

第十一届中国LHC物理会议

The 11th China LHC Physics Conference

Recent open heavy flavor and quarkonium measurements from ALICE experiment

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Xinxiang, November 01, 2025



Outline

- ✧ **Introduction**
- ✧ **HF production in pp collisions**
- ✧ **HF production in Pb-Pb collisions**
- ✧ **Summary and outlook**

Outline

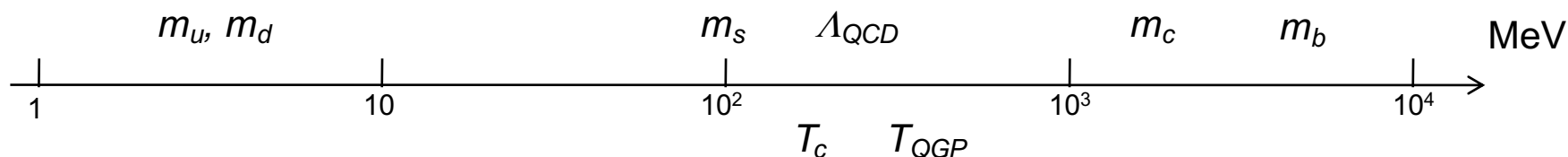
- ✧ **Introduction**
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Introduction

◆ pp collisions:

Key features: Produced early in the history of HIC / Calculable by pQCD

Observables: Cross sections / Hadronisation / Baseline for HIC ...



perturbative QCD:

$$\sigma^{pp \rightarrow Q\bar{Q}} = \int_0^1 dx_1 dx_2 \sum_{i,j} f_i(x_1, Q^2) f_j(x_2, Q^2) \sigma^{ij \rightarrow Q\bar{Q}}(x_1, x_2, Q^2)$$

Nucl. Phys. B263 (1986) 37.

Nucl. Phys. B151 (1979) 429.

Introduction

✧ pp collisions:

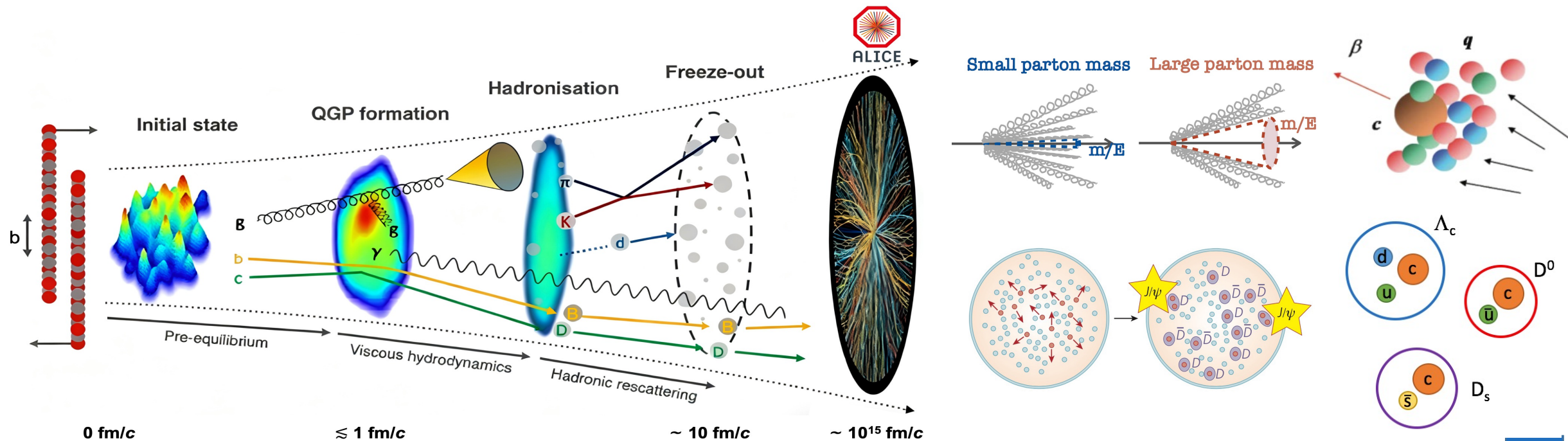
Key features: Produced early in the history of HIC / Calculable by pQCD

Observables: Cross sections / Hadronisation / Baseline for HIC ...

✧ Pb-Pb collisions:

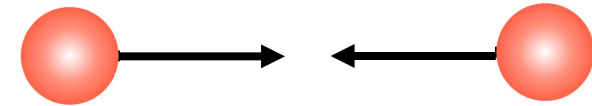
Key features: Witness of the system evolution / Sensitive to medium properties

Observables: Energy loss / Flow / Hadronisation / Polarization ...

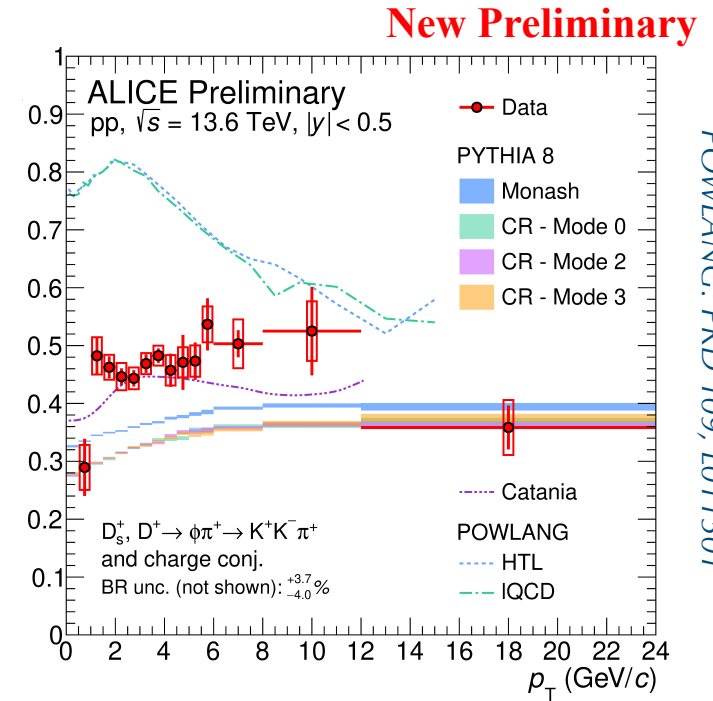
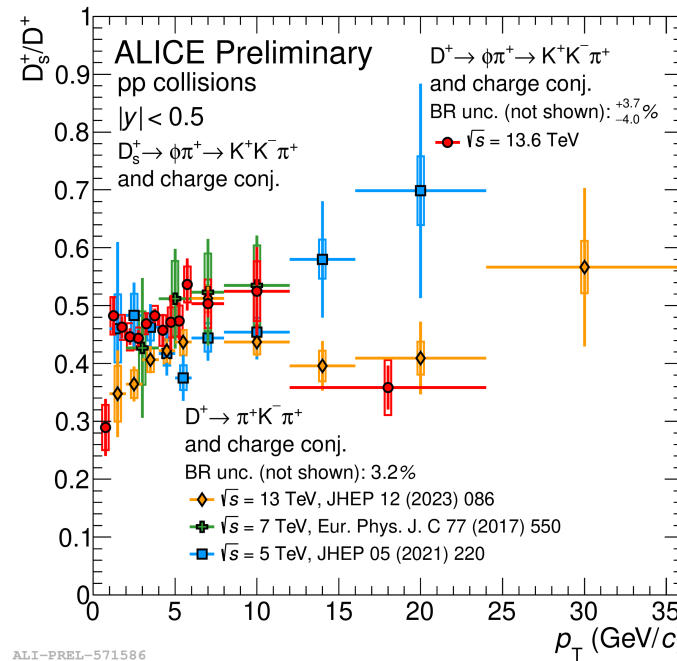
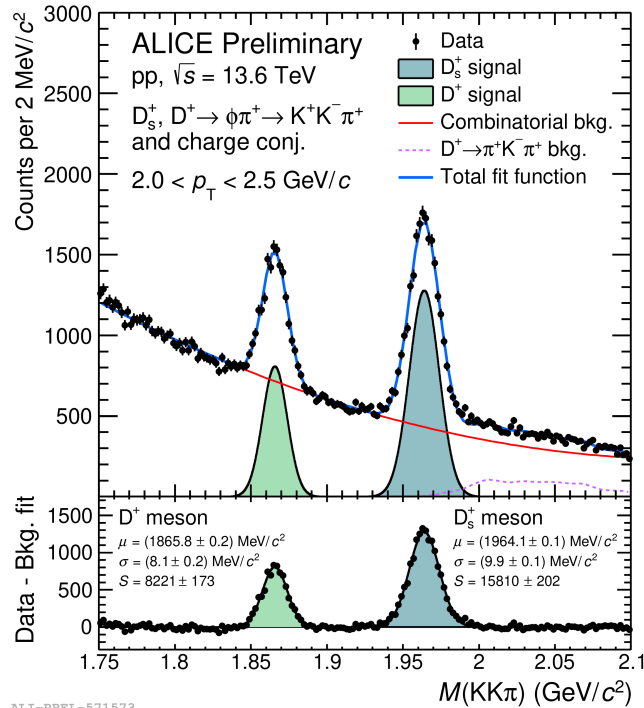


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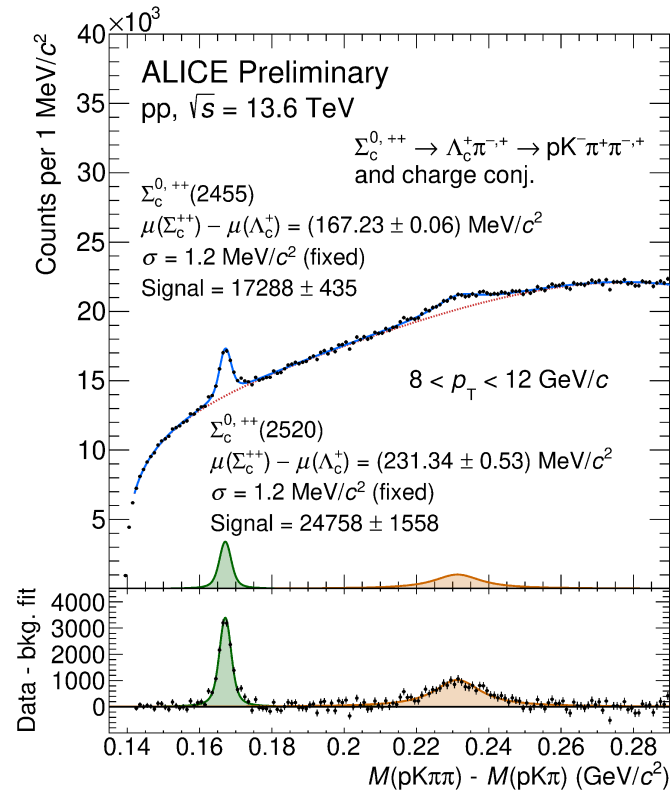
Prompt D_s^+ and D^+ in pp collisions at $\sqrt{s} = 13.6$ TeV



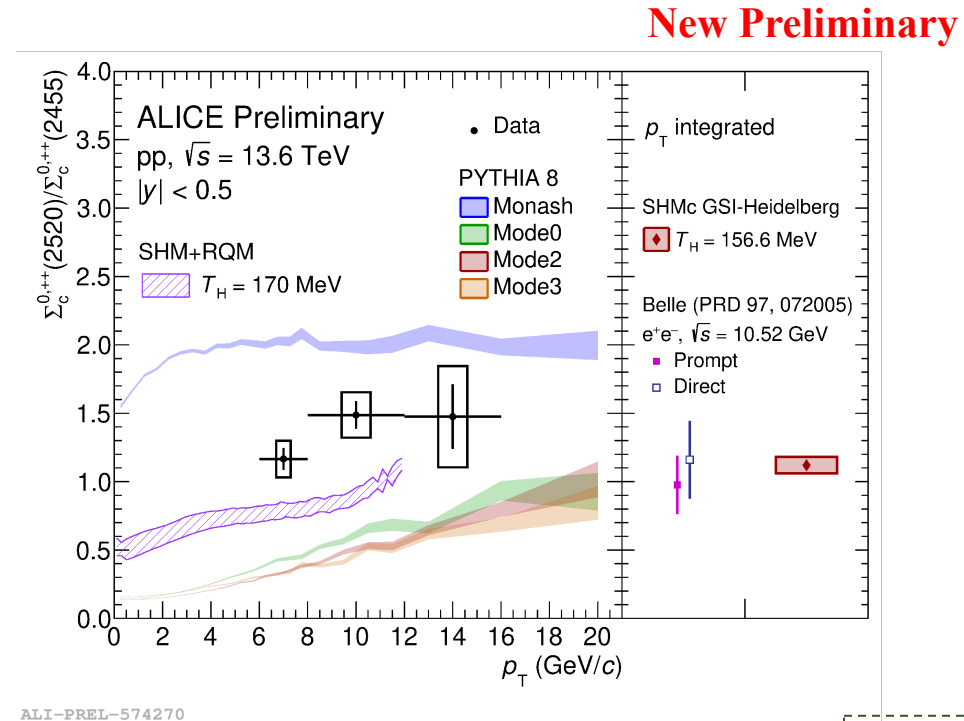
Mult. dependence:
Fang Tao@Oct. 31

- First measurement in pp collisions at $\sqrt{s} = 13.6$ TeV down to $p_T = 0$
- Improved precision for strangeness production in charm sector in small system.
- No obvious collision energy dependence observed.
- Catania (coalescence) gives best description, while POWLANG (local color recombination) and PYTHIA (string fragmentation) can not describe the data

$\Sigma_c^{0,++}$ in pp collisions at $\sqrt{s} = 13.6$ TeV



ALI-PREL-571534



ALI-PREL-574270

PYTHIA: EPJC 74 (2014) 8, 3024,
JHEP 08 (2015) 003
GSI-SHMc: JHEP 07 (2021) 035

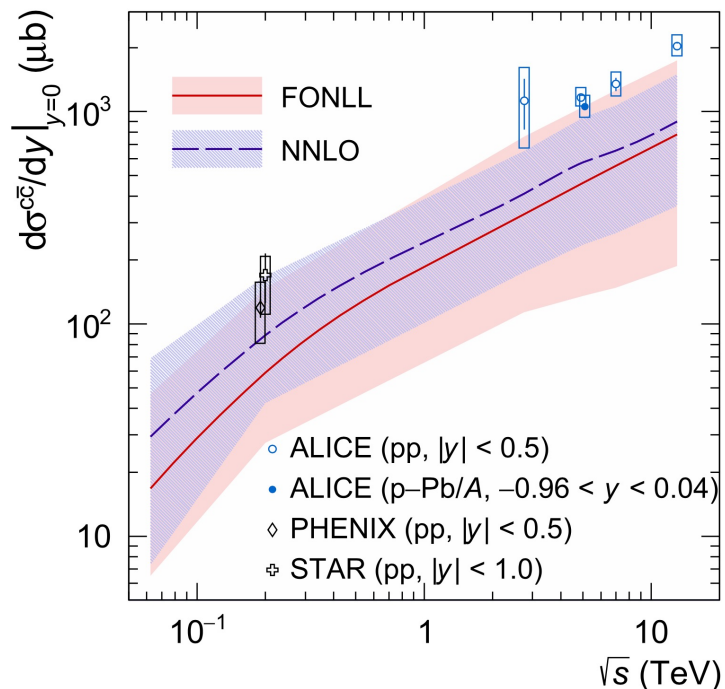
Ran Tu@Oct. 30

- ✦ First measurement of $\Sigma_c^{0,++}(2520)$ relative to $\Sigma_c^{0,++}(2455)$ in pp collisions at $\sqrt{s} = 13.6$ TeV
- ✦ No obvious difference w.r.t. e^+e^- collisions (Belle) within uncertainties
- ✦ PYTHIA 8 Monash (default tune) overestimates the ratio, PYTHIA 8 with additional color reconnection underestimates the ratio

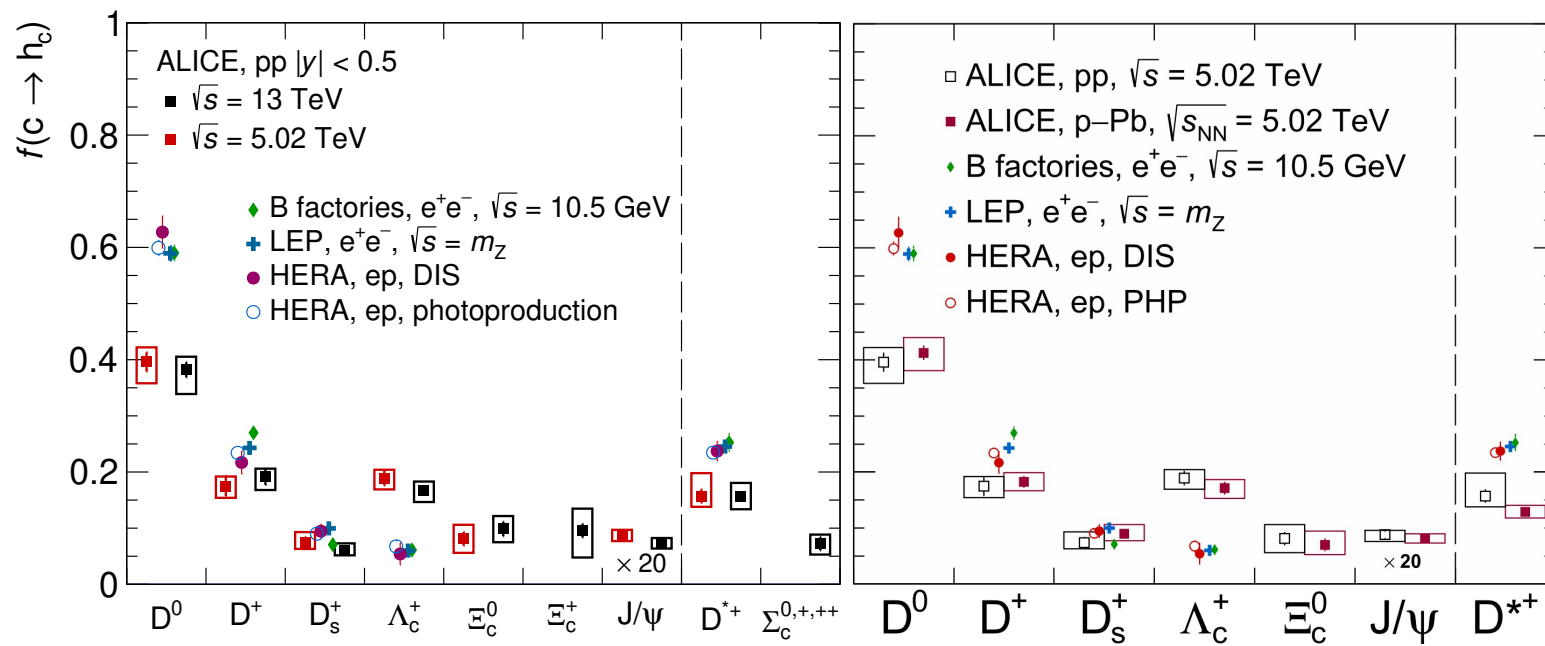
Charm production and fragmentation fractions

ALICE, EPJC 84 (2024) 1286

FONLL: JHEP 05 (1998) 007



ALICE, JHEP 12 (2023) 086



ALICE, EPJC 84 (2024) 1286

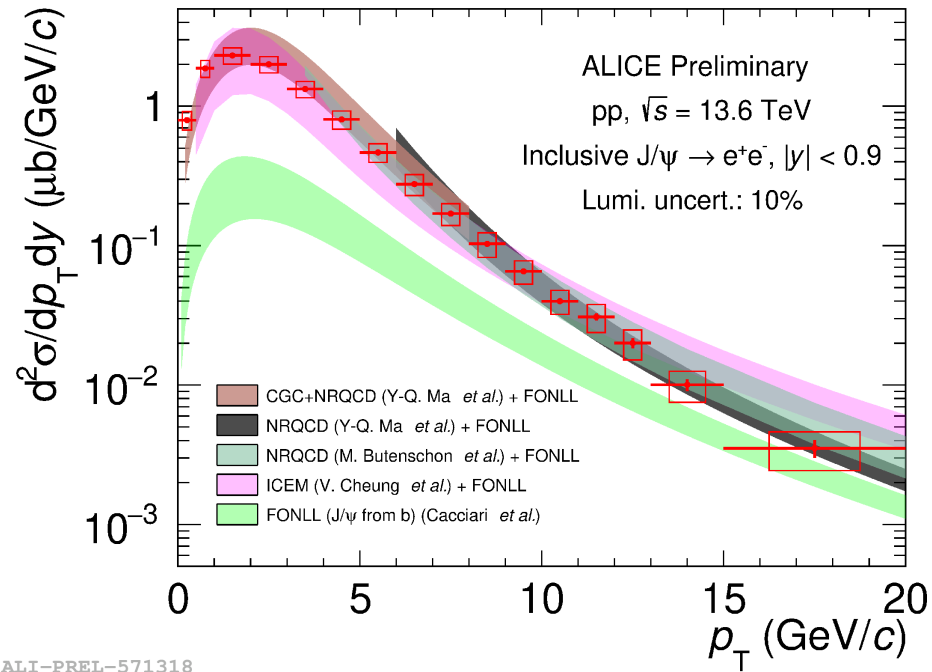
Total charm production cross section: consistent with FONLL upper limit at midrapidity.

Charm fragmentation fractions:

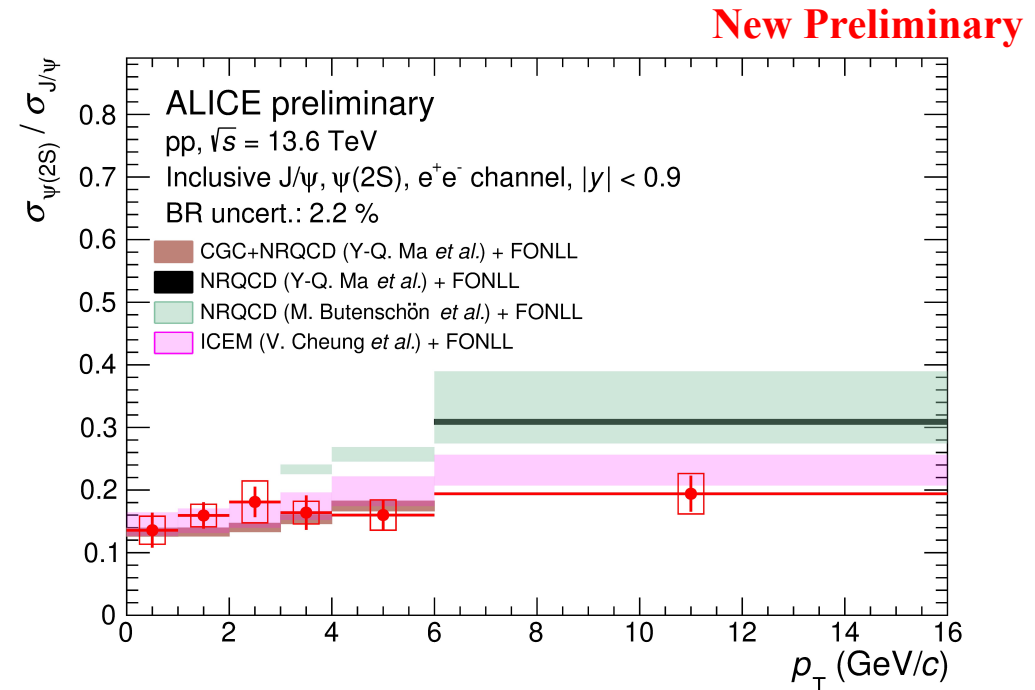
- ✧ No obvious collision energy dependence.
- ✧ Data from pp and p-Pb collisions are consistent within uncertainties.

Different w.r.t e^+e^- and ep collisions. **Baryon enhancement in small system** not fully understood.

Charmonia in pp collisions at $\sqrt{s} = 13.6$ TeV



ALI-PREL-571318

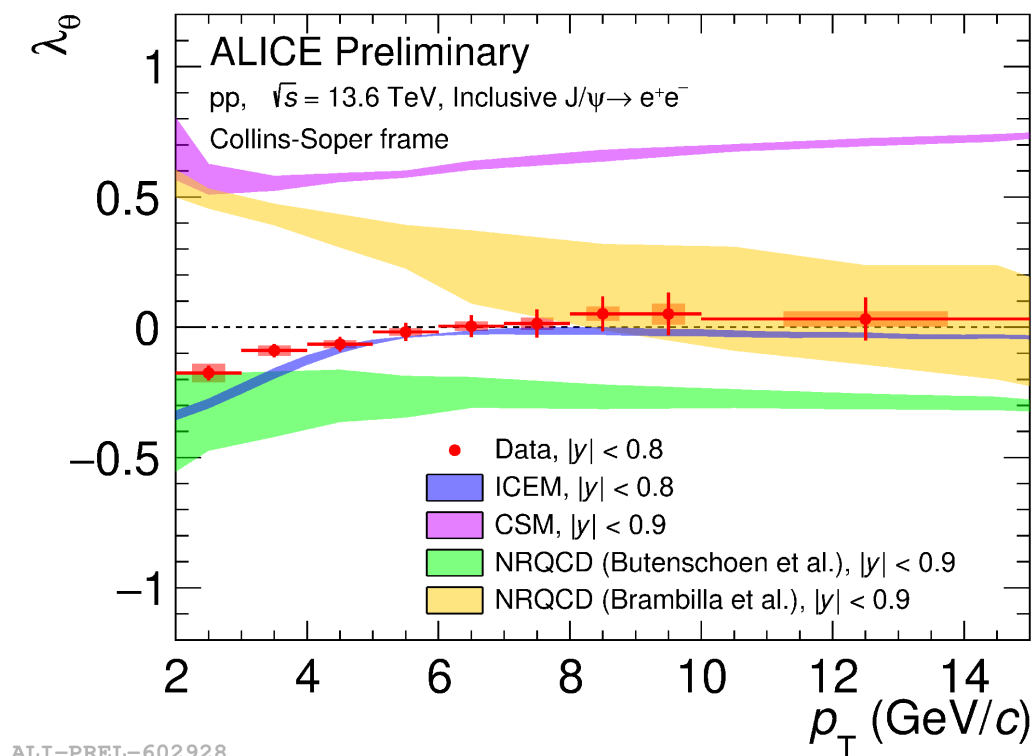


ICEM: Y.-Q. Ma *et al.*, PRD 94 (2016) 114029
NRQCD: B. A. Kniehl, *et al.*, PRD 73 (2006) 074022

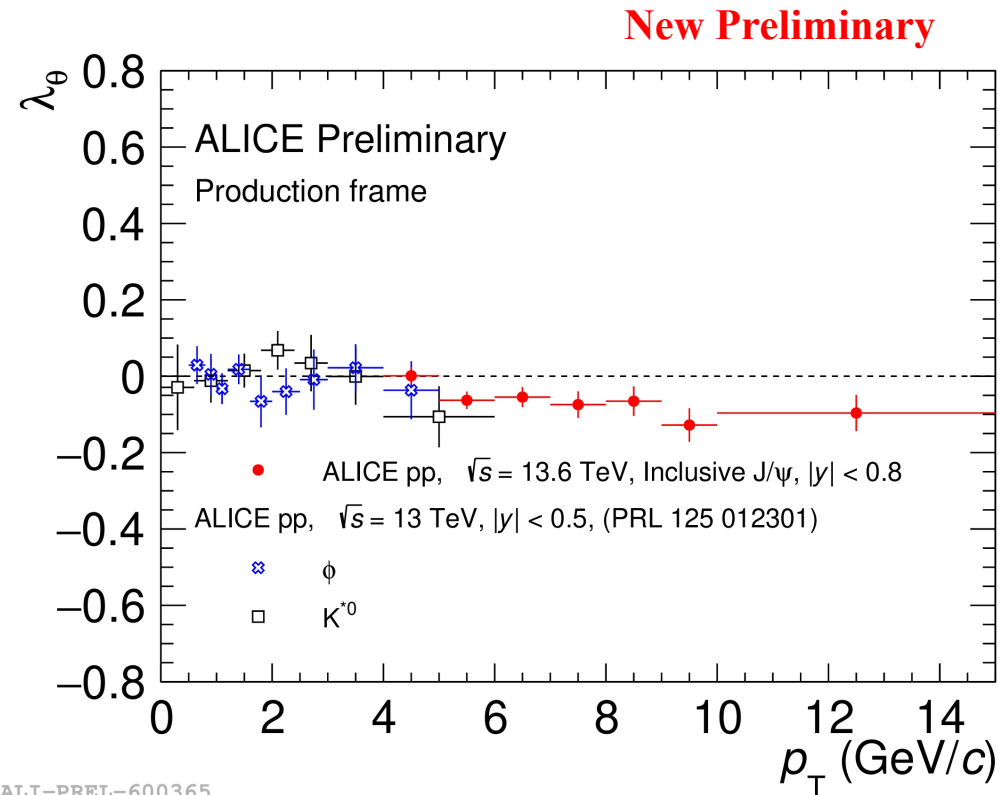
- ✦ Precision measurements of J/ψ and $\psi(2S)$ at midrapidity with significantly higher statistics collected in Run 3.
- ✦ The data are described by ICEM and NRQCD based models coupled with FONLL to account for the non-prompt J/ψ contribution.

Yiping Wang@Oct. 30

Charmonium polarization in pp collisions



ALI-PREL-602928

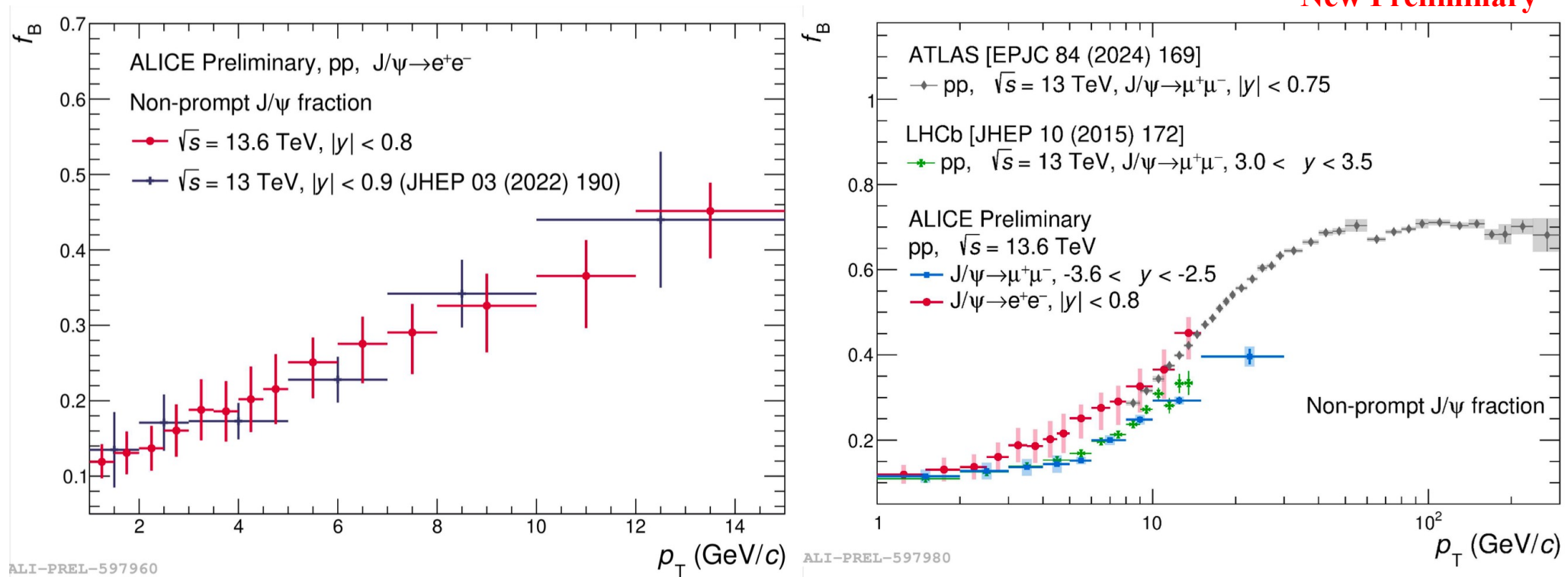


ALI-PREL-600365

Liang Dong@Oct. 30

- ✧ Hint of non-zero signals for CS / Production frame at low / high p_T , respectively.
- ✧ The data can be described by the ICEM calculations.

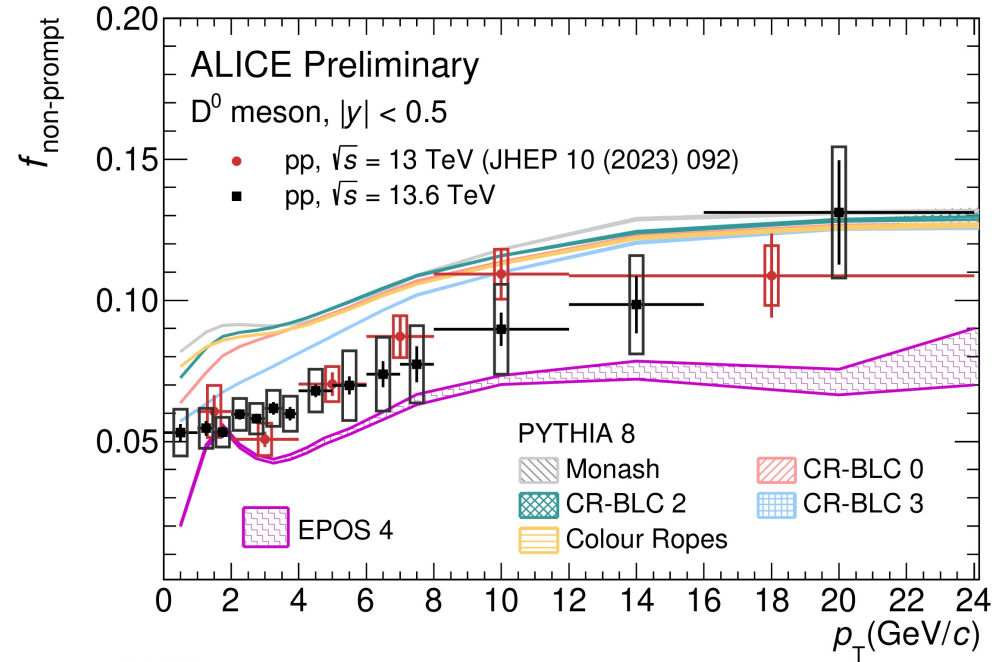
Non-prompt J/ψ in pp collisions



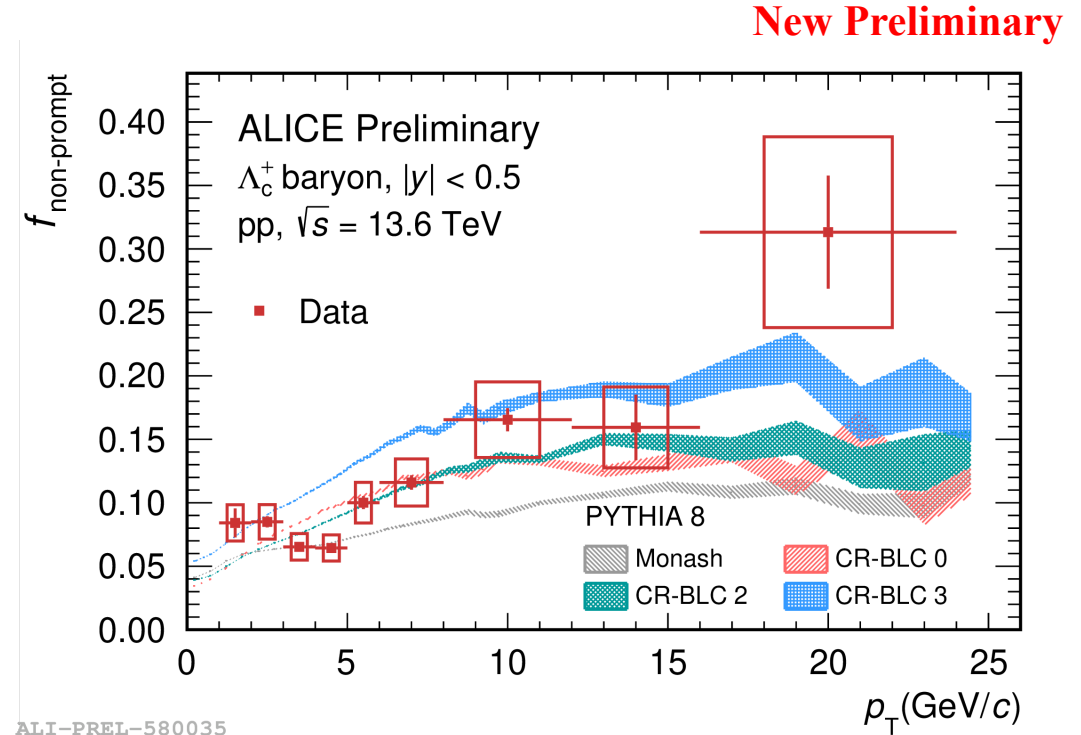
Yiping Wang@Oct. 30

- Improved statistics from Run 3. Consistent with Run 2 result at midrapidity.
- Systematically different from forward rapidity at intermediate p_T region.

Non-prompt D^0 and Λ_c^+ in pp collisions



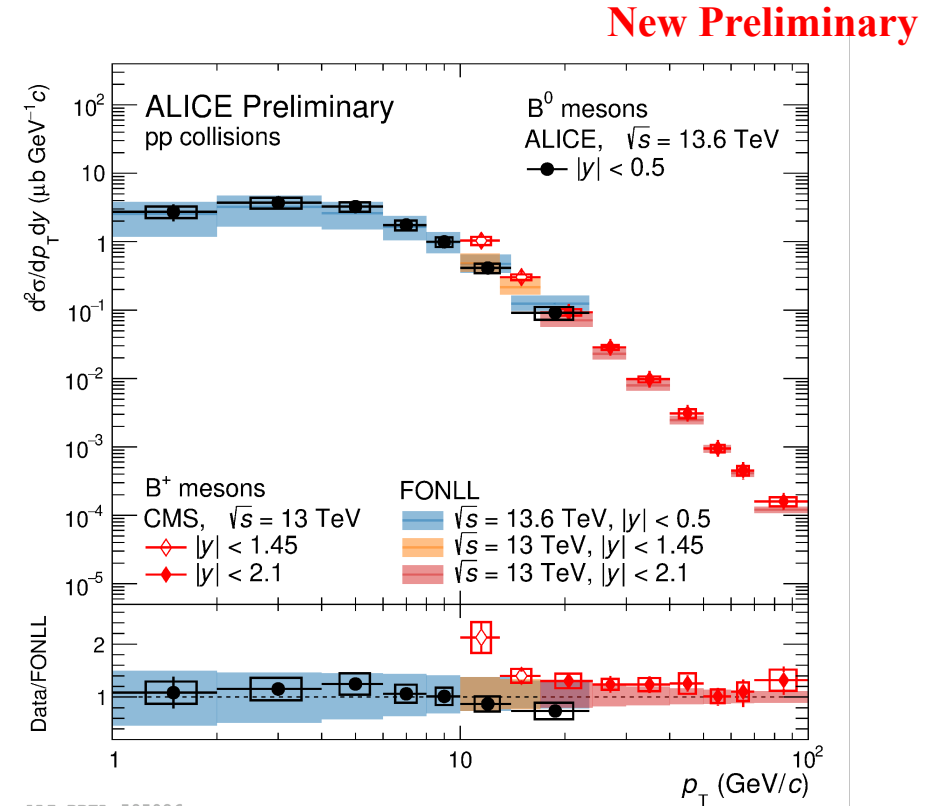
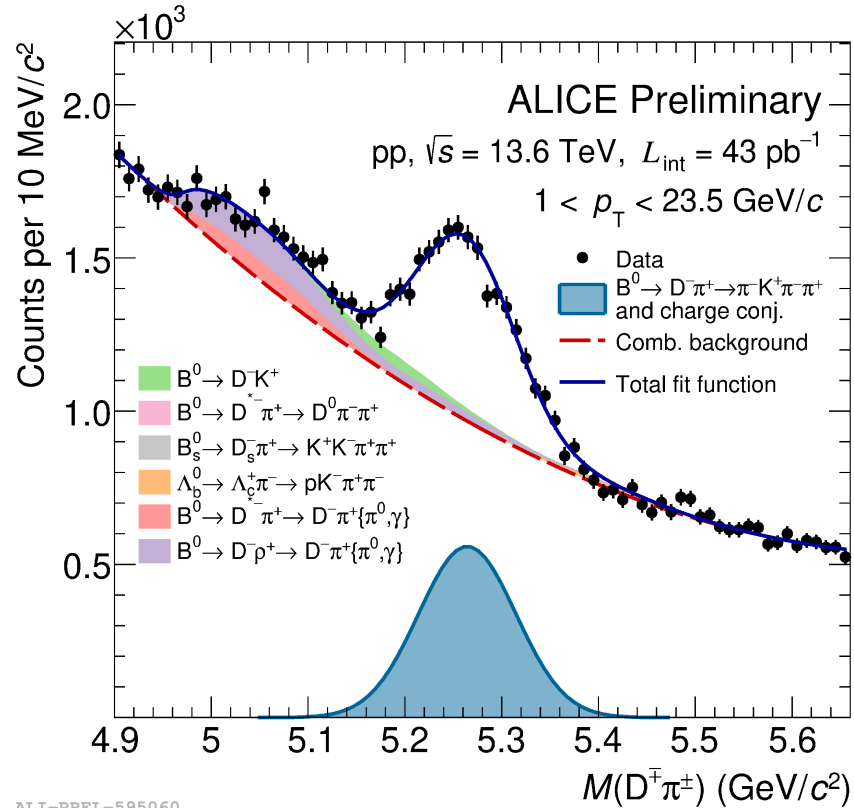
ALI-PREL-571369



ALI-PREL-580035

- ◆ Non-prompt D^0 and Λ_c^+ fractions measured extended down to $p_T = 0$ and 1 GeV/c, respectively
- ◆ Models can not describe D^0 and Λ_c^+ data simultaneously. Pythia color reconnection tuning reproduces Λ_c^+ result better.

Direct B^0 reconstruction in pp collisions

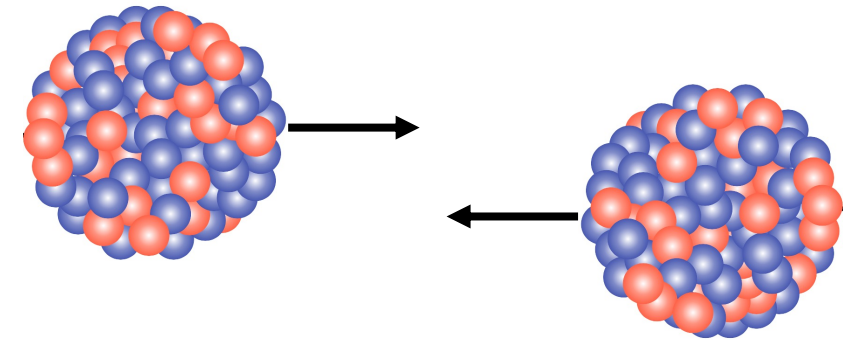


FONLL: JHEP 05 (1998) 007

- ✦ First direct observation of B^0 meson via hadronic decay reconstruction in ALICE
- ✦ New measurement widely extends the CMS result down to $p_T = 1 \text{ GeV}/c$
- ✦ In good agreement with FONLL calculations

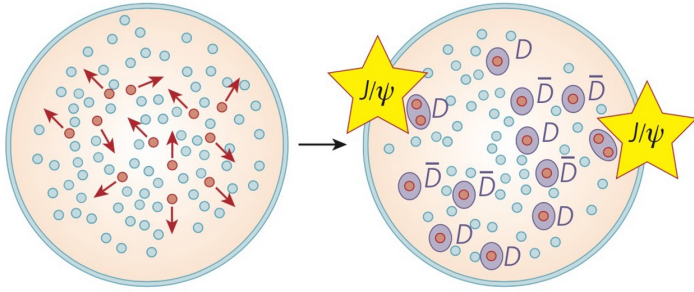
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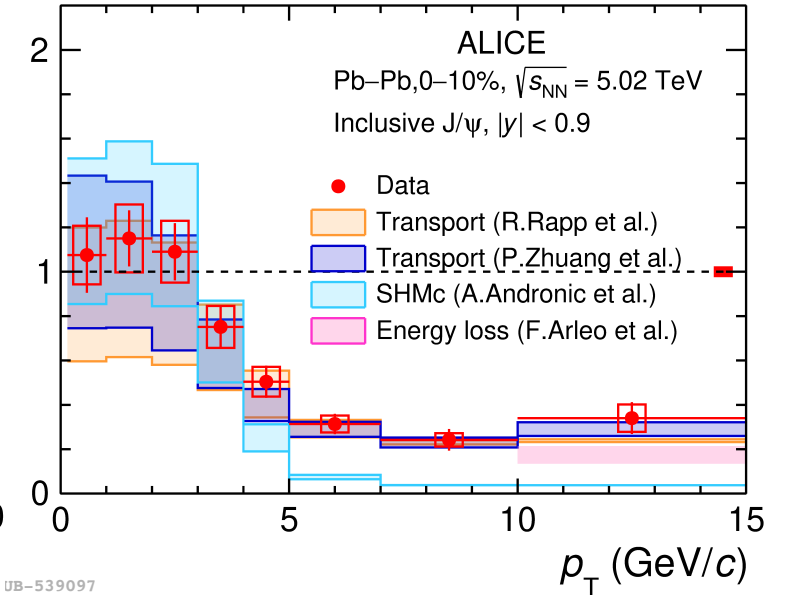
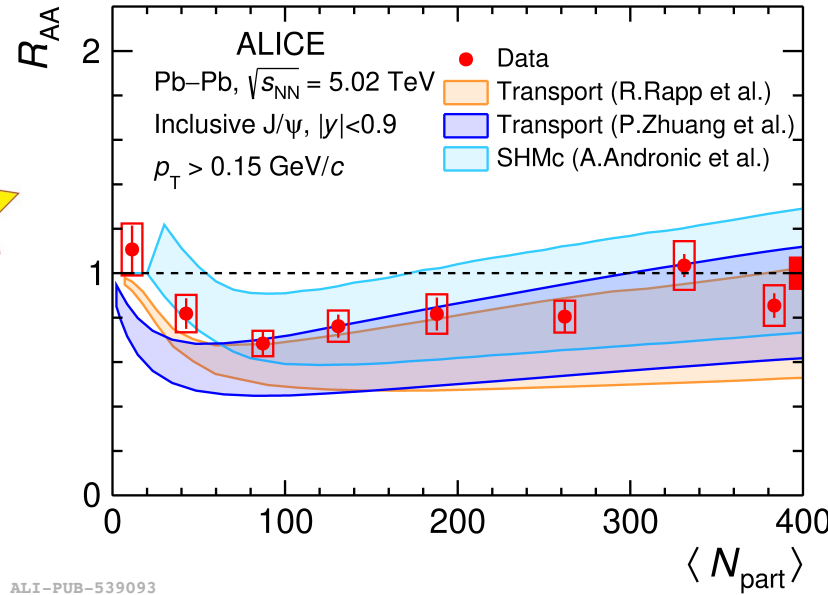


Inclusive J/ψ R_{AA}

P. Braun-Munzinger, J. Stachel,
Nature 448 (2007) 302



$$R_{AA}(p_T, y) \equiv \frac{1}{\langle T_{AA} \rangle} \frac{d^2 N_{AA}/dp_T dy}{d^2 \sigma_{pp}/dp_T dy}$$



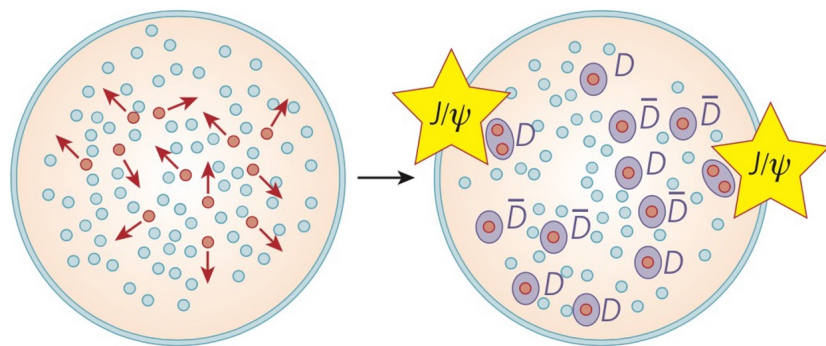
Du, X. et al., NPA 943, 147–158 (2015)
Zhou, K., et al., PRC 89, 054911 (2014)
Andronic, A, et al, PLB 797, 134836 (2019)

✦ Evidence for J/ψ (re-)generation in central collisions.

✦ All models can describe the integrated yield but suffer from large uncertainties. Differentially SHMc underestimates data at high p_T .

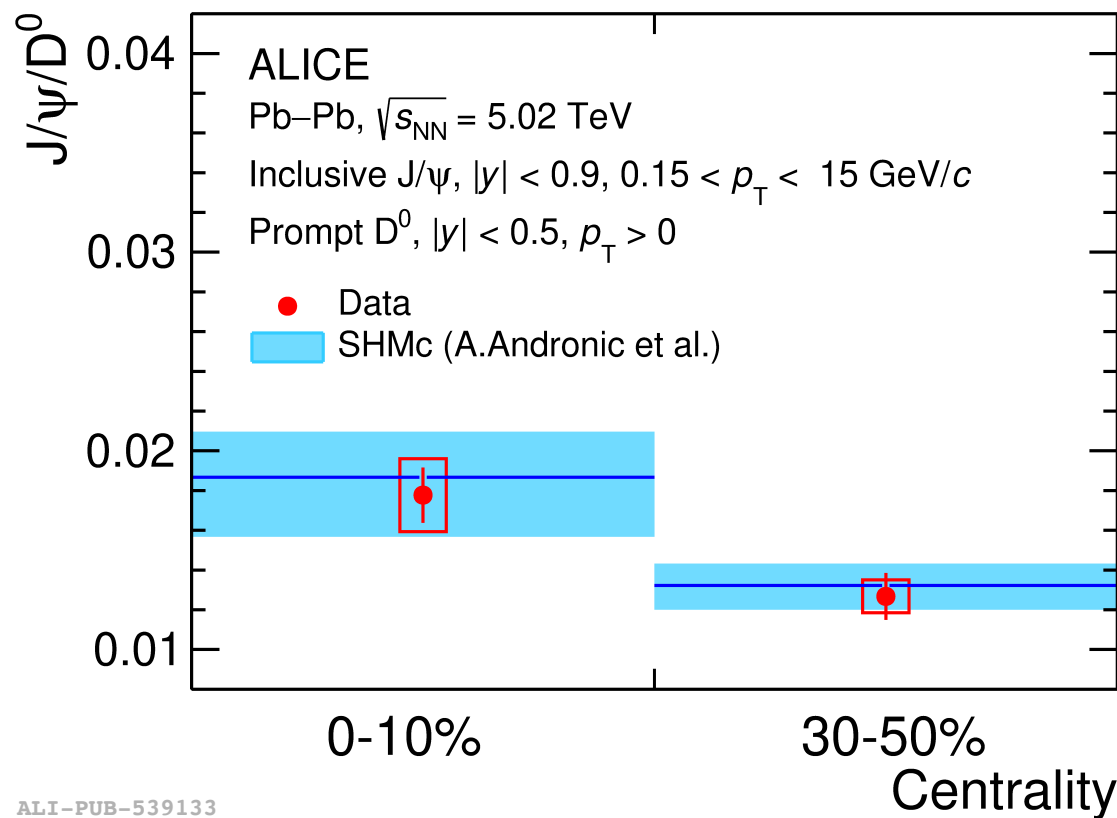
J/ψ-to-D⁰ ratio in Pb–Pb collisions

P. Braun-Munzinger, J. Stachel,
Nature 448 (2007) 302



Key for charm deconfinement

ALICE, PLB 849 (2024) 138451



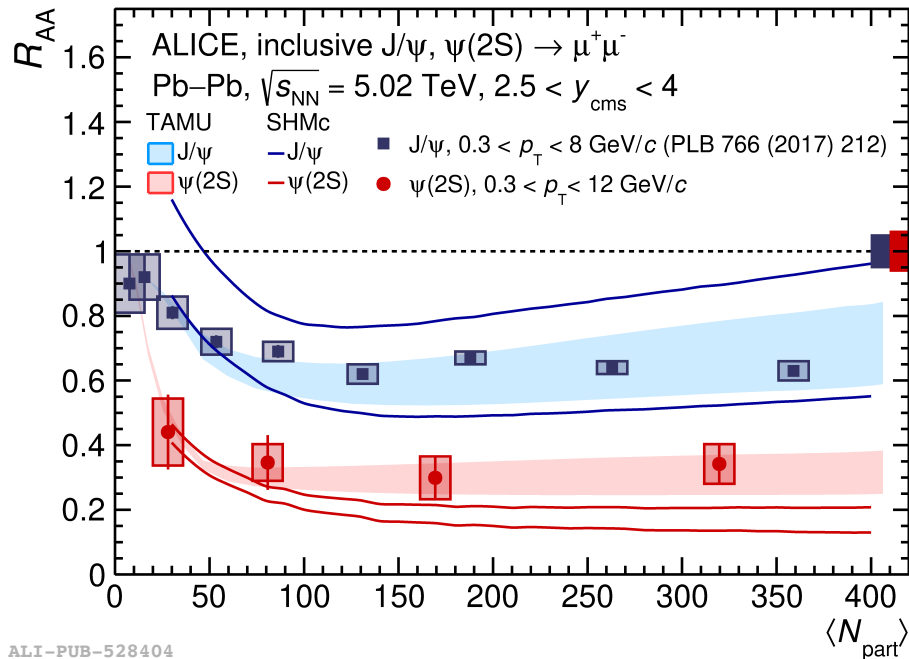
SHMc
Andronic, A, et al,
PLB 797, 134836 (2019)

ALI-PUB-539133

- ✦ Sensitive to hadronization mechanisms for open and hidden charm hadrons
- ✦ The centrality-dependent trend of the J/ψ to D⁰ ratio consistent with SHMc prediction considering the increase of charm abundance towards most central collisions.

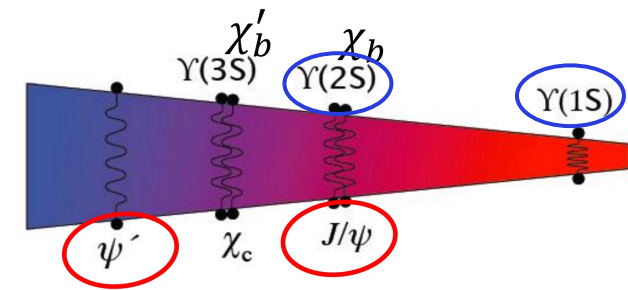
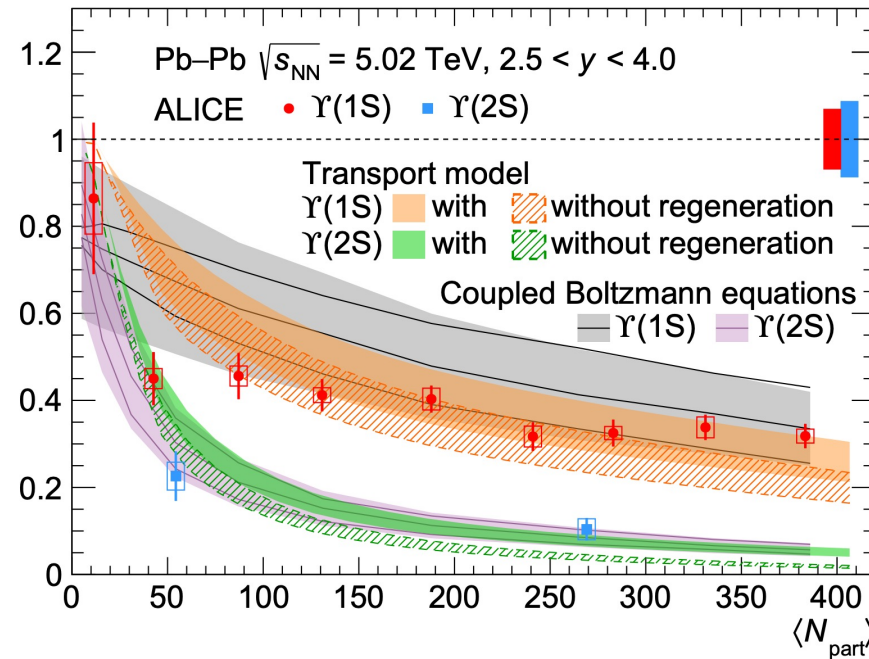
Sequential suppression of quarkonia R_{AA}

ALICE, PRL 132 (2024) 042301



ALI-PUB-528404

ALICE, PLB 822 (2021) 136579



TAMU

X. Du, et al., NPA943, 147-158 (2015)

SHMc

A. Andronic, et al., PLB797, 134836 (2019)

Transport

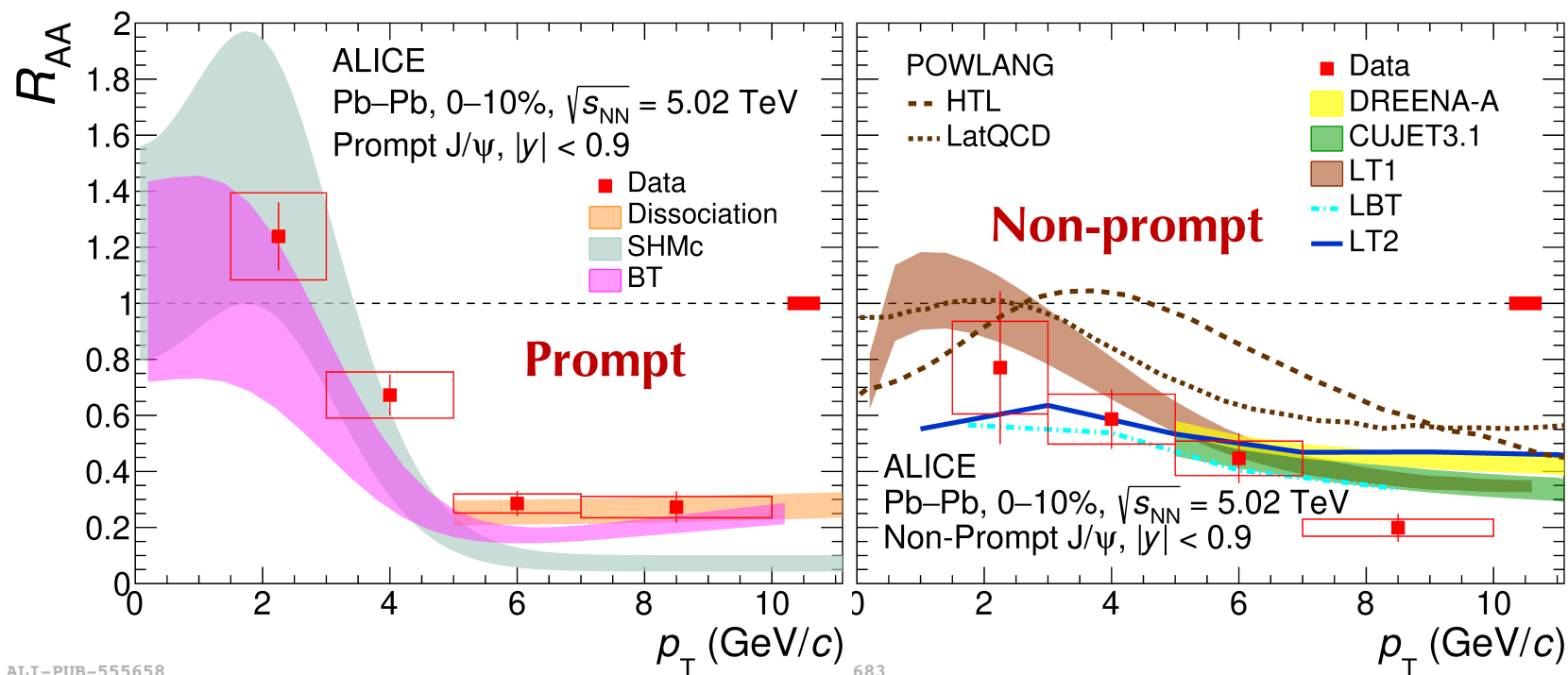
X. Du, et al., PRC96, 054901 (2017)

X. Yao, et al., JHEP21, 046 (2020)

- ✧ A **larger suppression** of the $\psi(2S)$ w.r.t the J/ψ is observed, similar for $Y(1S)$ and $Y(2S)$.
- ✧ Models with sequential melting of quarkonia mechanisms describe data.
- ✧ The $\psi(2S)$ R_{AA} increases at low p_T as a **hint of $\psi(2S)$ regeneration**.
- ✧ The regeneration effect for Y is negligible.

Non-prompt and prompt J/ψ R_{AA}

ALICE, JHEP 02 (2024) 066



DREENA-A:

Front. Phys. 10:957019 (2022),

Phys. Rev. C 105, L021901

CUJET3.1: *CPC 43 (2019) 044101*

LT1: *PRC107, 054917(2023)*

LBT: *PLB838(2023) 137733*

LBT2: *EPJC 81 848 (2021) 1035*

Dissociation: PLB 778 (2018) 384-391

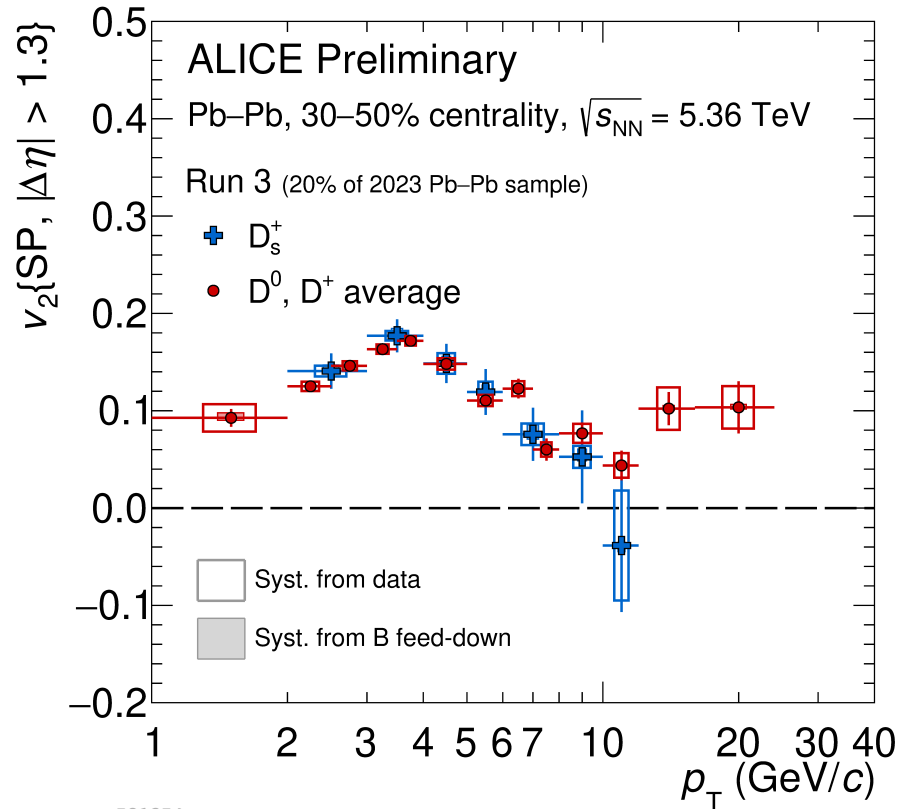
SHMc: *PLB 797 (2019) 134836*

BT: *CPC43 (2019) 124101*

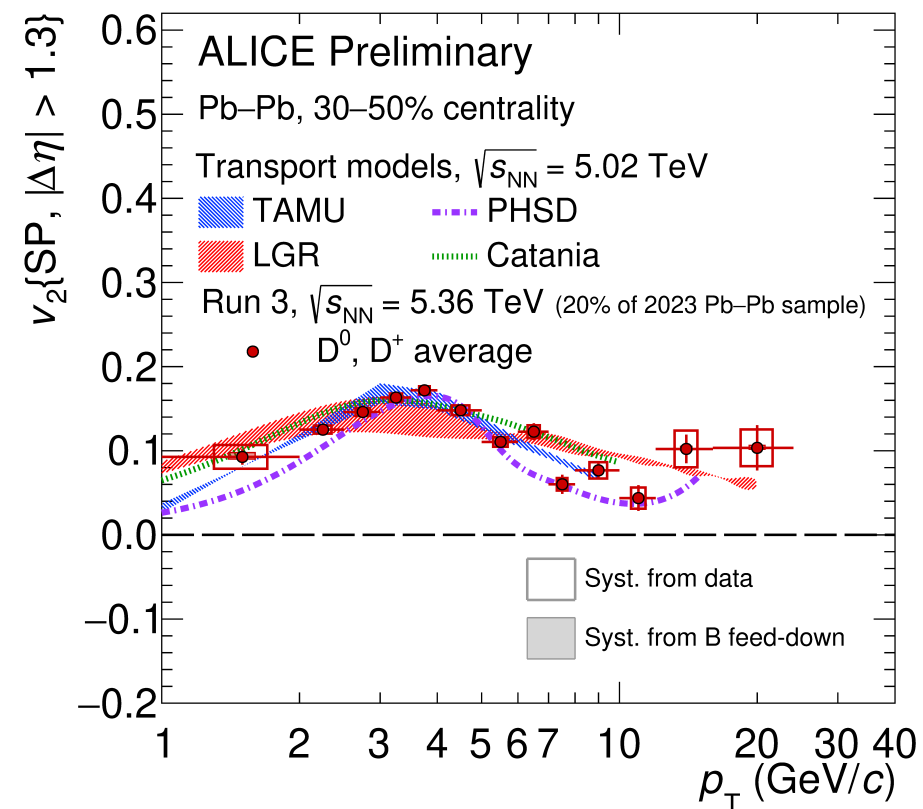
- ✧ The SHMc model and transport microscopic calculations that include a contribution from **regeneration** are compatible with the measured **prompt J/ψ R_{AA} at low p_T**
- ✧ **Non-prompt J/ψ R_{AA}** is described within uncertainties by models implementing **collisional and radiative energy loss** contributions. POWLANG with only collisional contributions, overestimate data.
- ✧ Hint of **no regeneration** contribution of non-prompt J/ψ compared with prompt J/ψ.

Strange and non-strange D-mesons elliptic flow

New Preliminary



ALI-PREL-581274

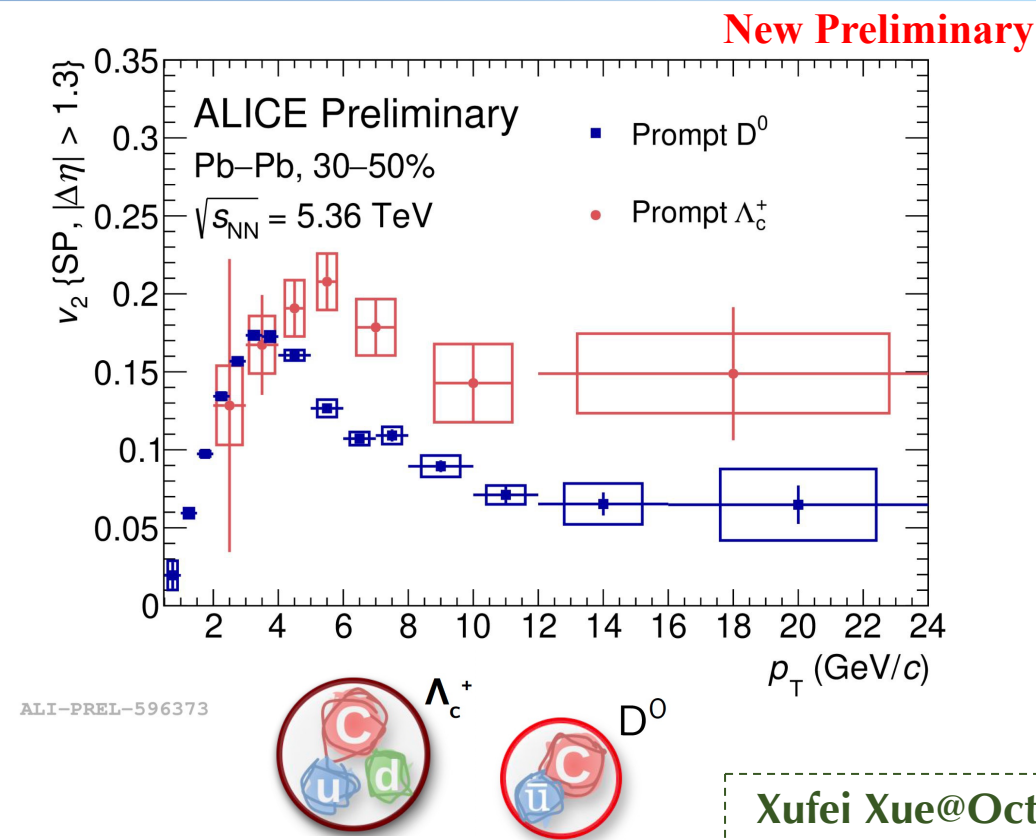
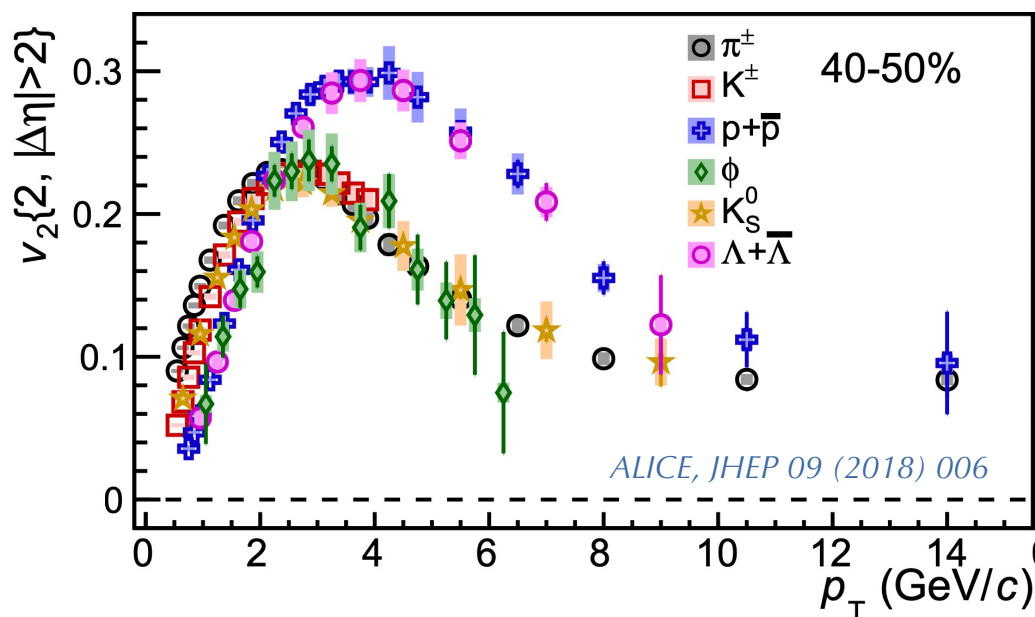


ALI-PREL-581255

Prompt D-meson v_2 measured using Run 3 Pb-Pb data sample

- ✦ No significant difference between strange and non-strange D mesons
- ✦ Data reproduced by the transport models with hydro evolution + coalescence hadronization

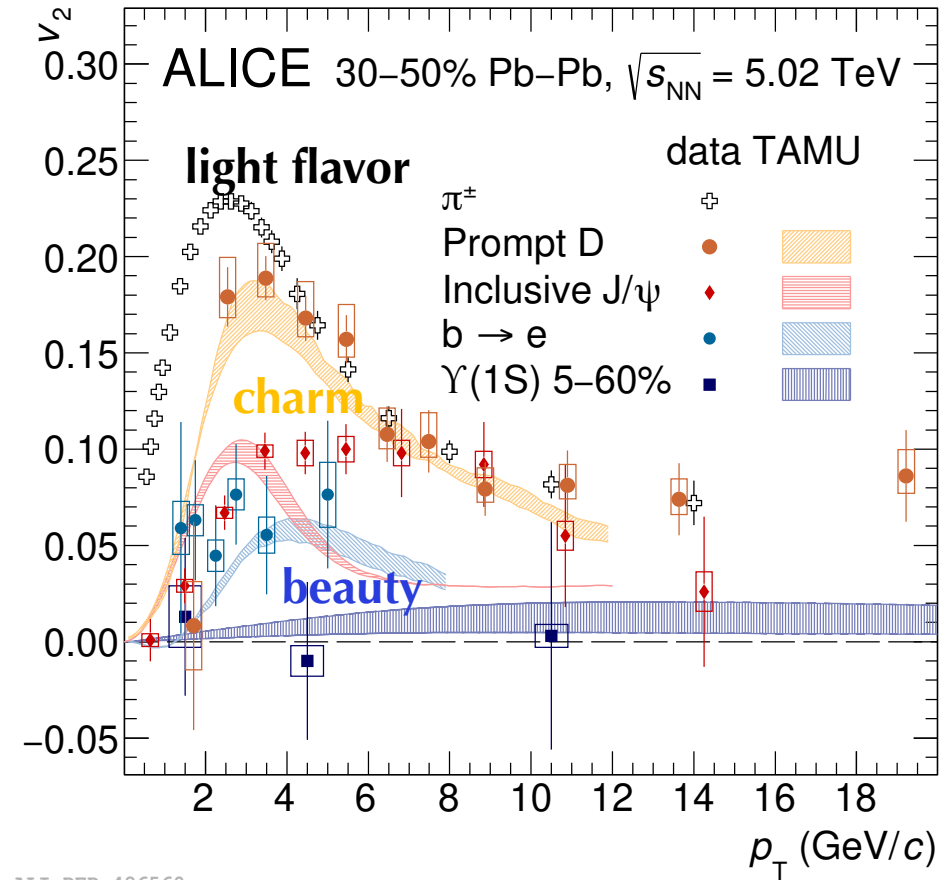
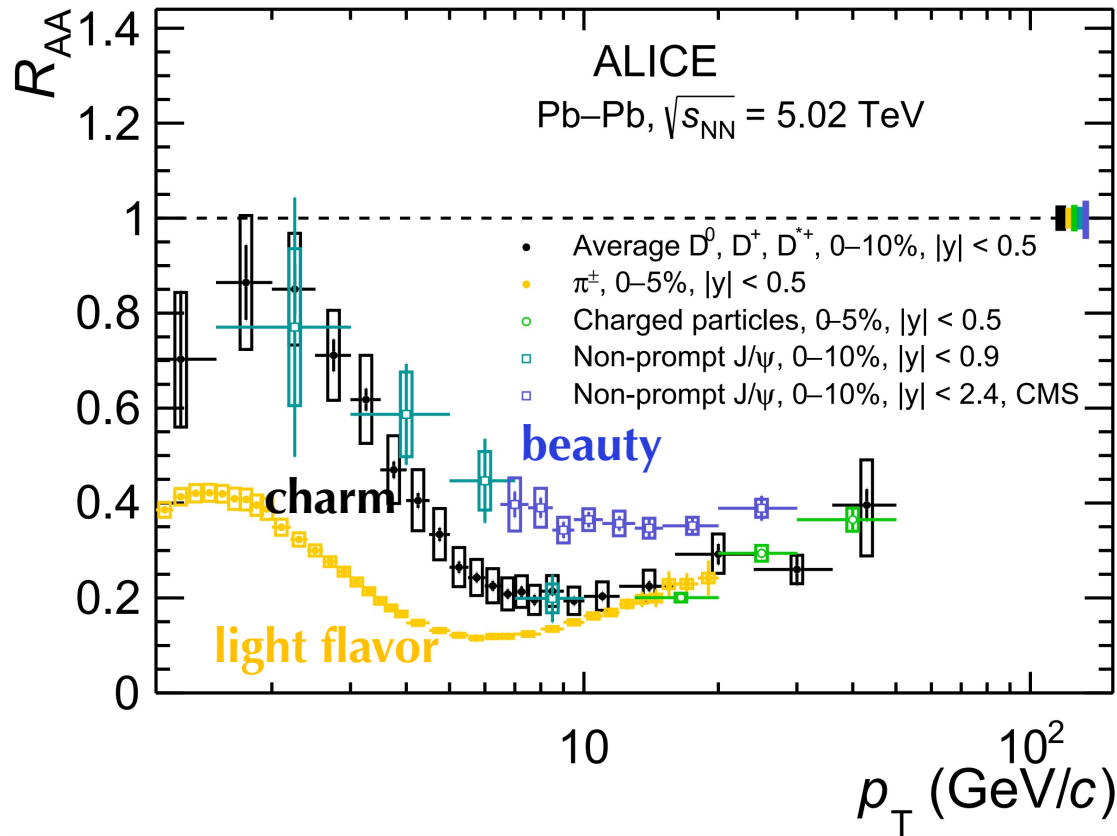
Charm baryon/meson v_2 splitting



Xuwei Xue@Oct. 30

- First prompt charm-baryon v_2 measurement in heavy-ion collisions
- Compatible within uncertainties with D^0 in the low p_T , $v_2(\Lambda_c^+) > v_2(D^0)$ with 3.6σ in the intermediate p_T , **evidence of charmed baryon/meson splitting, insensitive to flavors.**

Flavor dependence of R_{AA} and v_2

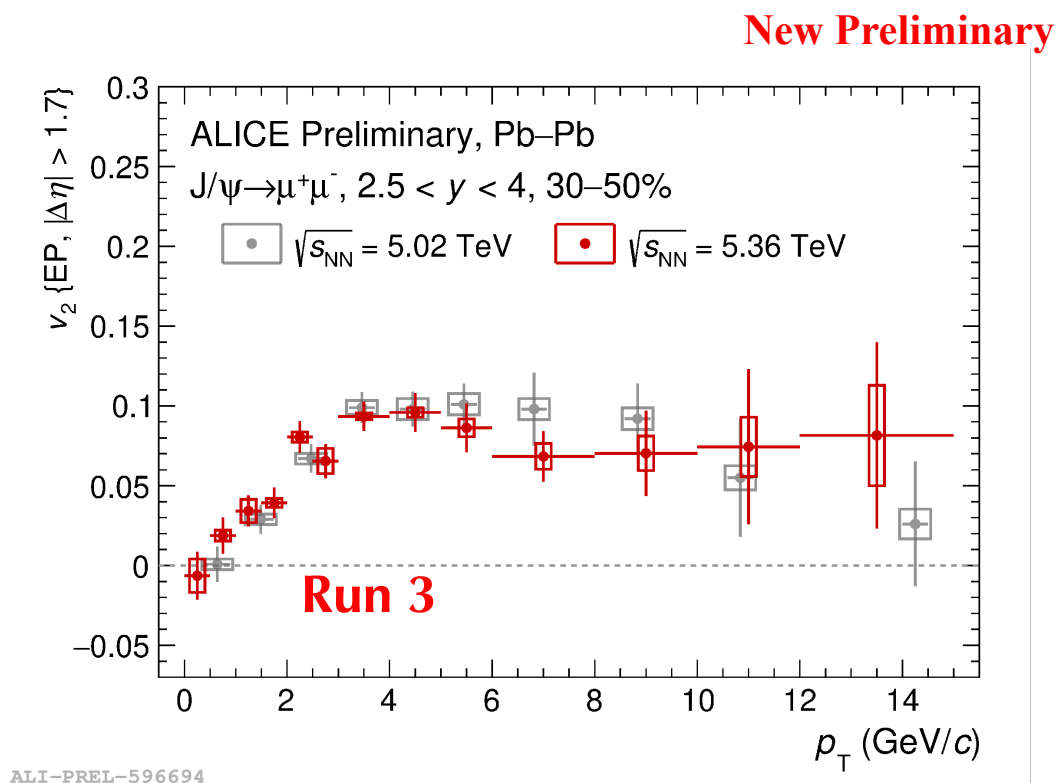
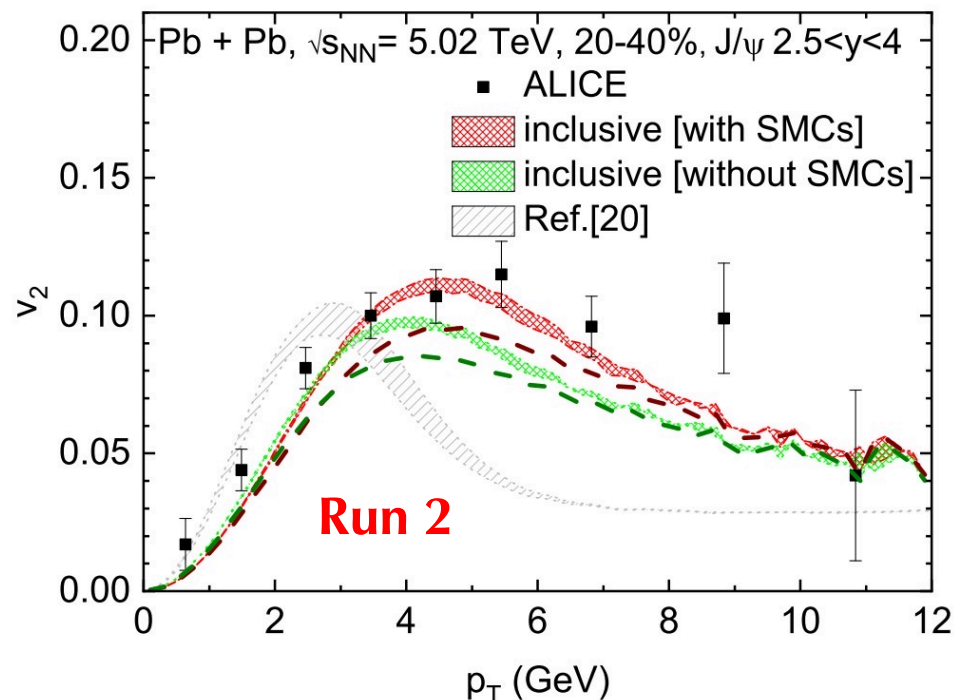


ALI-DER-486560

- ✦ Clear mass/flux dependent energy loss and elliptic flow observed at 5.02 TeV Pb-Pb collisions.
- ✦ Strong coupling with the medium and test thermalization degree with different quark mass.

Inclusive J/ψ elliptic flow

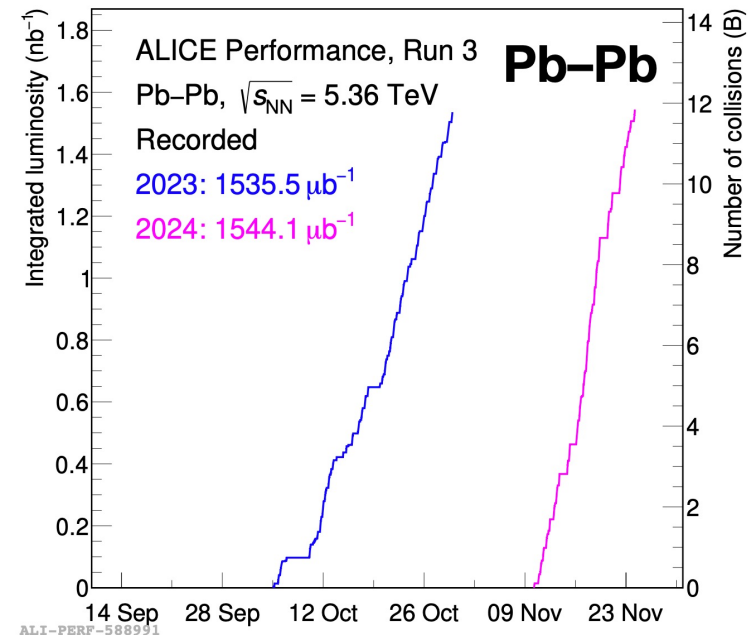
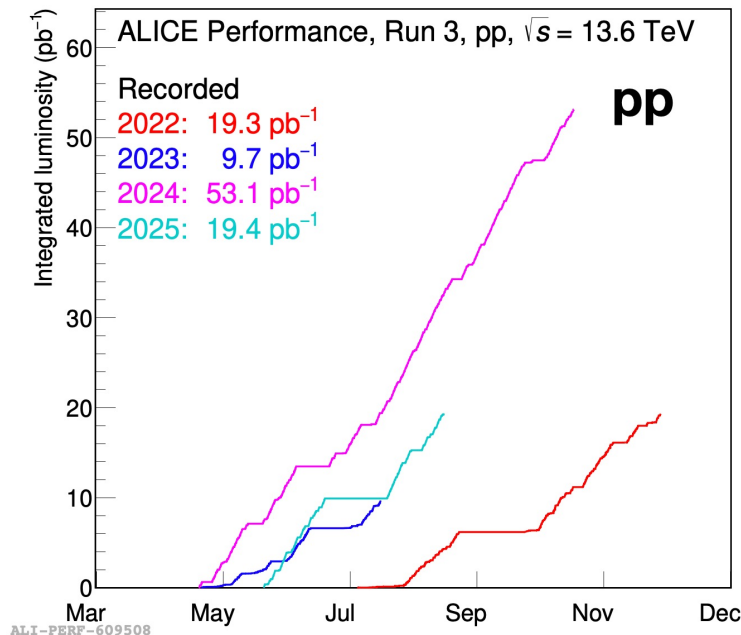
Model: M. He, et al., PRL.128, 162301 (2022)



- ✦ The new result at forward rapidity is consistent with Run 2 measurement: statistical precision improved at low p_T
- ✦ A significant J/ψ v_2 is observed at forward rapidity, how it is built up need further understanding.
- ✦ Resonance recombination model + SMC describes data, can it also explain result at mid-rapidity?

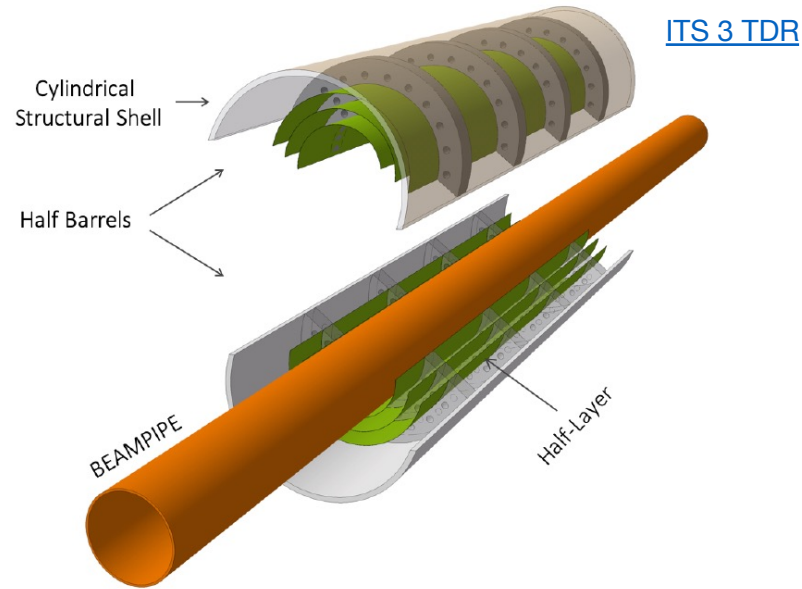
Summary and outlook

- Some new results with significantly improved precision of OHF and quarkonium measurements in pp and Pb-Pb collisions have been achieved.
- We expect more anticipated results coming soon from Run 3 pp (Pb-Pb) data with x1600 (x70) more statistics than Run 1+2.



Upgrading the ALICE detector (RUN 4)

ITS upgrades: ITS 3



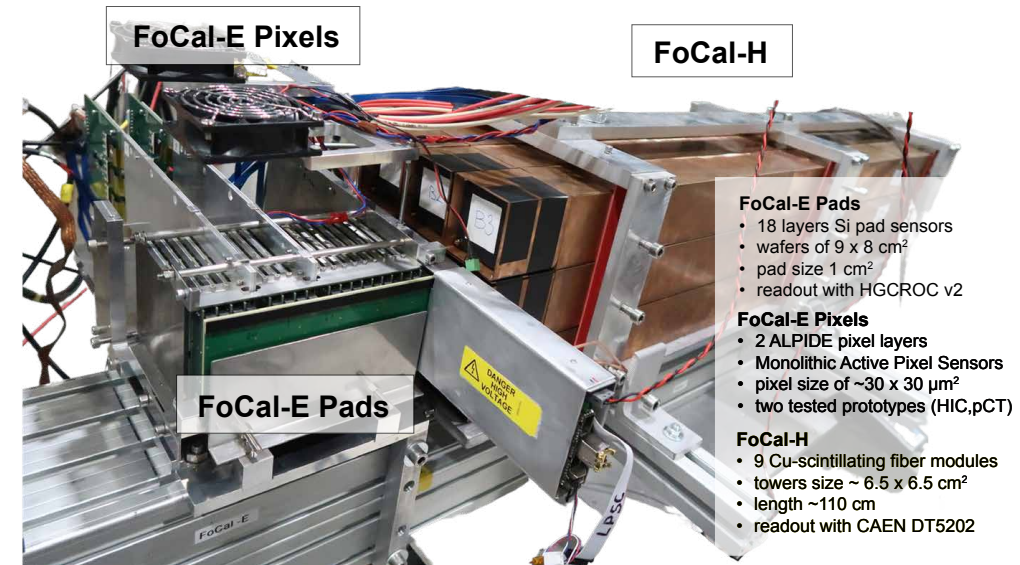
Wafer-scale, ultra-thin, truly cylindrical pixel sensors with minimum material budget.

Innermost radius 19 mm, x2 improvement in pointing resolution

Improve the measurements of heavy flavor and dielectrons at midrapidity

Zhongbao Yin@Oct.30
Xiaomei Li@Nov.2

New detector Focal FoCal



LHC LS-3 2026 – 2029

LHC Run4 2030 – 2033

FoCal-E calorimeter: High-granularity Si-W, FoCal-H: Cu-scintillator

Electron/photons, π^0 , jets at forward rapidity

Unexplored regions of small-x and low Q^2 gluons

Expect better signals for HF

Wenbin Zhao@Nov.1

Talks related to this topic, significant contributions from Chinese ALICE-group.

My apology for any that has not been covered.

Oct.30 **Pengzhong Lu** *J/ψ and D^0 associated production measurements with ALICE Run 3*

Oct.30 **Liang Dong** *J/ψ polarization measurement in pp collisions at 13.6 TeV*

Oct.30 **Yiping Wang** *Inclusive J/ψ and $\psi(2S)$ production in pp collisions at 13.6 TeV*

Oct.30 **Yunfan Liu** *Study of open heavy flavor spin polarization and momentum correlations with ALICE*

Oct.30 **Xufei Xue** *First measurement of Λ_c elliptic flow in 30-50% Pb-Pb collisions at 5.36 TeV with ALICE*

Oct.30 **Ran Tu** *Study of charm baryon production and hadronization with ALICE*

Oct.31 **Fang Tao** *Charm-baryon hadronization mechanism and its multiplicity dependence with ALICE*

...

Thank you for your attention