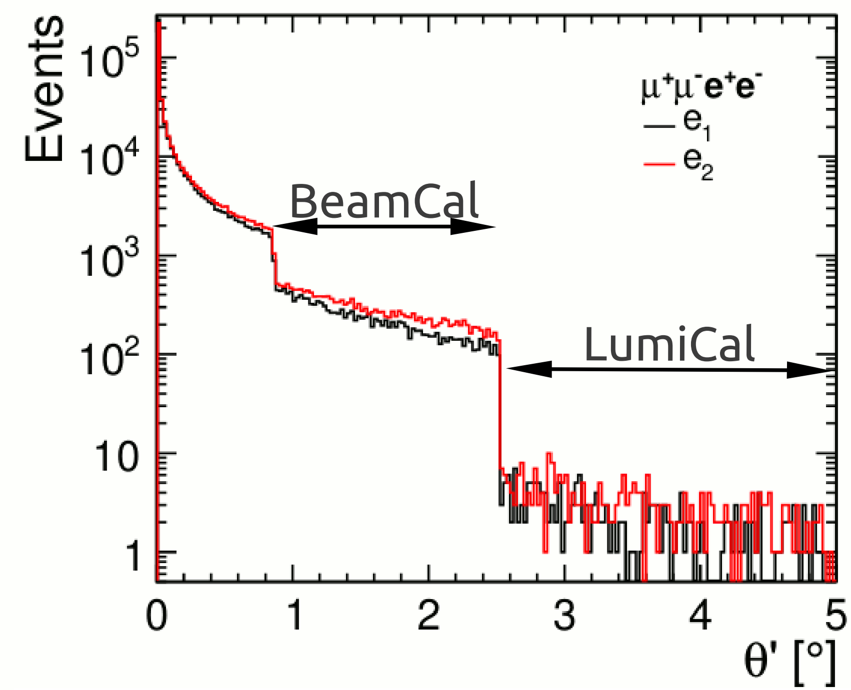
Fast simulation of forward shower tagging in physics analyses

S. Lukić, FCAL Workshop, Zeuthen, Oct. 2013

Motivation

- FCAL region, among else, to *improve detector hermeticity at low angles* (ILD LoI, SiD LoI, JINST 5 P12002, 2010)
- Many experiments can use particle identification in FCAL (some recent ones: Dark matter search, Higgs by ZZ fusion)
- Example: Study of Higgs decay to a pair of muons
    - At 3 TeV CLIC, the statistical uncertainty of $\sigma(ee \to h\nu\nu)$ x BR($h \to \mu\mu$) drops from 23% to 16% if electron-tagging is used to remove the 4 fermion background (C. Grefe, LCD-Note-2011-35)
- More on this in Mila's talk...



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

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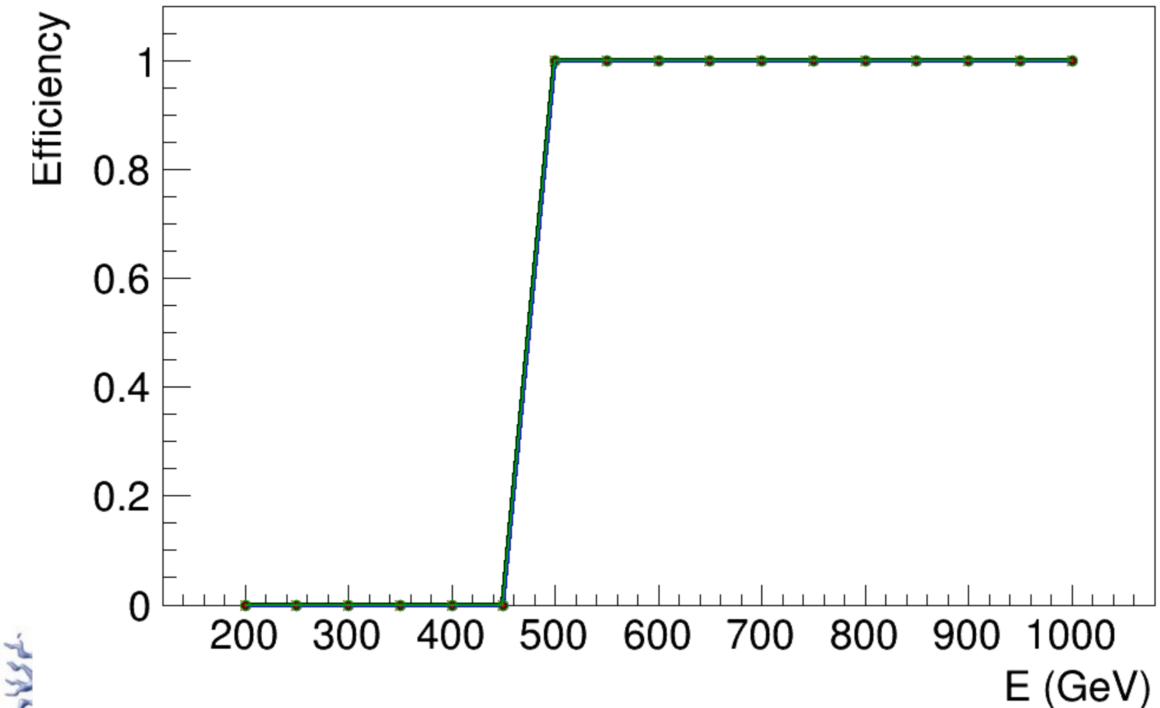
Covered so far

- BeamCal (André):
  - 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 probabilityfrom 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
- 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
- Distinguish EM and hadronic showers (at least)

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 including reconstruction
- Fast estimate by a reasonable parametrization?
- Naive, ad hoc, preliminary requirement

  The deposit from the electron has to be more than 2σ above backgd. in at least 10 layers
- Background deposition profile almost constant

→ *Require 4σ in the layer with maximum deposition* (Easier to handle in the parametrized approach)

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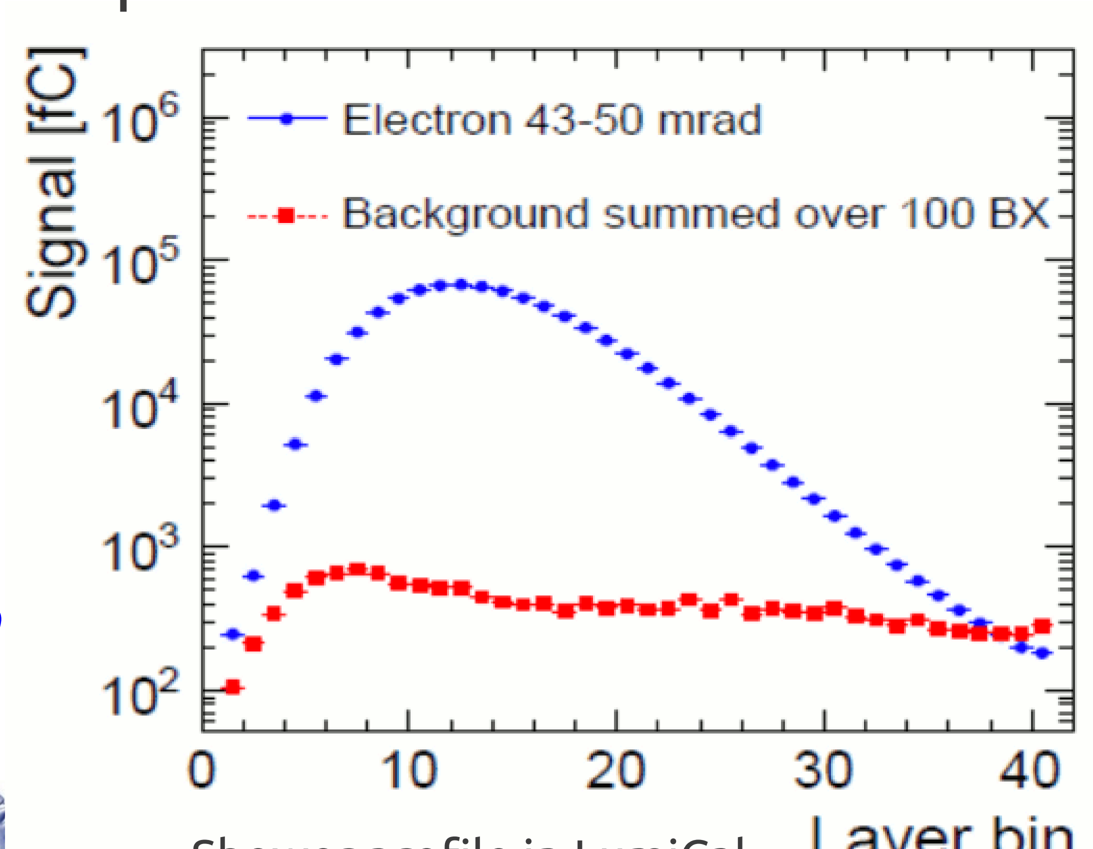
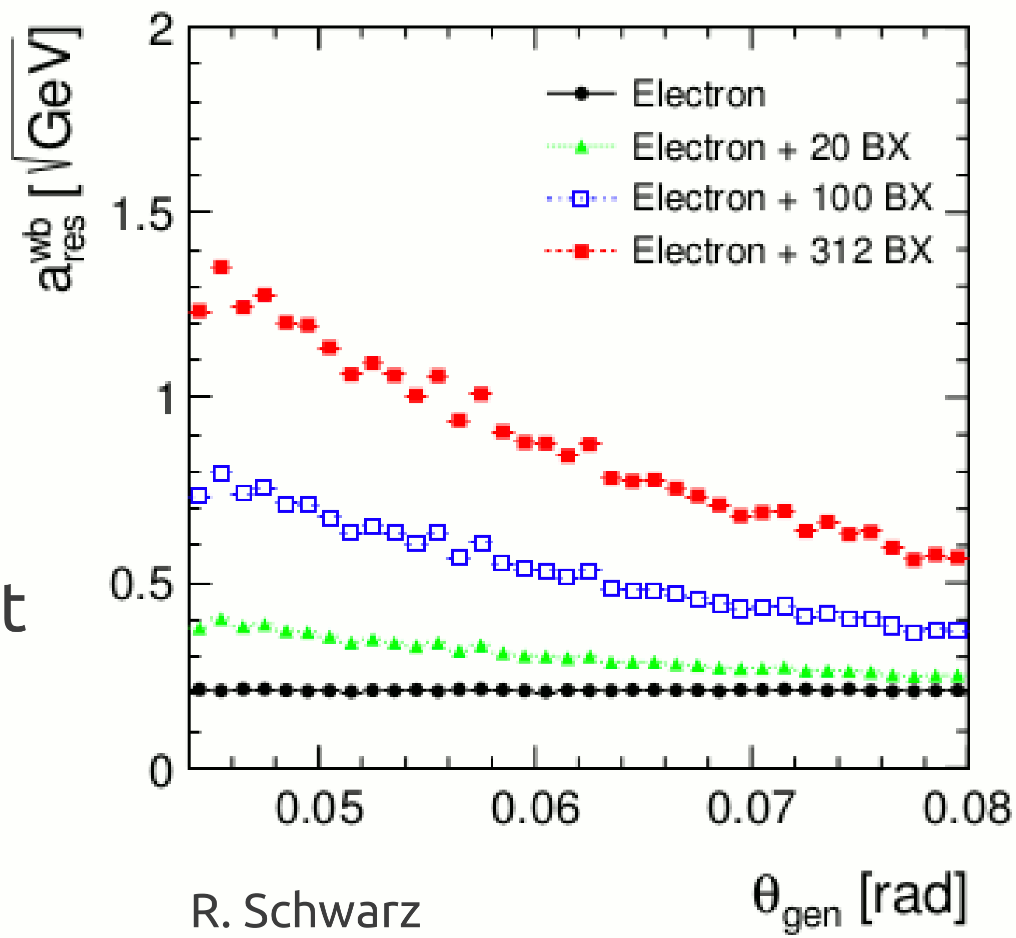


Shower profile in LumiCal

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



R. Schwarz

Tagging procedure for an event in LumiCal

- Loop over all final e^-/e^+ and γ in the event record (appropriate *MCParticle* collection)
- Add up 4-momenta of all other, previously untested, final $e^-/e^+/\gamma$ within 5 mrad from the same collection
- Is the resulting shower in the LumiCal angular range?
- Construct the equivalent energy deposit:

$$E_{dep} = E_{el} + \langle E_{bkgd} \rangle + \Delta E_{bkgd} + \Delta E_{res}$$

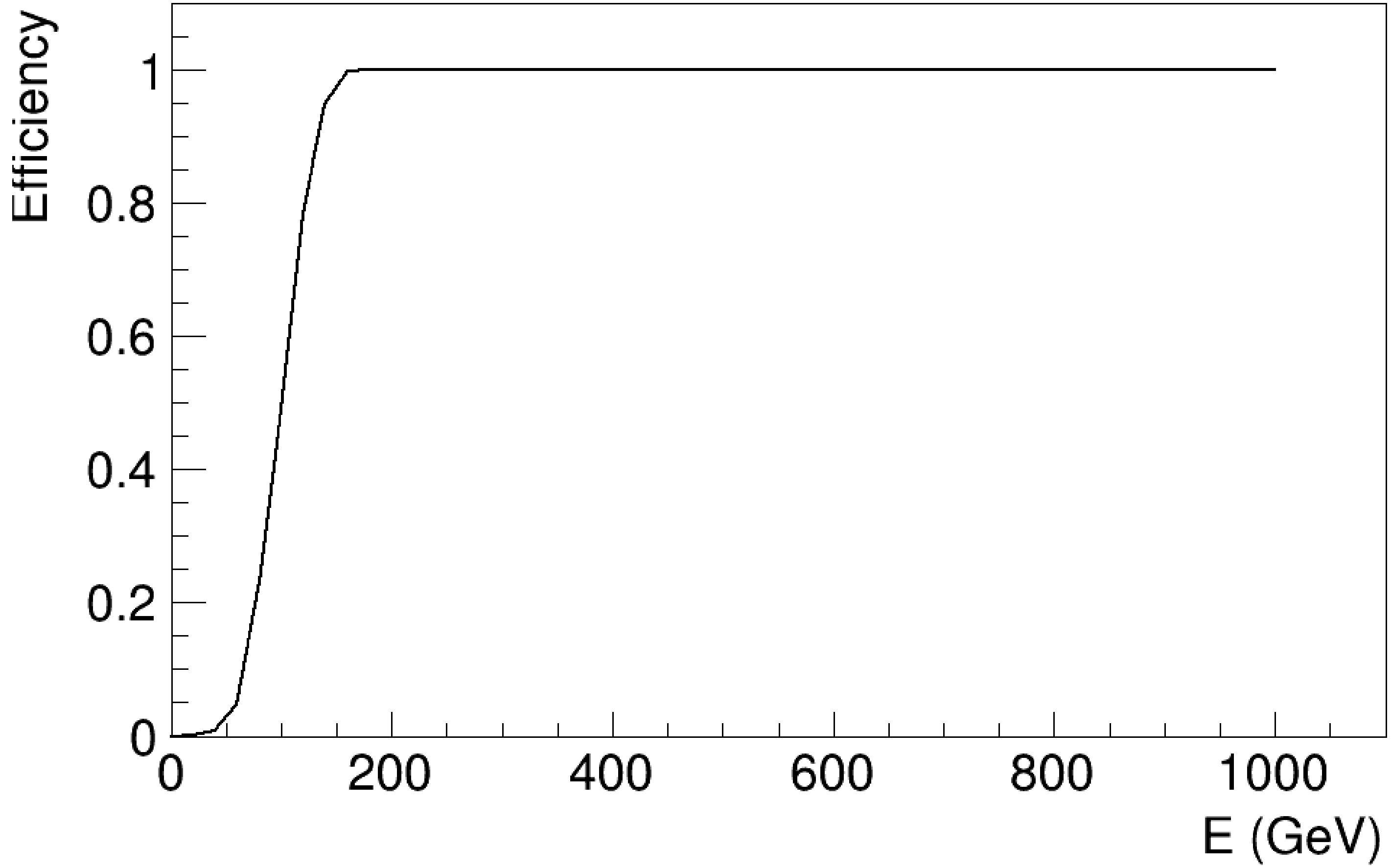
ΔE_{bkgd} is sampled from a Gaussian distribution with $\sigma_{bkgd}(\theta)$

ΔE_{res} is sampled from a Gaussian distribution with $\sigma_{res} = a_{res}\sqrt{E_{el}}$

- Test: $E_{dep} \overset{?}{>} \langle E_{bkgd} \rangle + 4\sigma_{bkgd}$
- Yes → Tag! No → loop

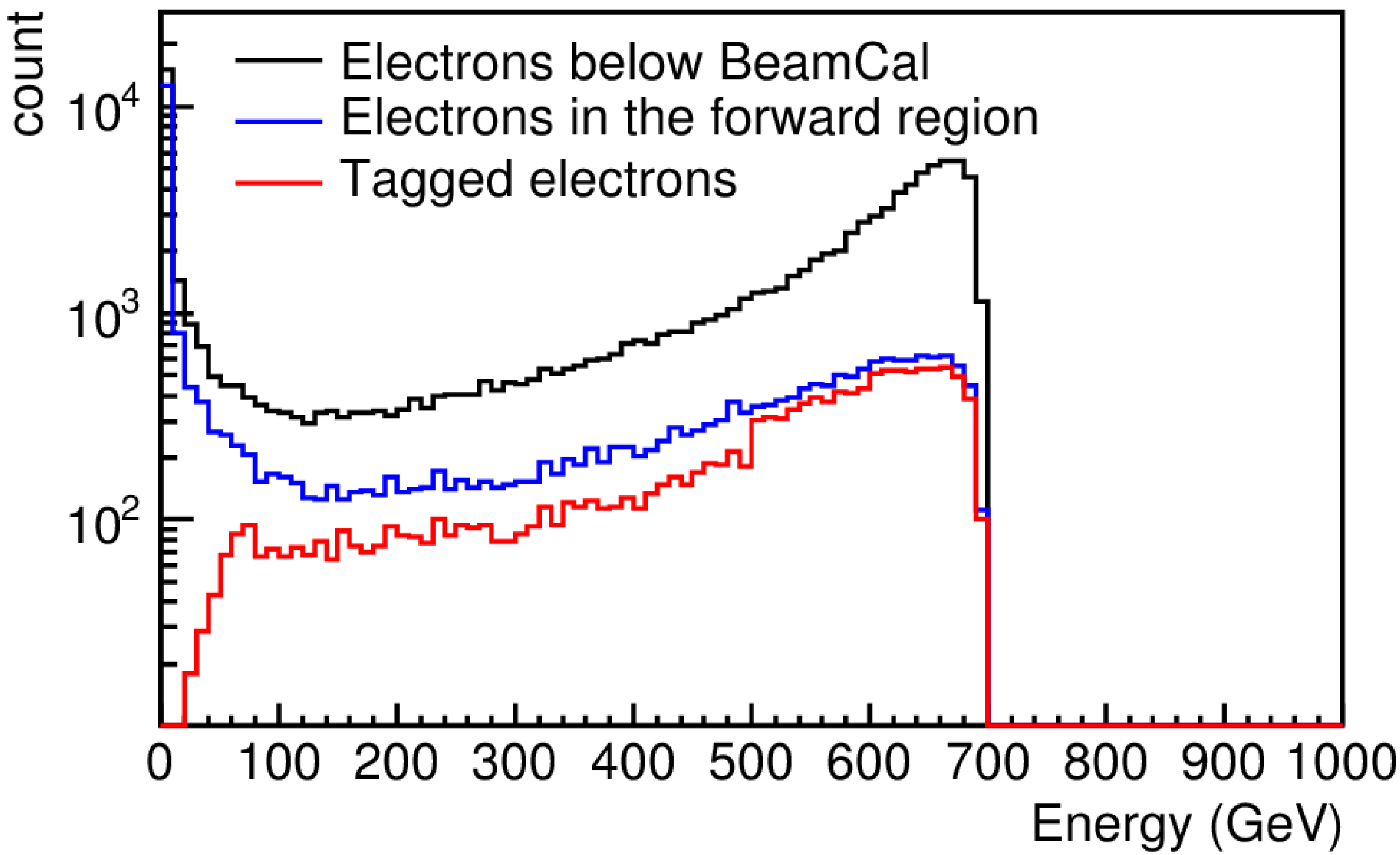
Tests on single electrons

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



Performance on a background sample in $H \to \mu\mu$ at 1.4 TeV

- Test on $ee \to ee\mu\mu$
- 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



Overall performance in the analysis of $H \to \mu\mu$ at 1.4 TeV

- Overall tagging rate for different processes:
  - 4-f background: 25%
  - $e\gamma \to e\mu\mu$: 15%
  - Signal: 0.2 %
- Statistical uncertainty of σ($h\nu\nu$) BR($h \to \mu\mu$) at 1.4 TeV drops from 31% to 29%
  (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
- Deposition in an *ad hoc* number of layers was required for tagging (defines the energy threshold). This should be fixed.
- Tagging rate for high-energy electrons 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
- BR uncertainty in $H \rightarrow \mu\mu$ at 1.4 TeV dominated by the small statistic of the signal, and by the irreducible background. At 3 TeV, significant improvement shown by Christian

Outlook

- Make tagging library available to everyone doing physics analyses for ILC and CLIC
- Simulate beam background and extract parameters for all energy stages on both machines
- Add distinction of EM and hadronic showers (more sims needed) → return a collection of “reconstructed showers”, characterized by the 4-momenta and EM/hadronic flag

ForwardTagger class

Depends on: ROOT, LCIO, TagProbability (Andre)

From Andre's library

```
class ForwardTagger : protected LCTagger, protected TagProbability
{
protected:
...

public:
// Constructor taking parameters for LumiCal and BeamCal probability file name
ForwardTagger(const Double_t bkg_params[3], TString BCalProbabilityFile);
// Constructor taking data for LumiCal parameters and BeamCal probability file
ForwardTagger(const char *LC_bkg_data, TString BCalProbabilityFile);

...

bool Tagged(IMPL::LCCollectionVec* mcParticles, bool &taggedLC,
       bool &taggedBC, bool &inLC, bool &inBC, bool crossAngle=true);
bool Tagged(IMPL::LCCollectionVec* mcParticles, bool crossAngle=true);

};
```

Backup

LCTagger class

```
class LCTagger : protected TF1
{
protected:
...

public:
...
static const Double_t bkg_params_CLIC_3TeV_100BX[3];
// R. Schwarz FCAL WS CERN, Nov 1012
static const Double_t ...[3];
...

// Constructor taking parameters of the background deposition sigma
LCTagger(const Double_t bkg_params[3]);
// Constructor taking data file name to fit the parameters
LCTagger(const char *bkg_data);

bool LCTag(TLorentzVector electron);

...
};
```