Ω_c^0 lifetime measurement

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Ω_c^0 lifetime measurement meeting

February 19, 2019

Outline

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2. 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
3. Efficiency estimation
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   - 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

Section 1

Data and simulation

Data and simulation

- 2016 data and simulation samples available for this analysis

Modes	Data	MC	
signal	$\Omega_c^0 \to pK^- K^- \pi^+$	Turbo	ReDecay $\tau = 250\,\mathrm{fs}$, 500 fs
normalization	$\Xi_c^0 \to pK^- K^- \pi^+$	Turbo	ReDecay
control	$\Omega_b^- \to \Omega_c^0(\to pK^- K^- \pi^+)\ \pi^-$	Stripping	Full Sim.
control	$\Omega_b^- \to \Omega_c^0(\to pK^- K^- \pi^+)\ \mu^- \overline{\nu}_\mu$	Stripping	Full Sim. $\tau = 250\,\mathrm{fs}$
control	$\Xi_b \to \Xi_c^0(\to pK^- K^- \pi^+)\ \mu^- \overline{\nu}_\mu$	Stripping	Full Sim.
control	$D^{*+} \to D^0(\to K^- K^+ \pi^- \pi^+)\pi^+$	Turbo	ReDecay
control	$B^+ \to \overline{D}^0(\to K^+ K^- \pi^+ \pi^-)\pi^+$	Stripping	Full Sim.

Section 2

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

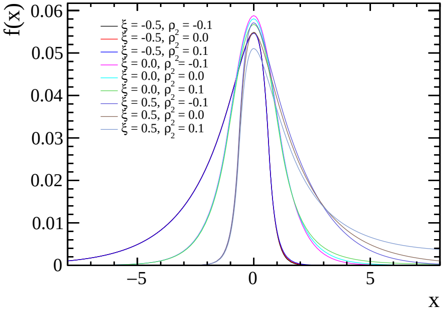
$$\mathcal{P}(x;\mu,\sigma,\xi,\rho_1,\rho_2)=\begin{cases}\exp\left\{\dfrac{(x-x_1)\xi\sqrt{\xi^2+1}\sqrt{2\ln 2}}{\sigma\left(\sqrt{\xi^2+1}-\xi\right)^2\ln\left(\sqrt{\xi^2+1}+\xi\right)}+\rho_1\left(\dfrac{x-x_1}{\mu-x_1}\right)^2-\ln 2\right\} & x\le x_1,\\ \exp\left\{-\left[\dfrac{\ln\left(1+2\xi\sqrt{\xi^2+1}\,\frac{x-\mu}{\sigma\sqrt{2\ln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

where

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

Illustration of the Bukin functions

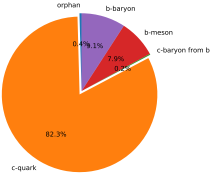
- Bukin functions with various asymetry and tail parameters with $\mu = 0, \sigma = 1, \rho_1 = 0$



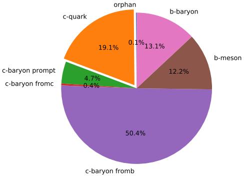
Prompt and secondary MC samples

- Prompt and secondary MC samples of Ω_c^0, Ξ_c^0 and D^0: acquired by apply `MC_MOTHER_ID` requirements to inclusive MC samples
- Components after all selections

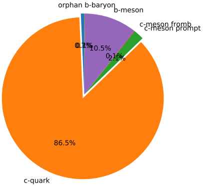
Components	orphan	c-quark	c-meson	c-baryon	b-meson	b-baryon
abs(MC_MOTHER_ID)	0	4	(400,500)	(4000,5000)	(500,600)	(5000,6000)



Ω_c^0



Ξ_c^0



D^0

- Validation needed with b-decay MC samples

The defination of the decay time

- Decay time t is defined as

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

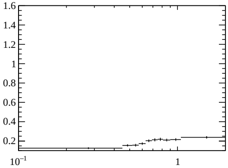
where $\vec{p}$ is the momentum vector, $\vec{r}$ the vector pointing from PV to decay vertex, and m the invariant mass of the charm hadron

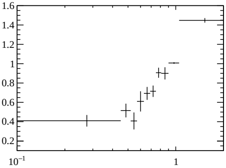
Fit with all parameters free in all decay time bins

- All fits converge with accurate error matrix
- μ: dependent on t with clear pattern for prompt and secondary
- σ: vary with t for prompt and secondary
- ξ: vary with t for prompt and secondary
- ρ_1, ρ_2: vary with t for prompt and secondary

Fit results in decay-time bins: μ

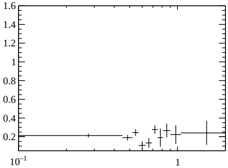
Prompt Ω_c^0

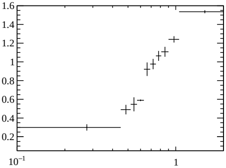




Secondary Ω_c^0

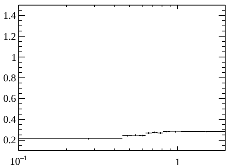
Prompt Ξ_c^0

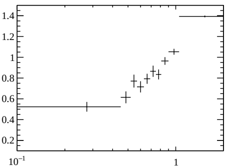




Secondary Ξ_c^0

Prompt D^0





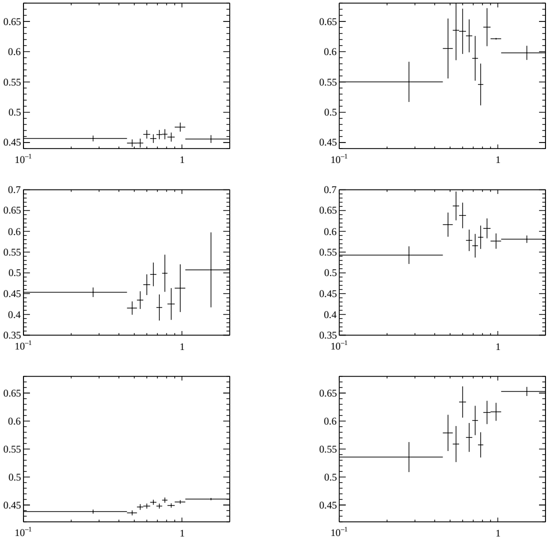
Secondary D^0

Fit results in decay-time bins: σ

Prompt Ω_c^0 | Secondary Ω_c^0

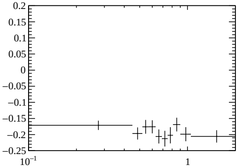
Prompt Ξ_c^0 | Secondary Ξ_c^0

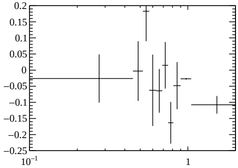
Prompt D^0 | Secondary D^0



Fit results in decay-time bins: ξ

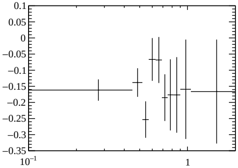
Prompt Ω_c^0

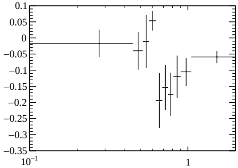




Secondary Ω_c^0

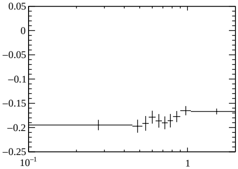
Prompt Ξ_c^0

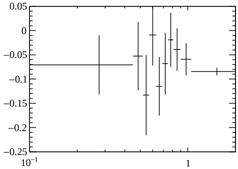




Secondary Ξ_c^0

Prompt D^0

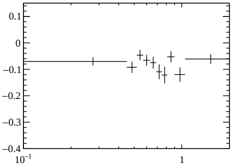


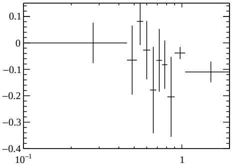


Secondary D^0

Fit results in decay-time bins: ρ_1

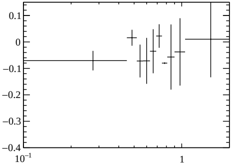
Prompt Ω_c^0

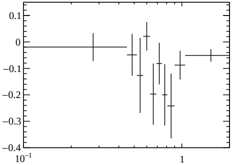




Secondary Ω_c^0

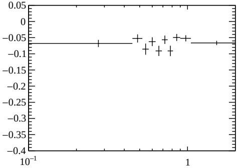
Prompt Ξ_c^0

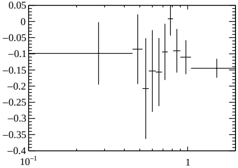




Secondary Ξ_c^0

Prompt D^0

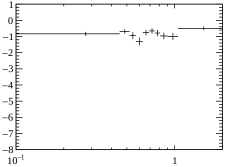


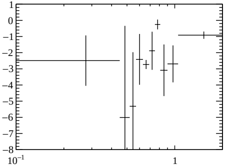


Secondary D^0

Fit results in decay-time bins: ρ_2

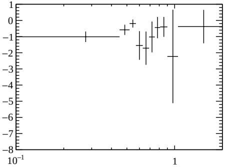
Prompt Ω_c^0

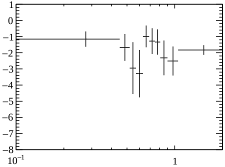




Secondary Ω_c^0

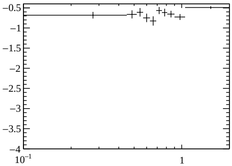
Prompt Ξ_c^0

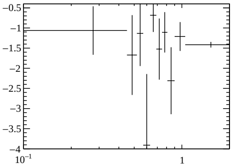




Secondary Ξ_c^0

Prompt D^0





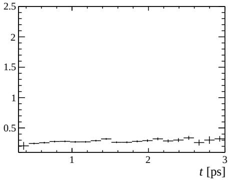
Secondary D^0

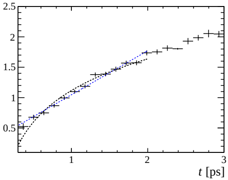
Fit D^0 MC in even decay time bins

- Fit with all parameters free in equally-sized 20 decay time bins between $0.3\,\mathrm{ps}$ and $3\,\mathrm{ps}$

D^0 results in even decay-time bins: μ

Prompt D^0

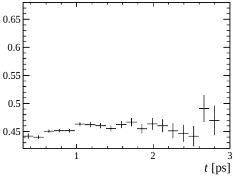


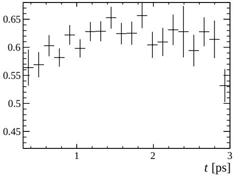


Secondary D^0

D^0 results in even decay-time bins: σ

Prompt D^0

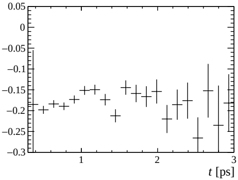


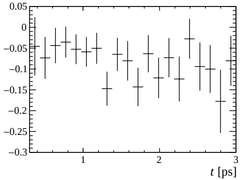


Secondary D^0

D^0 results in even decay-time bins: ξ

Prompt D^0

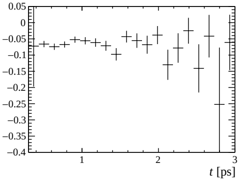


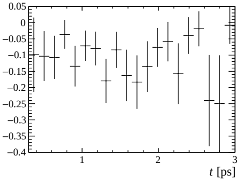


Secondary D^0

D^0 results in even decay-time bins: ρ_1

Prompt
D^0

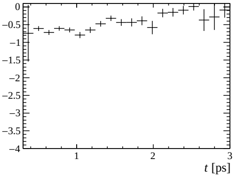


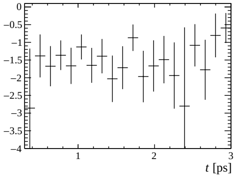


Secondary
D^0

D^0 results in even decay-time bins: ρ_2

Prompt D^0



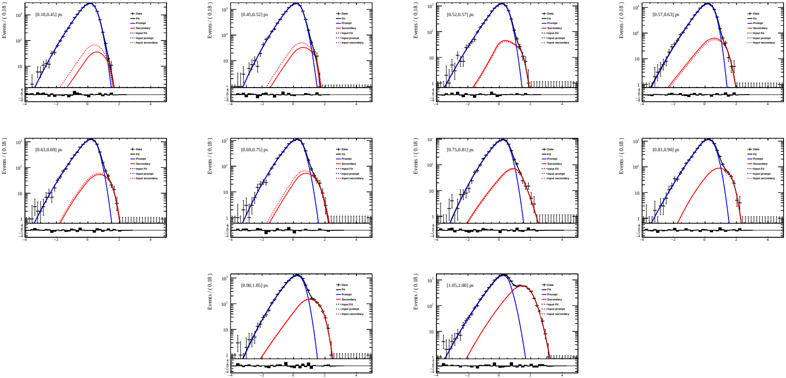


Secondary D^0

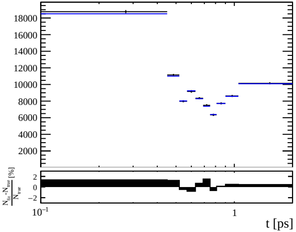
Sanity check: fit combined MC samples

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

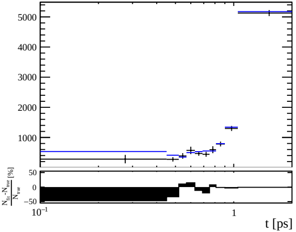
Fit results of combined MC samples: Ω_c^0



Comparison of input and extracted yield: Ω_c^0



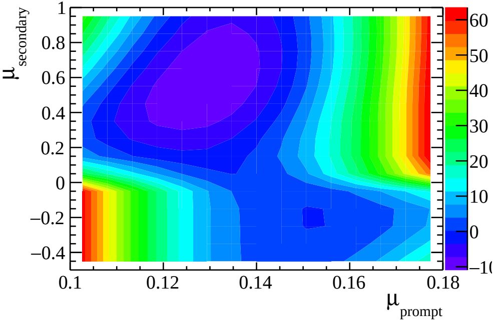
Prompt



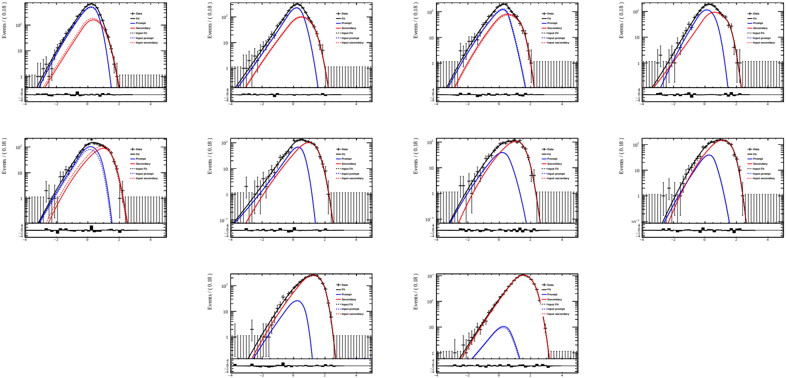
Secondary

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

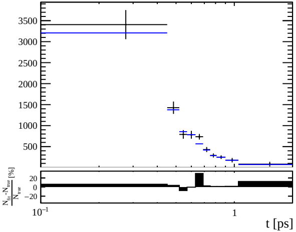
- Ω_c^0 bin 0



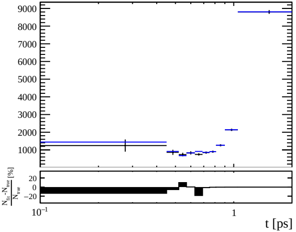
Fit results of combined MC samples: Ξ_c^0



Comparison of input and extracted yield: Ξ_c^0



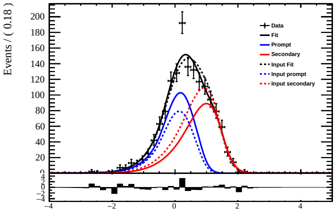
Prompt

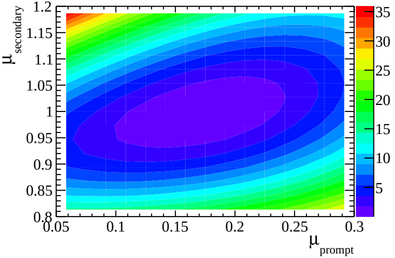


Secondary

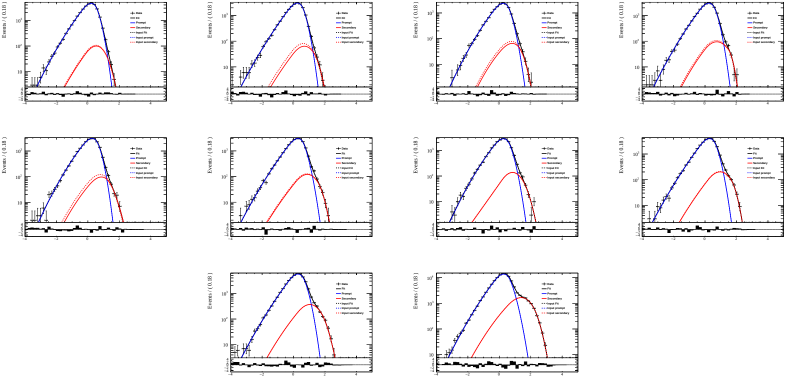
Likelihood scan of μ_{prompt} and $\mu_{\mathrm{secondary}}$

- Ξ_c^0 bin 4

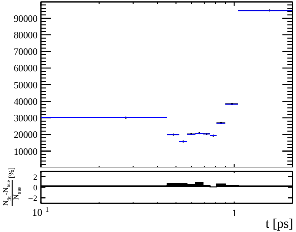




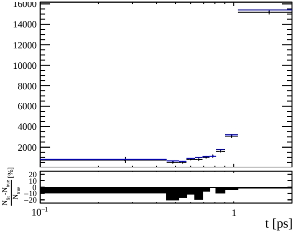
Fit results of combined MC samples: D^0



Comparison of input and extracted yield: D^0



Prompt

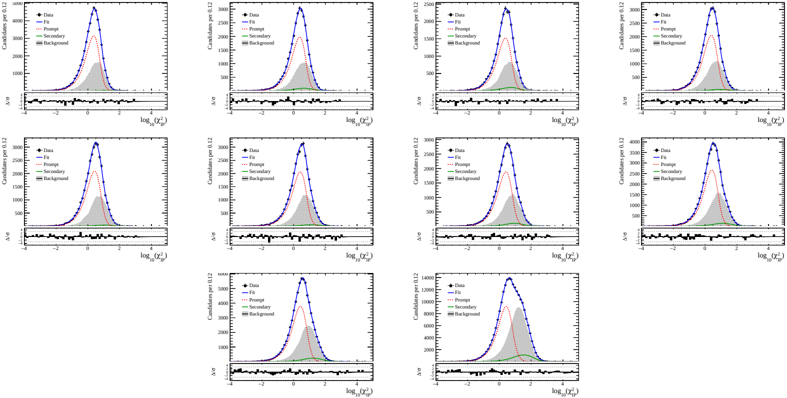


Secondary

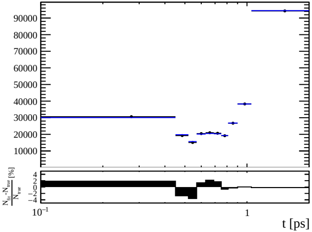
Sanity check: fit background-injected combined MC

- 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
  - μ_{prompt} and $\mu_{\text{secondary}}$ free to float
  - Other parameters fixed to separately-fit results
  - Number of background fixed to the input value

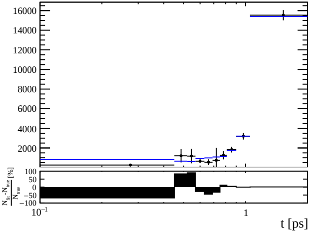
Fit results of background-injected combined MC



Comparison of input and extracted yield: D^0



Prompt



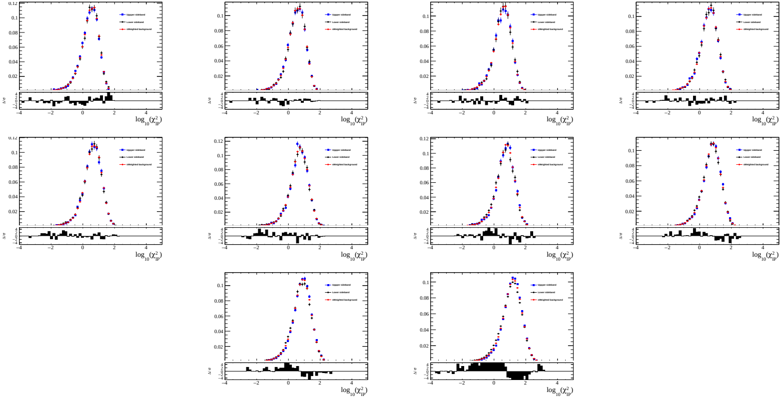
Secondary

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

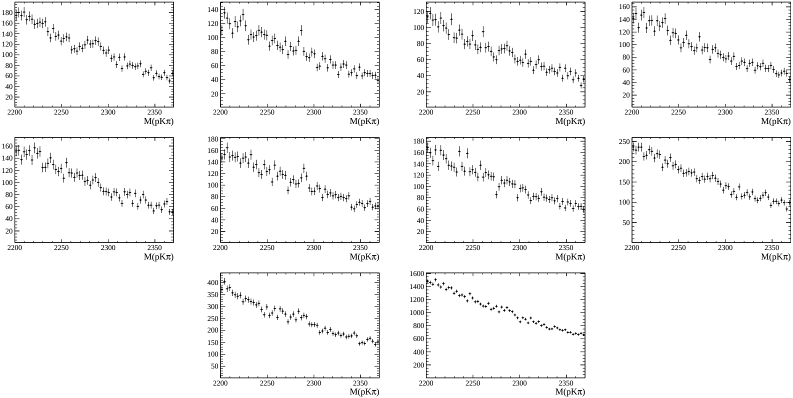
- Mass fit
  - In $1865 \pm 45\,\mathrm{MeV}/c^2$ mass region
  - Gaussian + 2^{nd}-order Chebychev
- IPCHI2 fit
  - In $1865 \pm 2.5 \times 5.65\,\mathrm{MeV}/c^2$ signal region
  - Prompt and secondary signal components: μ_{prompt} and $\mu_{\mathrm{secondary}}$ free and other parameters fixed to MC
  - Background: kernel estimation with mass-sideband data
    Lower sideband: $[1820, 1830]\,\mathrm{MeV}/c^2$
    Upper sideband: $[1900, 1910]\,\mathrm{MeV}/c^2$
  - 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

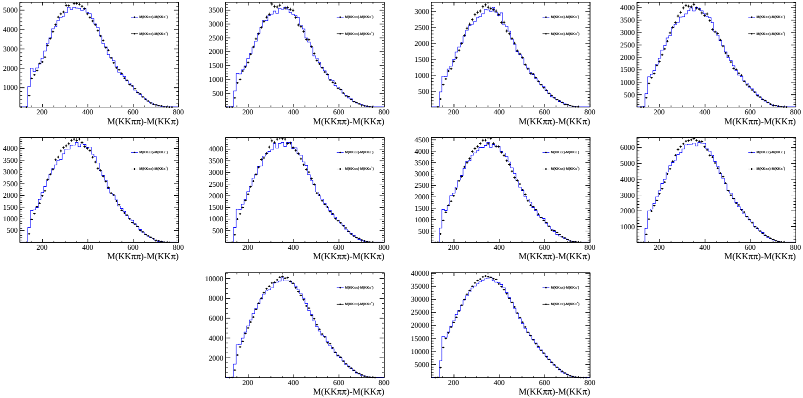


- Λ_c^+ background: p mis-identified as K^-
- Suppressed by tight PID cuts



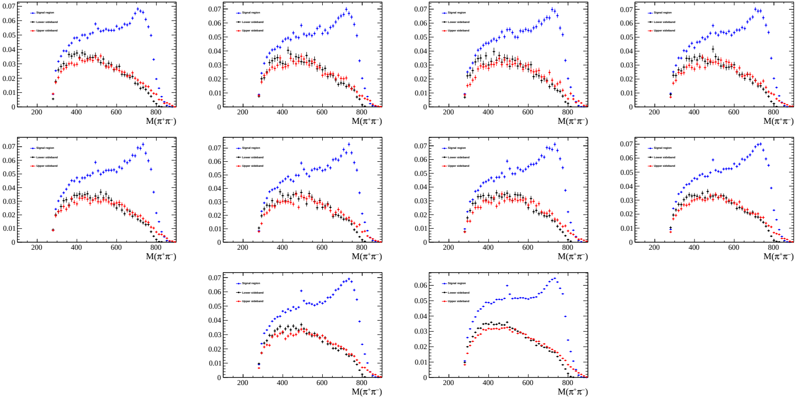
Physics backgrounds in $D^{*+} \to \pi^+ D^0 (\to K^- K^+ \pi^- \pi^+)$

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

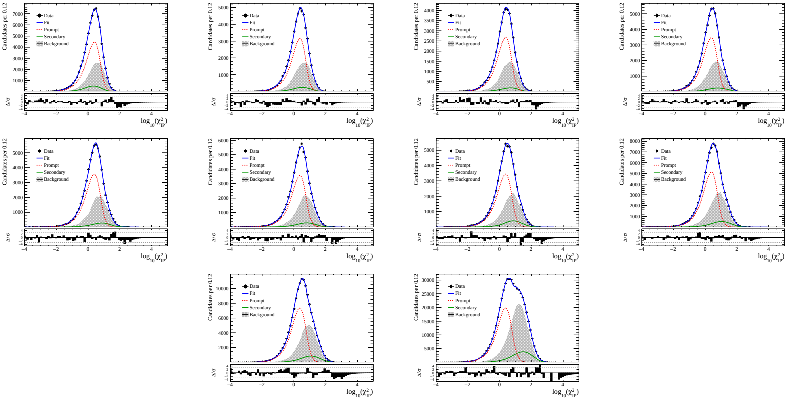


Physics backgrounds in $D^{*+} \to \pi^+ D^0 (\to K^- K^+ \pi^- \pi^+)$

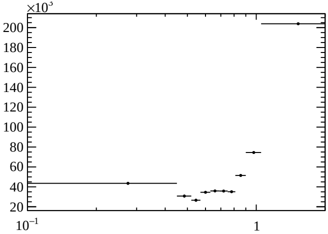
- K_S^0 background: $D^0 \to K^- K^+ K_S^0 (\to \pi^+ \pi^-)$
- Exist but not significant in the signal region



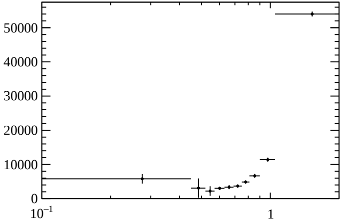
Fit results of D^0 data



Fit results of yields

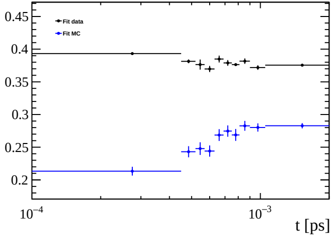


Prompt

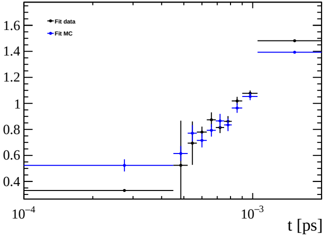


Secondary

Fit results of μ

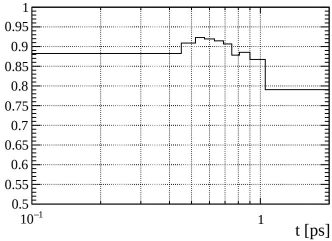


Prompt

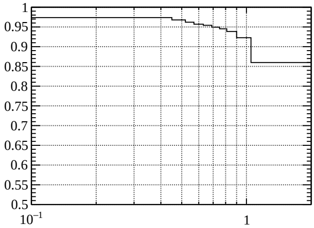


Secondary

Comparison of data and MC: prompt fraction

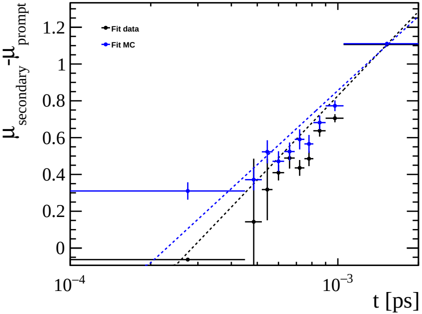


Data

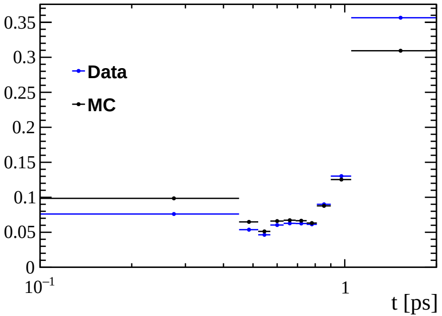


MC

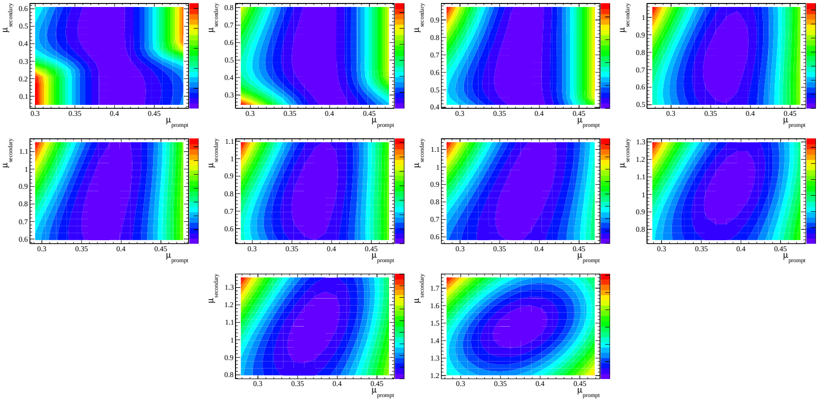
Comparison of data and MC: $\mu_{\text{prompt}} - \mu_{\text{secondary}}$



Comparison of data and MC: prompt yield

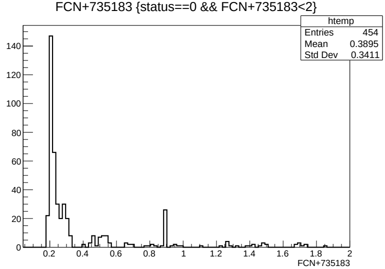


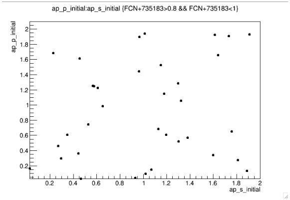
Likelihood scan of μ_{prompt} and $\mu_{\text{secondary}}$

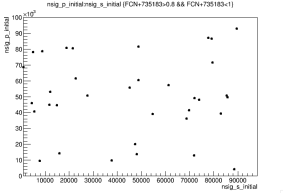


Effect of initial values

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



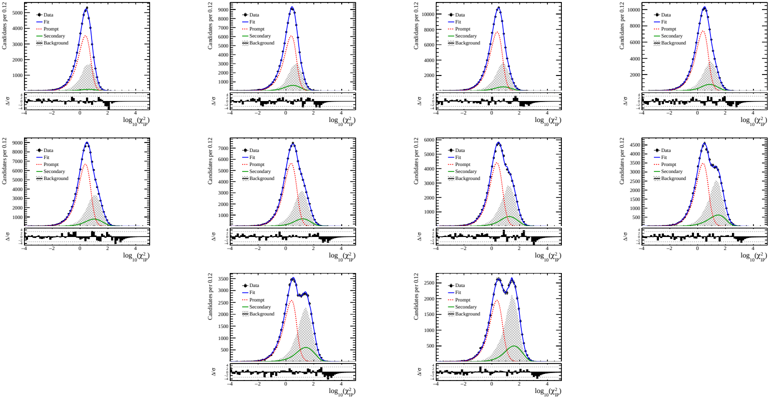




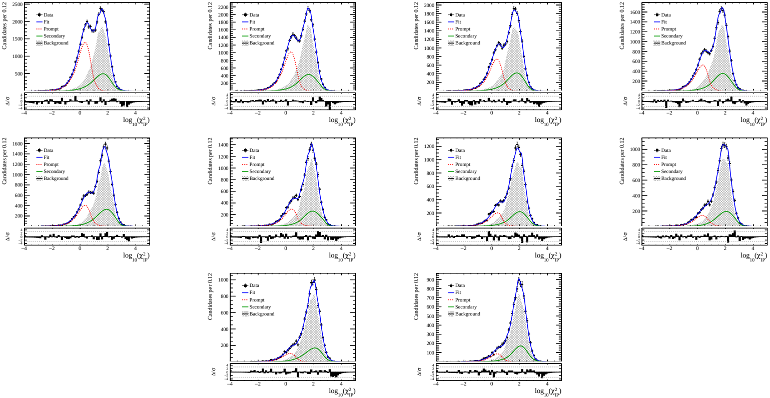
Fit D^0 data in even decay time bins

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

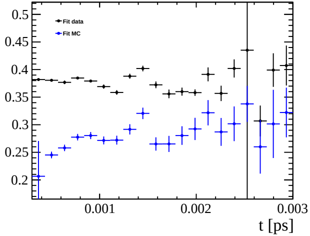
Fit results of D^0 data in even bins: bin 0-9



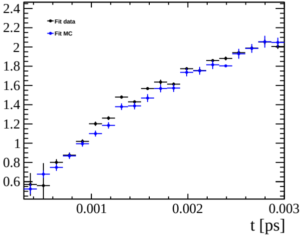
Fit results of D^0 data in even bins: 10-19



Fit results of μ in even bins

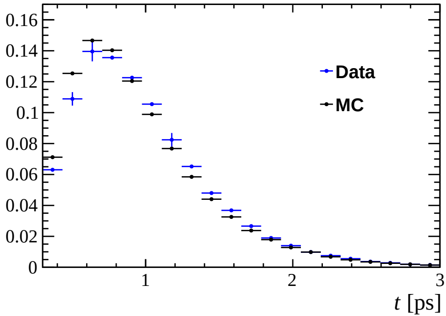


Prompt



Secondary

Comparison of prompt yield in even decay-time bins



Section 3

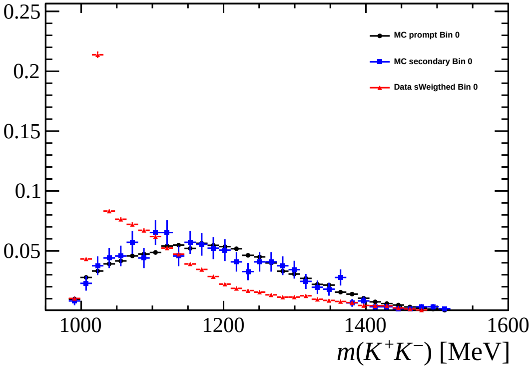
Efficiency estimation

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

- Five variables are needed to describe the $D^0 \to K^+K^-\pi^+\pi^-$ decay
- Choose Cabibbo-Maksymowicz (CM) variables
  - $m(K^+K^-)$
  - $m(\pi^+\pi^-)$
  - $\cos(\theta_{K^+}^{K^+K^-})$: 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
  - $\cos(\theta_{\pi^+}^{\pi^+\pi^-})$: 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 calcualted from mass fit
- Decay time binning scheme: equally-sized 20 decay time bins between 0.3 ps and 3 ps

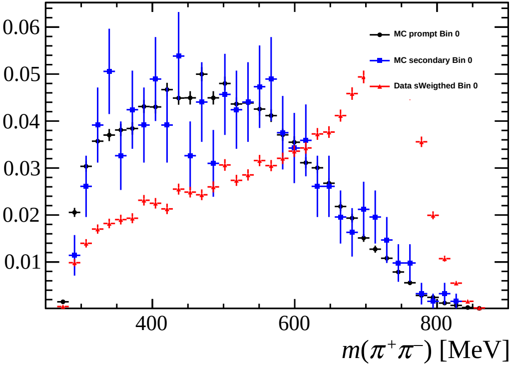
Comparison of $m(K^+K^-)$ in Bin 0

- No ϕ resonance in phase-space MC
- Prompt and secondary MC agree well



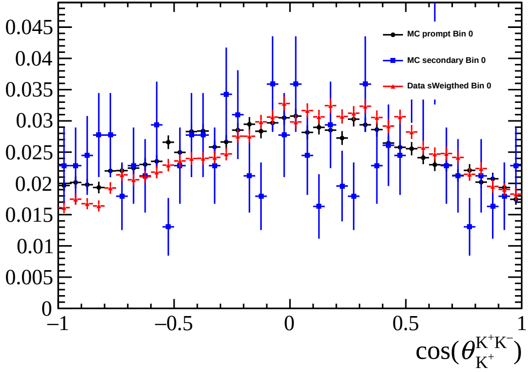
Comparison of $m(\pi^+\pi^-)$ in Bin 0

- No ρ resonance in phase-space MC
- Prompt and secondary MC agree well



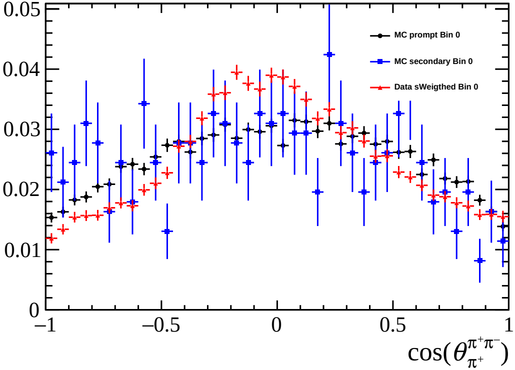
Comparison of $\cos(\theta_{K^+}^{K^+K^-})$ in Bin 0

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



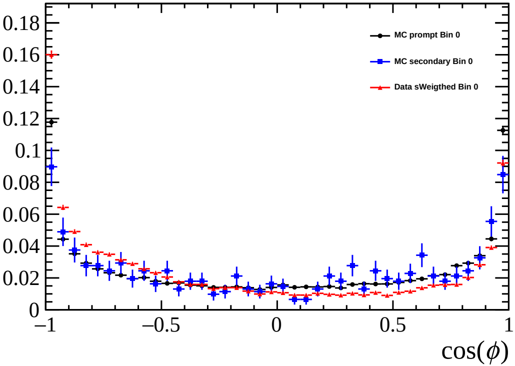
Comparison of $\cos(\theta_{\pi^+}^{\pi^+\pi^-})$ in Bin 0

- 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

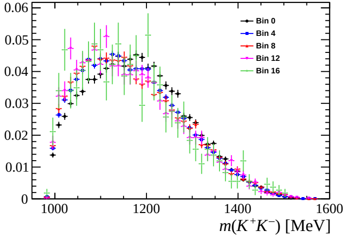


Decay time dependence of CM variables

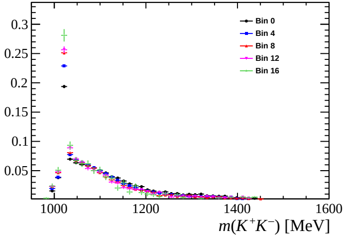
- Only the decay-time-dependent discrepency is relevant in this measurement

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

- Decay-time dependent



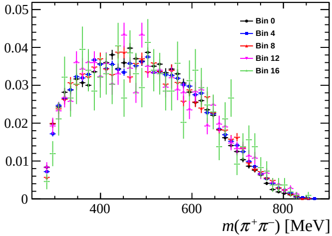
Prompt MC



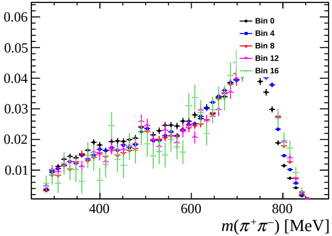
sWeighted data

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

- Weakly decay-time dependent



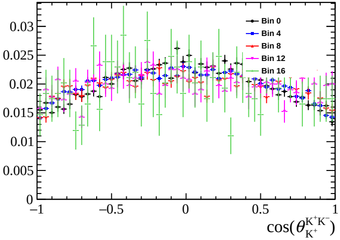
Prompt MC



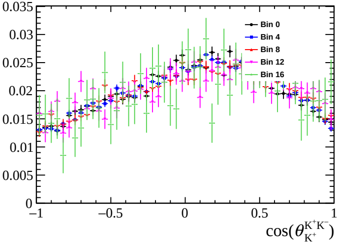
sWeighted data

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

- Decay-time independent



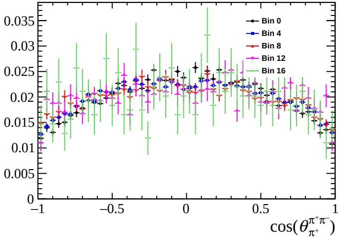
Prompt MC



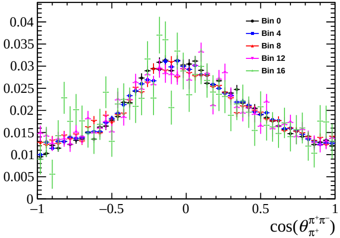
sWeighted data

Decay time dependence of $\cos(\theta^{\pi^+\pi^-}_{\pi^+})$

- Decay-time independent



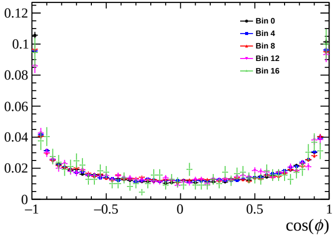
Prompt MC



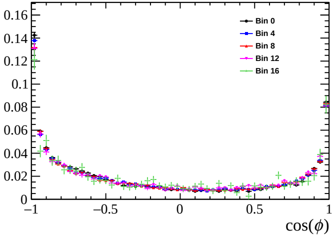
sWeighted data

Decay time dependence of cos(ϕ)

- Decay-time independent

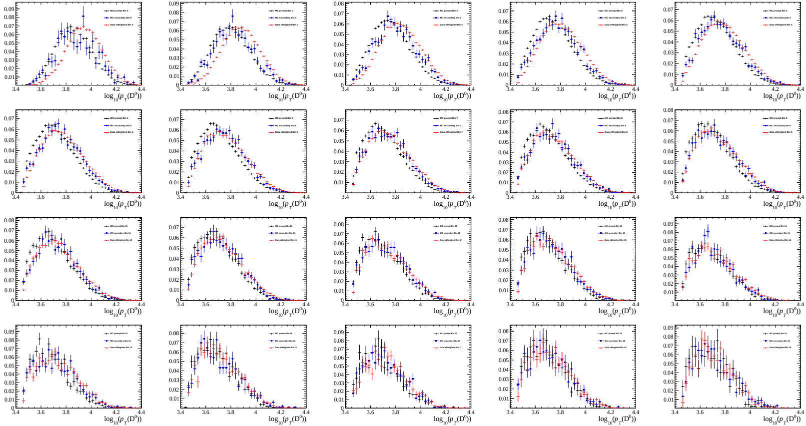


Prompt MC

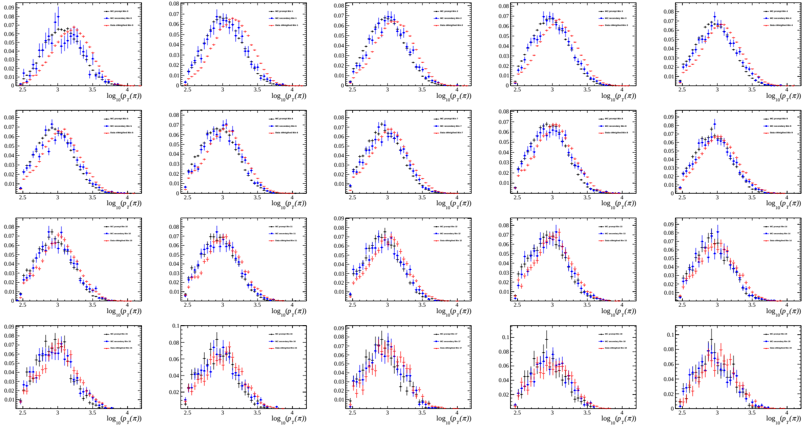


sWeighted data

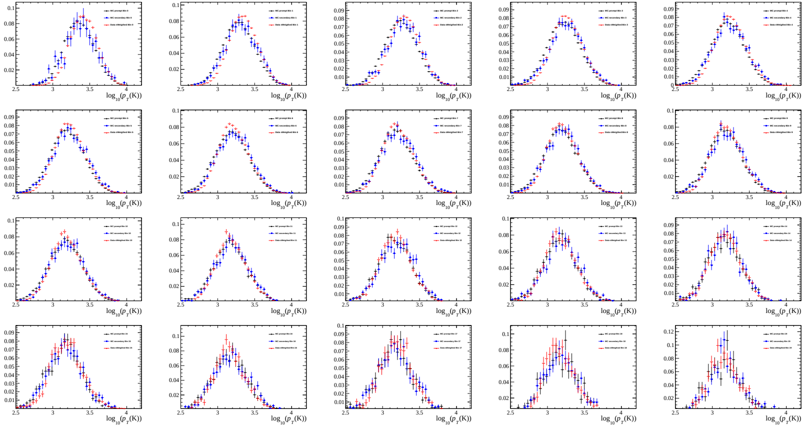
Comparison of p_{T} (D^0)



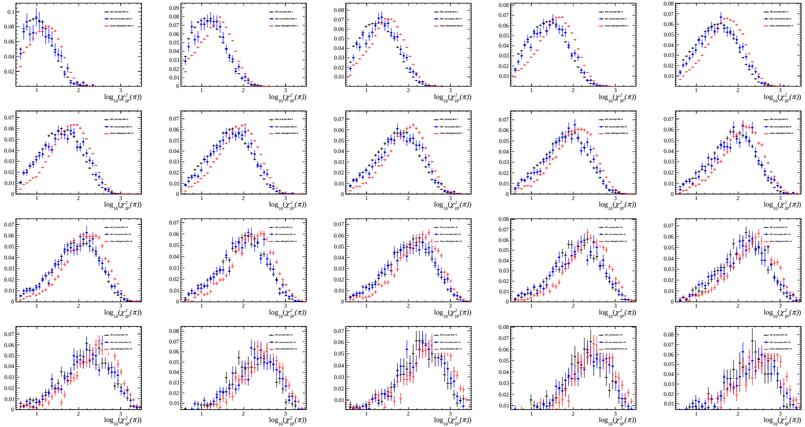
Comparison of p_{T} (π^+)



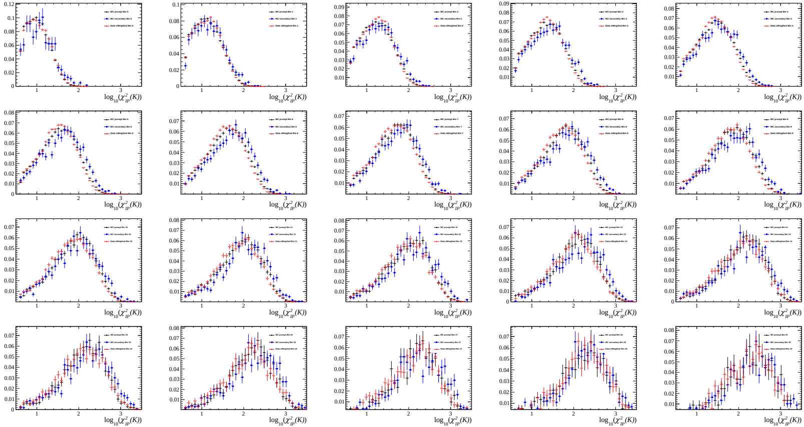
Comparison of p_{T} (K^{-})



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

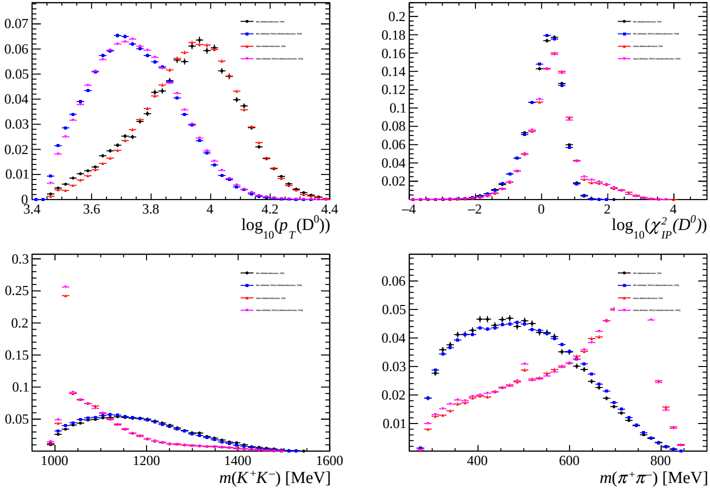


Comparison of $\log(\chi^2_{\mathrm{IP}}(K^-))$



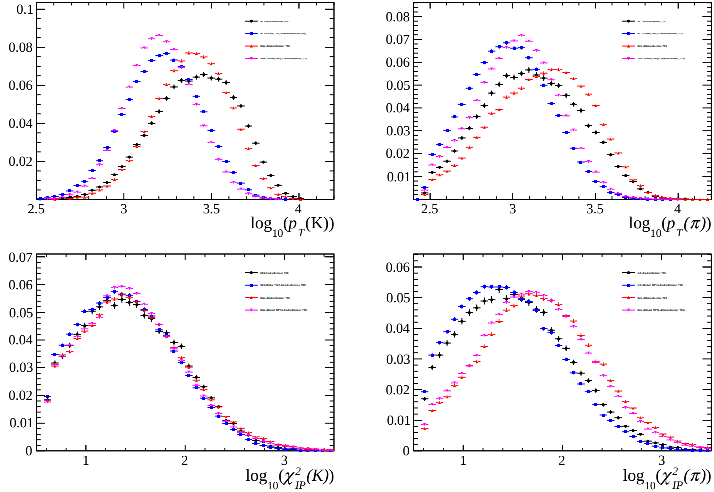
Comparison of samples with different L0 trigger

- `L0HadronDecision_TOS` v.s. `L0Global_TIS && !L0HadronDecision_TOS`
- D^0 p_{T} is quite different

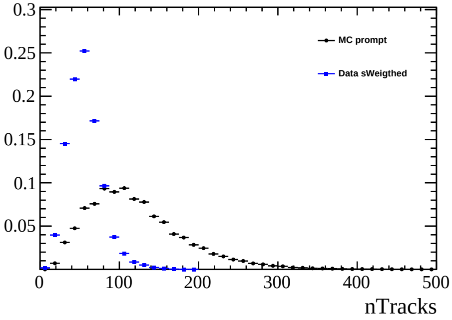


Comparison of samples with different L0 trigger (cont.)

- `L0HadronDecision_TOS` v.s. `L0Global_TIS && !L0HadronDecision_TOS`
- Daughters' p_{T} is quite different



Comparison of nTracks

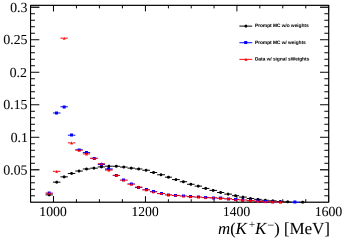


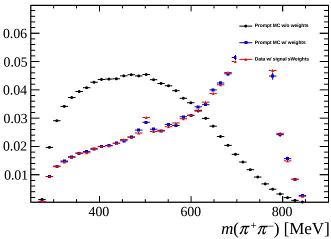
Corrections to MC by weighting

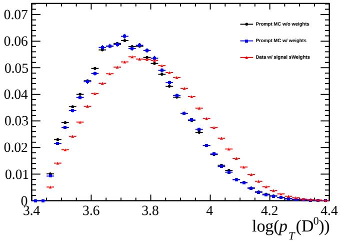
- Weights are calculated sequentially by comparing the decay-time-integrated MC prompt sample and sWeighted data
  - PID weights from PIDCalib
  - Based on PID weights, calculate $(m(K^+K^-), m(\pi^+\pi^-))$ weights
  - Based on PID and $(m(K^+K^-), m(\pi^+\pi^-))$ weights, calculate $p_{\mathrm{T}}(D^0)$ 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

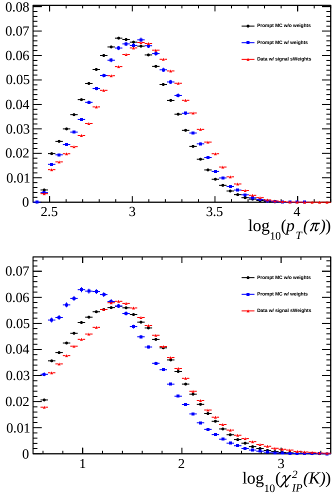






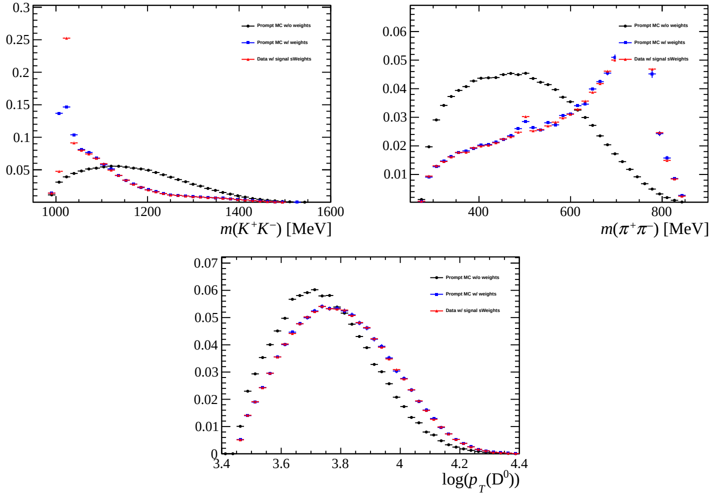
Comparison before and after corrections to MC (cont.)

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



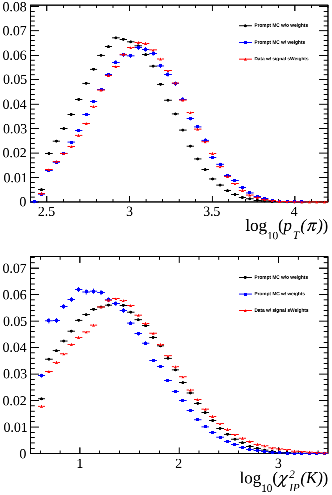
Comparison before and after corrections to MC

- Consider PID, $(m(K^+K^-), m(\pi^+\pi^-))$ and $p_{\mathrm{T}}(D^0)$ weights



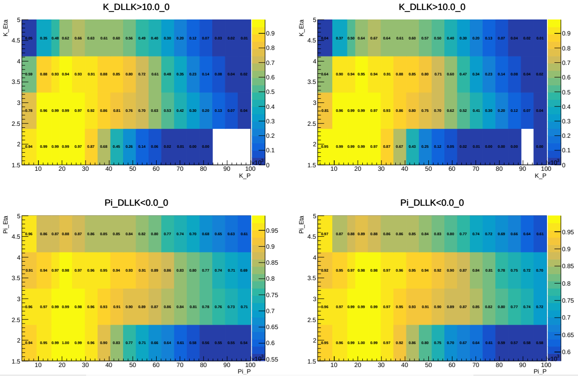
Comparison before and after corrections to MC (cont.)

- Consider PID, $(m(K^+K^-), m(\pi^+\pi^-))$ and $p_{\mathrm{T}}(D^0)$ 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
  - $P[\mathrm{GeV}/c]$:
    `[ 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 ]`
  - η: `[ 1.5, 2.375, 3.25, 4.125, 5.0 ]`
- Performance histograms: (left) Magdown and (right) MagUp



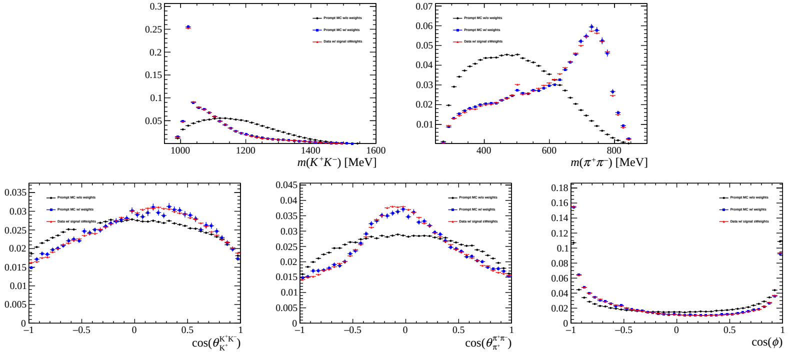
Reweighting with Boosted Decision Trees

- 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

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

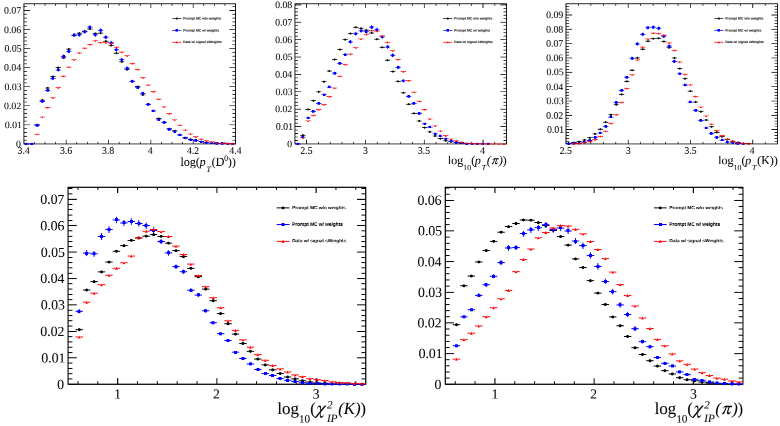
- Build unbiased predictions with folding algorithm
  - training data is splitted into n equal parts
  - train n reweighters, each one is trained using n-1 folds
  - predict each event with the reweighter that did not use it during training
- Here we assume the relevant distributions of the prompt and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

- Reweighting with `GBReweighter`

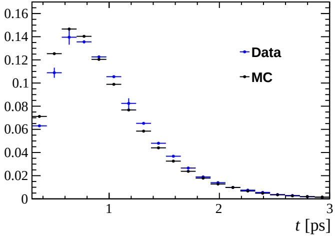


Comparison before and after corrections to MC (cont.)

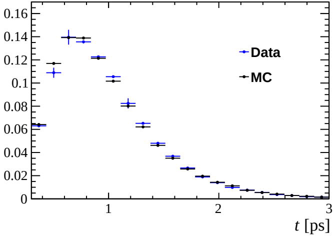
- Reweighting with `GBReweighter`



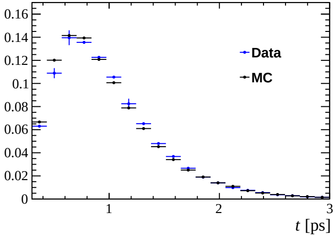
Decay time distribution with MC corrections



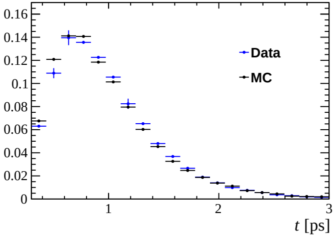
MC w/o corrections



MC w/ Dalitz weights



MC w/ PID and 2D-Dalitz weights

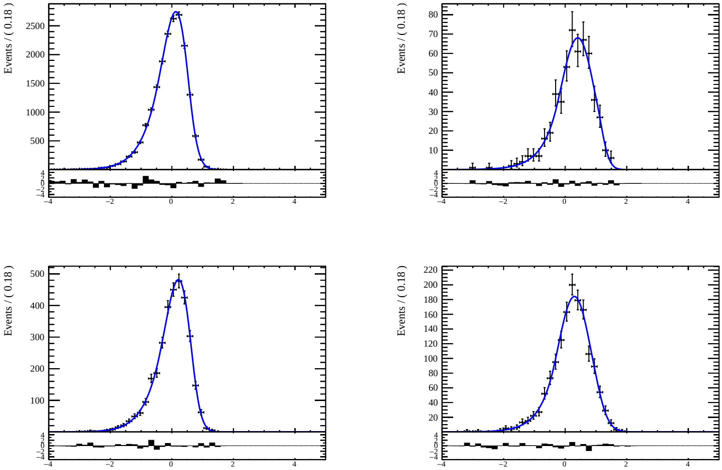


MC w/ PID and 5D-Dalitz weights

Backup

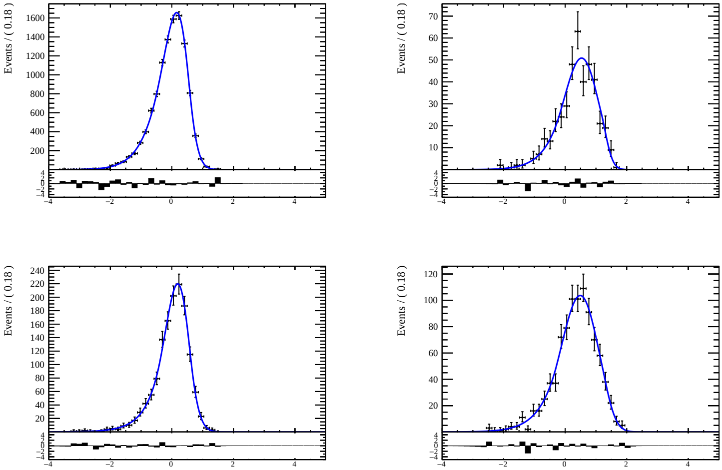
Fit with all parameters free: bin 0

- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



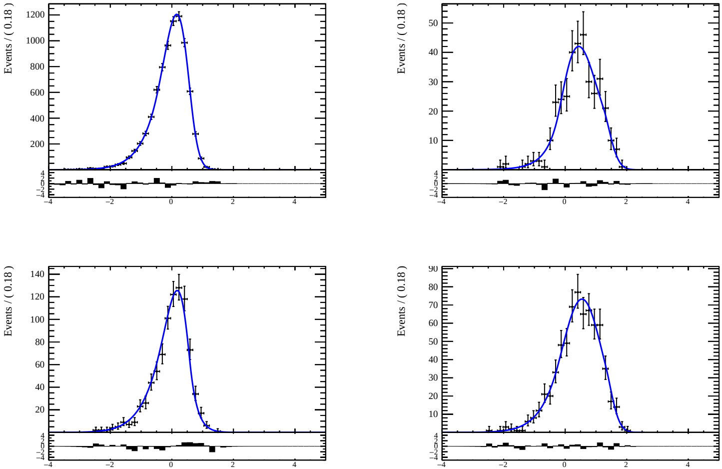
Fit with all parameters free: bin 1

- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



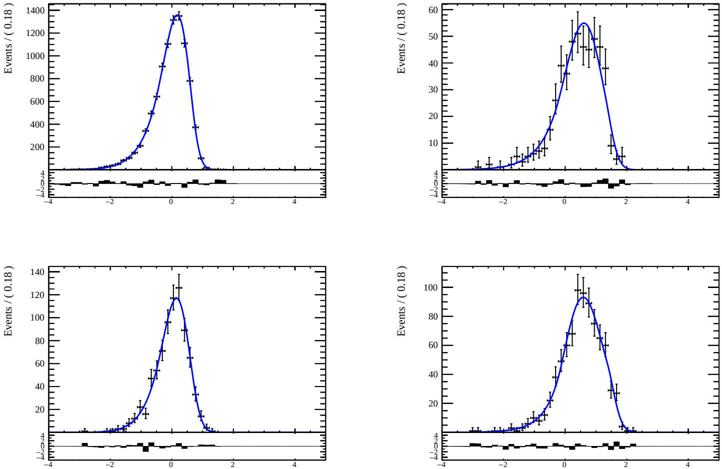
Fit with all parameters free: bin 2

- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



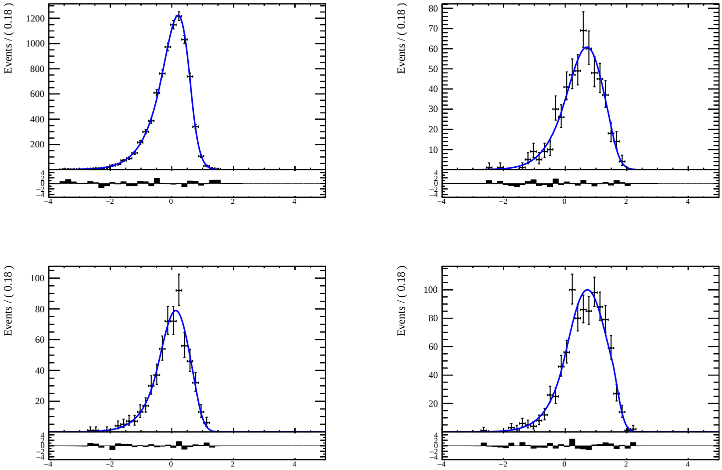
Fit with all parameters free: bin 3

- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



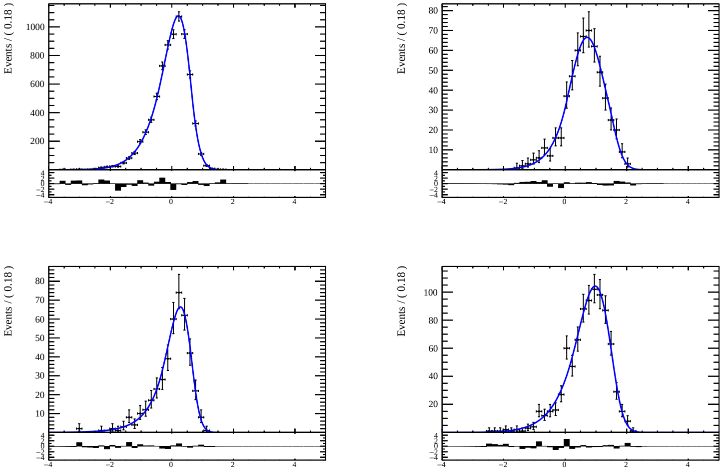
Fit with all parameters free: bin 4

- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



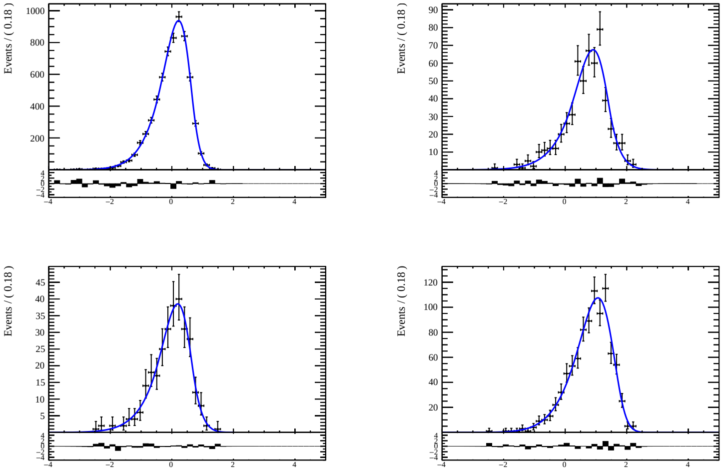
Fit with all parameters free: bin 5

- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



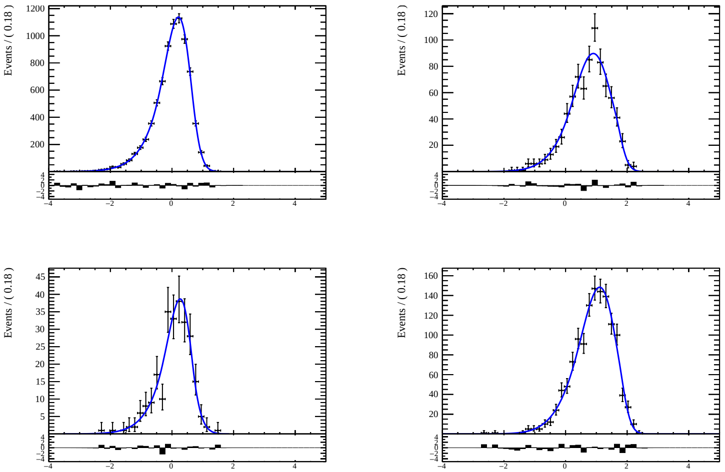
Fit with all parameters free: bin 6

- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



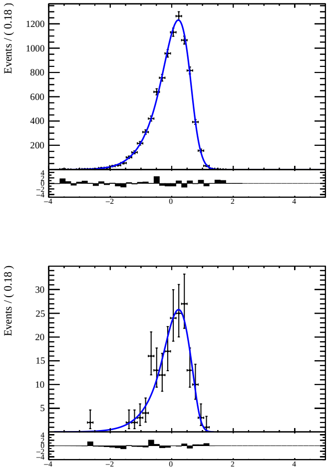
Fit with all parameters free: bin 7

- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



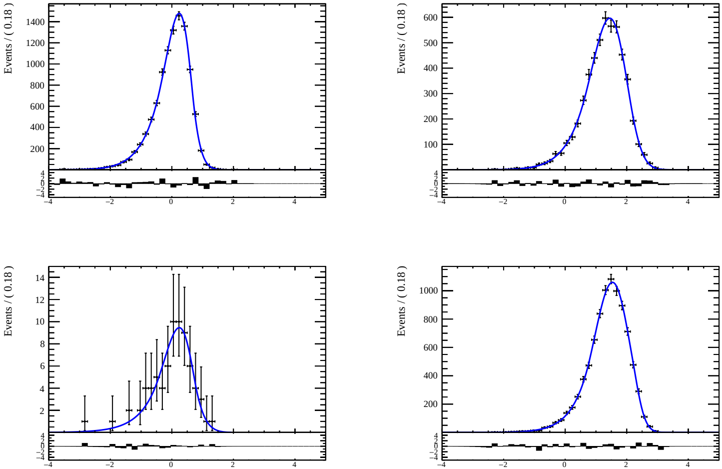
Fit with all parameters free: bin 8

- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



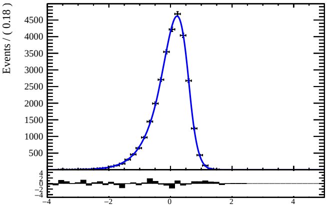
Fit with all parameters free: bin 9

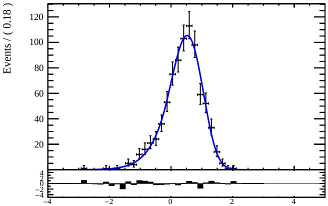
- (left) Prompt and (right) secondary for (top) Ω_c^0 and (bottom) Ξ_c^0



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

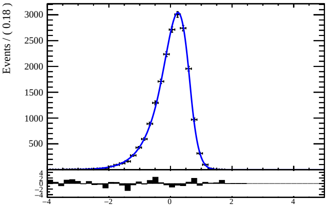
- (left) Prompt and (right) secondary

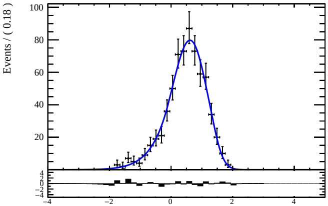




Fit D^0 MC with all parameters free: bin 1

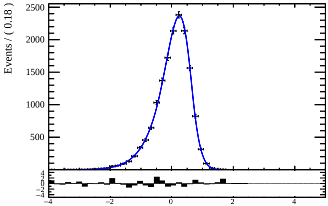
- (left) Prompt and (right) secondary

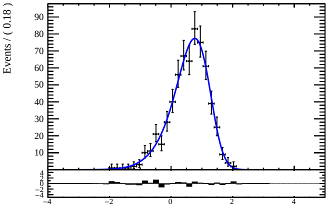




Fit D^0 MC with all parameters free: bin 2

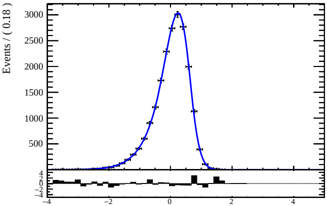
- (left) Prompt and (right) secondary

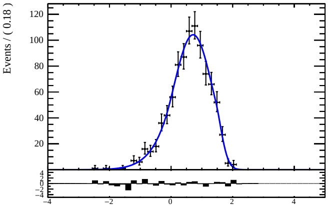




Fit D^0 MC with all parameters free: bin 3

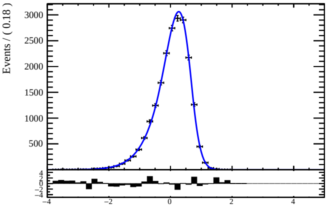
- (left) Prompt and (right) secondary

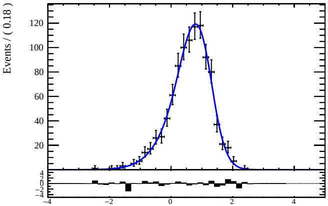




Fit D^0 MC with all parameters free: bin 4

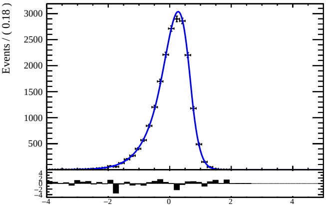
- (left) Prompt and (right) secondary

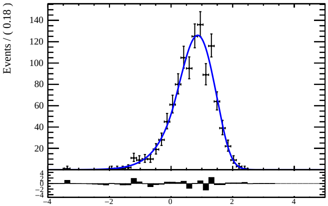




Fit D^0 MC with all parameters free: bin 5

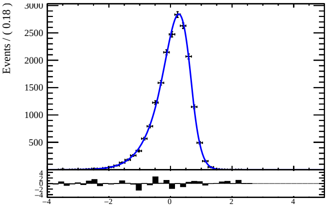
- (left) Prompt and (right) secondary

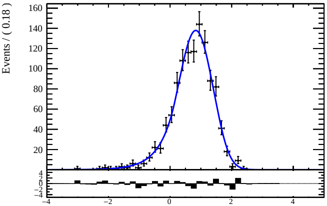




Fit D^0 MC with all parameters free: bin 6

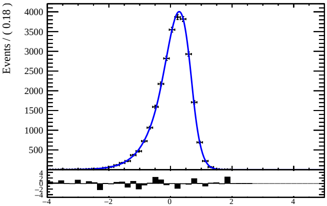
- (left) Prompt and (right) secondary





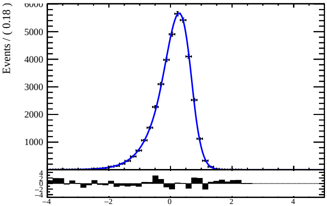
Fit D^0 MC with all parameters free: bin 7

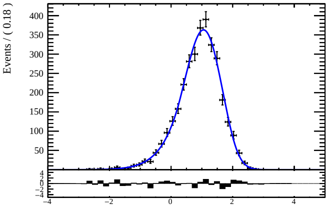
- (left) Prompt and (right) secondary



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

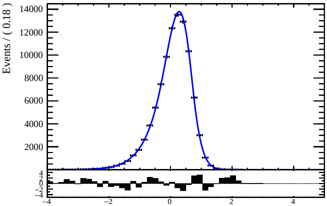
- (left) Prompt and (right) secondary

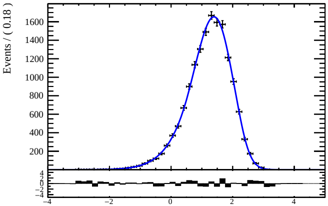




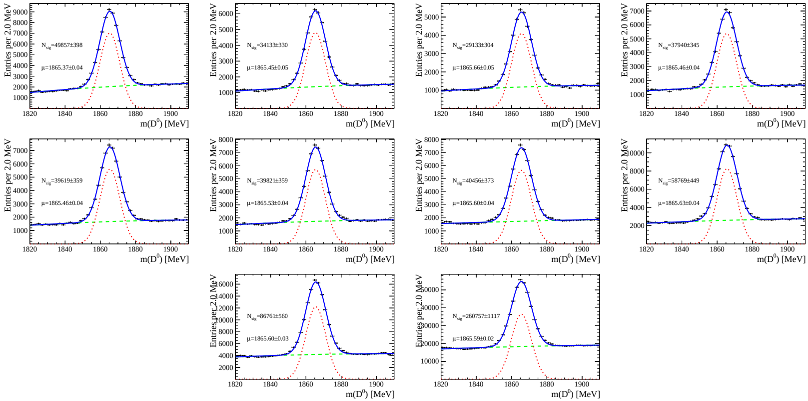
Fit D^0 MC with all parameters free: bin 9

- (left) Prompt and (right) secondary

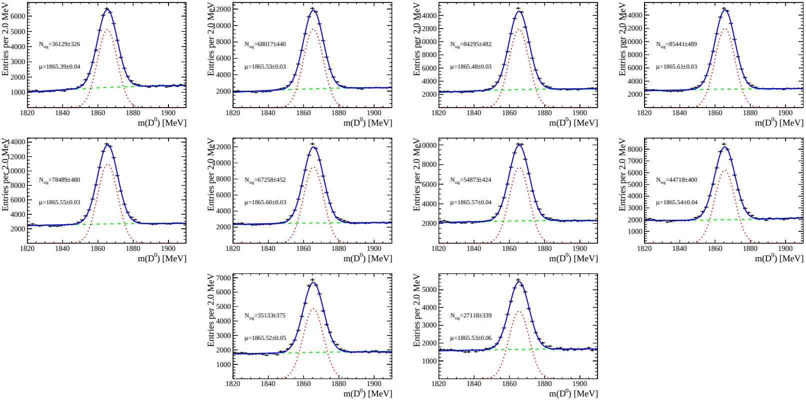




Fit mass of D^0 data



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



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