CMS Forward Detectors for Indirect Luminosity Measurements

Steve Schnetzer
Rutgers University

for the PLT and FSC Collaborations

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Two Forward Detector Systems

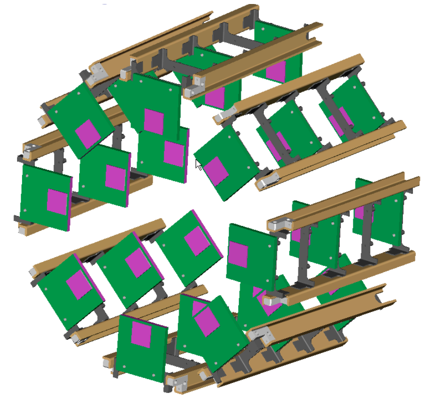
Pixel Luminosity Telescopes (PLT)

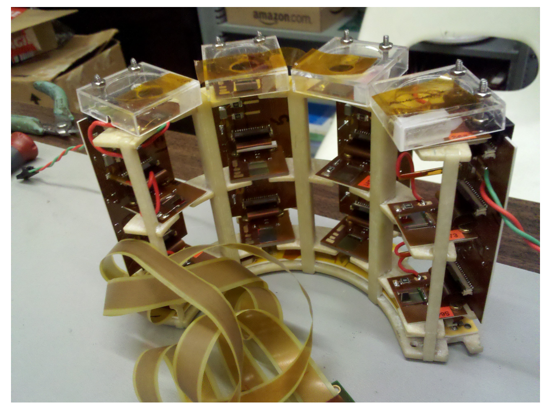
- Dedicated luminosity monitor
- Diamond pixel sensors
- Long term stability
- Percent precision on relative luminosity

Forward Shower Counters (FSC)

- Far forward scintillators
- Detector showers from high $|\eta|$ particles
- Discrimination from proton dissociative events
- Measurement of $pp \to p(\gamma\gamma)p \to pp\mu\mu$

The PLT





Telescope Arrays

- eight telescopes per CMS end
- location: $r \approx 5$ cm, $z \approx 1.75$ m
- $|\eta| \sim 4.5$

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 (40 MHz) using fast-or outputs of the PSI46 pixel chip
- Readout full pixel hit information of each plane at 1 to 10 kHz

Statistical Precision

Pythia 6.2 simulation

3-fold coincidences per bunch crossing at $L = 10^{34} \approx 2$

- 3-fold coincidence rate $\approx$ 80 MHz
- bunch-by-bunch 3-fold coincidence rate $\approx$ 30 kHz

$\Rightarrow$ 1% precision in less than 1 s

From pixel data alone $\rightarrow$ track rate $\approx$ 2 kHz

$\Rightarrow$ 1% precision in:

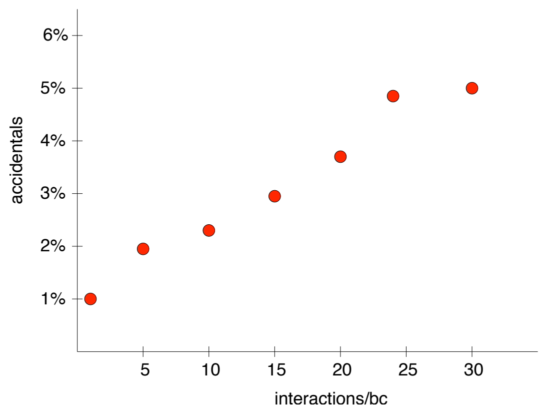
integrated $\rightarrow$ 5 s

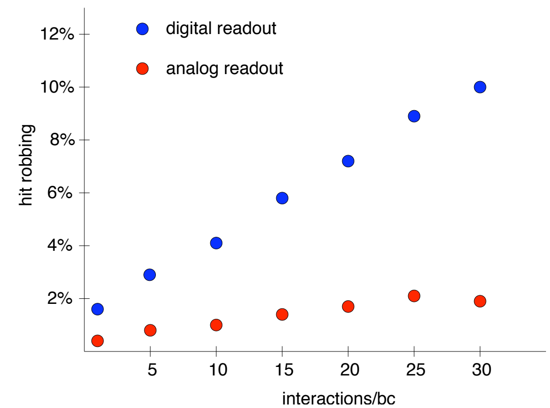
bunch-by-bunch $\rightarrow$ 4 hr

Systematic Errors

Accidentals and Particle Overlaps

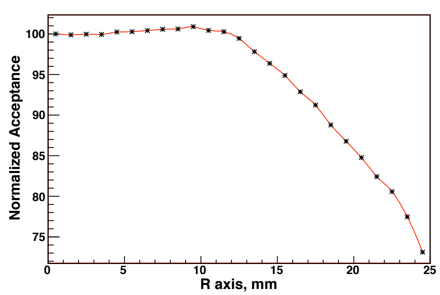
- few percent at $L = 10^{34}$
- corrected with pixel information



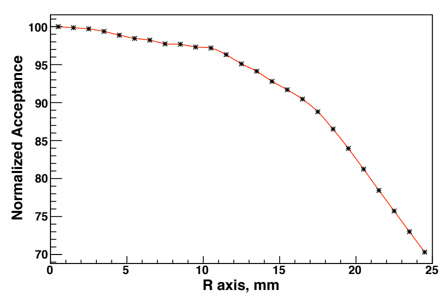


Displacement of Interaction Point

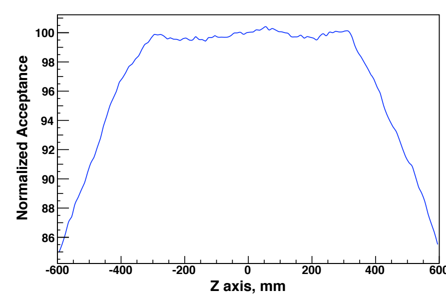
- Acceptance flat to 1% over $\Delta r < 4\text{mm}, \;\; \Delta z < \pm 30\text{cm}$



radial IP displacement
toward telescope



radial IP displacement
between telescopes



longitudinal IP displacement

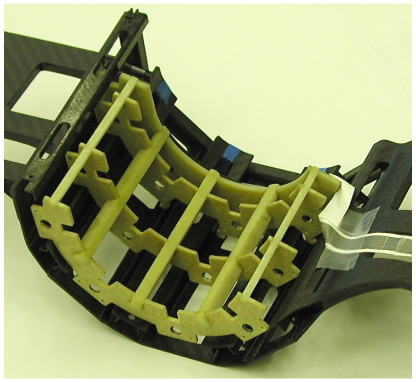
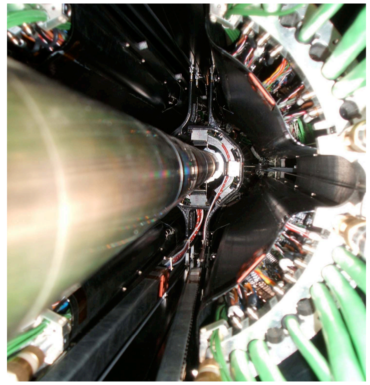
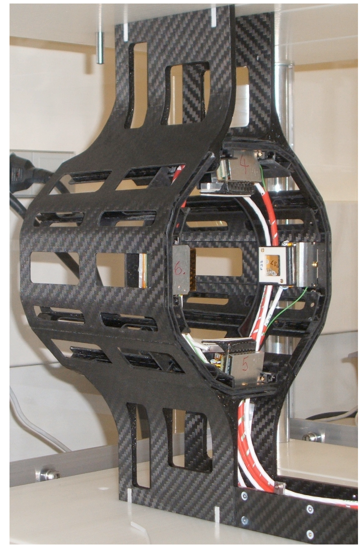
Stability

Data Aquistion

- independent of CMS data stream and trigger

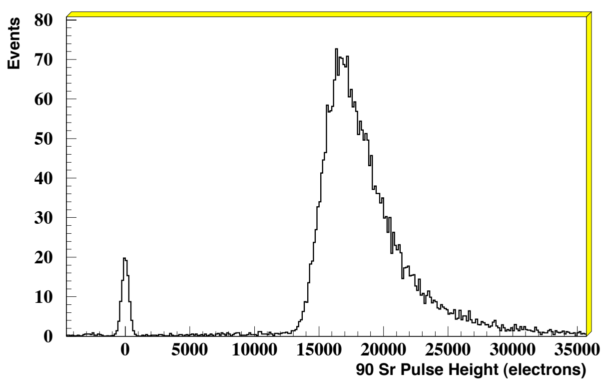
Repositioning accuracy

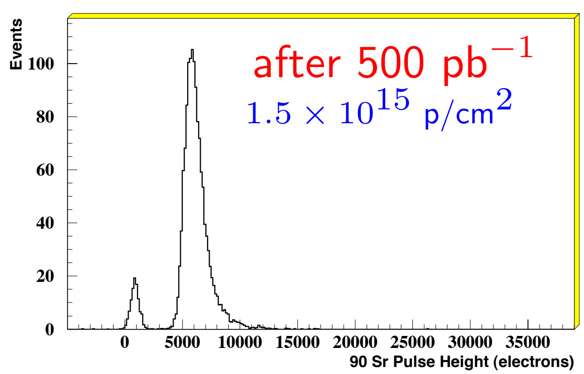
- cassette and carriage system
- guarantees acceptance change $< 1\%$

Efficiency

- in situ measurement with pixel information
- single crystal diamond sensor $\longrightarrow$ pulse height well separated from threshold





Compatibility with Low Luminosity Running

Low luminosity total cross section running

- $N_{\text{3-fold}}/\text{bx} = 2$ for $L = 10^{34}$, $N_{\text{b}} = 2808$
- Assume: $L = 2 \times 10^{28}$, $N_{\text{b}} = 156$

  $\Rightarrow$ $N_{\text{3-fold}}/\text{bx} = 7 \times 10^{-5}$
- Want noise coincidence to be 1% of this: $N_{\text{noise}}/\text{bx} = 7 \times 10^{-7}$

  $\Rightarrow$ Noise coincidence rate $<$ 30 Hz

Noise coincidence rate per telescope $<$ 2 Hz

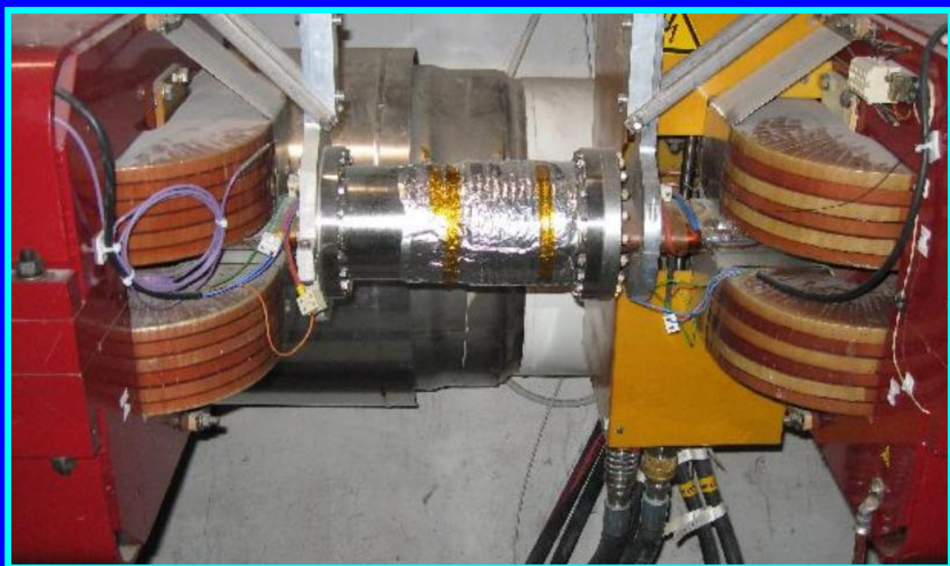
- This is readily achieved

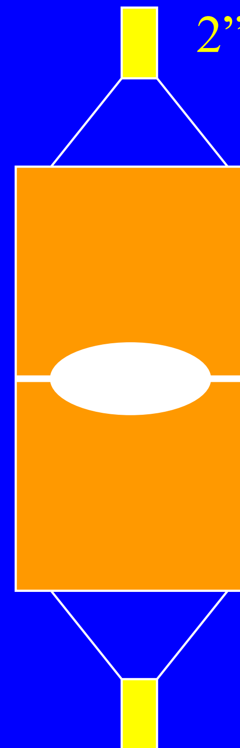
  – hot pixel channels masked off
- No acceptance change from larger beam size due to larger β^*

The FSC

Very simple, low tech: 8 PMTs on each side in 4 pairs.

Between 2 MBX magnets





2” PMT

25 cm x 25 cm scint.

Schematic of counter pair. Cut-out depends on location

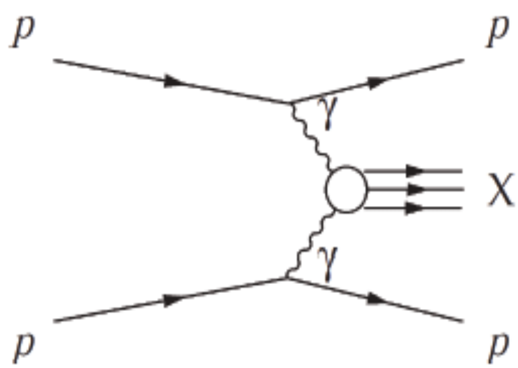
Four locations: z (m) = 59.2, 79.1, 88.5 and ~ 125 m (to be optimized)

Rapidity range: $7 < |\eta| < 11$

Detect showers produced by particles in beam pipe

Measurement of Two Photon Process

Theoretically clean process



- $X = l^+l^-$
- Purely electromagnetic process
- Known theoretically to high precision

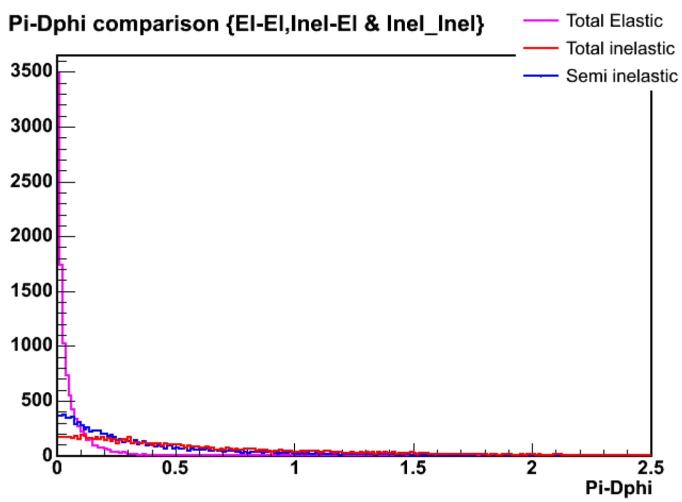
Experimental issues

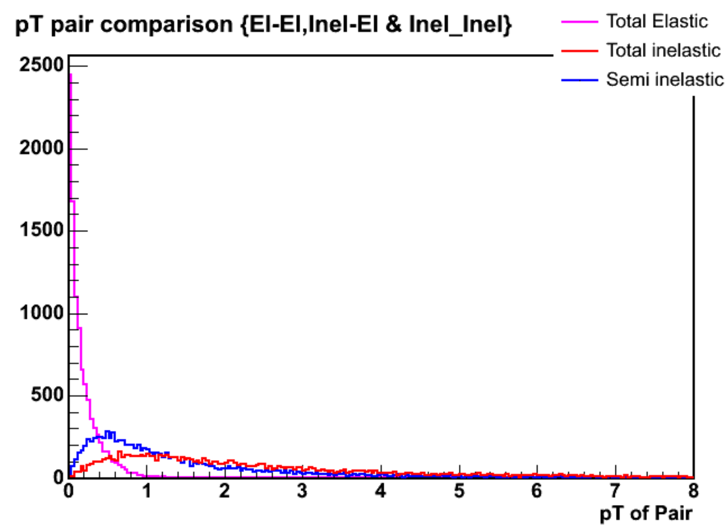
- $X = \mu\mu$ to trigger on low mass pairs
- Identify events in presence of pile up
- Scattered protons are not detected
- Distinguish from single and double proton inelastic events

Event Selection

- No other tracks from di-muon vertex
- Back-to-back in r-ϕ plane: $\Delta\phi_{\mu\mu} \approx \pi$
- No missing transverse momentum: $p_T^{\mu\mu} \approx 0$
- These are strongly correlated

LPAIR simulation, generator level only, no detector smearing





Need to distinguish the signal elastic-elastic events
from elastic-inelastic (30%) and inelastic-inelastic (10%)

Rejection of Proton Dissociative Events

- Don't rely on simulation for cut efficiency and rejection factor
- Use FSC to discriminate between the three contributions: (el-el, el-inel and inel-inel)
- Select "no-pileup" events ("empty" detector except for $\mu\mu$)
- Classify events as FSC empty both sides, one side or neither
- Compare $\Delta\phi_{\mu\mu}$ and $p_T^{\mu\mu}$ distributions for three classes
- Measures relative fraction of el-el, el-inel and inel-inel and tests factorization
- Provides templates for $\Delta\phi_{\mu\mu}$ and $p_T^{\mu\mu}$ distributions

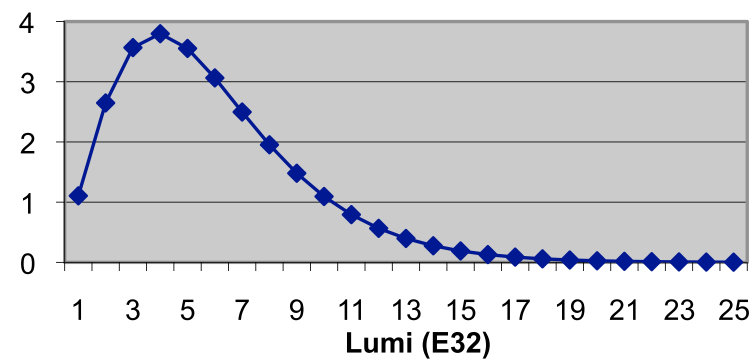
> Without FSC, precision luminosity measurement limited by knowledge of cross section for proton dissociation and associated cut kinematics.

Statistics

- Study requires collisions with no pile up events.
- Number of no pileup collisions depends on LHC run scenario
- Few if instantaneous luminosity becomes high

Effective single interaction luminosity

L_{eff} (pb^{-1}·day^{-1})



Estimate based on run scenario spanning
$L = 10^{32}$ - 10^{33} in 2011 run

$L_{\text{eff}} \approx 2$ pb^{-1}·day^{-1} $\qquad$ $\sigma_{pp\to pp\mu\mu} \approx 10$ pb

$\Rightarrow\ \approx 2000\quad pp \to pp\mu\mu$ no pileup events in 2011

Summary

CMS forward detector systems for luminosity measurements

Pixel Luminosity Telescopes (PLT)

- ≈ 1 % resolution on relative luminosity
- Systematic errors controlled by pixel information
- Long term stability
- Compatible with low luminosity running
- Installed for 2013 run (earlier if access available)

Forward Shower Counters (FSC)

- Key for $pp \to pp\mu\mu$ luminosity measurement
- Correction for proton dissociative events
- ≈ 2000 no pileup $pp \to pp\mu\mu$ events in 2011
- Installation for 2011 run