TESLA Forward Calorimeters
Recent Developments

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International Conference on Linear Collider
LCWS 2004, Paris, April 19 - 23 2004

Colorado Cracow Dubna London Minsk Moscow Prague Protvino Tel-Aviv
Forward Region – LumiCal (LAT) and BeamCal (LCAL) Calorimeters

The main functions:

- Precision luminosity measurements (LumiCal): $\Delta L / L \approx 10^{-4}$
- Fast beam diagnostic + physics (BeamCal)
- Detection of electrons and photons at very small angles
- Shield of inner (tracking) detector
- Supplied maximum hermiticity

**LumiCal**
- $z = 305$-$325$ cm
- $r = 8$-$28$ cm
- $26.2 < \theta < 82$ mrad
- $0 < \phi < 360$ deg

**BeamCal**
- $z = 365$-$385$ cm
- $R = 1.2$-$8$ cm
- $3.9 < \theta < 26.2$ mrad
- $0 < \phi < 360$ deg

Advantages:
- Reduce the leakage particles from LumiCal – help to achieve required precision in LUMI
- Less fakes can scatter from mask into ECAL
- More space for electronics
- Outer CAL better separated from beamstrahlung
- Shintake monitor can be used

$\Delta \theta \sim$ a few $\mu$rad: $\Delta L/L \approx 10^{-4}$ possible

The TDR design:
- $\Delta L/L$: $10^{-4}$ impossible
- $0.2 - 0.3$ mrad accuracy
Optimisation of shape and structure are studied to reach \( \Delta L / L \sim 10^{-4} \). Need laser alignment system.

Si (sensor) / W calorimeter
concentric cylinders (in \( r \)), sectors in (\( \phi \)) and rings in (\( z \))
Si : pads or strips

Realistic Monte Carlo
- rad. corrections (BHLUMI / BHWIDE) - Bhabha MC program
- beamstrahlung (CIRCE, Guinea-Pig \( \rightarrow e^-e^+ \) pairs background)
- full detector simulation
- reconstruction of events

Possible LumiCal segmentation :
- 15 - 32 cylinders in \( r \)
- 24 - 48 sectors in \( \phi \)
- 30 rings in \( z \) (readout from every 2nd)
- \( \sim 11500 \) channels

Resolution: \( \sigma(\theta) \sim 70 - 90 \) \( \mu \)rad feasible
possible improvement - reconstruction algorithm

Energy resolution: \( \sim 40\% \sqrt{E} \)

Energy resolution: \( \sim 31 - 43 \% \sqrt{E} \)
Detector Design

15 cylinders * 24 sectors * 30 rings = 10800 cells

LumiCal - Simulation

Reconstruction Algorithm

\[
< X > = \sum X_i E_i / \sum E_i
\]

\[
< X > = \sum X_i W_i / \sum W_i
\]

\[
W_i = \max \theta \left[ \cos \left( E_{\text{beam}} \right) + \ln \left( \frac{E_i}{E_T} \right) \right]
\]

\[
\sigma(\theta)(rad)\]

400 GeV

\[
\theta_{\text{rec}} - \theta_{\text{gen}} (rad)
\]

Constant value

Constant value
Energy and Angular resolution

Simulation: BHWIDE (Bhabha)+CIRCE (Beamstrahlung)+beamspred
Events selection: acceptance, energy balance, azimuthal and angular symmetry.

Final choice of LumiCal sensor geometry?
BeamCal - Beam Monitoring

Beam monitoring - observation $e^-e^+$ pairs from beamstrahlung which is sensitive to the machine parameters.

- pairs in BeamCal
- photons downstream

Severe conditions for work:
- thousands pairs (~15000 hits) per BX
- large energy deposition 10 – 20 TeV
- hard radiation
- 10 MGy per year. Required rad. hard sensors

In cold technology:

large bunch spacing
information can be used for feedback

Considered technologies:

- Diamond-W Sandwich
- Gas ionisation chamber
- Scintillator crystals
Beam Strahlung

Diagnostics of bunches at IP

3 potential sources of information
- energy-distribution of pairs
- number-distribution of pairs
- distribution of photons

Over-simplified detector simulation
- detectors subdivided into cells
- sum energy impact on cells
main source of uncertainty
  → stat. fluctuations of beam-str.

Linear approximation
Current Analysis Concept

**Beam Parameters**

- determine collision
- creation of beamstr.
- creation of $e^+e^-$ pairs

**Observables**

- characterize energy distributions in detectors

\[
\begin{bmatrix}
\text{Observables} \\
\text{nom}
\end{bmatrix} = \begin{bmatrix}
\text{Observables} \\
\text{nom}
\end{bmatrix} + \begin{bmatrix}
\text{Taylor} \\
\text{Matrix}
\end{bmatrix} \ast \begin{bmatrix}
\Delta \text{BeamPar}
\end{bmatrix}
\]

Solve by matrix inversion (Moore-Penrose Inverse)
## Beam Monitoring

### Single parameter analysis (one free parameter)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>nominal</th>
<th>old</th>
<th>new</th>
<th>norm.</th>
<th>Beam Diag.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch width x Ave.</td>
<td>553 nm</td>
<td>1.2</td>
<td>2.0</td>
<td>1.5</td>
<td>~ 10 %</td>
</tr>
<tr>
<td>Diff.</td>
<td></td>
<td>2.8</td>
<td>3.6</td>
<td>2.1</td>
<td>~ 10 %</td>
</tr>
<tr>
<td>Bunch width y Ave.</td>
<td>5.0 nm</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>Shintake</td>
</tr>
<tr>
<td>Diff.</td>
<td></td>
<td>0.1</td>
<td>0.5</td>
<td>0.5</td>
<td>Monitor</td>
</tr>
<tr>
<td>Bunch length z Ave.</td>
<td>300 μm</td>
<td>4.3</td>
<td>7.5</td>
<td>4.3</td>
<td>~ 10 %</td>
</tr>
<tr>
<td>Diff.</td>
<td></td>
<td>2.6</td>
<td>3.5</td>
<td>2.7</td>
<td>~ 10 %</td>
</tr>
<tr>
<td>Emittance in x Ave.</td>
<td>10.0 nm mm rad</td>
<td>1.0</td>
<td>---</td>
<td>---</td>
<td>?</td>
</tr>
<tr>
<td>Diff.</td>
<td></td>
<td>0.4</td>
<td>0.7</td>
<td>0.7</td>
<td>?</td>
</tr>
<tr>
<td>Emittance in y Ave.</td>
<td>0.03 nm mm rad</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>?</td>
</tr>
<tr>
<td>Diff.</td>
<td></td>
<td>0.001</td>
<td>0.004</td>
<td>0.002</td>
<td>?</td>
</tr>
<tr>
<td>Beam offset in x</td>
<td>0</td>
<td>7</td>
<td>30</td>
<td>6</td>
<td>5 nm</td>
</tr>
<tr>
<td>Beam offset in y</td>
<td>0</td>
<td>0.2</td>
<td>0.6</td>
<td>0.4</td>
<td>0.1 nm</td>
</tr>
<tr>
<td>Horizontal waist shift</td>
<td>0 μm</td>
<td>80</td>
<td>---</td>
<td>---</td>
<td>None</td>
</tr>
<tr>
<td>Vertical waist shift</td>
<td>360 μm</td>
<td>20</td>
<td>23</td>
<td>24</td>
<td>None</td>
</tr>
</tbody>
</table>

Good precision - determination of beam parameters look optimistic
### Beam Monitoring

**Multi parameter analysis**

Expected resolutions when 1, 2, 4 or 6 parameters are running.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\sigma_x$</th>
<th>$\Delta \sigma_x$</th>
<th>$\sigma_y$</th>
<th>$\Delta \sigma_y$</th>
<th>$\sigma_z$</th>
<th>$\Delta \sigma_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_x$</td>
<td>0.3 %</td>
<td>0.4 %</td>
<td>3.4 %</td>
<td>9.5 %</td>
<td>1.4 %</td>
<td>0.8 %</td>
</tr>
<tr>
<td>$\sigma_y$</td>
<td>0.3 %</td>
<td>0.4 %</td>
<td>3.5 %</td>
<td>11 %</td>
<td>1.5 %</td>
<td>0.9 %</td>
</tr>
<tr>
<td>$\sigma_z$</td>
<td>0.9 %</td>
<td>1.0 %</td>
<td>11 %</td>
<td>24 %</td>
<td>1.6 %</td>
<td>1.9 %</td>
</tr>
<tr>
<td>$\Delta \sigma_x$</td>
<td>5.7 %</td>
<td>24 %</td>
<td>1.6 %</td>
<td>1.9 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta \sigma_y$</td>
<td>1.8 %</td>
<td>1.1 %</td>
<td>16 %</td>
<td>27 %</td>
<td>3.2 %</td>
<td>2.1 %</td>
</tr>
</tbody>
</table>

Current analysis → we can measure 6 (more?) beam parameters simultaneously with reasonably accuracy.
First Look at Photons

nominal setting
(550 nm x 5 nm)

\( \sigma_x = 650 \text{ nm} \)
\( \sigma_y = 3 \text{ nm} \)

Zeuthen
Included in the simulation:
- ground motion,
- feedback system delay,
- emittance growth,
- lumi optimisation

The efficiency to identify a 100 GeV electrons close to the beam is nearly the same for RB and IB.

Total energy deposited in one pad of BeamCal near the beampipe is larger for real beam.
Resolution of energy deposition rms is similar.

Fake rate resulting from BG fluctuation is on the same level.
LumiCal / BeamCal - Potential Technologies

Challenge for detectors:
- high precise luminosity measurements
- fast, online, beam diagnostic and identification high energy electrons and photons
- radiation hard sensors

Calorimeters R&D →

• Diamond/Silicon – Tungsten (sandwich cal.)

• Gas Ionisation Chamber – Tungsten (sandwich cal.)
  Instead sensor → heavy gas C₃F₈
to measure energy deposit

• Heavy Crystal Calorimeter
  option with scintillating fibres
  option with ultra-thin photo-tiodes
Silicon Facilities:

- Prague
- Cracow
- Zeuthen
Design consideration

*a) polysilicon resistors:*
- should not be a problem to have resistors $\approx 10 \, \text{M}\Omega$;
- capacitors $\approx 1\text{-}10 \, \text{nF}$.

*b) punch through resistors:*
- resistors to be tested; if acceptable then it is a simple solution;
- capacitors as *a*).

Compatibility of process for variants *a)* and *b)* on one wafer? Option *a)* as a *baseline* for main sensor tile?
Electric characterization

I-V Diode with guardring
Tesla R-26, W=02

C-V Diode with guardring
Tesla R-26, W=02

I-V Ties
Tesla R-26, W=C2

I-V Diode with guardring
Tesla R-26, W=10
Silicon sensors

- Preamplifier based on Minsk „Tetrode”
- Bonding of silicon samples from Prague
- Testing of the pixel detector
- New preamplifiers ordered

Next steps:

- Tests of the pixel detector with source
- Tests of the silicon diode samples
- Preamplifiers based on AmpTek chips

8 x 32 pixels
At **DESY Zeuthen** we are able to perform (class 10k clean room):

- Ultrasonic wire bonding (Au, Al, down to 17.5 µm wires)
- Glueing with high mechanical precision and/or special hardening procedures (silver epoxies)
- Measurements of single and double sided sensors on different probe stations
- Long term measurements (darkness, special atmosphere: N₂ or similar)
- Chip testing (delivered probe cards can be adapted)
  
  **additional:** electronics workshop with automatic SMD placement and soldering tools
  mechanical workshop with NC machining/milling
  
  at **DESY Hamburg** a ‘state of the art’ programmable wire bonder

**Companies / Institutions we are used to work with:**

- Sensors: CiS Erfurt (D), Micron Ltd. (UK), SINTEF Oslo (N), Hamamatsu (J)
- Chip design: IDE AS, Oslo (N) and ASIC Laboratory of University of Heidelberg (D)
- Probe cards: Wentworth Deutschland GmbH, München (D)
- High precision printed circuit boards: Würth GmbH, Roth am See (D), Optiprint (CH)
- Thick film hybrids: Elbau GmbH, Berlin (D)
Position Measurement with Laser and CCD Camera

Requirements on alignment:
- Inner Radius of LumiCal < 1 µm
- Axial LumiCal position < 60 µm

Reconstruction of He-Ne red laser spot on CCD camera

X - distance

Laser translated in 50 µm steps

Next steps:
- Small-pixel camera, CCD technical data,
- Manually controlled sensitivity, BW camera,
- Micro pointing stability of lasers,
- Semiconductor laser,
- Piezoelectric movement of camera,
- More statistics.

Possible resolution of ~1 µm if the center of the light spot is determined with accuracy better than 0.1 pixel
Diamond Sensors

CVD diamonds from Frauenhofer Inst. Freiburg
12 samples (12 x 12 mm)
300 and 200 $\mu$m
different surface treatments:
#1 – substrate side polished; 300 $\mu$m
#2 – substrate removed; 200 $\mu$m
#3 – growth side polished; 300 $\mu$m
#4 – both sides polished; 300 $\mu$m
metallisation: 10 nm Ti + 400 nm Au

Measured:

- I-V characteristics
- Charge collection distance (CCD) – not irradiated samples
- CCD – irradiation studies
The samples were irradiated with Sr-source with estimated dose-rate of about 0.45 Gray per hour.

The total absorbed dose for all the samples was at least 5 Gy.

Parameters monitored during the irradiation:
- Sr-spectrum peak position
- width of the peak (-> noise)
- current in HV-circuit
- test pulse from a generator (-> electronics stability)

Raman spectroscopy and photoluminescence analysis
- no nitrogen, no silicon found

Tests on electron beam prepared for May
Examples

Group #2 (substrate side removed).
HV = 200V

Group #3 (growth side polished).
HV = 300V

In general Group #2 can work as detector.
Diamonds

Current step: Laboratory tests with $^{90}\text{Sr}$: Charge collection efficiency of 20%
Readout electronics ready for beam tests
Next step: First prototype for beam tests

Beam tests planned: PITZ / Zeuthen, CERN, HERA, TTF2

Probability of photon interaction within 300 $\mu$m of diamond sensor

5 MeV gamma energy
CVD Diamonds

Preparation for ionization radiation tests (Dubna) (alpha and beta spectra)

5 new diamond samples are available now (thickness: 110, 280, 290, 380, 380 microns)

The purity and optical properties

- Inpurities content → measur. the optical transmission spectra - UV visible and IR range
- The diamond quality → measur. of the spectral photoresponse in UV-visible (200-225 nm) range.

Ratio of photoresponse (UV to visible range) says about diamond quality – higher when this ratio increasing

Diamonds disks: 57 mm diameter, 250 and 350 µm thickness, laser cut, polished both sides, metallized Cr/Au electrodes deposited to growth and substrate side sides to compare their quality

The spectral photoresponse measured separately for growth and substrate side side

The spectral discrimination ~ six orders of magnitude for growth side
Two order of magnitude lower for substrate side → more defective structure

MPCVD device for diamond deposition

NSC GPI – Moscow / Dubna

5 new diamond samples are available now (thickness: 110, 280, 290, 380, 380 microns)
The measur. of optical properties, purity, I-V characteristics and irradiation tests are under the work
Gas Ionization Calorimeter W / C$_3$F$_8$

W / C$_3$F$_8$ Cal. → - good energy resolution
- high uniformity and stability
- simple calibration
- high radiation hardness
- low equivalent noise energy also at atm. pressure
- low cost

The volumes between absorber plates (W) are filled with gas C$_3$F$_8$ at 0.5 and higher atm pressure

C$_3$F$_8$ (octa fluoro propane) measurements:
density 0.0075 g/cm$^3$
molecular weight 188
drift velocity v = 0.07 mm / ns at ~ 800 V / atm
Gas Ionization Calorimeter W / C$_3$F$_8$

- Beam tests of prototypes with electrons up to 70 GeV (IHEP Protvino) at pressure up to 1.8 atm, lead absorber - 1.5 and 3 mm, 10mm gas bigap

- MC simulation – Tungsten as absorber

Efficiency to identify high energy electron - small and large background

PCB with redout pads to collect the ionization electrons
Crystal Calorimeter Option for BeamCal

Expectation: homogeneous crystal calorimeter – better energy and time resolution than a sandwich calorimeter

Example: PbWO$_4$ – Moliere radius $\sim 2.3$ cm

Readout via fibers reduces light yield to 14\%
Conclusions

The recent developments indicate on essential progress in most areas.