Luminosity detector at the International Linear Collider: Monte Carlo simulations and test beam preparation

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About me

Personal background

- Home country: USA
- Education:
  - Harvard University, BA 2008
  - K. A. Brown et al., Coaxial atomic force microscope tweezers. *Applied Physics Letters* **96**, 123109

MC-PAD

- ESR
  - AGH University of Science and Technology, Krakow, Poland
  - Polish Academy of Science - Inst. for Nuclear Physics (IFJ-PAN)
  - Supervisors: Marek Idzik (AGH) and Bogdan Pawlik (IFJ)
  - Partners with DESY-Zeuthen under P6
- Personal goal: gain research experience and apply to PhD programs

Forward calorimetry at the ILC

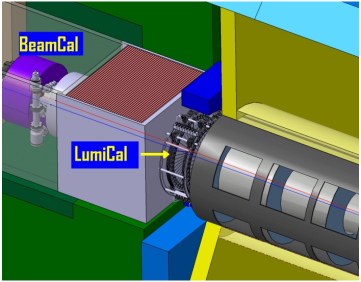
LumiCal goals

High precision in $\Delta\mathcal{L}/\mathcal{L}$

- Bhabha scattering: $e^+e^- \rightarrow e^+e^-$
- 10^{-3} ($\sqrt{s} = 500\text{GeV}$)
- 10^{-4} (GIGA-Z)

BeamCal goals

- Fast luminosity estimation (using beamstrahlung)
- Assist beam tuning
- Good hermeticity



ILD forward region

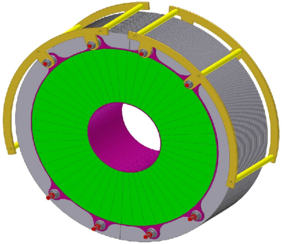
Challenges

- LumiCal: Mechanical precision and position monitoring
- BeamCal: Radiation hardness
- Both: Fast front-end electronics

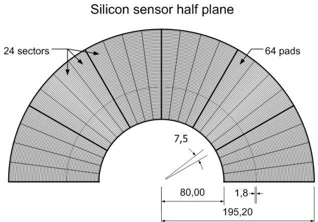
LumiCal introduction

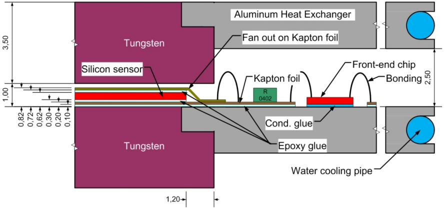
Parameters

Type	Si-W
# layers	30
Absorber Δz	1 X_0
Si Δz	300 μm
Layer rotation offset	**3.75^o**
Inner radius	32.0 mrad
Outer radius	77.9 mm
Distance from IP	2.5 m



(top) CAD drawing of LumiCal
(bottom) Partial side-on view





Simulation introduction

Stand-alone model

- Dependent only on Geant4 and ROOT
- Identical geometry to integrated model
- Portable - moved to local cluster computing facility which does not have the ILC software packages available

Simulation parameters

- Single e-
- $\phi \in [0, 2\pi]$
- $\theta \in [0.033, 0.073]$
- Energies [GeV]: 5, 25, 50, 100, 150, 200, 250, 500
- 4000 events/energy

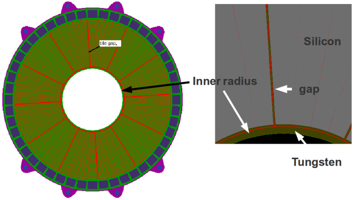
Tile gap effect

Energy resolution analysis

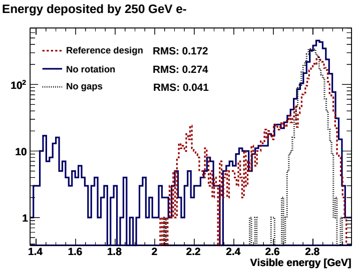
Accuracy of reconstructed energy:
$RMS(E_{rec}) / < E_{rec} >$
Can be parametrized as:

$$\frac{RMS}{E_{beam}} = \sqrt{\frac{a^2}{E} + b^2}$$

- a → stochastic contribution
- b → systematic (geometric) contribution



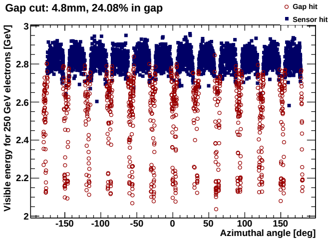
Simulated model



Energy deposition in the gaps

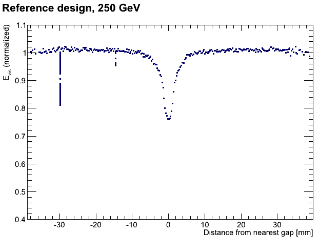
Correction methods

Gap-cutting



Remove particles in red; cut width can be varied

Gap-fitting



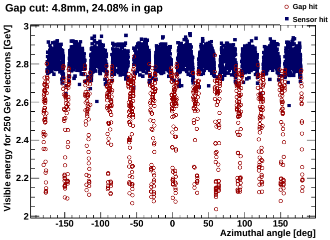
Hits projected onto one tile

Correction methods

$$f(x) = A - \frac{B}{1 + \left(\frac{x-C}{D}\right)^2} - E \cdot e^{-F \cdot x^2}$$

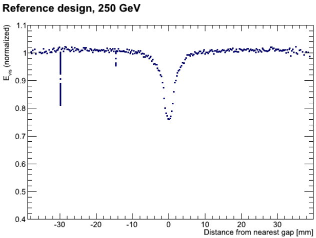
Correction methods

Gap-cutting



Remove particles in red; cut width can be varied

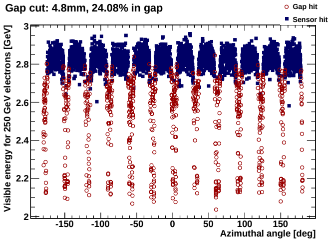
Gap-fitting



Hits projected onto one tile

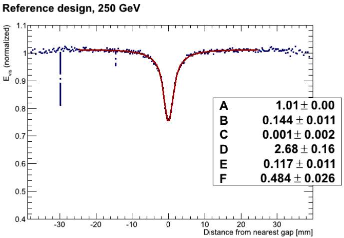
Correction methods

Gap-cutting



Remove particles in red; cut width can be varied

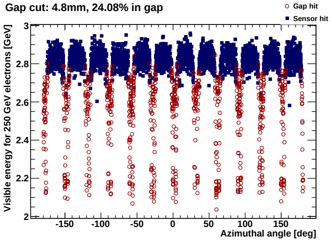
Gap-fitting



Hits projected onto one tile, with fitting

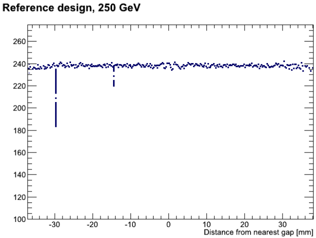
Correction methods

Gap-cutting



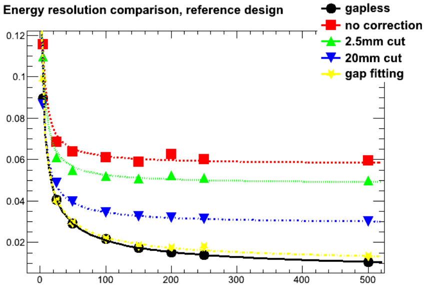
Remove particles in red; cut width can be varied

Gap-fitting



Hits projected onto one tile, flattened and scaled

Correction comparison



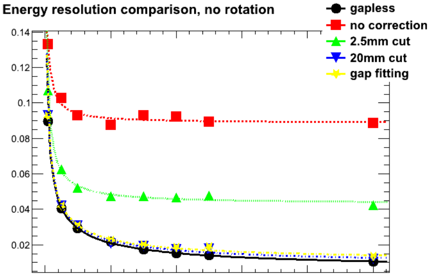
Comparison of different cut widths (width on *each* side of the gap) with the gap-fitting and ideal gap-less calorimeter cases.

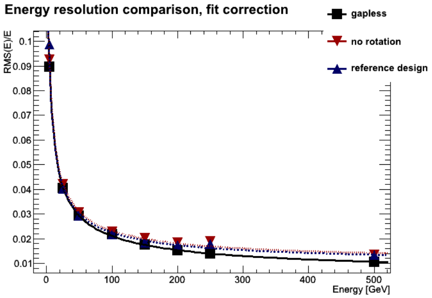
$$\frac{RMS_E}{E} = \sqrt{\frac{a^2}{E} + b^2}$$

Stochastic	Value	Error
No correction	0.2147	0.0032
2.5mm cut	0.2094	0.0029
20mm cut	0.1865	0.0025
gap-fitting	0.2006	0.0014
gapless	0.2027	0.0013
Geometric	**Value**	**Error**
No correction	0.058	0.029
2.5mm cut	0.048	0.024
20mm cut	0.029	0.015
gap-fitting	0.010	0.005
gapless	0.006	0.003

No rotation

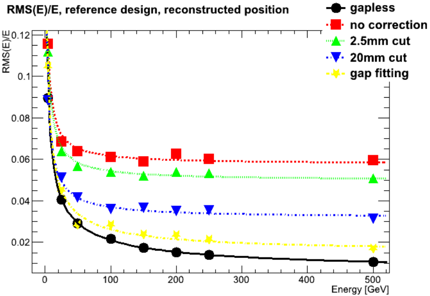
- Rotate LumiCal layers so that tile gaps are aligned
- Accept energy losses in the gaps and try to compensate mathematically

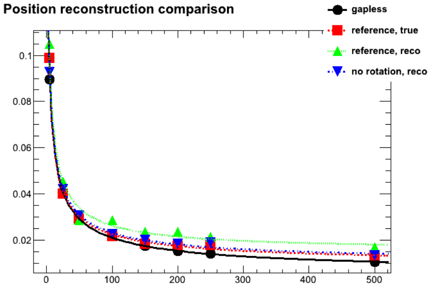




Position reconstruction

- Depends on knowing position of particle
- Previos plots: particle position known from software
- What if we reconstruct the position using only detector information?





Test beam introduction

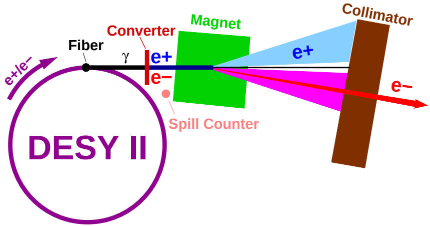
Test beams

DESY-Hamburg

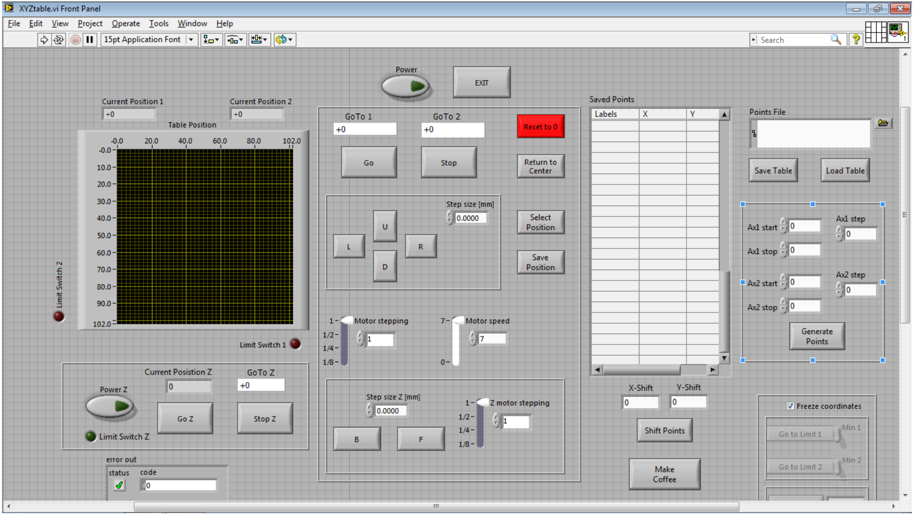
BeamCal and LumiCal groups

Goals

- Characterize readout chain (sensor - fanout - FE ASICs - further readout)
- Measure SNR, CCE (GaAs)
- Check sensor perfomance as a function of position
- Investigate edge effects in GaAs sensors



Motorized Position Control Interface



Program design

- Event-driven design conserves CPU usage.
- Three ways to set position:
  - Input manually
  - Step manually
  - Generated automatically

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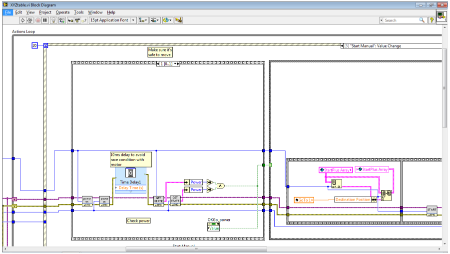
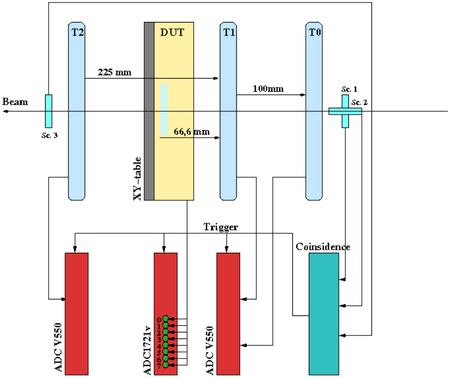
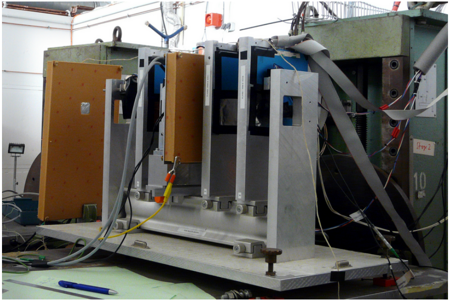
- Positions can be labeled and stored for later use.
- User can set axis motion limits to prevent crashing.
- Motor speed and step size control for high precision motion (up to 0.31 μm).
- Current maximum vertical load should be up to 6 kg.
- User manual and programming manual available.



Setup

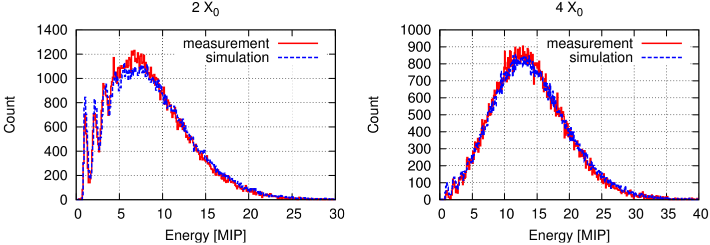


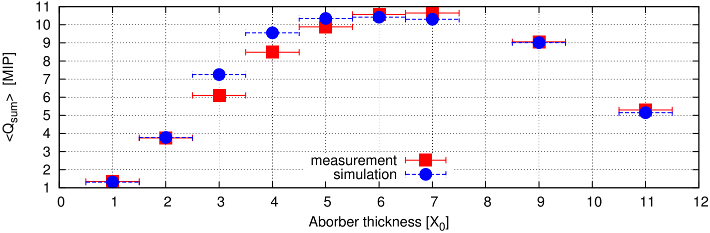
Schematic showing telescope planes and trigger electronics



Photograph of BeamCal sensors in place and LumiCal sensors behind telescope

Test beam simulations and measurements





Other activities

- Capacitance measurements for fanout (later replaced by test beam measurements)
- 3-D version of SensorMeas
- MSc thesis: "Luminosity detector at the International Linear Collider: Monte Carlo simulations and analysis of test beam data"
- Various internal publications
- TIPP proceedings (Physics Procedia): "Luminometer for the future International Linear Collider - simulation and beam test results"
- Co-editor of FCAL 2009 PRC report

Summary

- Simulations
  - Realistic LumiCal model implemented and simulated
  - Tile gap effect understood and calculated
  - "No-rotation" geometry produces good results, but must be investigated further
- Test beam
  - Simulation of the test beam good in general, but needs to be refined
  - X-Y table software implemented and improved over succesive test beams
  - (Backup slides) Good SNR ($\sim$18)
  - (Backup slides) Low crosstalk even from longest fanout channels
  - First tests of readout chain – sensors with FE ASICs – were successful!

Acknowledgments

- Marek Idzik and Bogdan Pawlik
- Wolfgang Lohmann and Olga Novgorodova
- Christan Joram and Veronique Wedlake
- MC-PAD training event organizers
- FCAL members, especially Szymon Kulis, Itamar Levy, Hans Henschel, and Andre Sailer

MC-PAD Reflection

Practical

- Understanding of many detector systems
- Great exposure to other scientists and labs, give talks and posters
- Career workshop very helpful in preparing applications
- Paid for my tuition at AGH
- Now I have an MSc from one of the top technical schools in Poland
- Fellowships like to give fellowships to people with fellowships

PhD application success

- 5/14 acceptances (now at Johns Hopkins University)
- 4 top-25 (US) institutions
- 3/5 acceptances came with an “internal” fellowship
- 1 outside fellowship (National Physical Science Consortium)

MC-PAD Reflection

Personal

- My research supervisors were great
- Enjoyed being part of collaboration
- More mature researcher
- Opportunity to travel, experience something new - now I speak (almost) Polish

Suggestions

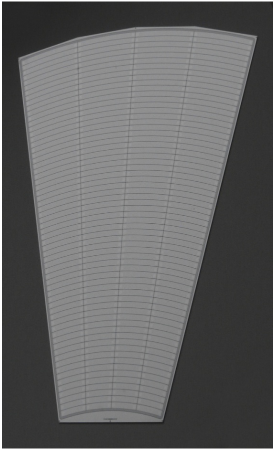
- Longer training events - maybe even an MC-PAD summer school?
- Maybe organize sessions where we present problems in our research, instead of results?

Backup slides

Lumical sensor description

Sensor design

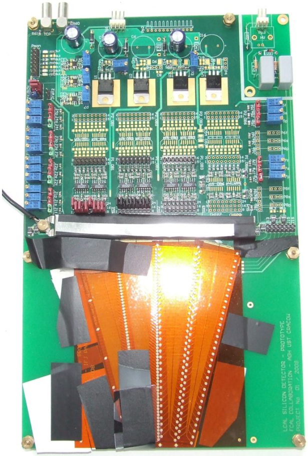
- Custom Hamamatsu sensors
- 1 tile (4 sectors)
- 64 pads/sector (1.8mm radial pitch)
- 300 μm high-resistivity n-type Si bulk
- p+ pads with Al metalization, DC coupled
- Capacitance $\sim$ 30pF at 50V



Readout chain

Components

- 16 sensor pads bonded
- Sensor and fanout glued on
- FE ASICs bonded onto PCB
- Output buffers
- Biasing and power blocks



Electronics

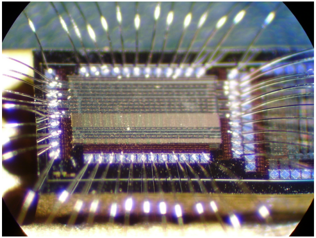
FE ASIC - custom

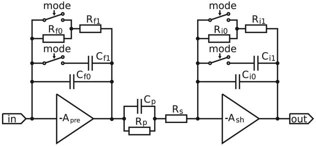
- Charge-sensitive amplifier with 1^{st}-order shaping
- $T_{peak} \sim 60$ns
- 2 modes of operation:
  - Calibration mode
  - Physics mode
- Active or passive feedback

M. Idzik. *et. al.*, NIM-A 2009, 608:169-174

ADC - commercial

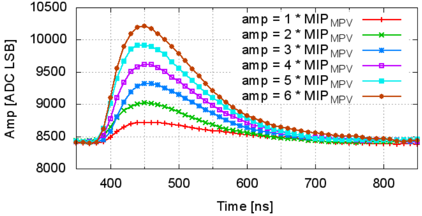
- CAEN VME-V1724
- 14 bits, 8 channels, 100 MSps

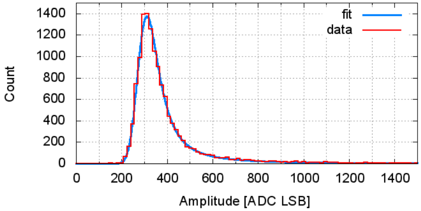




Results - Amplitude

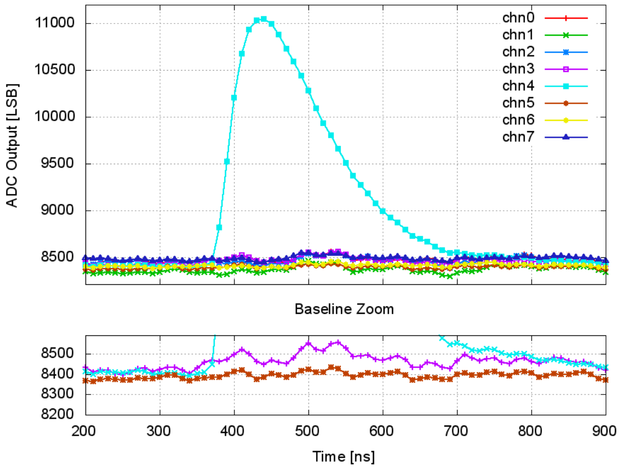
Good amplitude response





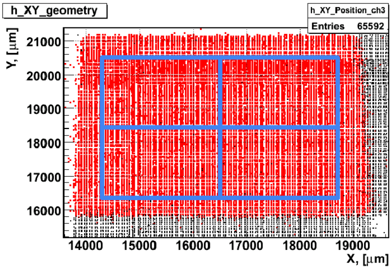
- (top) Time response to electrons with different energies
  - Shape does not depend on amplitude
- (bottom) Spectrum for 4.5GeV electrons
  - SNR $\sim$ 19 for largest sensor capacitance

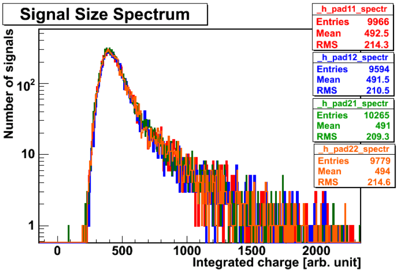
Results - Crosstalk



Crosstalk $\leqslant 1\%$

BeamCal charge collection





- Pad structure corresponds to $\sim 5 \times 5\ mm^2 + \sim 200\ \mu m$ gaps
- 4 independent pad areas show identical chare collection
- Signals in pads exhibit Landau distribution

- Two clusters of 8 pads each irradiated
- SNR: FET > 20, $R_f > 13$
- CCE: 33% at -60 V_{bias}