Analysis Towards $e^+e^- \rightarrow s\bar{s}$

LCWS2021

International Workshop on Future Linear Colliders

ILD

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Overview

1. Motivation
2. Process
3. Detector
4. Kaon ID
5. Towards $s\bar{s}$ Analysis
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1. Motivation

Discoveries anticipated at e^+e^- colliders

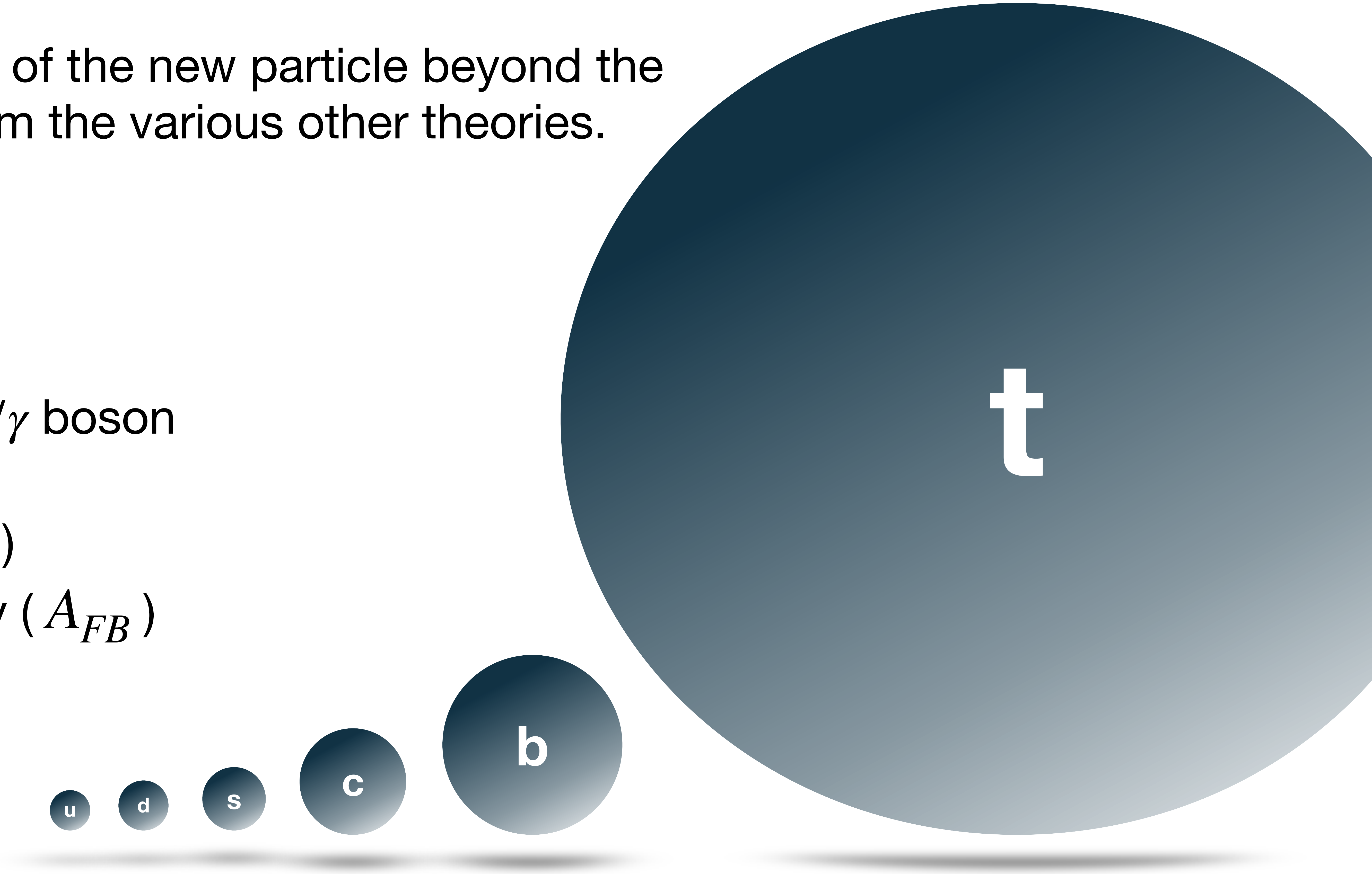
- Mechanism of electroweak symmetry breaking
- Fermion mass is closely related to this mechanism and the are theories which requires modification in fermion couplings.
- **ILC** can play a central role for the indirect searches of the new particle beyond the Standard Model predictions to distinguish them from the various other theories.

How is it done?

- Electroweak coupling between fermion pair and Z^0/γ boson

Key observables: $e^+e^- \to f\bar{f}$ cross section ($\sigma^{f\bar{f}}$)

Forward-backward Asymmetry (A_{FB})



1. Motivation

Electroweak Couplings and Physical Observables

- **Cross section** of $e^+e^- \to f\bar{f}$ process when polarization of beams are defined as (P_{e^-}, P_{e^+})

$$\sigma_{tot}(P_{e^-}, P_{e^+}) = (1 - P_{e^-}P_{e^+}) \cdot \frac{1}{4}\left\{(1 - P_{eff})\sigma_{LR} + (1 + P_{eff})\sigma_{RL}\right\}$$

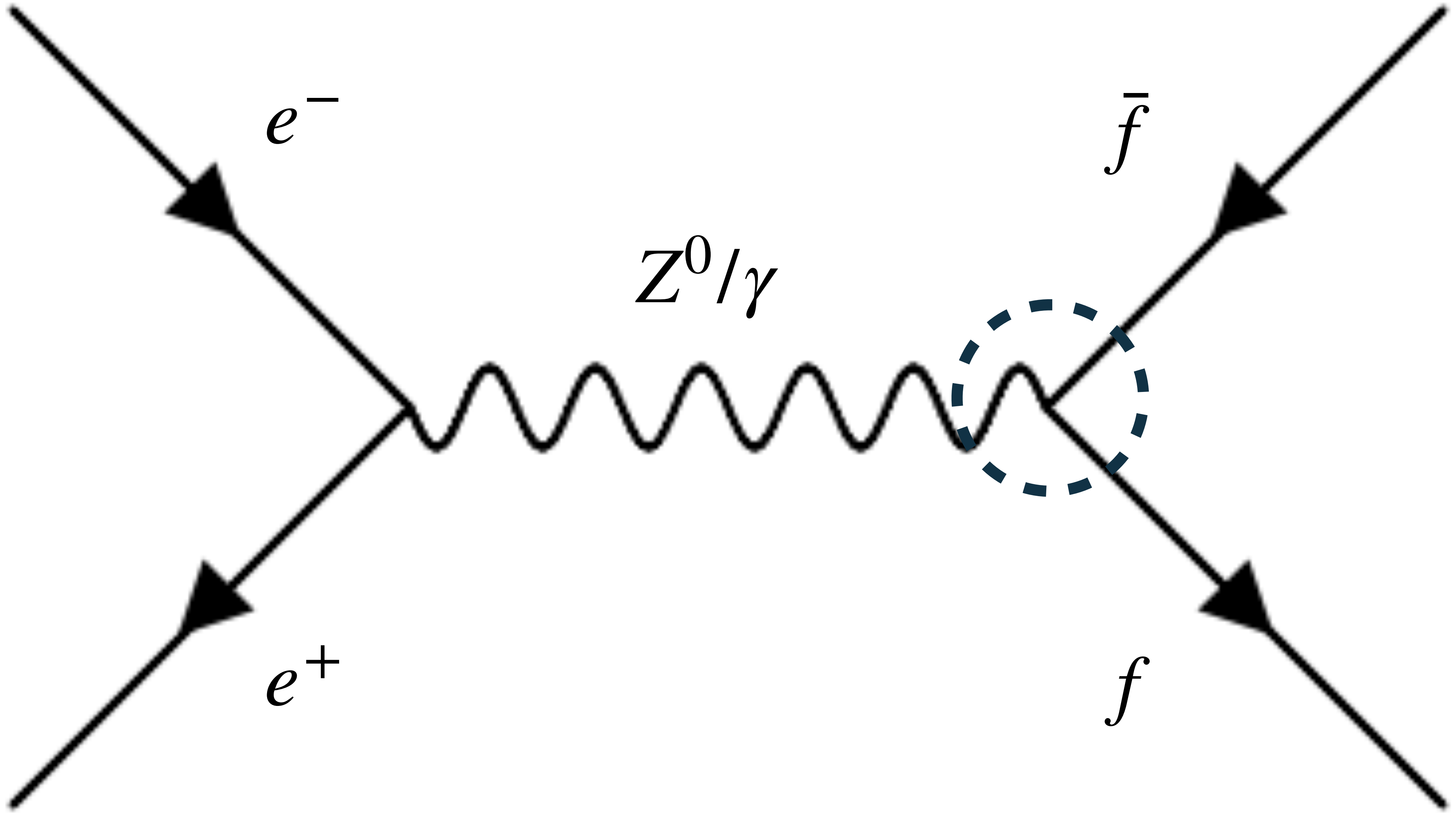
where $P_{eff} = \frac{P_{e^-} - P_{e^+}}{1 - P_{e^-}P_{e^+}}$, $\sigma_{ij} = \int \frac{d\sigma_{ij}}{d\cos\theta}(\cos\theta)\ d\cos\theta$. (with i,j = L,R)

- **Differential cross section**

$$\frac{d\sigma_{ij}}{d\cos\theta}(\cos\theta) = \Sigma_{ii}(1 + \cos\theta)^2 + \Sigma_{ij}(1 - \cos\theta)^2$$

where $\Sigma_{ij} \propto (g_R,\ g_L)$

Polarization of the beam is the key!



1. Motivation

Electroweak Couplings and Physical Observables

- **Forward-backward asymmetry**

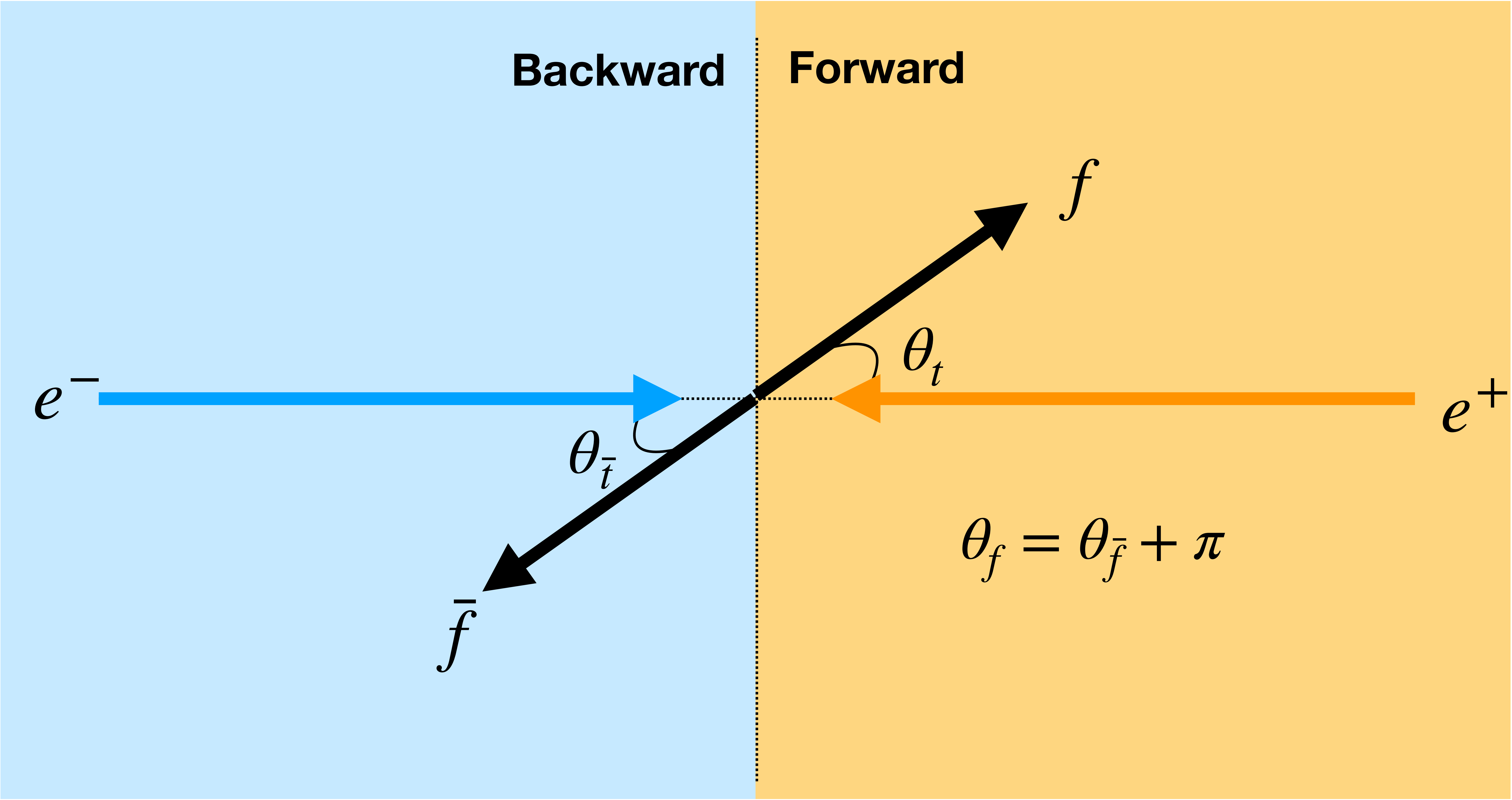
$$A_{FB}^{I} = \frac{3}{4}\frac{B_1 - B_2}{B_1 + B_2}$$

where

$$B_1 = \Sigma_{LL}(1 - P_{eff}) + \Sigma_{RR}(1 + P_{eff})$$
$$B_2 = \Sigma_{LR}(1 - P_{eff}) + \Sigma_{RL}(1 + P_{eff})$$

$$A_{FB} = \frac{\overbrace{\sigma_F(\cos\theta_t > 0)}^{\text{forward}} - \overbrace{\sigma_B(\cos\theta_t < 0)}^{\text{backward}}}{\sigma_F(\cos\theta_t > 0) + \sigma_B(\cos\theta_t < 0)}$$

$$\delta_{A_{FB}} = \sqrt{\frac{1 - A_{FB}^2}{N_{f\bar{f}}}}$$



2. Process

Production of $e^+e^- \to b\bar{b},\ s\bar{s}$ process

- Previous study suggested that electroweak coupling to the **heavy fermion pairs** ($t\bar{t},\ b\bar{b},\ c\bar{c}$) at $\sqrt{s} = 250,\ 500$ GeV running scenario can be measured to precision about **<u>0.5%</u>** for **top quark** and even more precise for other pairs.

- Extend these work to lighter quarks ($u\bar{u},\ d\bar{d},\ s\bar{s}$) at $\sqrt{s} = 250$ GeV scenario, to consolidate the results from the heavy quarks. The analysis requires the highest precision in $\pi/K/p$ separation.

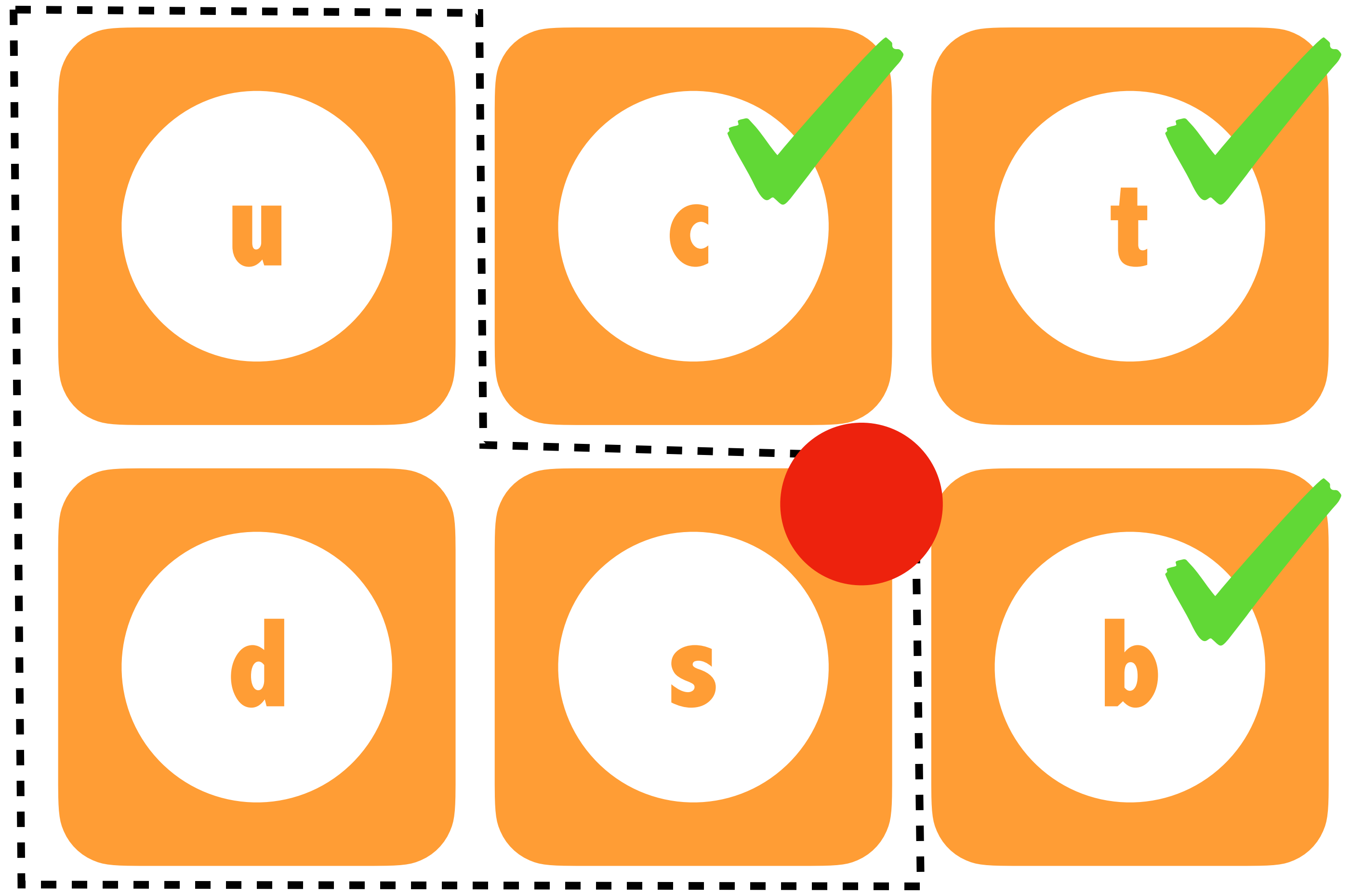
- The attempt was also made in SLD experiment at the Z-pole. (ref: arXiv:hep-ex/0006019)

- As a first step, re-examination of toolkits for $b\bar{b}$ was necessary to move on to the $s\bar{s}$ study

Cross sections at 250 GeV (L.O.)

	σ_L (fb)	σ_R (fb)
bb	6,300	1,600
cc	9,400	4,400
ss	6,300	1,600

Expected integrated luminosity of $2\ \text{ab}^{-1}$ at 250 GeV.

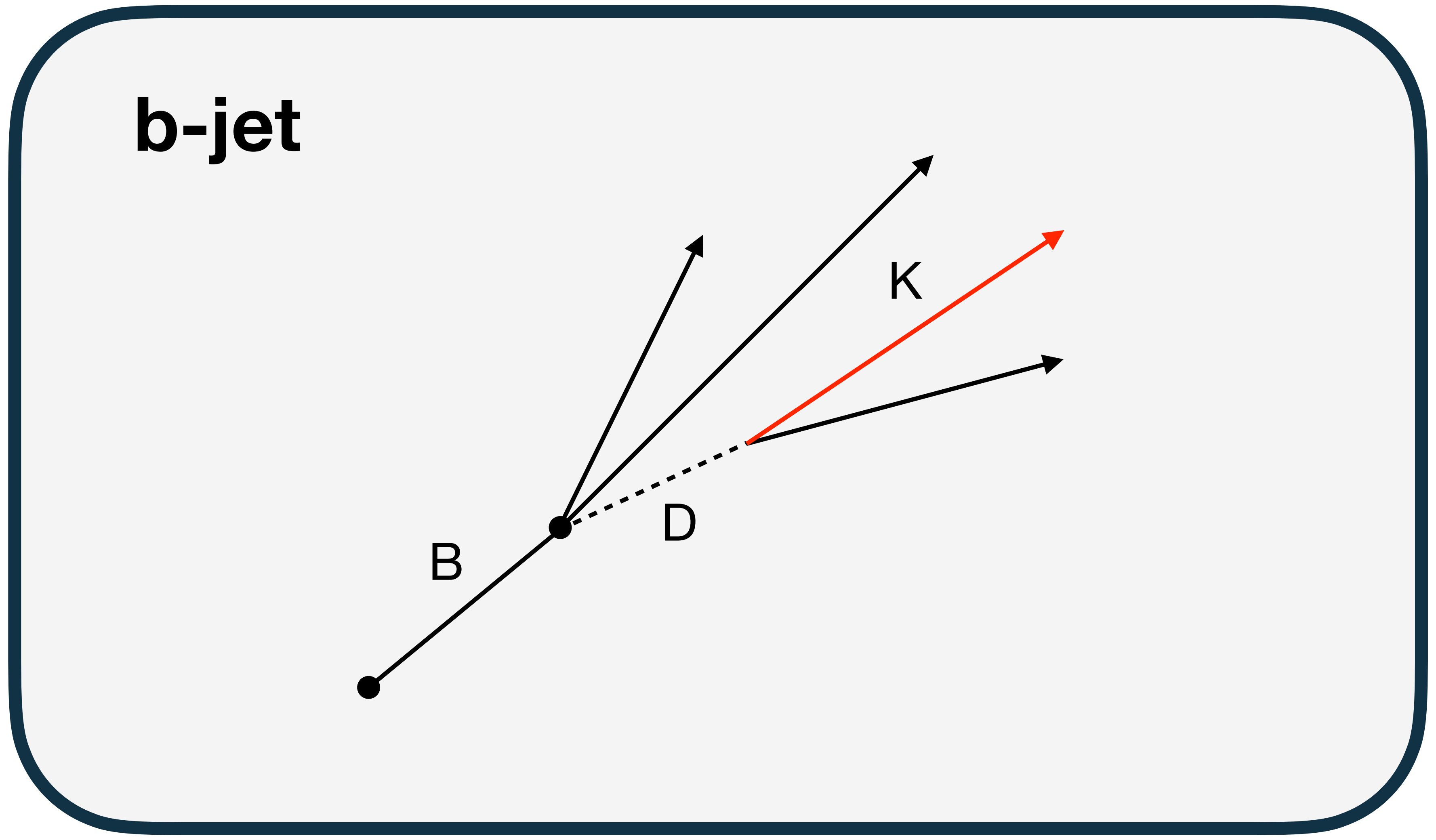


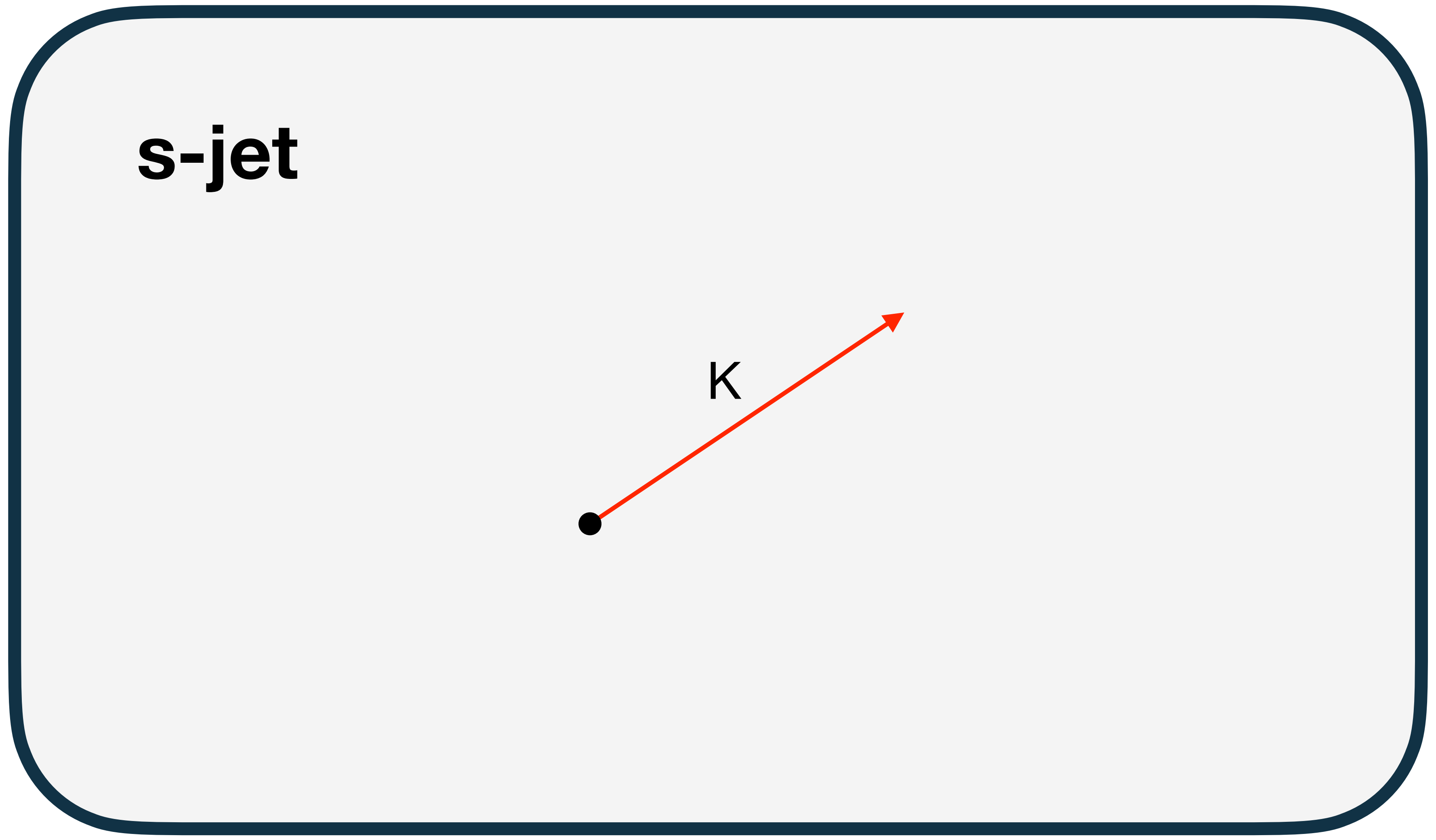
Topologies of fermion pair production

- Charge identification of jet is crucial for the forward-backward measurement for bb and ss.

- bb can use sum of charges associated to the secondary vertex (vertex charge) to identify charge. In order to avoid migration from wrong identification, as well as increasing efficiency, the identification can also be done using **kaon charge information.**

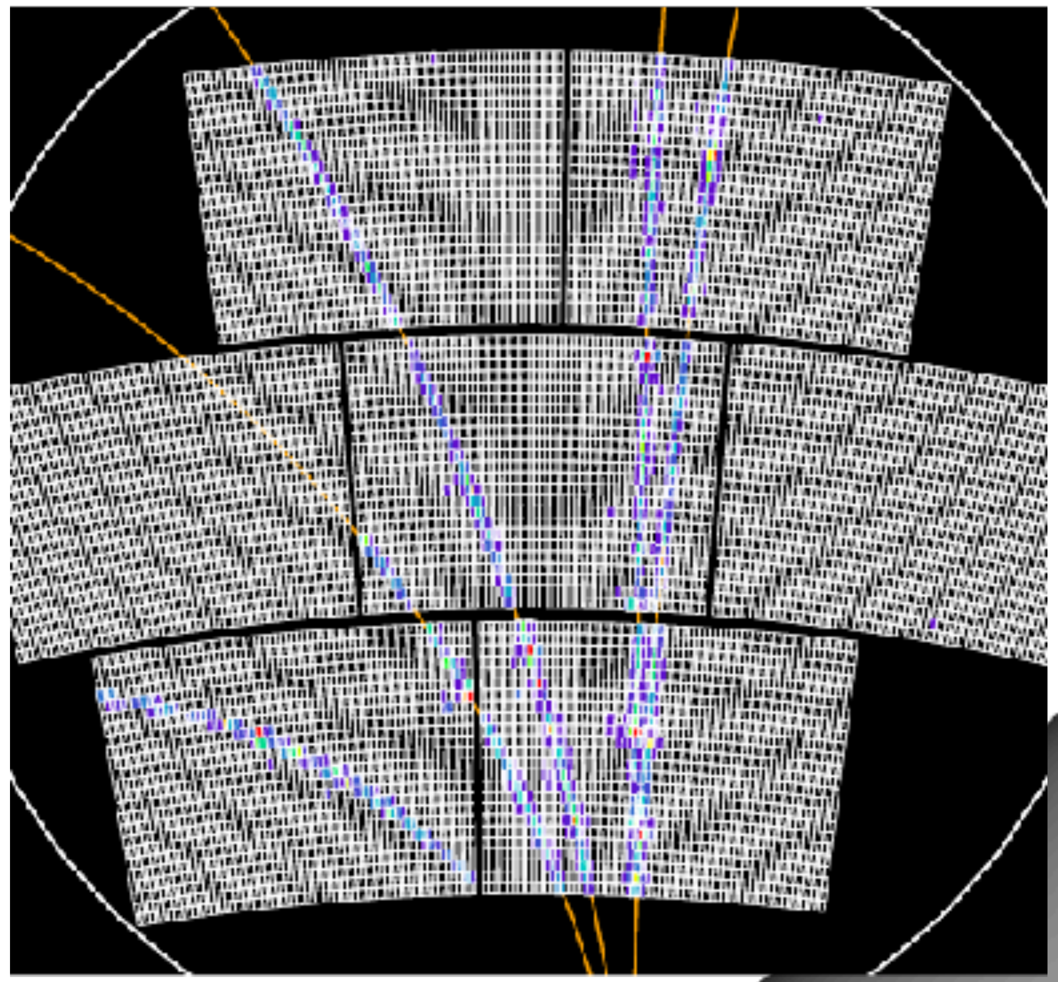
- One can identify those kaons by using **dEdx information** by identify the phase-space region dominated by kaon. Main source of backgrounds can come from pion, proton and electrons which shares the same region.



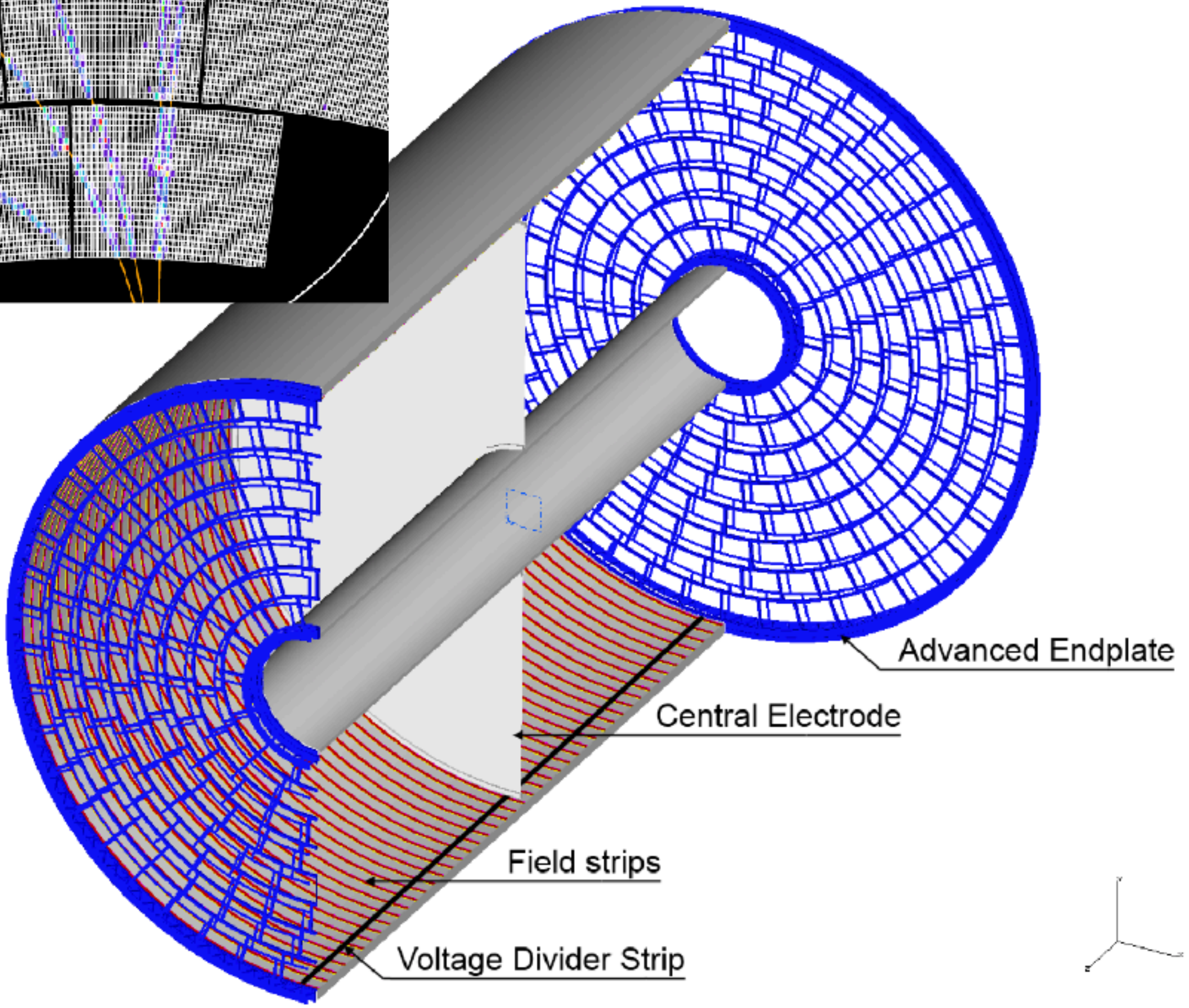


Time Projection Chamber (TPC)

- Central tracking detector in the ILD
- Charged particle inside the TPC would ionize the gas and creates a thread of electrons which would drift to the TPC endplate.
- Figure shows the recorded tracks using six micromegas modules equipped with 220 pad rows.



Parameter			
Geometrical parameters	r_{in} 329 mm	r_{out} 1808 mm	z ± 2350 mm
Solid angle coverage	up to $\cos\theta \simeq 0.98$ (10 pad rows)		
TPC material budget	$\simeq 0.05$ X_0 including outer fieldcage in r		
	< 0.25 X_0 for readout endcaps in z		
Number of pads/timebuckets	$\simeq$ 1-2 × 10^6/1000 per endcap		
Pad pitch/ no.padrows	$\simeq 1\times 6$ mm^2 for 220 padrows		
σ_{point} in $r\phi$	$\simeq$ 60 μm for zero drift, $<$ 100 μm overall		
σ_{point} in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)		
2-hit resolution in $r\phi$	$\simeq$ 2 mm		
2-hit resolution in rz	$\simeq$ 6 mm		
dE/dx resolution	$\simeq$ 5 %		
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq 10^{-4}$/GeV/c (TPC only)		



credit: ILC TDR Vol.4 Detectors

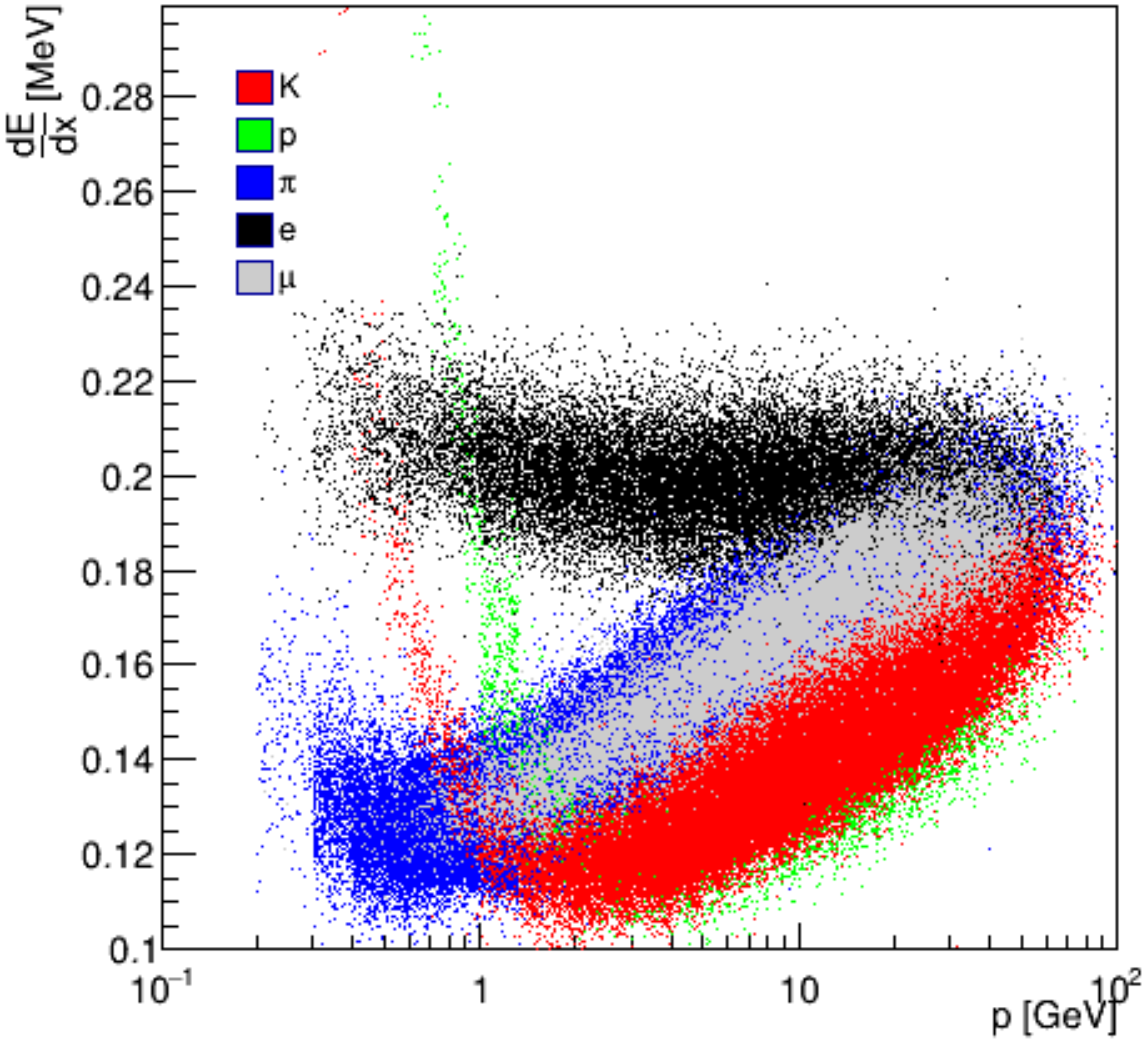
3. Detector

dEdx Measurement

- TPC can also reconstruct and identify particle species using energy loss (dE/dx)
- dEdx vs track momentum can be approximated the Bethe-Bloch formula, which is unique to different particles.

$$\frac{dE}{dx} \propto \frac{z^2}{\beta^2} \ln(a\beta^2\gamma^2) \quad p = m_0\beta\gamma c$$

- Kaons' dEdx distribution overlaps with the ones for pion and proton which becomes our primary background.
- Scanning through each phase-space in this distribution gives us the region which is dominated by the kaons with certain efficiency and purity.



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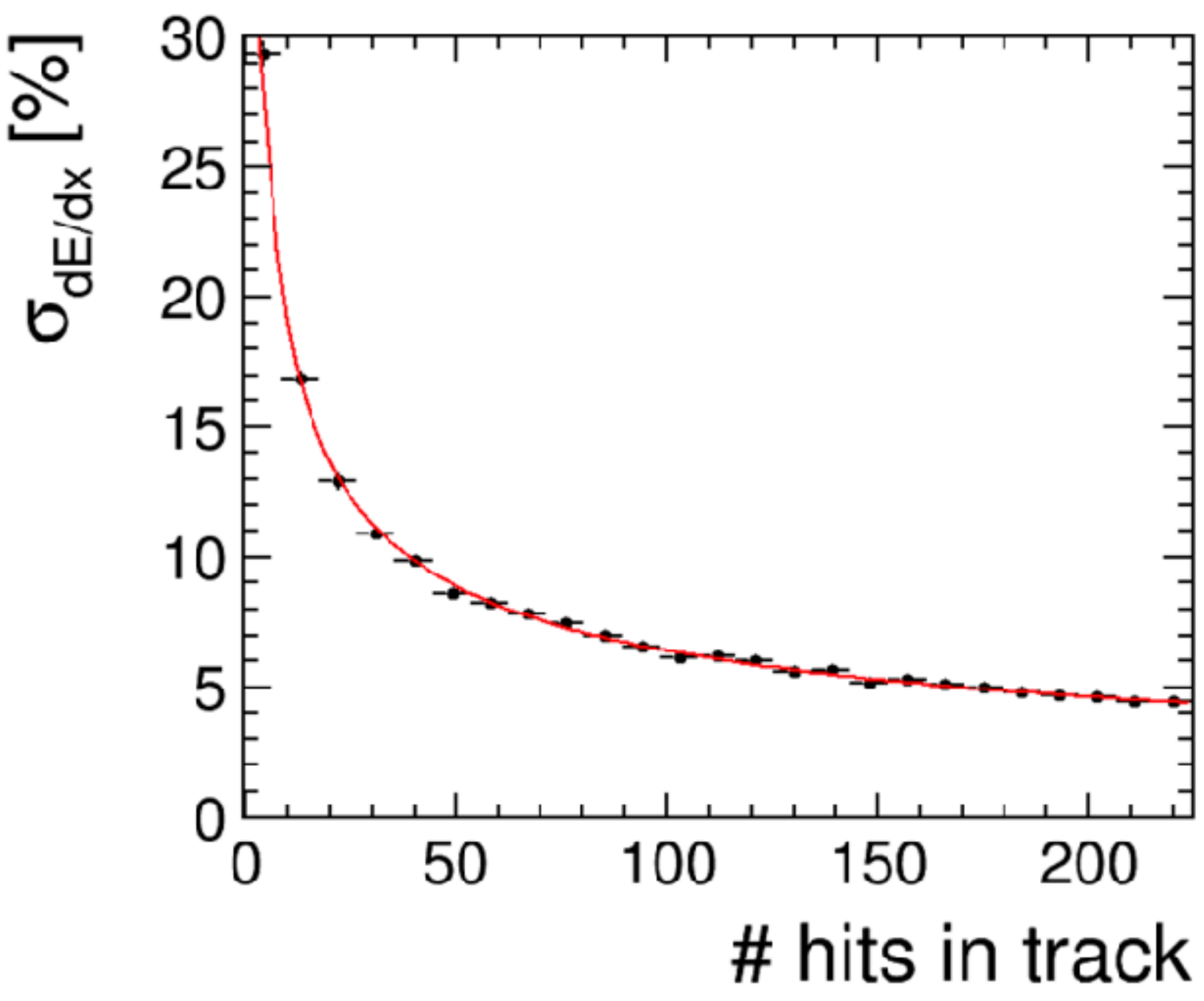
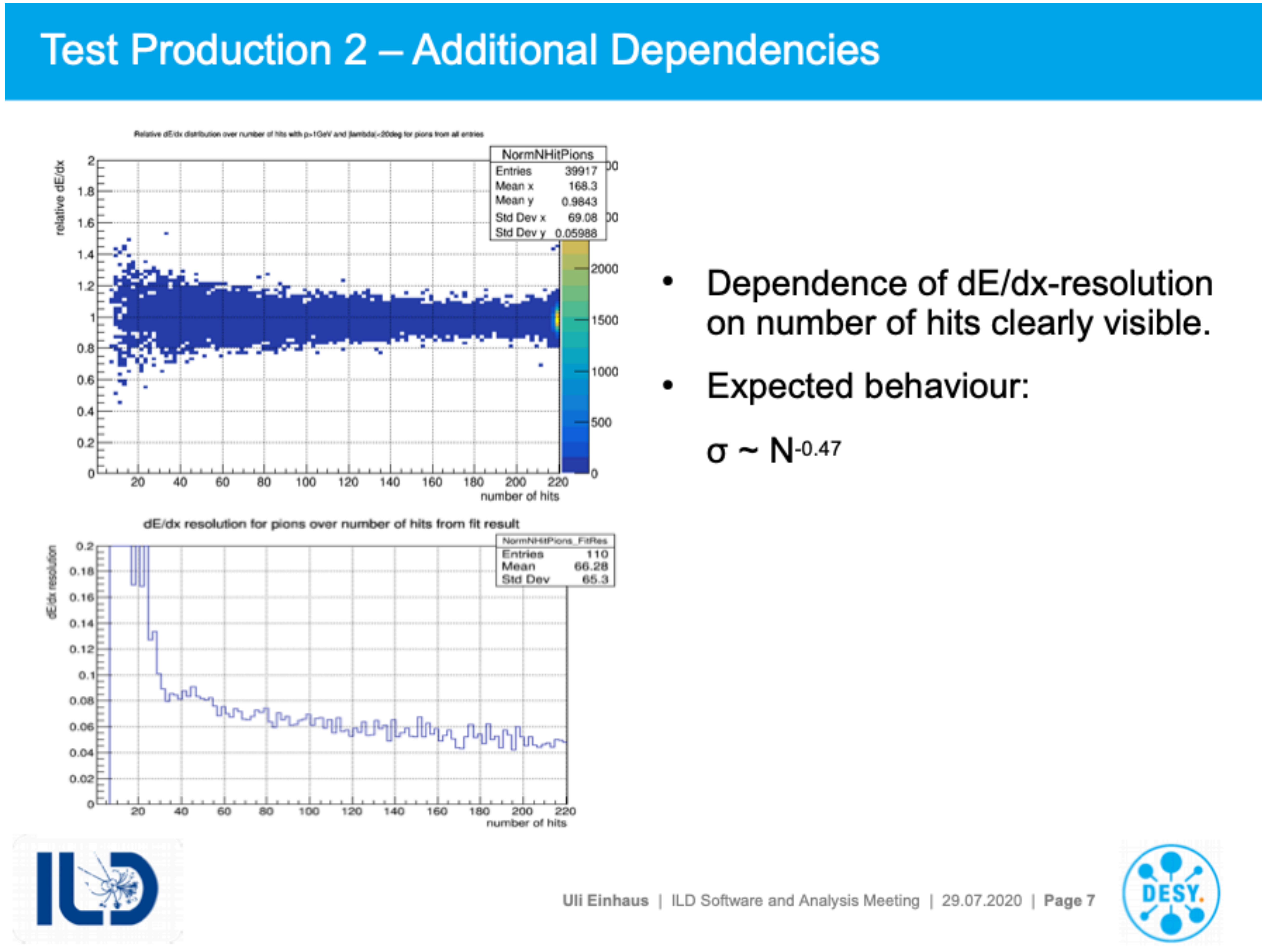
Number of hits and dEdx resolution

- The dEdx resolution is dependent on the number of hits. This comes from the fact that there is a potential double-hits due to overlapping tracks.
- Number of TPC readout pad rows available for the ILD is 220 pad rows $\rightarrow \sigma_{dE/dx} = 4.4\ \%$



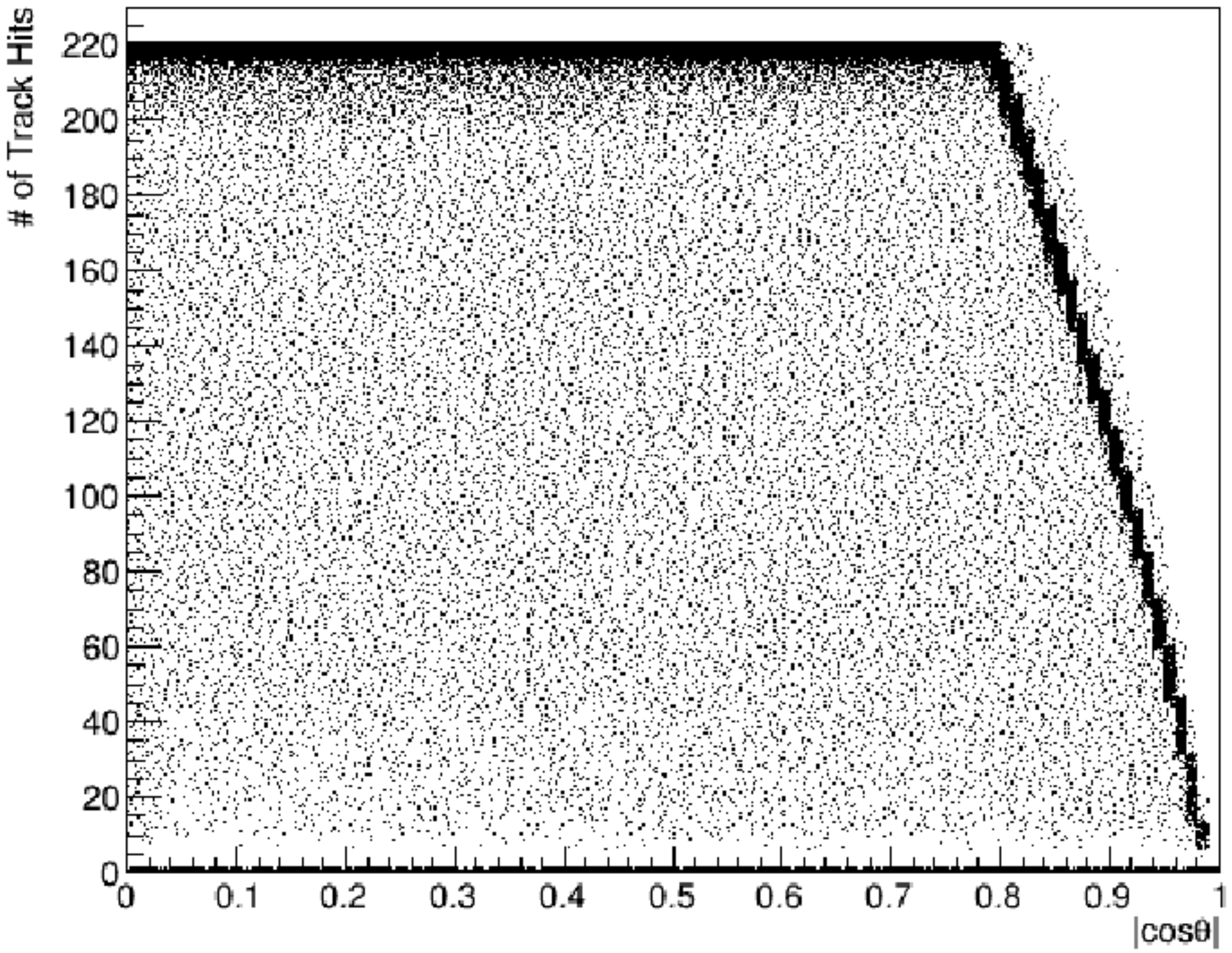
ref: arXiv:2006.08562v2



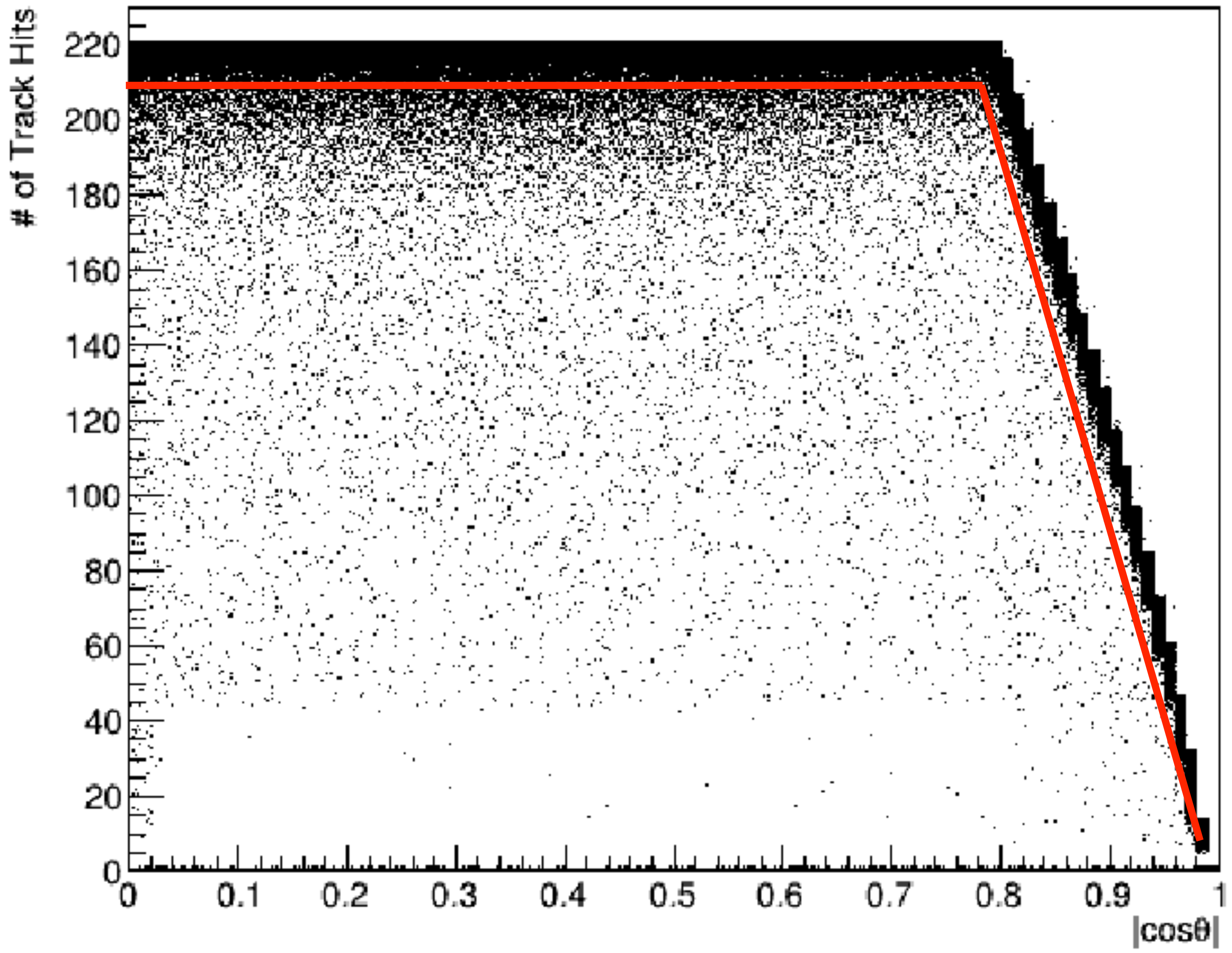
ref: U. Einhaus, ILD meeting 2020/07/29

TPC hits in kaon analysis

- After the kaon selection, number of hits to the TPC pads was examined since the identification heavily relies on dEdx information. One can observe almost all pads that is available are used to identify kaons, which indicates one do not need to worry about double hits.

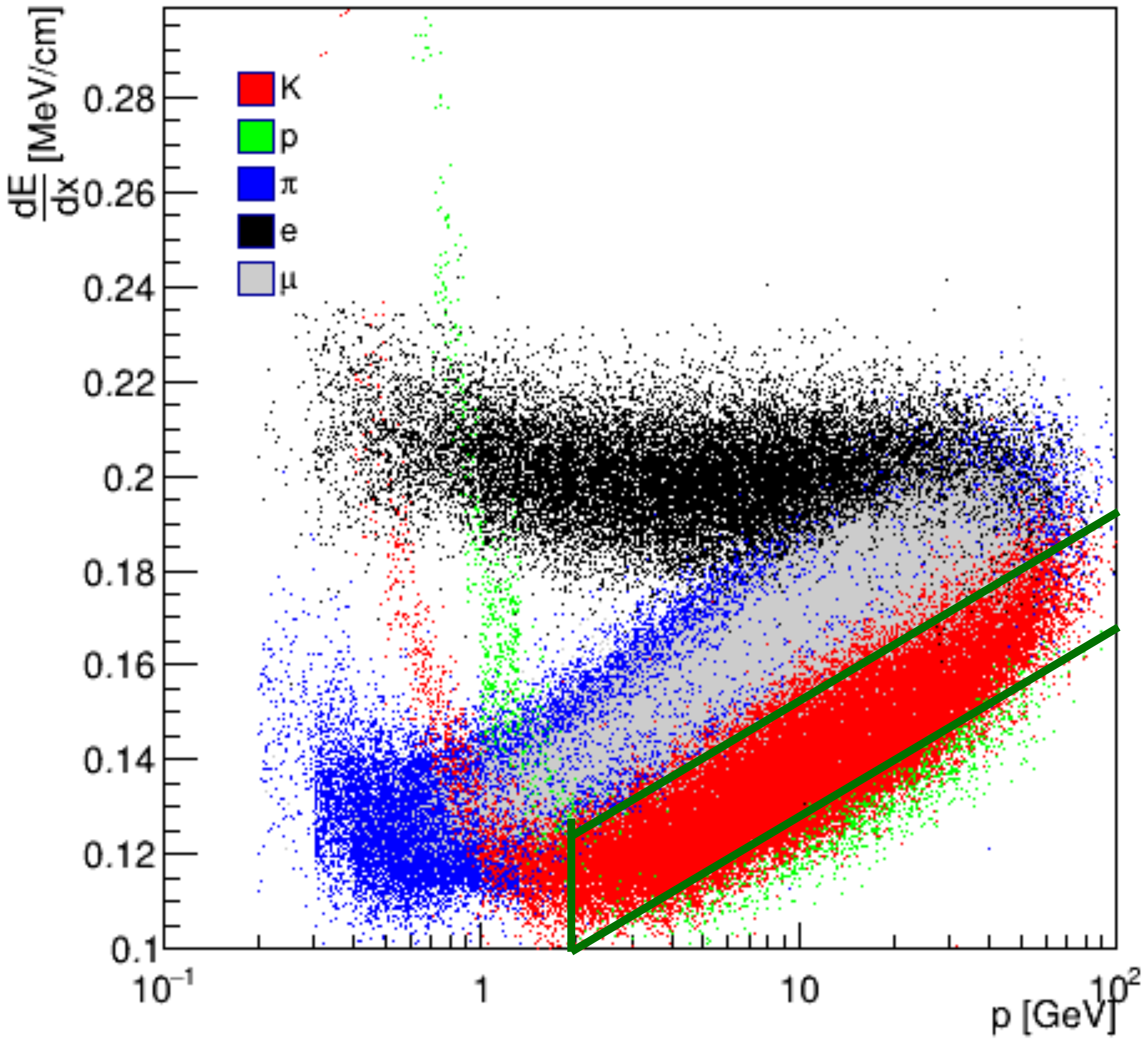


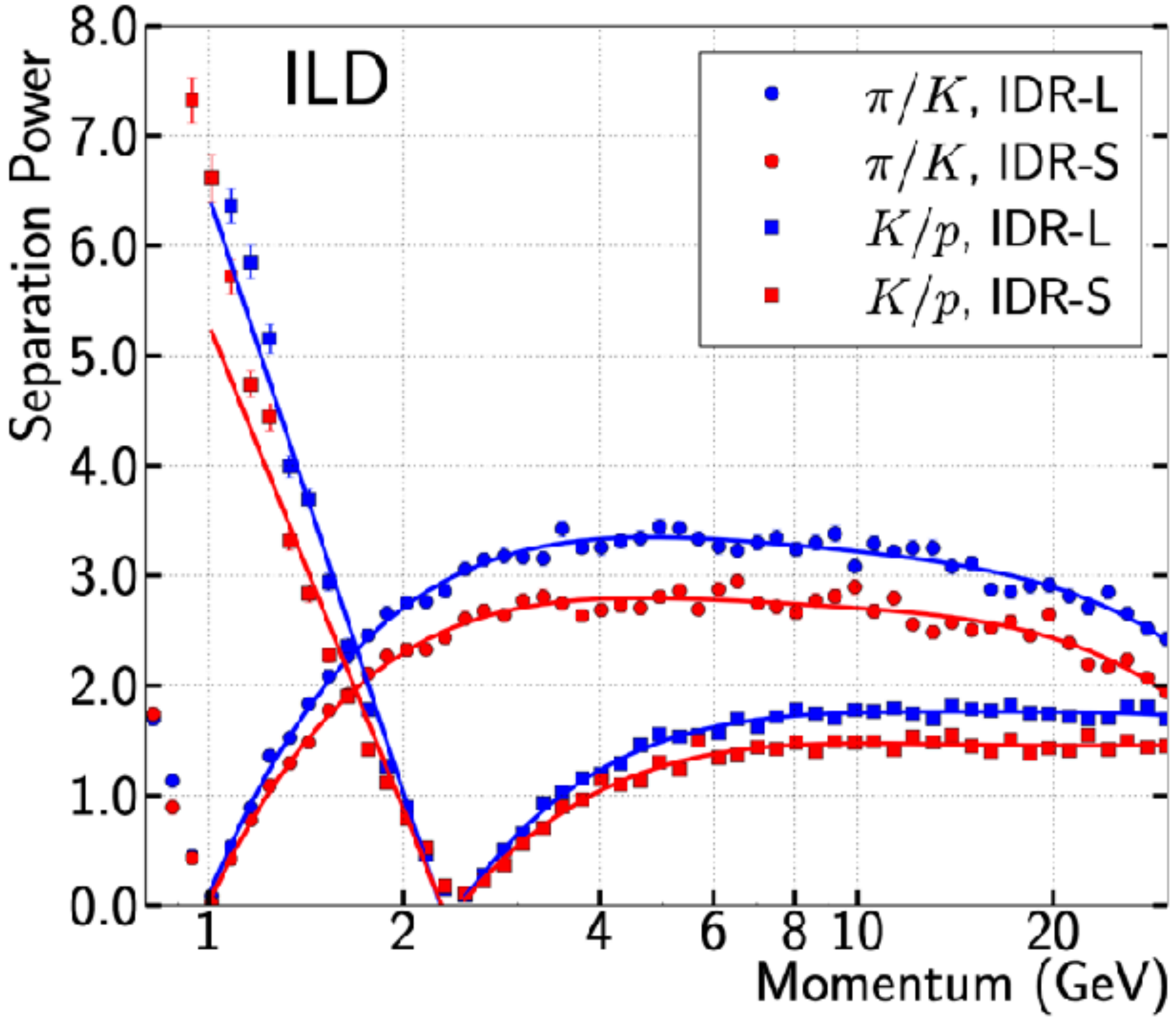
Number of hits of all PFOs reconstructed.

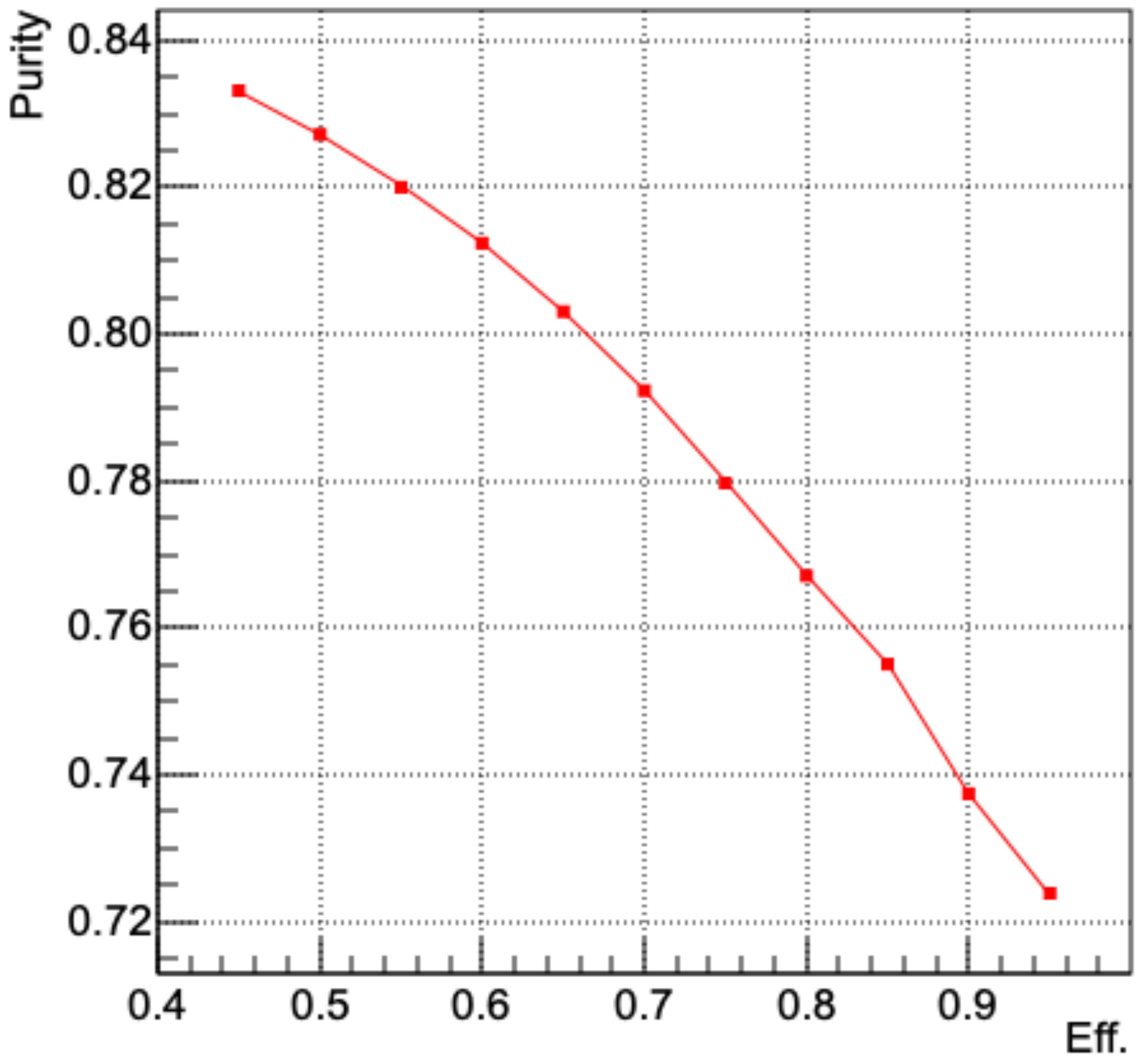


Number of hits associated to a kaon. One can see that the number of hits, which defines dEdx resolution, is maximized at any polar angle region. (**~87.7%** above red line)

Kaons identification



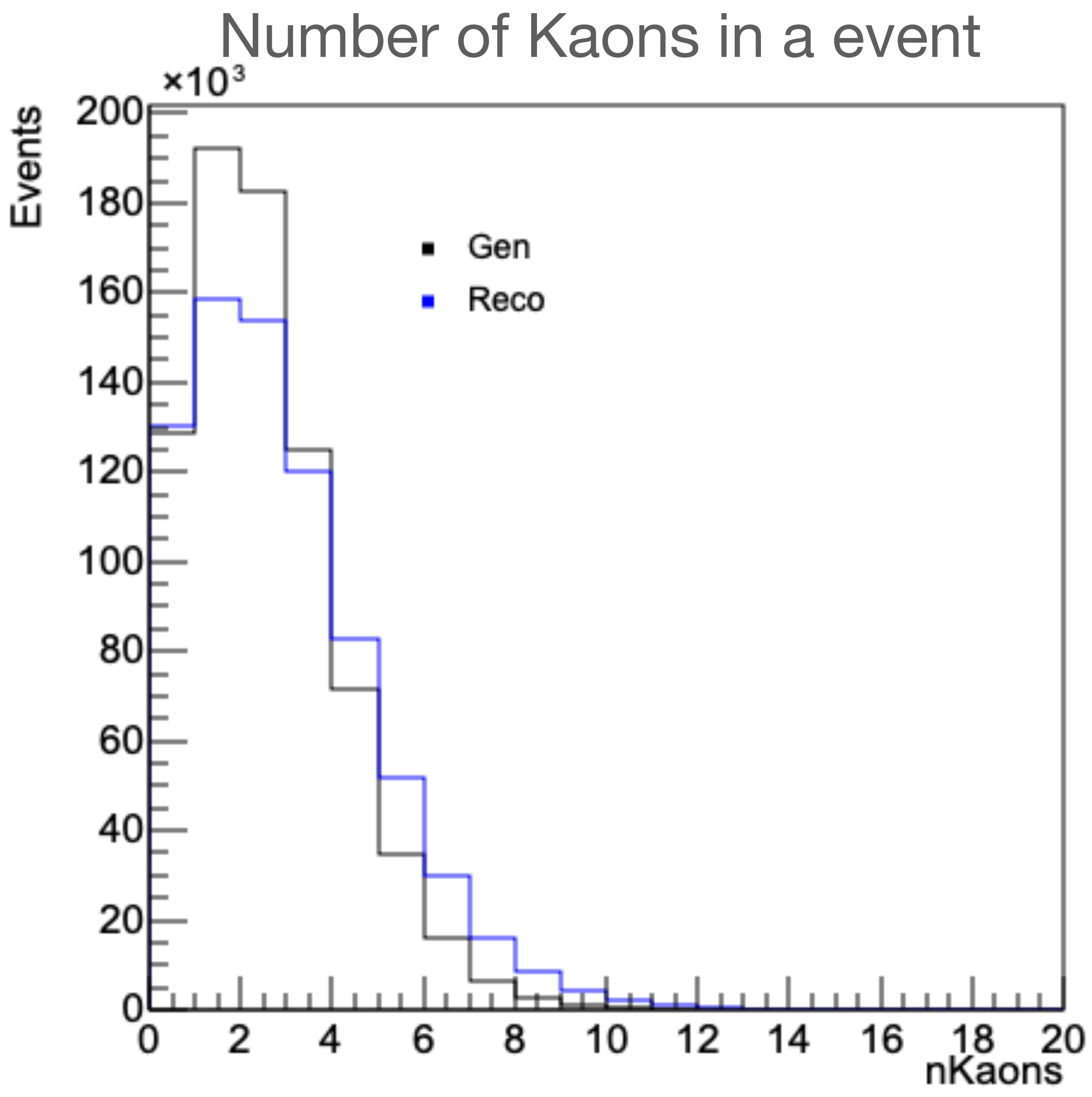


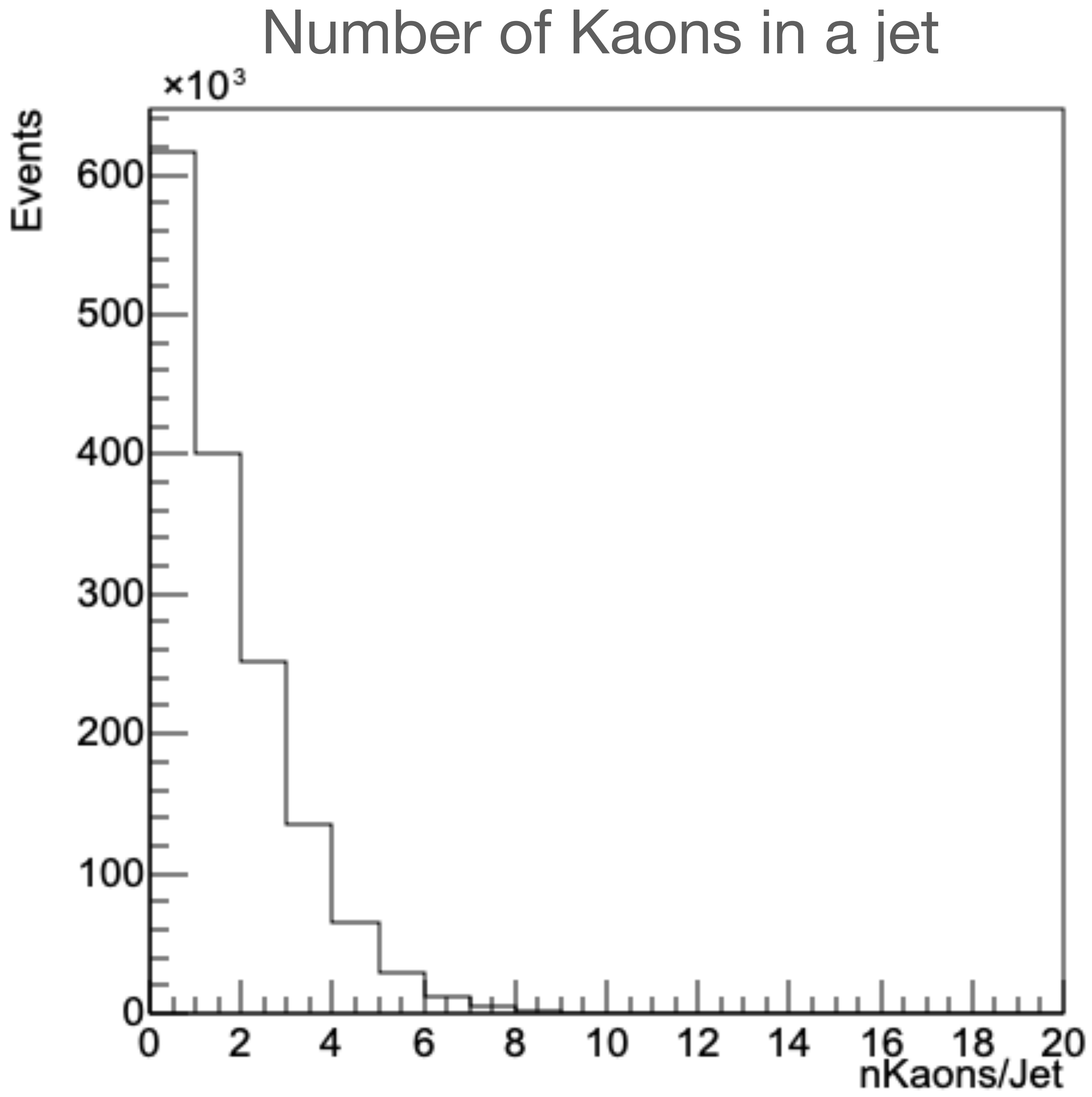


- *Left plot* shows the dEdx vs momentum distribution. Coloring is done based on MC relation PDG number for the sake of examining the region dominated by kaon. Identification of kaon is done by selecting the PFO in the region inside green line.
- *Center plot* shows the separation power of dE/dx. (ref: arXiv:2003.01116v1)
- *Right plot* shows purity vs efficiency of kaon selection.

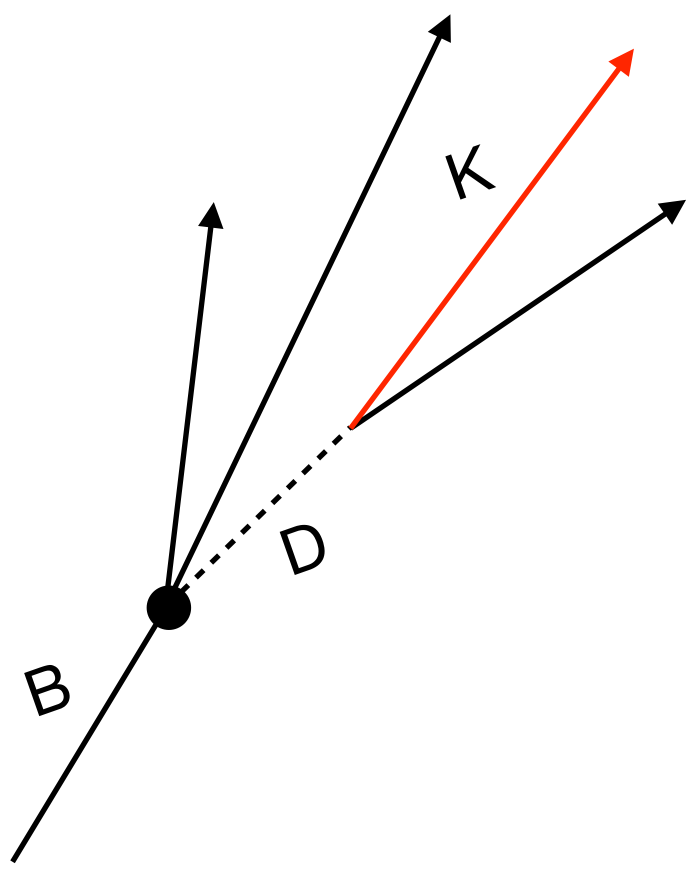
Kaons identification

- Middle and right plot shows the kaon multiplicities in a single event and jet.





b-jet

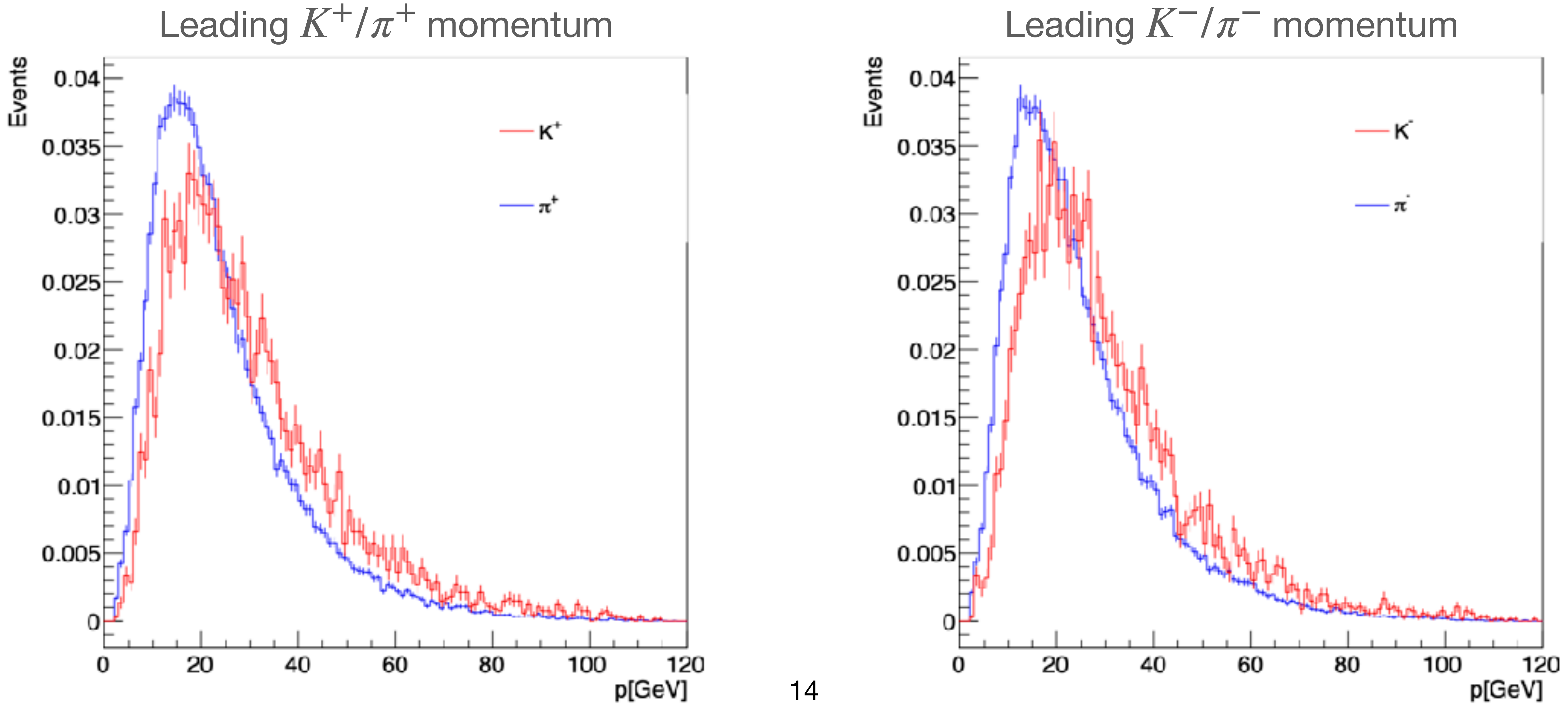


5. Towards $s\bar{s}$ Analysis

Leading Kaons in a Jet

- Leading kaons: A particle with the highest momentum in a jet, that is identified to be a kaon
- Leading kaons can be used to identify s-jets in $e^+e^- \rightarrow s\bar{s}$.
  - Heavy flavors $b\bar{b} + c\bar{c}$ can be separated using B/D vertex measurements.
  - Light flavors $u\bar{u} + d\bar{d}$ can be suppressed using leading pion as an identifier.
  - The experiment was conducted in SLD with estimated $K^{\pm}$ selection efficiency (purity) of 48% (91.5%) for $p > 9$ GeV. (ref: arXiv:hep-ex/0006019)

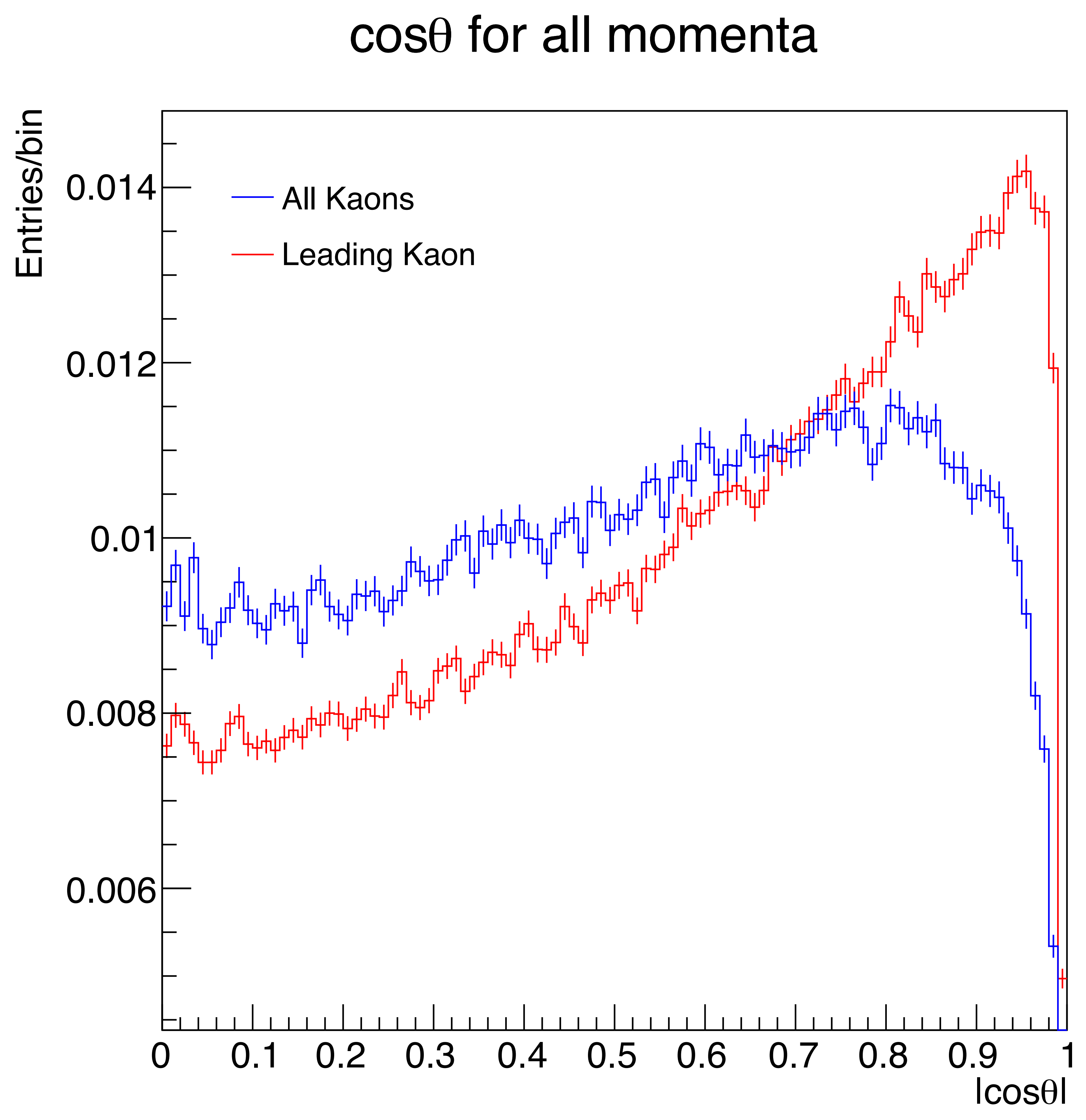
For $b\bar{b}$ sample

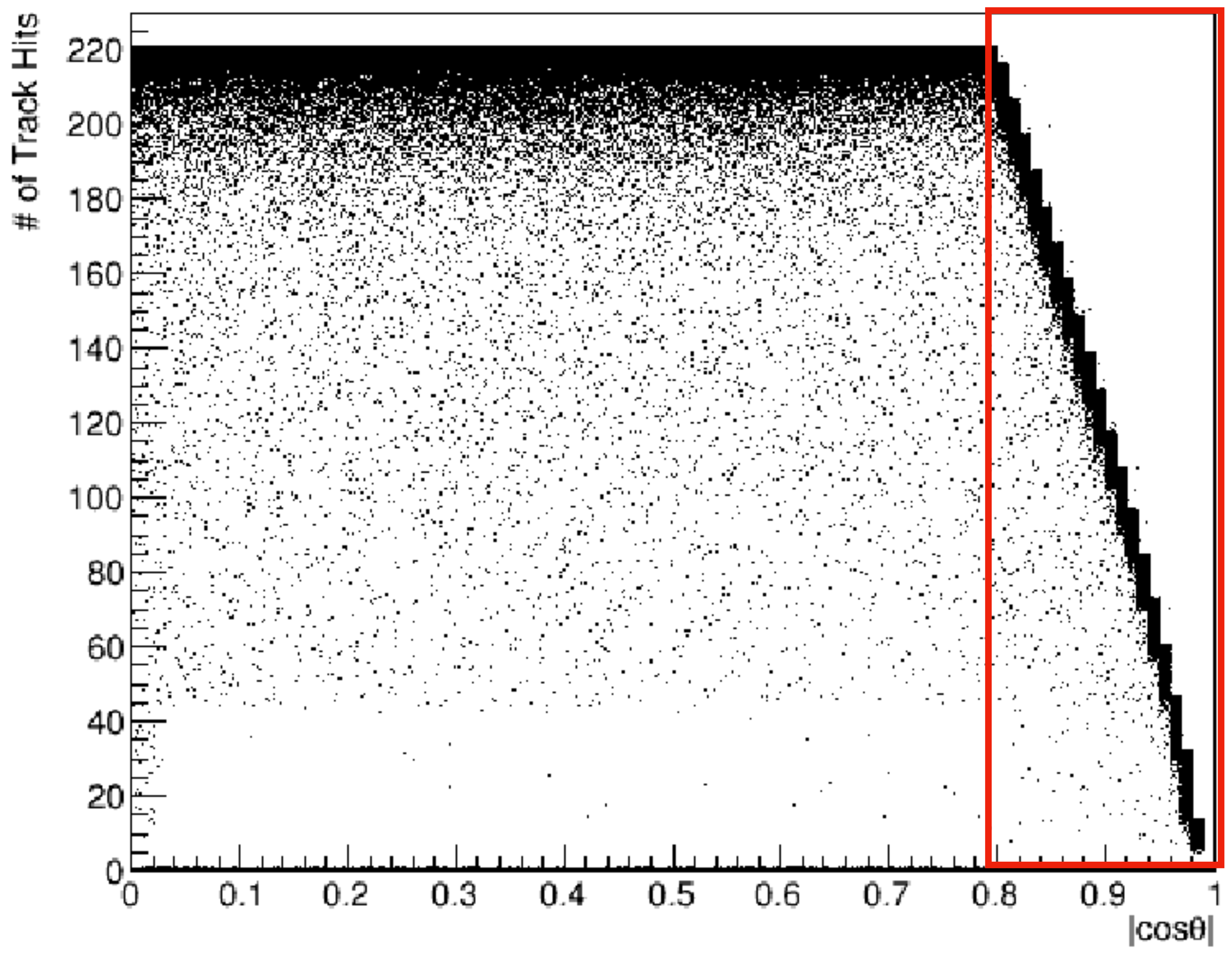


5. Towards $s\bar{s}$ Analysis

Leading Kaons in a Jet

- Most of the leading kaons are boosted into forward region of the detector.
- One needs to take extra care with these kaon as the available number of pad layers will be reduced.





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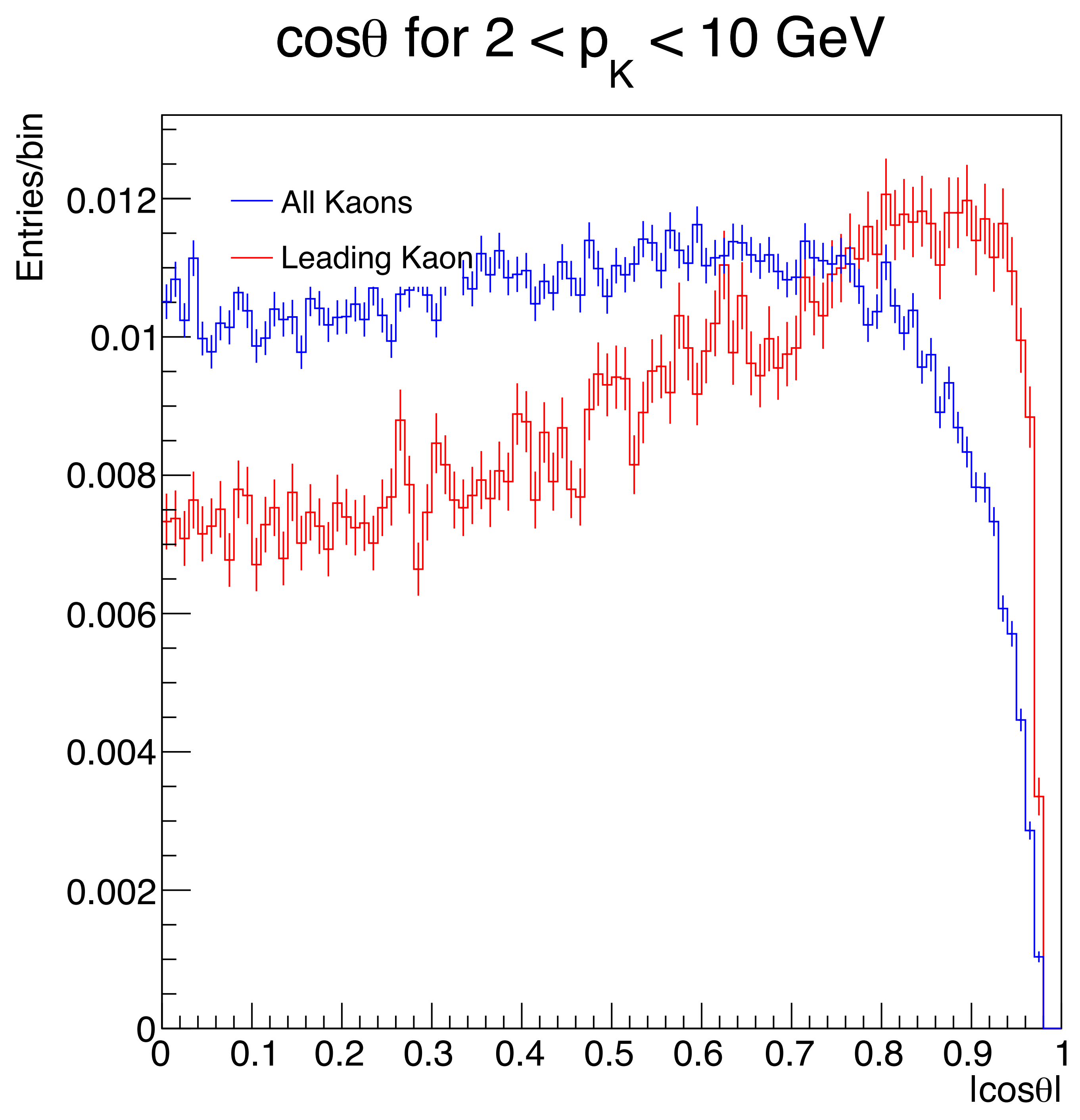

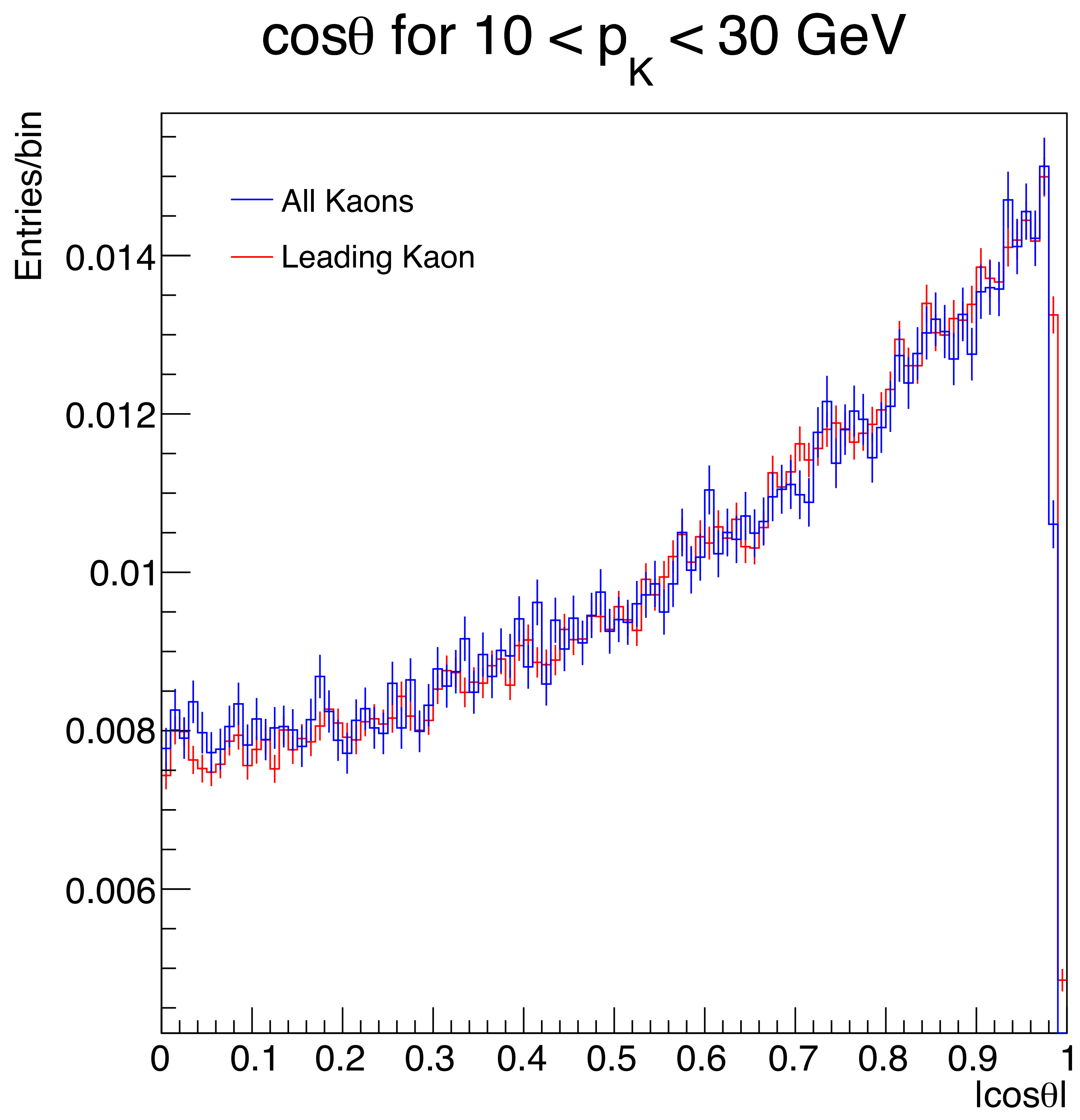

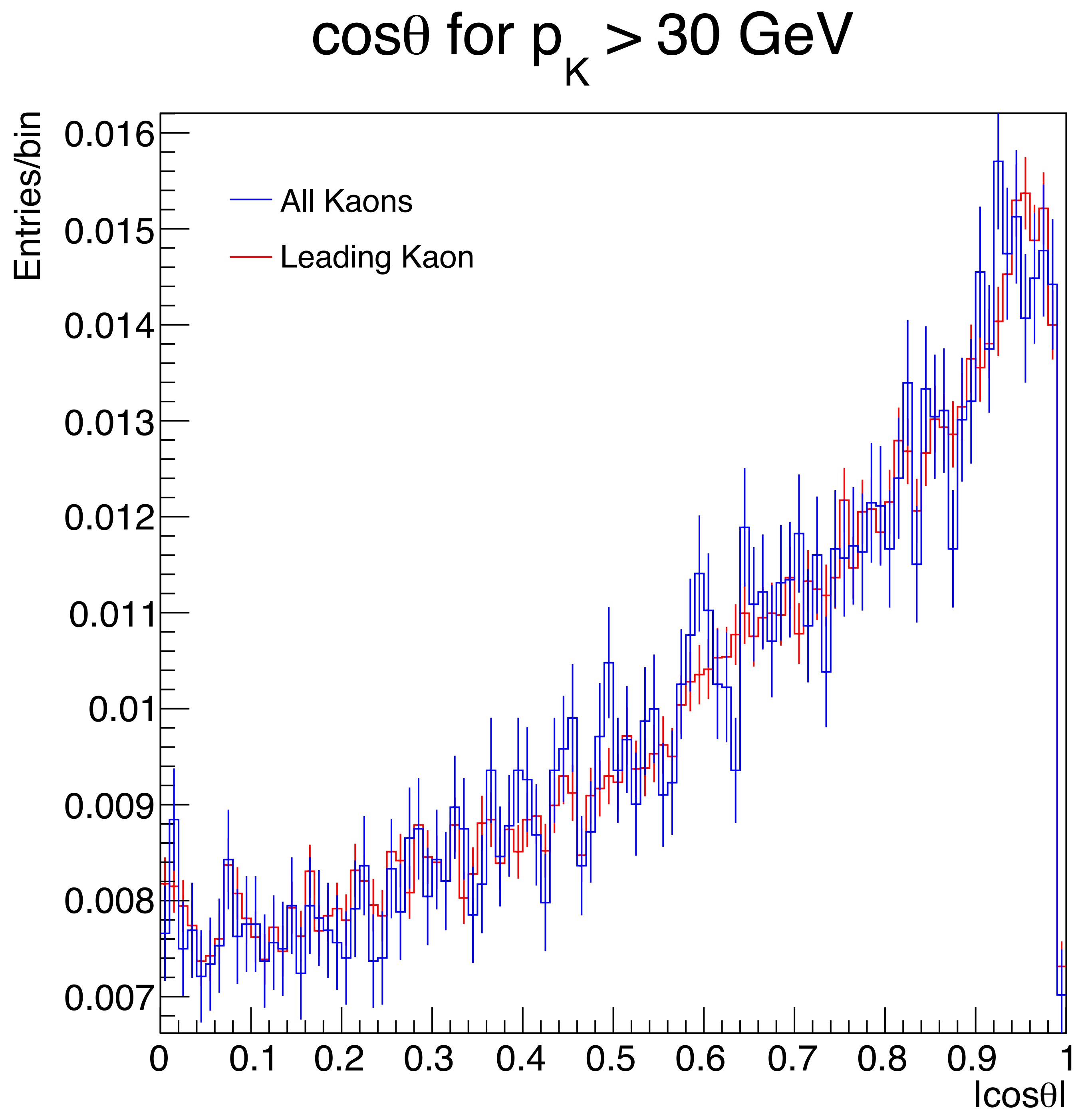

6. Outlook

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- Gathering tools for kaon identification towards $e^+e^- \to s\bar{s}$ studies.
  - Leading K with high momentum needs to be used to achieve high purity.
  - The separation of $K^\pm$ and $\pi^\pm$ becomes the prominent analysis.
- Heavy flavors quarks ($b\bar{b} + c\bar{c}$) can be rejected using vertex information.
- Separation of $s\bar{s}$ from light flavor quarks ($u\bar{u} + d\bar{d}$):
  1) Choose leading K with high momentum.
  2) From the opposite jet charge measurements