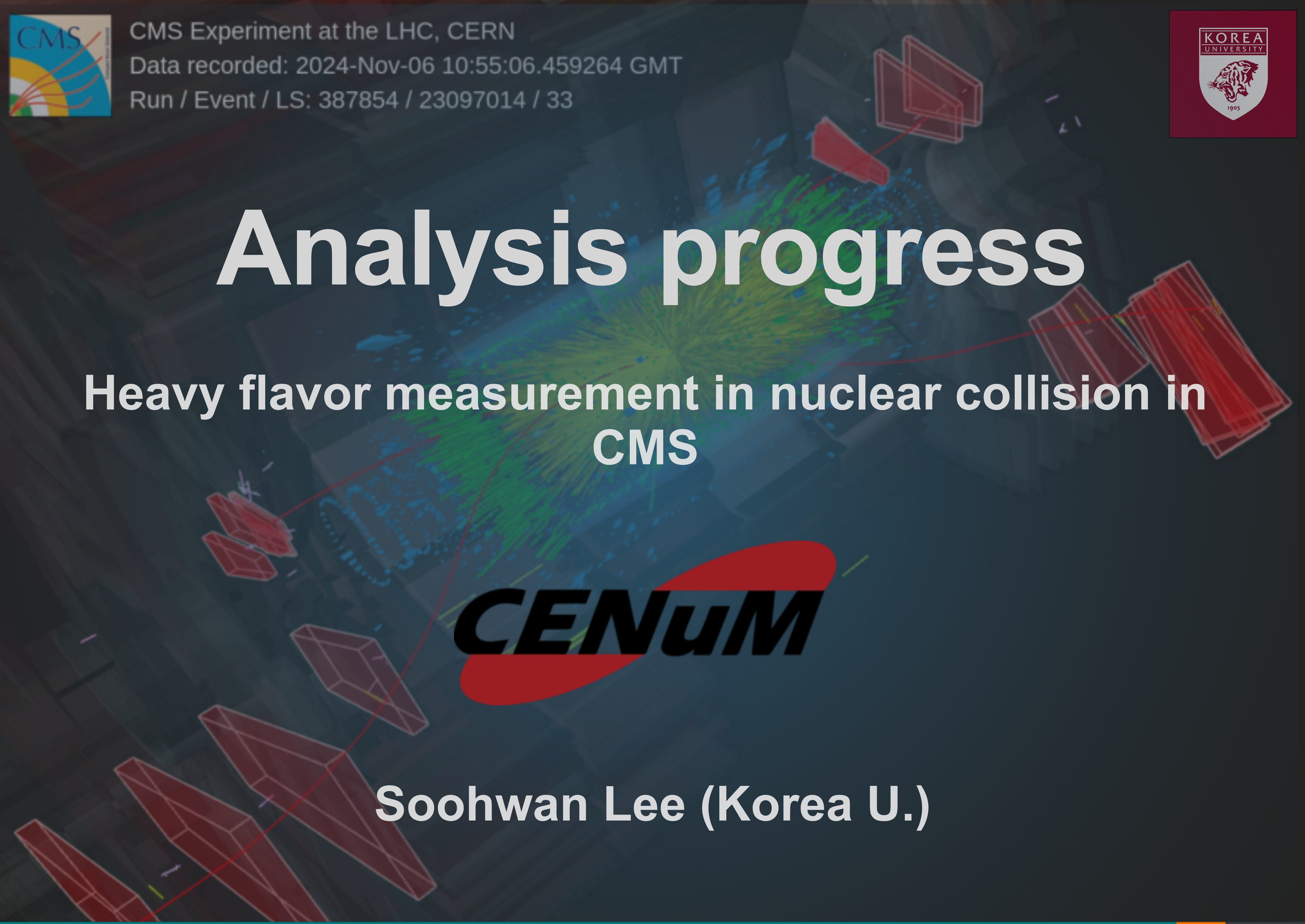


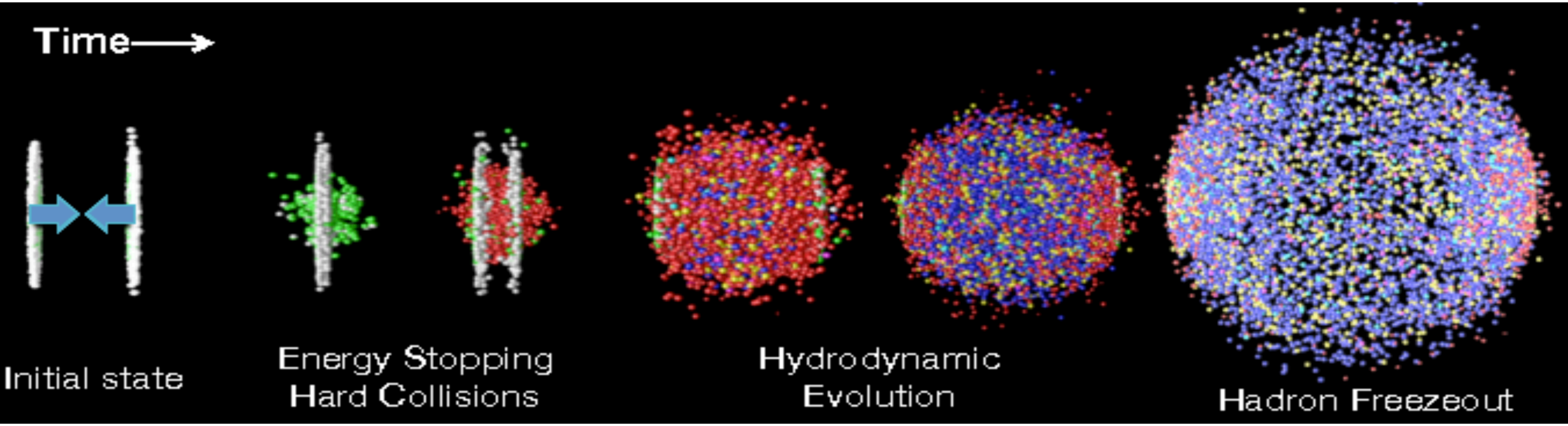
Analysis progress

Heavy flavor measurement in nuclear collision in CMS

Soohwan Lee (Korea U.)

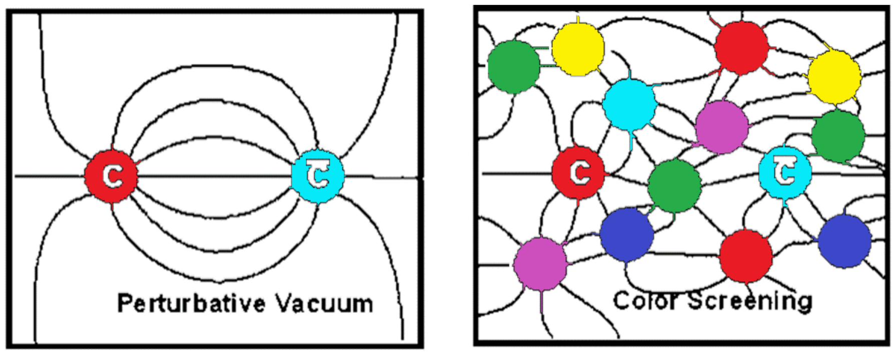
Introduction

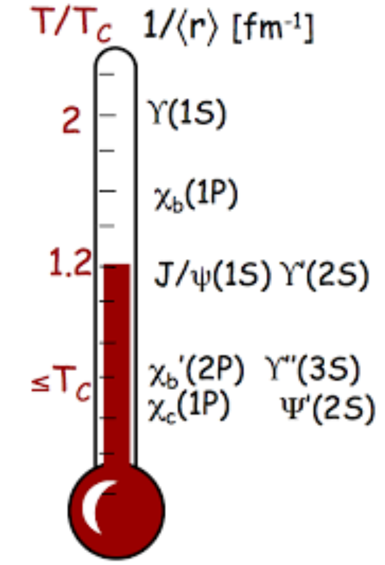
- Using heavy flavor (HF) quark is useful to understand both hot and cold QCD effects in heavy-ion collisions
  - Produced in initial hard scattering (~1 fm), HF's are able to encode information of evolution of QGP via strong interaction
- Heavy mass Q, in low $p_T \rightarrow$ good candidate to test NRQCD



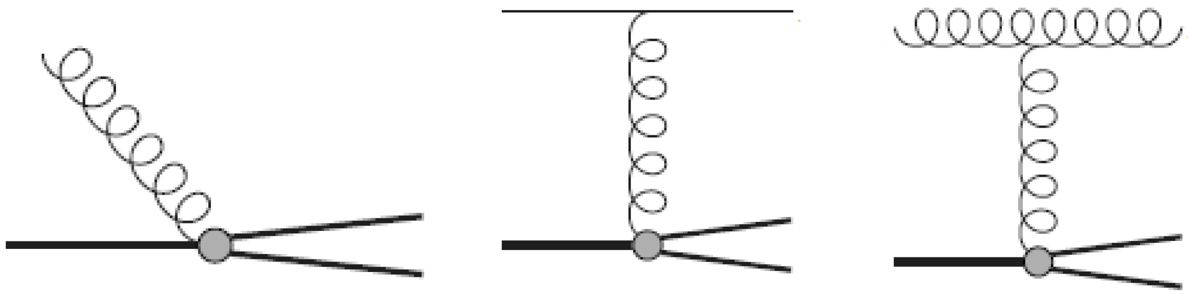
Quarkonia to probe the QGP

- Hot and cold effects in action in heavy-ion collisions
  - Cold nuclear matter effects → nPDF, nuclear absorption, Cronin effect, MPI
  - In QGP: static and dynamic dissociation



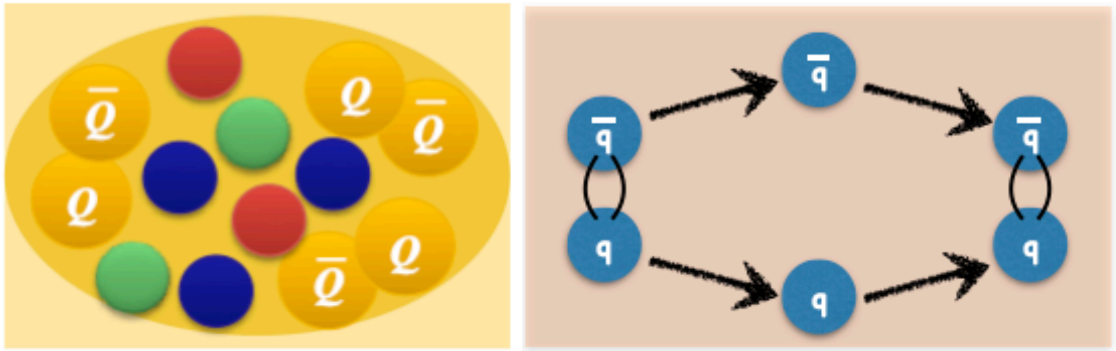


Phys. Rev. C 99, 034905 (2019)



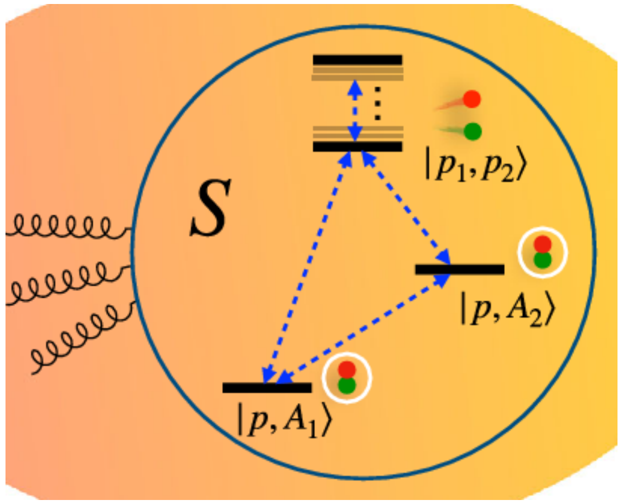
Gluo-dissociation

Inelastic parton scatter at NLO



Statistical effect strong for charmonia

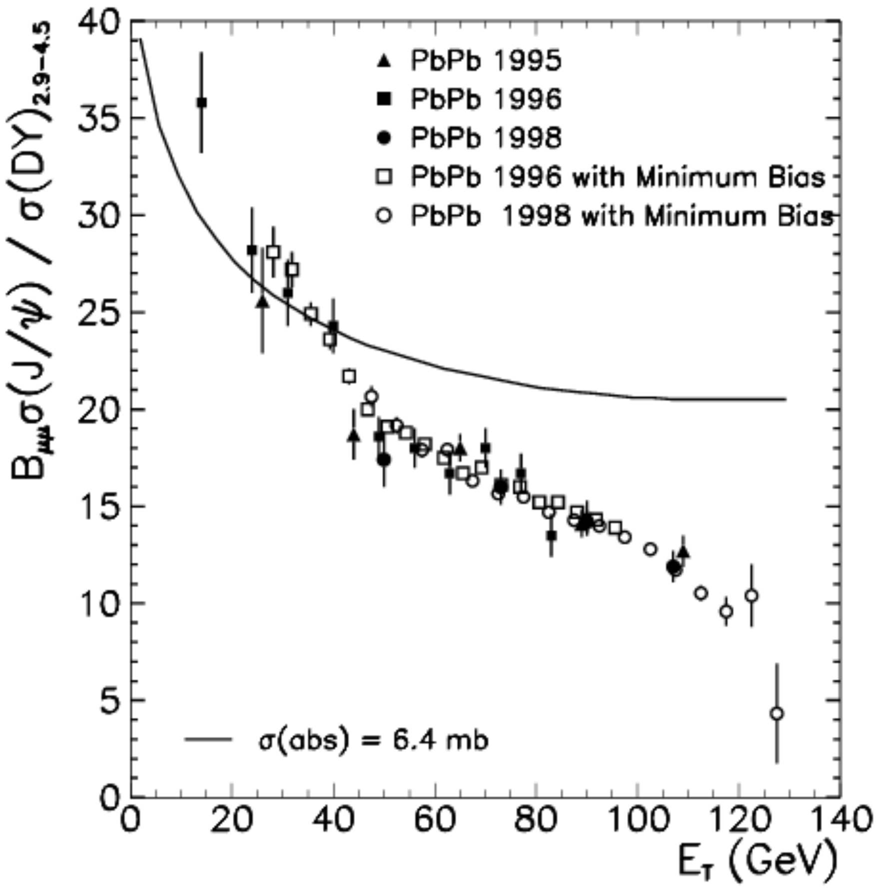
Recent findings[1,2] favor (correlated) recombination also for $b\bar{b}$

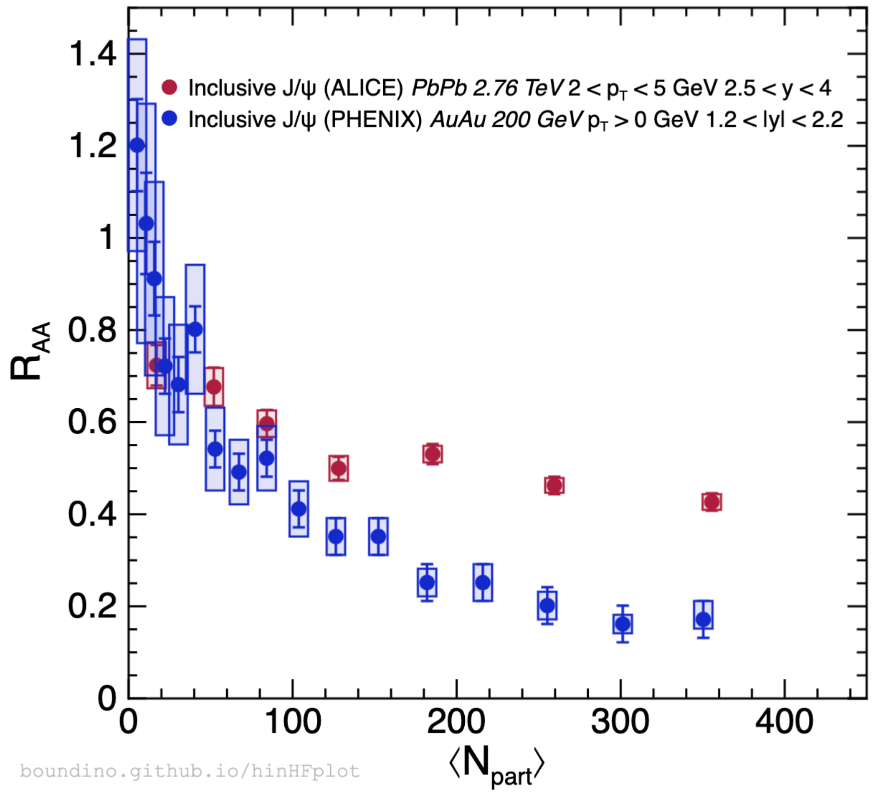


- Description constructed in open quantum system framework

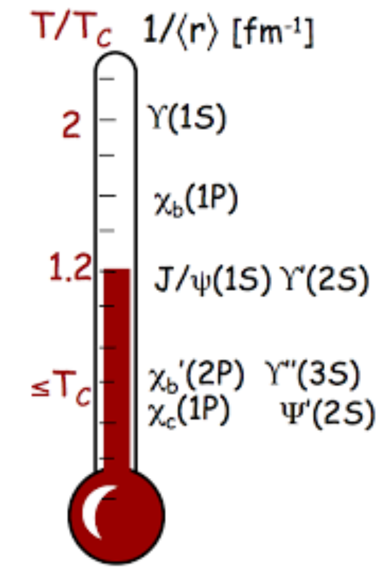
The suppression of Quarkonia

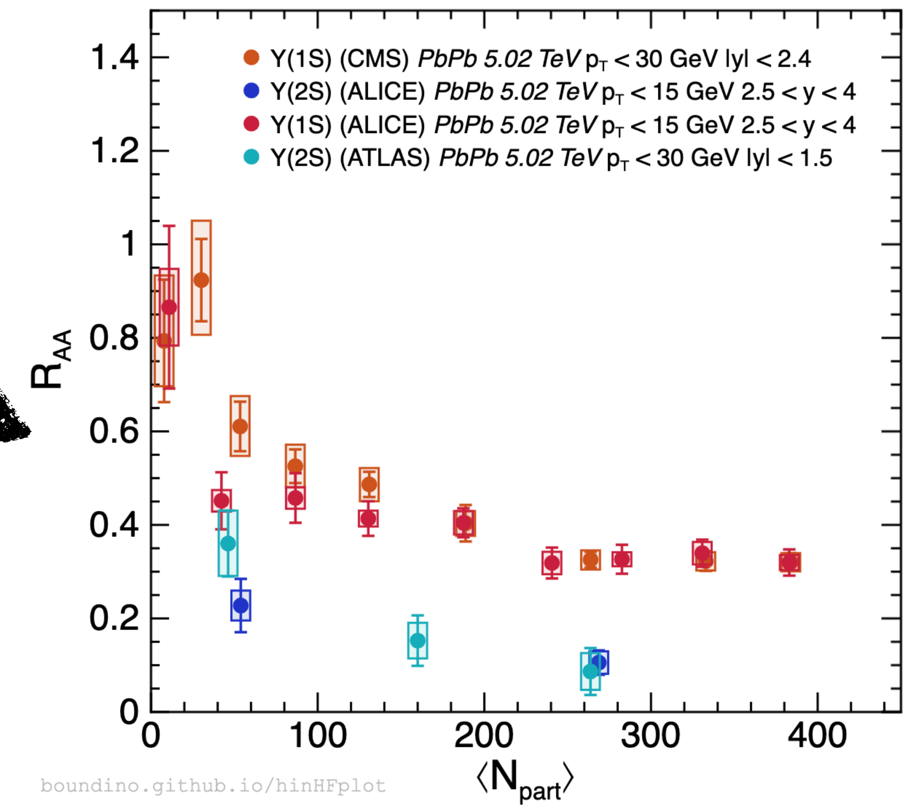
PLB 410 (1996) SPS NA50





→ JHEP 05 (2016) 179 → PRC 84 (2011) 054912



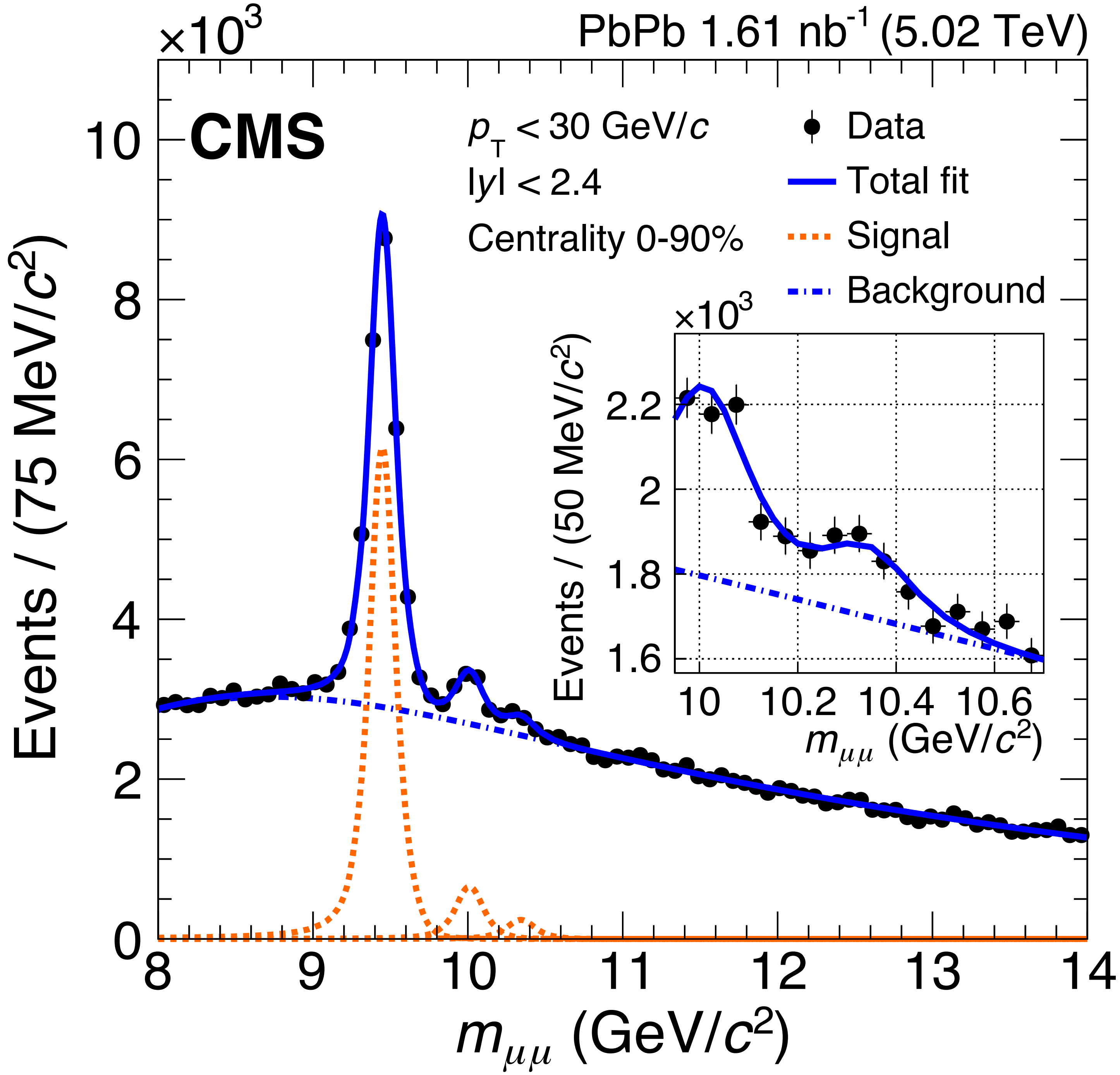


→ PLB 790 (2019) 270 → PLB 822 (2021) 136579
→ PLB 822 (2021) 136579 → PRC 107 (2023) 054912

Observation of the Υ(3S) meson

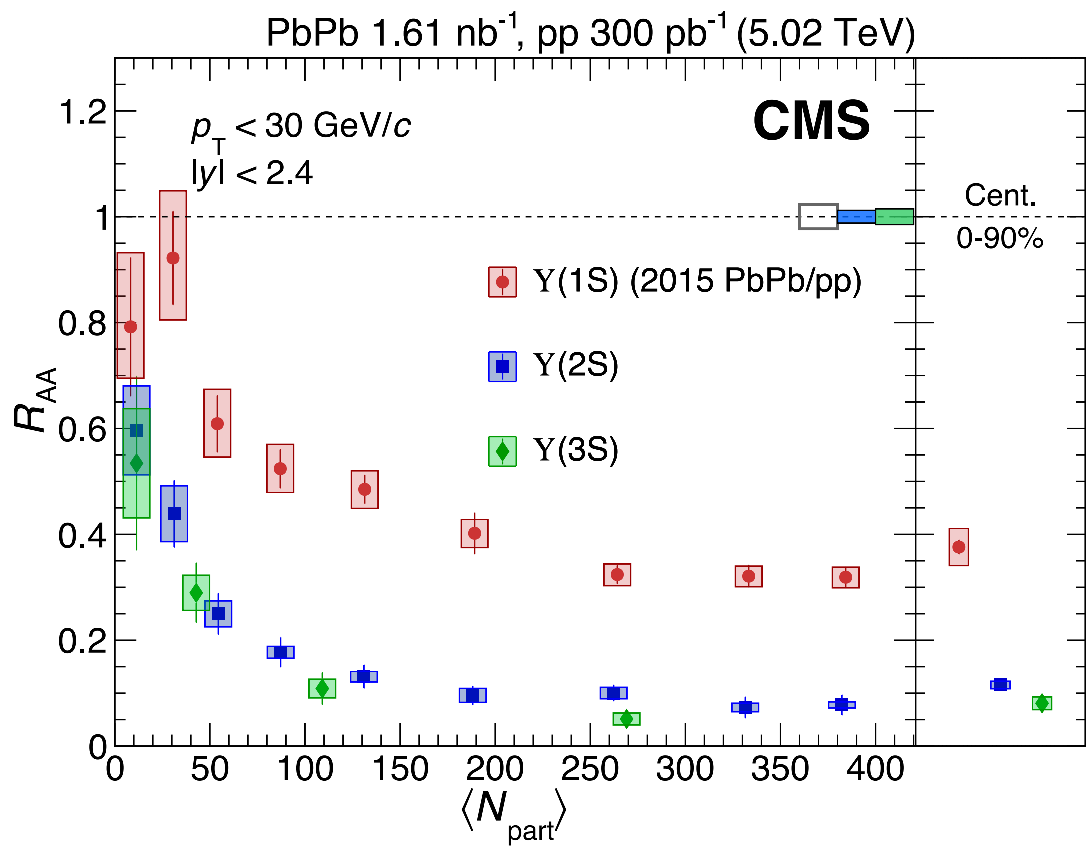
Phys. Rev. Lett. 133 (2024) 022302

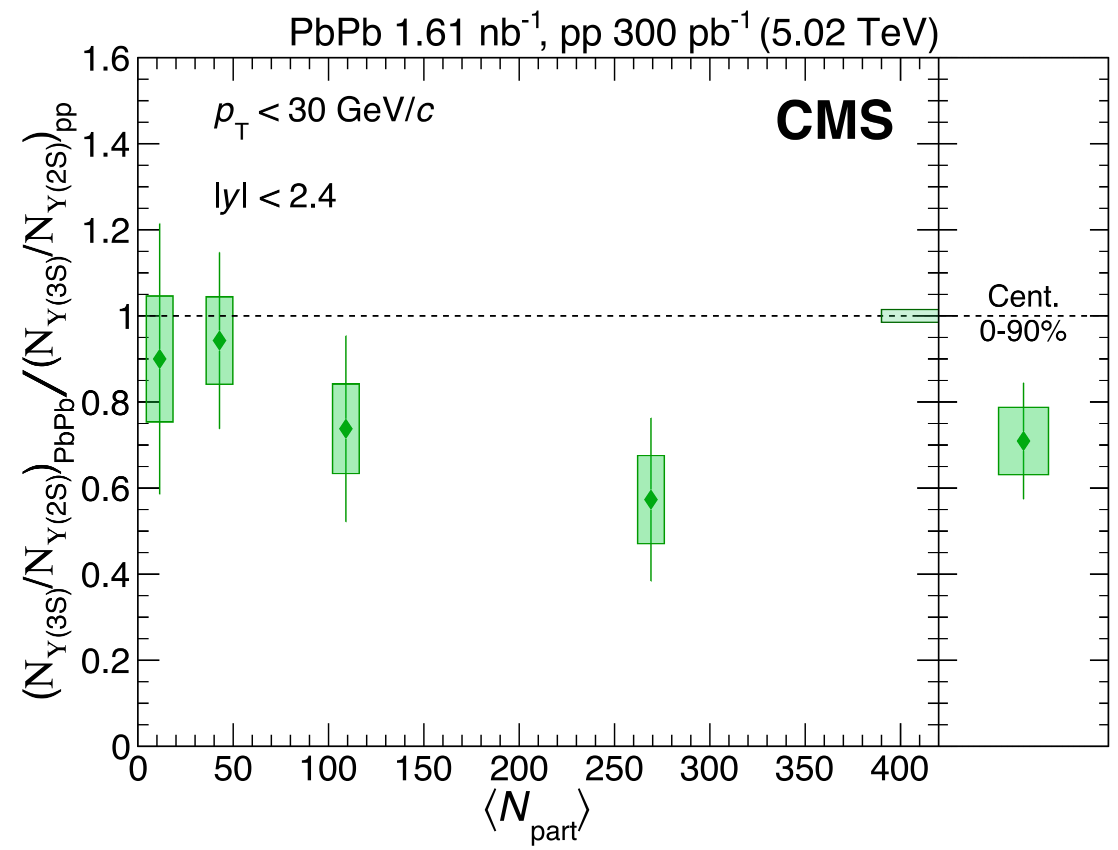
- Using CMS 2018 PbPb data
- Signal extracted with unbinned extended likelihood fit
- **Υ**(3S) observed in PbPb collisions with $> 5\sigma$
  - Signal clearly visible thanks to data control with BDT



Sequential melting of Quarkonia

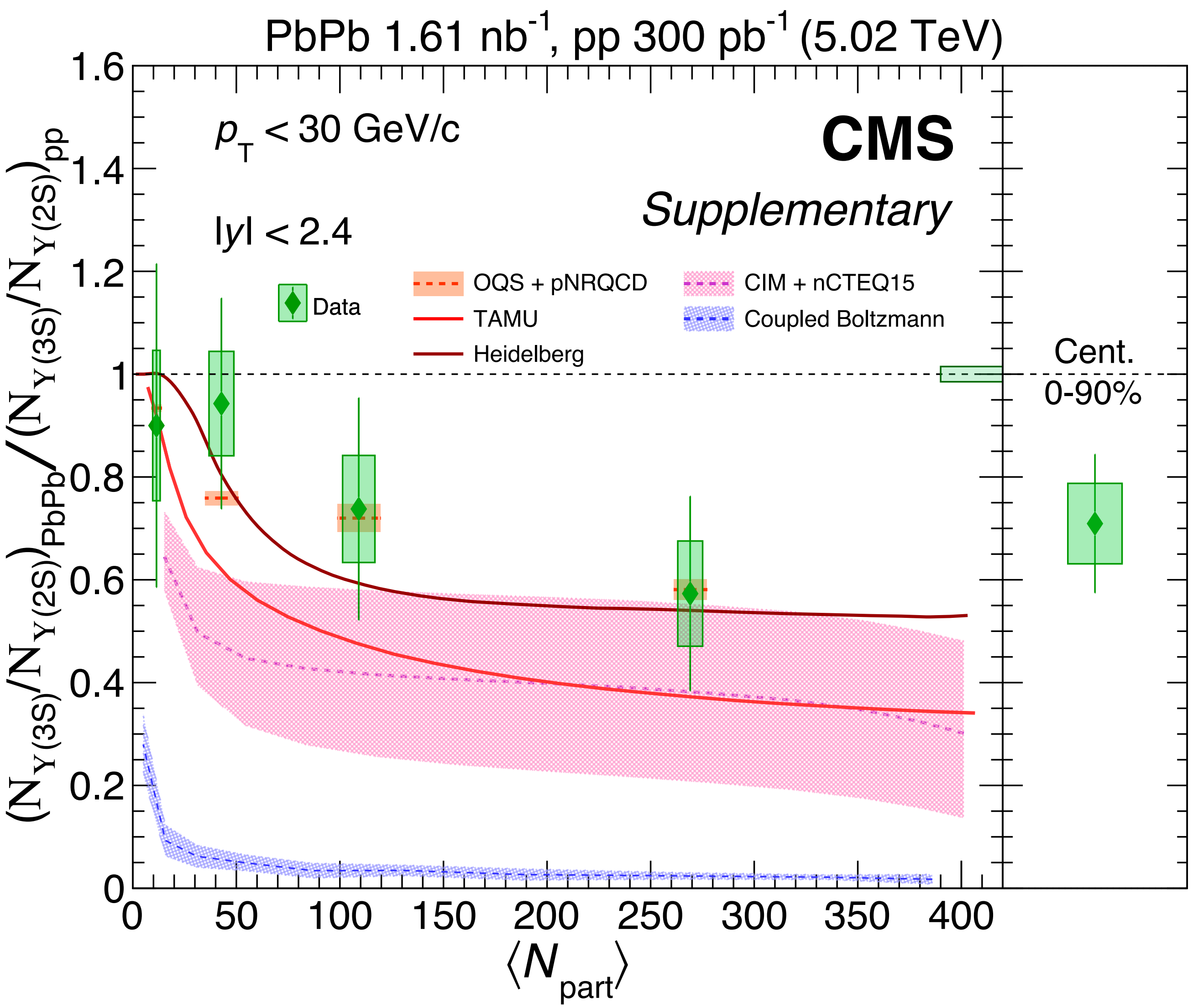
Phys. Rev. Lett. 133 (2024) 022302

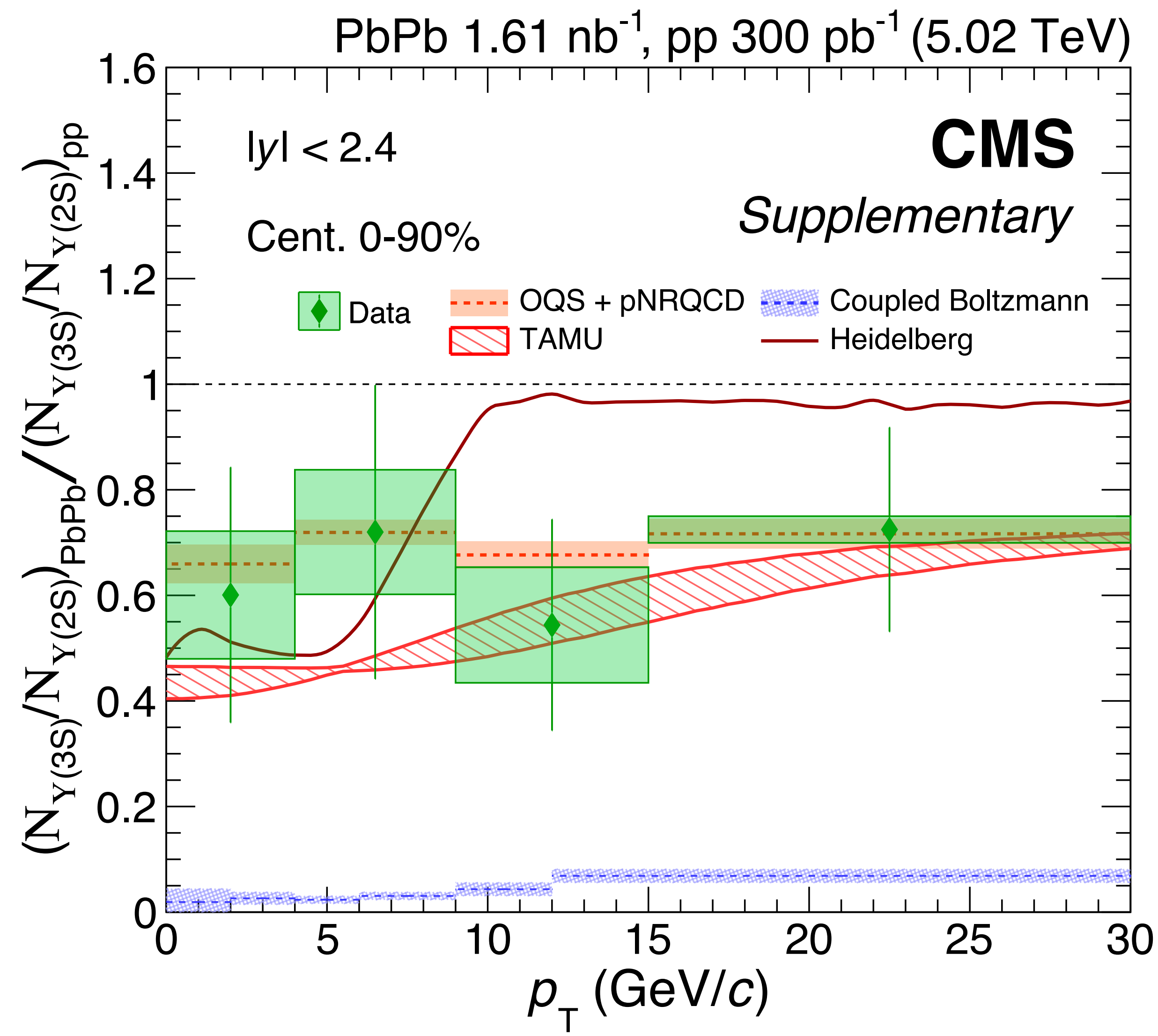




- Binding energy hierarchy of the suppression pattern in all $\langle N_{\text{part}} \rangle$ region (left)
- Υ(3S) suppression more heavily compared to Υ(2S) (right)

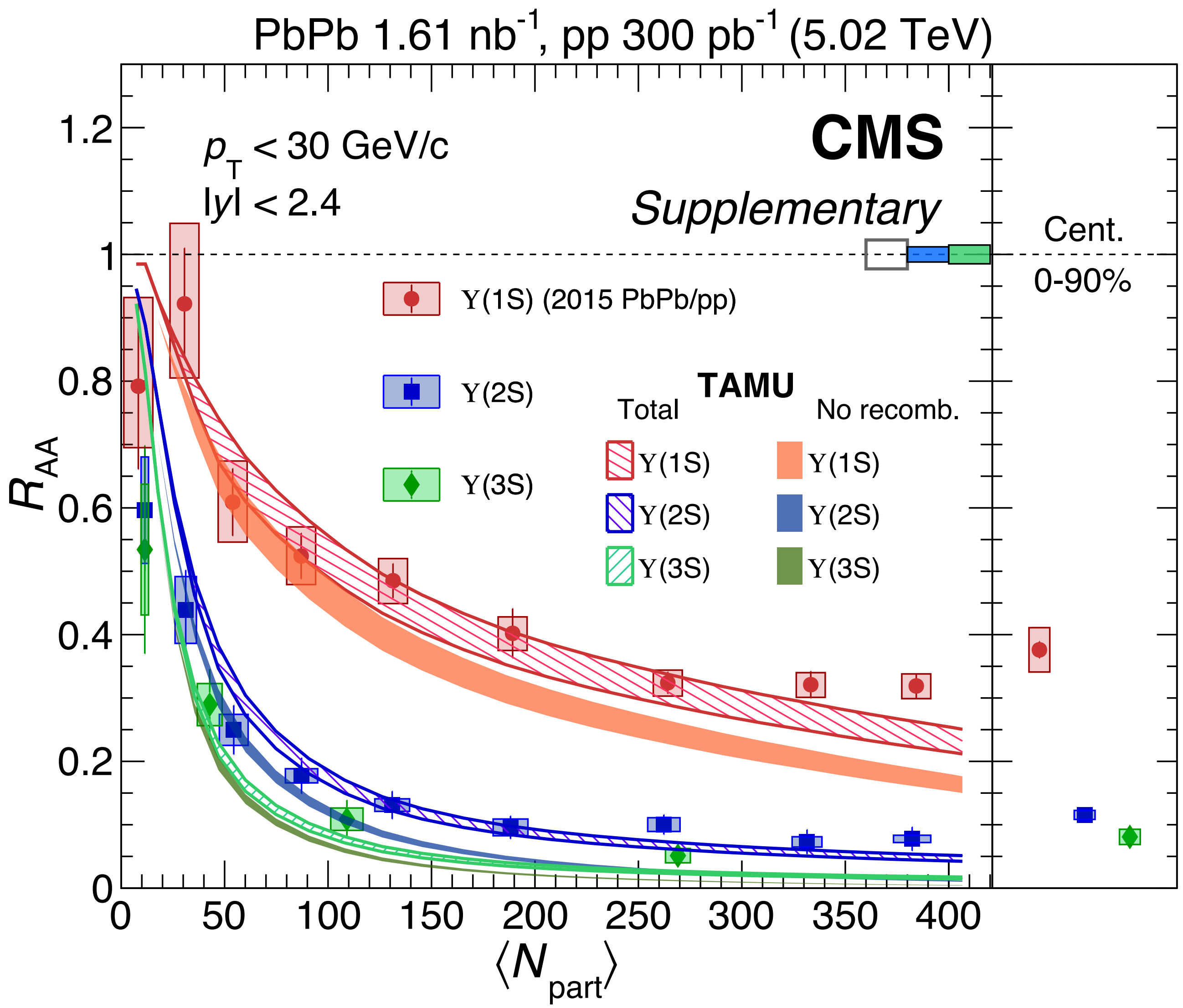
Phys. Rev. Lett. 133 (2024) 022302

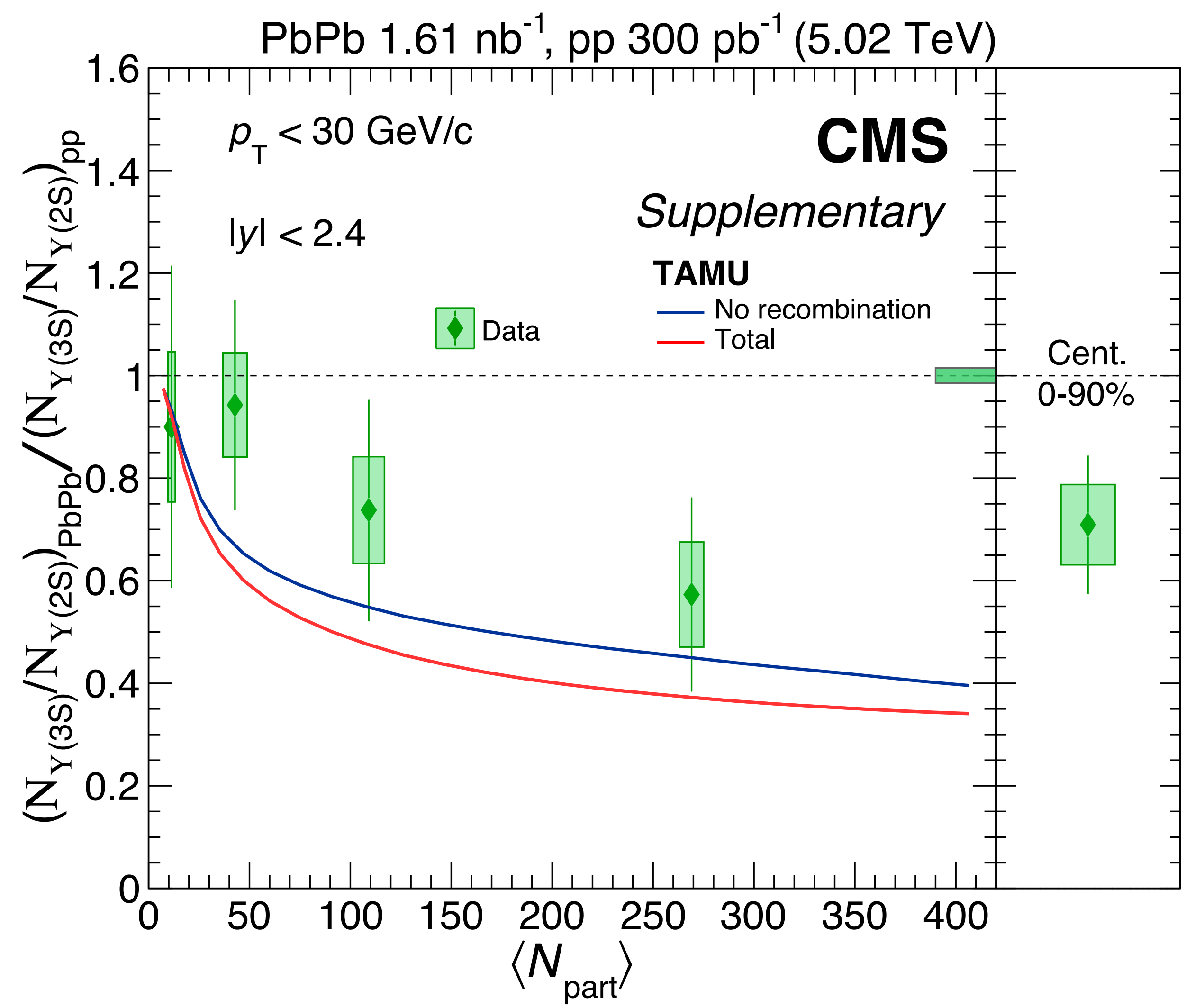




- Models can qualitatively describe data, but
  - Not 100% clear, all comovers (pink), cannot describe without recombination (blue)?

Recombination of bottomonia

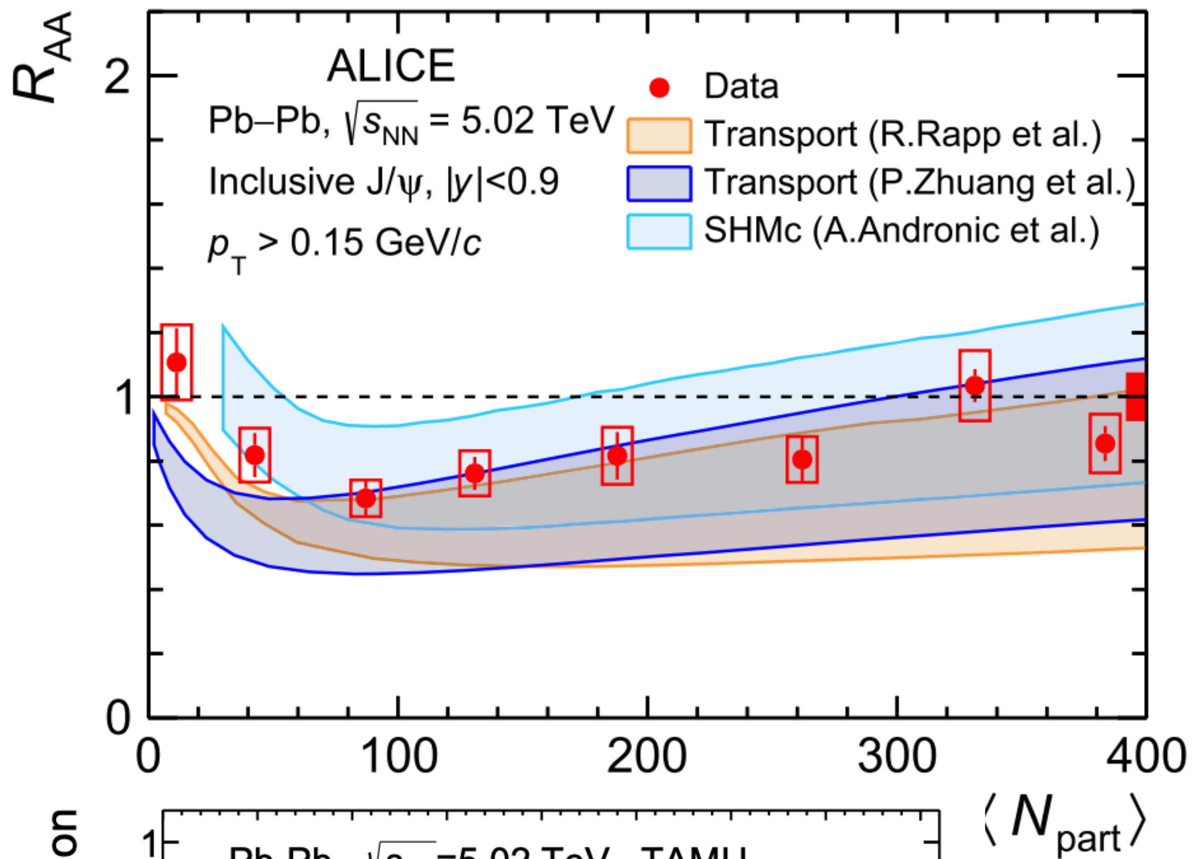


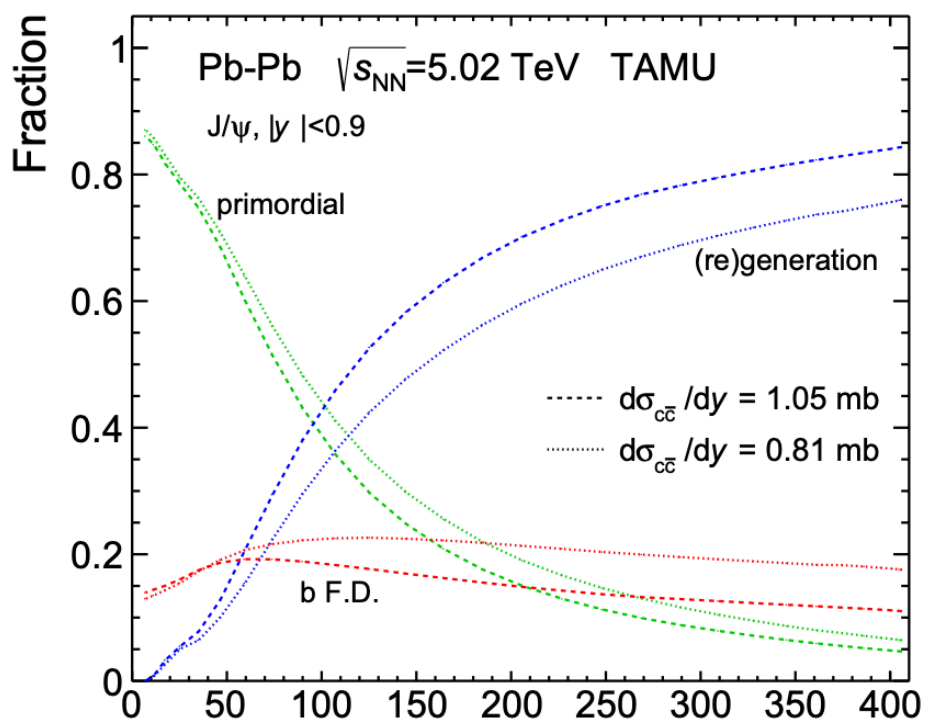


- Where still more precise data can provide information about the recombination scenario

What model-data comparison tells you

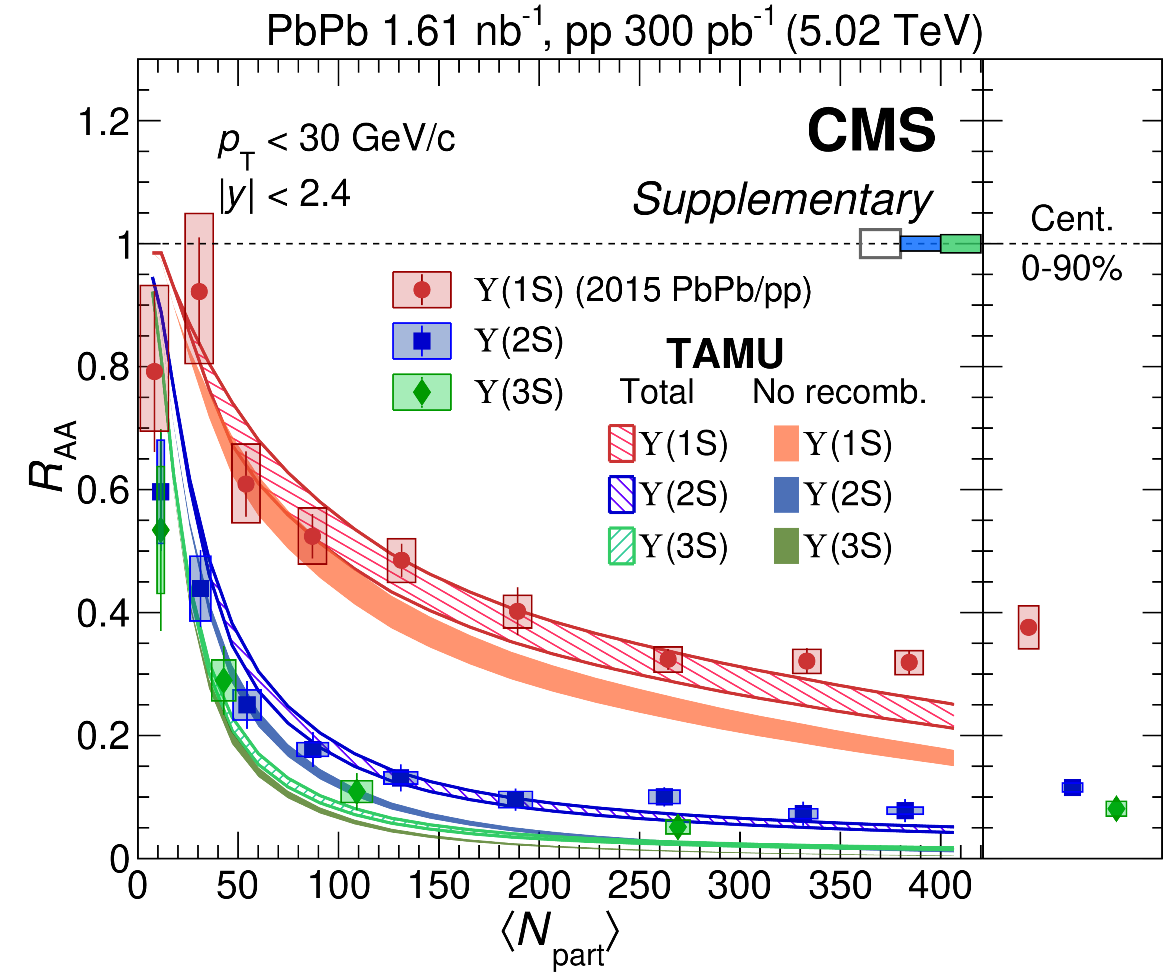
PLB 849 (2024) 138451





arXiv 2501.08290

Phys. Rev. Lett. 133 (2024) 022302



- Current data qualitatively describe the suppression pattern
    - But with a lot of moving parameters
- Describing multiple aspects of data is crucial

How are heavy quarks created?

$Q\bar{Q}$ production and correlation

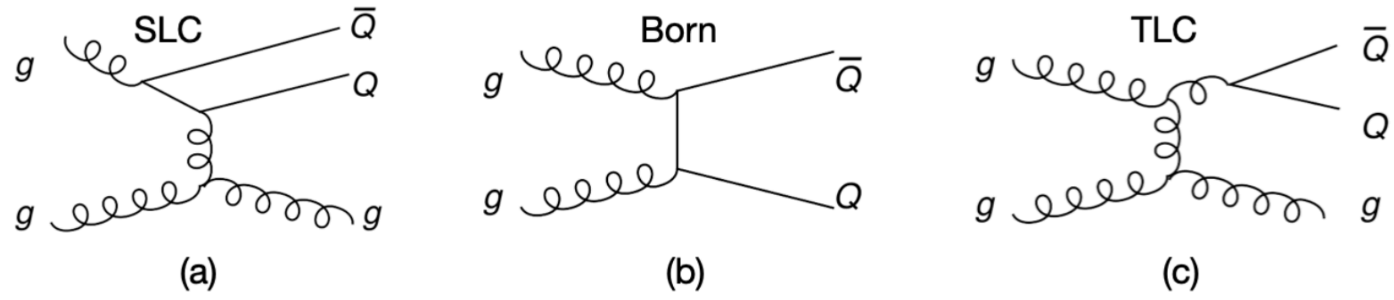
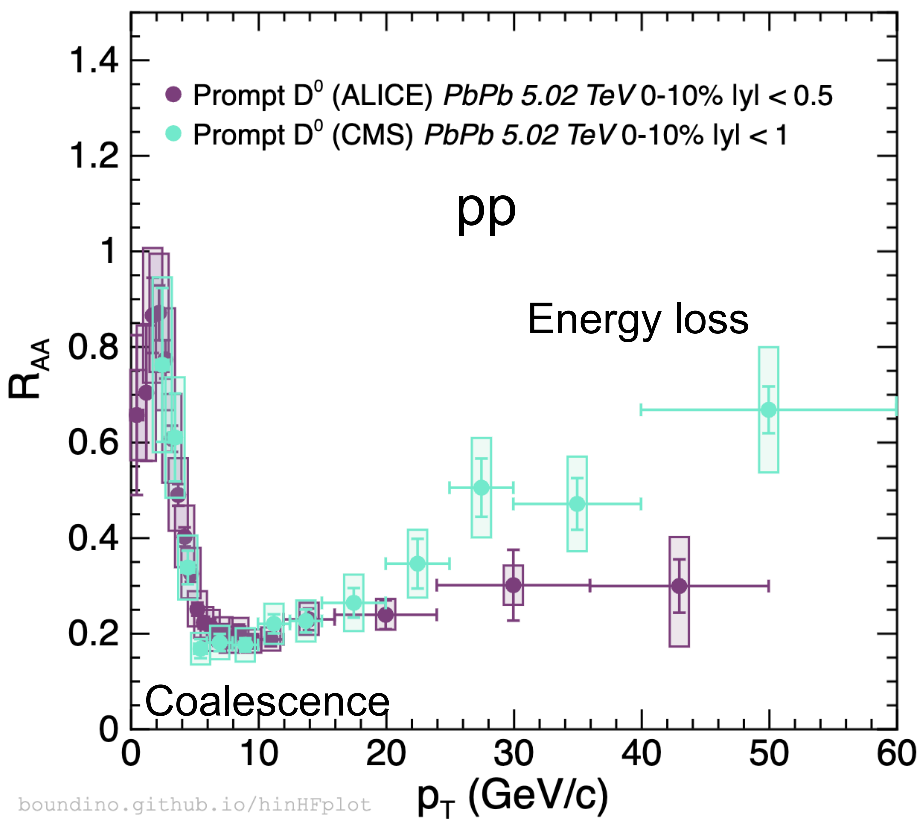
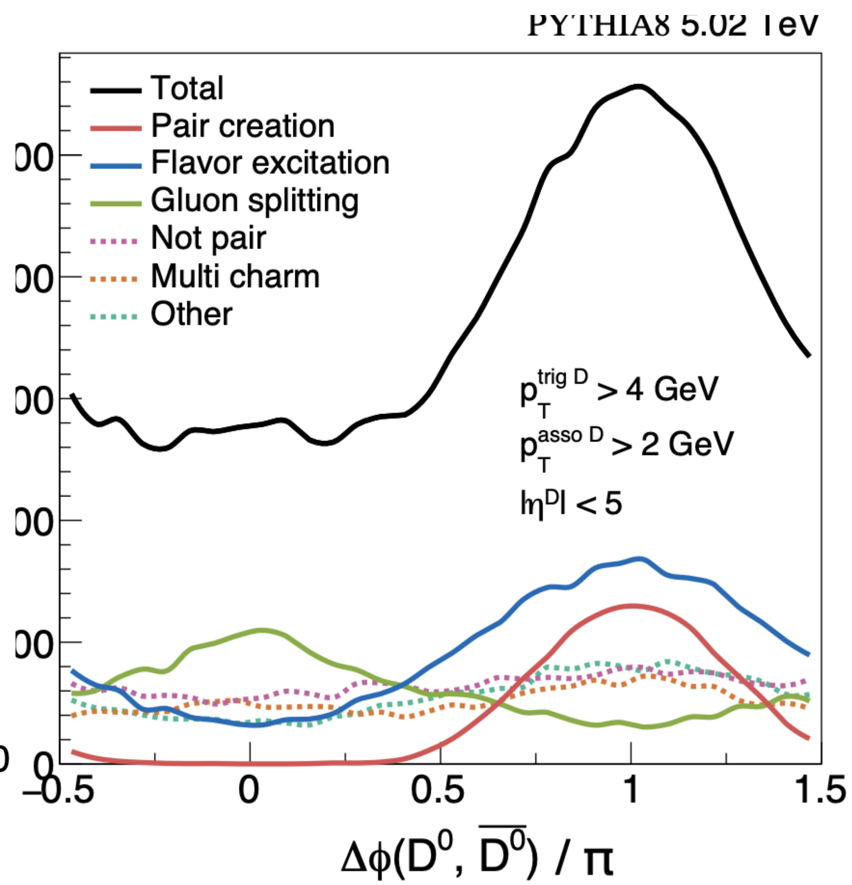


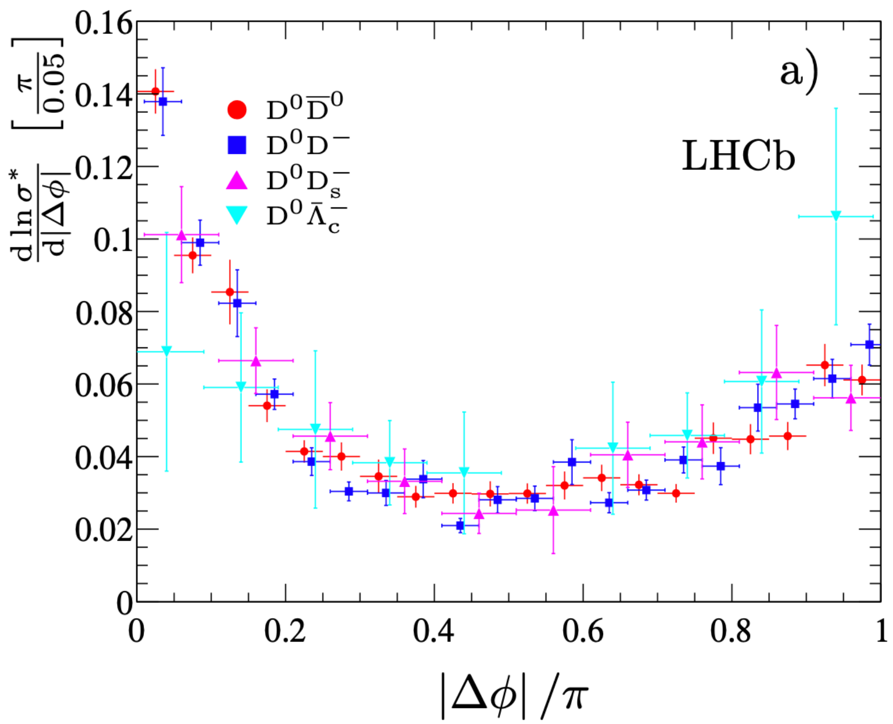
Figure 1: Different possibilities to create heavy flavor: (a) flavor excitation (space-like cascade (SLC)), (b) flavor creation (Born process), (c) gluon splitting (time-like cascade (TLC)).



→ JHEP 01 (2022) 174 → PLB 782 (2018) 474



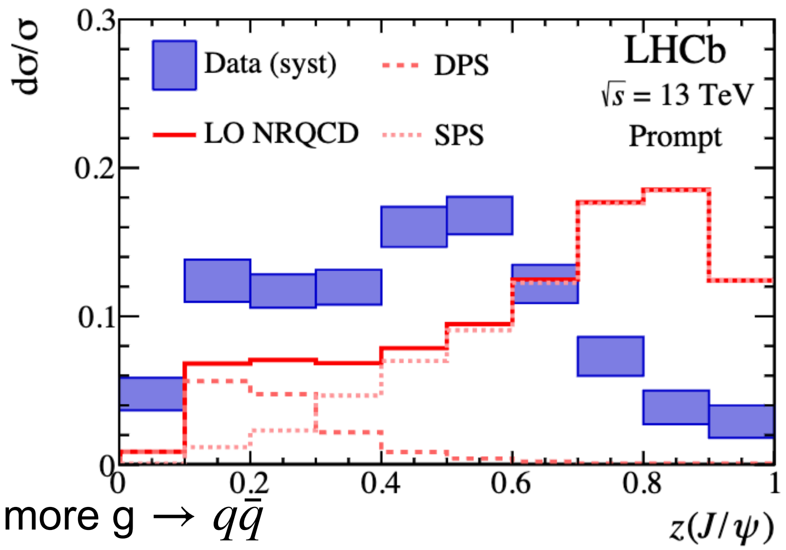
JHEP 06 (2012) 141



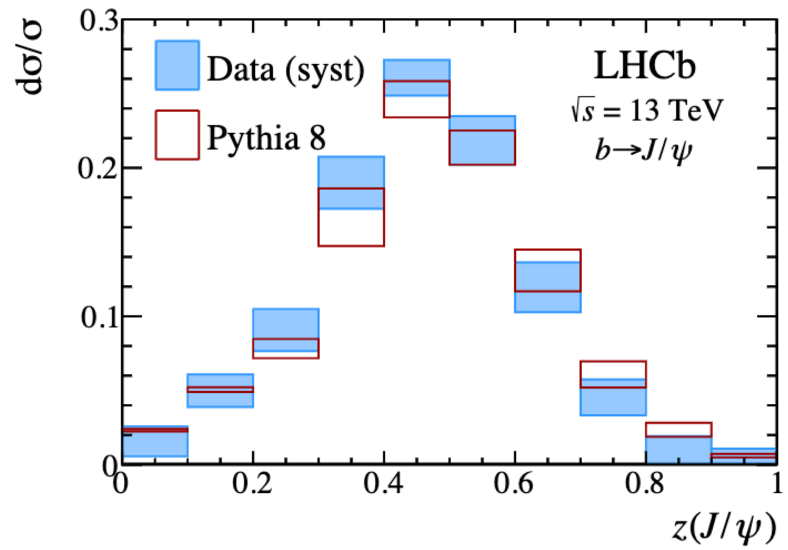
- Important to understand prompt $c\bar{c}$ creation in nuclear collisions!

$Q\bar{Q}$ production and correlation

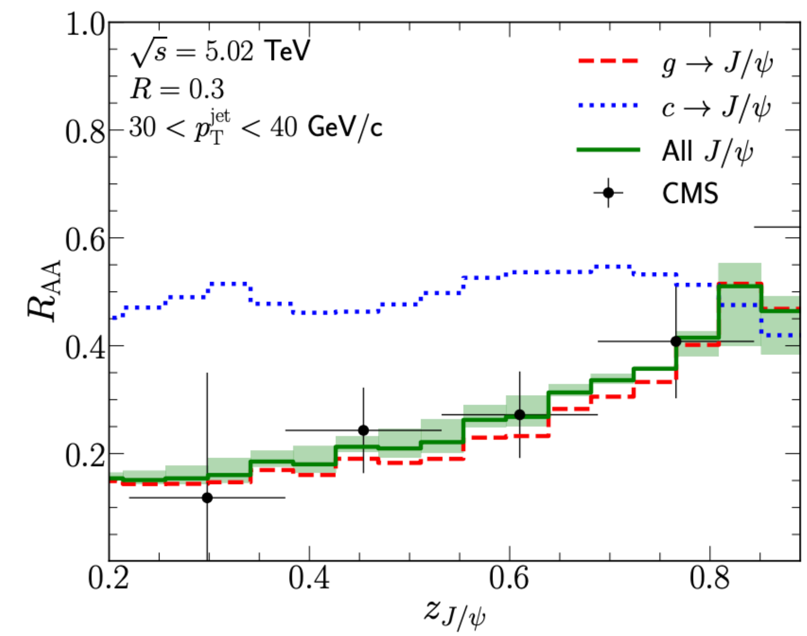
$$d\sigma[pp \to (\text{jet } J/\psi) + X] = \sum_i d\hat{\sigma}_{pp\to(\text{jet } i)+X} \otimes D_{i\to J/\psi}, \qquad D_{i\to J/\psi}(z,\mu_0) = \sum_{n} \hat{d}_{i\to[c\bar{c}(n)]}(z,\mu_0)\langle \mathcal{O}^{J/\psi}_{[c\bar{c}(n)]}\rangle$$

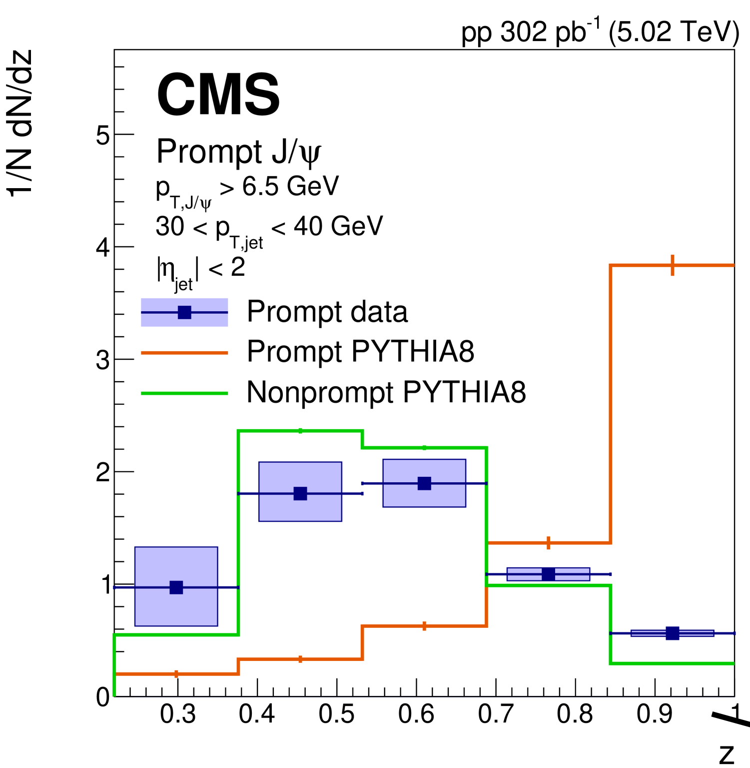


more g → $q\bar{q}$



arXiv.2403.12704



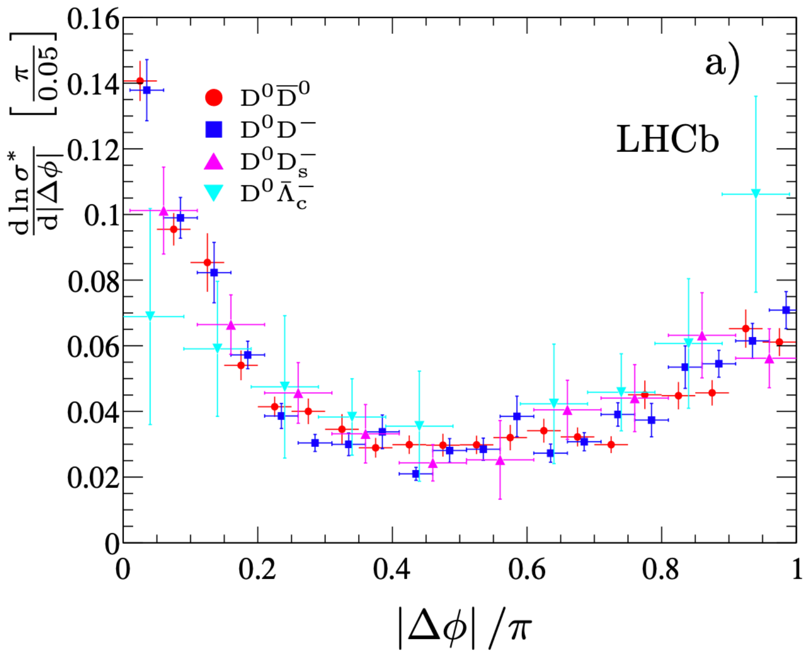


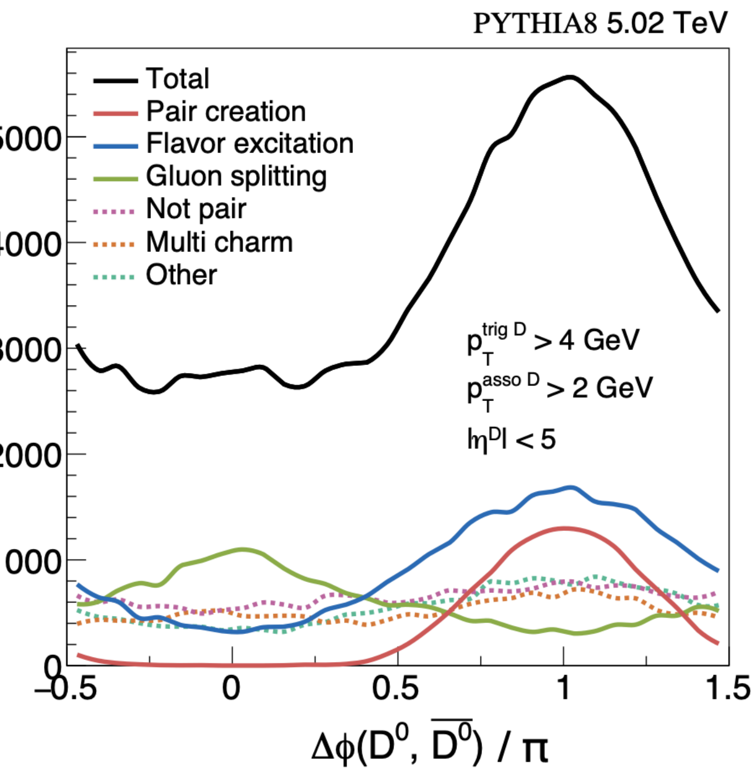
- Large NLO contribution expected for $c\bar{c}$
  - What compose `delayed' charmonia production from gluon radiation?
    - Fragmentation in AA
- How valid is $D_{i\to J/\psi}$ used for hadronic collisions?

Interesting to analyze different charmonia states with precision

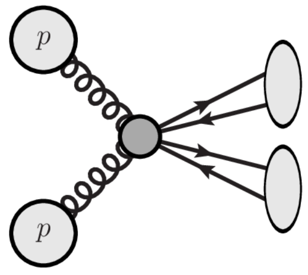
D-D correlation in nuclear collision

JHEP 06 (2012)

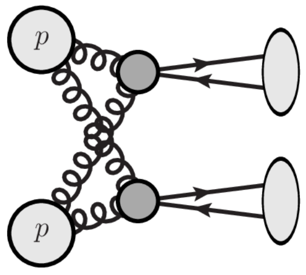




- Disclaimer: PYTHIA is LO generator
  ➡ NLO processes not accurate

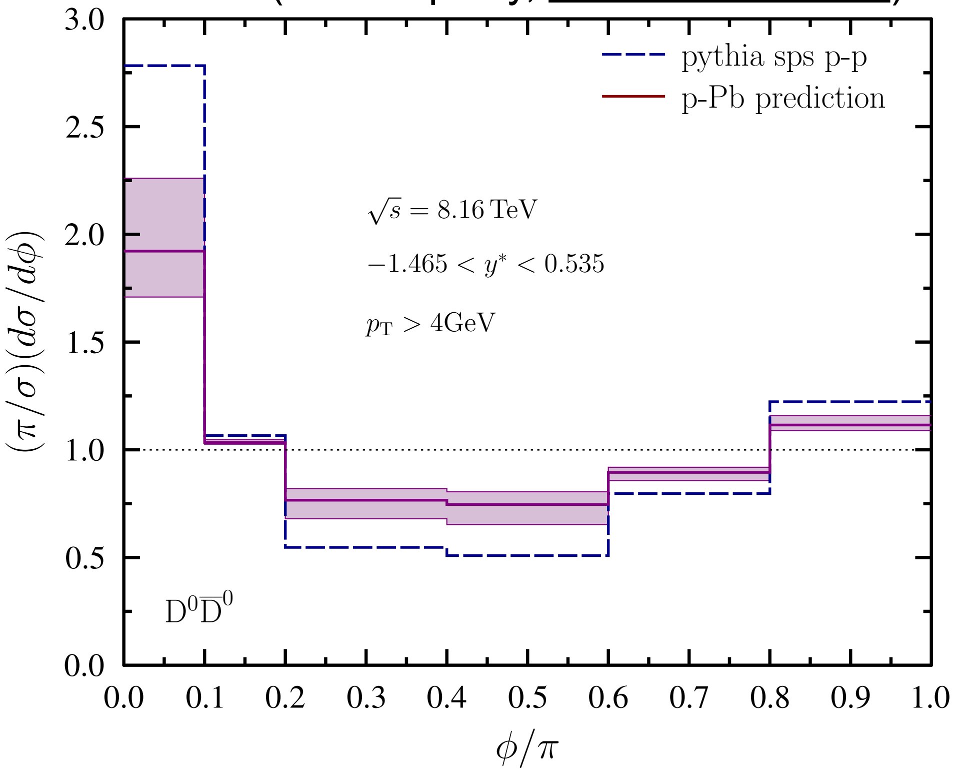


Single scatter (SPS)



Double scatter (DPS)
(Smear out correlation signal)

(CMS rapidity, PLB 2019 135084)

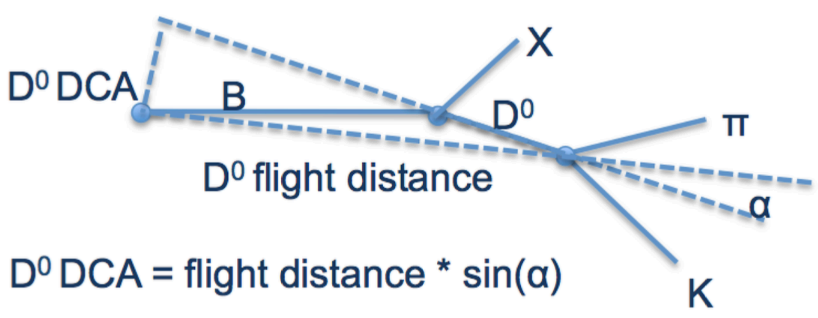


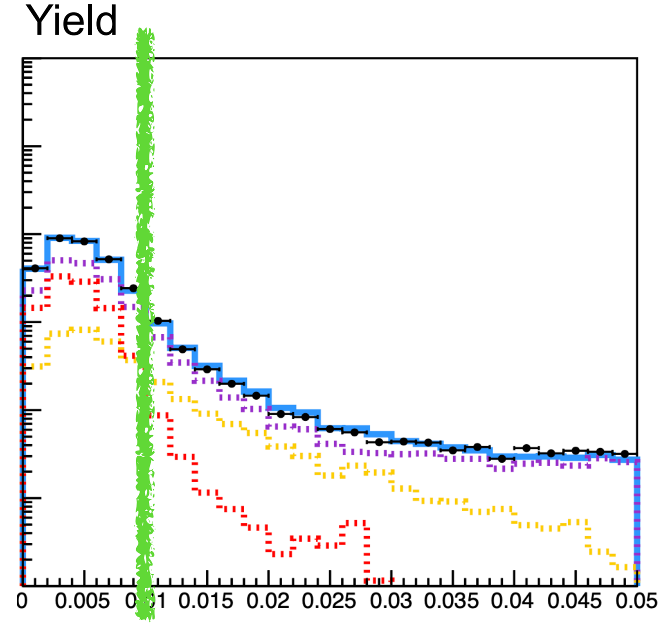
- Important to understand $c\bar{c}$ creation in HIC
- Analyzing pPb data helps understand heavy quark correlation, from cold QCD
  - Also developing analysis strategy for PbPb

Signal extraction method

- Fully reconstructed $\mathrm{D0} \rightarrow \mathrm{K} + \pi$ (c.c.) using charged tracks

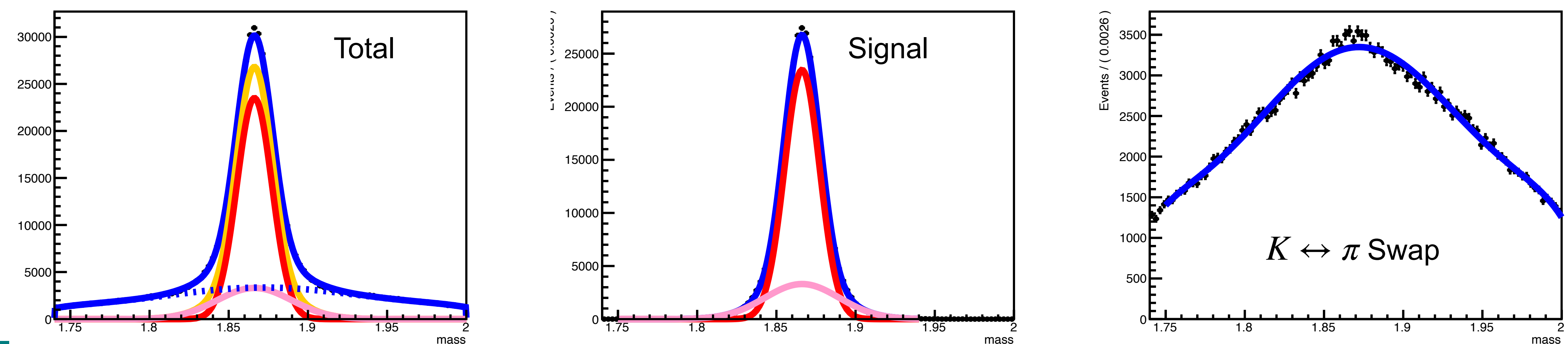
- Ensure prompt contribution with decay geometry cut





- No reliable PID in CMS, use statistical method to separate $\mathrm{D\bar{D}}$, $\mathrm{D\bar{D}}$

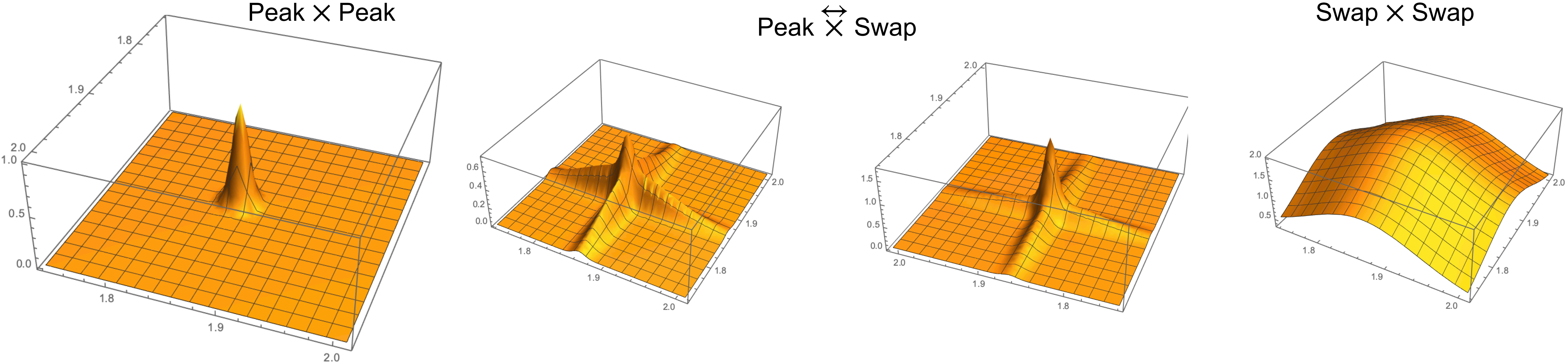
- Need to consider `swap' contribution in vertex reconstruction



Data Modeling

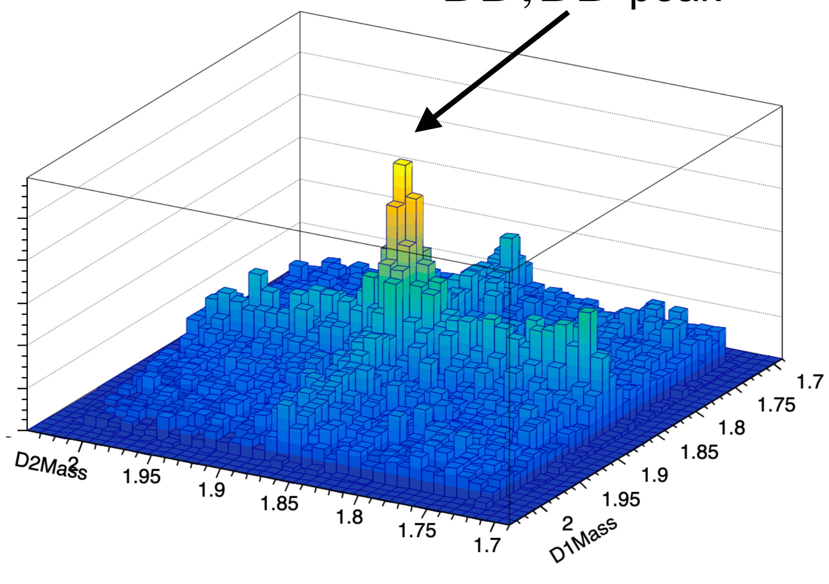
- Consider several signal related components, fixed parameters like peak vs. swap ratio with MC

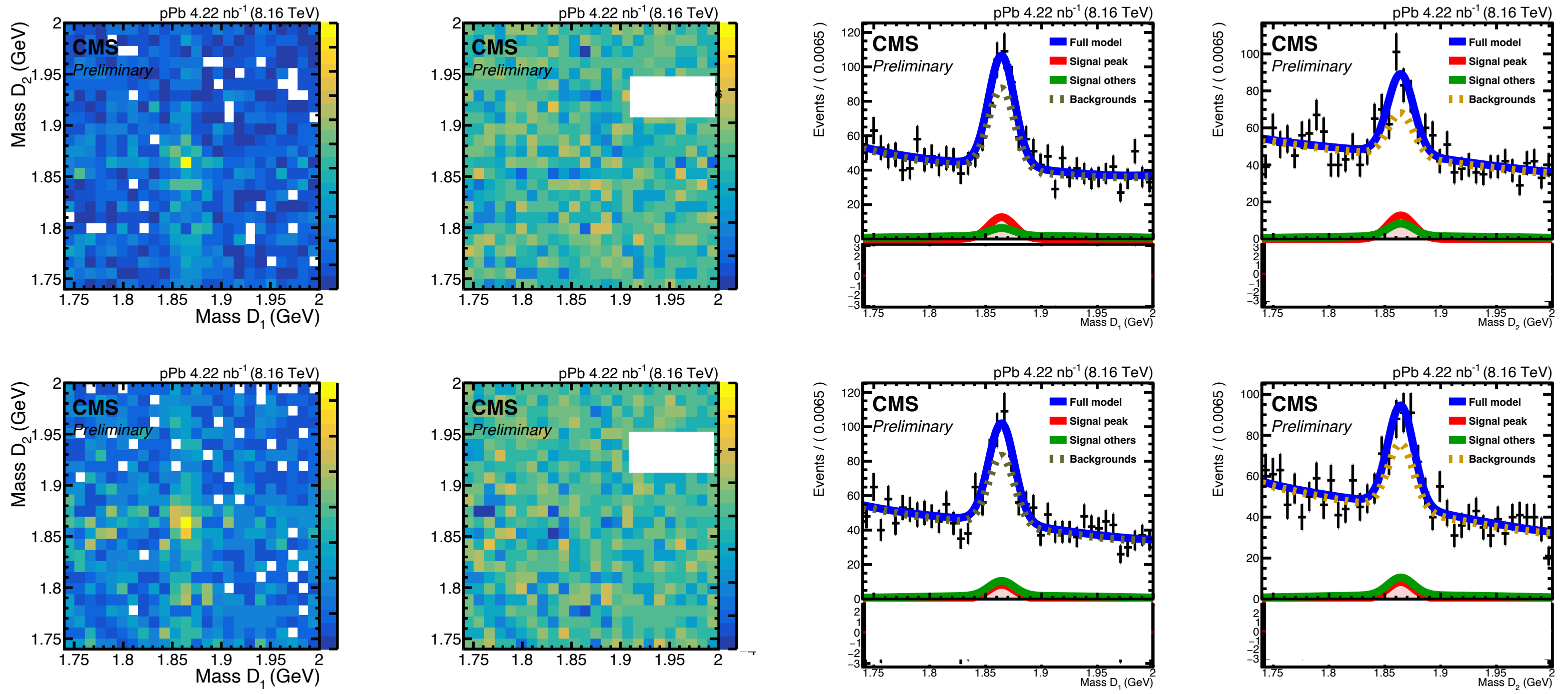
Peak × Peak — Peak $\overset{\leftrightarrow}{\times}$ Swap — Swap × Swap



- Perform fit with background, separate same sign, opposite sign on data simultaneously

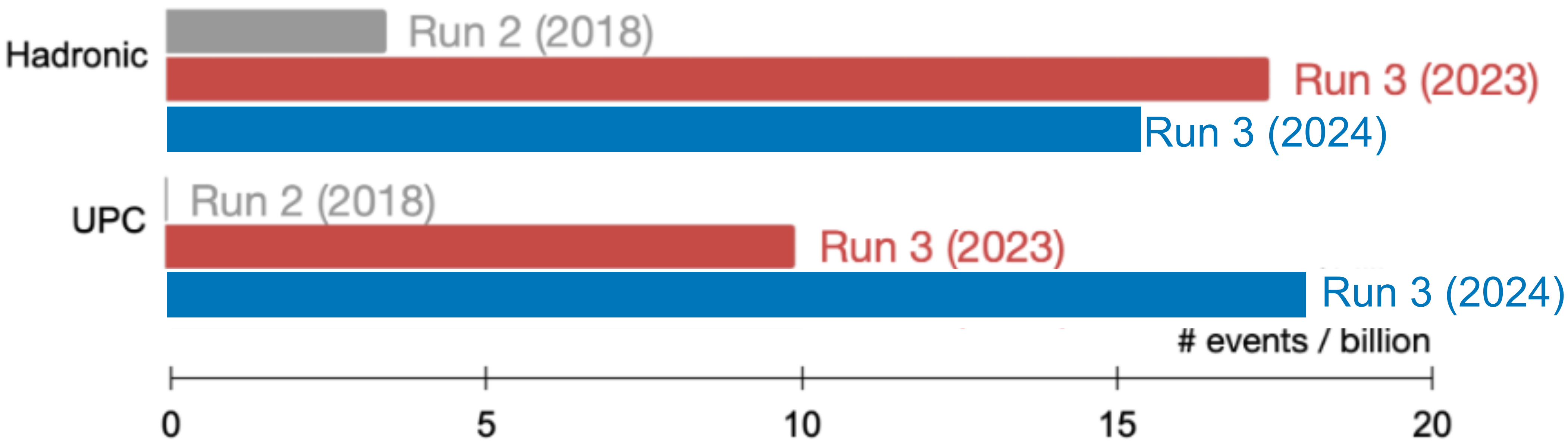
$DD, D\bar{D}$ peak





Plans for Run 3

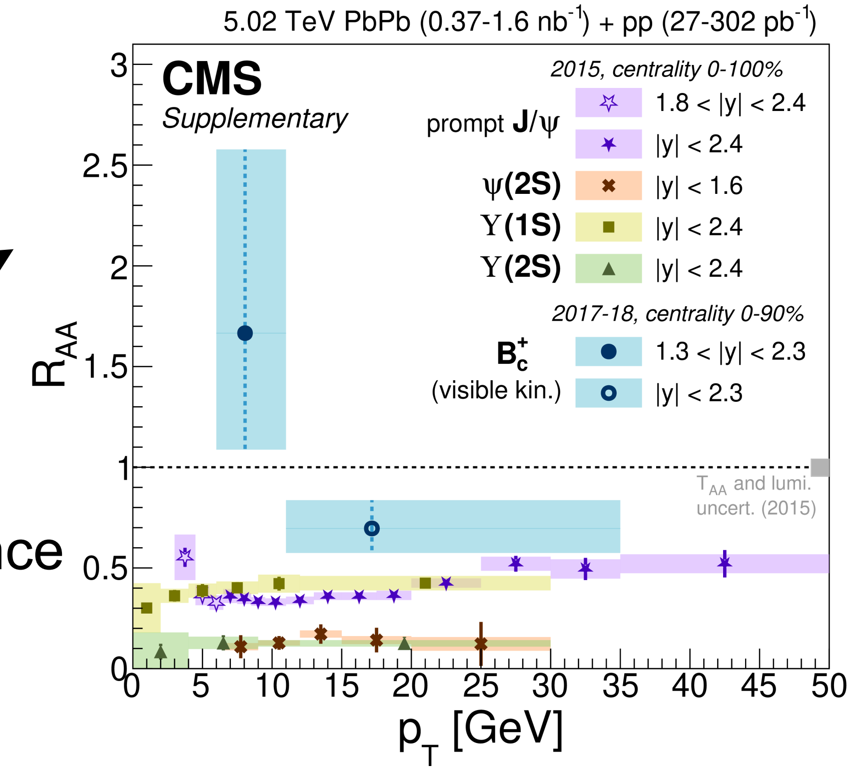
- Precision era arrives for HIN as well in run3
  - Expected ~3-4x larger lumi combined run3 compared to run2
    - Reconstruction and trigger efficiency gain also improved in tens of percents!
  - Full precision analysis to be done after 2026



Plans for Future

- Many questions to be revisited!
  - Expected ~3-4x larger lumi combined run3 compared to run2
  - Full precision analysis to be done after 2026

HIN-20-002, PRL 128 (2022) 252301

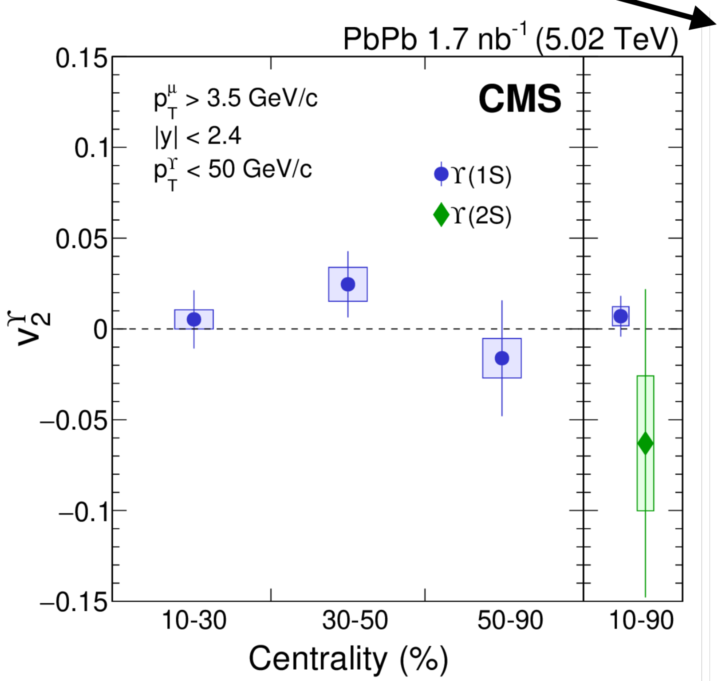


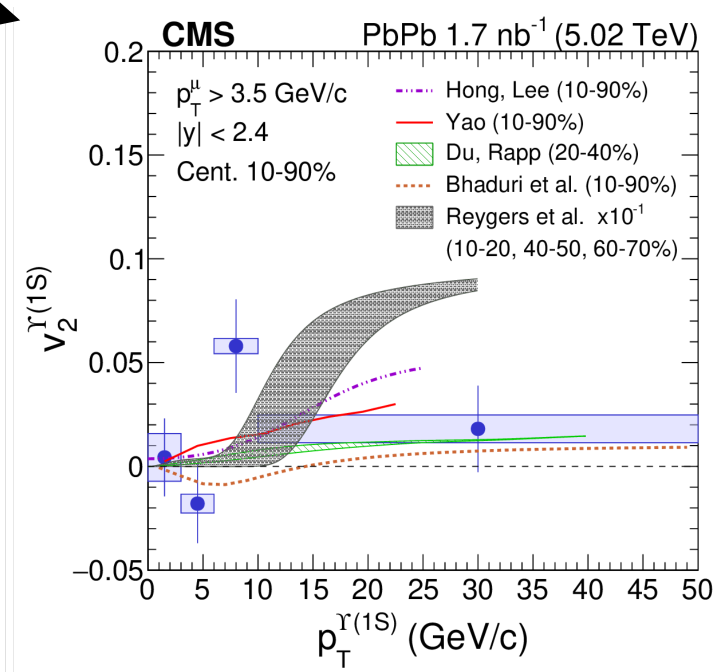
Heavy quark hadronization/coalescence

Υ too heavy to flow?

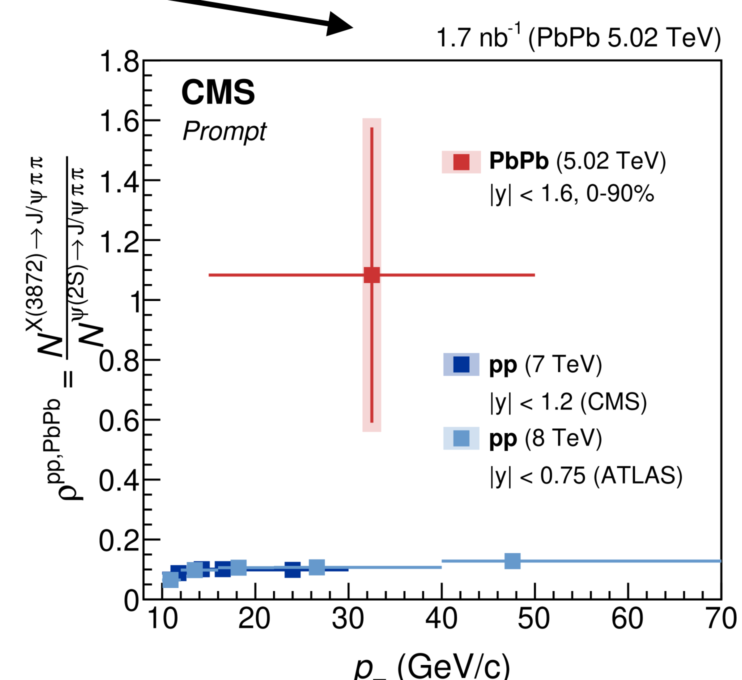
Exotic HF structure and hadronization mechanism

... and many more

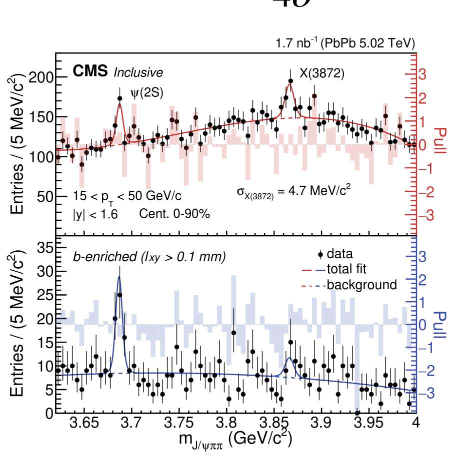




HIN-19-002, PLB 819 (2021) 136385



~4σ



HIN-19-005, PRL 128 (2022) 032001

Thank you!

Back up