Precise luminosity measurement in the presence of beam-beam effects at an e^+e^- collider

A simulation study

S. Lukić
On behalf of the HEP Group Vinča Belgrade

Vinča Institute of Nuclear Sciences, University of Belgrade

FCC-ee Physics Workshop TLEP8
27-29 October 2014 LPNHE, Paris

Introduction

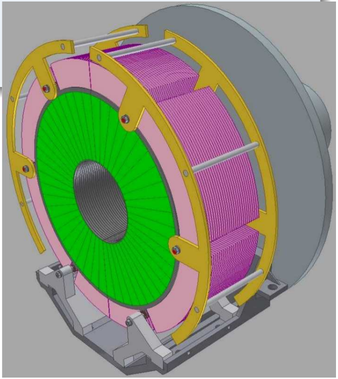
Luminosity measurement at a e^+e^- collider

Principle

- Bhabha scattering as the gauge process $L = \frac{N_{Bhabha}}{\sigma_{Bhabha}}$
  - High final energies
  - Small angles $\frac{d\sigma}{d\theta} \propto \theta^{-3}$
  - High cross section
  - Well known process - precise calculation
- Precision at LEP better than 0.6 permille

Instrumentation

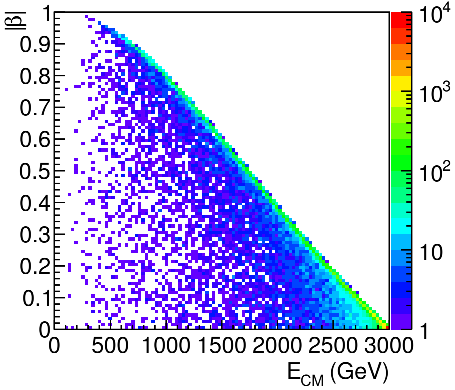
- Very forward luminosity calorimeter
  - W-semiconductor layers
  - Very compact
  - Fine segmentation
  - Limited angular range (ca. 2°– 5°)



FCAL Luminosity calorimeter concept for Linear Colliders

Energy loss and a 2D Luminosity spectrum

- High energy and charge density at future colliders
  - Beamstrahlung causes boost of the events.
  - 2D luminosity spectrum – $\mathcal{L}(E_{CM}, \beta)$ or $\mathcal{L}(E_1, E_2)$



The most extreme case among current e^+e^- collider projects: $\mathcal{L}(E_{CM}, \beta)$ at a 3 TeV CLIC (left)

Counting loss and correction

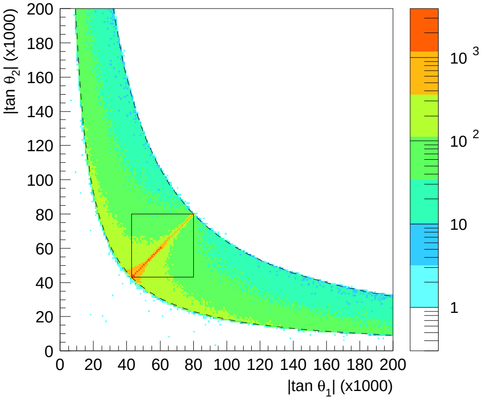
Boost and the counting loss

In practice, the luminosity figure is obtained as,

$$L = \frac{N(\Xi(\Omega_{1,2}^{lab}, E_{1,2}^{lab}))}{\sigma(Z(\Omega_{1,2}^{evt}, E_{1,2}^{evt}))}$$

However:

- Boost of the Bhabha event leads to acollinearity of the final angles and to counting loss
- First studied by C. Rimbault, P. Bambade, K. Mönig and D. Schulte in 2007
- A crucial issue is to match the selection criteria in the lab vs. the event frame in a **data-driven** way. If this is done by the bunch-crossing simulation, problem of large uncertainties of the beam parameters

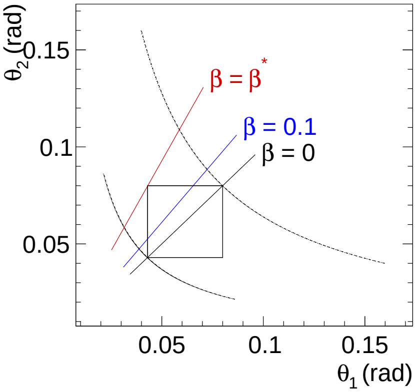


Distribution of polar angles of the final Bhabha particles in the lab frame at a 3 TeV CLIC. Selected for angular range in the collision frame.

Correction of the counting loss

- Kinematic properties (E_{CM}, β) of the collision frame of the Bhabha scattering accesible in the experiment
- Effective acceptance ϵ_{eff} of the luminosity calorimeter can be corrected using β deduced from final angles as long as $\beta < \beta^*$ (i.e. $\epsilon_{eff} > 0$)

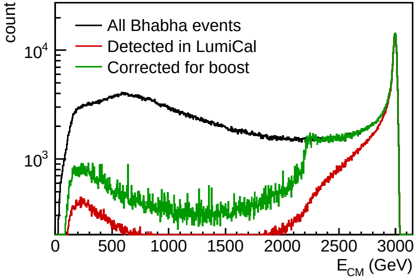
$$w(\beta) = \frac{\int_{\theta_{min}}^{\theta_{max}} \frac{\mathrm{d}\sigma}{\mathrm{d}\theta}\,\mathrm{d}\theta}{\int_{\theta^{coll}_{min}}^{\theta^{coll}_{max}} \frac{\mathrm{d}\sigma}{\mathrm{d}\theta}\,\mathrm{d}\theta}$$



Schematic of the mechanism of the counting loss and the proposed correction.

Results

- Method tested on MC particles. Detector effects approximated as:
  - Particles collinear to 5 mrad (Molière radius) lumped together
  - MC 4-momenta smeared for energy and angular resolutions
- Correction successful to better than 1 permille above ca. 70 – 80 % of the nominal CM energy (the exact E_{CM} limit depends on the calorimeter angular range)
- Most events below the E_{CM} limit have $\beta > \beta^*$



Correction of the effective acceptance loss due to the event boost at a 3 TeV CLIC

Cross section

The proposed correction allows unambiguous matching of the selection criteria for the cross-section calculation

Reminder: $$L = \frac{N(\Xi(\Omega_{1,2}^{lab}, E_{1,2}^{lab}))}{\sigma(Z(\Omega_{1,2}^{coll}, E_{1,2}^{coll}))}$$

Required cuts

- Angular cuts on the final particles are made in the collision frame
  - Straightforward in the generator
- Cut on the CM energy of the event –
  - Requires good criteria (i.e. collinearity cut for the FSR) which final particles participate in the reconstruction of the event – ultimately to be answered by full detector simulation

Summary

Summary

- Event boost due to Beamstrahlung causes a systematic counting loss in luminosity measurement at LC
- Challenge: correct expeimental acceptance loss in a **data-driven manner** so that the corresponding **cross-section can be integrated within well-defined cuts**
- Correction of the luminosity spectrum using β determined from final Bhabha particle angles
    - **Absolute** luminosity in the peak with permille precision
    - Experimental cuts linked to the cuts for the cross-section calculation in the **most direct way so far**
    - Limitation to the upper part of the luminosity spectrum