The H1 Silicon Tracker

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Tracking in High Multiplicity Environments

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- HERA and H1
- The H1 silicon tracker
- Recent results
- Water damage
- Radiation damage
The HERA ep Collider

- Located at DESY in Hamburg
- 27.5 GeV electrons/positrons on 920 GeV protons
- HERA-I: 1992-2000, 120pb$^{-1}$
- 2000: Luminosity upgrade
- HERA-II: 2001-2007
The H1 Detector

27.5GeV Positrons

920GeV Protons

Lar Calorimeter

Scattered Electron

Hadronic Final State

Forward Tr.

Central Tracker

SpaCal

Forward

Central

Backward

Silicon Tracker

Forward

Central

Backward
Physics Requirements (I)

● FST:
  ➢ Extend tracking (with vertexing capability) into forward direction:
    high track density!
    => good pattern recognition

● CST:
  ➢ Provide vertexing capability in central region (charm, beauty)
  ➢ Resolution dominated by multiple scattering:
    thin detector!
Physics Requirements (II)

BST:

- Measure and trigger scattered electron at low angles: suppress fake electrons from $\pi^0 \rightarrow \gamma \gamma$
- Generally low track density in backward direction

Separation of pions and electrons by measuring energy $E$ in the calorimeter and momentum $p$ in BST.

FST: Forward Silicon Tracker

Collaboration of DESY-Zeuthen, DESY, Prag, RAL

- 7 sensor wheels, 2 types: u/v and r
- 3384 cm² silicon
  - from CIS (Erfurt)
- 92160 channels
- Readout with APC (Analog Pipeline Chip)
  - developed at PSI
  - SACMOS: 1.2 μm CMOS
  - Manufactured by Faselec
  - Store signal in 128x32 capacitors, readout sequentially
FST Sensor types

- 5 wheels with u/v coordinate:
  - single sided silicon
  - u and v sensors mounted back-to-back
  - good signal/noise
  - 72μm pitch

- 2 wheels with r strips
  - single sided silicon
  - readout with 2nd metal layer
  - reasonable S/N
  - needed for pattern recognition in high multiplicity events (ambiguity resolution)
BST/FST Sensor Wheel

Asymmetric hole to accommodate elliptical beampipe

Beamspot

Synchrotron radiation fan
FST Performance

- **Signal/Noise:**
  - 30 for u/v detectors
  - 15 for r detectors

- **Resolution 12μm** (from triplet sagitta)

A multitrack event reconstructed in the FST
Water Damage to FST in 2004

- Imperfect crimp + hardening of plastic $\Rightarrow$ water leak
- Water condensation $\Rightarrow$ damage
- FST being rebuilt now
- Will be reinserted in Nov
New Readout Chips in 0.25\(\mu\)m Technology

- Some radiation damage observed, vulnerability of SACMOS chips also seen in CST => Design new chips in 0.25\(\mu\)m technology
- Translation from earlier design in only 3 months (2 chips!) Sep-Dec 2004
- Joint project Zeuthen-PSI-KIP Heidelberg
- Fabricated by UMC
- Production finished
BST: Backward Silicon Tracker

- **Sensor Wheels**
  - 6 double wheels with u/v coordinates, same as in FST: tracking
    - no r wheels needed, typically low multiplicity in backward direction
  - 4 wheels with pad detectors: triggering
    - Hit detection + track finding done on frontend, at 10.4MHz

- **Electronics**
BST Pad Hit Detection

ASIC PRO/A:
- 1.2μm CMOS process
- from IDE AS (Oslo)
- 32 channels per chip
- noise: 600e + 15e/pF
- shaping time 30ns

Pad sensors: 8×4=32 pads
BST Pad Trigger Concept

- One motherboard for 2 sectors (8 sensors), mounted directly behind sensor volume
- Complex Programmable Logic Devices (CPLDs) from ALTERA for trigger
  - Recognises tracks from IP
  - Rejects tracks from outside interaction region
  - Flexible, for shifted vertex runs
- Uses Content Adressable Memory (CAM) to compare hit patterns with predefined hit patterns from tracks
**Backgrounds**

- Proton beam
- Electron beam
- Collimator against backscattered synchrotron radiation
- Silicon Trackers

![Diagram with labels: Proton beam, Electron beam, Collimator against backscattered synchrotron radiation, Silicon Trackers, IP (interaction point), 0.3m, 43m]
Radiation Damage to BST

- In 2002: Dosimeters in BST showed up to 30kGy of dose
- High dose only in small region at -z end (around collimator), FST, CST, forward region of BST received <100Gy
- Damages:
  - APC chips of BST: do not hold charge long enough (1ms) for readout (same problem lead to installation of radhard chips in CST)
  - BST slow control circuitry damaged
  - line receivers, drivers damaged
  - ALTERA CPLD chips survived!
  - Voltage regulators for CST damaged (located at same z position as BST electronics)
- New hybrids+sensors inserted in 2003
- Now rad-hard design
Beam optimization using BST Pad Rates

- Use single pad rate to monitor beam conditions
- Very useful for beam tuning
- Problem:
  - Large background spikes (from beam missteering) deprogram CPLDs
- This was an unforeseen application, shows advantage of CPLDs: can be easily adapted to new demands

![Graphs showing beam optimization results](image-url)
The CST

- 2 barrel layers, 12+20 ladders
- 192 sensors $3.4 \times 5.9 \text{cm}^2$, $3850 \text{cm}^2$ silicon
- Double sided sensors, $50(\phi)/88(z) \mu\text{m}$ pitch
- 3 sensors read out together: 81920 channels
- Very thin: 1.4% $X_0$ in radial direction
- Floating ground for readout circuitry

- Analog readout with rad-hard DMILL APC
  - manufactured by ATMELE
- Optical signal transmission

Built by ETH Zurich, PSI, Uni. Zurich, DESY, RAL
CST Movement

- A nasty surprise: H1 beampipe too high by 4mm since switch to e- operation last November, beampipe moves due to magnetic forces on superconducting final focus quadrupoles => alignment difficult, but possible (once per lumi fill!)
- Next shutdown in Nov: Change CST support to avoid moving
CST Hardware Problems

- Hairline fractures on capton cables
- Reason: Capton sticky tape put on capton cable for insulation
- Repair: New 3-layer cables (made by Dyconex)
- Will be *soldered* onto old cables (avoids difficult re-bonding of complete ladders)
- Planned for coming shutdown in November
Summary

- HERA-II had a slow start, but is now on track
- Radiation damage occurred mainly from a single incident where synchrotron radiation directly hit a collimator
- Normal operation of HERA leads to doses ~100Gy/y
- Brittle cooling pipe -> water damage at FST in 2004
- Now complete rebuilding of FST + BST, including new rad-hard chips in 0.25μm technology
- CST fully equipped with radhard DMILL chips, running
- Alignment very difficult due to beampipe movement: Repeat global alignment for each lumi fill
- Fractures in capton cables in CST due to sticky tape & bending: Will be replaced in November
Reserve Slides
BST 1, 2, 3, 4

- **BST-1: Installed 1995:**
  - 4 wheels of r detectors × 16 sensors = 64 sensors, 40960 channels

- **BST-2: Upgrade 1998:**
  - 4 + 4 wheels of r detectors × 16 sensors = 128 sensors, 81920 channels
  - 8 prototype φ sensors (u coordinate): 5120 channels

- **Upgrade 2001:**
  - 8 wheels of r detectors × 12 sensors = 96 sensors, 61440 channels
  - BST-Pad: 4 wheels of pad detectors × 12 sensors: 48 sensors, 1536 pads

- **BST-3: Upgrade 2003:**
  - 5 1/2 double wheels of u/v detectors × 12 sensors = 132 sensors, 84480 channels
  - BST-Pad: 4 wheels of pad detectors × 12 sensors: 48 sensors, 1536 pads

- **BST-4: Repair 2005**
  - Compete rebuilding with new radiation-hard Chips
Some Lessons

Frontend electronics is subject to

➢ power glitches
➢ damaged control or power cables
➢ magnetic field changes
➢ particle bursts.

It must survive all these without intervention from outside:

● System must be in safe state at power-up
   ➢ Missing voltages should not damage the electronics
● Reset by a single signal should bring it back to this state
● Software errors should not lead to electronics damage
Things to have

- Some **monitoring** lines (power, temperature, radiation) that are **independent** of running frontend, DAQ etc.
- **Redundancy** for vital power and control lines (vital: failure leads to failure of large part of the detector)
- **Self-identifying frontend units** (serial number on chip or module):
  - Simpler logistics during assembly and testing
  - Control over cabling and software errors
The HERA ep Collider

HERA (at DESY, Hamburg):
- ep collider: 27.5GeV e, 920GeV p
- 10.4MHz bunch crossing frequency

● HERA-I:
  ➢ 1992-2000
  ➢ 70pb⁻¹ per year at end

● Lumi upgrade

● HERA-II:
  ➢ goal: 250pb⁻¹ per year
  ➢ magnets within experiments, complex interaction region

➢ slow start:
  ❓ understanding new machine
  ❓ vacuum => background
HERA Status, cont'd

- 2002/2003: Background problems limited currents => low lumi
- Bad vacuum leads to proton-induced background (hadrons),
  - Limit of 2000Gy for sensors imposes similar limits as ageing of jet chamber
  - Most of dose received in incidents/accidents
- March-June 2003: Shutdown
  - Detectors opened, some systems repaired
  - Numerous improvements to machine
  - H1 silicon detectors: All removed, repaired/augmented
- Since July: Bakeout to improve vacuum, progressing well
- Restart lumi operation in October
Overview

- 3 Silicon detectors: FST, CST, BST (Forward/Central/Backward Silicon Tracker)
  - FST:
    - 7 wheels with single sided strip detectors
  - CST:
    - 2 barrel layers with double sided strip detectors
  - BST:
    - 6 wheels with single sided strip detectors
    - 4 wheels with pad detectors for triggering

Analog readout after trigger