Design of a z-Vertex Trigger and its Operation Experience in the H1 Experiment at HERA

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I. The HERA Accelerator and the H1 Detector
II. Concept and Design of the $z$-Vertex Trigger System
III. Operation Experience and Results of the first Data Taking Period

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**I. - (1) The HERA accelerator**

**Hadron Electron Ring Accelerator (HERA):**

- Two storage rings each with 6.3 km circumference in opposite direction for Protons (E=920GeV, I_p=100mA) and Electrons (E=27.5GeV, I_e=50mA), supported from the DESY in Hamburg.
- Two points where electrons and protons collide
- Detectors around interaction point to reconstruct event (H1, Zeus)
- Interaction rate 10.4MHz, Bunch Crossing every 96ns
- Center-of-mass energy: $\sqrt{s} \approx 320 \text{ GeV}$

**Specific luminosity:** $1.82 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1}\text{mA}^{-2}$

**Integrated ep-luminosity in 2004:** 87pb$^{-1}$
I. - (2) The H1 Detektor

H1 Detector
At the northern interaction point of HERA

Components:

- instrumented iron (streamer tubes)
- Liquid Argon Calorimeter
- drift chambers (CJC)
- proportional chambers (CIP) for Trigger
- silicon strip detectors (forward, central, backward)

Protons

defined $z$-axis

Electrons/Positrons

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I. - (3) Triggering at H1

hadronic final state

\[ e^{-} \quad \gamma/Z^{0}(W^{\pm}) \quad e^{\prime}(\nu) \]

typical triggers:
- scattered electron
- energy thresholds
- muons
- charged particles (MWPC)

H1 Event Display 1.20/33

\[ E = 27.6 \times 920.0 \text{ GeV} \quad B = 11.6 \text{ kG} \]

RUN 389090 Event 50758

Triggered \( ep \) event
I. - (3)  

2000-2002: Upgrade of HERA

Goal: increase the luminosity $L$

$$L = \nu \cdot \frac{N(e) \times N(p)}{A}$$

→ Superconducting magnets inside the H1 detector for a stronger focusing of e-, p-beam. New strong magnets create high amount of synchrotron radiation inside the detector.
I. - (4) Synchrotron Radiation → Background events

Part of synchrotron radiation is absorbed at -11m

→ beam-gas events: off momentum particles collide with collimators C5A, C5B and produce secondary interaction vertices

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I. - (5)  H1 event display: ep and background event

**H1 Event Display 1.20/33**

- **E** = -27.6 x 920.0 GeV  **B** = 11.6 kG
- **RUN**  389090  **Event**  50758

**Typical ep event**
- moderate number of tracks
- $z_{\text{vertex}} = 0 \text{ cm}$

**H1 Event Display 1.20/33**

- **E** = -27.6 x 920.0 GeV  **B** = 11.6 kG
- **RUN**  389090  **Event**  53931

**Typical background event**
- high number of tracks
- $z_{\text{bkg}} < -50 \text{ cm}$
II. - (1) Concept and Requirements of the $z$-Vertex Trigger System

Goal: separate background and ep events on first trigger level

Hardware requirements:

- track recognition in high multiplicity environment
- trigger decision synchronous to HERA accelerator clock (10.4MHz)
- Maximum latency 2.3us
- pad readout

→ high granularity (~8500 pads)
→ pipelined trigger algorithm based on track reconstruction within 1us
→ storage capabilities for event readout

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II. - (2) MWPC with high granularity along the beam (z) axis

Development of a Multi Wire Proportional Chamber (MWPC) with cathode pad readout:
CIP2k in the innermost part of the H1 detector between silicon detectors and drift chambers
Fine segmentation along z (2 cm)
→ z-vertex resolution ~15 cm

Specifications:

- 5 layers
- cylindrical, 2.2m length
- 16 fold segmentation in ϕ (22.5°)
- radii from 15 to 20 cm
- ~8500 pads, up to 120 per layer and ϕ
II. - (3) Track Reconstruction for a typical Event:

1. Recognition of track pattern and sorting into bins
2. Counting of tracks in bins of \( z \)-Vertex histogram
3. Grouping of bins in \( ep \) - and background region
II. - (4) Trigger and Readout – Flow-diagram:

at the H1 Detector

5 layer MWPC

CIP2k

read out-electronics

CIP2k z-Vertex Trigger System:

H1 central trigger control
II. - (5) Front end Electronics and optical Link

Specifications:

- 8 layer PCB with one capton foil layer (10x13 cm size)
- 4 CIPix ASICs for amplification, shaping and digitization of chamber signals (60 signals each)
- 4 17to1 multiplexer (HP HDMP 1032)
- 1 optical hybrid with 6 optical fibers (4 sender, 2 receiver lines)
- 8 double boards per layer, 40 in total
II. - (6) The CIPix read out ASIC and optical link system

charge sensitive preamplifier  signal shaper  1-bit comparator  4 to 1 multiplexer  17 to 1 multiplexer  optical link 1 GBit/s

41.6 MHz clock
10.4 MHz HERA clock (sync. to bunch crossing)

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II. - (4) Trigger and Readout – Flow-diagram:

- digitalization in front-end systems
- 40m optical link for data transfer (160 channels with 1GBit/s each)
- Trigger System with integrated readout implemented in FPGAs
II. - (7) Trigger and Readout – the hardware:

at the H1 Detector

CIP2k $z$-Vertex Trigger System:

- Track-recognition
- sorting adding
- Trigger decision

storage of chamber data, DAQ

H1 central trigger control

readout of detector data: DAQ

Two types of FPGA-based cards:

- **Trigger Card**
- **Sum Card**
II. - (8) Trigger Card for one $\phi$-Sector:

5 layers of one $\phi$-sector

In the H1 Detector

5 layer CIP2k

Receiver Cards

Trigger Card

To Sum Card

- Trigger Card fulfills track recognition and counting of tracks (trigger algorithm)
- builds the $z$-Vertex histogram for one $\phi$-sector
- 16 Trigger Cards = 16 $\phi$-Sektoren
- Contains two Altera APEX 20k400 FPGAs
- VME Bus controller
- 250 inputs, 60 outputs (LVDS)
II. - (9) Block Diagram File in Trigger Card:

Signals distributed in both FPGAs (5 layers each)

Each FPGA holds:

- Ring memory to keep pad data of 32 BCs
- State machine to organize readout of triggered BC (5 BCs) via the VME bus
  → Readout Module

- Demultiplexer, Defect Pad Mask, Track reconstruction + adder
  → Trigger Module

Modules programmed in Verilog (Quartus)
90% of logic units in each FPGA are used
II. - (10)  Sum Card for 4 $\phi$-Sectors (4 Quarter):

Delivered Trigger Elements:

- Reference-Timing for good event (event T0)
- Ratio between # tracks in $ep$ - and Background – Region
- total # of tracks detected in an event

[to Quarter Sum Card / Trigger Decision]

$\phi$-Sector 0 / Quarter 0
$\phi$-Sector 1 / Quarter 1
$\phi$-Sector 2 / Quarter 2
$\phi$-Sector 3 / Quarter 3
III. - (1) Verification of Trigger Hardware...

**CIP2k trigger**

- **Chamber**
- **Trigger Cards**
- **Sum Cards**
- **H1**

**Available info:**
- Pad readout (hits)
- zVtx-histogram (tracks)
- Summed hist. (tracks)
- Trigger element (on or off)

**Compare to:**
- Extrapolated CJC-tracks
- Trigger simulation, based on pad readout

- Diagnostic tools to analyze every component of trigger system.
- Detailed tests with low multiplicity events (cosmic rays)
III. - (2) Chamber Performance: Single hit resolution

- single track events
- Event selected, if muon crosses both halves of the H1 drift chamber (CJC) near the z-axis.

Distance between active CIP pad and CJC track
Width dominated by pad size ~2 cm

correlation of CIP2k hit position and extrapolated CJC tracks
III. - (3) Trigger Performance: Timing

- cosmic ray tracks: not synchronized to HERA clock
- drift chamber reconstructs event timing with high precision
- CIP trigger sorts events into well defined bunch crossings

CIP2k cosmics-\tau_{\nu}\text{-timing: Compared to CJC T0 (Pipelineposition)}

Width \sim 15 \text{ ns}, driven by CIP and drift chamber resolution
III. - (4) Trigger Performance: z-Vertex reconstruction

- Cosmic ray events: number of tracks small...
- ... but performance with high multiplicity ep events?

z-Vertex resolution ~16 cm

Compare z-Vertex bins identified by CIP2k trigger to drift chamber z position
III. - (5) CIP Performance during 2003/2004 HERA II run

First HERA II runs: no CIP trigger

CIP design specification:
- reject background
- keep physics

CIP in operation with VETO condition:
- reject high multiplicity events with vertex < 50 cm (at first trigger level)
Summary and Outlook

I. HERA and H1 after luminosity upgrade:
   → \( z \)-Vertex (background) trigger is necessary

II. Realization with latest FPGA technology
    → Trigger Card, Sum Card programmed in Verilog

III. Commissioning phase:
    → Chamber resolution and trigger response as expected

IV. Operation experience:
    → excellent performance of CIP VETO
    → highly efficient physics trigger (not shown in detail)

collected 60 pb\(^{-1}\) of ep data during 2004
500 pb\(^{-1}\) expected in the coming years