Quark Pair Production at Lepton Colliders: Experimental challenges

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The XXVIII International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY 2021)

Outline of the talk

▶ **What?** top**/b/c-quark differential cross section** measurements (sensitive to EW couplings)

- Experimental prospects based on **full simulation** including a comprehensive study of the systematic uncertainties

- **Emphasis on the b-quark experimental case**

▶ Where? International Linear Collider, **ILC@250GeV,** and the International Large Detector **ILD**

- **Full simulation studies**

This talk (250 GeV)

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- **Full simulation studies**

This talk (250 GeV)

**Studies done in collaboration with
F. Richard, R. Poeschl et al (IJCLab Orsay)**

Motivation

ILC physics program

▶ **All Standard Model particles within reach of planned linear colliders**

▶ **Machine settings can be "tailored" for specific processes**
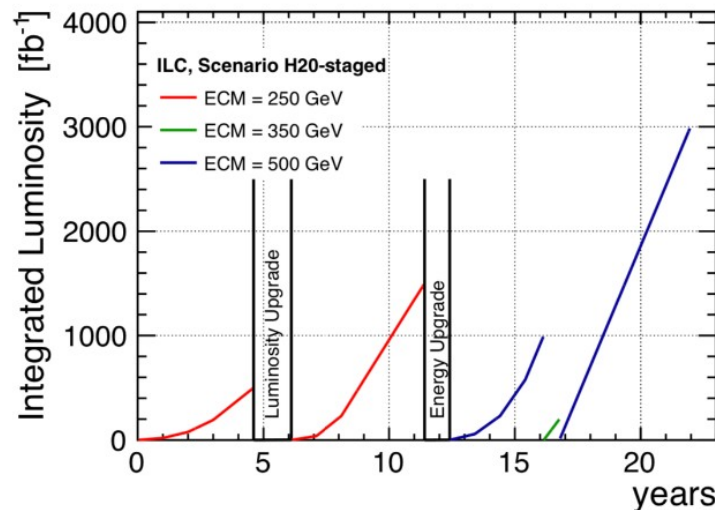
- **Centre-of-Mass energy**

- **Beams polarisation** (straightforward at linear colliders)

▶ Background free searches for BSM through beam polarisation

▶ **First phase at 250GeV**

- A Higgs Factory **and much more!**
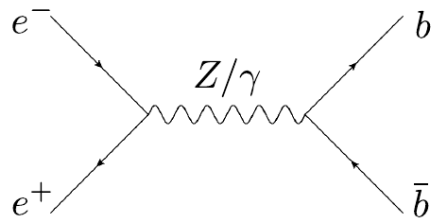
current ILC run plan: (basis of projections)

250 GeV: 2 ab-1, 500 GeV: 4ab-1, 350 GeV: 0.2 ab-1

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

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

Two fermion processes

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

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

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

e^- $\quad$ b

Z/γ

e^+ $\quad$ $\bar{b}$

- The helicity amplitudes Σ_{IJ}, contain the couplings g_L/g_R (or Form factors or EFT factors)
- Left≠right (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**

- Very comprehensive physics program at Z-Pole

- no access to the γ or Z/γ interference's ("cleaner" access to Z-couplings)

- Moderated quark tagging and/or charge measurements capabilities (or moderated statistics)

- Also moderated angular acceptance of the detectors

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

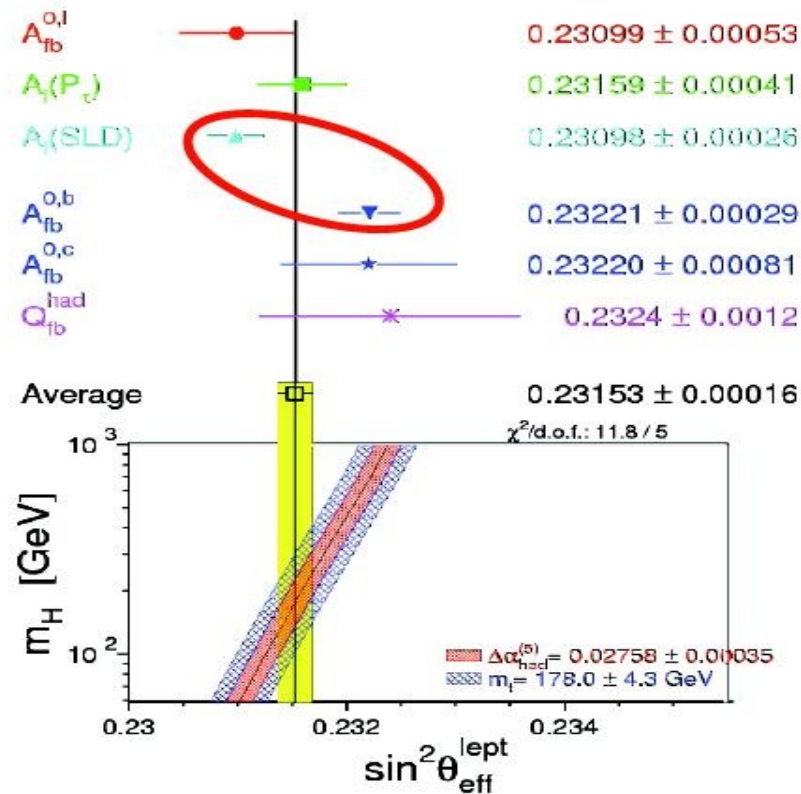▶ Current LEP & SLC best $sin^2\theta^l_{eff}$ **measurements** show **tension**

- This measurement is the one with **largest tension with the SM fit.**

- Most precise single Individual determination of $sin^2\theta^l_{eff}$

  from SLC → Left-right asymmetry of leptons

- Most precise single Individual determination of $sin^2\theta^l_{eff}$

  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 precission an order of magnitude
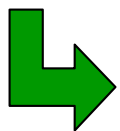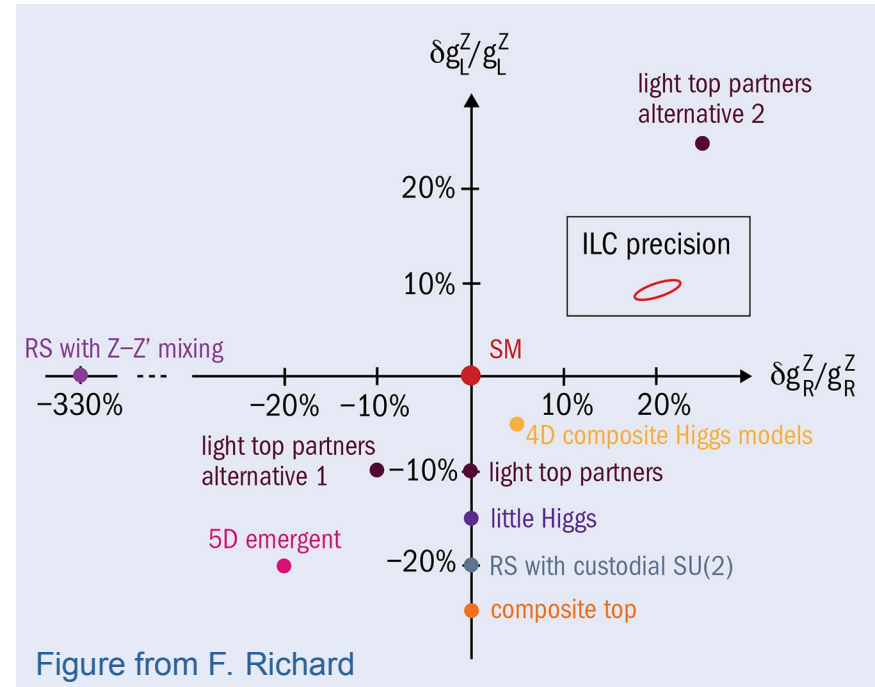
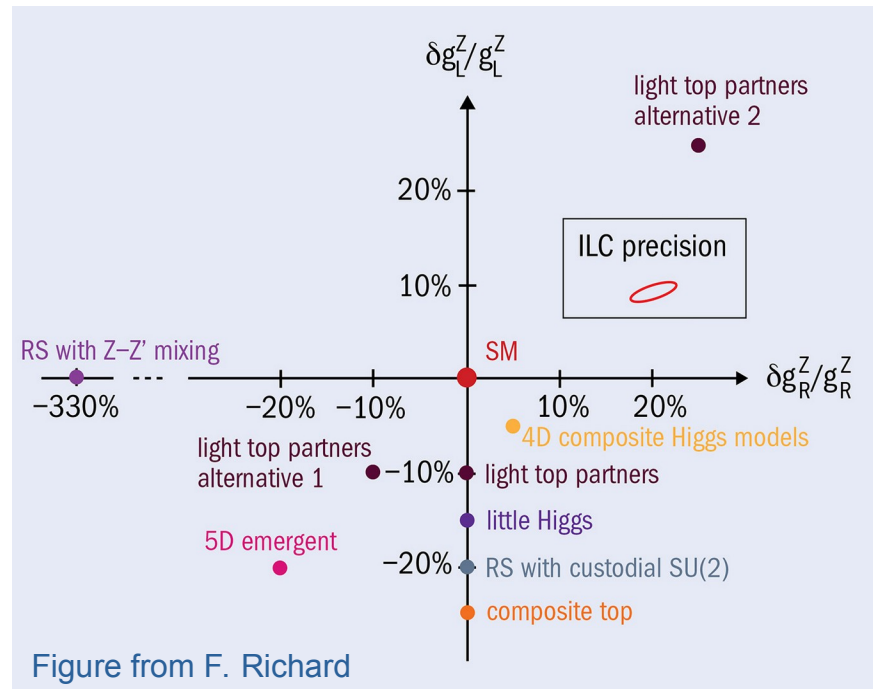Per mil level of experimental precision is required

Motivation: BSM Z' resonances

▶ 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


Figure from F. Richard

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Check Naoki Yamatsu's talk for a detailed discussion
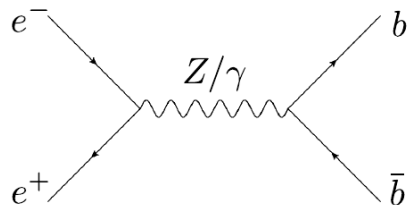

Figure from F. Richard

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Figure from F. Richard
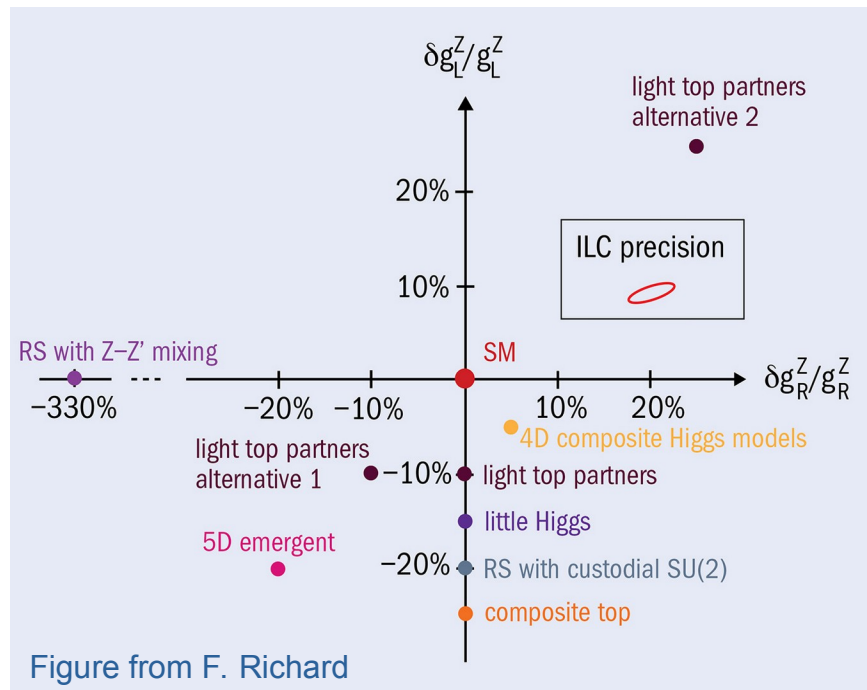
Probe such scenarios require at least per mil level for experimental precision
tt/**bb**/cc... (ss?) **Can we do it?**
(this talk)

Observables

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

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

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

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

e^- Z/γ b

e^+ $\bar{b}$

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

Angular Distribution.

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

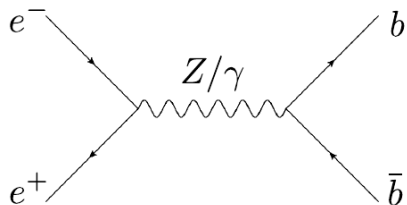Quark ID + charge measurement (quark – antiquark disentangling)

Gives access to all left/right couplings.

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Angular Distribution.

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Quark ID + charge measurement (quark – antiquark disentangling)

Gives access to all left/right couplings.

Normalized quantities are highly preferred:
to control (remove) **systematic uncertainties**

Experimental setup

(few) Experimental challenges

▶ **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 ac curacies
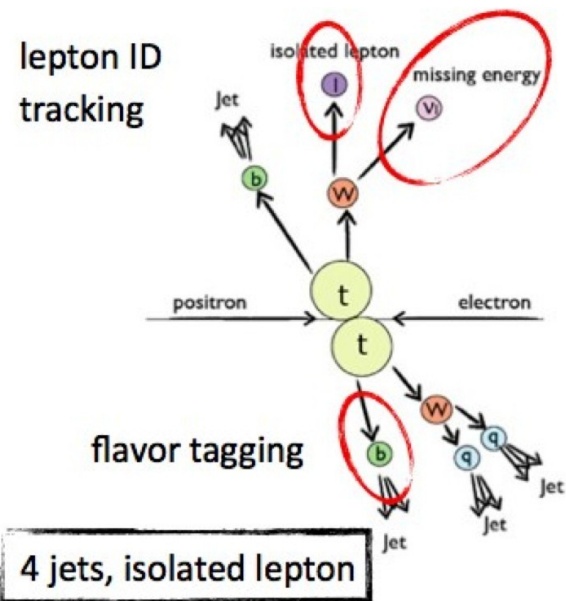
▶ **s-quark pairs (in progress)**

▶ **B-quark pairs**

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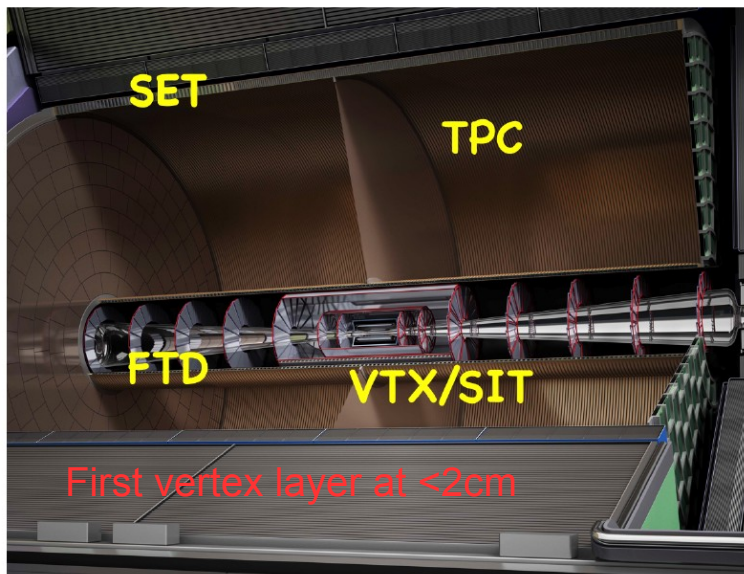
▶ **Charge Measurement**

- **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

▶ **top-quark pairs... decay before hadronizing**

lepton ID tracking

isolated lepton

missing energy

Jet

flavor tagging

positron   electron

4 jets, isolated lepton

ILD highlights

▶ **ILD snapshot**

First vertex layer at <2cm

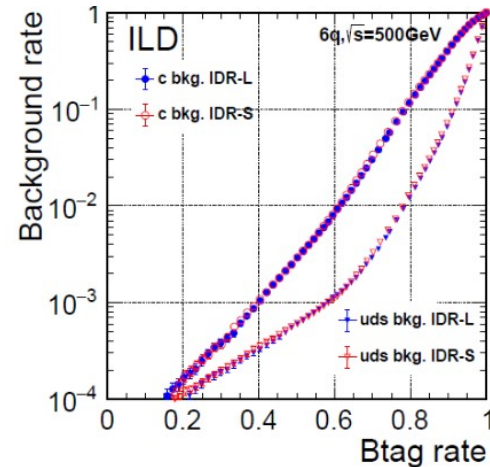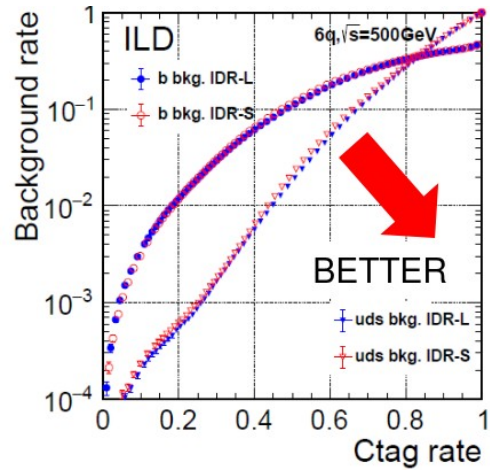▶ **High** angular **coverage** with **minimum material budge**t and **PID (TPC)**

▶ **Linear Colliders offer tiny beam spots**

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

- Beam IP constraint

- **Tracking efficiency (>99%)**

- **Secondary vertex separation and excellent flavour tagging**

▶ **Particle Flow optimized detector with high granularity calorimeters (>10^8 cells!)**
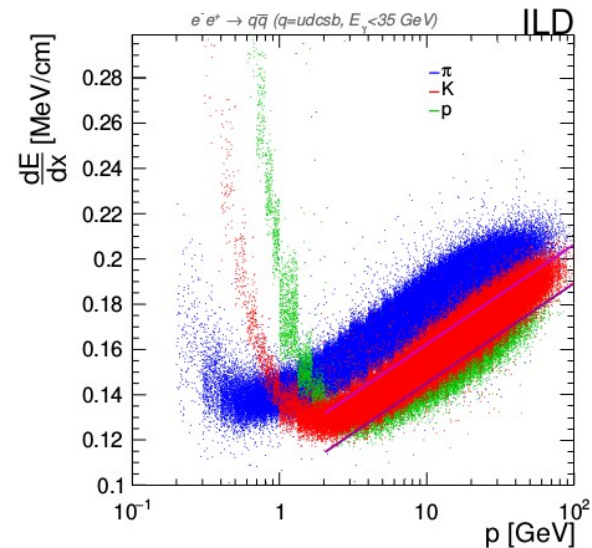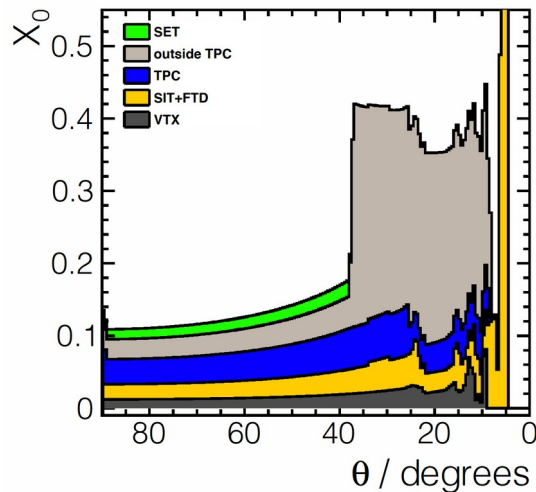
Flavour tagging

▶ **Dedicated tools for vertexing and flavour tagging: LCFIPlus (for lepton colliders)**

- A high-purity secondary vertex finder based on build-up vertex clustering,

- a jet clustering algorithm using vertex information

- and multivariate jet flavor tagging for the separation of b and c jet
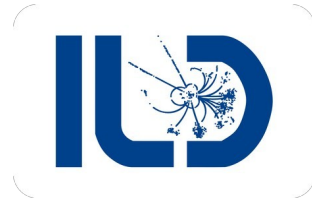
Design goals

- Impact parameter resolution
  $$\sigma(d_0) < 5 \oplus 10 / (p[GeV] \sin^{3/2}\theta) \, \mu m$$

- Transverse momentum resolution
  $$\sigma(1/p_T) = 2 \times 10^{-5} \, GeV^{-1} \oplus 1 \times 10^{-3} / (p_T \sin^{1/2}\theta)$$

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

Flavor tagging and charge measurement

▶ **Flavor tagging**

- Indispensable for analysis with any final state quarks

▶ **Quark charge measurements**

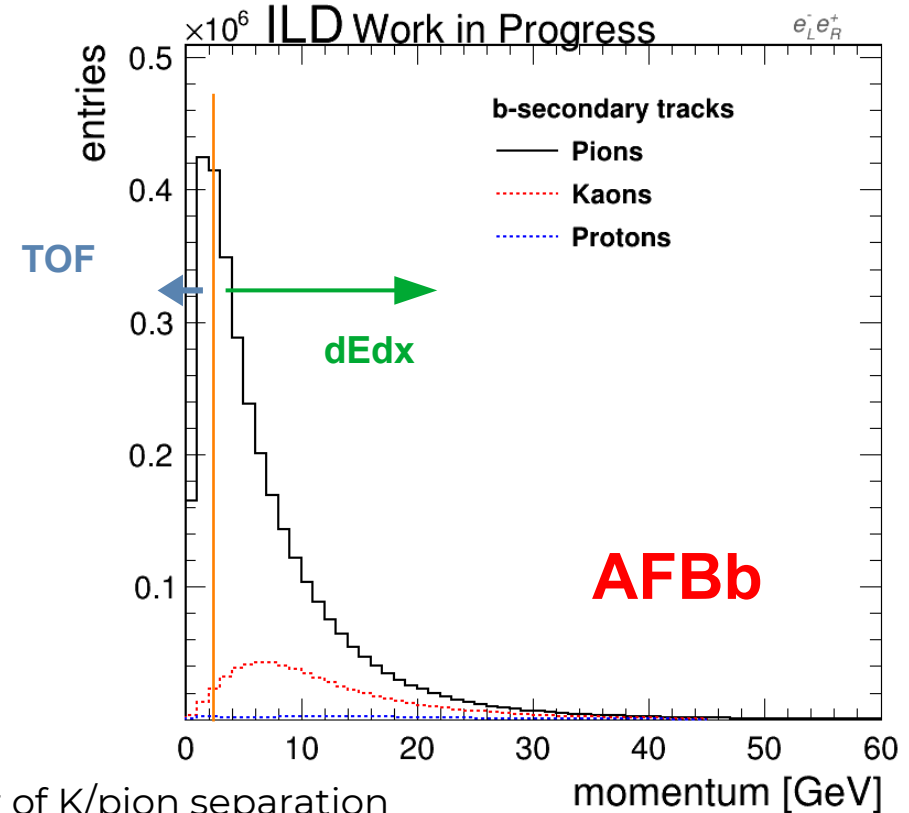- Important for top-quark studies but Indispensable for ee→ bb/cc/ss...

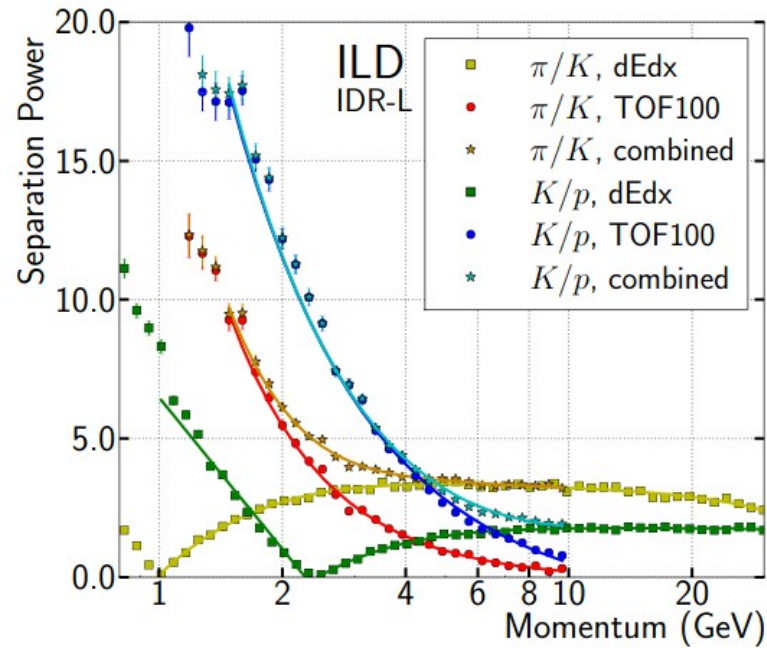▶ **Charge measurements:**

- Vtx charge and **Kaon Identification**

- High efficiency **(double tagging)**

- High purity → 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
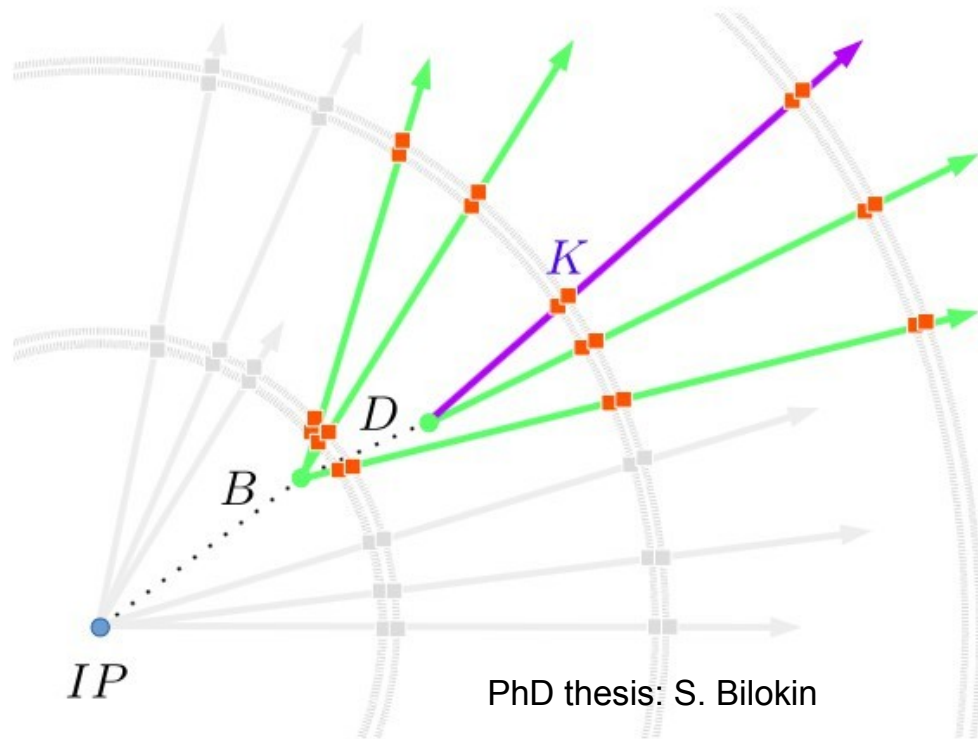
PhD thesis: S. Bilokin

▶ 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

PID via dEdx is considered in the following

The analysis

Analysis chain: preselection

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

▶ Main bkg ee→ Zγ(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 r**emaining ~10% are filtered by identifying photons** in the detector (efficiency of >90%)
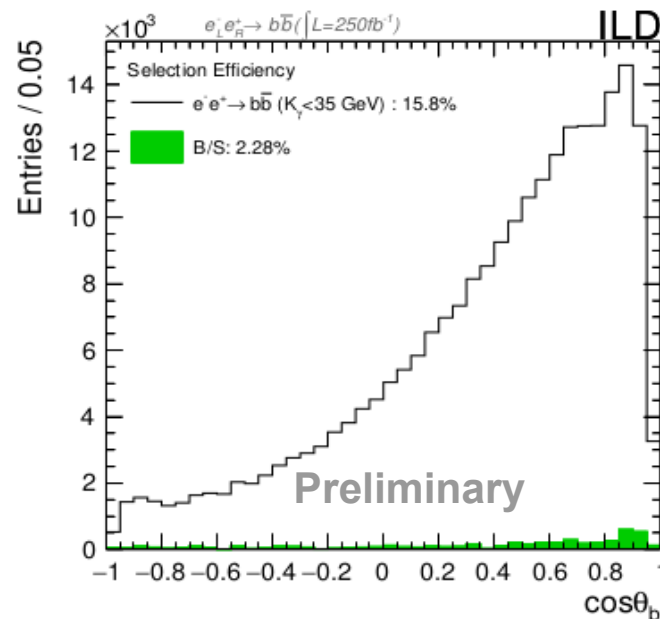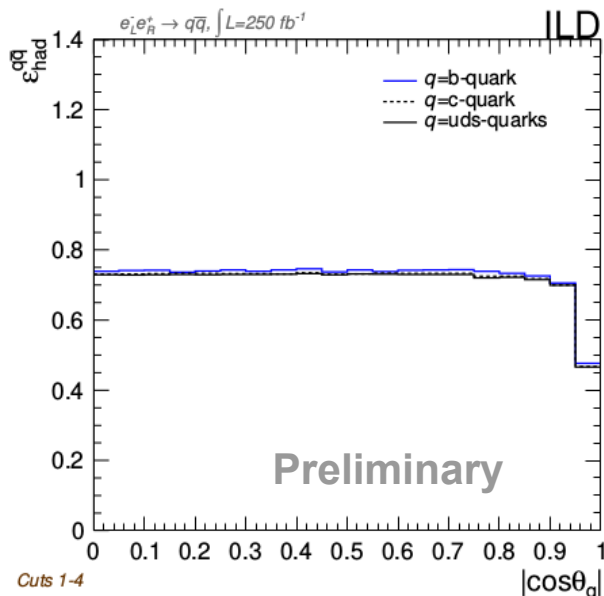
Arxiv:1709.04289, PoS(EPS-HEP2019)624

Analysis chain: Double Tag Method

▶ **The method is based on the comparison of** single vs double tagged samples

▶ **It is required to minimize the** modeling dependence on the efficiency of b-tagging → aiming to the per mil precision
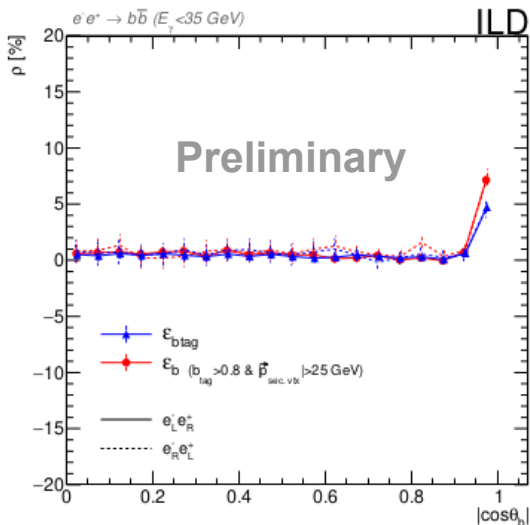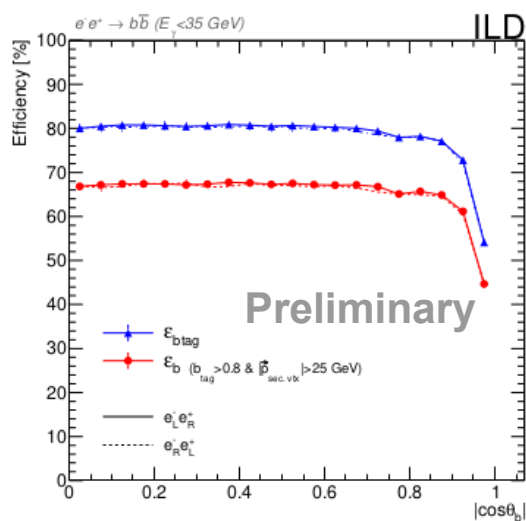

▶ **Excellent prospects for b-tagging** (or c-tagging) with very low correlation factor ~ 0% (~2% at LEP)

▶ **Differential measurements!**

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

▶ **Miss-efficiencies very small**

- <1% for c-quark
- ~0% for uds

Arxiv:1709.04289, PoS(EPS-HEP2019)624

Analysis chain: jet charge

▶ 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?
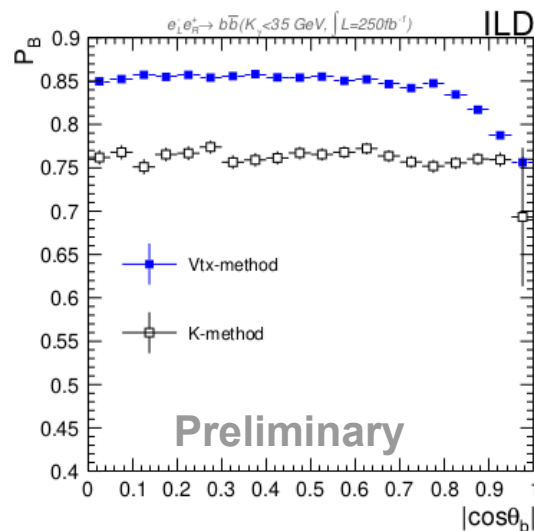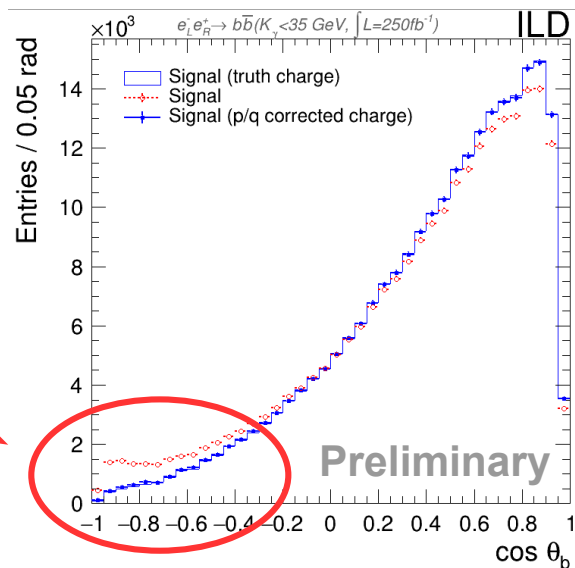
▶ P_B limited by vertex reconstruction efficiency, Particle ID efficiency and B0 oscillations.

Arxiv:1709.04289, PoS(EPS-HEP2019)624

Results
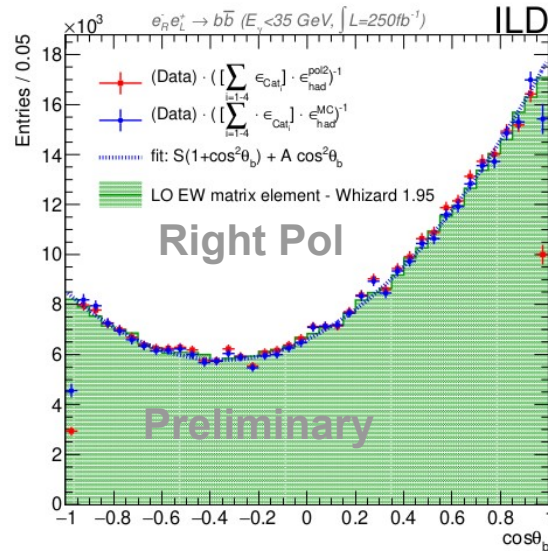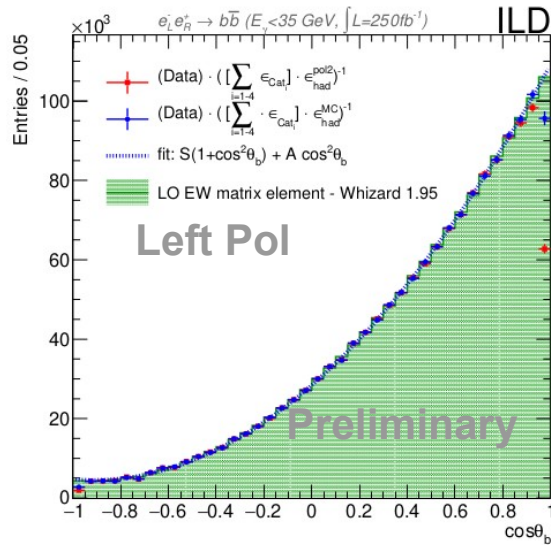
Excellent agreement between predicted and reconstructed distributions

▶ Gap between red dots and green histogram = acceptance drop.

▶ Blue dots = corrected acceptance

▶ The fit is restricted to |costheta|<0.8

- *Minimal impact of the corrections*

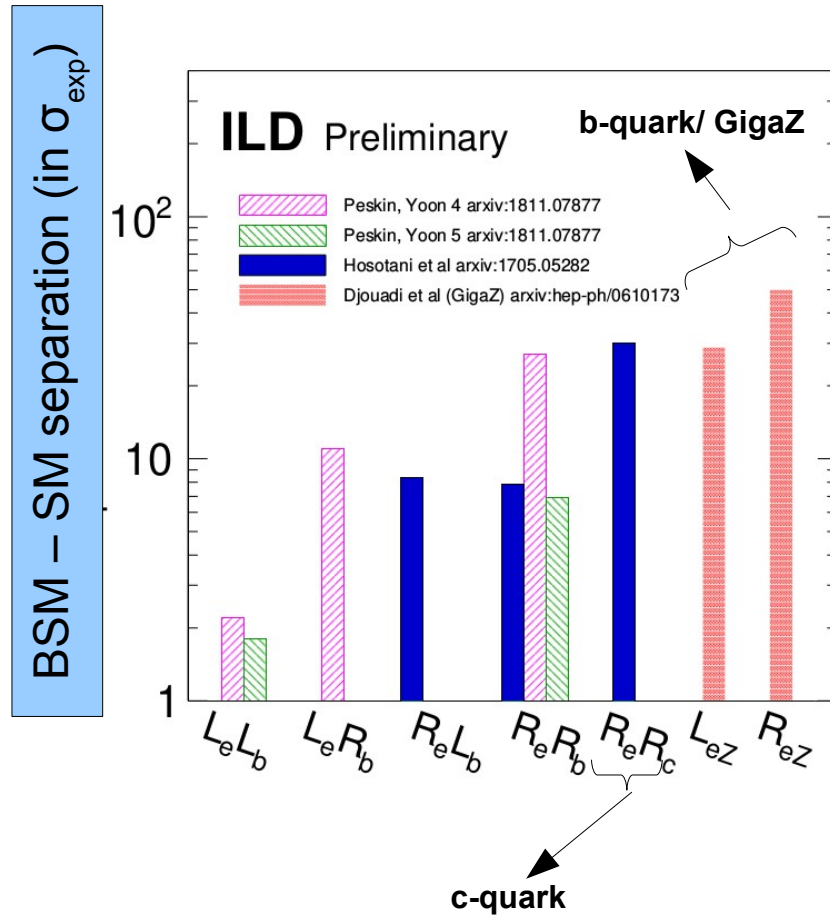**Stat unc (2000 fb-1)**

Syst unc.:
- Selection and background rejection
- quark tagging/mistagging (modelisation, QCD, correlations)
- Luminosity
- Polarisation

	Beam Polarisation	
	$(-+)$	$(+-)$
$\Delta R_b^{cont.}$	0.12 (stat.) $\pm$ 0.14 (syst.) %	0.15 (stat.) $\pm$ 0.13 (syst.) %
$\Delta A_{FB}^{b\bar{b}}$	0.30 (stat.) $\pm$ 0.05 (syst.) %	0.85 (stat.) $\pm$ 0.10 (syst.) %

Arxiv:1709.04289, PoS(EPS-HEP2019)624

Results (2) BSM benchmarks

► 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 mZ' ~ O(10-20) TeV at ILC250

Summary / conclusions

▶ **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 -> ~1 TeV)**

▶ **Achievable experimental precisions ~0.1 – 1%**

- Demanding analysis requiring the full detector capabilities: Vertex charge and particle ID, PFO for final state jets, etc
- **Comprehensive assessment of the systematic uncertainties done (b-quark)**
- or **in progress (top and 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 preliminiary stage)
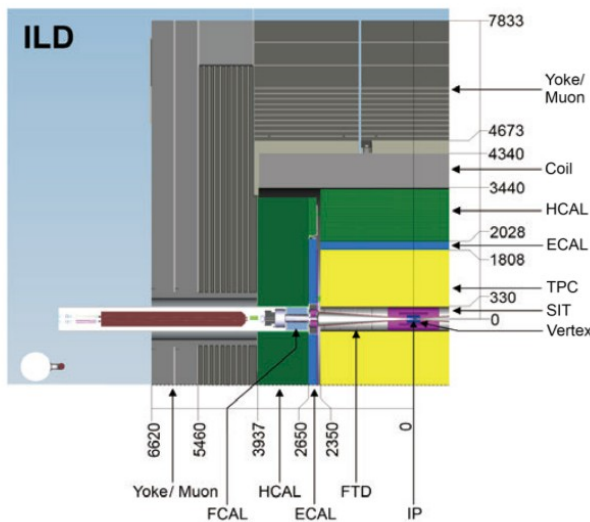- **Clear and unique pattern thanks to polarised beams**

Detector Technologies

Vertex: CMOS, DEPFET, FPCCD, …

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

ECAL:
Silicon (5x5mm^2) or
Scintillator (5x45mm^2)
with Tungsten absorber

HCAL:
Scintillator tile (3x3 cm^2)
or Gas RPC (1x1 cm^2)
with Steel absorber

All inside solenoidal coil of 3-4 T

Detector R&D collaborations:

10

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 $\sigma(d_0) < 5 \oplus 10 / (p[\text{GeV}] \sin^{3/2}\theta)$ µm	H→bb,cc,gg,ττ
• Transverse momentum resolution $\sigma(1/p_T) = 2 \times 10^{-5}$ 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_{jet} ~100 GeV)	H→invisible
• Hermeticity θ_{min} = 5 mrad	H→invisible; BSM

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

9

Beam spot size

	FCCee	ILC	SLC	LEP
σ_x[nm]	13700	516	1500	200000
σ_y[nm]	36	7.7	500	2500

Source SLC, LEP, PDG

©R. Poeschl

LEP   **>>**   **SLC**   **>>**   **ILC**

Cross sections

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

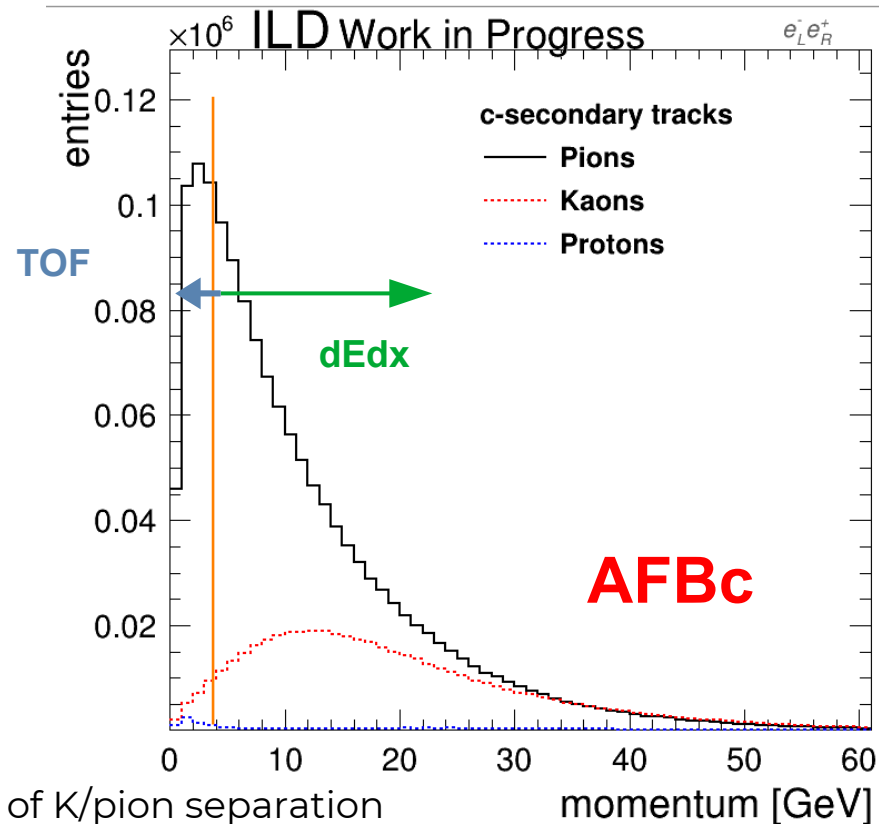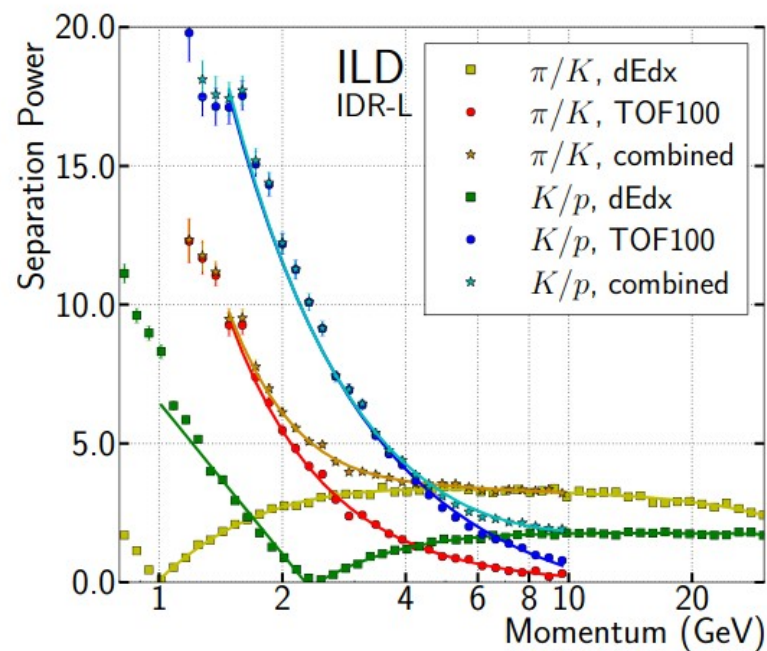|	Channel	σ_{unpol} [fb]	$\sigma_{-,+}$ [fb]	$\sigma_{+,-}$ [fb]
500 GeV	q=t	572	1564	724
	q=b	372	1212	276
	q=u+d+s+c	2208	6032	2793
250 GeV	q=t	--	--	--
	q=b	1756	5677	1283
	q=c	3020	8518	3565
	q=u+d+s	6750	18407	5463

► **Beam polarisation also enhances the cross section values**
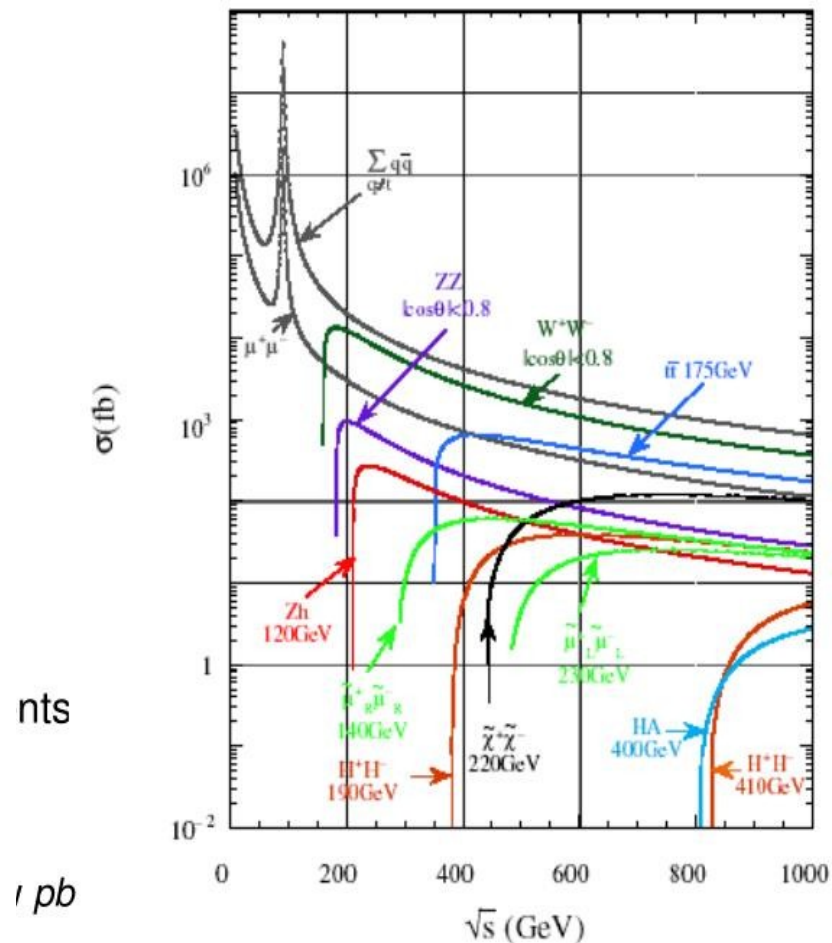
High Level Reco Challenges: Particle ID

▶ 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

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→ leptons events

▶ The method is based on the comparison of **single vs double tagged samples**

$$f_{1tag} = \varepsilon_{b-tag} R_b + \varepsilon_{c-tag} R_c + \varepsilon_{uds-tag}(1 - R_b - R_c) + BKGs$$

$$f_{2tag} = \varepsilon_{b-tag}^2(1 + \rho^2) R_b + \varepsilon_{c-tag}^2 R_c + \varepsilon_{uds-tag}^2(1 - R_b - R_c) + BKGs$$

$$where$$

$$R_b = \varepsilon_b^{pres} N_b / (\varepsilon_b^{pres} N_b + \varepsilon_c^{pres} N_c + \varepsilon_{uds}^{pres} N_{uds})$$

ideally →

$$f_{1tag} \simeq \varepsilon_{b-tag} R_b$$
$$f_{2tag} \simeq \varepsilon_{b-tag}^2 R_b$$
$$with$$
$$BKG \simeq 0$$
$$\varepsilon_b^{pres} \simeq \varepsilon_c^{pres} \simeq \varepsilon_{uds}^{pres}$$

New challenges at LC operating beams above from the Z-pole

Event selection → backgrounds from radiative return (x10 signal) events and WW/ZZ/HZ

b/c-quarks: reconstruction efficiencies

Arxiv:1709.04289, ILD Paper in progress

▶ **Double tagging (and charge measurement) techniques require:**

- **Preselection with similar efficiency for all quark flavours**

- **Preselection that cut out the main backgrounds**

▶ Require dedicated studies with full simulations: done at ILD for b and c-quark

- Profits from a highly efficient ISR photon identification (~XX %)

	Efficiency of selection for $e_L^- e_R^+ \to X$ [%]						
	$X = q\bar{q}\ (E_\gamma < 35\,GeV)$			$X = q\bar{q}\ (E_\gamma > 35\,GeV)$			
	$b\bar{b}$	$c\bar{c}$	$q\bar{q}\ (uds)$	$q\bar{q}\ (udscb)$	$X = ZZ$	$X = WW$	$X = HZ$
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

$q\bar{q}$ signal   Rad. Ret. BKG   Other BKG

Double charge measurements (b-quark)

▶ Mistakes in the charge calculation due to loss tracks (acceptance issues, mis reconstruction etc) have to be corrected and estimated using data → Mistakes produce migrations (flip of the cos(θ))

▶ The **migrations are restored** by determining the purity of the charge calculation using double charge measurements

- Accepted events, N_{acc}, with (-,+) compatible charges

- Rejected events, N_{rej}, non compatible (−,++) charges

pq-equation
Incognitas: pq and N.

$$N_{acc} = Np^2 + Nq^2$$
$$N_{rej} = 2Npq$$
$$1 = p + q$$

The **pq-equation** allows for correcting for migrations (finding the correct N) and in particular for the last and ultimate migration (dilution) due to B0 oscillations
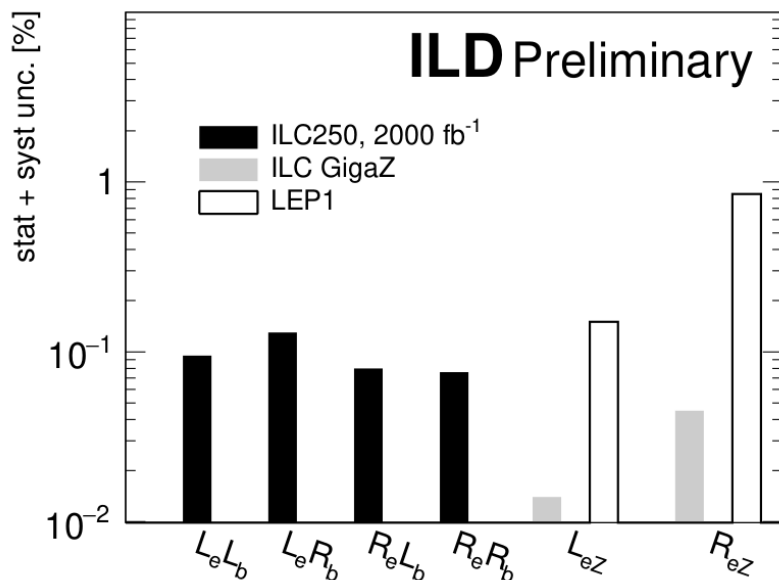
Couplings (notation for new resonances)

$$LeLb = QeQb + \frac{LeZLbZ}{s^2wc^2w}BWZ + \sum_{Z'}\frac{LeZ'LbZ'}{s^2wc^2w}BWZ'$$

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!!
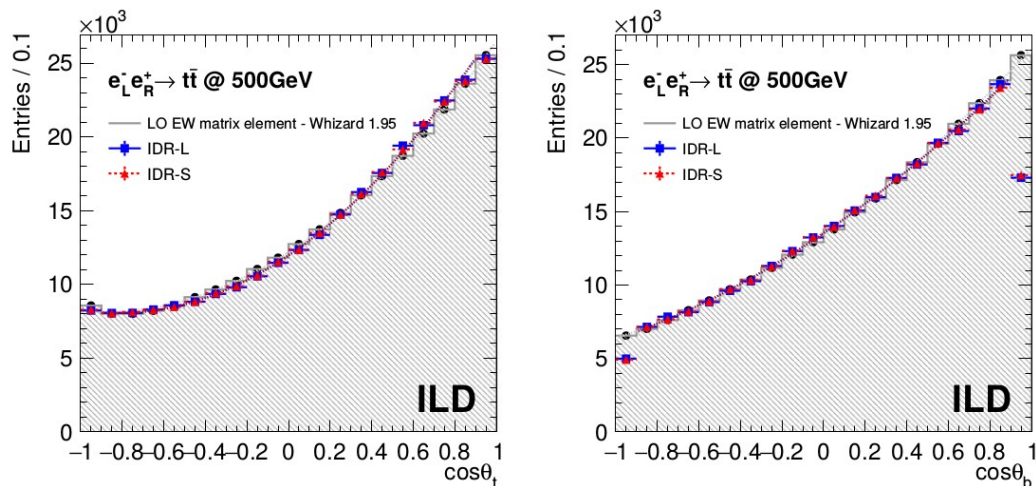
Arxiv:1709.04289, PoS(EPS-HEP2019)624
+GigaZ-ILC250 complementary arxiv:1905.00220

b/c-quarks: Results (2)
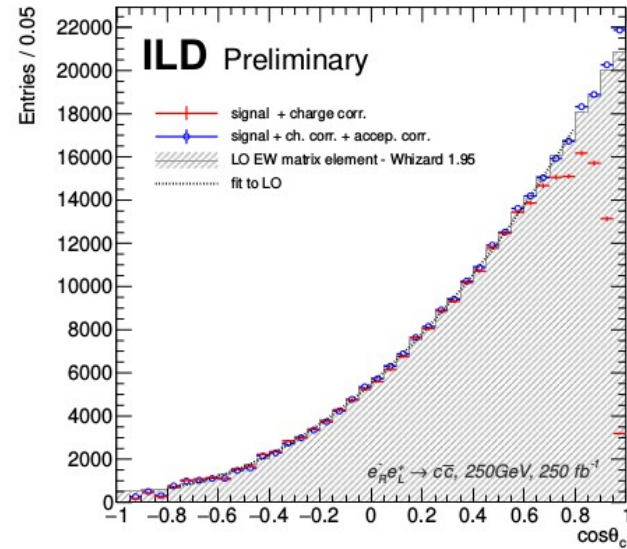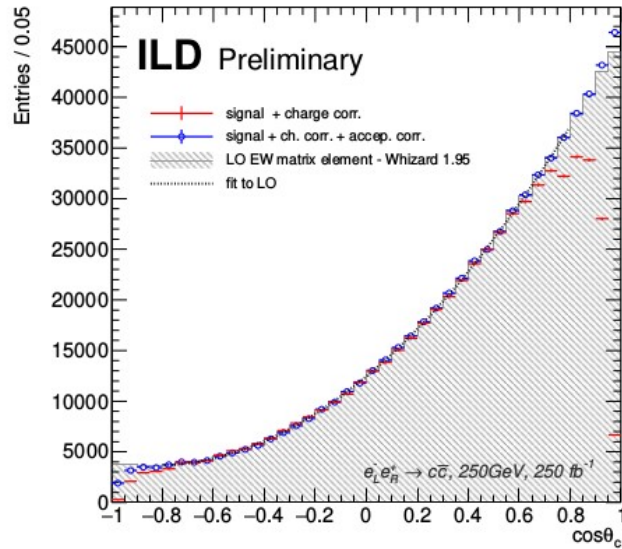
c-quark case

▶ Similar precision (work in progress, being updated with the most recent ILD samples)

▶ Lower tagging efficiency compensated by higher statistics for both polarisations.

▶ Kaon Identification becomes the most promising channel for the charge measurement

PoS(EPS-HEP2019)624

- ▶ 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 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: ~0.1%   Statistical precision on A FB : ~0.5%

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

IDR-L/S
Are two detector
Concepts compared
In the ILD
Interim Design Report ILD
Arxiv:2003.01116
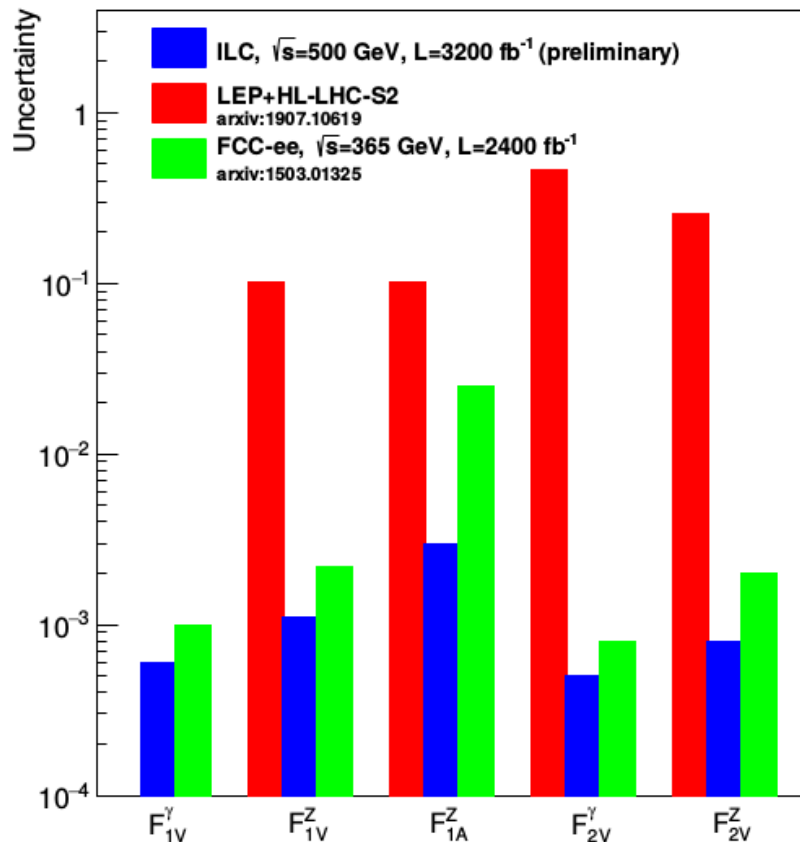
- ▶ e+e- collider way superior to LHC ($\sqrt{s}$ = 14 TeV)

- ▶ 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
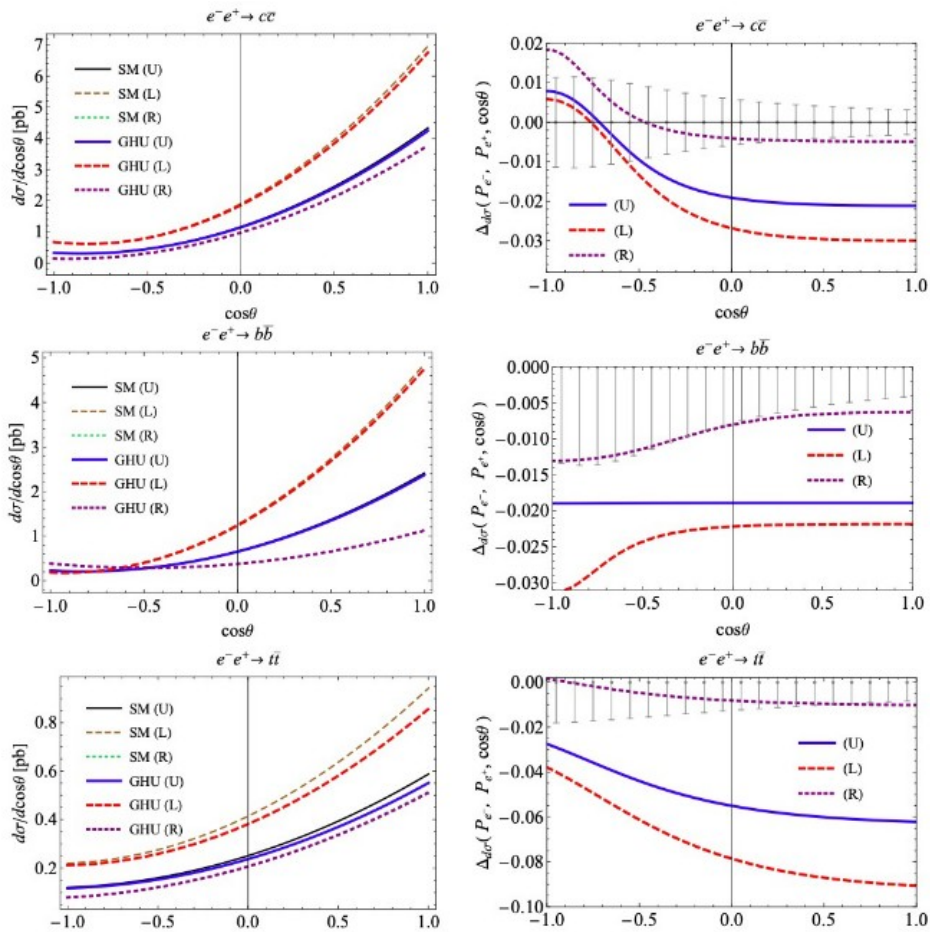
arxiv:2006.02157

- Model parameter is Hosotani angle θ_H yielding the Higgs-Potential as consequence of Aharanov-Bohm Phase in 5th 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 θ_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/γ exchange in $e^+e^- \to f\bar{f}$

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

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

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

at an *un*polarised collider:

$$A_{FB}^f \equiv \frac{(\sigma_F - \sigma_B)}{(\sigma_F + \sigma_B)} = \frac{3}{4}A_e A_f$$

=> no direct access to A_e, only via tau polarisation

While at a *polarised* collider:

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

$g^\gamma L$, $g^\gamma R$, $g^Z L$, $g^Z R$

$\propto F_{i,V/A}^X$

trading theory uncertainy:

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

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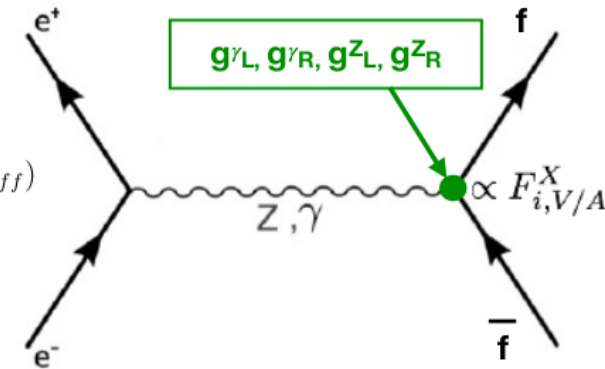
## Polarisation & Electroweak Physics at the Z pole

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
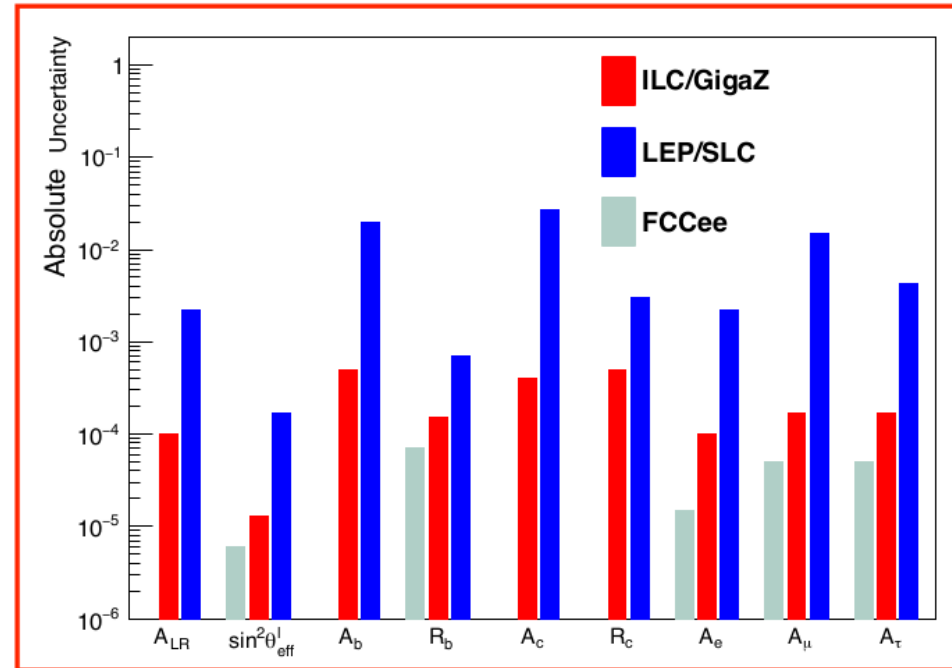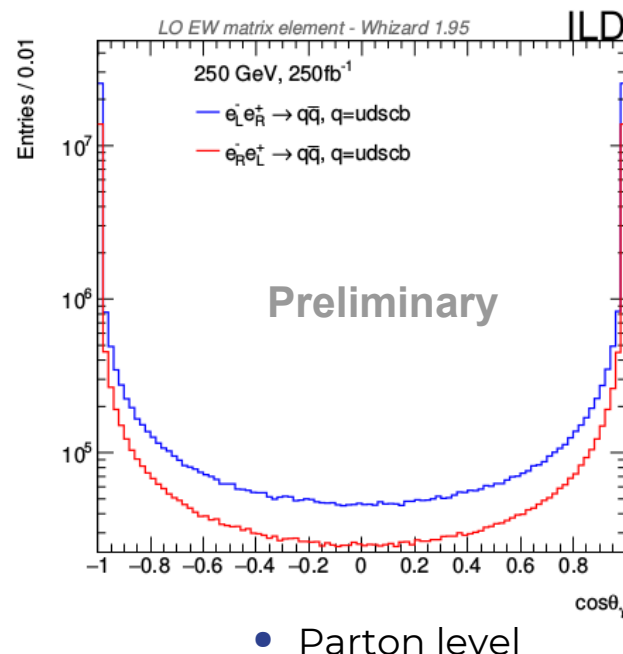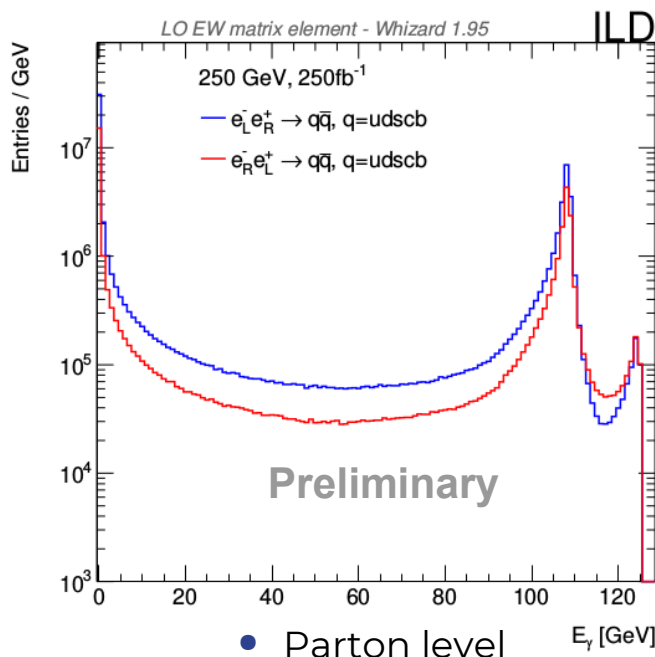

arXiv:1908.11299, talks by A.Irles & G, Wilson

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Predictions (as a function of the ISR)

► The cross section depends on the "effective" center of mass energy

- At which the Z/y couple to the quark-antiquark pair

$$\frac{d\sigma^{cont.}_{e^-e^+\to q\bar{q}}}{d\cos\theta_q}(s) \to$$

$$\to \frac{d\sigma^{cont.\bar{q}}_q}{d\cos\theta_q}(\hat{s} > s_{cut}) = \frac{d\sigma^{cont.}_{e^-e^+\to q\bar{q}}}{d\cos\theta_q}(E_\gamma < K_{cut})$$

- Parton level

- Parton level

▶ Alternatives to m(2jets) ?

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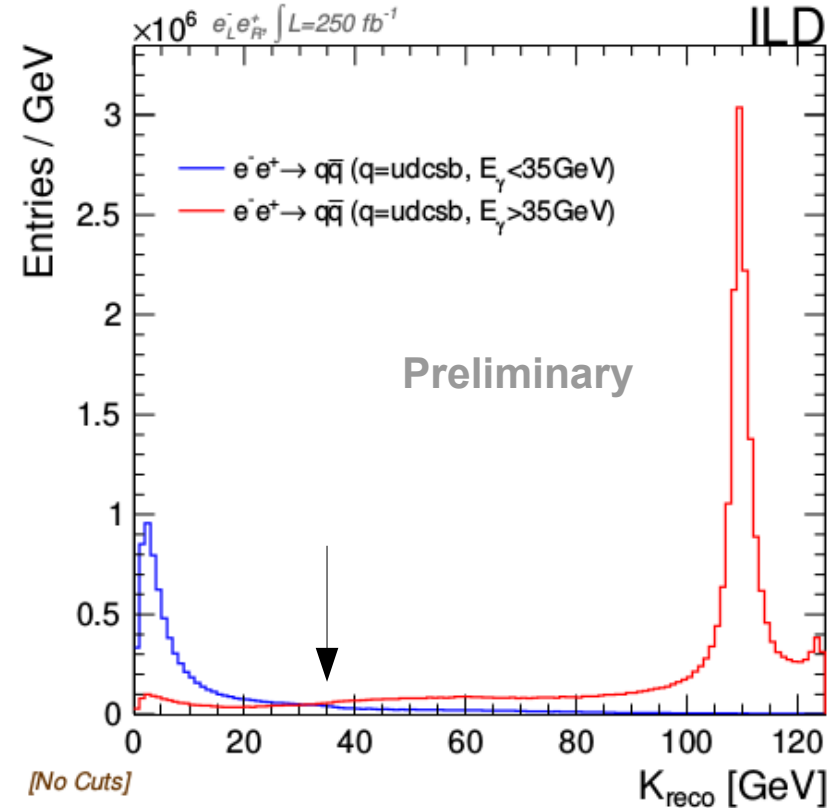
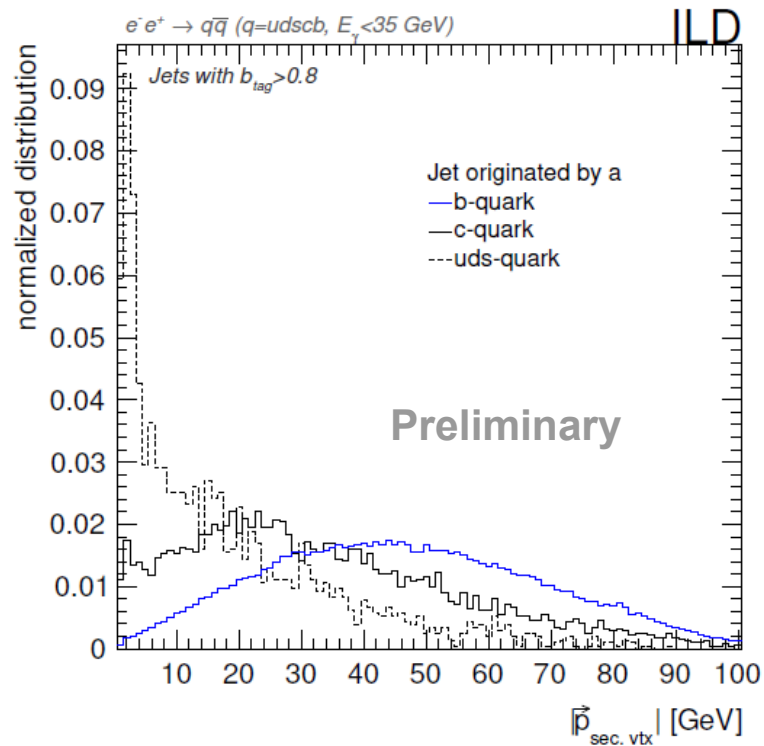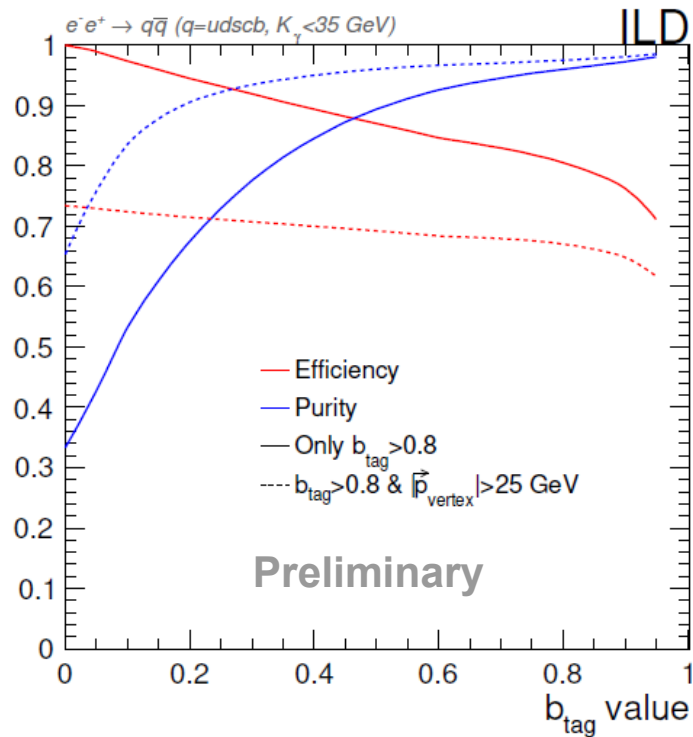$$|\vec{k}| \approx K_{reco} = \frac{250\,\text{GeV}}{\sin \Psi_{acol} + sin\theta_1 + sin\theta_2}.$$

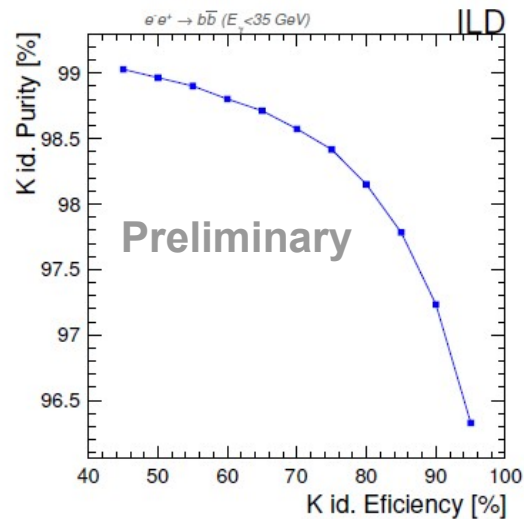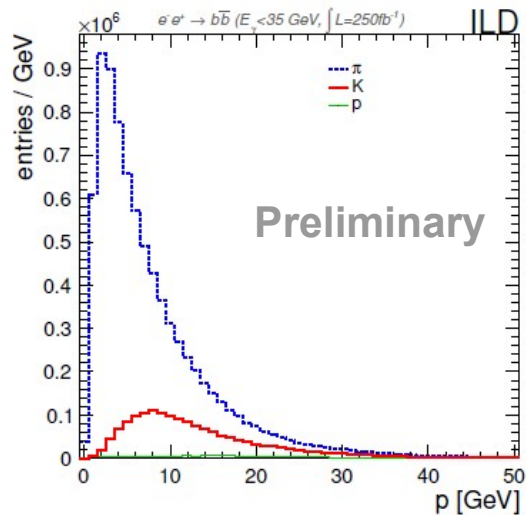Two jet acolinearity

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

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

Preselection : Kreco

▶ Estimator of the energy of the photon ISR

▶ We apply a cut of Kreco<35 GeV

▶ Some signal events have larger Kreco (~15%)

- Because of detector resolution and double photon ISR

▶ Some radiative return events have Kreco<35GeV (~7%)

- Because the photon(s) has not escaped through the beam pipe

▶ Can we identify the photon clustered in one or both jets and veto these events?

$e^- e^+ \to q\bar{q}$ (q=udscb, K_γ <35 GeV)

ILD

- Efficiency
- Purity
- Only b_{tag} >0.8
- b_{tag} >0.8 & $|\vec{p}_{vertex}|$ >25 GeV

Preliminary

b_{tag} value

$e^- e^+ \to q\bar{q}$ (q=udscb, E_γ <35 GeV)

ILD

Jets with b_{tag} >0.8

Jet originated by a
- b-quark
- c-quark
- uds-quark

Preliminary

normalized distribution

$|\vec{p}_{sec.\ vtx}|$ [GeV]

$$d_{ij} = min(E_i^{2p}, E_j^{2p}) \frac{1 - cos(\theta_{ij})}{1 - cos(R)}$$

$$d_{iB} = E_i^{2p}$$

ILD

Efficiency [%]

$e^-e^+ \rightarrow q\bar{q}$ (q=udcsb, E_γ <35 GeV)

Preliminary

Jet Distance: $d_{ij} = min(E_i, E_j) \frac{1-cos(\theta_{ij})}{1-cos(R)}$

K_{reco} <35 GeV & m_{j_1, j_2} >130 GeV
& photon veto cuts

R

ILD

Efficiency [%]

$e^-e^+ \rightarrow q\bar{q}$ (q=udcsb, E_γ >35 GeV)

Preliminary

Jet Distance: $d_{ij} = min(E_i, E_j) \frac{1-cos(\theta_{ij})}{1-cos(R)}$

K_{reco} <35 GeV & m_{j_1, j_2} >130 GeV
& photon veto cuts

R

▶ Cut on y23<0.015 (jet distance at which the 2 jet event would be clustered in 3 jets)

▶ Cut on mj1+mj2<100 GeV