Bhabha event pileup in the FCAL detectors

S. Lukić

Vinča institute of nuclear sciences, University of Belgrade

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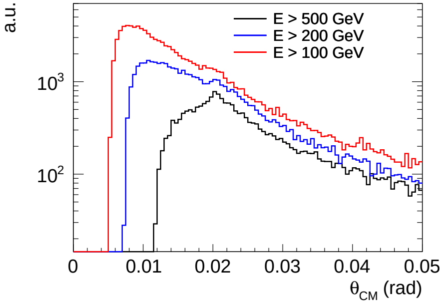
Introduction

Influence of Beamstrahlung on the Bhabha event rate in the FCAL detectors

- Bhabha cross-section scales with $1/s$ and with θ^{-3}
- Beamstrahlung effects:
  - Energy loss $\rightarrow$ Cross-section increases
  - Longitudinal boost $\rightarrow$ Particles from very small-angle Bhabha events reach the detector (with relatively low energy in the lab frame).
- Very different effect on the rate for detection of the **Bhabha event signature** vs. **1-side hits**



CM scattering angle of Bhabha particles detected above 20 mrad in the lab frame

Consequences of the pile up

- Boosted Bhabha events may "add electrons" to the analysed events and thus **change the apparent signature**
- Systematic uncertainty depends on the **probability of detection of a single particle from a bhabha event** in 1 timestamp (note: no dependence on the signal xs)

Analyses affected by the Bhabha event pileup

- Luminosity measurement
  - Pileup adds a third electron to the event
  - Need to distinguish the "guest" electron by the azimuthal angle and the time stamp
- Electron tagging
  - False tags due to single Bhabha electrons
  - High rates at the smallest angles
- Precise analyses with forward electrons in the signal final state (in the main detector)

Cross-section calculation

- WHIZARD 2.2 using luminosity files from Guinea-Pig and ISR in the collinear approximation. (No FSR)
- Bhabha xs uncertainties several % (comparison with BHWIDE)
- More important: 2D luminosity spectrum taken into account

Results

Luminosity measurement – 500 GeV ILC

Pileup adds a third electron (possibly also a fourth) to detected Bhabha events, leading to confusion in the reconstruction.

Process	cross-section (nb)	Pileup prob.
Signal	1.39	3.6×10^{-3}
Single-hit Bhabha / BX	2.05	5.3×10^{-3}
Coplanar single-hit ($\Delta\phi < 6°$) / BX	2.05	8.8×10^{-5}

- Lumi signature: $E_{CM} > 400\,\mathrm{GeV}$, $41\,\mathrm{mrad} < \theta < 67\,\mathrm{mrad}$ (2-side detection)
- Single-hit cut: E > 200 GeV, $41\,\mathrm{mrad} < \theta < 67\,\mathrm{mrad}$

Luminosity measurement – 1.4 TeV CLIC

Pileup adds a third electron (possibly also a fourth) to detected Bhabha events, leading to confusion in the reconstruction.

Process	cross-section (nb)	Pileup prob.
Signal / 312 BX	0.147	0.116
Signal / 20 BX	0.147	7.9×10^{-3}
Single-hit Bhabha / 312 BX	0.35	0.25
Single-hit Bhabha / 20 BX	0.35	0.019
Coplanar single-hit ($\Delta\phi < 6°$) / 312 BX	0.35	4.9×10^{-3}
Coplanar single-hit ($\Delta\phi < 6°$) / 20 BX	0.35	3.1×10^{-4}

- Lumi signature: $E_{CM} > 1000\,\text{GeV}$, $43\,\text{mrad} < \theta < 80\,\text{mrad}$ (2-side detection)
- Single-hit cuts: $E > 350\,\text{GeV}$, $43\,\text{mrad} < \theta < 80\,\text{mrad}$
- Important to use both the timing and the coplanarity cuts

Electron tagging – 500 GeV ILC

Pileup implies a loss of statistics due to false tagging of events.

Process	cross-section (nb)	Pileup prob.
Bhabha – tagging cut	6.07	0.036

Tagging cut (*ad hoc*):
At least one particle, E > 100 GeV, $20\,\mathrm{mrad} < \theta < 140\,\mathrm{mrad}$

Electron tagging – 1.4 TeV CLIC

Pileup implies a loss of statistics due to false tagging of events.

Process	cross-section (nb)	Pileup prob.
Bhabha – tagging cut / 312 BX	1.30	0.67
Bhabha – tagging cut / 20 BX	1.30	0.068

Tagging cut (*ad hoc*):
At least one particle, $E > 200$ GeV, $30\,\text{mrad} < \theta < 140\,\text{mrad}$

Electrons from piled-up Bhabha scattering in the MAIN detector

p_T cut	1.4 TeV CLIC		500 GeV ILC	
(GeV)	xs (nb)	P_{hit} (%)	xs (nb)	P_{hit} (%)
5	0.212	1.14	0.471	0.12
10	0.152	0.82	0.353	0.09
20	0.103	0.56	0.283	0.07
50	0.055	0.30	0.097	0.03

- Cut (at least one particle):
  - $140\,\text{mrad} < \theta < \pi - 140\,\text{mrad}$,
  - $p_T > p_{T,cut}$

Conclusions and outlook

Conclusions

- Pileup of Bhabha events needs to be taken into account in the following contexts:
  - **Luminosity measurement**: coplanarity and timing cuts required to reduce confusion to an acceptable level
  - **Electron tagging**: Angular and energy cuts required; reduction of event statistics to be taken into account
  - **Main detector**: Significant effects in precise measurements at CLIC

Outlook

- More detailed study of the luminosity measurement using detector simulation and reconstruction
- Write analysis code that takes reconstructed events as input. Test with realistic Bhabha pileup and beam backgrounds.

Thank you!

Spare slides

Luminosity measurement – 3 TeV CLIC

Process	cross-section (nb)	Pileup prob.
Signal / 312 BX	0.049	0.057
Signal / 20 BX	0.049	3.7×10^{-3}
Single-hit Bhabha / 312 BX	0.072	0.082
Single-hit Bhabha / 20 BX	0.072	5.4×10^{-3}
Coplanar single-hit ($\Delta\phi < 6°$) / 312 BX	0.072	1.4×10^{-3}
Coplanar single-hit ($\Delta\phi < 6°$) / 20 BX	0.072	9.1×10^{-5}

- Lumi signature: $E_{CM} > 2200\,\text{GeV}$, $43\,\text{mrad} < \theta < 80\,\text{mrad}$ (2-side detection)
- Single-hit cuts: $E > 800\,\text{GeV}$, $43\,\text{mrad} < \theta < 80\,\text{mrad}$
- To avoid systematics from the pile up, it is important to use at least the coplanarity cuts

Electron tagging – 3 TeV CLIC

Process	cross-section (nb)	Rel. syst. unc. (uncorrected)
Bhabha – tagging cut	0.60	0.045
4f – tagging cut	0.037	2.8×10^{-3}
4f – tagging cut hadrons only	7.4×10^{-3}	5.6×10^{-4}

- Tagging cut (at least one particle):
  - $E > 500$ GeV,
  - $20\,\text{mrad} < \theta < 140\,\text{mrad}$