Luminosity and heavy-ion physics

Lizardo Valencia Palomo

Meeting

22/05/2024

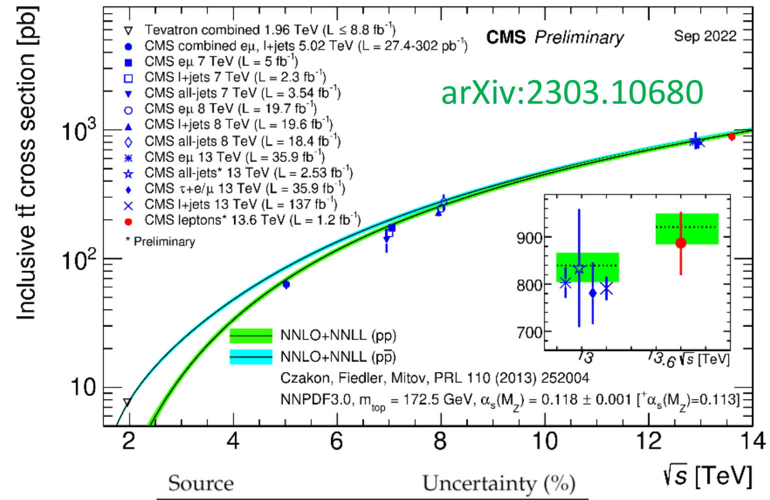
Luminosity

Main parameters in particle colliders: center of mass energy ($\sqrt{s}$) and luminosity ($\mathcal{L}$).

Real time luminosity needed by experiments and colliders to optimize data taking conditions.

Cross section measurements directly related to integrated luminosity ($L_{int} = \int_0^T \mathcal{L}\, dt$).

Precise determination of luminosity needed to constraint Standard Model (SM) predictions or unveiling beyond SM physics.



Source	Uncertainty (%)
Lepton ID efficiencies	1.6
Trigger efficiency	0.3
JES	0.7
b tagging efficiency	1.1
Pileup reweighting	0.5
ME scale, $t\bar{t}$	0.6
ME scale, backgrounds	0.1
ME/PS matching	0.1
PS scales	0.3
PDF and α_S	0.3
Single t background	1.0
Z+jets background	0.3
W+jets background	0.0
Diboson background	0.5
QCD multijet background	0.3
Statistical uncertainty	0.5
Combined uncertainty	2.6
Integrated luminosity	2.3

arXiv:2303.10680

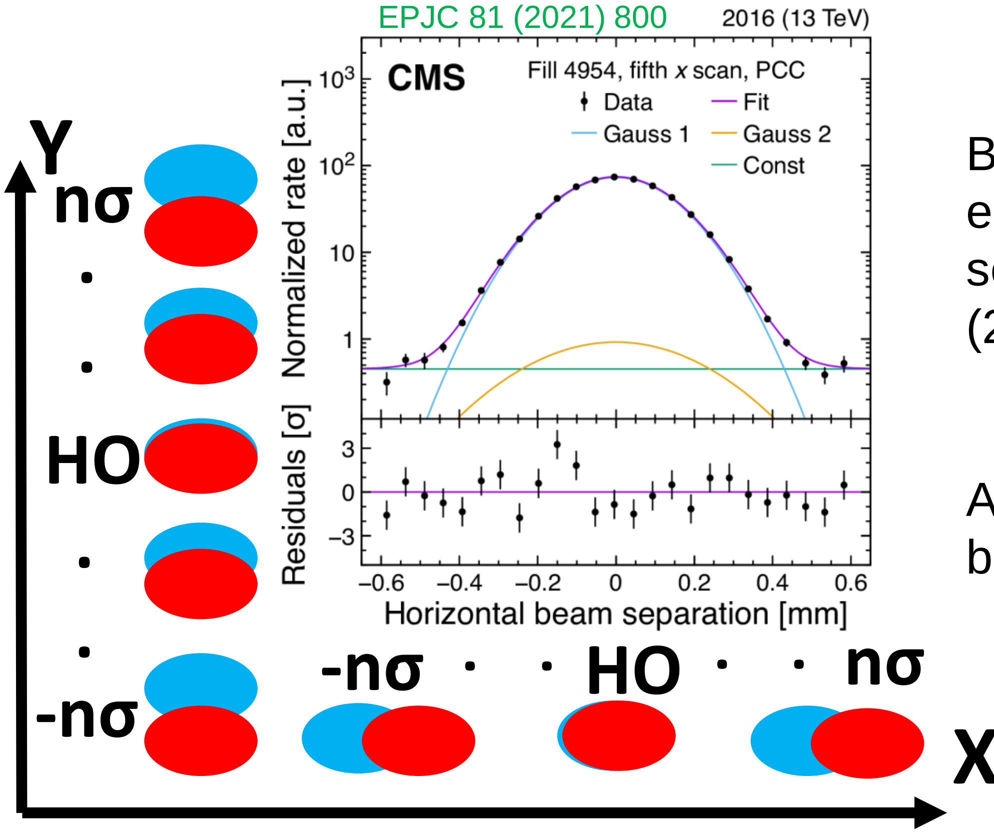
van der Meer method

Experimentally, $\mathcal{L}$ is measured as a ratio of R_{peak} and σ_{vis}

$$\mathcal{L} = \frac{R_{peak}}{\sigma_{vis}}$$

Measured with van der Meer (VdM) scans

$$\sigma_{vis} = \frac{2\pi\Sigma_x\Sigma_y}{N_1 N_2 \nu} R_{peak}$$



EPJC 81 (2021) 800

Beams are collided transversely across each other. Rates as a function of separation provide the luminous area $(2\pi\Sigma_x\Sigma_y)$ A_{eff}.

Accelerator dependent parameters: beam currents (N_i) and frecuency (ν).

Run 2 pp collisions at 13 TeV

Relative (%) systematic uncertainties in σ_{vis}

Source	2015	2016	2017	2018
L_{int}(fb^{-1})	2.27	36.3	41.5	59.8
Total uncertainty	1.6	1.2	2.3	2.5

2015 & 2016: EPJC 81 (2021) 800

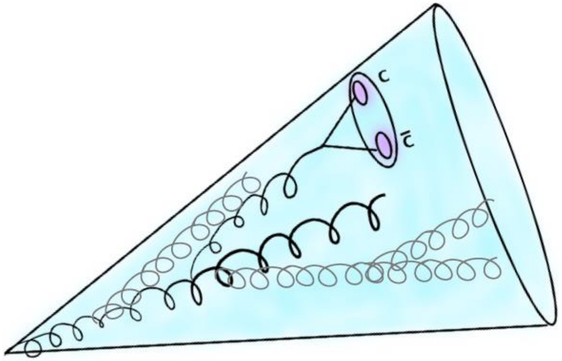
2017: CMS-PAS-LUM-17-004

2018: CMS-PAS-LUM-18-002

Currently involved in:

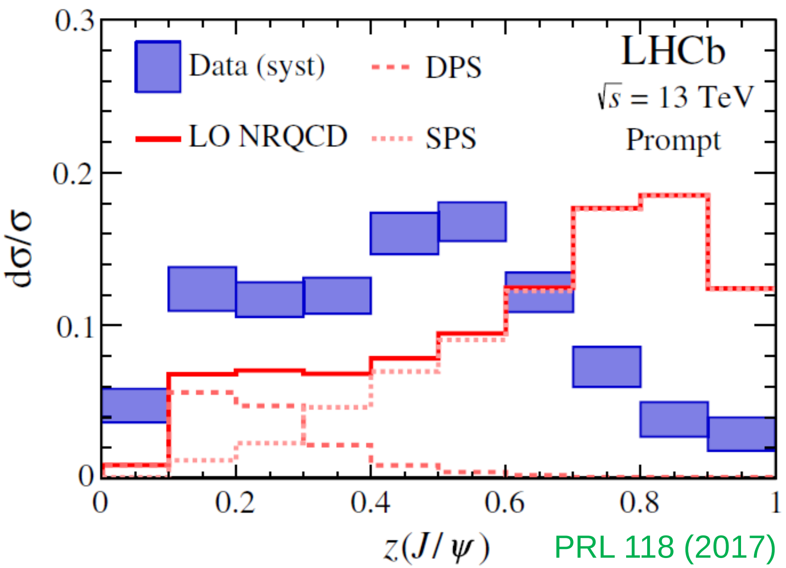
1. Run 2 legacy luminosity: aiming for 1% uncertainty in 2017 & 2018.
2. 2023 heavy-ion period and 2024 proton-proton collisions.

Quarkonium in jets



Quarkonium production not fully understood yet: models can not describe, simultaneously the different observables (pT, multiplicity, rapidity, etc. dependence).

LHCb paper reports prompt J/ψ production in jets

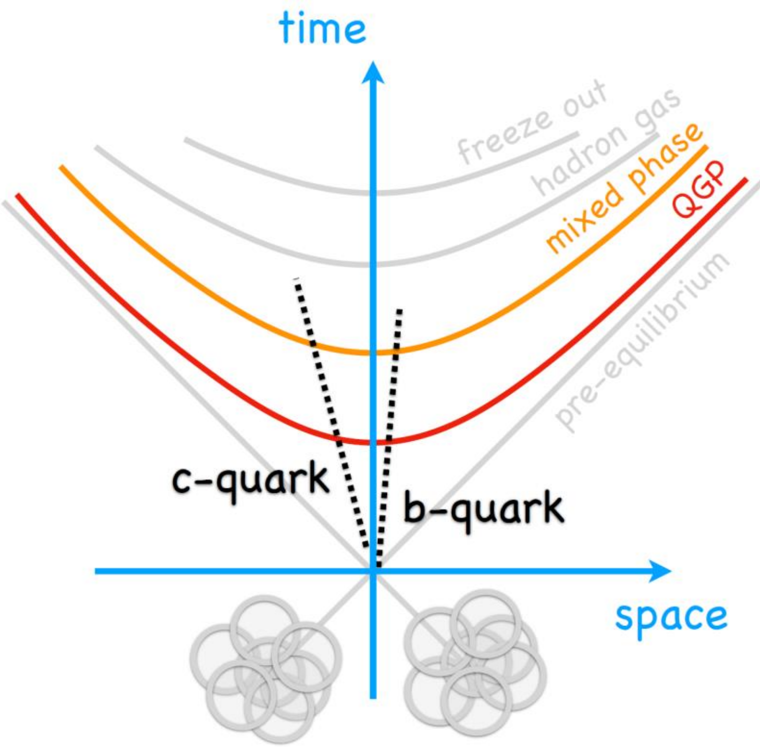


PRL 118 (2017) 192001

z = (J/ψ pT) / (jet pT)

Prompt J/ψ are produced with far more jet activity tan predicted by models.

Quarkonium in jets

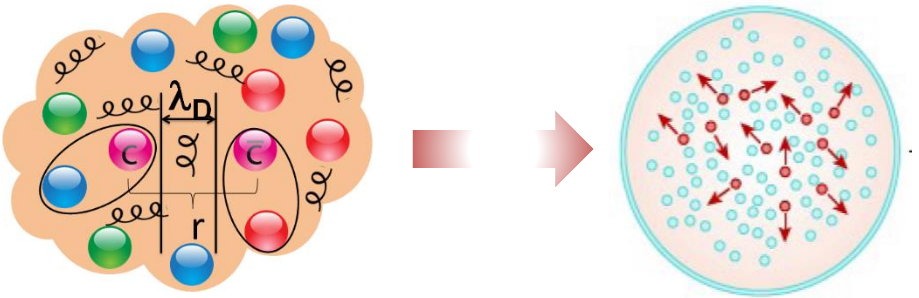


Quarkonium:

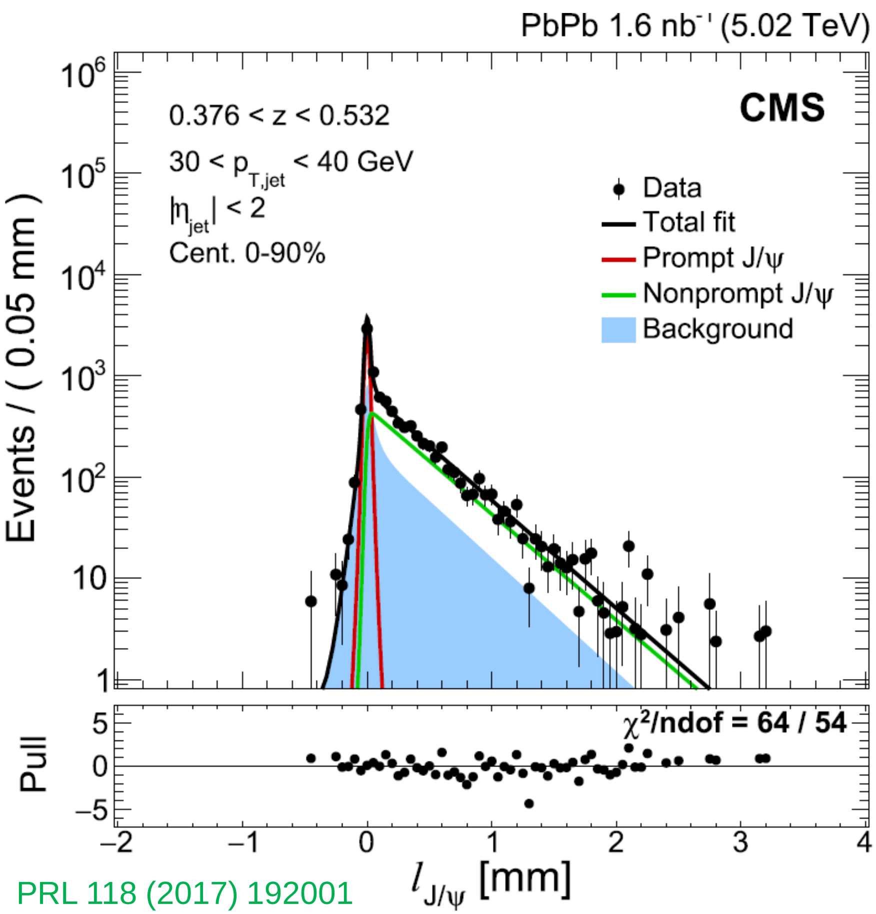
- Dissociation due to Debye screening.
- Modification of spectral properties.

Competing mechanisms for HF hadronization.

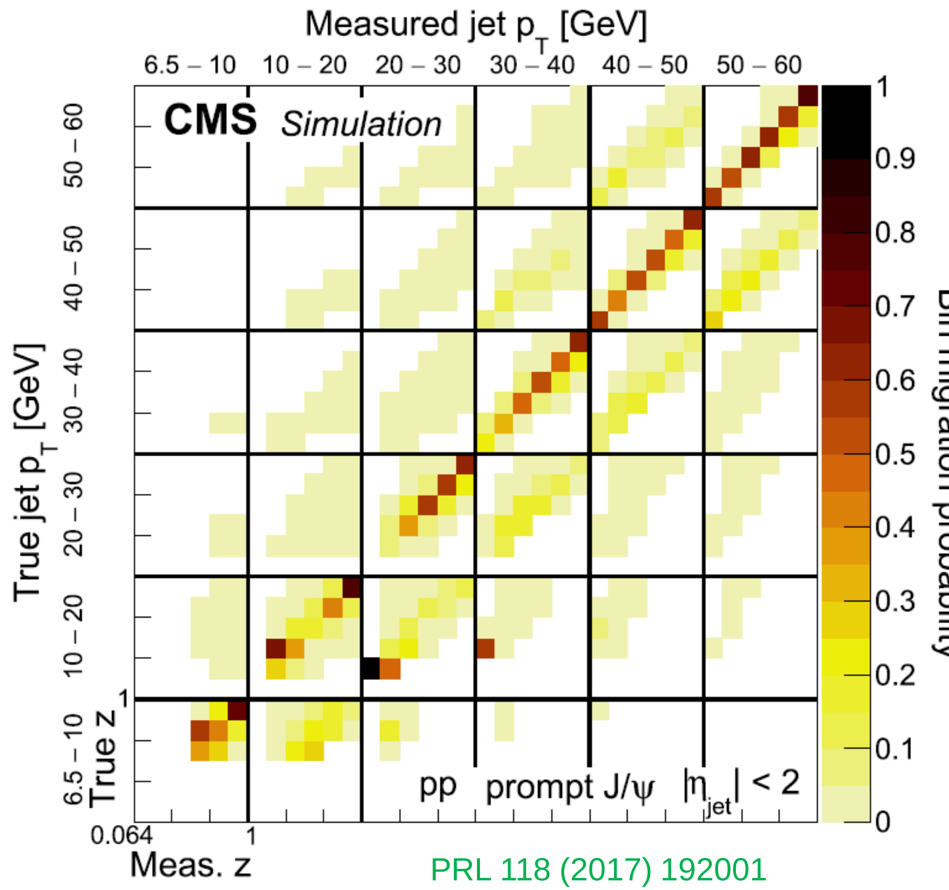
- Fragmentation: presence of QGP modifies fraction of parton momentum taken by the hadron. Dominant at high-p_T.
- Coalescence: partons close in phase space can recombine into hadrons. Effective at low-p_T.



Quarkonium in jets



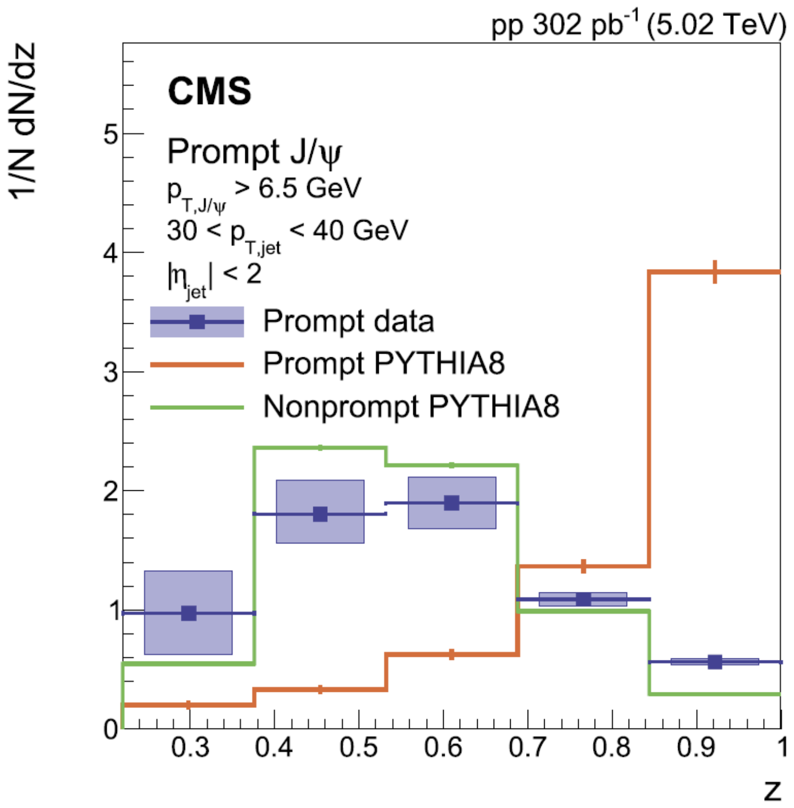
PRL 118 (2017) 192001



PRL 118 (2017) 192001

Pseudoproper decay length fit and detector response matrix for jets.

Quarkonium in jets

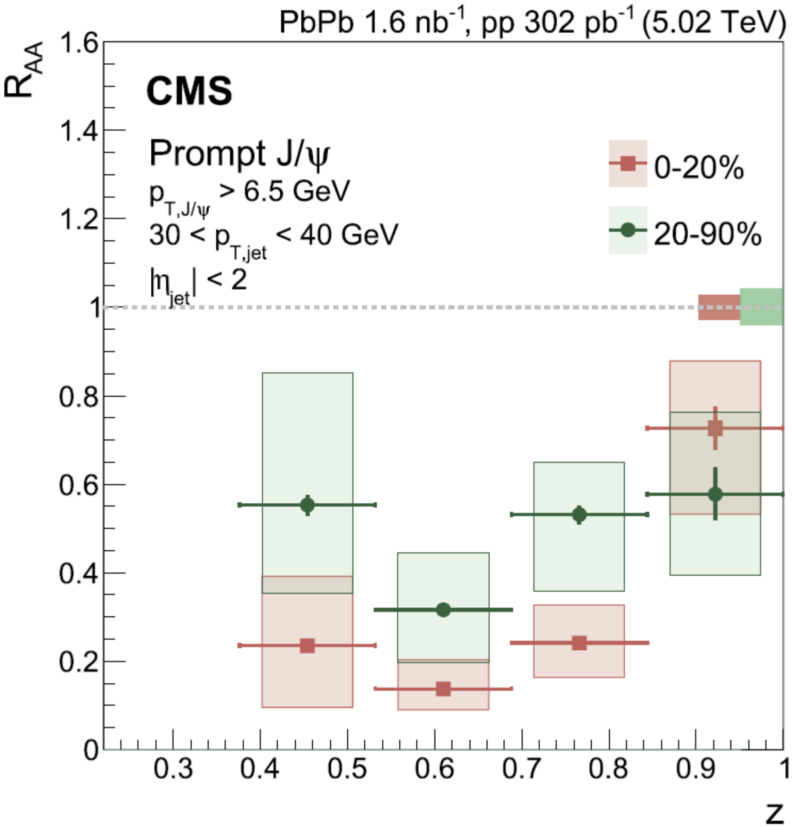


Prompt J/ψ production in a relatively large degree of surrounding jet activity.

Indication of J/ψ created inside parton showers.

Clear disagreement between Pythia 8 and data, in particular for z ≈ 1. Indeed, better description from non-prompt Pythia 8.

Quarkonium in jets



Prompt J/ψ production in a relatively large degree of surrounding jet activity.

Indication of J/ψ created inside parton showers.

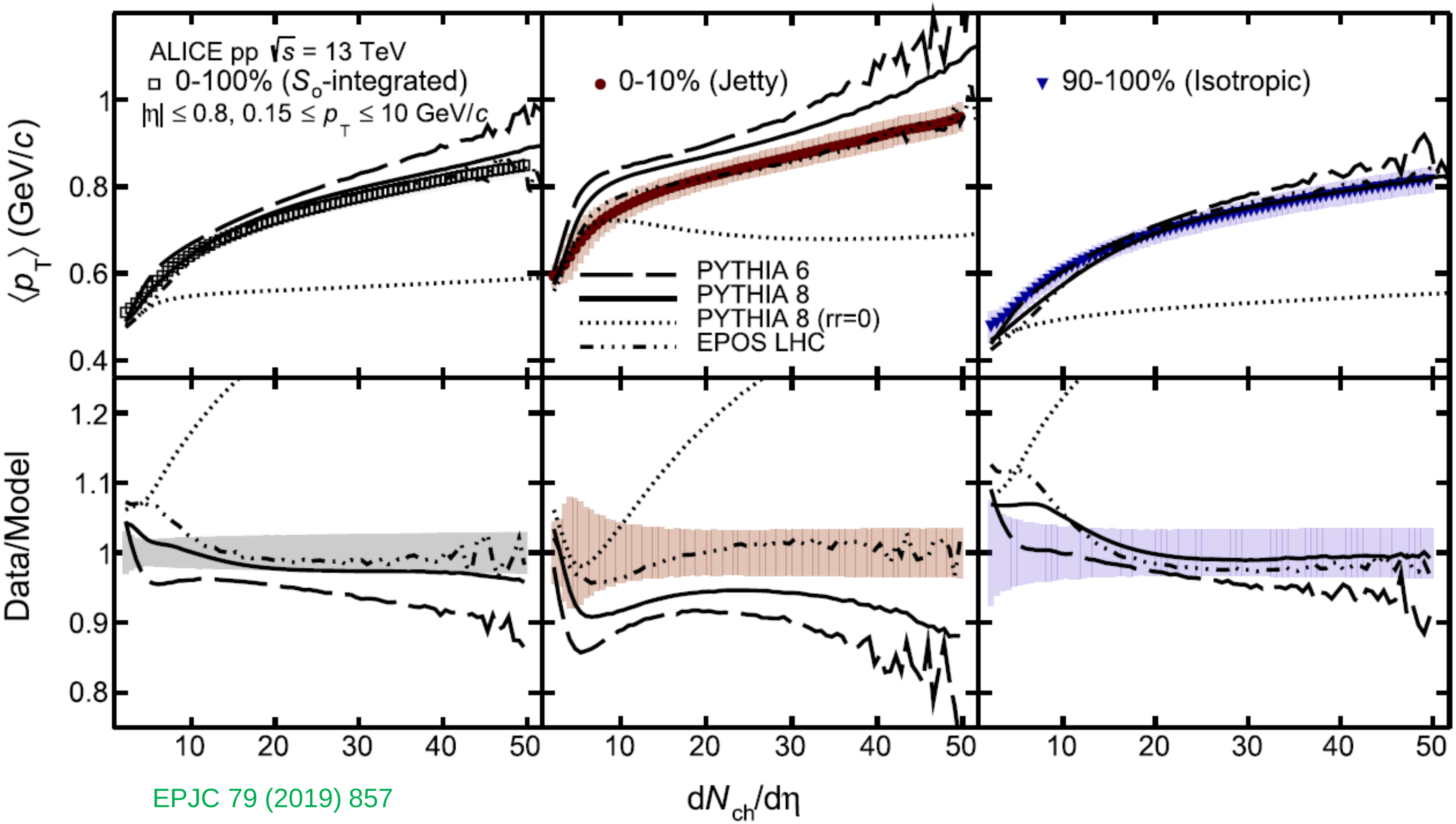
Clear disagreement between Pythia 8 and data, in particular for z ≈ 1. Indeed, better description from non-prompt Pythia 8.

Clear supression in Pb-Pb collisions, increasing trend towards z ≈ 1.

Hint of larger suppression for more central collisions, as expected.

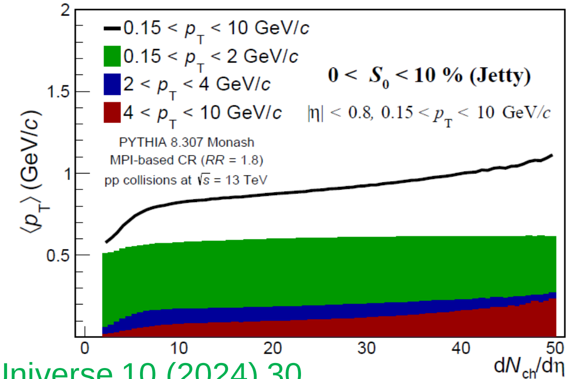
Currently: fragmentation of jets containing Upsilon (1S)

Outside CMS Collaboration

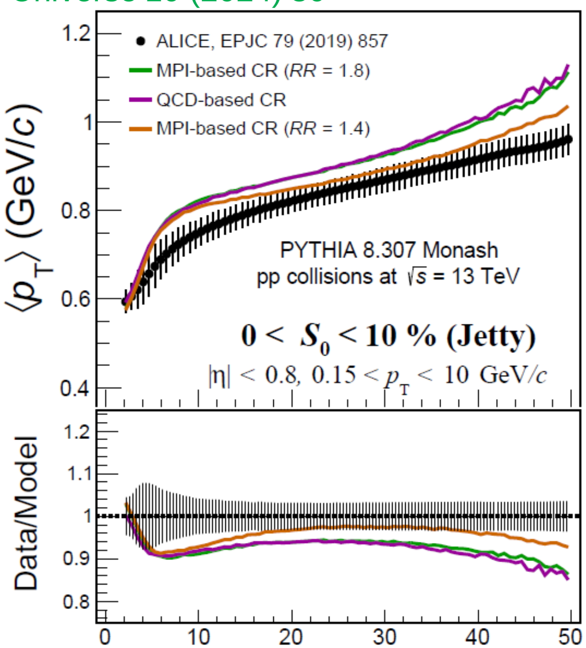


EPJC 79 (2019) 857

Outside CMS Collaboration



Universe 10 (2024) 30



Universe 10 (2024) 30

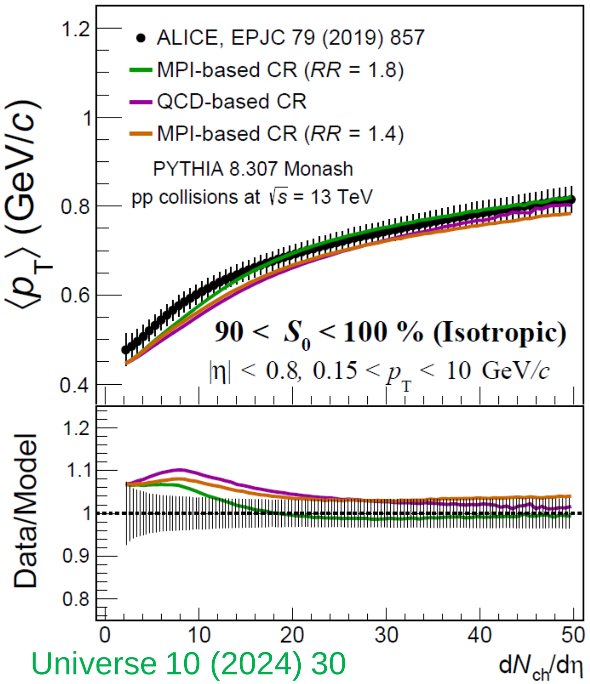
Colour Reconnection (CR): allows the interaction among partons from originally non-correlated MPI, implying a rich colored topology.

CR is governed by the Reconnection Range (RR) parameter.

Jetty events at high multiplicities: shape dominated by high-pT particles.

Decreasing the RR generates a better description of the data.

Outside CMS Collaboration



Universe 10 (2024) 30

Colour Reconnection (CR): allows the interaction among partons from originally non-correlated MPI, implying a rich colored topology.

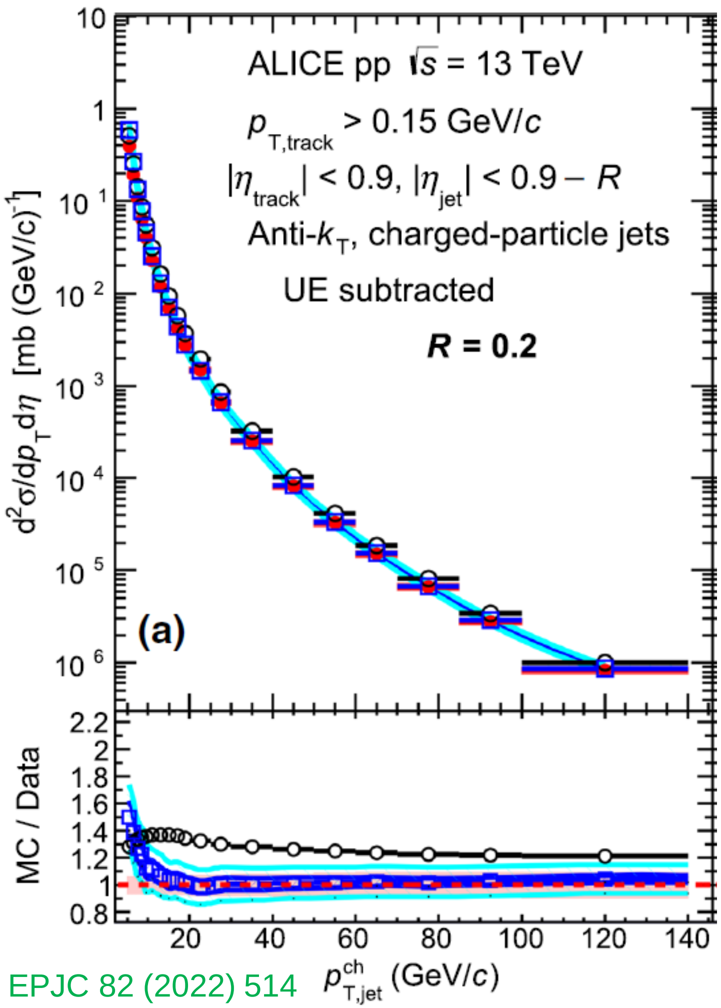
CR is governed by the Reconnection Range (RR) parameter.

Jetty events at high multiplicities: shape dominated by high-pT particles.

Decreasing the RR generates a better description of the data.

But this also affects the isotropic distribution. Albeit still within the uncertainties of the data.

Outside CMS Collaboration



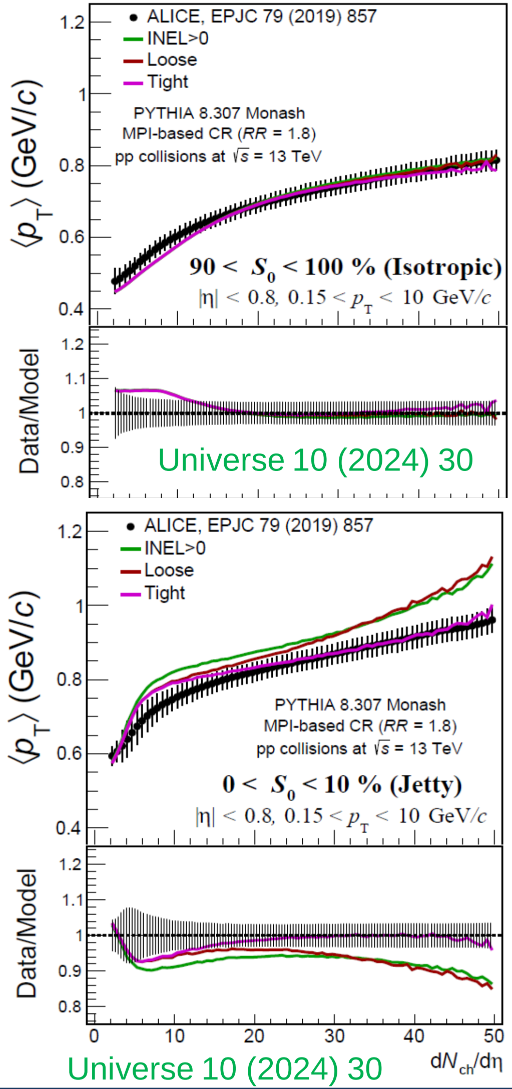
EPJC 82 (2022) 514

Pythia 8 already known to overestimate the differential cross section of jet production.

Idea: quantify this excess and subtract it to Pythia 8.

Loose or tight selection: remove only one jet or all.

Outside CMS Collaboration



Pythia 8 already known to overestimate the differential cross section of jet production.

Idea: quantify this excess and subtract it to Pythia 8.

Loose or tight selection: remove only one jet or all.

No modification on the isotropic prediction.

Jetty: small improvement with loose selection but a very good description of the data if tight cut is applied.

Summary

Developing physics analysis but also technical work within the CMS collaboration.

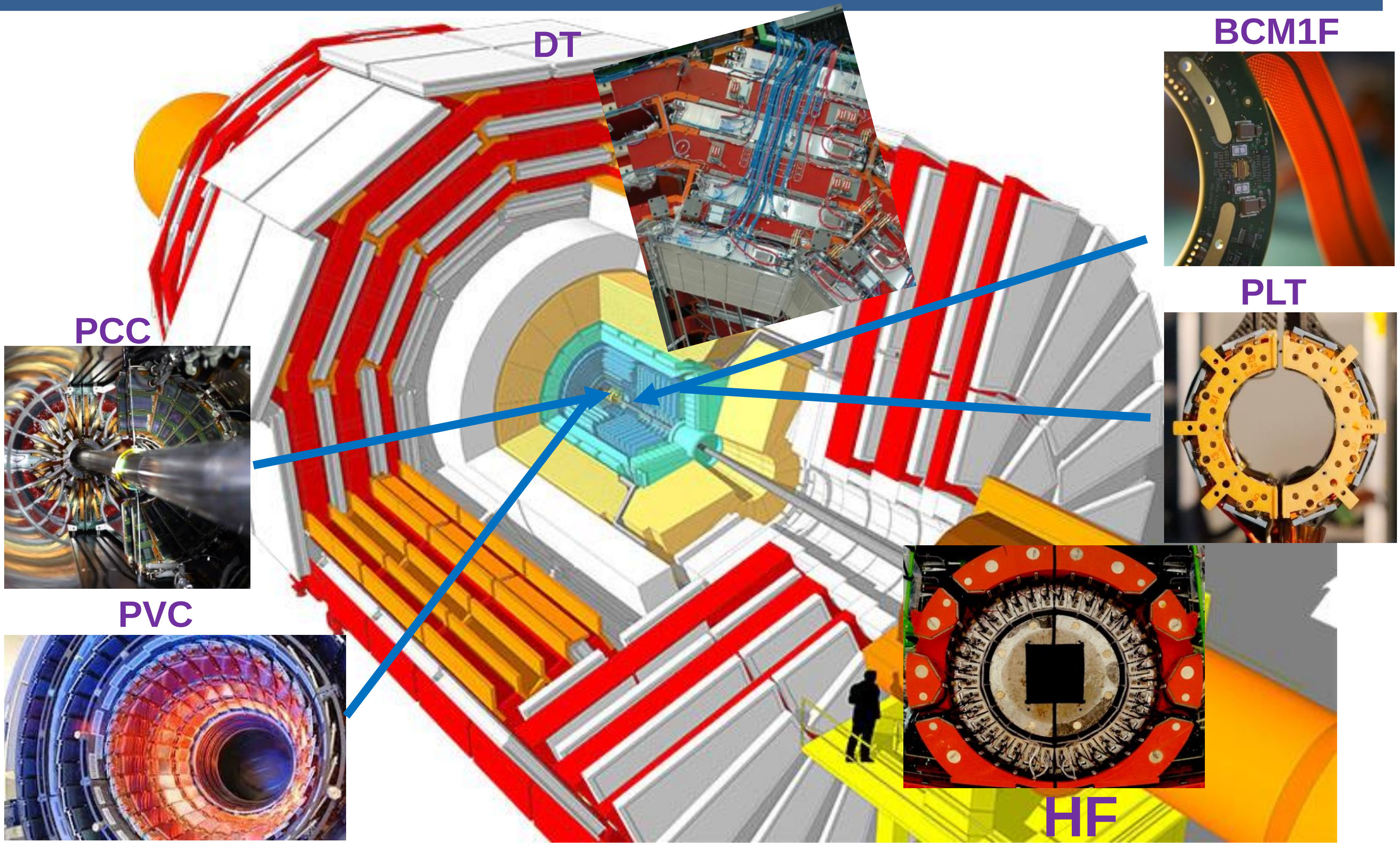
Different studies are still on going, stay tuned for new results soon.

Research not limited to the CMS collaboration, important phenomenology activities using published results.

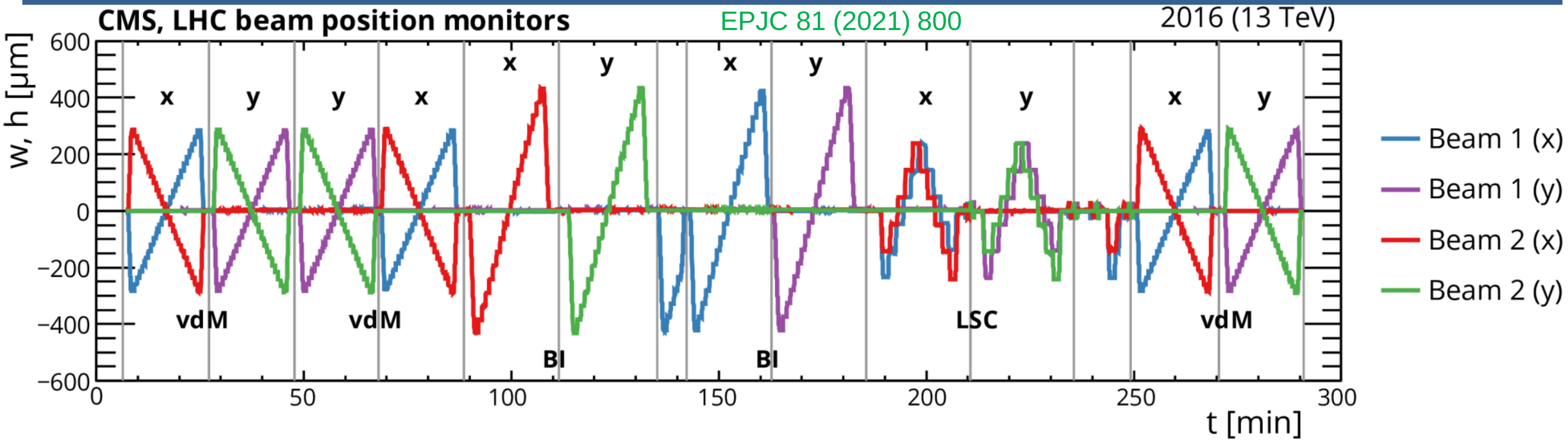
Thanks for your attention

Backup

Luminometers



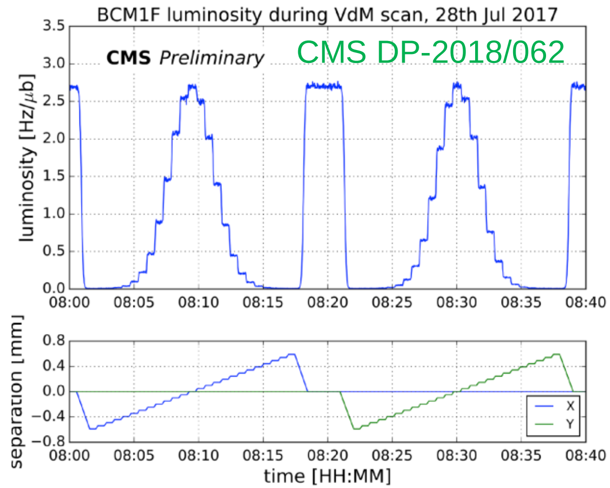
van der Meer scans: 2016 example



VdM scans: beams move 25 steps, 30 secs each, from $\pm6\sigma_{beam}$.

Beam imaging (BI) scans: one beam fixed and the other moves 19 steps of 40 secs over $\pm4.5\sigma_{beam}$.

Length Scale Calibration (LSC): both beams separated by $1\sigma_{beam}$ move together in $1\sigma_{beam}$ steps from $\pm2\sigma_{beam}$ position and then repeat from $-1\sigma_{beam}$ separation. In total 5+5 steps of 60 secs each.



Beam intensities

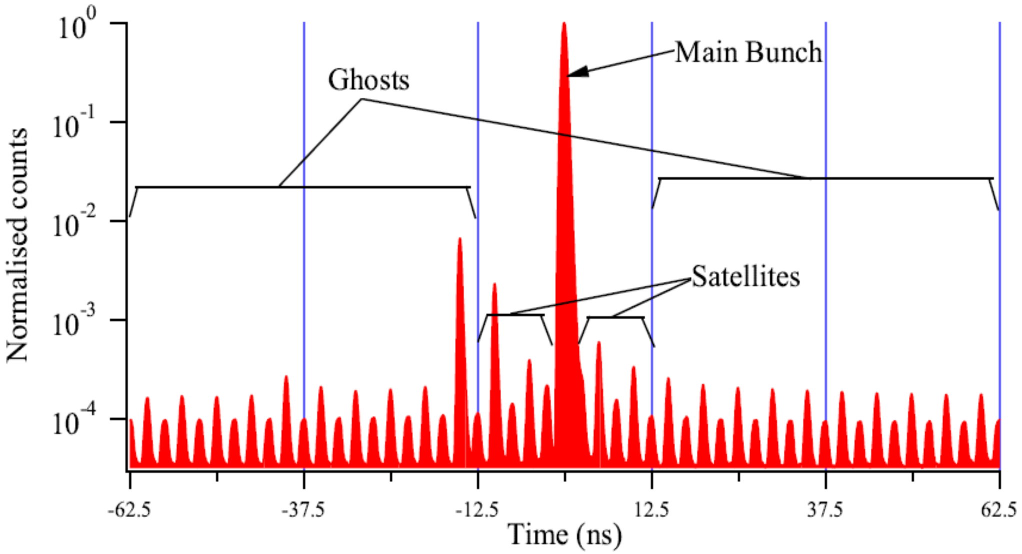
Several systematic effects, from detector or acelerator, can change the measurement of σ_{vis}

Beam intensities measured with DC current transformers while bunch currents with fast beam current transformer, both sensitive to charges outside colliding bunches that must be quantified and subtracted.

CERN-ATS-Note-2012-029 PERF

Ghosts: charge in nominally unfilled bunches

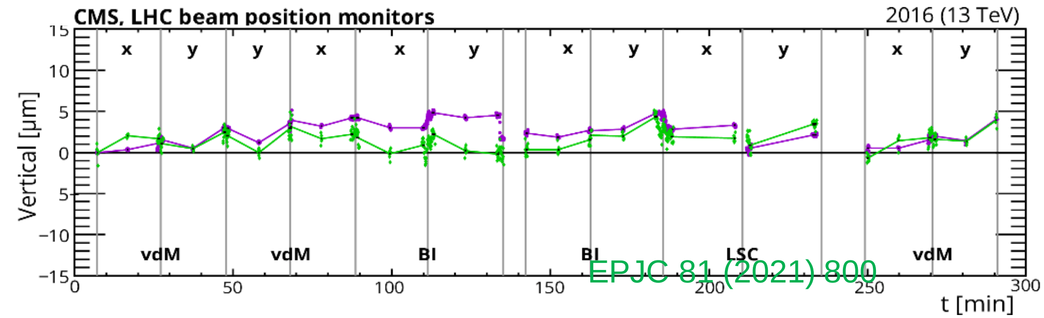
Satellites: charge in a nominally filled bunch but at least one RF period away the main bucket.



Beam position monitoring

Orbit Drift (OD): beam shifts from nominal position.

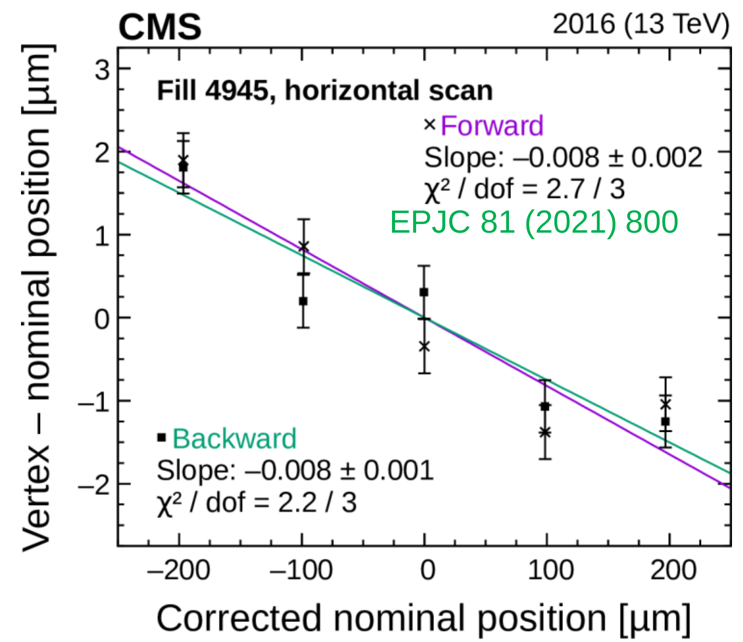
Measured with DOROS and LHC arc BPM.



Length scale (LS): actual beam displacement (and hence beam separation).

Produced by LHC steering magnets intended to produce a given nominal displacement.

Linear fit to the difference between measured and nominal position.

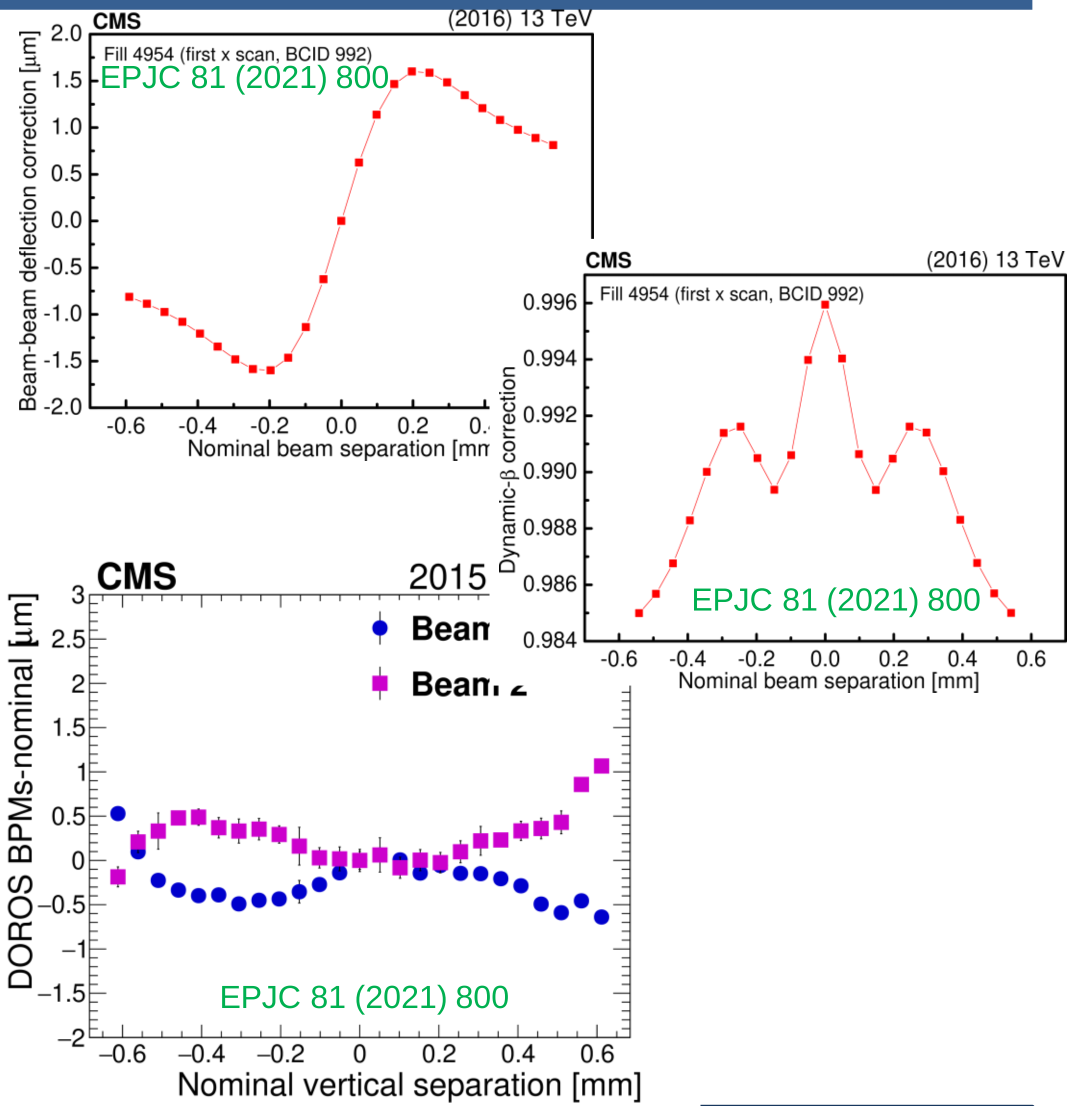


Beam position monitoring

Electromagnetic repulsion between colliding bunches generates the so-called beam-beam (BB) effects.

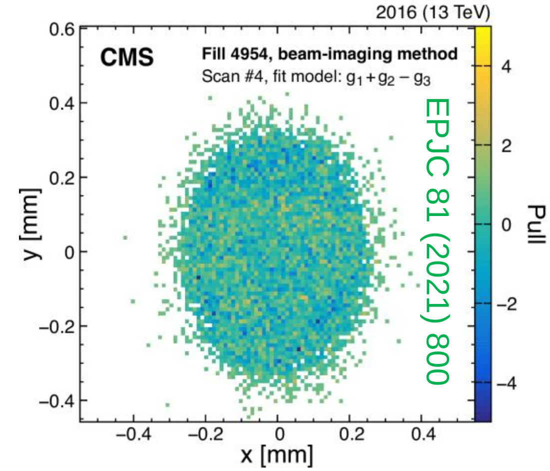
Defocusing of beams modifies the shape of transverse bunch profiles (dynamic β*)

Residual OD: difference between the nominal and corrected beam position after all known effects (BB, OD & LS) are taken into account.



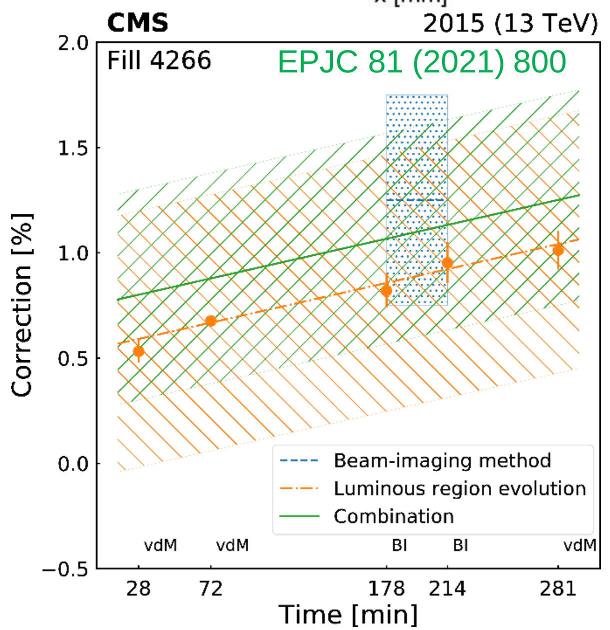
X-Y factorisation

VdM method assumes factorisation of bunch densities for A_{eff}.



BI method: reconstructed vertices used to obtain an image of the transverse bunch profiles (data driven).

Luminous región evolution: using luminous region and beam parameters, from 3D models of primary vertices distribution (bunch profiles are simulated).



Factorisation impact: compare luminosity from VdM to BI method and lumi region evolution.

Both methods provide consisten results.

Integration

Physics runs: collision rate maximized in order to produce large data sets.

Further corrections to ensure long-term stability.

Out of time pile-up: contributions not arising from in-time collisions within the bunch crossing window.

Radiation damage: affect detector response by reducing efficiency or increasing noise.

Cross-detector comparison: ratios among luminometers to exhibit time variations.

Linearity: instantaneous luminosity ratio from luminometers. Slope of linear fit studied as a function of time.