CMS Luminosity Monitoring and Measurement

Joint LHC Machine-Experiments Workshop

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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 ($10^{28} \sim 10^{34}$ $cm^{-2}s^{-1}$)
- 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 ~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

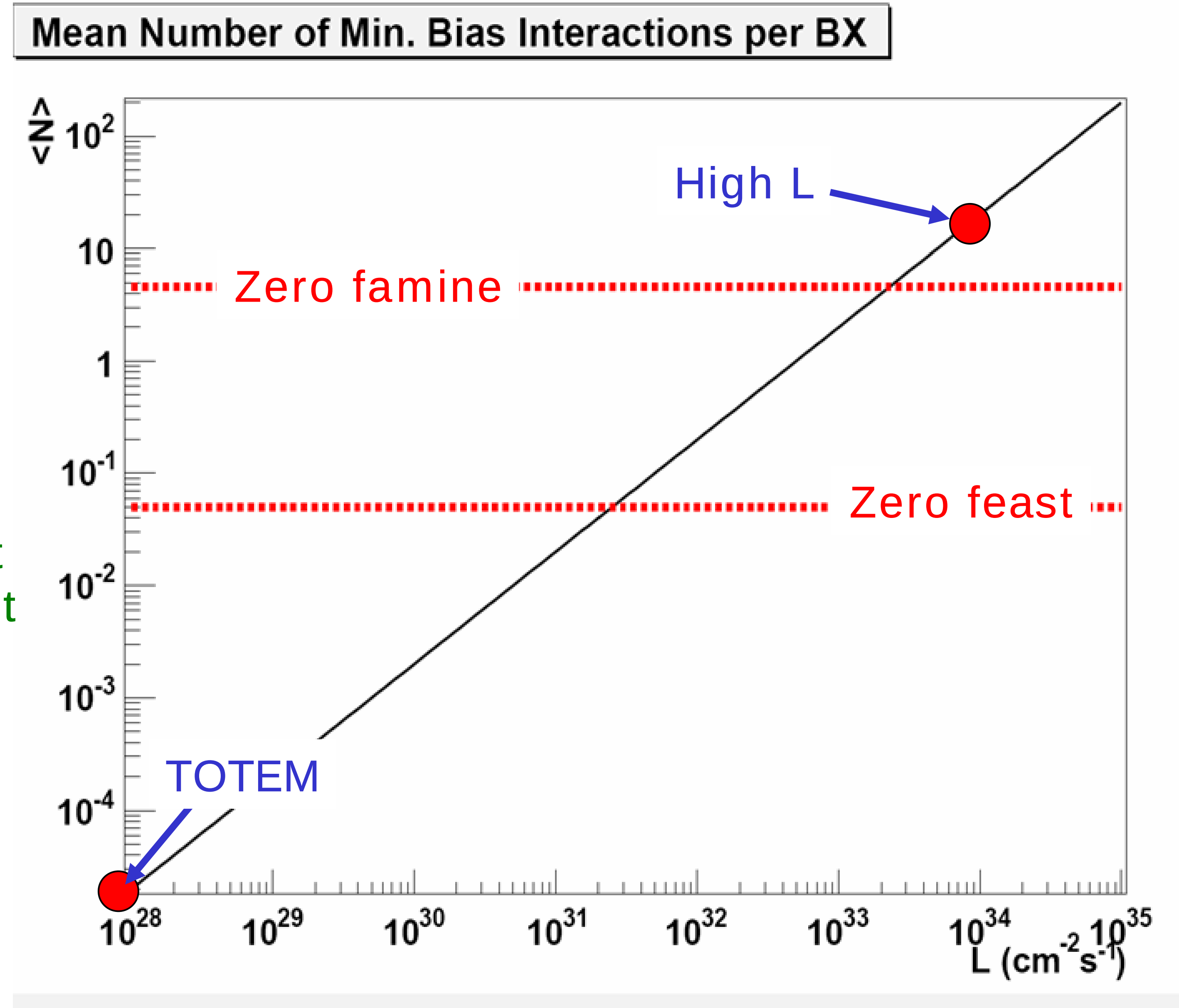
- If the mean number of interactions per BX, $\mu << 1$, measuring the luminosity is straightforward, since the probability of two events in a single BX is $\sim\mu^2$. It is enough just to count hits.
- For $\mu\sim1$, one must either be able to distinguish between single and double interactions (not generally possible in this context), or, one must "count zeroes"

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

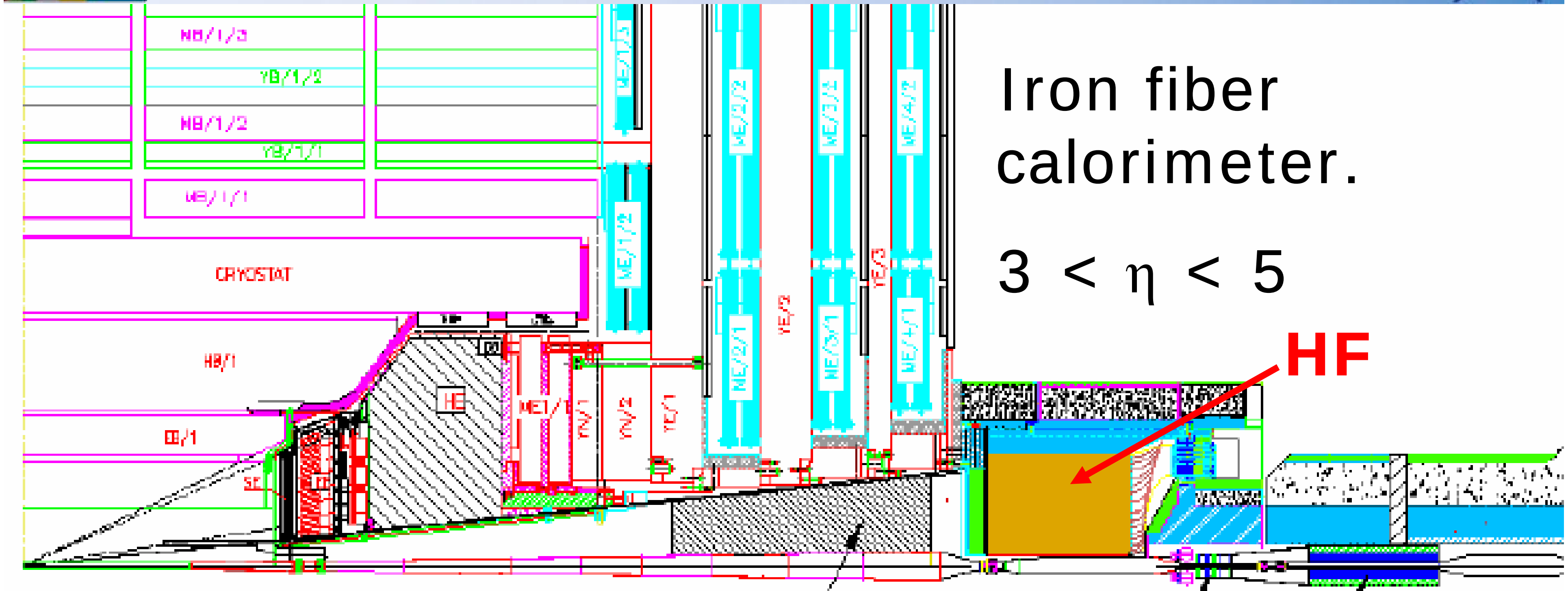
$$\Rightarrow \mu = -\log[p(0)]$$

General Strategy

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.

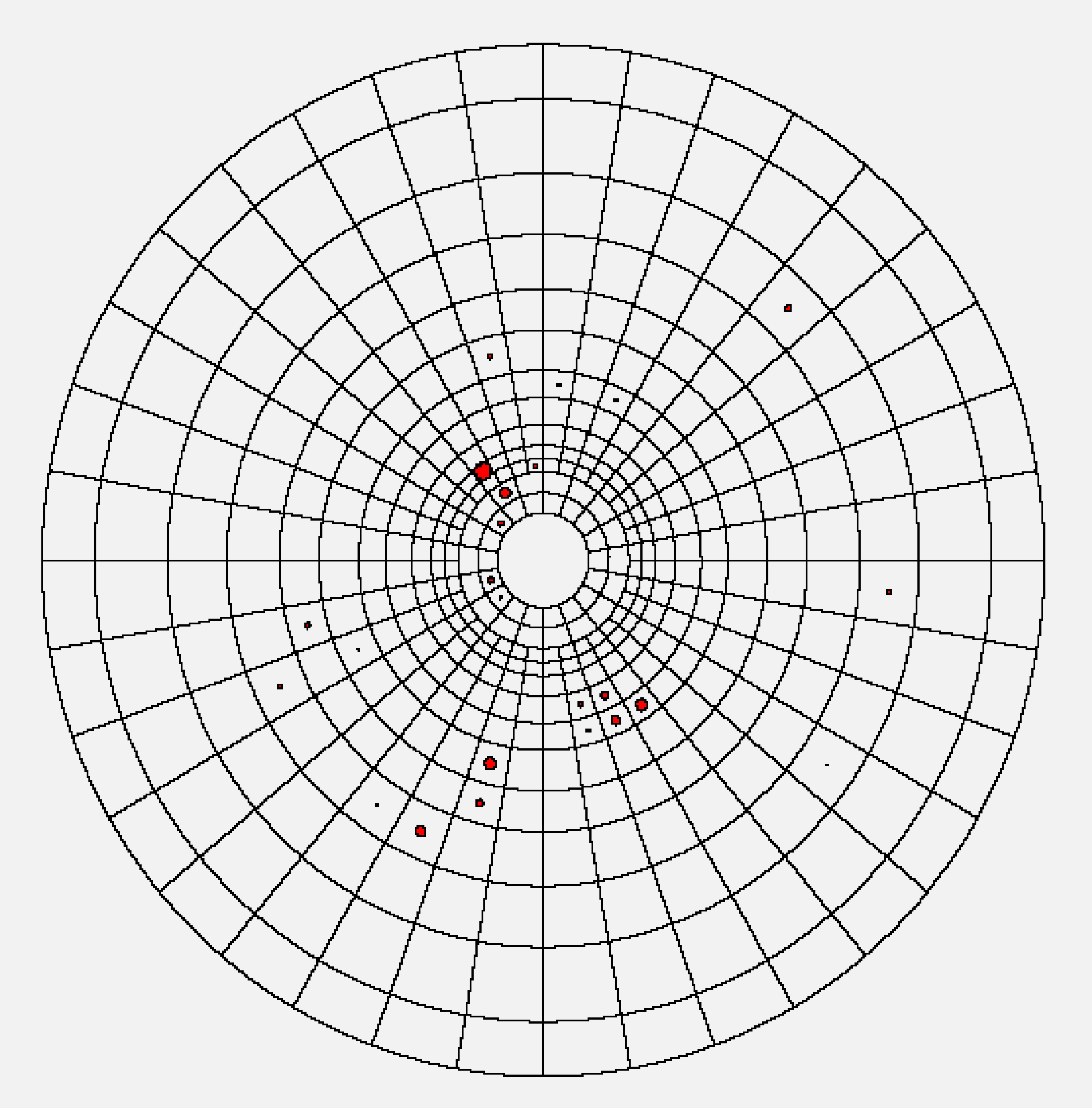
$3 < \eta < 5$

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

HF Energy Depositions



The energy depositions in single interactions are typically quite sparse.

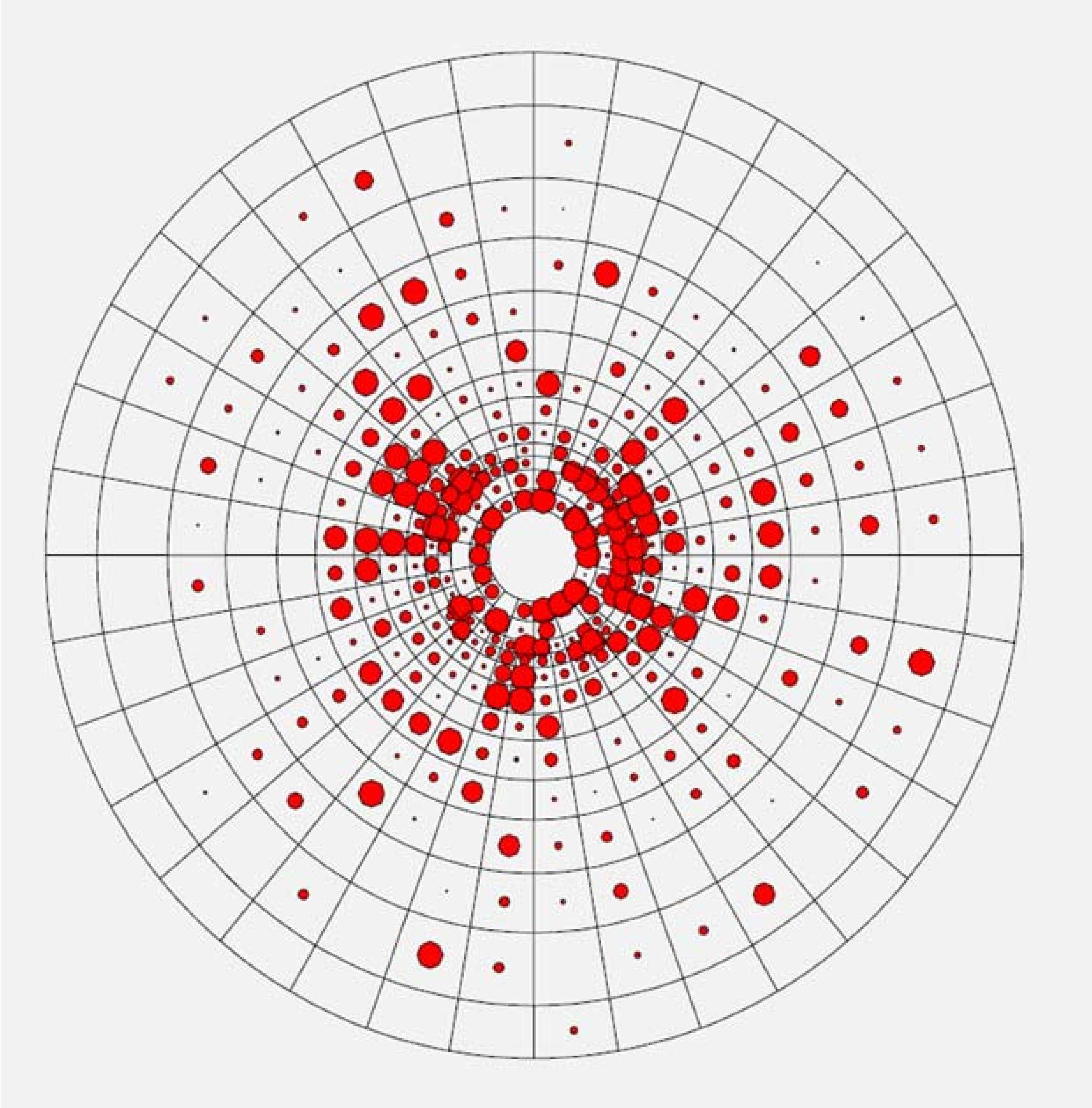
Simulation details:

• PYTHIA w. diffractive events added.

• DC04 (GEANT)

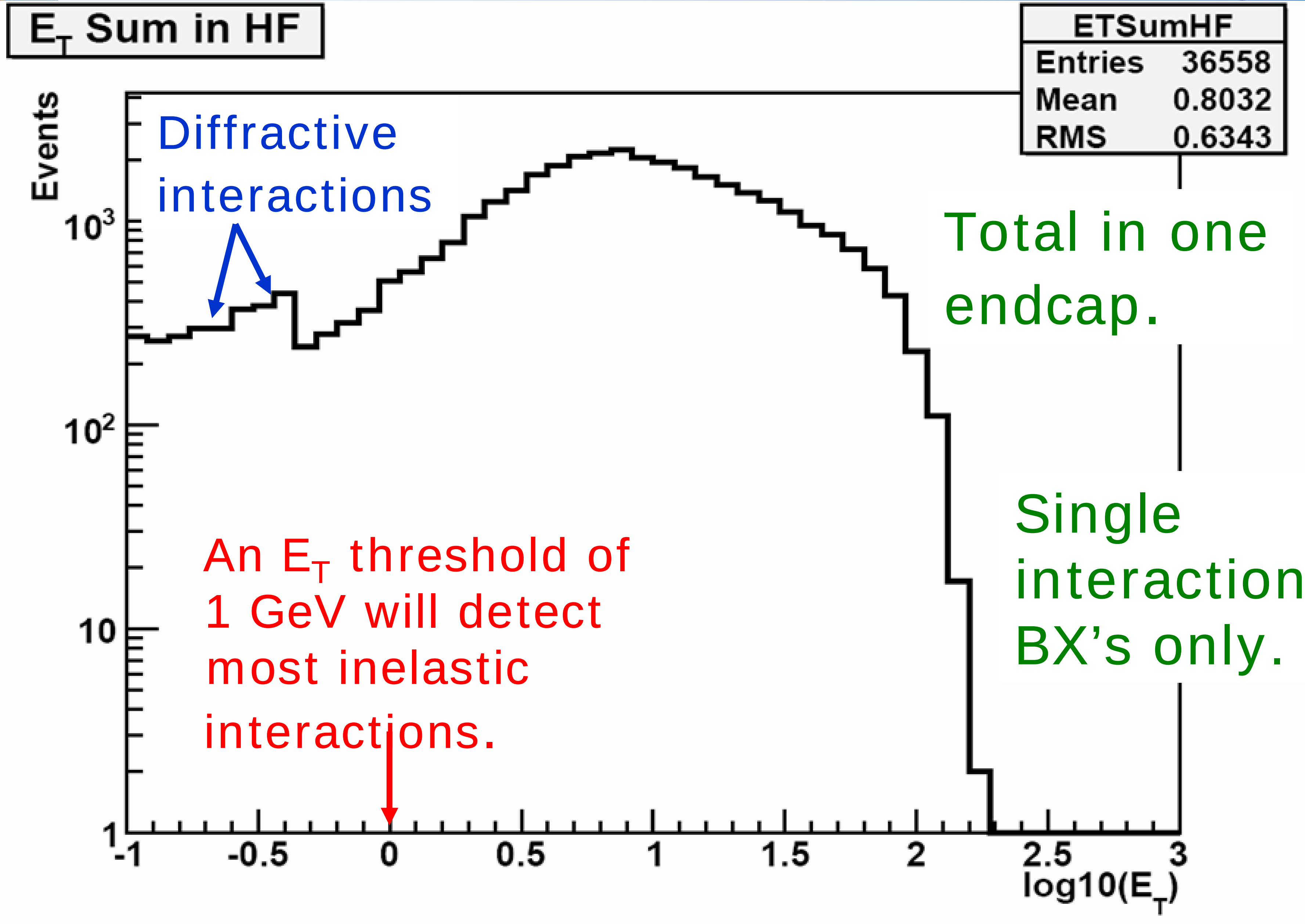
• Extract HF depositions to Rootuple.

Energy Depositions



At design luminosity, there are typically 25 interactions per BX.

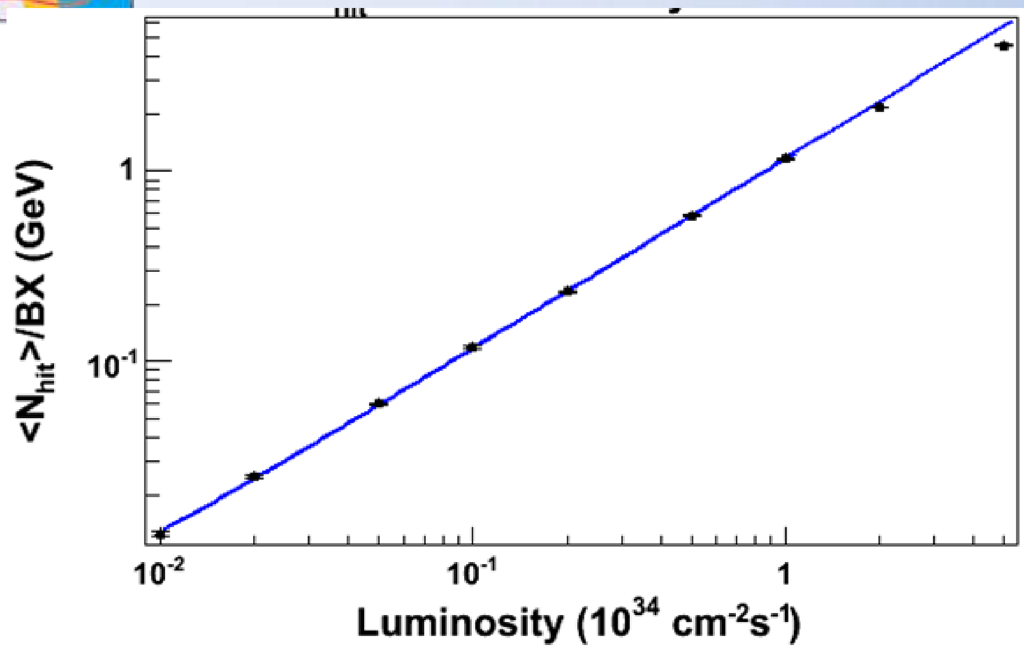
E_T Depositions

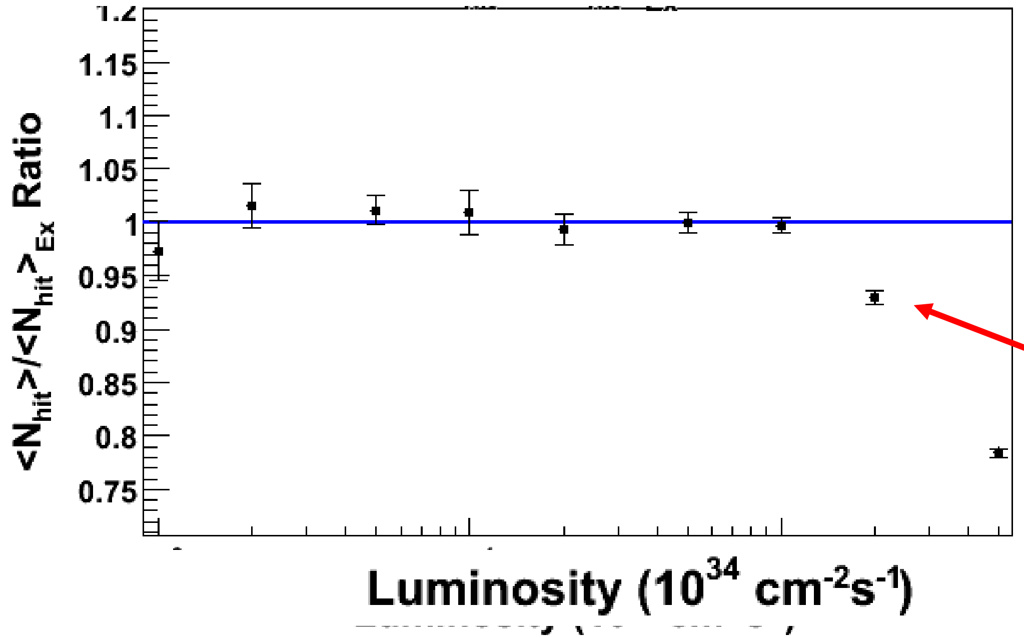


HF Zero Counting

- 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



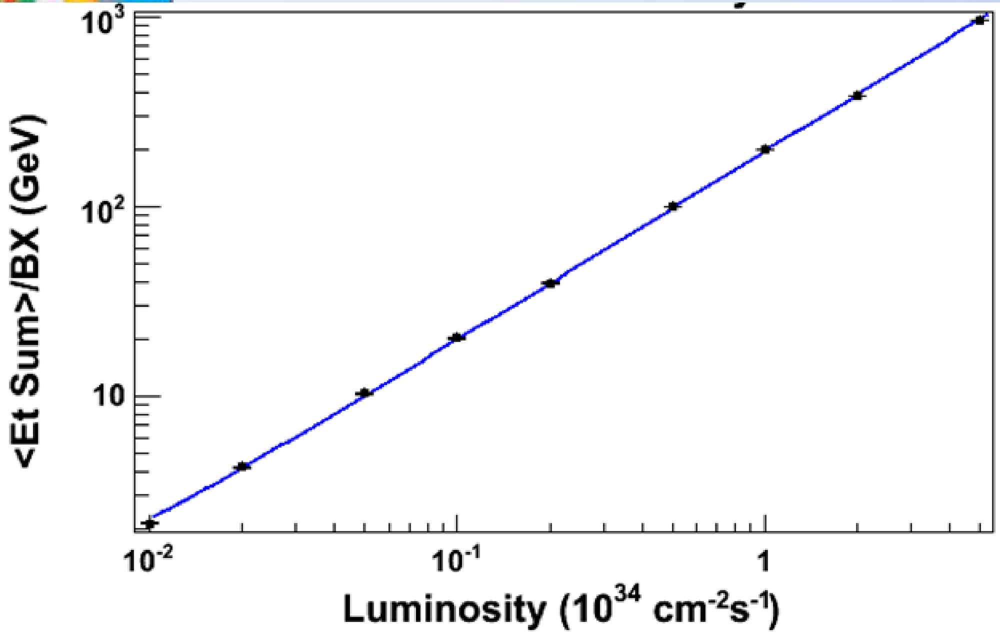


Full GEANT simulations with realistic modeling of readout chain.

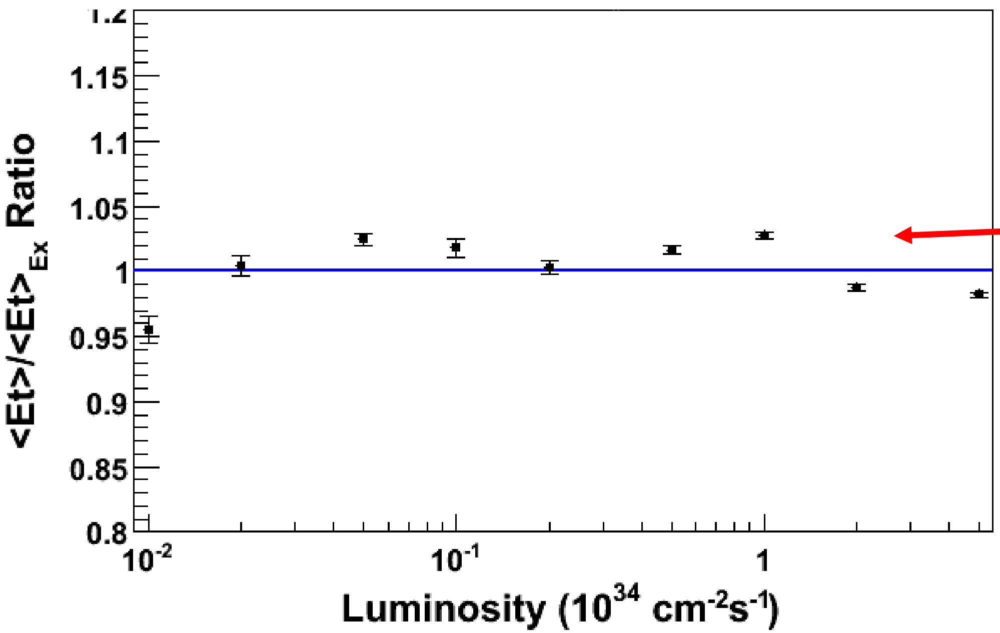
Linearity is the key performance parameter.

Deviation from linearity

MC Results: E_T Sum Method



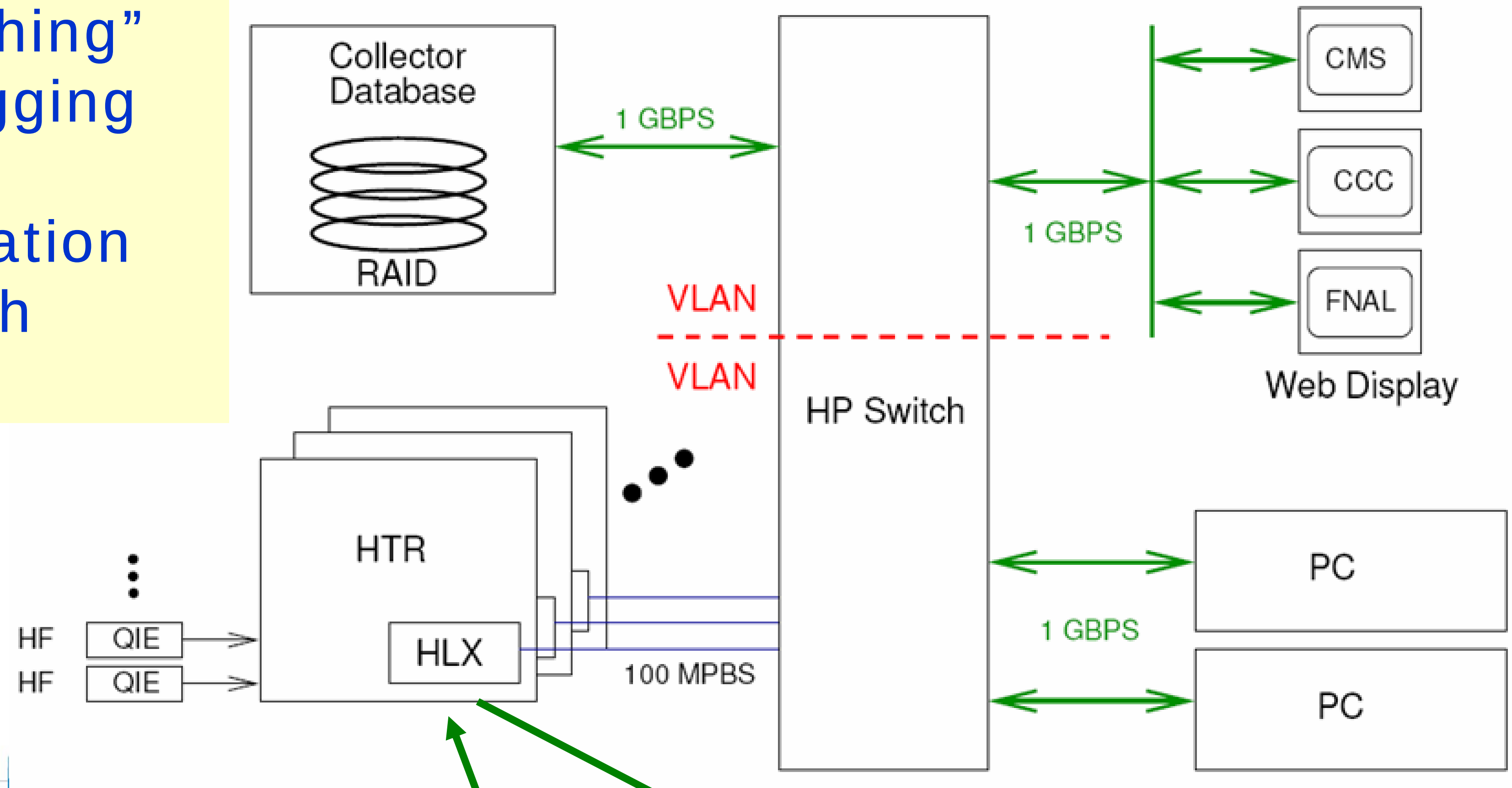
An average E_T sum also provides a linear response.



Deviation from linearity

HF Lumi Upper Level Design

"Publishing" and logging the information for each bunch.



HLX boards accumulate histograms

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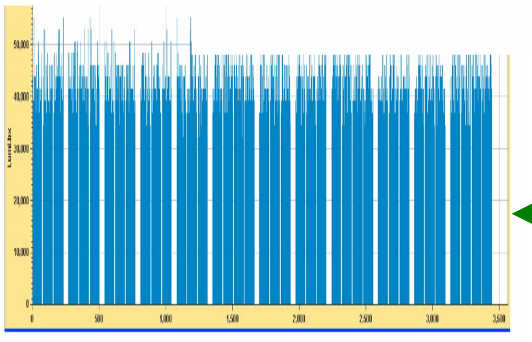
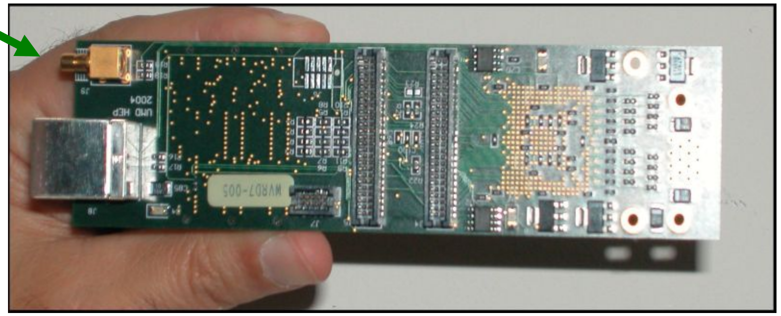
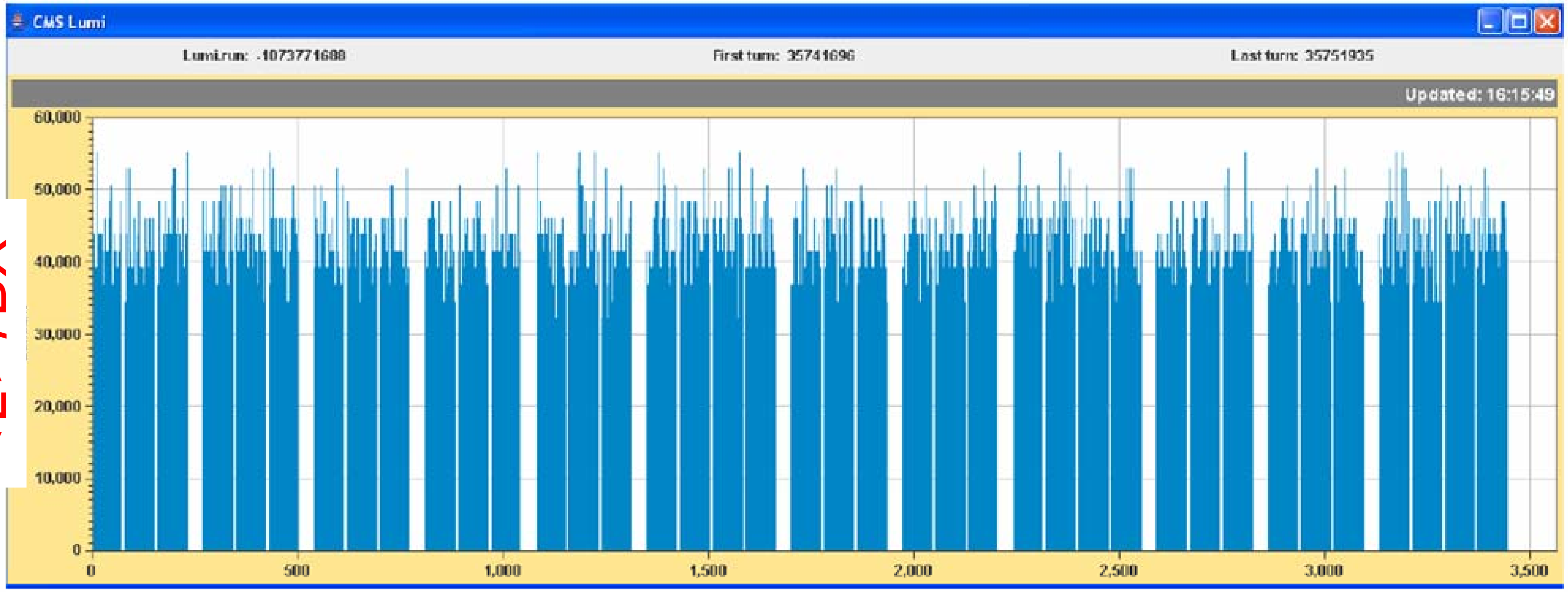


Bucket #



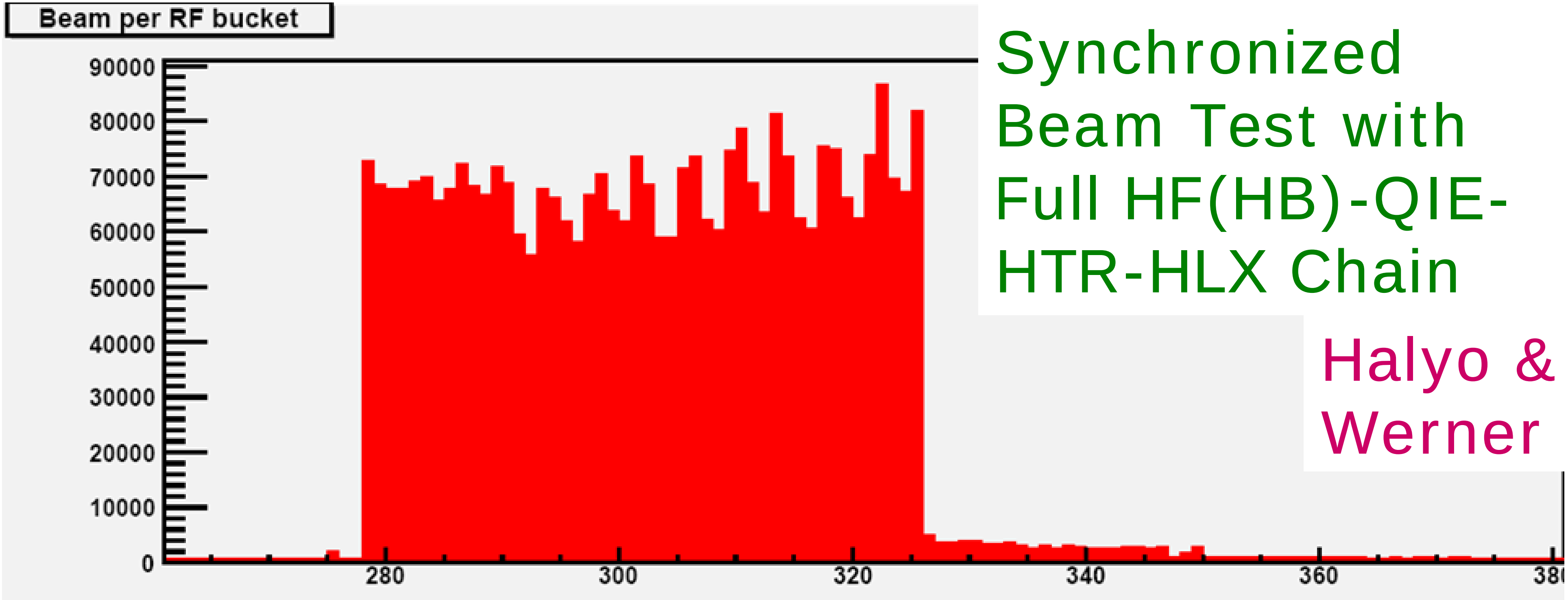
Bunch-by-Bunch Display



<L>/BX

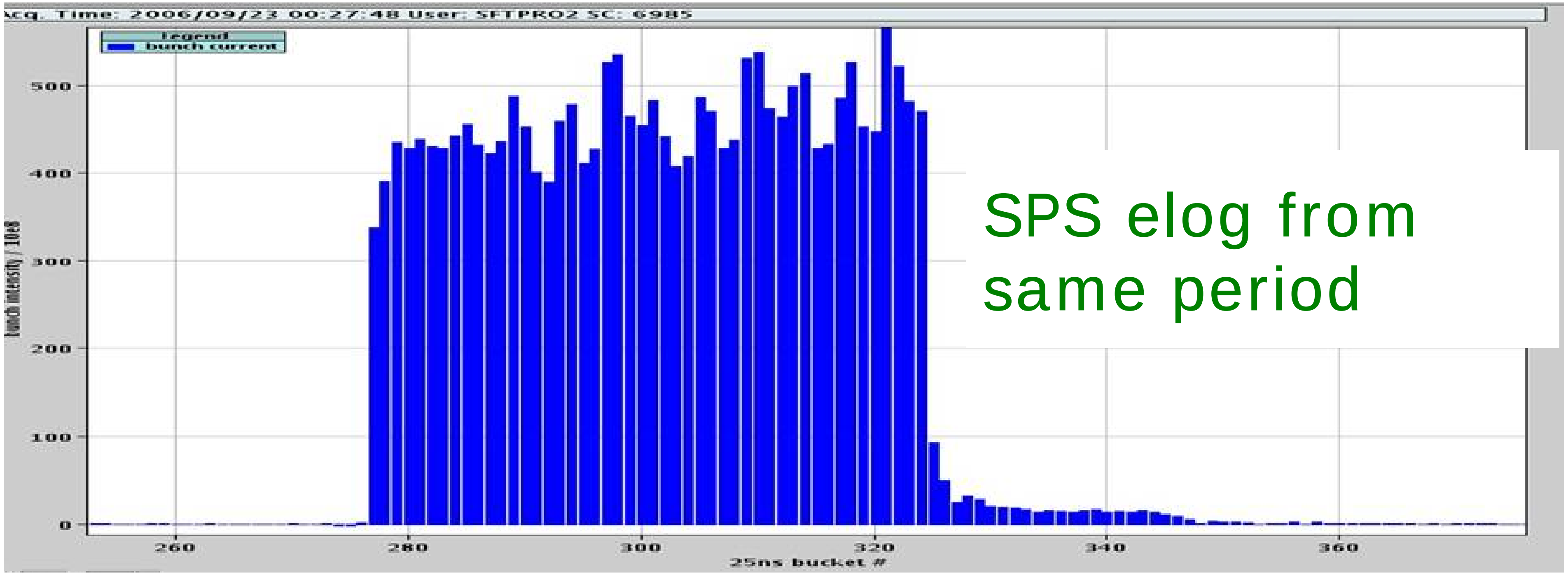
Bucket #

- 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)

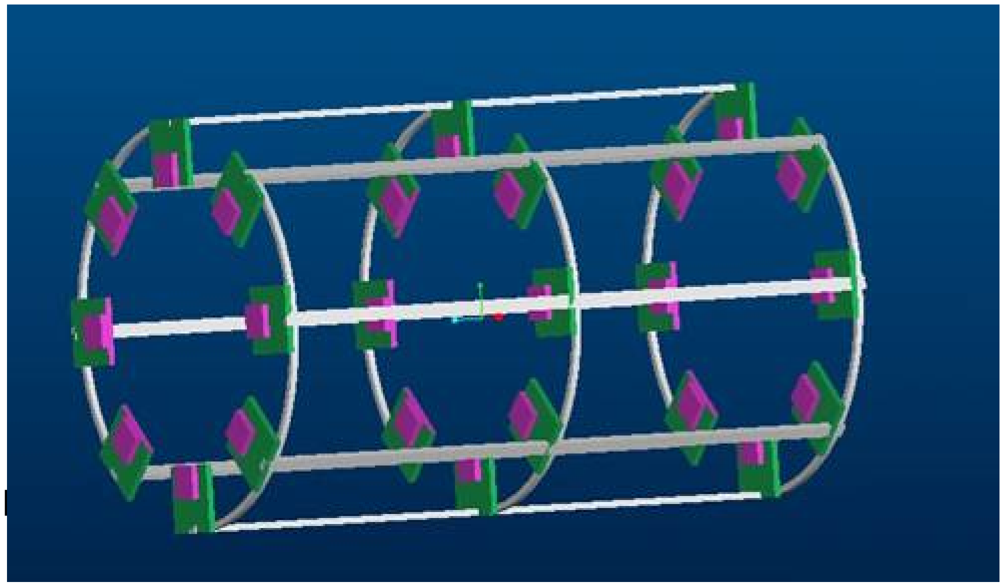
Measure luminosity bunch-by-bunch

- Small angle ($\sim 1^{o}$) 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

Count 3-fold coincidences on bunch-by-bunch basis.

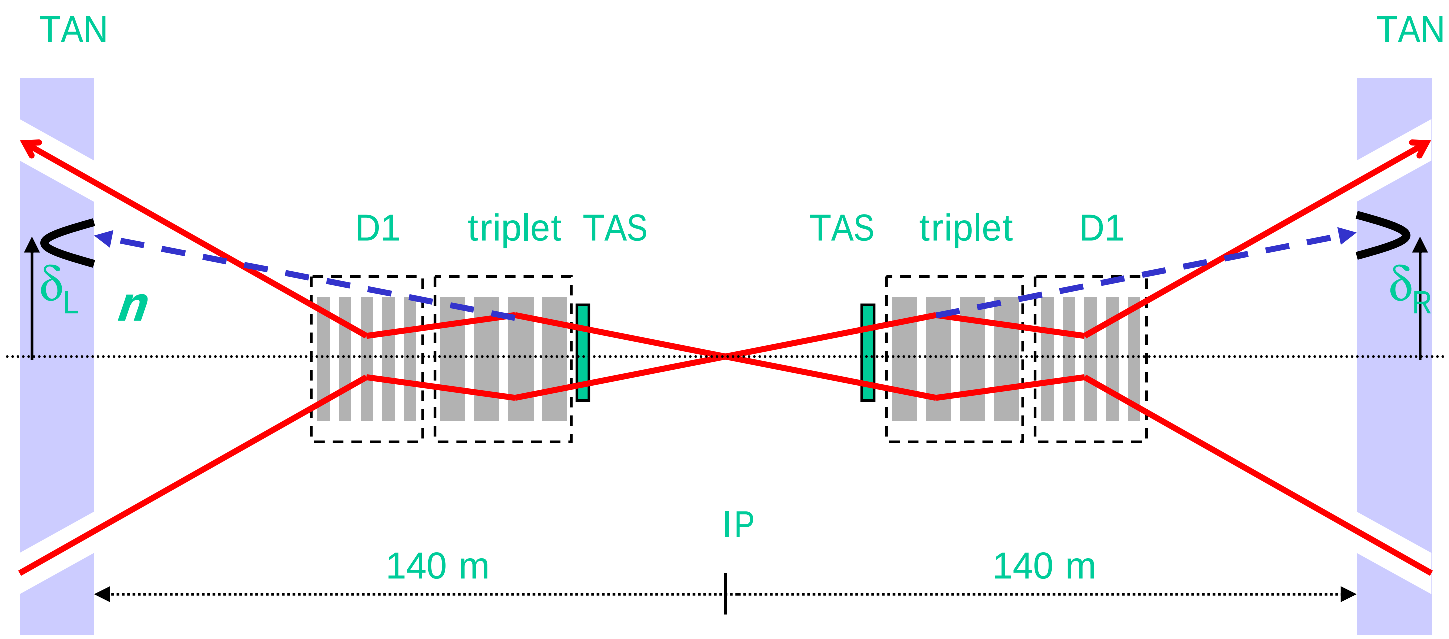
PLT systematics are complementary to those of the HF

Rutgers/Princeton/UC Davis



LHC Luminosity Monitor

- We also hope to use the TAN-region (z= ±140m) luminometers being developed by the LHC.

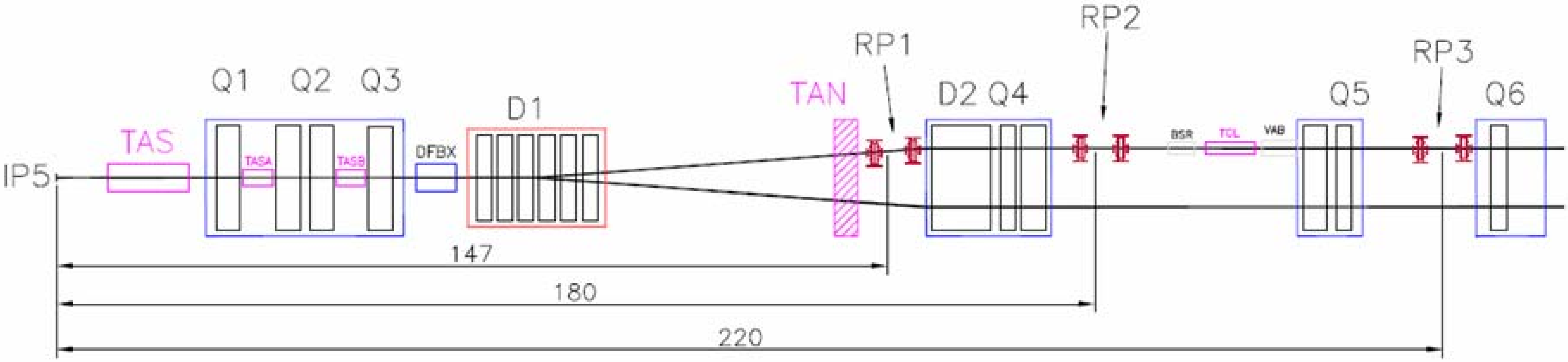


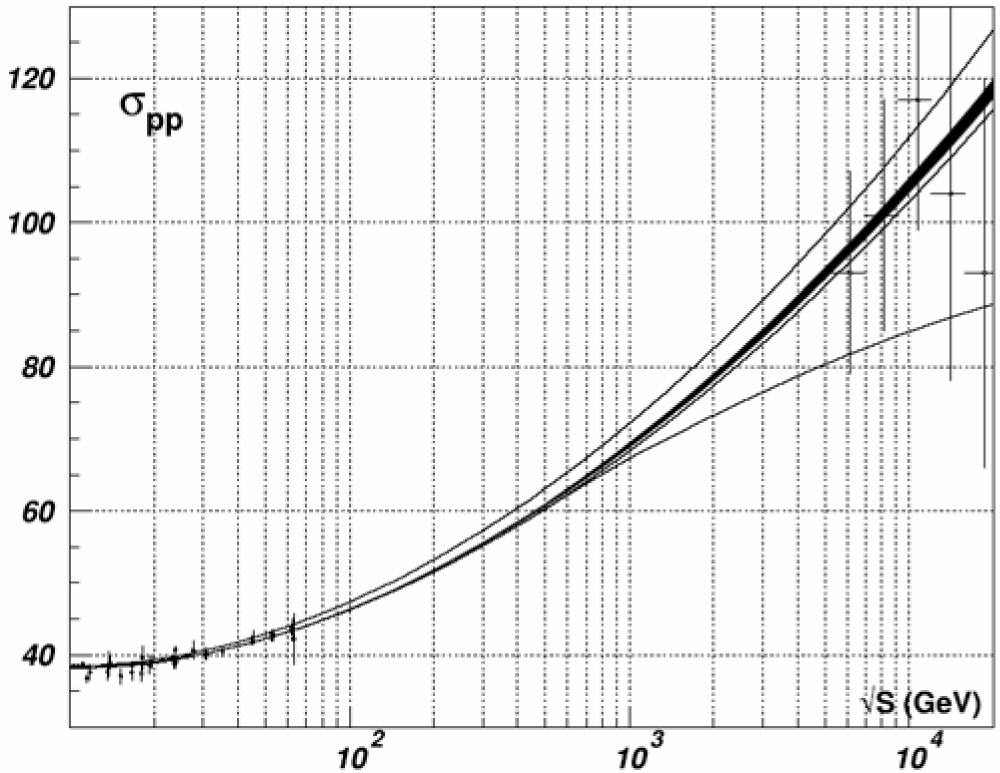
Absolute Normalization

- 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

TOTEM





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 %.

ty

Normalization Using W's and Z's

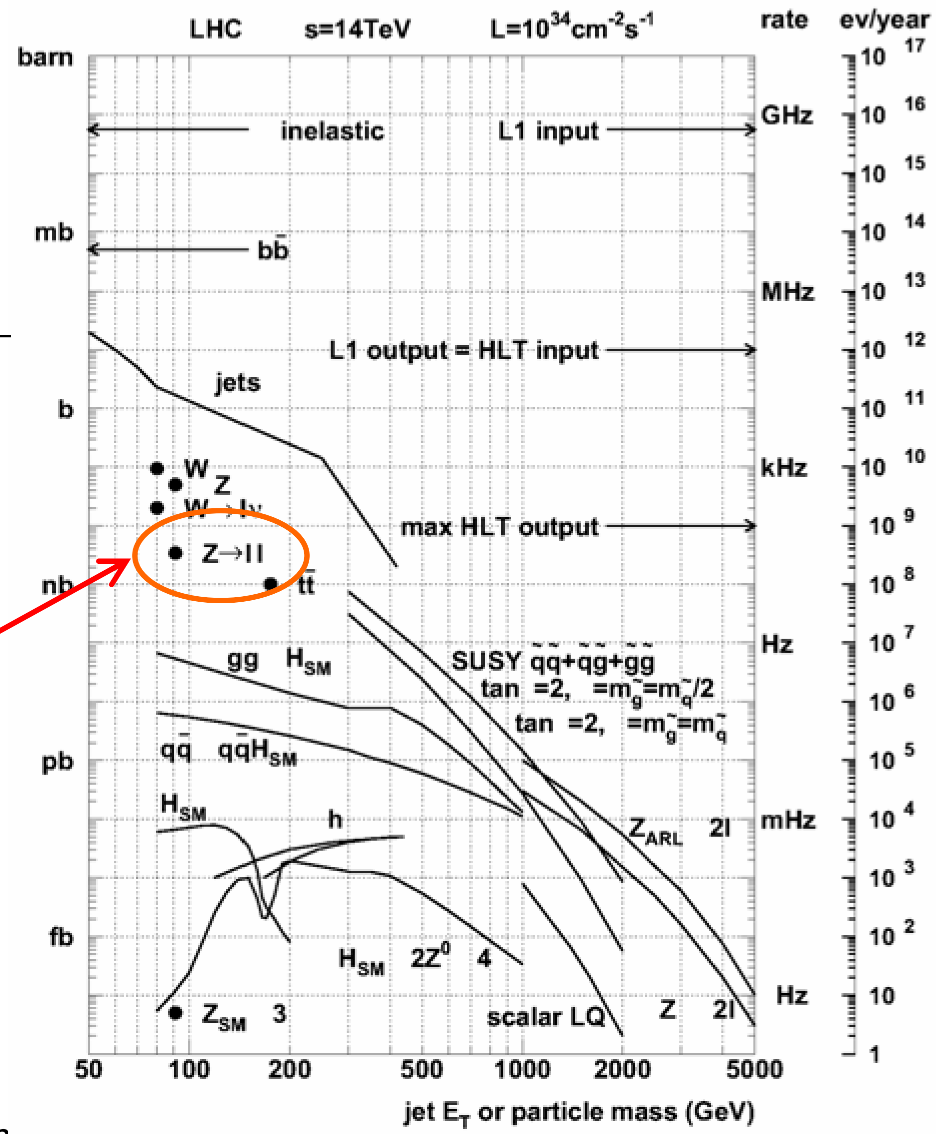
M. Dittmar et al.

Basic idea is to use

$$pp \rightarrow W \rightarrow \ell \nu \;\; \& \;\; pp \rightarrow Z \rightarrow \ell^{+} \ell^{-}$$

to determine "parton luminosity."

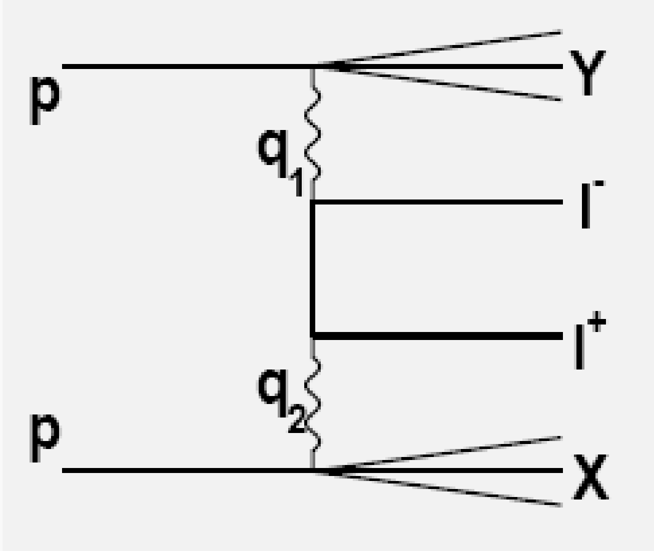
- Lots of rate
- Well understood theoretically
- Readily detectable



LHC event rates at 'nominal luminosity' CMS Trigger TDR

Dilepton Pair Method

See e.g.Krasny, Chwastowski, Slowikowsi (hep-ex 0610052)



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

Significant challenges associated with triggering and acceptance systematics.

Improved accuracy possible with hardware improvements.

Z rates for Various Run Conditions

#BX	Lumi	Z Rate Hz	Rate/day
43	3.8 10^{29}	0.001	90
156	5.6 10^{31}	0.16	14K
936	5 10^{32}	1.4	121K
2808	2.8 10^{33}	8	600K
2808	10^{34}	28	2.4M

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