NEW

Probing Gauge-Higgs Unification models at the ILC with AFB at center-of-mass energies above the Z-mass

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Plan de Recuperación, Transformación y Resiliencia
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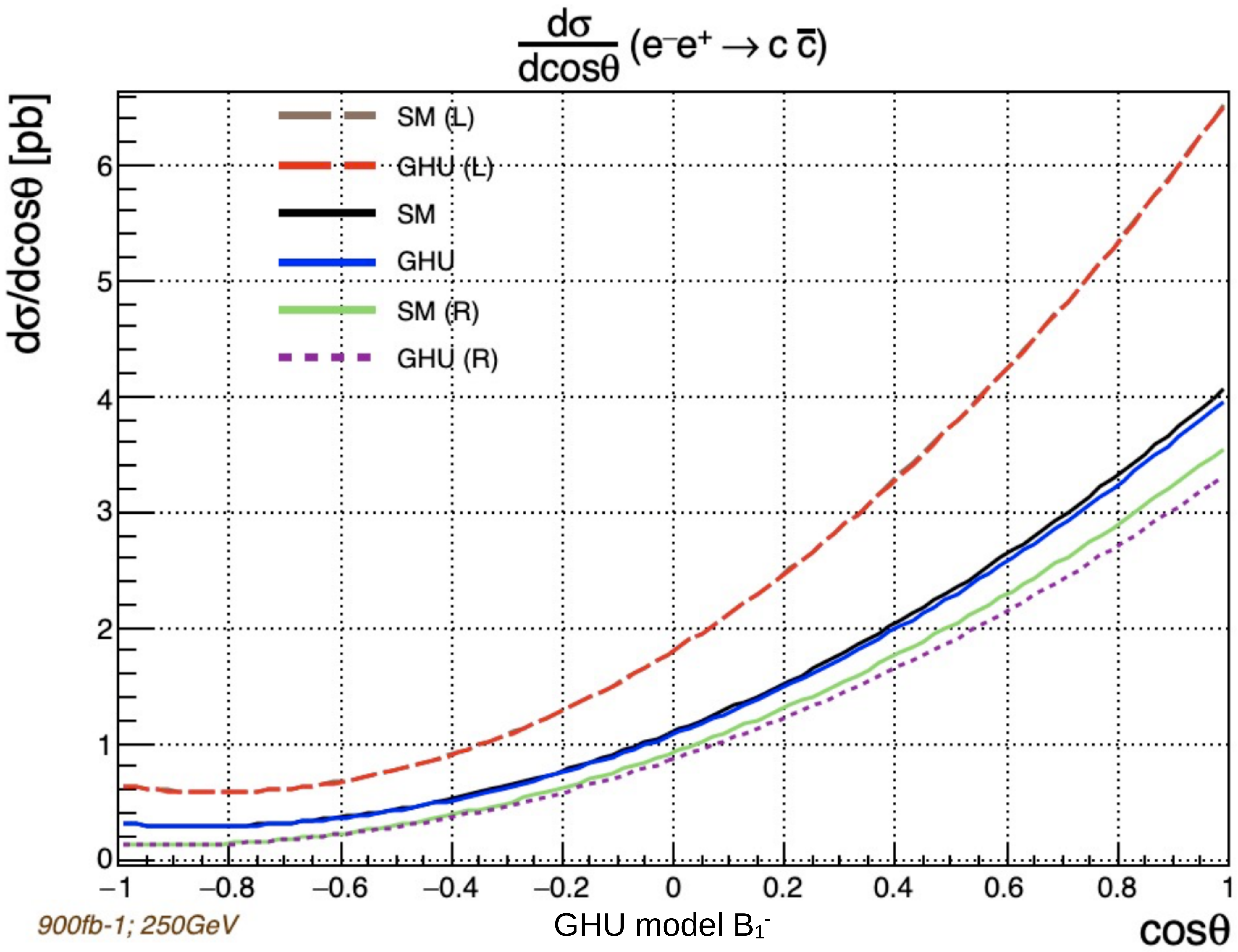
Gauge-Higgs Unification



- 5D metric
  - Introducing the Hosotani symmetry breaking mechanism
- Models have only one parameter:
  - **Hosotani angle $\theta_\mathbf{H}$:** projection of 5D fields
- **Prediction**:
  - Kaluza-Klein Resonances → Z' bosons $m_{Z'} > 7$ TeV
  - **Modifications of electroweak couplings**
  - Deviations visible at 250 GeV CME
- **Benchmark** scenario:
  - Funatsu, Hatanaka, Hosotani, Orikasa, Yamatsu GHU models

Studied Models

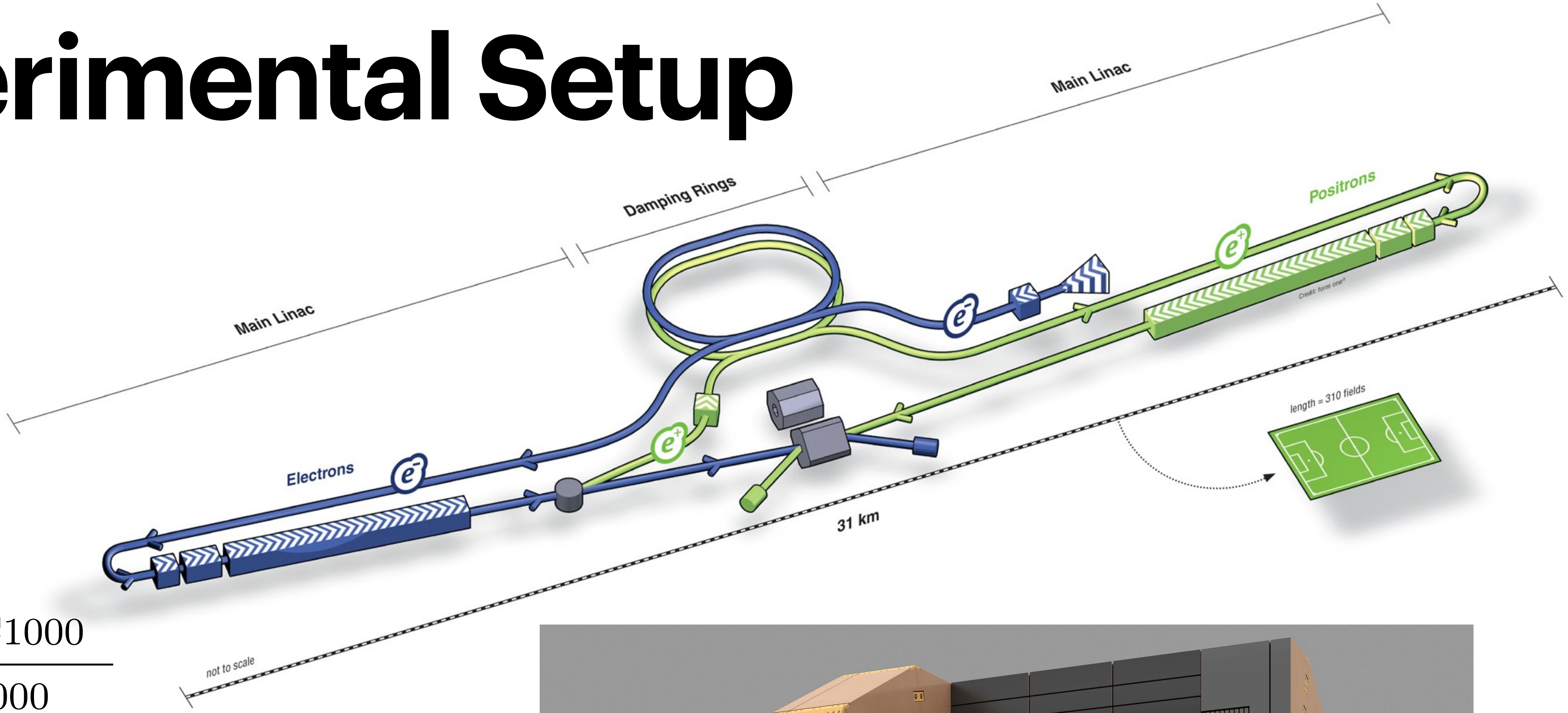
- **A-Models**: 1705.05282

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

- **B-Models**: 2309.01132, 2301.07833

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

Experimental Setup

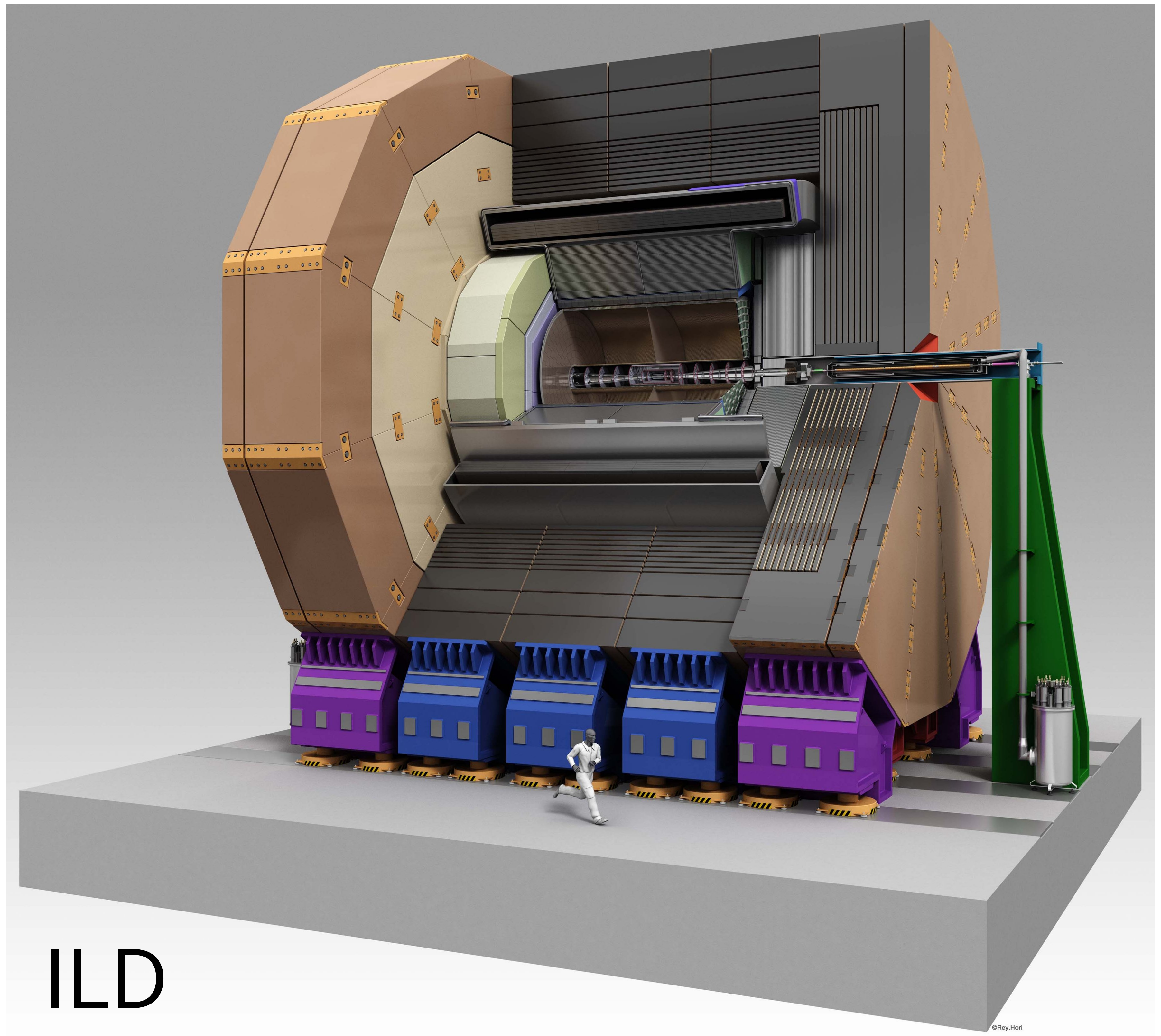


Assuming **H20-staged program**

	ILCGigaZ	ILC250	ILC500	ILC1000
$\int \mathcal{L}\ [fb^{-1}]$	100	2000	4000	8000
$(\lvert P_{e^-}\rvert, \lvert P_{e^+}\rvert)$	(0.8,0.3)	(0.8,0.3)	(0.8,0.3)	(0.8,0.2)
OSP|SSP [%]	40|10	45|5	40|10	40|10

International Linear Detector (ILD)

- Optimised for **Particle Flow**
- Precise tracking, vertexing, and PID



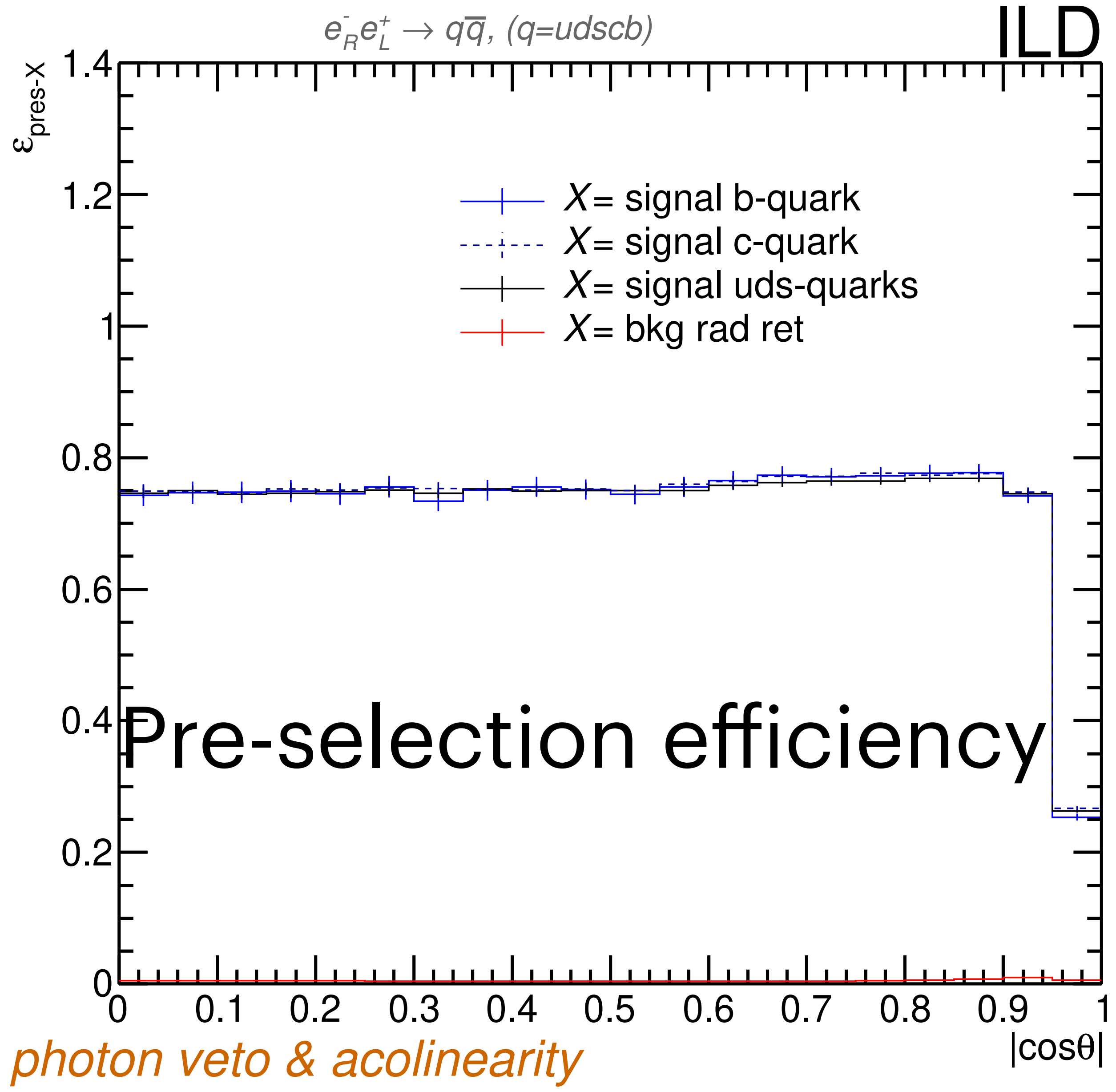
Analysis Strategy

- **Observable**: Forward-backward asymmetry
  - Two back-to-back **c- or b-jets**
  - **Full simulation** of International Large Detector (ILD)

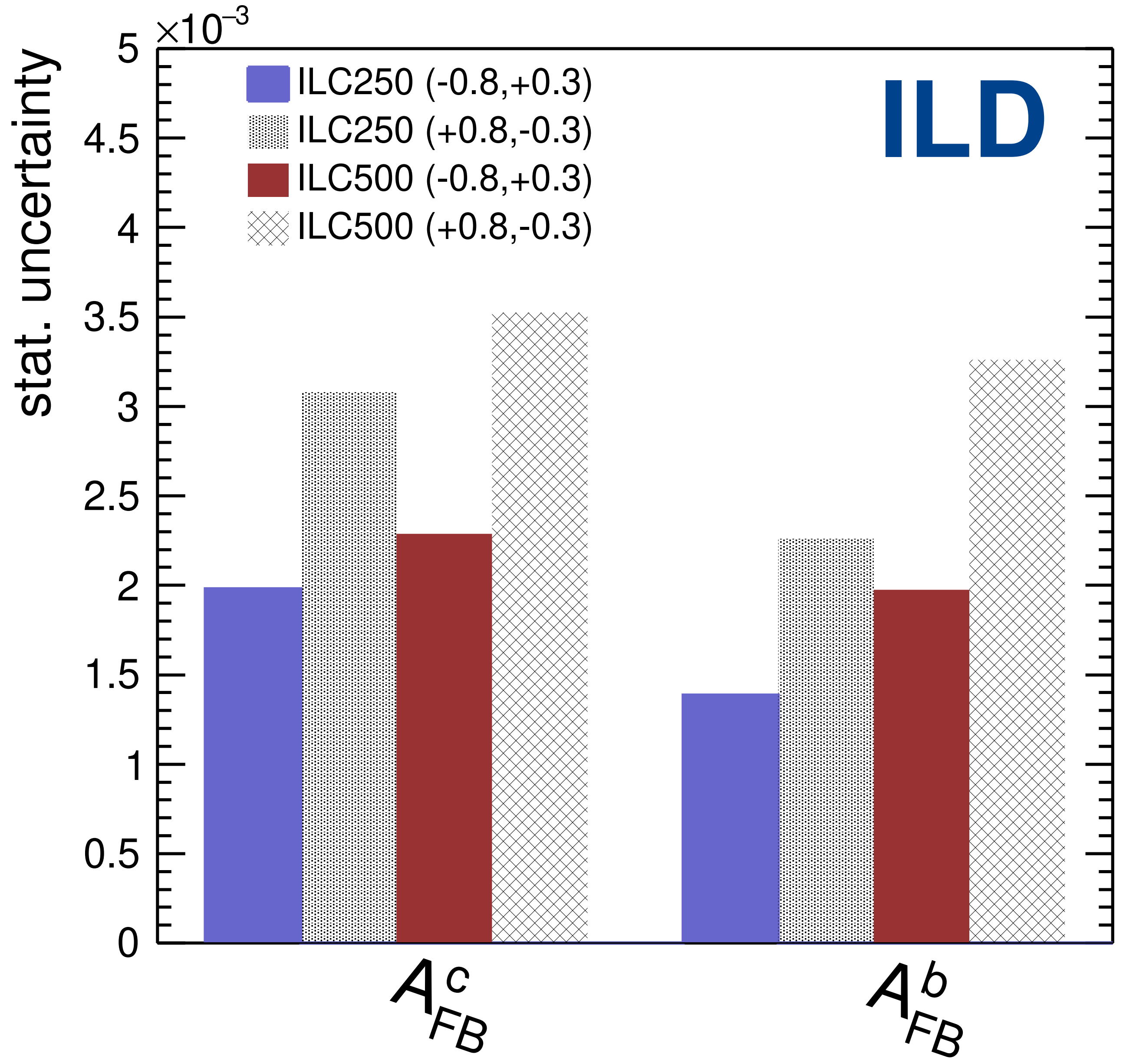
$$\frac{dN}{d\cos\theta} = \mathcal{L}\left[\boxed{\varepsilon_{pre}\varepsilon_{DTC}}\frac{d\sigma}{d\cos\theta} + \varepsilon_{bkg}\frac{d\sigma_{bkg}}{d\cos\theta}\right]$$

- General Strategy:
  - **Pre-selection**: background suppression
  - **Jet-Flavor ID**
    - Double Tag: reduce flavor tag unc.
  - **Jet-Charge**:
    - Double charge + data-driven correction
  - Compare measurements to GHU
- Estimated stat. unc. in permille region
  - ***What about systematic uncertainties?***

[2306.11413]



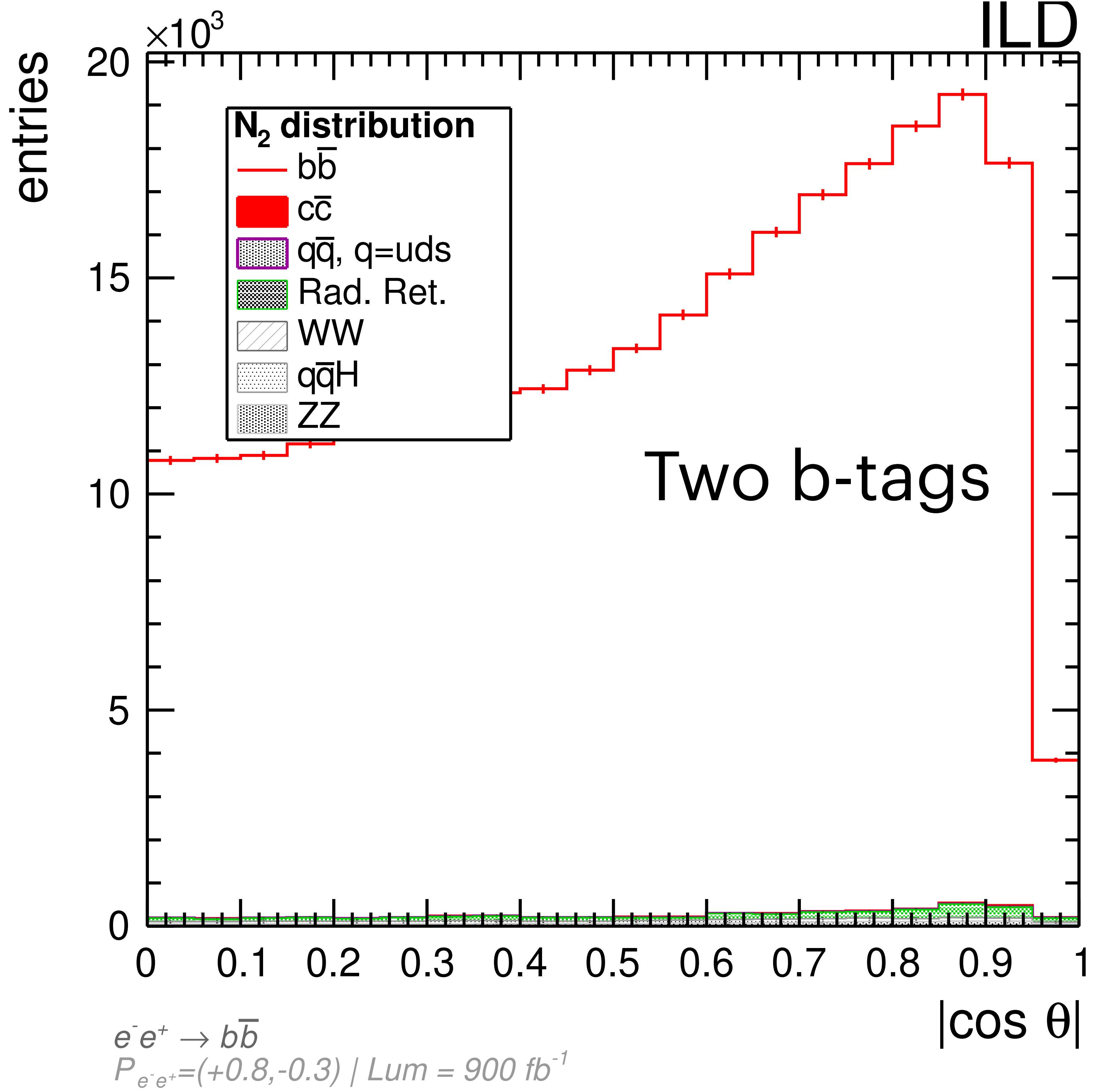
photon veto & acolinearity & m_{jj} & y_{23} cuts

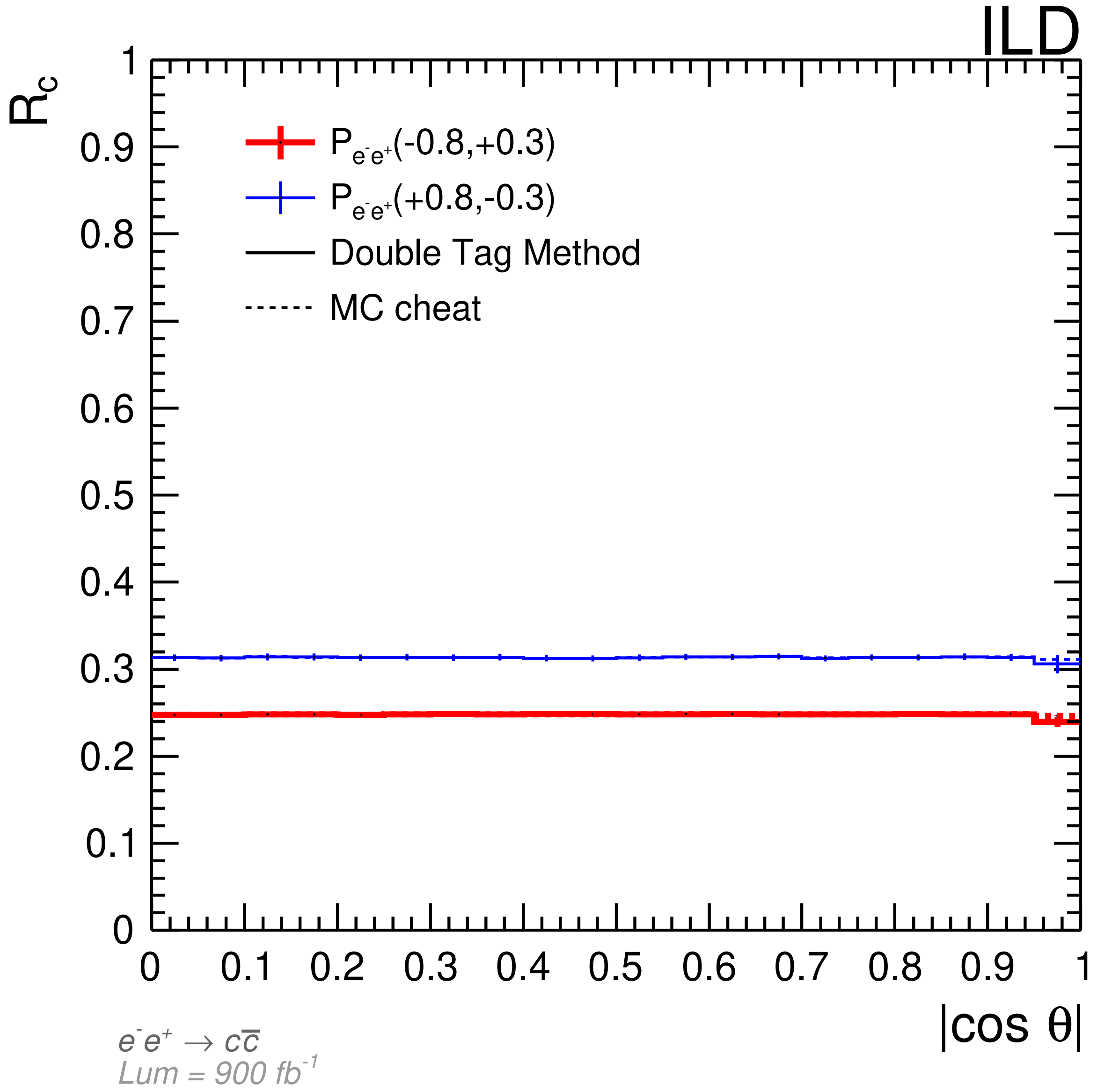


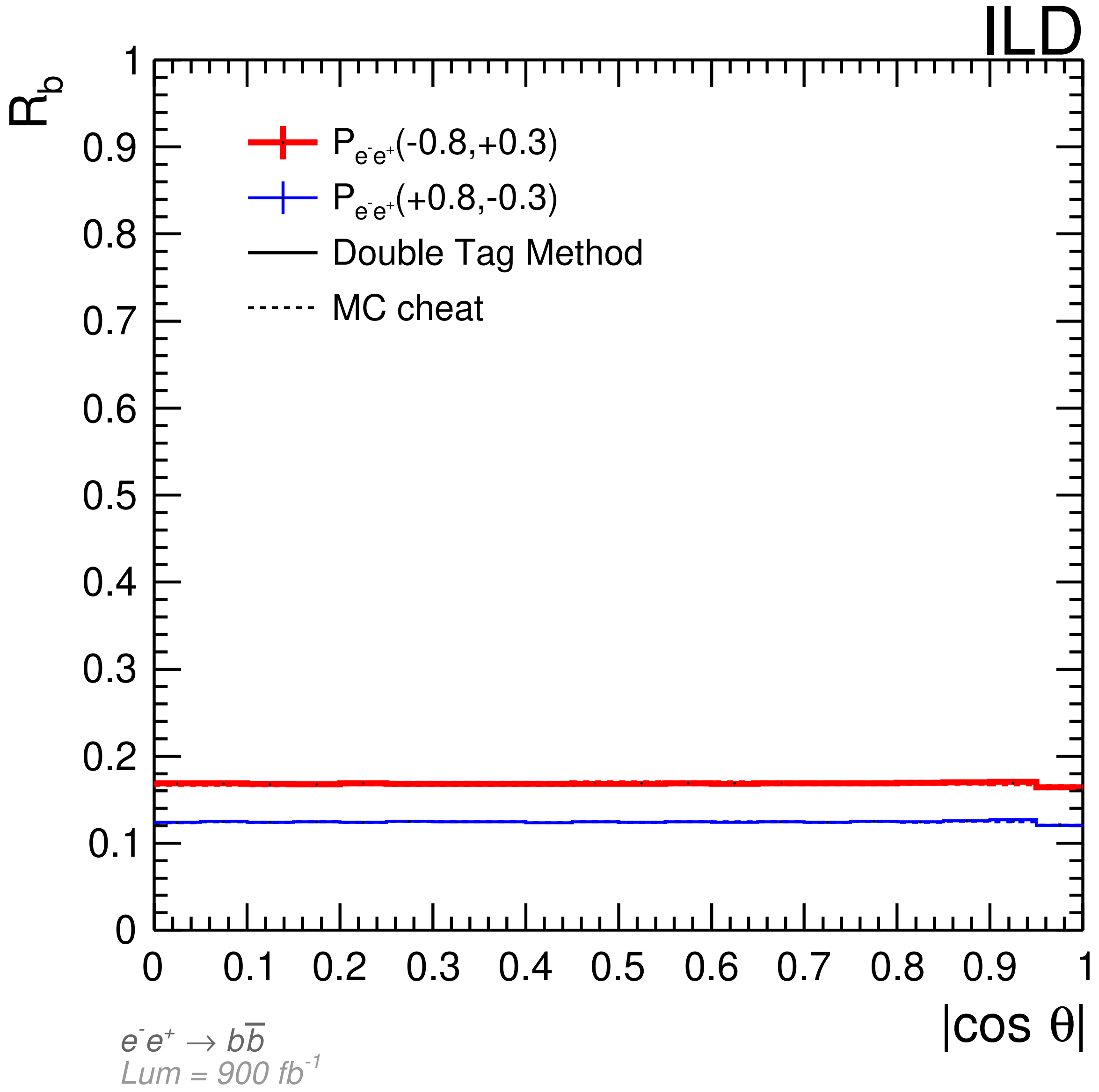
Double Tag Method

[2306.11413]

- **Pre-selection + Flavor tagging**:
  - Background free and pure flavor sample
- **Flavor tagging efficiency**:
  - Data-driven measurement
  - Construct ratios f_{1q}, f_{2q} for 1 and 2 tag selections
  - Measure hadronic cross-section fraction R_c, R_b
  - **Reduces uncertainty** due to MC modelling



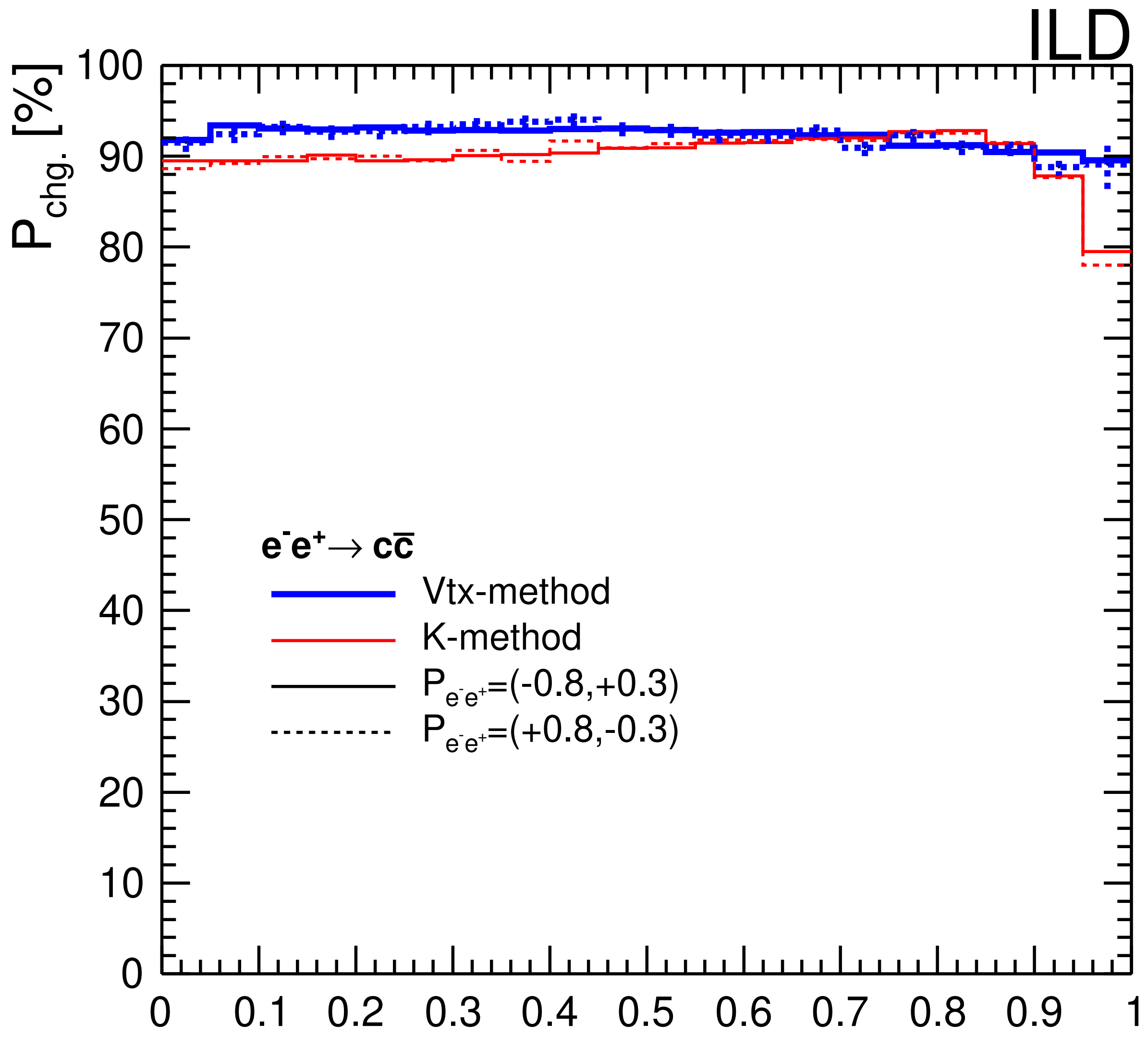




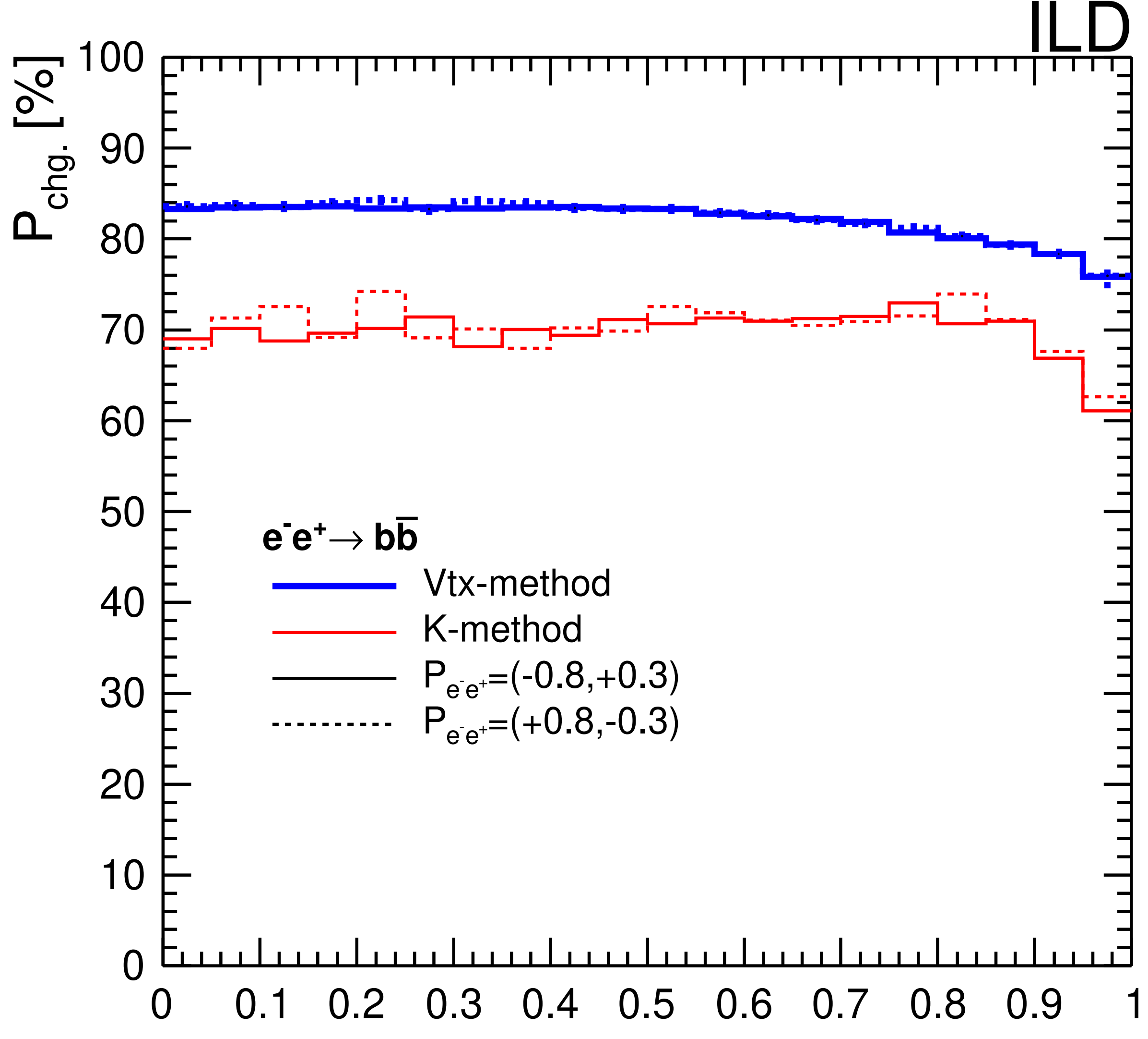
$$f_{1q}(|\cos\theta|) = \frac{N_q(|\cos\theta|) - N_q^{bkg.}(|\cos\theta|)}{2\times(N_0(|\cos\theta|) - N_0^{bkg.}(|\cos\theta|))}$$

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

Double Charge Method

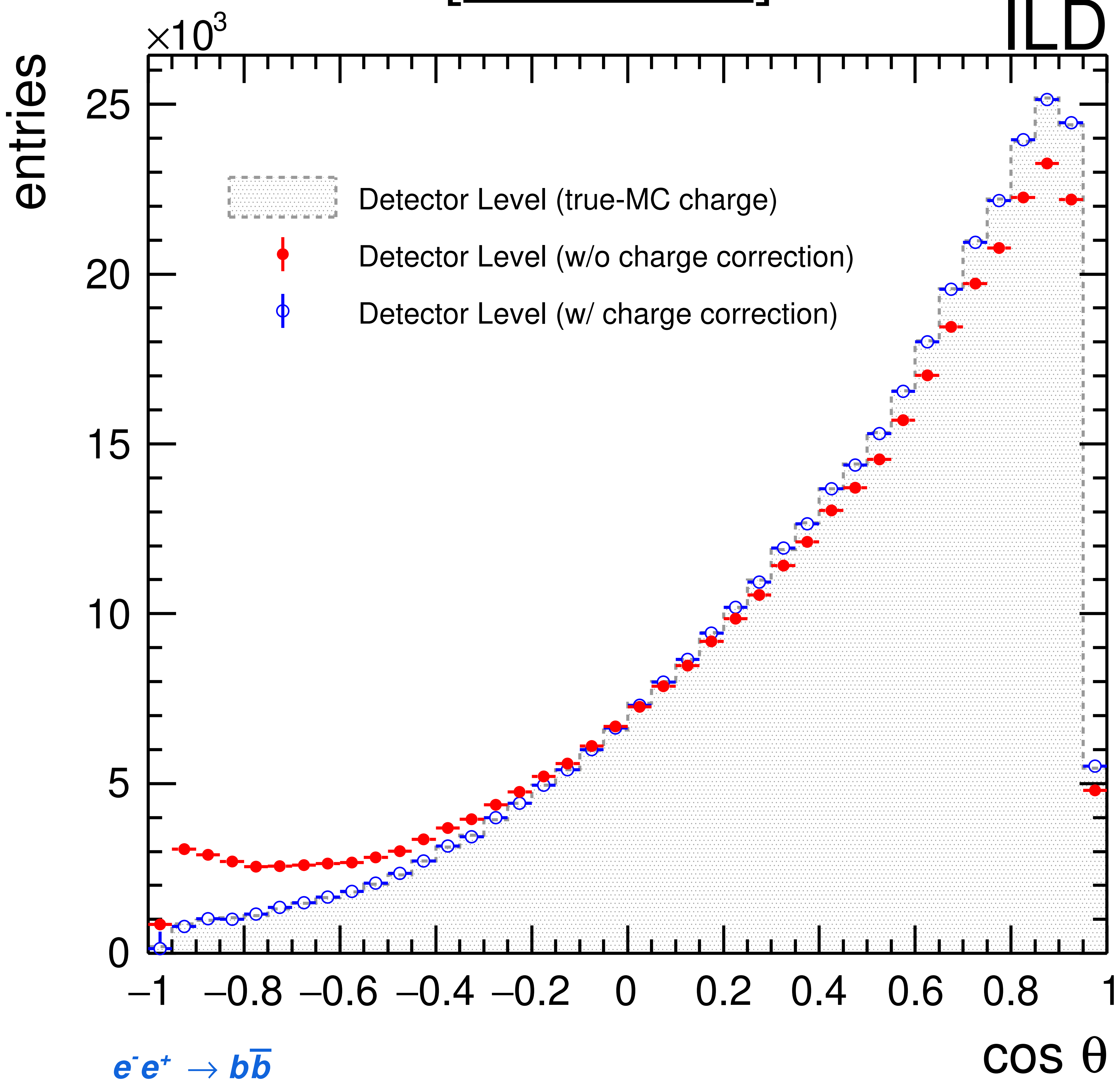


$e^-e^+ \rightarrow c\bar{c}$



$e^-e^+ \rightarrow b\bar{b}$

[2306.11413]



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

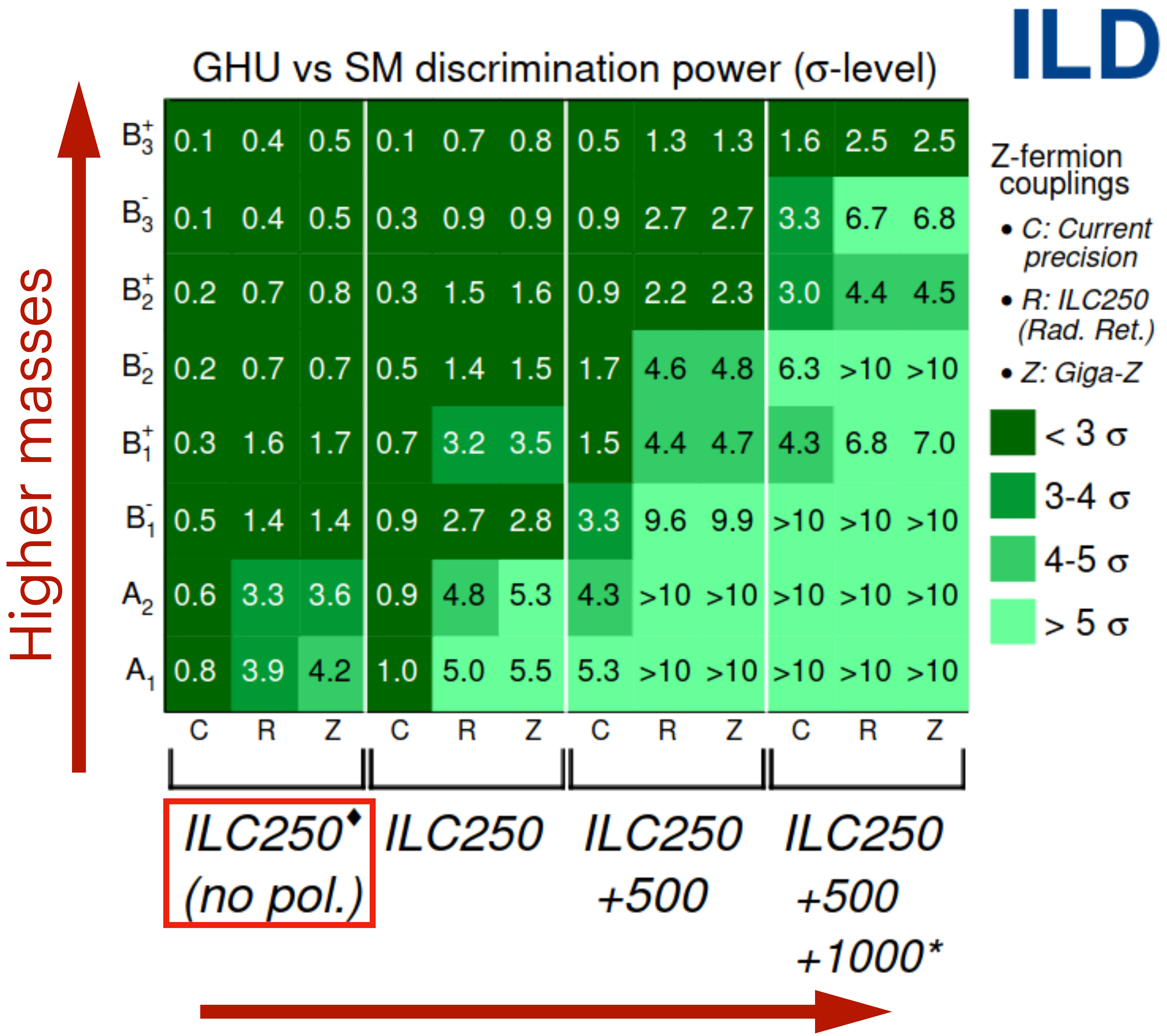
- **Data-driven method** reduces MC modelling dependence
- **K-ID** or full **Vtx** charge for measurement
- Measure probability to estimate jet-charge correctly P_{chg}
    - Apply migration correction

Results: GHU vs SM Discrimination

- **Statistical significance**

$$d_{ij} = \frac{|A_{FB,i} - A_{FB,j}|}{\Delta A_{FB,j}}$$

- Assuming normally distributed uncertainties
- **Multivariate Gaussian** used for combination
  - No correlations between measurements assumed
- **Three scenarios**:
  - Current coupling precision
  - ILC250 (radiative return) precision
  - ILC Giga-Z



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

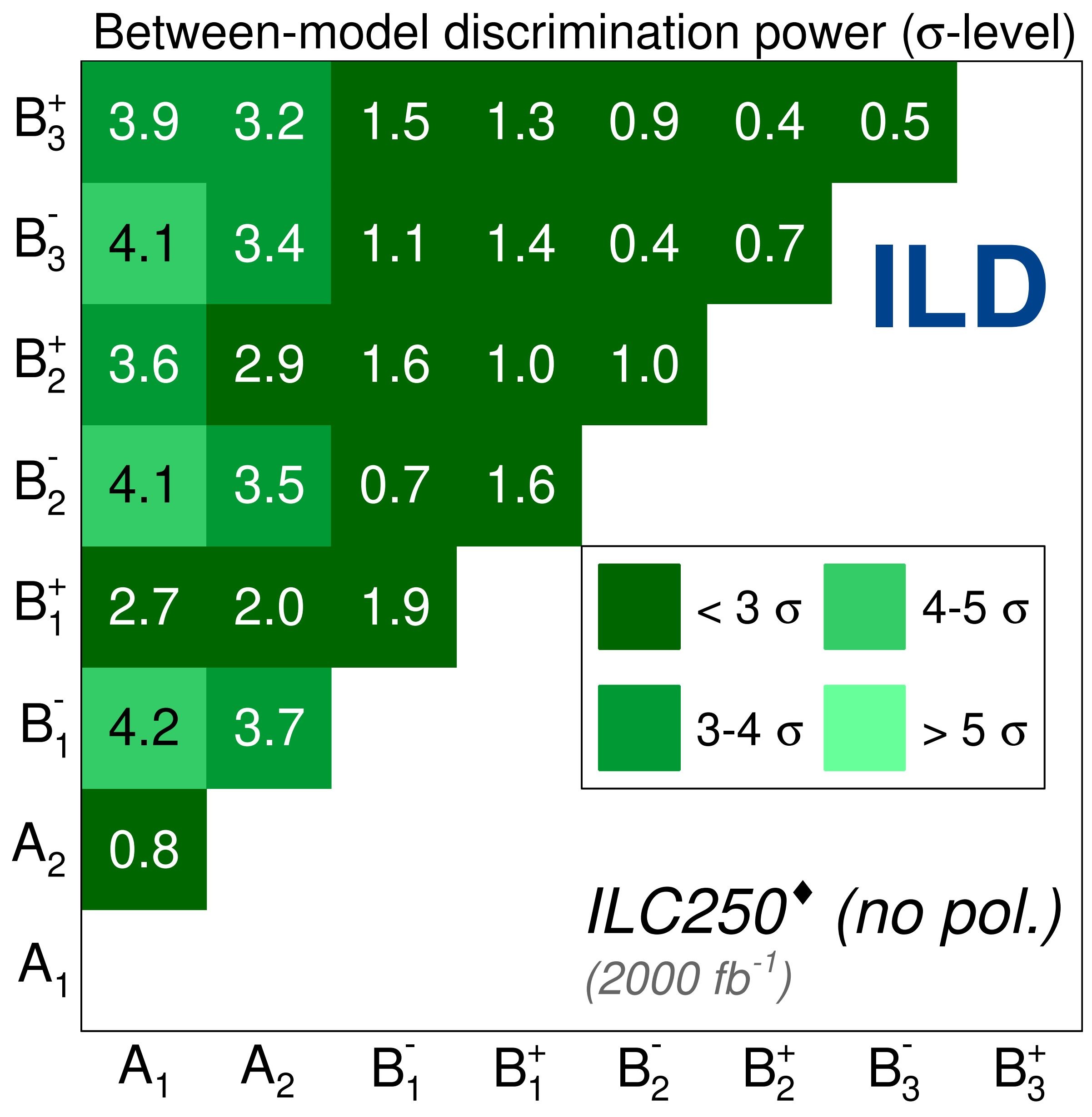
🟩 4-5 σ

🟩 > 5 σ

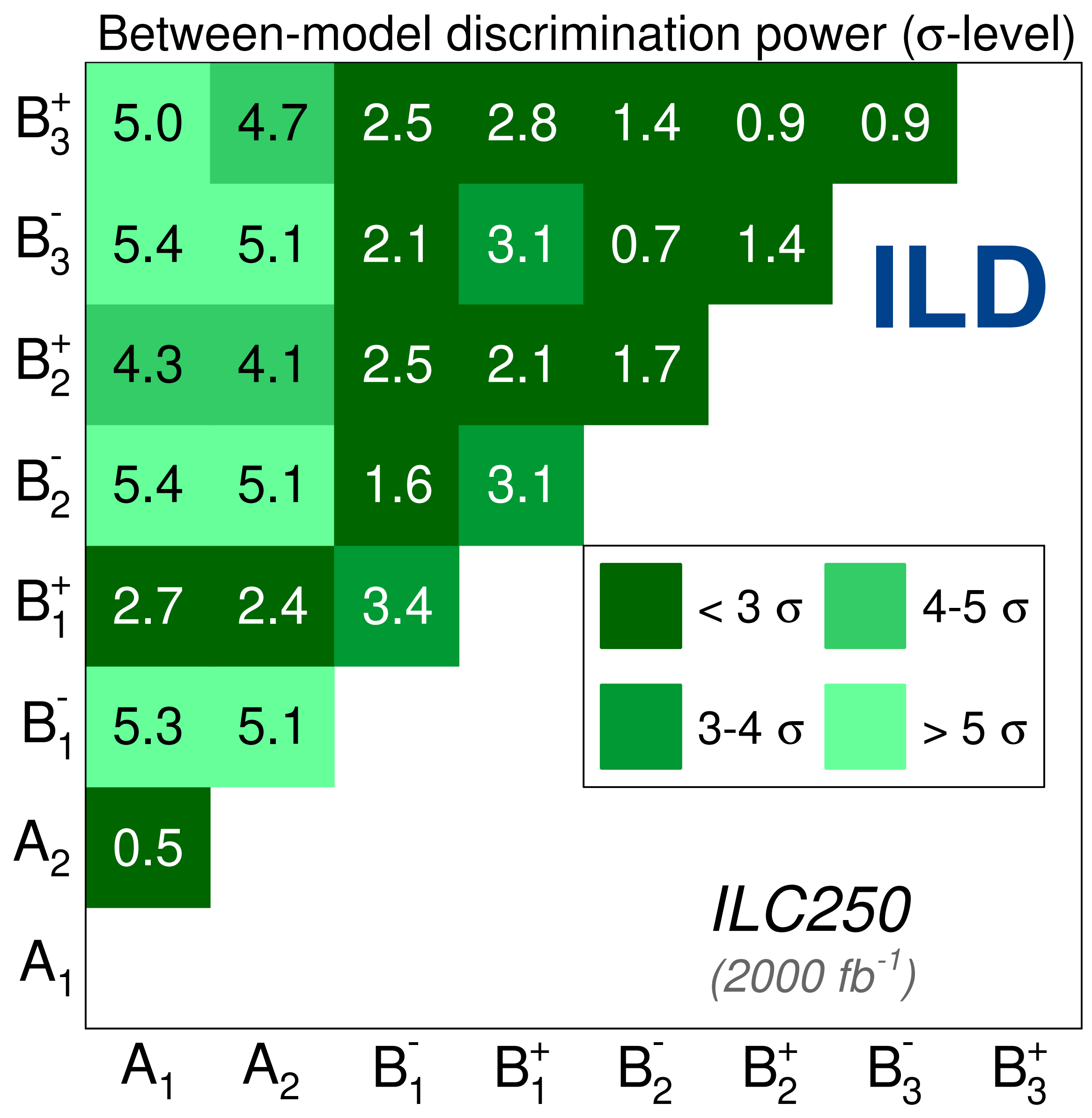
Higher masses

More data/higher energy

Results: GHU vs GHU Discrimination

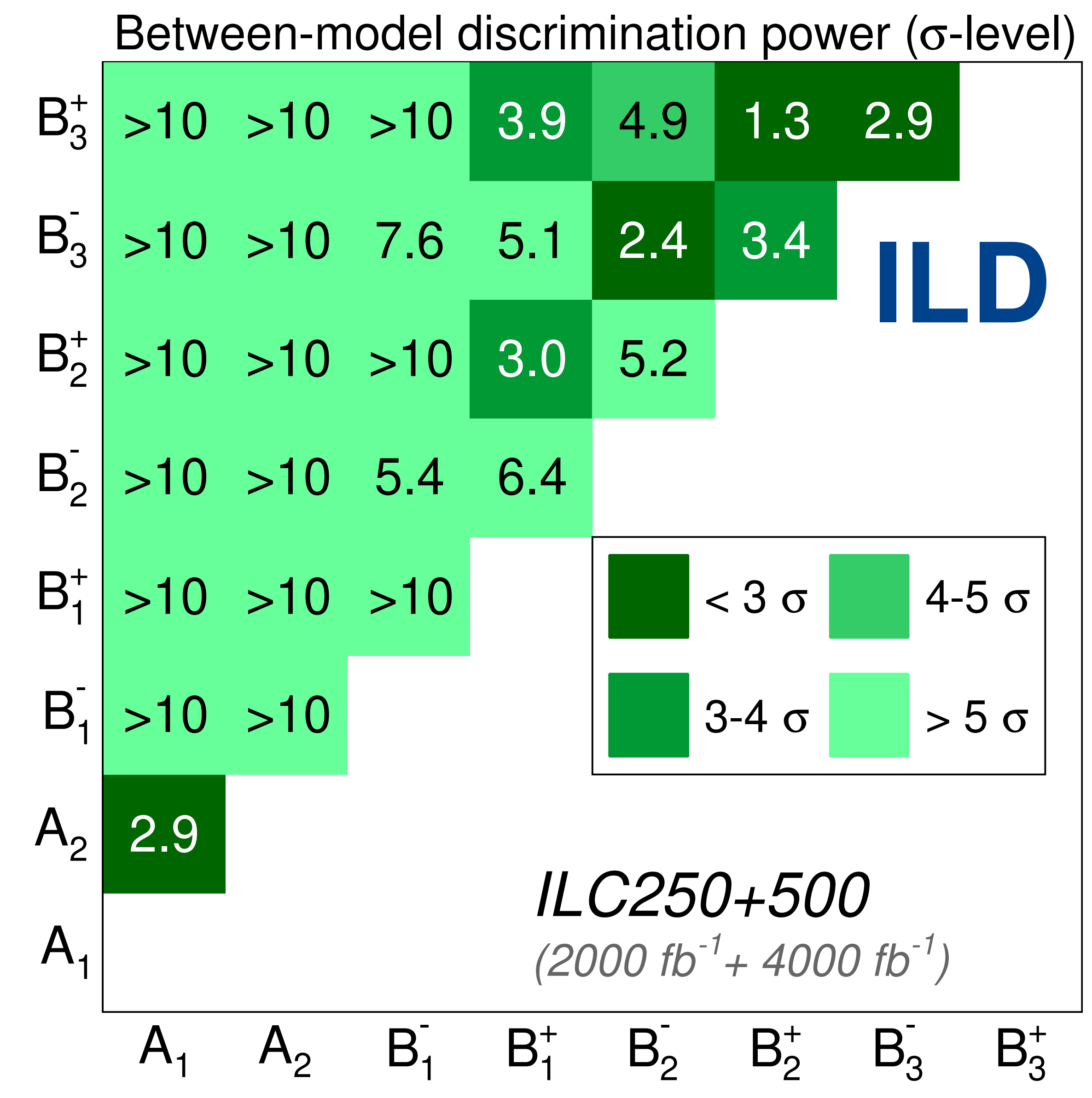


	A_1	A_2	B_1^-	B_1^+	B_2^-	B_2^+	B_3^-	B_3^+
B_3^+	3.9	3.2	1.5	1.3	0.9	0.4	0.5	
B_3^-	4.1	3.4	1.1	1.4	0.4	0.7		
B_2^+	3.6	2.9	1.6	1.0	1.0			
B_2^-	4.1	3.5	0.7	1.6				
B_1^+	2.7	2.0	1.9					
B_1^-	4.2	3.7						
A_2	0.8							
A_1								

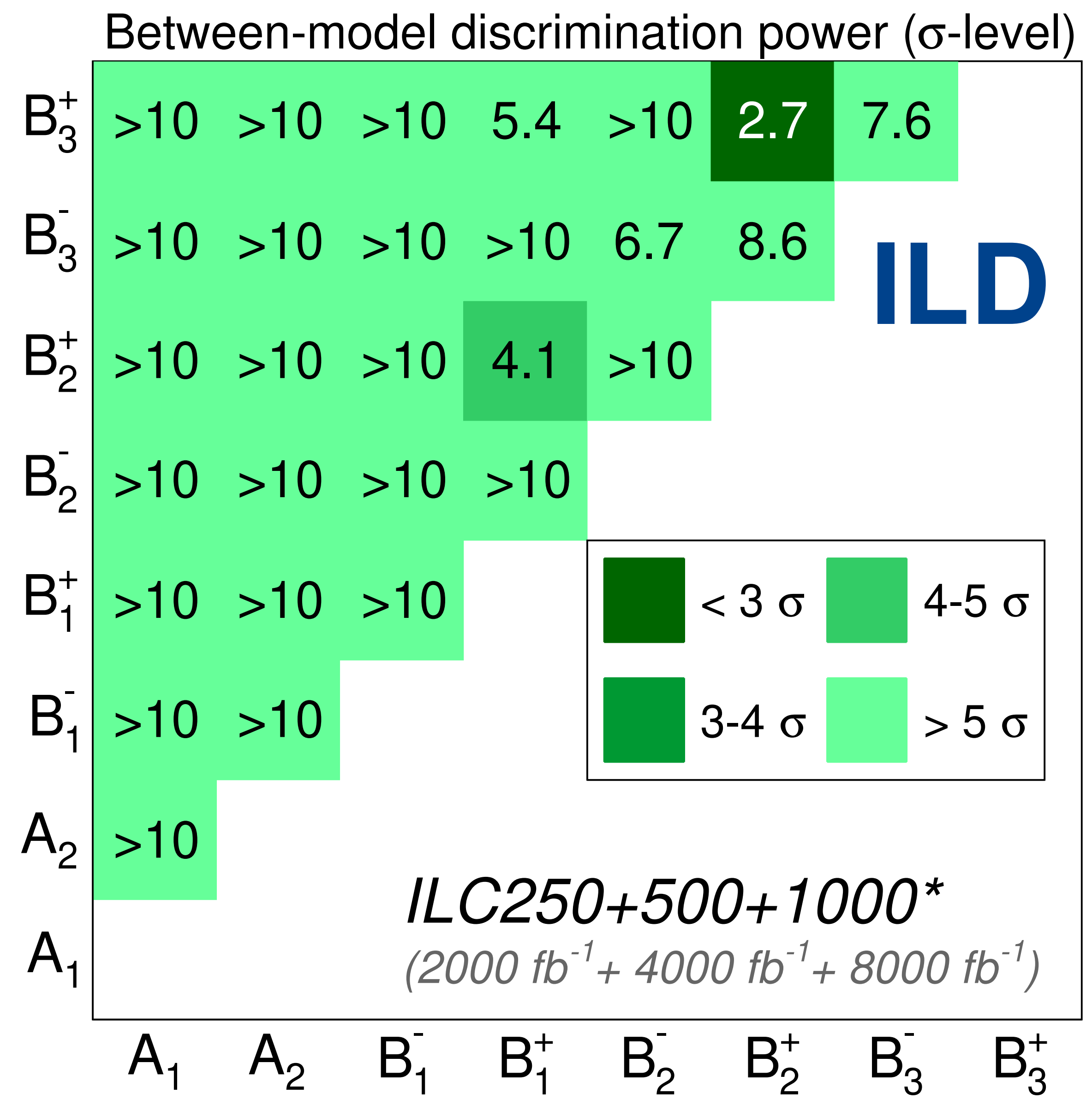


	A_1	A_2	B_1^-	B_1^+	B_2^-	B_2^+	B_3^-	B_3^+
B_3^+	5.0	4.7	2.5	2.8	1.4	0.9	0.9	
B_3^-	5.4	5.1	2.1	3.1	0.7	1.4		
B_2^+	4.3	4.1	2.5	2.1	1.7			
B_2^-	5.4	5.1	1.6	3.1				
B_1^+	2.7	2.4	3.4					
B_1^-	5.3	5.1						
A_2	0.5							
A_1								

- **Beam polarisation** enables discrimination already at 250 GeV
- **Almost all models can be discriminated with ILC250+500+1000**
- Additional studies:
  - Impact of **polarisation**
  - Impact of **PID**



	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								



	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								

Conclusion

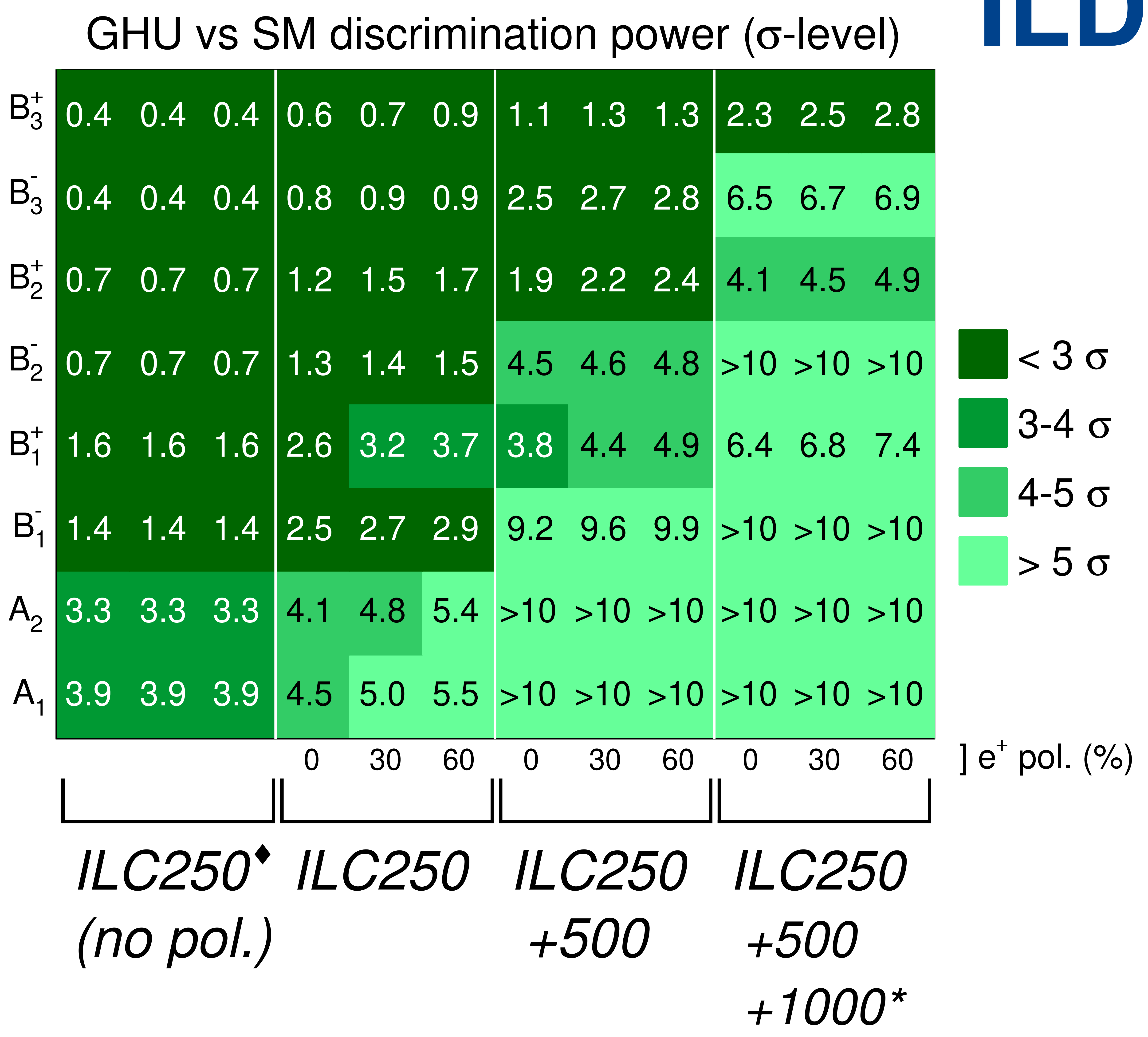
- The International Linear Collider offers a clean environment for BSM searches
- International Large Detector has excellent PID and vertexing capabilities
- Presented a **benchmark BSM search** at ILC
- **Expected statistical uncertainties are on permille level**
- Experimental uncertainties can be minimised through data-driven methods
- Measurements can lead to **observations or exclusion** of physics way above the energy reach of the collider
- Discrimination between models is also achievable

BACKUP

Impact of Beam Polarisation

ILD

- Plot similar to slide 8
- **Fixing Z-fermion couplings** to ILC250 radiative return case
- Impact of **0, 30, 60% positron beam polarisation** on the results is shown
- No polarisation is assumed for ILC250 (no pol.)



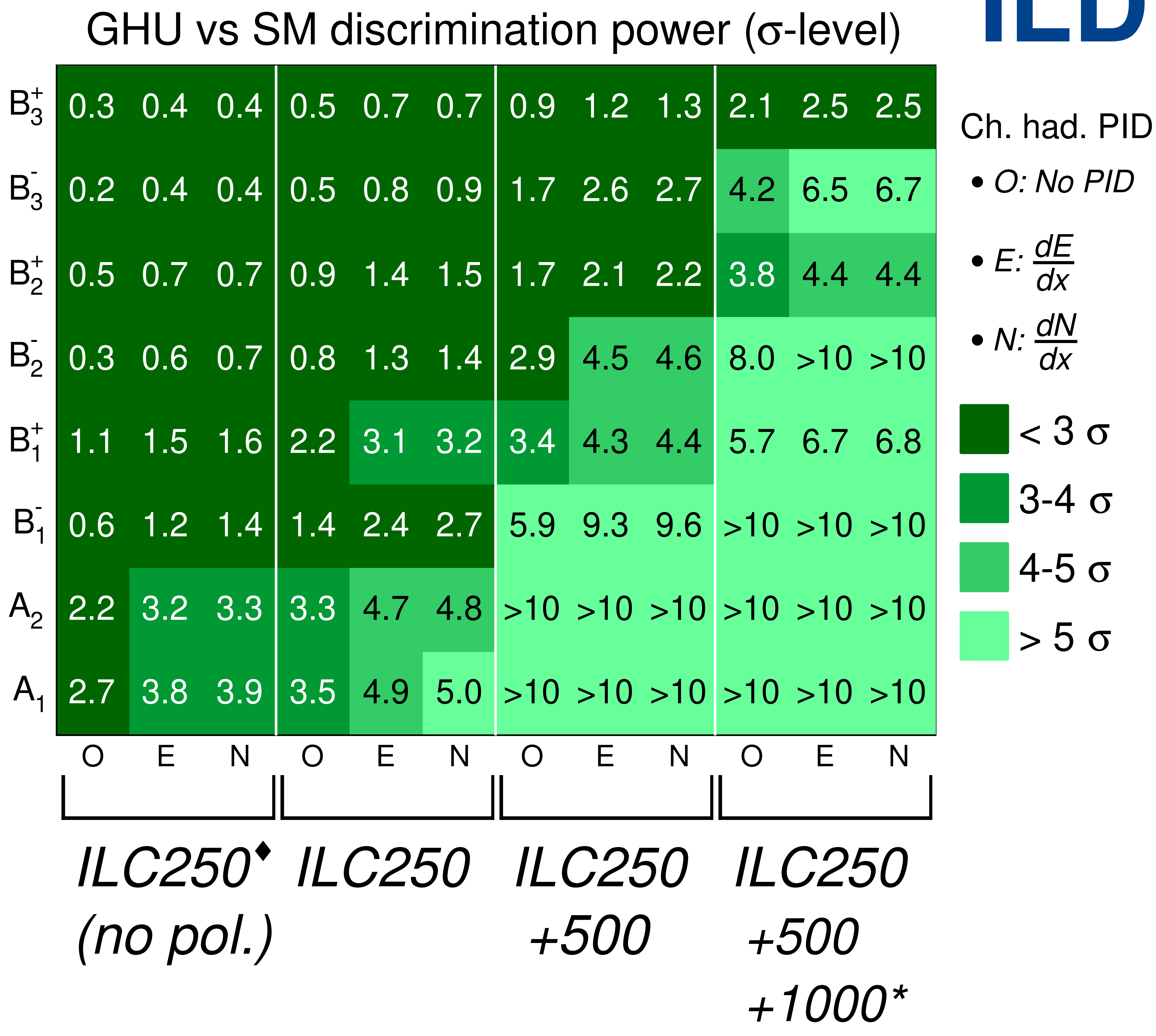
GHU vs SM discrimination power (σ-level)

	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

Impact of Particle Identification

- Plot similar to slide 8
- **Fixing Z-fermion couplings** to ILC250 radiative return case
- **Charged hadron particle identification** (PID) is studied
    - O: no PID
    - E: ILD baseline dE/dx PID
    - N: optimised TPC with cluster counting dN/dx
- No polarisation is assumed for ILC250 (no pol.)

ILD



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