CMS Luminosity Monitoring and Measurement

Joint LHC Machine-Experiments Workshop

Daniel Marlow*
Princeton University
January 26, 2007

*credit to N.Adam, V.Halyo, J.Werner
Talk Outline

• Goals & General Strategy
• Real time Techniques
  – HF
  – TAN-region LHC devices
  – Pixel Telescopes*
• Offline Techniques
  – Total cross section measurement (TOTEM)
  – W & Z Counting
  – Dileptons from two-photon
• Summary and Conclusions
  *pending approval & funding.
Design Goals: General Desirables

- Absolute calibration, based on a known cross section with a reliably calculated acceptance.

- Temporal stability against gain changes and other drifts: "countable objects" or self calibrating signals (e.g., MIP peak).

- Linearity over a large range of luminosities.

- Real time operation independent of full DAQ.

- Redundancy
  - There is no perfect method
  - Applies to both real time monitoring and to offline absolute normalization
Design Goals: Specific Issues

• Real time monitoring
  – Bunch by bunch (yes)
  – Update time: 1.0 s

• Offline
  – Robust logging
  – Easy access to luminosity records
  – Dynamic range \((10^{28} \sim 10^{34} \text{ cm}^{-2}\text{s}^{-1})\)

• Absolute Calibration
  – Target 5% (or better)
General Strategy

• Use real time techniques (HF, Pixel Telescopes, FIC) to monitor luminosity during running.

• Normalize using processes of \( \sim \) known cross section (e.g., W’s and Z’s)

• Use TOTEM measurement of total cross section at low luminosity as a cross calibration.
Zero Counting

- If the mean number of interactions per BX, $\mu < 1$, measuring the luminosity is straightforward, since the probability of two events in a single BX is $\sim \mu^2$. It is enough just to count hits.

- For $\mu \sim 1$, one must either be able to distinguish between single and double interactions (not generally possible in this context), or, one must “count zeroes”

\[
p(n; \mu) = \frac{\mu^n e^{-\mu}}{n!} \quad \Rightarrow \quad p(0; \mu) = e^{-\mu}
\]

\[
\Rightarrow \mu = -\log[p(0)]
\]
Although there is a very large spread in luminosity from commissioning conditions (and also TOTEM running), the extrapolation isn’t quite as large as it first seems, since the low-lumi running will be done with fewer filled bunches.
Signals From HF

Iron fiber calorimeter.

3 < \eta < 5

Minimal add’l hardware requirements
• Mezzanine board to tap into HF data stream and forward bits to a PC via Ethernet
• Autonomous (mini) DAQ system to provide “always on” operation

T1 & T2 are elements of TOTEM
The energy depositions in single interactions are typically quite sparse.

Simulation details:
- PYTHIA w. diffractive events added.
- DC04 (GEANT)
- Extract HF depositions to Rootuple.
At design luminosity, there are typically 25 interactions per BX.
**ET Depositions**

ET Sum in HF

Diffractive interactions

An $E_T$ threshold of 1 GeV will detect most inelastic interactions.

Total in one endcap.

Single interaction BX’s only.
HF Zero Counting

- Defeat the zero famine at high luminosity by counting zeroes in a much smaller solid angle.

- There are 864 HF “physical” towers.
- In effect these provide 864 quasi-independent measurements of the luminosity.

- Average to arrive at final result.
- Accumulate lumi on a bunch-by-bunch basis for all 3564 buckets
MC: Physical Tower Zero Counting

Full GEANT simulations with realistic modeling of readout chain.

Linearity is the key performance parameter.

Deviation from linearity
MC Results: $E_T$ Sum Method

An average $E_T$ sum also provides a linear response.

Deviation from linearity
“Publishing” and logging the information for each bunch.

HLX boards accumulate histograms
Bucket #

- Mock data published to CCC (& other places). Result shows emulated LHC bunch structure.
- Ongoing discussions with CMS SW & DB teams.
Synchronized Beam Test with Full HF(HB)-QIE-HTR-HLX Chain

Halyo & Werner

SPS elog from same period
Pixel Luminosity Telescope (PLT)

• The HF method is based on an existing detector, and thus has the advantage of being inexpensive and relatively easy to implement.

• It does not, however, really fit the bill when it comes to providing a luminosity measurement based on “countable objects.”

• Motivated by the CDF approach of counting MIPs using Cherenkov telescopes, we have proposed a charged-particle telescope system based on single-crystal diamond detectors readout by the CMS pixel chip.

• This system is not yet approved or funded.
Pixel Luminosity Telescope (PLT)

Measure luminosity bunch-by-bunch

- Small angle ($\sim 1^\circ$) pointing telescopes
- Three planes of diamond sensors (8 mm x 8 mm)
- Diamond pixels bump bonded to CMS pixel ROC
- Form 3-fold coincidence from ROC fast out signal
- Located at $r = 4.9$ cm, $z = 175$ cm
- Total length 10 cm
- Eight telescopes per side

PLT systematics are complementary to those of the HF
We also hope to use the TAN-region (z=±140m) luminometers being developed by the LHC.

\[ \delta_L \]

\[ n \]

\[ \delta_R \]
Absolute Normalization

- **Some methods**
  1. Estimate from LHC parameters (using Van der Meer scans)
  2. TOTEM total p-p cross section
  3. W & Z production
  4. Lepton-pair production via two photon interactions

- **There is likely to be a period at the beginning where methods 2~4 remain under study**
Luminosity Independent Method

\[ \sigma_{tot} = \frac{16\pi}{(1 + \rho^2)} \frac{(dN_{el}/dt)_{t=0}}{N_{el} + N_{inel}} \]

Measure elastic scattering in Roman Pots and inelastic in T1 and T2 (see next slide). Should give result good to a ~few %. 

January 26, 2007 CMS Luminosity 22
Normalizing Using W’s and Z’s

M. Dittmar et al.

Basic idea is to use $pp \rightarrow W \rightarrow \ell \nu$ & $pp \rightarrow Z \rightarrow \ell^+ \ell^-$

to determine “parton luminosity.”

- Lots of rate
- Well understood theoretically
- Readily detectable

January 26, 2007
See e.g. Krasny, Chwastowski, Slowikowski (hep-ex 0610052)

Theoretically calculable to ~3%. Samples of comparable statistical accuracy in one year at $10^{33}$ cm$^{-2}$s$^{-1}$

Improved accuracy possible with hardware improvements.

Significant challenges associated with triggering and acceptance systematics.
### Z rates for Various Run Conditions

<table>
<thead>
<tr>
<th>#BX</th>
<th>Lumi</th>
<th>Z Rate Hz</th>
<th>Rate/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>$3.8 \times 10^{29}$</td>
<td>0.001</td>
<td>90</td>
</tr>
<tr>
<td>156</td>
<td>$5.6 \times 10^{31}$</td>
<td>0.16</td>
<td>14K</td>
</tr>
<tr>
<td>936</td>
<td>$5 \times 10^{32}$</td>
<td>1.4</td>
<td>121K</td>
</tr>
<tr>
<td>2808</td>
<td>$2.8 \times 10^{33}$</td>
<td>8</td>
<td>600K</td>
</tr>
<tr>
<td>2808</td>
<td>$10^{34}$</td>
<td>28</td>
<td>2.4M</td>
</tr>
</tbody>
</table>
Summary and Conclusions

• Various techniques are being pursued for online luminosity monitoring.
  • HF
  • FIC
  • PLT

• The combination will provide redundancy and cross checks, but only for *relative* luminosity.

• Understanding absolute normalization will be an important task during early days of LHC operations.
Extra Slides