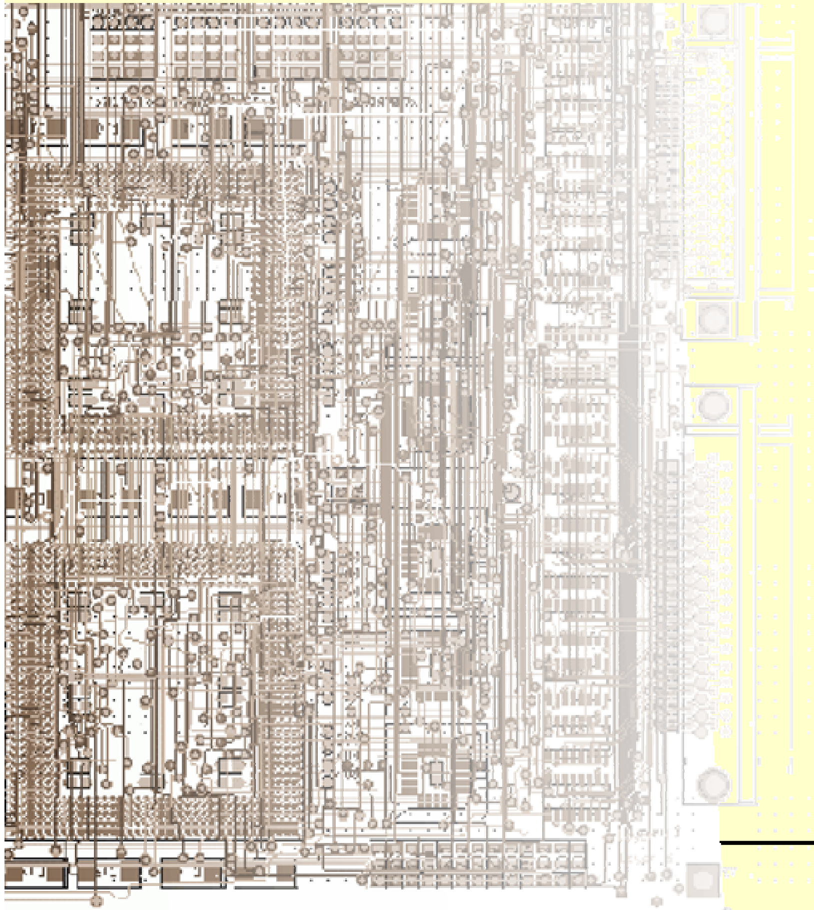
LECC 2004

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

Max Urban ,
University Zürich



I. The HERA Accelerator and the H1 Detector

II. Concept and Design of the *z*-Vertex Trigger System

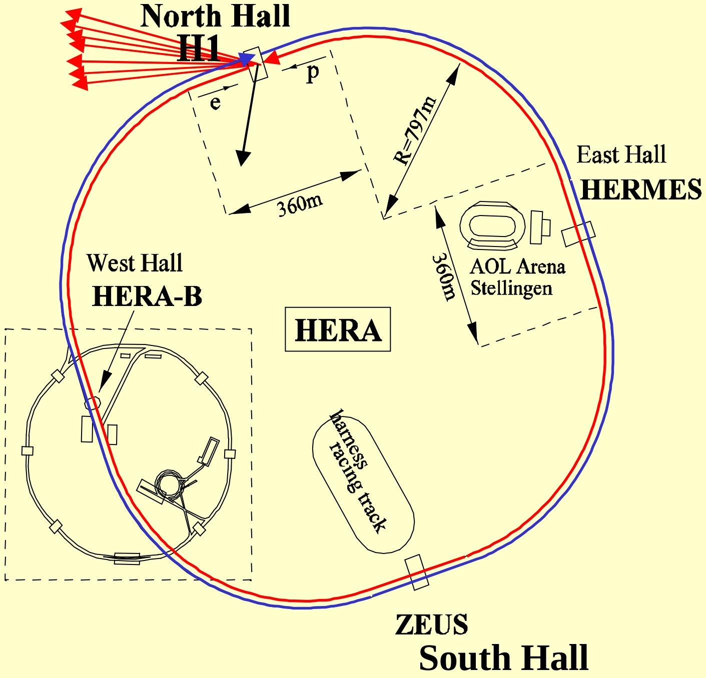
III. Operation Experience and Results of the first Data Taking Period

14.09.2004

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: $\sqrt{s} \approx 320\ GeV$



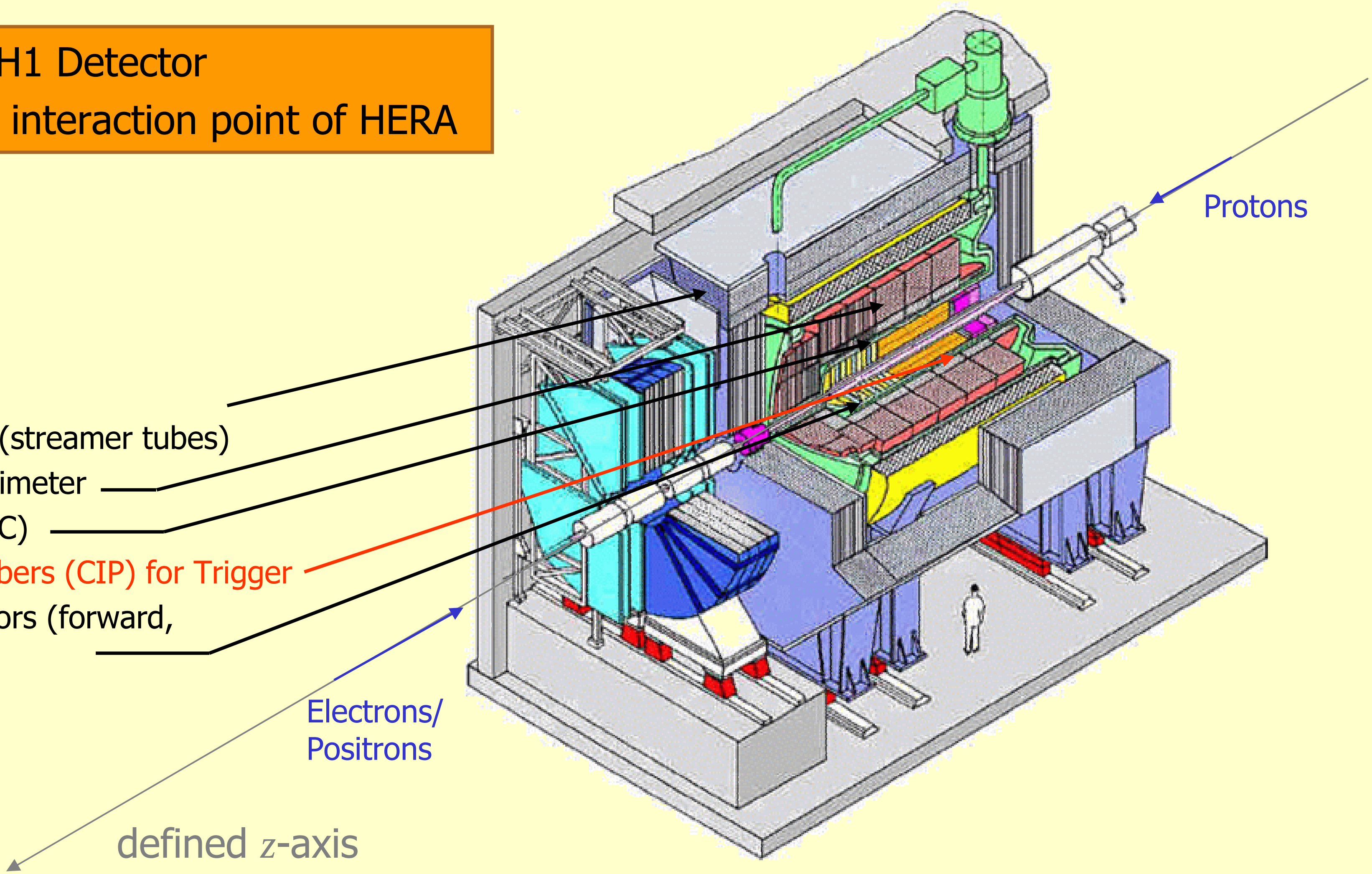
Specific luminosity: $1,82 \times 10^{30}\ cm^{-2}s^{-1}mA^{-2}$
Integrated *ep*-luminosity in 2004: $87pb^{-1}$

The H1 Detektor

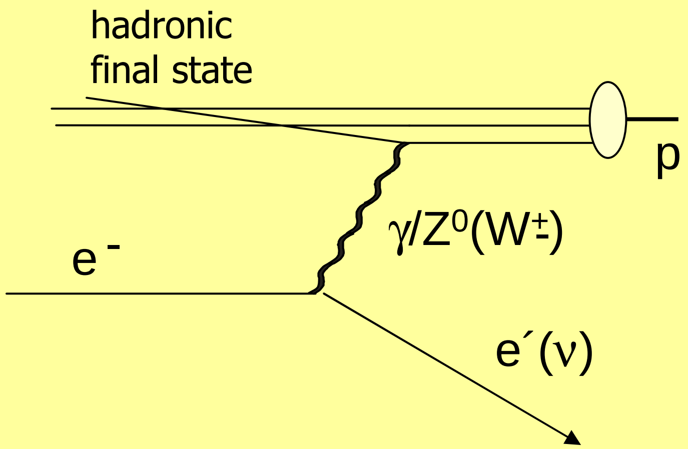
H1 Detector
At the northern interaction point of HERA

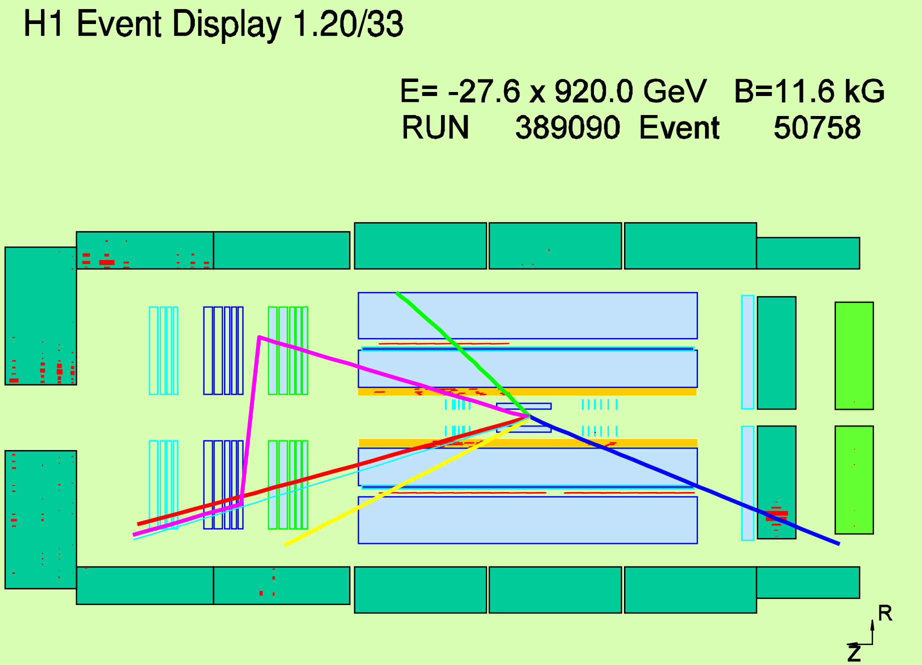
Components:

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



I. - (3) Triggering at H1





Triggered ***ep*** event

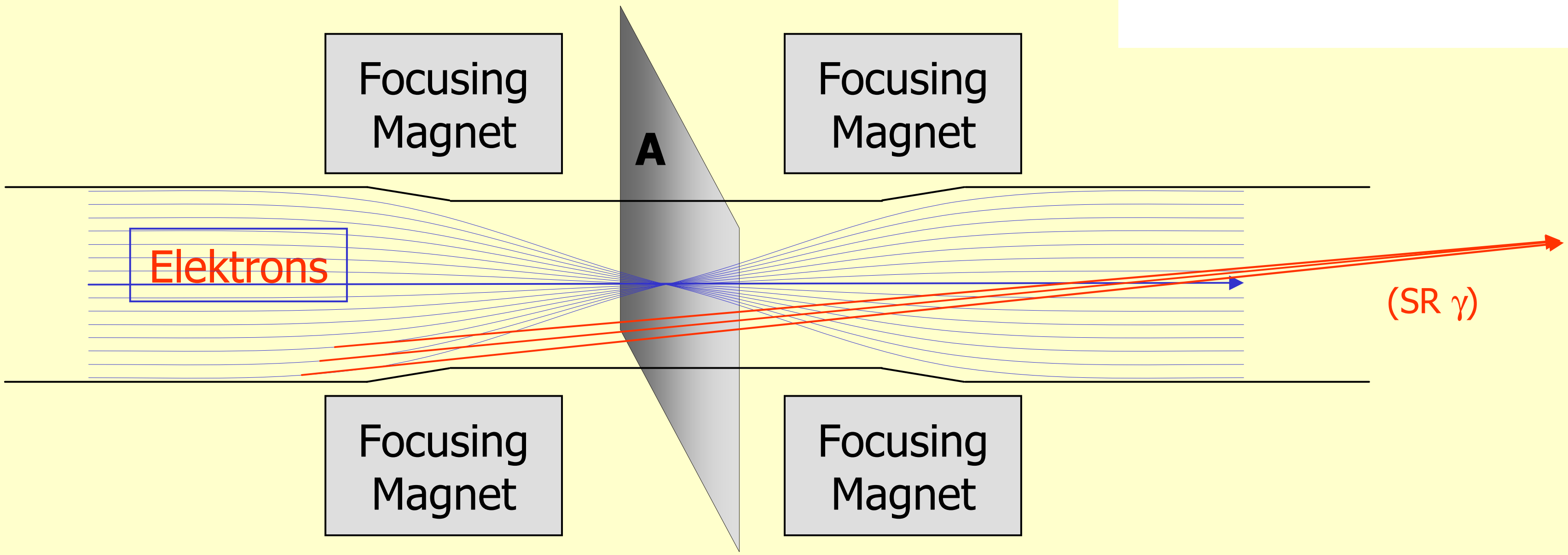
typical triggers:

- scattered electron
- energy thresholds
- muons
- charged particles (MWPC)

2000-2002: Upgrade of HERA

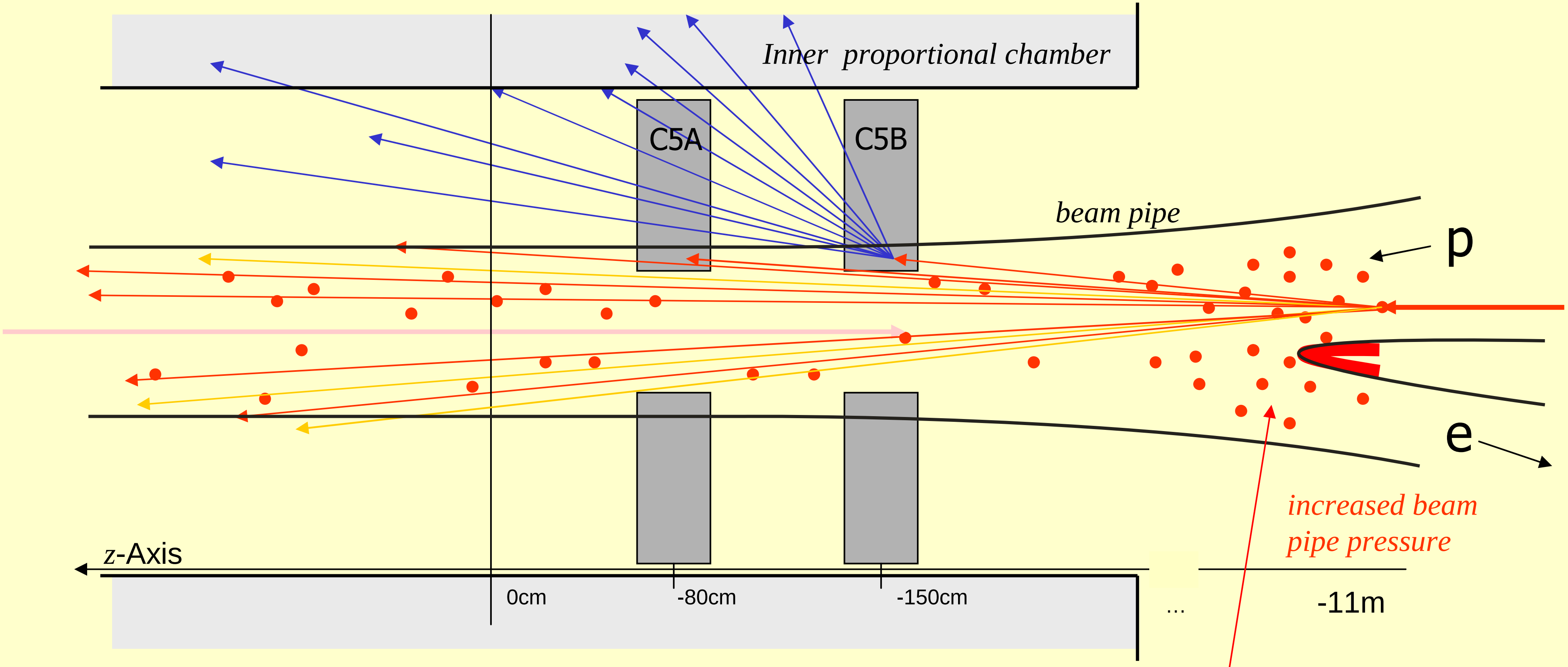
Goal: increase the luminosity L

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



→ Super conducting 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

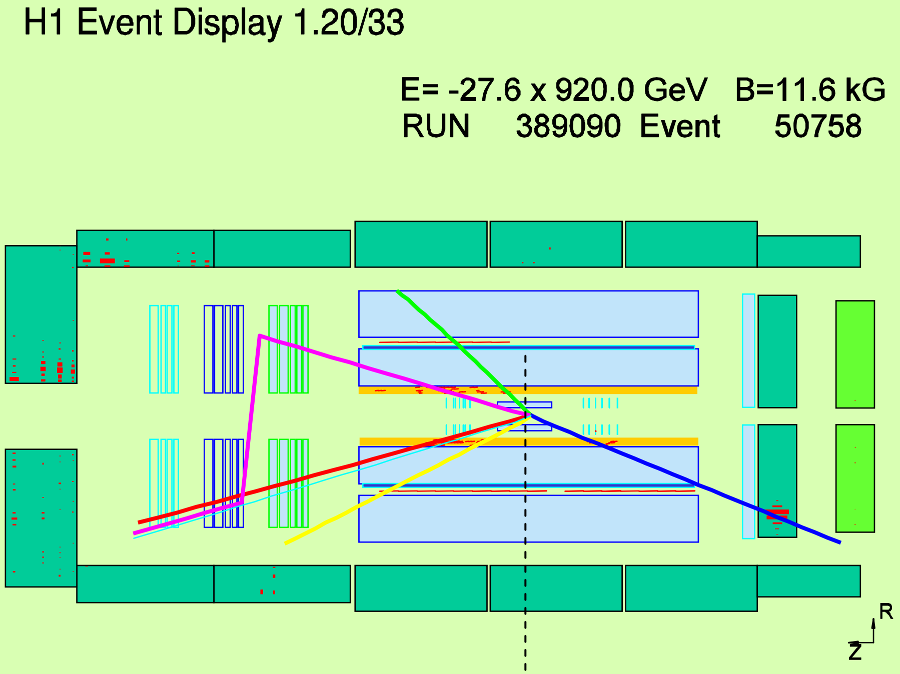
I. - (4) Synchrotron Radiation → Background events



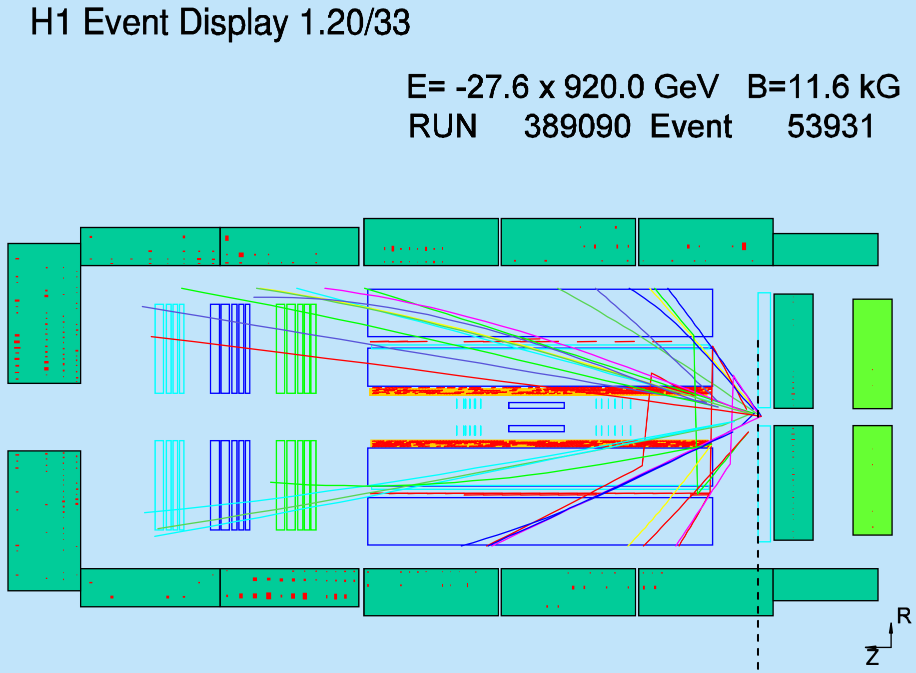
Part of synchrotron radiation is absorbed at -11m

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

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



Typical *ep* event



Typical background event

moderate number of tracks

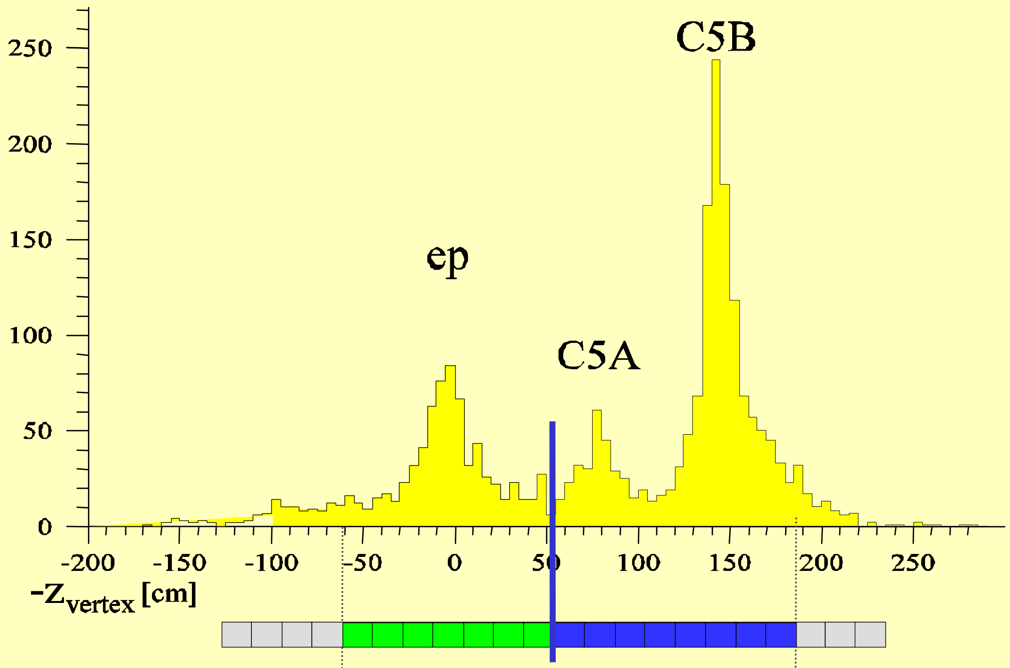
$z_{vertex} = 0$ cm

high number of tracks

$z_{bkg} < -50$ cm

II. - (1) Concept and Requirements of the *z*-Vertex Trigger System

Goal: separate background and ep events on first trigger level



z-Vertex histogram (22 bins, 16.4cm each) is a good handle to reach goal

Hardware requirements:

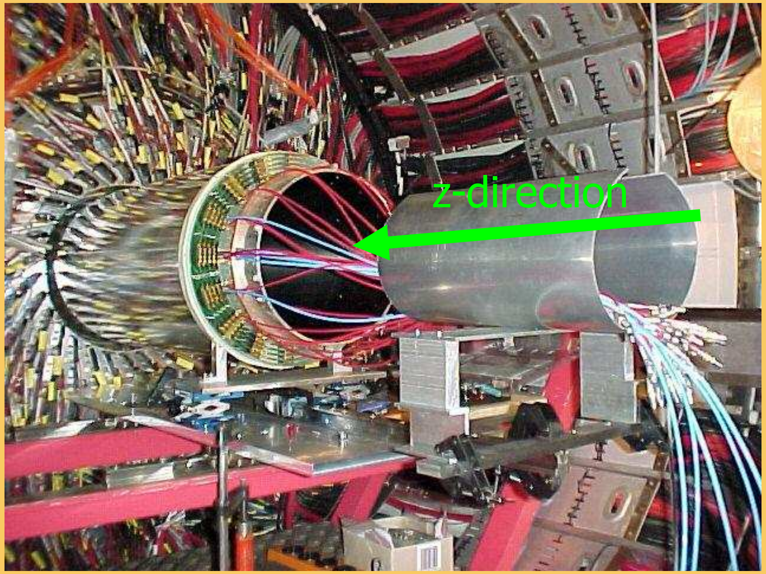
- track recognition in high multiplicity environment
- trigger decision synchronous to HERA accelerator clock (10.4MHz)
- Maximum latency 2.3us
- pad readout

→ high granularity (~8500 pads)

→ pipelined trigger algorithm based on track reconstruction within 1us

→ storage capabilities for event readout

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

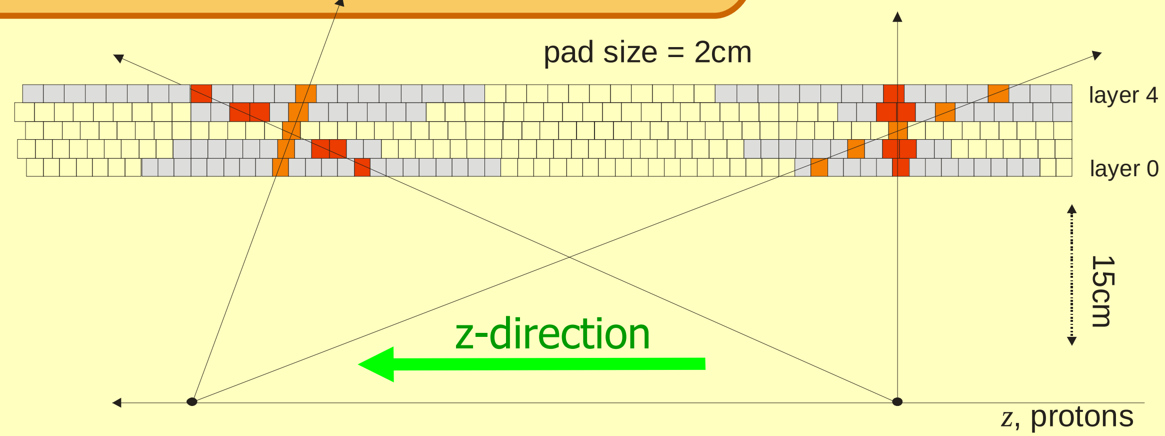


Development of a Multi Wire Proportional Chamber (MWPC) with cathode pad readout:

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

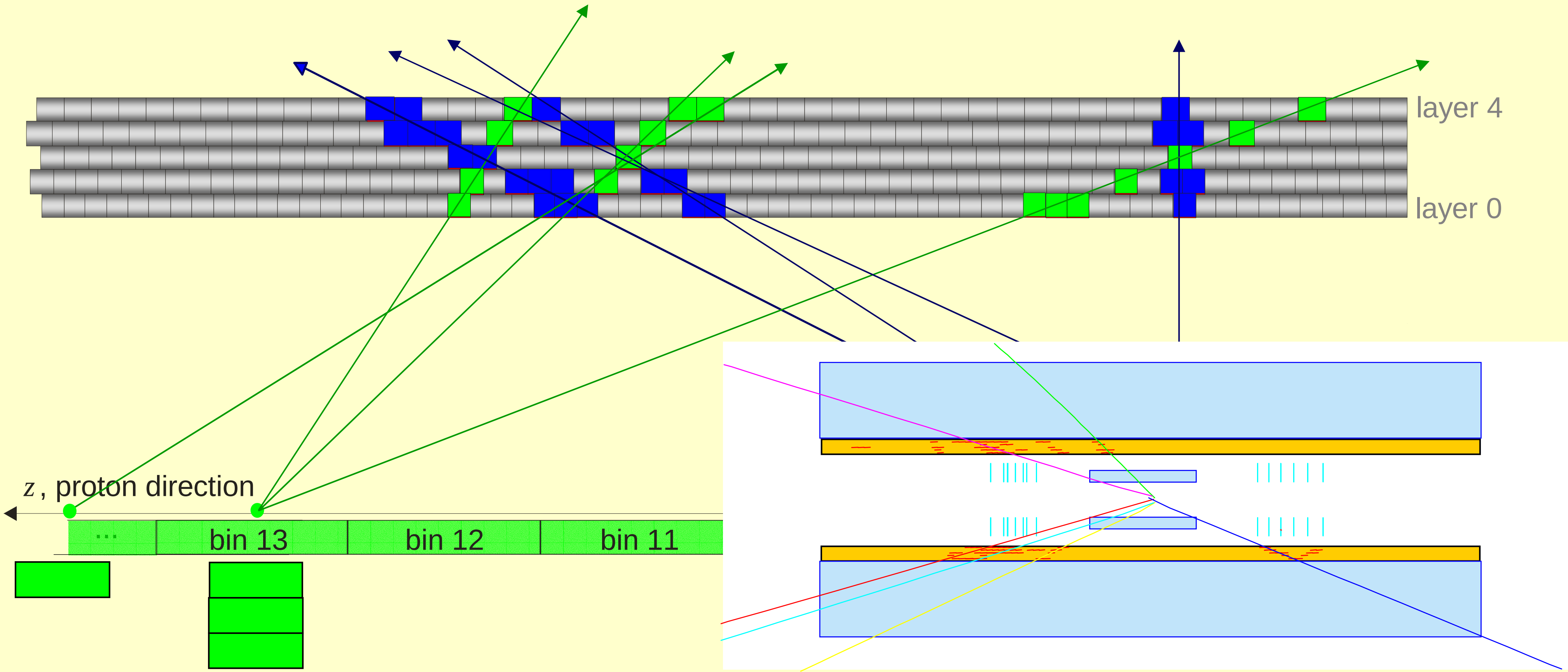


Specifications:

- 5 layers
- cylindrical, ***2.2m*** length
- ***16 fold*** segmentation in φ *(22.5°)*

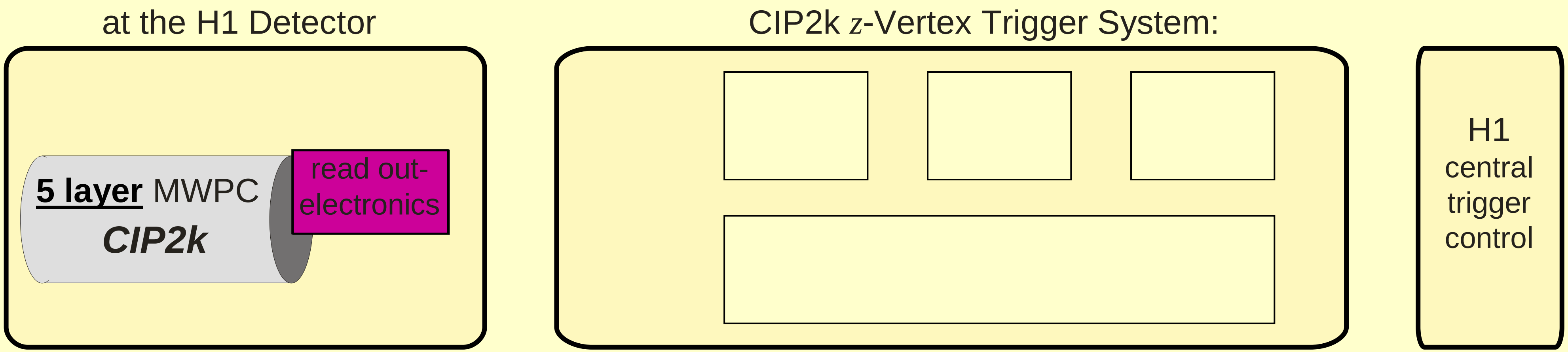
- radii from ***15** to **20 cm***
- ~***8500 pads***, up to ***120*** per layer and φ

II. - (3) Track Reconstruction for a typical Event:

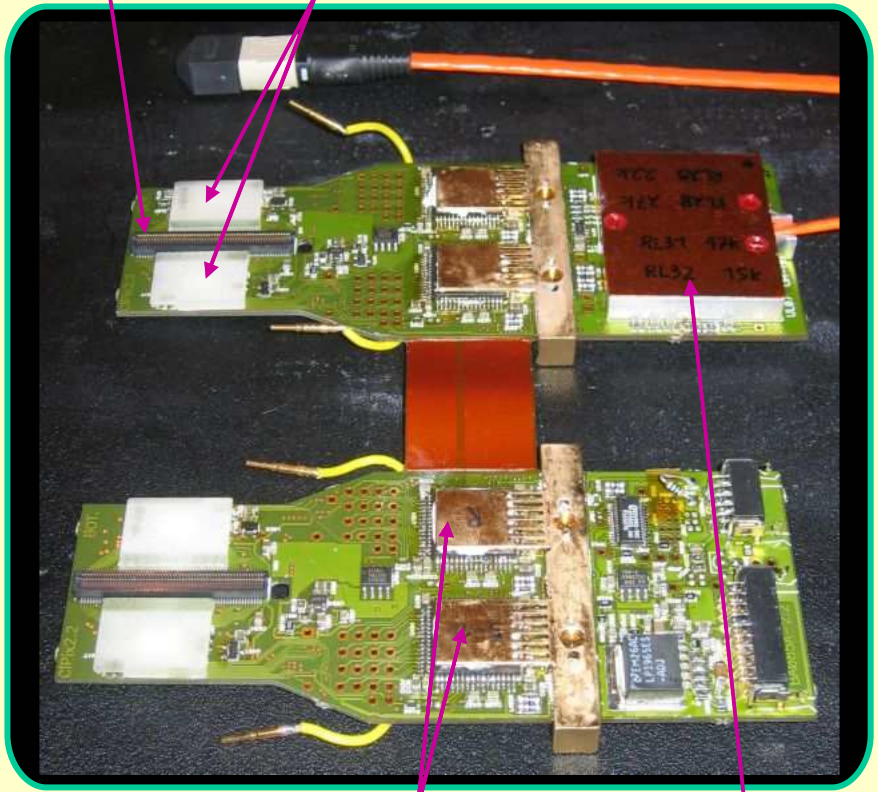


1. Recognition of track pattern and sorting into bins
2. Counting of tracks in bins of z-Vertex histogram
3. Grouping of bins in ***ep*** - and *backgrund* region

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



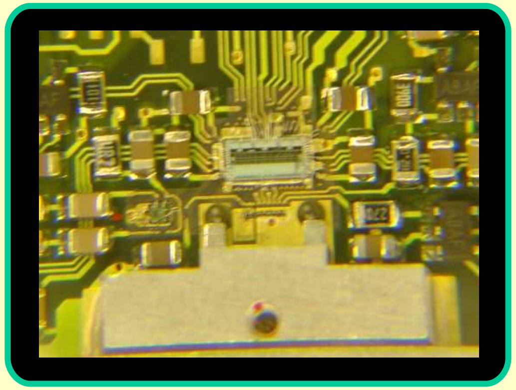
Front end Electronics and optical Link



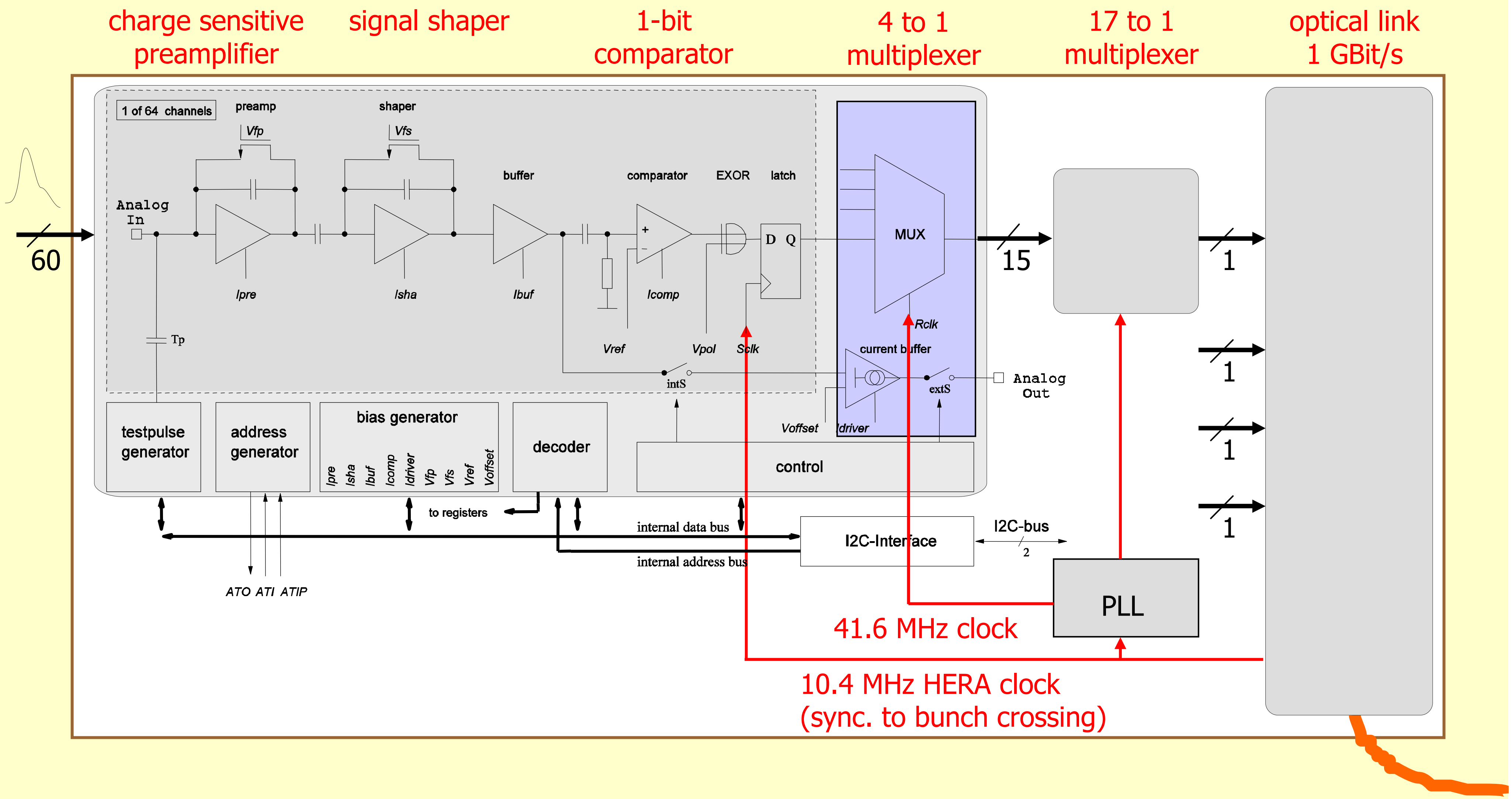
Specifications:

- 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)

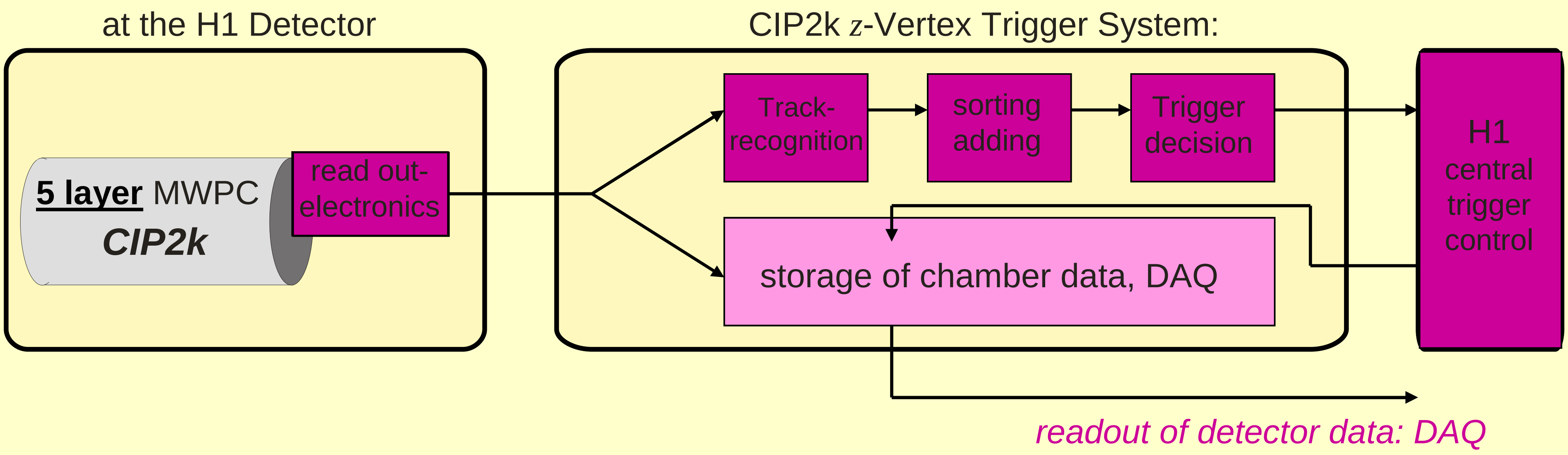
- 8 double boards per layer, 40 in total



II. - (6) The CIPix read out ASIC and optical link system

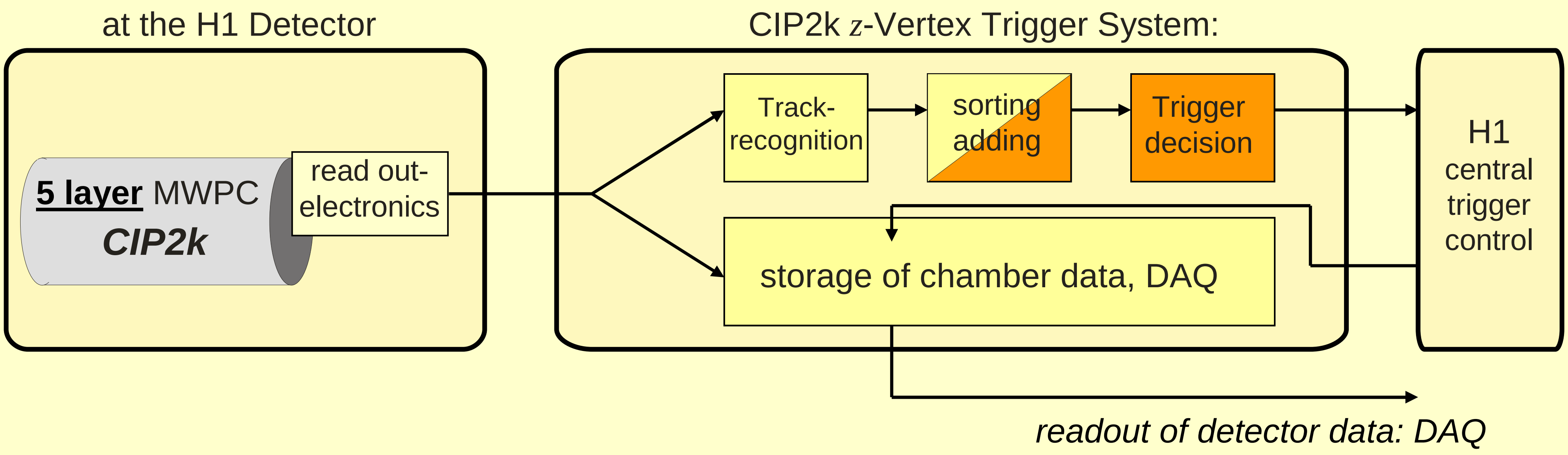


II. - (4) Trigger and Readout – Flow-diagram:



- 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

Trigger and Readout – the hardware:



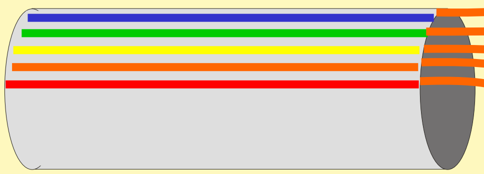
Two types of FPGA-based cards:

- Trigger Card
- Sum Card

Trigger Card for one φ-Sector:

5 layers of one φ-sector

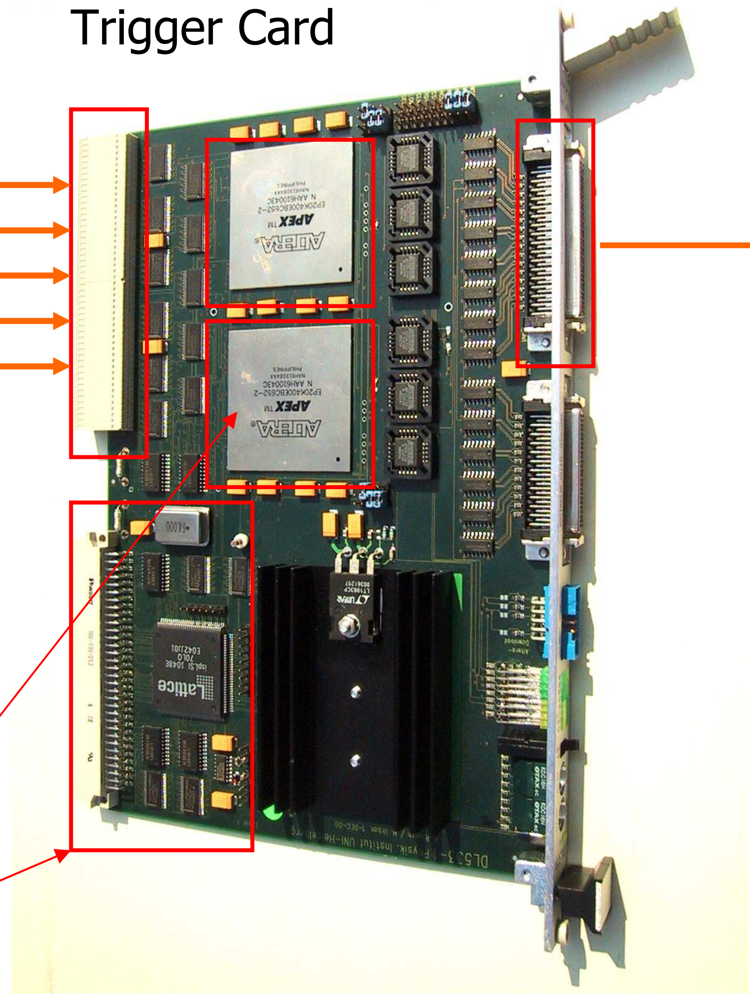
In the H1 Detector



<u>5 layer</u> CIP2k

Receiver Cards

Trigger Card



To Sum Card

Trigger Card fulfils track recognition and counting of tracks **(trigger algorithm)**

- builds the z-Vertex histogram for one φ-sector
- 16 Trigger Cards = 16 φ-Sektoren

- Contains two Altera APEX 20k400 FPGAs
- VME Bus controler
- 250 inputs, 60 outputs (LVDS)

II. - (9) Block Diagram File in Trigger Card:

Signals distributed in both FPGAs
(5 layers each)

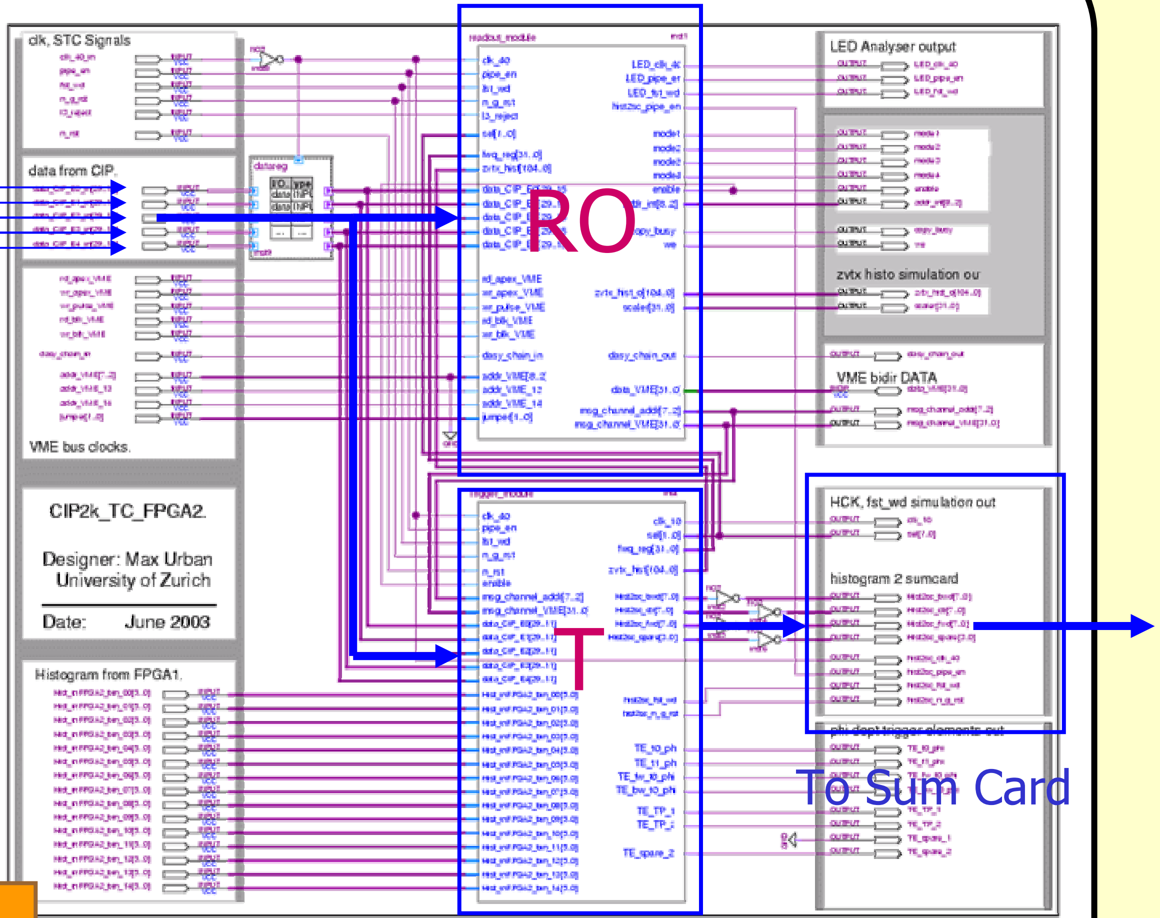
Each FPGA holds:

- 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



Block Diagram of FPGA II in Trigger Card

Modules programmed in Verilog (Quartus)

90% of logic units in each FPGA are used

II. - (10) Sum Card for 4 φ-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

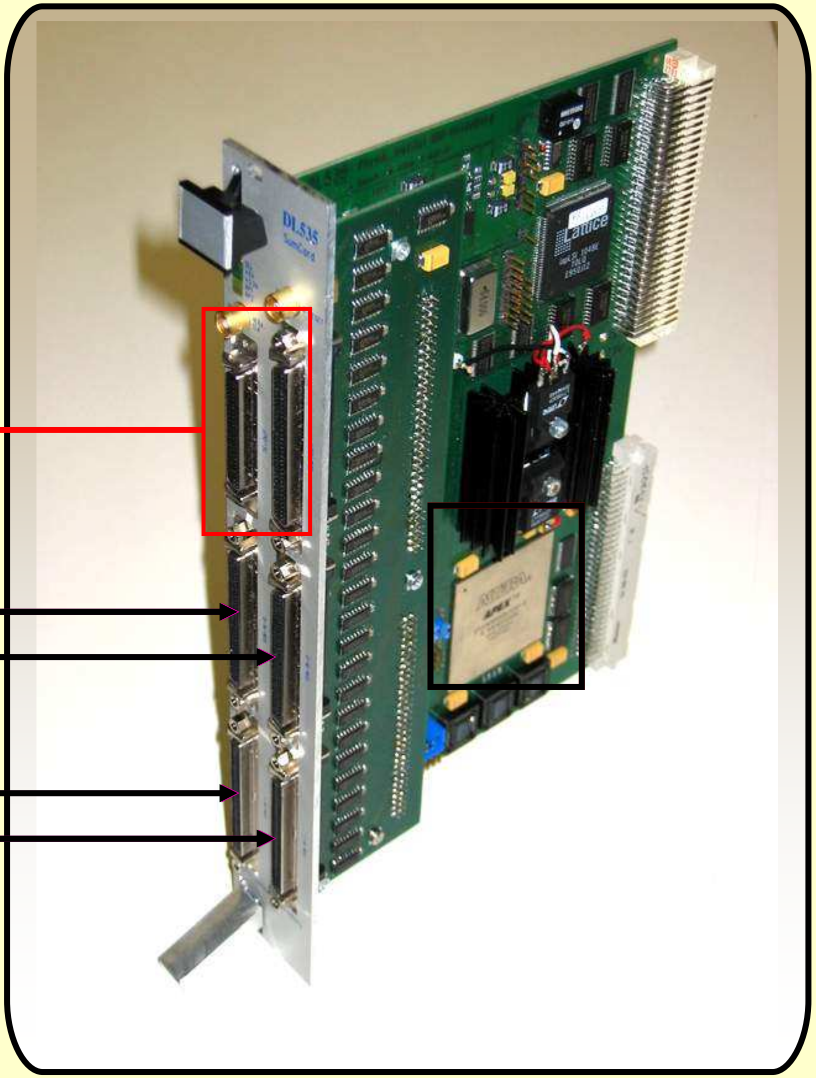
to Quarter Sum Card / Trigger Decision

φ-Sector 0 / Quarter 0

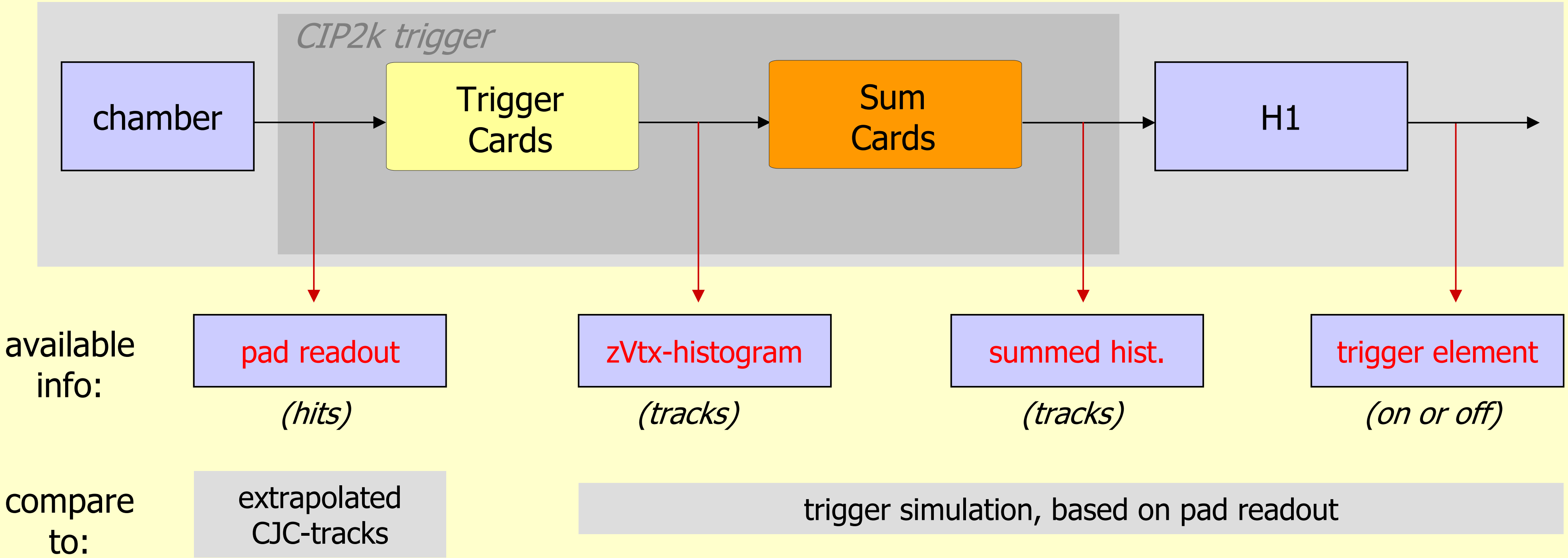
φ-Sector 1 / Quarter 1

φ-Sector 2 / Quarter 2

φ-Sector 3 / Quarter 3



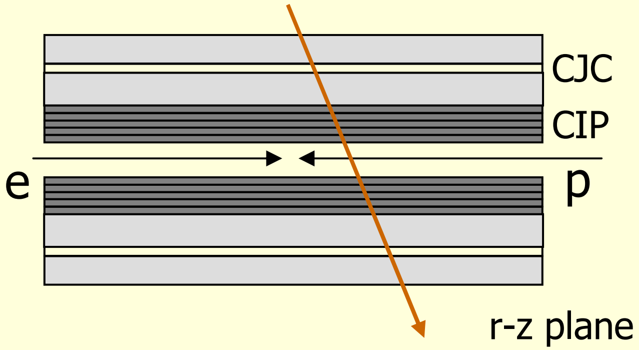
III. - (1) Verification of Trigger Hardware…



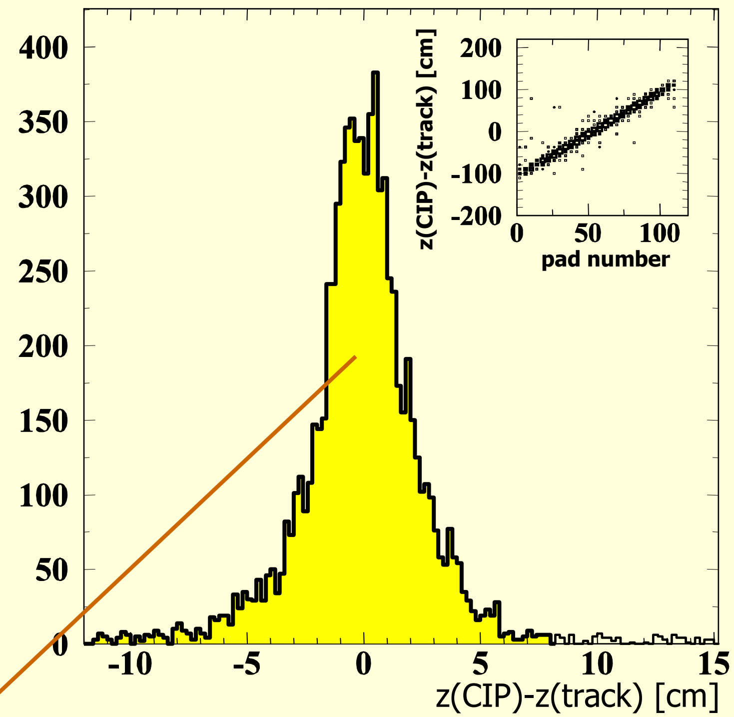
➔ diagnostic tools to analyze every component of trigger system.

➔ 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.

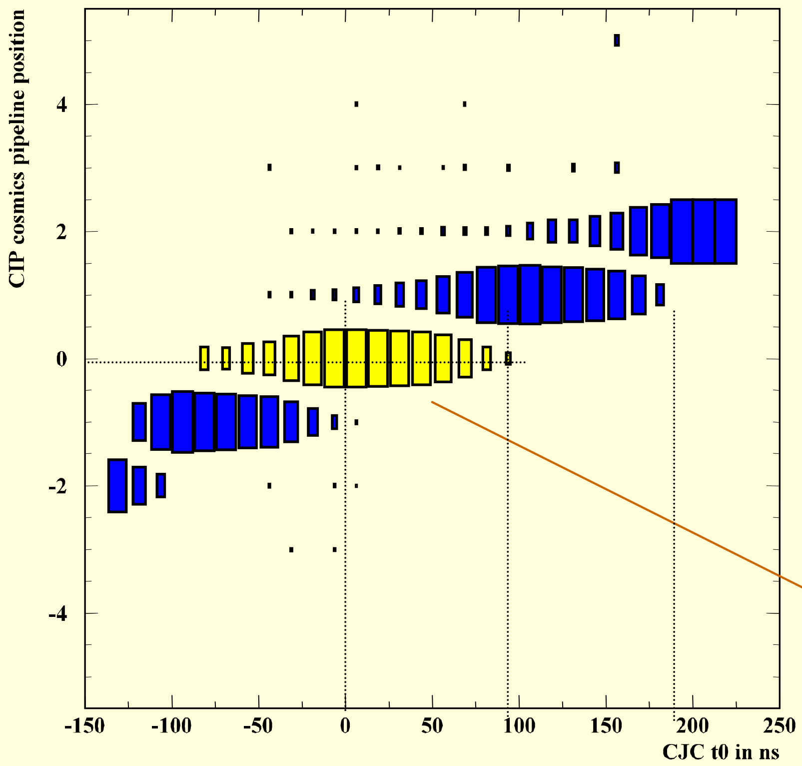


Distance between active CIP pad and CJC track

Width dominated by pad size ~2 cm

correlation of CIP2k hit position and extrapolated CJC tracks

Trigger Performance: Timing

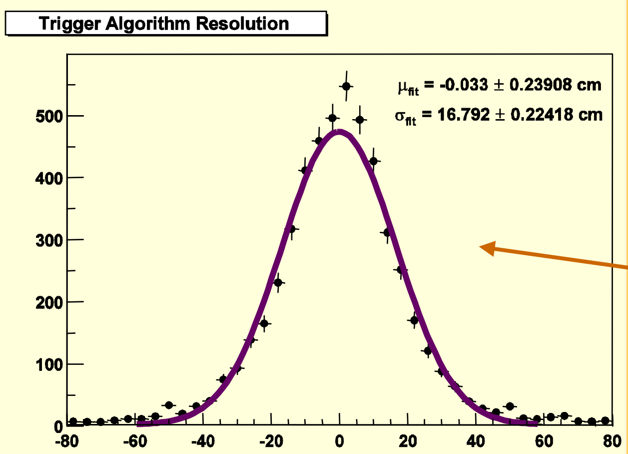


CIP2k cosmics-t_0-timing:
Compared to CJC T0 (Pipelineposition)

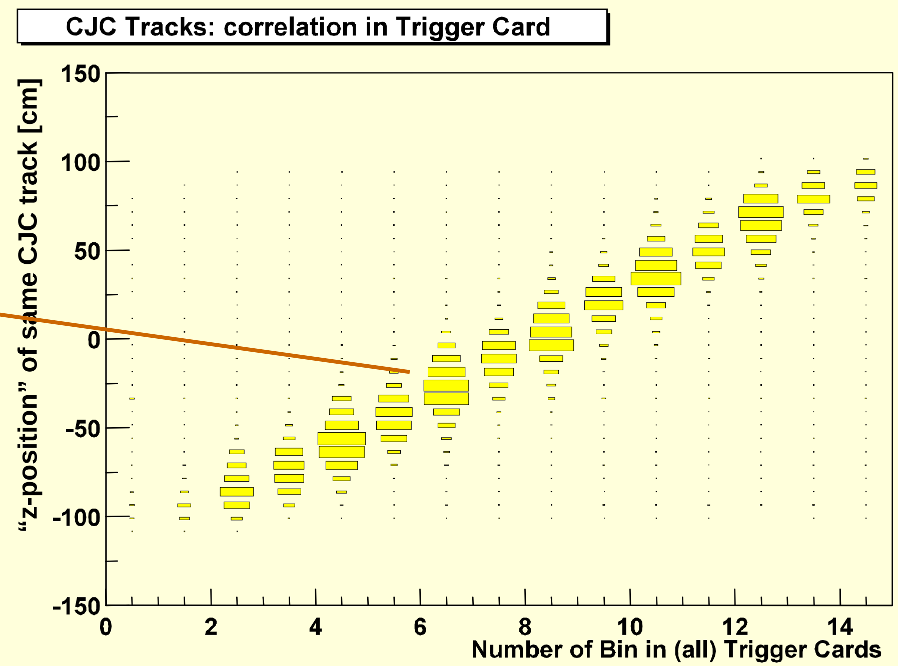
- cosmic ray tracks: not synchronized to HERA clock
- drift chamber reconstructs event timing with high precision
- CIP trigger sorts events into well defined bunch crossings

Width ~15 ns, driven by CIP and drift chamber resolution

III. - (4) Trigger Performance: z-Vertex reconstruction



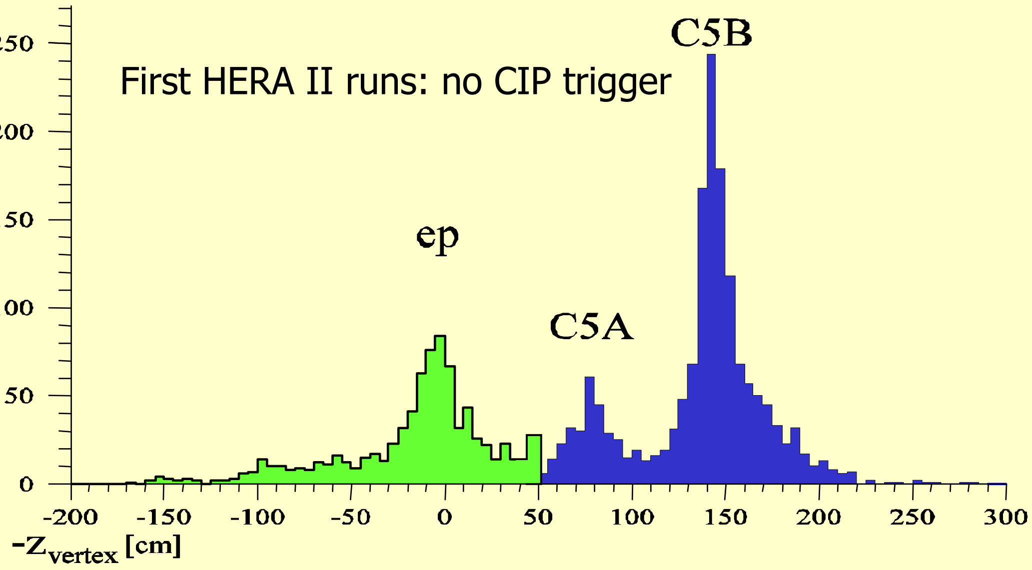
z-Vertex resolution ~16 cm



Compare z-Vertex bins identified by CIP2k trigger to drift chamber z position

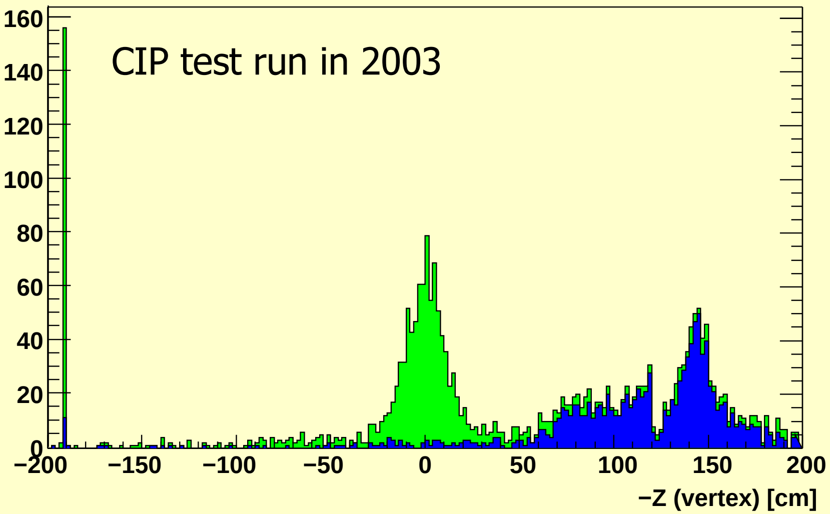
- cosmic ray events: number of tracks small…
- … but performance with high multiplicity ep events ?

III. - (5) CIP Performance during 2003/2004 HERA II run



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