Prototype CMS Pixel Luminosity Telescope (PLT) at MTest

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The Pixel Luminosity Telescope (PLT)

- Dedicated stand-alone luminosity monitor for CMS
  - independent of CMS trigger, other detector components
- Simple device stable over lifetime of CMS
- Precision measure of relative bunch-by-bunch luminosity
  - statistical precision of 1% in real time (a few seconds)
- Absolute luminosity calibration on:
  - electroweak process (≈ 5%)
  - Optical Theorem and forward scattering (≈ 2%)
  - QED process (≈ 1%)
- Small systematic errors
  - designed to be below 1%
  - linear over full range of luminosity
- Self monitoring and calibrating
  - backgrounds
  - efficiency
PLT Basic Design

- **Telescope Arrays**
  - eight telescopes per CMS end
  - location: $r \approx 5$ cm, $z \approx 1.75$ m

- **Telescopes**
  - three planes
  - total length 7.5 cm

- **Telescope Planes**
  - diamond pixel sensors
  - active area $4.0$ mm $\times$ $4.0$ mm
  - bump-bonded to PSI46v2 pixel ROC

- Measure number of 3-fold coincidences in each bunch crossing (40MHz) using fast-or outputs of the PSI46 pixel chip

- Readout full pixel hit information of each plane at 1 to 10 kHz
Location of PLT

- End of Be section of beam pipe (~ 1.7 m from IP)
- Just outside of beam pipe (~ 5 cm from beam line)
CMS PSI46 pixel chip has “fast” multiplicity counting built in

- Double column architecture
- Fast-Or output level
  - 0, 1, 2, 3, ≥4 double column hits
  - each bunch crossing
- Individual pixel thresholds adjustable
- Individual pixels can be masked
- Full pixel readout
  - address and pulse height of hit pixels
  - every L1 trigger

Diamond sensor
52 x 80 pixels
150 µm x 100 µm

8 mm
active area
8 mm

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Diamond Sensors

- Radiation hard (few \( \times 10^{15} \) p/cm\(^2\))
- No need for cooling
- Full charge collection < 0.2 V/\( \mu \)m
  - 18,000 e\(^-\) signal for 500 \( \mu \)m diamond
  - Landau 60% narrower than for Si
- Pulse height well separated from pedestal
  - compare poly crystalline diamond
Two Complimentary Readout Modes

- **Fast Or Output**
  - every bunch crossing (40 MHz)
  - level → number of double columns hit
  - bunch-by-bunch luminosity
  - abort gap particles

- **Full Pixel Readout**
  - 1 kHz to 10 kHz rate
  - hit pixel addresses and pulse heights
  - powerful diagnostic for fast hit output mode
  - corrections for accidentals and overlaps
  - pixel efficiencies
  - IP centroid measurement
  - beam halo
Telescope

Pig tails

diamond detector
bump bonded on PSI46 ROC

Bias HV

Hybrid board

HDI (4 layer flex circuit)
- TBM (chip communication, readout)
- PLT driver chip (amplifies analog FO)
- low/high voltage distribution
Custom Front-end Digitizer

- Same hardware as the standard CMS Pixels System FEDs.
- Modify firmware for hit data.
- Produce 3-fold coincidence for each telescope
- Maintain histogram for each telescope (one entry for each 3564 crossings per orbit)
- Strip out hit data for comparison with PLT pixel data in response to TTC trigger, include bunch crossing number.
Telescope System Test

- Optical Readout
- Configuration and *in situ* detector calibration & trimming
- Prompt analysis for immediate feedback.
Meson Test Beam Facility

- 120 GeV proton beam (6am - 4pm)
- 3mm by 10mm beam profile
- 4sec/min/spill, 5k trigs/min
- 0.7 M triggers

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Telescope Setup

Scintillators, 6mmx6mm

120 GeV
Taking Data

- Team: 4 faculty, 1 postdoc, 4 grad students
- Detailed and prompt analysis of the ongoing runs
- Developed a number of useful tools
- Built experience in solving realistic problems

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Pixel Yields

- Pixels at the boundary have different yields and charge collection and excluded from the analysis
- Noisy pixels could be masked out if they could not be trimmed out
FastOR vs TDC

- Can determine TDC timing for triple intime coincidence and remove early fastor’s
- Late coincidences contribute to the luminosity uncertainty
• Relative plane to beam alignment
  - plane 1 to 2
    • 30um in x
    • 50um in y
  - plane 1 to 3
    • 410um in x
    • 220um in y
Tracking

- Define cluster: group of neighboring “hit” pixels
- Define cluster position: center of gravity
- Correct for relative plane rotation
- Correct for relative plane offset
- Select events with one and only one cluster in each plane (>90% of events with hits in all three planes)
Pulse heights

- Require single cluster in all three planes
- For Plane c, require hit in regions of Planes a and b such that track is certain to pass through fiducial region of Plane c
- Plot pulse height summed over cluster

![Graphs showing pulse heights for different planes](image-url)
Conclusions

- A lot of help from Fermilab w/ beam test logistics!
- Successful test of optical readout of three-plane prototype PLT telescope
- Ongoing analysis of test beam data
  - Study fast-or timing
    TDC of trigger and clock
- The prototype meets all design requirements
- Pulse height for high energy protons: \(\sim 23k \text{ e}^-\)
- Pulse heights well above pixel threshold range
- Tracks readily and clearly reconstructed
- Rapid alignment (translation and rotation) of planes with beam
Schedule/Future Plans

• Passed CMS Engineering Design Review last fall
• Ongoing analysis of the test beam data
• Irradiated telescope planes ~ full LHC lifetime ($2 \times 10^{15}$ p/cm$^2$)
  - ongoing analysis
• In production mode
  - characterization and testing of 48+ planes w/ Sr90
• PLT ready for installation in CMS by mid-fall 2010
On course for PLT installation during 2010-2011 shutdown
Backup
Data Acquisition

- **Data Acquisition**
  - **Custom FED**: Set
  - **Standard FED**: Set
  - **Spy Data**: Set
  - **PLT Trig**: (1 kHz)
  - **Pixel Data (Addr. Pulse Ht.)**: (1 kHz)
  - **Hit Outputs 40 MHz**
  - **FEC**
  - **TTC**
  - **Hist. 3-fold coincidences (3564 channels) X 21**
  - **Raw FO 1 kHz (~16 kB/s)**
  - **16 Histograms 1 Hz (~230 kB/s)**
  - **Raw FO**: 1 kHz (~16 kB/s)
  - **PLT PC (1 or more)**
  - **Track Reconstruction**
  - **Diagnostic Comparison**
  - **Luminosity Calculation**
  - **Bunch Luminosity**
  - **Beam**
  - **Hot Spots**
  - **Orbit Gap**
  - **Histogram Sums (16)**
  - **Combined Histogram**
  - **PLT EDR**

**Notes**
- **11/5/09**
- 12/04/10