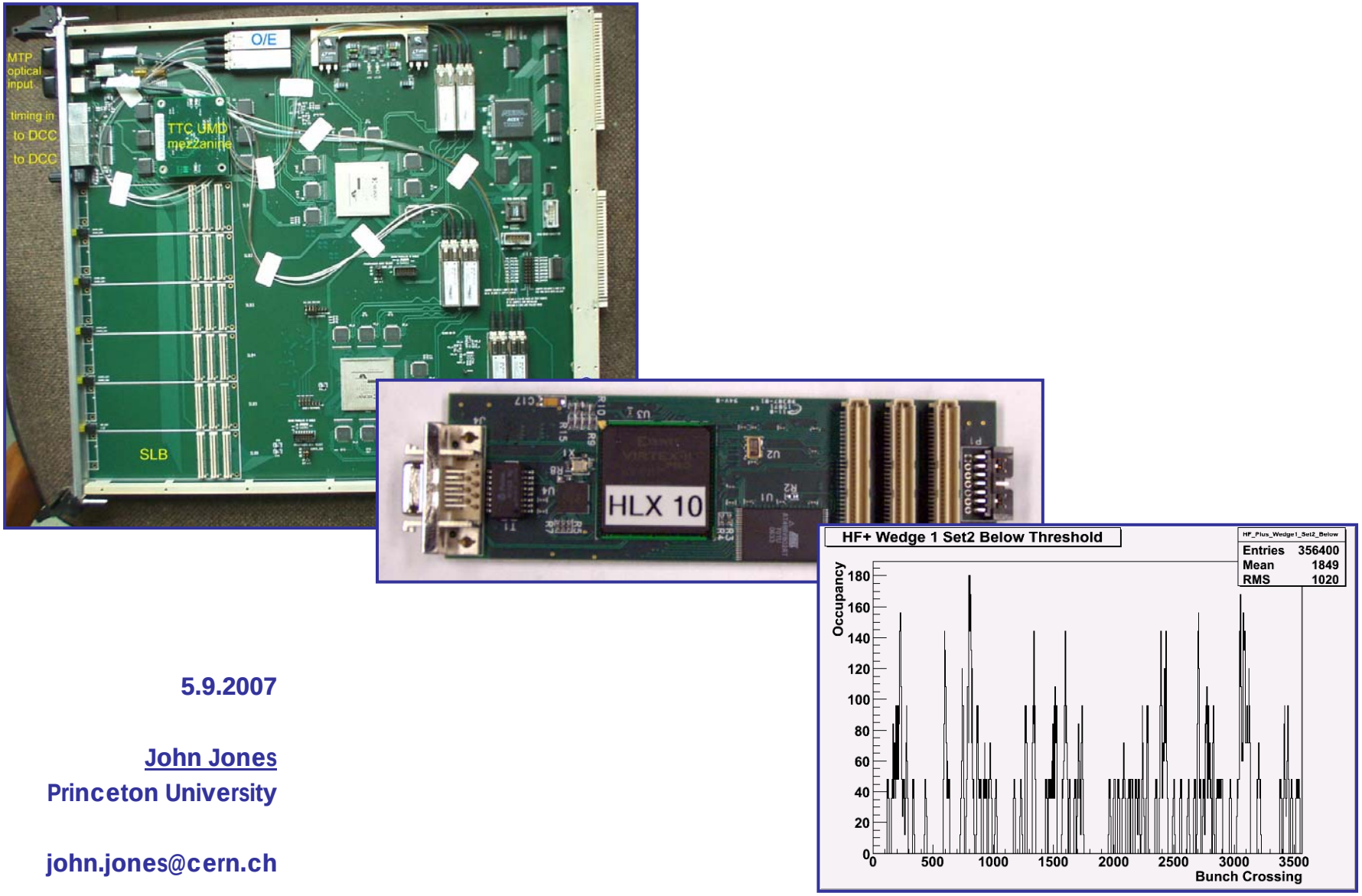
The CMS Luminosity System



5.9.2007

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Luminosity Measurement at the LHC

→ Luminosity important for many measurements at LHC
  → Related to x-section for a process – tells you your physics rates

→ Luminosity measured in two stages:
  → Absolute measurement first
  → Calibration of per-bunch relative measurement using absolute value
  → Can also be calibrated against a known x-section (e.g. W, Z)

→ Method used must be immune to fluctuations in detector behaviour
  → e.g. detector gain

→ Measurements have to be calibrated against absolute luminosity
  → Linear over large luminosity range

Luminosity Readout Methods at the LHC

Several methods/detectors used at LHC/CMS to measure luminosity:

- → BRAN / ZDC (Zero Degree Calorimeter)
  - → Both located at the TAN
    - → Point after triplets just before first superconducting magnet
    - → Where beam pipe splits, 140m from IP
  - → BRAN - Liquid Argon ionisation chamber, copper converter
    - → Measures flux of neutral particles forward from the IP
    - → Absolute luminosity measurement with error < 5%
  - → ZDC – Quartz fibre / PMT readout
    - → Useful for understanding beam backgrounds

- → Van der Meer scans
  - → Scan proton beams across each other
  - → Variation of interaction rate versus position of beams gives luminosity

- → TOTEM
  - → Cross-section / luminosity measurements can be used as a reference point

Luminosity Measurement at CMS I

Aims:

→ Bunch-by-bunch measurement of relative luminosity

→ Update interval of 1s for general monitoring

→ Online monitoring for HLT rates

→ Robust, reliable logging of luminosity information for retrieval offline.

→ Easy access to records.

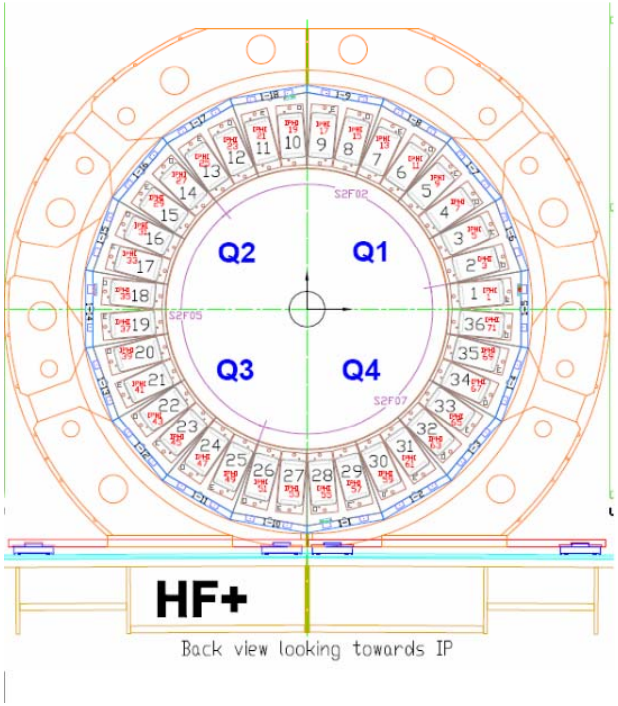
→ Absolute calibration

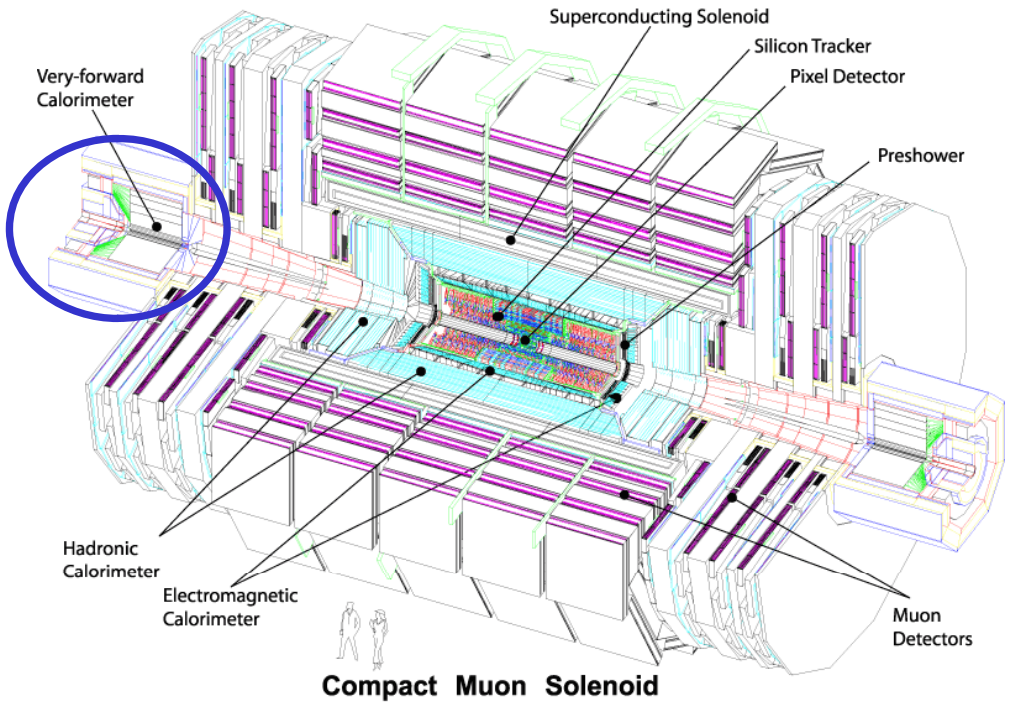
→ Accuracy 5-10%

Luminosity Measurement at CMS II

→ Developed fairly late in the history of CMS

→ Uses the HF calorimeter ($3 < |\eta| < 5$) to histogram E_T sums over an LHC orbit.





→ Quartz fibre, PMT readout

→ Two methods, using different calculation methods

→ One is based on 'zero counting' (number of towers with E_T < threshold)

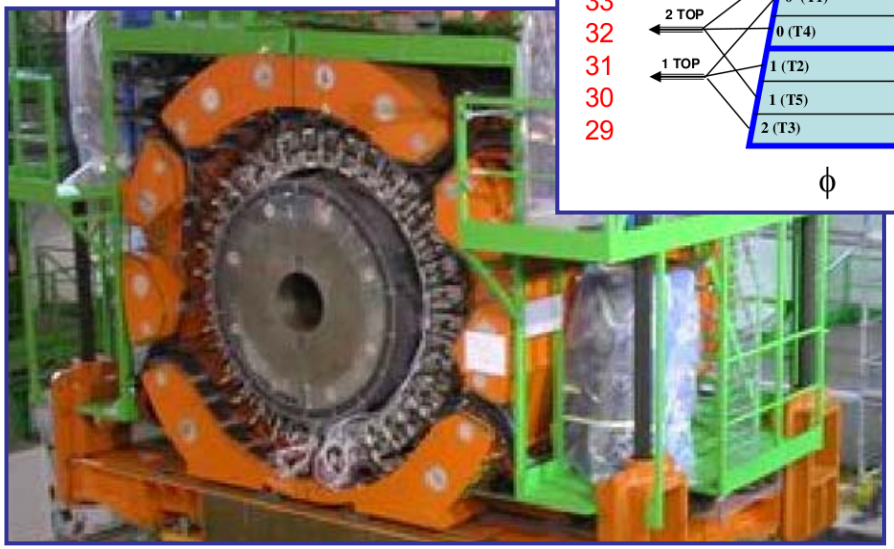
→ The other is based on an E_T sum

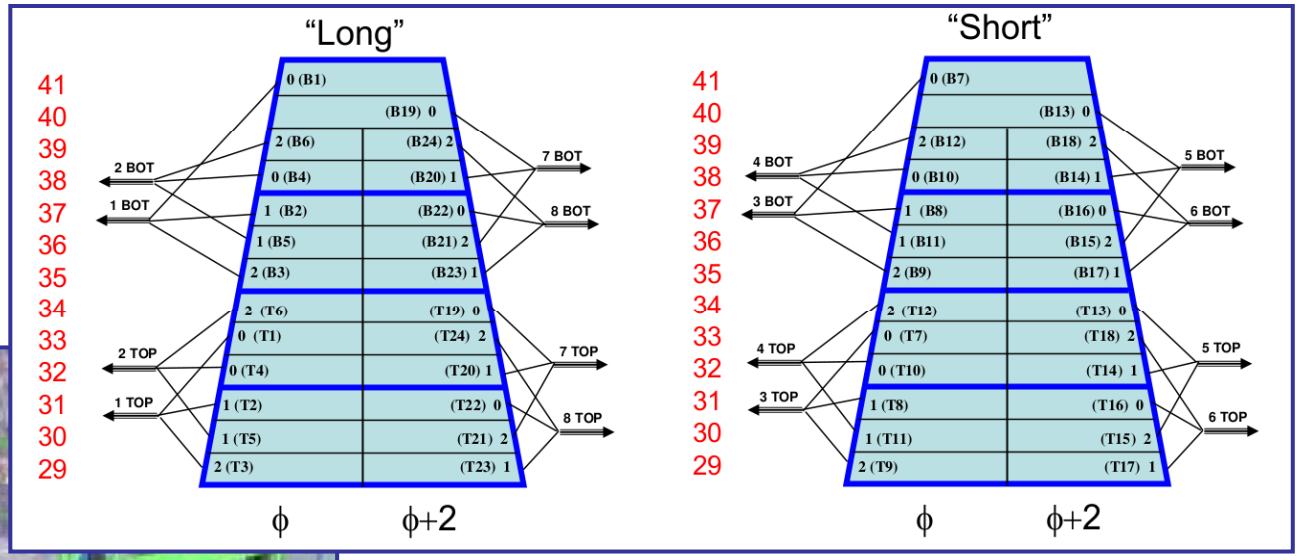
HF Calorimeter Readout

→ Each HF has 18 'wedges'.

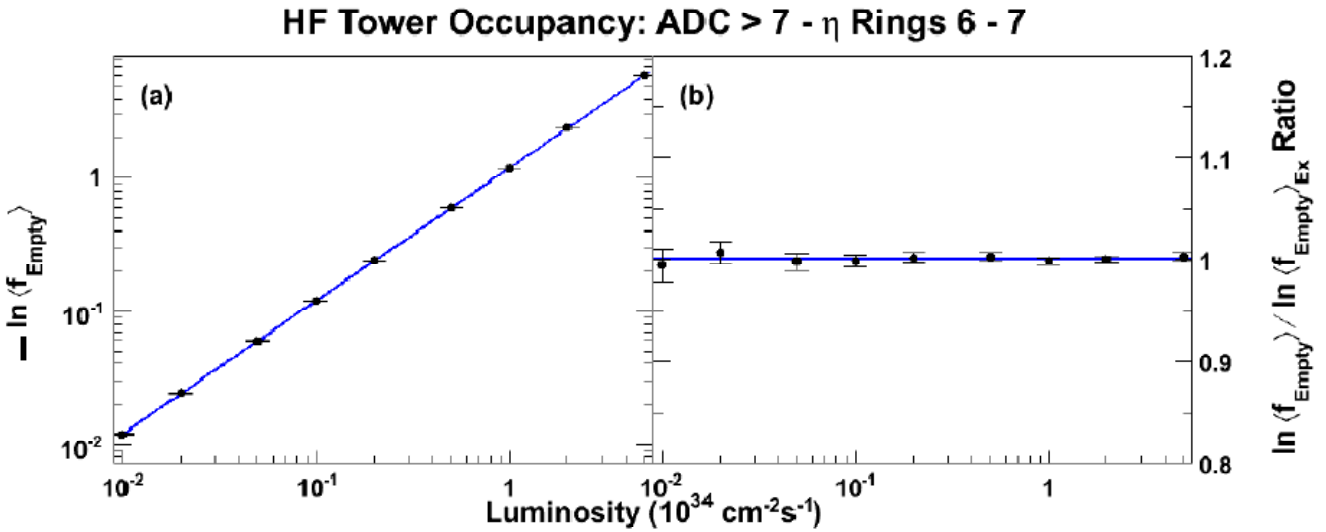
→ The data from each HF wedge is transmitted via optical fibre to an HCAL Trigger & Readout (HTR) board.

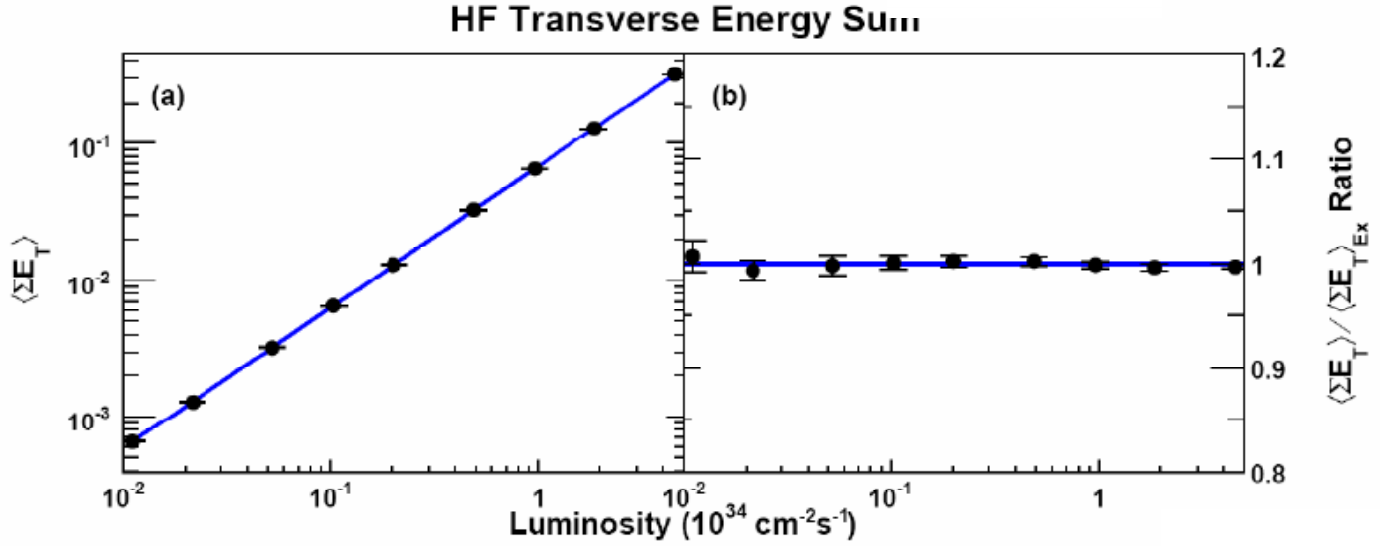
→ Data is processed via a look-up table and forwarded to a luminosity monitor board





Simulation of HF Luminosity Monitor Performance – N. Adam





The HLX (HCAL Luminosity Board)

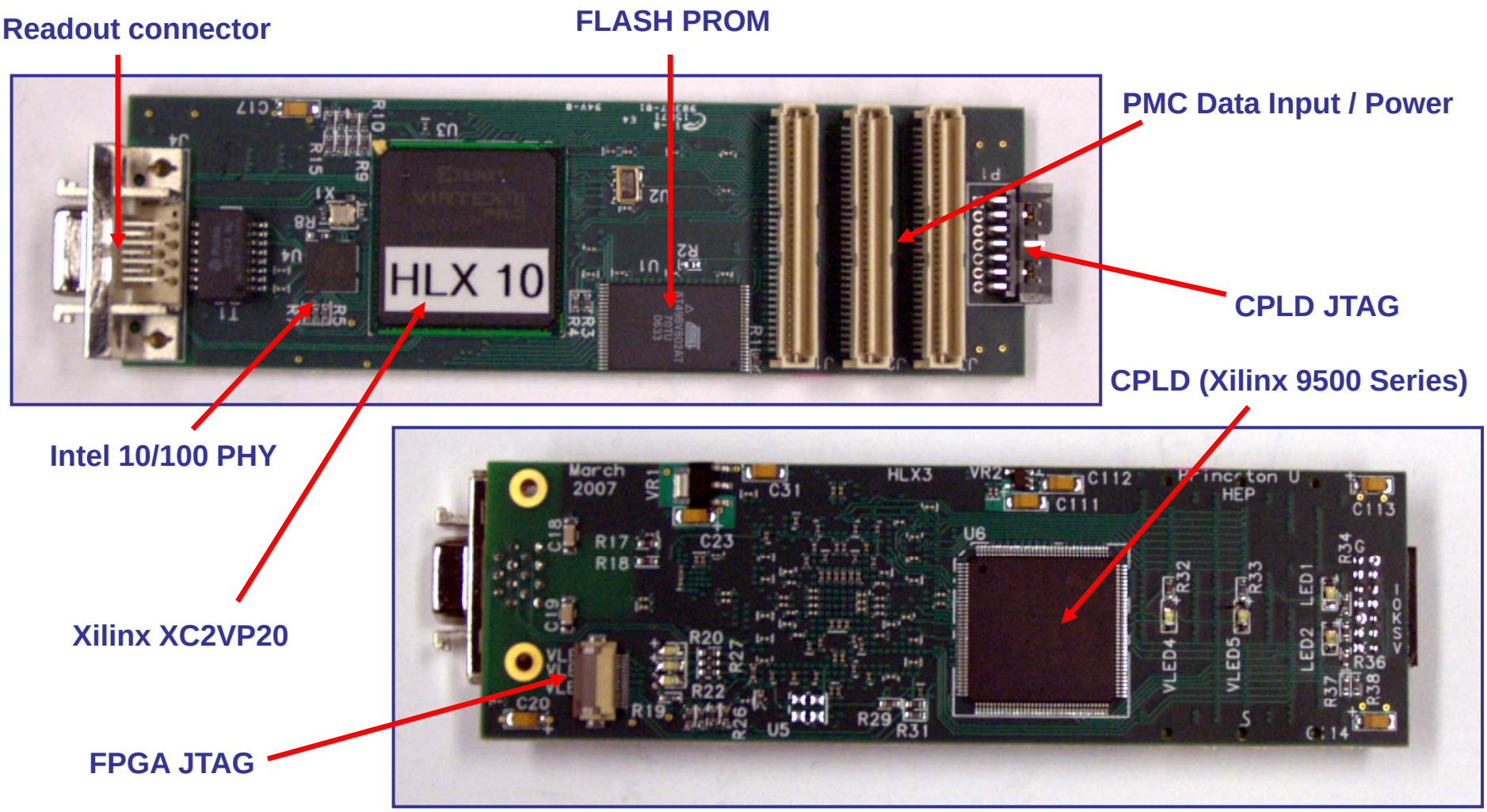
→ Used to process E_T data from HTR.
→ Contains a single Virtex-II Pro and a CPLD (used for FLASH loading of FPGA).
→ Readout is via Ethernet
    → Unusual in CMS.
    → Normally uses S-LINK.

→ However, CMS luminosity system is somewhat unique.
→ We have many different clients, with different data collection systems.
    → LHC (via DIP).
    → CMS event data (via Oracle DB / root file (NFS)).
    → CMS Data Quality Monitoring.
    → Ourselves (web browser).

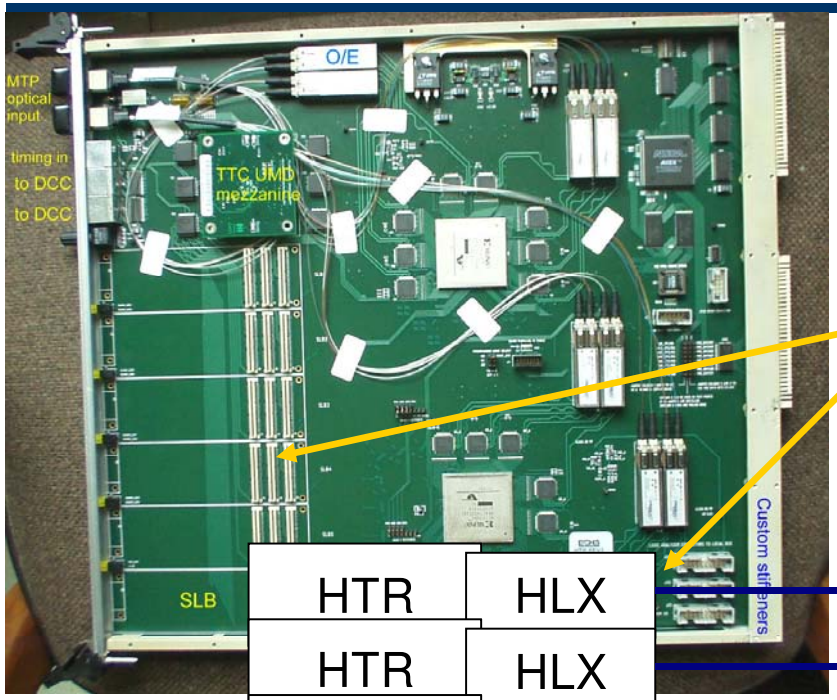
→ Total luminosity readout bandwidth is relatively low (~50Mb/s).

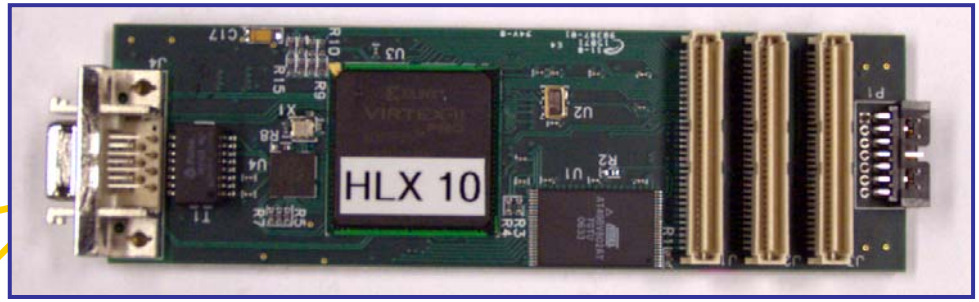
→ Readout solution chosen: 36 x HLX → Ethernet switch → PC.

HLX Board


Readout connector
FLASH PROM
PMC Data Input / Power
CPLD JTAG
CPLD (Xilinx 9500 Series)
Intel 10/100 PHY
Xilinx XC2VP20
FPGA JTAG
HLX 10
HLX3
March 2007

Data Interconnections





HTR
HLX
HTR
HLX
HTR
HLX

Ethernet Switch

PC

XDAQ

LHC

Fermilab

CMS

XDAQ

Control PC

CMS Trigger Supervisor

Luminosity Histogramming

→ Implemented as a modified circular buffer using a dual-port BRAM.

→ 'Dead-time-free'

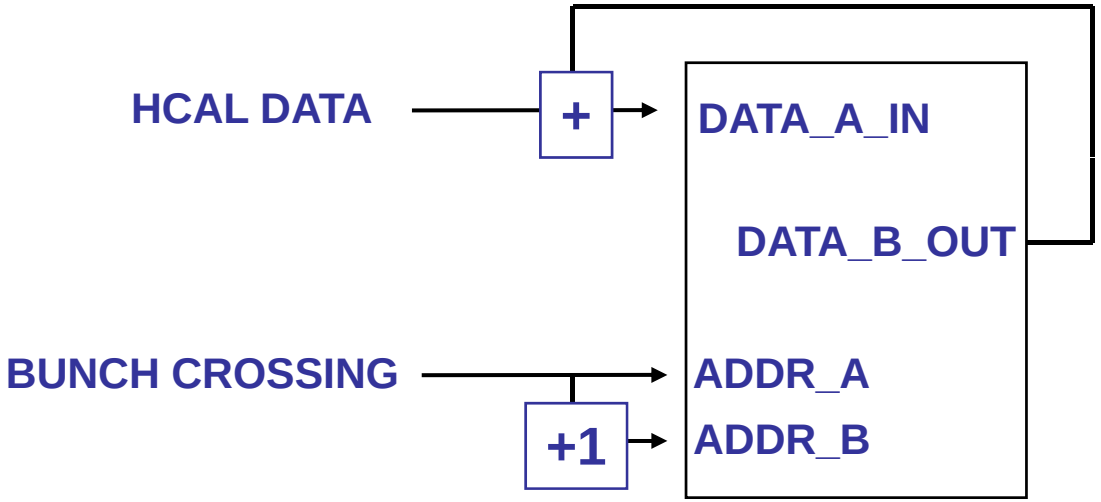
→ Two copies of every histogrammer.

→ One is read out while the other is accumulating.

→ Streaming Ethernet core (UDP)

→ Modified to produce a CRC checksum after the data packet.

→ Data is verified on PC before accumulation.



Aside - About Ethernet

→ Implementing Ethernet in an FPGA is not trivial.
→ Protocol is complex, requires a complex state machine.
    → Easiest done with a microprocessor (e.g. PPC).
    → Or a soft IP core microcontroller.
    → This is especially true if you want to use TCP.
    → You also need external memory for 'true' TCP to buffer for re-transmission.

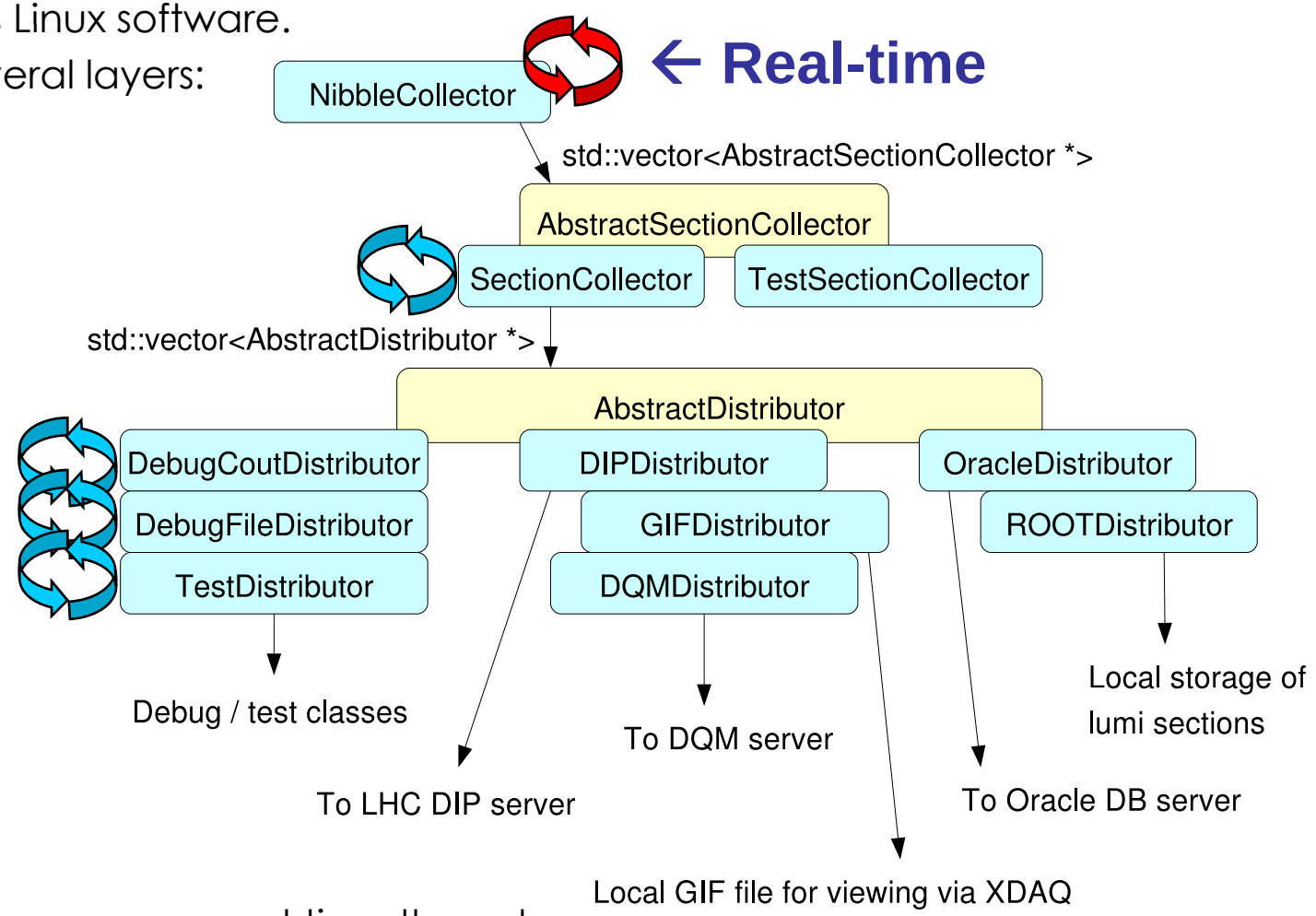
→ Even without TCP, it's not just UDP!
→ Ethernet has several layers.
    → **Frame** layer.
    → **IP** layer.
    → **UDP** layer.

→ For it to work properly, you also need **ARP** (Address Resolution Protocol).
    → Resolves IPs ←→ MAC addresses.
    → Like a voting register, you need to know who lives at the house!
    → Allows proper communication in a network.
→ Without it switches are **not happy**.

Readout Software

→ Single-process Linux software.

→ Consists of several layers:



→ NibbleCollector runs as a real-time thread…

→ Necessary to avoid packet loss in a standard OS like Linux.

→ Every distributor has it's own thread & buffer – allows them to **stall**…

System Tests

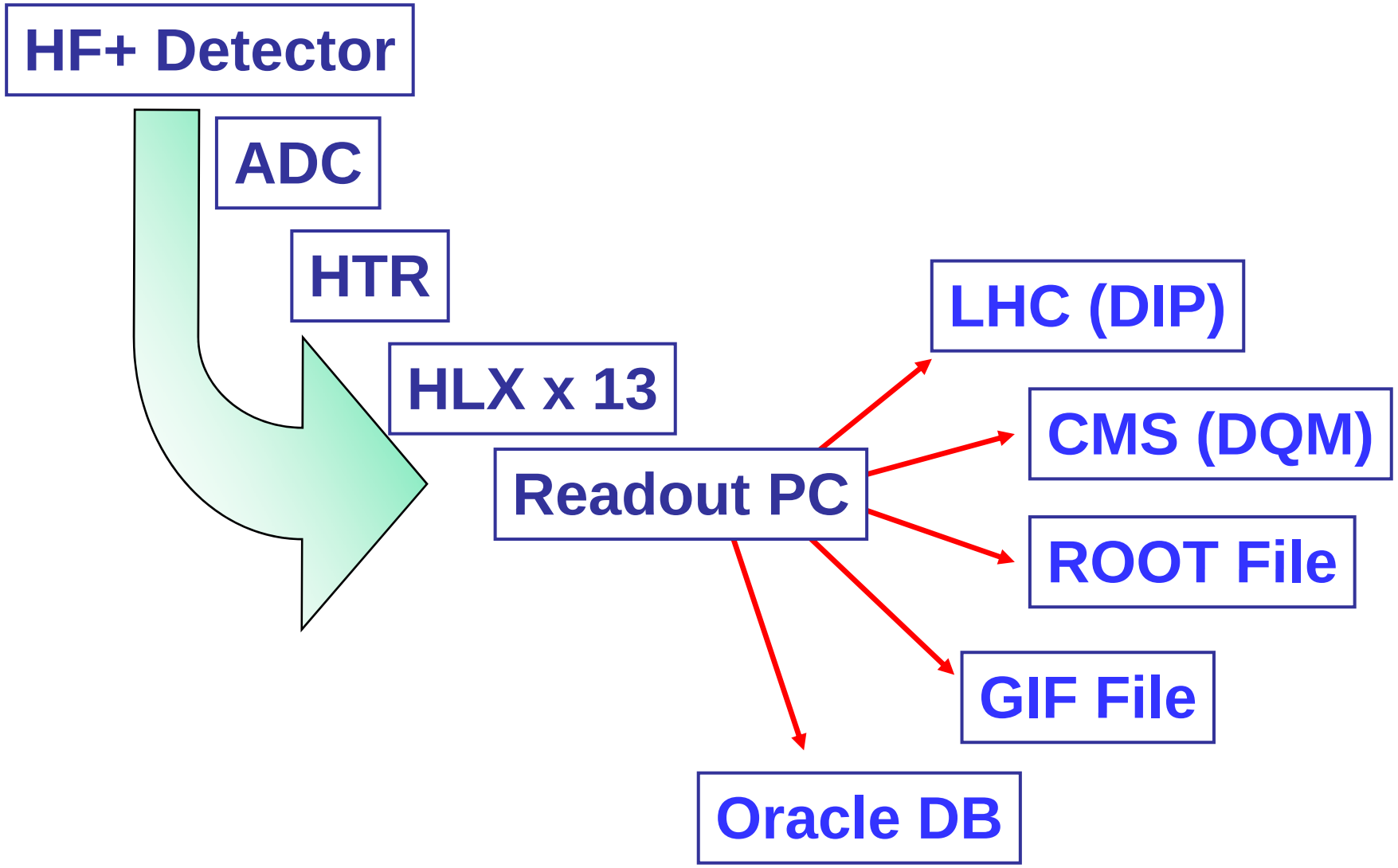
→ Initial testing with a single HLX.
→ Operating at up to 80Mb/s with no issues.
→ Testing with more HLXs introduced an interesting problem – packet loss.

→ The instantaneous rate of data arriving at the switch was too great.
    → Solution: phase-shift the data from each HLX
    → Manual time-division-multiplexing
        → Each HLX slightly out-of-phase with previous one.
        → Switch only sees ~constant rate of data flow.

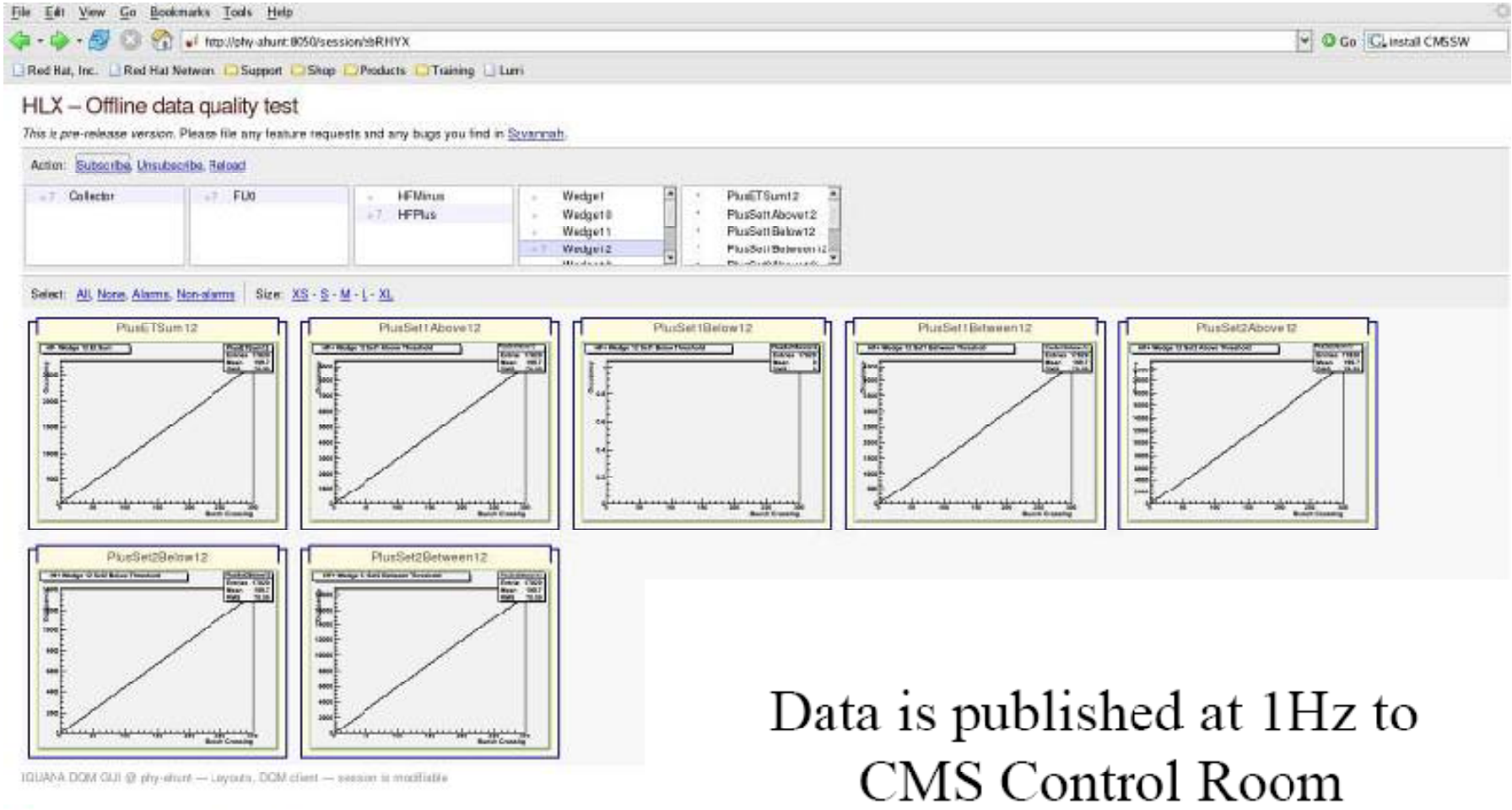
→ Once implemented, the system operated stably at ~70Mb/s (135%/nominal).

→ 13 HLXs tested simultaneously so far…
    → Planning to add more HLXs as they arrive at CERN (currently shipping).

August 2007 Global Run - Setup



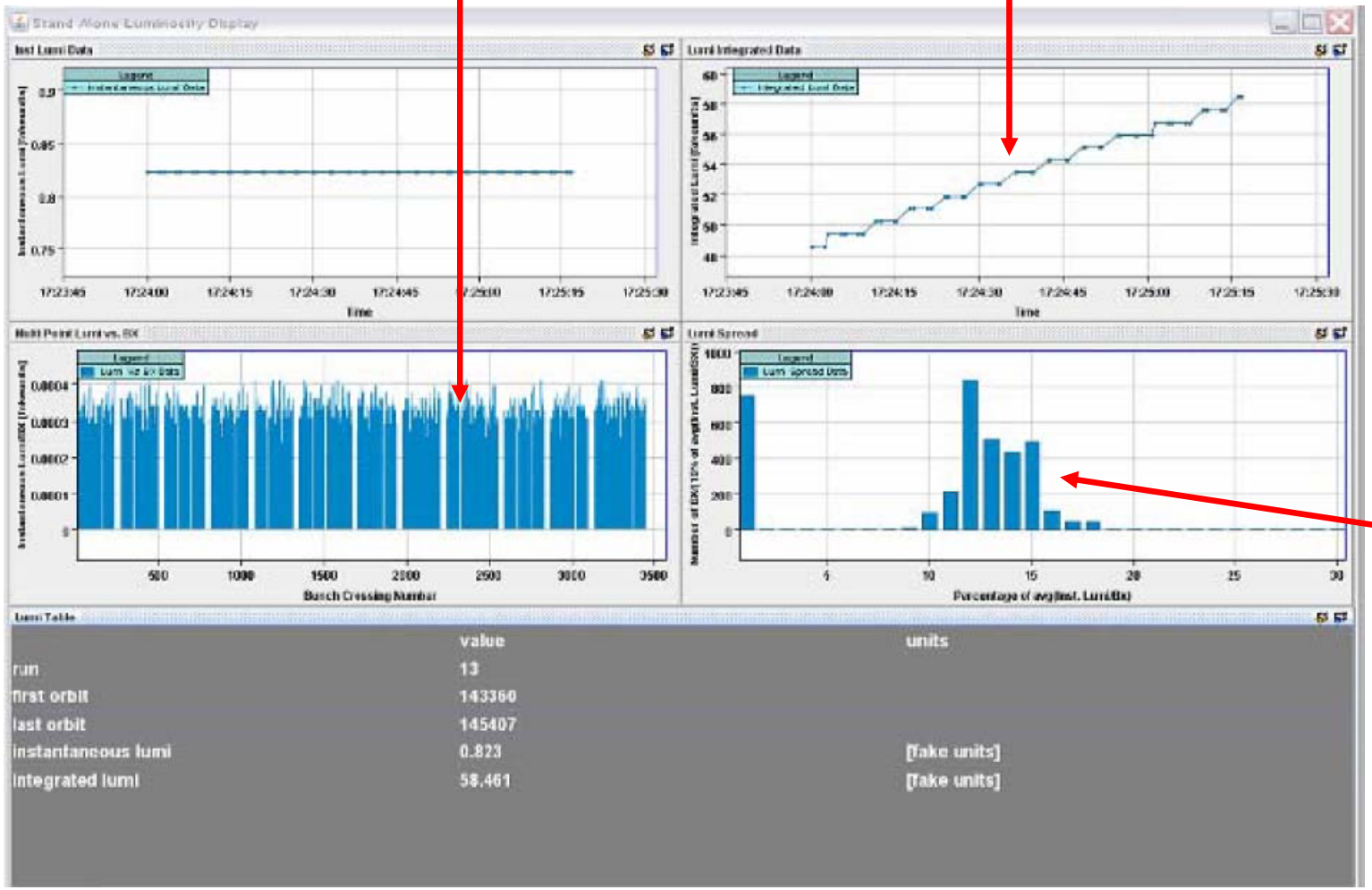
DQM Interface to CMS Control Room – A. Hunt



Data is published at 1Hz to CMS Control Room

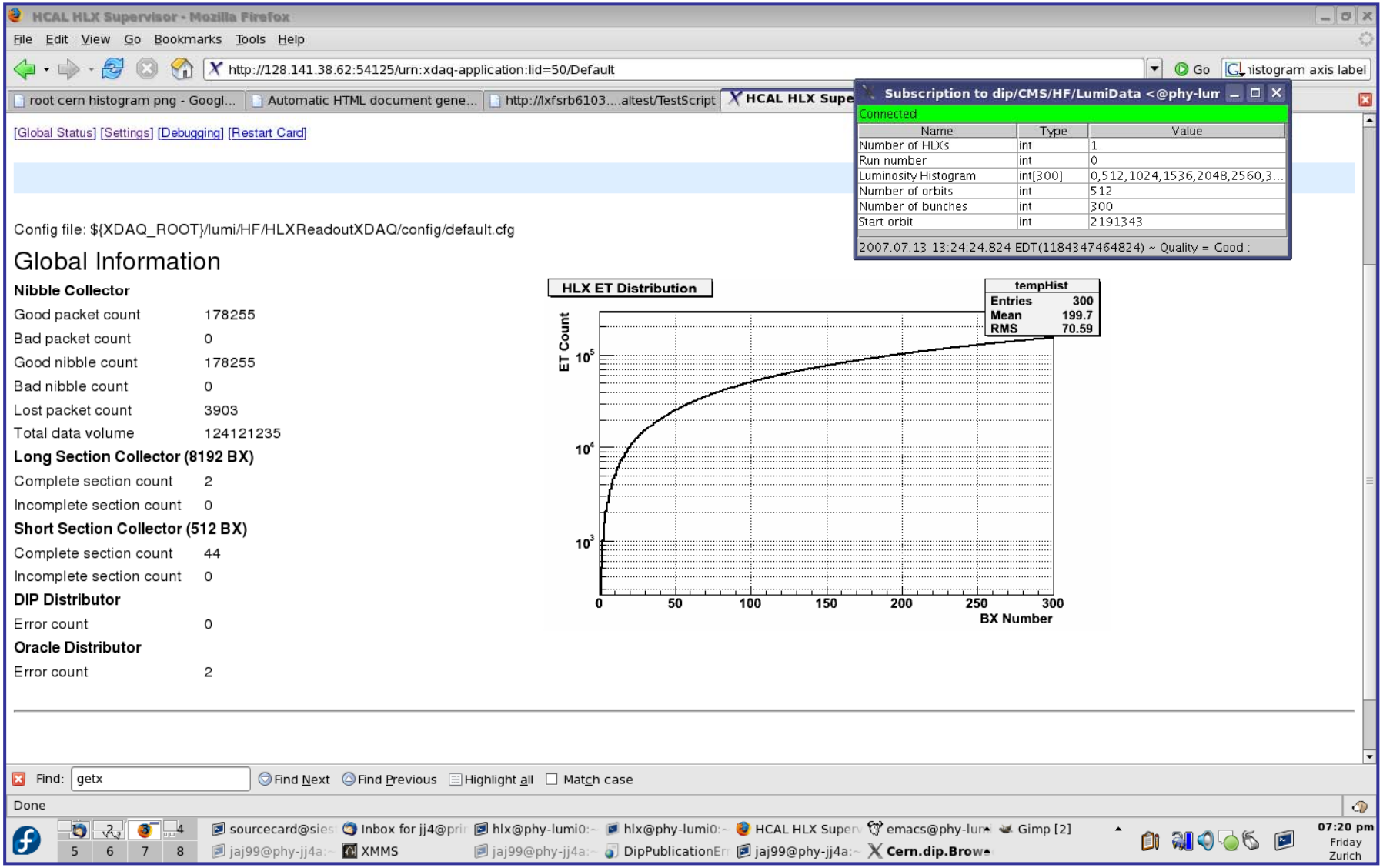
Per-bunch

Integrated

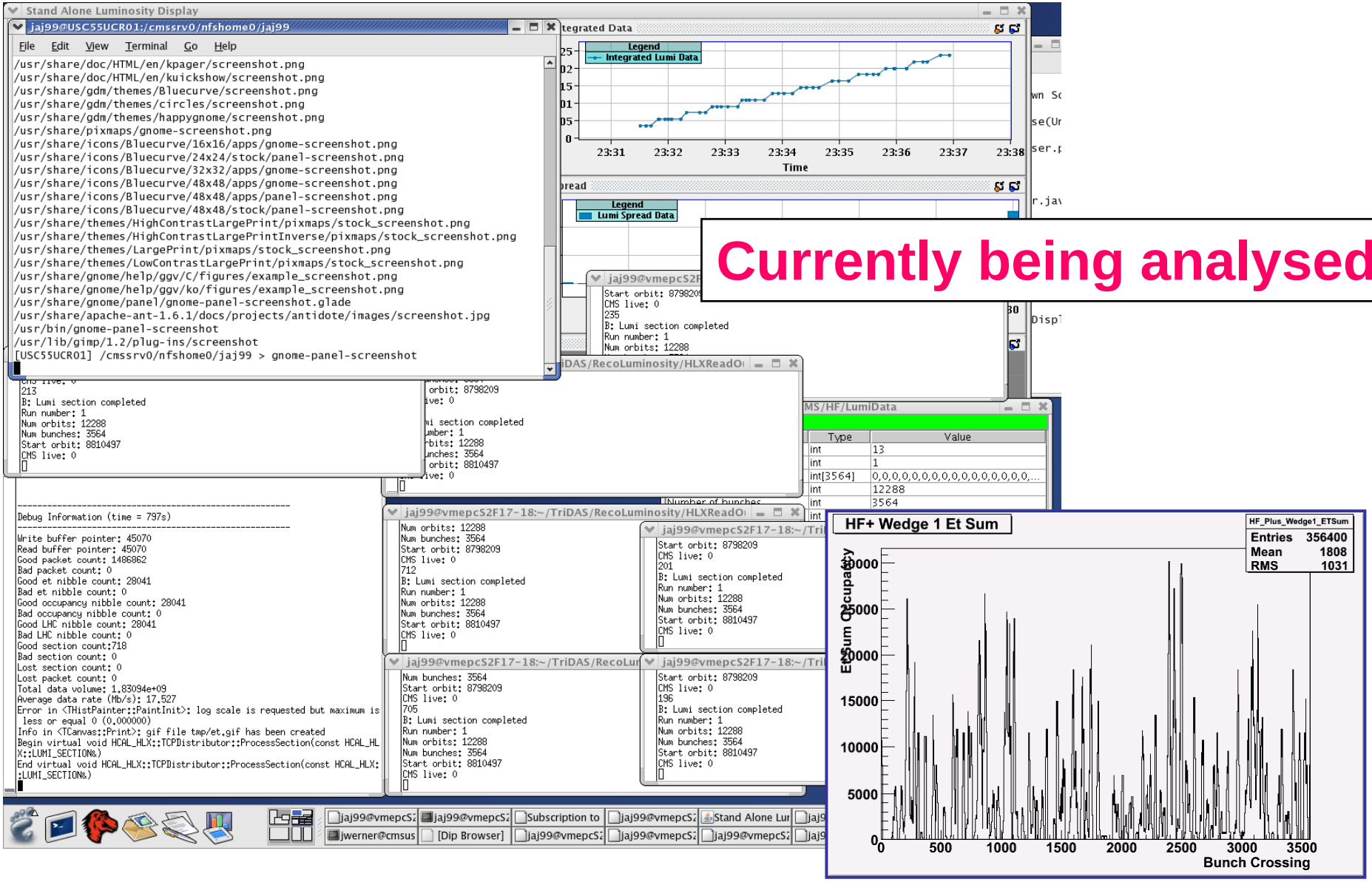


Spread

August 2007 Global Run – Results I (Test Mode)

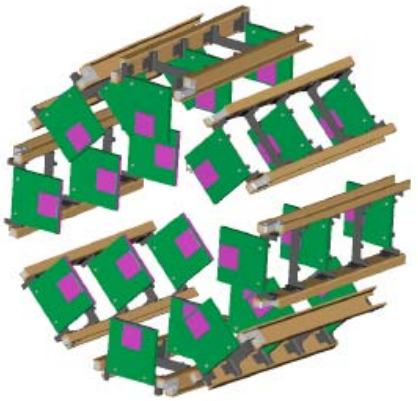


August 2007 Global Run – Results II (HF+ Readout)

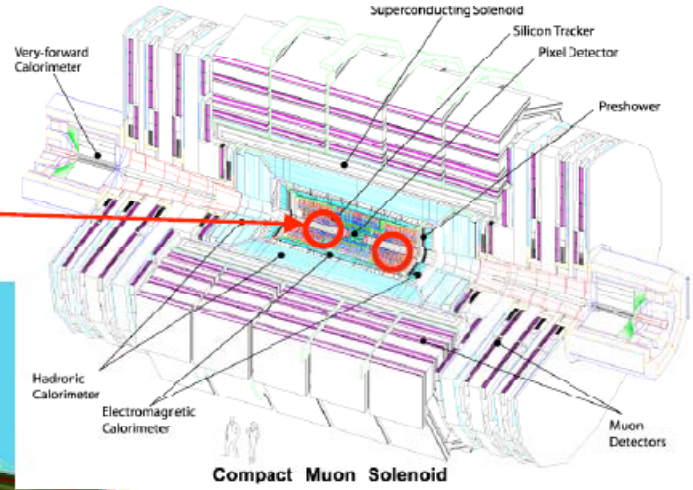


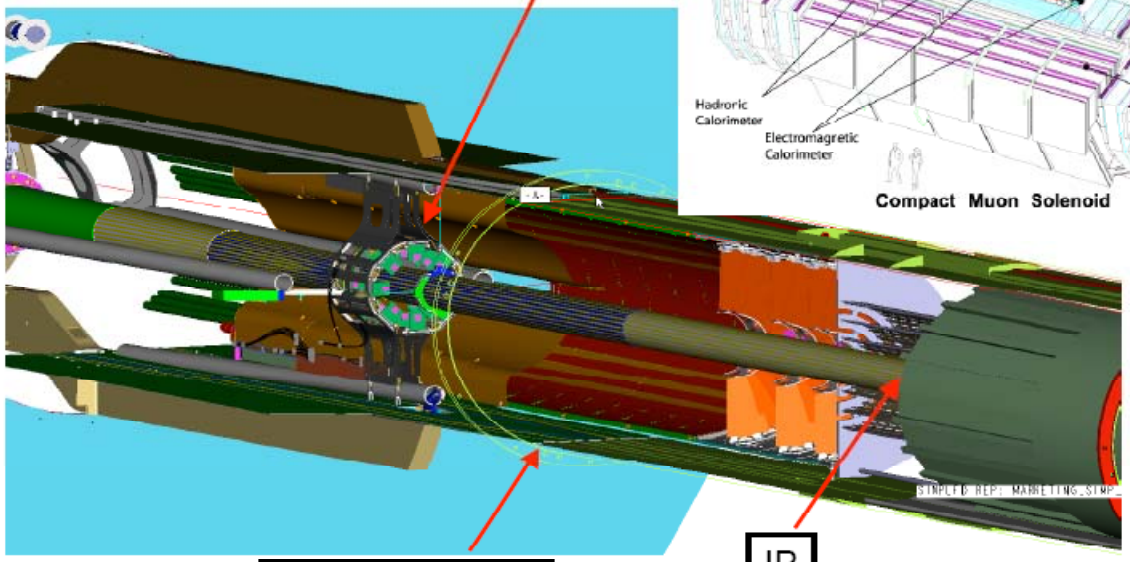
Future Plans – In Progress

→ Pixel Luminosity Telescope (PLT)
→ Relative luminosity measurement (as with HF)
→ Collaboration: Rutgers – Princeton – U.C. Davis
→ ~1% error for luminosity for 10^{28} – 10^{34} $cm^{-2}s^{-1}$



- End of Be section of beam pipe (~ 1.7 m from IP)
- Just outside of beam pipe (~ 5 cm from beam line)





Luminosity Workshop
May 22, 2007

7

Conclusions

→ 44 HLXs (36 required) have been produced & tested.
  → 100% yield (except for one that's being re-checked).

→ HLXs for HF+ has been installed (HF- detector not yet connected).
  → Commissioning is well underway.
  → Successfully participated in August 2007 global run.

→ System has been used both in testing and with 'real' (noise) data.
  → Moving on to LED testing, verifying long-term stability.

Looking forward to seeing some 'real' data!