High-energy particles in the FCAL detectors

S. Lukić

Vinča institute of nuclear sciences, University of Belgrade

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Introduction

Questions to be answered by this analysis

- Influence of single particles from coincident Bhabha events (and other processes) on the luminosity measurement
- Influence of the luminosity spectrum and longitudinal boost on the 4f backgrounds in the luminosity measurement
- Coincident events and the electron tagging
- How important is the distinction of hadrons in the very forward region?
  - Relevant to particle-type distinction in the FCAL detectors and the L* (importance of LHCAL)
  - The answer given here is limited to the context of the luminosity measurement and electron tagging.

Most important processes emitting high-energy particles in the FCAL angular range

- Bhabha scattering
  - High cross section
  - Cross-section scales with $1/s$ and with θ^{-3}
    $\rightarrow$ large numbers of particles boosted into the FCAL angular range due to Beamstrahlung
- Four-fermion scattering
  - Main source of hadronic background
  - Can give a Bhabha-event signature

Two ways in which these backgrounds affect measurements

- Mimicking the signal signature
  - Relative systematic uncertainty defined by the ratio σ_B/σ_S after event selection
- Coincidence with the signal
  - Events that occur very often may add particles to signal events
  - Relative systematic uncertainty defined by the probability of occurence of the background event in 1 timestamp (note: no dependence on the signal xs)

Analyses affected by high-energy particles in the FCAL detectors

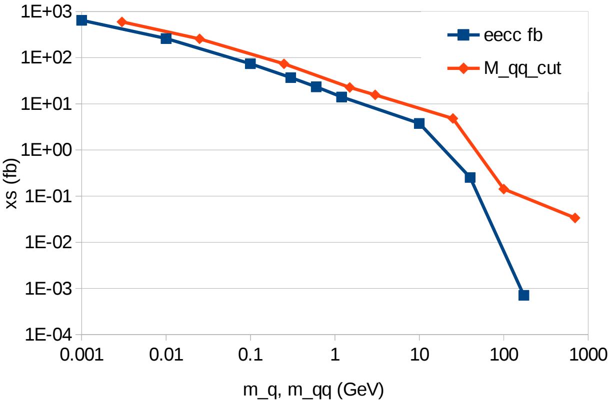
- Luminosity measurement
  - High precision required
  - Sensitive to processes faking the signature AND to processes producing one-side hits with high probability
- Electron tagging
  - Improtant for analyses with missing energy in the signal signature and with strong backgrounds with spectator electrons
  - Sensitive to processes producing one-side hits with high probability leading to false electron tags

Cross-section calculations

Cross-section calculation of relevant processes

- WHIZARD 2.2 using luminosity files from Guinea-Pig
- FSR not simulated at this stage (will be added later)
- Difficulty: For processes with the exchange of photons in the T-channel and/or associated production of very light or massless fermions, the scattering amplitude changes orders of magnitude for small angles. Reweighting of the phase-space grid difficult
- Bhabha scattering: Cut on the momentum exchange mandatory. All calculated Bhabha xs relatively stable with $-\sqrt{Q^2} \lesssim -4\,\text{GeV}$
- Four-fermion production:
  - Flavour summation gives **wrong** results because of nontrivial effect of particle masses on the cross sections
  - Reasonable stability of xs for $t\bar{t}$, $b\bar{b}$, $c\bar{c}$, $s\bar{s}$, $\tau^+\tau^-$, $\mu^+\mu^-$ produced alongside e^+e^- spectators
  - Difficult convergence for $e^+e^-u\bar{u}$, $e^+e^-d\bar{d}$ and $e^+e^-e^+e^-$– Cross-check by scanning the mass-dependence of the xs or by imposing a cut on the $\sqrt{s_{f\bar{f}}}$

Cross-section calculation of relevant processes



Dependence of the cross section for a fake Bhabha signature from the $e^+e^-q\bar{q}$ process

Results

Luminosity measurement – 500 GeV ILC

Process	cross-section (nb)	Rel. syst. unc. (uncorrected)
Signal	1.39	–
4f – lumi signature total	0.0063	4.5×10^{-3} (new)
4f – lumi signature hadrons	4.7×10^{-5}	3.3×10^{-5}
Coinc. Bhabha evts / one side	2.05	5.3×10^{-3}
4f total	0.087	2.4×10^{-4}
4f hadronic	0.0019	5.2×10^{-6}

- Lumi cut (one particle): $E > 200$ GeV, $41\,\mathrm{mrad} < \theta < 67\,\mathrm{mrad}$
- Lumi signature: Lumi cut + E_{CM} cut + 2-sides coincidence

Luminosity measurement – 1.4 TeV CLIC

Process	cross-section (nb)	Rel. syst. unc. (uncorrected)
Signal	0.147	–
4f – lumi signature total	0.00122	8.3×10^{-3}
4f – lumi signature hadrons	2.0×10^{-5}	1.4×10^{-4}
Coinc. Bhabha evts / one side	0.35	0.019
4f total	0.017	9.0×10^{-4}
4f hadronic	0.0025	1.3×10^{-4}

- Lumi cut (one particle): $E > 350$ GeV, $43\,\text{mrad} < \theta < 80\,\text{mrad}$
- Lumi signature: Lumi cut + E_{CM} cut + 2-sides coincidence

Electron tagging – 500 GeV ILC

Process	cross-section (nb)	Rel. syst. unc. (uncorrected)
Bhabha – tagging cut	6.07	0.016
4f – tagging cut	0.312	8.4×10^{-4}
4f – tagging cut hadrons only	0.034	9.1×10^{-5}

- Tagging cut: One particle, E $>$ 100 GeV, $\theta > 30\,\text{mrad}$

Electron tagging – 1.4 TeV CLIC

Process	cross-section (nb)	Rel. syst. unc. (uncorrected)
Bhabha – tagging cut	1.30	0.068
4f – tagging cut	0.079	4.3×10^{-3}
4f – tagging cut hadrons only	0.015	7.9×10^{-4}

- Tagging cut: One particle, E > 200 GeV, $\theta > 30\,\mathrm{mrad}$

Free bonus: Coincident electrons from Bhabha scattering in the MAIN detector – 1.4 TeV CLIC

p_T cut (GeV)	cross-section (nb)	P_{hit}(20 BX) %
5	0.212	1.14
10	0.152	0.82
20	0.103	0.56
50	0.055	0.30

- Cut (one particle): $140\,\mathrm{mrad} < \theta < \pi - 140\,\mathrm{mrad}$

Conclusions and outlook

Conclusions

- Bhabha events represent an important background in the electron tagging context, but also in the luminosity measurement!
- Updated calculations for four-fermion production as a background for the luminosity measurement (luminosity spectrum and the longitudinal event boost taken into account)
  - 500 GeV ILC: $\sigma_{4f}/\sigma_{Bhabha} = 4.5 \times 10^{-3}$
  - 1.4 TeV CLIC: $\sigma_{4f}/\sigma_{Bhabha} = 8.8 \times 10^{-3}$
- Distinction of hadrons at low angles (in the FCAL or LHCAL detectors) is of little importance for the Luminosity measurement and electron tagging
- Free bonus: Precise measurements ($\delta\sigma/\sigma < 1\%$) at CLIC should take into account electrons coming from Bhabha scattering in the main detector.

To be done

- Include FSR and tau decays – small increase in 4f cross sections expected due to muons and taus emitting FSR
- Apply selections to coincident backgrounds in luminosity measurement (coplanarity; pick the most energetic electron on each side)
- Review the status of the uncertainty of the luminosity measurement