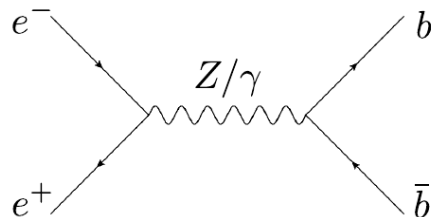


# Heavy quark production in ILC250

Y. Okugawa<sup>\*†</sup>, R. Poeschl<sup>\*</sup>, F. Richard<sup>\*</sup> and A. Irles<sup>‡</sup>  
*<sup>#</sup>IFIC (CSIC/UV), <sup>\*</sup>IJCLab (CNRS/IN2P3 U. Paris-Saclay), <sup>†</sup>Tohoku U.,*



- ▶ Differential cross section for (relativistic) di-fermion production



$$\frac{d\sigma}{d\cos\theta}(e_L^- e_R^+ \rightarrow f \bar{f}) = \Sigma_{LL}(1 + \cos\theta)^2 + \Sigma_{LR}(1 - \cos\theta)^2$$

$$\frac{d\sigma}{d\cos\theta}(e_R^- e_L^+ \rightarrow f \bar{f}) = \Sigma_{RR}(1 + \cos\theta)^2 + \Sigma_{RL}(1 - \cos\theta)^2$$

- The helicity amplitudes  $\Sigma_{ij}$ , contain the couplings  $g_L/g_R$  (or Form factors or EFT factors)
- Left/right asymmetries (characteristic for each fermion)
- ▶ **Only beam polarisation allows inspection of the 4 helicity amplitudes for all fermions**
  - Beam polarisation also enhances the cross section values
- ▶ **These processes have been deeply studied at LEP/SLC at the Z-pole**
  - no access to the  $\gamma$  or  $Z/\gamma$  interferences
  - Moderated quark tagging or charge measurements capabilities.
  - Also moderated angular acceptance of the detectors

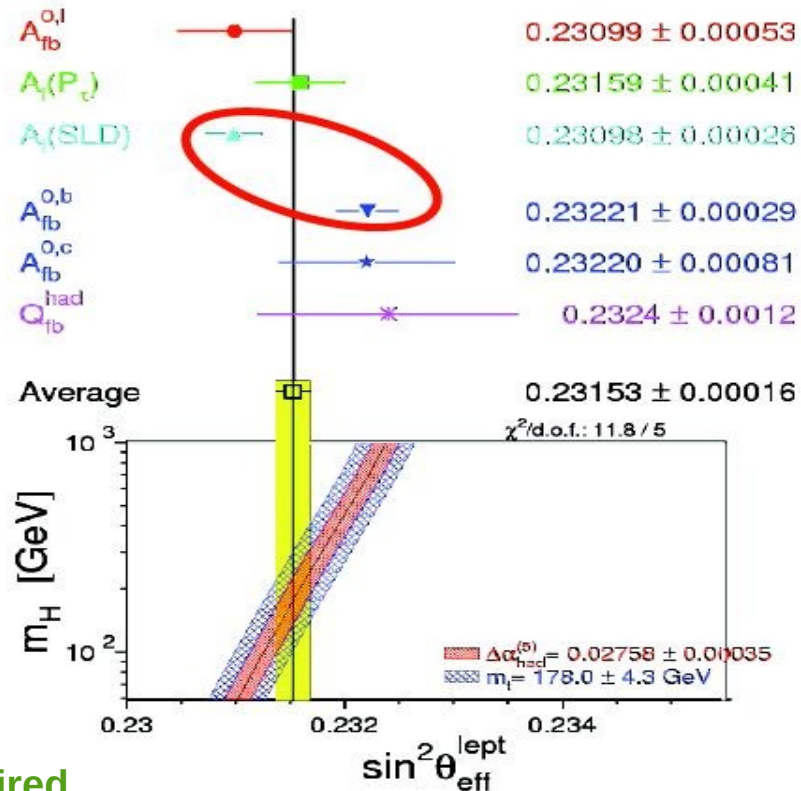
# LEP/SLC tension

- ▶ Current LEP & SLC best  $\sin^2\theta_{eff}^l$  measurements show **tension**
  - This measurement is the one with **largest tension with the SM fit**.
  - Most precise single Individual determination of  $\sin^2\theta_{eff}^l$  from SLC → Left-right asymmetry of leptons
  - Most precise single Individual determination of  $\sin^2\theta_{eff}^l$  from LEP → forward backward assymetry (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 by an order of magnitude



**Per mil level of experimental precision is required**



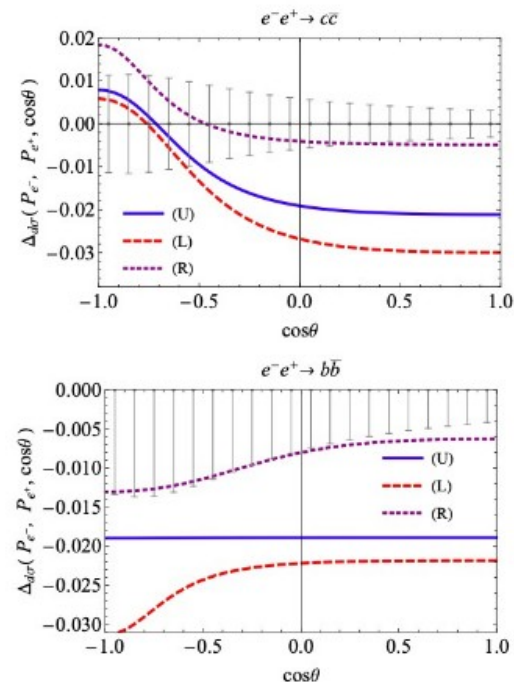
► Many **BSM scenarios** (i.e. Randal Sundrum, compositeness, Higgs unification models...) predict heavy resonances coupling to the (t,b) doublet and also lighter fermions (i.e. c/s quarks)

- **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
  - Hosotani et al arxiv:1705.05282 arxiv:2006.02157

► How do we probe these BSM scenarios ?

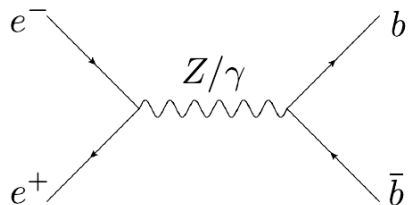
Probe such BSM predictions require at least **per mil level of experimental precision**

tt/**bb**/cc... (ss?) **Can we do it?**  
(this talk)



**Sensitivity to BSM resonances already at 250GeV with b/c/(s?) final states**

- ▶ Quark (fermion) **electroweak couplings** can be **inferred from cross section,  $R_q$**  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)

Gives access to all left/right couplings.

## ► Flavor tagging

- Indispensable for any analysis with final state quarks

## ► Quark charge measurements

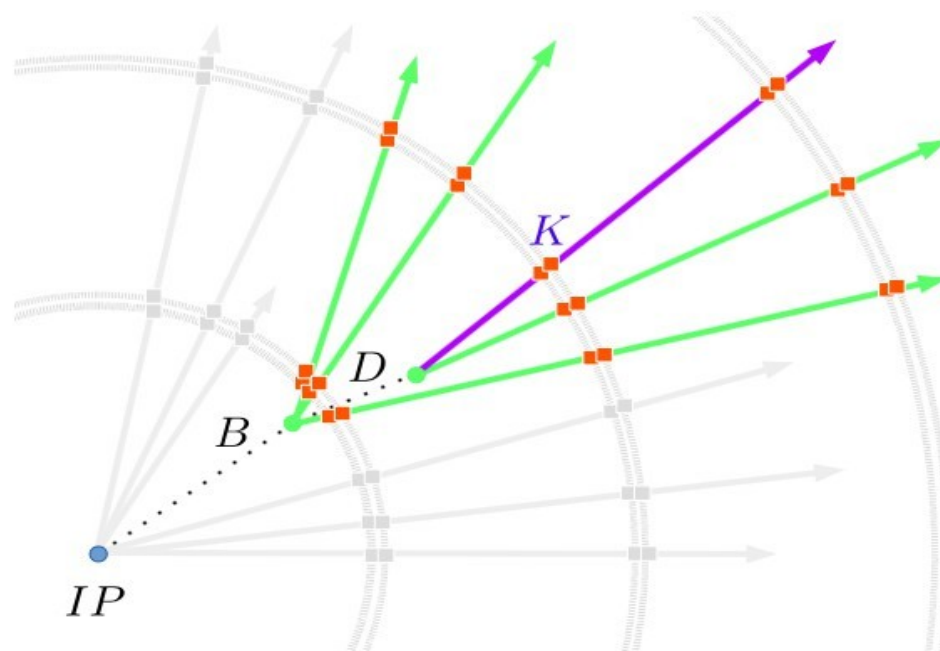
- Important for top-quark studies but Indispensable for  $ee \rightarrow bb/cc/ss\dots$

## ► Charge measurements:

- Vtx charge and **Kaon Identification**
- High efficiency (**double tagging**)
- High purity  $\rightarrow$  control of the migrations

## ► Future detectors can base their entire measurements on double Tagging and vertex charge

- LEP/SLC had to include single tags and semi-leptonic events



PhD thesis: S. Bilokin

## ▶ B-quark pairs

- ▶ High efficient flavour tagging for b-quarks expected at future colliders

## ▶ Charge Measurement

- **Primary method:** reconstruction of charged mesons → **Vtx-method**
- **Secondary method:** identification of Kaons produced in b-hadron decays → **K-method (requires PID)**

PID is very useful

## ▶ C-quark pairs

- ▶ High efficient flavour tagging for c-quarks expected at future colliders

## ▶ Charge measurement

- **Primary method:** identification of Kaons produced D-meson decays → **K-method (requires PID)**
- **Secondary method:** reconstruction of charged mesons → **Vtx-method**

PID is mandatory to reach competitive accuracies

## ▶ s-quark pairs

## ▶ Flavour tagging?

- check M. Basso's talk

## ▶ Charge measurement ?

- check Y. Okugawa's talk

**PID is crucial!**

Arxiv:1709.04289, PoS(EPS-HEP2019)624  
Paper in progress

- ▶ 2 back-to back jets topology
- ▶ Flavour tag eff/purity as main source of systematics in LEP/SLC:
  - The tagging efficiency needs to be measured (not MC estimated) to reach the per mil level of accuracy.

Experiment	<i>b</i> -quark		light quarks	
	Eff. [%]	Pur. [%]	Eff. [%]	Pur. [%]
DELPHI [19]	47%	86%	51%	82%
ILD (this note)	80%	98.7%	58%	96.1%

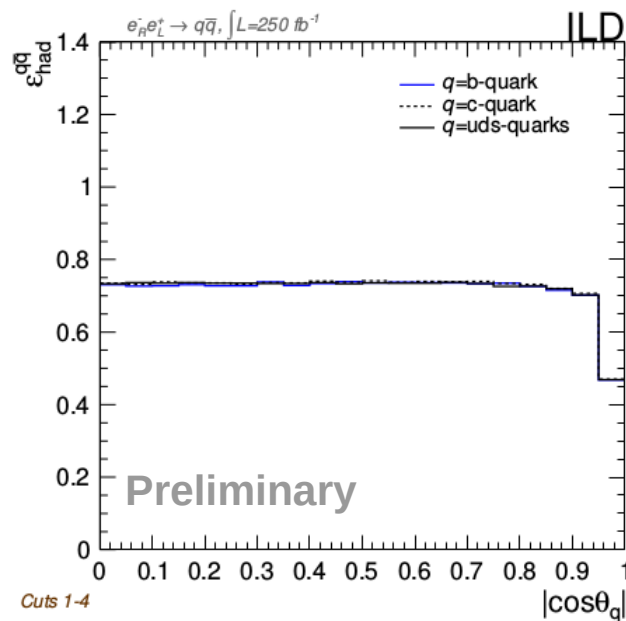
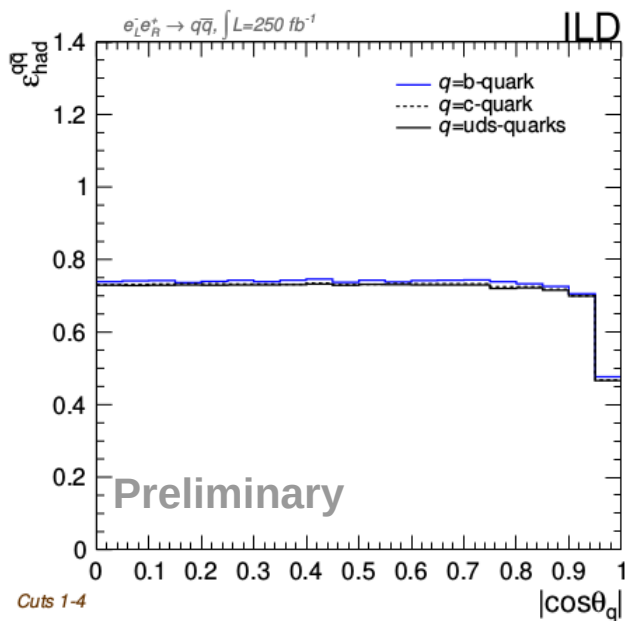
*ILD note in progress → See S. Taraifune's talk*

- ▶ New challenges at LC operating polarised beams far from the Z-pole
  - Beam polarisation
  - Event selection → **backgrounds from radiative return (x10 signal)** events and **WW/ZZ/HZ**

- ▶ **Method used to remove modeling dependence on the efficiency of b-tagging** → aiming to the per mil precision
- ▶ The sample consisted on events made of two hadronic jets (qqbar)
  - The LEP/SLC preselection consisted on a “simple” veto of  $Z \rightarrow$  leptons events
- ▶ The method is based on the comparison of **single vs double tagged samples**

# Double Tag Method

- ▶ **This method requires** (to minimise modelling uncertainties)
  - **Preselection with similar efficiency for all quark flavours (with acolinearity requirements)**
  - Preselection that reduces to the minimum the main backgrounds
  - High quark tagging efficiencies with minimal mis-tagging efficiencies

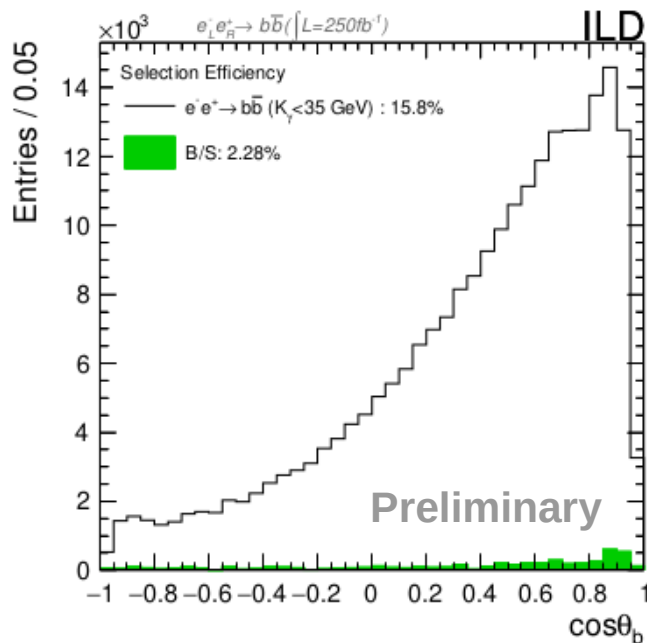


Arxiv:1709.04289, PoS(EPS-HEP2019)624

# Double Tag Method

► This method requires (to minimise modelling uncertainties)

- Preselection with similar efficiency for all quark flavours
- **Preselection that reduces to the minimum the main backgrounds**
- High quark tagging efficiencies with minimal mis-tagging efficiencies



► Main bkg  $ee \rightarrow Z\gamma(\text{ISR})$

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

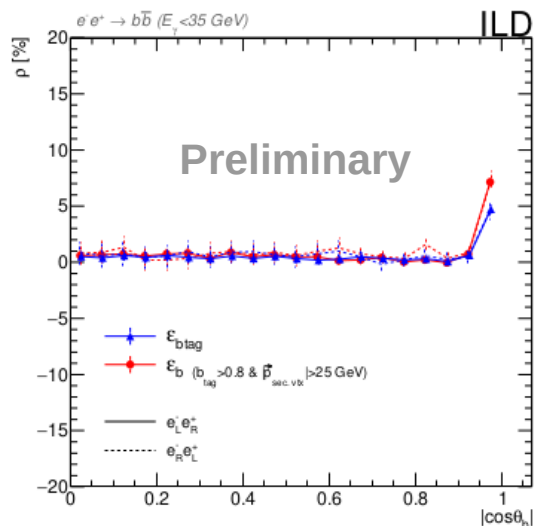
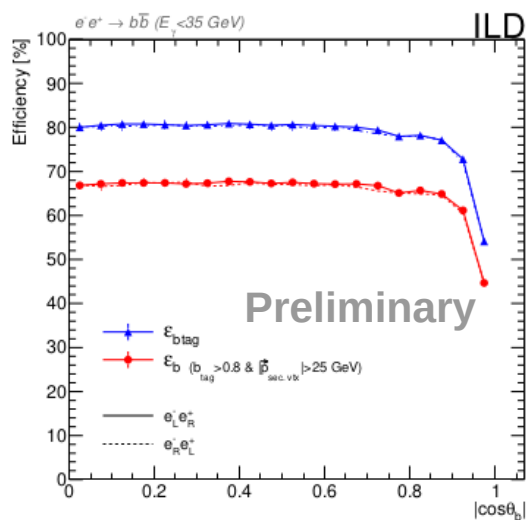
► Very small B/S  $\sim 2\%$

Arxiv:1709.04289, PoS(EPS-HEP2019)624

# Double Tag Method

► **This method requires** (to minimise modelling uncertainties)

- Preselection with similar efficiency for all quark flavours
- Preselection that reduces to the minimum the main backgrounds
- **High quark tagging efficiencies with minimal mis-tagging efficiencies**



► **Excellent prospects for b-tagging** (or c-tagging) with very low correlation factor  $\sim 0\%$  ( $\sim 2\%$  at LEP)

► **Differential measurements!**

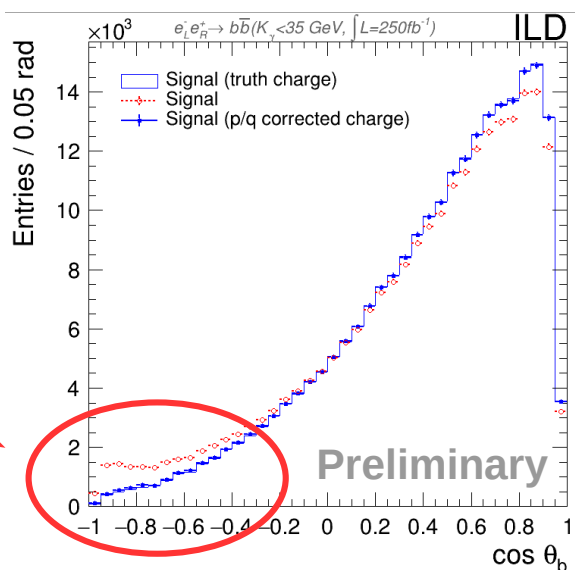
- Constant values for most of the angles
- Drop of acceptance the very forward region  $\rightarrow$  optimizations are under consideration

► **Miss-efficiencies very small**

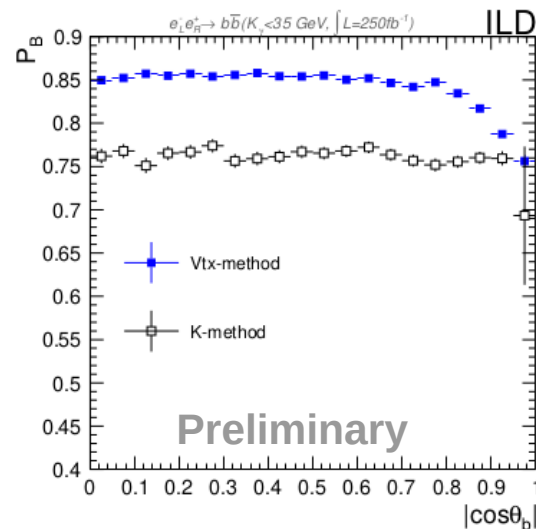
- $< 1\%$  for c-quark
- $\sim 0\%$  for uds

Arxiv:1709.04289, PoS(EPS-HEP2019)624

- ▶ Mis-measurements of the jet charge produce a flip of the sign in the differential distribution: **migrations**.
  - Mistakes due to lost tracks, mis-identification of kaons...
- ▶ 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.**

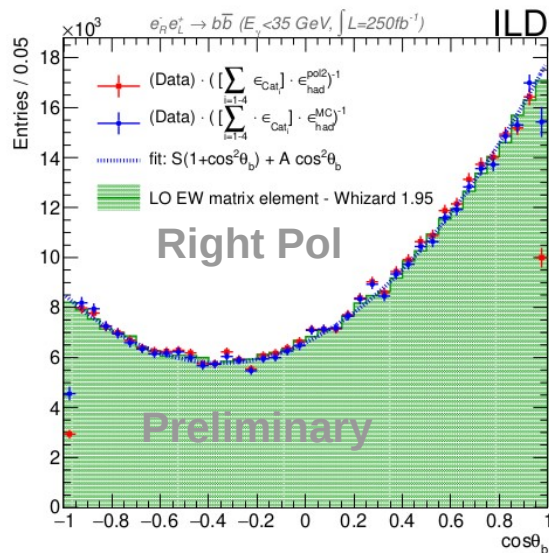
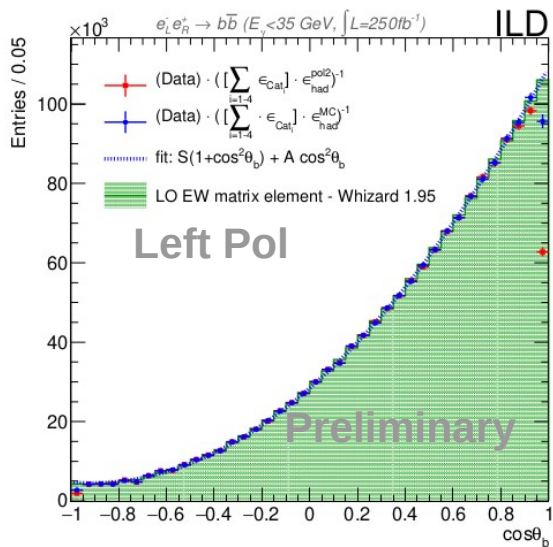


BSM or simple migrations?



▶  $P_B$  limited by vertex reconstruction efficiency, Particle ID efficiency and  $B^0$  oscillations.

Arxiv:1709.04289, PoS(EPS-HEP2019)624



## Excellent agreement between predicted and reconstructed distributions

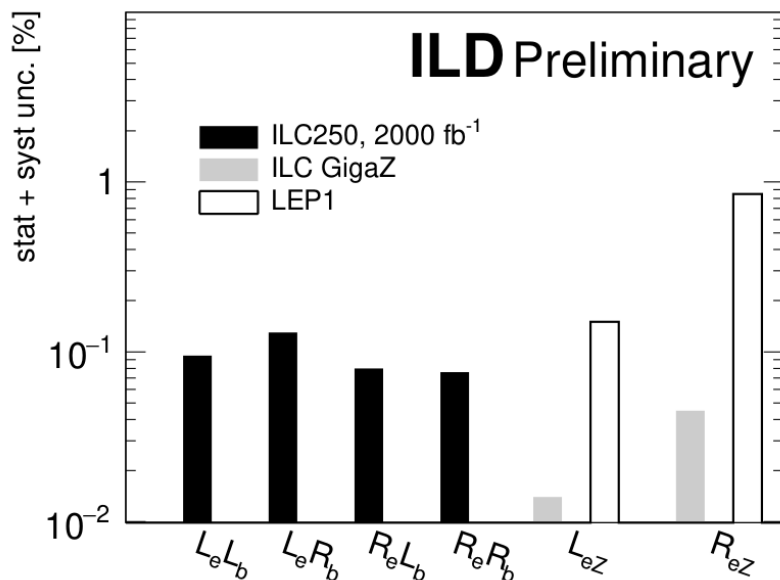
- ▶ Gap between red dots and green histogram = acceptance drop.
- ▶ Blue dots = corrected acceptance
- ▶ The fit is restricted to  $|\cos\theta_b| < 0.8$
- *Minimal impact of the corrections*

	Beam Polarisation	
	(-+)	(+-)
$R_b^{cont.}$	$0.173 \pm 0.12\% \text{ (stat.)} \pm 0.14\% \text{ (syst.)}$	$0.130 \pm 0.15\% \text{ (stat.)} \pm 0.13\% \text{ (syst.)}$
$A_{FB}^{b\bar{b}}$	$0.6823 \pm 0.15\% \text{ (stat.)} \pm 0.06\% \text{ (syst.)}$	$0.3487 \pm 0.75\% \text{ (stat.)} \pm 0.29\% \text{ (syst.)}$

### Stat unc (2000 fb<sup>-1</sup>)

#### Syst unc.:

- Selection and background rejection
- quark tagging/mistagging (modélisation, QCD, correlations)
- Luminosity
- Polarisation



## Couplings (notation for new resonances)

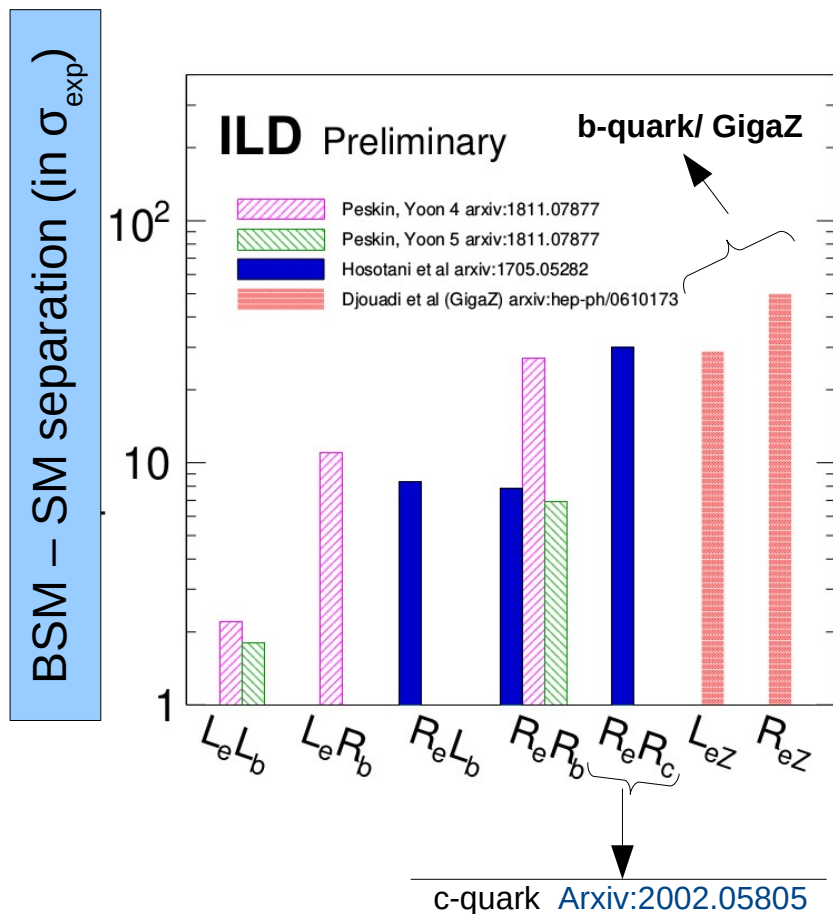
$$L_e L_b = Q_e Q_b + \frac{L_e Z L_b Z}{s^2 w c^2 w} BWZ + \sum_{Z'} \frac{L_e Z' L_b Z'}{s^2 w c^2 w} BWZ'$$

ILC250      SM      GigaZ      New resonances

Sensitive to Z-Z' mixing effects  
 (that could explain AFBb measurement of LEP?)

Prospects for couplings determination are order of magnitude better than at LEP

- ▶ Resolution of the LEP/SLC anomaly
- ▶ Full disentangling of helicity structure for all fermions only possible with polarised beams!!



► Many BSM predict deviations only for the right couplings

**BEAM POLARISATION is crucial**

Expected number of standard deviations for different **RS/compositeness BSM scenarios** when determining the different EW couplings to c- and b-quark at **ILC250** (with GigaZ input).

- Models that predict multi-TeV  $Z'$  resonances
- With or without mixing at Z-pole
- See backup for more details on the models

**Potential for discovery of new resonances  $m_{Z'} \sim \mathcal{O}(20)$  TeV at ILC250**

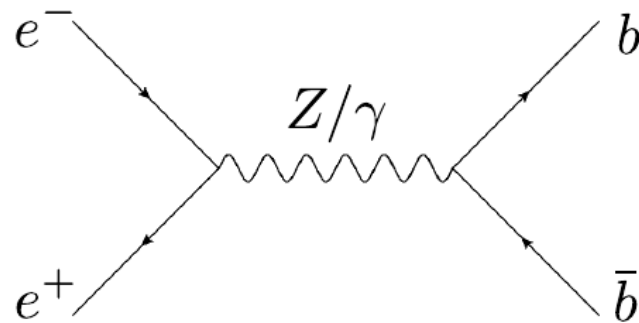
Arxiv:1709.04289, PoS(EPS-HEP2019)624

- ▶ ILC is ideally suited for precision measurements of two-fermion final states
- ▶ **ILC will have the answer whether new physics acts on heavy doublet (t,b) only or on all fermions**
  - Will/would probe helicity structure of electroweak fermion couplings over at least one order of magnitude in energy (Z-Pole  $\rightarrow$   $\sim 1$  TeV)
- ▶ **Achievable experimental precisions  $\sim 0.1 - 1\%$** 
  - Demanding analysis requiring the full detector capabilities: Vertex charge and hadron and photon ID etc
  - **Comprehensive assessment of the systematic uncertainties done (b-quark)** or in progress (top, charm, strange)
- ▶ **Effects may become already visible at 250 GeV stage for b quark and c quarks (and other light fermions)**
  - **Amplification of effects at higher energies** (studies at 500 GeV at preliminary stage)
  - **Clear and unique pattern thanks to polarised beams**



$$\sigma_{e^-e^+ \rightarrow q\bar{q}}$$

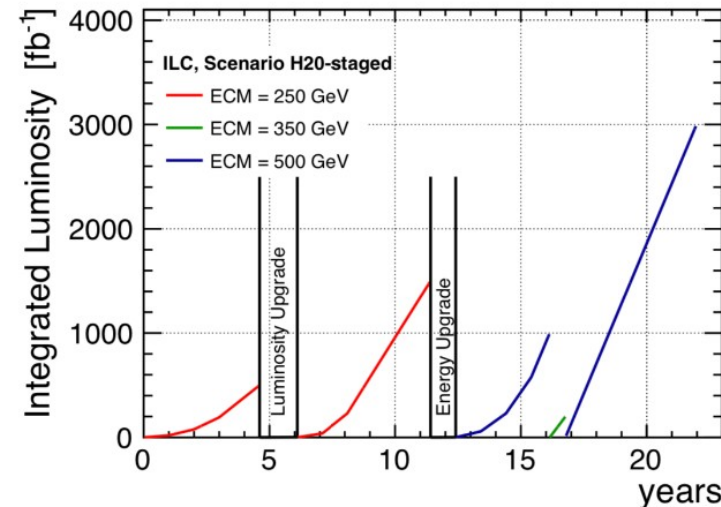
	Channel	$\sigma_{\text{unpol}}$ [fb]	$\sigma_{-,+}$ [fb]	$\sigma_{+,-}$ [fb]
500 GeV	q=t	572	1564	724
	q=b	372	1212	276
	q=u+d+s+c	2208	6032	2793
250 GeV	q=t	--	--	--
	q=b	1756	5677	1283
	q=c	3020	8518	3565
	q=u+d+s	6750	18407	5463



► Beam polarisation also enhances the cross section values

- ▶ All Standard Model particles within reach of planned ILC project
- ▶ High precision tests of Standard Model over wide range to detect onset of New Physics
- ▶ Machine settings can be “tailored” for specific processes
  - Centre-of-Mass energy
  - Beams polarisation (straightforward at linear colliders)
- ▶ Background free searches for BSM through beam polarisation

current ILC run plan: (basis of projections)



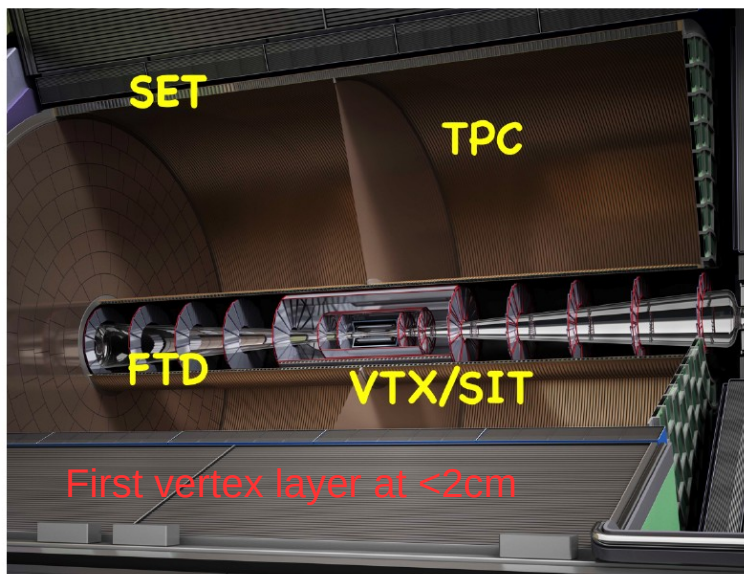
250 GeV: 2 ab<sup>-1</sup>, 500 GeV: 4ab<sup>-1</sup>, 350 GeV: 0.2 ab<sup>-1</sup>

also, runs at 91 GeV (5B Z's) and 1000 GeV (8 ab<sup>-1</sup>)

L upgrade: 5 Hz → 10 Hz; E upgrade: extend the linac

*M. Peskin Snowmass (EF Workshop 21<sup>st</sup> July 2020)*

► **ILD snapshot**

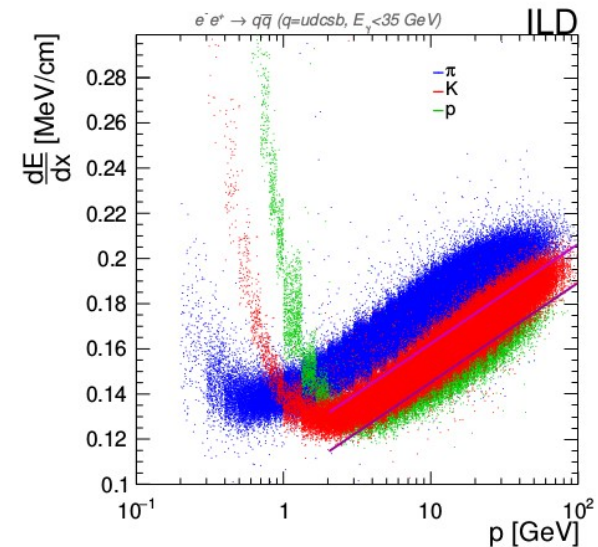
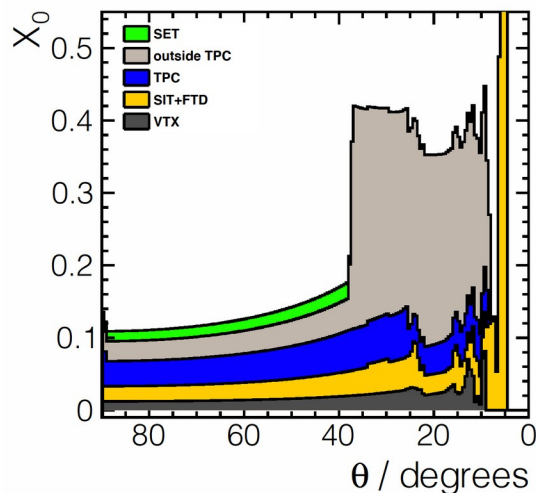


► **High angular coverage with minimum material budget and PID (TPC)**

► ILC experiments, as the **ILD**, will provide excellent:

- Beam IP constraint
- **Secondary vertex separation and excellent flavour tagging**
- Tracking **efficiency (>99%)**

► **Particle Flow optimized detector with high granularity calorimeters (>10<sup>8</sup> cells!)**



Polarization	$\sigma_{e^-e^+ \rightarrow q\bar{q}}(E_\gamma < 35 \text{ GeV})[\text{fb}]$			$\sigma_{e^-e^+ \rightarrow q\bar{q}}(E_\gamma > 35 \text{ GeV})[\text{fb}]$		
	$b\bar{b}$	$c\bar{c}$	$q\bar{q} (q = uds)$	$b\bar{b}$	$c\bar{c}$	$q\bar{q} (q = uds)$
$e_L^-e_R^+$	5677.2	8518.1	18407.3	20531.4	18363.8	57651.3
$e_R^-e_L^+$	1283.2	3565.0	5643.5	12790.8	11810.8	36179.5

Channel	$\sigma_{e_L^-e_R^+ \rightarrow X} [\text{fb}]$	$\sigma_{e_R^-e_L^+ \rightarrow X} [\text{fb}]$
$X = WW \rightarrow q_1\bar{q}_2q_3\bar{q}_4$	14874.4	136.4
$X = ZZ \rightarrow q_1\bar{q}_1q_2\bar{q}_2$	1402.1	605.0
$X = HZ \rightarrow q_1\bar{q}_1q_2\bar{q}_2$	346.0	222.0

# Double Tag Method

- ▶ **Method used to remove modeling dependence on the efficiency of b-tagging** → aiming to the per mil precision
- ▶ The sample consisted on events made of two hadronic jets (qqbar)
  - The LEP/SLC preselection consisted on a “simple” veto of  $Z \rightarrow$  leptons events
- ▶ The method is based on the comparison of single vs double tagged samples
  - $f_1$ = ratio of number jets that are tagged as b-jets
  - $f_2$ = ratio of events in which both jets are tagged as b-jets

$$f_1 = \epsilon_b R_b + \epsilon_c R_c + \epsilon_{uds} R_{uds}$$

$$f_2 = \epsilon_b^2 (1 + \rho_b) R_b + \epsilon_c^2 R_c + \epsilon_{uds}^2 R_{uds}$$

- $R_b$  and  $\epsilon_b$  are measured simultaneously.

- $\epsilon_b$  = b-tagging efficiency
- $\rho_b$  = b-tagging correlation factor
- $\epsilon_c$  = probability of tagging a c-quark jet as b-jet
- $\epsilon_{uds}$  = probability of tagging an uds-quark jet as b-jet

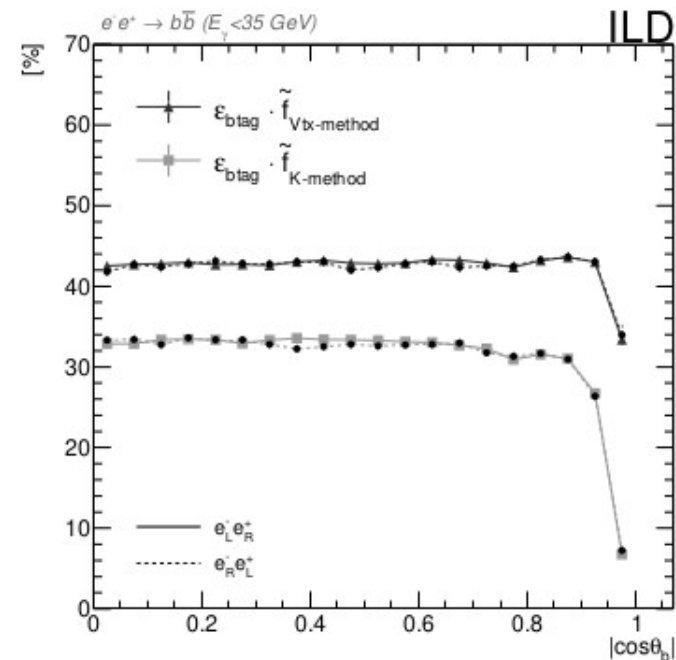
These values must be as small as possible and with small uncertainties  
to not spoil our accuracy (not covered in this talk)

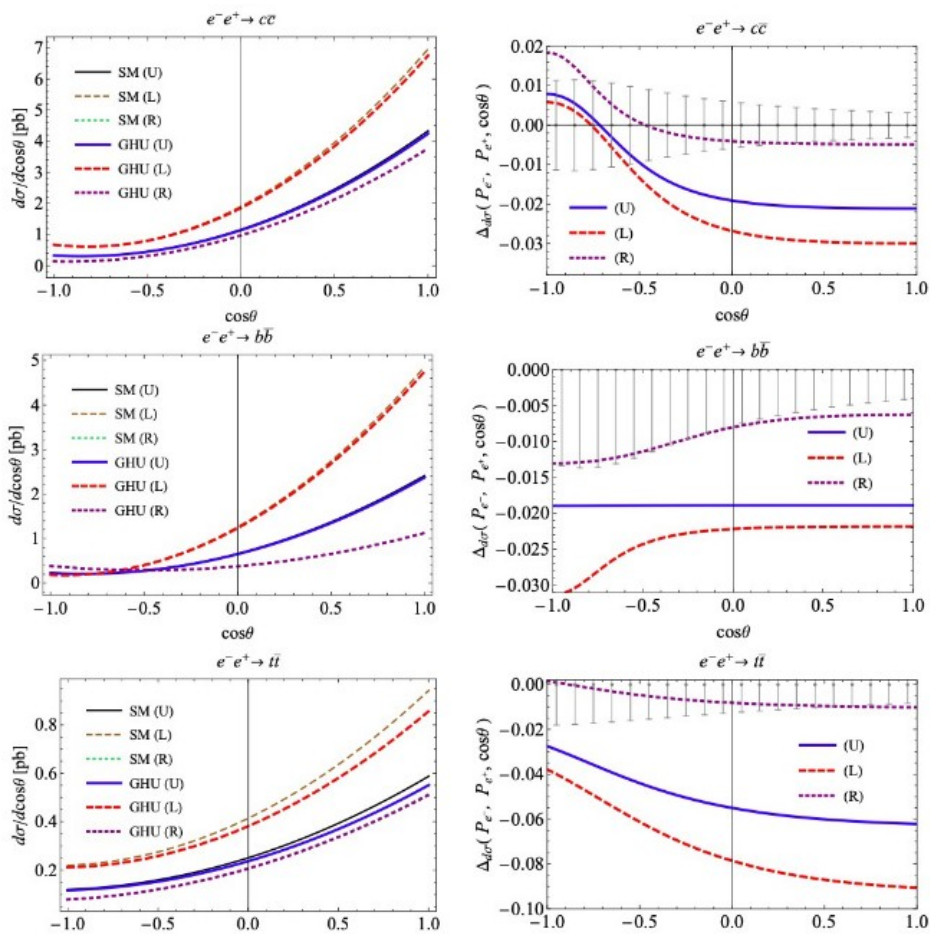
Efficiency of selection for $e_L^- e_R^+ \rightarrow X$ [%]							
	$X = q\bar{q} (E_\gamma < 35 \text{ GeV})$			$X = q\bar{q} (E_\gamma > 35 \text{ GeV})$			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q} (uds)$	$q\bar{q} (uds cb)$	$X = ZZ$	$X = WW$	$X = HZ$
No cuts	100%	100%	100%	100%	100%	100%	100
+ Cut 1	84.5%	84.9%	86.4%	6.7%	12.3%	11.7%	12.6
+ Cut 2	82.8%	82.0%	80.3%	1.2%	12.1%	11.1%	11.8
+ Cut 3	72.1%	71.7%	71.3%	0.7%	2.5%	5.0%	4.5
+ Cut 4	71.5%	71.1%	70.7%	0.7%	1.6%	3.6%	3.8

Efficiency of selection for $e_R^- e_L^+ \rightarrow X$ [%]							
	$X = q\bar{q} (E_\gamma < 35 \text{ GeV})$			$X = q\bar{q} (E_\gamma > 35 \text{ GeV})$			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q} (uds)$	$q\bar{q} (uds cb)$	$X = ZZ$	$X = WW$	$X = HZ$
No cuts	100%	100%	100%	100%	100%	100%	100
+ Cut 1	84.1%	85.2%	86.5%	7.0%	12.5%	12.6%	12.4
+ Cut 2	82.6%	82.2%	81.1%	0.7%	12.3%	11.8%	11.8
+ Cut 3	71.6%	72.3%	72.2%	0.4%	2.5%	5.6%	1.8
+ Cut 4	71.1%	71.6%	71.6%	0.4%	1.7%	4.3%	1.6

Table 3: Cut flow for the signal and background events.





arxiv:2006.02157

- Model parameter is Hosotani angle  $\theta_H$  yielding the Higgs-Potential as consequence of Aharanov-Bohm Phase in 5<sup>th</sup> dimension
- Model defined in Randall-Sundrum warped extra dimensions
  - KK excitations of gauge bosons and new bosons modify fermion couplings
- Predictions for ILC
  - $m_{KK} = 13$  TeV and  $\theta_H = 0.1$
- Deviations from SM of the order of a few %
  - Effects measurable already at 250 GeV
  - Effects amplified by beam polarisations
  - Effects for tt, bb and cc (and other light fermions)
- One concrete example for importance to measure full pattern of fermion couplings
- Full pattern only available with beam polarisation



## Polarisation & Electroweak Physics at high energies

- similarly, disentangle Z /  $\gamma$  exchange in  $e^+e^- \rightarrow f\bar{f}$

$g_{Lf}, g_{Rf}$  : helicity-dependent couplings of Z to fermions

$$\Rightarrow A_f = \frac{g_{Lf}^2 - g_{Rf}^2}{g_{Lf}^2 + g_{Rf}^2}$$

specifically for the electron:  $A_e = \frac{(\frac{1}{2} - \sin^2 \theta_{eff})^2 - (\sin^2 \theta_{eff})^2}{(\frac{1}{2} - \sin^2 \theta_{eff})^2 + (\sin^2 \theta_{eff})^2} \approx 8(\frac{1}{4} - \sin^2 \theta_{eff})$

at an **unpolarised** collider:

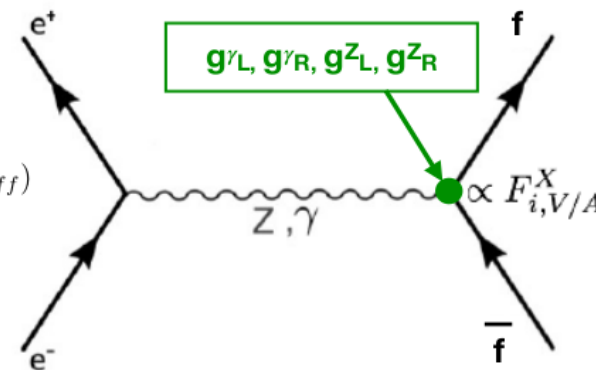
$$A_{FB}^f \equiv \frac{(\sigma_F - \sigma_B)}{(\sigma_F + \sigma_B)} = \frac{3}{4} A_e A_f \quad \Rightarrow \text{no direct access to } A_e, \text{ only via tau polarisation}$$

While at a **polarised** collider:

$$A_e = A_{LR} \equiv \frac{\sigma_L - \sigma_R}{(\sigma_L + \sigma_R)} \quad \text{and} \quad A_{FB,LR}^f \equiv \frac{(\sigma_F - \sigma_B)_L - (\sigma_F - \sigma_B)_R}{(\sigma_F + \sigma_B)_L + (\sigma_F + \sigma_B)_R} = \frac{3}{4} A_f$$

trading theory uncertainty:

the **polarised**  $A_{FB,LR}^f$  receives 7 x smaller radiative corrections than the **unpolarised**  $A_{FB}^f$  !



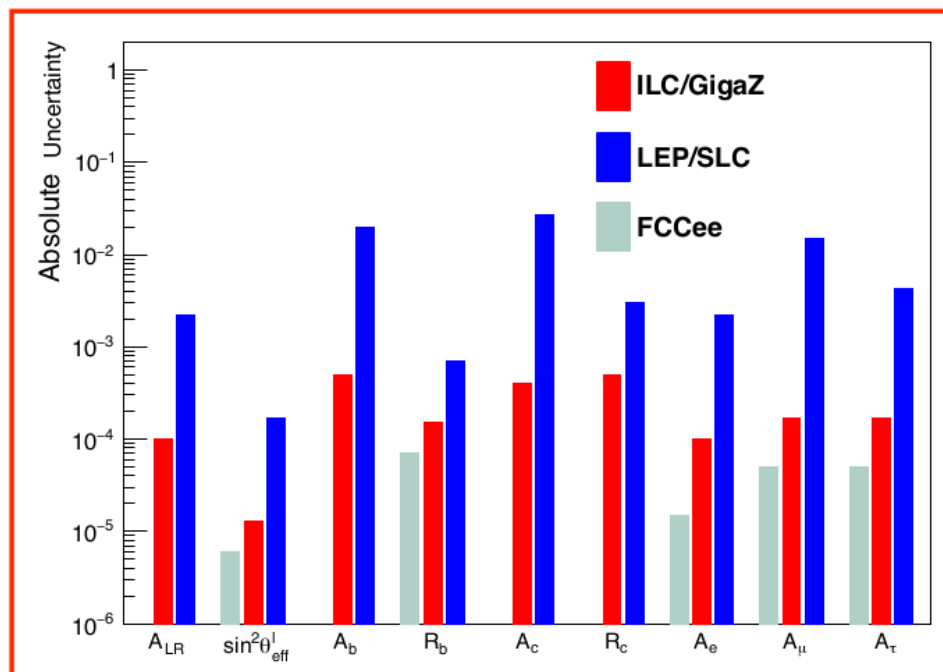


## Polarisation & Electroweak Physics at the Z pole

new detailed studies by **ILD**:

- at least factor 10, often ~50 improvement over **LEP/SLC**
- note in particular:
  - **$A_c$  nearly 100 x better** thanks to excellent charm / anti-charm tagging:
    - excellent vertex detector
    - tiny ILC beam spot
    - Kaon-ID via  $dE/dx$  in ILD's TPC

**typically only factor 2-3 less precise than FCCee's unpolarised TeraZ**  
 => polarisation buys  
 a factor of ~100 in luminosity



arXiv:1908.11299, talks by A.Irles & G, Wilson

7

## Detector Technologies

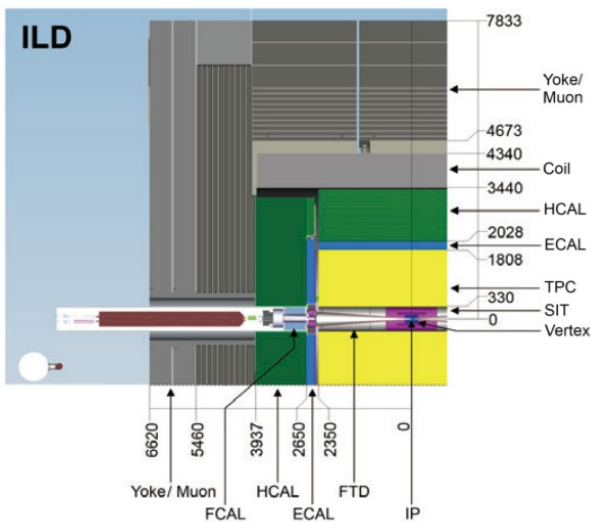
Vertex: CMOS, DEPFET, FPCCD, ...

Tracker:  
TPC (GEM, micromegas, pixel)  
+ silicon pixels/strips

ECAL:  
Silicon (5x5mm<sup>2</sup>) or  
Scintillator (5x45mm<sup>2</sup>)  
with Tungsten absorber

HCAL:  
Scintillator tile (3x3 cm<sup>2</sup>)  
or Gas RPC (1x1 cm<sup>2</sup>)  
with Steel absorber

All inside solenoidal coil of 3-4 T



## ILD Design Goals

Features of ILC:

low backgrounds, low radiation, low collision rate (5-10 Hz)

These allow us to pursue aggressive detector design:

### Detector Requirements

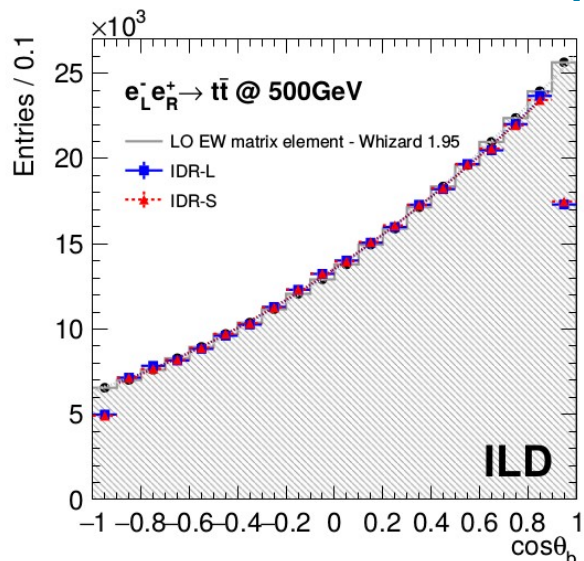
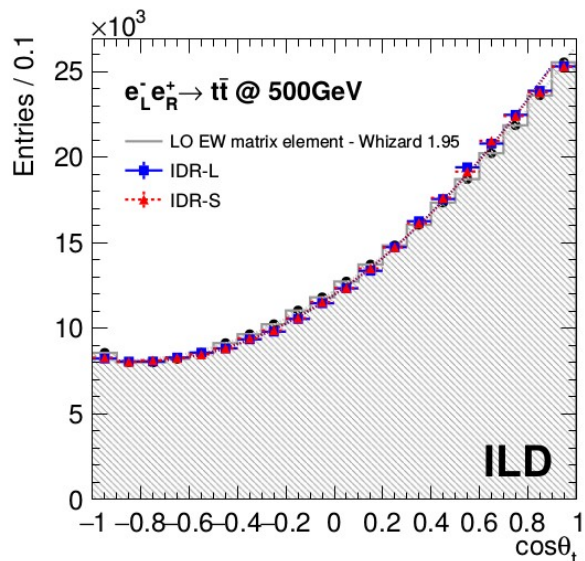
### Physics

- Impact parameter resolution  
 $\sigma(d_0) < 5 \oplus 10 / (p[\text{GeV}] \sin^{3/2}\theta) \mu\text{m}$   
H → bb, cc, gg, ττ
- Transverse momentum resolution  
 $\sigma(1/p_T) = 2 \times 10^{-5} \text{ GeV}^{-1} \oplus 1 \times 10^{-3} / (p_T \sin^{1/2}\theta)$   
Total e+e- → ZH cross section
- Jet energy resolution  
3-4% (around E<sub>jet</sub> ~ 100 GeV)  
H → invisible
- Hermeticity  
 $\theta_{\text{min}} = 5 \text{ mrad}$   
H → invisible; BSM

R. Ete: "The ILD Software Tools and Detector Performance"

Detector R&D collaborations:



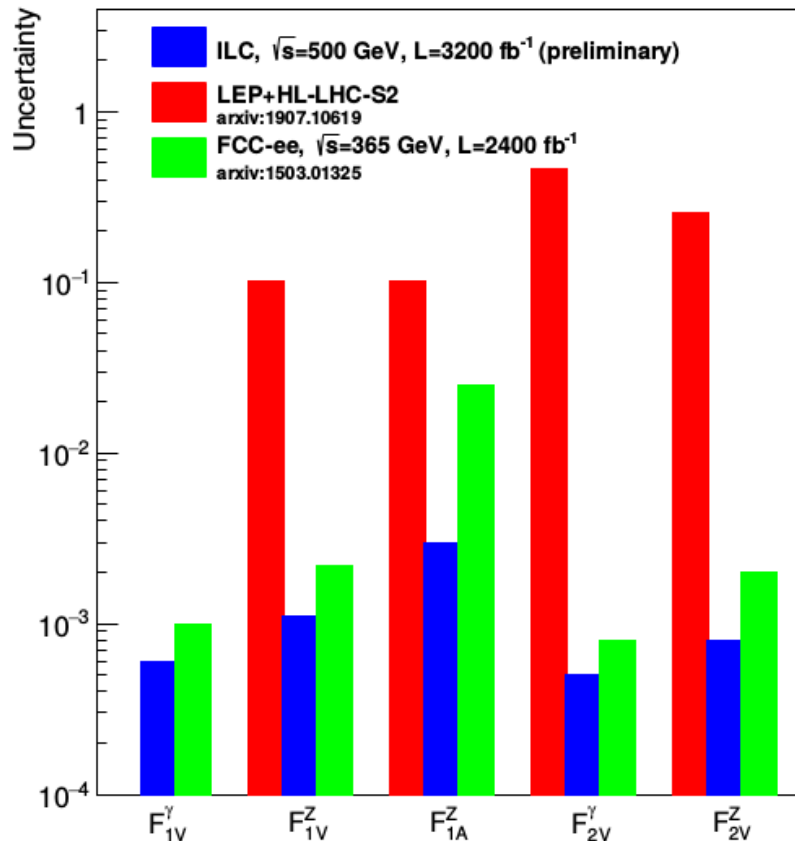


- ▶ Semi-leptonic channel
- ▶ Left polarisation plots
  - B-jet carries top direction information
  - Very useful for the hadronic channel!
- ▶ Right polarisation (not shown)
  - W-carries the top direction information → **lepton charge and c/s tagging become important**

- ▶ Integrated Luminosity  $4 \text{ fb}^{-1}$
- ▶ Thanks to the jet charge calculations capabilities, we could use all decay channels.
- ▶ Efficiencies of 75% (cross section) and 30% (differential cross section)
- ▶ Exact reproduction of generated spectra
  - Statistical precision on cross section:  $\sim 0.1\%$     Statistical precision on A FB :  $\sim 0.5\%$

Can expect that systematic errors will match statistical precision (but needs to be shown)

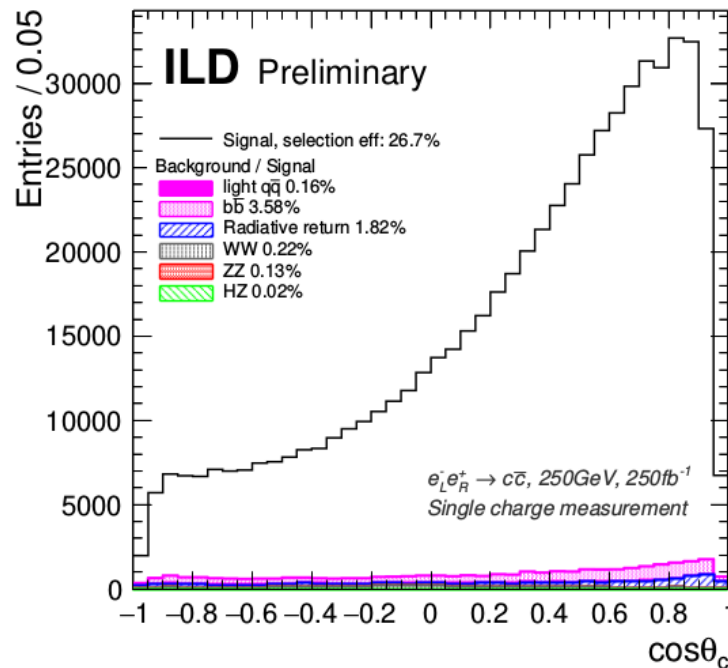
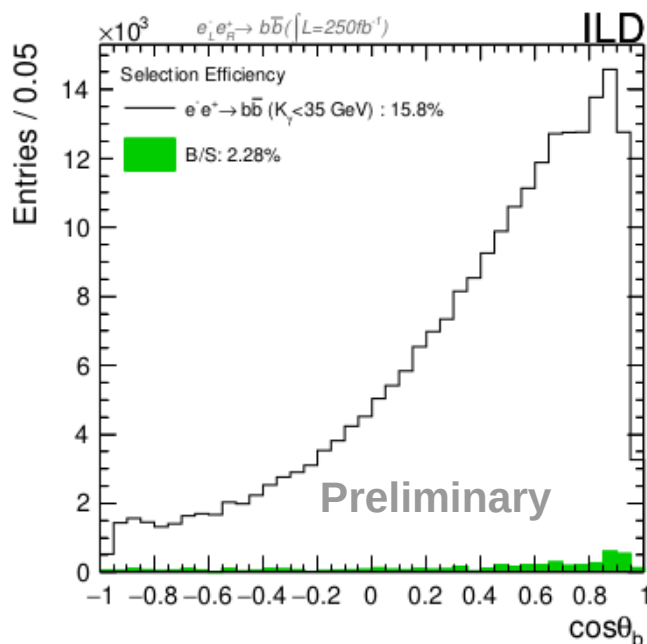
IDR-L/S  
Are two detector  
Concepts compared  
In the ILD  
Interim Design Report ILD  
Arxiv:2003.01116



- ▶ e+e- collider way superior to LHC ( $\sqrt{s} = 14$  TeV)
- ▶ Final state analysis at FCCee (polarisation)
  - Also possible at LC => Redundancy
- ▶ Two remarks:
  - 500 GeV is nicely away from QCD Matching regime
  - Less systematic uncertainties
  - The determination of axial form factors highly benefit from higher energies
- ▶ See M. Perelló's talk to interpret this plot in terms of EFT Wilson coefficients.

► After the preselection, we apply the b/c tagging including charge measurement for differential cross sections.

- Efficiencies for inclusive cross section are  $\sim x2$  larger



► Background  $\sim$ free analysis!

Arxiv:2002.05805

- ▶ Alternatives to  $m(2\text{jets})$  ?
- ▶ Estimator of the energy of the photon ISR using only the two reconstructed jets.
  - From momentum conservation (if the photon/s are emitted parallel to the beam pipe):

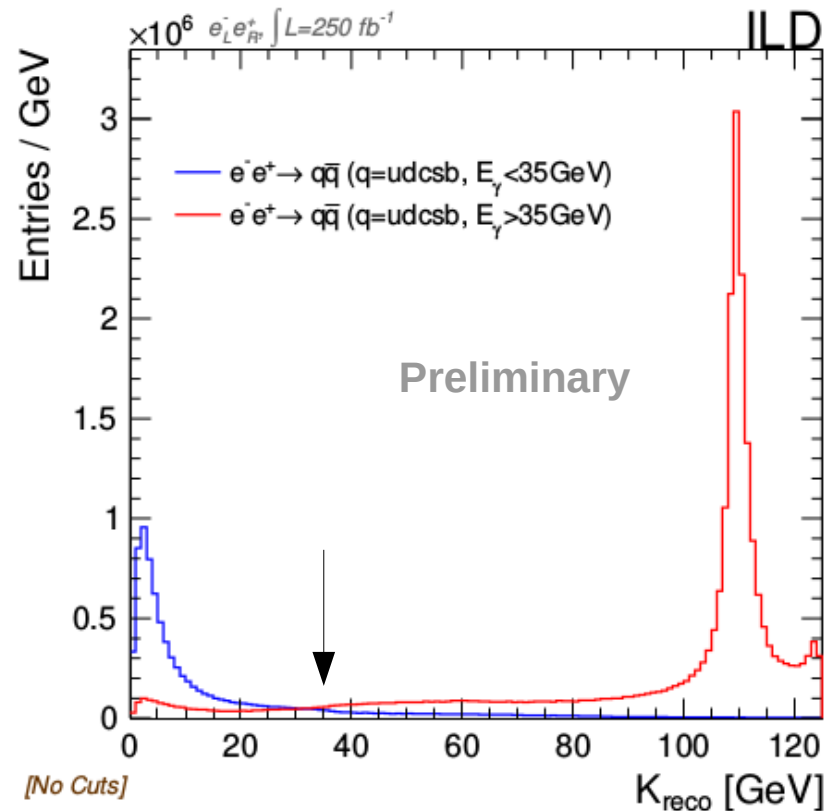
$$|\vec{k}| \approx K_{reco} = \frac{250 \text{ GeV}}{\sin \Psi_{acol} + \sin \theta_1 + \sin \theta_2}$$

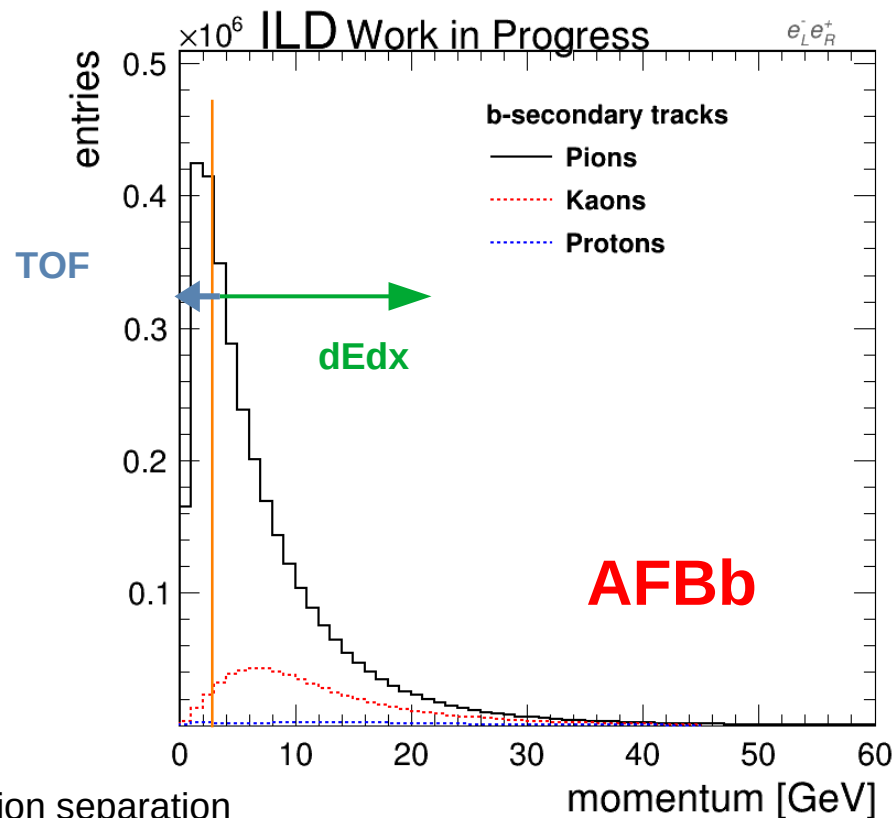
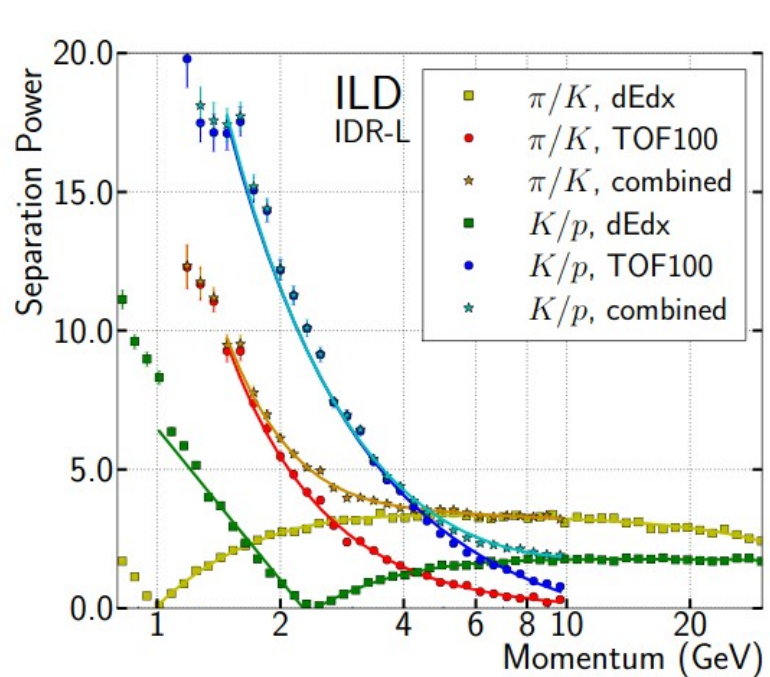
Two jet acolinearity

$$\sin \Psi_{acol} = \frac{|\vec{p}_{j_1} \times \vec{p}_{j_2}|}{|\vec{p}_{j_1}| \cdot |\vec{p}_{j_2}|}$$

Jet angular variables (w.r.t. detector frame)

- ▶ Estimator of the energy of the photon ISR
- ▶ We apply a cut of  $K_{reco} < 35$  GeV
  
- ▶ Some signal events have larger  $K_{reco}$  (~15%)
  - Because of detector resolution and double photon ISR
  
- ▶ Some radiative return events have  $K_{reco} < 35$  GeV (~7%)
  - Because the photon(s) has not escaped through the beam pipe
  - we identify the photon clustered in one or both jets and veto these events

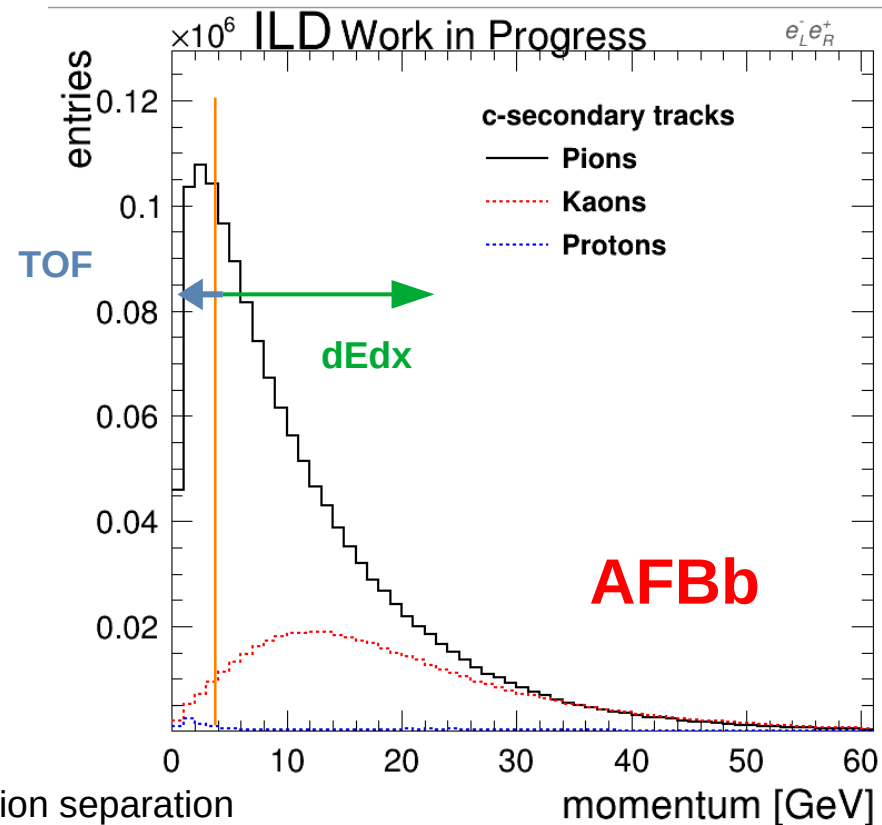
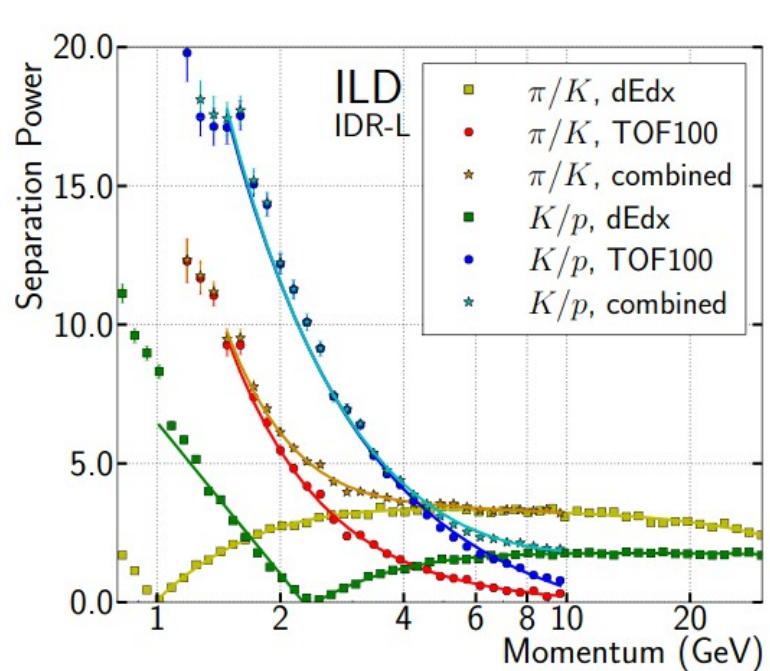




► For  $bb/cc/ss$  analysis we are interested in a high power of K/pion separation

► Possible solutions: using dEdx and/or TOF

- Yellow points



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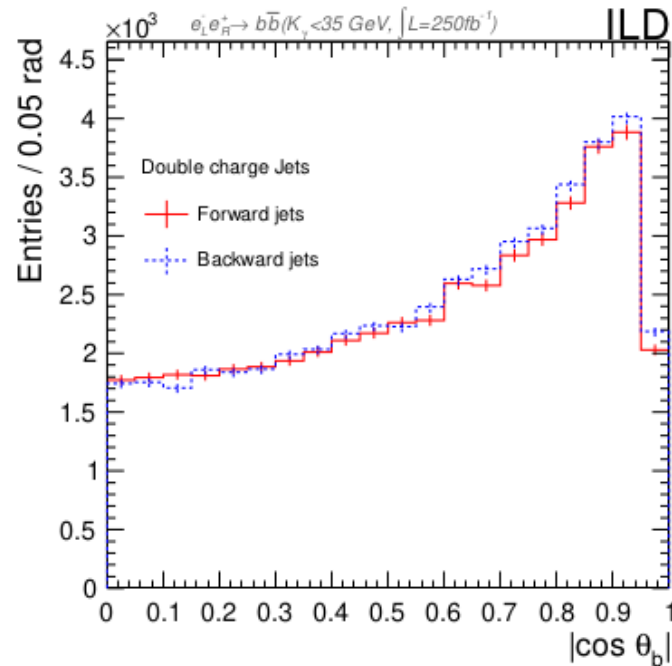


Figure 17: Reconstructed  $\cos \theta_b$  spectrum of the doubly charged jets, ++ and --, jets (using the  $Vtx$ -method method) reconstructed in the forward or backward region of the detector.