

DOE Grant # DE-SC0023491

# Production of $J/\psi$ vs Multiplicity

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

---

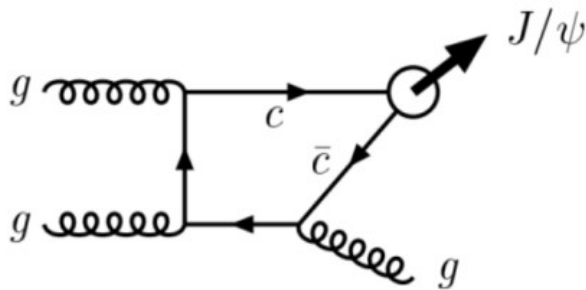
Brennan Schaefer (Lehigh University)  
for the STAR Collaboration



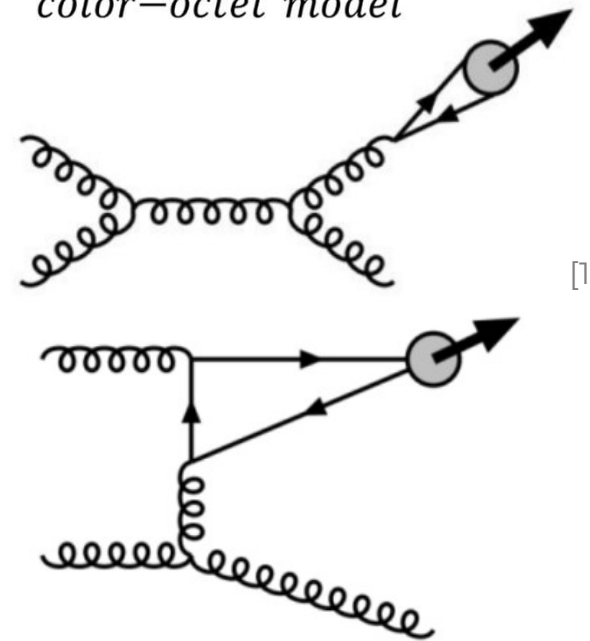
Accompanying model calculations for  $J/\psi$  production, are coinciding predictions for the underlying events

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

*color-singlet model*



*color-octet model*

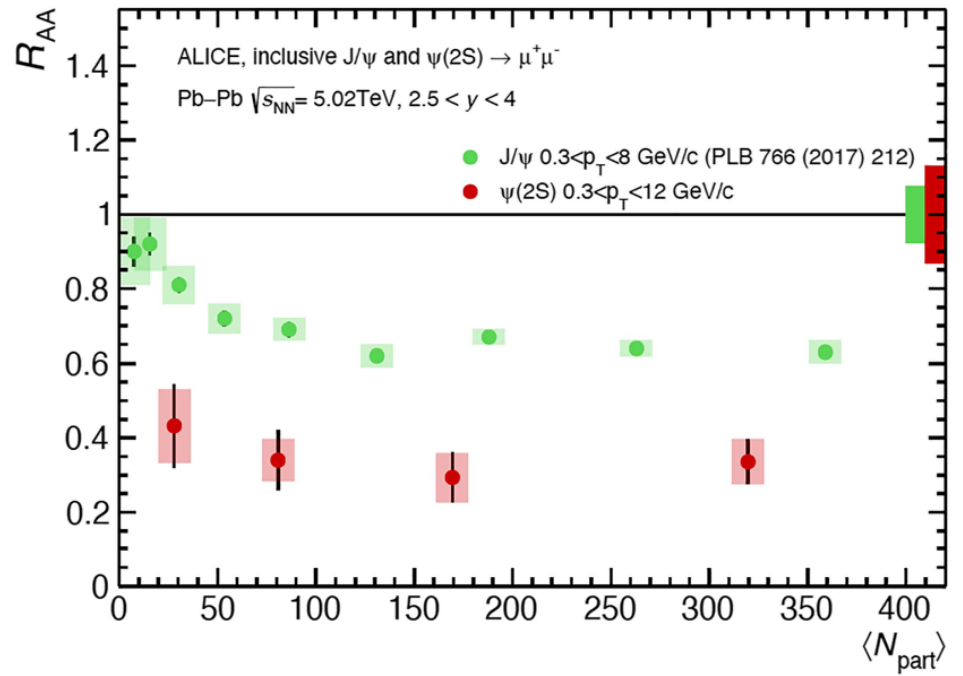
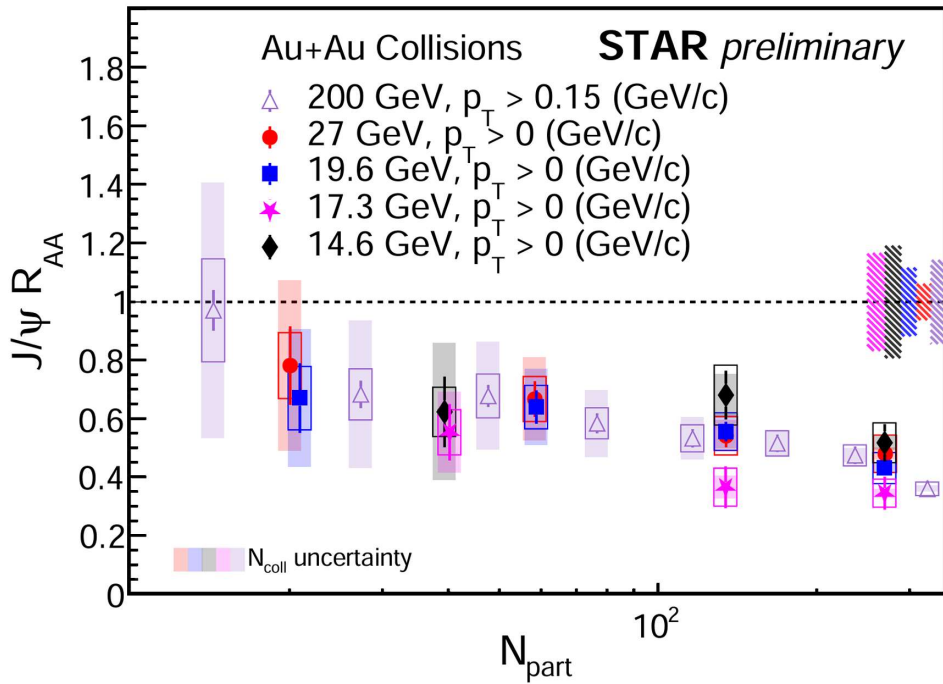


[1]

Suppression of  $J/\psi$  is seen more in central than peripheral A+A collisions

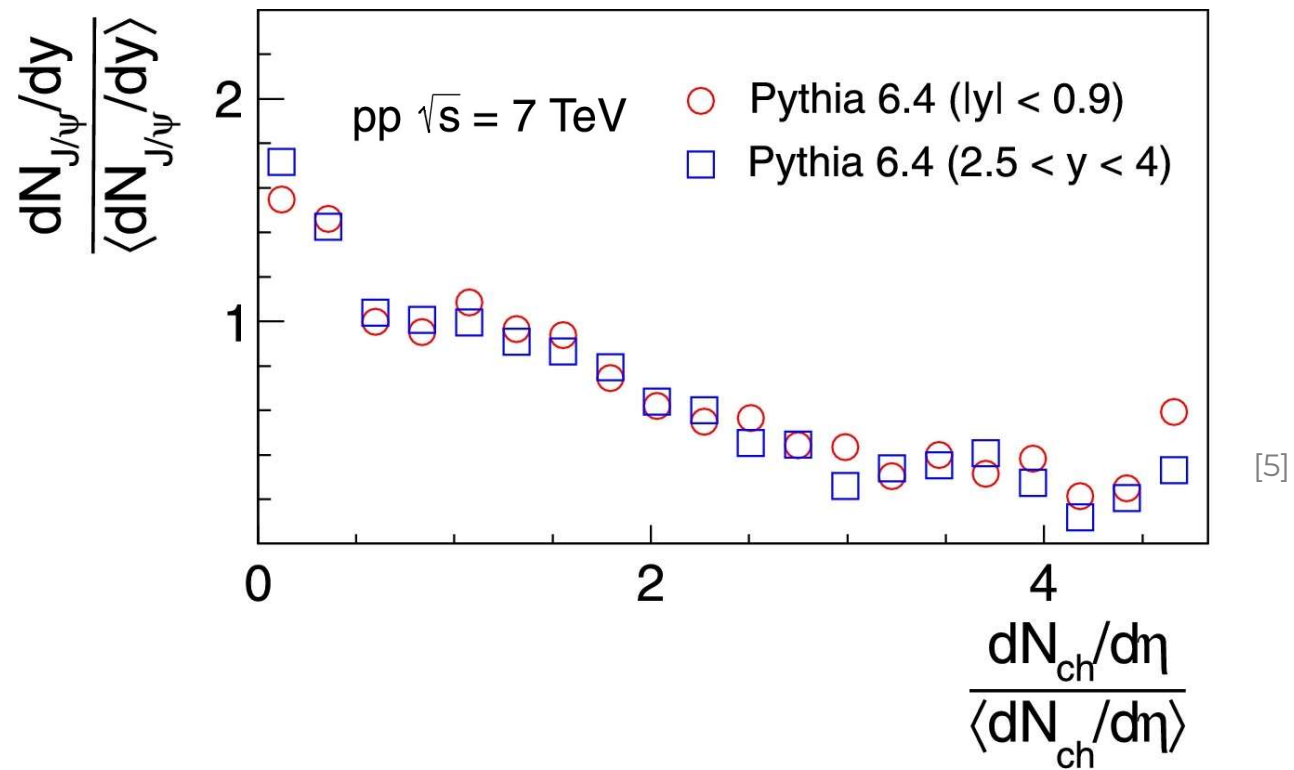
Also suppressed in high compared to low multiplicity p+p collisions

as seen in Wei Zhang's talk tomorrow

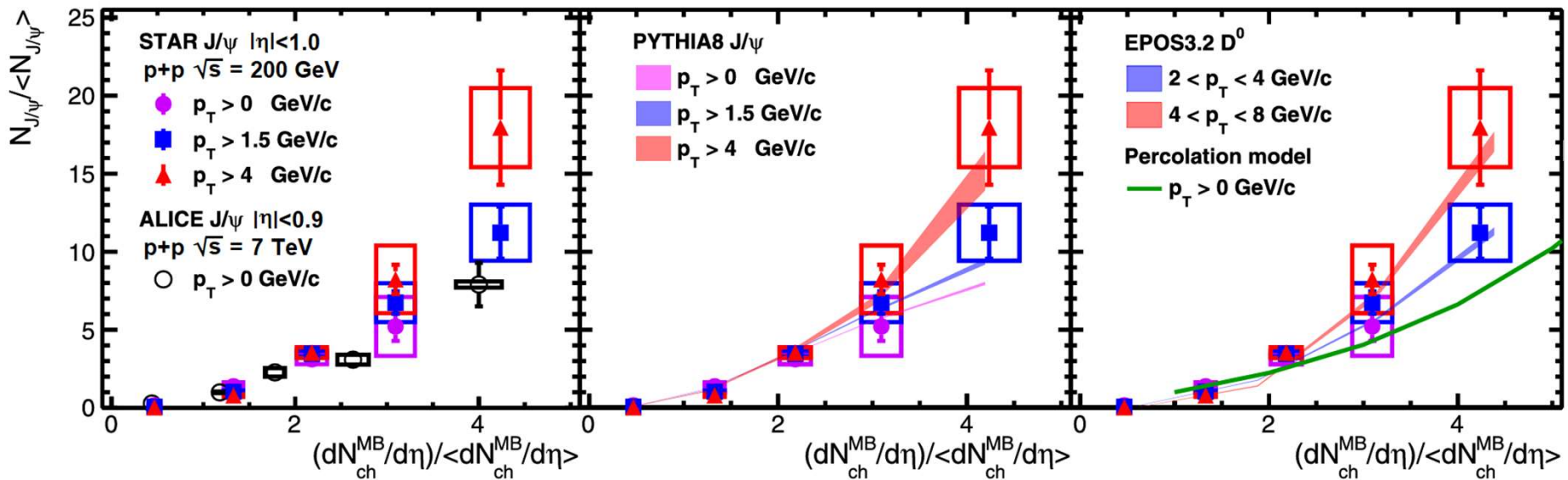


[2]

## Early predictions from model calculations



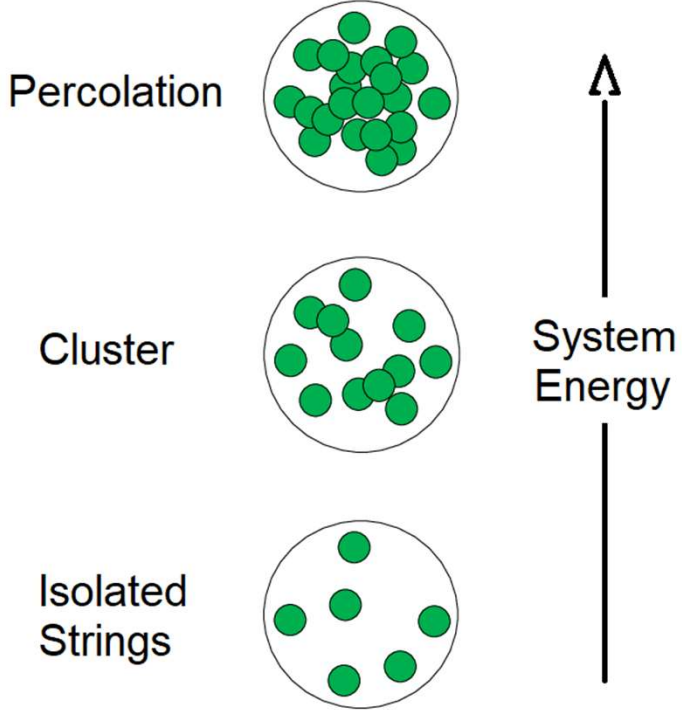
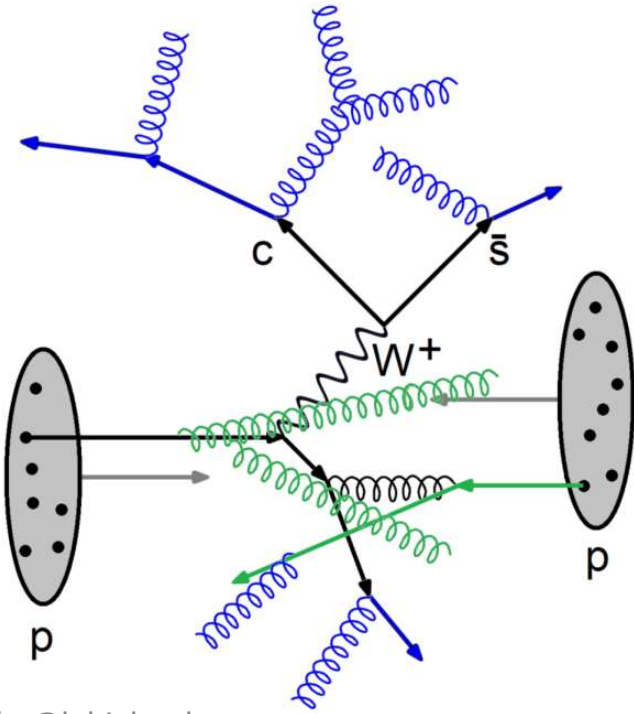
A faster than linear rise in  $J/\psi$  production has been found with respect to event multiplicity, consistent across multiple energies.



[3]

Events that feature more numerous multi-parton interactions (left) may also enhance  $J/\psi$  production due to small  $b$  of opposing partons and hence hard scattering

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



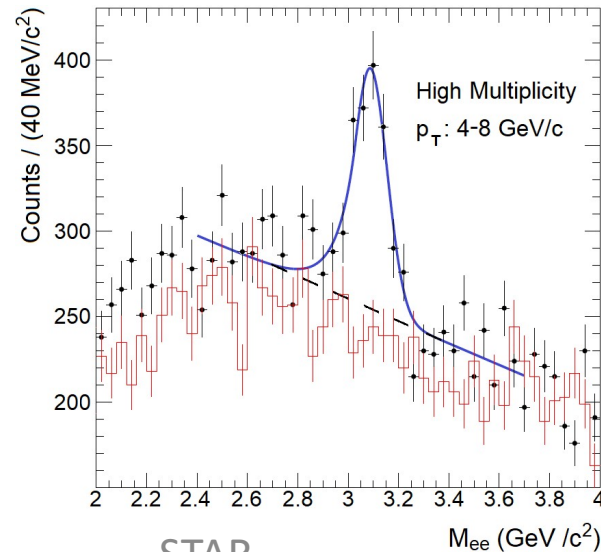
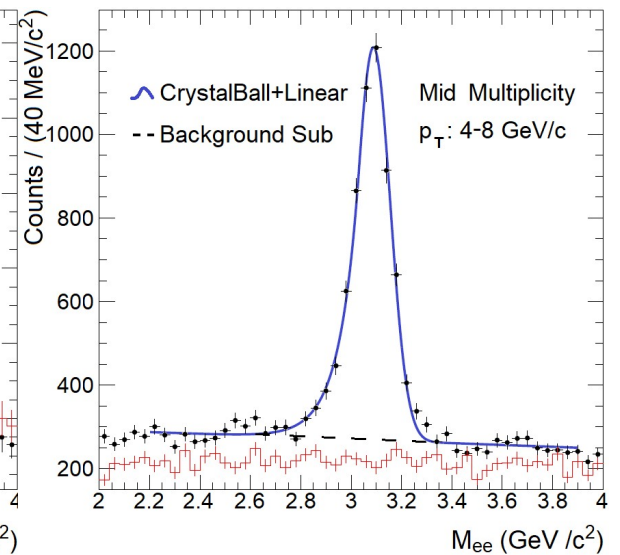
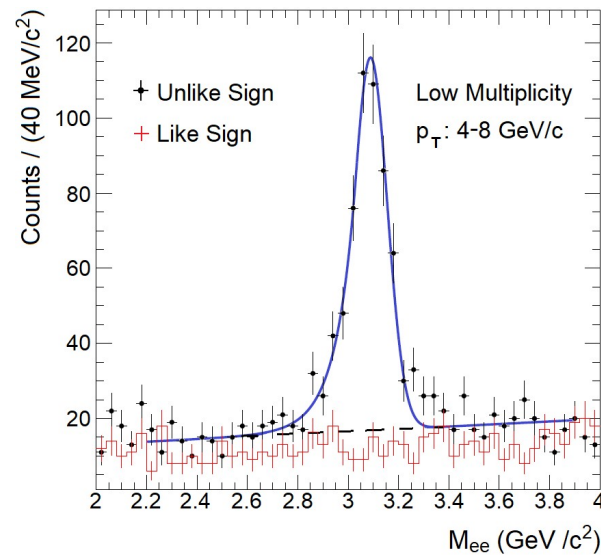
2017 STAR p+p 510 GeV  
(79.5 pb<sup>-1</sup>)

4x increase in luminosity  
above 200 GeV p+p

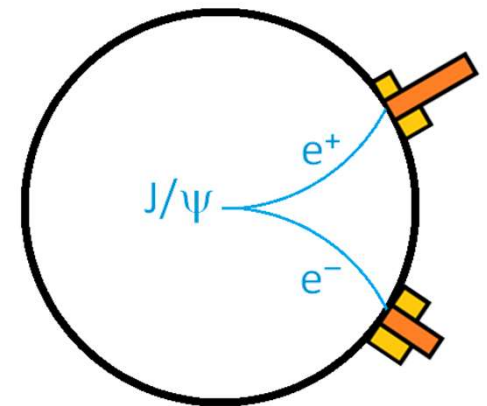
Triggering on events with  
4.2 GeV/c EMCal electron

Associate tracks from TOF  
or EMCal-E/p requirement

Centroid of C.B. core fixed  
to PDG world ave, width  
is variable in fit



STAR



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

# Analysis Procedure

To reconstruct  $J/\psi$  in the **dielectron channel**, using the **invariant mass method**:

Events are triggered using B.EMCal

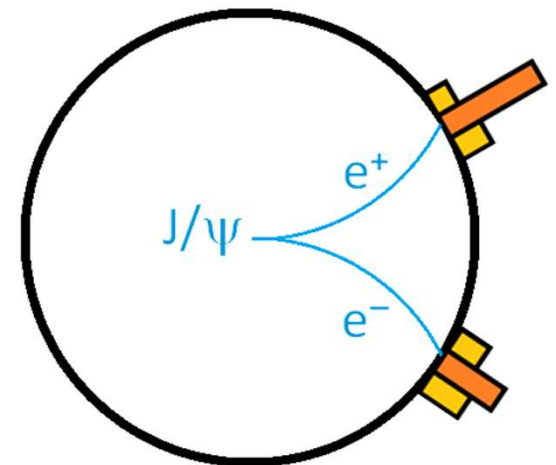
Tracks are associated to the highest hit energy track are selected from either

- OR – TOF matched && passing a **slow veto**
- other B.EMCal (E/p selected) electron hits

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

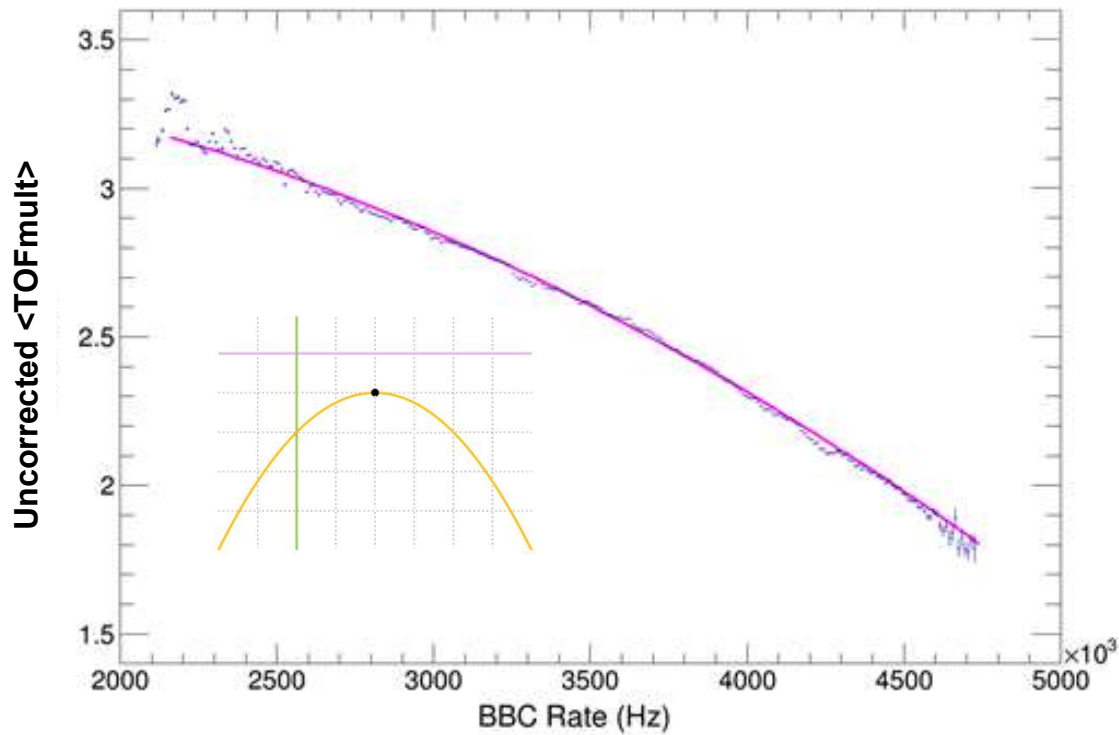
Event activity is characterized using TOF-multiplicity

Event counts are scaled to min-bias multiplicity





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



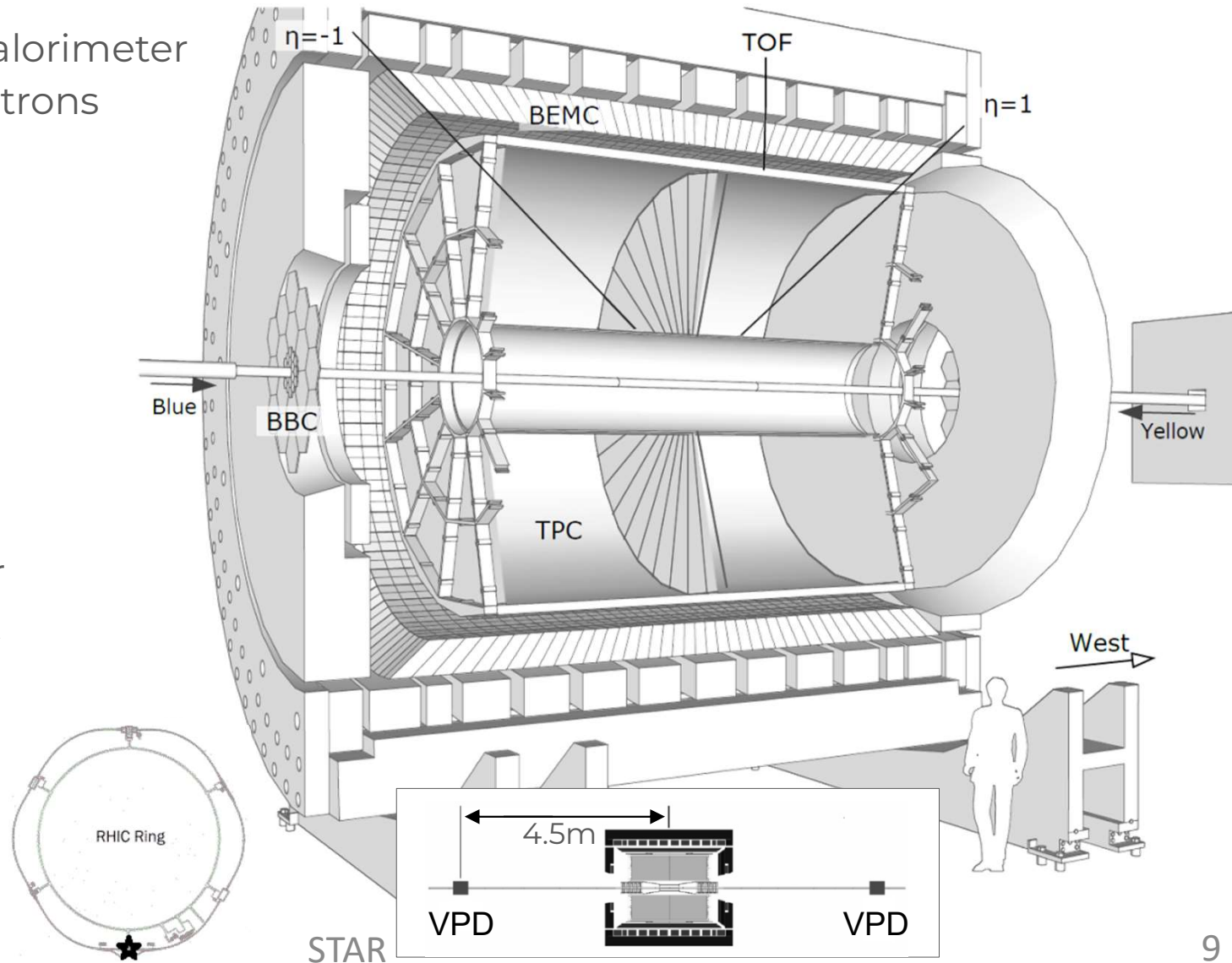
Barrel Electromagnetic Calorimeter  
Trigger on, identify electrons

Time of Flight  
Pileup track rejection  
Slow non  $e^\pm$  veto

Beam-Beam Counter  
Min-bias trigger

Time Projection Chamber  
Momentum and  $dE/dx$

Vertex Position Detector



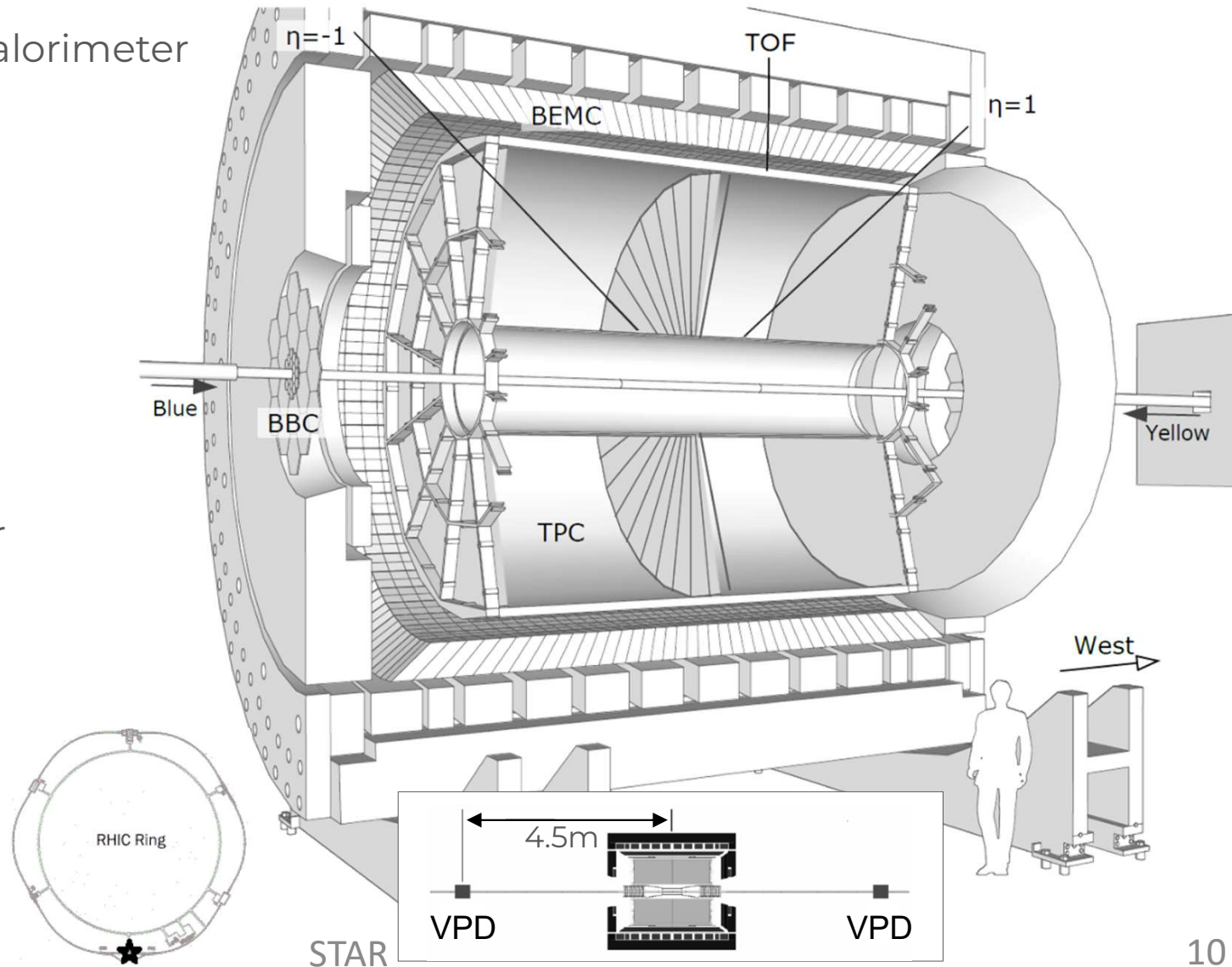
Barrel Electromagnetic Calorimeter  
60m<sup>2</sup>  $|\eta| < 1.0$

Time of Flight  
 $r=208\text{cm}$ ,  $\Delta t=100\text{ps}$

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

Time Projection Chamber  
52.8 m<sup>3</sup>

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



# Systematics Table

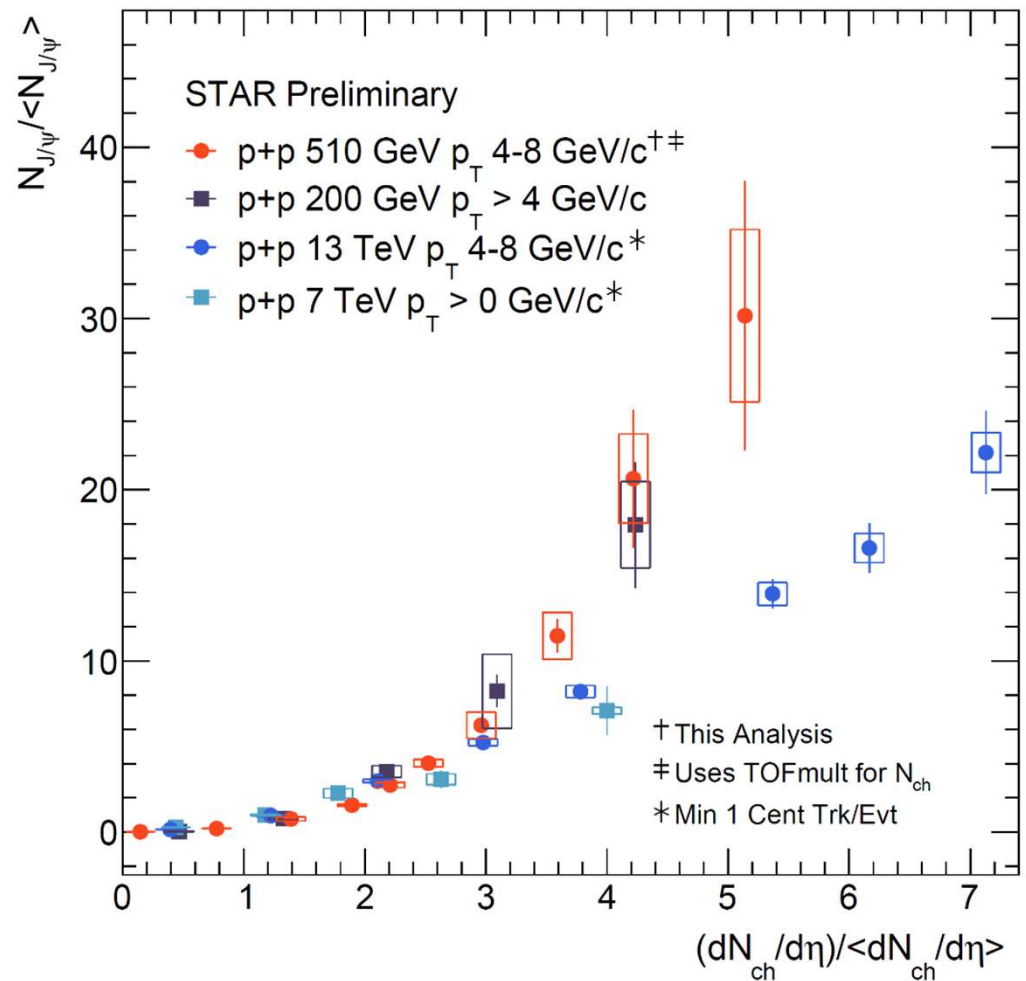
Print number table with last  
two sources

High reach in multiplicity

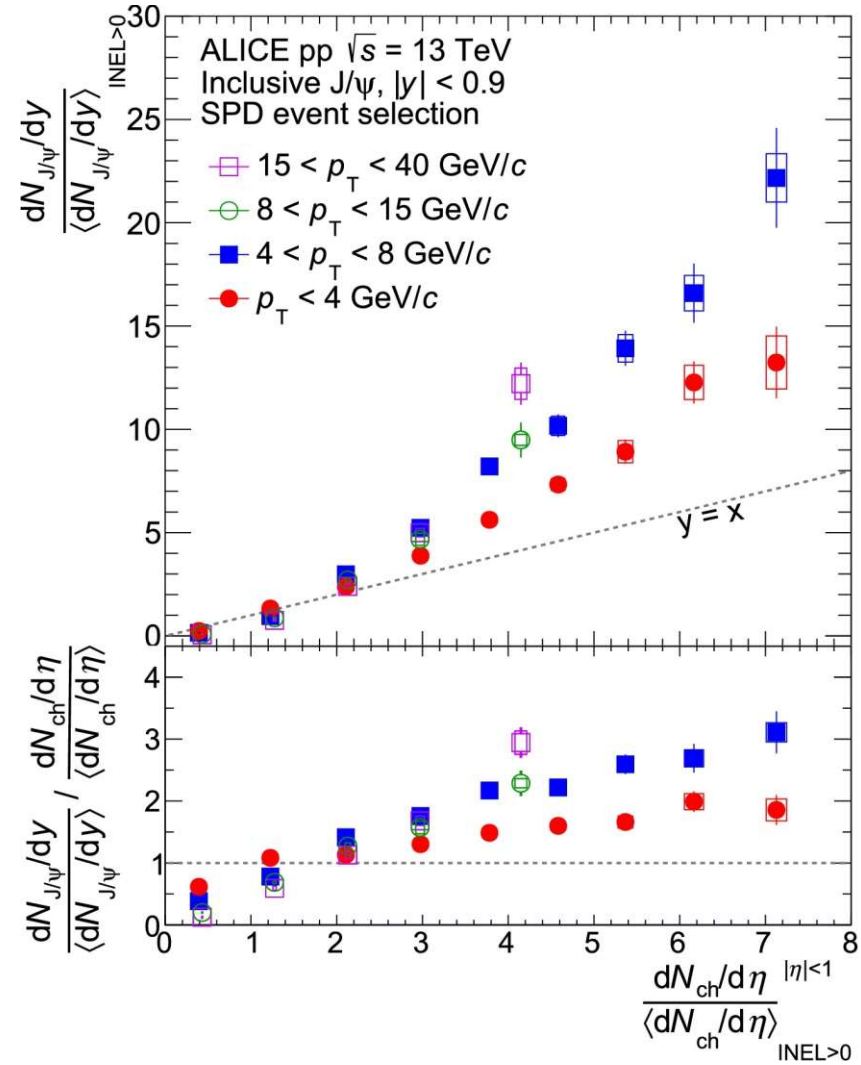
Improved granularity

Yields at 510 consistent with  
200 GeV/c

Hint of splitting between RHIC  
and LHC energies



# Lorem Ipsum

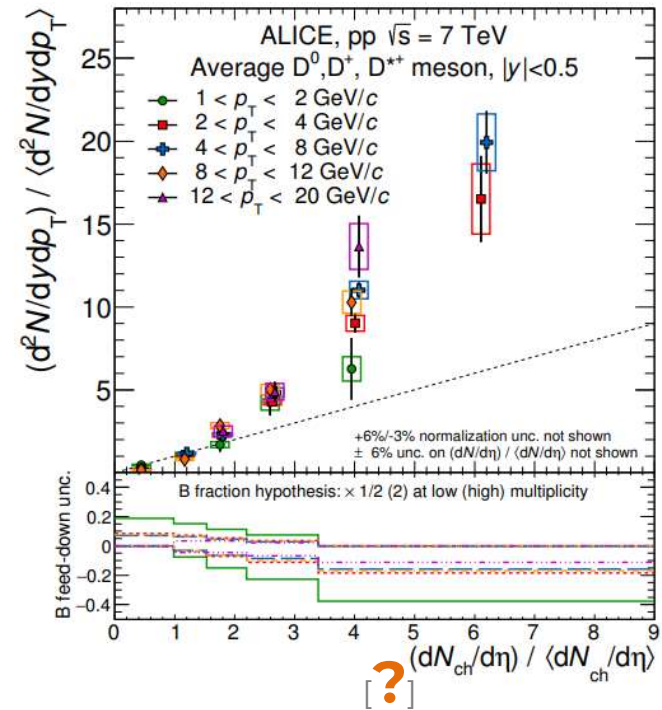
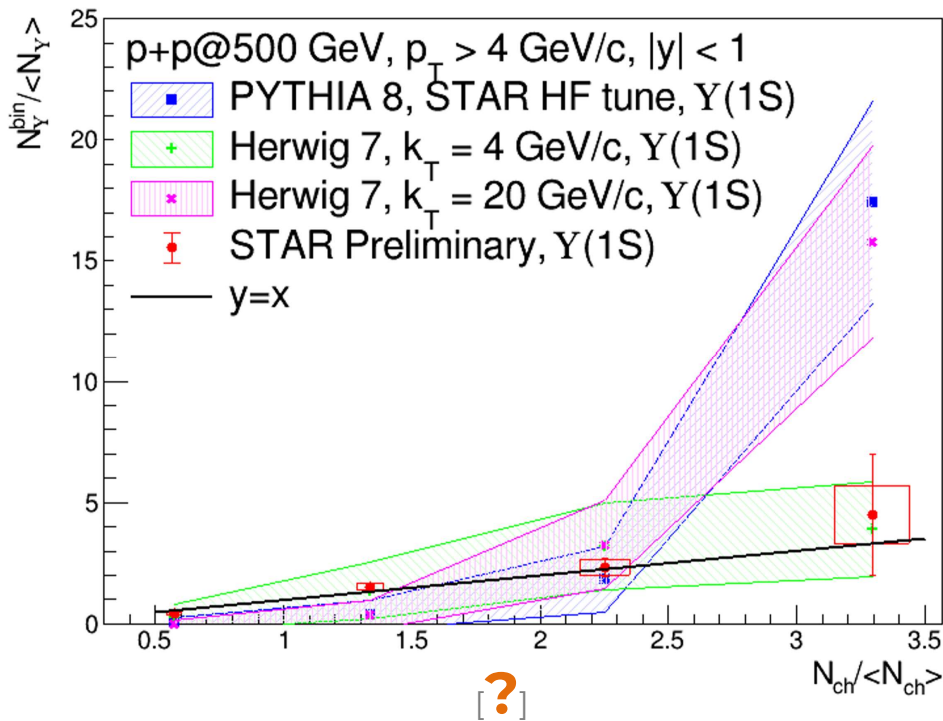


[7]

- [1] M. Kramer, Quarkonium Production at high-energy colliders, hep-ph/0106120
- [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

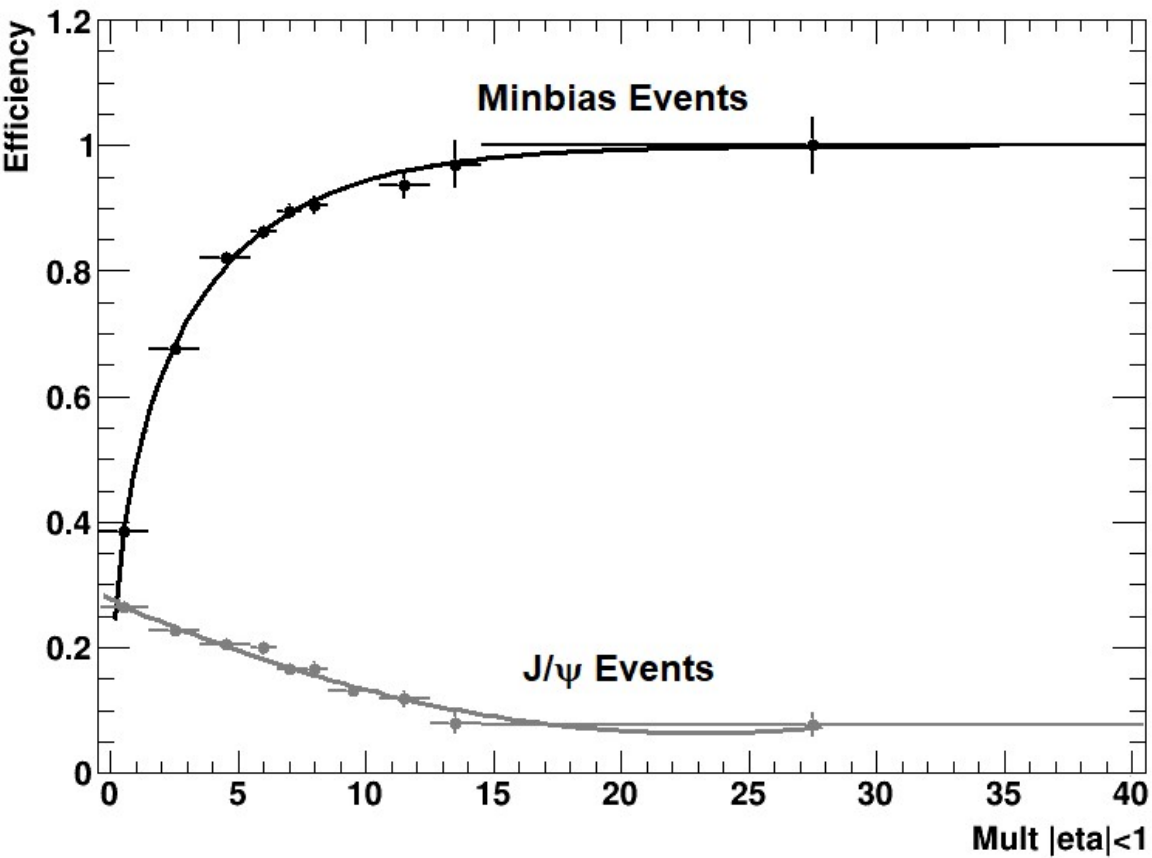
# Backup

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



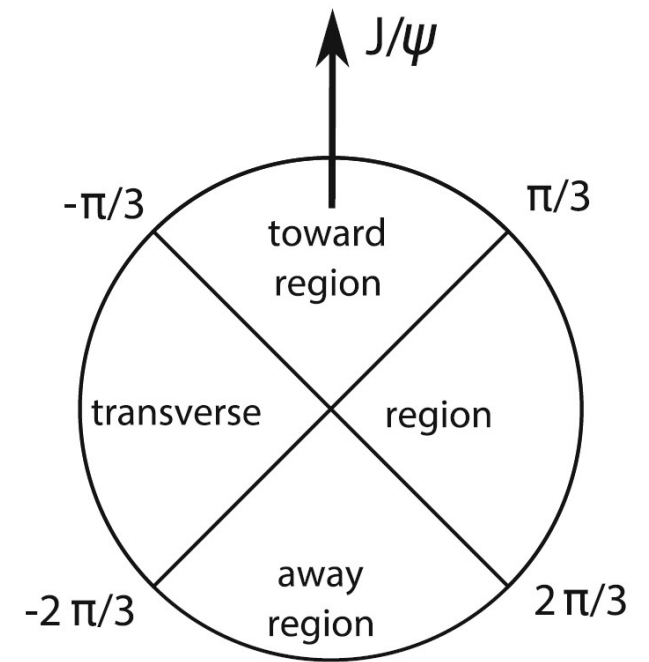
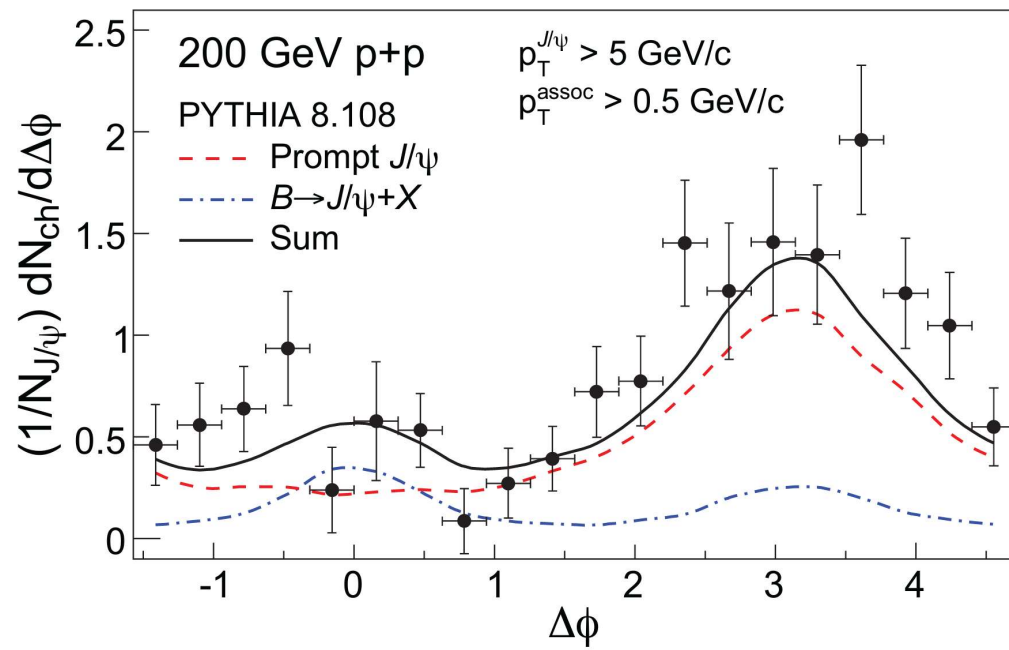


Separate efficiency vs multiplicity event selection corrections are necessary for the  $J/\psi$  and min-bias distributions



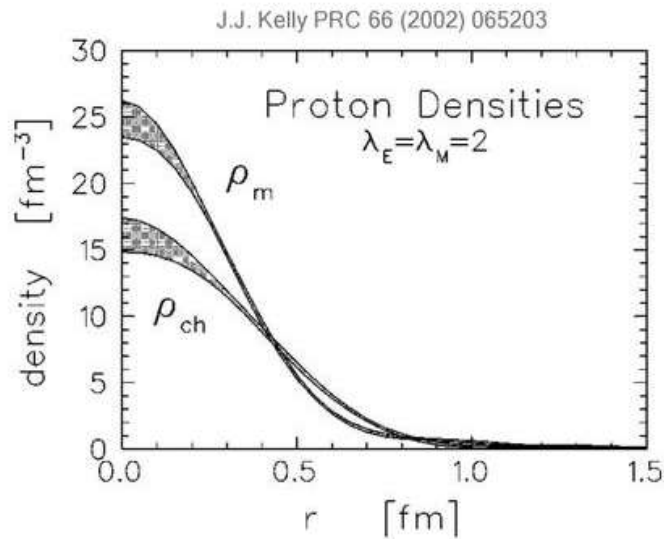
Pythia events  
• STAR HF Tune  
• MB  
embedded into  
zerobias and  
reconstructed

# 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.



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

### Dipole behaviour

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

# 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

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

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

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

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

---

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

[4]