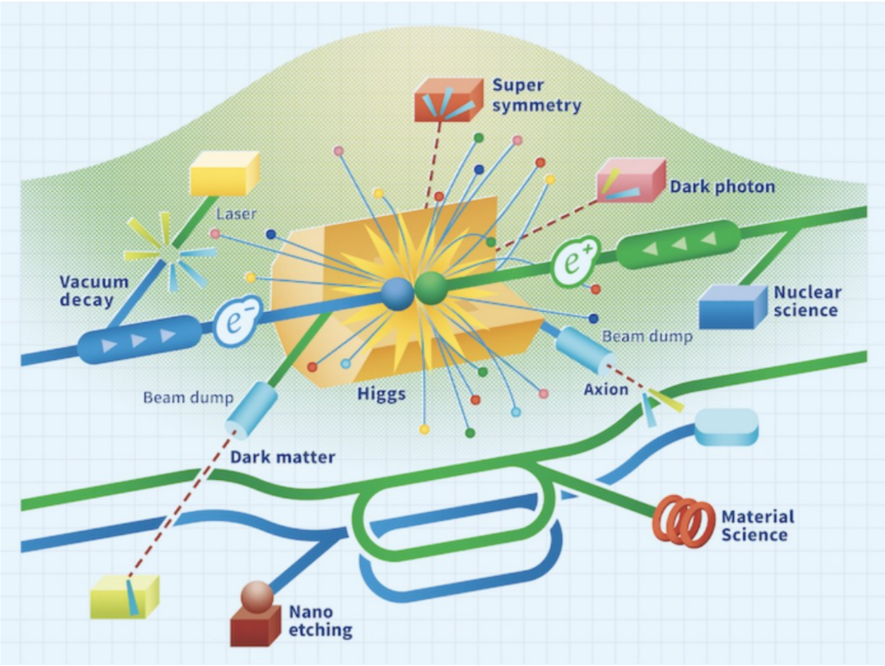


$e^-e^+ \to s\bar{s}$ at $\sqrt{s}$ = 250 GeV in future linear colliders

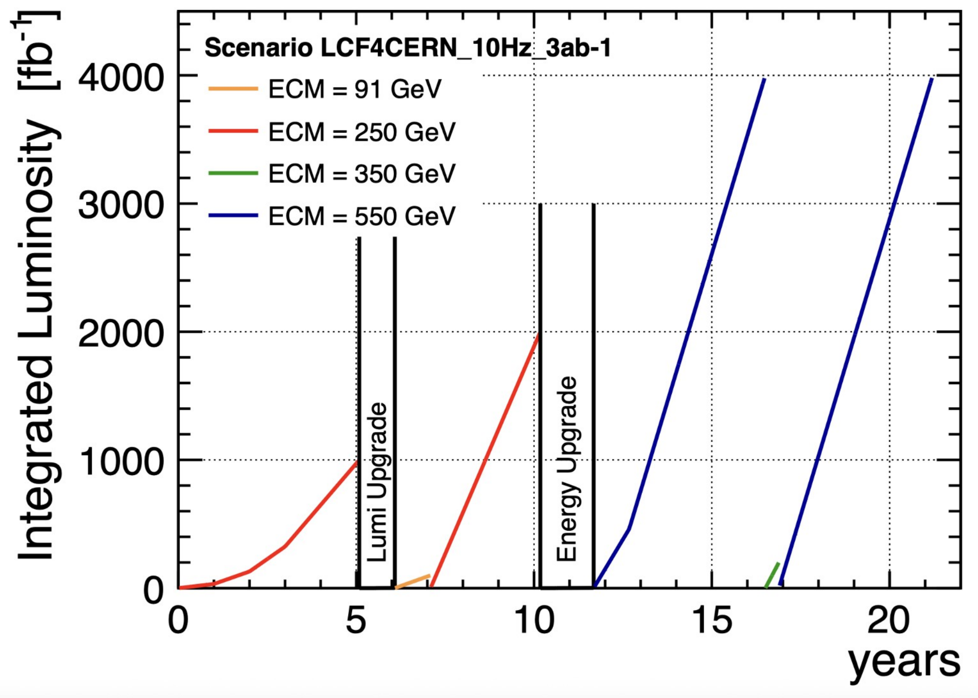
Jesús P. Márquez Hernández (IJCLAB, CNRS)

cnrs IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis ILD CALO5D A new dimension in shower reconstruction IRN TeraScale

Linear Collider Facility at CERN

- Proposed linear collider that updates the ILC concept:
  - $P(e^-,e^+) = (\pm0.8, \pm0.3)$
  - Possibility of improve $P(e^+) = (\pm0.6)$
  - 2 IPs

- Flexibility to adopt CLIC-like or C^3-like acceleration technology in the future
  - Reaching 1-3 TeV or more!



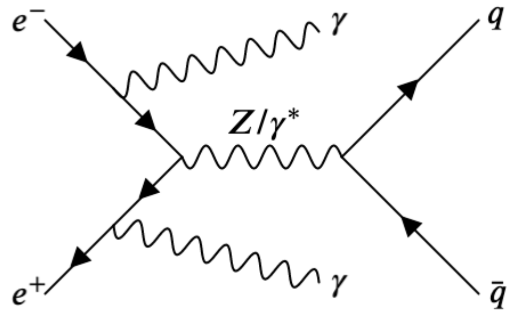
For a deeper introduction: I recommend you *an introductory talk (by* J. List) or the Linear Collider Vision paper introducing it (2503.24049)

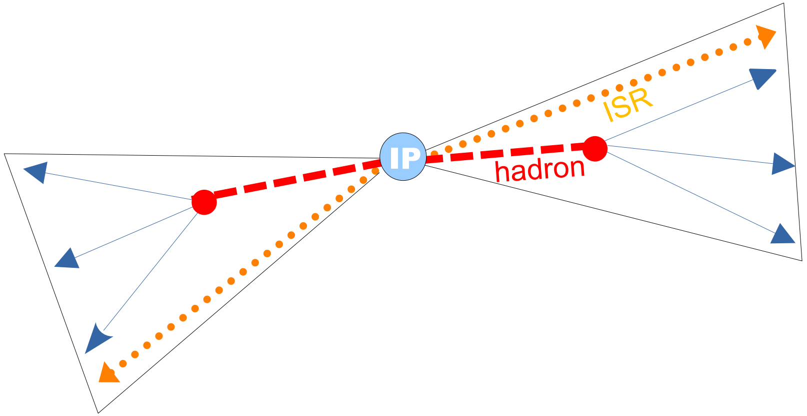
(b & c) diquark production in $e^- e^+$ collisions

- Topology: Two back-to-back jets
- MC simulations at 250 GeV
  - $P(e^-, e^+) = (-0.8, +0.3), (+0.8, -0.3)$
  - Full simulation of the International Large Detector (ILD)
- Procedure:
  - 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)
  - Charge measurement → Quark-Antiquark identification
    - Double charge

R_q

A_{FB}

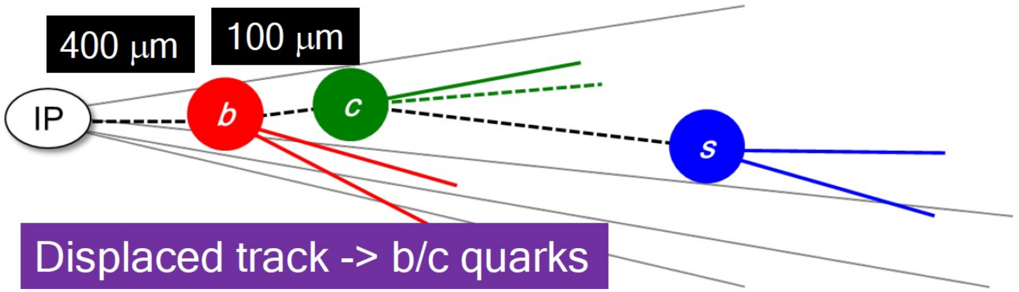




How can we move from here to strange quarks (or u/d quarks)?
Can we get ‰-level uncertainties like for the b & c quarks?

From b/c to strange quark

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



- 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

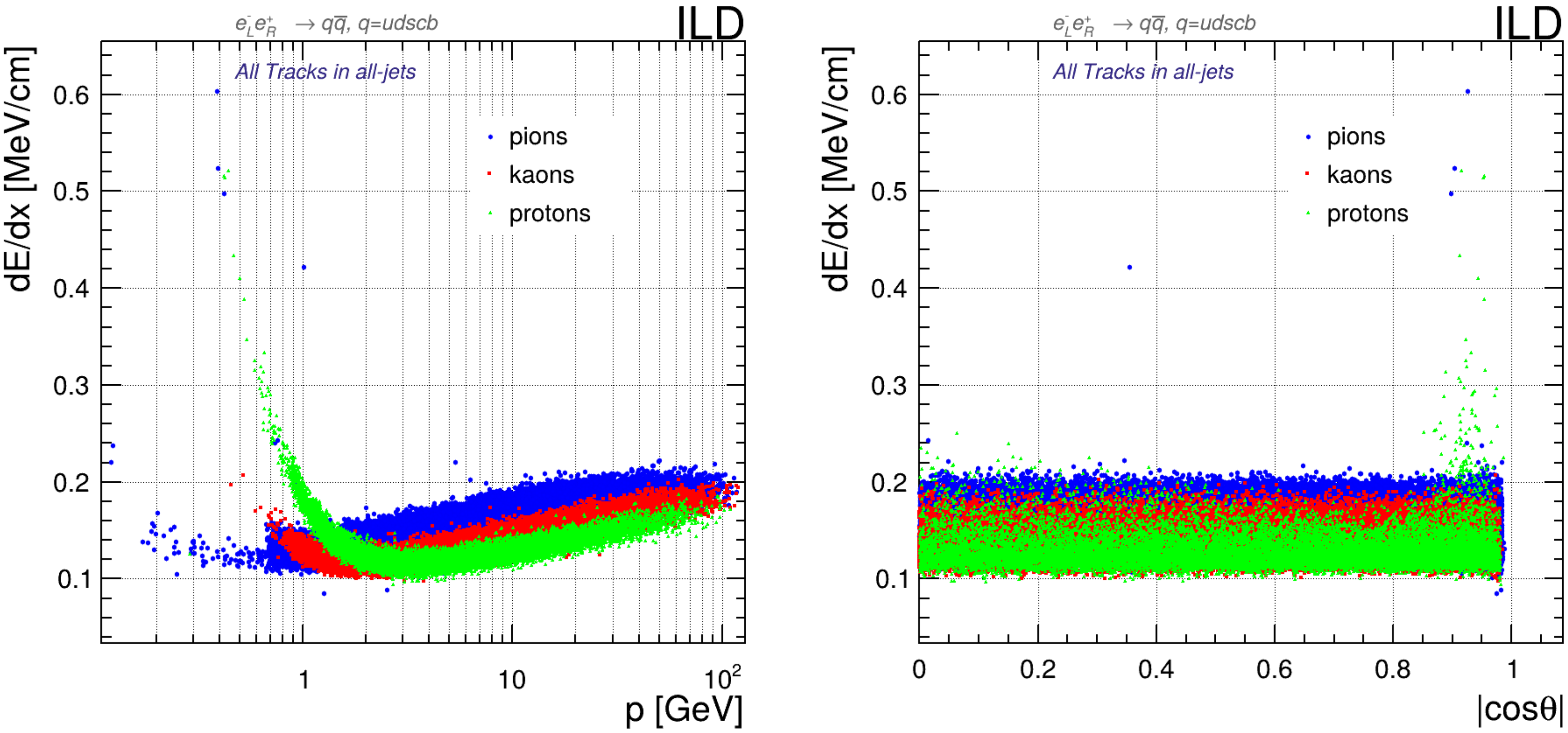
Redoing of the ssbarAnalysis

- Preselection of the s-quark/ud-quark signals (Modification of Y. Okugawa's analysis)
  - After the $q\bar{q}$ preselection

Group	#	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

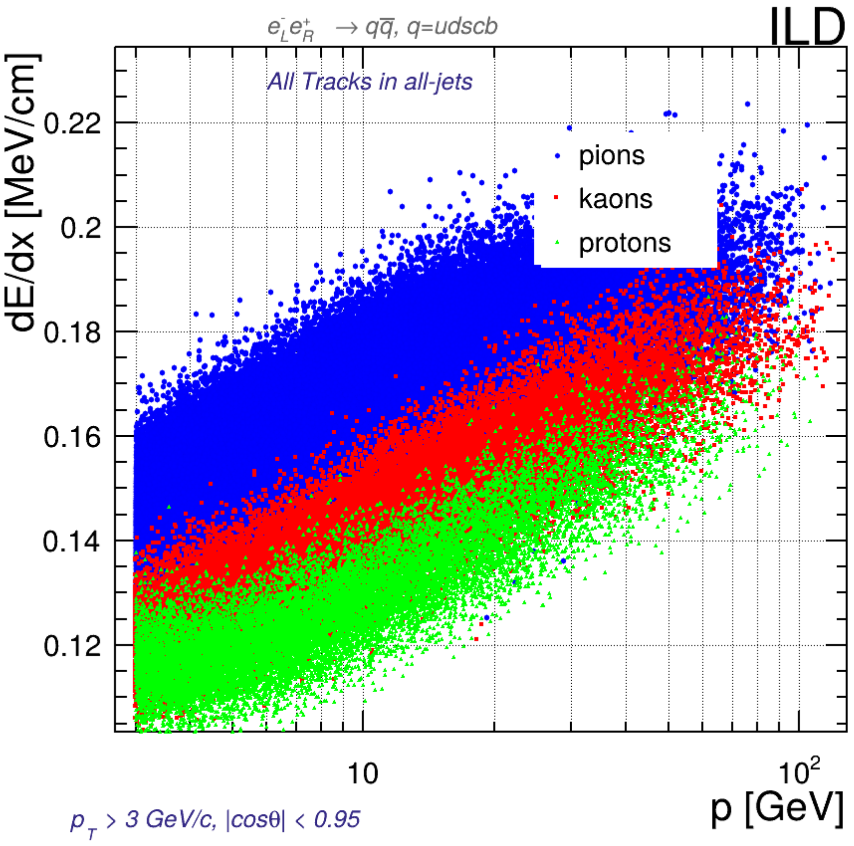
PID via dE/dx: Starting point

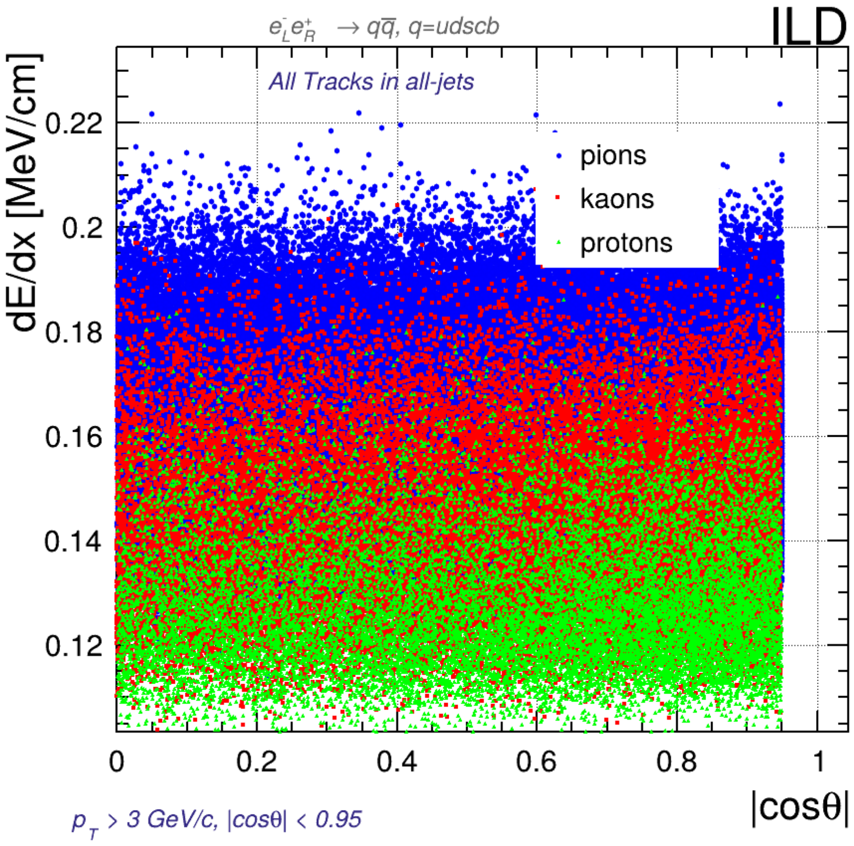
- Not all tracks/PFOs are valid for dE/dx



PID: Preselection

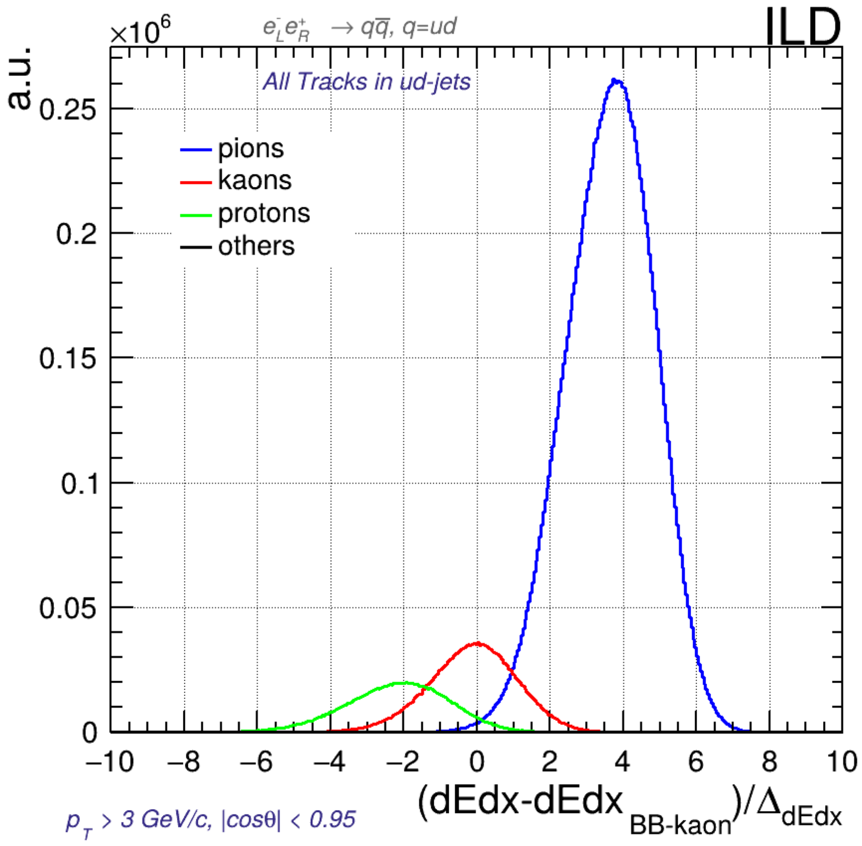
- These three bands can be used to measure an statistical distance

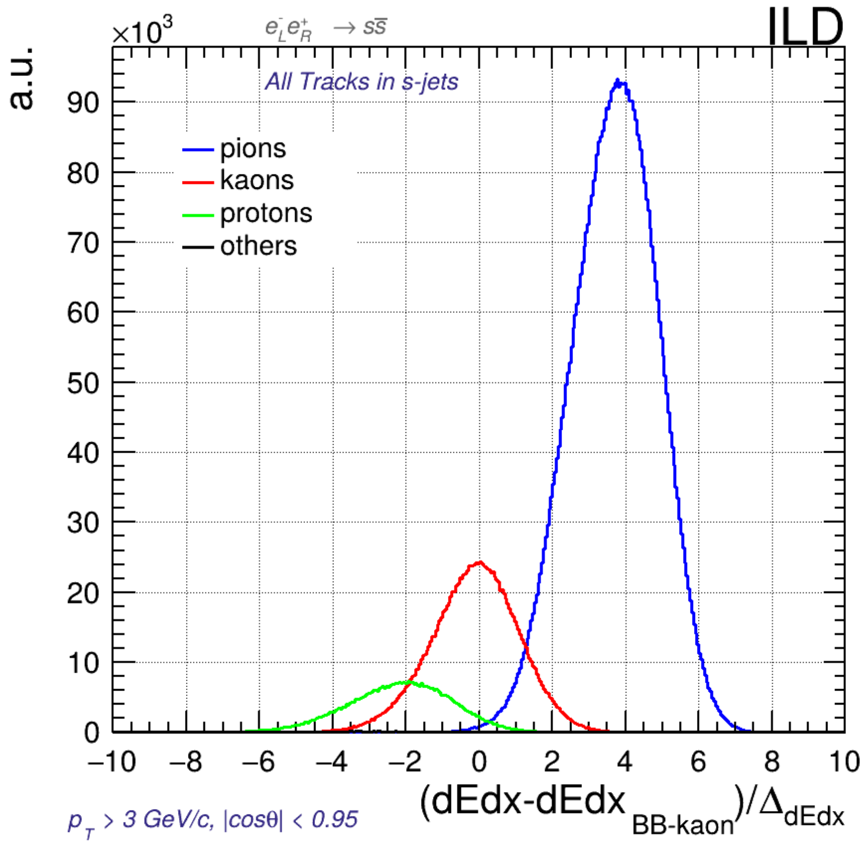




s vs ud: k-distance of tracks

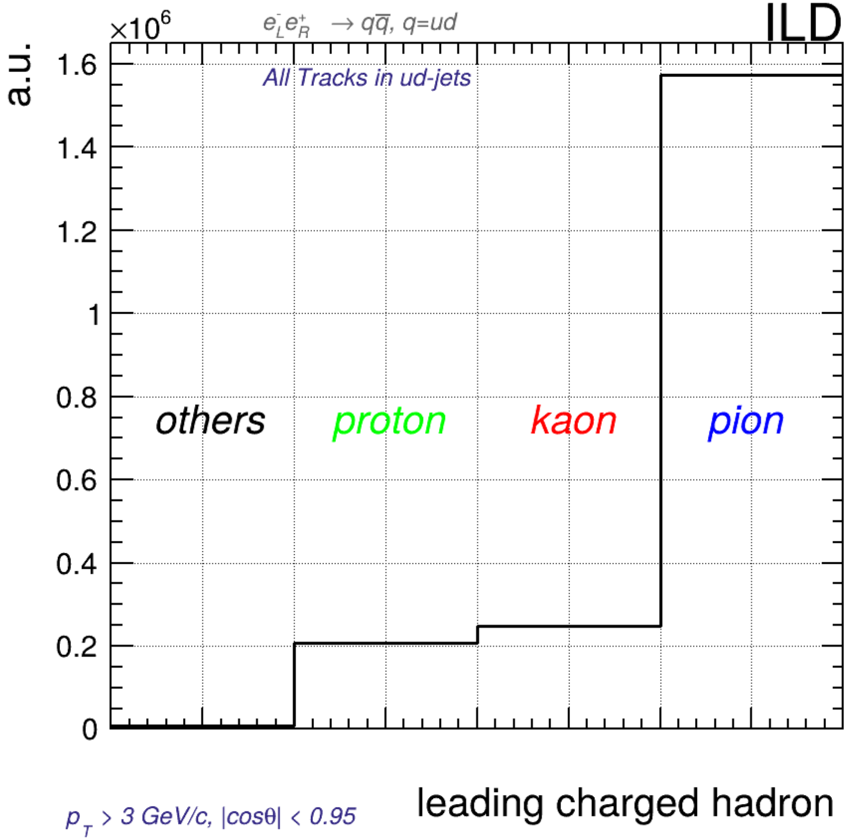
- Example of distance from tracks dE/dx and the theoretical values for kaons

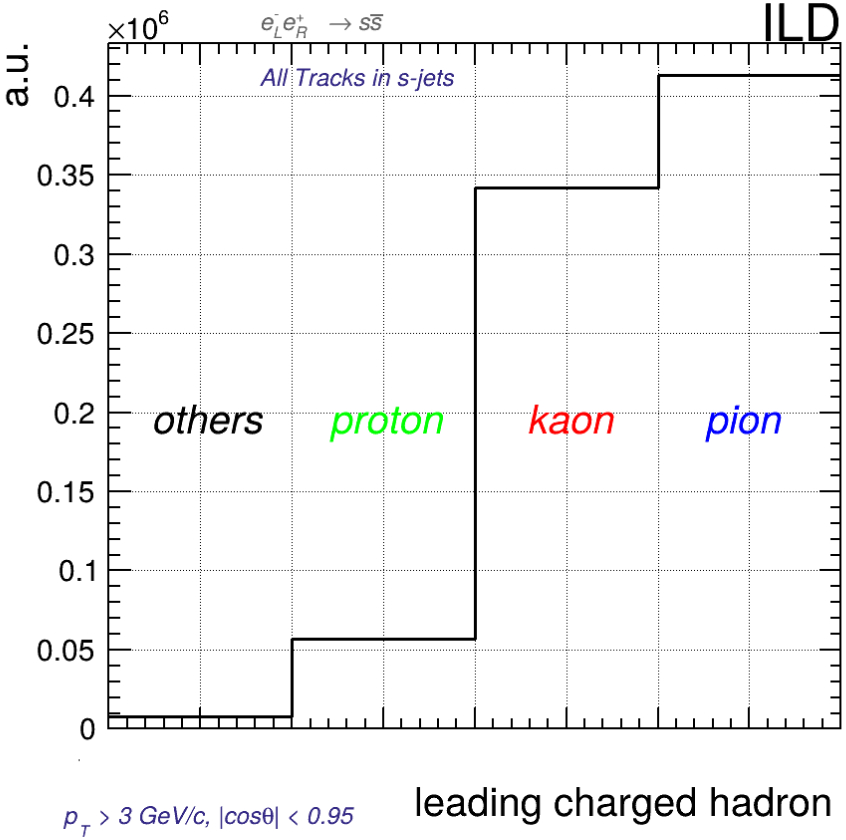




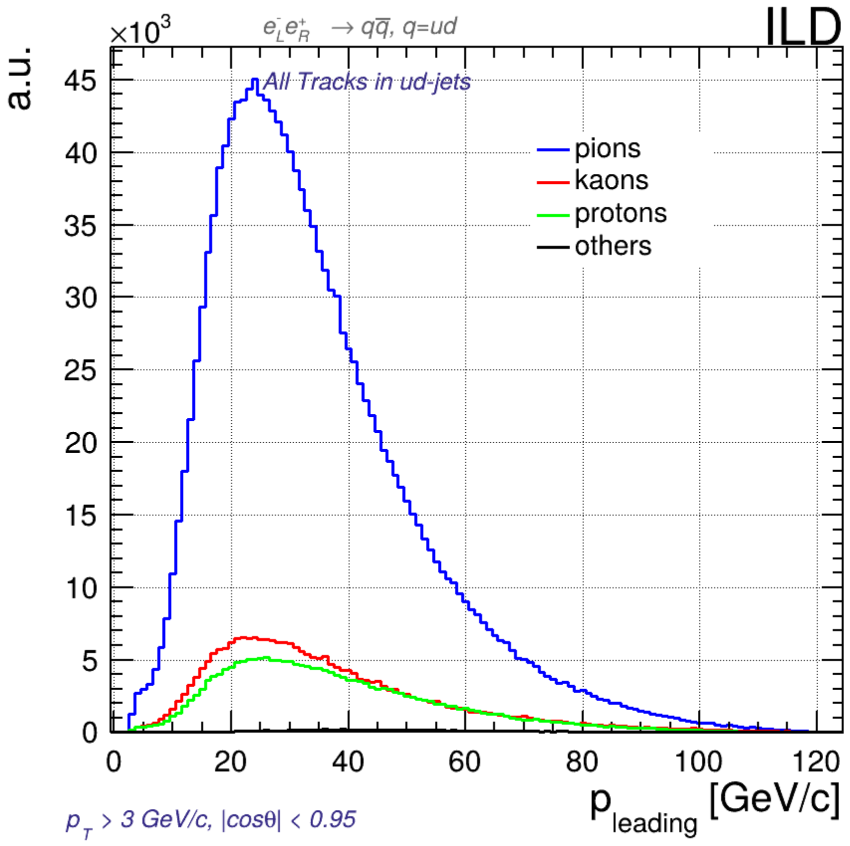
s vs ud: leading charged hadrons

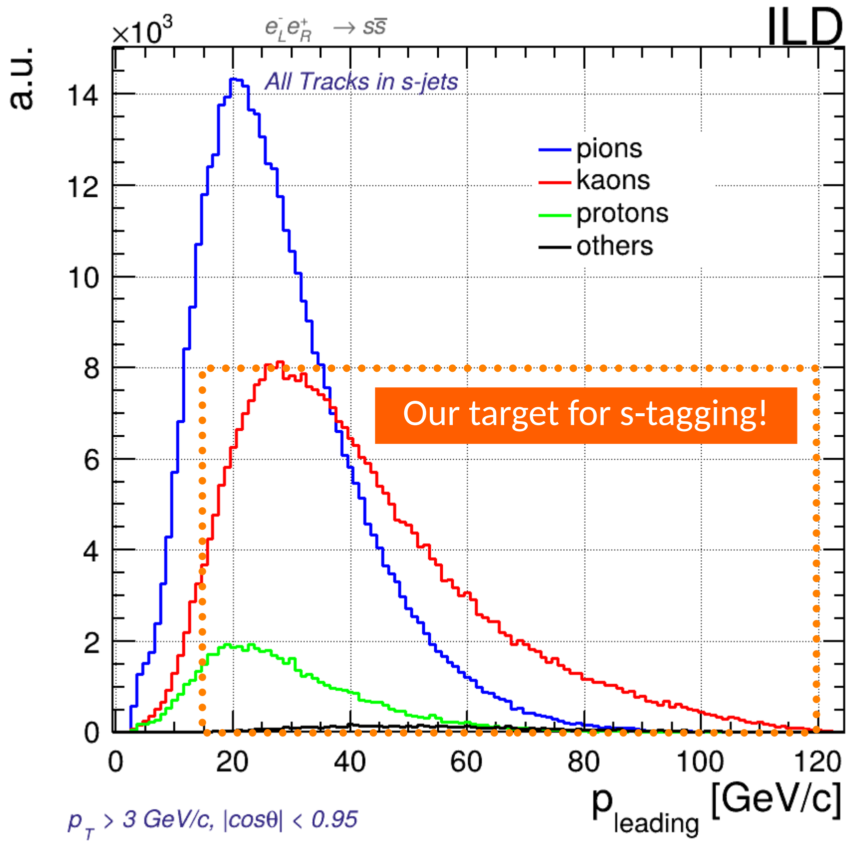
- Different leading track population between s-jets and u/d-jets





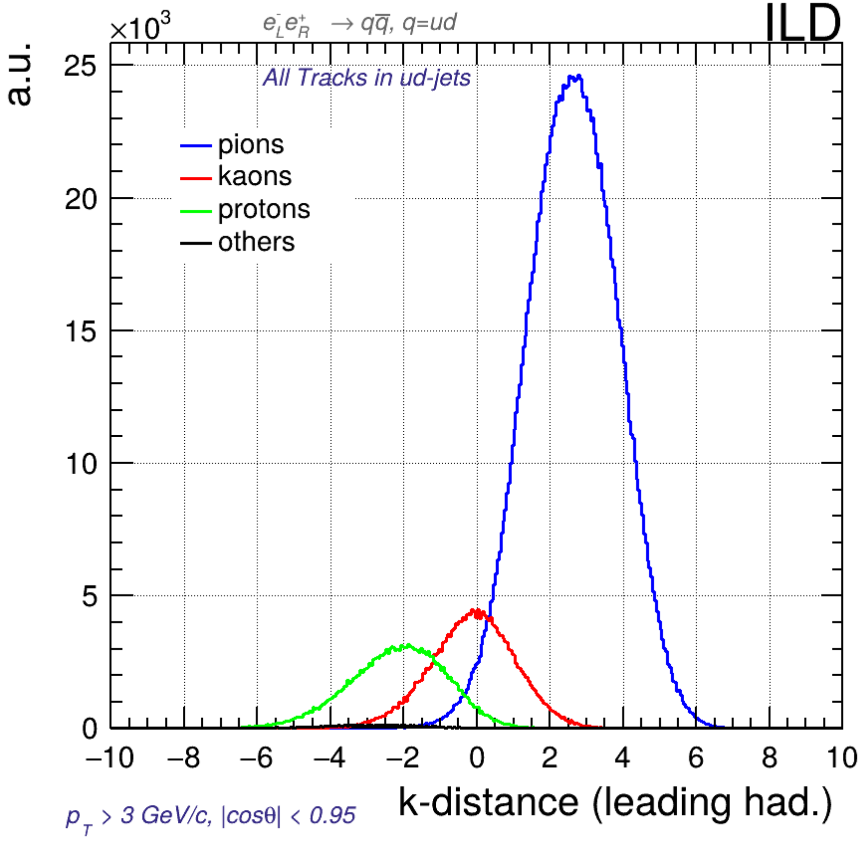
s vs ud: leading charged hadrons

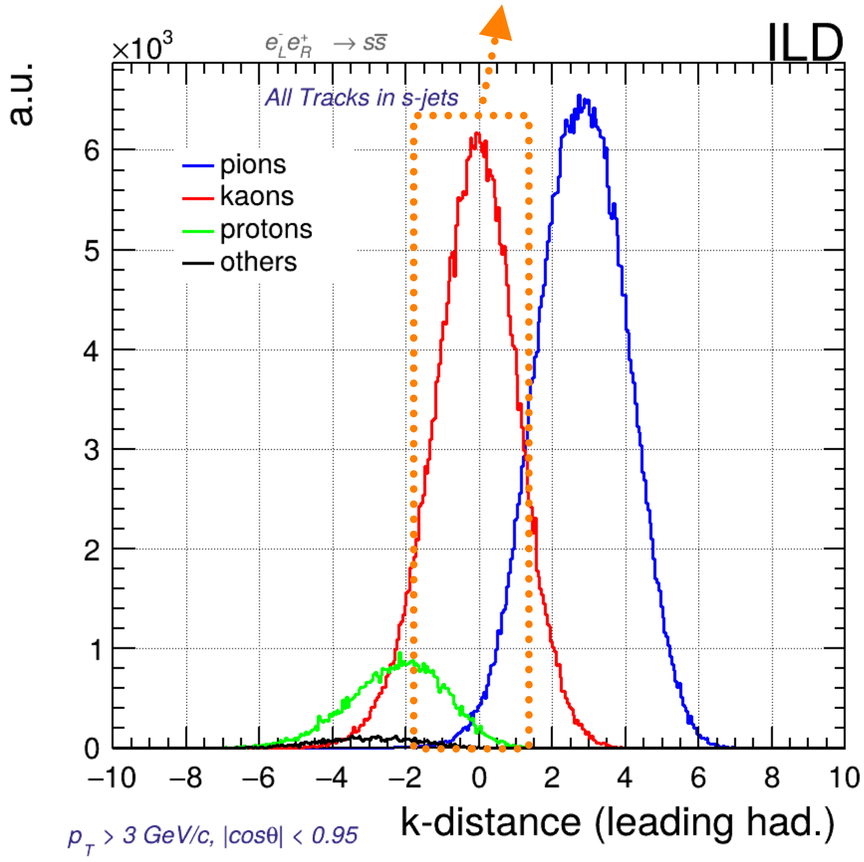




s vs ud: k-dist of leading charged hadrons

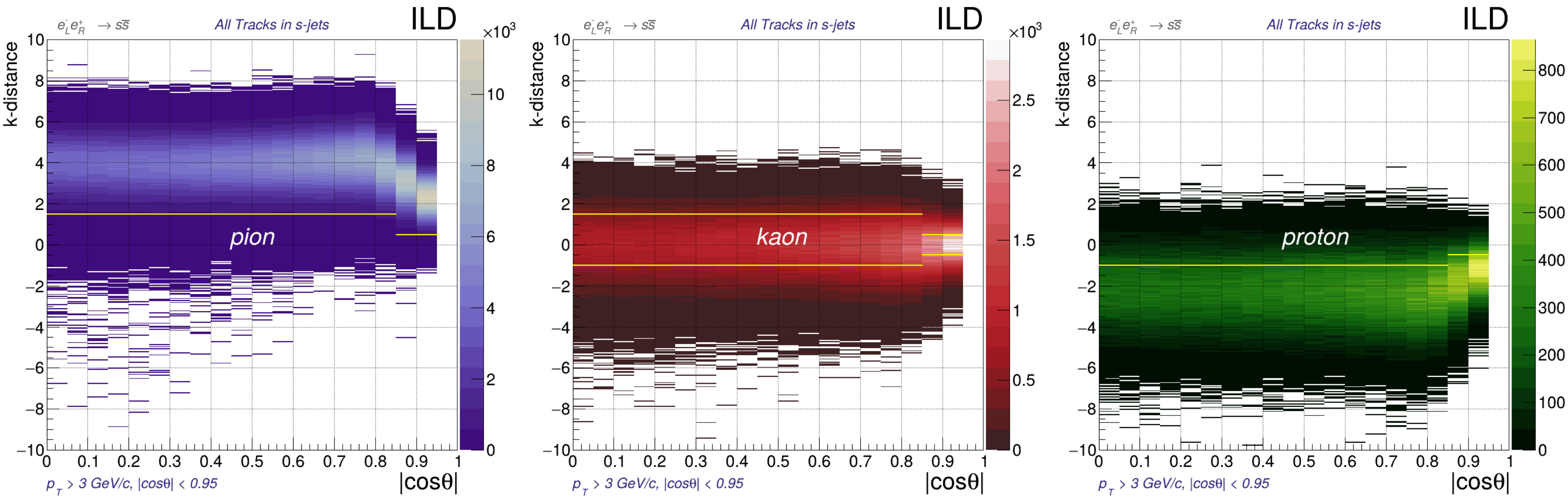
Our target for s-tagging!





2d view of k-distance (s quarks)

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



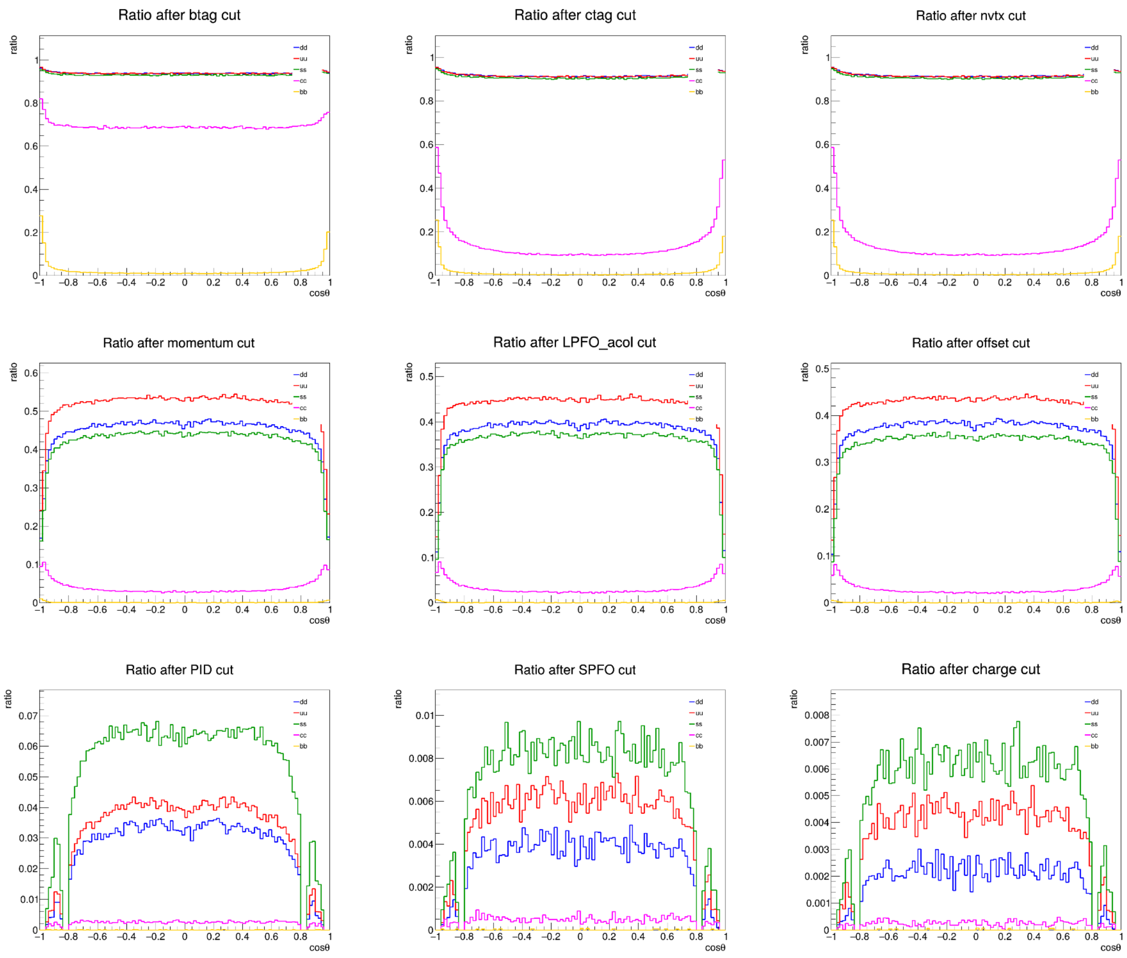
Caveat: The cuts shown here are defined by eye; we'll see later how to refine them

Cuts visualization (K selection for s-jets)

- 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 angular distributions of backgrounds and doing a set of corrections to the selected signal:
  - Efficiency estimation
  - Kaon PID stability
  - Charge migration (p-q method)

$$A_{FB} = \frac{\int_0^1 d\sigma_\theta d\cos\theta - \int_{-1}^0 d\sigma_\theta d\cos\theta}{\int_{-1}^1 d\sigma_\theta d\cos\theta}$$

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

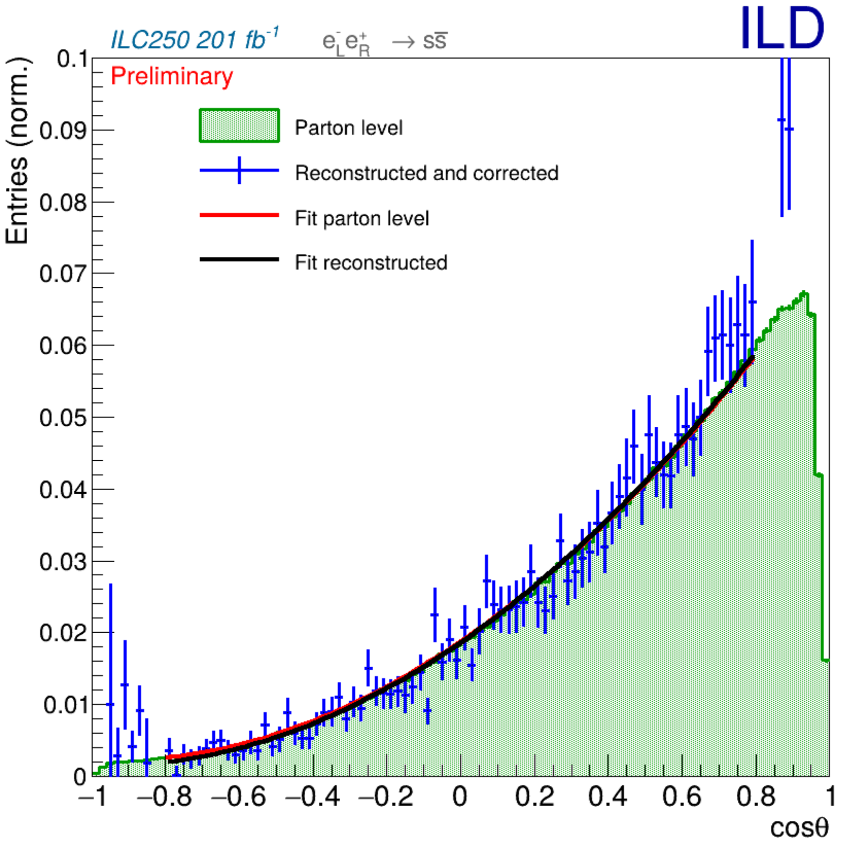
- A fit is performed to the corrected signal:

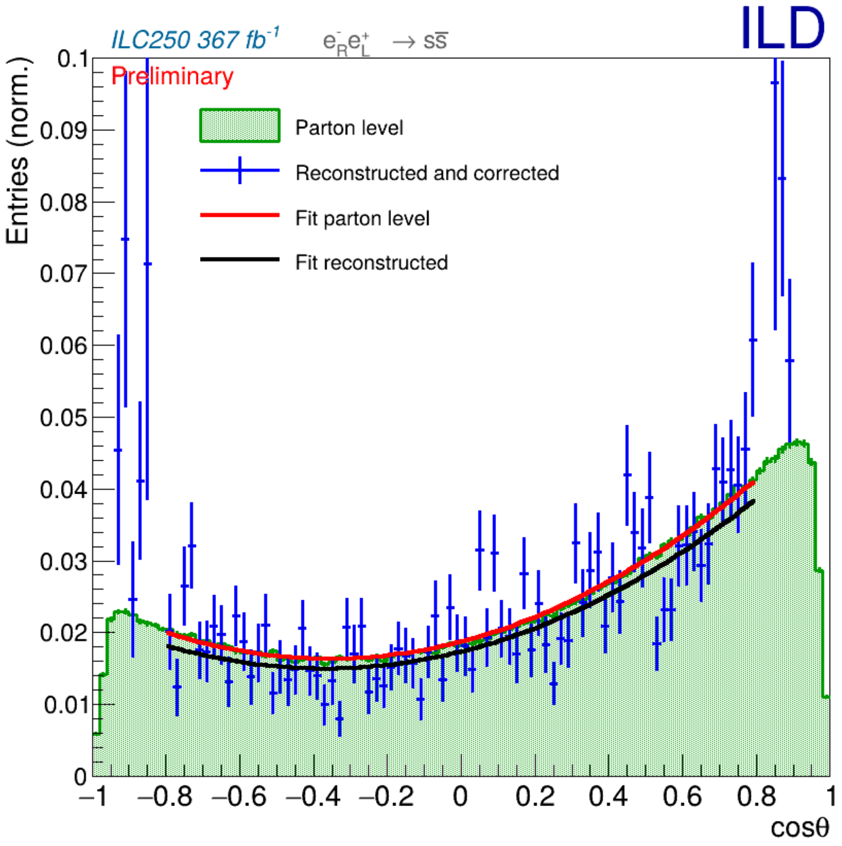
$$\frac{d\sigma}{d\cos\theta} = S\left(1+\cos^2\theta\right) + A\cos\theta$$

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

Fit to reconstructed signal

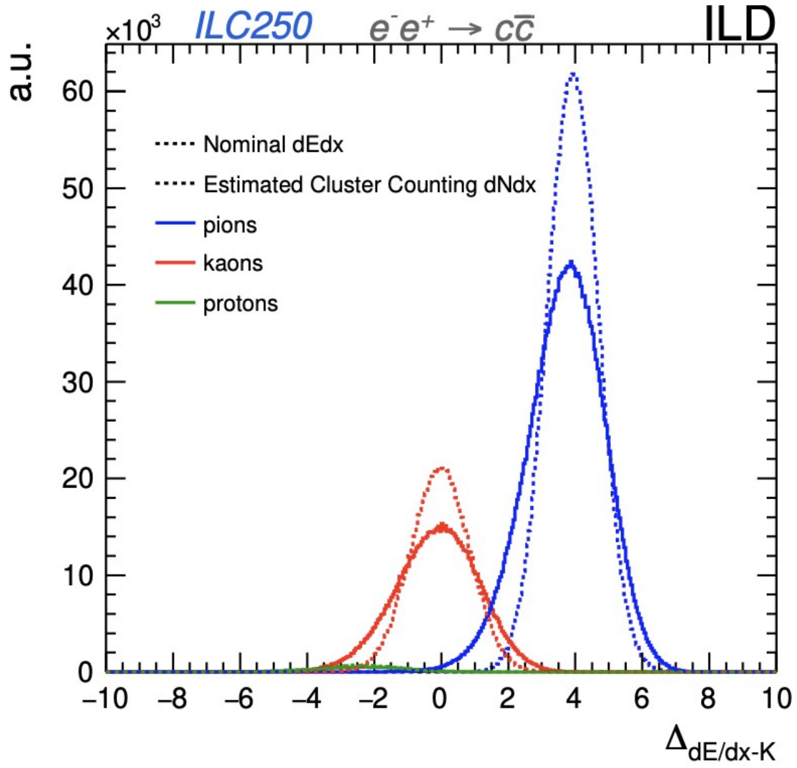
- Fit constrained to |cosθ| < 0.8 shows good agreement





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 a Perfect PID case
- Only PFOs with PID available are improved

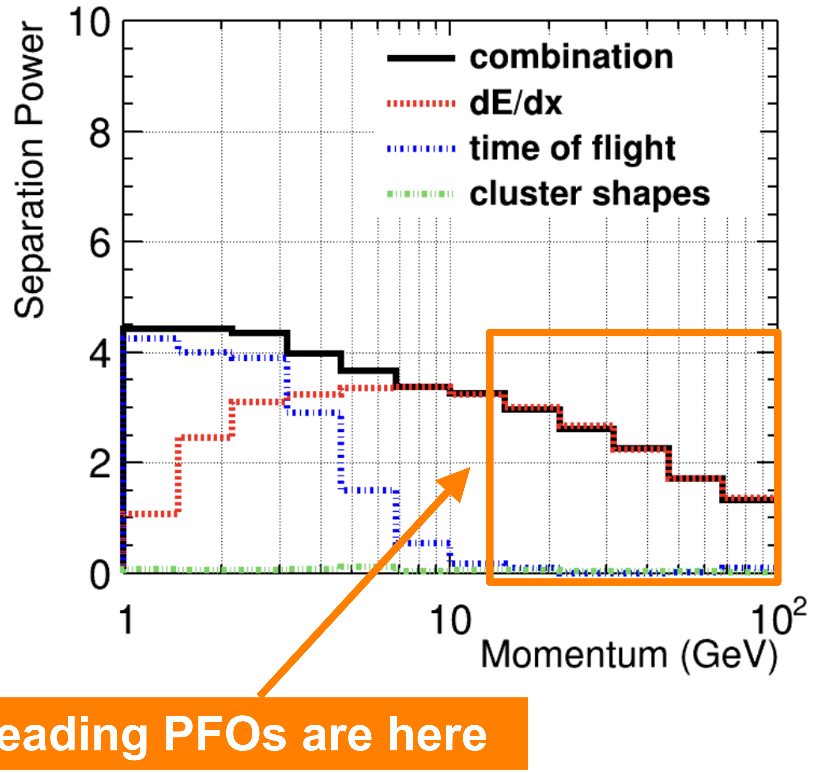


https://github.com/QQbarAnalysis/CheatdEdxDist

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

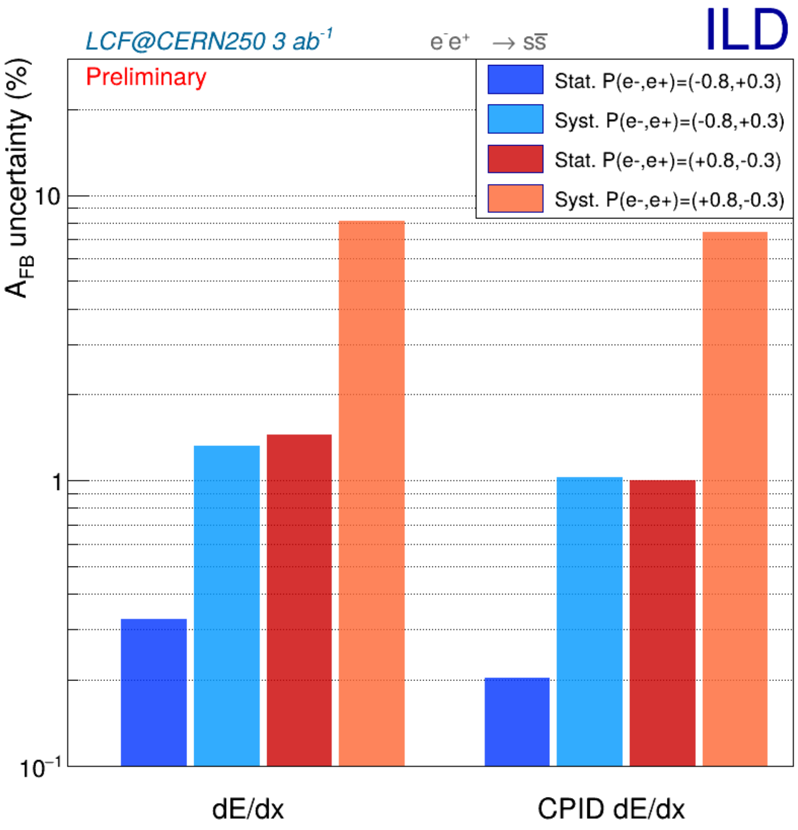
- ►In our case, the CPID was trained tackling our leading PFOS:
  - ▷Only Kaon/Pion/Proton separation
  - ▷3 GeV < Momentum < 100 GeV

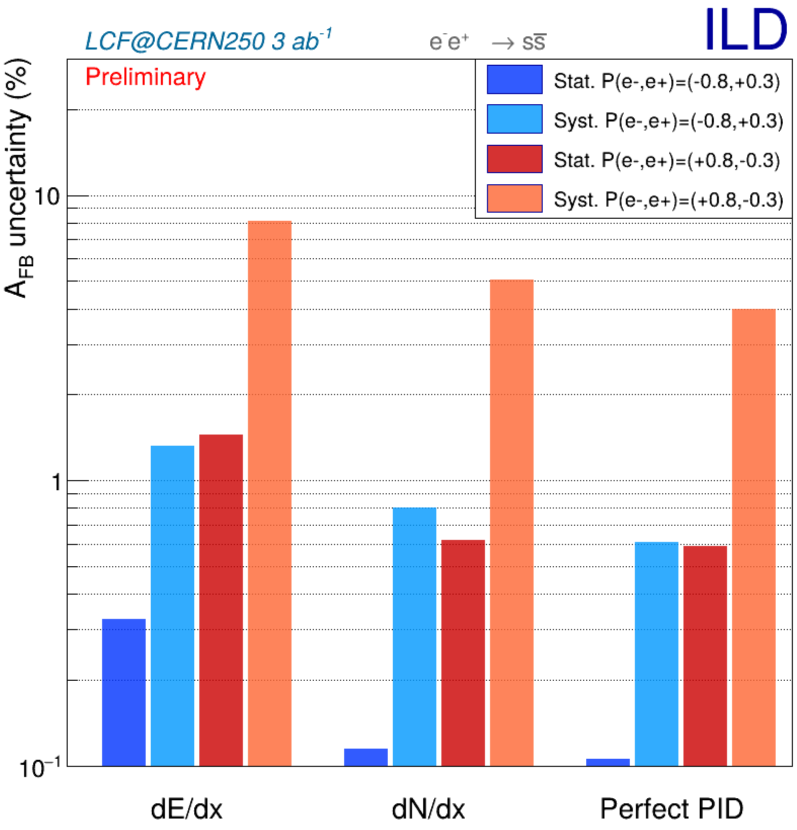


https://arxiv.org/abs/2307.15635 (U. Einhaus)

Preliminary results (LCF@CERN250)

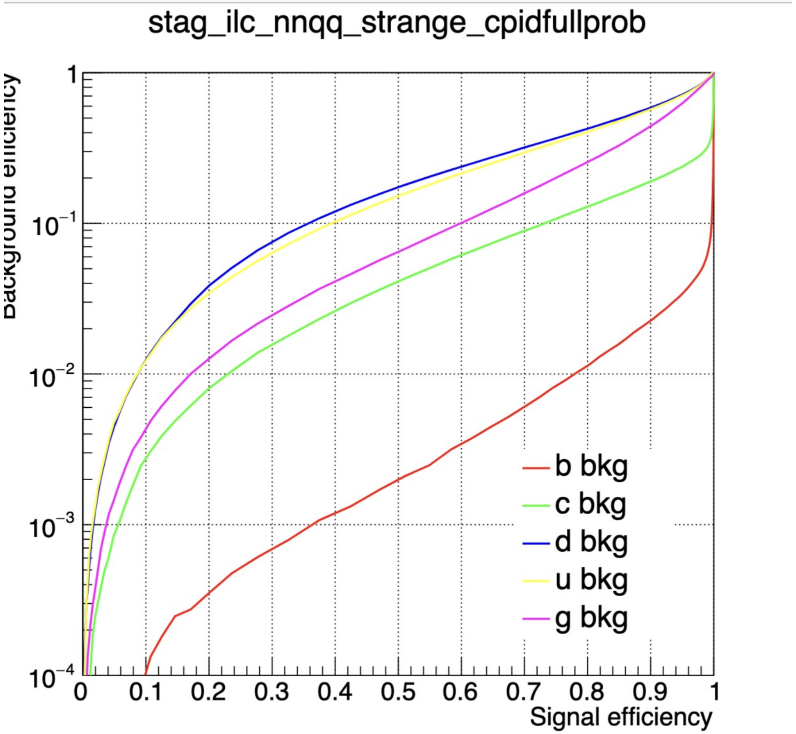
- Caveat: Working points (WP) are not fully optimized yet





Ongoing work: ParT s-tagging

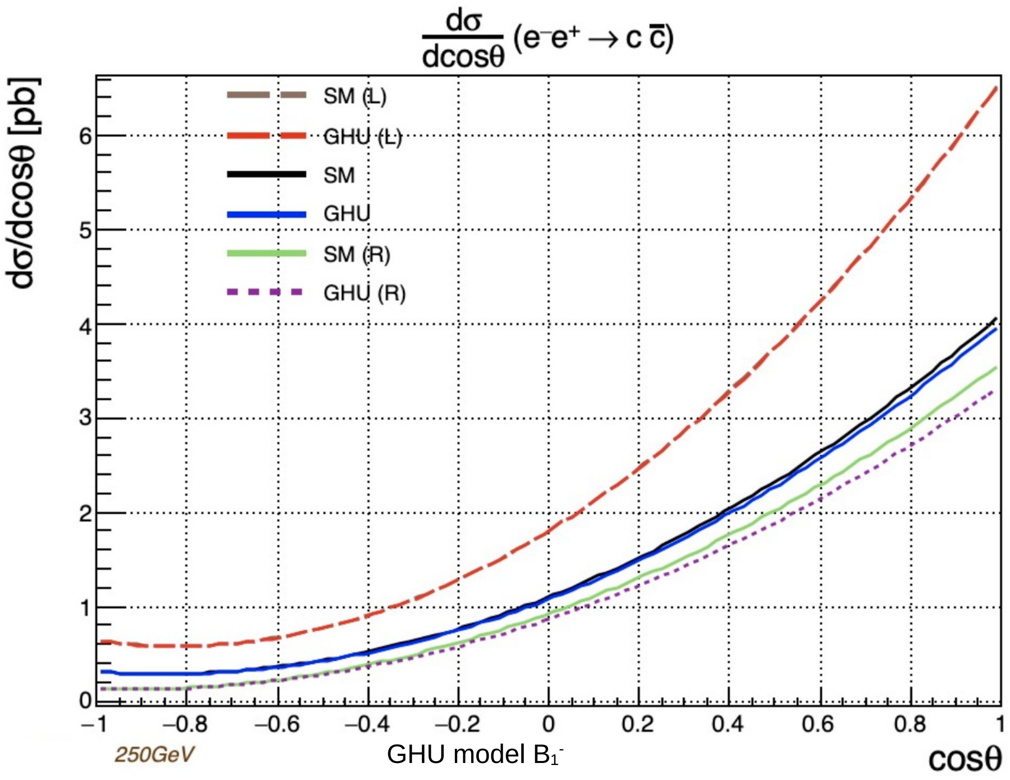
- Particle Transformers: state-of-the-art ML software
- It uses *CPID* for the tracks PID
- It not only uses PID but all the jet variables
- It can be ~10x better than the cut-based approach
- Still has to be fully incorporated in the analysis (WIP)
  - I'm running in 11-categories tagging (q, $\bar{q}$, gluon), which can reduce the cuts in the analysis into basically one:
    - S-tag + $\bar{s}$-tag combined cut (or ML selection)
      - And then check migration corrections



1% ss signal with 0.02% u/d backgrounds

Gauge-Higgs Unification Models (GHU)

- **Randall-Sundrum metric (5D)**
- The symmetry breaking pattern is different than in the SM and features the **Hosotani mechanism**:
  - Masses are generated dynamically from the extra-dimension properties
- Only one parameter, **Hosotani's angle θ_H** , determines the projection of the 5D fields, fixing all physical effects:
  - **KK resonances** of the Z/γ with $m_{kk} \sim O(10)$ TeV.
  - **Modifications and new EW couplings/helicity amplitudes.**
  - Already **visible deviations at 250GeV**.



As **Benchmark**, we use the [Funatsu, Hatanaka, Hosotani, Orikasa, Yamatsu] models.

Future plans: GHU phenomenology

- 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.)			ILC250			ILC250 +500			ILC250 +500 +1000*		
		B	C	Q	B	C	Q	B	C	Q	B	C	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.)			ILC250			ILC250 +500			ILC250 +500 +1000*		
		B	C	Q	B	C	Q	B	C	Q	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

Previous paper published with b & c quarks (2403.09144). An extension including s quark will be done with a new set of heavier models (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 PID

- There are many plans for the future of this analysis:
  - New MC simulation data will be produced *in a couple of months*
  - ParT double tagging is behind implemented
  - Extension to 500 GeV is possible!
  - GHU discovery prospects can be done combining all the full simulation results

THANKS FOR YOUR ATTENTION

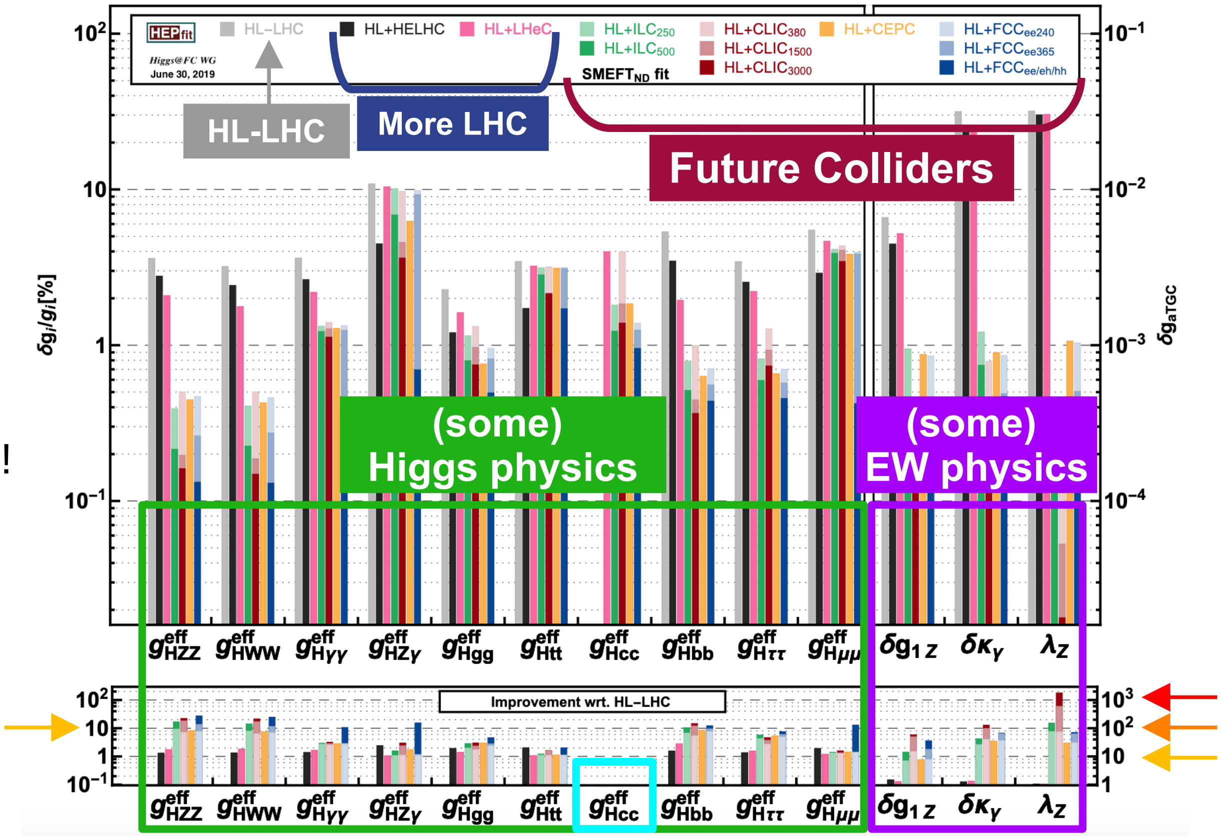
BACK-UP

Particle Colliders: What's next?

- Just some example: Expected sensitivity in **Higgs and aTGC couplings** (From SMEFT global fit)

Some measurements are O(10), O(10^2), or even O(10^3) better!

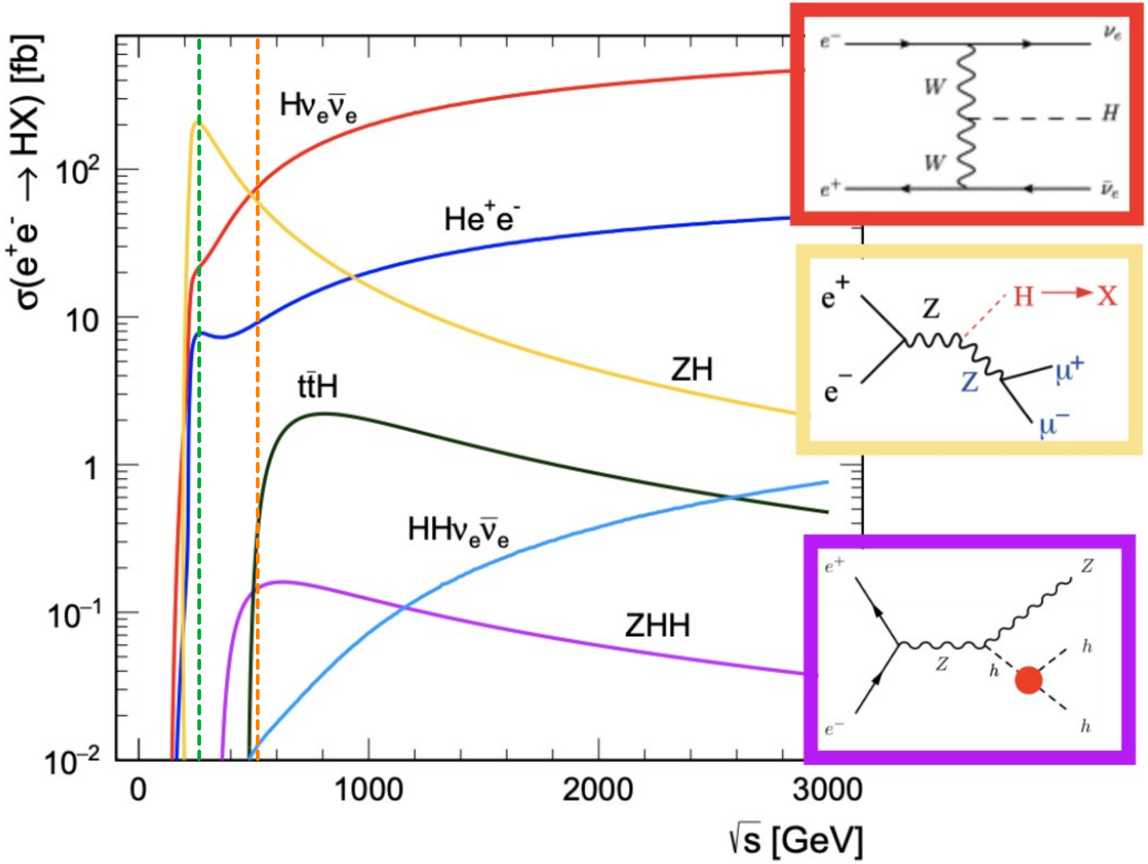
Others are unlocked by these experiments!



Future colliders: Unprecedented precisions for testing the SM and looking for BSM physics!

Relevant cross sections for e⁻e⁺ (I)

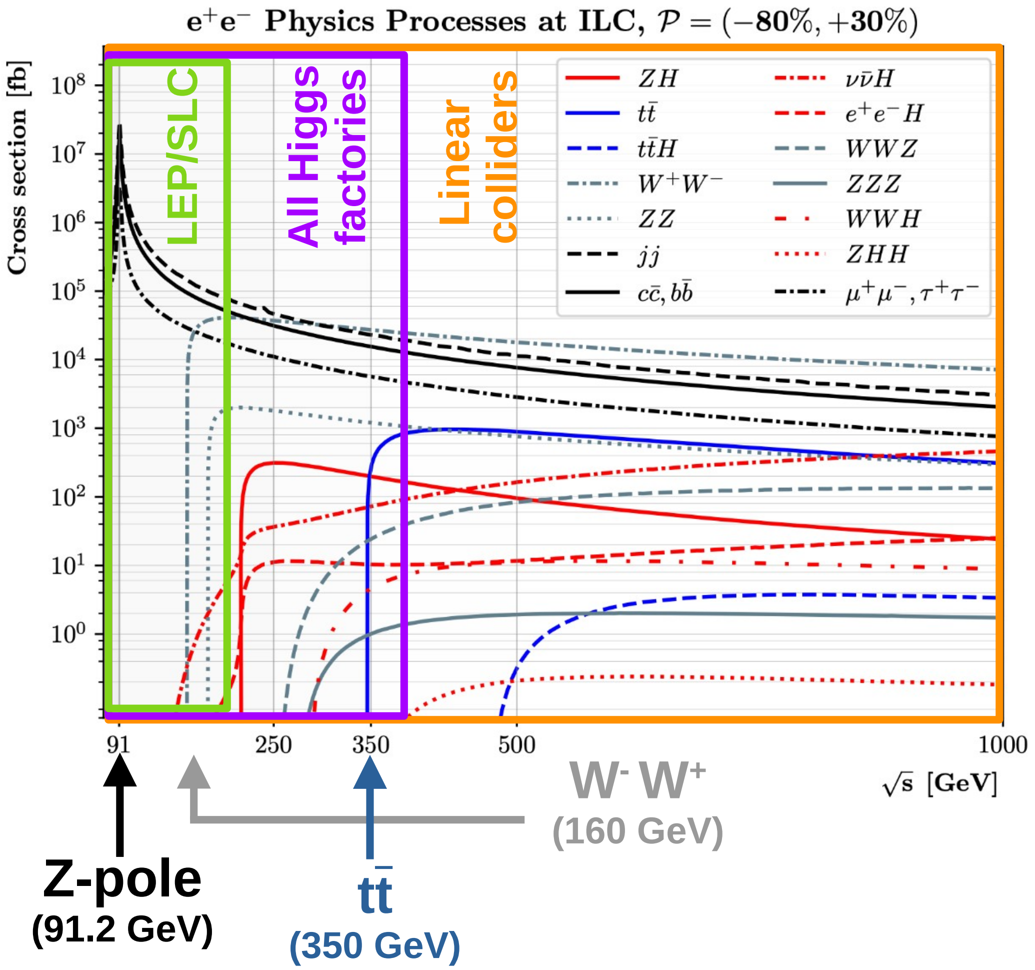
Unpolarized e⁻e⁺



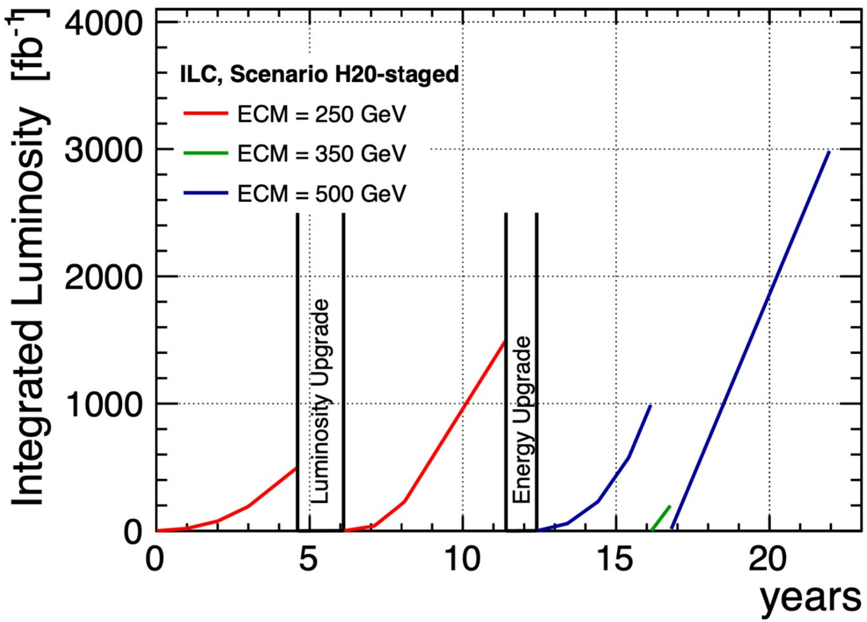
- **At 250 GeV:**
  - ZH dominates.
- **Over 500 GeV:**
  - Hνν dominates.
  - $t\bar{t}$H opens up.
  - ZHH opens up.

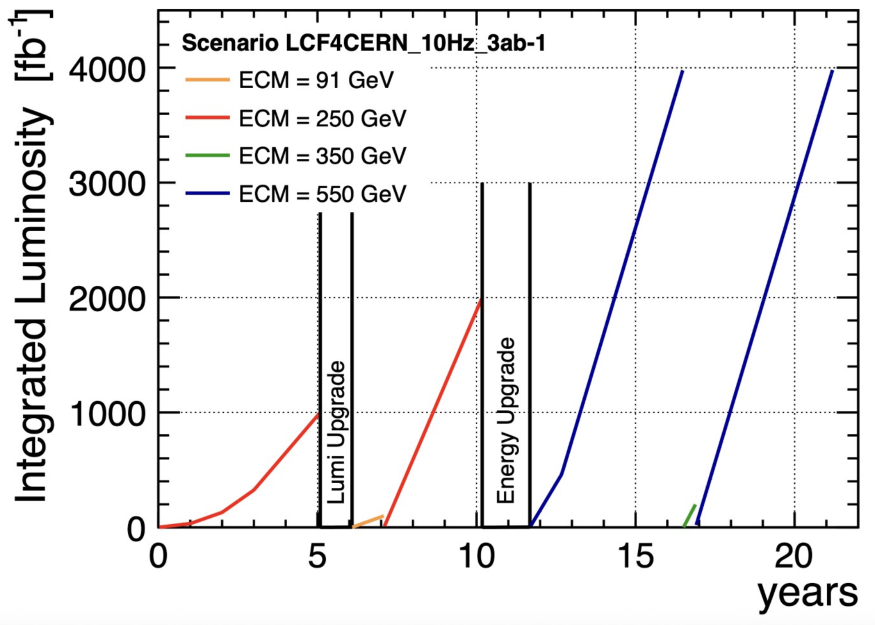
Relevant cross sections for e^-e^+ (II)

Polarized e^-e^+



ILC H20-staged & LCF4CERN run plans



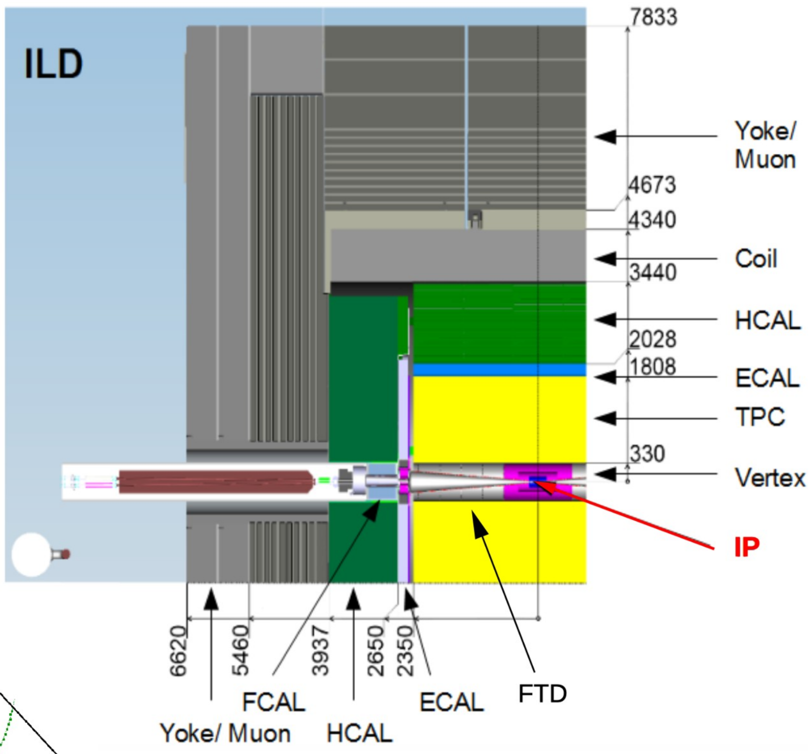


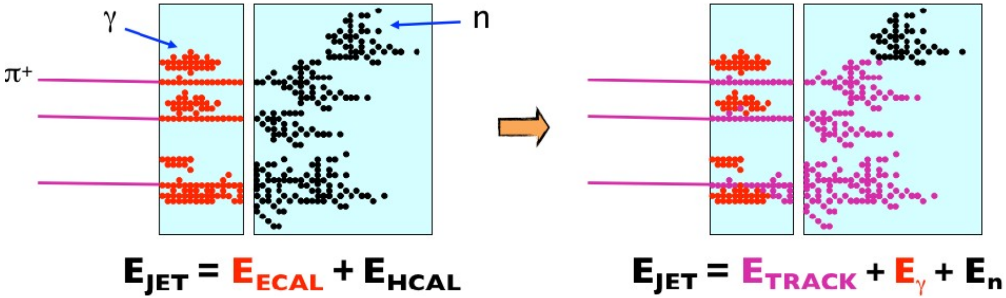
	91 GeV	250 GeV	350 GeV	500 GeV	1000 GeV
$\int \mathcal{L}$ (ab^{-1})	0.1	2	0.2	4	8
duration (yr)	1.5	11	0.75	9	10
beam polarization (e^-/e^+; %)	80/30	80/30	80/30	80/30	80/20
(–, -+, +-, ++) (%)	(10,40,40,10)	(5,45,45,5)	(5,68,22,5)	(10,40,40,10)	(10,40,40,10)
δ_{ISR} (%)	10.8	11.7	12.0	12.4	13.0
δ_{BS} (%)	0.16	2.6	1.9	4.5	10.5

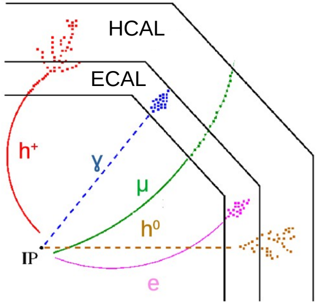
Quantity	Symbol	Unit	Initial-250	Upgrades		Initial-550	Upgrade
Centre-of-mass energy	$\sqrt{s}$	GeV	250	250	550	550	550
Inst. Luminosity	$\mathscr{L}$	(10^{34}cm^{-2}s^{-1})	2.7	5.4	7.7	3.9	7.7
Polarisation	$\lvert P(e^-)\rvert / \lvert P(e^+)\rvert$	(%)	80 / 30	80 / 30	80 / 60	80 / 30	80 / 60
Bunches per pulse	n_{bunch}	1	1312	2625	2625	1312	2625
Average beam power	P_{ave}	MW	10.5	21	46	23	46
Site AC power	P_{site}	MW	143	182	322	250	322
Construction cost		BCHF	8.29	+0.77	+5.46	13.13	+1.40
Operation & maintenance		MCHF/y	170	196	342	291	342
Electricity		MCHF/y	66	77	142	115	142
Operating Personnel		FTE	640	640	850	850	850

International Large Detector (ILD)

- ▶It features excellent tracking, vertexing and IP constraining capabilities with minimal material budget
- ▶**High granularity, compact** and **hermetic calorimetry system**
- ▶**Full simulation available**: detailed geometry, materials, reconstruction chain, etc.
- ▶**Optimized for Particle Flow**:
  - ▷Determination of single particles
  - ▷Based on Particle Flow Algorithms (PFA)
  - ▷Powerful Particle identification (PID) tools
    - Jet energy measurement, flavor tagging, etc.

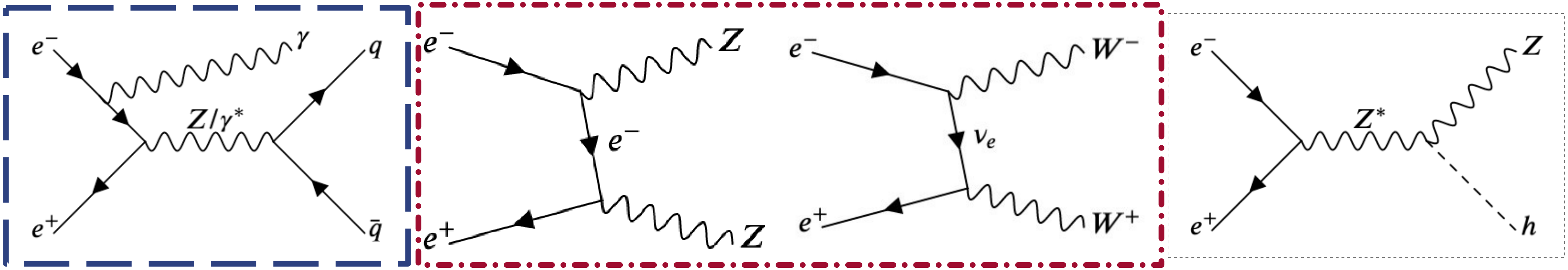






Preselection of $q\bar{q}$ signals

- 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

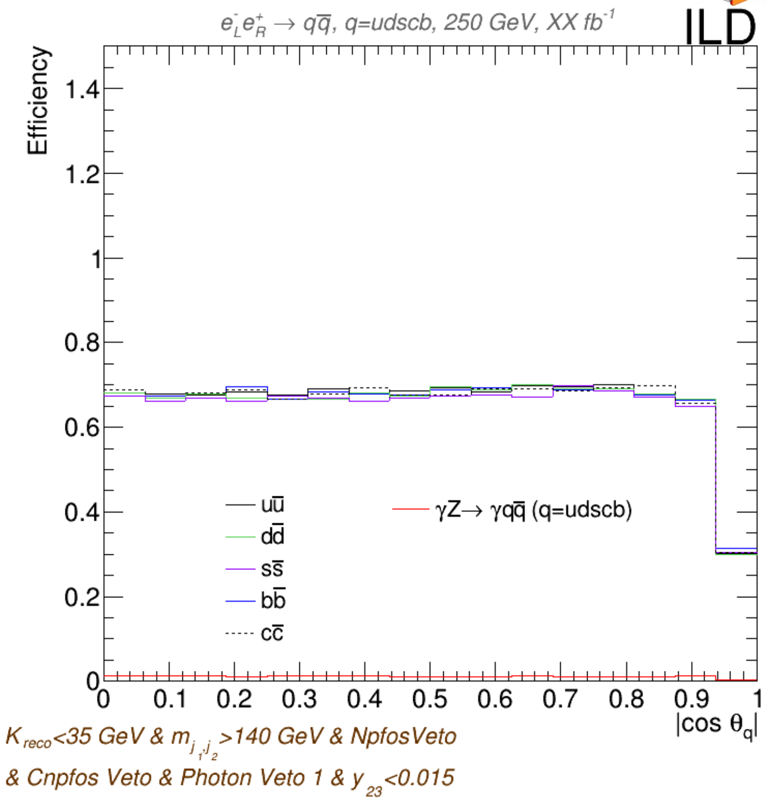
VLC Algorithm parameters:

- 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

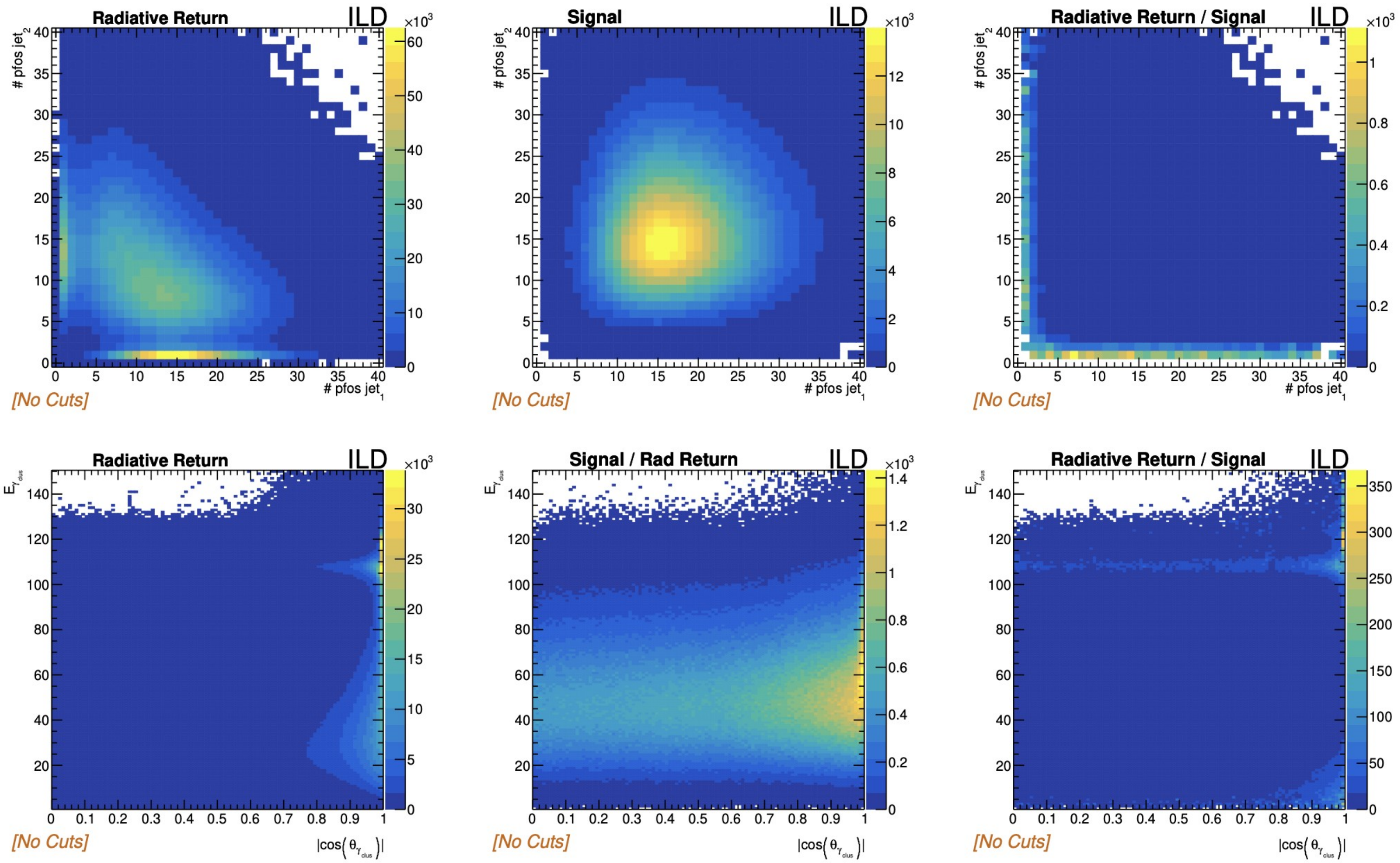
← |cosθ| < 0.9

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

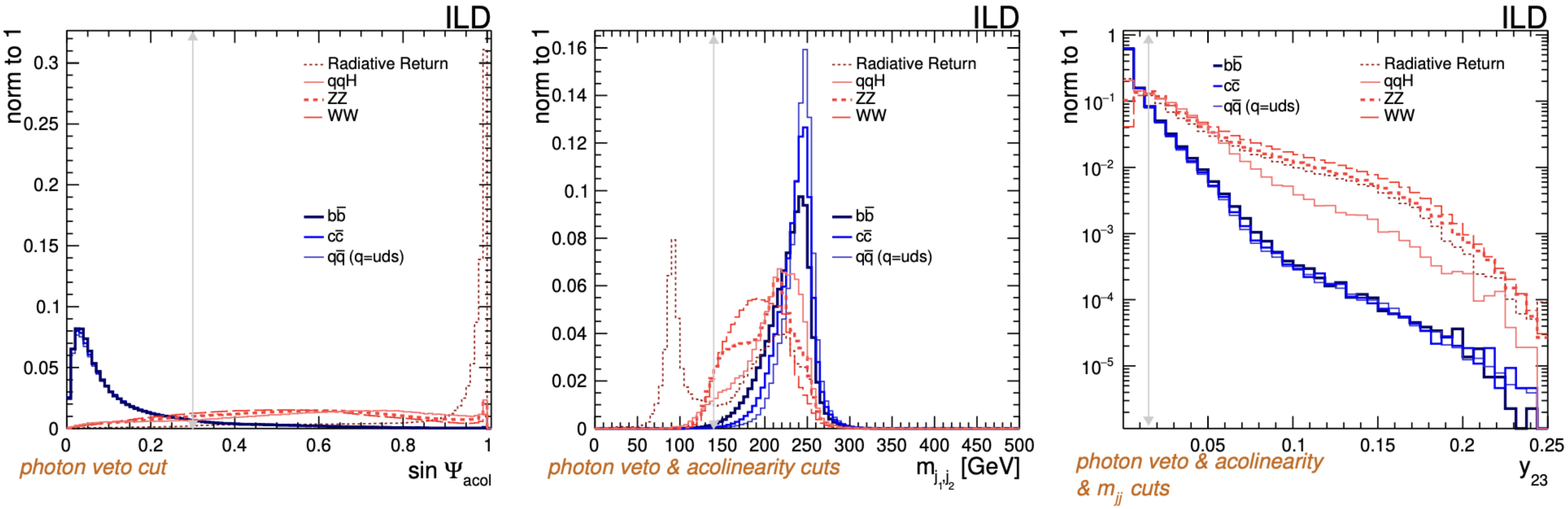


Efficiency of the preselection for the different quark flavours vs the angular distribution of the two jet system (new samples, final configuration)

Radiative return event rejection

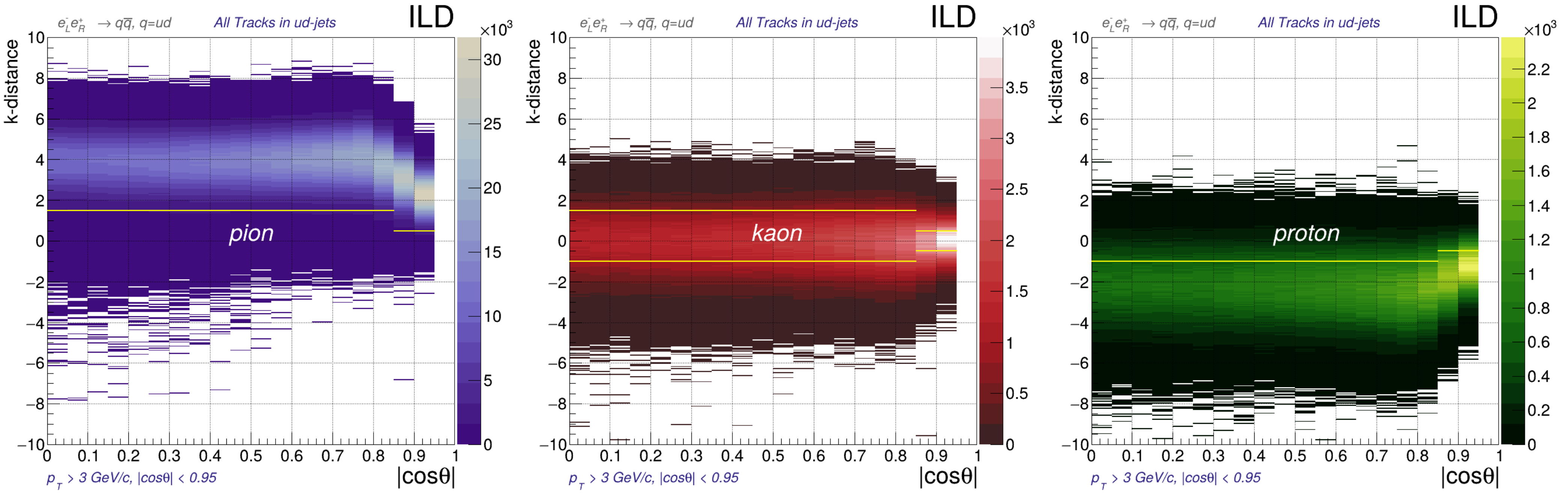


Background rejection



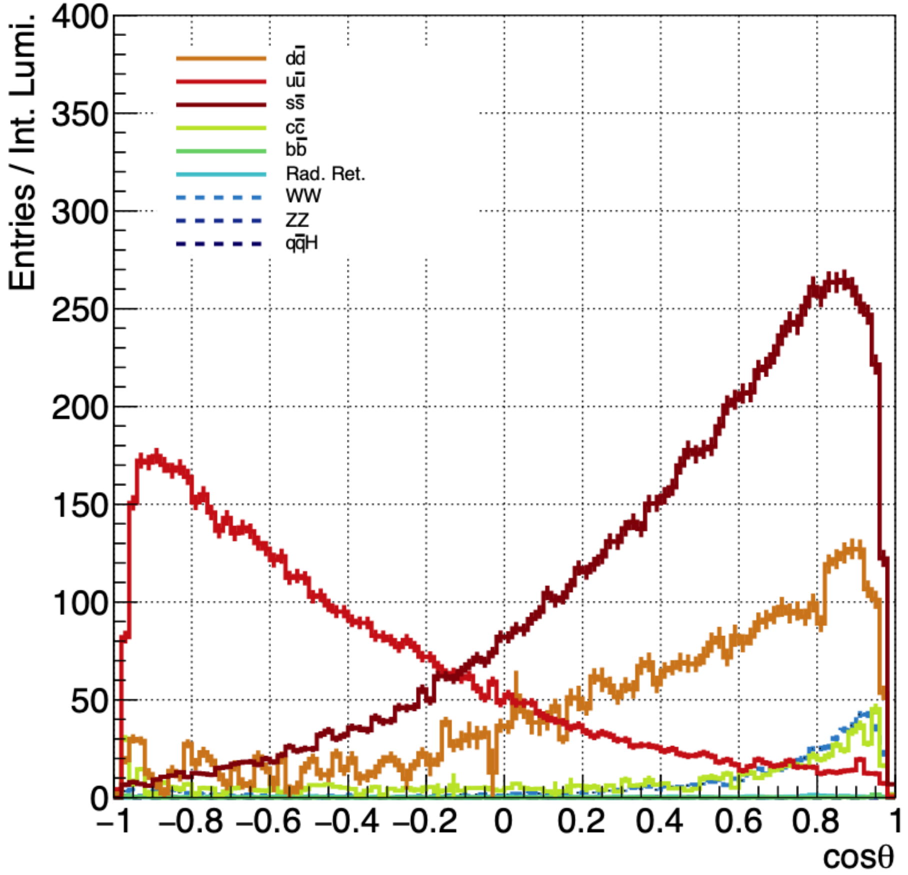
2d view of k-distance (ud quarks)

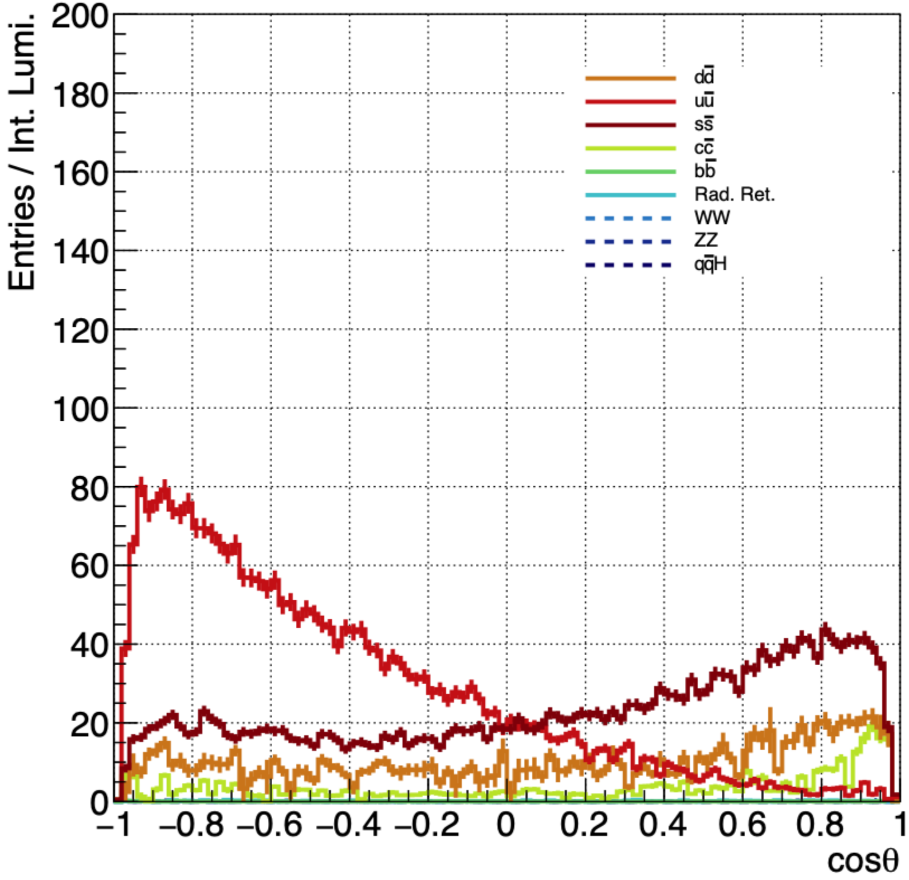
- Angular cuts are performed in these distributions for selection of pions



Contributions after preselection

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





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 (K mode for s selection)

dN/dx

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

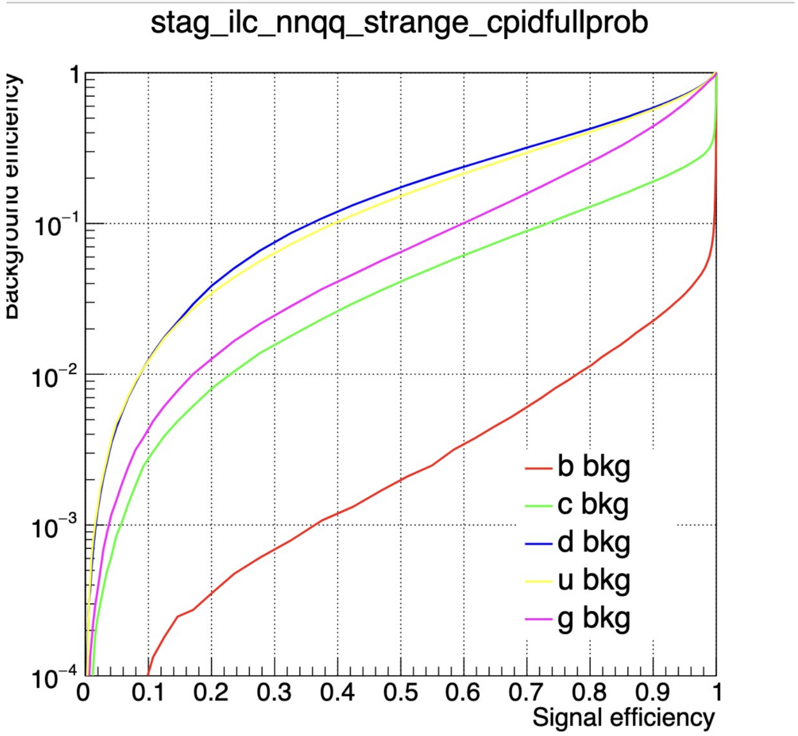
	dd	uu	ss	cc	bb
+ Cut 1	93.9%	93.8%	93.1%	69.5%	2.67%
+ Cut 2	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 3	91.7%	91.6%	90.9%	14.7%	1.83%
+ Cut 4	45.1%	52.6%	42.4%	4.76%	0.166%
+ Cut 5	38.1%	44.4%	35.7%	3.94%	0.119%
+ Cut 6	36.2%	42.2%	33.4%	3.5%	0.0776%
+ Cut 7	0.348%	0.524%	3.55%	0.144%	0.0011%
+ Cut 8	0.0389%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

The “holy grail”: ParT s-tagging

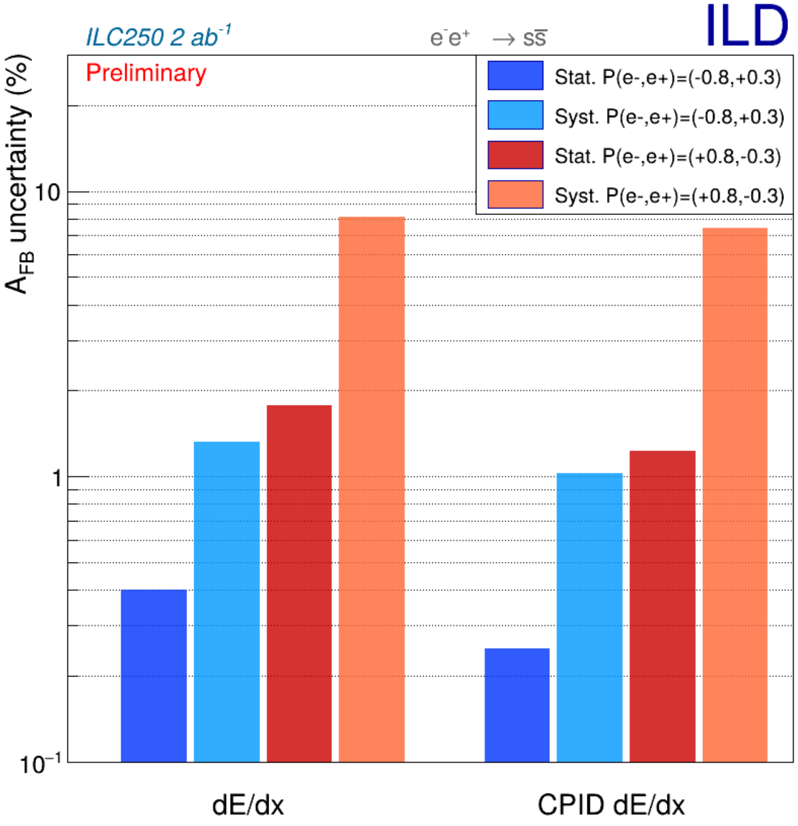
- Particle Transformers is state-of-the-art ML software
- It uses *CPID* for the tracks PID
- It can be 10x better than the cut-based approach
  - But how? Is this code available? Trying to get access to it to incorporate it into a chain of analysis
  - Can reduce the cuts in the analysis into:
    -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

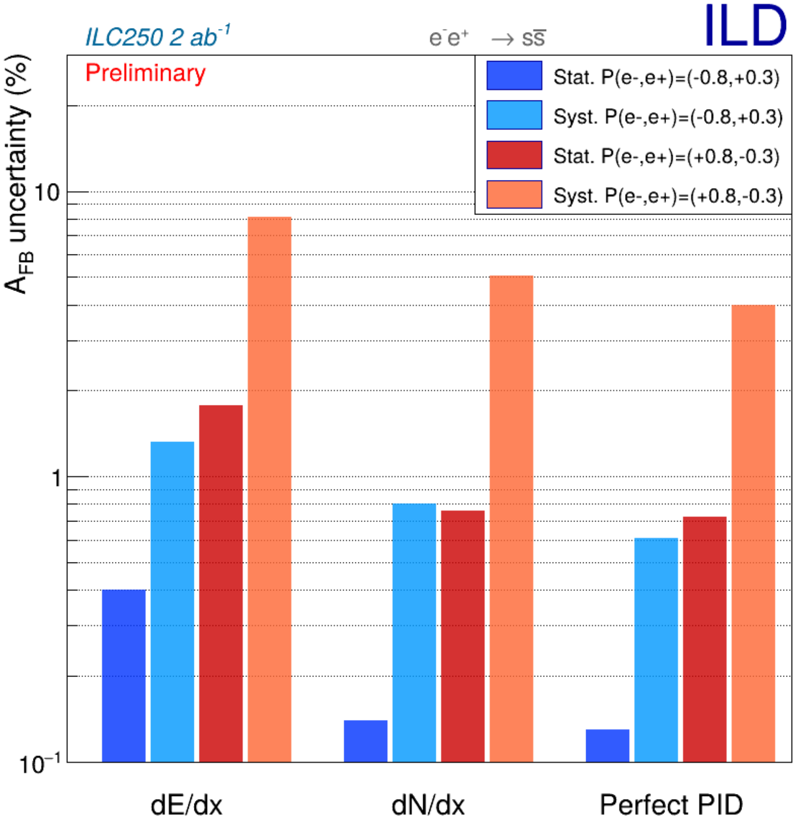


1% ss signal with 0.02% u/d backgrounds? Expected B/S = 0.33

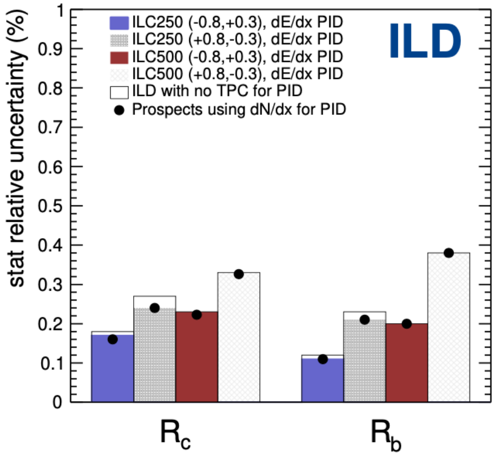
Preliminary results (ILC250)

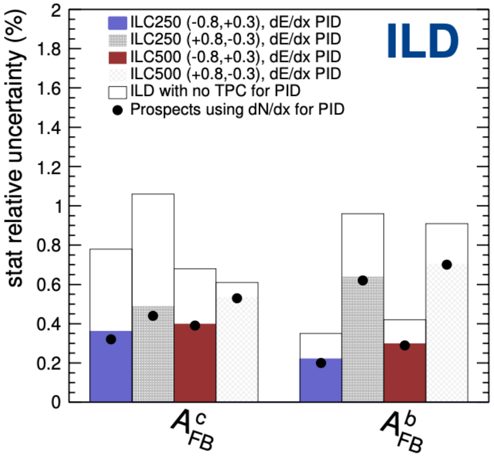
- Working points (WP) are not fully optimized yet

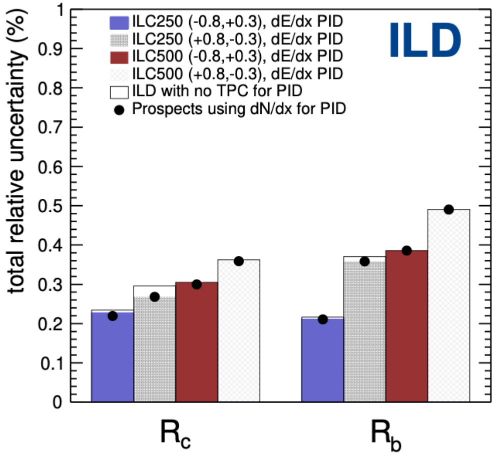


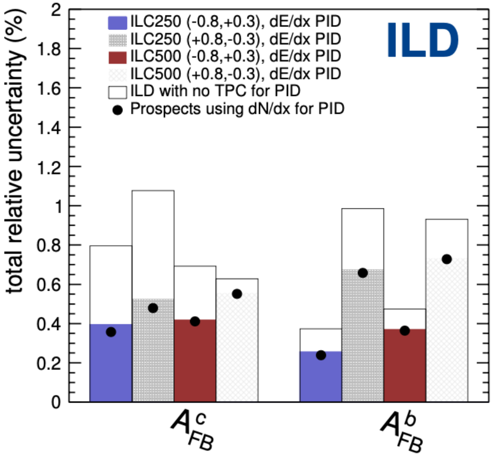


Results for b & c







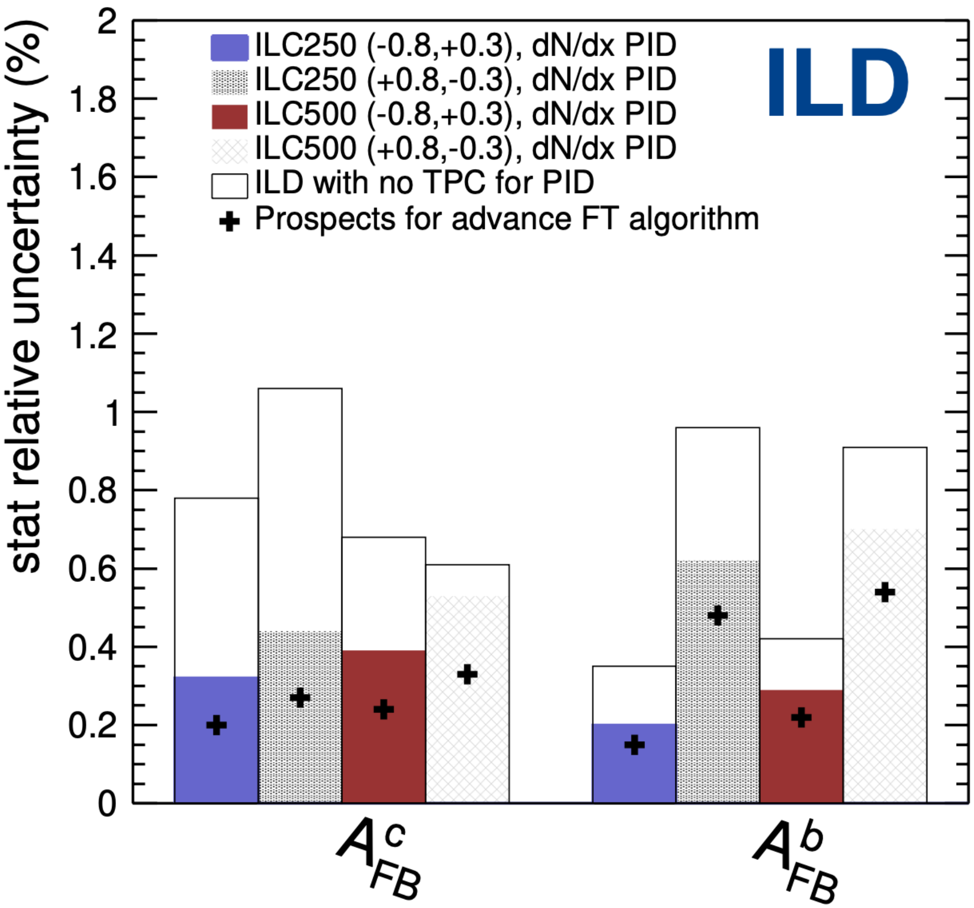


ParT prospects (b & c quarks)

- ▶ Moving from “traditional” ML (BDTs) to new methods: **Transformers**
  - ▷ **Particle Transformer** (**ParT**), developed originally by DESY/U. Hamburg researchers for optimizing jet tagging inATLAS and CMS
  - ▷ The developers of LCFI+ are adapting ParT to the ILC/LCF environment

	b-tag 80% efficiency		c-tag 50% efficiency	
Method	c-bkg acceptance	d-bkg acceptance	b-bkg acceptance	d-bkg acceptance
LCFIPlus (at 250 GeV)	6.3 %	0.79 %	7.4 %	1.2 %
ParT (at 91 GeV)	1.3 %	0.25 %	1.0 %	0.43 %
ParT (at 250 GeV, modified)	0.48 %	0.14 %	0.86 %	0.34 %

https://arxiv.org/pdf/2205.12160



Gauge-Higgs Unification Models (GHU)

- A models: (arxiv:1705.05282)

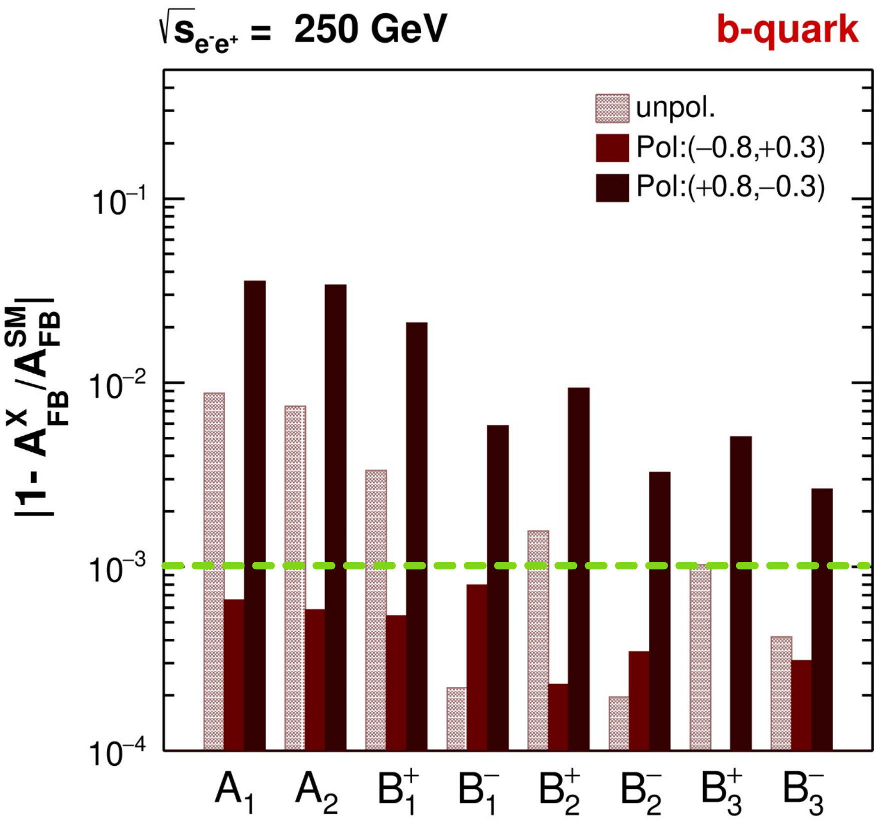
$$A_1 : \theta_H = 0.0917, m_{KK} = 8.81 \text{ TeV} \rightarrow m_{Z^1} = 7.19 \text{ TeV};$$
$$A_2 : \theta_H = 0.0737, m_{KK} = 10.3 \text{ TeV} \rightarrow m_{Z^1} = 8.52 \text{ TeV},$$

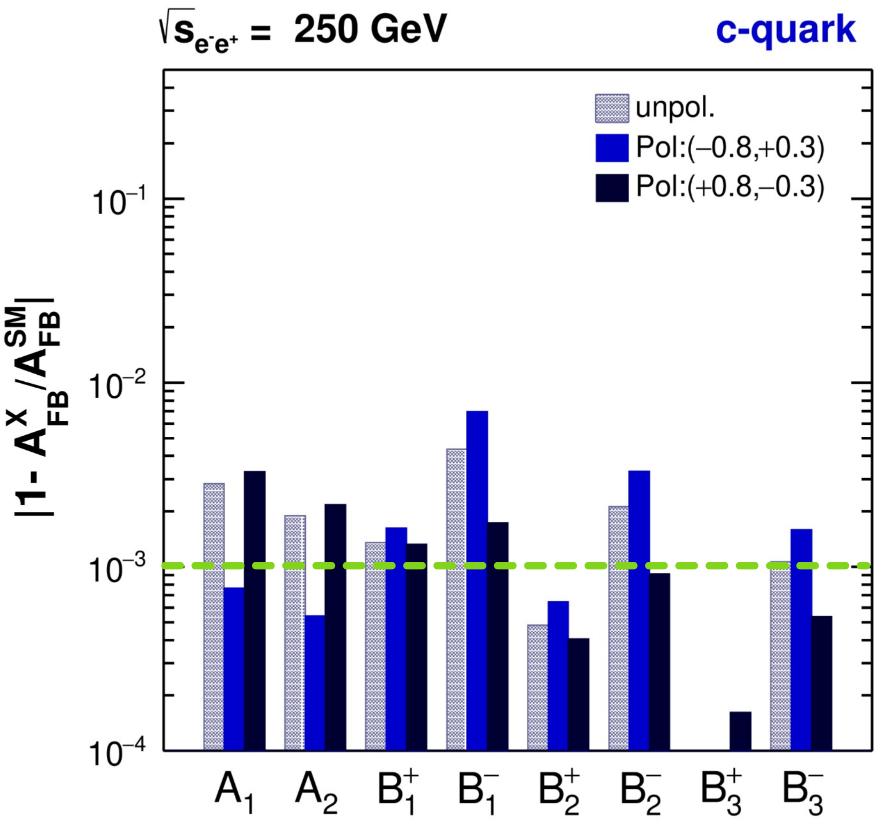
- B models: (arxiv:2309.01132) (arxiv:2301.07833)

$$B_1^{\pm}: \theta_H = 0.10, m_{KK} = 13 \text{ TeV} \rightarrow m_{Z^1} = 10.2 \text{ TeV};$$
$$B_2^{\pm}: \theta_H = 0.07, m_{KK} = 19 \text{ TeV} \rightarrow m_{Z^1} = 14.9 \text{ TeV};$$
$$B_3^{\pm}: \theta_H = 0.05, m_{KK} = 25 \text{ TeV} \rightarrow m_{Z^1} = 19.6 \text{ TeV};$$

Resonances of O(10) TeV: Only indirect measurements are possible!

GHU vs SM (250 GeV)



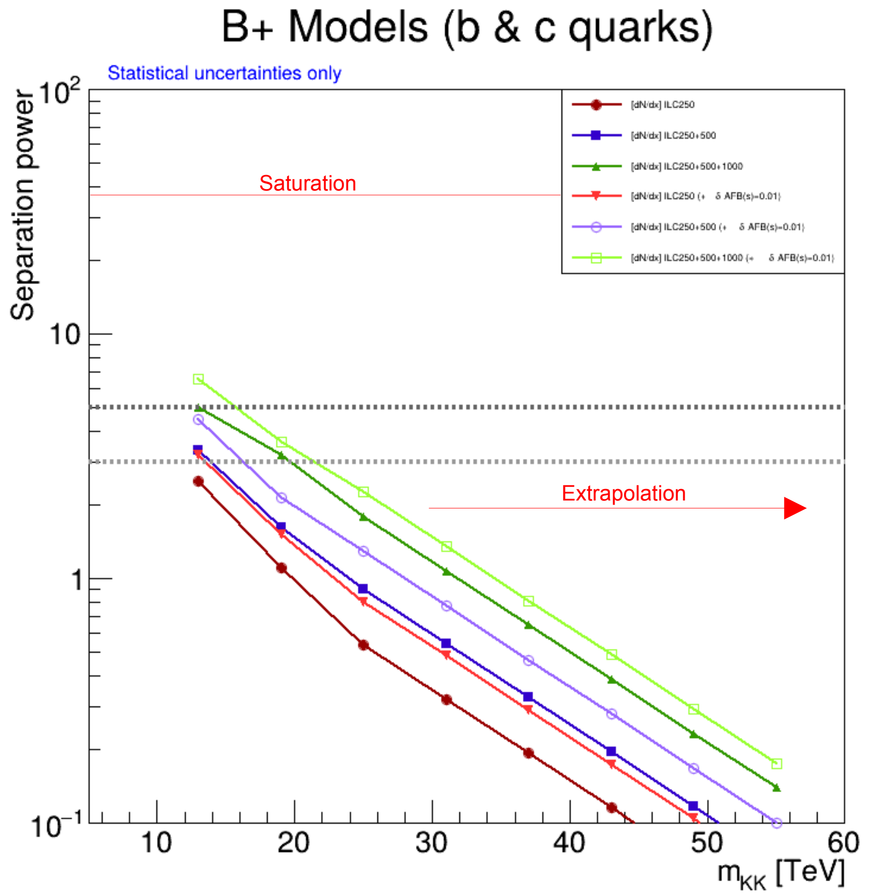


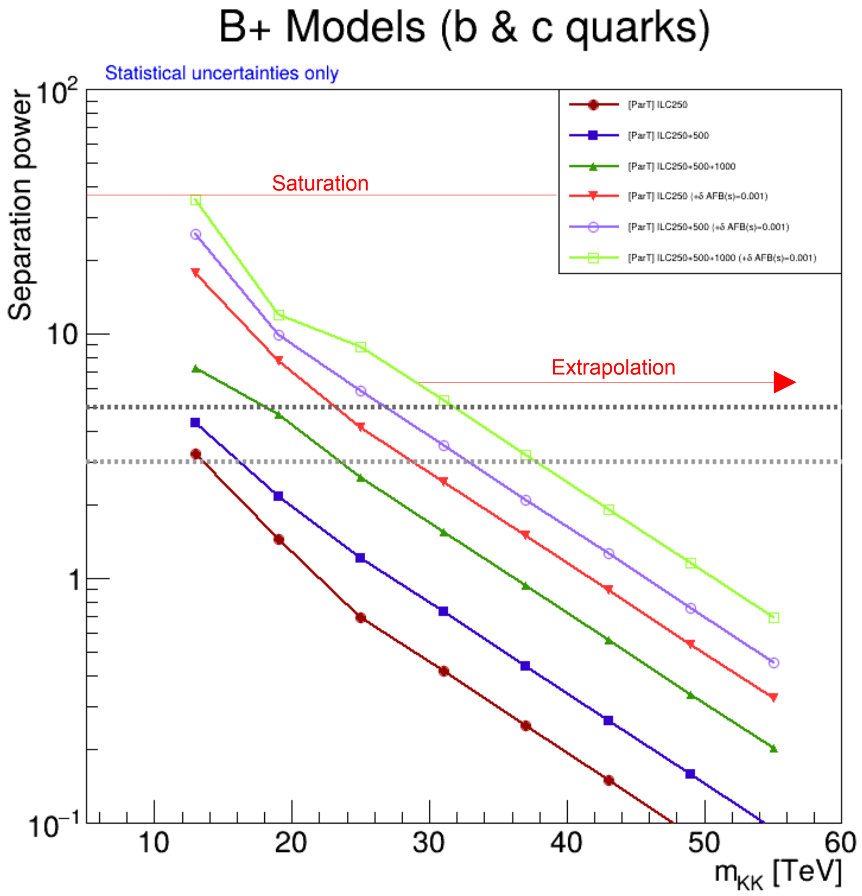
$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

Deviations at the per mil level

B+ models mass scale

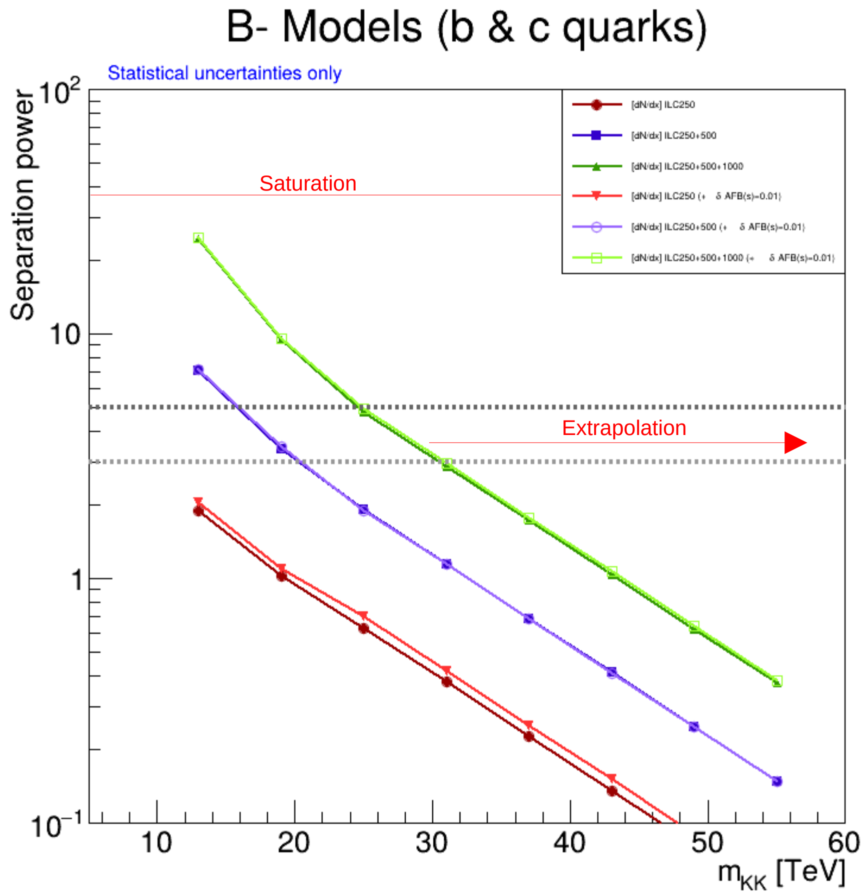
- Worst (dN/dx + 1% δA_{FB} for s-quark) vs best (ParT + 1‰ δA_{FB} for s-quark) pr

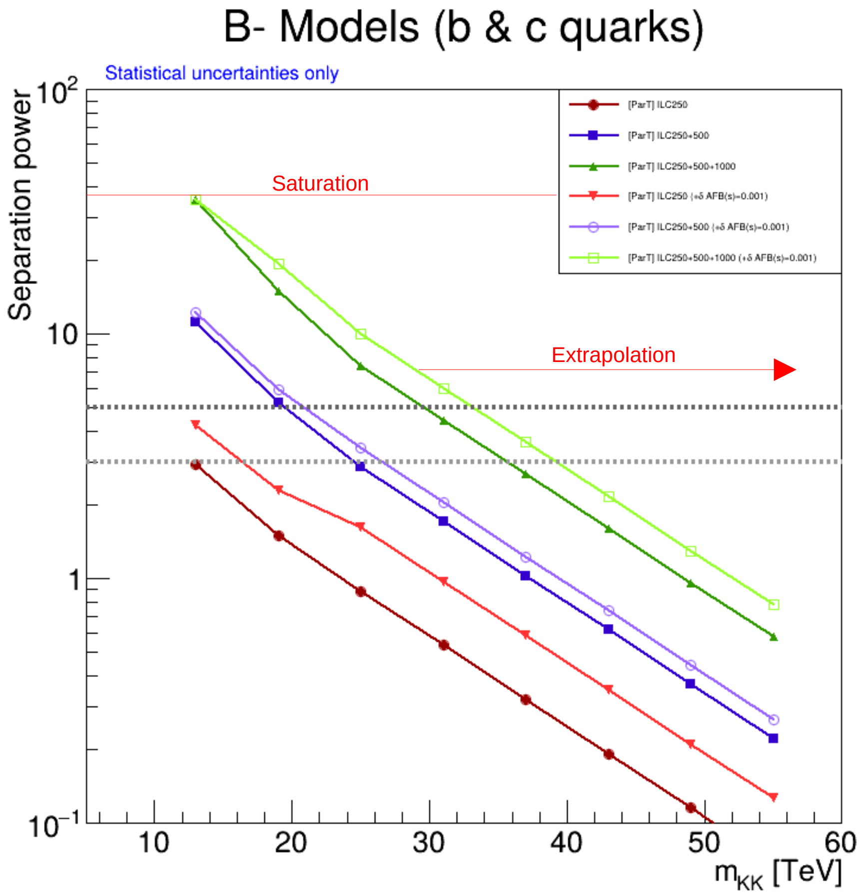




B- models mass scale

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





Adding s quark (1% relative error)

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

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

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	0.4	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

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

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	0.5	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

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

GHU vs SM (separation power)

$m_{Z'}$ [TeV]		ILC250♦ (no pol.)			ILC250			ILC250 +500			ILC250 +500 +1000*		
		B	C	Q	B	C	Q	B	C	Q	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

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

GHU vs SM (separation power)

$m_{Z'}$ [TeV]		ILC250♦ (no pol.)			ILC250			ILC250 +500			ILC250 +500 +1000*		
		B	C	Q	B	C	Q	B	C	Q	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