A hybrid-less micro strip telescope for the DESY II Test Beam Facility

LYCORIS Telescope: Large Area x-Y Coverage Readout Integrated Strip Telescope

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Electron beam provided by DESY II synchrotron.
- \(e^+/e^-\) particles with energy up to 6 GeV.
- 1.35 T Dipole magnet in T21.
- Three EUDET silicon pixel Telescopes (Datura/Duranta/Azalea), based on Mimosa 26, in T21, T22 and T24.
- 1 T Superconducting solenoid (PCMAG) in T24/1.
The Lycoris Telescope

An AIDA project

- A new large area strip telescope within the Test Beam Area 24/1 solenoid:
  - Wall thickness of 20% $X_0$.
  - Magnetic field strength of up to 1T.

- Telescope demands complementary to existing EUDET Telescopes and user demands:
  - Larger area $\sim 10 \times 10 \text{ cm}^2$.
  - Less than 3.5 cm of space per telescope module.
  - Spatial resolution requirements better than:
    - $\sigma_{\text{Bend}} = \sim 10 \ \mu\text{m}$.
    - $\sigma_{\text{opening}} = \sim 1 \ \text{mm}$.
  - Higher time resolution ($< 100 \ \mu\text{s}$).
The SiD Silicon Strip Sensor

Hybrid-Less silicon strip sensor designed by SLAC for the ILC:

- A strip pitch of 25 μm.
- ~7 micron tracking resolution.
- Alternate strips are being read out.
- An integrated pitch adapter and digital readout (KPiX).
  - Directly bump bonded to sensor surface.
- Thickness of 320 μm.
- Material budget of 0.3% $X_0$.

Fig.: Assembled Tracker Module
KPiX readout chip

- 1024 channel fully digital readout with 13 bit resolution (8192 ADC).
- 100 MHz clock → 10 ns flexible acq. Clock period.
- Can work in two modes:
  - Self/Internal trigger = 4 events per channel per cycle stored.
  - External trigger = 4 events per cycle stored.
- Power pulsing operation → Only open for a short time frame.
- Length of the opening period depends on timing resolution.

Acquisition Cycle

- Only open for a maximum time of 8192*8*acq.clock.
  → For example with a 320 ns acq.clock = 20.97 ms.
The final system: The cassette

Fig.: Cassette Housing without Carbon Fiber Cover

- Carbon fiber window for protection + grounding shield
- Torlon frame to carry the sensor.
- Aluminium frame for mechanical stability
- Two stacks of three layers of sensors side by side
  $0^\circ$, $-2^\circ$, $+2^\circ$ orientation with 15 mm distance
- 12.1 cm
- 32.1 cm
- 3.3 cm
The final system: The rail structure

Rail structure for movement along magnet angle

Rail structure for movement along magnetic field axis

Fig.: T24/1 Solenoid with Telescope
System overview: Mechanics

- All mechanical components have been assembled.
- Functionality has been shown in first tests with dummies.
- Sensors were installed in the Cassette for first test beam.
- Average radiation length in beam path per cassette = \( \sim 1\% X_0 \).
  - Carbon Fiber windows = \( \sim 0.1\% X_0 \).
  - Araldite2011 = \( \sim 0.03\% X_0 \).
  - Aluminium foil = \( \sim 0.015\% X_0 \).
  - Silicon Sensors = \( \sim 0.7\% X_0 \).

Fig.: Cassette Housing with Carbon Fiber Cover
Fig.: PCMAG with cassette rails
System Overview: New Electronics

- All new electronic components are at DESY and currently under test.
- AIDA trigger logic unit (TLU):
  - Needed for synchronized data readout of DUT and telescope.
  - Can provide a common clock to all devices.
- New data acquisition (DAQ) board:
  - Provides necessary interfaces between new electronics and AIDA TLU.
  - Hardware/Firmware improvements compared to old system.
- Cassette boards:
  - Interface between the inside and outside of the cassette.
  - Provides on board power distribution and noise filtering
  - Ensures inside of the cassette needs not be touched during normal operation
System Status: Sensors

- Multiple sensor modules assembled:
  - Shown the functionality of overall principle.
  - Sensor depletes through wire bonds and shows sensitivity to light and radioactive sources.
  - Functionality of sensors confirmed through calibration, pedestal data taking as well as multiple test beam campaigns.

![Channel 10](image)

Fig.: Pedestal distribution of a single channel

![Channel 10](image)

Fig.: ADC response to input charge during calibration
System Status: Sensors

Self triggering operation

- Full coincidence:
  - SiD Strip Tracker ↔ SiD ECAL Pixel Sensor ↔ Beam Scintillators.

- Just completed very successful testbeam campaign using multiple tracker and ECAL sensors.
- Recorded ~ 600,000 beam spills, split between different running modes, positions, angles, bias voltages etc.

Fig.: Testbeam setup with the tracker in front and ECAL in the back.

Fig.: Mapping of trigger hits to ECAL (left) and tracker (right)
System Status: Sensors

External triggering operation

- Final running operation with many DUT is going to be in external triggering
- Current system noise is $\sim 0.19 \, \text{fC}^*$
- $\sim 3 \, \text{fC}$ expected signal charge in 320 micron silicon
- $\rightarrow \text{S/N} = \sim 15^*$

*Preliminary as this was measured with the old electronics
System Status: Reconstruction

External triggering operation

- Very early steps into cluster reconstruction shows promising results but:
  - Current clustering is very sensitive to single high charge channels → Need to mask noisy channels
  - As a result of floating strips there are two cases, one of which the current clustering does not take into account correctly:
    - Case 1: Readout strip hit = high amounts of charge in a single strip → Ideal starting candidate for clustering
    - Case 2: Floating strip hit = 40% of charge gets transferred to adjacent strips → No single strip with very high charge
System Status: Reconstruction
External triggering operation

- Clearly visible strip correlation between two modules.
- Offset between Module 1 and Module 2 of roughly 20 strips = 1 mm.
- Agreement with tilt of modules to the electron beam as a result of stage tilt.

Strip correlation

Strip offset between Module 1 and Module 2

Electron Beam

Module 2

Module 1

1 mm
Summary and Outlook

- New telescope based on hybrid-less silicon sensors is nearing completion.
- Works well to complement the current EUDET-type telescopes in operational features.
- The components of the new telescope system are all in place.
- Assembled the first telescope modules.
  - Successful communication with and calibration of both chips.
  - Completed multiple tests of the sensor in the laboratory and at the DESY II Test Beam Facility.
  - Shown capability of track finding with multiple tracker sensors.

- Next steps towards system completion:
  - Test campaign with full 6 sensor layers.
  - Use newly arrived electronics.
  - Further development of reconstruction and analysis software.
  - Write Documentation.

- Testbeam of LYCORIS within T24/1 solenoid with EUDET telescope as reference, scheduled for 04/2019.
Thank you for your attention
The LYCORIS Project In the Context of ILC
Silicon Telescopes

- High precision silicon trackers
- Used to provide reference measurements of particle track
- Multiple layers placed before and after the Device Under Test (DUT)
  → Provide tracking through the DUT even in the case of multiple scattering
Challenge: Distortion of particle trajectory as a result of multiple scattering or inhomogeneous electric fields

Solution: Reference measurement of the particle position before and after the DUT

Challenge: Smearing of particle momentum as a result of interactions with the magnet wall

Solution: Accurate measurement of the momentum after magnet wall

Fig.: Sketch explanation for the need of a reference trajectory

Fig.: Momentum distribution after interaction with the PCMAG wall

(Felix Müller | DOI: 10.3204/PUBDB-2016-02659)
System Status: Sensors

- 27 Bump Bonded sensors tested:
  - Good behaviour:
    - ~100 nA currents, stable up to 300 V
    - Depletion voltage for all sensors at ~50 V
  - Two sensors show breakdown beginning at 280 V

![Bump Bonded Sensor with flex cable on the probe station](image)

![IV (top) and CV (bottom) of the sensors](image)
The DESY II Energy Cycle

- DESY II energy cycle follows a sinoidal curve
- Time difference between minimal energy signal and signal in the test area is measured using scintillator triggers in the area

![DESY II energy cycle diagram]

Fig.: Time difference from min. energy to trigger signal

![First and last DESY signal in a cycle for different energies]

Fig.: First and last DESY signal in a cycle for different energies
**System Status: Sensors**

Self triggering operation

- Without Pedestal Subtraction
- SiD ECAL Pixel Sensor

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**Preliminary**

Electron Beam

**Fig.:** Mapping of trigger hits to ECAL (left) and tracker (right)

- Recently completed first Testbeam with multiple tracker sensors
- Recorded ~ 600.000 beam spills, split between different running modes, positions, angles, bias voltages...

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**Fig.:** High threshold charge distribution for the tracker with landau gauss convolution fit

- Full coincidence:
  - SiD Strip Tracker ↔ SiD ECAL Pixel Sensor ↔ Beam Scintillators.

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**Fig.:** Mapping of trigger hits to ECAL (left) and tracker (right)
System Status: Sensors

External triggering operation

* Deeper look into hit profile candidates for analysis.

* We expect 1 particle per trigger within the sensor with multiple cases depending on where/what it hits

  * Case 1: readout strip → look for 1 single channel per trigger with ~3 fC
  * Case 2: floating strip → look for 1 single candidate of 2 adjacent strips per trigger each with charge ~1.2 fC

...
System Status: Sensors

External triggering operation

- Operation works quite well for the ECAL
KPiX synchronisation, DUT and Beam

- KPiX needs to be synchronised to beam spill of the accelerator and the DUT
- \(T_0\): Accelerator signal for synchronisation with beam spill
- \(T_{\text{Start}}\): User adjustable delay between \(T_0\) and KPiX switch on.
- \(T_{\text{Setup}}\): Setup time of KPiX. At the end of which KPiX can start the data taking
- \(T_{\text{End}}\): User adjustable signal telling all devices that KPiX has stopped data taking
- New AIDA TLU (Trigger Logic Unit) will be able to provide these signals and distribute a common clock
Heat production

- As a result of power pulsing and only 1024 channels, a low power consumption is expected (40 mW in total)
- Measurement of heat production done via infrared camera

- Overall power consumption and heat generation is negligible
  → No active cooling needed
## Radiation Length

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>General Radiation Length (≈ 1 X0)</th>
<th>Final Radiation length (as multiples of X0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Fiber Window</td>
<td>0.03 cm</td>
<td>~29 cm</td>
<td>0.103%</td>
</tr>
<tr>
<td>Aluminium Foil (Al)</td>
<td>0.0013 cm</td>
<td>8.897 cm</td>
<td>0.015%</td>
</tr>
<tr>
<td>Silicon Sensor (Si)</td>
<td>0.032 cm</td>
<td>9.37 cm</td>
<td>0.342%</td>
</tr>
<tr>
<td>Kapton Cable (Cu)</td>
<td>maximum 0.025 cm</td>
<td>1.436 cm</td>
<td>1.74% (maximum)</td>
</tr>
<tr>
<td>Kapton Cable (Kapton)</td>
<td>maximum 0.025 cm</td>
<td>57.6 cm</td>
<td>0.043% (maximum)</td>
</tr>
<tr>
<td>KPIX (Si)</td>
<td>0.032 cm</td>
<td>9.37 cm</td>
<td>0.342%</td>
</tr>
<tr>
<td>Araldite (2011) by ATLAS</td>
<td>~0.01 cm</td>
<td>33.5 cm</td>
<td>0.030%</td>
</tr>
<tr>
<td>Araldite (2011) by calculation</td>
<td>~0.01 cm</td>
<td>46.24 cm</td>
<td>0.022%</td>
</tr>
</tbody>
</table>

The materials in question are the following:

1. Carbon Fiber Window + Aluminium Sheet + Stycast
2. Master ↔ Slave Interboard Kapton Flex
3. Sensor 1 (+Kapton Flex && Araldite2011 || +KPiX)
4. Sensor 2 (+Kapton Flex && Araldite2011 || +KPiX)
5. Sensor 3 (+Kapton Flex && Araldite2011 || +KPiX)
6. Carbon Fiber Window + Aluminium Sheet + Stycast
7. DUT
8. Carbon Fiber Window + Aluminium Sheet + Stycast
9. Sensor 4 (+Kapton Flex && Araldite2011 || +KPiX)
10. Sensor 5 (+Kapton Flex && Araldite2011 || +KPiX)
11. Sensor 6 (+Kapton Flex && Araldite2011 || +KPiX)
12. Master ↔ Slave Interboard Kapton Flex
13. Carbon Fiber Window + Aluminium Sheet + Stycast
Radiation Length

- Copper traces
- Grounding plane
- Components
System Status: Mechanics

- After first manual assemblies, a new tool was designed and built to provide reproducible results through:
  - Controlled glue application
  - Fine adjustable gluing pressure
  - Precise cable positioning
  - Able to be used for further assembly of sensors into Torlon frames

First assembly with new tool expected to start next week.
System Status: Sensors

- First sensors assembled and tests on the first sensors are nearing completion:
  - Both readout chips can be talked to.
  - Sensor depletes through wire bonds and shows sensitivity to light
  - First pedestal data taking and calibration measurements **completed**
Time Coincidence

Calculate Difference

\[ \Delta 4 < \Delta 3 < \Delta 2 < \Delta 1 < \ldots < \Delta N \]

\[ \Rightarrow \Delta 4 = \text{Time difference for channel K} \]

\[ \text{Calculate Difference} \]

\[ \text{Time/bunchClkCount} \]

\[ \text{#entries/100 cycles} \]

\[ \text{extern_extern_trig_diff} \]

\[ \Delta T (\text{BunchClkCount}) \]
The expected resolution

- Analytical calculations using GeneralBrokenLines (GBL) by Claus Kleinwort with a 25 μm pitch strip sensor.
- Depending on the orientations, correlations between planes severely limit the resolution.

Fig.: Achievable curvature and z resolution of the telescope, with multiple scattering, depending on angular orientation.
Stereo angle variation
Parameter correlation

correlation of parameters for different sensor orientations

Orientations

Correlation

- curv_phi
- curv_lambda
- curv_dca
- curv_z0
- phi_lambda
- phi_dca
- phi_z0
- lambda_dca
- lambda_z0
- dca_z0