Overview of the CMS results

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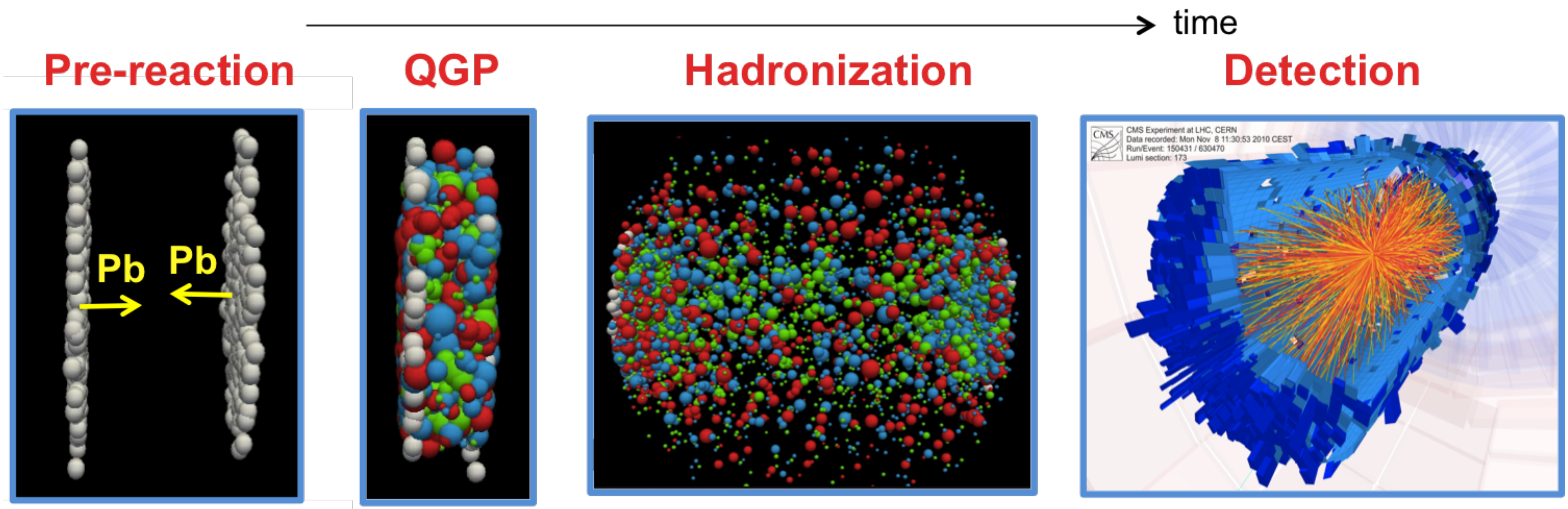
On behalf of the CMS collaboration

Rencontres QGP France 2018

Introduction

The goal : study the properties of the quark-gluon plasma (QGP)

Different final states provide insight into various stages of heavy-ion (HI) collisions



Hard probes :

- Colourless objects : EW bosons – standard candles in the QGP, nPDFs
- Colour objects : jets, hadrons – partonic energy loss in the QGP; quarkonia – Debye screening effect

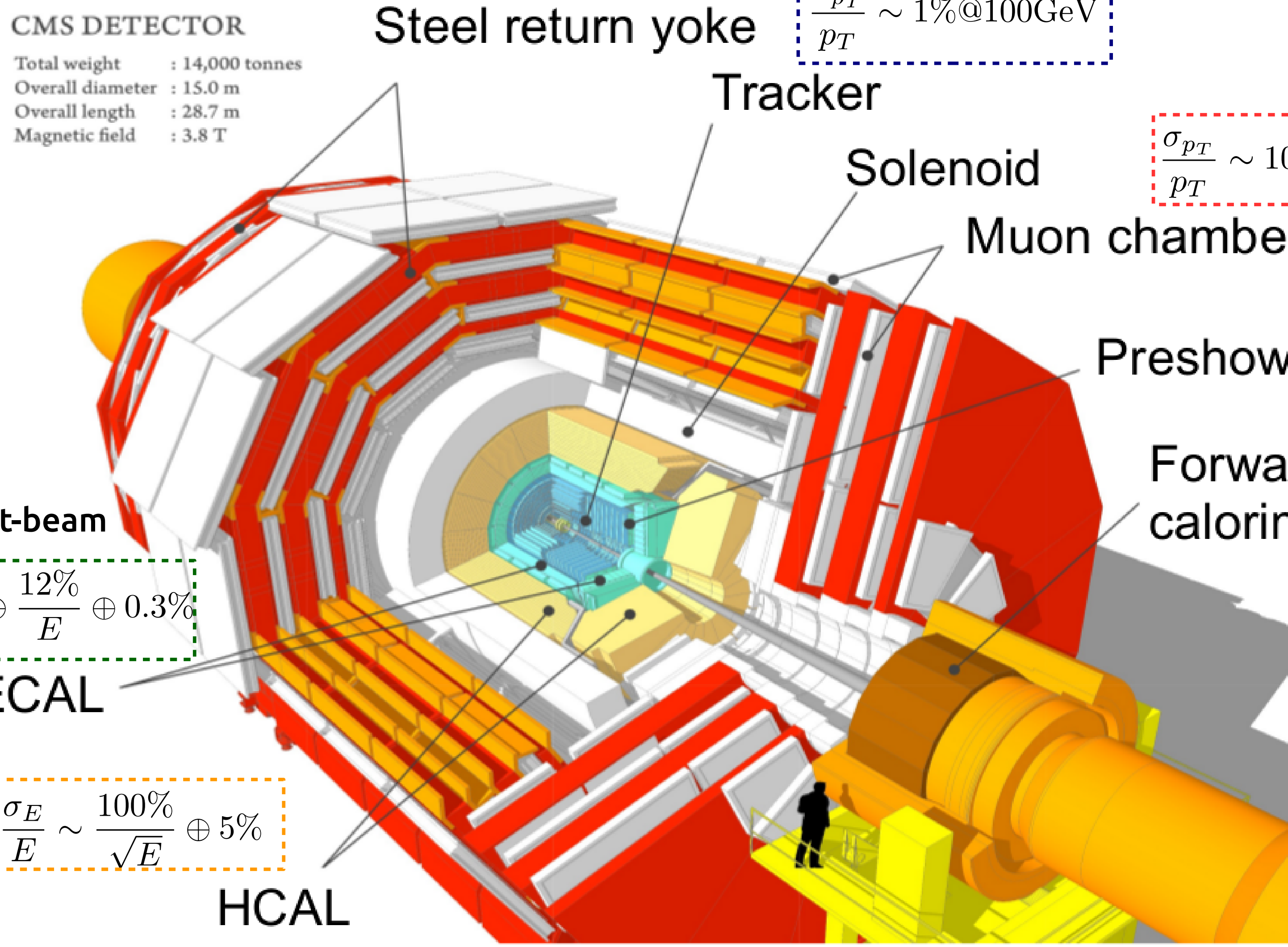
Bulk production :

- Initial geometry, initial conditions, collective behavior

} PbPb, pPb, pp collisions

XeXe : new from 2017

Compact Muon Solenoid



$$\frac{\sigma_{p_T}}{p_T} \sim 1\%@100\text{GeV}$$

$$\frac{\sigma_{p_T}}{p_T} \sim 10\%@1\text{TeV}$$

From the test-beam

$$\frac{\sigma_E}{E} \sim \frac{2.8\%}{\sqrt{E}} \oplus \frac{12\%}{E} \oplus 0.3\%$$

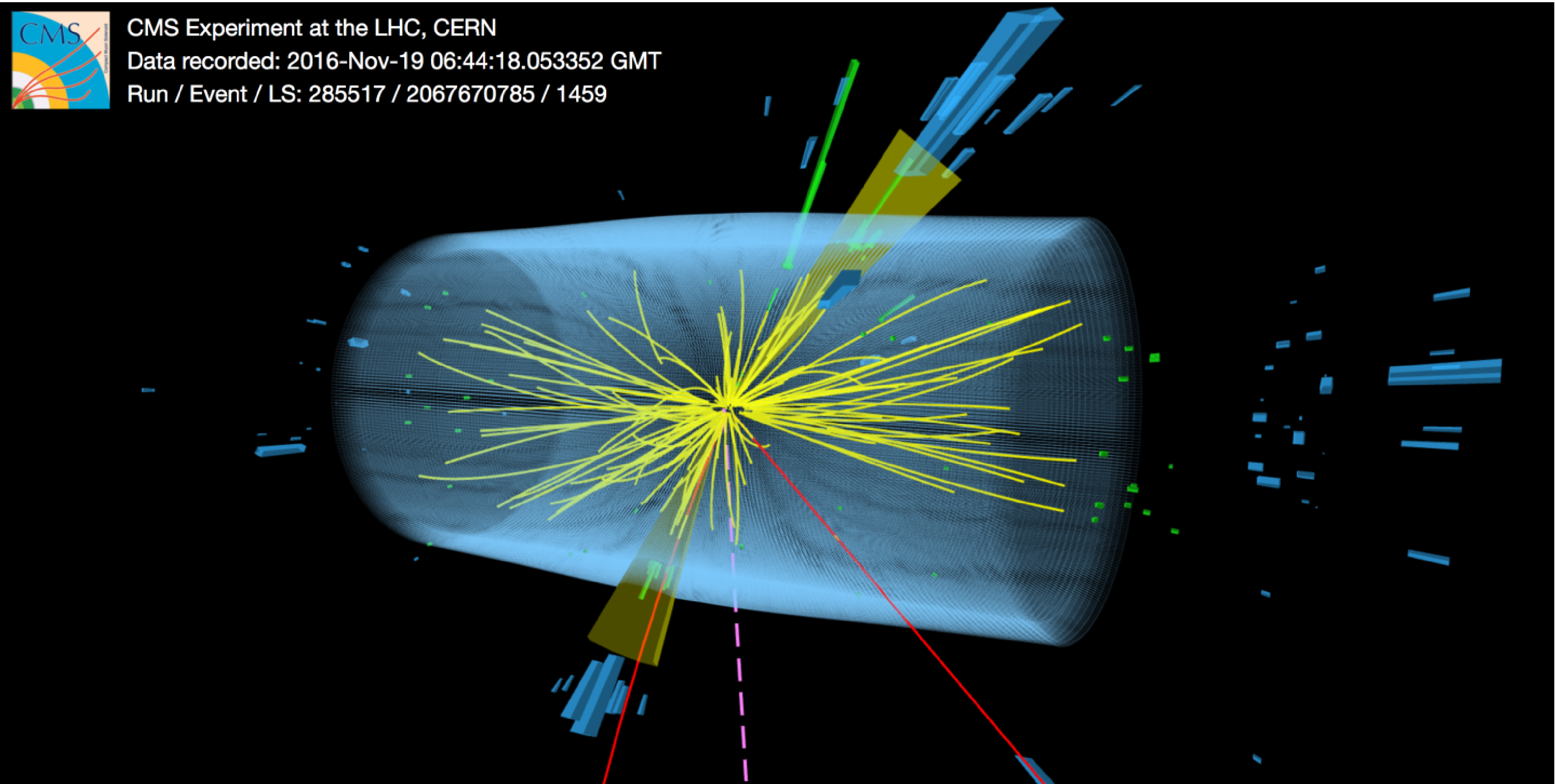
$$\frac{\sigma_E}{E} \sim \frac{100\%}{\sqrt{E}} \oplus 5\%$$

Pseudorapidity:

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

Hard probes:

Electroweak bosons
Top quark
Quarkonia & HF

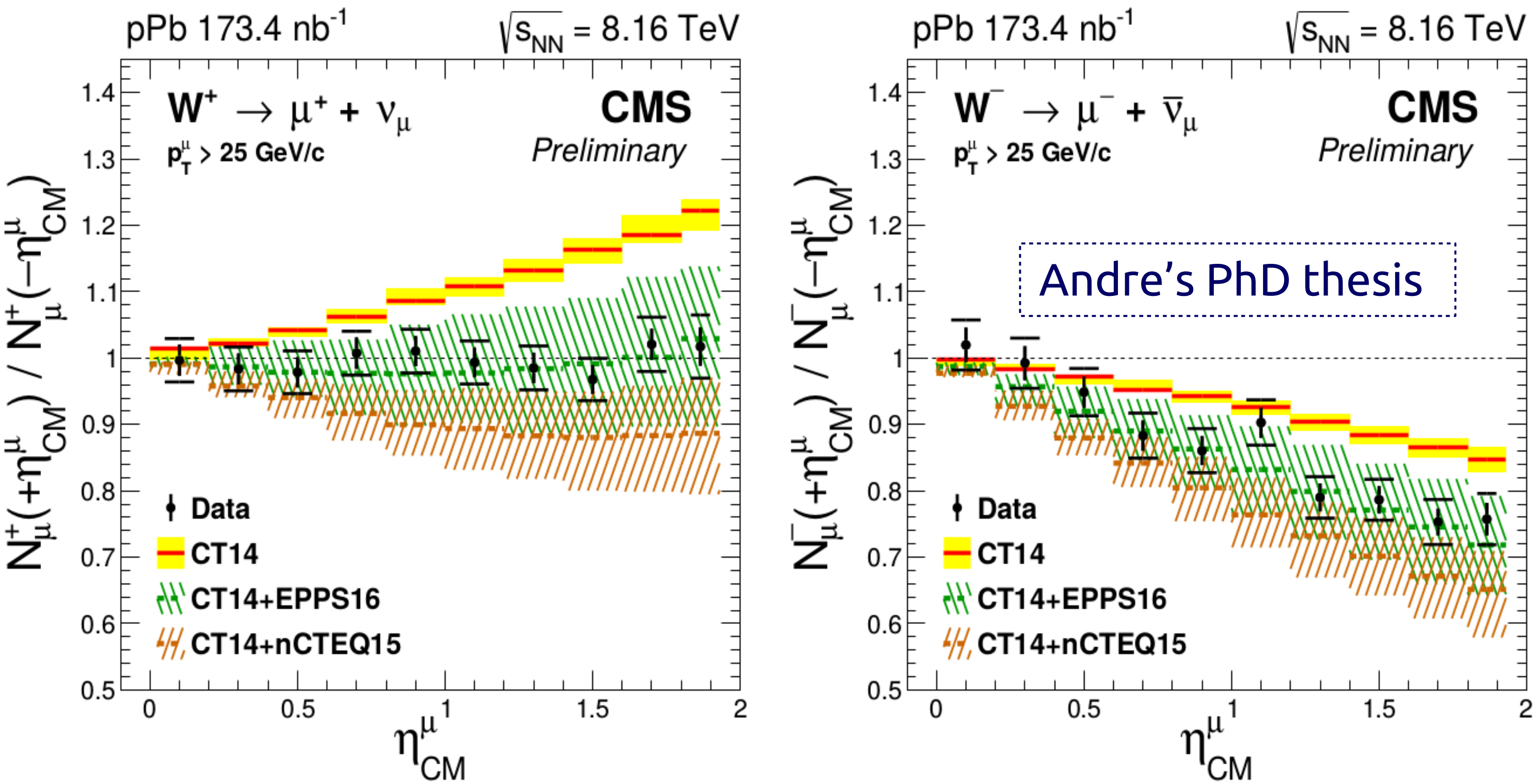


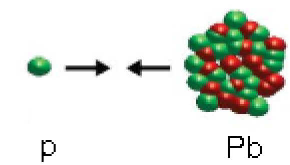
Nuclear PDFs with W boson

CMS-PAS-HIN-17-007

The measurements of EW boson production in p-A and AA collisions provide constraints to nuclear modifications of the parton distribution functions (PDFs).

Forward-backward asymmetries for the positive and negative muons :





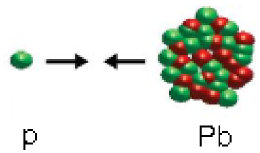
Nuclear modification of the quark PDF needed to describe the data

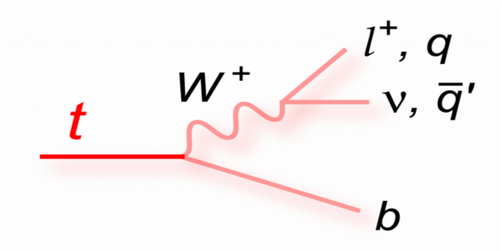
Small experimental uncertainties → a significant reduction of the current uncertainties of the quark and antiquark nPDFs in the range $10^{-3} < x < 10^{-1}$

Nuclear PDFs with top quark

PRL 119 (2017) 242001

In p-A collisions, the top quark is a novel and theoretically precise probe of the nuclear gluon density at high virtualities $Q^2 \approx m_t^2$ in the unexplored high Bjorken-x region : $x \gtrsim 2m_t/\sqrt{s_{NN}} \approx 0.5$





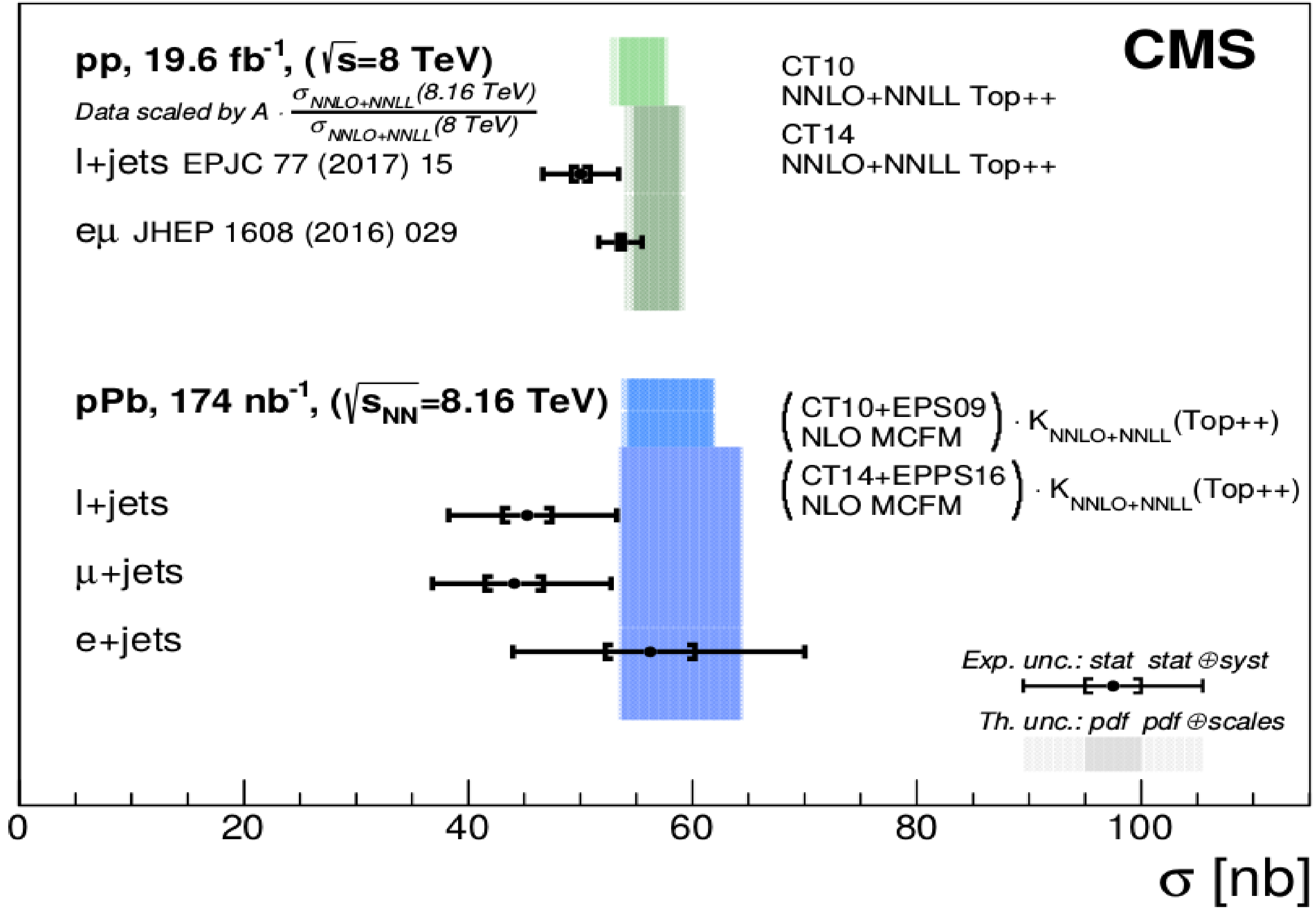
Event selection :

$1\ \mu/e$

> 4 jets

3 cat :

$0b,\ 1b,\ 2b$ jets

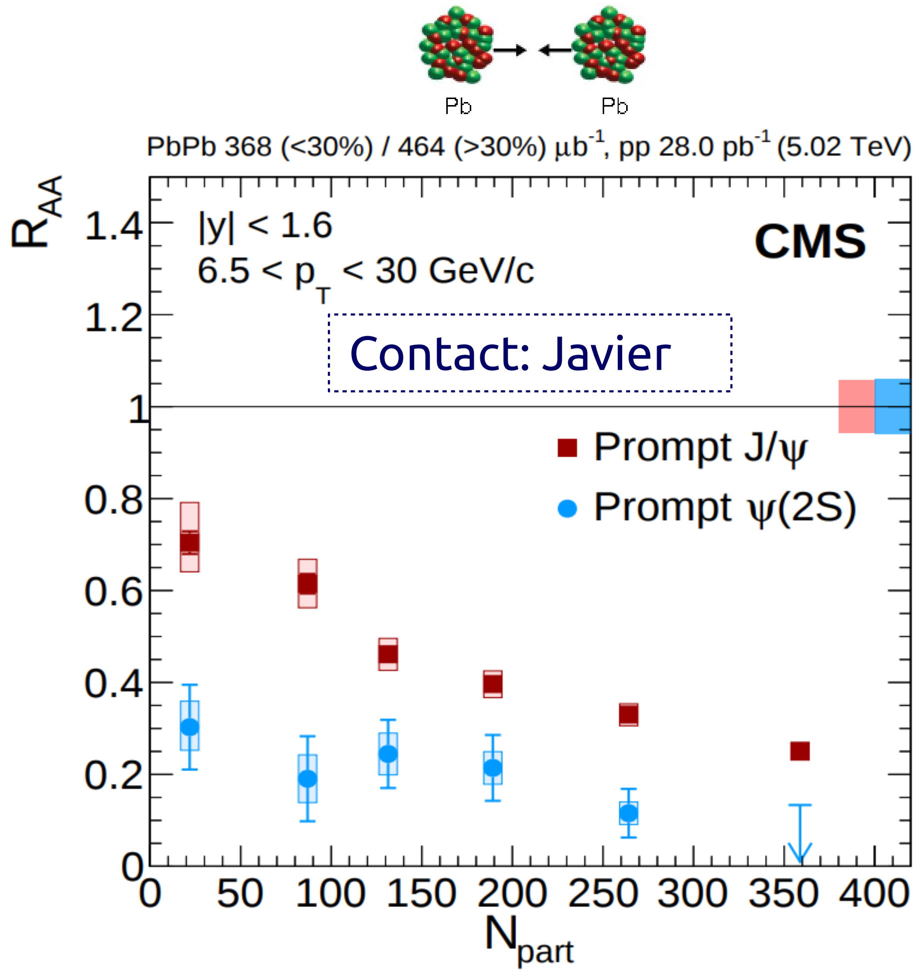


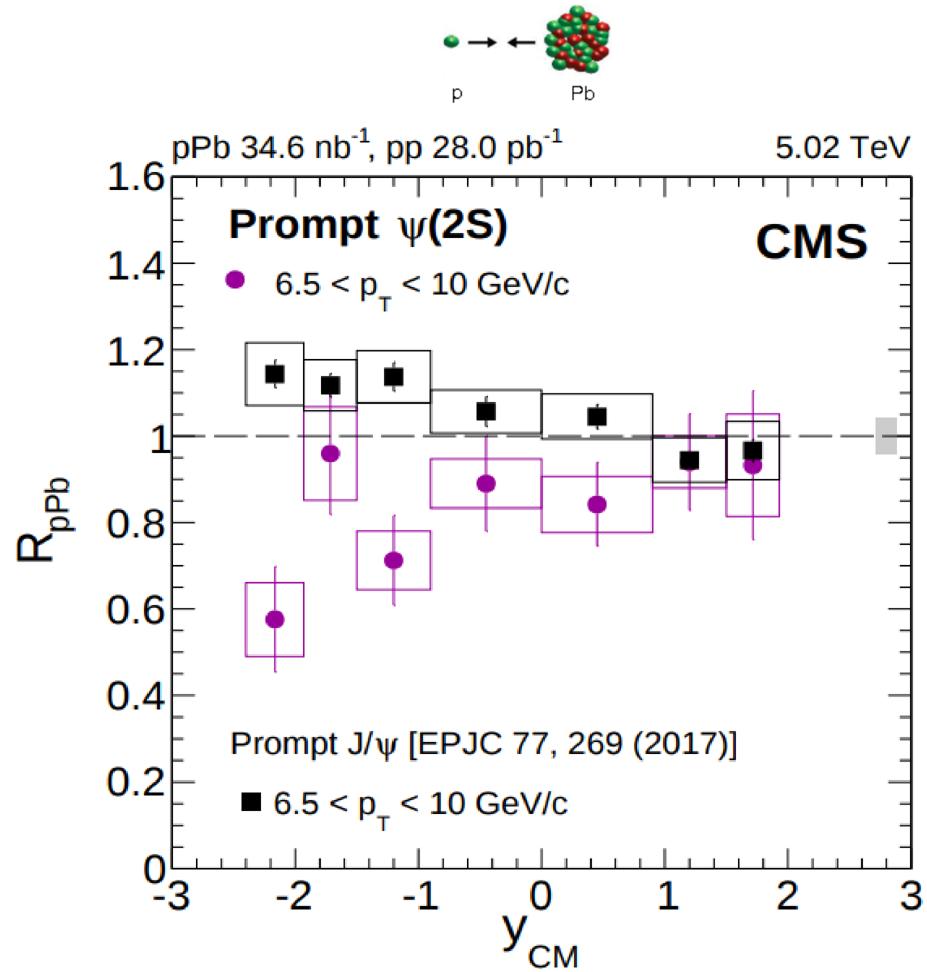
$$\sigma_{t\bar{t}} = 45 \pm 8 \text{ nb}$$

Measured cross section is consistent with the expectations from scaled pp data as well as perturbative QCD calculations.

Charmonia

Nuclear modification factor (R_{AA}) of prompt J/ψ and ψ(2S) in PbPb and pPb collisions :





ψ(2S) are more strongly suppressed than the J/ψ mesons

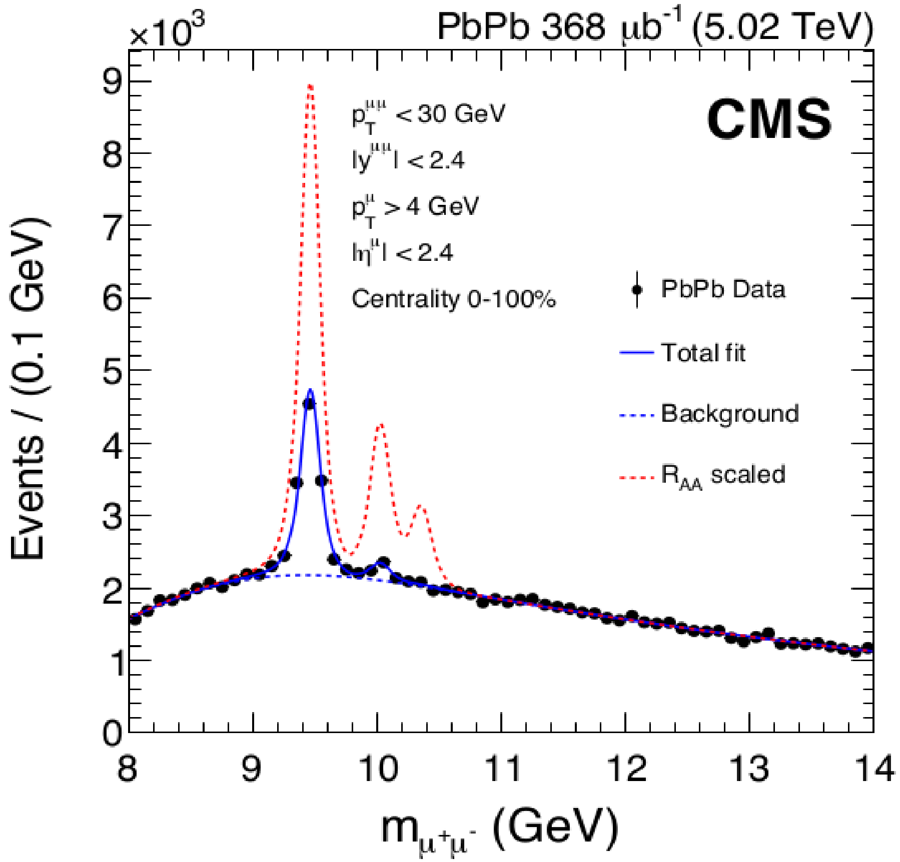
The effects of nPDFs or coherent energy loss are expected to affect the prompt J/ψ and ψ(2S) by a similar amount.

Different nuclear effects in the production of the two states.
Effects beyond shadowing and energy loss in pPb?

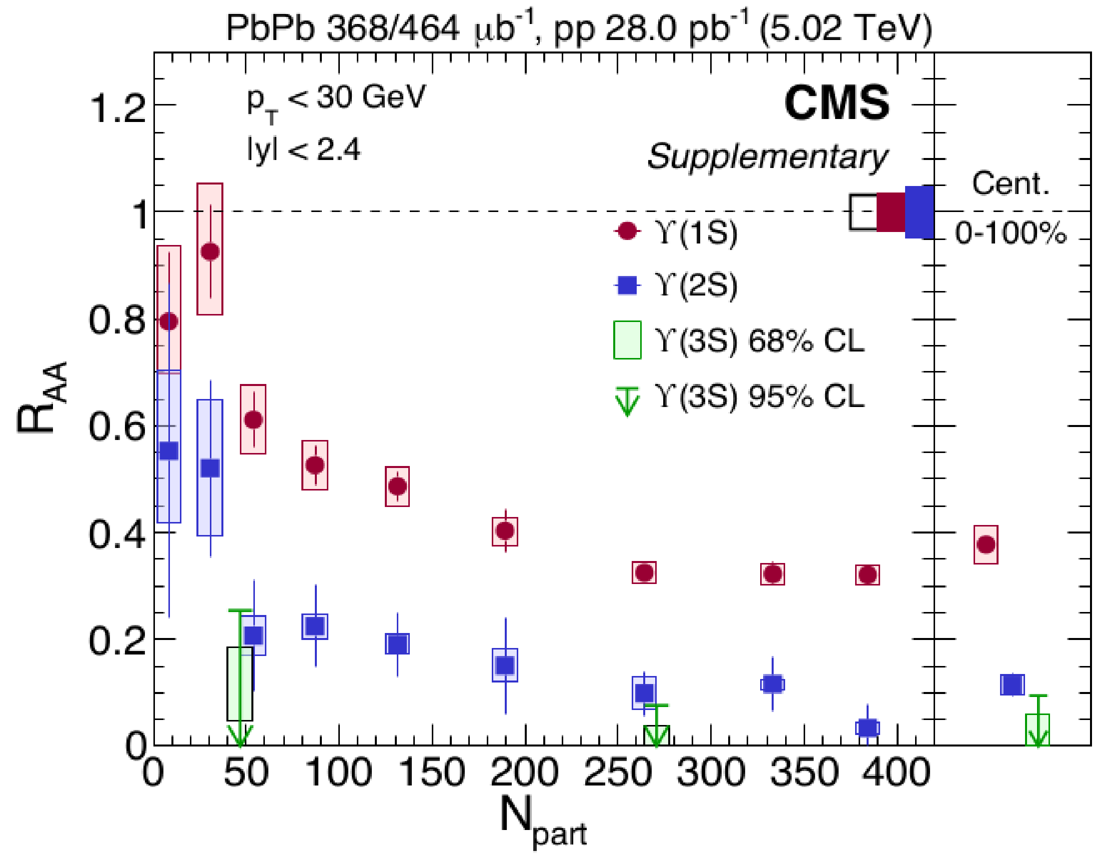
Bottomonia

arXiv:1805.09215

R_{AA} of Υ(1S), Υ(2S), and Υ(3S) in PbPb collisions :



Limits were put on the minimal suppression of Υ(3S)



Yields of three states are significantly suppressed.

Compatible with a sequential ordering of the suppression :

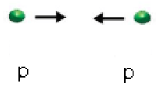
$$R_{AA}(\Upsilon(1S)) > R_{AA}(\Upsilon(2S)) > R_{AA}(\Upsilon(3S))$$

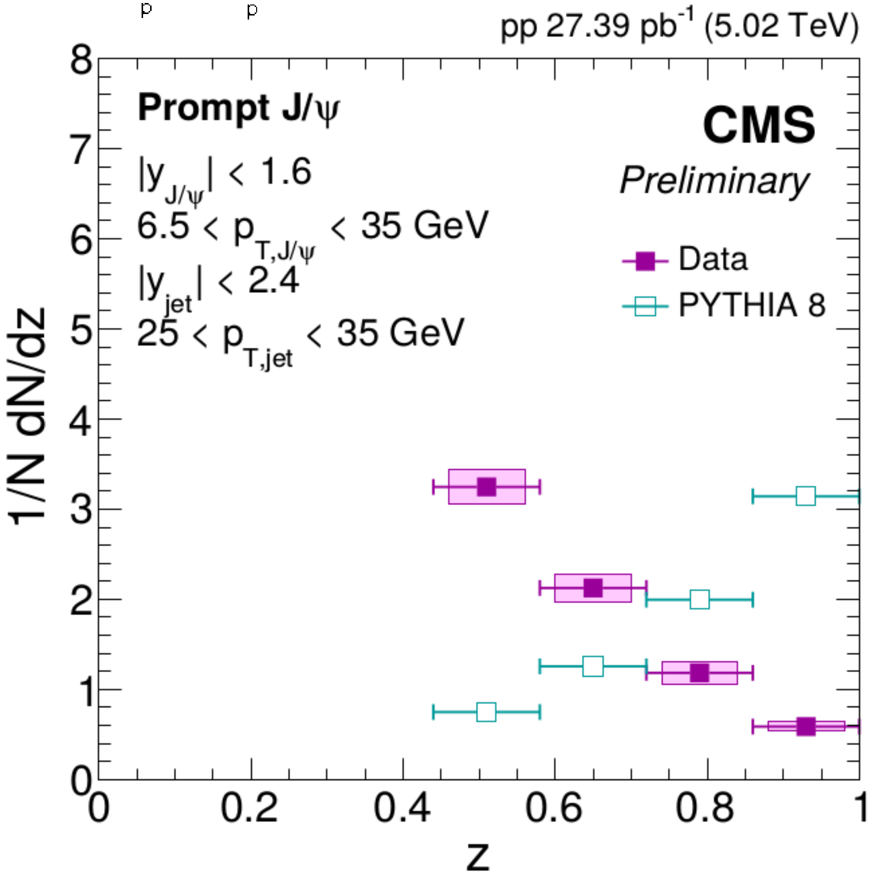
J/ψ inside jets in pp collisions

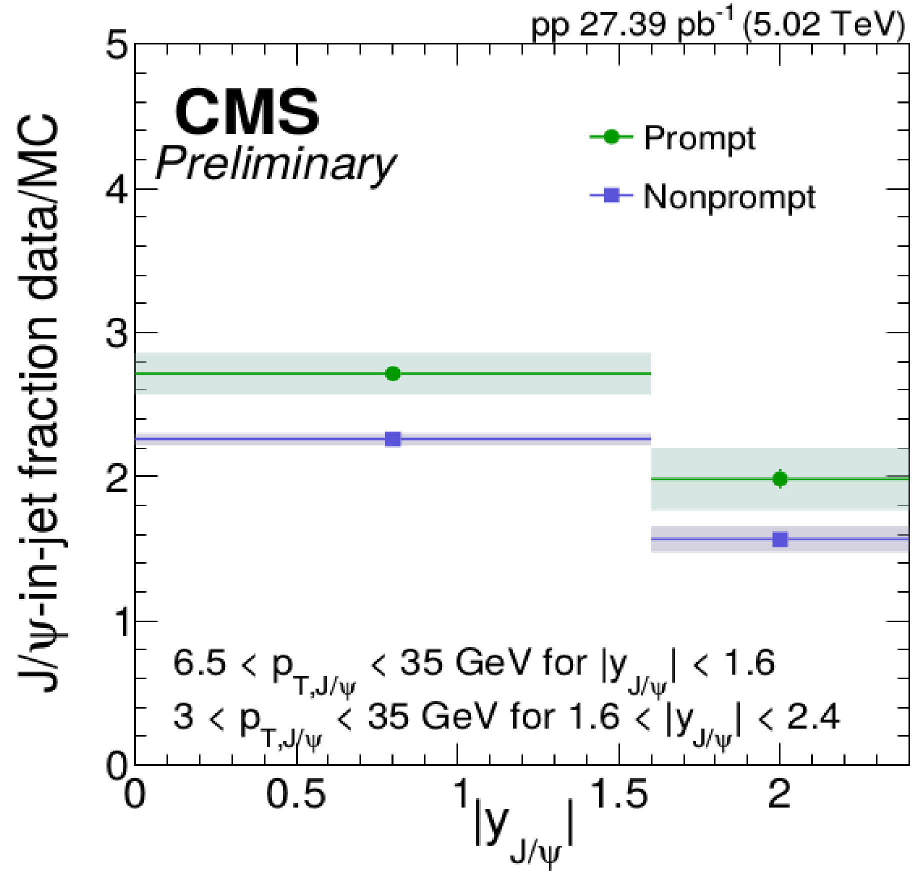
CMS-PAS-HIN-18-012

Contact : Batoul

Fragmentation of J/ψ in jets : $z = \frac{p_{T,J/\Psi}}{p_{T,jet}}$







Prompt J/ψ is less isolated in data → Pythia underestimates the jet activity

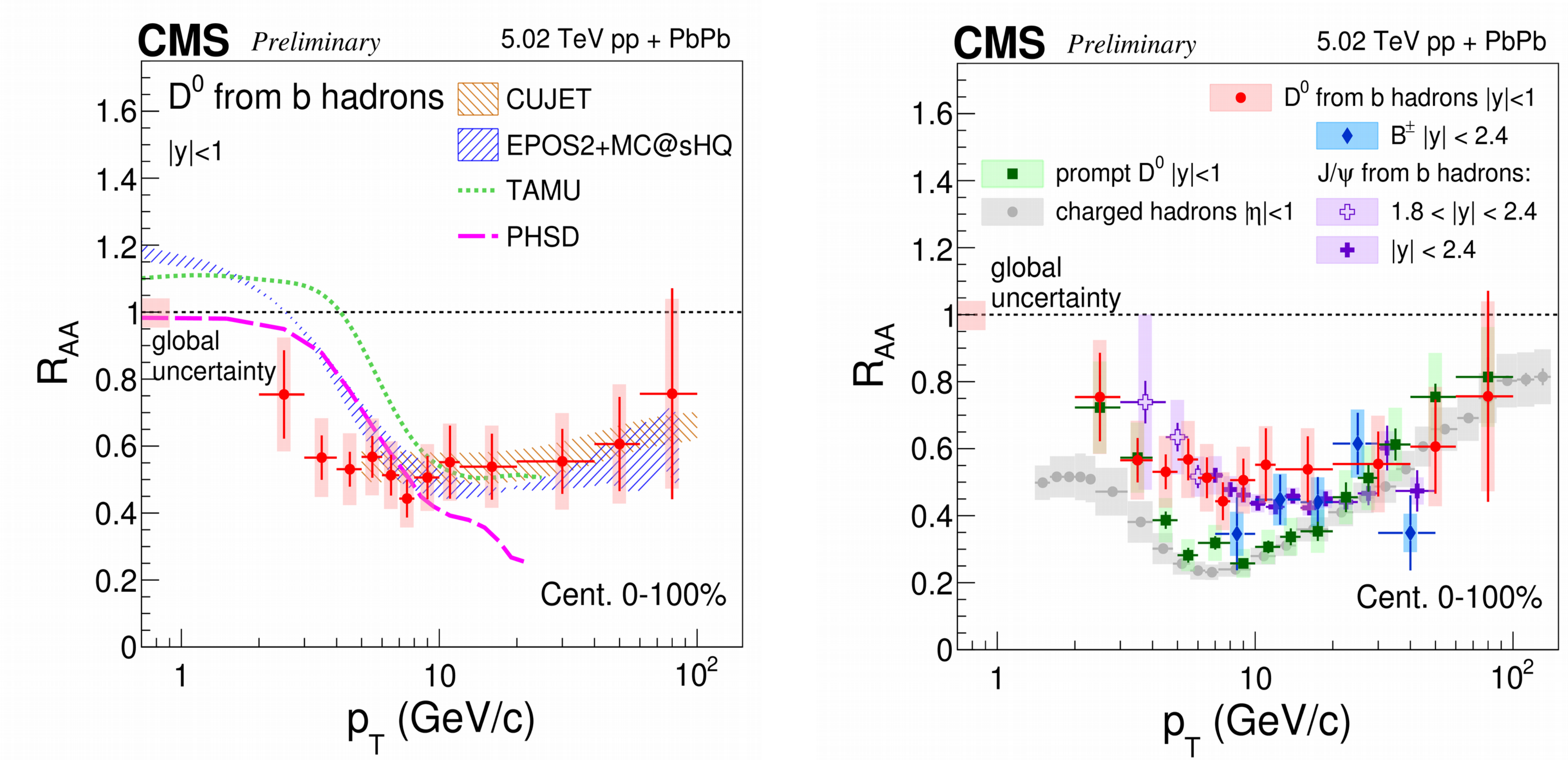
Fraction of J/ψ in jets under-predicted

This fact might have an impact on the interpretation of J/ψ suppression results in PbPb collisions

Beauty suppression via non-prompt D

CMS-PAS-HIN-16-016
arXiv:1712.08959

First measurement of non-prompt (from b hadron) D0 R_{AA}

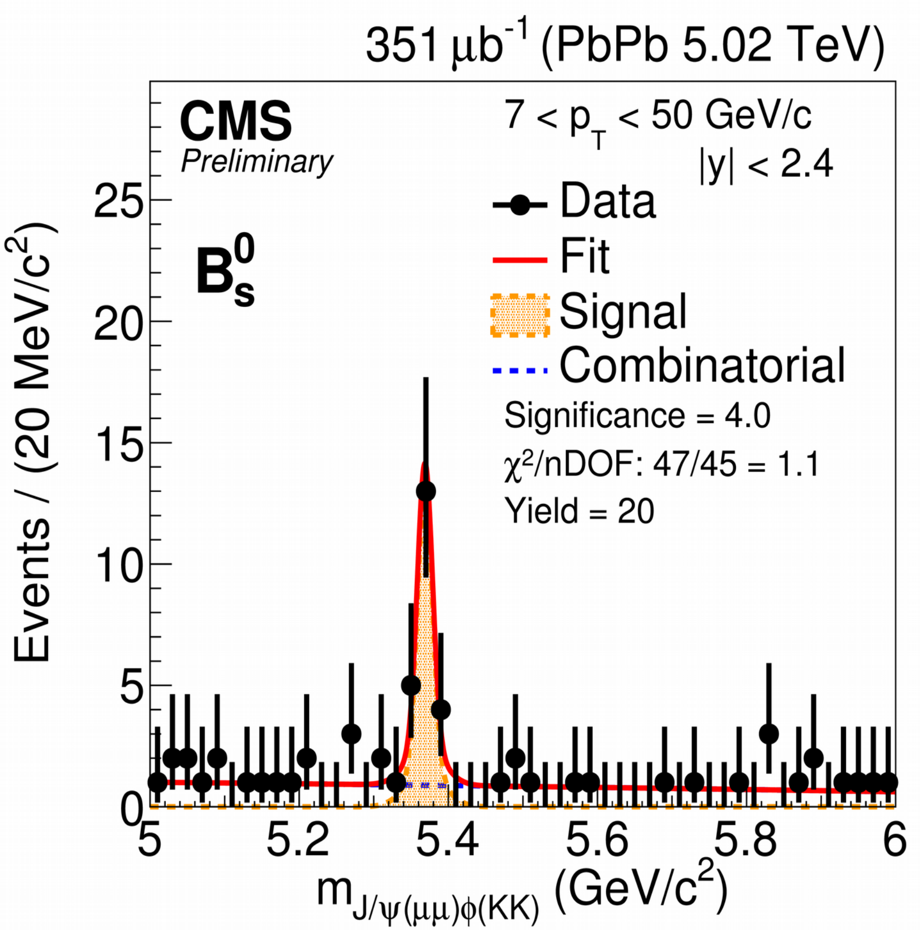


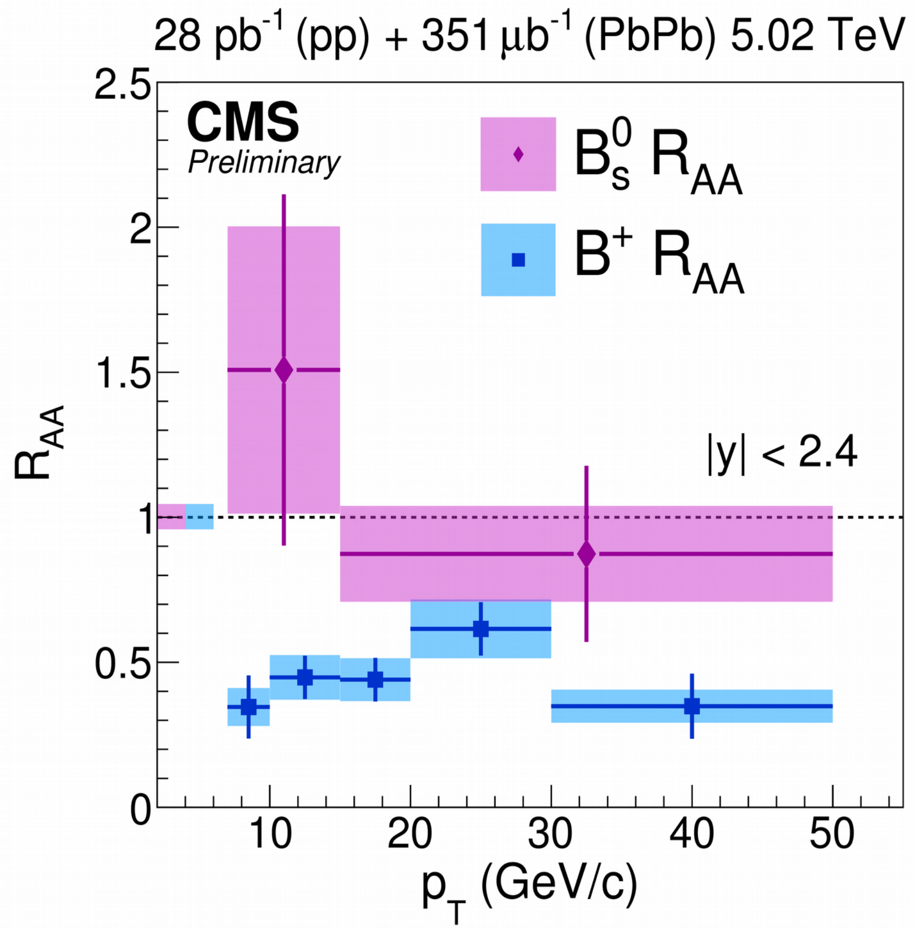
5<pT <15 GeV : Non-prompt D0 and J/ψ less suppressed than prompt D0 and charged hadrons

Strange B mesons

CMS-PAS-HIN-17-008

First probe of recombination between beauty and strange quarks



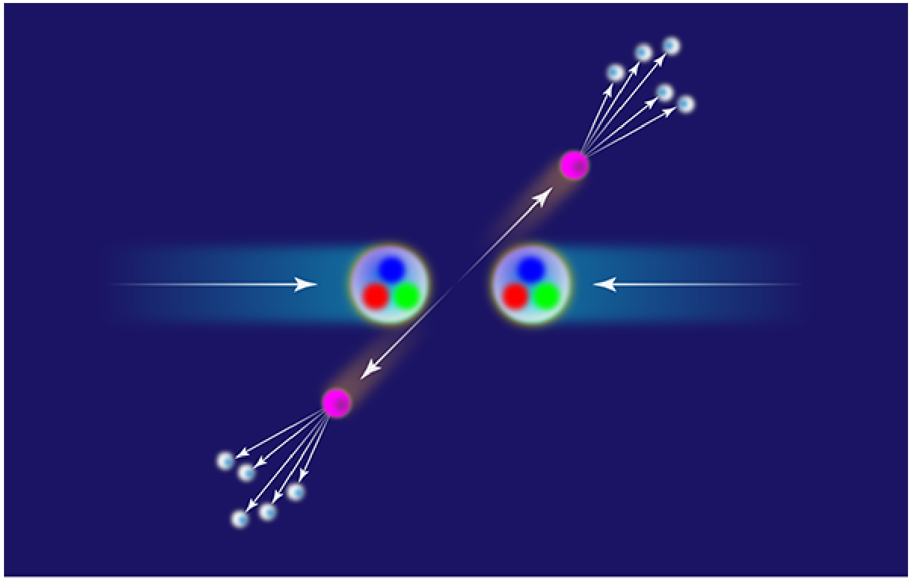


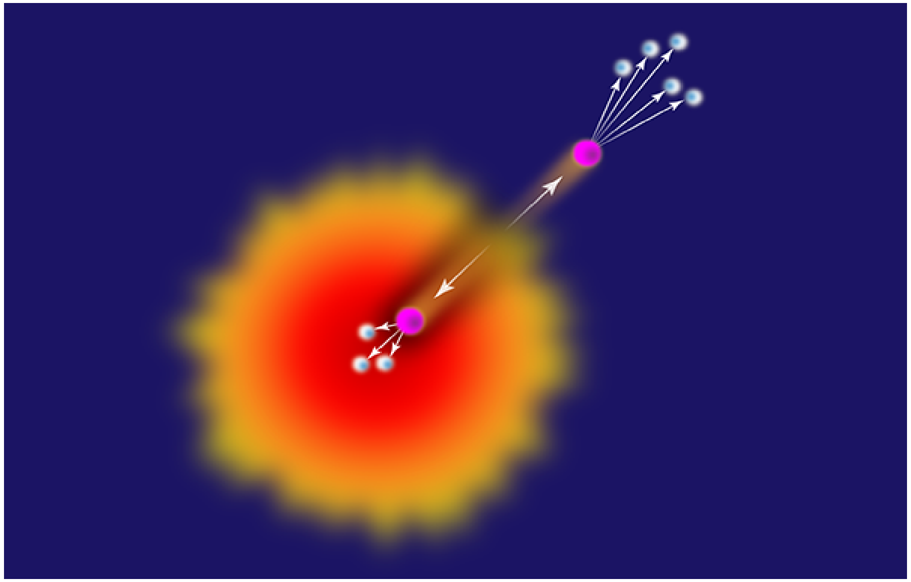
Hint for enhancement of Bs with respect to B+

Effect of recombination due to strangeness enhancement in QGP?

Hard probes:

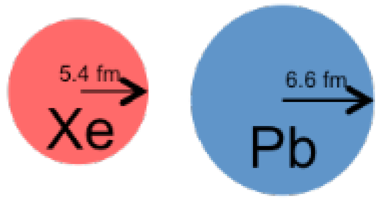
Charged hadrons
Jets





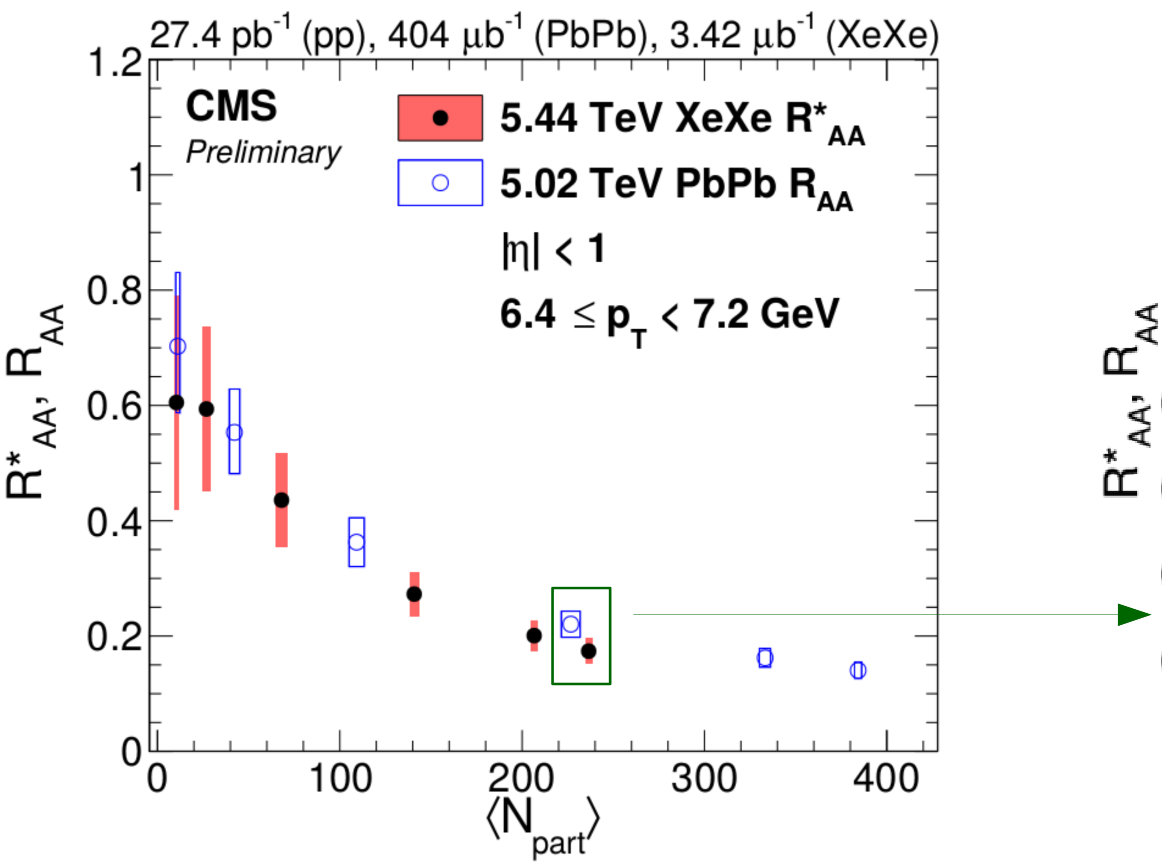
XeXe: charged hadron Raa

CMS-PAS-HIN-18-004



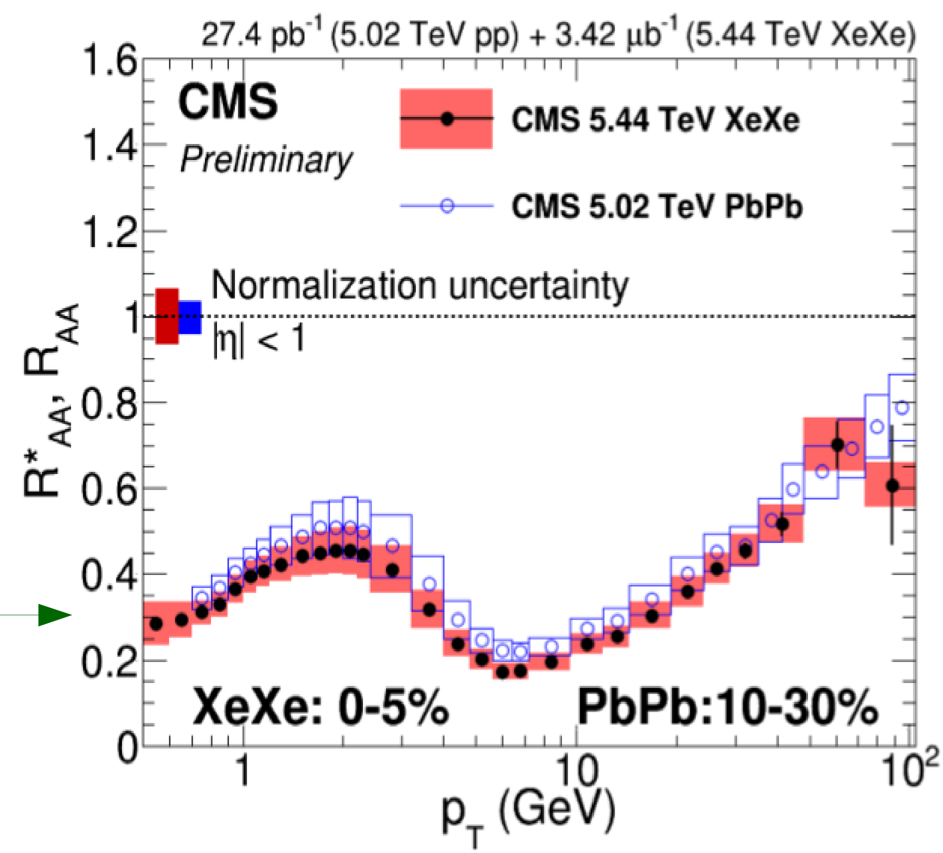
- XeXe : Mid-size collision system
- Test of the suppressions vs system size : $R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{1}{T_{\mathrm{AA}}} \frac{\mathrm{d}N^{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma^{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$

R_{AA} vs N_{part}



Similar scaling in XeXe and PbPb

R_{AA} for centrality ranges with similar values of N_{part}

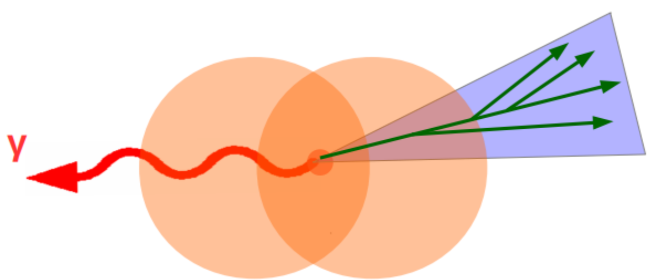


R_{AA} are consistent within the uncertainties

Photon-tagged jet fragmentation

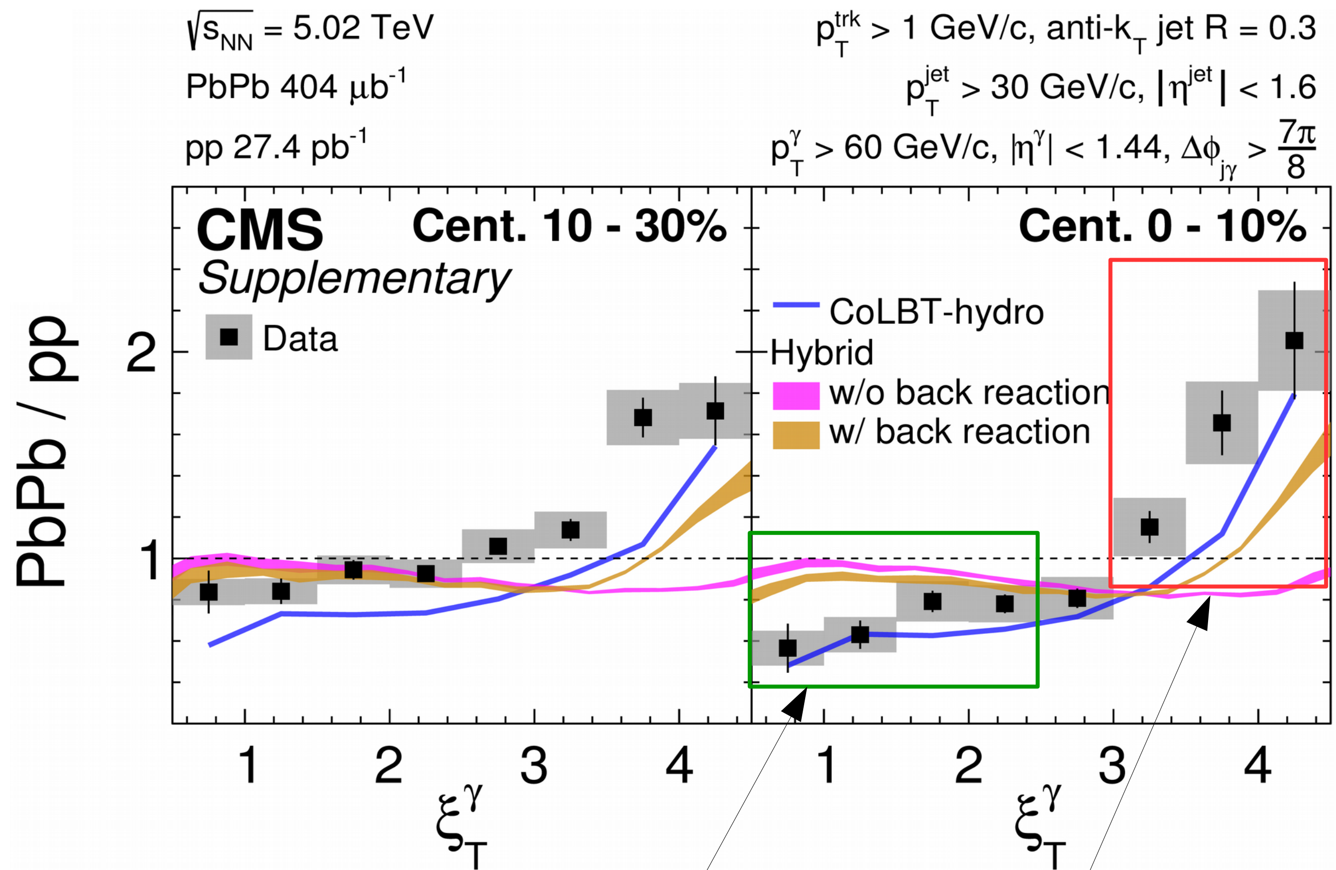
arXiv:1801.04895

Fragmentation functions of jets associated with isolated photons : initial parton energy constrained by photon pT.
Quark enriched jet sample: flavor dependence of jet quenching



Projection of the tracks pT on photon pT axis :

$$\zeta_T^{\gamma} = \ln \frac{-|\boldsymbol{p}_{\mathrm{T}}^{\gamma}|^2}{\boldsymbol{p}_{\mathrm{T}}^{\mathrm{trk}} \cdot \boldsymbol{p}_{\mathrm{T}}^{\gamma}}$$



Central PbPb collisions : a depletion of high-pT particles (sensitive to hard parton shower) and enhancement of low-pT particles (recoil)

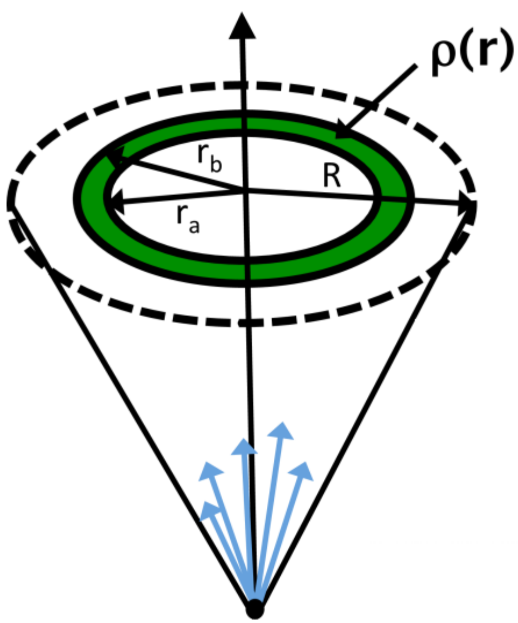
Jet shapes : light quarks vs gluons

PLB 730 (2014) 243

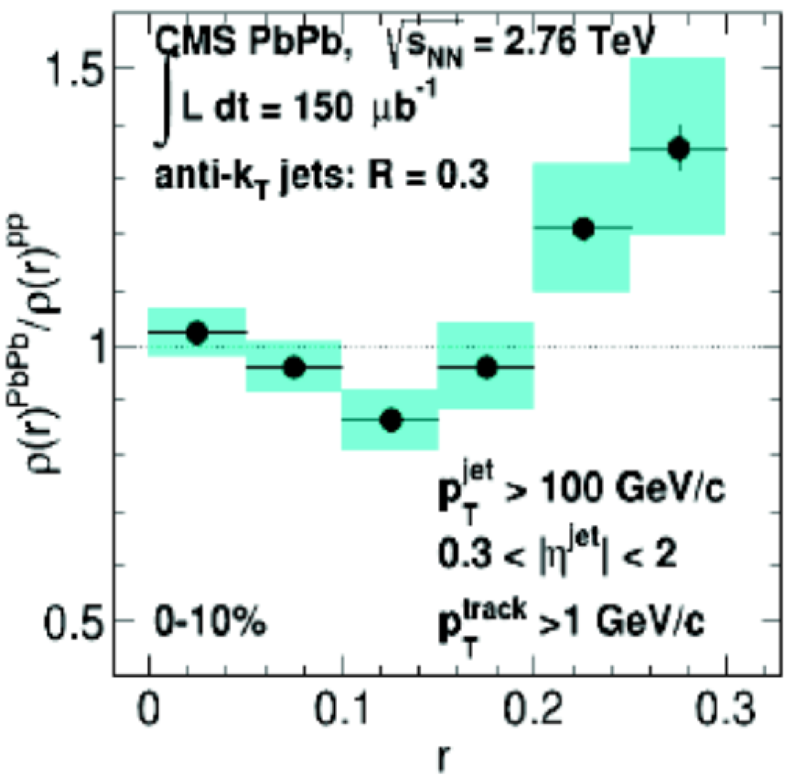
Jet shape (JS) measurements made with inclusive jet or dijet samples.

+ High statistics
-- No control over kinematics before quenching

$$\rho(r) = \frac{1}{\delta r} \frac{1}{N_{\text{jet}}} \sum_{\text{jets}} \frac{\sum_{\text{trk} \in [r_a, r_b)} p_T^{\text{trk}}}{p_T^{\text{jet}}}$$



Inclusive: Quark/Gluon mixture



Redistribution of the jet energy: a depletion of jet transverse momentum fraction at intermediate radii, 0.1 < r < 0.2, and an excess at large radii, r > 0.2.

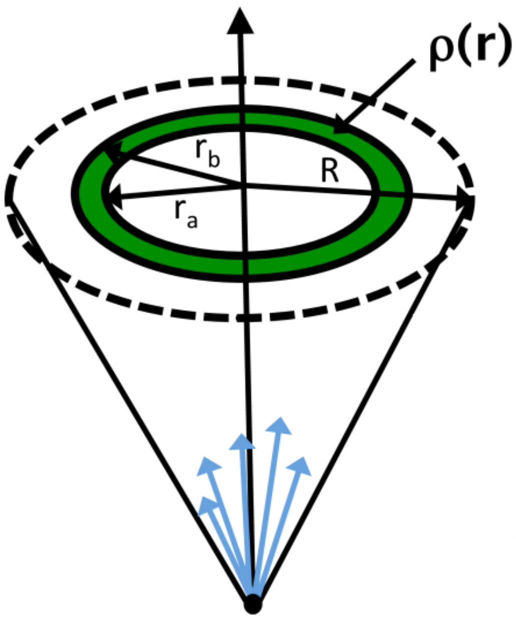
Jet shapes : light quarks vs gluons

CMS-PAS-HIN-18-006

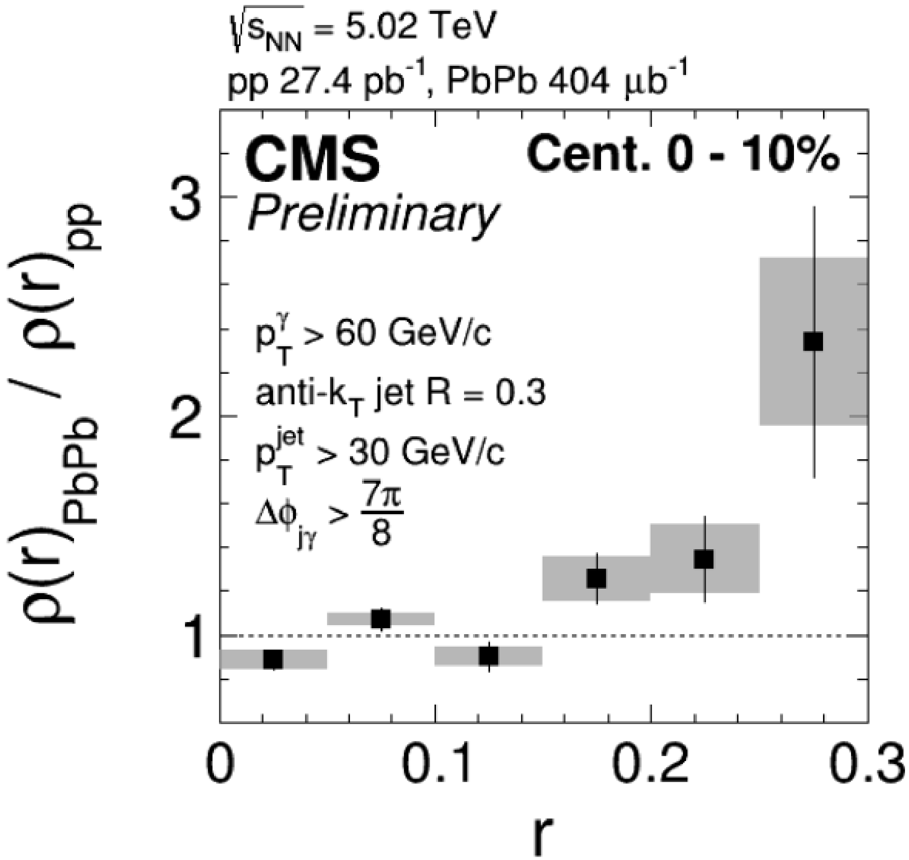
JS made with isolated-photon-tagged jets in PbPb and pp collisions.

Motivation : understand QCD properties of the medium via modification of parton shower in transverse direction

$$\rho(r) = \frac{1}{\delta r} \frac{1}{N_{\text{jet}}} \sum_{\text{jets}} \frac{\sum_{\text{trk} \in [r_a, r_b)} p_T^{\text{trk}}}{p_T^{\text{jet}}}$$



Photon-jet: Quark dominated

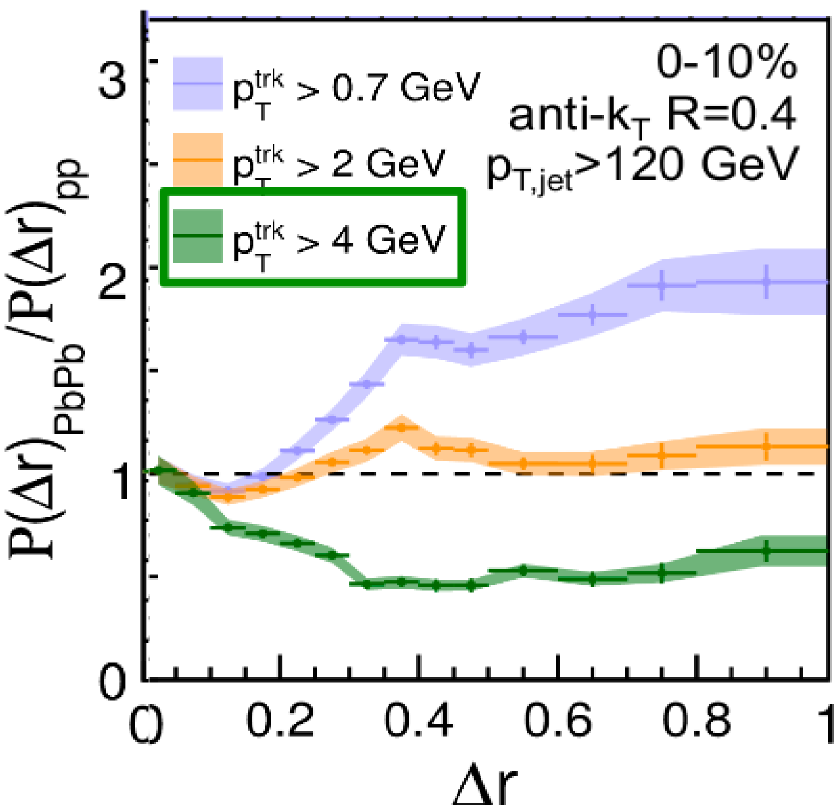


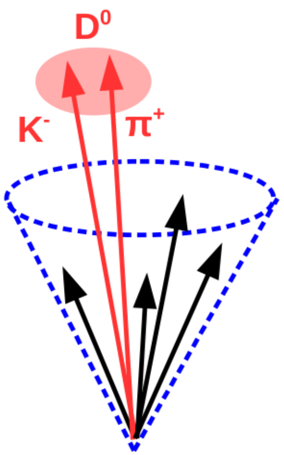
γ+jet compared to inclusive jet: Larger enhancement at large r.
Increased quark fraction (70-80%)? Lower jet pT threshold (higher fraction of quenched jets)?

arXiv:1803.00042
CMS-PAS-HIN-18-006
CMS-PAS-HIN-18-007

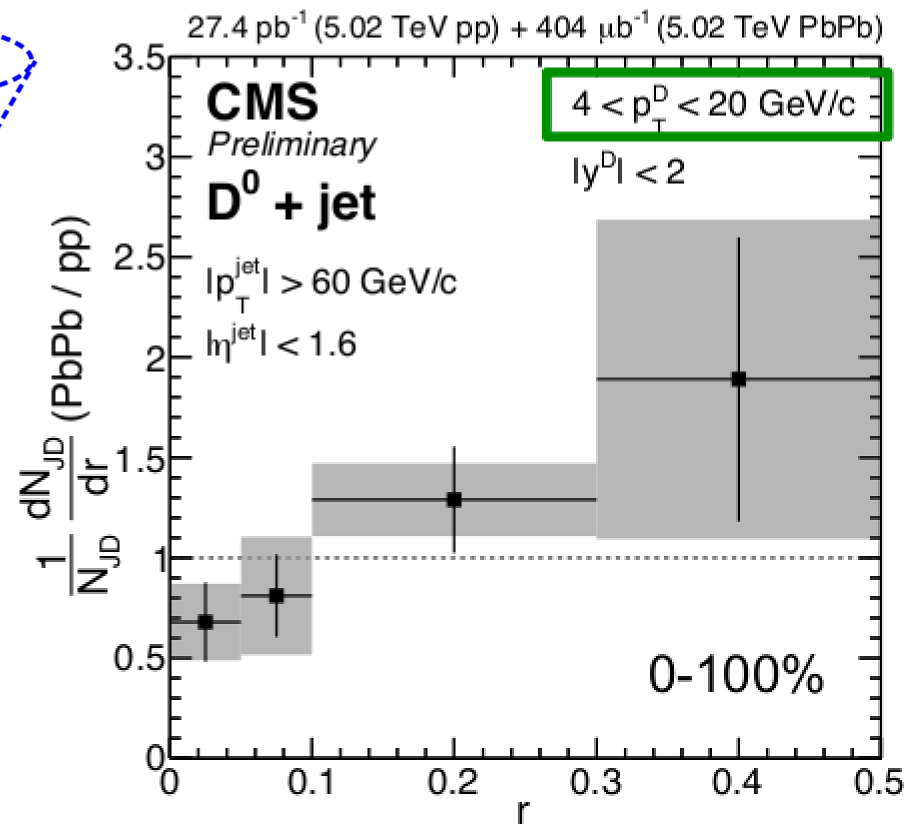
Jet shapes : light vs heavy

Inclusive: Quark/Gluon mixture





D-jet: Heavy flavor dominated



pT < 2 GeV: enhancement
pT > 4 GeV: depletion

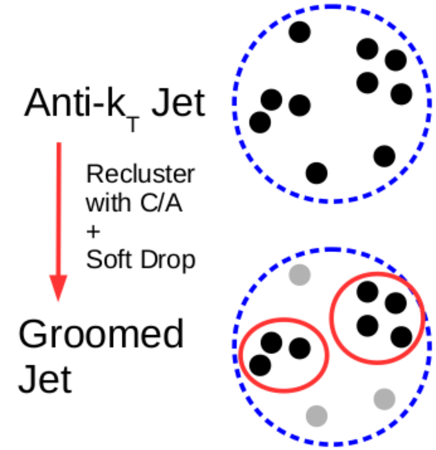
Possible hint of D0 mesons with pT>4 GeV appearing at large angle

Jet substructure

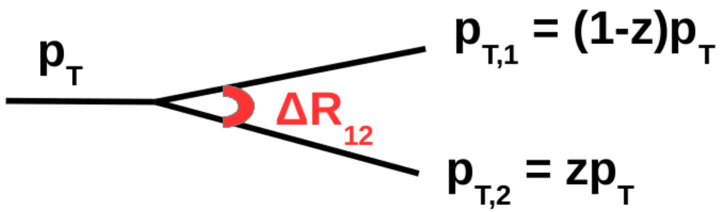
arXiv:1805.05145

Jet grooming: removes soft divergences and isolates the hard structure → can be used as a proxy to the hard splitting.

One of the methods : SoftDrop (SD)



$$z_g = \frac{\min(p_{T,i}, p_{T,j})}{p_{T,i} + p_{T,j}} > z_{cut} \left(\frac{\Delta R_{ij}}{R_0} \right)^{\beta}$$



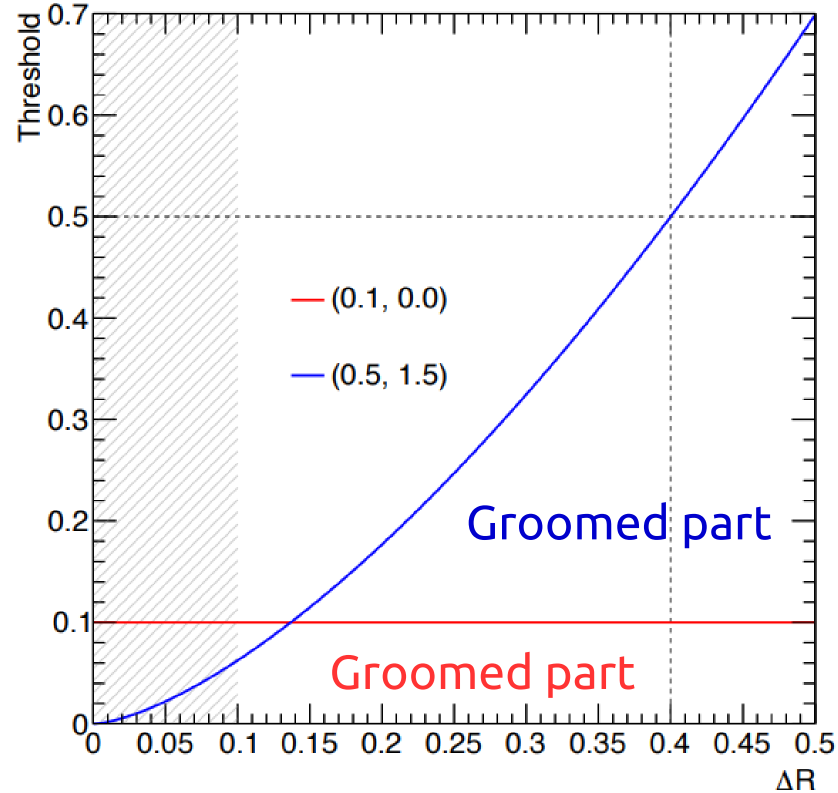
SD settings (z_cut , β) :

(0.1, 0.0) :

Ignore angular separation
Insensitive to high order QCD

(0.5, 1.5) :

Stronger rejection for large angle radiation
Focus on jet core

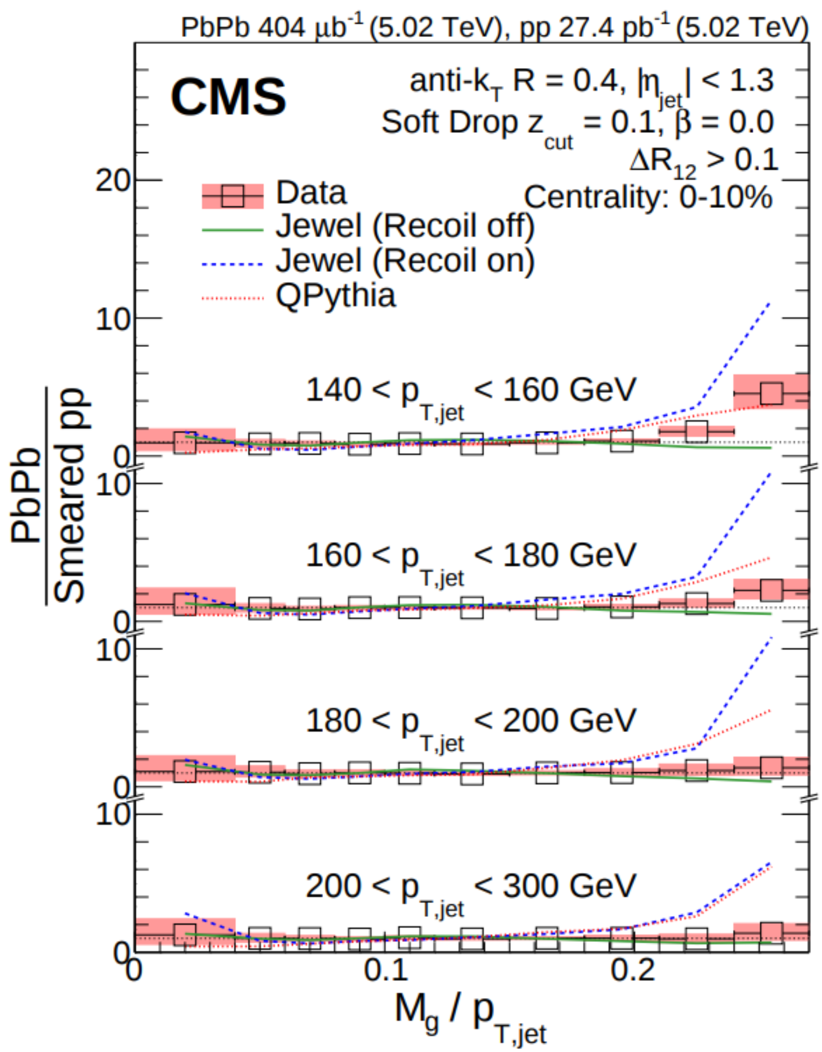


Jet substructure: groomed jet mass

arXiv:1805.05145

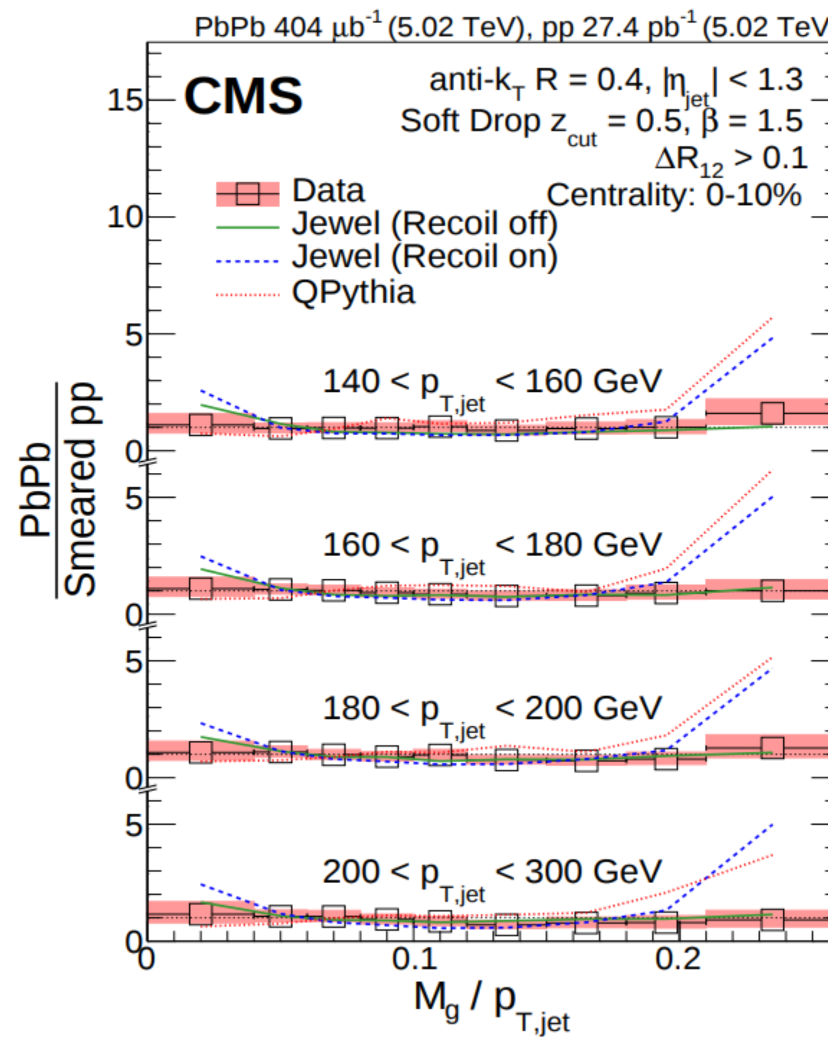
Observable : groomed jet mass divided by the ungroomed jet transverse momentum

(0.1, 0.0)



No significant modification in jet core → Modifications happen for less balanced and large angle hard splittings ?

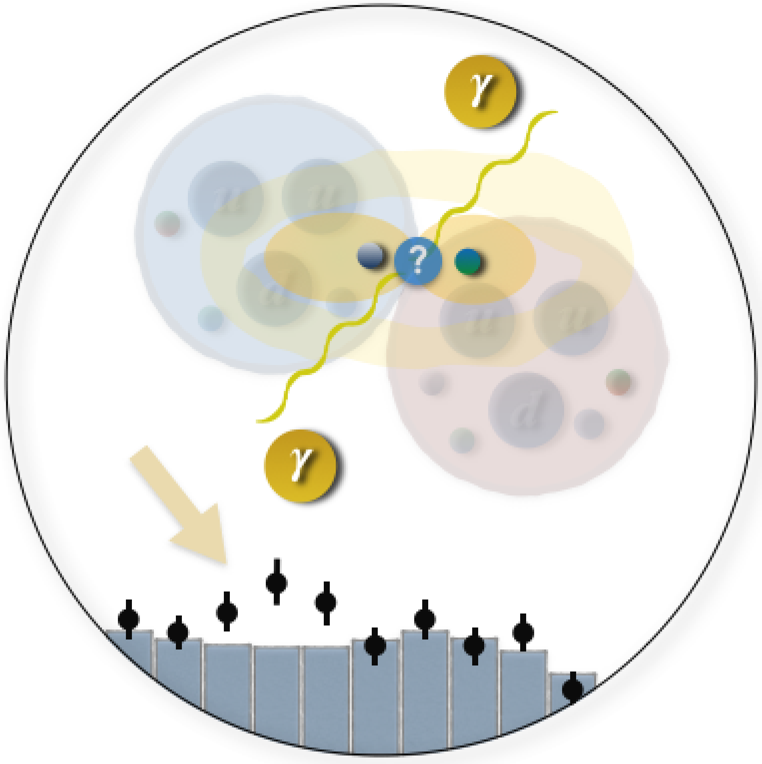
(0.5, 1.5)



Models predict large modification at large mass. Modification weakens with increasing pT

New physics :

Chiral magnetic effect
Light-by-light scattering

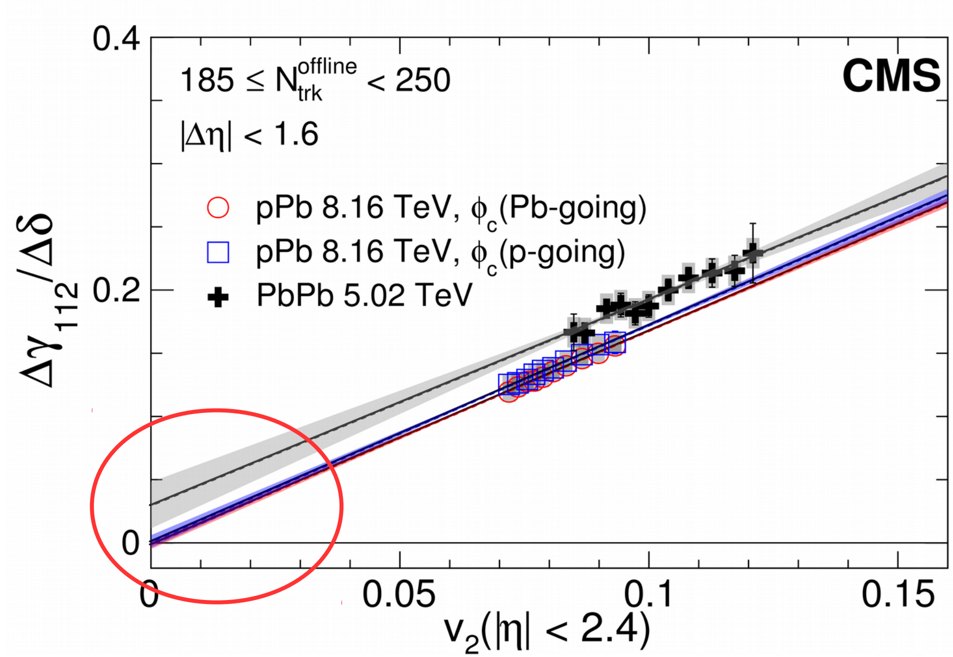


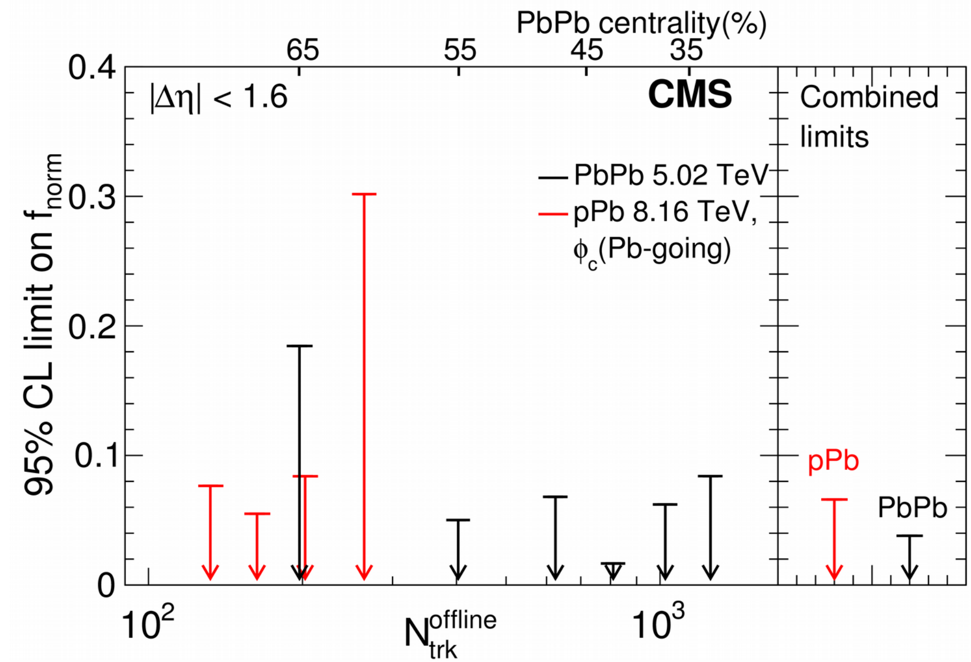
Chiral magnetic effect

Phys. Rev. C, 97, 044912

Charge-dependent correlation with respect to the reaction plane

$$\frac{\Delta\gamma}{\Delta\delta} = \kappa \cdot v_2 + \frac{\Delta\gamma^{CME}}{\Delta\delta}$$



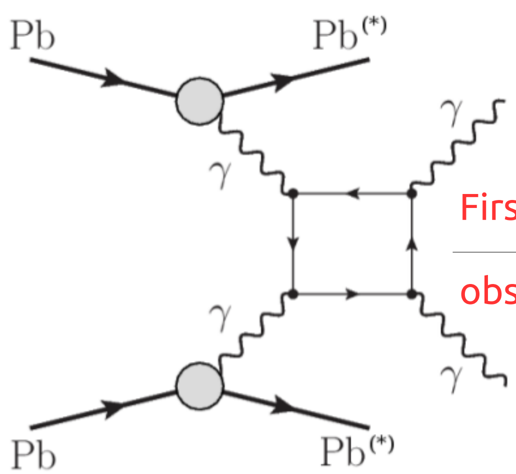


Possible CME signal (at LHC energies) is less than 7% for PbPb collisions @ 95% CL

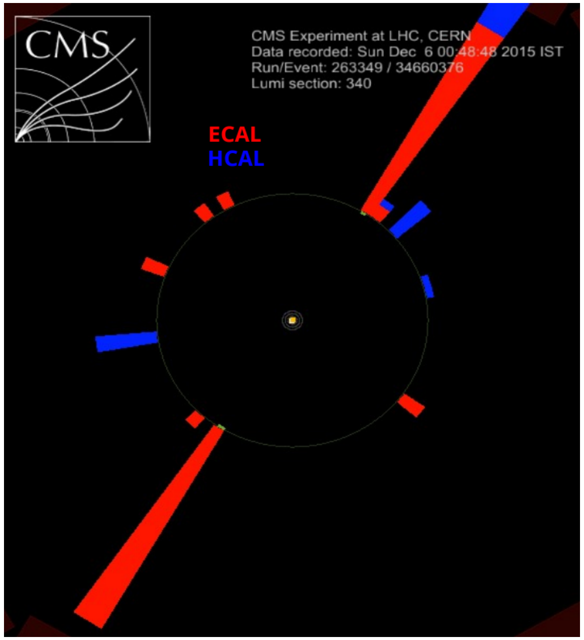
Light-by-light scattering

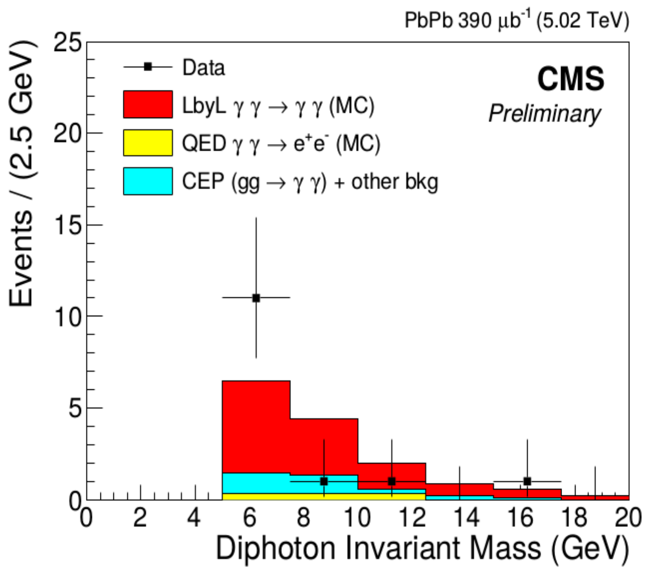
CMS-PAS-FSQ-16-012

Ultraperipheral PbPb collisions : Pure quantum mechanical process in the QED (coupling α), via virtual box diagrams containing charged particles



First time observed in CMS





14 candidates → significance = 4.1σ (4.4σ) observed (expected)

$$\sigma_{fid} = 122 \pm 46\ (\mathrm{stat}) \pm 4\ (\mathrm{theo})\ \mathrm{nb}$$

consistent with Standard Model : $\sigma_{fid} = 138 \pm 14\ \mathrm{nb}$

Summary

- Many new results from CMS in 2018 :

  ➤ First results from Xe+Xe run at 5.44 TeV in October 2017
  ➤ Important findings also in pp and pPb data

- Parton shower modifications in various aspects :

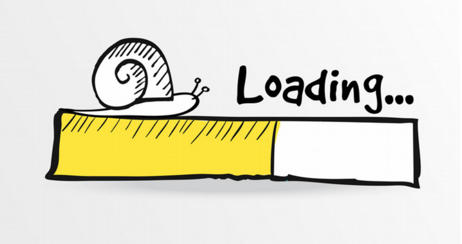
  ➤ jet fragmentation functions
  ➤ jet shapes
  ➤ groomed jet substructure
  ➤ flavor dependence

- Important results in Quarkonia :

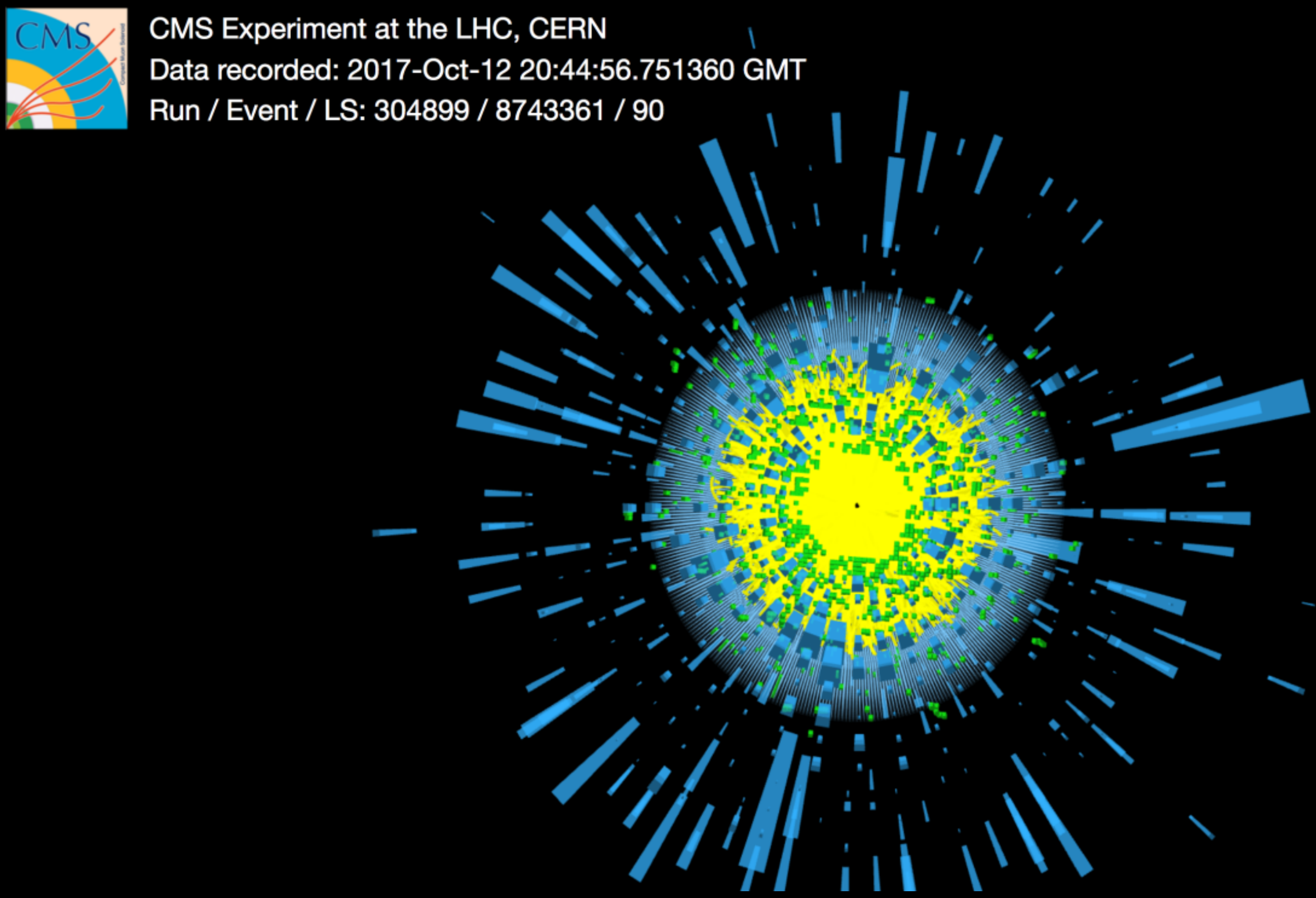
  ➤ sequential melting of $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ in PbPb
  ➤ possible different nuclear effects in prompt J/ψ and $\psi(2S)$ production

- Looking for new physics effects with CME and light-by-light scattering

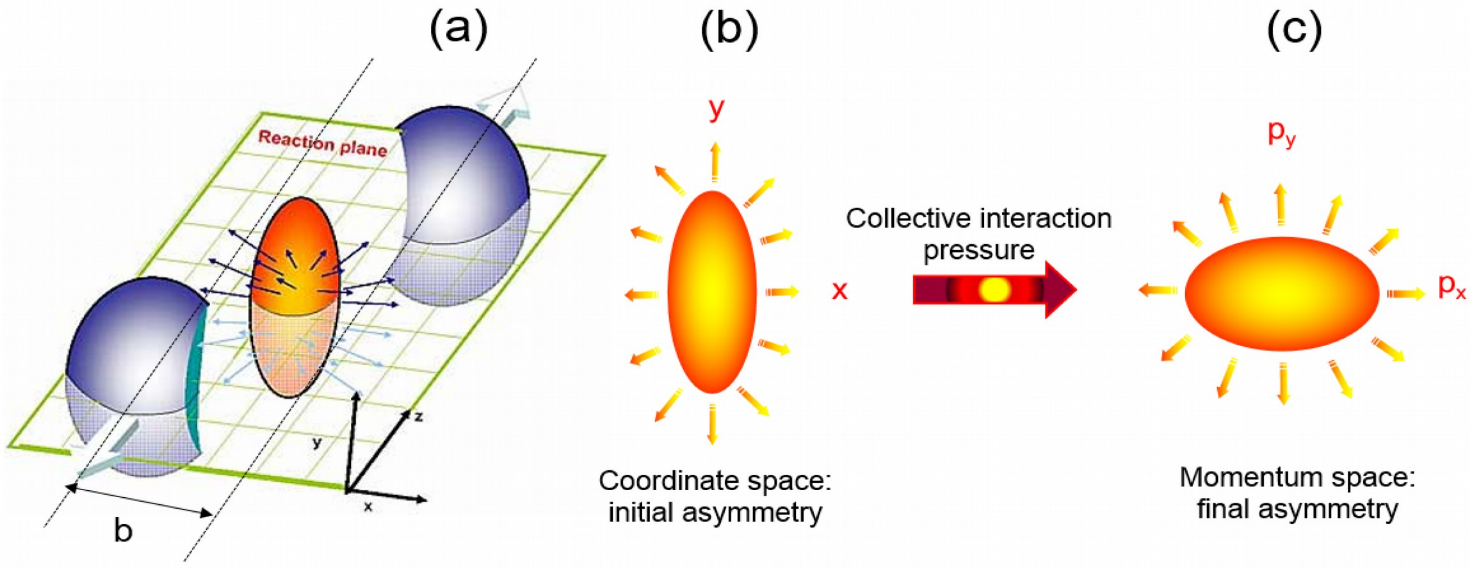
- New PbPb data-taking : November 2018 ...



Thank you!

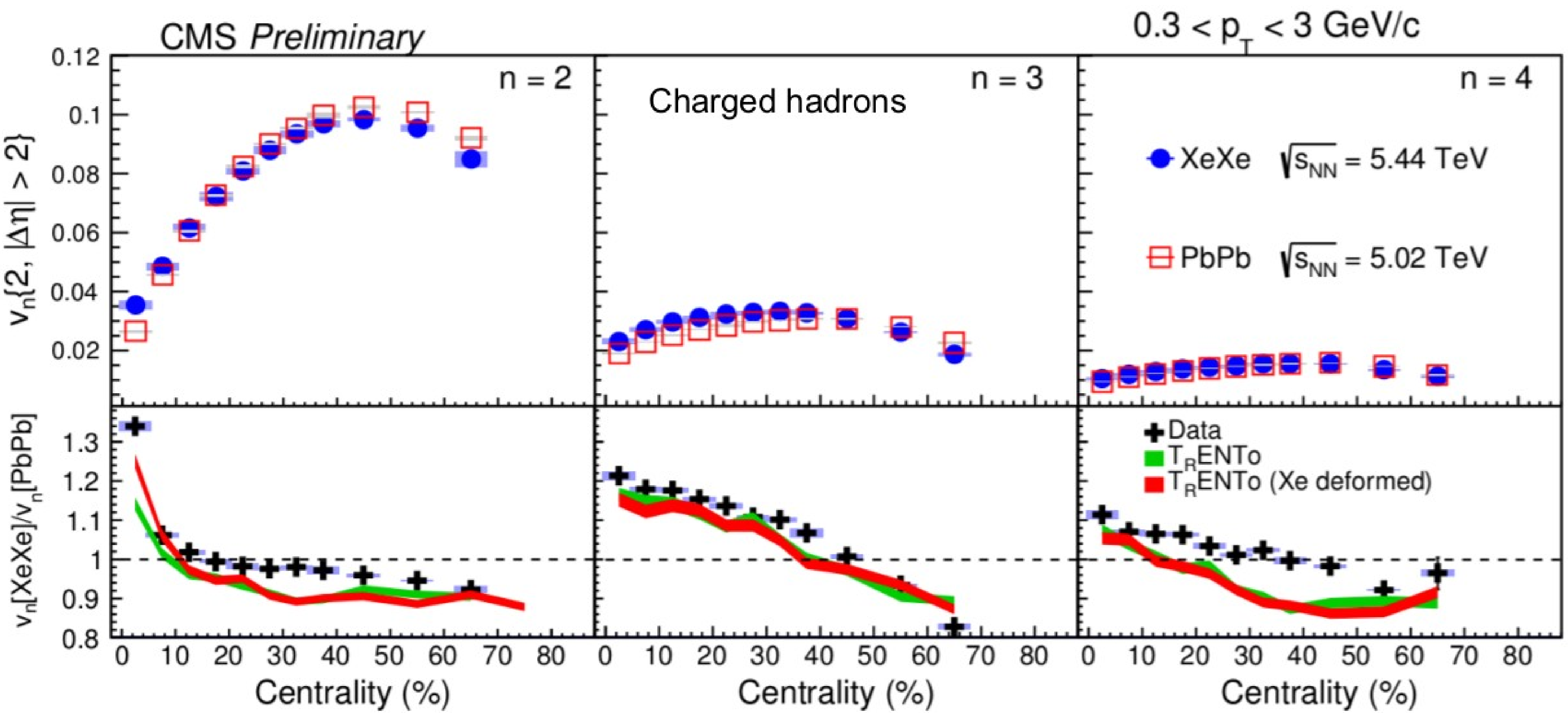

CMS
CMS Experiment at the LHC, CERN
Data recorded: 2017-Oct-12 20:44:56.751360 GMT
Run / Event / LS: 304899 / 8743361 / 90

Collective effects



Flow in XeXe

CMS-PAS-HIN-18-001



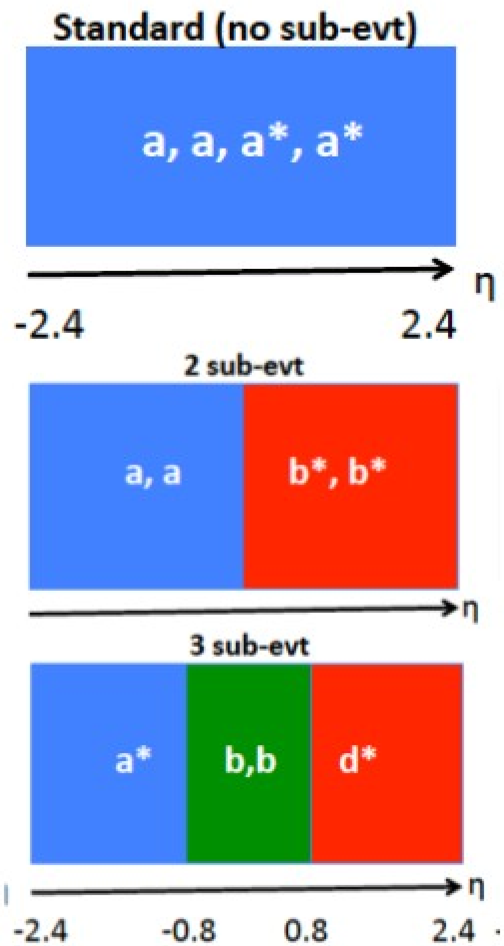
Difference between PbPb and XeXe might be explained
by quadrupole deformation of Xe ion

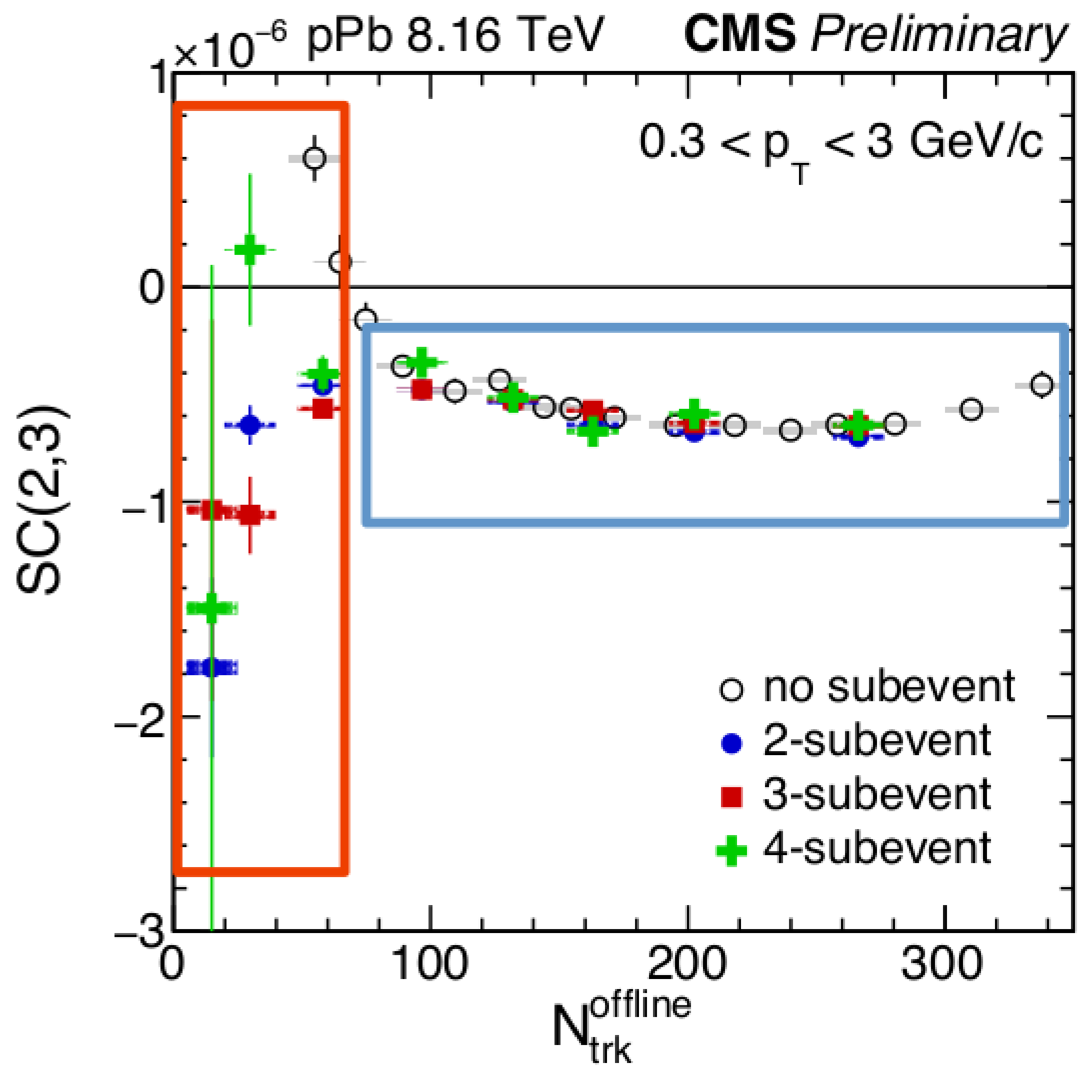
Collectivity in small systems

CMS-PAS-HIN-18-015

Suppressing non-flow contamination in low multiplicity events using subevents

Goal: understand onset of collective behaviour





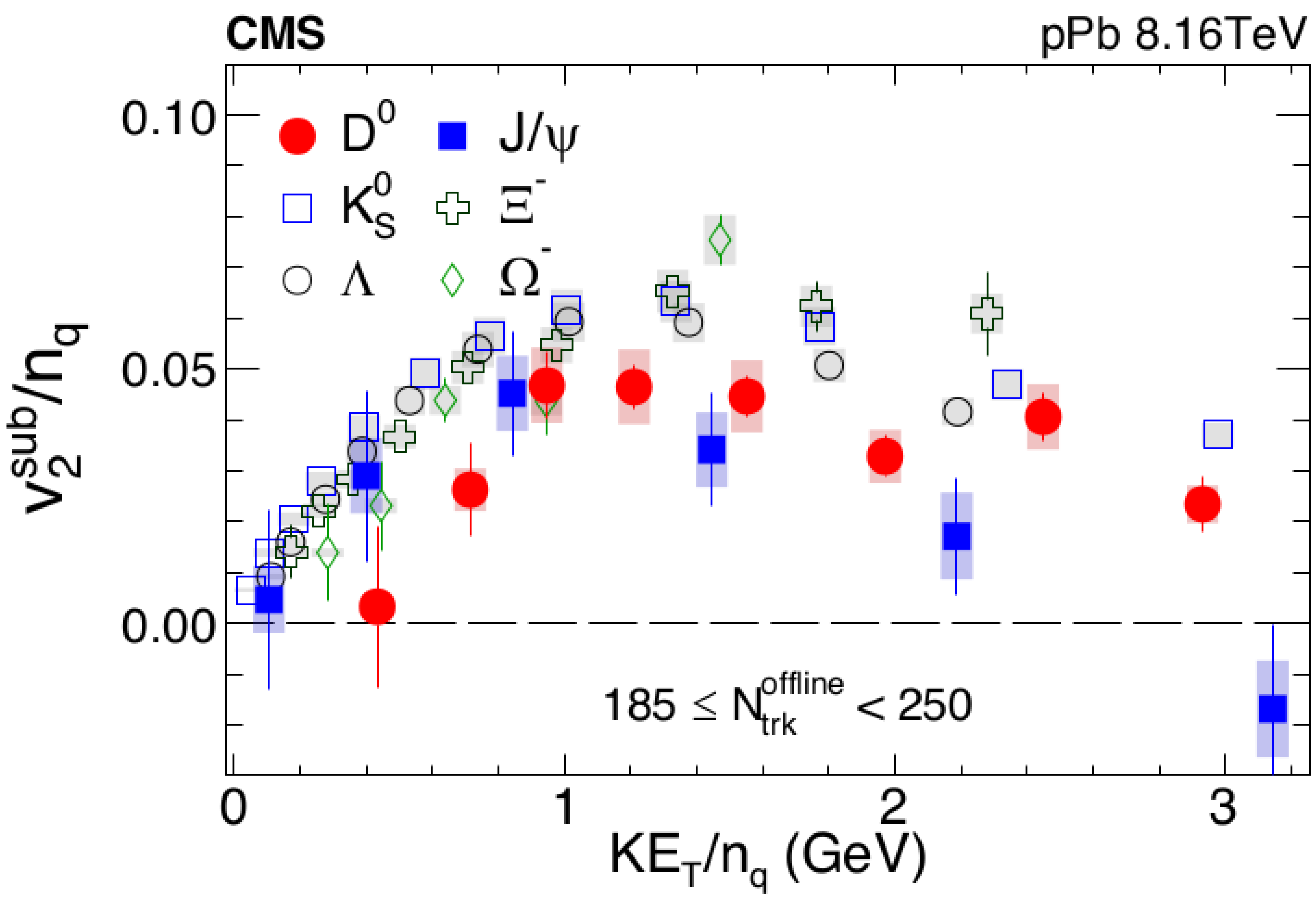
High multiplicity (Ntrk > 80): all methods consistent → non-flow negligible

Low multiplicity (Ntrk > 80): non-flow suppressed using subevents . v2 and v3 anti-correlated down to Ntrk =50 in pPb collisions

Strange and charm v2 in pPb

arXiv:1804.09767,
CMS-PAS-HIN-18-010

New results of charm (D0 , J/Ψ) and strange flow in pPb

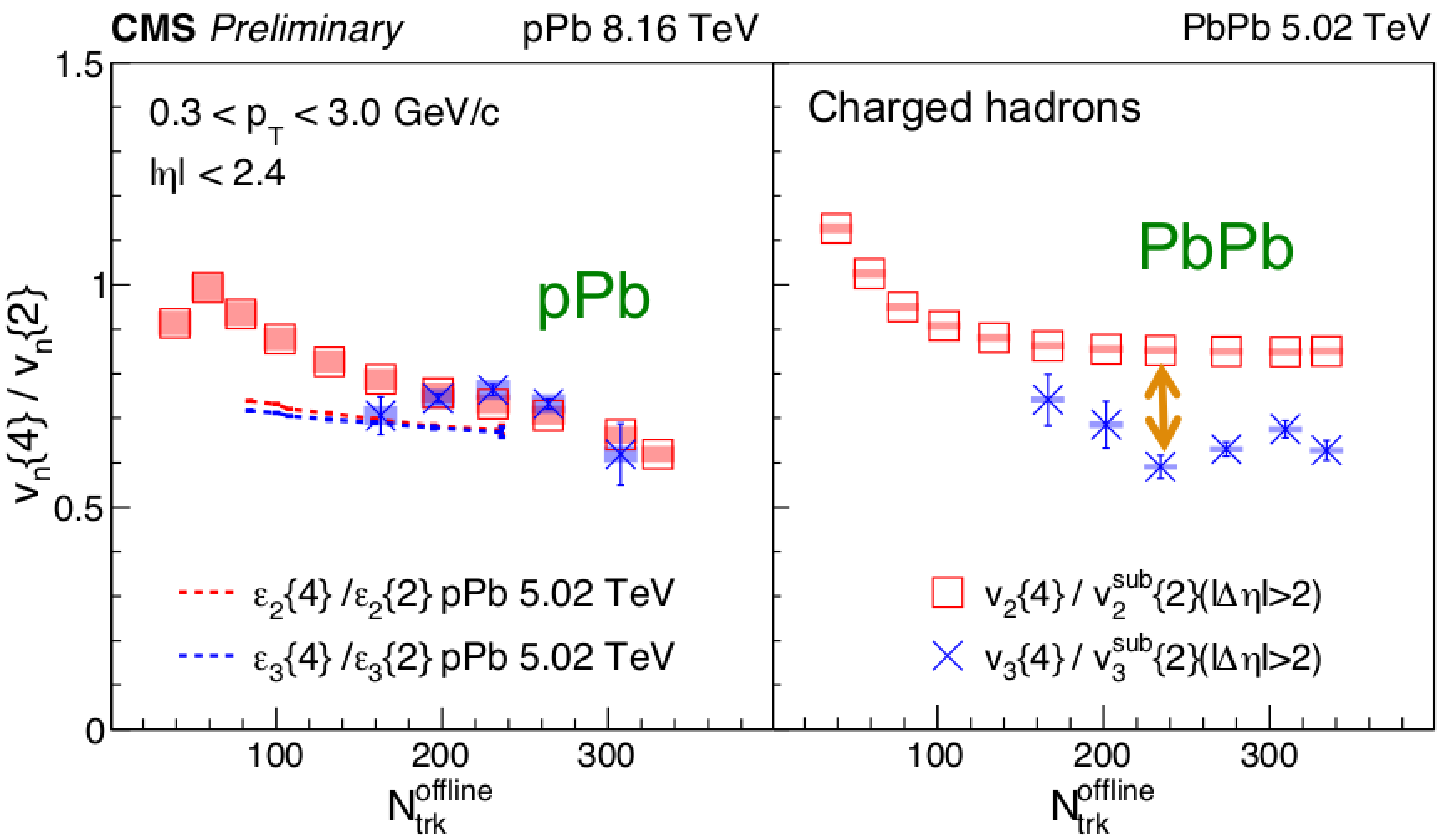


Charm v2 observed in pPb collisions. Weaker than for light quarks
Less collectivity for charm quarks in pPb?

Higher harmonics

CMS-PAS-HIN-17-004

First v3 {4} measurement in pPb collisions



PbPb: vn{4}/vn{2} larger for v2 than v3 → global geometry dominant for v2

pPb: vn{4}/vn{2} similar for v2 and v3 → initial-state fluctuations dominant