Baryon structure and charmonium production in high multiplicity proton-proton collisions

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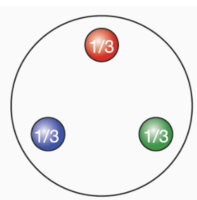
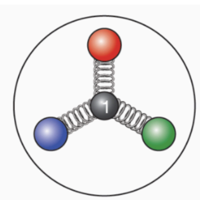
Phys. Rev. D 108, 054002 (2023)
arXiv:2306.14298



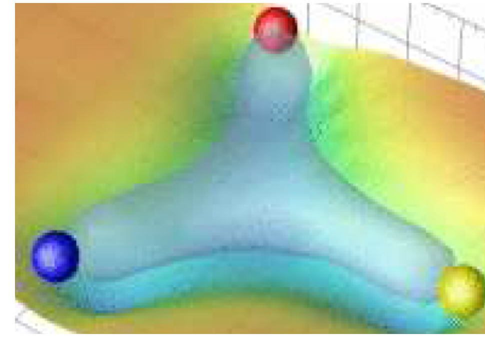
Valence quarks carry baryon number



Junctions carry baryon number

1st Workshop on Baryon Dynamics from RHIC to EIC

The baryon junction



lattice QCD

X. Artru, Nucl.Phys. B85, 442 (1975)

G.C. Rossi and G. Veneziano, Nucl.Phys. B123, 507 (1977)

D. Kharzeev, Phys. Lett. B 378, 238 (1996)

X. Artru's talk

G. Veneziano's talk

David Frenklakh's talk

Rongrong Ma's talk

What Carries the Baryon Number?

Valence Quarks

- Carry large momentum fractions
- Hard to be stopped at midrapidity
  - $dN/d\Delta y \sim \exp(-2.4\Delta y)$ (PYTHIA)
  - $\Delta y = Y_{beam} - y$
- Ensemble basis: $Q \sim B \times Z/A$

Junctions

- Consist of low-momentum gluons
- Easier to be stopped at midrapidity
  - $dN/d\Delta y \sim \exp(-0.5\Delta y)$ (theory)

Theory: D. Kharzeev, PLB 378 (1996) 238

- Ensemble basis: $Q < B \times Z/A$

✓ **THREE TESTS**

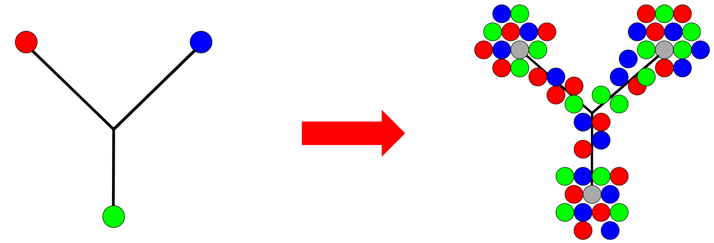
1) Compare Q vs. $B \times Z/A$ in Ru+Ru and Zr+Zr collisions
2) Net-proton $dN/d\Delta y$ in γ+Au events
3) Net-proton $dN/d\Delta y$ in hadronic Au+Au collisions

01/22/2024 Rongrong Ma, CFNS-Baryon, Stony Brook

We will study another manifestation of the BJ based on geometrical aspects

Baryon junction in high energy pp collisions

Boost: Y-shaped spatial distribution survives the QCD evolution

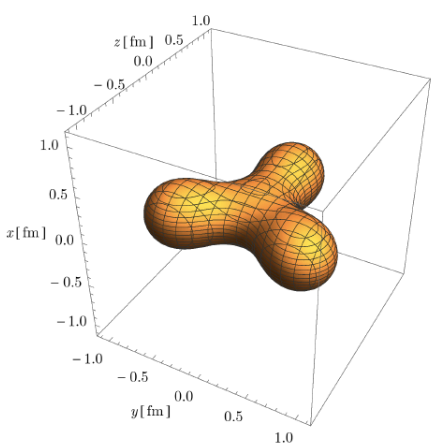


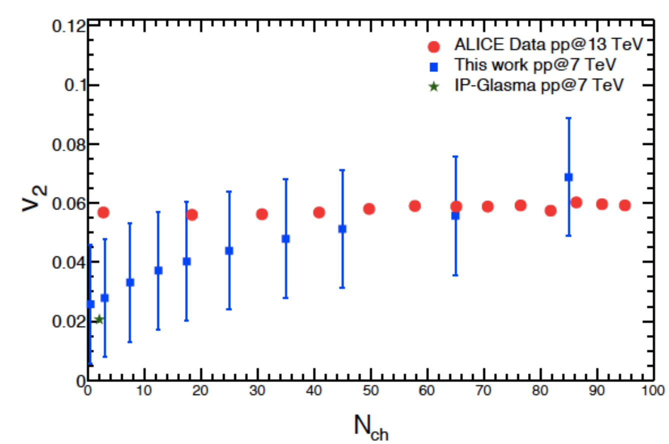
Mantysaari, Schenke, Shen and Zhao, Phys. Rev. Lett. 131, 062301 (2023)

"We conclude that the fuctuations in the nuclear geometry originating from the deformed structure are not washed out by the JIMWLK evolution, and we expect the deformations previously seen in low-energy experiments to also be visible in high-energy electron-ion collisions at the EIC "

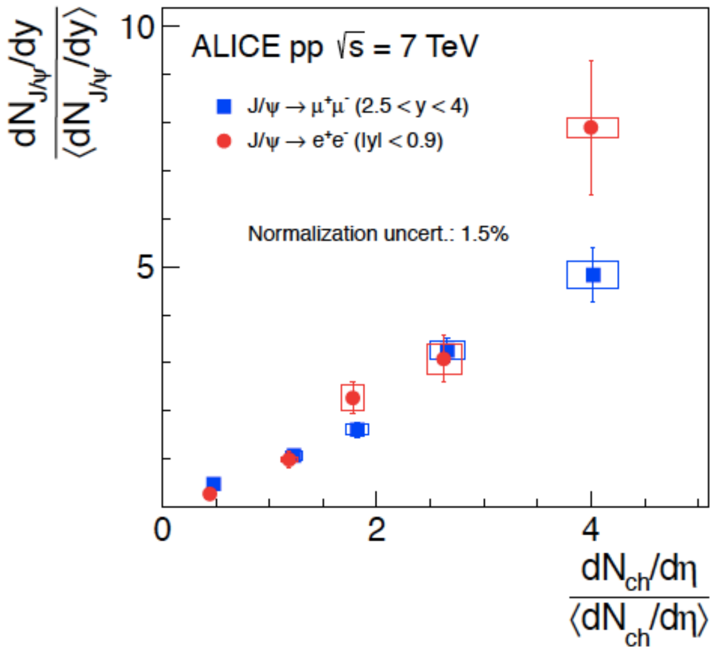
Y shaped matter distribution used in the Glauber model

Deb, Sarwar, Thakur, Subramani, Sahoo and J.e. Alam, Phys. Rev. D 101, 014004 (2020)

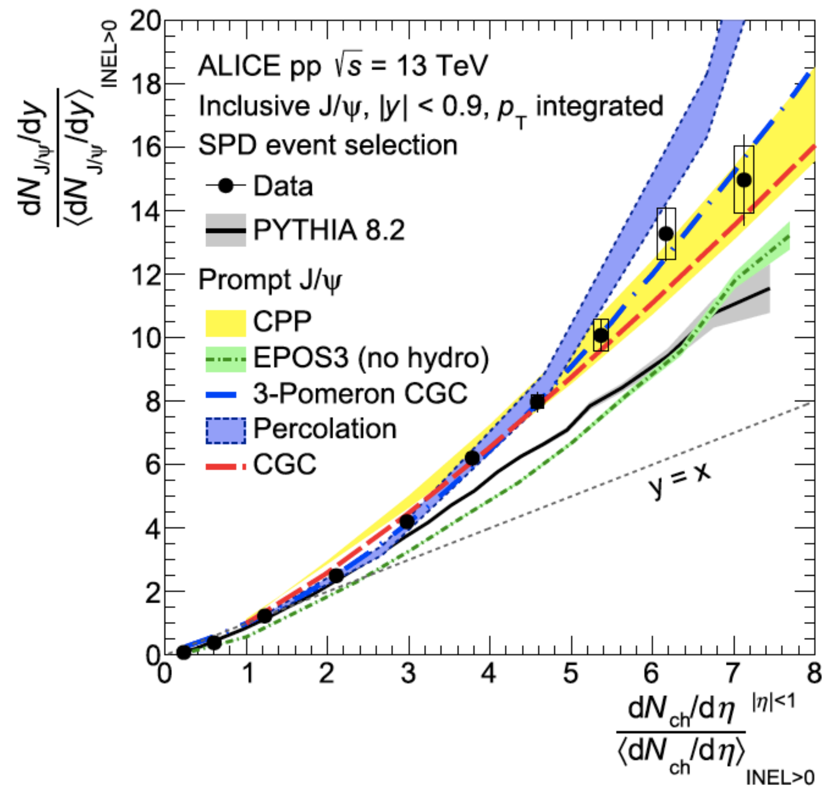




Charmonium production in pp high multiplicity events



ALICE arXiv:1202.2816



ALICE arXiv:2005.11123

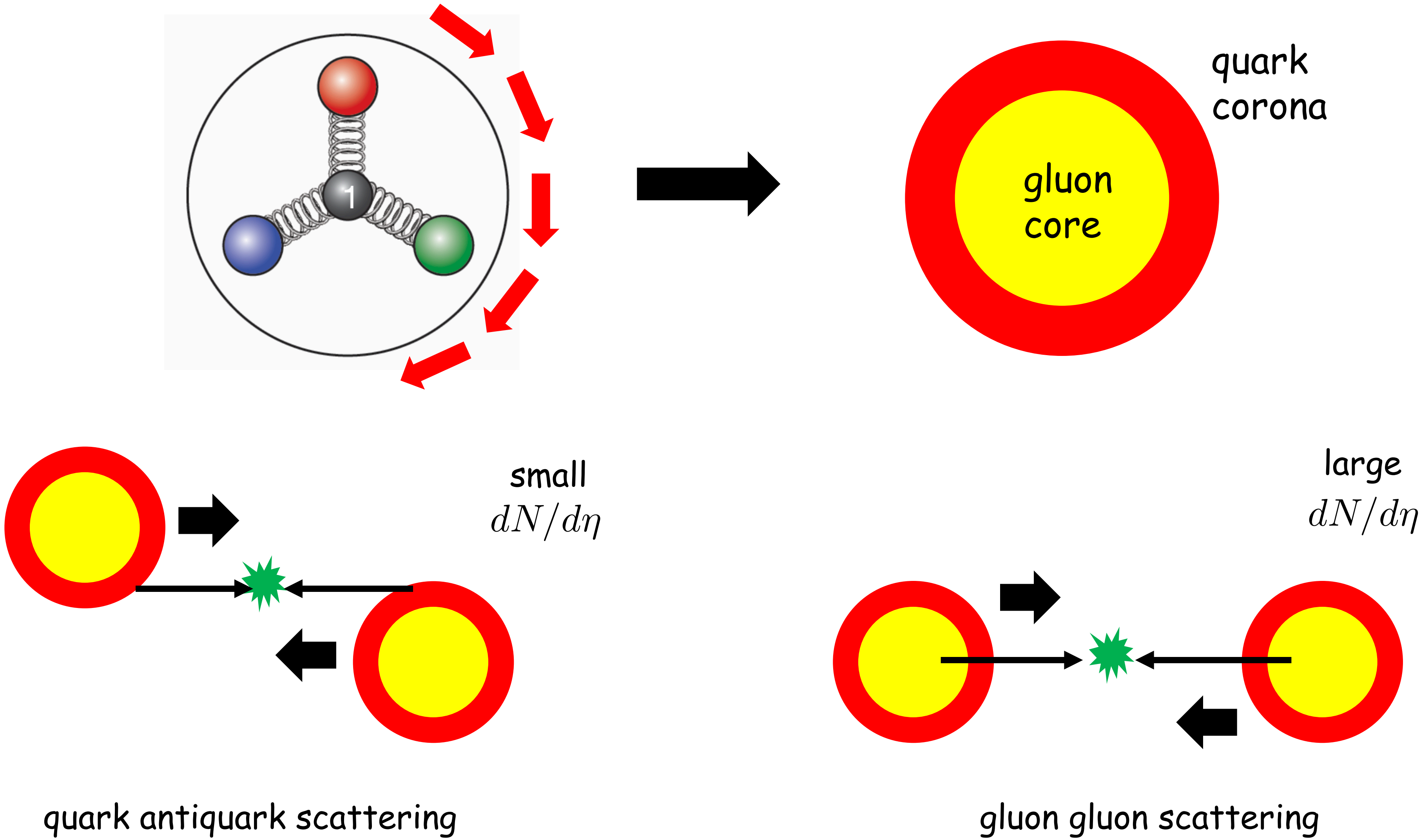
Multiple parton scattering?

Color Glass Condensate?

Hydrodynamics?

M. Strikman, Phys. Rev. D 84, 011501(R) (2011)

Baryon junction and charm production



$$\sigma(q\,\bar{q} \to c\,\bar{c}) \;<<\; \sigma(g\,g \to c\,\bar{c})$$

Glauber model for pp collisions

C. Loizides, Phys. Rev. C 94, 024914 (2016).

P. Bozek, W. Broniowski, and M. Rybczynski, Phys. Rev. C 94, 014902 (2016).

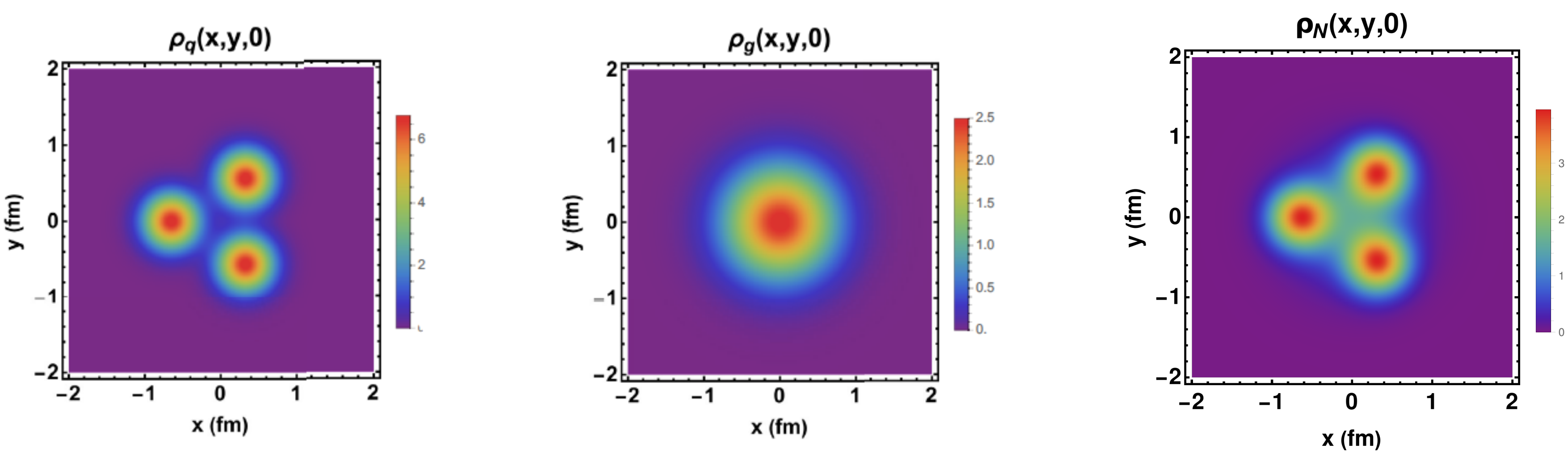
proton density profile: $$\rho_p(\mathbf{r};\mathbf{r}_1,\mathbf{r}_2,\mathbf{r}_3)=\sum_{i=1}^{3}\rho_q(\mathbf{r}-\mathbf{r}_i)+\rho_g$$

quarks gluons

$$\rho_q(r)=(1-\kappa)\frac{N_g}{3}\frac{e^{-r^2/2r_q^2}}{(2\pi)^{3/2}r_q^3}$$

$$\rho_g(r)=\kappa N_g\frac{e^{-r^2/2r_g^2}}{(2\pi)^{3/2}r_g^3}$$

Parameters: $N_g\ \kappa\ r_q\ r_g$



Parameters taken from S. Deb, G. Sarwar et al., Phys. Rev. D 101, 014004 (2020)

Glauber model for pp collisions

Miller, Reygers, Sanders and Steinberg, Ann. Rev. Nucl. Part. Sci. 57, 205 (2007)

Thickness $$T_p(x,y) = \int \rho_p(x,y,z)dz = T_p^q(x,y) + T_p^g(x,y)$$

Overlap $$T_{pp'}(b) = \int T_p(x-b/2,y)T_{p'}(x+b/2,y)dxdy$$

$$N_{\rm coll} = T_{pp'}(b)\sigma^{pp}$$ $\sigma^{pp} =$ parton-parton cross section

$$N_{\rm part}(b) = N_{\rm coll}^x(b)$$ $x = 0.75$

$$\frac{dN}{d\eta}(\eta=0) = n_{pp}(s)\left\{(1-f)\frac{N_{\rm part}}{2} + fN_{\rm coll}\right\}$$

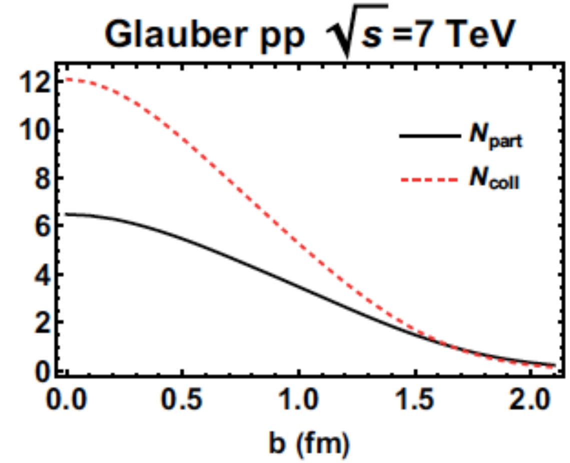
$$n_{pp}(s) = 2.5 - 0.25\log[s] + 0.023(\log[s])^2$$

$f =$ fraction of the hard processes

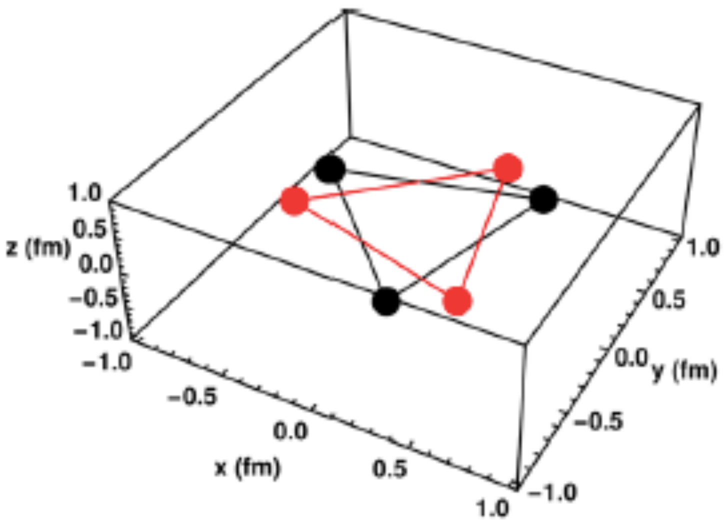
Kharzeev, Nardi, Phys. Lett. B 507, 121 (2001)

TABLE I. Input used in the parton densities and in the Glauber model. See text for definitions.

N_g [17]	10
κ [17]	0.5
r_q(fm) [17]	0.25
r_g(fm) [33]	0.5
σ^{pp}(mb) ($\sqrt{s} = 7$ TeV) [37,38]	4.3
σ^{pp}(mb) ($\sqrt{s} = 13$ TeV) [37,38]	7.6
d(fm) [17]	1.3
x [36]	0.75



Glauber model for pp collisions



● $$\mathbf{r}_i = \frac{d}{2}(\cos(\phi_i + \alpha), \sin(\phi_i + \alpha))$$

● $$\mathbf{r}'_i = \frac{d}{2}(\cos(\phi_i + \beta), \sin(\phi_i + \beta))$$

$$\phi_1 = \pi/3 \qquad \phi_2 = -\pi/3 \qquad \phi_3 = -\pi$$

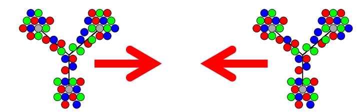
choose alfa and beta randomly and take the average

d = distance of the quarks from the center

Charmonium production in the Color Evaporation Model

$$\sigma^{\rm CEM} = \mathbf{F} K \sum_{i,j} \int_{(2m_c)^2}^{(\Lambda)^2} dm^2 \int dx_1 dx_2 f_i(x_1,\mu_F^2) f_j(x_2,\mu_F^2)\, \sigma_{ij}(m^2,\mu_R^2)\delta(m^2 - x_1 x_2 s) \quad = \sigma_{gg}^{\rm CEM} + \sigma_{q\bar{q}}^{\rm CEM}$$

$$\sigma_{gg}(m^2,\mu_R^2) = \frac{\pi\alpha_s^2(\mu_R^2)}{3m^2}\left\{\left(1 + \frac{4m_c^2}{m^2} + \frac{m_c^4}{m^4}\right)\ln\left(\frac{1+\lambda}{1-\lambda}\right) - \frac{1}{4}\left(7 + \frac{31m_c^2}{m^2}\right)\lambda\right\}$$



$$\sigma_{q\bar{q}}(m^2,\mu_R^2) = \frac{8\pi\alpha_s^2(\mu_R^2)}{27m^2}\left(1 + \frac{2m_c^2}{m^2}\right)\lambda,$$

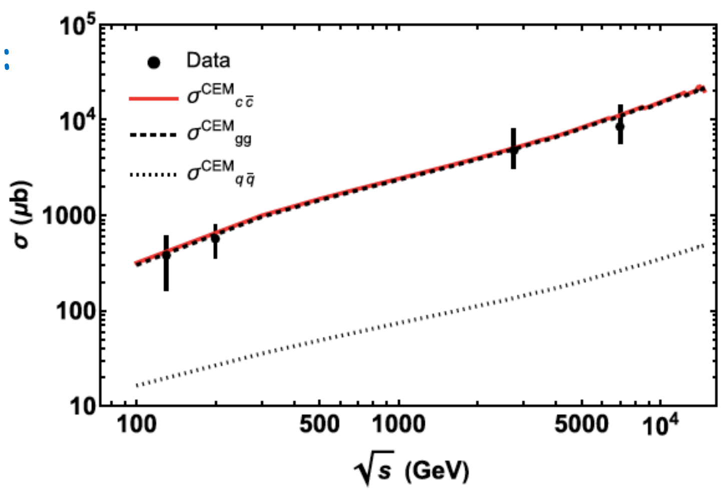
$$\alpha_s(\mu_R^2) = \frac{12\pi}{(33 - 2N_f)\ln\left(\frac{\mu_R^2}{\Lambda_{\rm QCD}^2}\right)} \qquad \lambda = \left(1 - \frac{(2m_c)^2}{m^2}\right)^{1/2},$$

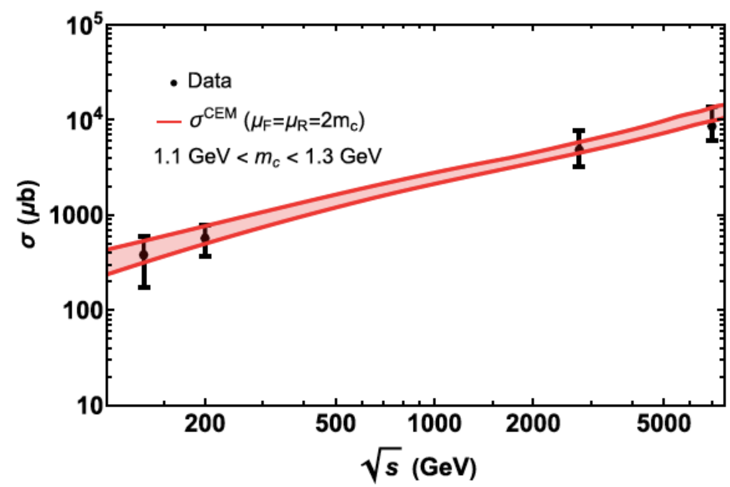
TABLE II. Input used for J/ψ production. See text for definitions.

	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 13$ TeV
f	19% [51,52]	16% [51,52]
F	2.3% [23,24]	3.4% [23,24]
$\langle dN/d\eta \rangle$	6.0 [53]	6.4 [54]
$\langle dN_{J/\psi}/dy \rangle$	8.2×10^{-5} [1]	7.9×10^{-5} [6]

Open charm: fix K

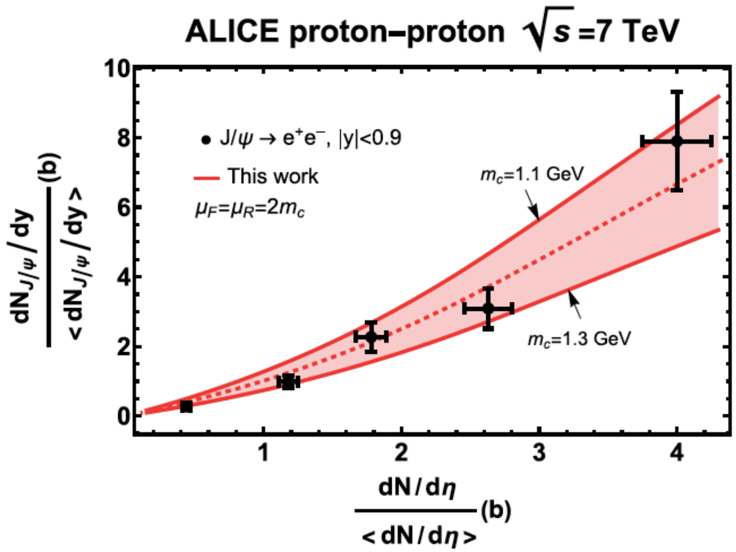
K ~ 3

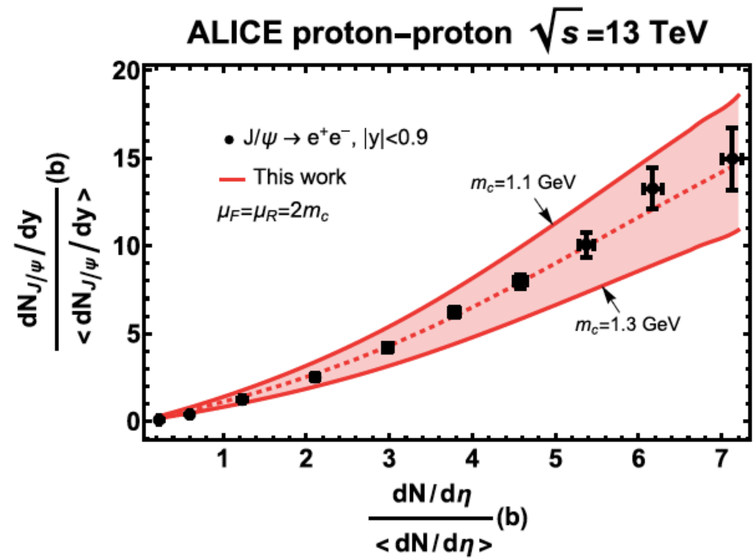


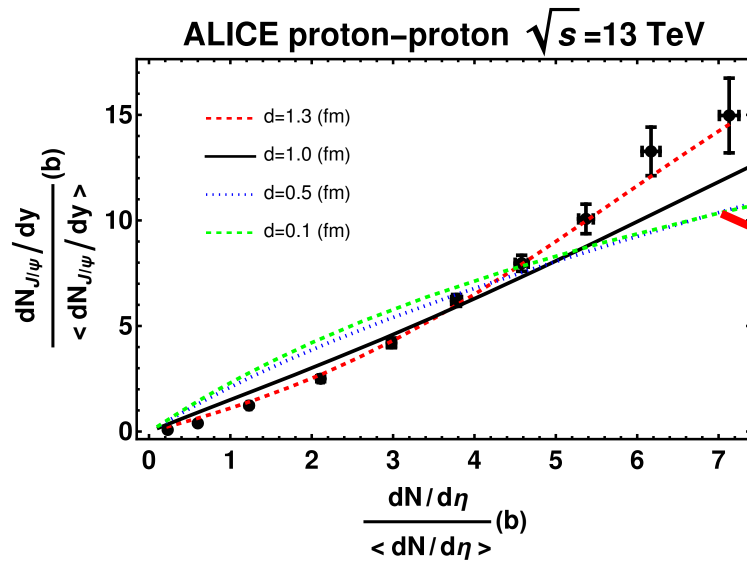


Charmonium production in pp high multiplicity events

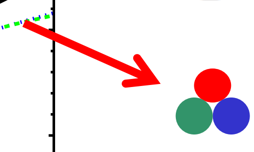
$$\frac{dN_{c\bar{c}}}{dy}(b) = T^{gg}_{pp'}(b)\frac{d\sigma^{\rm CEM}_{gg}}{dy} + T^{qq}_{pp'}(b)\frac{d\sigma^{\rm CEM}_{qq}}{dy}$$







$$\mathbf{r}_i = \frac{d}{2}(\cos(\phi_i+\alpha), \sin(\phi_i+\alpha))$$



All quarks in the center:
no junction

Summary

We have looked for a signature of the BJ based on density profiles

We have used a Y-shape model of the proton to study charmonium production

Y-shape density

Glauber model

Color evaporation model

We get a good description of ALICE data

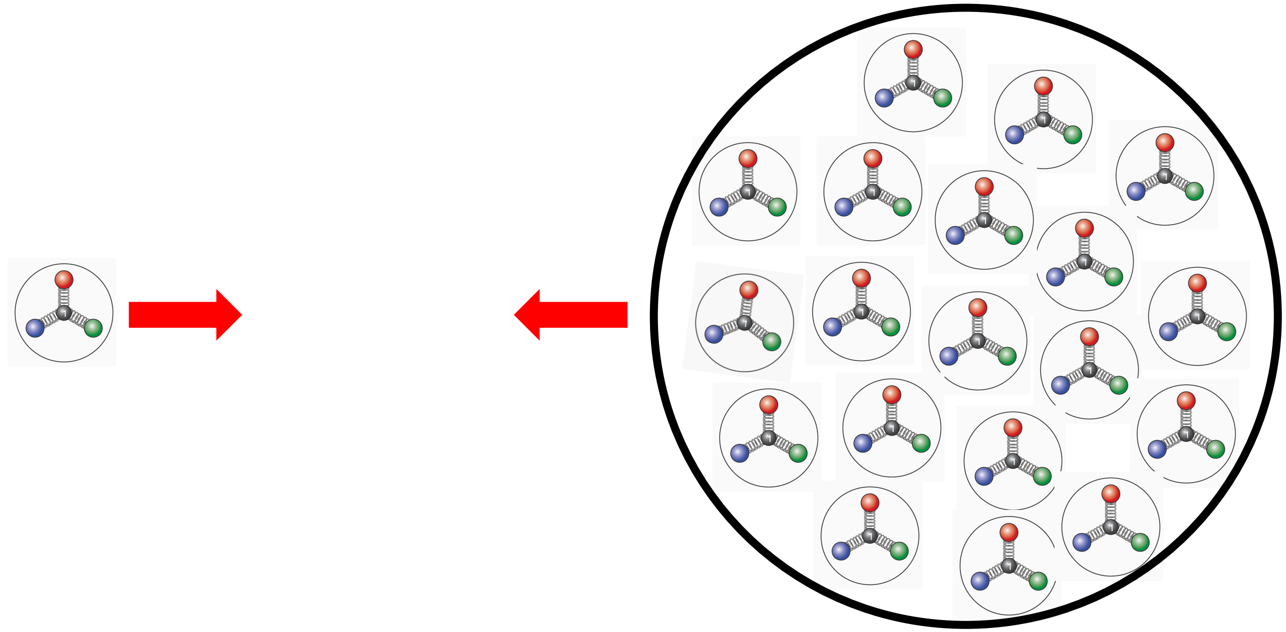
Many parameters but some constraints and possibly more...

d-test: shrinking the junction spoils the agreement with data

Back-ups

Charmonium production in pA high multiplicity events

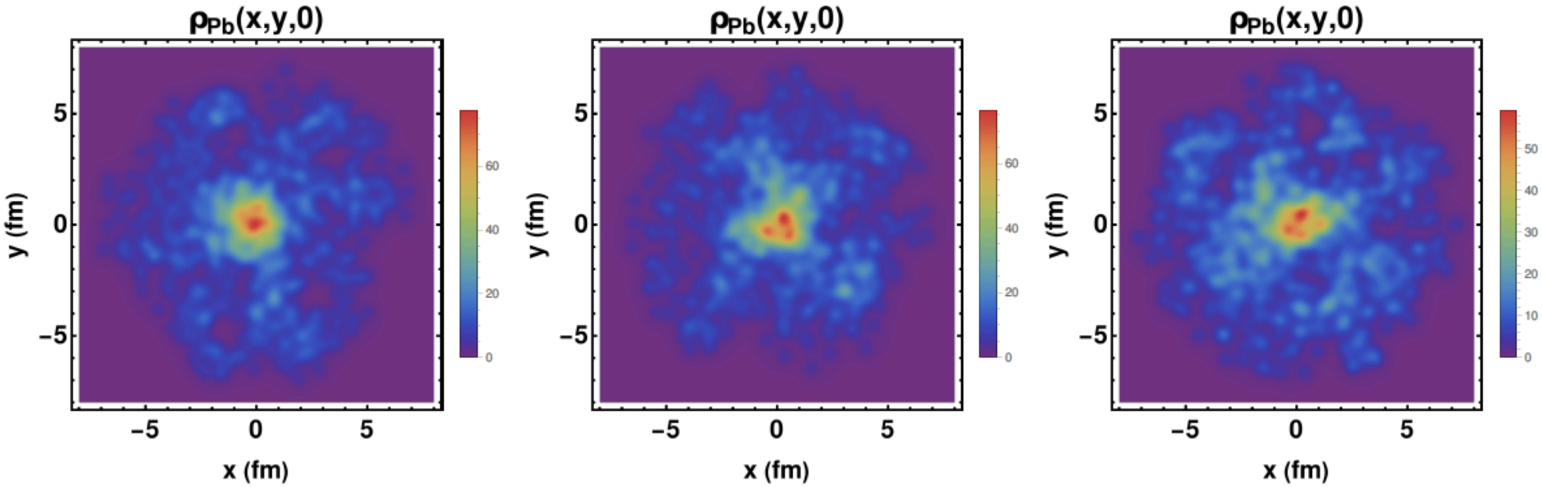
(in progress)

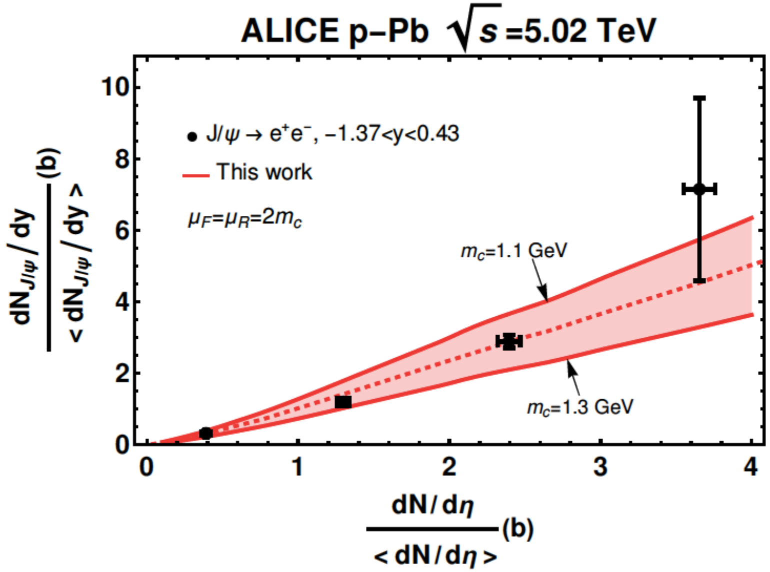


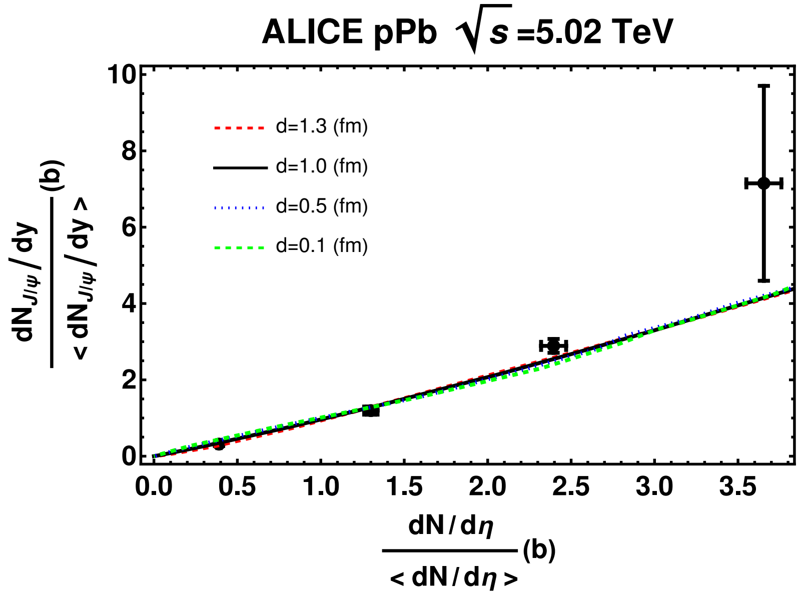
Nucleus with uniform distribution of nucleons

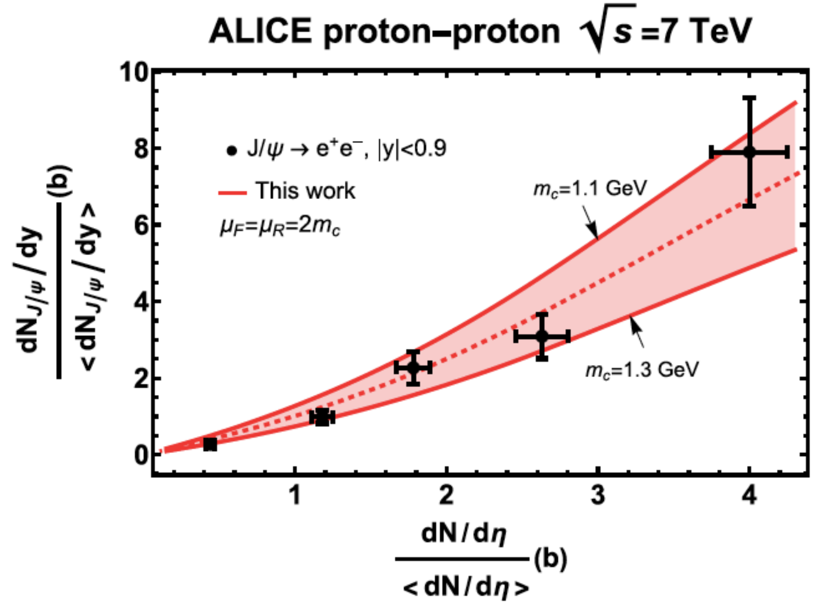
Charmonium production in pA high multiplicity events

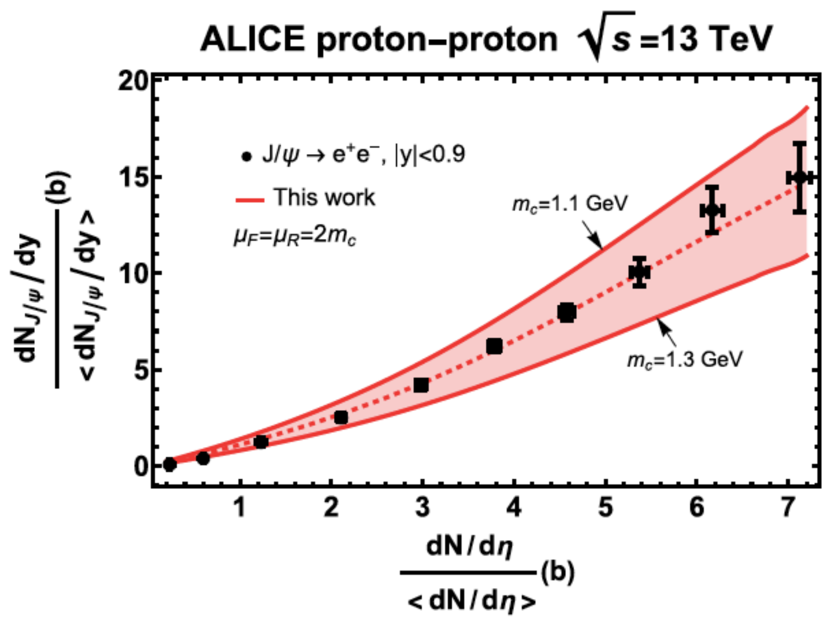
$$\rho_{Pb}(\mathbf{r}) = \sum_{n=1}^{208} \rho_n(\mathbf{r}; \mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3)$$





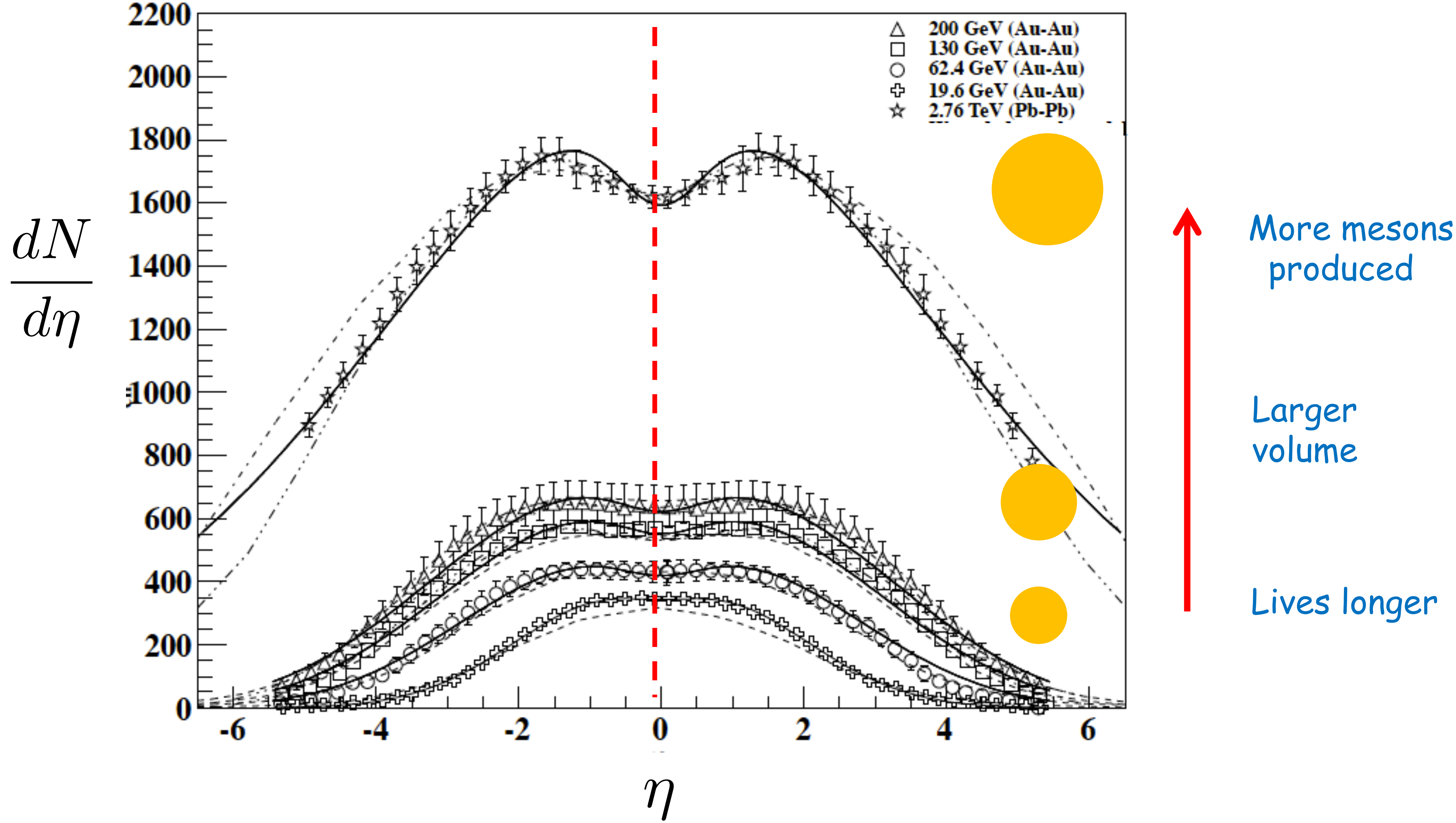



ALICE proton–proton √s =7 TeV
J/ψ → e+e−, |y|<0.9
This work
μF=μR=2mc
mc=1.1 GeV
mc=1.3 GeV
dNJ/ψ/dy / <dNJ/ψ/dy> (b)
dN/dη / <dN/dη> (b)

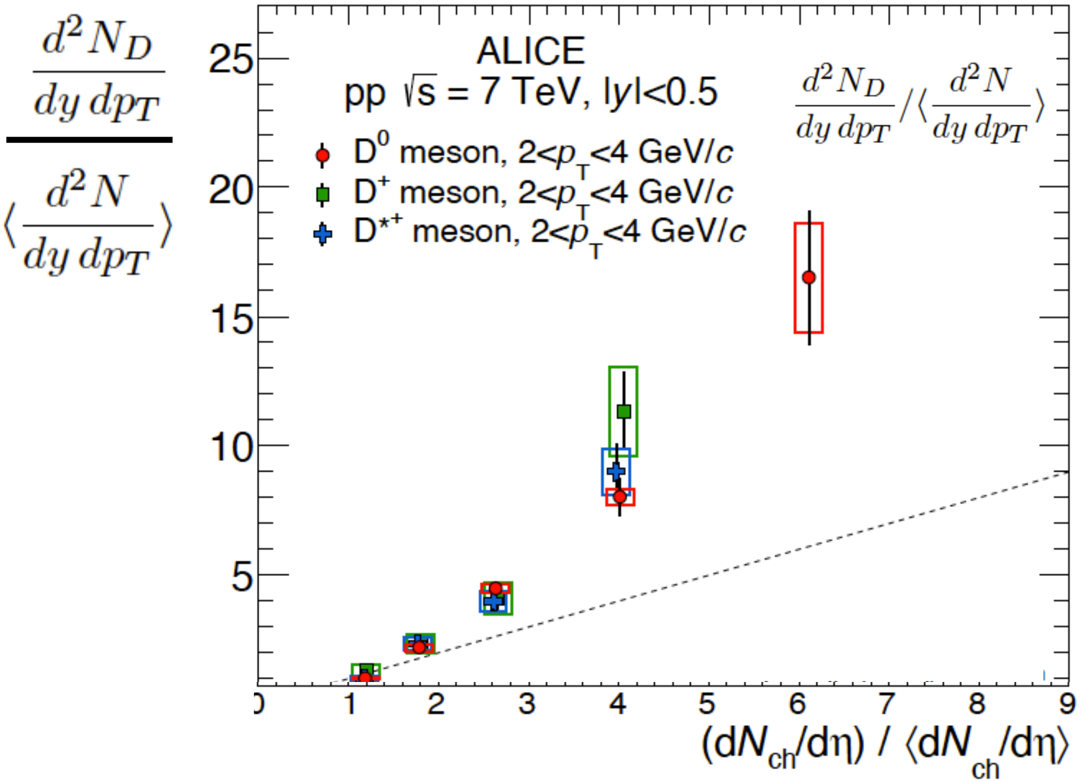

ALICE proton–proton √s =13 TeV
J/ψ → e+e−, |y|<0.9
This work
μF=μR=2mc
mc=1.1 GeV
mc=1.3 GeV
dNJ/ψ/dy / <dNJ/ψ/dy> (b)
dN/dη / <dN/dη> (b)

System Size

$$\left(\frac{dN}{d\eta}\right)_{\eta=0} \qquad \mathcal{N} = \left[\left(\frac{dN}{d\eta}\right)_{\eta=0}\right]^{1/3}$$



System size and number of charm quarks



ALICE, JHEP (2015), arXiv:1505.00664

$$\frac{d^2N_D}{dy\,dp_T}/\langle\frac{d^2N}{dy\,dp_T}\rangle = \alpha' \left(\frac{dN_{ch}}{d\eta}/\langle\frac{dN_{ch}}{d\eta}\rangle\right)^\beta$$

$$\beta = 1.6$$

Assume that:

$$N_D \propto (\mathcal{N}^3)^\beta$$

$$N_c \propto (\mathcal{N}^3)^\beta$$

Fix the constant using EXHIC estimates:

$$N_c = 7.9 \times 10^{-5}\,\mathcal{N}^{4.8}$$