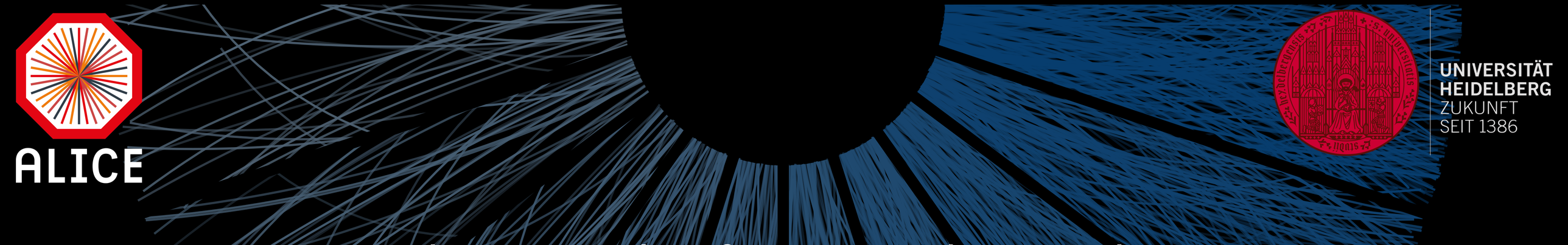


ALICE

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

42nd International Conference on High Energy Physics

Studying QCD production mechanisms and medium effects on quarkonium formation with ALICE

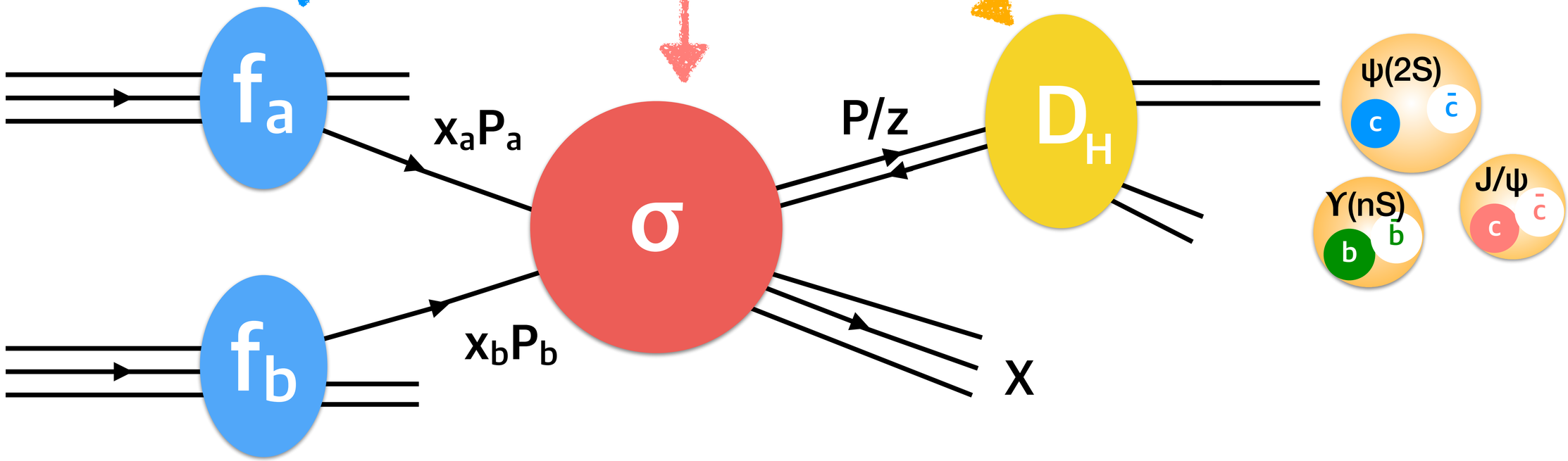
Jinjoo Seo
for the ALICE Collaboration
Physikalisches Institut - Universität Heidelberg

19.07 2024

Quarkonium production in pp collisions

Parton distribution func. | Heavy quark production | Quarkonium formation

$$f_{a/A}(x_a) \otimes f_{b/B}(x_b) \otimes \mathrm{d}\sigma_{\mathrm{ab}\to\mathrm{Q\bar{Q}}} \otimes D_{\mathrm{Q\bar{Q}}\to\mathrm{H}} = \mathrm{d}\sigma_{\mathrm{AB}\to\mathrm{HX}}$$



Quarkonium production in pp collisions

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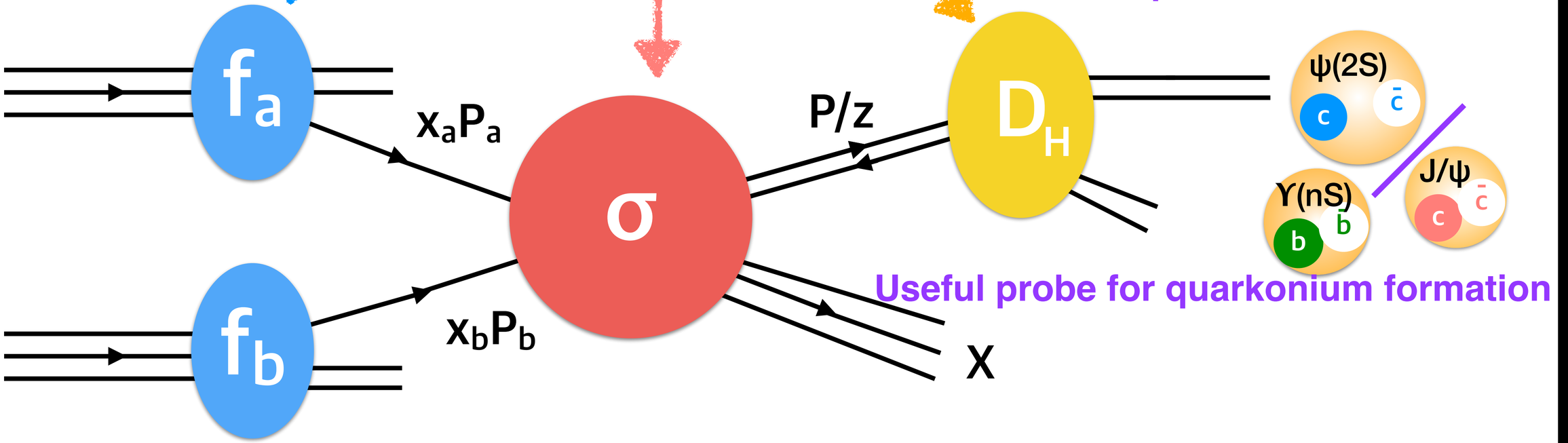
pQCD

non-pQCD

Test production mechanism

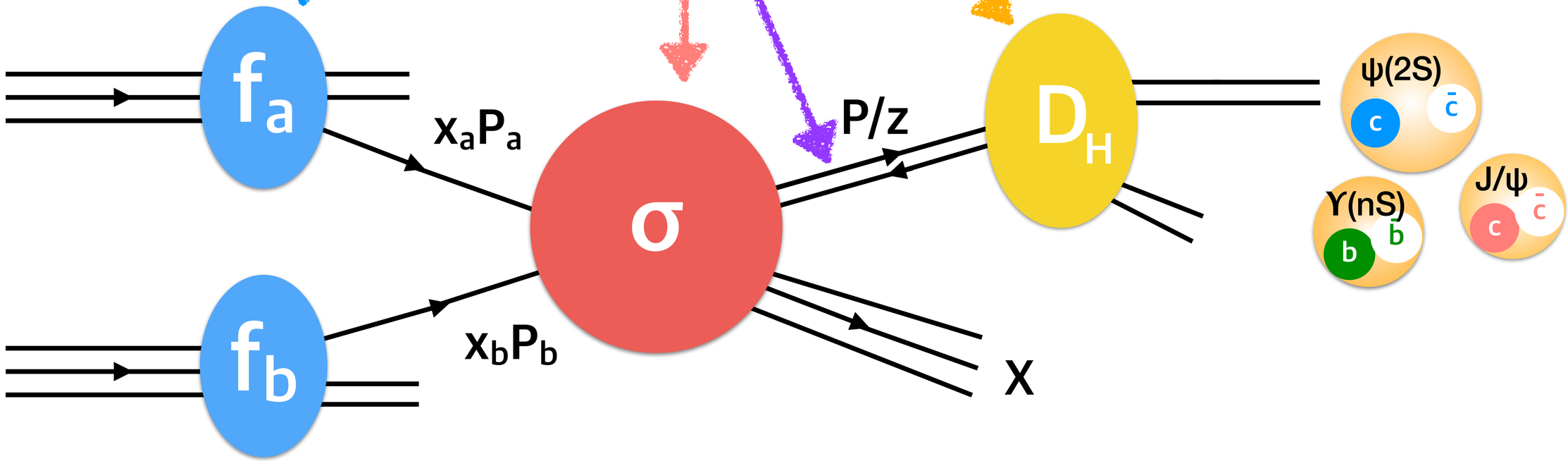


Useful probe for quarkonium formation

Quarkonium production in pp collisions

if) Pb—Pb **Medium interaction** $\otimes P_{Q\bar{Q}\to Q'\bar{Q}'}$ **Reference systems without QGP formation**

$$f_{a/A}(x_a) \otimes f_{b/B}(x_b) \otimes \mathrm{d}\sigma_{ab\to Q\bar{Q}} \otimes D_{Q\bar{Q}\to H} = \mathrm{d}\sigma_{AB\to HX}$$

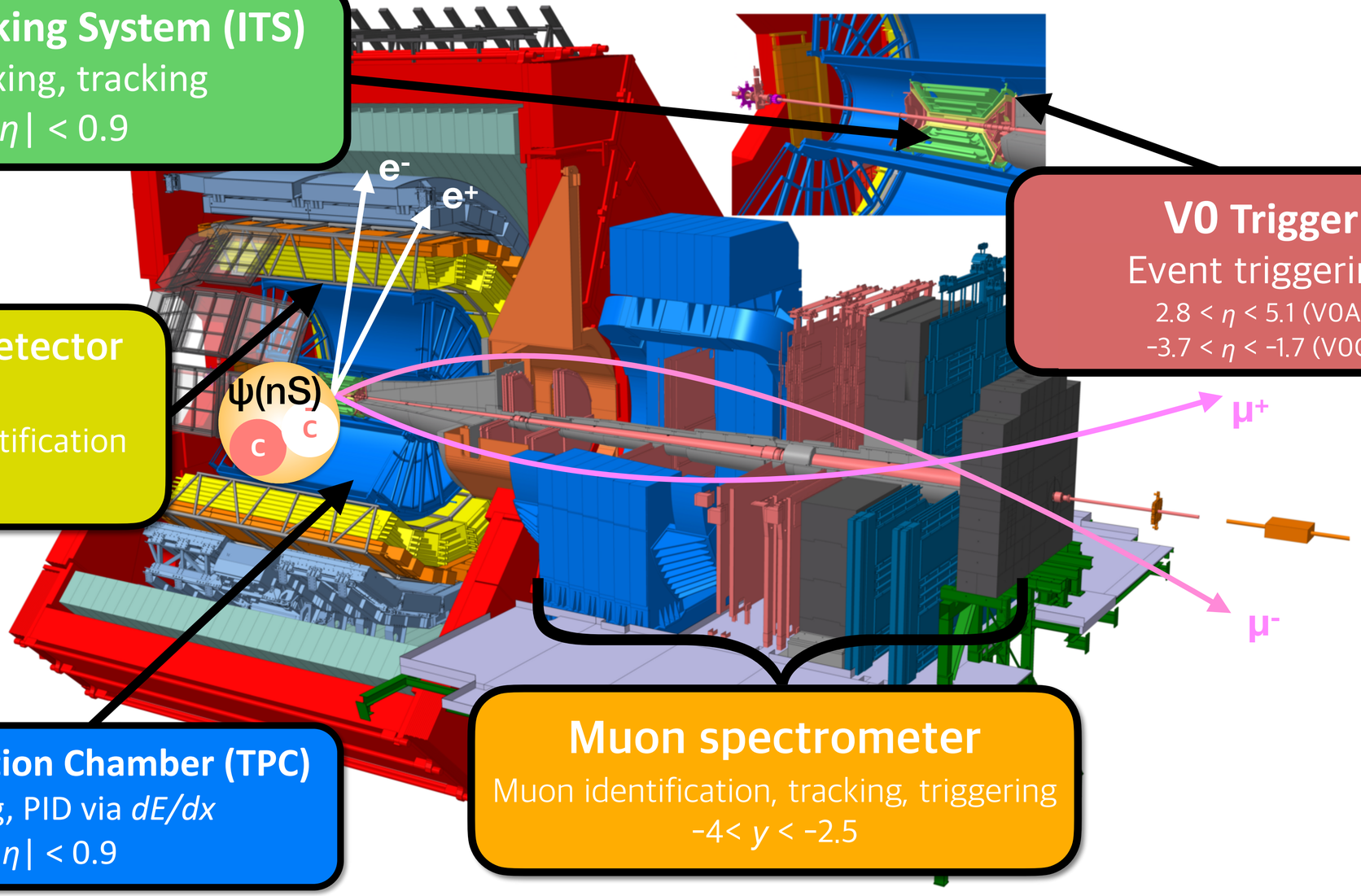


ALICE Detector

Inner Tracking System (ITS)
Vertexing, tracking
$|\eta| < 0.9$

Transition Radiation Detector (TRD)
Electron triggering and identification
$|\eta| < 0.8$

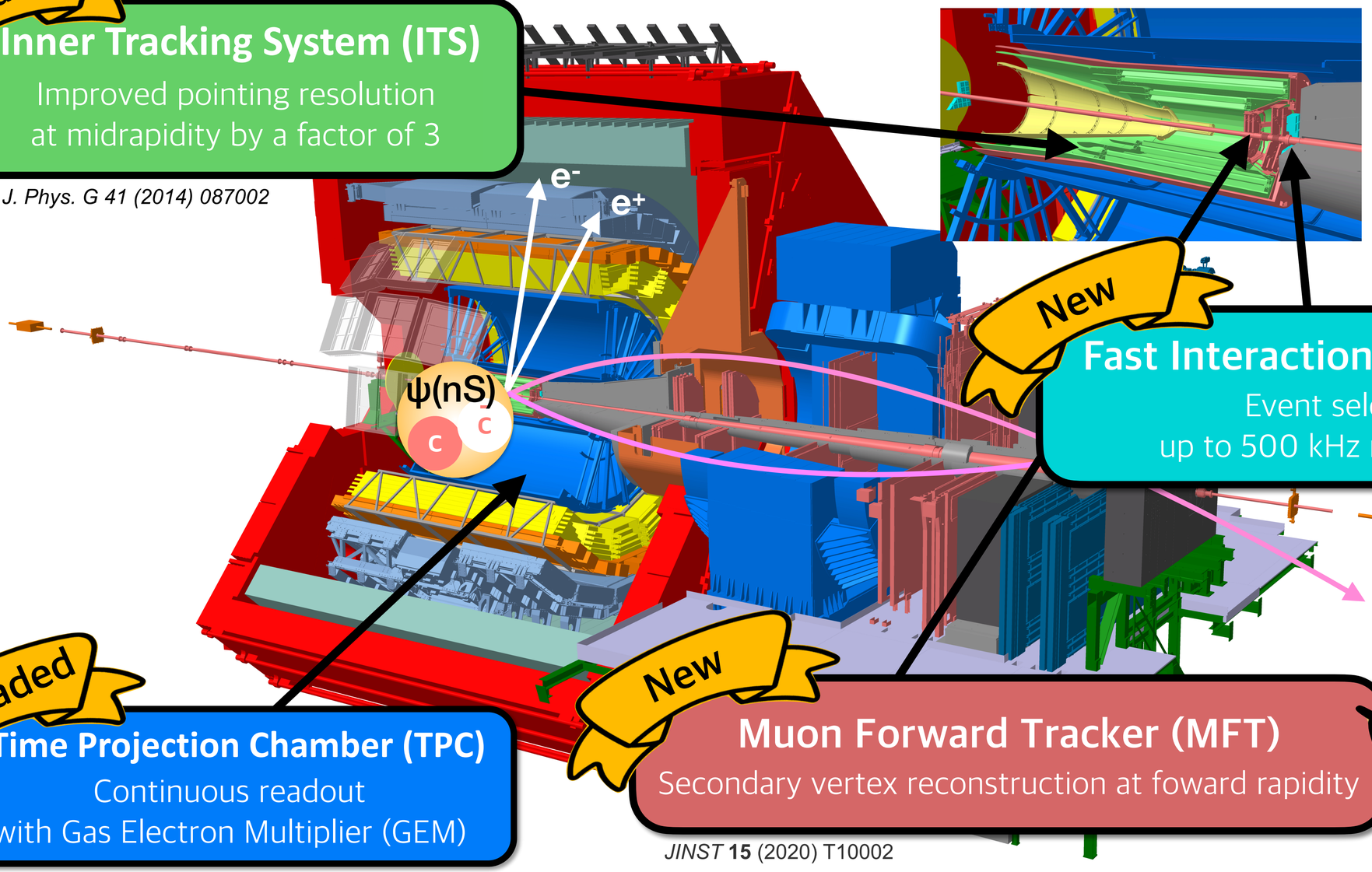
Time Projection Chamber (TPC)
tracking, PID via *dE/dx*
$|\eta| < 0.9$



V0 Trigger
Event triggering
$2.8 < \eta < 5.1$ (V0A)
$-3.7 < \eta < -1.7$ (V0C)

Muon spectrometer
Muon identification, tracking, triggering
$-4 < y < -2.5$

ALICE 2 Detector



Upgraded

Inner Tracking System (ITS)

Improved pointing resolution
at midrapidity by a factor of 3

J. Phys. G 41 (2014) 087002

Jian Liu
18/07, 10:45

New

Fast Interaction Trigger (FIT)

Event selection
up to 500 kHz readout rate

Yury Melikyan
19/07 08:48

Upgraded

Time Projection Chamber (TPC)

Continuous readout
with Gas Electron Multiplier (GEM)

New

Muon Forward Tracker (MFT)

Secondary vertex reconstruction at foward rapidity

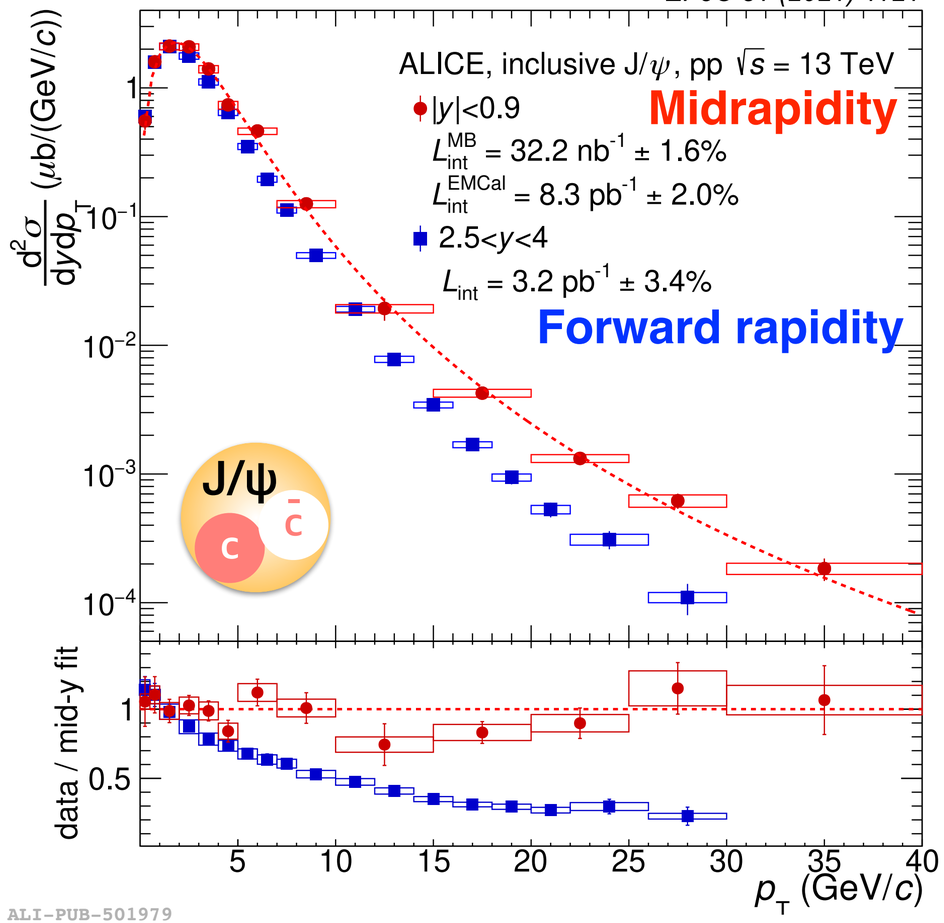
JINST **15** (2020) T10002

Guillaume Betigne
20/07 16:45

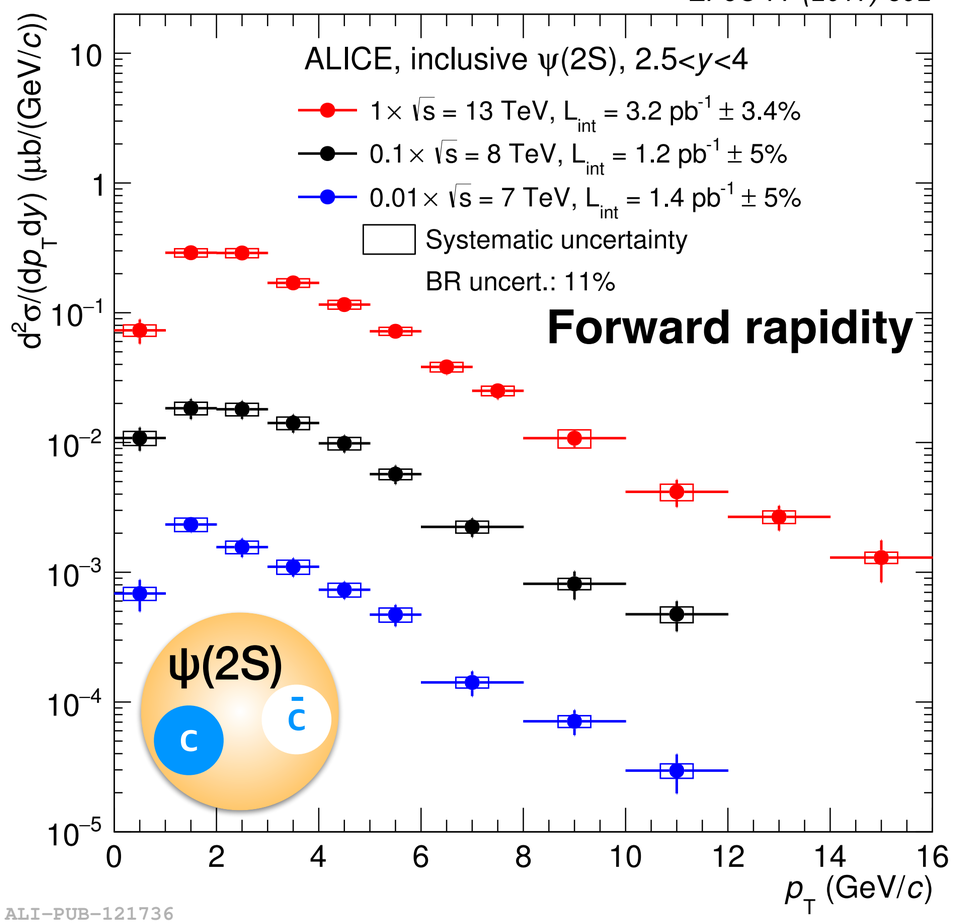
J/ψ and ψ(2S) production in pp

- J/ψ production at mid and forward rapidity down to $p_{\mathrm{T}} = 0$
- ψ(2S) production at forward rapidity down to $p_{\mathrm{T}} = 0$

EPJC 81 (2021) 1121



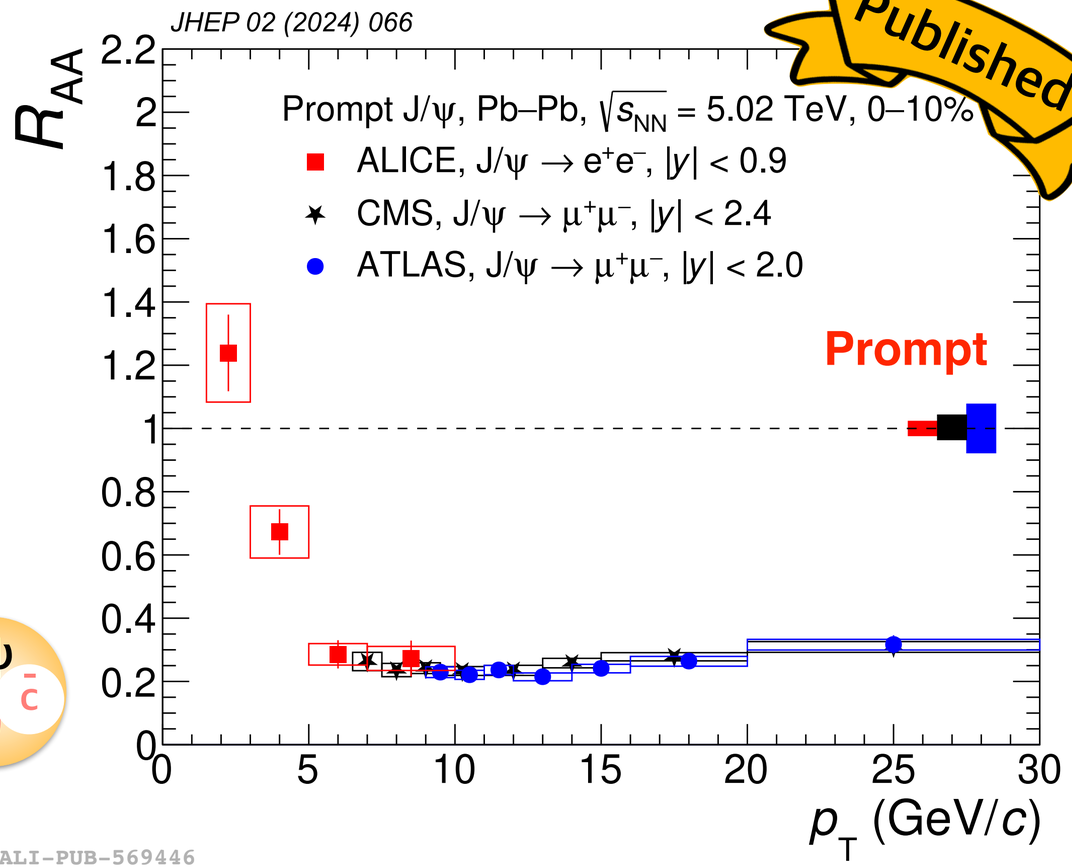
EPJC 77 (2017) 392

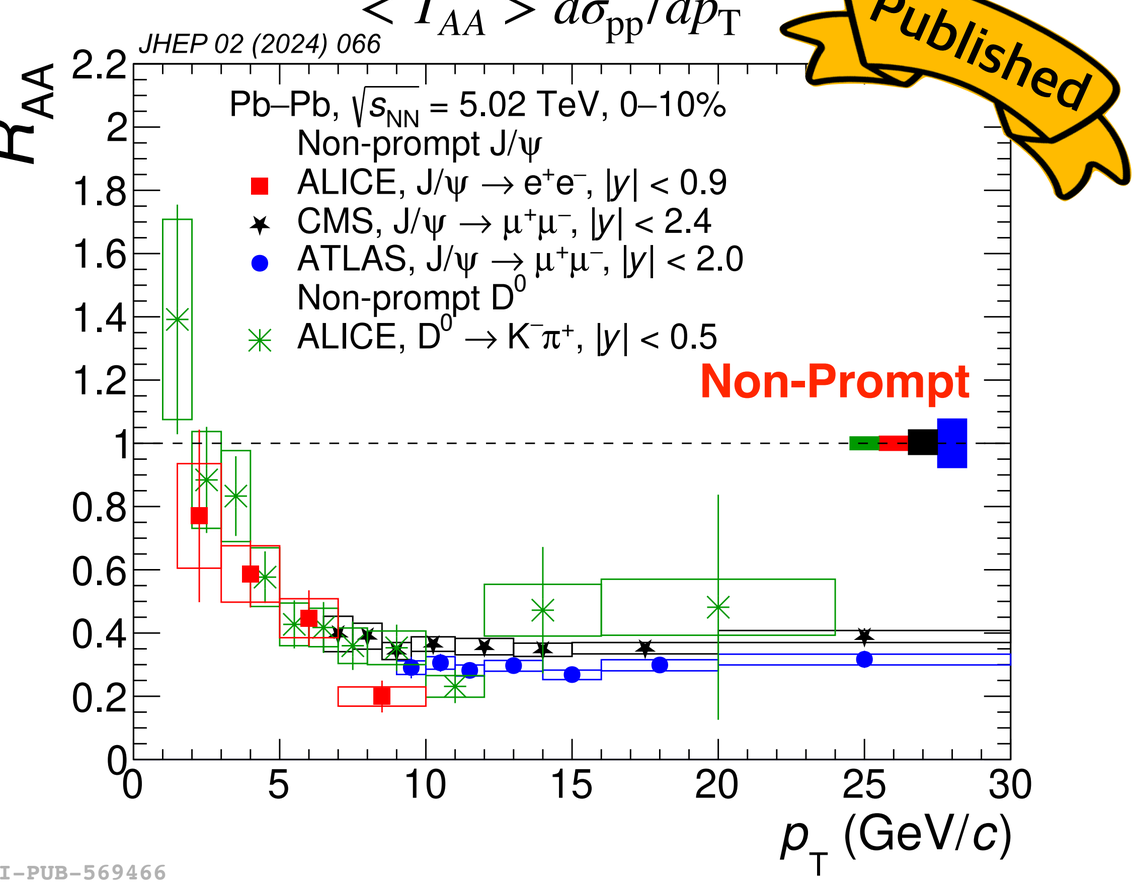


Nuclear modification factor

- Prompt J/ψ: increases towards low p_{T}, and exceeds unity in the lowest p_{T} interval
- Non-prompt J/ψ: increases towards low p_{T}, compatible with non-prompt D^0 measurements
- Agreement among results from LHC experiments

$$R_{\mathrm{AA}} = \frac{dN_{\mathrm{AA}}/dp_{\mathrm{T}}}{< T_{AA} > d\sigma_{\mathrm{pp}}/dp_{\mathrm{T}}}$$

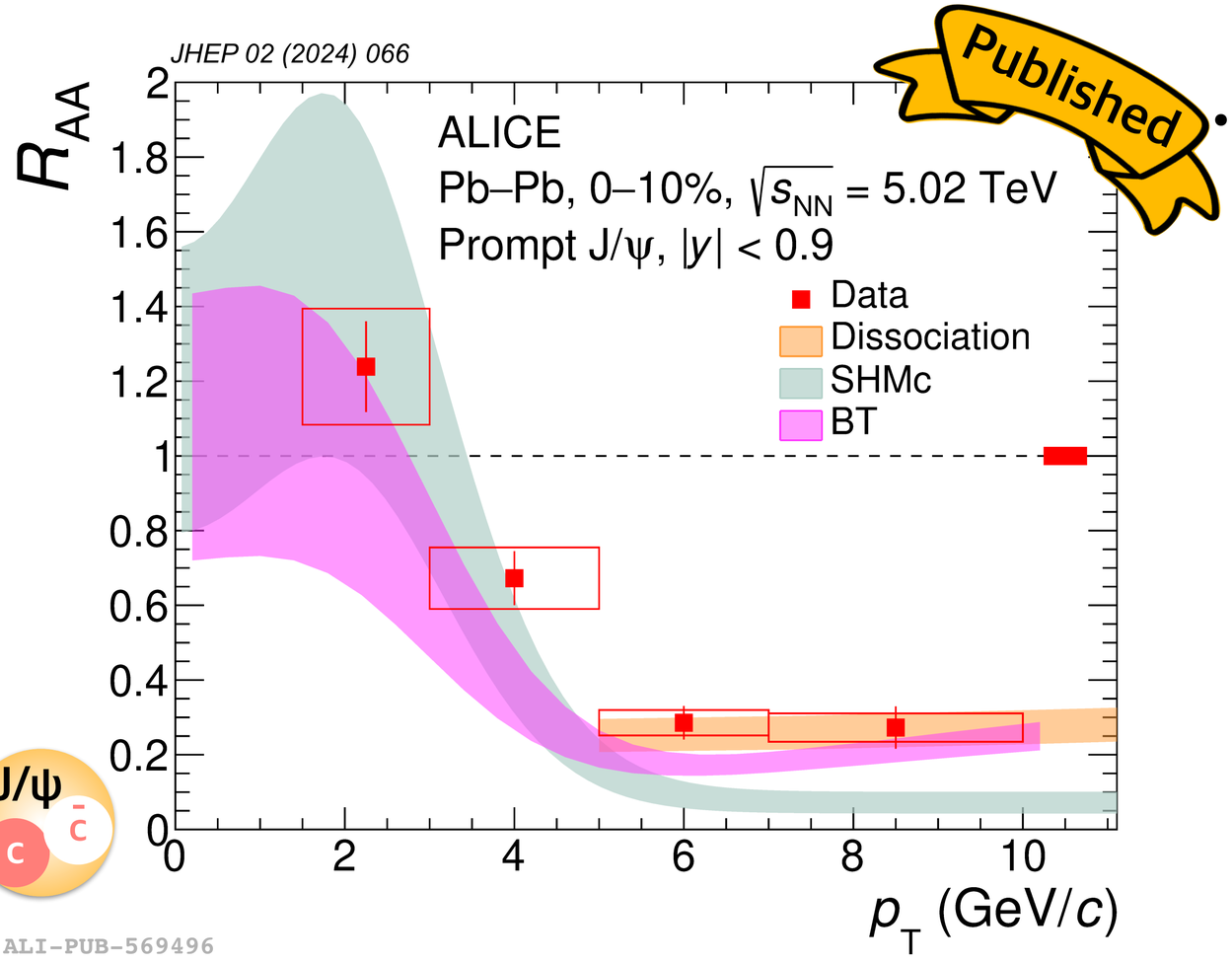




Nuclear modification factor

- Prompt J/ψ: **Dissociation model** provides a good description for $p_{\mathrm{T}} > 5\ \mathrm{GeV}/c$

SHMc: PLB 797 (2019) 134836
BT: CPC43 (2019) 124101
Dissociation: PLB 778 (2018) 384-391

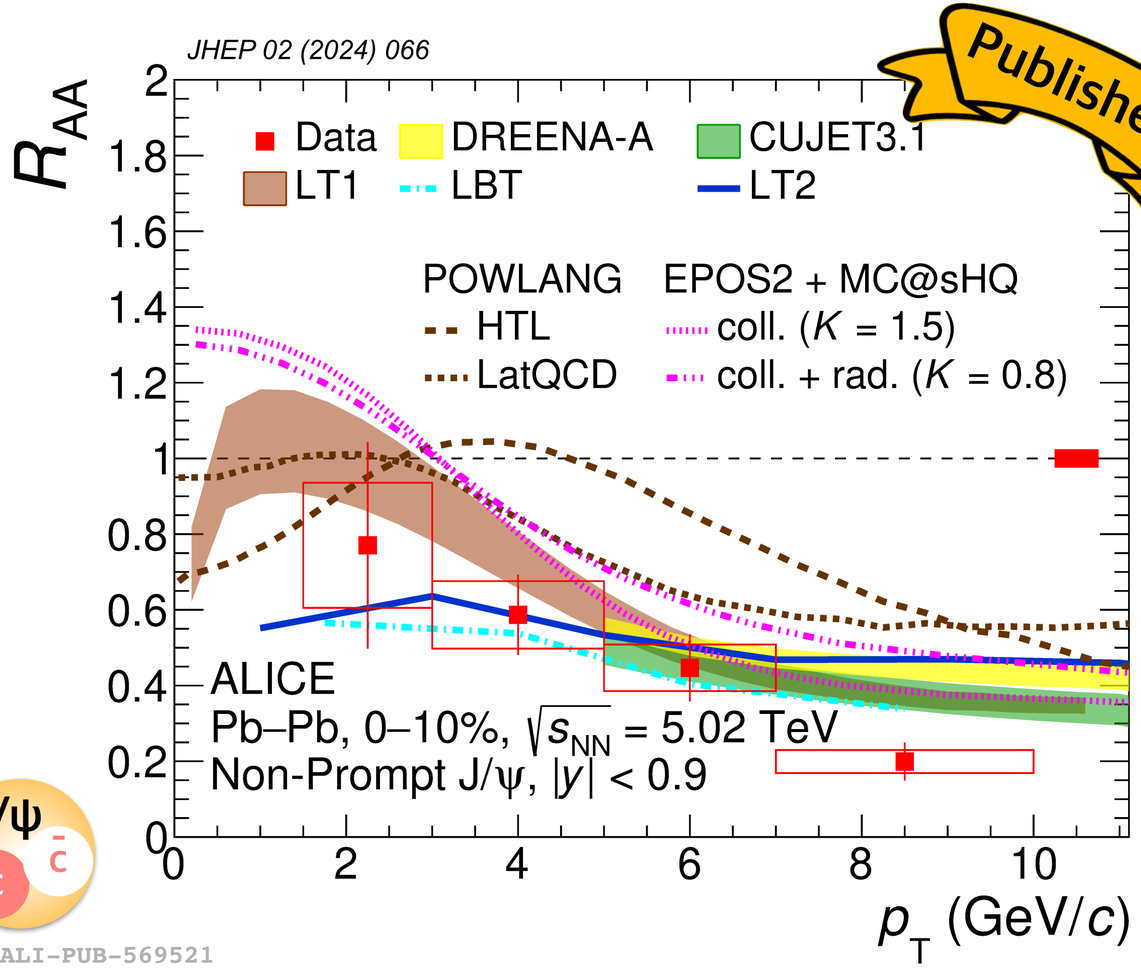


- **Dissociation model**
  - Rate equation, collisional dissociation and color screening
  - Medium modelled by (2+1)-dimensional viscous hydrodynamic
  - Negligible CNM (Cold Nuclear Matter) for $p_{\mathrm{T}} > 5\ \mathrm{GeV}/c$

Nuclear modification factor

- Non-prompt J/ψ: **LBT** & **LT2** are compatible with measurements in the full p_{T} range

DREENA-A: Phys. Rev. C 105, L021901
CCUJJET3.1: CPC 43 (2019) 044101
LT1: PRC107, 054917(2023)
LBT: PLB838(2023) 137733
LT2: EPJC 81 848 (2021) 1035



LBT (Linear Boltzmann Transport)

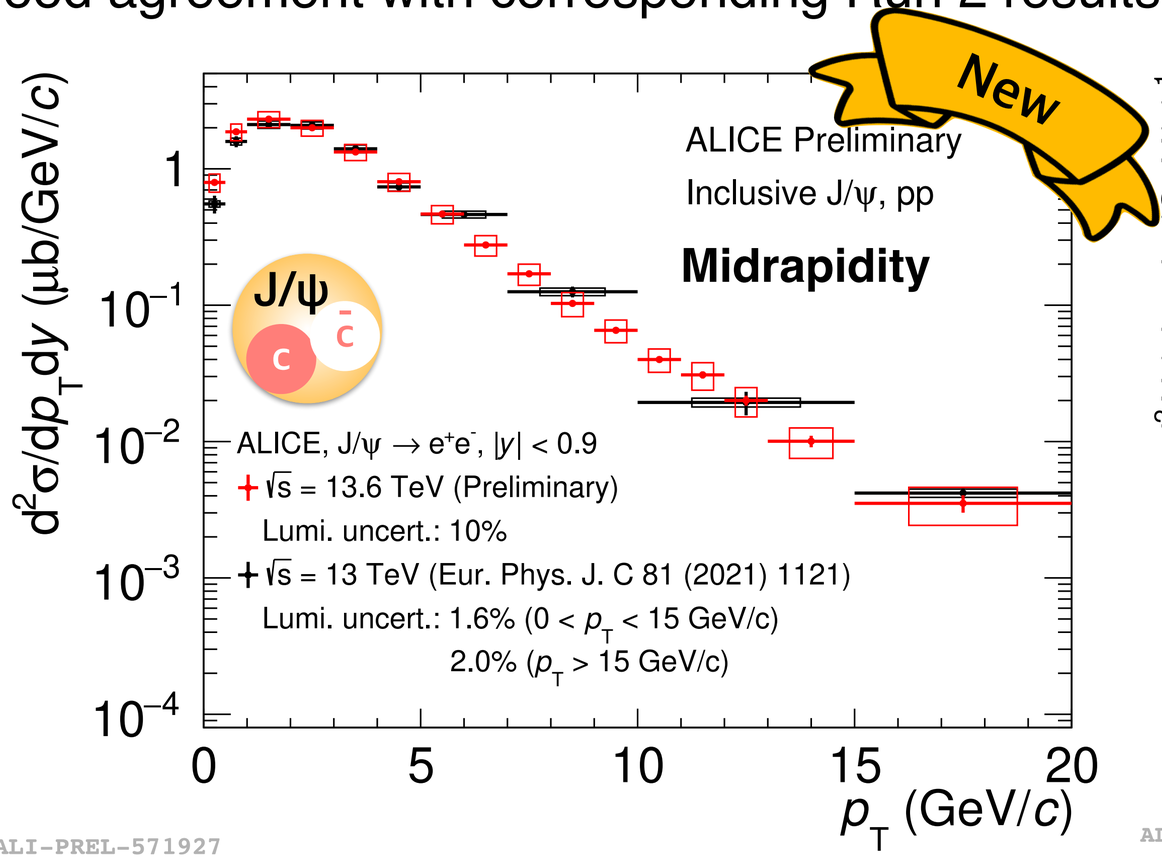
- Initial heavy quark distribution from FONLL
- Interaction with QGP: extended linear Boltzmann transport (LBT) equation including short and long-range interactions

LT2 (improved Langevin transport)

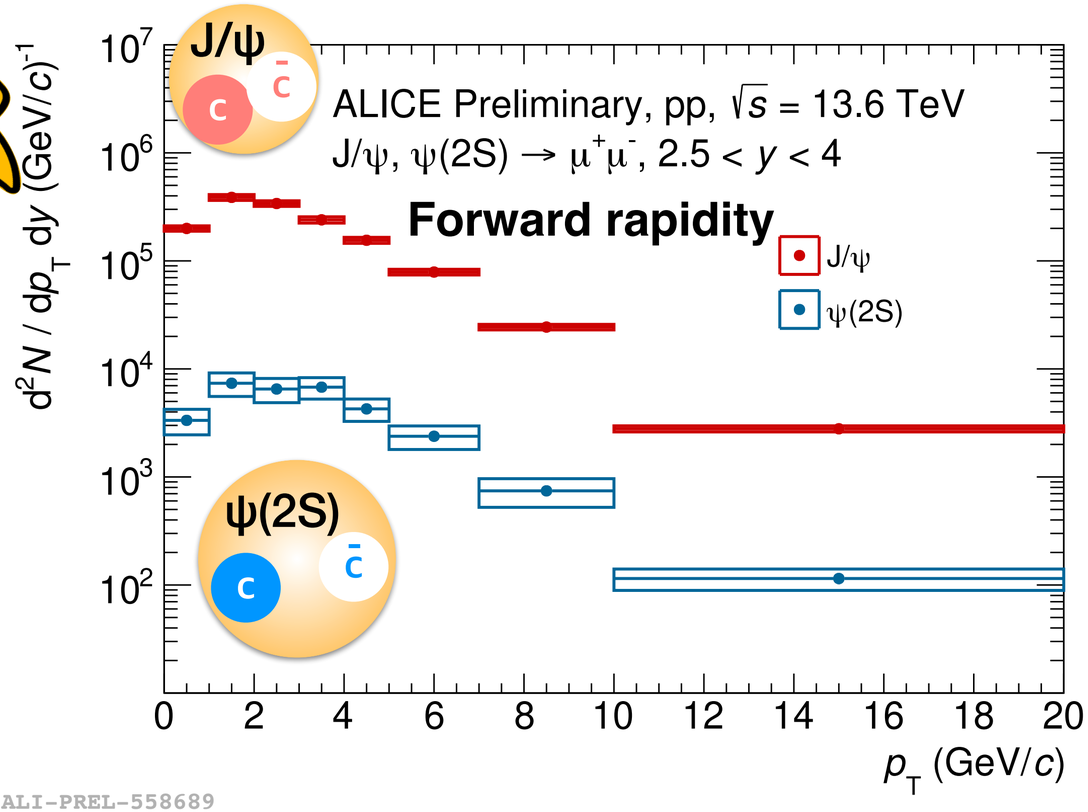
- Initial heavy quark distribution from FONLL
- Interaction with QGP: improved Langevin approach

J/ψ and ψ(2S) production in Run 3

- Significant improvement thanks to the detector upgrades and the continuous readout in Run 3
- Midrapidity: very narrow p_{T} binning now achievable!
  - Possibility to study precisely both ground (J/ψ) and excited (ψ(2S)) charmonium states
- Good agreement with corresponding Run 2 results



ALI-PREL-571927

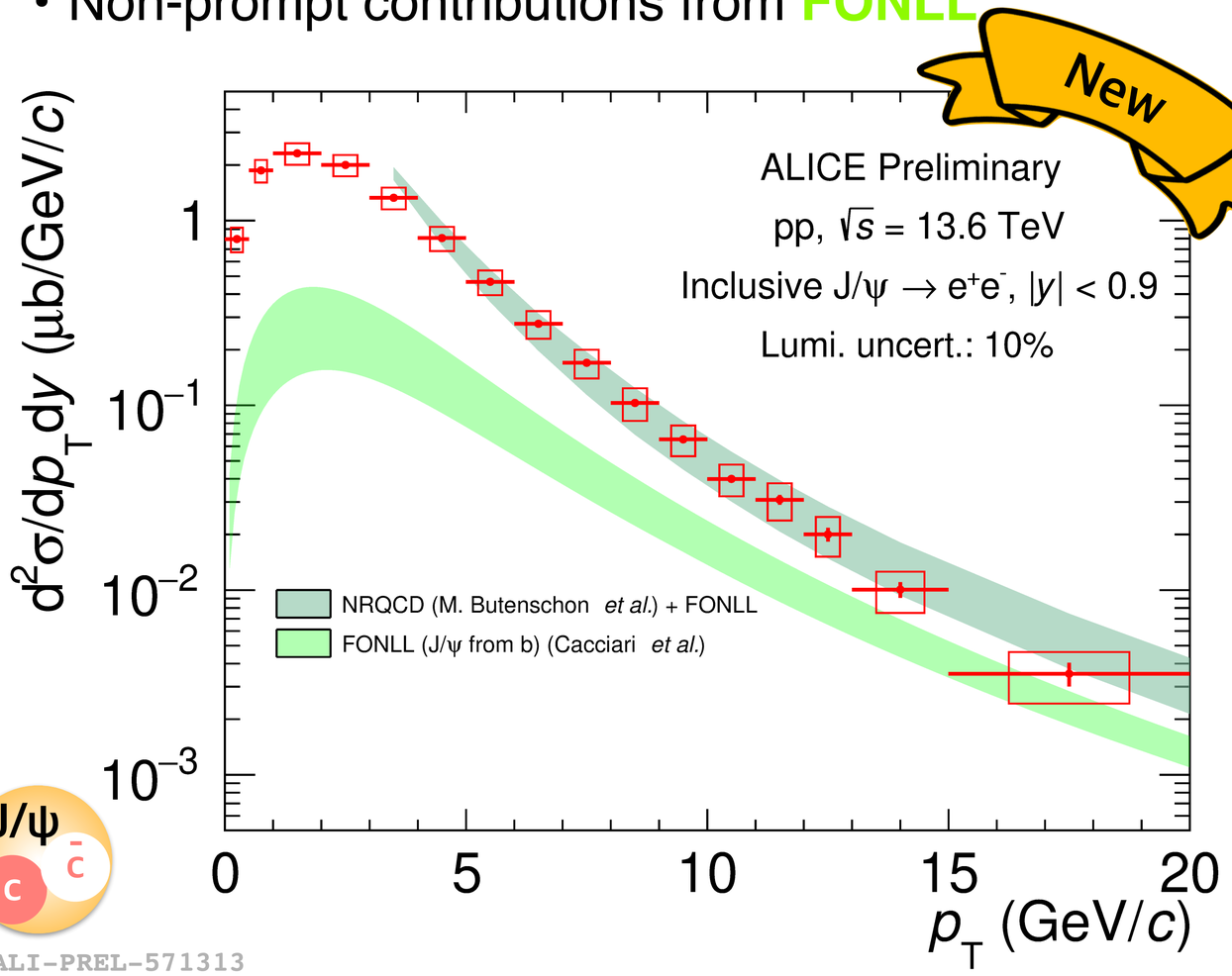


ALI-PREL-558689

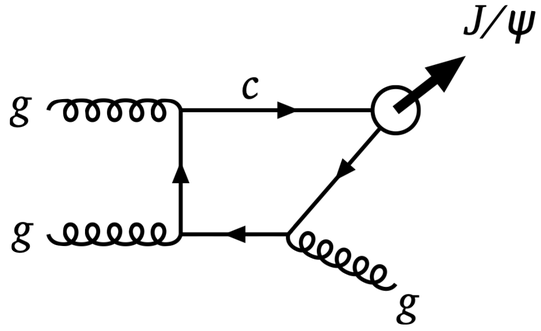
Charmonium with model comparison

M. Butenschön et al., PRL 106 (2011) 022033
M.Cacciari et al., JHEP 10 (2012) 137

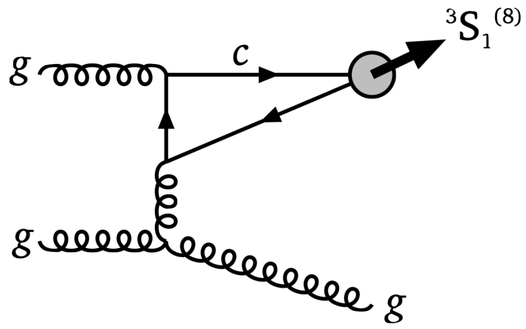
- Well described by **NRQCD**-based models
  - Non-prompt contributions from **FONLL**



- **NRQCD (Non-Relativistic QCD)**
  - Non-perturbative hadronisation to ψ(nS)
    - Neutralization of CO state via soft gluon emission
  - Assuming universal LDMEs (Long Distance Matrix Elements)



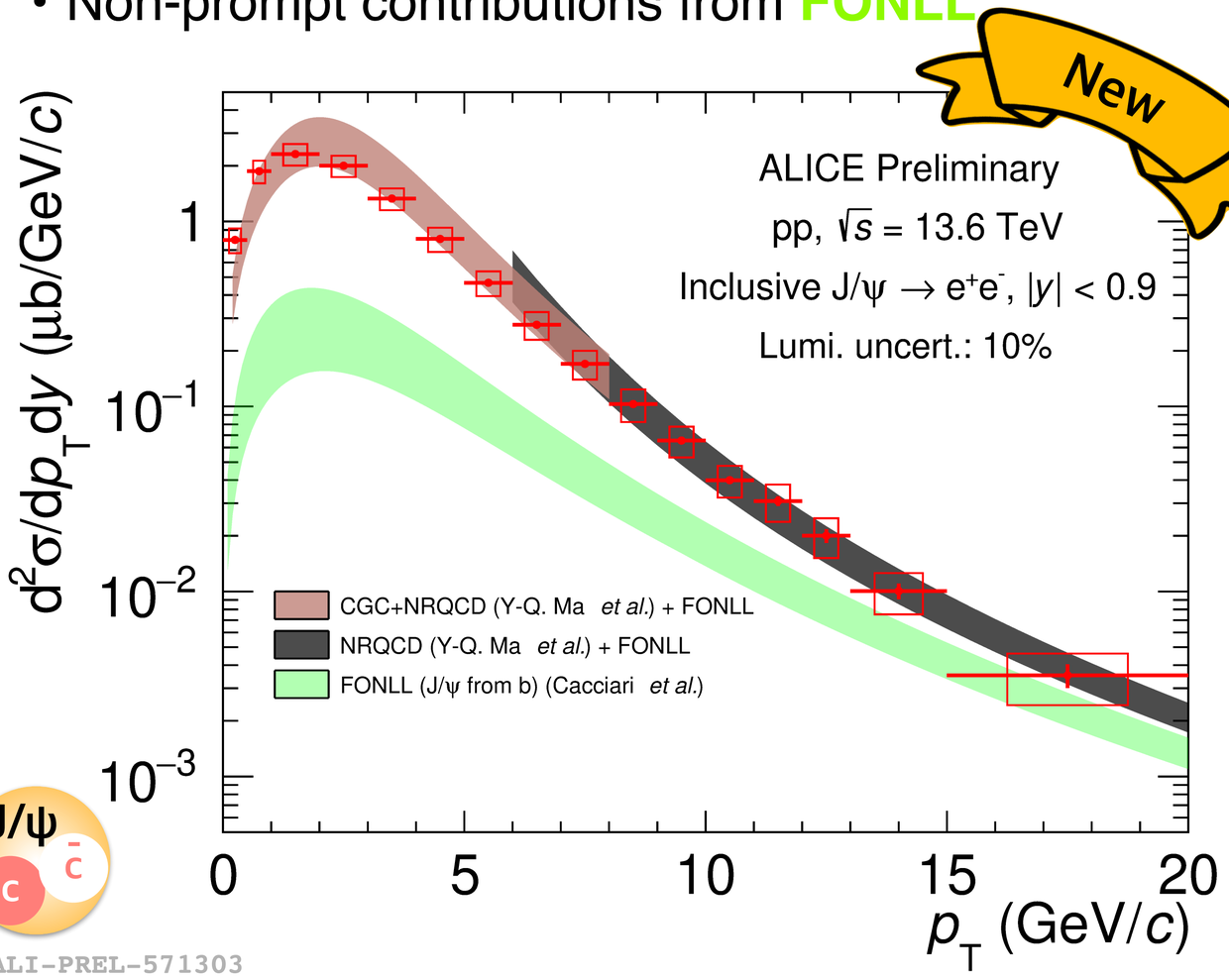
Color Singlet (CS)



Color Octet (CO)

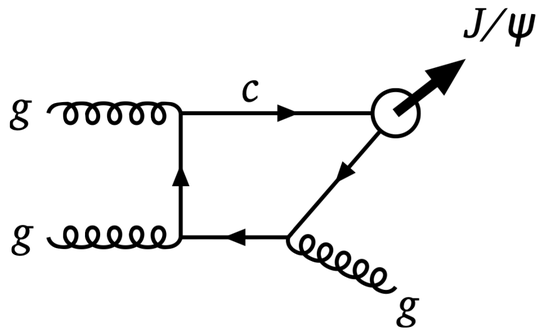
Charmonium with model comparison

- Well described by **NRQCD**-based models
  - Non-prompt contributions from **FONLL**

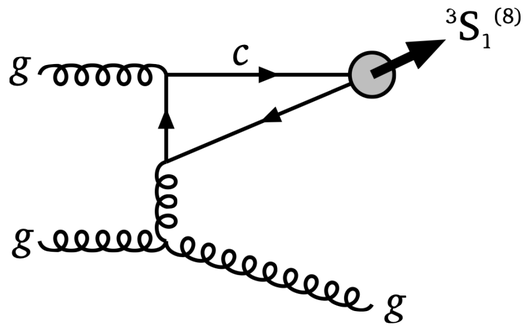


Y-Q. Ma et al., PRL 106 (2012) 042002
Y-Q. Ma et al., JHEP12(2018)057
M.Cacciari et al., JHEP 10 (2012) 137

- **CGC (Color Glass Condensate) + NRQCD**
  - CGC for calculation of gluon distribution



Color Singlet (CS)

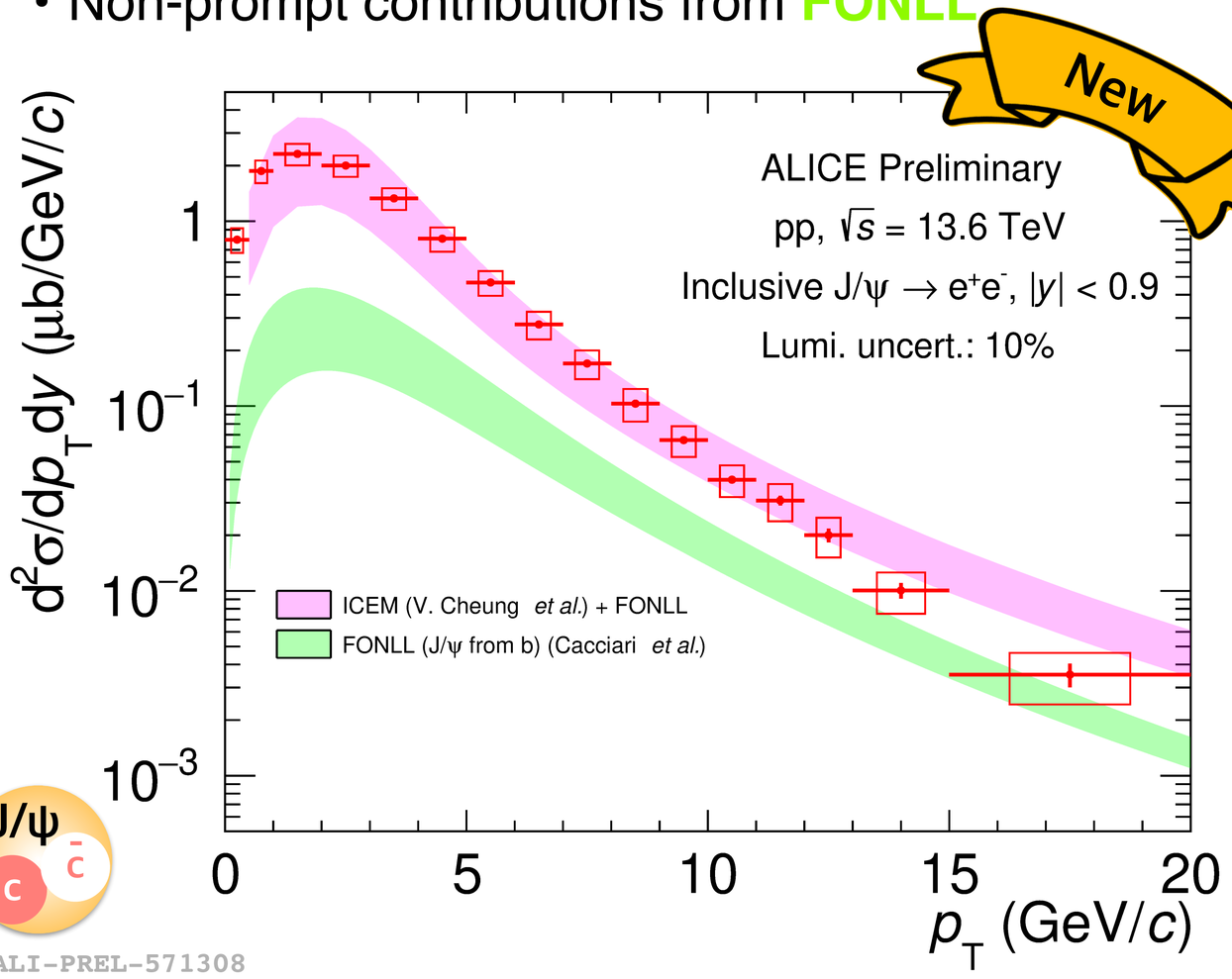


Color Octet (CO)

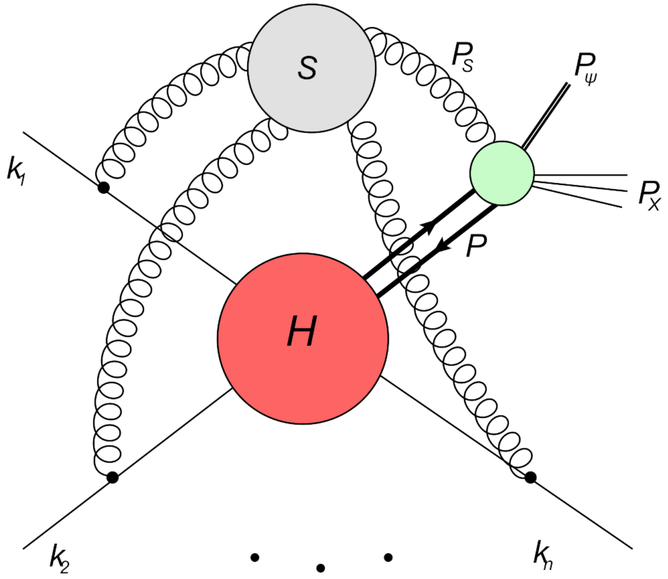
Charmonium with model comparison

V.Cheung et al., PRD 98 (2018) 114029
M.Cacciari et al., JHEP 10 (2012) 137

- Well described by **ICEM**
  - Non-prompt contributions from **FONLL**



- **ICEM (Improved Color Evaporation Model)**
  - Hadronisation to ψ(nS)
    - $m_{c\bar{c}} <$ D-meson threshold
    - Emitting soft gluons in the hadronisation



Charmonium with model comparison

V.Cheung et al., PRD 98 (2018) 114029
M.Cacciari et al., JHEP 10 (2012) 137

- Well described by **ICEM**
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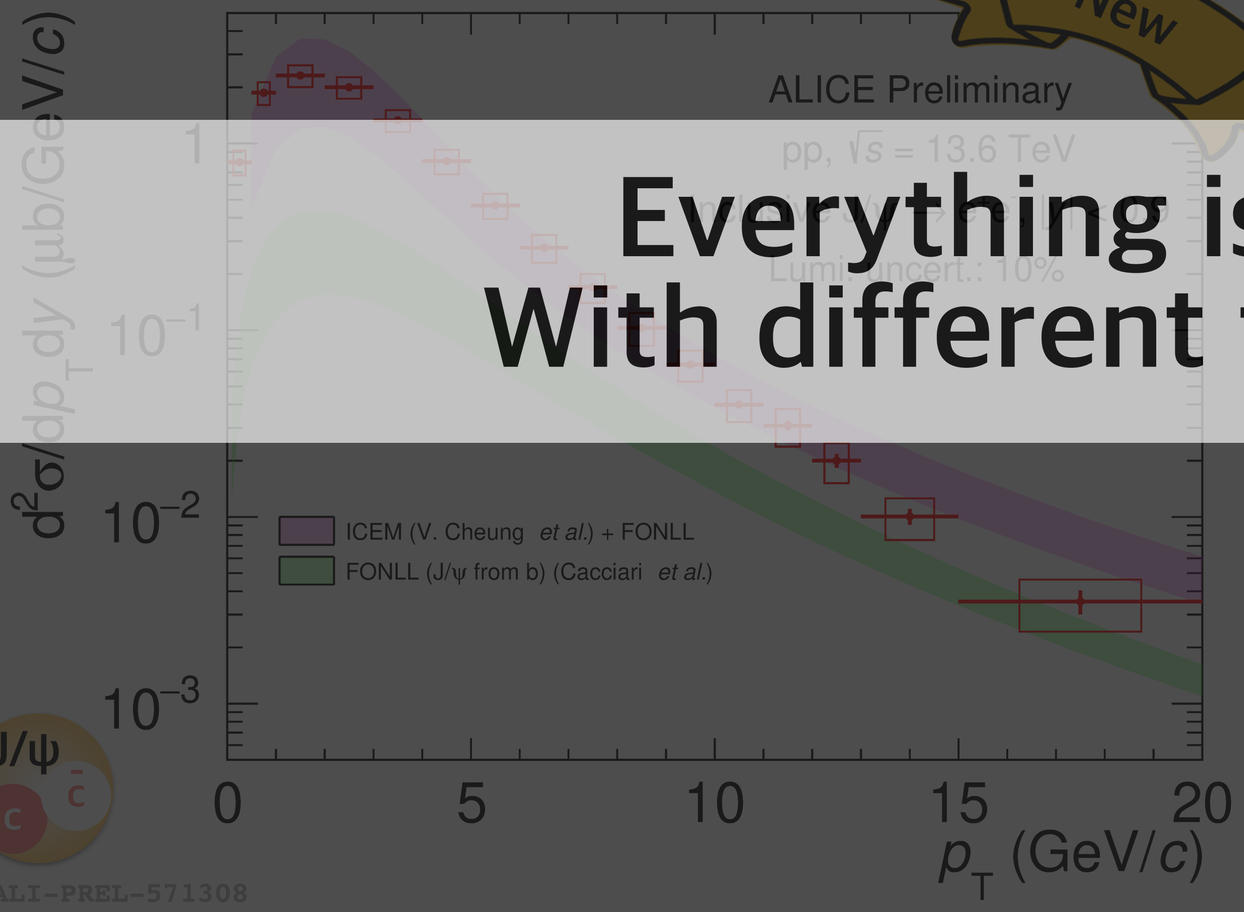
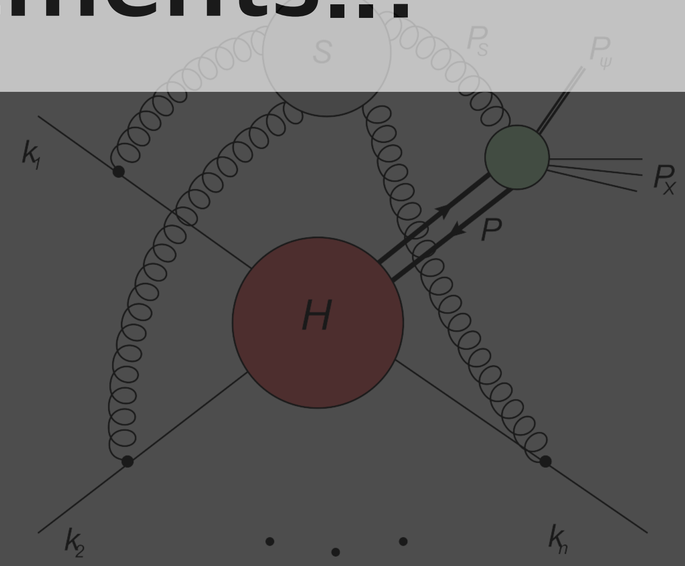


New

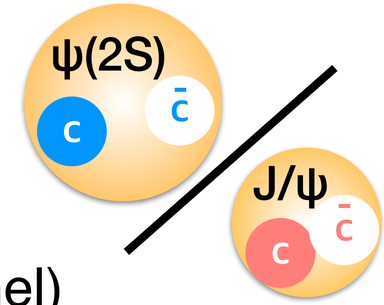
- **ICEM (Improved Color Evap… …del)**
  - Hadronisation to ψ(nS)
  - … threshold
  - Emitting soft gluons in the hadronisation

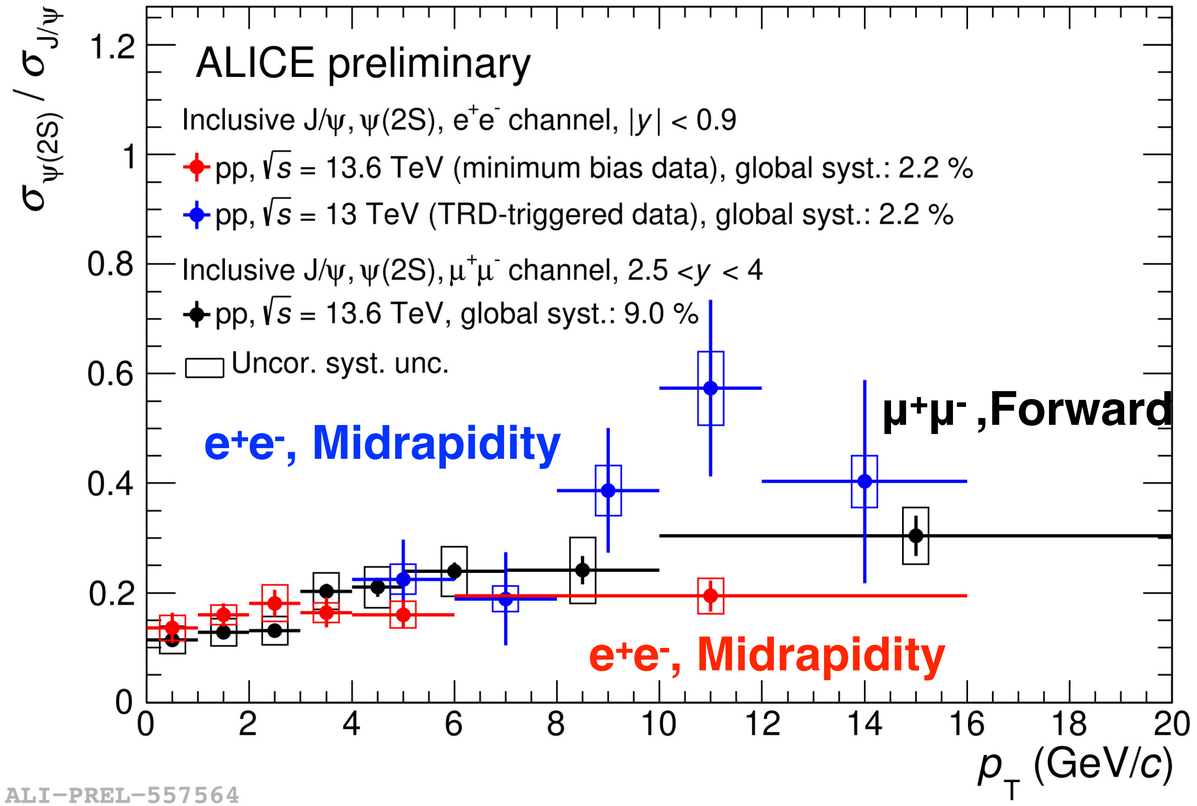


Everything is possible?
With different treatments..?

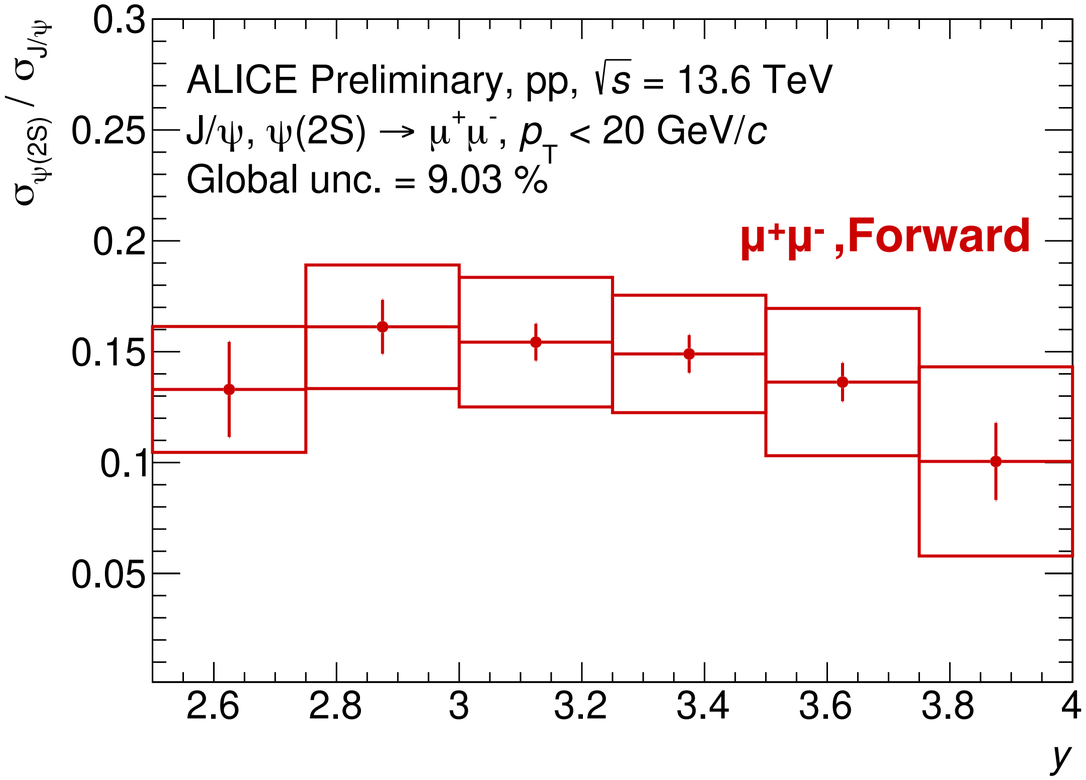
ψ(2S)-to-J/ψ ratio

- Useful to understand the formation of charmonia $D_{Q\bar{Q}\to H}$
- All measurements are in agreement within uncertainties
  - Run 2 (e^+e^- channel) ≃ Run 3 (e^+e^- channel, $\mu^+\mu^-$ channel)
  - **No rapidity dependence**: Midrapidity(e^+e^- channel) ≃ forward rapidity ($\mu^+\mu^-$ channel)





ALI-PREL-557564

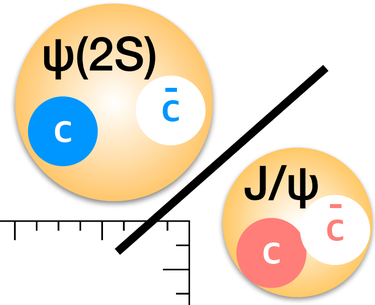


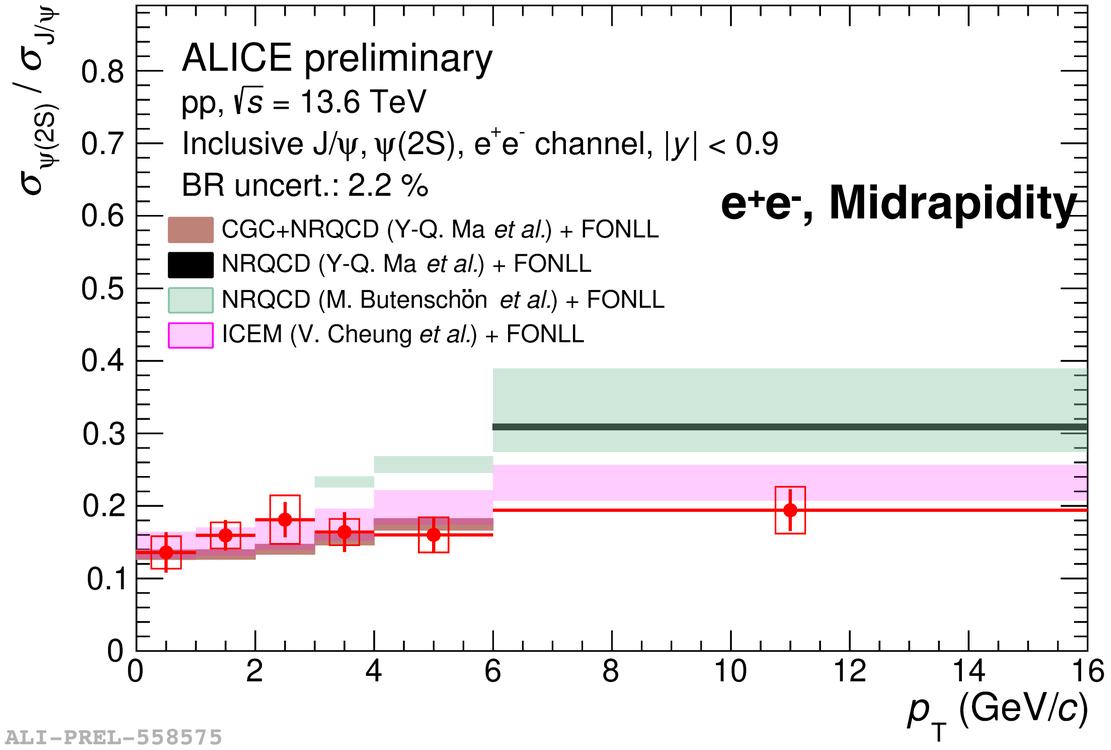
ALI-PREL-558880

ψ(2S)-to-J/ψ ratio

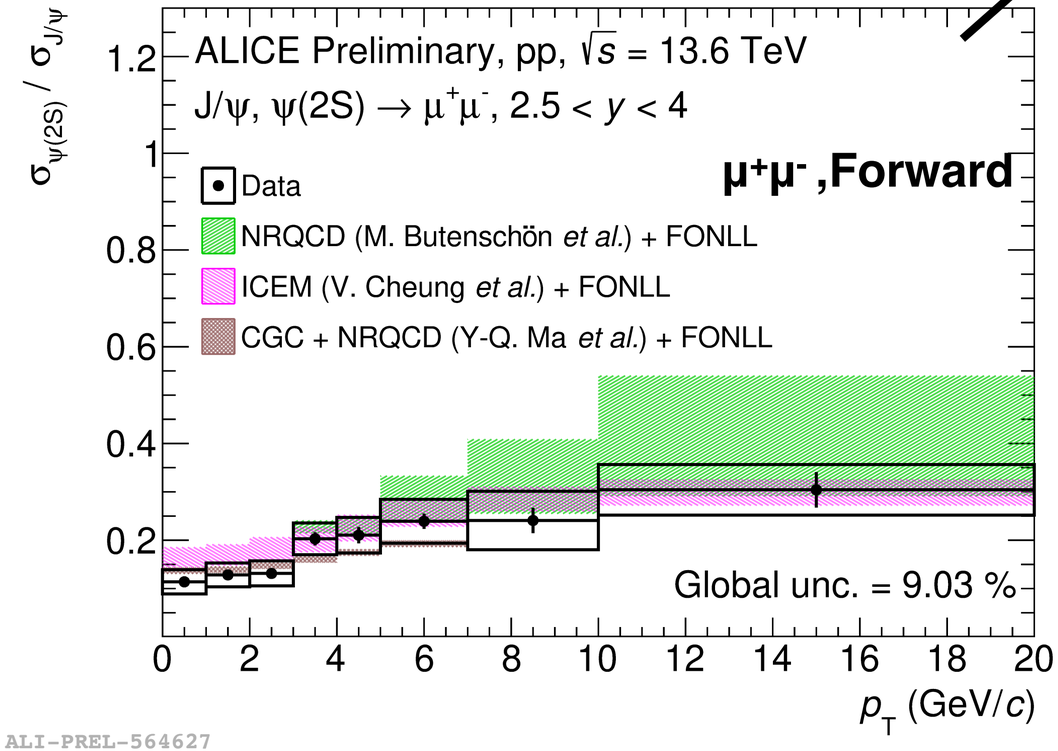
- Cancellation of theoretical uncertainties (renormalisation, factorisation scale..)
- **NRQCD**: Overestimates the ratio despite agreement with J/ψ cross section
- **CGC+NRQCD**: reproduces the measurements
- **ICEM**: Describes data well within uncertainties

Y-Q. Ma et al., PRL 106 (2012) 042002
V.Cheung et al., PRD 98 (2018) 114029
M. Butenschön et al., PRL 106 (2011) 022033
Y-Q. Ma et al., PRD 94 (2016) 11 114029
M.Cacciari et al., JHEP 10 (2012) 137





ALI-PREL-558575



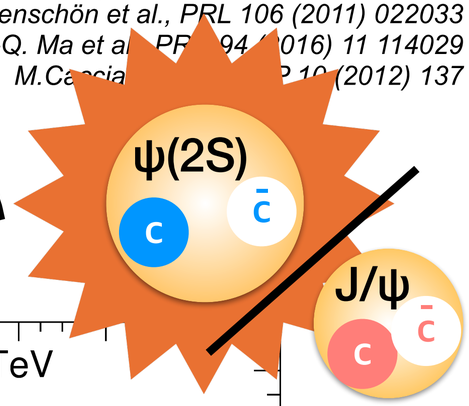
ALI-PREL-564627

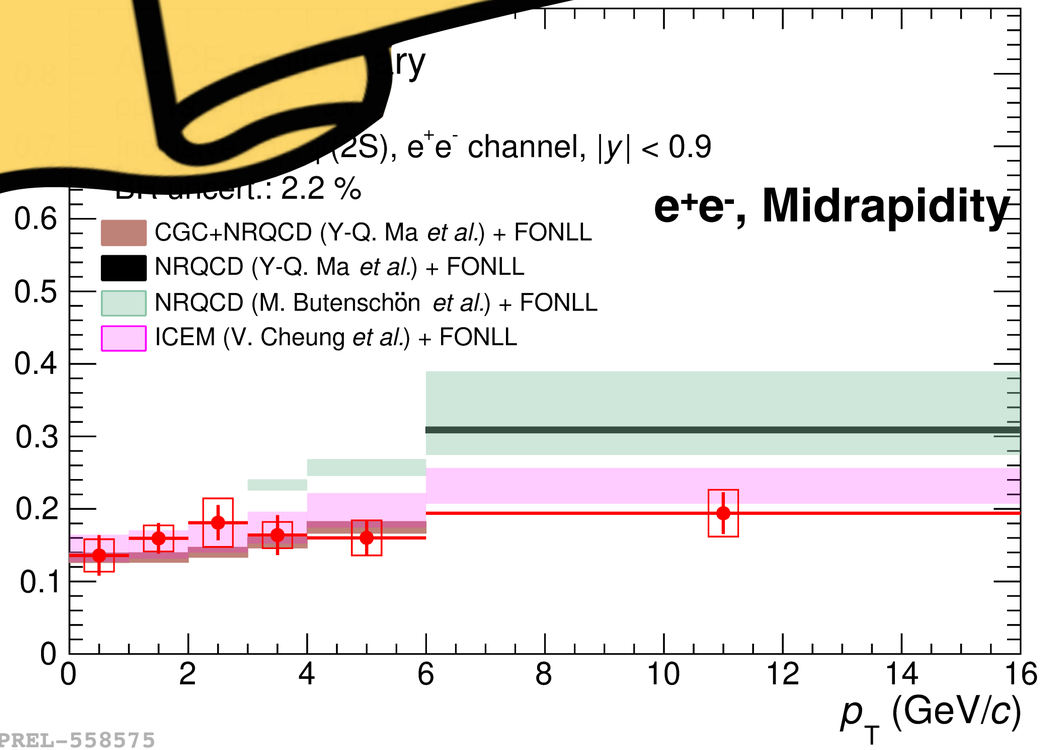
ψ(2S)-to-J/ψ ratio

- Cancellation of theoretical uncert
- **NRQCD**: Overestim
- **CGC+NRC**
- **IC**

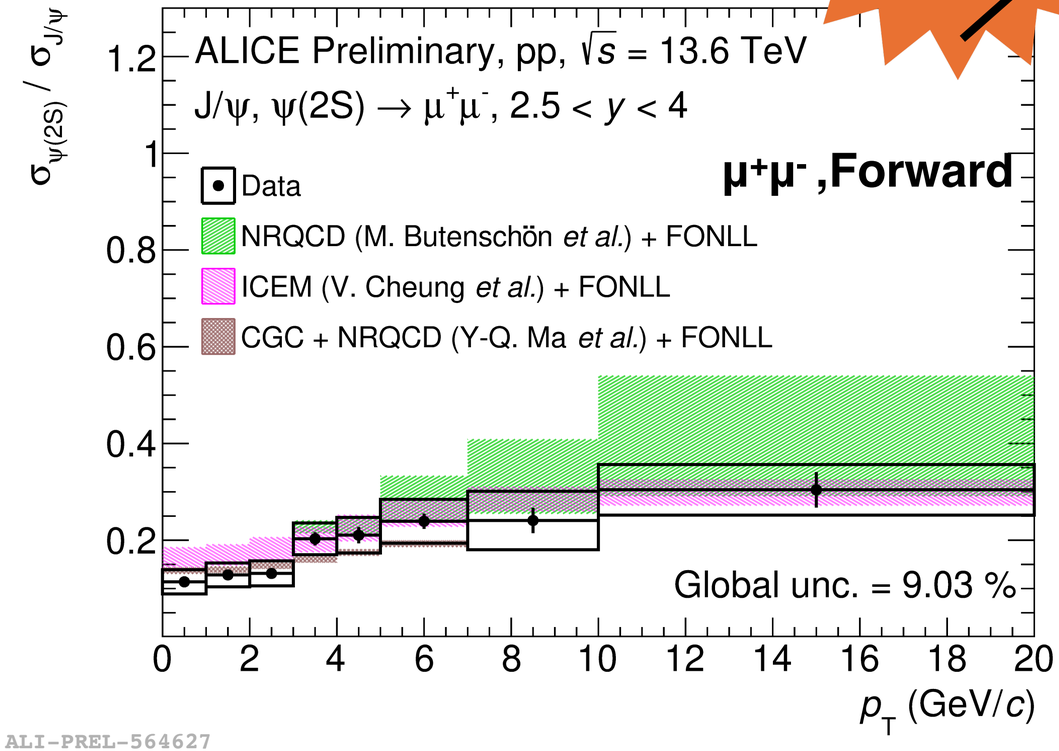
Exploiting the full statistics in Run3&4 will provide strong constraints!

Y-Q. Ma et al., PRL 106 (2012) 042002
V.Cheung et al., PRD 98 (2018) 114029
M. Butenschön et al., PRL 106 (2011) 022033
Y-Q. Ma et al., PR 94 (2016) 11 114029
M.Cacciari P 10 (2012) 137





ALI-PREL-558575



ALI-PREL-564627

ALCE has measured charmonia from Run 1 and Run 2

Run 3 data allows more precise and granular measurements

J/ψ measurement is described by ICEM and NRQCD-based models

Precise measurements will provide strong constraints

2009

2013

2015

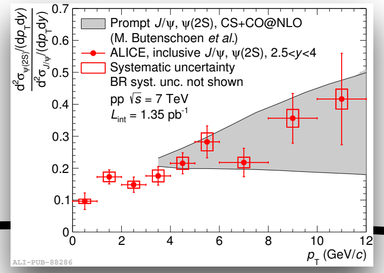
2018

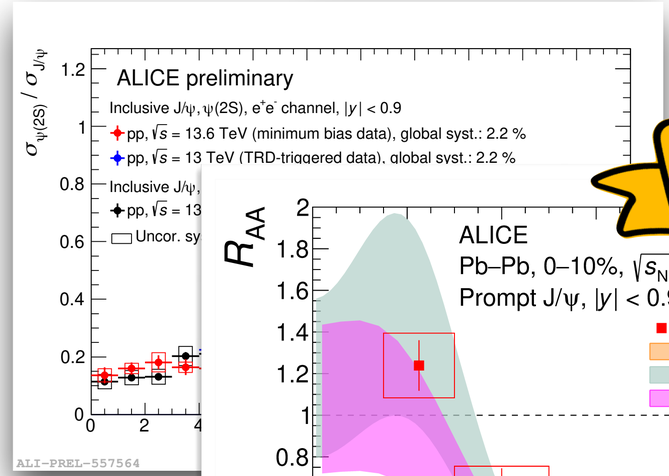
2022

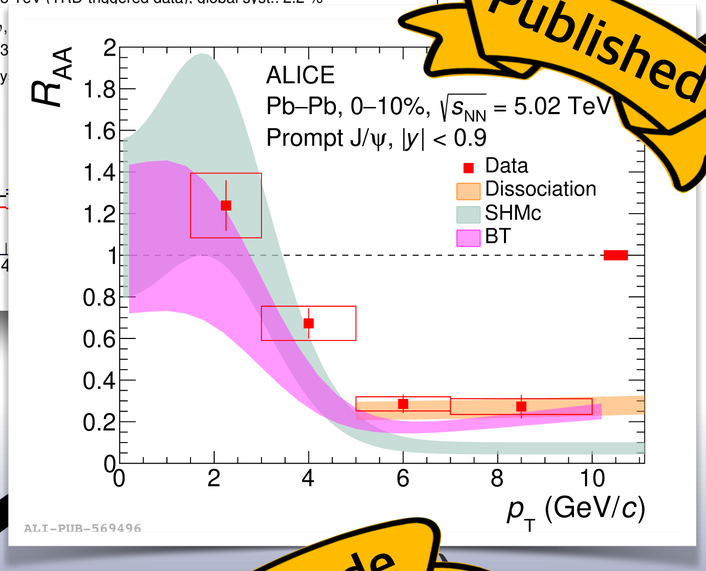
Published

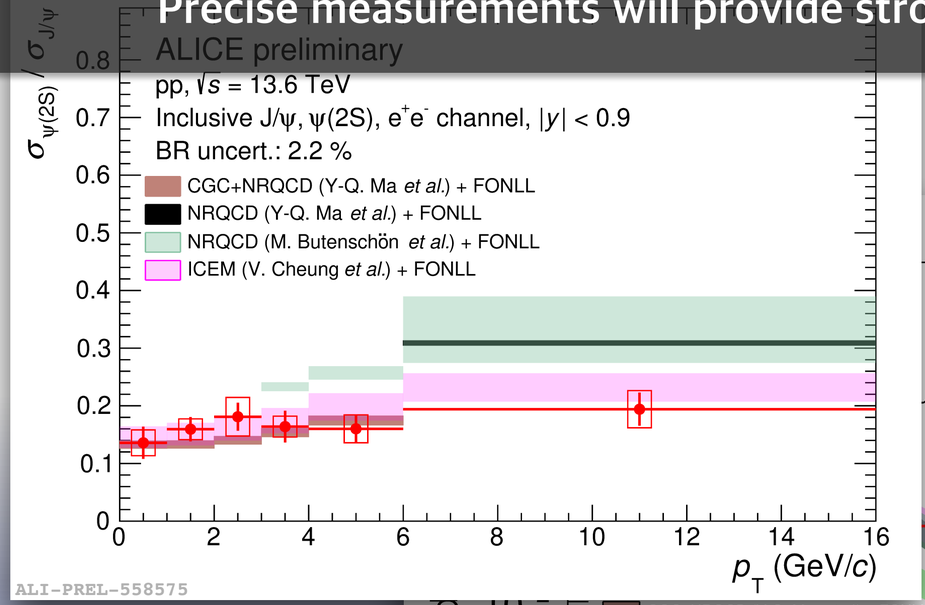
Upgrade

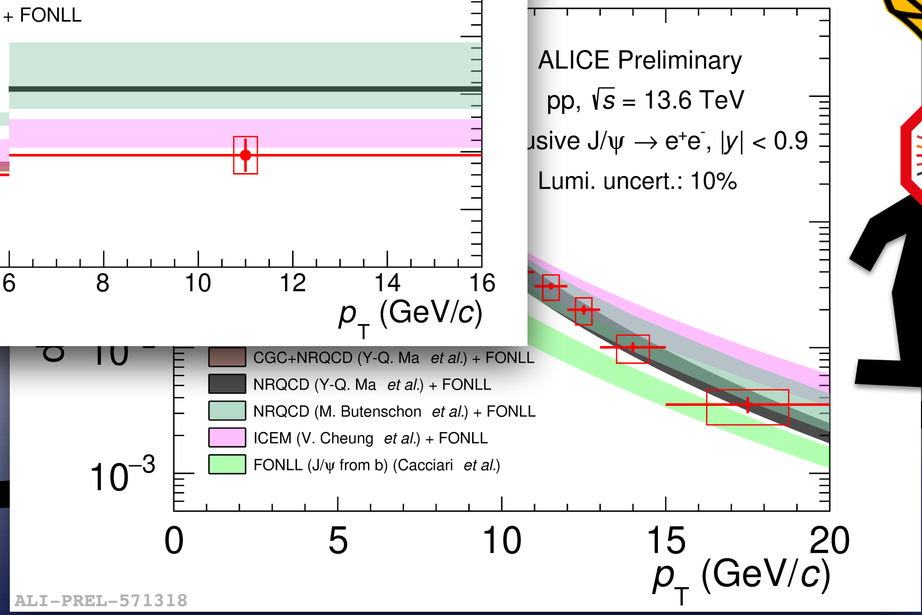
New

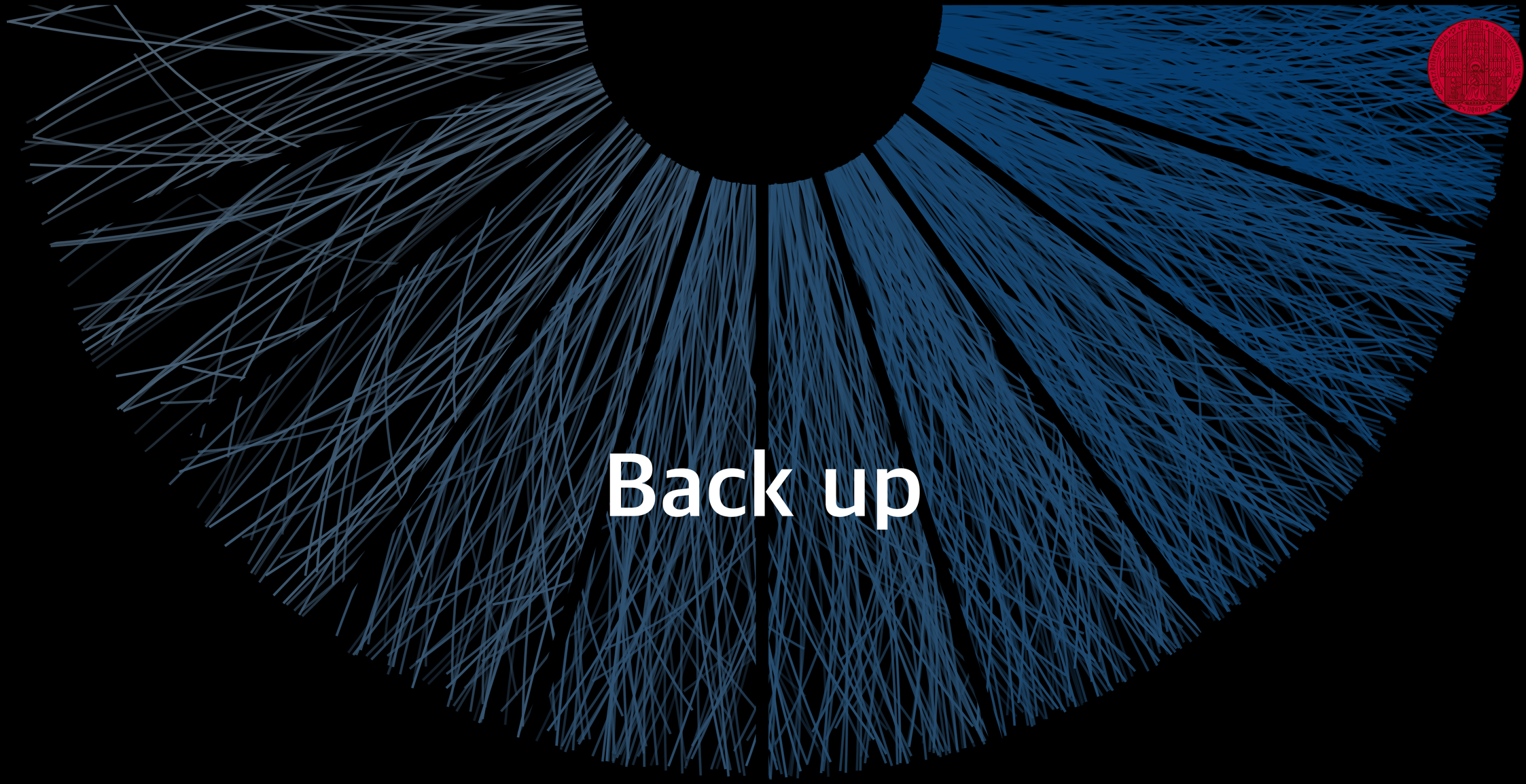








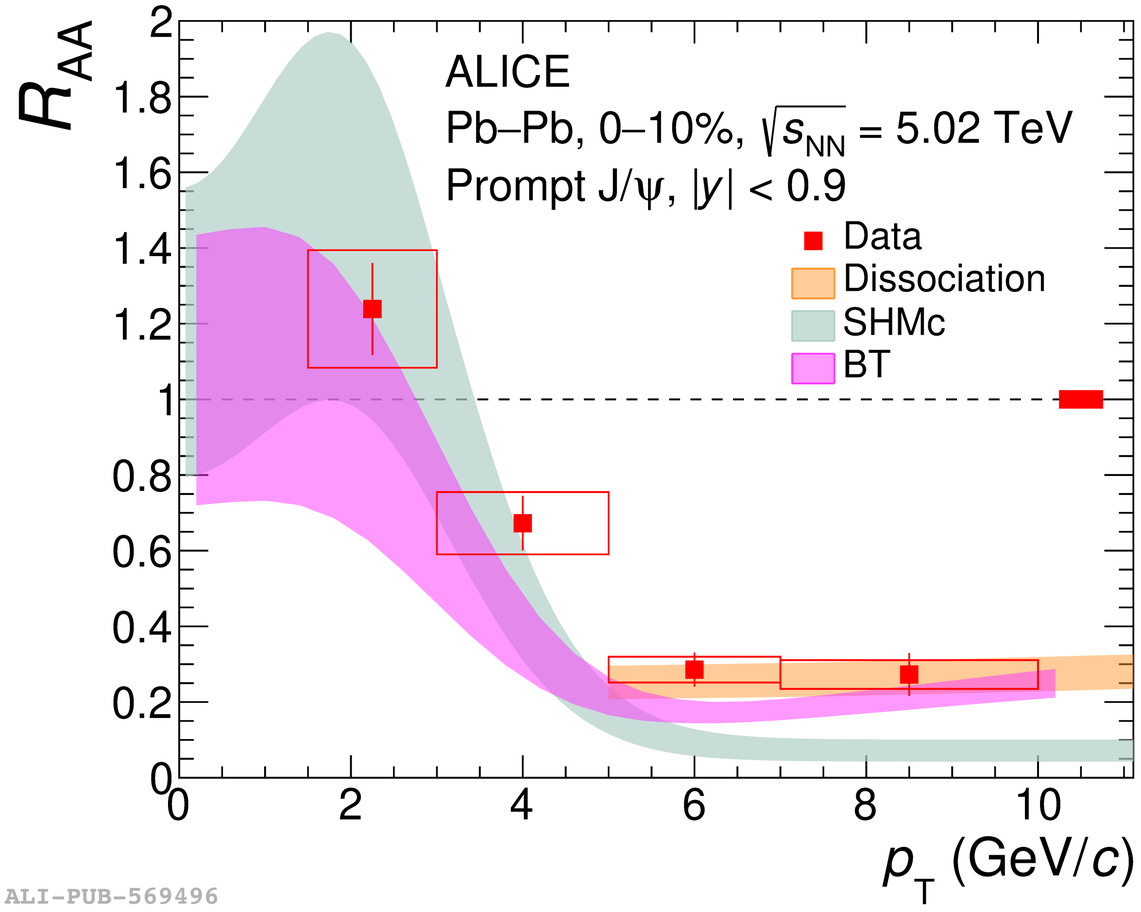




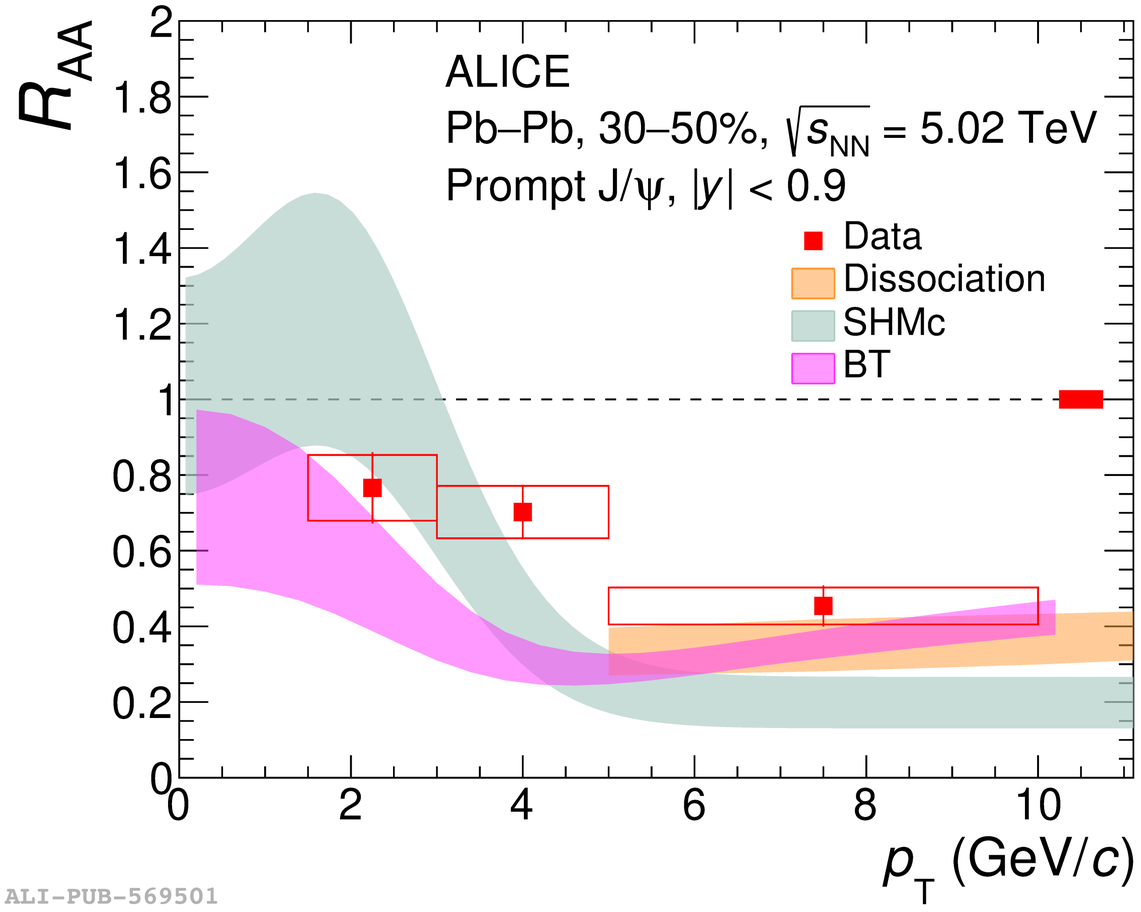
Back up

Nuclear modification factor

- SHMc: reproduces the results at low p_{T}, significantly below the data for $p_{\mathrm{T}} > 5$ GeV/c
- BT: good description of the measurements in most central collisions, underpredicts in 30–50%

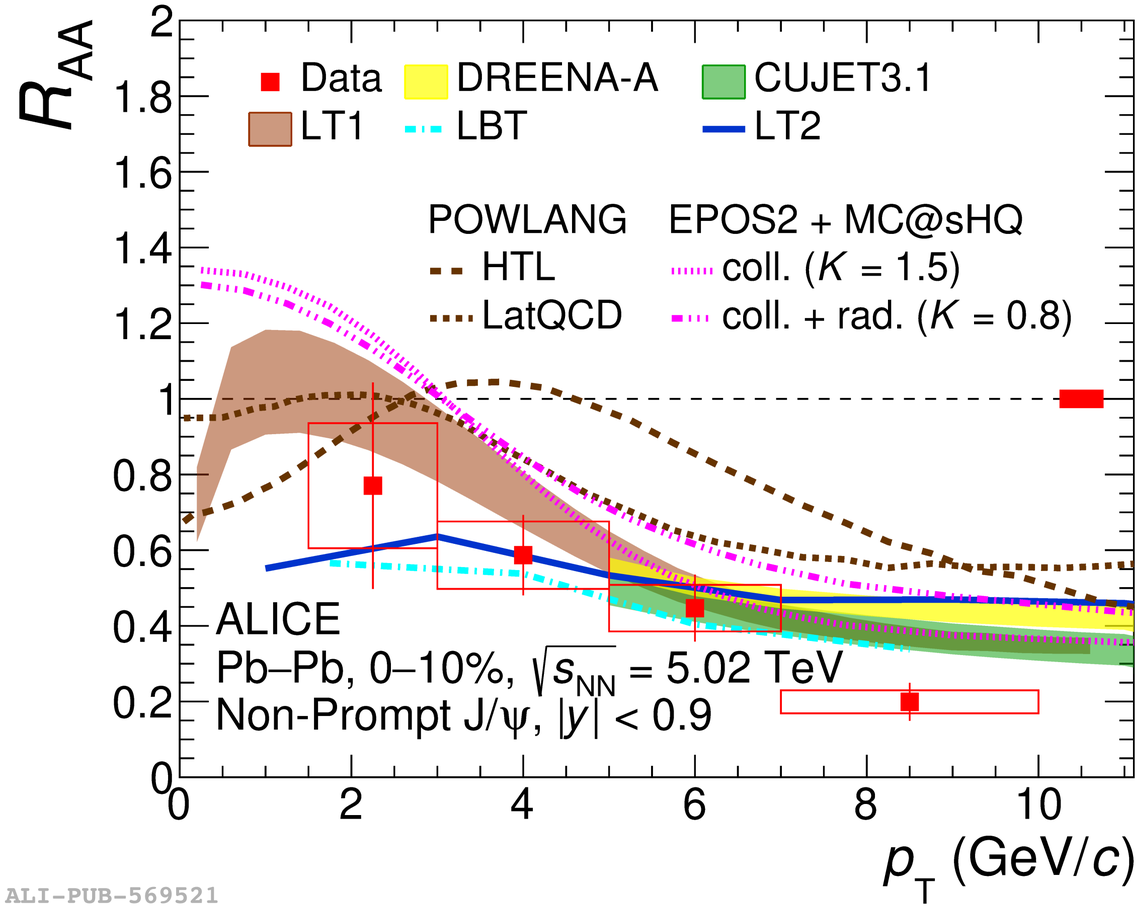


ALI-PUB-569496

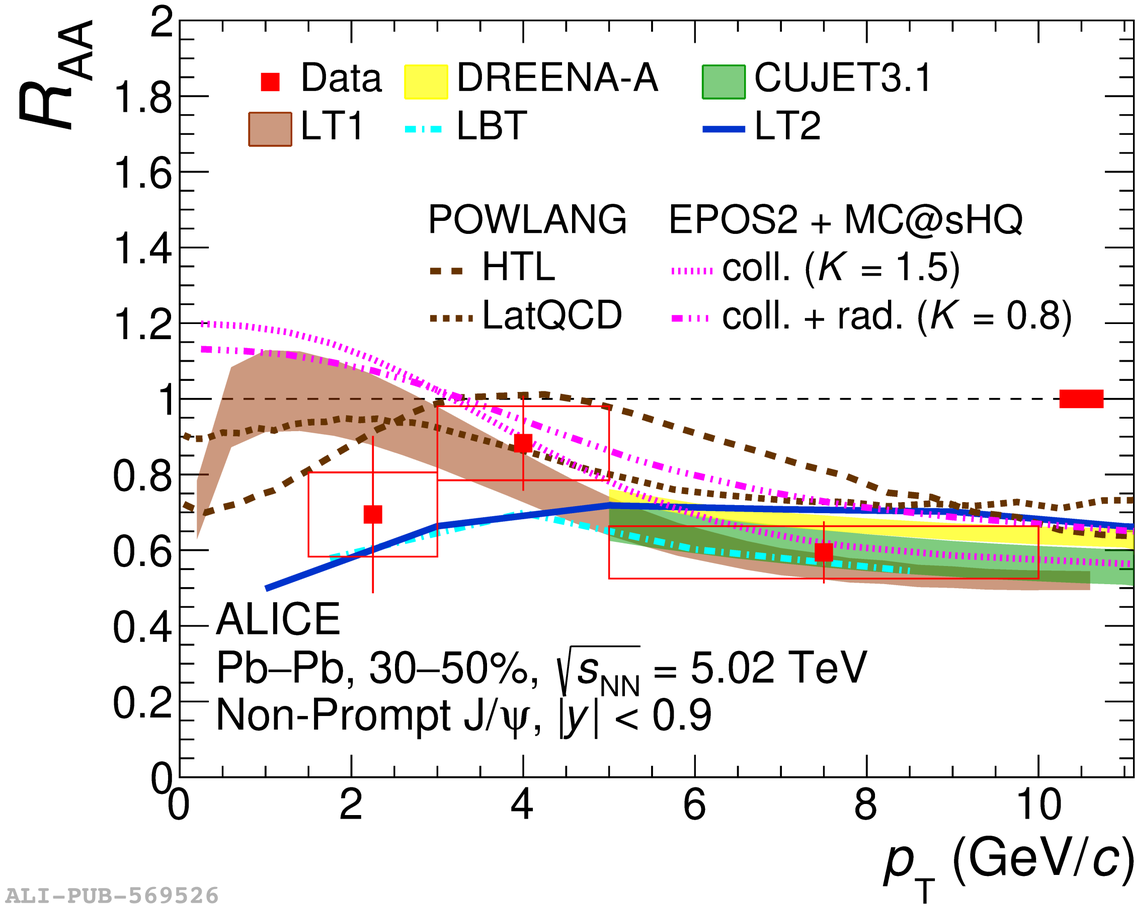


ALI-PUB-569501

Nuclear modification factor

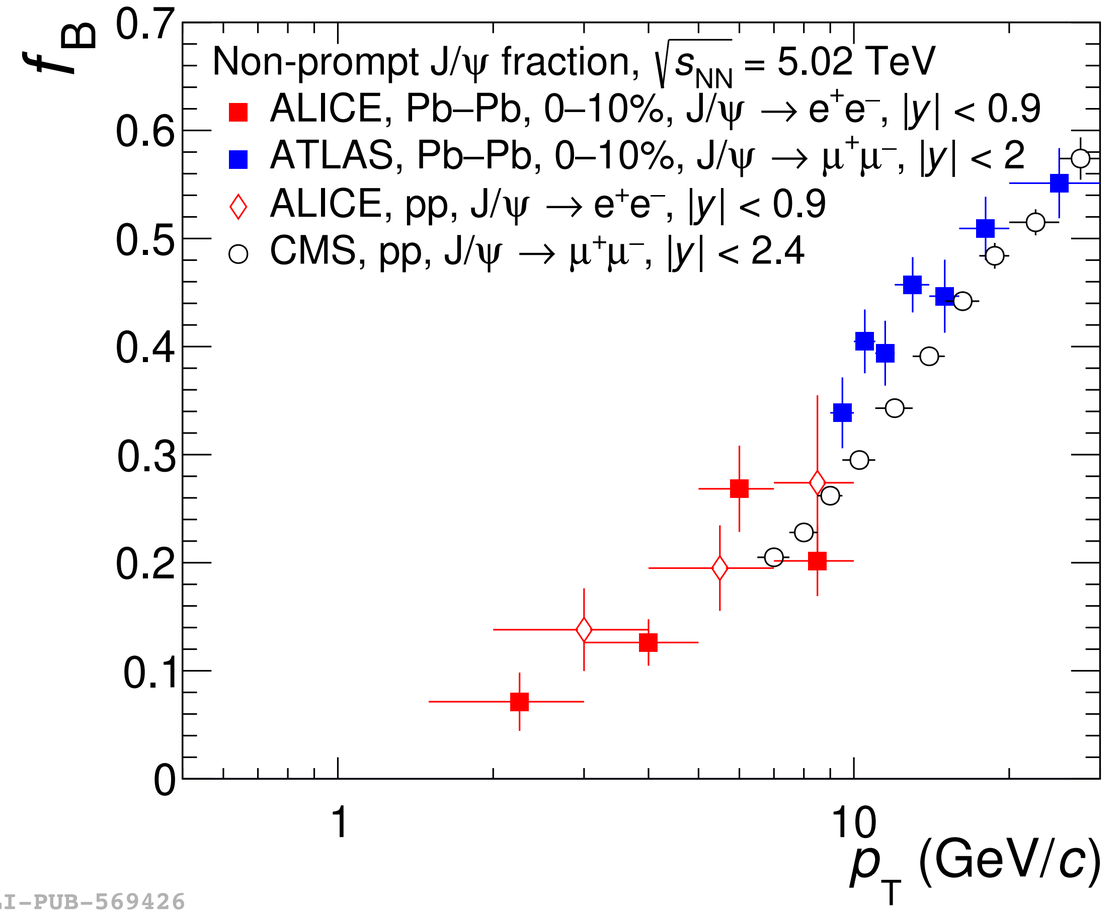


ALI-PUB-569521



ALI-PUB-569526

Non-prompt J/ψ fraction



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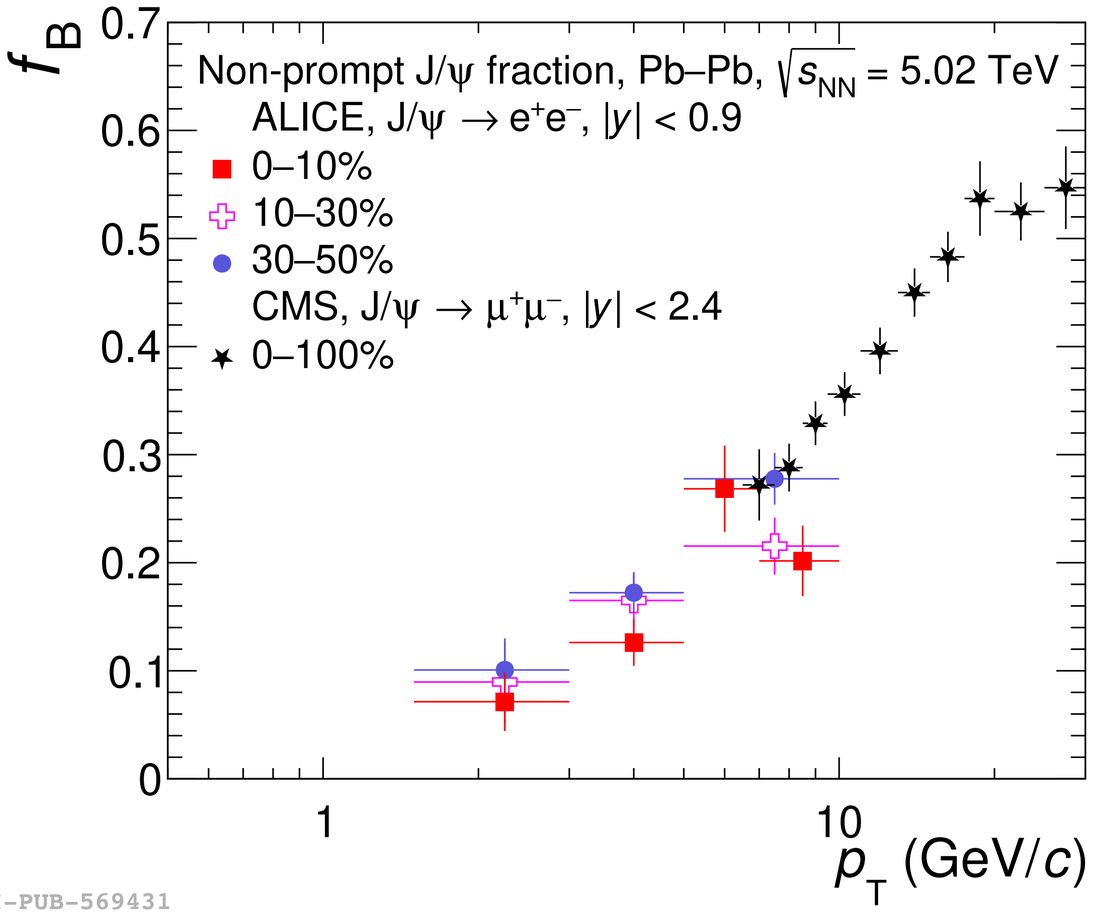
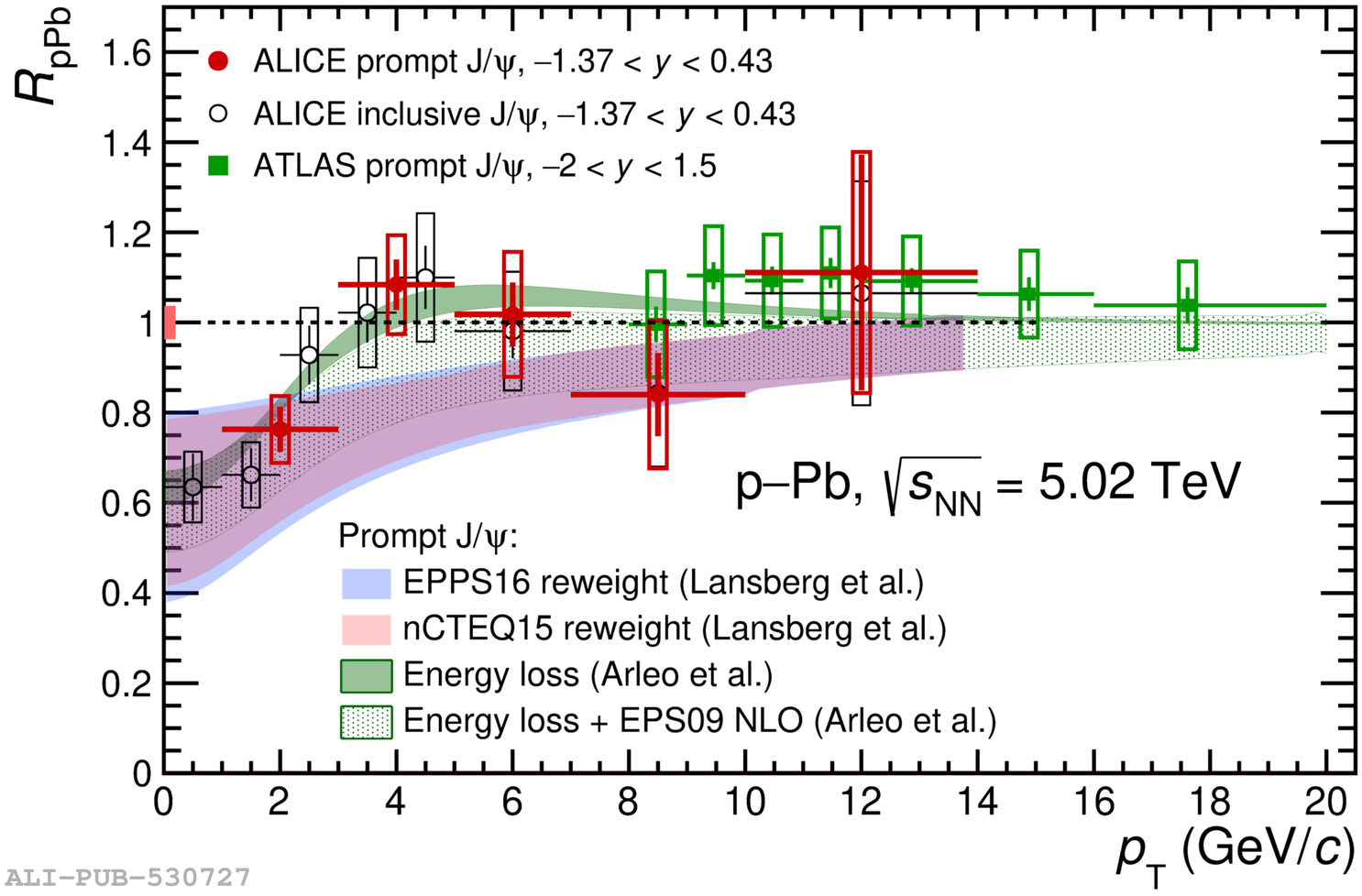


ALI-PUB-569431

Nuclear modification factor



Transition Radiation Detector

- **ALICE TRD (Drift Chamber + Transition Radiator)**
  - Electron ID for $p_T > 1$ GeV/c , Trigger on high-p_T electrons
  - Transition radiation occurs for relativistic particle ($\gamma > 800$) crossing between materials with different dielectric constants

The ALICE Transition Radiation Detector: Construction, operation, and performance
ALICE Collaboration, NIM A881 (2018) 88