Heavy quark production in high energy electron positron collisions

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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**
ILC physics program

- ILC is a Linear Collider Project, to be hosted in Japan.
  - Matured technology: 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)

- Integrated Luminosity [fb⁻¹]
- Years
- ECM: 250 GeV: 2 ab⁻¹, 500 GeV: 4 ab⁻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

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

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

- 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!)

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

See T. Tanabe's (30/07) talk on ILD
Motivation: LEP/SLC tension

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

- This measurement is the one with largest tension with the SM fit.
- Most precise single Individual determination of $\sin^2 \theta^l_{\text{eff}}$
  from SLC → Left-right asymmetry of leptons
- Most precise single Individual determination of $\sin^2 \theta^l_{\text{eff}}$
  from LEP → forward backward asymmetry (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 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
- 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

\[
\frac{d\sigma}{d\cos\theta}(e^- e^+ \rightarrow f \bar{f}) = \Sigma_{LL}(1 + \cos\theta)^2 + \Sigma_{LR}(1 - \cos\theta)^2
\]

\[
\frac{d\sigma}{d\cos\theta}(e^- e^+ \rightarrow f \bar{f}) = \Sigma_{RR}(1 + \cos\theta)^2 + \Sigma_{RL}(1 - \cos\theta)^2
\]

- 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

- 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
Cross sections

\[ \sigma_{e^- e^+ \rightarrow q\bar{q}} \]

<table>
<thead>
<tr>
<th>Channel</th>
<th>(\sigma_{\text{unpol}}) [fb]</th>
<th>(\sigma_{-,+}) [fb]</th>
<th>(\sigma_{+,+}) [fb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 GeV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q=t</td>
<td>572</td>
<td>1564</td>
<td>724</td>
</tr>
<tr>
<td>q=b</td>
<td>372</td>
<td>1212</td>
<td>276</td>
</tr>
<tr>
<td>q=u+d+s+c</td>
<td>2208</td>
<td>6032</td>
<td>2793</td>
</tr>
<tr>
<td>250 GeV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q=t</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>q=b</td>
<td>1756</td>
<td>5677</td>
<td>1283</td>
</tr>
<tr>
<td>q=c</td>
<td>3020</td>
<td>8518</td>
<td>3565</td>
</tr>
<tr>
<td>q=u+d+s</td>
<td>6750</td>
<td>18407</td>
<td>5463</td>
</tr>
</tbody>
</table>

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**, $R_q$ and forward backward asymmetry $AFB$ observables.

$$R_q^0 = \frac{\Gamma_{qq}}{\Gamma_{\text{had}}(Z-\text{pole})}$$

$\rightarrow$ $R_q^\text{cont.} = \frac{\sigma_{qq}}{\sigma_{\text{had}}(s>Z-\text{pole})}$

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

Angular Distribution.

Quark ID + charge measurement (quark – antiquark disentangling)

Gives access to all left/right couplings.

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$
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 $ee \rightarrow bb/cc/ss...$

- **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/c-quarks: reconstruction efficiencies

- 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

<table>
<thead>
<tr>
<th>Polarization</th>
<th>$\sigma_{e^- e^+ \rightarrow q\bar{q}}(E_\gamma &lt; 35 \text{ GeV})$ [fb]</th>
<th>$\sigma_{e^- e^+ \rightarrow q\bar{q}}(E_\gamma &gt; 35 \text{ GeV})$ [fb]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$bb$</td>
<td>$bb$</td>
</tr>
<tr>
<td>$e_L^- e_R^+$</td>
<td>5677.2</td>
<td>20531.4</td>
</tr>
<tr>
<td>$e_R^- e_L^+$</td>
<td>1283.2</td>
<td>12790.8</td>
</tr>
<tr>
<td>$cc$</td>
<td>8518.1</td>
<td>18363.8</td>
</tr>
<tr>
<td>$q\bar{q}$ ($q = \text{uds}$)</td>
<td>18407.3</td>
<td>57651.3</td>
</tr>
<tr>
<td>$q\bar{q}$ ($q = \text{uds}$)</td>
<td>11810.8</td>
<td>36179.5</td>
</tr>
</tbody>
</table>

$q\bar{q}$ 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 $Z \rightarrow$ 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

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

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

- $\epsilon_b =$ 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

To remove modelling dependence on the efficiency of b-tagging

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

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
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→ 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 remaining ~10% are filtered by identifying photons in the detector (efficiency of ~90%)

▶ Very small B/S ~2%

Arxiv:1709.04289, PoS(EPS-HEP2019)624
ILD Note in progress
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 ~ 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 $|\cos \theta_b| < 0.8$
  - *Minimal impact of the corrections*

<table>
<thead>
<tr>
<th>Beam Polarisation</th>
<th>$(-+)$</th>
<th>$(+-)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta R_b^{cont.}$</td>
<td>0.12 (stat.) ± 0.14 (syst.) %</td>
<td>0.15 (stat.) ± 0.13 (syst.) %</td>
</tr>
<tr>
<td>$\Delta A_{FB}^{bb}$</td>
<td>0.30 (stat.) ± 0.05 (syst.) %</td>
<td>0.85 (stat.) ± 0.10 (syst.) %</td>
</tr>
</tbody>
</table>

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)**

\[
LeLb = QeQb + \frac{LeZLbZ}{s^2wc^2w} \cdot BWZ + \sum_{z'} \frac{LeZ'LbZ'}{s^2wc^2w} \cdot BWZ'
\]

- 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)

- 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: $\sim 0.1\%$  Statistical precision on A FB : $\sim 0.5\%$

Can expect that systematic errors will match statistical precision (but needs to be shown)
Top quark: results (2)

- 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.
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=M2V2RCtYbTFrVi9Ub01kc8h3WFVoZz09

Thanks for your attention.
a BSM example: GUT Inspired Grand Higgs Unificaton Model

- Model parameter is Hosotani angle $\theta_H$
  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 $\theta_H = 0.1$

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

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

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

specifically for the electron:

$$A_e = \frac{\left( \frac{1}{2} - \sin^2 \theta_{eff} \right)^2 - \left( \sin^2 \theta_{eff} \right)^2}{\left( \frac{1}{2} - \sin^2 \theta_{eff} \right)^2 + \left( \sin^2 \theta_{eff} \right)^2} \approx 8 \left( \frac{1}{4} - \sin^2 \theta_{eff} \right)$$

at an unpolarised collider:

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

$\Rightarrow$ no direct access to $A_\theta$, only via tau polarisation

While at a polarised collider:

$$A_e = A_{LR} \equiv \frac{\sigma_L - \sigma_R}{(\sigma_L + \sigma_R)}$$

and

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

trading theory uncertainty:

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

Detector Technologies

Vertex: CMOS, DEPFET, FPCCD, ...

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

ECAL:
Silicon (5x5mm²) or Scintillator (5x45mm²) with Tungsten absorber

HCAL:
Scintillator tile (3x3 cm²) or Gas RPC (1x1 cm²) 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

- Impact parameter resolution
  \( \sigma(d_p) < 5 \times 10^{-10} / (p_{\text{GeV}} \sin^{3/2}\theta) \) µm

- Transverse momentum resolution
  \( \sigma(1/p_T) = 2 \times 10^{-5} \text{ GeV}^{-1} \left( 1 \times 10^{-3} / (p_T \sin^{1/2}\theta) \right) \)

- Jet energy resolution
  3-4% (around \( E_{\text{jet}} \sim 100 \text{ GeV} \))

- Hermeticity
  \( \theta_{\text{min}} = 5 \text{ mrad} \)

Physics

- H\( \rightarrow \)bb, cc, gg, tt
- Total e+e\( \rightarrow \)ZH cross section
- H\( \rightarrow \)invisible
- H\( \rightarrow \)invisible, BSM

R. Ete: “The ILD Software Tools and Detector Performance”
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
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

### Total cross section
- Typical selection efficiencies for 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

**Table 1:**

<table>
<thead>
<tr>
<th>General selection cuts</th>
<th>IDR-L</th>
<th>IDR-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated Lepton</td>
<td>92.1%</td>
<td>92.1%</td>
</tr>
<tr>
<td>$btag_1 &gt; 0.8$ or $btag_2 &gt; 0.3$</td>
<td>81.2%</td>
<td>81.1%</td>
</tr>
<tr>
<td>Thrust &lt; 0.9</td>
<td>81.2%</td>
<td>81.1%</td>
</tr>
<tr>
<td>Hadron mass</td>
<td>78.2%</td>
<td>78.2%</td>
</tr>
<tr>
<td><strong>Reconstructed $m_W$ and $m_t$</strong></td>
<td>73.4%</td>
<td>73.4%</td>
</tr>
<tr>
<td>$\gamma_t^{had} + \gamma_t^l &gt; 2.4$</td>
<td>62.2%</td>
<td>61.8%</td>
</tr>
<tr>
<td>$p_B^{had} &gt; 15$ GeV</td>
<td>34.5%</td>
<td>33.9%</td>
</tr>
<tr>
<td><strong>“$tt$ identification”</strong></td>
<td>30.6%</td>
<td>30.2%</td>
</tr>
<tr>
<td>$b$ quark polar angle spectrum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No additional cuts</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2:**

<table>
<thead>
<tr>
<th>General selection cuts</th>
<th>IDR-L</th>
<th>IDR-S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated Lepton</td>
<td>94.1%</td>
<td>94.0%</td>
</tr>
<tr>
<td>$btag_1 &gt; 0.8$ or $btag_2 &gt; 0.3$</td>
<td>84.9%</td>
<td>84.8%</td>
</tr>
<tr>
<td>Thrust &lt; 0.9</td>
<td>84.9%</td>
<td>84.8%</td>
</tr>
<tr>
<td>Hadron mass</td>
<td>82.2%</td>
<td>82.3%</td>
</tr>
<tr>
<td><strong>Reconstructed $m_W$ and $m_t$</strong></td>
<td>77.6%</td>
<td>77.5%</td>
</tr>
<tr>
<td>$\gamma_t^{had} + \gamma_t^l &gt; 2.4$</td>
<td>64.1%</td>
<td>64.1%</td>
</tr>
<tr>
<td>$b$ quark polar angle spectrum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Vtx + Vtx$</td>
<td>10.8%</td>
<td>10.3%</td>
</tr>
</tbody>
</table>
Predictions (as a function of the ISR)

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

\[
\frac{d\sigma^\text{cont.}}{d\cos\theta_q} (s) \rightarrow \\
\rightarrow \frac{d\sigma_q^{\text{cont.}}}{d\cos\theta_q} (\hat{s} > s_{\text{cut}}) = \frac{d\sigma_{e^-e^+\rightarrow q\bar{q}}}{d\cos\theta_q} (E_\gamma < K_{\text{cut}})
\]
Predictions (as a function of the ISR)

\[ \frac{d\sigma^{\text{cont.}}}{d\cos \theta_q}(E_\gamma < K_{\text{cut}}) \]

- 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 $m(2\text{jets})$?
- 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

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

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

\[ \text{neutraleness}_j = \frac{\sum E_i}{E_j}. \]

**signal**

\[ e^+ e^- \rightarrow b \bar{b} \] \( (K_\gamma < 35 \text{ GeV}) \)

ILD

**radiative return**

\[ e^+ e^- \rightarrow b \bar{b} \] \( (K_\gamma > 35 \text{ GeV}) \)

ILD

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 $y_{23}<0.015$ (jet distance at which the 2 jet event would be clustered in 3 jets)
- Cut on $m_{j1}+m_{j2}<100$ GeV
Preselection summary

- Cut 1:
  - $K_{reco} < \text{GeV} \& m(2\text{jets}) > 130$ GeV

- Cut 2:
  - Photon veto cuts

- Cut 3:
  - $y_{23} < 0.015$

- Cut 4:
  - $m_j1 + m_j2 < 100$ GeV

What is the preselection efficiency $\varepsilon_{qq}$ for each flavour?

- It is flat in almost all the detector
- Almost equal for all flavours