Forward electron tagging in the $h \rightarrow \mu \mu$ analysis at 1.4 TeV

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Motivation

- Remove part of the background by identifying electrons in Lumical and BeamCal
- Example: Study of the Higgs decay to a pair of muons
  - At 3 TeV CLIC, the statistical uncertainty of $\sigma(ee \rightarrow h\nu\nu) \times BR(h \rightarrow \mu\mu)$ drops from 23% to 16% if electron-tagging is used to remove the 4 fermion background (Christian, LCD-Note-2011-35; Christian PhD thesis)

Angular distributions of the first and the second most energetic electron after application of electron tagging (C. Grefe, LCD-Note-2011-35)
Methods so far

- Christian: Select the two most energetic electrons and declare tagged in 99% of cases in LumiCal, and in 70% of cases in BeamCal
  - Reasonable assumptions, demonstrated effectiveness in removing background
  - Realistic assumptions on efficiency, confirmed by BeamCal simulation by Andre
- Missing:
  - Energy dependence of tagging
  - Lower-energy electrons and gammas not in the picture.
- Is there a significant difference in the end result?
Methods so far

- Andre (as of ECFA 2013):
  - Tagging efficiency in BeamCal for electrons with $E \geq 500$ GeV, from simulation under background conditions of 3 TeV CLIC, integrated over 40 BX
  - C++ library with functions to extract the tagging probability from simulated data, or to tag an event, based on the 4-momentum of the electron
  - Above 500 GeV, $\varepsilon \approx 100\%$
  - Below 500 GeV, no data, so $\varepsilon = 0$
Desired properties of the tagging method

- Tag all events containing particles that would generate a shower *distinct from background* in LumiCal or BeamCal
- No restriction on the two most energetic electrons
- Include gammas
- Add together the 4-momenta of electrons and gammas that are closer than 5 mrad to each other
- Determine and/or parametrize the tagging probability in a fast and efficient way (avoid simulation of a large number of electrons in the forward region for each of the energy options)
Shower distinct from background

- Which particle will generate a shower distinct from background in one of the forward calorimeters?
  - Rigorous answer only by full simulation at many different energies
- Fast estimate by a reasonable parametrization?
- Naive, ad hoc, preliminary requirement

*The deposit from the electron has to be more than $2\sigma$ above backgd. in at least 10 layers*

- Background deposition profile almost constant
  - Require $4\sigma$ in the layer with maximum deposition
    (Easier to handle in the parametrized approach)
Shower distinct from background

• *What is the RMS background fluctuation in the layer with maximum deposit?*

• Simulation of energy depositions of background in LumiCal at the 3TeV CLIC, R. Schwarz, FCAL workshop in CERN, Nov 2012

• Fluctuations of the background energy deposit as a function of the polar angle (Given in terms of $a_{res}$ for a 1500 GeV electron)

• Extract $\sigma_{bkgd}(\theta)$ independent of the electron energy, for 100 BX
Tagging procedure for an event in LumiCal

- Loop over all final electrons, positrons or gamma (EPG) in the event record (*MCParticleSkimmed* collection)
- Add up 4-momenta of all other, previously untested, final EPG within 5 mrad from the same collection
- Is the resulting shower in the LumiCal angular range?
- Construct the equivalent energy deposit:
  \[ E_{\text{dep}} = E_{\text{el}} + \langle E_{\text{bkgd}} \rangle + \Delta E_{\text{bkgd}} + \Delta E_{\text{res}} \]

\( \Delta E_{\text{bkgd}} \) is sampled from a Gaussian distribution with \( \sigma_{\text{bkgd}}(\theta) \)

\( \Delta E_{\text{res}} \) is sampled from a Gaussian distribution with \( \sigma_{\text{res}} = a_{\text{res}} \sqrt{E_{\text{el}}} \)

- Test: \( E_{\text{dep}} > \langle E_{\text{bkgd}} \rangle + 4 \sigma_{\text{bkgd}} \)
- Yes → Tag! No → loop
Tests on single electrons

- Efficiency in LumiCal, at $\theta = 50$ mrad
  Tested 1000 “electrons” per energy point
  $4\sigma_{bkgd} \approx 100 \text{ GeV}$
Performance on a background sample

- Test on $ee \rightarrow e\mu\mu$
- Tagging in LumiCal from 38 to 140 mrad
- Tagging in BeamCal (library by Andre) from 15 to 35 mrad
- Background conditions of the 3 TeV CLIC
- Visible kink due to BeamCal at 500 GeV

![Energy distribution graph](chart.png)
Tagging probability & co.

• Taging probability for the two most energetic electrons (4-f background):
  • LumiCal: 98.5%
  • BeamCal: 52%

• Ratio of tagged events to events tagged on one of the two most energetic electrons (4-f background)
  • Lumical : 1.08 : 1
  • BeamCal: At the moment no tags below 500 GeV

• Overall tagging rate for different processes:
  • 4-f background: 25%
  • $e\gamma \rightarrow e\mu\mu$ : 15%
  • Signal: 0.2 %

• Statistical uncertainty of $\sigma(h\nu\nu) \cdot BR(h \rightarrow \mu\mu)$ at 1.4 TeV drops from 30% to 28% (low statistic of the signal + irreducible background)
Conclusions

• Tagging probability can be simulated by parametrization of background deposit fluctuations in the calorimeter
  • A single simulation of background in the forward calorimeters sufficient for each energy option

• Tagging rate close to 100% in LumiCal confirmed under conservative assumptions (background from 3 TeV)
  • Inclusion of low-energy electrons and gammas results in a small increase in the number of tagged events

• The tagging rate for the signal is 0.2% → no need for an additional energy threshold to spare the signal

• Ad hoc number of layers required for recognition of an EM shower (defines the basic energy threshold for tagging)

• BR uncertainty in $h \rightarrow \mu\mu$ dominated by the small statistic of the signal, and by the irreducible background