Forward electron tagging at ILC/CLIC

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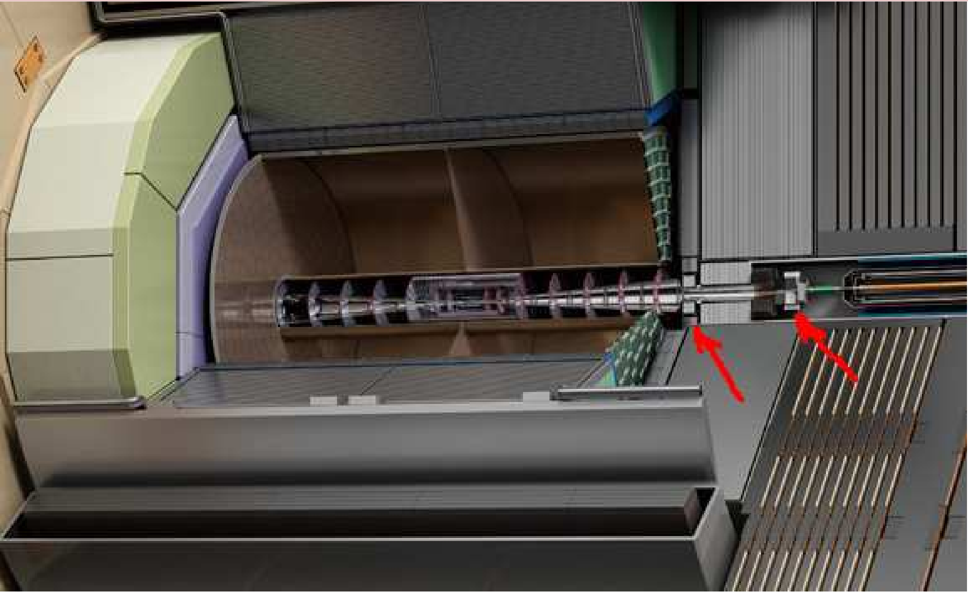
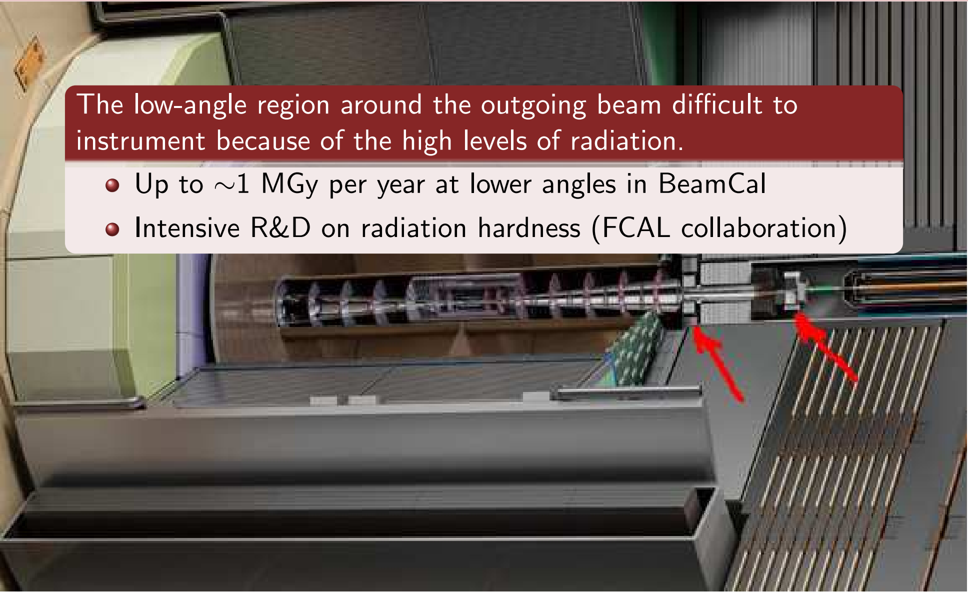
Instrumentation of the very-forward region



Instrumentation of the very-forward region



The low-angle region around the outgoing beam difficult to instrument because of the high levels of radiation.

- Up to ∼1 MGy per year at lower angles in BeamCal
- Intensive R&D on radiation hardness (FCAL collaboration)

Instrumentation of the very-forward region

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Purpose(s) of the forward calorimetry

- Fast luminosity estimate and beam diagnostics (BeamCal)
- Precise luminosity measurement (Lumical)
- *Improve detector hermeticity at low angles* (ILD LoI, SiD LoI, JINST 5 P12002 (2010))

Physics case for electron tagging

Analyses with missing-energy signature

Processes with spectator electrons are an important source of background – electrons escaping at low angles mimick missing energy

Other analyses that could potentially profit from tagging low-angle particles

- ZZ-fusion
- Search for the dark matter
- More topics might open up if other types of particles can be tagged.

Limitations

Available information on particles at low angles

Information limited to (finely segmented) calorimetry

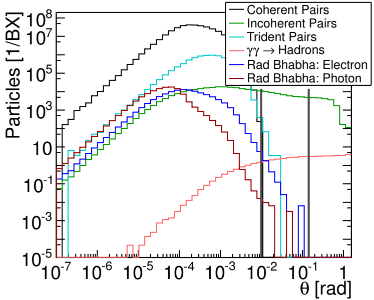
- Calorimetric energy measurement
- Precise measurement of the polar angle
- In principle, discrimination between types of particles possible by the shower profile (e.g. hadrons vs. EM particles)

ECAL

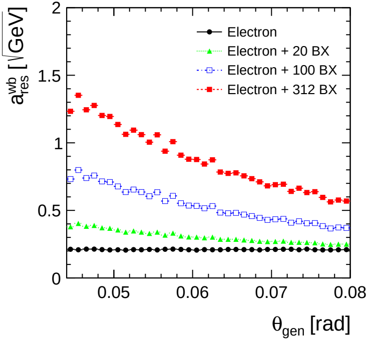
- Gap between the outer edge of LumiCal and the minimum tracking angle - ECAL information available
- Include into the tagging context

Beam-induced backgrounds

- High energy doses, particularly at lower angles
  - Lower-energy particles buried in the noise
  - Energy measurement affected by the fluctuation of the background



Angular distribution of beam-induced backgrounds at 3 TeV CLIC (Dannheim and Sailer, LCD-Note-2011-021)



Effect of background depositions on electron energy resolution in LumiCal (R. Schwarz, FCAL workshop Nov 2012, CERN)

Coincident Bhabha events

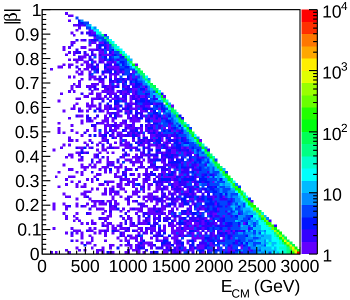
Cross section without beam-beam effects

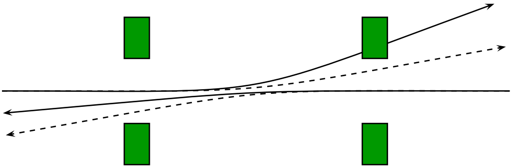
$$\sigma_{Bh}(s) \approx \frac{32\pi\alpha^2}{s} \int_{\theta_{min}}^{\theta_{max}} \frac{\mathrm{d}\theta}{\theta^3}$$

	1.4 TeV CLIC	3 TeV CLIC
$\sigma_{Bh}(s)$ (nb)	2.3	0.51
$p(n_{hit} \geq 1; 20BX; s)$	9%	4%

Angular cut: 15 mrad $\leq \theta \leq$ 140 mrad

Bhabha rate with the 2D luminosity spectrum $f^*(\sqrt{s}, \beta)$





Boost of the outgoing angles of a Bhabha event

	1.4 TeV CLIC	3 TeV CLIC
$\sigma_{Bh}(s)$ (nb)	2.3	0.51
$\sigma_{Bh,eff}(tag, f^*(\sqrt{s}, \beta))$ (nb)	> 5	> 10
$p(n_{hit} \geq 1; 20BX; s)$	9%	4%
$p(tag; 20BX; f^*(\sqrt{s}, \beta))$	$> 30\%$	$> 30\%$

Angular cut: 15 mrad $\leq \theta \leq$ 140 mrad

Reduction of coincident Bhabha rate by cuts

- Introduce additional tagging cuts:
- Example (from the $h \to \mu\mu$ analysis at 1.4 TeV):
  $\theta > 30 mrad$, $E > 200 GeV$
  - E cut well above sensitivity limit
  - Probability to tag a Bhabha event in 20 BX at 1.4 TeV: $p_{Bh} \approx 7\%$

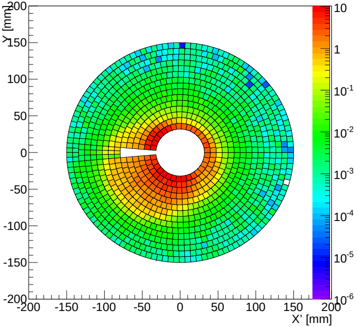
Existing simulation tools

Simulation with background superposition (overlay)

- Tens of thousands of background particles per BX – particle-by-particle simulation CPU/time expensive
- Quantities of importance for Physics analyses: Distributions of deposited energy in calorimeter cells

Superposition of deposits from background samples randomly selected from a pre-simulated pool

- Generation of beam-induced background: Guinea-Pig
- Generation of deposits: Mokka
- Mapping and overlay of deposits...



Overlay tools

Marlin overlay drivers

- Using Mokka lcio output with deposition maps
- Standard tool, already used for the benchmark studies in other detector subsystems

FCalClusterer and TagProbability libraries (André)

- Deposition maps as root vectors, storing only essential information
- Superimpose the deposition map at reconstruction, or...
- Create and use maps of tagging probability as a function of E, θ and ϕ – Significantly faster but less detailed in energy and angular points

Fast parametrized approach

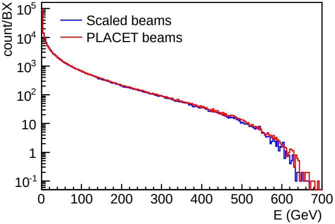
- Basic idea: fast recognition of MC particles which induce showers that are tagged in the forward calorimeters
  - Sum up particles closer than one Molière radius
  - Are the particles within the angular range of the calorimeters?
  - Is the deposited energy sufficient for recognition? (Include fluctuations of the background and the intrinsic resolution)
- Used for the $h \to \mu\mu$ analysis at 1.4 TeV and for the estimate of the coincident Bhabha tagging rate
- Pros:
  - Fast and simple to implement
  - Reproduces roughly the most pertinent characteristics of the tagging process (energy- and angular dependence)
- Cons:
  - Low level of detail (no shower leaks, no cutaway for the incoming beam in BeamCal...)
  - Contains *ad hoc* parameters (~~can~~ should be tuned by comparison with full simulation)

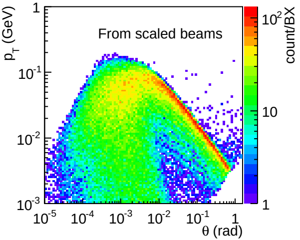
Ongoing work

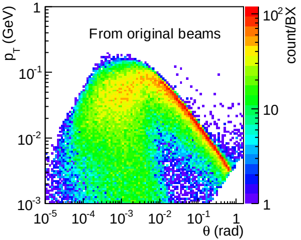
Production of beam-induced backgrounds

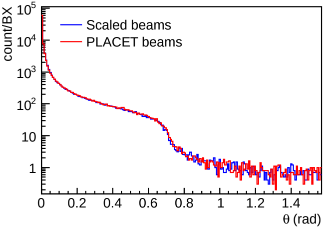
Few existing datasets on beam-induced backgrounds at 1.4 TeV

- Small number of input beam samples at 1.4 TeV – Scale the 3 TeV beams
- Scale by the ratio of distribution widths for all three components of coordinate and momentum









Background distributions with the original 1.4 TeV beams and with the scaled beams

Outlook

Current status

- Produced 2000 samples of beam-induced backgrounds at 1.4 TeV
- Production of BeamCal deposition maps underway
- Testing reconstruction with "electron gun"

To do:

- Assess the performance of full-simulation tagging (are "shortcuts" necessary?)
- Estimate Bhabha coincident tagging rates with full simulation
- Tune fast simulation algorithms, if these are needed
- Examine particle discrimination capabilities of the forward calorimeters
- Other ideas?

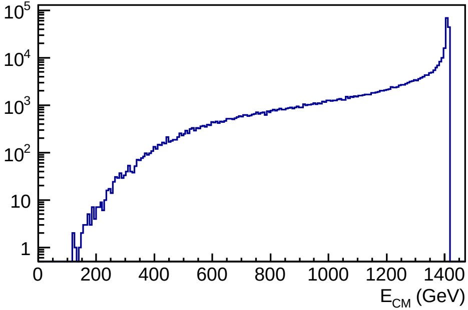
Conclusions

- Tagging important for suppression of backgrounds in physics studies with missing energy
- Potentially some particle-discrimination capabilities
- Intense background at low angles
- Radiation-induced boost of Bhabha events has a highly non-trivial effect on the Bhabha particle rate in the very forward region
  - Angular and energy cuts required in order to limit the coincident tagging rate
  - Tagging efficiency is reduced
  - Coincident Bhabha tagging rate needs to be precisely calculated and taken into account in the analysis
- Efforts towards an optimal simulation underway

Thank you!

Backup slides

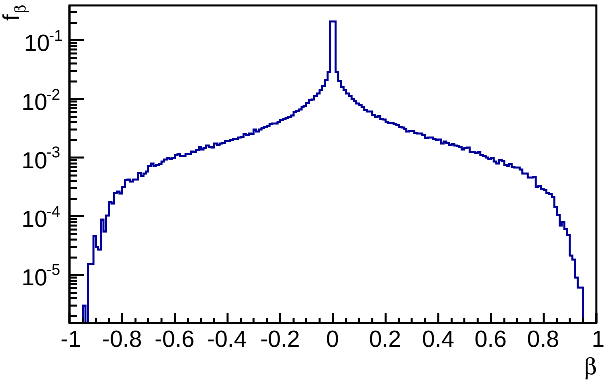
Cross section with 1D luminosity spectrum



	1.4 TeV CLIC	3 TeV CLIC
$\sigma_{Bh}(s)$ (nb)	2.3	0.51
$\sigma_{Bh}(f(\sqrt{s}))$ (nb)	3.9	1.4
$p(n_{hit} \geq 1; 20BX; s)$	0.091	0.038
$p(n_{hit} \geq 1; 20BX; f(\sqrt{s}))$	0.15	0.10
Ratio $\sigma_{Bh}(f(\sqrt{s}))/\sigma_{Bh}(s)$	1.66	2.72

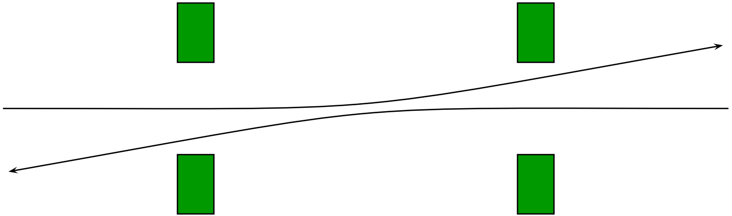
Angular cut: 15 mrad $\leq \theta \leq$ 140 mrad

Beamstrahlung-induced boost of events



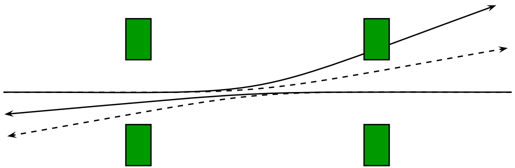
Distribution of longitudinal boost of event CM frames at 1.4 TeV CLIC. Calculated from a Guinea-Pig luminosity file.

Effect of boost on Bhabha events



High cross section at low angles

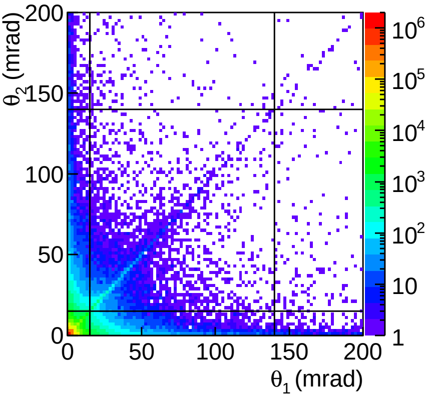
Effect of boost on Bhabha events



Movement of the CM frame - angles boosted in the lab frame

Angular acceptance for single Bhabha hits

- Bhabha Events generated in the angular range reaching $\theta_{min} \leq 1$ mrad
- Scaled and tracked in Guinea-Pig
- Probability for 1 hit close to unity when $\theta_{min} \to 0$



Effect on the measurement of $h \to \mu\mu$ decay at 1.4 TeV

- Consequences of the introduction of the tagging threshold for the reduction of the coincident Bhabha rate:
  - Tagging rate for $ee \to ee\mu\mu$ drops from 25% to 18%
  - Tagging rate for $e\gamma \to e\mu\mu$ drops from 15% to 11%
- Reduction of all processes by 7% by coincident Bhabha tagging
  - The uncertainty of this number enters the systematics
  - Requires precise determination (Minsk Bhabha generator + detector sim?)
- No significant impact on the statistical uncertainty of the $\sigma(ee \to h\nu\nu) \times BR(h \to \mu\mu)$ at 1.4 TeV