$e^-e^+ \rightarrow s\bar{s}$ at ILC 250 GeV

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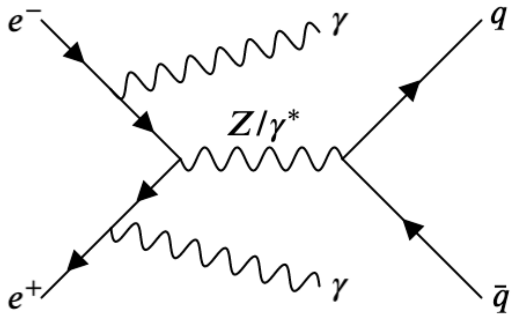
15/10/25

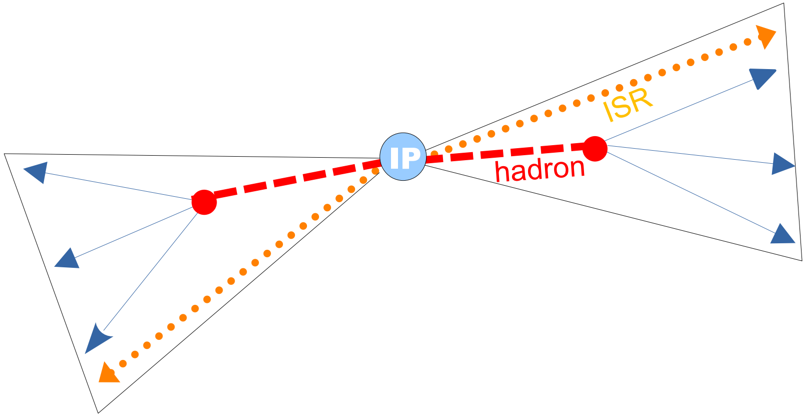
(b & c) diquark production in $e^- e^+$ collisions

- MC simulations at 250.
  - International Linear Collider (ILC) run plan.
  - Full simulation of the International Large Detector (ILD).
- Topology: Two back-to-back jets.
- Procedure:

R_q
  - Background suppression → Selection of $q\bar{q}$ events.
  - Flavor tagging → Selection of $b\bar{b}$ & $c\bar{c}$ events.
    - Double tagging (b-tag, c-tag).

A_{FB}
  - Charge measurement → Quark-Antiquark identification.
    - Double charge.

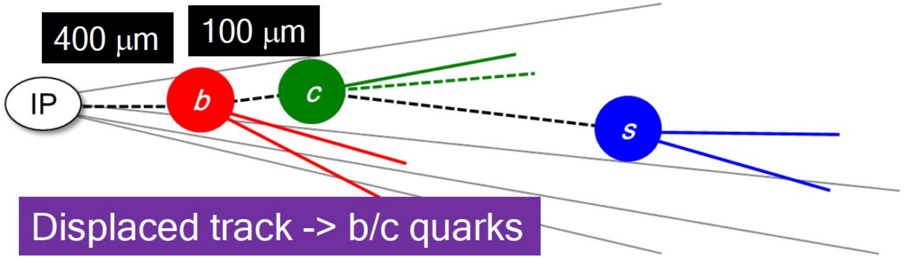




How can we move from here to strange quarks (or u/d quarks)?
Can we get ‰-level uncertainties like for the b & c quarks?

From b/c to strange quark

- Flavor tagging of b and c jets is “easy”:
  - Decay of b and c hadrons: Displaced vertexes from de IP, at a distance ($\tau_q \cdot c$)



- But the strange quark produce kaons... no decays in the tracker to be used
  - We need to build/use an s-tag relying on **kaon PID**
    - Our first attempt is a “classic” cut-based analysis
      - I worked on top of the previous analysis done by Y. Okugawa in his thesis, (directed by R. Poeschl)

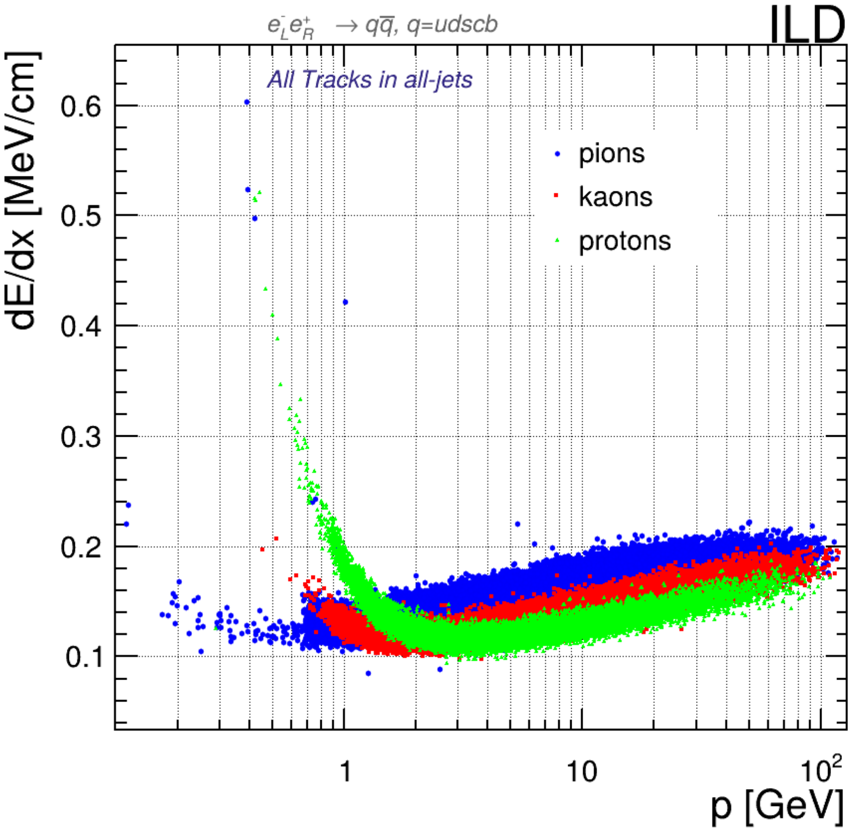
Redoing of the ssbarAnalysis

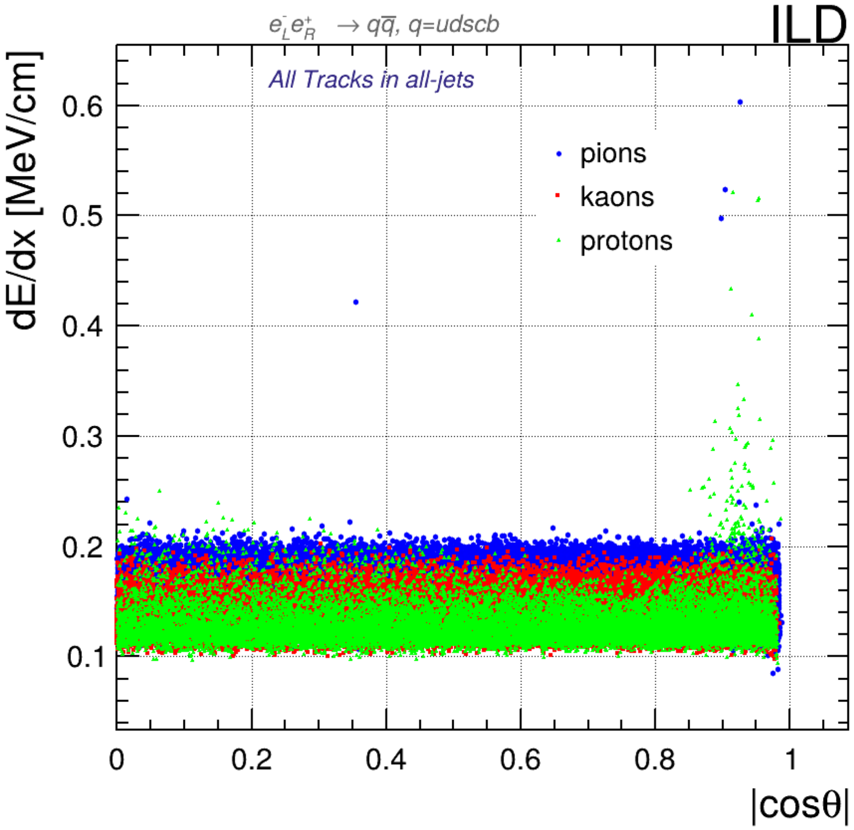
- Preselection of the diquark signals (Modification of Yuichi Okugawa's analysis)

	#	Name	Quantity	Description
uds selection	1	b-tag	$btag < 0.3$	Reject events with b-like jets
	2	c-tag	$ctag < 0.65$	Reject events with c-like jets
	3	nvtx	$nvtx = 1$	Jets should have only PV as vertex
Cut-based s-tag (or ud-tag)	4	Leading momentum	$p_{LPFO} > 15\,\mathrm{GeV}$	Leading momentum cut
	5	LPFO acollinearity	$\cos\theta_{LPFO_{1,2}} > 0.97$	LPFOs should be back-to-back
	6	Offset	$V_0 = \sqrt{d_0^2 + z_0^2} < 1\,\mathrm{mm}$	Offset cut to reject Λ_0 contribution
	7a	dE/dx PID (π)	**New angular k-distance cuts**	$\pi^{\pm}$ identification
	7b	dE/dx PID (K)		$K^{\pm}$ identification
Migration correction	8	SPFO	Veto $p_{SPFO} > 10\,\mathrm{GeV}$ and charge opposite to LPFO.	Attenuate the charge migration by rejecting oppositely charge LPFO competitor
	9	Charge	$Q_{LPFO1} \times Q_{LPFO2} < 0$ opposite charge.	Charge of LPFOs from both sides has

PID via dE/dx: Starting point

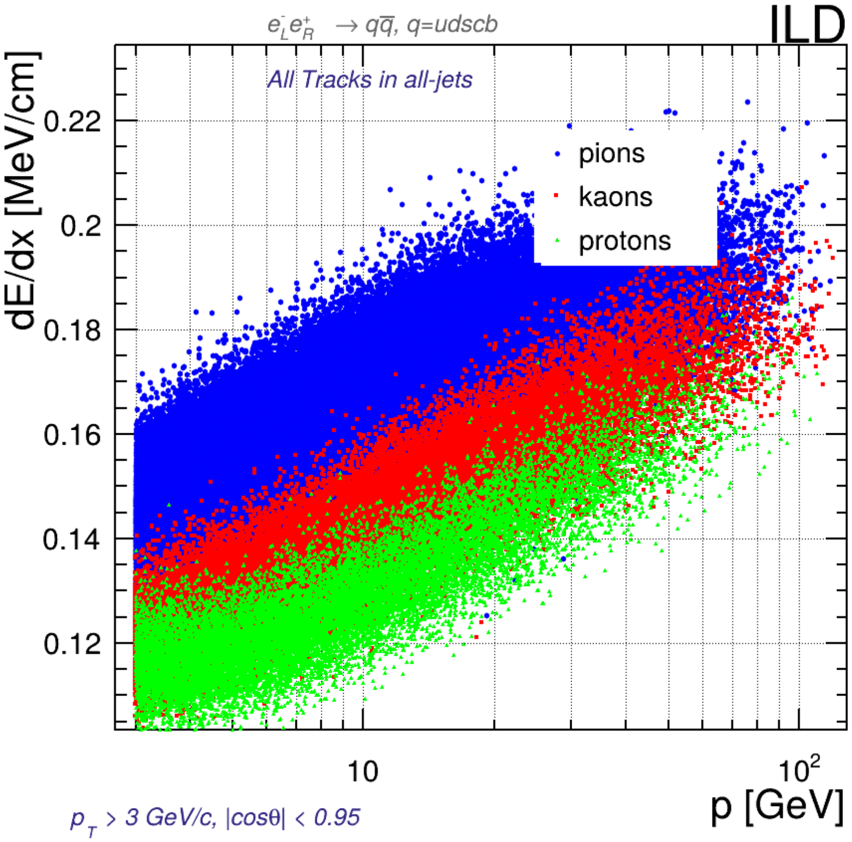
- Not all tracks/PFOs are valid for dE/dx

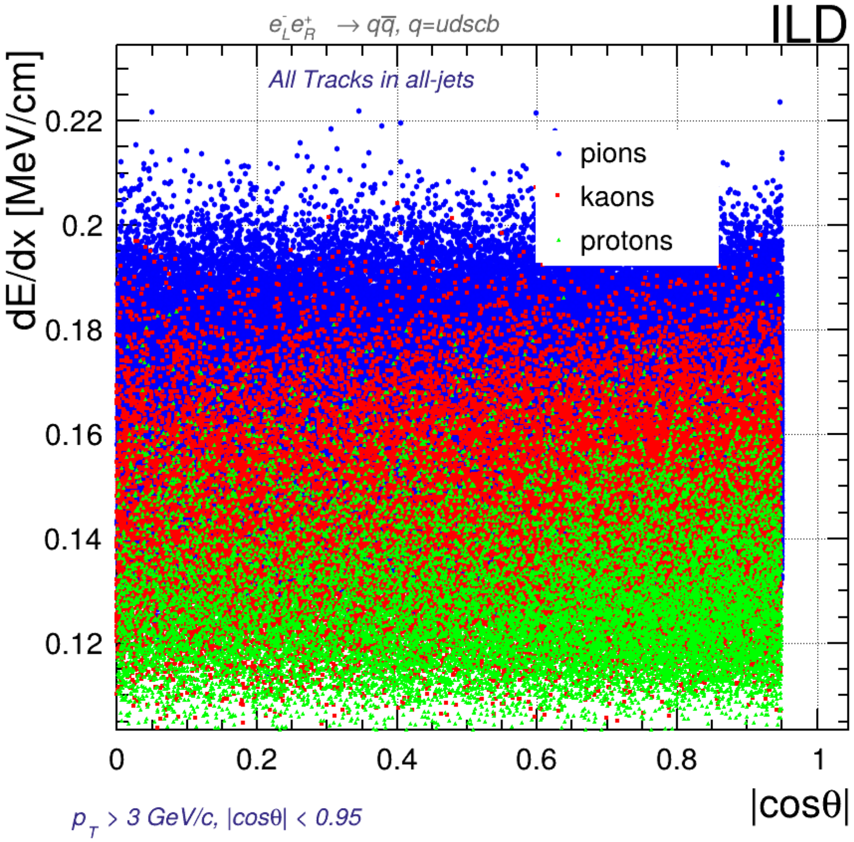




PID: Preselection

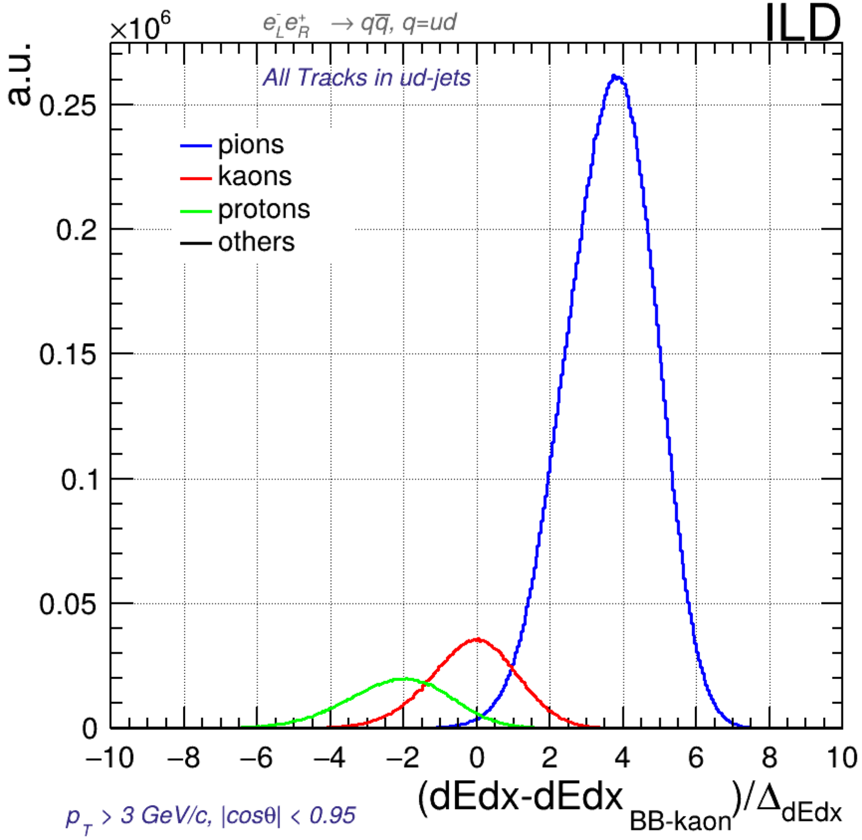
- These three bands can be used to measure an statistical distance

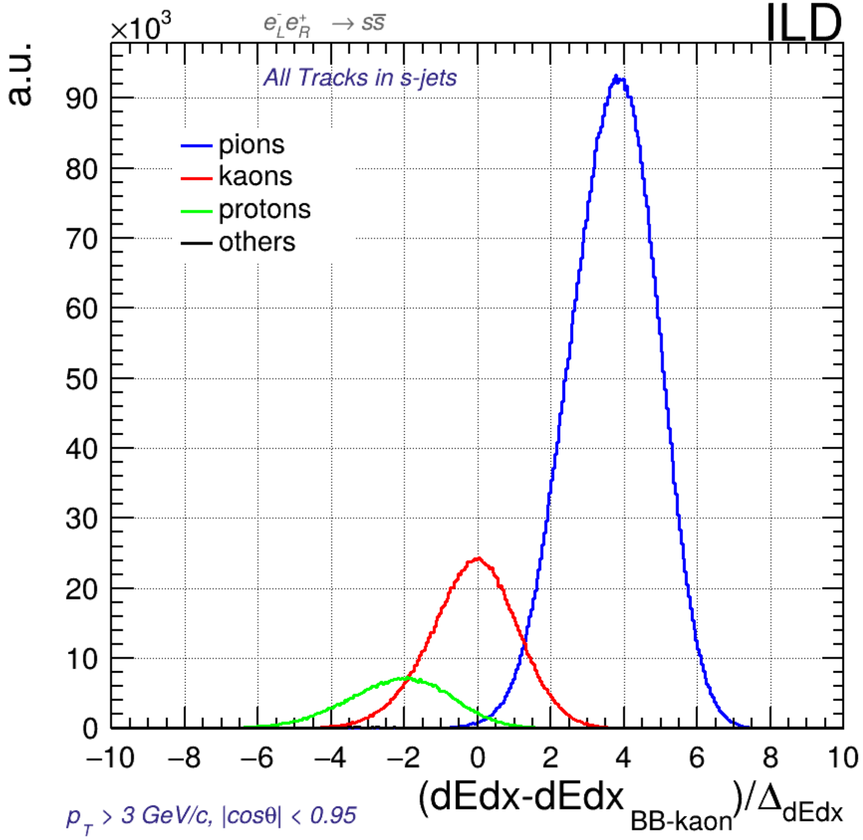




s vs ud: k-distance of tracks

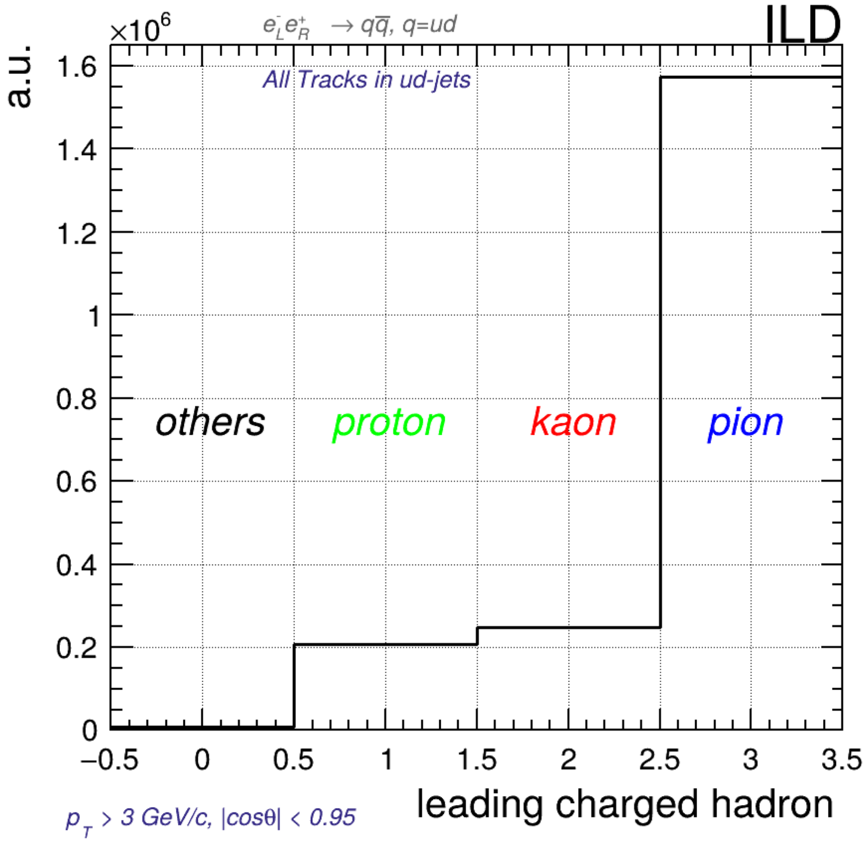
- Example of distance from tracks dE/dx and the theoretical values for kaons

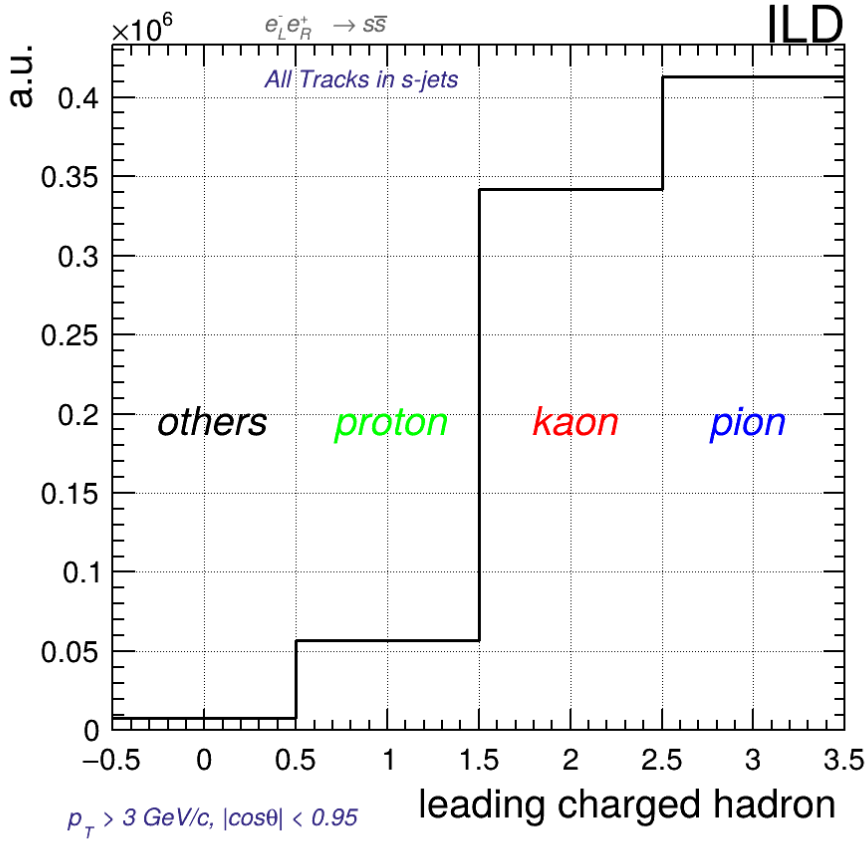




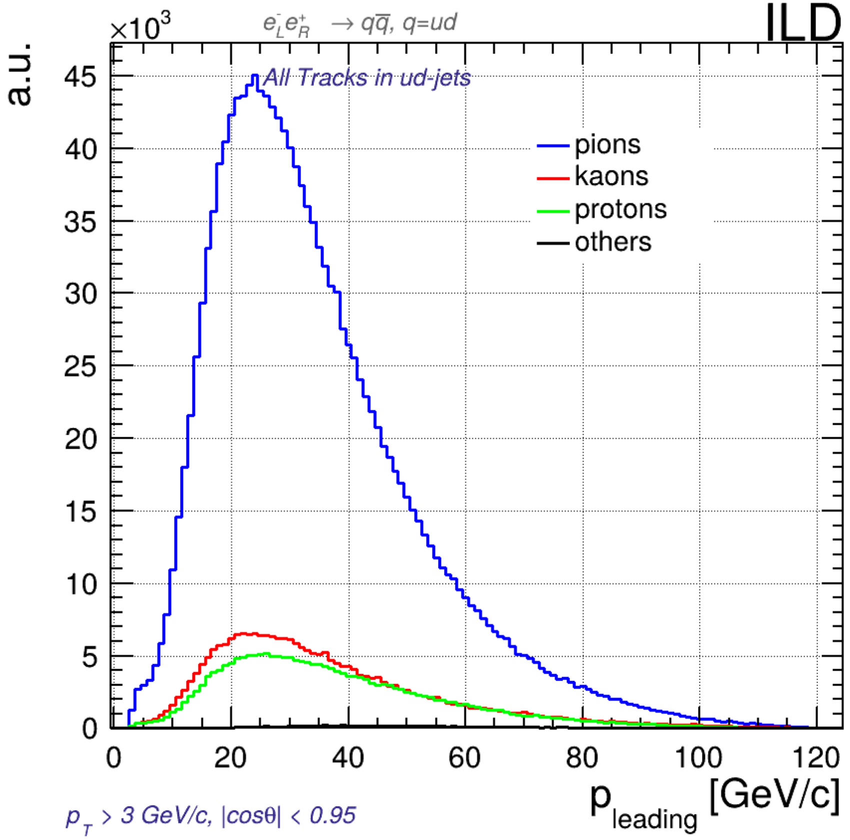
s vs ud: leading charged hadrons

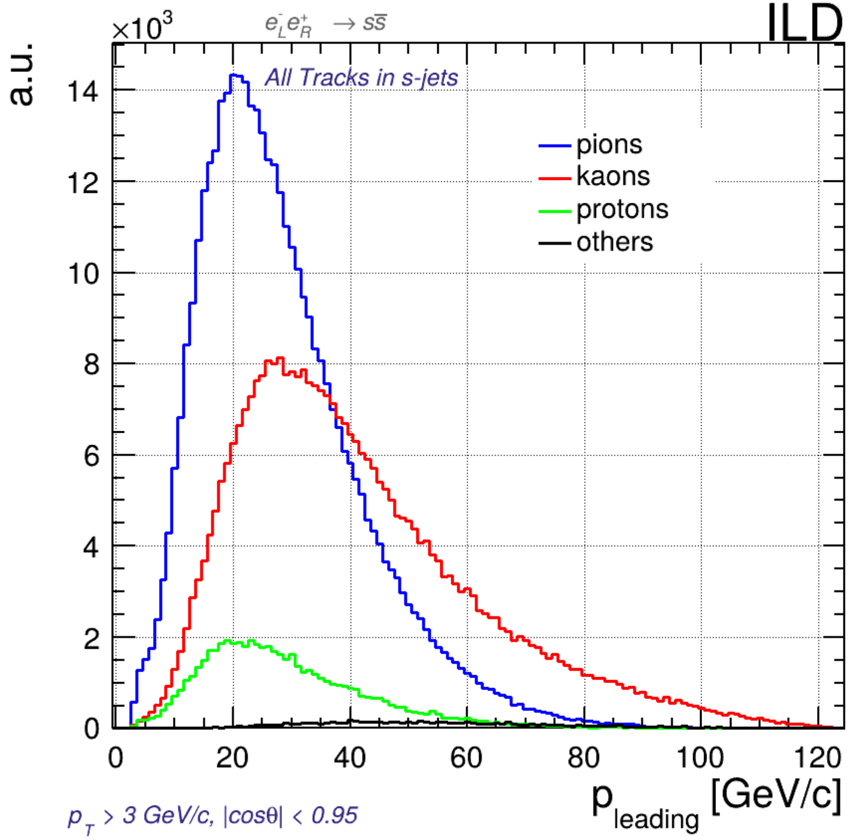
- Inspecting only the leading track shows the difference between s-jets and u/d-jets





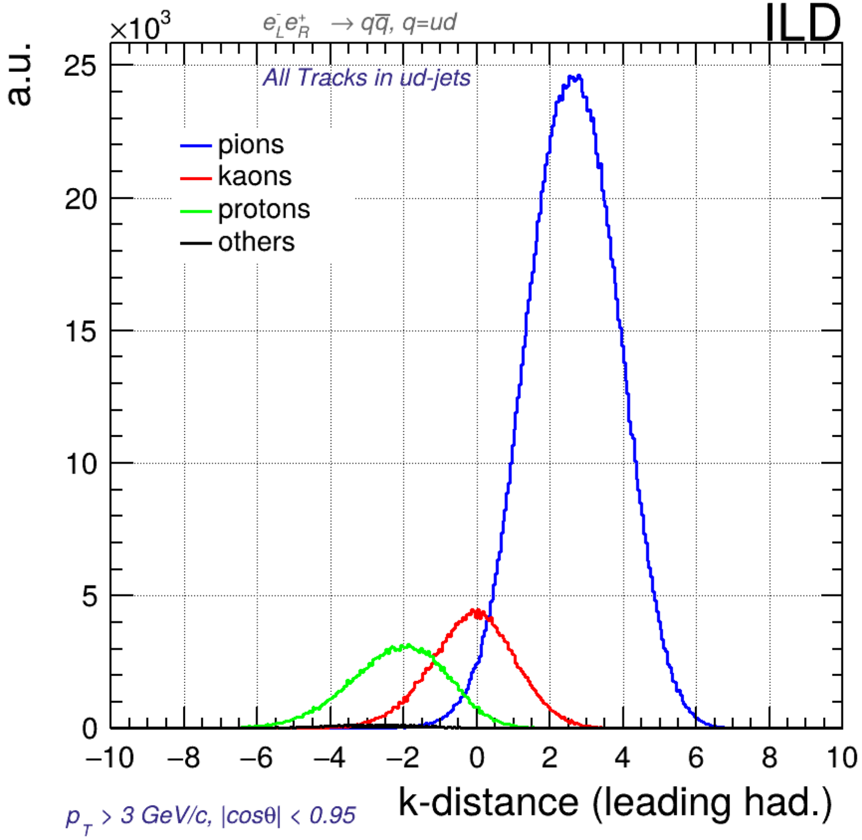
s vs ud: leading charged hadrons

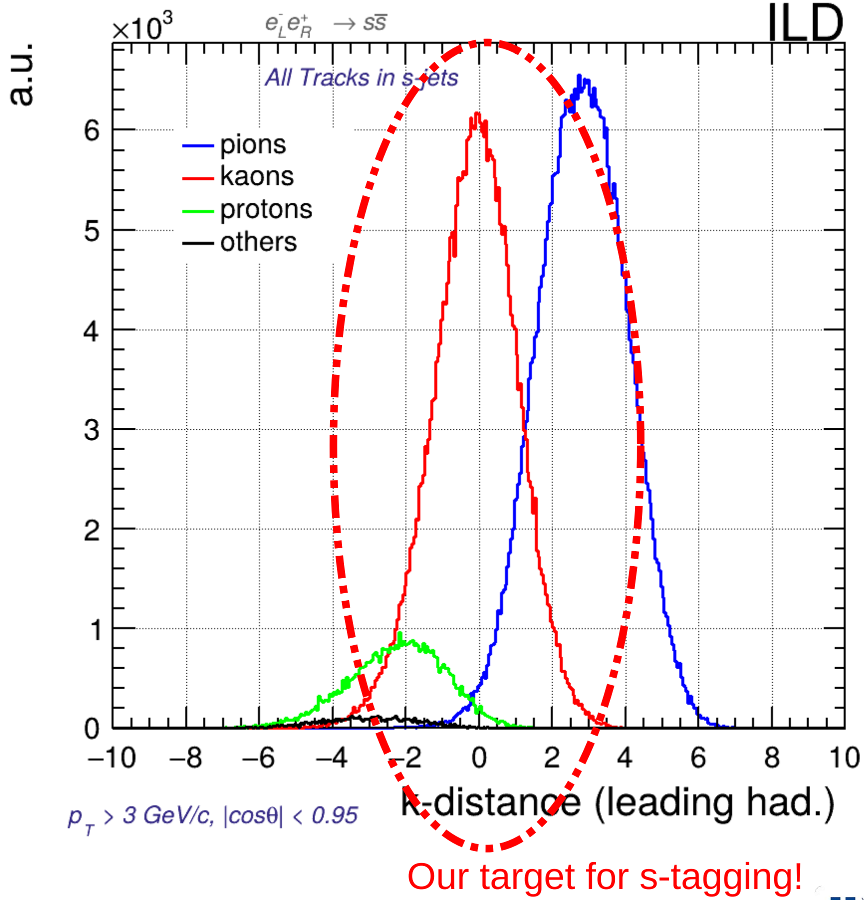




s vs ud: k-dist of leading charged hadrons

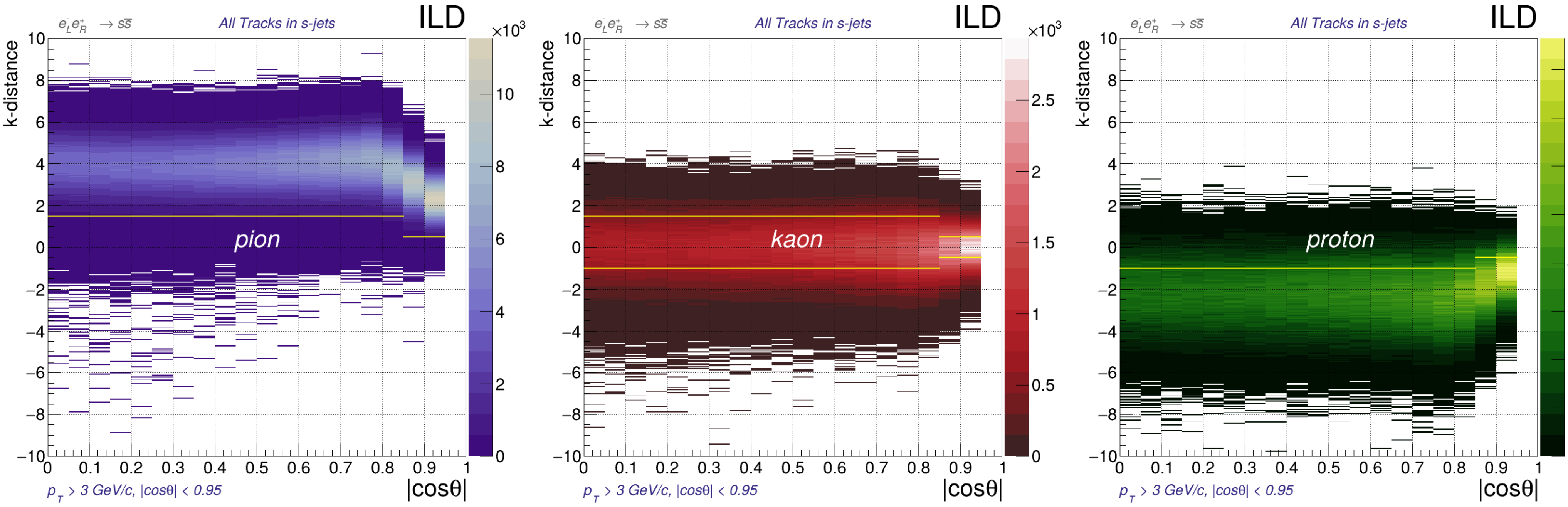
- Similar review was done via pi-distance, but shows similar behavior (as expected)





2d view of k-distance (s quarks)

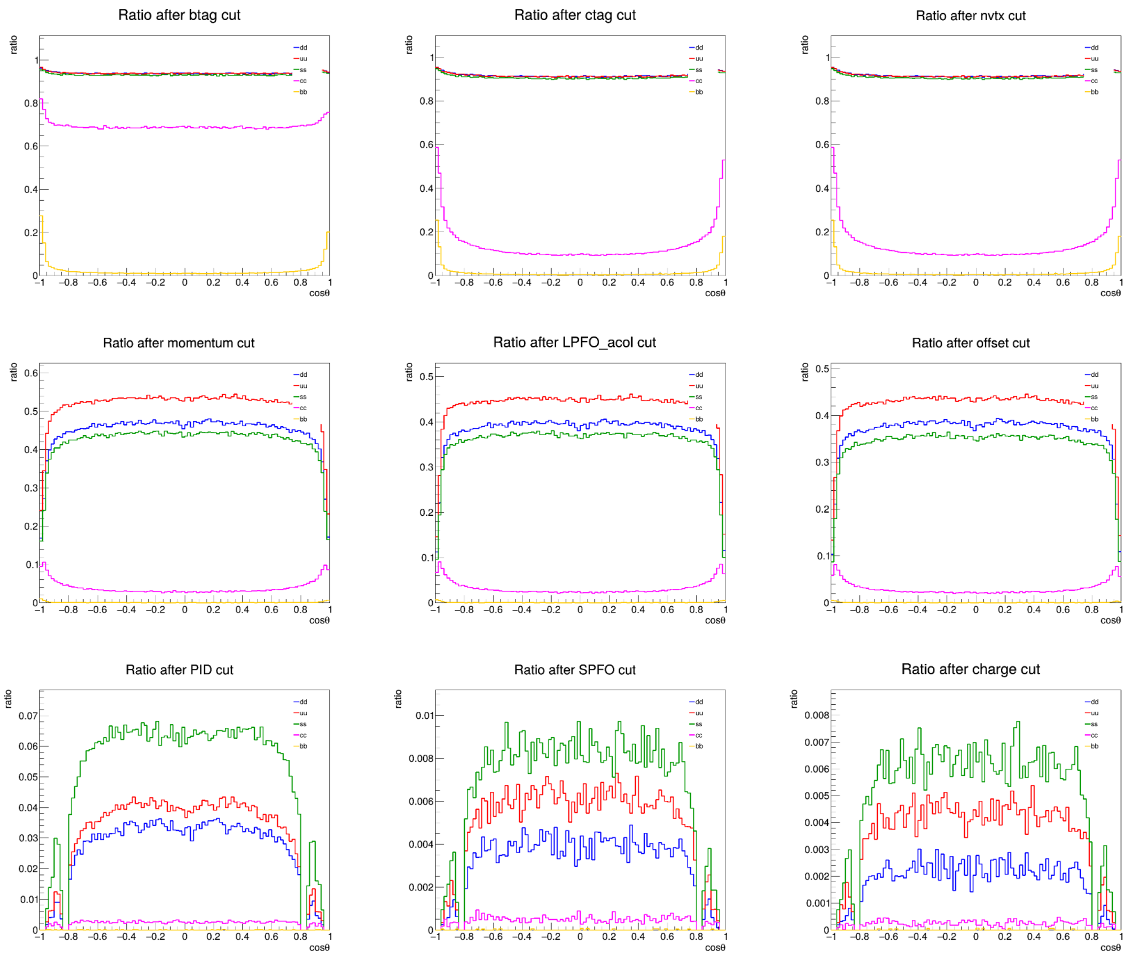
- Angular cuts are performed in these distributions for selection of pions/kaons



Cuts visualization (K for s-quark selection)

- Results for P(e-,e+)=(-0.8,+0.3)
- Flat when |cos(θ)| < 0.8

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.3%	2.12%
+ Cut 2	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 3	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 4	44.9%	51.7%	42.3%	4.02%	0.0755%
+ Cut 5	38.2%	43.9%	35.9%	3.37%	0.0589%
+ Cut 6	36.8%	42.3%	34.1%	3.12%	0.0489%
+ Cut 7	2.37%	2.9%	4.8%	0.218%	0.00191%
+ Cut 8	0.285%	0.464%	0.634%	0.0432%	0.00115%
+ Cut 9	0.163%	0.329%	0.481%	0.0207%	0.000573%



Preliminary results

Reconstruction of A_{FB}

- The signal data is estimated by resting the expected backgrounds to the count of events and doing several corrections to it:
  - Efficiency estimation
  - Kaon PID stability
  - Charge migration (p-q method)

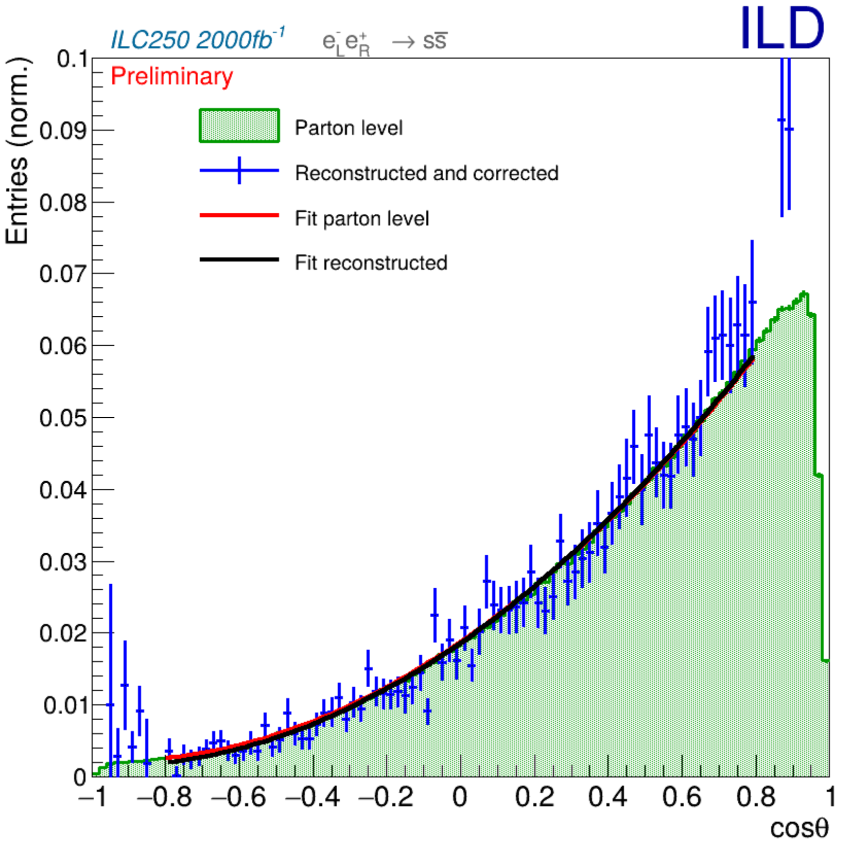
- A fit is performed to the corrected signal, following the function:

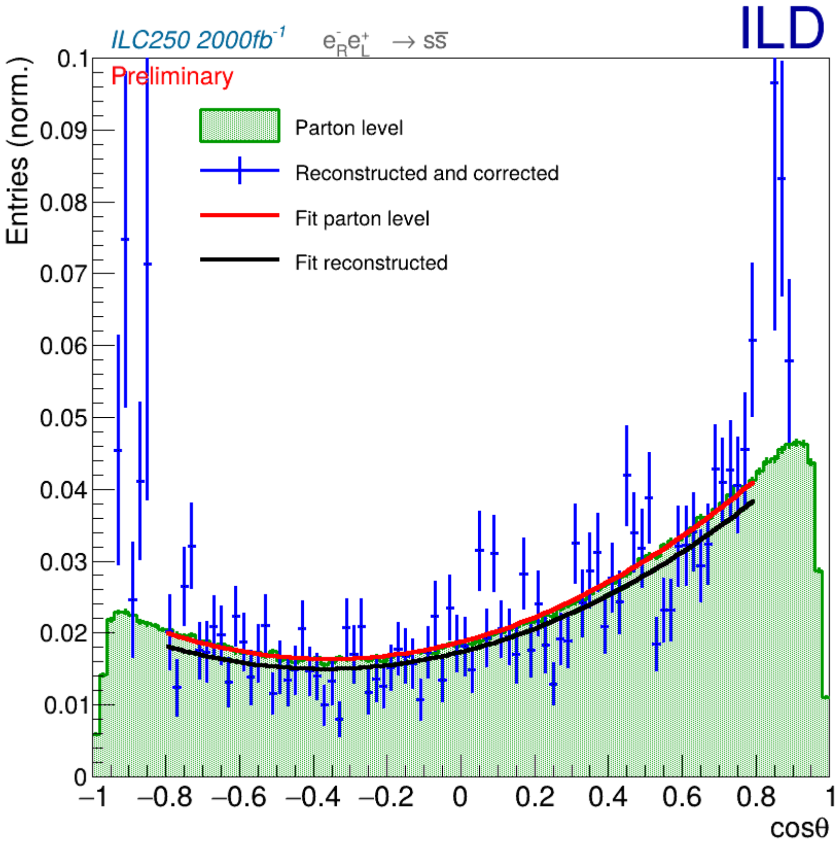
$$\frac{d\sigma}{d\cos\theta} = S\left(1+\cos^2\theta\right) + A\cos\theta$$

- Pseudo-experiments are performed for an estimation of systematical uncertainties due to the “tagging and correction” process
  - Other systematical uncertainties are not yet consider (beam polarization, diboson backgrounds, angular correlations, etc.), but minor contributions are expected

Fit to reconstructed signal

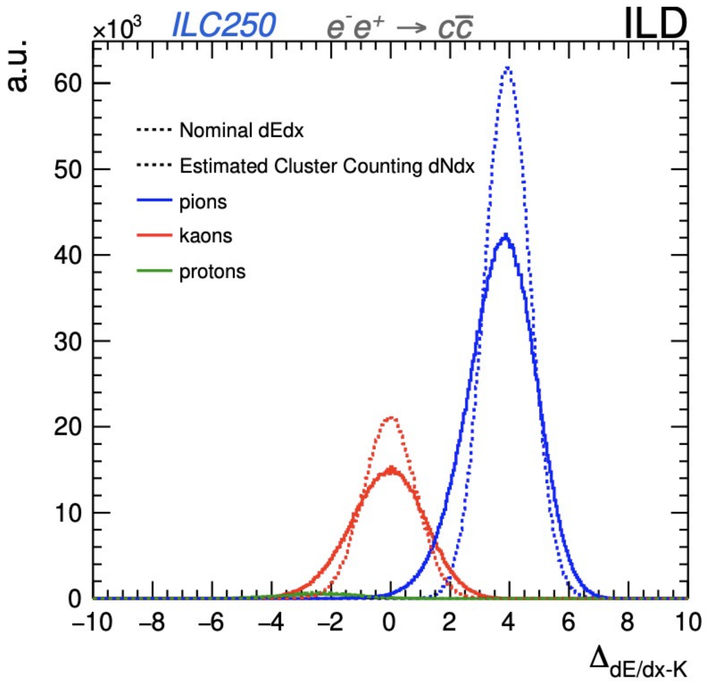
- Fit constrained to |cosθ| < 0.8 shows good agreement





PID hardware prospects

- A Marlin processor "CheatdEdxProcessor" is used for estimates of better PID cases
  - It uses fits to the bins of the 2D k-distance distribution
  - Then narrows those fits and rewrites the PFO info
- We consider two different cases:
  - 30% improvement for a pixel TPC PID case (dN/dx)
  - 99% improvement for an ideal TPC PID case
- Caveat: Only PFOs with PID available are improved

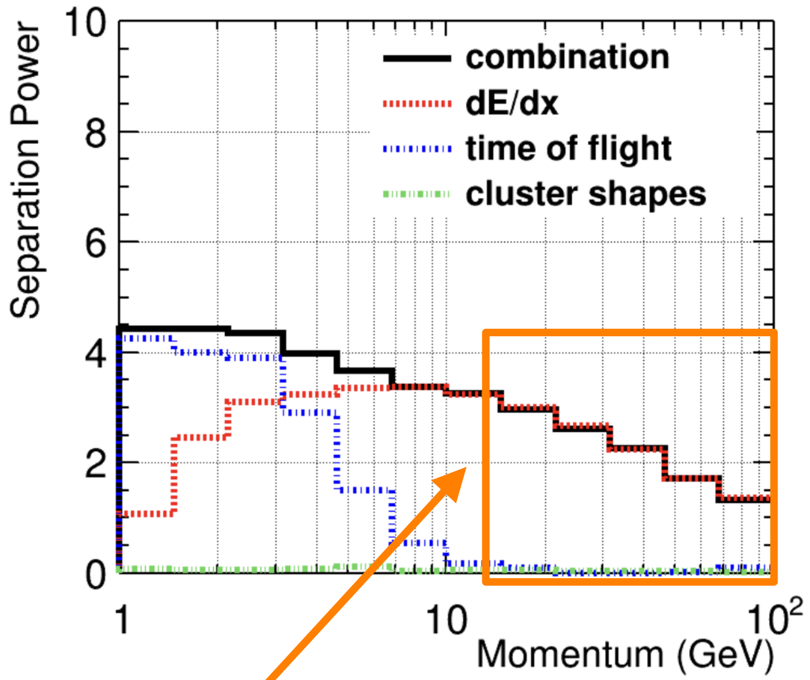


CPID for Kaon/Pion/Proton ID

- **C**omprehensive **P**article **ID** Marlin processor:
  - Uses different PID inputs (dE/dx, TOF, etc.)
  - Uses a BDT-based ML algorithm for classification
  - Easy to adapt to different MC ids or PID info

- In our case, the CPID was trained tackling our leading PFOS:
  - Only Kaon/Pion/Proton separation
  - 3 GeV < Momentum < 100 GeV

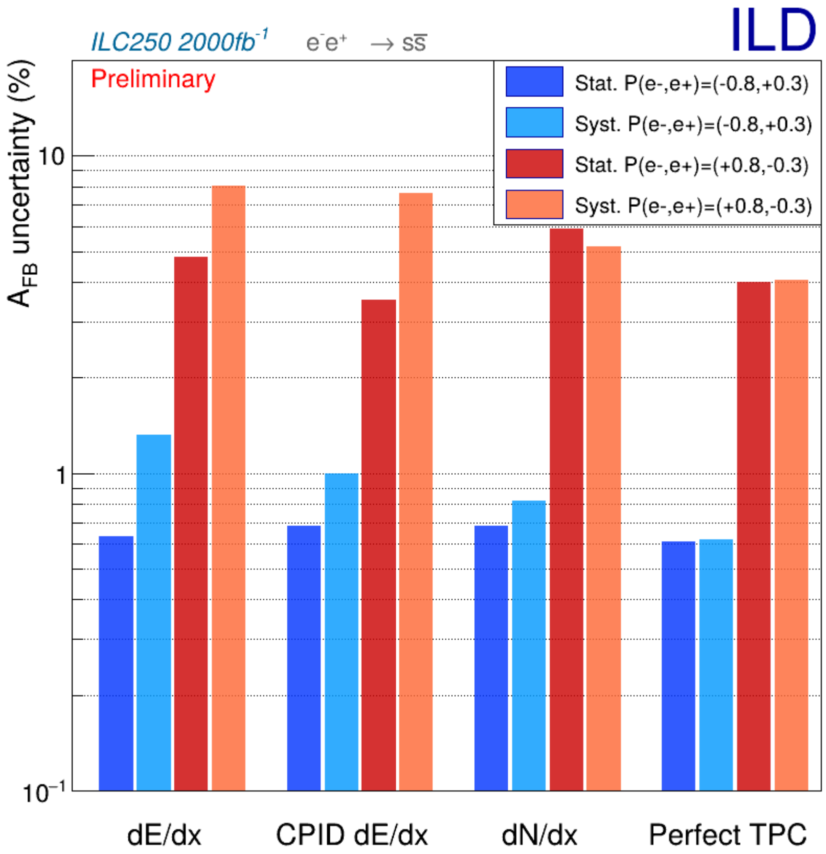
https://arxiv.org/abs/2307.15635 (U. Einhaus)



Leading PFOs are here

Preliminary results

- Purer signal as we move from left to right



Application into GHU phenomenology (TBD)

- 1% stat. unc. for s-quark A_{FB} (left) vs 1‰ stat. unc. for s-quark A_{FB} (right)

[Prospects for ParT FT for b & c quarks + s quark with 1% stat. unc.]

ILD

GHU vs SM (separation power)

$m_{Z'}$ [TeV]		ILC250♦ (no pol.) B	ILC250♦ (no pol.) C	ILC250♦ (no pol.) Q	ILC250 B	ILC250 C	ILC250 Q	ILC250 +500 B	ILC250 +500 C	ILC250 +500 Q	ILC250 +500 +1000* B	ILC250 +500 +1000* C	ILC250 +500 +1000* Q
19.6	B_3^+	0.4	0.0	0.5	0.7	0.1	0.9	0.8	0.7	1.5	0.9	2.2	2.9
19.6	B_3^-	0.1	0.4	0.5	0.4	0.6	0.9	0.8	2.6	2.9	1.6	7.1	7.5
14.9	B_2^+	0.6	0.2	0.8	1.3	0.3	1.8	1.5	1.3	2.6	1.9	4.1	4.9
14.9	B_2^-	0.0	0.8	0.8	0.5	1.3	1.6	0.9	5.1	5.3	2.5	>10	>10
10.2	B_1^+	1.4	0.5	1.7	3.0	0.8	3.8	3.7	1.9	5.3	3.8	6.1	8.4
10.2	B_1^-	0.0	1.6	1.6	0.9	2.6	2.9	1.9	>10	>10	5.1	>10	>10
8.5	A_2	3.2	0.7	3.4	4.9	0.7	5.3	>10	4.1	>10	>10	>10	>10
7.2	A_1	3.8	1.0	4.0	5.1	0.9	5.9	>10	6.3	>10	>10	>10	>10

Quark flavor
- *B: b-quark*
- *C: c-quark*
- *Q: scb*

< 3 σ | 3-4 σ | 4-5 σ | > 5 σ

[Prospects for ParT FT for b & c quarks + s quark with 0.1% stat. unc.]

ILD

GHU vs SM (separation power)

$m_{Z'}$ [TeV]		ILC250♦ (no pol.) B	ILC250♦ (no pol.) C	ILC250♦ (no pol.) Q	ILC250 B	ILC250 C	ILC250 Q	ILC250 +500 B	ILC250 +500 C	ILC250 +500 Q	ILC250 +500 +1000* B	ILC250 +500 +1000* C	ILC250 +500 +1000* Q
19.6	B_3^+	0.4	0.0	0.9	0.7	0.1	4.1	0.8	0.7	5.8	0.9	2.2	8.9
19.6	B_3^-	0.1	0.4	0.6	0.4	0.6	1.6	0.8	2.6	3.4	1.6	7.1	>10
14.9	B_2^+	0.6	0.2	1.5	1.3	0.3	7.7	1.5	1.3	9.9	1.9	4.1	>10
14.9	B_2^-	0.0	0.8	1.1	0.5	1.3	2.3	0.9	5.1	5.9	2.5	>10	>10
10.2	B_1^+	1.4	0.5	3.2	3.0	0.8	>10	3.7	1.9	>10	3.8	6.1	>10
10.2	B_1^-	0.0	1.6	2.2	0.9	2.6	4.2	1.9	>10	>10	5.1	>10	>10
8.5	A_2	3.2	0.7	3.6	4.9	0.7	>10	>10	4.1	>10	>10	>10	>10
7.2	A_1	3.8	1.0	4.4	5.1	0.9	>10	>10	6.3	>10	>10	>10	>10

Quark flavor
- *B: b-quark*
- *C: c-quark*
- *Q: scb*

< 3 σ | 3-4 σ | 4-5 σ | > 5 σ

We have a new set of heavier models to explore this further (Thanks to N. Yamatsu)

Conclusions/Overview

- A cut-based analysis has been re-tested and improved considering:
  - Software improvements: Using CPID for optimal dE/dx handling
  - Hardware prospects: A pixel TPC (dN/dx) or a “perfect” TPC

- There seem to be a bottleneck of statistics due to Kaon selection
  - But the ML approach shows potential for reducing systematics

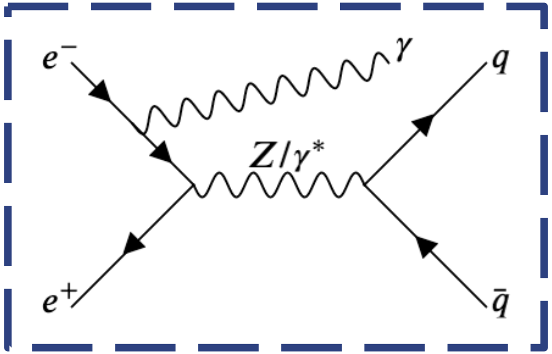
- There are many plans for the future of this analysis:
  - Using more MC simulation data
  - Using Particle Transformer (ParT) s-tagging
  - Running at 500 GeV
  - Re-scaling results to the LCF@CERN
  - Applying the obtained precisions to BSM (GHU prospects)

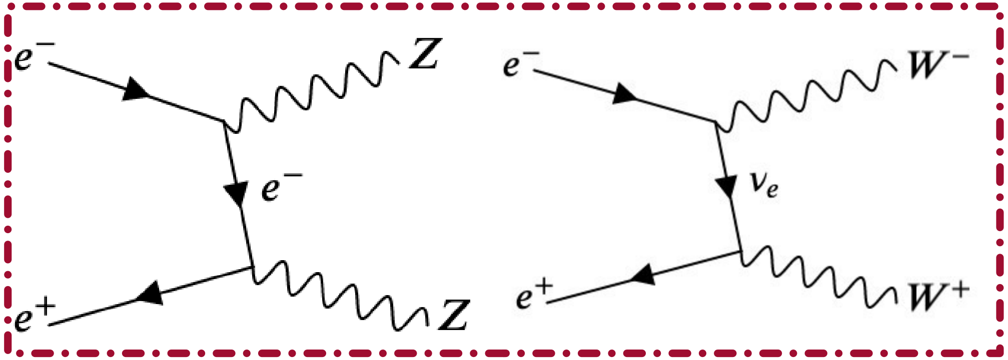
THANKS FOR YOUR ATTENTION

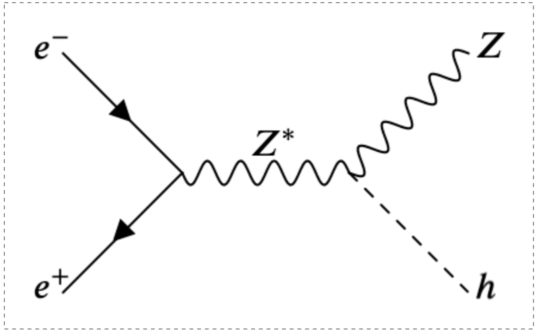
BACK-UP

Preselection of $q\bar{q}$ signals

- Once we have the reconstructed pfos of the events with different targets:
  - We cluster the signal in jets (VLC algorithm):
    - The algorithm packs together the PFOs into two jets.
    - Signal is expected in a back-to-back topology (but not the backgrounds!)
      - Most of the background is **radiative return ($\gamma q\bar{q}$)**
      - And most of the data is background!
        - x3 for $e^-_L e^+_R$ and x6 for $e^-_R e^+_L$ at 250 GeV
        - x4 for $e^-_L e^+_R$ and x7 for $e^-_R e^+_L$ at 500 GeV
  - Then we apply different cuts to the signal to remove the background processes







Preselection for 250 GeV

Cuts:

- K_{reco} < 35 GeV
- m_{2jets} > 140 GeV
- Charged N pfos
- Photon veto
- Y_{23} < 0.015

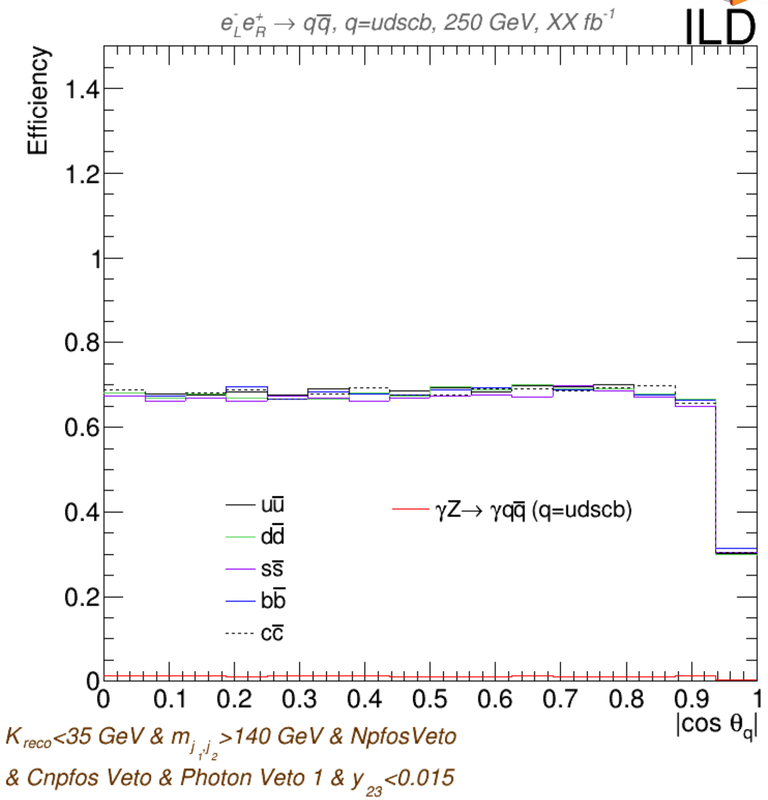
VLC Algorithm parameters:

- R = 1.0
- γ = 0.0
- β = 1.0

	Efficiencies (%)				
R	$b\bar{b}$	$c\bar{c}$	$q\bar{q}$ (uds)	ISR	S/B
1.0	64.7	64.6	64.3	0.9	23.7
	68.3	68.5	68.1	1.1	28.1

|cosθ| < 0.9

Total efficiency of the preselection for the different quark flavours and radiative return for the chosen configuration (γ=0). The second row is for |cosθ| < 0.9



Efficiency of the preselection for the different quark flavours vs the angular distribution of the two jet system (new samples, final configuration)

Re-run of previous analysis

CALO5D

A new dimension in shower reconstruction

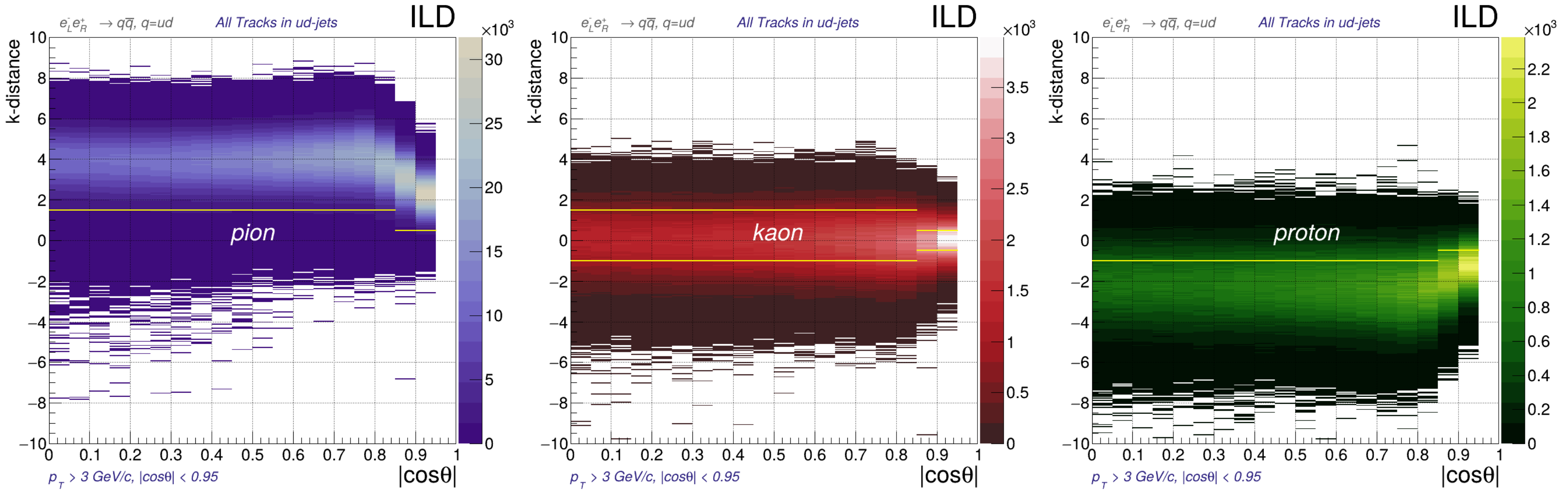
IJCLab

Irène Joliot-Curie

Laboratoire de Physique des 2 Infinis

2d view of k-distance (ud quarks)

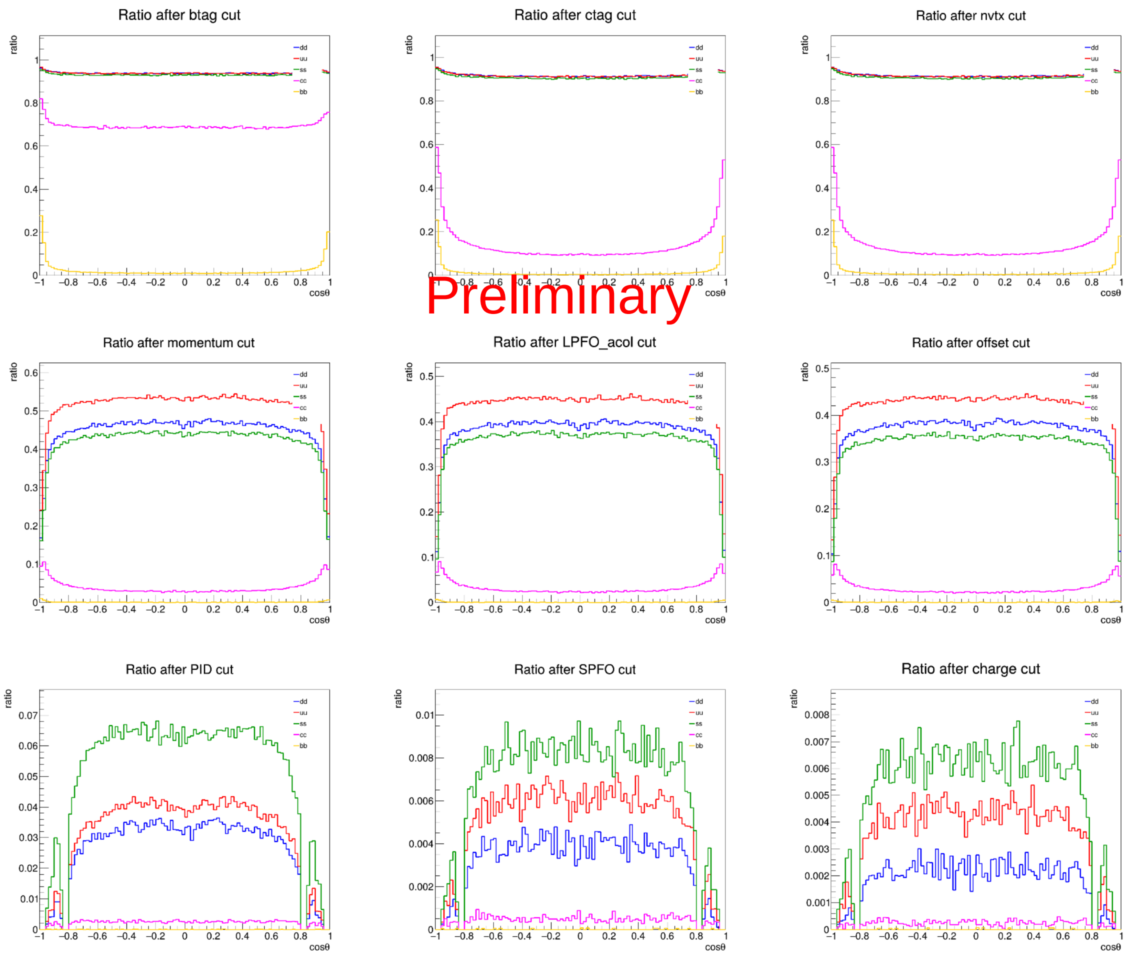
- Angular cuts are performed in these distributions for selection of pions



Cuts visualization (K for s-quark selection)

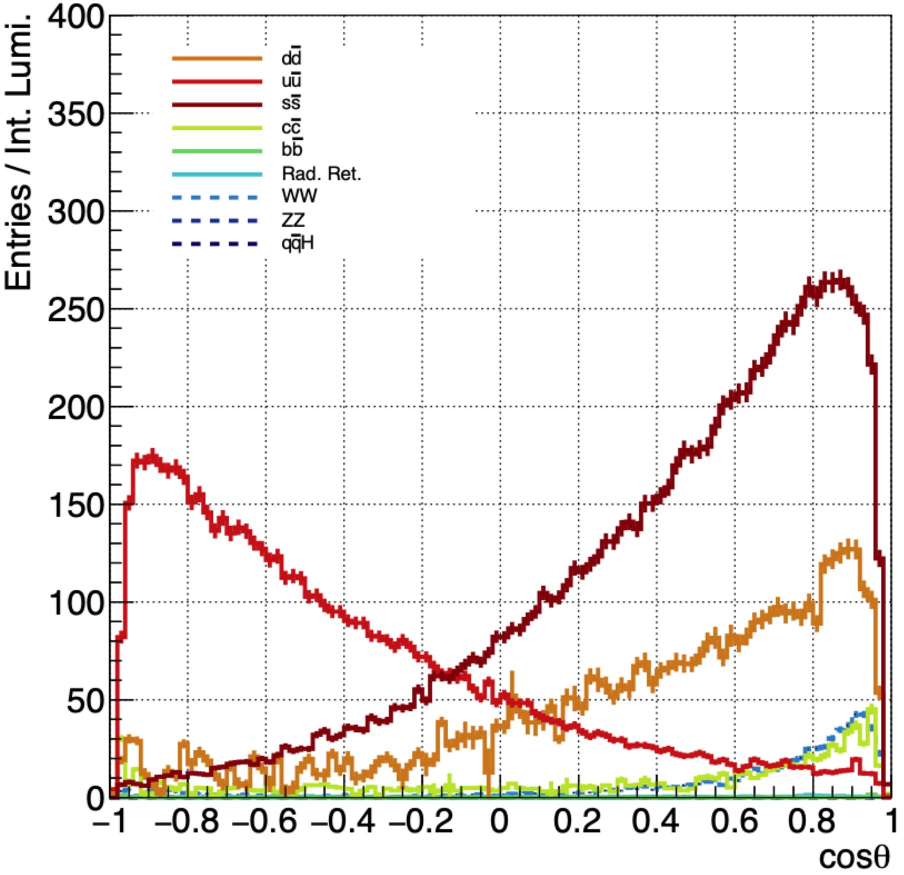
	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.3%	2.12%
+ Cut 2	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 3	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 4	44.9%	51.7%	42.3%	4.02%	0.0755%
+ Cut 5	38.2%	43.9%	35.9%	3.37%	0.0589%
+ Cut 6	36.8%	42.3%	34.1%	3.12%	0.0489%
+ Cut 7	2.37%	2.9%	4.8%	0.218%	0.00191%
+ Cut 8	0.285%	0.464%	0.634%	0.0432%	0.00115%
+ Cut 9	0.163%	0.329%	0.481%	0.0207%	0.000573%

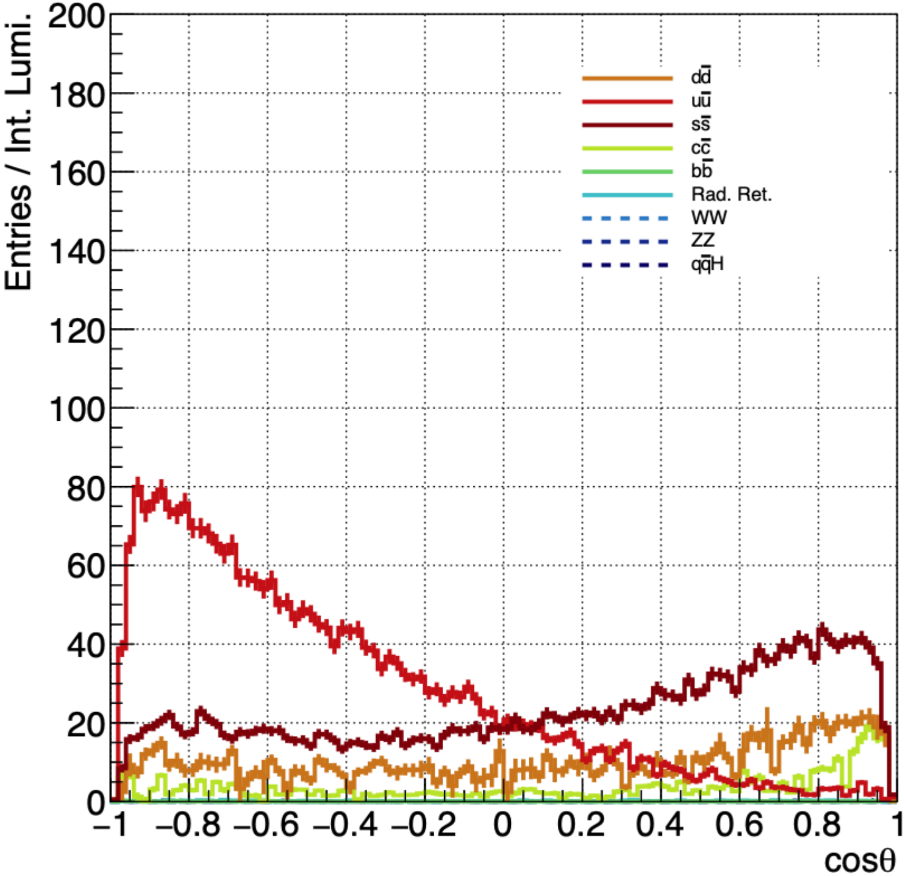
Preliminary



Contributions after preselection

- After K LPFO selection (Plots from Yuichi’s analysis)





Preliminary results (π mode for u/d selection)

CPID dE/dx

B/S=0.23

- Selecting u/d quarks
  - Results for $e^-_L e^+_R$
    - (Left) New dE/dx analysis vs (right) CPID dE/dx

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.3%	2.12%
+ Cut 2	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 3	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 4	44.9%	51.7%	42.3%	4.02%	0.0755%
+ Cut 5	38.2%	43.9%	35.9%	3.37%	0.0589%
+ Cut 6	36.8%	42.3%	34.1%	3.12%	0.0489%
+ Cut 7	12.8%	12.9%	5.61%	0.667%	0.0105%
+ Cut 8	1.72%	1.93%	0.86%	0.162%	0.00287%
+ Cut 9	1%	1.22%	0.503%	0.0823%	0.00172%

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.3%	2.12%
+ Cut 2	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 3	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 4	44.9%	51.7%	42.3%	4.02%	0.0758%
+ Cut 5	38.2%	43.9%	35.9%	3.37%	0.0589%
+ Cut 6	36.8%	42.3%	34.1%	3.12%	0.0485%
+ Cut 7	19.4%	19.8%	8.74%	1.02%	0.0196%
+ Cut 8	2.59%	2.97%	1.33%	0.247%	0.00546%
+ Cut 9	1.51%	1.89%	0.778%	0.126%	0.00222%

From 0.23 to 0.23 B/S

Preliminary results (K mode for s selection)

CPID dE/dx

B/S=0.78

- Selecting s quark
  - Results for $e^-_L e^+_R$
    - (Left) New dE/dx analysis vs (right) CPID dE/dx

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.3%	2.12%
+ Cut 2	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 3	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 4	44.9%	51.7%	42.3%	4.02%	0.0755%
+ Cut 5	38.2%	43.9%	35.9%	3.37%	0.0589%
+ Cut 6	36.8%	42.3%	34.1%	3.12%	0.0489%
+ Cut 7	2.37%	2.9%	4.8%	0.218%	0.00191%
+ Cut 8	0.285%	0.464%	0.634%	0.0432%	0.00115%
+ Cut 9	0.163%	0.329%	0.481%	0.0207%	0.000573%

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.3%	2.12%
+ Cut 2	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 3	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 4	44.9%	51.7%	42.3%	4.02%	0.0758%
+ Cut 5	38.2%	43.9%	35.9%	3.37%	0.0589%
+ Cut 6	36.8%	42.3%	34.1%	3.12%	0.0485%
+ Cut 7	0.991%	1.43%	4.21%	0.267%	0.00364%
+ Cut 8	0.13%	0.228%	0.548%	0.0495%	0.00142%
+ Cut 9	0.0674%	0.162%	0.421%	0.0262%	0.000607%

From 1.36 to 0.78 B/S

Preliminary results (π mode for u/d selection)

dN/dx

- Selecting u/d quarks
  - Results for $e^-_L e^+_R$
    - (Left) New dE/dx analysis vs (right) dN/dx

B/S=0.20

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.3%	2.12%
+ Cut 2	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 3	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 4	44.9%	51.7%	42.3%	4.02%	0.0755%
+ Cut 5	38.2%	43.9%	35.9%	3.37%	0.0589%
+ Cut 6	36.8%	42.3%	34.1%	3.12%	0.0489%
+ Cut 7	12.8%	12.9%	5.61%	0.667%	0.0105%
+ Cut 8	1.72%	1.93%	0.86%	0.162%	0.00287%
+ Cut 9	1%	1.22%	0.503%	0.0823%	0.00172%

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.8%	93.1%	69.5%	2.67%
+ Cut 2	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 3	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 4	45.1%	52.6%	42.4%	4.76%	0.166%
+ Cut 5	38.1%	44.4%	35.7%	3.94%	0.119%
+ Cut 6	36.2%	42.2%	33.4%	3.5%	0.0776%
+ Cut 7	20.2%	20.6%	7.65%	0.95%	0.0184%
+ Cut 8	2.5%	2.85%	1.07%	0.215%	0.00482%
+ Cut 9	1.49%	1.85%	0.632%	0.116%	0.00219%

From 0.23 to 0.20 B/S

Preliminary results (K mode for s selection)

- Selecting s quark
  - Results for $e^-_L e^+_R$
    - (Left) New dE/dx analysis vs (right) dN/dx

dN/dx

B/S=0.34

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.3%	2.12%
+ Cut 2	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 3	91.7%	91.6%	90.9%	14.1%	1.37%
+ Cut 4	44.9%	51.7%	42.3%	4.02%	0.0755%
+ Cut 5	38.2%	43.9%	35.9%	3.37%	0.0589%
+ Cut 6	36.8%	42.3%	34.1%	3.12%	0.0489%
+ Cut 7	2.37%	2.9%	4.8%	0.218%	0.00191%
+ Cut 8	0.285%	0.464%	0.634%	0.0432%	0.00115%
+ Cut 9	0.163%	0.329%	0.481%	0.0207%	0.000573%

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.8%	93.1%	69.5%	2.67%
+ Cut 2	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 3	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 4	45.1%	52.6%	42.4%	4.76%	0.166%
+ Cut 5	38.1%	44.4%	35.7%	3.94%	0.119%
+ Cut 6	36.2%	42.2%	33.4%	3.5%	0.0776%
+ Cut 7	0.348%	0.524%	3.55%	0.144%	0.0011%
+ Cut 8	0.0389%	0.0865%	0.457%	0.022%	0.000438%
+ Cut 9	0.0214%	0.0629%	0.366%	0.0109%	0.000219%

From 1.36 to 0.34 B/S

Preliminary results (π mode for u/d selection)

- Selecting u/d quarks
  - Results for $e^-_L e^+_R$
    - (Left) dNdx vs (right) Perfect TPC PID

Perfect TPC PID

B/S=0.19

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.8%	93.1%	69.5%	2.67%
+ Cut 2	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 3	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 4	45.1%	52.6%	42.4%	4.76%	0.166%
+ Cut 5	38.1%	44.4%	35.7%	3.94%	0.119%
+ Cut 6	36.2%	42.2%	33.4%	3.5%	0.0776%
+ Cut 7	20.2%	20.6%	7.65%	0.95%	0.0184%
+ Cut 8	2.5%	2.85%	1.07%	0.215%	0.00482%
+ Cut 9	1.49%	1.85%	0.632%	0.116%	0.00219%

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.5%	2.66%
+ Cut 2	91.7%	91.6%	90.9%	14.7%	1.82%
+ Cut 3	91.7%	91.6%	90.9%	14.7%	1.82%
+ Cut 4	45.1%	52.5%	42.3%	4.76%	0.165%
+ Cut 5	38.2%	44.4%	35.7%	3.94%	0.115%
+ Cut 6	36.2%	42.2%	33.4%	3.5%	0.0743%
+ Cut 7	20.2%	20.6%	7.41%	0.907%	0.017%
+ Cut 8	2.5%	2.84%	1.04%	0.206%	0.00503%
+ Cut 9	1.49%	1.85%	0.608%	0.113%	0.00262%

From 0.20 to 0.19 B/S

Preliminary results (K mode for s selection)

- Selecting s quark
  - Results for $e^-_L e^+_R$
    - (Left) dNdx vs (right) Perfect TPC PID

Perfect TPC PID

B/S=0.28

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.8%	93.1%	69.5%	2.67%
+ Cut 2	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 3	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 4	45.1%	52.6%	42.4%	4.76%	0.166%
+ Cut 5	38.1%	44.4%	35.7%	3.94%	0.119%
+ Cut 6	36.2%	42.2%	33.4%	3.5%	0.0776%
+ Cut 7	0.348%	0.524%	3.55%	0.144%	0.0011%
+ Cut 8	0.0389%	0.0865%	0.457%	0.022%	0.000438%
+ Cut 9	0.0214%	0.0629%	0.366%	0.0109%	0.000219%

	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.9%	93.1%	69.5%	2.66%
+ Cut 2	91.7%	91.6%	90.9%	14.7%	1.82%
+ Cut 3	91.7%	91.6%	90.9%	14.7%	1.82%
+ Cut 4	45.1%	52.5%	42.3%	4.76%	0.165%
+ Cut 5	38.2%	44.4%	35.7%	3.94%	0.115%
+ Cut 6	36.2%	42.2%	33.4%	3.5%	0.0743%
+ Cut 7	0.385%	0.571%	4.85%	0.185%	0.00175%
+ Cut 8	0.0472%	0.0924%	0.601%	0.0263%	0.000437%
+ Cut 9	0.0258%	0.0683%	0.497%	0.0146%	0.000218%

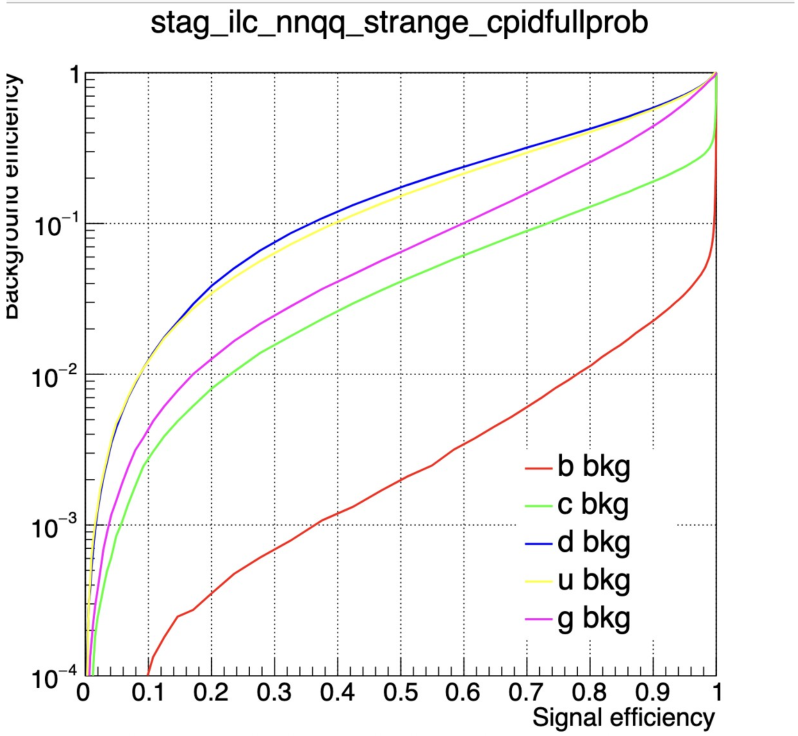
From 0.34 to 0.28 B/S

Preliminary results (numbers)

	$e^-e^+ \to s\bar{s}$					
	$P_{e^-e^+}(-0.8, +0.3)$			$P_{e^-e^+}(+0.8, -0.3)$		
	$\delta A_{FB}^{stat}(\%)$	$\delta A_{FB}^{syst}(\%)$	B/S	$\delta A_{FB}^{stat}(\%)$	$\delta A_{FB}^{syst}(\%)$	B/S
dE/dx	0.63	1.32	1.38	4.80	8.03	2.32
CPID (dE/dx)	0.68	1.00	0.79	3.53	7.62	1.54
dN/dx	0.68	0.82	0.37	5.91	5.19	0.58
Perfect TPC	0.61	0.62	0.28	4.01	4.05	0.48

The “holy grail”: ParT s-tagging

- Particle Transformers is state-of-the-art ML software
- It uses *CPID* for the tracks PID
- It can be 10x better than the cut-based approach
  - But how? Is this code available? Trying to get access to it to incorporate it into a chain of analysis
  - Can reduce the cuts in the analysis into:
    - B-tag
    - C-tag
    - S-tag → Much more powerful than kaon ID
    - Migration cuts:
      - Secondary PFO candidate cut
      - Opposite charge LPFO cut



1% ss signal with 0.02% u/d backgrounds? Expected B/S = 0.33

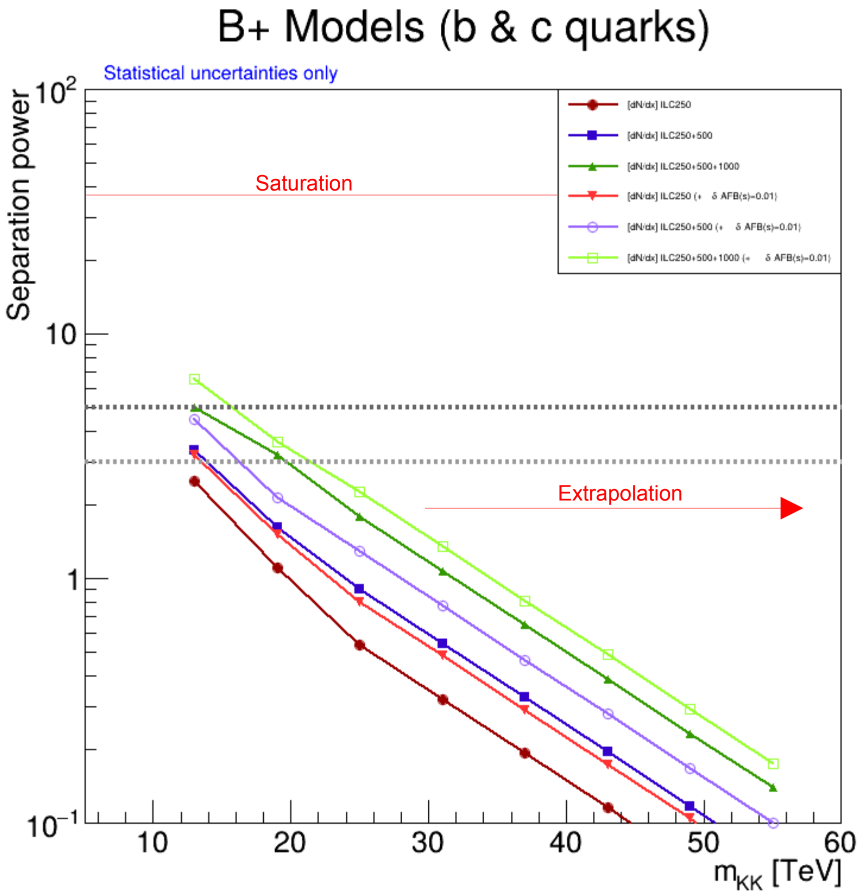
GHU phenomenology

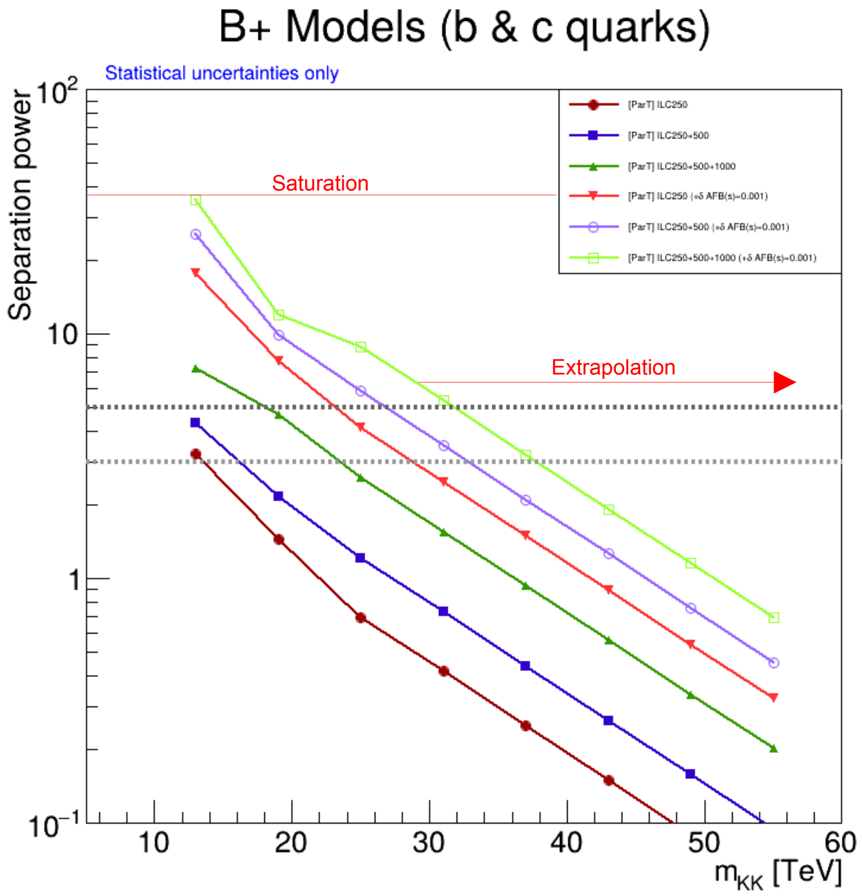
CALO5D
A new dimension in shower reconstruction

IJCLab
Irène Joliot-Curie
Laboratoire de Physique
des 2 Infinis

B+ models mass scale

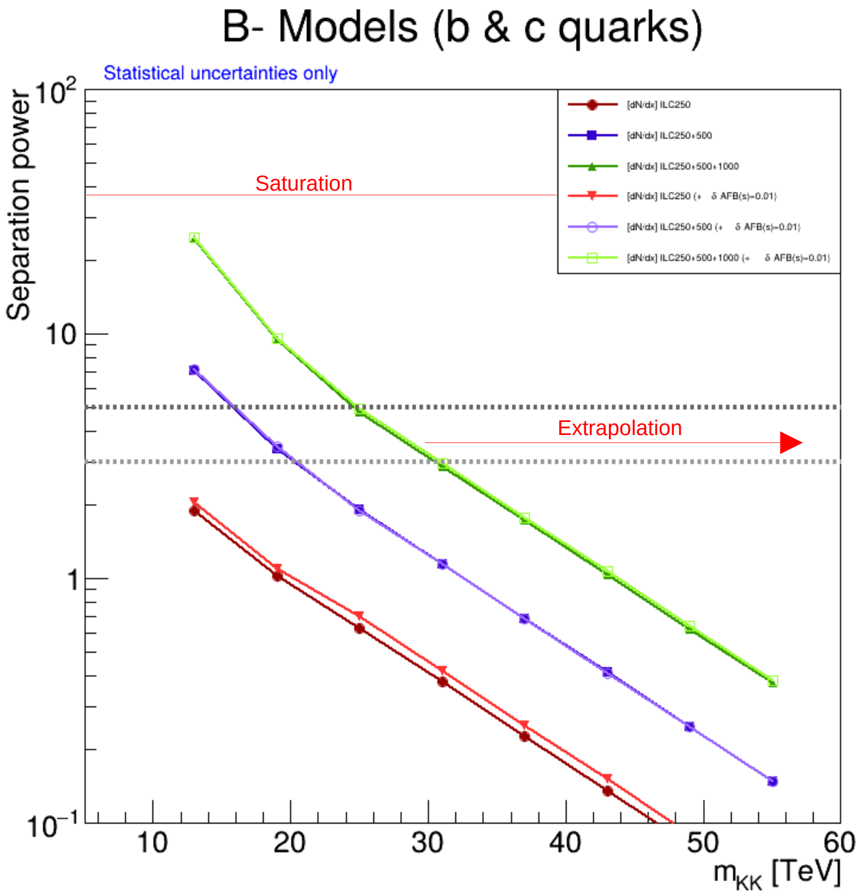
- Worst (dN/dx + 1% δA_{FB} for s-quark) vs best (ParT + 1‰ δA_{FB} for s-quark) prospects

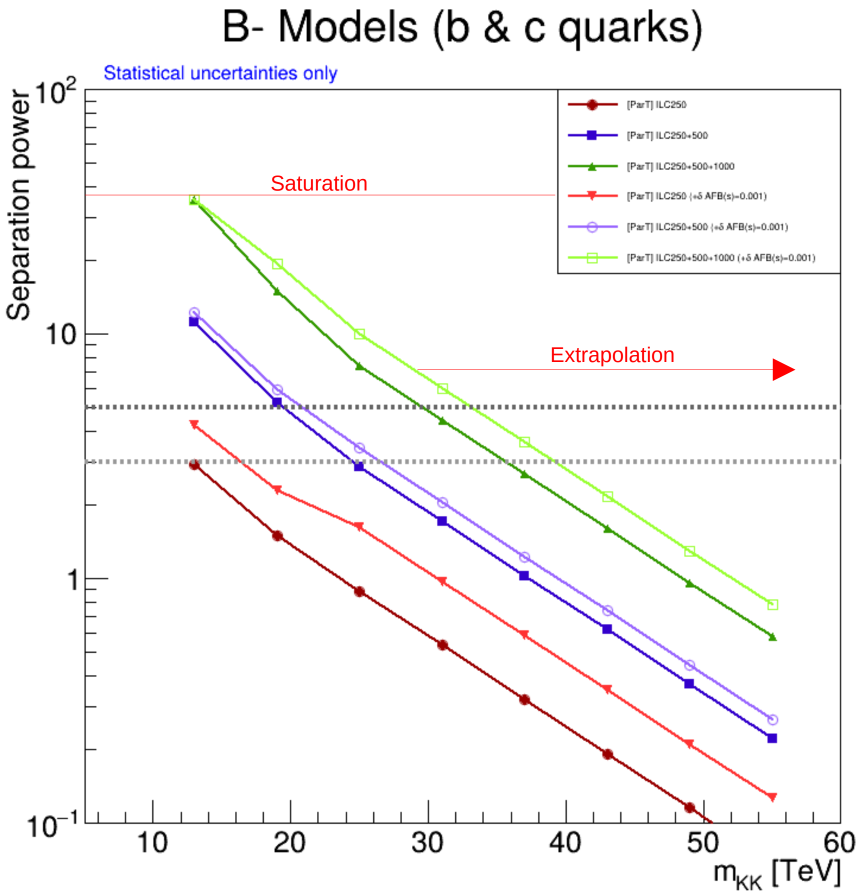




B- models mass scale

- Worst (dN/dx + 1% δA_{FB} for s-quark) vs best (ParT + 1‰ δA_{FB} for s-quark) prospects





Adding s quark (1% relative error)

- ILC with pixel TPC (dN/dx for PID) || ILC with prospects using ParT flavour tagging

[Current ILD (dNdx PID) for b & c quarks + s quark with 1% stat. unc.]

GHU vs SM (separation power) — ILD

$m_{Z'}$ [TeV]		ILC250♦ (no pol.) B	ILC250♦ (no pol.) C	ILC250♦ (no pol.) Q	ILC250 B	ILC250 C	ILC250 Q	ILC250 +500 B	ILC250 +500 C	ILC250 +500 Q	ILC250 +500 +1000* B	ILC250 +500 +1000* C	ILC250 +500 +1000* Q
19.6	B_3^+	0.3	0.0	0.4	0.5	0.0	0.8	0.6	0.4	1.3	0.8	1.4	2.3
19.6	B_3^-	0.1	0.2	0.3	0.3	0.4	0.7	0.6	1.7	1.9	1.3	4.5	4.9
14.9	B_2^+	0.5	0.1	0.6	1.0	0.2	1.5	1.2	0.8	2.1	1.6	2.6	3.6
14.9	B_2^-	0.0	0.5	0.5	0.4	0.8	1.1	0.8	3.2	3.5	1.9	9.2	9.6
10.2	B_1^+	1.1	0.3	1.3	2.3	0.5	3.2	2.9	1.3	4.4	2.9	3.8	6.6
10.2	B_1^-	0.0	0.9	1.0	0.8	1.6	2.0	1.6	6.8	7.1	4.0	>10	>10
8.5	A_2	2.5	0.4	2.6	3.8	0.4	4.3	>10	2.6	>10	>10	9.9	>10
7.2	A_1	2.9	0.6	3.1	3.9	0.6	4.8	>10	3.9	>10	>10	>10	>10

Quark flavor
- *B: b-quark*
- *C: c-quark*
- *Q: scb*

< 3 σ | 3-4 σ | 4-5 σ | > 5 σ

[Prospects for ParT FT for b & c quarks + s quark with 1% stat. unc.]

GHU vs SM (separation power) — ILD

$m_{Z'}$ [TeV]		ILC250♦ (no pol.) B	ILC250♦ (no pol.) C	ILC250♦ (no pol.) Q	ILC250 B	ILC250 C	ILC250 Q	ILC250 +500 B	ILC250 +500 C	ILC250 +500 Q	ILC250 +500 +1000* B	ILC250 +500 +1000* C	ILC250 +500 +1000* Q
19.6	B_3^+	0.4	0.0	0.5	0.7	0.1	0.9	0.8	0.7	1.5	0.9	2.2	2.9
19.6	B_3^-	0.1	0.4	0.5	0.4	0.6	0.9	0.8	2.6	2.9	1.6	7.1	7.5
14.9	B_2^+	0.6	0.2	0.8	1.3	0.3	1.8	1.5	1.3	2.6	1.9	4.1	4.9
14.9	B_2^-	0.0	0.8	0.8	0.5	1.3	1.6	0.9	5.1	5.3	2.5	>10	>10
10.2	B_1^+	1.4	0.5	1.7	3.0	0.8	3.8	3.7	1.9	5.3	3.8	6.1	8.4
10.2	B_1^-	0.0	1.6	1.6	0.9	2.6	2.9	1.9	>10	>10	5.1	>10	>10
8.5	A_2	3.2	0.7	3.4	4.9	0.7	5.3	>10	4.1	>10	>10	>10	>10
7.2	A_1	3.8	1.0	4.0	5.1	0.9	5.9	>10	6.3	>10	>10	>10	>10

Quark flavor
- *B: b-quark*
- *C: c-quark*
- *Q: scb*

< 3 σ | 3-4 σ | 4-5 σ | > 5 σ

Adding s quark (1‰ relative error)

- ILC with pixel TPC (dN/dx for PID) || ILC with prospects using ParT flavour tagging

[Current ILD (dNdx PID) for b & c quarks + s quark with 0.1% stat. unc.]

ILD

GHU vs SM (separation power)

$m_{Z'}$ [TeV]		ILC250♦ (no pol.) B	C	Q	ILC250 B	C	Q	ILC250 +500 B	C	Q	ILC250 +500 +1000* B	C	Q
19.6	B_3^+	0.3	0.0	0.9	0.5	0.0	4.1	0.6	0.4	5.8	0.8	1.4	8.7
19.6	B_3^-	0.1	0.2	0.4	0.3	0.4	1.5	0.6	1.7	2.6	1.3	4.5	8.3
14.9	B_2^+	0.5	0.1	1.4	1.0	0.2	7.7	1.2	0.8	9.8	1.6	2.6	>10
14.9	B_2^-	0.0	0.5	0.9	0.4	0.8	1.9	0.8	3.2	4.4	1.9	9.2	>10
10.2	B_1^+	1.1	0.3	2.9	2.3	0.5	>10	2.9	1.3	>10	2.9	3.8	>10
10.2	B_1^-	0.0	0.9	1.7	0.8	1.6	3.6	1.6	6.8	8.7	4.0	>10	>10
8.5	A_2	2.5	0.4	2.9	3.8	0.4	>10	>10	2.6	>10	>10	9.9	>10
7.2	A_1	2.9	0.6	3.6	3.9	0.6	>10	>10	3.9	>10	>10	>10	>10

Quark flavor
- *B: b-quark*
- *C: c-quark*
- *Q: scb*

< 3 σ
3-4 σ
4-5 σ
> 5 σ

[Prospects for ParT FT for b & c quarks + s quark with 0.1% stat. unc.]

ILD

GHU vs SM (separation power)

$m_{Z'}$ [TeV]		ILC250♦ (no pol.) B	C	Q	ILC250 B	C	Q	ILC250 +500 B	C	Q	ILC250 +500 +1000* B	C	Q
19.6	B_3^+	0.4	0.0	0.9	0.7	0.1	4.1	0.8	0.7	5.8	0.9	2.2	8.9
19.6	B_3^-	0.1	0.4	0.6	0.4	0.6	1.6	0.8	2.6	3.4	1.6	7.1	>10
14.9	B_2^+	0.6	0.2	1.5	1.3	0.3	7.7	1.5	1.3	9.9	1.9	4.1	>10
14.9	B_2^-	0.0	0.8	1.1	0.5	1.3	2.3	0.9	5.1	5.9	2.5	>10	>10
10.2	B_1^+	1.4	0.5	3.2	3.0	0.8	>10	3.7	1.9	>10	3.8	6.1	>10
10.2	B_1^-	0.0	1.6	2.2	0.9	2.6	4.2	1.9	>10	>10	5.1	>10	>10
8.5	A_2	3.2	0.7	3.6	4.9	0.7	>10	>10	4.1	>10	>10	>10	>10
7.2	A_1	3.8	1.0	4.4	5.1	0.9	>10	>10	6.3	>10	>10	>10	>10

Quark flavor
- *B: b-quark*
- *C: c-quark*
- *Q: scb*

< 3 σ
3-4 σ
4-5 σ
> 5 σ