Probing gauge-Higgs Unification models at the ILC with $\mathrm{AFB}_{q\bar{q}}$ at center-of-mass energies above the Z mass

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MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
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Study based on full simulation analysis

▷ ILD note and previous works

- ILC250 experimental case **ILD-PHYS-PUB-2023-001**
- 250GeV and 500 GeV, with Particle ID and flavour tagging optimization using TPC **ILD-PHYS-PROC-2023-013**

▶ Work presented also in

- in LCWS23, EPS-HEP23, SUSY2024 (J.P. Márquez)
- ECFA HTE workshops DESY and Paestum (A. Irles)
- ICHEP2024 next week (A. Saibel)

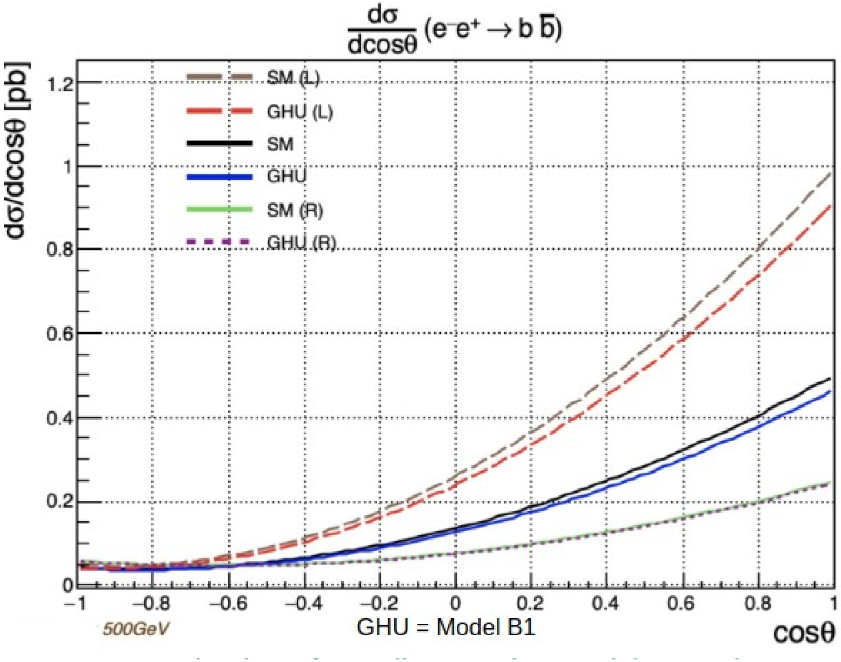
Eur.Phys.J.C 84 (2024) 5, 537

Irles, Marquez, Poeschl, Richard, Yamamoto, Namatsu, Saibel

NEW
2024!

TwoF physics case

- ▷TwoF Physics case is well established for Future Colliders – Z-couplings, EW, BSM searches,
- ▷As **Benchmark**, we will use the [Funatsu, Hatanaka, Hosotani, Orikasa, Yamatsu] Gauge-Higgs Unification models
- ▷The symmetry breaking pattern is different than in the SM and features the so-called Hosotani's mechanism.
- ▷Only one parameter, Hosotani angle , determines the projection of the 5D fields, fixing all physical effects:
  - KK resonances of the Z/γ with mkk~10-25TeV
  - Modifications and new EW couplings/helicity amplitudes.
  - Already visible effects at 250GeV



Gauge-Higgs Unification Models

▷ A models: (arxiv:1705.05282)

$$\begin{aligned} A_1 &: \theta_H = 0.0917, m_{KK} = 8.81 \text{ TeV} \rightarrow m_{Z'} = 7.19 \text{ TeV}; \\ A_2 &: \theta_H = 0.0737, m_{KK} = 10.3 \text{ TeV} \rightarrow m_{Z'} = 8.52 \text{ TeV}, \end{aligned}$$

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

$$\begin{aligned} B_1^+ &: \theta_H = 0.10, m_{KK} = 13 \text{ TeV} \rightarrow m_{Z'} = 10.2 \text{ TeV}; \\ B_1^- &: \theta_H = 0.10, m_{KK} = 13 \text{ TeV} \rightarrow m_{Z'} = 10.2 \text{ TeV}; \\ B_2^+ &: \theta_H = 0.07, m_{KK} = 19 \text{ TeV} \rightarrow m_{Z'} = 14.9 \text{ TeV}; \\ B_2^- &: \theta_H = 0.07, m_{KK} = 19 \text{ TeV} \rightarrow m_{Z'} = 14.9 \text{ TeV}; \\ B_3^+ &: \theta_H = 0.05, m_{KK} = 25 \text{ TeV} \rightarrow m_{Z'} = 19.6 \text{ TeV}; \\ B_3^- &: \theta_H = 0.05, m_{KK} = 25 \text{ TeV} \rightarrow m_{Z'} = 19.6 \text{ TeV}, \end{aligned}$$

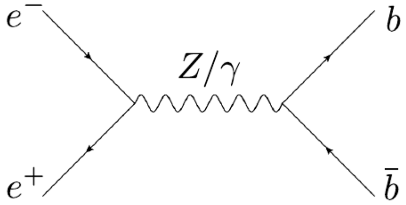
Observables

- ▷ Quark (fermion) **electroweak couplings** can be **inferred from cross section, Rq** and forward backward asymmetry **AFB** observables.

$$R_q^0 = \Gamma_{q\bar{q}} / \Gamma_{had} (Z - pole)$$

$$\rightarrow R_q^{cont.} = \sigma_{q\bar{q}} / \sigma_{had} (s > Z - pole)$$

→ Quark identification. No need to measure an angular distribution (but possible)



$$\frac{d\sigma}{d\cos\theta}$$

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

→ Angular Distribution.

Quark ID + charge measurement (quark – antiquark disentangling)

Normalized & differential observables are highly preferred: to control (remove) **systematic uncertainties**

Observables

This work focuses on the off-pole case → Sensitivity to Z, gamma, Z', mixing…

Experimental reconstruction

Preselection

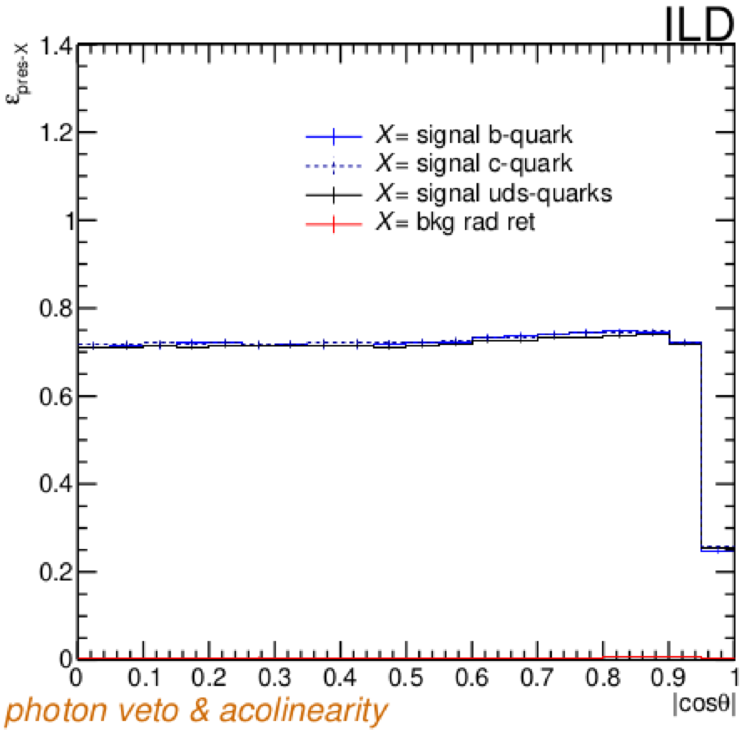
▷ **Topology: 2 back-to-back jets (pencil-like topology)**

▷ **Preselection aiming for high background rejection and high efficiency.**

▷ Main bkg ee→ Zγ(radiative return through ISR)

- ~x10 larger than signal
- **~90% of such ISR photons are lost in the beam pipe** → events filtered by energy & angular mom. conservation arguments
- The **remaining ~10% are filtered by identifying photons** in the detector (efficiency of >90%)
- PFA detector!!

▶ Other backgrounds from diboson production decaying hadronically are removed with extra toplogical cuts.



photon veto & acolinearity & m_{j1j1} & y_{23} cuts

arxiv:2306.11413

Double Tag Method : minimizing flavour tagging unc.

▷ **Compare samples with 1 tag vs 2 tags (after preselection)**

▷ **Assumptions**

- Minimal contribution from the backgrounds (next slide)
- the preselection efficiency is the same for all flavours (seen in previous slide)

$$f_{1q}(|\cos\theta|) = \frac{N_q(|\cos\theta|) - N_q^{bkg.}(|\cos\theta|)}{2\times(N_0(|\cos\theta|) - N_0^{bkg.}(|\cos\theta|))}$$

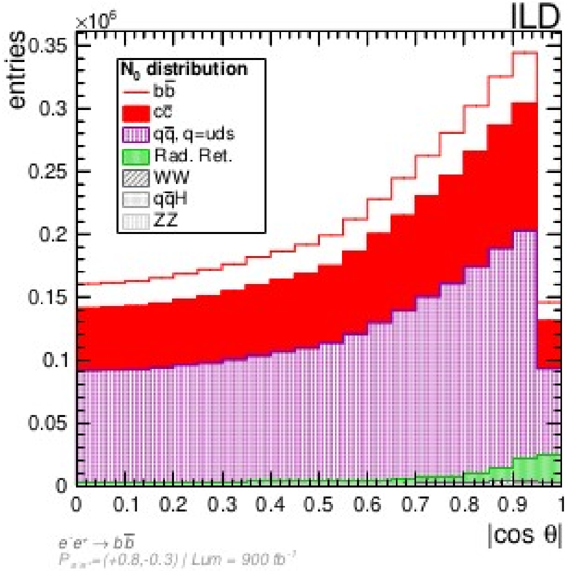
$$f_{2q}(\cos\theta) = \frac{N_{2q}(|\cos\theta|) - N_{2q}^{bkg.}(|\cos\theta|)}{N_0(|\cos\theta|) - N_0^{bkg.}(|\cos\theta|)}$$

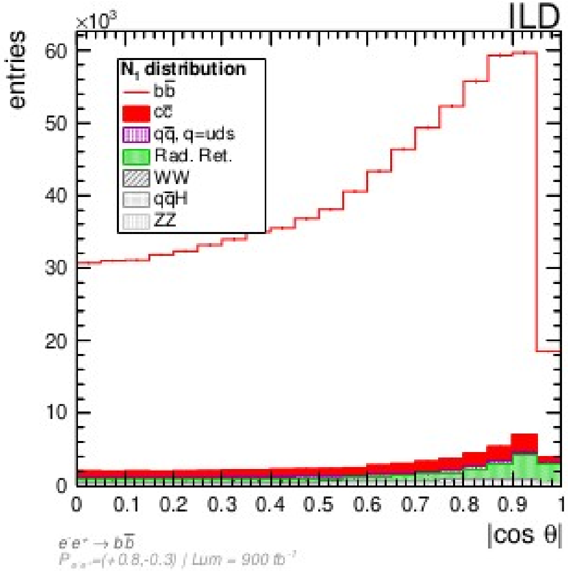
Double Tag Method

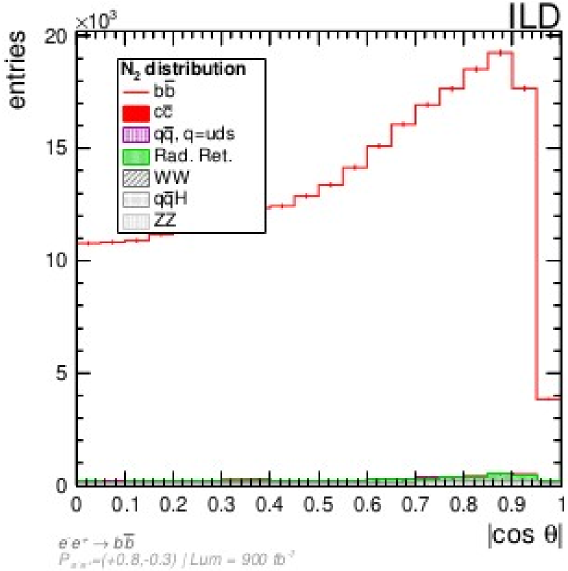
N0, N1, N2
for e+e- → b$\bar{b}$

Minimal contribution from the backgrounds

green and gray histograms







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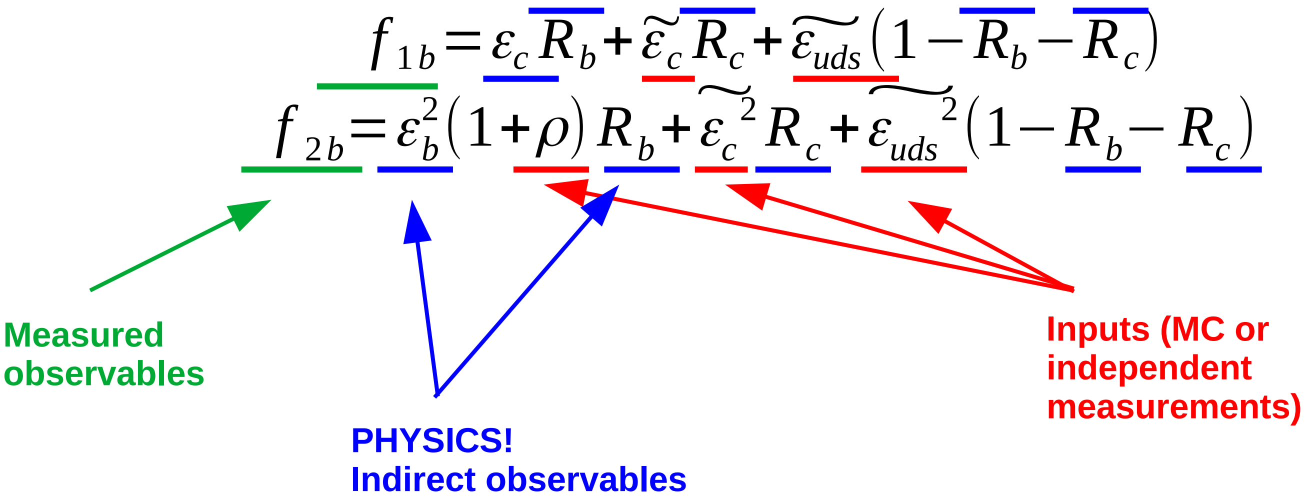
Double Tag Method

- Compare samples with 1 tag vs 2 tags (after preselection)



$$f_{1b} = \varepsilon_c R_b + \tilde{\varepsilon}_c R_c + \widetilde{\varepsilon_{uds}} (1 - R_b - R_c)$$

$$f_{2b} = \varepsilon_b^2 (1 + \rho) R_b + \widetilde{\varepsilon_c}^2 R_c + \widetilde{\varepsilon_{uds}}^2 (1 - R_b - R_c)$$

Measured observables

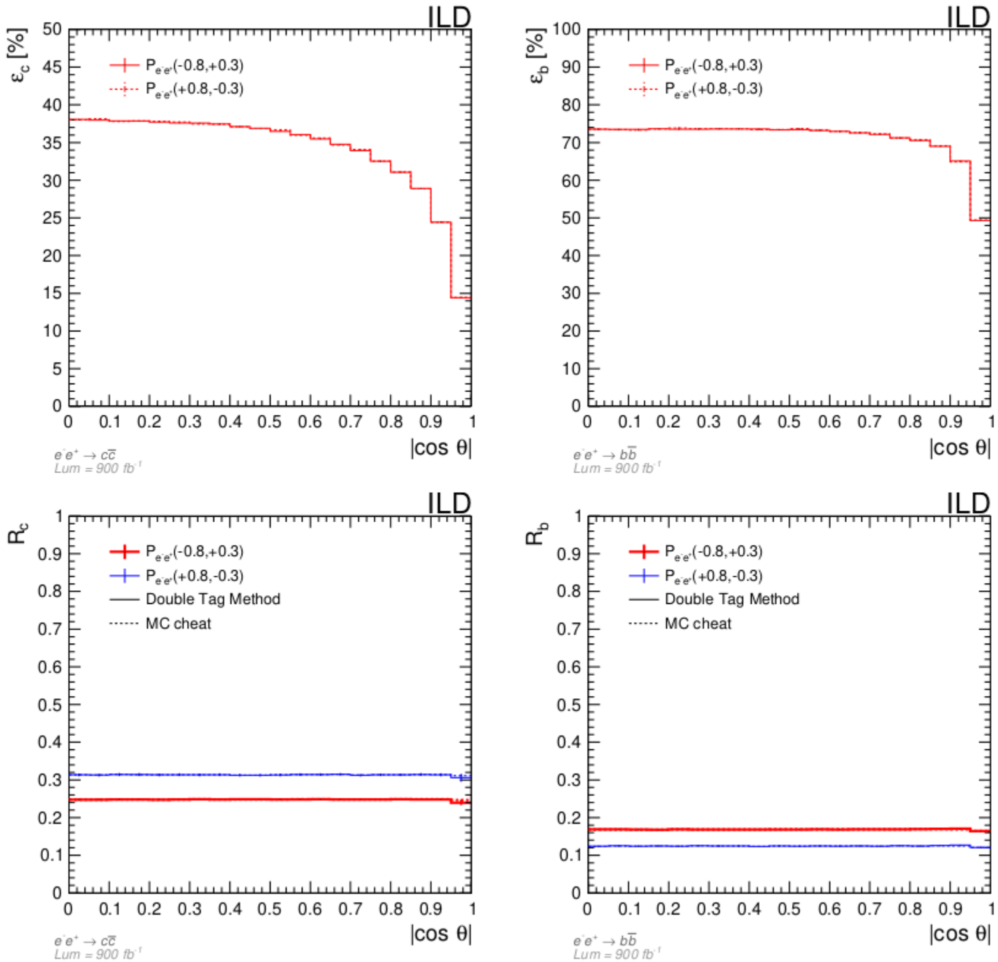
PHYSICS!
Indirect observables

Inputs (MC or independent measurements)

Similar set of equations for the c-quark
solved simultaneously

Summary Rq

- ▷ **Flavour tagging efficiency will be measured**
  - Not estimated with MC
  - **Per mil level reachable** because the contamination from lighter quarks is minimal and the tight IP constraint
- ▷ **Fully differential analysis !!**
- ▷ **Rb and Rc measured at the same time**
  - No assumption needed in Ruds
- ▷ **Per mil level stat. Uncertainty – dominant unc.**
- ▷ **Exp syst. uncertainty**
  - Dominated by flavour tagging and followed by angular correlations



arxiv:2306.11413

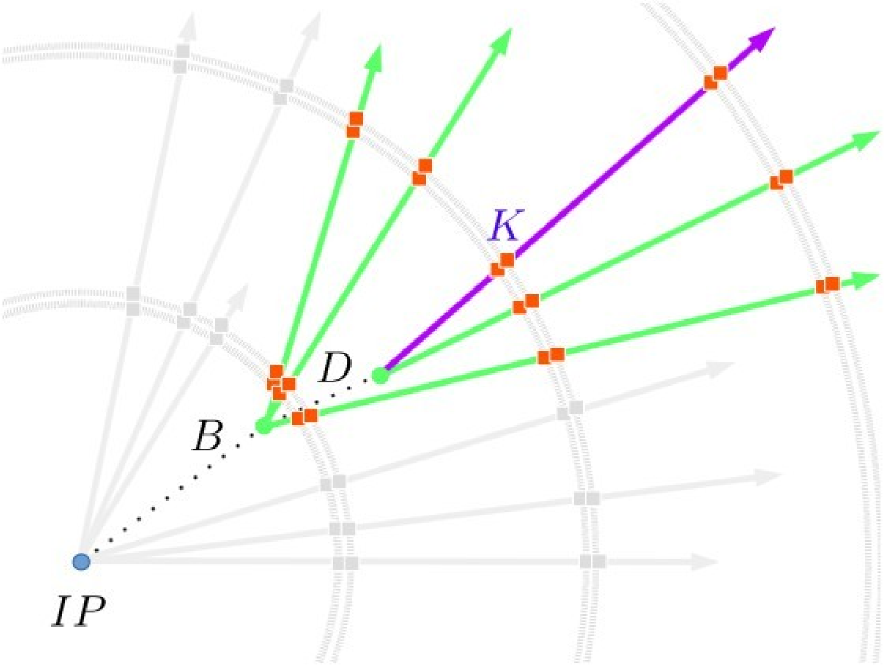
Jet charge

- We start from a very pure & background-free **double tagged** sample

- We are required to **measure the jet charge**
  - Using K-ID and/or full Vtx charge measurement
  - K-ID is better suited for the C-quark (Vtx is better suited for b-quark)

- K-ID: via TPC (dEdx or dNdx)

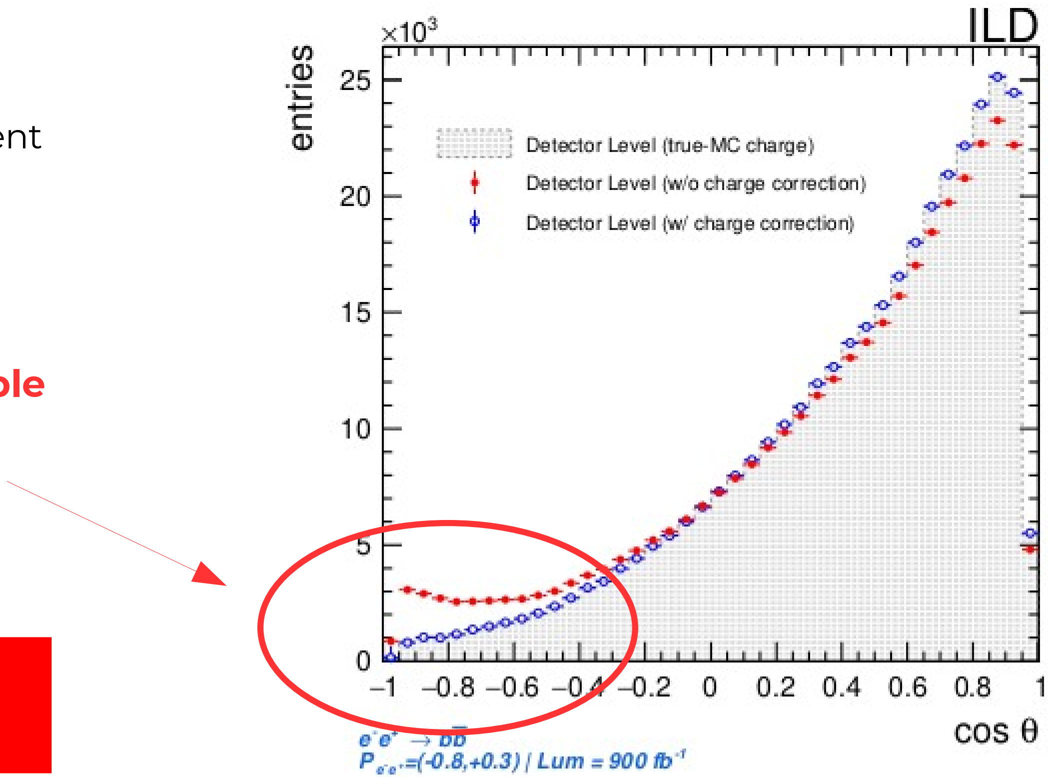
- We use the **double charge** measurements
  - To control / reduce the systematic uncertainties



Double Charge Method

- ▷ **We start from a ~100% pure bbbar or ccbar sample (Double Tag)**
- ▷ **For AFB we proceed with Double Charge**
  - Both jets need to have a charge measurement compatible with the 2 quarks back to back scenario
- ▷ Double mistakes are unlikely but still not negligible and lead to “sign flip” → migrations

BSM or simple migrations?



Red shows the distribution withtout sign correction.

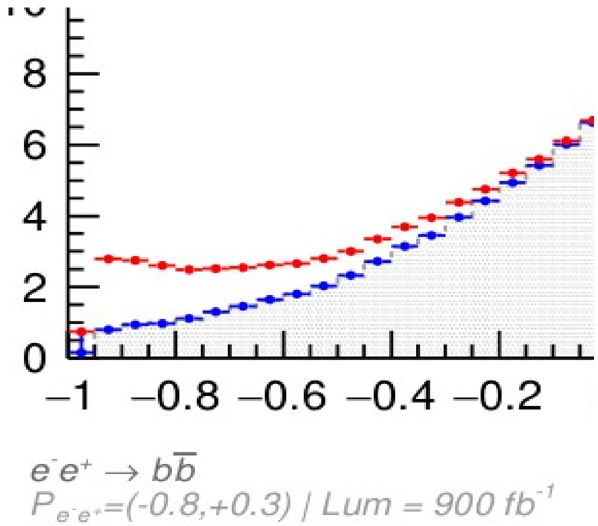
Gray is the parton level distribution

arxiv:2306.11413

Migration correction

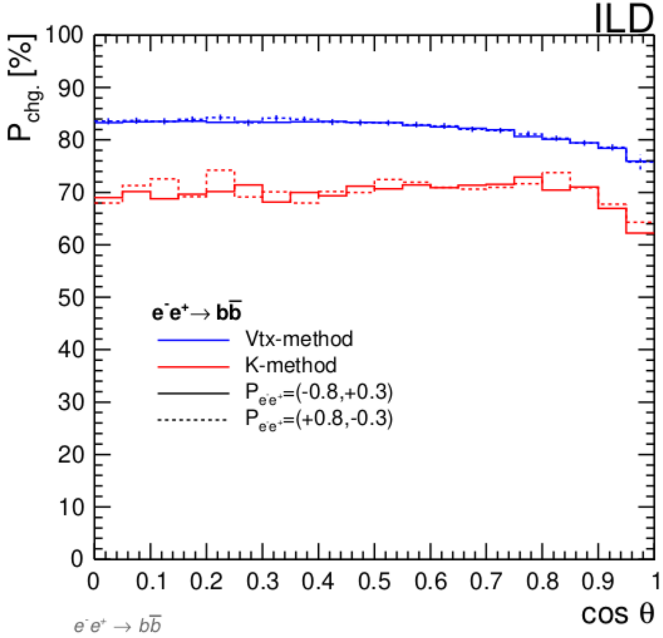
▷Migrations look as “new physics” → we need to correct them

- **Using data: double charge measurements** with same and opposite charges (see back-up slides)
- We measure the probability to reconstruct correctly the charge (P_B) and use it for correction
- **DATA DRIVEN METHOD → non sensitive to fragmentation modelling.**



blue shows the distribution after sign correction.

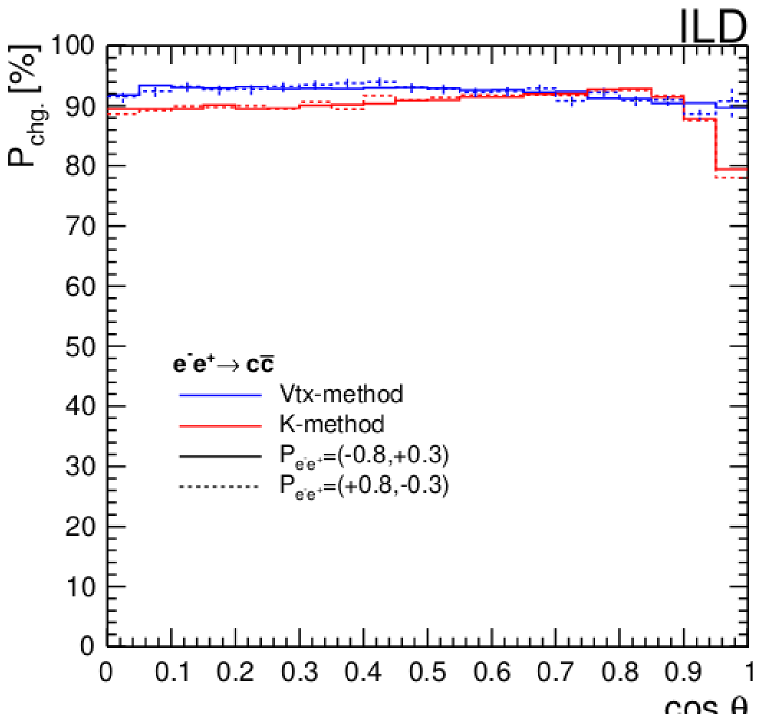
Gray is the parton level distribution



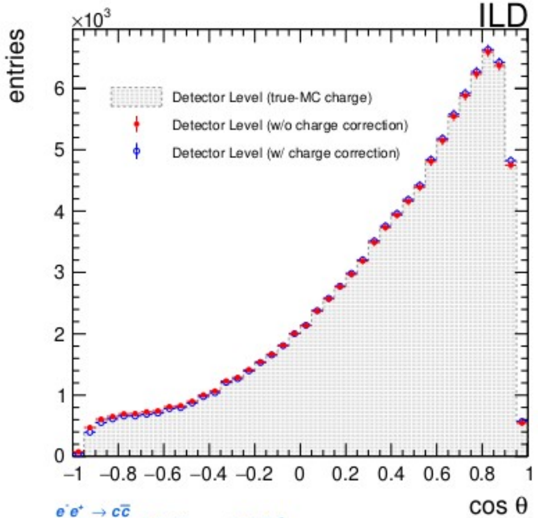
▷**Pchg limited by vertex reconstruction efficiency, Particle ID efficiency and B0 oscillations** (b-quark case)**.**

arxiv:2306.11413

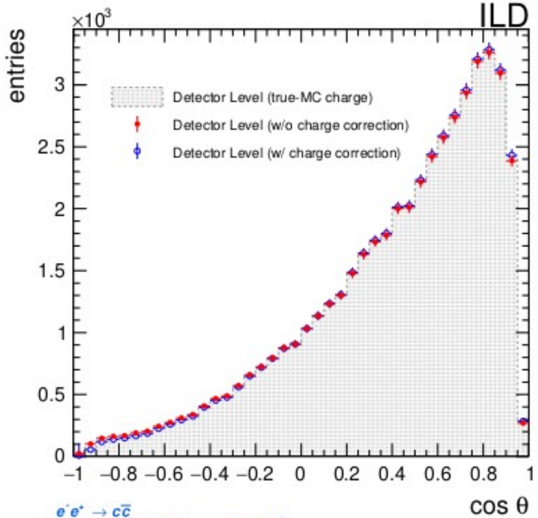
Migration correction – cquark case



$e^-e^+ \to c\bar{c}$



$e^-e^+ \to c\bar{c}$
$P_{e^-e^+}$=(-0.8,+0.3) | Lum = 900 fb^{-1}



$e^-e^+ \to c\bar{c}$
$P_{e^-e^+}$=(+0.8,-0.3) | Lum = 900 fb^{-1}

Minimal migration effects (and corrections!)

arxiv:2306.11413

Result and fit

▷Efficiency and charge miscalculation corrections → comparison to parton level

▷**At least 4 observables for AFB at ILC250 per energy point**

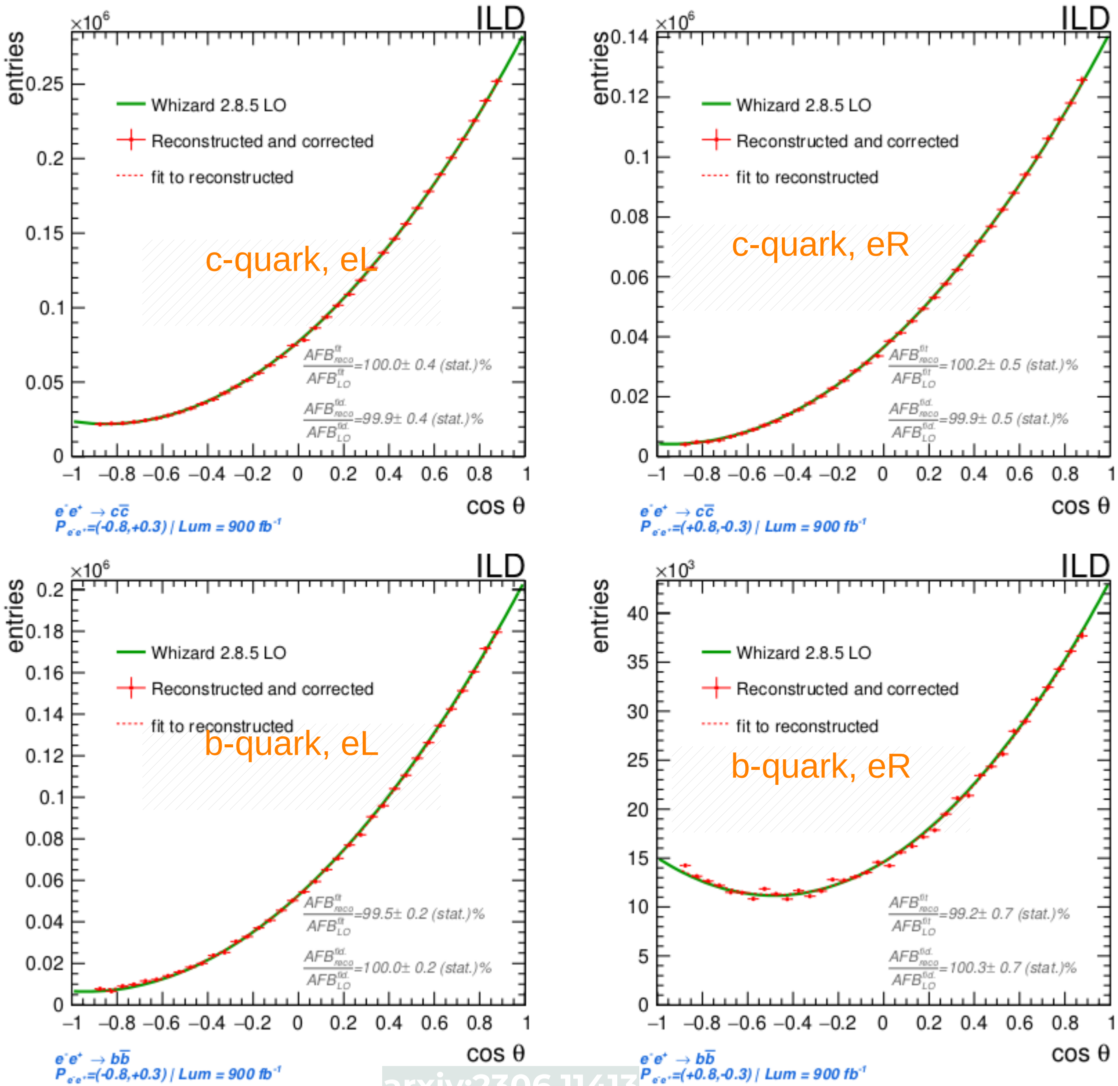
- 2 quarks and 2 polarisations (eLpR, eRpL)

▶ **Per mil level statistical uncertainties** reachable for the nominal **ILC250 program**

▶ **Comparable/smaller exp syst. Uncertainties**

- Preselection efficiency (radiative return removal) followed by angular correlations

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



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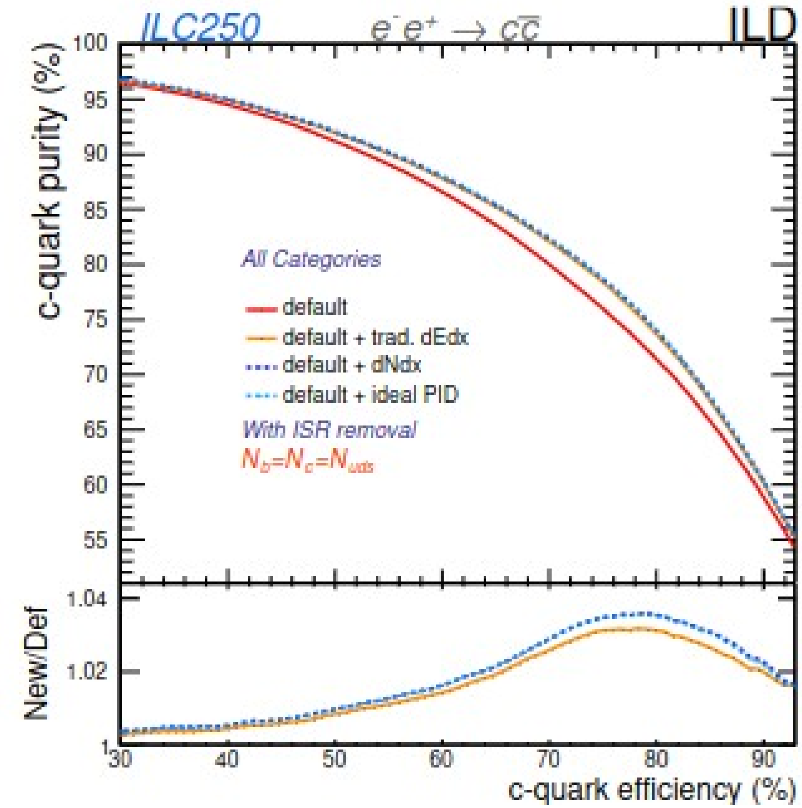
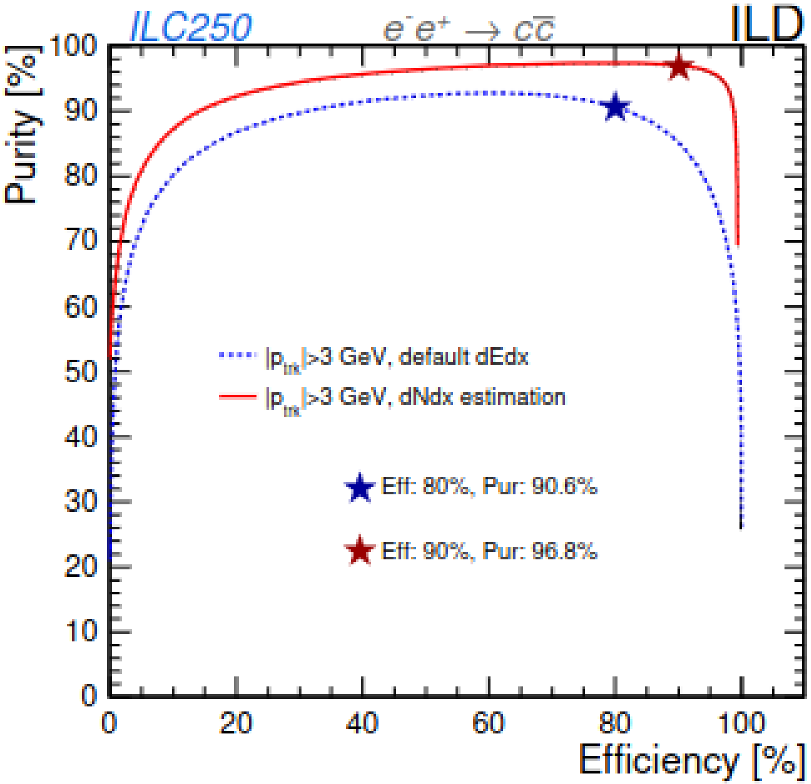
Pixel TPC → from dEdx to dNdx



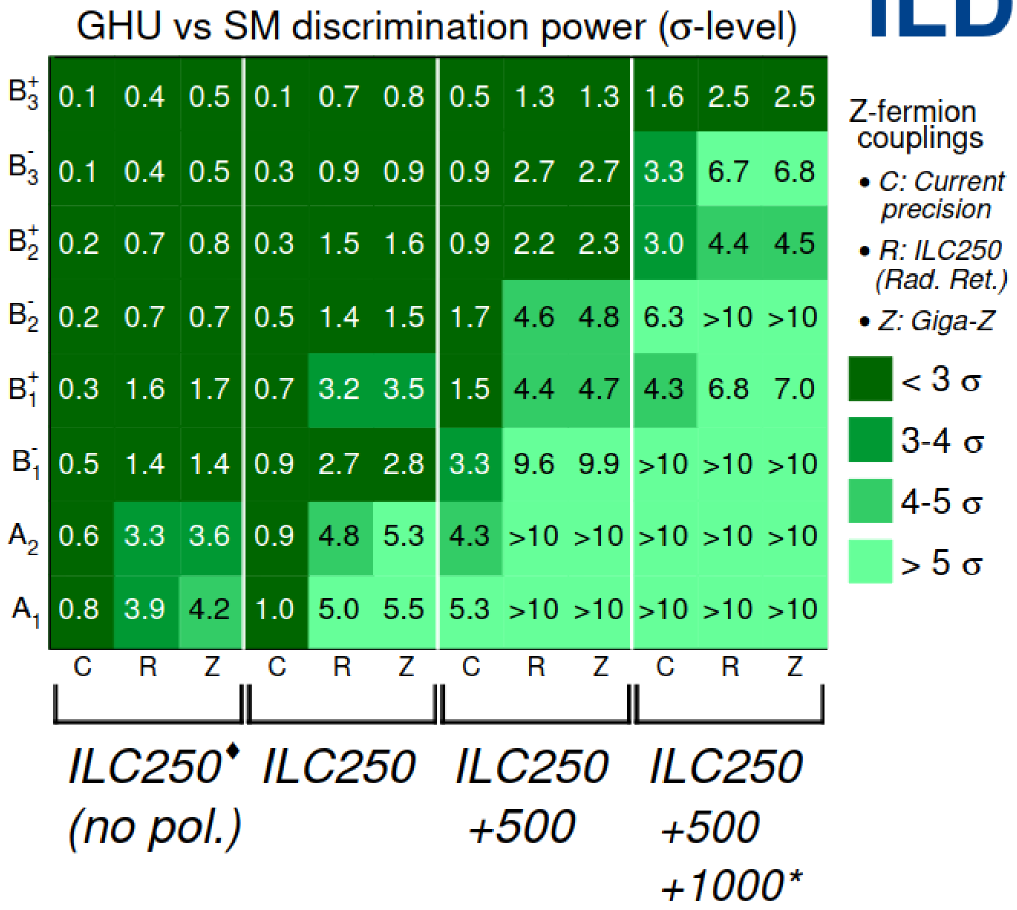


arxiv:2307.14888

BSM Physics prospects

GHU vs SM discrimination power

ILD



GHU vs SM discrimination power (σ-level)

	ILC250♦ (no pol.)			ILC250			ILC250 +500			ILC250 +500 +1000*		
	C	R	Z	C	R	Z	C	R	Z	C	R	Z
B_3^+	0.1	0.4	0.5	0.1	0.7	0.8	0.5	1.3	1.3	1.6	2.5	2.5
B_3^-	0.1	0.4	0.5	0.3	0.9	0.9	0.9	2.7	2.7	3.3	6.7	6.8
B_2^+	0.2	0.7	0.8	0.3	1.5	1.6	0.9	2.2	2.3	3.0	4.4	4.5
B_2^-	0.2	0.7	0.7	0.5	1.4	1.5	1.7	4.6	4.8	6.3	>10	>10
B_1^+	0.3	1.6	1.7	0.7	3.2	3.5	1.5	4.4	4.7	4.3	6.8	7.0
B_1^-	0.5	1.4	1.4	0.9	2.7	2.8	3.3	9.6	9.9	>10	>10	>10
A_2	0.6	3.3	3.6	0.9	4.8	5.3	4.3	>10	>10	>10	>10	>10
A_1	0.8	3.9	4.2	1.0	5.0	5.5	5.3	>10	>10	>10	>10	>10

Z-fermion couplings

- *C: Current precision*
- *R: ILC250 (Rad. Ret.)*
- *Z: Giga-Z*

🟩 < 3 σ
🟩 3-4 σ
🟩 4-5 σ
🟩 > 5 σ

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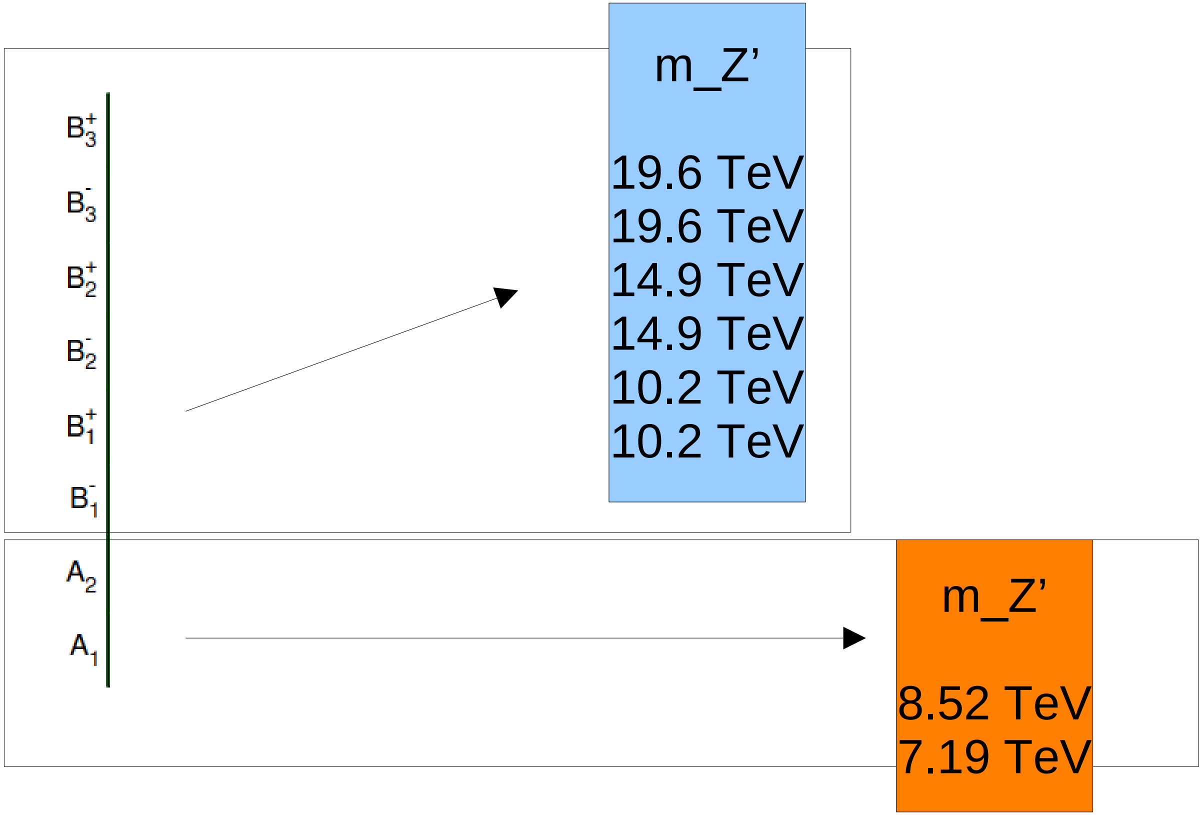
GHU vs SM discrimination power



B_3^+
B_3^-
B_2^+
B_2^-
B_1^+
B_1^-

m_Z'

19.6 TeV
19.6 TeV
14.9 TeV
14.9 TeV
10.2 TeV
10.2 TeV

A_2
A_1

m_Z'

8.52 TeV
7.19 TeV

GHU vs SM discrimination power

Hypothetical case
ILC250⬩ no pol
2000fb⁻¹
Full ILD simulation
assuming no beam pol

H20-staged program

ILC250
(Pe-=0.8,Pe+=0.3)
2000fb⁻¹

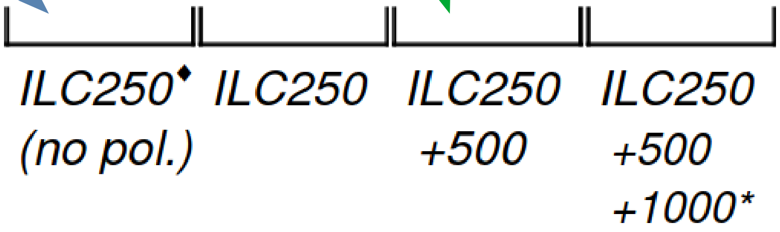
ILC500
(Pe-=0.8,Pe+=0.3)
4000fb⁻¹

Full ILD simulation
assuming beam pol

H20-staged program

ILC1000
(Pe-=0.8,Pe+=0.2)
8000fb⁻¹

Not full sim studies
but extrapolations from ILC500



GHU vs SM : c.m.e.

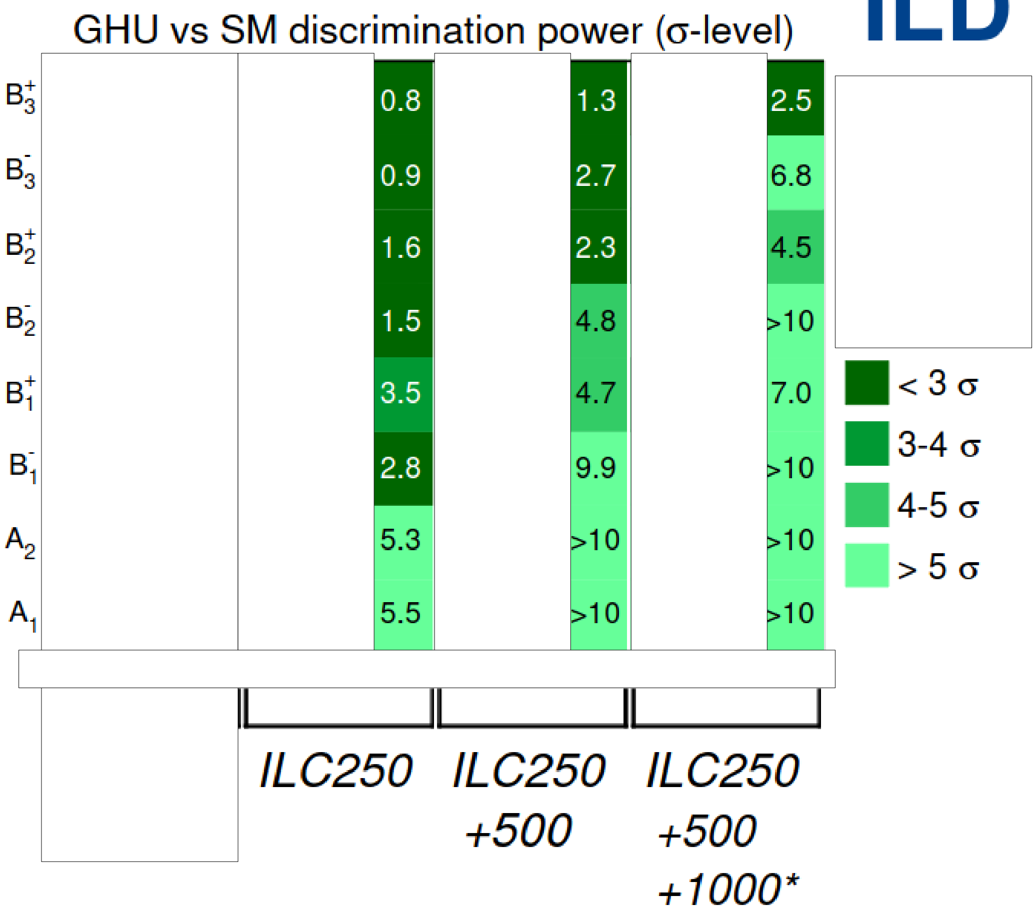
m_Z’

19.6 TeV
19.6 TeV
14.9 TeV
14.9 TeV
10.2 TeV
10.2 TeV

m_Z’

8.52 TeV
7.19 TeV

ILD



GHU vs SM discrimination power (σ-level)

	ILC250	ILC250 +500	ILC250 +500 +1000*
B_3^+	0.8	1.3	2.5
B_3^-	0.9	2.7	6.8
B_2^+	1.6	2.3	4.5
B_2^-	1.5	4.8	>10
B_1^+	3.5	4.7	7.0
B_1^-	2.8	9.9	>10
A_2	5.3	>10	>10
A_1	5.5	>10	>10

- 🟩 < 3 σ
- 🟩 3-4 σ
- 🟩 4-5 σ
- 🟩 > 5 σ

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GHU vs SM : Precision on Z-couplings

m_Z’

19.6 TeV
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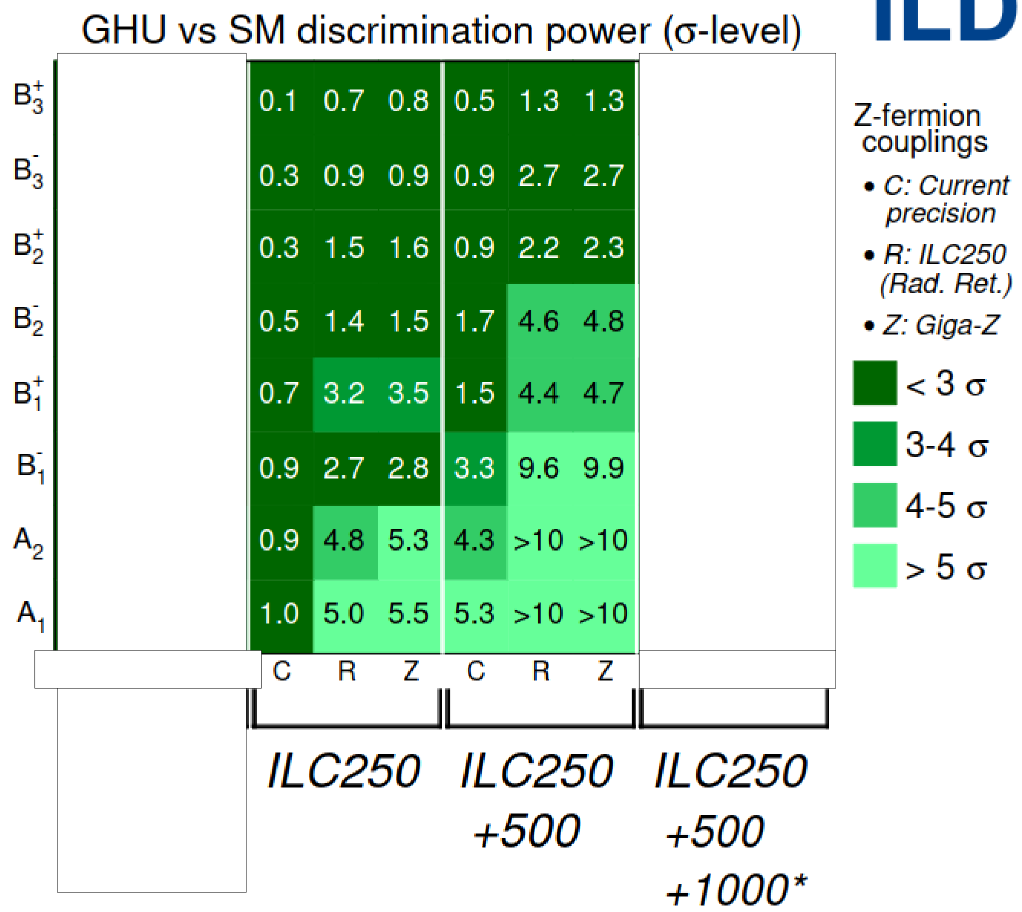
14.9 TeV
14.9 TeV
10.2 TeV
10.2 TeV

m_Z’

8.52 TeV
7.19 TeV

ILD



GHU vs SM discrimination power (σ-level)

	ILC250			ILC250 +500			ILC250 +500 +1000*
	C	R	Z	C	R	Z	
B_3^+	0.1	0.7	0.8	0.5	1.3	1.3	
B_3^-	0.3	0.9	0.9	0.9	2.7	2.7	
B_2^+	0.3	1.5	1.6	0.9	2.2	2.3	
B_2^-	0.5	1.4	1.5	1.7	4.6	4.8	
B_1^+	0.7	3.2	3.5	1.5	4.4	4.7	
B_1^-	0.9	2.7	2.8	3.3	9.6	9.9	
A_2	0.9	4.8	5.3	4.3	>10	>10	
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Z-fermion couplings

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GHU vs SM : Precision on Z-couplings

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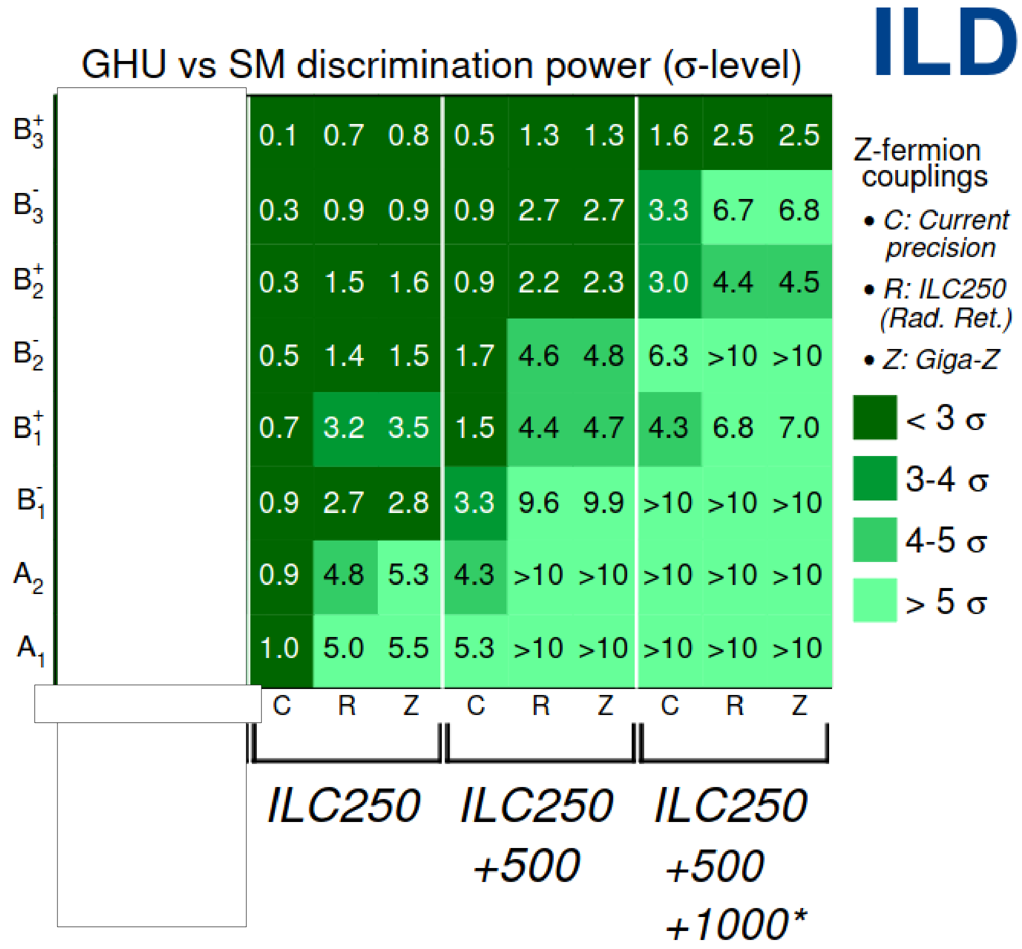

ILD

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B_2^+	0.3	1.5	1.6	0.9	2.2	2.3	3.0	4.4	4.5
B_2^-	0.5	1.4	1.5	1.7	4.6	4.8	6.3	>10	>10
B_1^+	0.7	3.2	3.5	1.5	4.4	4.7	4.3	6.8	7.0
B_1^-	0.9	2.7	2.8	3.3	9.6	9.9	>10	>10	>10
A_2	0.9	4.8	5.3	4.3	>10	>10	>10	>10	>10
A_1	1.0	5.0	5.5	5.3	>10	>10	>10	>10	>10

Z-fermion couplings

- *C: Current precision*
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🟩 < 3 σ
🟩 3-4 σ
🟩 4-5 σ
🟩 > 5 σ

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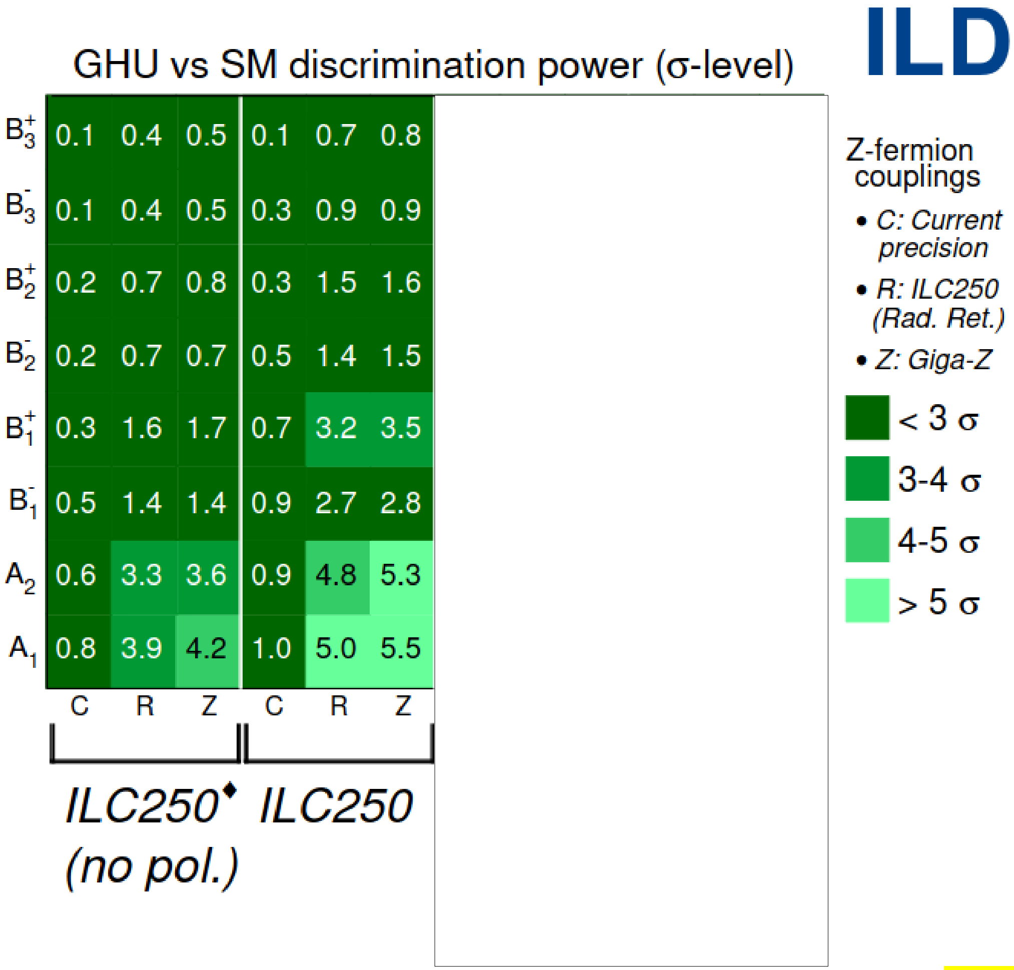
GHU vs SM : beam(s) polarization

m_Z'

19.6 TeV
19.6 TeV
14.9 TeV
14.9 TeV
10.2 TeV
10.2 TeV

m_Z'

8.52 TeV
7.19 TeV



ILD

GHU vs SM discrimination power (σ-level)

	ILC250♦ (no pol.)			ILC250		
	C	R	Z	C	R	Z
B_3^+	0.1	0.4	0.5	0.1	0.7	0.8
B_3^-	0.1	0.4	0.5	0.3	0.9	0.9
B_2^+	0.2	0.7	0.8	0.3	1.5	1.6
B_2^-	0.2	0.7	0.7	0.5	1.4	1.5
B_1^+	0.3	1.6	1.7	0.7	3.2	3.5
B_1^-	0.5	1.4	1.4	0.9	2.7	2.8
A_2	0.6	3.3	3.6	0.9	4.8	5.3
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Z-fermion couplings

- *C: Current precision*
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🟩 < 3 σ
🟩 3-4 σ
🟩 4-5 σ
🟩 > 5 σ

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Irles A., 9th July 2024

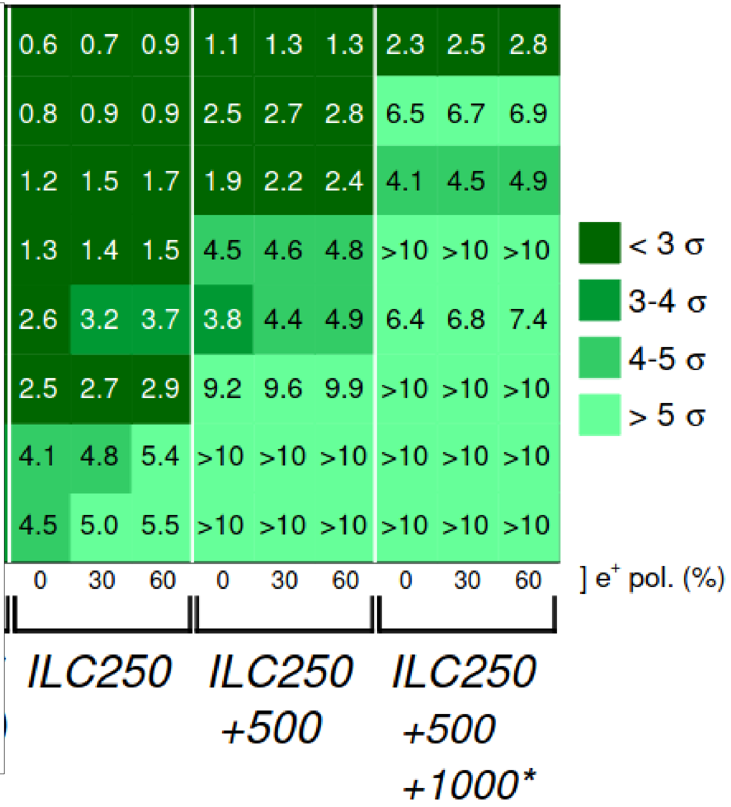
GHU vs SM : positron polarisation

m_Z'
19.6 TeV
19.6 TeV
14.9 TeV
14.9 TeV
10.2 TeV
10.2 TeV

m_Z'
8.52 TeV
7.19 TeV

ILD

GHU vs SM discrimination power (σ-level)



ILC250			ILC250 +500			ILC250 +500 +1000*		
0.6	0.7	0.9	1.1	1.3	1.3	2.3	2.5	2.8
0.8	0.9	0.9	2.5	2.7	2.8	6.5	6.7	6.9
1.2	1.5	1.7	1.9	2.2	2.4	4.1	4.5	4.9
1.3	1.4	1.5	4.5	4.6	4.8	>10	>10	>10
2.6	3.2	3.7	3.8	4.4	4.9	6.4	6.8	7.4
2.5	2.7	2.9	9.2	9.6	9.9	>10	>10	>10
4.1	4.8	5.4	>10	>10	>10	>10	>10	>10
4.5	5.0	5.5	>10	>10	>10	>10	>10	>10
0	30	60	0	30	60	0	30	60

] e$^+$ pol. (%)

🟩 < 3 σ
🟩 3-4 σ
🟩 4-5 σ
🟩 > 5 σ

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GHU vs SM : positron polarisation

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

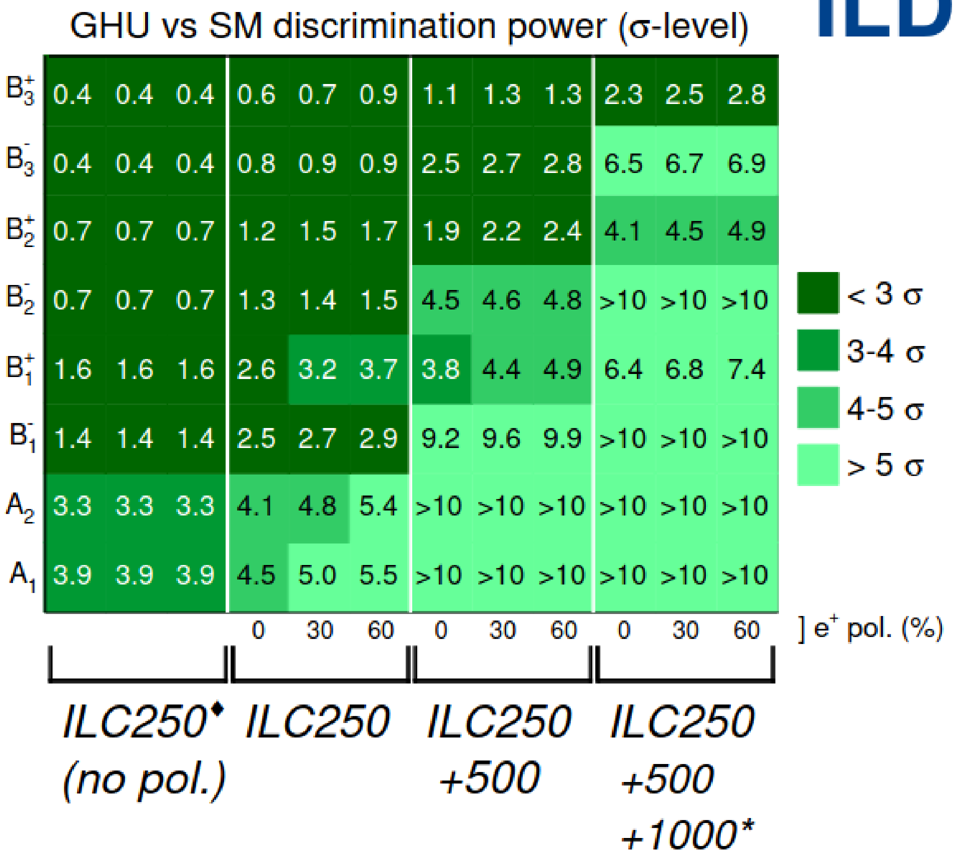
m_Z'

19.6 TeV
19.6 TeV
14.9 TeV
14.9 TeV
10.2 TeV
10.2 TeV

m_Z'

8.52 TeV
7.19 TeV

ILD



GHU vs SM discrimination power (σ-level)

	ILC250♦ (no pol.)			ILC250			ILC250 +500			ILC250 +500 +1000*		
e⁺ pol. (%)				0	30	60	0	30	60	0	30	60
B_3^+	0.4	0.4	0.4	0.6	0.7	0.9	1.1	1.3	1.3	2.3	2.5	2.8
B_3^-	0.4	0.4	0.4	0.8	0.9	0.9	2.5	2.7	2.8	6.5	6.7	6.9
B_2^+	0.7	0.7	0.7	1.2	1.5	1.7	1.9	2.2	2.4	4.1	4.5	4.9
B_2^-	0.7	0.7	0.7	1.3	1.4	1.5	4.5	4.6	4.8	>10	>10	>10
B_1^+	1.6	1.6	1.6	2.6	3.2	3.7	3.8	4.4	4.9	6.4	6.8	7.4
B_1^-	1.4	1.4	1.4	2.5	2.7	2.9	9.2	9.6	9.9	>10	>10	>10
A_2	3.3	3.3	3.3	4.1	4.8	5.4	>10	>10	>10	>10	>10	>10
A_1	3.9	3.9	3.9	4.5	5.0	5.5	>10	>10	>10	>10	>10	>10

■ < 3 σ
■ 3-4 σ
■ 4-5 σ
■ > 5 σ

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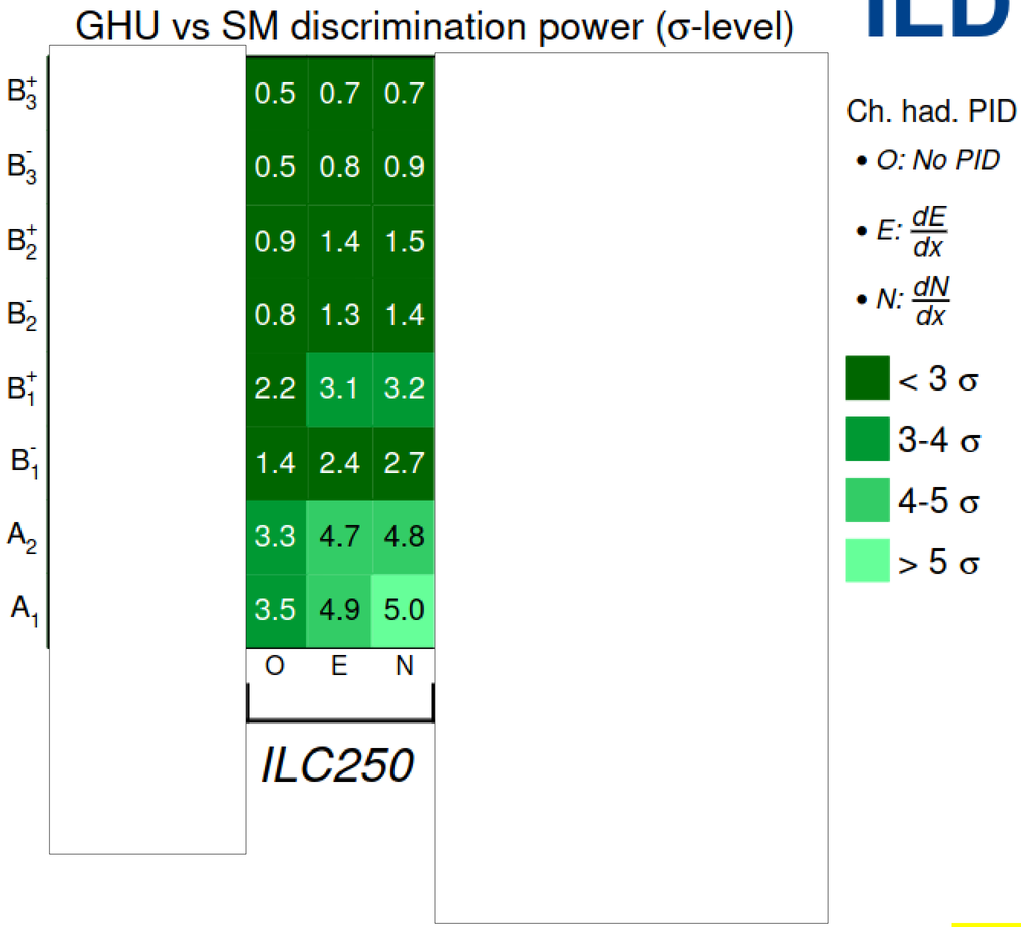
GHU vs SM: Particle ID dependence

m_Z'

19.6 TeV
19.6 TeV
14.9 TeV
14.9 TeV
10.2 TeV
10.2 TeV

m_Z'

8.52 TeV
7.19 TeV



ILD

GHU vs SM discrimination power (σ-level)

	O	E	N
B_3^+	0.5	0.7	0.7
B_3^-	0.5	0.8	0.9
B_2^+	0.9	1.4	1.5
B_2^-	0.8	1.3	1.4
B_1^+	2.2	3.1	3.2
B_1^-	1.4	2.4	2.7
A_2	3.3	4.7	4.8
A_1	3.5	4.9	5.0

ILC250

Ch. had. PID

- *O: No PID*
- *E:* $\frac{dE}{dx}$
- *N:* $\frac{dN}{dx}$

🟩 < 3 σ
🟩 3-4 σ
🟩 4-5 σ
🟩 > 5 σ

Eur.Phys.J.C 84 (2024)

GHU vs SM: Particle ID dependence

m_Z'

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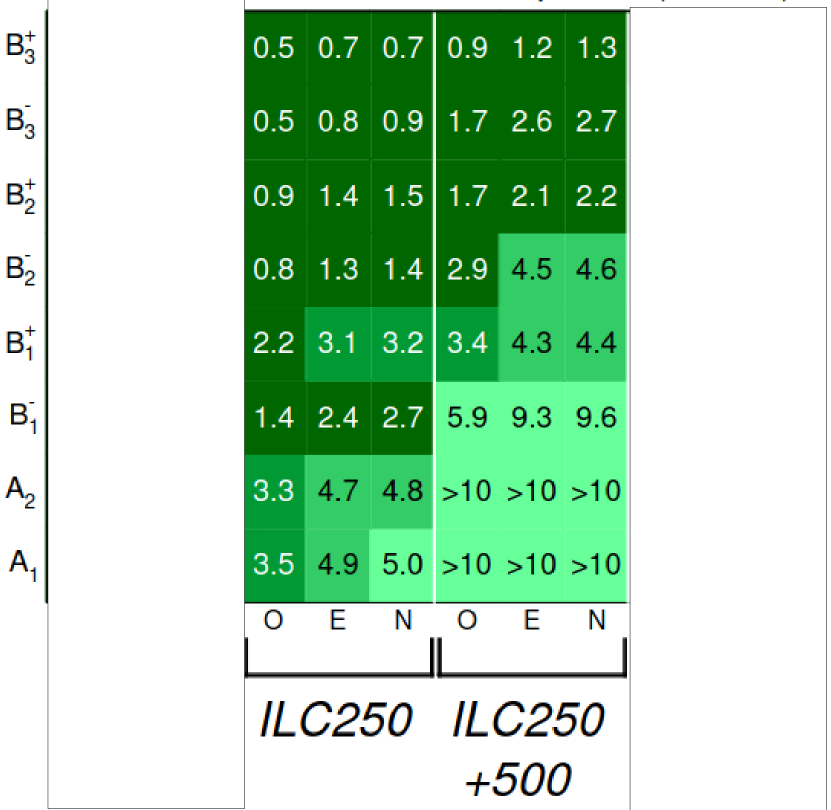

GHU vs SM discrimination power (σ-level)

	ILC250			ILC250 +500		
	O	E	N	O	E	N
B_3^+	0.5	0.7	0.7	0.9	1.2	1.3
B_3^-	0.5	0.8	0.9	1.7	2.6	2.7
B_2^+	0.9	1.4	1.5	1.7	2.1	2.2
B_2^-	0.8	1.3	1.4	2.9	4.5	4.6
B_1^+	2.2	3.1	3.2	3.4	4.3	4.4
B_1^-	1.4	2.4	2.7	5.9	9.3	9.6
A_2	3.3	4.7	4.8	>10	>10	>10
A_1	3.5	4.9	5.0	>10	>10	>10

ILD

Ch. had. PID

- *O: No PID*
- *E: $\frac{dE}{dx}$*
- *N: $\frac{dN}{dx}$*

🟩 < 3 σ
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Eur.Phys.J.C 84 (2024)

GHU vs SM: Particle ID dependence

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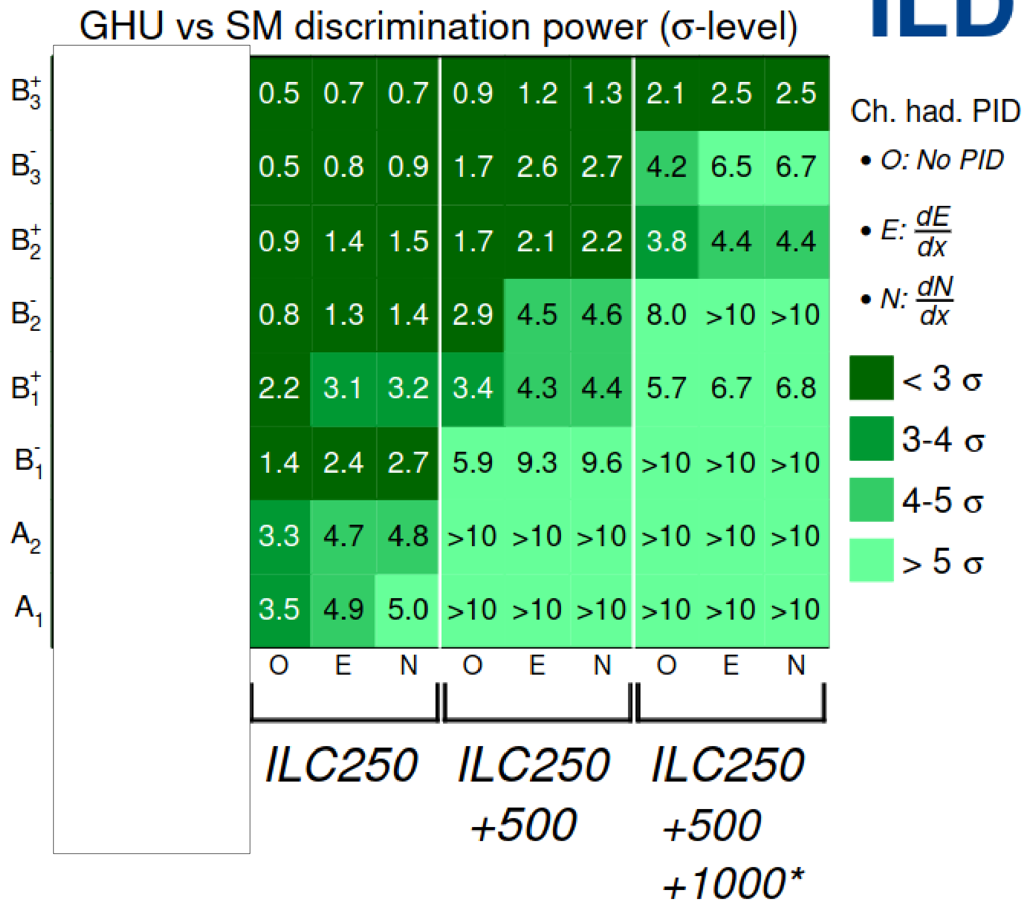

ILD

GHU vs SM discrimination power (σ-level)

	ILC250			ILC250 +500			ILC250 +500 +1000*		
	O	E	N	O	E	N	O	E	N
B_3^+	0.5	0.7	0.7	0.9	1.2	1.3	2.1	2.5	2.5
B_3^-	0.5	0.8	0.9	1.7	2.6	2.7	4.2	6.5	6.7
B_2^+	0.9	1.4	1.5	1.7	2.1	2.2	3.8	4.4	4.4
B_2^-	0.8	1.3	1.4	2.9	4.5	4.6	8.0	>10	>10
B_1^+	2.2	3.1	3.2	3.4	4.3	4.4	5.7	6.7	6.8
B_1^-	1.4	2.4	2.7	5.9	9.3	9.6	>10	>10	>10
A_2	3.3	4.7	4.8	>10	>10	>10	>10	>10	>10
A_1	3.5	4.9	5.0	>10	>10	>10	>10	>10	>10

Ch. had. PID
- *O: No PID*
- *E: $\frac{dE}{dx}$*
- *N: $\frac{dN}{dx}$*

🟩 < 3 σ
🟩 3-4 σ
🟩 4-5 σ
🟩 > 5 σ

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GHU vs SM: Particle ID dependence

m_Z'

19.6 TeV
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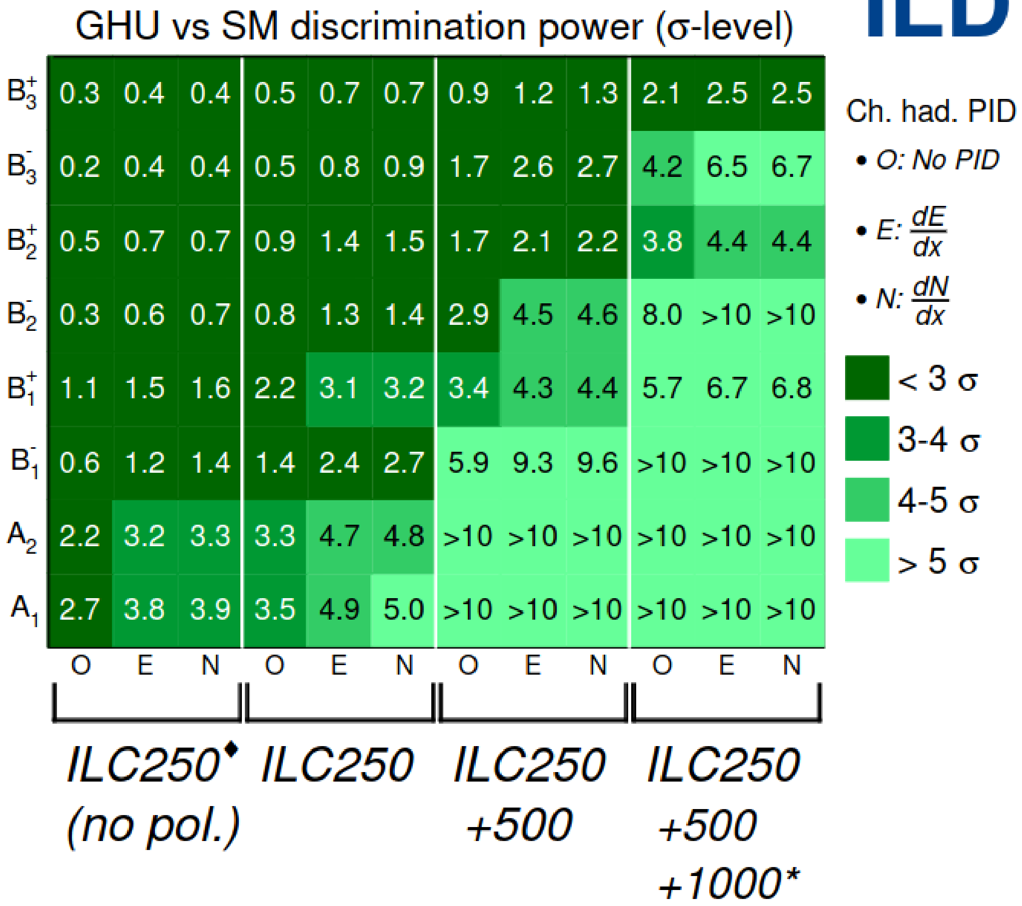
m_Z'

8.52 TeV
7.19 TeV



	ILC250◆ (no pol.)			ILC250			ILC250 +500			ILC250 +500 +1000*		
	O	E	N	O	E	N	O	E	N	O	E	N
B_3^+	0.3	0.4	0.4	0.5	0.7	0.7	0.9	1.2	1.3	2.1	2.5	2.5
B_3^-	0.2	0.4	0.4	0.5	0.8	0.9	1.7	2.6	2.7	4.2	6.5	6.7
B_2^+	0.5	0.7	0.7	0.9	1.4	1.5	1.7	2.1	2.2	3.8	4.4	4.4
B_2^-	0.3	0.6	0.7	0.8	1.3	1.4	2.9	4.5	4.6	8.0	>10	>10
B_1^+	1.1	1.5	1.6	2.2	3.1	3.2	3.4	4.3	4.4	5.7	6.7	6.8
B_1^-	0.6	1.2	1.4	1.4	2.4	2.7	5.9	9.3	9.6	>10	>10	>10
A_2	2.2	3.2	3.3	3.3	4.7	4.8	>10	>10	>10	>10	>10	>10
A_1	2.7	3.8	3.9	3.5	4.9	5.0	>10	>10	>10	>10	>10	>10

ILD

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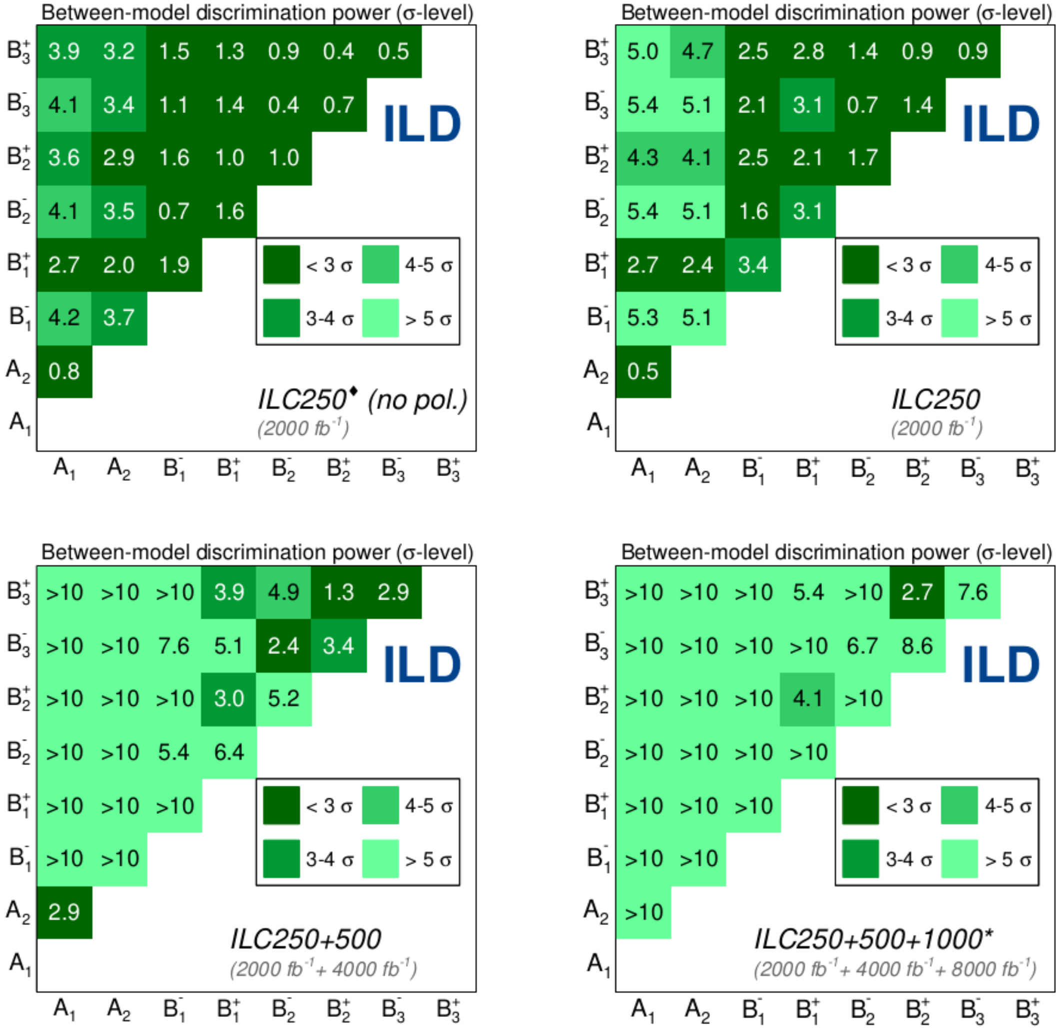
Discrimination between models



Between-model discrimination power (σ-level)

ILD

ILC250♦ (no pol.) (2000 fb^{-1})

	A_1	A_2	B_1^-	B_1^+	B_2^-	B_2^+	B_3^-	B_3^+
B_3^+	3.9	3.2	1.5	1.3	0.9	0.4	0.5	
B_3^-	4.1	3.4	1.1	1.4	0.4	0.7		
B_2^+	3.6	2.9	1.6	1.0	1.0			
B_2^-	4.1	3.5	0.7	1.6				
B_1^+	2.7	2.0	1.9					
B_1^-	4.2	3.7						
A_2	0.8							
A_1								

Between-model discrimination power (σ-level)

ILD

ILC250 (2000 fb^{-1})

	A_1	A_2	B_1^-	B_1^+	B_2^-	B_2^+	B_3^-	B_3^+
B_3^+	5.0	4.7	2.5	2.8	1.4	0.9	0.9	
B_3^-	5.4	5.1	2.1	3.1	0.7	1.4		
B_2^+	4.3	4.1	2.5	2.1	1.7			
B_2^-	5.4	5.1	1.6	3.1				
B_1^+	2.7	2.4	3.4					
B_1^-	5.3	5.1						
A_2	0.5							
A_1								

Between-model discrimination power (σ-level)

ILD

ILC250+500 (2000 fb^{-1} + 4000 fb^{-1})

	A_1	A_2	B_1^-	B_1^+	B_2^-	B_2^+	B_3^-	B_3^+
B_3^+	>10	>10	>10	3.9	4.9	1.3	2.9	
B_3^-	>10	>10	7.6	5.1	2.4	3.4		
B_2^+	>10	>10	>10	3.0	5.2			
B_2^-	>10	>10	5.4	6.4				
B_1^+	>10	>10	>10					
B_1^-	>10	>10						
A_2	2.9							
A_1								

Between-model discrimination power (σ-level)

ILD

*ILC250+500+1000** (2000 fb^{-1} + 4000 fb^{-1} + 8000 fb^{-1})

	A_1	A_2	B_1^-	B_1^+	B_2^-	B_2^+	B_3^-	B_3^+
B_3^+	>10	>10	>10	5.4	>10	2.7	7.6	
B_3^-	>10	>10	>10	>10	6.7	8.6		
B_2^+	>10	>10	>10	4.1	>10			
B_2^-	>10	>10	>10	>10				
B_1^+	>10	>10	>10					
B_1^-	>10	>10						
A_2	>10							
A_1								

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Conclusion/ summary

Summary

- ▷**e+e- → qqbar in the continuum** are challenging analysis
  - Require excellent tracking and vertexing, flavour tagging, PID, ...
  - Excellent for detector benchmarking and optimization
- ▷A **comprehensive experimental study** has been performed
  - With detailed assessment of the major systematic uncertainties → we can **control systematic uncertainties thanks to double tag+charge methods .**
  - **Not fully exploited at LEP/SLC** because moderated flavour performance or statistics.
- ▷**Excellent capabilities for indirect BSM searches**
  - Reach up to **mZ'~ 15TeV at ILC500** (higher if more flavours included)
  - Reach up to **mZ'~ 20TeV at ILC500** (higher if more flavours included)
- ▷Requirements for indirect BSM searches (a short list)
  - High kaon/pion separation for tracks above 10GeV (aka pixel TPC)
  - Longitudinal beam polarisation (at least for electron beam, ideally for both)
  - Energy upgradability

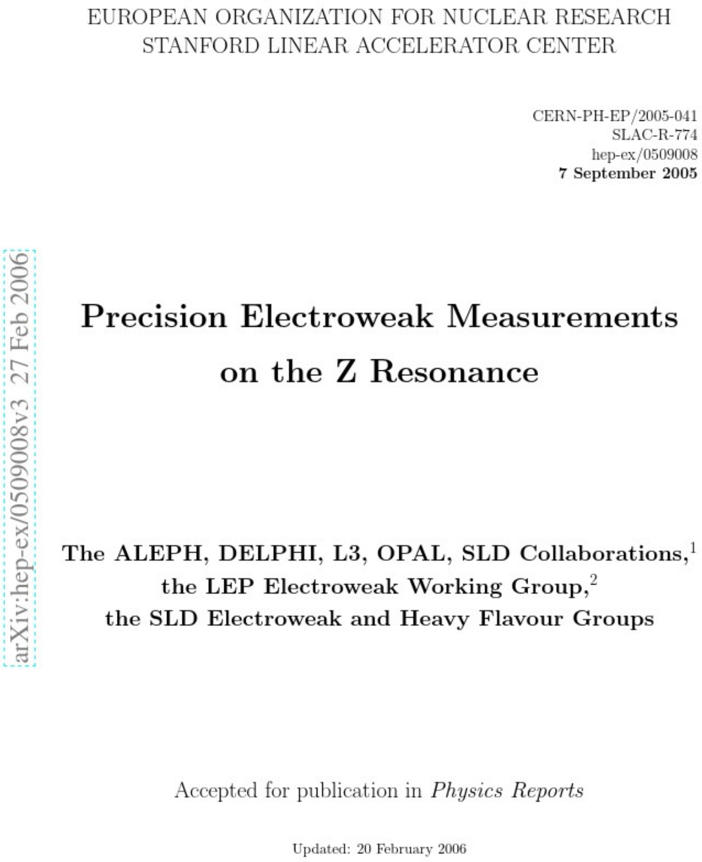
Backup slides

Two fermion processes

▷ **These processes have been deeply studied at** **LEP/SLC at the Z-pole**

- Very comprehensive physics program at Z-Pole
- no access to the γ or Z/γ interference's (“cleaner” access to Z-couplings)
- LEP: “Moderated” quark tagging and/or charge measurements capabilities
- SLC: “Moderated” statistics
- Also moderated angular acceptance of the detectors

$$Q^{SM}_{e_X q_Y} = \frac{e^2}{s} + \frac{g^X_{Ze} g^Y_{Zq}}{(s - m^2_Z) + i m_Z \Gamma_Z}$$



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
STANFORD LINEAR ACCELERATOR CENTER

CERN-PH-EP/2005-041
SLAC-R-774
hep-ex/0509008
7 September 2005

arXiv:hep-ex/0509008v3 27 Feb 2006

Precision Electroweak Measurements on the Z Resonance

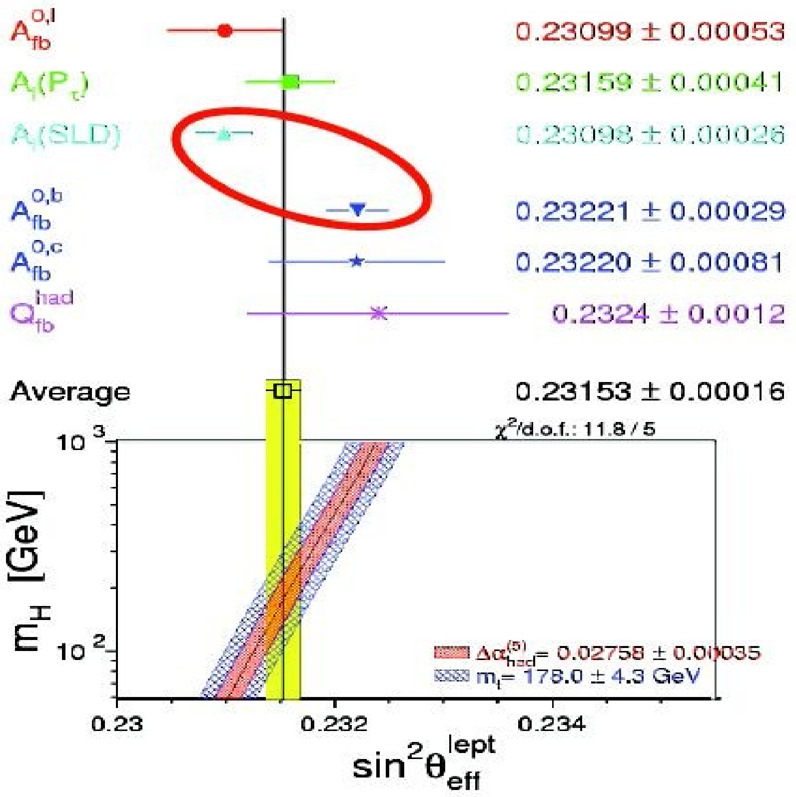
The ALEPH, DELPHI, L3, OPAL, SLD Collaborations,[1]
the LEP Electroweak Working Group,[2]
the SLD Electroweak and Heavy Flavour Groups

Accepted for publication in *Physics Reports*

Updated: 20 February 2006

Motivation: LEP/SLC tension

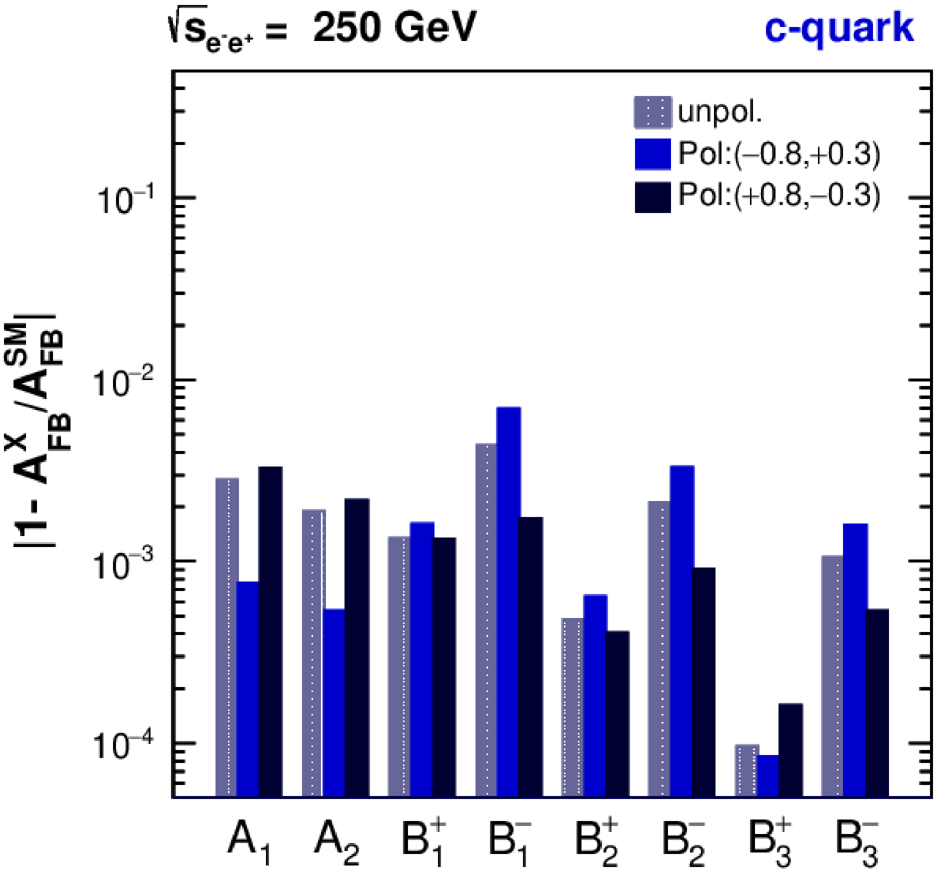
- ▷ Current LEP & SLC best ***$\sin^2\theta^l_{eff}$*** **measurements** show **tension**
  - This measurement is the one with **largest tension with the SM fit.**
  - SLC: ***$\sin^2\theta^l_{eff}$*** →from Left-right asymmetry of leptons
  - LEP: ***$\sin^2\theta^l_{eff}$*** from forward backward asymmetry (b-quark)
- ▷ Heavy quark effect, effect on all quarks/fermions, no effect at all?

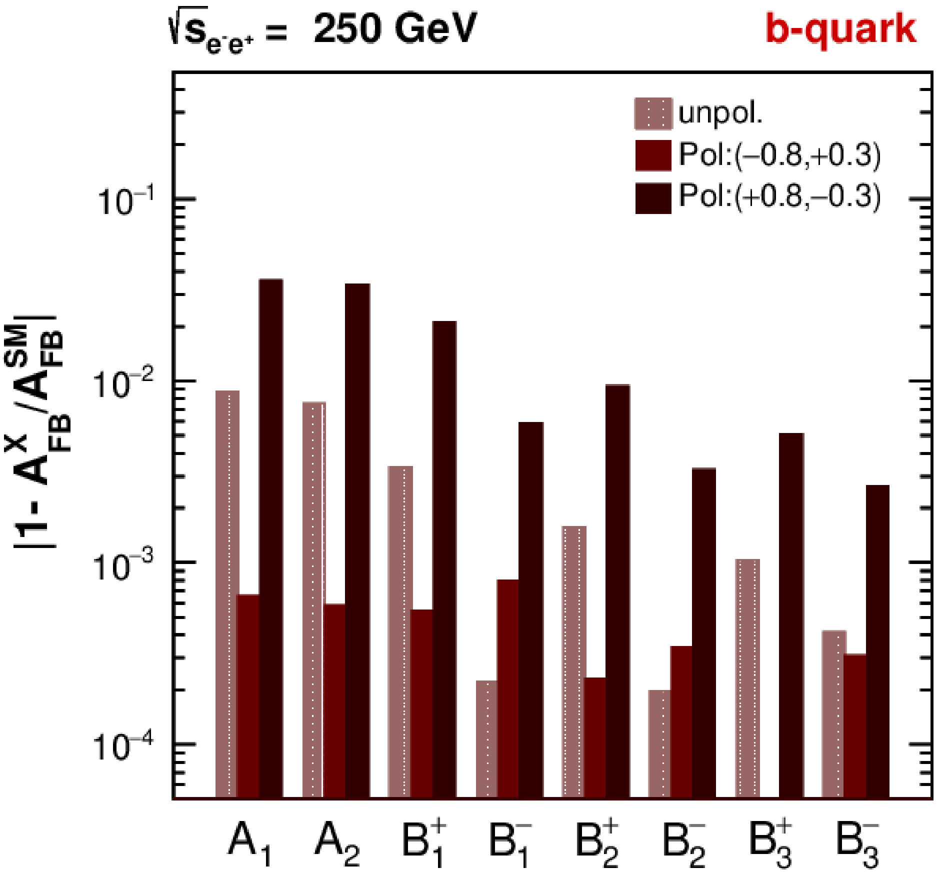


The **resolution** of this issue requires improving the the measurements precision an order of magnitude

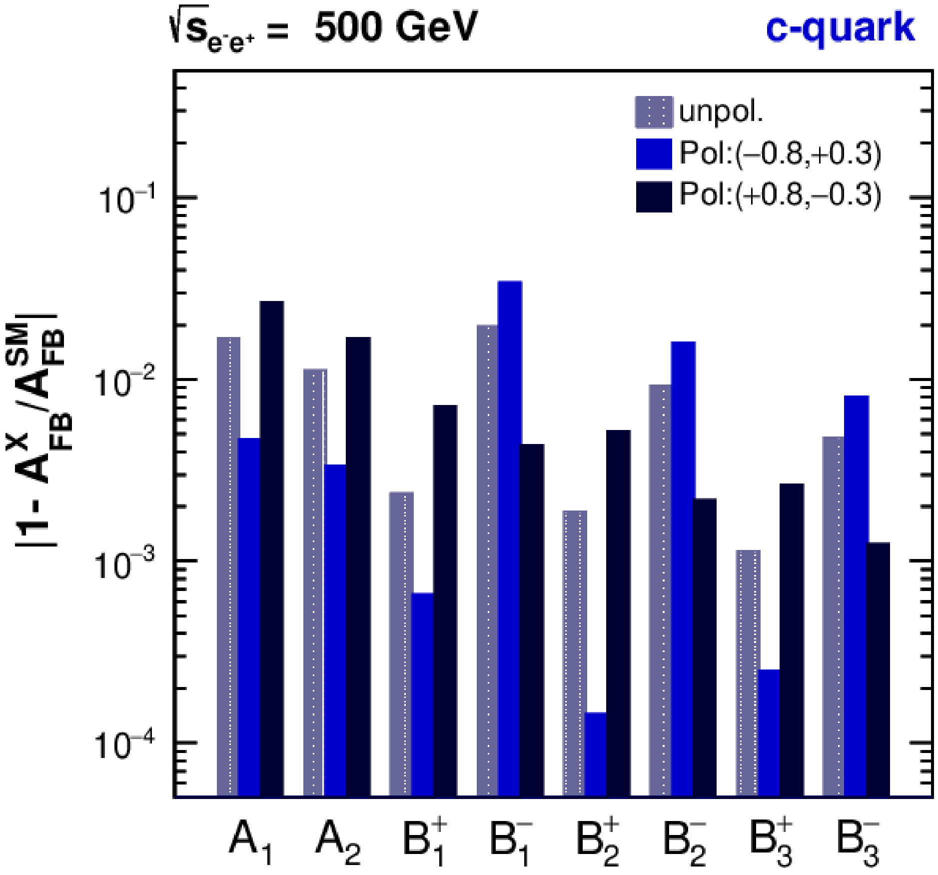
Per mil level of experimental precision is required

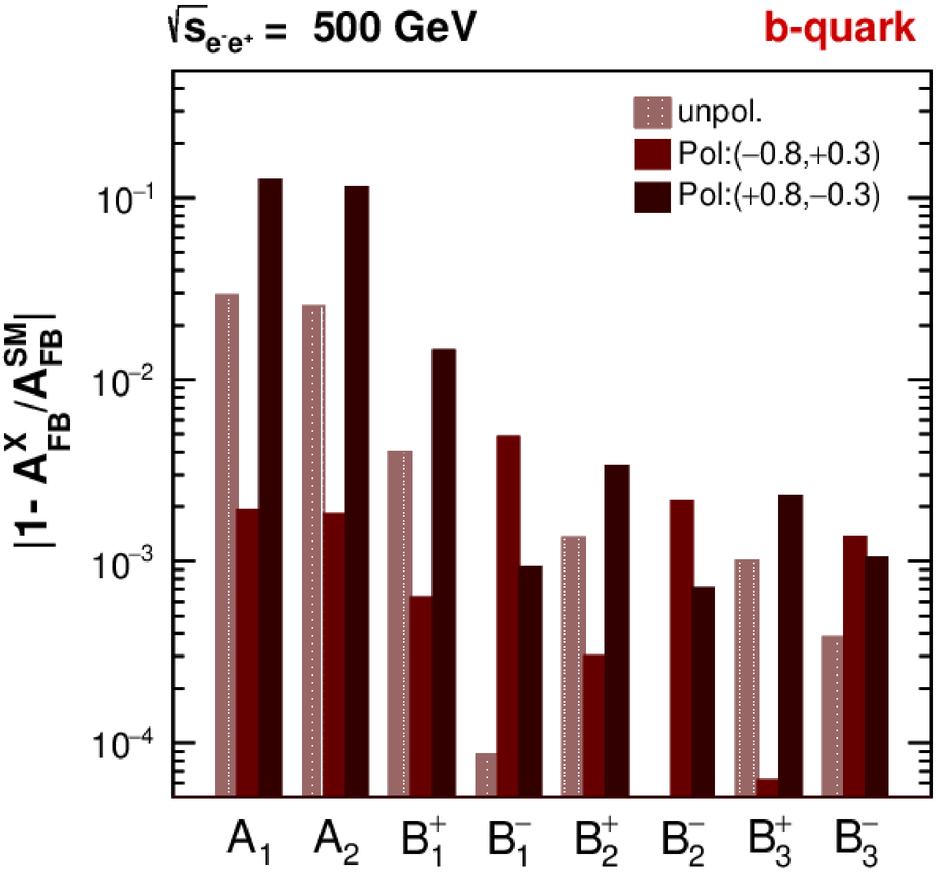
GHU vs SM (250 GeV)



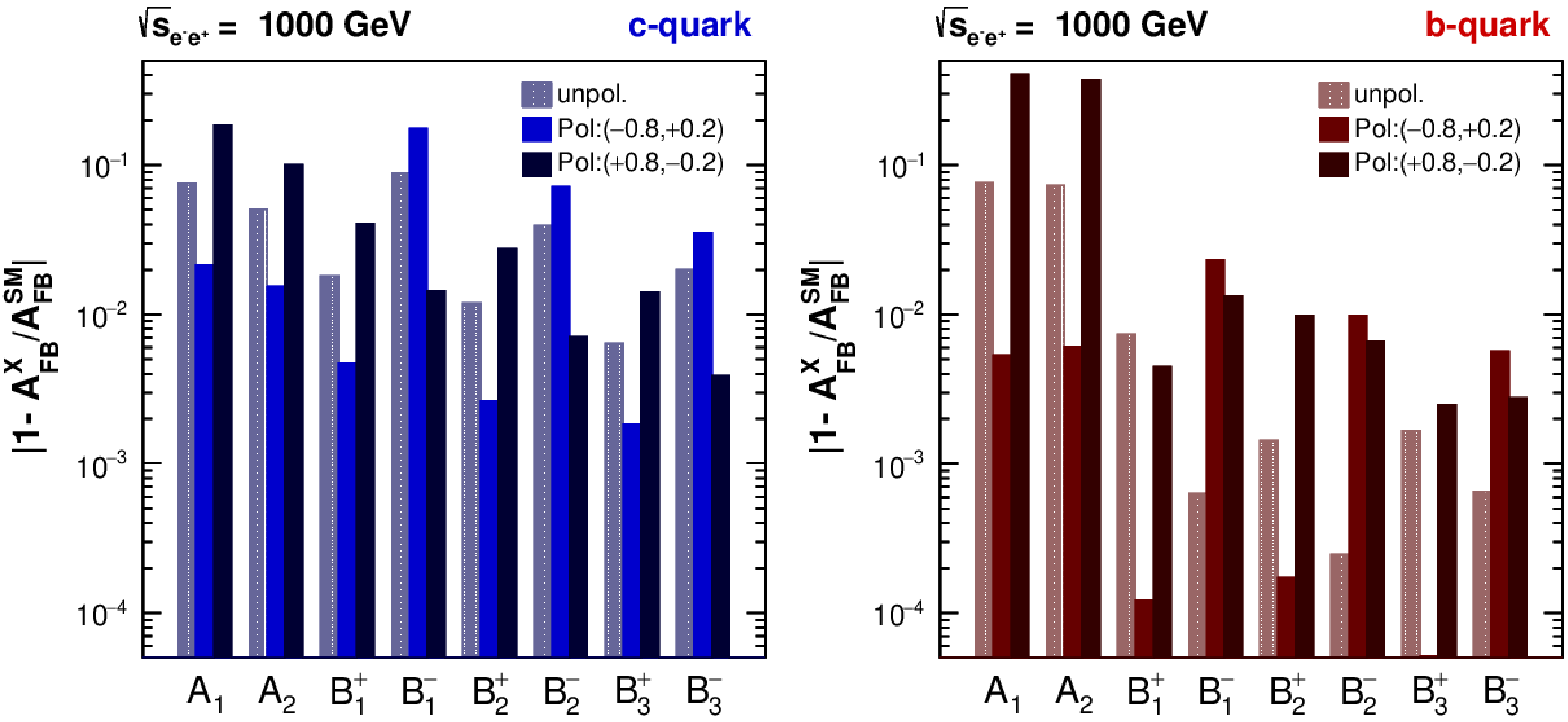


GHU vs SM (500 GeV)

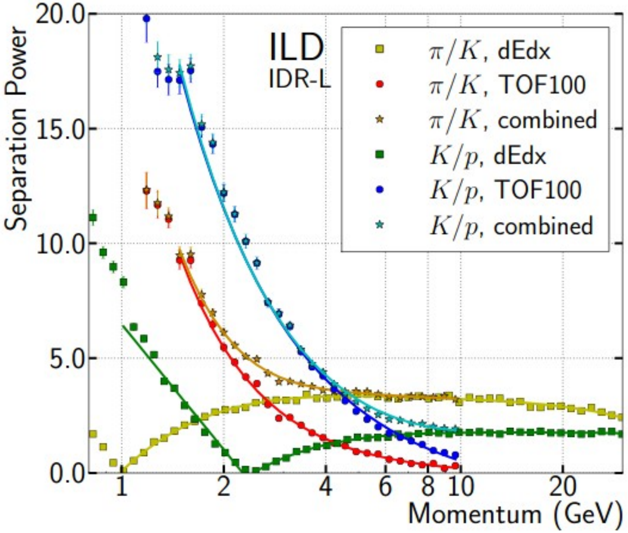


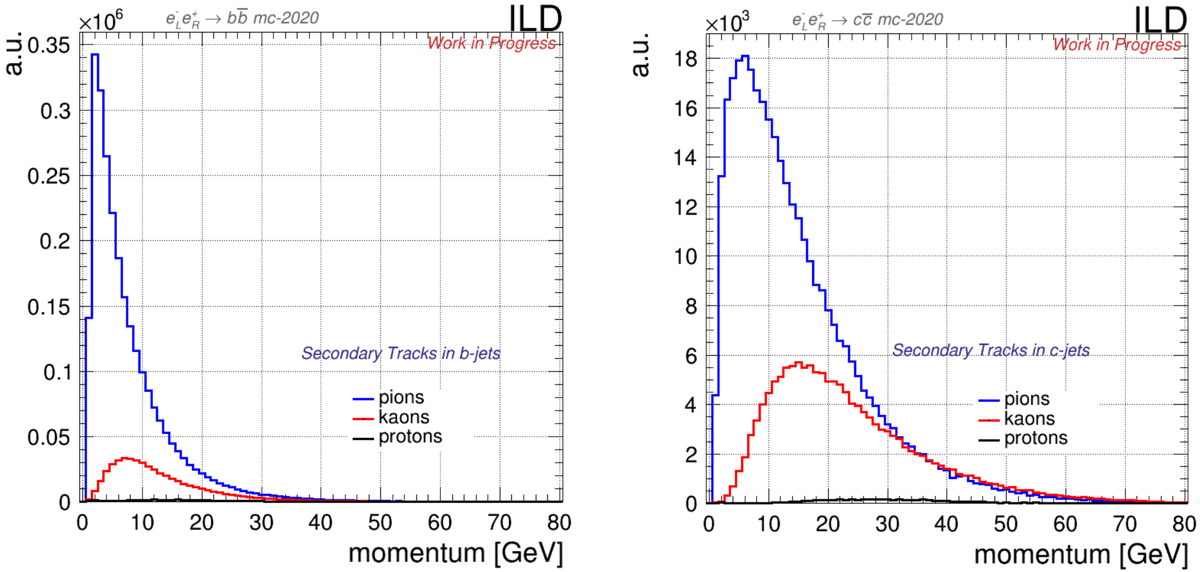


GHU vs SM (1TeV)



High Level Reco Challenges: Particle ID





- For AFB measurements we are required to measure the jet-charge
- Therefore we are interested in a high power of K/pion separation
- Possible solutions: using TPC-PID and/or TOF → Yellow points
  - we are interested in “high” momentum tracks (i.e. dEdx!)

Pixel TPC → from dEdx to dNdx

▷A pixel TPC seems a realistic possibility

- Check here and here for more info

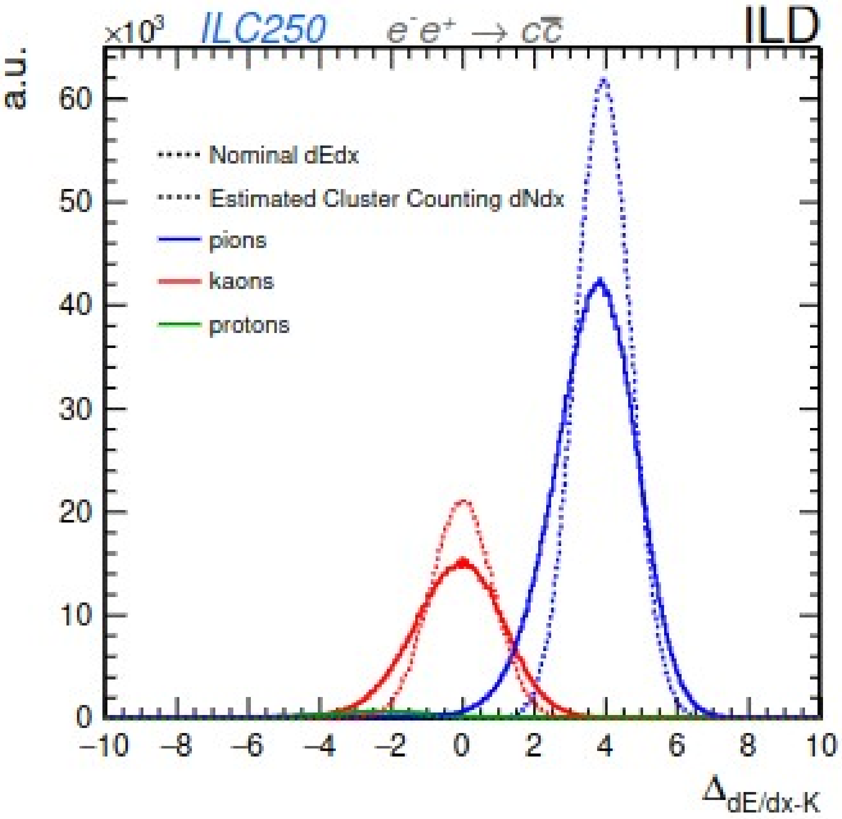
▷First estimations show that a improvement on the dEdx resolution from ~5 to ~4 % is possible if we use cluster counting (i.e. dNdx)

▷This improvement would translate into a 30-40% improvement of the K/Pi separation

- Check here for more info

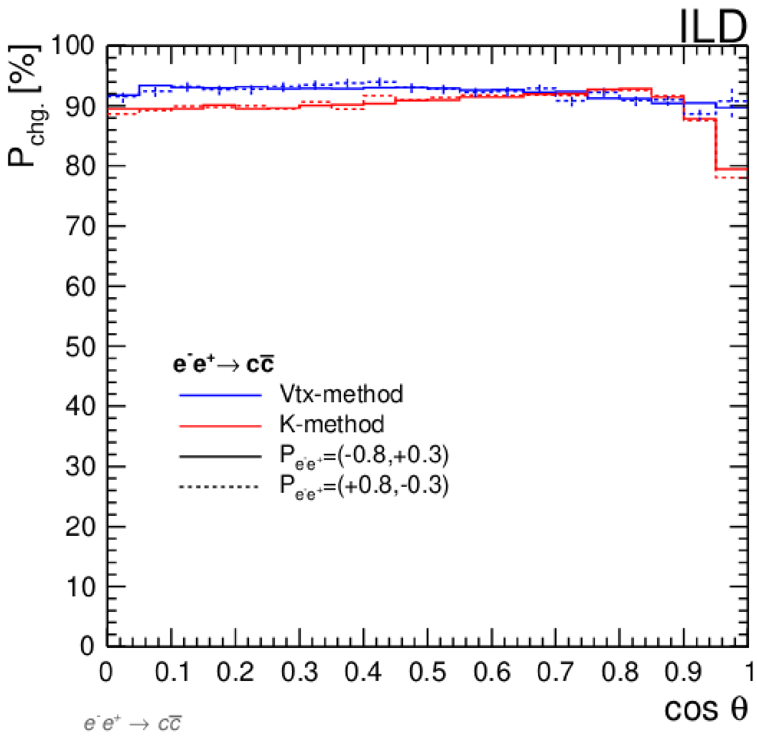
▷dNdx reconstruction is not available in the ILD software (yet)

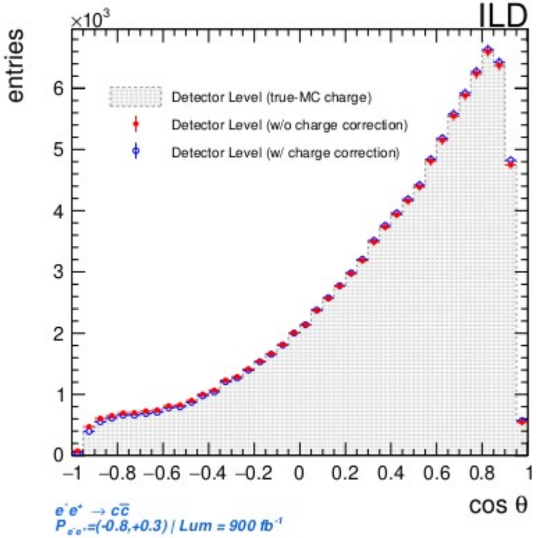
- we estimate its impact on the analysis by "artificially" increasing the separation power capabilities of our discrimination variable.

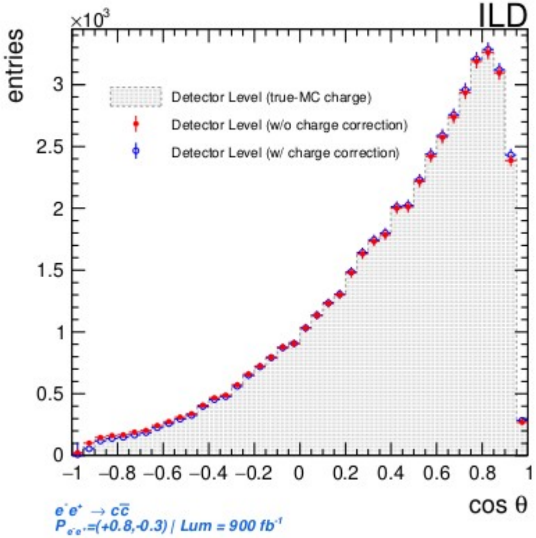


arxiv:2307.14888

Migration correction – cquark case







Minimal migration effects (and corrections!)

arxiv:2306.11413