Latest results on high multiplicity pp and pPb collisions with CMS

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on behalf of the CMS Collaboration

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Small systems

Before the LHC:

- Quark Gluon Plasma created only in A-A collisions.
- pA used to study cold nuclear matter effects.
- pp is the baseline for heavy-ion physics.

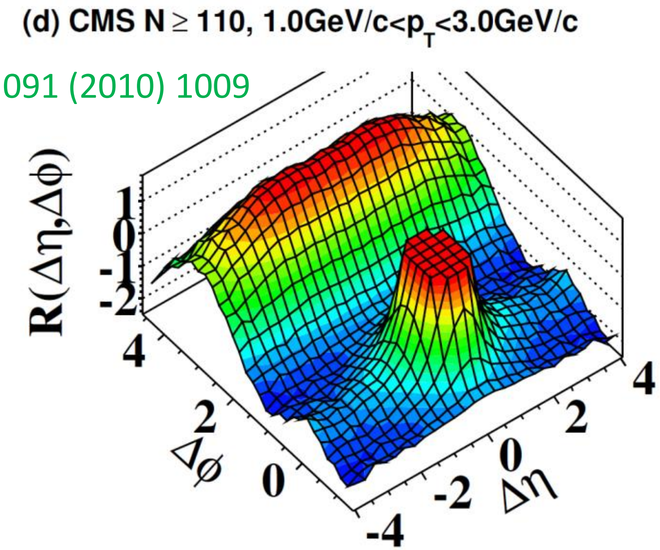
The discovery of collectivity phenomena in pp and pPb has changed our previous knowledge: small systems show QGP-like characteristics!

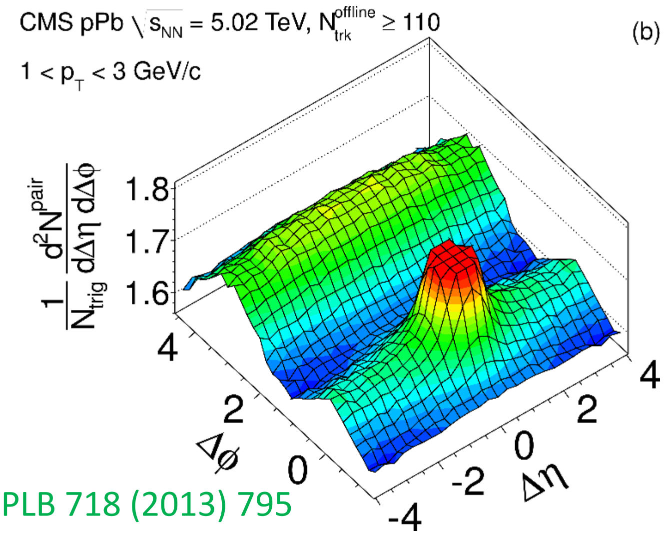
Currently there are two main explanations:

- Quantum correlations from Color Glass Condensate framework (initial state)
- Hydrodynamic models (final state).

In this talk I will review the latest results on high multiplicity pp and pPb collisions with CMS.

JHEP 091 (2010) 1009





PLB 718 (2013) 795

Azimuthal anisotropy

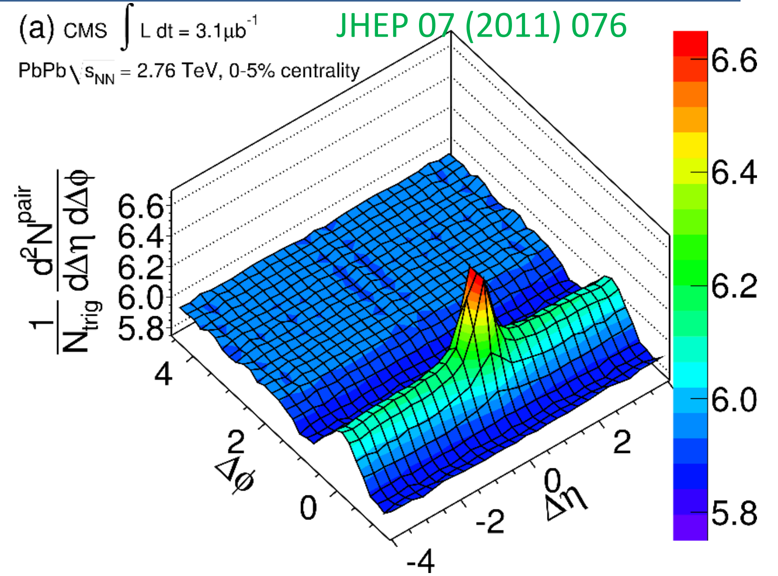
Strong collectivity in A-A collisions manifests in long range azimuthal correlations, characterized by a ridge-like structure in the near side ($\Delta\Phi \approx 0$).

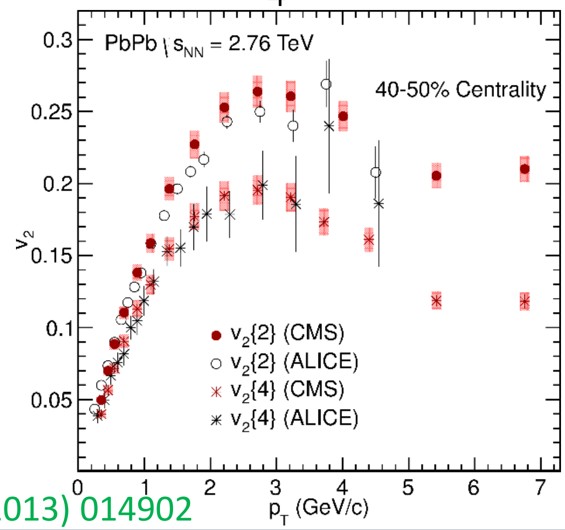
For non-central collisions, these correlations are dominated by the 2nd order Fourier component of the azimuthal distribution.

$$\frac{\mathrm{d}N}{\mathrm{d}\varphi} = \frac{N_0}{2\pi}\left(1 + 2 \cdot v_1 cos(\varphi - \Psi_1) + 2 \cdot v_2 cos[2(\varphi - \Psi_2)] + \dots\right)$$

Elliptic flow (v_2) directly reflects the medium response to the initial collision geometry and its fluctuations.

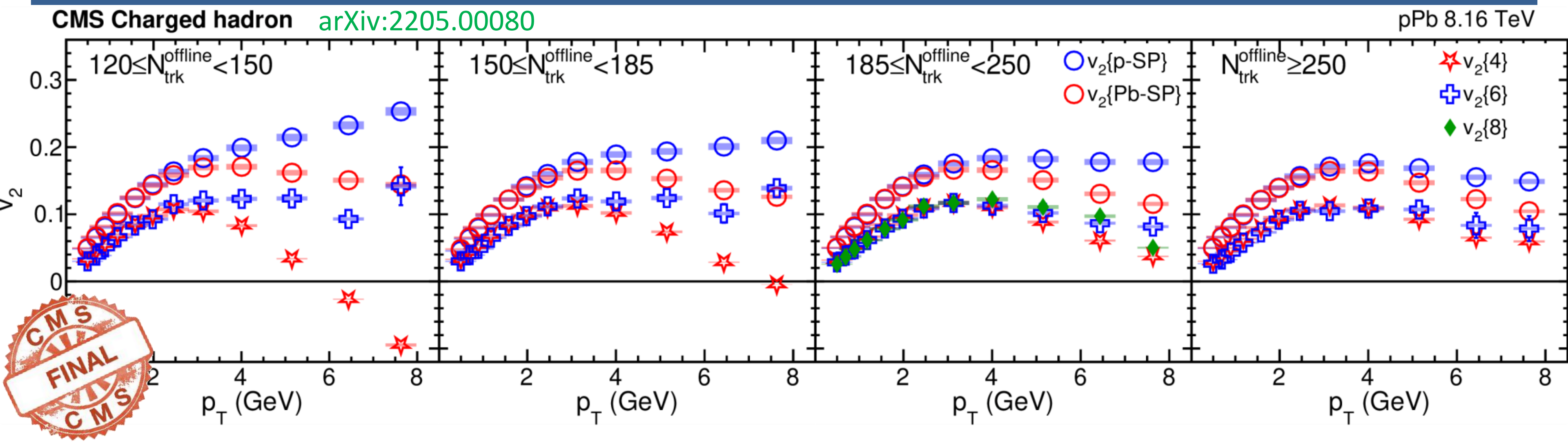
JHEP 07 (2011) 076





PRC 87 (2013) 014902

Azimuthal anisotropy: charged hadrons

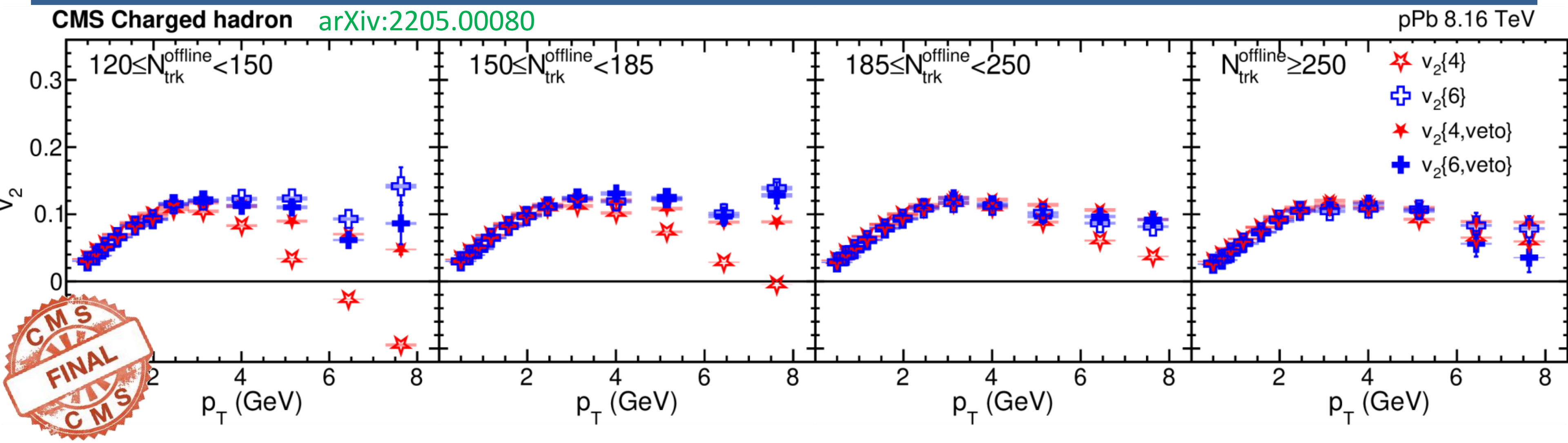


Greater values for v2{SP} relative to multiparticle flow coefficients are consistent with the expectation of event-by-event fluctuation of the elliptic flow observable.

v2{SP} results in the p-going side are systematically larger compared to the Pb-going side, suggesting a larger non-flow contribution.

Clear separation of v2{4} and v2{6} at low multiplicity and at high pT. The difference can be attibuted to jet-related non-flow correlations.

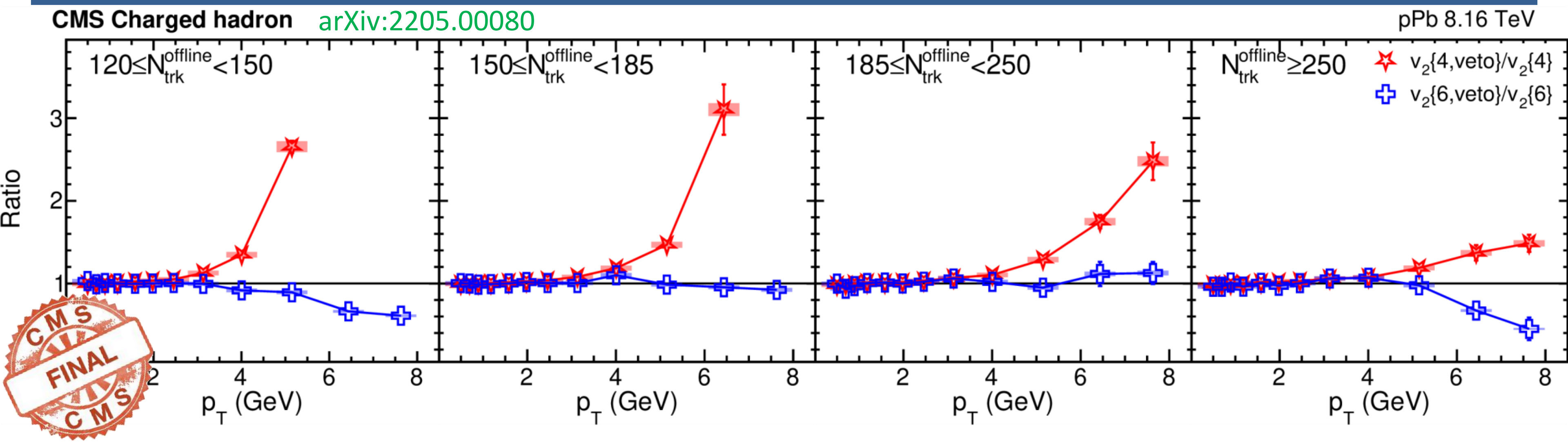
Azimuthal anisotropy: charged hadrons



After rejecting the jet events (veto), the v2{4,veto} is larger than the inclusive one. Confirming previous hypothesis.

In contrast, v2{6,veto} is consistent with the inclusive result. This can be better appreciatted plotting the ratio of both results.

Azimuthal anisotropy: charged hadrons



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Larger multiplarticle flow coefficients involve more particles in the calculation, reducing the effect of few particle correlations.

Azimuthal anisotropy: c & b

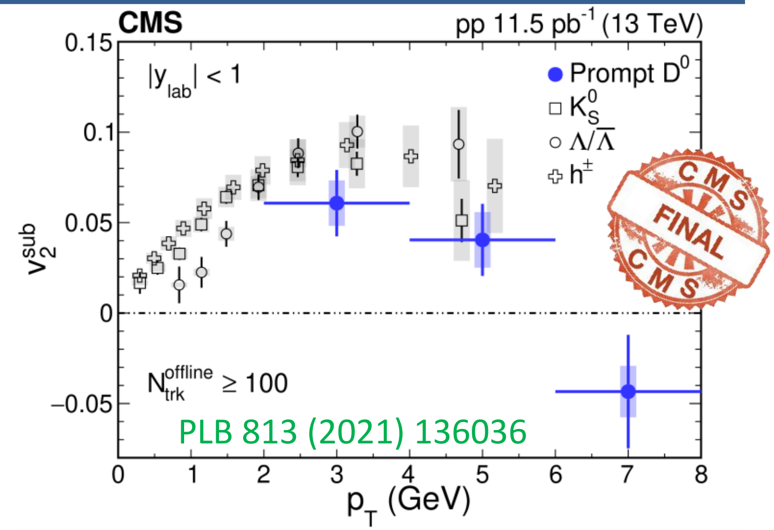
In pp, there is a positive v2 signal in the 2 < pT < 4 GeV range for prompt charm hadrons (indication of the collectivity of charm quarks in pp collisions).

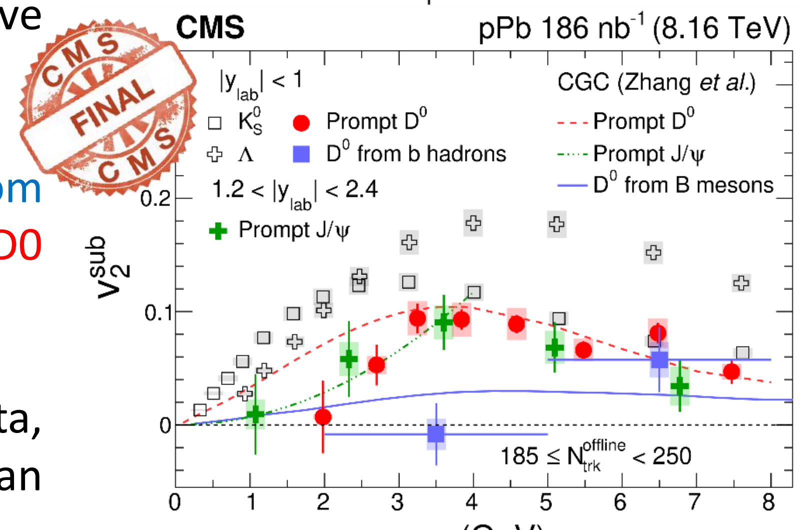
The magnitude of the elliptic flow is comparable with light flavour hadrons.

In pPb: at low pT D0 from *b* hadrons v2 is consistent with zero, while at high pT there is a hint of positive elliptic flow.

Furthermore, in this high pT regime, the v2 of D0 from *b* compatible with prompt J/ψ and with prompt D0 (within uncertainties).

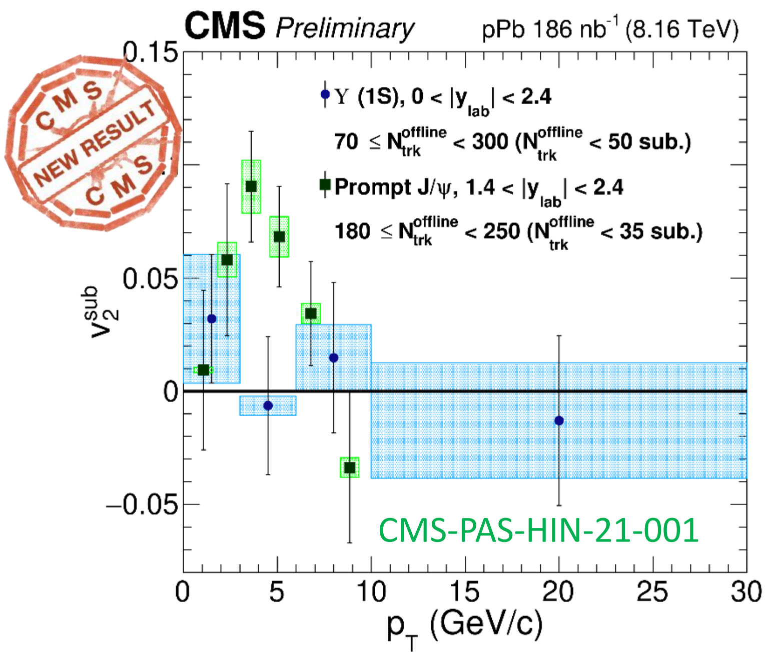
CGC predictions qualitatively reproduce the data, indicating that initial stage effects may play an importat role.

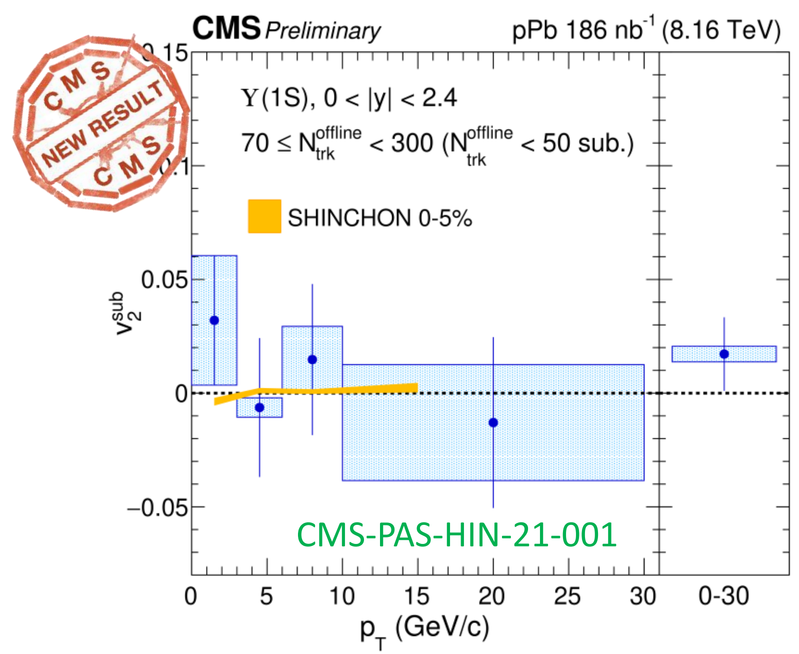




PLB 813 (2021) 136036

Azimuthal anisotropy: c & b





First elliptic flow measurement of Upsilon (1S) in pPb collisions! Results are consistente with zero, as in Pb-Pb.

Comparison to J/ψ ➔ *b* quarks experience less collective motion than charm.

Model with final-state interactions only can correctly describe the data.

V2-pT correlations

Mean pT ([pT]) reflects the strenght of radial flow, related to the initial fireball energy density.

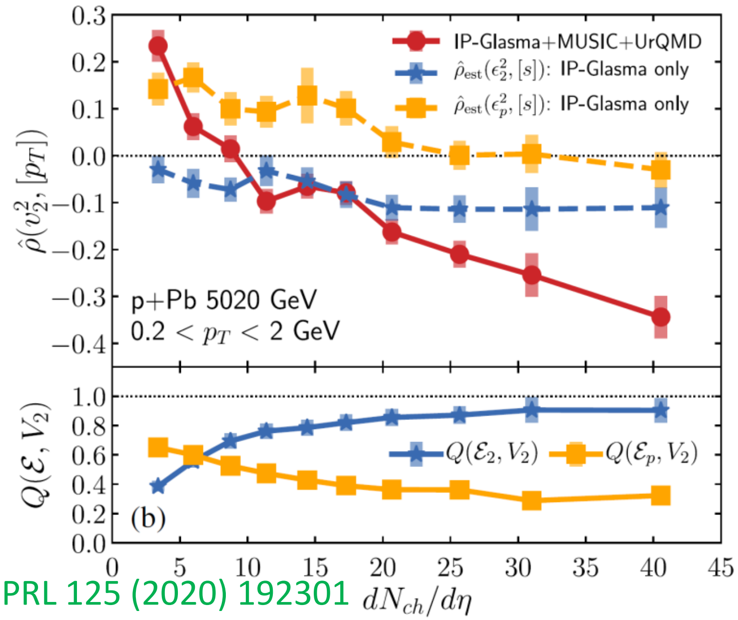
Correlations between vn and [pT] probe the fluctuations of the initial density profile.

Correlations carry information about the origin of the observed momentum anisotropy.

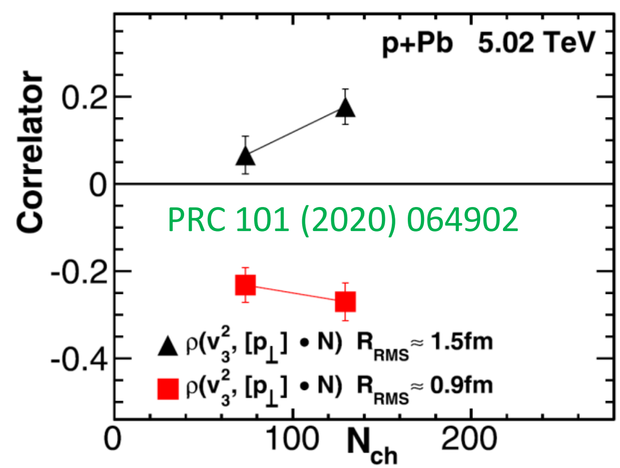
No sign change at low multiplicity without initial v2 from CGC.

Sensitive to the transverse size of the initial fireball.

$$\rho(v_n^2, [p_\mathrm{T}]) = \frac{\mathrm{cov}(v_n^2, [p_\mathrm{T}])}{\sqrt{\mathrm{Var}(v_n^2)_\mathrm{dyn}}\sqrt{\mathrm{Var}([p_\mathrm{T}])_\mathrm{dyn}}}$$



PRL 125 (2020) 192301



PRC 101 (2020) 064902

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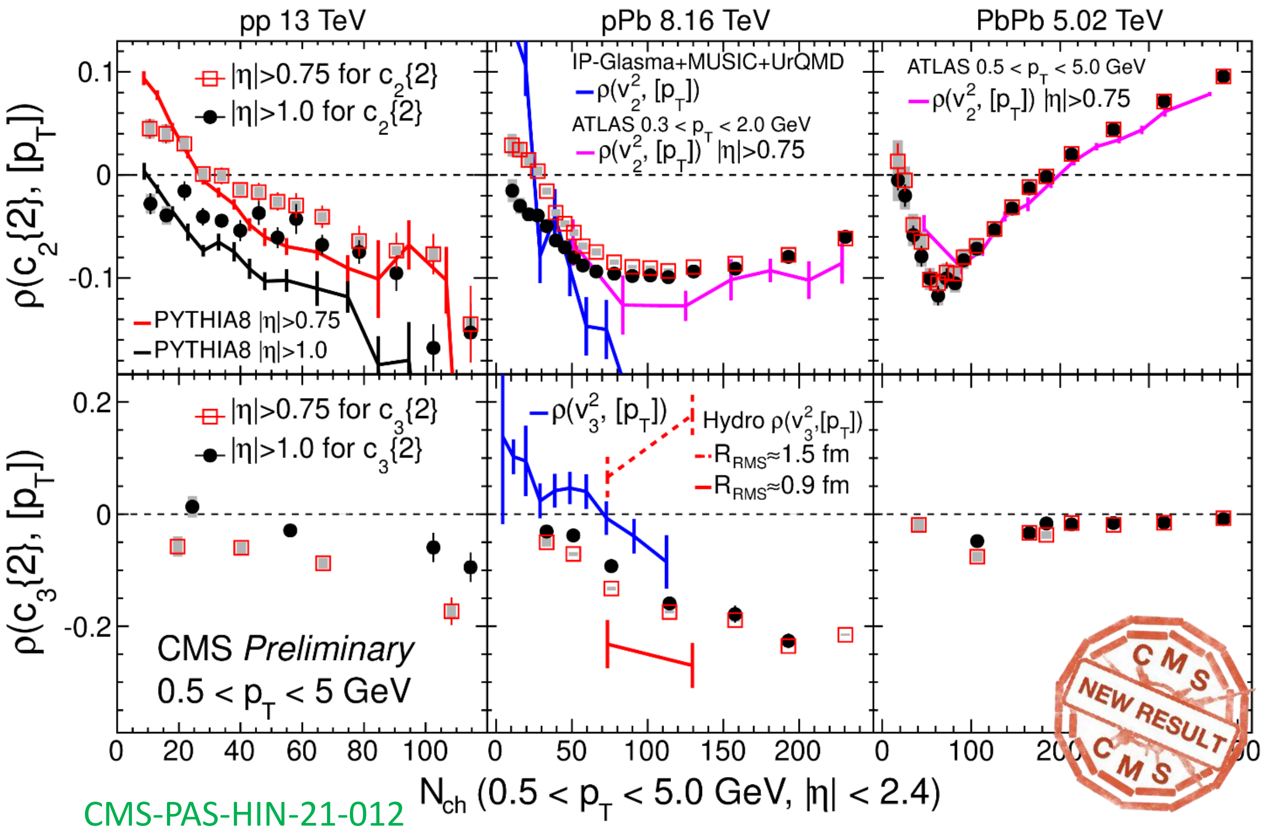


CMS-PAS-HIN-21-012

pp and pPb: sign change at low multiplicity. Disappears when a larger η gap is used (non-flow removed).

As a consequence, there is no evidence of CGC in the data.

For pPb the results are compared to hydro simulation. Better description achieved with a smaller initial fireball.

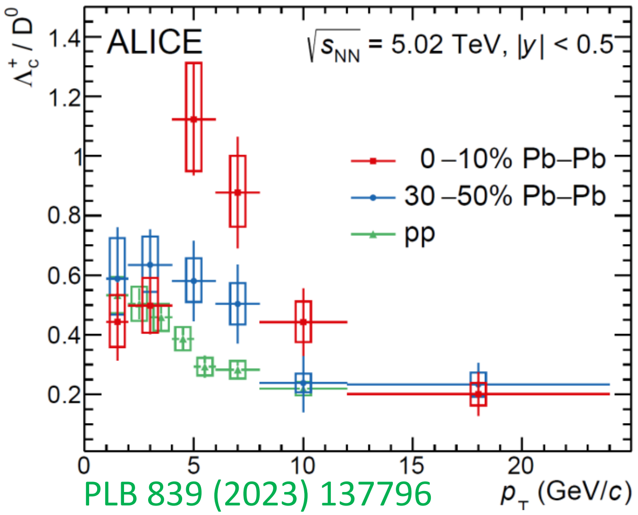
Charm baryon to meson ratio

Besides collectivity, hadronization processes are also affected by final-state effects.

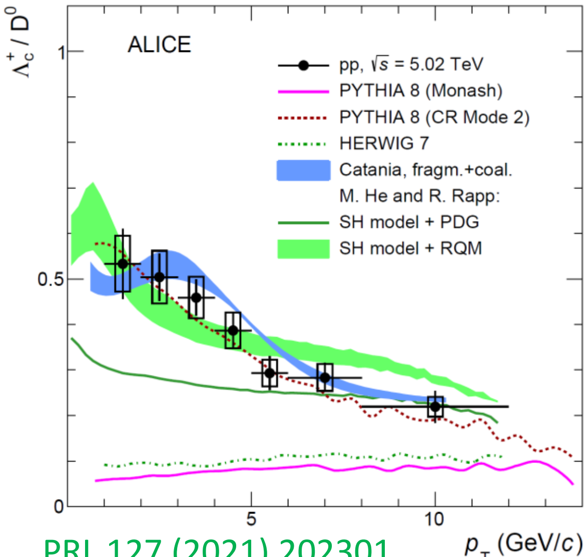
Parton coalescence effects are expected to be stronger with the increasing system size and can enhance the baryon to mesons yield at intermediate pT: larger ratios in Pb-Pb compared to pp.

Recent measurements for Λ_c^+/D^0 ratios in pp and pPb show that coalescence process play an important role in hadronization.

Besides this, multiplicity dependece for strange particles show an increasing trend from low to high multiplicity in pp, pPb and Pb-Pb (PLB 768 (2017) 103).



PLB 839 (2023) 137796



PRL 127 (2021) 202301

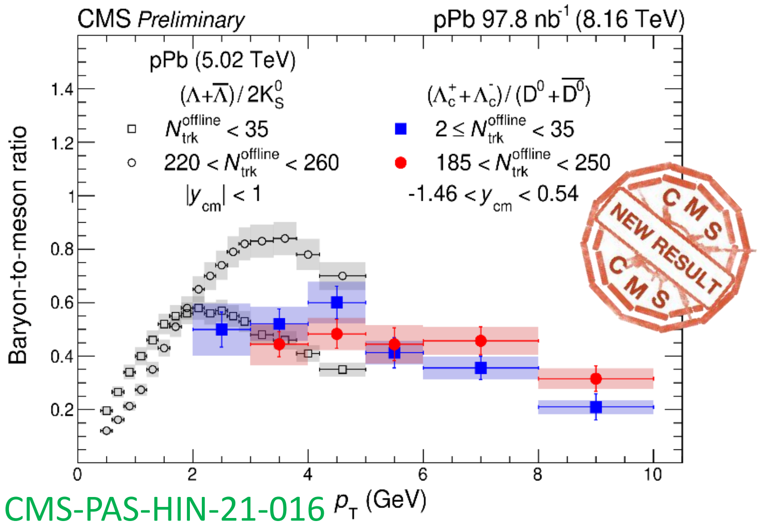
Charm baryon to meson ratio

Λ_c^+/D^0 (CC included): whithin uncertainties, there is no multiplicity dependence.

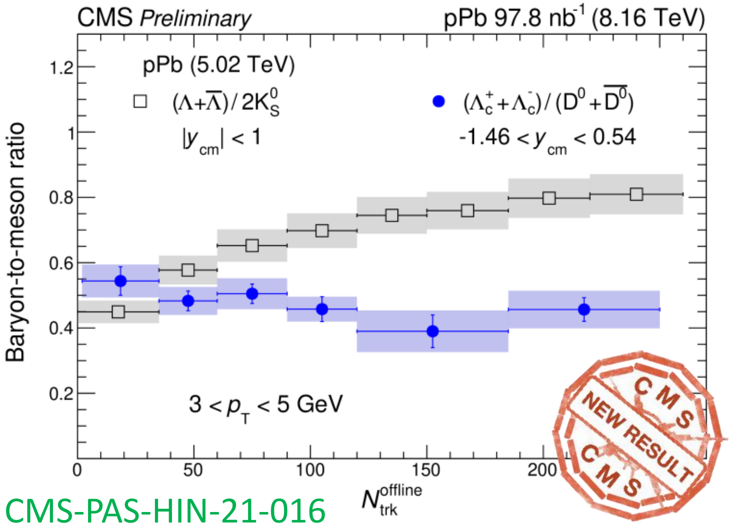
For low multiplicities the ratio is shown to decrease towards high pT regime. High multiplicity events show exactly the same behavior.

Strange baryons to meson ratios show same tendency, but the difference between low and high multiplicity is important at mid pT.

Baryons to mesons ratios as a function of multiplicity show, once again, important difference. On one hand strange hadrons ratio increases by a factor 2. On the other hand, charm hadrons ratio is flat.



CMS-PAS-HIN-21-016



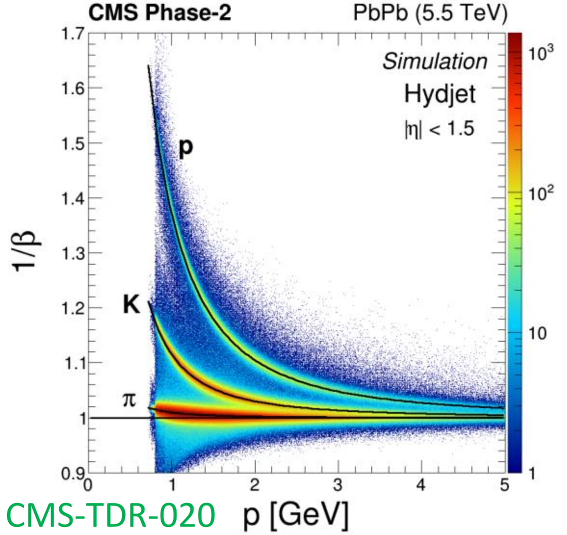
CMS-PAS-HIN-21-016

HL-LHC: MIP Timing Detector

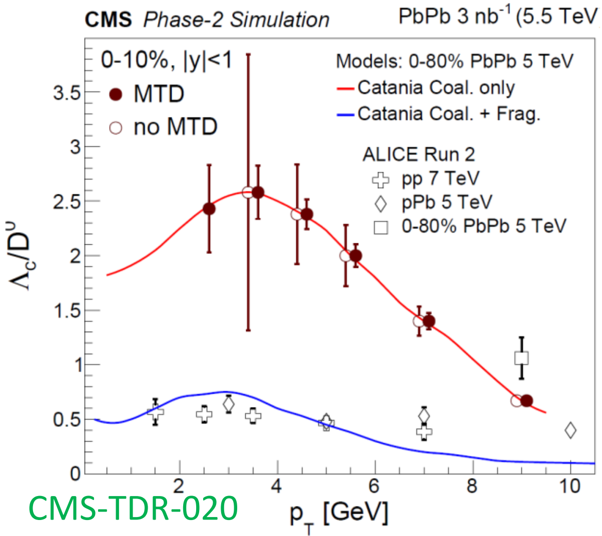
Unique hermetique particle identification coverage.

Will further enhance CMS capabilities in the heavy-ion physics programe.

Detailed characterization of HF hadron collectivity and hadronization in high multiplicity pp and pPb collisions.



CMS-TDR-020



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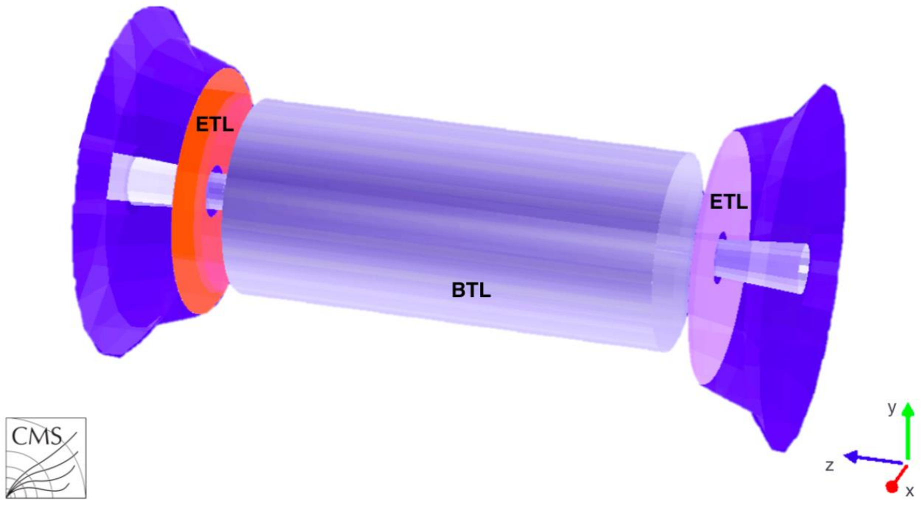

Summary

CMS has a broad program to study the physics of high multiplicity pp and pPb collisions.

In pPb: important non-flow correlations at low multiplicities and high pT for v2{4} and v2{6}, hint of positive elliptic flow at high pT for D0 from *b* hadrons, v2-pT correlations better described by hydro models with an initial fireball of R_{RMS} = 0.9 fm and no multiplicity dependence for Λ_c^+/D^0.

Positive elliptic flow for prompt charm hadrons in proton-proton collisions.

MTD will allow a deeper understanding of the small systems in HL-LHC era.

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Thanks for your attention