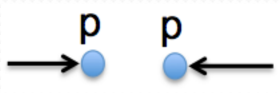
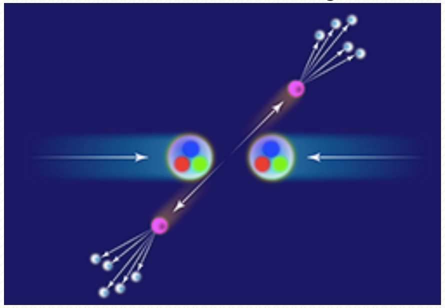
Heavy Ions: soft physics (CMS)

Jovan Milošević
University of Belgrade
Vinča Institute of Nuclear Sciences, Serbia

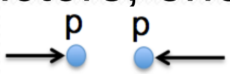
Outline

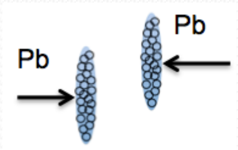
- a possible onset of collective behavior in a smallest system – jets formed in pp coliissions



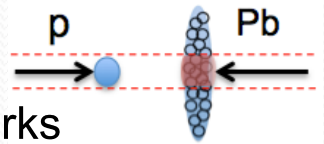


- new insights into the dynamics of jet evolution in the vacuum

- By B^+ and B^0_S nuclear modification factors, energy loss and hadronization is studied using 

and 

  - Comparison with charged hadrons and D^0
  - Comparison with different models
  - Providing constraints for the models

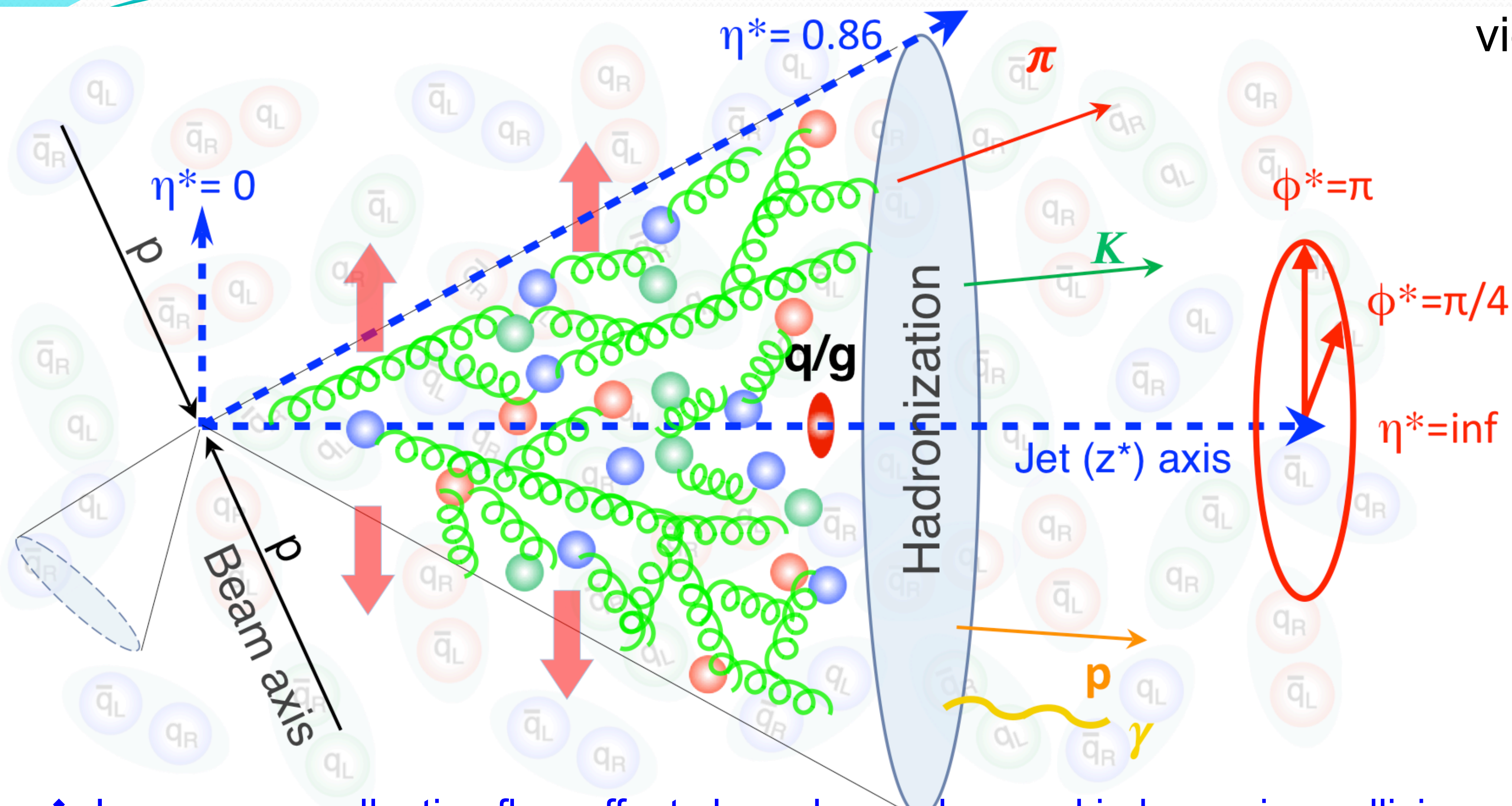
- Ratio of $\psi(2S)$ and J/ψ meson production in 

  - Constraints hadronization models for heavy quarks
  - Supporting picture of co-moving particles that may dissociate weakly-bound excited state of charmonia more than the ground state

- Conclusions

Collectivity from jets in pp collisions

Schematic view



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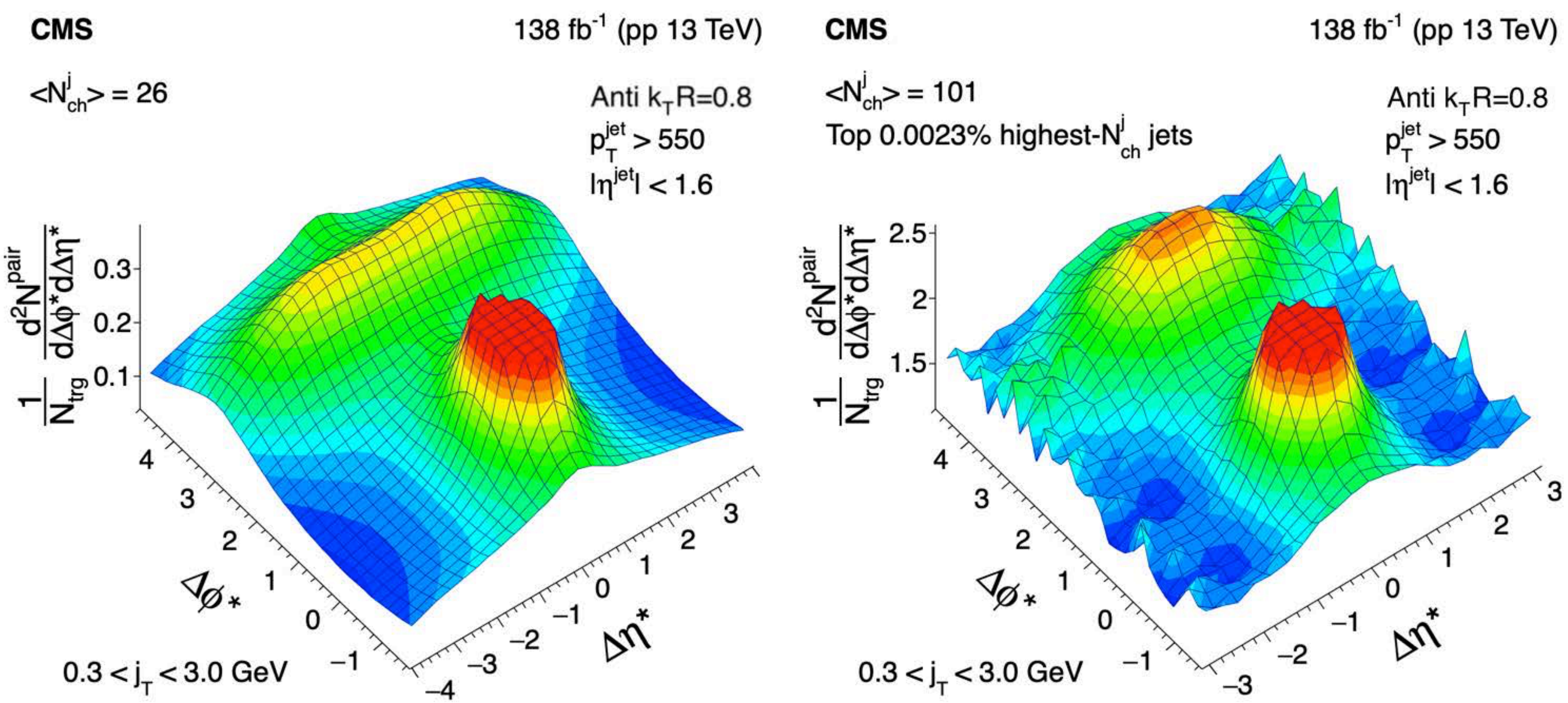
arXiv: [hep-ex] 2312.17103

- ❖ Long-range collective flow effects have been observed in heavy ion collisions
- ❖ Collective hydrodynamic behavior was not expected in small systems like pp.
- ❖ Notwithstanding these expectations, such a collectivity has been observed in high-multiplicity pp collisions [ATLAS PRL116(2016)172301 and CMS PRL116(2016)172302]
- ❖ Could one expect developments of collective effects in high multiplicity jets too?
- ❖ Two-particle correlations wrt coordinate system defined with respect to the jet axis

Two-particle correlations from jets' charged particles



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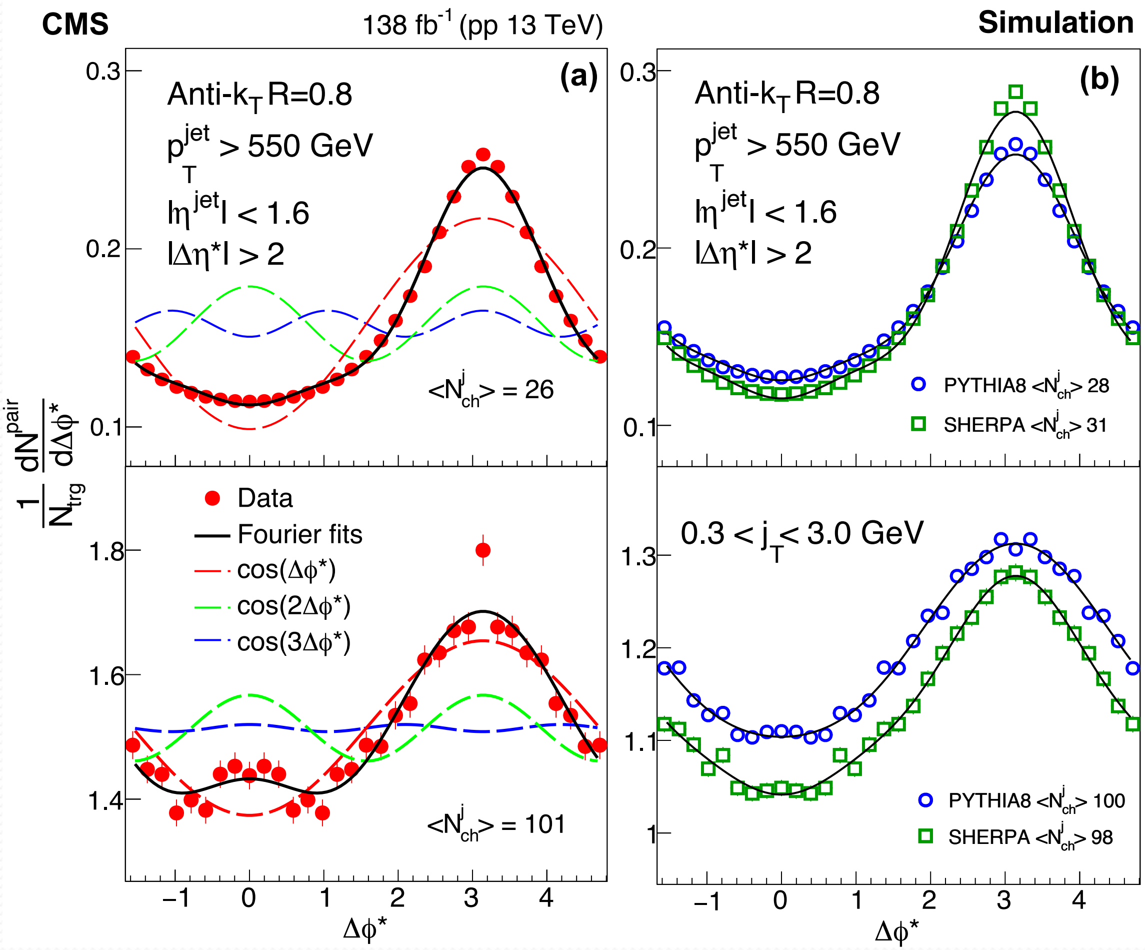
$$\frac{1}{N_{ch}^{trg}} \frac{d^2 N^{pair}}{d\Delta\eta^* d\Delta\phi^*} = B(0,0) \frac{S(\Delta\eta^*, \Delta\phi^*)}{B(\Delta\eta^*, \Delta\phi^*)}$$ where $$S(\Delta\eta^*, \Delta\phi^*) = \frac{1}{N_{ch}^{trg}} \frac{d^2 N_{ch}^{sig}}{d\Delta\eta^* \Delta\phi^*}$$ and $$B(\Delta\eta^*, \Delta\phi^*) = \frac{1}{N_{ch}^{trg}} \frac{d^2 N_{ch}^{combin}}{d\Delta\eta^* \Delta\phi^*}$$

1D Fourier decomposition $$\frac{1}{N_{ch}^{trg}} \frac{dN^{pair}}{d\Delta\phi^*} = C\left[1 + 2\sum_{n=1}^{\infty} V_{n\Delta}^* \cos(n\Delta\phi^*)\right]$$

The cut $\Delta\eta^* > 2$ is applied in order to remove short-range correlations

At high-N^j_{ch} class, near-side ridge at $\Delta\phi^*$=0. The factorization $v_2^* = \sqrt{V_{n\Delta}^*}$ is assumed

1D $\Delta\phi^*$ correlation functions



Examples of 1D $\Delta\phi^*$ correlation function with $0.3<j_T<3.0$ GeV in two N_{ch}^j classes

Redefined particle momentum

$$\vec{p}^* = \left(j_T, \eta^*, \phi^*\right)$$

where j_T is the particle p_T wrt jet axis

High-N_{ch}^j class corresponds to ~10^{-5} of all jets with p_T^{jet}>550 GeV

At high-N_{ch}^j class a near-side ridge is observed.

Near-side ridge in jet is less prominent than the one observed in pp or in pA collisions
PYTHIA 8 or SHERPA does not produce corresponding near-side enhancement

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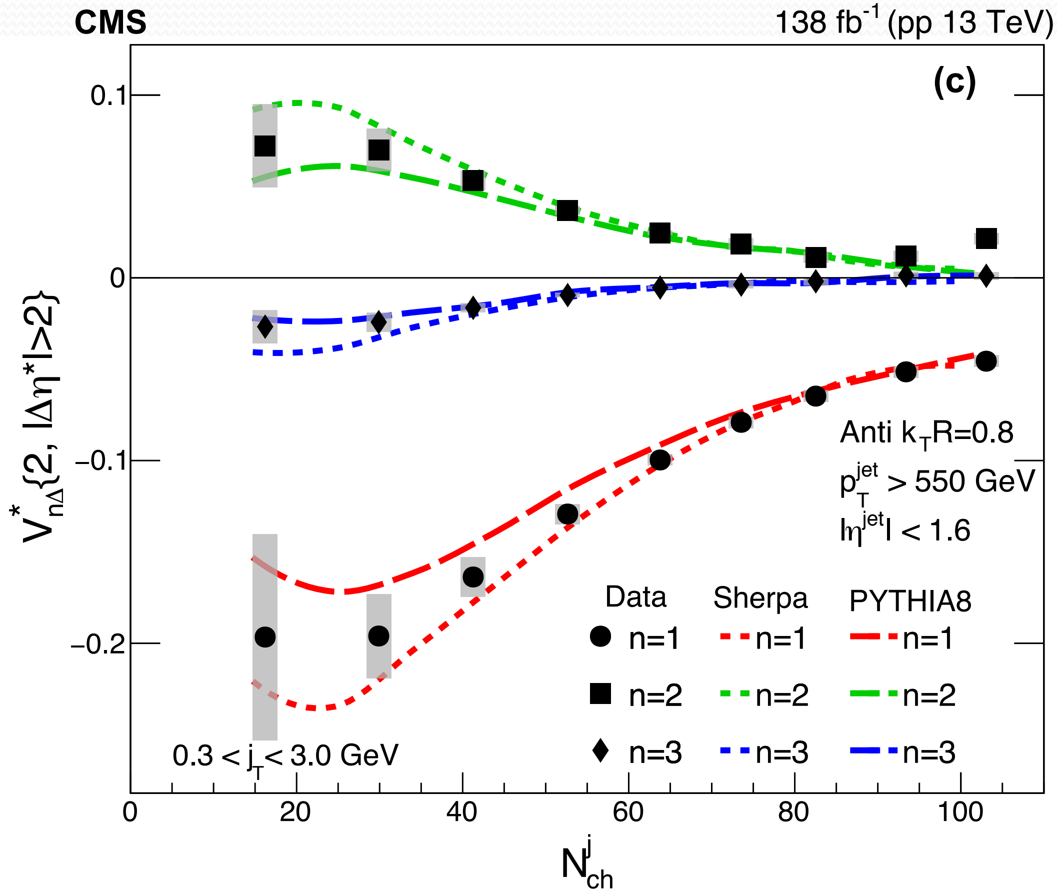
2-particle $V_{n\Delta}^{*}$ coefficents



Fourier fits used to extract $V_{n\Delta}^{*}$ show that a negative $V_{1\Delta}^{*}$ dominates

$V_{1\Delta}^{*}$ and $V_{3\Delta}^{*}$ are negative, while $V_{2\Delta}^{*}$ is positive

$V_{n\Delta}^{*}$ coefficients with n>3 are negligible

$V_{n\Delta}^{*}$ decrease with the increase of N_{ch}^{j} as expected

These features are consistent with back-to-back correlations

The MC generators are mainly successful in describing the experimental data

There is a slight deviation between the MC and data at high N_{ch}^{j}

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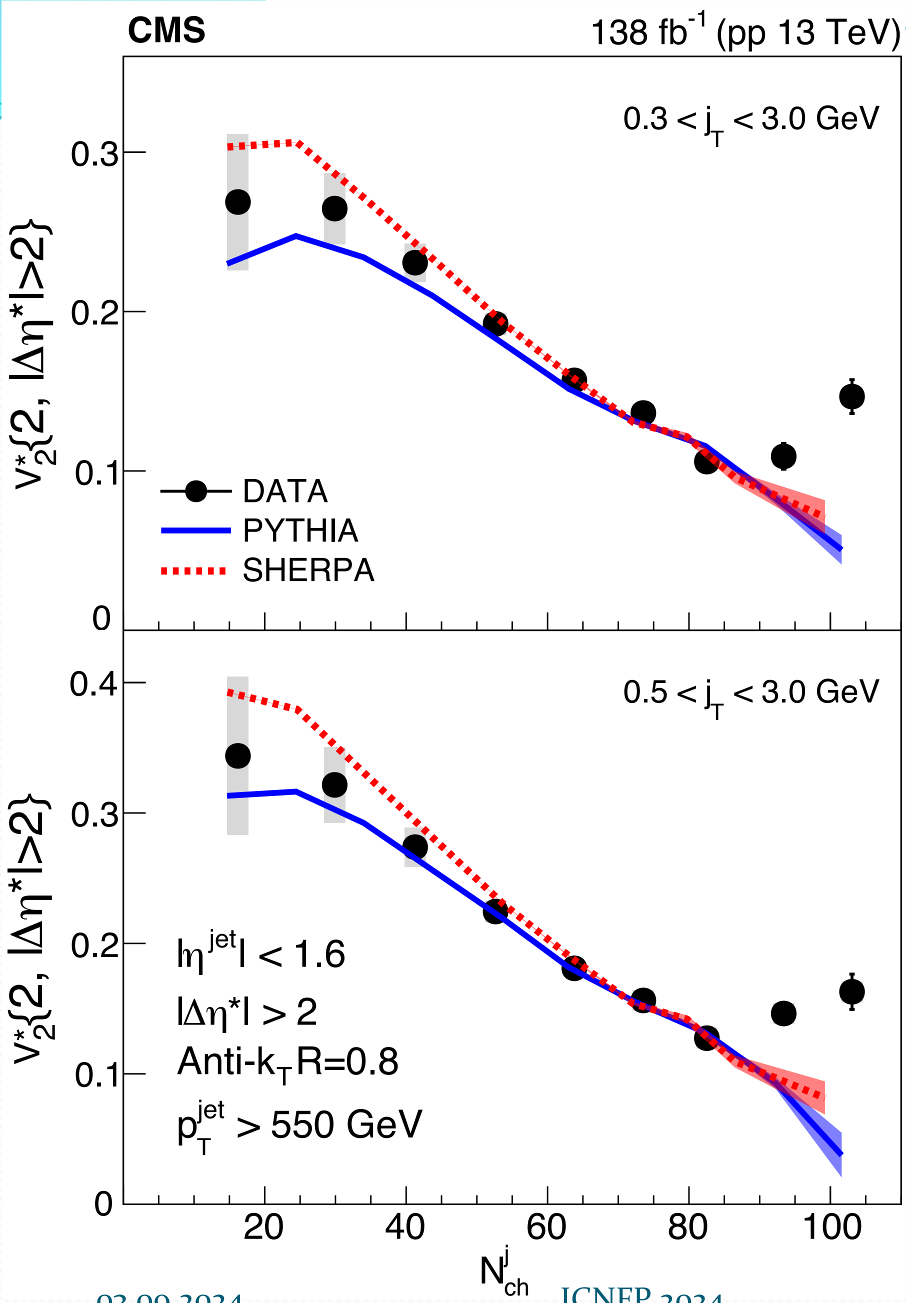
Single-particle elliptic anisotropy v_n^*



Single particle elliptic anisotropy coefficient

$$v_2^* = \sqrt{V_{2\Delta}^*}$$

?

as a function of N_{ch}^j

To investigate possible j_T dependence, two j_T ranges: 0.3-3.0 and 0.5-3.0 GeV are studied

MC describes well the data

For N_{ch}^j>80, v_2^* no longer diminishes with the increase of N_{ch}^j, in fact they show a steady increase with further increase of N_{ch}^j

It may indicate an onset of a novel QCD phenomena related with nonperturbative dynamics of a parton fragmenting in vacuum

These phenomena could include the emergence of collective effects

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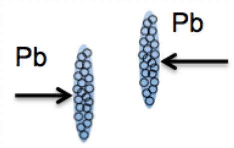
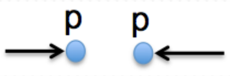
Nuclear modification factor of B^+ and B^0_S mesons

$$B^+ \to J/\psi\left(\mu^+\mu^-\right)K^+ \qquad B_S^0 \to J/\psi\left(\mu^+\mu^-\right)\phi(1020)\left(K^+K^-\right)$$

The nuclear modification factor, R_{AA}, is the meson yield ratio in nucleus-nucleus (AA) and pp collisions normalized by the number of inelastic NN collisions:



$$R_{AA}\left(p_T\right) = \frac{1}{T_{AA}} \frac{\dfrac{dN_{PbPb}^{B^+,B_S^0}}{dp_T}}{\dfrac{d\sigma_{pp}^{B^+,B_S^0}}{dp_T}}$$



T_{AA} is the average number of binary collisions per PbPb interaction divided by the NN total inelastic cross section

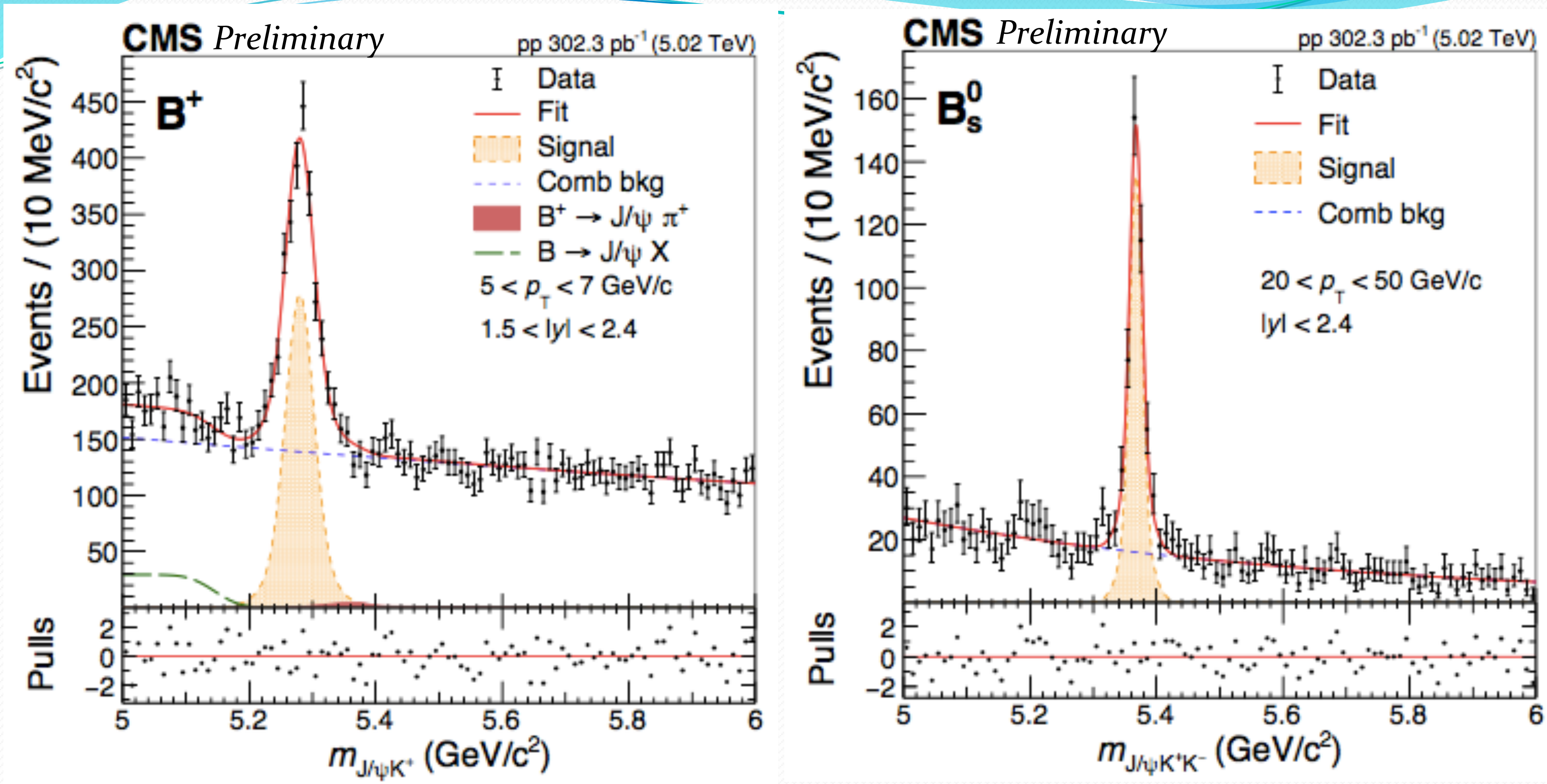
The differential cross section for B meson production in pp collisions is

$$\frac{d\sigma_{pp}}{dp_T} = \frac{1}{2}\frac{N_{obs}\left(p_T\right)}{\mathcal{B}\mathcal{L}}\frac{1}{\Delta p_T}\left\langle \frac{1}{\alpha\left(p_T,y\right)\varepsilon\left(p_T,y\right)} \right\rangle$$

N_{obs} is the raw signal yield in each p_T interval of width Δp_T, $\mathcal{B}$ is the branching fraction and $\mathcal{L}$ is the integrated luminosity

The acceptance and the efficiency factor is $1/\langle\alpha(p_T,y)\varepsilon(p_T,y)\rangle$

Examples of invariant mass B^+ and B^0_S distributions



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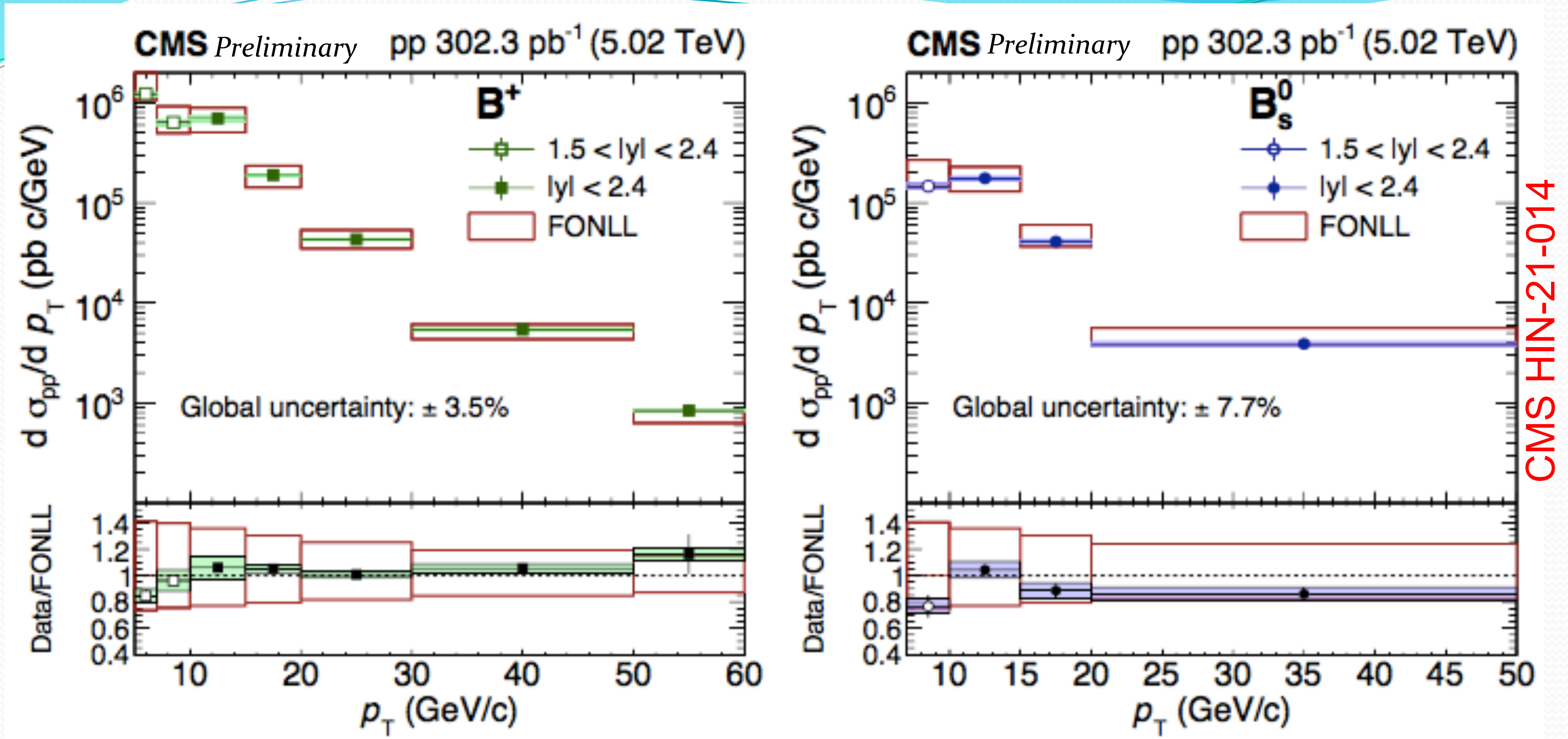
The dimuon candidates are required to have an invariant mass within $1<m_{\mu\mu}<5$ GeV/c^2

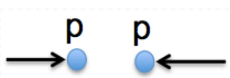
Final B candidates are selected via multivariate discriminators based on a BDT. For B^0_S, an additional selection is used: the absolute difference between reconstructed and nominal ϕ(1020) mass

The BDT training is individually optimized for each meson and p_T to maximize $S/\sqrt{S+B}$

Cross section of B^+ and B^0_S mesons



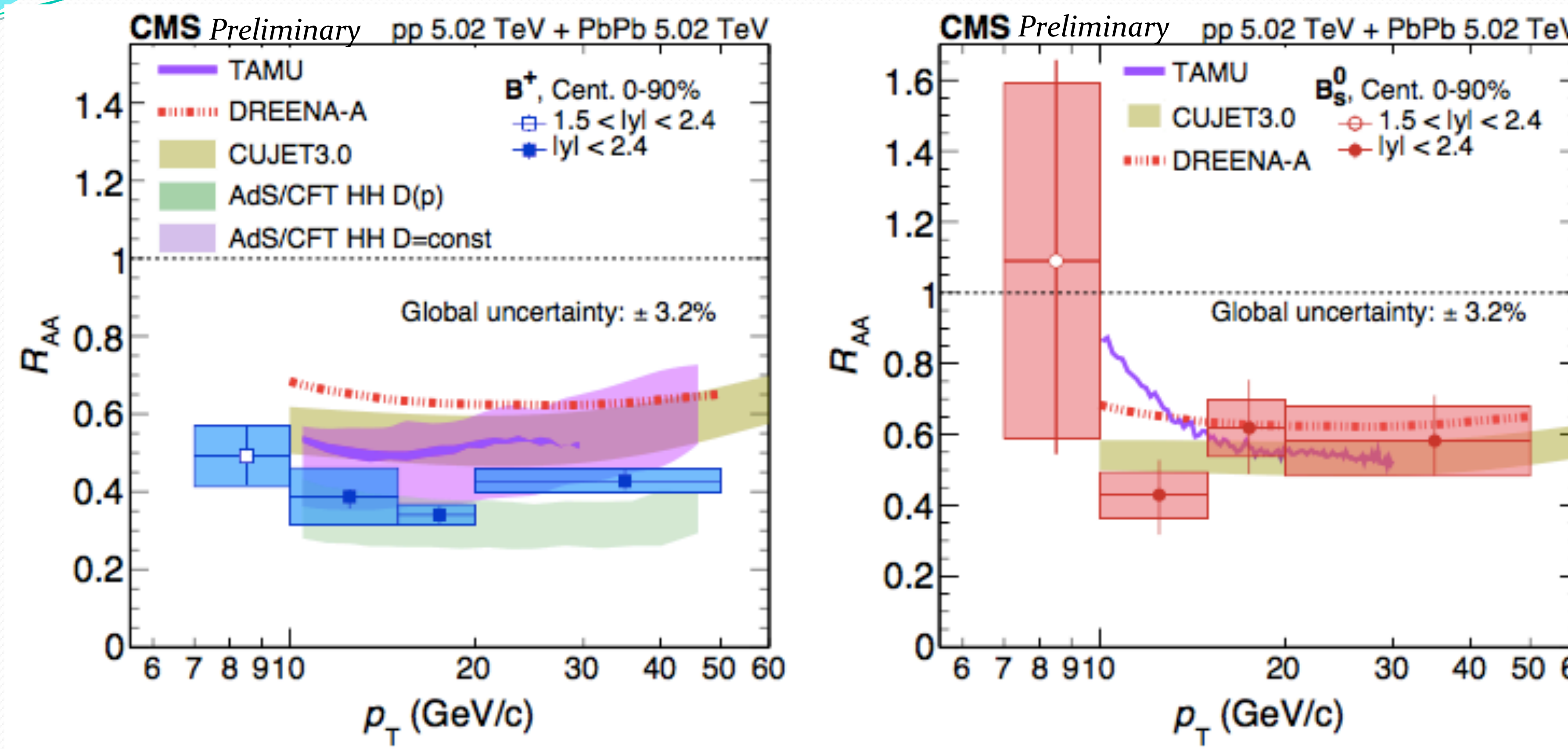
The p_T-differential cross section of B^+ and B^0_S in pp collisions at 5.02 TeV



The calculated FONLL reference spectra are consistent with pp data within the uncertainties

The measured cross sections deviate from the FONLL calculations by less than 20%

Nuclear modification factor of B^+ and B^0_S mesons



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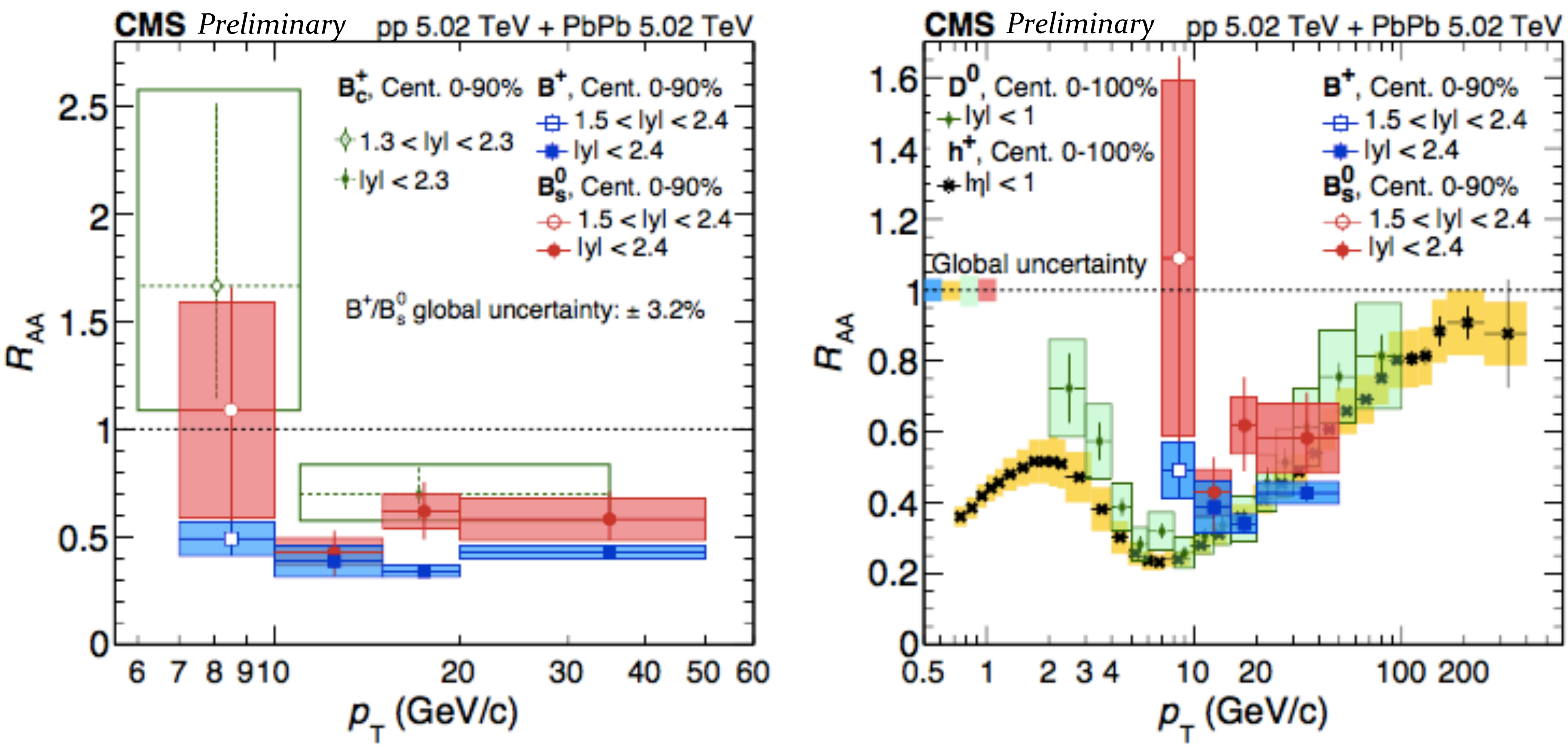
A strong suppression is observed for B^+ meson.

B^0_S meson: a hint of production enhancement is found at $7 < p_T < 10$ GeV/*c*, while for $10 < p_T < 50$ GeV/*c* the R_{AA} are smaller than unity, but larger than those found for the B^+ meson

The measured R_{AA} of B^+ and B^0_S mesons is compared to three types of models

Comparisons of B^+ and B^0_S mesons' R_{AA}



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A comparison with B_c mesons (left) and with D^0 meson and charged hadrons (right)

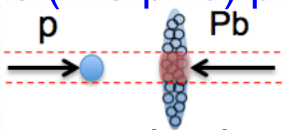
The R_{AA} of B_c meson is higher than that of B^+ with B^0_S values falling in between
For p_T > 10 GeV/c, the B^+ mesons' R_{AA} is consistent with those of D^0 meson and charged hadrons. At lower p_T a reduced level of suppression is observed – quark mass dependence of parton energy loss

$\psi(2S)$ and J/ψ meson production cross section

Heavy flavor quarks are important in study heavy ions because they experience the entire evolution of the system. So, they are excellent probe of the quark gluon plasma (QGP)

At LHC energies, the main influence on quarkonium production within the QGP is anticipated to be suppression resulting from medium color screening and the partial compensation from bound state regeneration

Quarkonium production measurements in smaller colliding systems (like pPb) provide additional insights into these processes



A notable suppression of excited charmonia $\psi(2S)$ wrt its ground state J/ψ is observed

There is an interest in investigating quarkonium suppression in high-multiplicity small-system collisions as a probe for QGP

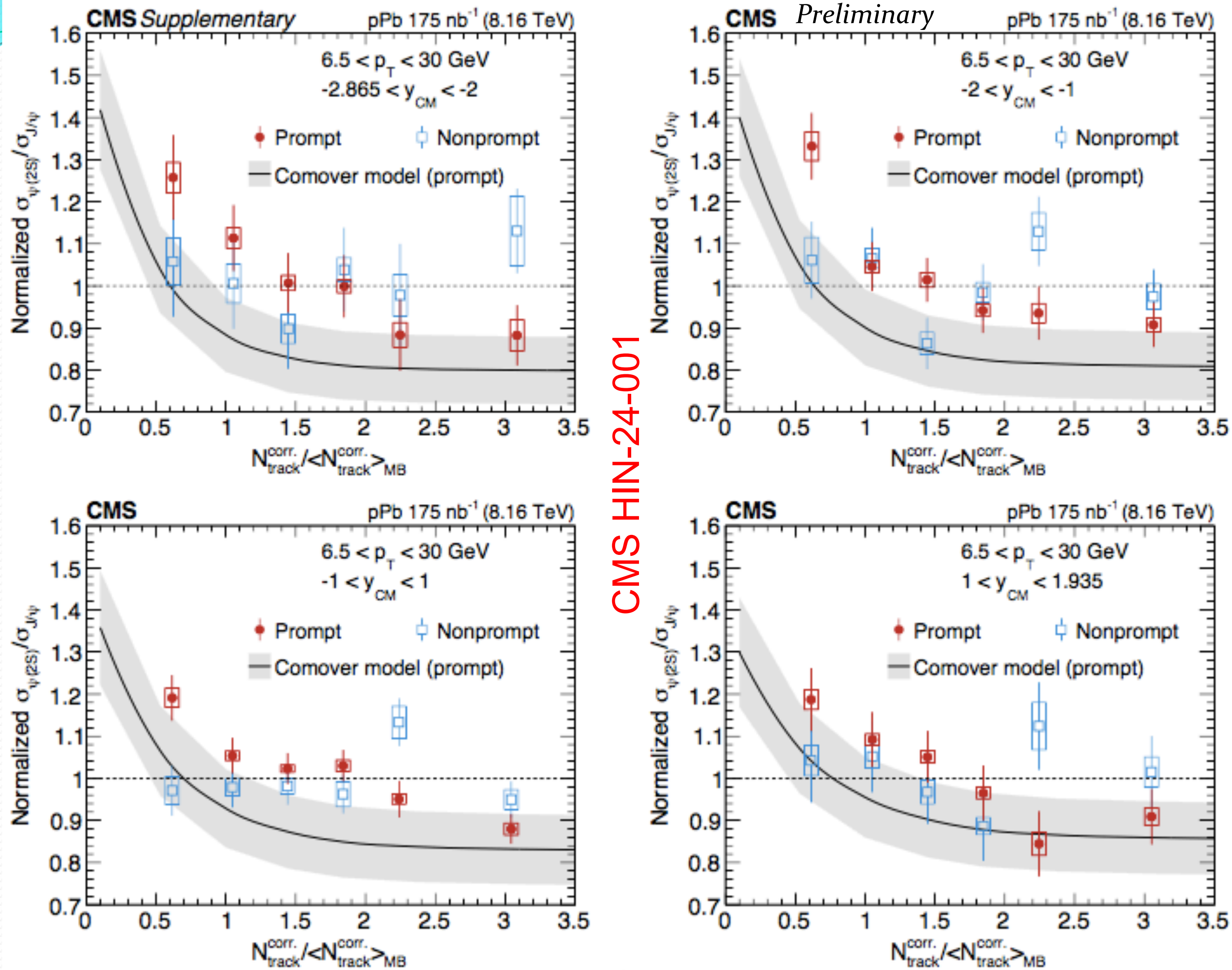
The cross section for prompt and nonprompt J/ψ and $\psi(2S)$ is $\sigma(p_T, y) = \dfrac{N(p_T, y)}{\mathcal{L}\varepsilon(p_T, y)\mathcal{B}}$

The used observable is defined as the yield ratio of $\psi(2S)$ to J/ψ normalized with the integrated yield ratio

$$\text{Normalized } \frac{\sigma_{\psi(2S),in_{track}}}{\sigma_{J/\psi,in_{track}}} = \frac{\sigma_{\psi(2S),in_{track}} / \sigma_{J/\psi,in_{track}}}{\sum \sigma_{\psi(2S)} / \sum \sigma_{J/\psi}}$$

where in_{track} is the bin index for multiplicity

Production rate of charmonia vs multiplicity



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In all four rapidity bins prompt normalized ratio shows a decreasing trend with norm. N^{corr}_{track}

Higher density of co-moving particles – lower production rate of $\psi(2S)$ to J/ψ

No significant mult. dependence in case of nonprompt charmonia

Nonprompt charmonia originate from B hadrons (appear after the initial stage) – expected to be immune from be broken up by comoving particles

The discrepancy between the model and the data is less than 2 standard deviations

Production rate of charmonia vs multiplicity and y_{CM}

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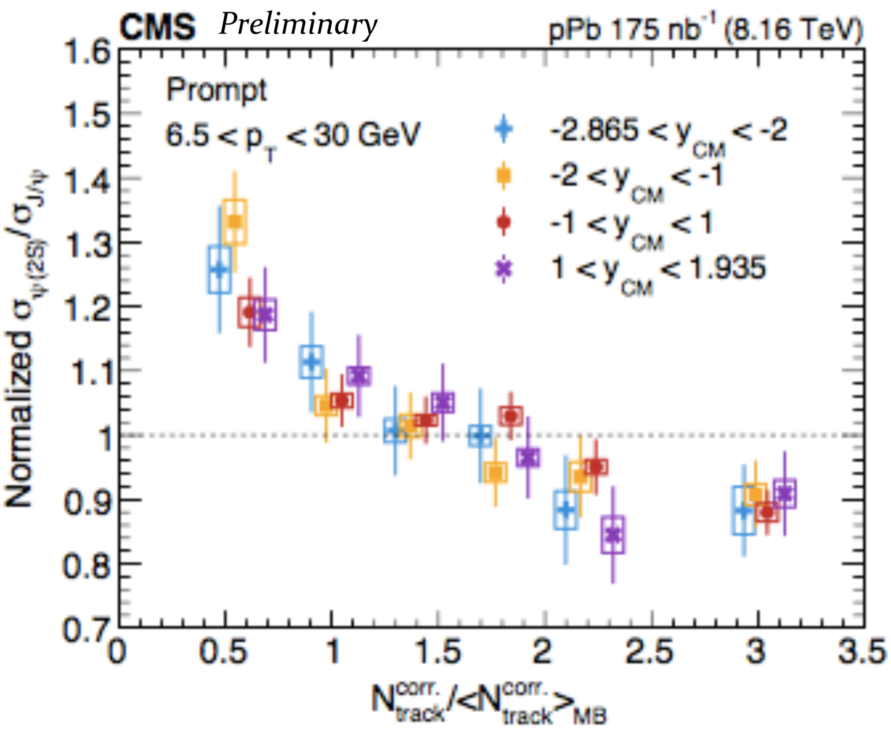

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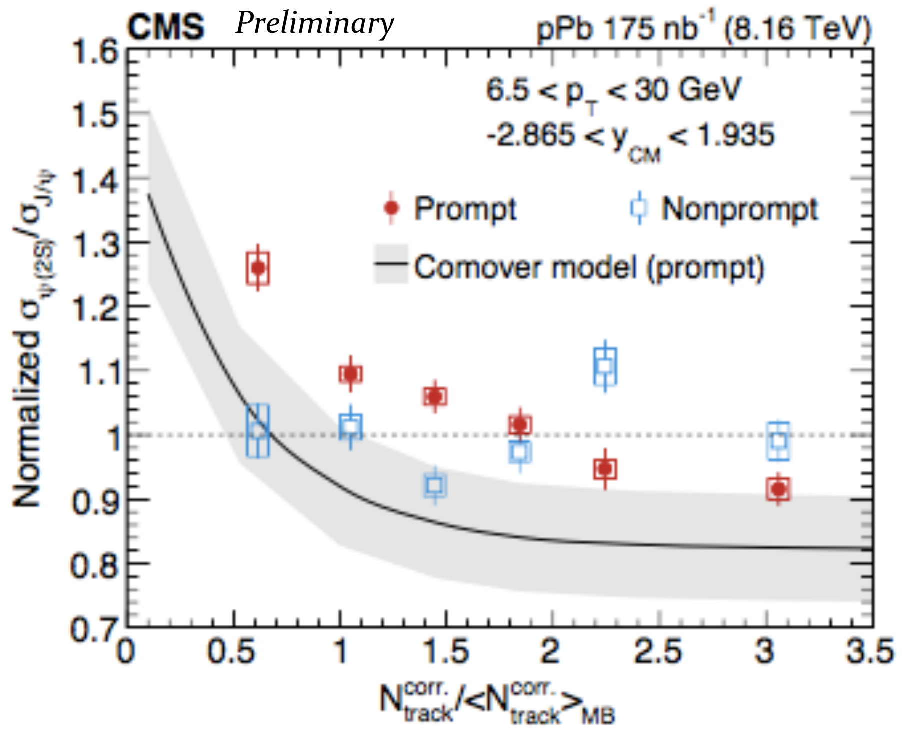

A comparison between 4 rapidity ranges for prompt data. No clear rapidity dependence is observed

All four y ranges combined into a single inclusive measurement of ratio vs multiplicity

The first observation of multiplicity dependence of the cross-section ratio for prompt charmonia in pPb collisions. Nonprompt data does not show such a dependence

Conclusions

- The first search for long-range near-side correlations and QCD collective effects in jets produced in pp collisions at 13 TeV
- Two-particle correlations are studied as a function of the number of charged particles in the jet, N^j_{ch}
- While the data and MC predictions are in good agreement for $N^j_{ch} < 80$, the v_2^* shows an increase for $N^j_{ch} > 80$ − onset of collective behavior ?
- The R_{AA} of B^0_S and B^+ are lower than unity for $p_T > 10$ GeV/c, while at low p_T the B^0_S have larger R_{AA} than the one found for B^+
- The results are compared to theoretical calculations and to charged hadrons and D^0 data
- The R_{AA} values from 7 to 10 GeV/*c* are consistent with expectations based on the quark mass dependence of parton energy loss.
- Normalized production cross-section ratio of ψ(2S) to J/ψ vs multiplicity in pPb at 8.16 TeV for both, prompt and nonprompt data is presented
- In contrast to nonprompt data, prompt data shows a decreasing trend with multiplicity
- The results imply that co-moving particles may dissociate weakly-bound excited state of charmonia more than the ground state

Backup