

ILD Analysis/Software Meeting

Updates on SSbar Analysis

Yuichi Okugawa
Feb 16th, 2022



Introduction



Di-fermion Production

- Di-fermion production

- $e^+e^- \rightarrow s\bar{s}$
- CME 250 GeV.
- eL pR
- Int. Lumi. 120 fb⁻¹

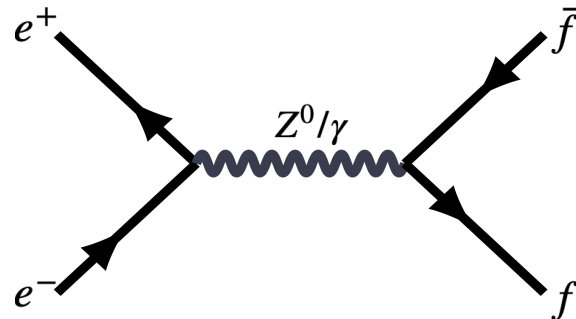
- Differential Cross Section

- Couplings can be extracted from helicity amplitudes included within the Differential Cross section

$$\frac{d\sigma}{d\cos\theta} = S(1 + \cos^2\theta) + A\cos\theta$$

- Extracted via forward-backward asymmetry. (AFB)

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

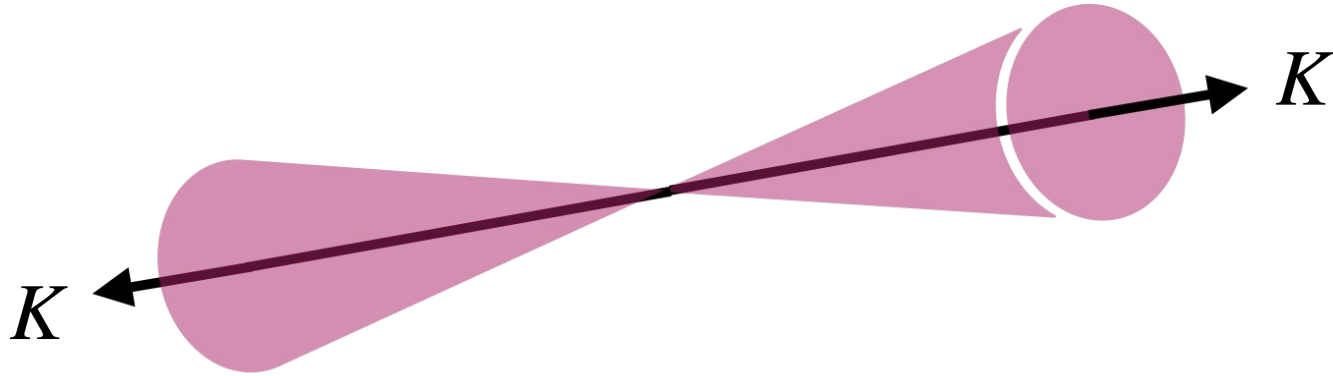


Energy	Process	Goal of measurements
91 GeV	$e^+e^- \rightarrow Z^0$	Z^0 physics and calibration
250 GeV	$e^+e^- \rightarrow Z^0 H$	Higgs couplings
	$e^+e^- \rightarrow f\bar{f}$	Z^0/γ couplings
350 GeV	$e^+e^- \rightarrow t\bar{t}$	top mass precision
	$e^+e^- \rightarrow \nu\bar{\nu}H$	Higgs couplings
500 GeV	$e^+e^- \rightarrow t\bar{t}$	top couplings
	$e^+e^- \rightarrow t\bar{t}H$	Higgs-top coupling
	$e^+e^- \rightarrow Z^0 HH$	Higgs self coupling
1000 GeV	$e^+e^- \rightarrow \nu\bar{\nu}HH$	Higgs self coupling

SSbar Analysis

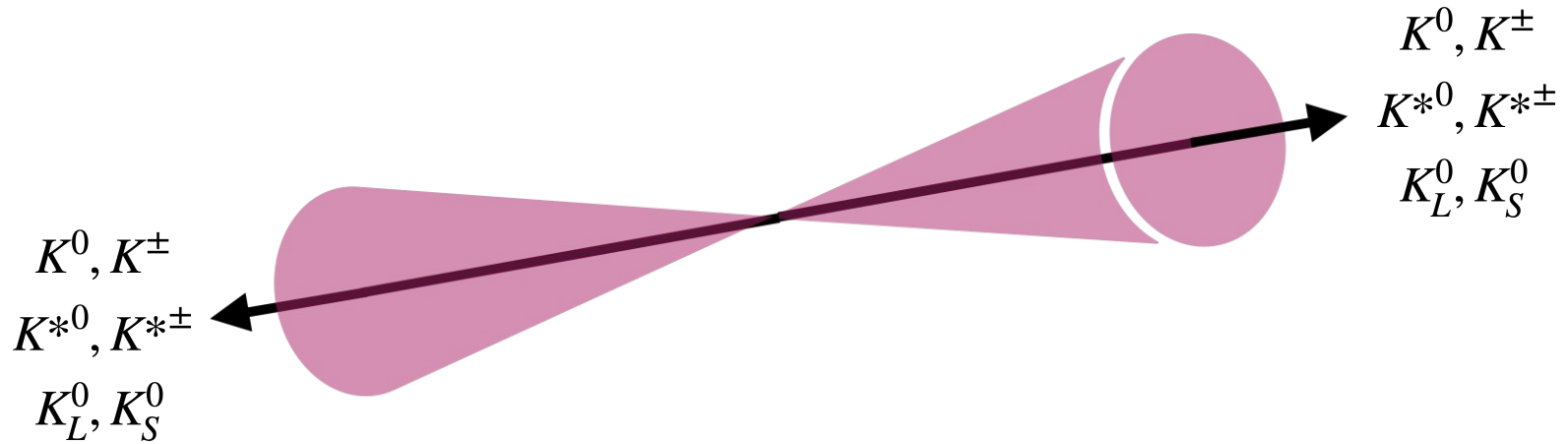
SSbar Process

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



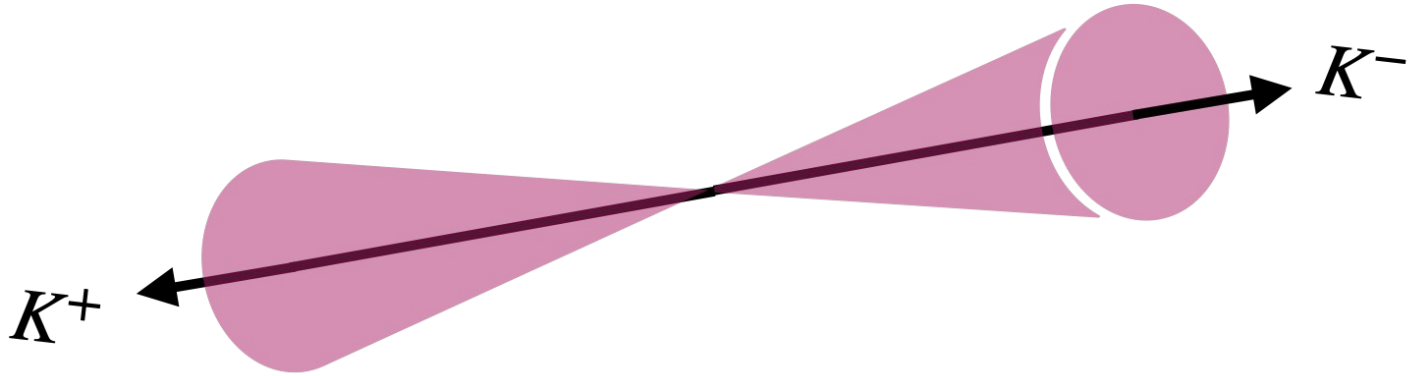
SSbar Process

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

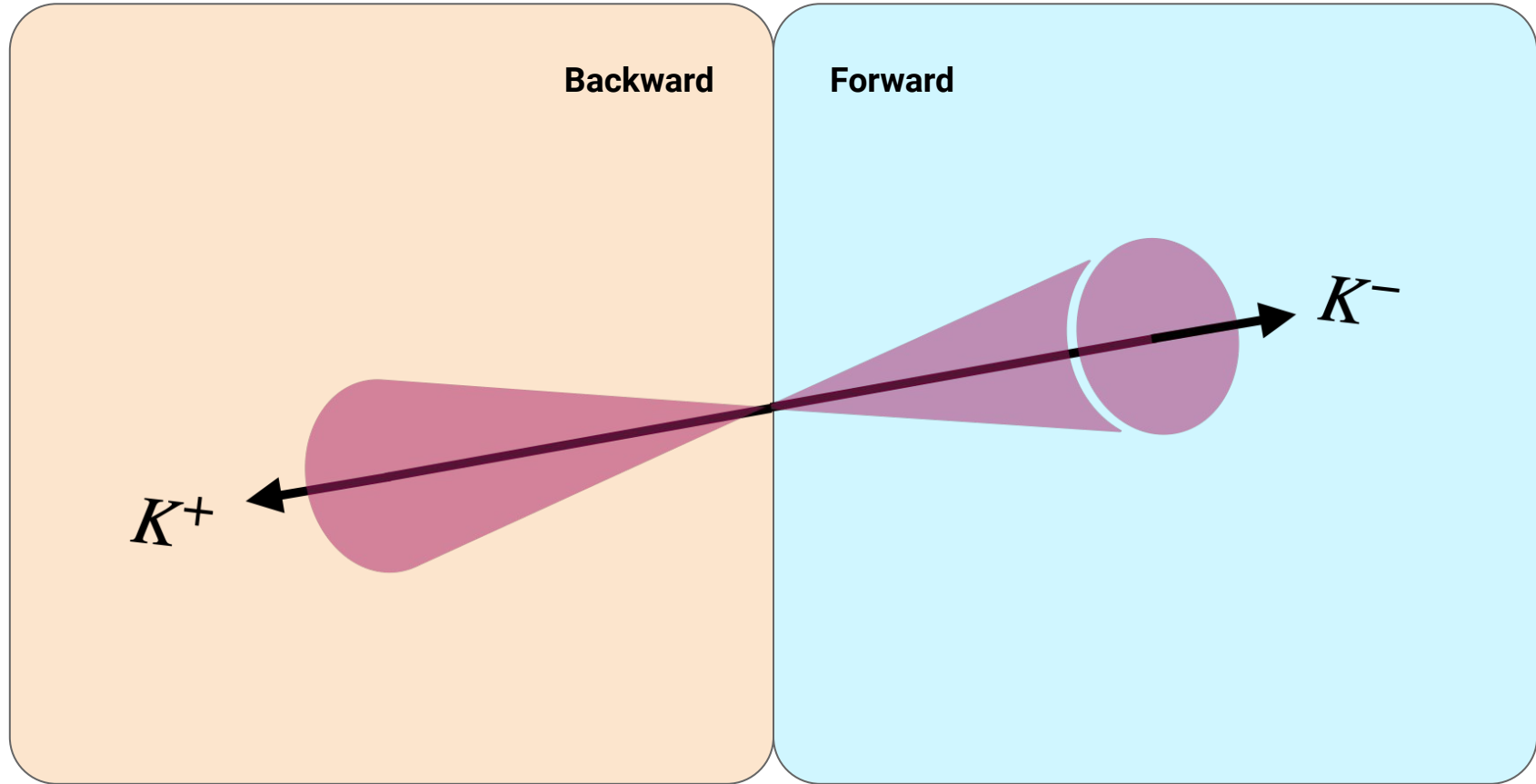


SSbar Process

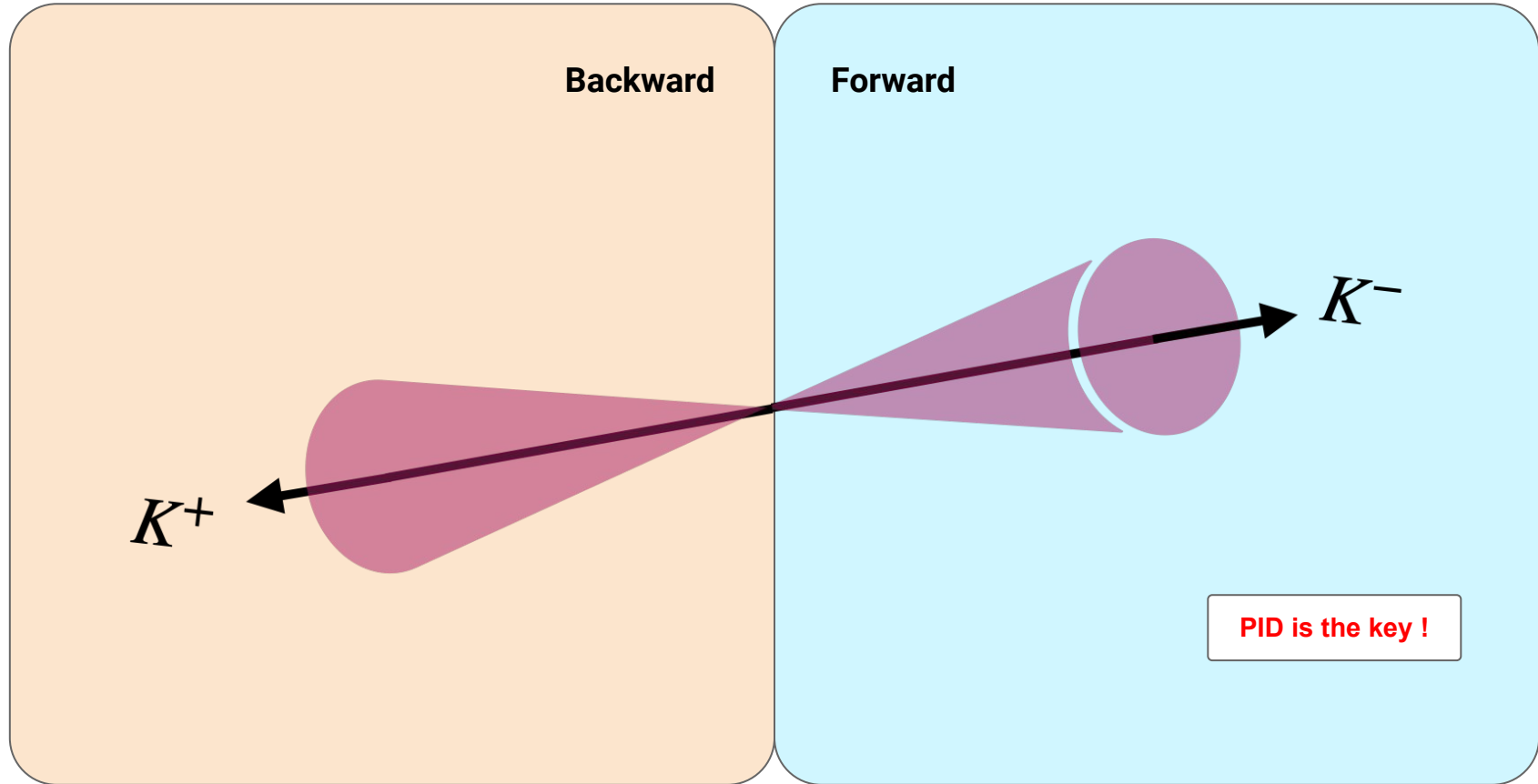
$$e^+e^- \rightarrow s\bar{s}$$



SSbar Process



SSbar Process



Analysis Steps

- Reconstruct SSbar process using generator information
 - Summer 2021
 - PID was performed by checking with the Generator Information.
 - Done to **explore the maximum efficiency** that can be achieved by this analysis.
 - Understanding the characteristics of the process itself.
- Reconstruct SSbar process using dE/dx distance PID
 - Fall 2021 - Winter 2022
 - PID was performed using **dE/dx distance information**.
 - Still use **Gen Info for Signal Selection**
 - Tight selection was applied to **achieve high purity**.
- Analysis Refinement
 - Winter 2022
 - Counter migration
 - Increase selection efficiencies.
 - Start of use **Reco Info for ISR removal**.

SSbar Reconstruction

Reconstruction Steps

LPFO Selection

Charge Check

Momentum Check

TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check

Gen Signal Selection

- SSbar back-to-back

$$0.95 < \cos \theta_{S\bar{S}}$$

- Total Energy

$$120 < E_{S,\bar{S}} < 127 \text{ GeV}$$

Leading PFO

LPFO Selection

Charge Check

Momentum Check

TPC Hit Check

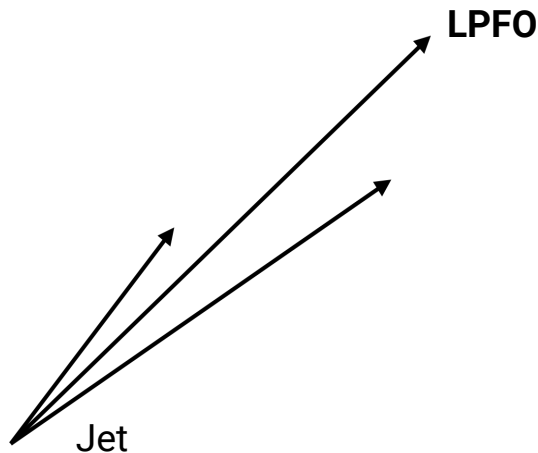
IP Check

dE/dx Minimum Check

SPFO Check

Leading PFO (LPFO)

- Particle with *highest* momentum within a Jet.
- SSbar typically disintegrate into a pair of energetic kaons.
- We choose LPFO among **charged PFOs** inside a jet.



Charge & Momentum

LPFO Selection

Charge Check

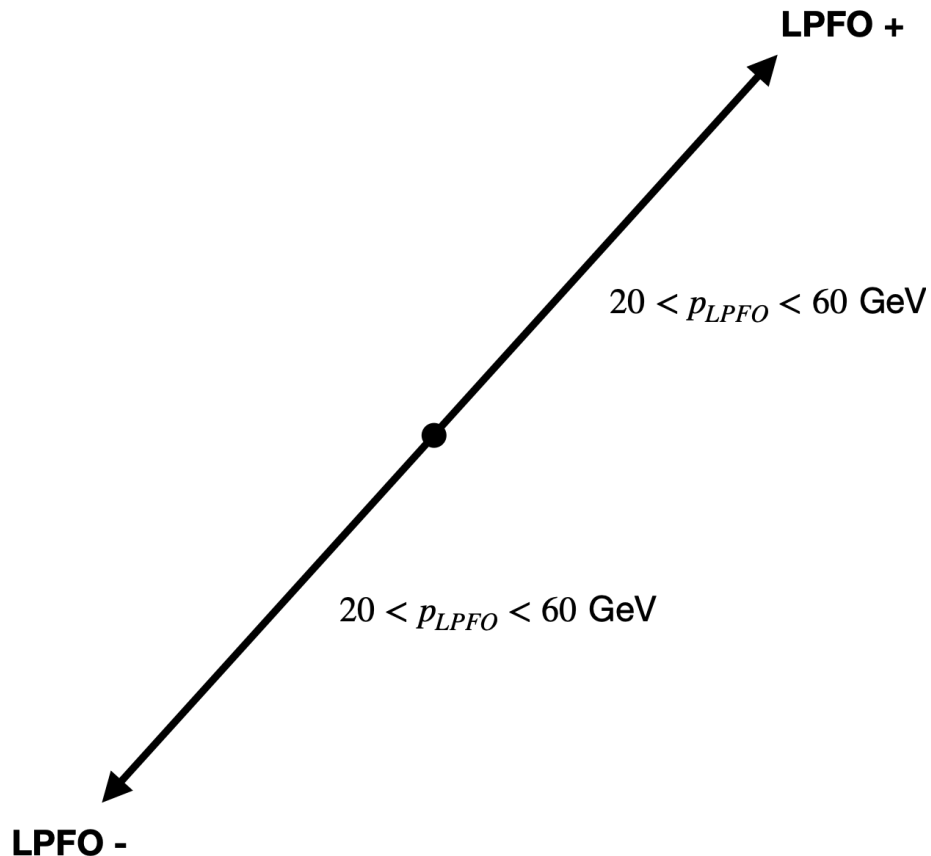
Momentum Check

TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check



TPC Hits

LPFO Selection

Charge Check

Momentum Check

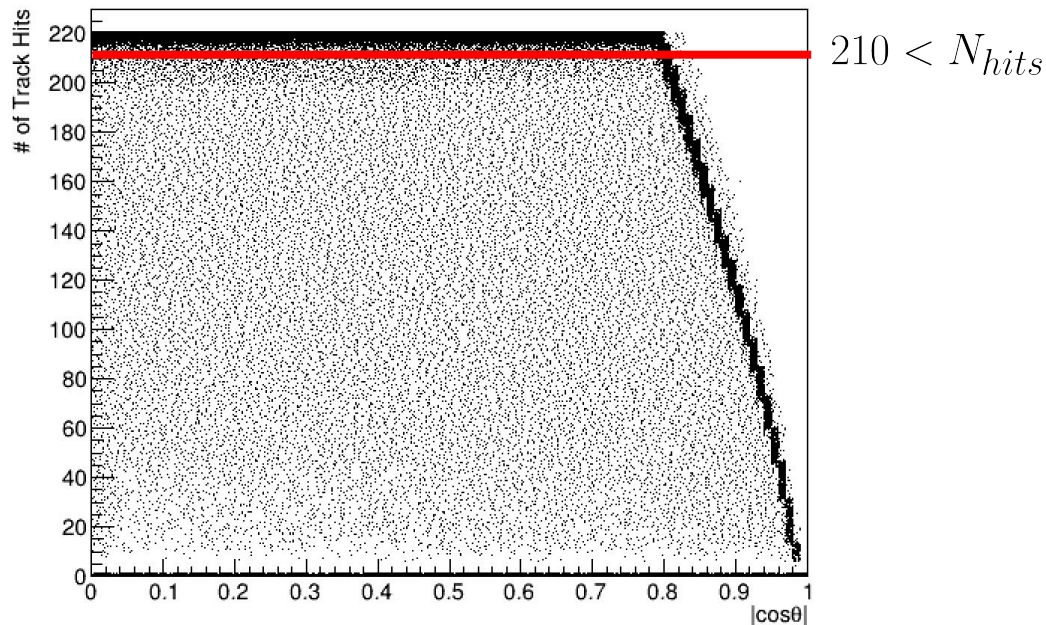
TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check

$$\sigma_{dE/dx} \propto \frac{1}{\sqrt{N_{hits}}}$$



Impact Parameter

LPFO Selection

Charge Check

Momentum Check

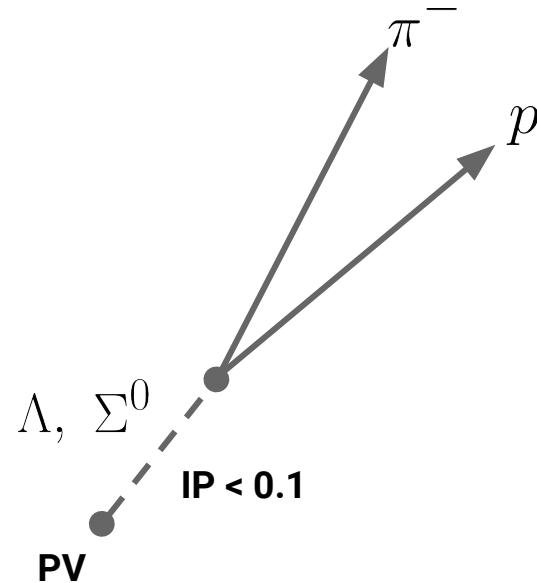
TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check

Hyperon Suppression



dE/dx Minimum

LPFO Selection

Charge Check

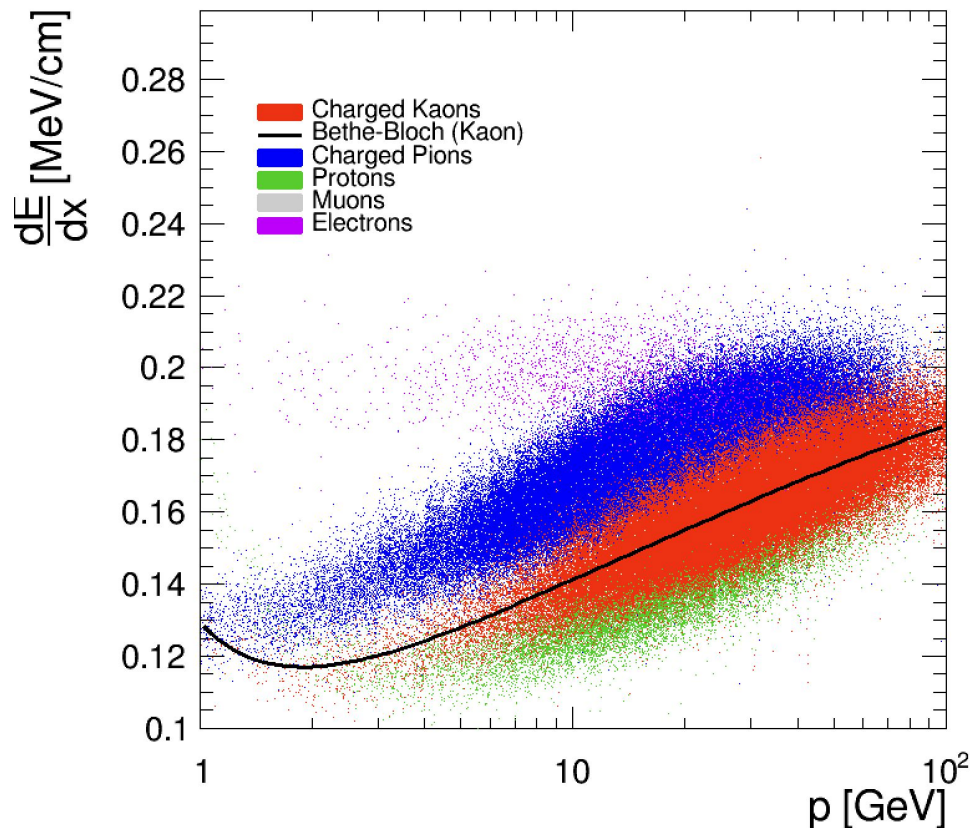
Momentum Check

TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check



dE/dx Minimum

LPFO Selection

Charge Check

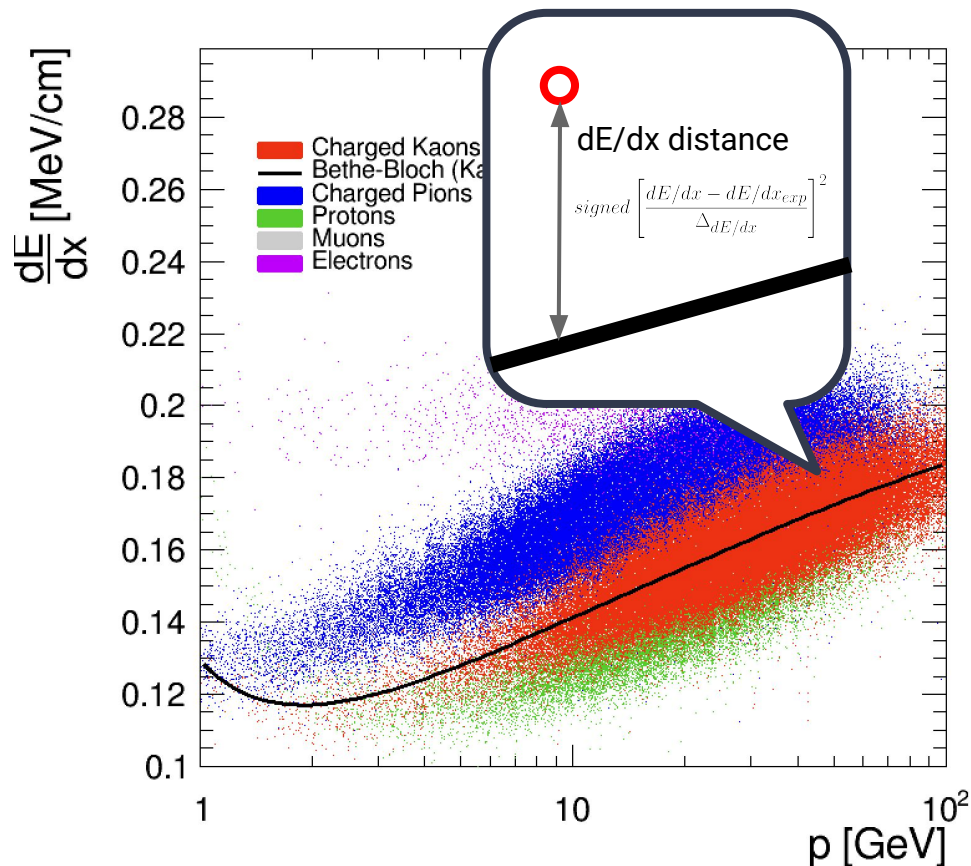
Momentum Check

TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check



dE/dx Minimum

LPFO Selection

Charge Check

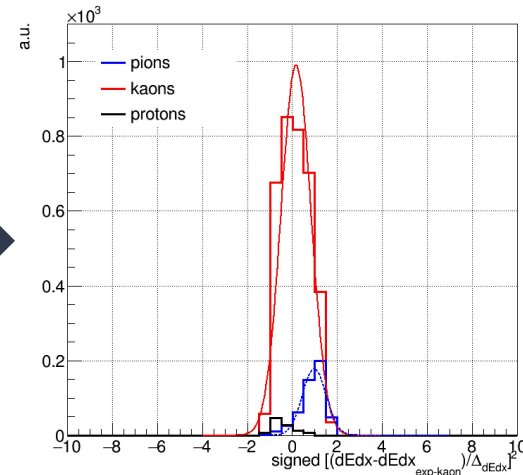
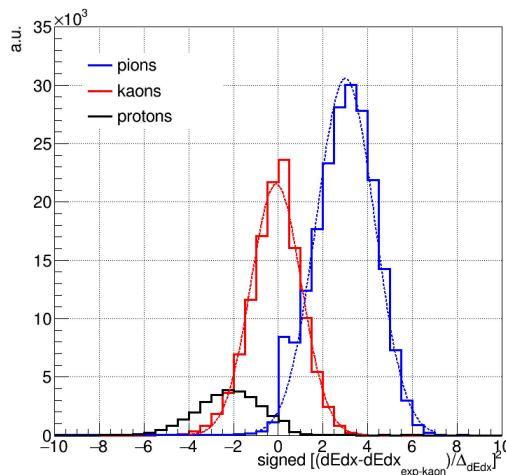
Momentum Check

TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check



dE/dx distance minimization

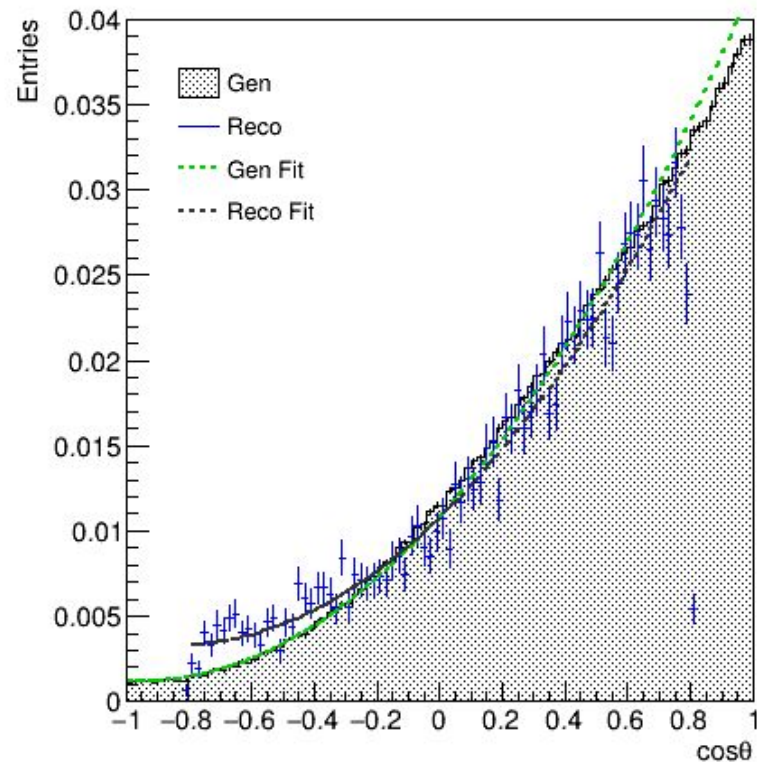
- $k \text{ dE/dx distance} < \pi \text{ dE/dx distance}$
- $k \text{ dE/dx distance} < p \text{ dE/dx distance}$

Results I

First Attempt

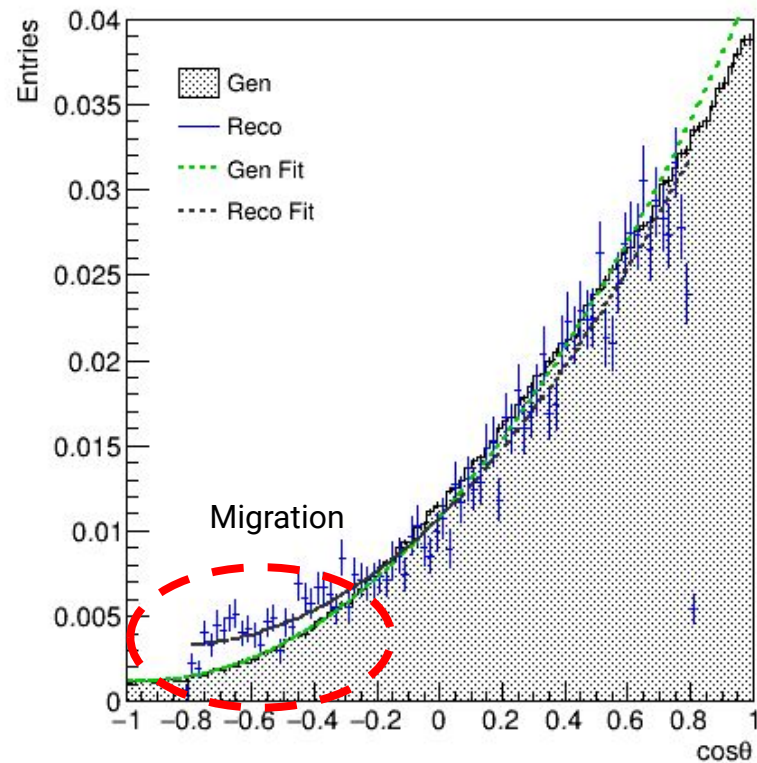
First Attempt

# Total Events (ss)	2,512,257
ISR removed (Gen)	374,399
Charge check	201,967
Momentum check	53,227
TPC hit check	27,921
Offset check	26,848
dEdx dist min check	4,211

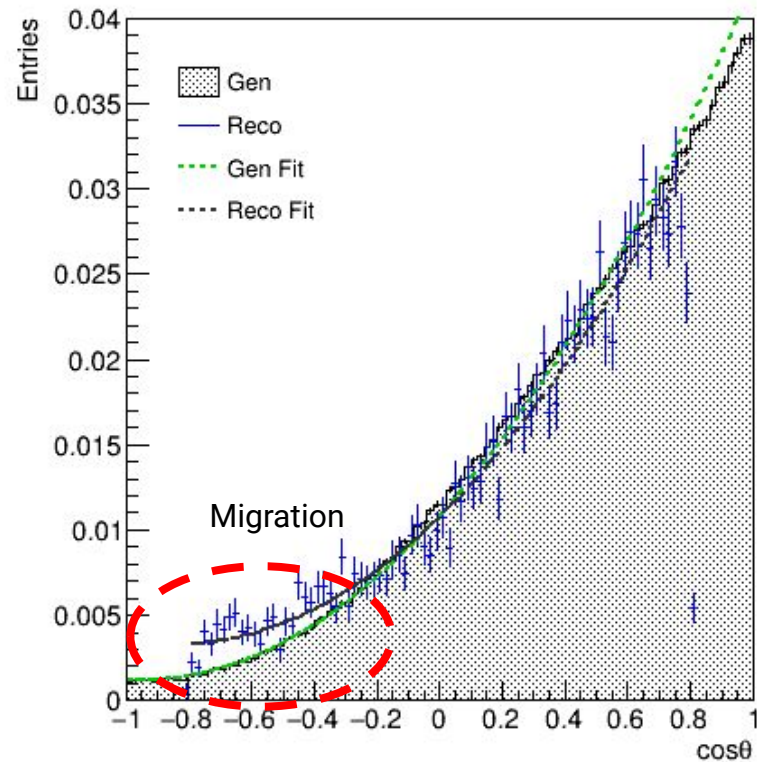
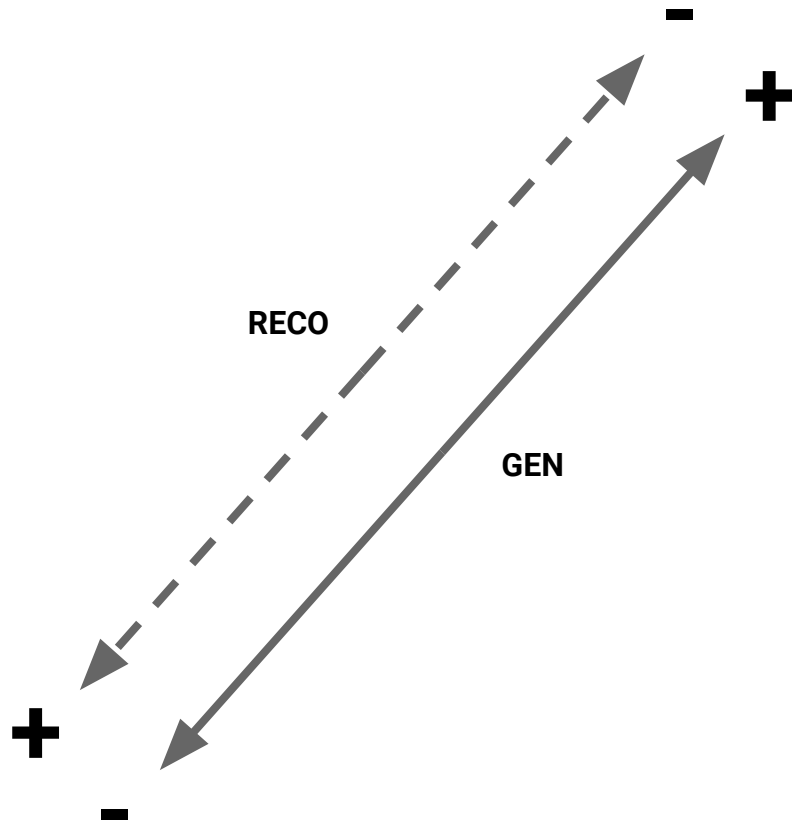


SPFO Removal

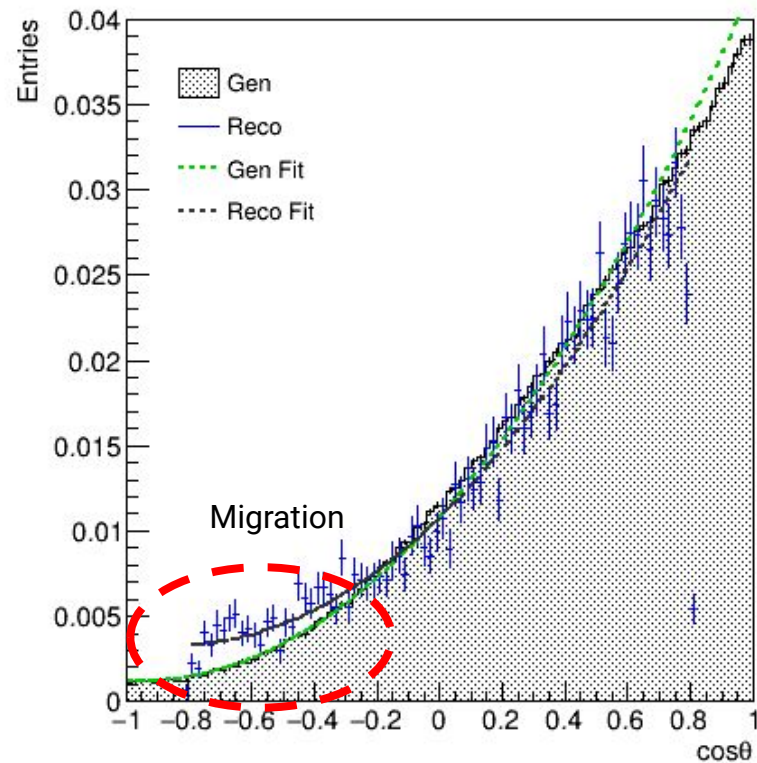
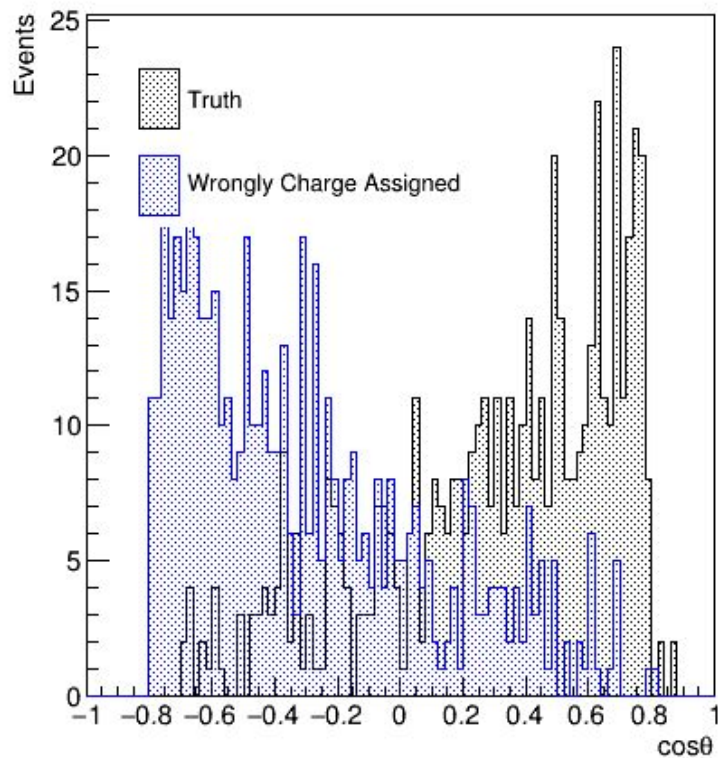
Migration



Migration



Migration



Interference

LPFO Selection

Charge Check

Momentum Check

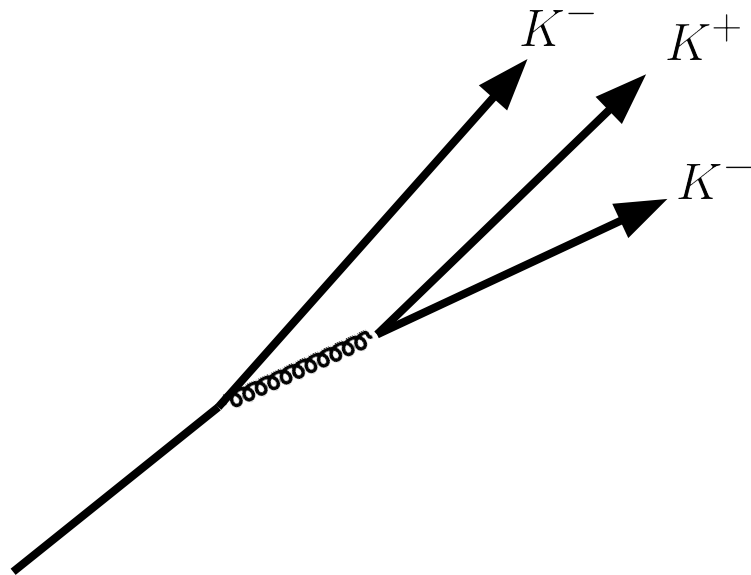
TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check

Secondary PFO (SPFO) Check



SPFO Check

LPFO Selection

Charge Check

Momentum Check

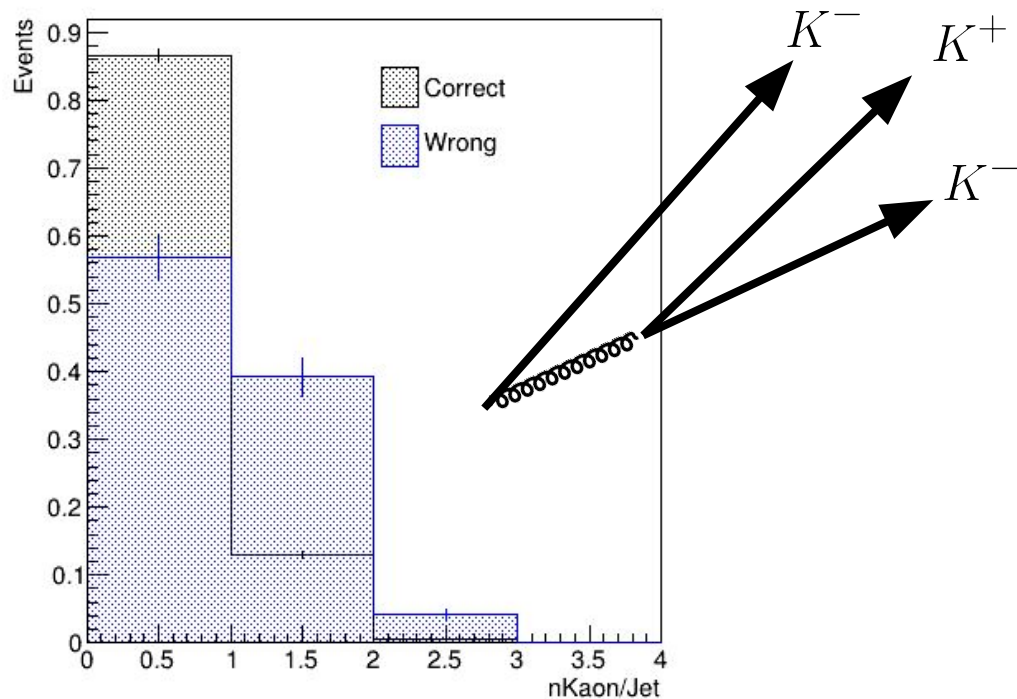
TPC Hit Check

IP Check

dE/dx Minimum Check

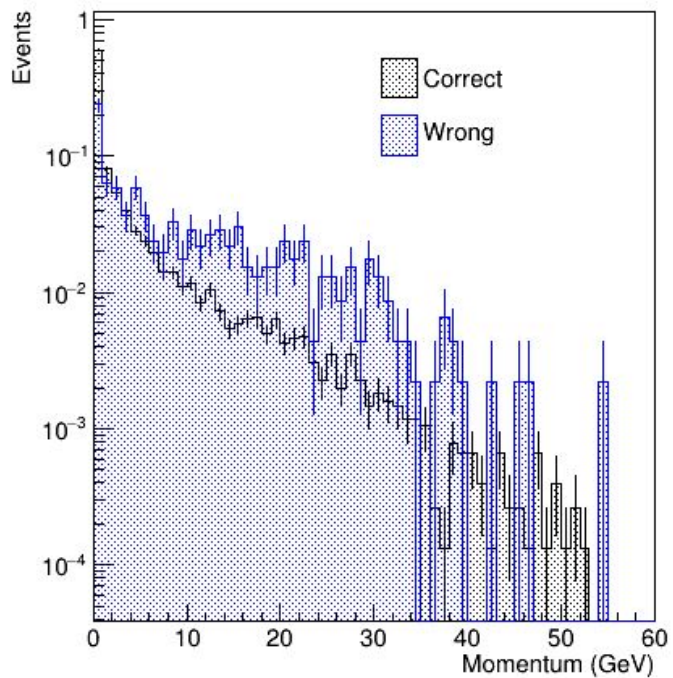
SPFO Check

Secondary PFO (SPFO) Check

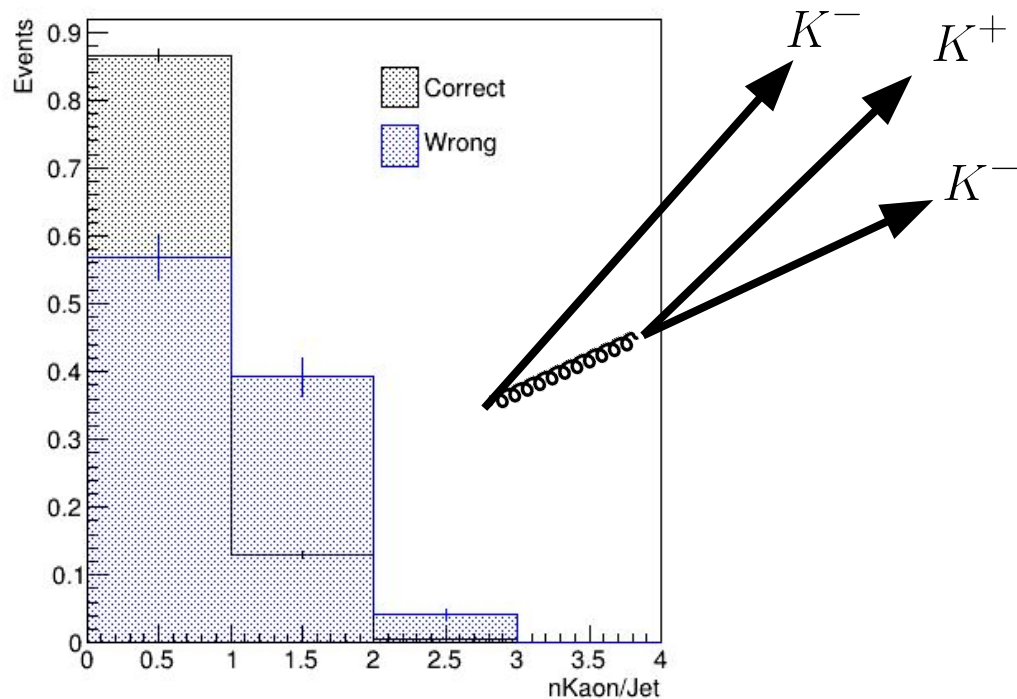


SPFO Check

LPFO Selection



Secondary PFO (SPFO) Check



SPFO Check

LPFO Selection

Charge Check

Momentum Check

TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check

Secondary PFO (SPFO) Check

- Find SPFO such that:
 - Charged Kaon
 - Charge must be opposite to LPFO Kaon
(same sign does not create confusion)
 - Must have least 10 GeV momentum
- If there is such SPFO -> veto

Results II

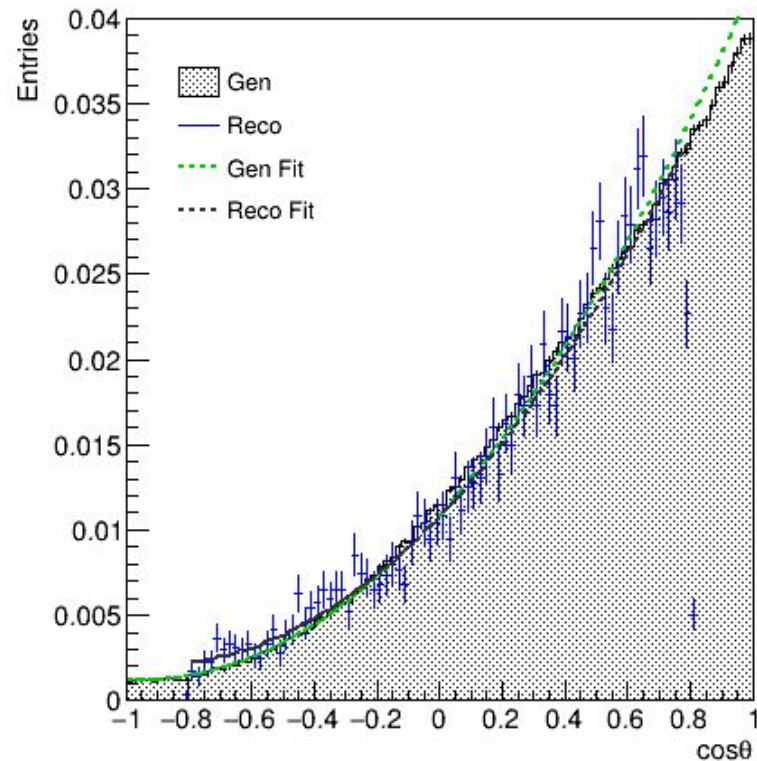
After SPFO Removal



After SPFO Removal

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Charge check	201,967
Momentum check	53,227
TPC hit check	27,921
Offset check	26,848
dEdx dist min check	4,211
Opp K SPFO check	3,036
Migration	86 (2.8%)

Purity : 97.3% **Efficiency : ~1.0%**



What can we do?

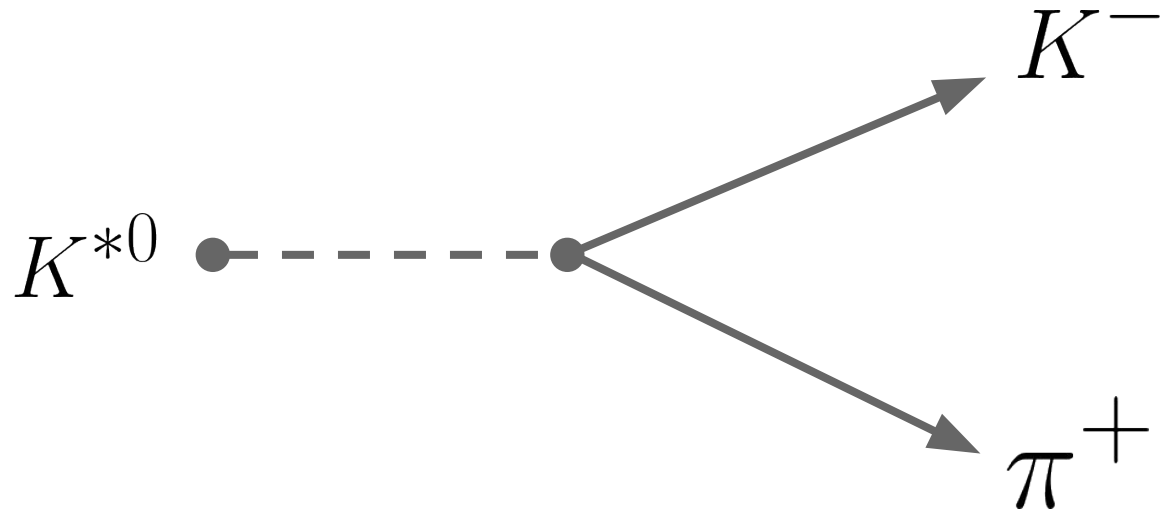
Efficiency Refinement

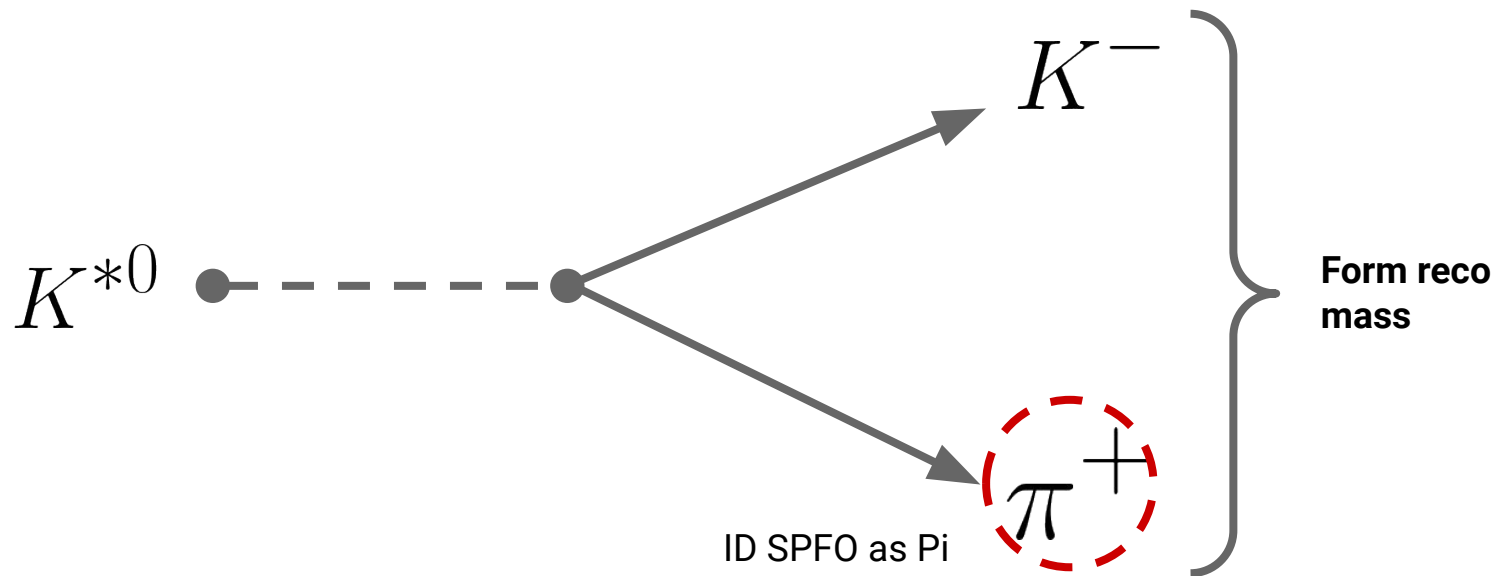
- Change in Signal Selection
 - Back-to-Back : $0.95 < \cos \theta_{s\bar{s}}$
 - Total Energy : $120 < E_{s,\bar{s}} < 127 \text{ GeV}$
- Consider K^*

Other Possible Leading Ks

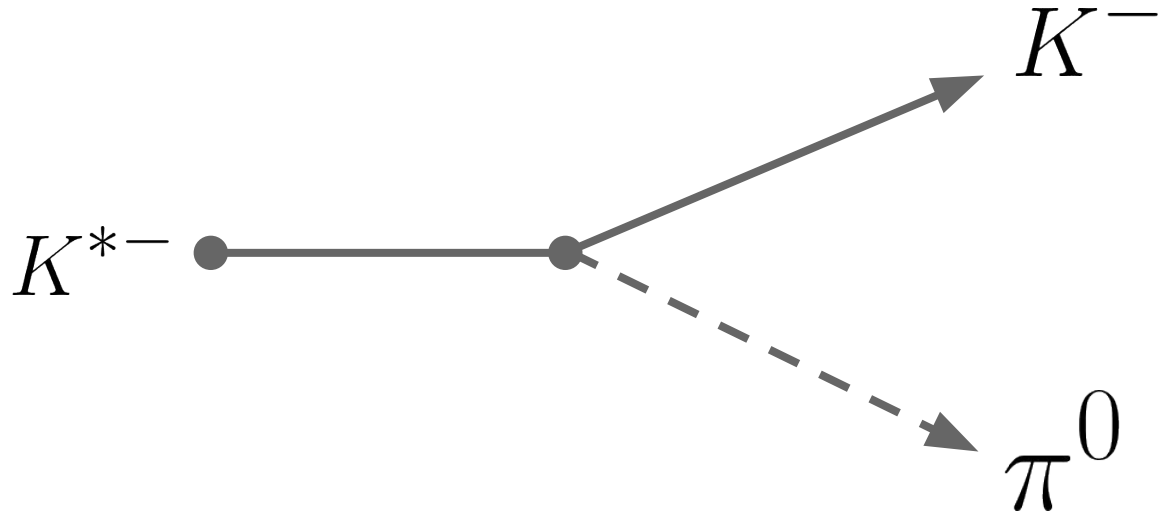


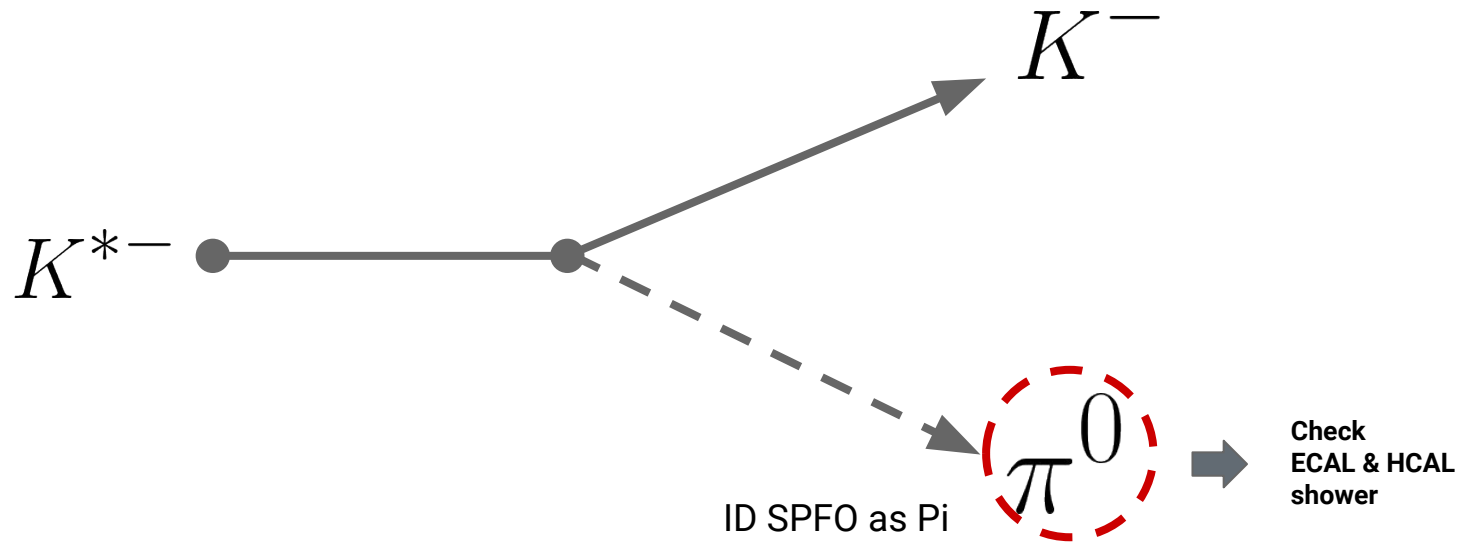
K^*



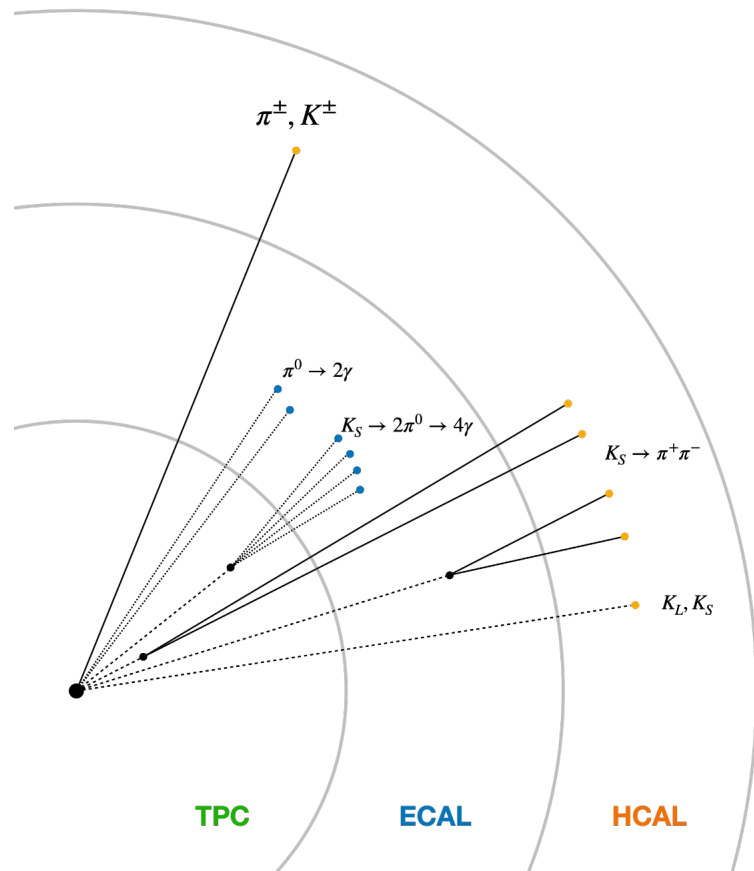
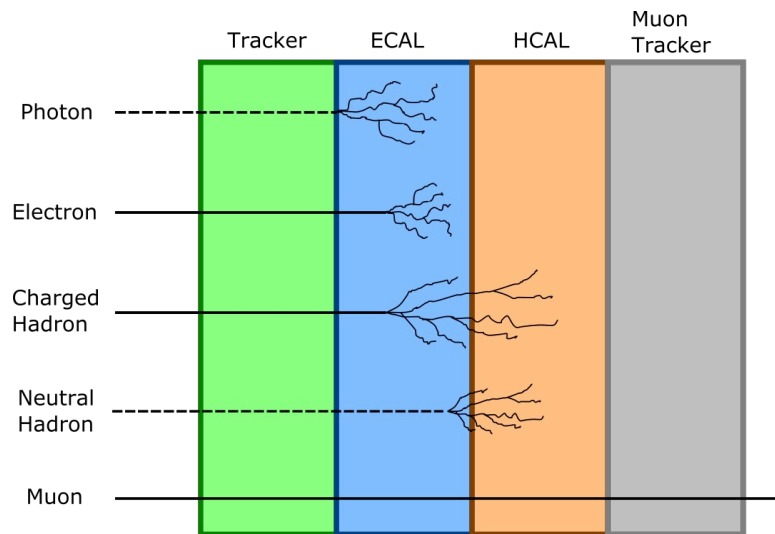


K^*





Why Migration?



Summary & Prospects



Summary & Prospects

Summary

- SSbar reconstruction was performed, using dE/dx PID.
 - Kaon identification
- Purity up to 96% was achieved with current selection.
- Suffers significantly from the efficiency loss

Prospects

- Retrieve efficiency
 - Loose selection criteria (e.g. momentum)
 - Include cases with K^*
 - Include neutrals using HCAL info
- ISR study
 - ISR analysis is already in progress
 - LPFO charged Kaon opening angle
 - Total visible energy

Backup Slides

ISR Suppression

ISR Suppression

Signal Definition

- SSbar back-to-back

$$0.95 < \cos \theta_{s\bar{s}}$$

- Total Energy

$$220 < E_s + E_{\bar{s}}$$

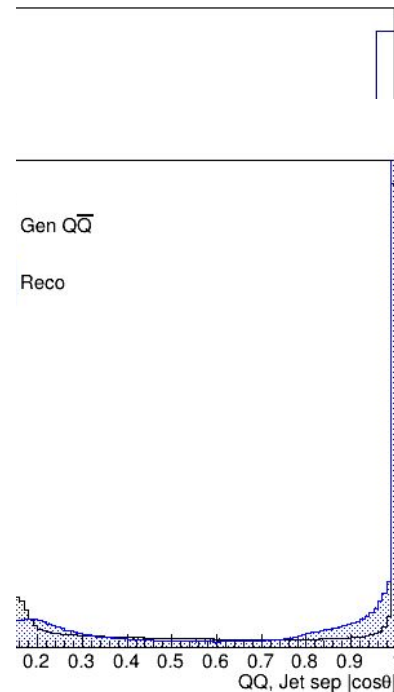
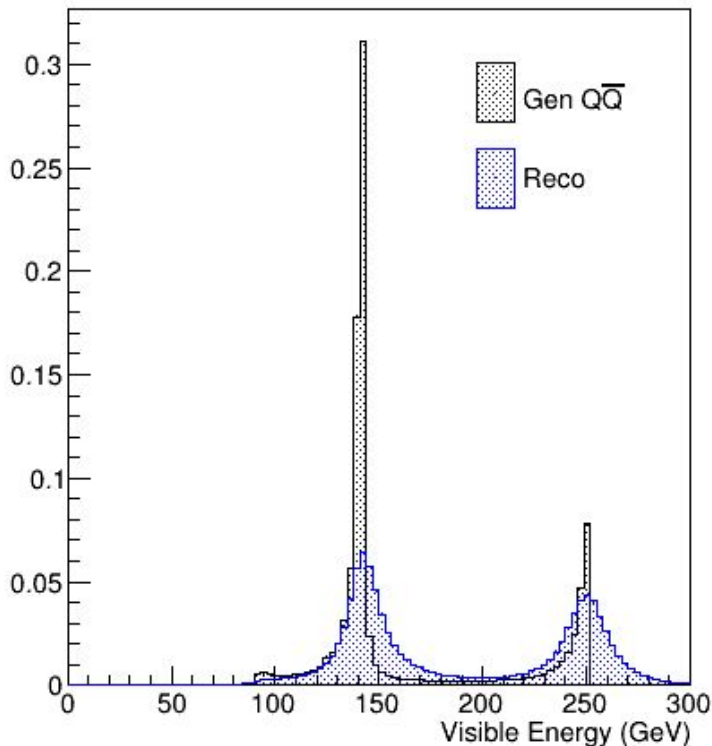
Reco ISR Removal

- LPFO back-to-back

$$0.95 < \cos \theta_{jets}$$

- Total Energy

$$220 < E_{vis}$$



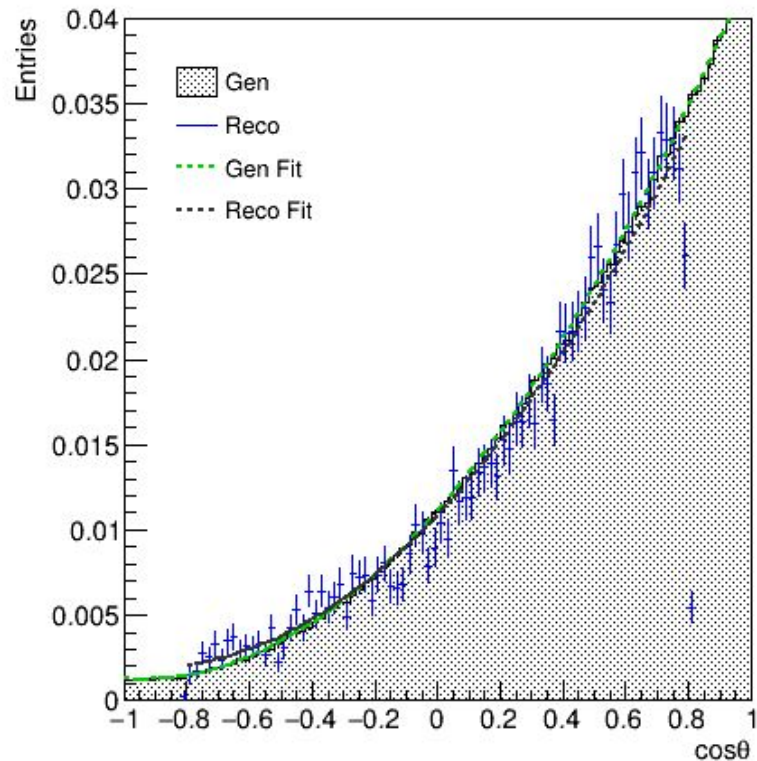
Results III

After Reco ISR Removal



Polar Angle Distribution

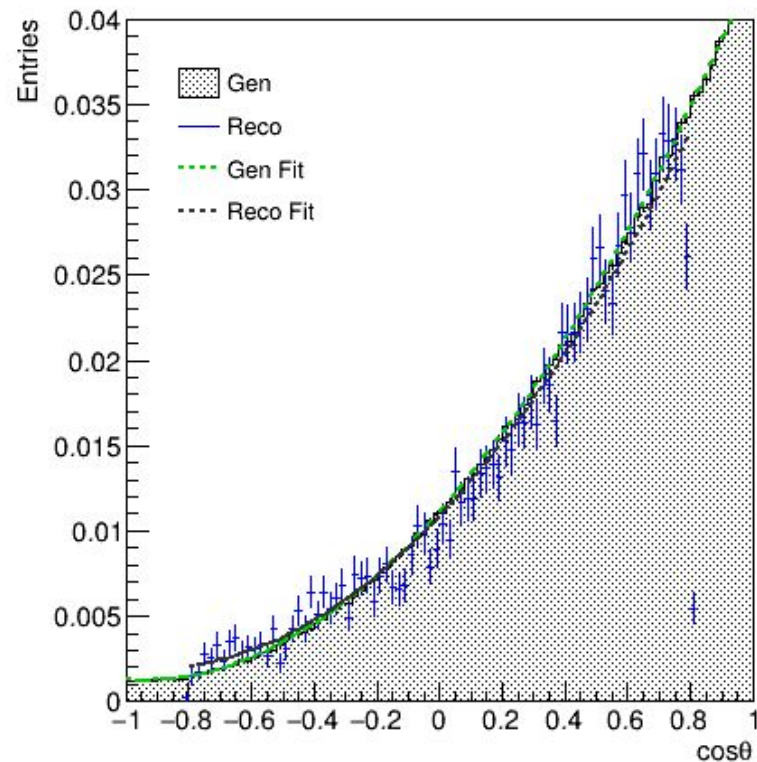
# Total Events (ss)	2,515,387
ISR removed	678,231
Charge check	361,681
Momentum check	71,287
TPC hit check	36,184
Offset check	34,749
dEdx dist min check	5,494
Opp K SPFO check	3,977
Migration	108 (2.7%)



Polar Angle Distribution

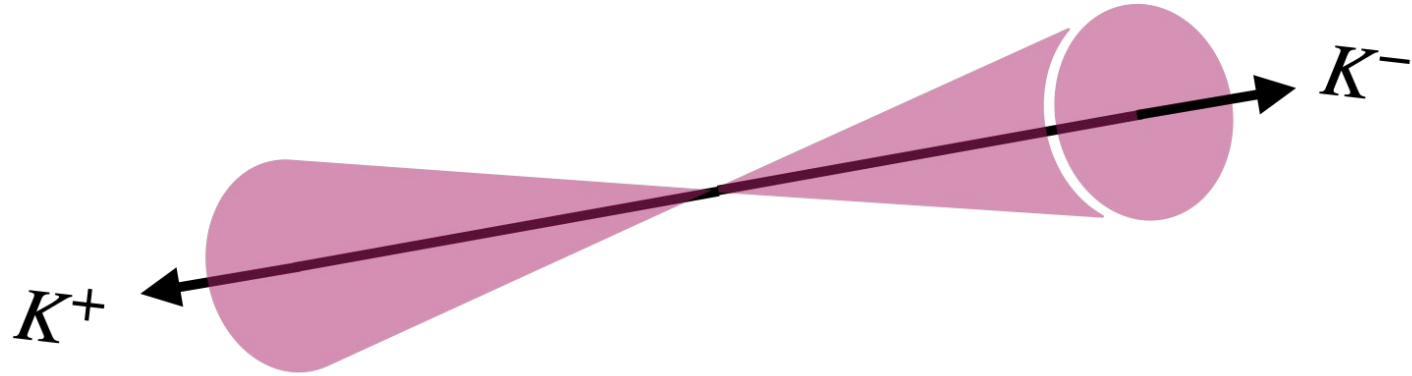
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Purity : 97.3% Efficiency : ~1.0%

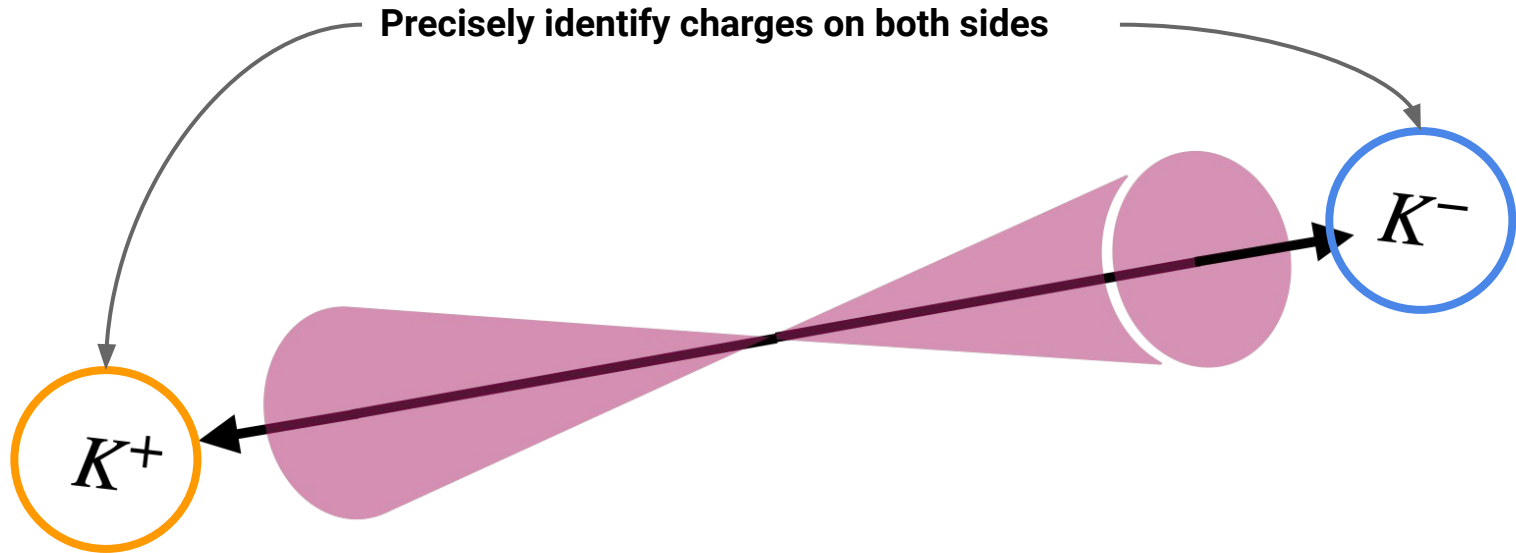


Migrated Event Analysis

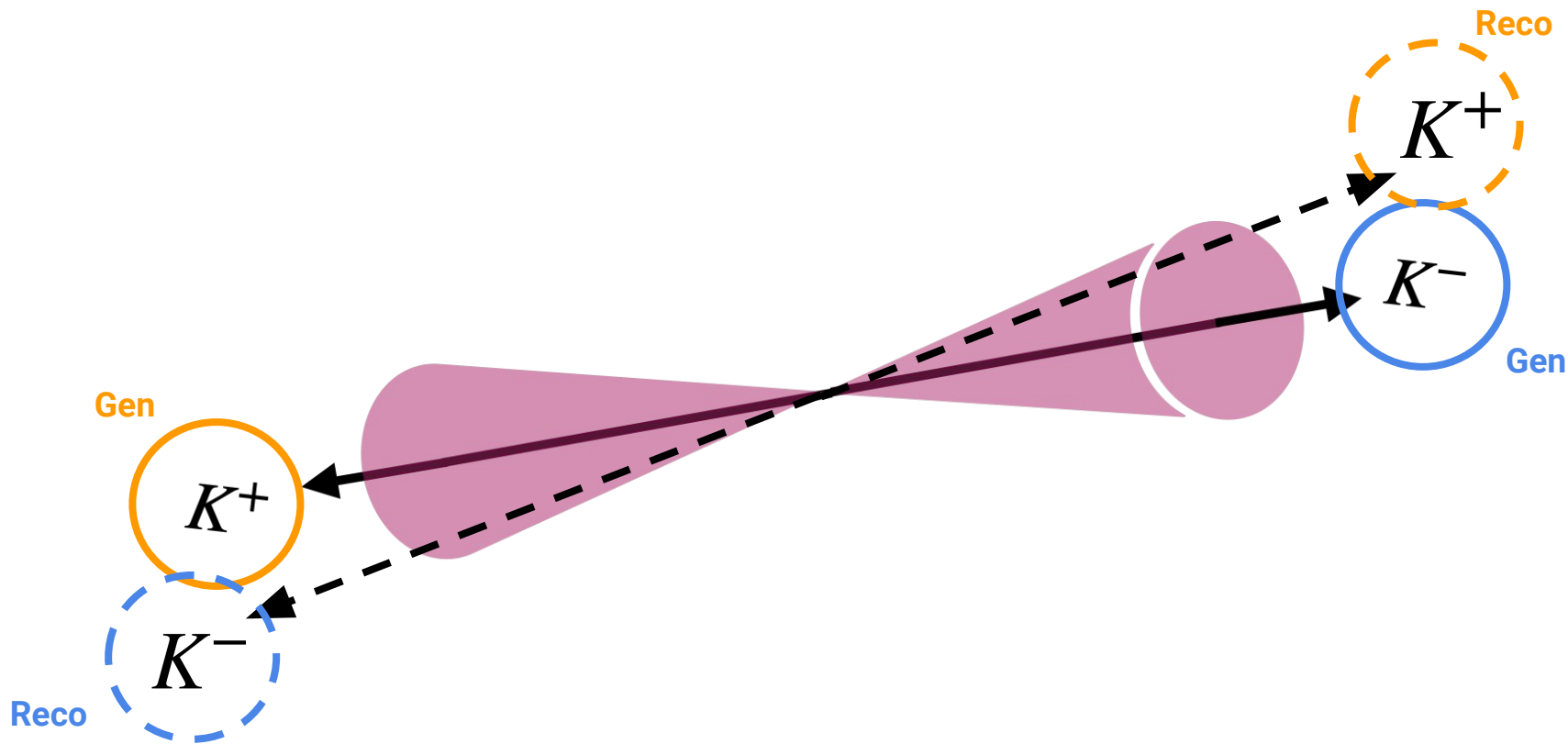
What is Migration?



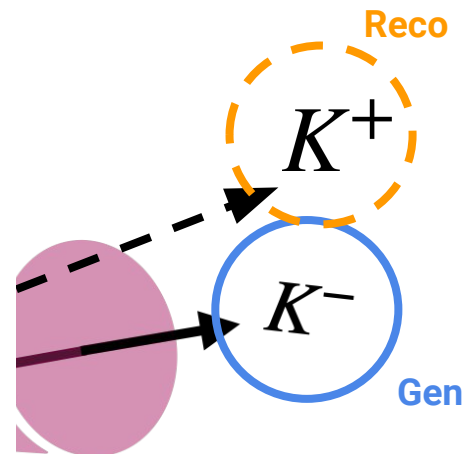
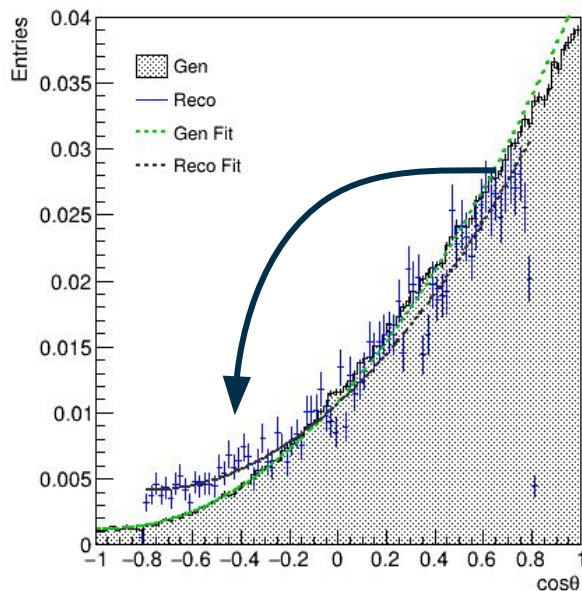
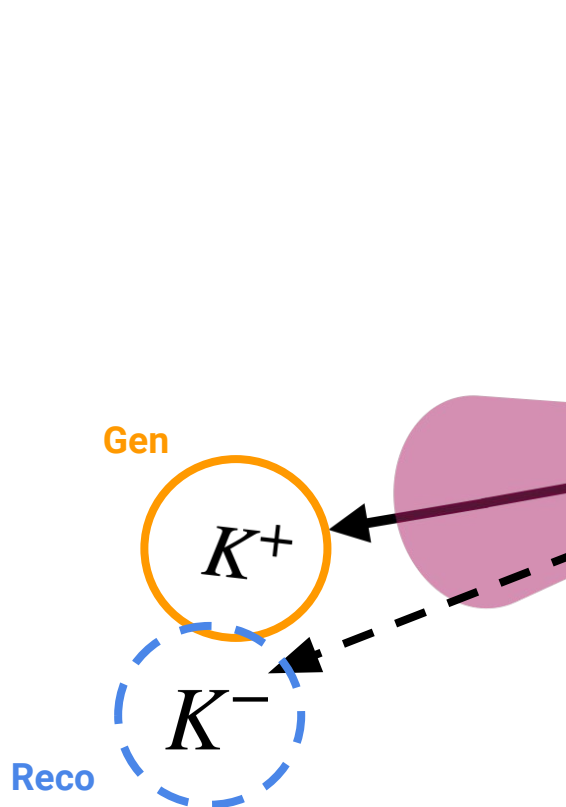
What is Migration?



What is Migration?



What is Migration?



Why Migration?

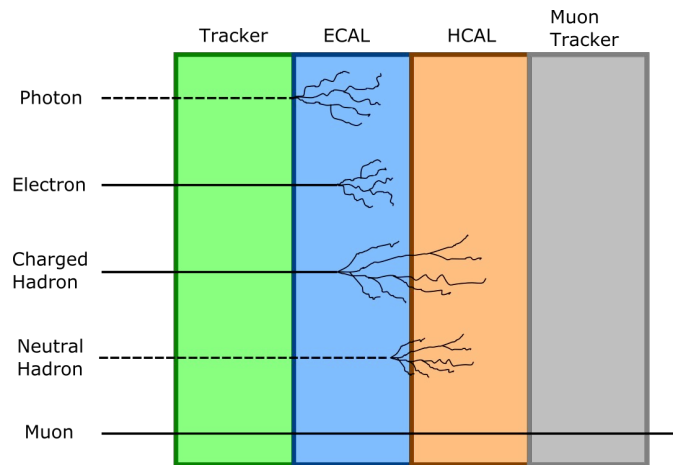


Why Migration?

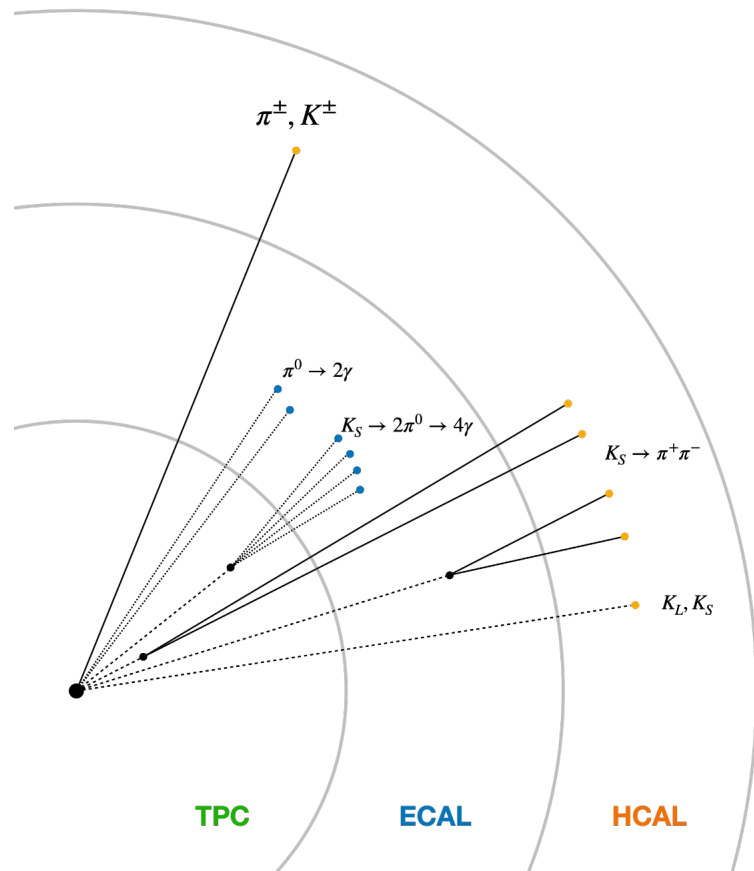
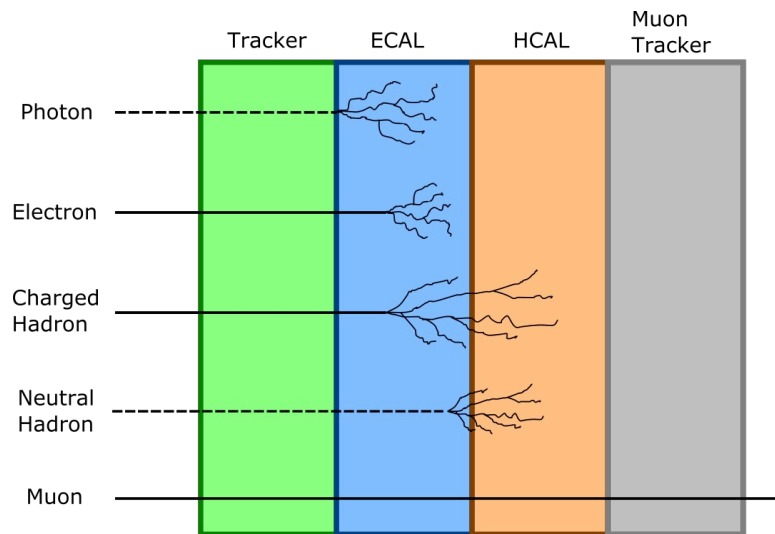


Possible types of Kaons from $s\bar{s}$ pair

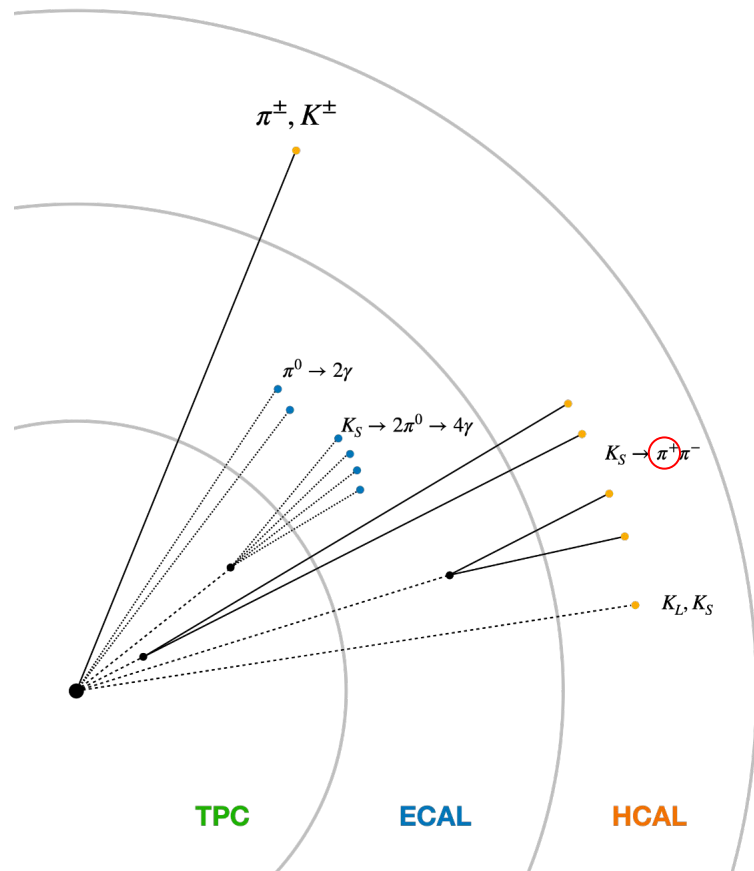
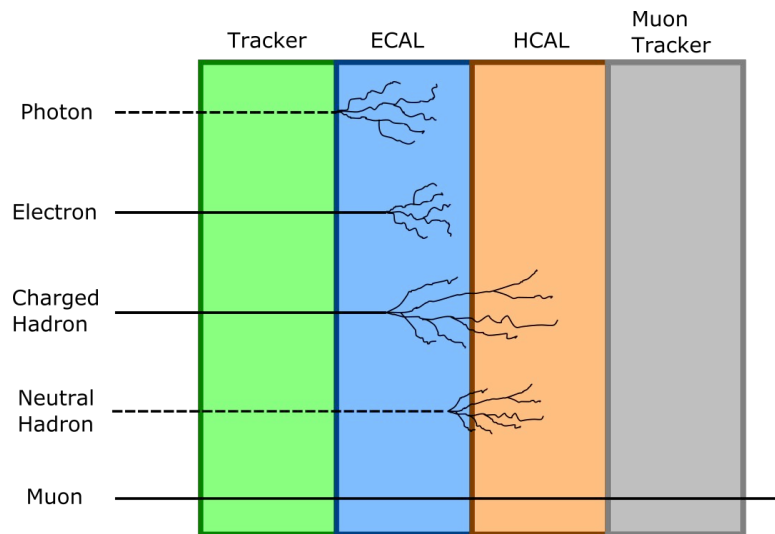
$$K^- = s\bar{u}, K^+ = \bar{s}u, K_L \approx \frac{(s\bar{d} - d\bar{s})}{\sqrt{2}}, K_S \approx \frac{(s\bar{d} + d\bar{s})}{\sqrt{2}}$$



Why Migration?



Why Migration?

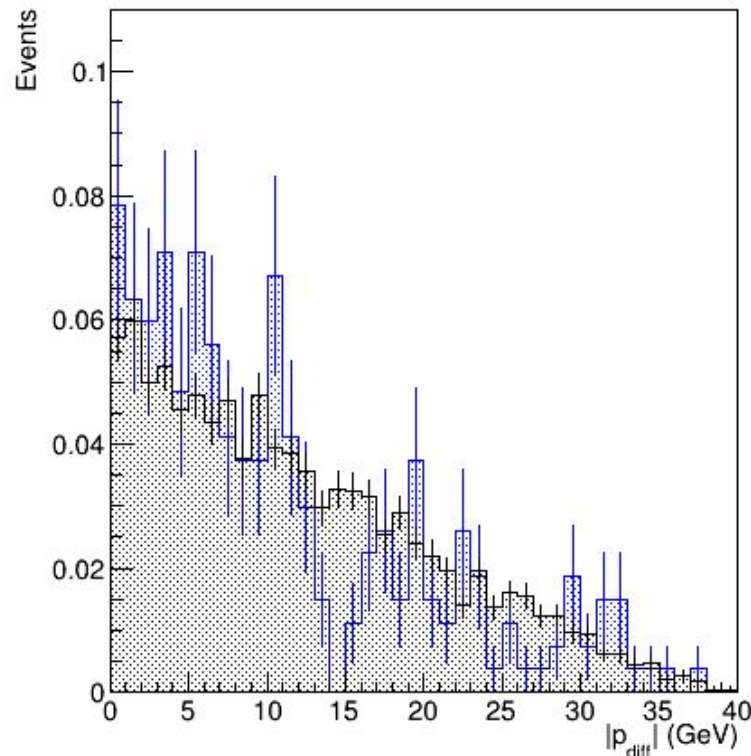


Full Stats

Migration

LPFO momentum separation

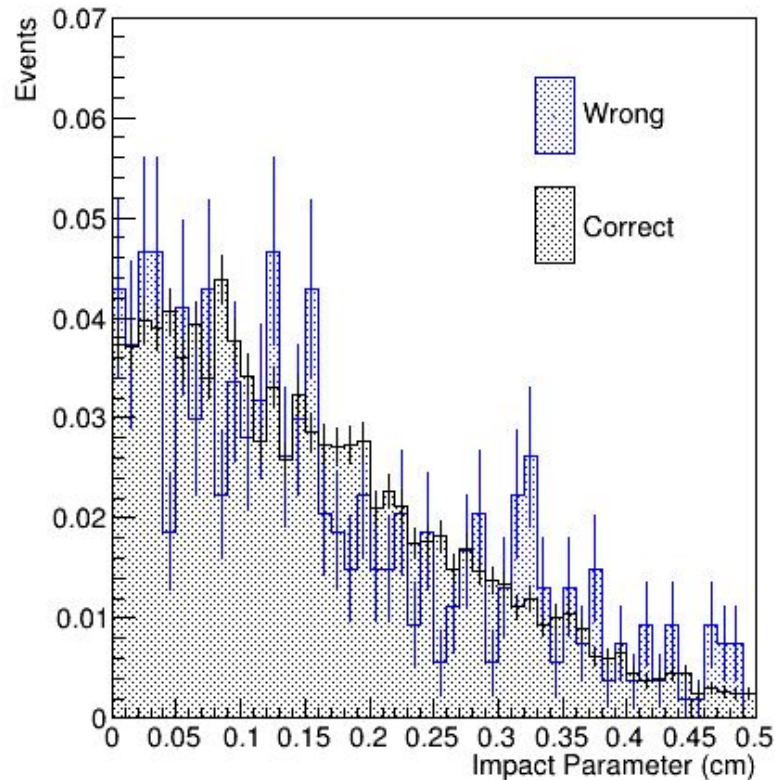
- eLpR full polarized
 - ss: 375,000 events \rightarrow 125 fb $^{-1}$
- Computation
 - LPFOp0 - LPFO p1
- Distribution at $p > 15$.



Migration

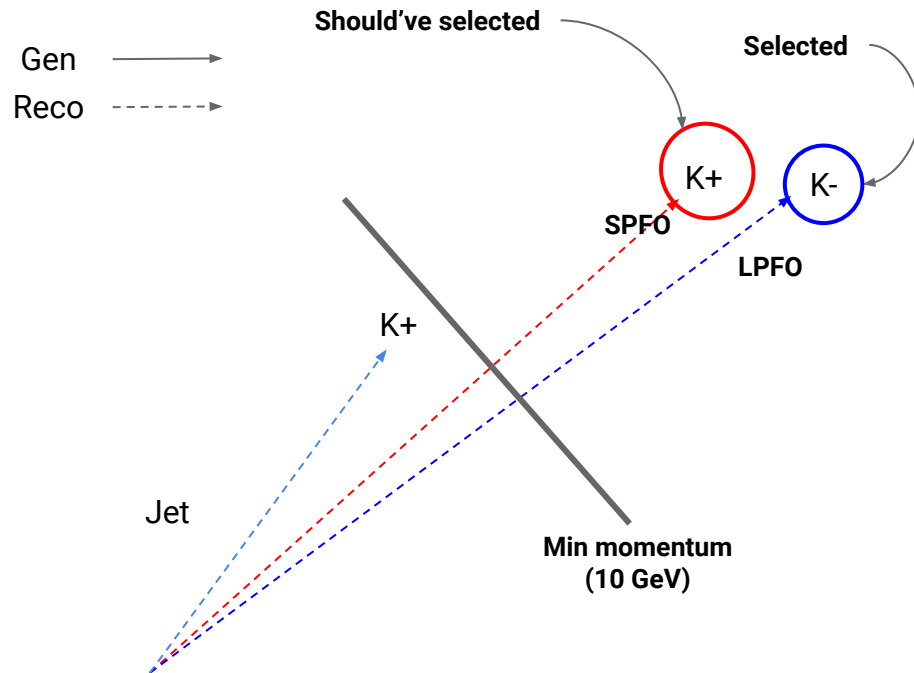
LPFO Impact Parameter

- Peak at 0.3
 - Lambda decay?
- More statistics needed?



Migration

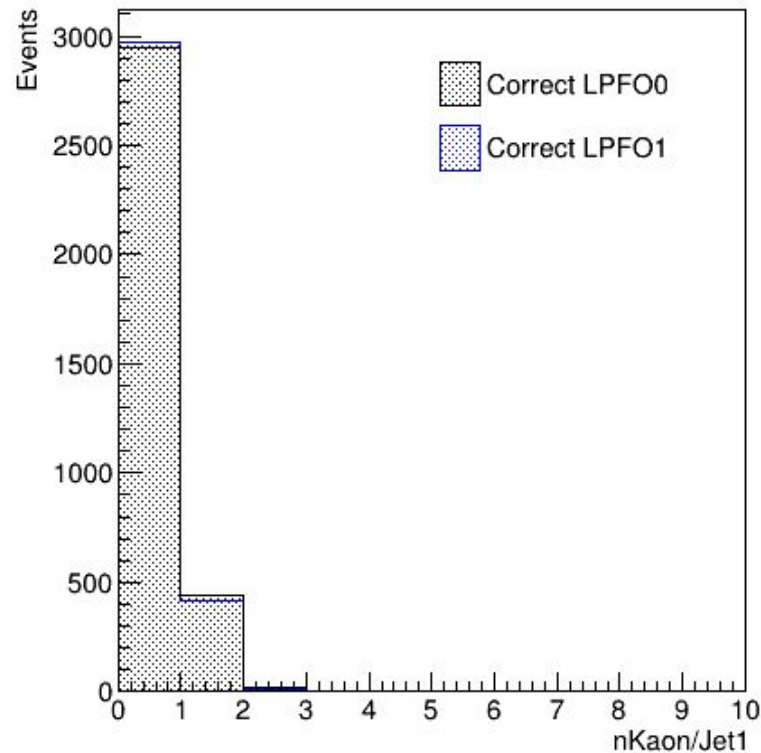
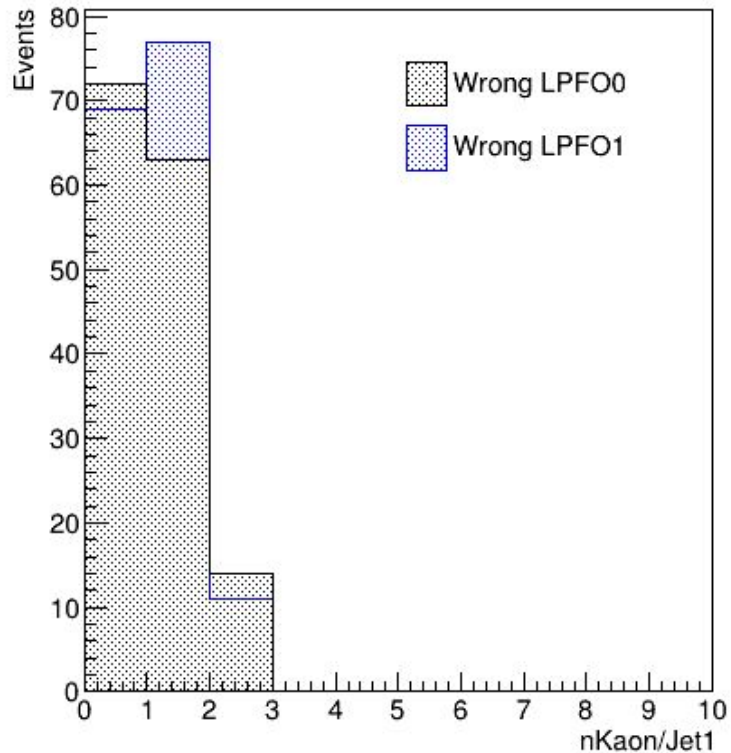
- We look for **Secondary PFOs (SPFO)** with opposite charge to LPFO.
- Wrong events should have SPFO with momentum close to LPFO. (Other **stole** original s-quark)
- Definition for **SPFO Kaon** with **opposite charge**
 - Not leading
 - LPFO is Kaon (ID MC gen partner)
 - SPFO is Kaon (ID MC gen partner)
 - Has opposite charge respect to LPFO
 - Min momentum : 10 GeV



WRONG EVENT

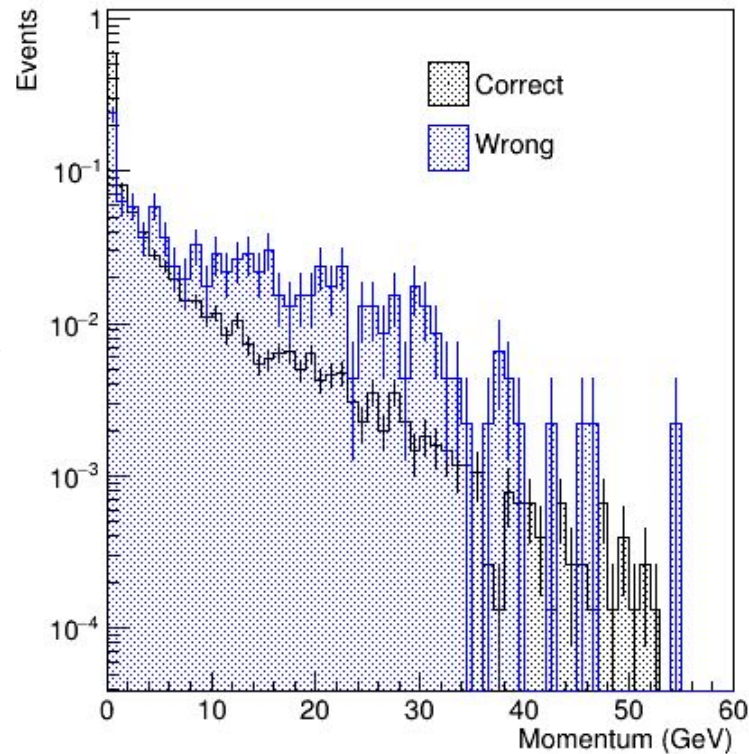
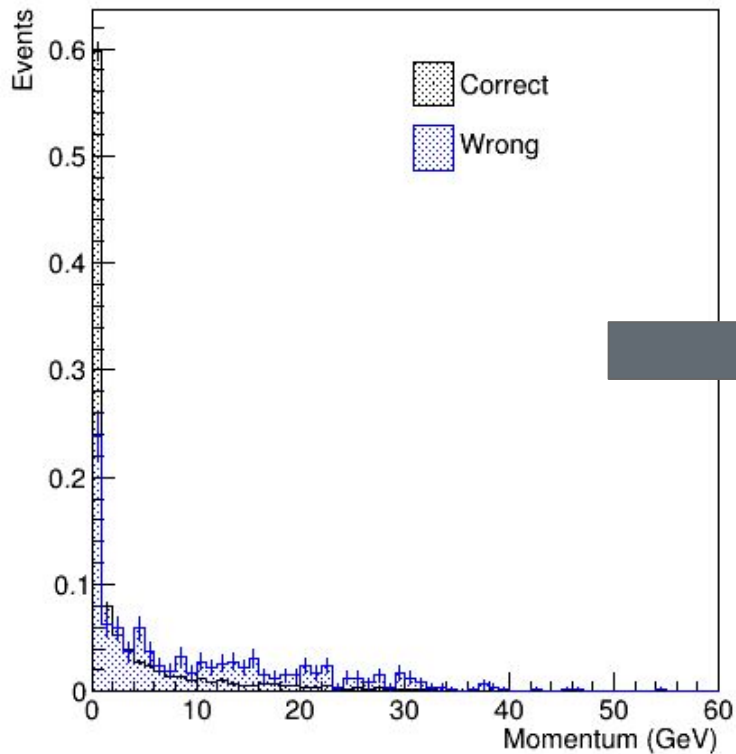
Migration

SPFO Kaon Opposite Charge Multiplicity



Migration

SPFO Kaon Opposite Charge Momentum



Selections (ss)

Cut MC

ISR suppression

- $QQ \cos \theta_{sep} > 0.95$
- $120 < QQ \text{ mom} < 127$

Cut PFO

General PFO

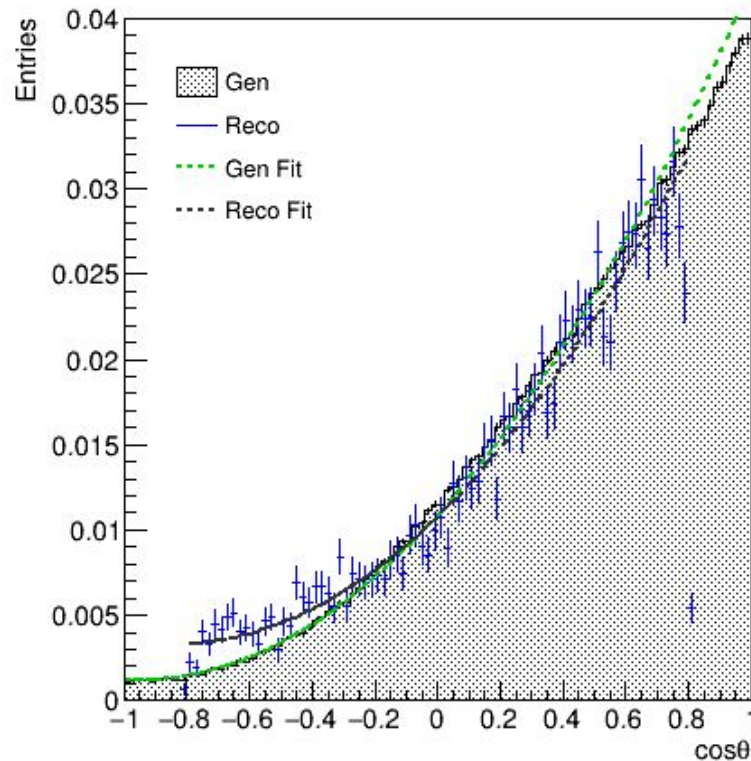
- PFO match (It should fall into either jet0 or jet1)
- # PFO tracks == 1 (more than 2 tracks cannot be associated to make 1 PFO)

Lead PFO (double tag)

- Both PFO should have momentum window
 $20 < \text{Lead PFO mom} < 60$
- Lead PFO charge \pm or $-+$
- # TPC hits **$210 < \text{Lead PFO hits}$**
- Offset cut < 1.0
- $k_{dEdx_dist} < (p_{dEdx_dist} \& \text{pidEdx_dist})$

Notes

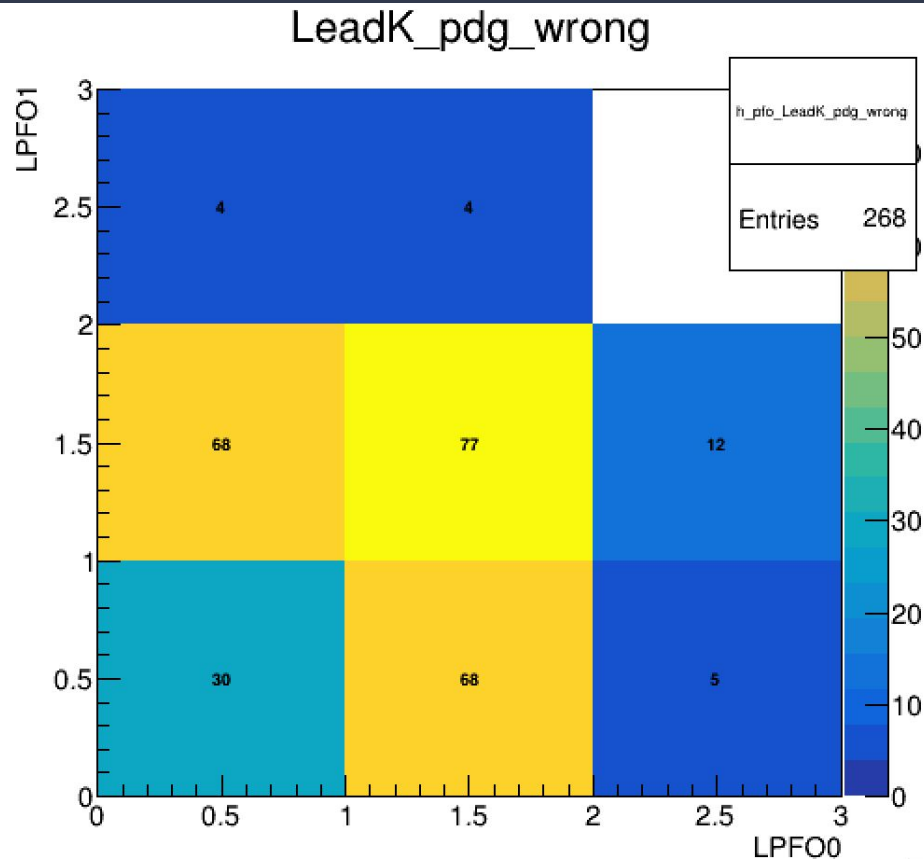
- TPC hits \rightarrow changed from base
- Normalization changed (integrate from $-0.8 < \cos \theta < 0.8$) because of cut in # TPC hits
- Momentum window minimum changed from 10 \rightarrow 20 GeV



Migration after pcut20

Right plot shows the PDG of leading PFOs for the migrated events when the momentum of both LPFO0 && LPFO1 > 20 GeV.

Config	#Events	%
K-K	77	28.7
Pi-Pi	30	11.2
Pi-K	136	50.7
Pi-p	9	3.3
p-K	16	6.0
p-p	0	0



SPFO Removal

Selections (ss)

Cut MC

ISR suppression

- $QQ \cos \theta > 0.95$
- $120 < QQ \text{ mom} < 127$

Cut PFO

General PFO

- PFO match (It should fall into either jet0 or jet1)
- # PFO tracks == 1 (more than 2 tracks cannot be associated to make 1 PFO)

Lead PFO (double tag)

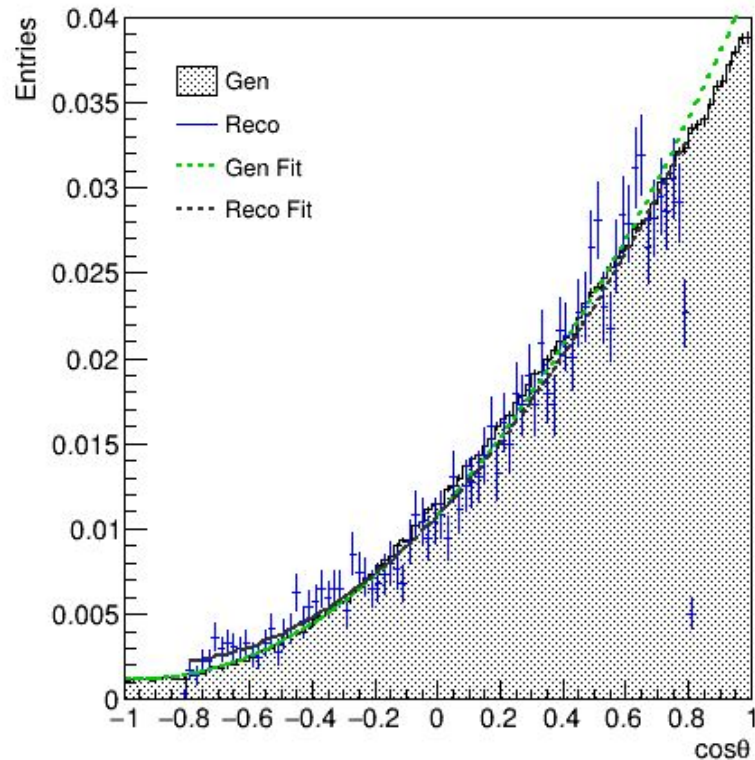
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 $20 < \text{Lead PFO mom} < 60$
- Lead PFO charge \pm or $-+$
- # TPC hits **$210 < \text{Lead PFO hits}$**
- Offset cut < 1.0
- $k dE_{dx_dist} < (p dE_{dx_dist} \& \text{pid} E_{dx_dist})$

Secondary PFO Counting

- SPFO is not LPFO
- SPFO is Kaon (**determined from dEdx dist**)
- SPFO has opposite charge compared to LPFO
- SPFO should at least have 10 GeV momentum.
- Count number of such SPFO. (should be = 0)

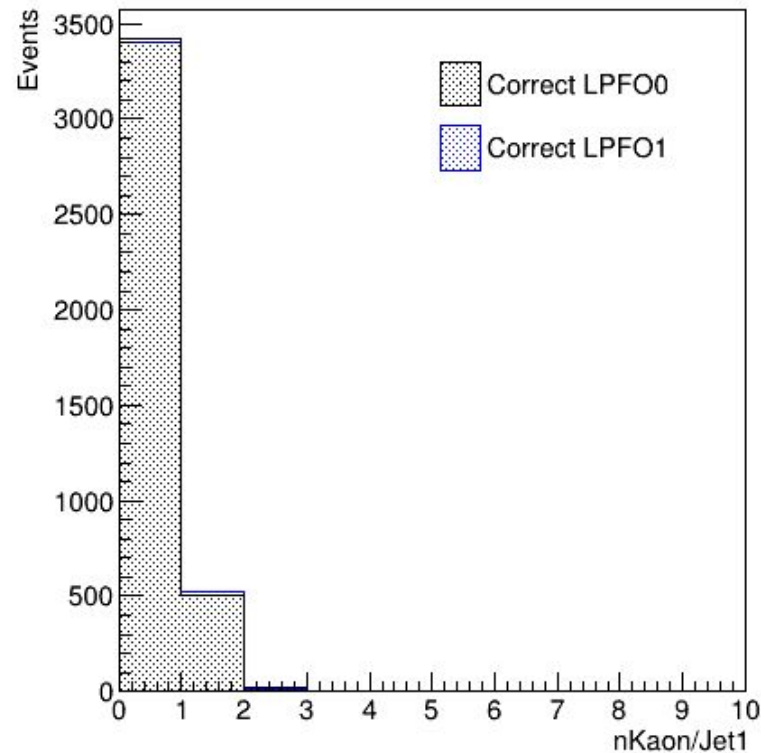
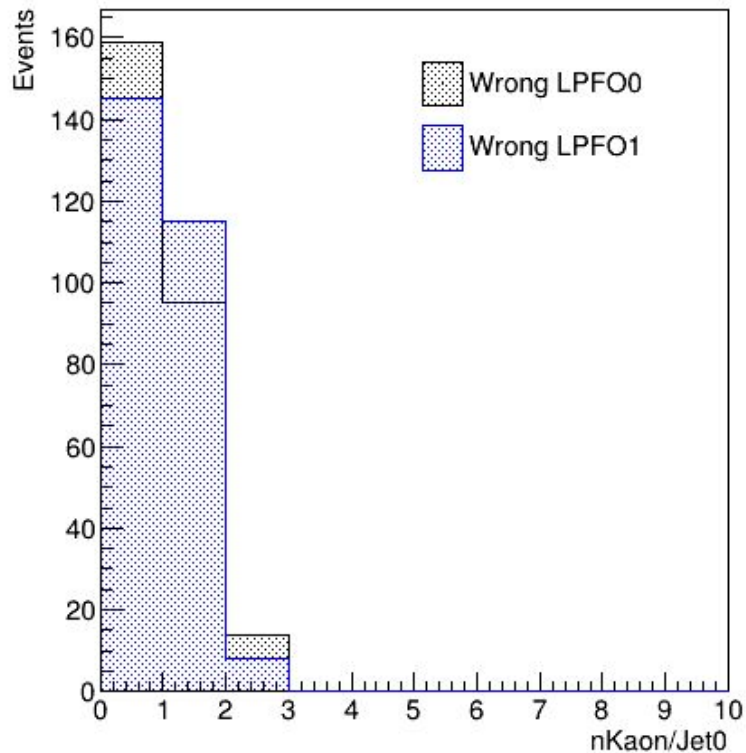
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- Momentum window minimum changed from 10 -> 20 GeV



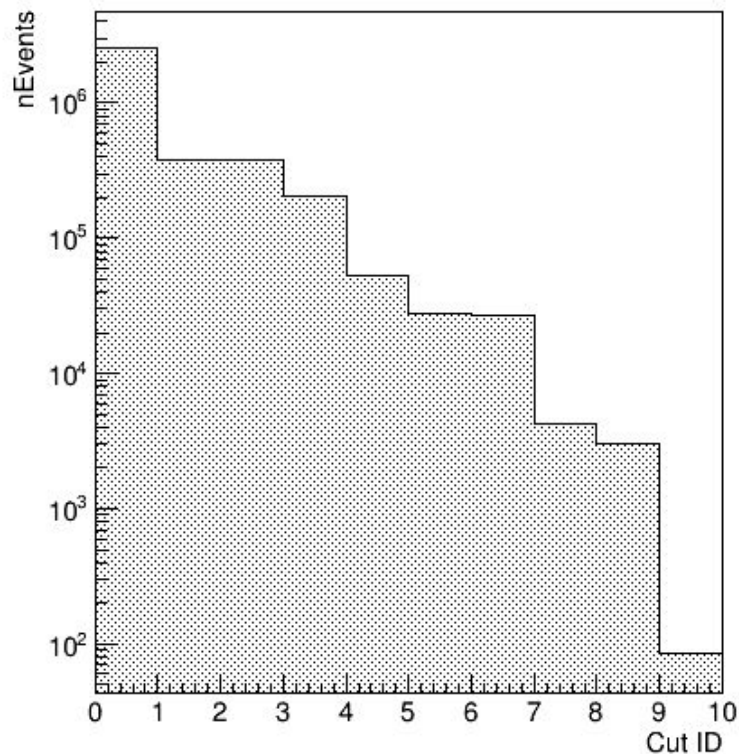
Migration

SPFO Kaon Opposite Charge Multiplicity



Number of Events

0	# Total Events (ss)	2,512,257
1	# after Gen sel	374,563
2	# after PFO sel	374,399
3	Charge check	201,967
4	Momentum check	53,227
5	TPC hit check	27,921
6	Offset check	26,848
7	dEdx dist min check	4,211
8	Opp K SPFO check	3,036
9	Migration	86 (2.8%)



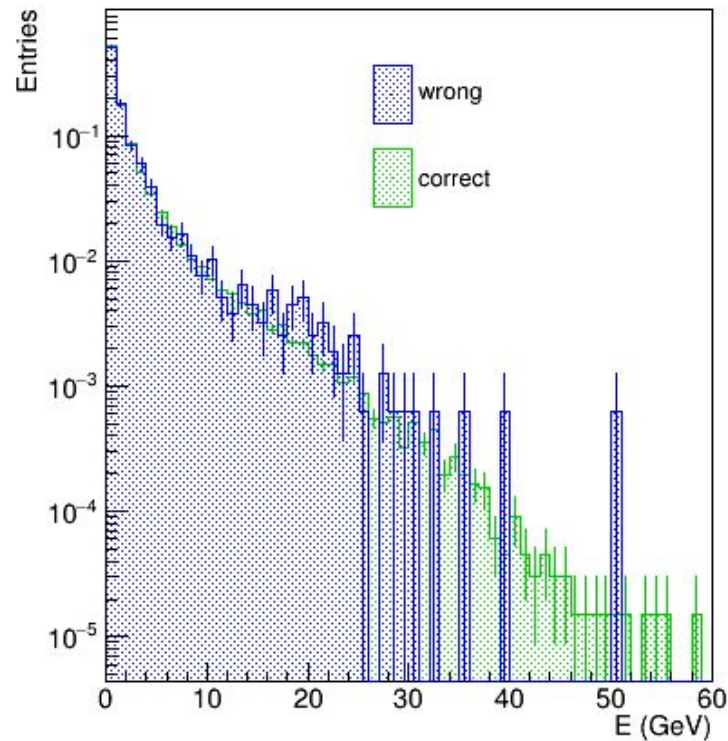
Neutral PFOs

Difference in Number

- LPFO Selection
 - Currently LPFO is selected among the charged PFOs.
 - This is done by 2 ways:
 - PFO should have 1 track.
 - LPFO should be charged.
 - The first selection was removed to take a look at neutral PFOs in selected events.
 - $\text{Events w/ Neutral PFOs} \subset \text{Events w/o Neutral PFOs}$
 - Thus, in current code, it will dump the event if the LPFO has charge 0.

Energy Neutral PFO

Energy of Neutral PFOs



Number of Events

0	# Total Events (ss)	2,512,257
1	# after Gen sel	374,563
2	# after PFO sel	374,563
3	Charge check	70,516
4	Momentum check	35,222
5	TPC hit check	17,967
6	Offset check	17,306
7	dEdx dist min check	3,138
8	Opp K SPFO check	2,215
9	Migration	53 (2.4%)

