Recent results on Heavy ion physics from CMS

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on behalf of the CMS collaboration

BPU 12 Congress
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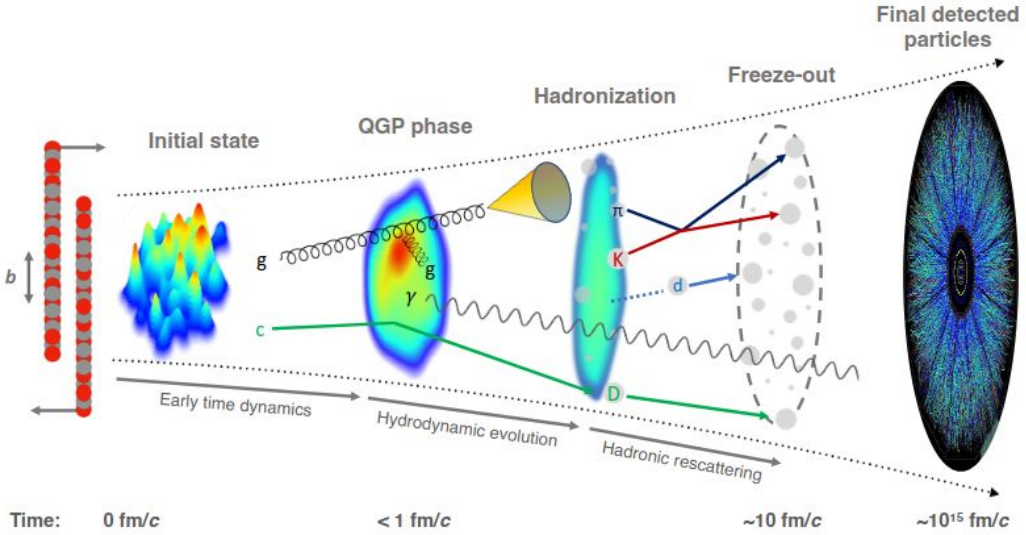
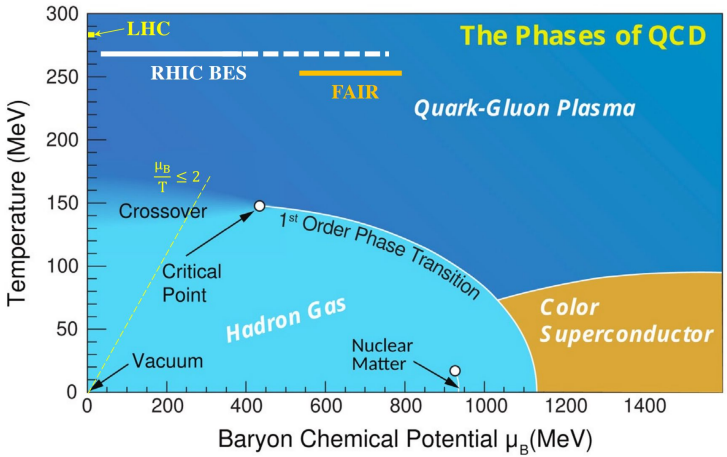
Heavy ion collisions

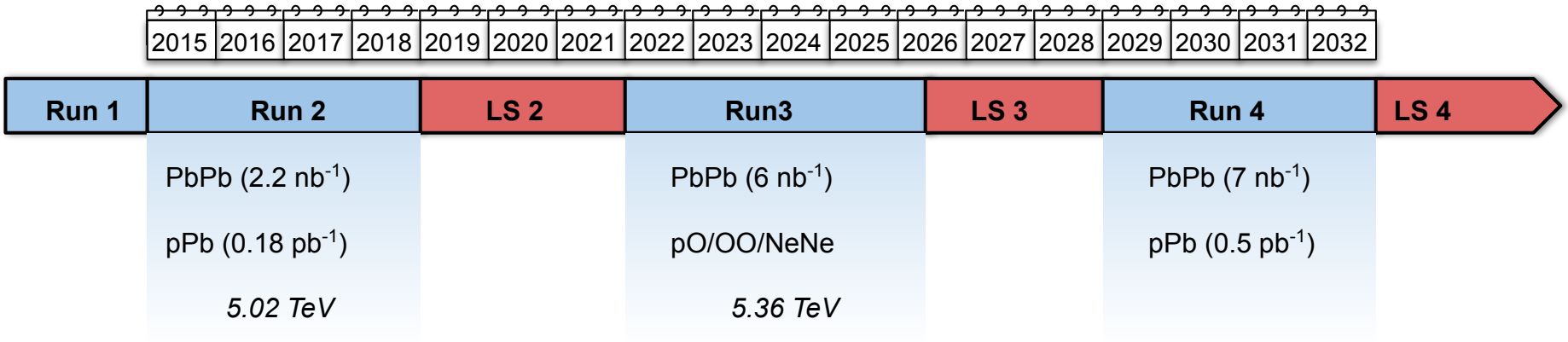
- Heavy ion collision - probing the high-temperature and high-density limit of the phase diagram of nuclear matter
- Production of high-temperature, strongly interacting phase of nuclear matter **Quark Gluon Plasma (QGP)**

arXiv:2303.17254





CMS Heavy ion program



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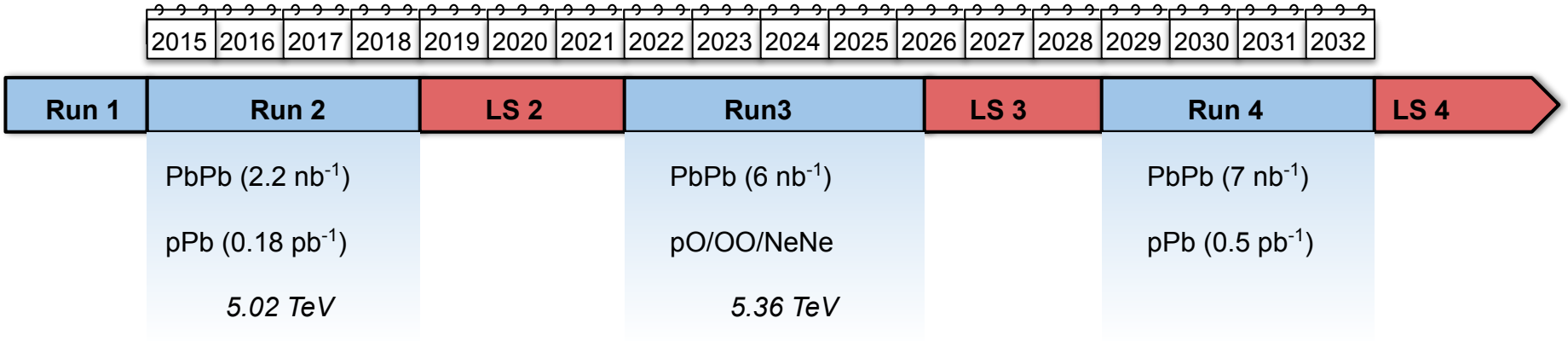
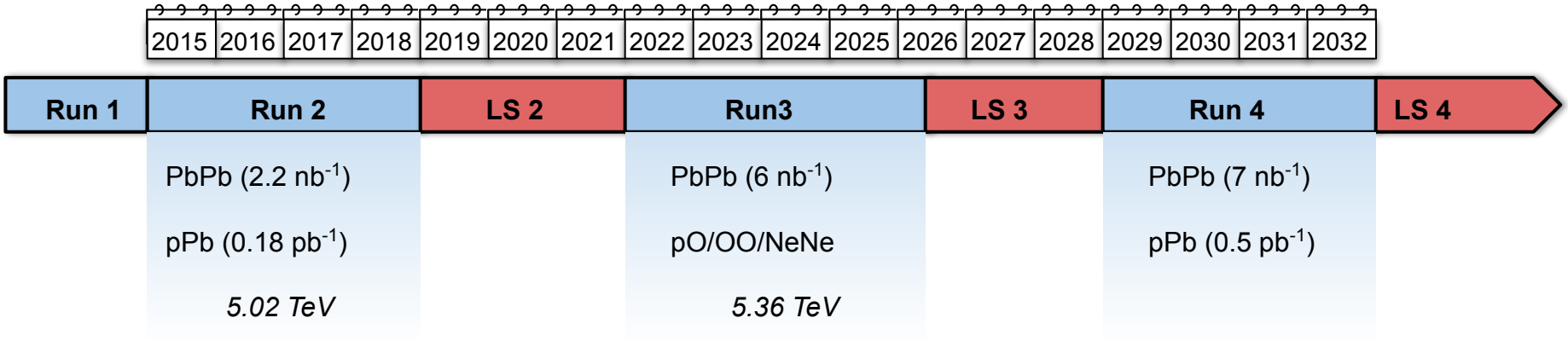


Wide program that includes studies of:

- Conditions of the system in the initial state
- Emerging properties and medium-induced effects
- Collectivity features in small collision systems
- Nature of exotic hadrons and rare phenomena

CMS HI published results and preliminary results

CMS Heavy ion program



Wide program that includes studies of:

- Conditions of the system in the initial state
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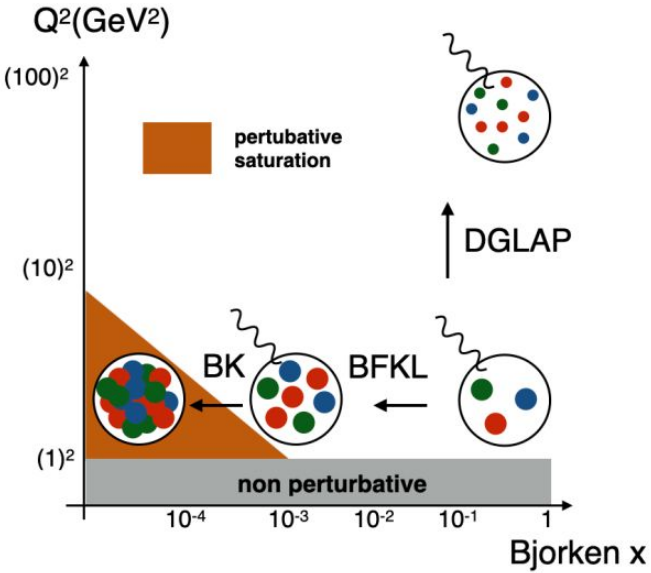
In this talk some of the most recent Heavy ion results from the CMS collaboration are presented

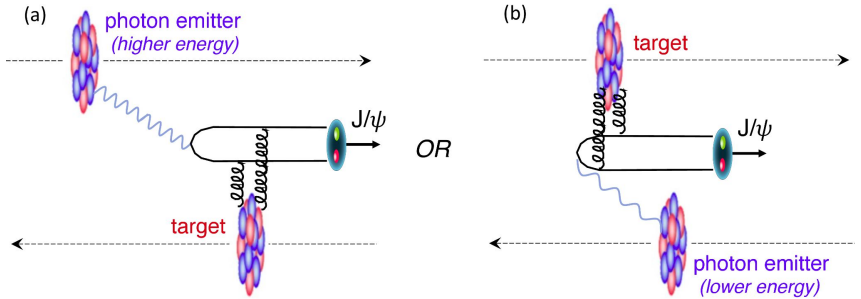
CMS HI published results and preliminary results

Small-x physics

- Structure of nucleons and nuclei - increasingly dominated by gluons when probed at higher energies (or smaller x)
- At small x - nonlinear QCD effects are expected to eventually saturate the growth of the gluon density (**gluon saturation**)
- Understanding the dynamics of strong interactions and the formation of nuclear matter under extreme conditions



- Quasireal photons exchanged in relativistic heavy ion interactions - powerful probes of the gluonic structure of nuclei (**"ultraperipheral collision" or UPC**)

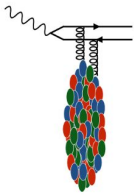


➢ Vector meson photoproduction in UPCs - possibility of probing the poorly known **nuclear gluonic structure and dynamics in the low Bjorken-x region**

Incoherent J/ψ in UPC

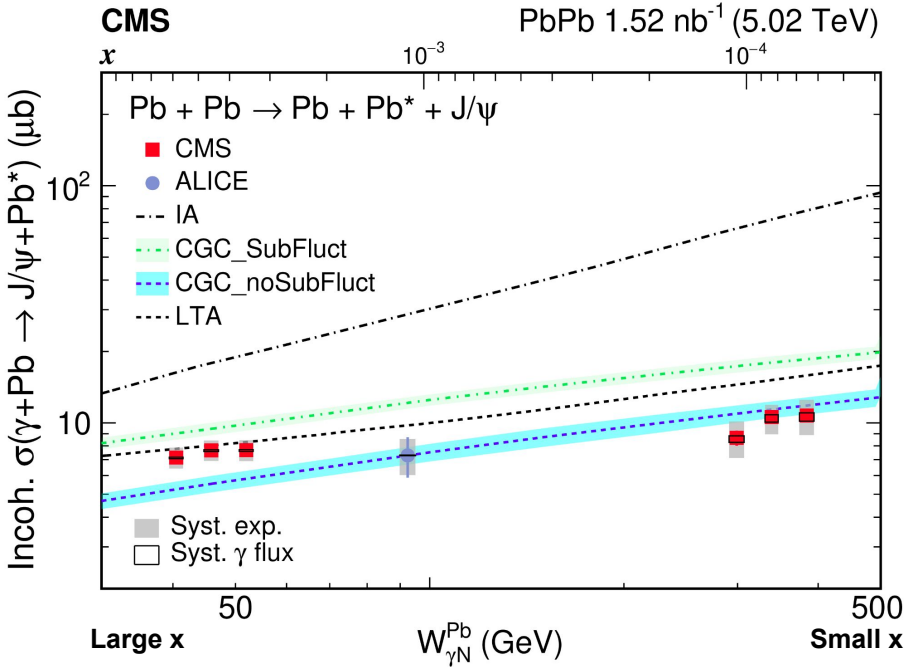
CMS-HIN-23-009

Submitted to Phys. Rev. Lett.



- **Incoherent photoproduction of J/ψ mesons** - the photon interacts with localized, fluctuating gluonic hotspots rather than the entire nucleus

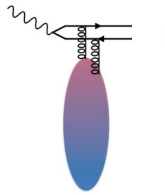
- Strong suppression compared to no-nuclear effects predictions (IA)
  - ➜ Stronger suppression towards higher W
- Leading-twist Approximation (LTA) model (nuclear shadowing based) describe the data at low W
- CGC Ipsat without Sub-N fluctuations better describe data at W>90 GeV



Photon-nucleus center of mass energy per nucleon

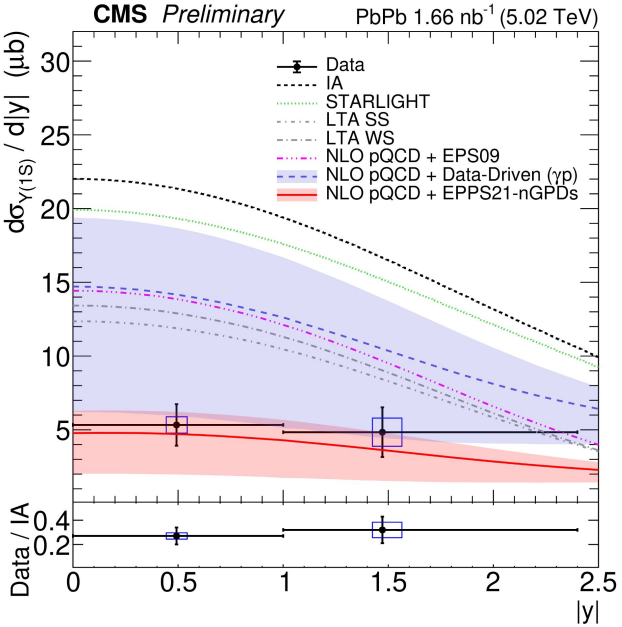
Coherent Υ(1S) in UPC

CMS-PAS-HIN-24-013



- The energy scale of coherent Υ photoproduction - ~10 times higher than that of J/ψ photoproduction, providing sensitivity to a different kinematic region

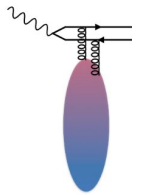
- Strong suppression for Υ(1S) compared to no-nuclear effects predictions (IA)
- Consistent with standard pQCD at NLO (using EPPS21 nPDF) prediction



Coherent ϕ in UPC

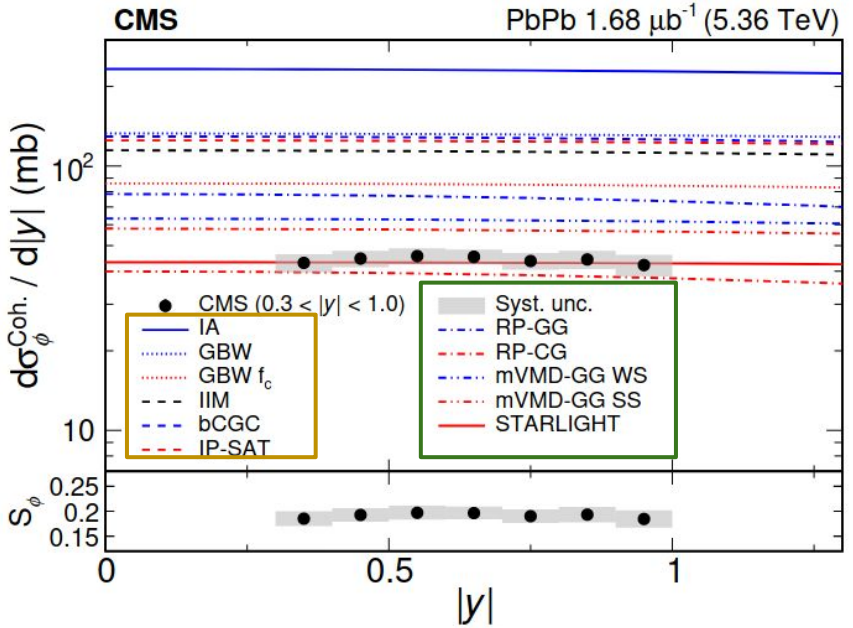
CMS-HIN-24-009

Submitted to Phys. Rev. Lett.



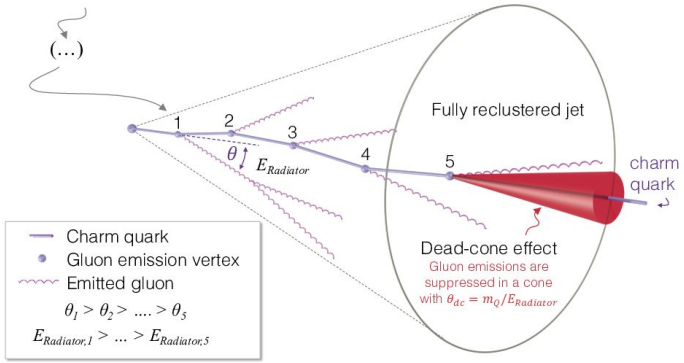
- The ϕ meson - sensitivity to intermediate energy scales, possibility to investigate the interplay of gluon saturation and other QCD dynamics

- Significantly suppressed (by a factor of ~5) compared to no-nuclear effects predictions (IA)
- Better description by models that account for the **nuclear shadowing** compared to those that incorporate **gluon saturation effects**



The dead-cone effect in QCD

- Gluon radiation by a particle of mass ***m*** and energy ***E*** is suppressed within a cone of angular size ***m/E*** around the emitter



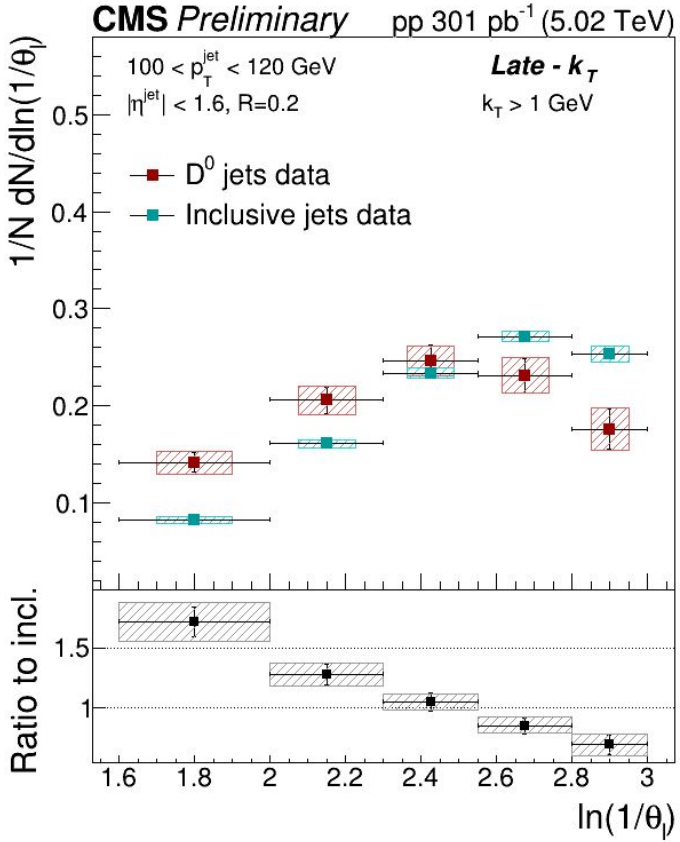
[Nature 605, 440-446 (2022)]

- Sizeable implications of the dead-cone effect is expected for **charm** and **beauty** quarks
- Experimental measurement of the dead-cone effect very challenging
- The development of **declustering techniques** - reconstructing the evolution of the jet shower, access to the the splittings at the smallest angles

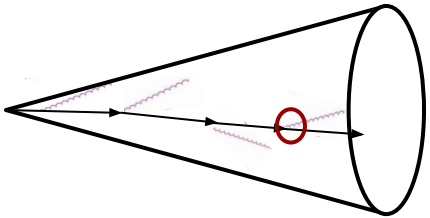
- Measurements sensitive to the heavy-quark mass and how it affects the jet shower - inputs to improve the description of heavy-flavour jet showers

Charm dead cone

CMS-PAS-HIN-24-007



- Measurement of the angular structure of jets containing a **prompt D^0 meson** and of **inclusive jets** in pp collisions



Splitting selected with **late-k_T grooming algorithm:**

➜ most collinear splitting with k_T >1 GeV

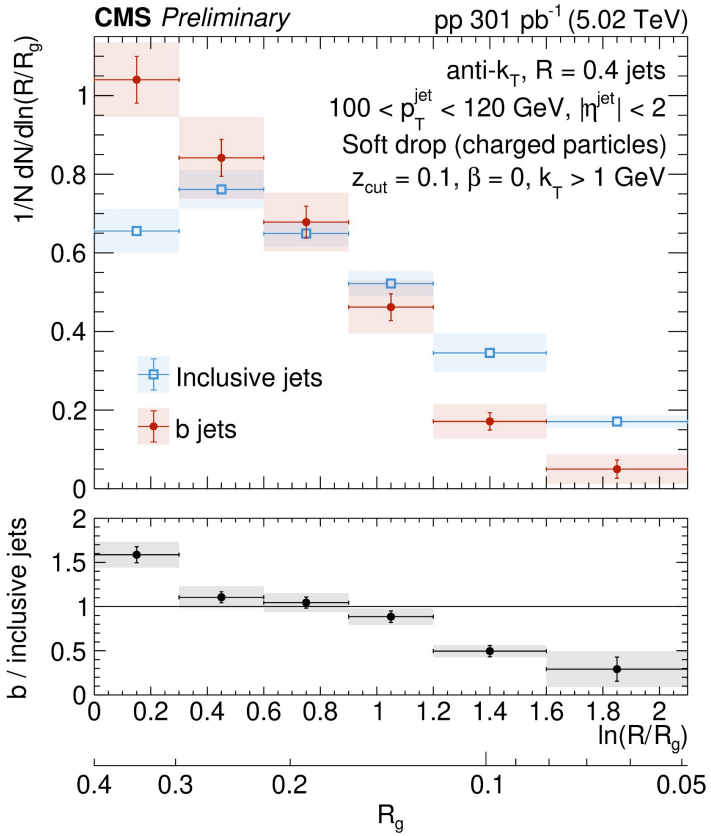
Phys.Rev.D 107 (2023) 9, 094008

- High-p_T jet in range 100-120 GeV
  - ➜ description in the framework of perturbation theory
  - ➜ visualization of a sizeable impact of the dead-cone effect

- **Shift observed towards bigger angles** with respect to the inclusive jets - expected from dead-cone effect

Beauty dead cone

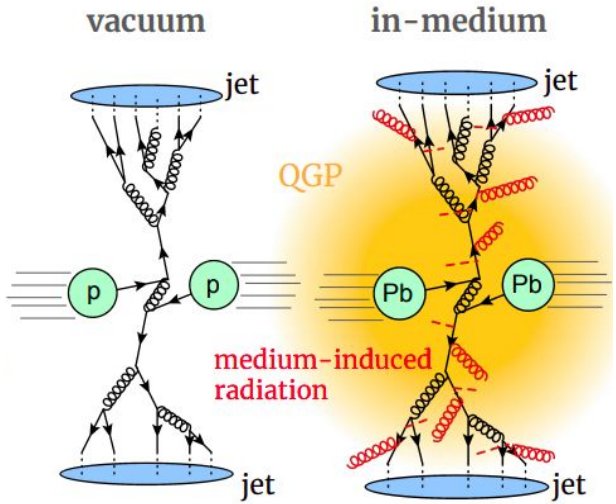
CMS-PAS-HIN-24-005



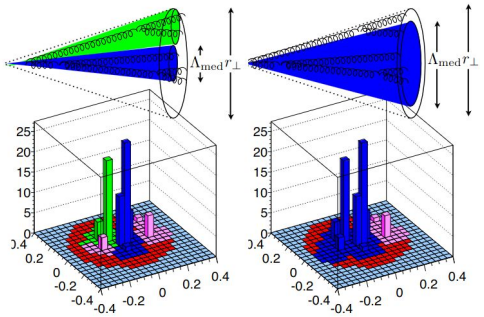
- New method developed to aggregate the particles from the secondary vertex into a b pseudohadron
  - ➜ Identifying decay products (BDT) and cluster
- Increase in b-jet statistics - enable reclustering analyses for b jet
- **First observation of a reduction of the collinear radiation** for b jets
- Charm and beauty quark dead cone measurement - provide baseline for heavy ion studies

Jets in medium

- Reduction of the jet energy and modification of the jet radiation pattern due to the interaction with medium - **jet quenching**
- Main interaction mechanism between the jet constituents and the medium at short distance scales - **medium-induced radiation**
- **Medium response -** propagating jet drags the medium, development of **diffusion wake**



Sketch by Vangelis Vladimirov

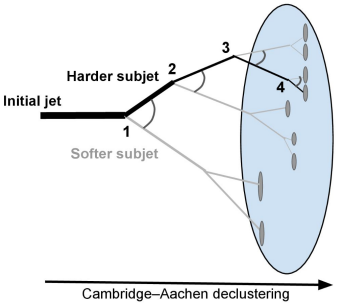


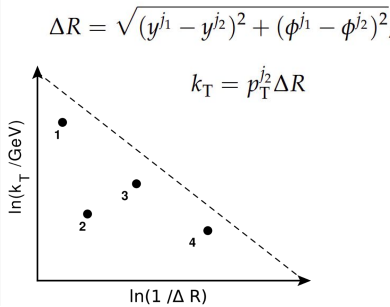
- The medium resolution length - angular separation between two partons or subjets below which the medium cannot resolve them as independent color charge (θ_c)

[Phys.Lett.B725 (2013)]

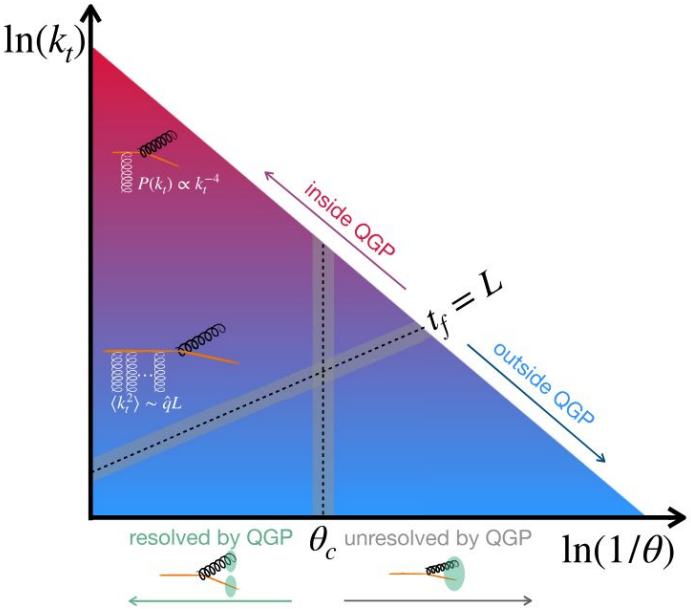
Lund jet plane in PbPb

- Lund planes - 2D representation of the phase-space of 1→2 splittings
- **Primary Lund jet plane** - emissions obtained by declustering the harder subjet at each step of the declustering process
- Provides information about the radiation pattern of the jet





- Internal structure of the jet - **iterative jet declustering** using the Cambridge–Aachen (CA) algorithm

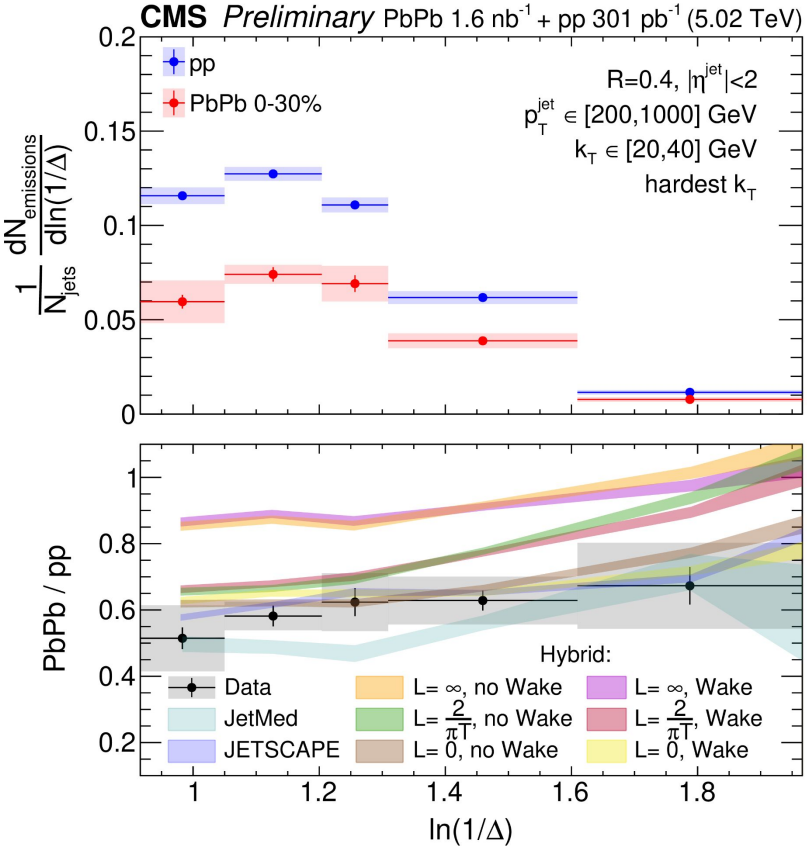


Different effects due to QGP manifest in different regions of the Lund plane:

- **High k_T** - expect vacuum-like emissions and elastic scattering at high
- **Smaller k_T** - onset of color decoherence

First k_T scan of Lund Jet Plane in PbPb

CMS-PAS-HIN-24-016

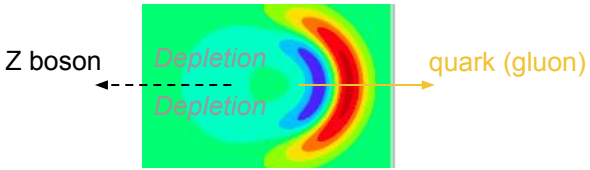


- Ratio less than unity – emissions are softened inside medium and are pushed towards lower values of k_T
- Angular structure of hardest emissions consistent between PbPb and pp within uncertainties at highest k_T – possible sign of vacuum emissions
- Observable largely independent of wake for all resolution lengths
- Ratio most consistent with fully incoherent energy loss case (L=0)

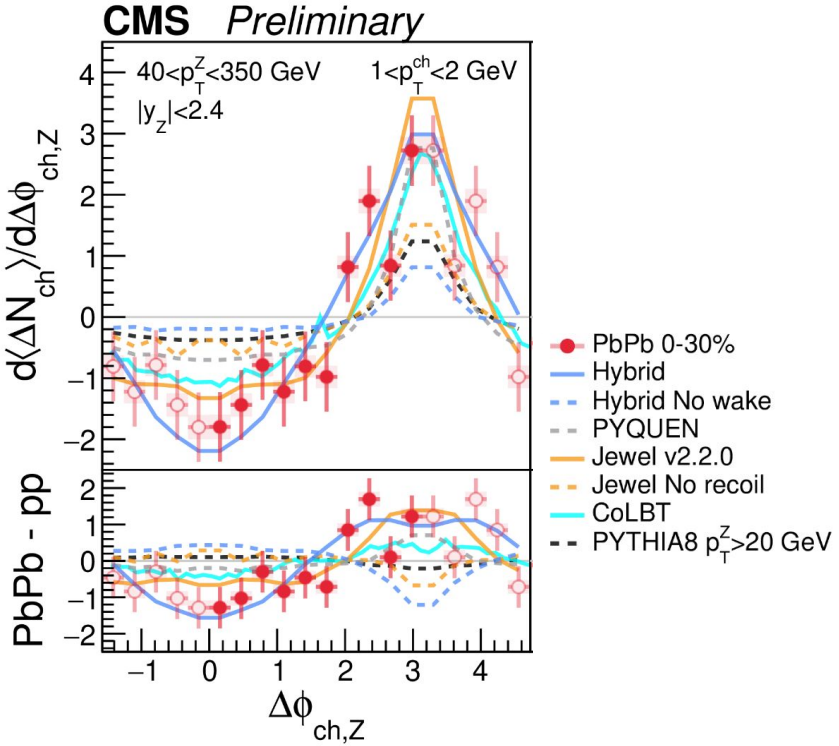
Z-hadron correlations

CMS-PAS-HIN-23-006

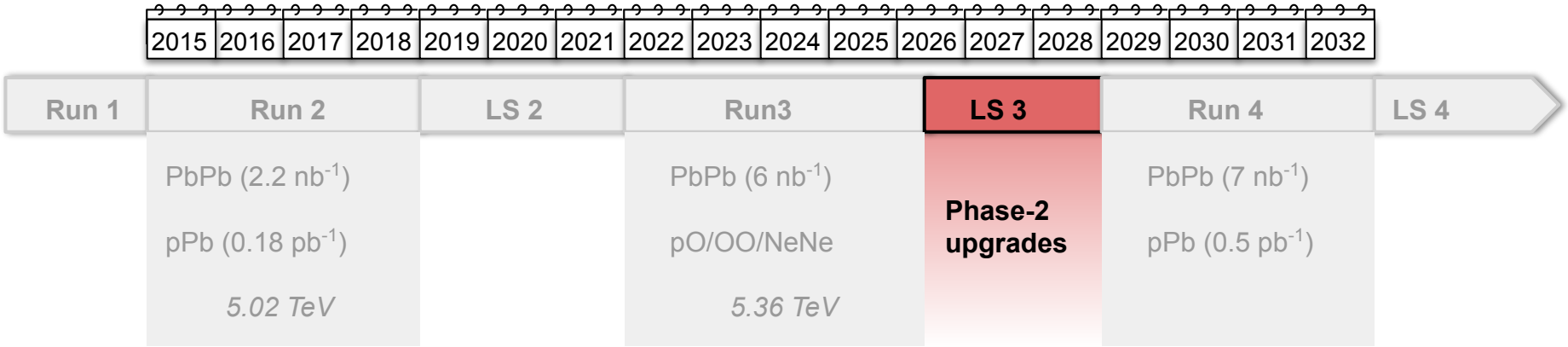
- Measurement of azimuthal angle and pseudorapidity distributions of charged hadrons relative to Z bosons



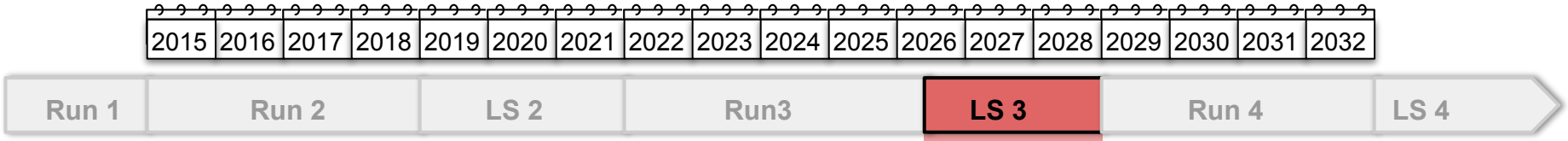
- Depletion on Z side in both φ and y projection
  - ➜ Models without wake/recoil effect under-predict the depletion in PbPb on the Z side
  - ➜ Good agreement with models when including medium response
- Direct evidence of medium response in QGP



CMS HI - Phase 2 Upgrade



CMS HI - Phase 2 Upgrade

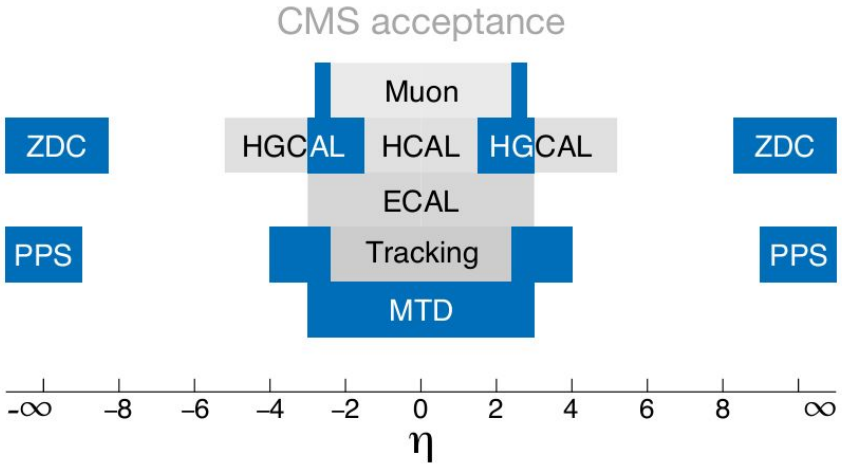


Wider acceptance
- Inner tracker $|\eta| < 2.4 \rightarrow |\eta| < 4$
- Muon detector $|\eta| < 2.4 \rightarrow |\eta| < 2.8$

Higher precision
- Tracker pixel 100x150 → 50x50 μm2
- High granularity end-cap HGCAL

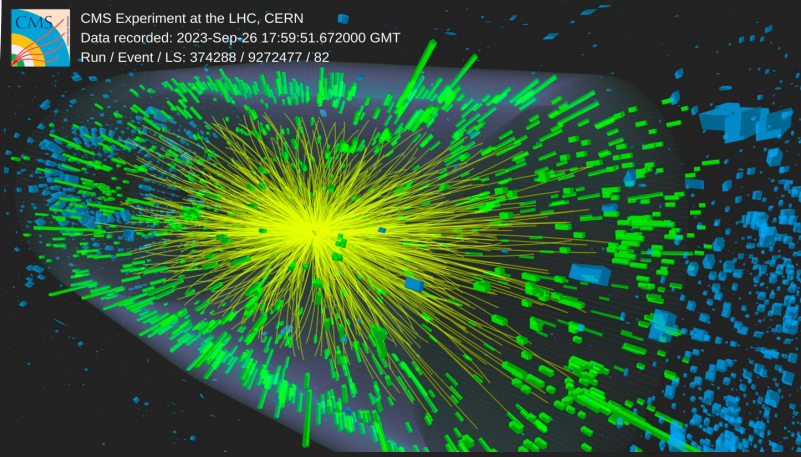
Forward detector
- ZDC tagging neutron → Radiation hard
- PPS tagging out-going proton

Timing info
- MTD as TOF for charged hadron PID
- End-cap HGCAL with timing



Summary

- CMS collaboration has produced many results studying macroscopic and microscopic properties of the quark-gluon plasma
- Studies done using pp, pPb, PbPb and XeXe collisions - soon pO, OO, NeNe
- Heavy ion program at the LHC (Run 3 and 4) with the upgraded CMS detector will provide opportunities for more precise measurements and studies of rare probes



CMS HI published results and preliminary results

Thank you for your attention!