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Production of J/ψ vs Multiplicity

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

The style of speaking that I prefer is to tell a story, and stop along the way for short explanations. I include RED annotations herein to show my accompanying thoughts for the talk.

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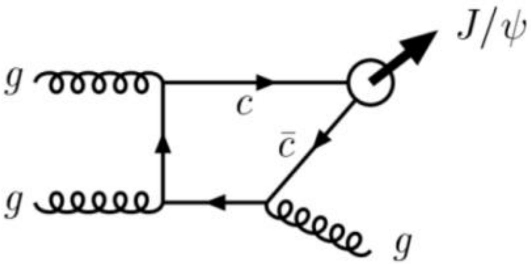
LEHIGH UNIVERSITY STAR Brookhaven National Laboratory U.S. DEPARTMENT OF ENERGY

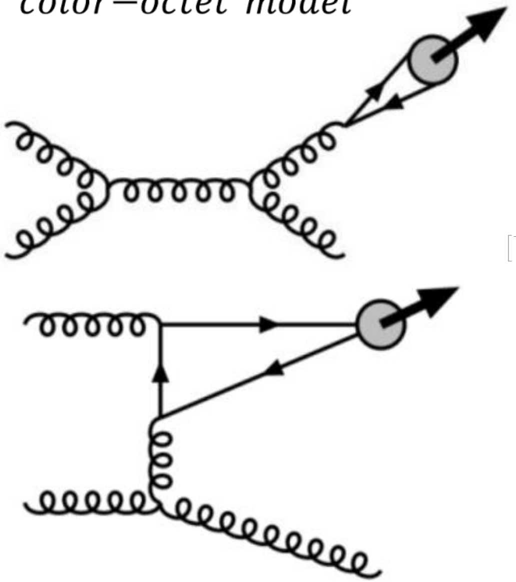
Accompanying model calculations for J/ψ production, are coinciding predictions for the underlying events

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

color−singlet model



color−octet model



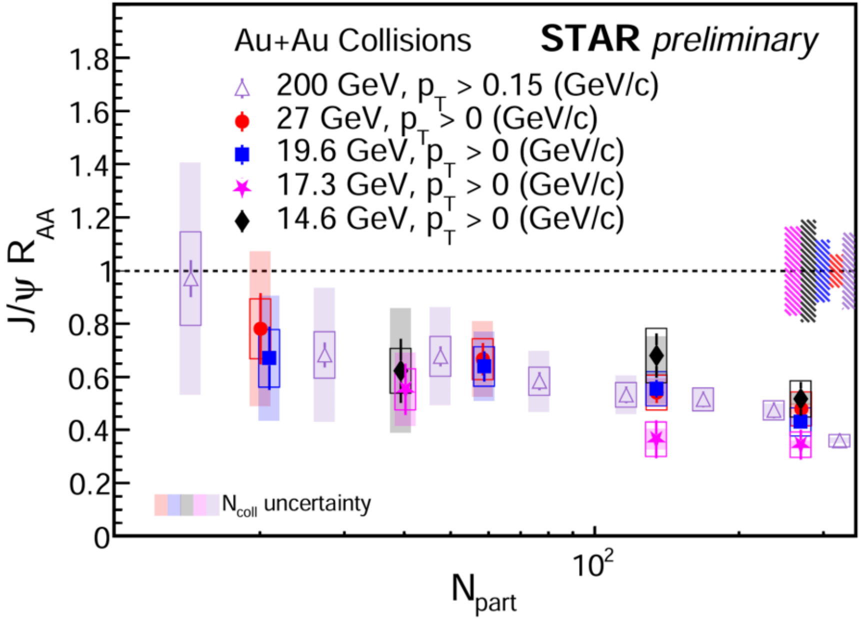
[1]

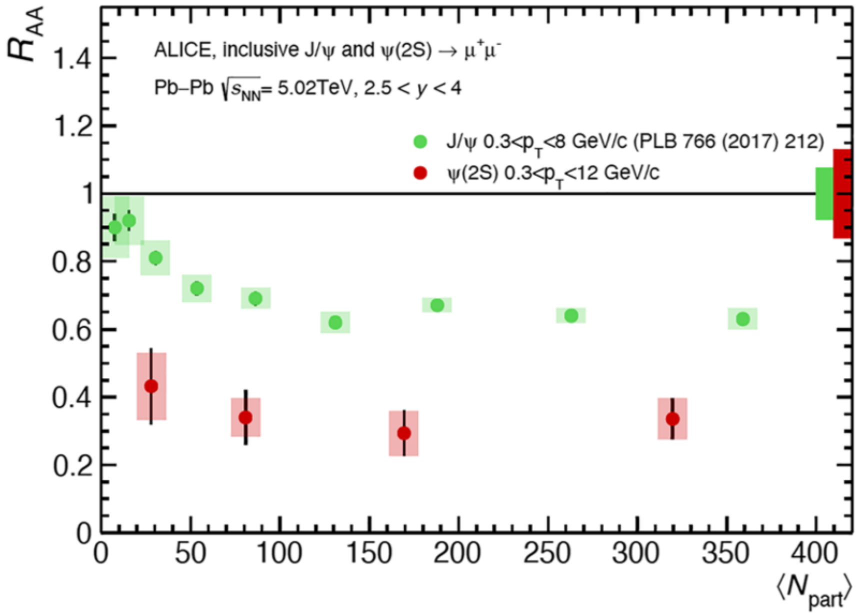
This story is roughly chronological. Each of these production mechanisms show extra gluons coming off, and the COM show colored J/psi that will later emit more gluons. These are testable predictions.

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



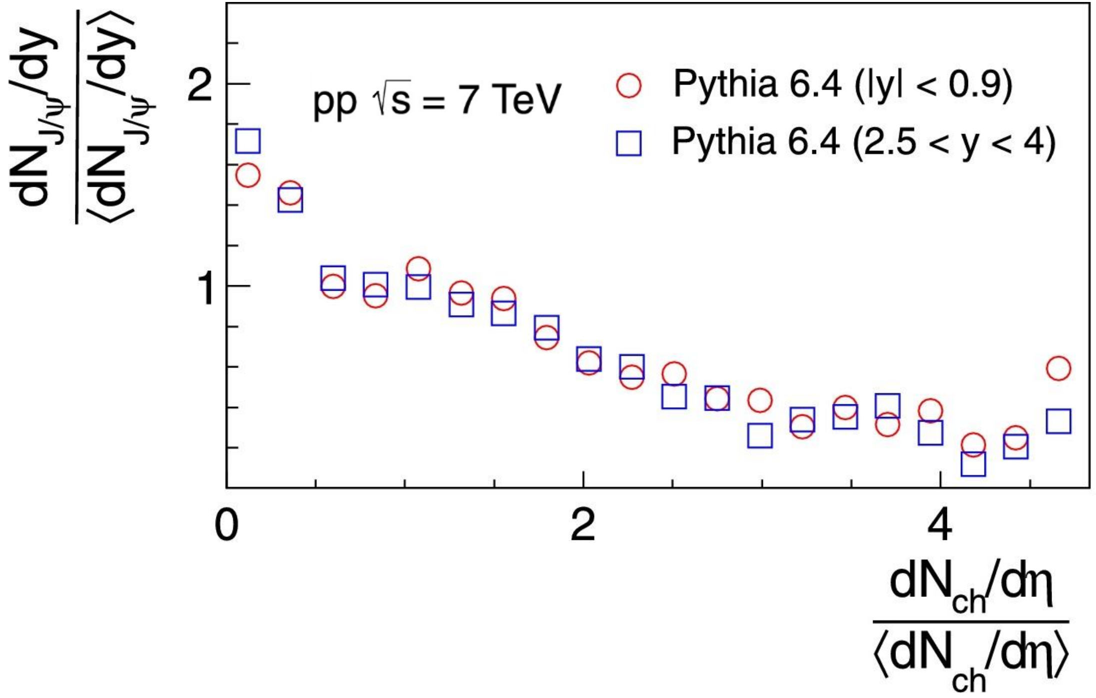


We have known for a long time that in A+A collisions, higher multiplicity means lower J/psi per event. This is true at RHIC and CERN energy. Will this also be the case in p+p? We will see in coming slides. Suspense!

[2]

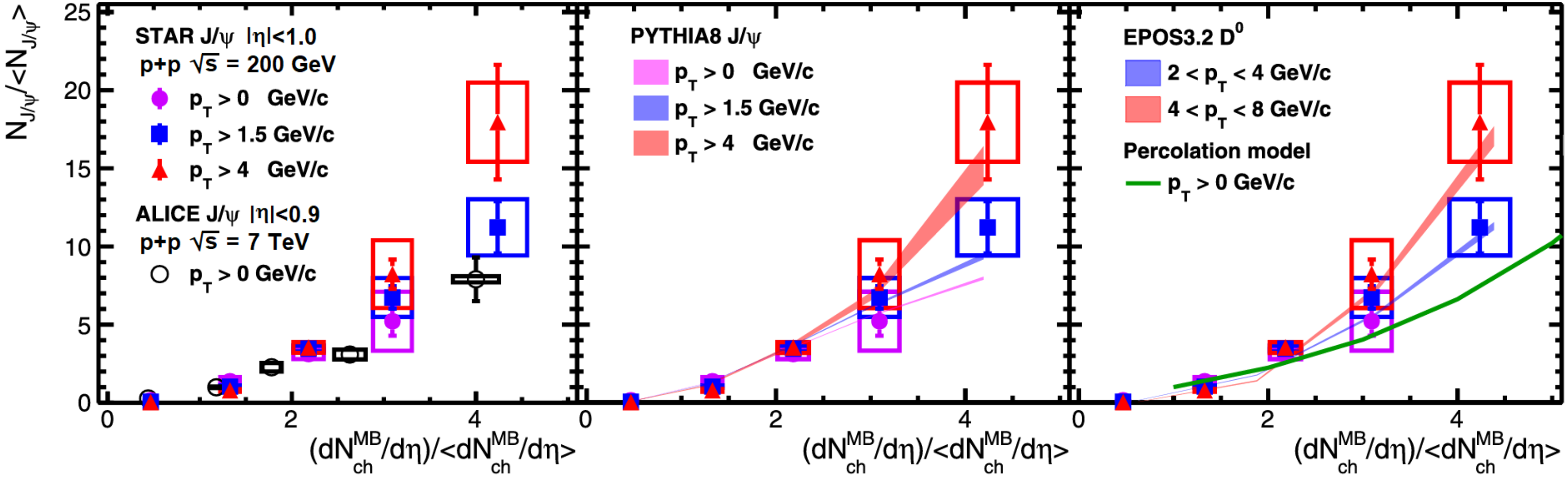
(at this point in my story, I have not shown what the behavior of J/psi vs multiplicity is). This plot shows what the predictions were before it had been measured, and it's completely wrong. This is a published plot though, and its feature is more similar to A+A where higher multiplicity means lower J/psi yield per event count.

Early predictions from model calculations



[5]

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



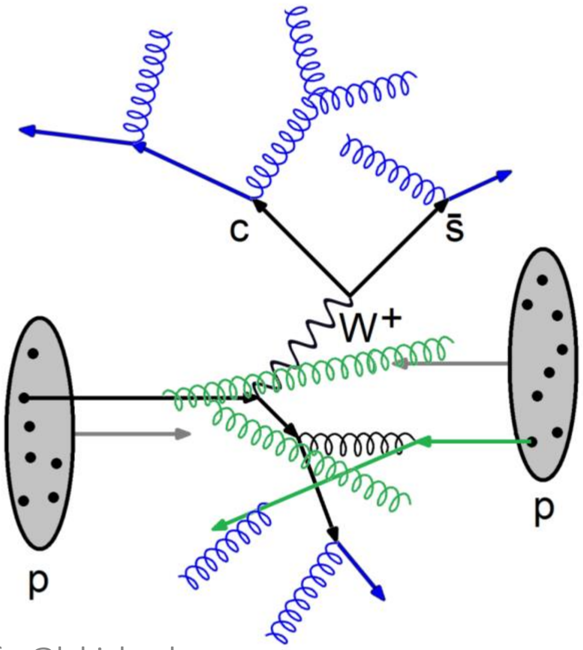
[3]

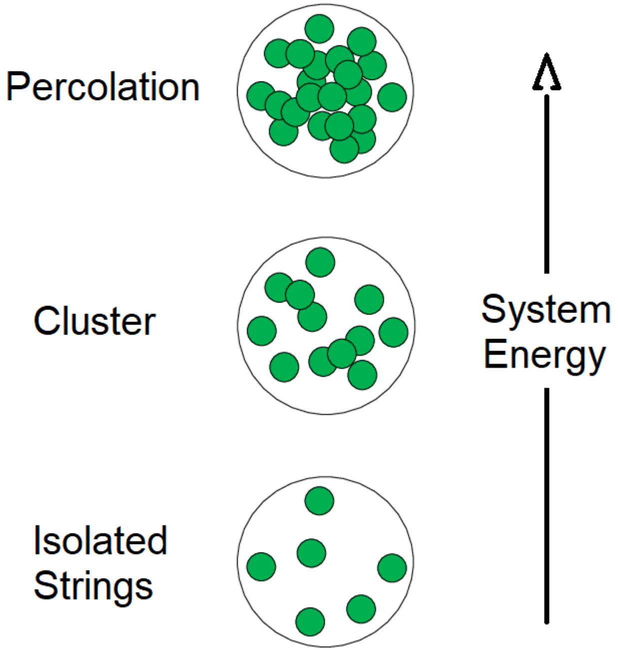
Surprise! When it was at last measured, it was found that higher multiplicity events favor J/psi production and that the rise is faster than linear.
The style I have chosen is intended to be reminiscent of a publication. I realize this is a little different, but I think it looks pretty clean. The reference is indicated here.

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

To explain this unusual production dependency, here are two mechanisms that work in different ways to increase J/psi yield.

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





Plot parameters were removed before HP2023 and QM, because these are only performance plots that do not have preliminary approval.
Better plots for publication will need NJ/psi, width, etc.

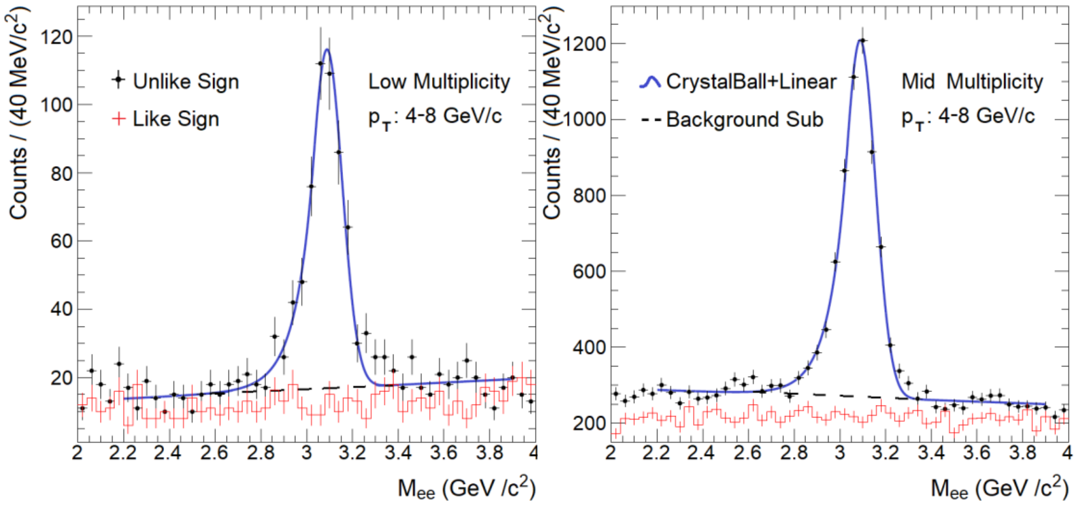
2017 STAR p+p 510 GeV (79.5 pb-1)

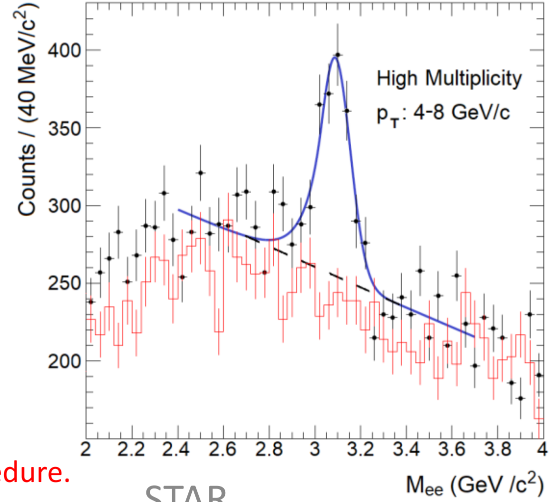
4x increase in luminosity above 200 GeV p+p

Triggering on events with 4.2 GeV/c EMCal electron

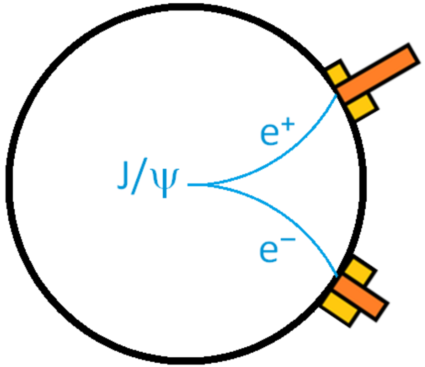
Associate tracks from TOF or EMCal-E/p requirement

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





STAR



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

I no longer use these binnings, and these plot are only to illustrate without a strong physics statement, the procedure.

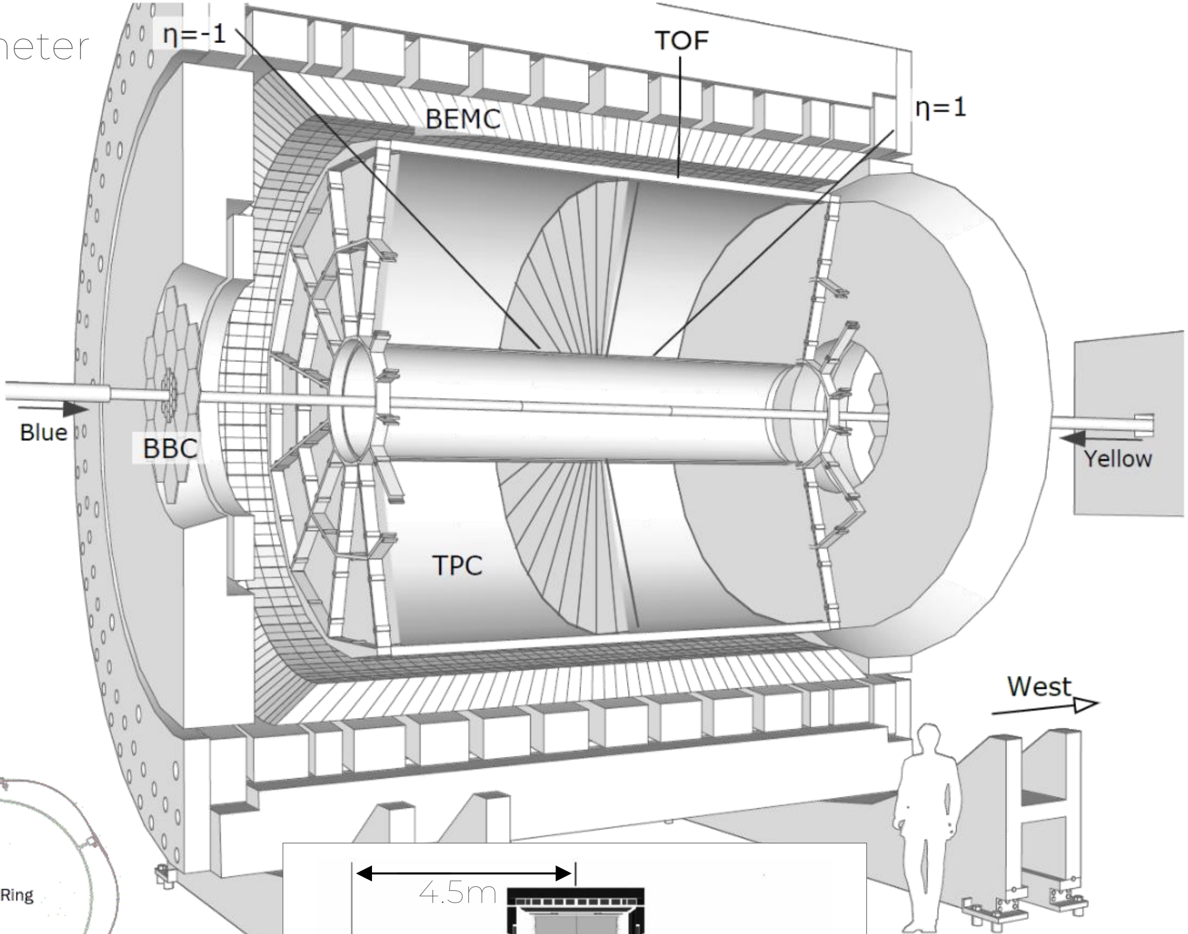
(BEMC) Barrel Electromag. Calorimeter
Trigger on, identify electrons

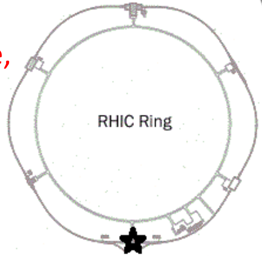
(TOF) Time of Flight
Pileup track rejection
Slow non $e^{\pm}$ veto

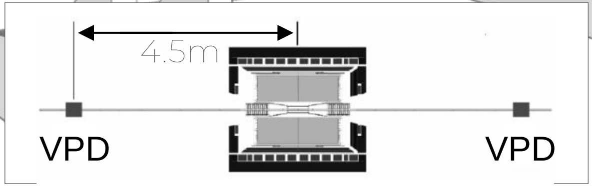
(BBC) Beam-Beam Counter
Min-bias trigger

(TPC) Time Projection Chamber
Momentum and dE/dx

(VPD) Vertex Position Detector







STAR

I have changed the order of the slides here, as the 'Analysis Procedure' will make more sense if I introduce the detector first. Thanks to Yi!

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Barrel Electromagnetic Calorimeter

$60m^2$ $|\eta|<1.0$

Time of Flight

$r=208cm$, $\Delta t=100ps$, $|\eta|< 1.0$

Beam-Beam Counter

$3.8 < |\eta| < 5.1$

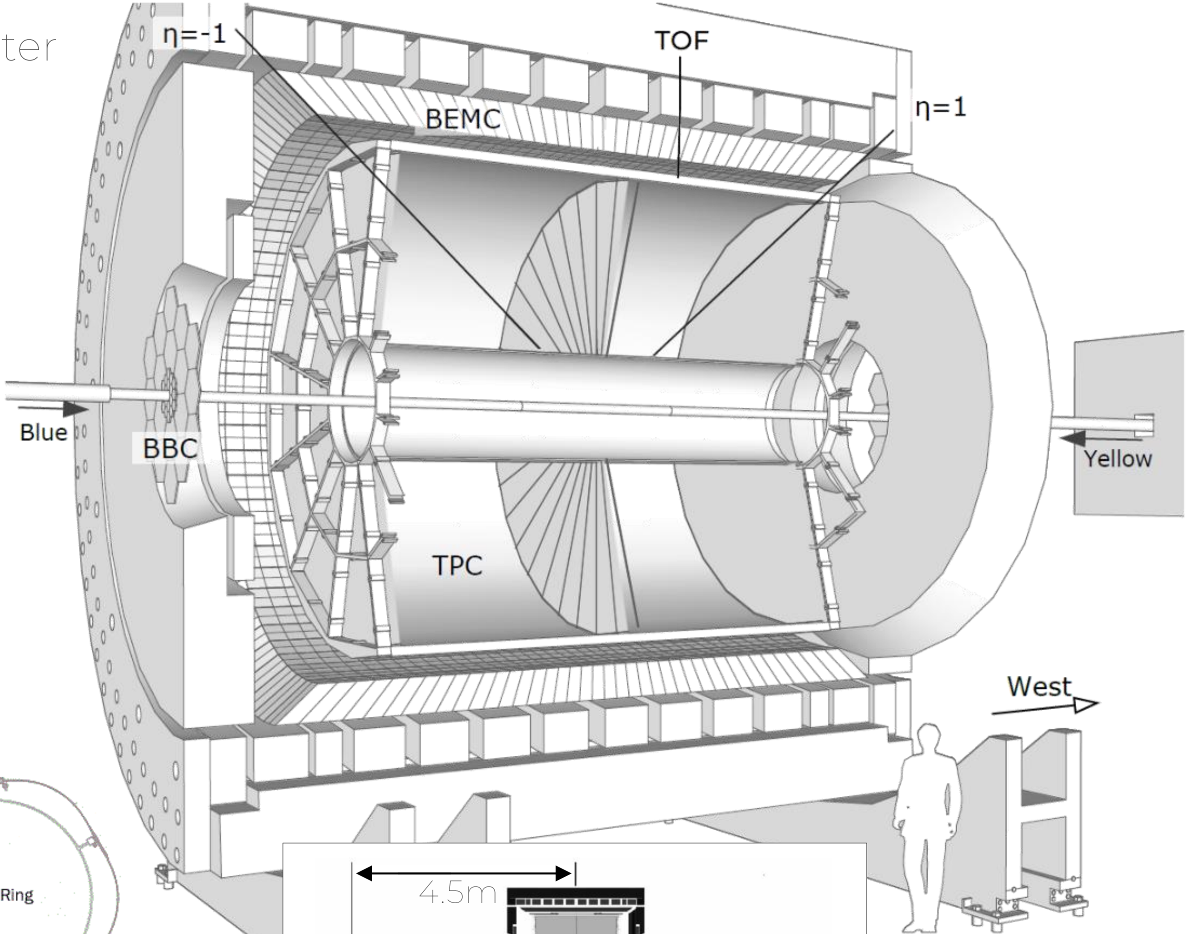
Time Projection Chamber

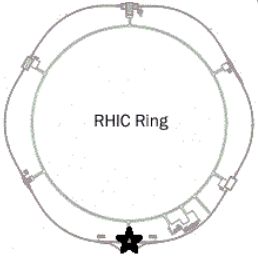
$52.8\ m^3$, $|\eta|< 1.0$

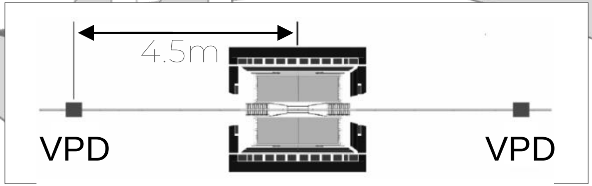
Vertex Position Detector

$4.24 < |\eta| < 5.1$

In my explanation I intend to highlight TOF and BEMC







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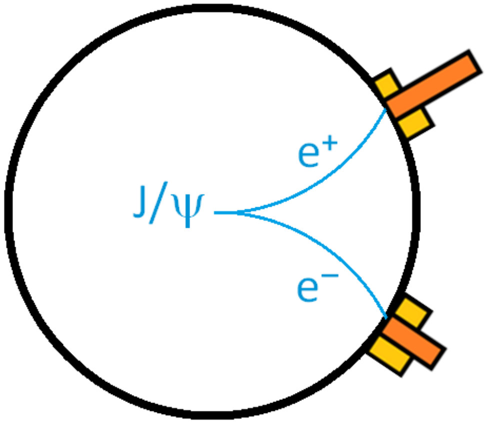
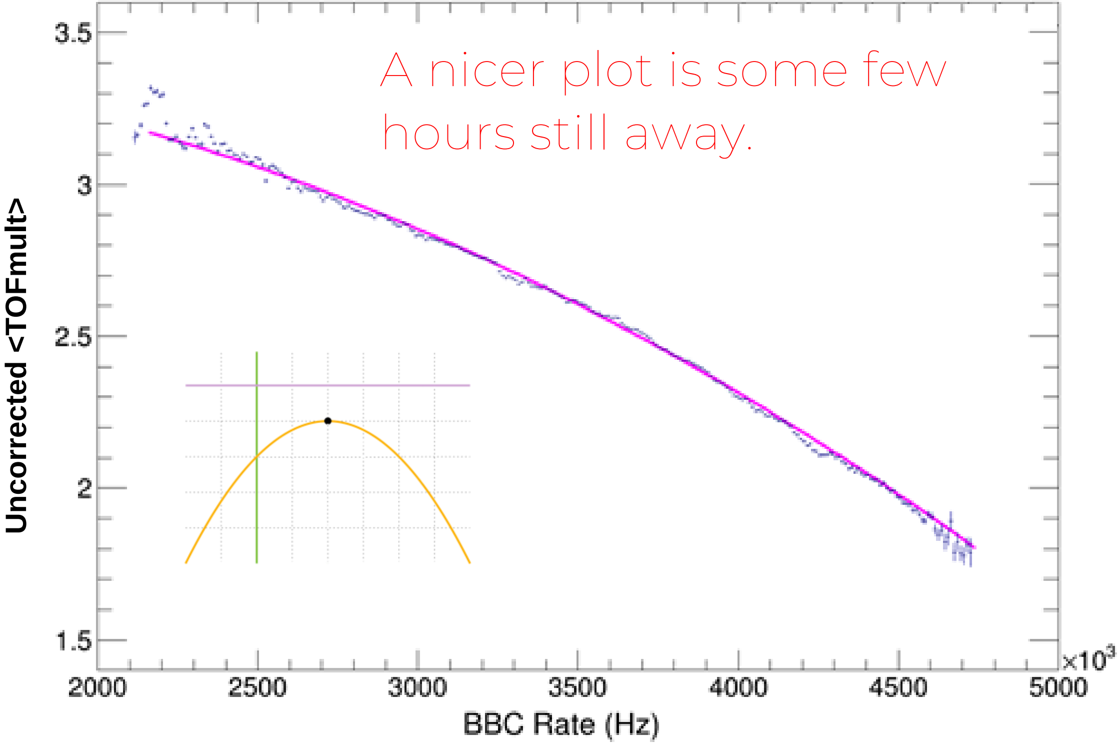
Analysis Procedure

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

- Events are triggered using BEMC
- Tracks are associated to the highest hit energy track are selected from either
  - TOF matched && passing a slow veto
  - OR
  - 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



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



Systematics Table

This is still a few hours out. To avoid specific STAR language, I am grouping the systematic uncertainty contributions according to:

- Tracking quality
- PID/separation
- Signal and background fitting
- Trigger efficiency

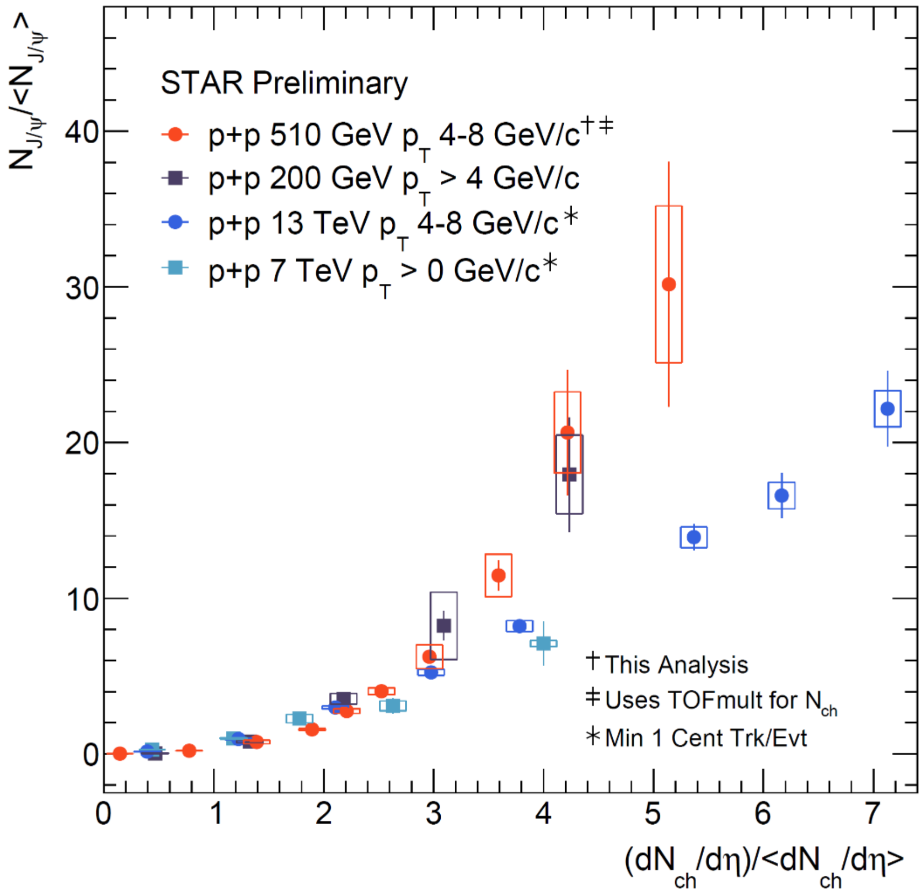
Results

High reach in multiplicity

Improved granularity

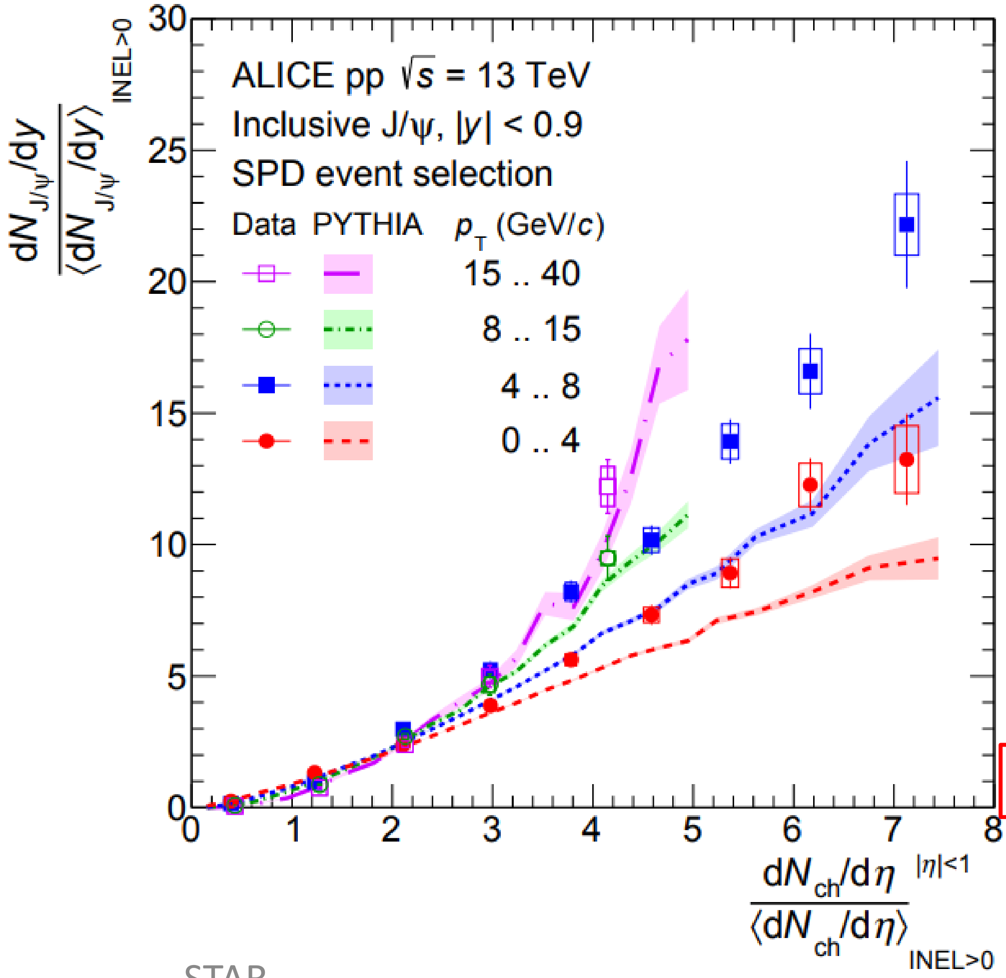
Yields at 510 consistent with 200 GeV/c

Hint of splitting between RHIC and LHC energies



Lorem Ipsum

I am still finding material
To discuss here



[?]

[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 √s =200 GeVPhysics 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 √s = 7 TeV, Physics Letters B, 712 (2012) 165–175

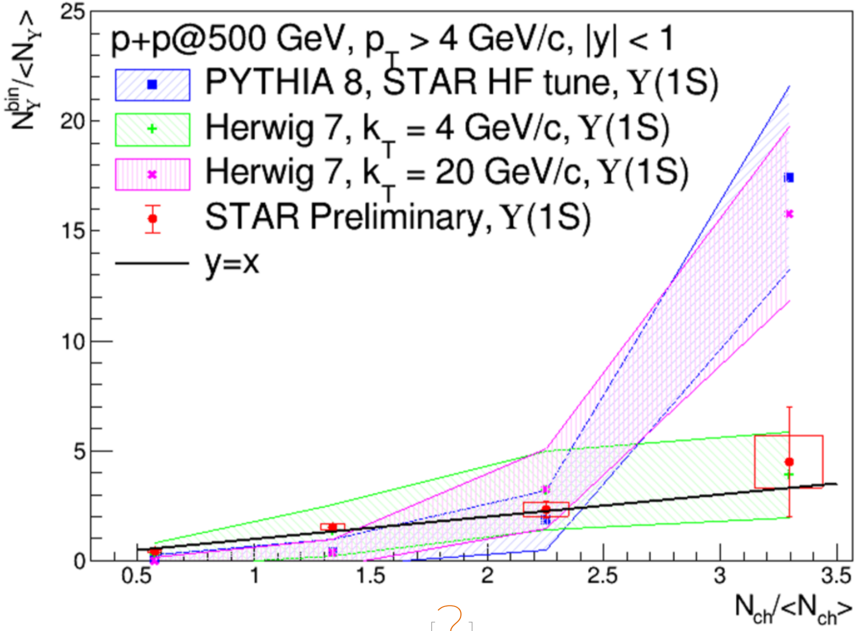
[6] B. Martin, G. Shaw,, Nuclear and Particle Physics, 3rd Ed, p. 190

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

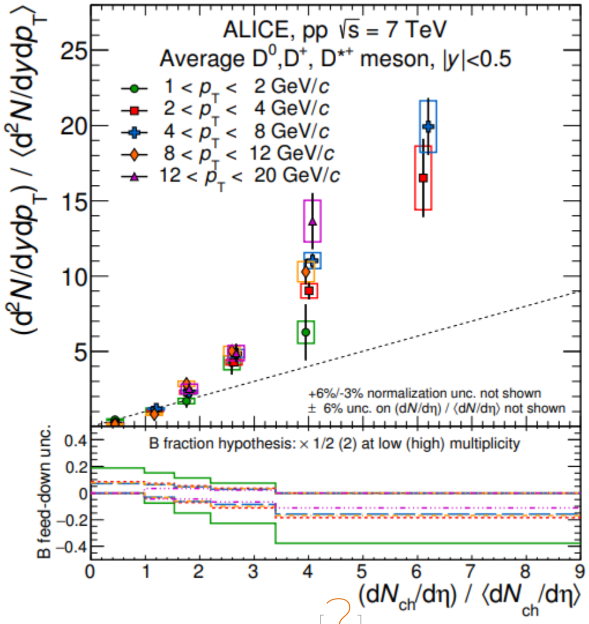
[8] S. Weber, et al. Elucidating the multiplicity dependence of J/ψ production in proton-proton collisions with PYTHIA8, Eur. Phys. J. C (2019) 79:36

Backup

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

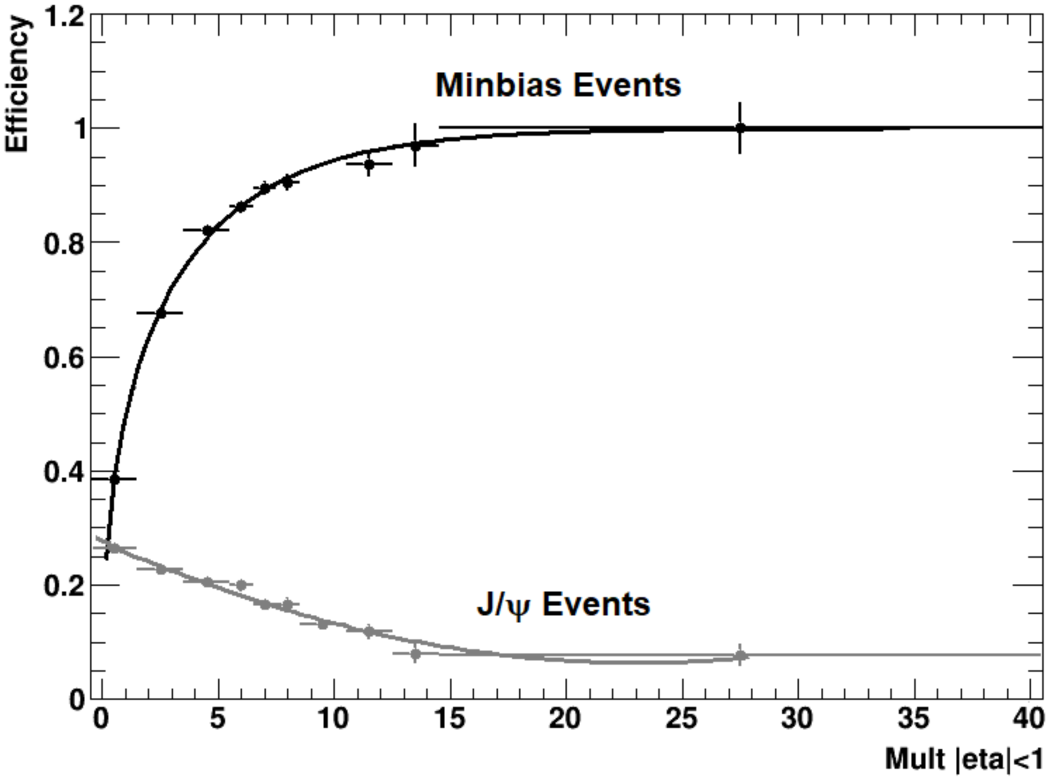


[?]



[?]

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

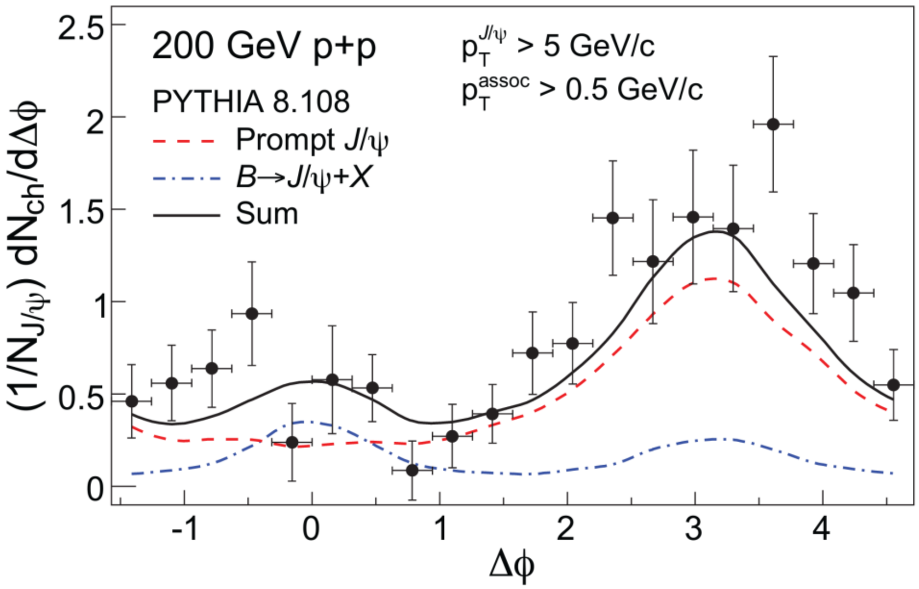


Pythia events

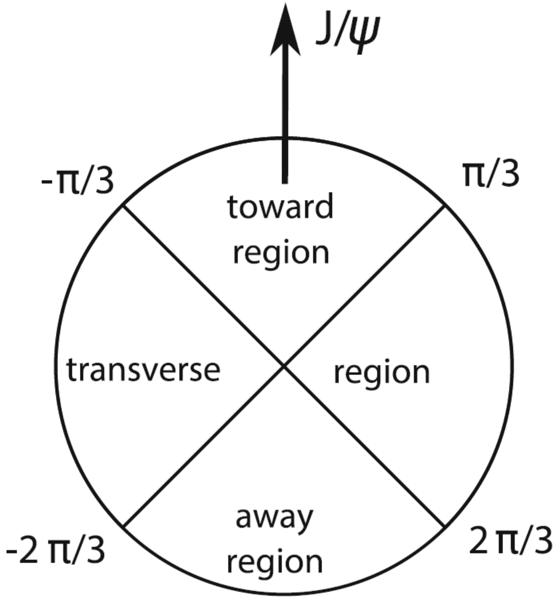
- STAR HF Tune
- MB

embedded into zerobias and reconstructed

Backup



200 GeV p+p
PYTHIA 8.108
Prompt J/ψ
B→J/ψ+X
Sum
$p_T^{J/\psi}$ > 5 GeV/c
p_T^{assoc} > 0.5 GeV/c
(1/N$_{J/\psi}$) dN$_{ch}$/dΔφ
Δφ

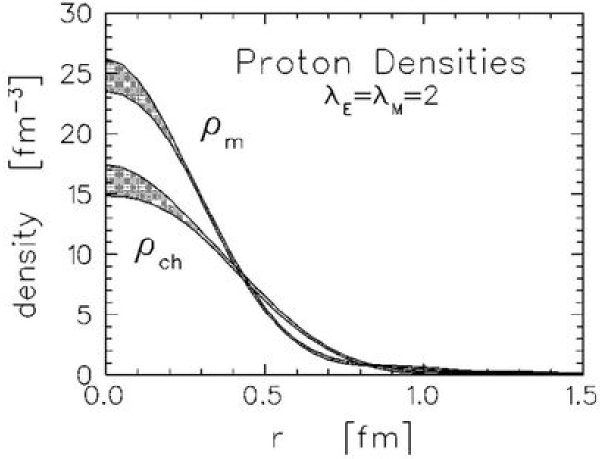


J/ψ
-π/3
π/3
toward region
transverse
region
away region
-2 π/3
2 π/3

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

- 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



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

Dipole behaviour

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

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

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

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]