Heavy quark production in high energy electron positron collisions

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on behalf of the **ILD Collaboration**

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VIRTUAL CONFERENCE
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Outline of the talk

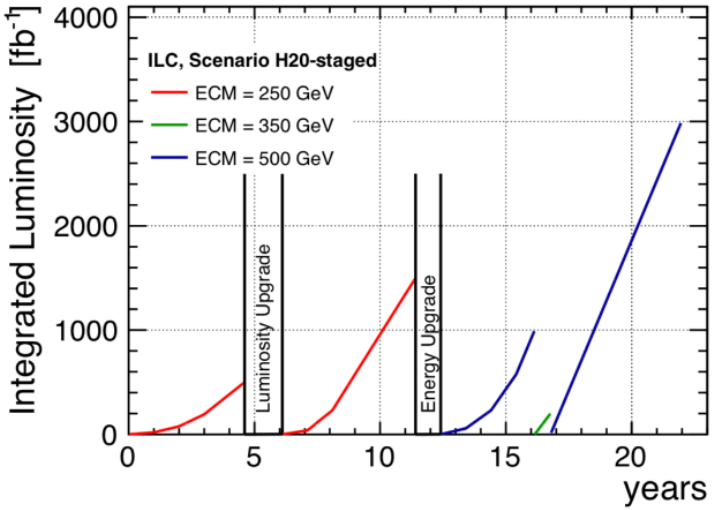
- **What? top/b/c-quark electroweak couplings** extracted from **differential cross section** measurements
  - Experimental prospects based on full simulation including a comprehensive study of the systematic uncertainties
  - **Emphasis on the b-quark experimental case**
- Where? International Linear Collider, **ILC@250GeV,** and the International Large Detector **ILD**

This talk

ILC physics program

- ILC is a Linear Collider Project, to be hosted in Japan.
  - **Matured technollogy: TDR since 2013**.
- **All Standard Model particles within reach of planned linear colliders**
- 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-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)

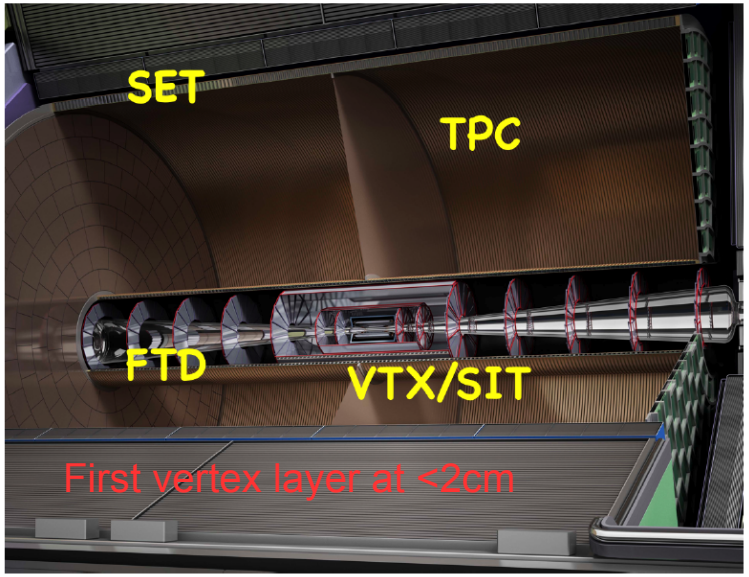
L upgrade: 5 Hz → 10 Hz; E upgrade: extend the linac

M. Peskin Snowmass (EF Workshop 21st July 2020)

See J. List (30/07) and G. Wilson (28/07)'s talks for more information on Linear Colliders and ILC

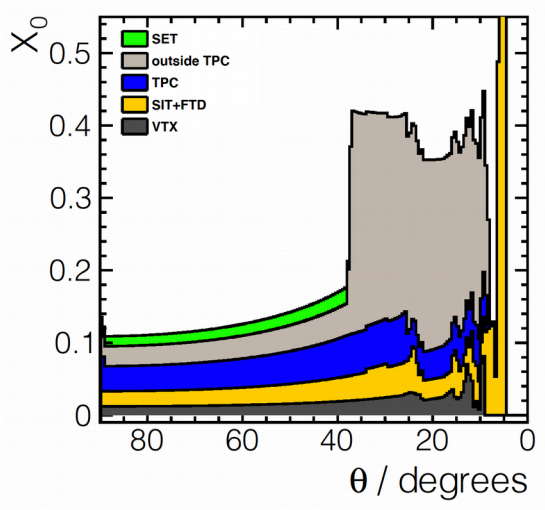
ILD highlights

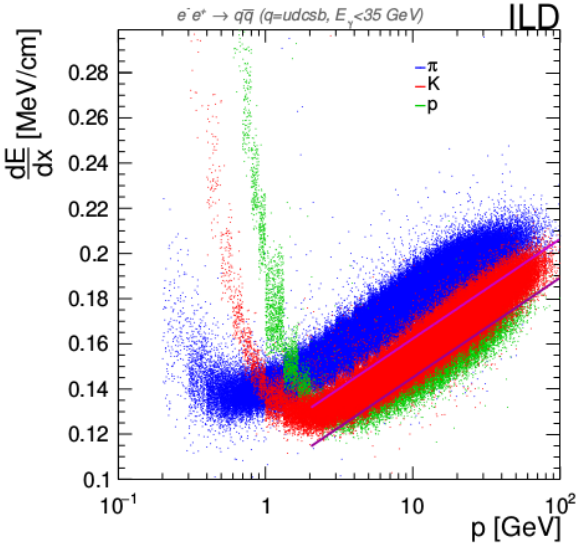
- **ILD snapshot**



- **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 (>10^8 cells!)**





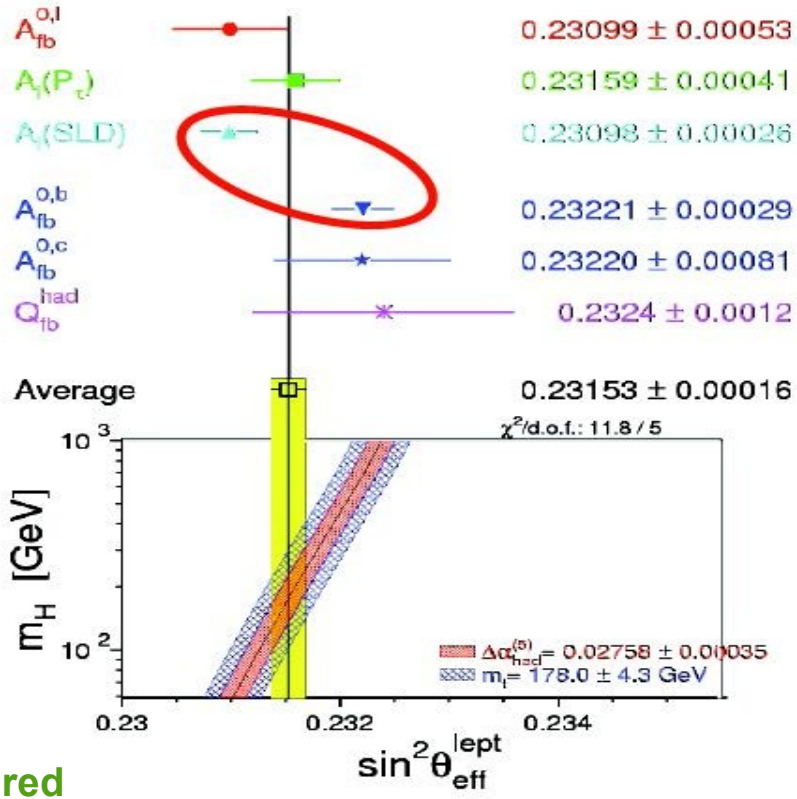
See T. Tanabe's (30/07) talk on ILD

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

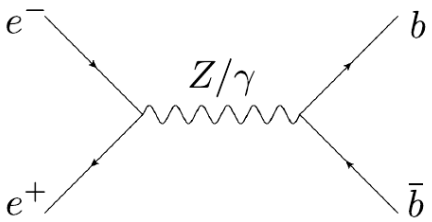
    → Hosotani et al arxiv:1705.05282 arxiv:2006.02157

  - For an EFT review see M. Perelló's talk and arxiv:1907.10619
- **How do we probe these BSM scenarios ?**

Probe such BSM require at least per mil level of experimental precision
tt/**bb**/cc… (ss?) **Can we do it?**
(this talk)

Two fermion processes

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



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

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

- The helicity amplitudes Σ_{IJ}, contain the couplings g_L/g_R (or Form factors or EFT factors)
- Left/right asymmetries (characteristic for each fermion)

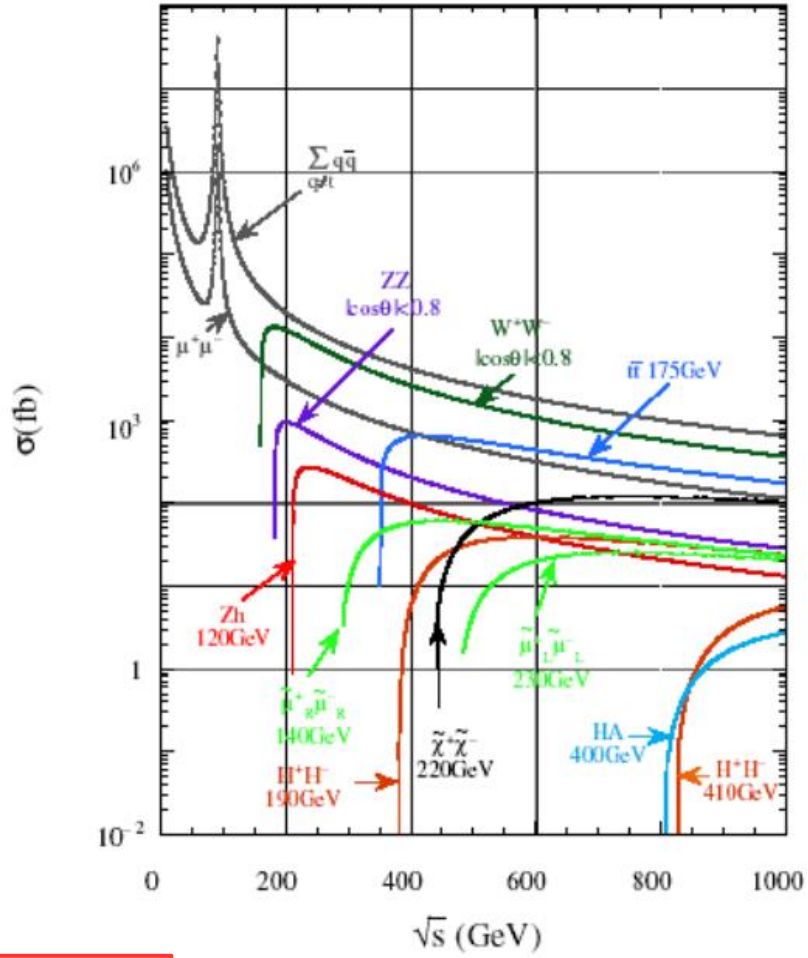
- **Only beam polarisation allows inspection of the 4 helicity amplitudes for all fermions**

- **These processes have been deeply studied at LEP/SLC at the Z-pole**
  - no access to the γ or Z/γ interferences
  - Moderated quark tagging or charge measurements capabilities.
  - Also moderated angular acceptance of the detectors

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**

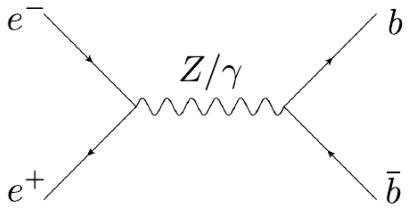
This talk concentrates on b-quark pair production at 250 GeV

Observables

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

$$R_q^0 = \Gamma_{q\bar{q}} / \Gamma_{had} (Z - pole)$$
$$\rightarrow R_q^{cont.} = \sigma_{q\bar{q}} / \sigma_{had} (s > Z - pole)$$

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



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

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

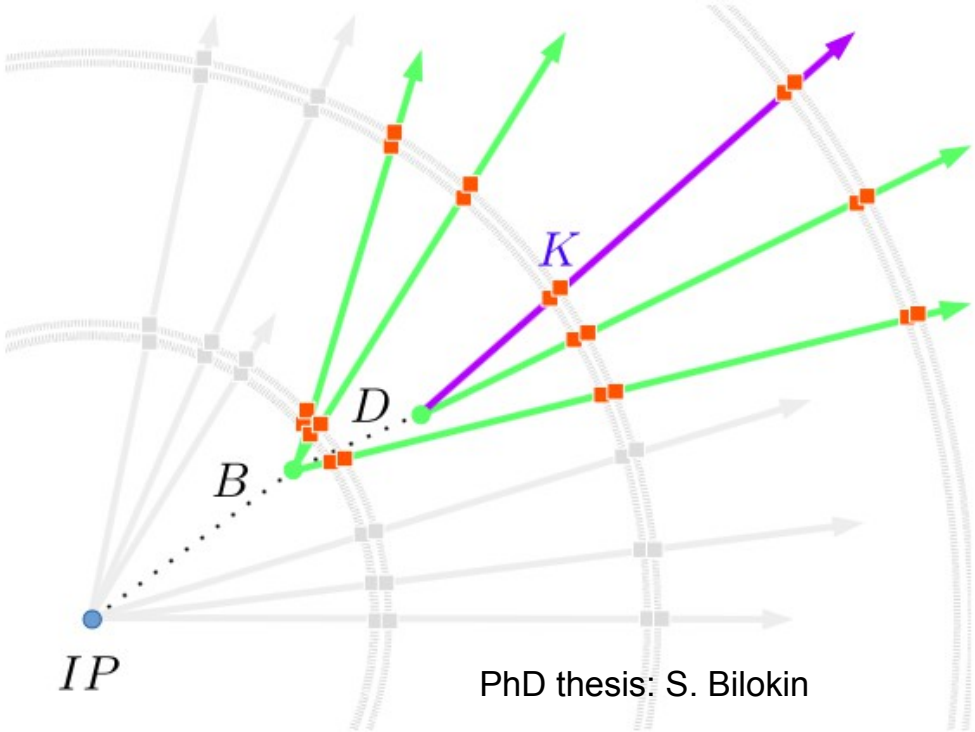
Angular Distribution.

Quark ID + charge measurement (quark – antiquark disentangling)

Gives access to all left/right couplings.

Flavor tagging and charge measurement

- **Flavor tagging**
  - Indispensable for analysis with 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

b/c-quarks: reconstruction efficiencies

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

- 2 ~back-to back jets topology
- Main source of systematics in LEP/SLC:
  - Uncertainties related to tagging efficiency
  - The tagging efficiency needs to be measured (not MC estimated) to reach the per mil level of accuracy.

- New systematics sources for LC operating polarised beams far from the Z-pole
  - Beam polarisation
  - Event selection → **backgrounds from radiative return** events and **WW/ZZ/HZ**

Polarization	$\sigma_{e^-e^+\to q\bar{q}}(E_\gamma < 35\,GeV)$[fb]			$\sigma_{e^-e^+\to q\bar{q}}(E_\gamma > 35\,GeV)$[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

$q\bar{q}$ signal

Rad. Ret. BKG

Up to x10 signal

Double Tag Method

- Needed to reach 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
  - f1= ratio of number jets that are tagged as b-jets
  - f2= ratio of events in which both jets are tagged as b-jets

To remove modelling dependence on the efficiency of b-tagging

$$f_1 = \epsilon_b R_b + \epsilon_c R_c + \epsilon_{uds} R_{uds}$$
$$f_2 = \epsilon_b^2 (1+\rho_b) R_b + \epsilon_c^2 R_c + \epsilon_{uds}^2 R_{uds}$$

- Rb and ε_b are measured simultaneously.

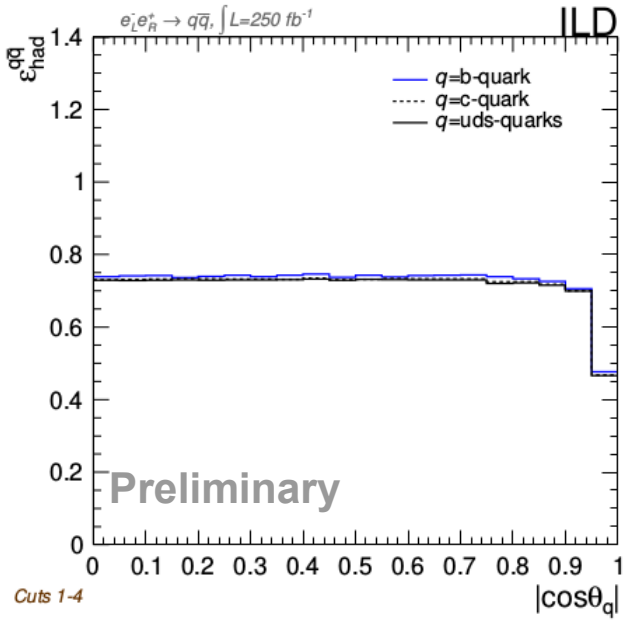
- **ε_b = b-tagging efficiency**
- ρ_b = b-tagging correlation factor
- ε_c = probability of tagging a c-quark jet as b-jet
- ε_{uds} = probability of tagging an uds-quark jet as b-jet

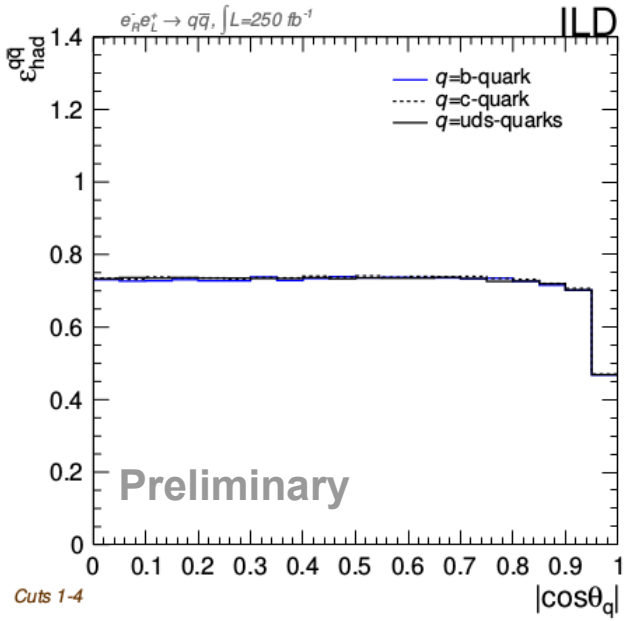
These values must be as small as possible and with small uncertainties

to not spoil our accuracy (not covered in this talk)

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





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

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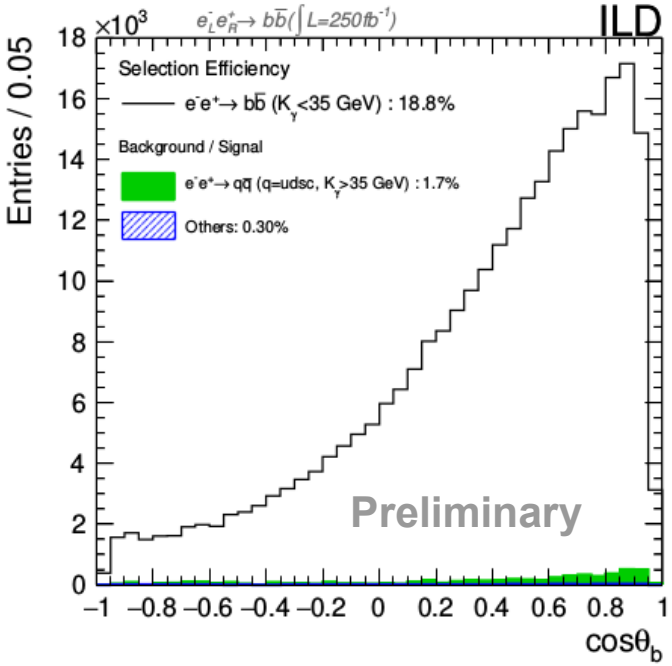

- Main bkg ee→ Zγ(ISR)
  - ~x10 larger than signal
  - For **~90% of such ISR photons are lost in the beam pipe** → events filtered by energy (angular) conservation arguments
  - The r**emaining ~10% are filtered by identifying photons** in the detector (efficiency of ~90%)
- Very small B/S ~2%

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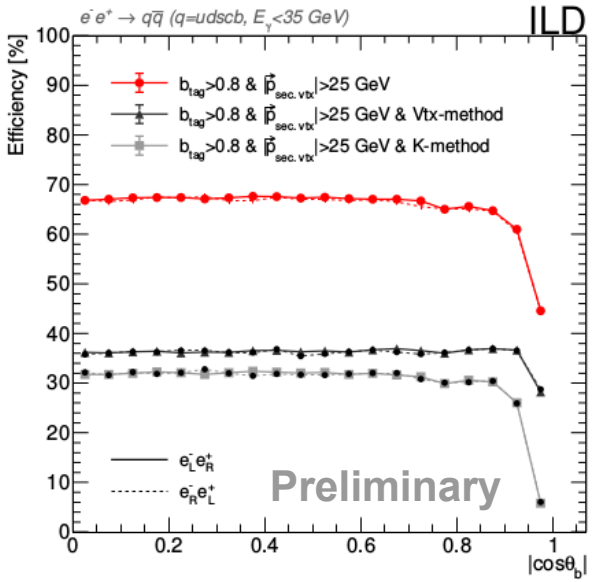
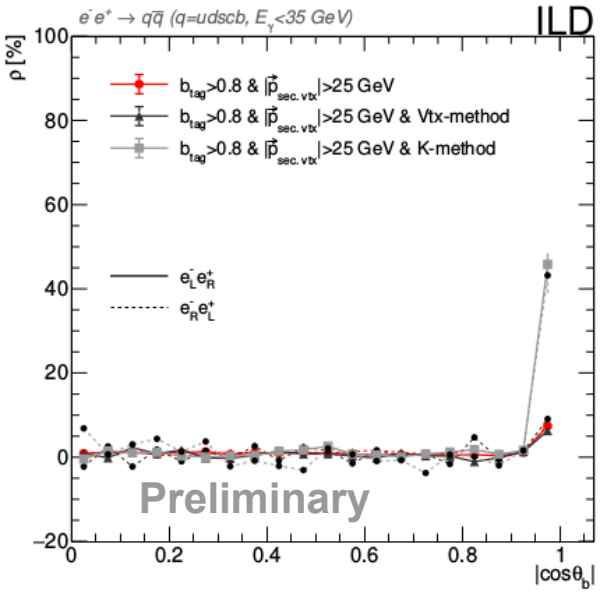




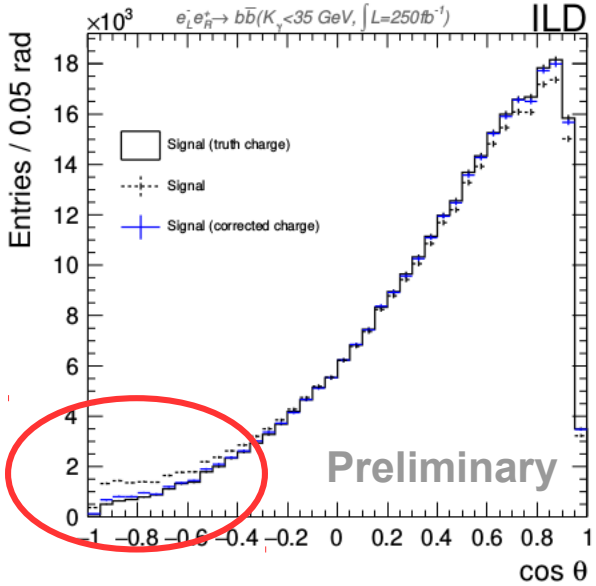
- **Excellent prospects for b-tagging** (or c-tagging) with very low correlation factor ~ 0% (~2% at LEP)
- **Differential measurements!**
  - Constant values for most of the angles
  - Drop of acceptance the very forward region → optimizations are under consideration
- **Miss-efficiencies very small**
  - <1% for c-quark
  - ~0% for uds

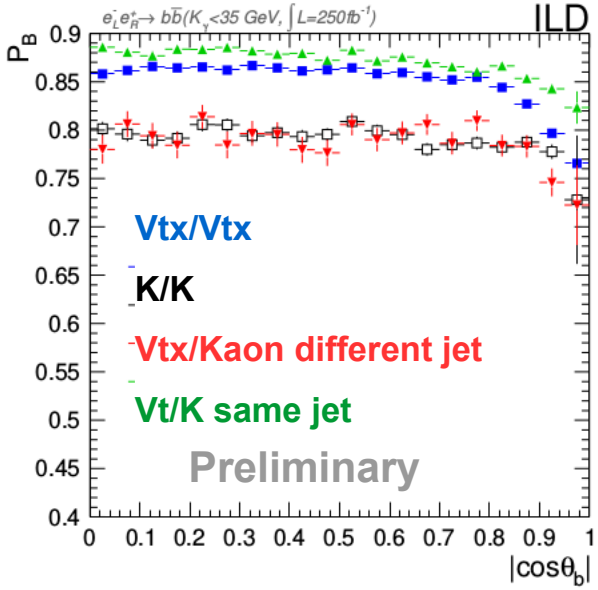
Arxiv:1709.04289, PoS(EPS-HEP2019)624
ILD Note in progress

Charge measurement: migrations

- 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?

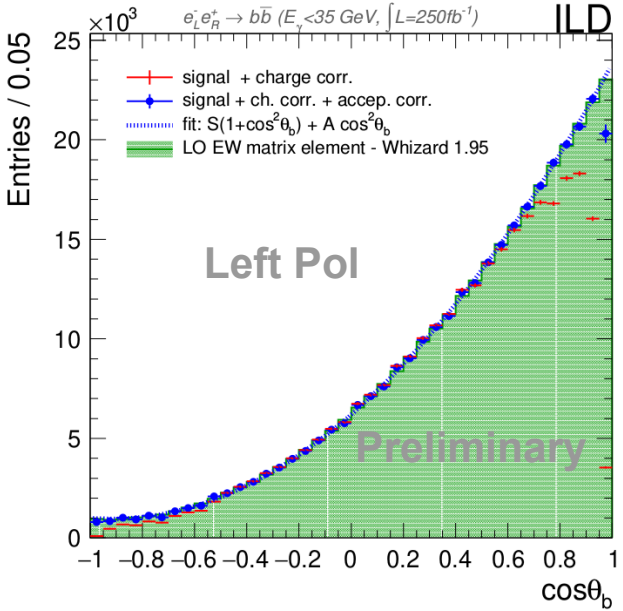


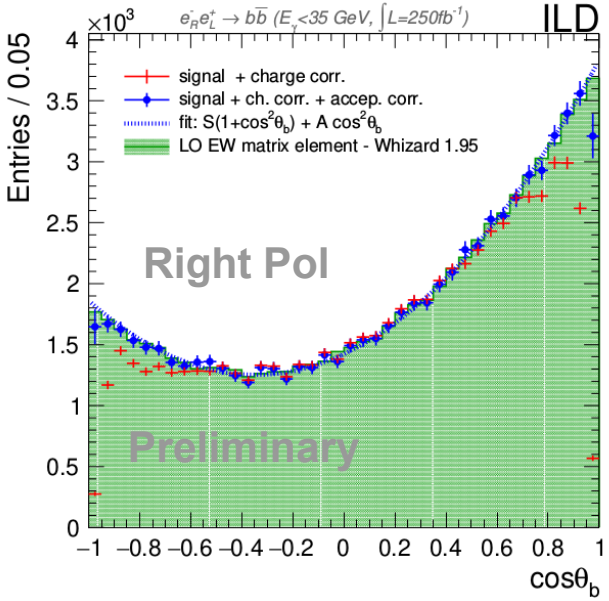


- **P_B limited by vertex reconstruction efficiency, Particle ID efficiency and B0 oscillations.**

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

Results (1)





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*

	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.) %

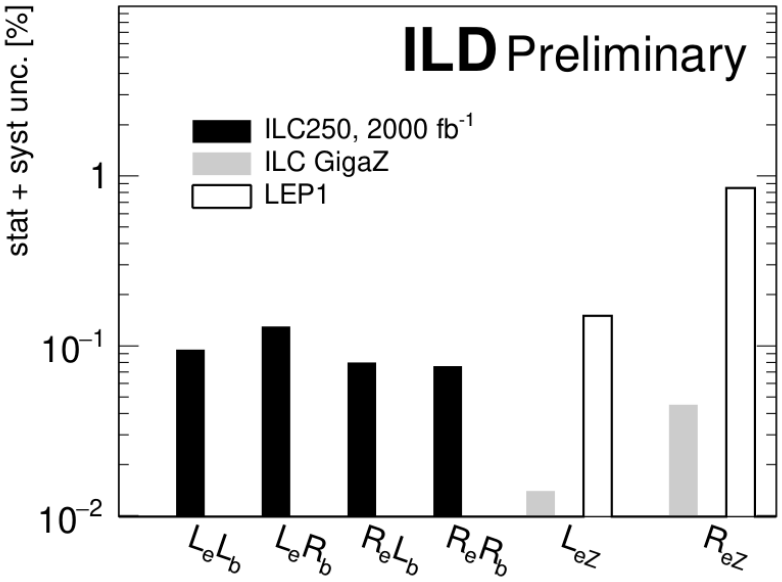
Stat unc (2000 fb-1)

Syst unc.:

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

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

Results (2)



Couplings (notation for new resonances)

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

ILC250 SM GigaZ New resonances

Sensitive to Z-Z' mixing effects

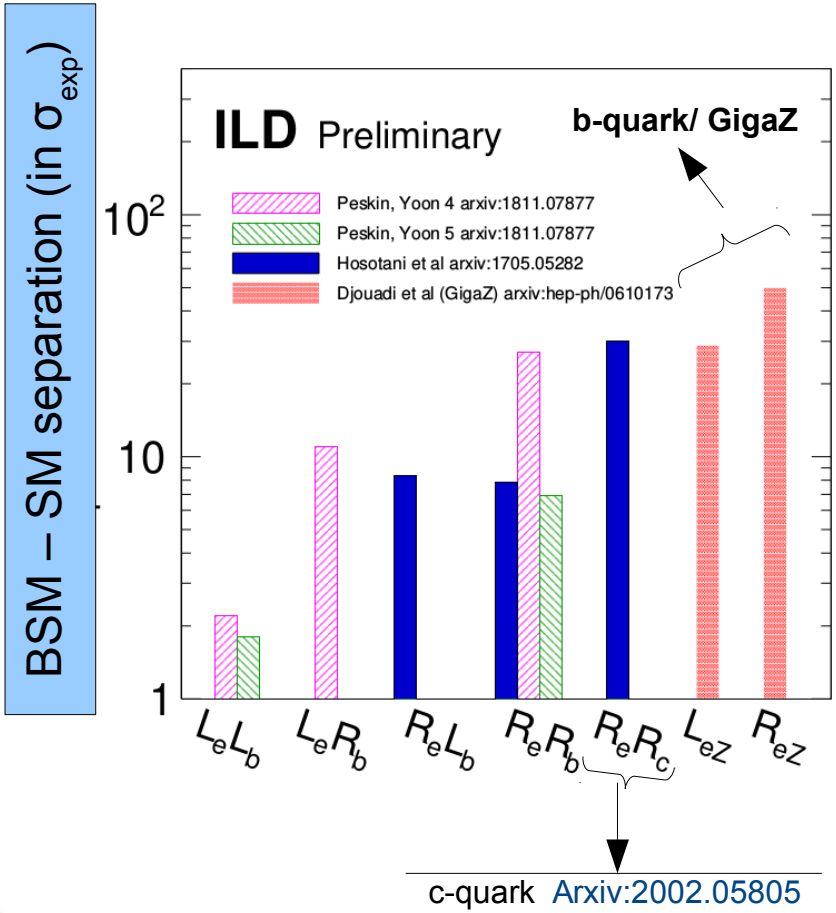
(that could explain AFBb measurement of LEP?)

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
ILD Note in progress

Results (3) 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).

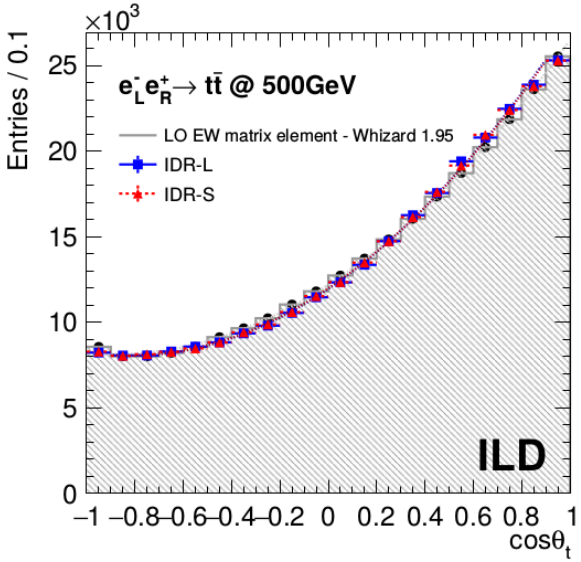
- Models that predict multi-TeV Z' resonances
- With or without mixing at Z-pole
- See backup for more details on the models

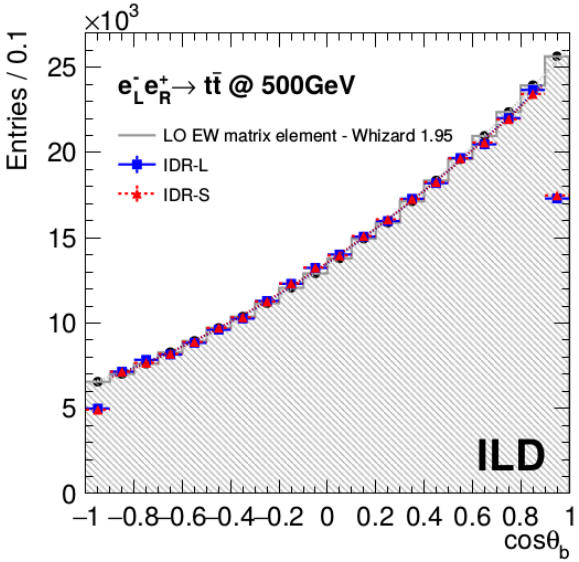
Potential for discovery of new resonances mZ' ~ O(20-30) TeV at ILC250

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

Top quark: results (1)

ILD-PHYS-PUB-2019-007





- 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**

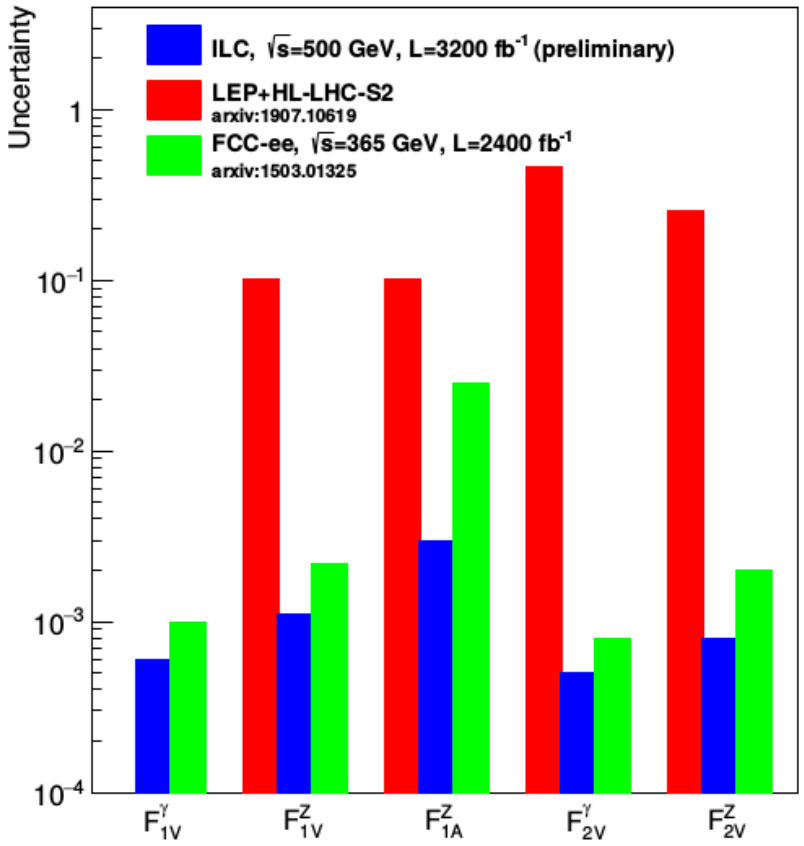
- Integrated Luminosity 4 fb^{-1}
- Thanks to the jet charge calculations capabilities, we could use all decay channels.
- Efficiencies of 75% (cross section) and 30% (differential cross section)
- Exact reproduction of generated spectra
  - Statistical precision on cross section: ~0.1% Statistical precision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

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

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

Top quark: results (2)

ILD-PHYS-PUB-2019-007



- e+e- collider way superior to LHC (√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.

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)
- **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**

- Active phenomenological studies in terms of global analyses (EFT) and concrete models (not covered in this talk)
- Theory challenges (not covered in this talk)
  - Need at least NLO electroweak predictions (and MC programs) for correct interpretation of results

Zoom session for further questions

on this and all other ILC-related talks:

Friday, July 31,

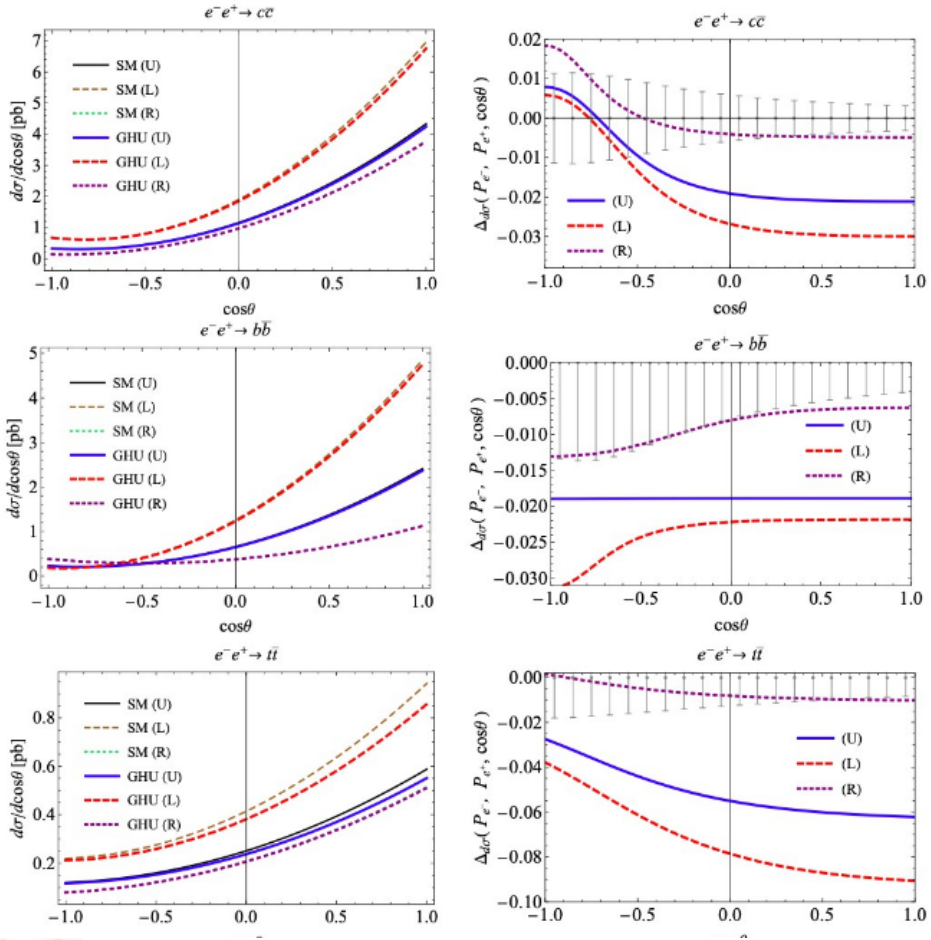
7:00 am Pacific, 9:00 am Texas,

4:00 pm Prague, 11:00 pm Tokyo

https://stanford.zoom.us/j/99671238654?pwd=M2V2RCtYbTFrVi9Ub01kckh3WFVoZz09

Thanks for your attention.

a BSM example: GUT Inspired Grand Higgs Unificaton Model



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

Slide borrowed from R. Poeschl (EF04 Snowmass process)

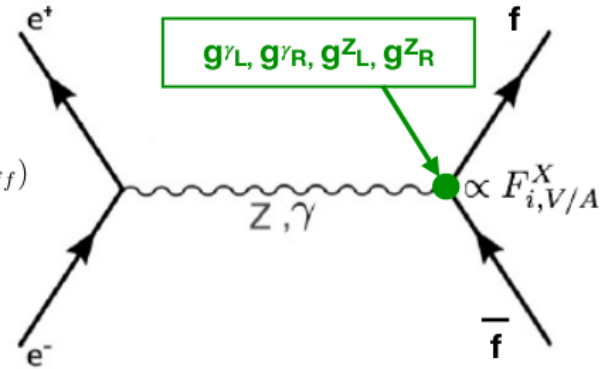
Polarisation & Electroweak Physics at high energies

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

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

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

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 *un*polarised collider:

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

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

While at a *polarised* collider:

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

trading theory uncertainy:

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

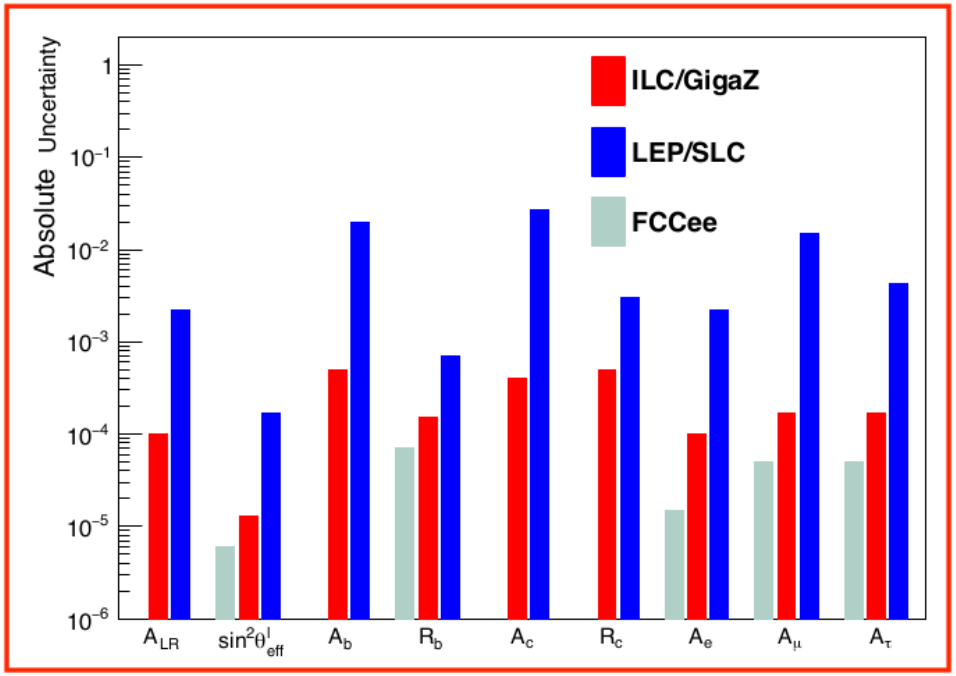
5

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

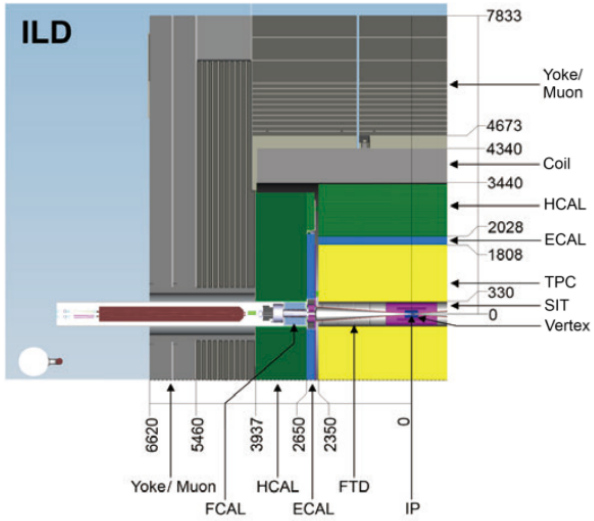
Vertex: CMOS, DEPFET, FPCCD, …

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

ECAL:
Silicon (5x5mm^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: CALICE Calorimeter for ILC, LC-TPC, FCAL Collaboration

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:

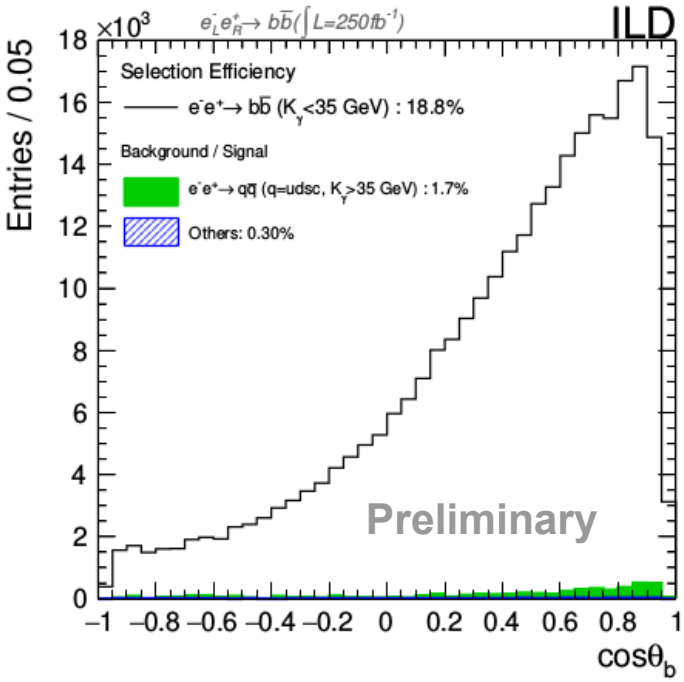
Detector Requirements	Physics
• Impact parameter resolution $\sigma(d_0) < 5 \oplus 10 / (p[\mathrm{GeV}] \sin^{3/2}\theta)$ μm	H→bb,cc,gg,ττ
• Transverse momentum resolution $\sigma(1/p_T) = 2 \times 10^{-5}\ \mathrm{GeV}^{-1} \oplus 1 \times 10^{-3} / (p_T \sin^{1/2}\theta)$	Total e+e-→ZH cross section
• Jet energy resolution 3-4% (around E_{jet} ~100 GeV)	H→invisible
• Hermeticity θ_{min} = 5 mrad	H→invisible; BSM

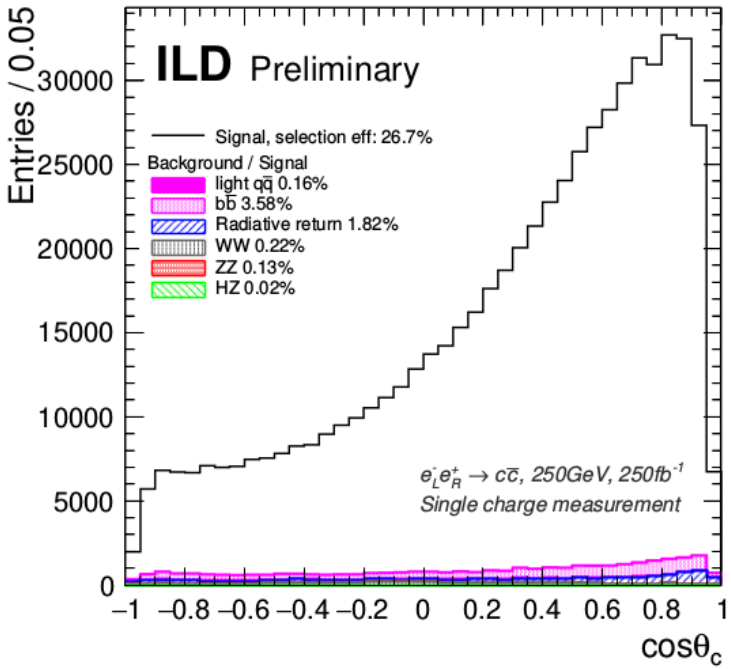
R. Ete: "The ILD Software Tools and Detector Performance"

9

b/c-quarks: reconstruction efficiencies

- After the preselection, we apply the b/c tagging including charge measurement for differential cross sections.
  - Efficiencies for inclusive cross section are ~x2 larger

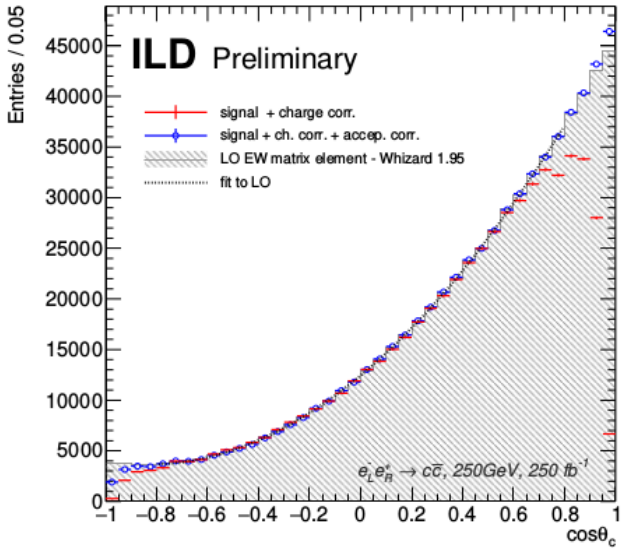


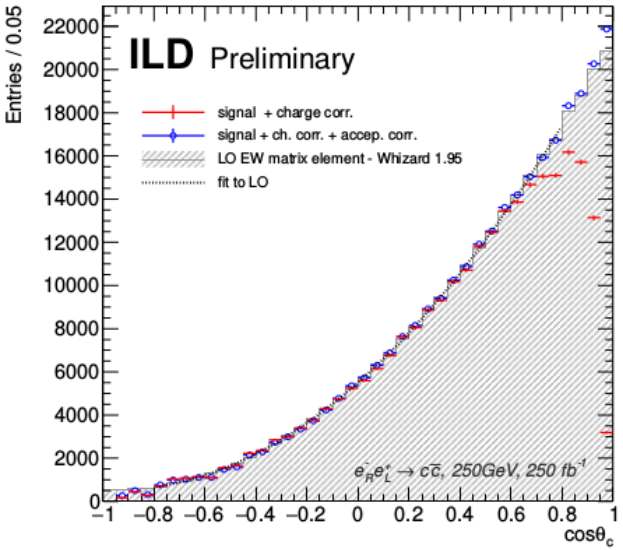


- Background ~free analysis!

Arxiv:2002.05805

b/c-quarks: Results (2)





c-quark case

- Similar precisions (work in progress)
- Lower tagging efficiency compensated by higher statistics for both polarisations.
- Kaon Identification becomes the most promising channel for the charge measurement

Arxiv:2002.05805

Top-quark: Reconstruction efficiencies

$e_L^- e_R^+ \to t\bar{t}$ at 500 GeV

General selection cuts	IDR-L	IDR-S
Isolated Lepton	92.1%	92.1%
$btag_1 > 0.8$ or $btag_2 > 0.3$	81.2%	81.1%
Thrust < 0.9	81.2%	81.1%
Hadronic mass	78.2%	78.2%
Reconstructed m_W and m_t	73.4%	73.4%
t quark polar angle spectrum		
$\gamma_t^{had.} + \gamma_t^{\ell} > 2.4$	62.2%	61.8%
$\lvert p_{B,had} \rvert > 15\,\mathrm{GeV}$	34.5%	33.9%
"$t\bar{t}$ identification"	30.6%	30.2%
b quark polar angle spectrum		
No additional cuts		

$e_R^- e_L^+ \to t\bar{t}$ at 500 GeV

General selection cuts	IDR-L	IDR-S
Isolated Lepton	94.1%	94.0%
$btag_1 > 0.8$ or $btag_2 > 0.3$	84.9%	84.8%
Thrust < 0.9	84.9%	84.8%
Hadronic mass	82.2%	82.3%
Reconstructed m_W and m_t	77.6%	77.5%
t quark polar angle spectrum		
$\gamma_t^{had.} + \gamma_t^{\ell} > 2.4$	64.1%	64.1%
b quark polar angle spectrum		
Vtx+Vtx	10.8%	10.3%

Total cross section

- Typical selection efficiencies fo the 75%
- Independent of beam polarisation

Differential cross section

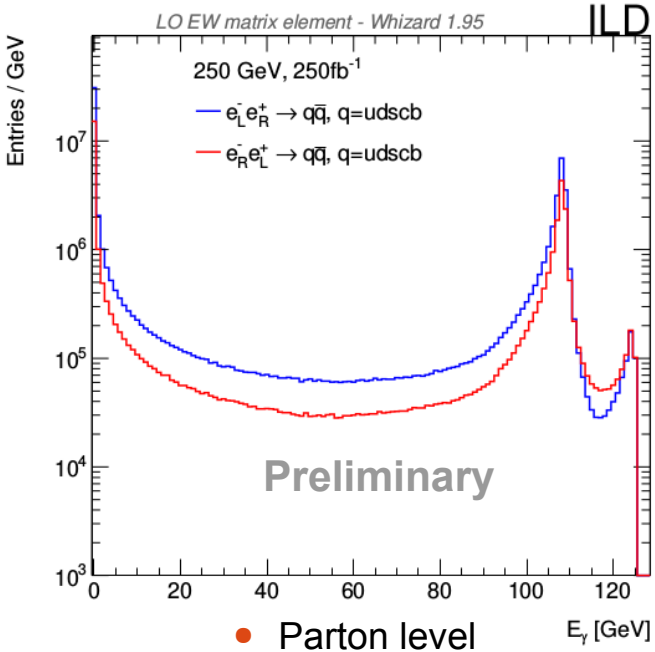
- Differences for beam polarisations
- Left hand polarisation more vulnerable to migrations
- Requires information from the hadronic state
- Vertex / Kaon as in the bb-case

Predictions (as a function of the ISR)

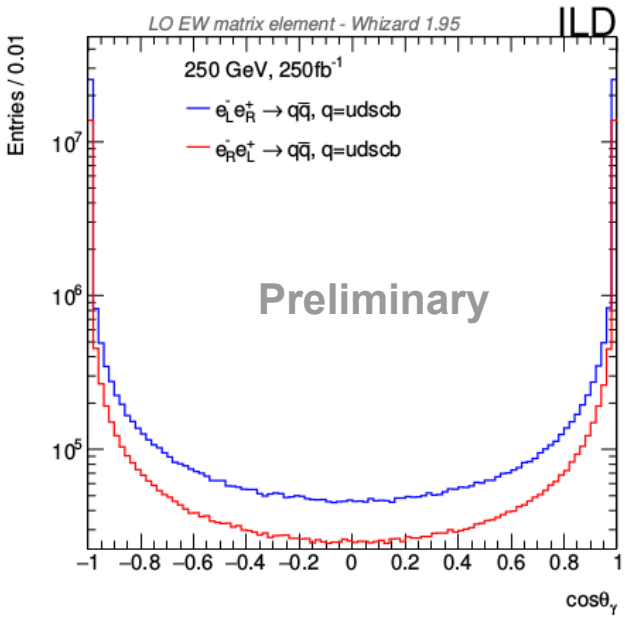
- The cross section depends on the “effective” center of mass energy
  - At which the Z/y couple to the quark-antiquark pair

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

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



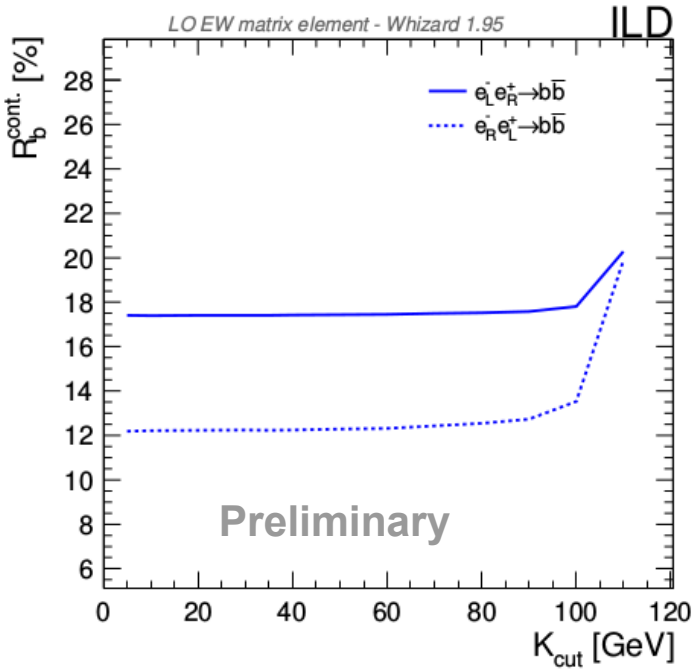
- Parton level

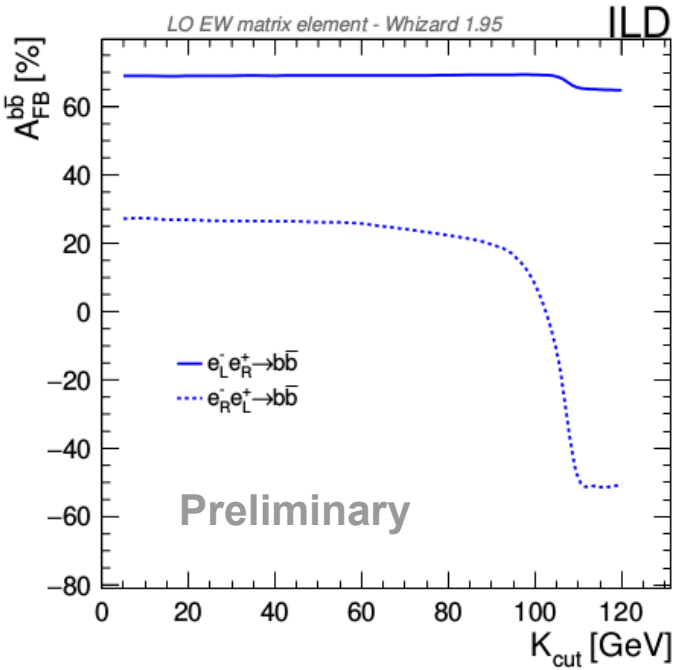


- Parton level

Predictions (as a function of the ISR)

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





- The observables remain basically flat for a large range of the Kcut
- Drastic change when the photn ISR is large enough to produce a return to the Z-pole
  - We need to avoid that region of the phase space.

Preselection

- 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):

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

Two jet acolinearity

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

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

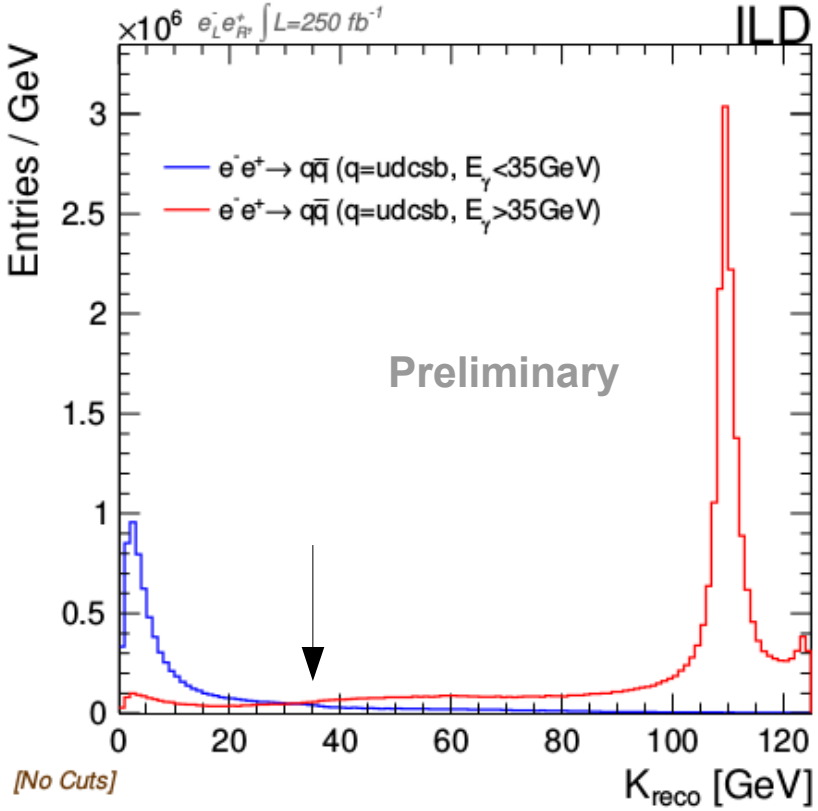
Preselection : Kreco

- 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?

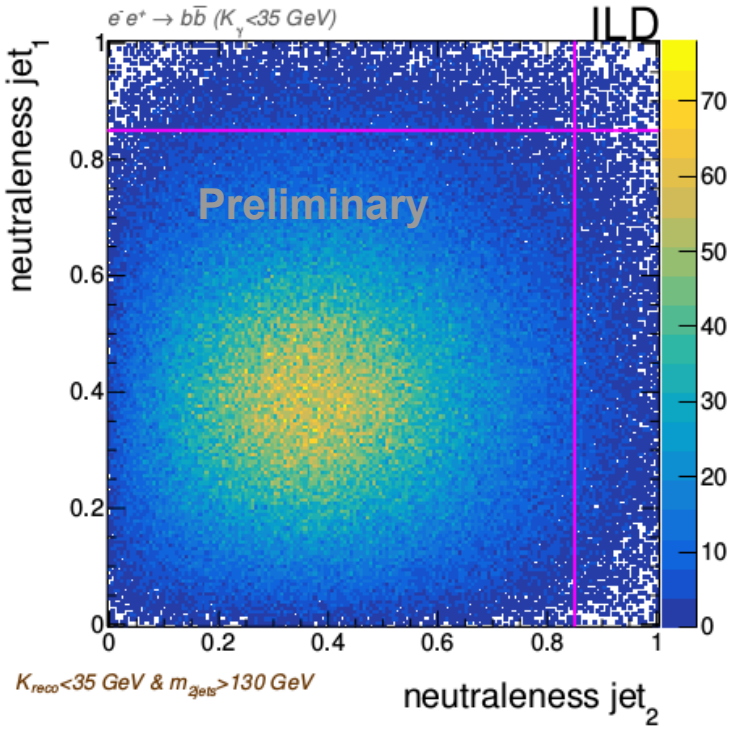


Preselection : Photon Veto

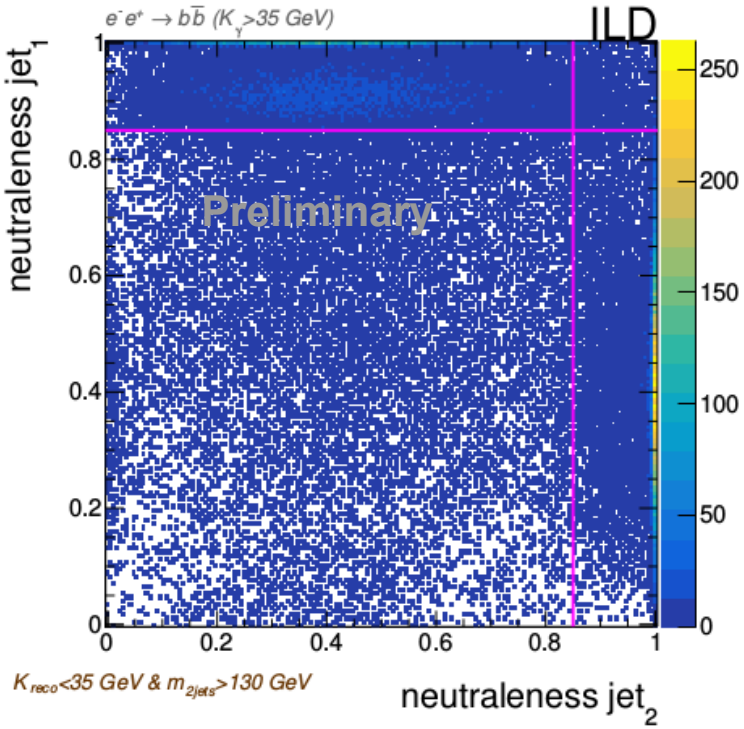
- We look at the neutraleness of the jets

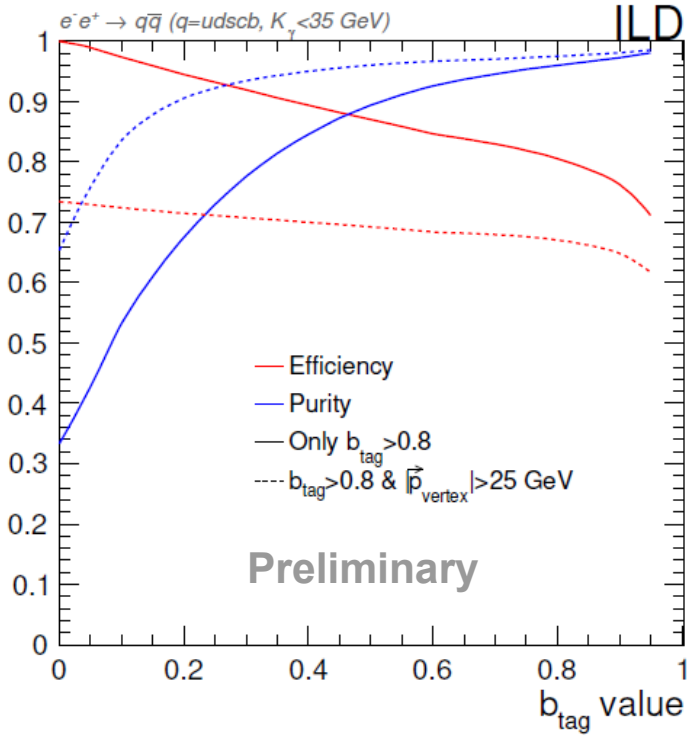
$$\text{neutraleness}_j = \frac{\sum_{i=nPFO} E_i}{E_j}.$$

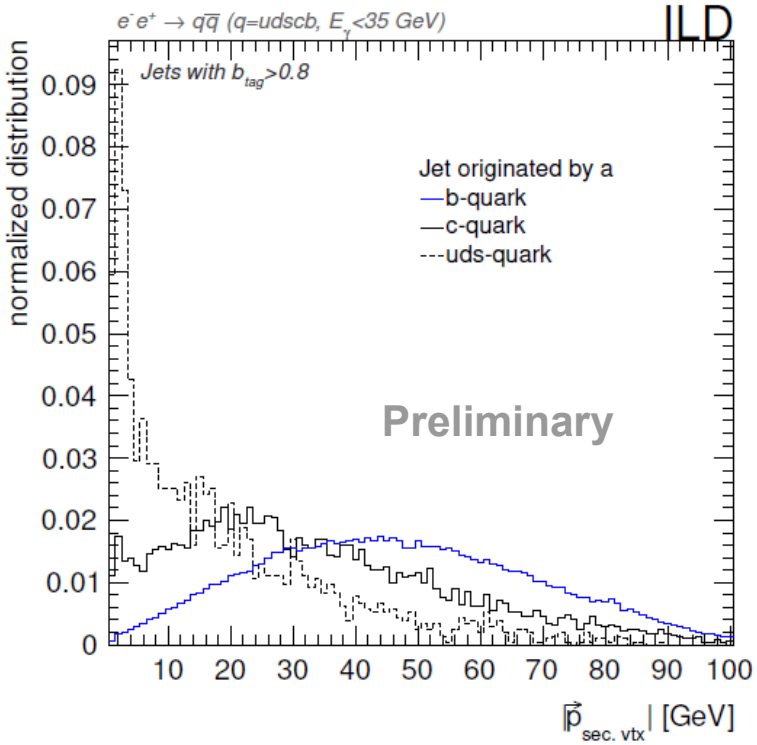
signal

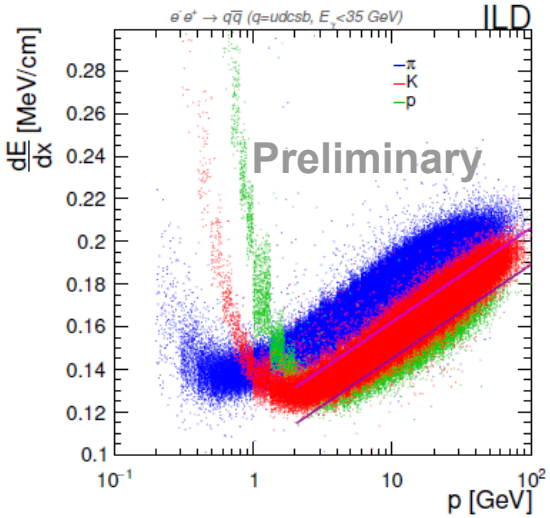


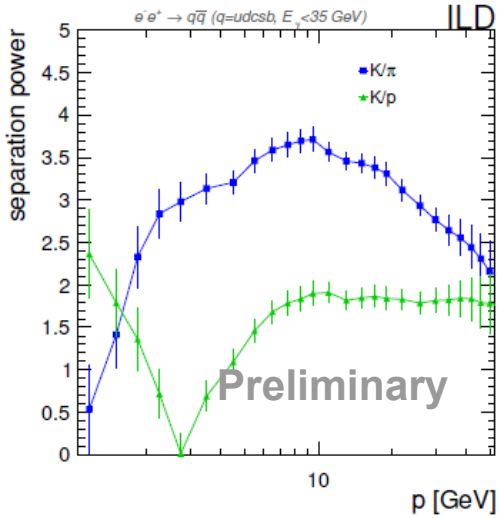
radiative return

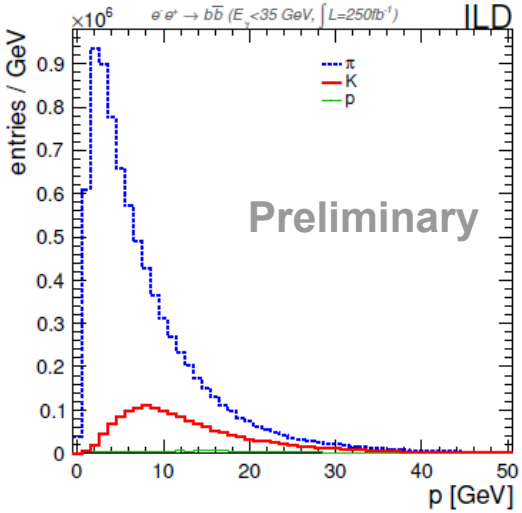


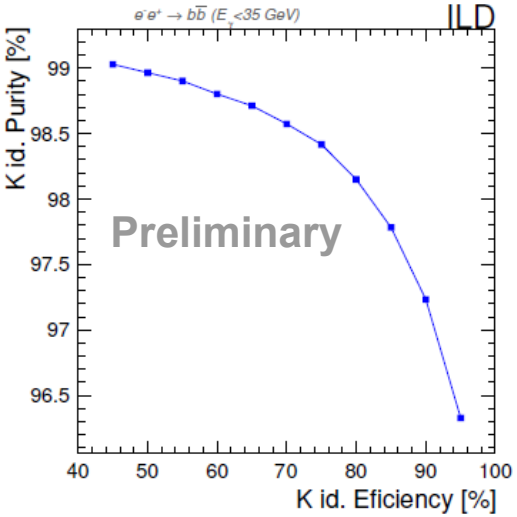

$e^-e^+ \to q\bar{q}$ (q=udscb, K_γ<35 GeV)
ILD
Efficiency
Purity
Only b_{tag}>0.8
b_{tag}>0.8 & $|\vec{p}_{vertex}|$>25 GeV
Preliminary
b_{tag} value


$e^-e^+ \to q\bar{q}$ (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]


$e^-e^+ \to q\bar{q}$ (q=udcsb, E_γ<35 GeV)
ILD
$\frac{dE}{dx}$ [MeV/cm]
p [GeV]
π
K
p
Preliminary

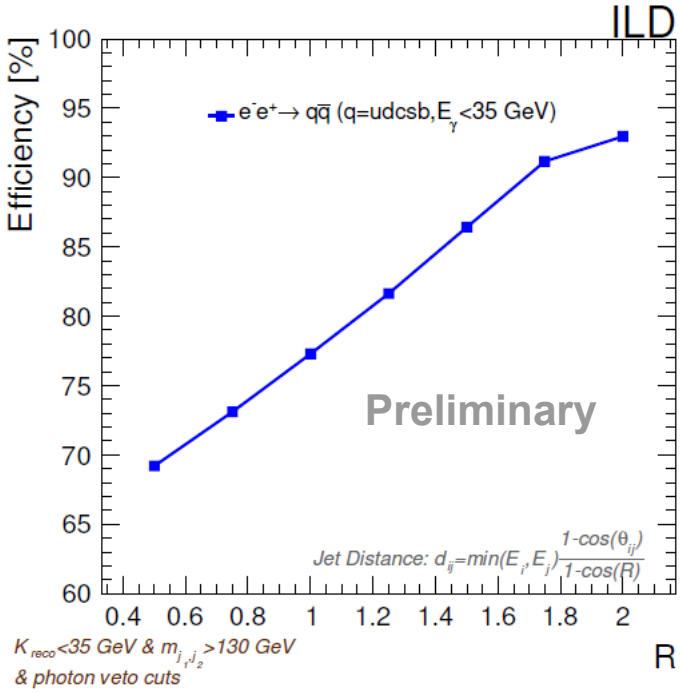

$e^-e^+ \to q\bar{q}$ (q=udcsb, E_γ<35 GeV)
ILD
separation power
p [GeV]
K/π
K/p
Preliminary

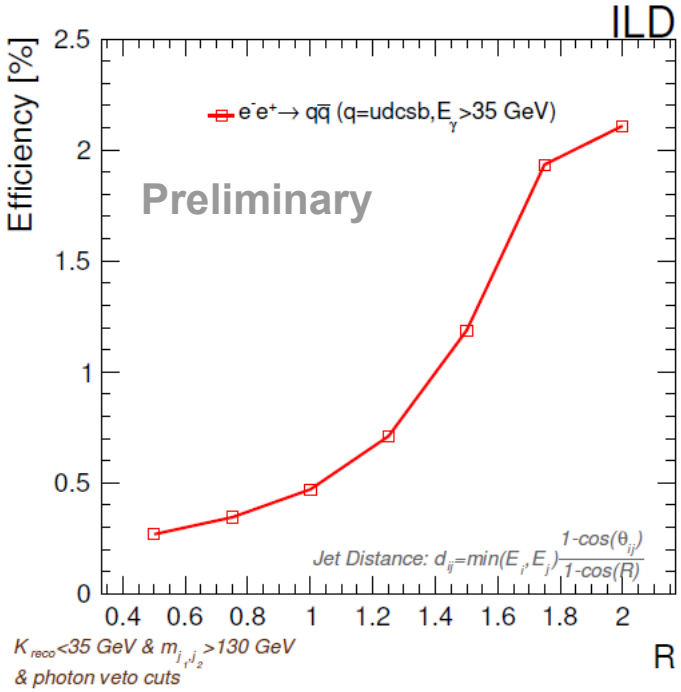

$e^-e^+ \to b\bar{b}$ (E_γ<35 GeV, $\int L$=250fb^{-1})
ILD
entries / GeV
p [GeV]
π
K
p
Preliminary


$e^-e^+ \to b\bar{b}$ (E_γ<35 GeV)
ILD
K id. Purity [%]
K id. Eficiency [%]
Preliminary

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

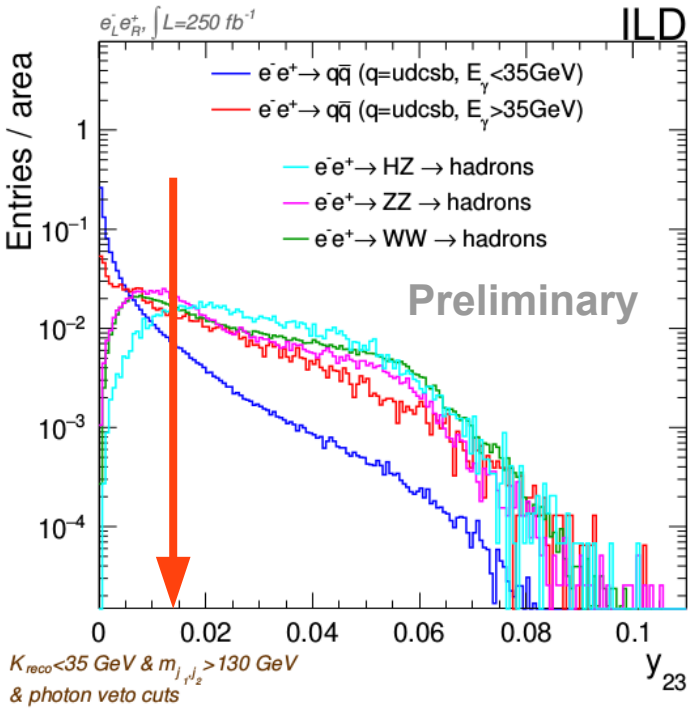
$$d_{iB} = E_i^{2p}$$

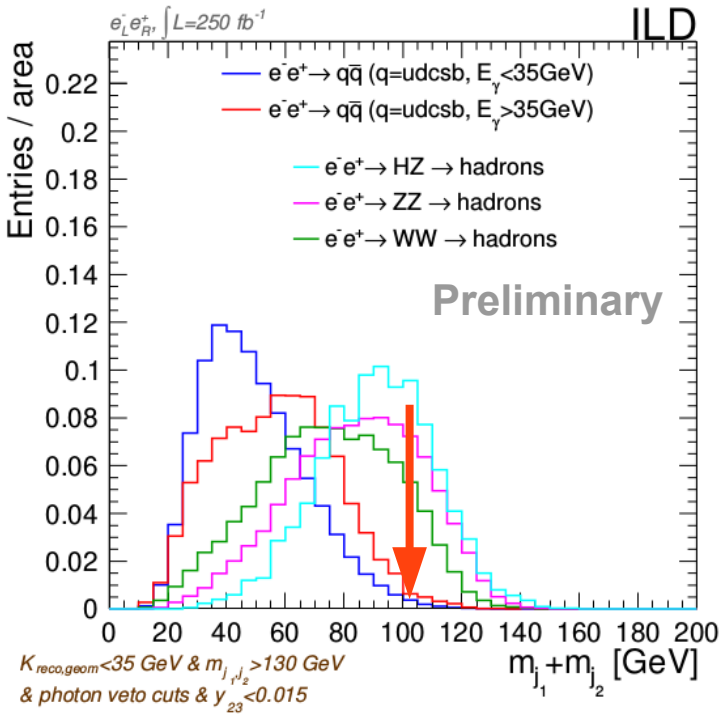




Final steps of the preselection

- 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





Preselection summary

- Cut 1:
  - Kreco<GeV & m(2jets)>130 GeV
- Cut 2:
  - Photon veto cuts
- Cut 3:
  - y23<0.015
- Cut 4:
  - mj1+mj2<100 GeV

- What is the preselection efficiency $\varepsilon_{q\bar{q}}$ for each flavour?
  - It is flat in almost all the detector
  - Almost equal for all flavours