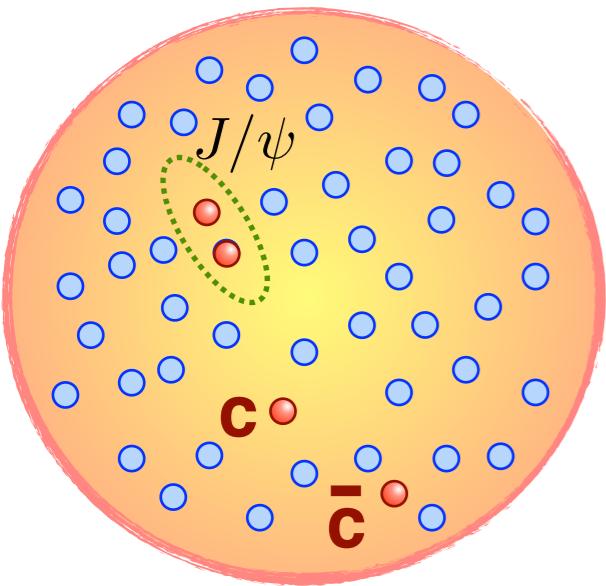


Fragmentation of jets containing a J/ ψ meson in PbPb with CMS

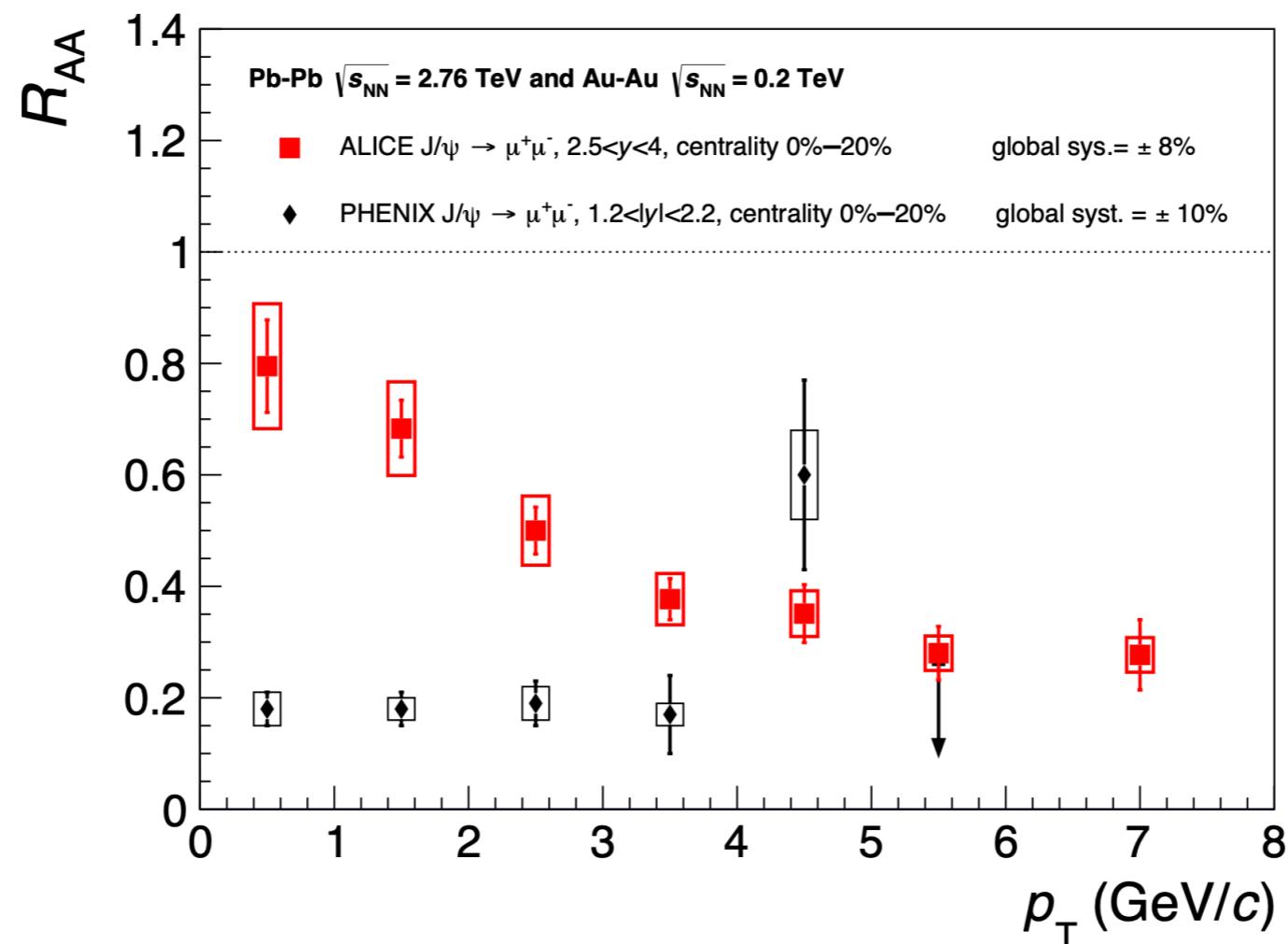
Batoul Diab

LHC-EW WG: Jets and EW bosons
17/10/2022

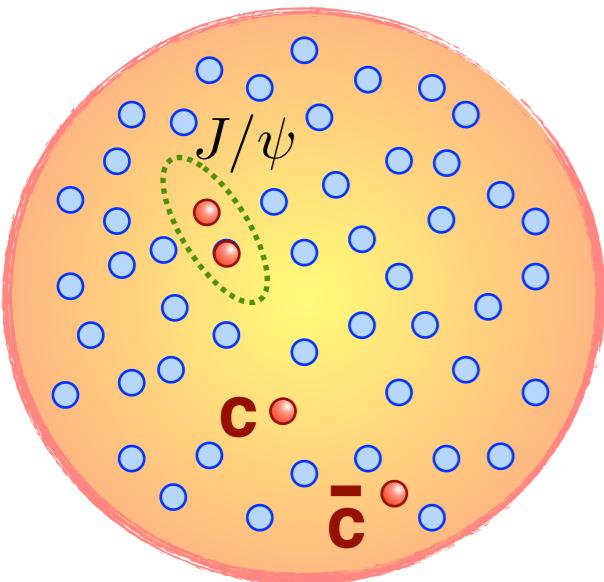
J/ ψ in heavy ion collisions



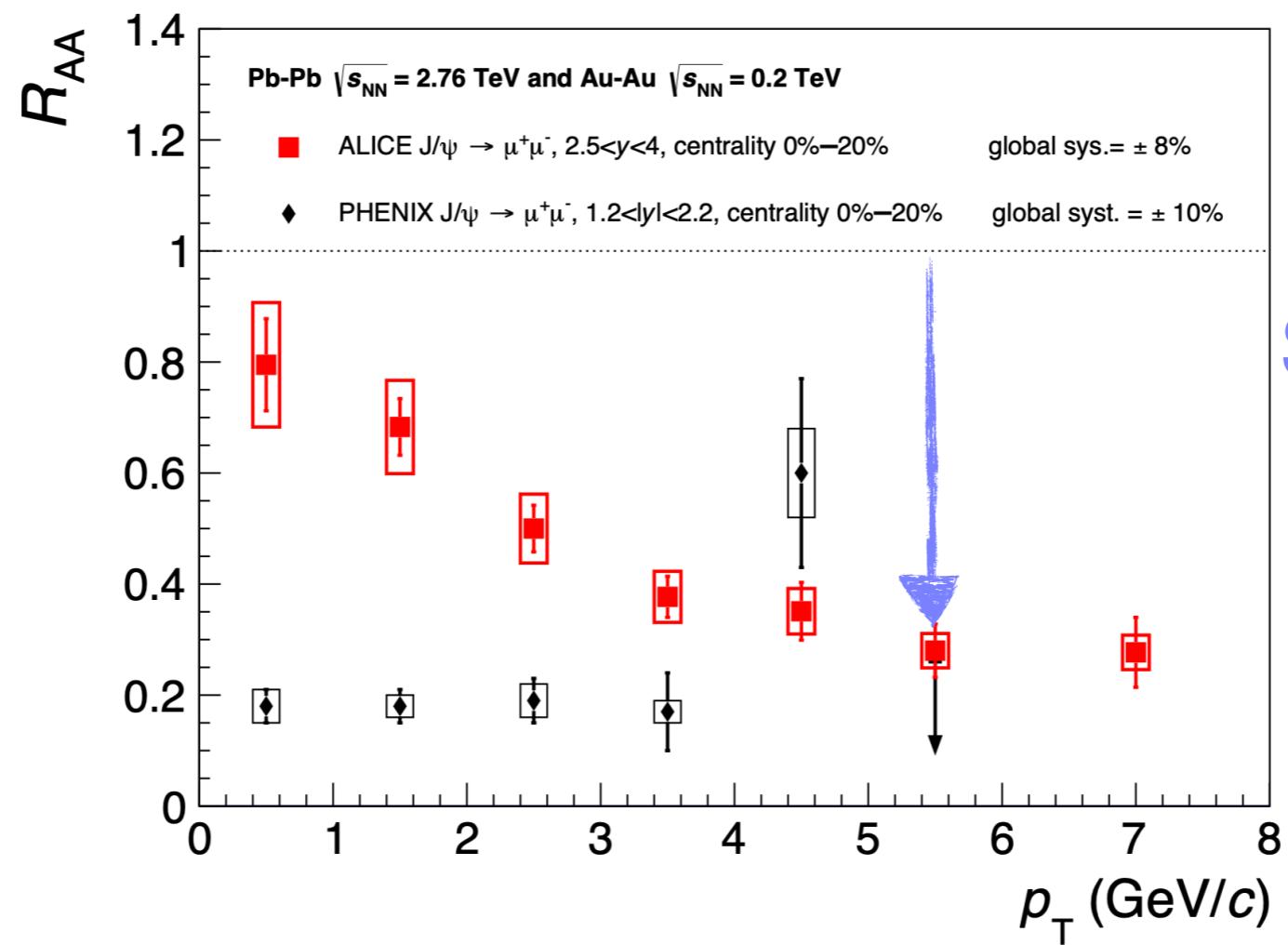
J/ ψ in HI: one of the classic probes of the QGP



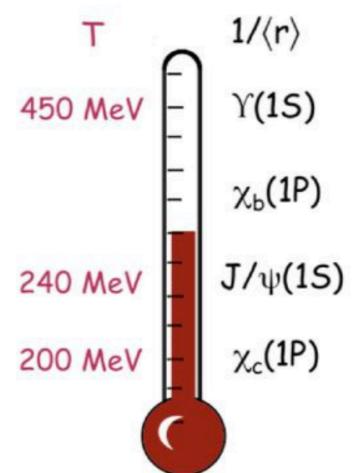
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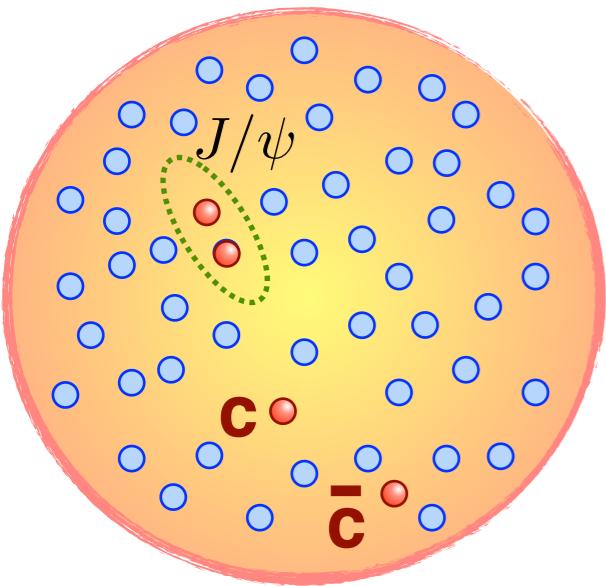
J/ ψ in HI: one of the classic probes of the QGP



Suppression
↳ Debye screening

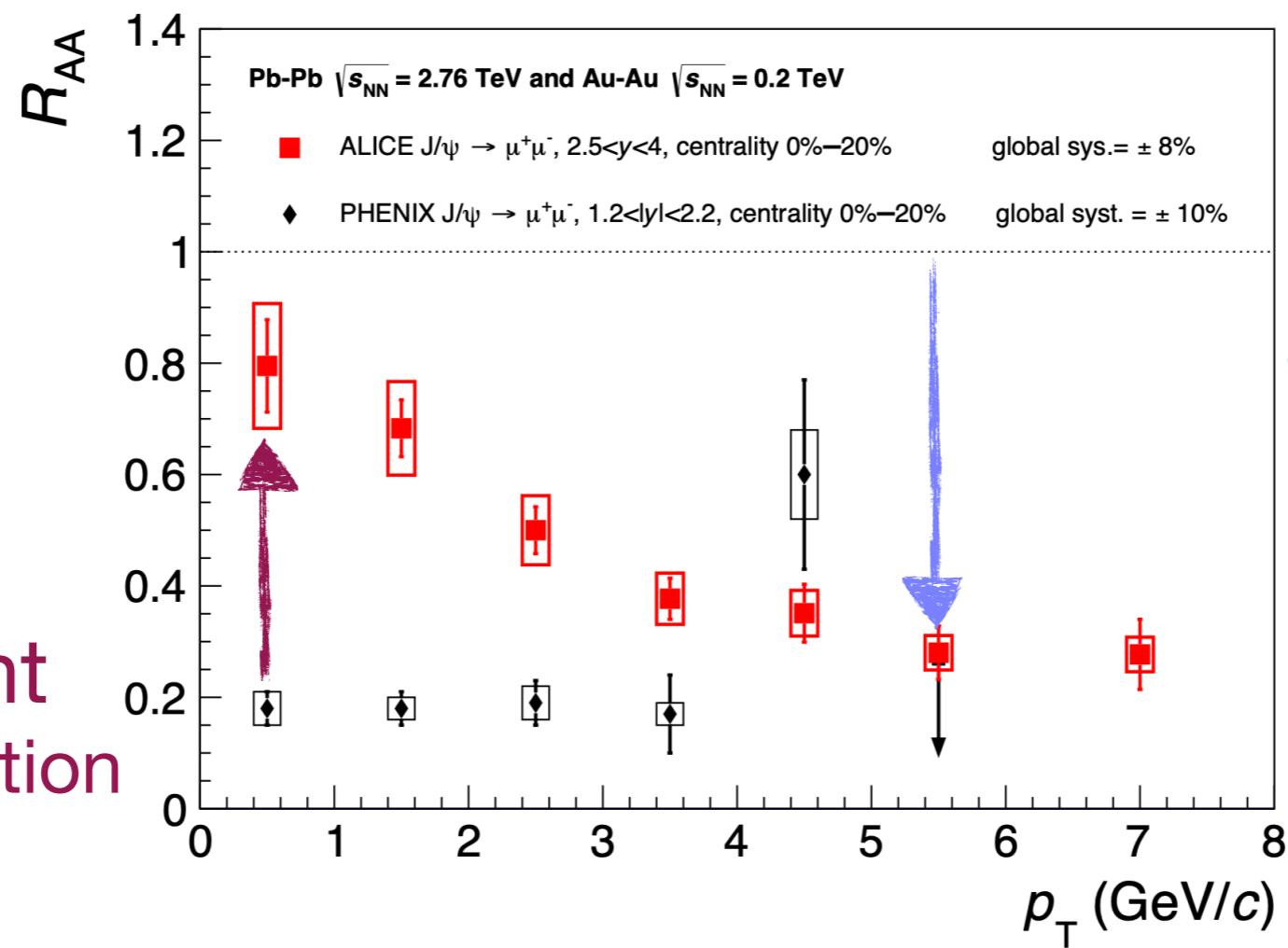


J/ ψ in heavy ion collisions

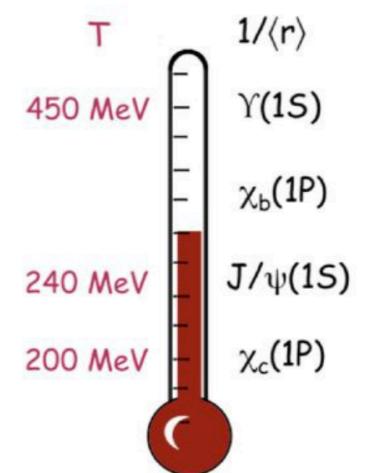


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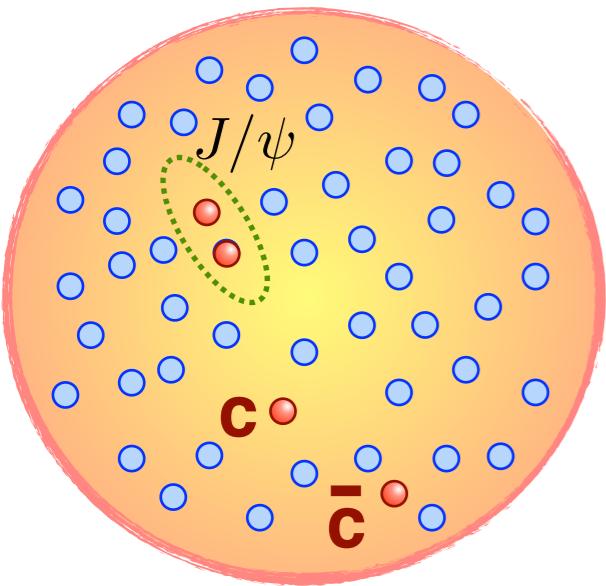
Enhancement
↳ Recombination



Suppression
↳ Debye screening

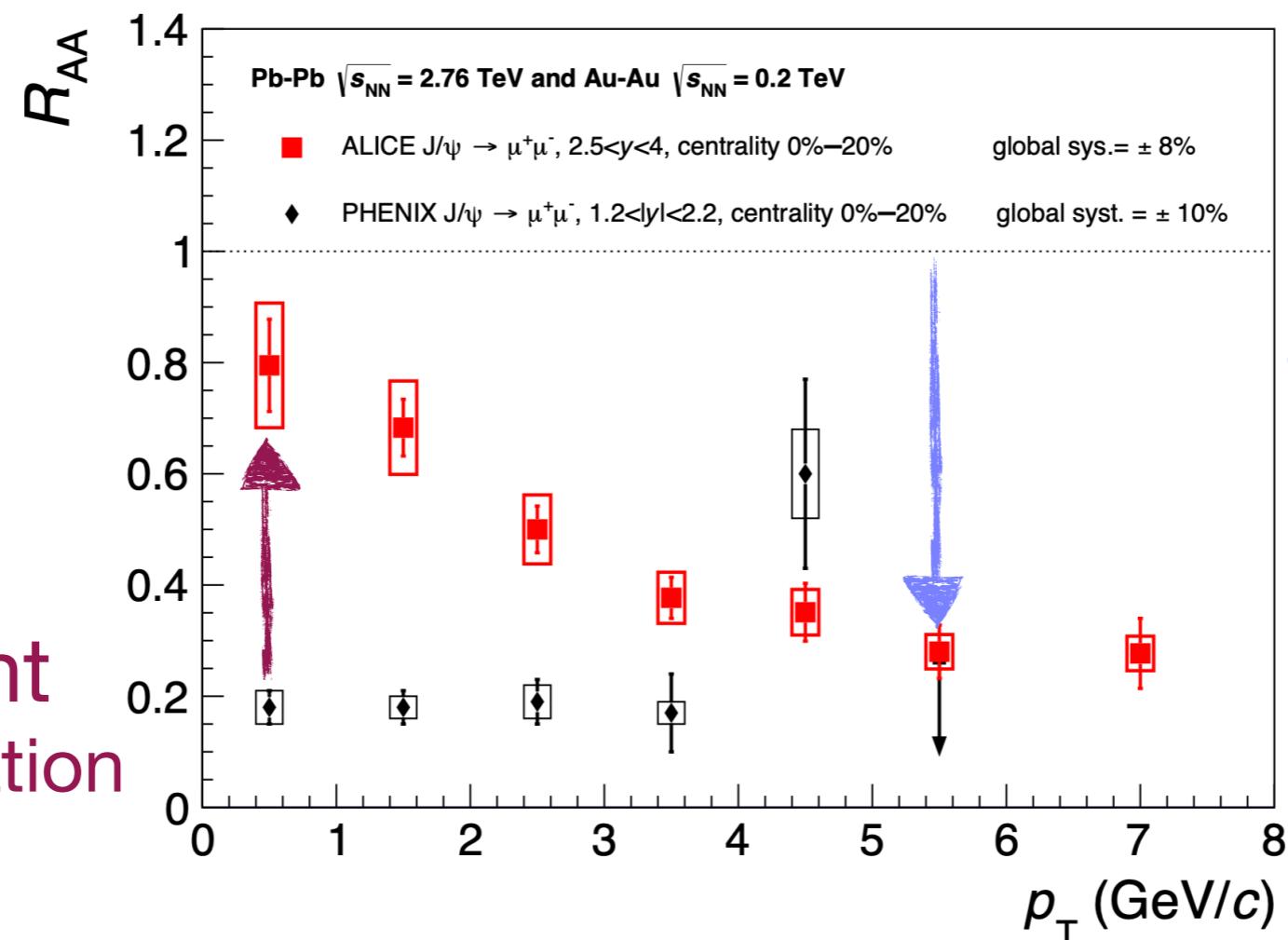


J/ ψ in heavy ion collisions

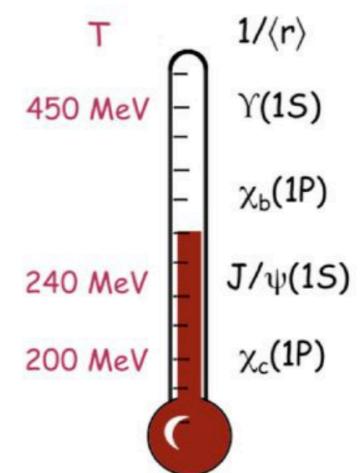


J/ ψ in HI: one of the classic probes of the QGP

Enhancement
↳ Recombination



Suppression
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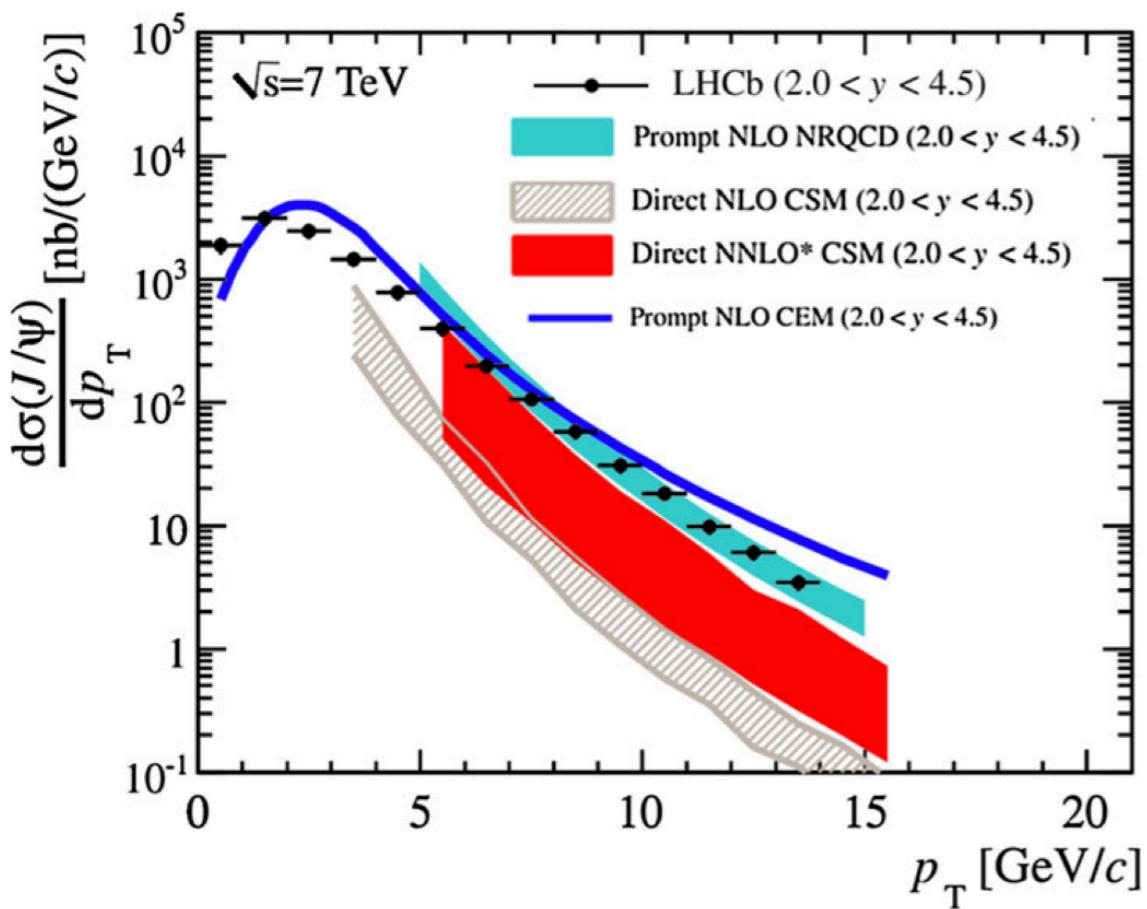


This picture assumes the production of the $c\bar{c}$ pair at early times

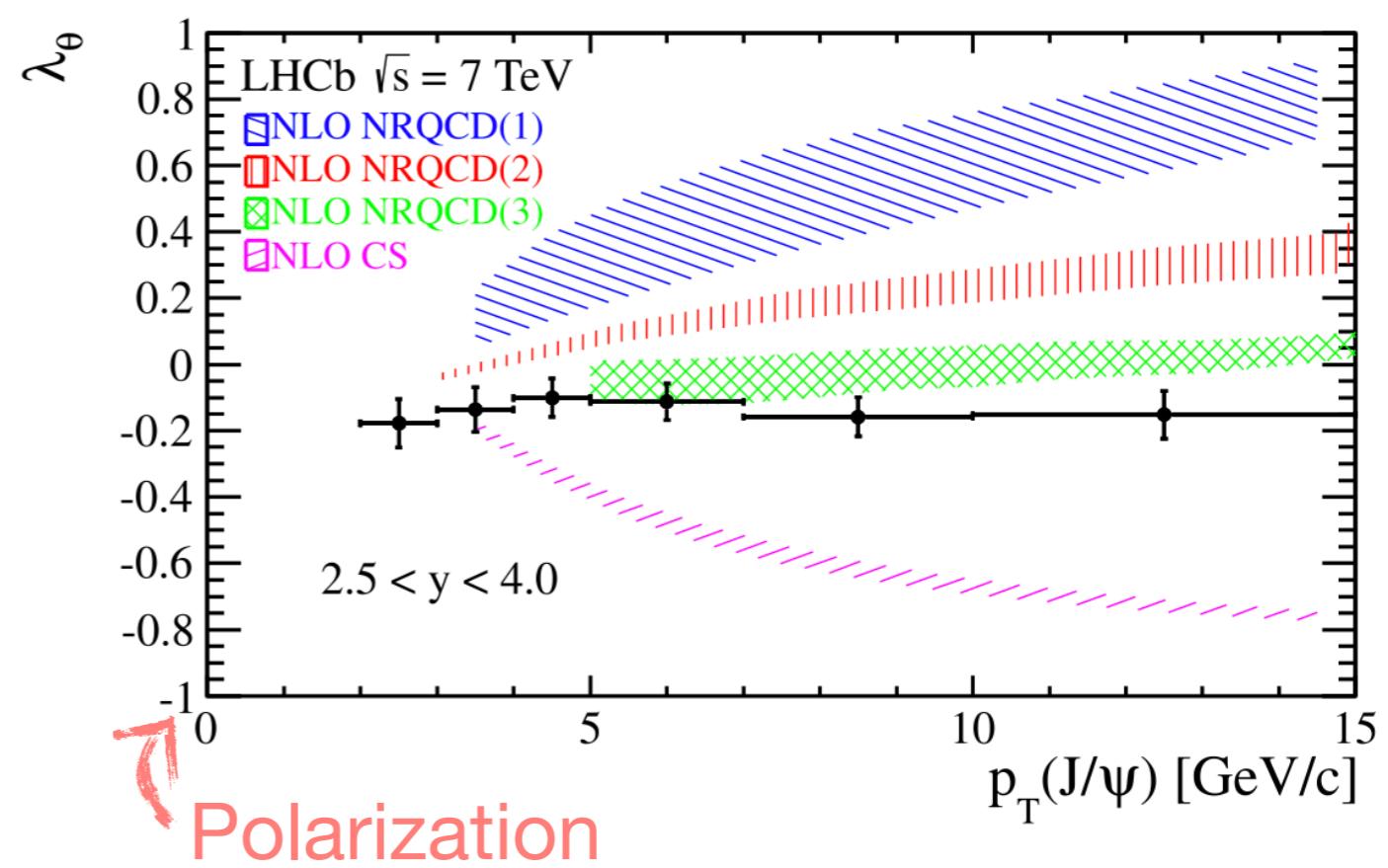
J/ ψ production in pp

J/ ψ production is not fully understood

Models can't reproduce both cross section and polarization



A. Andronic et al. EPJC 76 (2016) 107

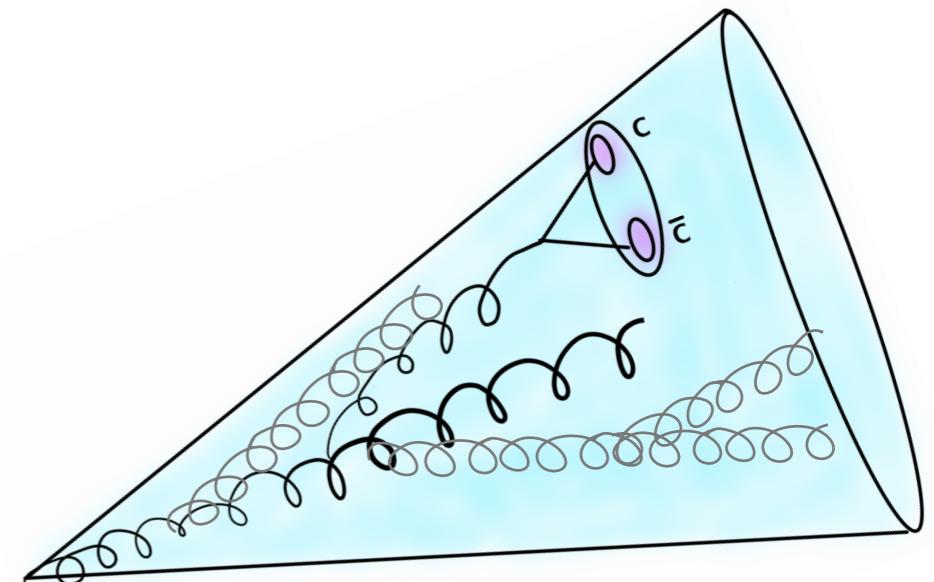
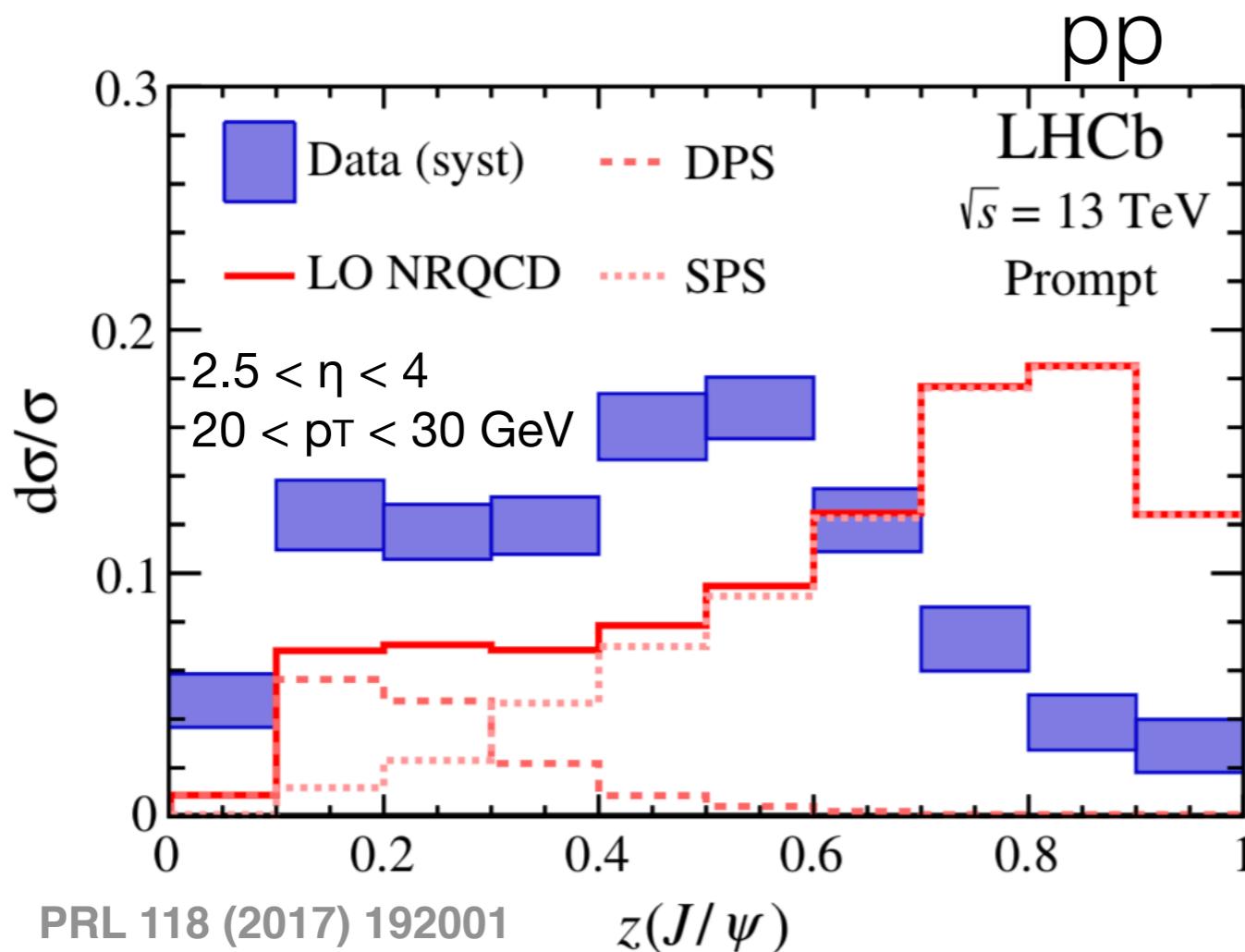


EPJC 73 (2013) 2631

J/ ψ in jets in pp

Recent measurement by
LHCb: J/ ψ in jets

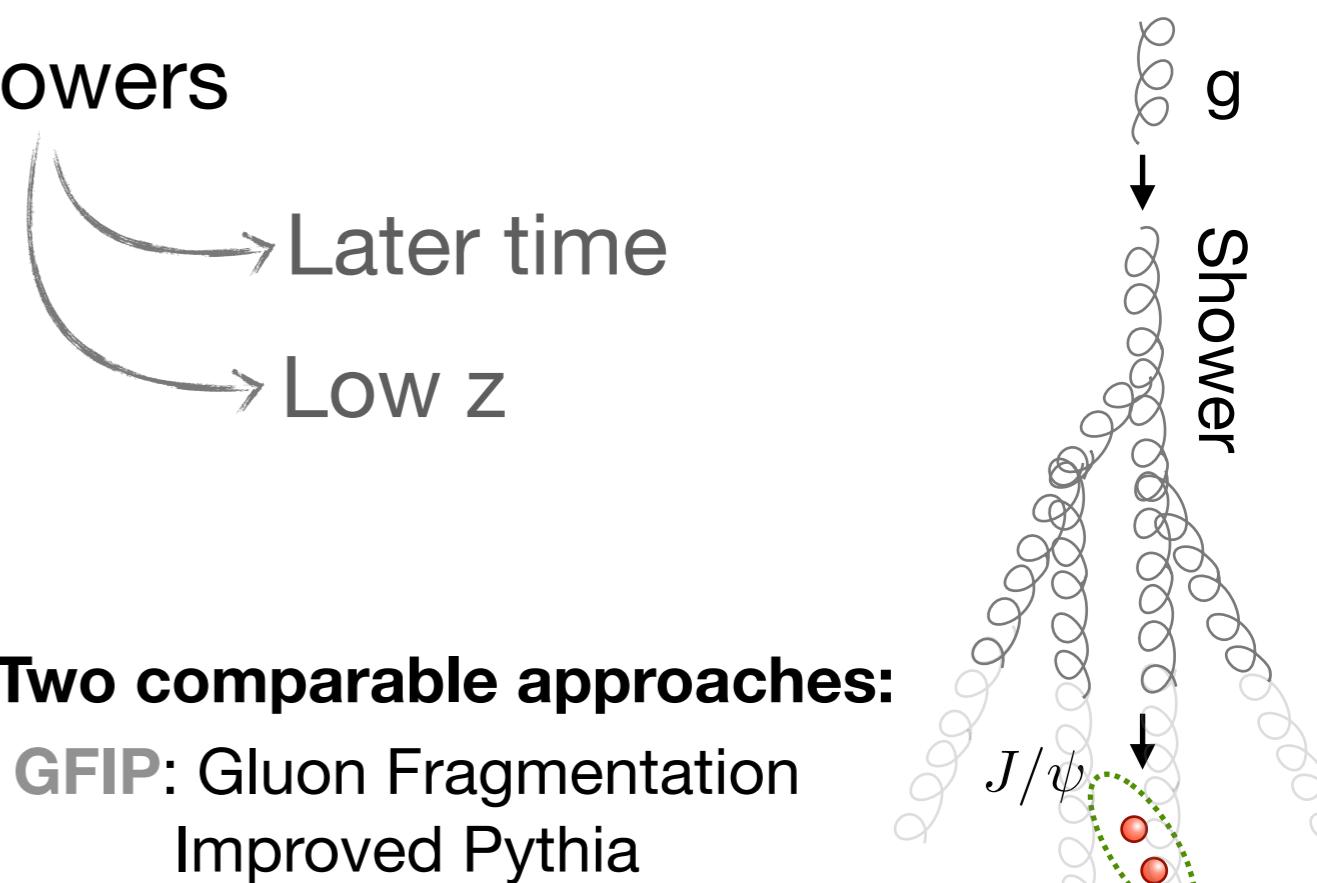
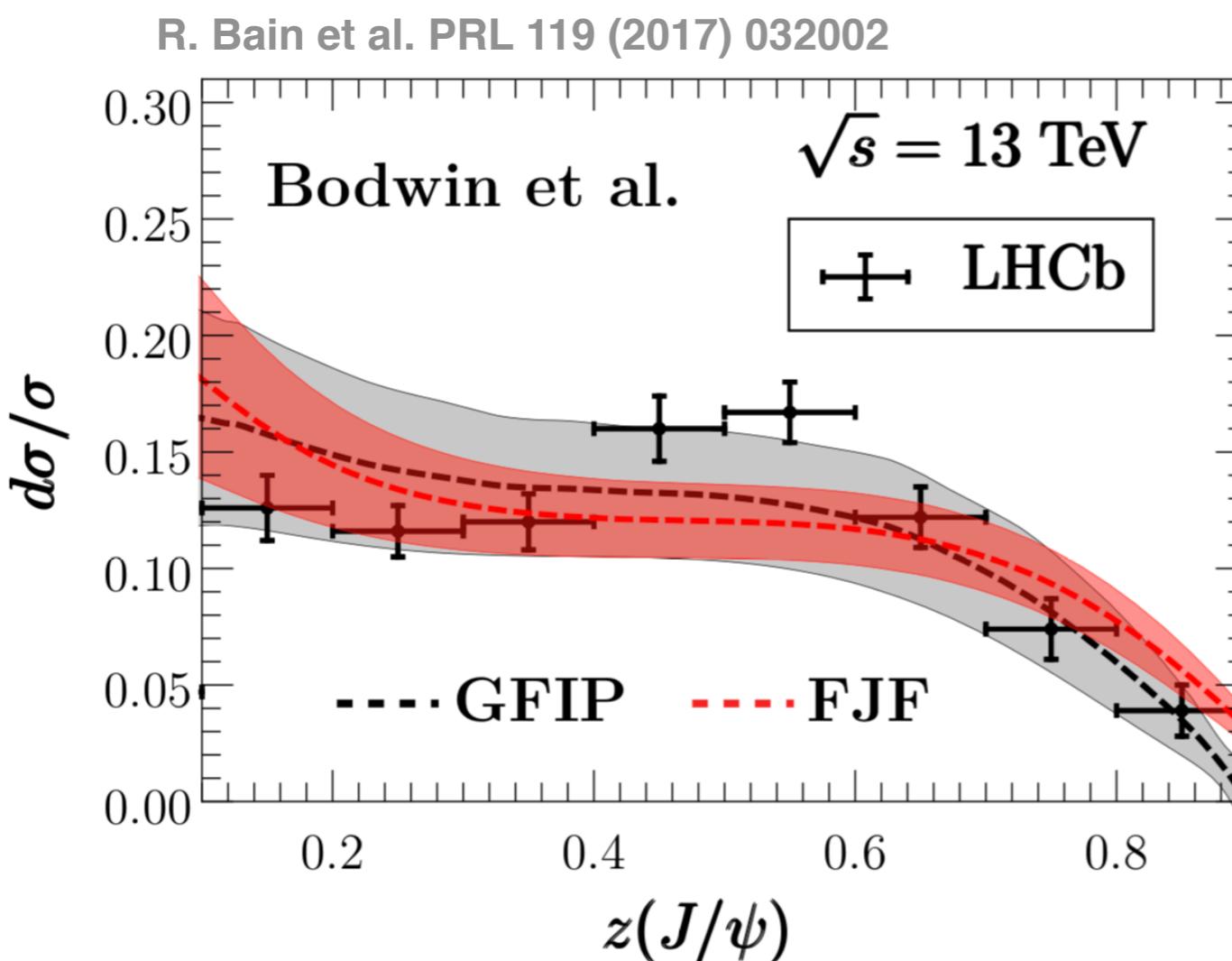
$$z = \text{J}/\psi \text{ p}_T / \text{jet p}_T$$



prompt J/ ψ are produced
with far more jet activity
than predicted by models

NRQCD vs LHCb

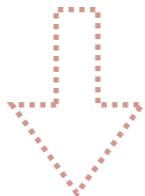
Fixed order calculations are not enough to understand the J/ ψ puzzle
J/ ψ could be produced in parton showers



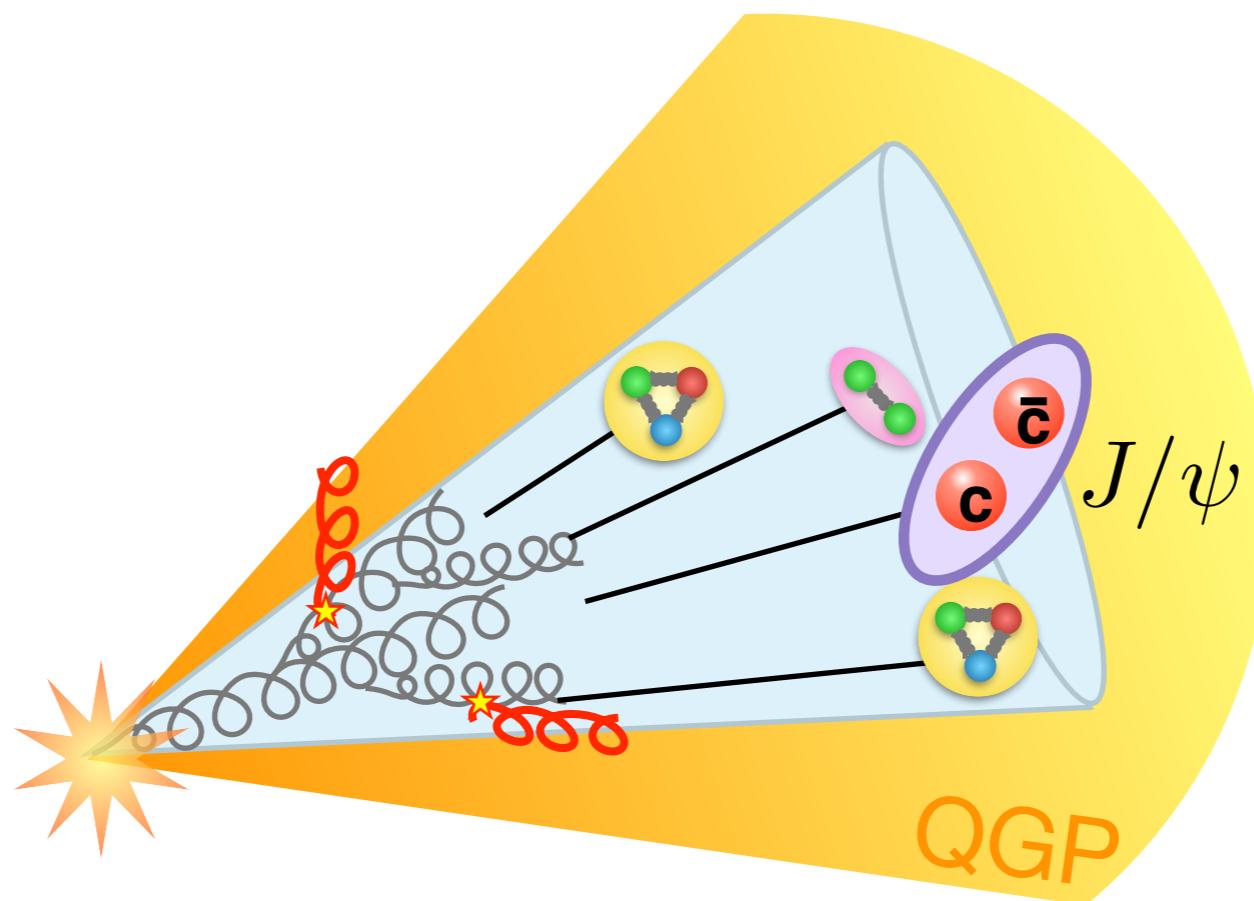
Better agreement with LHCb results than LO NRQCD

J/ ψ production in AA collisions

J/ ψ may also be produced in parton showers



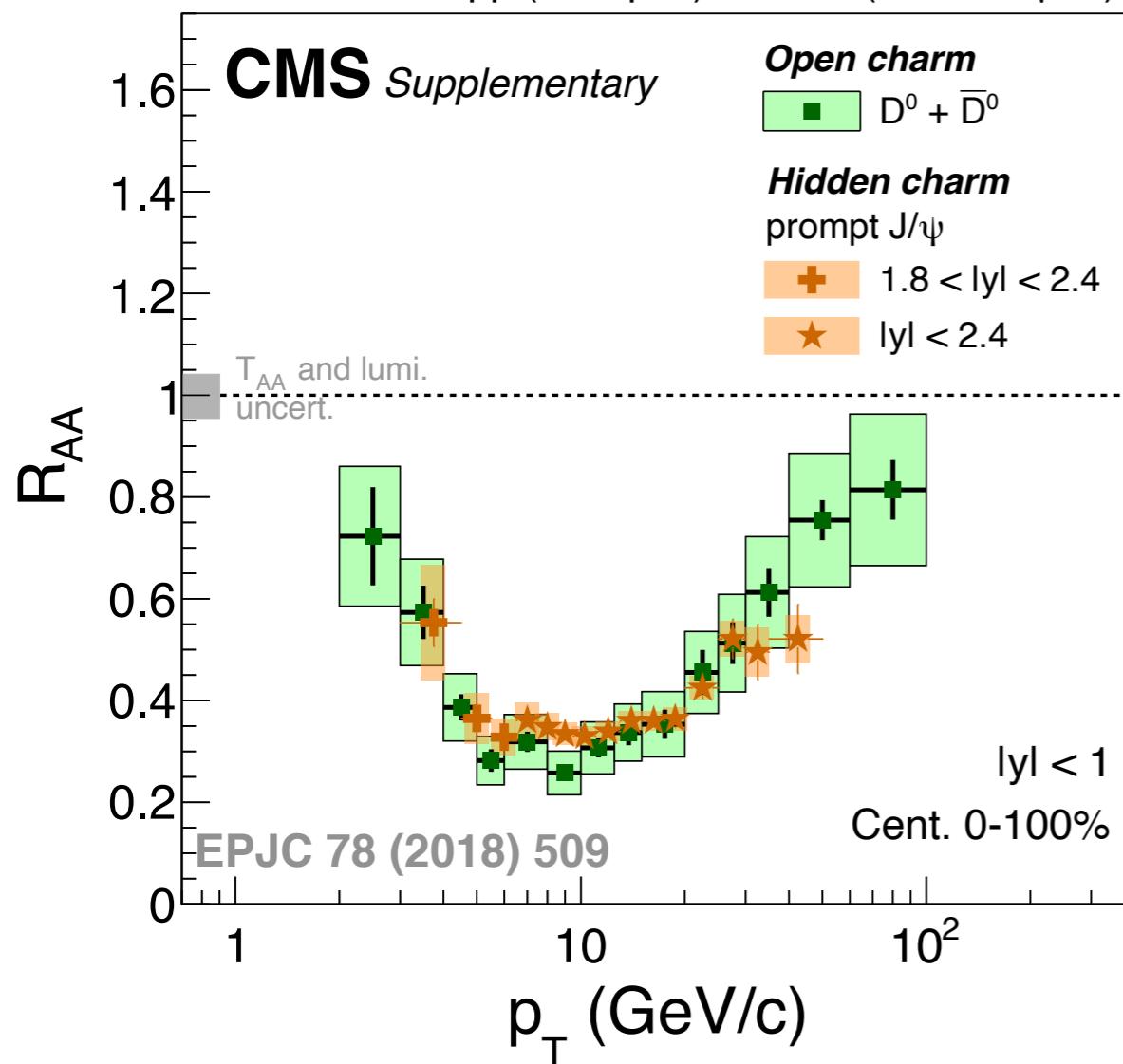
In the course of the interaction of the partons with the QGP



Important implications for the interpretation of J/ ψ in HI

Another look at RAA

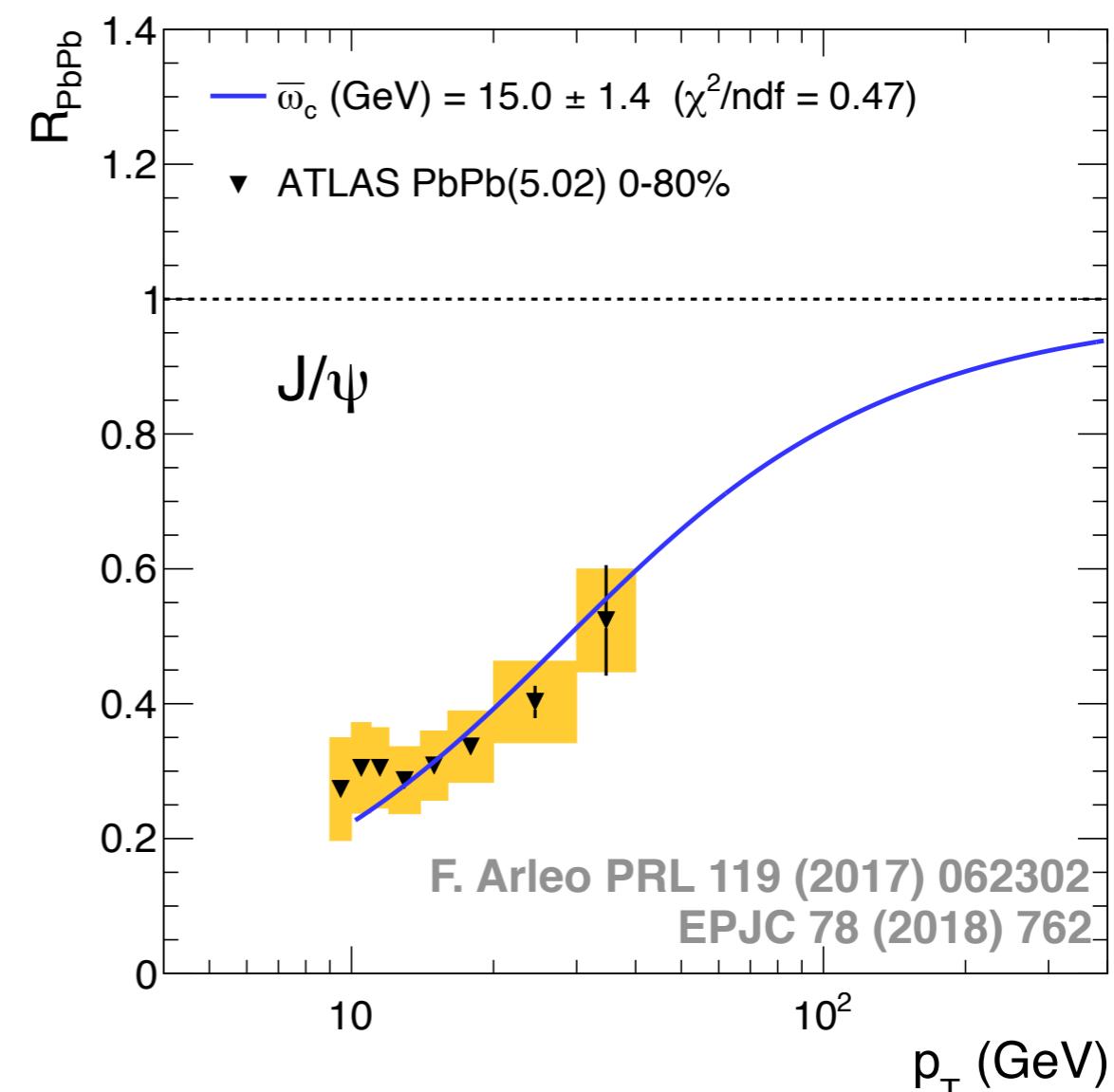
5.02 TeV pp (27.4 pb^{-1}) + PbPb ($530/368 \mu\text{b}^{-1}$)



Well described by calculations of parton energy loss

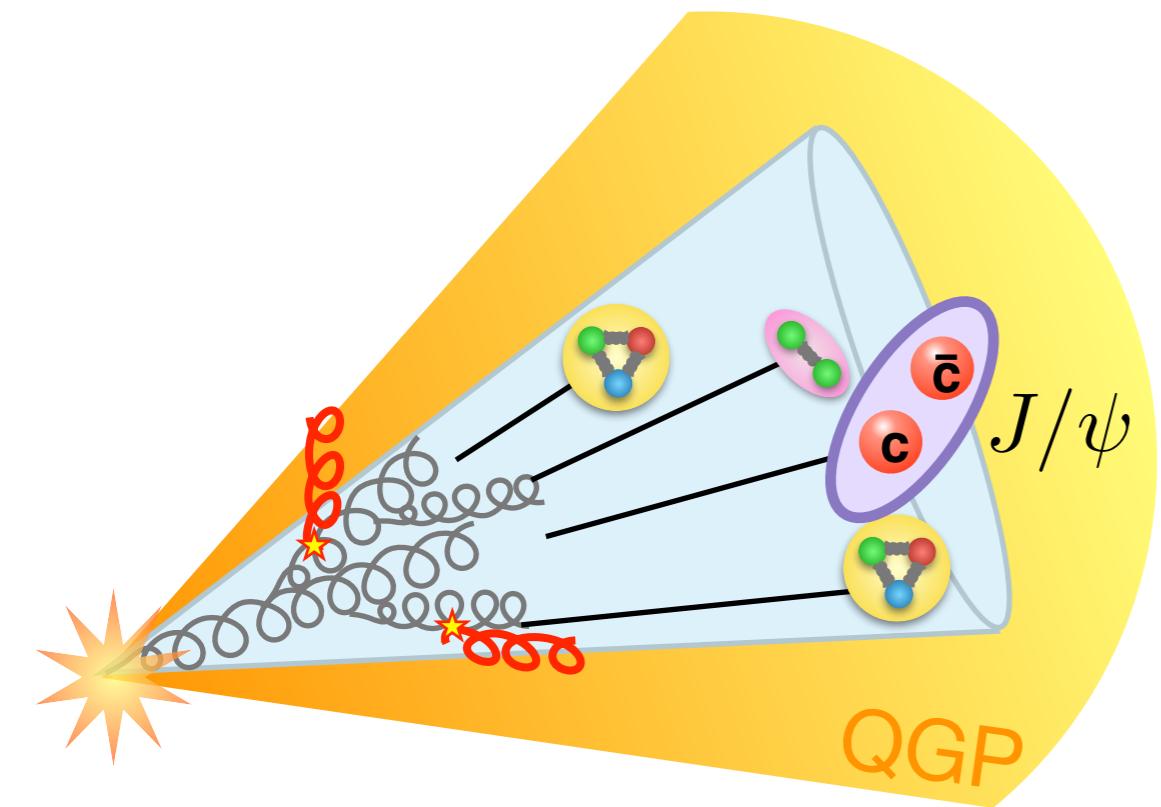
Prompt J/ψ R_{AA} has a similar behaviour to other hadrons

Universal behavior



J/ ψ production in AA collisions

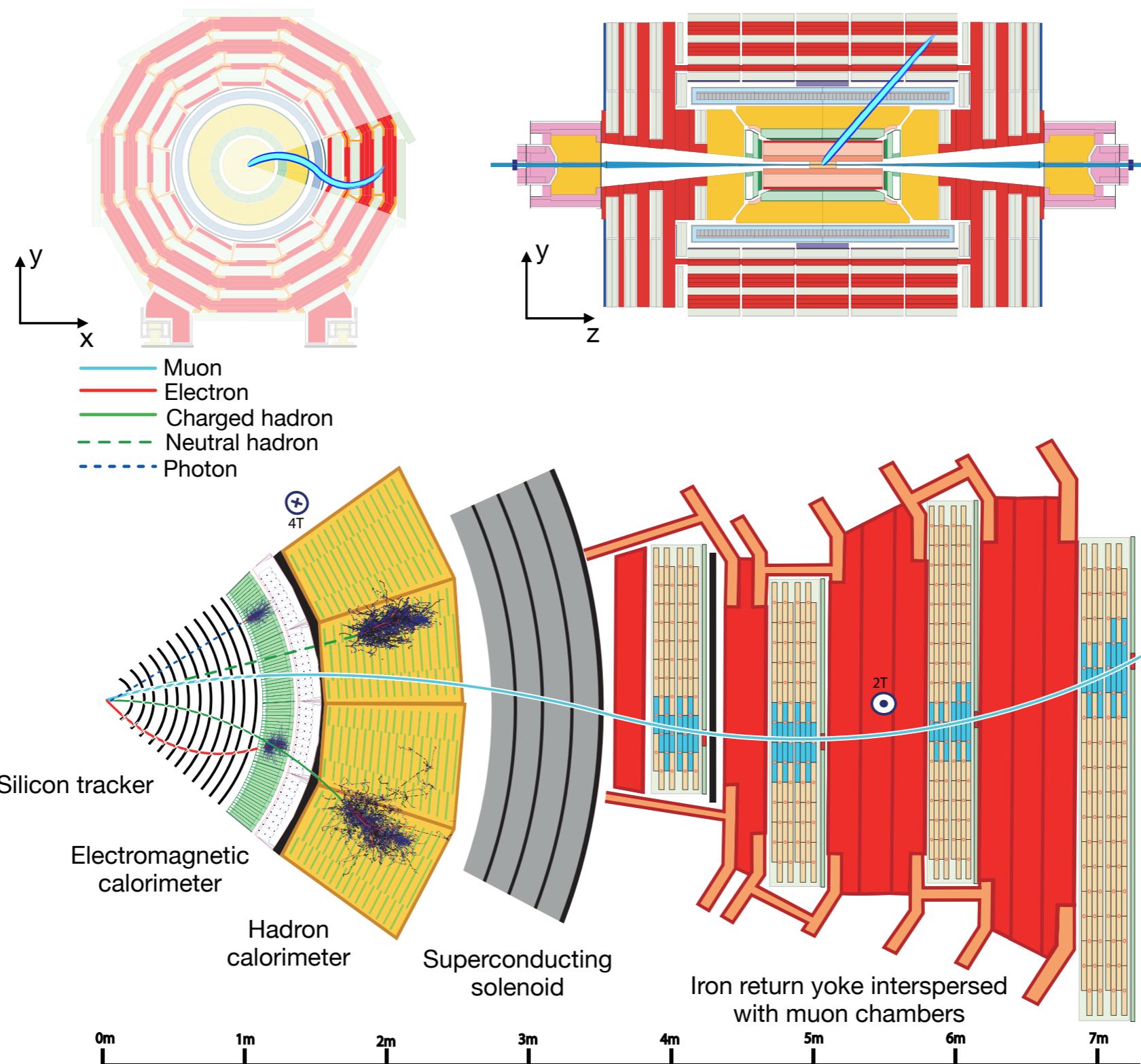
Jet quenching might be relevant in J/ ψ suppression



Measure the fragmentation function in PbPb collisions

$$z = p_{T,J/\psi} / p_{T,\text{Jet}}$$

The Compact Muon Solenoid



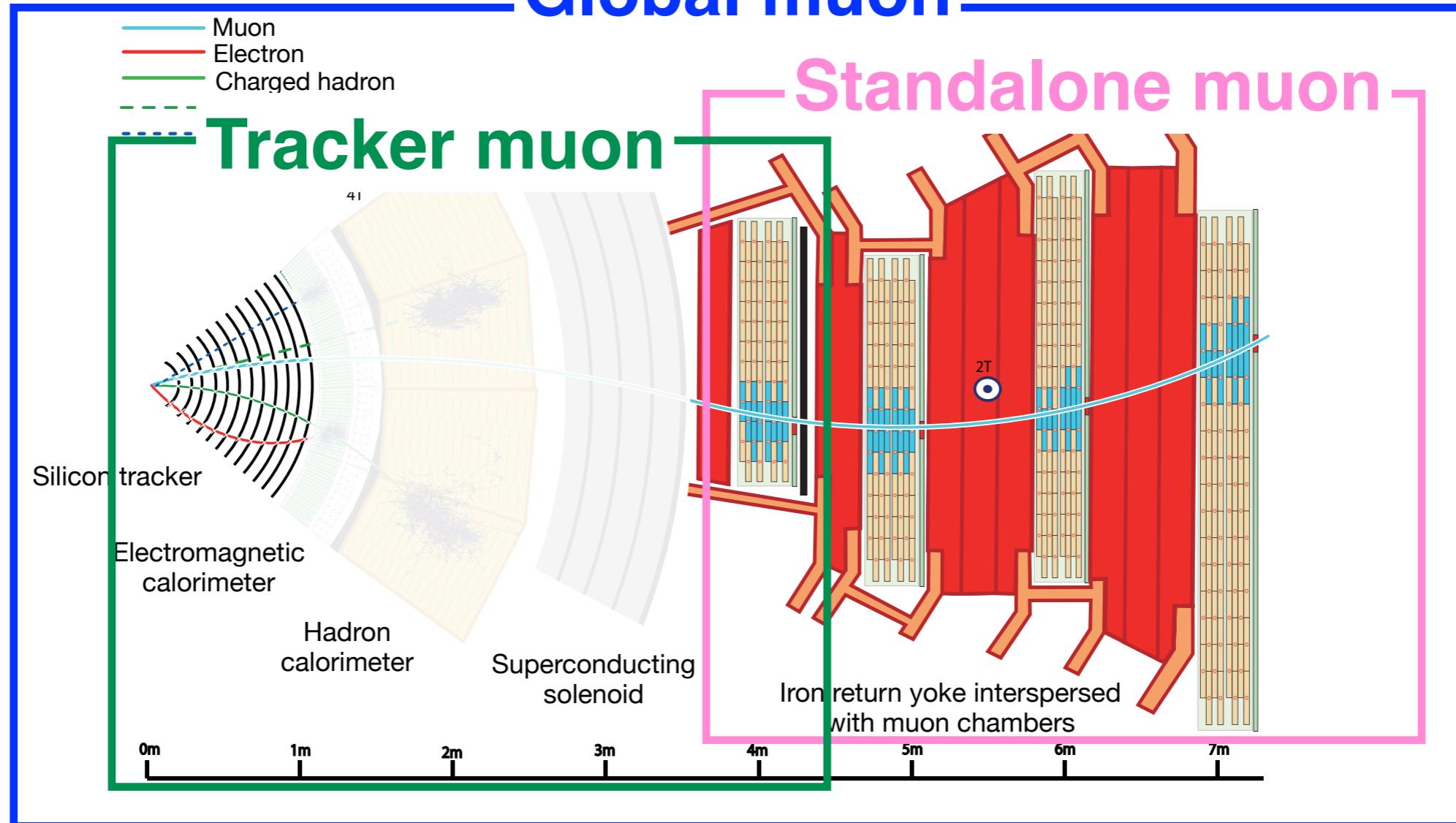
Muons in CMS

Decay channel: $J/\psi \rightarrow \mu\mu$

Muon detection in CMS: the tracker and the muon chambers

Three kinds of muons are reconstructed

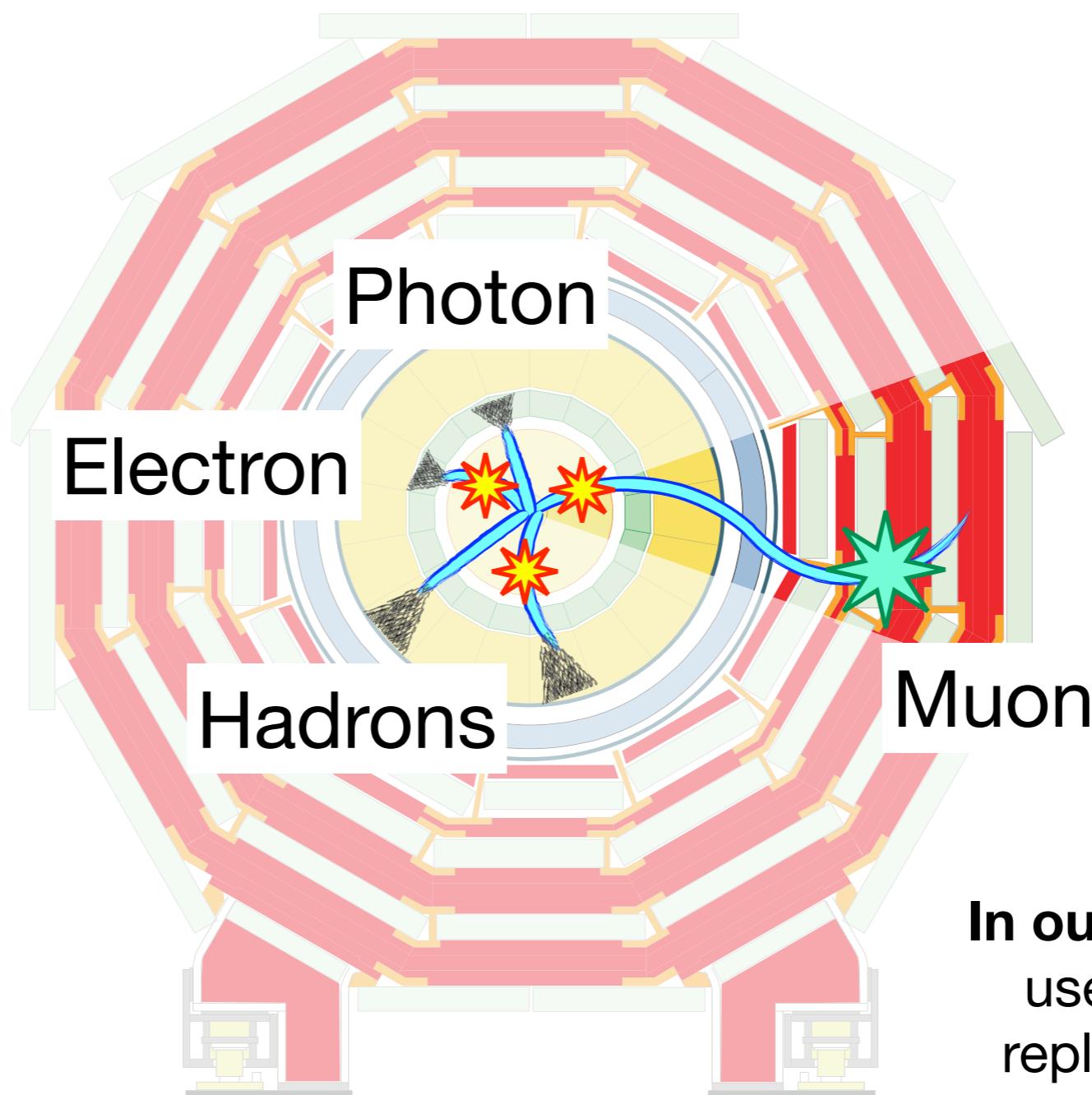
Global muon



Jet reconstruction in CMS

JINST 12 (2017) P10003

Particle Flow: Information from all subdetectors are collected to individually reconstruct each particle in the event



In our analysis, the J/ψ is used as a constituent replacing decay muons

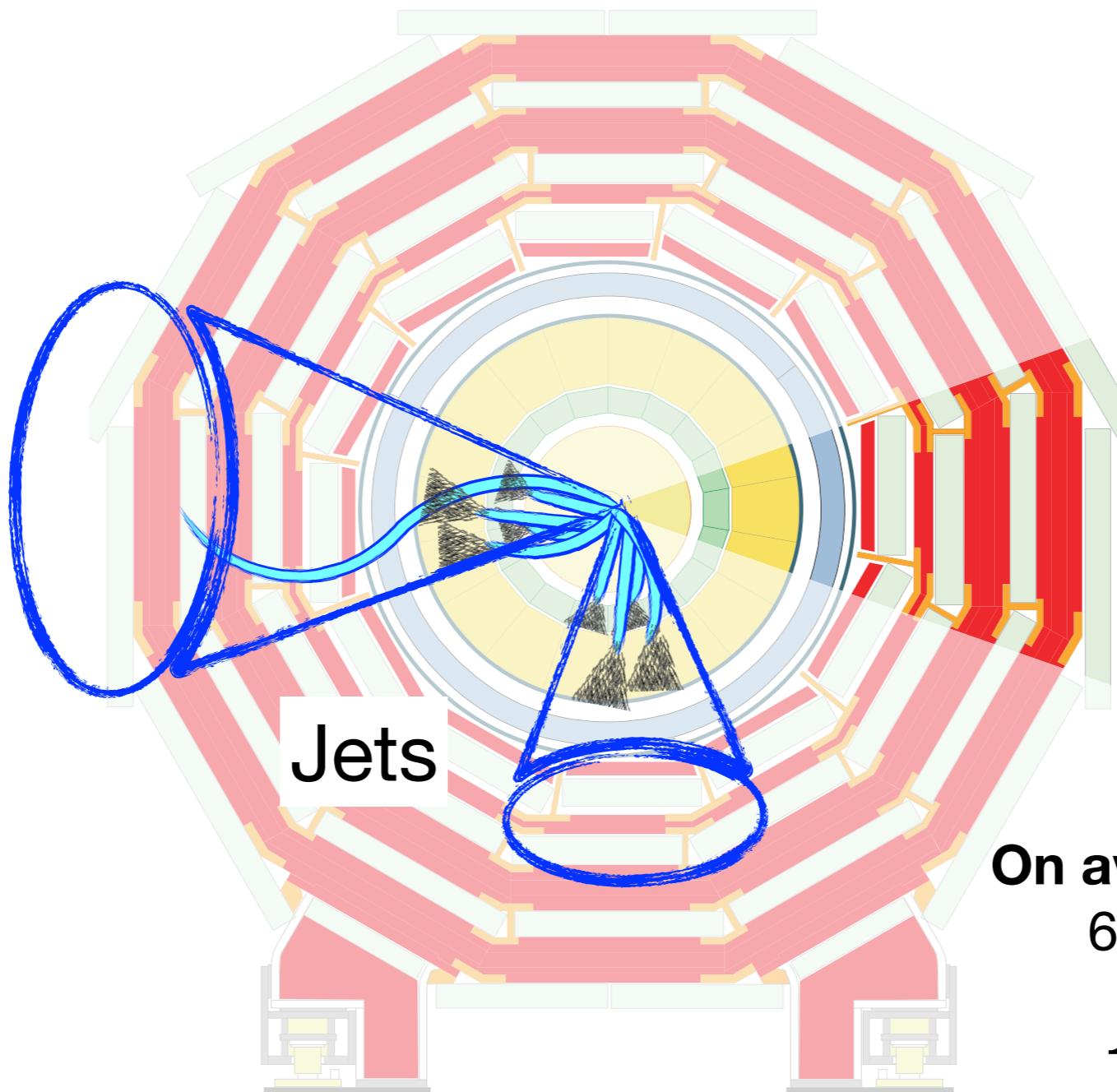
Jet reconstruction in CMS

JINST 12 (2017) P10003

Particle Flow: Information from all subdetectors are collected to individually reconstruct each particle in the event

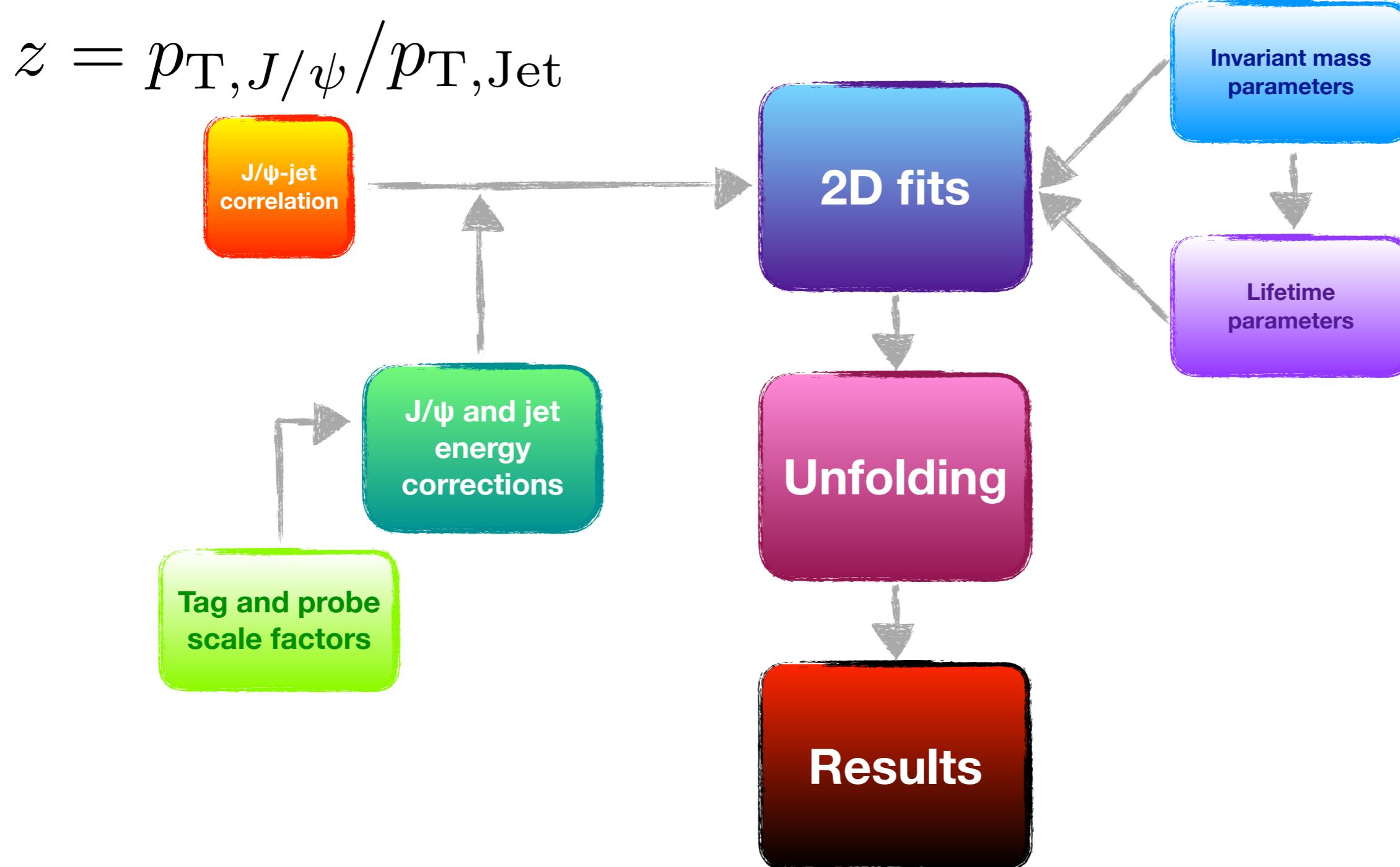
Jets are reconstructed with the anti- k_T clustering algorithm

JHEP 04 (2008) 063



On average, jets are made of:
65% charged hadrons
25% photons
10% neutral hadrons

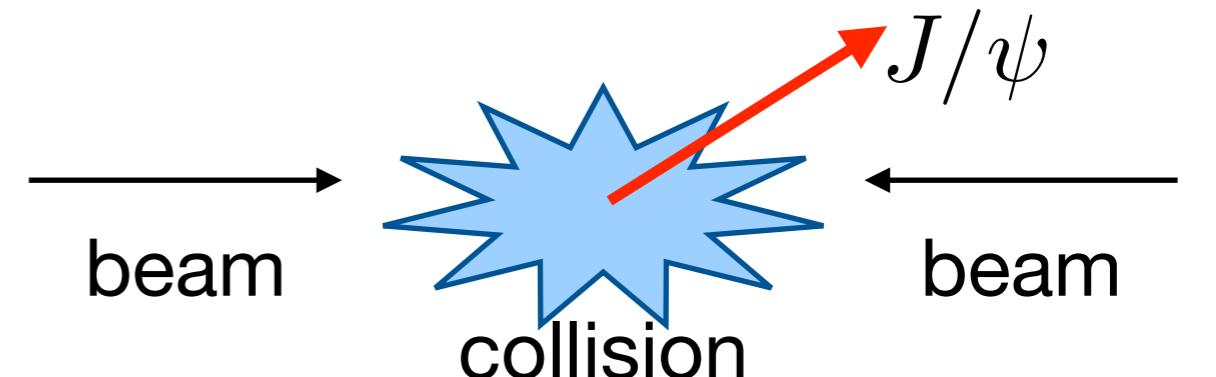
Analysis workflow



Prompt vs nonprompt J/ ψ

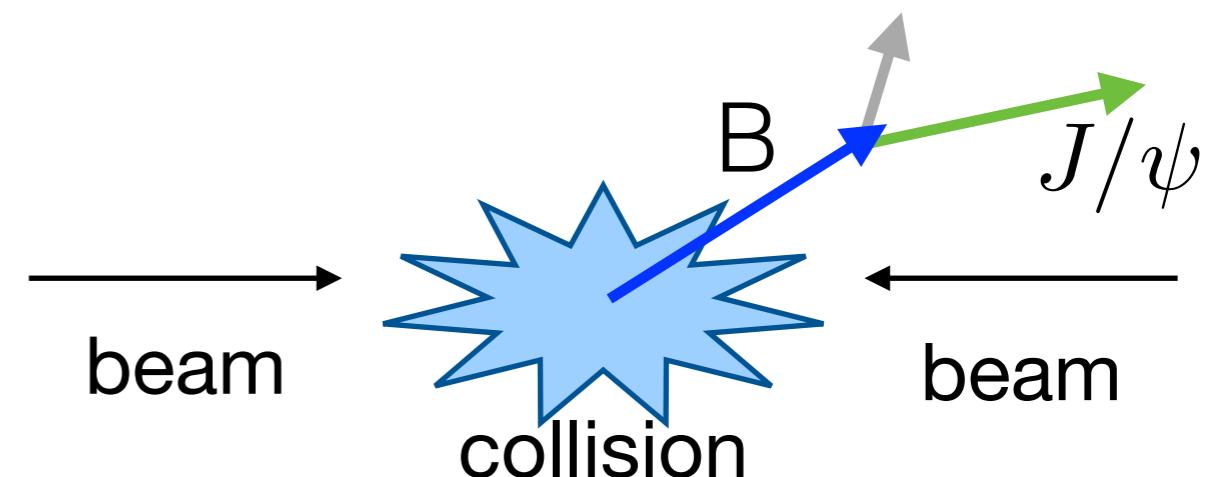
Prompt:

Directly in the collision
Decay of heavier charmonium states

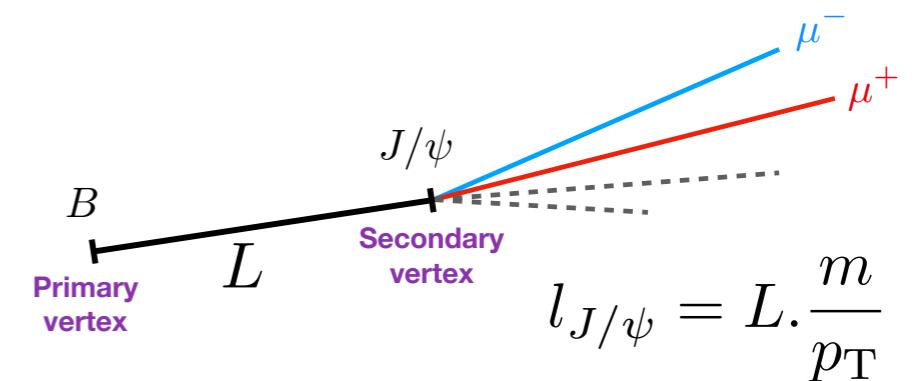


Nonprompt:

Decay of b hadrons



Separation based on the lifetime:
pseudo-proper decay length $\ell_{J/\psi}$



Signal extraction

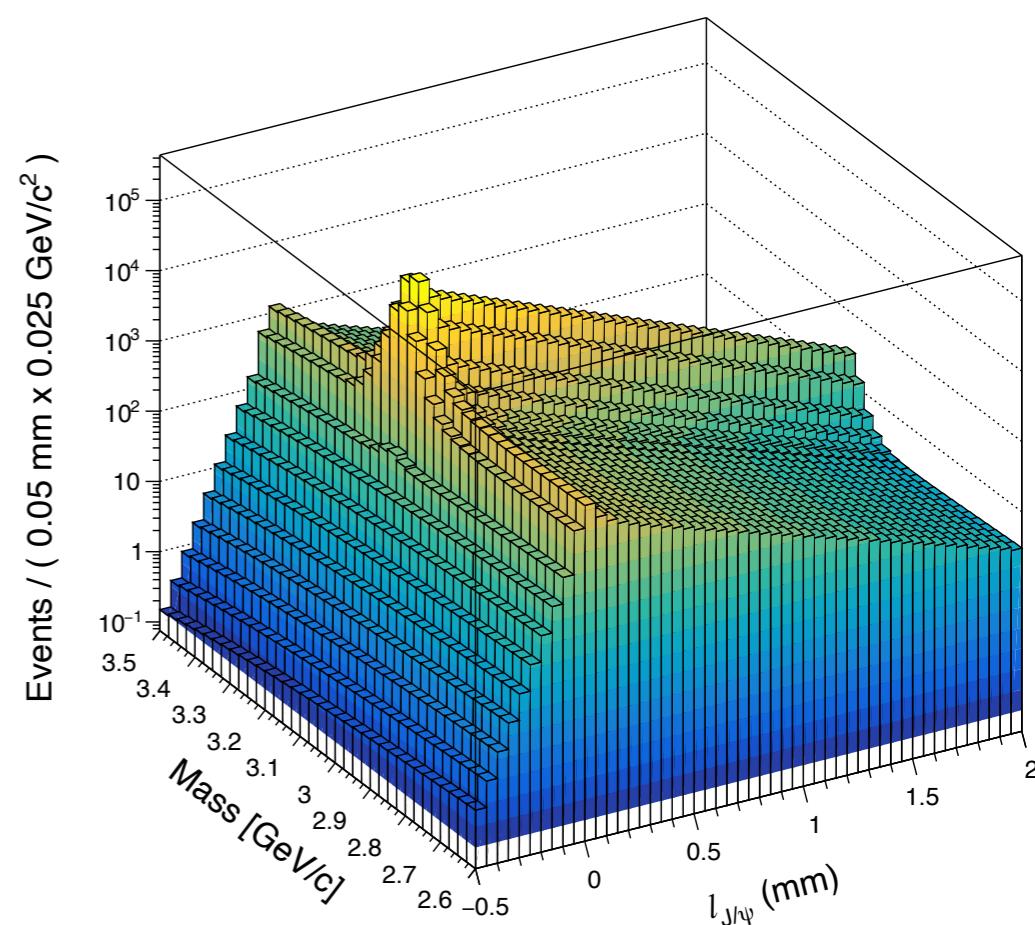
Extraction the J/ψ yields:

- Disentangle Signal/background
- Separate prompt/nonprompt

Done using a 2D fitting procedure: Invariant mass and the pseudo-proper decay length

Most parameters are fixed to values extracted from 1D fits on data

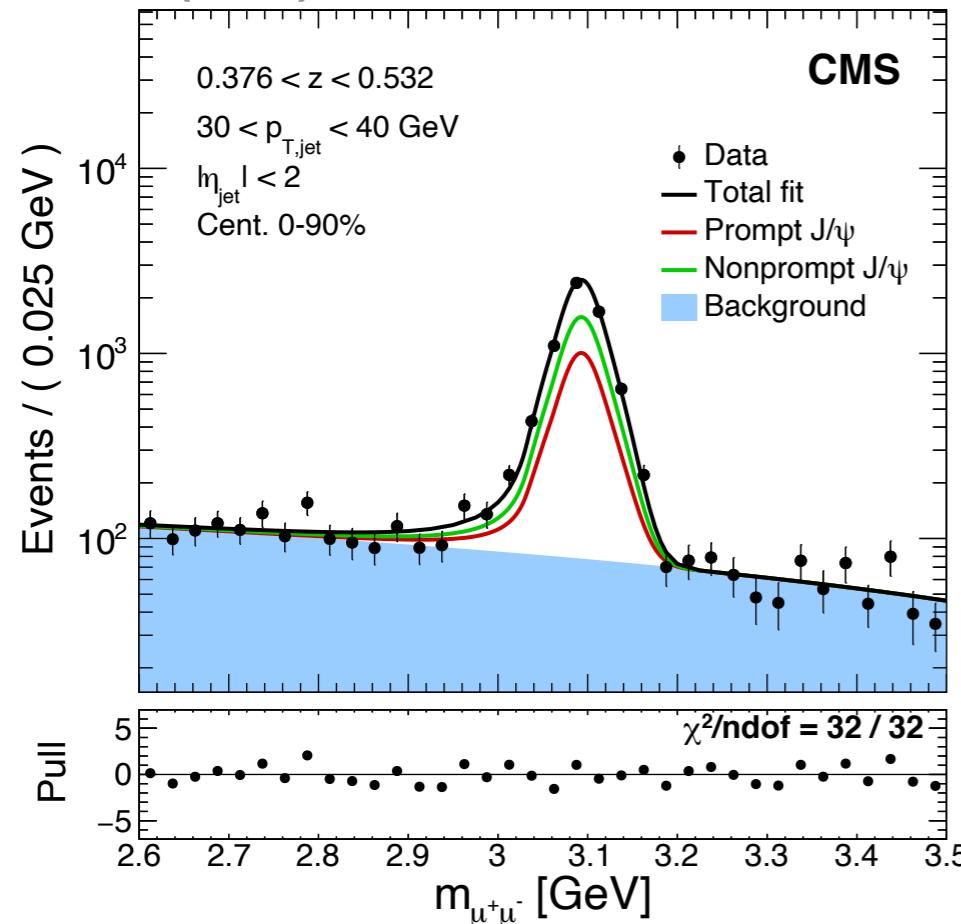
The fits are performed in z and jet p_T bins



Signal extraction: invariant mass

PLB 825 (2021) 136842

PbPb 1.6 nb^{-1} (5.02 TeV)



Mass fit = signal + background



Double Crystal Ball

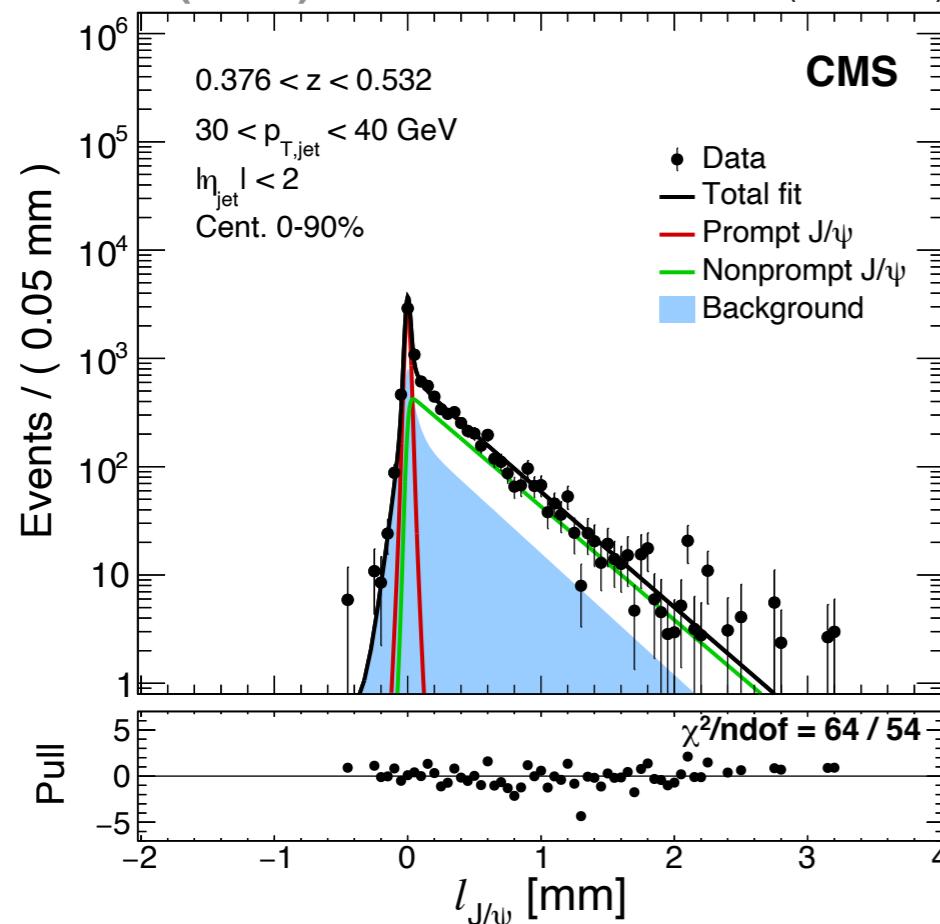


Chebychev polynomial

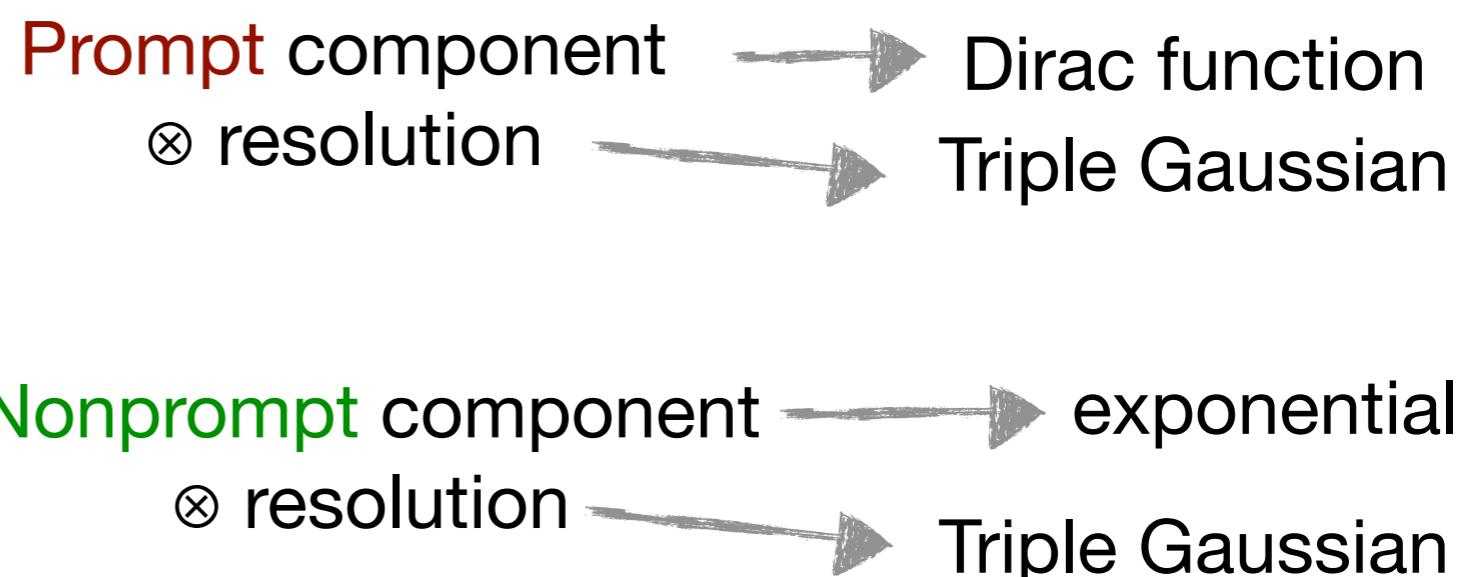
Signal extraction: $\ell\bar{\psi}$

PLB 825 (2021) 136842

PbPb 1.6 nb^{-1} (5.02 TeV)



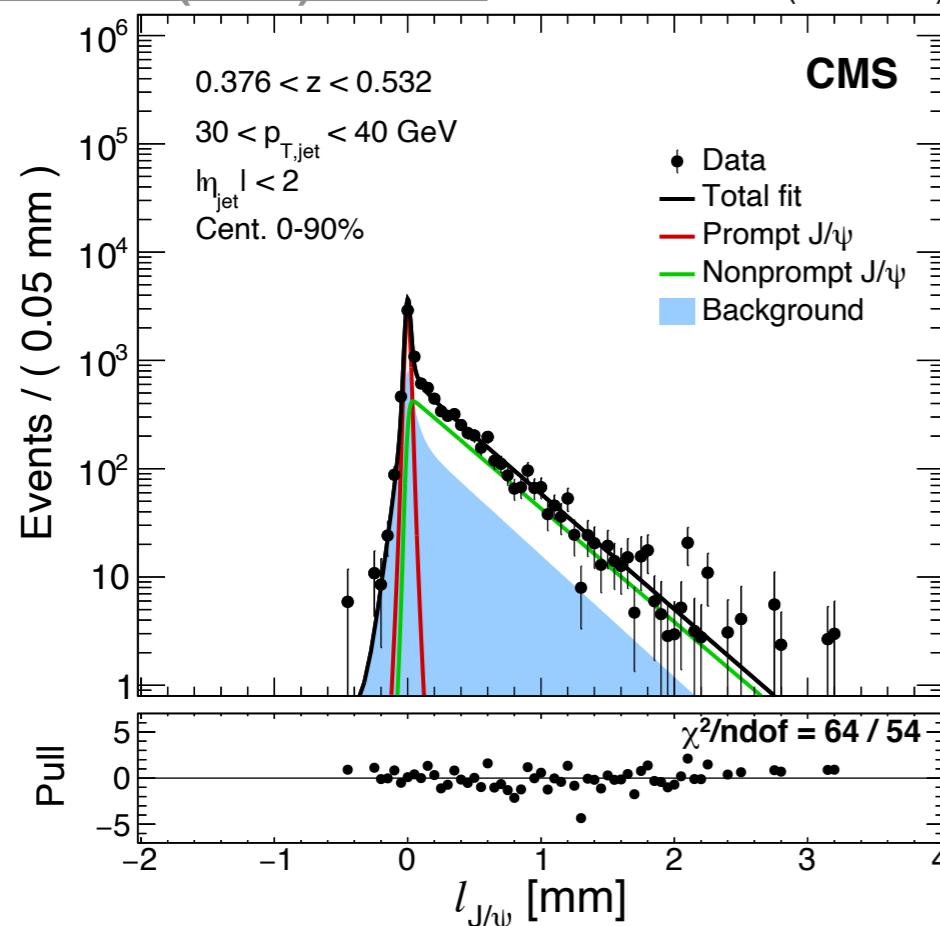
$$\ell\bar{\psi} \text{ fit} = \text{signal} + \text{background}$$



Signal extraction: $\ell J/\psi$

PLB 825 (2021) 136842

PbPb 1.6 nb^{-1} (5.02 TeV)



$$\ell J/\psi \text{ fit} = \text{signal} + \text{background}$$

Prompt component
⊗ resolution

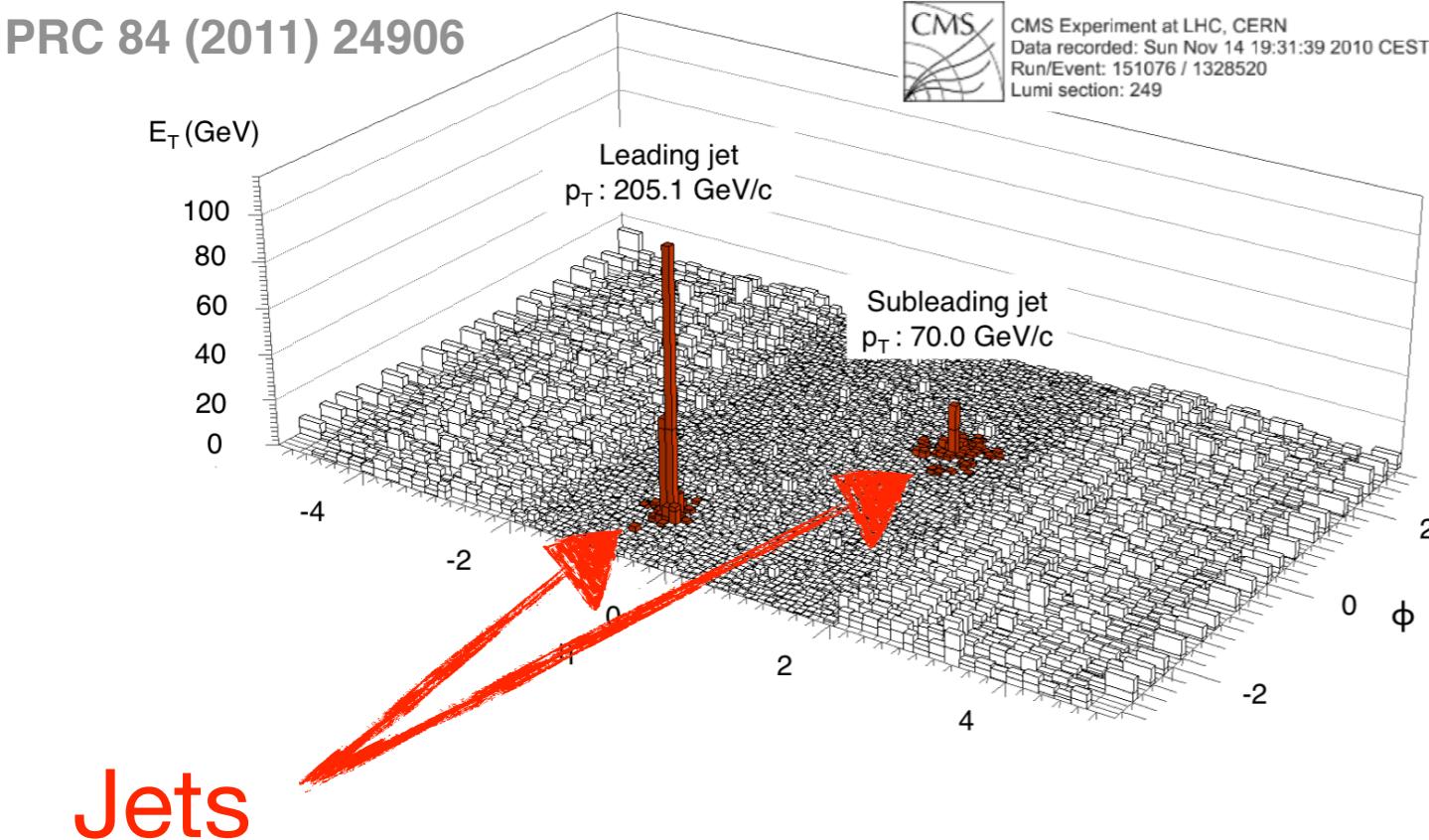
Prompt-like
component ⊗
resolution

Nonprompt component
⊗ resolution

nonprompt-like
component ⊗
resolution

Jet p_T determination

Challenges: detector response + background fluctuations

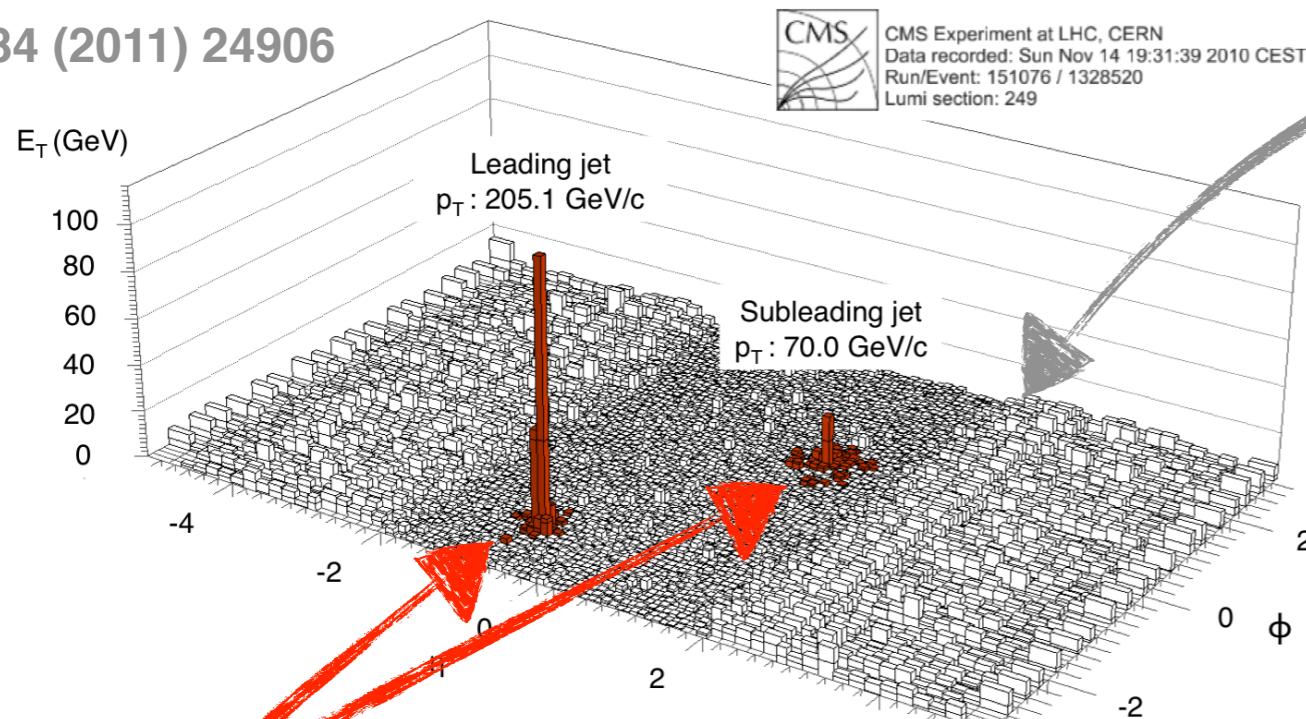


Low p_T jets can be hard to distinguish from the background

Jet p_T determination

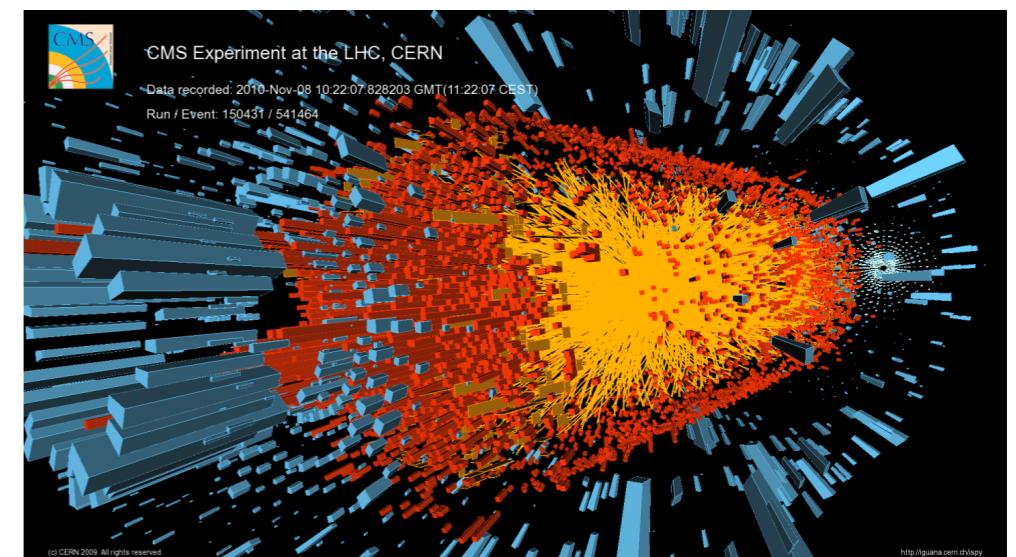
Challenges: detector response + background fluctuations

PRC 84 (2011) 24906



Jets

Underlying event

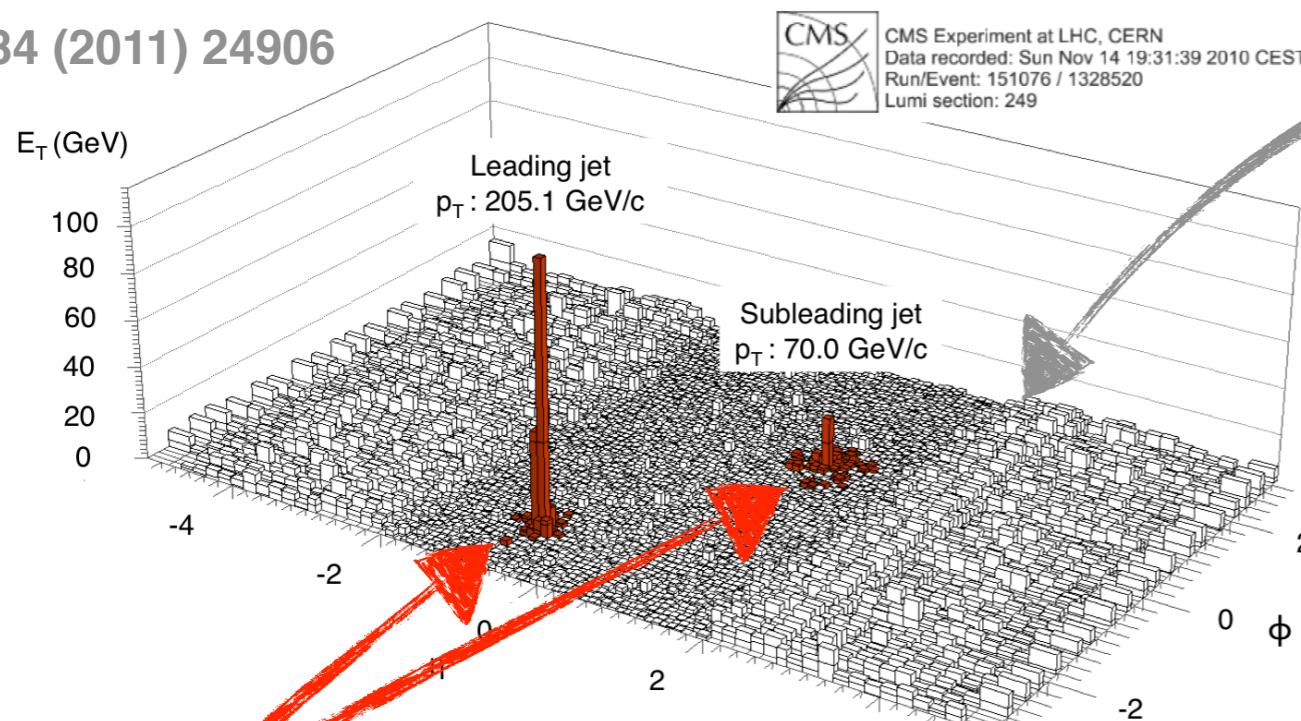


Low p_T jets can be hard to distinguish from the background especially in central PbPb events

Jet p_T determination

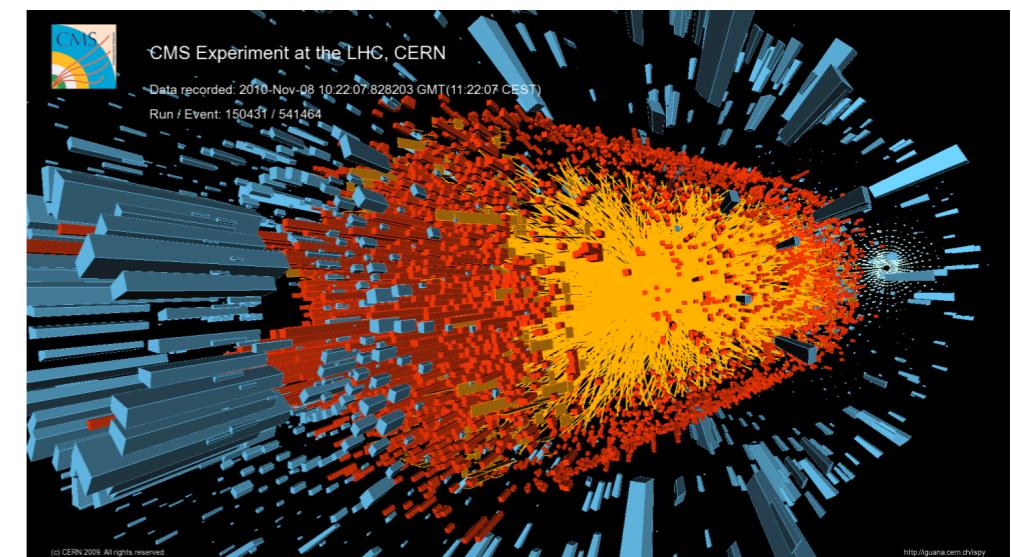
Challenges: detector response + background fluctuations

PRC 84 (2011) 24906



Jets

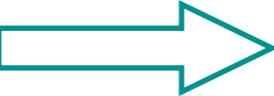
Underlying event



Low p_T jets can be hard to distinguish from the background especially in central PbPb events

Unfolding is needed

Unfolding

Extracted yields  Iterative Bayesian
Unfolding  results

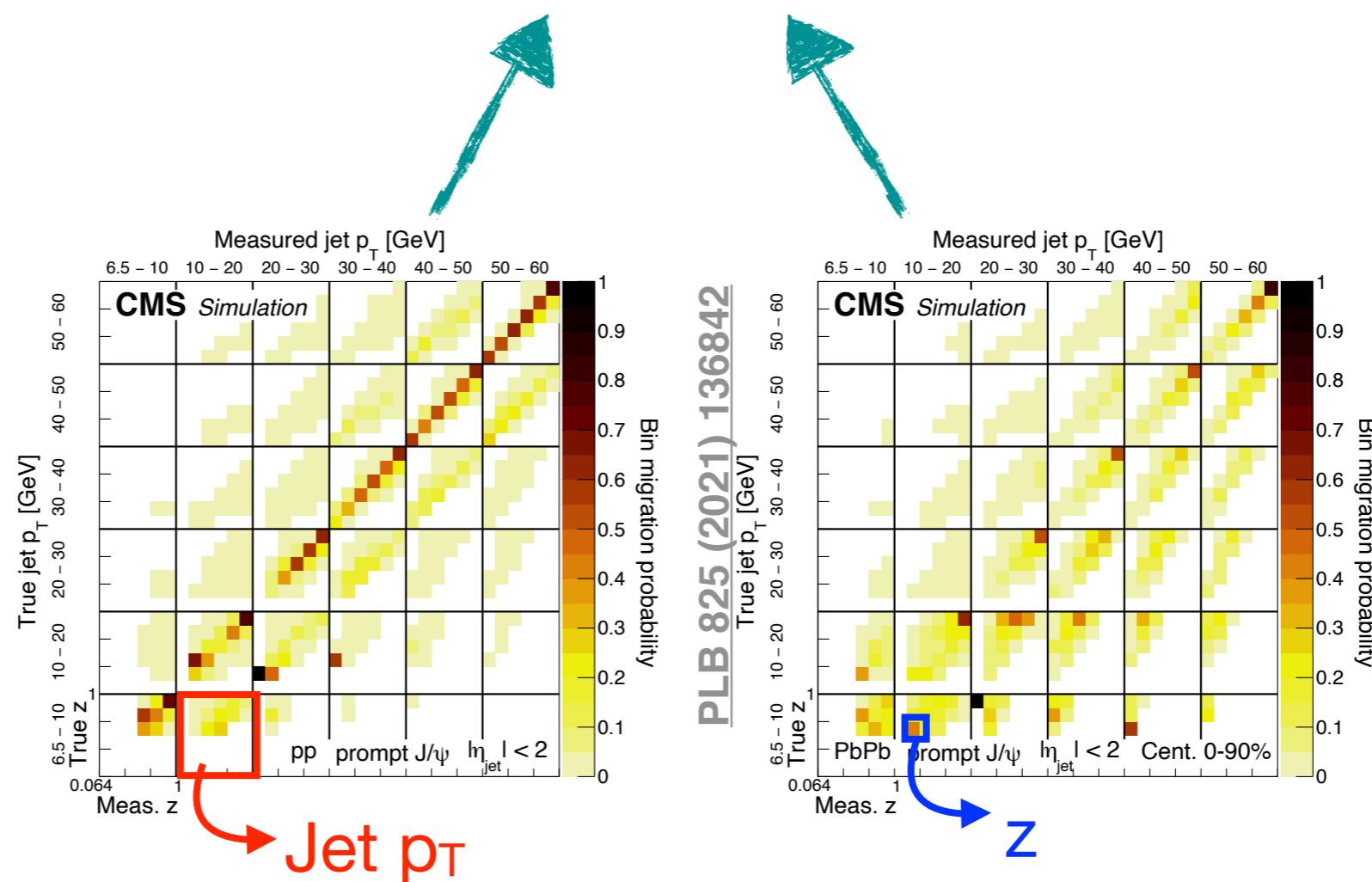
D'Agostini, NIMA 362 (1995) 487

Unfolding

Extracted yields \rightarrow Iterative Bayesian Unfolding \rightarrow results

D'Agostini, NIMA 362 (1995) 487

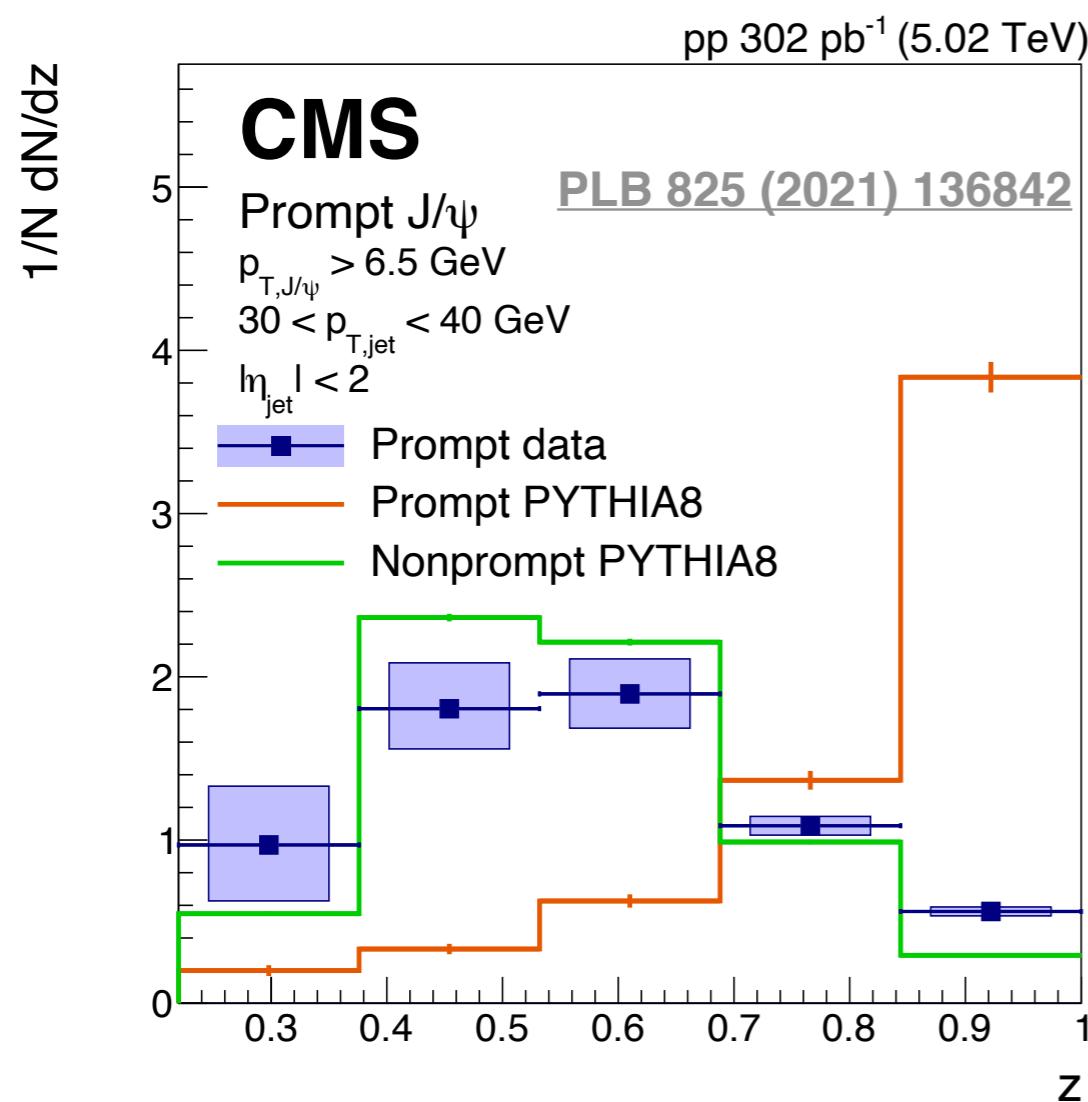
Transfer matrices
from simulations



Results

z distributions in pp data and MC

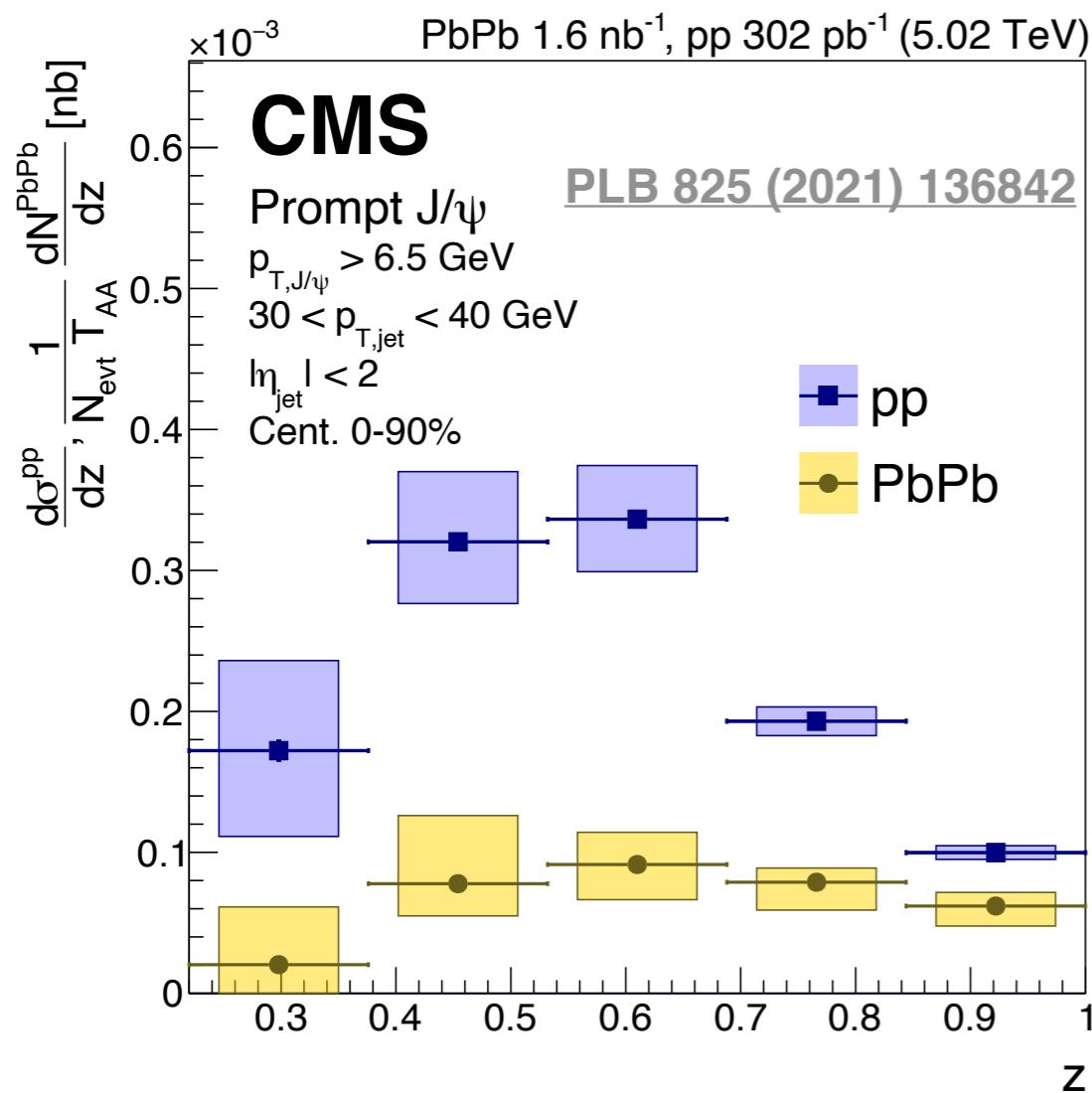
Self-normalised z distributions in pp data and simulation
Sizable jet component, as opposed to isolated J/ ψ



Prompt data more similar to
nonprompt PYTHIA8 than
prompt PYTHIA8

z distributions in pp and PbPb

Per-event yield of prompt J/ ψ mesons in PbPb collisions and the cross section in pp collisions, as a function of the fragmentation variable z

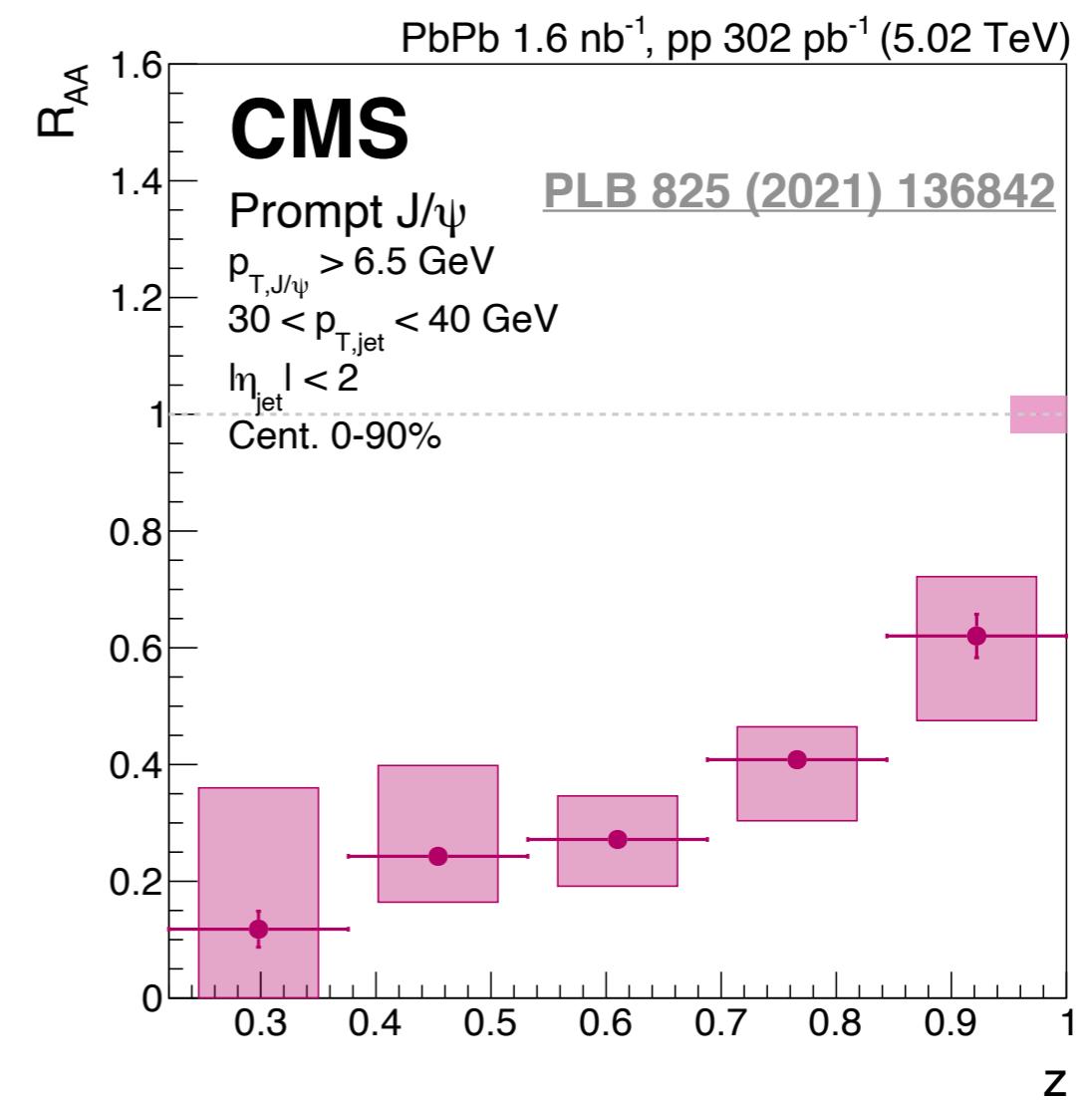
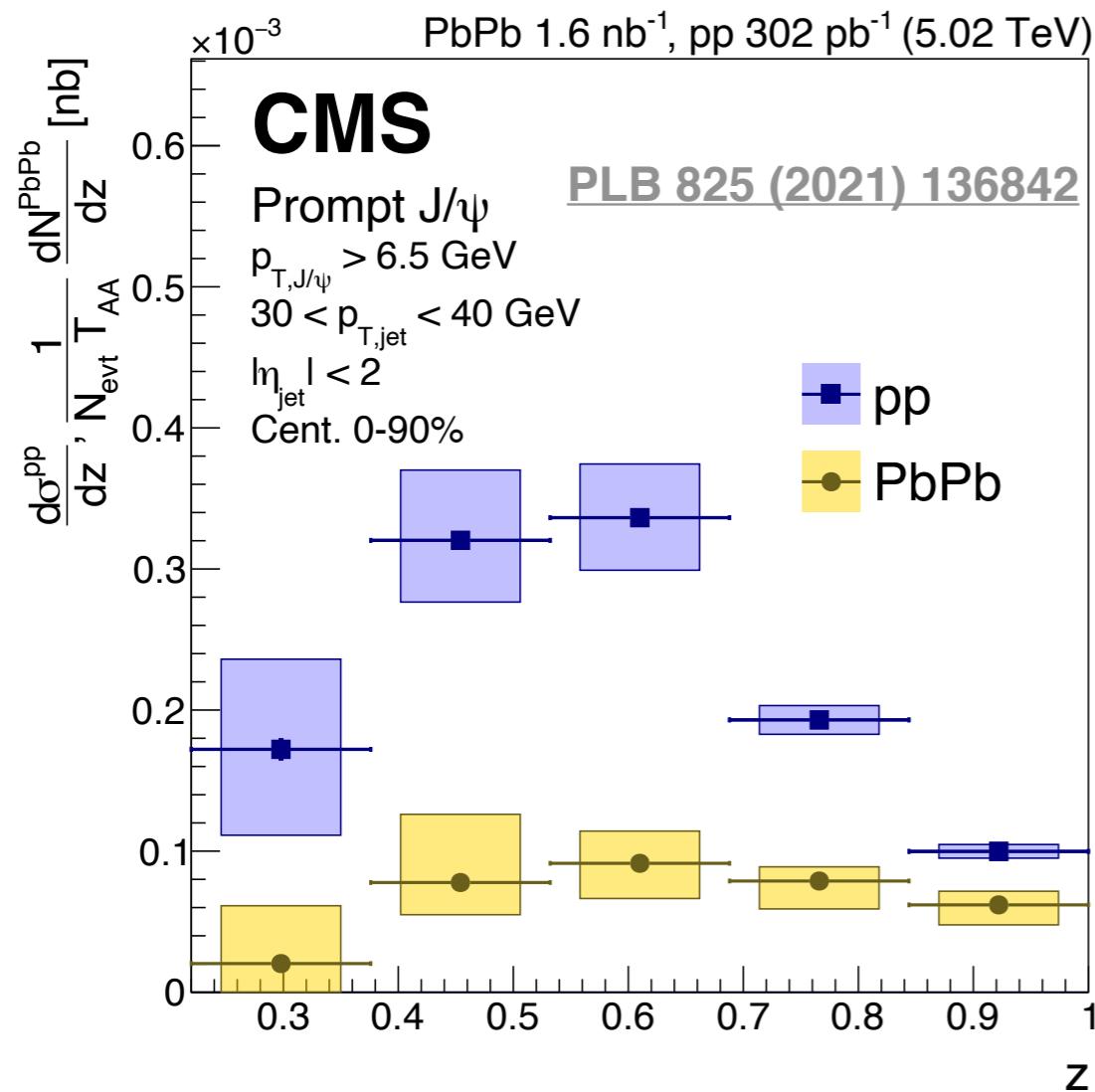


pp and PbPb have similar trends
Suppression in PbPb in all z bins

R_{AA} of J/ ψ in jets

Rising trend as a function of z

Less suppression for isolated J/ ψ compared to J/ ψ with larger jet activity



R_{AA} of J/ ψ in jets

Rising trend as a function of z

Less suppression for isolated J/ ψ compared to J/ ψ with larger jet activity

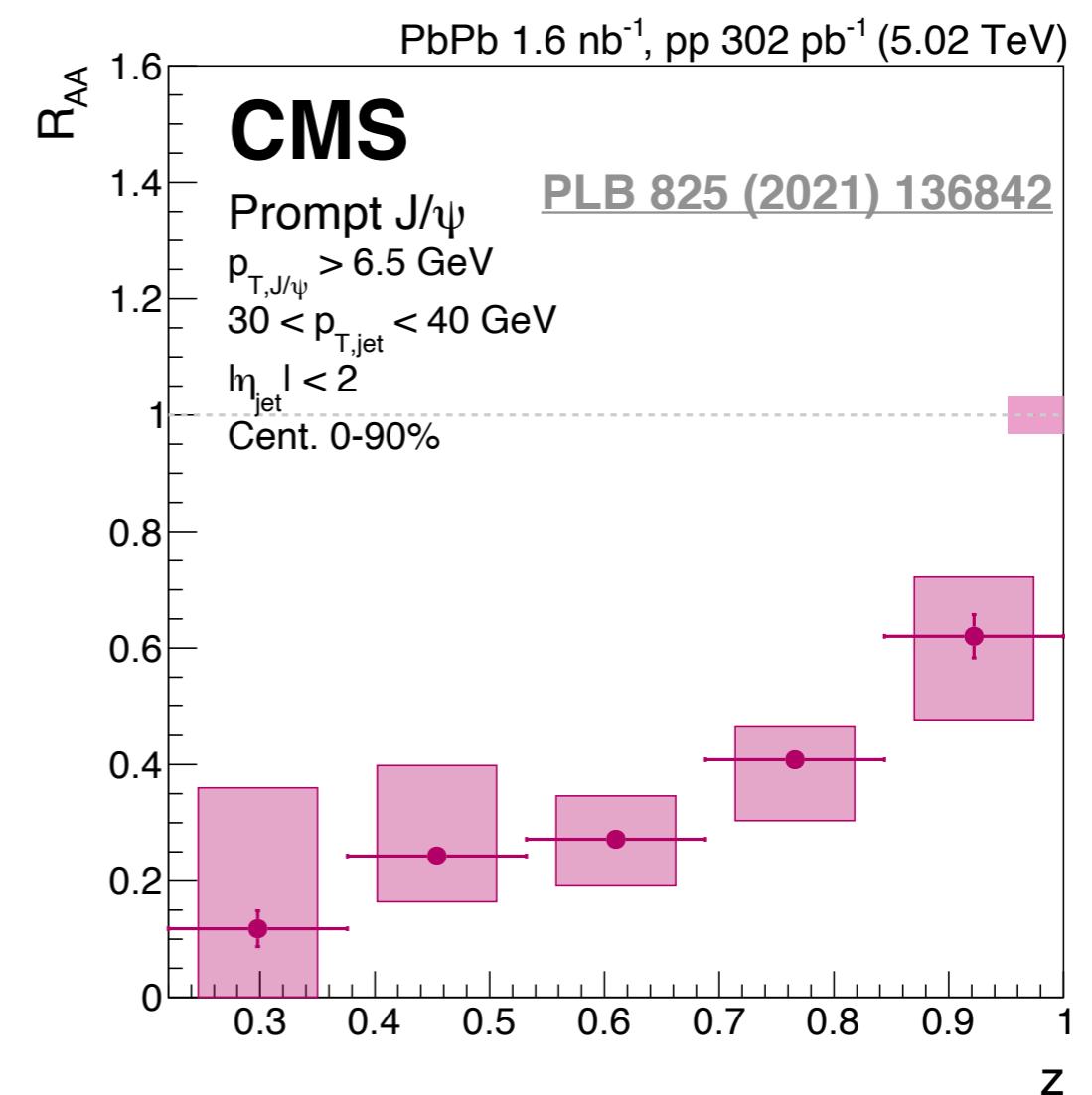
Lower z



J/ ψ produced later in parton shower



Larger degree of interaction with the QGP

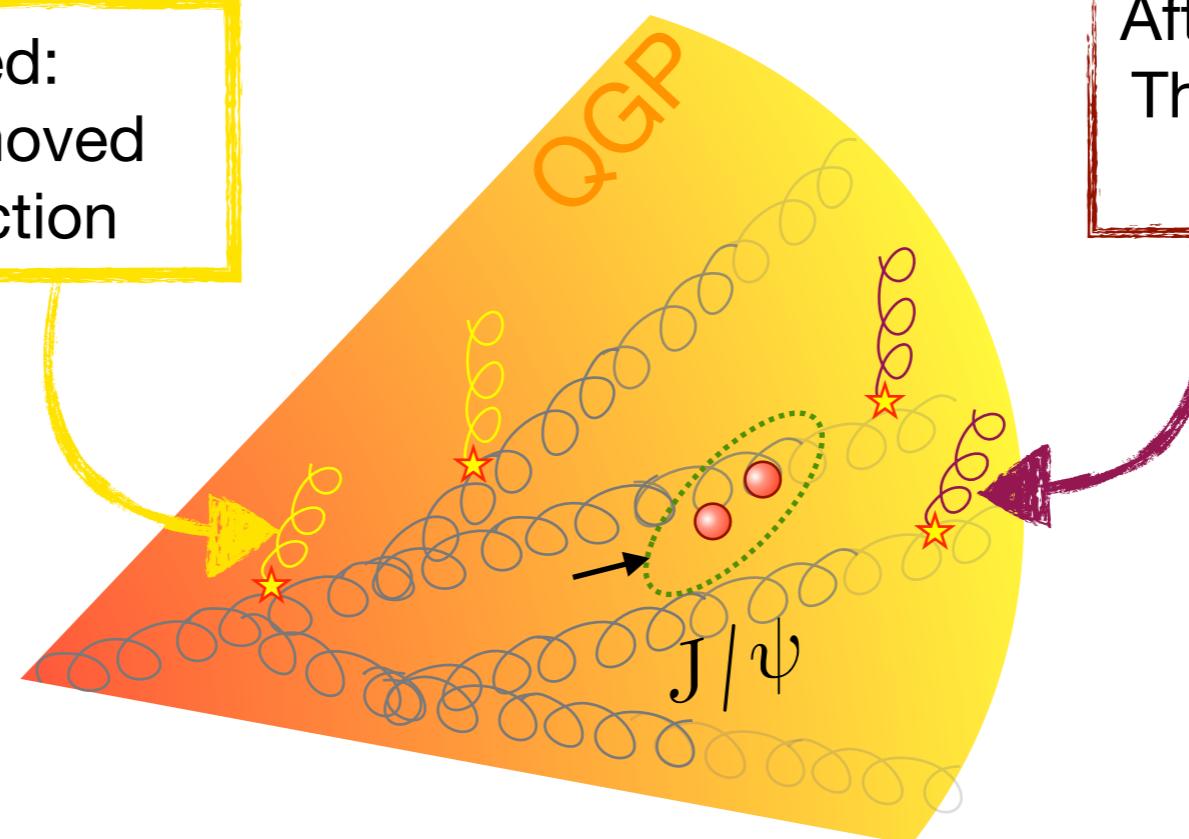


R_{AA} of J/ ψ in jets

Jet quenching happens when the partons of the jet interact with the QGP and radiate gluons

Before the J/ ψ is formed:
entire jet suppressed or moved
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The J/ ψ shifts towards
higher z values

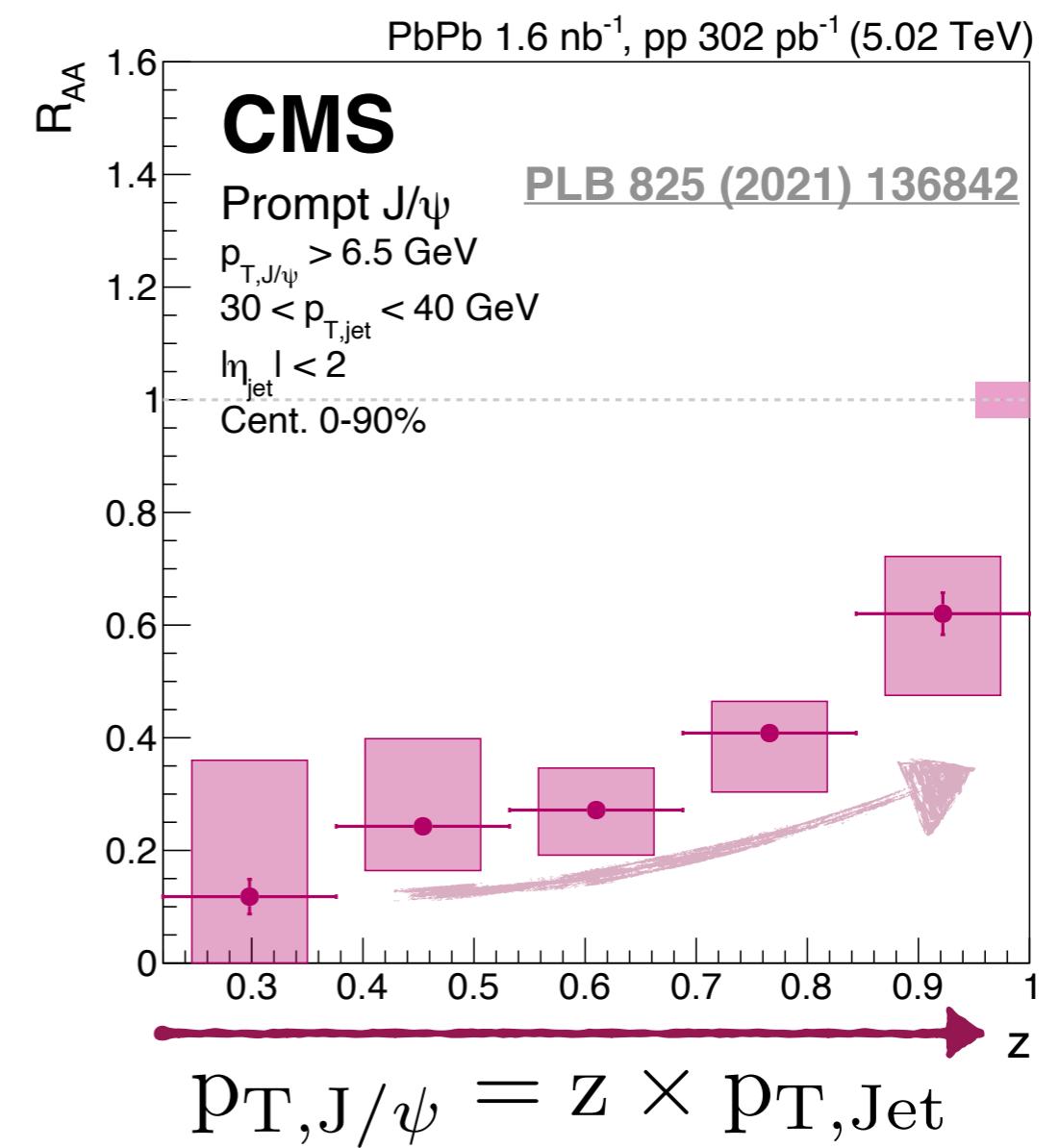
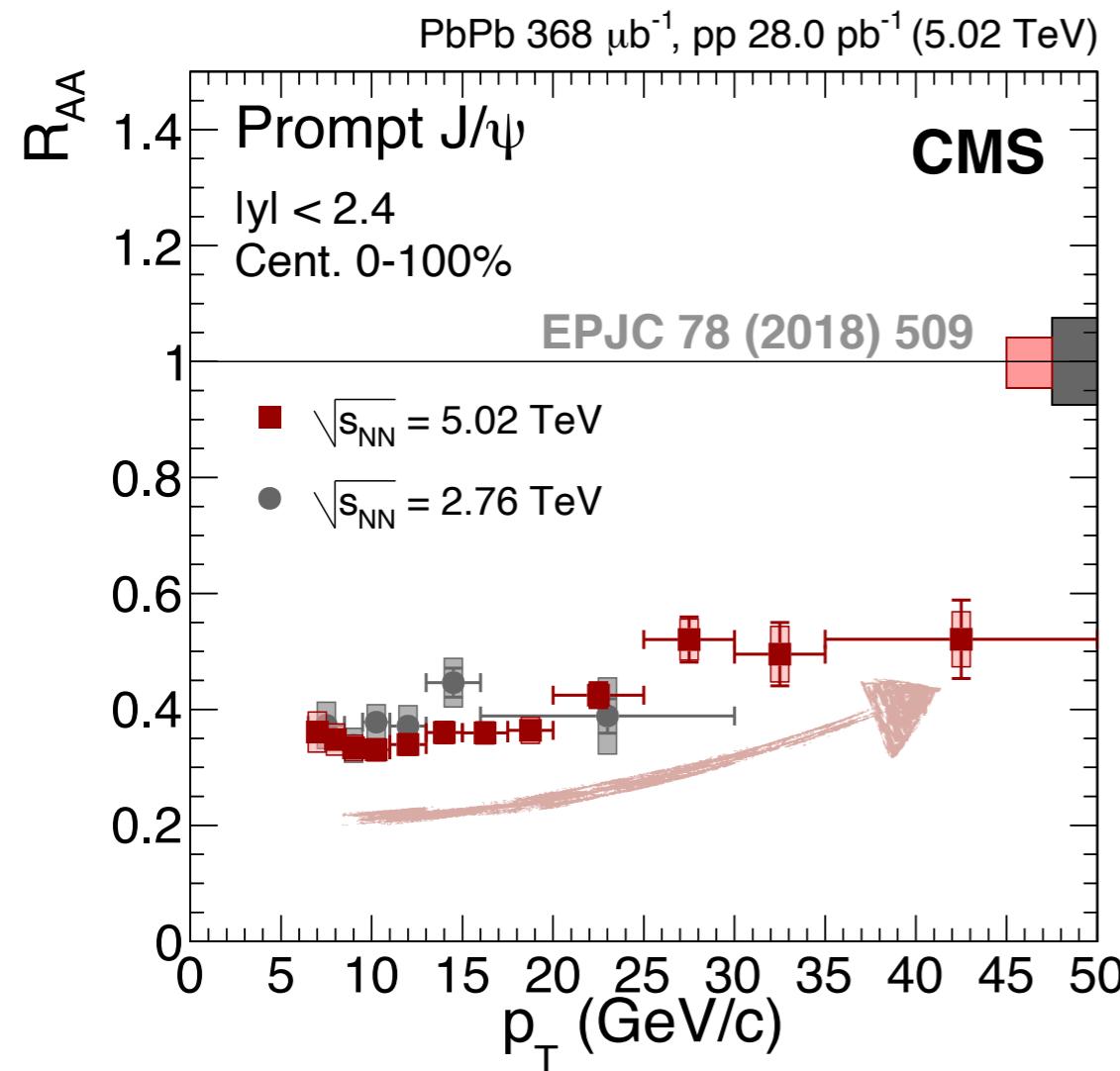


(The J/ ψ is also sensitive to Debye screening)

R_{AA} of J/ ψ in jets vs R_{AA}

z increases with increasing p_T

Rising trend in inclusive prompt R_{AA} might be explained by jet quenching

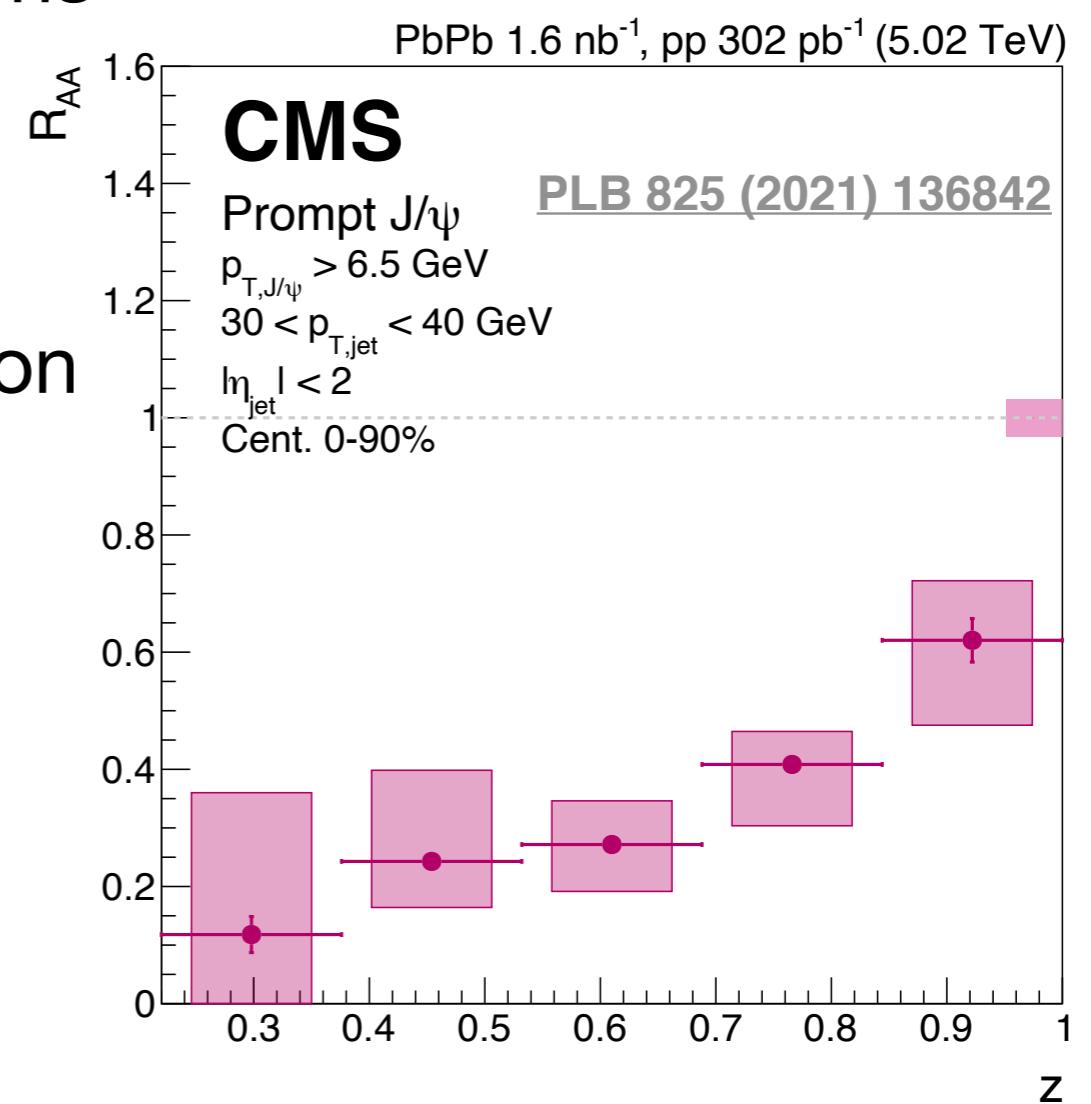


Summary

We measured the jet fragmentation function of prompt J/ ψ in pp and PbPb collisions

RAA showed a rising trend with z

These results support an interpretation of jet quenching as a relevant mechanism for J/ ψ suppression



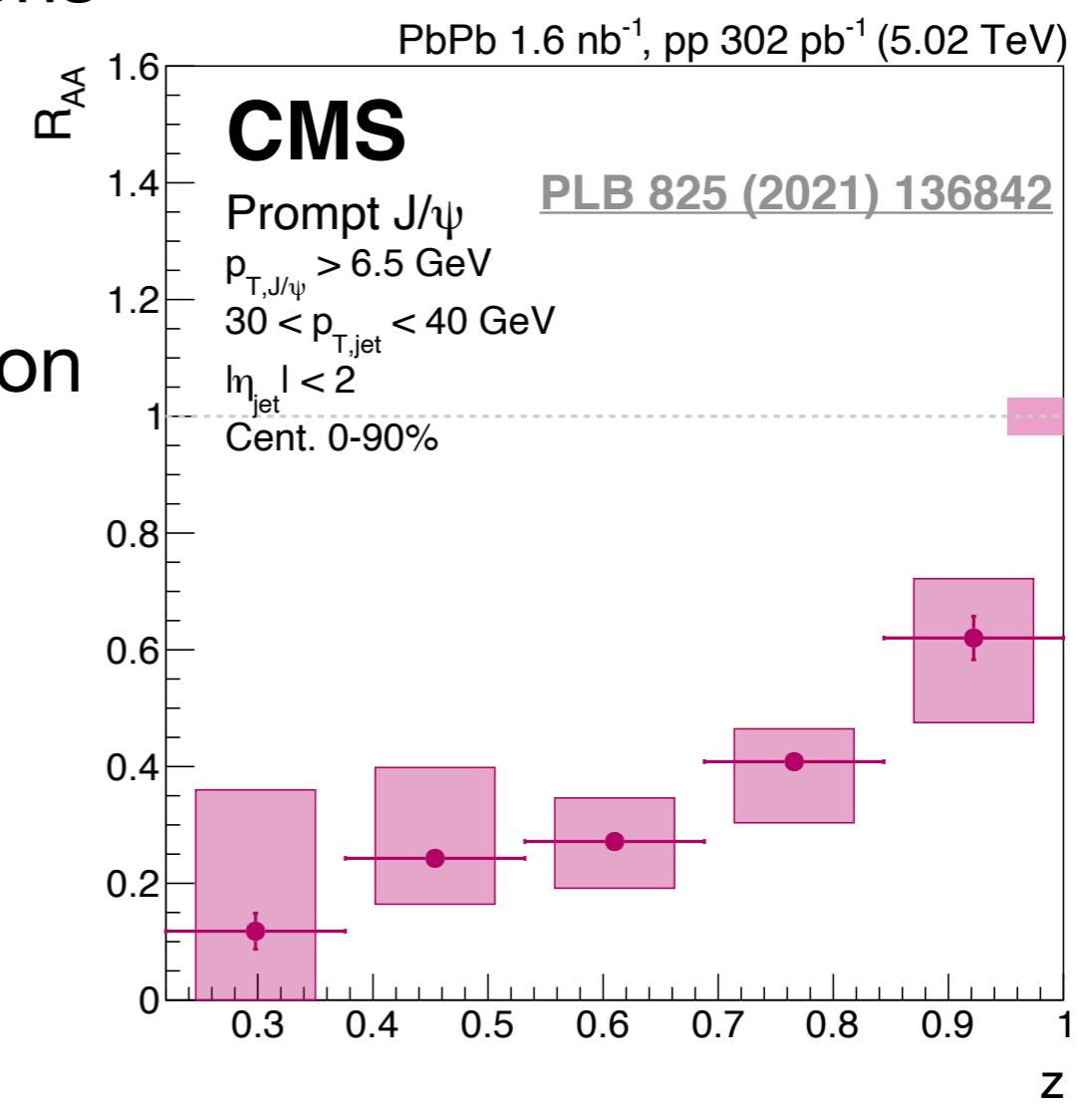
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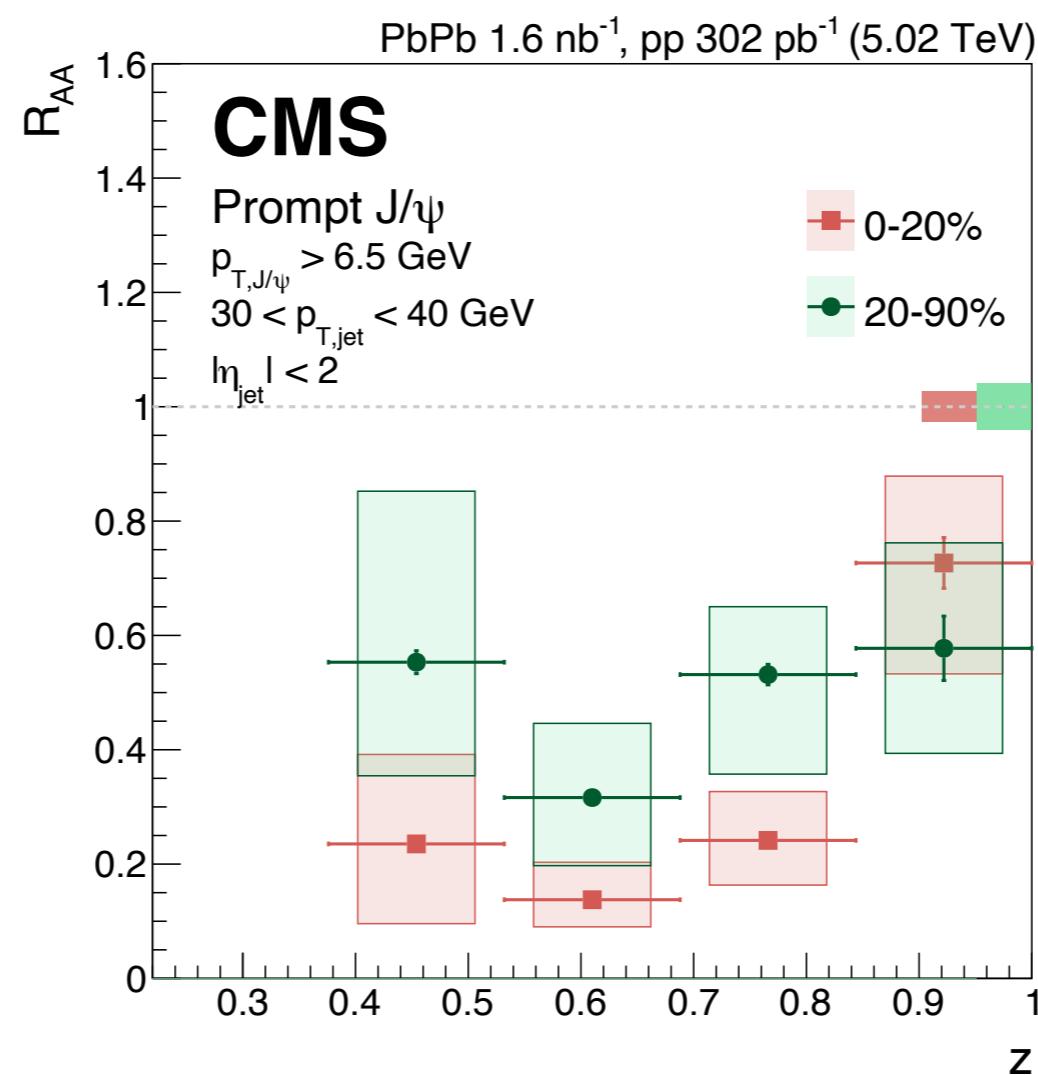
Thank you



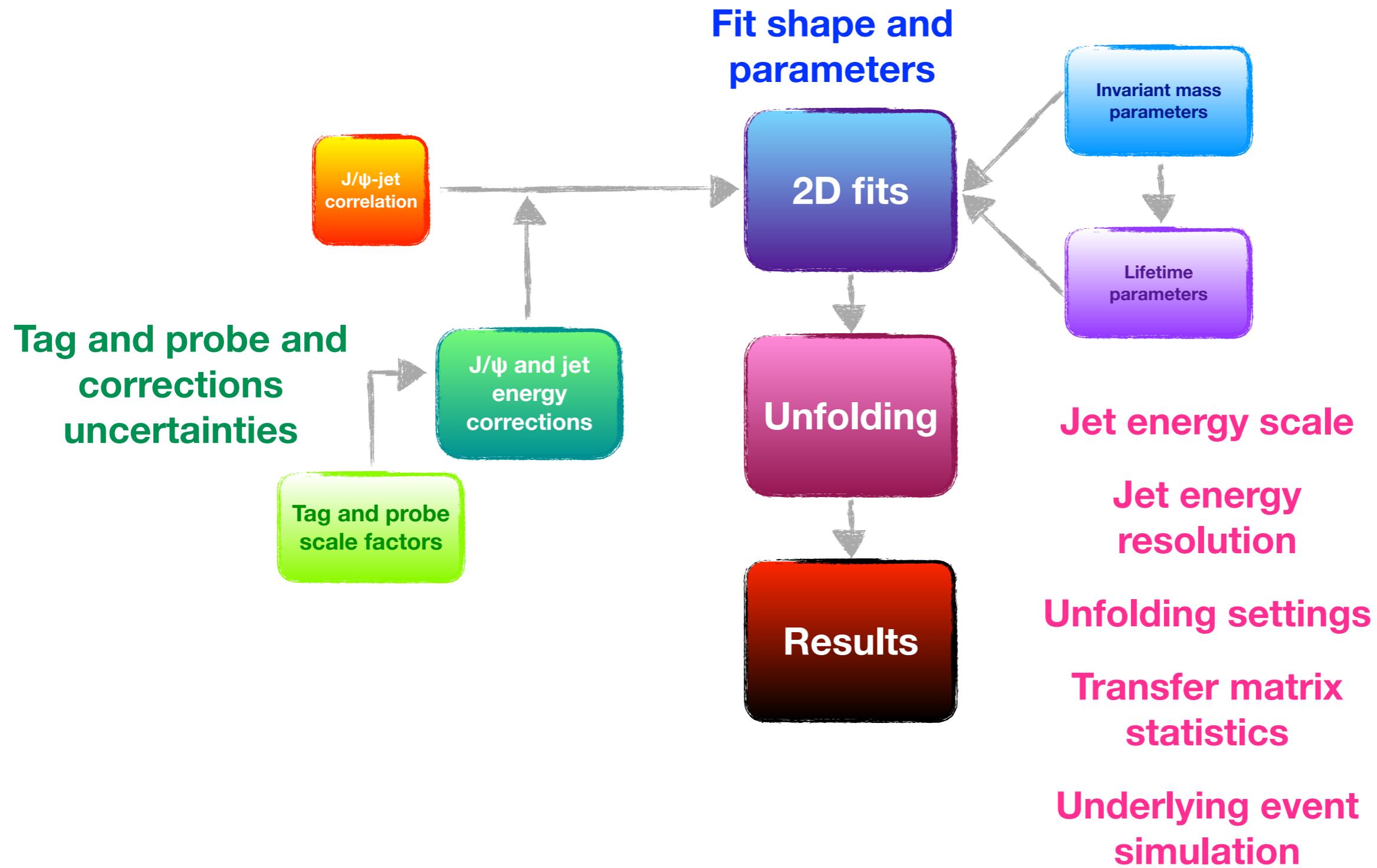
Backup

RAA of prompt J/ ψ in jets

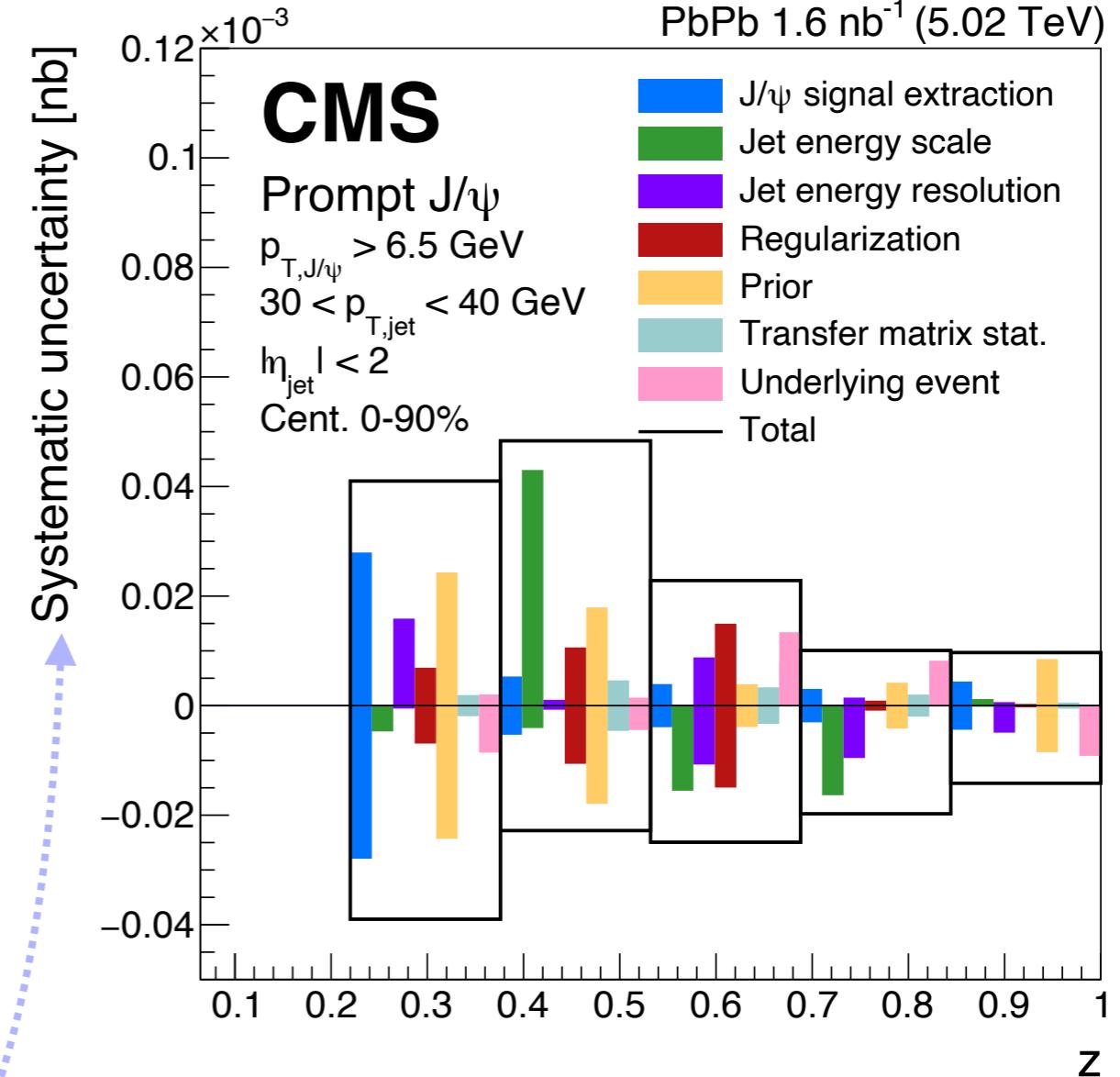
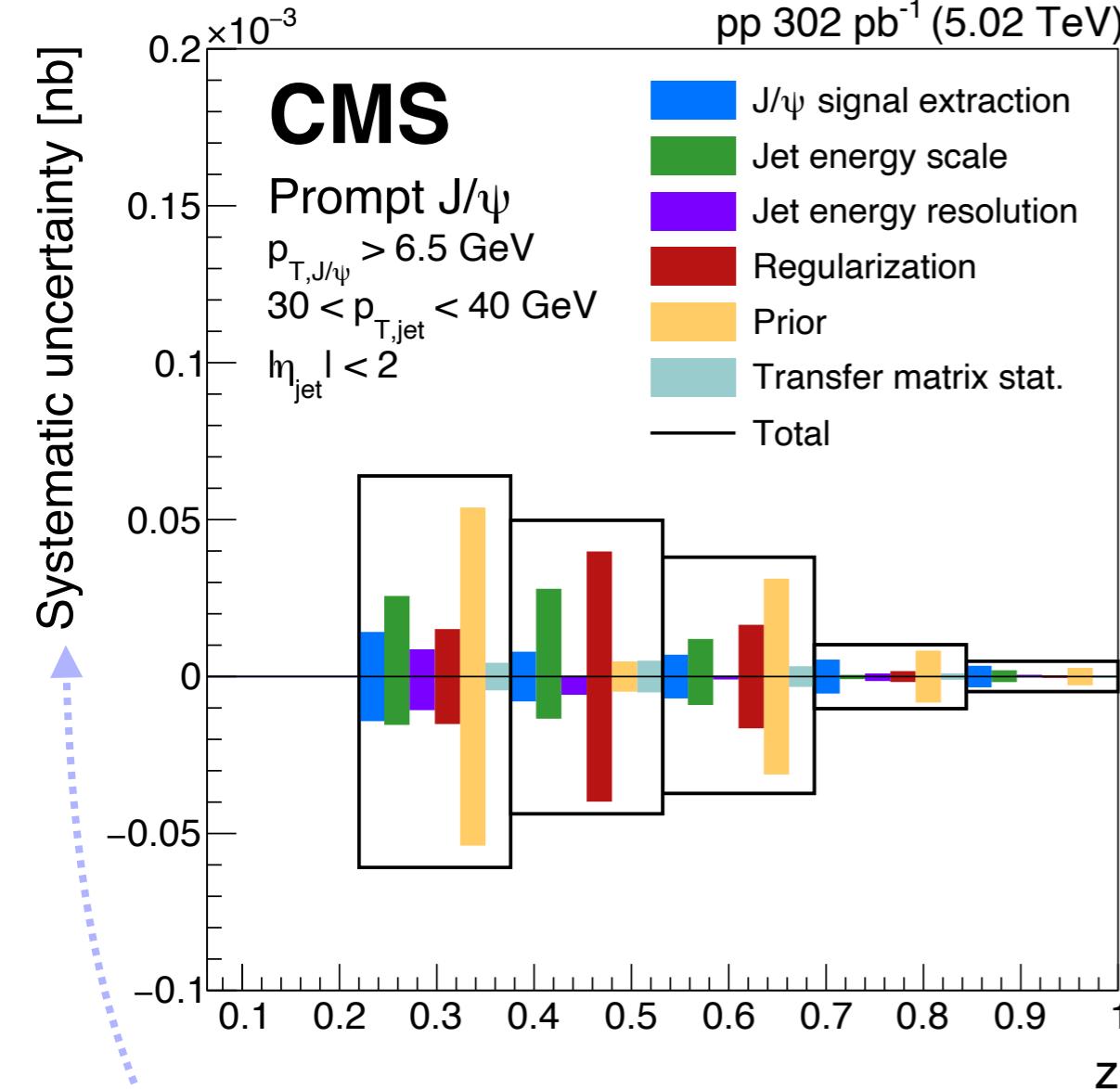
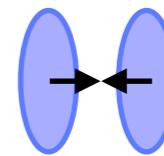
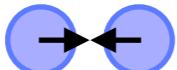
- Larger suppression for central events



Systematic uncertainties



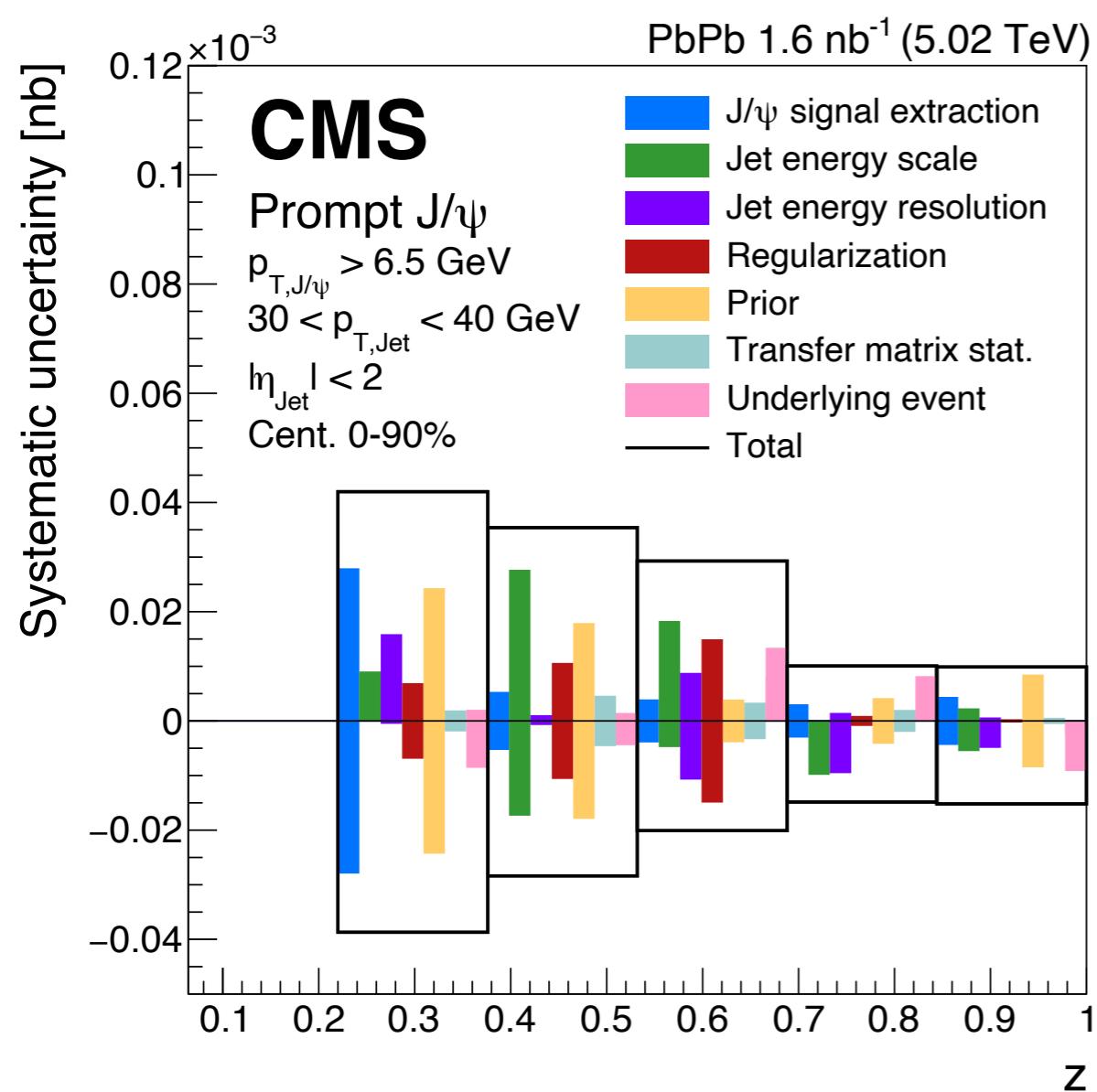
Systematic uncertainties



Absolute uncertainties

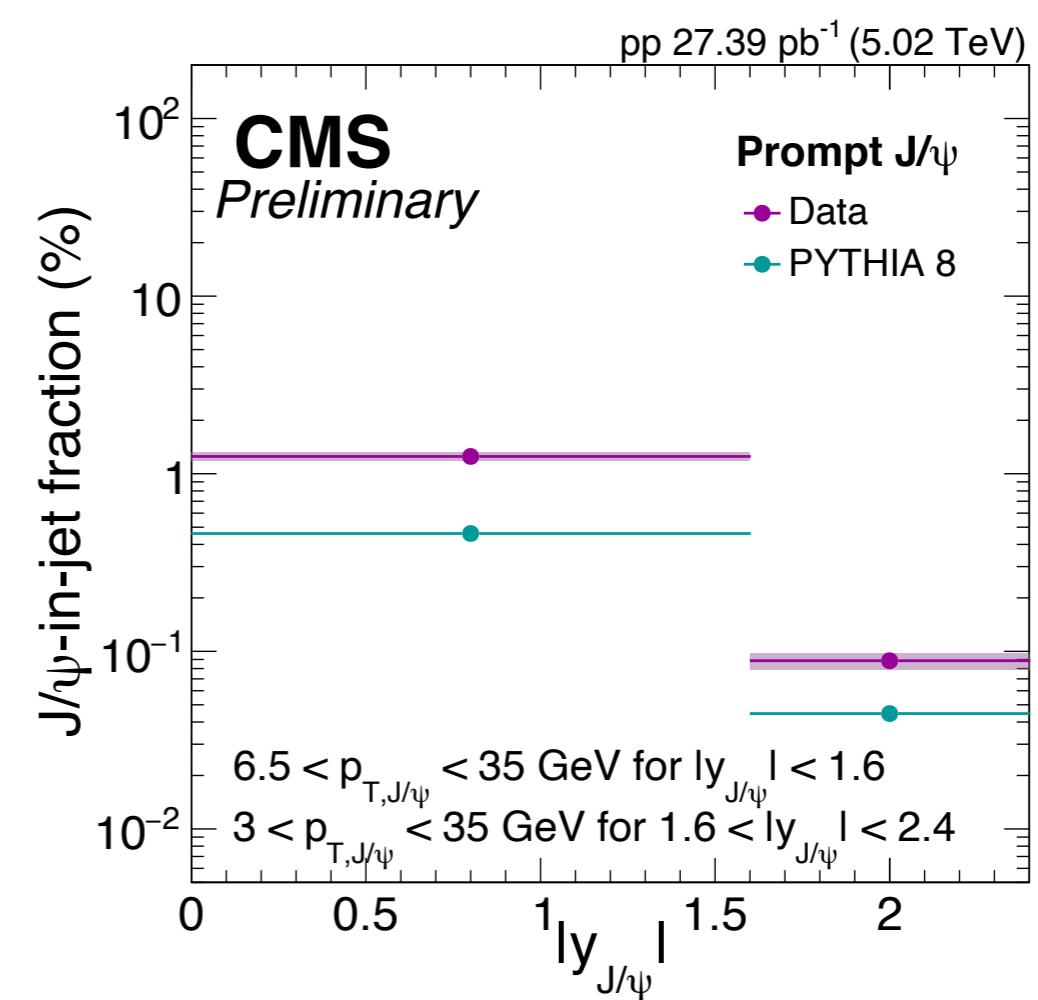
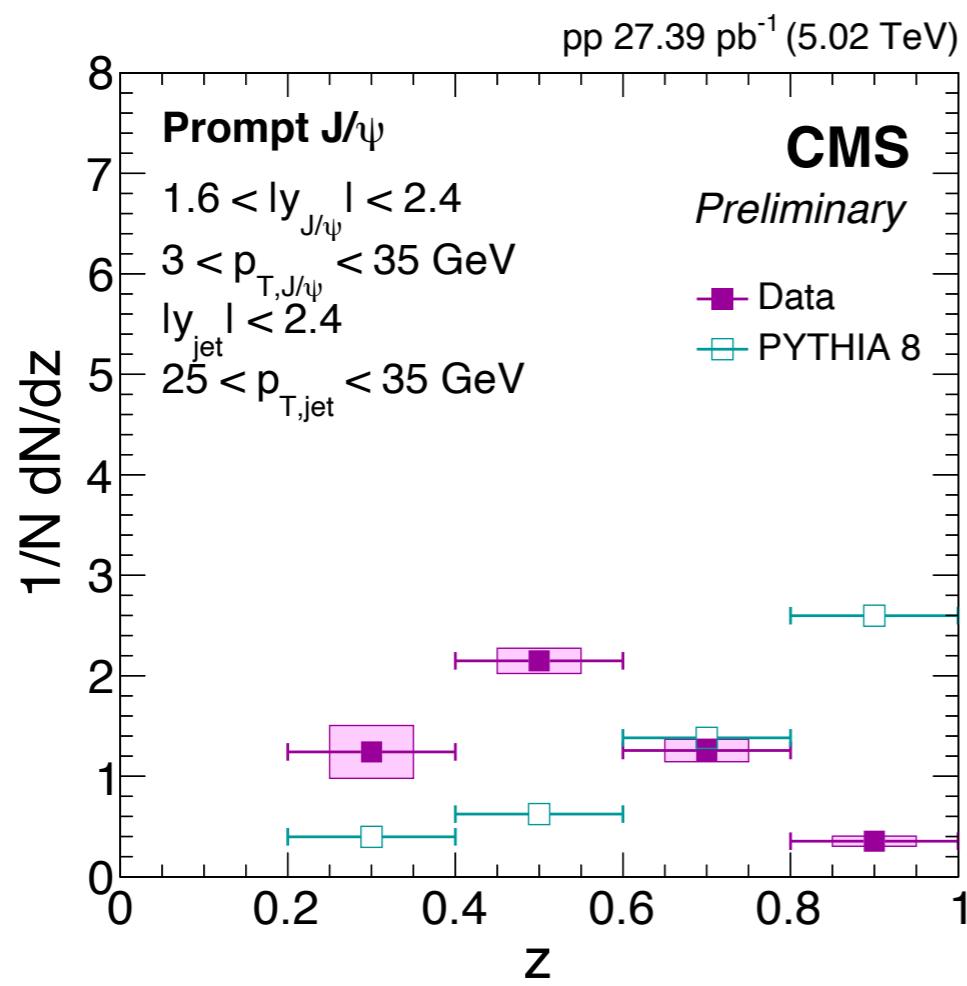
Systematic uncertainties

jet energy scale and resolution is evaluated from dijet and γ +jet balancing methods



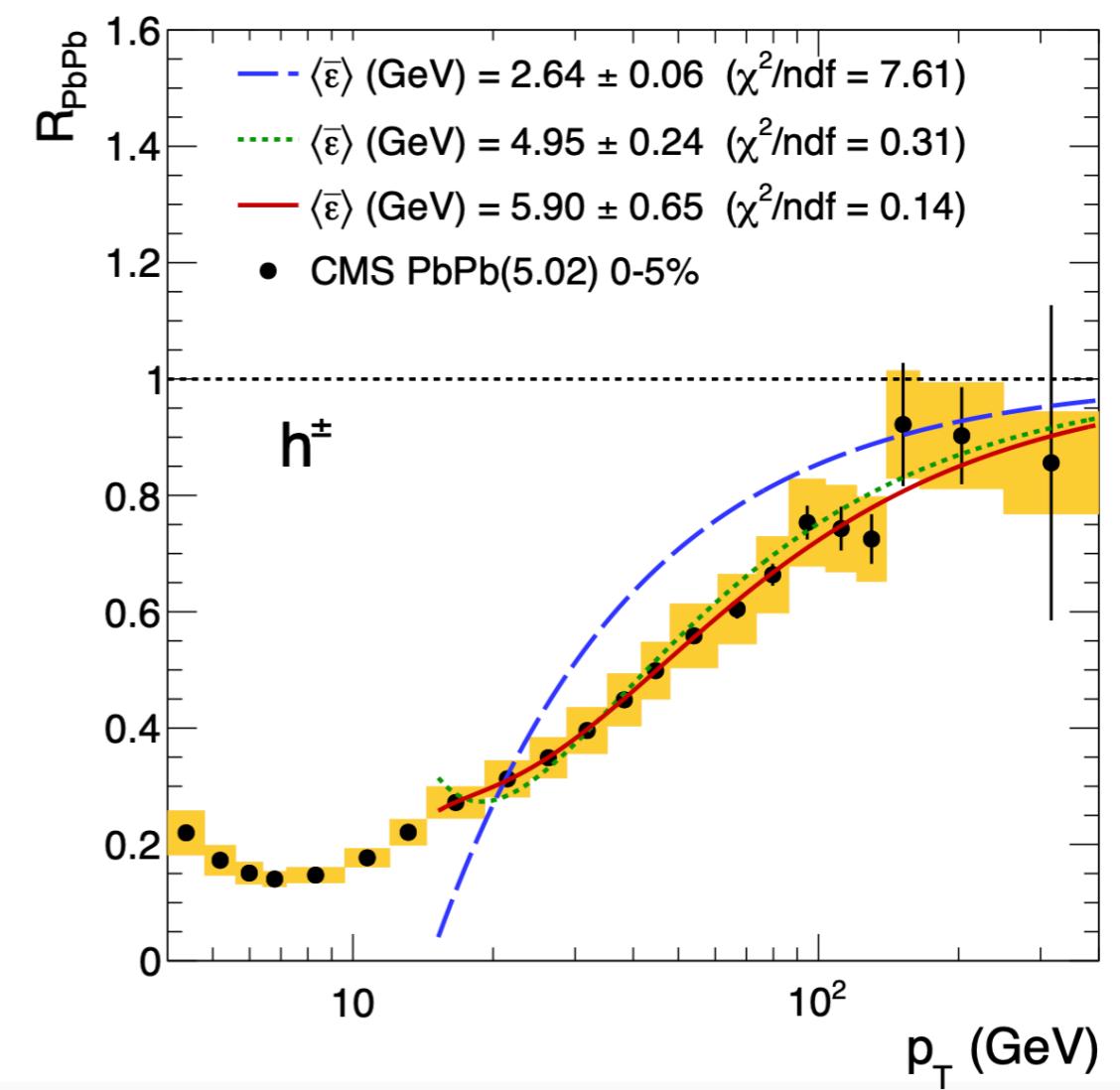
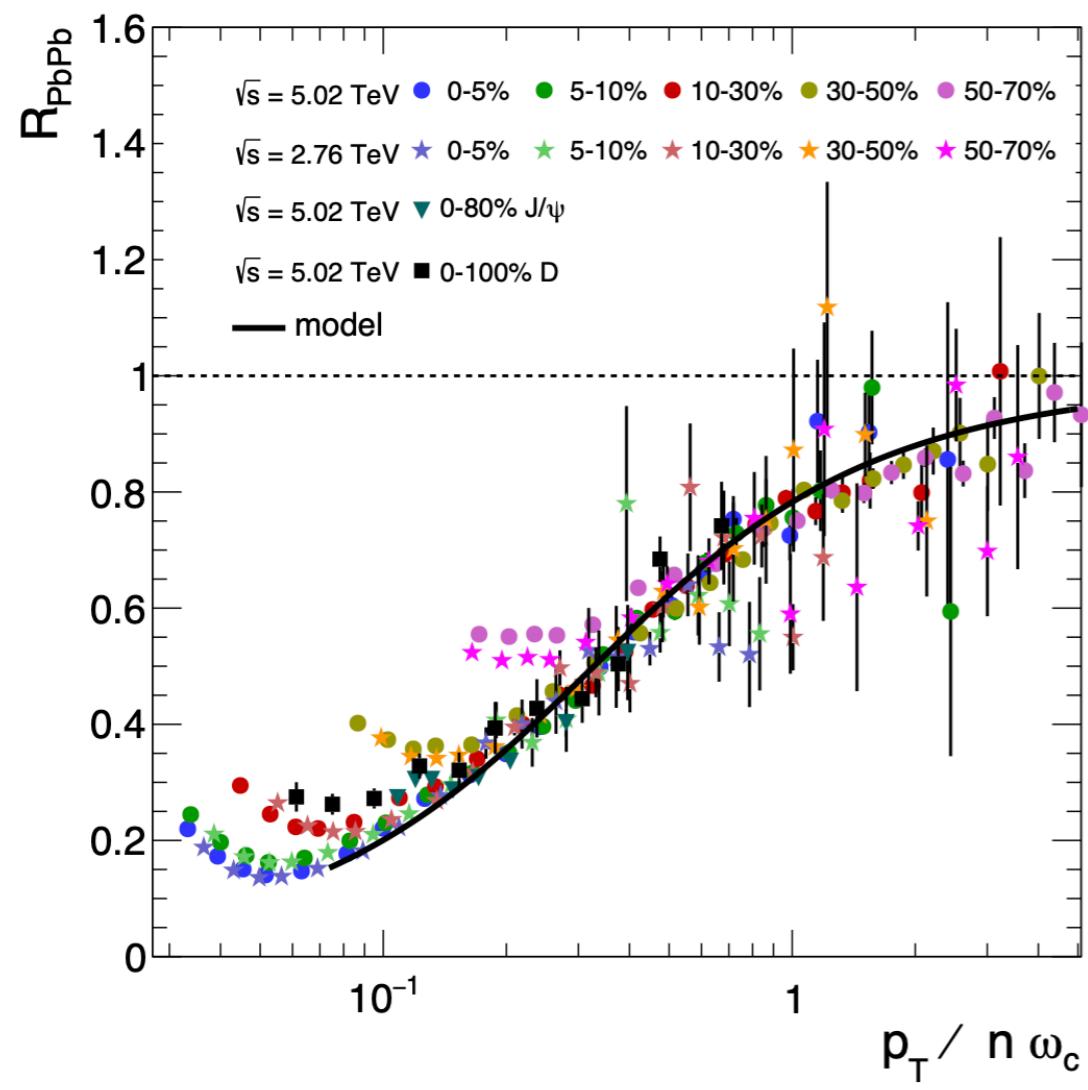
J/ ψ -in-jet fraction

- Similar trend to at forward rapidity with jet p_T range
- Less than 2% of prompt J/ ψ are produced with jets of 25-35 GeV
- CMS measurement at 8 TeV: $84.0 \pm 0.1\%$ of J/ ψ are produced with a jet PLB 804 (2020) 135409



CMS-PAS-HIN-18-012

Universal behavior



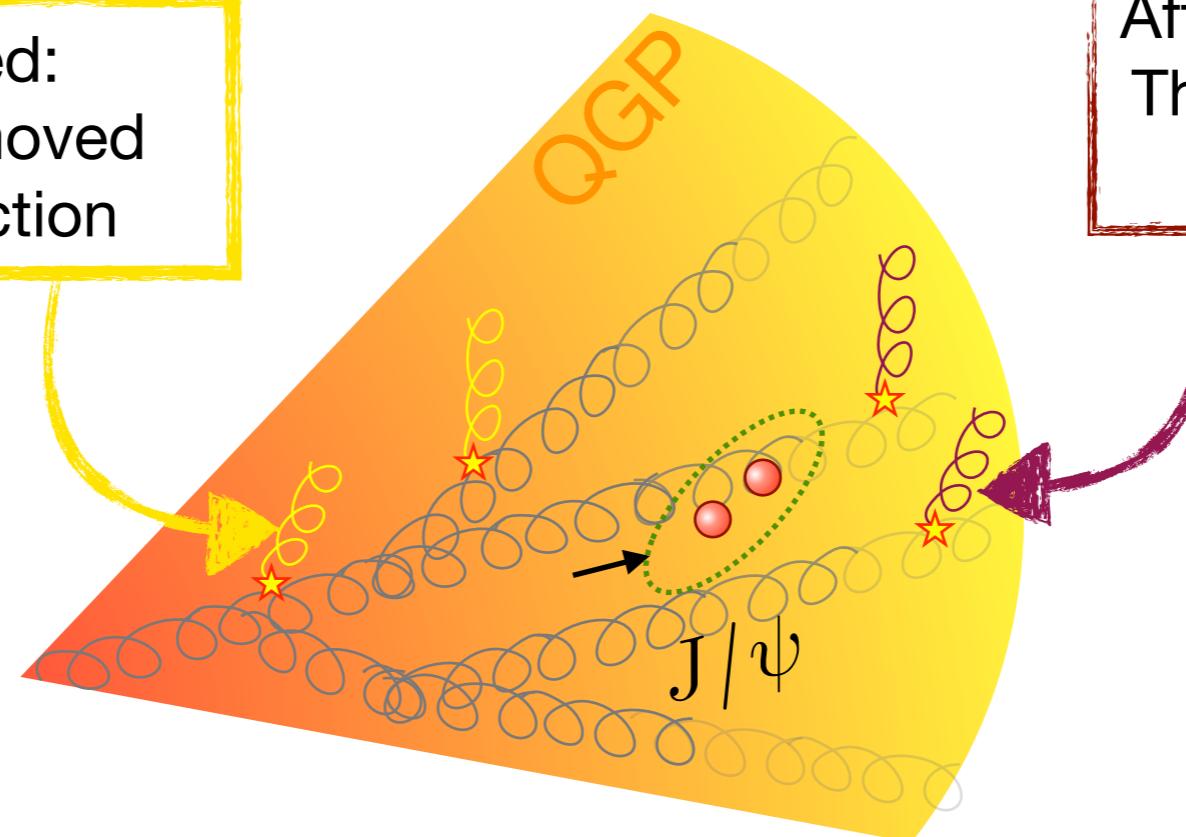
F. Arleo PRL 119 (2017) 062302

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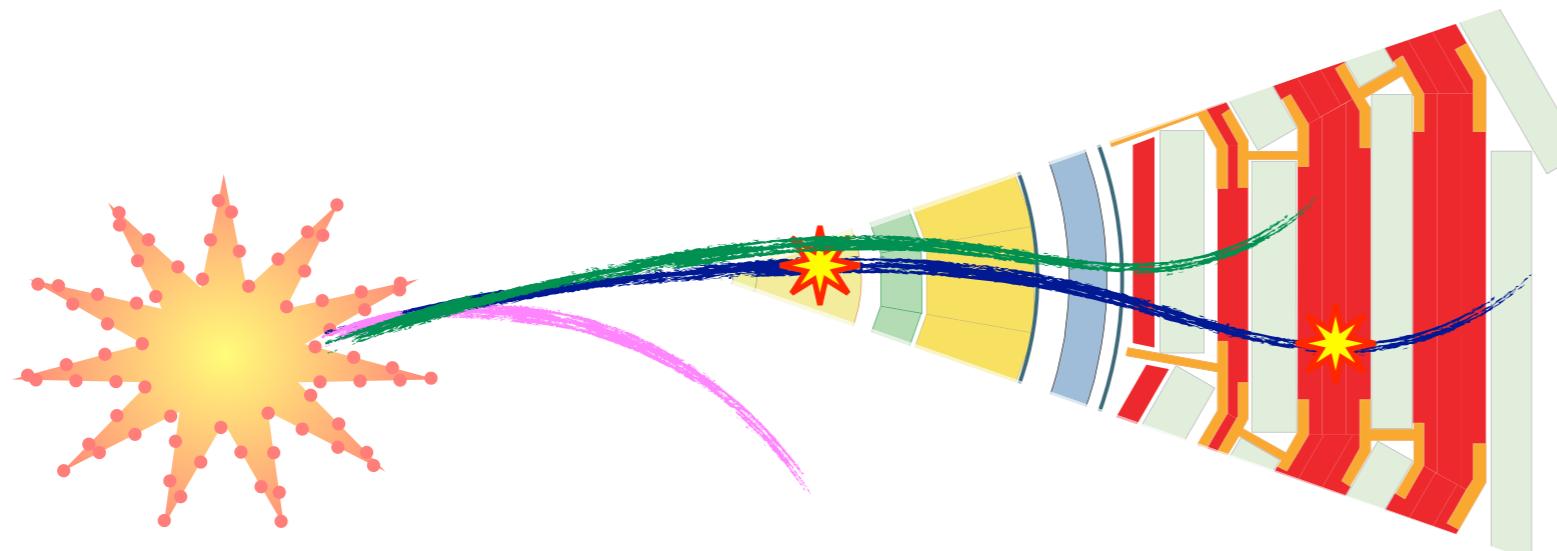
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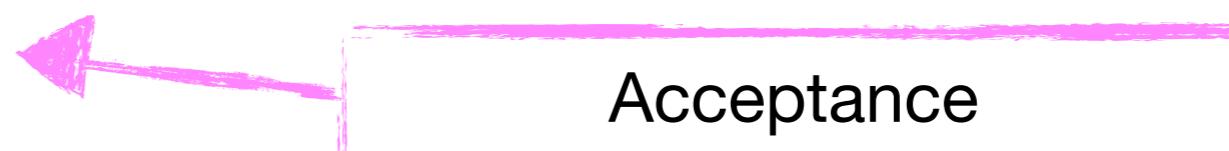
(The J/ ψ is also sensitive to Debye screening)

Acceptance and efficiency corrections



We use muons reconstructed in the tracker and the muon chambers

Some muons do not reach the detector



p_T and rapidity dependant

Some muons reach the detector but do not get reconstructed or do not pass the selection



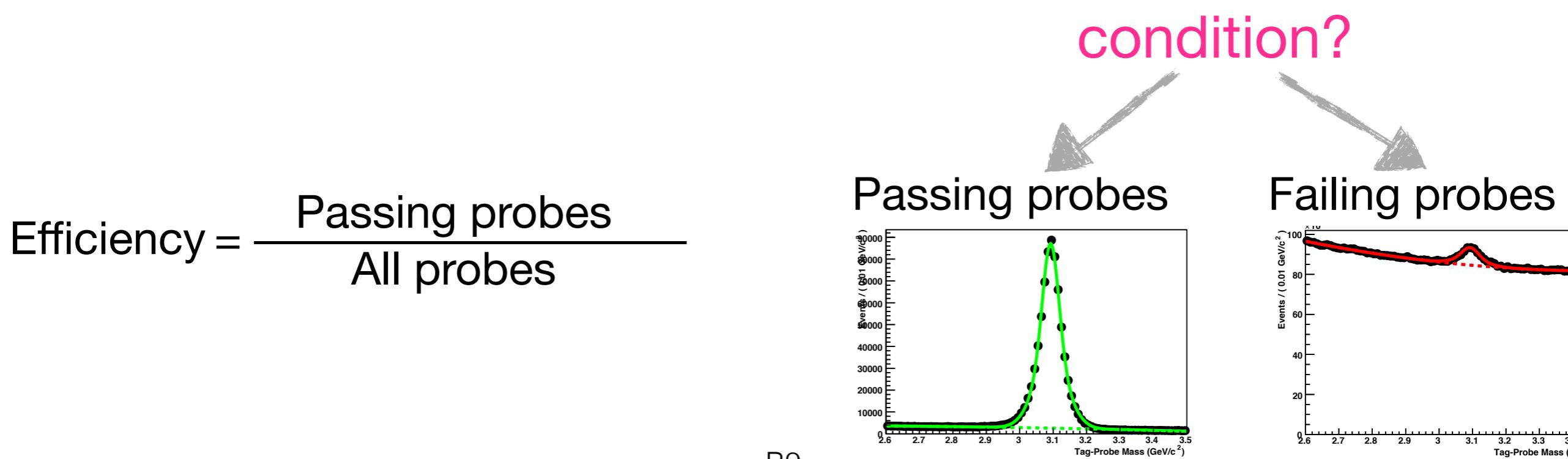
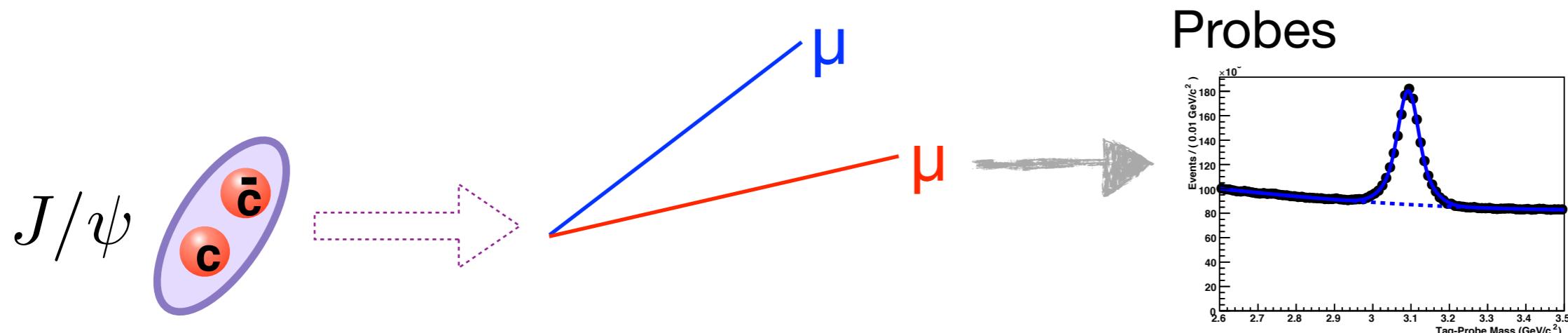
p_T , rapidity and centrality dependant

Monte Carlo simulations are used to calculate the acceptance and efficiency to correct the J/ψ yields

Tag and probe corrections

Simulations do not describe data perfectly

Tag-and-probe is a data-driven efficiency calculation method

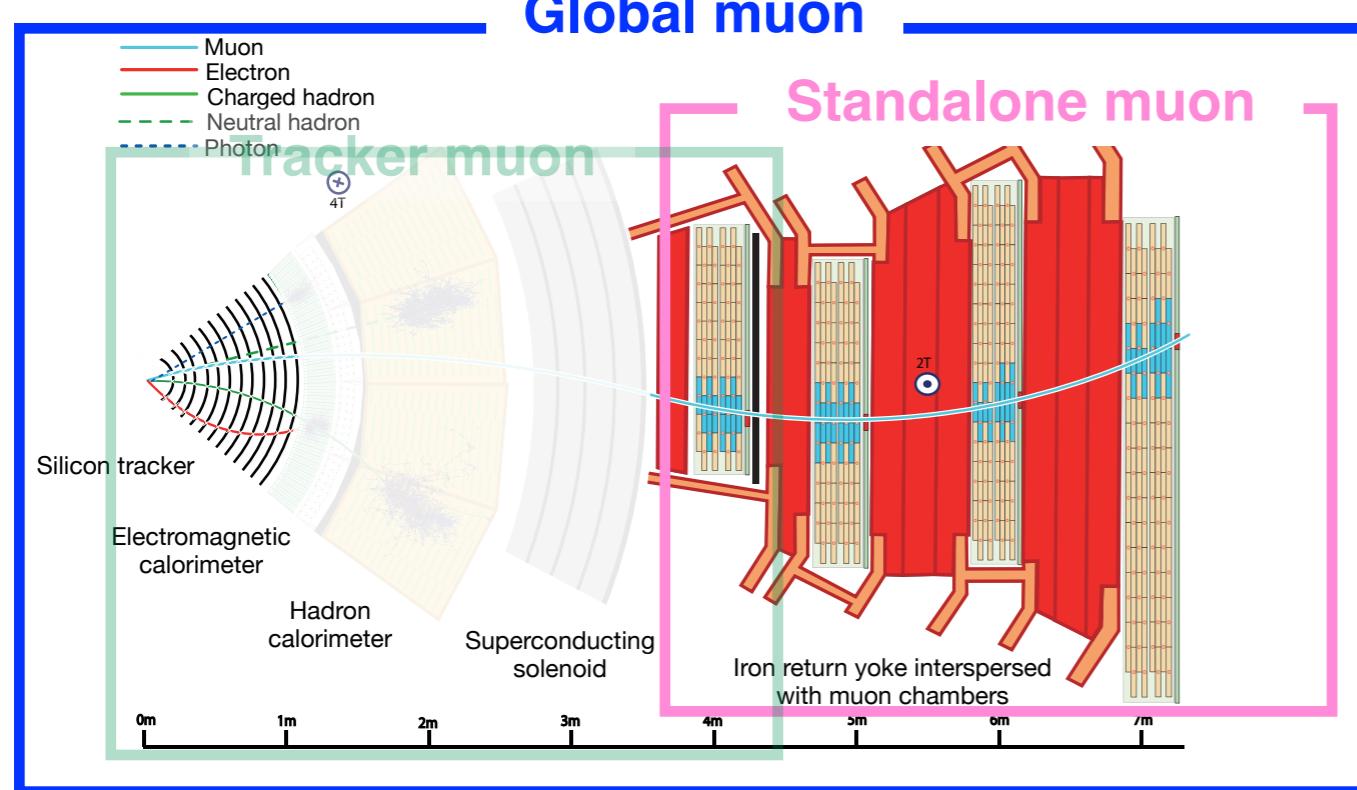


Tag and probe: tracking

For 2018 PbPb data the efficiencies are derived for the tracking, the muon identification and the trigger

For tracking: take standalone muons and check if they are global or not

Very good efficiency with small differences between data and MC



Outlook

J/ ψ in jets in jet p_T bins

Jet fragmentation functions are usually measured as function of jet p_T

Useful for comparison with theoretical models

$\psi(2S)$ in jets

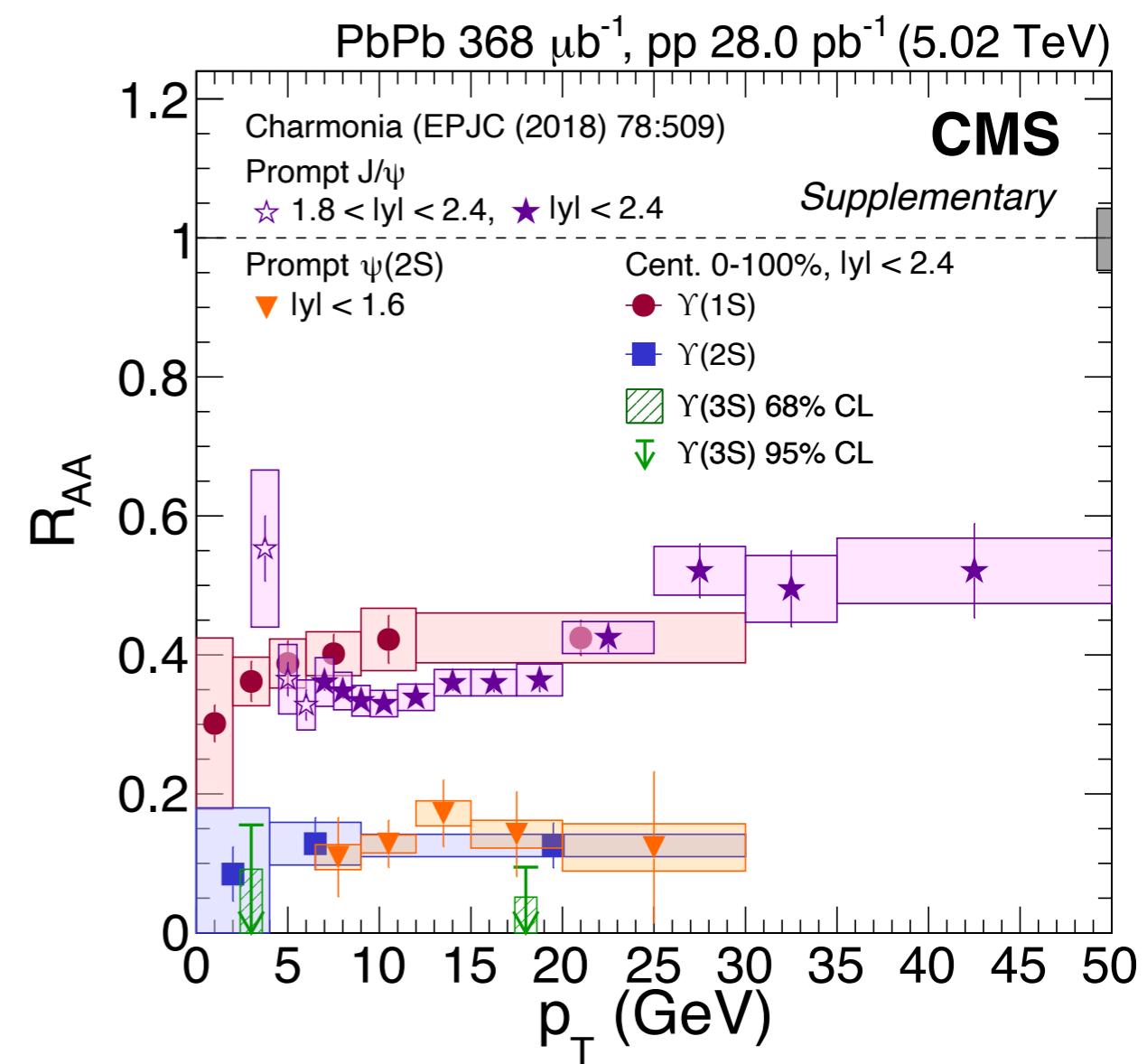
E_{Loss} processes are not sensitive to the final state

Bottomonia in jets

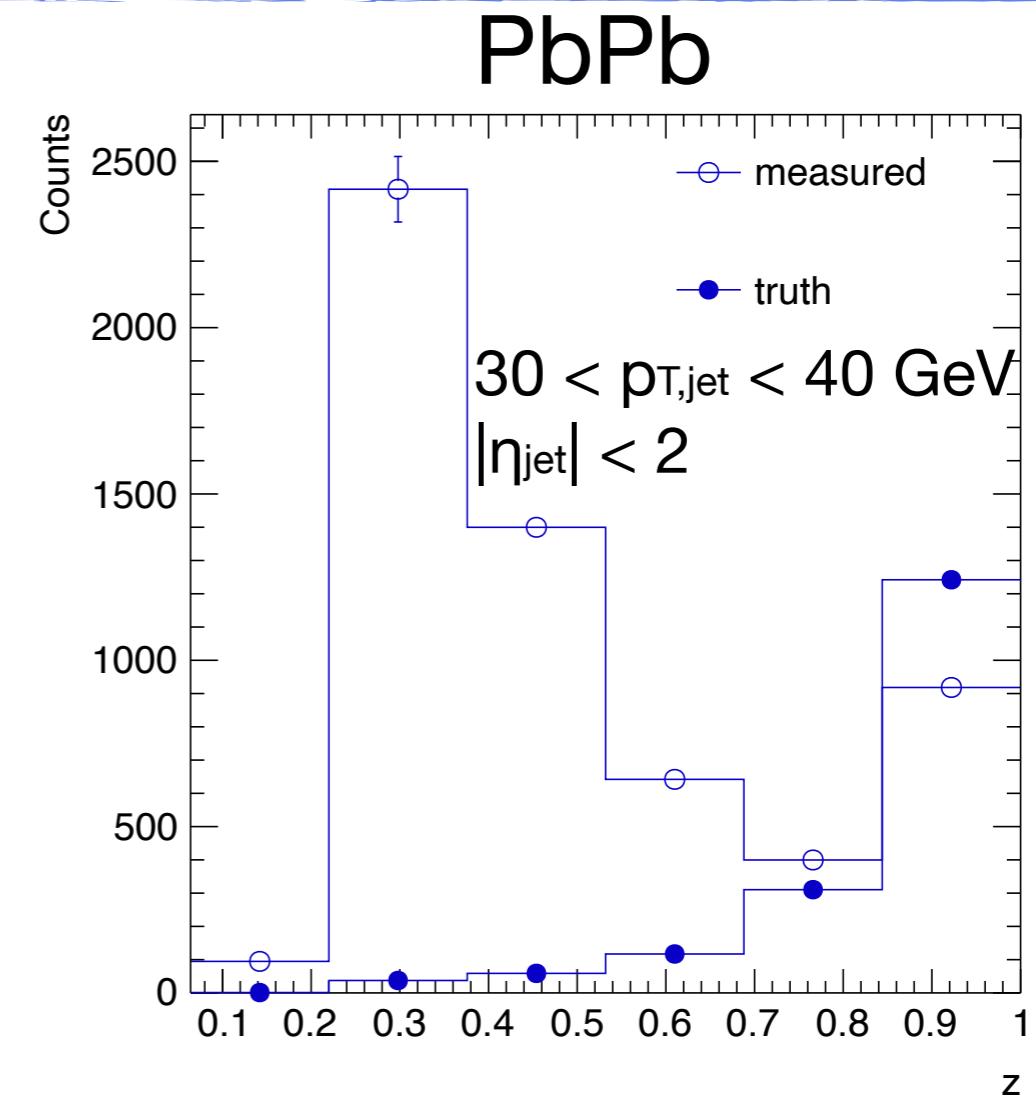
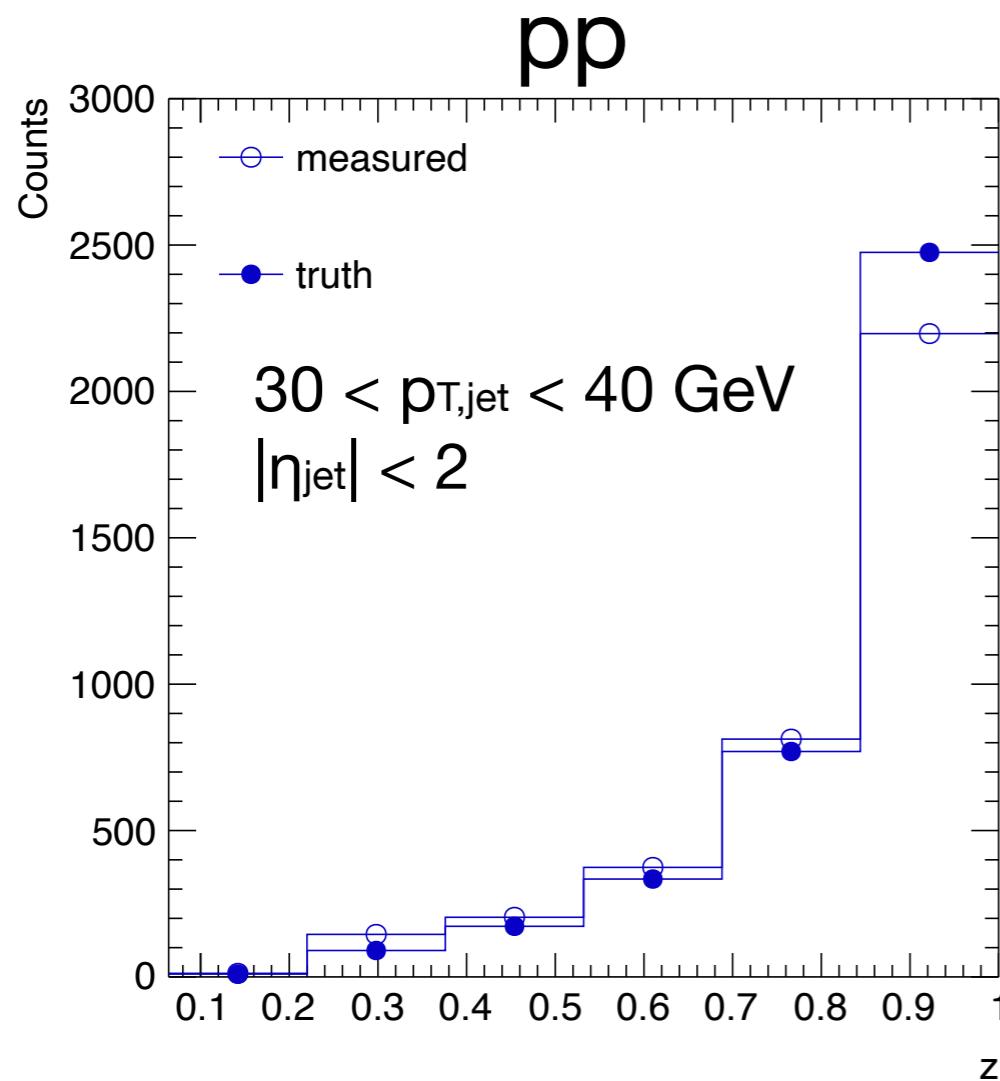
Υ R_{AA} vs J/ ψ R_{AA} is used to disentangle quarkonium suppression effect

Υ in jets can provide a direct comparison to quarkonium production models

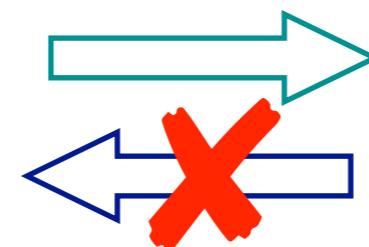
R_{AA} of Υ in jets in PbPb can be compared to the R_{AA} of J/ ψ in jets



Bin migration



True distribution



Measured distribution

Unfolding is needed for data