Experimental prospects for BSM searches in $e^+e^- \rightarrow q\bar{q}$ (q = b, c) at Higgs Factories

EPS HEP2023 HAMBURG

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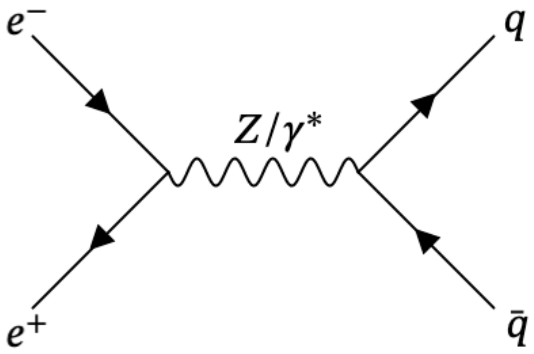
Outline

- **ILC physics** program for heavy quark studies.
  - **Full Simulation** at 250 & 500 GeV.
- BSM framework: **Gauge-Higgs Unification (GHU)**.
  - Phenomenology of two kinds of models (A & B).
- Physical observables at **ILC250/500**.
  - **Forward-backward asymmetry** (**A_{FB}**).
- **TPC PID** role in flavour tagging & charge measurement.
- **Discrimination power** for GHU's Models.

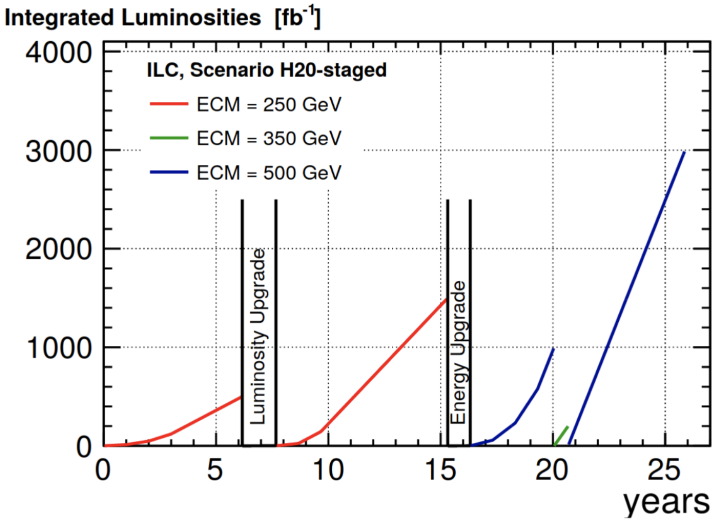


ILC physics program

- The ILC is more than a Higgs factory:
  - It provides access to **all SM particles**.
- It also features polarized beams $P(e^-,e^+)=(\pm0.8,\pm0.3)$.
  - Allow us to inspect all 4 helicity amplitudes:

$$\frac{d\sigma^{q\bar{q}}_{XY}}{d\cos\theta}(\cos\theta) \approx \frac{s}{32\pi}\left\{(1+\cos\theta)^2\,\underbrace{|Q_{eXqX}|^2} + (1-\cos\theta)^2\,\underbrace{|Q_{eXqY}|^2}\right\}$$

- It can aim for specific processes by adjusting:
  - **Center-of-mass energy**.
  - **Beam polarisation**.
- ILC run plan:
  - Also envisions runnings at Z-pole and 1 TeV.



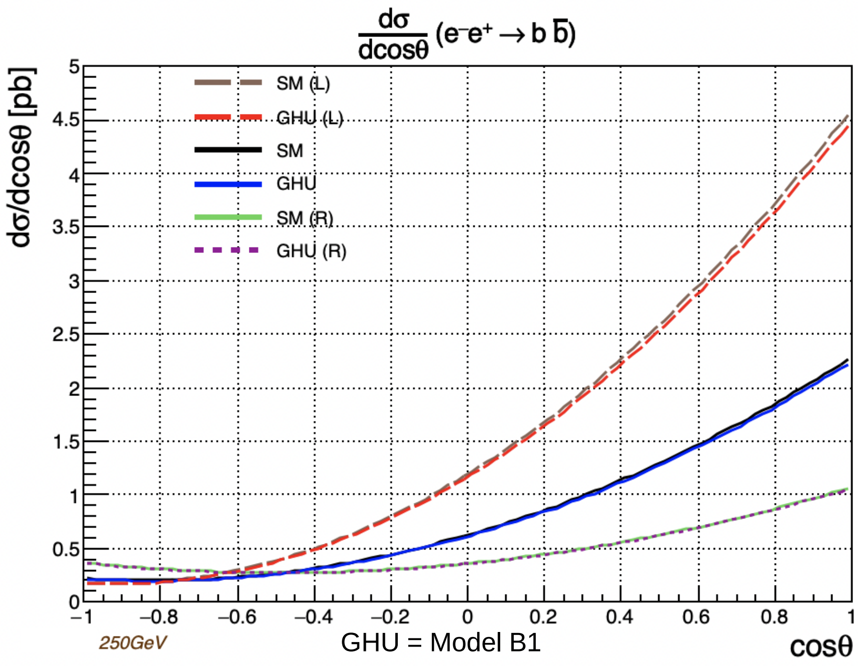
Luminosity upgrade: 5 Hz to 10 Hz.
Energy upgrade: Extend the linac

	sgn(P(e⁻),P(e⁺))			
	(-,+)	(+,-)	(-,-)	(+,+)
$\sqrt{s}$	Int. Luminosity (fb^{-1})			
250 GeV	900	900	100	100
350 GeV	135	45	10	10
500 GeV	1800	1800	200	200

Gauge-Higgs Unification Models

- GHU [Hos. et al] models unify all forces under the same gauge group. It's defined in a Randall-Sundrum metric (5D).
- The symmetry breaking pattern is different than in the SM and features the so-called *Hosotani's mechanism*.
  - **One parameter**, ϕ_H, determines the projection of the 5D fields, fixing most of the physical effects:
    - **KK-resonances** of Z/ɣ!
      - But m_{kk}~10 TeV, **only indirect measurements**.
    - Effects in **EW couplings/helicity amplitudes**.
    - Deviations from SM **scale with energy**:
      - **It start being noticeable at 250 GeV!**
  - We distinguish **A-Models** and **B-Models**.
    - A-Models are more sensitive to Right-Handed helicity & B-Models to Left-Handed helicity.
    - A-Models (1705.05282) & B-Models (2006.02157).

      [Funatsu, Hatanaka, Hosotani, Orikasa, Yamatsu]



Projection of couplings and EW mixing angle:

$$g_Y^{5D} = \frac{g_A g_B}{\sqrt{g_A^2 + g_B^2}} \qquad \sin\theta_W^0 = \frac{s_\phi}{\sqrt{1+s_\phi^2}}$$

Observable (A_{FB})

- **Forward-backward asymmetry (A_{FB})**:
  - Quark ID + charge measurement.
  - Angular measurement needed.

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

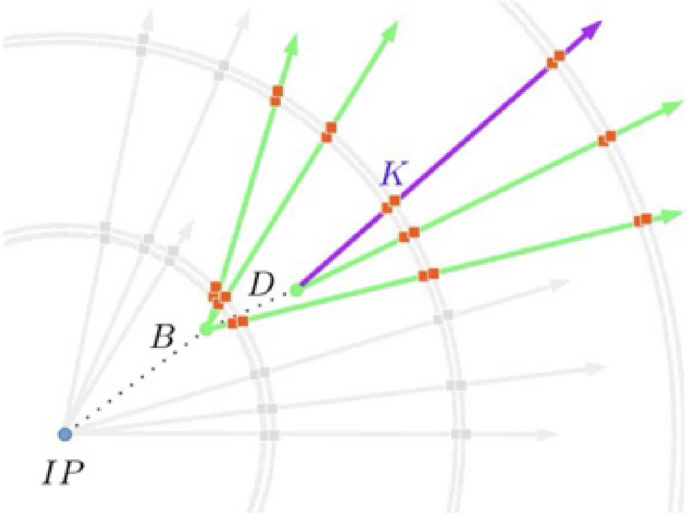
$$A_{FB}^{Exp} = \frac{N_F - N_B}{N_{Total}}$$

Normalized & **differential** observables are highly preferred:
Control of systematic uncertainties.

Up to a total of 8 *different measurements*.

Preselection of $b\bar{b}$ & $c\bar{c}$ signals

- Experimental procedure:
  - Preselection of $q\bar{q}$ events.
    - Removal of backgrounds.
      - Mostly **radiative return**.
        - Up to x10 more data than the signal!
  - Flavour tagging.
    - Using standard ILD Tool: **LCFI+**.
      - Boosted Decision Trees (ROOT TMVA).
  - Jet charge measurement:
    - **VTX method**: Use all secondary tracks.
    - **Kaon method**: Use **TPC's kaon PID**



Double Tag method: *Only* events with 2 opposite-charged identified jets are accepted.

Previous Full Simulation Study (250 GeV). Public ILD Note (2306.11413).
A. Irles, R. Poeschl, F. Richard

Kaon ID in A_{FB} (250 GeV)

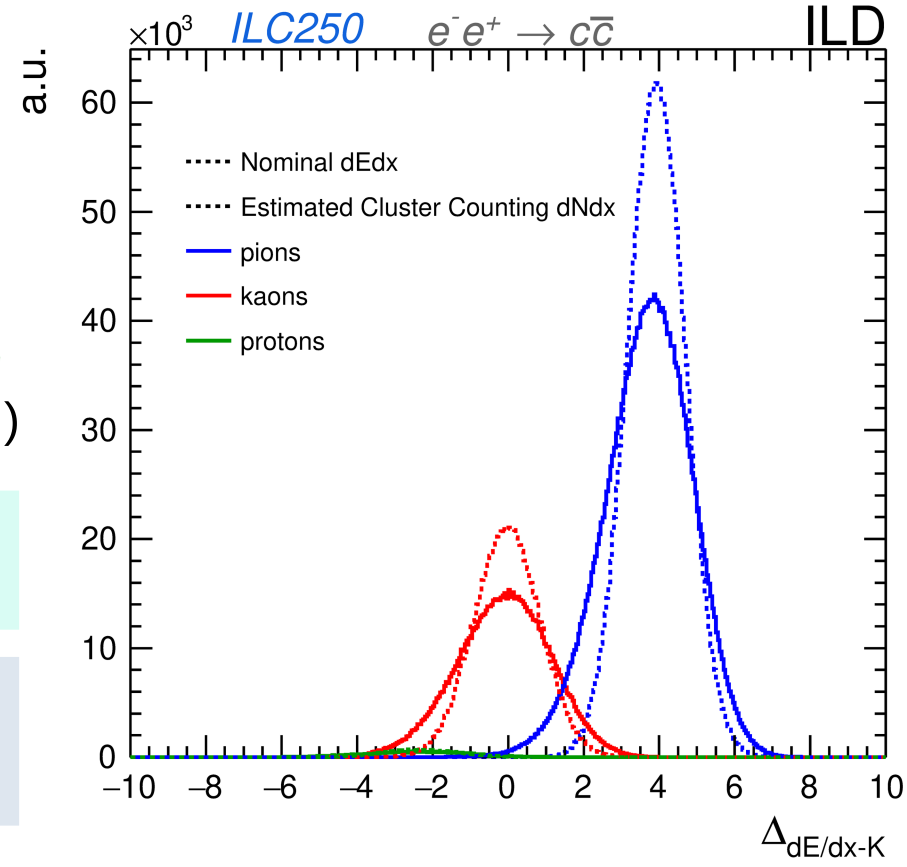
- Note how:
  - A_{FB} highly depends of identifying Kaons for charge measurement. After applying the **double-charge** selection criteria:
    - B-jets: Only ~18% of events survive.
      - Of which ~**40% requires PID**.
    - C-jets: Only ~4% of events survive.
      - Of which ~**90% requires PID!**

Improving the use of TPC PID

- New ways to improve the use of TPC-PID:
  - Include PID in the **Flavour Tagging (LCFI+)**.
    - More details in back-up!
  - Improve the PID performance itself.
    - From traditional dEdx to **cluster counting** method (+35%[1] in K/p separation power!)

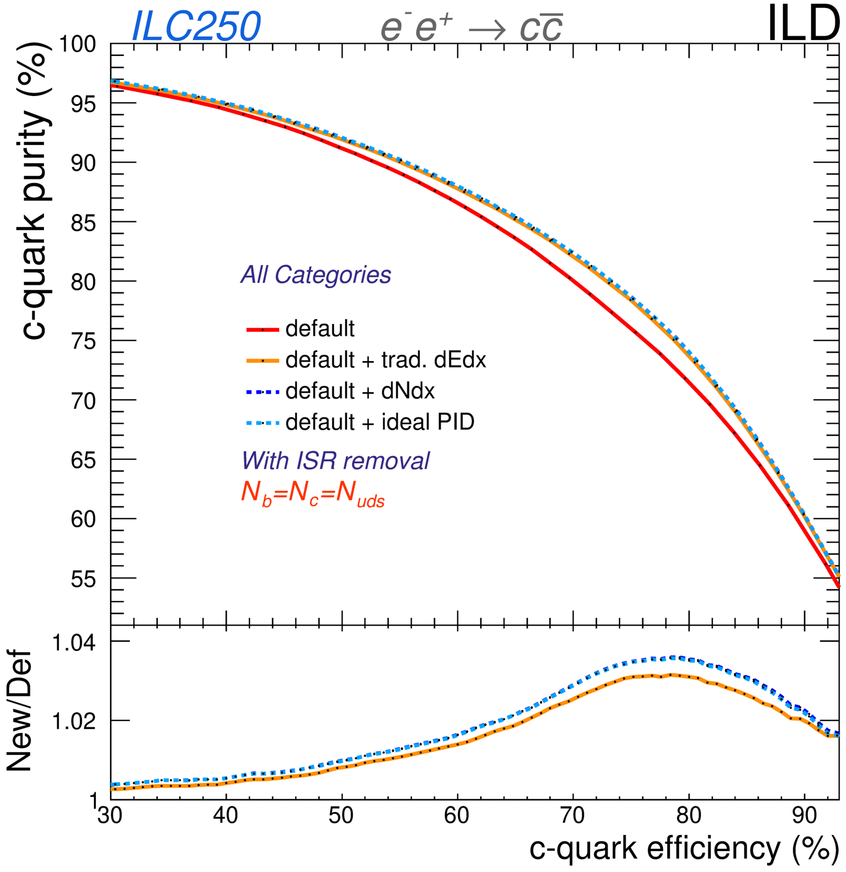
Cluster Counting (dNdx) improvement in PID is rewritten into the NTuples by an ILCSOFT processor

Full retraining of the flavour tagging is performed for each case by using a Particle Swarm Optimisation (PSO). More info in back-up.

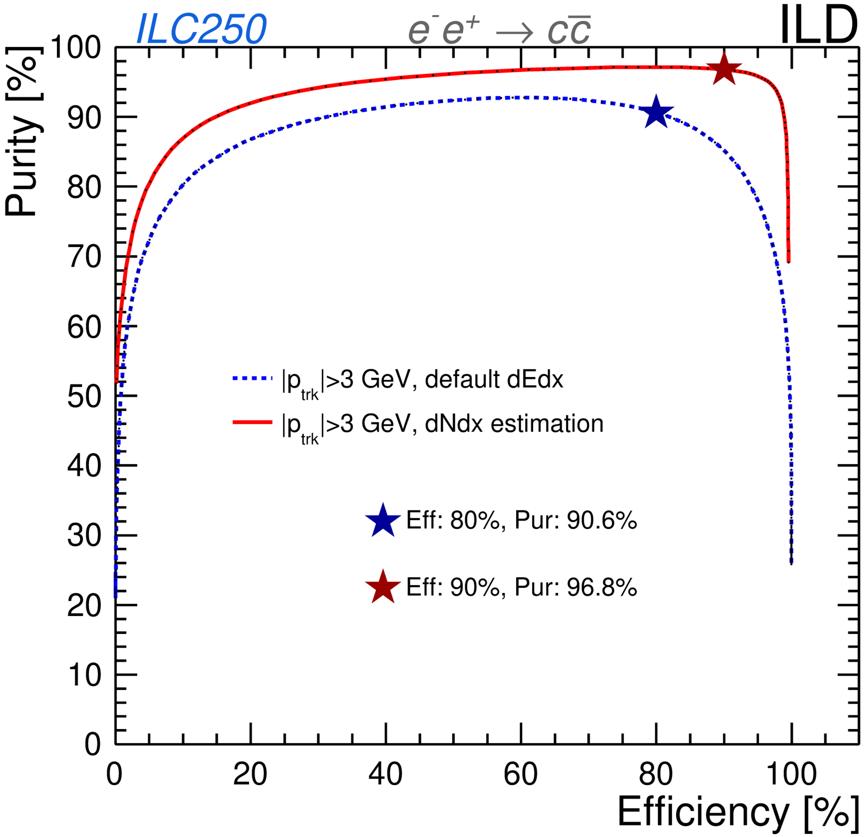


[1] *Y. Aoki et al.*, Double hit separation and dE/dx resolution of a time projection chamber with GEM readout, JINST 17 11 (2022) P11027, arXiv: 2205.12160 [physics.ins-det]

Effects of improving the use of PID

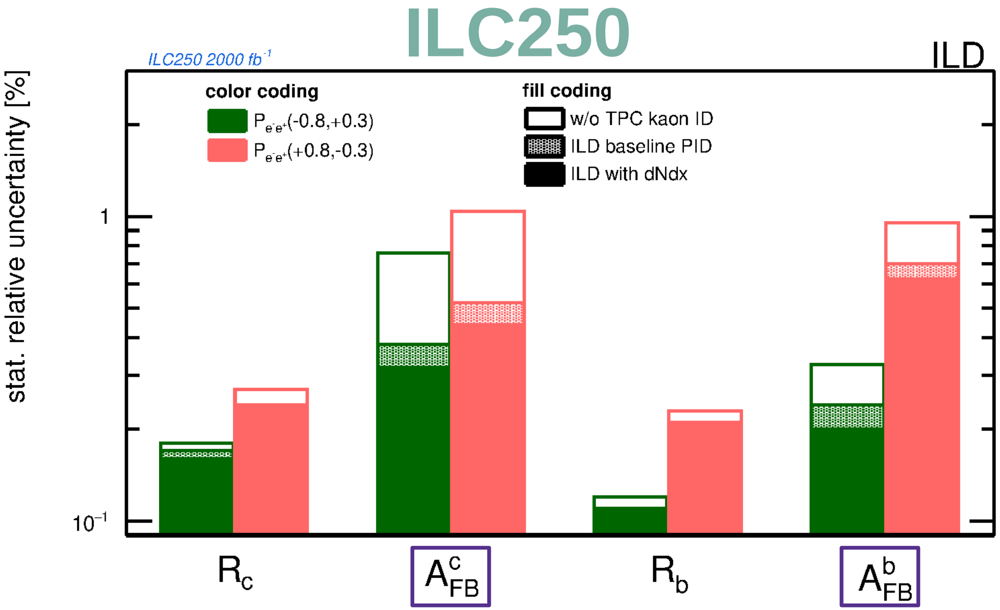


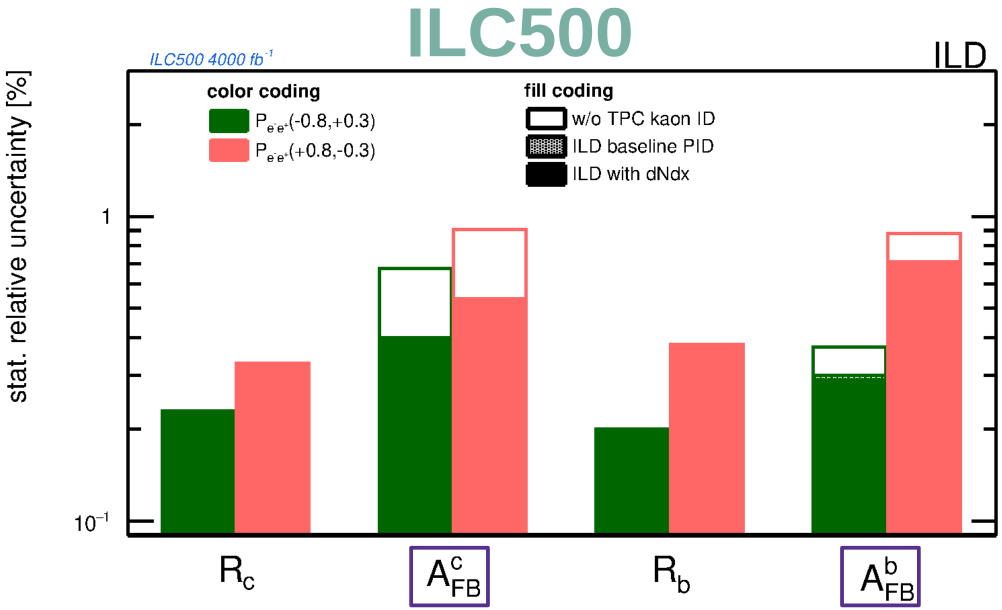
Effects in **Flavour Tagging**



Effects in **Kaon ID** for charge reco.

Statistical Uncertainties for R_q and A_{FB}





Full Simulation Studies. (arXiv 2307.14888). A. Irles, J. P. Márquez

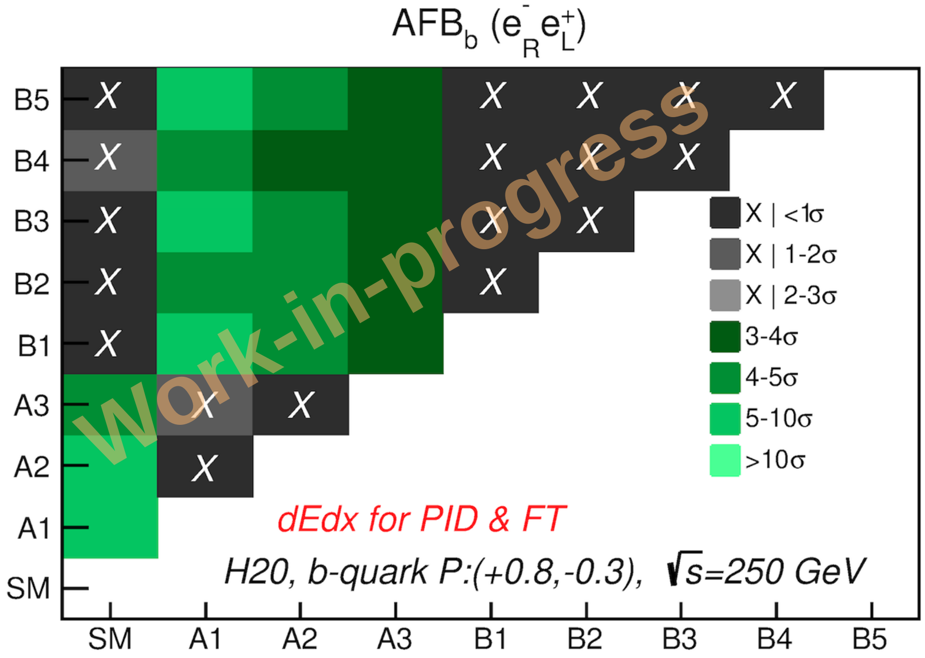
A comprehensive assessment of the dominant systematic uncertainties have been done (back-up)

Discrimination of BSM Models

- Assumption: A measurement of one specific model is conducted.
  - Row/Column combination for comparison.

- The uncertainties are considered normally distributed:
  - **Significance in σ**: $d_\sigma = \frac{\|AFB_{test} - AFB_{ref}\|}{\Delta_{AFB_{ref}}}$
  - P-value: Gaussian at d_σ.

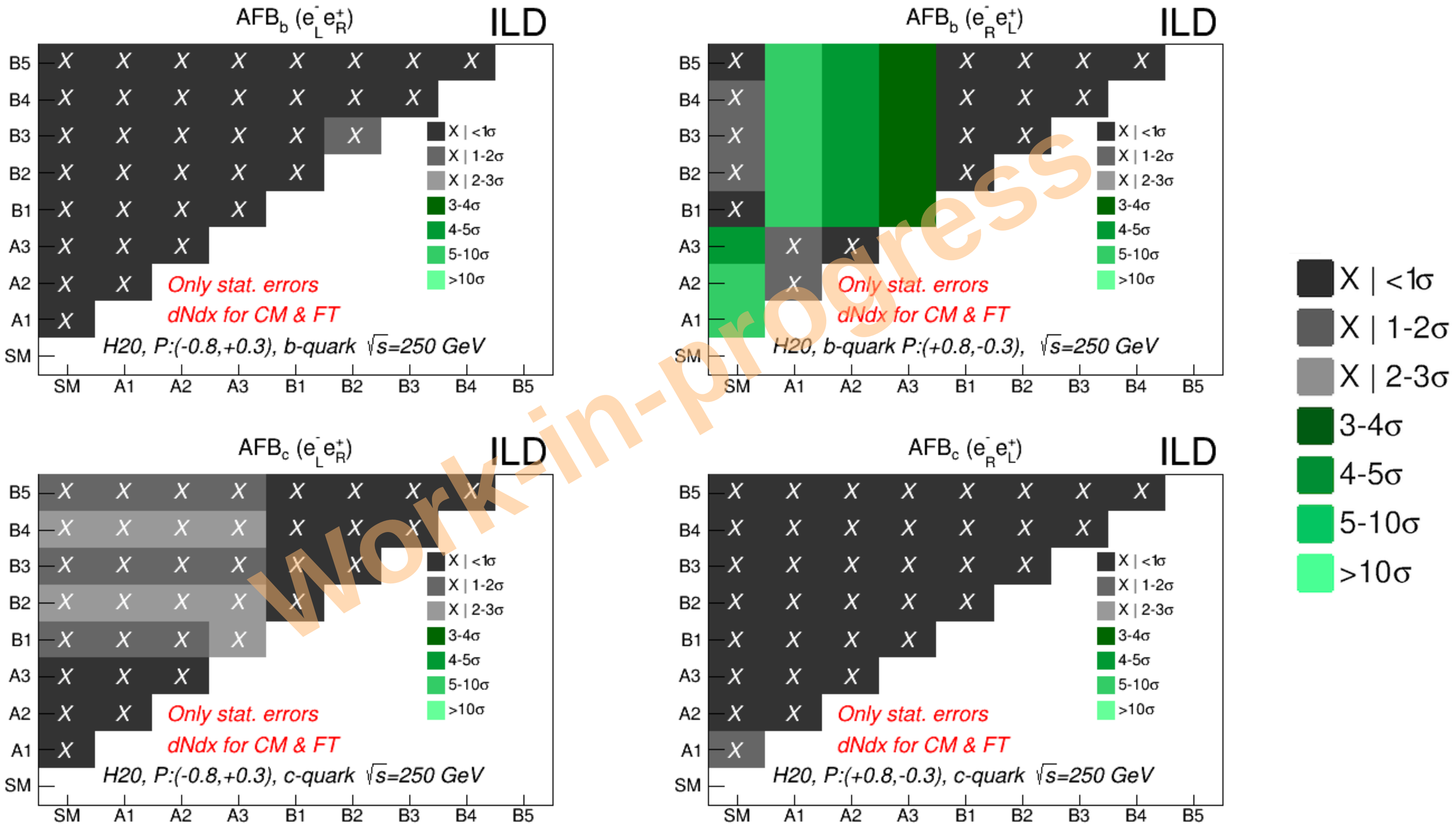
- Combination of multiple measurements is done with a *multivariate gaussian*.
  - Assuming no correlations for A_{FB}.



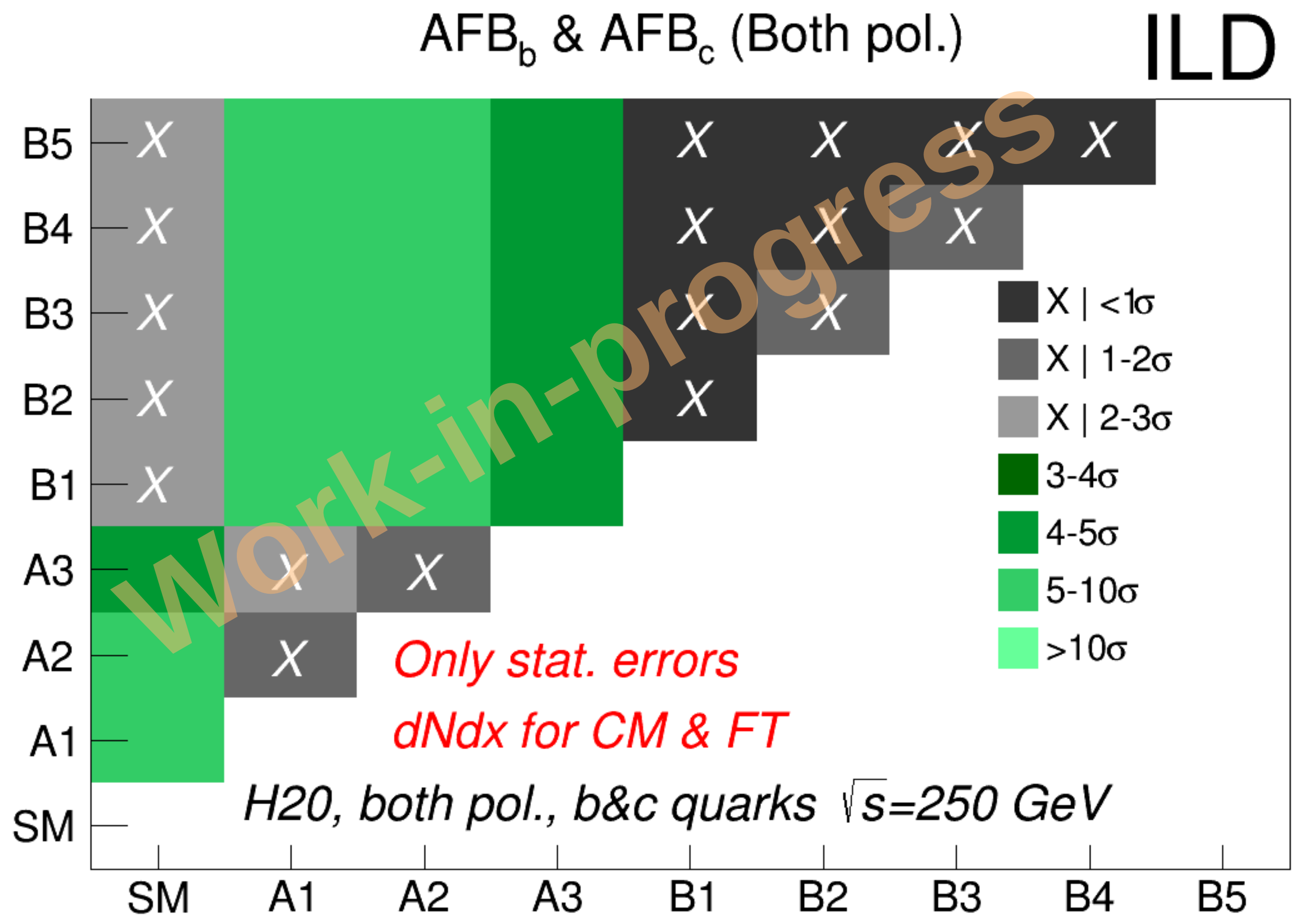
Only A_{FB} is being used.

R_q expected to be highly correlated

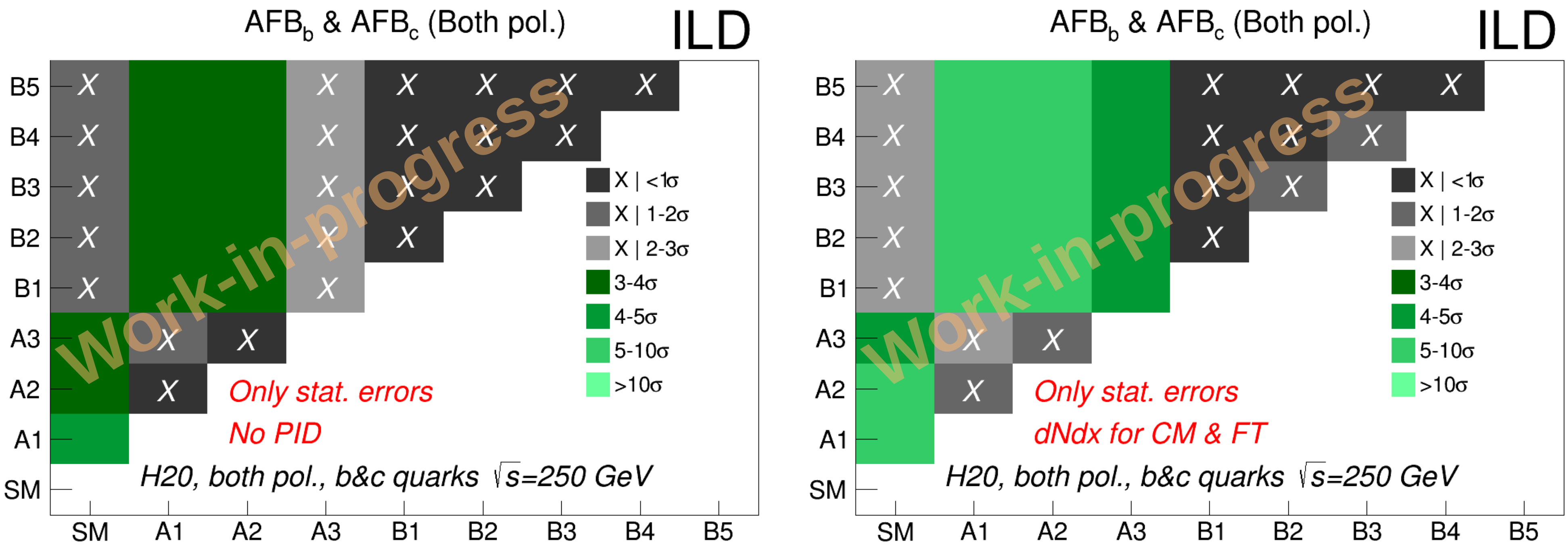
GHU's Models ILC250



GHU's Models ILC250 (combined)

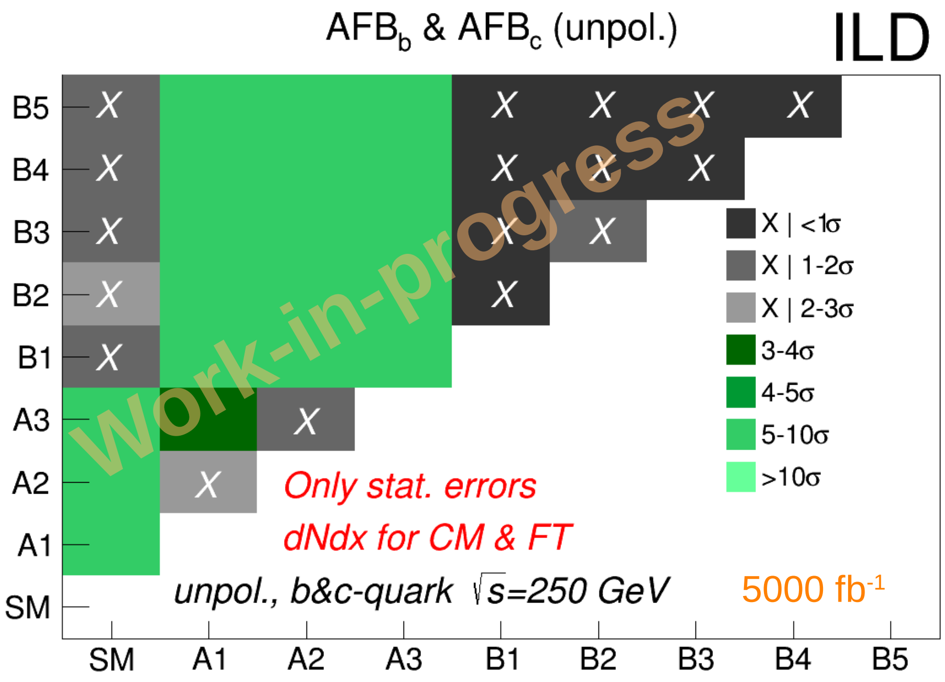


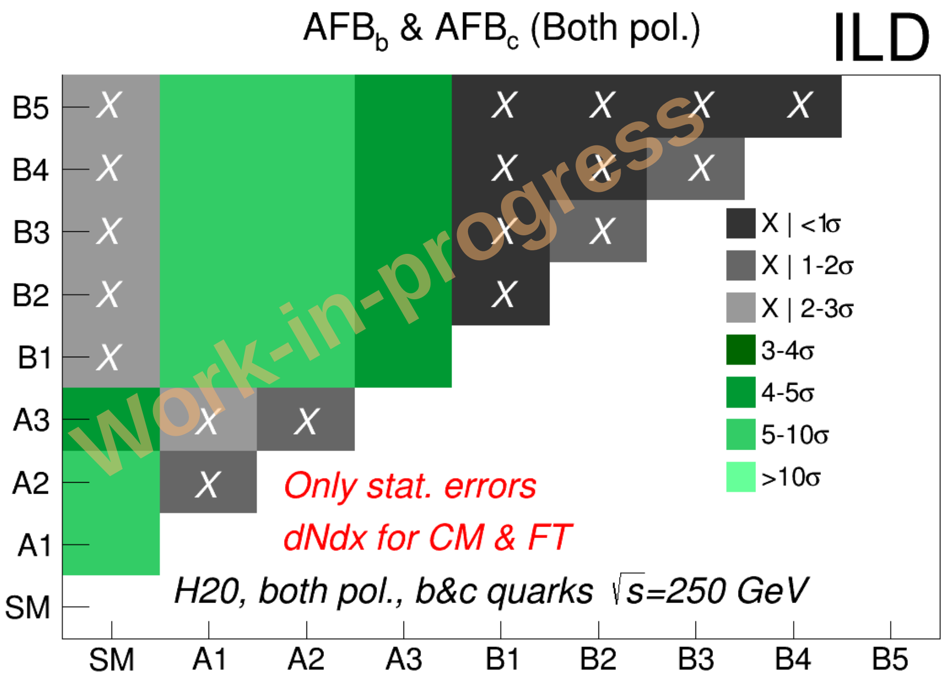
GHU's Models ILC250 (TPC impact)



We do **need TPC PID** to discriminate these models

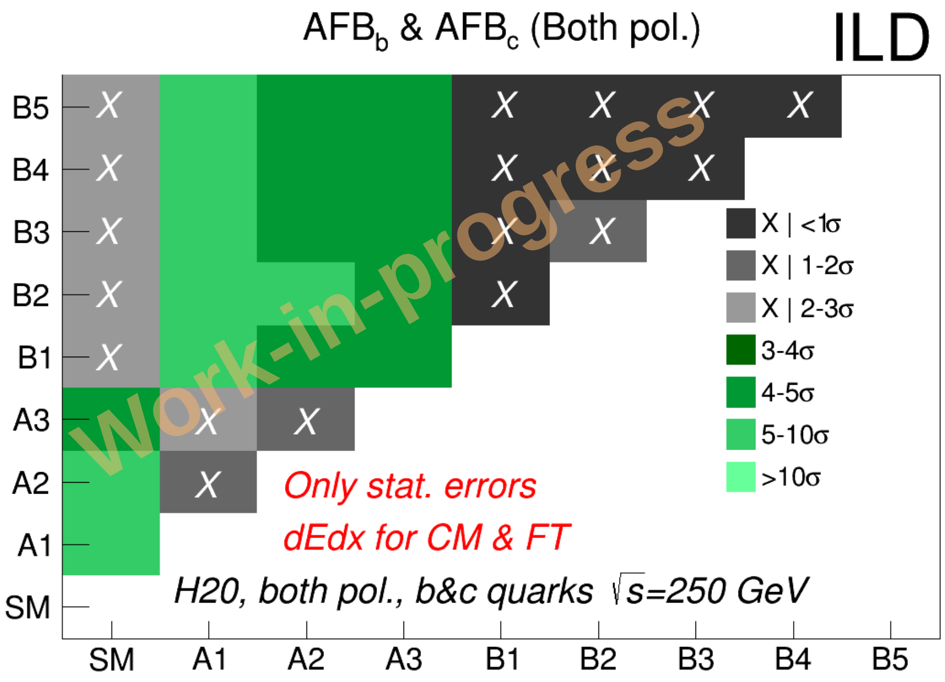
GHU's Models ILC250 (Polarisation impact)

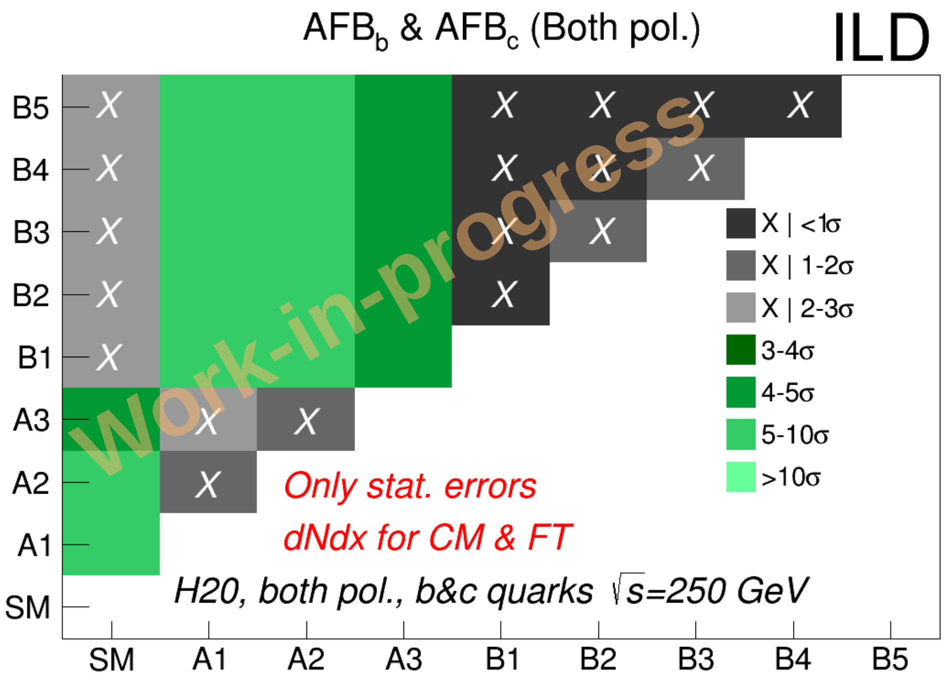




Effects of **polarised beams** at 250 GeV

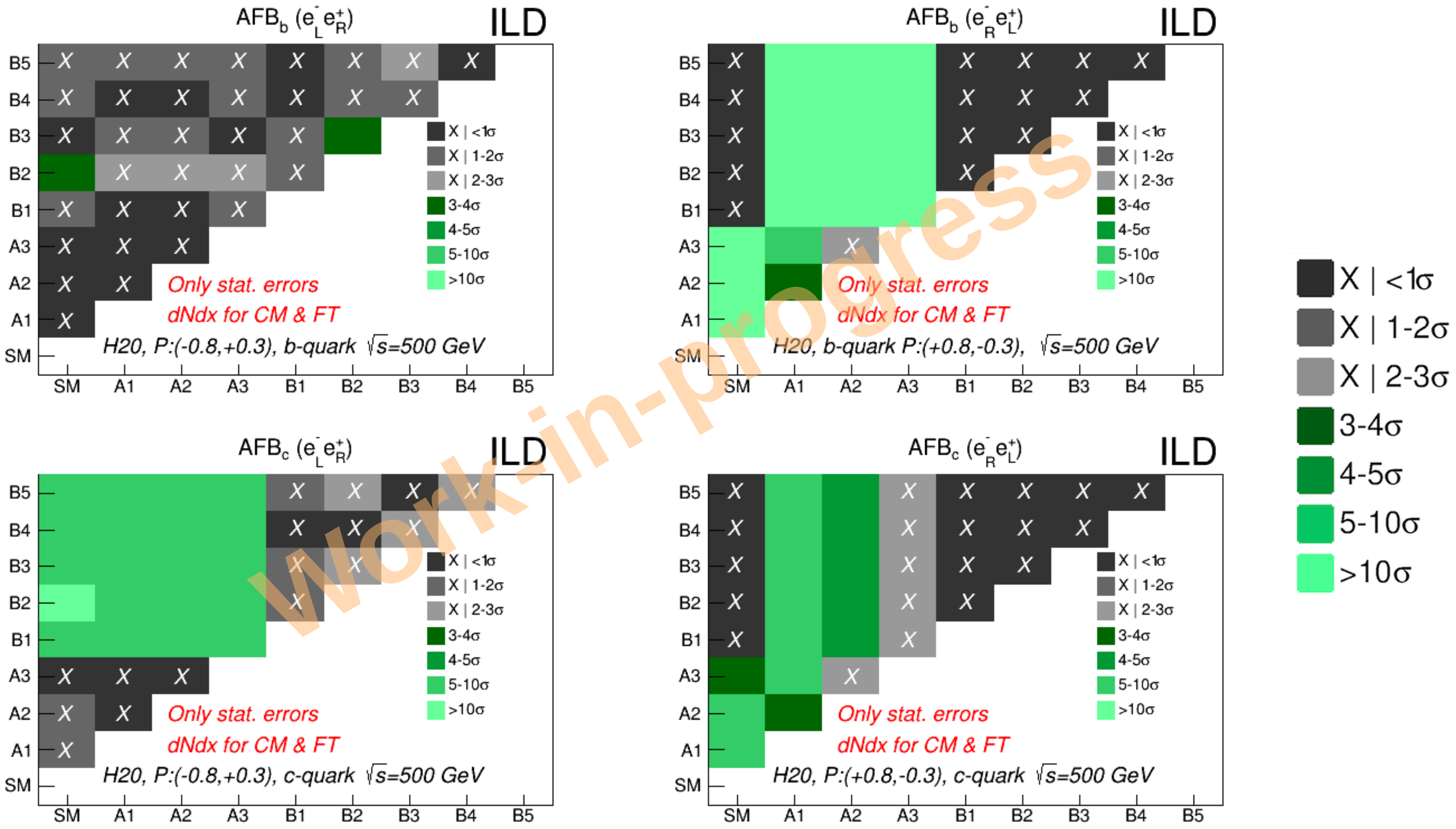
GHU's Models ILC250 (TPC+dNdx impact)





Using **dNdx** optimises the use of the TPC

GHU's Models ILC500



GHU's Models ILC500 (combined)

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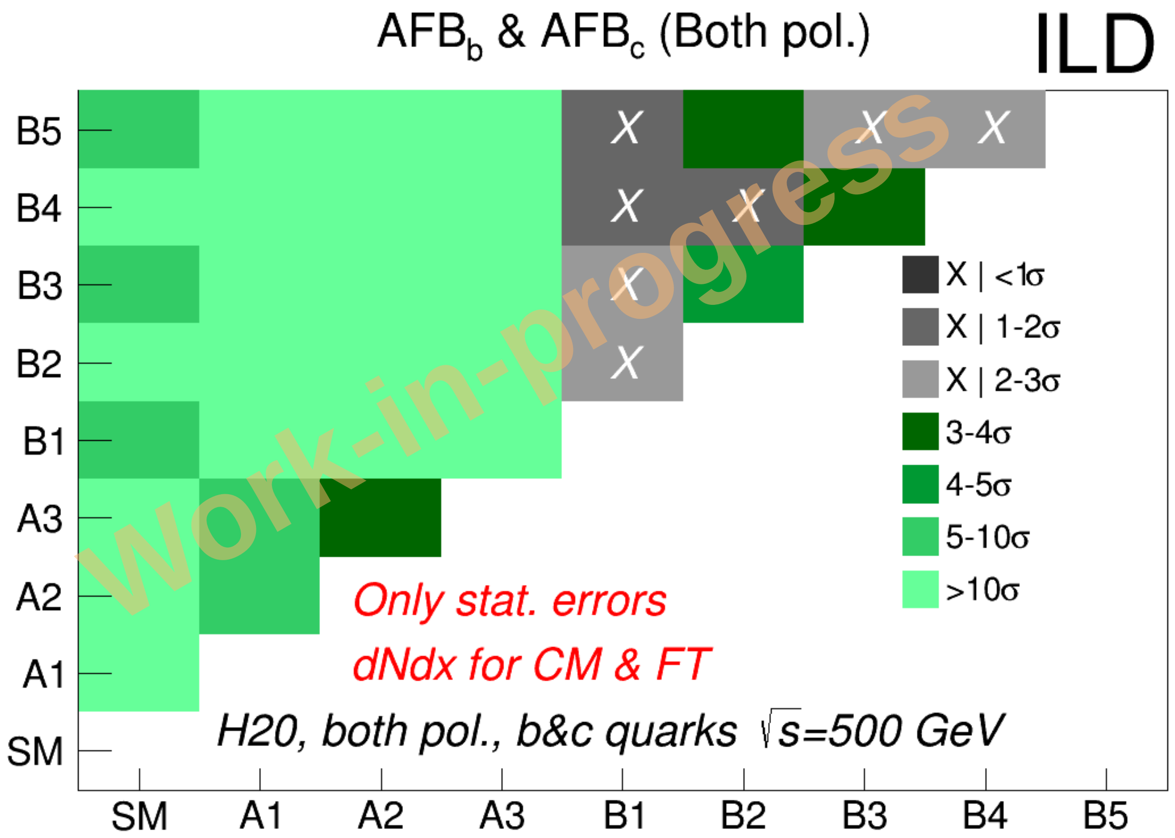
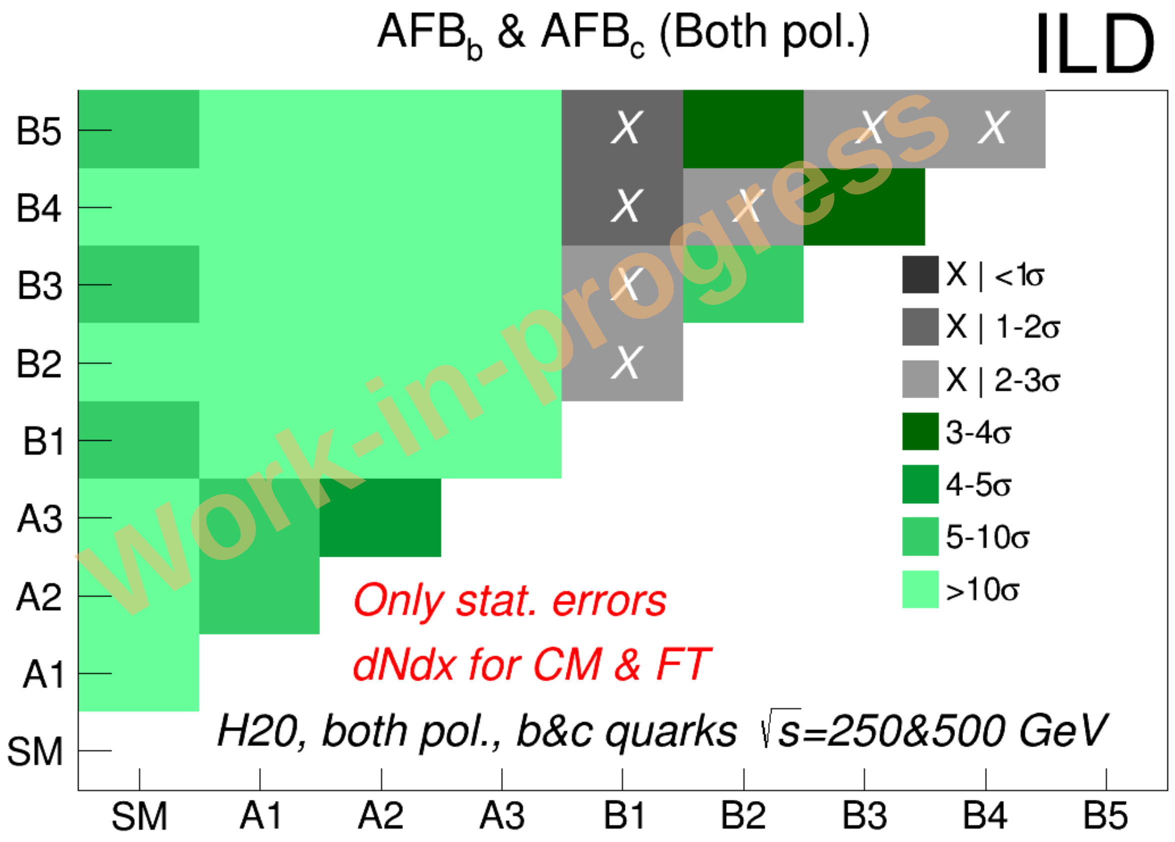


Accessing **higher energies** is a key factor to discriminate these models!

GHU's Models ILC250+500 (combined)



Above 5σ level wrt SM for all models, above 10σ for most of them!

Summary/Conclusions

- ILC+ILD are powerful tools to discriminate BSM Models thanks to:
  - Polarisation.
  - Energy range.

  } **Up to 4 different measurements per energy!**

  - **Key role of TPC PID**.
    - Flavour Tagging & jet charge reconstruction.

Full discrimination for GHU models is possible combining ILC250/500.

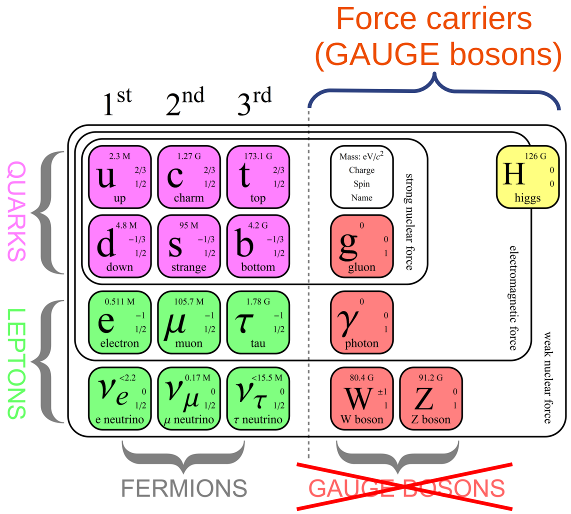
Thanks for your attention!

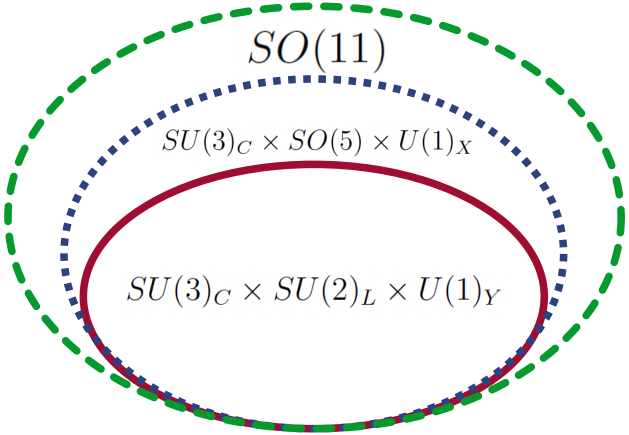
BACK-UP

GHU *Hosotani*'s Models

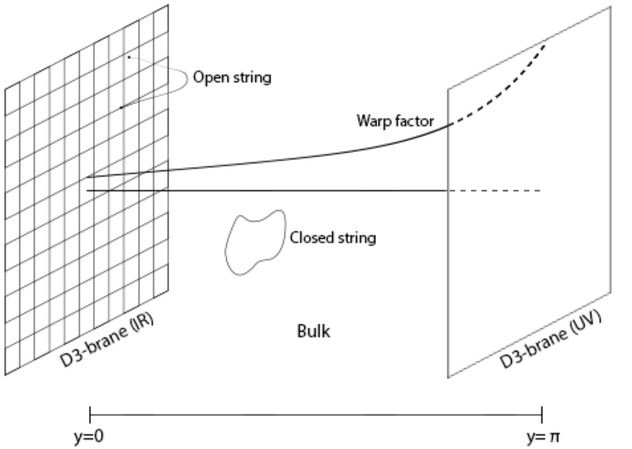
Gauge-Higgs Unification (GHU) Models

- In the Hosotani Models the GHU unify all the force carriers under a single gauge group by using an extra physical dimension (Randall-Sundrum metric):





$$ds^2 = g_{MN}dx^M dx^N = e^{-2\sigma(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2,$$



- The breaking pattern is way more complex than in the SM and features the Hosotani's mechanism.
  - Most of the fields are localized in the bulk and we feel the IR-projections.
  - We distinguish **A-Models** (GHU) and **B-Models** (GHU+GUT).

Projection of couplings and EW mixing angle:

$$g_Y^{5D} = \frac{g_A g_B}{\sqrt{g_A^2 + g_B^2}} \qquad \sin\theta_W^0 = \frac{s_\phi}{\sqrt{1+s_\phi^2}}$$

Gauge-Higgs Unification (GHU) Models

- The metric of the warped Randall-Sundrum space-time:

$$ds^2 = g_{MN}dx^M dx^N = e^{-2\sigma(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2,$$

- This is inspired by conformal symmetry, a.k.a. “scale symmetry”; used in cosmology, string theory and holography.
  - Conformal coordinates:

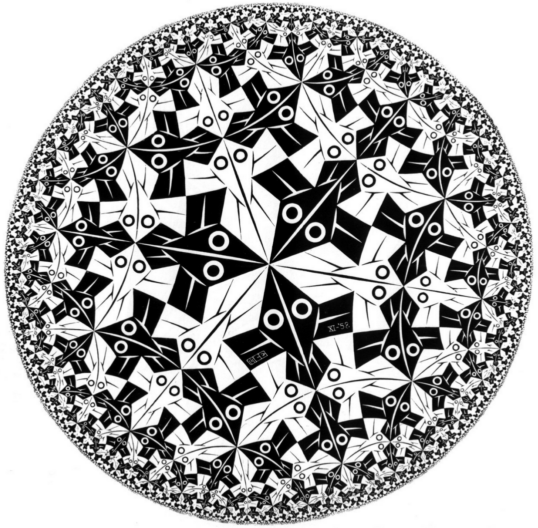
$$z = e^{ky}$$

  - The metric in conformal coordinates:

$$ds^2 = \frac{1}{z^2}\left(\eta_{\mu\nu}dx^\mu dx^\nu + \frac{dz^2}{k^2}\right)$$

Extra-dimension (+1D)

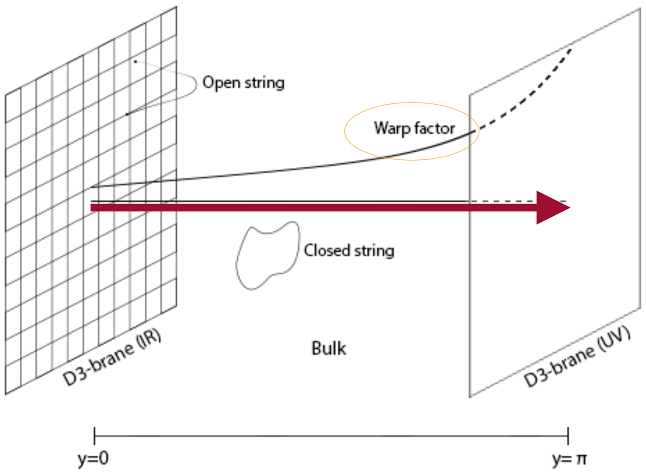
Minkowski space-time (4D)

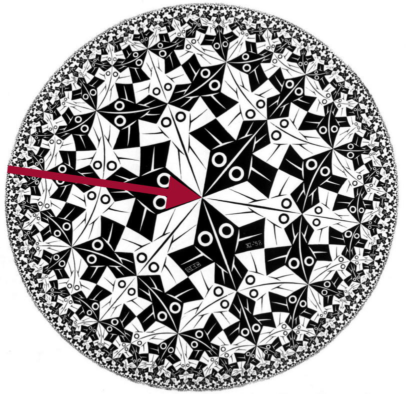


M. C. Escher “Circle Limit 1”. Example of conformal symmetry with hyperbolic scaling

Gauge-Higgs Unification (GHU) Models

- How the Randall-Sundrum space-time works:



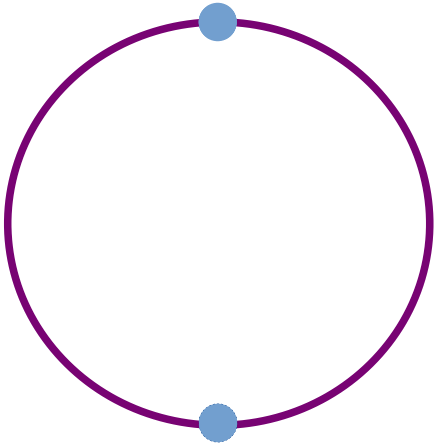


warping

$$ds^2 = g_{MN}dx^M dx^N = \underbrace{e^{-2\sigma(y)}}_{\text{warping}}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2,$$

5h dimension compactified in a ring-shaped, two branes at opposite points, orbifold b.c. in both parts of the circle

This side is symmetric to

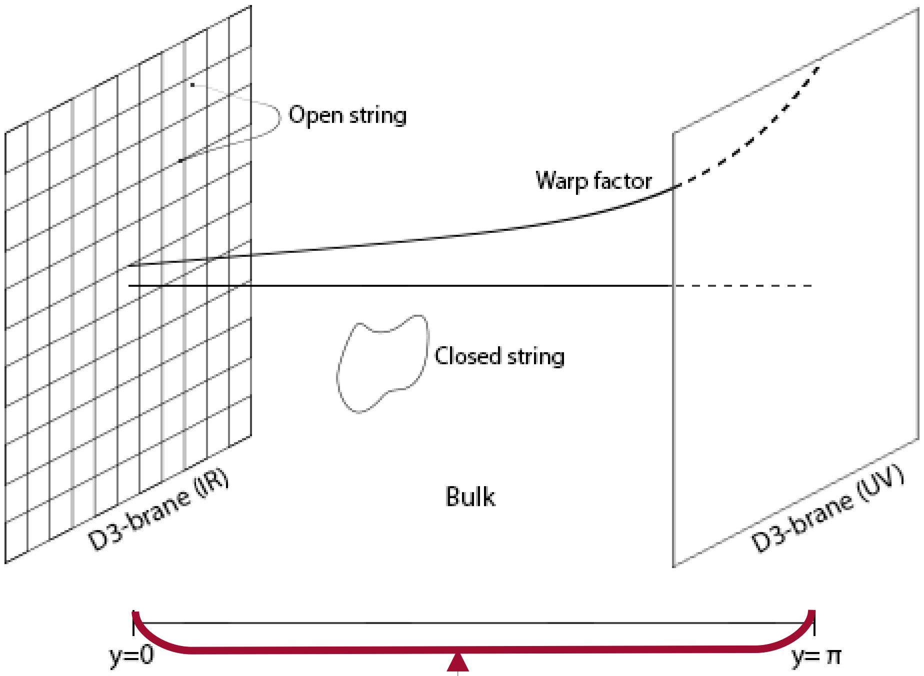


this other side

This was proposed as a way to explain why gravity is so much weaker that the rest of the forces: gravitons (closed strings) leak into the extra-dimension

Gauge-Higgs Unification (GHU) Models

- Kaluza-Klein resonances:



Normal modes over this interval (fifth component)

KK-resonances!

Gauge-Higgs Unification (GHU) Models

- How the Hosotani's Models work:
  - Most of the fields are localized in the bulk and the effects in our brane are projections.
  - The breaking pattern is way more complex than in the SM and features the Hosotani's mechanism:

$$SU(3)_C \times SO(5) \times U(1)_X$$

$$\underset{BC}{\rightarrow} \; SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X \quad \text{at } y = 0, L$$

$$\underset{\langle\Phi\rangle}{\rightarrow} \; SU(3)_C \times SU(2)_L \times U(1)_Y \quad \text{by the VEV } \langle \Phi_{(\mathbf{1},\mathbf{4})} \rangle \neq 0 \text{ at } y = 0$$

$$\underset{\theta_H}{\rightarrow} \; SU(3)_C \times U(1)_{EM} \qquad \text{by the Hosotani mechanism,}$$

	B-model	A-model
Quark Lepton	$(\mathbf{3},\mathbf{4})_{\frac{1}{6}}$ $(\mathbf{3},\mathbf{1})^{+}_{-\frac{1}{3}}$ $(\mathbf{3},\mathbf{1})^{-}_{-\frac{1}{3}}$ $(\mathbf{1},\mathbf{4})_{-\frac{1}{2}}$	$(\mathbf{3},\mathbf{5})_{\frac{2}{3}}$ $(\mathbf{3},\mathbf{5})_{-\frac{1}{3}}$ $(\mathbf{1},\mathbf{5})_{0}$ $(\mathbf{1},\mathbf{5})_{-1}$
Dark fermion	$(\mathbf{3},\mathbf{4})_{\frac{1}{6}}$ $(\mathbf{1},\mathbf{5})^{+}_{0}$ $(\mathbf{1},\mathbf{5})^{-}_{0}$	$(\mathbf{1},\mathbf{4})_{\frac{1}{2}}$
Brane fermion	$(\mathbf{1},\mathbf{1})_{0}$	$(\mathbf{3},[\mathbf{2},\mathbf{1}])_{\frac{7}{6},\frac{1}{6},-\frac{5}{6}}$ $(\mathbf{1},[\mathbf{2},\mathbf{1}])_{\frac{1}{2},-\frac{1}{2},-\frac{3}{2}}$
Brane scalar	$(\mathbf{1},\mathbf{4})_{\frac{1}{2}}$	$(\mathbf{1},[\mathbf{1},\mathbf{2}])_{\frac{1}{2}}$

Field content in the group representation

  - Different limits for the two types of models:
    - **A-Models** (1705.05282): Adjusted to LEP data (Z-Pole and ~200GeV range). Constrained with LHC pp-collisions (non detection of Z'). Up to 0.01% deviation in Z couplings to leptons.
    - **B-Models** (2006.02157): Similar constrains from LHC. Up to 0.1% deviation in Z couplings to leptons.

In both cases, only indirect measurement of Z' is possible (m>1 TeV)

General

Observables

- Differential Cross-Section:
  - General case with polarisation dependence:

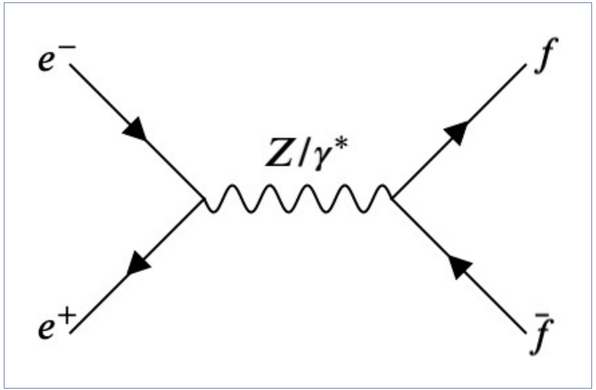
$$\frac{d\sigma^{f\bar{f}}}{d\cos\theta}(P_{e^-}, P_{e^+}, \cos\theta) = (1 - P_{e^-}P_{e^+})\frac{1}{4}\left\{(1 - P_{eff})\frac{d\sigma_{LR}^{f\bar{f}}}{d\cos\theta}(\cos\theta) + (1 + P_{eff})\frac{d\sigma_{RL}^{f\bar{f}}}{d\cos\theta}(\cos\theta)\right\}$$

$$P_{\text{eff}} \equiv \frac{P_{e^-} - P_{e^+}}{1 - P_{e^-}P_{e^+}}$$

  - Polarization contributions:

$$\frac{d\sigma_{LR}^{f\bar{f}}}{d\cos\theta}(\cos\theta) \simeq \frac{s}{32\pi}\left\{(1+\cos\theta)^2\left|Q_{e_L f_L}\right|^2 + (1-\cos\theta)^2\left|Q_{e_L f_R}\right|^2\right\}$$

$$\frac{d\sigma_{RL}^{f\bar{f}}}{d\cos\theta}(\cos\theta) \simeq \frac{s}{32\pi}\left\{(1+\cos\theta)^2\left|Q_{e_R f_R}\right|^2 + (1-\cos\theta)^2\left|Q_{e_R f_L}\right|^2\right\}$$



- Helicity amplitudes from the s-channel (may include BSM mediators):
  - They could only be inspected by using polarisation.

$$Q_{e_X f_Y} = \sum_i \frac{g_{V_i e}^X g_{V_i f}^Y}{(s - m_{V_i}^2) + i m_{V_i}\Gamma_{V_i}}$$

Observables

- **Hadronic fraction (R_q):**
  - Quark ID (flavour tagging).
  - Angular measurement *possible*, but not needed.

$$R_q = \frac{\sigma_{e^-e^+\to q\bar{q}}}{\sigma_{hadron}}$$

- **Forward-backward asymmetry (A_{FB}):**
  - Quark ID + charge measurement.
  - Angular measurement needed.

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

Normalized & **differential** observables are highly preferred:
Control of systematic uncertainties.

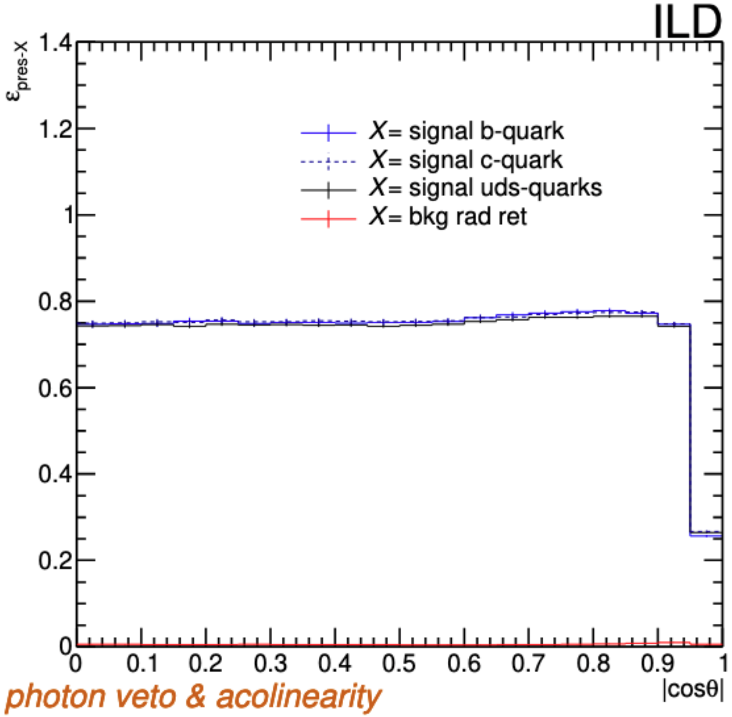
$$A_{FB}^{Exp} = \frac{N_F - N_B}{N_{Total}}$$

$$R_q^{Exp} = \frac{N_q}{N_{hadron}}$$

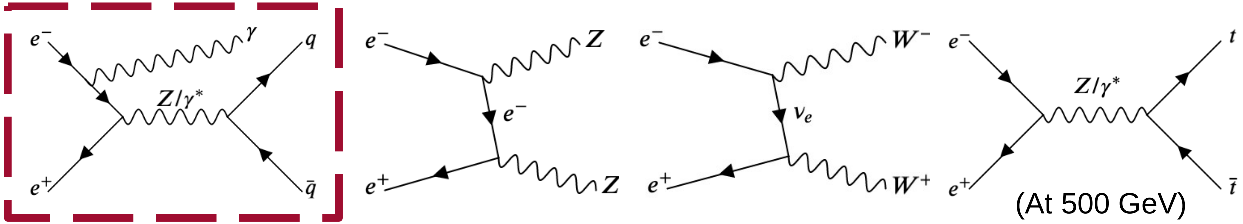
Up to a total of *16 different measurements*.
But this study **will only explore result on AFB**.

Preselection of $q\bar{q}$ signals

- ILCSOFT cluster the pfos in jets (VLC algorithm):
  - The algorithm packs together the PFOs into two back-to-back jets.
  - Most of the data is background! (~x10).
    - Most of the background is **radiative return ($\gamma q\bar{q}$)**.
  - Most of the backgrounds (ZZ, WW, ISR, tt) are removed with topological, kinematical and energetic cuts.
    - And additional cut by identifying photon pfos in the detector is used for ISR.
      - PFA detector!



photon veto & acolinearity & m_{jj} & y_{23} cuts



(At 500 GeV)

Systematical uncertainties (250 GeV)

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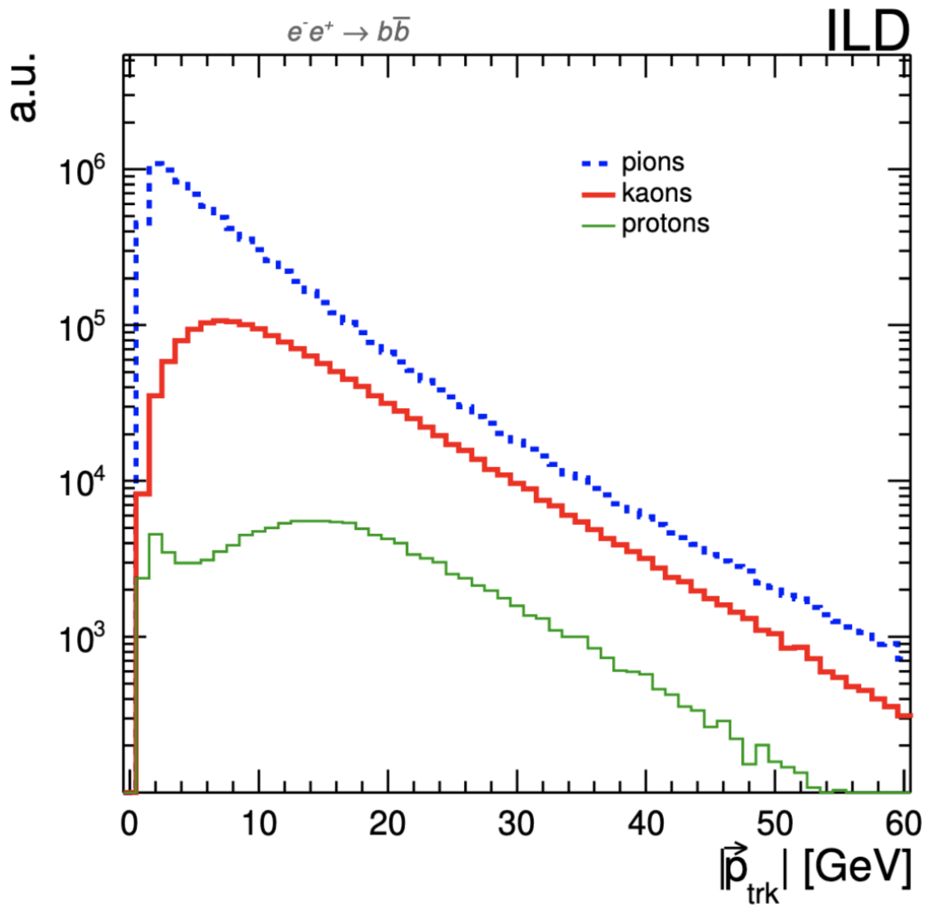
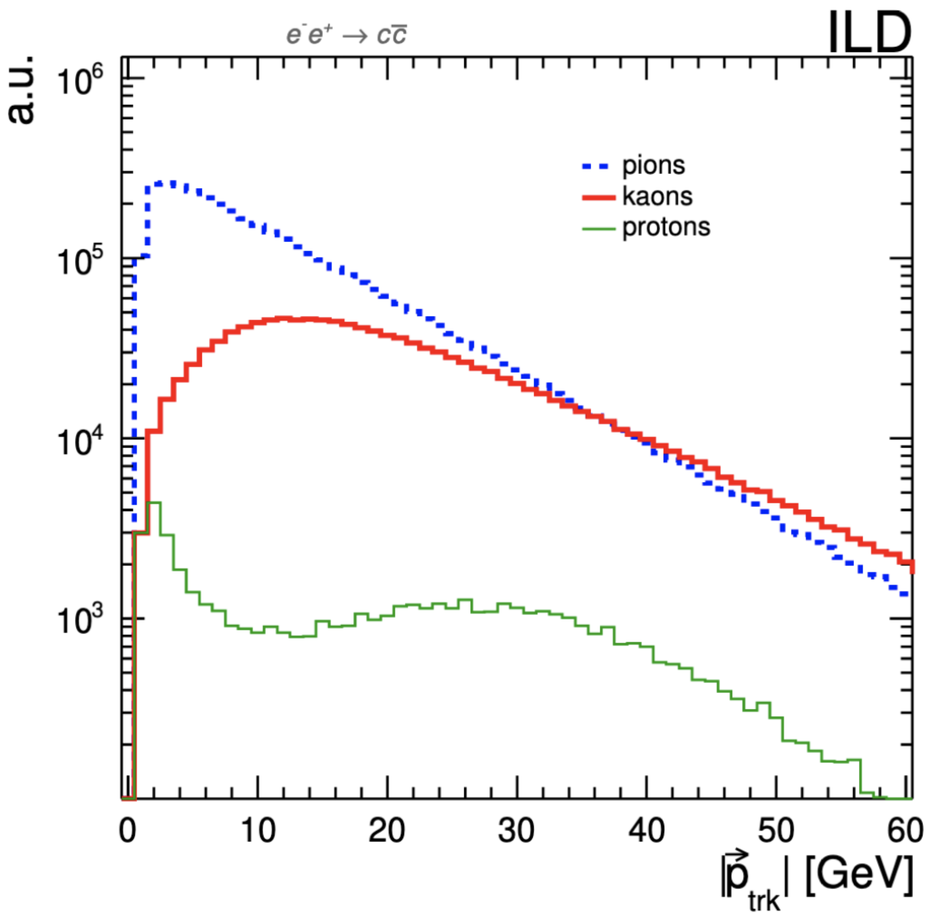
Source	$e^- e^+ \to c\bar{c}$				$e^- e^+ \to b\bar{b}$			
	$P_{e^-e^+}(-0.8,+0.3)$		$P_{e^-e^+}(+0.8,-0.3)$		$P_{e^-e^+}(-0.8,+0.3)$		$P_{e^-e^+}(+0.8,-0.3)$	
	R_c	$A_{FB}^{c\bar{c}}$	R_c	$A_{FB}^{c\bar{c}}$	R_b	$A_{FB}^{b\bar{b}}$	R_b	$A_{FB}^{b\bar{b}}$
Statistics	**0.18%**	**0.38%**	**0.27%**	**0.52%**	**0.12%**	**0.24%**	**0.23%**	**0.70%**
Preselection eff.	<0.01%	0.12%	0.02%	0.16%	<0.01%	0.08%	0.06%	0.12%
Background	0.01%	0.01%	0.02%	0.02%	0.01%	0.01%	0.06%	<0.01%
heavy quark mistag	0.11%	<0.01%	0.06%	<0.01%	0.12%	<0.01%	0.22%	<0.01%
uds mistag	0.03%	<0.01%	0.02%	<0.01%	0.08%	<0.01%	0.14%	<0.01%
Angular correlations	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
Beam Polarisation	<0.01%	<0.01%	0.02%	0.01%	<0.01%	0.01%	0.03%	0.15%
Systematics	**0.15%**	**0.16%**	**0.12%**	**0.19%**	**0.18%**	**0.13%**	**0.29%**	**0.22%**
Total	**0.24%**	**0.41%**	**0.30%**	**0.55%**	**0.21%**	**0.27%**	**0.37%**	**0.73%**

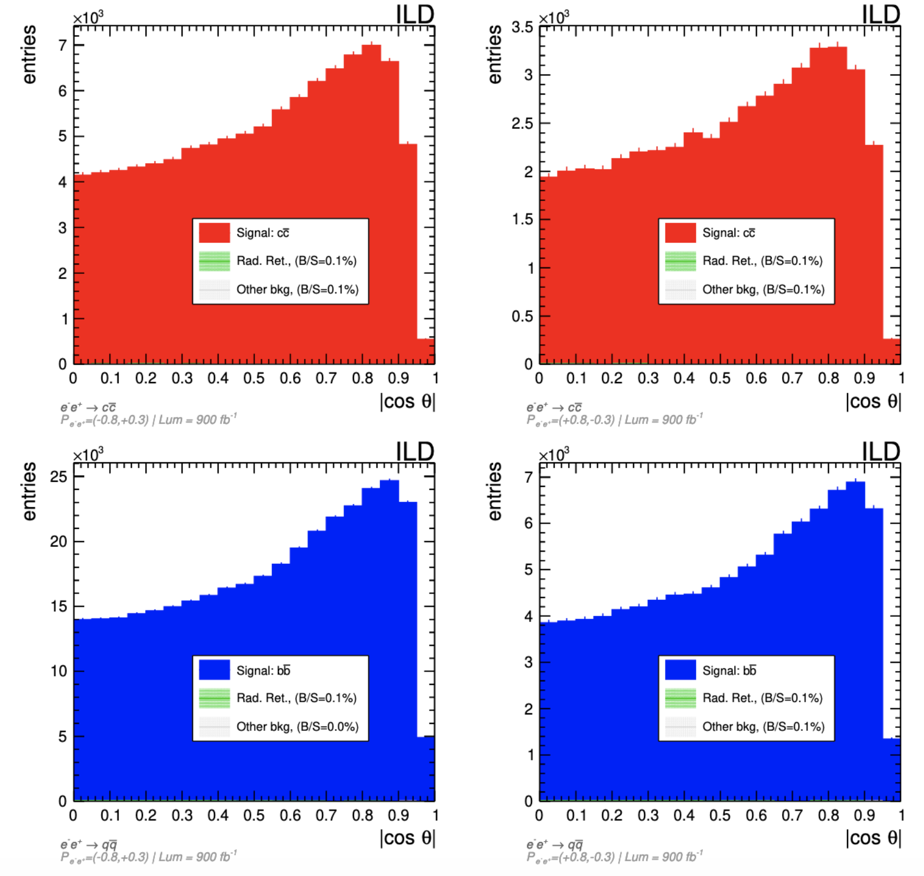
Kinematics of secondary tracks





Selection efficiency for A_{FB}

b-quarks & c-quarks after applying the double-charge method to them



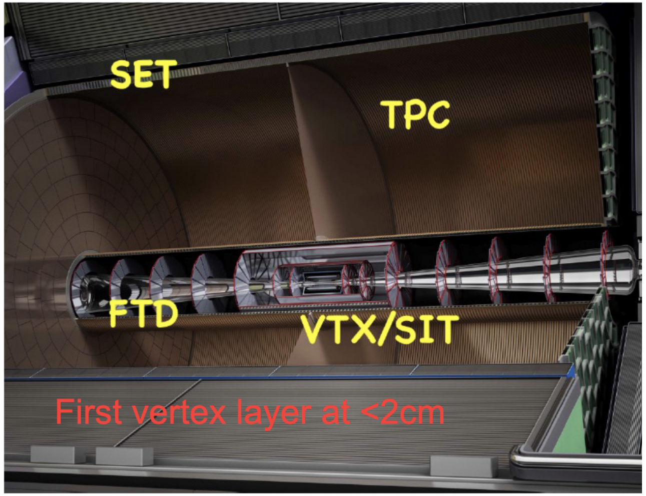
b-quarks & c-quarks Signals are close to:

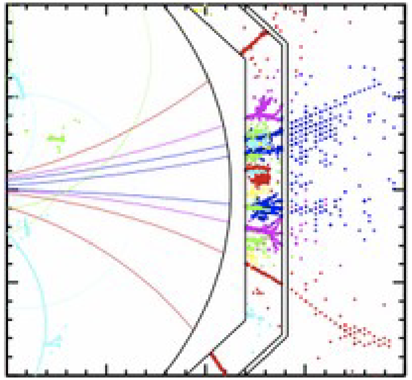
- Background-free
- uncorrelated

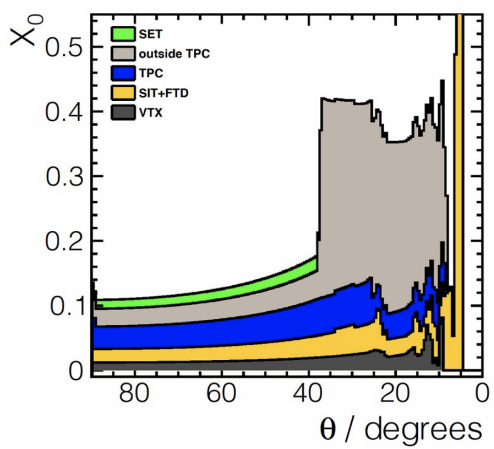
ILD overview

- ILD: International Large Detector.
  - Excellent resolution:
    - Beam IP constraining capability.
    - Tracking efficiency (>99%).
    - Vertexing.
      - Secondary vtcs and flavour tagging!
  - Compact and hermetic high granularity calorimetry system (>10^8 cells!).
  - Optimized for Particle Flow Concept, i.e., single particle reconstruction.

ILD design



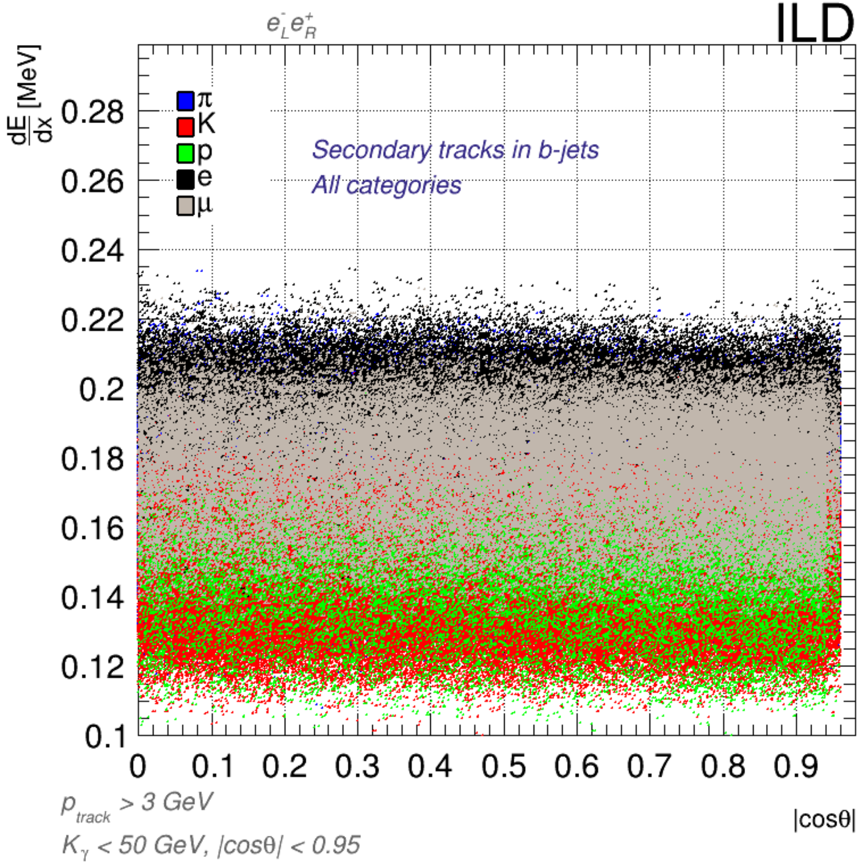


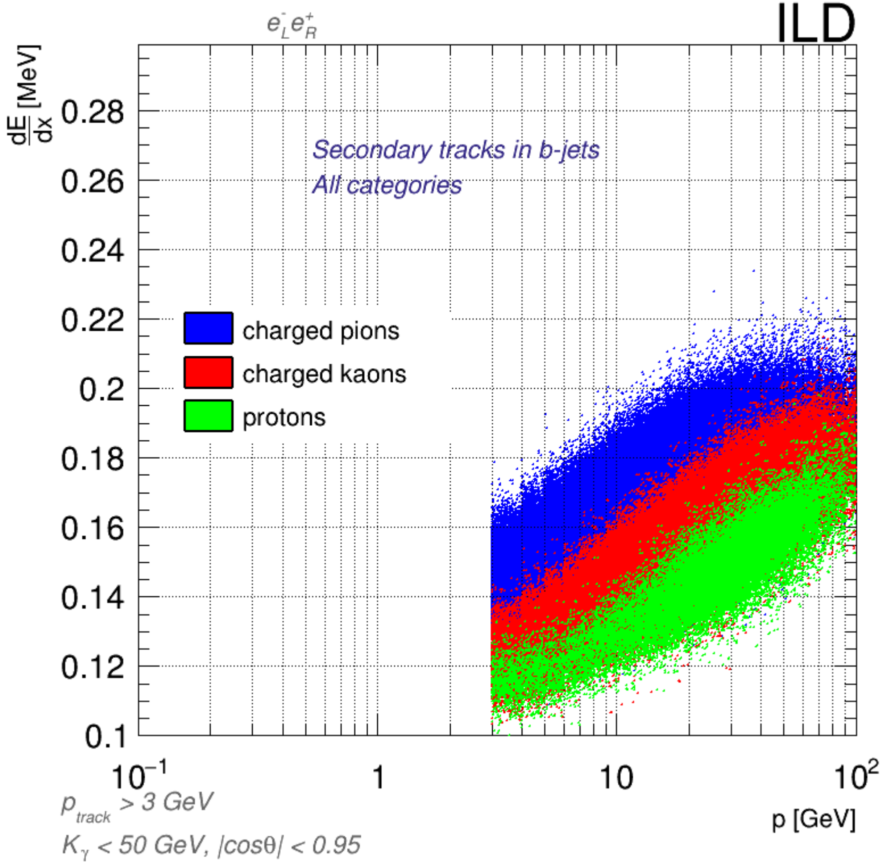


ILD: Interim Design Report.
ArXiv:1003.01116

Adding PID in FT (LCFI+)

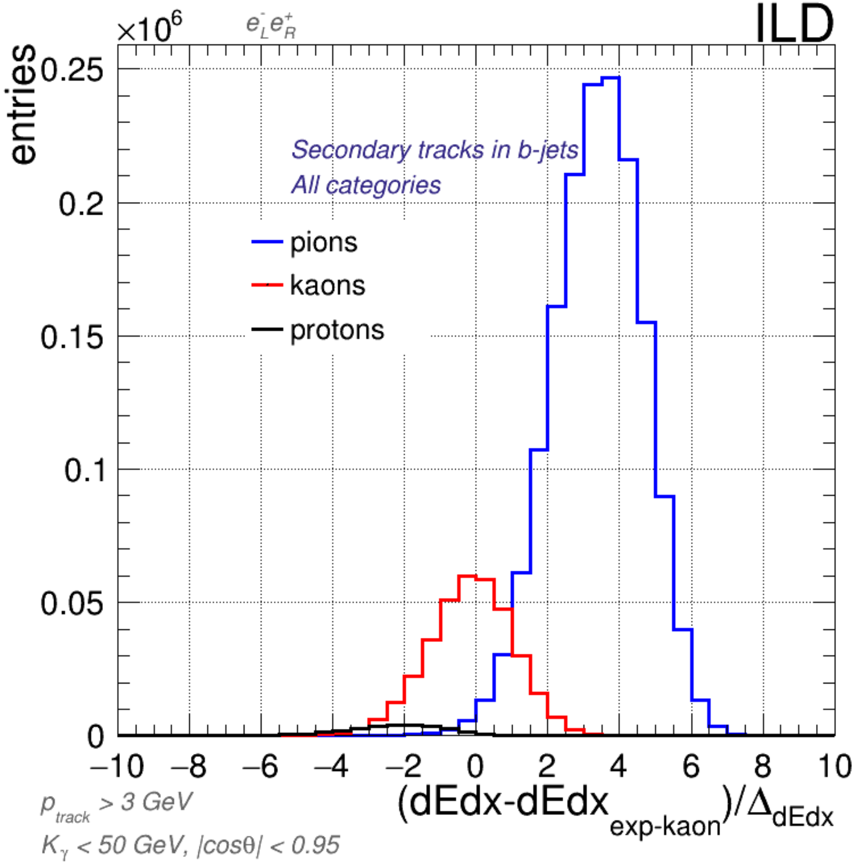
dEdx – Preselection of pfos

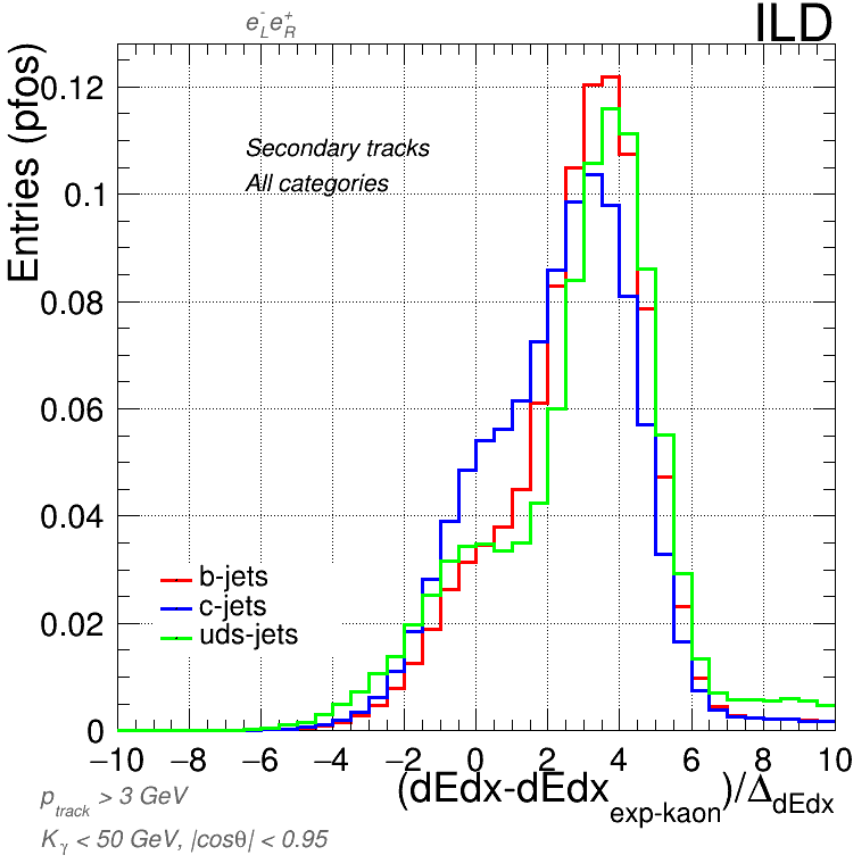




Adjusting this points to the Bethe-Bloch formula: Estimate PID

dEdx – KDS for different quark flavours

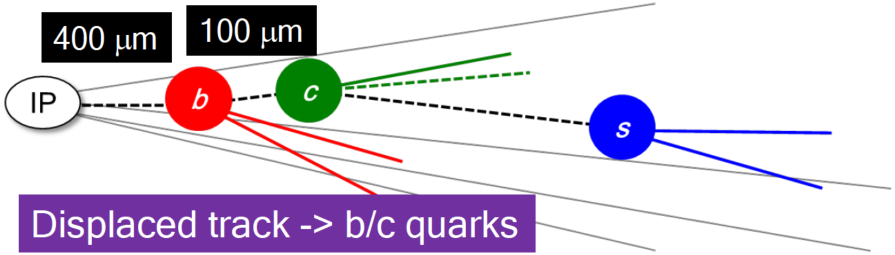


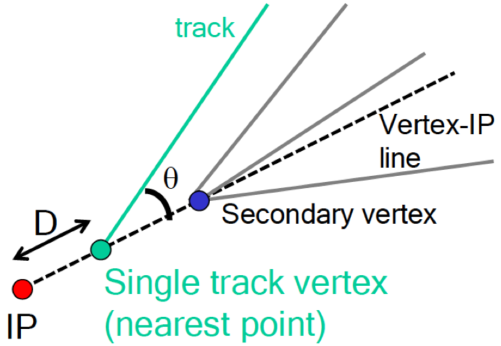


We repeat this also with Pions and Protons.
We build 3 variables NKaonSec, NPionSec & NProtonSec and add them to the FT!

Flavour tagging: LCFI+

- Vertex finder:
  - Reconstruct collinear or close-to-collinear vertexes by merging particle tracks from the event information.
  - Distance ($\tau_q \cdot c$) from the IP is key for b and c quark ID: Displaced vertexes.
  - We also encounter single track vertexes: pseudo-vertexes.
- Jet Clustering & vertex refiner:
  - Use the vertexing information.
  - Different algorithms could be used (k_T, Durham, **VLC**, etc.).
  - In our case, we expect two back-to-back jets with ISR.
- Flavour tagging:
  - TMVA (BDT based).
  - 3-class classifier b/c/uds.





arXiv:1506.08371

Events for each category

With ISR removal

Z-Pole (LCFI+ paper[1])

Events (%)			
Cat.	b jets	c jets	uds jets
A	22.9	59.5	98.1
B	39.7	39.8	1.80
C	13.5	0.54	0.02
D	23.8	0.19	0.04

1. LCFIPlus: A Framework for Jet Analysis in Linear Collider Studies

250 GeV samples

Events (%)			
Cat.	b jets	c jets	uds jets
A	13.9	46.2	98.2
B	30.5	51.0	1.59
C	23.9	2.29	0.11
D	31.7	0.55	0.14

500 GeV samples

Events (%)			
Cat.	b jets	c jets	uds jets
A	11.2	35.8	96.7
B	28.6	58.3	2.64
C	22.9	4.65	0.26
D	37.3	1.27	0.42

Category	A	B	C	D
Number of vertices	0	1	1	2
Number of single-track pseudovertices	0-2	0	1	0

Re-training flavor tagging (coding)

TrackNtuple.cc+TrackProb.C ← Prepare track info: D0/Z0/vertexing tolerance, etc.

↓

MakeNtuple.cc ← Creates the Ntuples used for the training process. (It needs the track info for many of them.)

↓

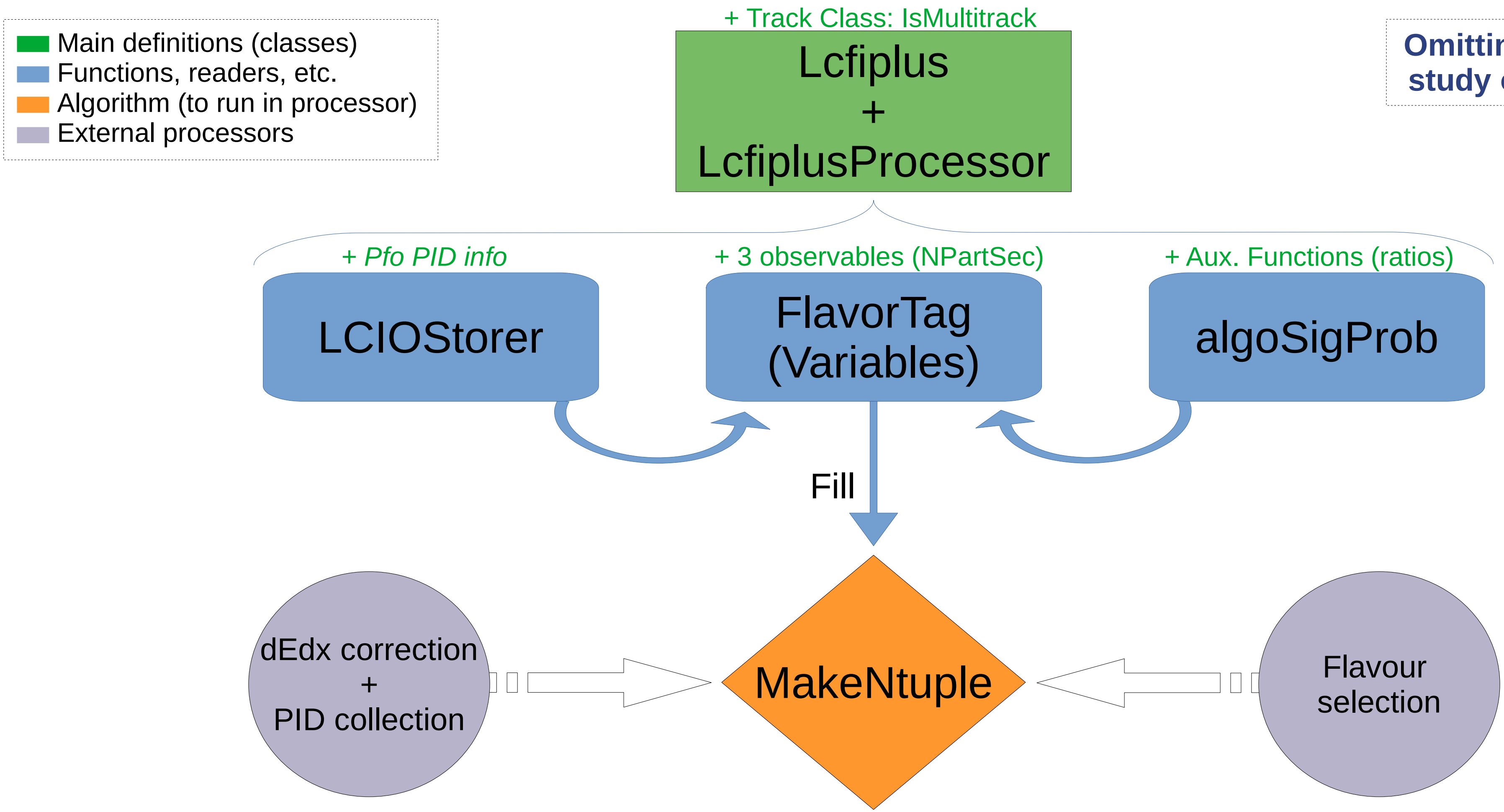
TrainMVA.cc ← Run the TMVA with the BDTs for each category. Creates the weight files for b/c-tag.

To introduce dEdx in the training process we need to:

1. Load it into the Ntuples when we run MakeNtuple.cc
2. Re-Train to get new weights.
3. Check that this training is optimal:

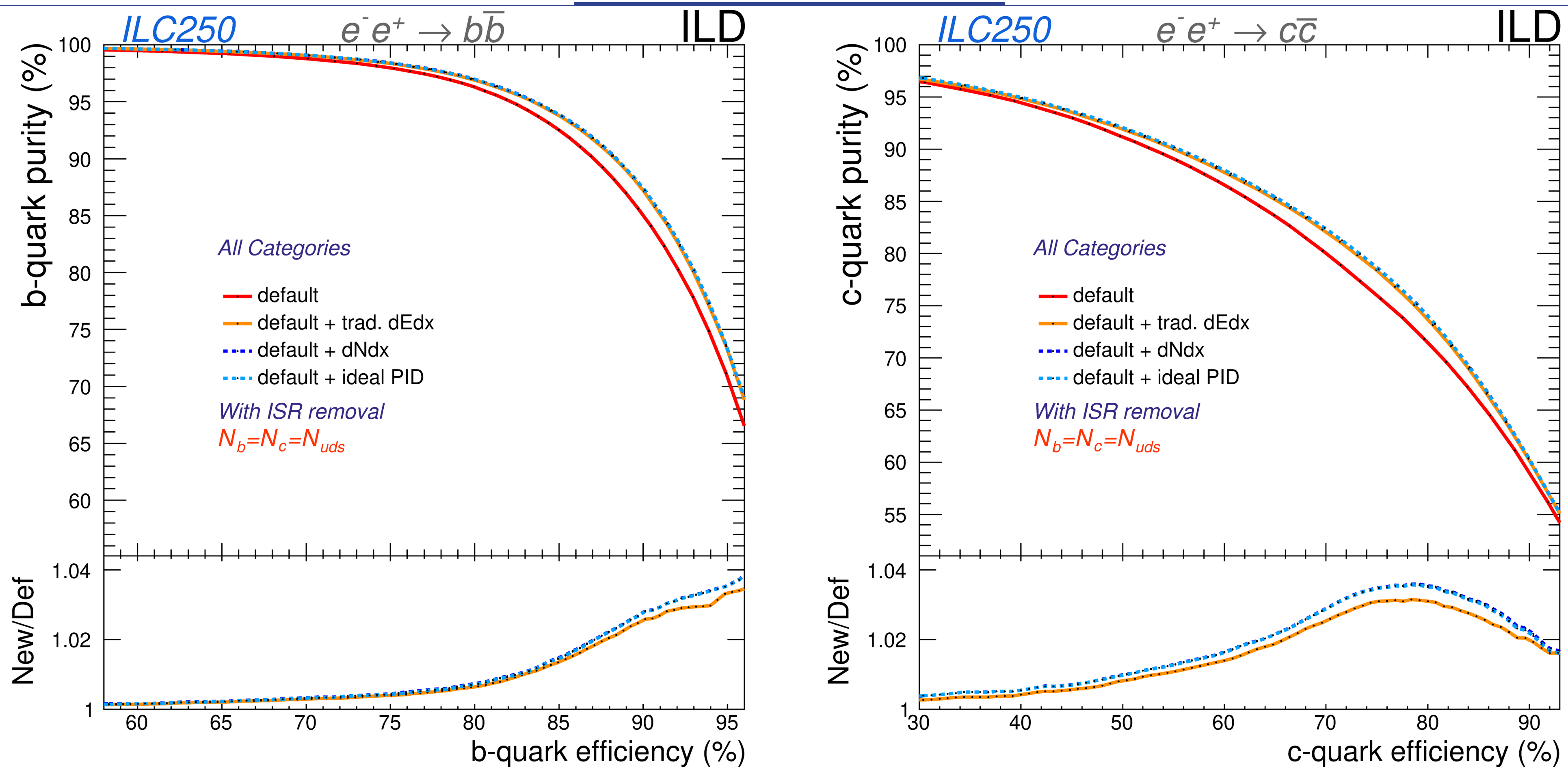
3.1 **Particle Swarm Optimization** + Statistical tests (KS & AD)

LCFI+ MakeNtuple Workflow (+dEdx)

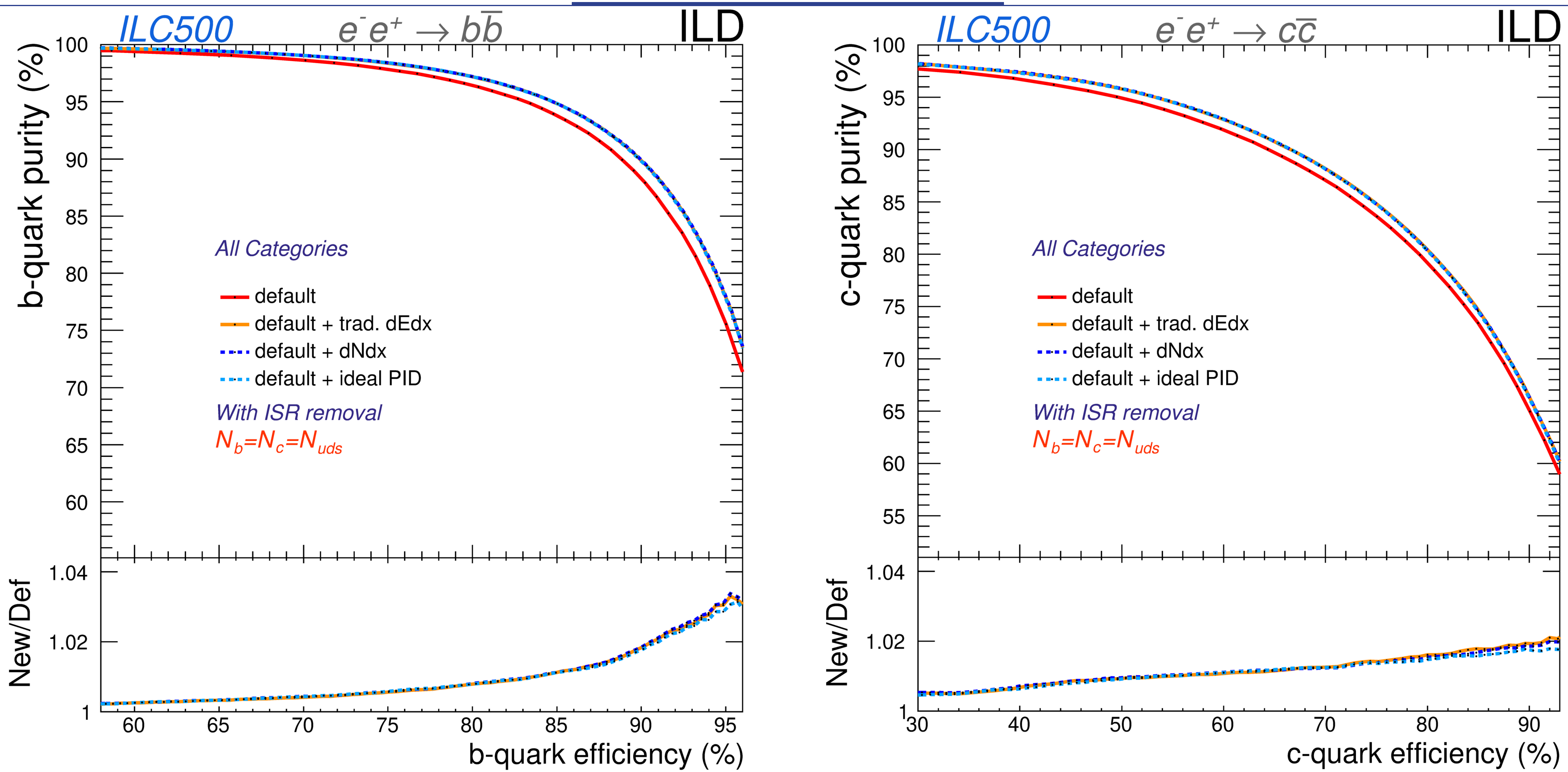


Omitting parts I didn't study or interact with

Effects of dNdx in Flavour Tagging (250 GeV)



Effects of dNdx in Flavour Tagging (500 GeV)



Particle Swarm Optimisation

Boosted Decision Trees (BDT) - TMVA

- We are already working with these Gradient Boosted Decision trees using ROOT's Toolkit for MultiVariate data Analysis (TMVA). We use the following parameters:
  - BoostType=Grad.
  - NTrees.
  - Shrinkage.
  - UseBaggedBoost:BaggedSampleFraction.
    - Bagging: A new sampling is performed before each step (removes biases).
  - NCuts (binning used when sampling).
  - MaxDepth (Nº of leaves).

The Particle Swarm Algorithm optimizes the use of *these parameters*

We used all but the orange ones, which are method definitions

PSO - Overview

- Particle Swarm Optimization is a Gradient-free, bio-inspired, stochastic, population-based algorithm to optimize any kind of process towards a certain goal:
  - No maths involved in the optimization (no gradients or loss functions!).
  - It just try configurations and saves the *best-performing one*.
    - It mimics how animals look for resources, by trial and error.
- How it works:
  - We have N "particles" (in our case: configurations of the BDT). Then:
    1) The BDT runs with the configuration of the particle.
    2) When finished, each particle gets a performance score.
       -We define a Function Of Merit (FOM) for this scoring
    3) We track each particle's best configuration and the best global one.
    4) The particles move to a new configuration (next slide).

For each iteration

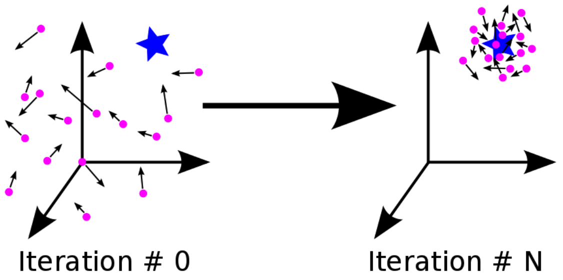
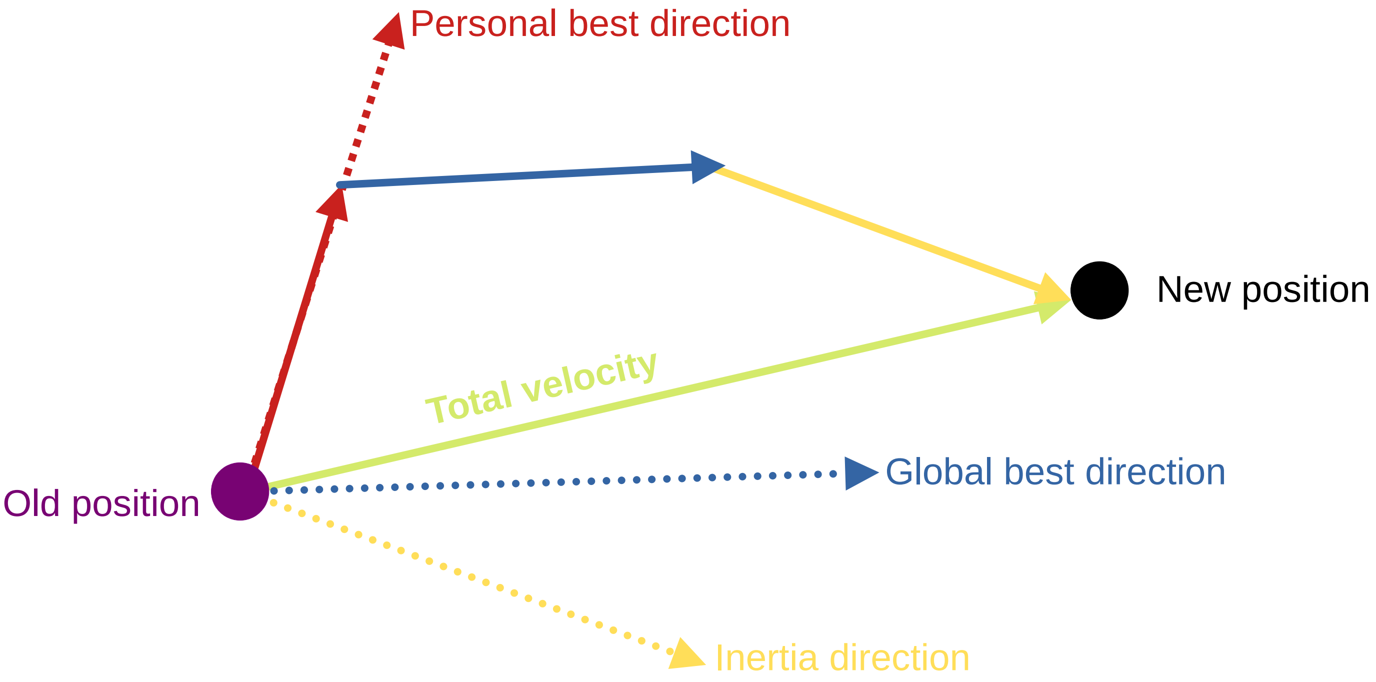


Image taken from a website

PSO - Overview

Position: $\overrightarrow{X_i^{t+1}} = \overrightarrow{X_i^t} + \overrightarrow{V_i^{t+1}}$

Velocity: $\overrightarrow{V_i^{t+1}} = w\overrightarrow{V_i^t} + c_1 r_1 \left(\overrightarrow{P_i^t} - \overrightarrow{X_i^t}\right) + c_2 r_2 \left(\overrightarrow{G^t} - \overrightarrow{X_i^t}\right)$



PSO – Adaptation to FT in LCFI+

- We need:
  - A 3-class classifier (b quarks, c quarks, uds quarks).
  - We also want to avoid overfitting:
    - Kolmogorov-Smirnov test
    - Anderson-Darling test

    Control biased test scores. (more info in back-up)
  - We need a FOM adapted to 3 different classes.
  - Important remark: A final check is **always needed**:

Trial and error can go wrong sometimes!

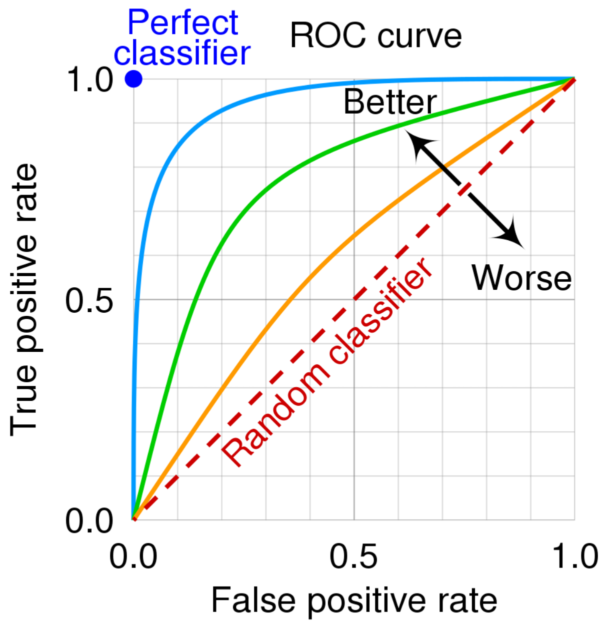
PSO – Function Of Merit (FOM)

- The FOM being used is the averaged value of the Integral of the Receiver Operating Characteristic curve for each of the 3 data classes.
  - Considering the target class as signal and the others as background.

- Our FOM is simply:

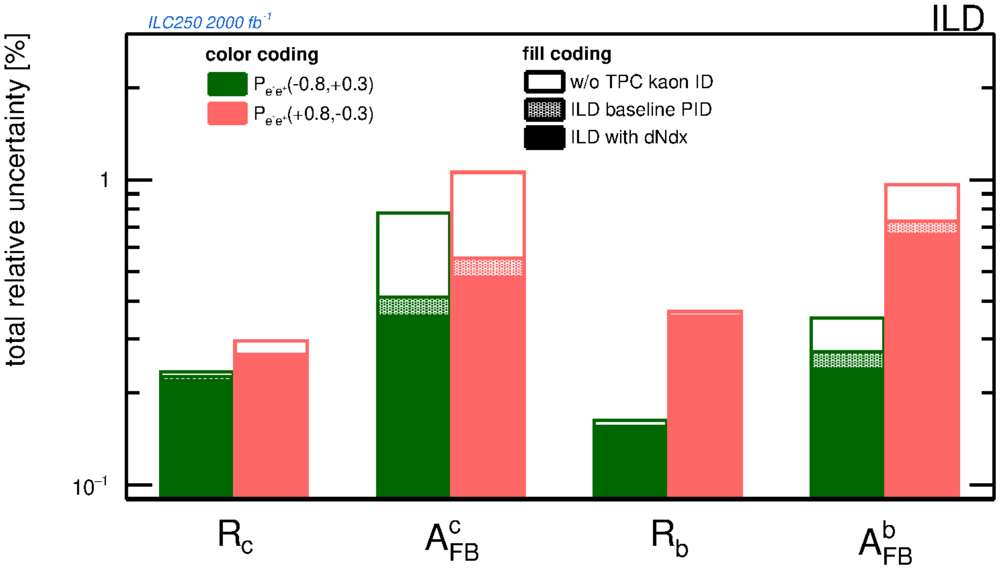
  $$FOM = (AUC[b_{quark}] + AUC[c_{quark}] + AUC[uds_{quarks}]) / 3,$$

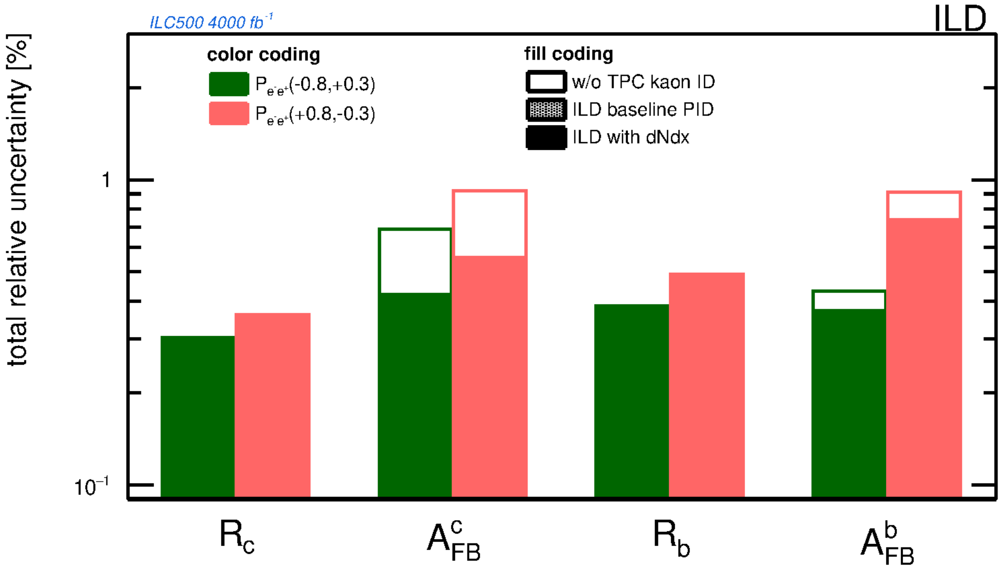
  where AUC = "Area Under Curve" (ROC Integral).



GHU phenomenology

Total Uncertainties for R_q and A_{FB}

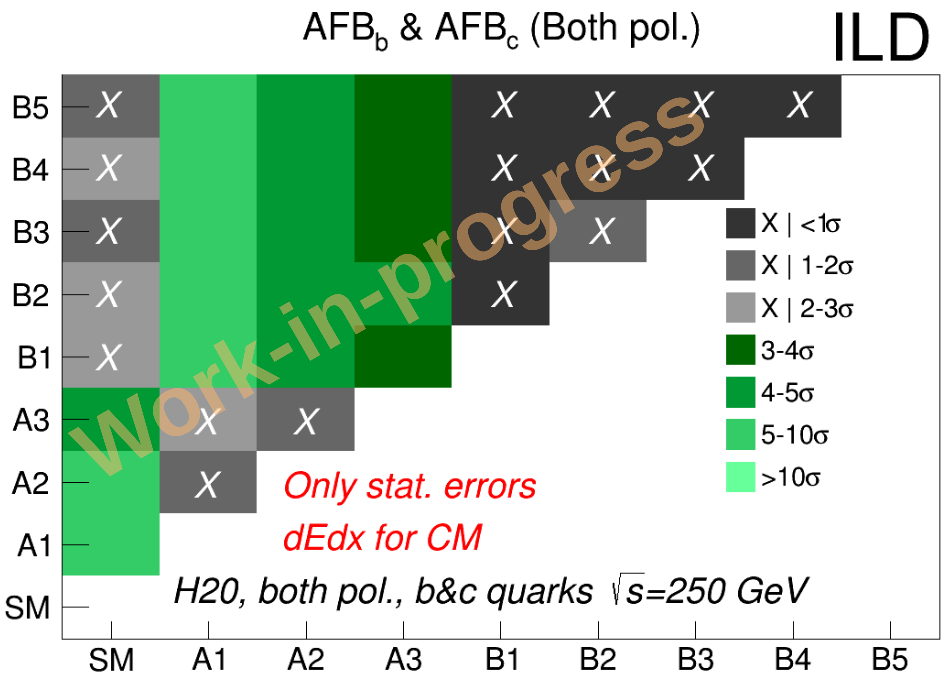


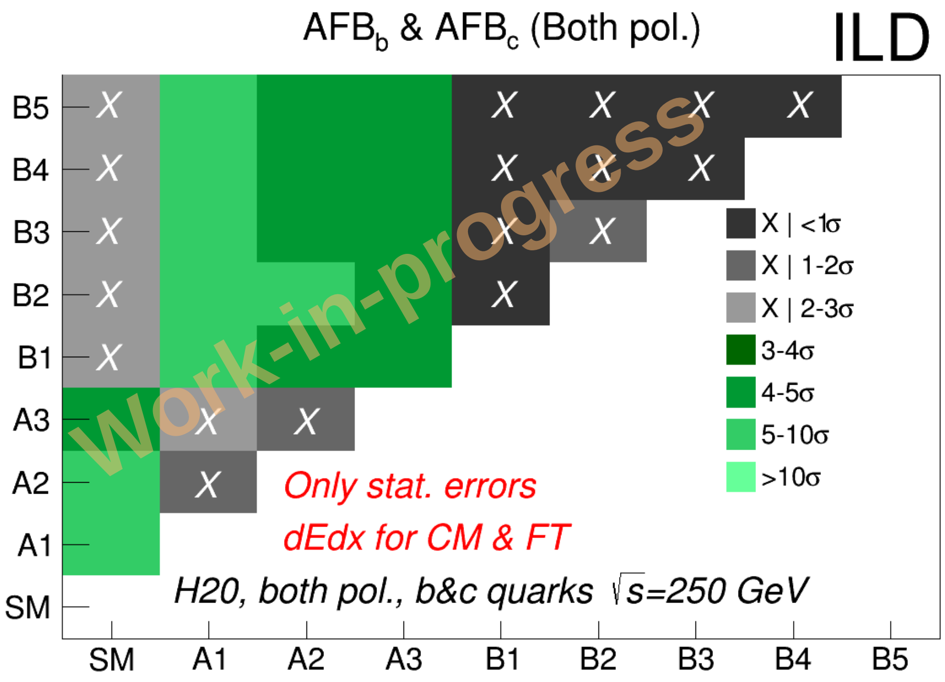


Full Simulation Studies. (arXiv 2307.14888)

A. Irles, J. P. Márquez

GHU's Models ILC250 (PID in Flavour Tagging)





Effects of introducing **PID** in **Flavour tagging**.