Performance of the Pixel Luminosity Telescope for Luminosity Measurement at CMS during Run2

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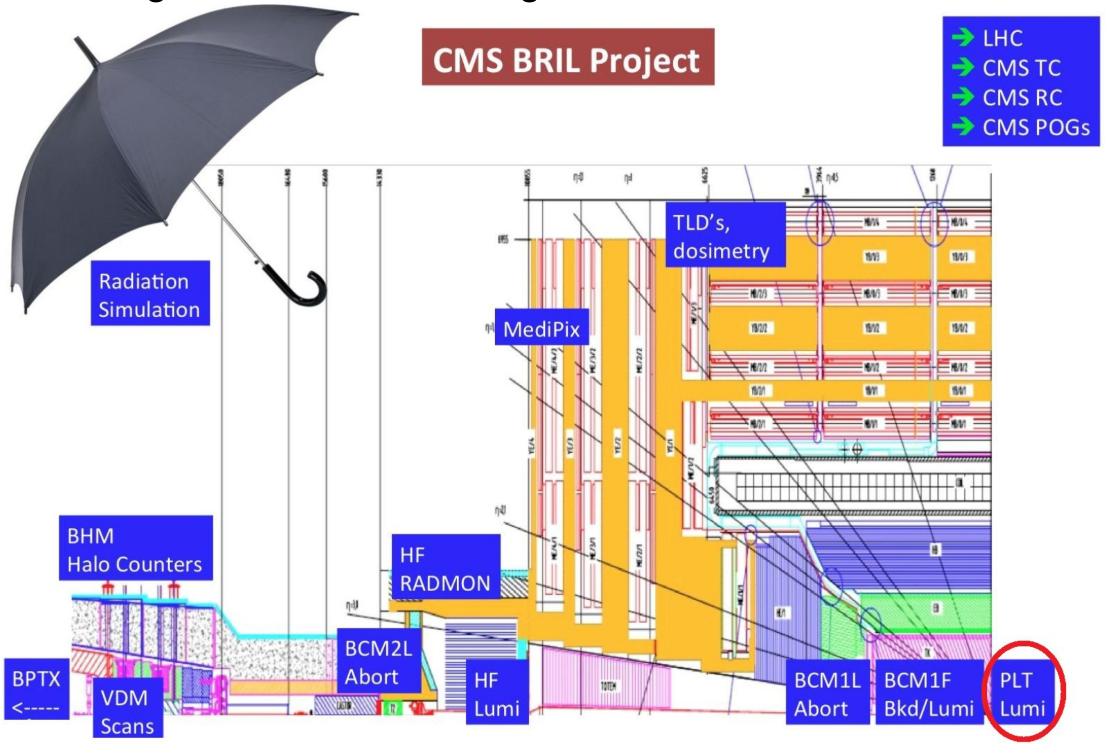
Motivations and overview

- Precision measurement of the luminosity is extremely important
  - Online: real-time feedback on LHC performance and operation
  - Offline: crucial component of every physics analysis (cross-section, coupling, upper limit, …)
- BRIL (Beam Radiation, Instrumentation, and Luminosity) group oversees luminosity measurements, beam condition monitoring, radiation monitoring and simulation

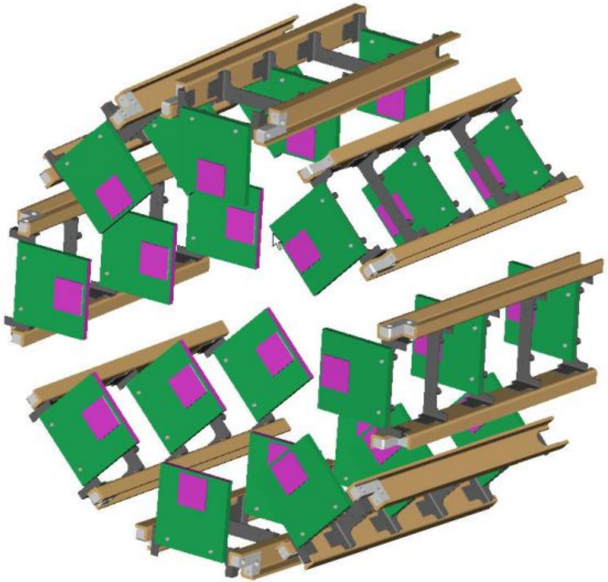


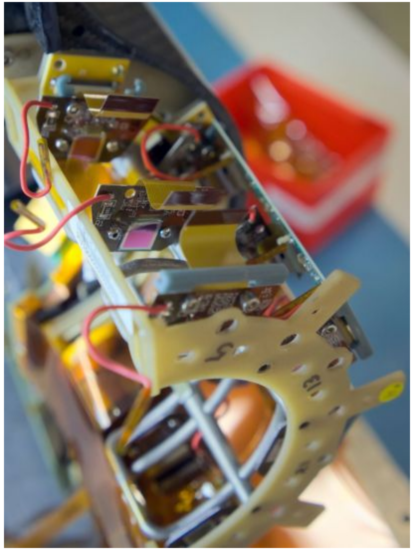
Pixel Luminosity Telescope (PLT)

- Silicon pixel detector, installed at CMS in 2015 for LHC Run2

- Located 1.75m from the IP (interaction point) at both ends of CMS ($|\eta| \approx 4.2$)

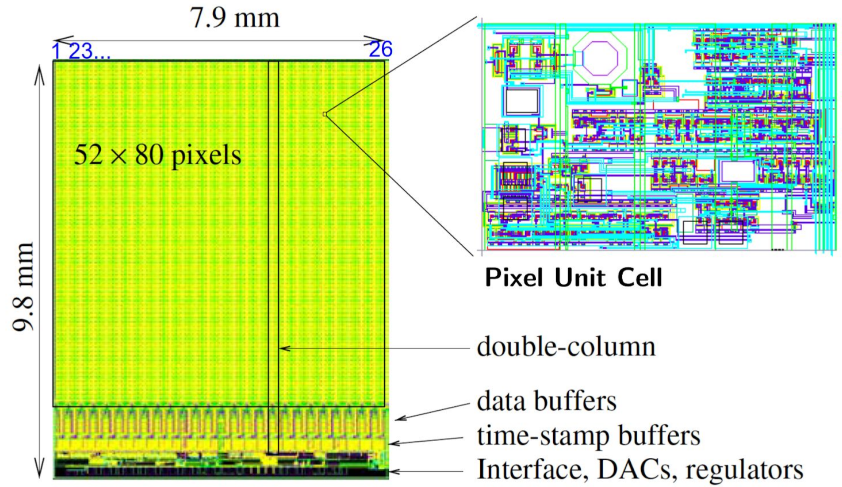
- 16 telescopes (8 one side + 8 other side of CMS)
  - Each telescope is 7.5 cm long, 5 cm away from the beam pipe, and contains 3 individual sensors
  - Sensor and PSI46v2 readout chips (ROCs) developed for the CMS phase-0 Pixel detector



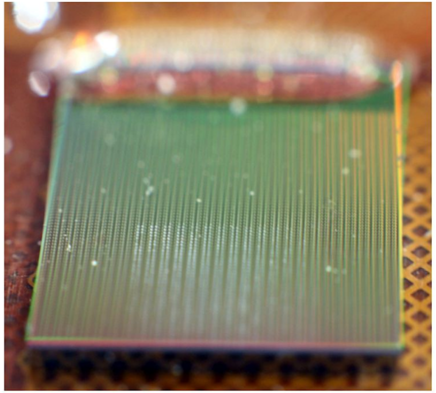


Sensor and readout chips

- n-in-n silicon sensor. Pixel size: 150 x 100 μm^2 and active thickness of 285 μm
- PSI46v2 ROC
  - records hit position and amount of charge deposited in the silicon sensor
  - time resolution of 25 ns
  - active area is an array of 52 × 80 pixel unit cells (26 double columns of 160 pixels each)



Floor plan of PSI46v2 readout chip



- ROC read out mode
  - fast-or: info on double columns with pixels above threshold in a given 25 ns bunch crossing
  - full pixel: dedicated trigger at rate of ~3 kHz for additional studies

Luminosity measurement

The PLT provides bunch-by-bunch luminosity with statistical precision of ~1% every 1.5 s

1. Detect "triple coincidences":
   events where each plane registers at least one fast-or hit

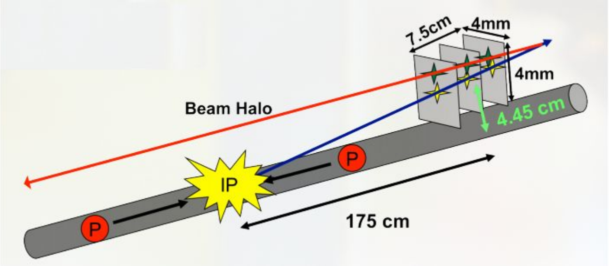
2. Use "Zero-counting" method:
   count fraction of events where no triple coincidence is found and then use L ~ -ln <p0>
   avoid systematic issues from events with two or more tracks

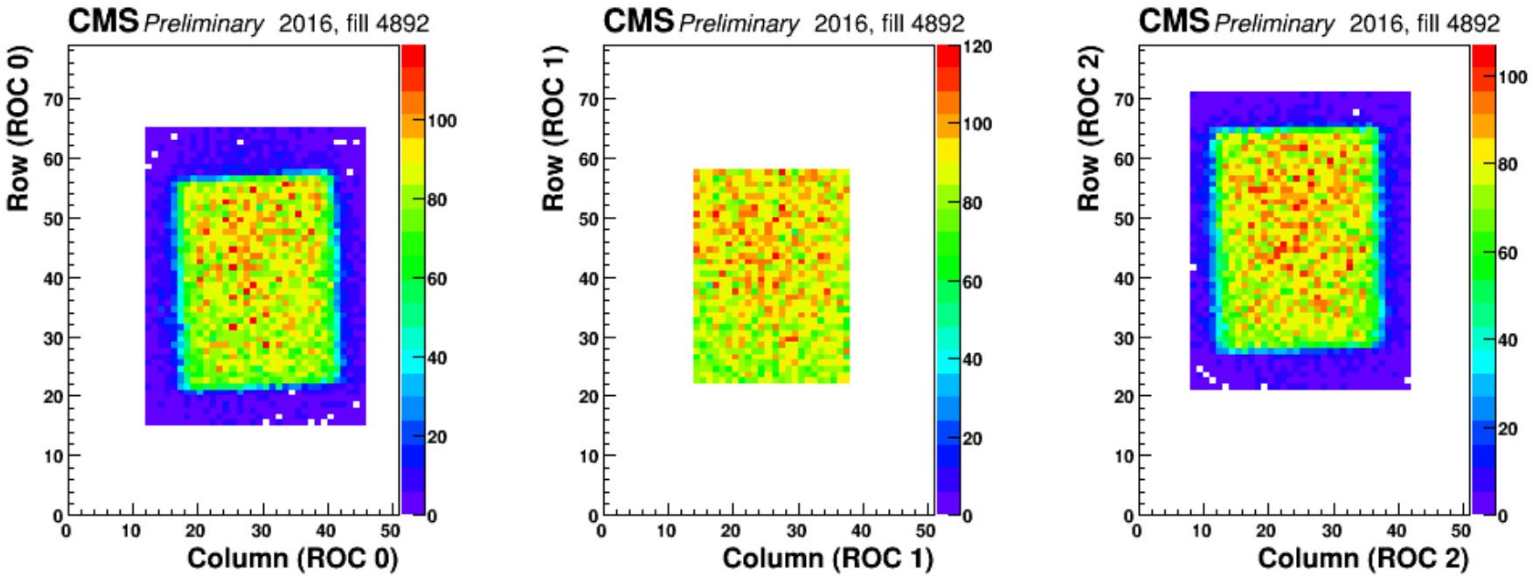
3. Calibrate with "Van der Meer" scan:
   calibrate absolute luminosity

4. Luminosity corrections:
   "accidentals" events where we have a triple coincidence but not from a real track from the IP
   (either combination of random hits, or track from other source)
   "linearity/slope": detector response

Track, occupancy, and accidentals

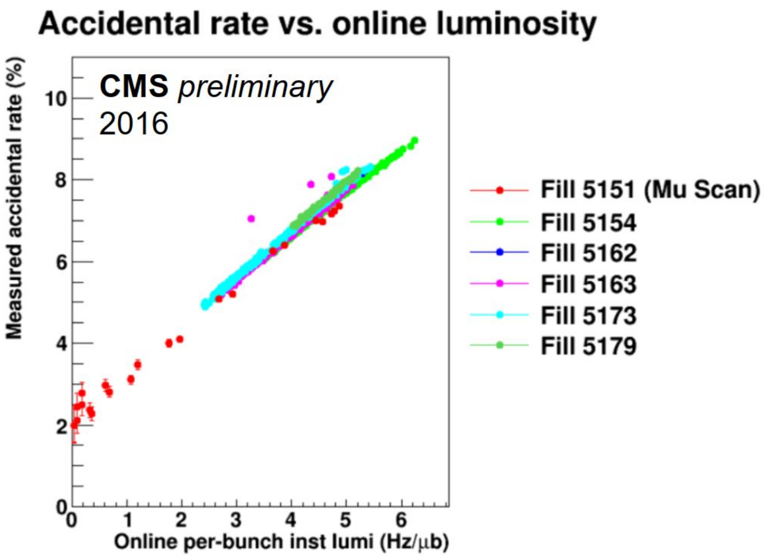
- Using full pixel readout, look at events in a single telescope, and select only hits which can be reconstructed as a single track
- The active area of the sensor planes is
  - 3.6x3.6 (3.9x3.8) mm^2 on the center (outer planes)
    -> to reduce the contribution from accidentals
  - displaced (1st, 3d) or centered (2nd)
    -> correct for alignment effects





Corrections of accidentals

- "Accidentals" are triple coincidences observed not caused by a track originating from the IP:
  - tracks from particles elsewhere (e.g., beam halo, or activated material surrounding PLT)
  - random coincidence of hits from different tracks (for example, two tracks that do not individually pass through all three planes of the PLT could combine to make a triple coincidence)
- Algorithm:
  - look at distribution of tracks in reconstructed slopes
  - measure the mean slope and fit residual
  - reject any track more than 5 standard deviations away from the mean



Van der Meer scan

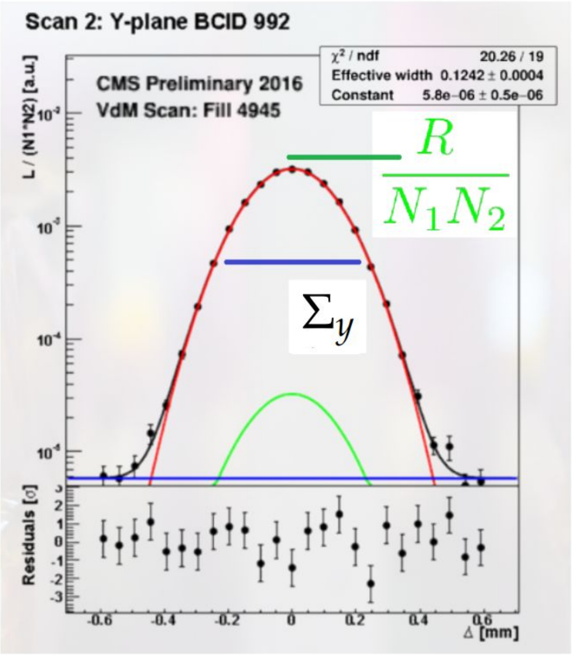
The luminosity is calibrated with σ_{vis} measured with the Van der Meer scan

- Assume beams with a Gaussian profile $L = \overbrace{N_1 N_2}^{\text{beam intensities}} \underbrace{\nu_{orb}}_{\text{orbit frequency}} \overbrace{N_b}^{\text{\# of colliding bunches}} / 2\pi \underbrace{\Sigma_x \Sigma_y}_{\text{effective beam sizes}}$

- Gradually vary beam separation in X and Y directions

- The resulting luminosity curve is fit with
  a double (2016, 2017) or single (2018) Gaussian, and
  the background either modelled with a constant term (2016),
  or subtracted (2017, 2018)

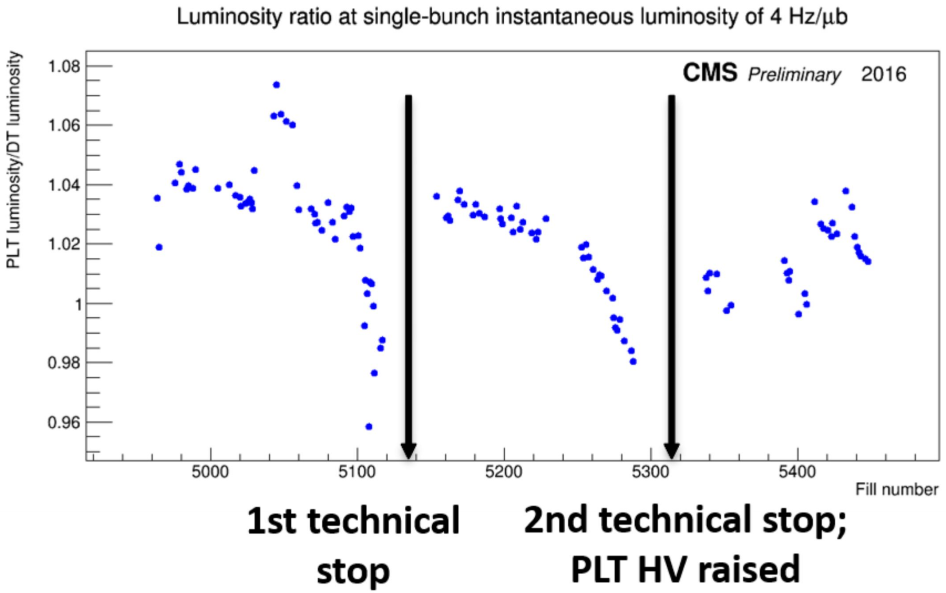
  $\sigma_{vis} = R/N_1N_2\, 2\pi\, \Sigma_x\, \Sigma_Y / \nu_{orb}$
  N_1N_2 provided by LHC
  from fit extract
  - peak: R/N_1N_2
  - profile width: Σ_x and Σ_Y



Relative rate monitoring, and detector performance

- PLT rates are periodically compared to other CMS luminosity detectors
- Relative change in measured rates between detectors can be indicative of issues, e.g. radiation damage from accumulated dose

Ratio of PLT luminosity to luminosity from muon rate in the drift tubes (DT) per fill at a given single-bunch instantaneous luminosity (SBIL)



- Drop in ratio resulted from increased radiation damage and mitigated by
  - increase in HVs (2016-2017)
  - adjust the thresholds used in the PLT readout chips to determine hit pixels (2018)

Corrections due to detector performance

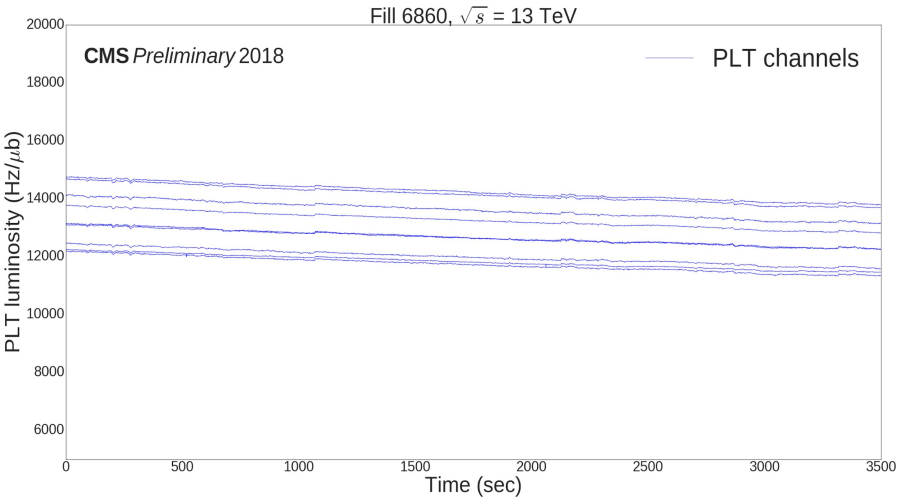
Ideal luminometer would have a perfectly linear response as a function of the instantaneous luminosity with a single calibration constant relating the two. In reality, need to take into account corrections for:

- linearity (Slope)
- efficiency (Eff)

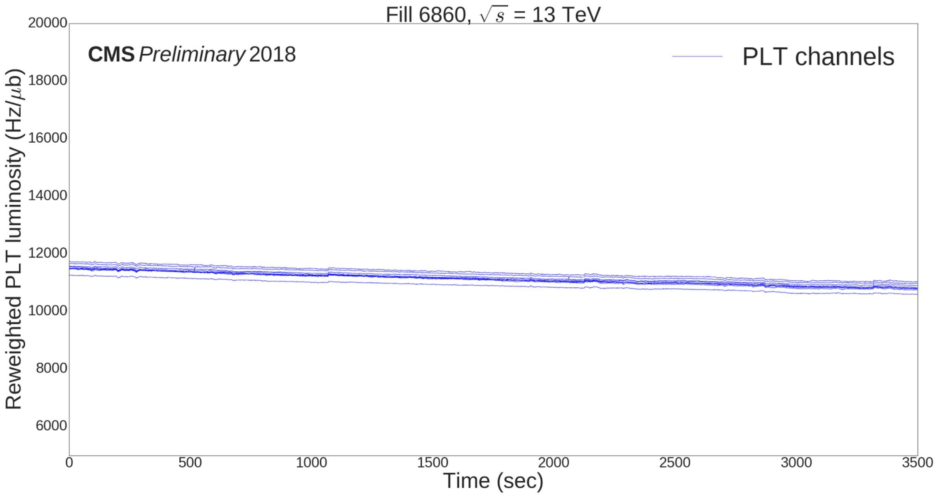
Use emittance scans (ES) (mini Van der Meer scans at the beginning and end of a fill)

- linearity: σ^{ES}_{vis} vs SBIL as individual bunches within a single fill can exhibit substantially different SBIL
- efficiency: $\sigma^{ES}_{vis}/\sigma^{vdM}_{vis}$
- Linearity and efficiency corrections are applied channel by channel, and weights are measured separately for leading and training bunches: $\mathrm{SBIL_{corr}} = (\mathrm{SBIL_{raw}}/\mathrm{Eff}) - (\mathrm{SBIL_{raw}}/\mathrm{Eff})^2 \cdot \mathrm{Slope}/100$

No correction applied



Correction applied (much better agreement across channel)



Conclusions

- Luminosity measurement very important at CMS
  Luminosity studies under BRIL group, which includes several dedicated detectors

- Pixel Luminosity Telescope luminometer has been operating successfully during the LHC Run2

- PLT provides online and offline luminosity measurement with high precision

- With the current Long Shutdown 2, PLT is under upgrades to substitute ROCs, sensors, and other components close to their expected end-of-life, mainly due to radiation damage

- Look forward to excellent data-taking within LHC Run 3 at CMS

Back up slides

Readout scheme for a single PLT quarter