ILC-Japan Physics 1st Working GM

$e^+e^- \to s\bar{s}$ Study at 250 GeV

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INVESTISSEMENTS D'AVENIR
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IFIC INSTITUT DE FÍSICA CORPUSCULAR
AITANA MATTER AND TECHNOLOGY

Introduction

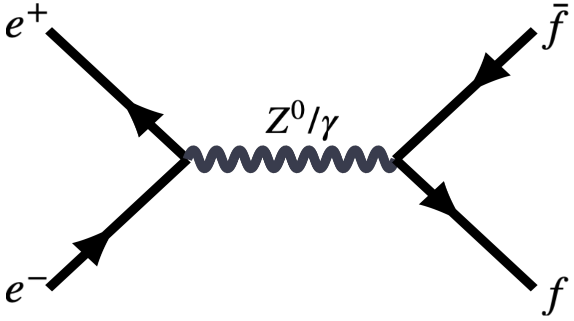
Di–fermion Production

- Di-fermion production
  - e+e- -> ss
  - CME 250 GeV.
  - eL pR
  - Int. Lumi. 4300 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)

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

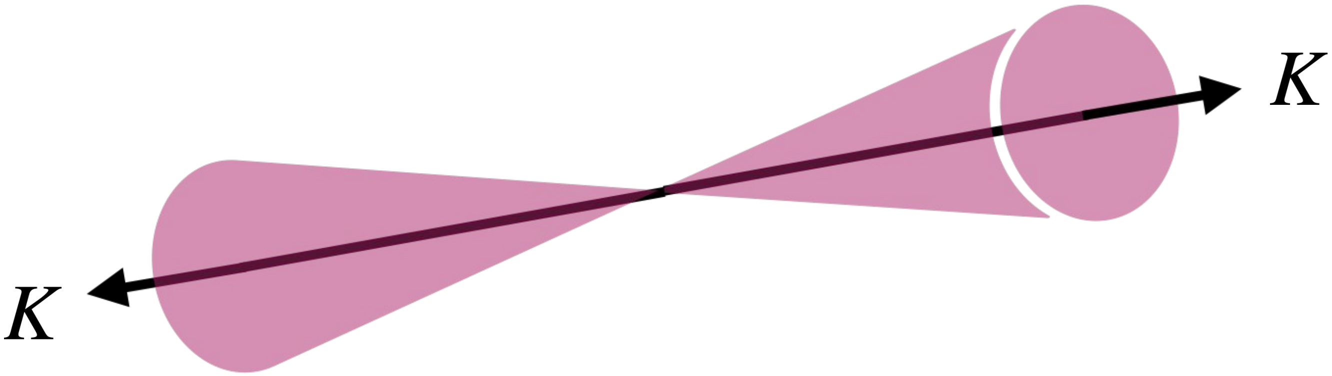


Energy	Process	Goal of measurements
91 GeV	$e^+e^- \to Z^0$	Z^0 physics and calibration
250 GeV	$e^+e^- \to Z^0H$	Higgs couplings
	$e^+e^- \to f\bar{f}$	Z^0/γ couplings
350 GeV	$e^+e^- \to t\bar{t}$	top mass precision
	$e^+e^- \to \nu\bar{\nu}H$	Higgs couplings
500 GeV	$e^+e^- \to t\bar{t}$	top couplings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

SSbar Analysis

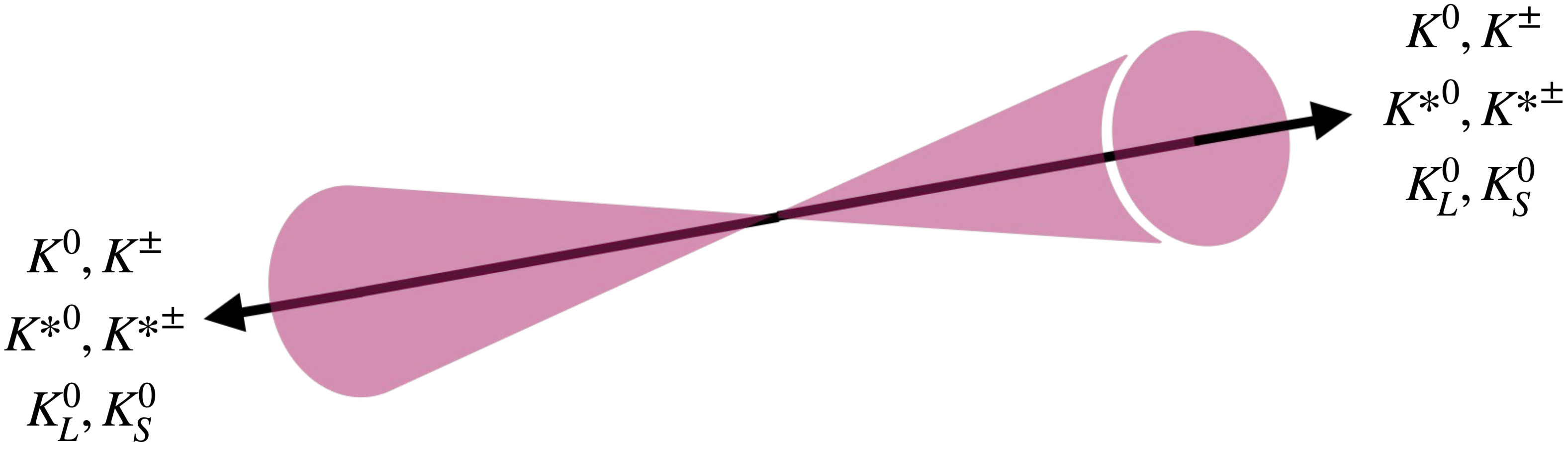
SSbar Process

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



SSbar Process

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



SSbar Process

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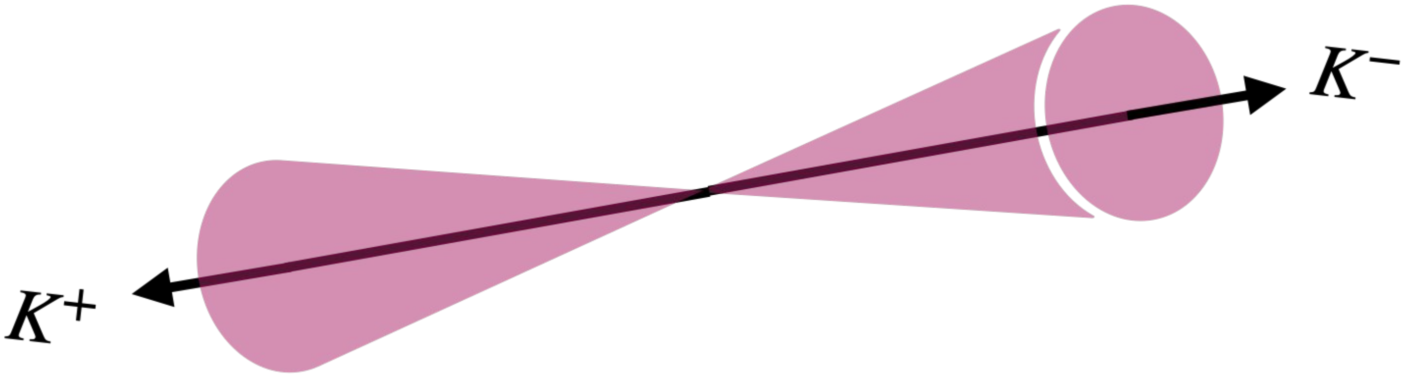
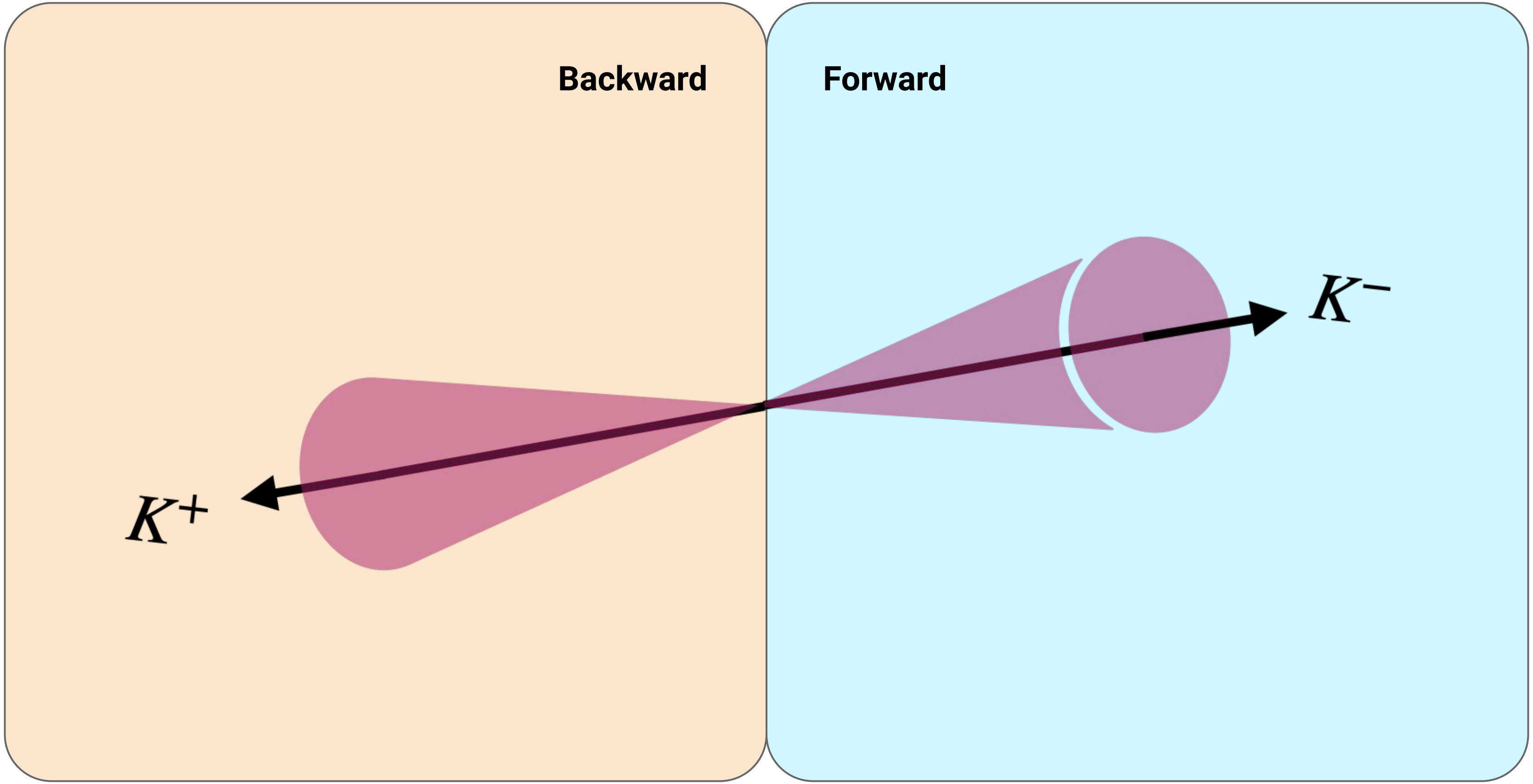
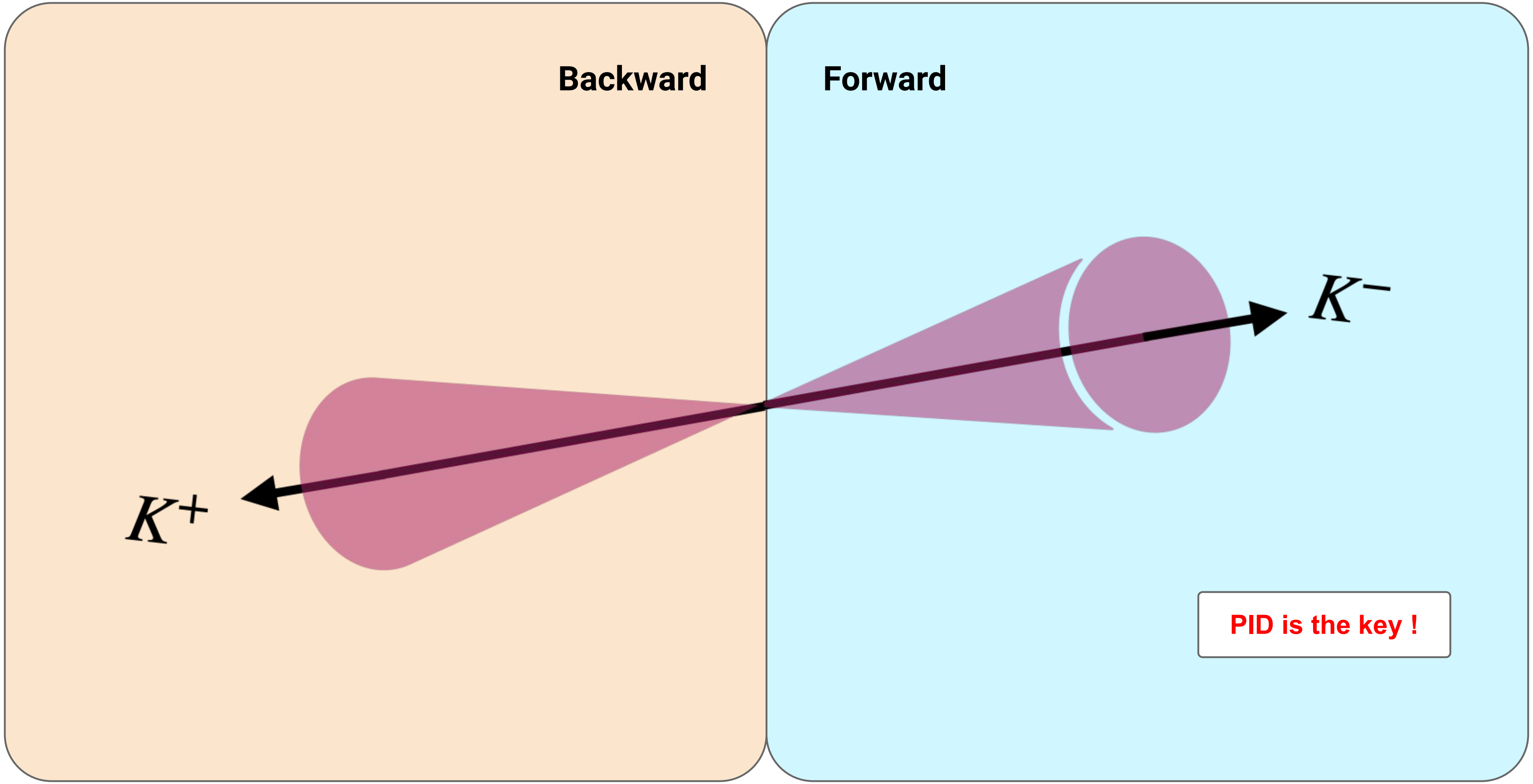


SSbar Process



SSbar Process



Event Selection

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

$$120 < E_{s,\bar{s}} < 127\ \mathrm{GeV}$$

Leading PFO

LPFO Selection

Charge Check

Momentum Check

TPC Hit Check

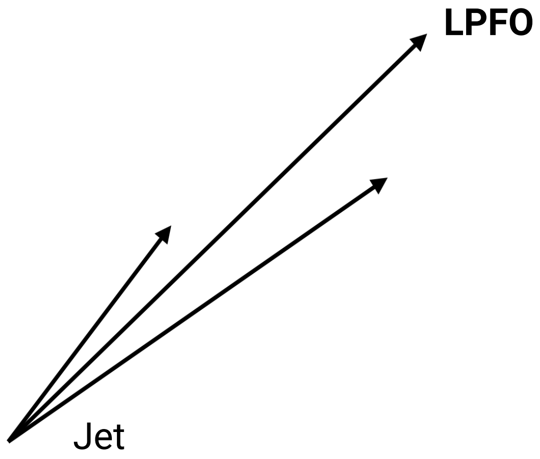
IP Check

dE/dx Minimum Check

SPFO Check

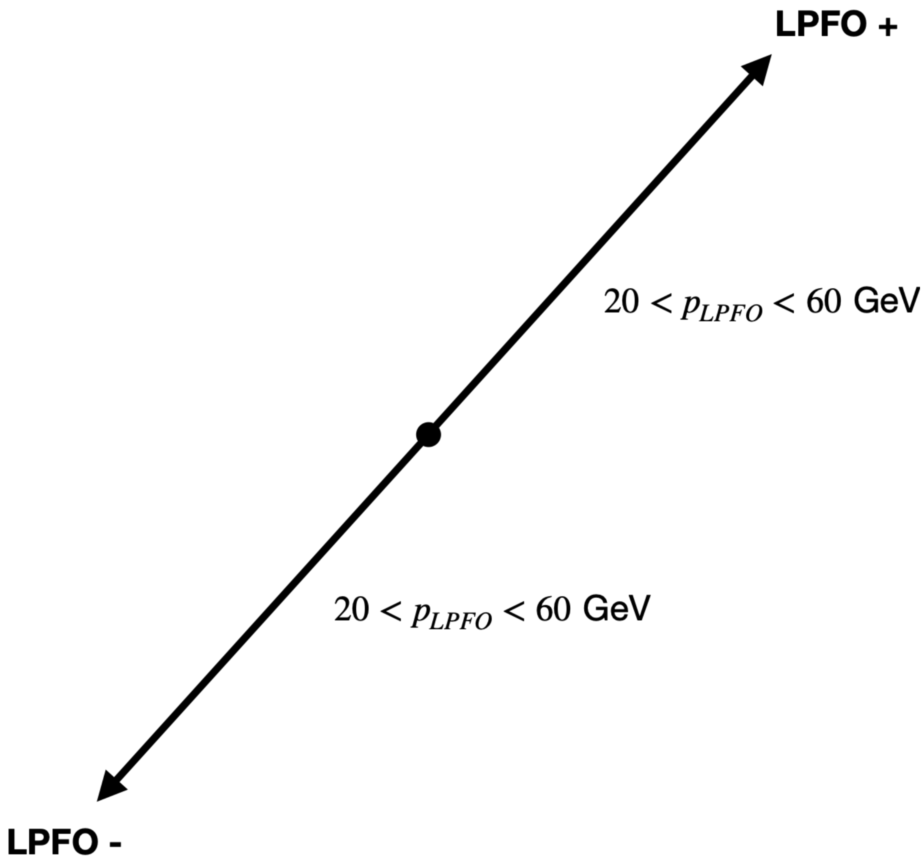
Leading PFO (LPFO)

- 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

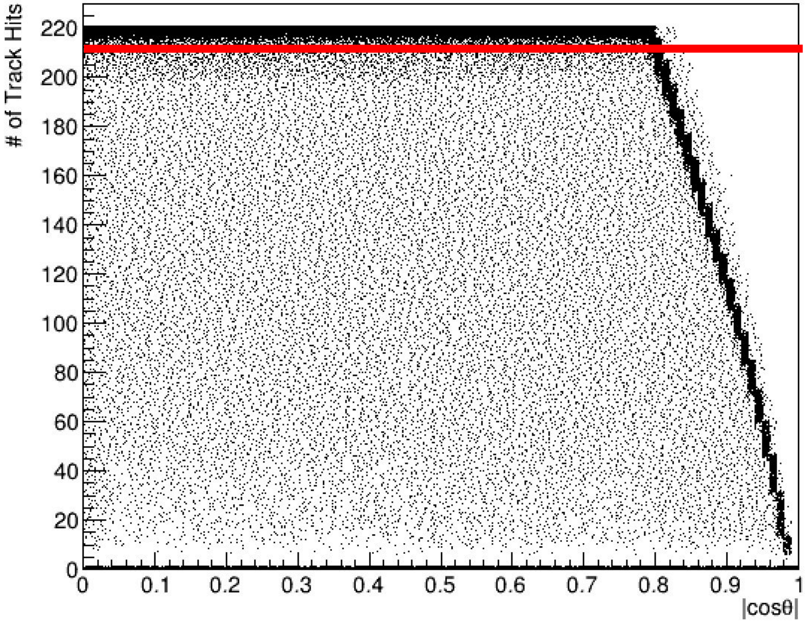
- LPFO Selection
- **Charge Check**
- **Momentum Check**
- TPC Hit Check
- IP Check
- dE/dx Minimum Check
- SPFO Check



TPC Hits

- LPFO Selection
- Charge Check
- Momentum Check
- **TPC Hit Check**
- IP Check
- dE/dx Minimum Check
- SPFO Check

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

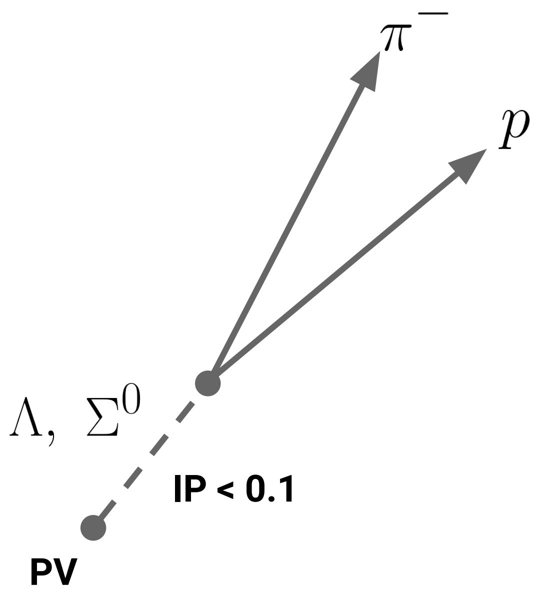


$210 < N_{hits}$

Impact Parameter

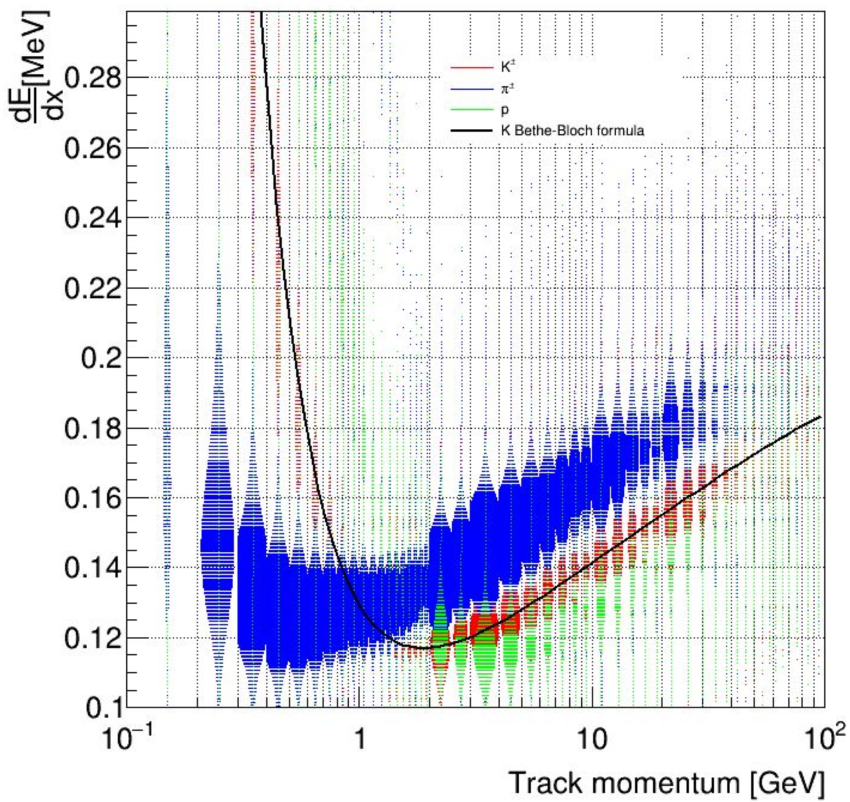
- LPFO Selection
- Charge Check
- Momentum Check
- TPC Hit Check
- **IP Check**
- dE/dx Minimum Check
- SPFO Check

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
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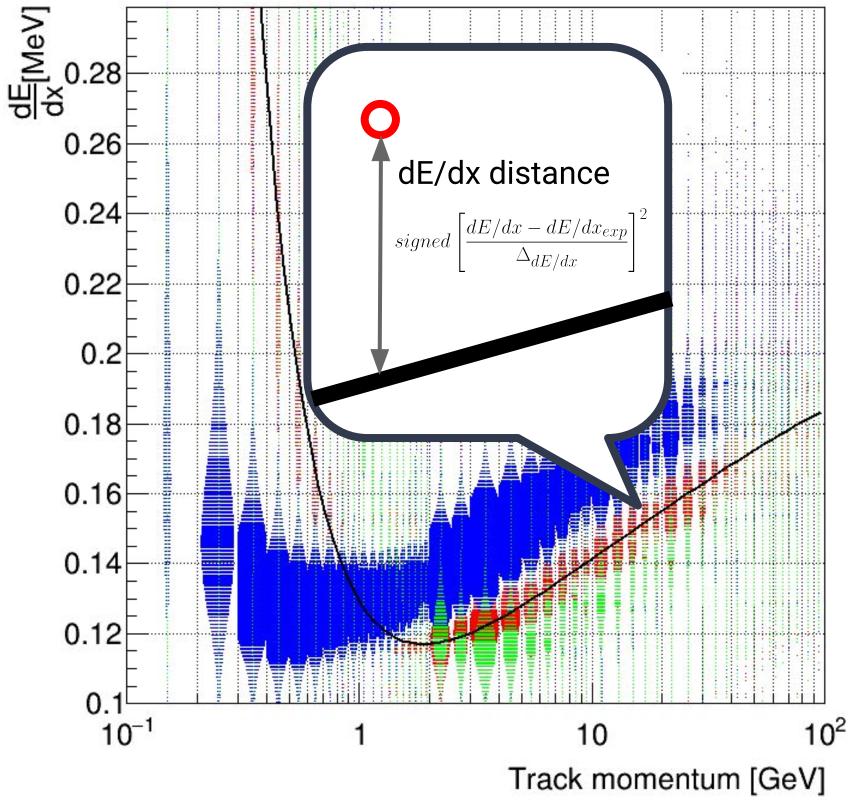
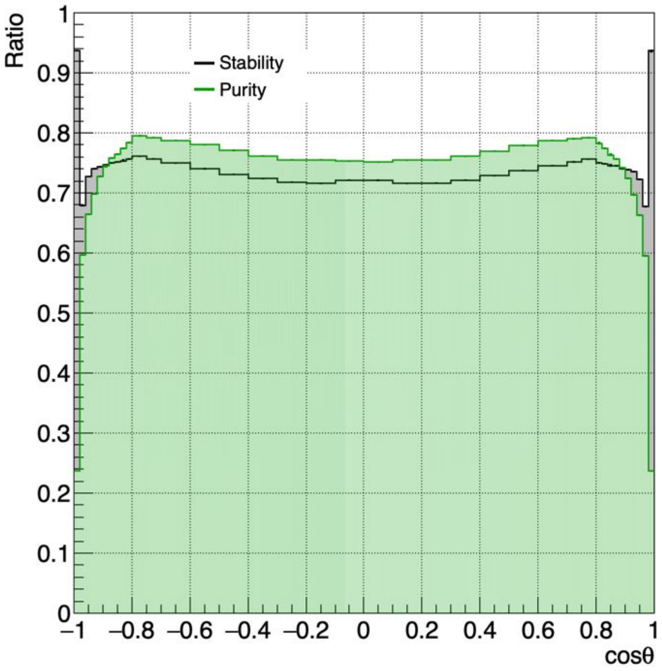
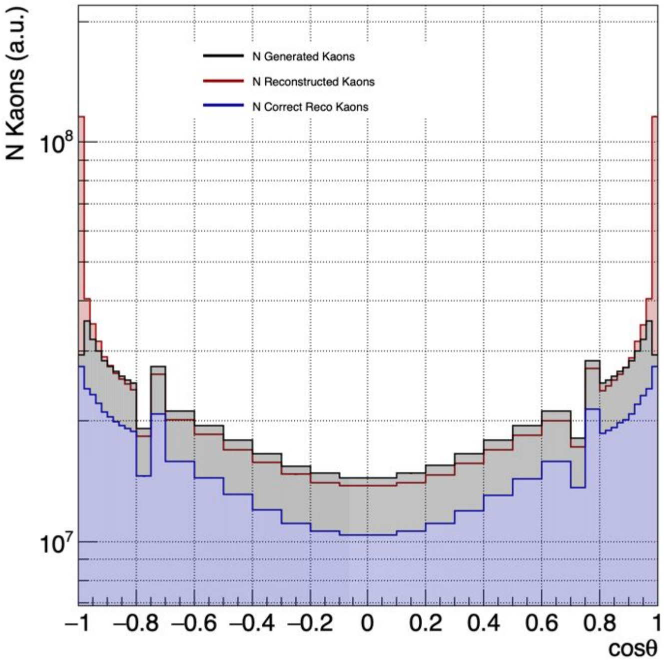
- IP Check
- **dE/dx Minimum Check**
- SPFO Check



dE/dx Minimum

Using PFO_cheat | p > 5 GeV





SPFO Check

*Definitions of stability and purity are described here

dE/dx Minimum

LPFO Selection

Charge Check

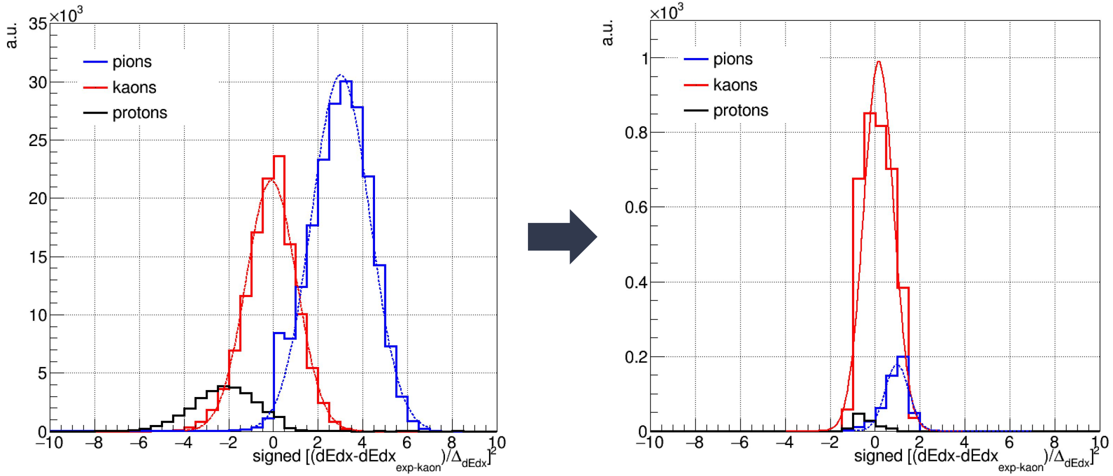
Momentum Check

TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check



dE/dx distance minimization

- k dE/dx distance < π dE/dx distance
- k dE/dx distance < p dE/dx distance

SPFO Check

LPFO Selection

Charge Check

Momentum Check

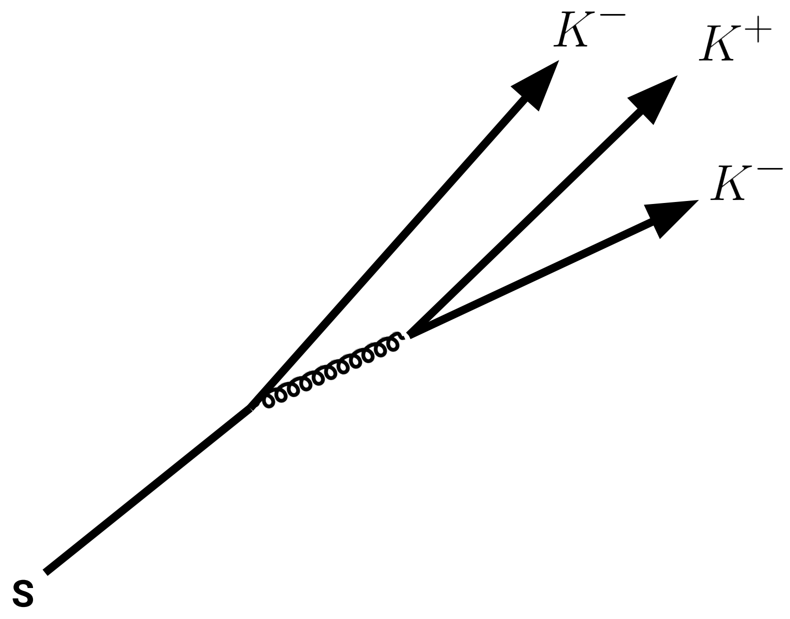
TPC Hit Check

IP Check

dE/dx Minimum Check

SPFO Check

Secondary PFO (SPFO) Check



SPFO Check

- LPFO Selection
- 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

Polar Angle Result

Polar Angle Result

Fit function:

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

Gen:

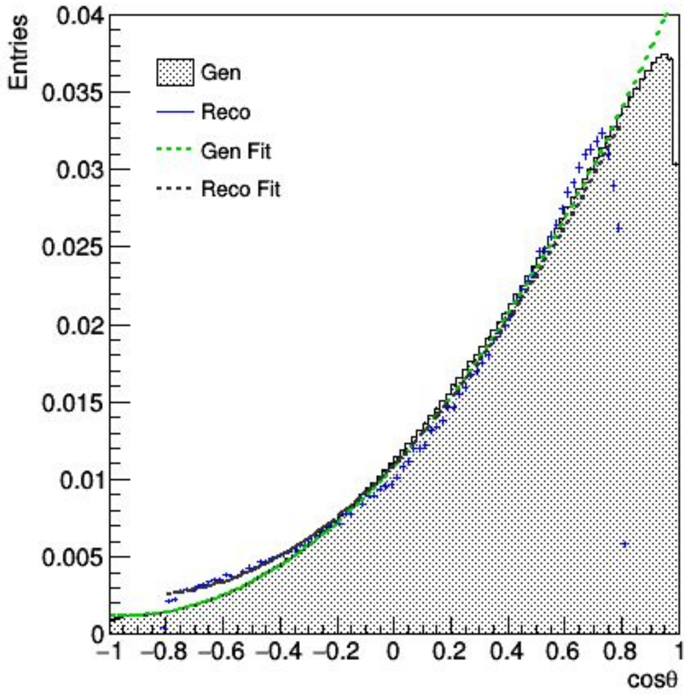
S = 1.07E-2 ± 1.7E-6

A = 2.01E-2 ± 3.7E-6

Reco:

S = 1.08E-2 ± 1.9E-5

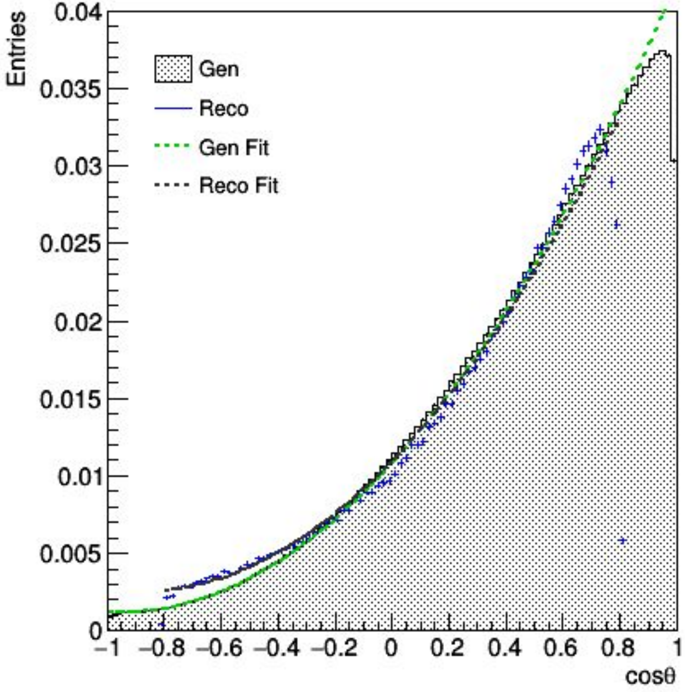
A = 1.90E-2 ± 4.7E-5



Polar Angle Result

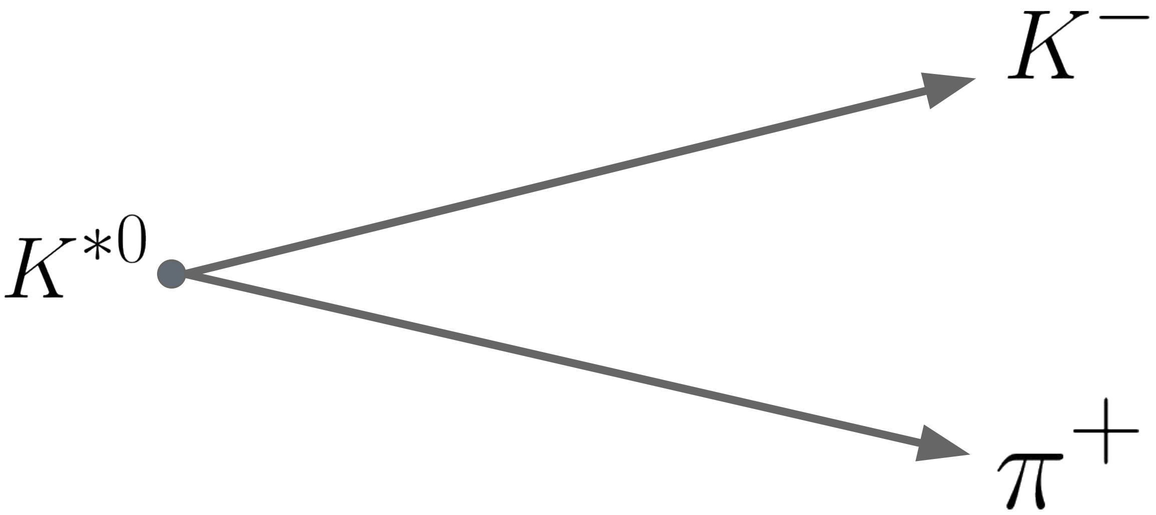
Number of Events and Efficiencies

- All data ee→qq processed
  - **26M events** (ss: ISR removed)
  - **Luminosity 4.6 ab-1**
- SSbar reconstruction
  - Total valid events: 168k events
  - **Efficiency: 0.64%**

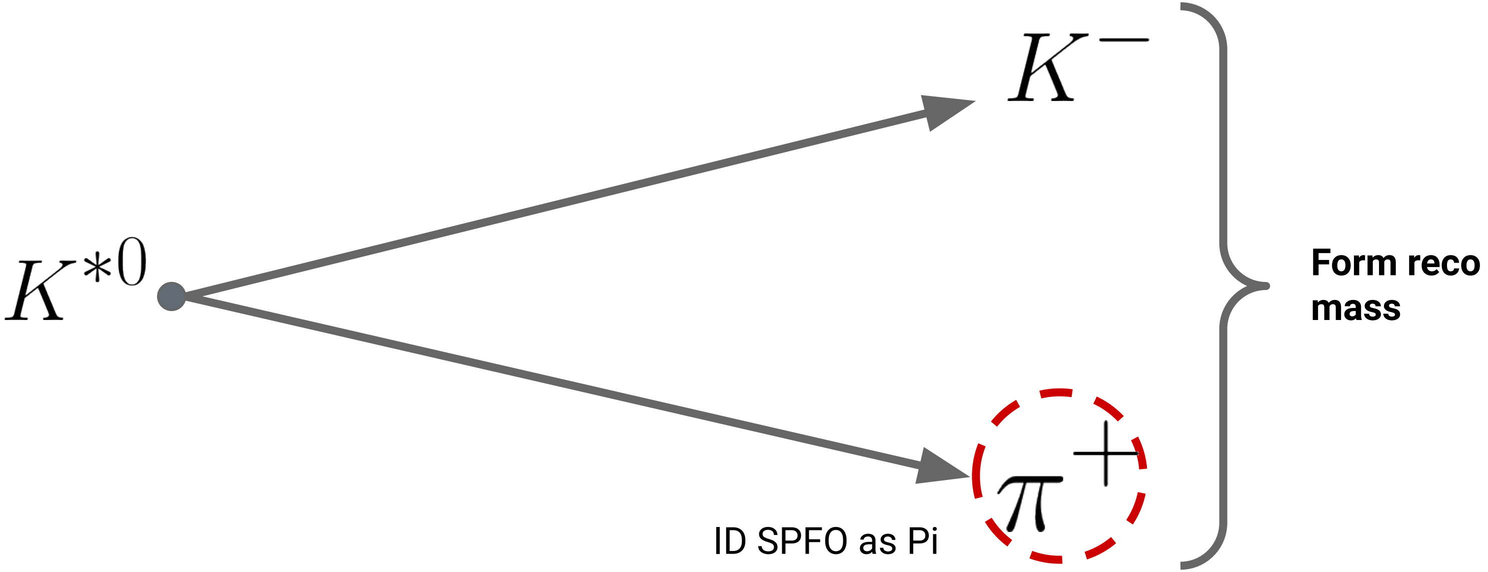


K^{*0}

K^{*0}

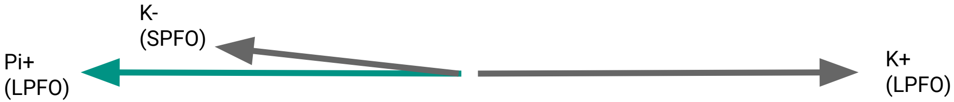


K*0



K^{*0}

Conditions for K*0 identification:



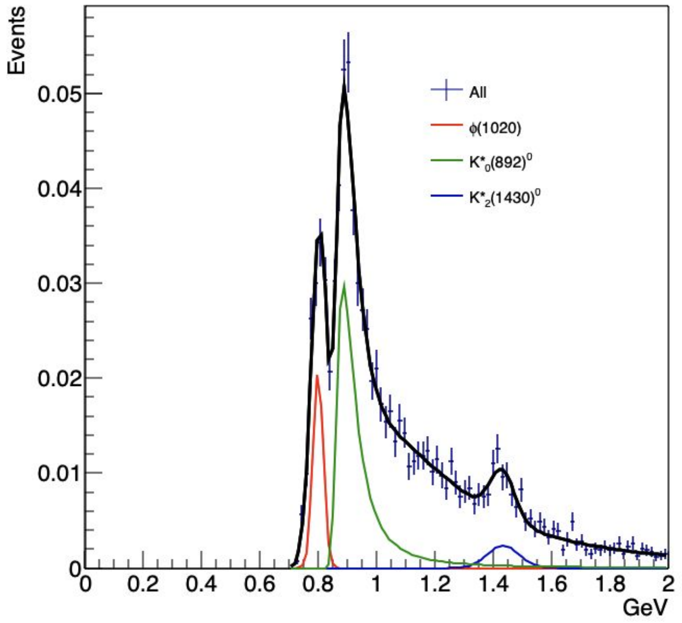
Case: if one of jets have K0* and the other doesn't

1. Identify Particles
    a. Pion as LPFO
    b. Kaon as SPFO
2. Check 2 LPFOs have same charges.
3. Check charges of Pi-K and make sure they're opposite.
4. Momentum cut on Kaon (> 10GeV) for kinematic constraints.
5. Reconstruct invariant masses for all possible combinations of Pion and Kaons.

Invariant Mass

Invariant Mass Reconstruction

- Invariant mass plot on the right shows the combined mass of **Leading Pion** and **Secondary Kaons**.
- See clear peak at 0.8, 0.9 and 1.4 GeV
- MC parent information shows that those pions and kaons are coming from phi(1020), K*0(892) and K*0(1430)
- Phi mass distribution might be coming from the misidentification of pions from dE/dx information?
    - Phi decay into charged kaon pair.
    - Checking the leading pion MC PID.
      If it is misidentification of kaon as pion, those mass should be changed to kaon mass to obtain correct reconstructed phi mass at 1020 MeV



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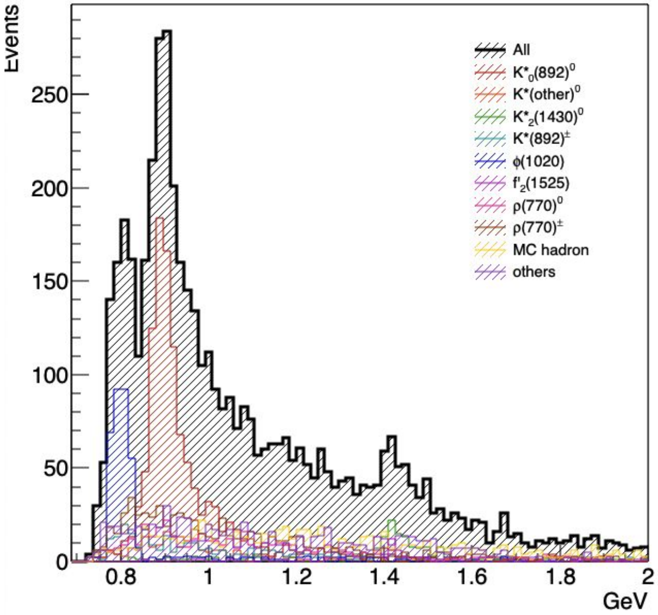
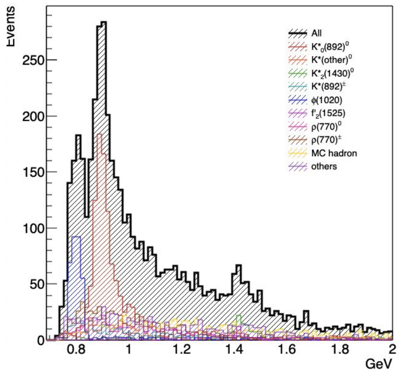


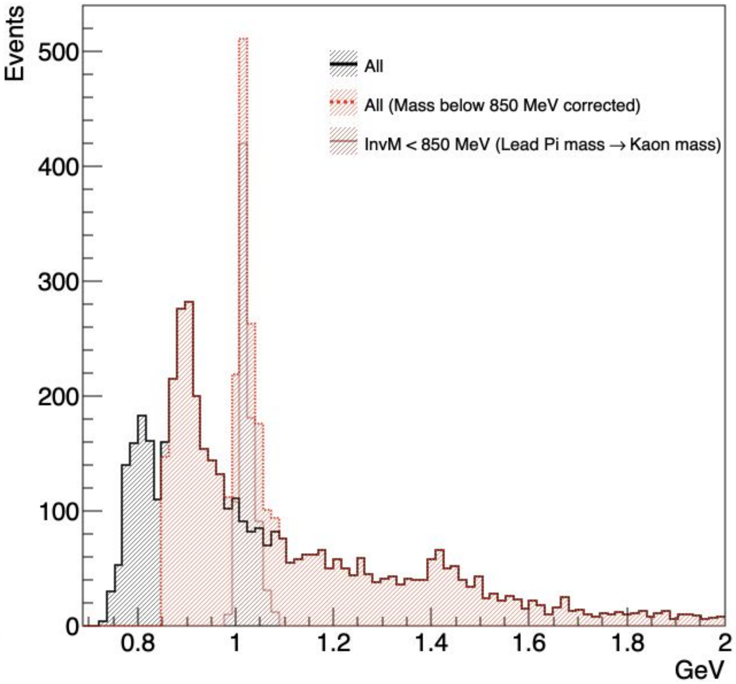
Invariant Mass

Full Luminosity Simulation

- φ→KK
- Cutting invariant mass at 850 MeV
- Replace leading pion mass hypothesis by the kaon mass
- Extreme peak at 1020 MeV

  Corresponds to φ mass.





Polar Angle Result for K^{*0}

Polar Angle Result (K^{*0})

Fit function:

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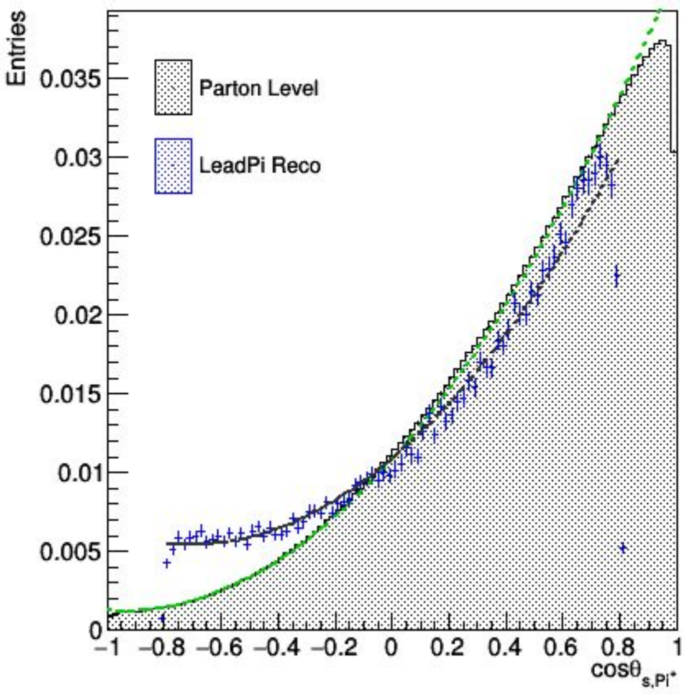


pq method

pq method

pq calculation

- Solve :

$$N_{acc} = p^2 N + q^2 N$$
$$N_{rej} = 2pqN$$
$$1 = p + q$$

p : Probability of getting the configuration right.
q : Probability of getting the configuration wrong.

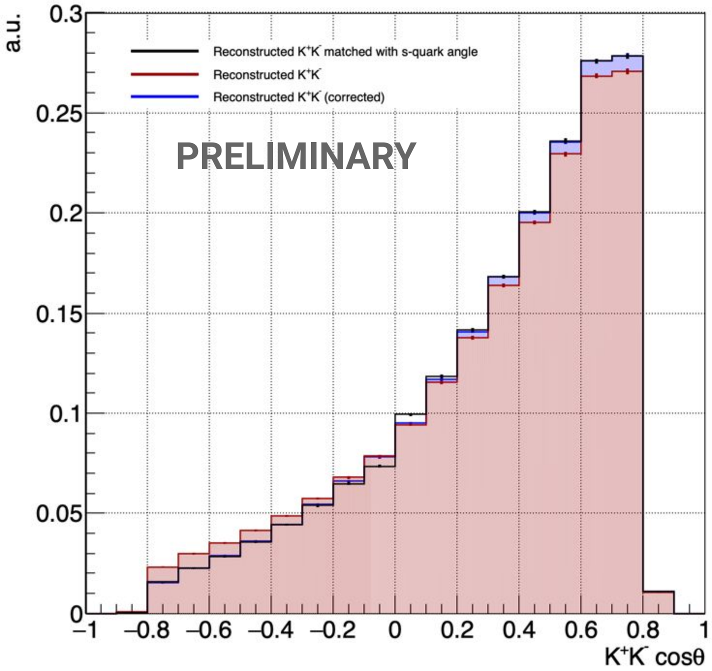
- Solution :

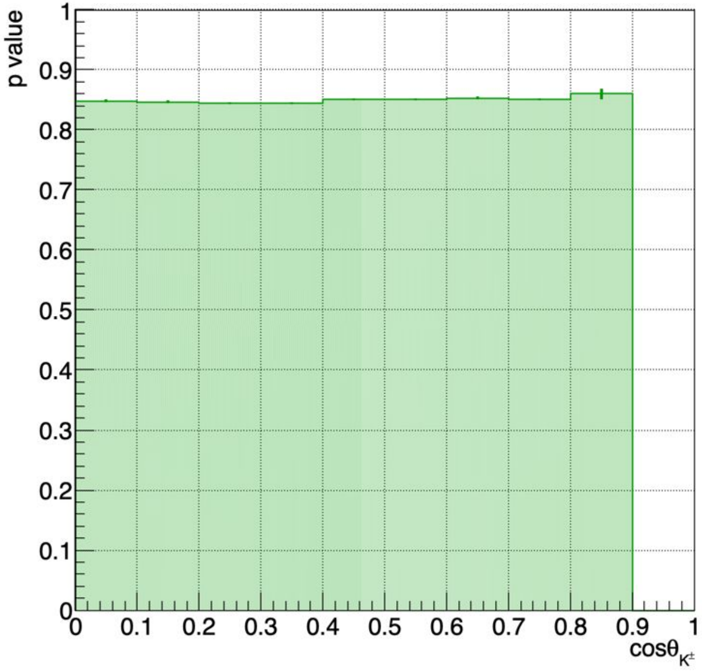
$$p = \frac{N \pm \sqrt{N(N - 2N_{rej})}}{2}$$
$$q = \frac{N \mp \sqrt{N(N - 2N_{rej})}}{2}$$

- Weight
  - Scale each bin in AFB plot so that we will obtain N_acc with eq on the right.
  - Take average of p values over 4 different points with polar angle value ± stat errors

pq method (4.3 ab-1)

LPFO 20.0 < p < 60.0 GeV





N (KxK) = 161724

Loosening Selections

Efficiency

The Main Efficiency Killer

- TPC Hits cut
  - Restricts detector acceptance region ($0.8 < |\cos\theta|$)
- Momentum cut
  - Tight cut for LPFO momentum selection ($20 < p < 60$ GeV)
- dE/dx distance selection
  - The minimum K dE/dx distance is selected.

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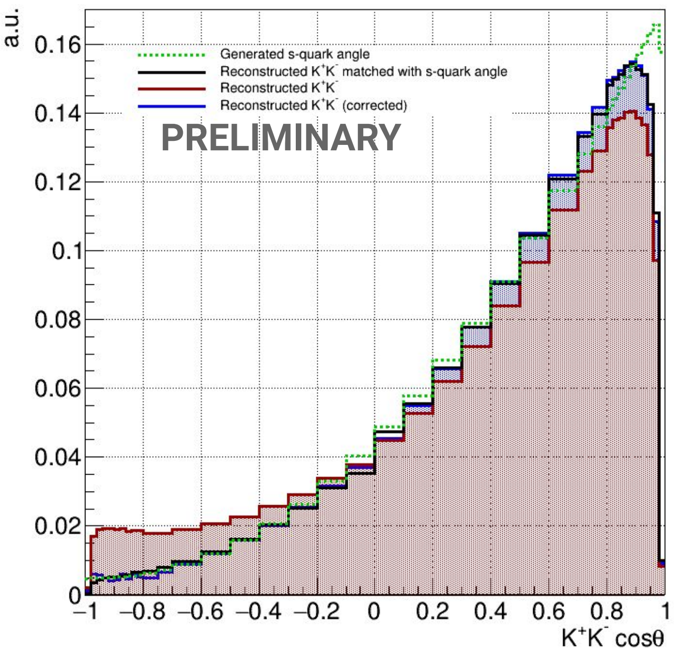
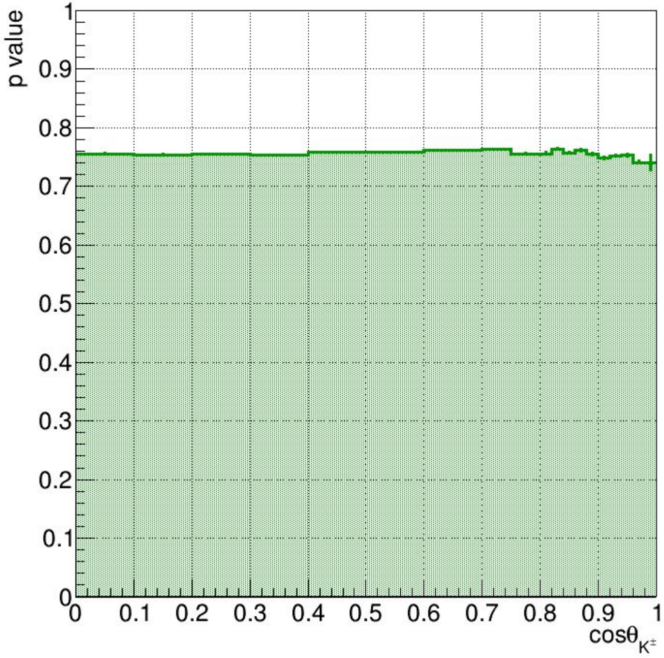
pq method (4.3 ab-1)

LPFO 20.0 < p < 60.0 GeV | 0 < TPC Hits

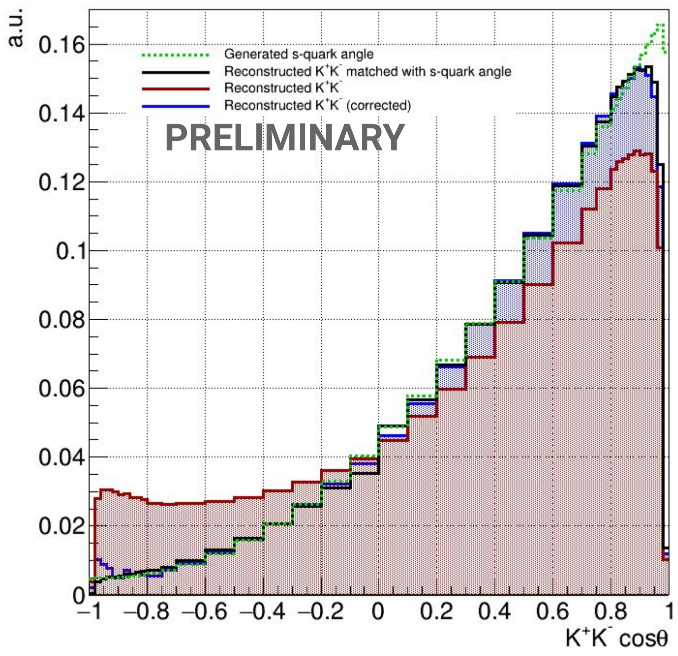


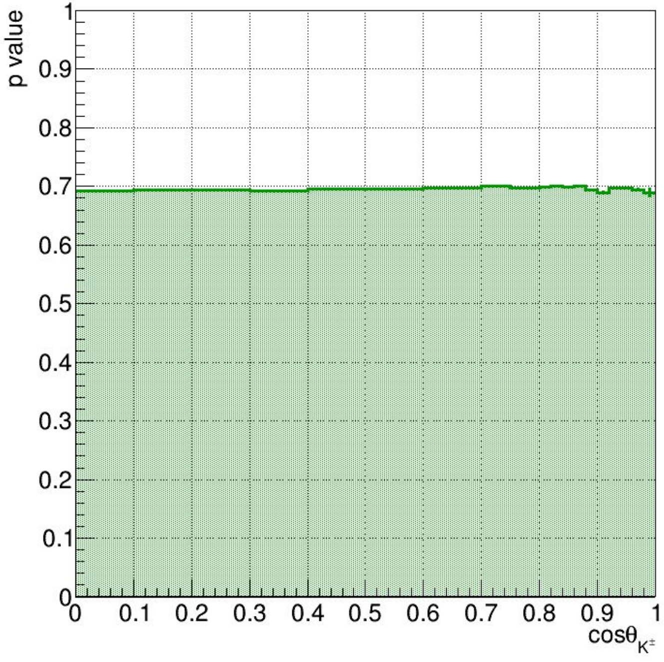


N (KxK) = 489246

pq method (4.3 ab-1)

LPFO 10.0 < p GeV | 0 < TPC Hits





N (KxK) = 1681872

Summary & Prospects

Summary & Prospects

Summary

- SSbar reconstruction was performed, using dE/dx distance PID.
    - Kaon identification
- Multiple methods were used to reject backgrounds and salvage rejected events.
    - K*0 method
    - pq-method
- The pq-method has shown that the method works well for the double tagging cases such as in this ssbar analysis.

Prospects

- Mix other light/heavy quark pair production events.
    - uu/dd/cc/bb
- Can we do better with K*0?
    - Apply pq-method to the polar angle, which will give us extra handle on K*0
- Calculation of couplings from the fitted parameters.

Backup Slides

ISR Suppression

ISR Suppression

Signal Definition

- SSbar back-to-back

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

- Total Energy

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

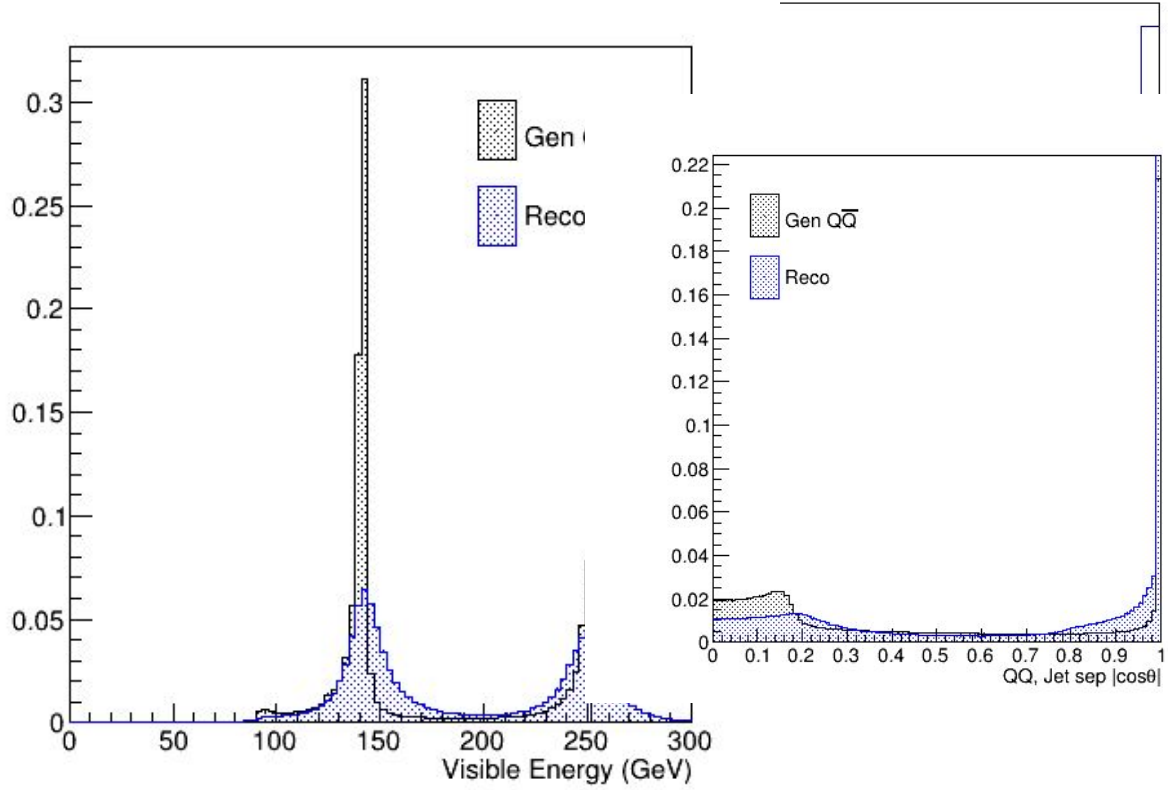
Reco ISR Removal

- LPFO back-to-back

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

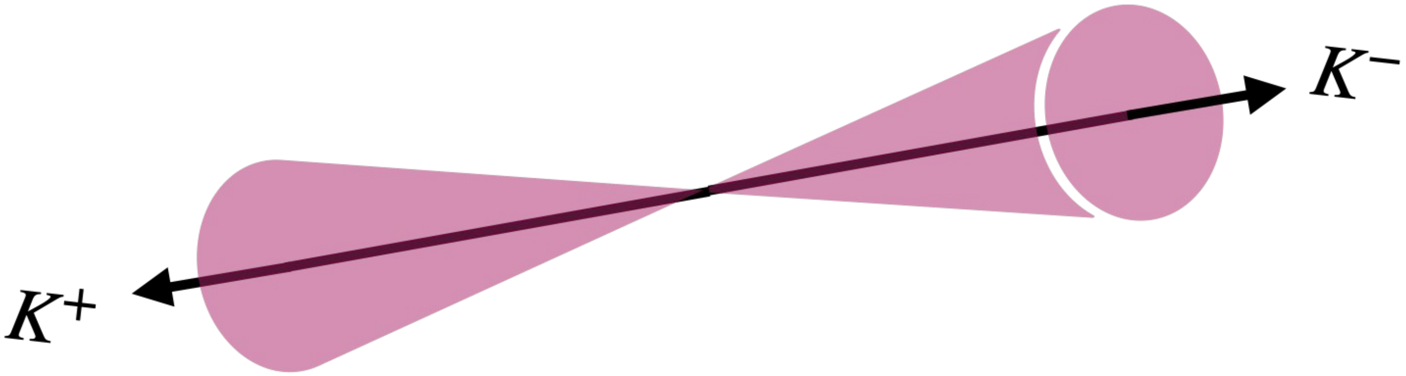
- Total Energy

$$220 < E_{vis}$$



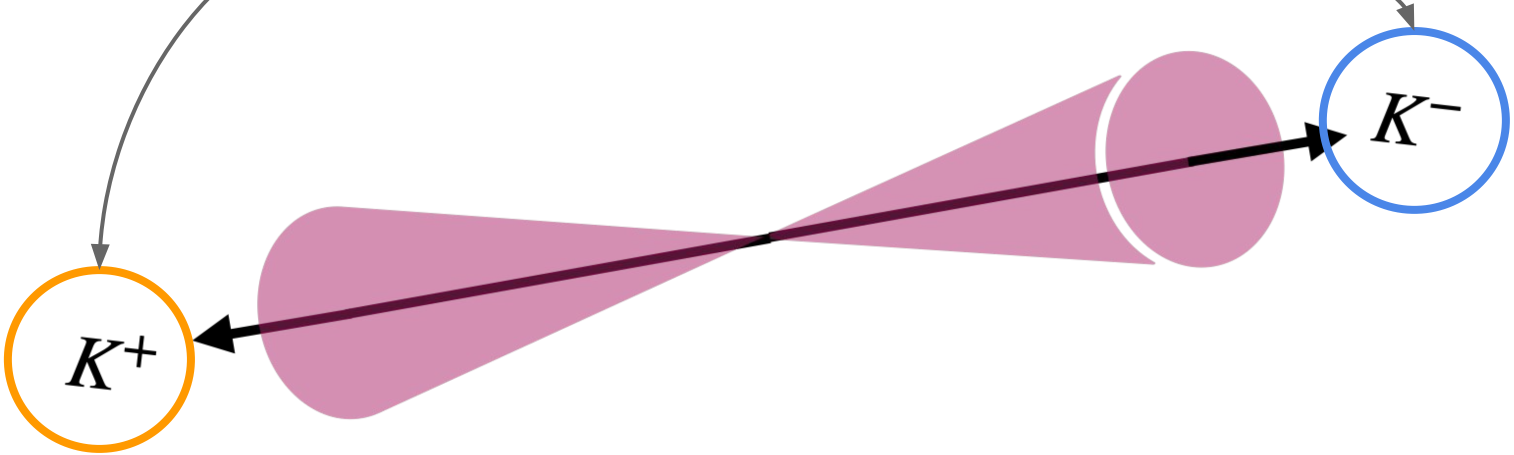
Migrated Event Analysis

What is Migration?



What is Migration?

Precisely identify charges on both sides



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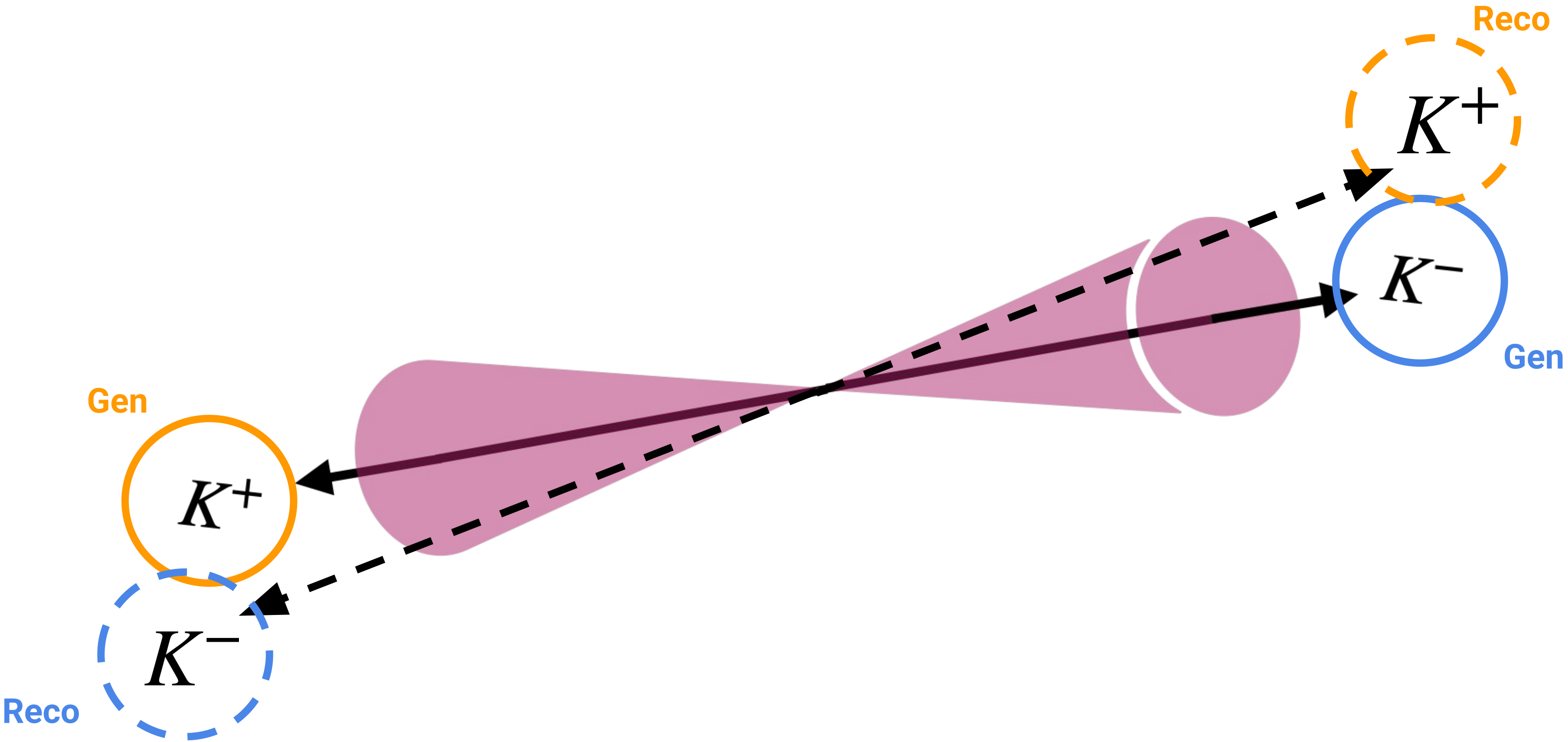

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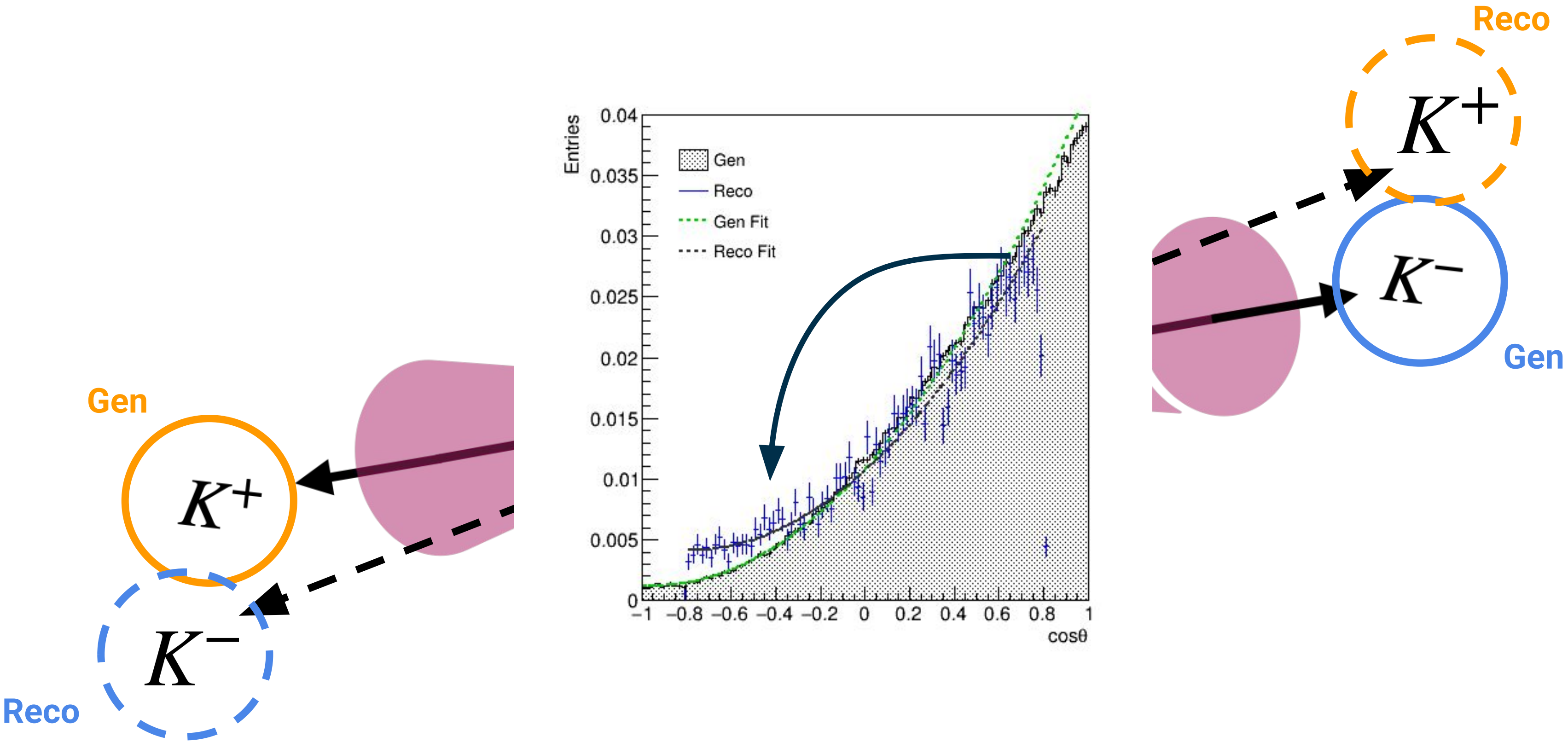
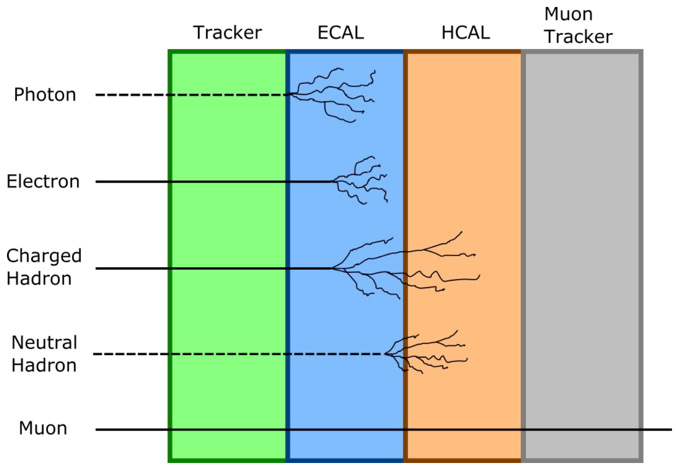


Why Migration?

Why Migration?

Possible types of Kaons from ssbar pair

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



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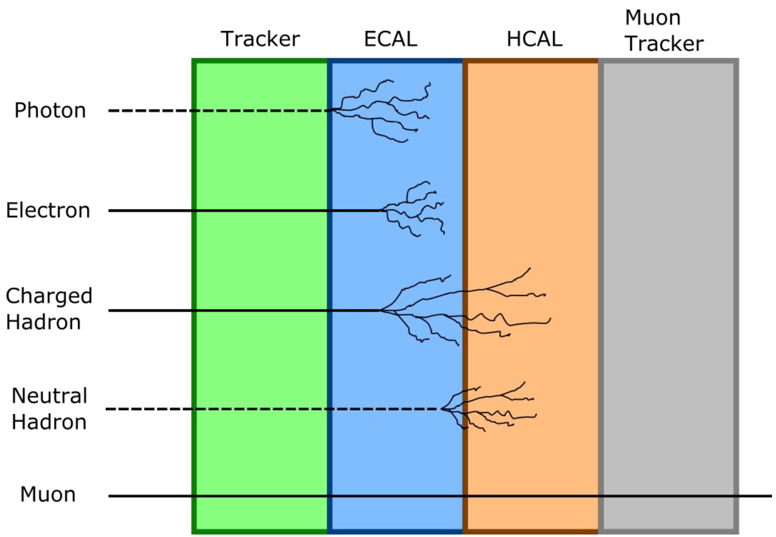

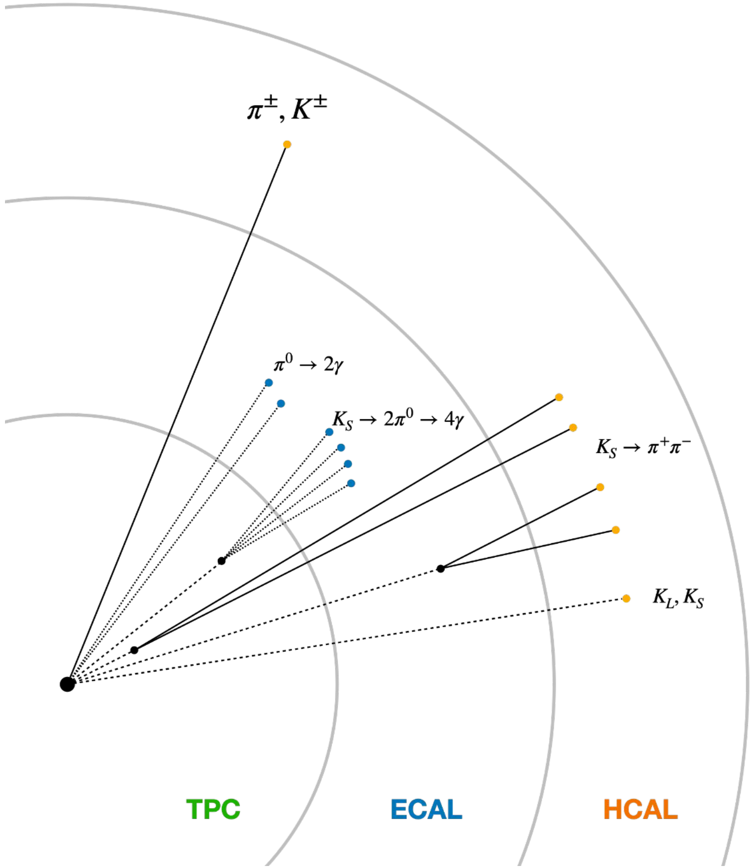

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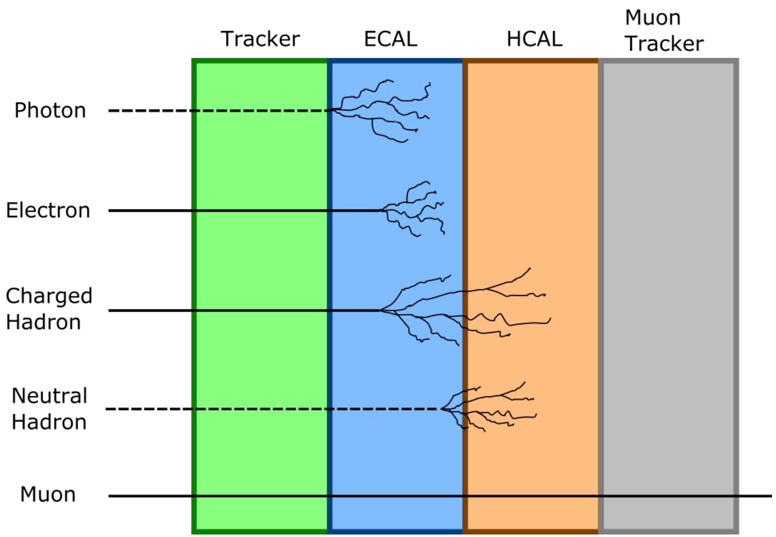
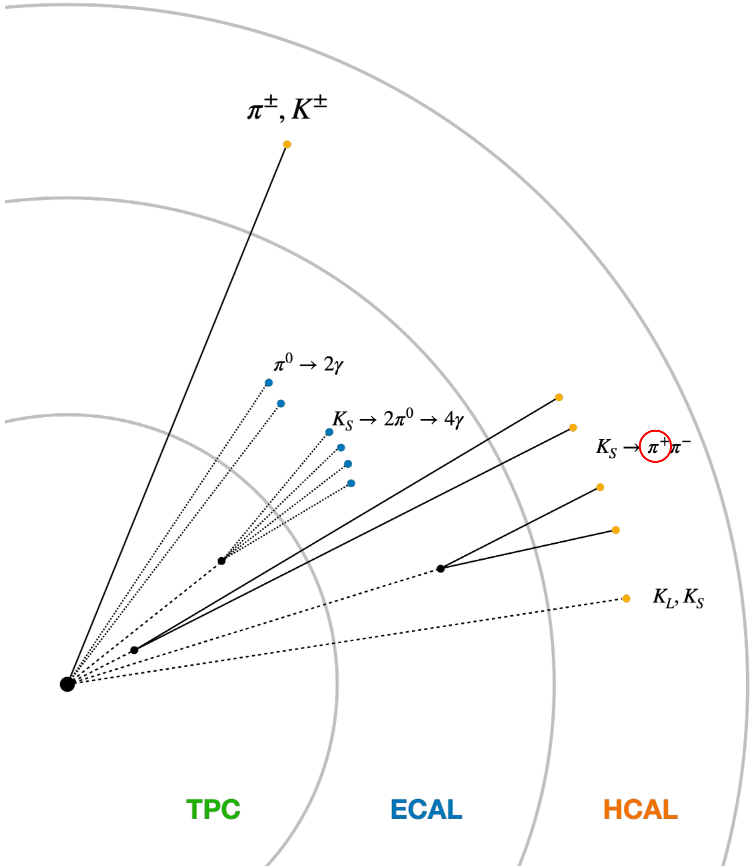


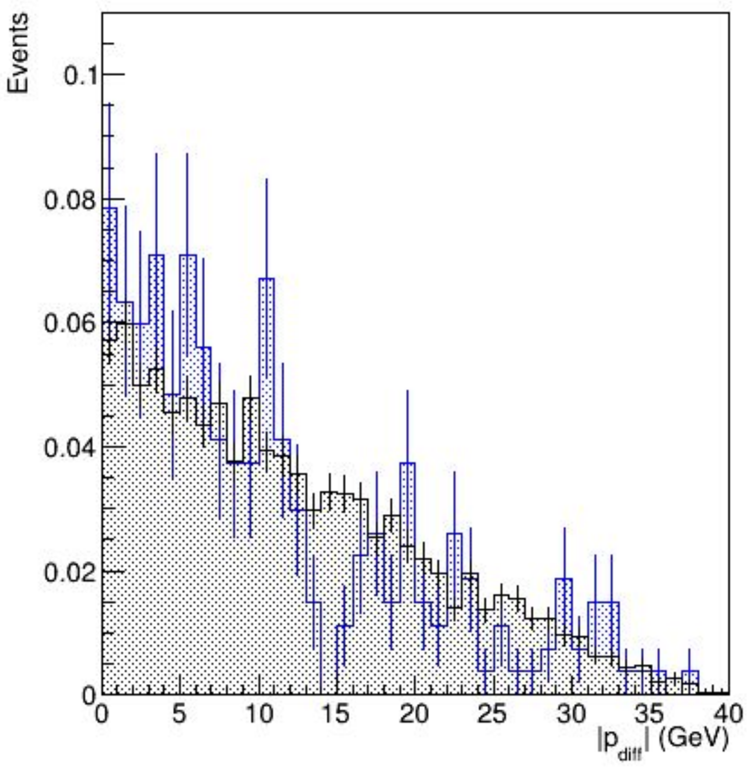


Full Stats

Migration

LPFO momentum separation

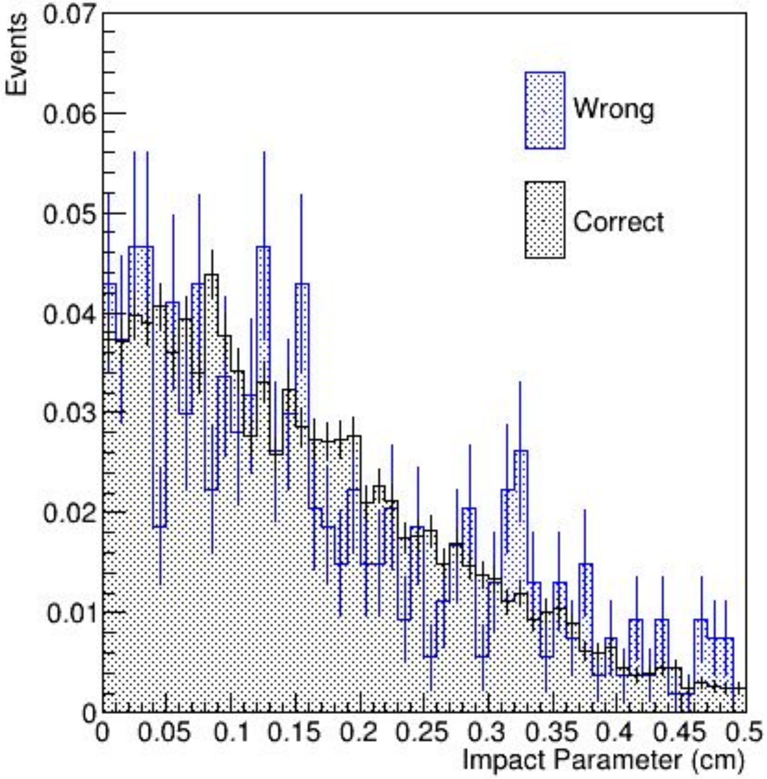
- eLpR full polarized
  - ss: 375,000 events -> 125 fb-1
- Computation
  - LPFOp0 - LPFO p1
- Distribution at p > 15.



Migration

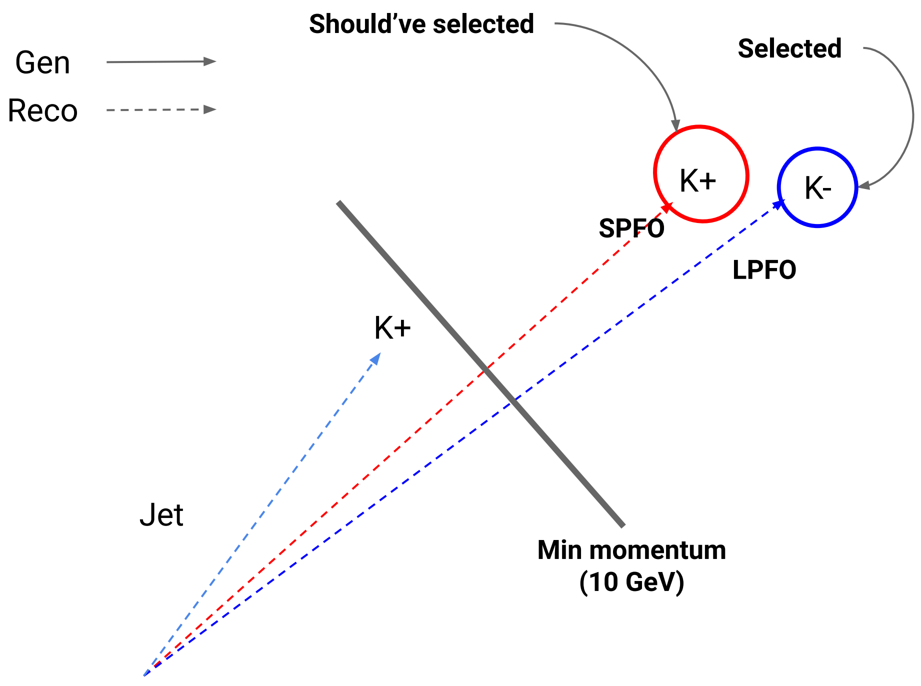
LPFO Impact Parameter

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



Migration

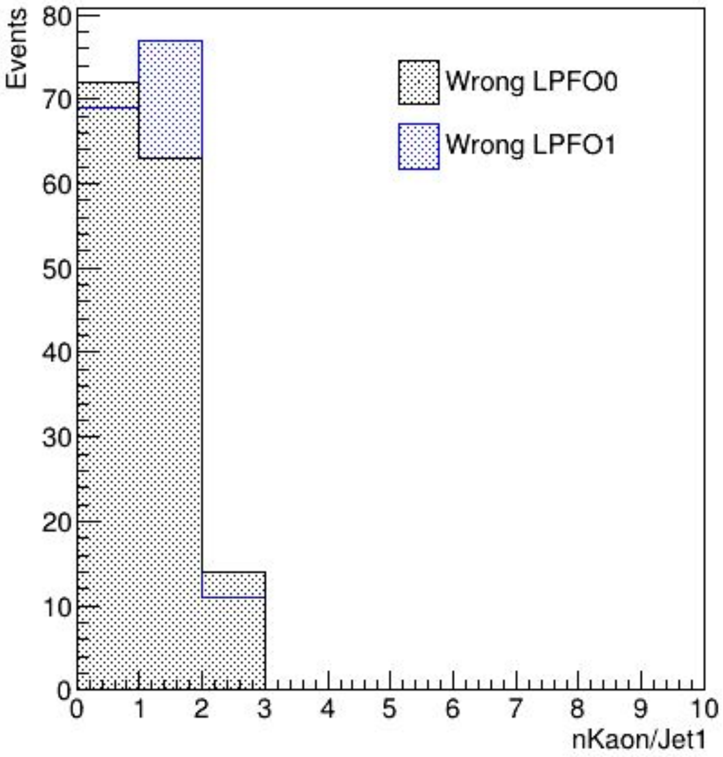
- We look for **Secondary PFOs (SPFO)** with opposite charge to LPFO.
- Wrong events should have SPFO with momentum close to LPFO. (Other **stole** original s-quark)
- Definition for **SPFO Kaon** with **opposite charge**
  - Not leading
  - LPFO is Kaon (ID MC gen partner)
  - SPFO is Kaon (ID MC gen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

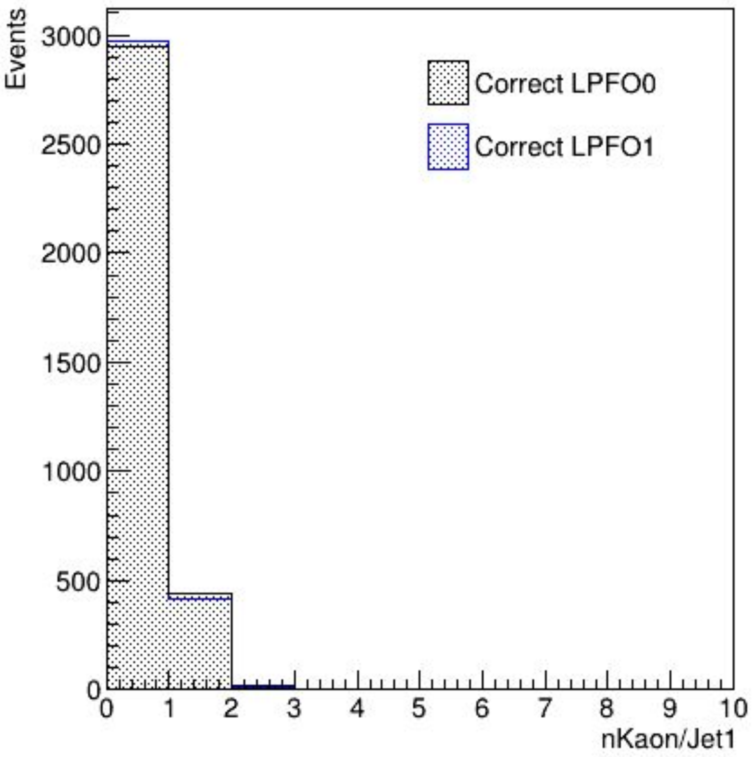


WRONG EVENT

Migration

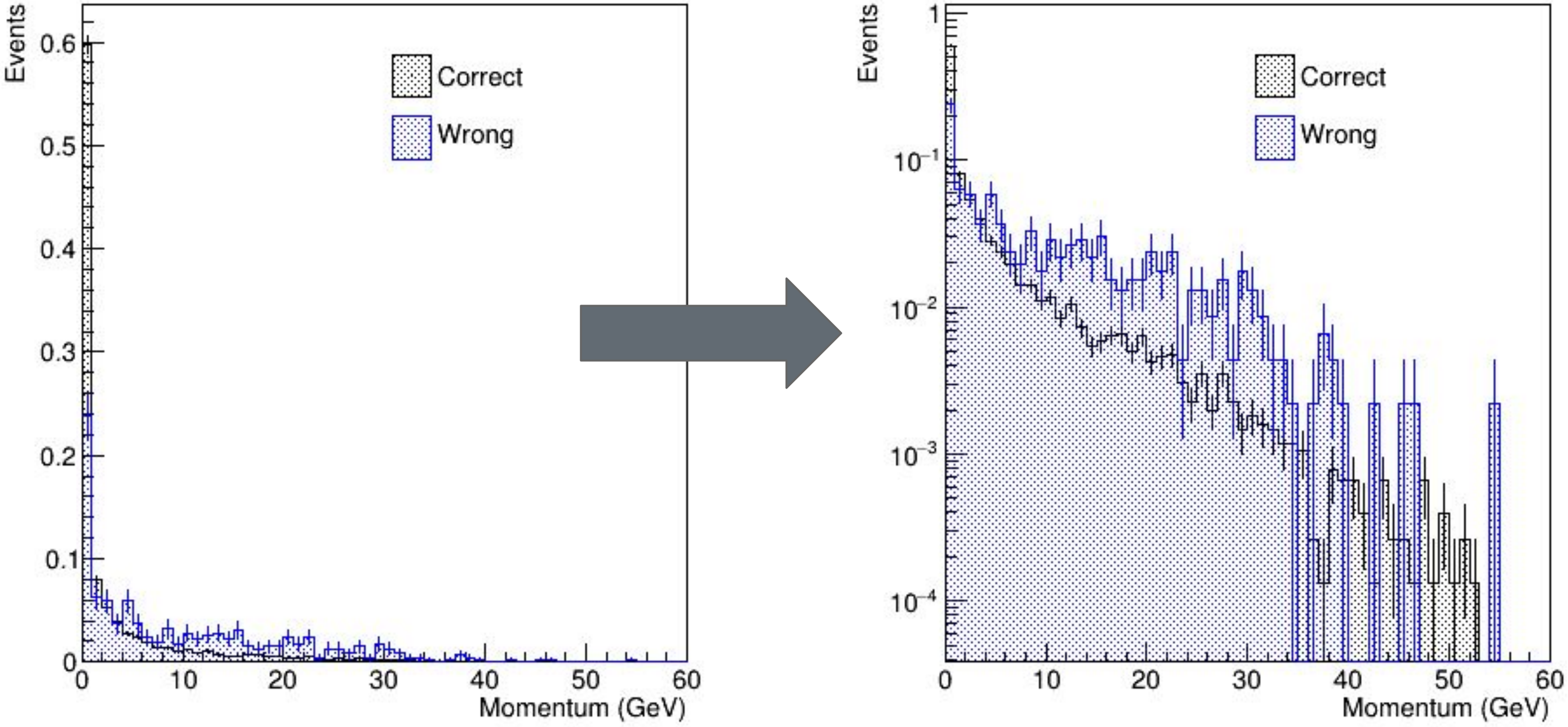
SPFO Kaon Opposite Charge Multiplicity





Migration

SPFO Kaon Opposite Charge Momentum



Selections (ss)

Cut MC

ISR suppression

- QQ cos sep > 0.95
- 120 < QQ mom < 127

Cut PFO

General PFO

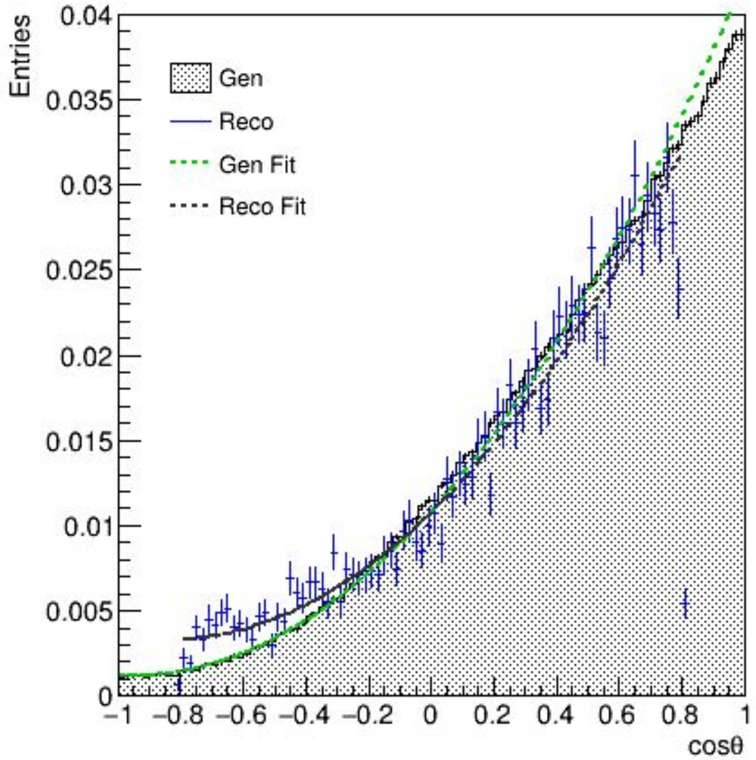
- PFO match (It should fall into either jet0 or jet1)
- # PFO tracks == 1 (more than 2 tracks cannot be associated to make 1 PFO)

Lead PFO (double tag)

- Both PFO should have momentum window **20 < Lead PFO mom < 60**
- Lead PFO charge ± or -+
- # TPC hits **210 < Lead PFO hits**
- Offset cut < 1.0
- kdEdx_dist < (pdEdx_dist & pidEdx_dist)

Notes

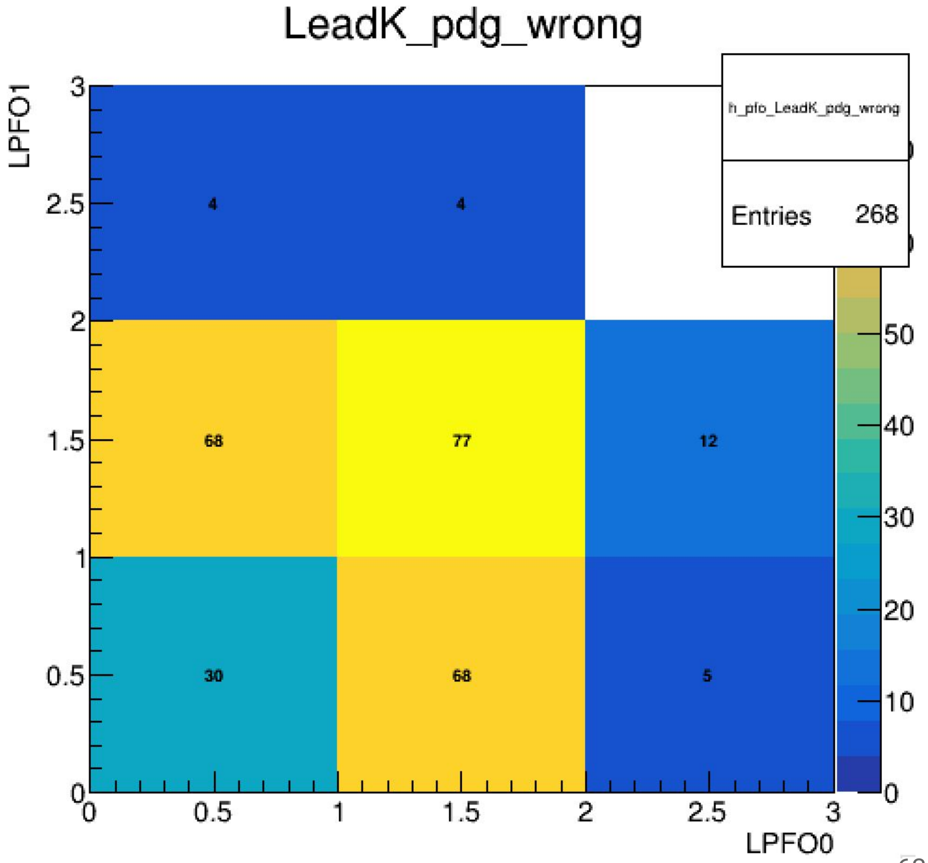
- TPC hits -> changed from base
- Normalization changed (integrate from -0.8 < cos < 0.8) because of cut in # TPC hits
- Momentum window minimum changed from 10 -> 20 GeV



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 sep > 0.95
- 120 < QQ 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)

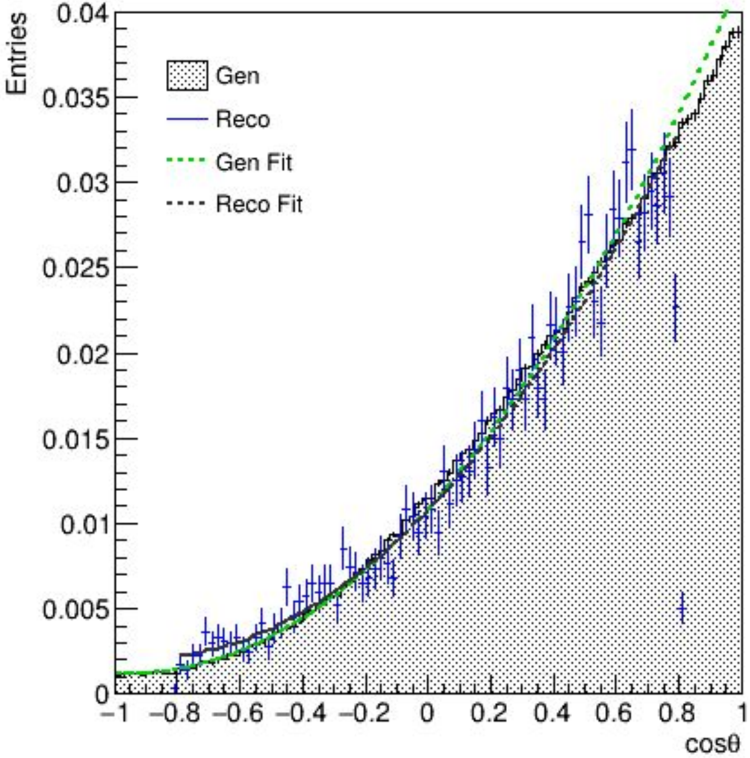
- Both PFO should have momentum window
  20 < Lead PFO mom < 60
- Lead PFO charge ± or -+
- # TPC hits **210 < Lead PFO hits**
- Offset cut < 1.0
- kdEdx_dist < (pdEdx_dist & pidEdx_dist)

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)

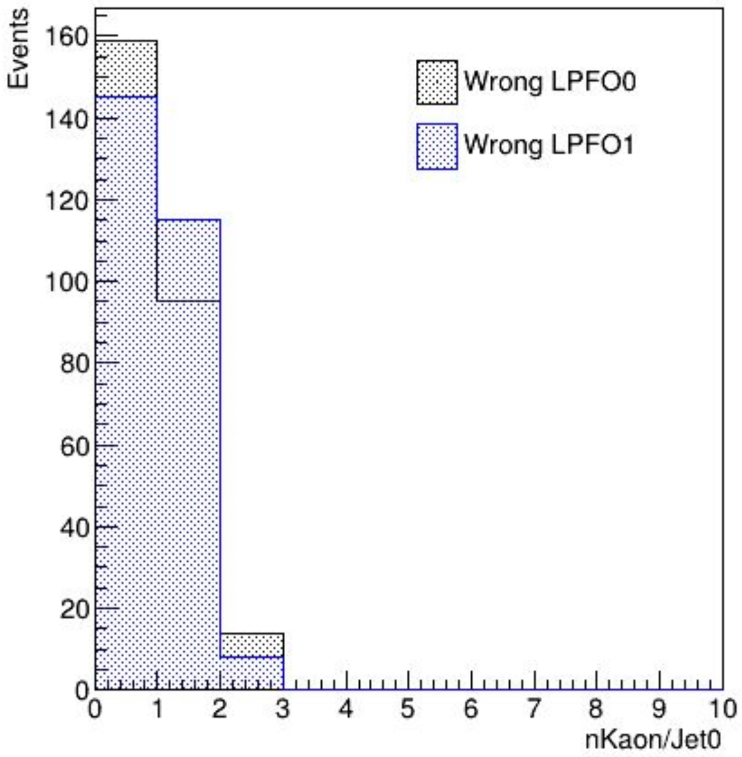
Notes

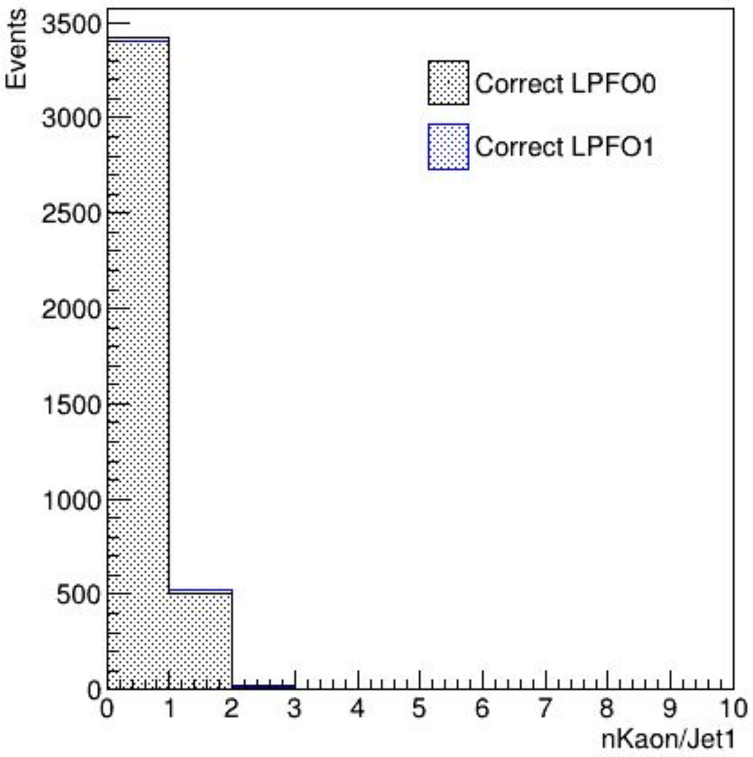
- TPC hits -> changed from base
- Normalization changed (integrate from -0.8 < cos < 0.8) because of cut in # TPC hits
- Momentum window minimum changed from 10 -> 20 GeV



Migration

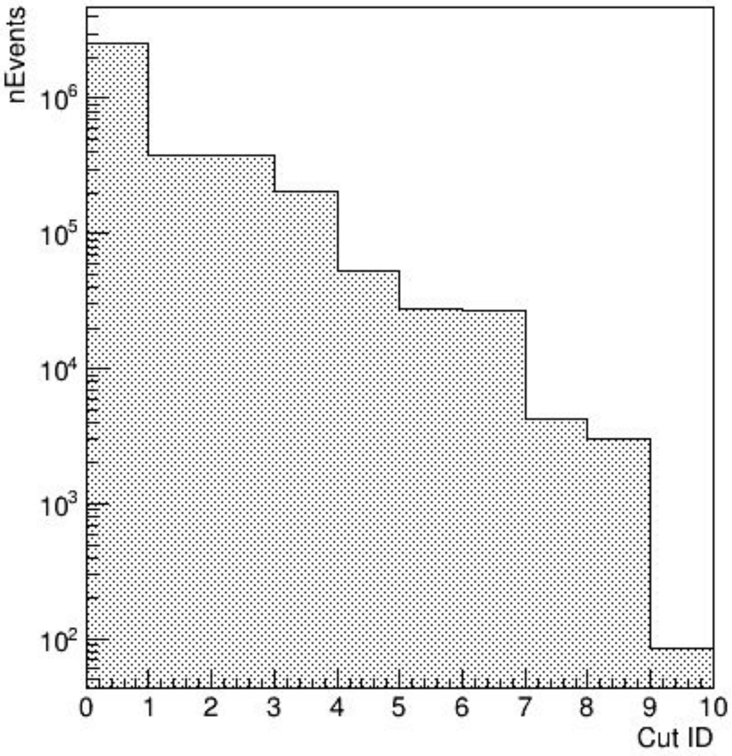
SPFO Kaon Opposite Charge Multiplicity





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%)



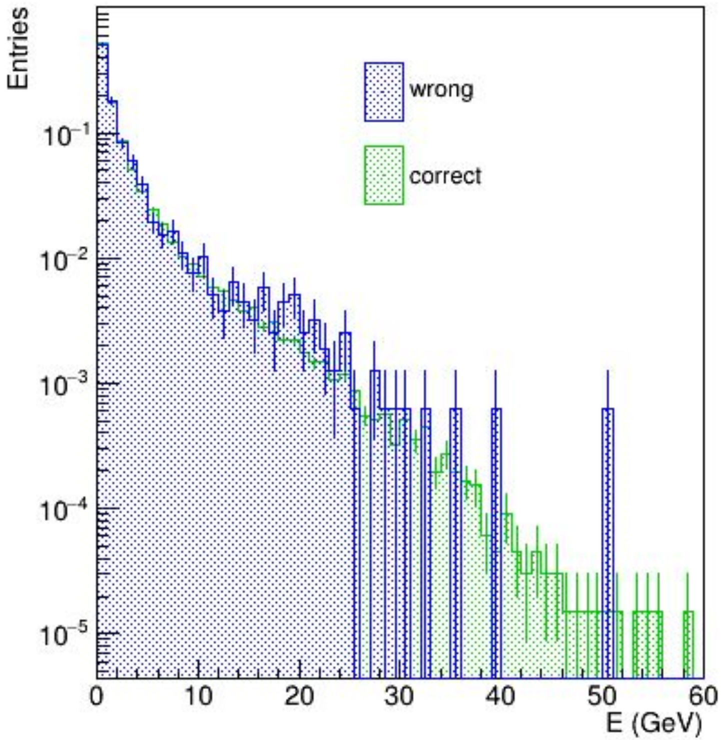
Neutral PFOs

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.
    - Events w/ Neutral PFOs ⊂ Events w/o Neutral PFOs
  - Thus, in current code, it will dump the event if the LPFO has charge 0.

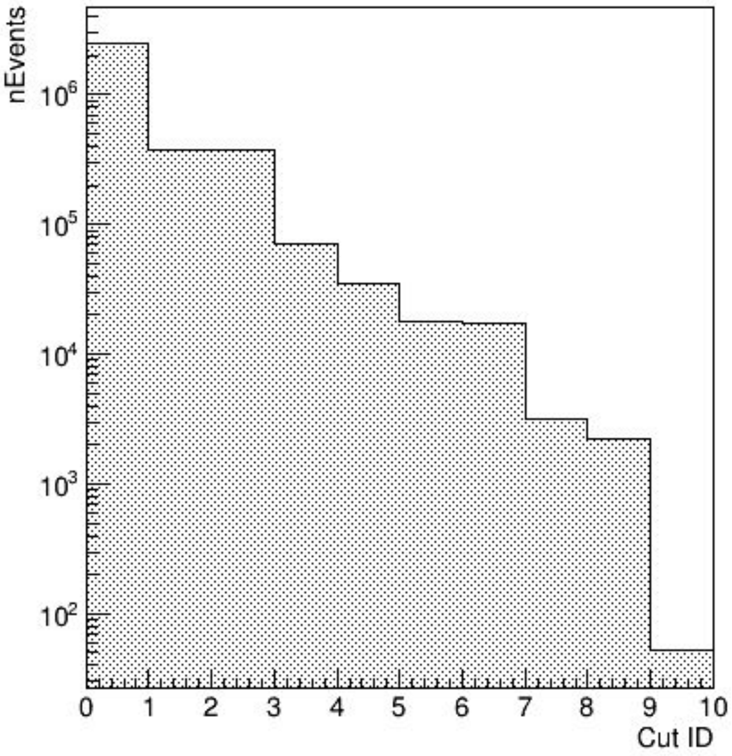
Energy Neutral PFO

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%)



Analysis Steps

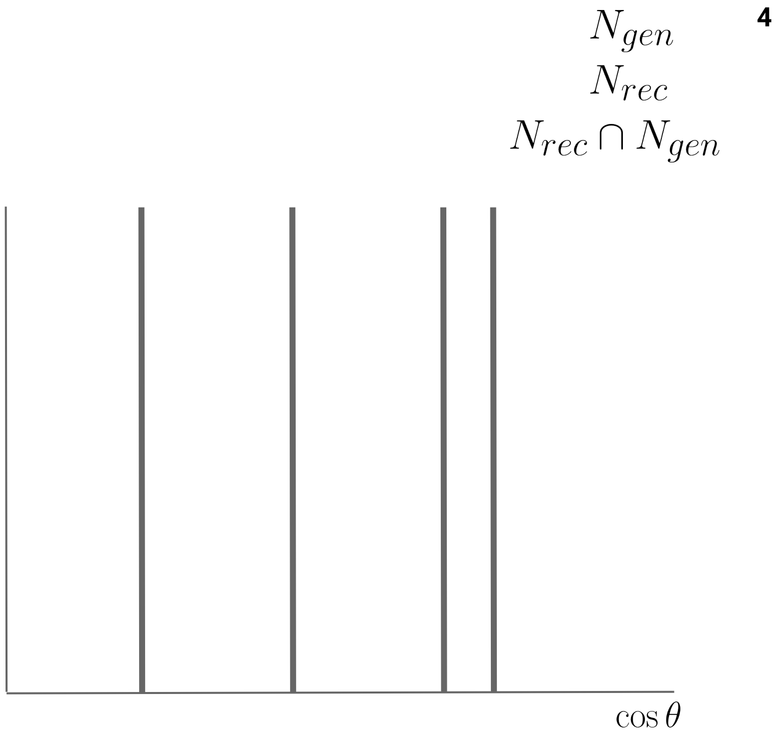
- Reconstruct SSbar process using generator information
  - Summer 2021
  - PID was performed by checking with the Generator Information.
  - Done to **explore the maximum efficiency** that can be achieved by this analysis.
  - Understanding the characteristics of the process itself.
- Reconstruct SSbar 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**.

Definitions of Stability and Purity

Stability and Efficiency

$$\text{stability} = \frac{N_{rec} \cap N_{gen}}{N_{gen}}$$

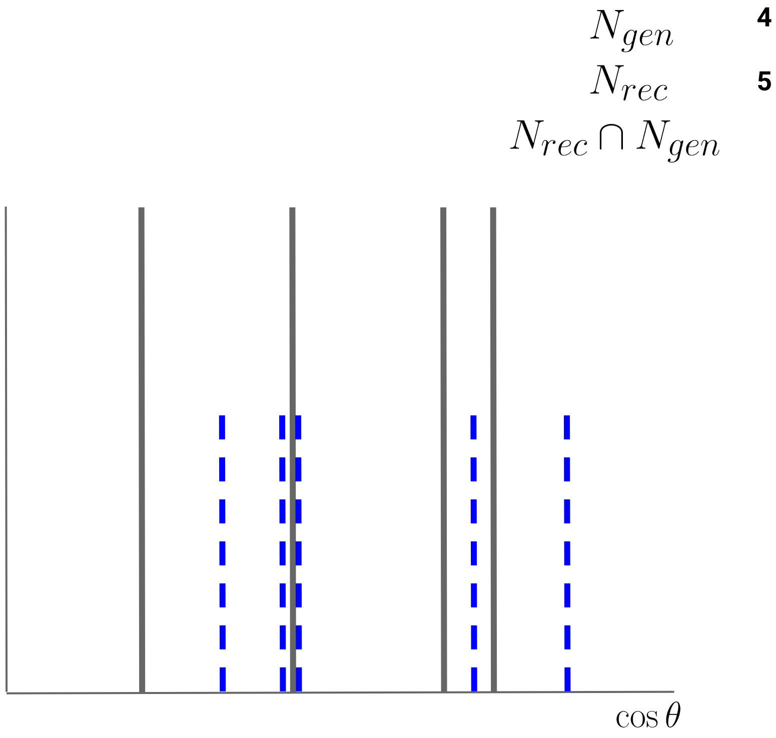
$$\text{purity} = \frac{N_{rec} \cap N_{gen}}{N_{reco}}$$



Stability and Efficiency

$$\text{stability} = \frac{N_{rec} \cap N_{gen}}{N_{gen}}$$

$$\text{purity} = \frac{N_{rec} \cap N_{gen}}{N_{reco}}$$



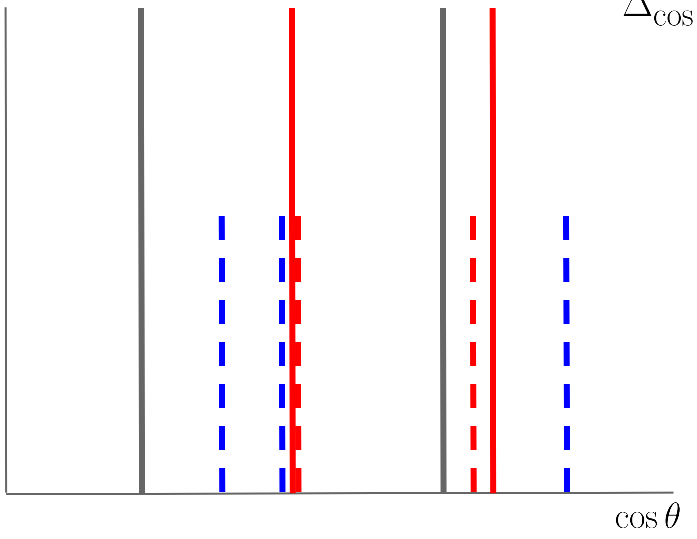
Stability and Efficiency

$$\text{stability} = \frac{N_{rec} \cap N_{gen}}{N_{gen}}$$

$$\text{purity} = \frac{N_{rec} \cap N_{gen}}{N_{reco}}$$

N_{gen}	**4**
N_{rec}	**5**
$N_{rec} \cap N_{gen}$	**2**

$\Delta_{\cos\theta} < 0.02$



Stability and Efficiency

$$\text{stability} = \frac{N_{rec} \cap N_{gen}}{N_{gen}}$$

$$\text{purity} = \frac{N_{rec} \cap N_{gen}}{N_{reco}}$$

N_{gen}	4
N_{rec}	5
$N_{rec} \cap N_{gen}$	2

$\Delta_{\cos\theta} < 0.02$

$\text{stability} = 0.5$

$\text{purity} = 0.4$