BSM physics at ILC250/500

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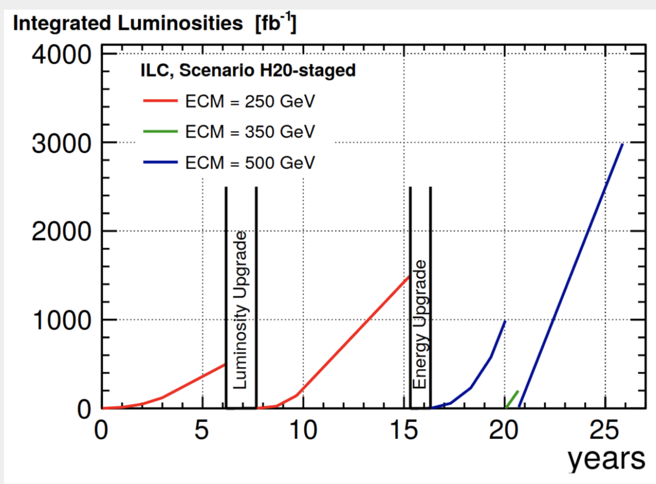
LCWS2023 INTERNATIONAL WORKSHOP ON LINEAR COLLIDERS

ILC Run Plan & Physical Observables for Heavy-Quark Production

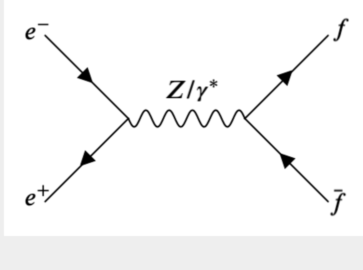


Luminosity upgrade: 5 Hz to 10 Hz.
Energy upgrade: Extend the linac.

Higgs factory & $f\bar{f}$ production:

The ILC features e^-e^+ collisions at 91.2 GeV (Z-Pole), **250 GeV, 500 GeV** and 1 TeV. Both beams (e^+, e^-) are polarised (80% e^-, 30% e^+). Beam polarization enables the inspection of the chiral structure of nature (left/right helicities).

$\sqrt{s}$	sgn(P(e⁻),P(e⁺)) (−,+)	(+,−)	(−,−)	(+,+)
	Integrated Luminosity (fb⁻¹)			
250 GeV	900	900	100	100
350 GeV	135	45	10	10
500 GeV	1600	1600	400	400



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

$$Q_{e_X f_Y} = \sum_i \frac{g^X_{V_i e} g^Y_{V_i f}}{(s-m^2_{V_i}) + i m_{V_i}\Gamma_{V_i}}$$

Experimental observables:

- Hadronic fraction (R_q):
  - Quark ID (flavour tagging).
  - Angular measurement *possible*, but not needed.
- Forward-Backward Asymmetry (A_{FB}):
  - Quark ID + charge measurement.
  - Angular measurement needed.

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

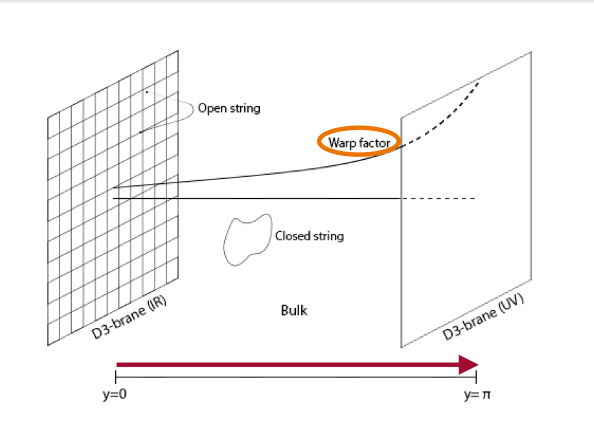
$$A_{FB} = \frac{\int_0^1 \frac{d\sigma}{d\cos\theta}d\cos\theta - \int_{-1}^0 \frac{d\sigma}{d\cos\theta}d\cos\theta}{\int_{-1}^1 \frac{d\sigma}{d\cos\theta}d\cos\theta}$$

$$A^{Exp}_{FB} = \frac{N_F - N_B}{N_{Total}} \quad R^{Exp}_q = \frac{N_q}{N_{hadron}}$$

Normalised & Differential observables are highly preferred: Control of systematic uncertainties

This poster: Only A_{FB}

Gauge-Higgs Unification (GHU) Models: Concepts & Phenomenology

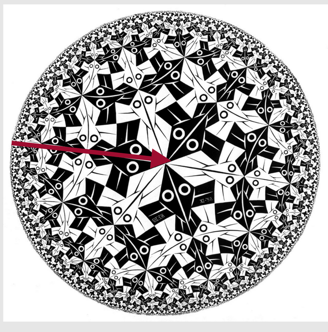


$$ds^2 = g_{MN}dx^M dx^N = e^{-2\sigma(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

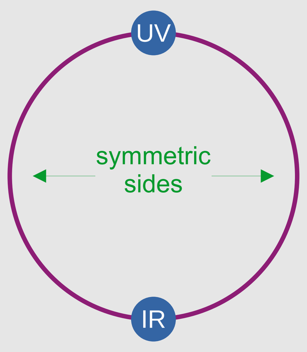
Unify all forces under the same gauge group in a Randall-Sundrum (RS) metric.

The RS metric features a **warped** extra dimension:

- **Conformal** symmetry ("scale symmetry").
- *Compactified* in a **ring-shape**.
  - **KK-resonances** (Z',γ')!
- **Two branes** (IR & UV), at opposite points.
- **Orbifold** b. c. in both parts of the circle.



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



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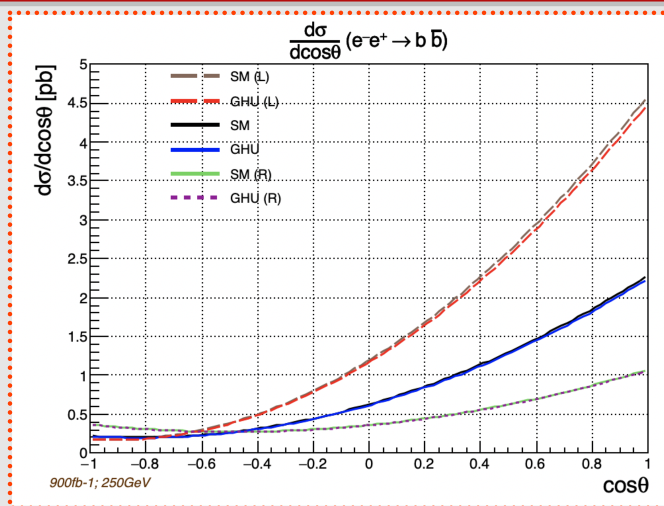
Only one parameter, ϕ_H, determines the projection of the 5D fields, fixing all physical effects:

- m_{KK}~10 TeV (*only* **indirect measurement**).
- **EW couplings** and **Weinberg's angle** (θ^0_W).

$$g^{5D}_Y = \frac{g_A g_B}{\sqrt{g_A^2+g_B^2}} \qquad \sin\theta^0_W = \frac{s_\phi}{\sqrt{1+s_\phi^2}}$$

Two kinds of models with different gauge group structure:

- **Models A** [1]: More sensitive to RH helicities.
- **Models B** [2]: More sensitive to LH helicities.



First remarkable deviations at 250 GeV!

[1] S. Funatsu, H. Hatanaka, Y. Hosotani, and Y. Orikasa. Distinct signals of the gauge-Higgs unification in e⁺e⁻ collider experiments. Phys. Lett. B, 775:297–302, 2017.
[2] S. Funatsu, H. Hatanaka, Y. Hosotani, Y. Orikasa, N. Yamatsu. Fermion pair production at e⁻e⁺ linear collider experiments in GUT inspired gauge-Higgs unification. Phys. Rev. D, 102(1):015029, 2020.

Preselection of Signals & Use of PID

Experimental procedure:

1)Preselection:

To remove backgrounds. Mostly **radiative return**.

2)Flavour tagging:

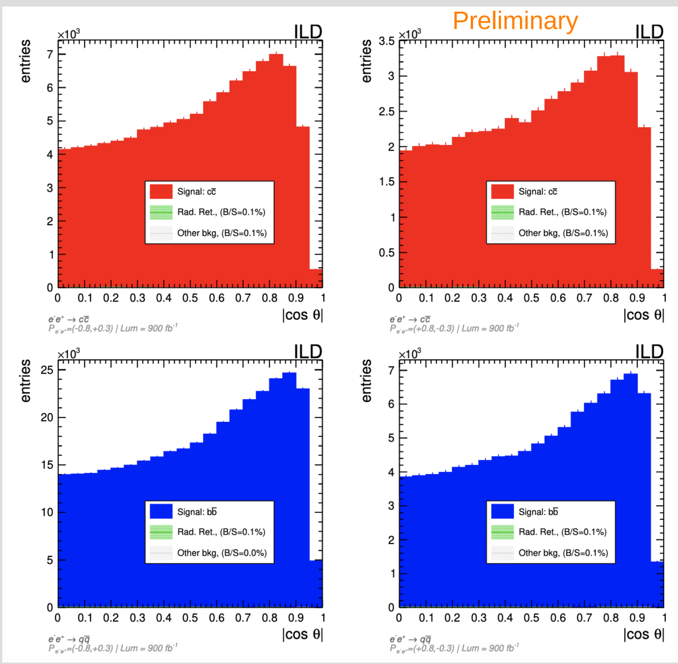
Using standard ILD Tool: **LCFI+**.

3)Jet charge measurement:

VTX method: Use all secondary tracks.

Kaon method: Use **TPC's kaon PID**

Double Tag Method: Only events with two opposite-charged identified jets are accepted



How to improve the use of TPC PID:

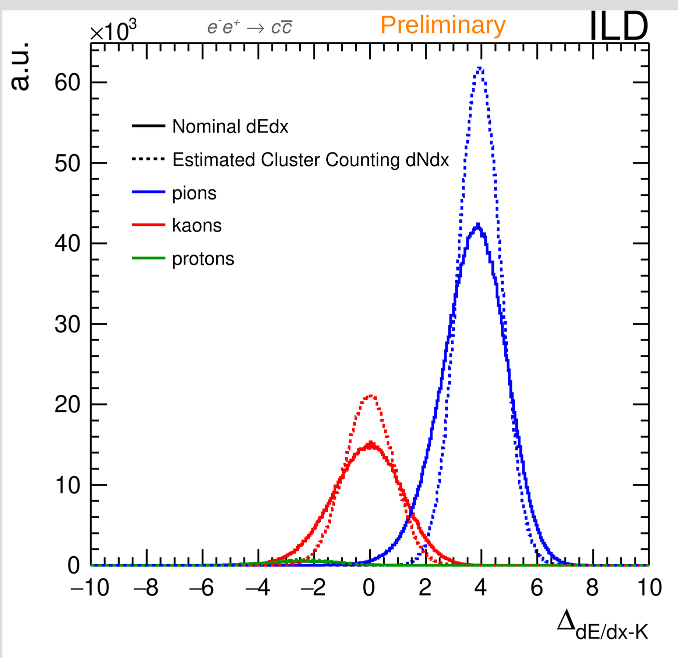
1) Including it into the Flavour Tagging process.

- Use the PID to count particles in secondary vtcs.

2) Improve the PID performance itself.

- From dE/dx to dN/dx (**cluster counting**).
  - ~35% improvement in K/p separation power[3].
  - ~25% smaller standard deviation for each distribution.

The PID is being rewritten to simulate the improvements expected from the use of dN/dx



[3] Einhaus U, Krämer U, Malek P. Studies on Particle Identification with dE/dx for the ILD TPC. arXiv:1902.05519. 2019 Feb 14.

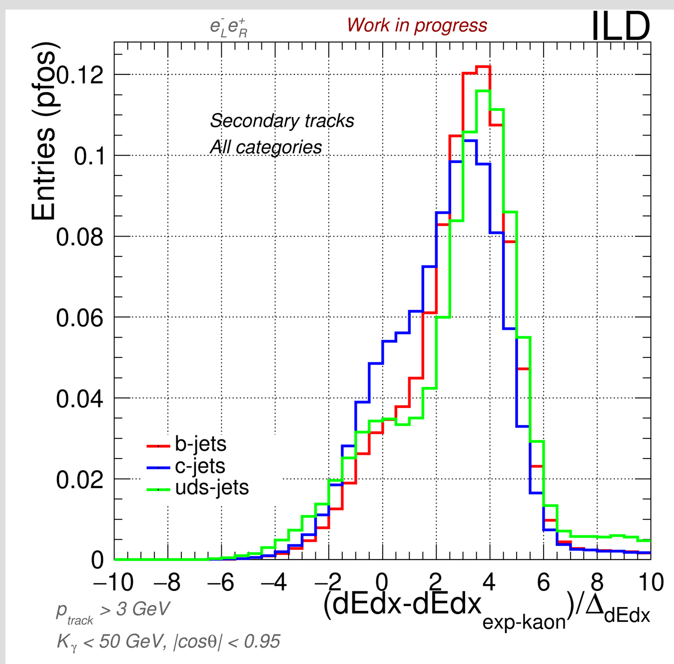
Optimization of LCFI+ & Implementation of PID

About LCFI+[4]:

- Based on Boost Decision Trees (BDTs).
- Sequence: Vertexing, Jet clustering, Making of NTuples and **flavour tagging**.
  - Heavily relies on displaced vertices.
  - 4 categories: number of vtx. and/or pseudovtx.
  - 3-class classifier: b jets, c jets & uds jets.

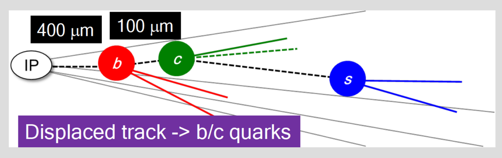
Adding PID:

- ID of secondary tracks by using the significance wrt. the Bethe-Bloch formula value for a certain particle.
  - 3 new variables: **Kaon, Proton & Pion**.



Particle Swarm Optimization:

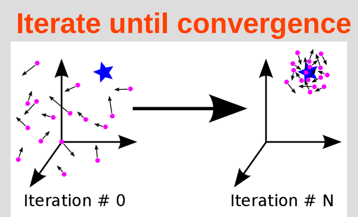
Gradient-free, bio-inspired, stochastic, population-based algorithm that optimises any kind of process towards a certain goal.



It start with N "particles" (in our case: *configurations of the BDTs*).

Then:

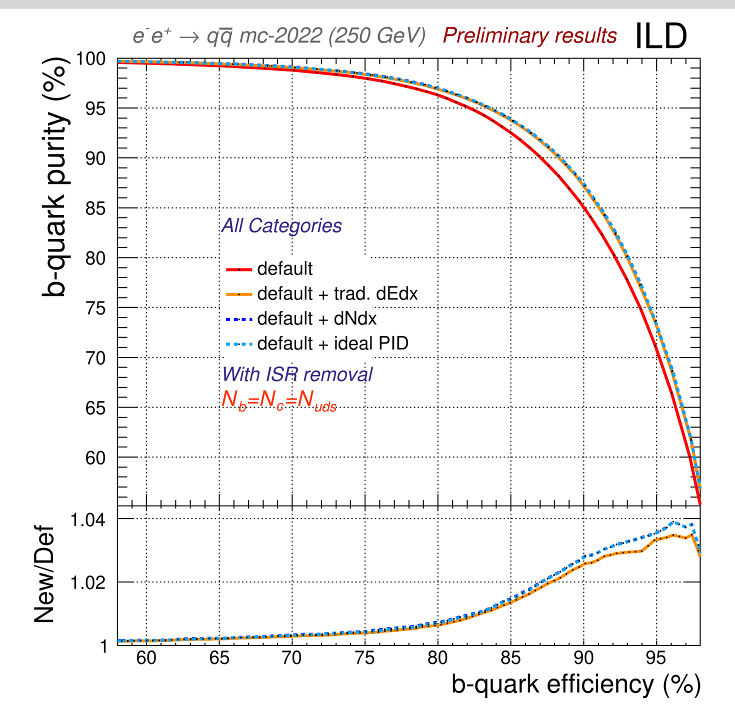
1) The BDT runs with the configuration of the particle.
2) When finished, each particle gets a performance score.
   - Filtered with statistical tests: Removal of biased results.
3) Move to a new configuration, influenced by the best ones.

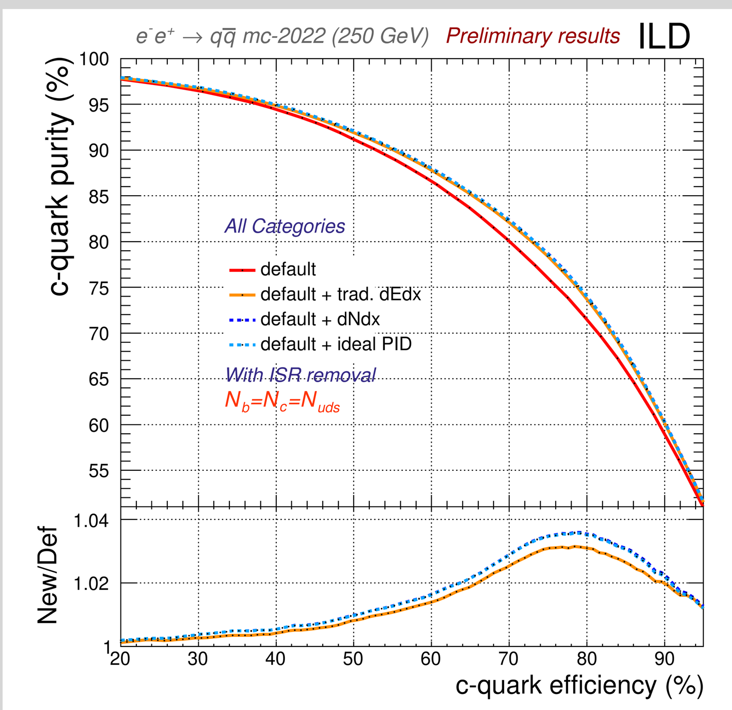


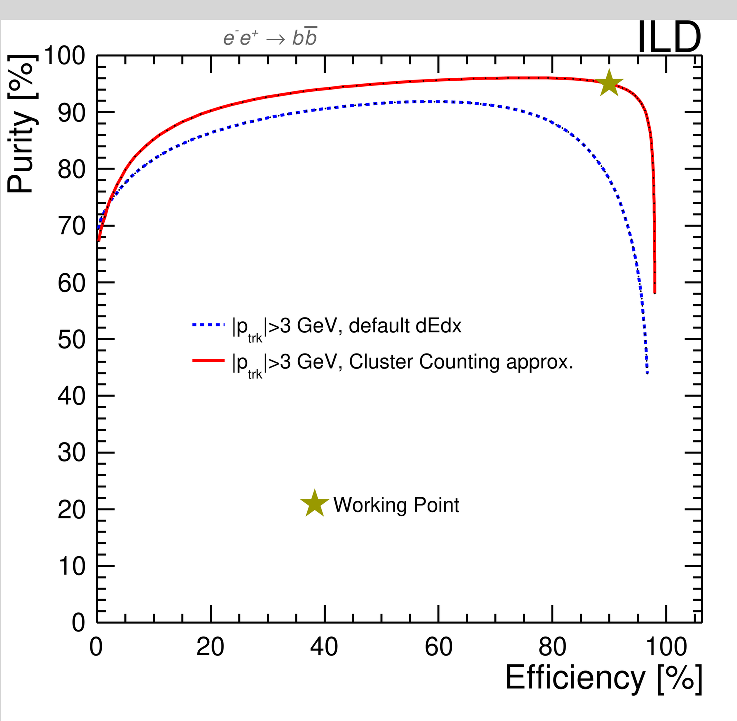
And optimisation is perform for each category. Different weights for dE/dx and dN/dx.

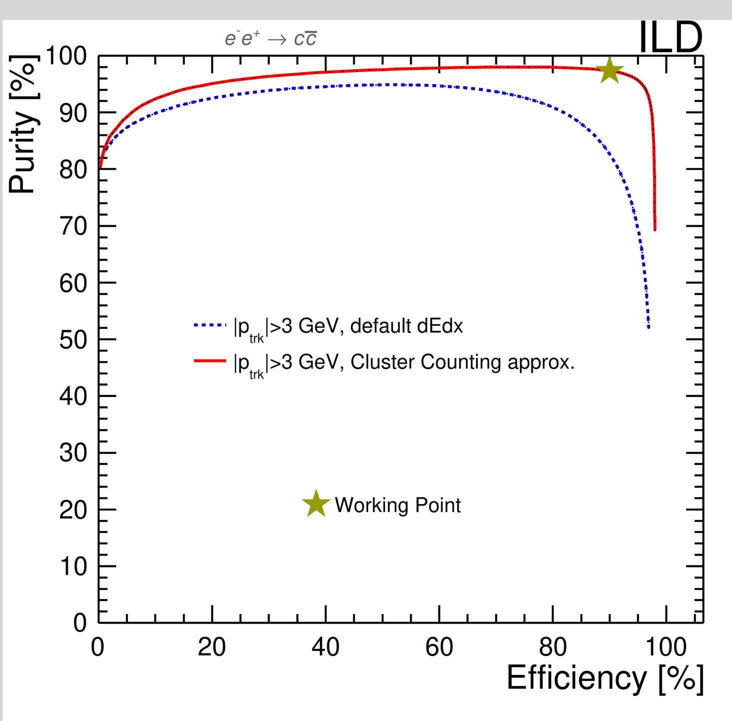
[4] Suehara T, Tanabe T. LCFIPlus: a framework for jet analysis in linear collider studies. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 2016 Feb 1;808:109-16.

PID in Flavour Tagging and Charge Measurement



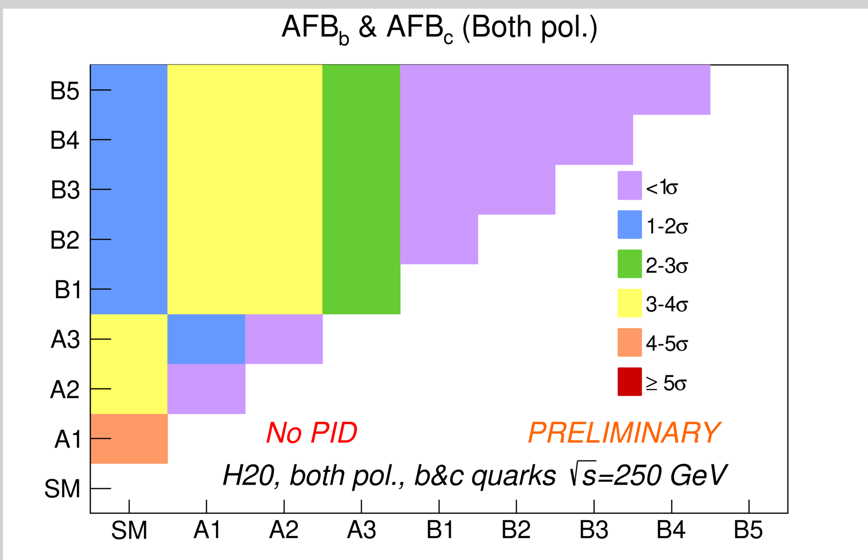


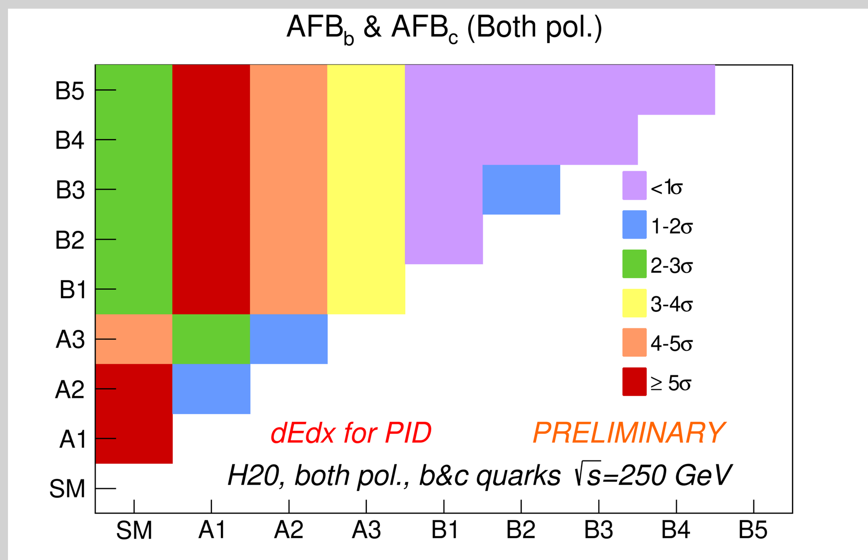


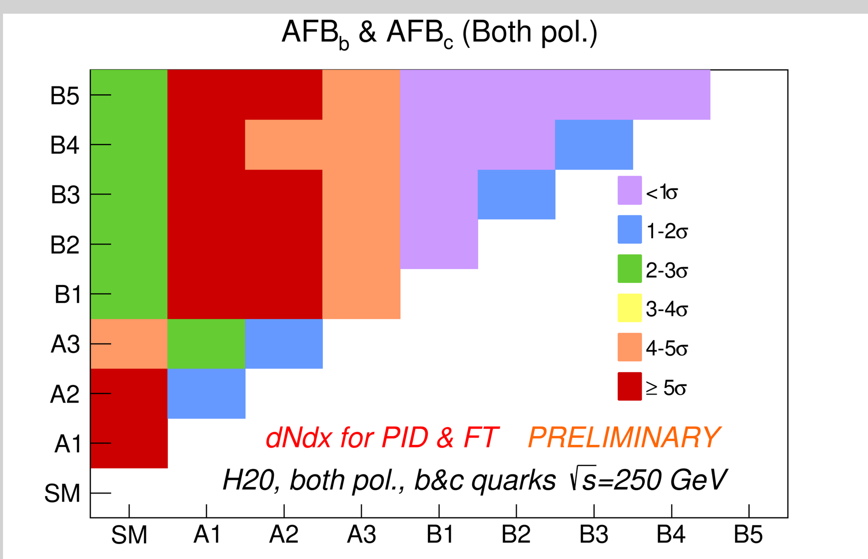


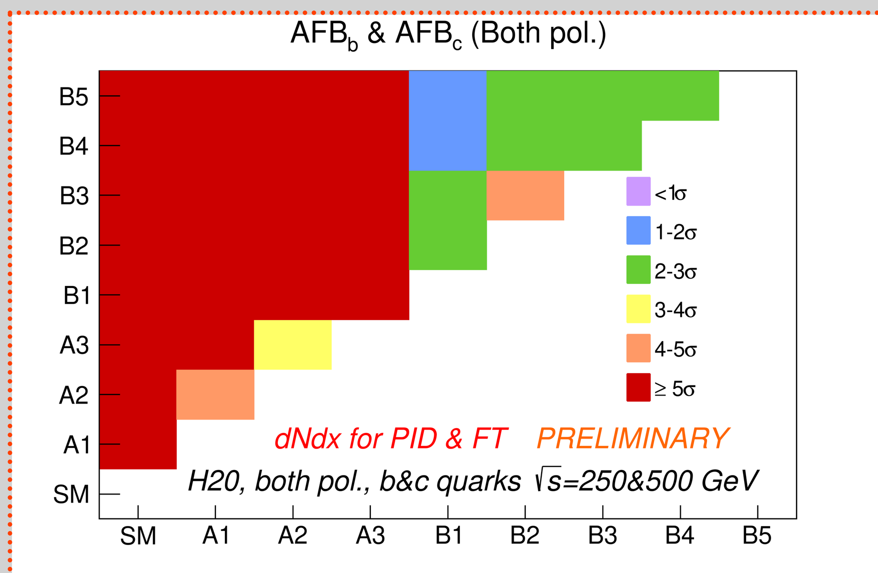
Experimental Prospects for GHU

Results from full simulation studies using ILCSOFT.
ILD Note on preparation!









Combining results from both polarisations, using dNdx for both PID & FT and getting access to 500 GeV allows full discrimination from the SM!

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