Fragmentation of J/ψ in jets in pp and PbPb collisions with CMS

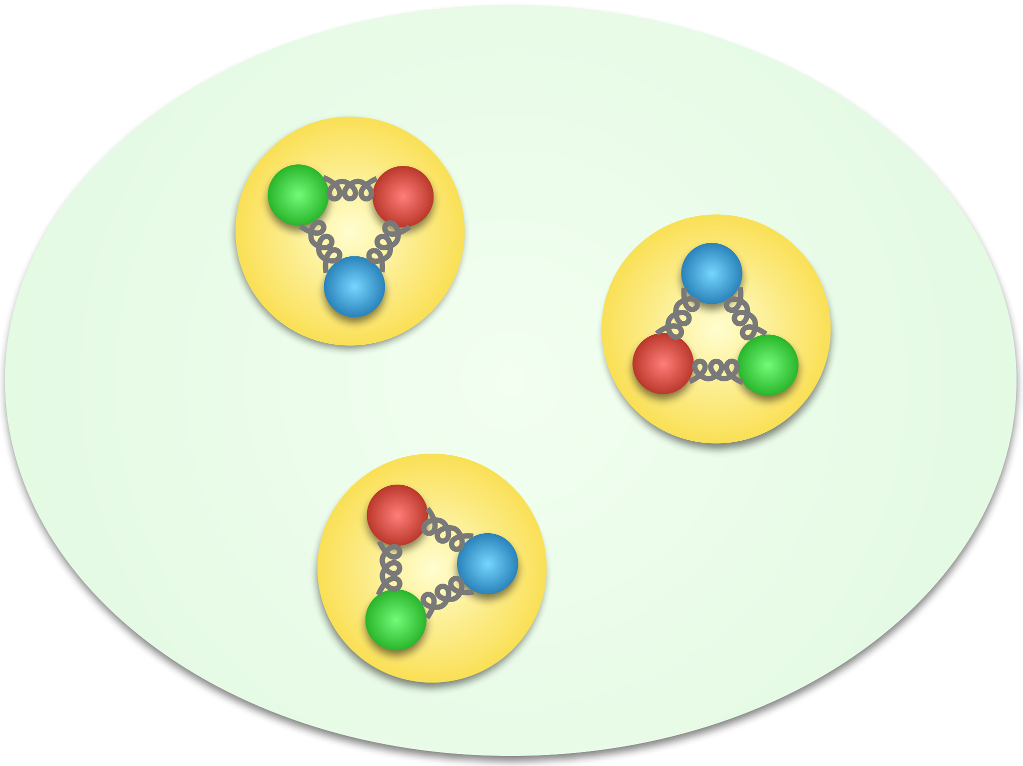
Quarkonia As Tools

Batoul Diab

11/01/2023

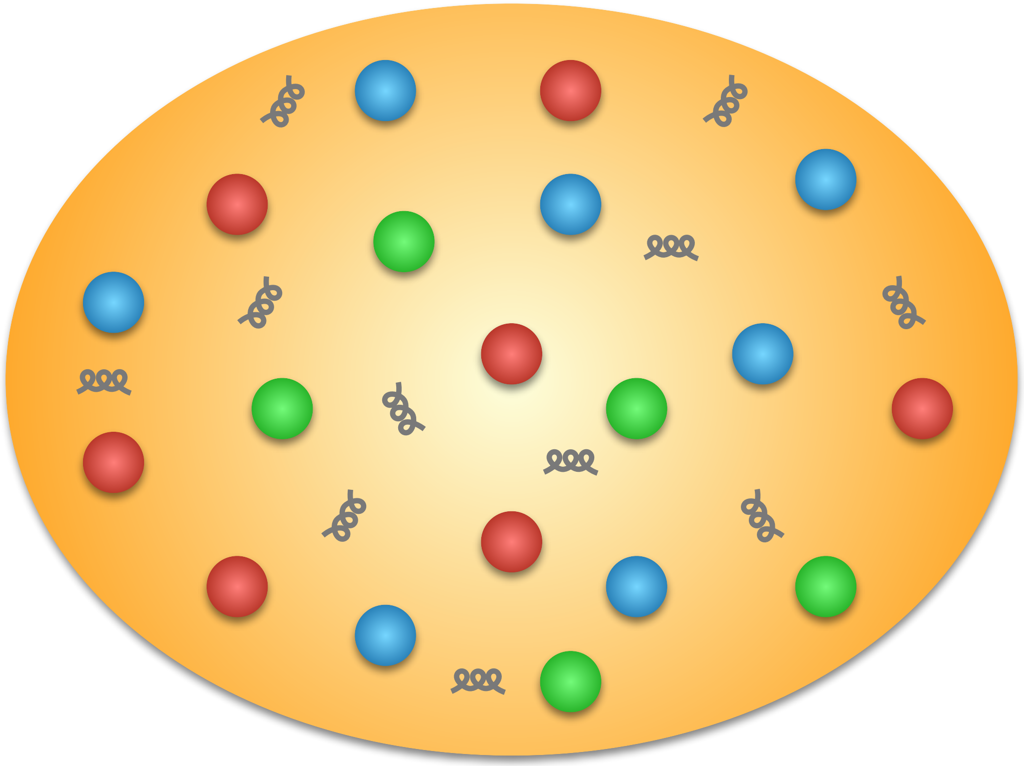
Different states of matter

Normal matter



Quarks and gluons are confined in hadrons

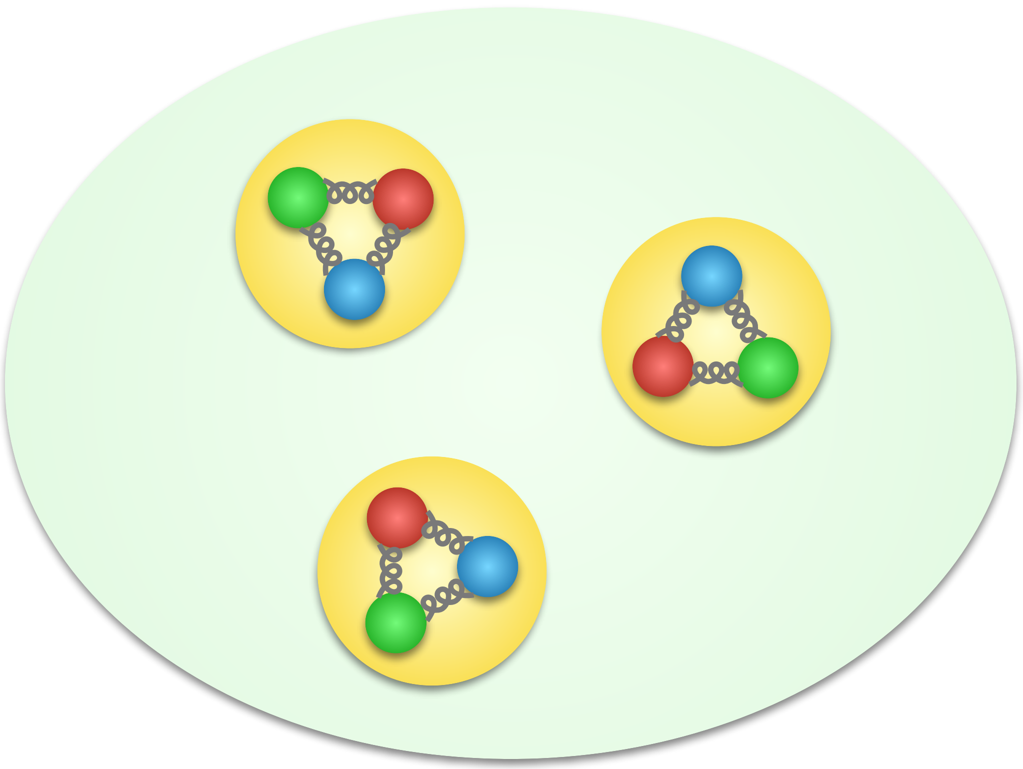
High density/temperature systems



Deconfined state of matter: The Quark Gluon Plasma

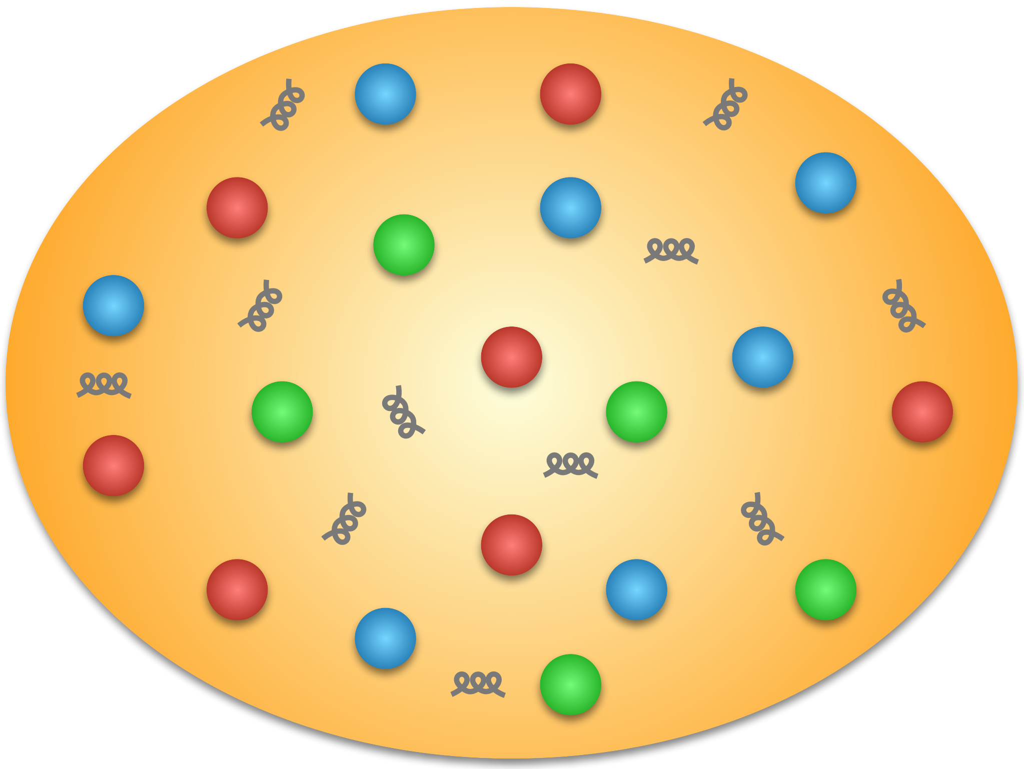
Different states of matter

Normal matter



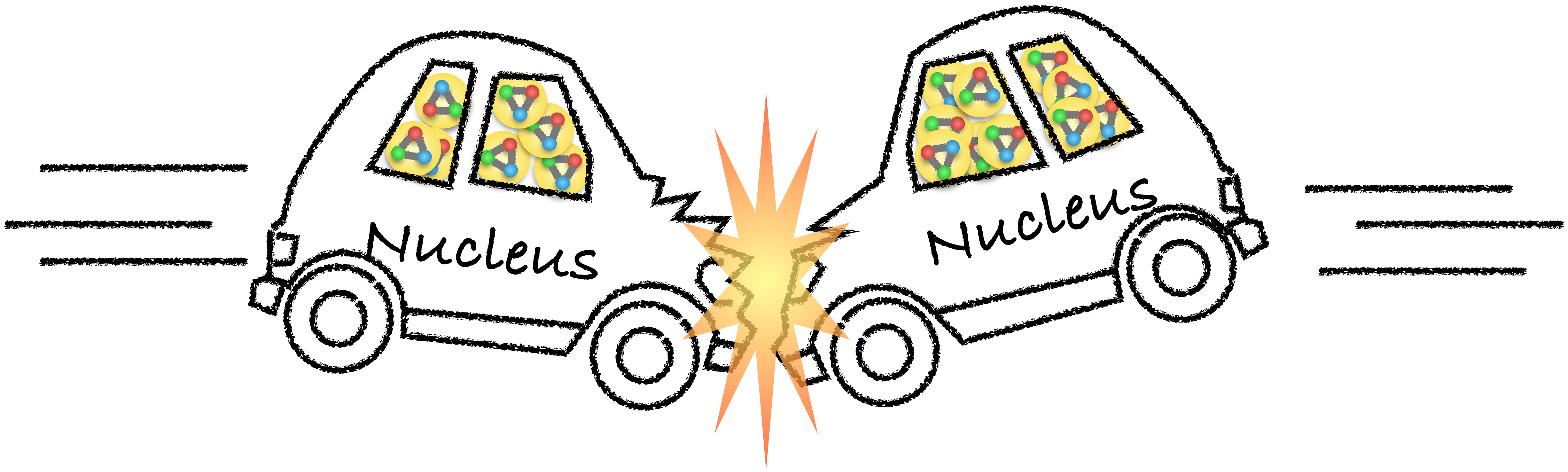
Quarks and gluons are confined in hadrons

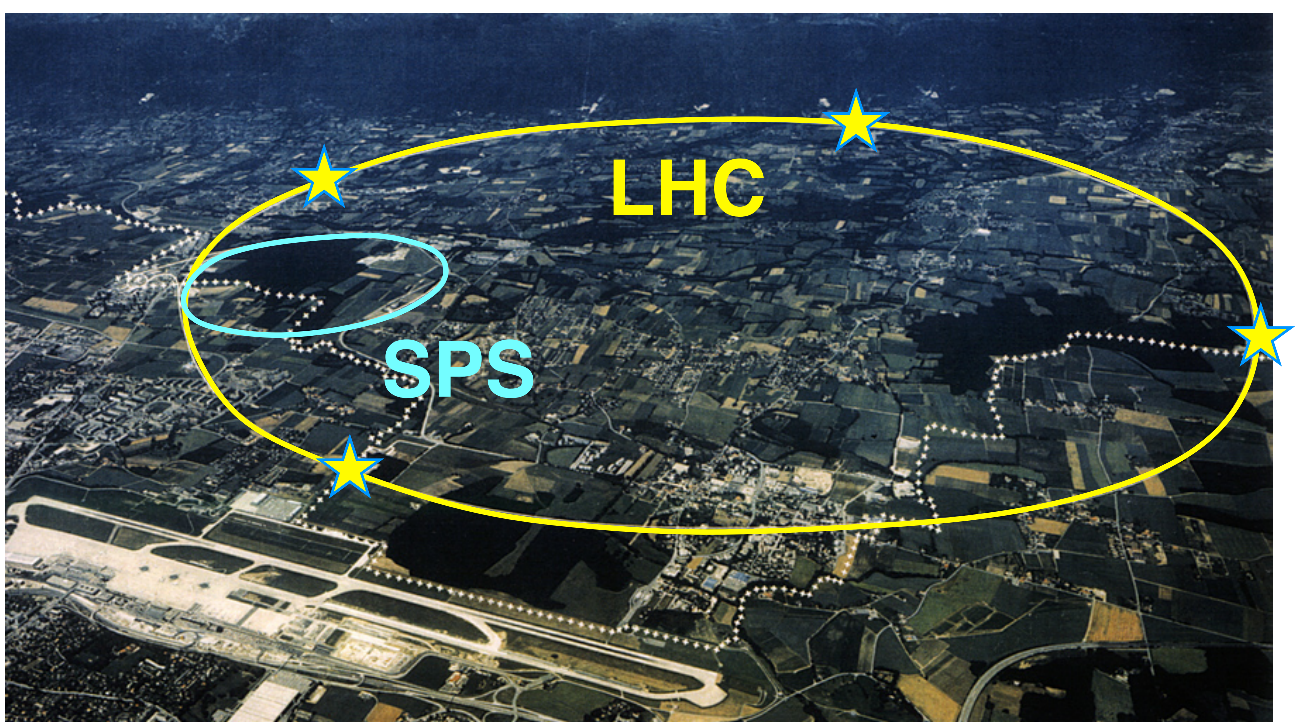
High density/temperature systems



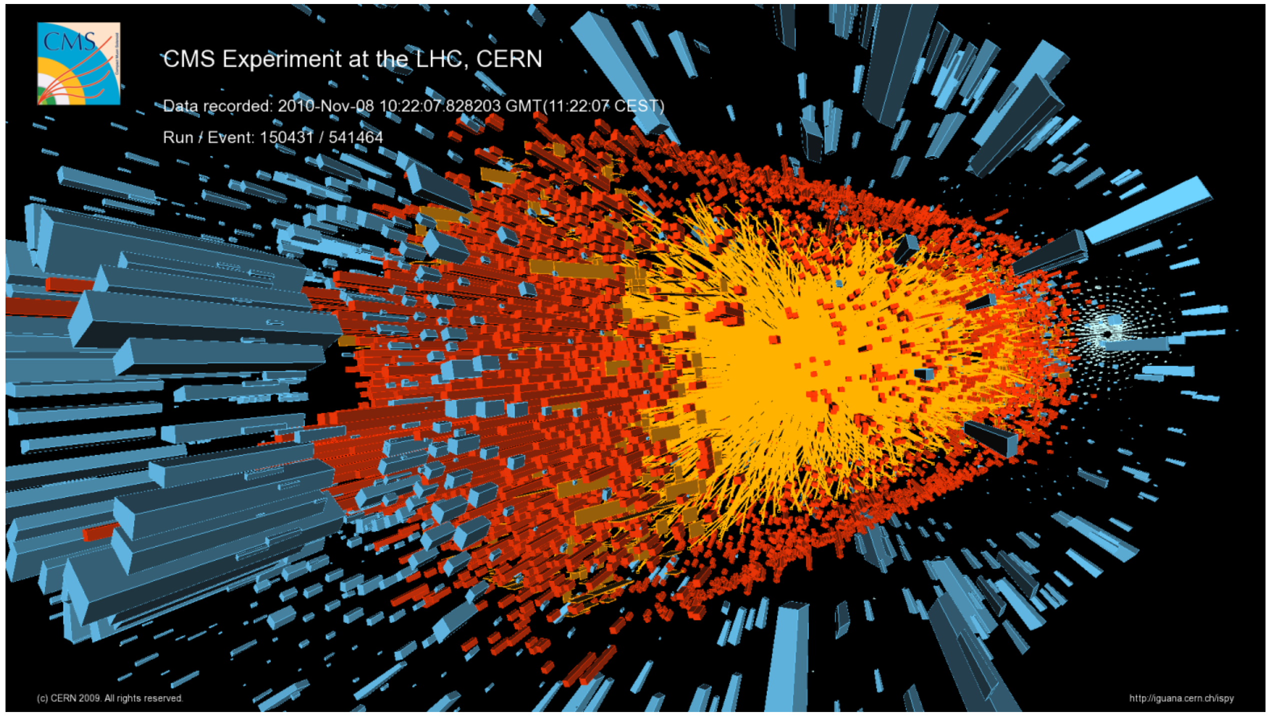
Deconfined state of matter: The Quark Gluon Plasma

Heavy ion collisions



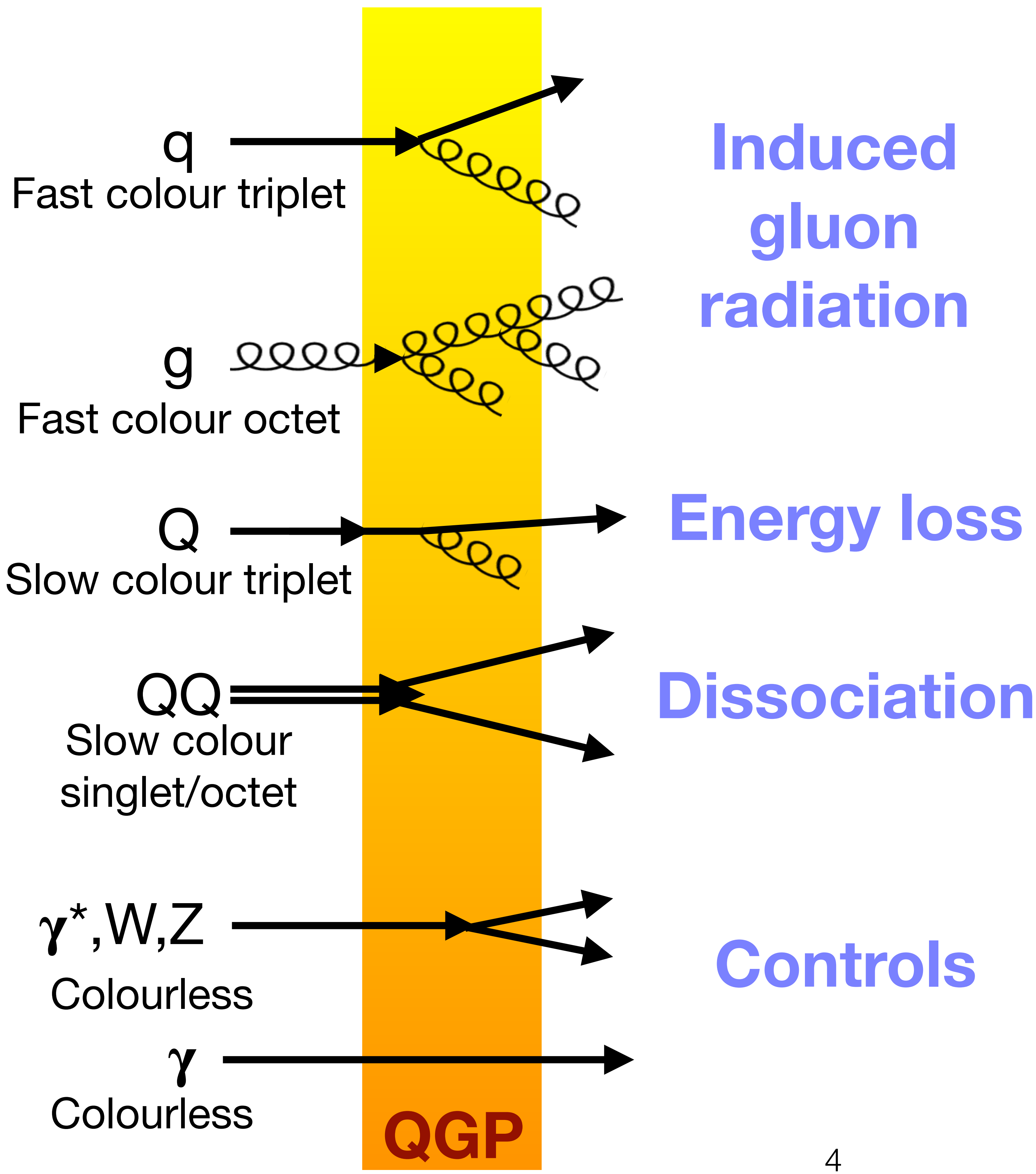


Smash particles at high energies



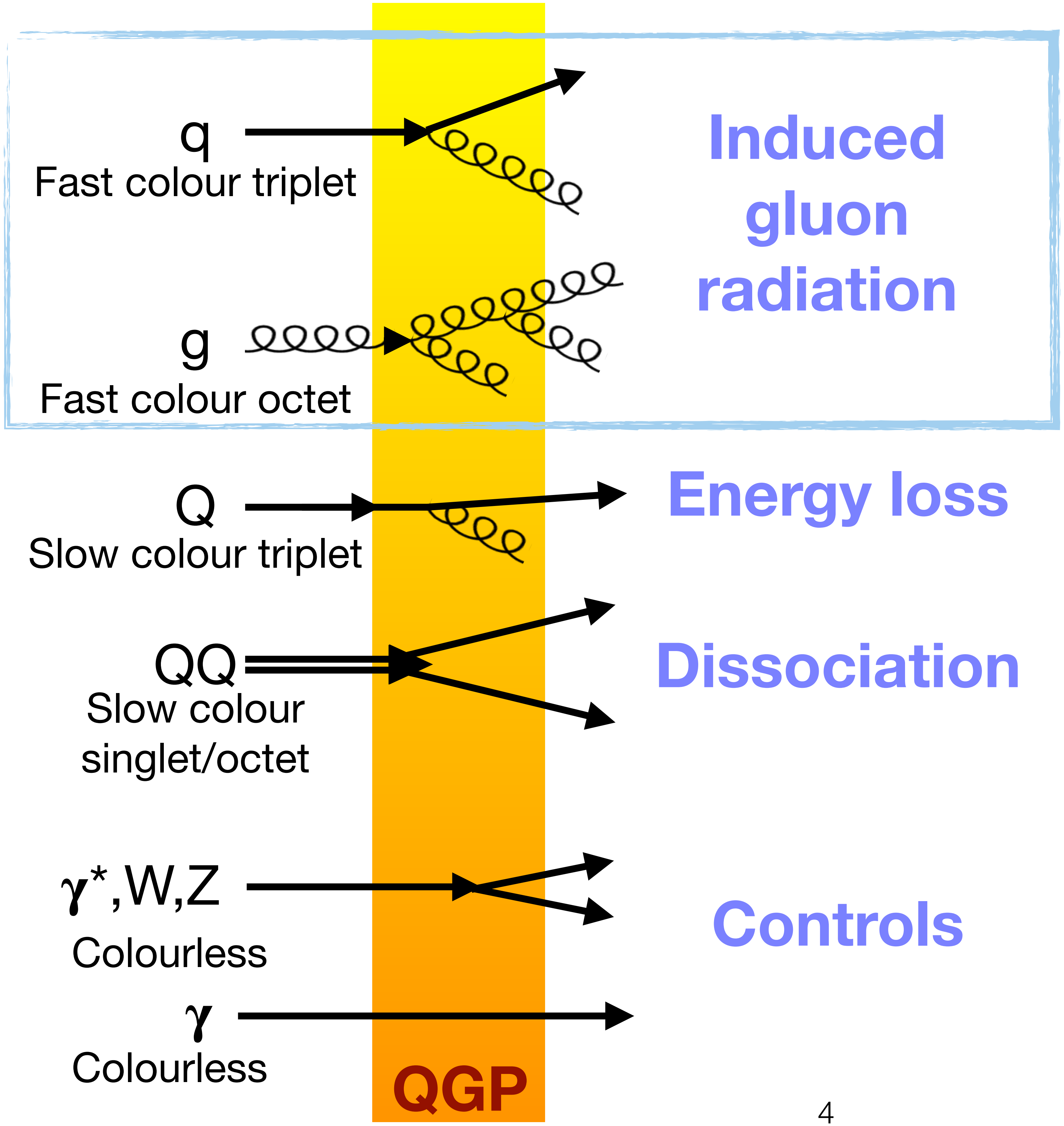
Detect and study the outcome

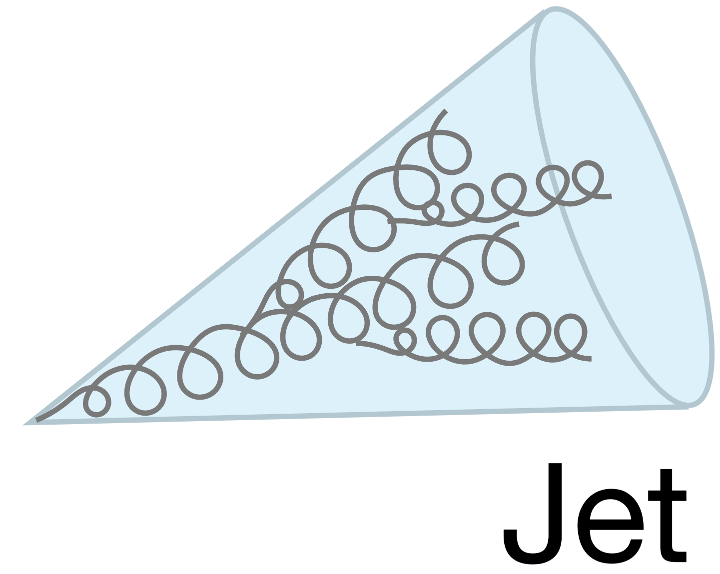
Probes of the Quark Gluon Plasma



Adapted from D. d'Enterria, Landolt-Bornstein 23 (2010) 471

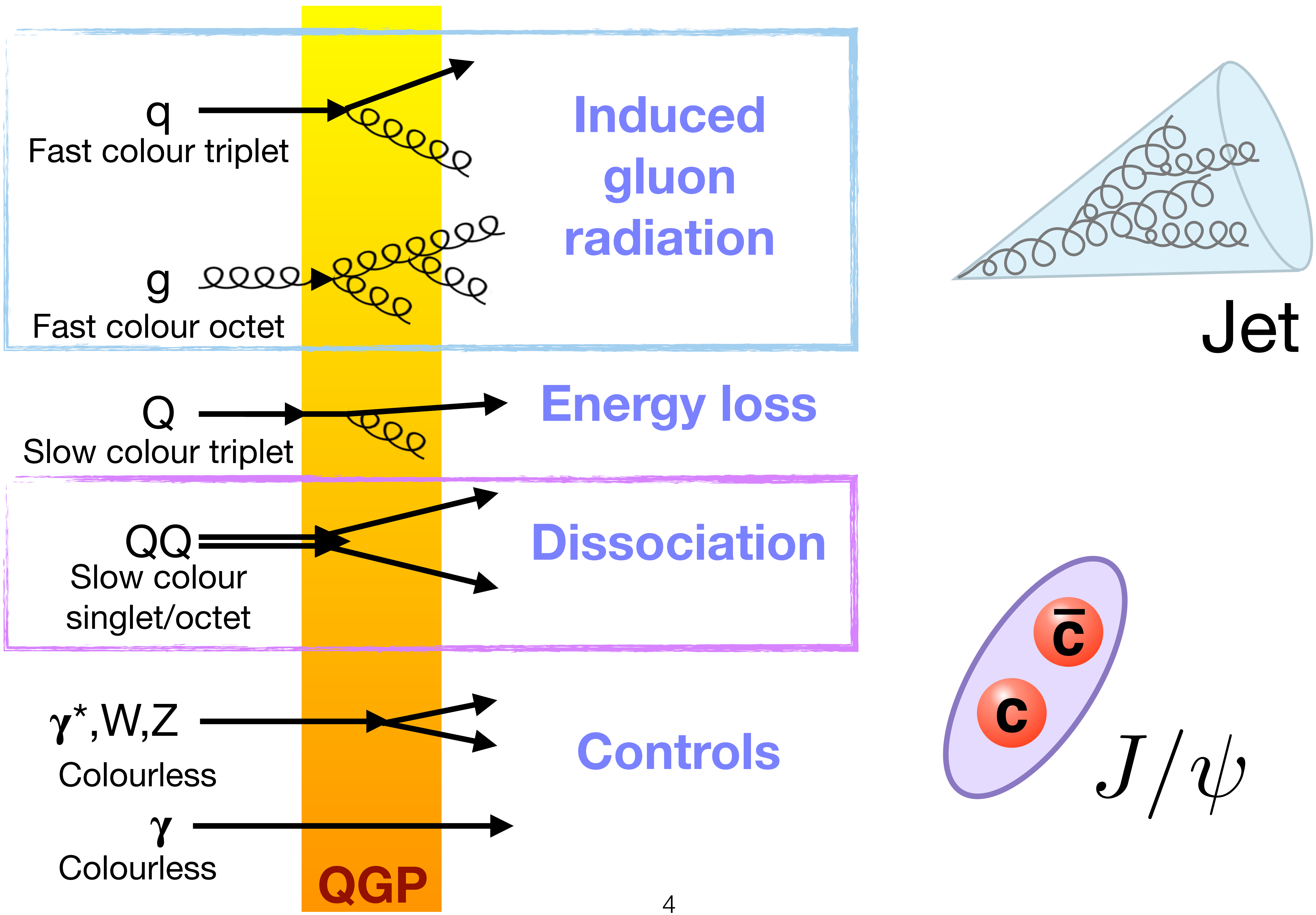
Probes of the Quark Gluon Plasma





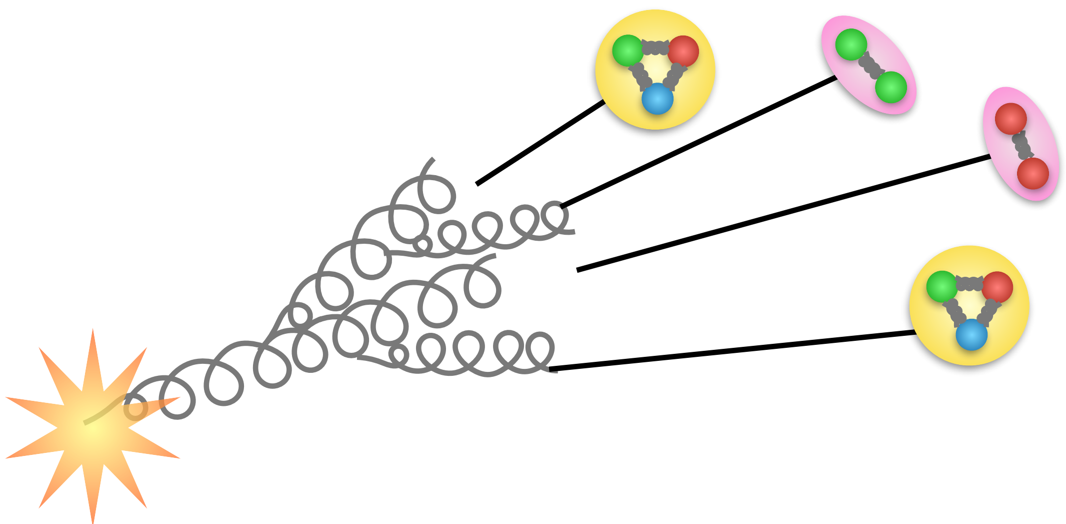
Adapted from D. d’Enterria, Landolt-Bornstein 23 (2010) 471

Probes of the Quark Gluon Plasma



Adapted from D. d'Enterria, Landolt-Bornstein 23 (2010) 471

Jets in hadronic collisions



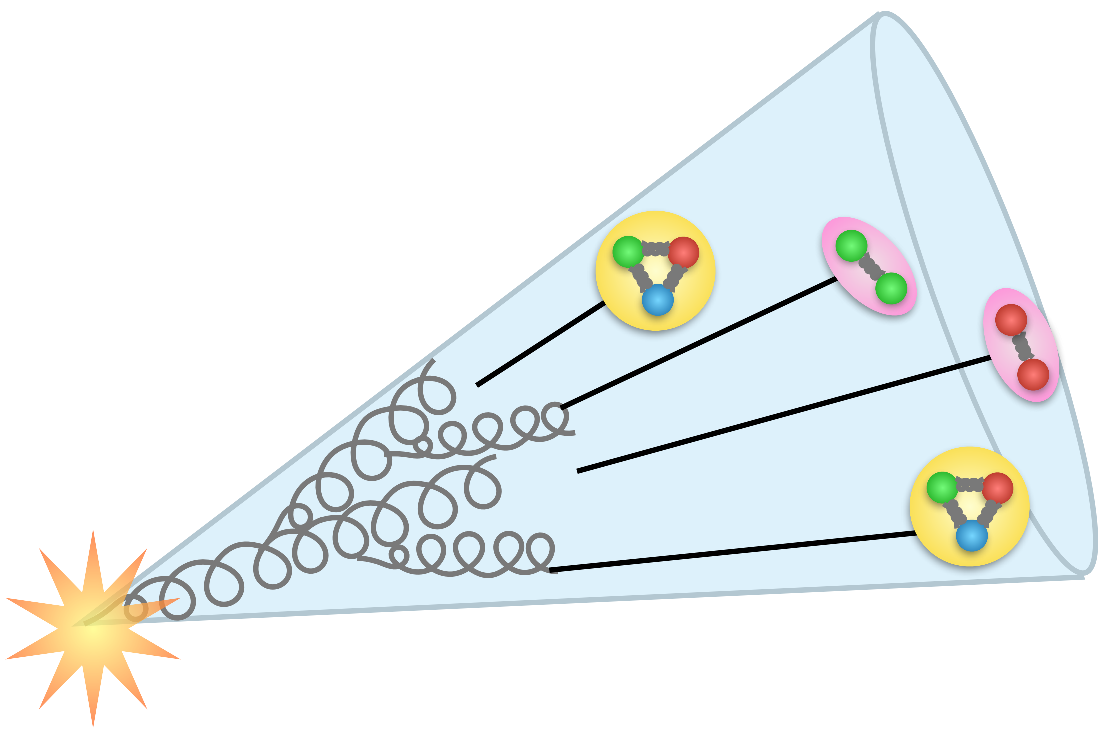
Collision

Partons with large momentum

Gluon radiation

Hadrons

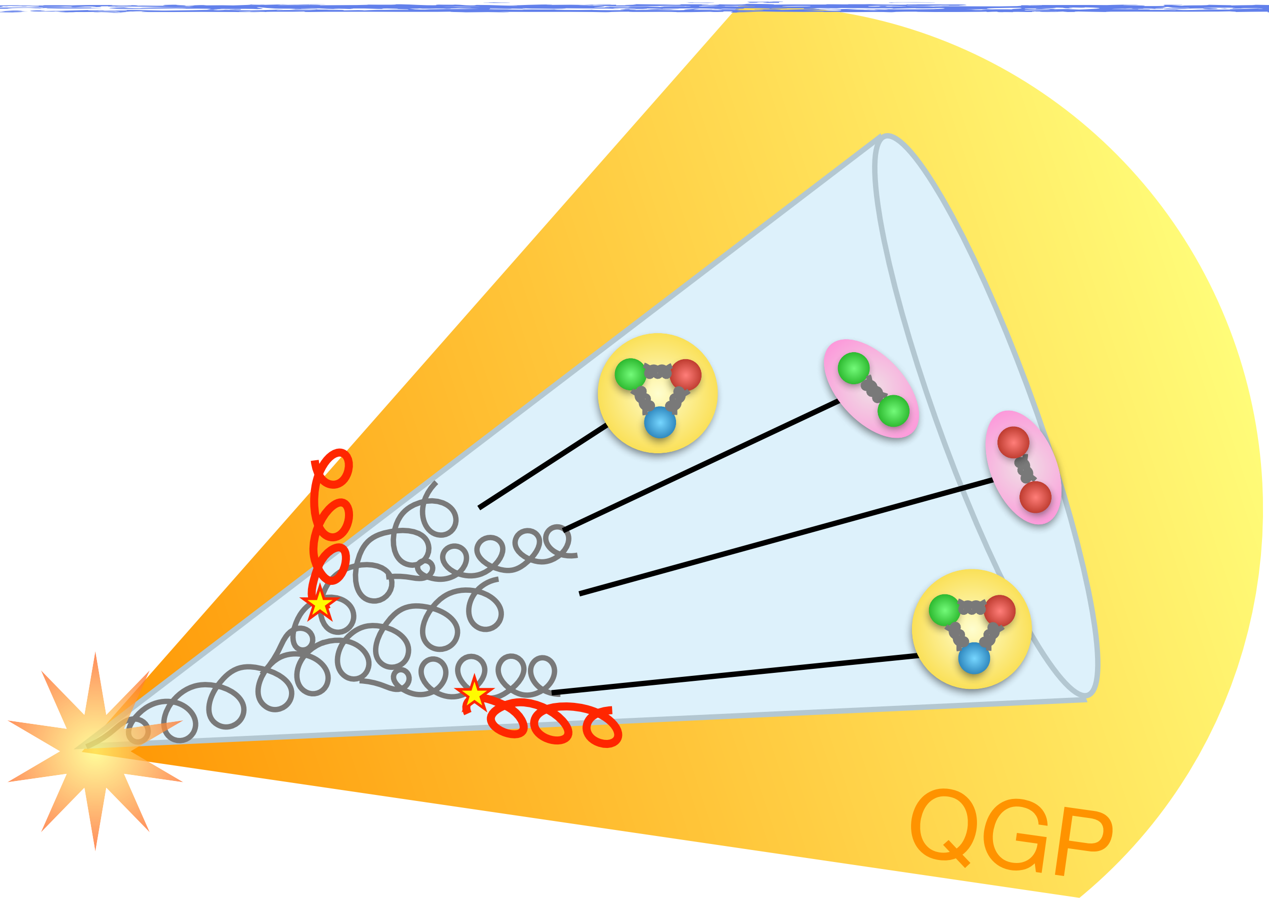
Jets in hadronic collisions



The hadrons move along the same direction

Jets

Jets in heavy ion collisions

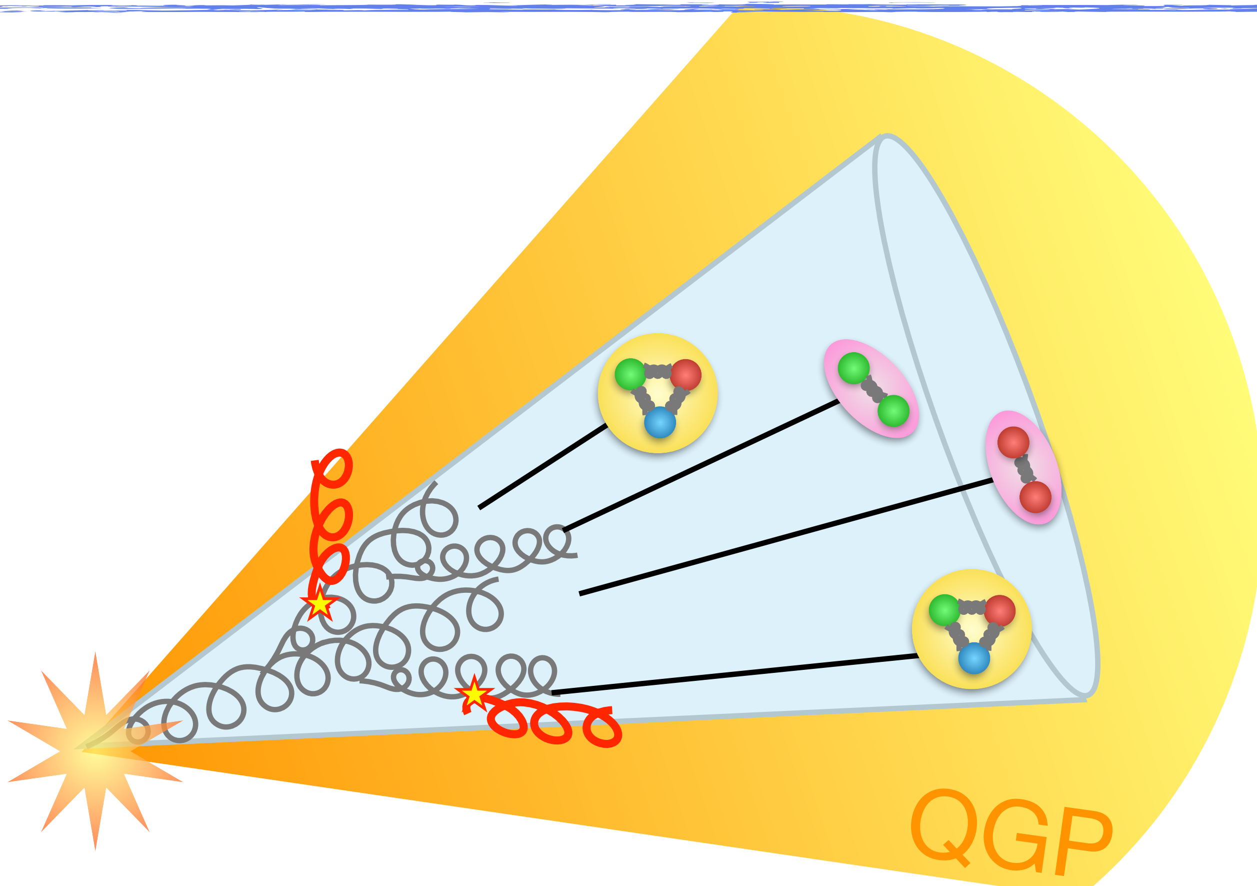


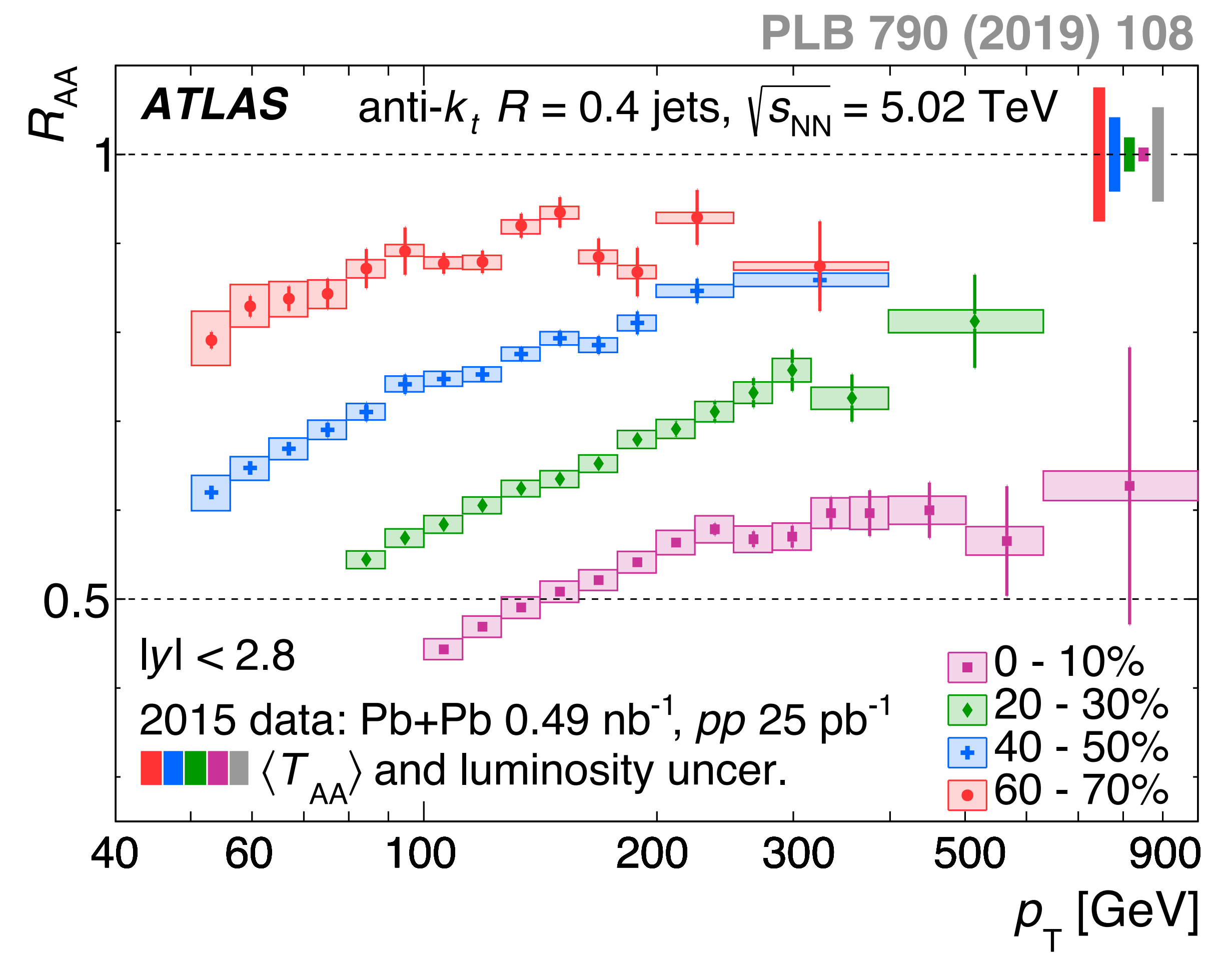
The partons interact
with the plasma

jet loses energy

jet quenching

Jets in heavy ion collisions





The partons interact with the plasma

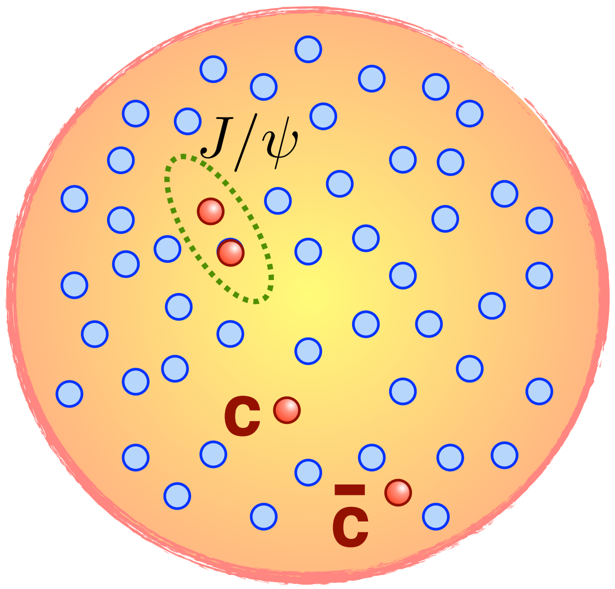
jet loses energy

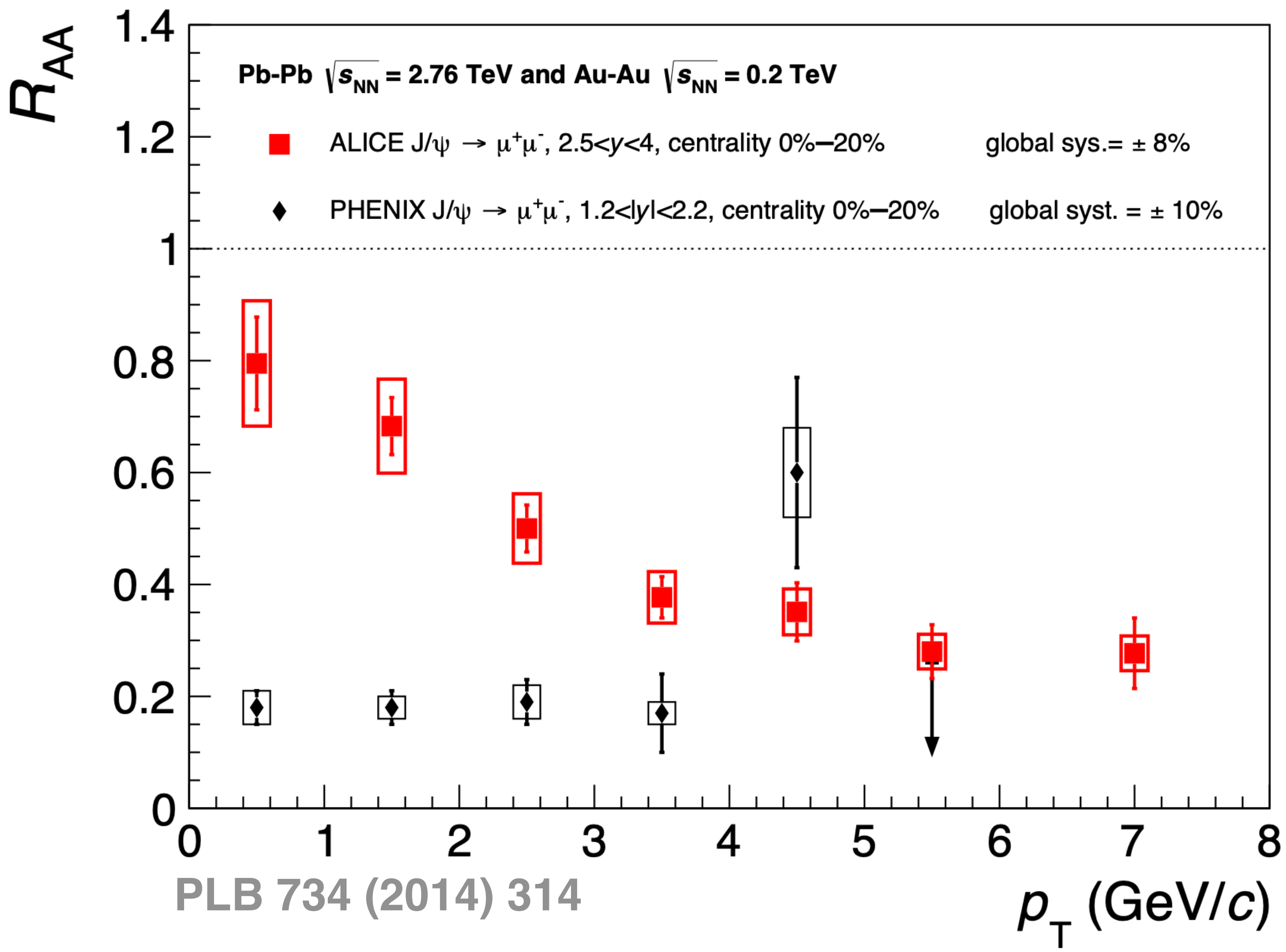
R_{AA} is the yield in PbPb over the expectation from pp

$R_{AA} < 1$

jet quenching

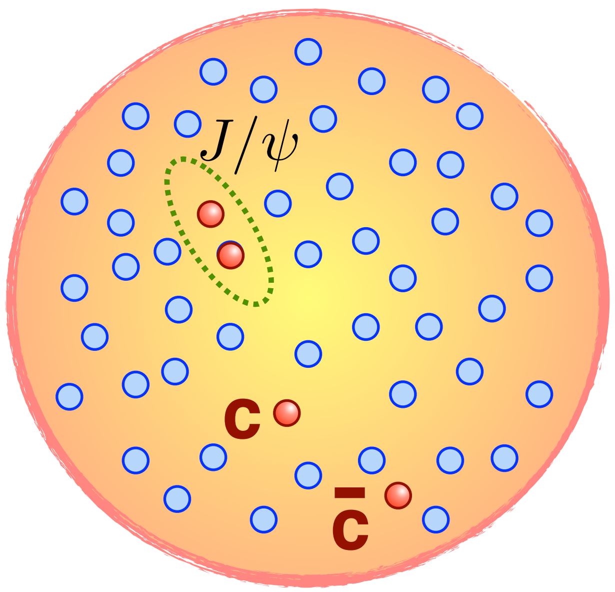
J/ψ in heavy ion collisions

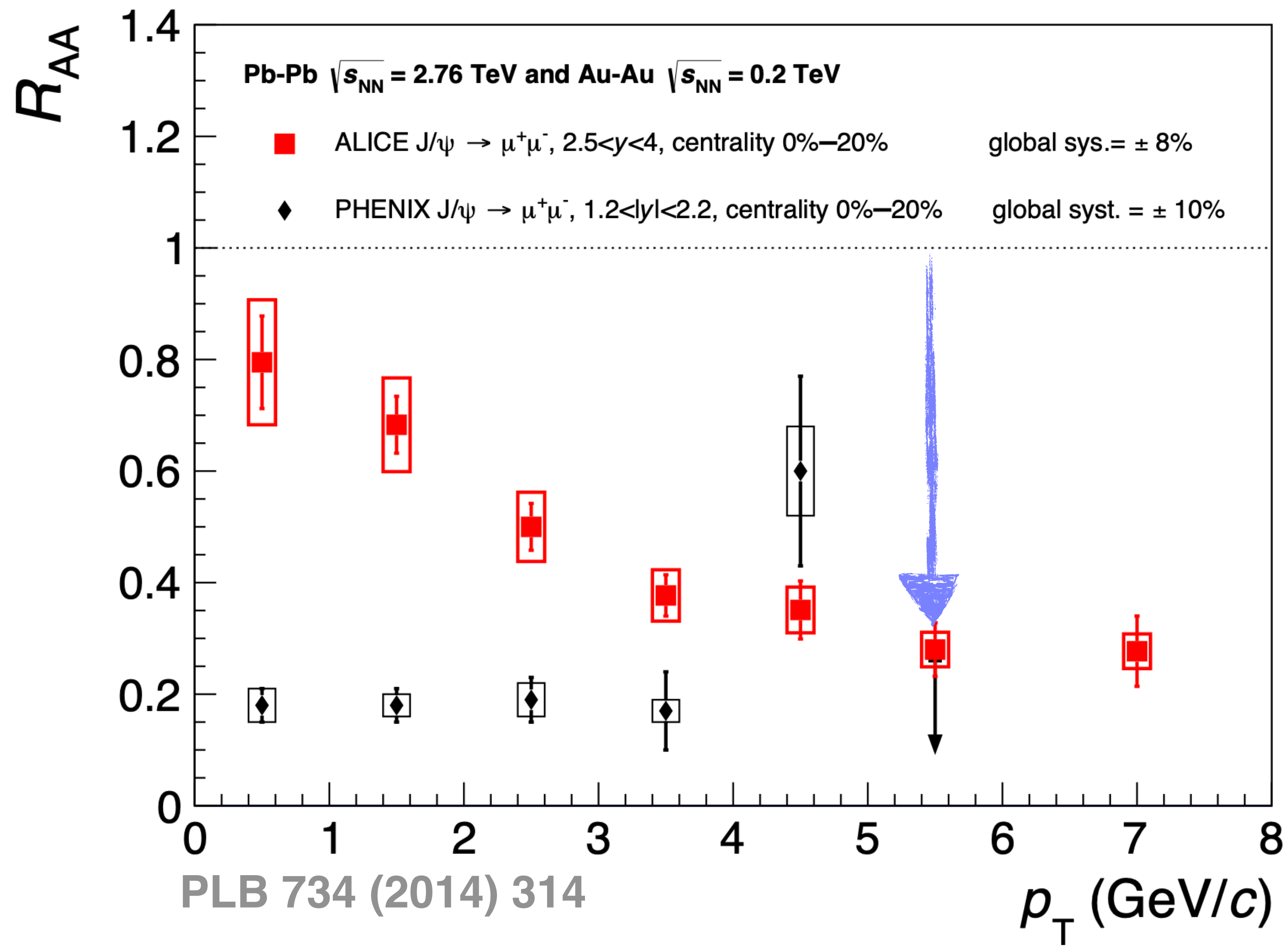




PLB 734 (2014) 314

J/ψ in heavy ion collisions

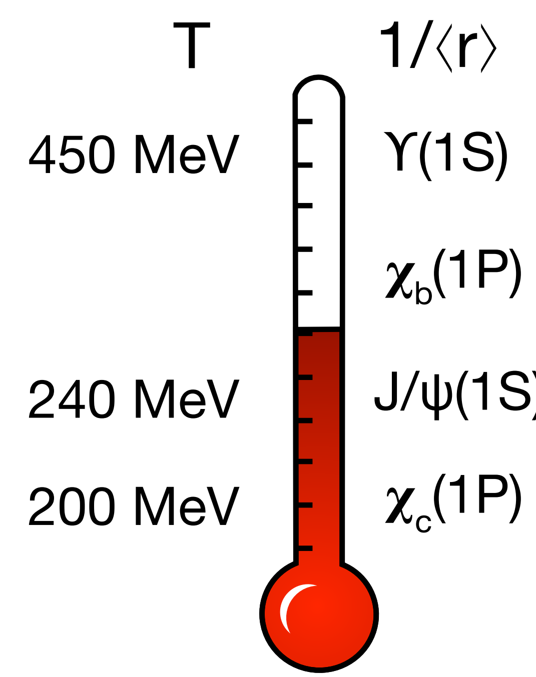




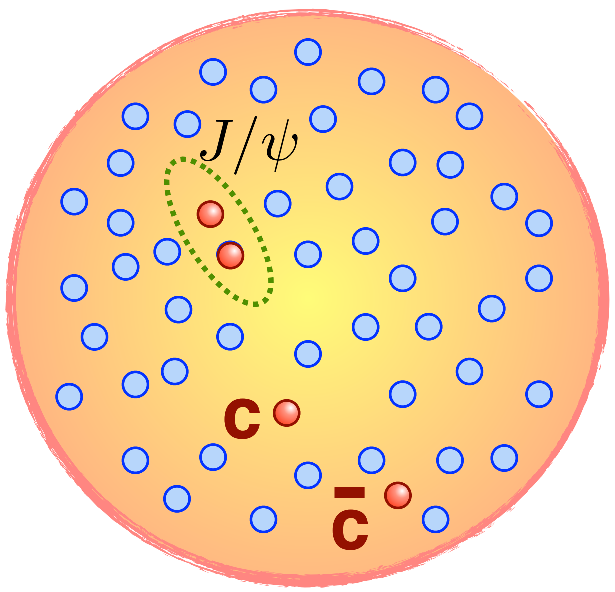
PLB 734 (2014) 314

Suppression
↳Debye screening

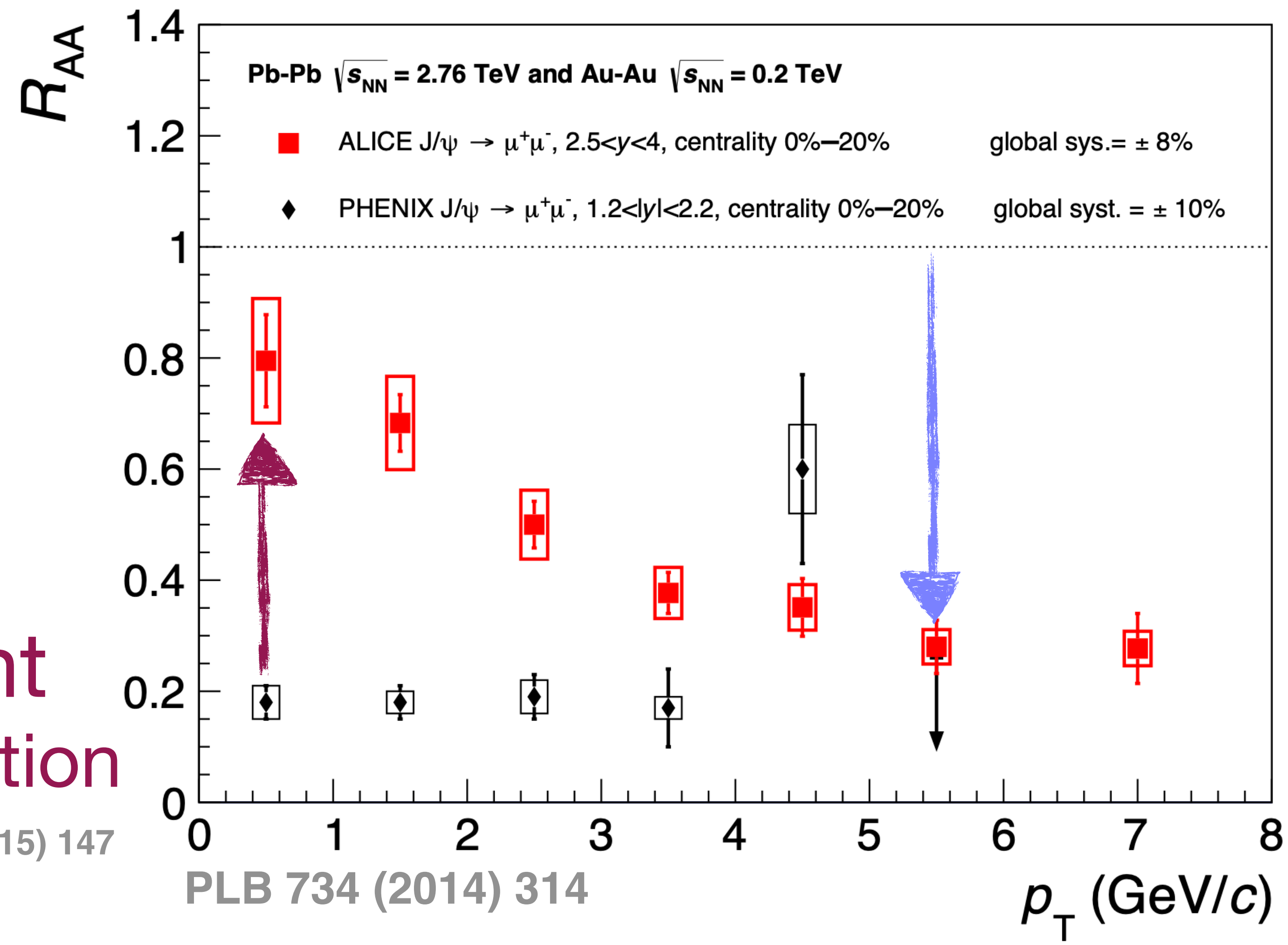
Matsui and Satz, PLB 178 (1986) 416



J/ψ in heavy ion collisions

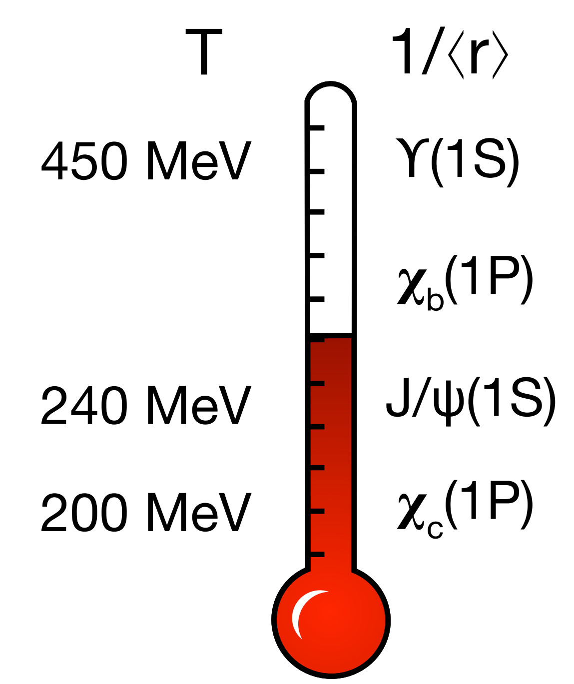


Enhancement
↳ Recombination
Du and Rapp, NPA 943 (2015) 147

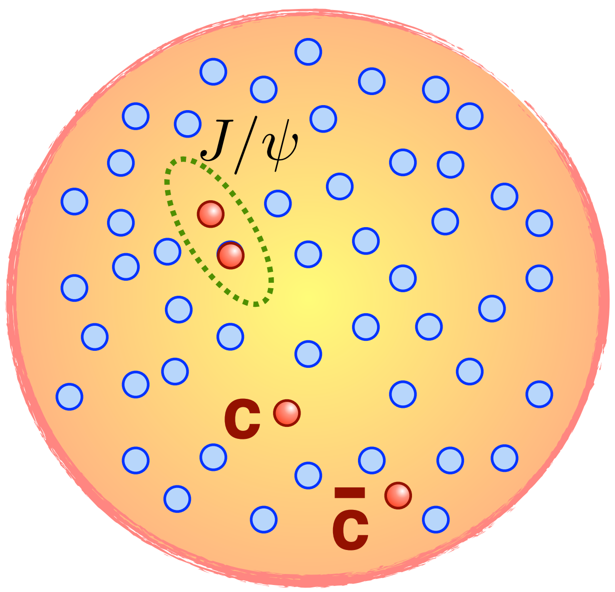


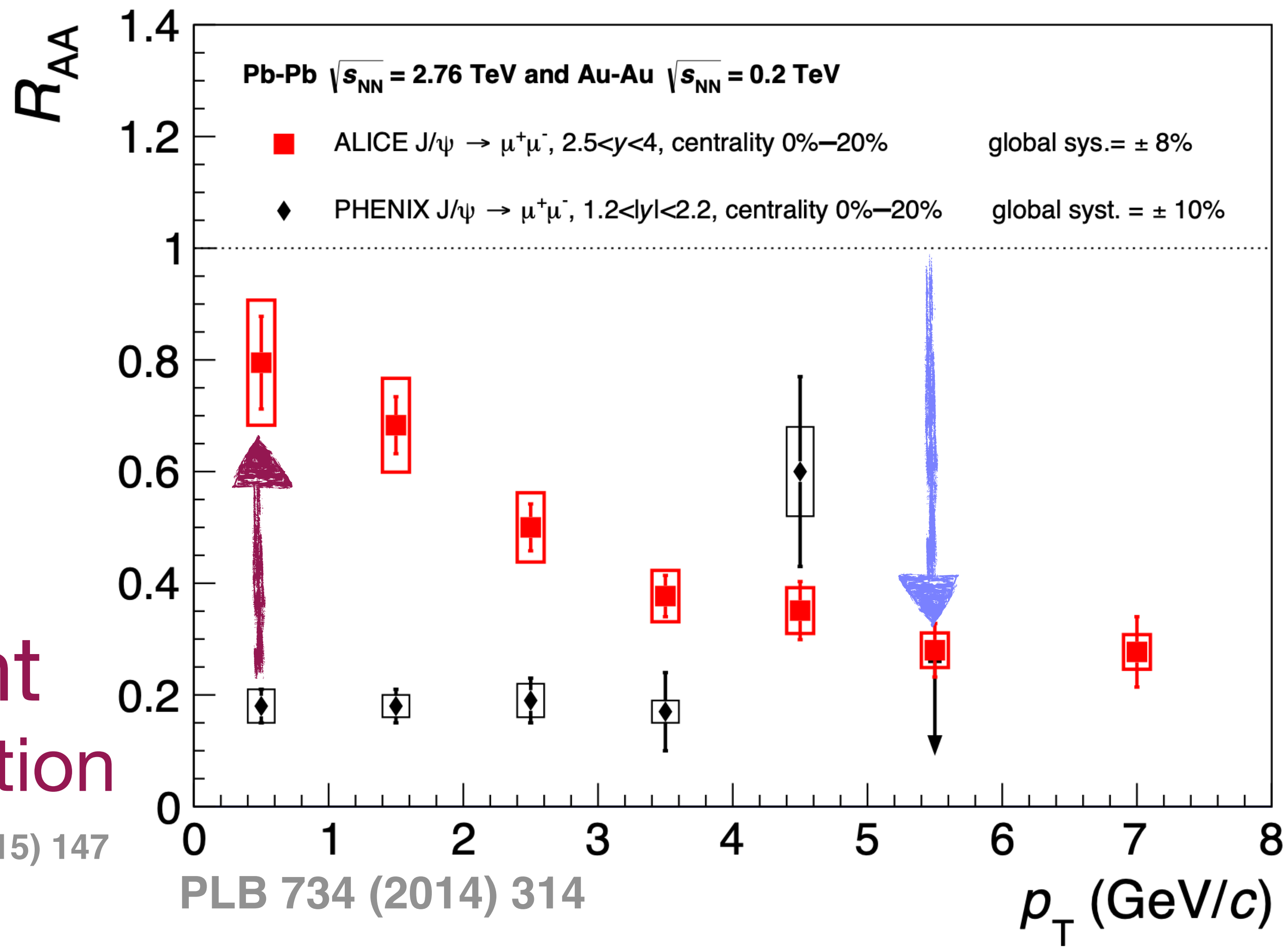
PLB 734 (2014) 314

Suppression
↳ Debye screening
Matsui and Satz, PLB 178 (1986) 416



J/ψ in heavy ion collisions

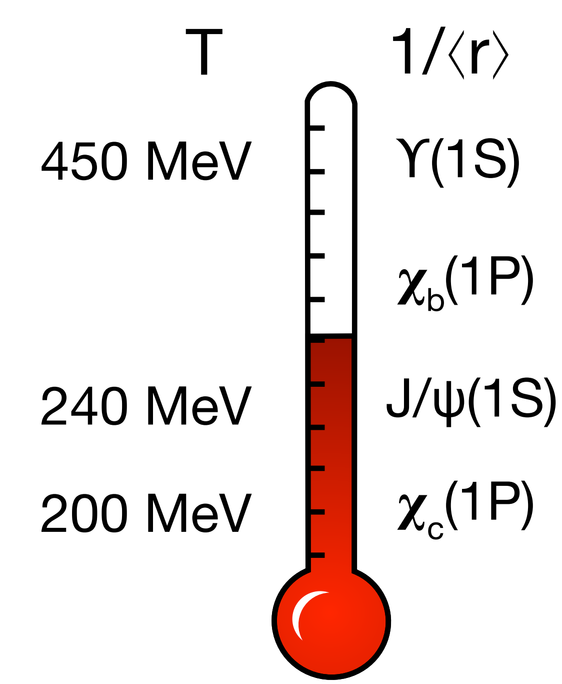




PLB 734 (2014) 314

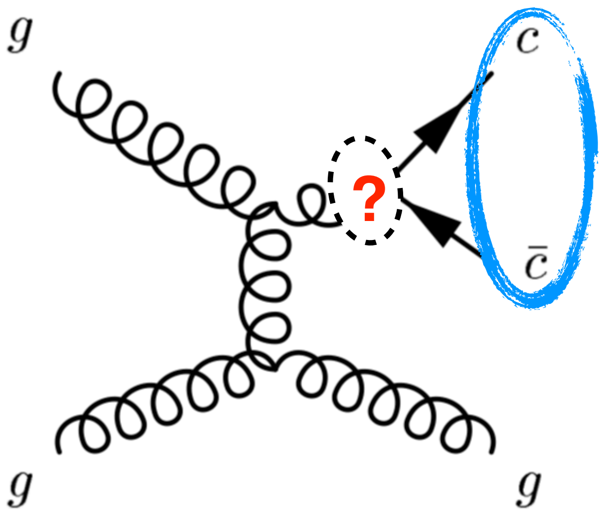
Suppression
↳ Debye screening
Matsui and Satz, PLB 178 (1986) 416

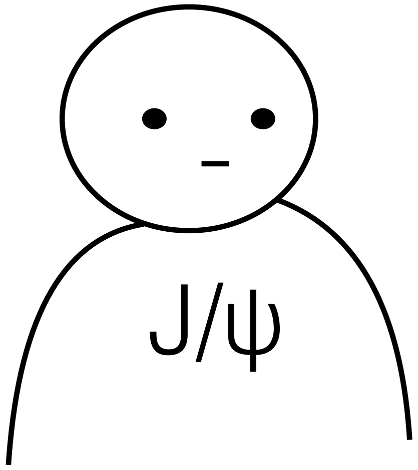
Enhancement
↳ Recombination
Du and Rapp, NPA 943 (2015) 147



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

J/ψ puzzle

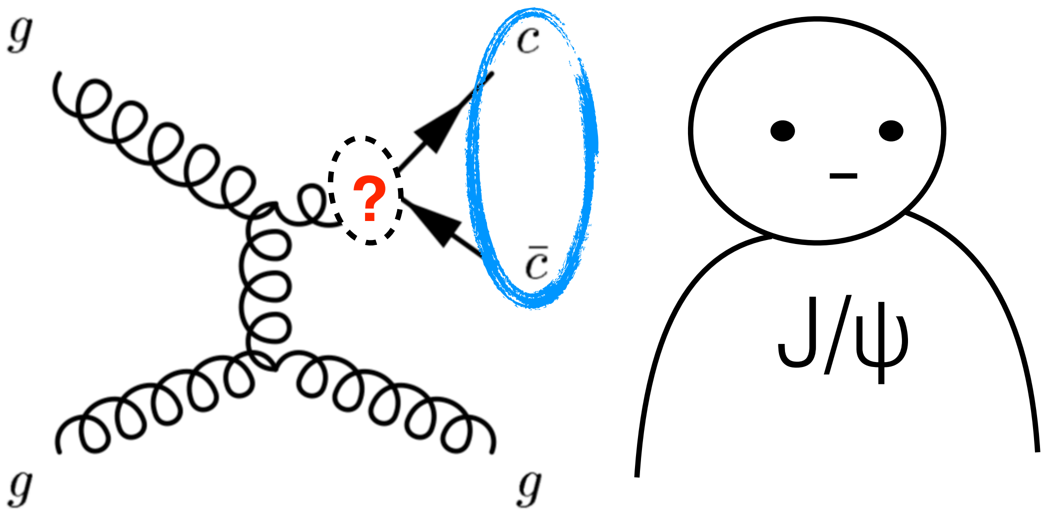




charm formation
➔ bound state

not fully understood

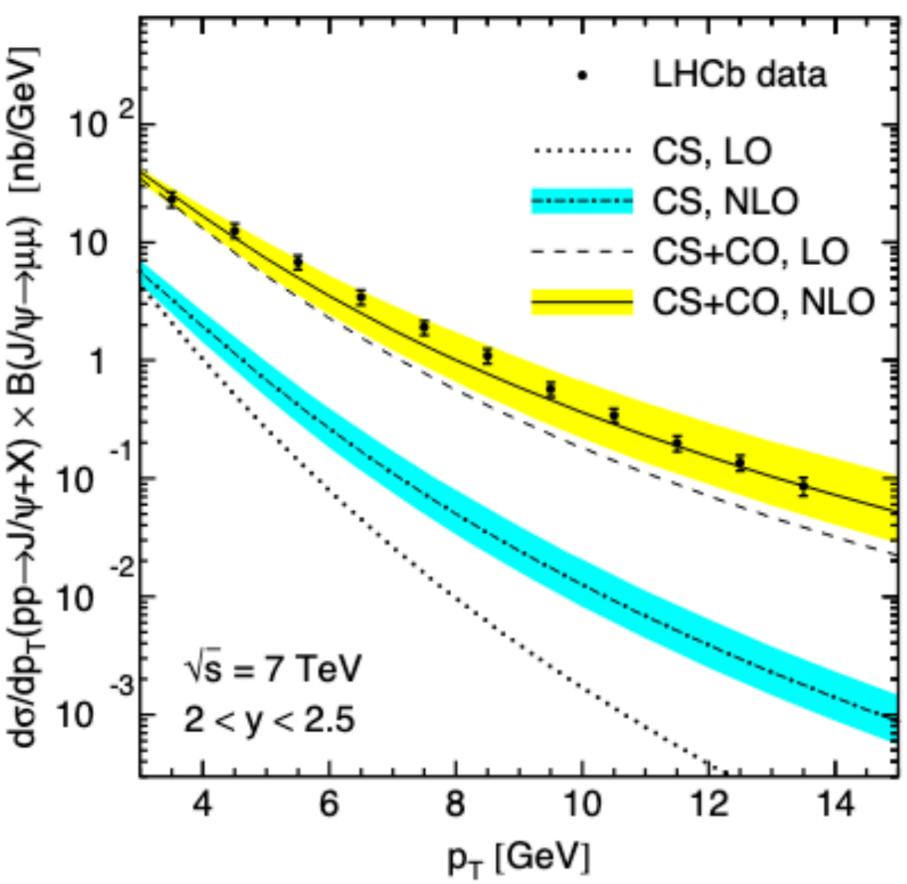
J/ψ puzzle



charm formation
➔ bound state

not fully understood

Models can't reproduce all data measurements



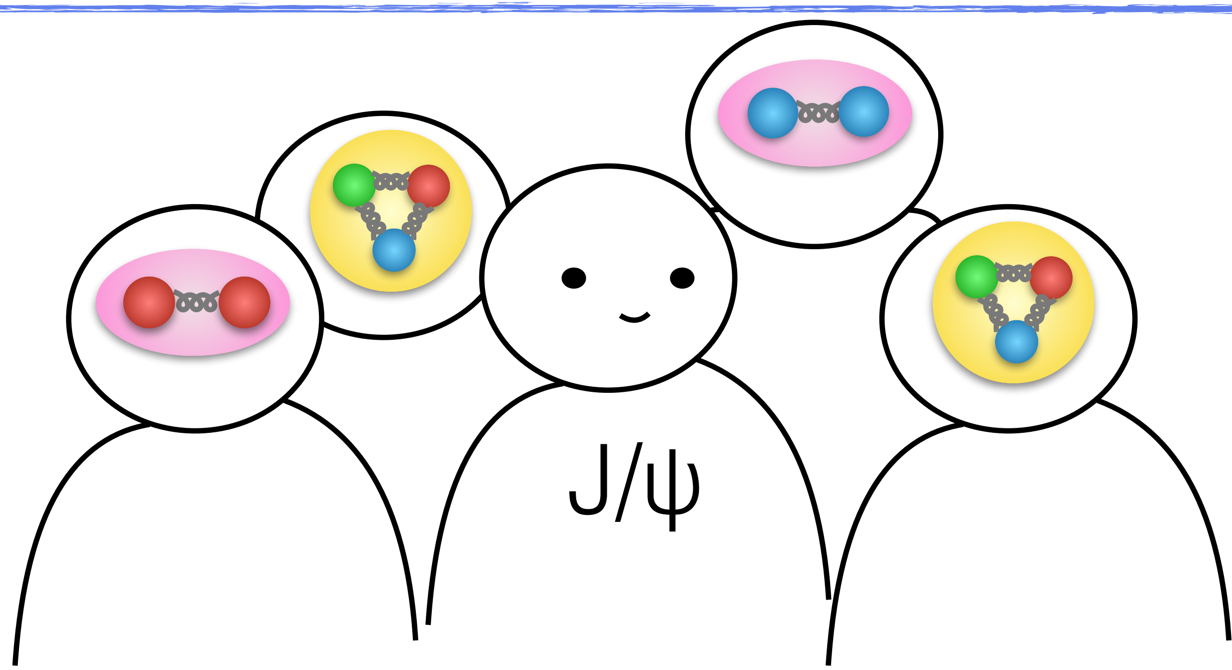
M. Butenschoen. et al *MPLA* 28 (2013) 1350027

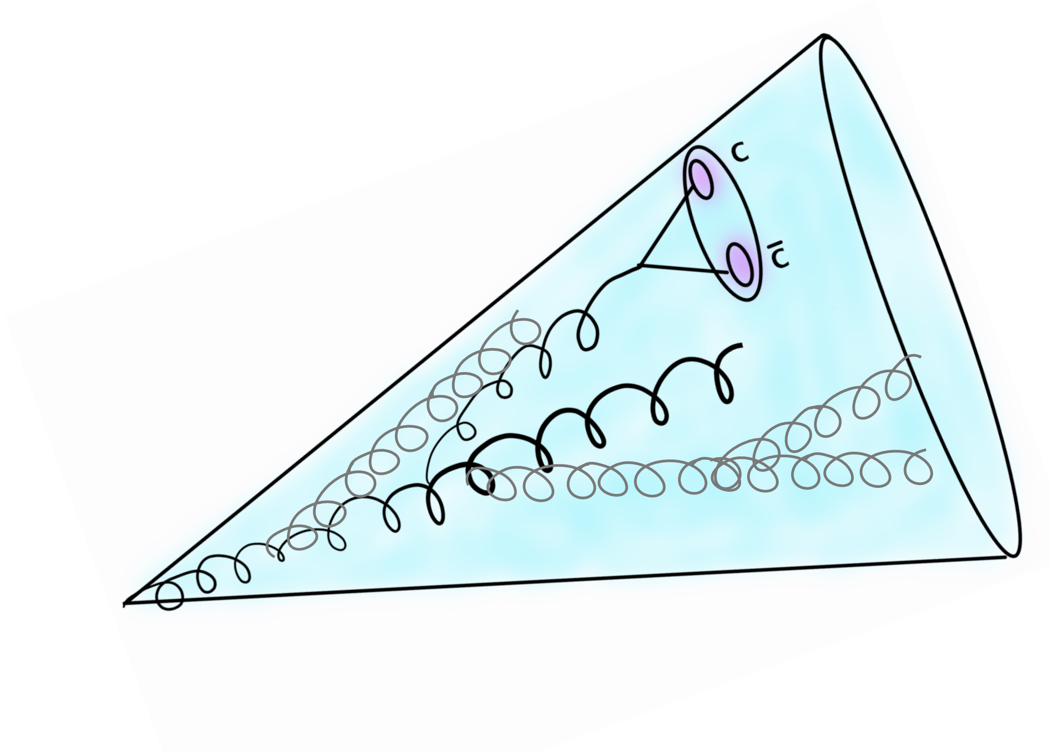
Problems: Polarisation

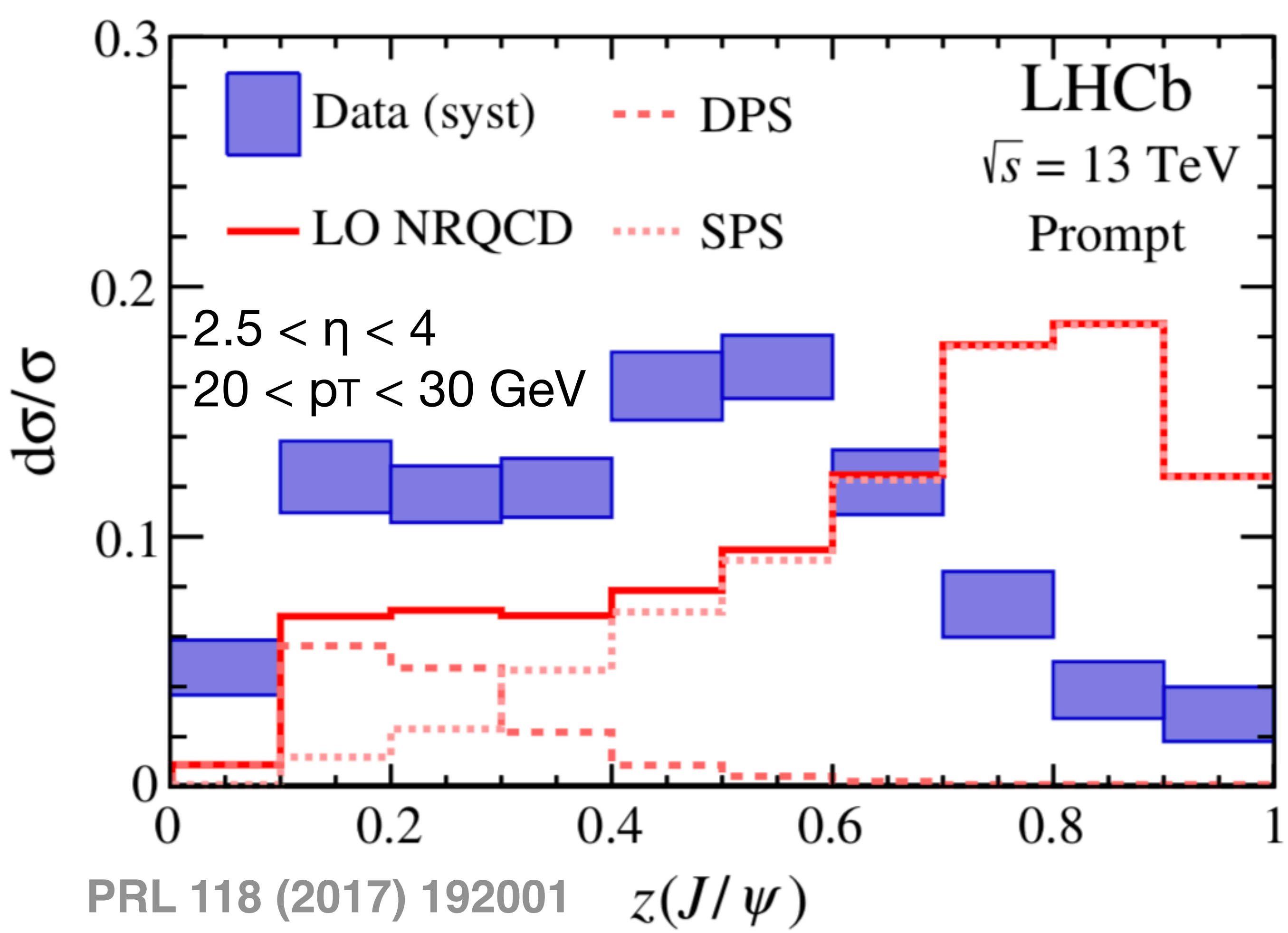
LDME fit	J/ψ hadropr.	J/ψ photopr.	J/ψ polar.	η_c hadropr.
Butenschön et al.	✓($p_T > 3$ GeV)	✓	✗	✗
Chao et al. + η_c	✓($p_T > 6.5$ GeV)	✗	✓	✓
Zhang et al.	✓($p_T > 6.5$ GeV)	✗	✓	✓
Gong et al.	✓($p_T > 7$ GeV)	✗	✓	✗
Chao et al.	✓($p_T > 7$ GeV)	✗	✓	✗
Bodwin et al.	✓($p_T > 10$ GeV)	✗	✓	✗

Maxim's talk on Monday

J/ψ in jets in pp







PRL 118 (2017) 192001

Recent measurement by LHCb: J/ψ in jets

z = J/ψ p_T / jet p_T

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

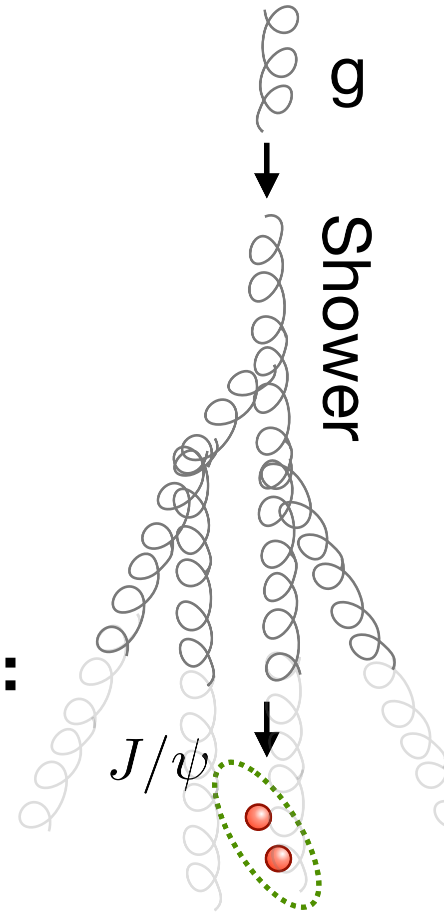
NRQCD vs LHCb

Fixed order calculations are not enough to understand the J/ψ puzzle

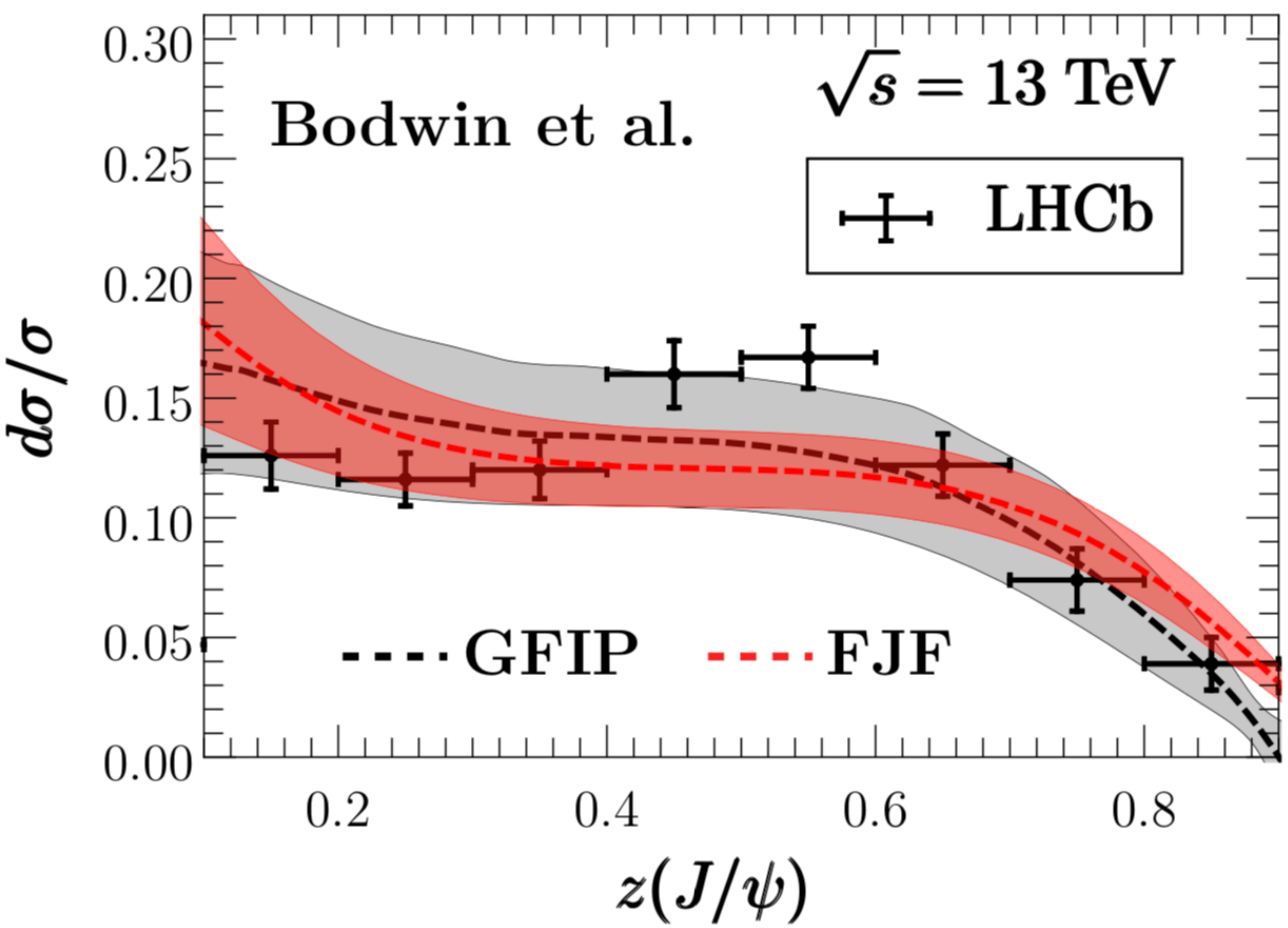
J/ψ could be produced in parton showers

→ Later time

→ Low z



R. Bain et al. PRL 119 (2017) 032002



Two comparable approaches:

GFIP: Gluon Fragmentation Improved Pythia

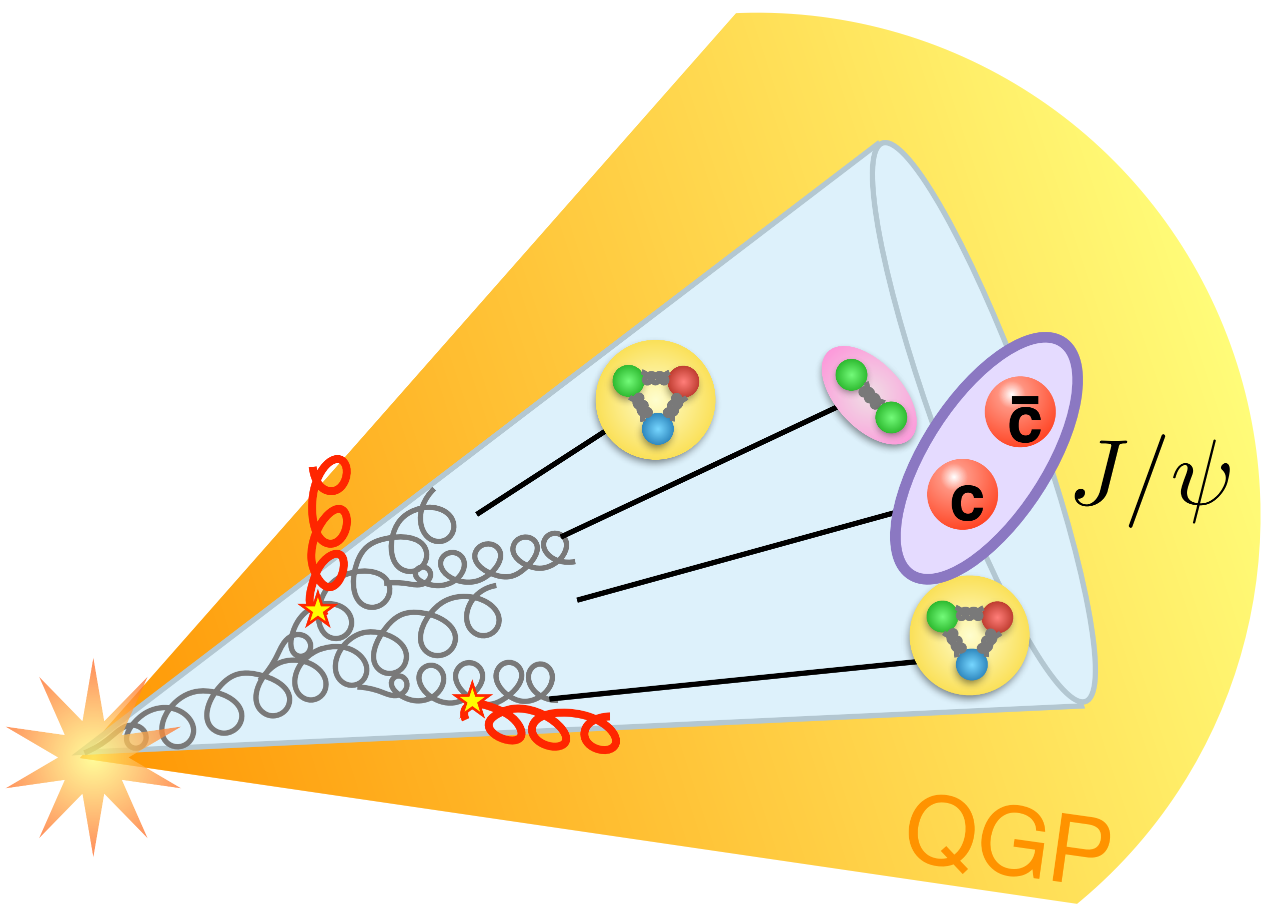
FJF: Fragmentation Jet Functions

Better agreement with LHCb results than LO NRQCD

J/ψ production in AA collisions

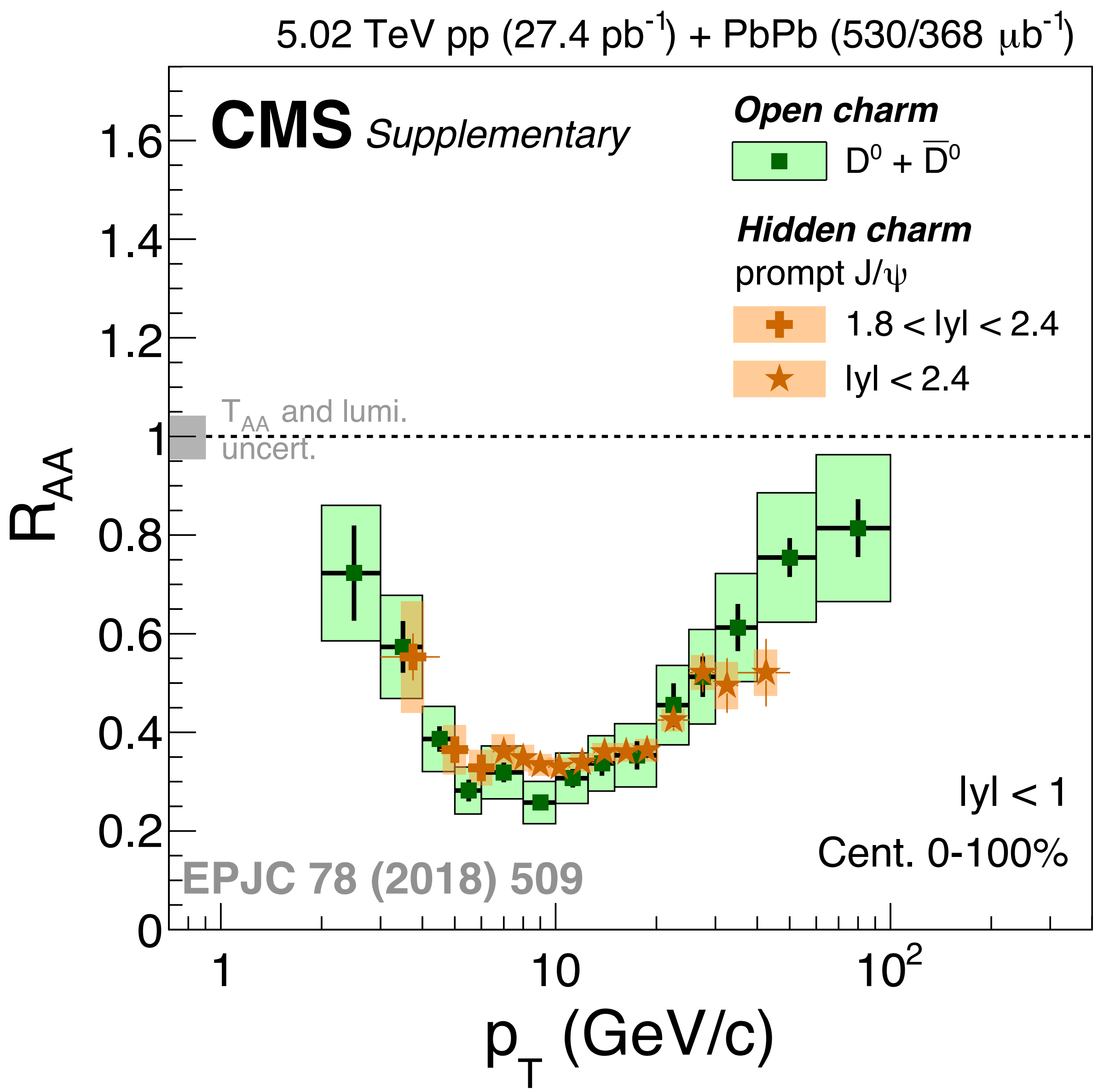
J/ψ may also be produced in parton showers

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



Important implications for the interpretation of J/ψ in HI

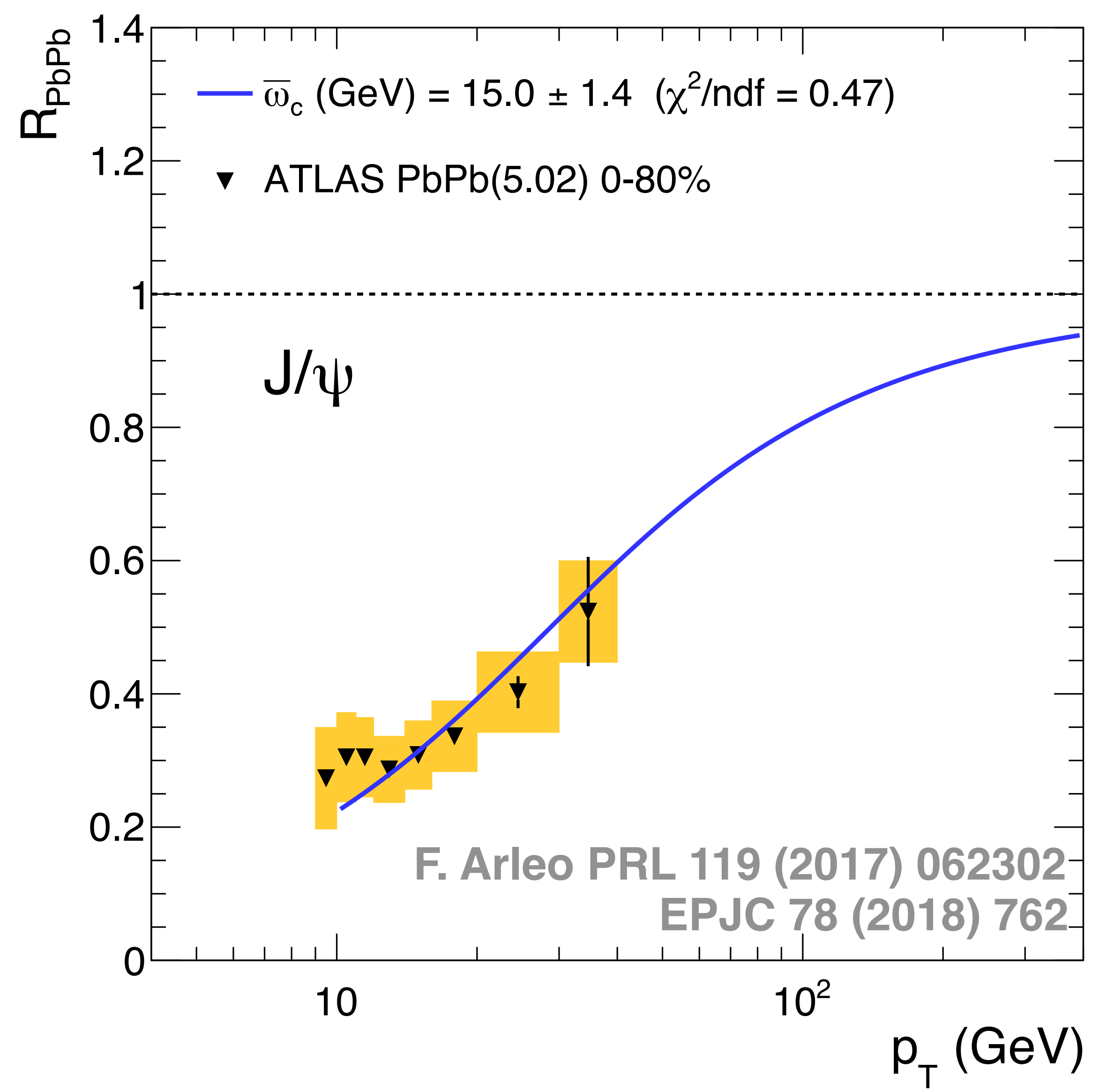
Another look at RAA



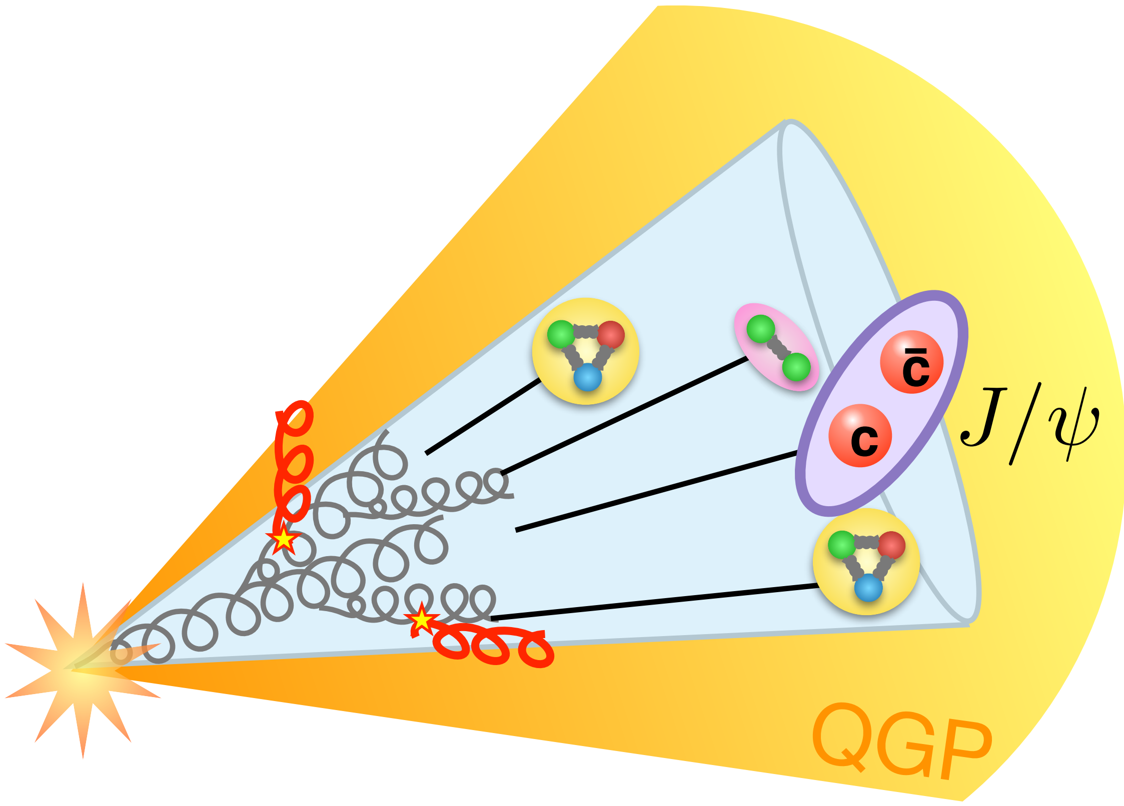
Prompt J/ψ RAA has a similar behaviour to other hadrons

Universal behavior

Well described by calculations of parton energy loss



J/ψ production in AA collisions



Jet quenching might be relevant in J/ψ suppression

Measure the fragmentation function in PbPb collisions

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

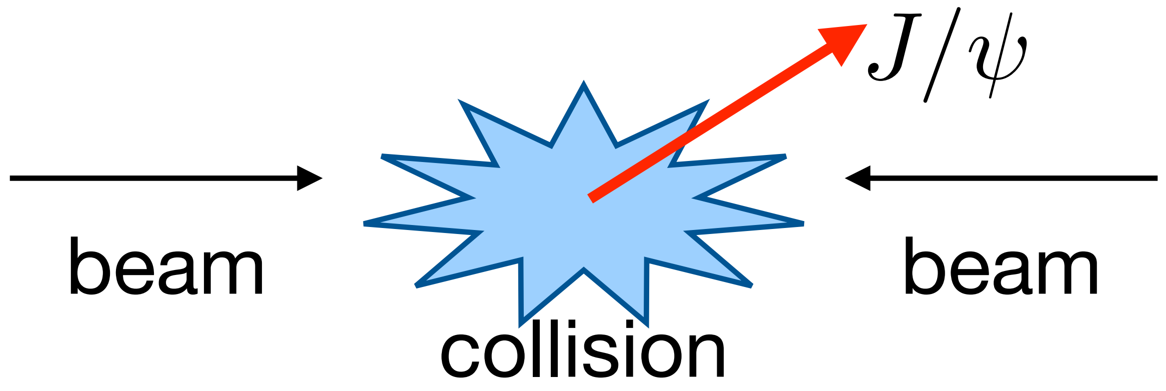
Analysis in CMS

Prompt vs nonprompt J/ψ

Prompt:

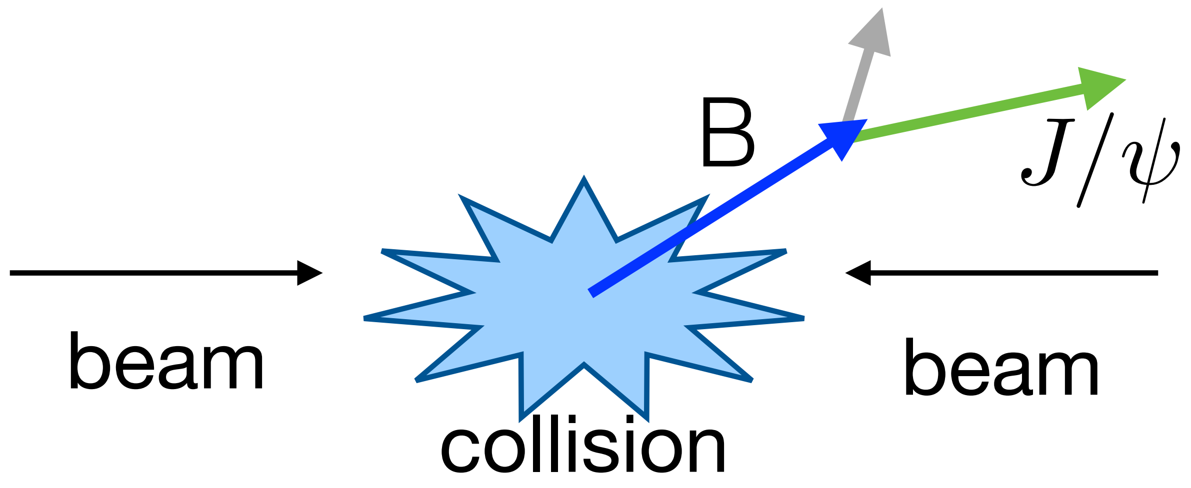
Directly in the collision

Decay of heavier charmonium states



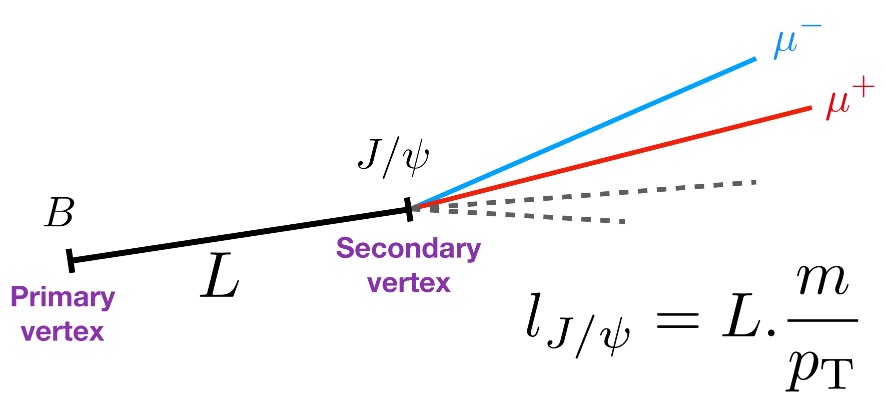
Nonprompt:

Decay of b hadrons



Separation based on the lifetime:

pseudo-proper decay length $\ell_{J/\psi}$



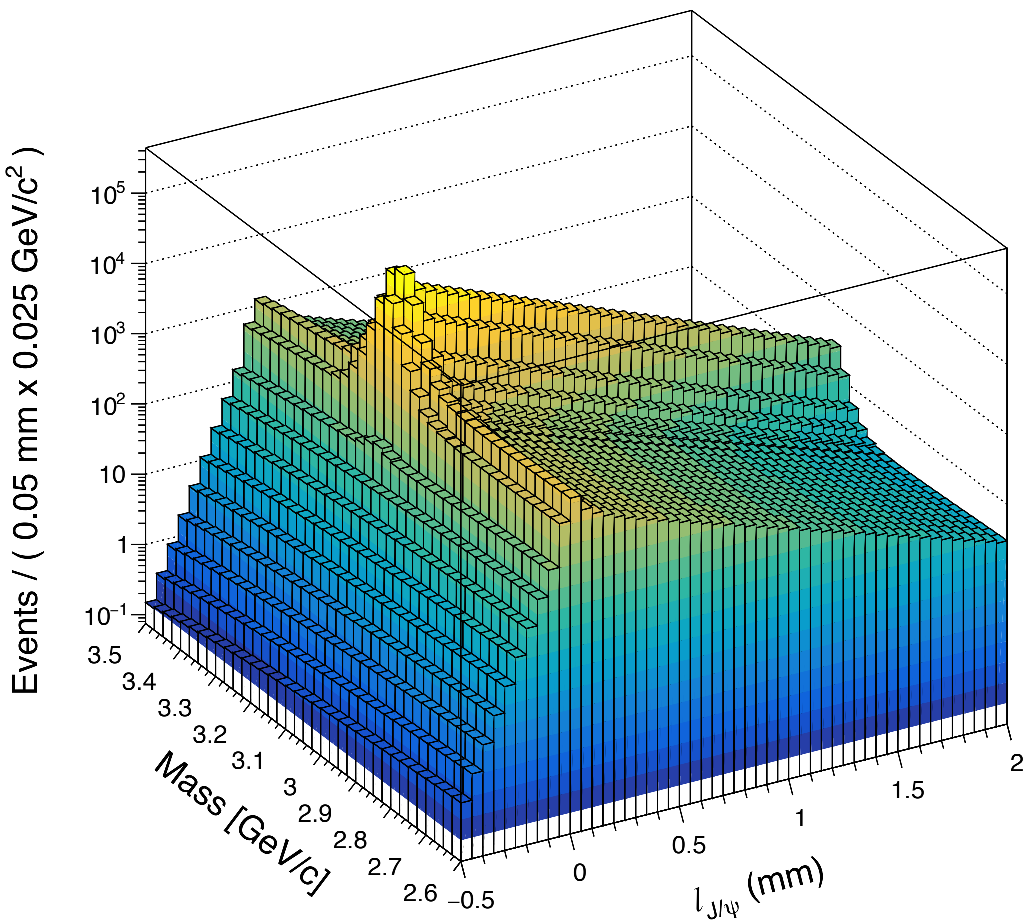
Signal extraction

Extraction the J/ψ yields:

Disentangle Signal/background

Separate prompt/nonprompt

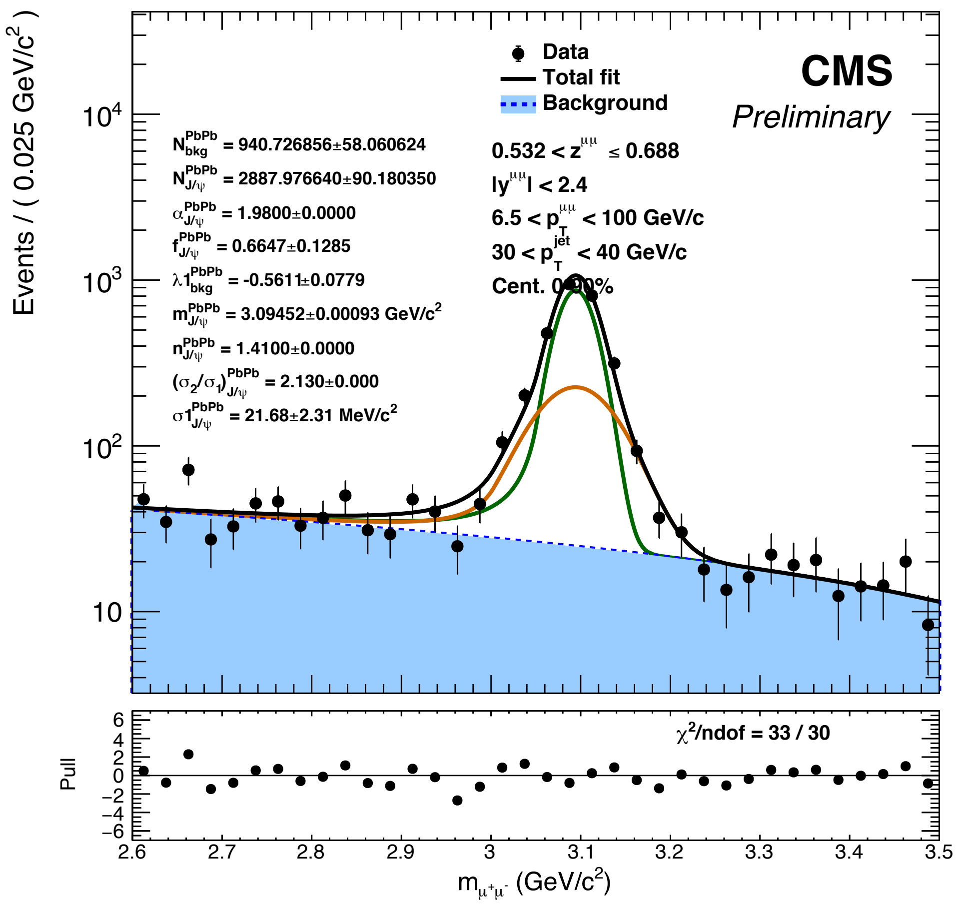
Done using a 2D fitting procedure: Invariant mass and the pseudo-proper decay length



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

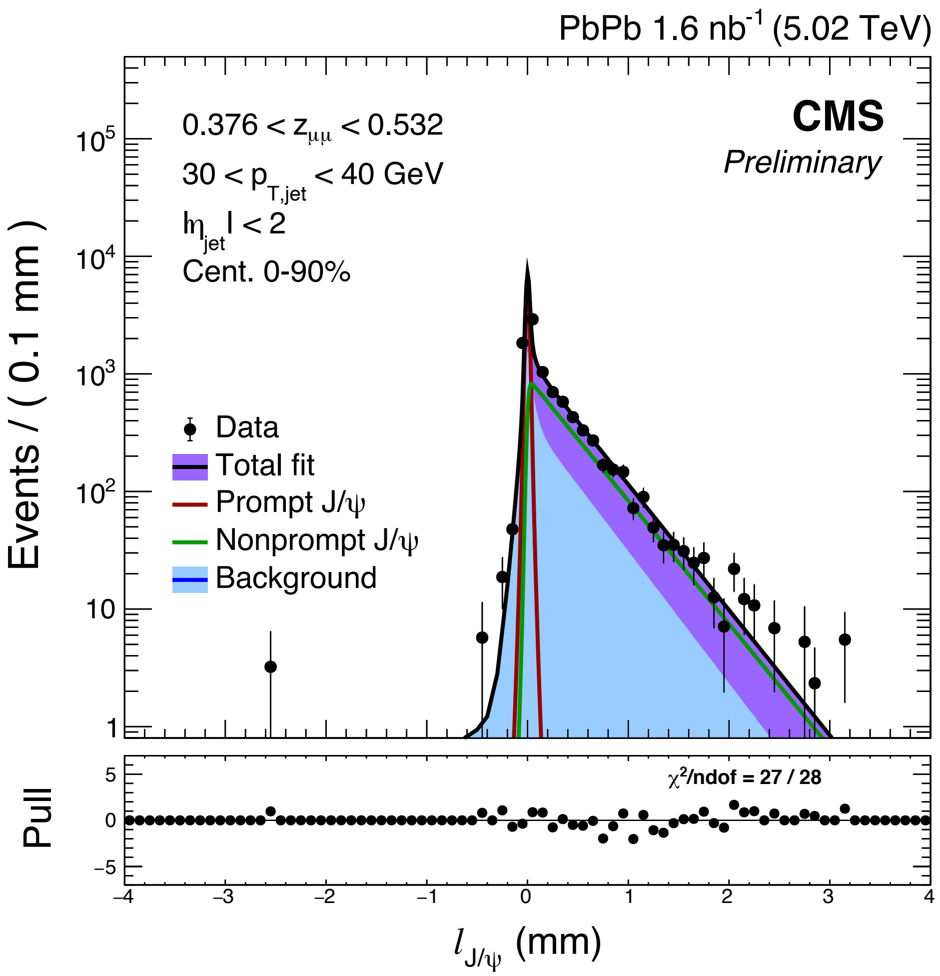


Mass fit = signal + background

Double Crystal Ball

Chebychev polynomial

Signal extraction: $\ell_{J/\psi}$

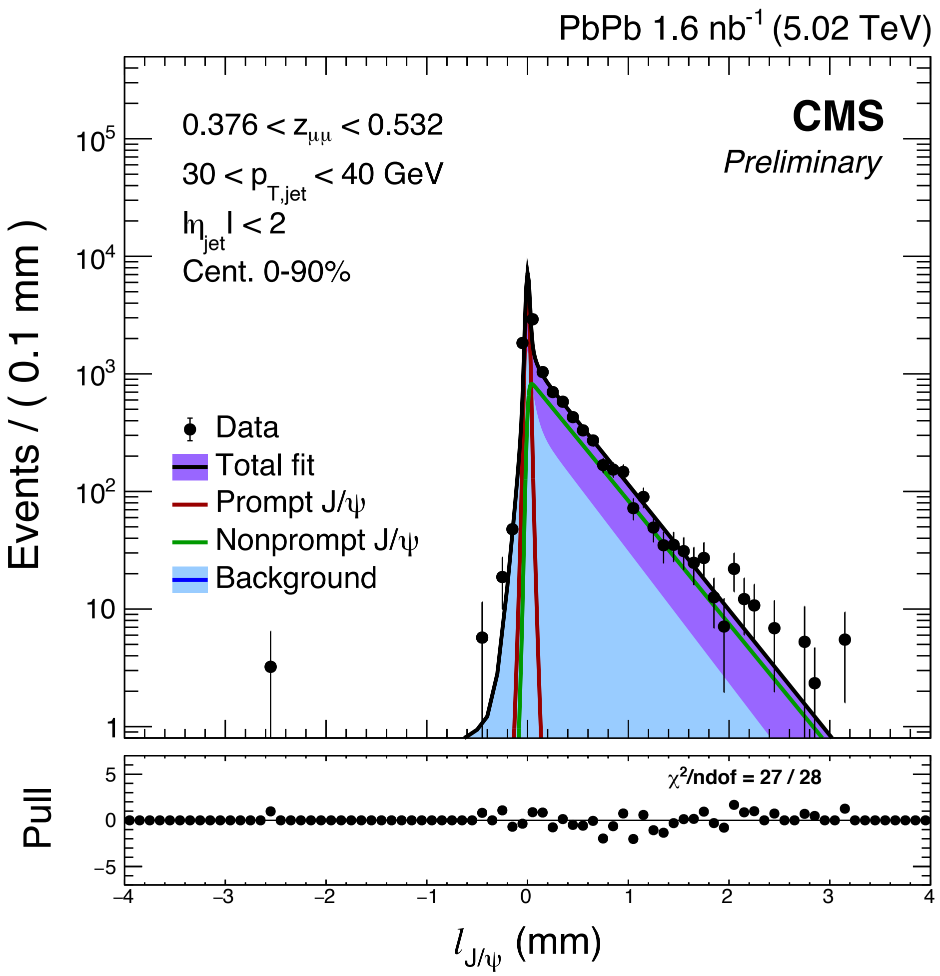


$\ell_{J/\psi}$ fit = signal + background

Prompt component ⊗ resolution → Dirac function, Triple Gaussian

Nonprompt component ⊗ resolution → exponential, Triple Gaussian

Signal extraction: $\ell_{J/\psi}$



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

Prompt component ⊗ resolution

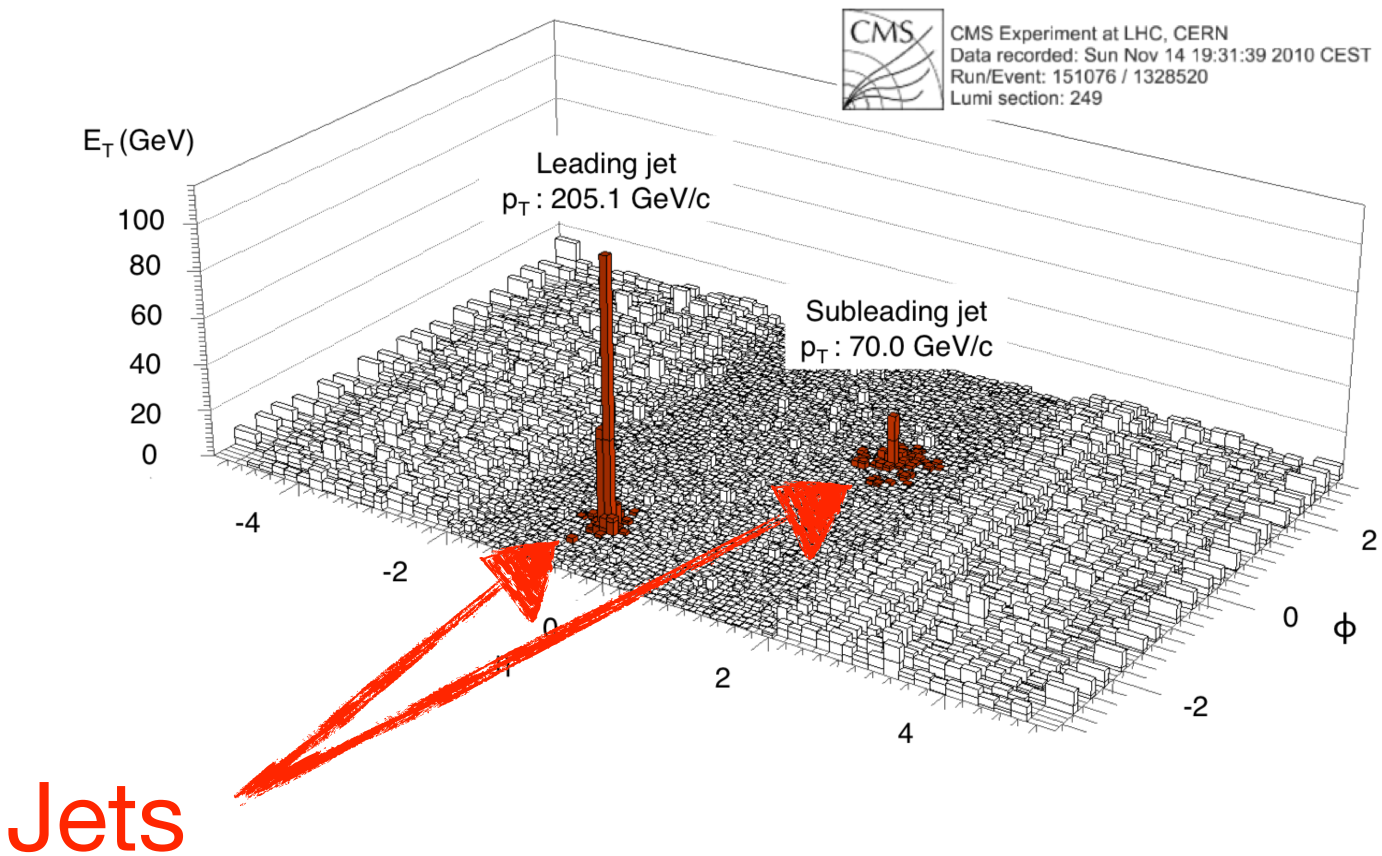
Nonprompt component ⊗ resolution

Prompt-like component ⊗ resolution

nonprompt-like component ⊗ resolution

Jet p_T determination

Challenges: detector response + background fluctuations

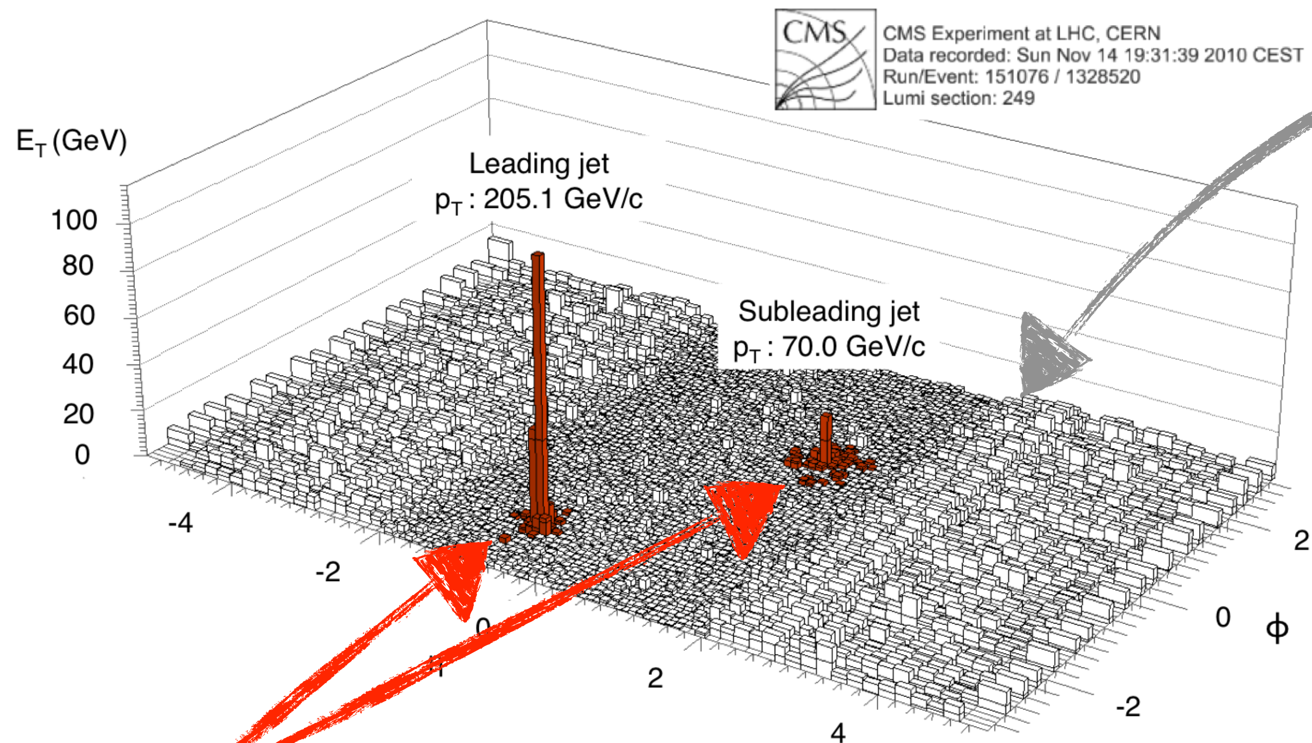


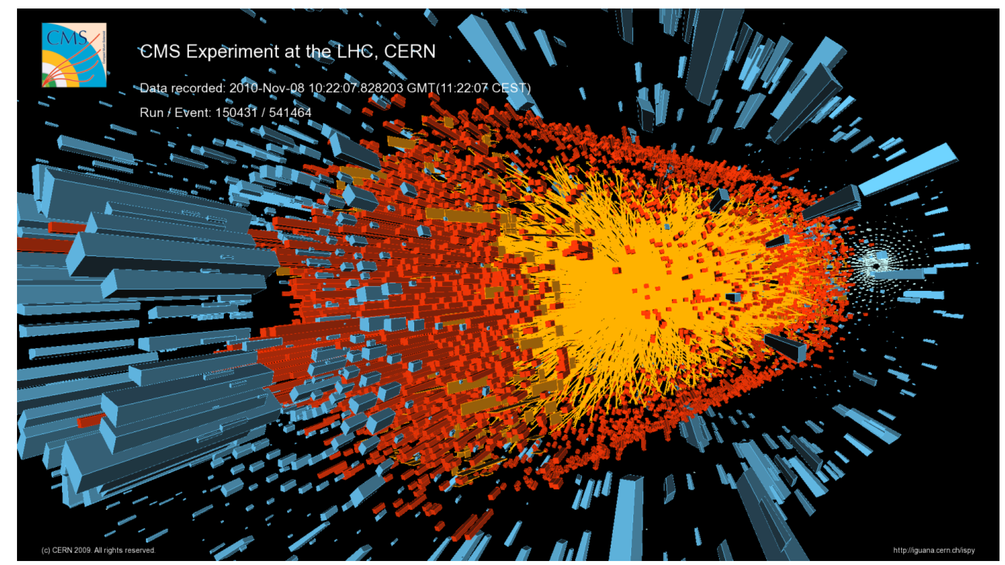
Low p_T jets can be hard to distinguish from the background

Jet p_T determination

Challenges: detector response + background fluctuations

Underlying event

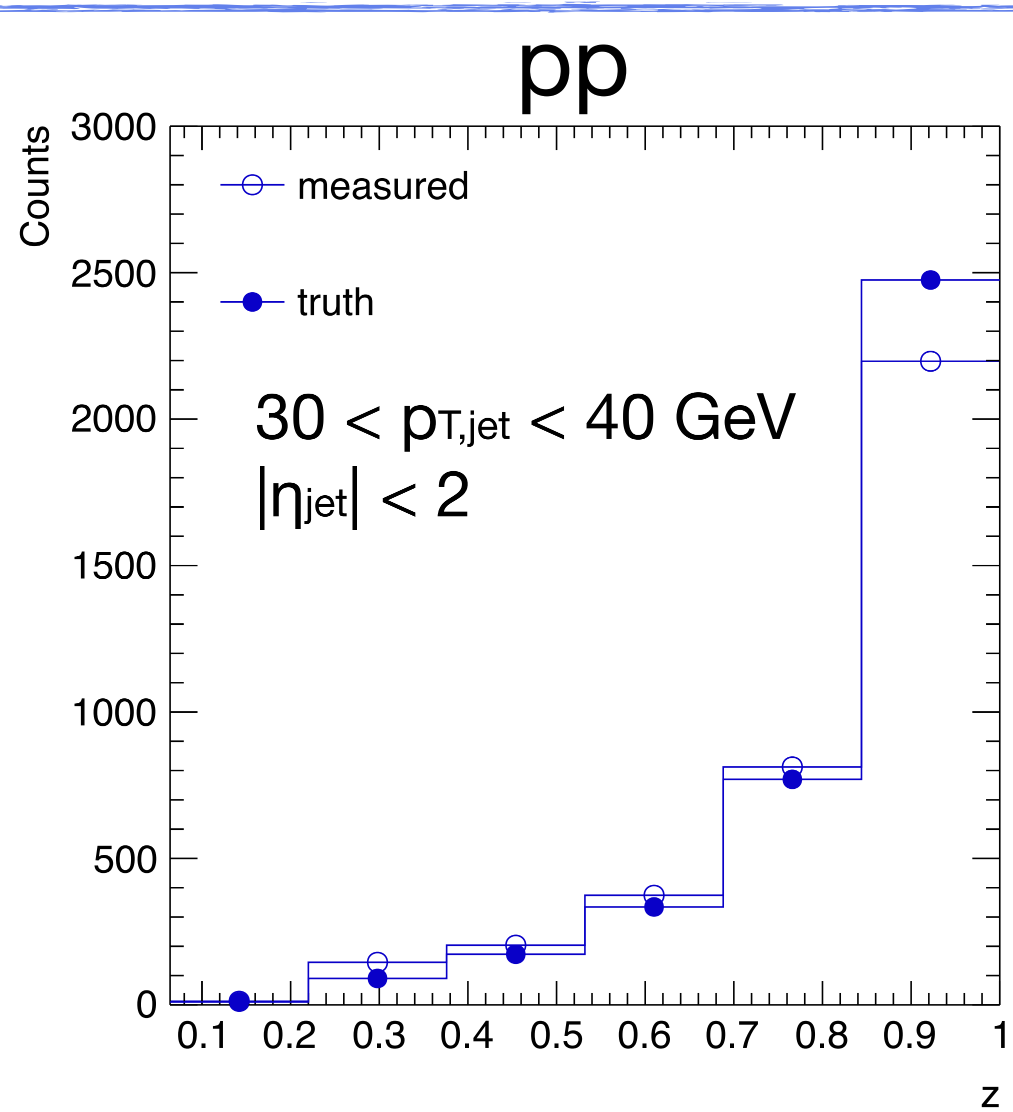


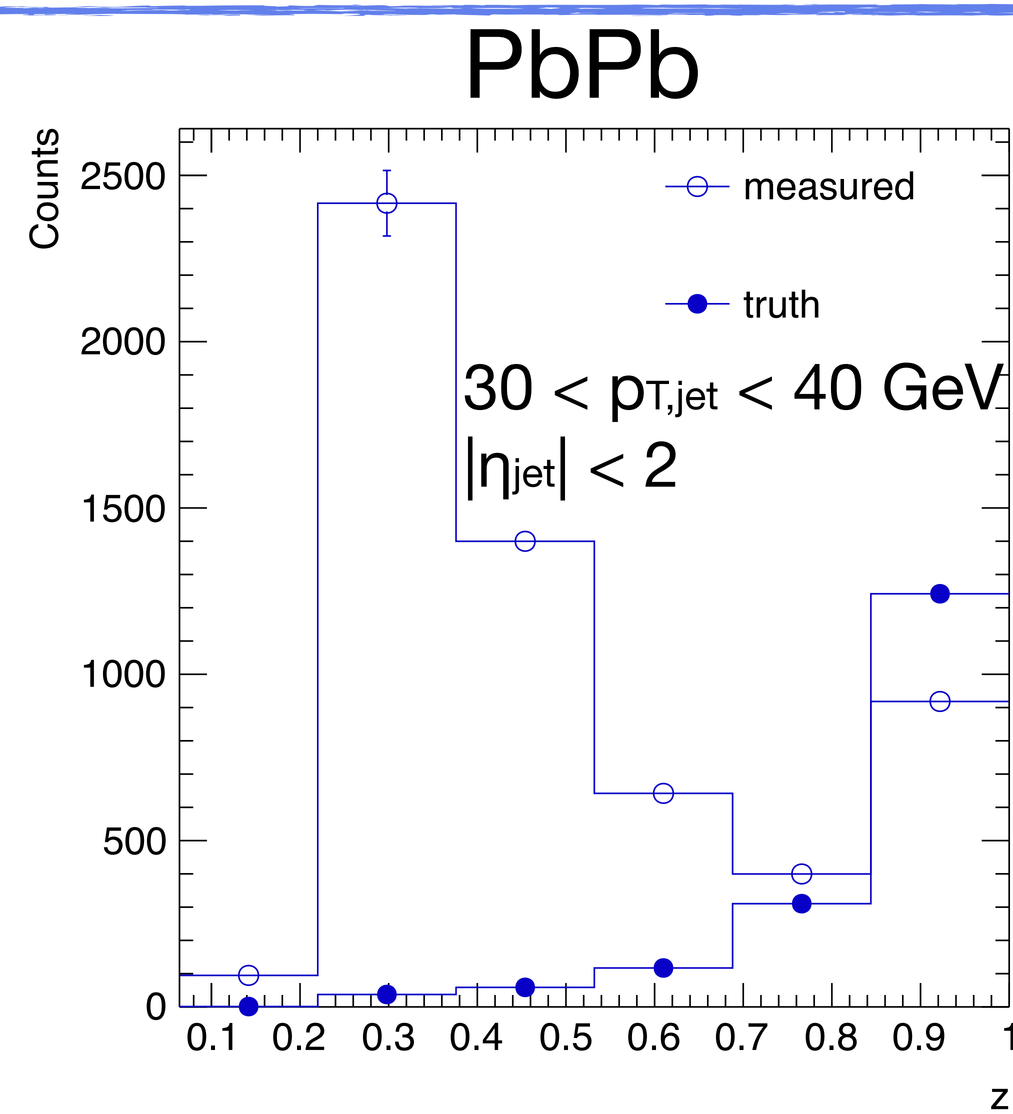


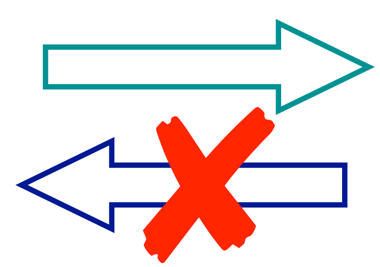
Jets

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

Bin migration

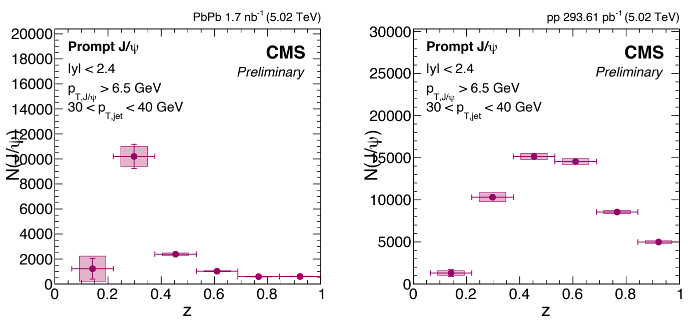




True distribution  Measured distribution

Unfolding is needed for data

Unfolding



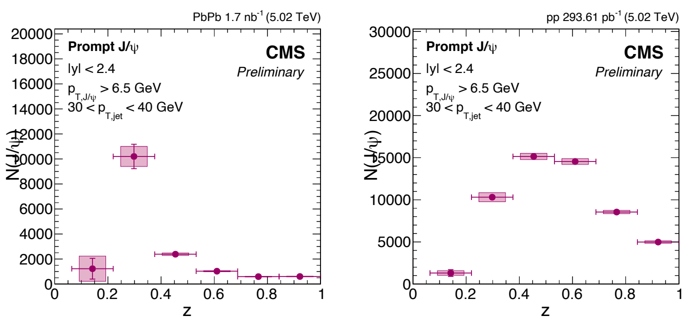
Extracted yields

Iterative Bayesian Unfolding

D'Agostini, NIMA 362 (1995) 487

results

Unfolding



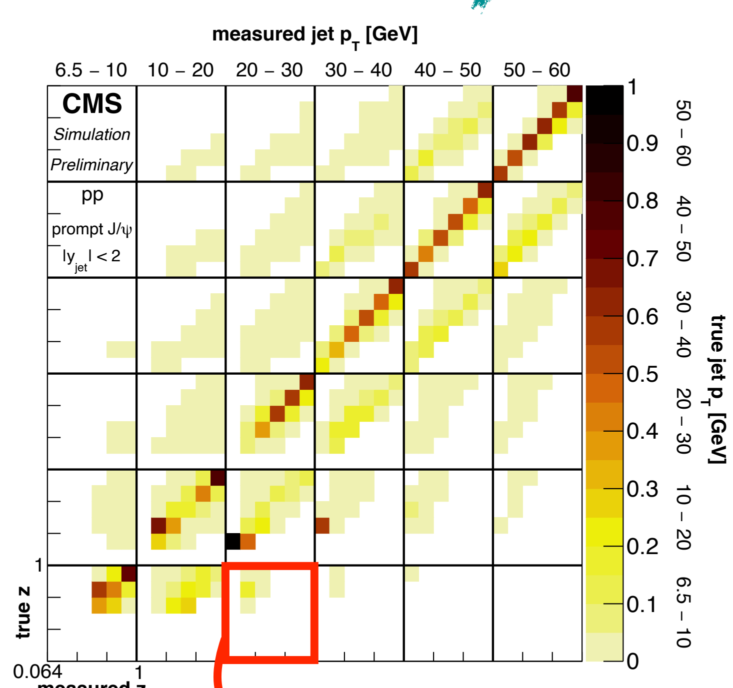
Extracted yields

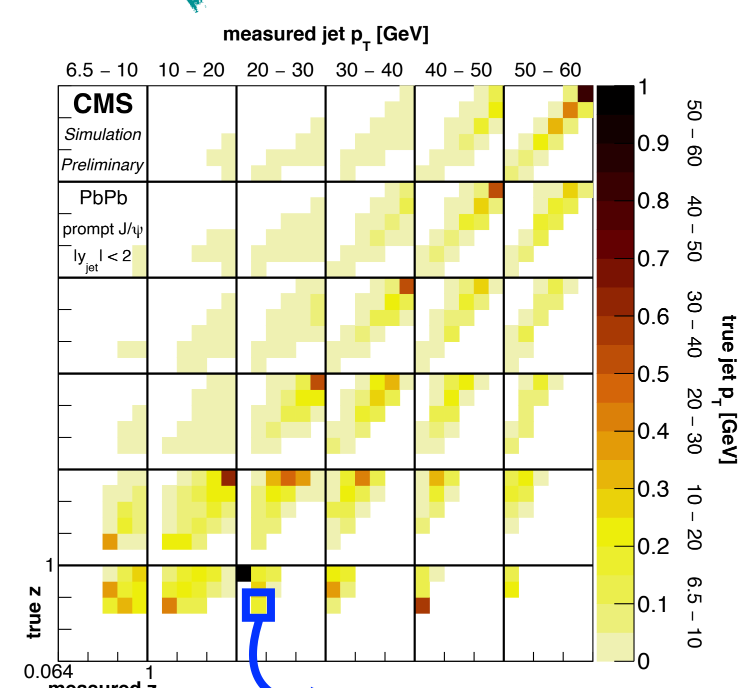
Iterative Bayesian Unfolding

D'Agostini, NIMA 362 (1995) 487

results

Transfer matrices from simulations





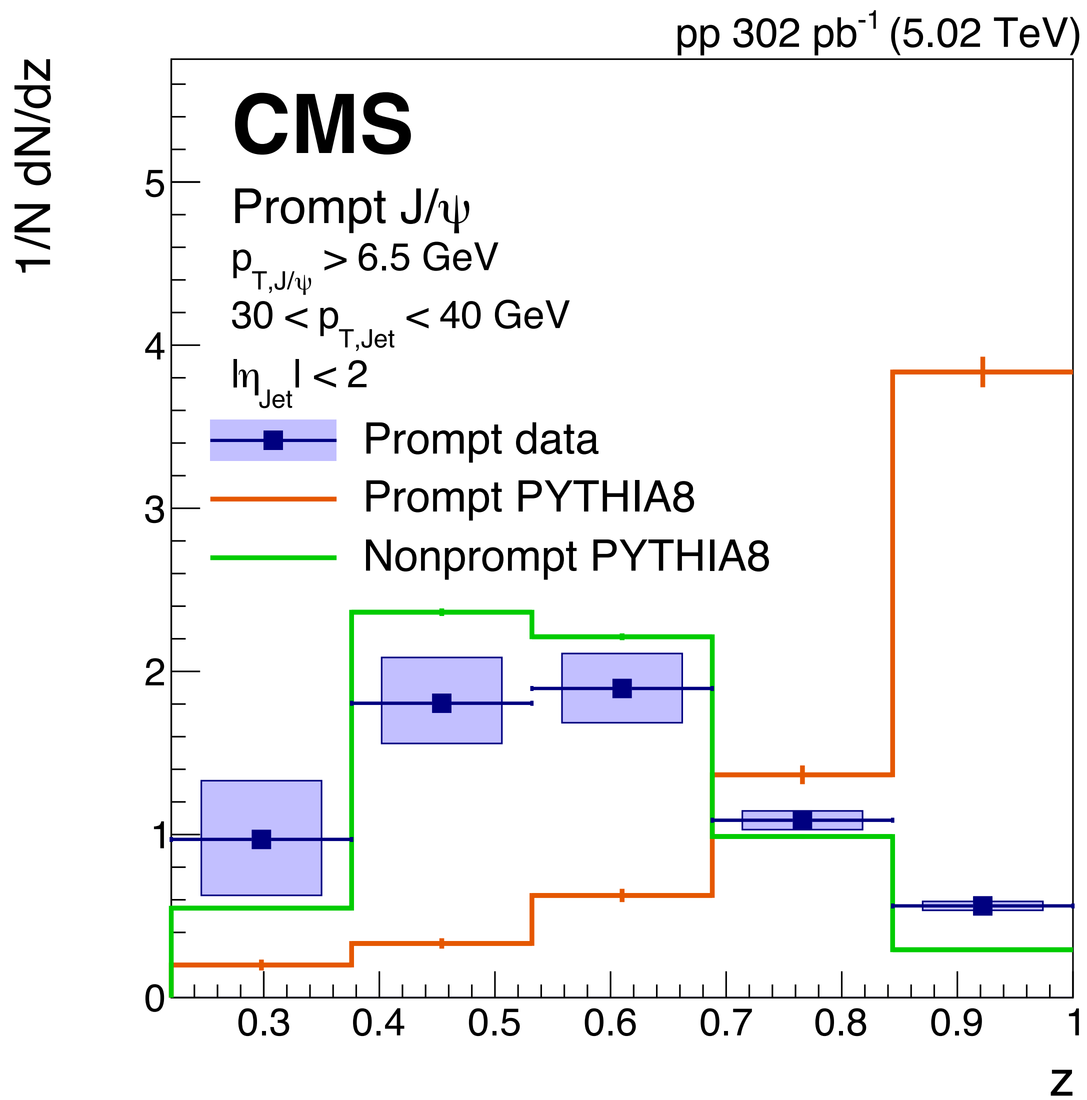
Jet p_T

z

Results

Prompt J/ψ in pp data and MC

Starting point for my thesis in CMS
Start with pp data and then move to PbPb
Different kinematic ranges

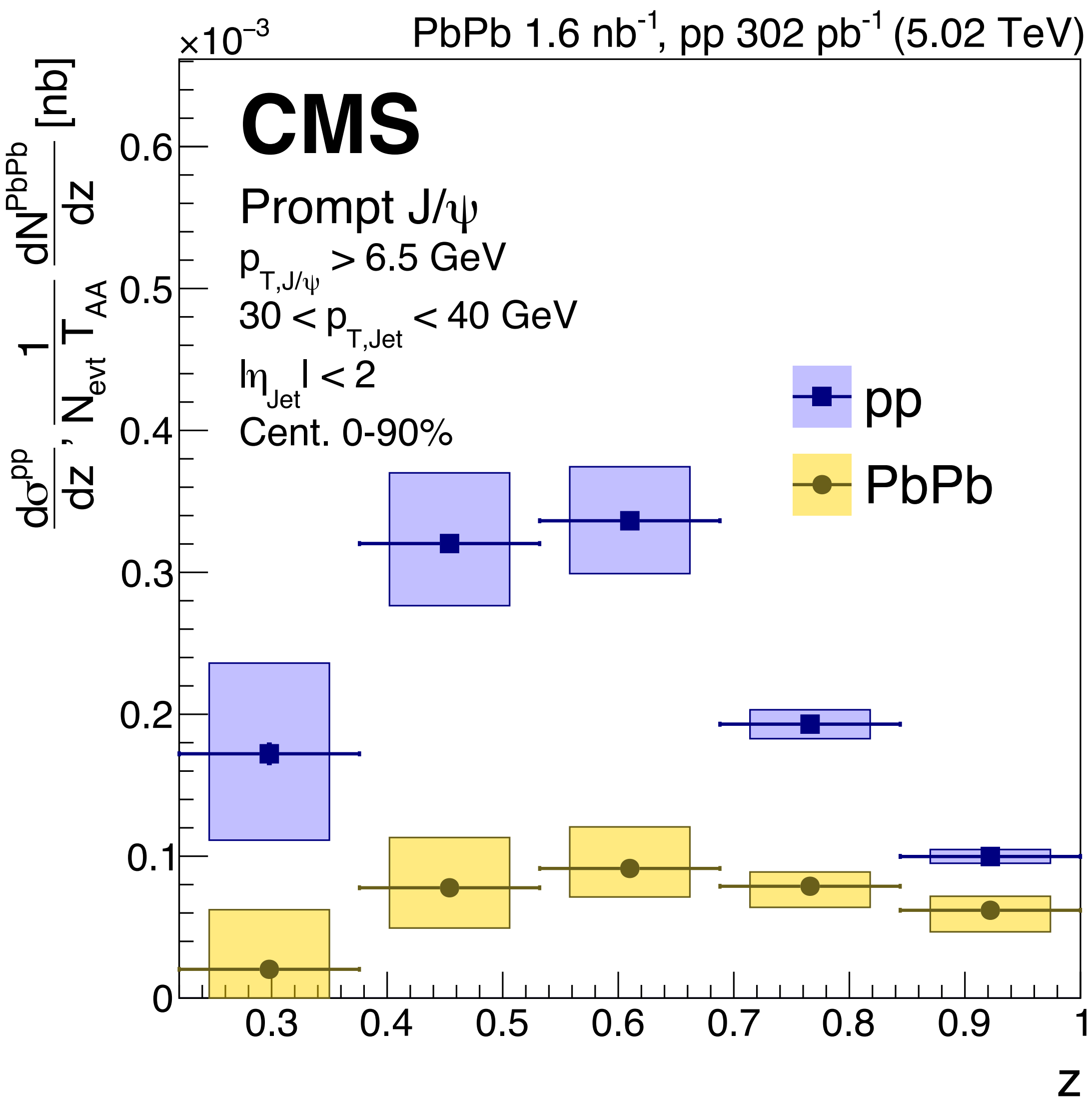


Similar results to LHCb

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 scaled by T_{AA} and the cross section in pp collisions, as a function of the fragmentation variable z



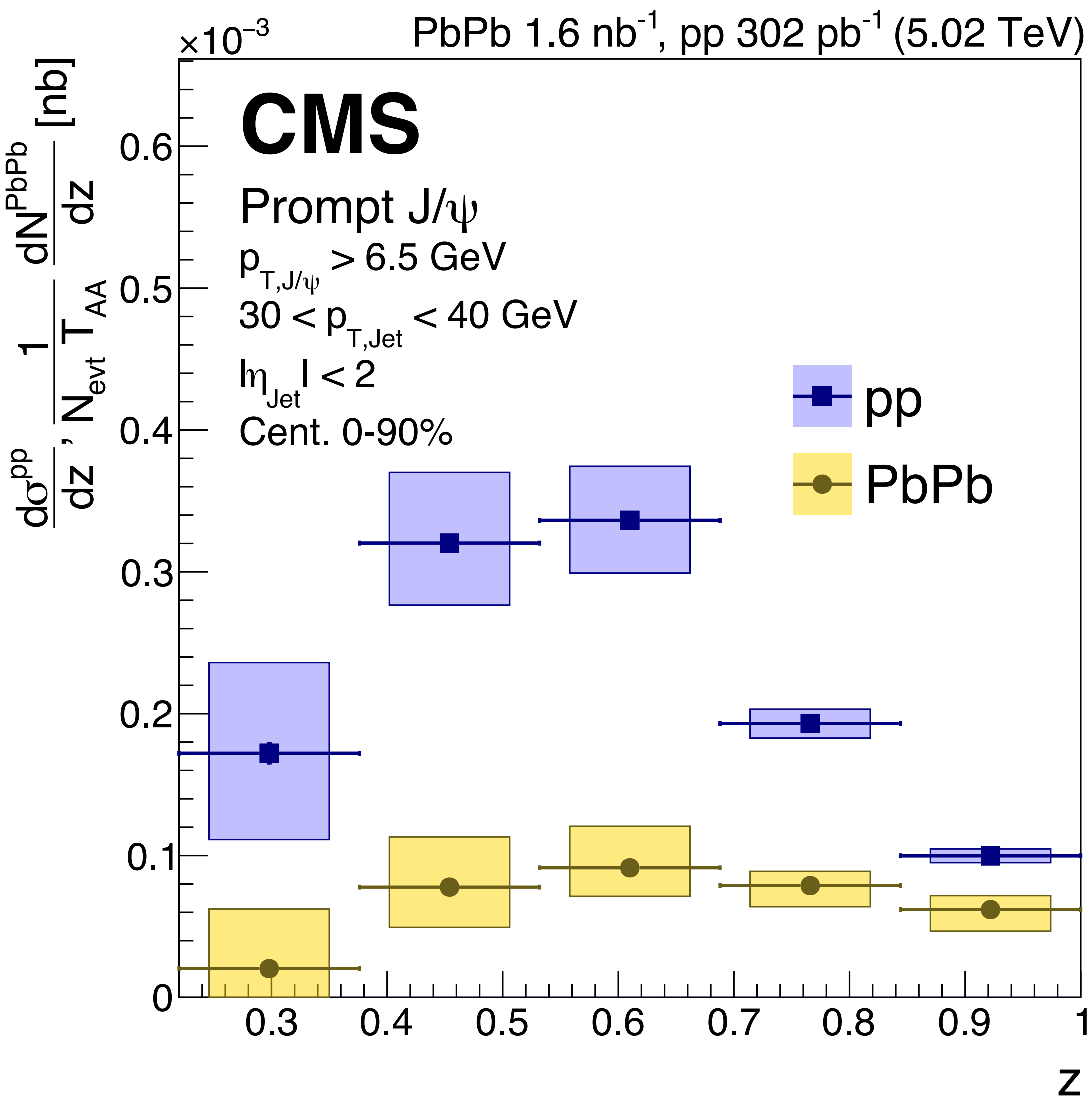
pp and PbPb have similar trends

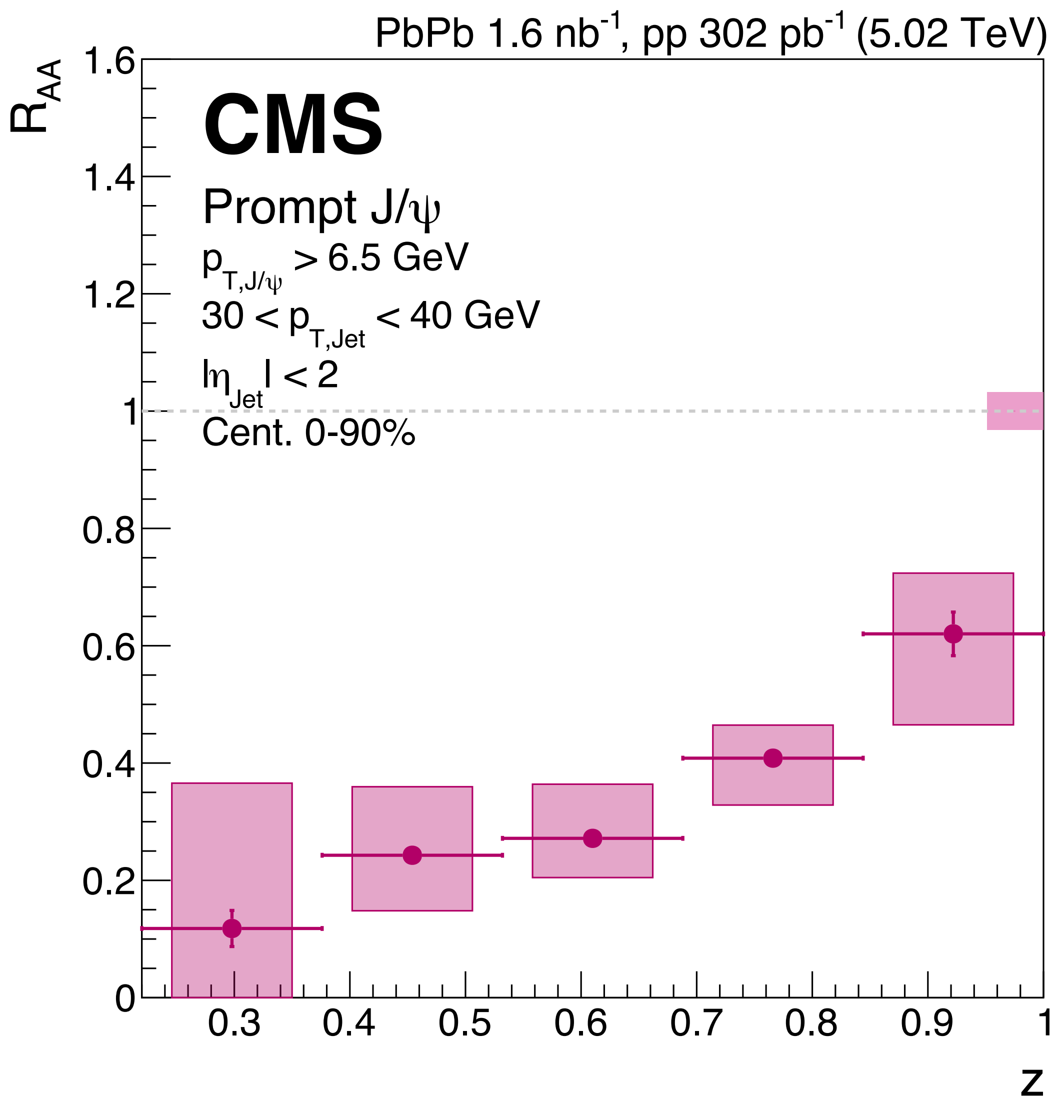
Suppression in PbPb in all z bins

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



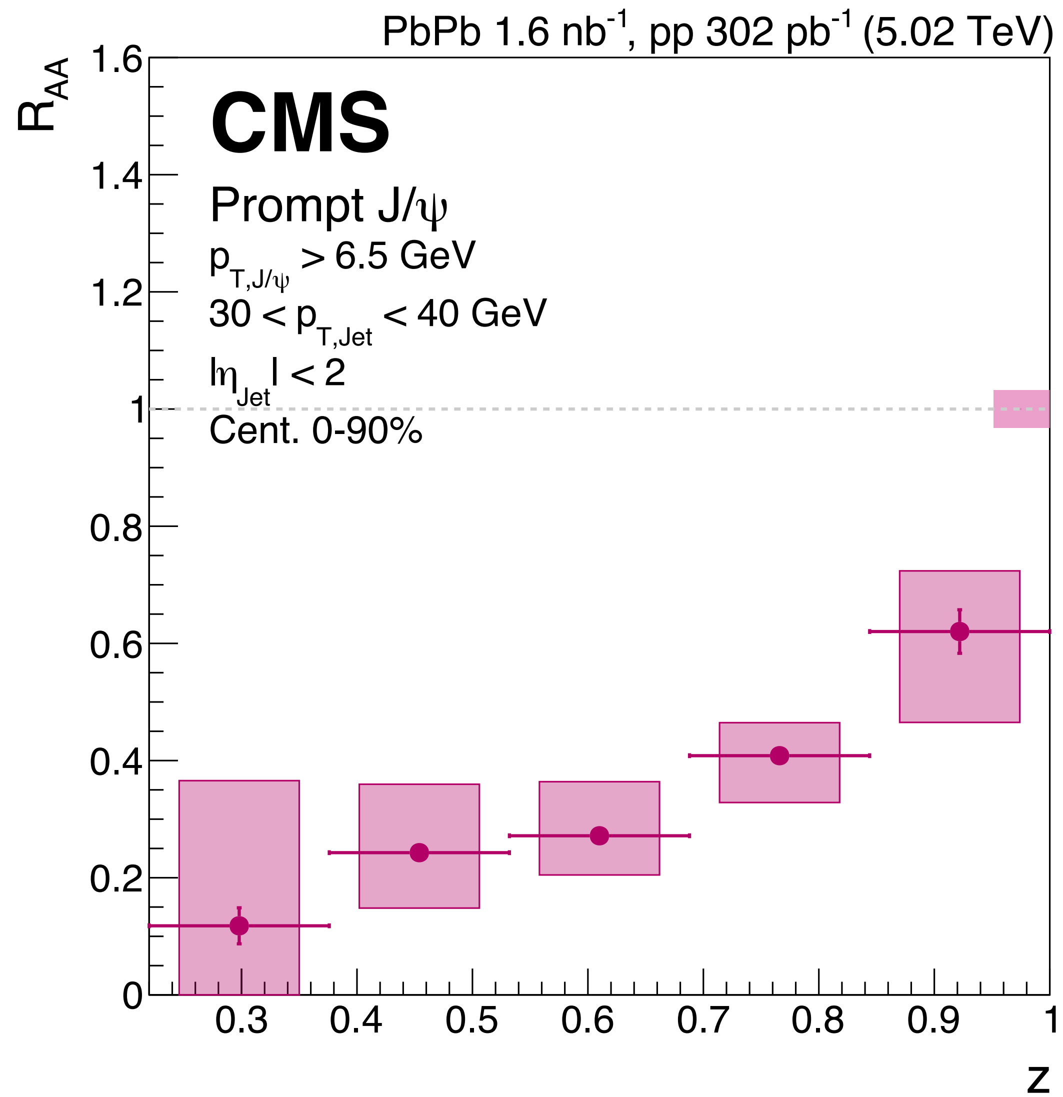


R_{AA} of J/ψ in jets

Lower z

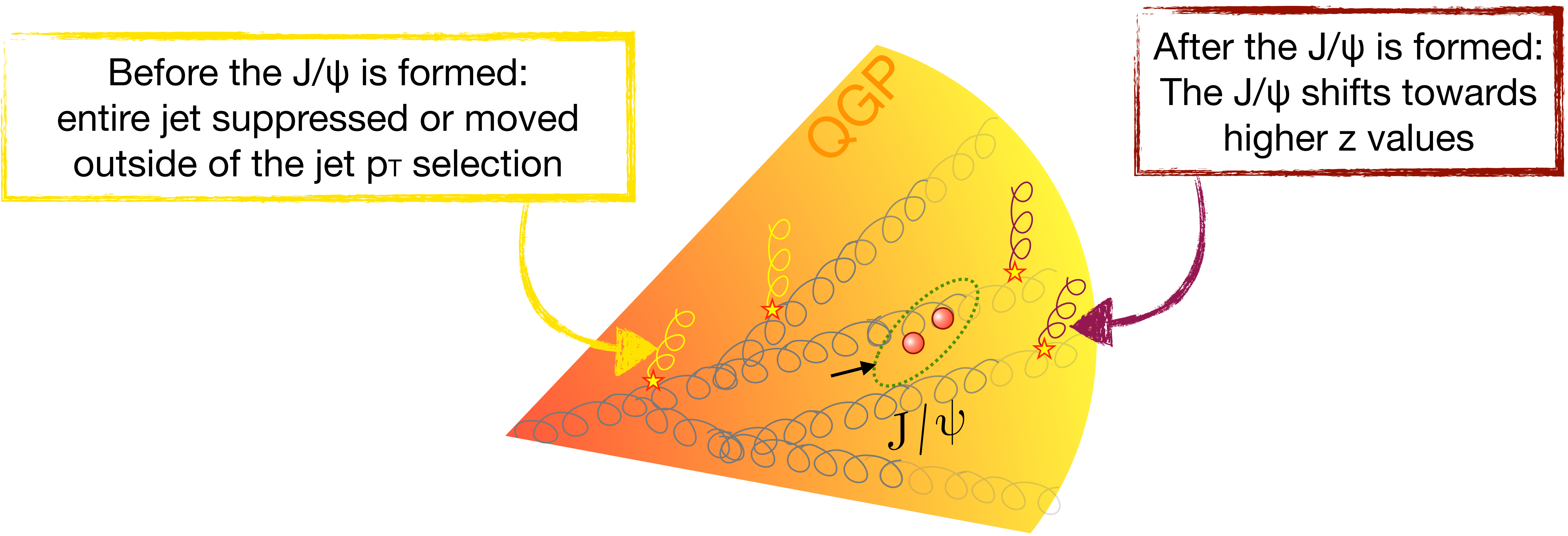
J/ψ produced later in parton shower

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

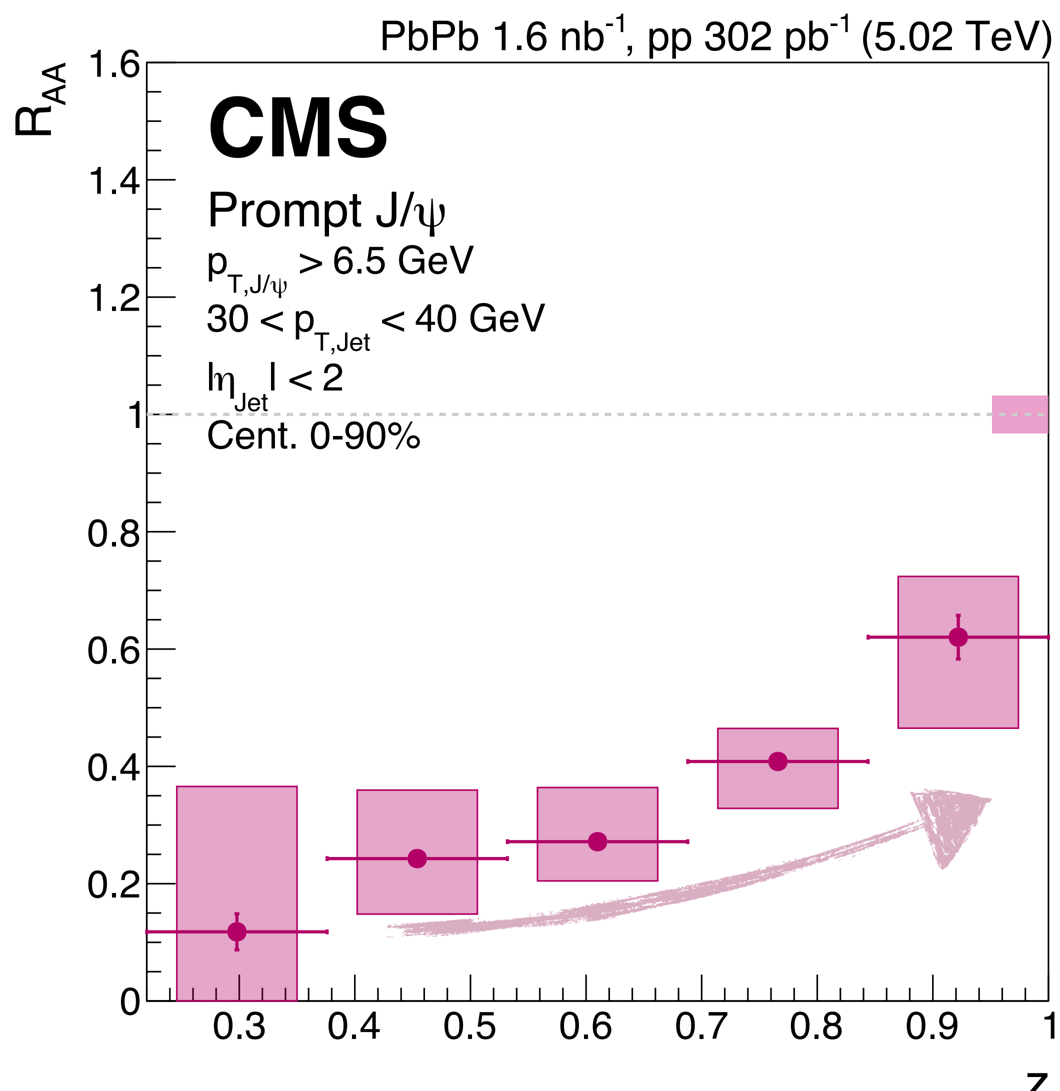


(The J/ψ is also sensitive to Debye screening)

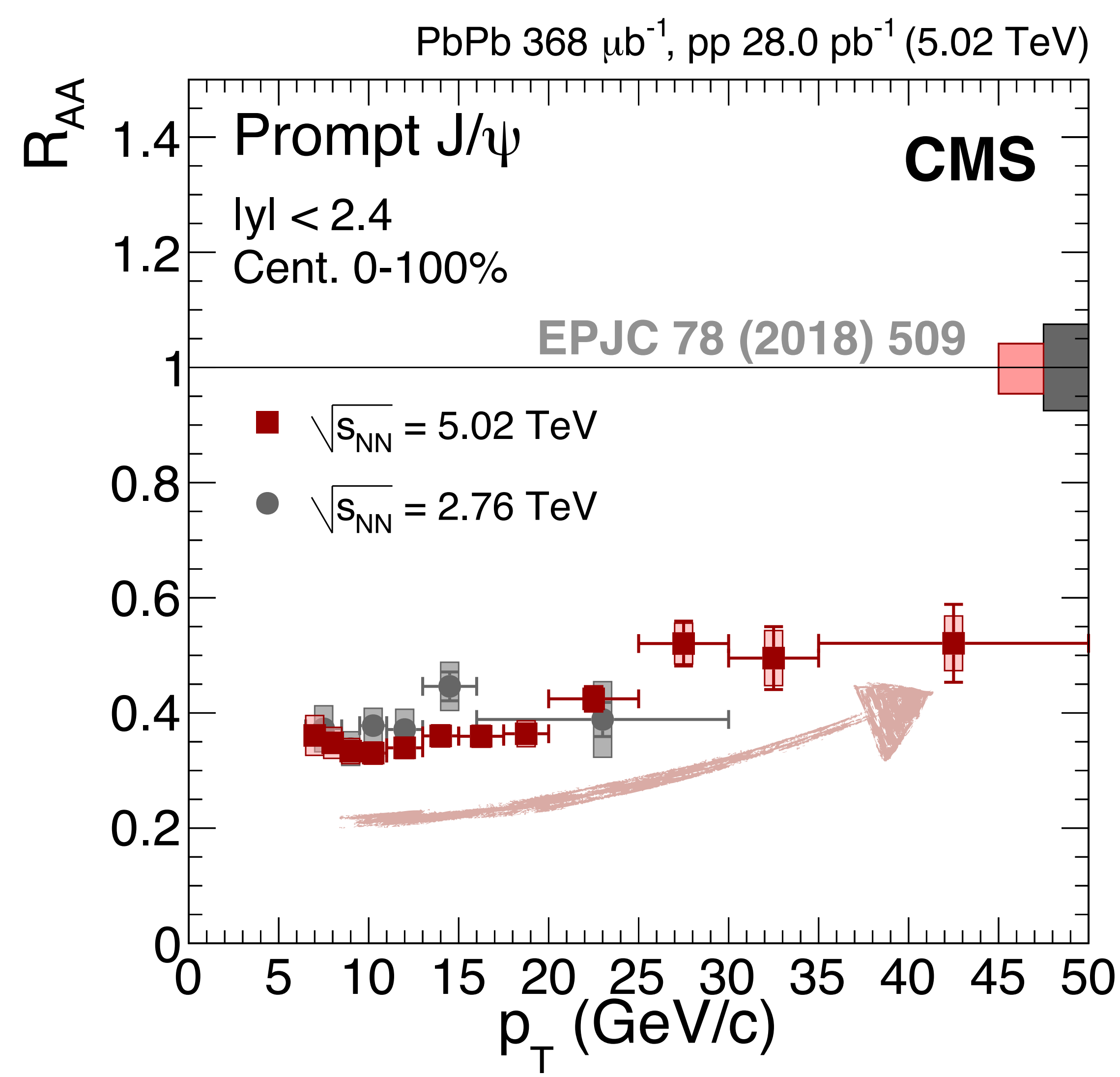
R_{AA} of J/ψ in jets vs R_{AA}

z increases with increasing p_T

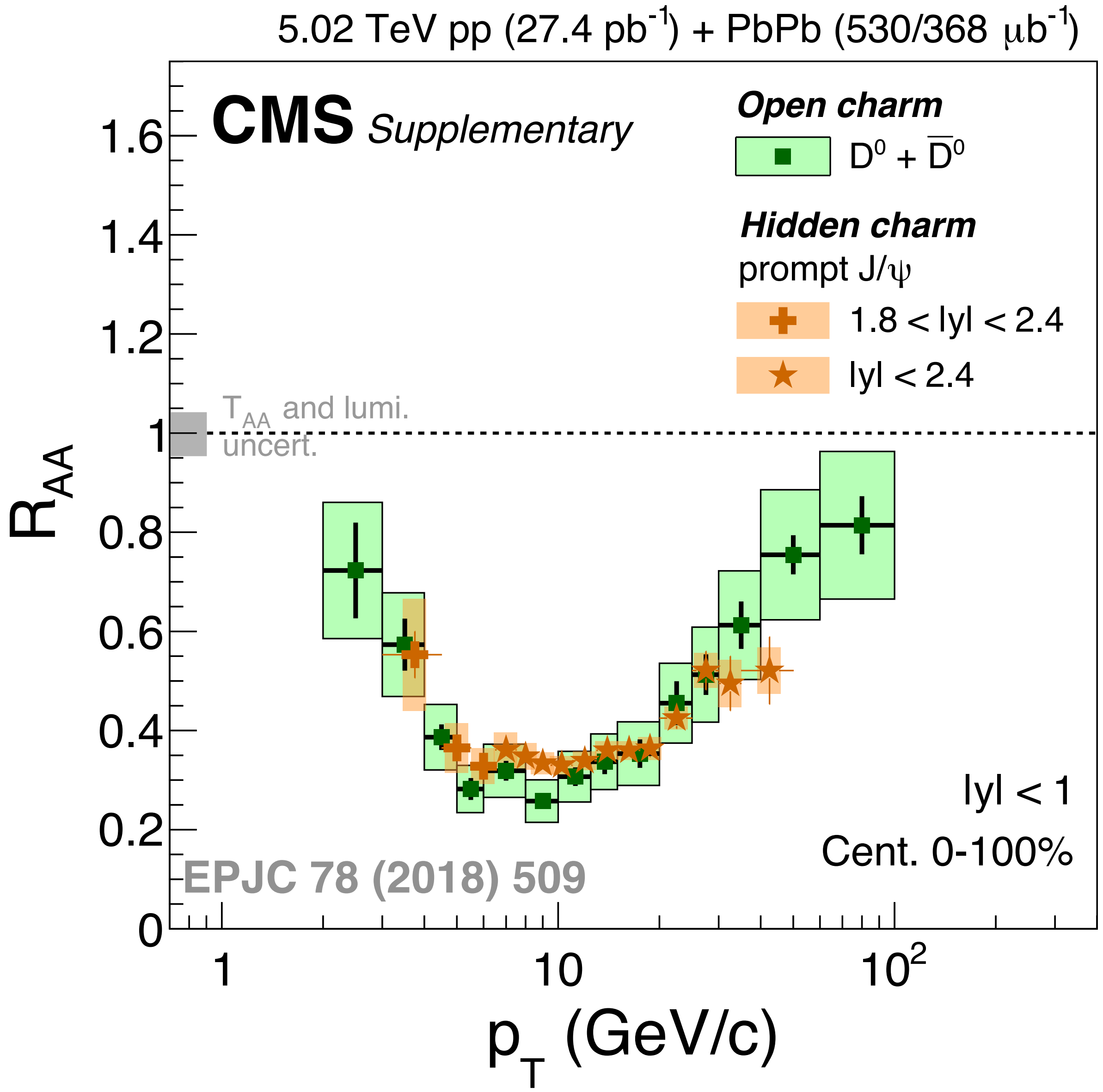
Rising trend in inclusive prompt R_{AA} might be explained by jet quenching



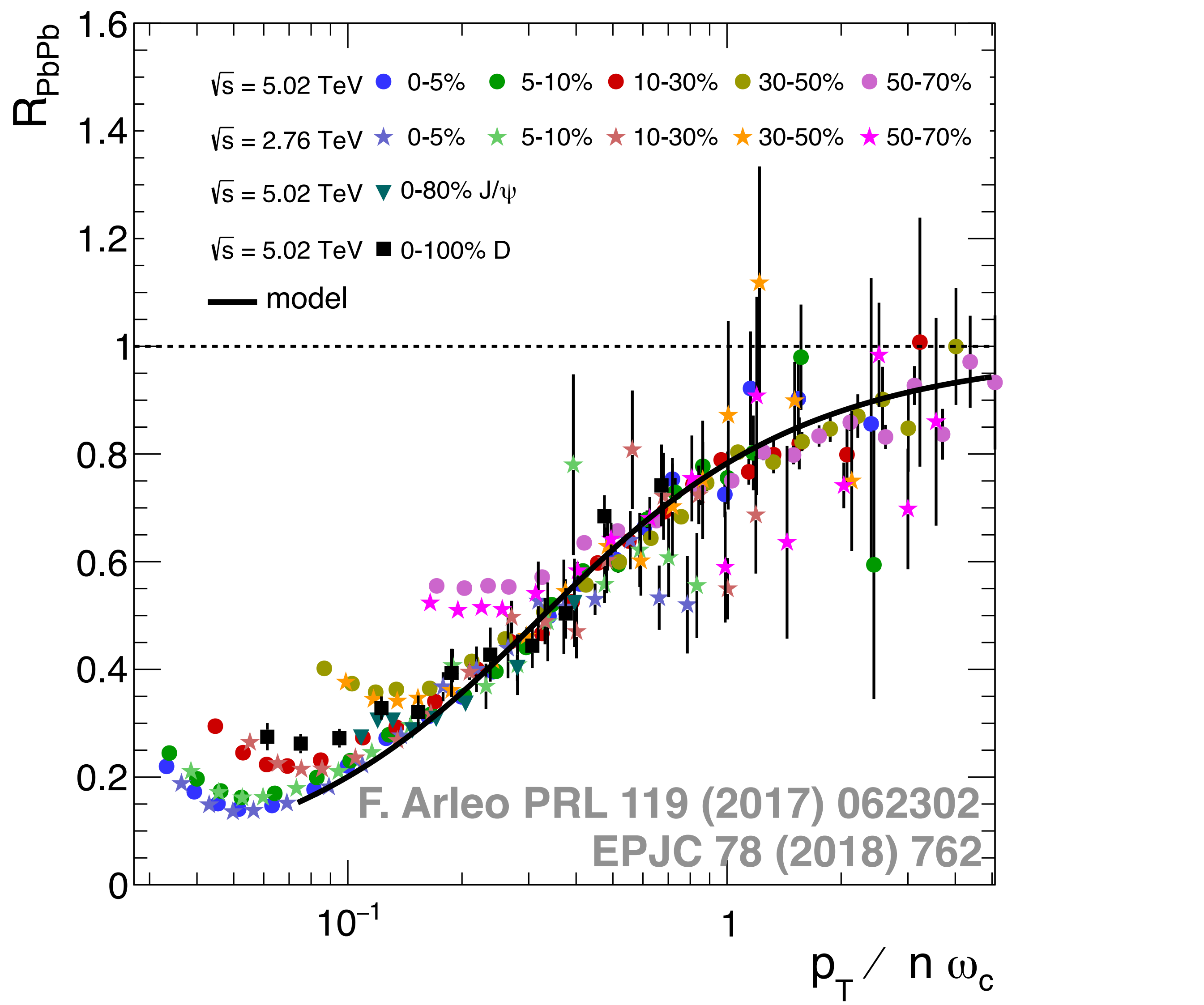
$$p_{T,J/\psi} = z \times p_{T,Jet}$$



Another look at R_{AA}



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



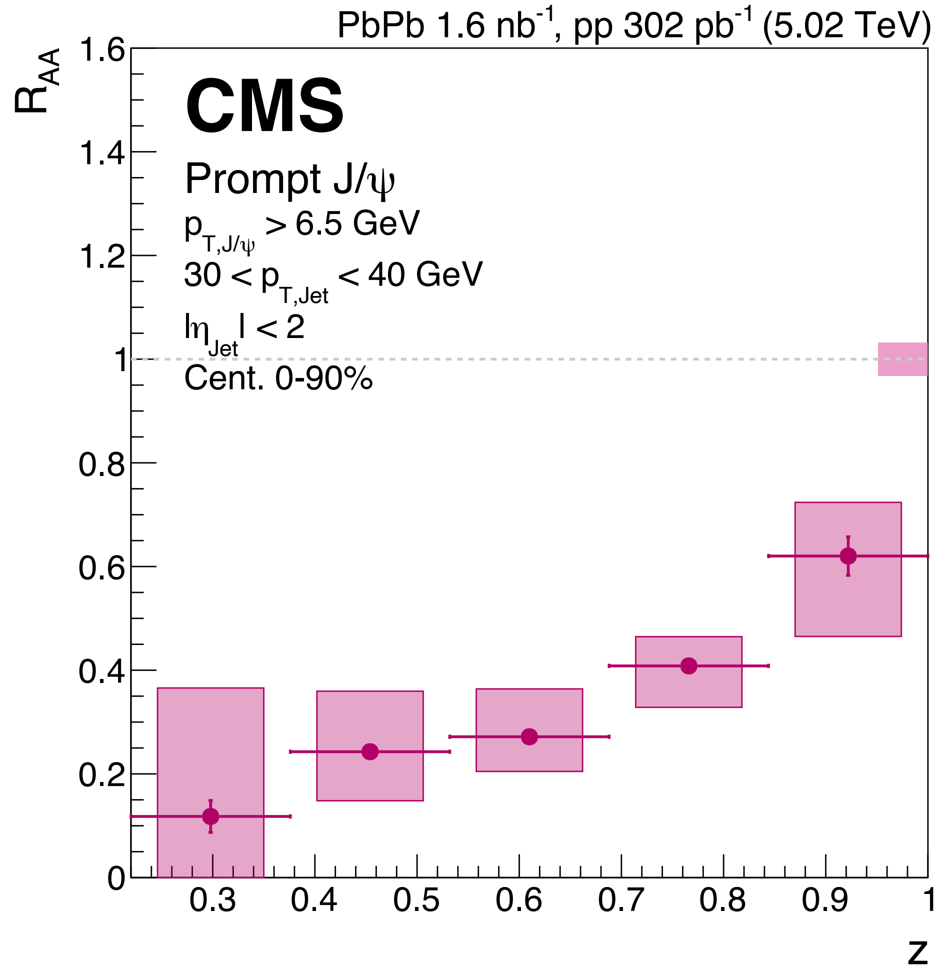
Well described by calculations of parton energy loss

Conclusions and outlooks

I measured the jet fragmentation function of the J/ψ meson in pp and PbPb collisions

Prompt J/ψ R_{AA} showed a rising trend with z

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

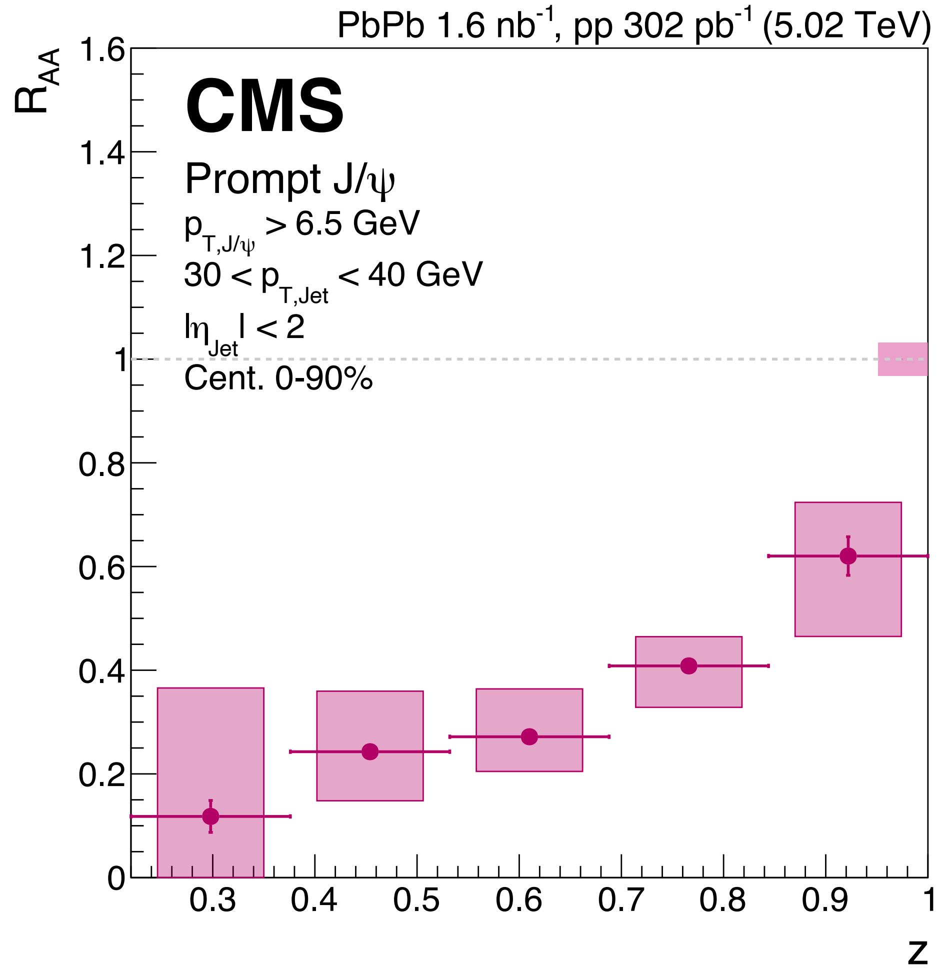


Conclusions and outlooks

I measured the jet fragmentation function of the J/ψ meson in pp and PbPb collisions

Prompt J/ψ R_{AA} showed a rising trend with z

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



Ongoing effort to study Υ in jets in pp with CMS

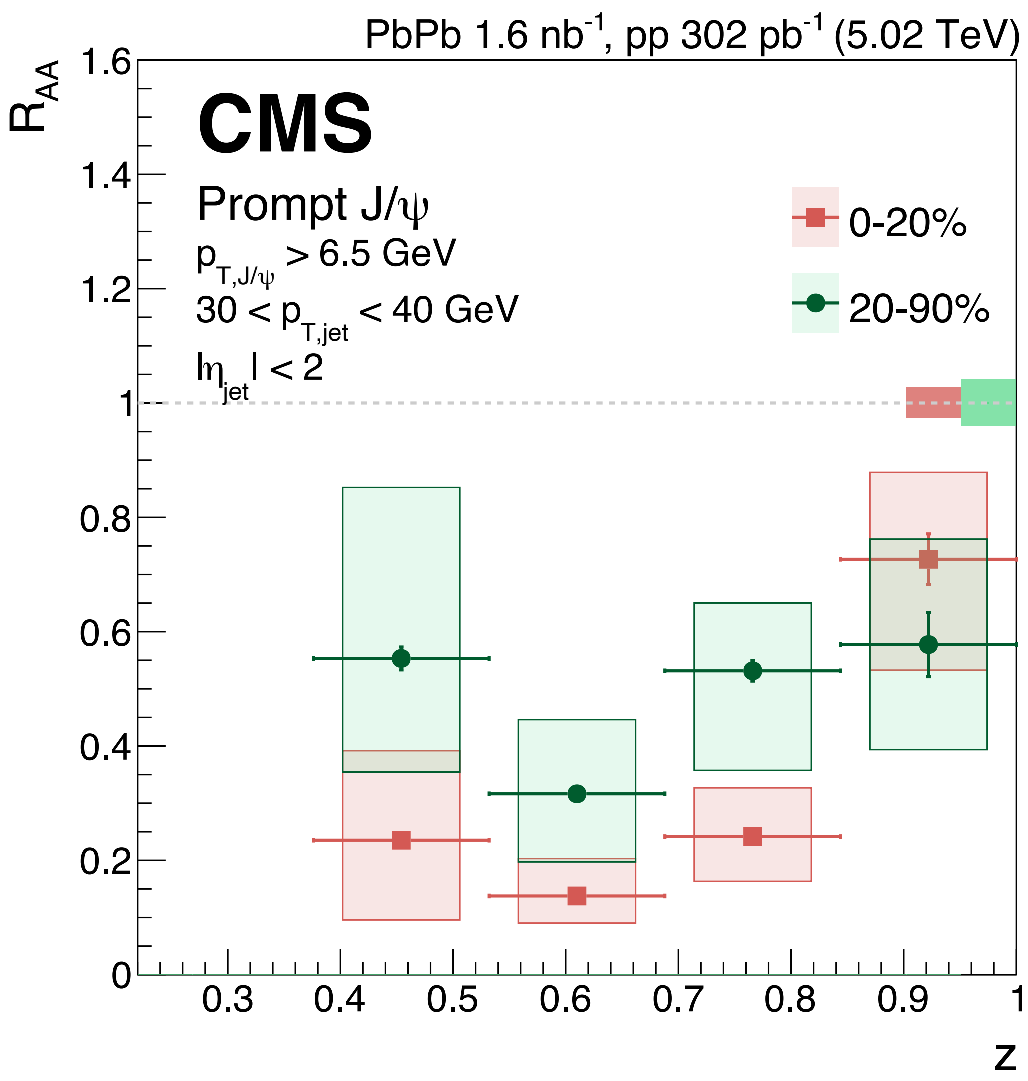
J/ψ + recoil jet could be interesting

Fragmentation function of open heavy flavor in jets

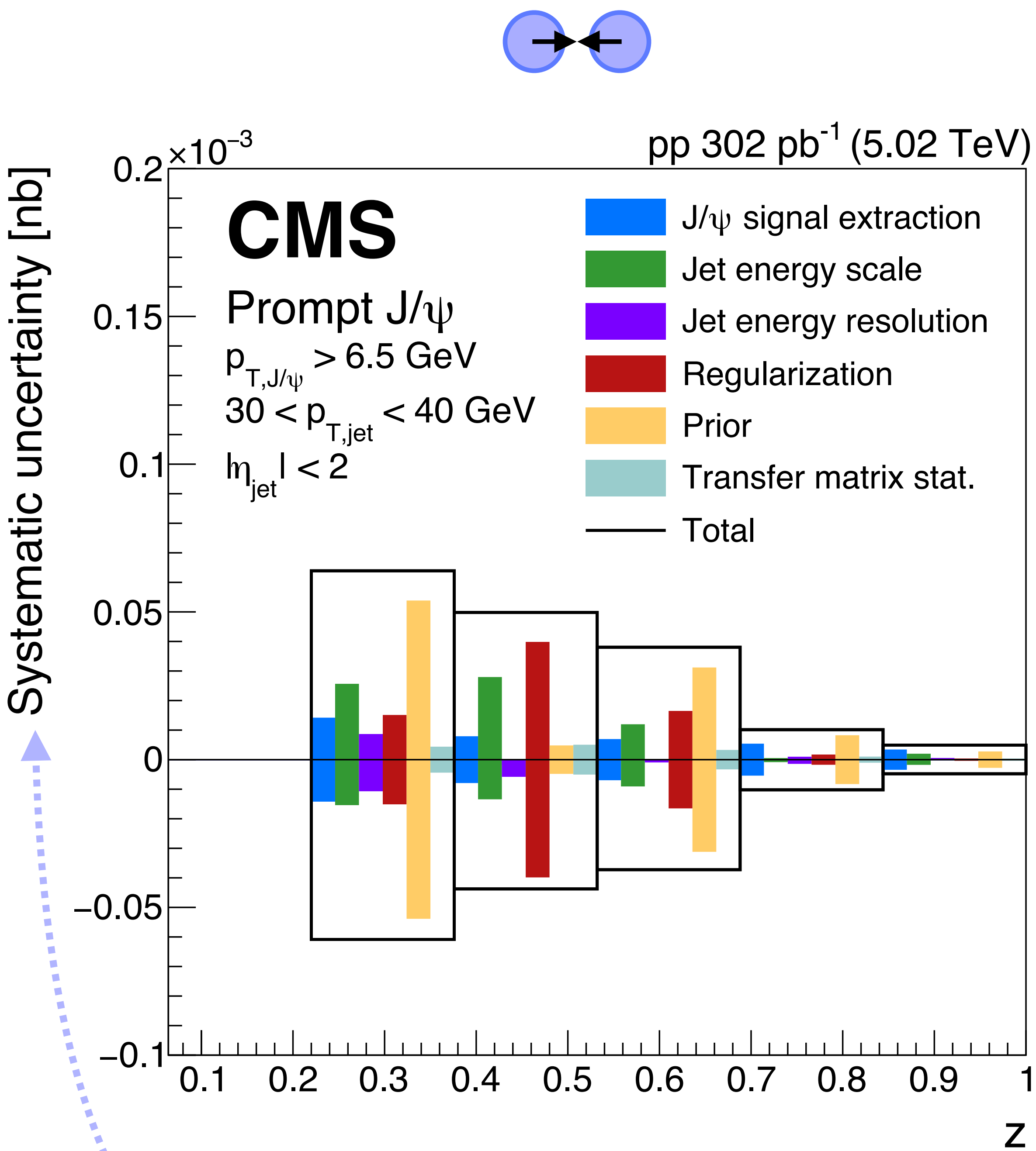
Backup

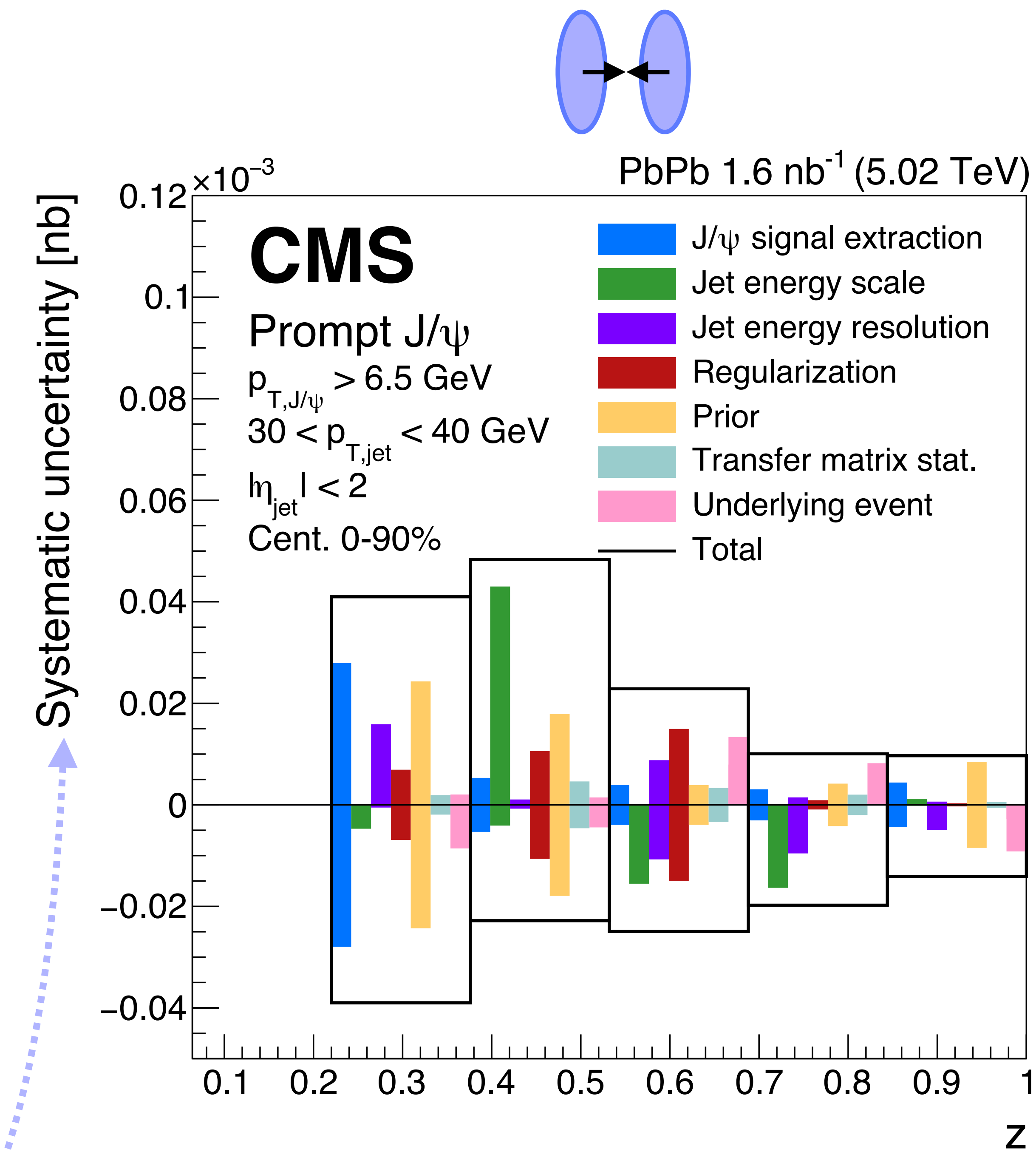
RAA of prompt J/ψ in jets

- Larger suppression for central events



Systematic uncertainties





Absolute uncertainties

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

ψ(2S) in jets

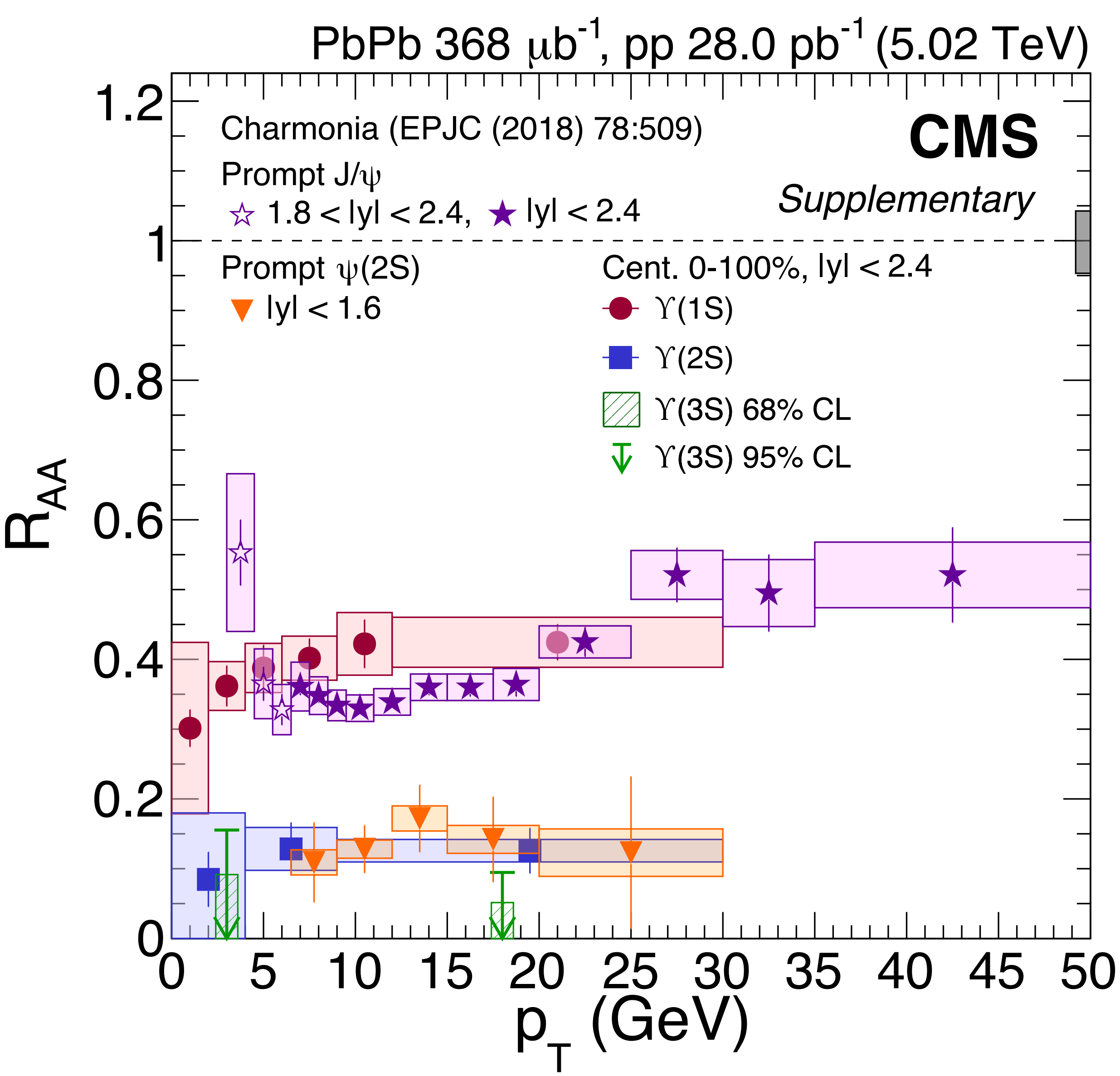
E_{Loss} processes are not sensitive to the final state

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

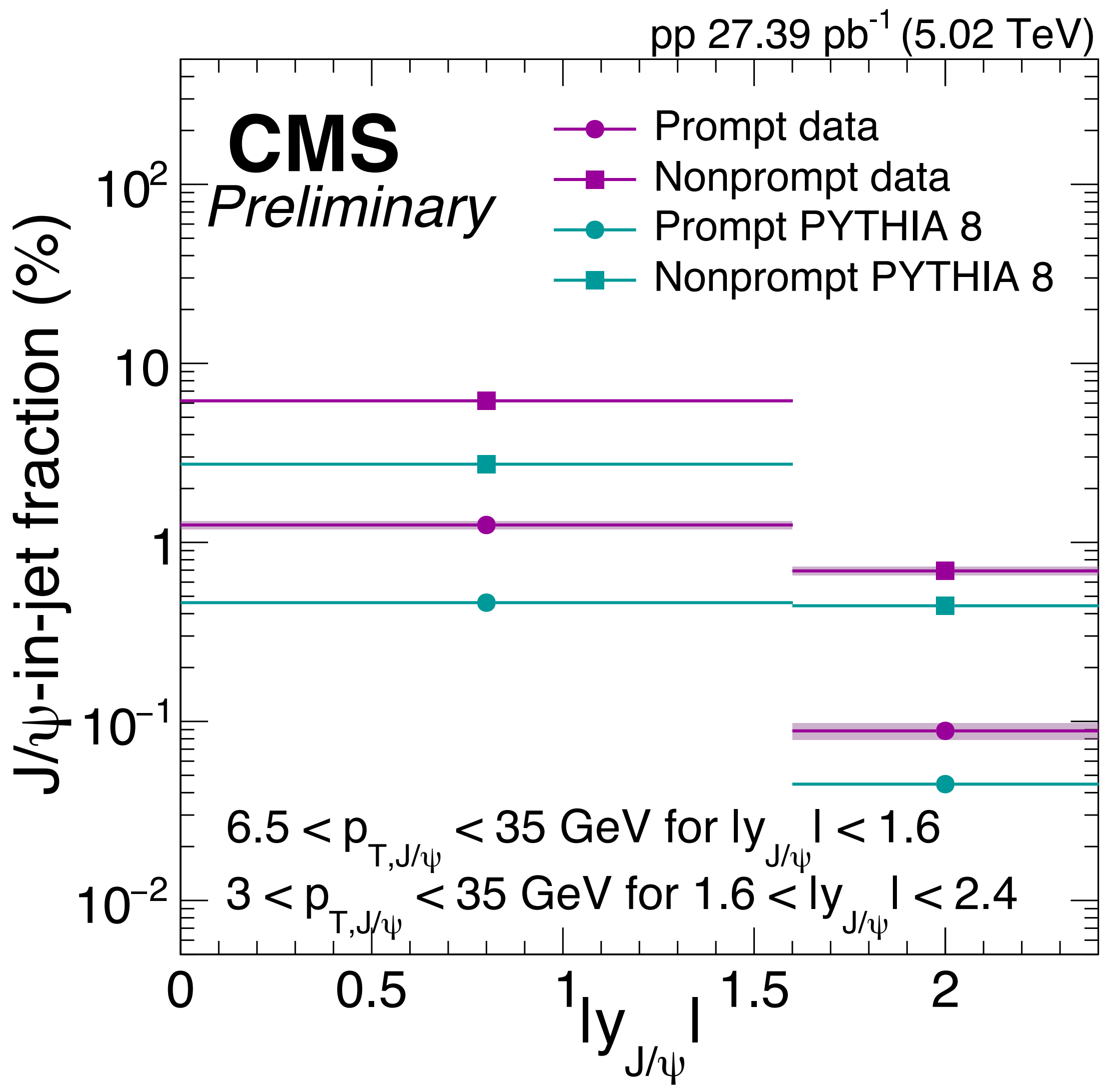


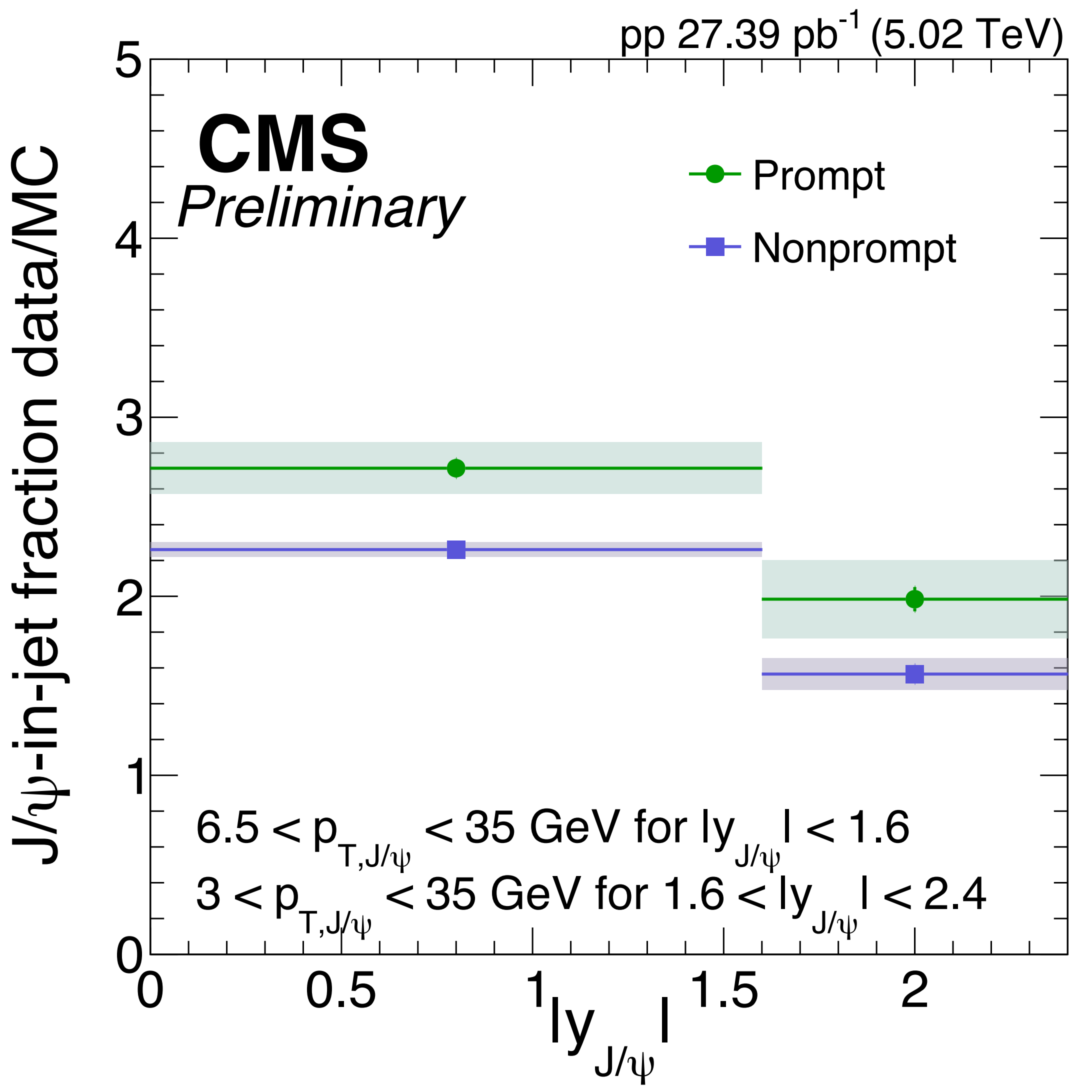
J/ψ-in-jet fraction

Ratio of J/ψ produced in jets in our selection over the total number of J/ψ

Less than 7% are produced in jets in our selection

Under-predicted in PYTHIA8



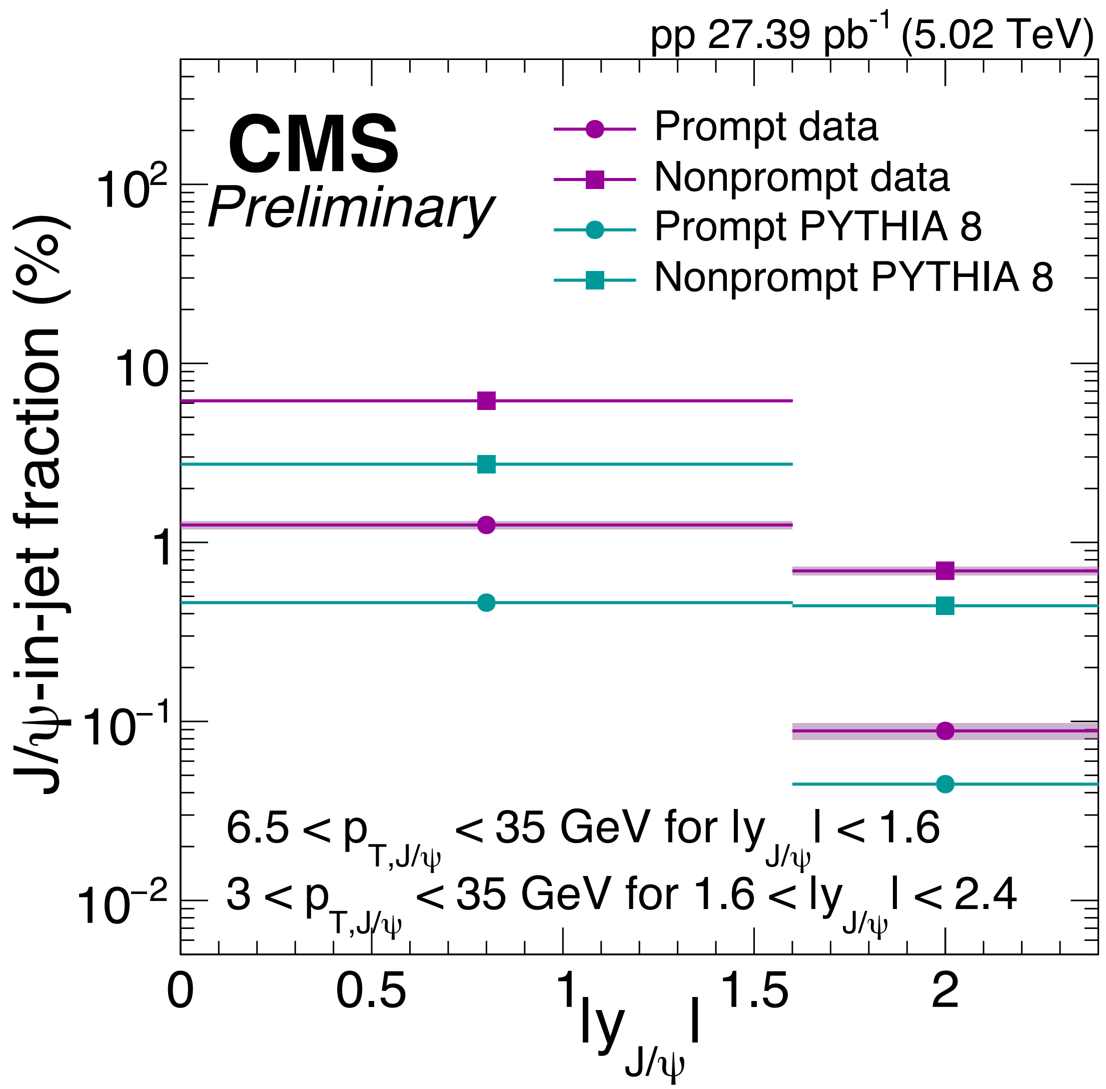


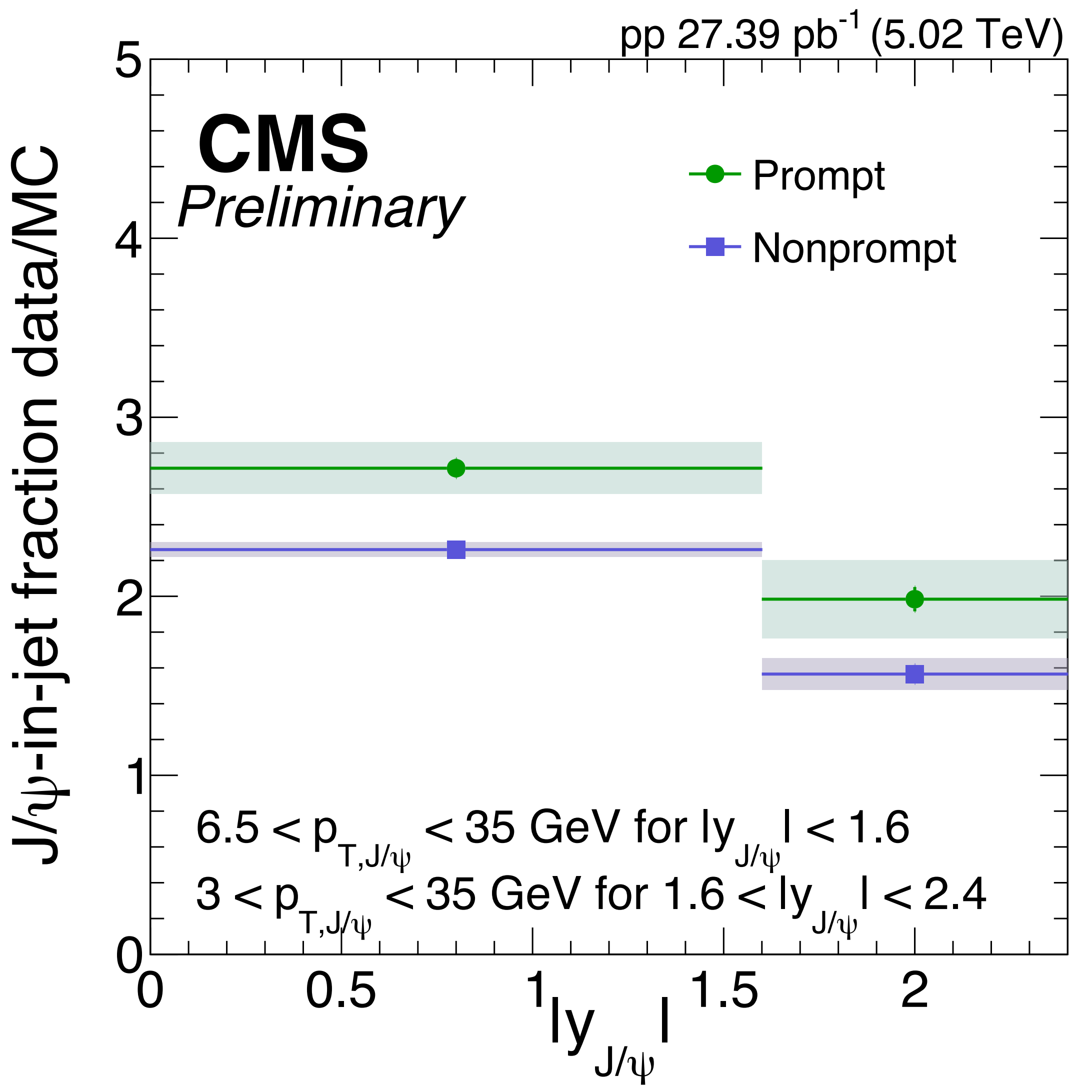
J/ψ-in-jet fraction

Ratio of J/ψ produced in jets in our selection over the total number of J/ψ

Less than 7% are produced in jets in our selection

Under-predicted in PYTHIA8



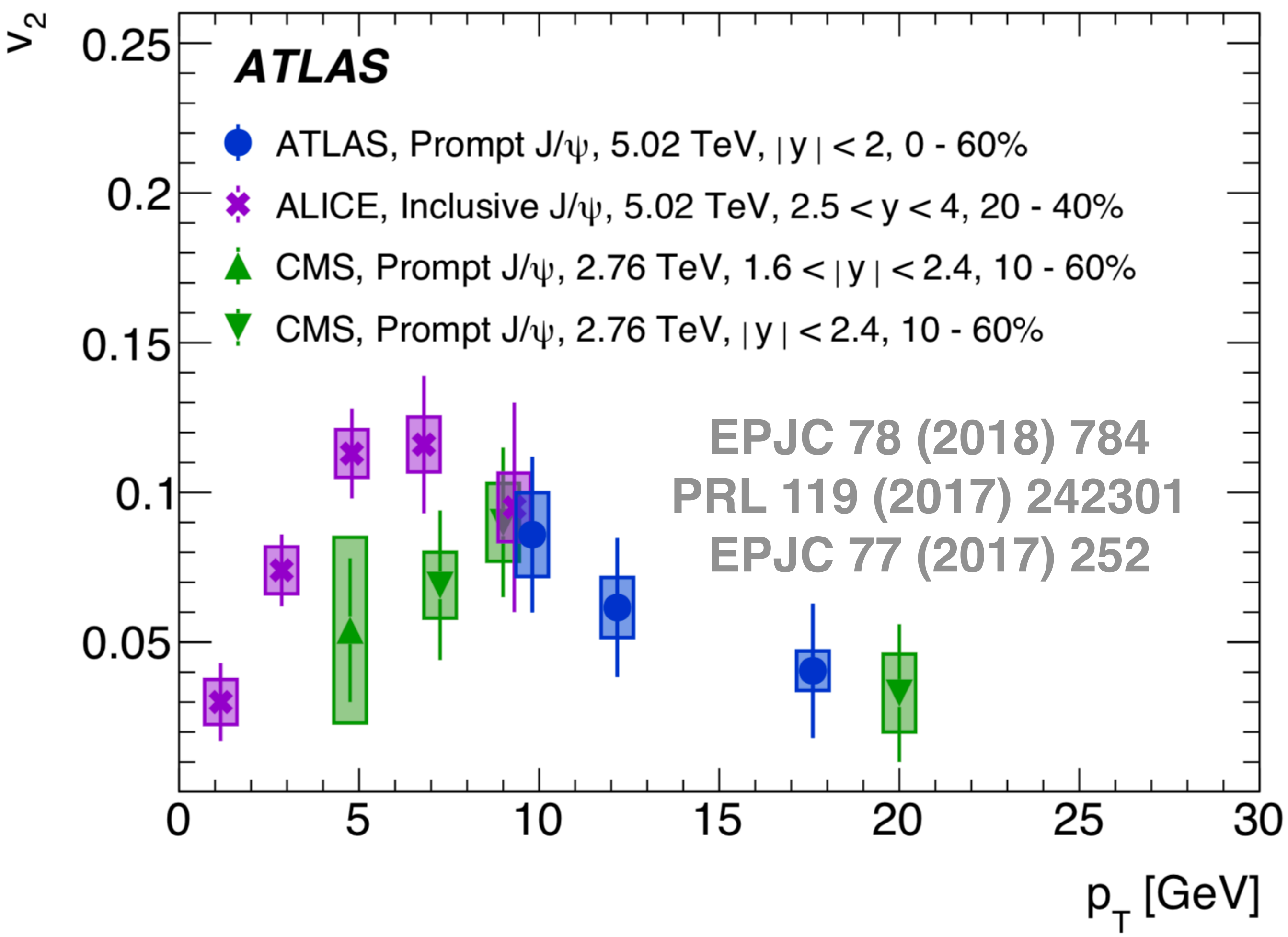


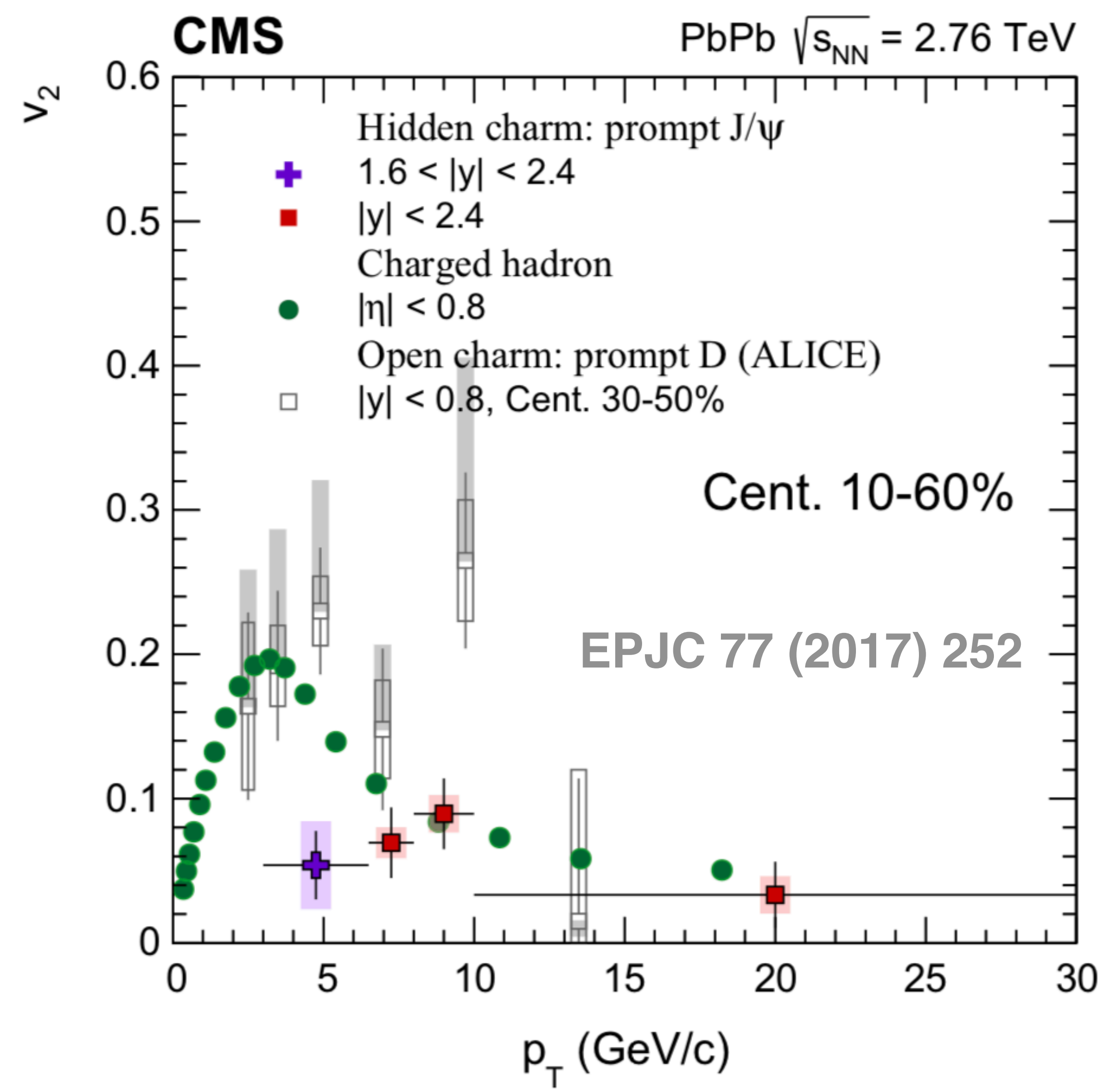
PLB 804 (2020) 135409

CMS measurement at 8 TeV:

(85 ± 3(stat) ± 7(syst))% of J/ψ ($E_{J/ψ}$>15 GeV) are produced with a jet (E_{Jet}>19 GeV)

Elliptic flow in PbPb



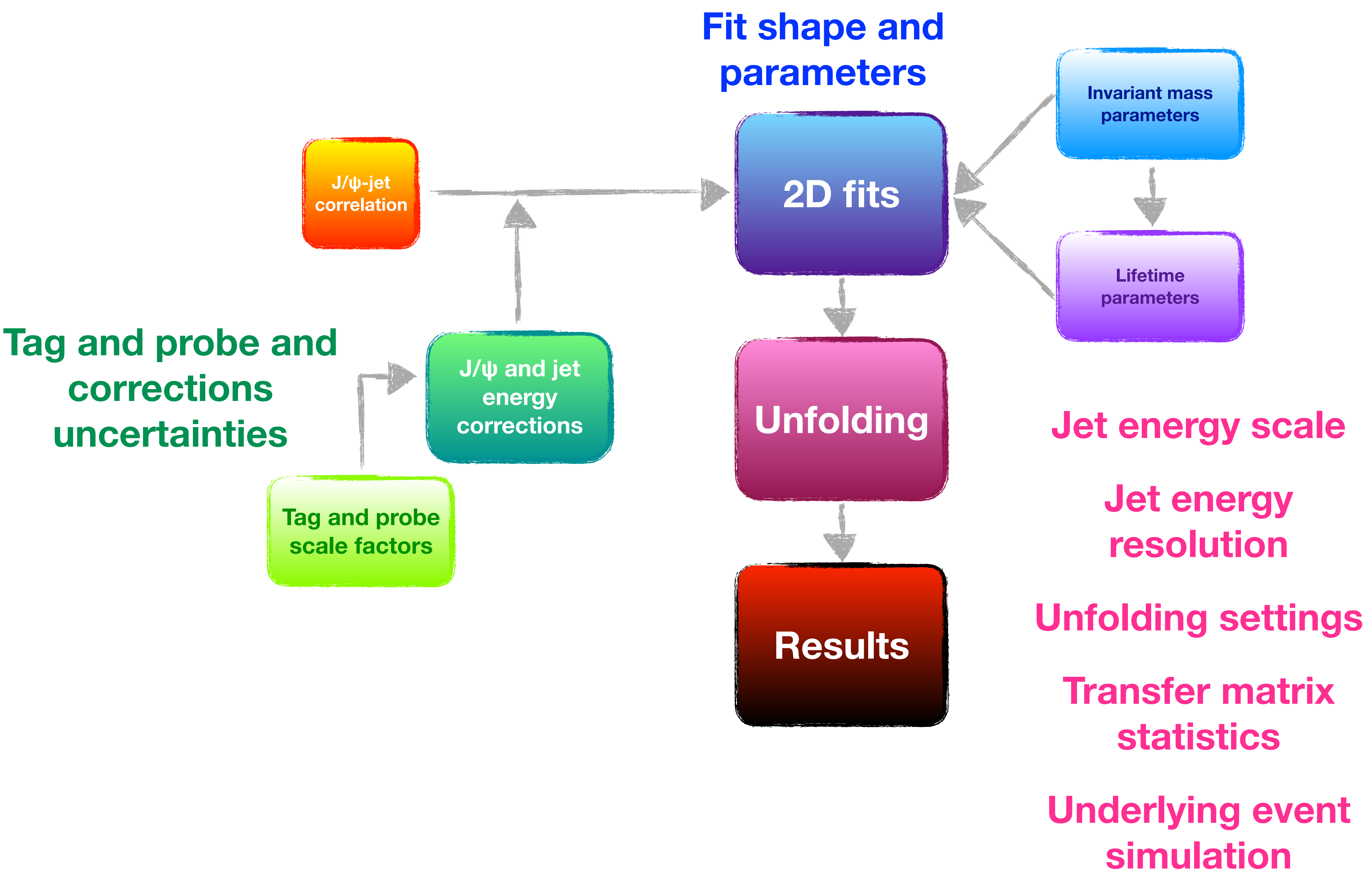


Unexpected non zero v_2 for prompt J/ψ at high p_T

Similar to other hadrons at high p_T

Path-length dependence of energy loss

Systematic uncertainties

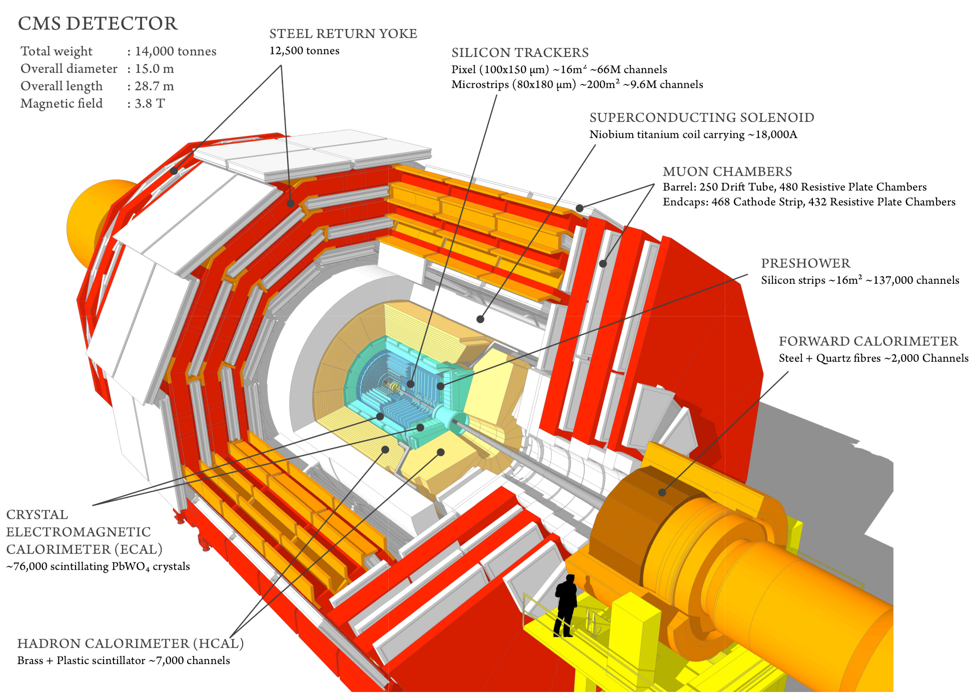


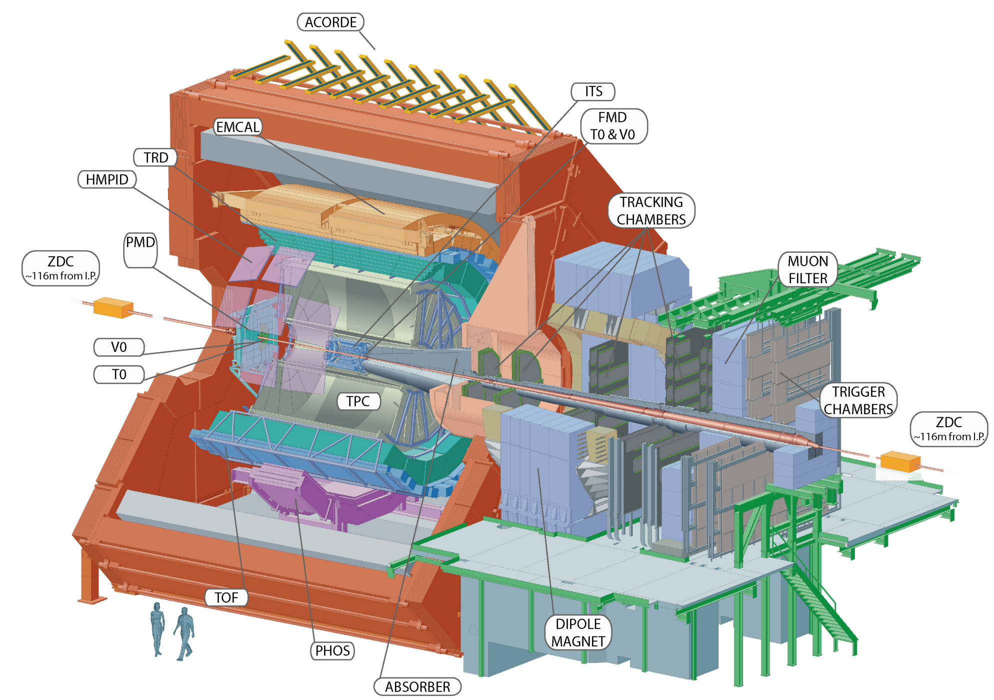
From CMS to ALICE

Moved from CMS to ALICE

$J/\psi \rightarrow \mu\mu$ in jets cannot be done in ALICE

But similar tools can be used in many analyses



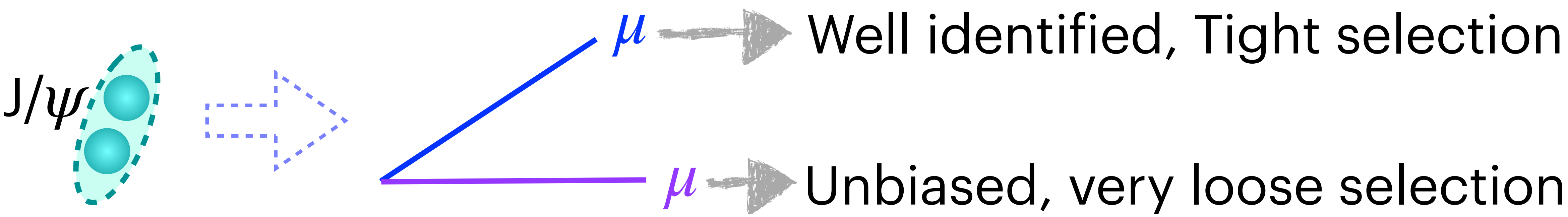


-> seperation of prompt and nonprompt J/ψ

-> efficiency calculation studies

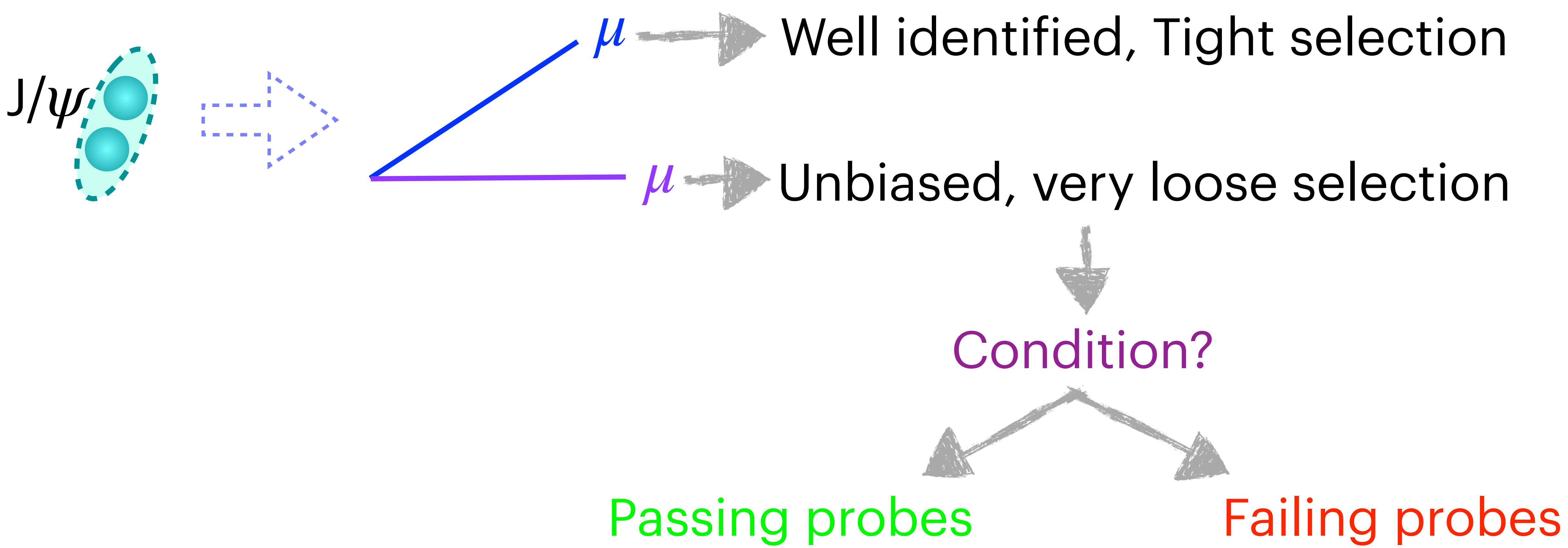
The Tag-and-Probe method

- Tag-and-Probe (T&P) is a data-driven efficiency calculation technique
- Simulations are not ideal → need data calibration
- based on the decays of known resonances, e.g. J/ψ



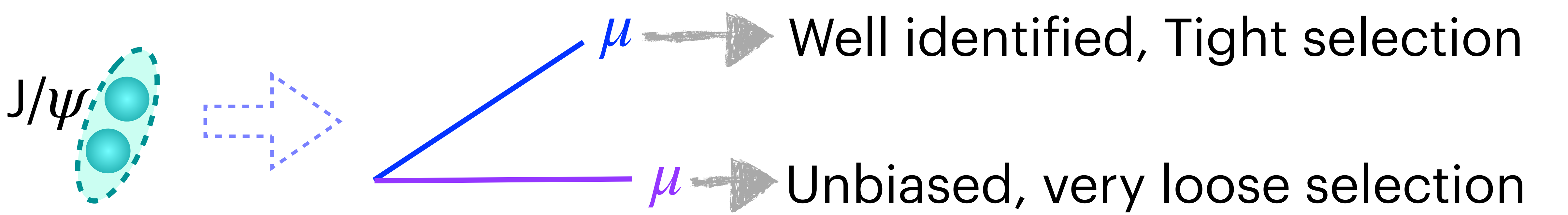
The Tag-and-Probe method

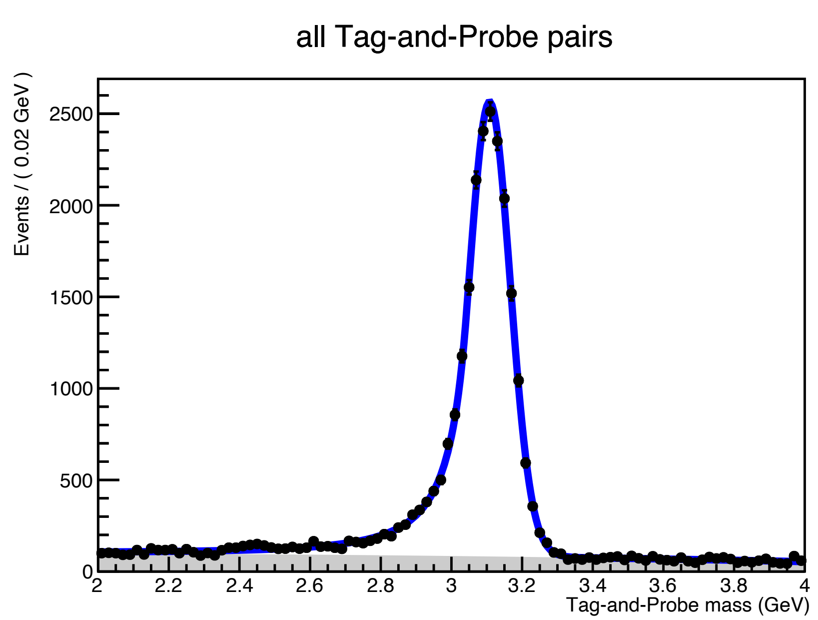
- Tag-and-Probe (T&P) is a data-driven efficiency calculation technique
- Simulations are not ideal → need data calibration
- based on the decays of known resonances, e.g. J/ψ

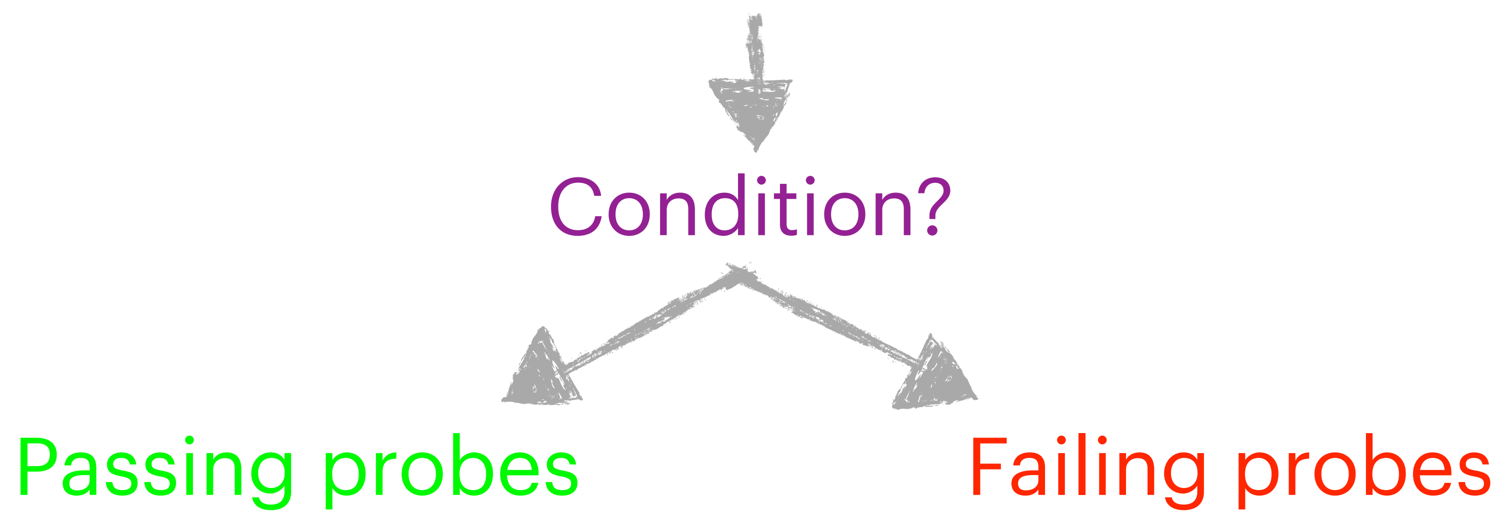


The Tag-and-Probe method

- Tag-and-Probe (T&P) is a data-driven efficiency calculation technique
- Simulations are not ideal → need data calibration
- based on the decays of known resonances, e.g. J/ψ

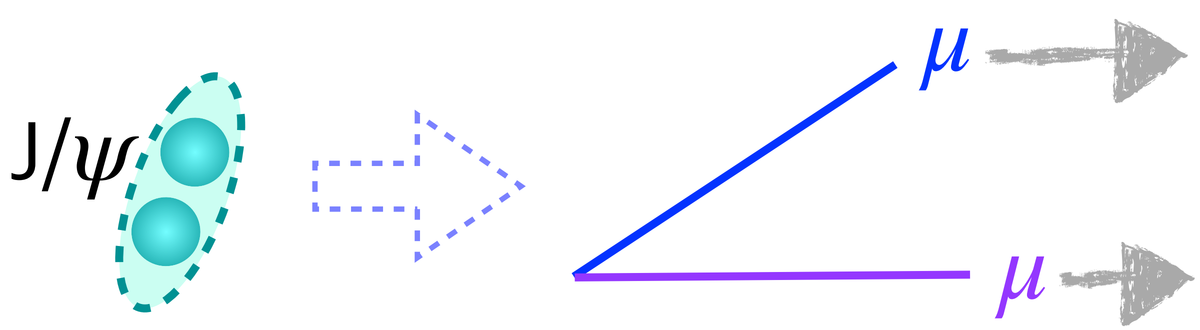






The Tag-and-Probe method

- Tag-and-Probe (T&P) is a data-driven efficiency calculation technique
- Simulations are not ideal → need data calibration
- based on the decays of known resonances, e.g. J/ψ



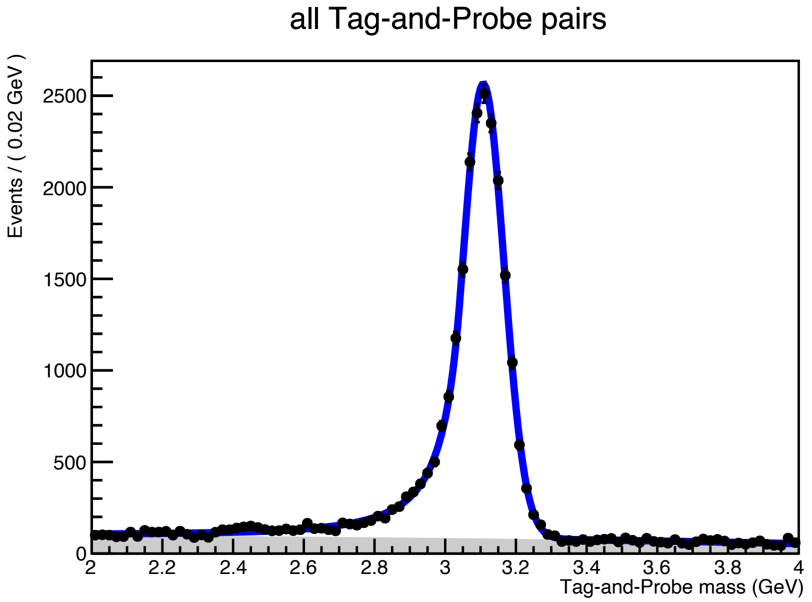
Well identified, Tight selection

Unbiased, very loose selection

Condition?

Passing probes

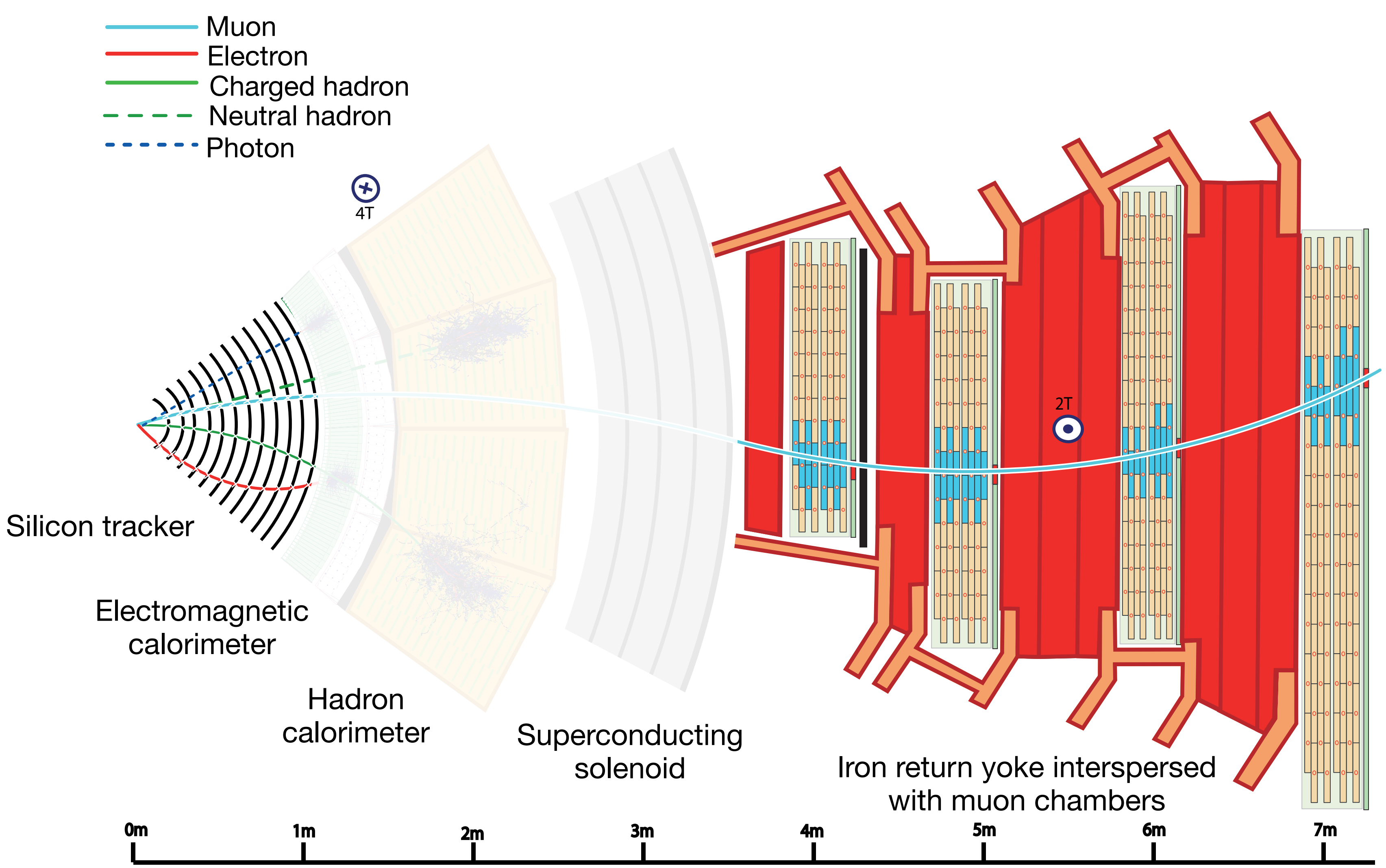
Failing probes



$$\varepsilon = \frac{\text{probes passing condition}}{\text{all probes}}$$

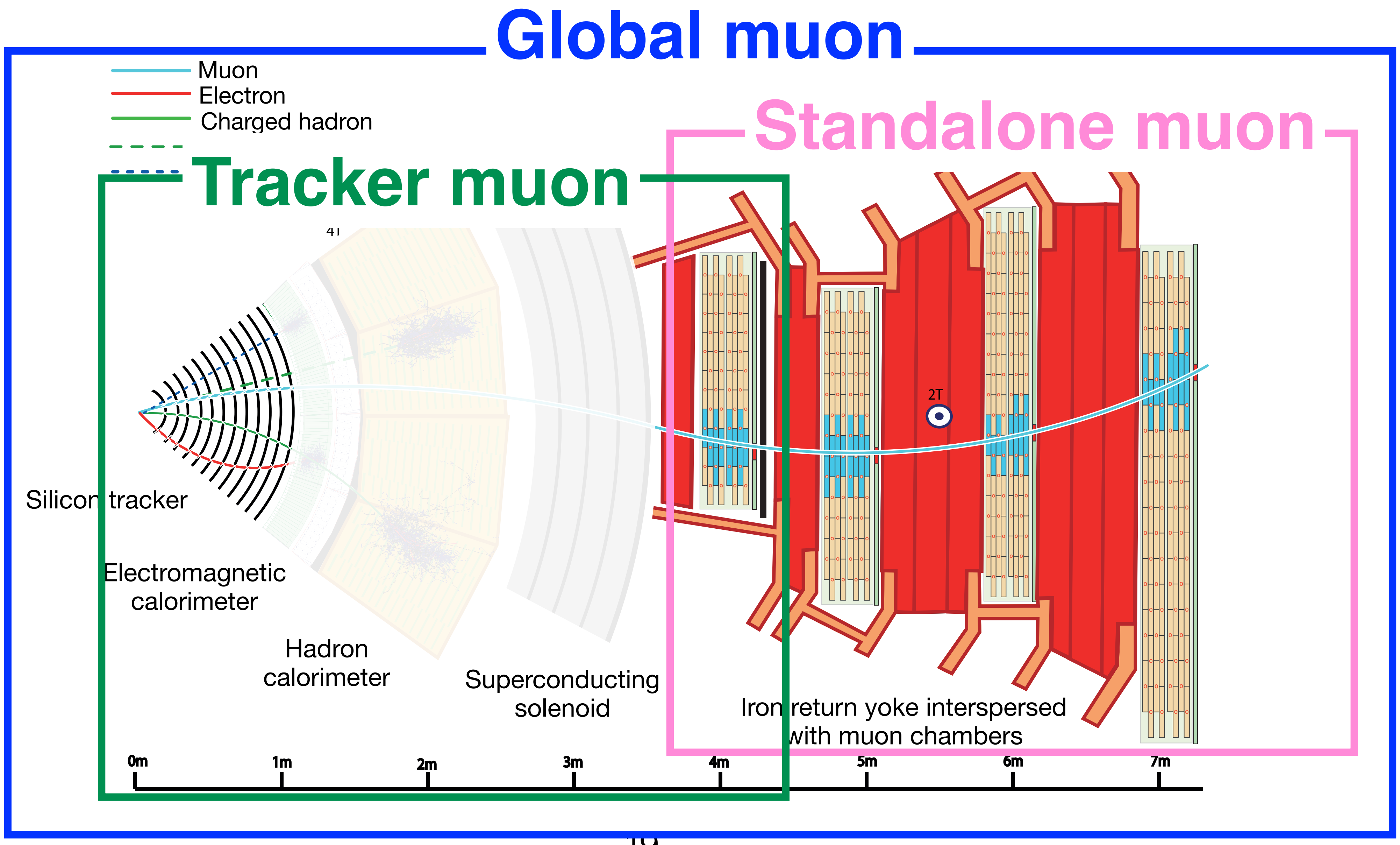
Muon systems in CMS

- Muons are measured in two subsystems in CMS
- The silicon tracker: very precise momentum determination but busy environment
- The muon chambers: very clean signal
- Together they give very precise and clean muon detection
- $p_T > 3$ GeV for $|\eta| < 1.2$, $p_T > 1.5$ GeV for $2.1 < |\eta| < 2.4$



Tag-and-Probe in CMS

- Three types of muons are defined in CMS
- Standalone muons: reconstructed in the muon chambers
- Tracker muons: tracker + first layer in the muon chambers
- Global Muons: tracker + muon chambers
- Works in favor of efficiency measurements like Tag-and-Probe



Tag-and-Probe tracking efficiency

- For the tracking efficiency we can look at standalone muons and check if they are reconstructed in the tracker as well (Global muons)
- For 2018 PbPb run: very good efficiency that only depends on rapidity
- Small differences between data and simulation