Instrumental asymmetries

M. Dorigo, D. Ghosh, M. Mantovano, S. Raiz, D. Tonelli
(University and INFN Trieste)

Belle II Italy
May 29, 2022

Motivation

- Measurement of CP asymmetries in B decays are a key part of the Belle II physics program.
  E.g. $\mathscr{A}_{CP}(B^+ \to D^0 K^+)$ to measure γ , $\mathscr{A}_{CP}(B^+ \to \rho^+\rho^0)$ and $\mathscr{A}_{CP}(B^+ \to \pi^+\pi^0)$ for α, $\mathscr{A}_{CP}(B^+ \to K^+\pi^0)$ for testing isospin sum-rules.
- To measure CP asymmetries in these decays we need to subtract spurious asymmetries introduced due to:

  1. Different interaction cross section of particle/antiparticle (e.g. K^+/K^-) with the detector;
  2. Different reconstruction and PID efficiencies for oppositely charged particles.

- These detection asymmetries ($\mathscr{A}_{det}$) can be measured with high precision using control channels with expected CPV ~ 0 (or known with high precision).
- We measured $\mathscr{A}_{det}(K\pi)$ and $\mathscr{A}_{det}(\pi)$ using $D^0 \to K^-\pi^+$ and $D^+ \to K_s^0\pi^+$ decays. From these, we can also obtain $\mathscr{A}_{det}(K)$.

$\mathscr{A}_{\rm det}$ from D control channels

- *Observed charge asymmetries $\mathscr{A}_{\rm obs}$ are due to the combination of CP-violating effects, instrumental asymmetries and forward-backward asymmetry.*

$$\mathscr{A}_{\rm obs} = \frac{N^{+}_{(D^0\to K^-\pi^+)} - N^{-}_{(\bar{D}^0\to K^+\pi^-)}}{N^{+}_{(D^0\to K^-\pi^+)} + N^{-}_{(\bar{D}^0\to K^+\pi^-)}} = \mathscr{A}_{CP} + \mathscr{A}_{det} + \mathscr{A}_{\rm FB}$$

Observed asymmetry

CP-violating asymmetry

Instrumental asymmetry

Forward-backward asymmetry

- *Assume $\mathscr{A}_{CP}(D^0 \to K\pi) = 0$, $\mathscr{A}_{CP}(D^+ \to K_s^0\pi^+) =$ (–0.41 ± 0.09)% from PDG.*

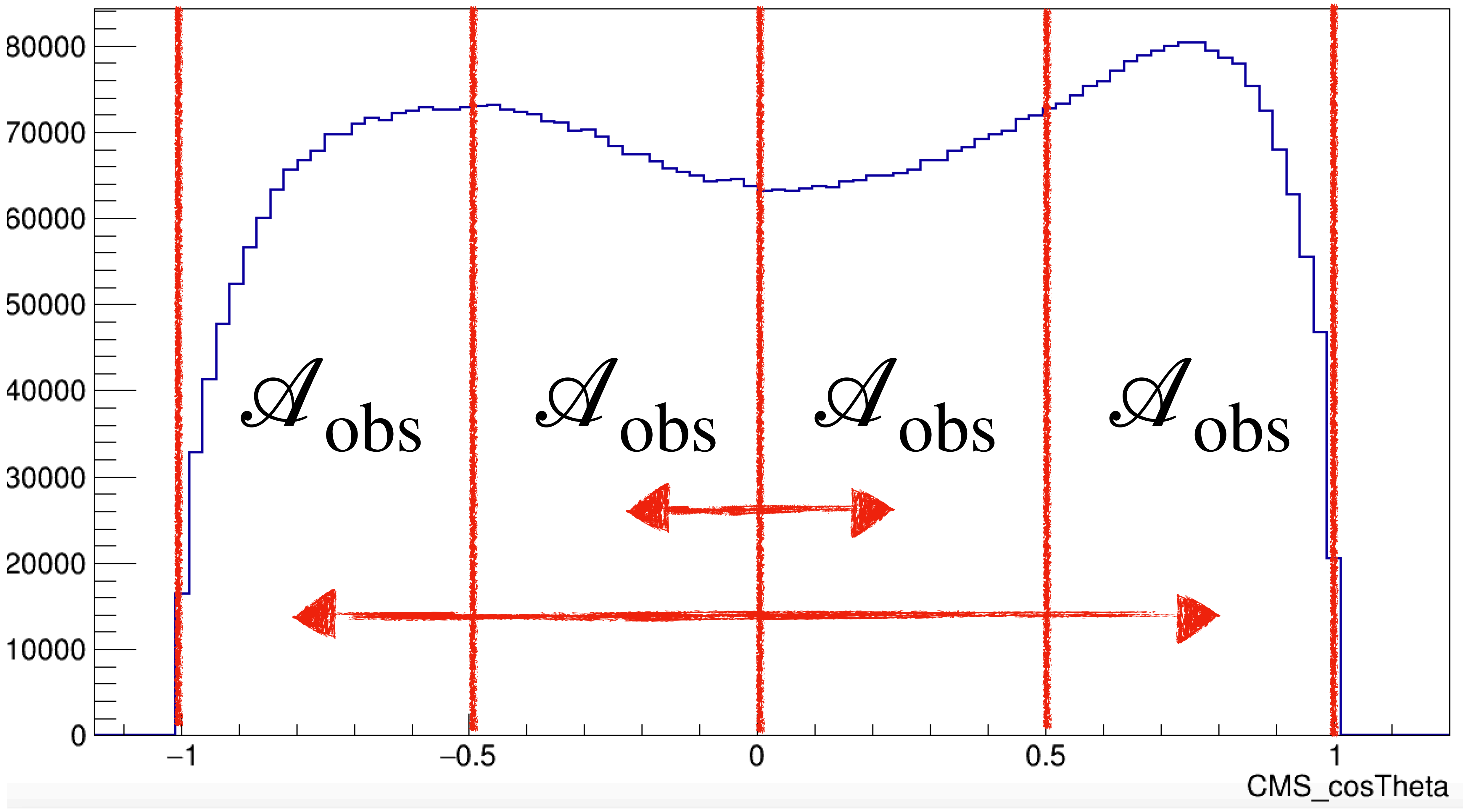
- *For $D^+ \to K_s^0\pi^+$, $\mathscr{A}_{det}(K_s^0\pi^+) \simeq \mathscr{A}_{det}(K_s^0) + \mathscr{A}_{det}(\pi^+)$. We assume $\mathscr{A}_{det}(K_s^0) = 0$ (neglect tiny asymmetry induced by K^0 CP-asymmetry).*

Forward-backward production asymmetry

- $\mathscr{A}_{FB}$ contribution due to $\gamma^* - Z^0$ interference in $e^+e^- \to c\bar{c}$.
- $\mathscr{A}_{FB}$ is antisymmetric as function of $cos(\theta^*)$ (angle of D meson production in CM system).

  https://arxiv.org/ftp/arxiv/papers/1808/1808.10567.pdf

- *Assume that $\mathscr{A}_{\text{det}}$ is not antisymmetric as function of $cos(\theta^*)$, we can cancel $\mathscr{A}_{FB}$ by combining measurement of $\mathscr{A}_{obs}$ in opposite bins of $cos(\theta^*)$:*



$$\mathscr{A}_{\text{det}} = \frac{\mathscr{A}_{obs}(cos(\theta^*)) + \mathscr{A}_{obs}(-cos(\theta^*))}{2}$$

Sample and selection

Data: Proc12 + buckets16-25 (189.26 fb^{-1}).

SignalMC: from MC14ri-a (300 fb^{-1}).

Vertex fit on D: treefit

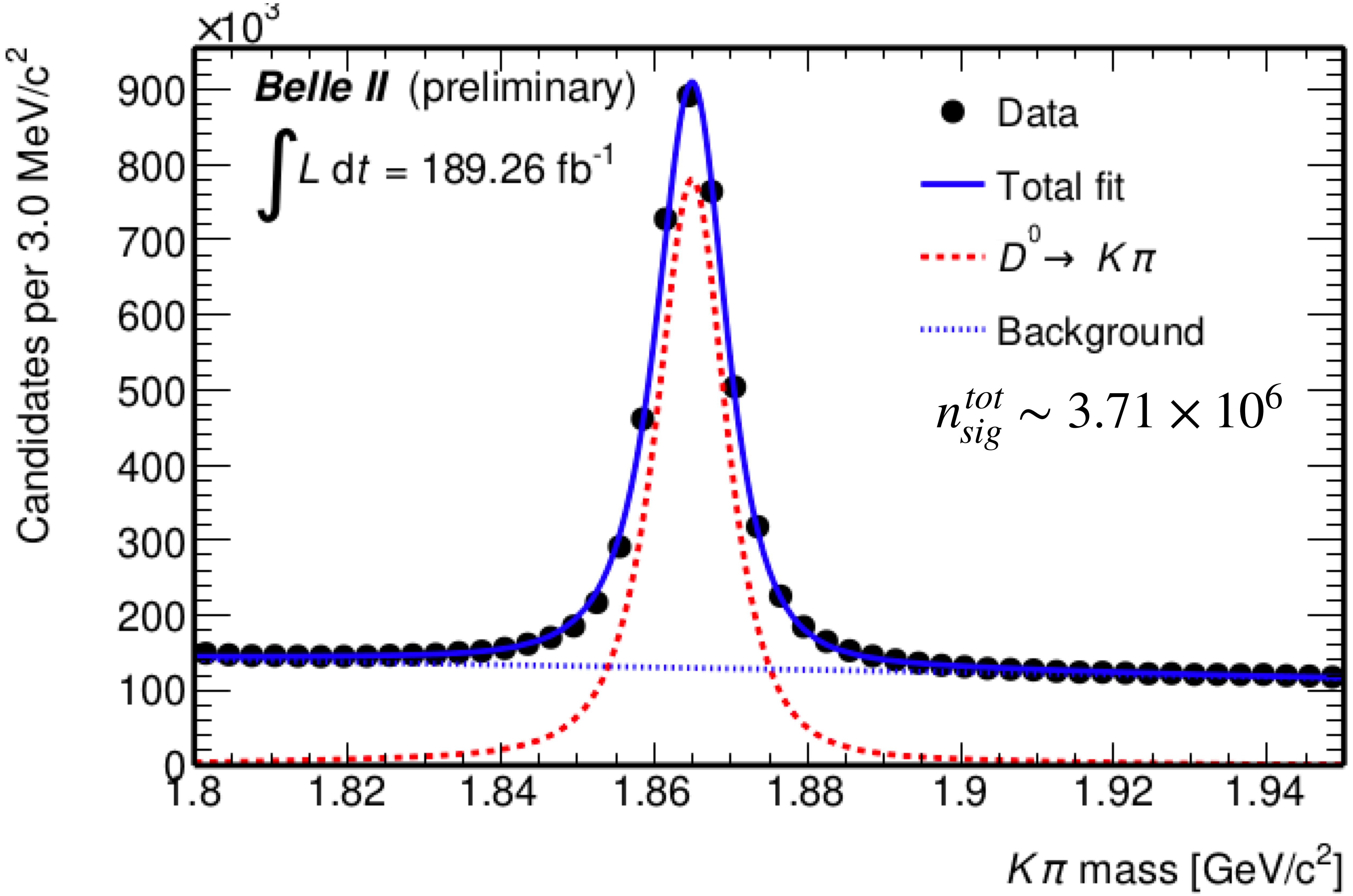
Applied the latest beam energy and momentum corrections.

Tracks:thetaInCDCAcceptance + |dr| <0.5 + |dz| <3 + chiProb>0 + CDCHits>0

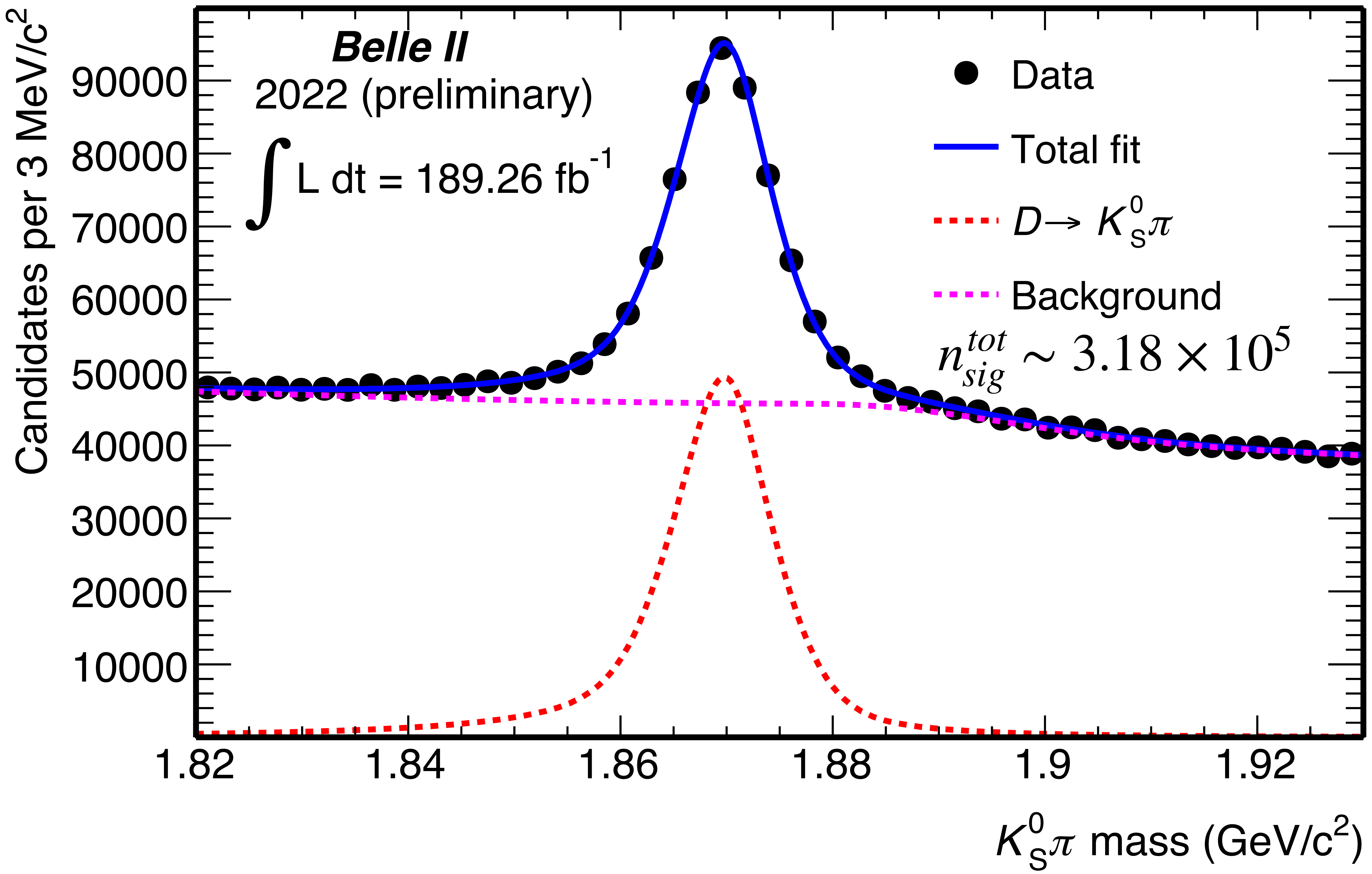
$D^0 \to K^-\pi^+$	$D^+ \to K_s^0\pi^+$
KaonID>0.25 + CMS_p>2.5 GeV/c	CMS_p>2.5 GeV/c + 0.4942GeV/c^2<m(Ks)<0.5014Gev/c^2+ KsSignificanceOfDistance>44.5 + KsChiProb>0

$D^0 \to K^-\pi^+$ and $D^+ \to K_s^0\pi^+$ samples

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



$D^+ \to K_s^0\pi^+$



Determining $\mathscr{A}_{\rm det}$ dependence in data

Study $\mathscr{A}_{\rm det}$ binning the sample in:

- p *: interaction probabilities with matter depend on momentum;*
- $cos(\theta)$*: different material budget traversed by the particle;*
- *CDC hits: tracking and dE/dx resolution depends on number of hits, and these differ on average for track with opposite curvature.*

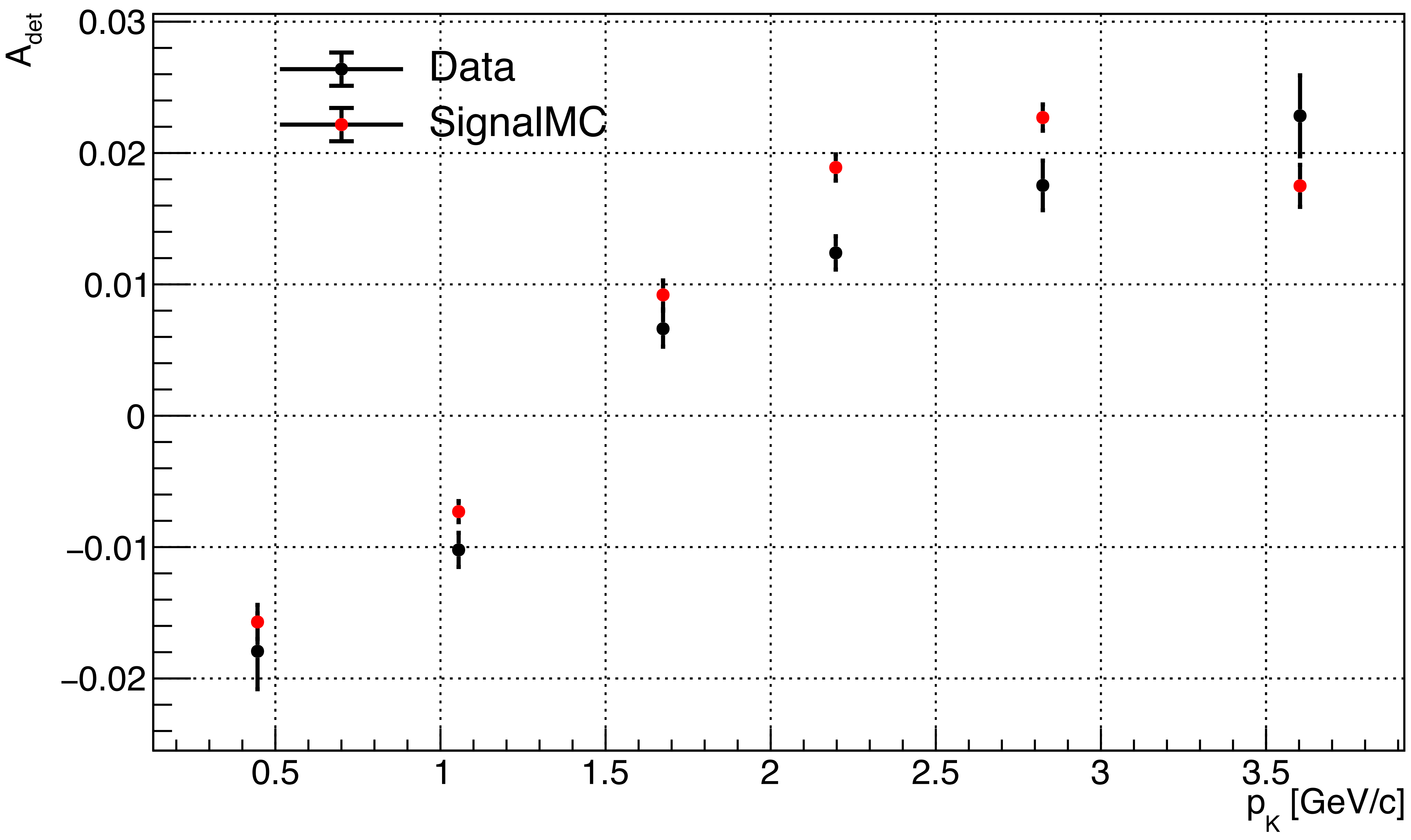
- *For $K\pi$, $\mathscr{A}_{\rm det}$ as a function of kaon variables ($\mathscr{A}_{det}(K\pi) \simeq \mathscr{A}_{det}(K) + \mathscr{A}_{det}(\pi)$ and $\mathscr{A}_{det}(K) \gg \mathscr{A}_{det}(\pi)$);*
- *For $K_s^0\pi$, $\mathscr{A}_{\rm det}$ as a function of pion variables ($\mathscr{A}_{det}(K_s^0) = 0.$).*

Split the sample in D^0 and $\bar{D}^0$ candidates and fit D mass to compute the signal yield and calculate $\mathscr{A}_{\rm obs} = [N(D^0) - N(\bar{D}^0]/[N(D^0) + N(\bar{D}^0)]$ .Subtract $\mathscr{A}_{\rm FB}$ by doing the measurement in opposite bins of $cos(\theta*)$ and obtain $\mathscr{A}_{\rm det}$.

These three variables are correlated. Will show the dependence one by one only for illustration.

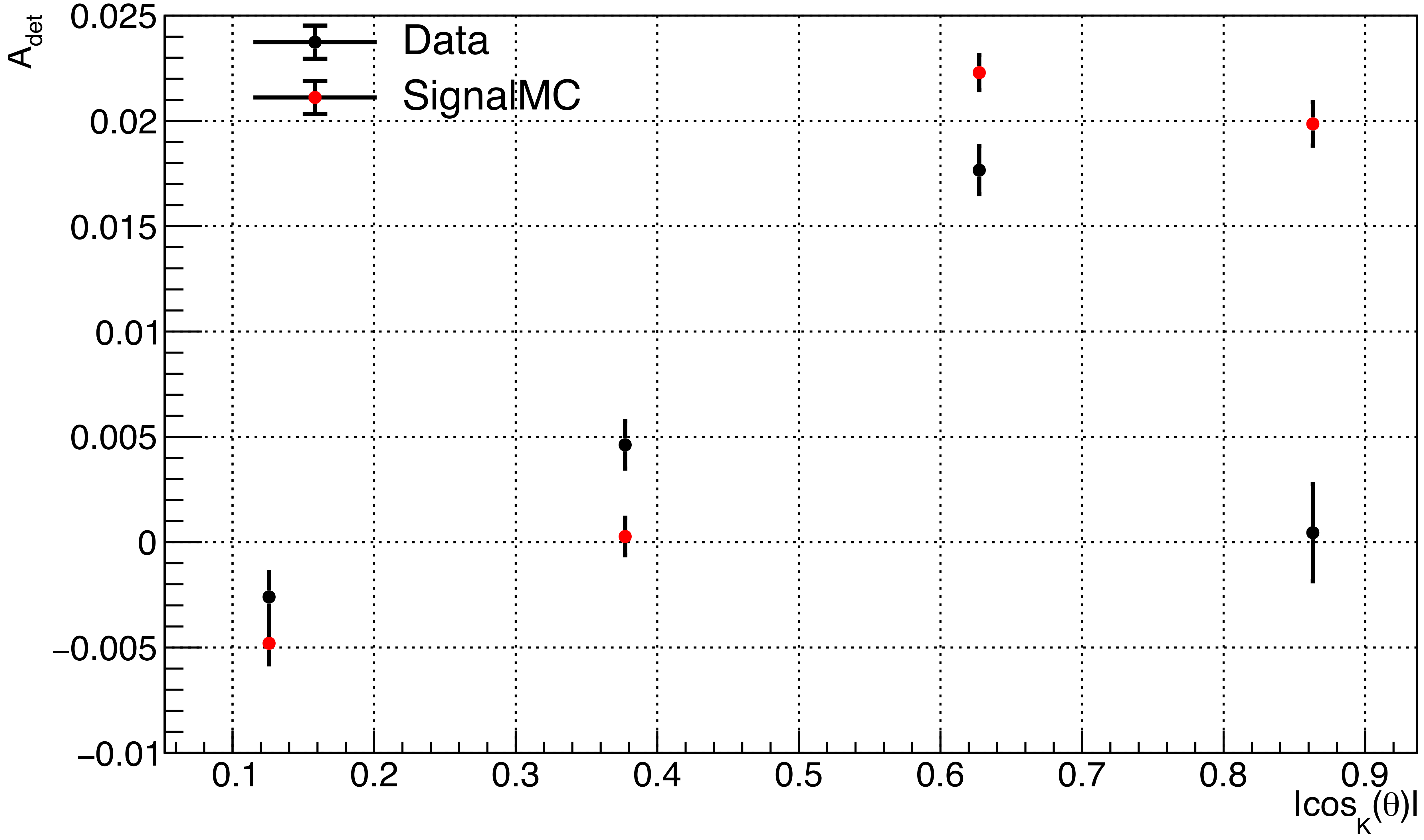
$\mathscr{A}_{\text{det}}$ *dependences :* $D^0 \to K^-\pi^+$

Check marginal distribution: integrate over $cos_K(\theta)$ and K_CDC_hits.



$\mathscr{A}_{det}$ depends on p_K

Check marginal distribution: integrate over $p_K(\theta)$ and K_CDC_hits.

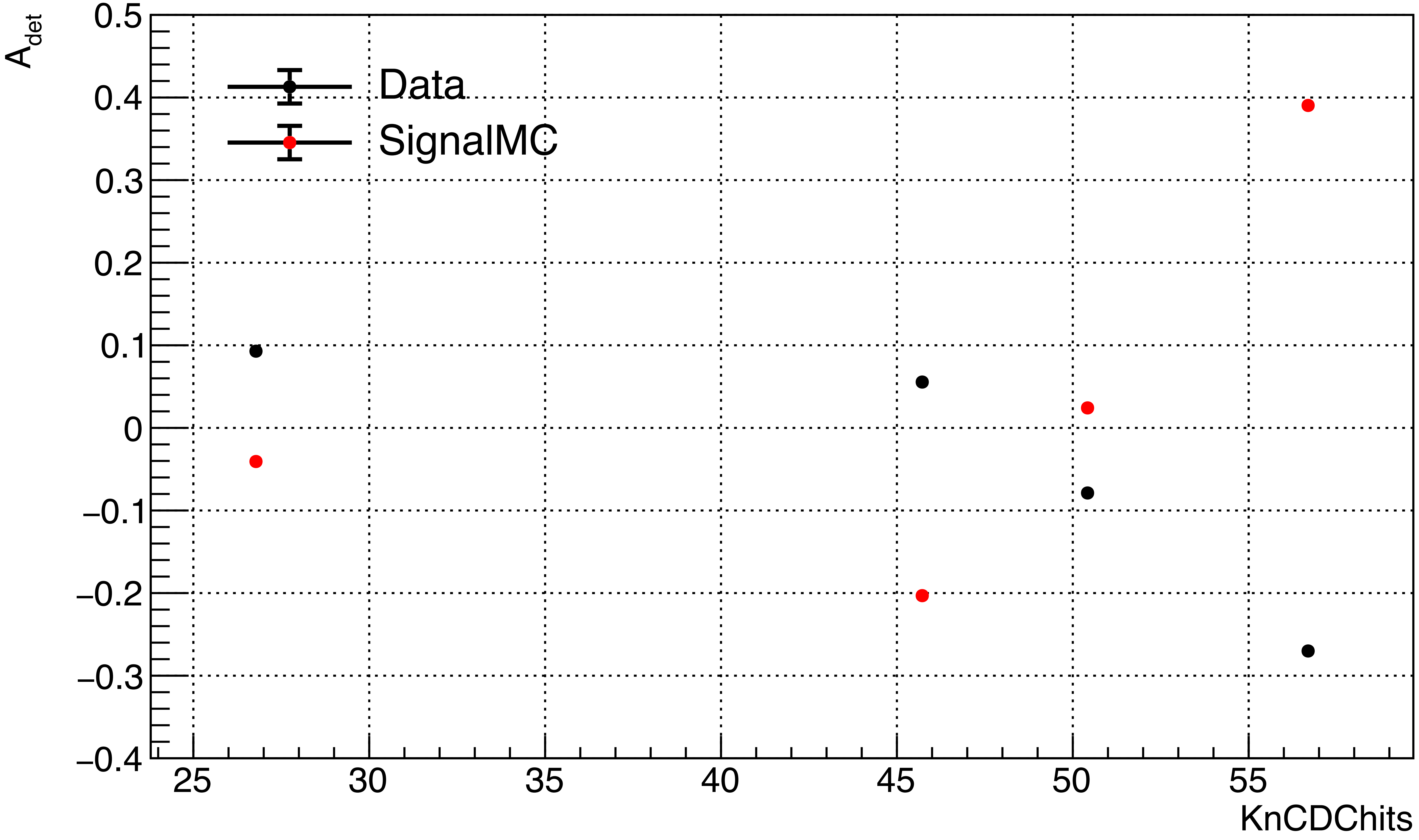


$\mathscr{A}_{det}$ depends on $cos_K(\theta)$

MC shown only for comparison.

$\mathscr{A}_{\rm det}$ *dependences :* $D^0 \to K^- \pi^+$

Integrate over all kinematic variables.



Strong dependence of $\mathscr{A}_{det}$ on KCDChits.

The discrepancy between data and MC is known and it is due to a drift time mis-calibration in the CDC simulated in MC.

Strategy to evaluate $\mathscr{A}_{\rm det}$ for the analyses

- *$\mathscr{A}_{\rm det}$ is sample-dependent: different values according to different kinematics and number of CDChits of a track.*
- *Need to consider to (p, $cos(\theta)$,CDChits) distributions of kaon and pion in decays, which might differ from those of our control channel.*
- *Apply weights to correct the distributions of the control channel such that they match those of any given B decay:*

  1. *Split the control channel in bins of CDChits and in each bin:*

     A. *Correct the ($p, cos(\theta)$) distributions of the control channel (weight from MC);*

     B. *Determine $\mathscr{A}_{\rm det}$ on the corrected-sample.*

  2. *Average the $\mathscr{A}_{\rm det}$ values considering the CDChits distribution of the B decay (from data).*

- *Will show a closure test in MC that validates the method.*

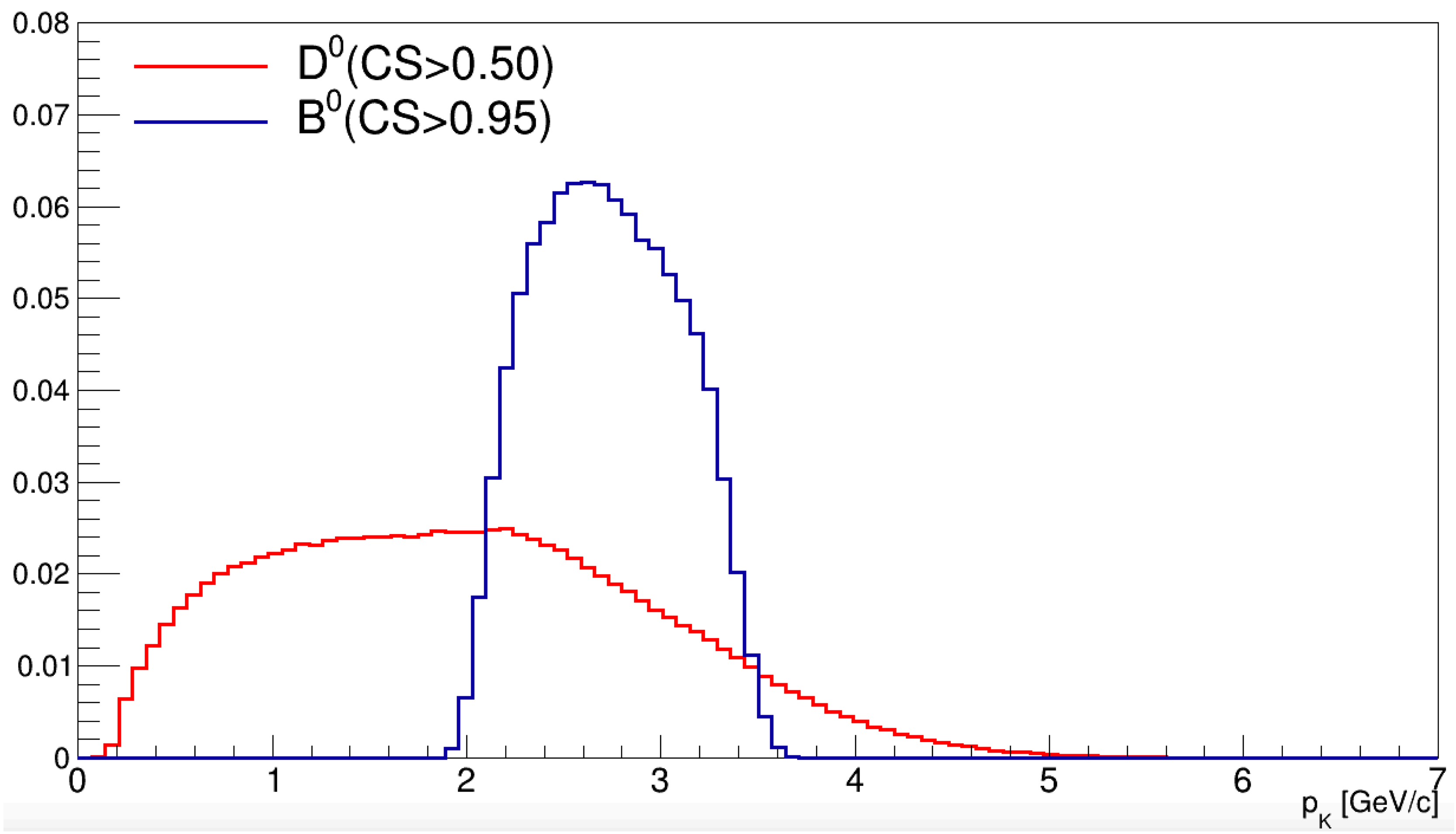
$\mathscr{A}_{\rm det}(K\pi)$ closure-test with MC

- *Take as example $B^0 \to K\pi$ decays. Standard selections on tracks, with a tight cut on continuum-suppression BDT (CS>0.95), and kaonID>0.25. Known value of $\mathscr{A}_{\rm det}(K\pi) = 0.0012 \pm 0.0015$ in MC: this is the target.*

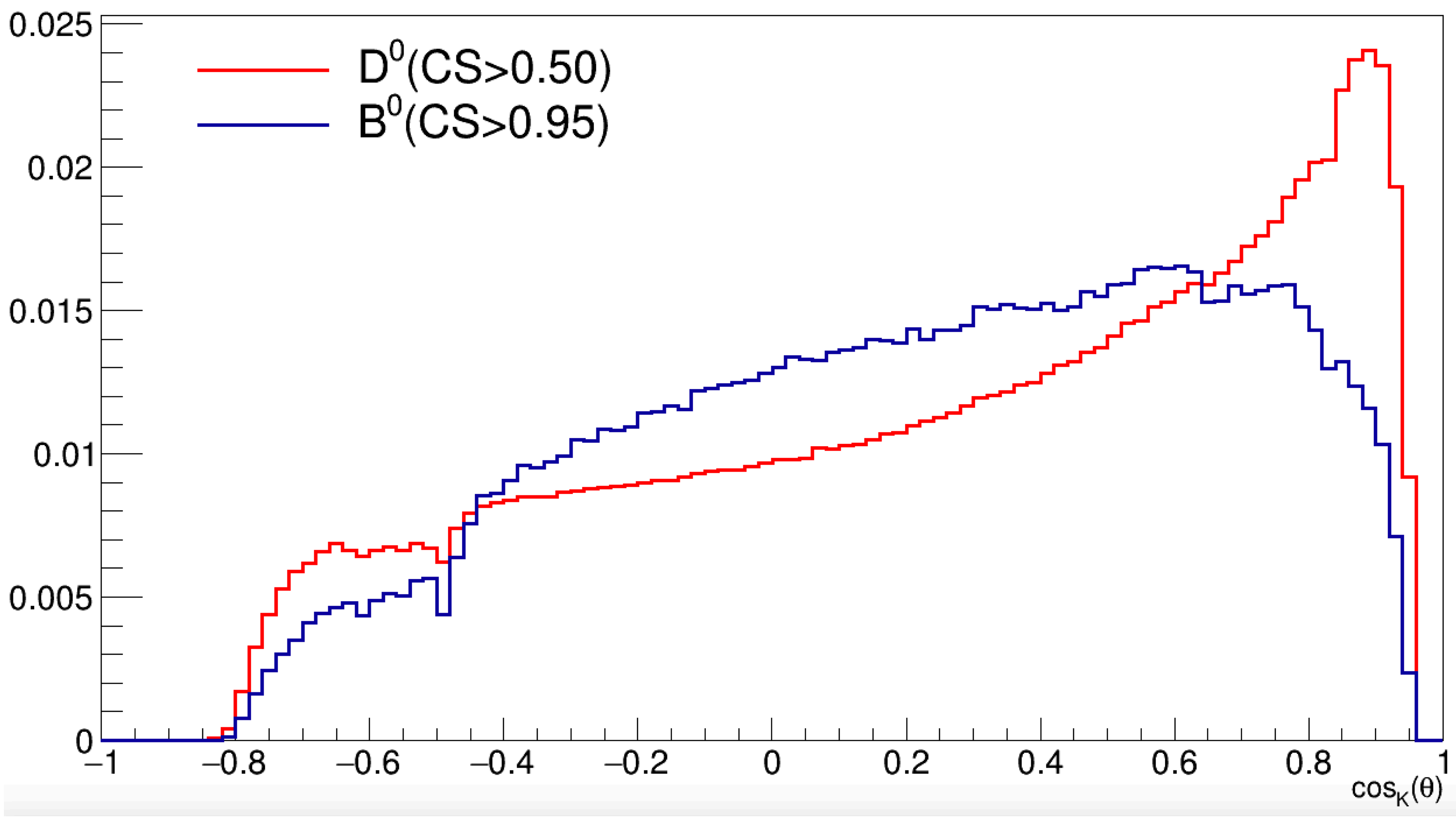
- *Consider $D^0 \to K\pi$ control channel (CS>0.50, KaonID>0.25). Measured $\mathscr{A}_{\rm det}(K\pi) = -0.0076 \pm 0.0007$.*

- *Different values as expected since p_K, $cos_K(\theta)$ and CDChits(K) differs:*

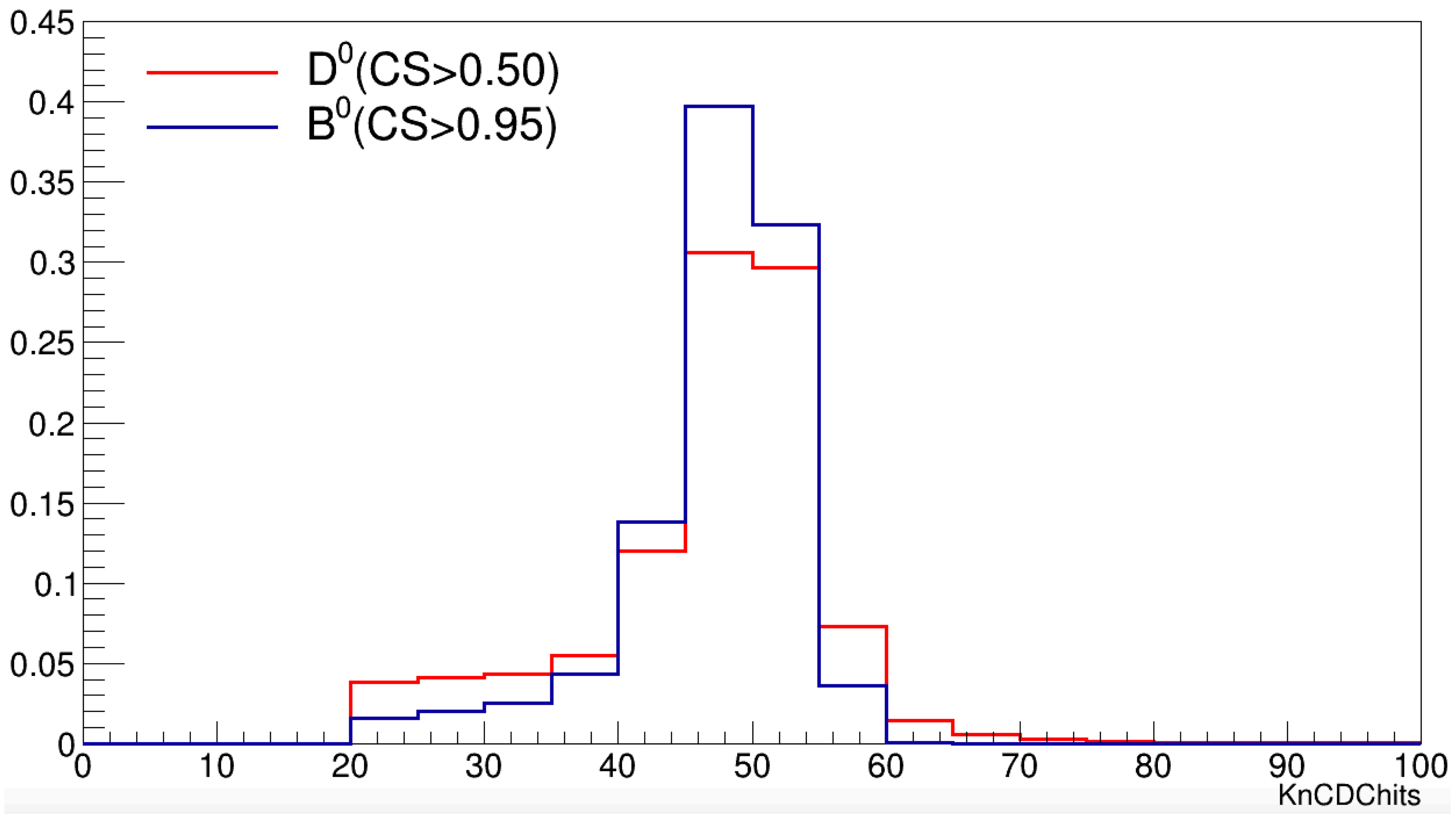
p_K *distributions*



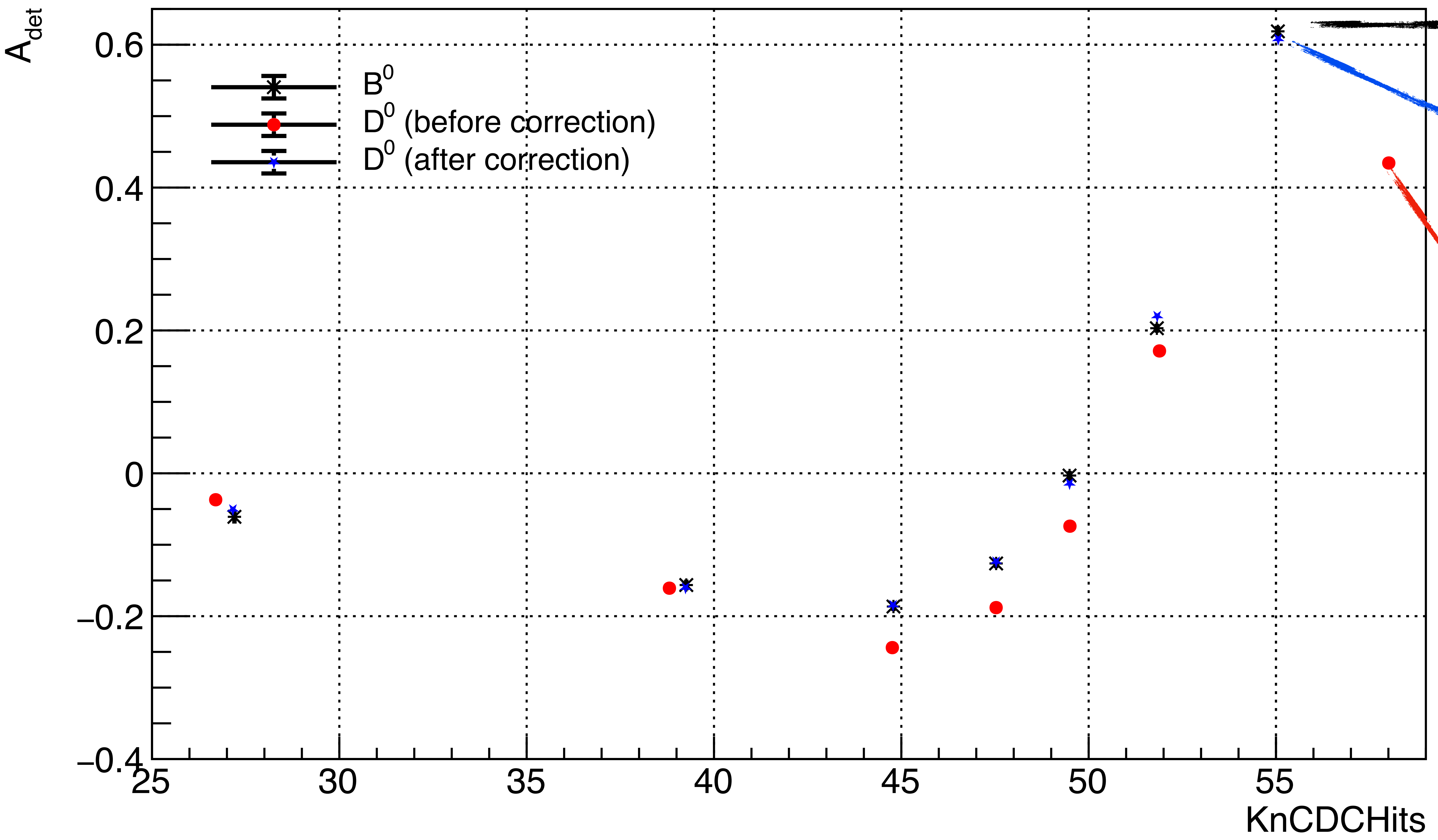
$cos_K(\theta)$ *distributions*



KnCDChits distributions



$\mathcal{A}_{\text{det}}(K\pi)$ *closure-test with MC*



$\mathcal{A}_{det}$ from $B^0 \to K\pi$

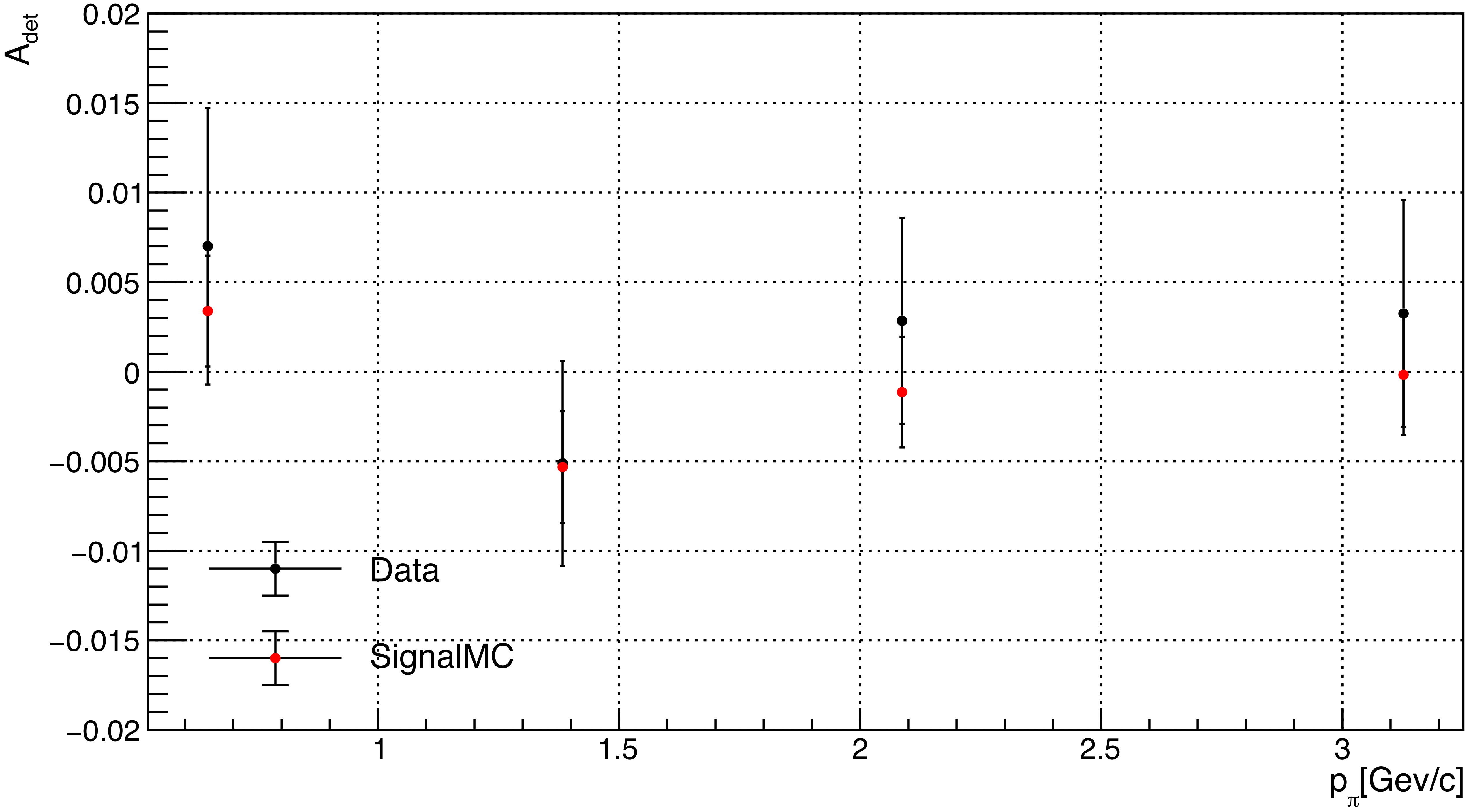
$\mathcal{A}_{det}$ from $D^0 \to K\pi$ after the correction: match the target value

$\mathcal{A}_{det}$ from $D^0 \to K\pi$ without any correction for p_K and $cos_K(\theta)$ distributions.

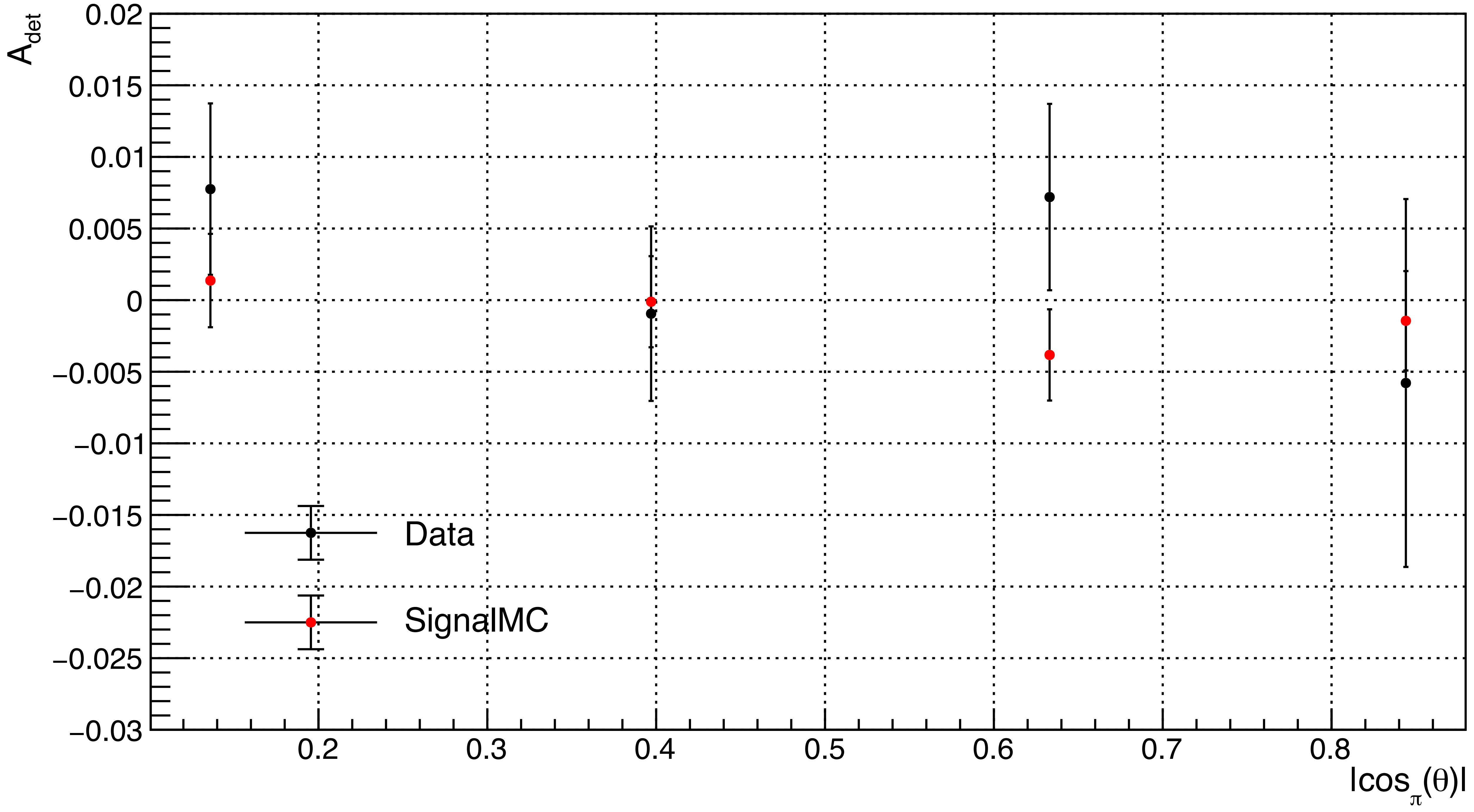
- *The points are placed at the average of the CDChits distribution in the bin: it might differs for B^0 and D^0(before the correction).*
- *Average of the $\mathcal{A}_{det}(K\pi)$ values from corrected $D^0 \to K\pi$ sample, considering CDChits distribution of $B^0 \to K\pi$:* 0.0015 ± 0.0007 *in agreement with target* 0.0012 ± 0.0015
- *We checked the procedure for different PID and CS selections and get expected results.*

$\mathscr{A}_{\mathrm{det}}$ *dependences :* $D^+ \to K_s^0 \pi^+$

Check marginal distribution: integrate over $cos_\pi(\theta)$ and pi_CDC_hits.



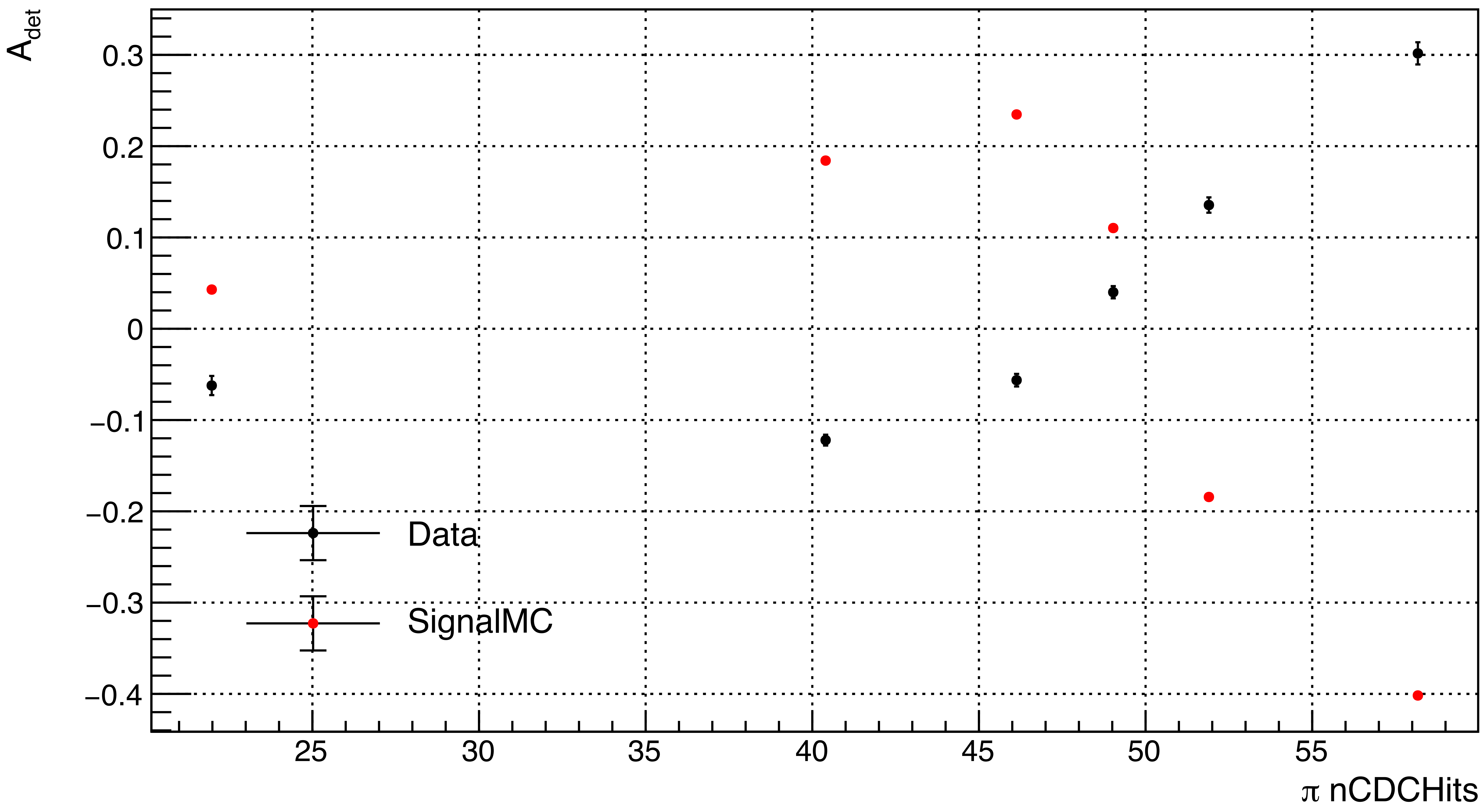
Check marginal distribution: integrate over $p_\pi(\theta)$ and pi_CDC_hits.



Observe soft $\mathscr{A}_{det}$ dependencies as a function of $p_\pi(\theta)$ and $cos_\pi(\theta)$.

$\mathscr{A}_{\text{det}}$ *dependences :* $D^+ \to K_s^0 \pi^+$

Integrate over all kinematic variables.



Strong dependence of $\mathscr{A}_{det}$ on piCDChits.

$\mathscr{A}_{\rm det}(\pi)$ *from* $D^+ \to K^0_s\pi^+$

- *The method to compute* $\mathscr{A}_{det}(\pi)$ *using* $D^+ \to K^0_s\pi^+$ *for a given decay is the same used to compute* $\mathscr{A}_{det}(K\pi)$*.*

- *A closure-test to compute* $\mathscr{A}_{det}(\pi)$ *for* $B^+ \to \rho^+(\to \pi^+\pi^0)\rho^0(\to \pi^+\pi^-)$ *decay using this control channel is ongoing.*

- *We can also use* $D^0 \to K^-\pi^+$ *and* $D^+ \to K^0_s\pi^+$ *to compute* $\mathscr{A}_{det}(K)$*:*

    1. *Given (*p_K*,* $cos_K(\theta)$*,KnCDChits) distributions of a B decay, we can compute* $\mathscr{A}_{det}(K\pi)$ *using* $D^0 \to K^-\pi^+$ *channel;*

    2. *Weight the* π *distributions of* $D^+ \to K^0_s\pi^+$ *to match those of* $K\pi$*;*

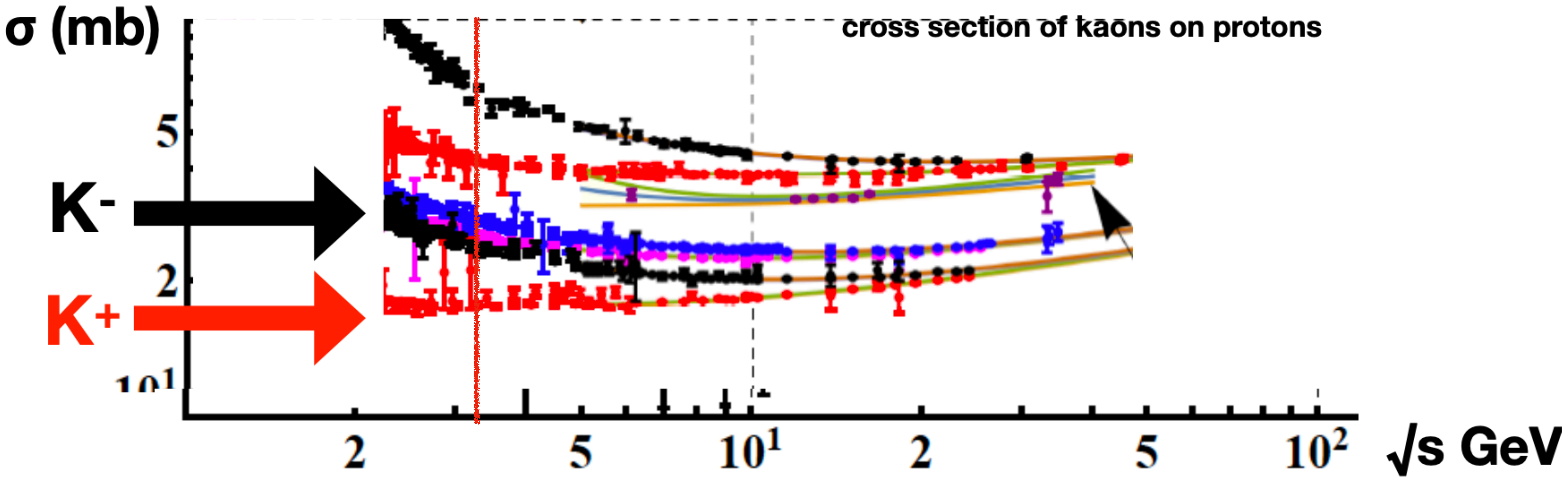
    3. *Compute* $\mathscr{A}_{det}(K) = \mathscr{A}_{det}(K\pi) - \mathscr{A}_{det}(\pi)$*.*

Summary

- Measured $\mathscr{A}_{det}$ for $K\pi$ and π, with a precision of $\mathcal{O}(1^o/_{oo})$ and $\mathcal{O}(3^o/_{oo})$ using $D^0 \to K^-\pi^+$ and $D^+ \to K_s^0\pi^+$.
- First study of the dependence of $\mathscr{A}_{det}$. Found large dependence as a function of p, $cos(\theta)$ and CDChits of the tracks.
- Developed a method to compute $\mathscr{A}_{det}$ from control channel for any given decay, taking into account these dependences.
- Will release a tool for analysts and document everything in a supporting note.
- Will be used in analyses targeting ICHEP, e.g. GLW with $B^+ \to D^0h^+$, and measurement of $\mathscr{A}_{CP}$ in $B^+ \to h^+\pi^0$ and $B^0 \to K^*\pi^0$ decays.

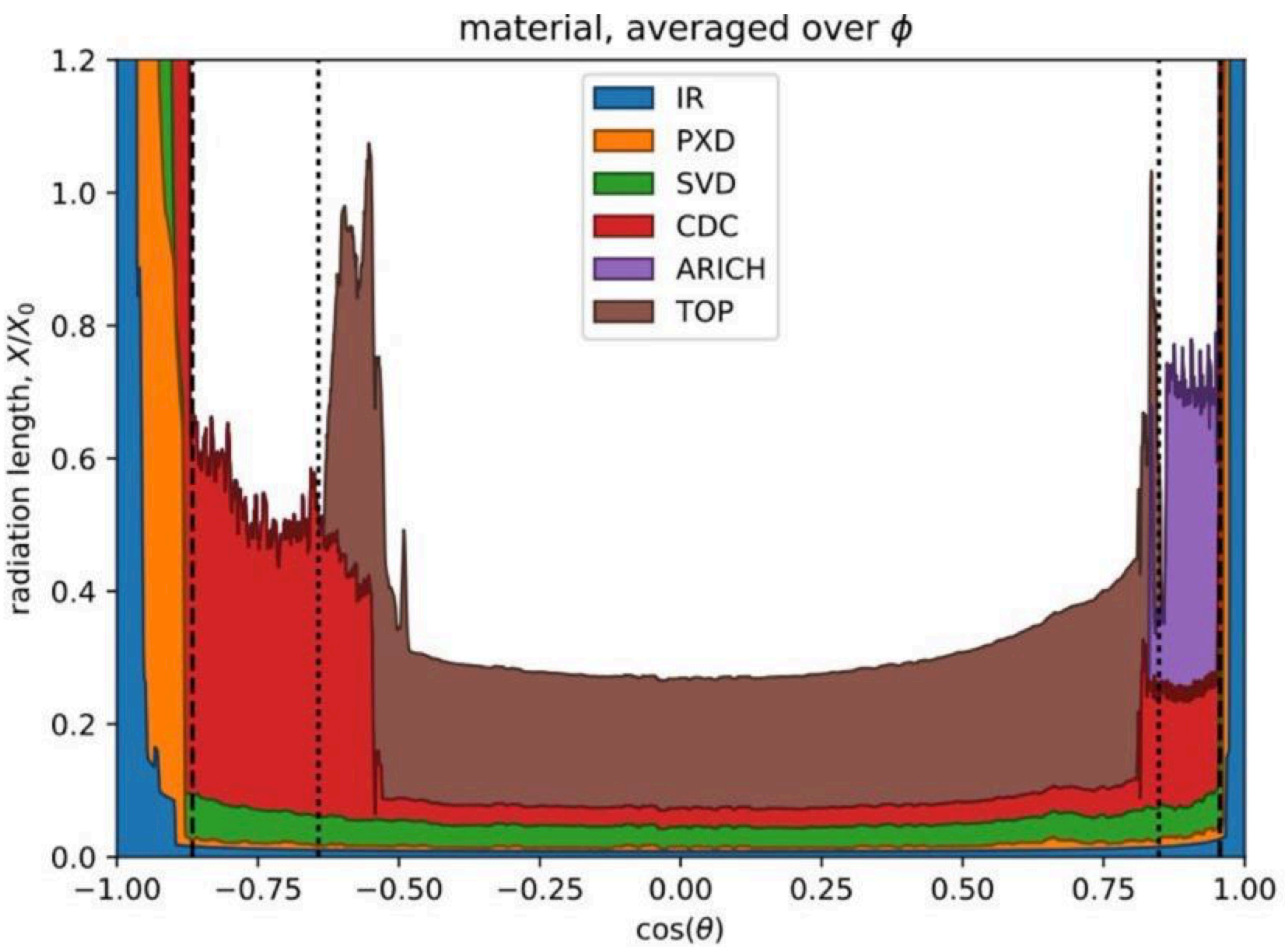
Backup

$\mathscr{A}_{\text{det}}$ dependences : $D^0 \to K^-\pi^+$



$\mathscr{A}_{det}$ depends on p_K ⟷ Interaction probabilities between K^+/K^- depend on momentum.

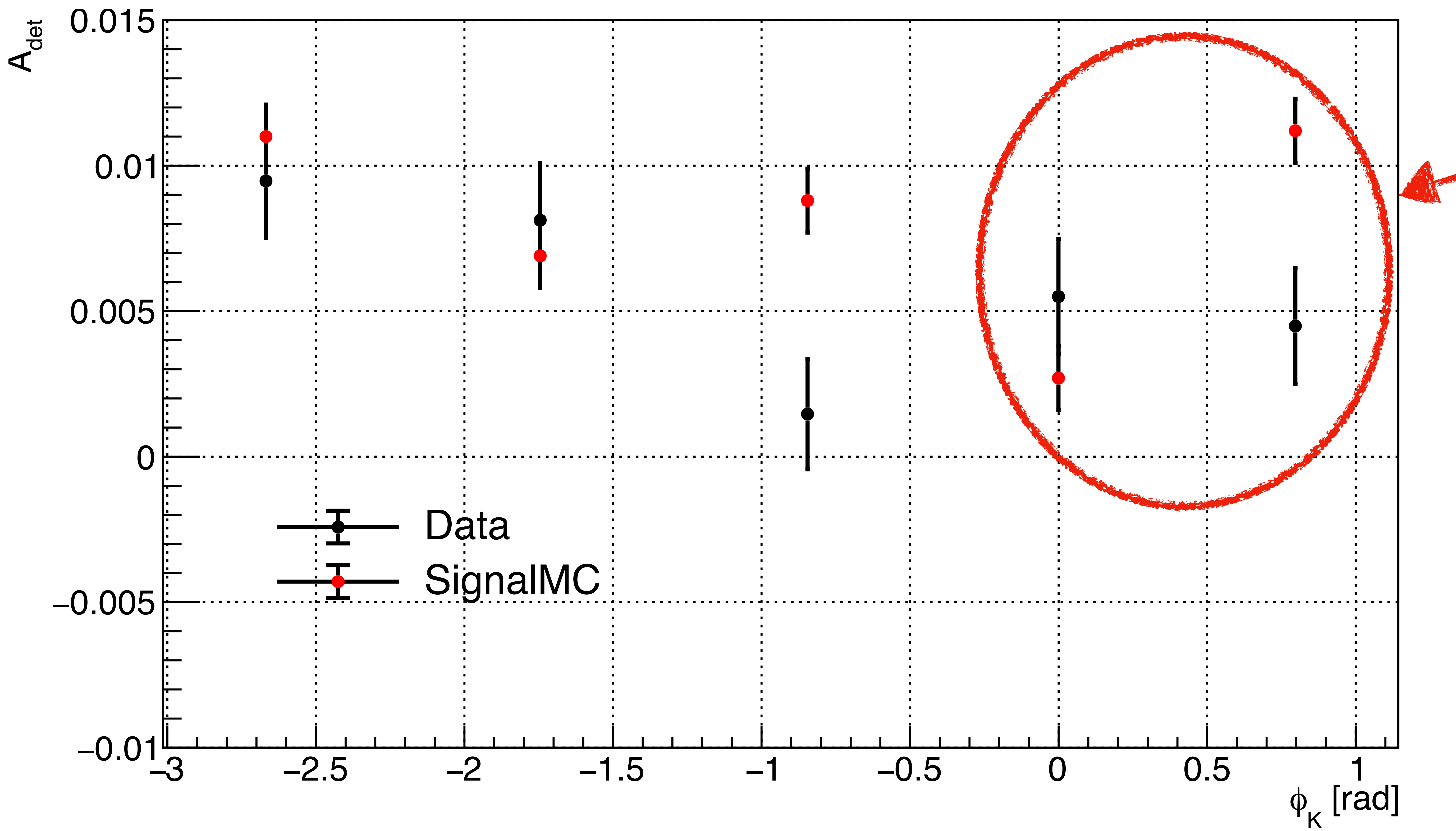
$\mathscr{A}_{\rm det}$ *dependences :* $D^0 \to K^- \pi^+$

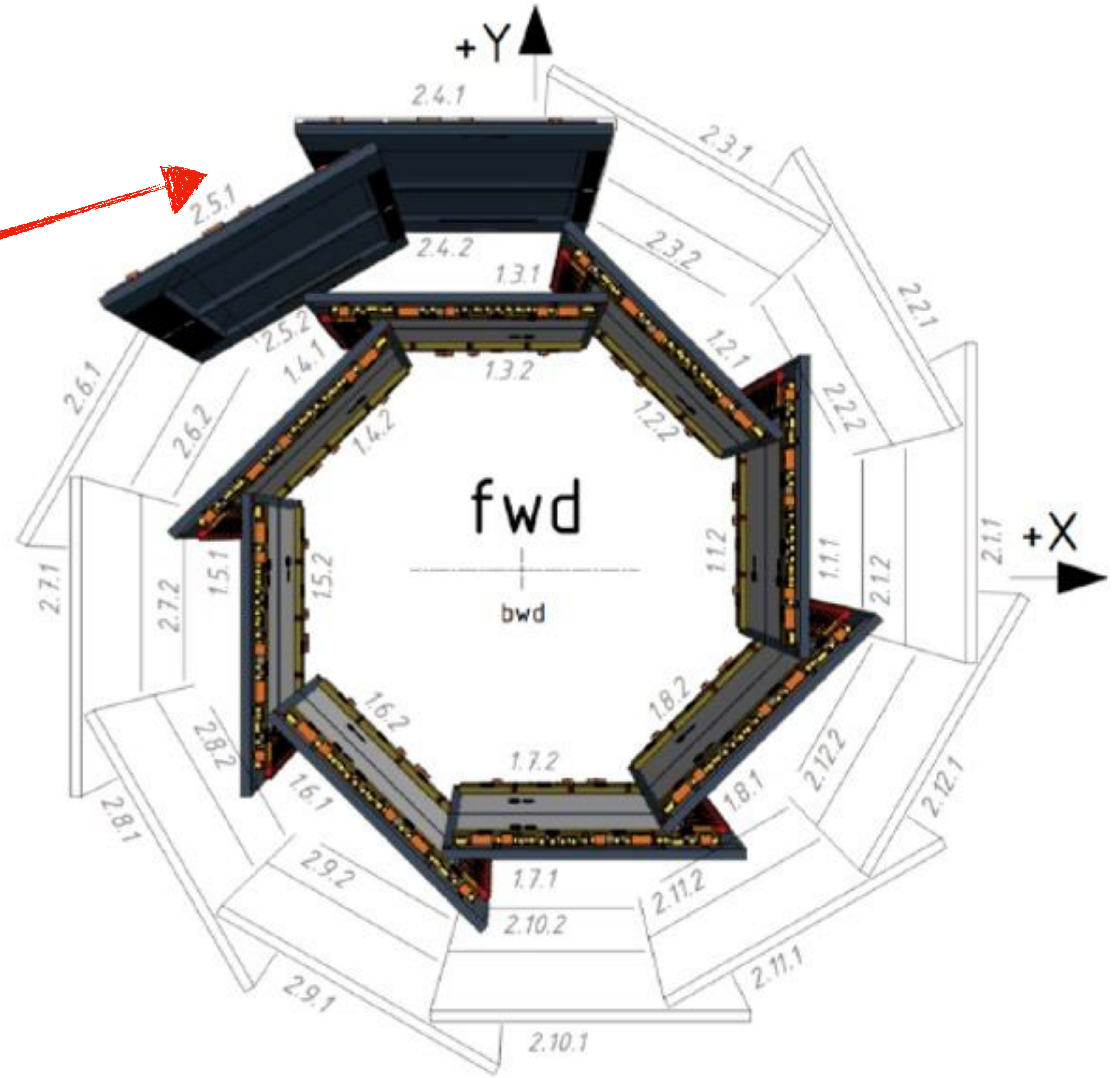


$\mathscr{A}_{det}$ depends on $cos_K(\theta)$ ⟷ different material budget traversed by particle.

$\mathscr{A}_{\text{det}}$ *dependences :* $D^0 \to K^-\pi^+$

Integrate over all kinematic variables and K_CDC_hits.





The circled points represent the $\mathscr{A}_{\text{det}}$ *values* in the ϕ_K region in which there are two layers of PXD (more material budget traversed by particle). In any case, we assume no dependence on ϕ_K.