# Instrumental asymmetries

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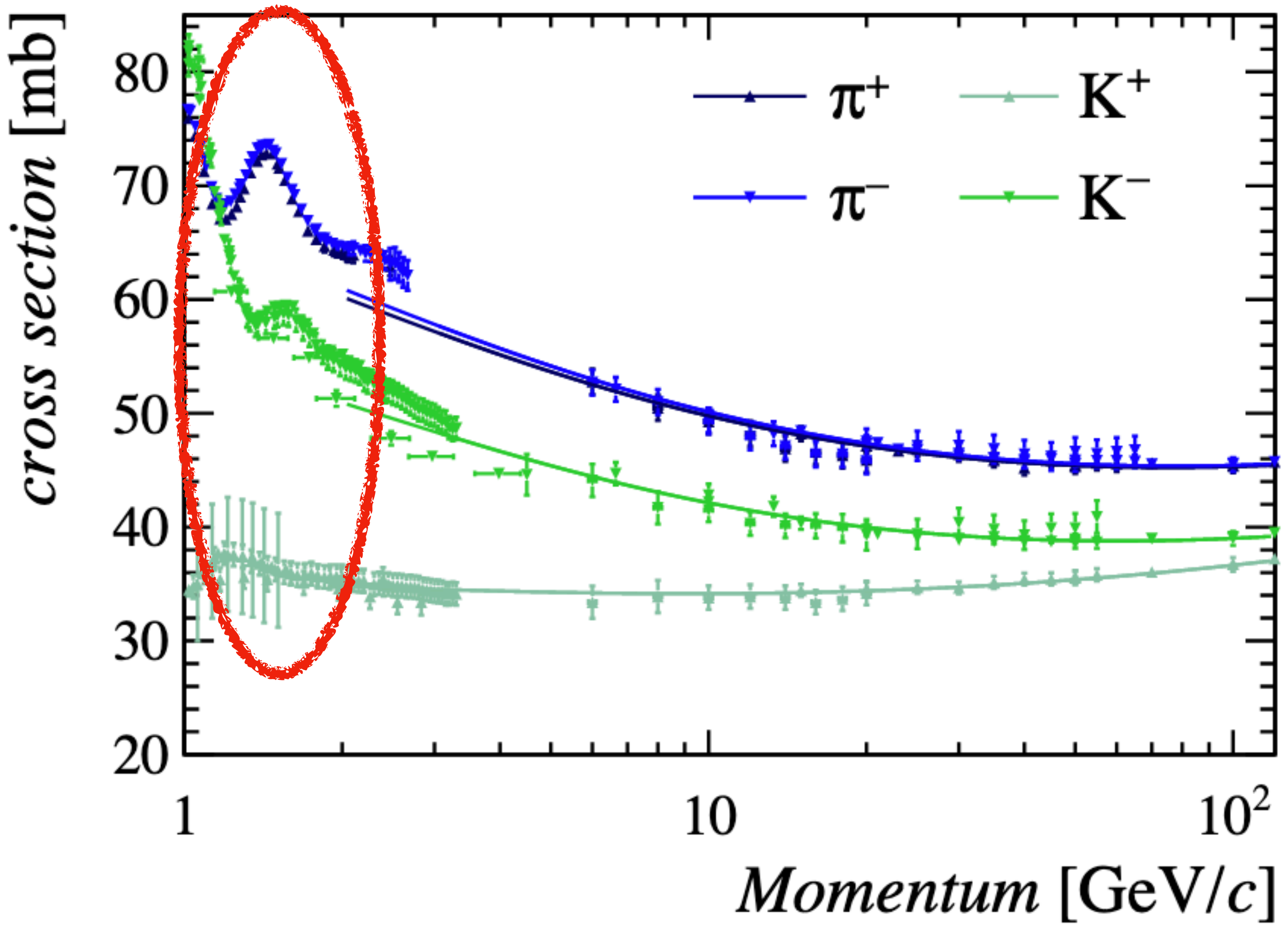
# Motivation

- Measurement $\mathscr{A}_{CP}$ asymmetries are a key part of the Belle II physics program.
- To measure $\mathscr{A}_{CP}$ we need to subtract detection asymmetries ($\mathscr{A}_{det}$) due to:
  1. Different interaction cross section of particle/antiparticle with matter.

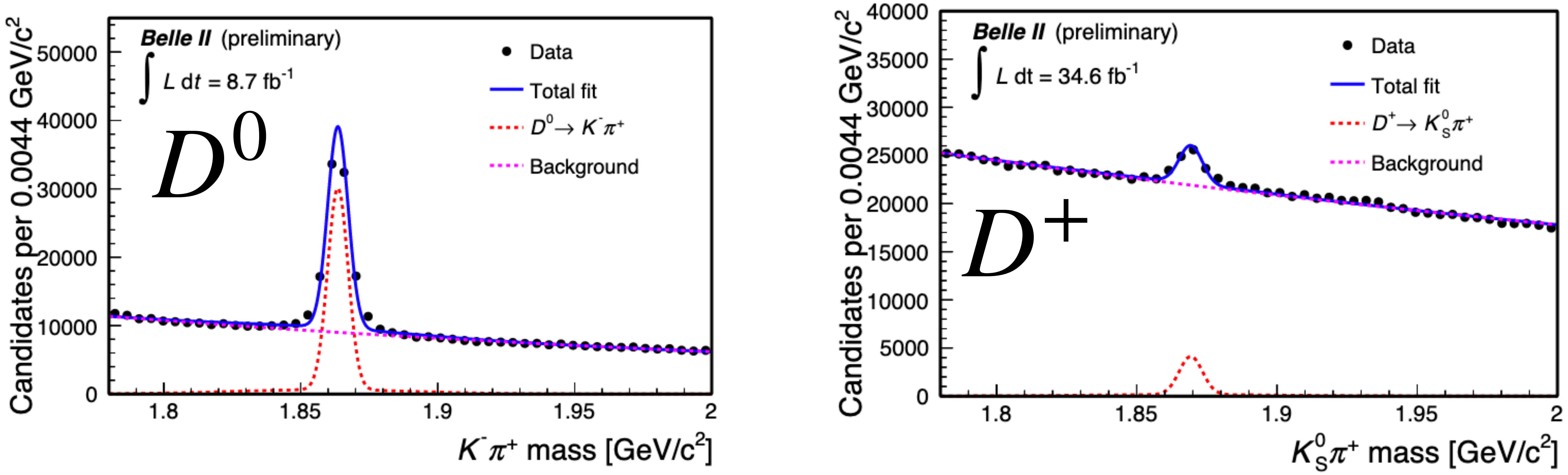



  2. Different reconstruction and PID efficiencies for oppositely charged particles.

- Cannot trust simulation to model $\mathscr{A}_{det}$: need to measure them in data.

# Status

- We determine $\mathscr{A}_{det}(K\pi)$ and $\mathscr{A}_{det}(\pi)$ using $D^0 \to K^-\pi^+$ and $D^+ \to K_s^0\pi^+$ decays. Can obtain $\mathscr{A}_{det}(K) = \mathscr{A}_{det}(K\pi) - \mathscr{A}_{det}(\pi)$
- Already measured last year by S.Raiz *et al.* with $\mathcal{O}(1-3\%)$ precision.
  https://docs.belle2.org/record/2038?ln=en




- We improve over this work
  -better selection, measurement of $\mathscr{A}_{det}$ dependences, remove $\mathscr{A}_{\mathrm{FB}}$ asymmetries
- Today: how to determine $\mathscr{A}_{det}$ for physics analyses.

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

- Observed charge asymmetries $\mathscr{A}_{\rm obs}$:

$$\mathscr{A}_{\rm obs} = \frac{N_D - N_{\bar{D}}}{N_D + N_{\bar{D}}} = \mathscr{A}_{CP} + \mathscr{A}_{det} + \mathscr{A}_{\rm FB}$$

Observed asymmetry

CP-violating asymmetry

Instrumental asymmetry

Forward-backward asymmetry

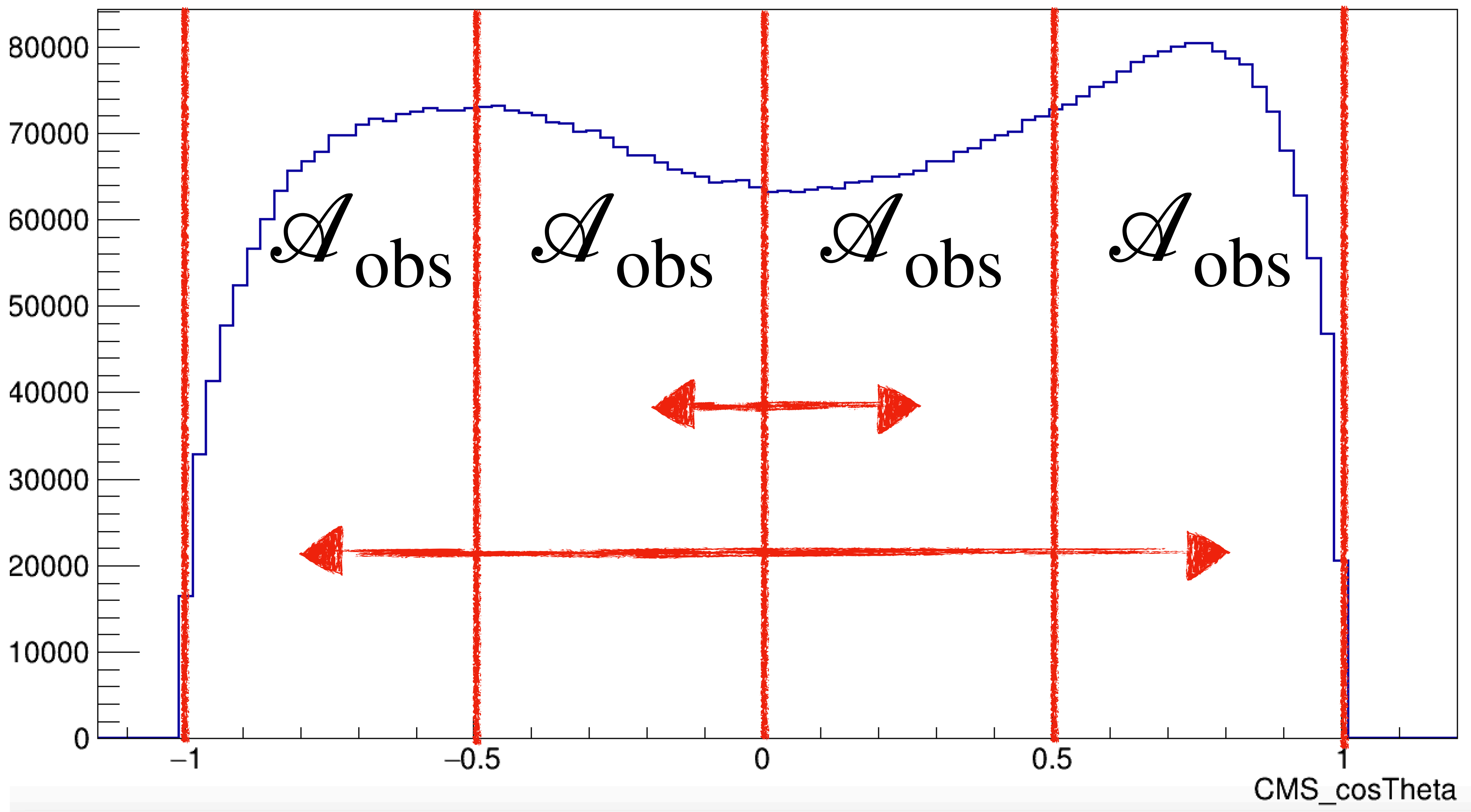
- $\mathscr{A}_{\rm CP}$ known for $D^0 \to K^-\pi^+$ and $D^+ \to K^0_s\pi^+$:

$$\mathscr{A}_{CP}(K\pi) = 0 \quad \text{and} \quad \mathscr{A}_{CP}(K^0_s\pi) = (-0.41 \pm 0.09)\,\%$$

- $\mathscr{A}_{\rm FB}$ remains to be subtracted.

# 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 a function of $cos(\theta^*)$ (angle of D momentum in the CMS).
  [https://arxiv.org/abs/1406.6311](https://arxiv.org/abs/1406.6311)
- Cancel $\mathscr{A}_{FB}$ by combining measurement of $\mathscr{A}_{obs}$ in opposite bins of $cos(\theta^*)$:




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

NB: Assume that $\mathscr{A}_{det}$ is not antisymmetric as a function of $cos(\theta^*)$.

# Sample and selection

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

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

Vertex fit on D: treefit

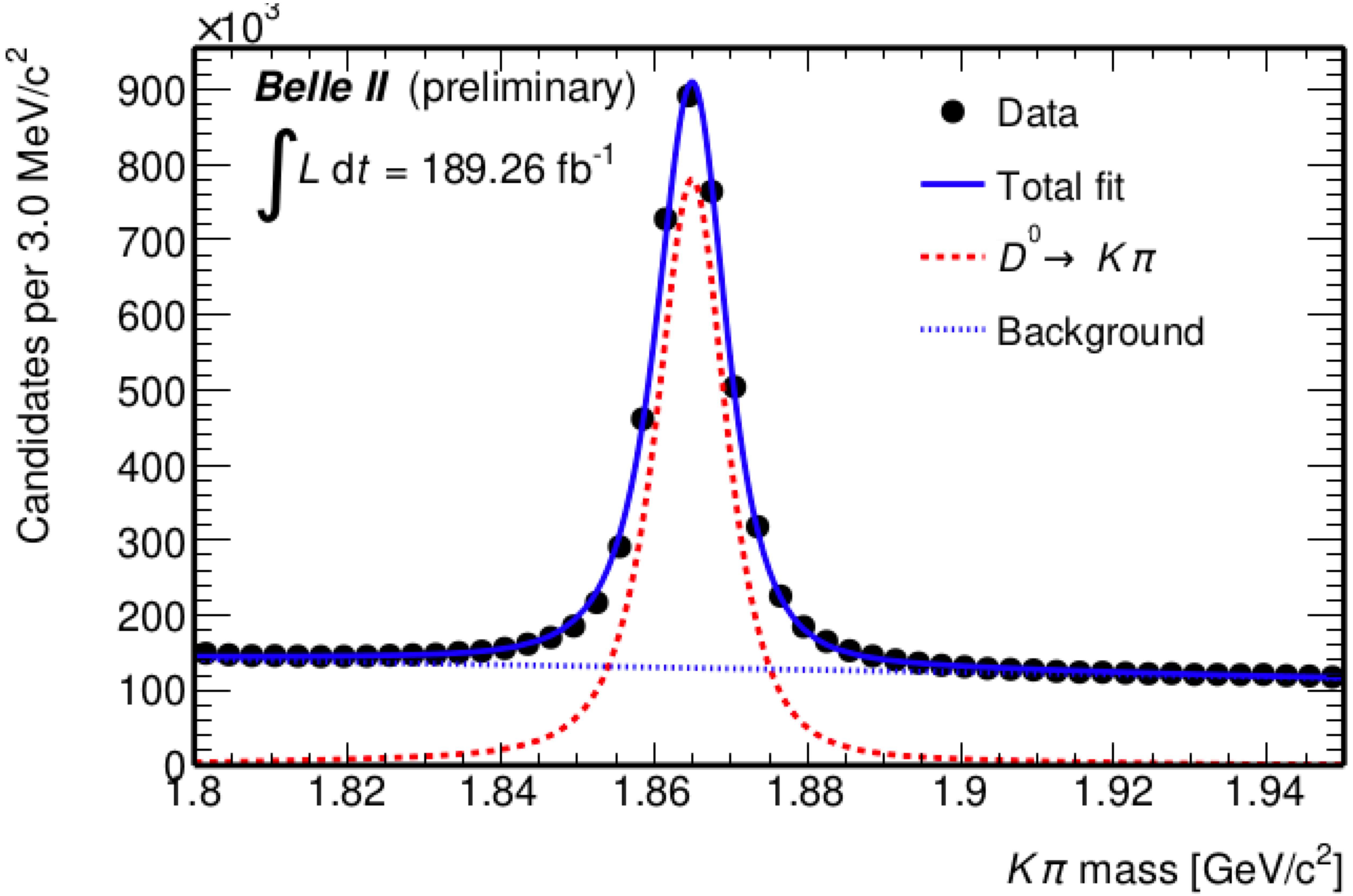
Applied the latest beam energy and momentum corrections.

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

| $D^0 \rightarrow K^- \pi^+$ | $D^+ \rightarrow K_s^0 \pi^+$ |
|---|---|
| KaonID>0.25 + p_CMS(D) >2.5 GeV/c | p_CMS(D) >2.5 GeV/c + 0.4942GeV/$c^2$<m(Ks)<0.5014Gev/$c^2$+ Significance of distance (Ks) >44.5 |

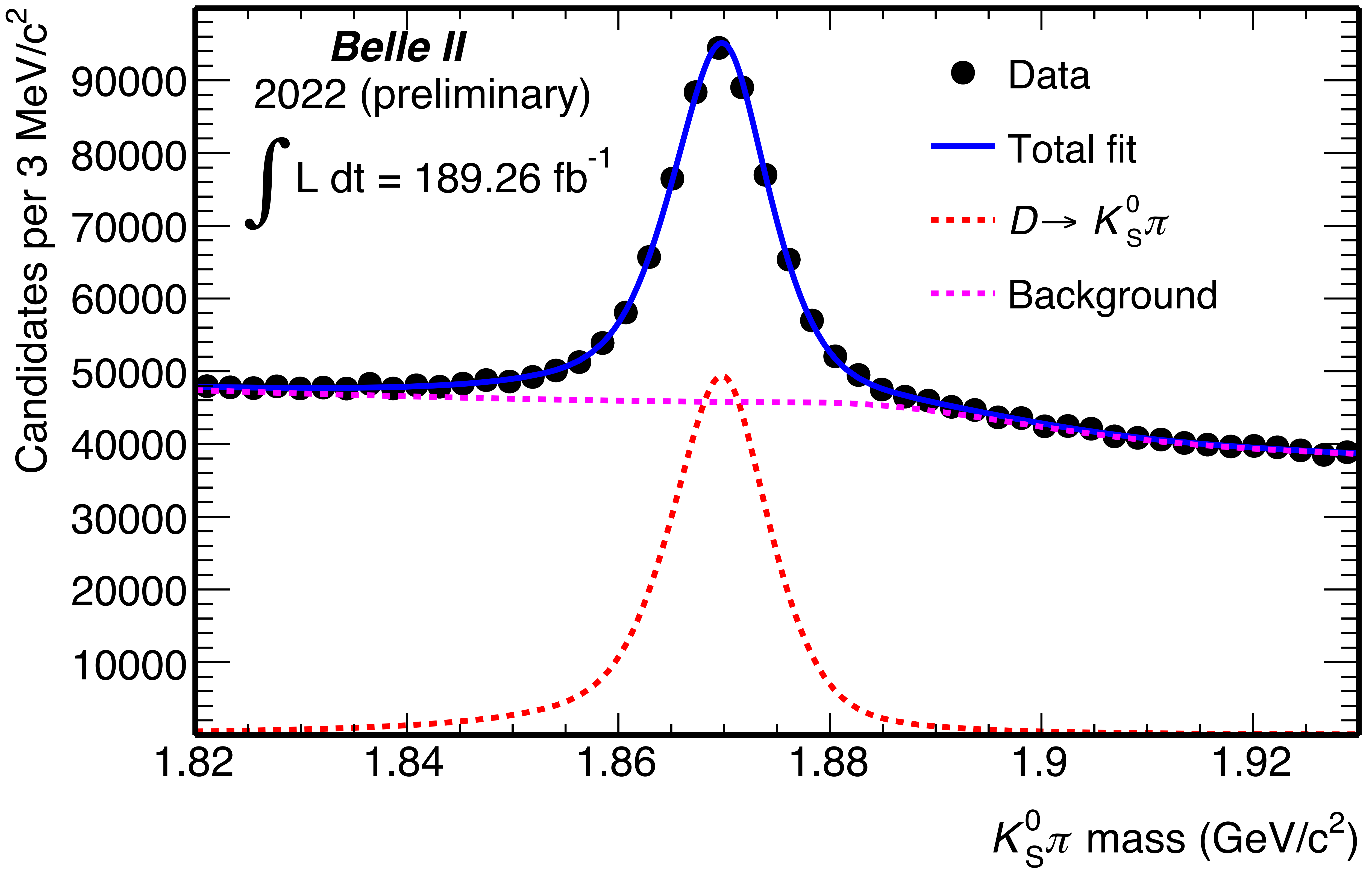
# $D^0 \to K^-\pi^+$ and $D^+ \to K_s^0\pi^+$ samples

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




$n_{sig} \sim 3.71 \times 10^6$

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




$n_{sig} \sim 3.18 \times 10^5$

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

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

- Study $\mathscr{A}_{\text{det}}(K\pi)$ 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.

There might be also other dependences, but we identify these 3 as those only relevant at the current level of precision.

- Study $\mathscr{A}_{\text{det}}(K\pi)$ as a function of kaon variables.

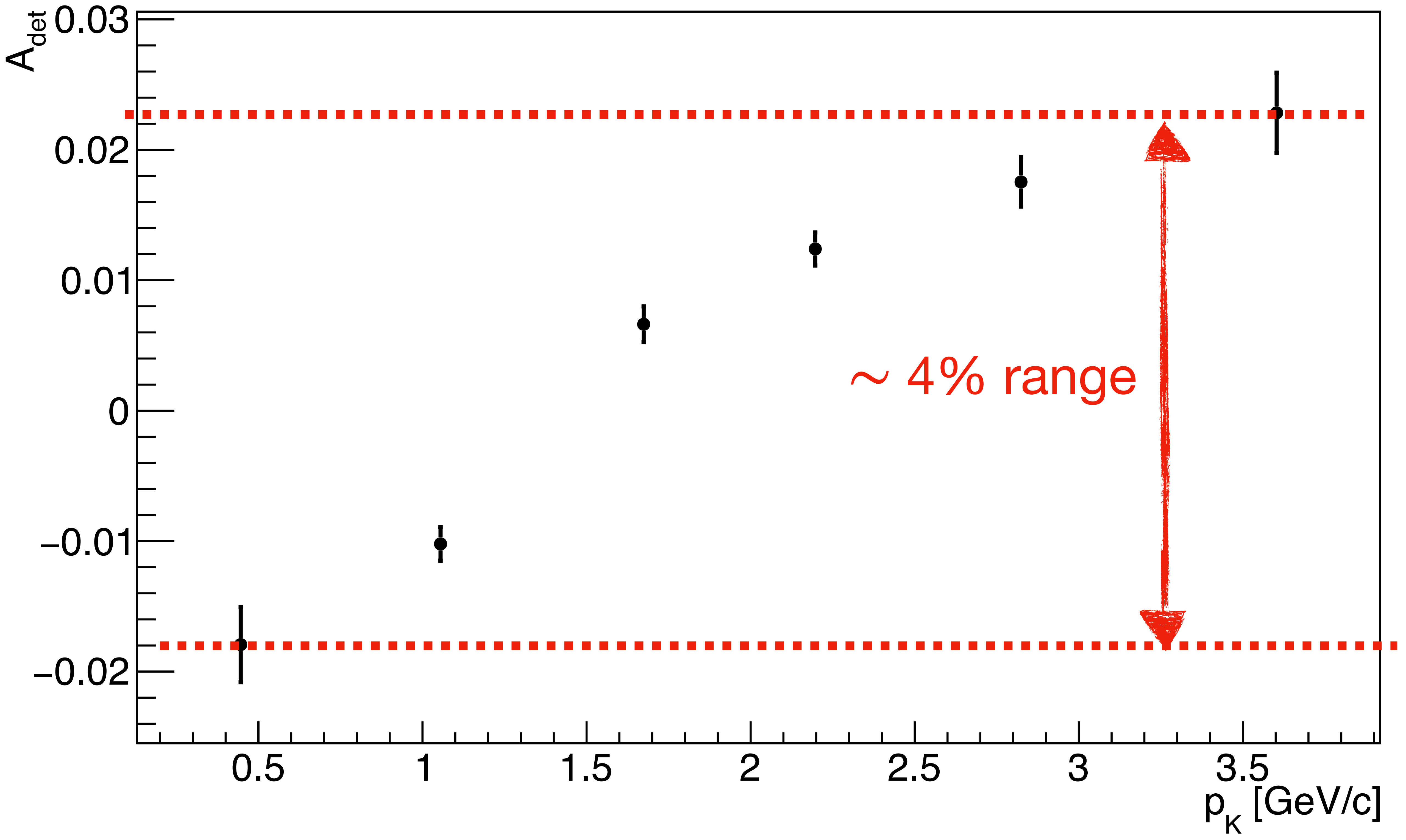
$$\mathscr{A}_{det}(K\pi) \simeq \mathscr{A}_{det}(K) + \mathscr{A}_{det}(\pi)$$

$$\mathscr{A}_{det}(K) \gg \mathscr{A}_{det}(\pi)$$

# $\mathscr{A}_{\text{det}}(K\pi)$ dependence on momentum and polar angle

$$\mathscr{A}_{\text{obs}} = \frac{N_{D^0} - N_{\bar{D}^0}}{N_{D^0} + N_{\bar{D}^0}}$$

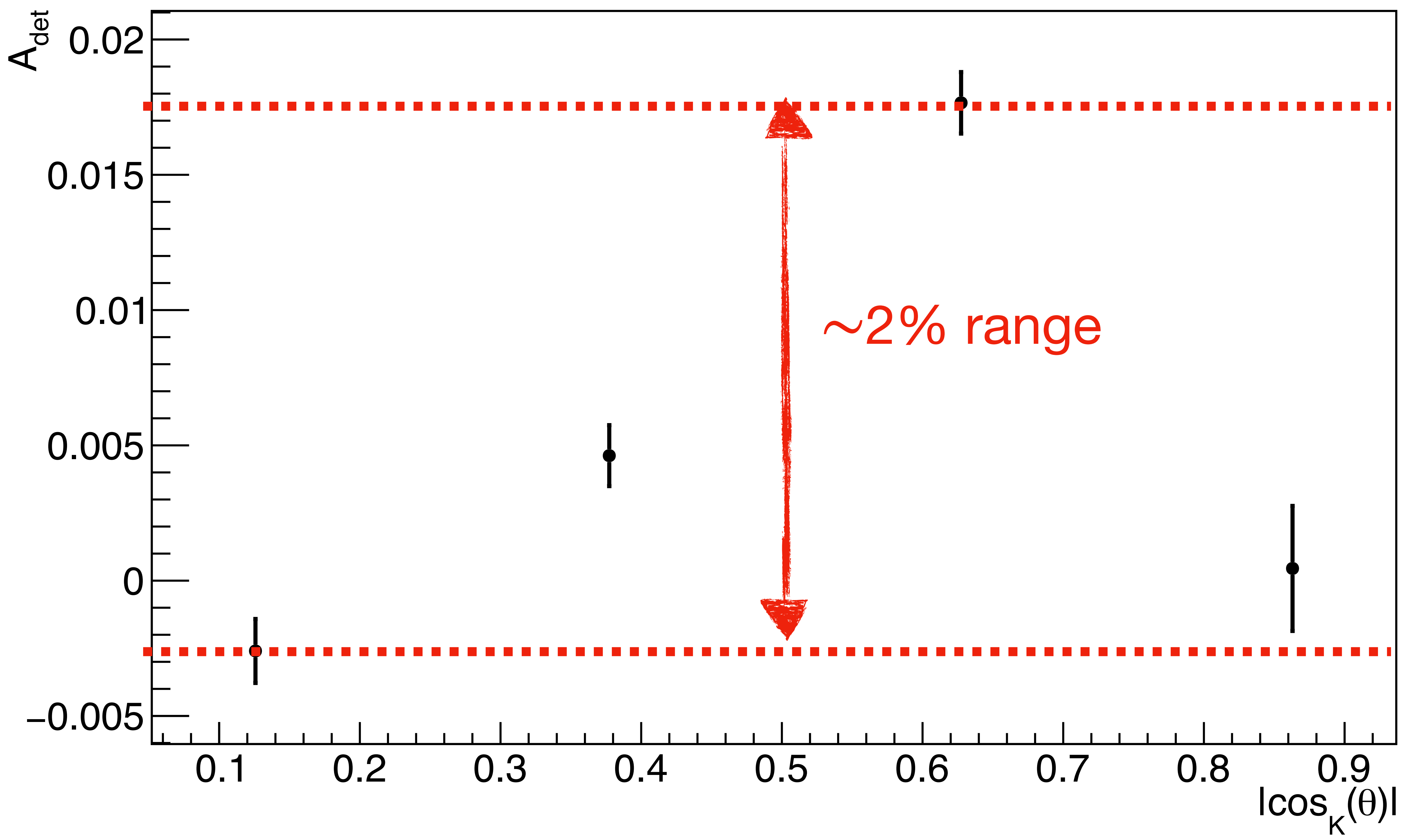
Check marginal distribution:
integrate over $cos_K(\theta)$ and CDC hits of kaon.




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

different interaction probabilities with matter

Check marginal distribution:
integrate over $p_K(\theta)$ and CDC hits of Kaon.



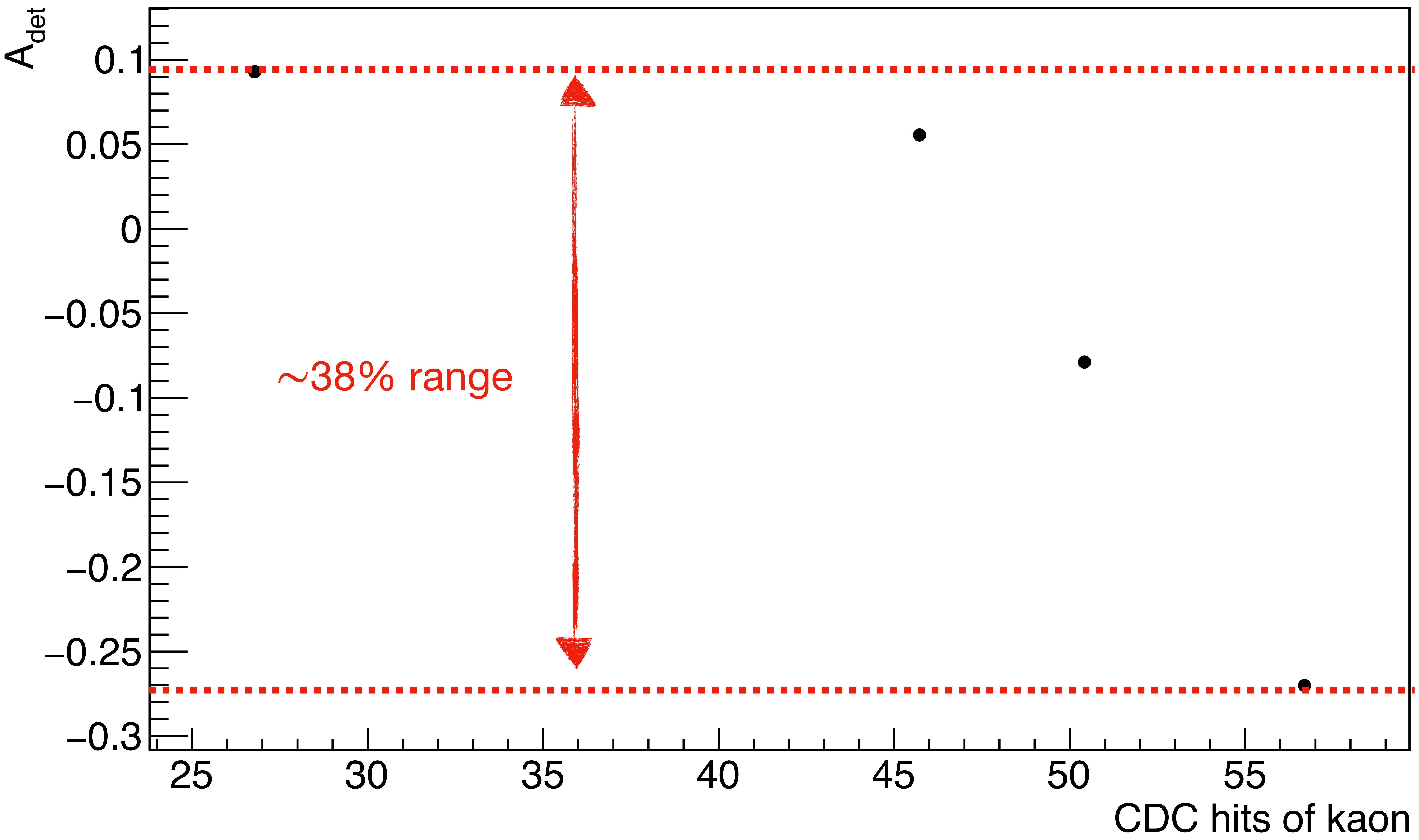

$\mathscr{A}_{det}$ depends on $cos_K(\theta)$

different material budget traversed by particle

# $\mathscr{A}_{\text{det}}(K\pi)$ dependence on CDC hits

$$\mathscr{A}_{\text{obs}} = \frac{N_{D^0} - N_{\bar{D}^0}}{N_{D^0} + N_{\bar{D}^0}}$$

Integrate over all kinematic variables.




Strong dependence of $\mathscr{A}_{det}$ on CDC hits of kaon

# $\mathscr{A}_{\text{det}}(K\pi)$ for physics analyses

- $p$, $cos(\theta)$,CDChits distributions of target analyses can be different from our control channel.
- Correct the distributions of the control channel to match those of any target decay:
    1. Split the control channel in bins of CDC hits;
    2. In each bin:
        A. Correct the ($p, cos(\theta)$) distributions of the control channel (weights from MC);
        B. Determine $\mathscr{A}_{\text{det}}$ on the corrected-sample.
    3. Average the $\mathscr{A}_{\text{det}}$ values considering the CDC hits distribution of the target decay (known data-MC discrepancy (drift-time mismodeling) → take it from data).

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

- Consider $B^0 \to K\pi$ decays (CS>0.95, KaonID>0.25).

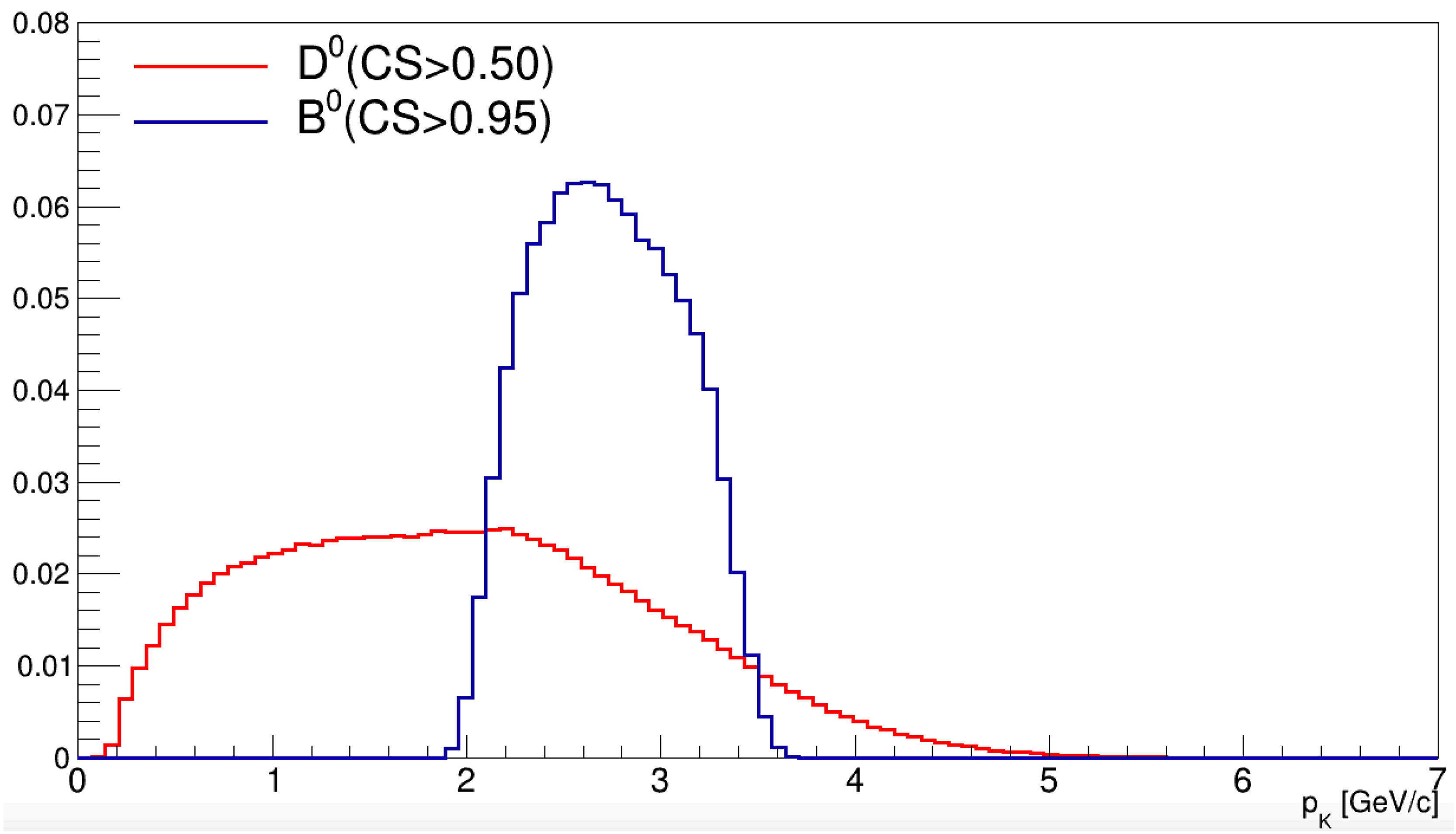
  $\mathscr{A}_{\text{det}}(K\pi) = 0.0012 \pm 0.0015$ (target).

- $D^0 \to K\pi$ control channel (CS>0.50, KaonID>0.25).

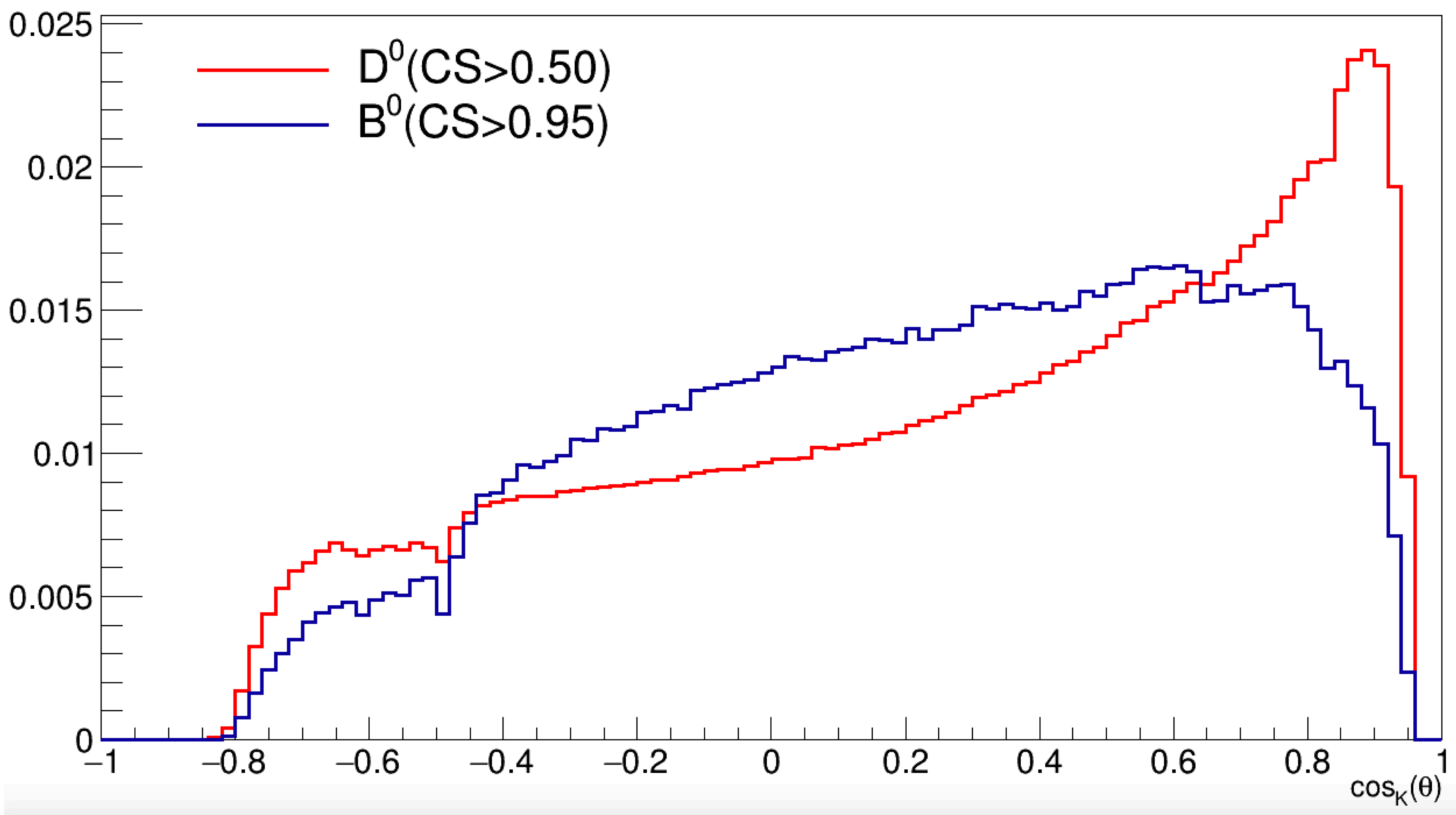
  $\mathscr{A}_{\text{det}}(K\pi) = -0.0076 \pm 0.0007$ (start value).

- Different $\mathscr{A}_{\text{det}}(K\pi)$ values are expected since $p_K$, $cos_K(\theta)$,CDChits(K) distributions differs:

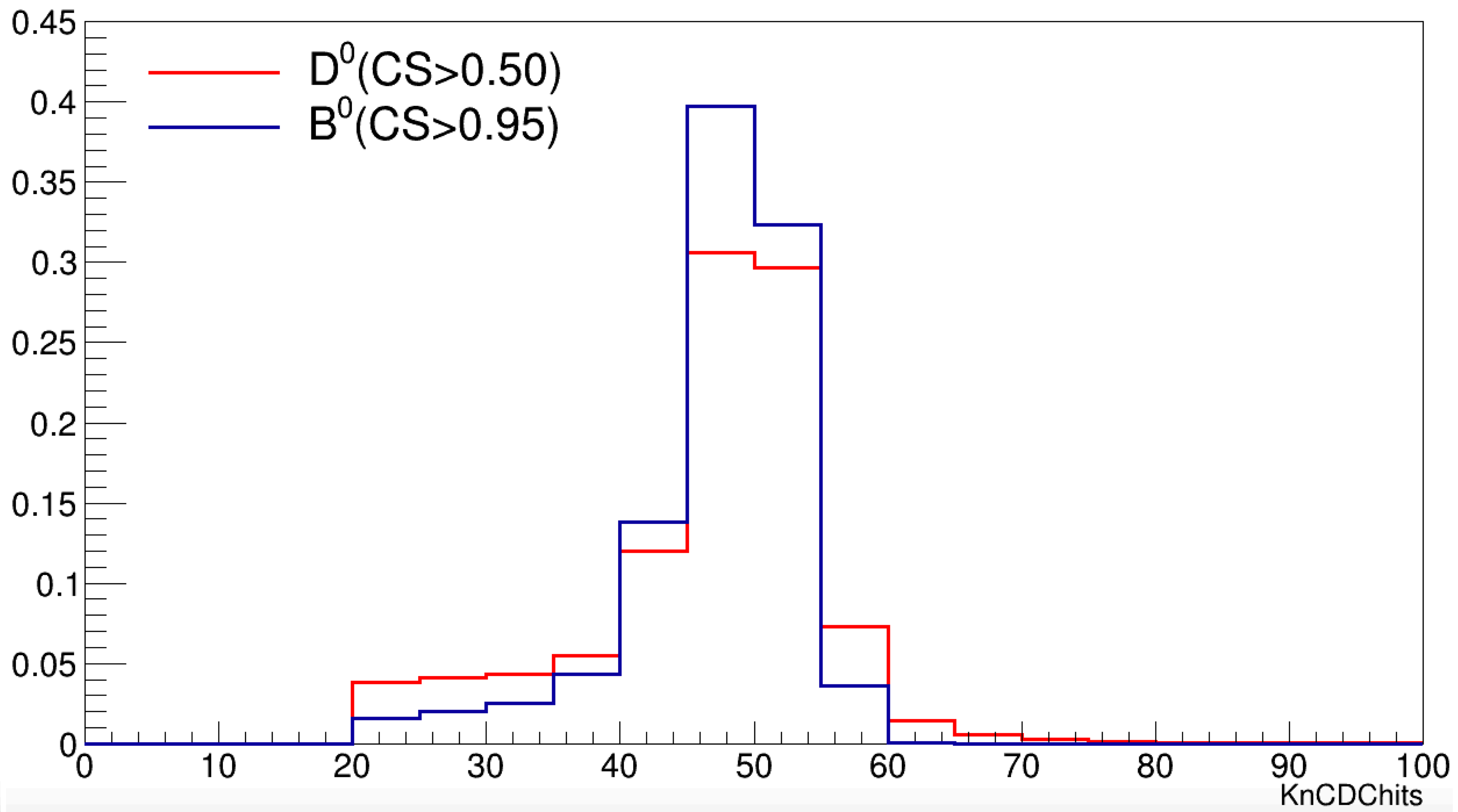
$p_K$ distributions




$cos_K(\theta)$ distributions



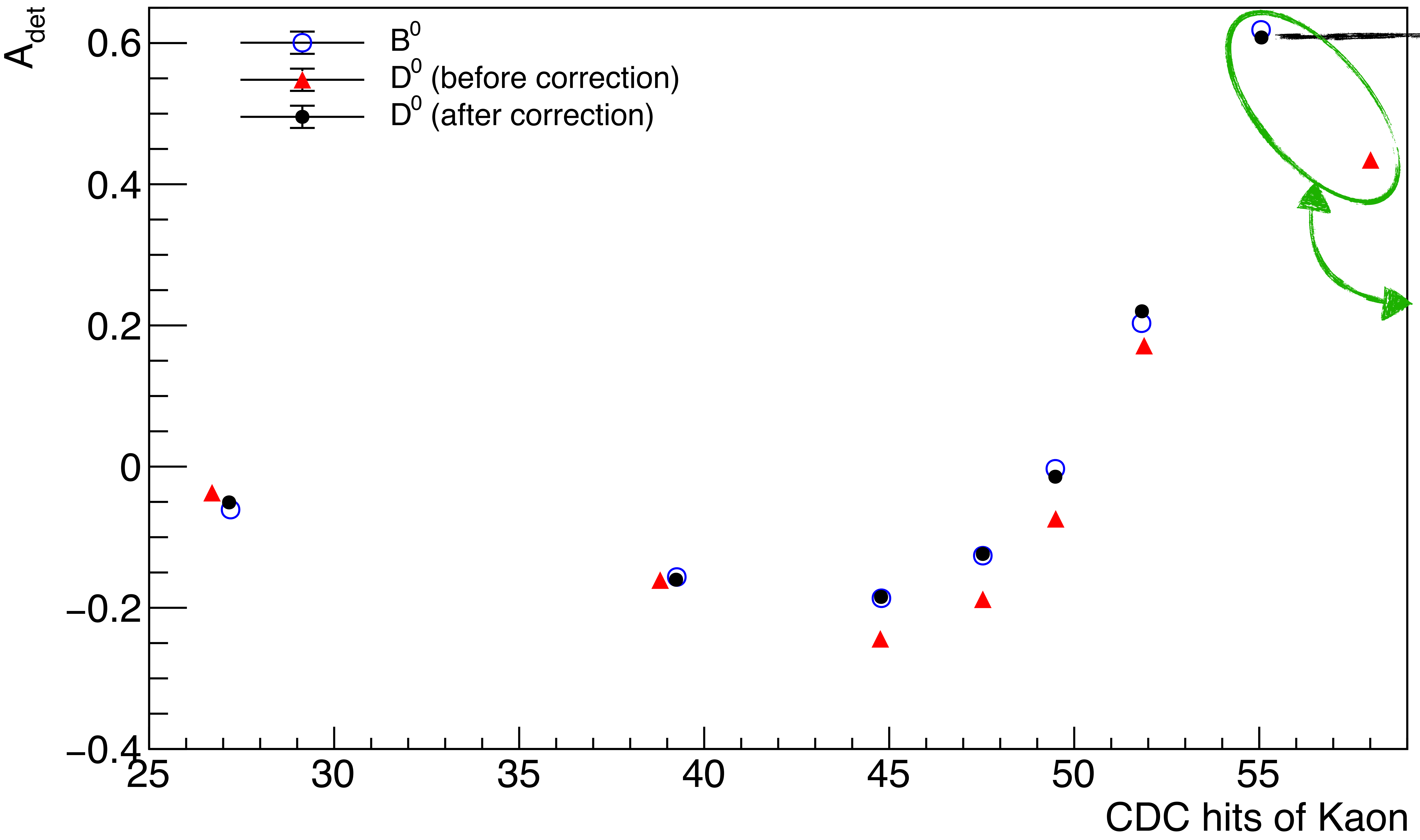

CDChits(K) distributions



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

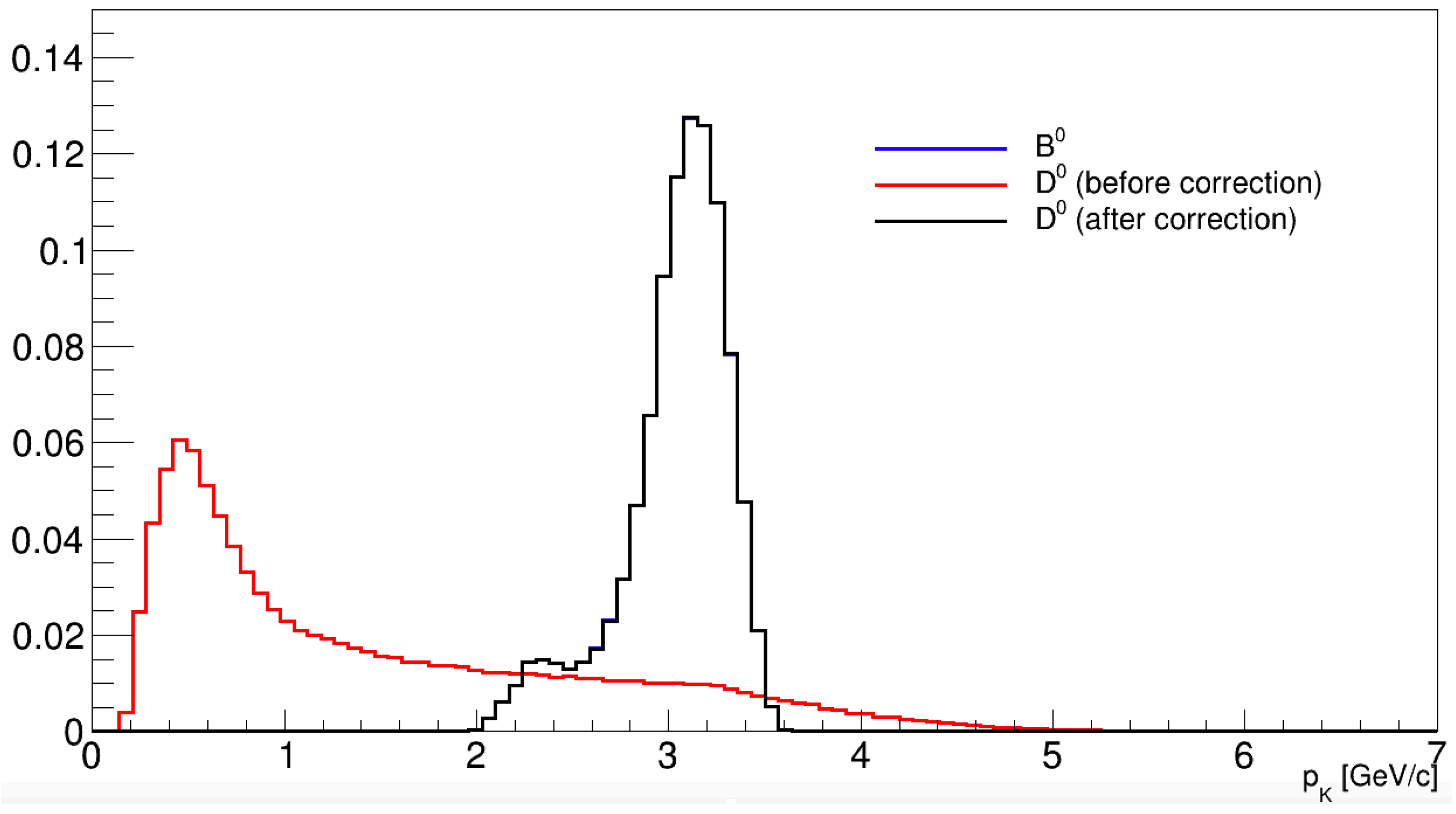

The points are placed at the average of the CDChits distribution in the bin.

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

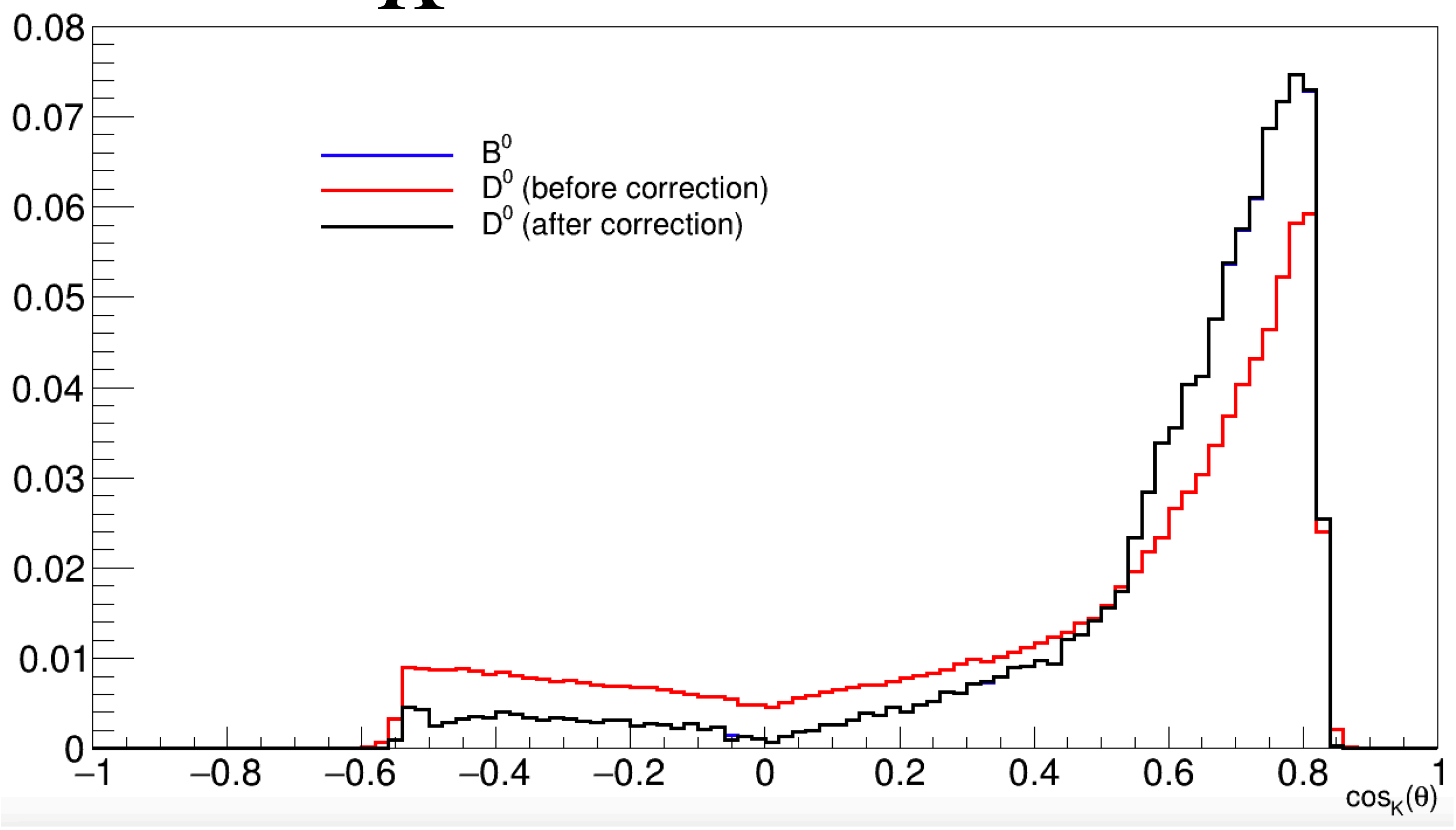



$\mathscr{A}_{det}$ from $D^0 \to K\pi$ after the correction: match the target value.

## $p_K$ distributions




## $cos_K(\theta)$ distributions



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

- Average $\mathscr{A}_{det}(K\pi)$ values from corrected $D^0$ sample, considering CDChits distribution of $B^0$:

$$\mathscr{A}_{det}(K\pi) = 0.0015 \pm 0.0007 \text{ (after correction)}$$

in agreement with

$$\mathscr{A}_{det}(K\pi) = 0.0012 \pm 0.0015 \text{ (target)}$$

- We checked the procedure for different PID and CS selections and get expected results.

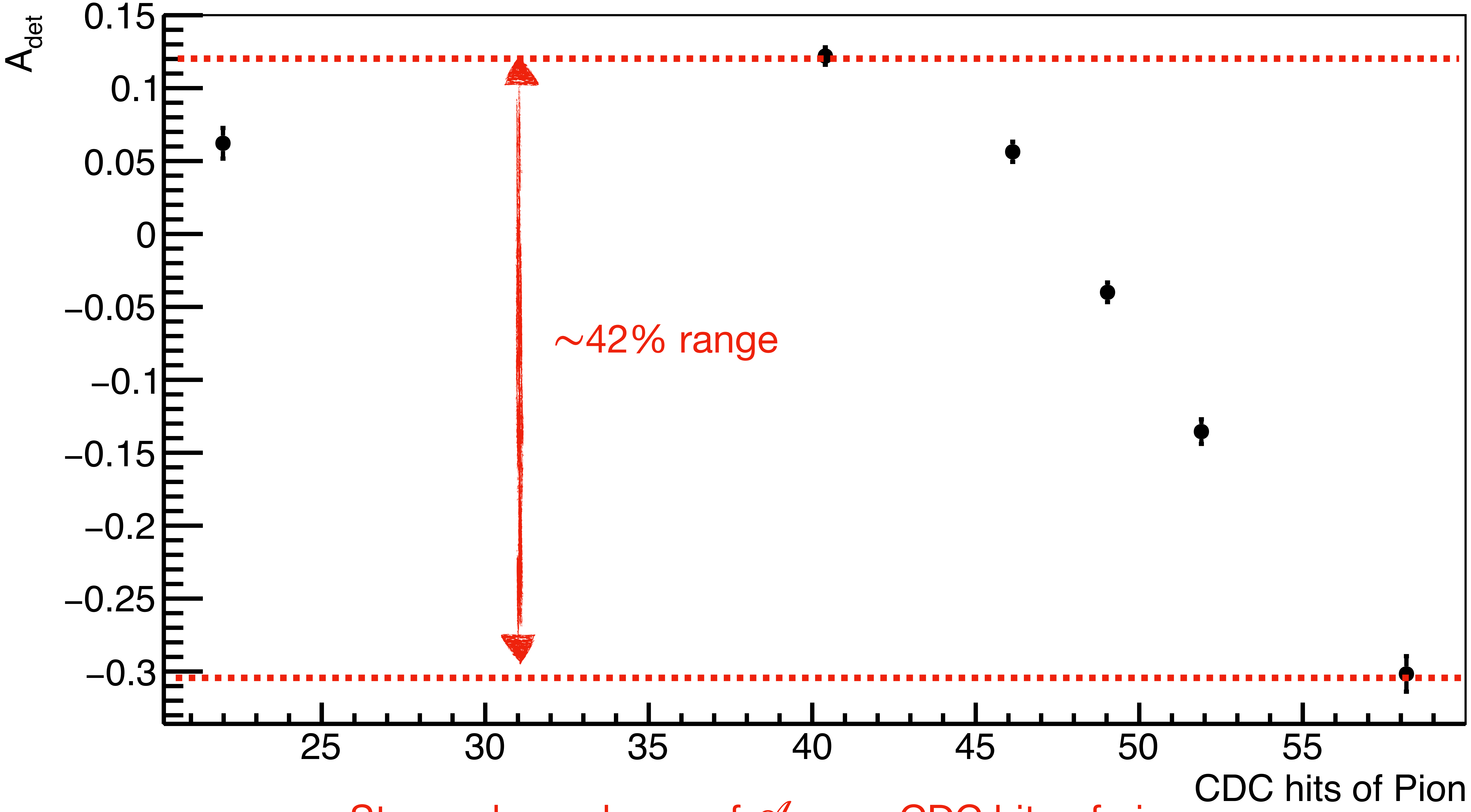
# $\mathscr{A}_{det}(\pi)$ from $D^+ \to K_s^0\pi^+$

# $\mathscr{A}_{\rm det}(\pi)$ dependence on CDC hits

$$\mathscr{A}_{\rm obs} = \frac{N_{D^-} - N_{D^+}}{N_{D^-} + N_{D^+}}$$

- Study $\mathscr{A}_{\rm det}(\pi)$ as a function of pion variables. Assume $\mathscr{A}_{det}(K_S^0) = 0$.

Integrate over all kinematic variables.

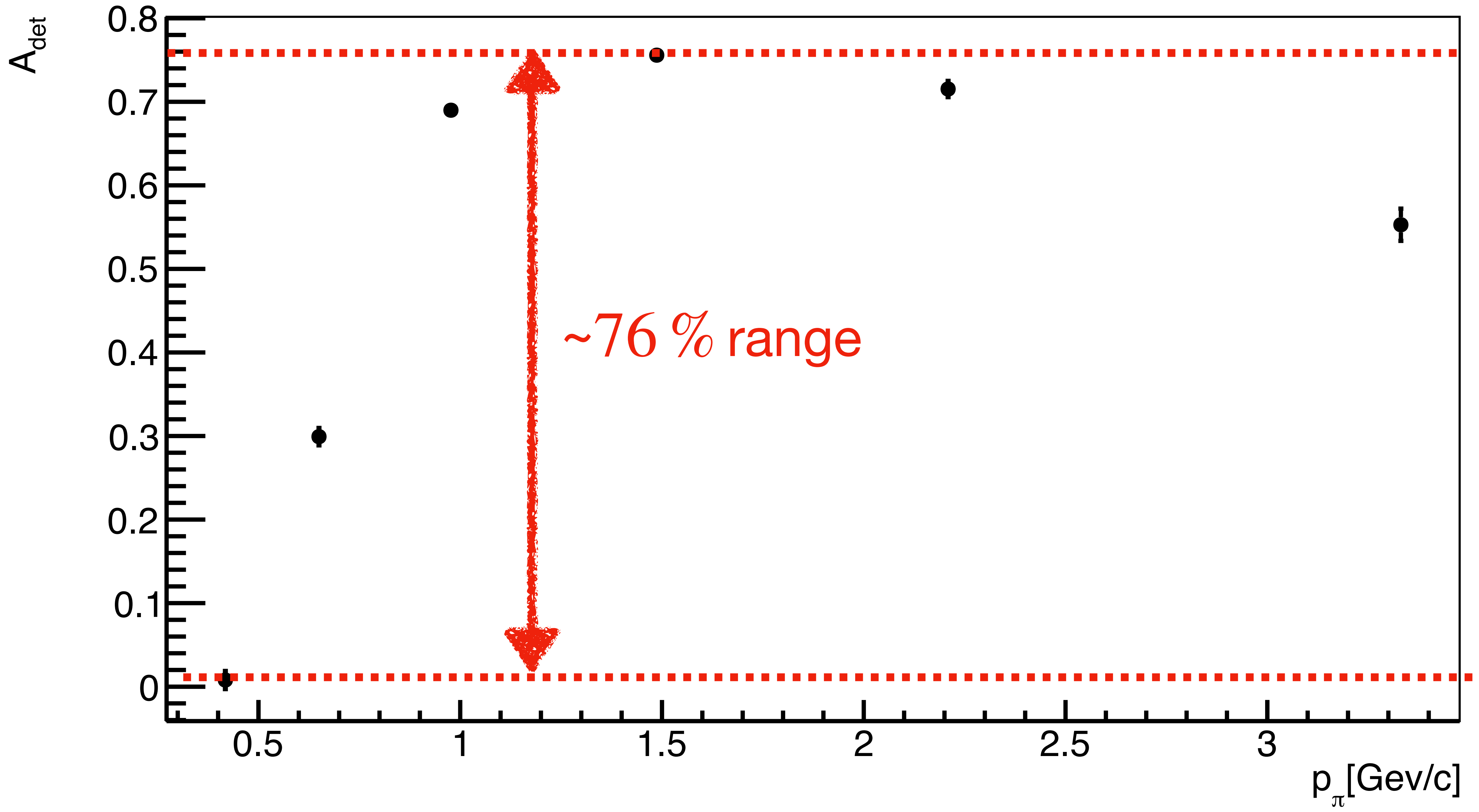



Strong dependence of $\mathscr{A}_{det}$ on CDC hits of pion.

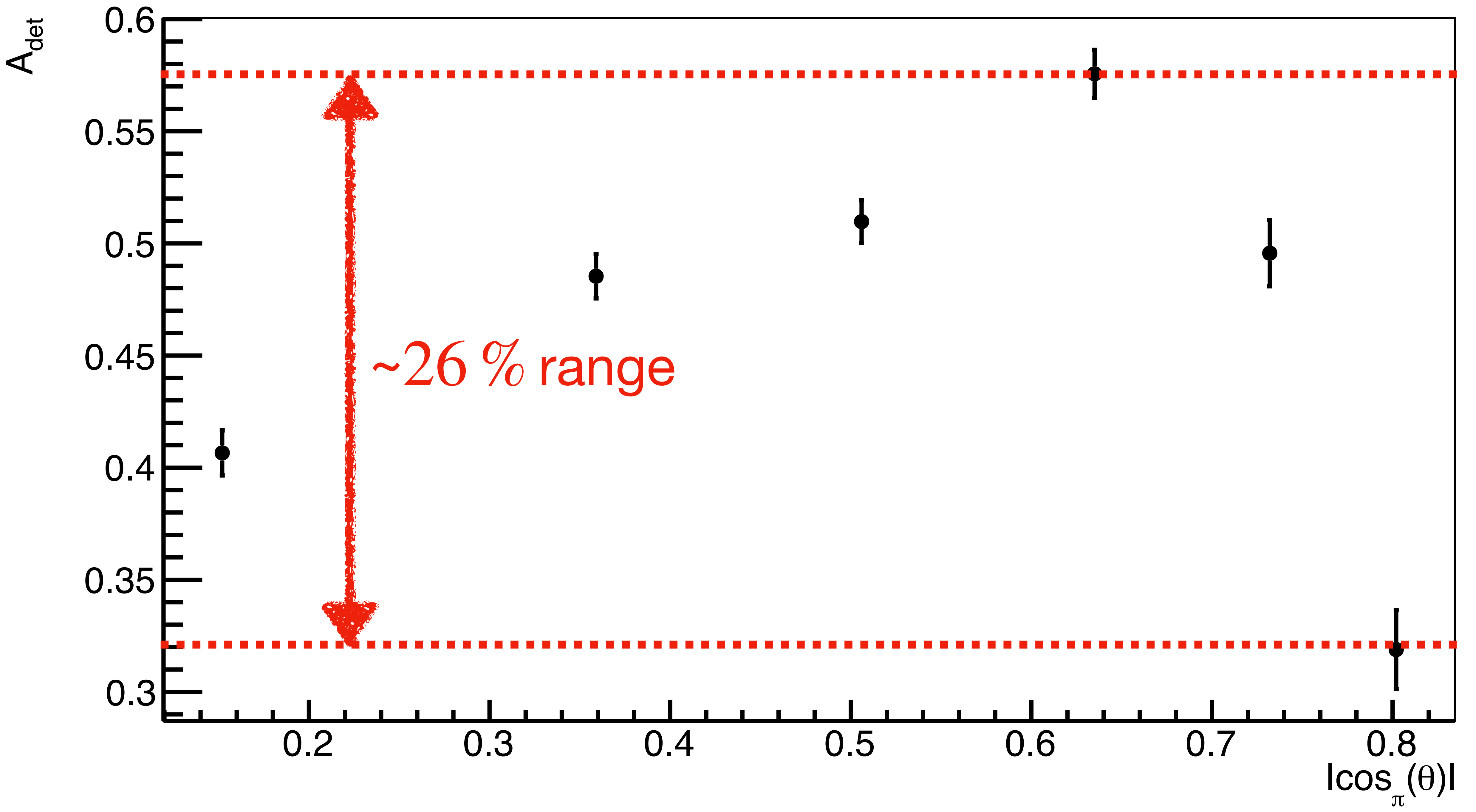
# $\mathscr{A}_{\text{det}}(\pi)$ dependence on momentum and polar angle

$$\mathscr{A}_{\text{obs}} = \frac{N_{D^-} - N_{D^+}}{N_{D^-} + N_{D^+}}$$

$\mathscr{A}_{det}(\pi)$ as a function of $\pi$'s momentum in a particular region of CDC hits (54 to 60 hits)




$\mathscr{A}_{det}(\pi)$ as a function of $\pi$'s polar angle in a particular region of CDC hits (54 to 60 hits)




Strong dependence of $\mathscr{A}_{det}$ on $p_\pi$ and $cos_\pi(\theta)$ in bins of CDC hits of pions

# $\mathscr{A}_{\mathrm{det}}(\pi)$ and $\mathscr{A}_{\mathrm{det}}(K)$

- The method is the same to compute $\mathscr{A}_{det}(\pi)$ using $D^+ \to K_s^0\pi^+$ for a given decay.
- 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 $D^+ \to K_s^0\pi^+$ to compute $\mathscr{A}_{det}(K)$:
    1. Given ($p_K$, $cos_K(\theta)$,CDChits(K)) distributions of a target decay, we can compute $\mathscr{A}_{det}(K\pi)$ using $D^0 \to K^-\pi^+$ channel;
    2. Weight the $\pi$ distributions of $D^+ \to K_s^0\pi^+$ 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 $\pi$, with a precision of $\mathcal{O}(1^o/_{oo})$ and $\mathcal{O}(3^o/_{oo})$ using $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K_s^0\pi^+$.

- 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.

- Can be used in analyses targeting ICHEP, e.g. GLW with $B^+ \rightarrow D^0h^+$, and $\mathscr{A}_{CP}$ in $B^+ \rightarrow h^+\pi^0$.

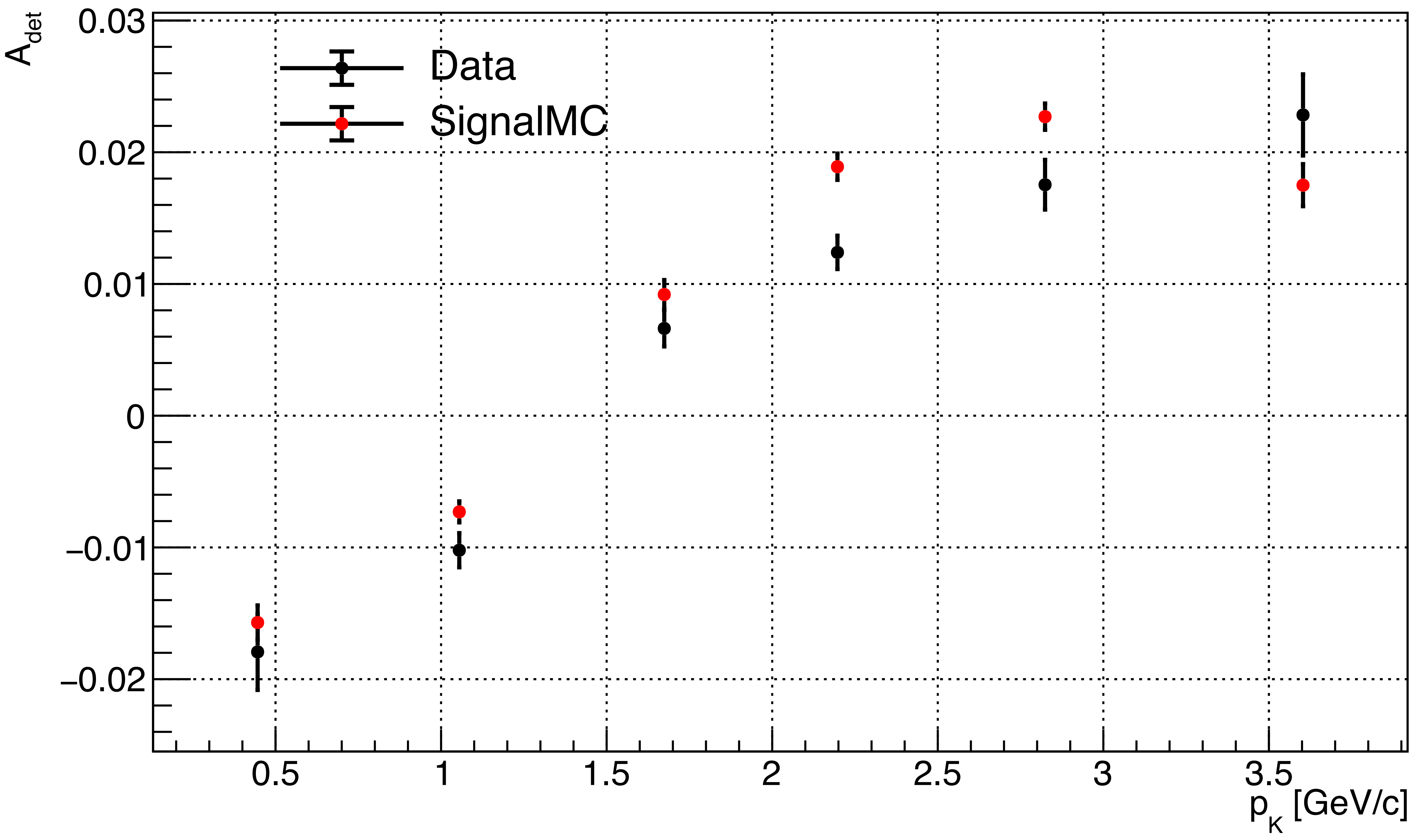
*Backup*

# $\mathscr{A}_{det}(K\pi)$ from $D^0 \to K^-\pi^+$

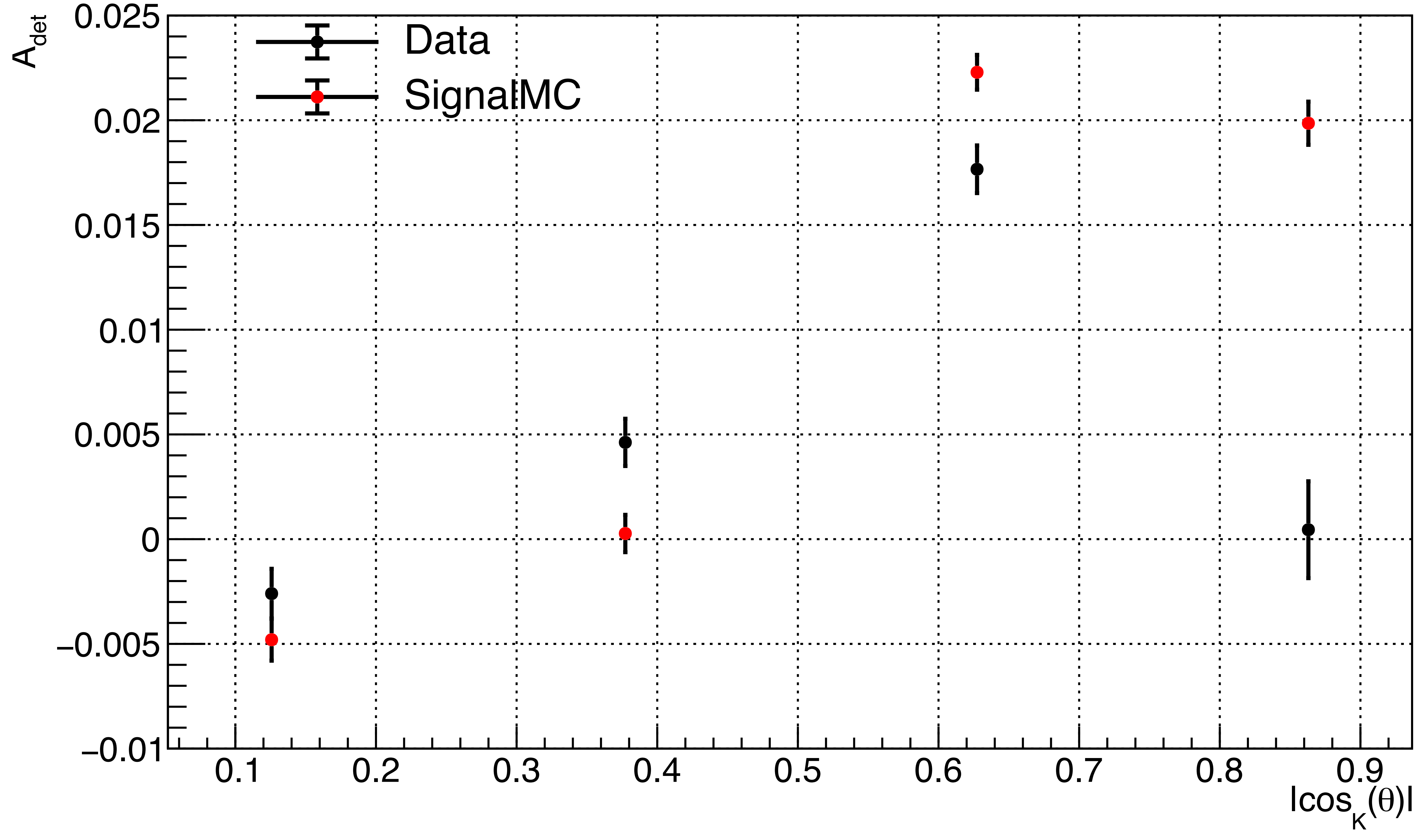
# $\mathscr{A}_{\text{det}}(K\pi)$ kinematics dependences: data vs MC

$$\mathscr{A}_{\text{obs}} = \frac{N_{D^0} - N_{\bar{D}^0}}{N_{D^0} + N_{\bar{D}^0}}$$

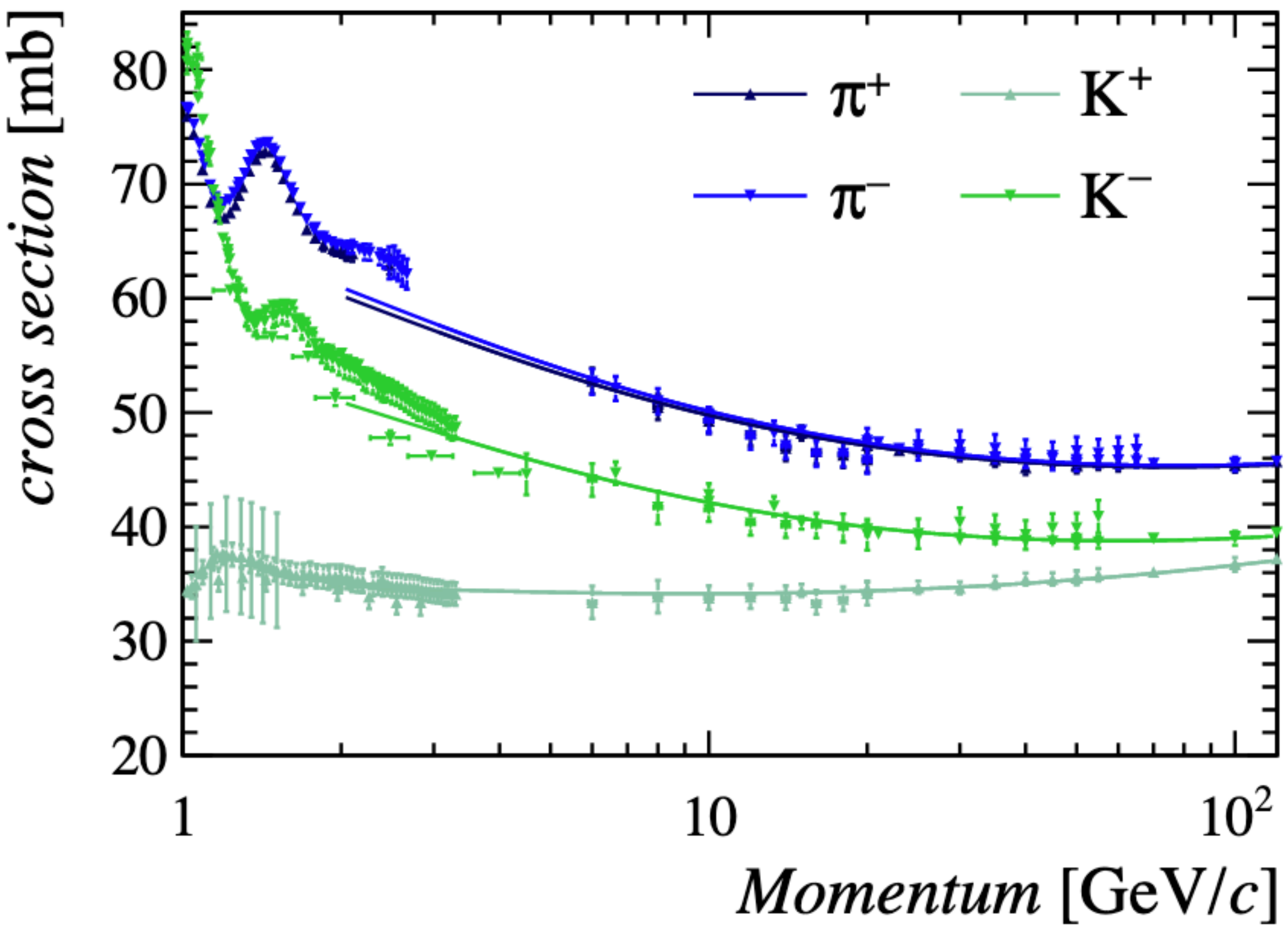
Check marginal distribution:
integrate over $cos_K(\theta)$ and CDC hits of kaon.




Check marginal distribution:
integrate over $p_K(\theta)$ and CDC hits of Kaon.

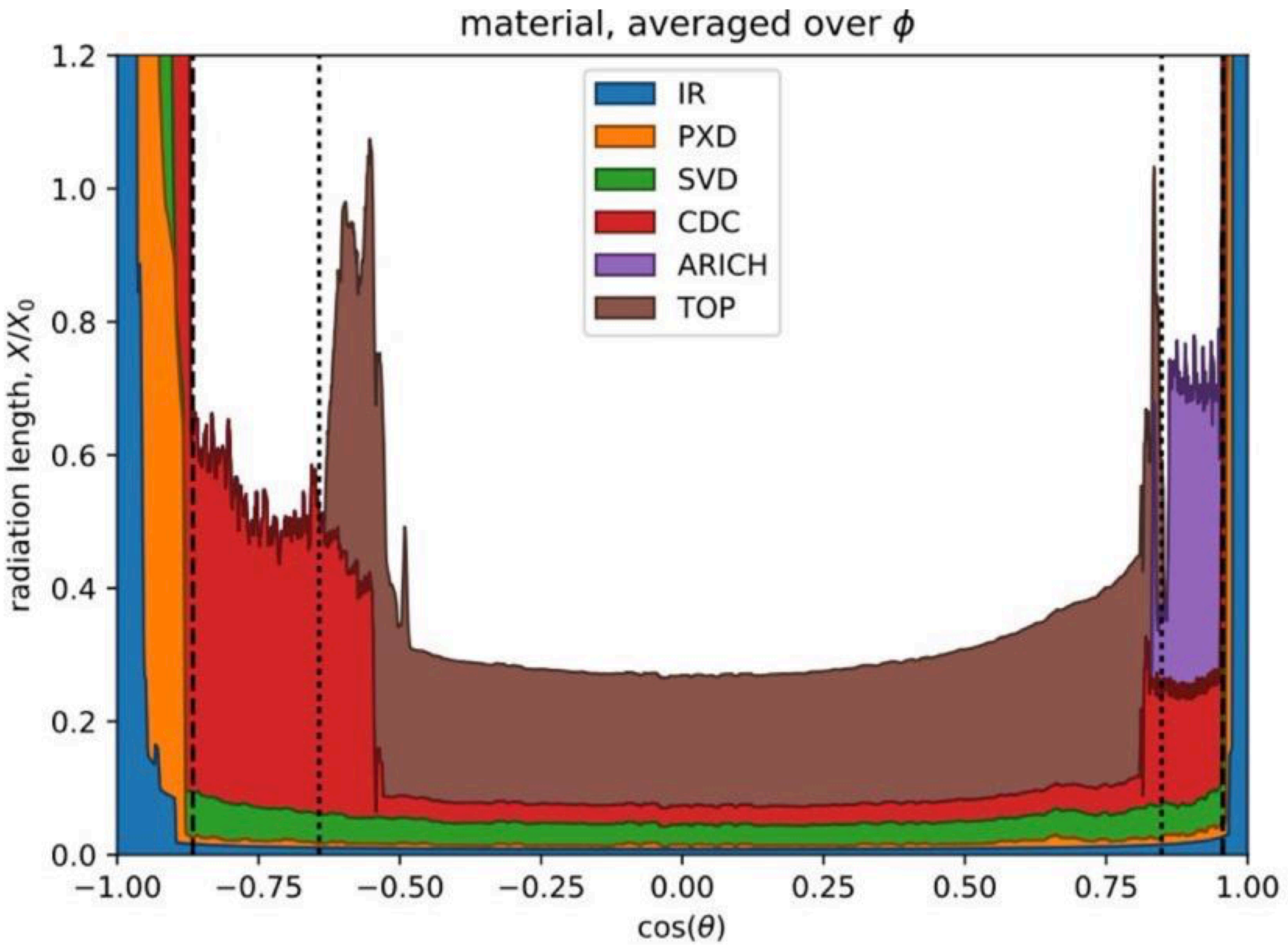


# $\mathscr{A}_{\text{det}}(K\pi)$ dependence on momentum




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

# $\mathscr{A}_{\text{det}}(K\pi)$ dependence on polar *angle*

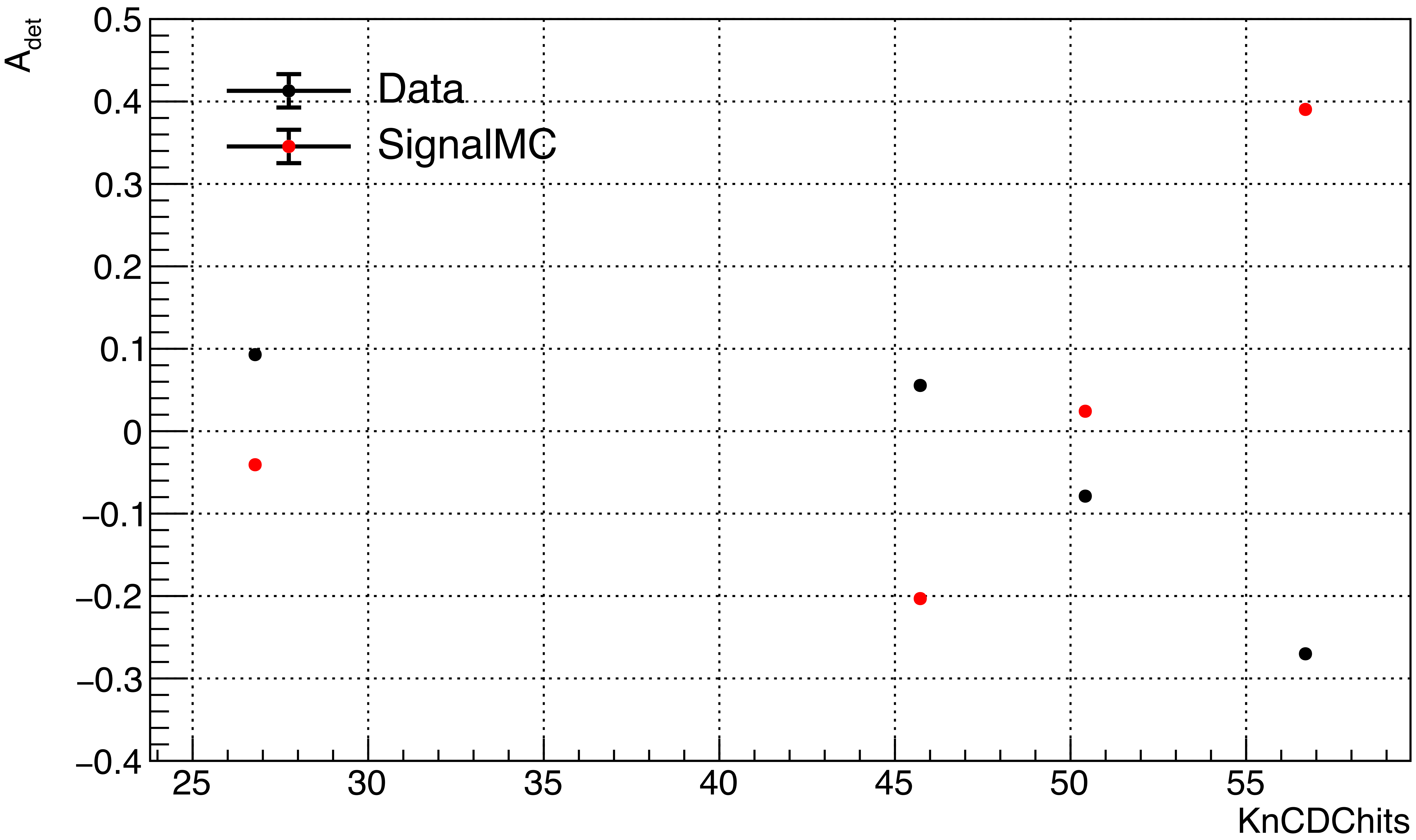



$\mathscr{A}_{det}$ depends on $cos_K(\theta)$ ⟷ different material budget traversed by particle.

# $\mathscr{A}_{\text{det}}(K\pi)$ dependence on CDC hits: data vs MC

$$\mathscr{A}_{\text{obs}} = \frac{N_{D^0} - N_{\bar{D}^0}}{N_{D^0} + N_{\bar{D}^0}}$$

Integrate over all kinematic variables.

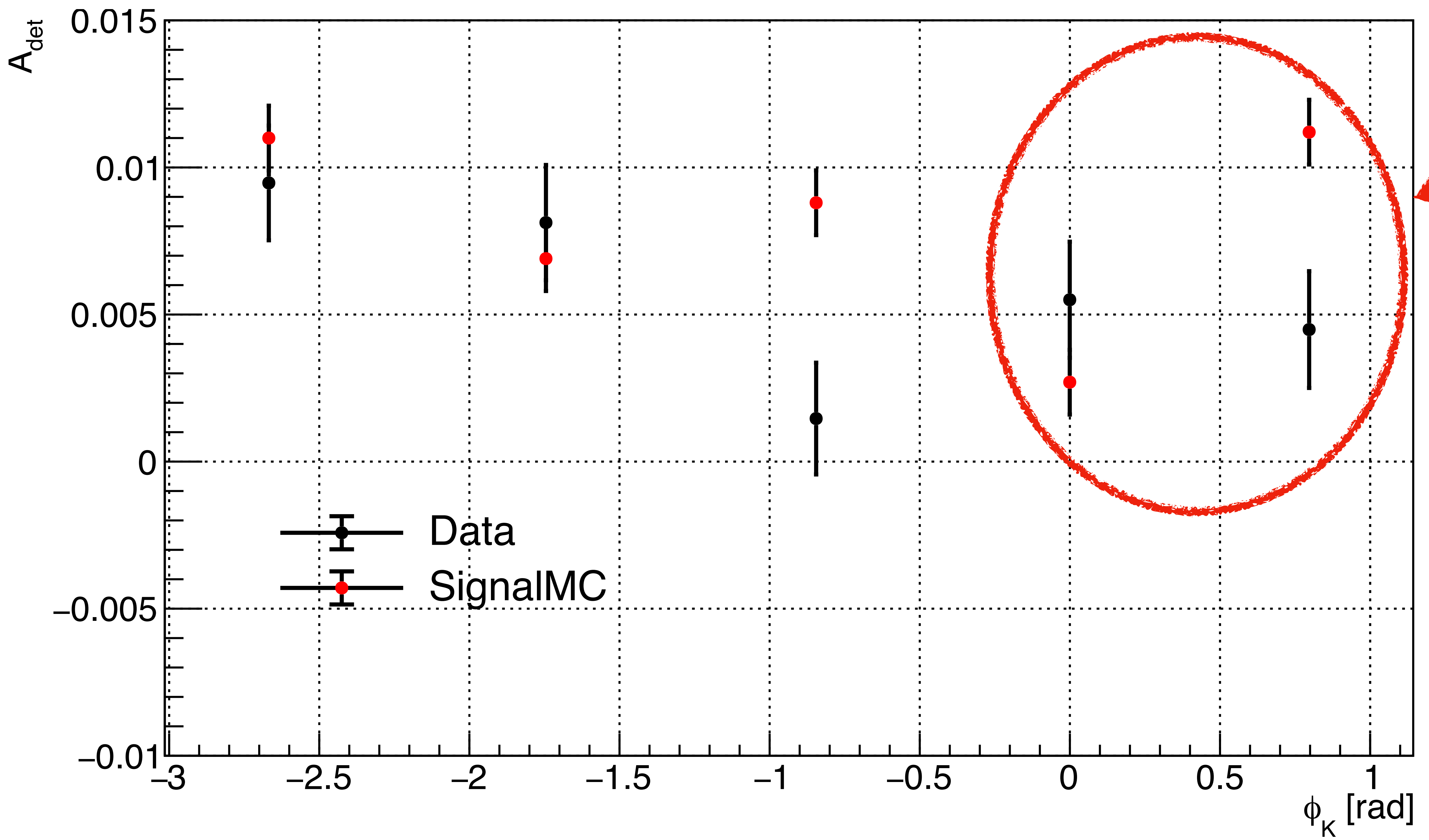


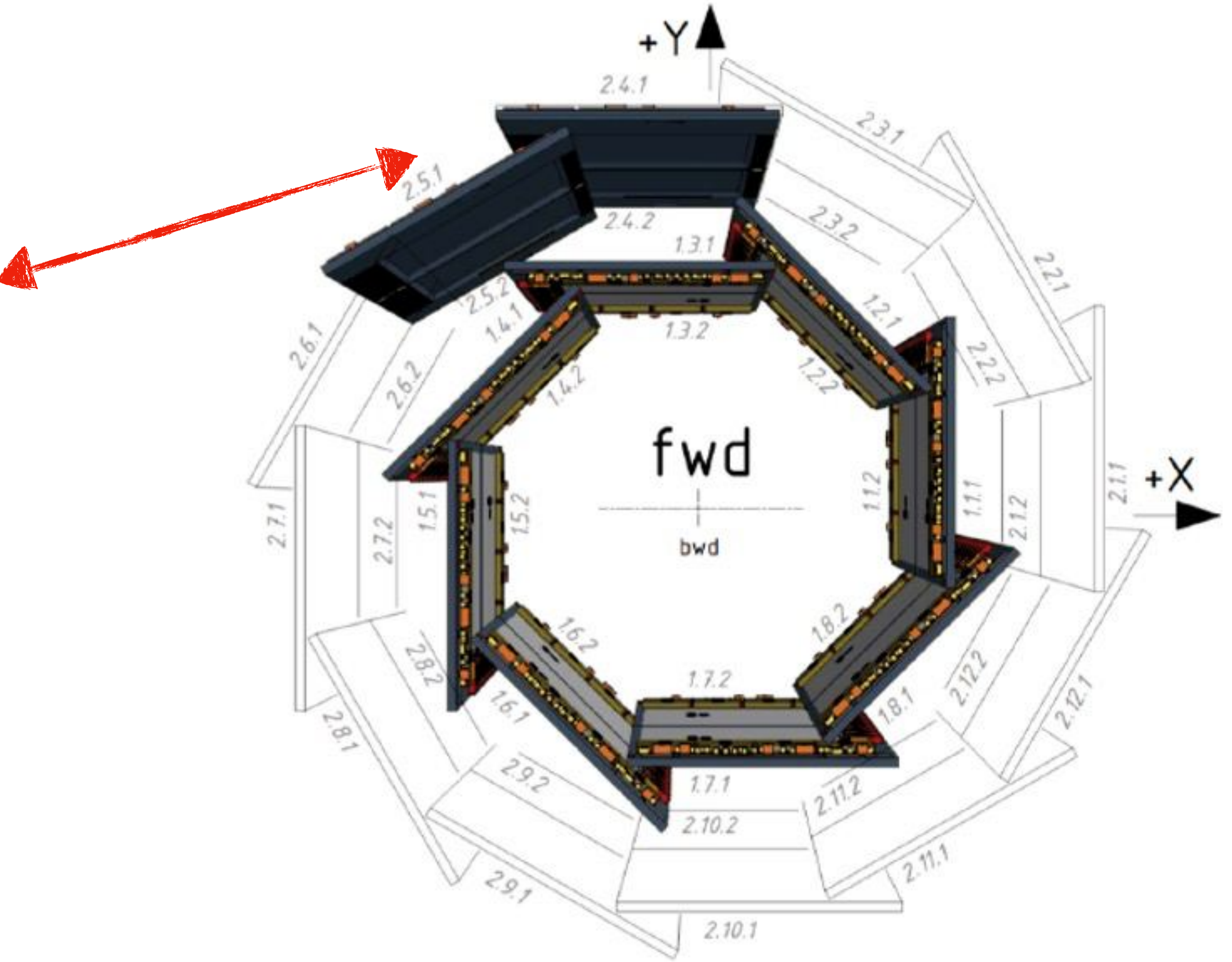

Strong dependence of $\mathscr{A}_{det}$ on CDC hits of kaon

Known Data-MC discrepancy due to CDC drift-time mismodeling.

# $\mathscr{A}_{\text{det}}(K\pi)$ dependence on azimuthal angle

Integrate over all kinematic variables and CDC hits of Kaon.




The circled points represent the $\mathscr{A}_{\text{det}}$ *values* in the $\phi_K$ region in which there are two layers of PXD (more material ).

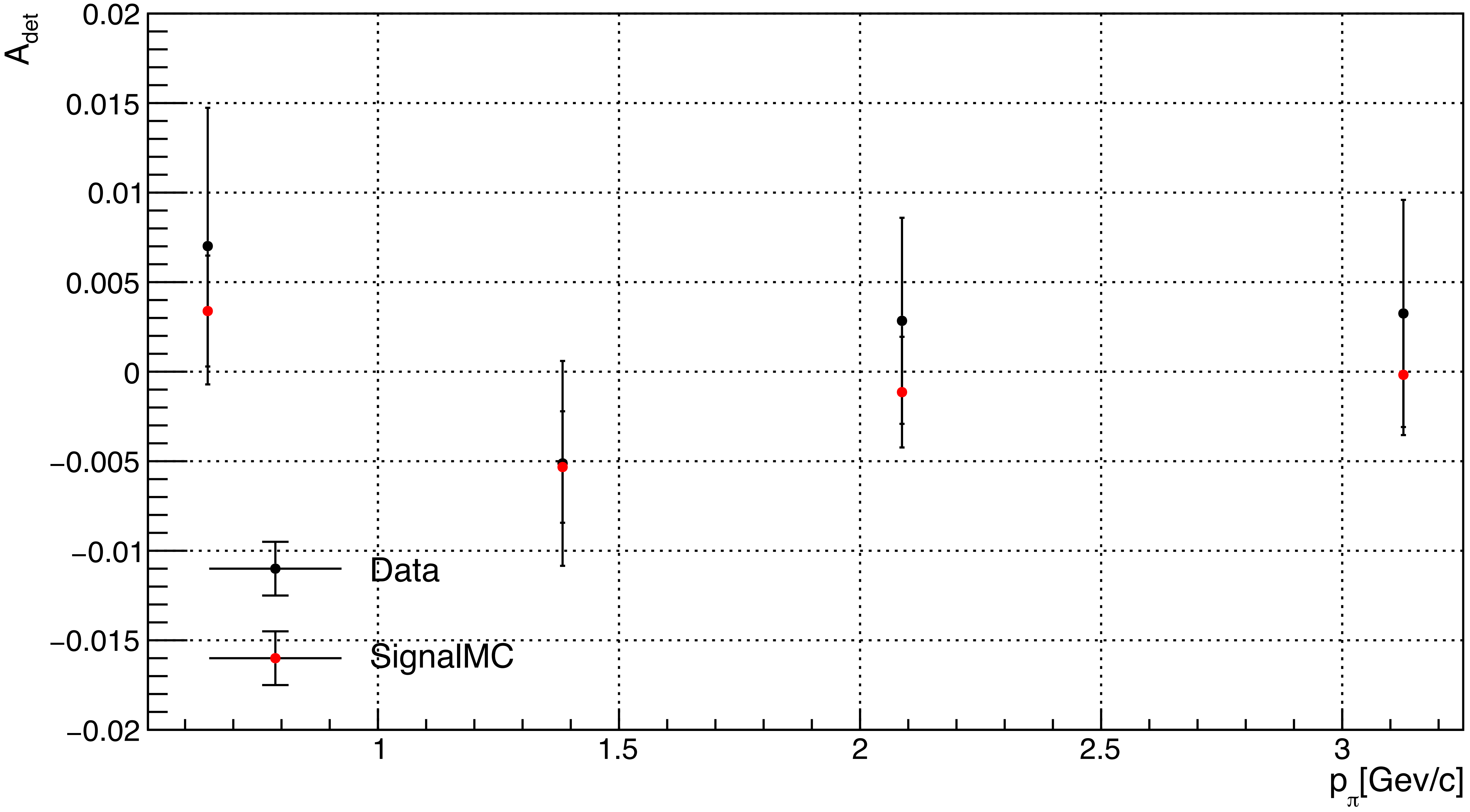
In any case, we assume no dependence on $\phi_K$.

# $\mathscr{A}_{det}(\pi)$ from $D^+ \to K_s^0 \pi^+$

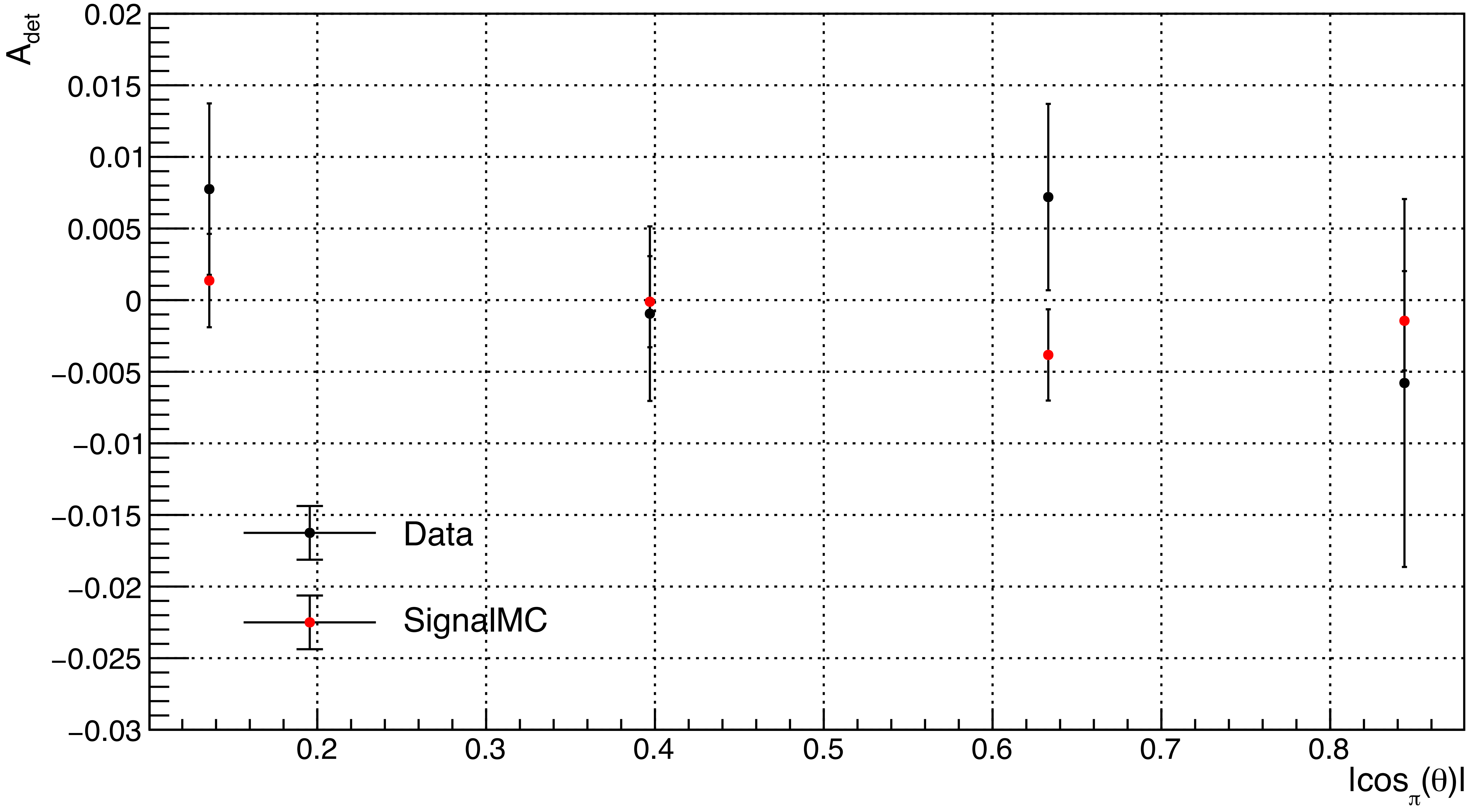
# $\mathscr{A}_{\text{det}}(\pi)$ kinematics dependences : data vs MC

$$\mathscr{A}_{\text{obs}} = \frac{N_{D^-} - N_{D^+}}{N_{D^-} + N_{D^+}}$$

Check marginal distribution:
integrate over $cos_\pi(\theta)$ and CDC hits of pion.



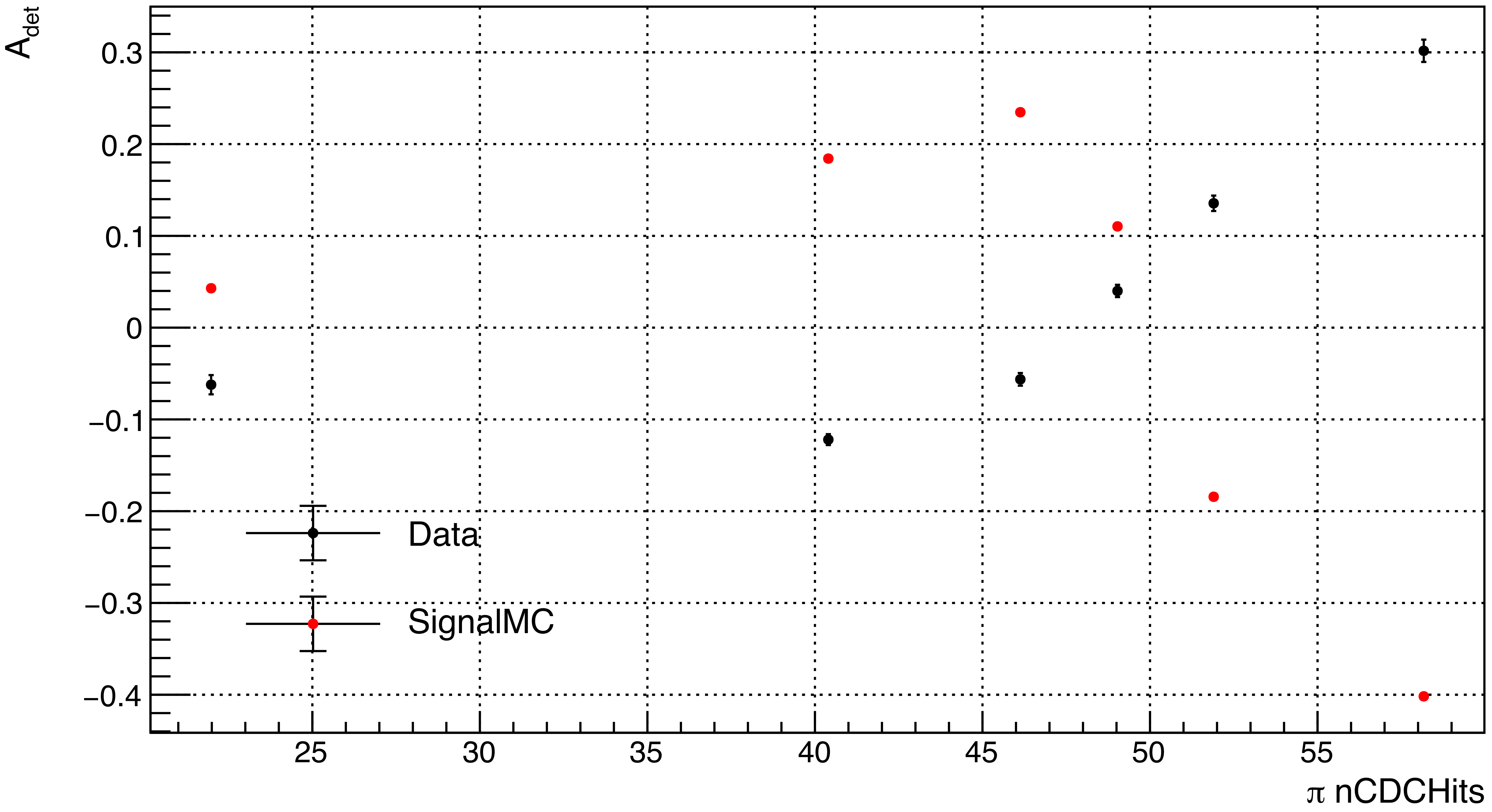

Check marginal distribution:
integrate over $p_\pi(\theta)$ and CDC hits of pion.



# $\mathscr{A}_{\mathrm{det}}(\pi)$ dependence on CDC hits: data vs MC

$$\mathscr{A}_{\mathrm{obs}} = \frac{N_{D^-} - N_{D^+}}{N_{D^-} + N_{D^+}}$$

Integrate over all kinematic variables.

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