the decay-time-dependent discrepancy is relevant in this measurement
- Use three coarse decay time bins to study the effect
  - Bin 0:  $[0.0003, 0.0012]$  ns
  - Bin 1:  $[0.0012, 0.0021]$  ns
  - Bin 2:  $[0.0021, 0.0030]$  ns

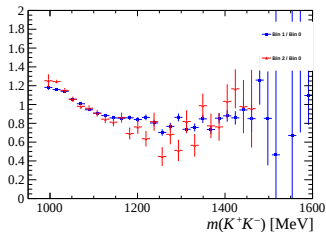
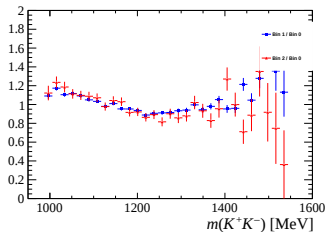
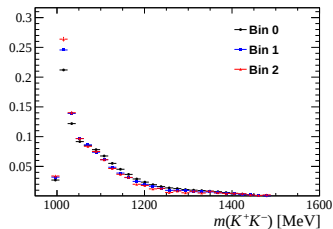
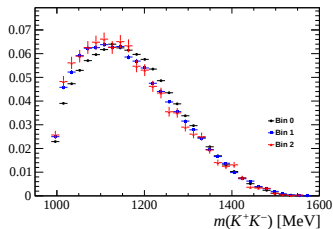
# Generator-level MC distributions

- No difference at generator level



# Decay time dependence of $m(K^+K^-)$

- (Top) distributions and (bottom) ratios

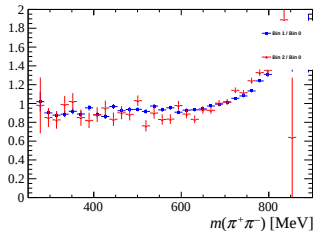
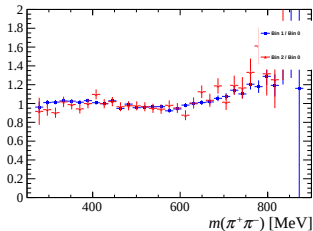
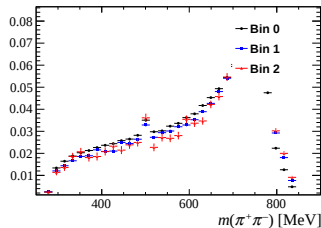
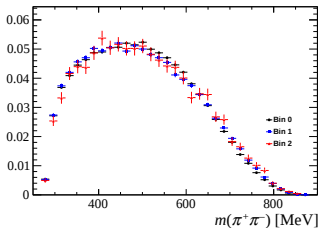


Prompt MC

sWeighted data

# Decay time dependence of $m(\pi^+\pi^-)$

- (Top) distributions and (bottom) ratios

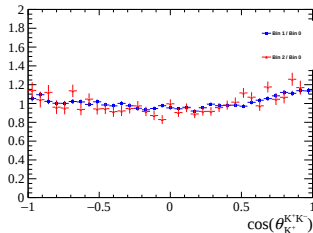
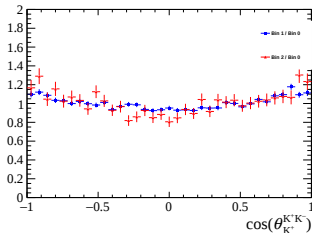
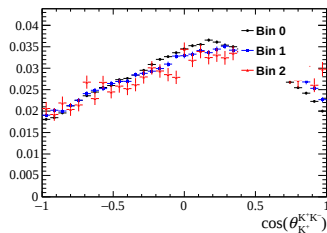
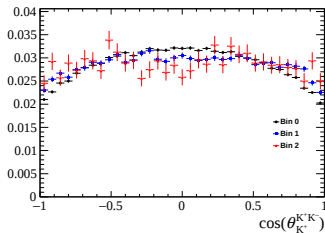


Prompt MC

sWeighted data

# Decay time dependence of $\cos(\theta_{K^+K^-}^{K^+K^-})$

- (Top) distributions and (bottom) ratios

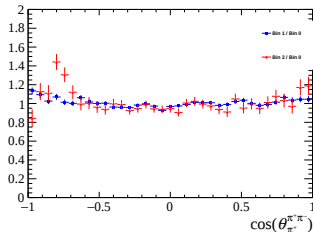
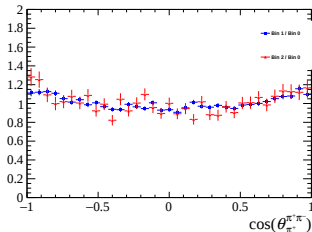
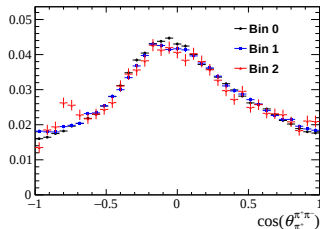
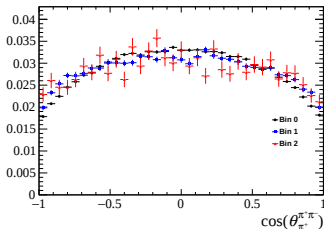


Prompt MC

sWeighted data

# Decay time dependence of $\cos(\theta_{\pi^+\pi^-}^+)$

- (Top) distributions and (bottom) ratios

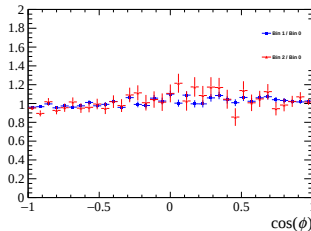
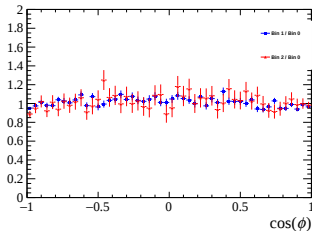
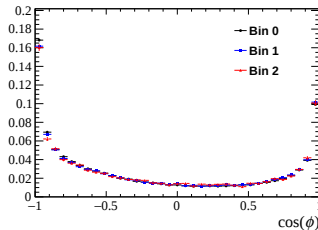
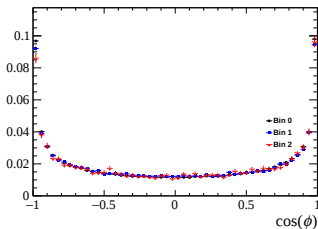


Prompt MC

sWeighted data

# Decay time dependence of $\cos(\phi)$

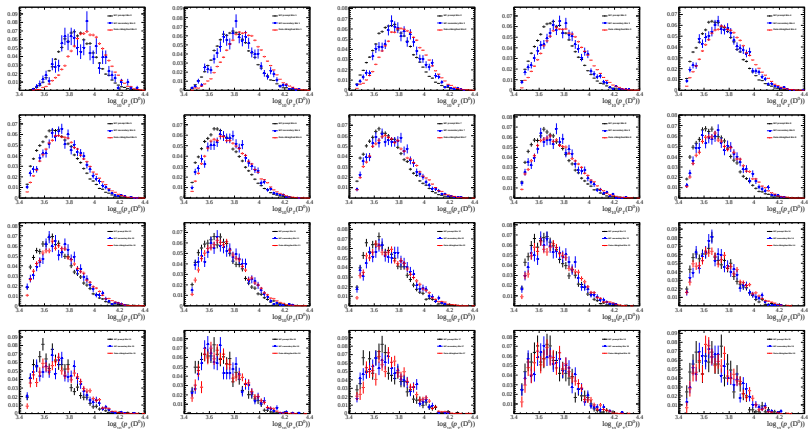
- (Top) distributions and (bottom) ratios



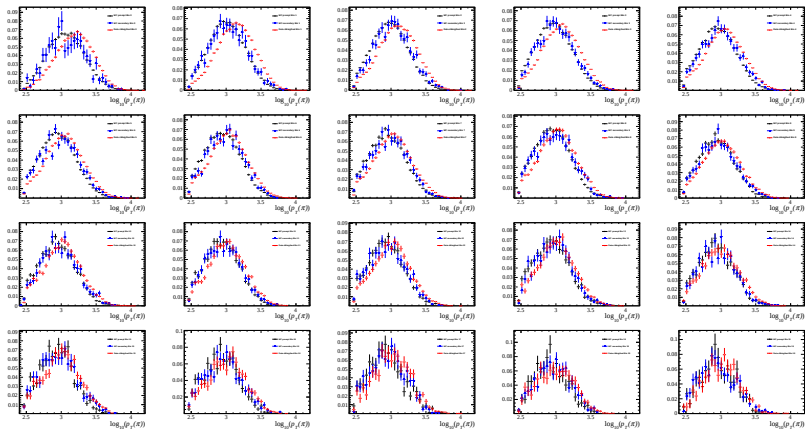
Prompt MC

sWeighted data

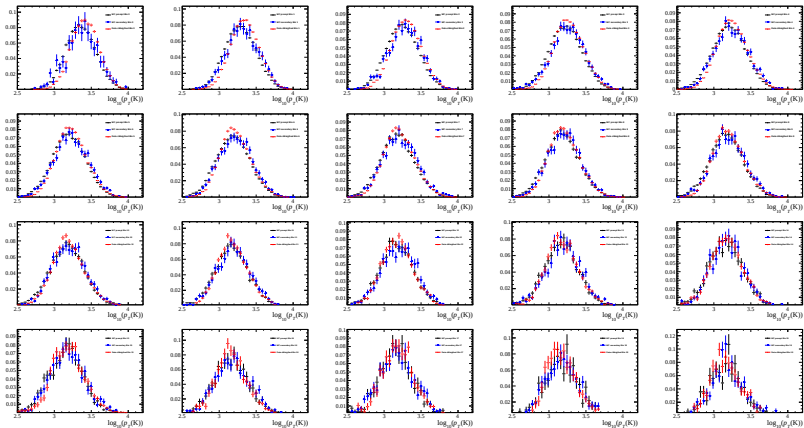
# Comparison of $p_T$ ( $D^0$ )



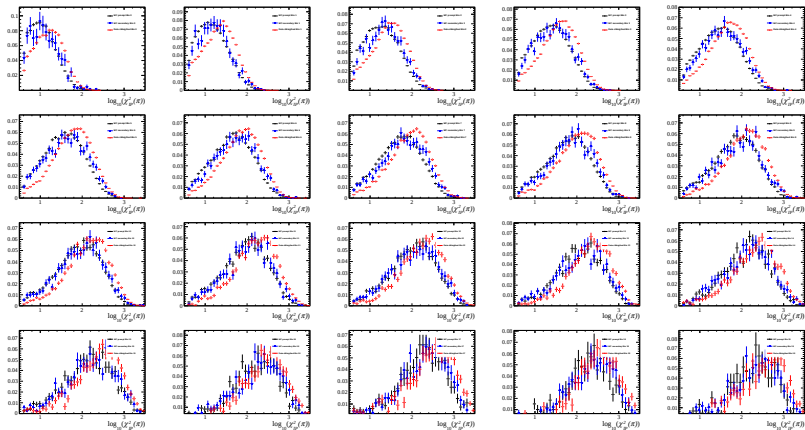
# Comparison of $p_T(\pi^+)$



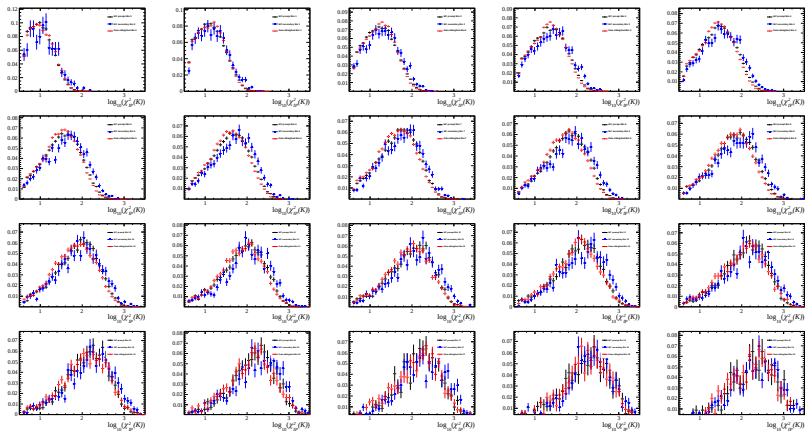
# Comparison of $p_T(K^-)$



# Comparison of $\log(\chi^2_{\text{IP}}(\pi^+))$

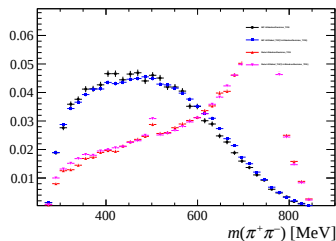
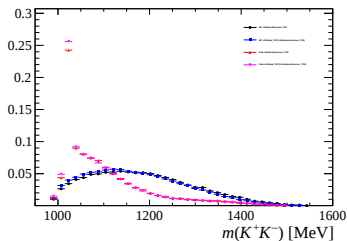
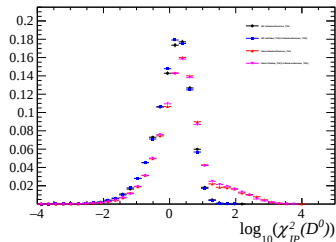
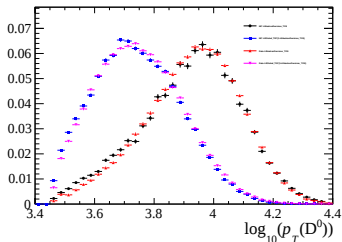


# Comparison of $\log(\chi^2_{\text{IP}}(K^-))$



# Comparison of samples with different L0 trigger

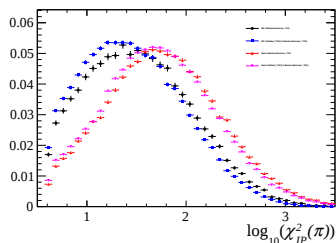
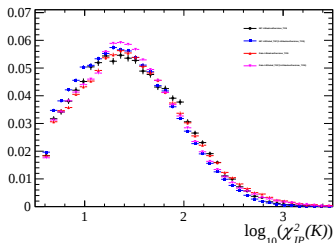
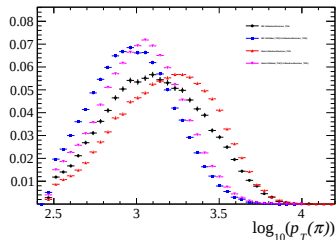
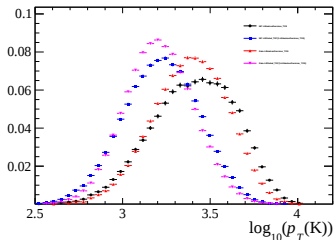
- L0HadronDecision\_TOS v.s. L0Global\_TIS && !L0HadronDecision\_TOS
- $D^0$   $p_T$  is quite different



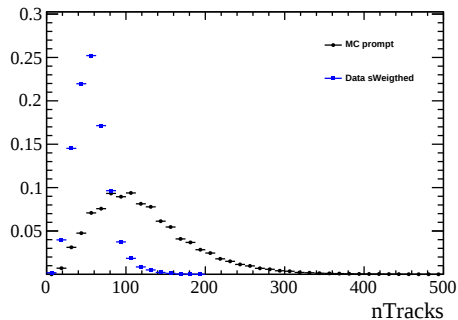
# Comparison of samples with different L0 trigger (cont.)

■ L0HadronDecision\_T0S v.s. L0Global\_TIS && !L0HadronDecision\_T0S

■ Daughters'  $p_T$  is quite different



# Comparison of nTracks

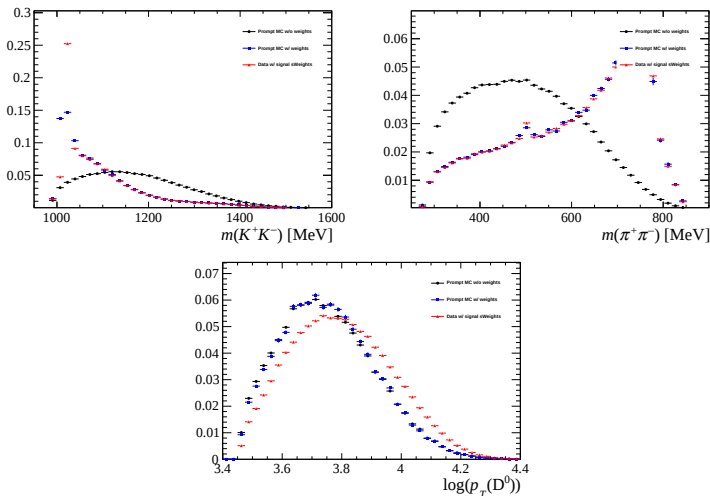


# Corrections to MC by weighting

- Weights are calculated sequentially by comparing the decay-time-integrated MC prompt sample and sWeighted data
  - PID weights from PIDCalib
  - Based on PID weights, calculate  $(m(K^+K^-), m(\pi^+\pi^-))$  weights
  - Based on PID and  $(m(K^+K^-), m(\pi^+\pi^-))$  weights, calculate  $p_T(D^0)$  weights
- $\cos(\theta_{K^+}^{K^+K^-}), \cos(\theta_{\pi^+}^{\pi^+\pi^-}), \cos(\phi)$  not weighted due to weak dependence on decay time
- Here we assume the relevant distributions of the prompt and secondary components in data are the same

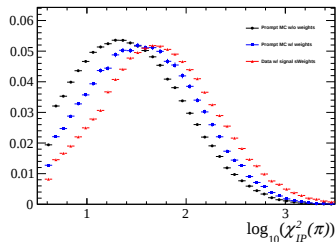
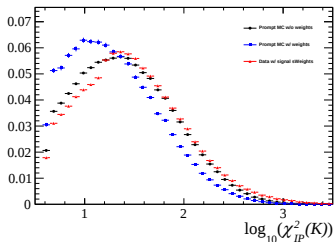
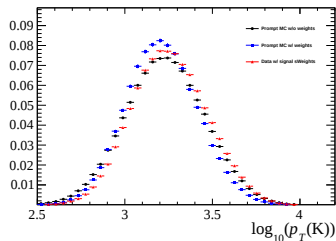
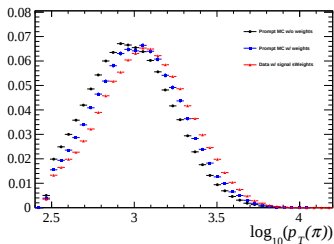
# Comparison before and after corrections to MC

- Consider PID and  $(m(K^+K^-), m(\pi^+\pi^-))$  weights



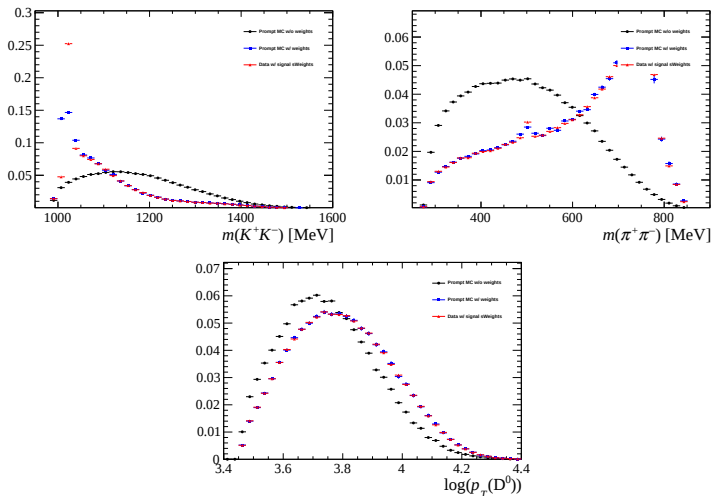
# Comparison before and after corrections to MC (cont.)

- Consider PID and  $(m(K^+K^-), m(\pi^+\pi^-))$  weights



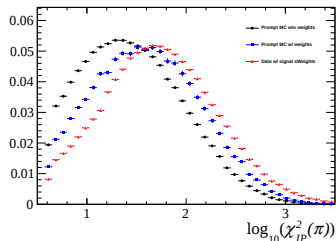
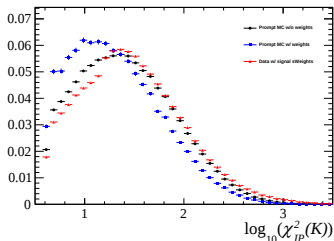
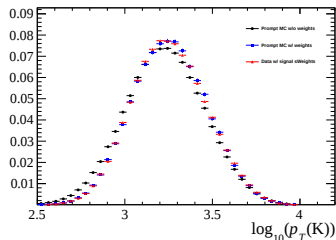
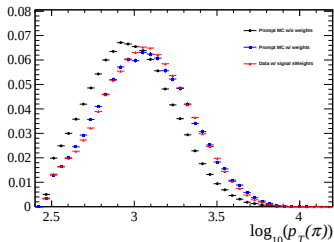
# Comparison before and after corrections to MC

- Consider PID,  $(m(K^+K^-), m(\pi^+\pi^-))$  and  $p_T(D^0)$  weights



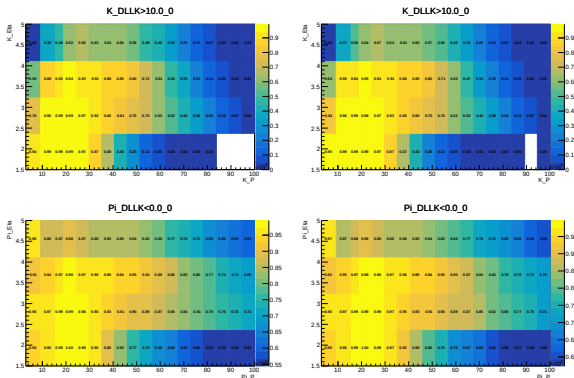
# Comparison before and after corrections to MC (cont.)

- Consider PID,  $(m(K^+K^-), m(\pi^+\pi^-))$  and  $p_T(D^0)$  weights



# PID corrections with PIDCalib

- PID cuts applied: Kaon  $DLL_{K\pi} > 10$  and Pion  $DLL_{K\pi} < 0$
- Use PIDCalib to get the correct PID efficiency
- Use default binning scheme
  - $P$  [GeV/c]:  
[ 3.0, 9.3, 15.6, 19.0, 24.4, 29.8, 35.2, 40.6, 46.0, 51.4 ]  
[ 51.4, 56.8, 62.2, 67.6, 73.0, 78.4, 83.8, 89.2, 94.6, 100.0 ]
  - $\eta$ : [ 1.5, 2.375, 3.25, 4.125, 5.0 ]
- Performance histograms: (left) Magdown and (right) MagUp



# Reweighting with Boosted Decision Trees

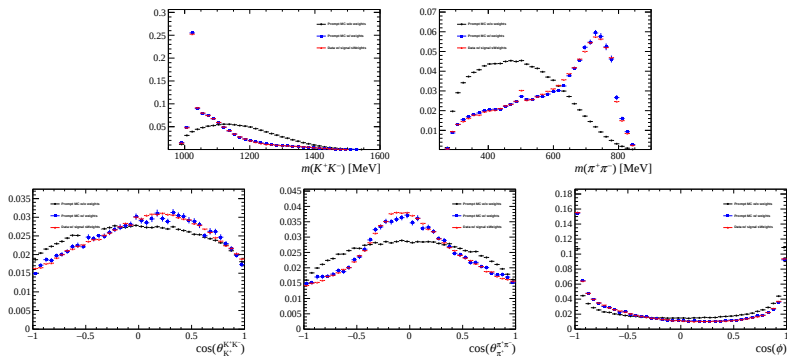
- Try to reweight MC with GBReweighter from the `hep_ml` package, a reweighter algorithm based on ensemble of regression trees
  - PID weights from PIDCalib
  - Based on PID weights, calculate

$$w(m(K^+K^-), m(\pi^+\pi^-), \cos(\theta_{K^+}^{K^+K^-}), \cos(\theta_{\pi^+}^{\pi^+\pi^-}), \cos(\phi))$$

- Build unbiased predictions with folding algorithm
  - training data is splitted into n equal parts
  - train n reweighters, each one is trained using n-1 folds
  - predict each event with the reweighter that did not use it during training
- Here we assume the relevant distributions of the prompt and secondary components in data are the same, i.e. subtract the background in real data by fitting the mass spectrum

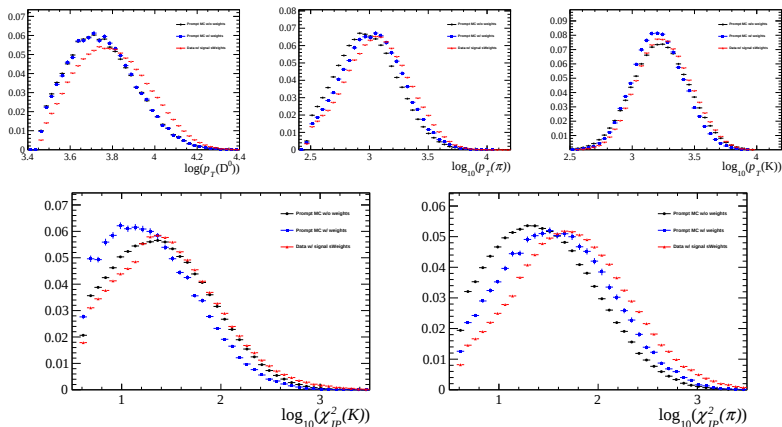
# Comparison before and after corrections to MC

## ■ Reweighting with GBReweighter

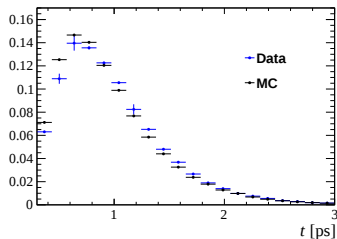


# Comparison before and after corrections to MC (cont.)

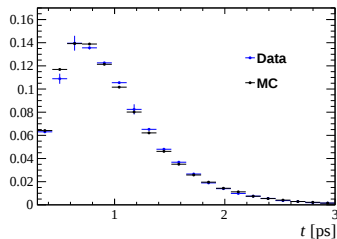
## ■ Reweighting with GBReweighter



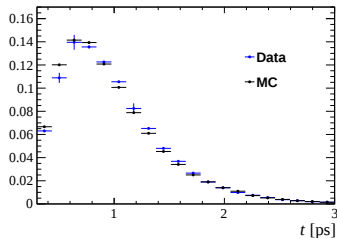
# Decay time distribution with MC corrections



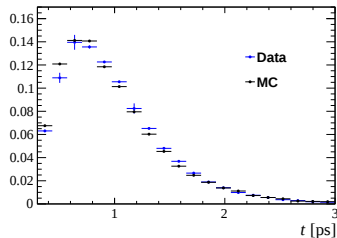
MC w/o corrections



MC w/ Dalitz weights



MC w/ PID and 2D-Dalitz weights



MC w/ PID and 5D-Dalitz weights

## Section 3

### Efficiency studies of L0 Hadron TOS sample

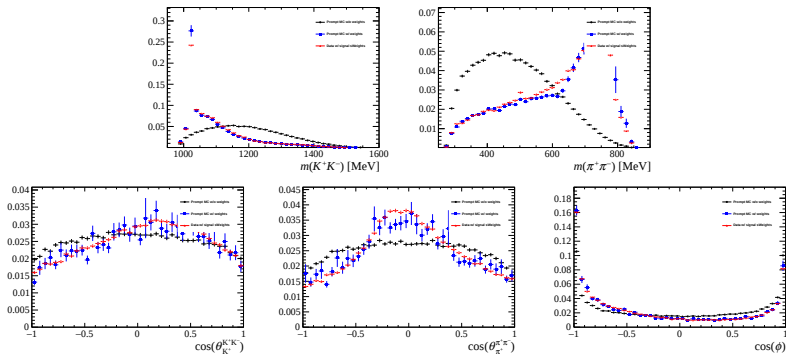
# Efficiencies of L0 trigger requirements in MC

| $D^0$              | TOS [%] | TIS [%] |
|--------------------|---------|---------|
| L0Global           | 14      | 39      |
| L0HadronDecision   | 12      | 22      |
| L0ElectronDecision | 2       | 16      |
| L0PhotonDecision   | 0       | 8       |
| L0MuonDecision     | 1       | 6       |
| L0DiMuonDecision   | 0       | 1       |

- Require L0HadronDecision TOS on  $D^0$  in the following studies
- Fit the mass and IPCHI2 of the L0 TOSed data sample to estimate the prompt yield
- Apply PIDCalib and Dalitz weights to MC sample for comparison

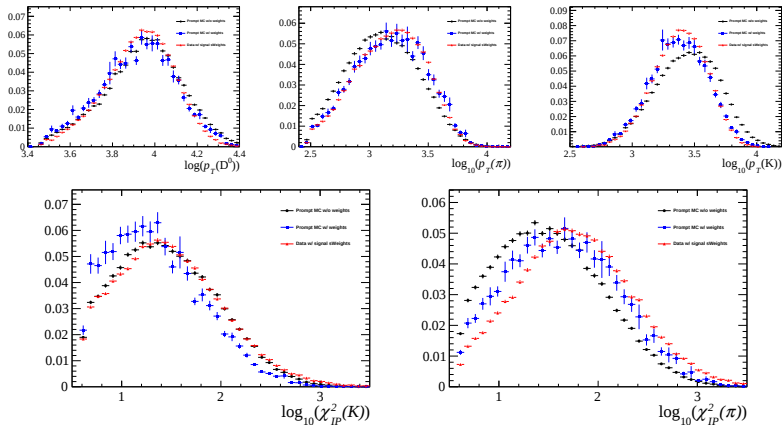
# Comparison before and after corrections to MC

## ■ Reweighting with GBReweighter

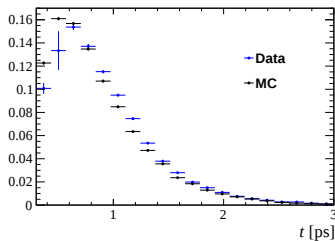


# Comparison before and after corrections to MC (cont.)

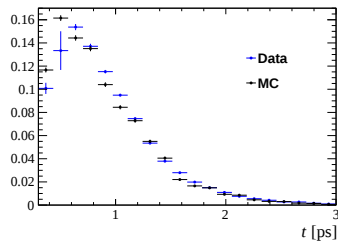
- $p_T$  agrees well
- IPCHI2 still agrees not well



# Decay time distribution with MC corrections



MC w/o corrections



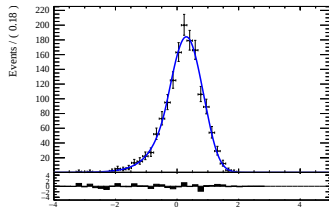
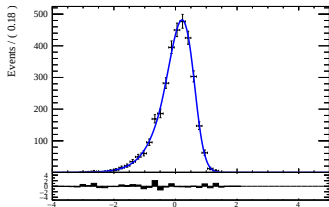
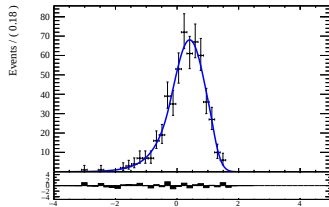
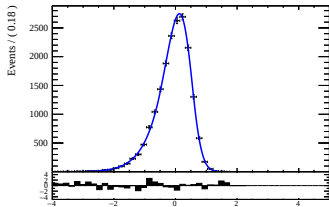
MC w/ PID and Dalitz weights

BACKUP

|                 |                                                                                                                   |
|-----------------|-------------------------------------------------------------------------------------------------------------------|
| DaughtersCuts   | TRCHI2D0F < 3.0<br>PT > 250.0<br>P > 1000.0<br>MIPCHI2DV(PRIMARY) > 3.0                                           |
| $K$             | PIDK > 5                                                                                                          |
| $\pi$           | PIDK < 5                                                                                                          |
| CombinationCuts | (APT1+APT2+APT3+APT4) > 1800.0<br>AP > 25000.0<br>ADOCA(i,4) < 100.0, i=1,2,3<br>ACHI2DOCA(i,4) < 10.0, i=1,2,3   |
| MotherCuts      | CHI2VXNDOF < 12.0<br>PT > 2000.0<br>P > 30000.0<br>BPVDIRA > cos( 0.02 )<br>BPVLTIME() > 0.0001<br>BPVVDCHI2 > 25 |

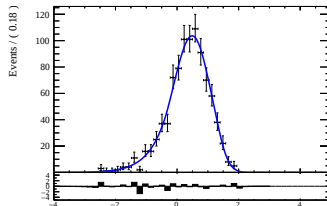
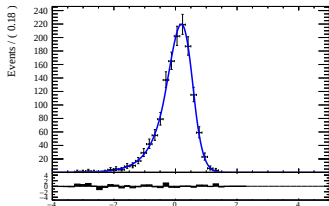
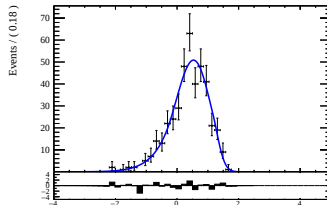
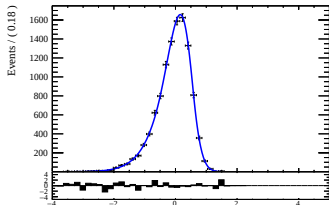
# Fit with all parameters free: bin 0

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



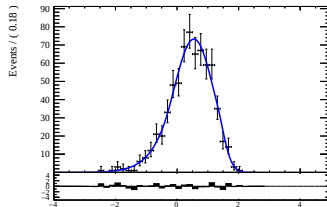
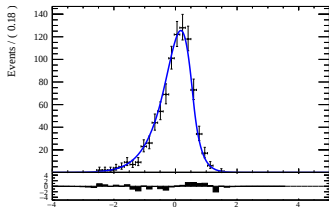
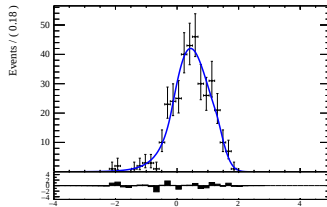
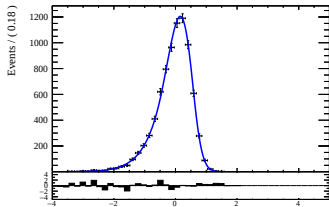
# Fit with all parameters free: bin 1

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



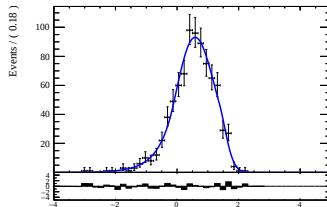
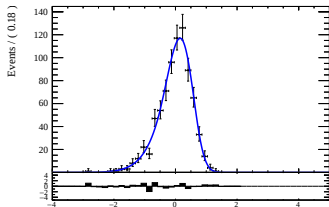
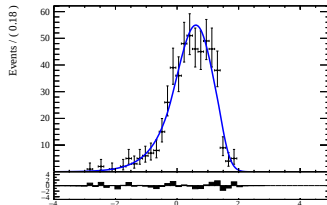
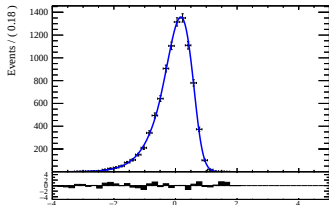
# Fit with all parameters free: bin 2

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



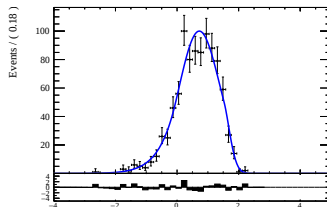
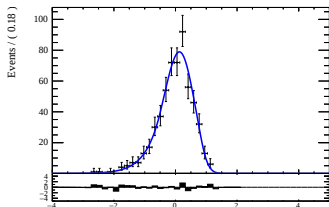
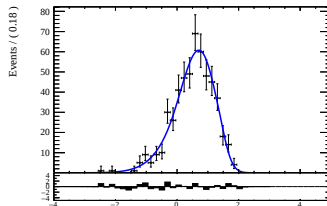
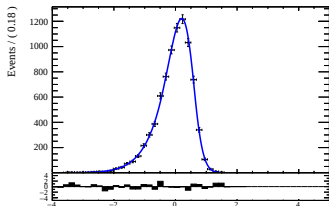
# Fit with all parameters free: bin 3

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



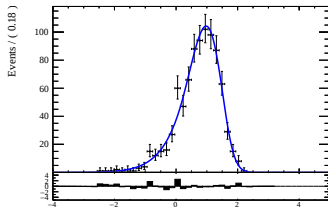
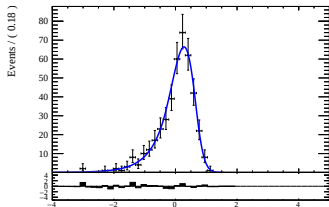
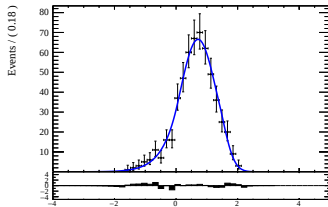
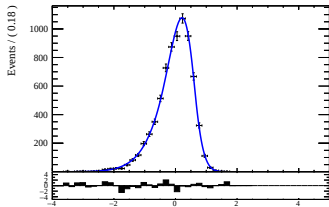
# Fit with all parameters free: bin 4

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



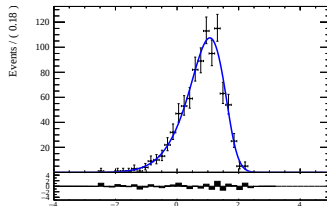
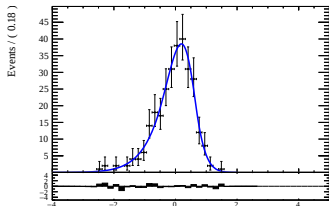
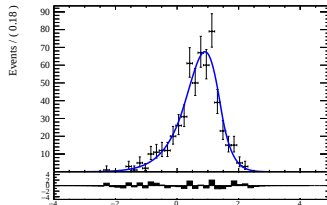
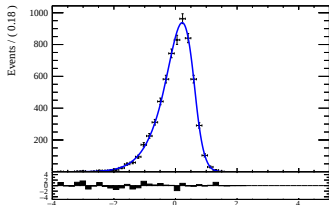
# Fit with all parameters free: bin 5

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



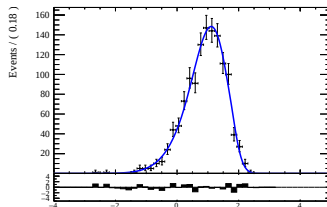
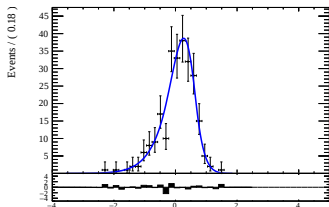
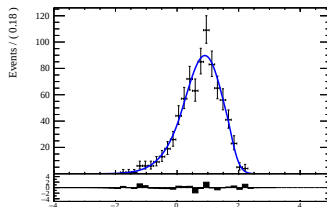
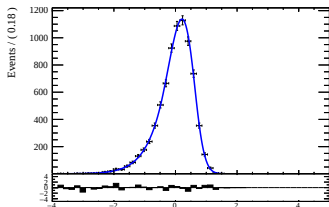
# Fit with all parameters free: bin 6

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



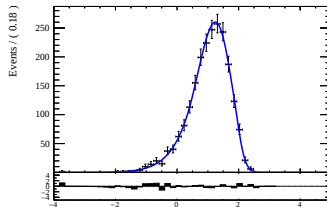
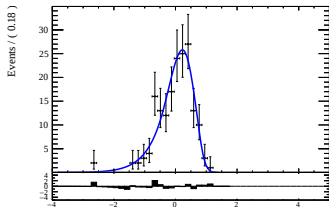
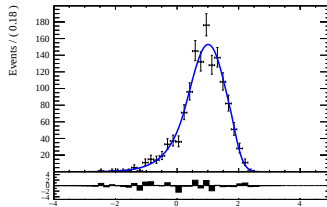
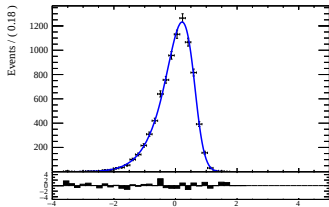
# Fit with all parameters free: bin 7

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



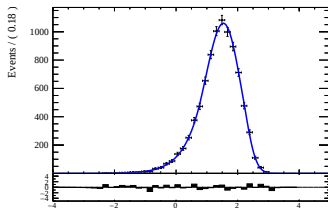
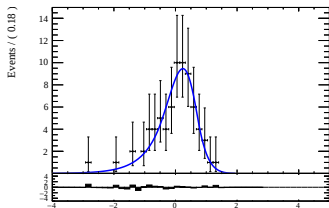
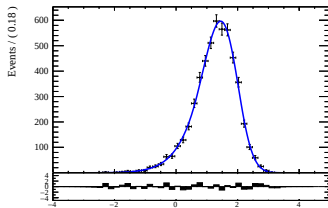
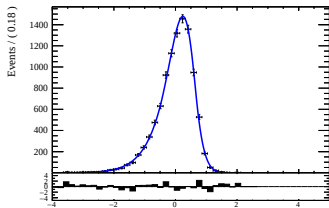
# Fit with all parameters free: bin 8

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



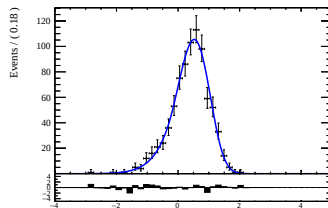
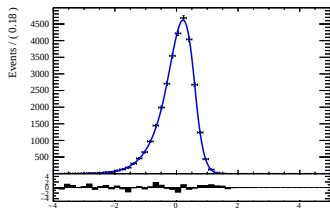
# Fit with all parameters free: bin 9

- (left) Prompt and (right) secondary for (top)  $\Omega_c^0$  and (bottom)  $\Xi_c^0$



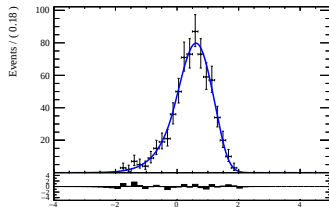
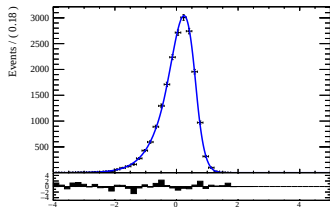
# Fit $D^0$ MC with all parameters free: bin 0

- (left) Prompt and (right) secondary



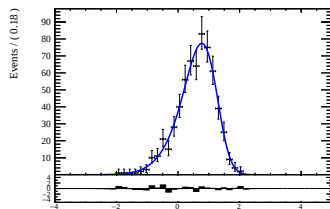
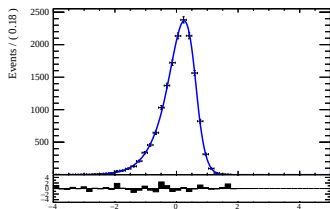
# Fit $D^0$ MC with all parameters free: bin 1

- (left) Prompt and (right) secondary



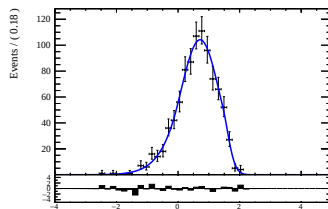
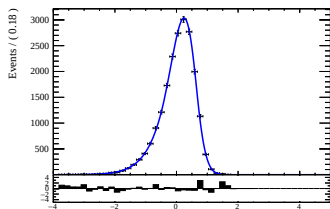
# Fit $D^0$ MC with all parameters free: bin 2

- (left) Prompt and (right) secondary



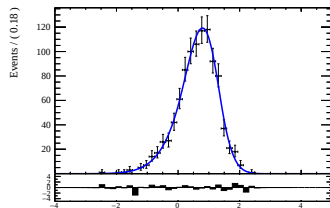
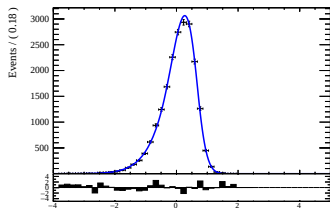
# Fit $D^0$ MC with all parameters free: bin 3

- (left) Prompt and (right) secondary



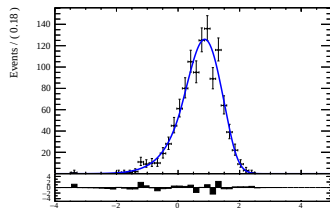
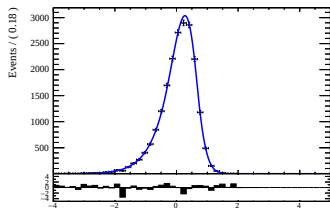
# Fit $D^0$ MC with all parameters free: bin 4

- (left) Prompt and (right) secondary



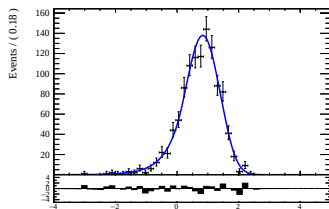
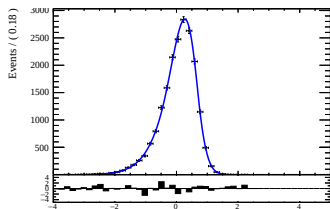
# Fit $D^0$ MC with all parameters free: bin 5

- (left) Prompt and (right) secondary



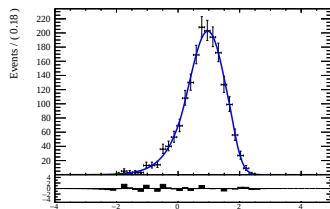
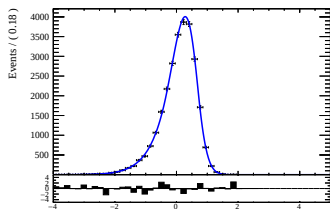
# Fit $D^0$ MC with all parameters free: bin 6

- (left) Prompt and (right) secondary



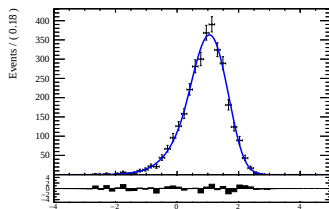
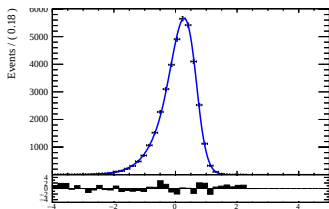
# Fit $D^0$ MC with all parameters free: bin 7

- (left) Prompt and (right) secondary



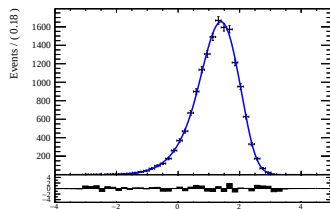
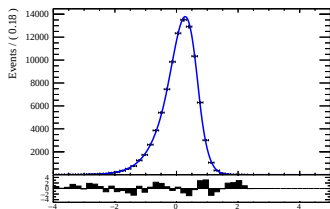
# Fit $D^0$ MC with all parameters free: bin 8

- (left) Prompt and (right) secondary

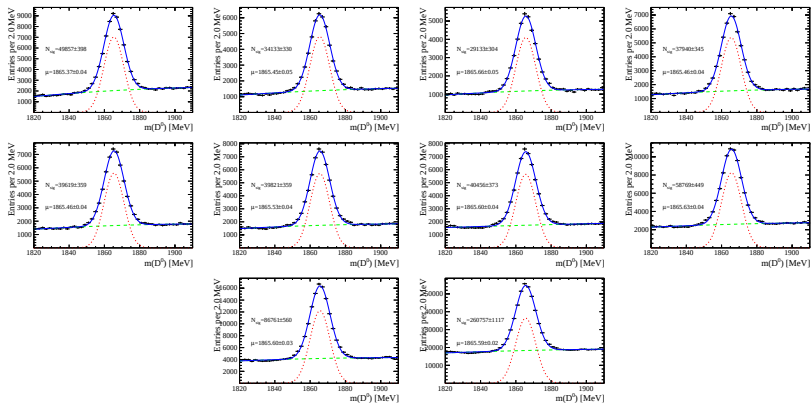


# Fit $D^0$ MC with all parameters free: bin 9

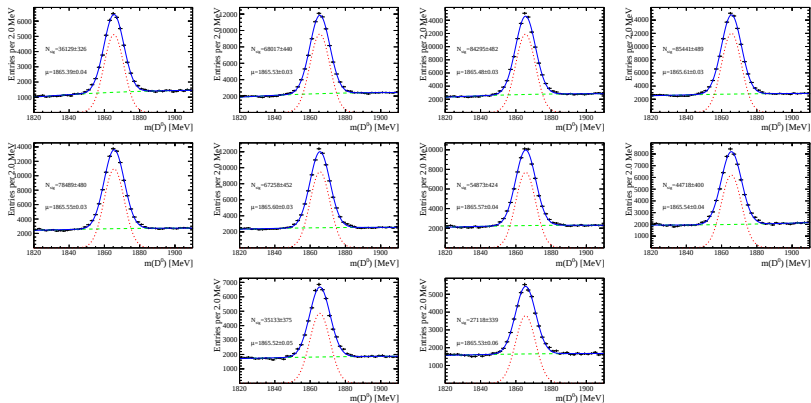
- (left) Prompt and (right) secondary



# Fit mass of $D^0$ data



# Fit mass of $D^0$ data in even bins: bin 0-9



# Fit mass of $D^0$ data in even bins: bin 10-19

