Accessing **Saturation** and **Sub-Nuclear Structure** with Multiplicity Dependent J/ψ production in p+p and p+Pb Collisions

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Based on: F. Salazar, B. Schenke, and A. Soto-Ontoso. Phys.Lett.B 827 (2022) 136952, ArXiv: 2112.04611

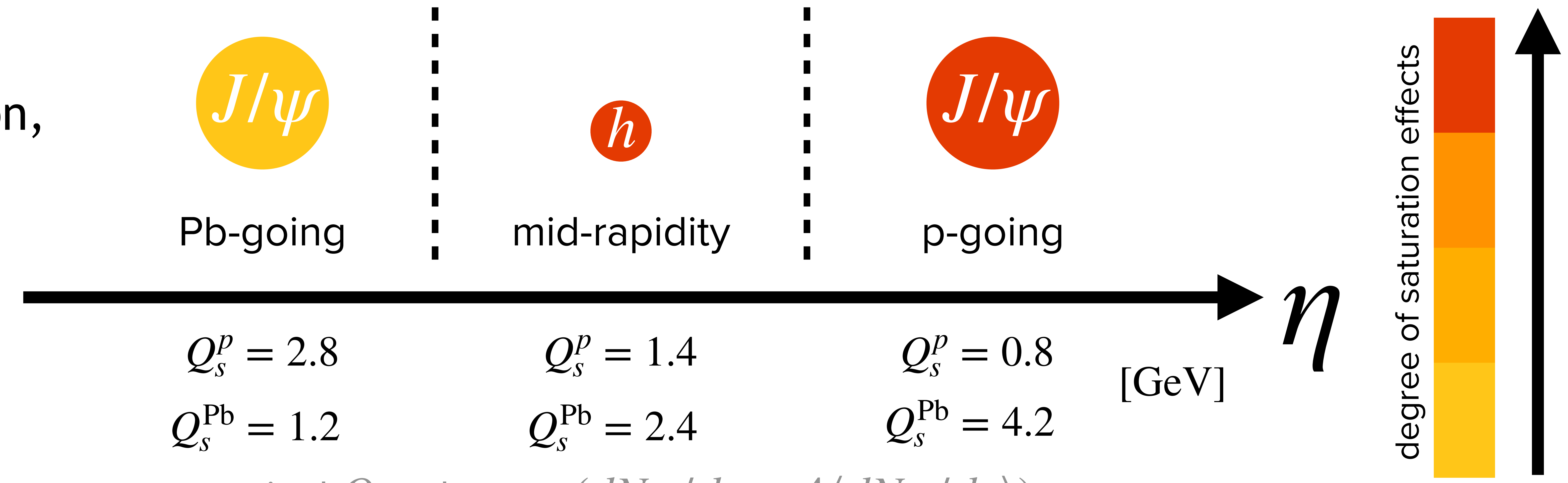
Scanning Saturation with J/ψ and charged hadron

Study production of J/ψ at forward and backward rapidities relative to charged hadrons at mid-rapidity

Expect varying sensitivity to saturation, depending on probed Q_s and mass:

J/ψ $m_{J/\psi} = 3.1\,\text{GeV}$

h $m_{h_c} \approx 0.5\,\text{GeV}$



typical Q_s values at $(dN_{\rm ch}/d\eta = 4\langle dN_{\rm ch}/d\eta\rangle)$

Spatial dependence in $T_A(\boldsymbol{R}_\perp)$ includes fluctuations of nucleon positions and nucleon substructure:

3 hot spots locations per nucleon sampled from

$$P(\boldsymbol{R}_{\perp,i}) = \frac{1}{2\pi B_{\rm qc}} e^{-\boldsymbol{R}^2_{\perp,i}/(2B_{qc})}$$ and hot spot density distribution $$T_q(\boldsymbol{R}_\perp - \boldsymbol{R}_{\perp,i}) = \xi_{Q_s^2} e^{-(\boldsymbol{R}_\perp - \boldsymbol{R}_{\perp,i})^2/(2(\xi_{B_q})B_q)}$$

fluctuating normalization

fluctuating size

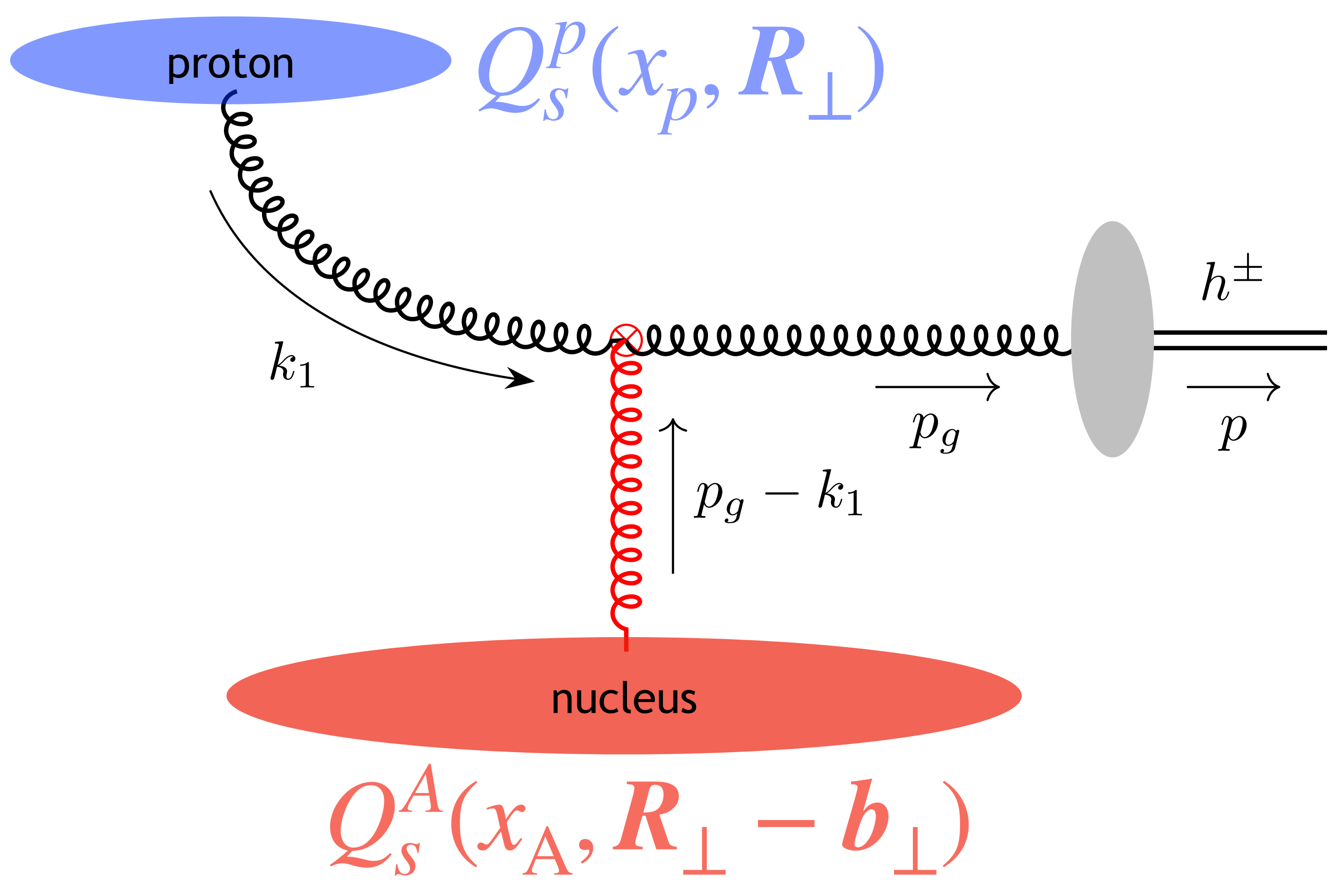
Theory: charged hadron and J/ψ production

- k_T-factorization for gluon production

$$\frac{\mathrm{d}N_g(\boldsymbol{b}_\perp)}{\mathrm{d}^2\boldsymbol{p}_{g\perp}\mathrm{d}y_g} = \frac{\alpha_s}{(\sqrt{2}\pi)^6 C_F}\frac{1}{\boldsymbol{p}_{g\perp}^2}\int_{\boldsymbol{k_1}_\perp,\boldsymbol{R}_\perp}\phi^p(x_p;\boldsymbol{k_1}_\perp;\boldsymbol{R}_\perp)\,\phi^A(x_A;\boldsymbol{p}_{g\perp}-\boldsymbol{k_1}_\perp;\boldsymbol{R}_\perp-\boldsymbol{b}_\perp)$$

- Unintegrated gluon distributions ϕ^p and ϕ^A from BK evolution with MV initial conditions + spatial dependence

- Hadronize using KKP fragmentation function



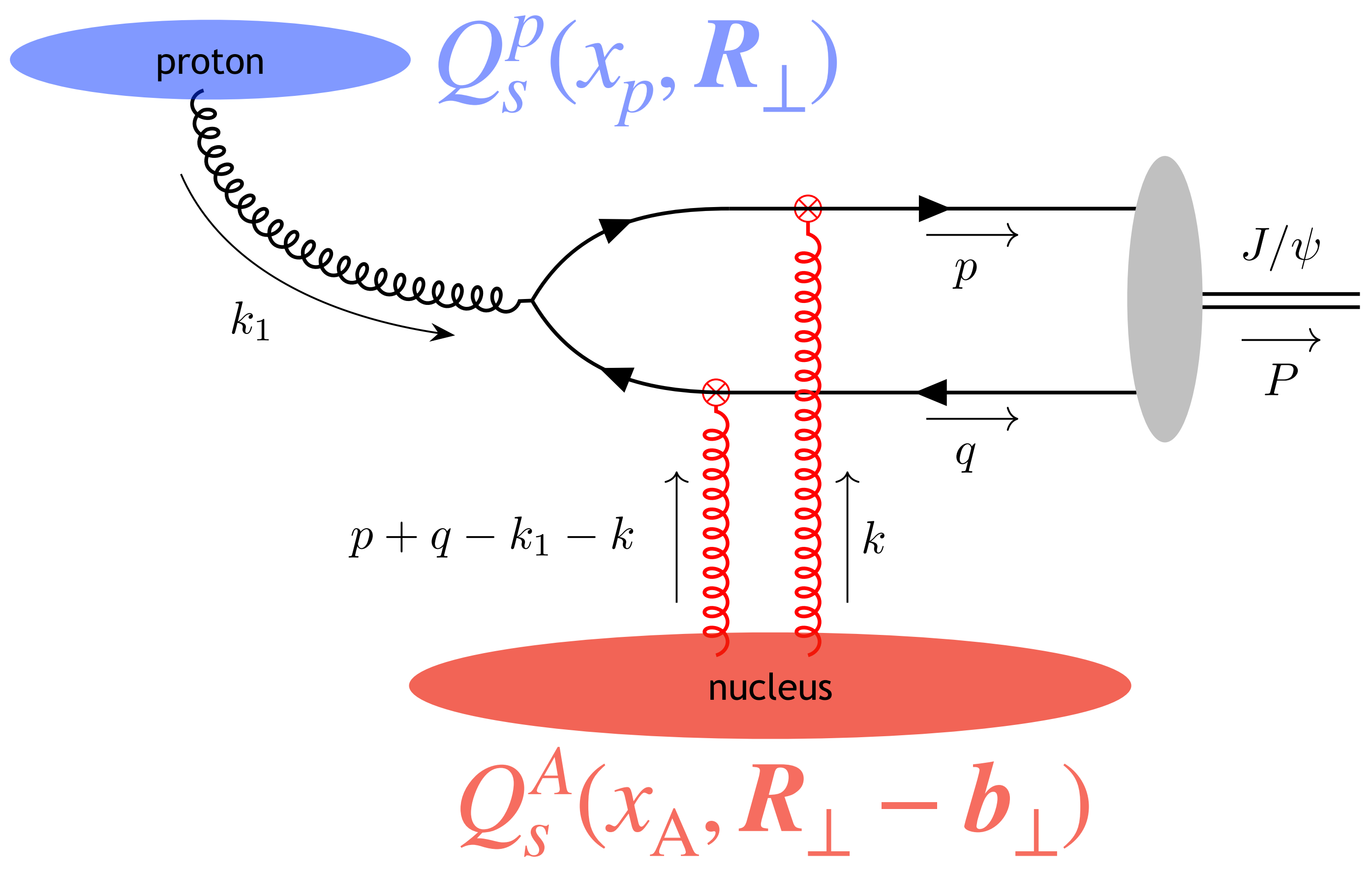
- $c\bar{c}$-pair production in NRQCD for quantum state κ

$$\frac{\mathrm{d}N^\kappa_{c\bar{c}}(\boldsymbol{b}_\perp)}{\mathrm{d}^2\boldsymbol{P}_\perp\mathrm{d}Y} = \frac{\alpha_s}{(2\pi)^9 2N_c C_F}\int_{\boldsymbol{k_1}_\perp,\boldsymbol{k}_\perp,\boldsymbol{k}'_\perp,\boldsymbol{R}_\perp}\mathcal{H}^\kappa(\boldsymbol{P}_\perp-\boldsymbol{k_1}_\perp,\boldsymbol{k}_\perp,\boldsymbol{k}'_\perp)\frac{\phi^p(x_p,\boldsymbol{k_1}_\perp,\boldsymbol{R}_\perp)}{\boldsymbol{k_1}_\perp^2}\,\tilde{\Xi}^\kappa(x_A;\boldsymbol{P}_\perp-\boldsymbol{k_1}_\perp,\boldsymbol{k}_\perp,\boldsymbol{k}'_\perp;\boldsymbol{R}_\perp-\boldsymbol{b}_\perp)$$

- $\mathscr{H}^\kappa$ are the hard factors, and the $\tilde{\Xi}^\kappa$ contain dipole amplitudes (related to ϕ^A)

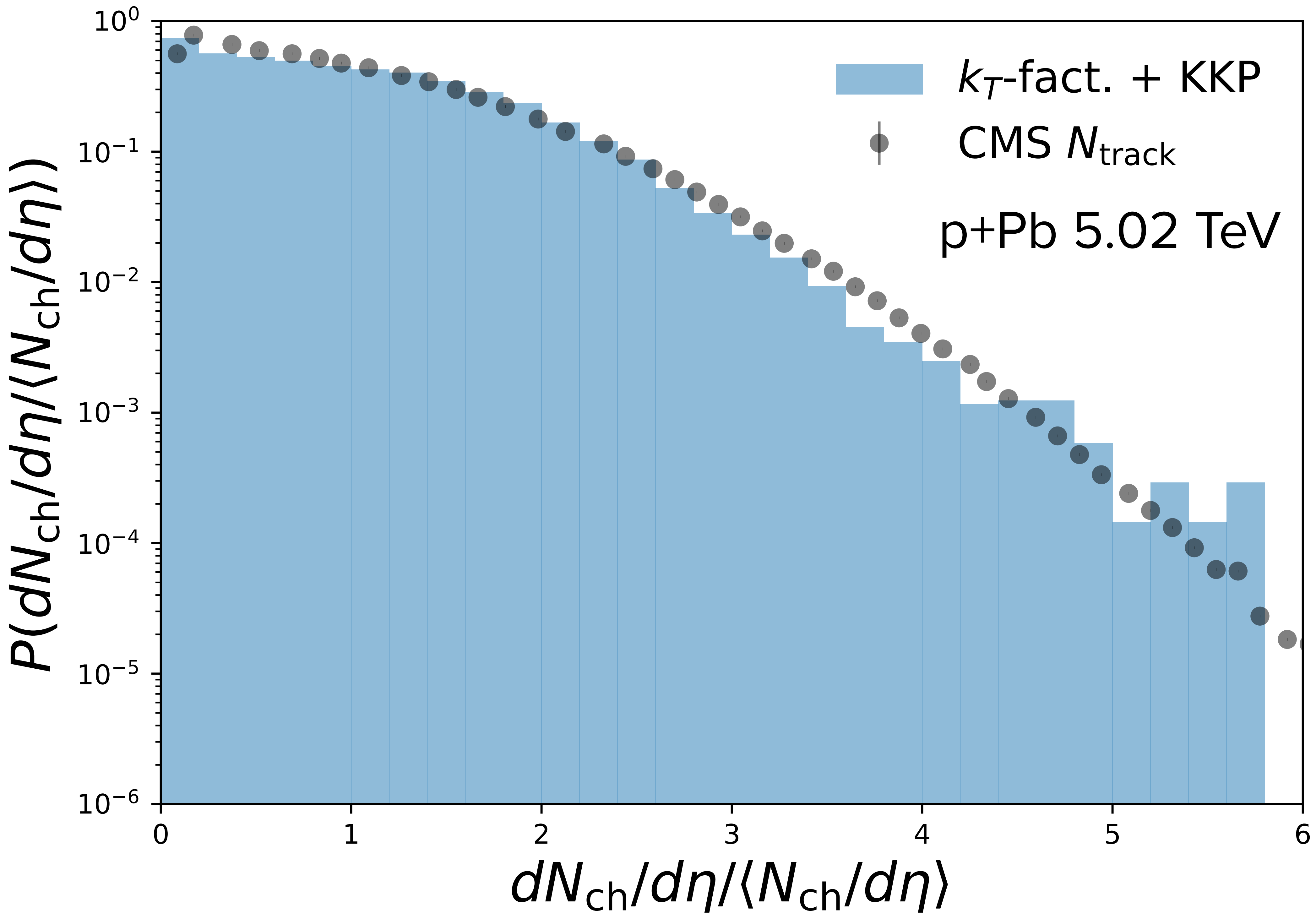
$$\frac{\mathrm{d}N_{J/\psi}(\boldsymbol{b}_\perp)}{\mathrm{d}^2\boldsymbol{P}_\perp\mathrm{d}Y} = \sum_\kappa \frac{\mathrm{d}N^\kappa_{c\bar{c}}(\boldsymbol{b}_\perp)}{\mathrm{d}^2\boldsymbol{P}_\perp\mathrm{d}Y}\langle\mathcal{O}_\kappa^{J/\psi}\rangle$$

with non-perturbative long-distance matrix elements $\langle\mathscr{O}_\kappa^{J/\psi}\rangle$



Results: Fluctuations

Charged hadron multiplicity distribution



Parameter	Value
N_q	3
B_{qc}	$3\,\mathrm{GeV}^{-2}$
B_q	$1\,\mathrm{GeV}^{-2}$
σ_{B_q}	0.7
$\sigma_{Q_s^2}$	0.1
$S_\perp$	13 mb

Parameter	Value
α_s	0.16
m_{IR}	0.2 GeV
$m_{J/\psi}$	3.1 GeV
m_c	$m_{J/\psi}/2$
m_D	1.87 GeV

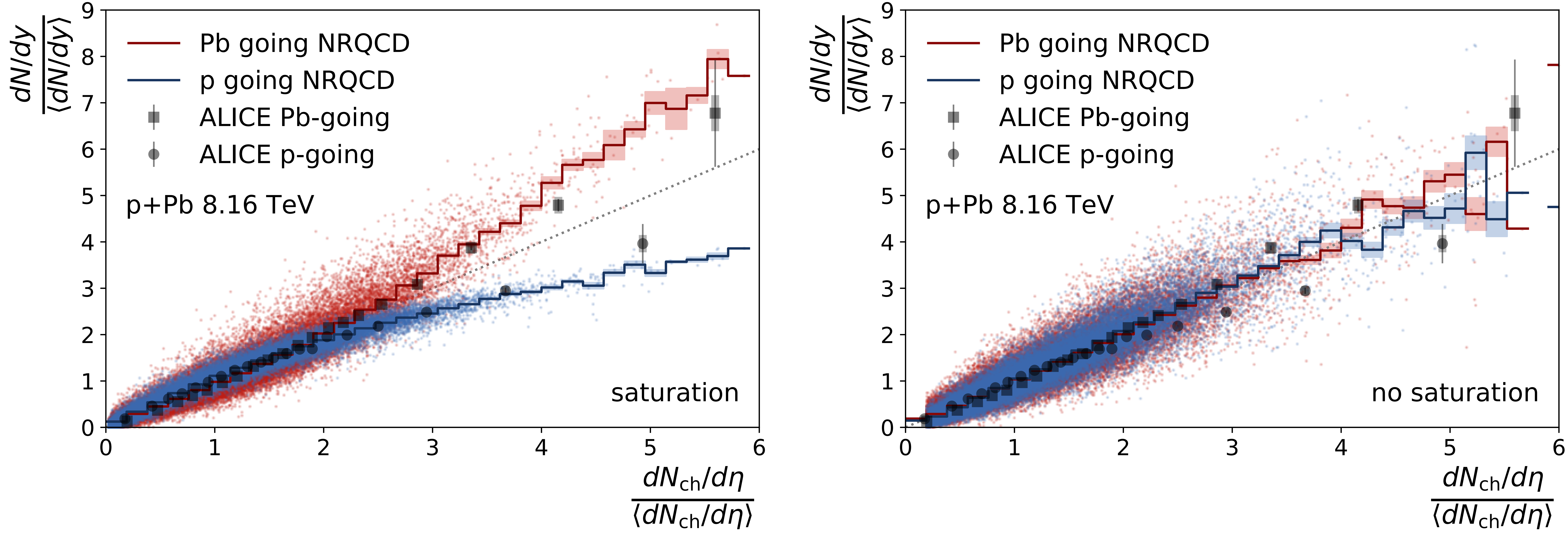
σ_{B_q} and σ_{Q_s}: width parameters in log-normal fluctuations ξ

m_{IR}: infrared regulator in the charged hadron calculation

Experimental data: CMS Collaboration, Phys.Lett. B718, 795 (2013), https://twiki.cern.ch/twiki/bin/view/CMSPublic/ PhysicsResultsHIN12015

Results: J/ψ vs charged hadron yield

Saturation drives the correlation between J/ψ and charged hadrons

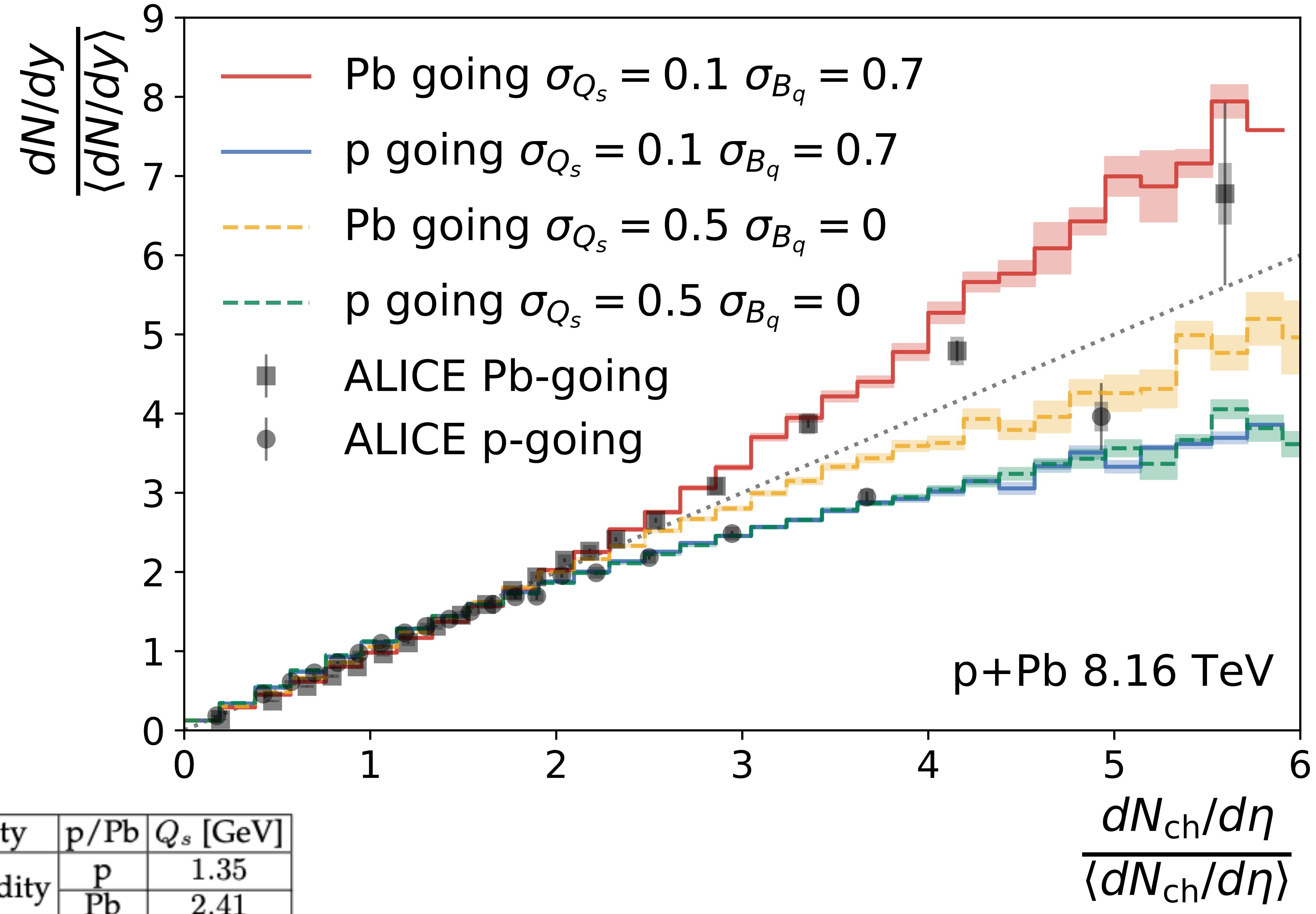


Rapidity	p/Pb	Q_s [GeV]
midrapidity	p	1.35
	Pb	2.41
p-going	p	0.78
	Pb	4.18
Pb-going	p	2.78
	Pb	1.18

Experimental data: S. Acharya et al. (ALICE), JHEP 09, 162 (2020), arXiv:2004.12673 [nucl-ex].

Results: fluctuations affect saturation and mean p_T

- More normalization fluctuations (less size fluctuations) lead to stronger saturation effects on the J/ψ in the Pb-going direction



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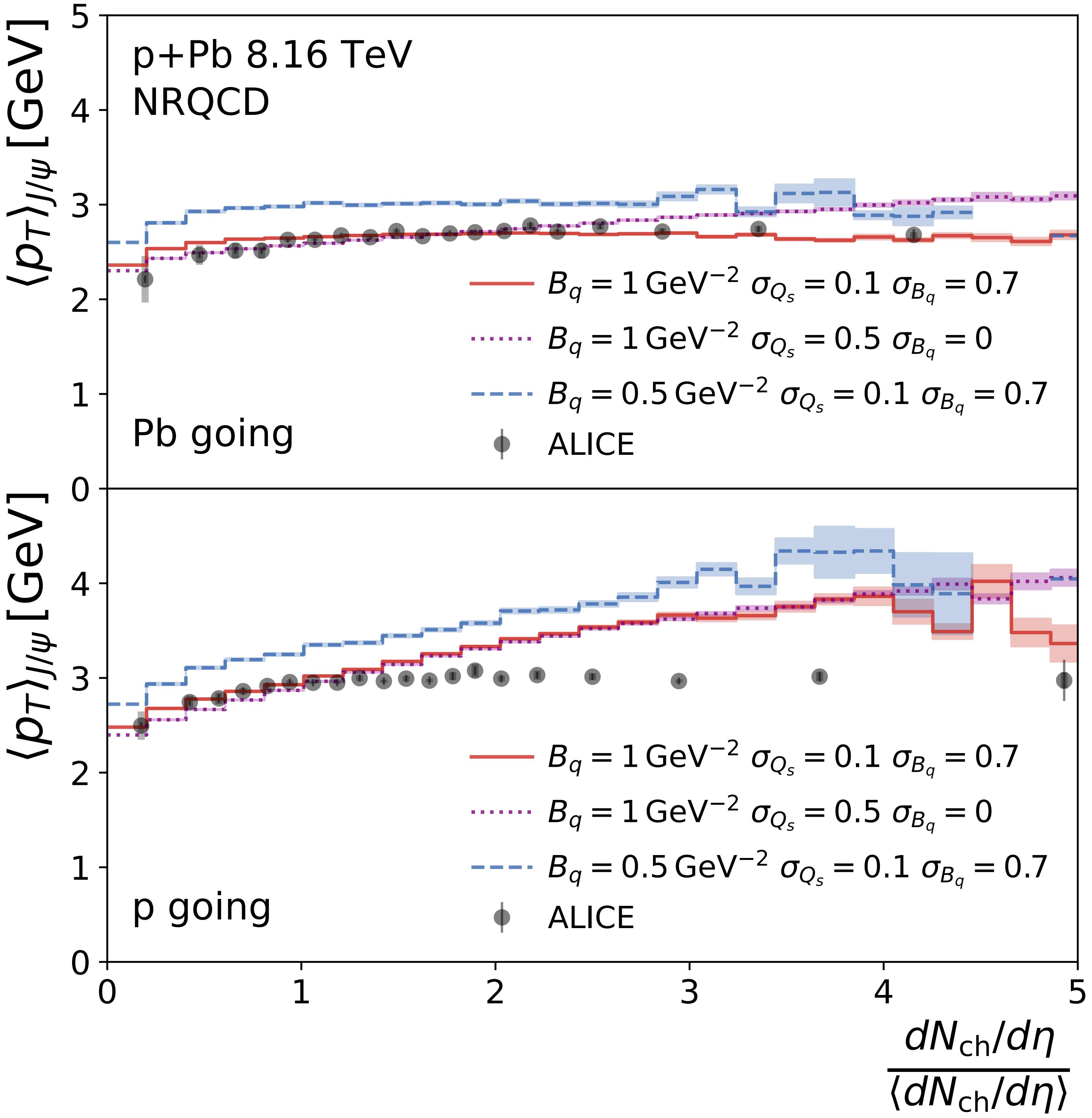
$dN_{ch}/d\eta = 4\langle dN_{ch}/d\eta \rangle$

- Mean p_T driven by mass and Q_s
- Q_s fluctuations and hot spot size matter



Experimental data: ALICE Collaboration, JHEP 09, 162 (2020)