Disentangling Z decays to light quarks

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20.12.2023

Motivation

The Standard Model is the most successful theory describing particle interactions so far but it is not "self-explanatory":

- 19 free parameters?
- neutrino masses?
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New Physics is needed; if it is too heavy to be observed directly, **precision measurements** are crucial to finding any hints of its existence.

Precision EW observables

- Precision electroweak observables may shed light on the existence of BSM physics, e.g. extra gauge bosons.
- Possible discrepancies in the values of the Z couplings to *heavy* quarks can be measured by proper identification of the quark flavour (b-tagging, c-tagging, ...).
- But so far, u- and d-tagging are not available... how to proceed?

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Measurement at e^+e^- colliders

Separate measurements of $\Gamma_{had} \sim (3c_d + 2c_u)$ and $\Gamma_{had+\gamma} \sim (3c_d + 8c_u)$ allow disentangling of the couplings c_d and c_u!

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$$q \in \{u, d\}$$

However, experimentally measured photons can originate not only from the Final State Radiation but also from the Initial State Radiation, hadronisation and decays...

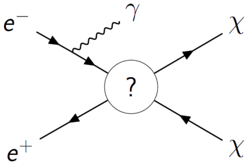
Monte Carlo generation of radiative events

At the Monte Carlo generation level, it is even more complicated:

- $\longrightarrow$ Matrix Element calculations may be either divergent or very slow for small angles,
- $\longrightarrow$ ISR structure function can be used for small angles but a proper matching procedure is needed,
- $\longrightarrow$ FSR showers are important to account for QCD emissions but they may cause double-counting,
- $\longrightarrow$ photons coming from hadronisation and decays have to be included.

Starting point

Some part of the work has already been done...



Simulating hard photon production with WHIZARD
J. Kalinowski *et al.*, arXiv:2004.14486

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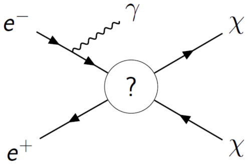

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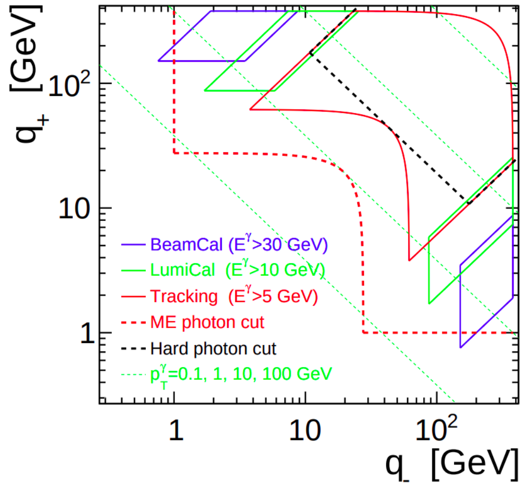
General idea:

- soft ISR photons simulated using the built-in structure function
- hard ISR photons simulated at the ME level
- matching in $q_\pm$ and E_γ ('ISR rejection'):

$$q_- = \sqrt{4E_0E_\gamma}\sin\frac{\theta_\gamma}{2}$$
$$q_+ = \sqrt{4E_0E_\gamma}\cos\frac{\theta_\gamma}{2}$$

(q_+, q_-) plane



CLIC 380 GeV, arXiv:2004.14486

Extension of the procedure

Simulating events with Whizard and Pythia6 (shower and hadronisation)

1. ME cuts:
   - all γ's: $q_{\pm} > 1$ GeV and $E > 1$ GeV and $M(\gamma, q_i) > 1$ GeV
   - any γ: $p^T > 2$ GeV and $5^\circ < \theta < 175^\circ$ [useful for efficiency]

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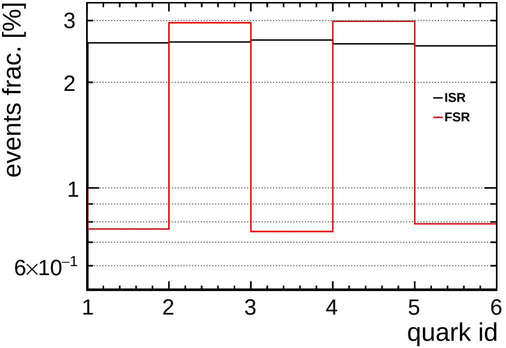
2. event selection:
   - all ISR SF γ's: $q_{\pm} < 1$ GeV or $E < 1$ GeV or $M(\gamma, q_i) < 1$ GeV
   - all FSR show. γ's whose parents are initial $q/\bar{q}$:

     $q_{\pm} < 1$ GeV or $E < 1$ GeV or $M(\gamma, q_i) < 1$ GeV

Efficiency of the procedure

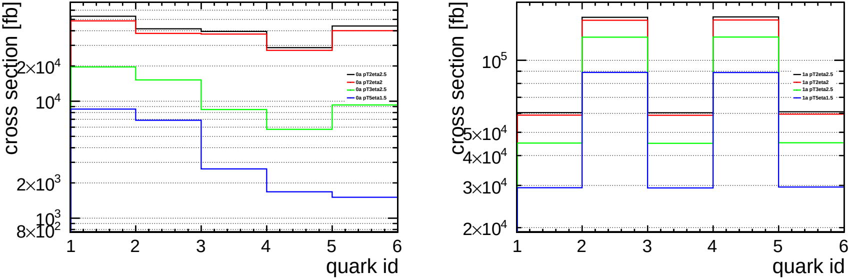
- At the Z-pole, the ISR is reduced so the dominant contribution should come from the FSR.
- Only 4% of Whizard events are rejected.



normalised per flavour

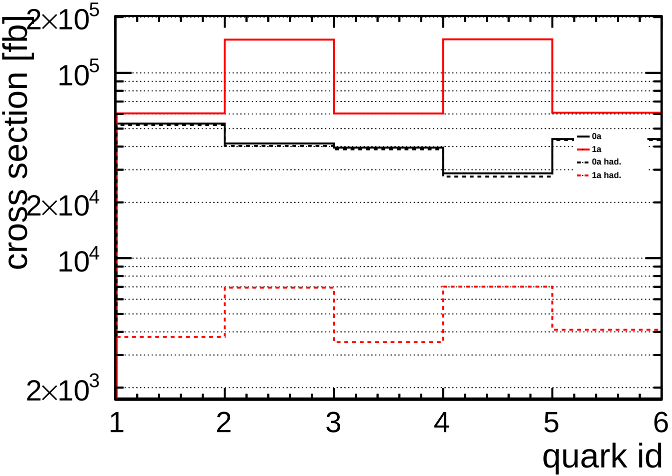
Reconstruction

- detector simulation in Delphes with default *ILCgen* cards
- analysis cuts:
  - 2 jets
  - exactly 1 reconstructed photon with specific (p^T, η)
  - no other activity in the detector

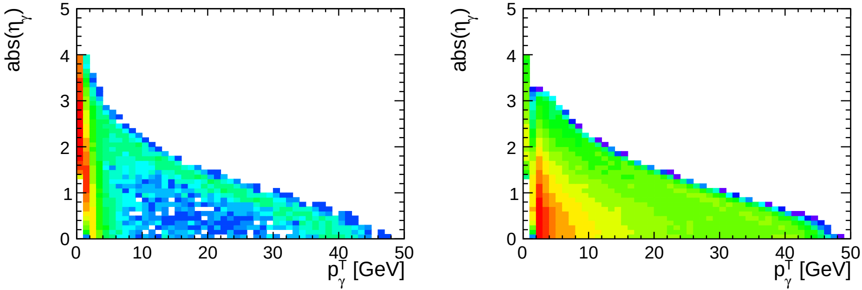


0γ vs. 1γ

Hadronisation photons



(p^T, η) distribution



0γ vs. 1γ

By a wise choice of the cuts, one may obtain a ratio of $N_{1\gamma}/N_{0\gamma} > 20$, keeping the event statistics at a reasonable level.

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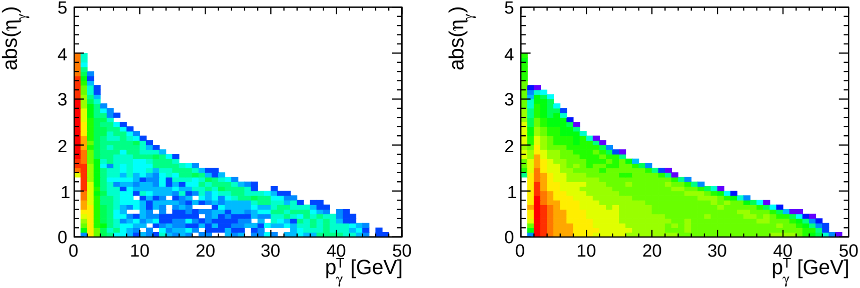

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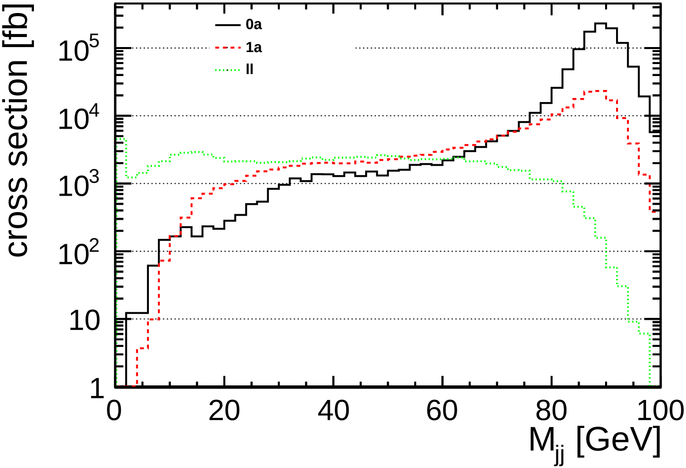
Disclaimer: $Z \rightarrow \tau^+\tau^-$ has to be kept under control.

M_{jj}



0a
1a
ll
cross section [fb]
10^5
10^4
10^3
10^2
10
1
0
20
40
60
80
100
M_{jj} [GeV]

Prospects and conclusions

- We wanted to estimate how well couplings of the Z boson to light quarks can be measured.
- We have established a dedicated generation procedure accounting for photons coming from different sources.
- We have performed preliminary studies on the experimental cuts and their efficiency.
- The next step is to study photon isolation criteria which are crucial for reducing the contribution originating from hadronisation and decay.
- Our ultimate goal is to estimate the uncertainty of the measurement at ILC depending on the reconstruction criteria and experimental cuts.
- Work in progress...