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Production of J/ψ vs Multiplicity

In $\sqrt{s}$ = 510 GeV p+p Collisions with STAR at RHIC

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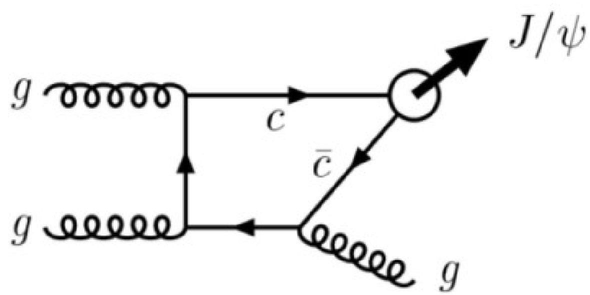
for the STAR Collaboration 24.09.24

SEPT 22-27 HP2024 NAGASAKI

Hard Scattering Processes within NRQCD

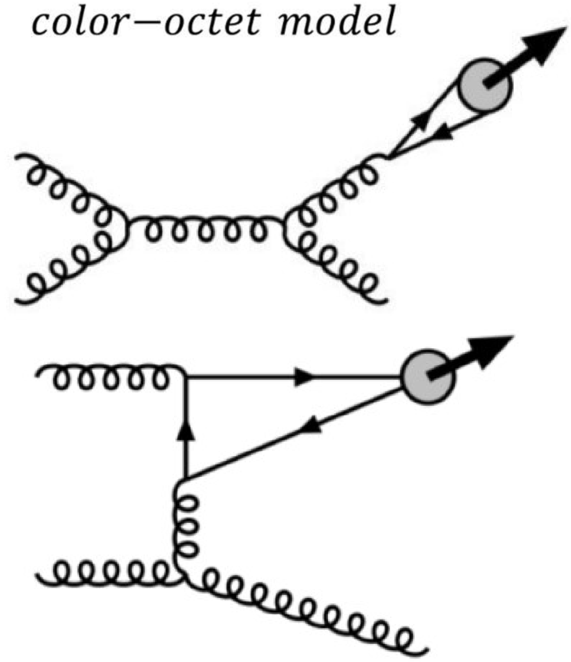
$$d\sigma \sim f(x_1) \otimes f(x_2) \otimes \hat{\sigma}^{x_1 + x_2 \rightarrow [c\bar{c}] + X} \otimes H^{[c\bar{c}] \rightarrow J/\psi}$$

color−singlet model



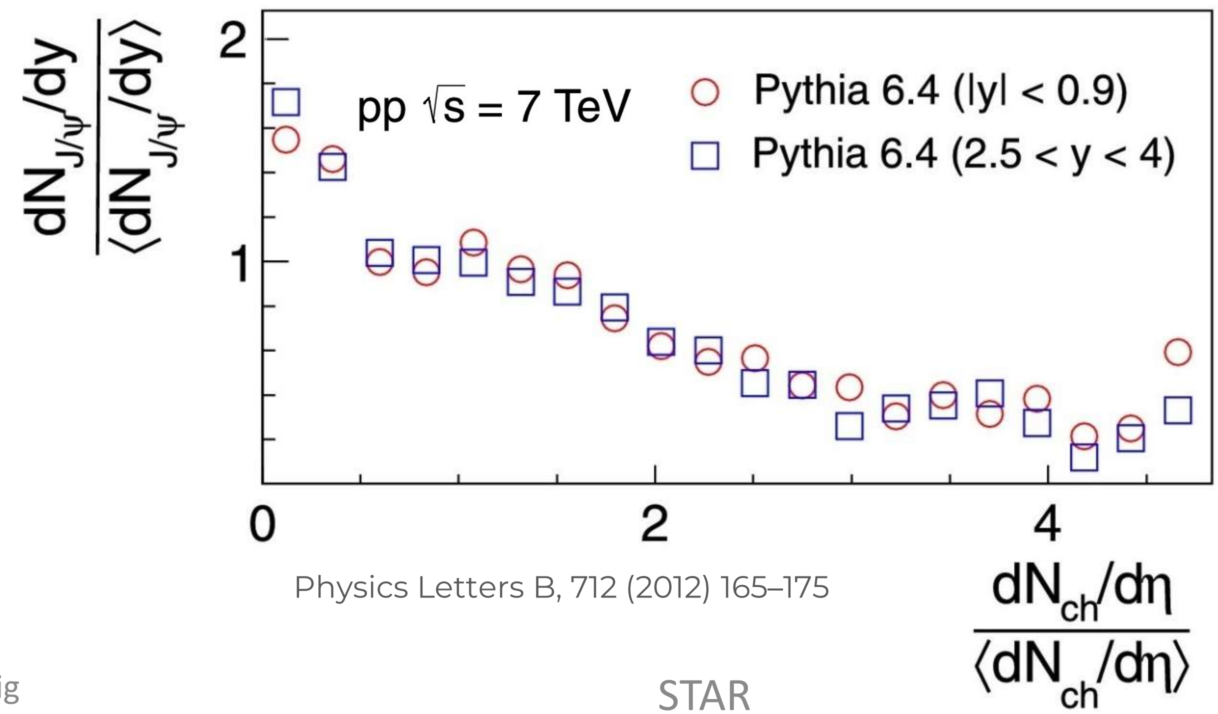
M. Kramer hep-ph/0106120

color−octet model



A production baseline

Predictions from NRQCD, purposefully involving only hard scattering, and neglecting parton clusters with multi-parton interactions. Even beauty hadron feeddown is absent.



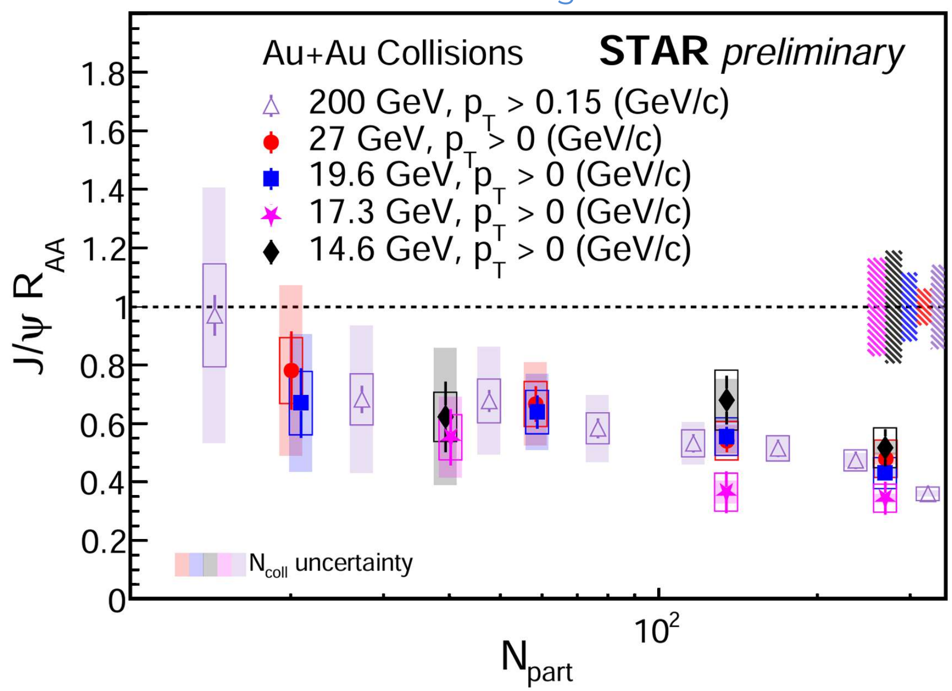
Physics Letters B, 712 (2012) 165–175

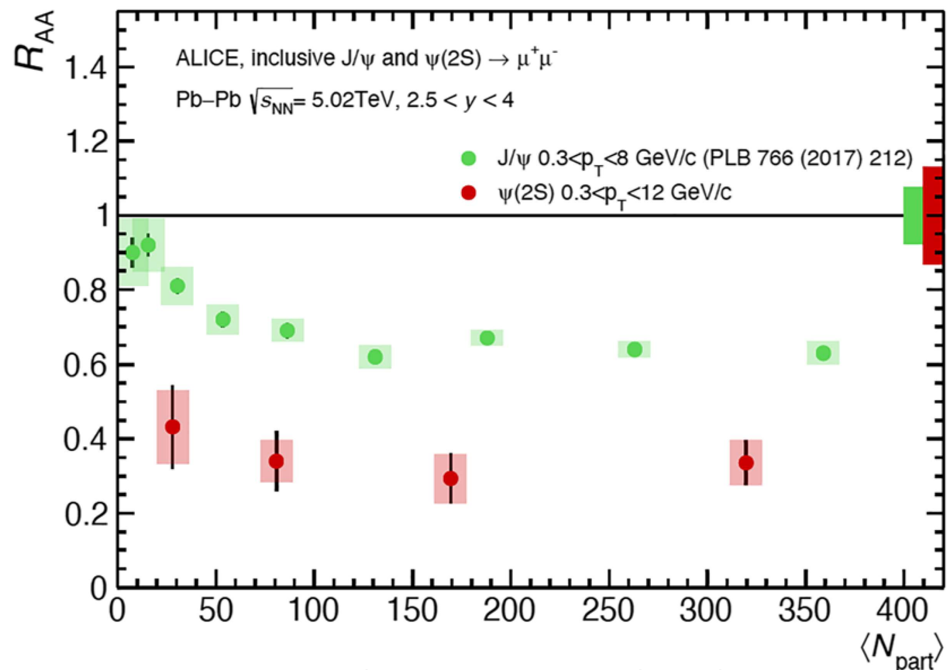
Central A+A -> Peripheral A+A -> p+p?

Suppression of J/ψ is seen more in central than peripheral A+A collisions

Also suppressed in high compared to low multiplicity p+p?

as seen in Wei Zhang's talk tomorrow

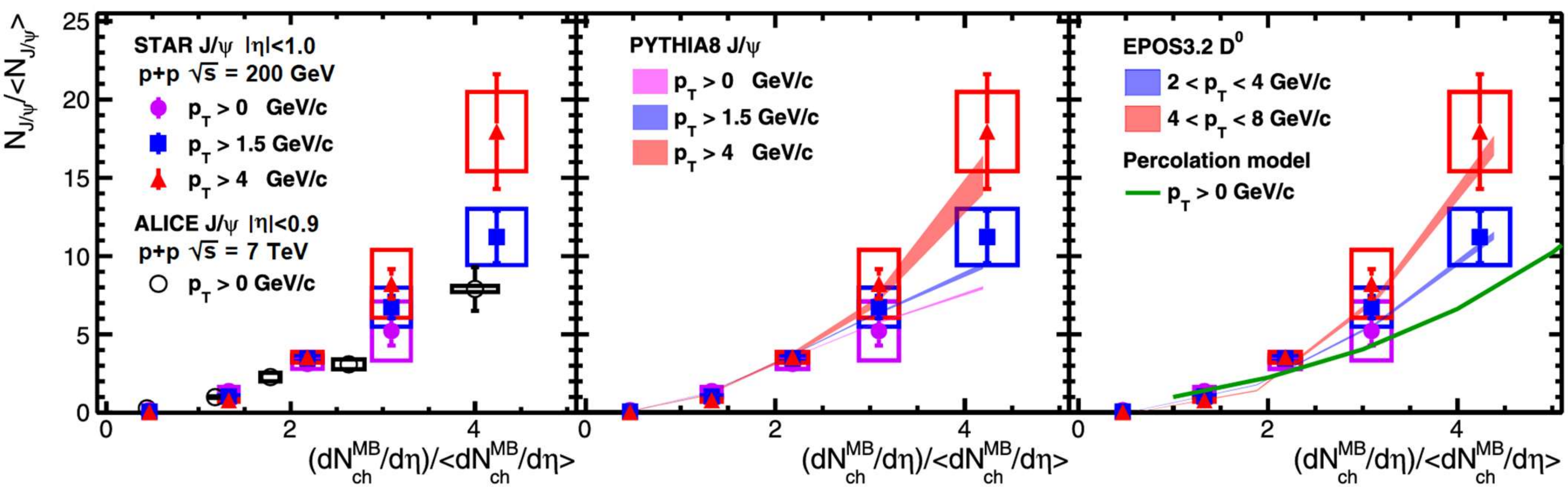




Phys. Rev. Lett. 132 (2024) 042301

Earlier Measurements

At multiple energies, J/ψ production has been found to rise with respect to event multiplicity, at rates that are faster than linear.

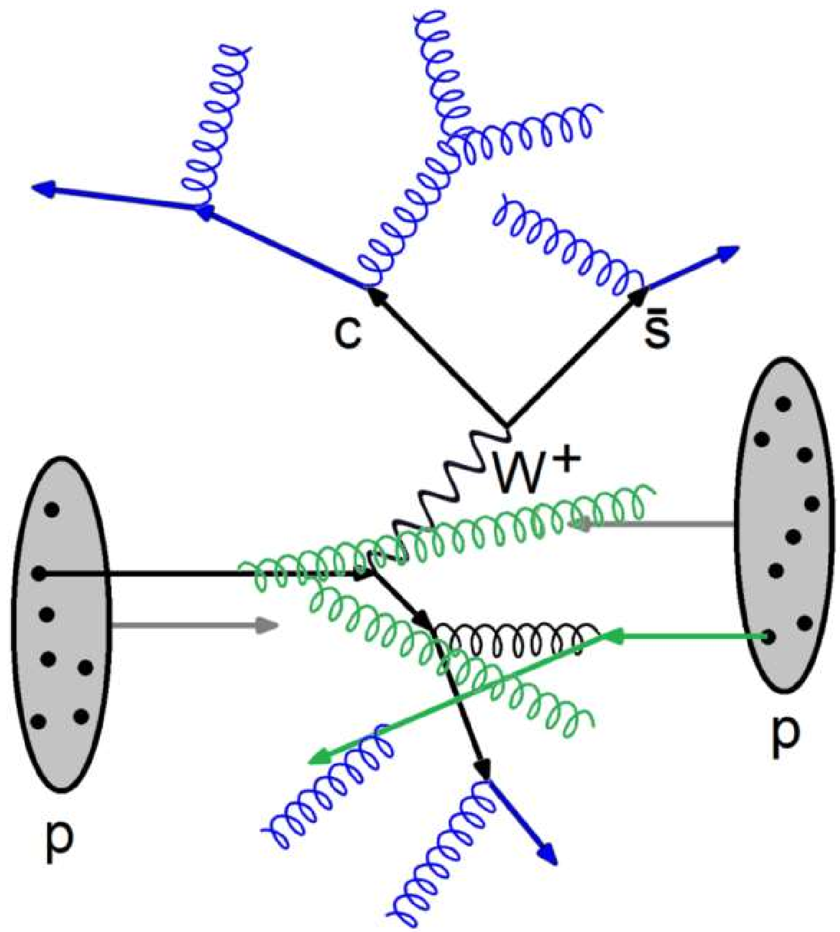


Physics Letters B 786 (2018) 87–93

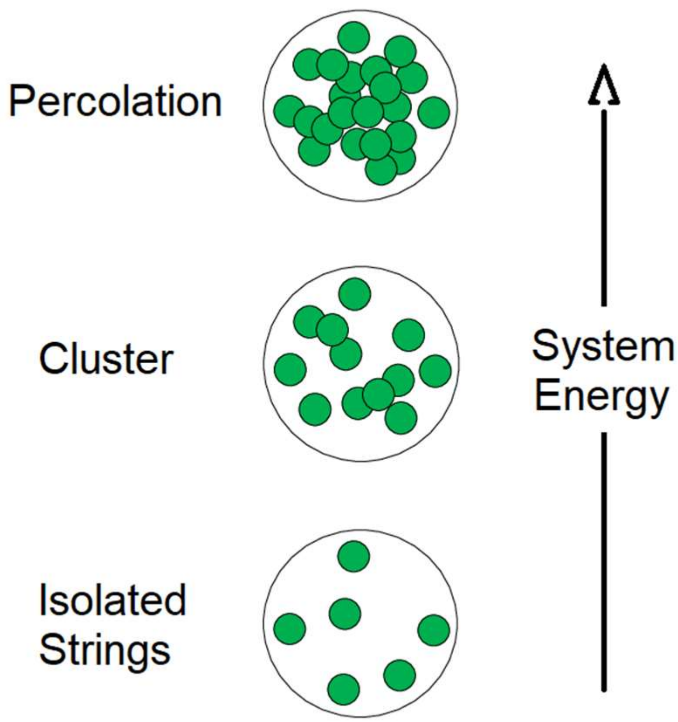
Multi-Parton Interactions

Events that feature more numerous multi-parton interactions are more likely to feature small impact parameters of opposing partons, resulting in enhanced hard scattering processes such as J/ψ production

Eur. Phys. J. C (2019) 79:36



Percolation



Percolation of color strings may similarly contribute by diminishing soft hadron production

Phys.Rev.C 86 (2012) 034903

The STAR Detector

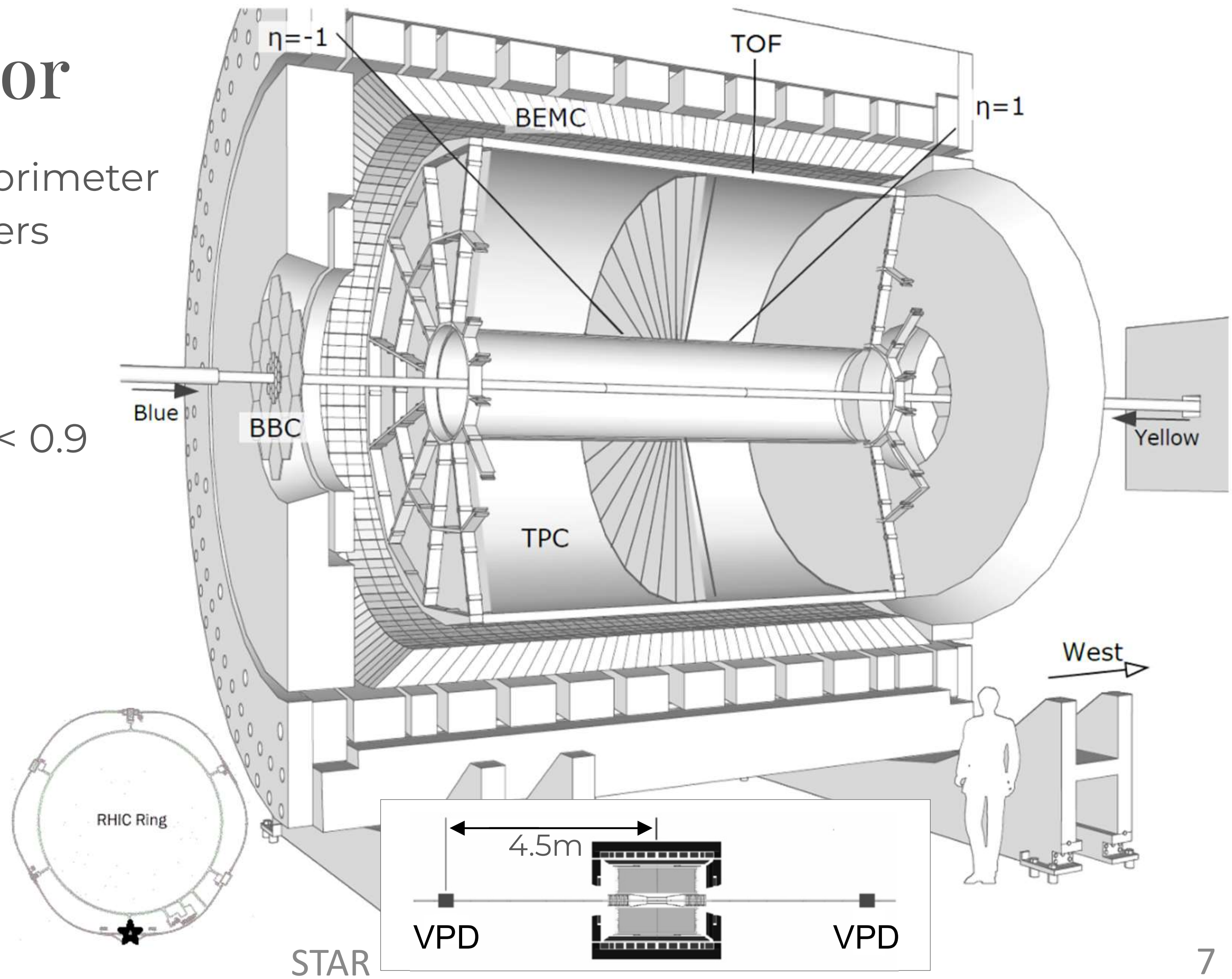
Barrel Electromagnetic Calorimeter
0.05 x 0.05 (phi x eta) towers
$|\eta|<1.0$

Time of Flight
r=208cm, Δt=100ps, $|\eta|< 0.9$

Beam-Beam Counter
$3.8 < |\eta| < 5.1$

Time Projection Chamber
52.8 m^3, $|\eta|< 1.0$

Vertex Position Detector
$4.24 < |\eta| < 5.1$



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Detector Usage

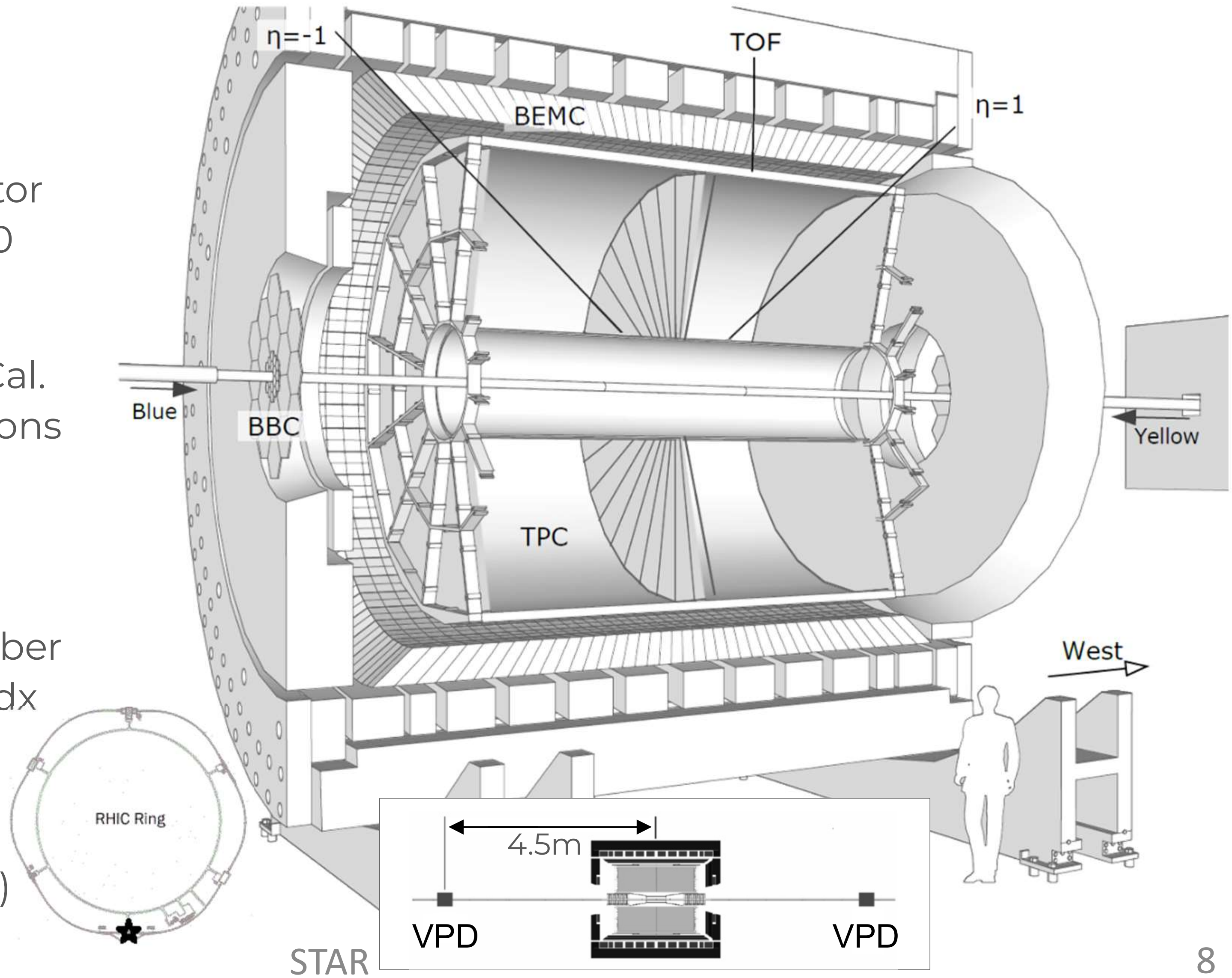
(VPD) Vertex Position Detector
Events in ±40cm from z=0
with vertex quality cut

(BEMC) Barrel Electromag. Cal.
Trigger on, identify electrons

(BBC) Beam-Beam Counter
Min-bias trigger

(TPC) Time Projection Chamber
Mom > 0.2 GeV/c and dE/dx

(TOF) Time of Flight
Pileup track rejection
Slow non $e^{\pm}$ veto (β > 0.97)



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Analysis Procedure

To reconstruct J/ψ in the dielectron channel, using the invariant mass method:

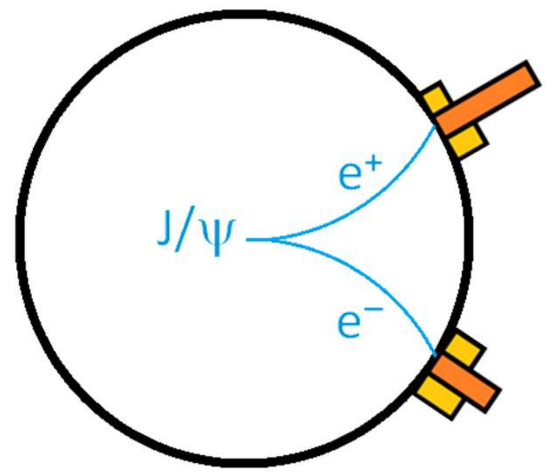
Events are triggered by 4.2 GeV BEMC. Tracks are associated to the highest hit energy and are selected from either

OR
- TOF matched && passing slow veto (β>0.97)
- other BEMC (E/p selected) electron hits

(trig. and assoc. tracks must both pass quality cuts)

Event activity is characterized using TOF-multiplicity

Event counts are scaled to min-bias multiplicity



The Dataset

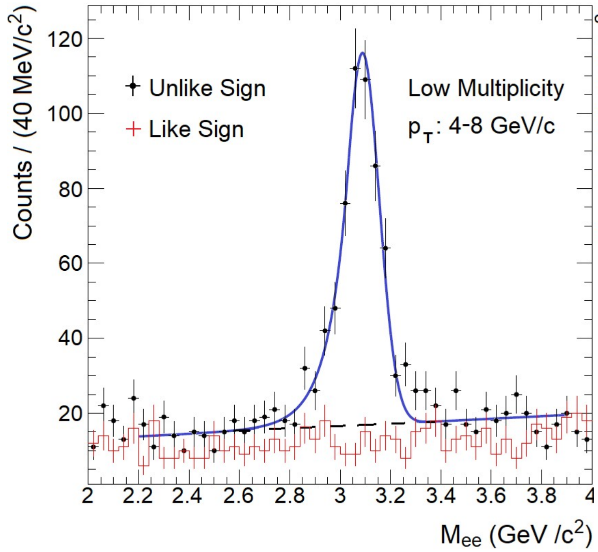
2017 STAR p+p at $\sqrt{s}$ = 510 GeV (79.5 pb-1)

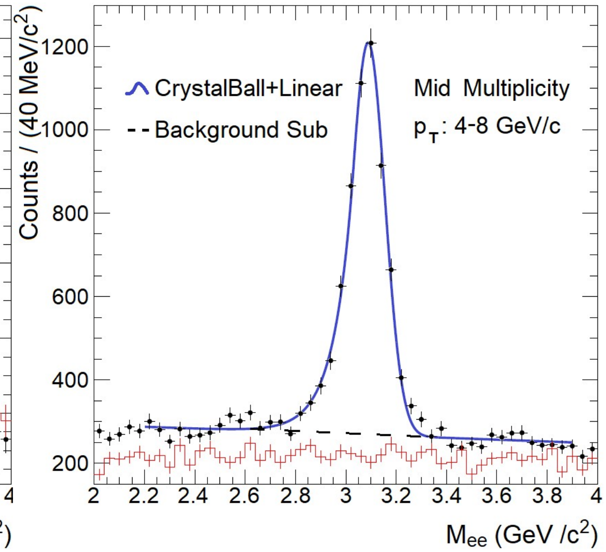
4x increase in luminosity above J/ψ vs mult. in p+p 200 GeV result

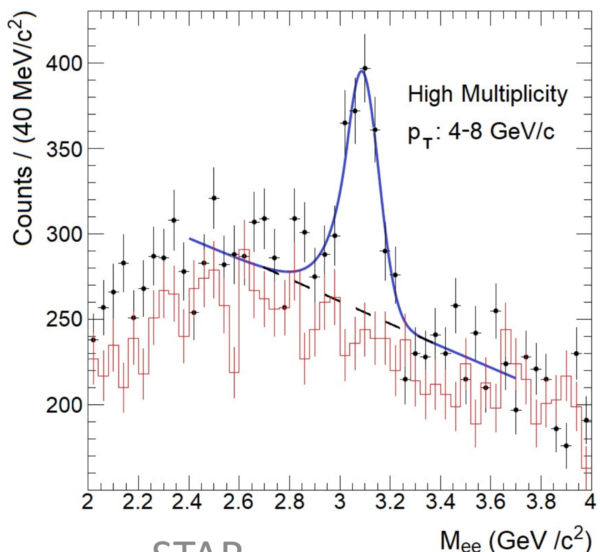
Signal Extraction

Centroid of CrystalBall core fixed to PDG world ave

Width is variable in fit







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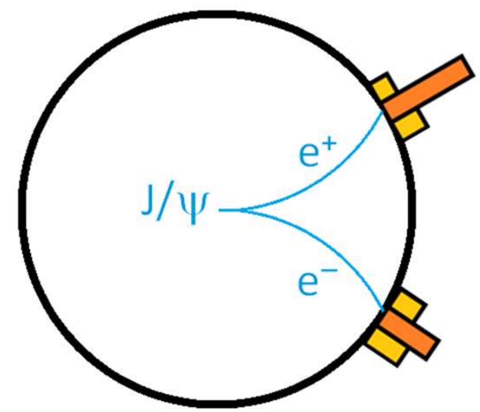
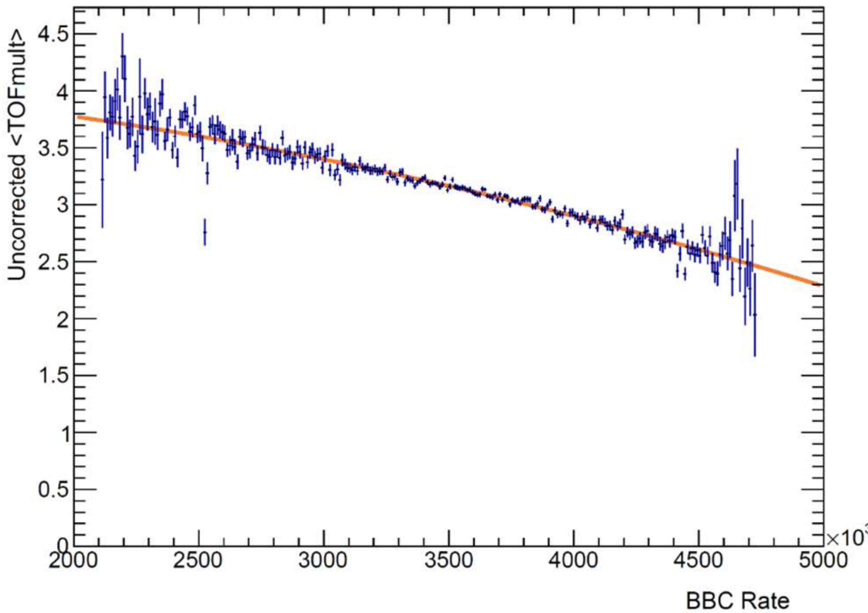


$$M^2 = (E_1 + E_2)^2 - \|\mathbf{p}_1 + \mathbf{p}_2\|^2$$

Event Multiplicity Corrections

A correction is necessary to account for the dependence of tracking efficiencies from occupancy effects accompanying the luminosity rate



Subsequently the trigger efficiencies found from simulation are applied

Uncertainties

Systematic Uncertainties		
	Track Quality	1 - 12%
	Daughter Electron Selection	1 - 9%
	Trigger Efficiency Correction	0 - 13%
	Signal & Background	3 - 16%
	Total	3 - 17%
Statistical Uncertainties		3 - 26%

Conclusion and Summary

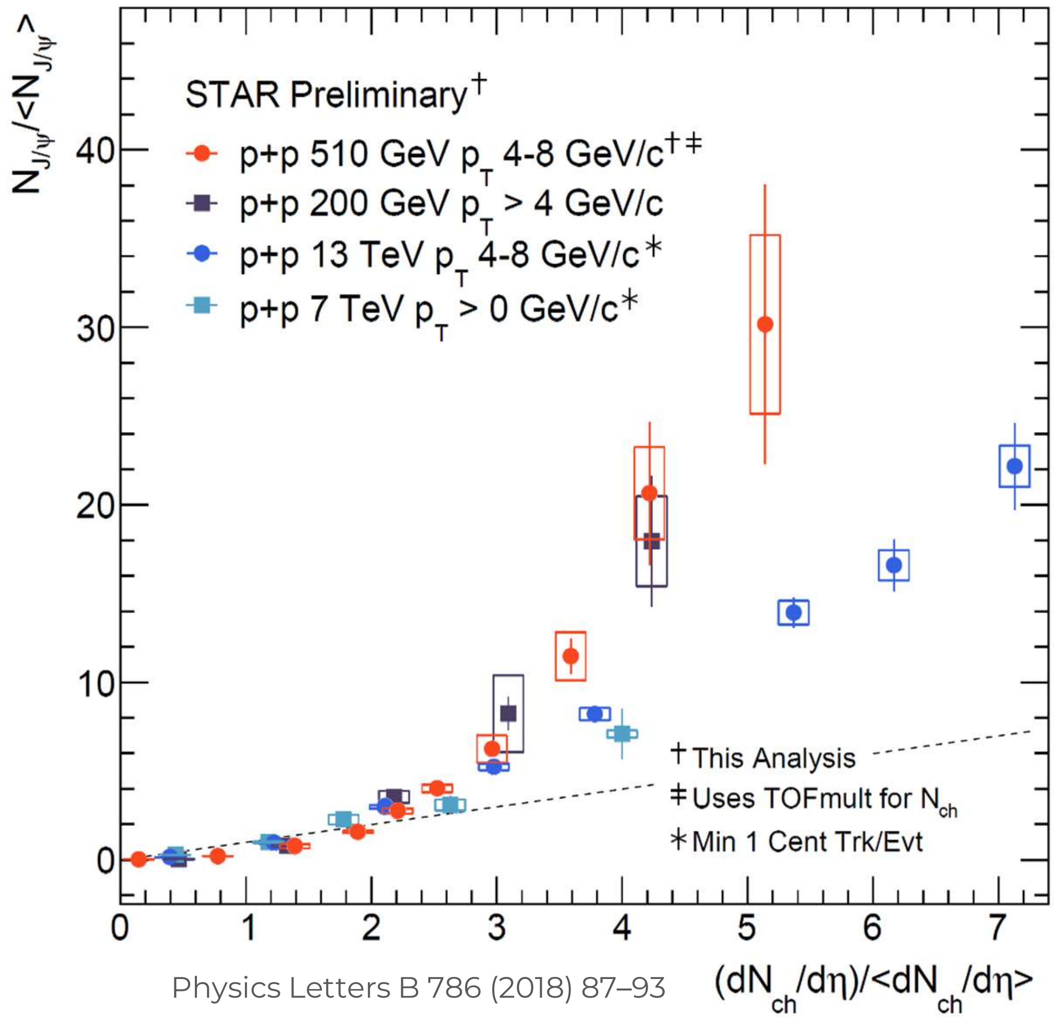
High reach in multiplicity

Improved granularity

Normalized yields at 510 consistent with 200 GeV

Hint of splitting between RHIC and LHC energies

Unfolding is needed to convert TOFmult to ideal multiplicity



Physics Letters B 786 (2018) 87–93
Phys. Lett. B 810 (2020) 135758
Physics Letters B, 712 (2012) 165–175

References

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[2] J. Harris, B. Müller, et al, QGP Signatures revisited Eur. Phys. J. C (2024) 84:247

[3] J. Adam, J /ψ production cross section and its dependence on charged-particle multiplicity in p+p collisions at $\sqrt{s}$ =200 GeV, Physics Letters B 786 (2018) 87–93

[4] Rubin P, et. al. (CLEO) Observation of the $^1P_1$ state of charmonium, Phys Rev D, 72 092004, 2005

[5] B. Abelev et. al. (ALICE) , J/ψ production as a function of charged particle multiplicity in pp collisions at $\sqrt{s}$ = 7 TeV, Physics Letters B, 712 (2012) 165–175

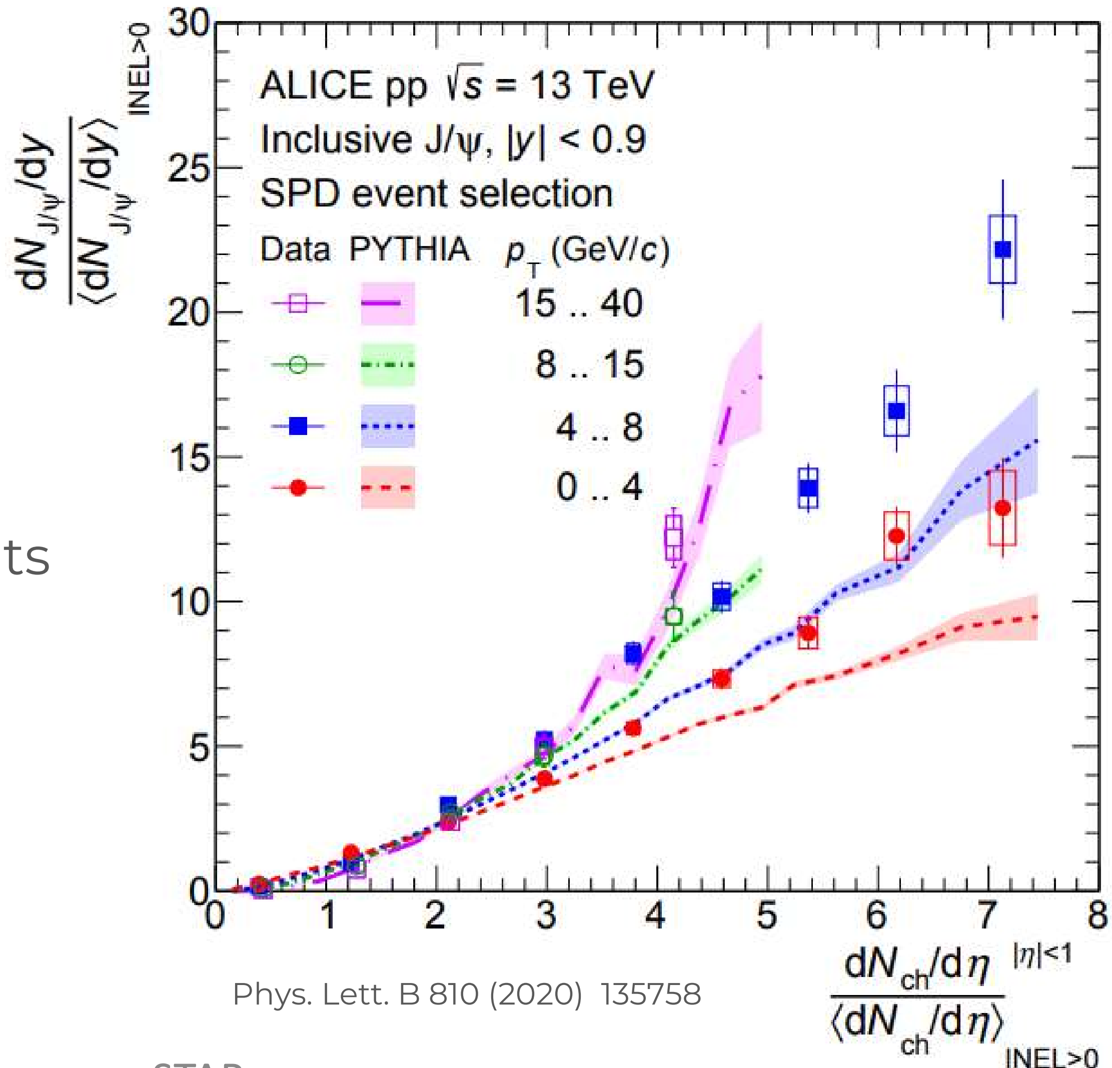
[6] B. Martin, G. Shaw, Nuclear and Particle Physics, 3rd Ed, p. 190

[7] S. Acharya, et al. (ALICE) Multiplicity dependence of inclusive J/ψ production at $\sqrt{s}$ = 13 TeV, Phys. Lett. B 810 (2020) 135758

[8] S. Weber, et al. Elucidating the multiplicity dependence of J/ψ production in proton-proton collisions with PYTHIA8, Eur. Phys. J. C (2019) 79:36

Backup

Model calculations at high multiplicity show qualitative agreement with measurements at LHC energy.

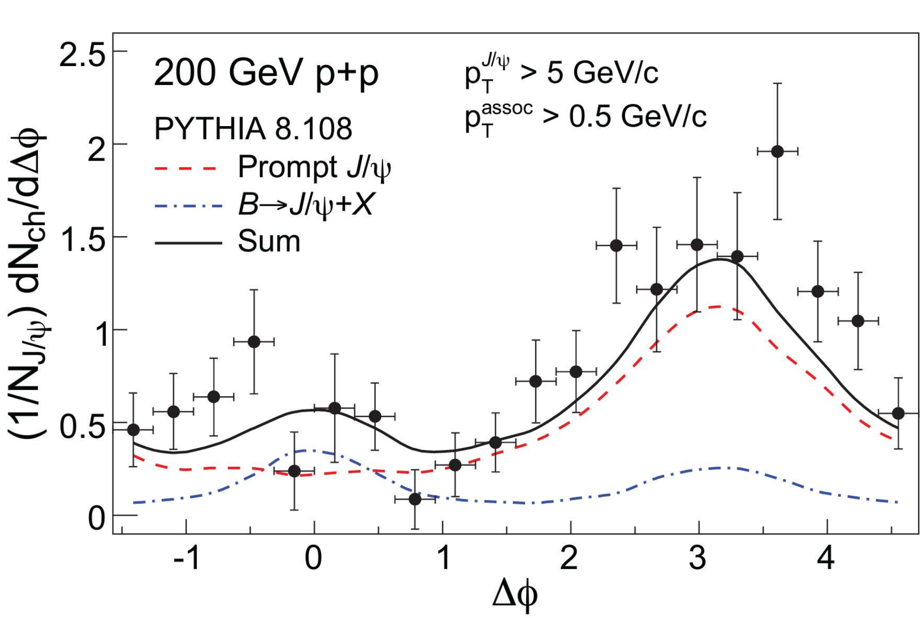


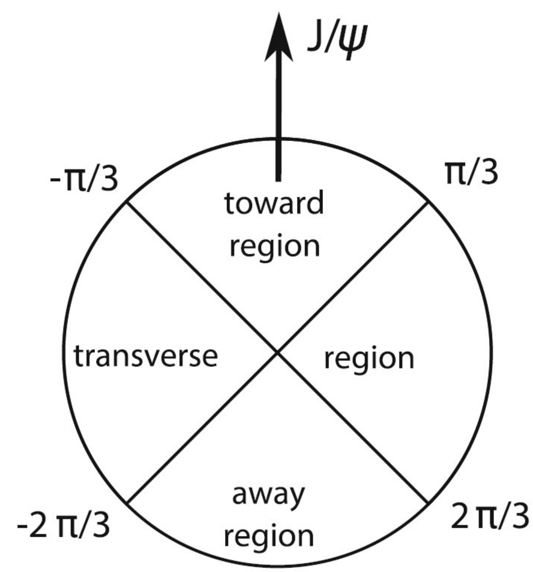
[7]

Phys. Lett. B 810 (2020) 135758

Backup

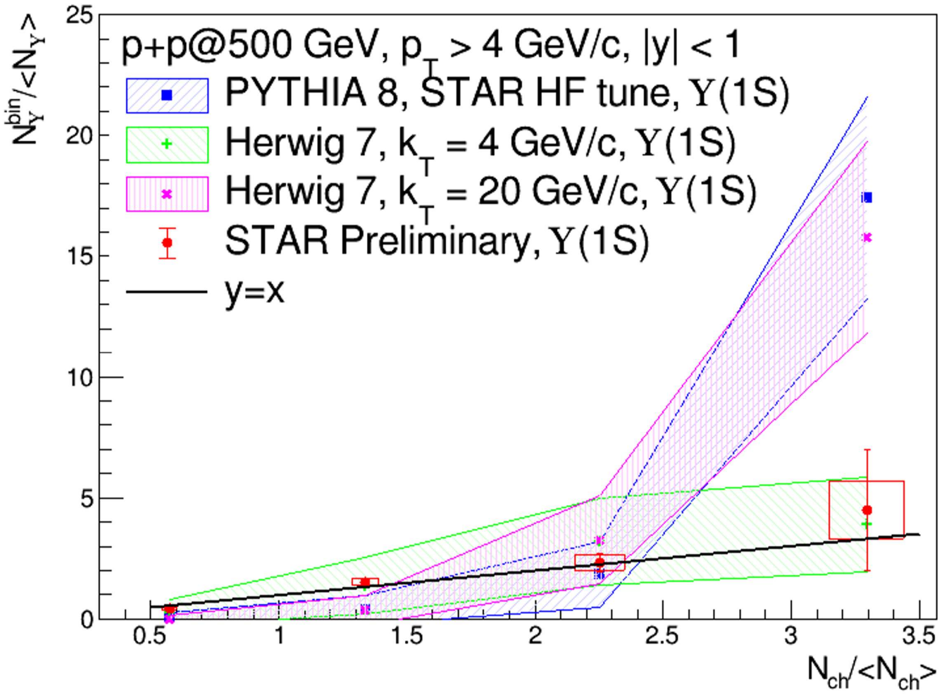
Model calculations are able to describe the azimuthal distribution with respect to the J/ψ in underlying events

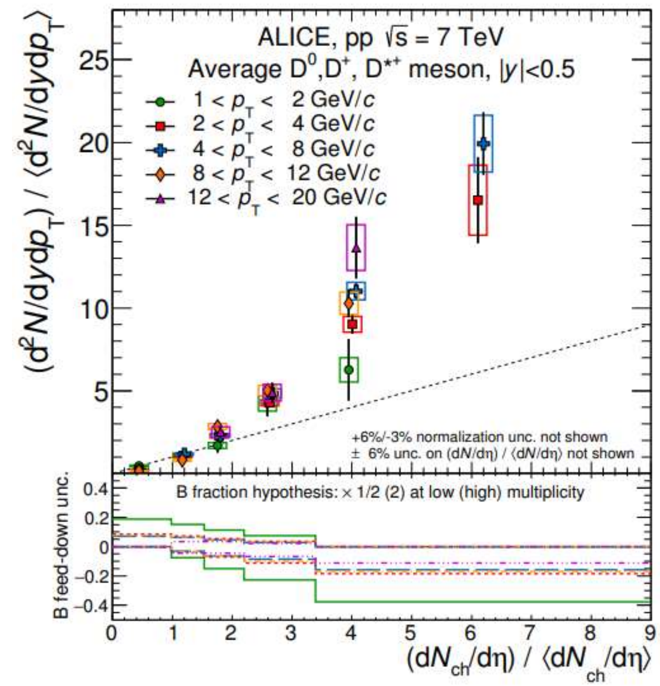




Backup

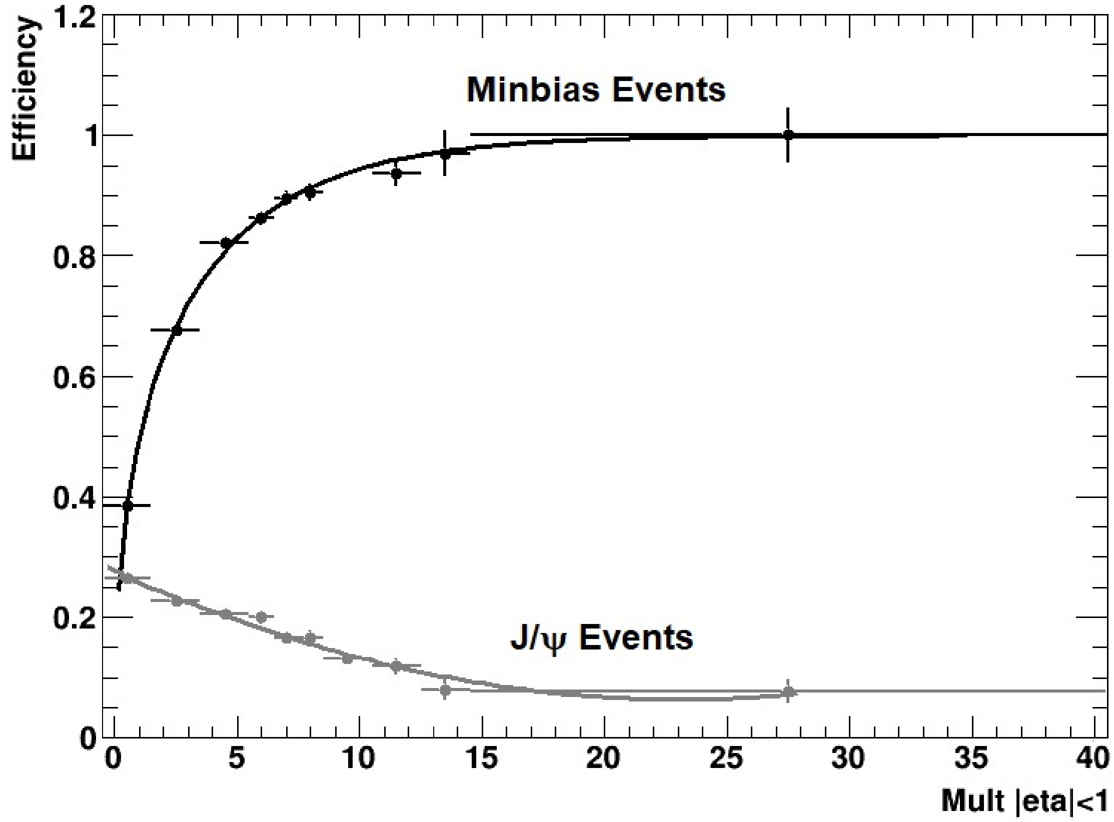
Comparable event activity dependence featured in production of other open and hidden heavy flavor hadrons





Backup

Separate efficiency vs multiplicity event selection corrections are necessary for the J/ψ and min-bias distributions



Pythia events

- STAR HF Tune
- MB

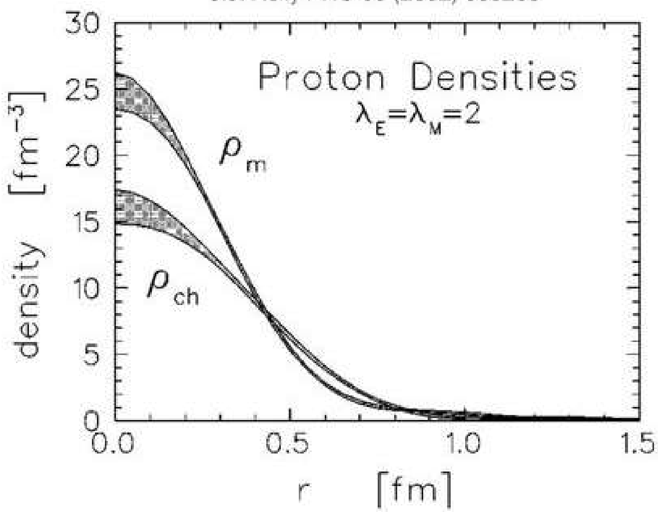
embedded into zerobias and reconstructed

Backup

$$F(Q^2) = \frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + 2\tau \tan^2\left(\frac{\theta_e}{2}\right) G_M^2(Q^2)$$

- Within a **non-relativistic approach**, electromagnetic **form factors** can be interpreted as the **Fourier transform** of the charge and current **densities** inside the nucleon.

J.J. Kelly PRC 66 (2002) 065203



$$\rho_{ch}(r) = \frac{2}{\pi}\int_0^\infty dQ\, Q^2 j_0\left(Qr/\sqrt{1+\left(Q^2/4M^2\right)}\right) G_E\left(Q^2\right)\left[1+\left(Q^2/4M^2\right)\right]^{\lambda_E}$$

Dipole behaviour

$$\rho(r) = \frac{\lambda^3}{8\pi}\exp[-\lambda r] \;\rightarrow\; F(k) = \int \rho(r)\exp[i k\cdot r]d^3r = \frac{\lambda^4}{\left(k^2+\lambda^2\right)^2}$$

Backup

Further insight into this deviation from linearity can be obtained by investigating the impact parameter dependence of MPI. As mentioned earlier, in PYTHIA the number of MPI per event is related to the matter overlap in the pp collisions and, hence, to the impact parameter b [21]. Figure 3 (left panel) shows the average self-normalized number of MPI per event as a function of the self-normalized b^{-1}. In the most central collisions, the average number of MPI saturates at 3.3 times the mean value. Even higher number of MPI, as

[5]

5.2.1 The strong coupling constant

The strong interaction derives its name from the strong forces acting at distances of order 1 fm that, among other things, bind quarks in hadrons. However, many of the remarkable phenomena discussed in this chapter depend on the fact that the interaction gets weaker at short distances; that is, on asymptotic freedom. Such short-distance interactions are associated with large momentum transfers $|\mathbf{q}|$ between the particles, with

$$|\mathbf{q}| = \mathrm{O}(\hbar/r), \tag{5.6}$$

where $r = |\mathbf{r}|$ is the distance at which the interaction occurs. For example, the amplitude (1.47) for scattering from a spherically symmetric potential $V(r)$ becomes

$$\mathcal{M}(q) = 4\pi \int_0^\infty V(r) \left(\frac{\sin(qr)}{qr} \right) r^2 \mathrm{d}r \tag{5.7}$$

on integrating over all angular directions. The dominant contributions arise from r values of order q^{-1} as asserted, since for smaller r the integrand is suppressed by the factor r^2, while for large r it is suppressed by the average over the rapidly oscillating sine factor. Hence in discussing

[10] The numerical factor multiplying α_s (i.e. $-4/3$ in this case) depends on the colour state chosen, and we will not discuss it further.

[4]