High-energy π^0 efficiency systematic uncertainty

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Overview

Obtain π^0 reconstruction efficiency systematic uncertainty for high-energy π^0's (using π^0 selection of $B^0 \to \pi^0\pi^0$ analysis).

Use $D^* \to D\pi$ decays (updated method wrt https://indico.belle2.org/event/6306/contributions/33313/attachments/15615/23408/NewPi0Efficiency_Charmless.pdf).

Koga-San has already done a similar work (π^0 efficiency as a function of momentum): https://docs.belle2.org/record/2096/files/ver5-1.pdf.

Recap on π^0 efficiency determination

π^0 reconstruction efficiency may be not well reproduced in MC.

Measure and compare π^0 efficiency in data and MC using ratio of yields of the topologically similar "π^0 channel" and "track-only" control channels, assuming that the joint efficiency for n particle factorizes:

$$\varepsilon(\pi^0) = \frac{\text{Yield}(D^0 \to K^-\pi^+\pi^0)}{\text{Yield}(D^0 \to K^-\pi^+)} \frac{\mathscr{B}(D^0 \to K^-\pi^+)}{\mathscr{B}(D^0 \to K^-\pi^+\pi^0)\mathscr{B}(\pi^0 \to \gamma\gamma)}$$

Efficiency uncertainty is due to yield uncertainties (from the fit) and *BF* uncertainties (from the PDG).

Ratio btw efficiencies $\varepsilon_{\text{MC}}(\pi^0)/\varepsilon_{Data}(\pi^0)$ determines an efficiency correction; its uncertainty determines a systematic uncertainty.

$$\frac{\varepsilon_{\text{MC}}}{\varepsilon_{Data}} = R \pm \sigma_R$$

Selection and fit strategy

$D^{*+} \to D^0(K^-\pi^+)\pi^+$ cut values are selected in order to match the $D^{*+} \to D^0(K^-\pi^+\pi^0)\pi^+$ signal-efficiency (avoid "artificial" modification of π^0 efficiency).

Selection:

$D^{*+} \to D^0(K^-\pi^+\pi^0)\pi^+$		$D^{*+} \to D^0(K^-\pi^+)\pi^+$
1.75 < $m(K^-\pi^+\pi^0)$ < 2 GeV/c²		1.8 < $m(K^-\pi^+)$ < 1.92 GeV/c²
144.8 < Δm < 146.1 MeV/c²	same sig. eff.	144.7 < Δm < 146.7 MeV/c²
$p(D^0)_{CMS}$ > 2.5 GeV/c		$p(D^0)_{CMS}$ > 2.17 GeV/c
K_kaonID > 0.1		K_kaonID > 0.047
π^0 selections: same as in $B^0 \to \pi^0\pi^0$ (photonMVA is applied)		
Bkg under peak: 3.6%		Bkg under peak: 2.2%

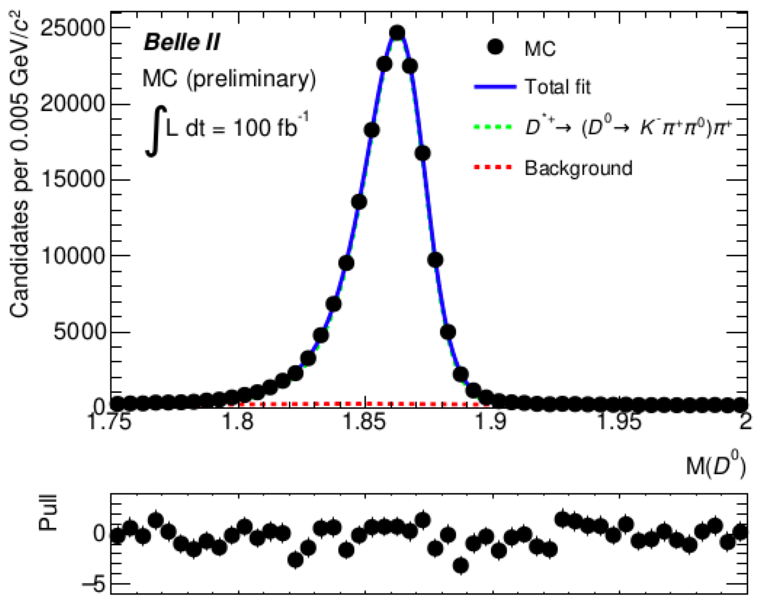
Fit strategy:

	Signal	Background
D->Kpi	2xJohnson	Exp
D->Kpipi0	2xJohnson	Pol2+Gauss

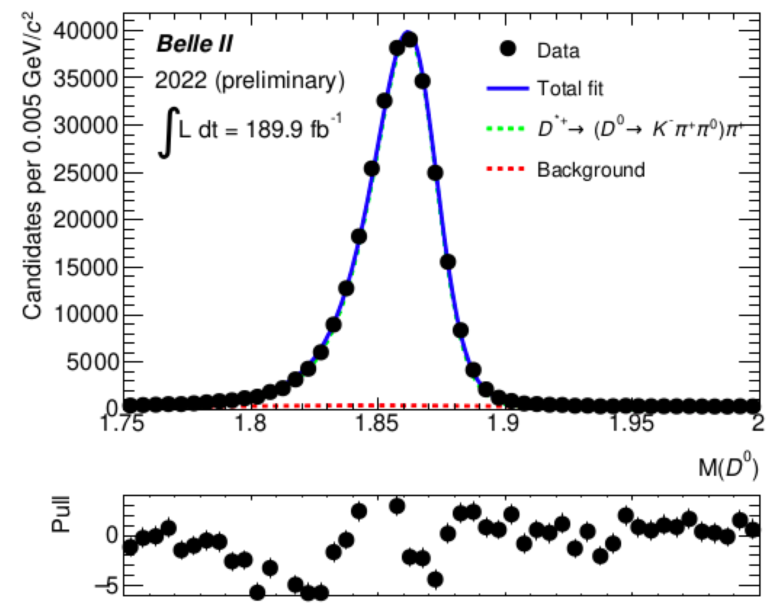
Fix signal shape from MC with additional mean shift and fudge factor.

Fit results

Numerator
$D^0 \to K^- \pi^+ \pi^0$

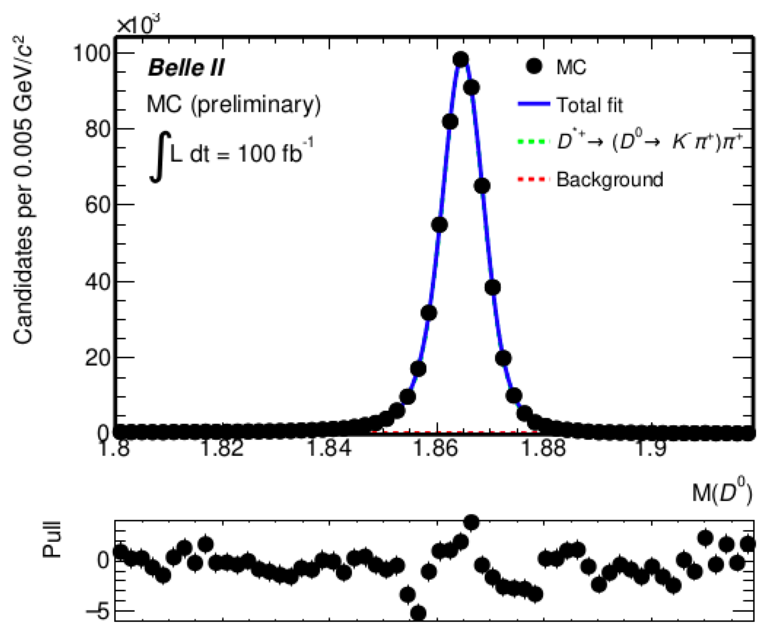


Signal yield = 167090 ± 431

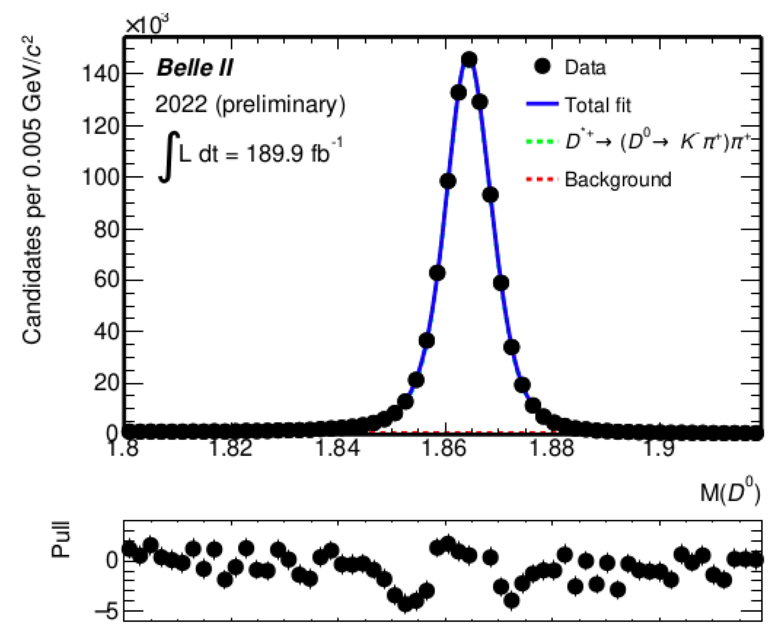


Signal yield = 283290 ± 561

Denominator
$D^0 \to K^- \pi^+$



Signal yield = 558170 ± 771



Signal yield = 912880 ± 995

$$\frac{\varepsilon_{\text{Data}}}{\varepsilon_{MC}} = R \pm \sigma_R = 1.036 \pm 0.037$$

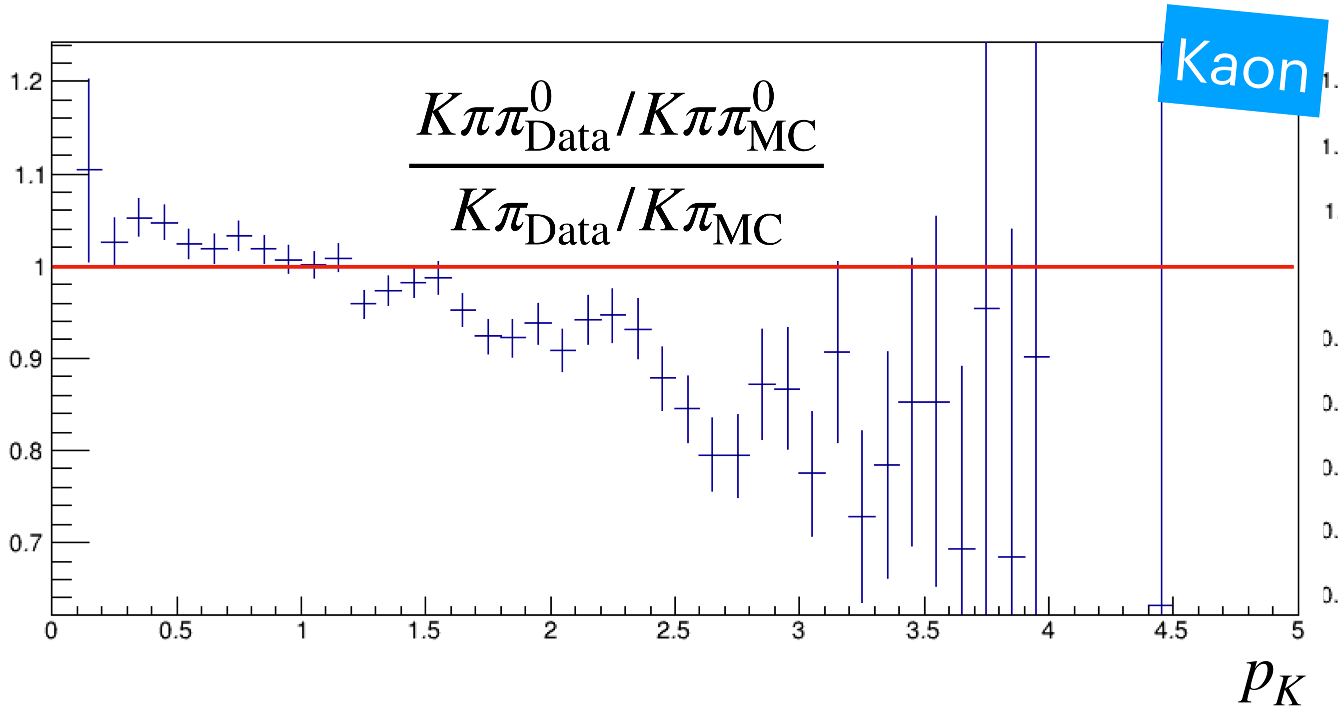
Uncertainty coming from fit and *BF* uncertainty (in data)

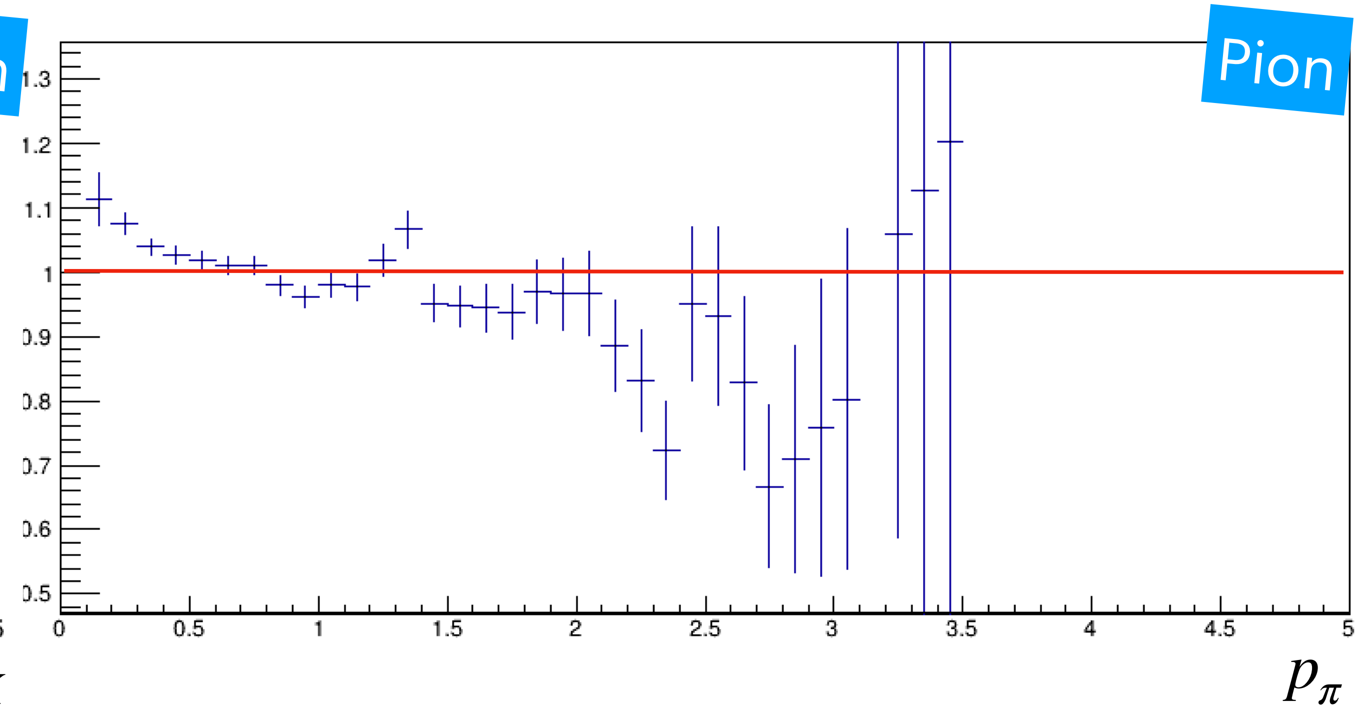
Systematics

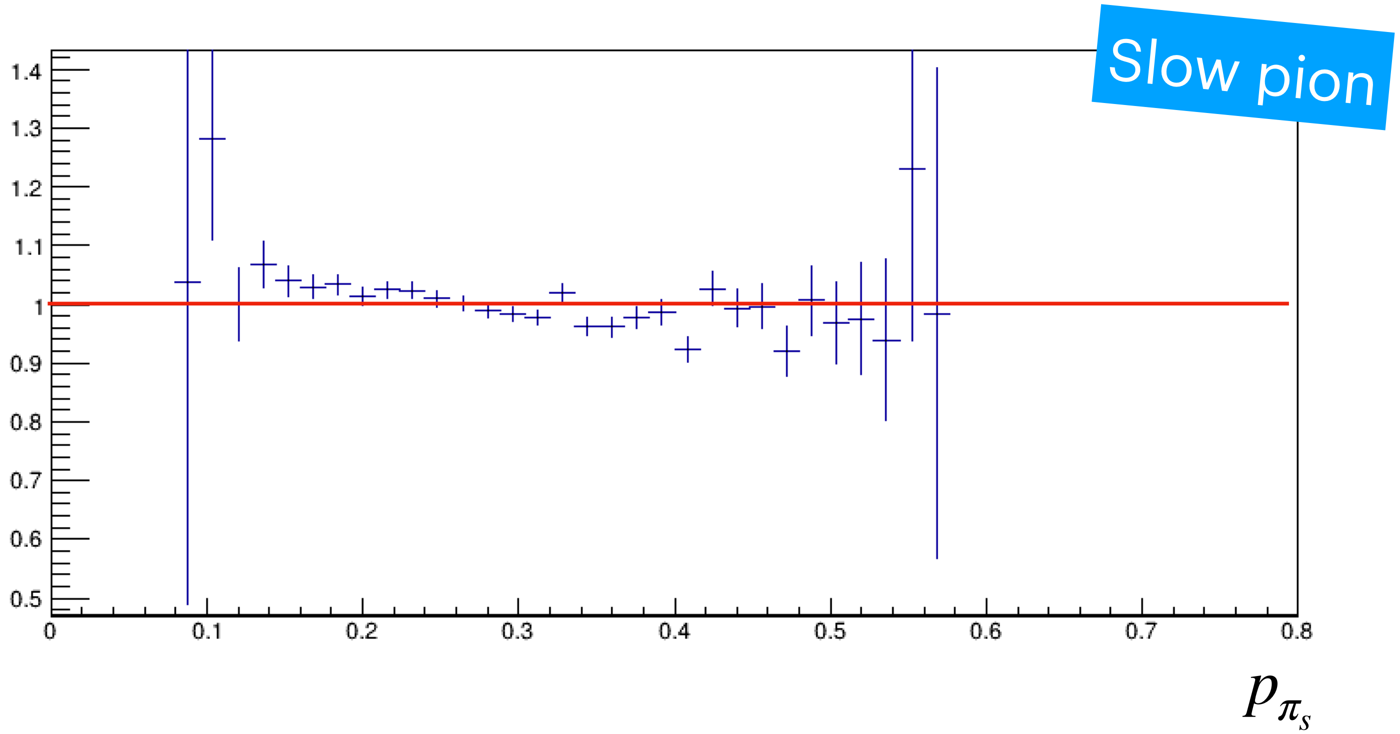
$$\varepsilon(\pi^0)\frac{\varepsilon(\mathrm{PID, Tracks, Others})_{D^0\to K^-\pi^+\pi^0}}{\varepsilon(\mathrm{PID, Tracks, Others})_{D^0\to K^-\pi^+}} = \frac{\mathrm{Yield}(D^0 \to K^-\pi^+\pi^0)}{\mathrm{Yield}(D^0 \to K^-\pi^+)} \frac{\mathscr{B}(D^0 \to K^-\pi^+)}{\mathscr{B}(D^0 \to K^-\pi^+\pi^0)\mathscr{B}(\pi^0 \to \gamma\gamma)}$$

Track efficiencies

Possible data-MC differences in track reconstruction efficiencies.







Assign systematic uncertainty of 0.3% for each K and π (tracking).

No systematic for the π_{slow}.

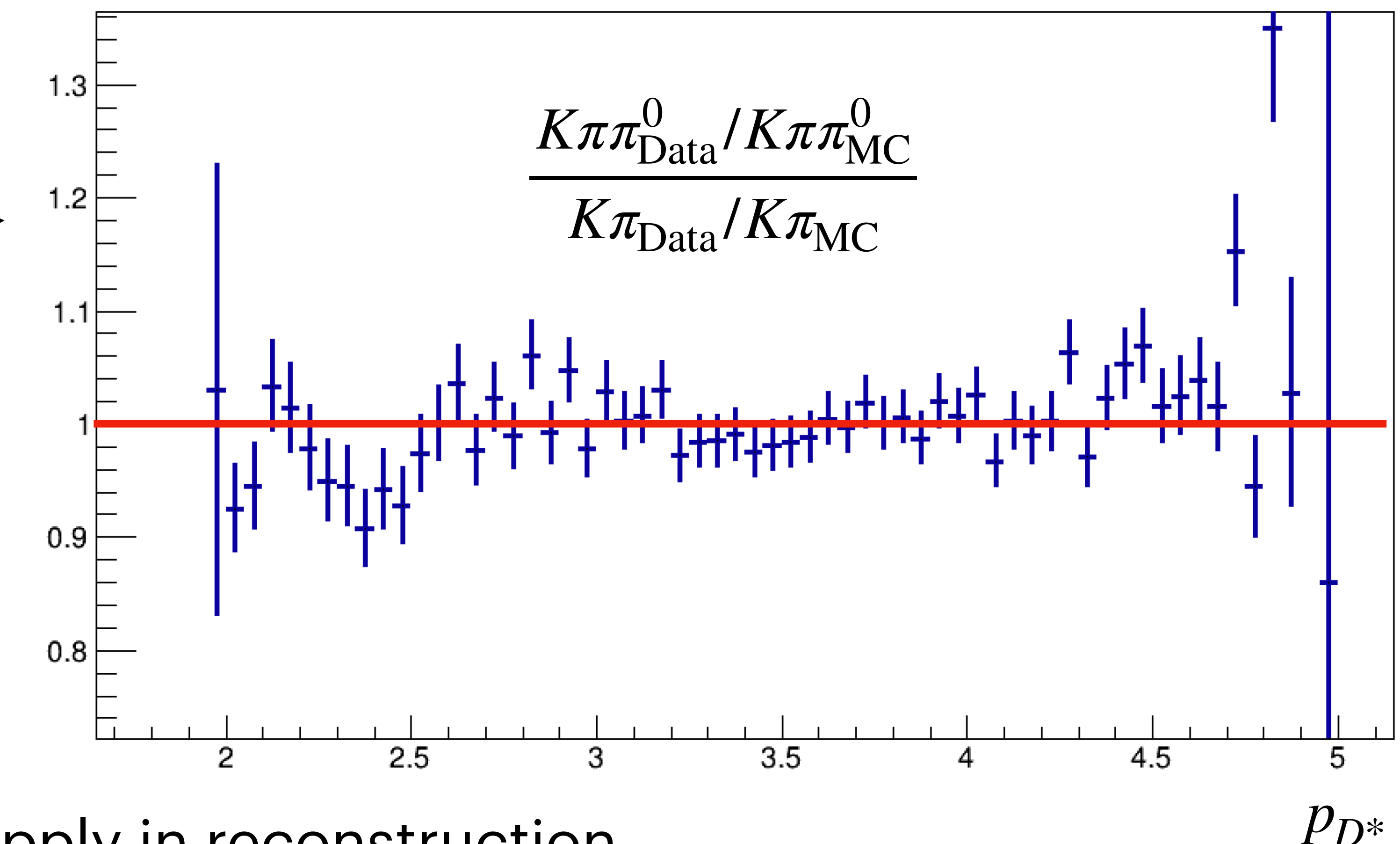
Track efficiency systematic: 0.85%

Dalitz systematic

Revisit our choice of assigning a systematic due to data/MC discrepancies in Dalitz model. This because we don't apply a selection on it → no differences in efficiency at first order.

Consider biases only related to momenta of tracks (already checked) and $p(D^*)$ (on which we cut).

Good agreement with 1: no systematic needed.



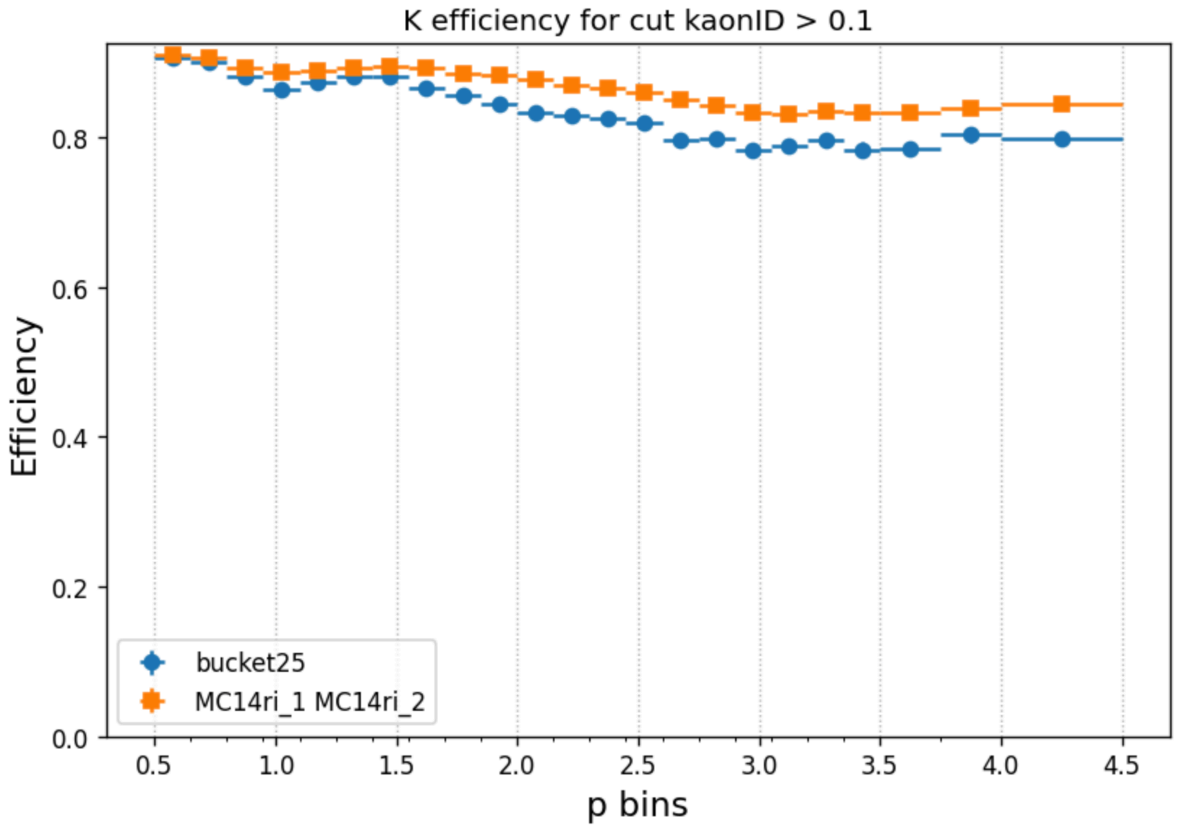
Note: we apply in reconstruction the cut p(D*) > 2 GeV

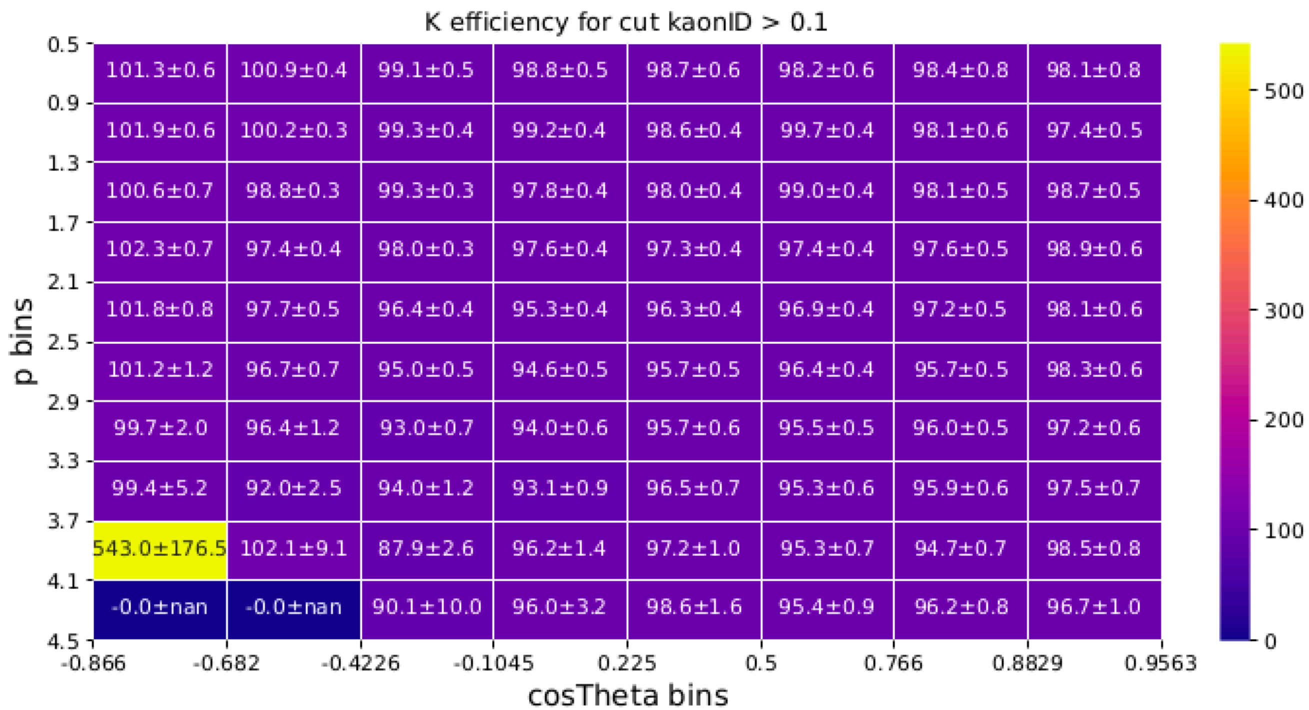
PID systematic

Possible data/MC discrepancies in PID distributions.

Use “systematic_correction_framework” to obtain $\frac{\varepsilon_{\mathrm{Data}}}{\varepsilon_{\mathrm{MC}}}$ in bins of kaon momentum and cosTheta.

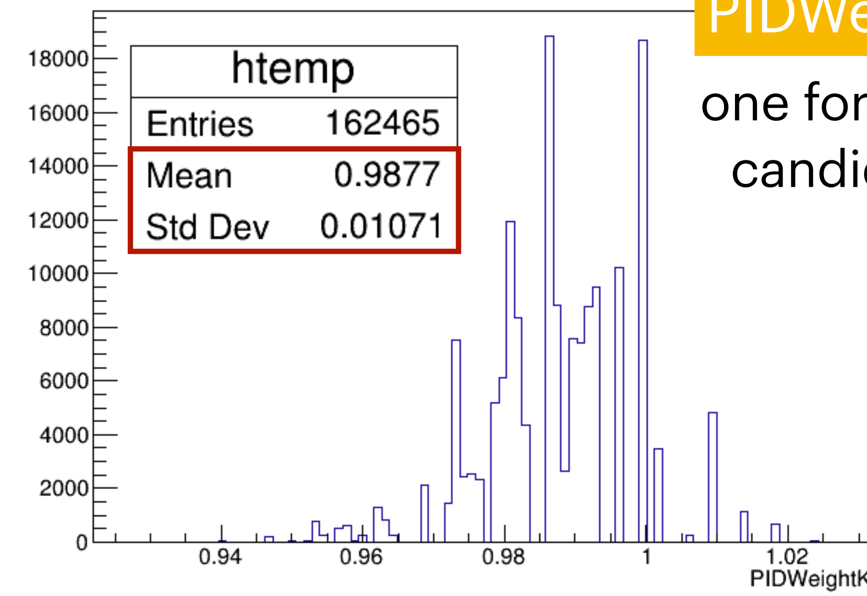
Use “pidvar framework” to obtain weight for each candidate.





PID systematic

Variables saved in the ntuple by the framework:
- PIDWeight: main PID correction weight ($\frac{\varepsilon_{\text{Data}}}{\varepsilon_{\text{MC}}}$)
- PIDWeight_<N>: variations calculated from stat. and sys. uncertainties



PIDWeight

one for each candidate

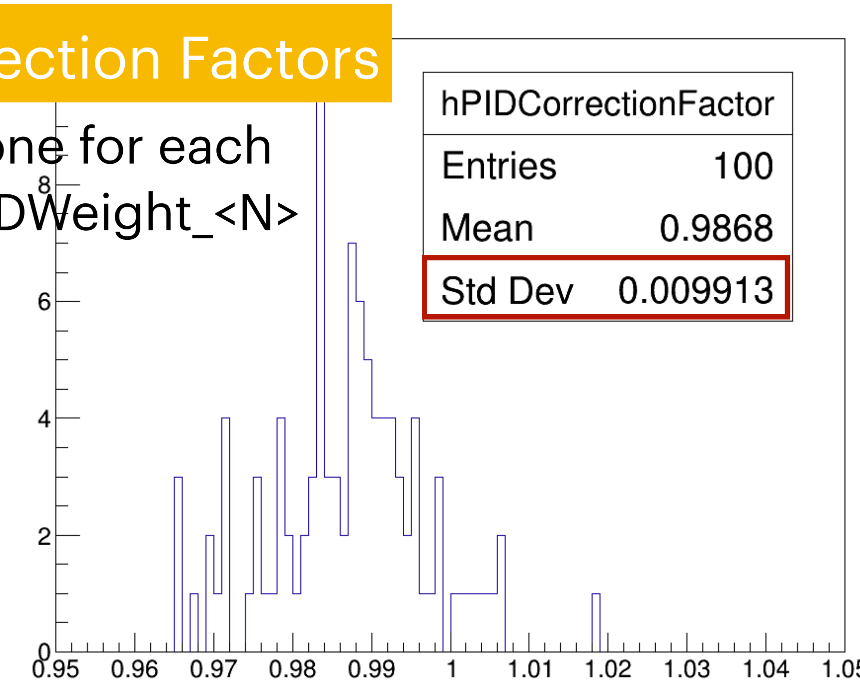
$$\epsilon^{\text{variation}_i}_{\frac{\text{Data}}{\text{MC}}} = \epsilon^{\text{nom}}_{\frac{\text{Data}}{\text{MC}}} + \mathcal{N}\left(\mathbf{0}, \boldsymbol{\sigma}^{\text{T}}_{\text{stat}}\rho_{\text{stat}}\boldsymbol{\sigma}_{\text{stat}}\right)_i + \mathcal{N}\left(\mathbf{0}, \boldsymbol{\sigma}^{\text{T}}_{\text{sys}}\rho_{\text{sys}}\boldsymbol{\sigma}_{\text{sys}}\right)_i, \quad i \in \{0, \cdots N_{\text{variations}}\}$$

https://indico.belle2.org/event/3899/contributions/23592/attachments/11963/18239/pid_systematics.pdf

PID systematic:
- calculate mean value for each PIDWeight_<N> (that is the correction factor);
- plot distribution of means;
- take as uncertainty the standard deviation of this distribution.

Correction Factors

one for each PIDWeight_<N>



$$\frac{\varepsilon_{\text{Data}}}{\varepsilon_{\text{MC}}}\Big|^{K\pi\pi^0}_{PID} = 98.77 \pm 0.99\ \%$$

$$\frac{\varepsilon_{\text{Data}}}{\varepsilon_{\text{MC}}}\Big|^{K\pi}_{PID} = 98.12 \pm 0.37\ \%$$

PID systematic

Include this uncertainty directly in the formula.

$$\varepsilon(\pi^0)_{\mathrm{MC}} = \frac{\mathrm{Yield}(D^0 \to K^-\pi^+\pi^0)_{\mathrm{MC}} \cdot \frac{\varepsilon_{\mathrm{Data}}}{\varepsilon_{\mathrm{MC}}}\Big|^{K\pi\pi^0}_{PID}}{\mathrm{Yield}(D^0 \to K^-\pi^+)_{\mathrm{MC}} \cdot \frac{\varepsilon_{\mathrm{Data}}}{\varepsilon_{\mathrm{MC}}}\Big|^{K\pi}_{PID}} \frac{\mathcal{B}(D^0 \to K^-\pi^+)}{\mathcal{B}(D^0 \to K^-\pi^+\pi^0)\mathcal{B}(\pi^0 \to \gamma\gamma)}$$

these factors have an uncertainty

Old value w/o PID corrections

$$\frac{\varepsilon_{\mathrm{Data}}}{\varepsilon_{MC}} = R \pm \sigma_R = 1.036 \pm 0.037$$

→ Uncertainty coming from fit and *BF* uncertainty (in data)

New value w/ PID corrections

$$\frac{\varepsilon_{\mathrm{Data}}}{\varepsilon_{MC}} = R \pm \sigma_R = 1.029 \pm 0.037$$

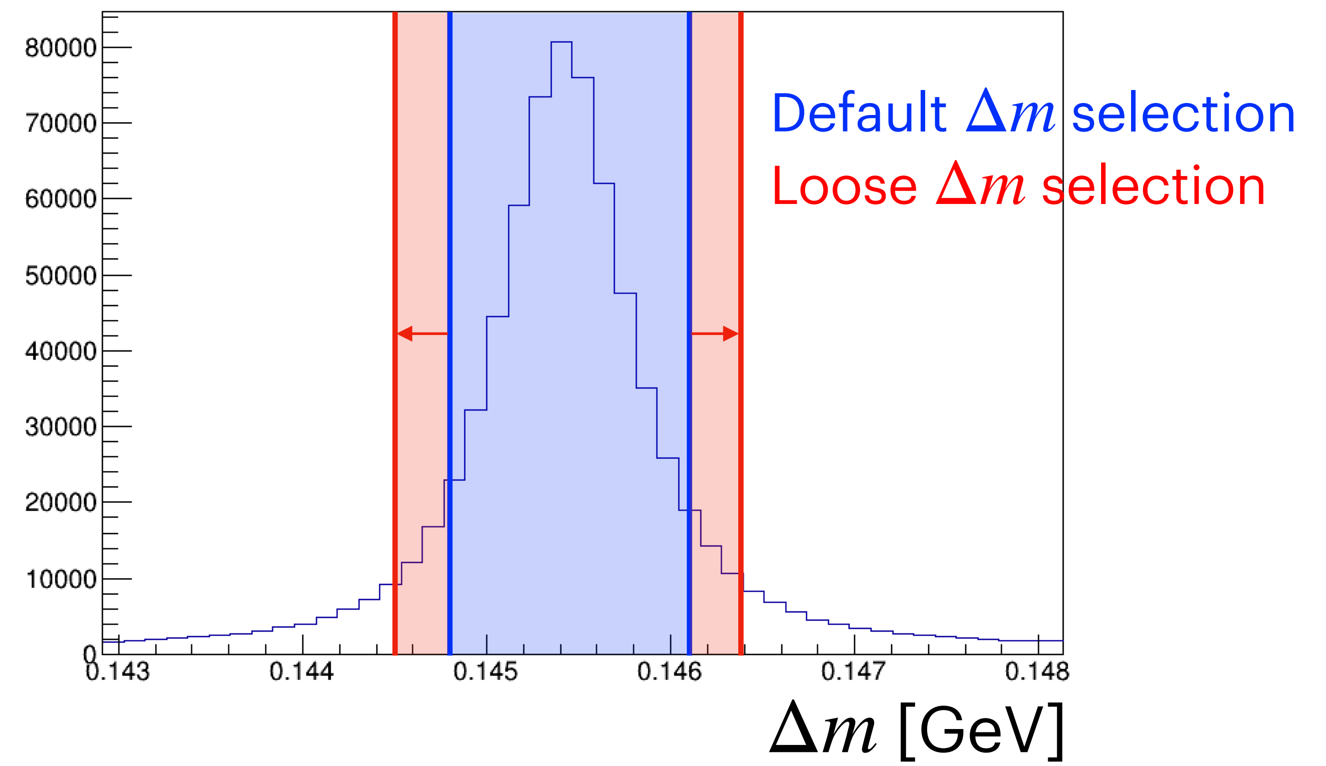
→ Uncertainty coming from fit, *BF* uncertainty, and PID corrections

Other systematics

Assumptions in fit models:

- repeat study by using alternative signal model. Compare measured ratio with default value and take difference as systematic. Systematic uncertainty: 0.1%.
- repeat study by varying background. Compare measured ratio with default value and take difference as systematic. Systematic uncertainty: 0.5%.

Residual data/MC discrepancies (e.g. Δm) can bias the result: repeat fits after loosening the Δm selection (enlarge the window by ±20%).
Compare measured ratio with default value and take difference as systematic.
Systematic uncertainty: 1%.



Summary

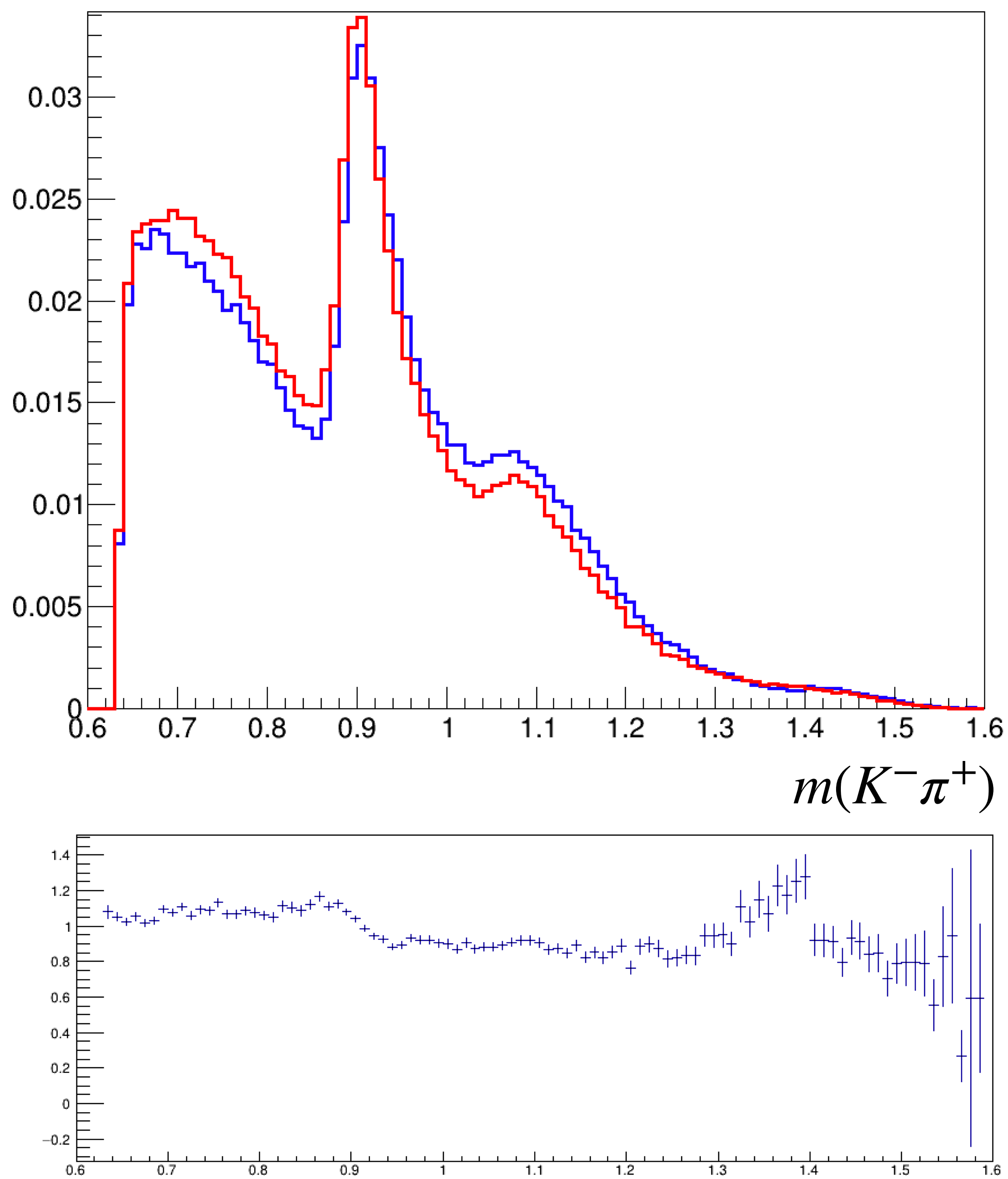
Obtain π^0 reconstruction efficiency systematic uncertainty for high-energy π^0's ($B^0 \to \pi^0\pi^0$ selections) using $D^* \to D\pi$ decays.

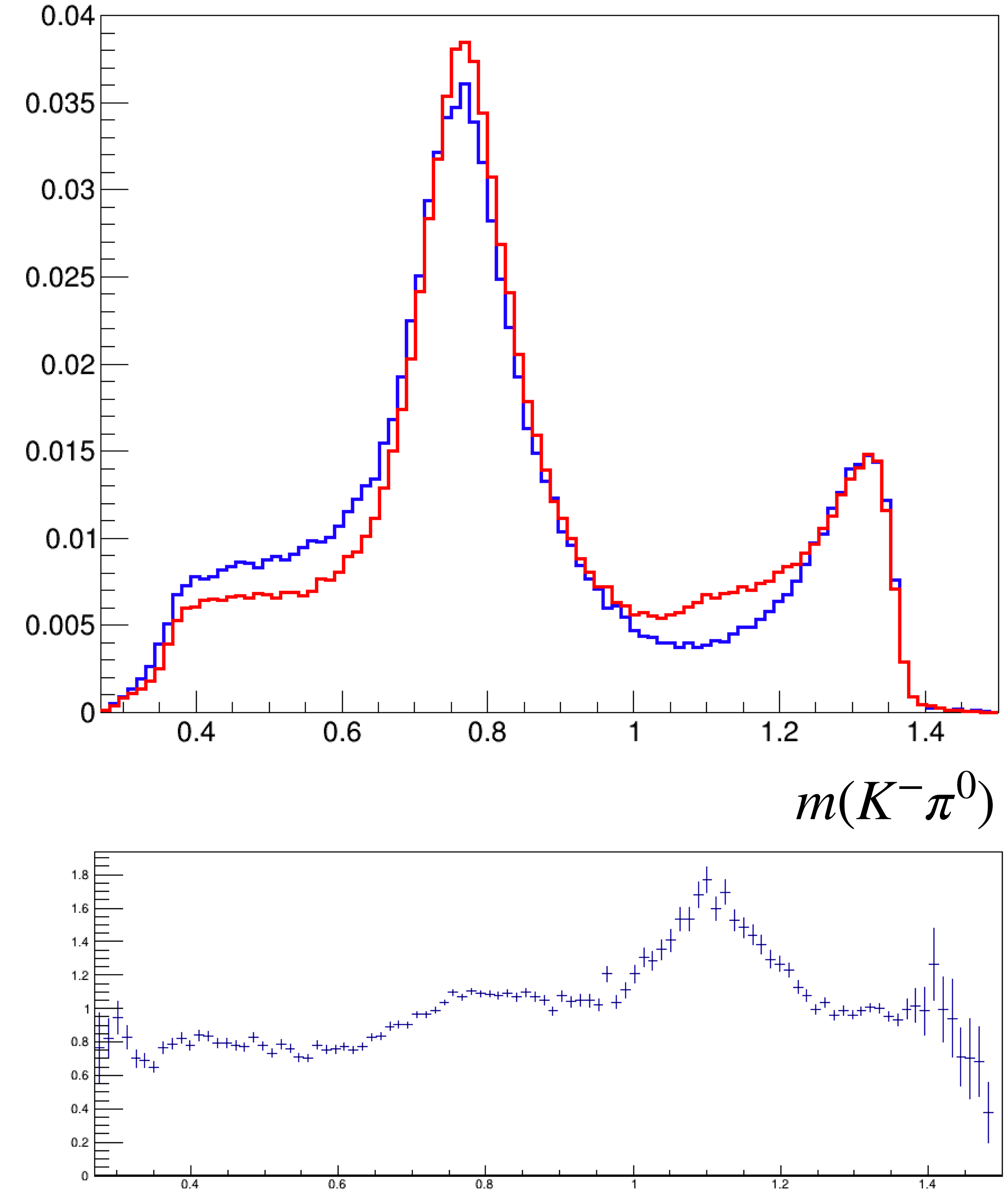
$$\frac{\varepsilon_{\mathrm{Data}}}{\varepsilon_{MC}} = R \pm \sigma_R^{stat} \pm \sigma_R^{sys} = 1.029 \pm \boxed{0.040}$$

Sum in quadrature of all uncertainties: statistical+*BF*+PID+tracks +fit models+Δm

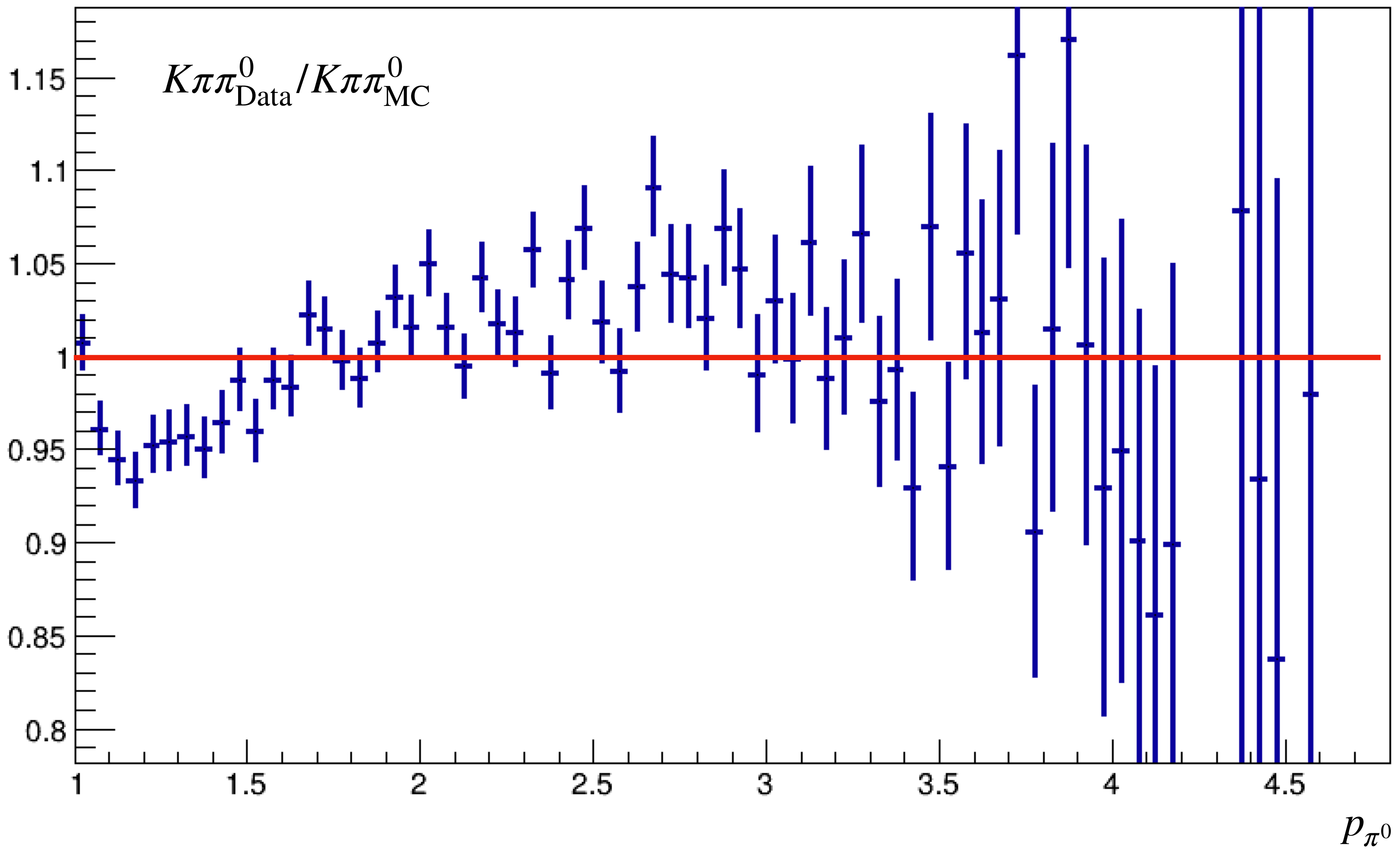
Backup

Dalitz discrepancies

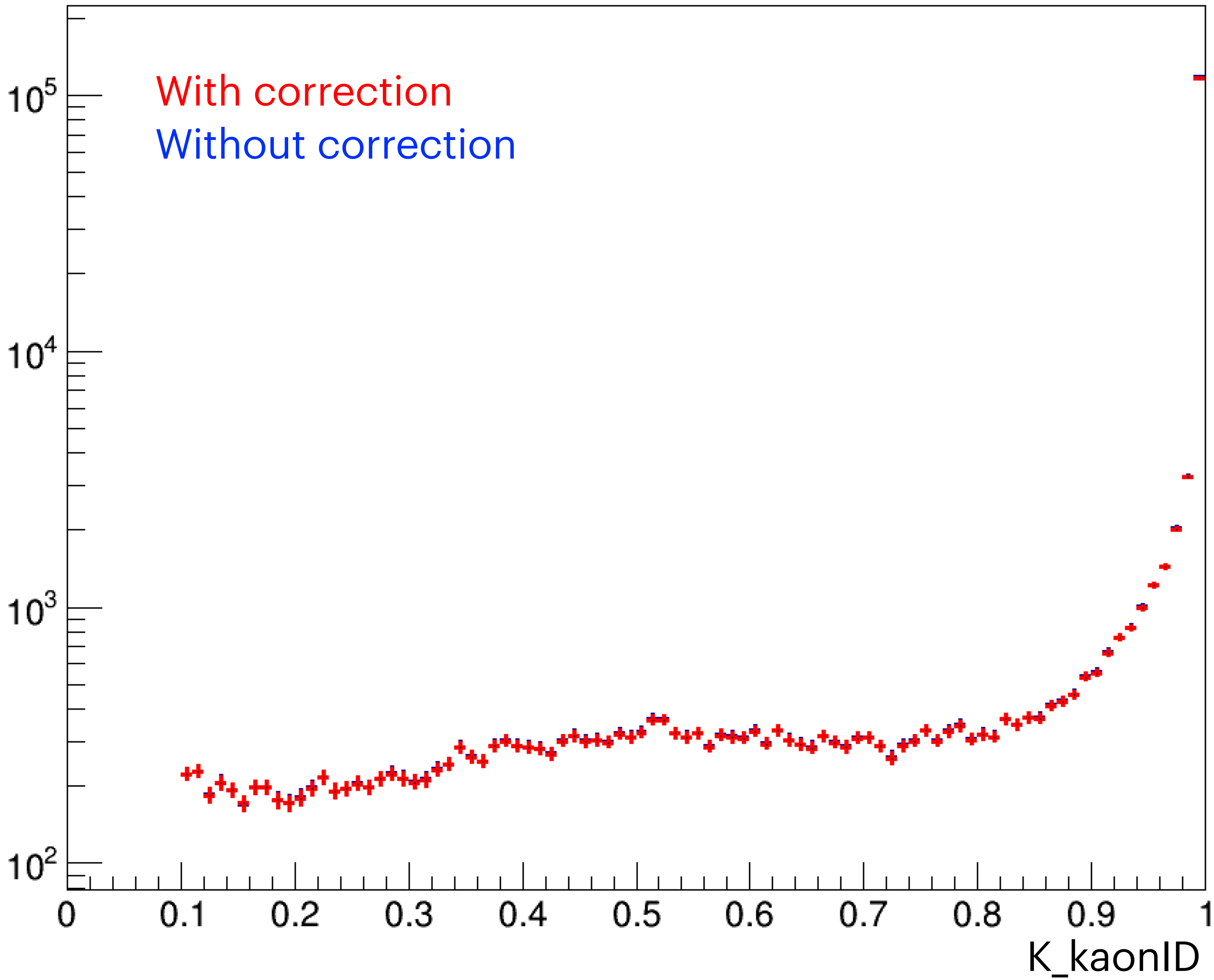




Pi0 momentum



KaonID



No large difference