General Meeting

Yuichi Okugawa
January 2022

Conference

- **Jan 10 - 14 :   LP 2021**
  - Jan 10 - 11 : Poster Session (2.0h)

STRANGE PAIR PRODUCTION IN HIGH ENERGY ELECTRON POSITRON COLLISIONS

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Introduction

A key physics topic anticipated at electron-positron colliders is the detailed investigation of Electroweak (EW) symmetry breaking. There are theories beyond the standard model that explain this mechanism, which requires modification in fermion coupling to weak bosons. ILC can play a central role in such investigation, as it can measure its coupling with higher precision than ever before.

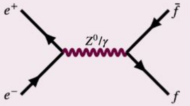


Figure 1 *Feynman diagram for fermion pair production at e+e- collision through Z^0/γ at Leading Order. Studies of $t\bar{t}$/ $b\bar{b}$/$c\bar{c}$ pair production are being conducted.*

Theory

Differential Cross Section

The differential cross section of $e^+e^- \to f\bar{f}$ [1]:

$$\frac{d\sigma_{f\bar{f}}}{d\cos\theta} = \frac{3}{8}\sigma_{f\bar{f}}^{tot}(1 - \mathscr{P}_e\mathscr{A}_e)(1+\cos^2\theta) + 2(\mathscr{A}_e - \mathscr{P}_e)\mathscr{A}_f\cos\theta \quad (1)$$

where
θ : The production angle of the fermion
$\sigma_{f\bar{f}}^{tot}$: Total cross section of $e^+e^- \to f\bar{f}$
$\mathscr{P}_e$: Electron beam helicity (Left: negative, Right: positive)

Asymmetry parameters $\mathscr{A}_f$ are defined as:

$$\mathscr{A}_f = 2 \cdot \frac{g_{Vf}/g_{Af}}{1 + (g_{Vf}/g_{Af})^2} \quad (2)$$

with g_{Vf}, g_{Af} being vector and axial vector coupling constants, respectively.

ILC & ILD

International Linear Collider (ILC)

- Center of mass energy: 250 GeV, 500 GeV, 1TeV (to be extended)
- Well defined initial states with controllable beam polarization (L:80%, R:30%)
- Clean events with less backgrounds compared to hadron colliders

Figure 2 Schematic view of ILC. Planned to be constructed along the Kitakami mountains, Tohoku. [2]

International Large Detector (ILD)

- Capable of reconstructing every particle inside the detector and store them as objects, called Particle Flow Objects (PFOs)
- High tracking efficiencies.
- Time projection chamber facilitates the particle identification through dE/dx measurements

Figure 3 *The cross sectional view of the ILD. TPC is highlighted in yellow. [3]*

TPC

The time projection chamber (TPC) is the central detector in ILD.
- When a charged particle crosses the chamber, the ionized gas will create a thread of electrons which drift to the TPC endplate.
- The time and charge of each hit are recorded.
- From these, the track parameters and ionization energy loss (dE/dx) can be measured.

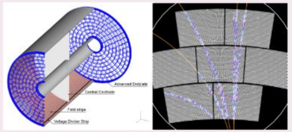


Figure 4 *Schematic view of TPC (left) and track reconstruction performed by the Endplate equipped with micromegas at test beam (right). The endplate in the current ILD TPC design has 220 pad rows and micromegas is one of the technical options.*

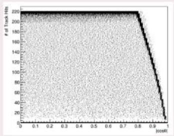


Figure 5 *Number of TPC hits are plotted against $\cos\theta$. Due to the short distance in projection for forward emitted particles, number of endplate hits in the forward region is low, causing larger statistical uncertainties in dE/dx measurements.*

Process

The analysis focuses on $e^+e^- \to s\bar{s}$ production at high effective centre-of-mass energy.
- $E_{CM} = 250$ GeV
- Integrated Luminosity $\int \mathscr{L}dt = 100$ fb^{-1}
- Full Geant4 simulation of ILD.

Figure 7 *Schematic diagram of $s\bar{s}$ production after its hadronization. Neutral kaons are being ignored for the time being. In reality, these jets will include mixture of pion and proton even in the pure $s\bar{s}$ events.*

Particle ID

dE/dx vs track momentum can be approximated by the Bethe-Bloch formula [4], which is unique to different particles.
dE/dx distance is also calculated as following:

$$\text{signed}\left[\left(\frac{dE/dx - dE/dx_{exp-kaon}}{\Delta_{dE/dx}}\right)^2\right] \quad (3)$$

where
$dE/dx_{exp-kaon}$: dE/dx value expected from kaon Bethe-Bloch formula.
$\Delta_{dE/dx}$: Statistical error for dE/dx measurements.

The +/- sign that was lost upon squaring the quantity will be retained afterwards (thus "signed")

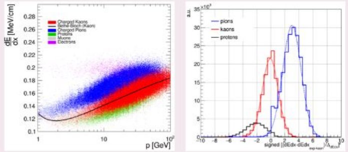


Figure 6 *dE/dx vs p distribution (left) and dE/dx distance calculated by eq (2) for $e^+e^- \to s\bar{s}$ process. The dominant backgrounds are pions and protons.*

Analysis

Selection

- Choose PFOs with the highest momentum within each jet, calling it "Leading PFOs" (LPFO).
- Both LPFOs should satisfy:
  - Momentum: $20 < p_{LPFO} < 60$ GeV
  - LPFOs have non-zero and opposite charge.
  - ≥ 210 TPC hits to ensure good dedx measurement
  - Impact parameter < 0.1 cm to remove proton backgrounds.
  - dE/dx distance from kaon Bethe-Bloch formula is smaller compared to the ones for pions and protons.

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

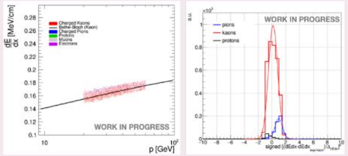


Figure 8 *dE/dx vs p distribution (left) and dE/dx distance (right) for selected LPFOs in $e^+e^- \to s\bar{s}$ events. Two major backgrounds pions and protons were drastically removed with the selection.*

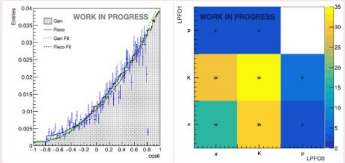


Figure 9 *Polar angle distribution of LPFOs after the selection (left) and true PDG information of LPFO with wrongly reconstructed charge (right). Note that due to the TPC detector acceptance (# of hits), there is little to no sensitivity at the forward region ($|\cos\theta| > 0.8$)*

Conclusion & Outlook

Conclusion
Reconstruction of strange quark pair charges at ILC for both 250 GeV scenario was examined. Such process requires precise selection in Kaons using dE/dx information. For this analysis, we were able to achieve **~ 85 % purity** for the kaon identification in **pure $s\bar{s}$ samples**.

Outlook
Prospects include of full background samples (u,d,c) and optimization of kaon selection as currently sacrifice efficiencies in exchange of purity.

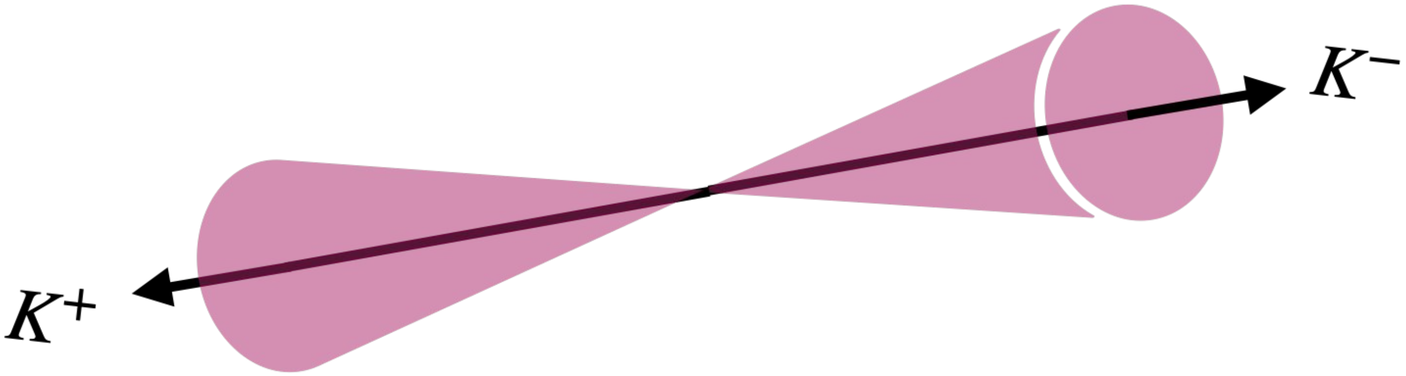
References

(1) Electroweak, The SLD, et al. "Precision electroweak measurements on the Z resonance." Physics Reports 427.5-6 (2006): 257-454.
(2) Behnke, Ties, et al. "The international linear collider technical design report-volume 1: Executive summary." arXiv preprint arXiv:1306.6327 (2013).
(3) ILD Collaboration. "International Large Detector: Interim Design Report." arXiv preprint arXiv:2003.01116 (2020).
(4) K. Nakamura. Review of particle physics. Journal of Physics G: Nuclear and Particle Physics, 37:075021, 2010.

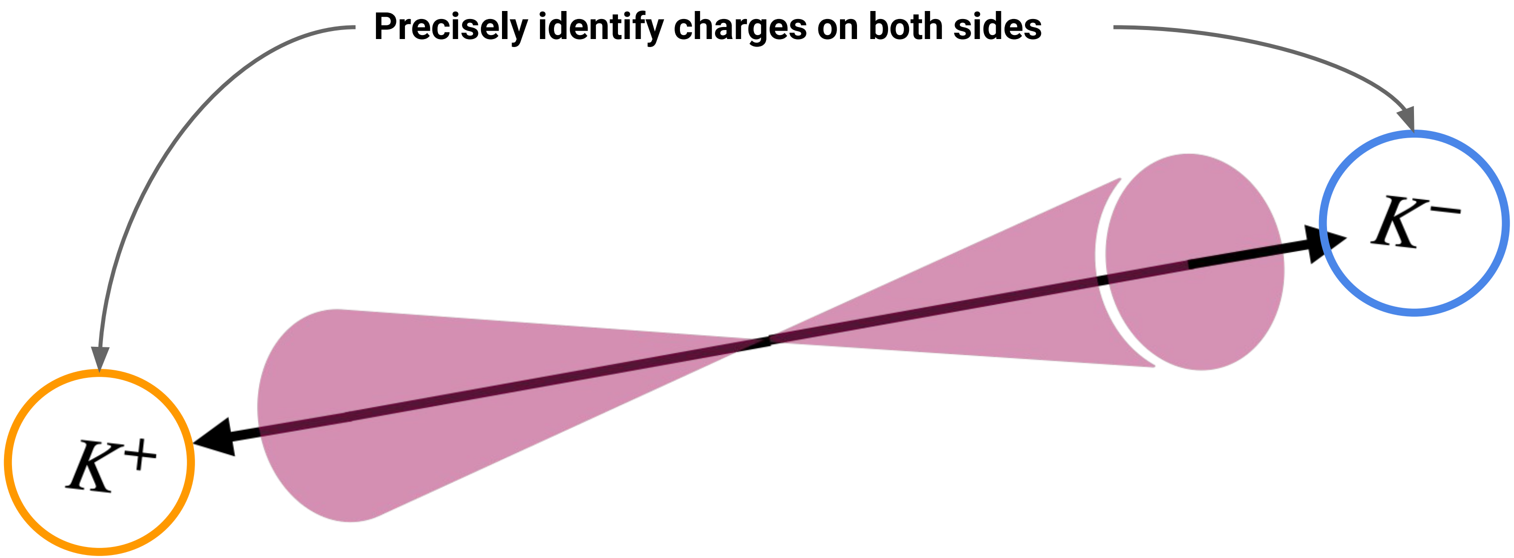
On behalf of the ILD Concept Group

Migrated Event Analysis

What is Migration?



What is Migration?



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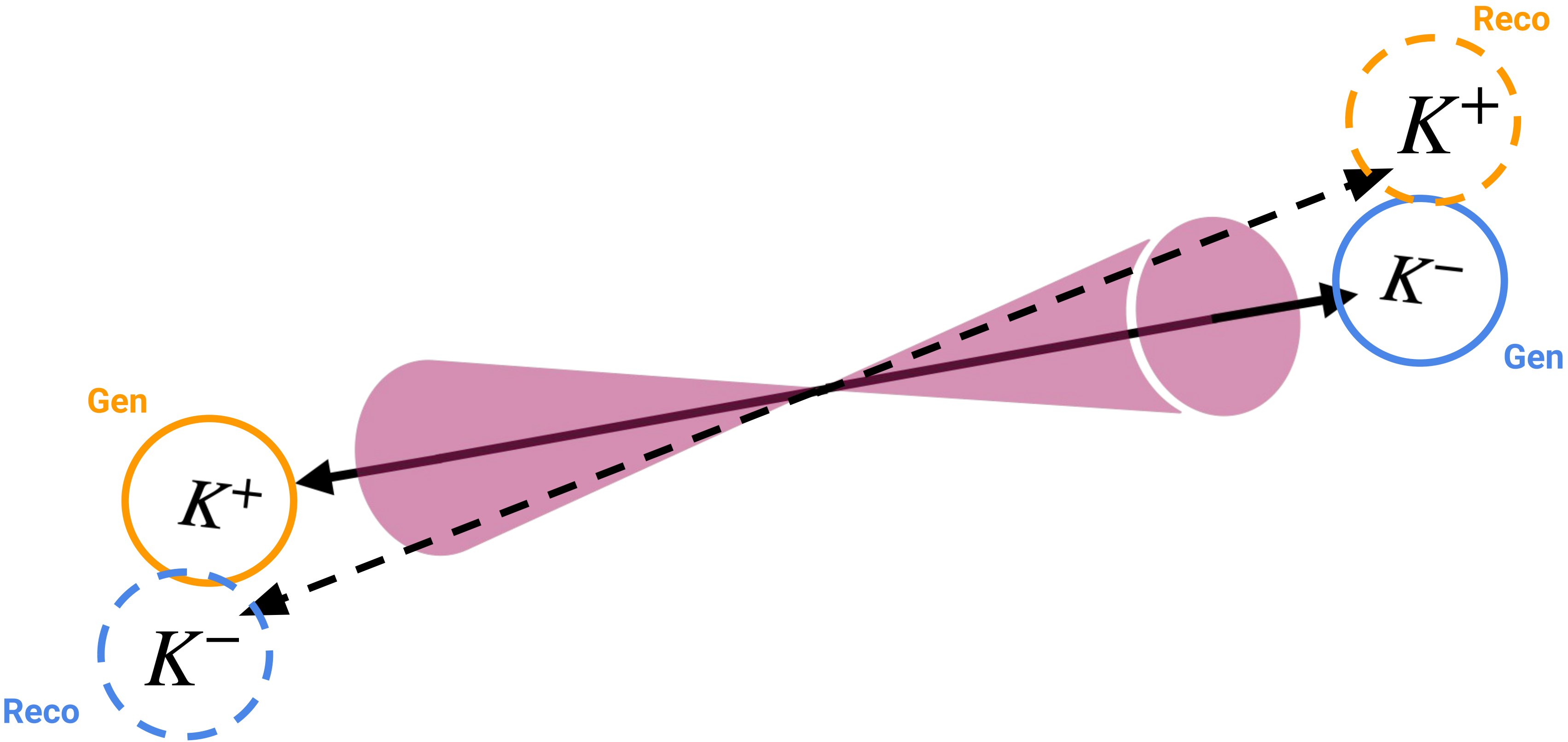

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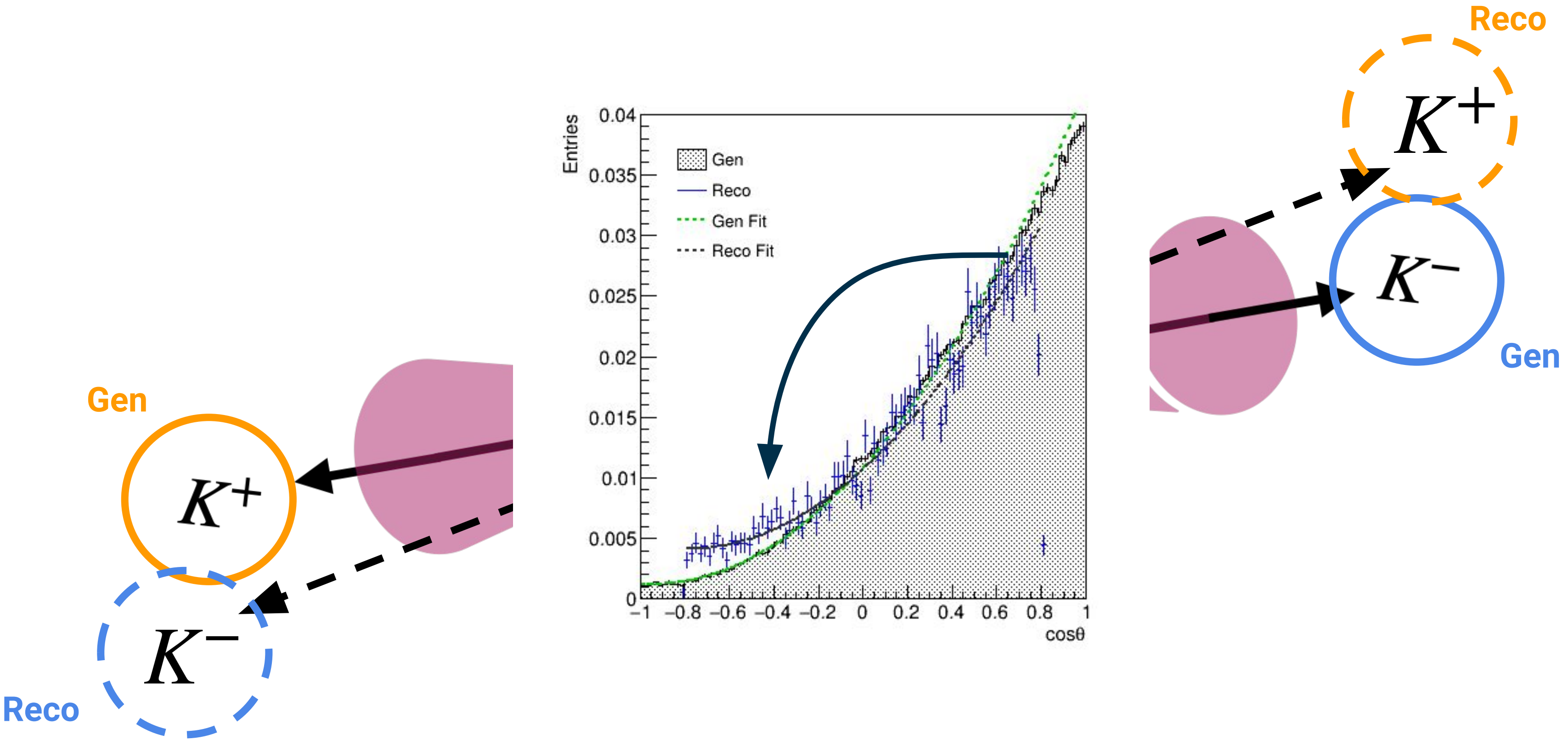
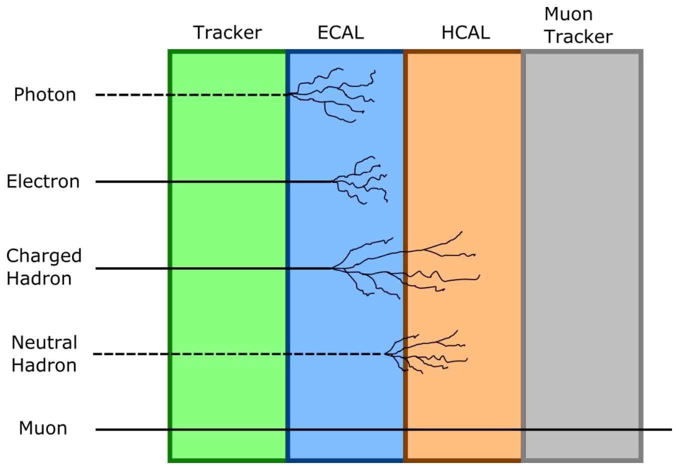


Why Migration?

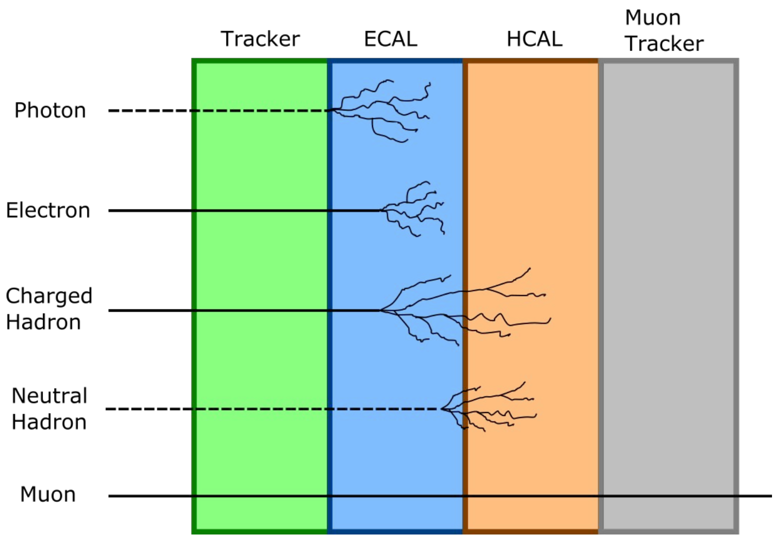
Why Migration?

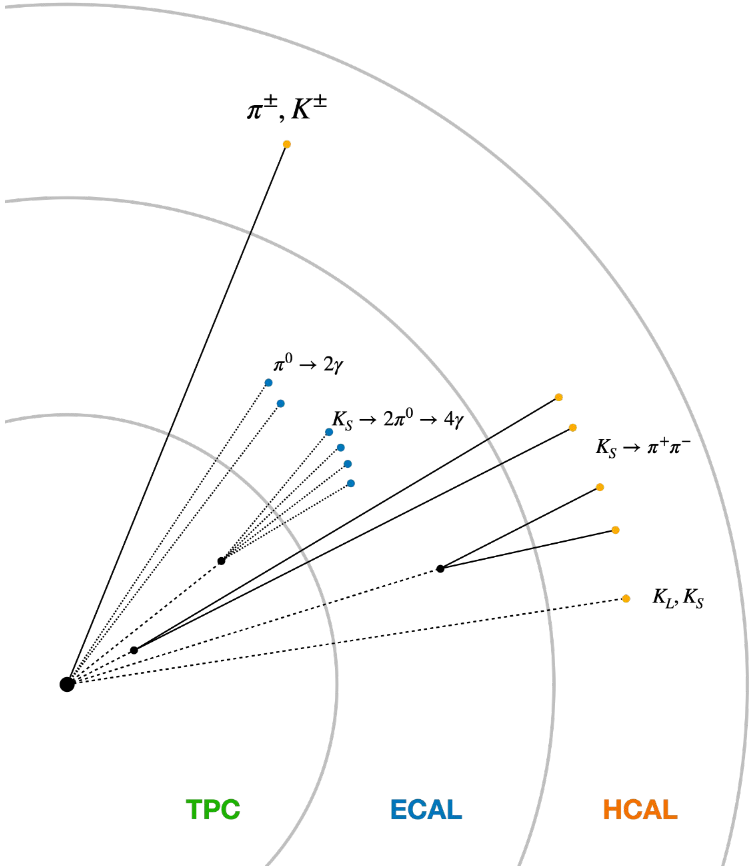
Possible types of Kaons from ssbar pair

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



Why Migration?





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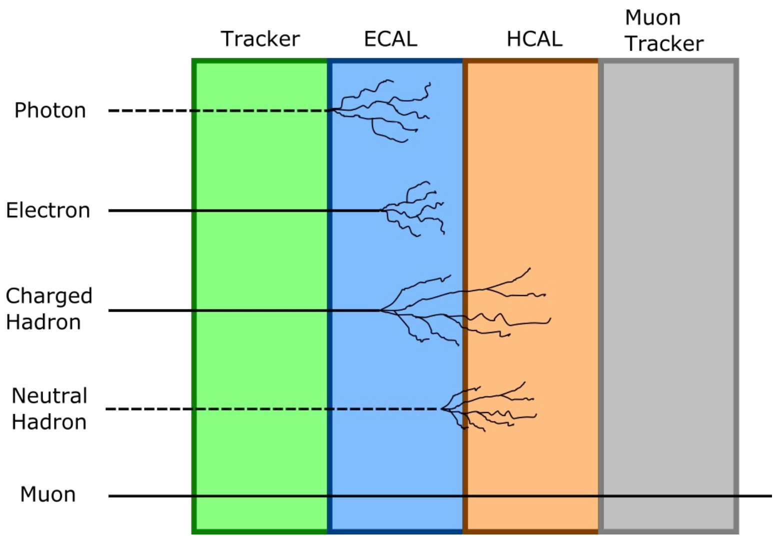
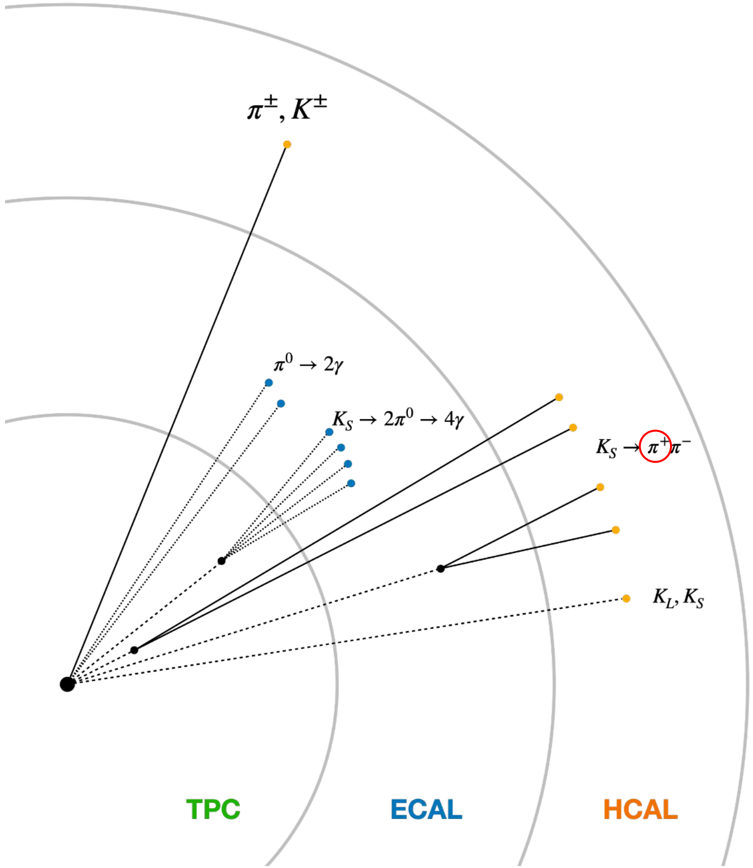
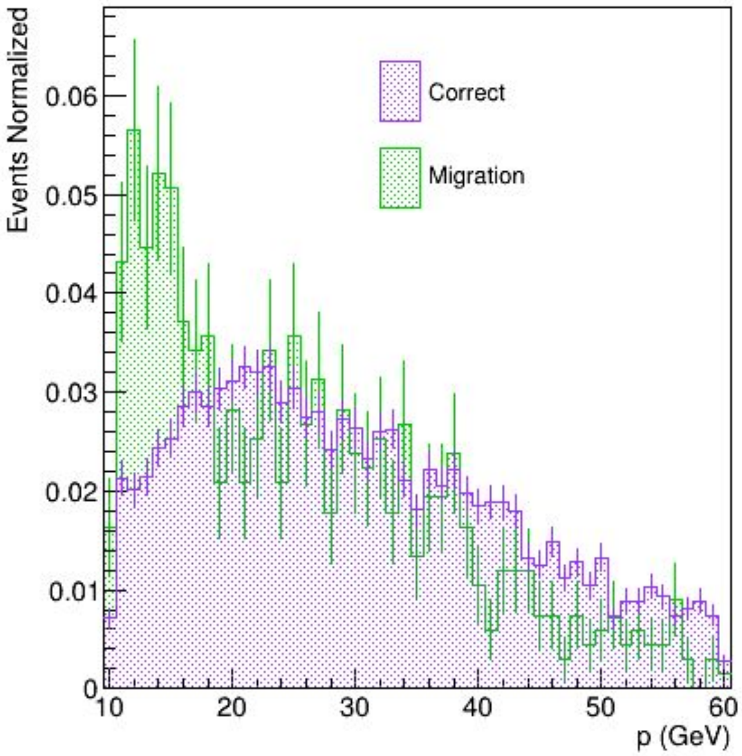




Migration

Right plot shows the momentum of migrated (green) and correct (violet) events.



Selections (ss)

Cut MC

ISR suppression

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

Cut PFO

General PFO

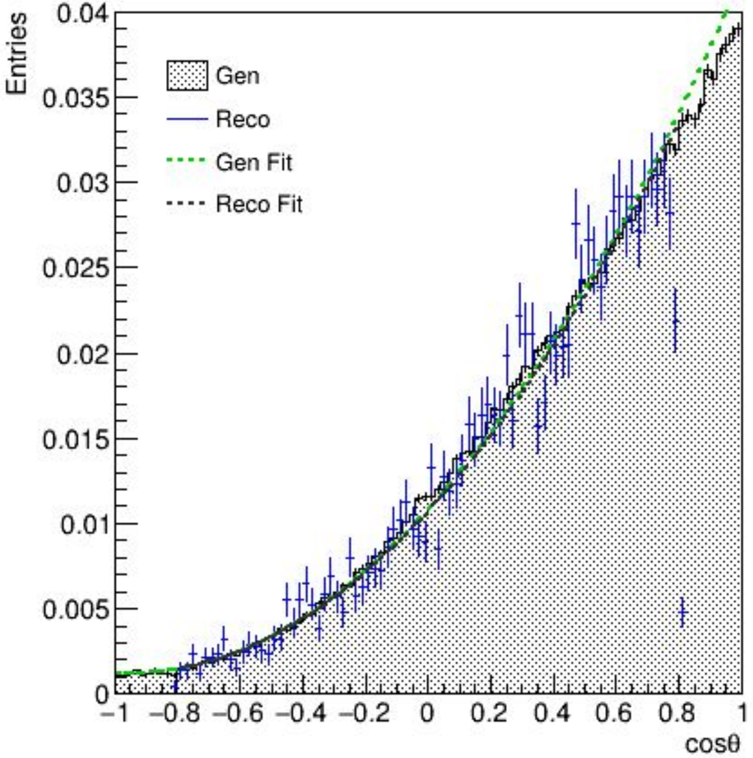
- PFO match (It should fall into either jet0 or jet1)
- # PFO tracks == 1 (more than 2 tracks cannot be associated to make 1 PFO)

Lead PFO (double tag)

- Both PFO should have momentum window
  10 < 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
- **Ignore migrations (cheat)**



Selections (ss)

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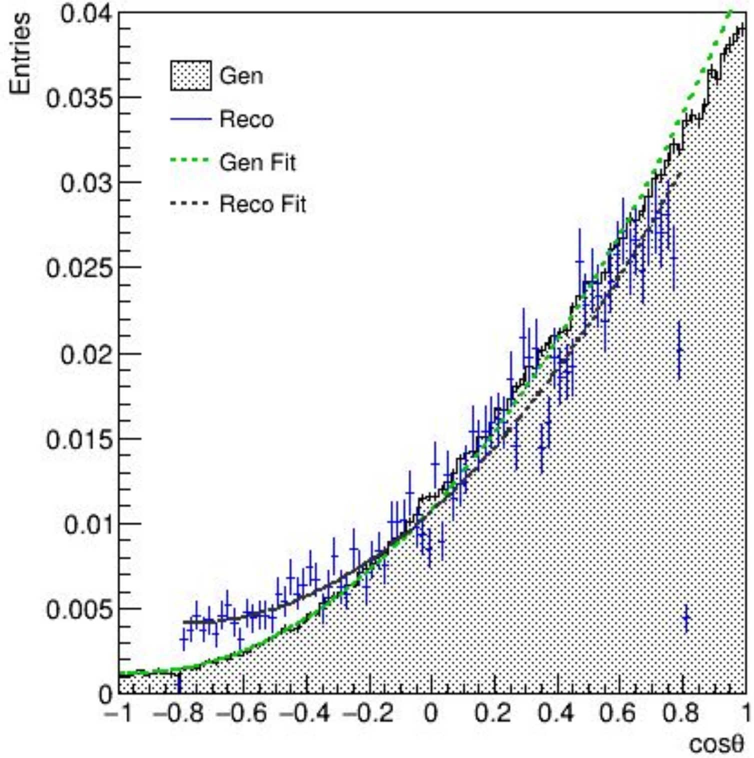
- kdEdx_dist < (pdEdx_dist & pidEdx_dist)

Notes

- TPC hits -> changed from base
- Normalization changed (integrate from -0.8 < cos < 0.8) because of cut in # TPC hits



Selections (ss)

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- 120 < QQ mom < 127

Cut PFO

General PFO

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- # PFO tracks == 1 (more than 2 tracks cannot be associated to make 1 PFO)

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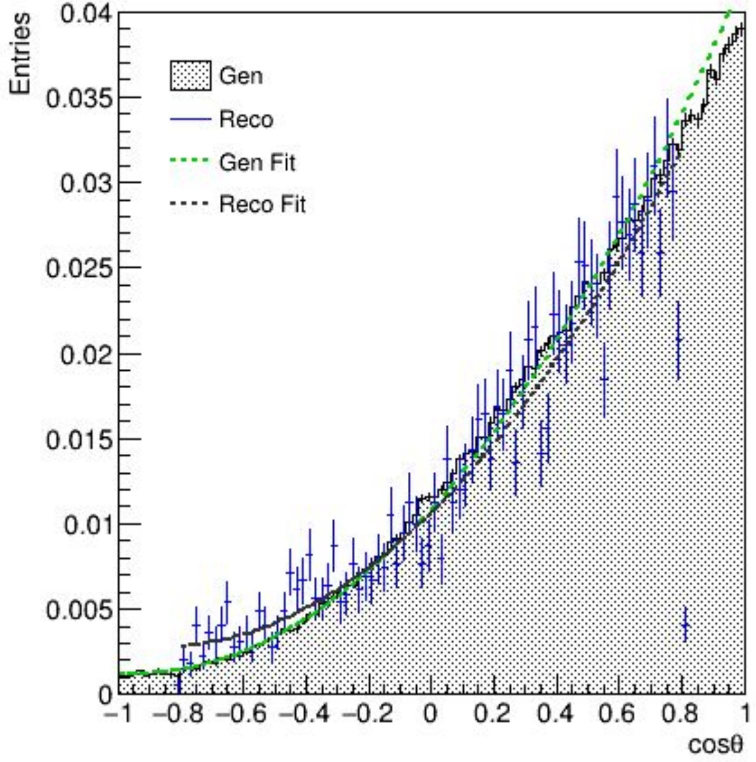
- Offset cut < 1.0
- kdEdx_dist < (pdEdx_dist & pidEdx_dist)

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



of events

Table on the right shows the # of events after each cuts. (note: # of polar angle histogram entry is **x2**)

Cut MC

ISR suppression

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

Cut PFO

General PFO

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- # PFO tracks == 1 (more than 2 tracks cannot be associated to make 1 PFO)

Lead PFO (double tag)

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- Lead PFO charge ± or -+
- # TPC hits **210 < Lead PFO hits**
- Offset cut < 1.0
- kdEdx_dist < (pdEdx_dist & pidEdx_dist)

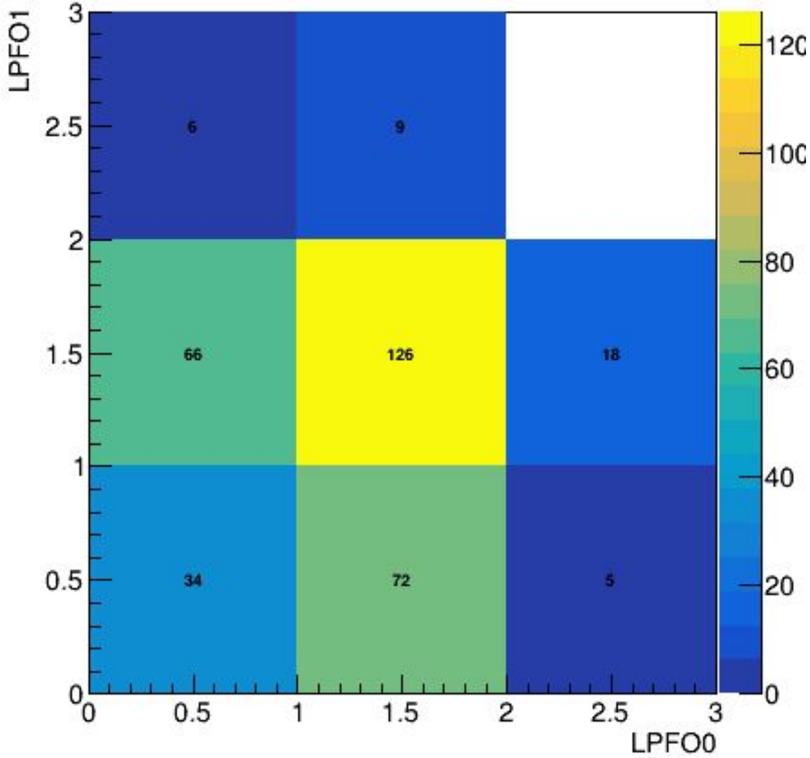
# Total Events	1215036
# after Gen sel	181296
# after PFO sel	181295
# Events after LeadK sel (double tag)	
Charge check	97720
Momentum check	25762
TPC hit check	13536
Offset check	13020
dEdx dist min check	2062
Migration	122

Migration

Right plot shows the PDG of leading PFOs for the migrated events.

Config	#Events	%
K-K	126	37.5
Pi-Pi	34	10.1
Pi-K	138	41.0
Pi-p	11	3.2
p-K	27	8.0
p-p	0	0

Events: 336



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	35	28.7
Pi-Pi	16	13.1
Pi-K	58	47.5
Pi-p	5	4.1
p-K	8	6.6
p-p	0	0