AIDA-SLIDE-2015-046

**AIDA**

Advanced European Infrastructures for Detectors at Accelerators

**Presentation**

# Potential and challenges of the physics measurements with very forward detectors at linear colliders

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09 July 2014

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project AIDA, grant agreement no. 262025.

This work is part of AIDA Work Package **9: Advanced infrastructures for detector R&D**.



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# Potential and challenges of the physics measurements with very forward detectors at linear colliders

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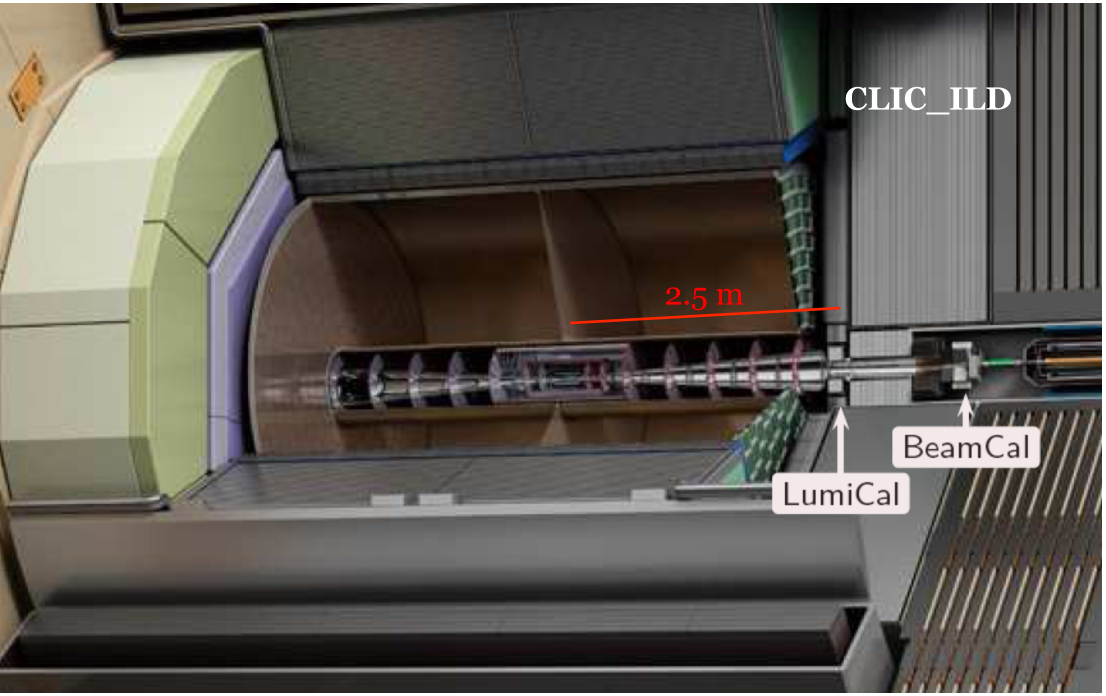
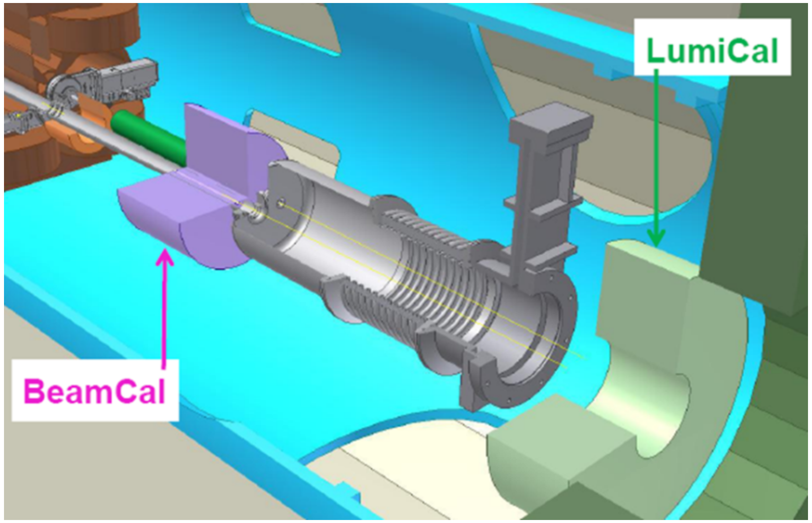
ICHEP 02-09 July, Valencia, Spain

# Overview

- Instrumentation of the very forward region
- Physics and technological challenges
- Luminosity spectrum and measurement
- Particle tagging at low angles
- FCAL impact on other physics measurements
- Conclusion




## Layout

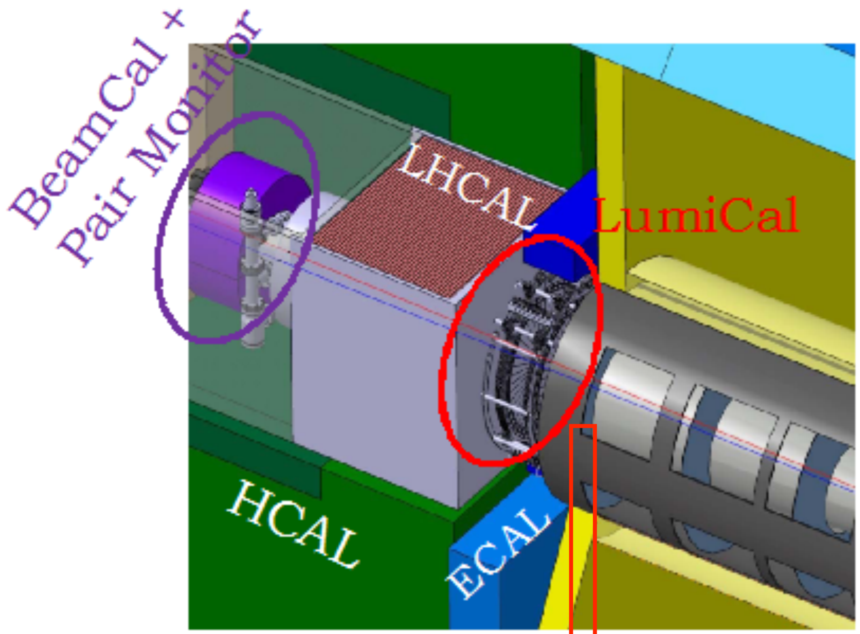
- Angular coverage down to the lowest polar angles (5/15 mrad at ILC/CLIC)
- Fast and precise luminosity measurement
- Shielding of the inner tracker from backscattered particles
- Beam-induced backgrounds at low angles determine calorimeters apertures, drive radiation-hardness requirements and trade-off between granularity and occupancies
- Detector hermeticity + particle identification → impact on physics analyses

# Forward calorimeters

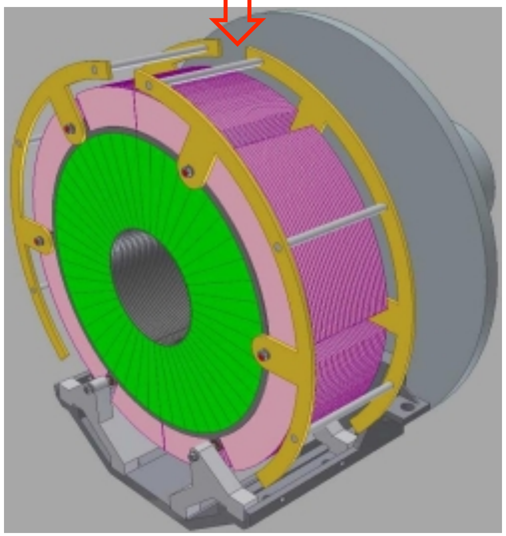
- Twin Si-W sampling calorimeters (30/40 layers at ILC/CLIC)
- Compact calorimeters – Molière radius ~ 1 cm
- LumiCal sampling Si-W (48/64 azimuthal/radial segmentation)

$$\Delta\theta = 3.2 \times 10^{-3} mrad$$
$$\sigma_\theta = 2.2 \times 10^{-2} mrad$$
$$\frac{\sigma_E}{E} = \frac{0.21}{\sqrt{E/GeV}}$$

- BeamCal W absorber + poly- (mono-) crystaline CVD diamond/GaAs/rad-hard Si
- Pair Monitor $2 \cdot 10^5$ Si pixel $(0.4 \times 0.4)$ mm




| Acceptance [mrad] | ILC | CLIC |
|---|---|---|
| BeamCal | 5-45 | 15-38 |
| LumiCal | 42-67 | 38-110 |



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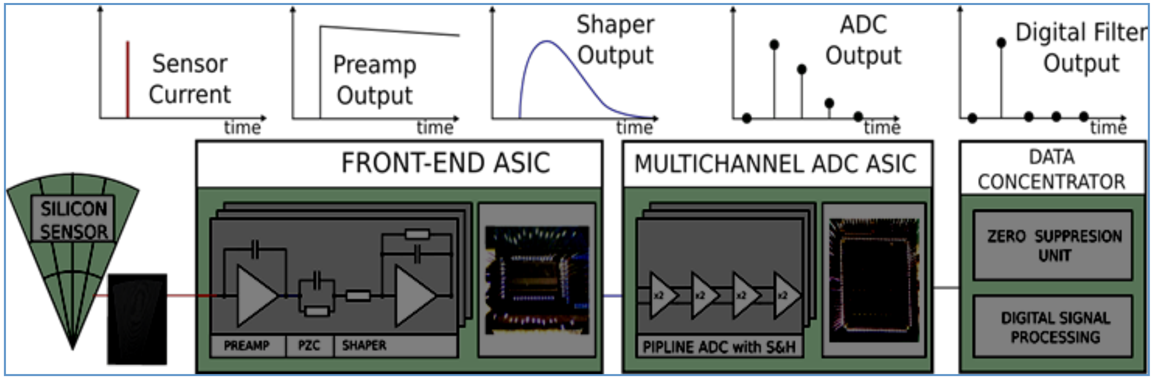
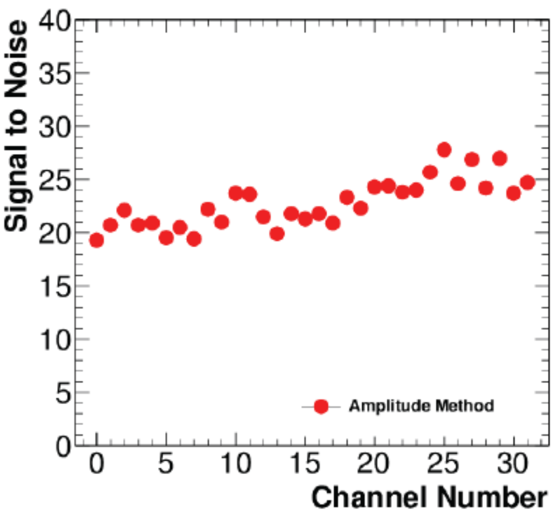
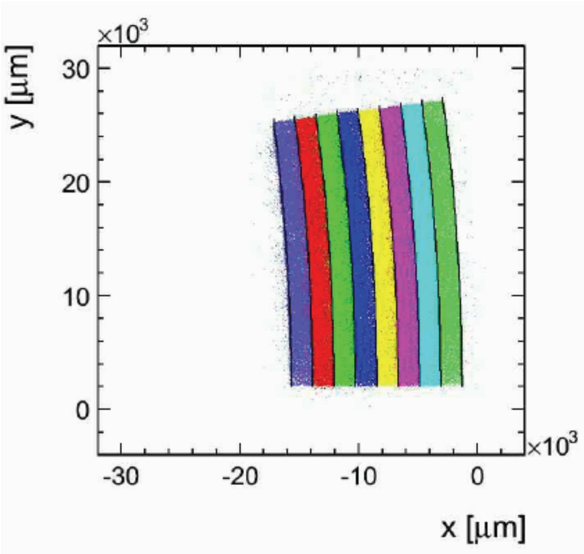



- Very good signal to noise ratio
- Homogeneous response of the pad signal
- Edge-loss about 10% of the signal.

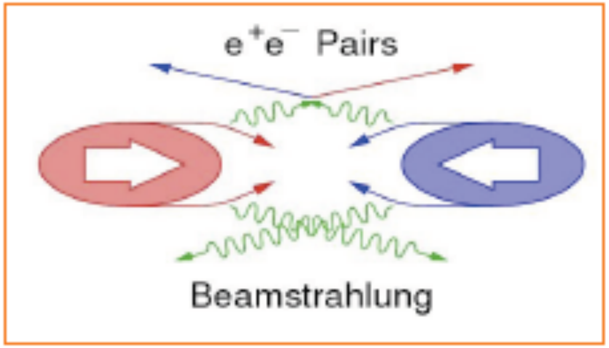
## Status of the FCAL R&D

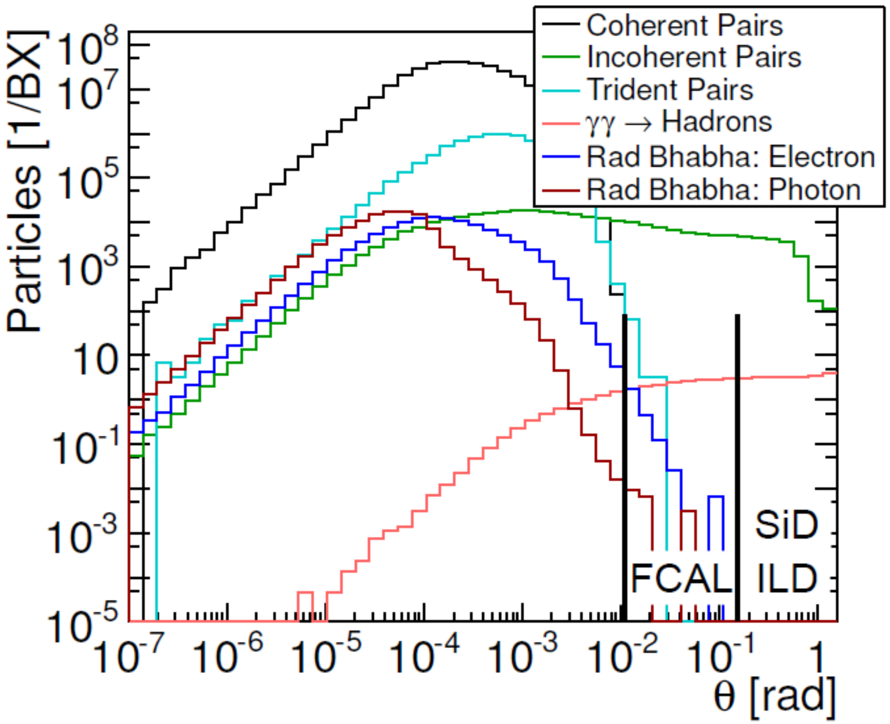
- Electrical characterization: 40 prototype LumiCal sensors and 30 prototype BeamCal sensors (compensated GaAs) tested – *all prototypes meet the requirements*
- Sensor + Front-end ASIC + ADC ASIC (32 channels fully equipped) in the test-beam (2-4.5 GeV electrons at DESY)
- Future:
  - Multilayer readout, new ASICs, novel connectivity,
  - Construction of demonstrator calorimeter, test $E$ and $\theta$ resolution and biases

*see the FCAL poster on R&D with the very forward detectors at linear colliders*

# Beam backgrounds

- High EM-fields of colliding bunches are causing Beamstrahlung (BS) +EM deflection
- Intense BS is causing distortion of the luminosity spectrum, incoherent production of $e^+e^-$ pairs converted from BS photons, hadron production from $\gamma_{BS}\,\gamma_{BS}$
- Impact on forward detector design and technology choices
- Impact on particle reconstruction (high-energy electron) at low angles
- Impact on physics measurements (luminosity, Higgs coupling measurements, BSM searches…)



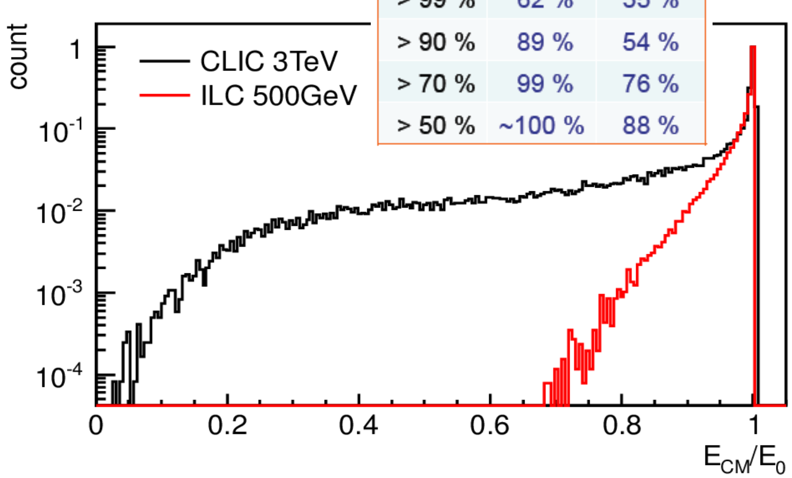

*Angular distribution of beam-induced backgrounds at 3 TeV*

# Challenges:

## Physics

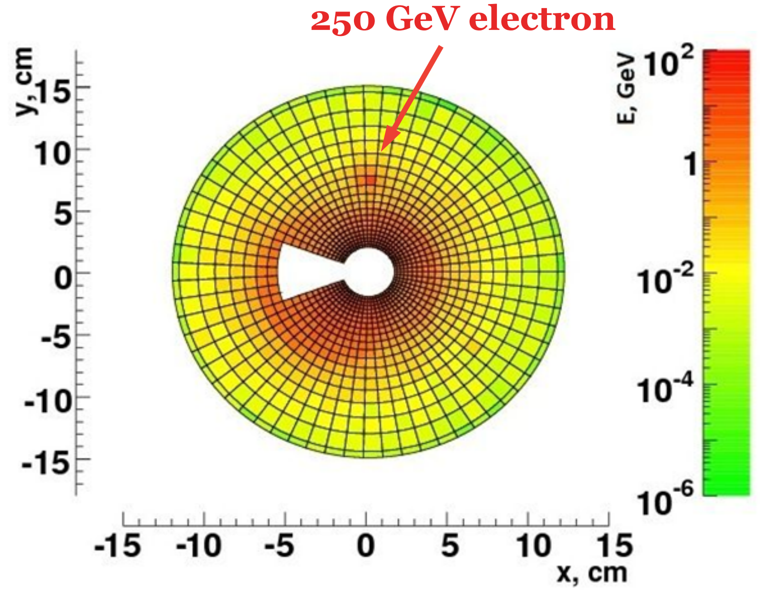
- Count-loss in luminosity measurement O(10%) - data driven correction needed
- Boost of the collision system along the z-axis distorts the kinematics of i.e. SUSY processes
- If undetected, low angle electrons can fake $E_{mis}$ signature (dark matter searches, Higgs production in WW fusion)

| √s' /√s | 0.5 TeV | 3 TeV |
|---|---|---|
| > 99 % | 62 % | 35 % |
| > 90 % | 89 % | 54 % |
| > 70 % | 99 % | 76 % |
| > 50 % | ~100 % | 88 % |




## & technology

- High-granularity calorimetry
- Radiation hard sensors (i.e $3 \cdot 10^5$ incoherent pairs/BX at 3 TeV CLIC)
- Fast read-out
- Apertures of the forward detectors, design of the beam-pipe



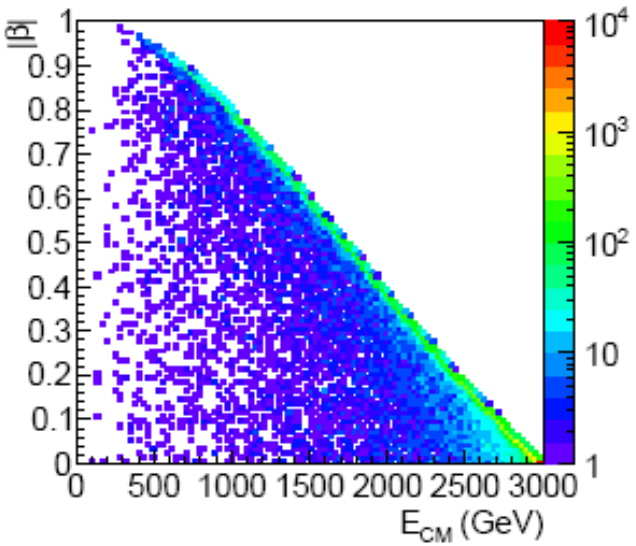

*Energy deposited by beamstrahlung pairs after one bunch crossing in the sensors of BeamCal + 250 GeV electron*

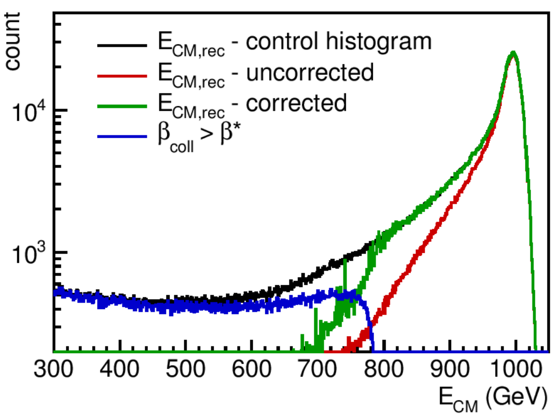
# Beam-induced effects and luminosity spectrum

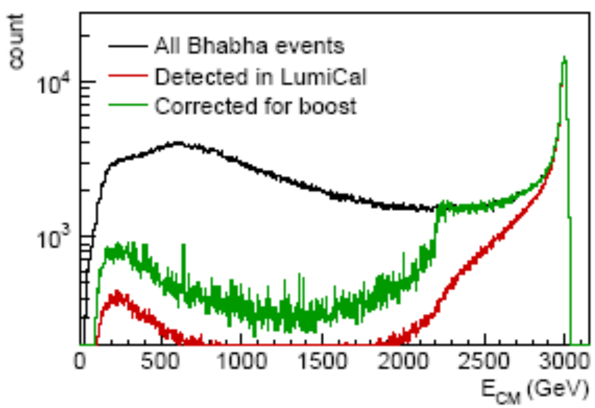
- Beamstrahlung is a random phenomenon that leads to:
  - Asymmetric energy loss,
  - Boost of the CM frame (β),
  - Acolinearity of the final state particles
- Irradiated energy:

$$E \sim \frac{\gamma^2 N^2}{\sigma_z \left(\sigma_x + \sigma_y\right)^2}$$

- Boost can be calculated from final state particle angles
- Correction by weighting on event-by-event basis
- Uncertainty after correction at the permille level in the upper 30% of the luminosity spectrum



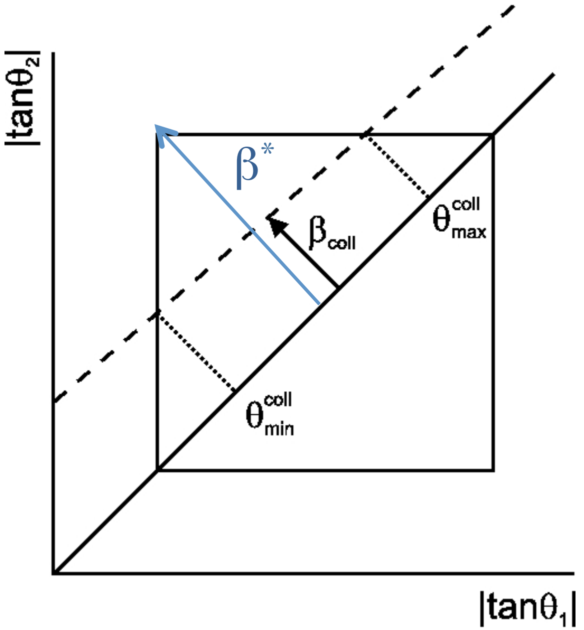




*S. Lukic et al., JINST 8 (2013) P05008*

# Bhabha counting loss - reweighting method

- $e^+e^-$ CM system after BS+ISR and before FSR (collision frame) is moving with $\beta_{coll}$ w.r.t. the lab frame
- $$\beta_{coll} = \frac{\sin(\theta_1^{lab} + \theta_2^{lab})}{\sin\theta_1^{lab} + \sin\theta_2^{lab}}$$

  approximated to be collinear with z axis
- Events with $\beta > \beta^*$ ($\beta^* \sim 0.24$ at ILC_ILD) are irreducibly lost from the detector fiducial volume
- $\beta_{coll}$ can be used to calculate weighting factor $w(\beta_{coll})$ to correct for the angular loss on the event-by-event basis




$$w(\beta_{coll}) = \frac{\int_{\theta_{min}}^{\theta_{max}} \frac{d\sigma}{d\theta} d\theta}{\int_{\theta_{min}^{coll}}^{\theta_{max}^{coll}} \frac{d\sigma}{d\theta} d\theta}$$

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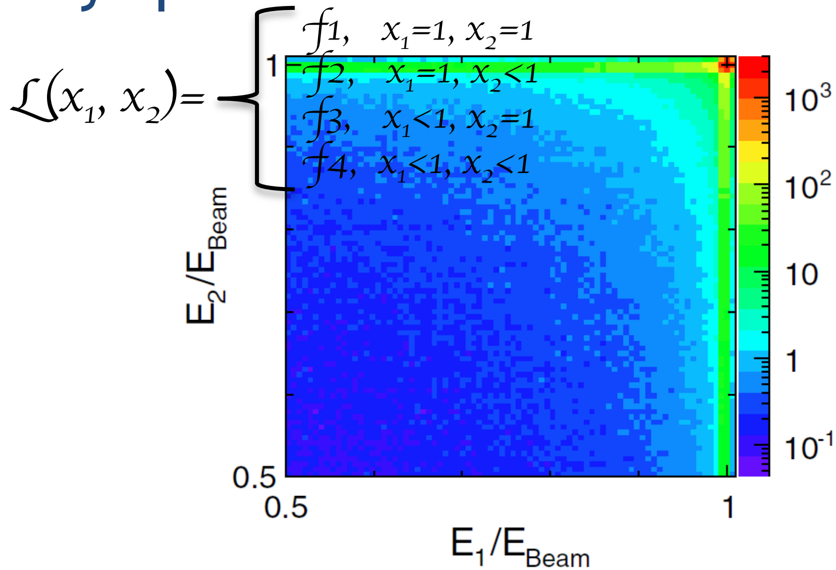
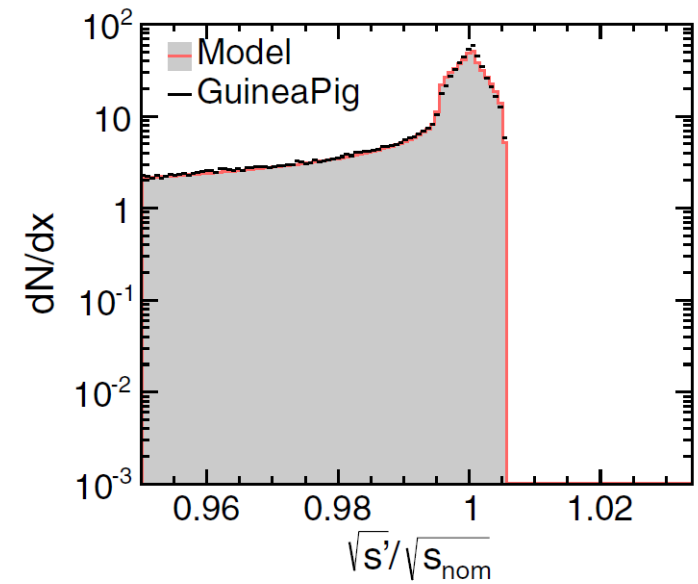
# Low-energy part of the luminosity spectrum

- Fit of a 19-parameter model of the luminosity-spectrum describing a distribution of three observables:
  - Acollinearity
  - energies (E1, E2) of both final state electrons
- Data from the entire detector (wide-angle Bhabha) is used to obtain the measured distribution
- Excellent reconstruction of the spectrum shape
- 5% precision down to $0.5\sqrt{s}_{nom}$

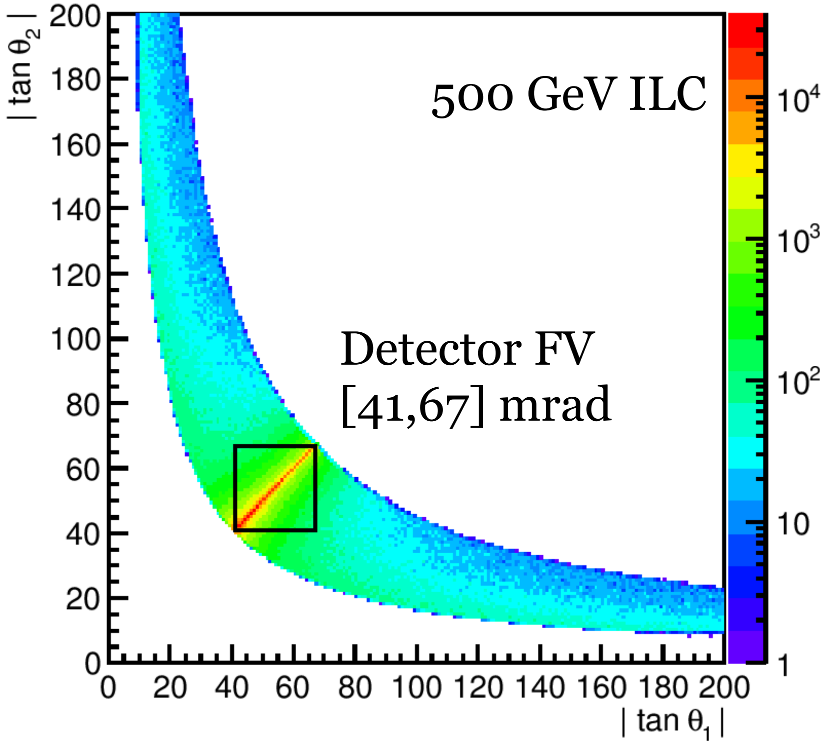
*S. Poss and A. Sailer, Eur. Phys. J C74 (2014) 2833*



## Luminosity measurement

- Bhabha coincidence is often lost due to the boost of the final state electrons
- The effect is severe: 8.4% (250 GeV), 12.8% (500 GeV) and 14.0% (1 TeV) in the top 20% of the luminosity spectrum
- For boost ($\beta$) larger than some critical value, the acollinearity is larger than the angular range of the detector
  - Irrecoverable events
- In the peak region (>80% of the nominal CM energy), the fraction of irrecoverable events is small ( ≤1.5 permille) and can be reduced further by event selection (acoplanarity requirement).



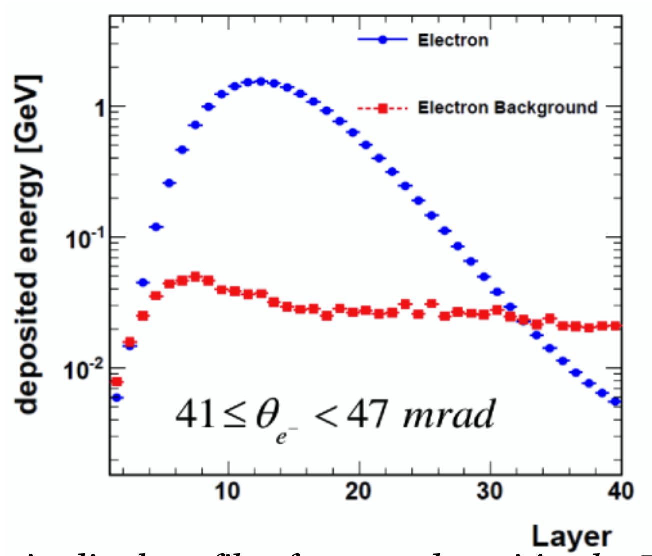

Restriction on acoplanarity reduces the fraction of irrecoverable events (suppresses events with off-axis radiation) from ~1.5 permille to ~0.4 permille at ILC

*I. Bozovic-Jelisavcic et al., JINST 8 (2013) P08012*

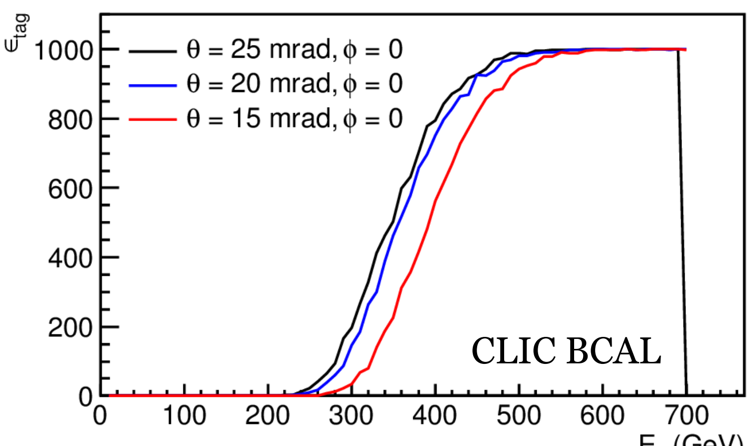
# High-energy electron identification

- Some electrons escape at low angles → either losing or faking signal
- Tagging particles in the FCAL region important for the analysis
- Study of tagging by simulation:
- Approach 1: Full simulation with background overlay
- Approach 2: Parametrized simulation
  - Parametrize the distribution of background deposits as a function of $\theta$
  - Add Gaussian variations from $E$ resolution and background deposit distribution to MC particles and test threshold condition for tagging
- Approach 3: Store tagging probability maps as a function of $E$, $\theta$ and $\varphi$.

Tagging probability has the same $E$ dependence in all approaches



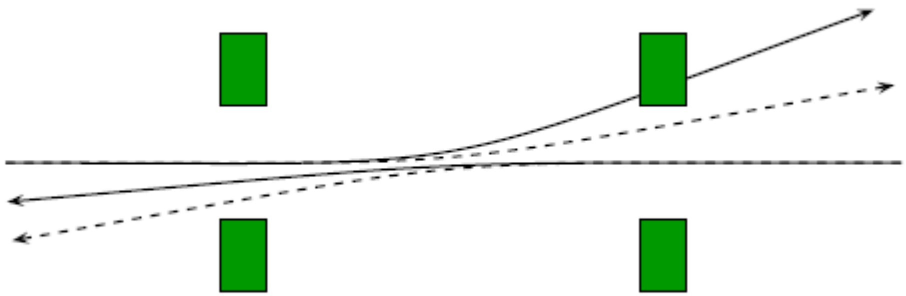

*Longitudinal profile of energy deposition by EM showers and by incoherent pairs in LumiCal at CLIC*




*e-tag efficiency in BeamCal on top of background from incoherent pairs integrated over 20 BX*

# Bhabha coincidence

- Signal can be coincident with Bhabha particles and rejected by e-tagging
- Boost of the CM of Bhabha events dramatically increases one-side Bhabha hit probability in the FCAL.
  - Probability to tag at least one final Bhabha particle in 10 ns time-frame is several dozen percent
- Tagging in coincidence with Bhabha particles can be reduced by energy and angular cuts



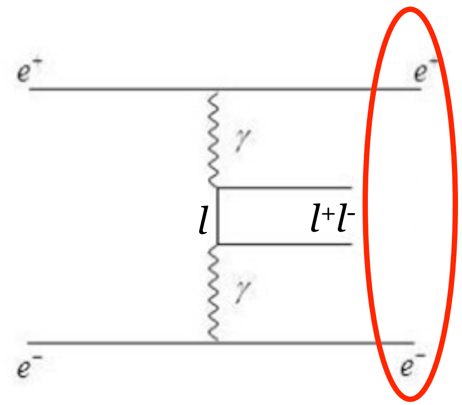
*Distortion of Bhabha electron angles due to boost $\beta$*

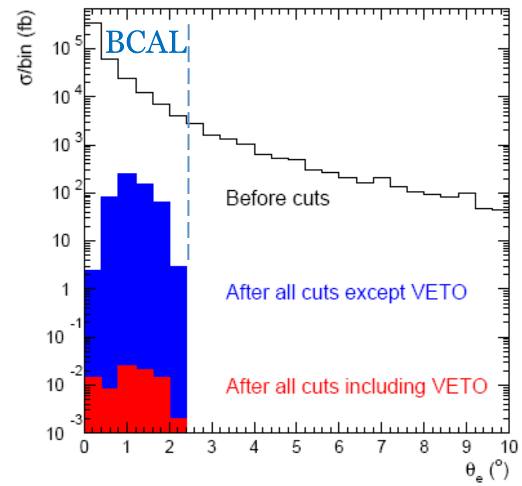
| | 1.4 TeV CLIC | 3 TeV CLIC |
|---|---|---|
| $\sigma_{collinear}$ [nb] | 2.3 | 0.51 |
| $\sigma_{boosted}$ [nb] | $> 5$ | $> 10$ |
| $P_{collinear}$ (20 BX) | 9% | 4% |
| $P_{boosted}$ (20 BX) | $> 30\%$ | $> 30\%$ |

15 mrad $\leq \theta \leq$ 140 mrad

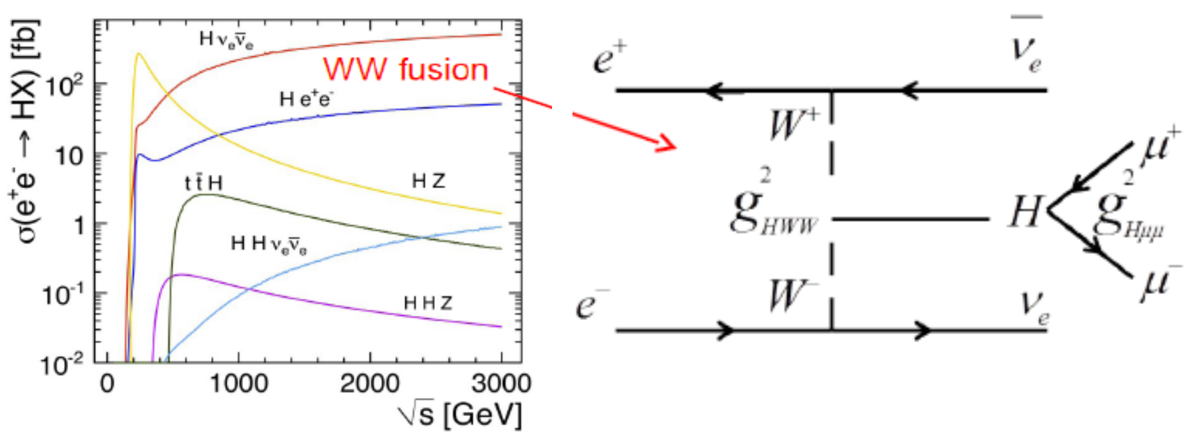
# FCAL impact on other physics measurements

- Already known example: DM study at ILC [arXiv: 0801.4888]
  - Tagged e- above 75 GeV, $\varepsilon_{tag}$ ranging from 20% for 75 GeV up to ~100% for 250 GeV electron
- $e^+e^- \rightarrow e^+e^- f^+f^-$ processes have a large cross-section and unidentified spectators can fake $E_{miss}$ signature.
- These SM processes are relevant background also for other physics measurements, i.e. Higgs production in WW fusion, $H\rightarrow\mu^+\mu^-$...




*Angular distribution of spectator electrons from 4-fermion tau production at 400 GeV ILC*



# Electron tagging in BR(H→μμ) at CLIC

- $e^+e^- \rightarrow e^+e^- f^+f^-$ and $e^\pm\gamma \rightarrow e^\pm f^+f^-$ are ~$10^4$ times more frequent than the signal
- Constant tagging efficiencies assumed at 3 TeV (separate for LumiCal and BeamCal)
- Parameterized approach at 1.4 TeV
- In both analyses forward e-tagging improves the statistical uncertainty of the measurement

| | $\text{LumiCalCut}_{95}$ | $\text{LumiCalCut}_{99}$ | $\text{BeamCalCut}_{30}$ | $\text{BeamCalCut}_{70}$ |
|---|---|---|---|---|
| Signal events | $120 \pm 17$ | $127 \pm 18$ | $130 \pm 18$ | $132 \pm 18$ |
| Signal efficiency | 49.3% | 53.2% | 55.1% | 55.9% |
| $\sigma_{h\nu_e\bar{\nu}_e} \times BR_{h\to\mu^+\mu^-}$ | 0.121 fb | 0.119 fb | 0.118 fb | 0.118 fb |
| Stat. uncertainty | 23.3%→ 15.0% | 14.3% | 14.1% | 13.8% |

*Impact of e-tagging on stat. uncertainty of $\sigma_{prod}\times BR(H\rightarrow\mu\mu)$ at 3 TeV CLIC*
*C. Grefe, LCD-Note-2011-035*

| Process | Rejection rate by EM shower tagging | Total rejection including random Bhabha coincidence |
|---|---|---|
| $e^+e^-\rightarrow e^+e^-\mu^+\mu^-$ | 44% | 48% |
| $e^\pm\gamma\rightarrow e^\pm\mu^+\mu^-$ | 38% | 42% |
| Signal | 0.2% | 7% |

*Background and signal rejection rates in $\sigma_{prod}\times BR(H\rightarrow\mu\mu)$ measurement at 1.4 TeV CLIC, Bhabha coincidence is reduced by requiring: $\theta$>30 mrad, E>200 GeV*

# Conclusions

- FCAL deliverables:
  - Fast luminosity estimate, beam-parameter estimation
  - Precise integral luminosity measurement (permille level in the top 20% of the spectrum at ILC and CLIC)
  - Luminosity spectrum reconstruction (within 5% at CLIC)
  - Low-angle electron tagging
- Instrumentation of the very forward region is relevant for physics analyses with missing energy signatures (DM searches, Higgs rare decays from WW fusion production) or whenever the signal is peaked very forward.