BND Graduate School
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Luminosity measurements at the LHC

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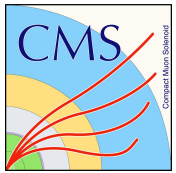


Luminosity

- measure of collision rate

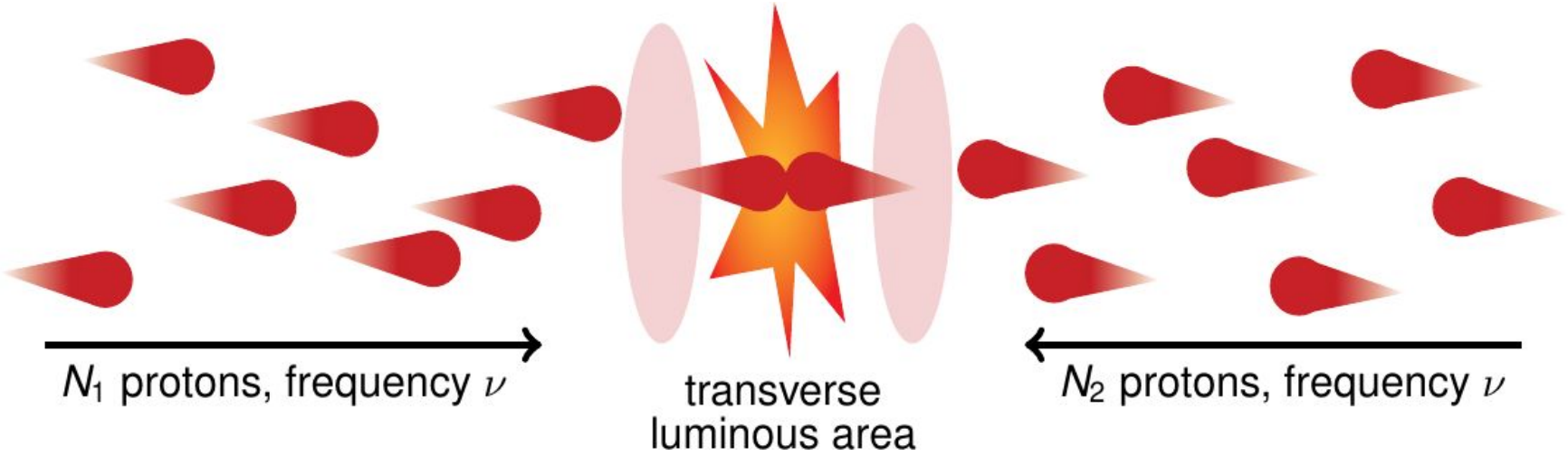
$$\frac{dN}{dt}(pp \to X) = \mathcal{L} \cdot \sigma(pp \to X)$$

- key accelerator parameter next to center-of-mass energy

- luminosity from beam parameters

$$\mathcal{L} = \frac{\nu N_1 N_2}{A_{\text{luminous}}}$$

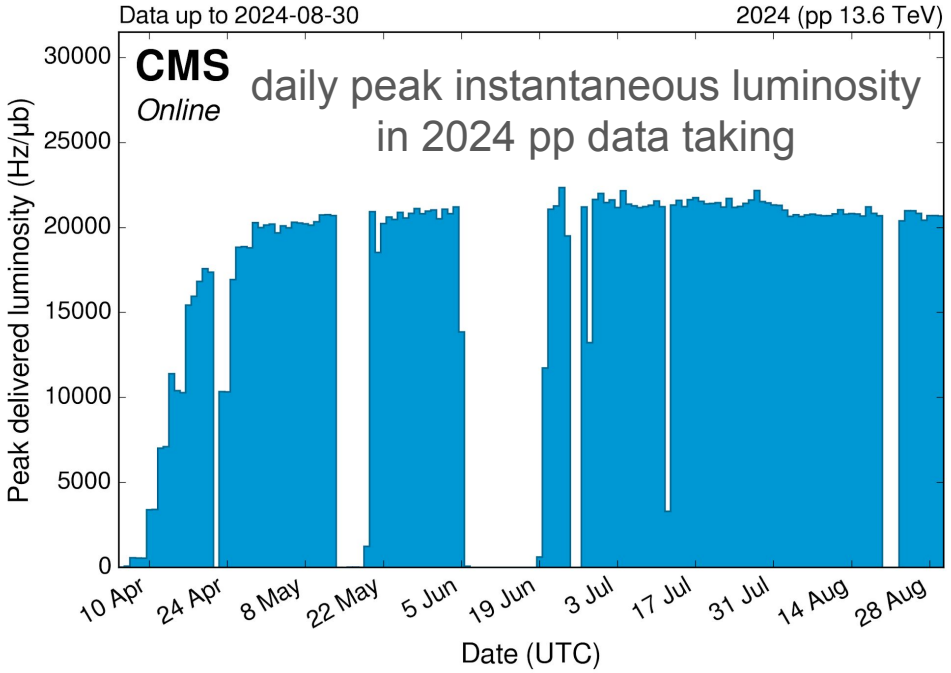
- difficult to estimate A_{luminous} in regular data-taking conditions



Instantaneous luminosity

$$\frac{dN}{dt}(pp \to X) = \mathcal{L} \cdot \sigma(pp \to X)$$

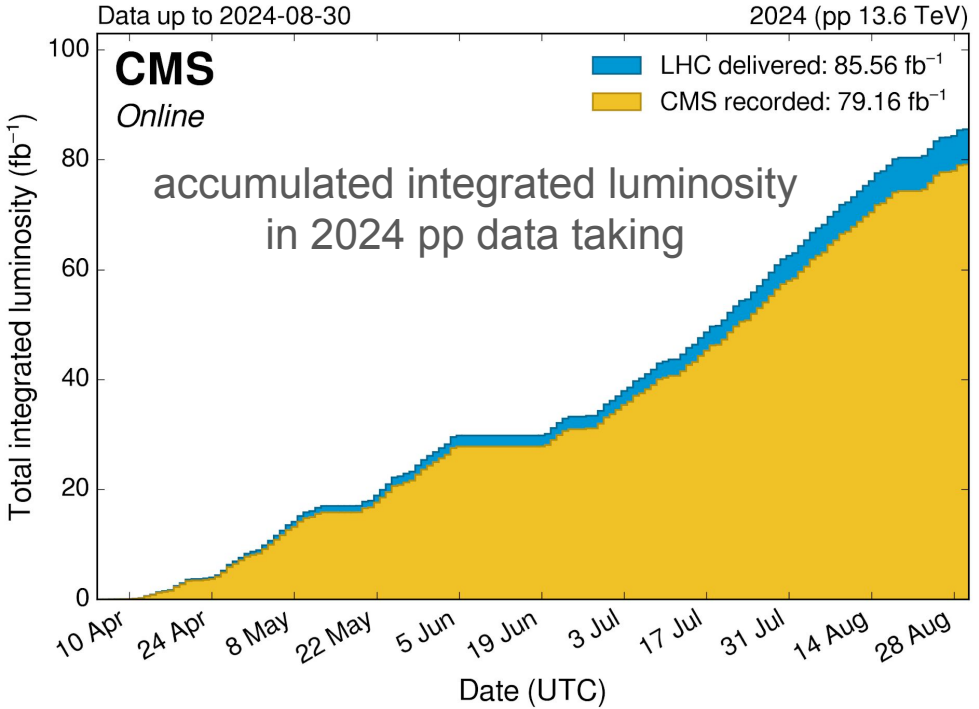
- units: “per luminous area per time”
  - $cm^{-2}\ s^{-1}$ or Hz/μb
- convert to “number of pp collisions per time” by multiplying with total inelastic cross section
  - CMS value: 69.2 mb
- example: 2024 pp data taking
  - peak instantaneous luminosity: 22.4 Hz/nb
  - pp collision rate: 1550 MHz, or 39 collisions every 25 ns
  - σ(tt̄) = 924 pb, thus 21 tt̄ events per second



LumiPublicResults

Integrated luminosity

- units: “per luminous area”
  - cm^{-2} or fb^{-1}
- instantaneous luminosity integrated over time of data taking
- quantifies the amount of data
  - *delivered* by the LHC
  - *recorded* by the CMS
  - differences: detector problems, trigger deadtime
- example: 2024 pp data taking
  - integrated luminosity so far: 85.6/fb
  - more than 79 million $t\bar{t}$ events so far



Importance of luminosity

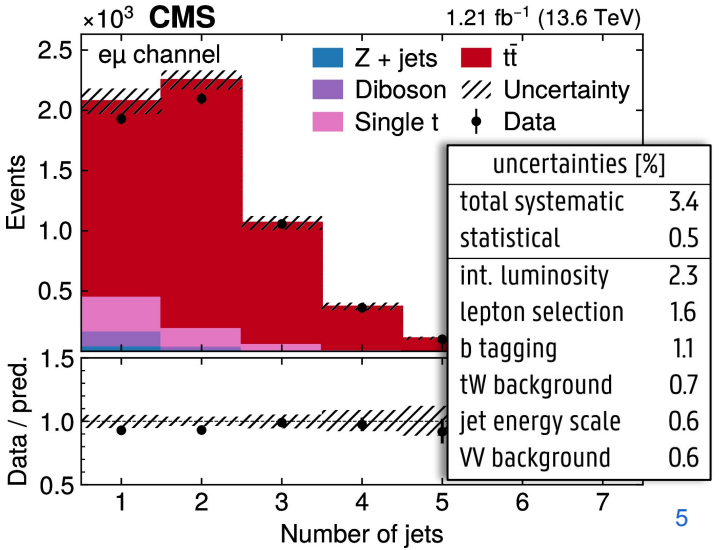
Instantaneous luminosity:

- significant performance parameter for accelerator
- critical for beam tuning and collision optimization
- essential for trigger system (scale or throttle data throughput)

Integrated luminosity:

- uncertainty on luminosity is systematic uncertainty in (almost) all CMS analyses
- dominant uncertainty in precision cross-section measurements (e.g. Drell−Yan, tt̄)

first measurement of the tt̄ cross section at 13.6 TeV, [JHEP 08 (2023) 204]



CMS luminosity detectors

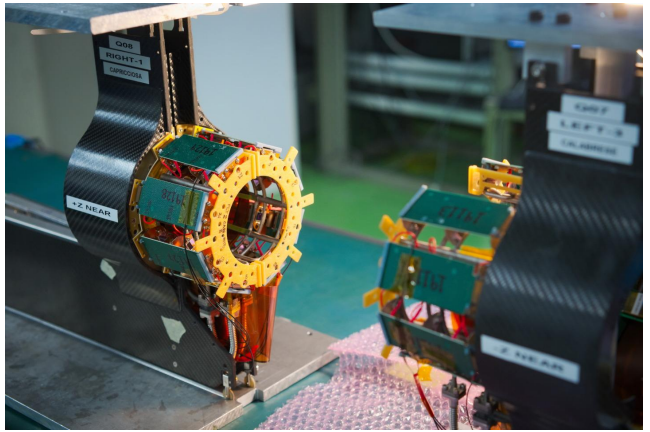
2 dedicated systems, both at z ≈ ±1.8m from the interaction point and radius ≈ 6 cm:

- Fast Beam Condition Monitor (**BCM1F**)
  - C-shaped PCBs with 2 rings at each side of CMS, silicon sensors
  - High time resolution (6.25 ns per bin)
- Pixel Luminosity Telescope (**PLT**)
  - 16 total (8 at each side of CMS)
  - Fast cluster-counting signal (40 MHz)

“Regular” detectors also used for luminosity measurements:

- Hadronic Forward (**HF**) calorimeter
  - Steel absorber with quartz fibers
- and others

BCM1F

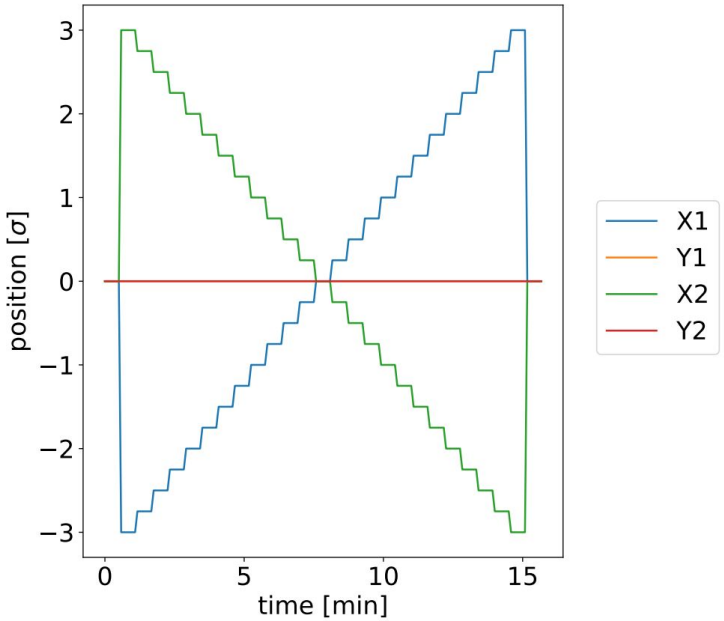


PLT

Van der Meer method

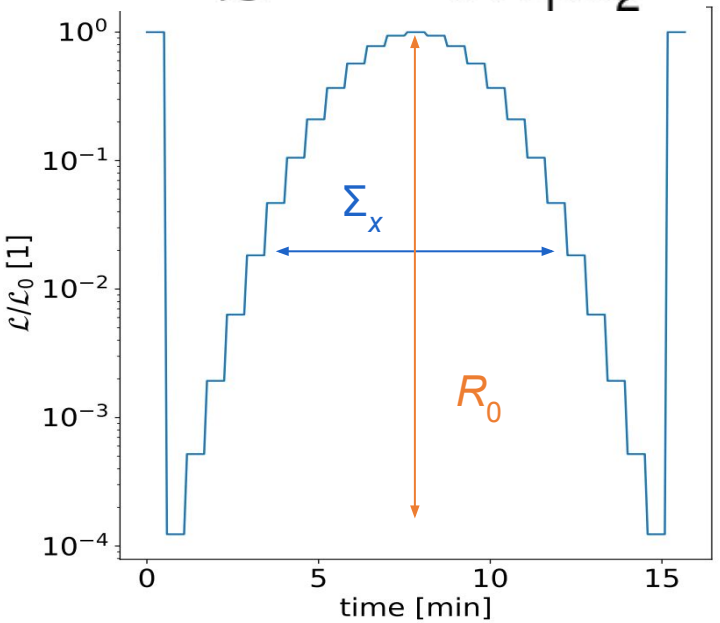
- luminous area from two orthogonal beam-separation scans:

$$A_{\text{luminous}} = 2\pi\Sigma_x\Sigma_y$$



- calibration of detector-specific “visible” cross section:

$$\sigma_{\text{vis}} = \frac{R_0}{\mathcal{L}} = \frac{2\pi\Sigma_x\Sigma_y R_0}{\nu N_1 N_2}$$



Project overview

- Measure instantaneous & integrated luminosity for four LHC fills recorded in 2024:
  a. Analyze short scans performed at the start of each fill to calibrate detector.
  b. Integrate measured rate and normalize with calibration constant.

- Different groups will use different detectors for the luminosity measurement.

- Additional tasks: study systematic effects and their impact on the precision of the luminosity measurement (per-bunch calibration, beam currents, beam positions).

- Who can provide the most precise luminosity measurement?