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

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Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea NextGenerationEU

SECOND • ECFA • WORKSHOP
on e^+e^- Higgs / Electroweak / Top Factories

Introduction & motivation

Motivation: BSM Z’ resonances

▶ Many **BSM scenarios** (i.e. Randal Sundrum, compositeness, Gauge Higgs unification models…) predict heavy resonances coupling to the (t,b) doublet and also lighter fermions (i.e. c/s quarks)

- **BSM resonances** tend to **couple** to the **right components.**
- Only coupling to (t,b) doublet

  → Peskin, Yoon arxiv:1811.07877
  → Djouadi et al arxiv:hep-ph/0610173

- Coupling also to lighter fermions [Funatsu, Hatanaka, Hosotani, Orikasa, Yamatsu

  (arxiv:1705.05282) (2309.01132) (arxiv:2301.07833)

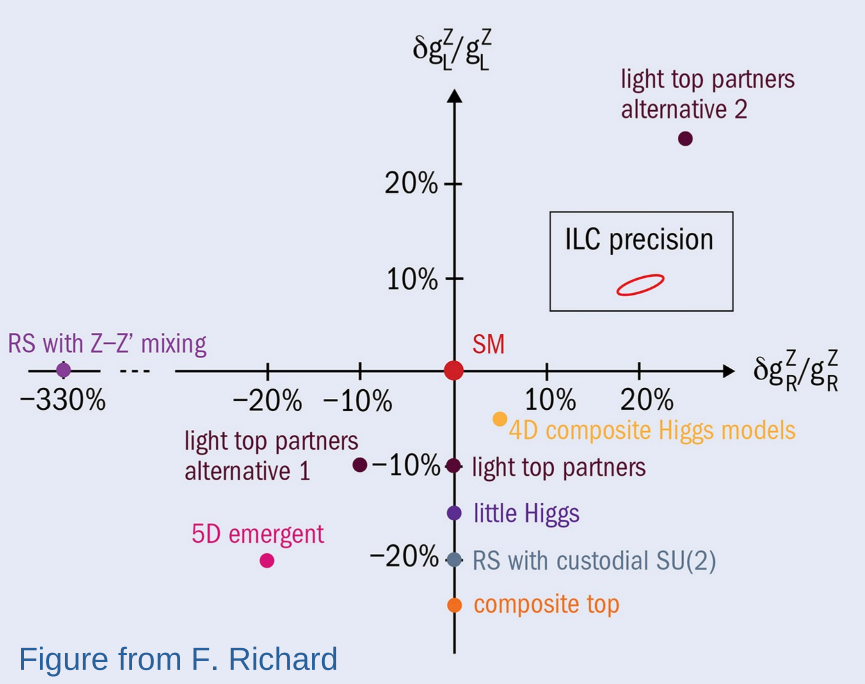


Figure from F. Richard

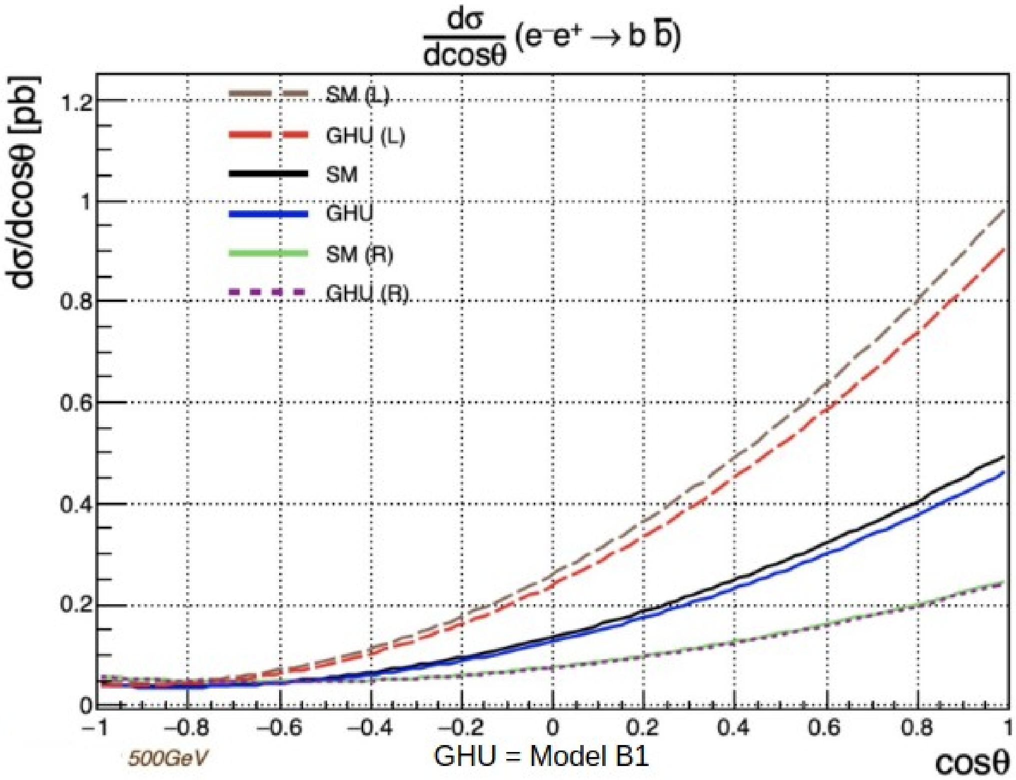
Probe such scenarios require at least per mil level for experimental precision

tt/**bb**/cc/ss/… **Can we do it?**

Gauge-Higgs Unification Models

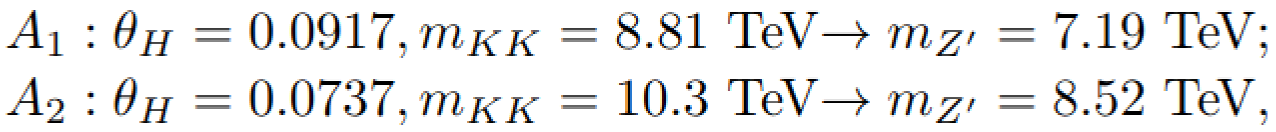
- ▶ The symmetry breaking pattern is different than in the SM and features the so-called Hosotani's mechanism.
- ▶ Only one parameter, Hosotani angle , determines the projection of the 5D fields, fixing all physical effects:
  - KK resonances of the Z/γ with mkk~10-25TeV
  - Modifications and new EW couplings/helicity amplitudes.
  - Already visible effects at 250GeV

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



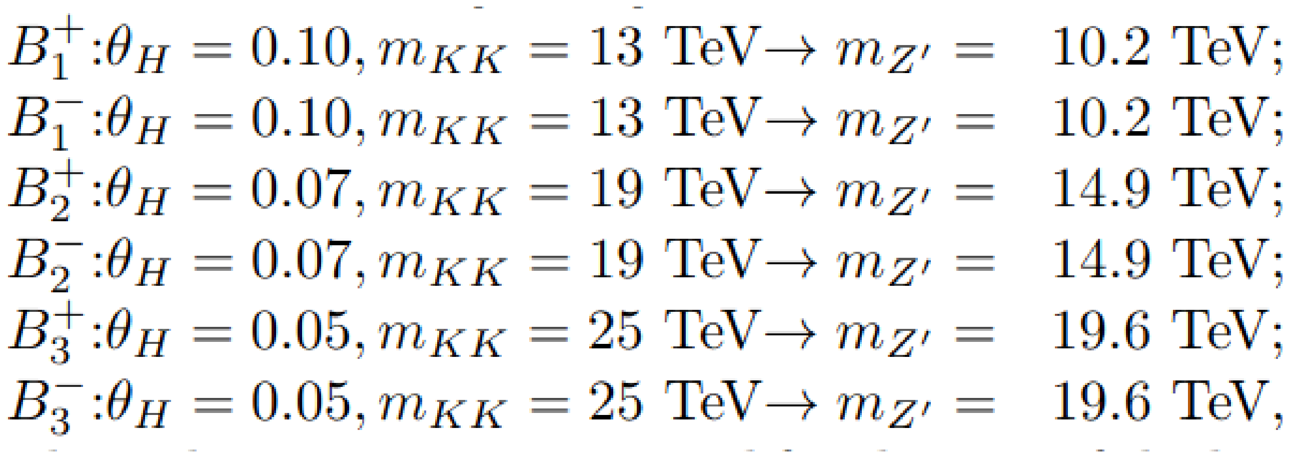
Gauge-Higgs Unification Models

- A models: (arxiv:1705.05282)



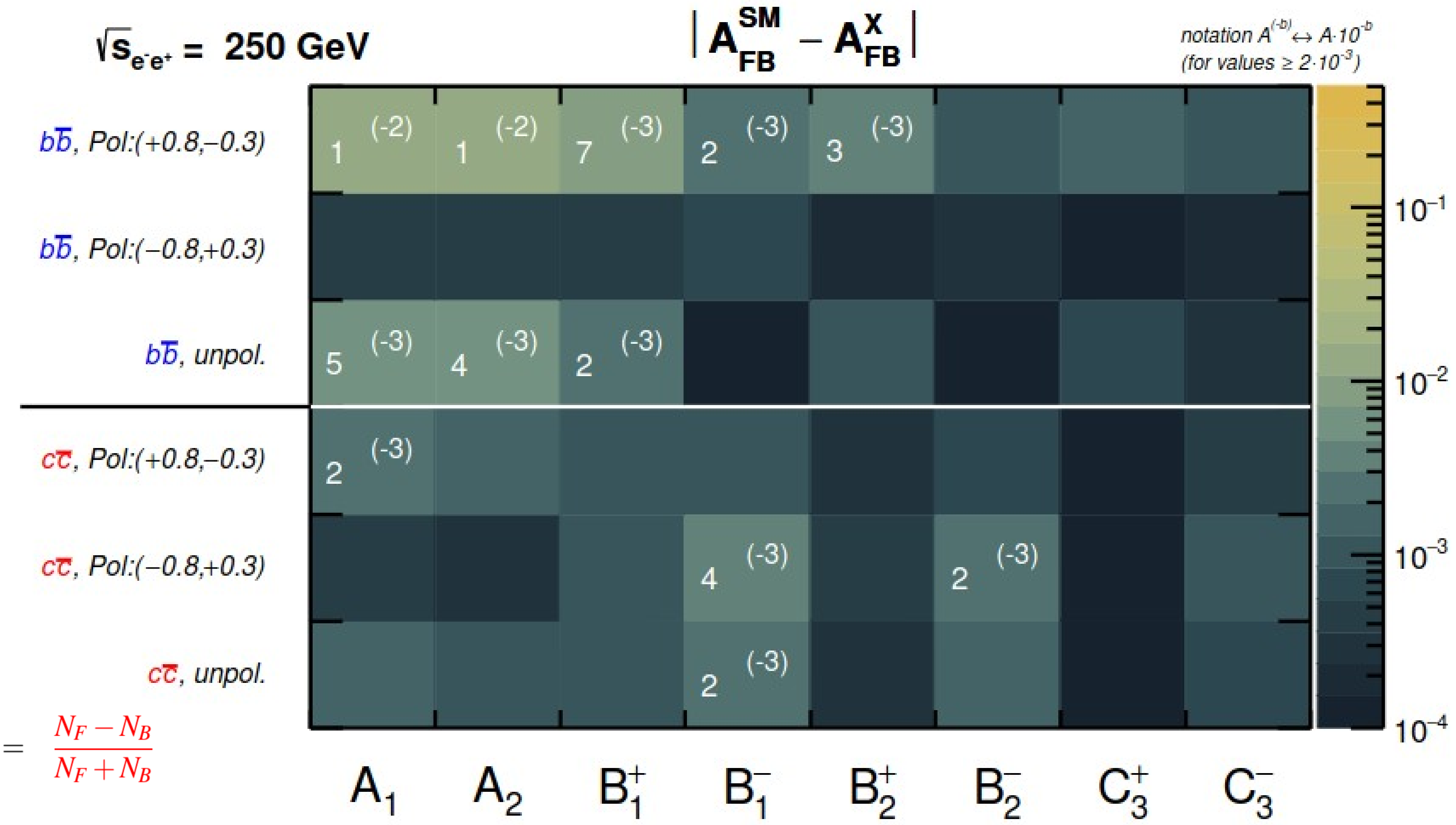
$$A_1 : \theta_H = 0.0917, m_{KK} = 8.81 \text{ TeV} \rightarrow m_{Z'} = 7.19 \text{ TeV};$$
$$A_2 : \theta_H = 0.0737, m_{KK} = 10.3 \text{ TeV} \rightarrow m_{Z'} = 8.52 \text{ TeV},$$

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



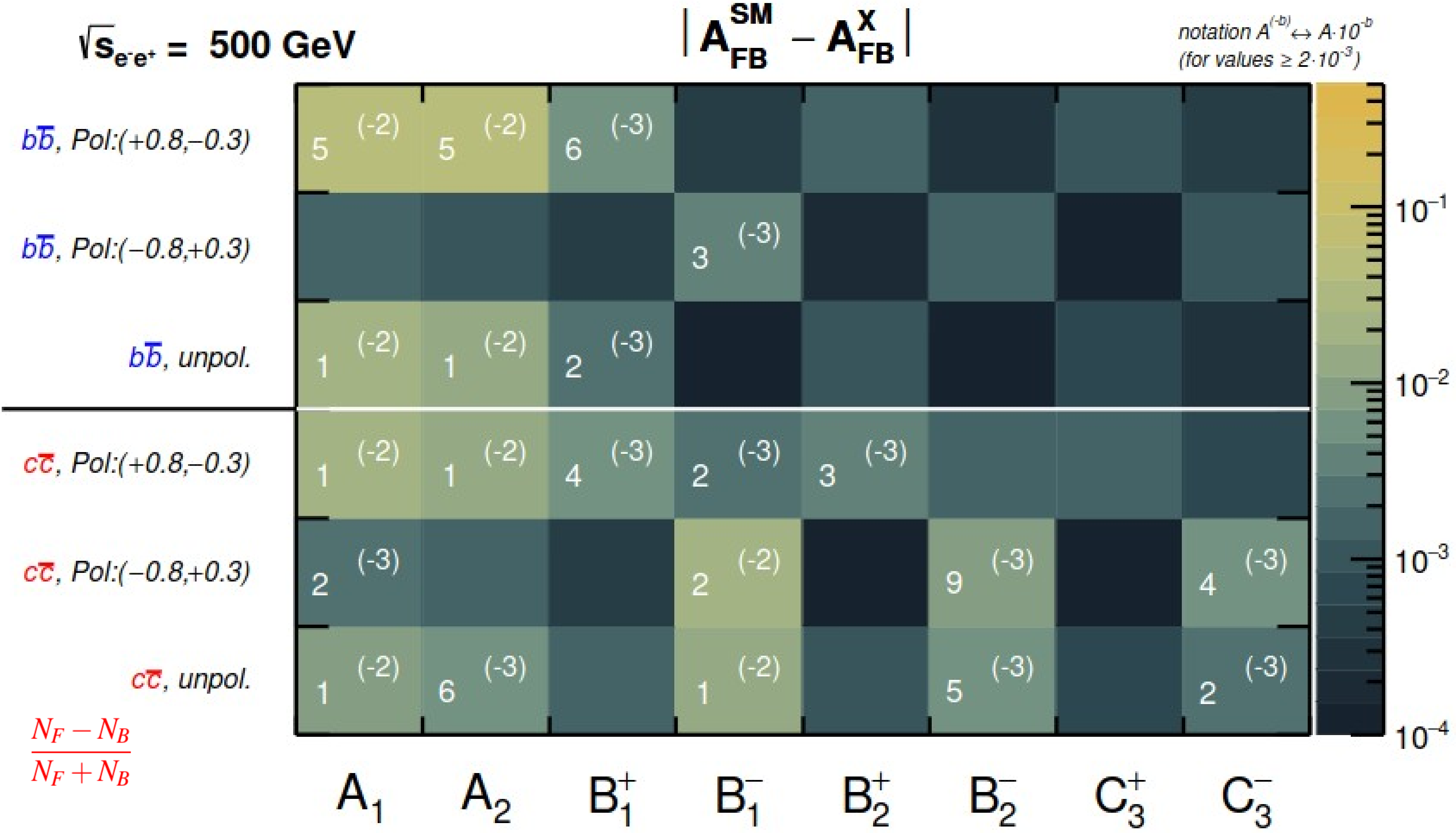
$$B_1^+ : \theta_H = 0.10, m_{KK} = 13 \text{ TeV} \rightarrow m_{Z'} = 10.2 \text{ TeV};$$
$$B_1^- : \theta_H = 0.10, m_{KK} = 13 \text{ TeV} \rightarrow m_{Z'} = 10.2 \text{ TeV};$$
$$B_2^+ : \theta_H = 0.07, m_{KK} = 19 \text{ TeV} \rightarrow m_{Z'} = 14.9 \text{ TeV};$$
$$B_2^- : \theta_H = 0.07,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

GHU vs SM (250 GeV)



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

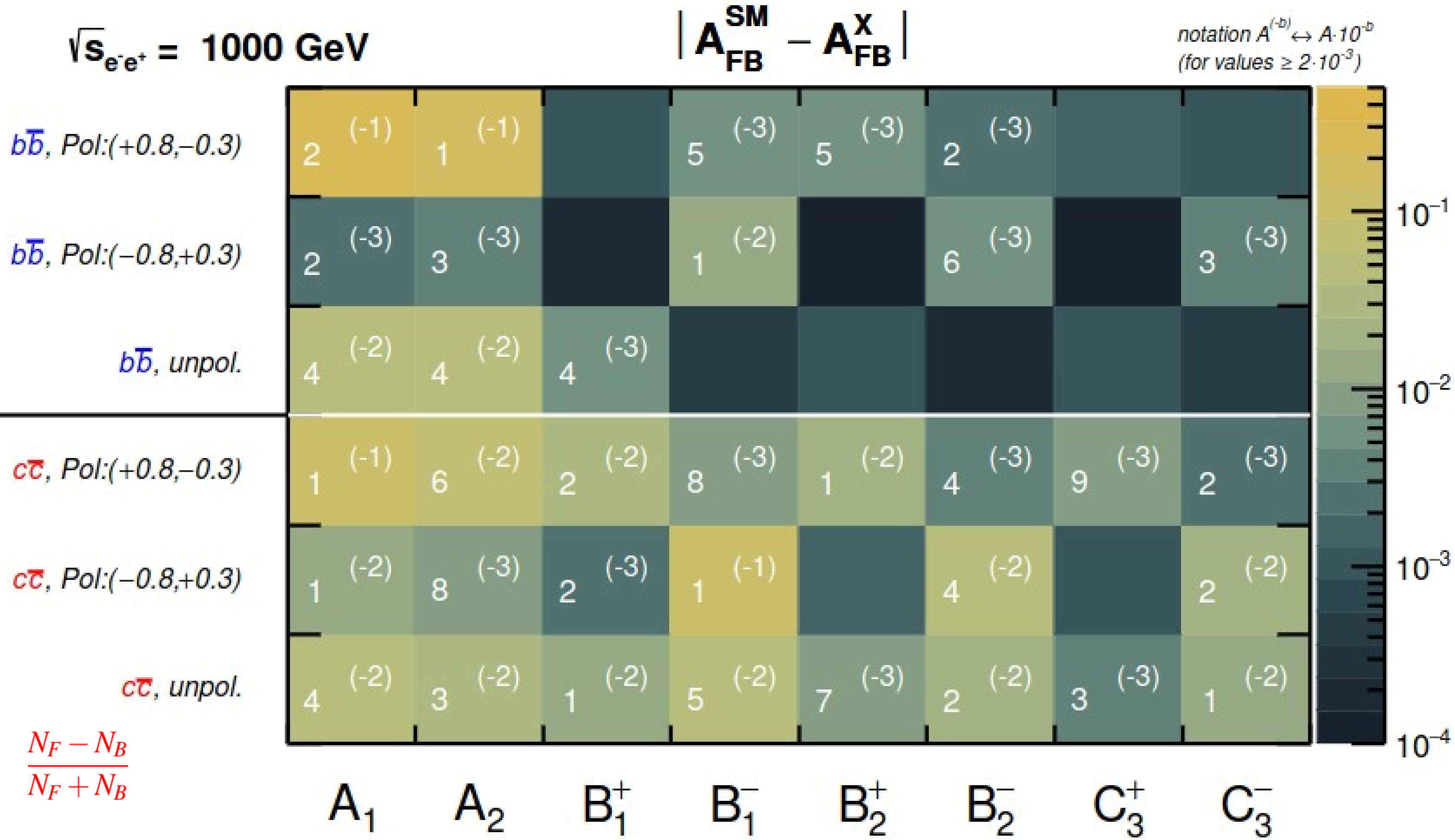
GHU vs SM (500 GeV)



	A_1	A_2	B_1^+	B_1^-	B_2^+	B_2^-	C_3^+	C_3^-
$b\bar{b}$, Pol:(+0.8,–0.3)	5 (-2)	5 (-2)	6 (-3)					
$b\bar{b}$, Pol:(–0.8,+0.3)				3 (-3)				
$b\bar{b}$, unpol.	1 (-2)	1 (-2)	2 (-3)					
$c\bar{c}$, Pol:(+0.8,–0.3)	1 (-2)	1 (-2)	4 (-3)	2 (-3)	3 (-3)			
$c\bar{c}$, Pol:(–0.8,+0.3)	2 (-3)			2 (-2)		9 (-3)		4 (-3)
$c\bar{c}$, unpol.	1 (-2)	6 (-3)		1 (-2)		5 (-3)		2 (-3)

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

GHU vs SM (1000 GeV)



	A_1	A_2	B_1^+	B_1^-	B_2^+	B_2^-	C_3^+	C_3^-
$b\bar{b}$, Pol:(+0.8,−0.3)	2 (-1)	1 (-1)		5 (-3)	5 (-3)	2 (-3)		
$b\bar{b}$, Pol:(−0.8,+0.3)	2 (-3)	3 (-3)		1 (-2)		6 (-3)		3 (-3)
$b\bar{b}$, unpol.	4 (-2)	4 (-2)	4 (-3)					
$c\bar{c}$, Pol:(+0.8,−0.3)	1 (-1)	6 (-2)	2 (-2)	8 (-3)	1 (-2)	4 (-3)	9 (-3)	2 (-3)
$c\bar{c}$, Pol:(−0.8,+0.3)	1 (-2)	8 (-3)	2 (-3)	1 (-1)		4 (-2)		2 (-2)
$c\bar{c}$, unpol.	4 (-2)	3 (-2)	1 (-2)	5 (-2)	7 (-3)	2 (-2)	3 (-3)	1 (-2)

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

Experimental study with full simulation

Study based on full simulation analysis

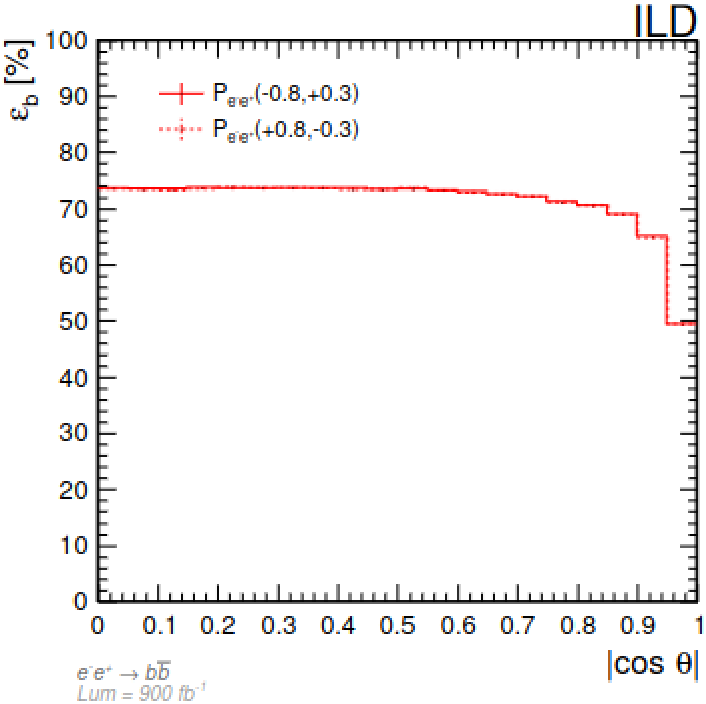
- ILD note and previous works https://inspirehep.net/literature/2669897
  - ILC50, b and c studies

Recent updates/progresses:

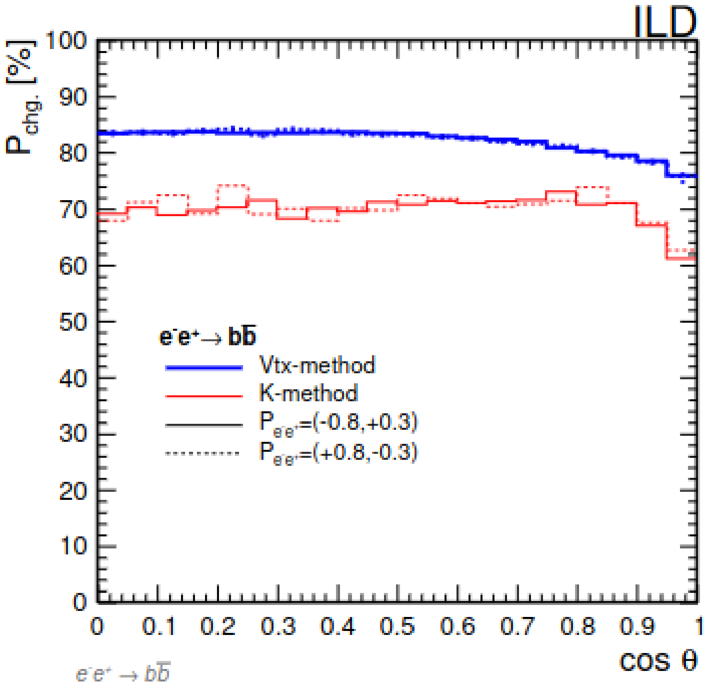
- Work presented in LCWS (J.P. Márquez)
  - Proceeding https://inspirehep.net/literature/2682331
  - Talk https://indico.slac.stanford.edu/event/7467/contributions/5977/attachments/2862/8042/LCWS2023_JPMH.pdf
  - ILC250+ILC500 comparing scenarios with different PID (no PID, dEdx, dNdx)
- Work presented in EPS-HEP (J.P. Márquez)
  - First theory prospects
  - https://indico.desy.de/event/34916/contributions/147224/

- Experimental cut-based analysis using “traditional” BDT algorithms for flavour tagging.

Flavour tagging



jet charge (kaon ID)



- ▶ Double tagging & charge measurement methods
  - To maximally reduce the usage of MC tools (control of fragmentation, QCD correlations… uncertainties)

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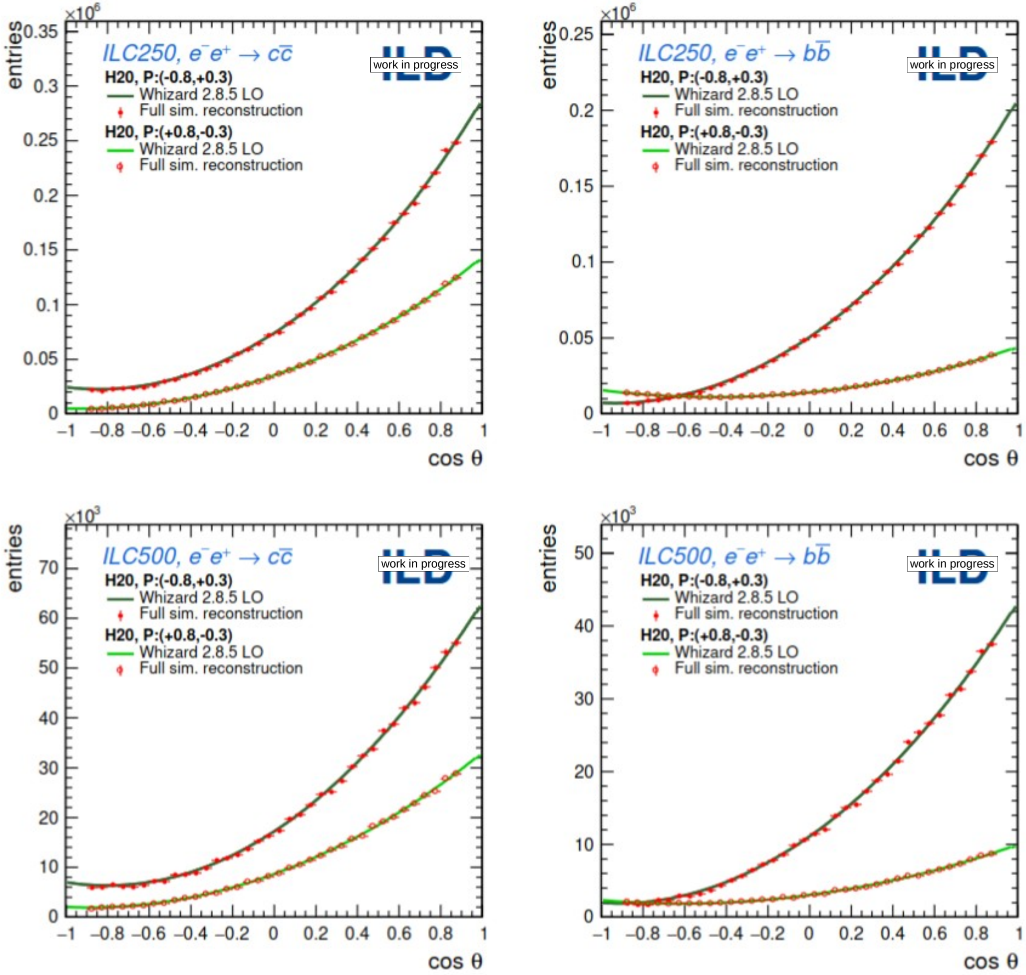
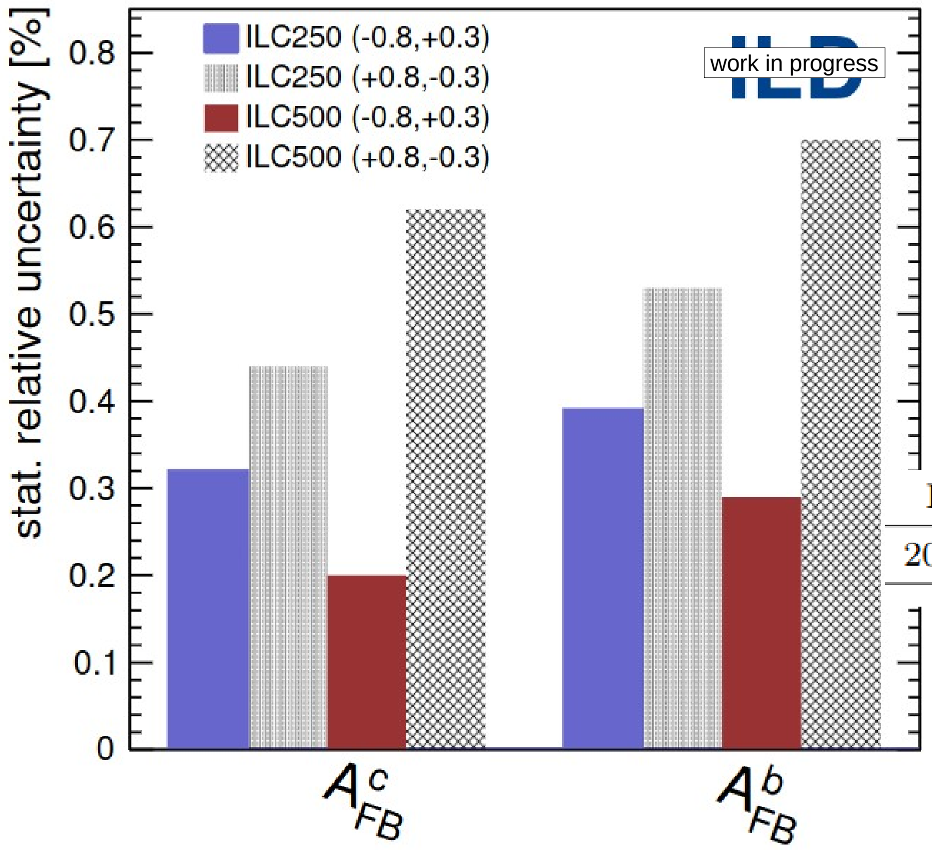
Result and fit

- ▶ **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**
  - **Smaller exp syst. Uncertainties**
  - Fragmentation, angular correlations, preselection efficiency...



Results – ILC250&ILC500



ILC250	ILC500	ILC1000
2000 fb^{-1}	4000 fb^{-1}	8000 fb^{-1}

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Discrimination power between GHU & SM

GHU vs SM discrimination power

- Assumption: A measurement of one specific model is conducted.

- The uncertainties are considered normally distributed:
  - Significance in σ:
  - P-value: Gaussian at dσ.

$$\mathrm{d}_\sigma = \frac{||\mathrm{AFB}_{\mathrm{test}} - \mathrm{AFB}_{\mathrm{ref}}||}{\Delta_{\mathrm{AFB}_{\mathrm{ref}}}}$$

- Combination of multiple measurements is done with a multivariate gaussian.
  - Assuming no correlations for AFB.

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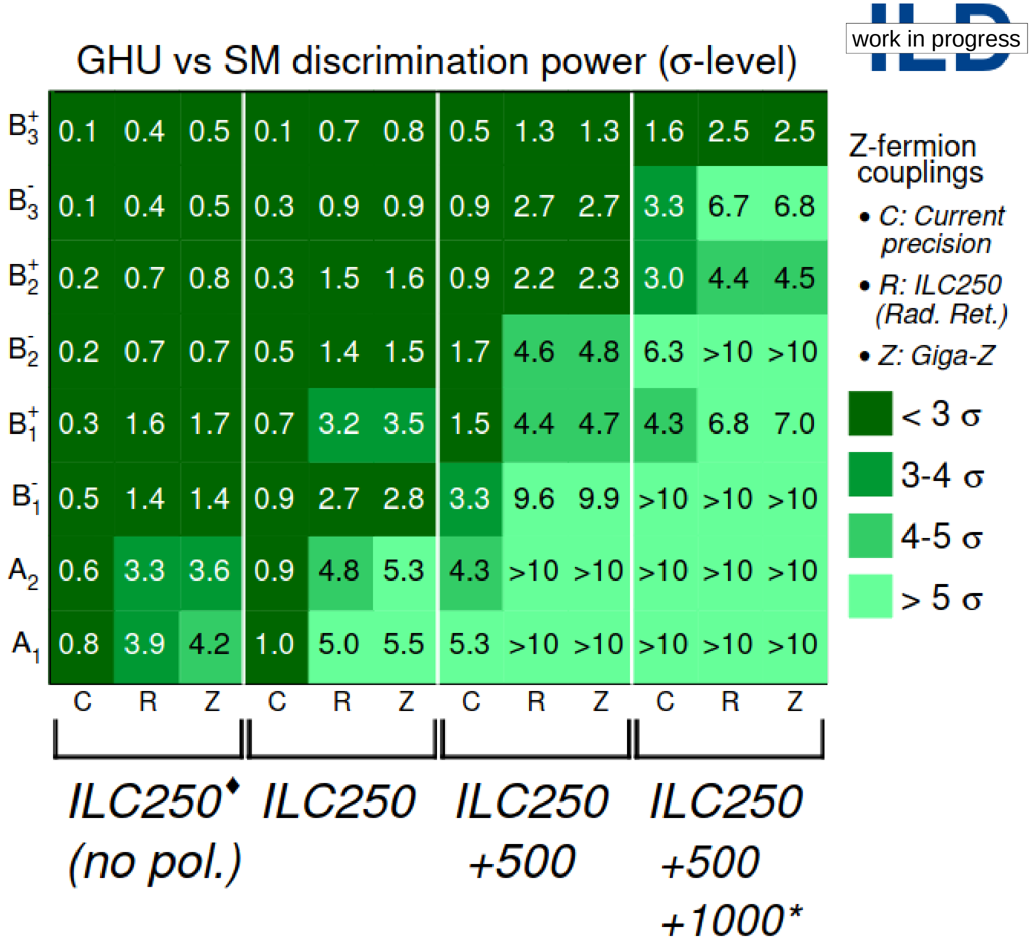
GHU vs SM discrimination power



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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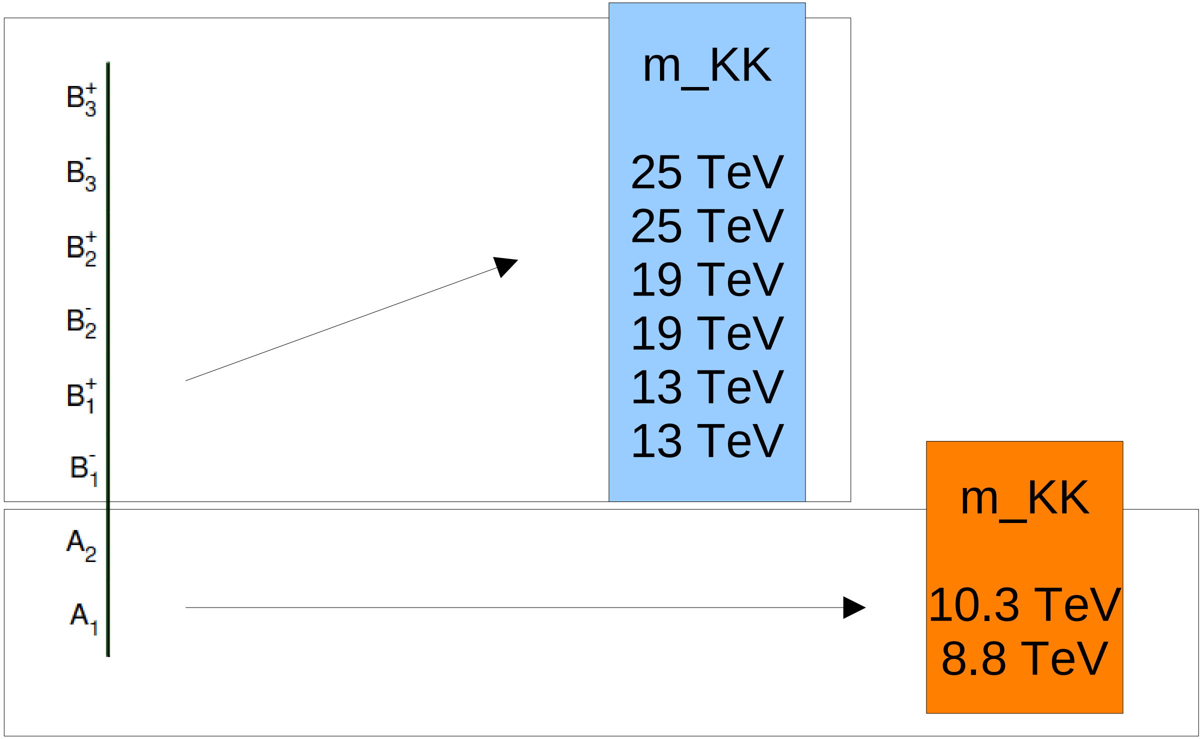
GHU vs SM discrimination power



m_KK

25 TeV
25 TeV
19 TeV
19 TeV
13 TeV
13 TeV

m_KK

10.3 TeV
8.8 TeV

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GHU vs SM discrimination power

Hypothetical case
ILC250♦ no pol
2000fb^{-1}
Full ILD simulation
assuming no beam pol

H20 nominal program

ILC250
(Pe-=0.8,Pe+=0.3)
2000fb^{-1}

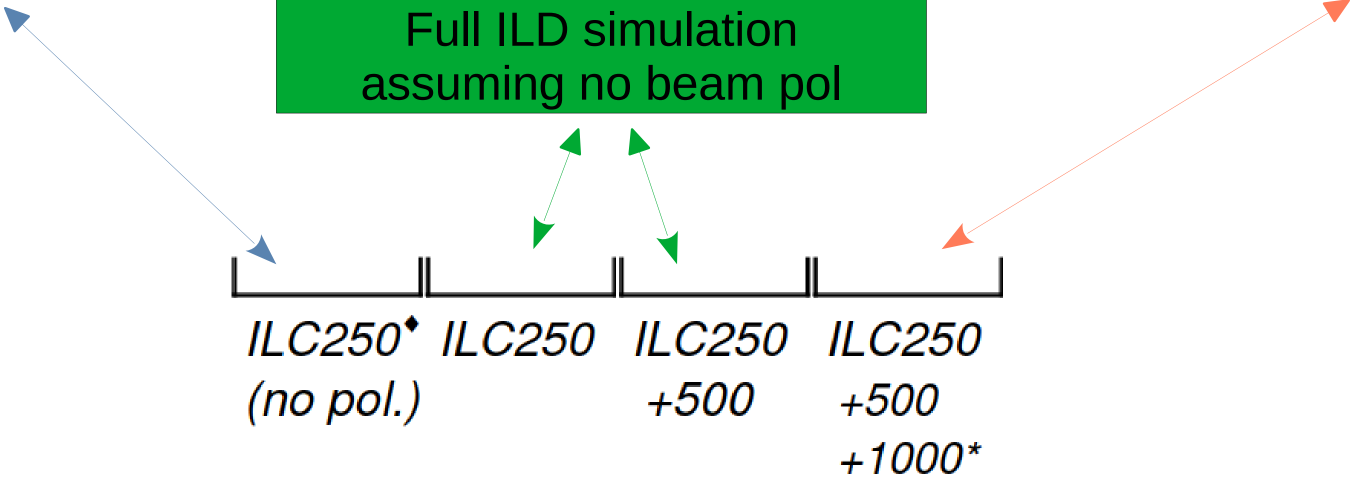
ILC500
(Pe-=0.8,Pe+=0.3)
4000fb^{-1}

Full ILD simulation
assuming no beam pol

H20 nominal program

ILC1000
(Pe-=0.8,Pe+=0.2)
8000fb^{-1}

Not full sim studies
but extrapolations from ILC500



ILC250♦
(no pol.)

ILC250

ILC250
+500

ILC250
+500
*+1000**

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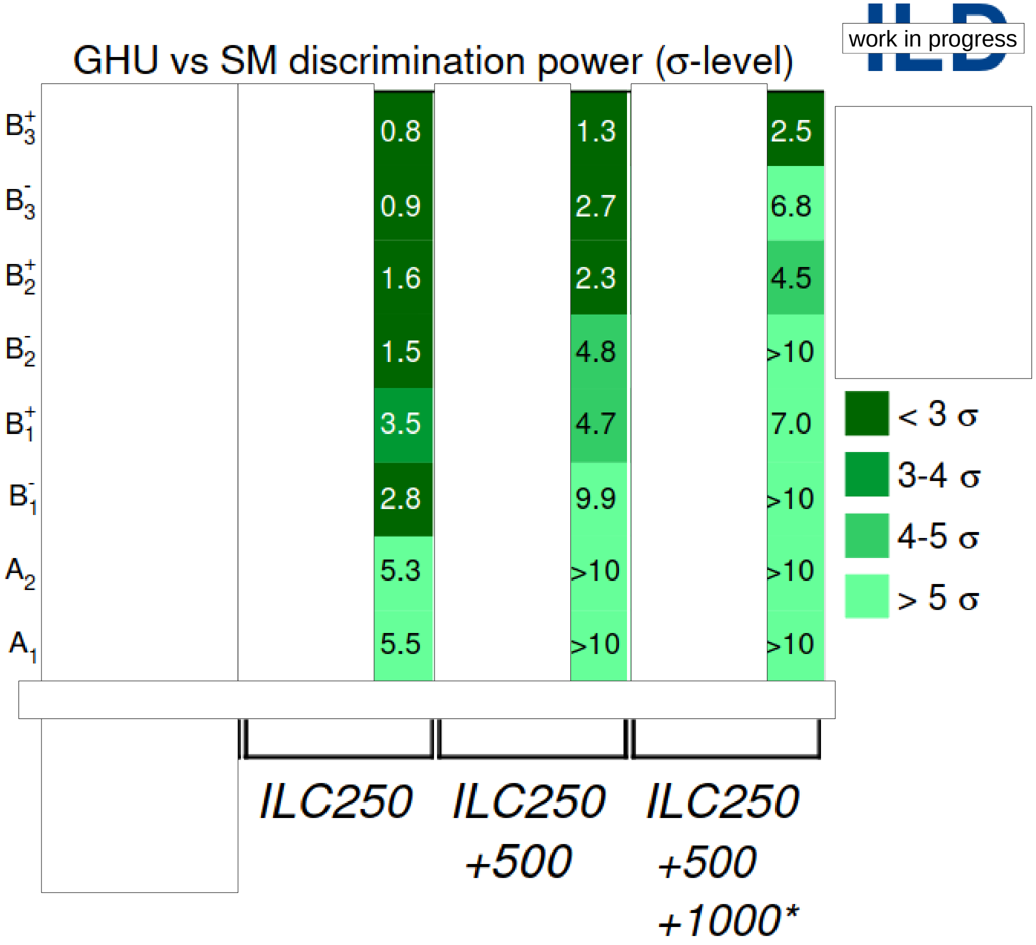
GHU vs SM : c.m.e.



	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

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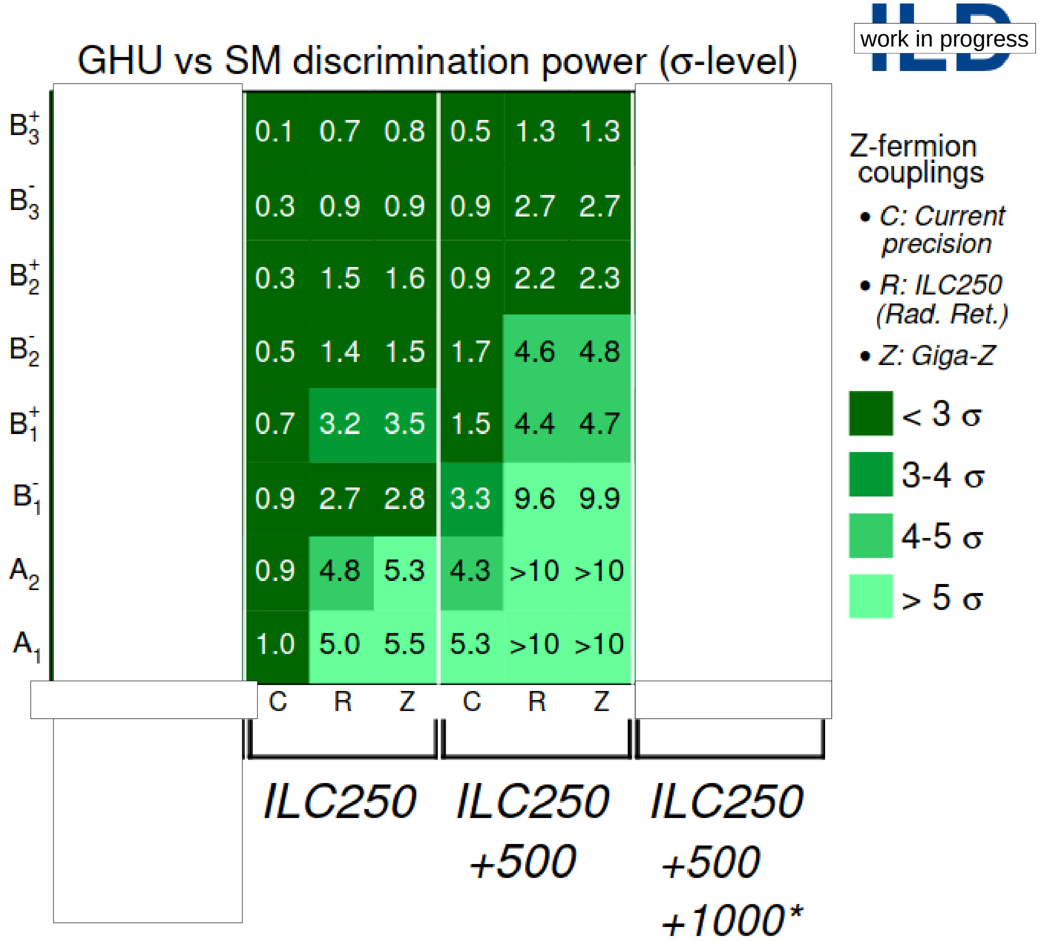
GHU vs SM : Precision on Z-couplings



GHU vs SM discrimination power (σ-level)

work in progress

	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	
A_1	1.0	5.0	5.5	5.3	>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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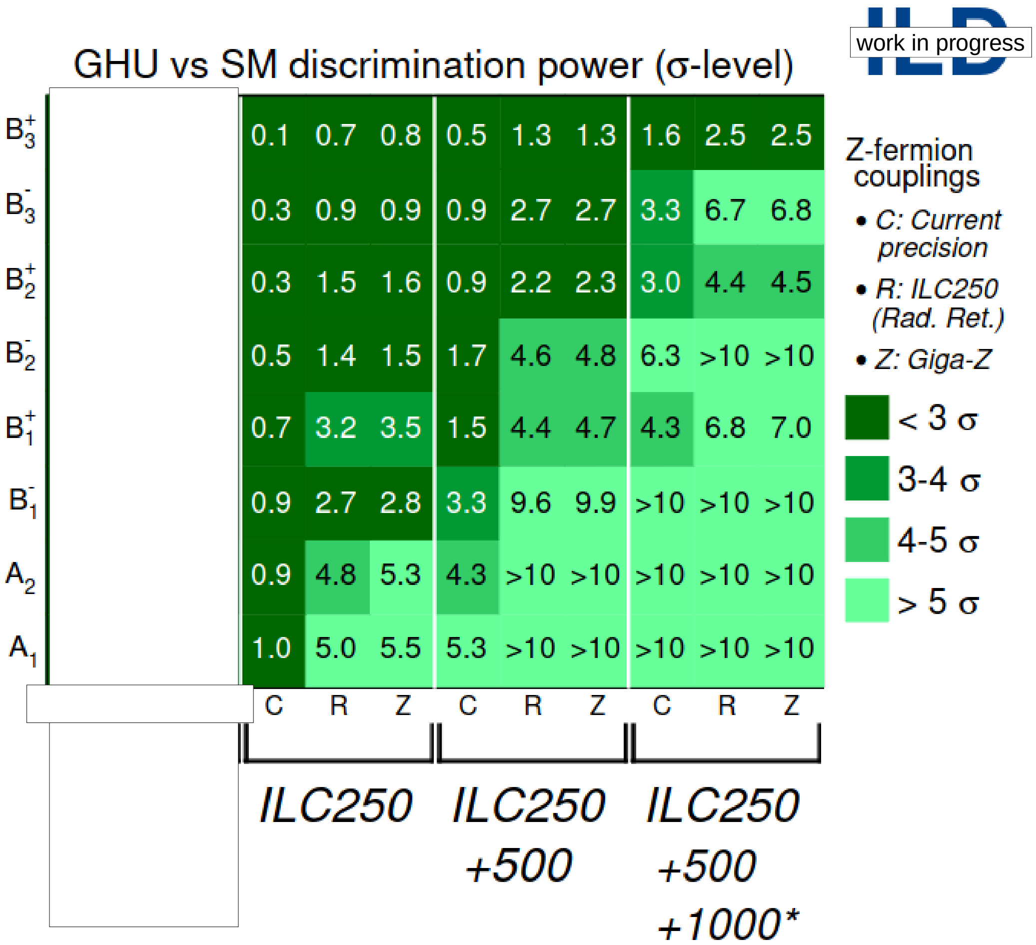
GHU vs SM : Precision on Z-couplings



work in progress

GHU vs SM discrimination power (σ-level)

	ILC250			ILC250 +500			ILC250 +500 +1000*		
	C	R	Z	C	R	Z	C	R	Z
B_3^+	0.1	0.7	0.8	0.5	1.3	1.3	1.6	2.5	2.5
B_3^-	0.3	0.9	0.9	0.9	2.7	2.7	3.3	6.7	6.8
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*
- *R: ILC250 (Rad. Ret.)*
- *Z: Giga-Z*

🟩 < 3 σ
🟩 3-4 σ
🟩 4-5 σ
🟩 > 5 σ

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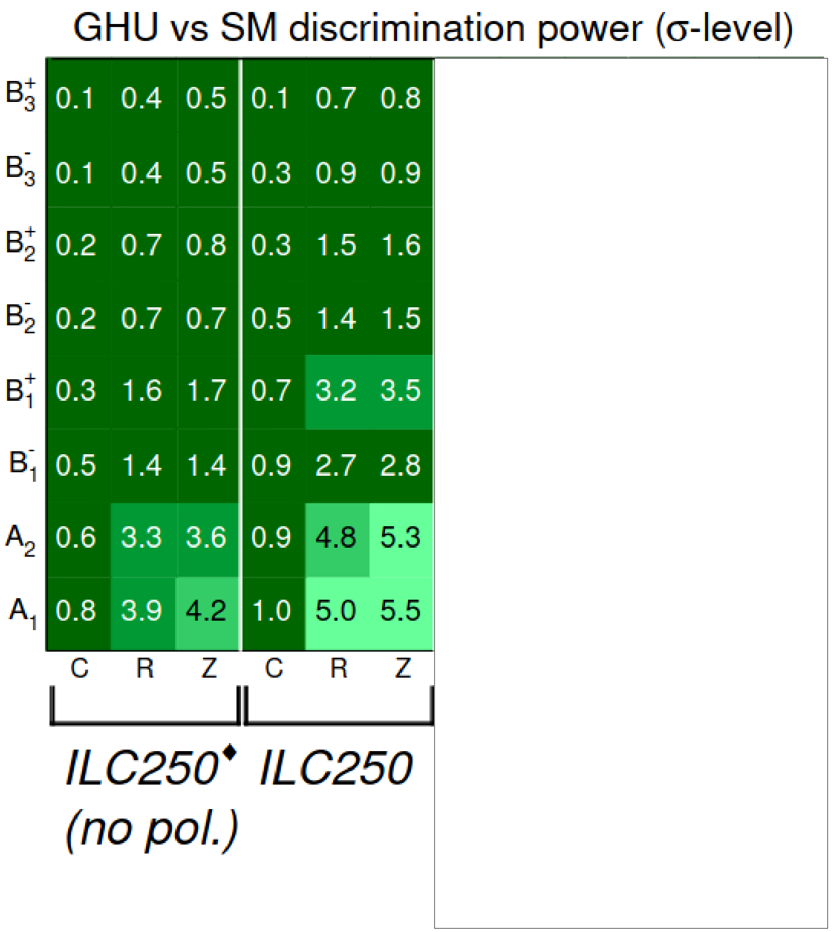
GHU vs SM : beam(s) polarization

work in progress



GHU vs SM discrimination power (σ-level)

	ILC250♦ (no pol.) C	ILC250♦ (no pol.) R	ILC250♦ (no pol.) Z	ILC250 C	ILC250 R	ILC250 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
A_1	0.8	3.9	4.2	1.0	5.0	5.5

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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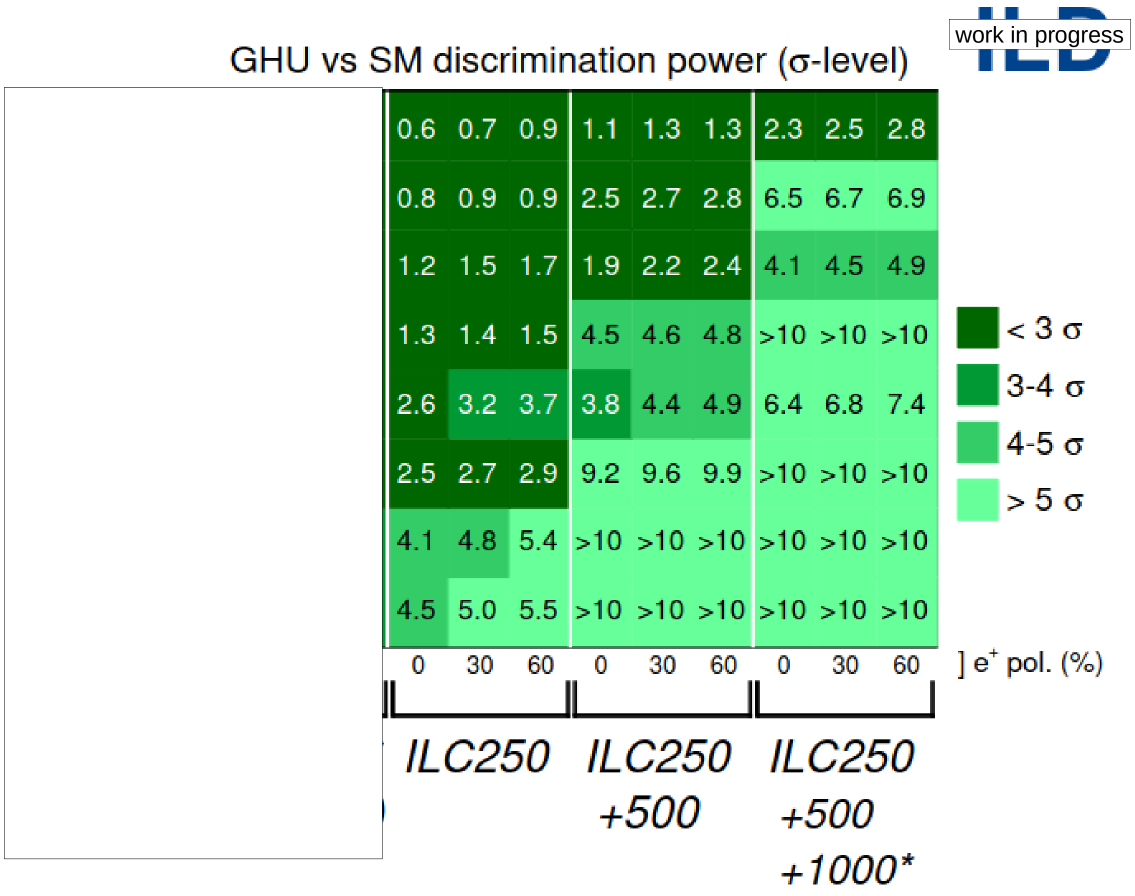
GHU vs SM : positron polarisation



GHU vs SM discrimination power (σ-level)

work in progress

ILC250			ILC250 +500			ILC250 +500 +1000*		
0	30	60	0	30	60	0	30	60
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

] e^+ pol. (%)

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

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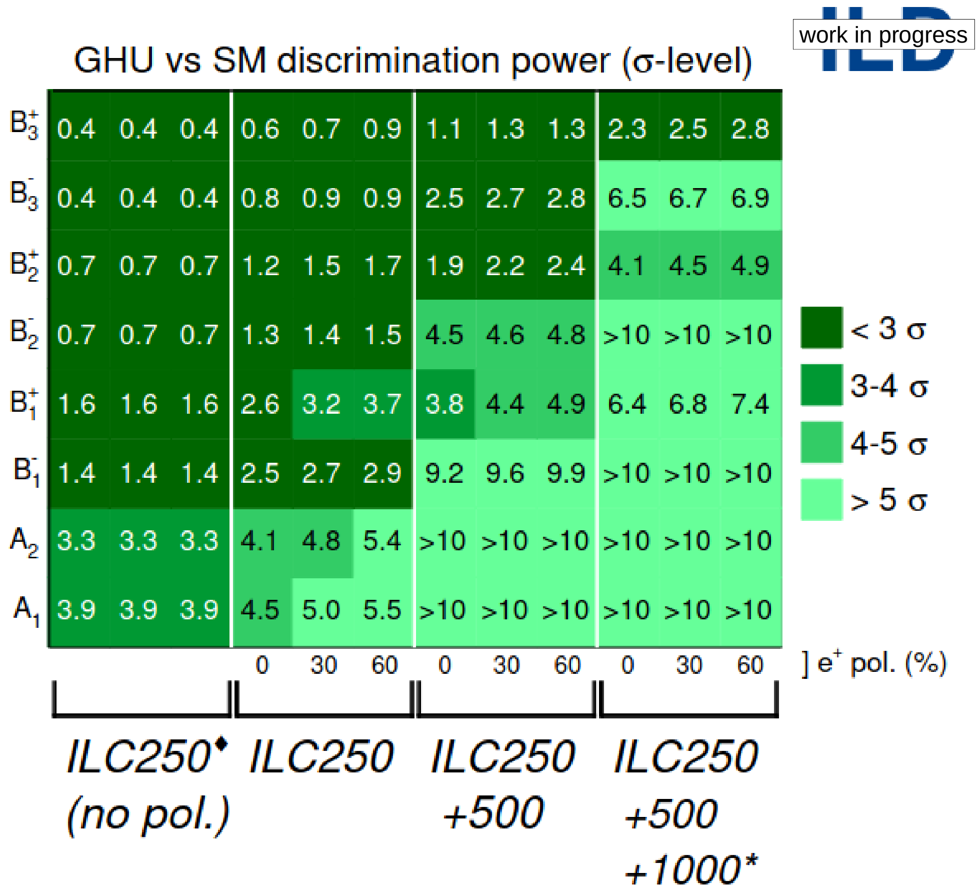
GHU vs SM : positron polarisation



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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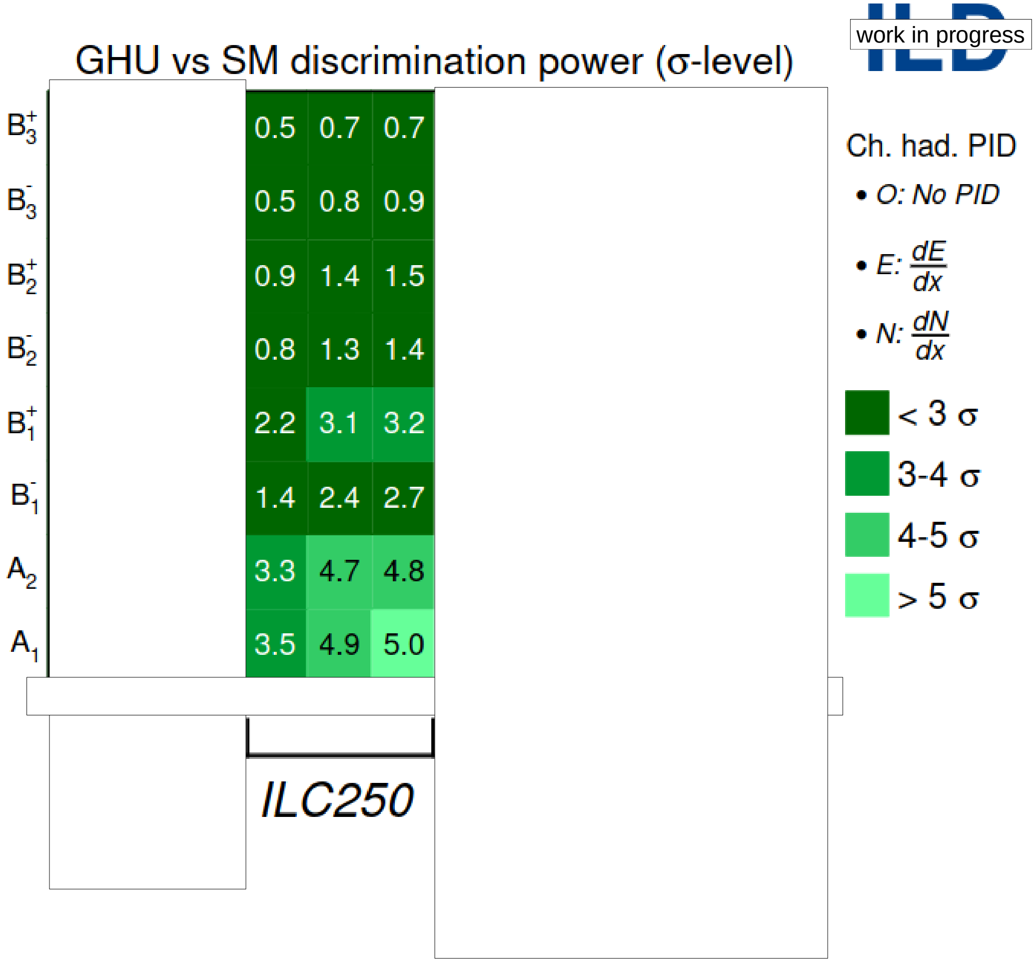
GHU vs SM: Particle ID dependence



GHU vs SM discrimination power (σ-level)

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

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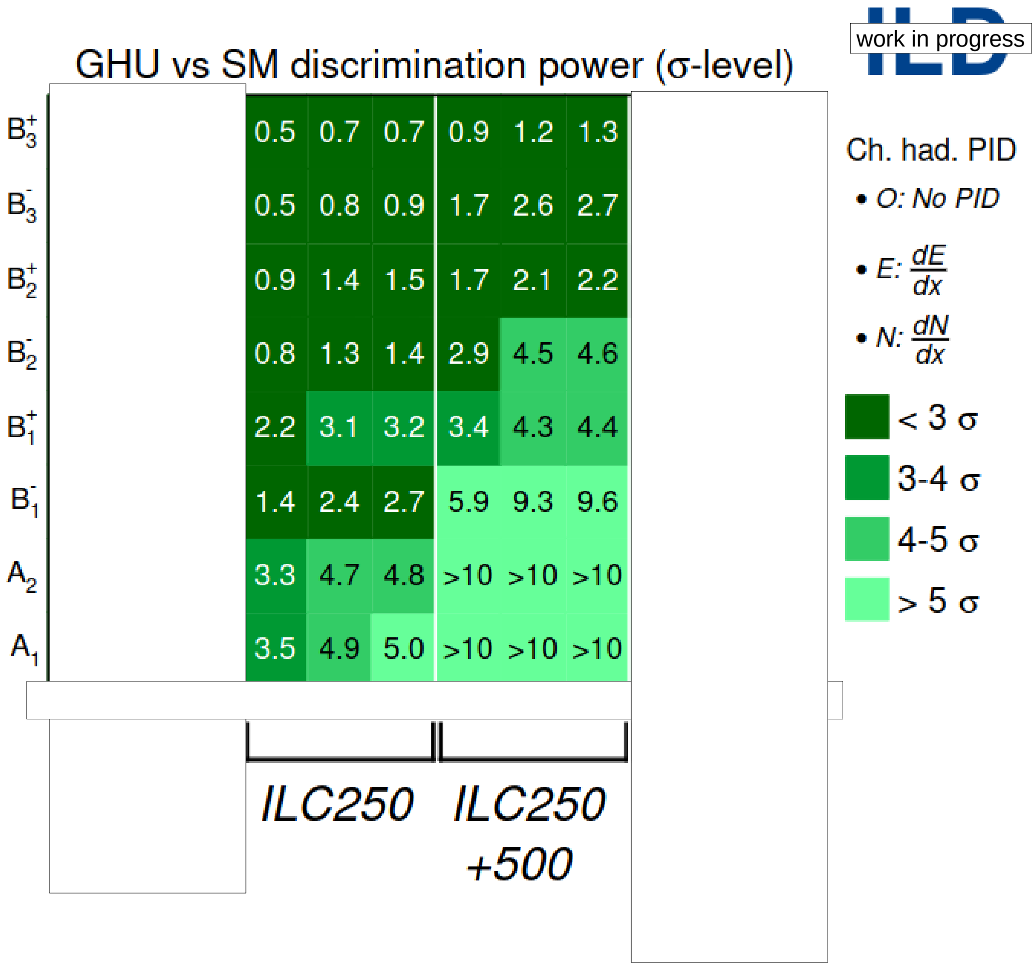
GHU vs SM: Particle ID dependence



GHU vs SM discrimination power (σ-level)

	ILC250			ILC250 +500		
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

Ch. had. PID

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

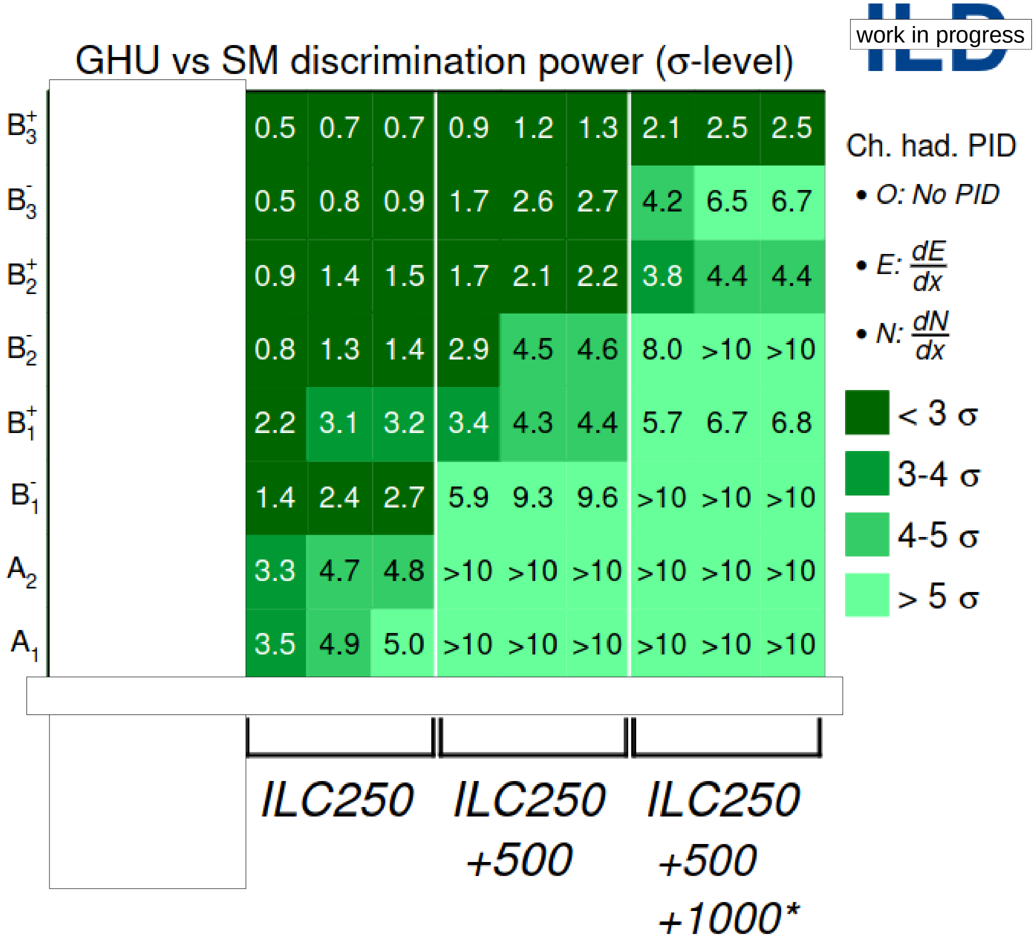
🟩 < 3 σ

🟩 3-4 σ

🟩 4-5 σ

🟩 > 5 σ

GHU vs SM: Particle ID dependence



GHU vs SM discrimination power (σ-level)

work in progress

	ILC250			ILC250 +500			ILC250 +500 +1000*		
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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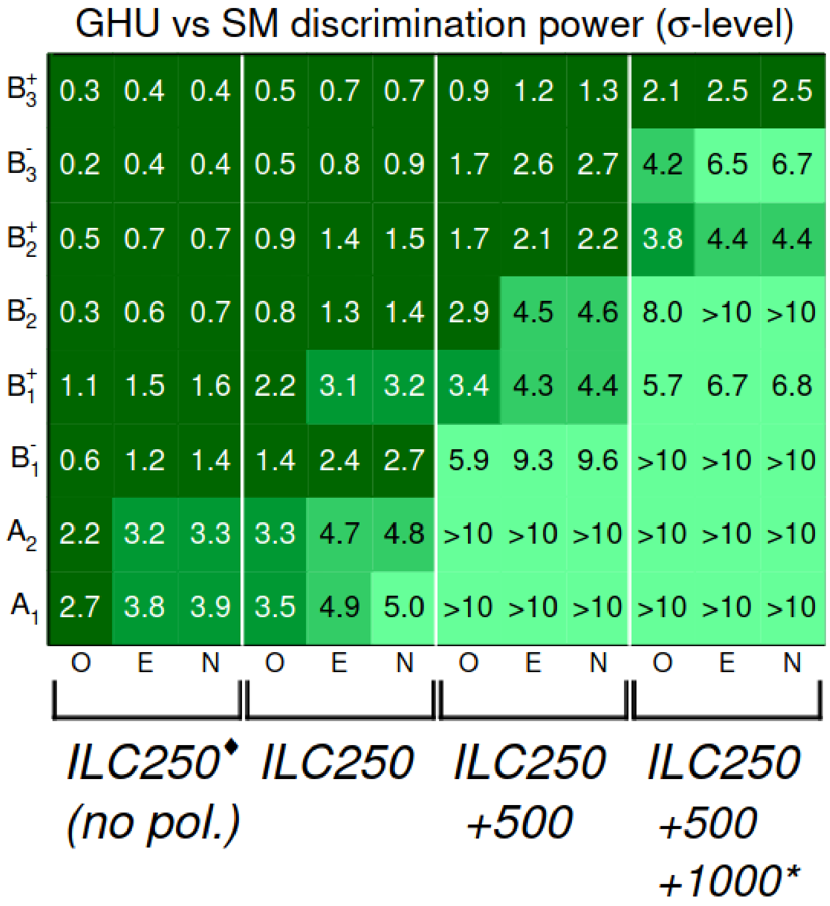
GHU vs SM: Particle ID dependence

work in progress



GHU vs SM discrimination power (σ-level)

	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

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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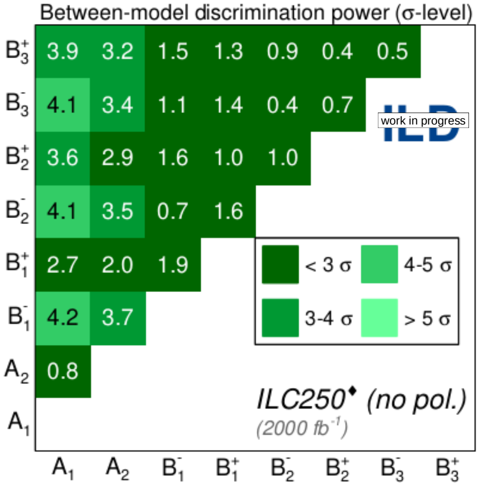
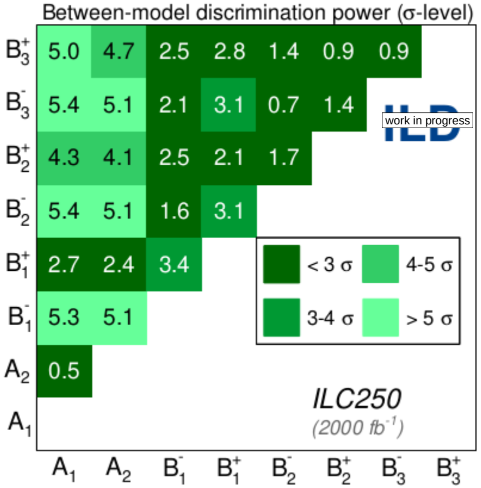
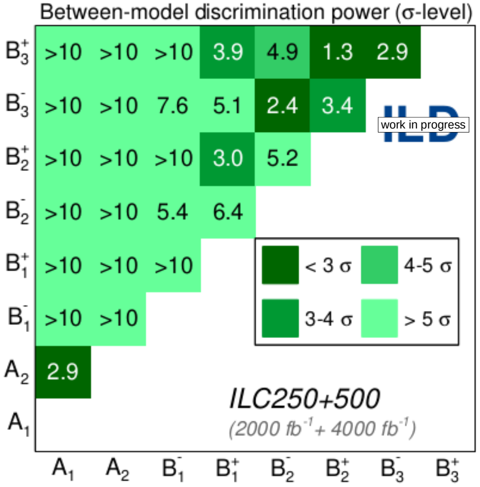
Discrimination between models


Between-model discrimination power (σ-level)

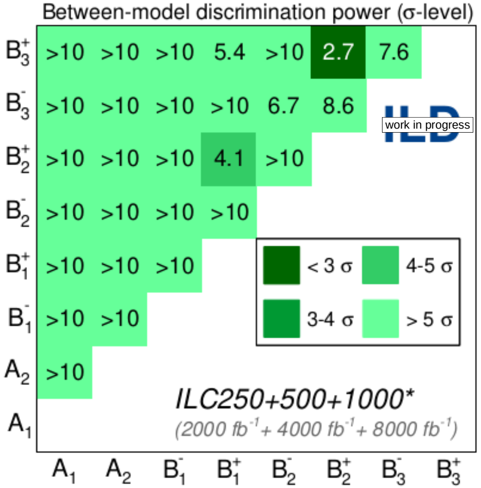
	A_1	A_2	B_1^-	B_1^+	B_2^-	B_2^+	B_3^-	B_3^+
B_3^+	3.9	3.2	1.5	1.3	0.9	0.4	0.5	
B_3^-	4.1	3.4	1.1	1.4	0.4	0.7		
B_2^+	3.6	2.9	1.6	1.0	1.0			
B_2^-	4.1	3.5	0.7	1.6				
B_1^+	2.7	2.0	1.9					
B_1^-	4.2	3.7						
A_2	0.8							
A_1								


Between-model discrimination power (σ-level)

	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)

	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)

	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

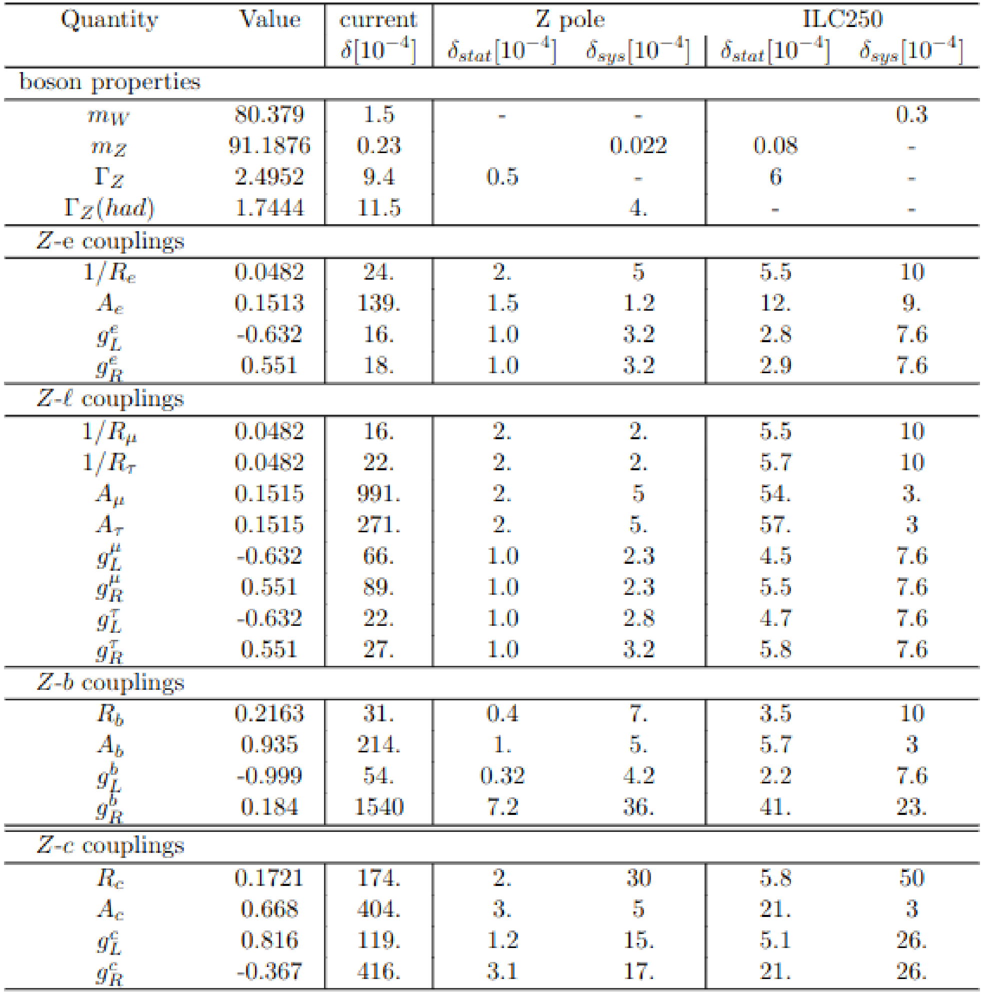
Conclusions and summary

- Comprehensive study done at ILC250/ILC500 with ILD simulations
  - Backgrounds, beam features, polarization, realistic reconstruction tools
  - Uncertainties dominated by statistics, above the Z-pole
  - Room for improvement (modern algorithms for flavour tagging, event selection, etc)
- AFB studies for c and b-quark above the Z-pole
  - Flavour tagging and jet charge determination with kaon ID are key
- ILC offers unique capabilities to explore these signatures and discriminate GHUvsSM
  - High energy reach
  - Electron and positron beam polarization → enhancing the sensitivity but also allowing for measurements with different BSM sensitivity (for control of systematics)
  - (ILD) PID capabilities (kaon)

back-up

Z-couplings

- https://arxiv.org/pdf/2203.07622.pdf



Quantity	Value	current	Z pole		ILC250	
		$\delta[10^{-4}]$	$\delta_{stat}[10^{-4}]$	$\delta_{sys}[10^{-4}]$	$\delta_{stat}[10^{-4}]$	$\delta_{sys}[10^{-4}]$
boson properties						
m_W	80.379	1.5	-	-		0.3
m_Z	91.1876	0.23		0.022	0.08	-
Γ_Z	2.4952	9.4	0.5	-	6	-
$\Gamma_Z(had)$	1.7444	11.5		4.	-	-
Z-e couplings						
$1/R_e$	0.0482	24.	2.	5	5.5	10
A_e	0.1513	139.	1.5	1.2	12.	9.
g_L^e	-0.632	16.	1.0	3.2	2.8	7.6
g_R^e	0.551	18.	1.0	3.2	2.9	7.6
Z-ℓ couplings						
$1/R_\mu$	0.0482	16.	2.	2.	5.5	10
$1/R_\tau$	0.0482	22.	2.	2.	5.7	10
A_μ	0.1515	991.	2.	5	54.	3.
A_τ	0.1515	271.	2.	5.	57.	3
g_L^μ	-0.632	66.	1.0	2.3	4.5	7.6
g_R^μ	0.551	89.	1.0	2.3	5.5	7.6
g_L^τ	-0.632	22.	1.0	2.8	4.7	7.6
g_R^τ	0.551	27.	1.0	3.2	5.8	7.6
Z-b couplings						
R_b	0.2163	31.	0.4	7.	3.5	10
A_b	0.935	214.	1.	5.	5.7	3
g_L^b	-0.999	54.	0.32	4.2	2.2	7.6
g_R^b	0.184	1540	7.2	36.	41.	23.
Z-c couplings						
R_c	0.1721	174.	2.	30	5.8	50
A_c	0.668	404.	3.	5	21.	3
g_L^c	0.816	119.	1.2	15.	5.1	26.
g_R^c	-0.367	416.	3.1	17.	21.	26.

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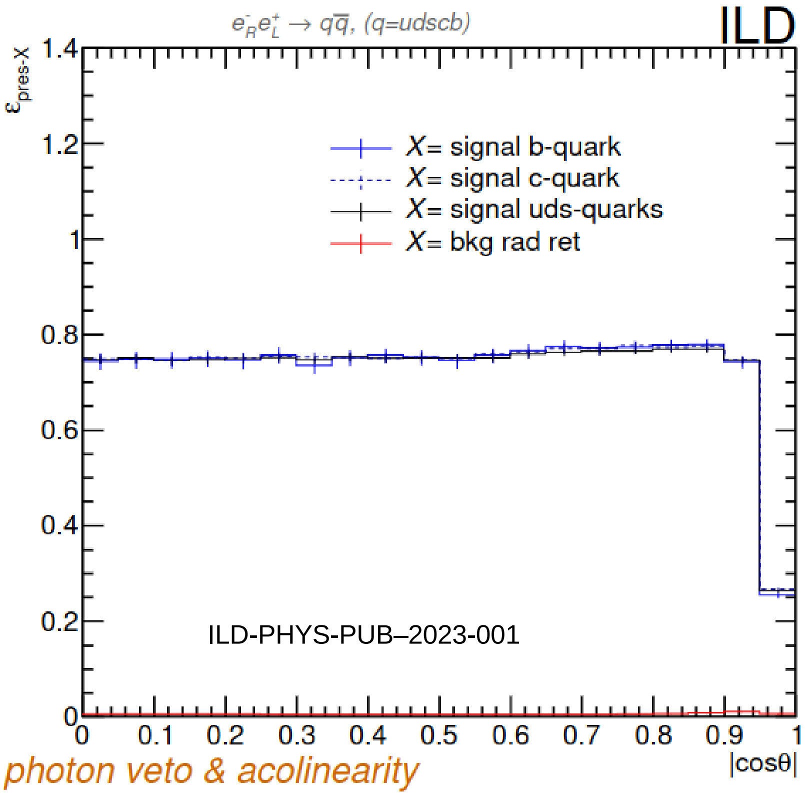
Preselection

- **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_{jj} & y_{23} cuts

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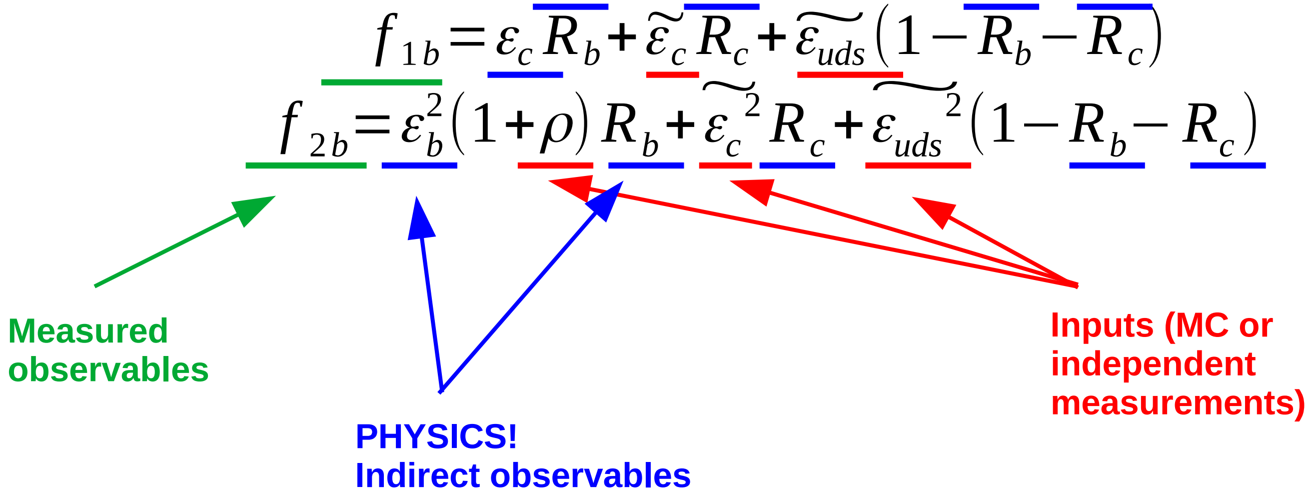
Double Tag Method

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



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

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

Measured observables

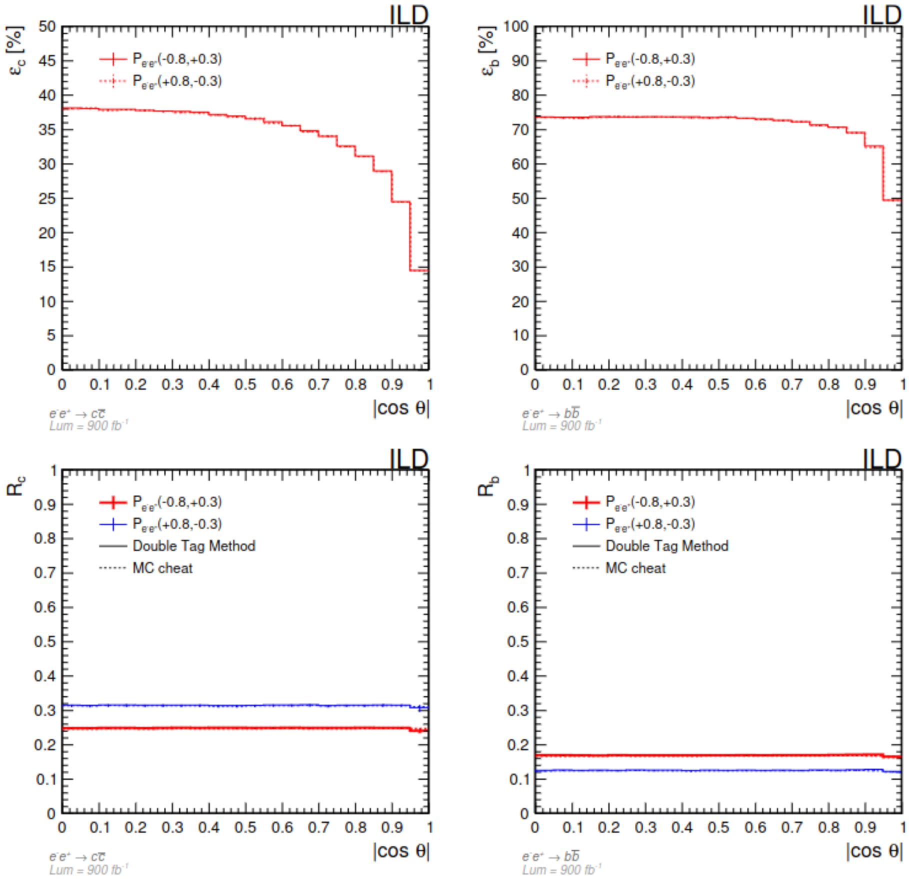
PHYSICS!
Indirect observables

Inputs (MC or independent measurements)

Similar set of equations for the c-quark
solved simultaneously

Double flavour tagging – control of systematics

- **Flavour tagging efficiency will be measured (double tagging)**
  - **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**
  - **than the tagging efficiencies**
  - No assumption needed in Ruds
- **Per mil level stat. Uncertainty**
- **Comparable/lower exp syst. uncertainty**
  - Dominated by flavour tagging and followed by angular correlations



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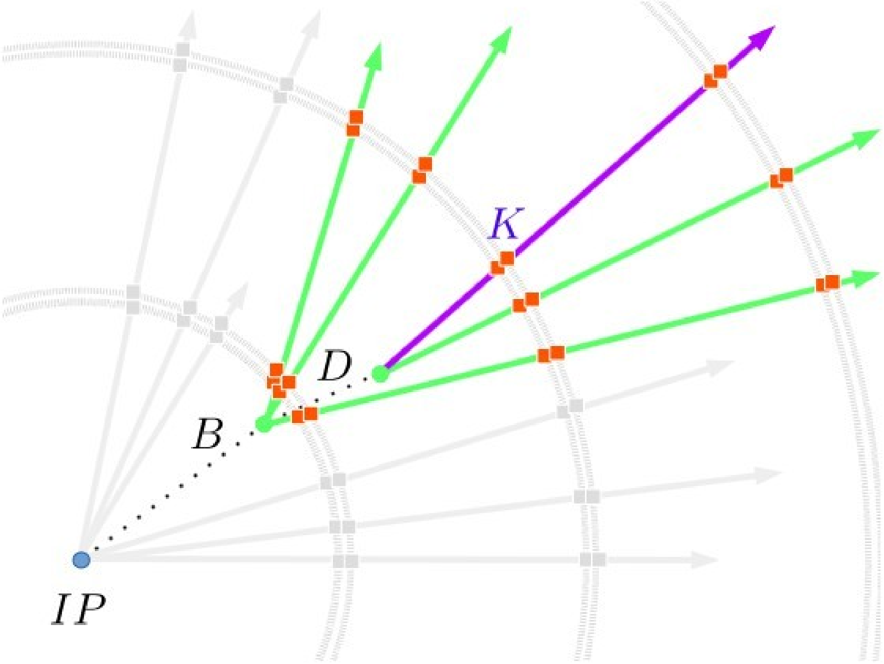
Jet charge

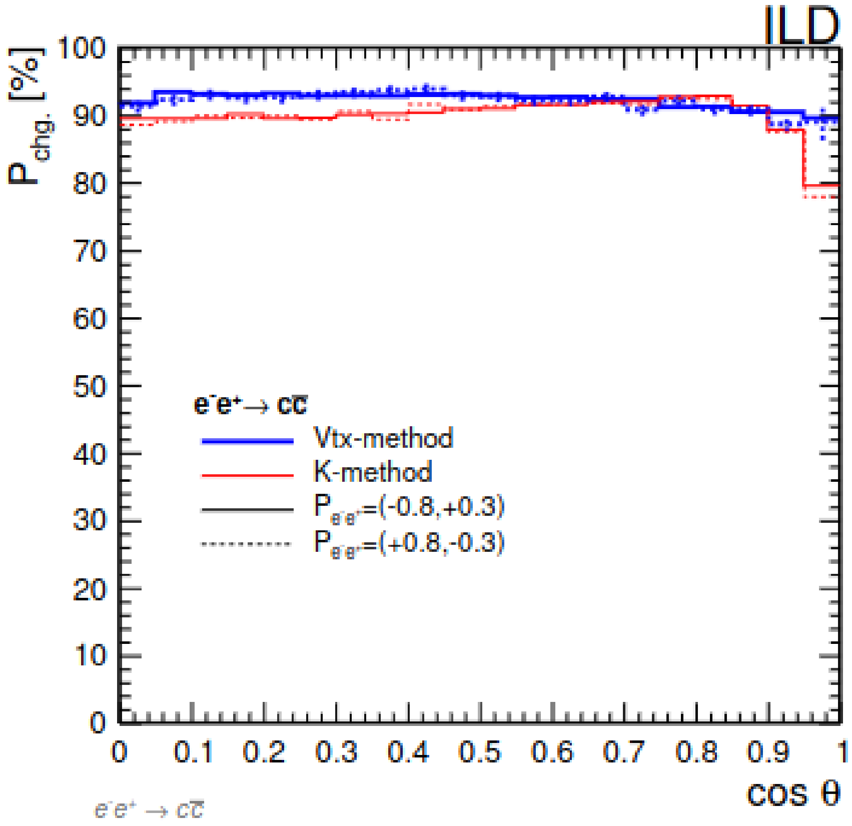
- We start from a very pure & background-free **double tagged** sample

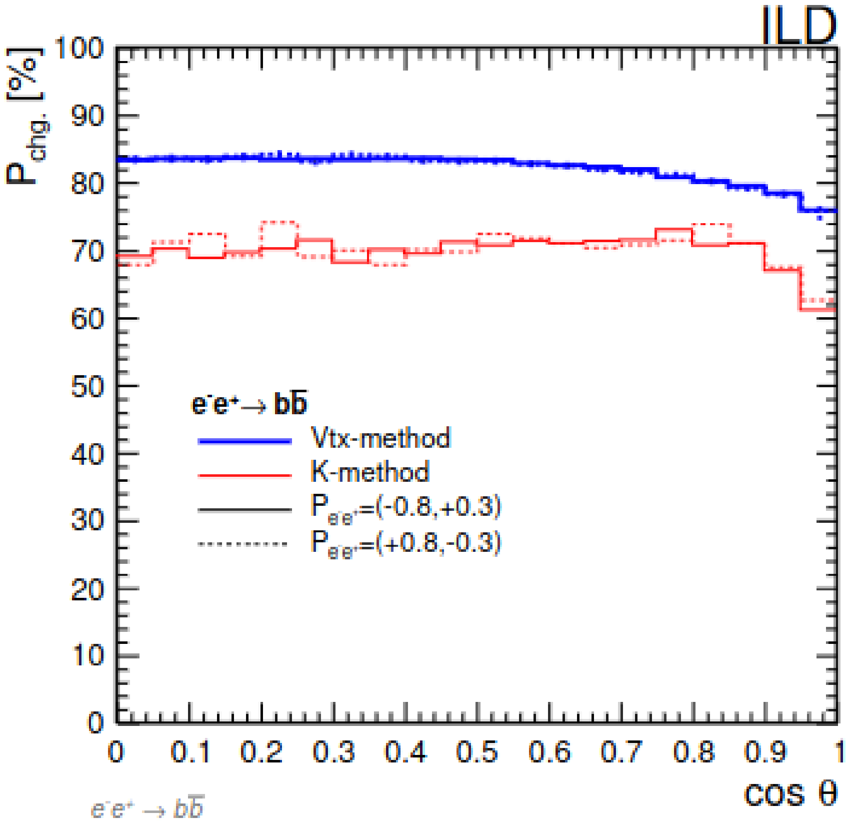
- We are required to **measure the jet charge**
  - Using K-ID and/or full Vtx charge measurement
  - K-ID is better suited for the C-quark (Vtx is better suited for b-quark)

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



Jet charge





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Double Charge Method

▶ **Double Tag + Double Charge**

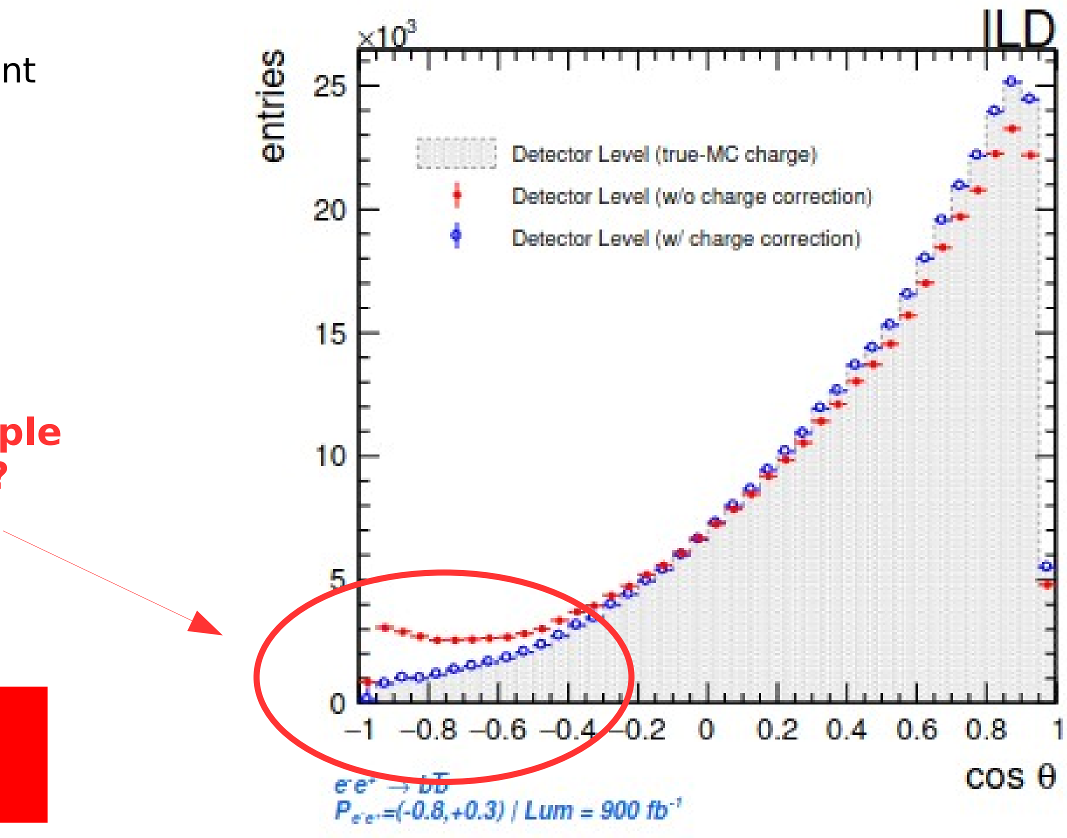
- Both jets need to have a charge measurement compatible with the 2 quarks back to back scenario

▶ 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



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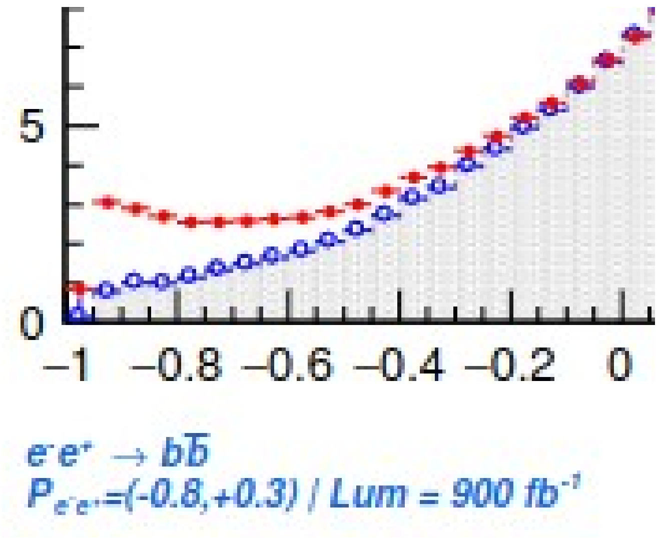
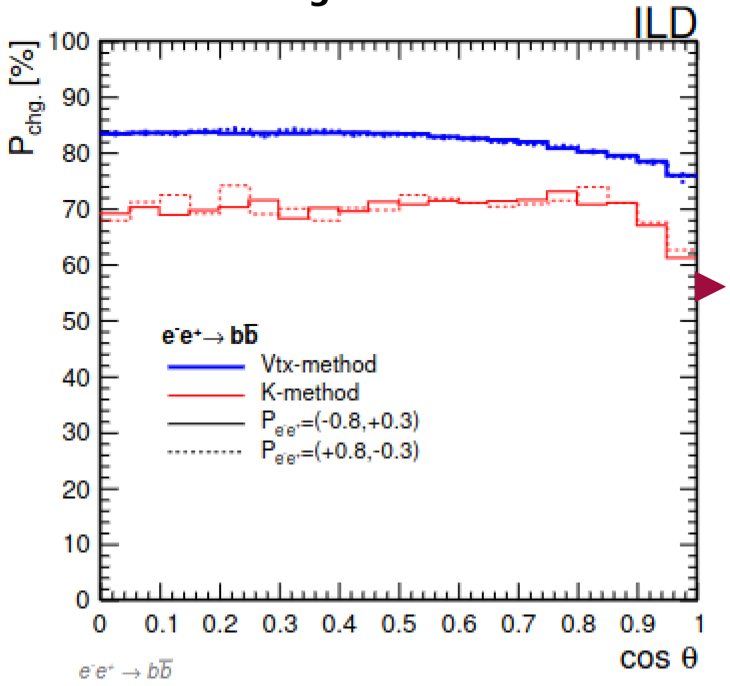
Migration correction

- 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



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

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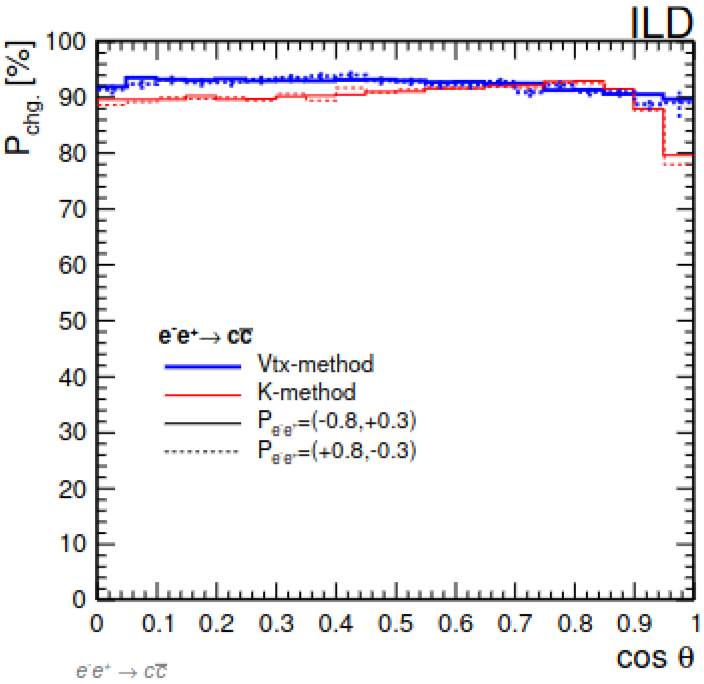
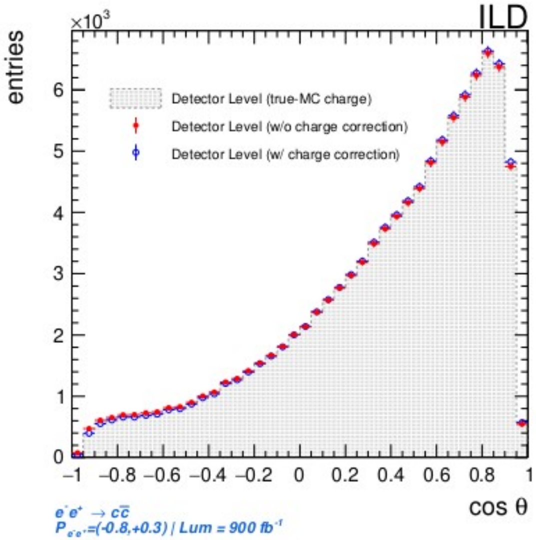
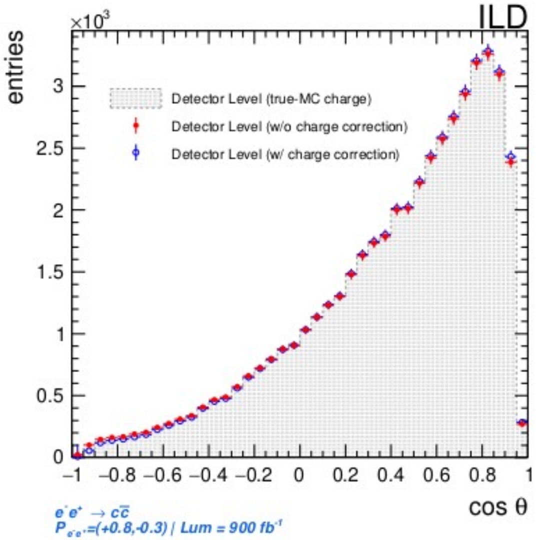
Migration correction – cquark case







Minimal migration effects (and corrections!)

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