

THE McDIPPER

A NOVEL SATURATION-BASED 3D INITIAL STATE
FRAMEWORK FOR HEAVY-ION COLLISIONS

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In collaboration with
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Bundesministerium
für Bildung
und Forschung



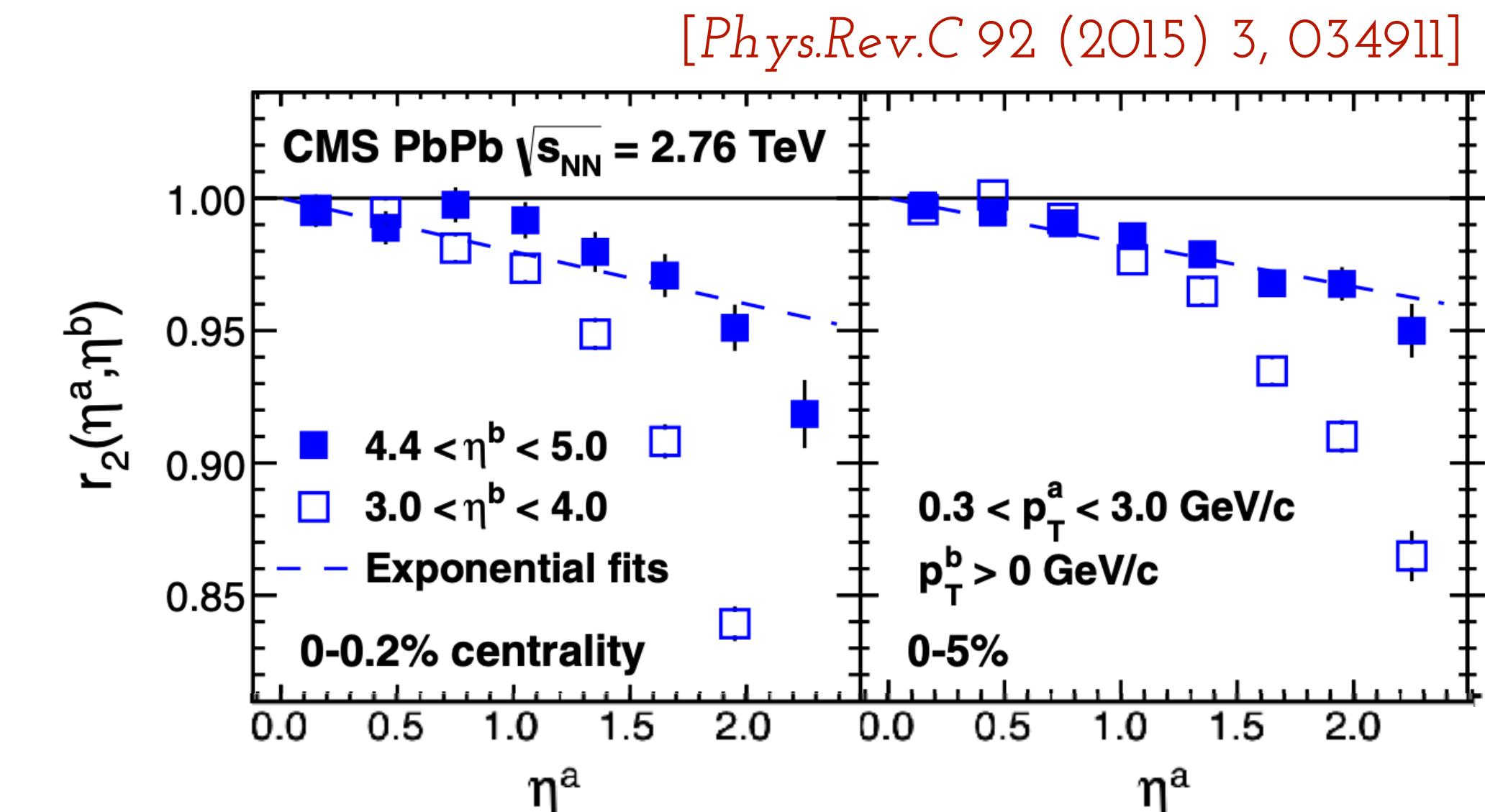
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MOTIVATION

- New experimental and theoretical insights towards the forward/backward rapidity window

└ Long. Correlations (multiplicity and geometry)

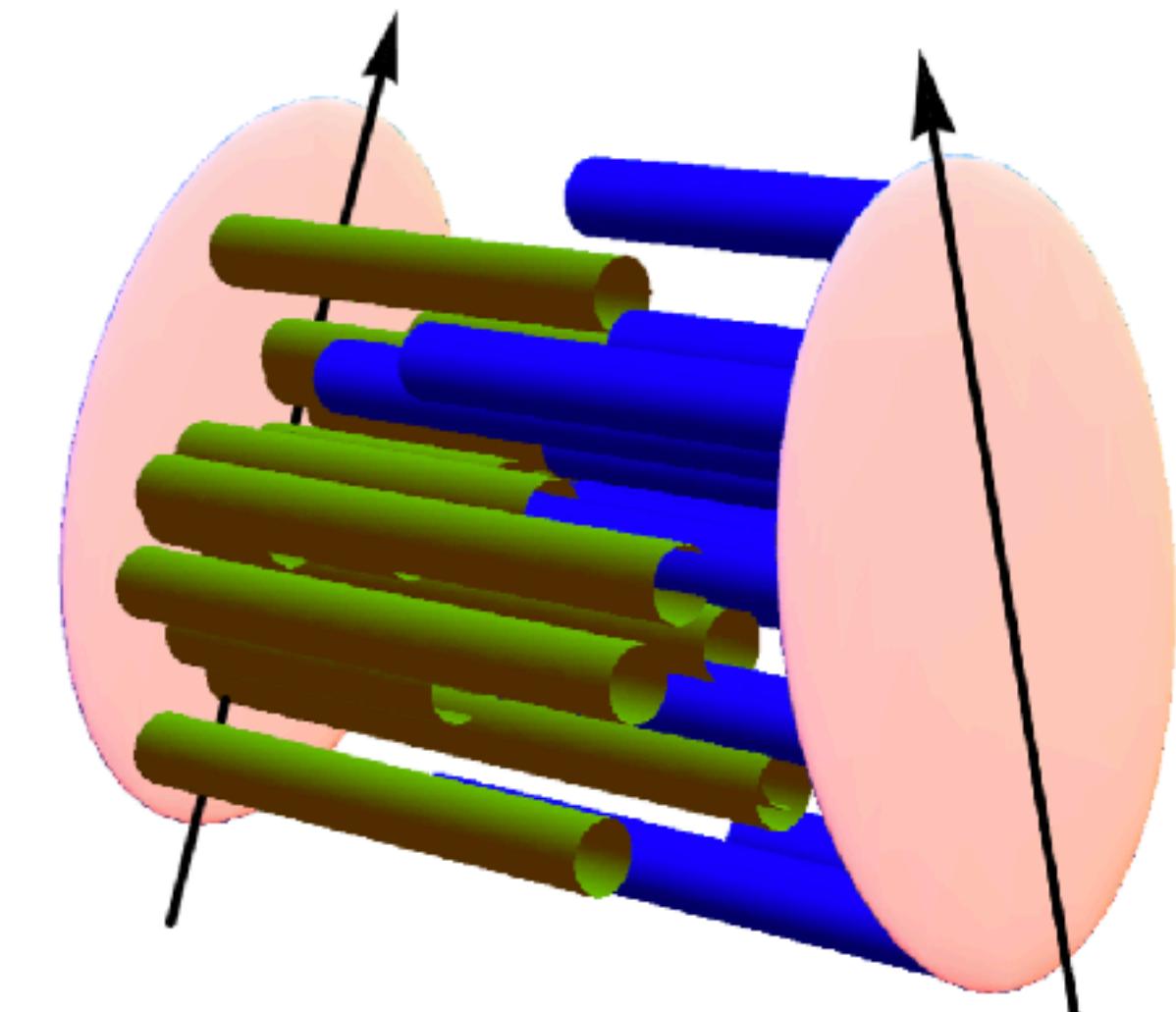


- Limited available models

└ Dif. DoFs: partons, hadrons, strings ...

[Bozek, Broniowski, PLB 752, 206 (2016)]
[Pang, et al, EPJ A52, 97 (2016)]
[Schäfer et al, EPJA 58 (2022) 11, 230]
[Chen, Alzhrani, PRC 102 (2020) 1, 014909]

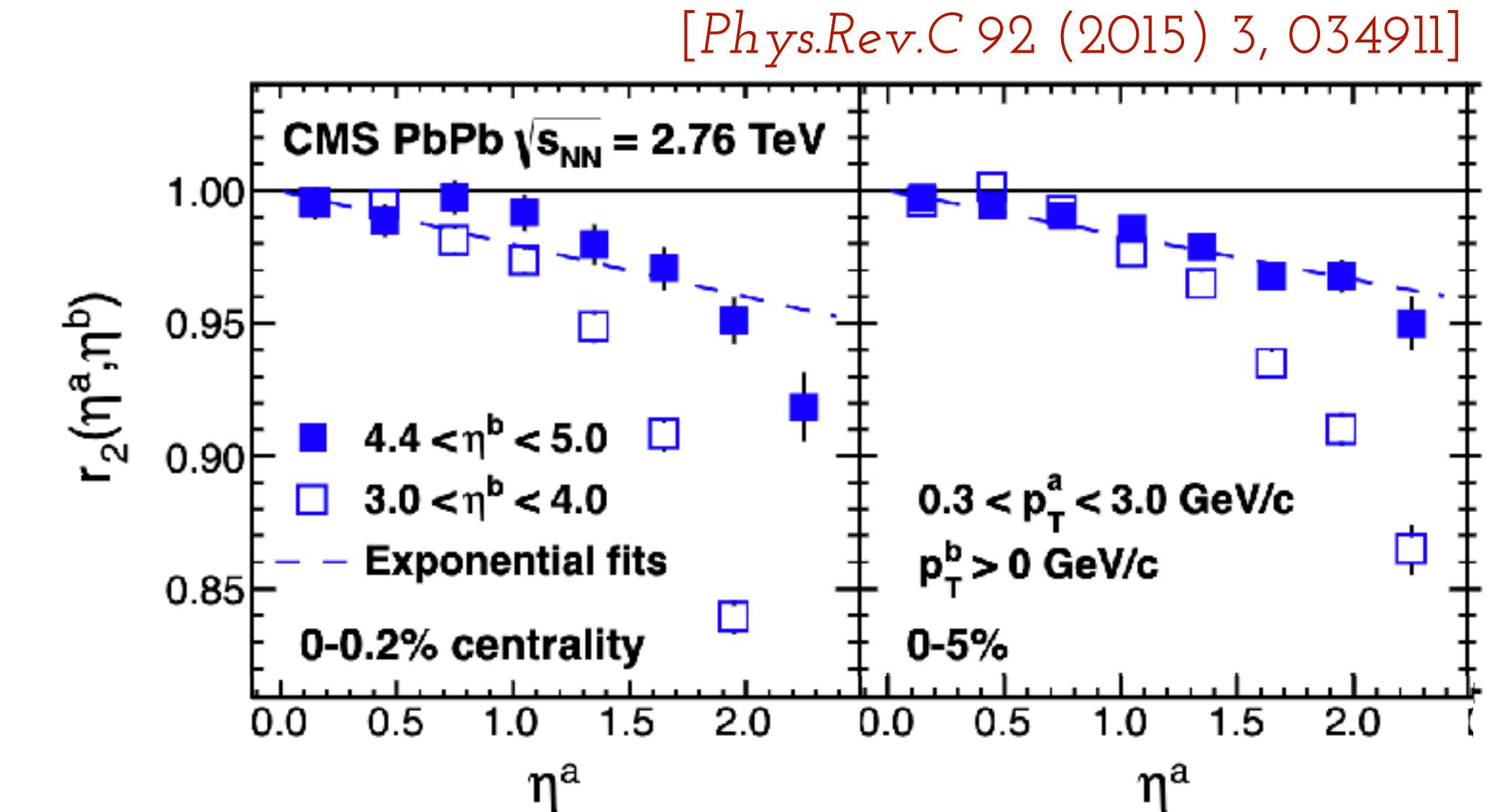
- Needed: A first-principles inspired framework to compute and compare Event-by-Event ICs in Heavy Ion Collisions



MOTIVATION

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└ Long. Correlations (multiplicity and geometry)

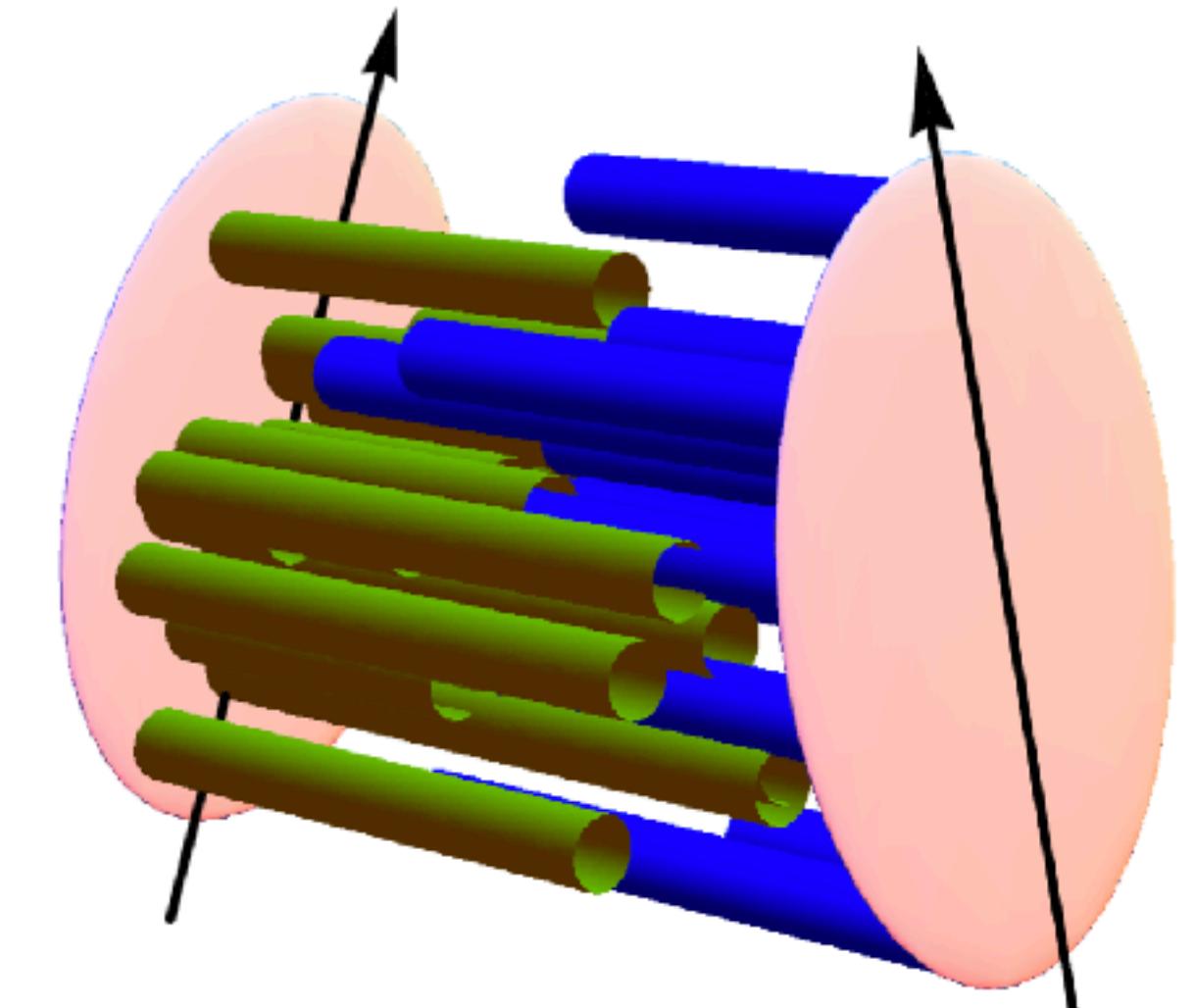


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- Also needed: framework for comprehensive comparison of saturation physics results/models.

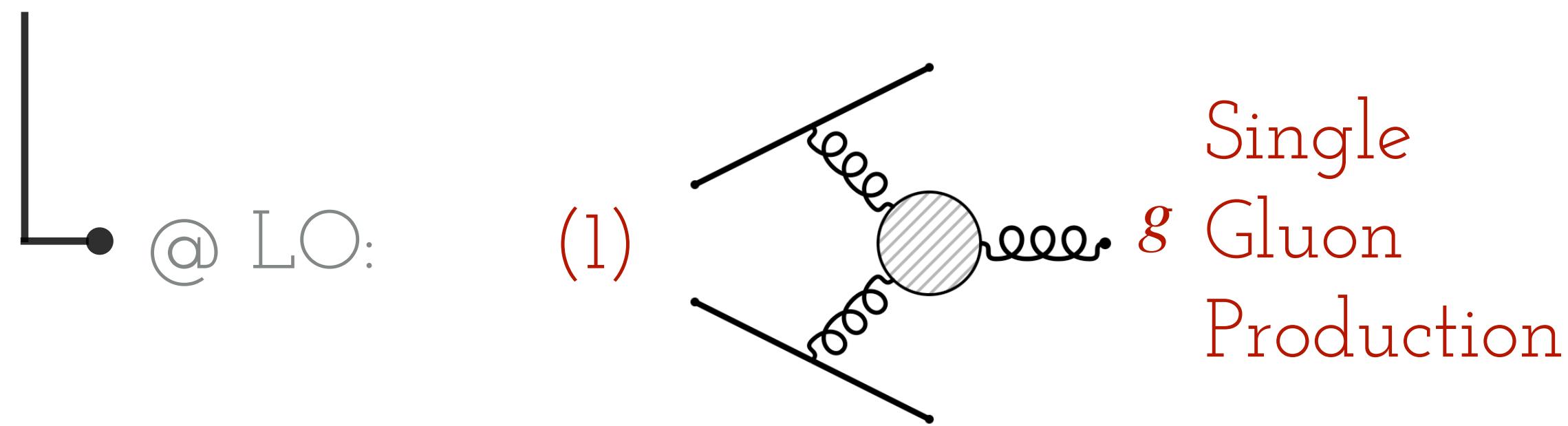
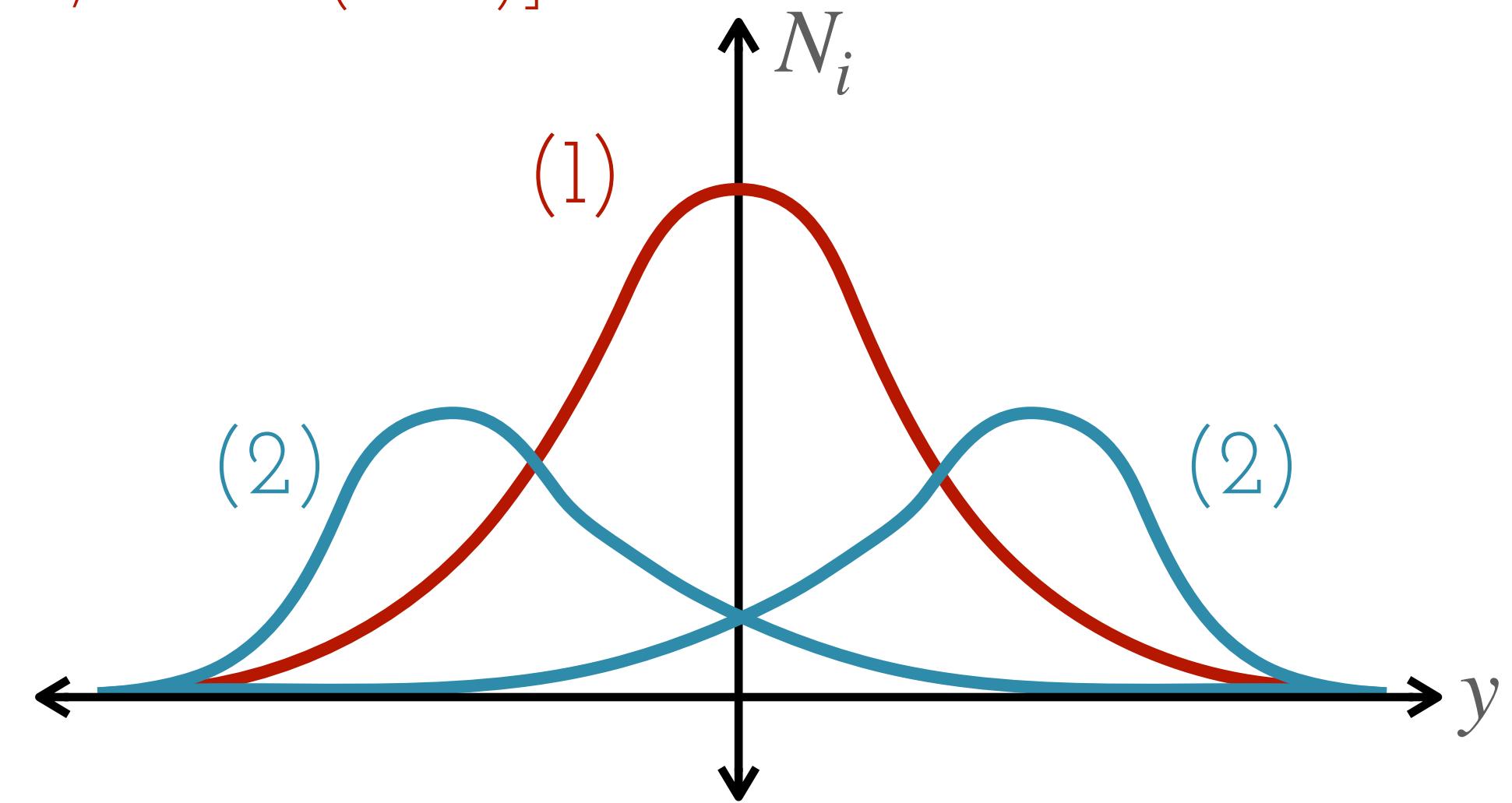


THE INITIAL STATE OF A HIC

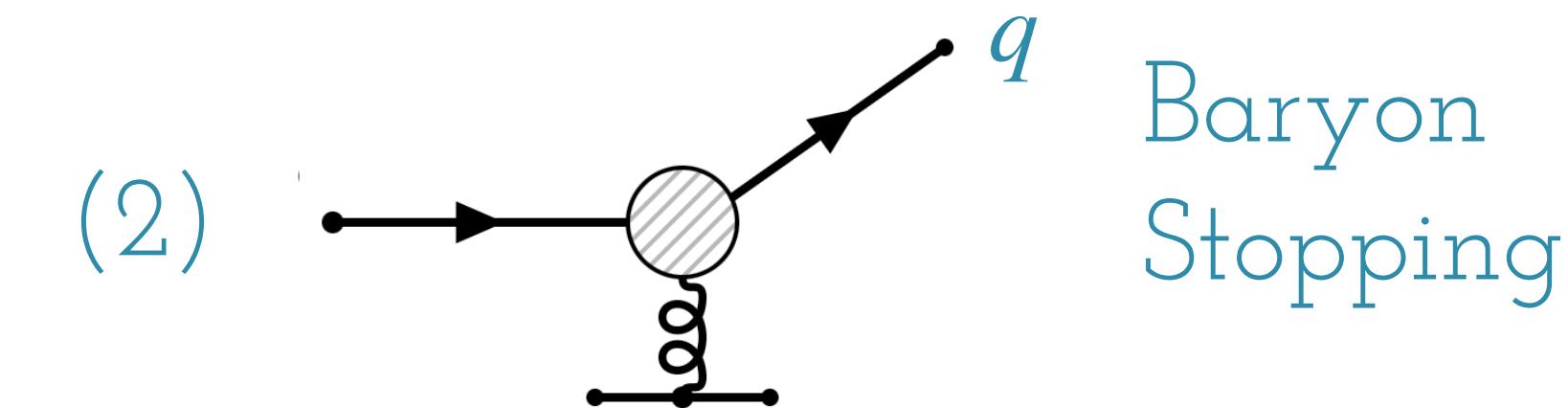
CONSERVED CHARGE DEPOSITION FROM THE CGC FORMALISM

- Energy deposition in high-energy collisions dominated by small- x gluons
 - MC-KLN, IP-Gasma...
- At forward/backward rapidities, particle production dominated by baryon stopping
- Use the dilute-dense approximation the Color Glass Condensate (CGC) Effective Field Theory (EFT) to produce both!
 - @ LO:

[PRC 76, 041903 (2007)]
[PRC 94,no.4,044907(2016)]



Single
g Gluon
Production



THE McDIPPER

Monte-Carlo Dipole Parallel Event GeneRator

Framework for comparison of saturation model predictions and creation of IC for HE
Heavy-Ion Collisions

HOW DOES IT WORK?

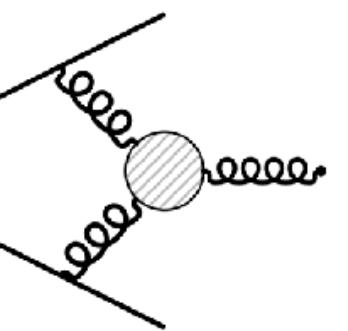
- 
- Model input: gluon unintegrated distribution function (uGDF) + (collinear) parton distribution functions (PDFs)
 - Compute energy and charges using single particle production formulas and tabulate (η, T_1, T_2)
 - Use Glauber sampling to produce events -fast- using (η, T_1, T_2) as an event-by-event input.

FROM MICRO TO MACRO

CONSERVED CHARGE DEPOSITION FROM THE CGC FORMALISM

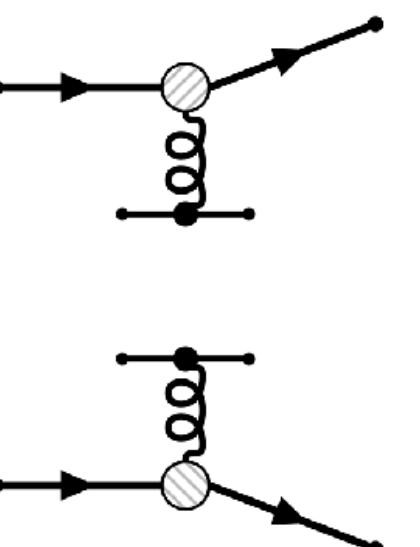
- Low- x gluons dominate the midrapidity region

$$\frac{dN_g}{d^2\mathbf{x} d^2\mathbf{p} dy} = \frac{g^2}{8\pi^5 C_F p^2} \int \frac{d^2\mathbf{q}}{(2\pi)^2} \frac{d^2\mathbf{k}}{(2\pi)^2} (2\pi)^2 \delta(\mathbf{p} + \mathbf{q} - \mathbf{p}) \\ \times \Phi_1(x_1, \mathbf{x}, \mathbf{q}) \Phi_2(x_2, \mathbf{x}, \mathbf{k})$$



- At forward/backward rapidities, particle production dominated by baryon stopping

$$\frac{dN_{q_f}}{d^2\mathbf{x} d^2\mathbf{p} dy} = \frac{x_1 q_f^A(x_1, \mathbf{p}^2, \mathbf{x}) D_{\text{fun}}(x_2, \mathbf{x}, \mathbf{p})}{(2\pi)^2} \\ + \frac{x_2 q_f^A(x_2, \mathbf{p}^2, \mathbf{x}) D_{\text{fun}}(x_1, \mathbf{x}, \mathbf{p})}{(2\pi)^2}.$$



Systematically Improvable e.g. by including NLO $gg \rightarrow q\bar{q}$ production through gluon fusion

THE INPUT

Low- x gluons

uGDFs $\rightarrow \Phi_i(x, \mathbf{r}, \mathbf{q}) \sim \mathbf{q}^2 D_{\text{adj}}(x, \mathbf{r}, \mathbf{q})$

Dipoles $\rightarrow D_{\text{adj}}(x, \mathbf{r}, \mathbf{q})$, $D_{\text{fun}}(x, \mathbf{r}, \mathbf{q})$

GBW, IP-Sat, MV...

High- x partons

PDFs $\rightarrow x_i q_f(x_i, \mathbf{p}^2)$

Different PDF sets*.

*Accessible in the McDIPPER through the LHAPDF library

FROM MICRO TO MACRO

CONSERVED CHARGE DEPOSITION FROM THE CGC FORMALISM

- Macroscopic quantities (energy, charges) are computed as moments of the single particle distributions

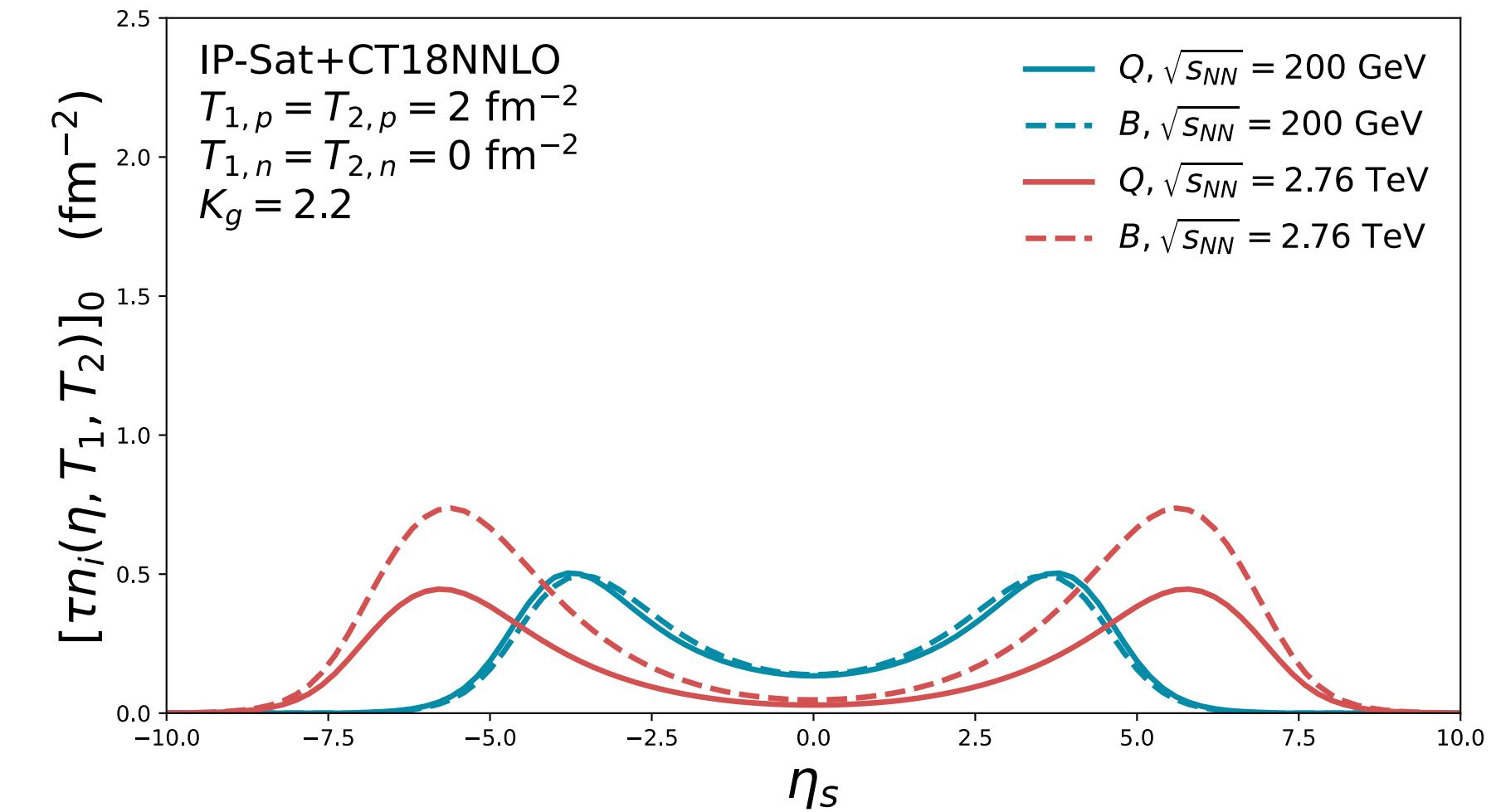
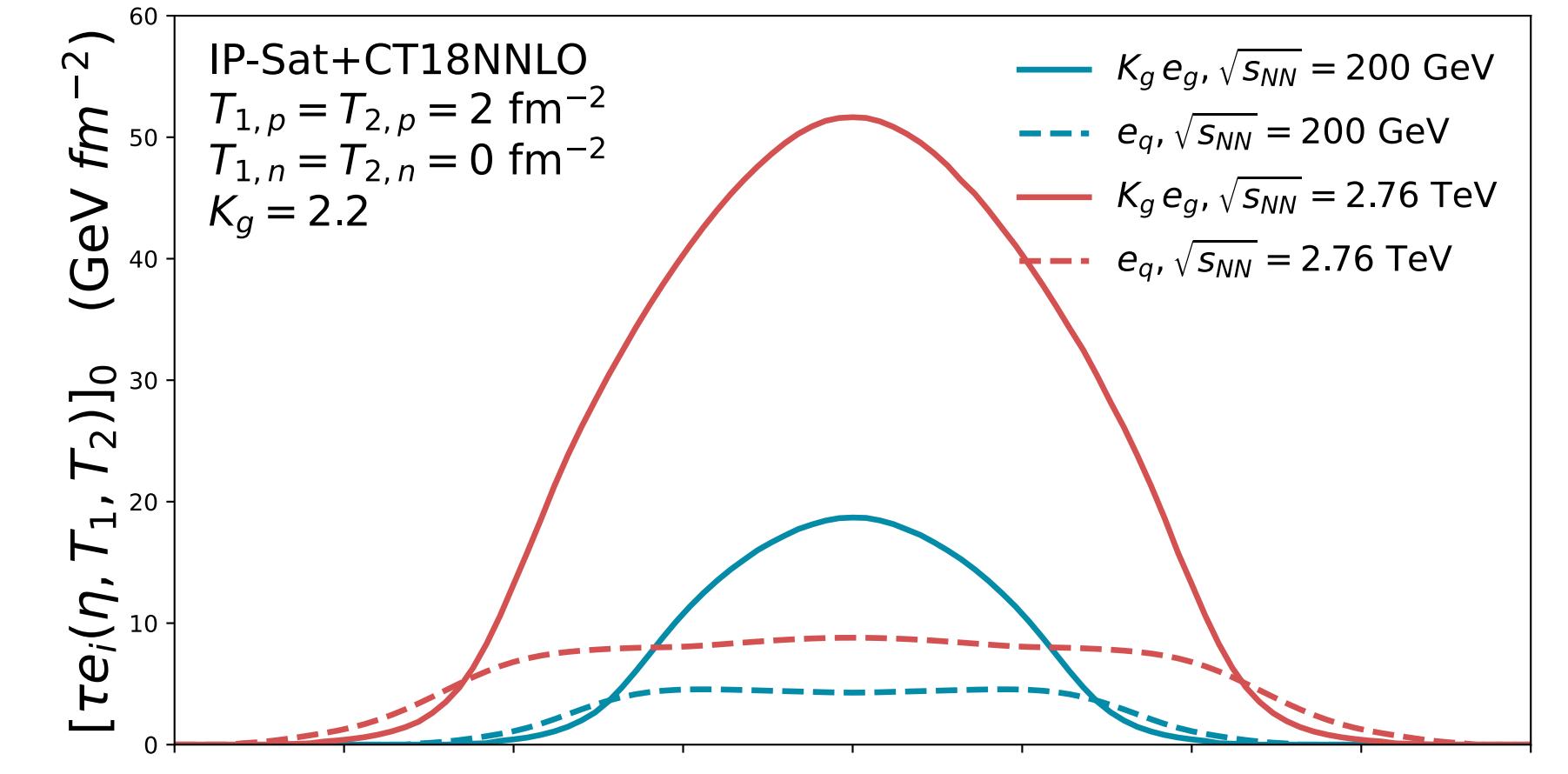
• Total energy deposition

$$(e\tau)_0 = \int d^2\mathbf{p} |\mathbf{p}| \left[K_g \frac{dN_g}{d^2\mathbf{x} d^2\mathbf{p} dy} + \sum_{f,\bar{f}} \frac{dN_{q_f}}{d^2\mathbf{x} d^2\mathbf{p} dy} \right]_{y=\eta_s}$$

• Charges (u,d,s) deposited can be used to compute conserved charges such as, i.e. electric charge,

$$\underline{(Q\tau)_0} = \sum_f Q_f \int d^2\mathbf{p} \left[\frac{dN_f}{d^2\mathbf{x} d^2\mathbf{p} dy} - \frac{dN_{\bar{f}}}{d^2\mathbf{x} d^2\mathbf{p} dy} \right]_{y=\eta_s}$$

$$\underline{(B\tau)_0} = \sum_f B_f \int d^2\mathbf{p} \left[\frac{dN_f}{d^2\mathbf{x} d^2\mathbf{p} dy} - \frac{dN_{\bar{f}}}{d^2\mathbf{x} d^2\mathbf{p} dy} \right]_{y=\eta_s}$$



TUNING

FIXING THE K-FACTOR

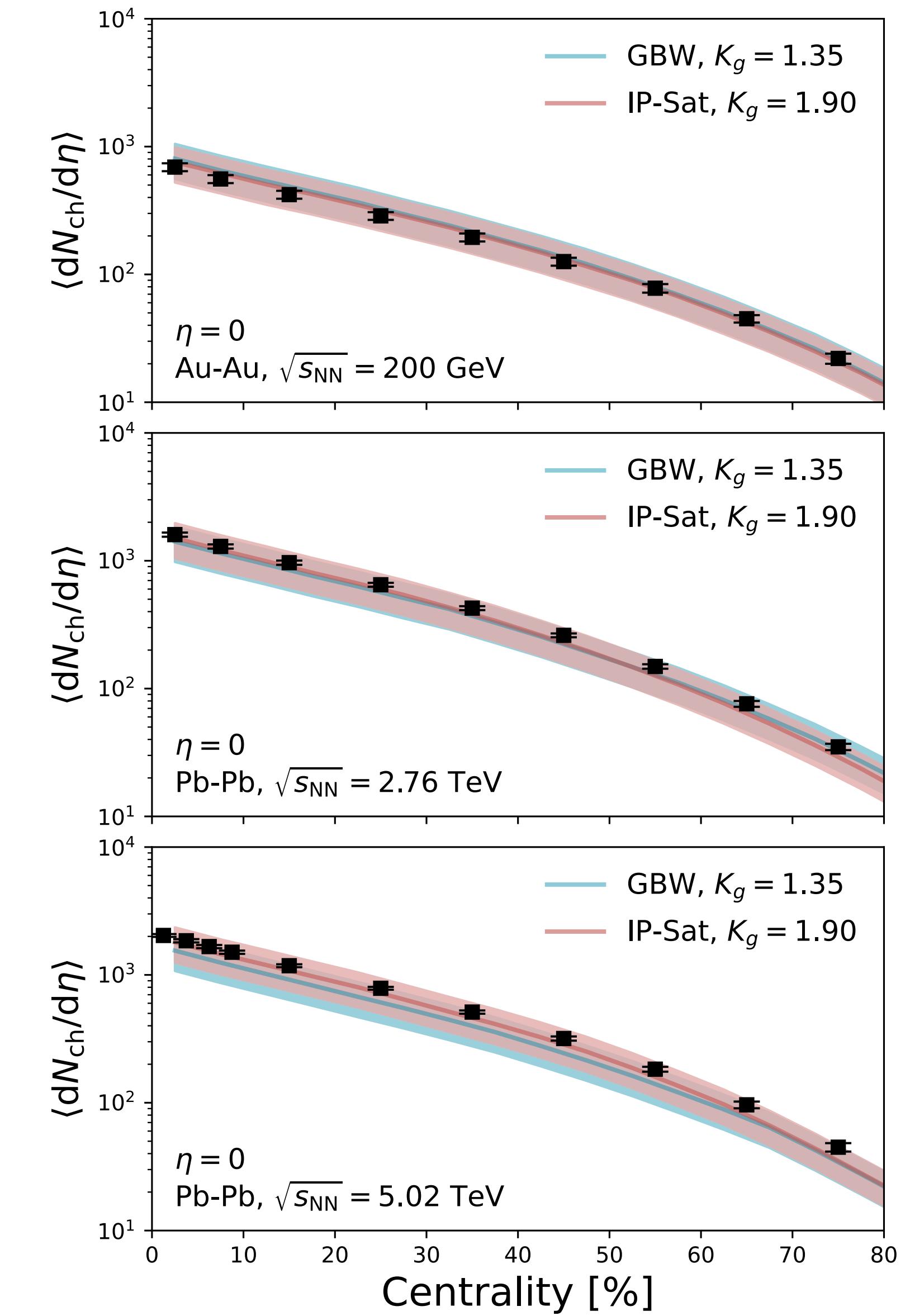
- Input model parameters can be fixed by other experiments, e.g DIS ($e+p$)
- Overall normalization of $(e_g\tau)_0$ treated as a free parameter, K_g to account for perturbative corrections
- Tune K_g using E_T in pp min. bias collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$.

$K_g = 1.35$ {GBW}

$K_g = 1.90$ {IP-Sat}

- Multiplicity can be then estimated using [PRL. 123, 262301]

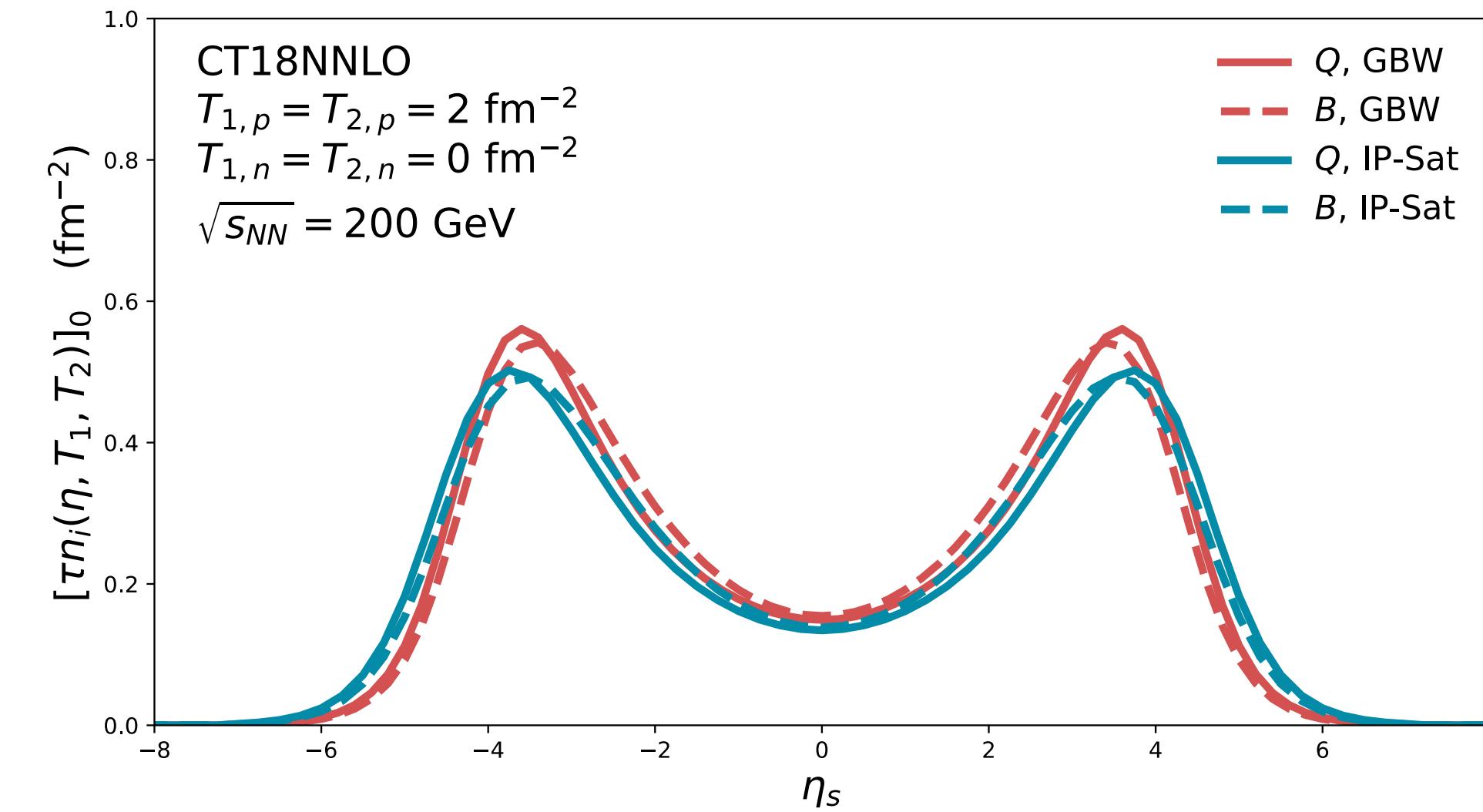
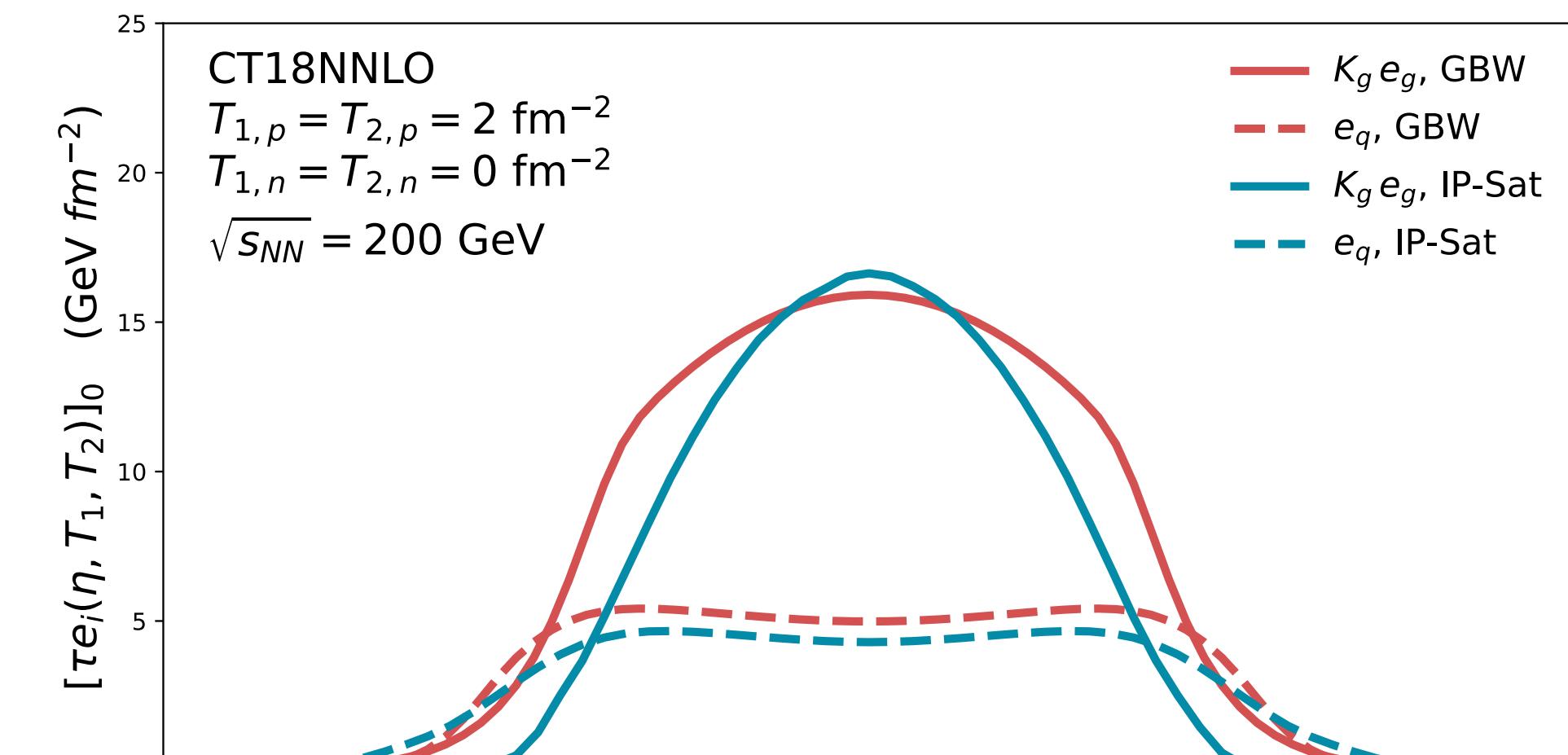
$$\left\langle \frac{dN_{\text{ch}}}{dy} \right\rangle = \frac{4}{3} \frac{N_{\text{ch}}}{S} C_\infty^{3/4} \left(4\pi \frac{\eta}{s} \right)^{1/3} \left(\frac{\pi^2}{30} \nu_{\text{eff}} \right)^{1/3} \int d^2x [\tau e(y, x)]_0^{2/3}$$



ANATOMY OF THE FRAMEWORK

CONSERVED CHARGE DEPOSITION FROM THE CGC FORMALISM

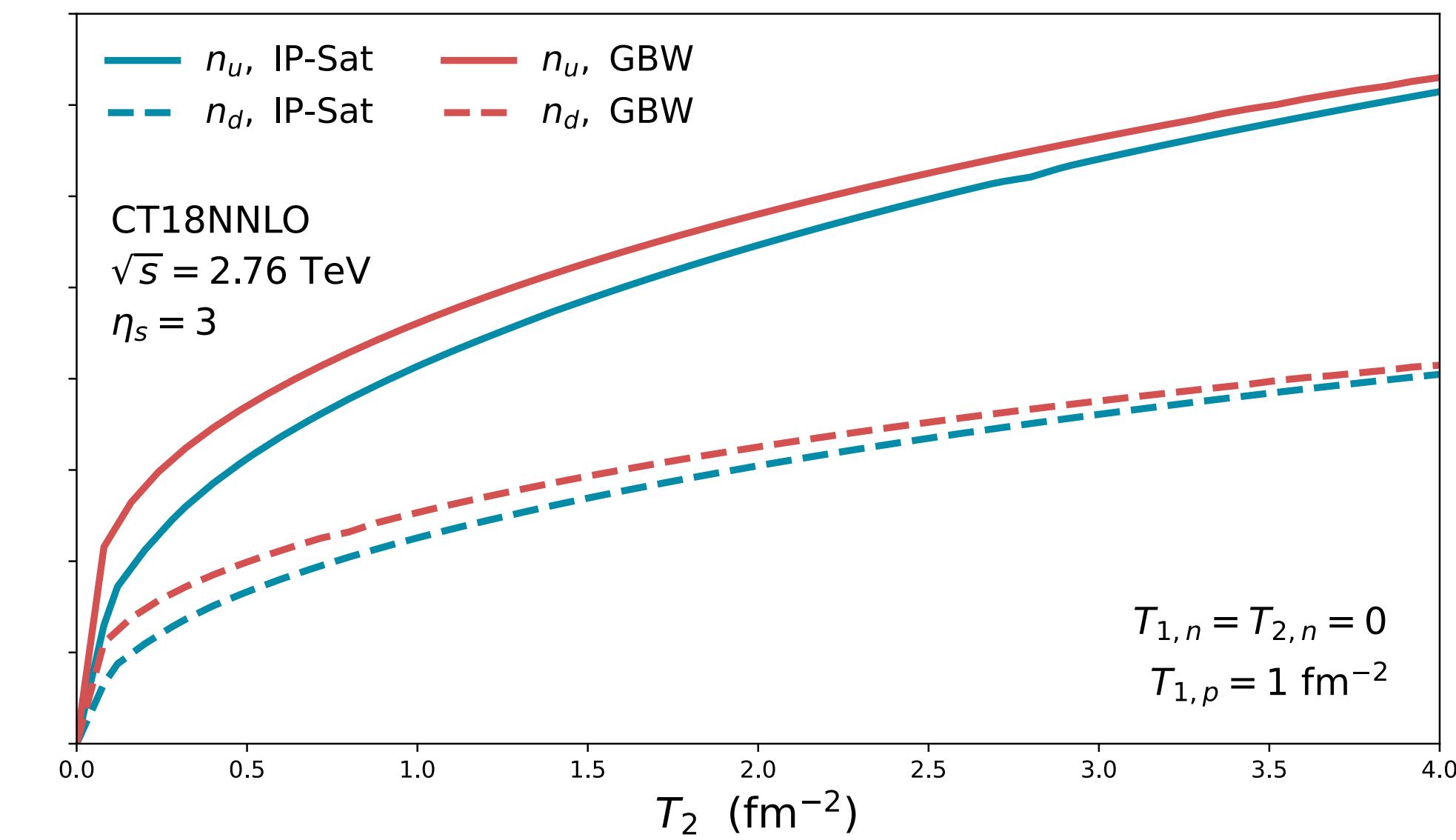
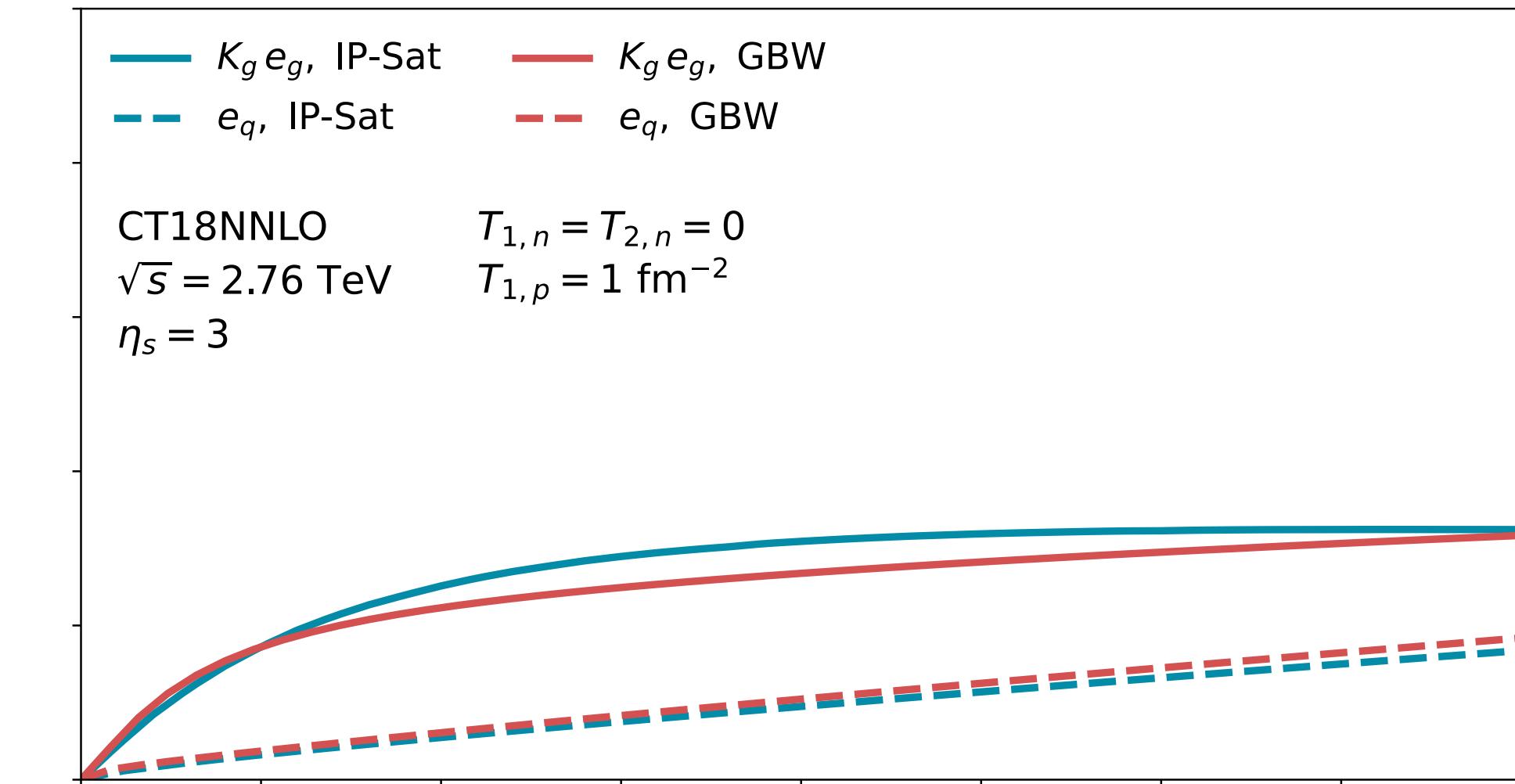
- Basic building blocks in McDIPPER, $Q_i = Q_i(\eta, T_1, T_2)$ allow for comparison between models, *a priori* and *a posteriori*
- Non-boost invariant rapidity profiles arise naturally from the x -dependence of the input distributions (uGDs, PDFs)



ANATOMY OF THE FRAMEWORK

CONSERVED CHARGE DEPOSITION FROM THE CGC FORMALISM

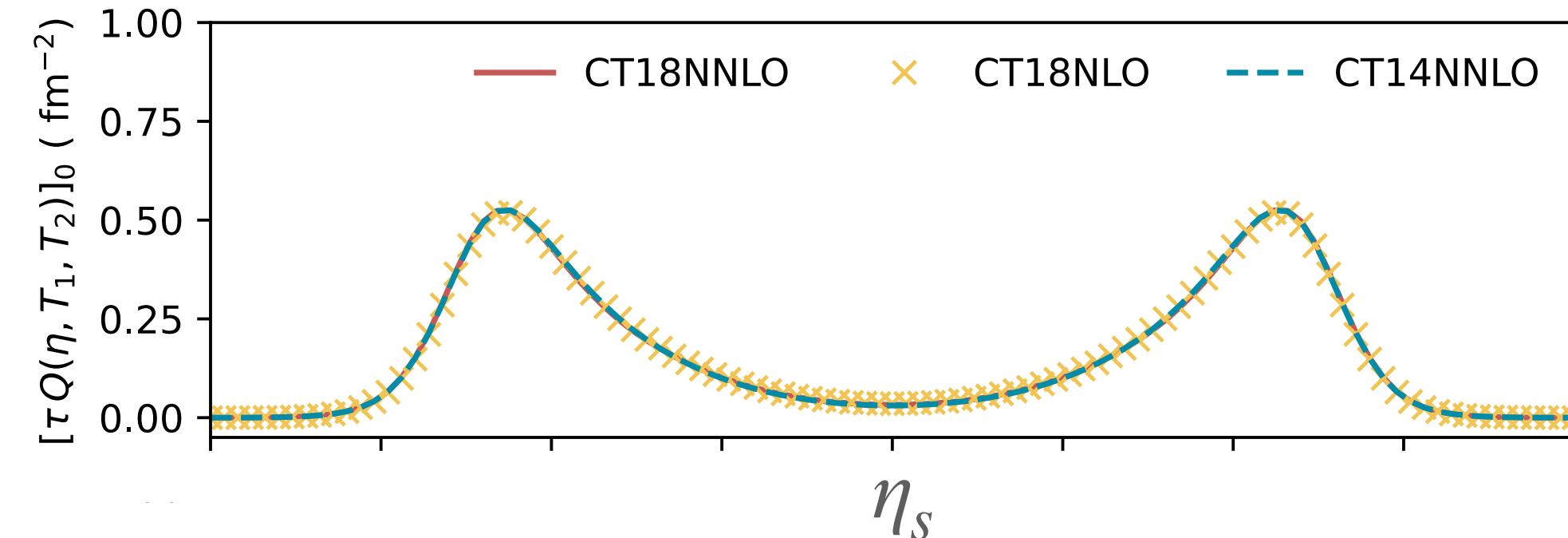
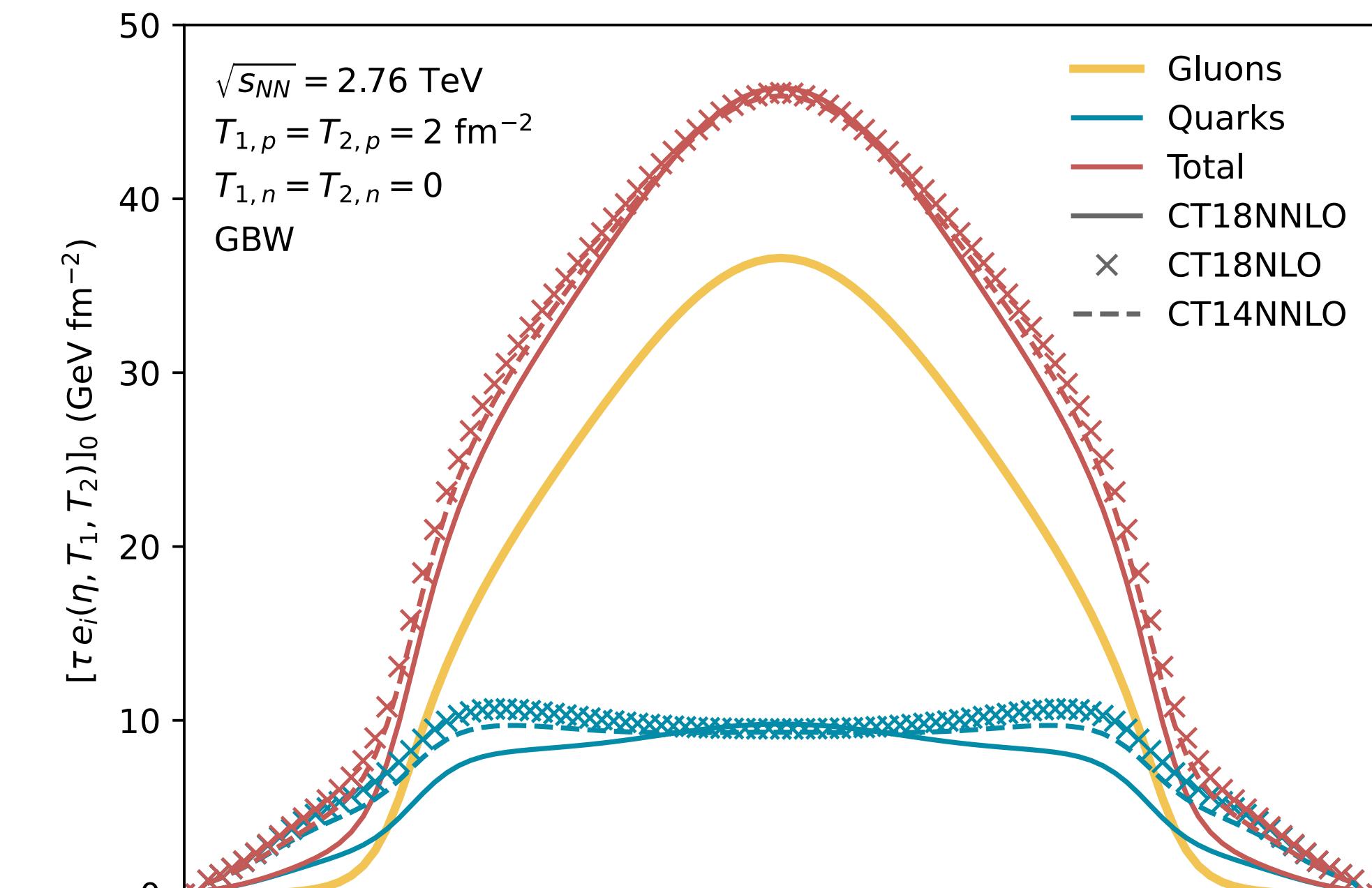
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- Non-trivial nuclear thickness resolution from T-dependence of uGDs (e.g. in IP-Sat) and PDF parton flux.



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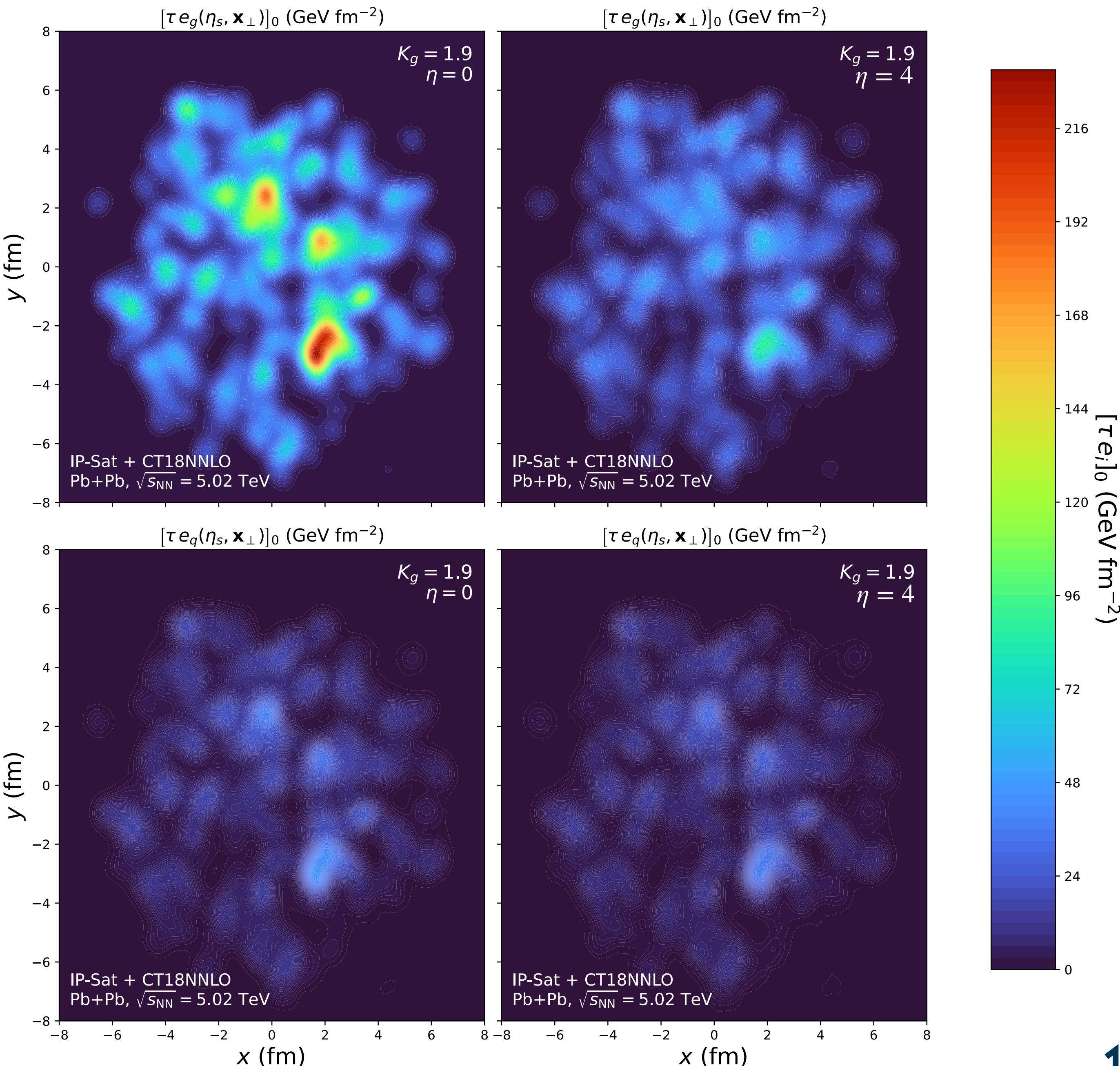
CONSERVED CHARGE DEPOSITION FROM THE CGC FORMALISM

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- Non-boost invariant rapidity profiles arise naturally from the x -dependence of the input distributions (uGDs, PDFs)
- Non-trivial nuclear thickness resolution from T-dependence of uGDs (e.g. in IP-Sat) and PDF parton flux.
- McDIPPER enables PDF-dependence comparisons for the baryon-stopping.



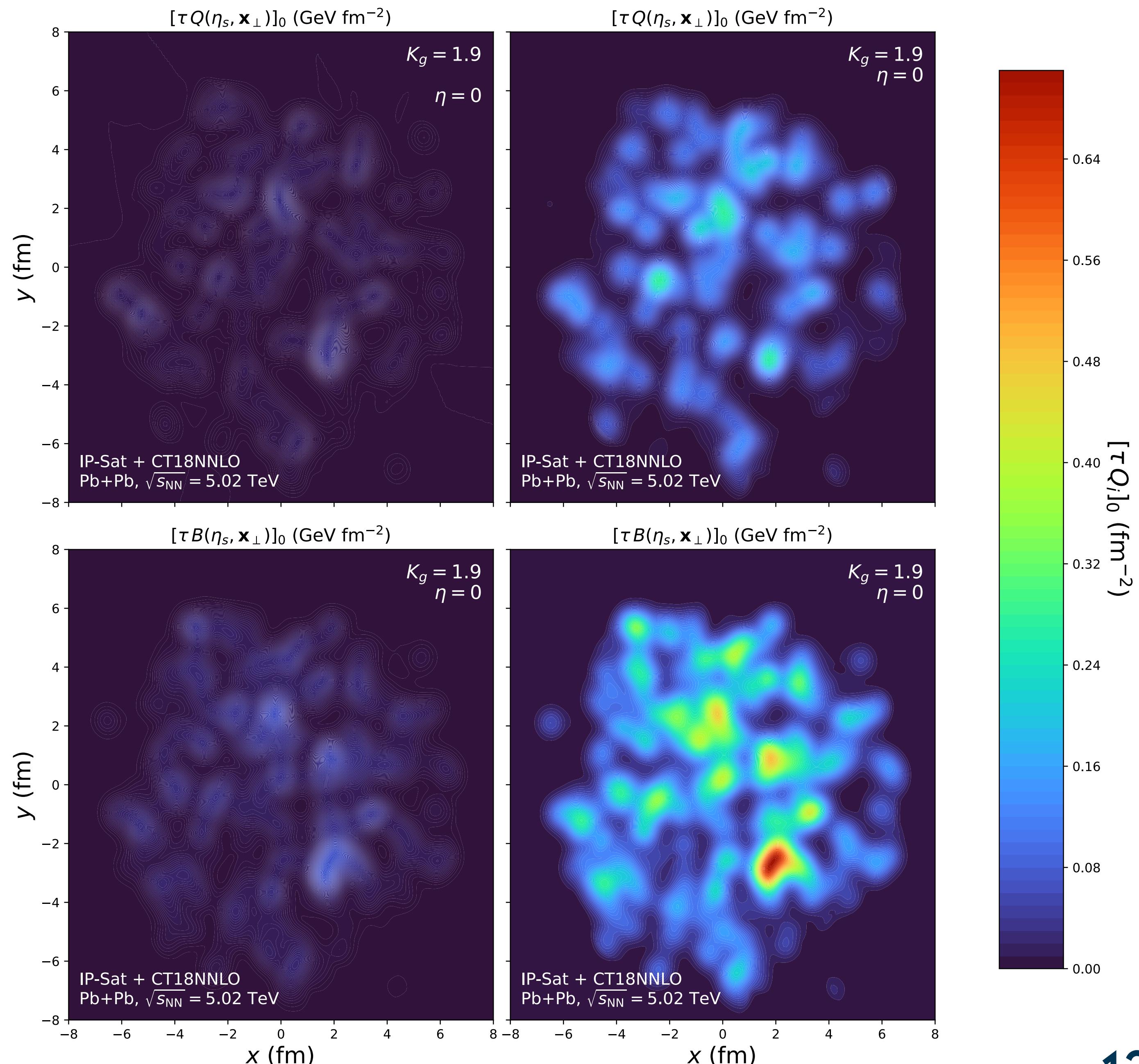
ENERGY DEPOSITION

- Glauber sampling → Nucleon fluct.
- Further fluct. can be build upon:
 - Hotspot model [PLB 770 (2017) 149-153]
 - PDF/Dipole fluctuations
- Events are trans. and long resolved.



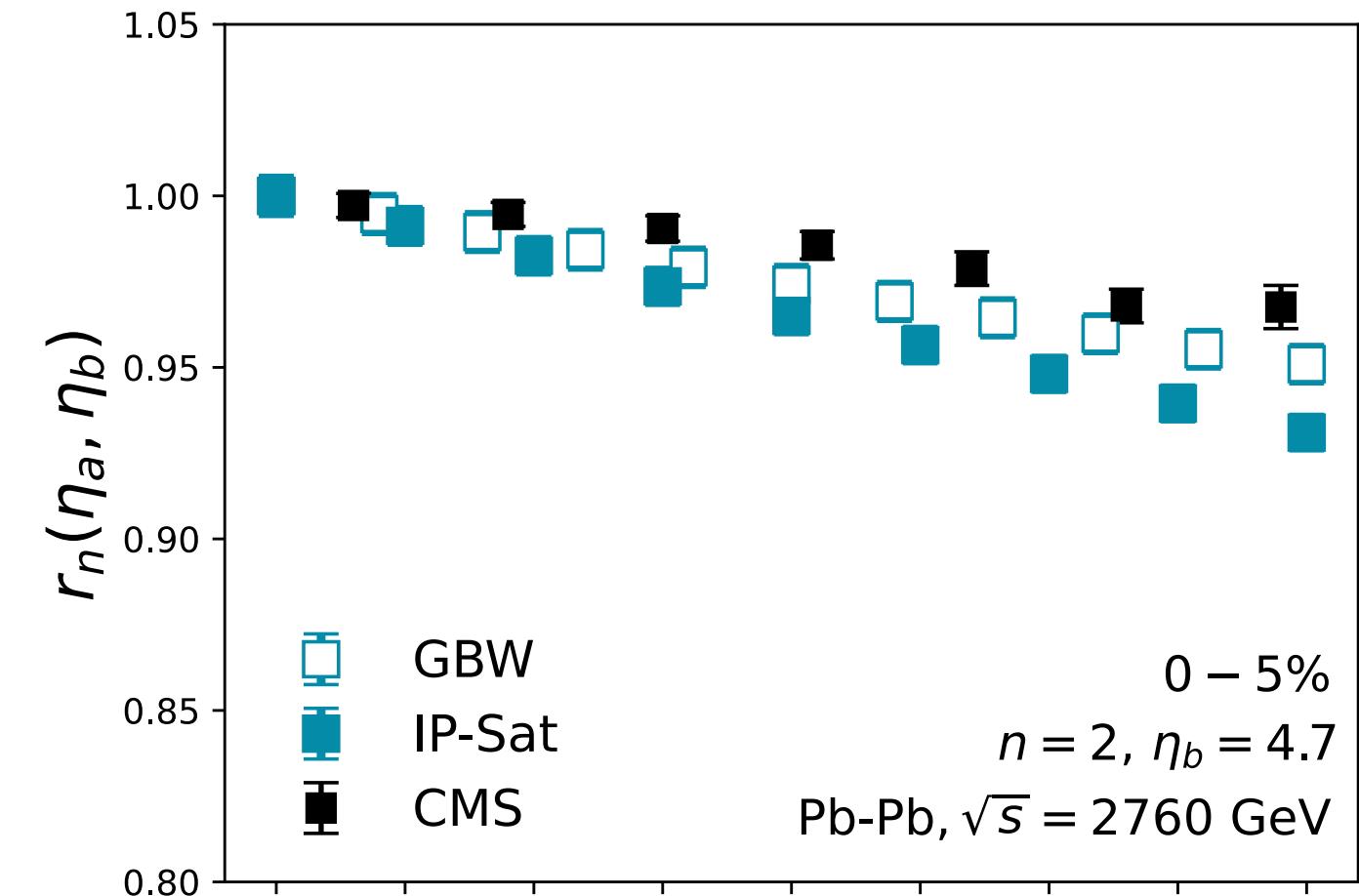
CHARGE DEPOSITION

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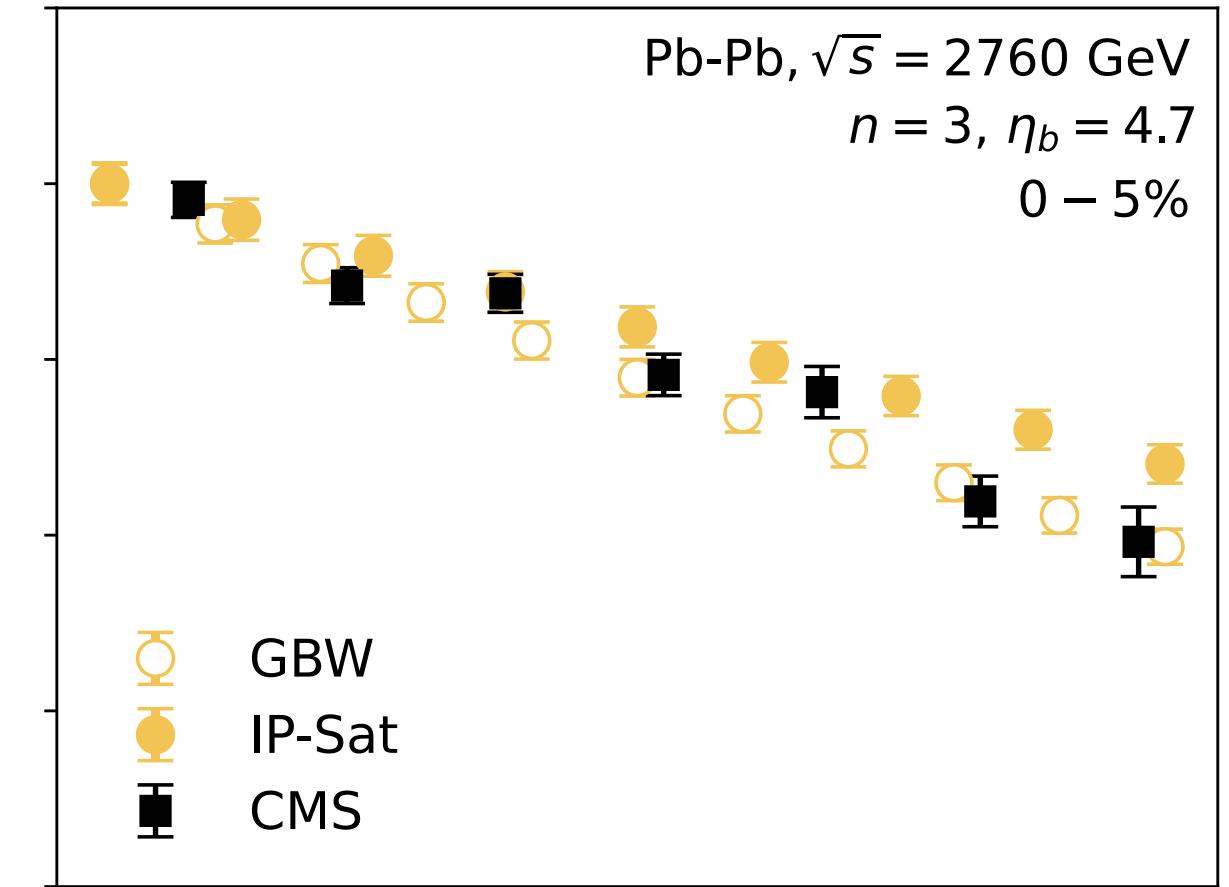


LONGITUDINAL CORRELATIONS

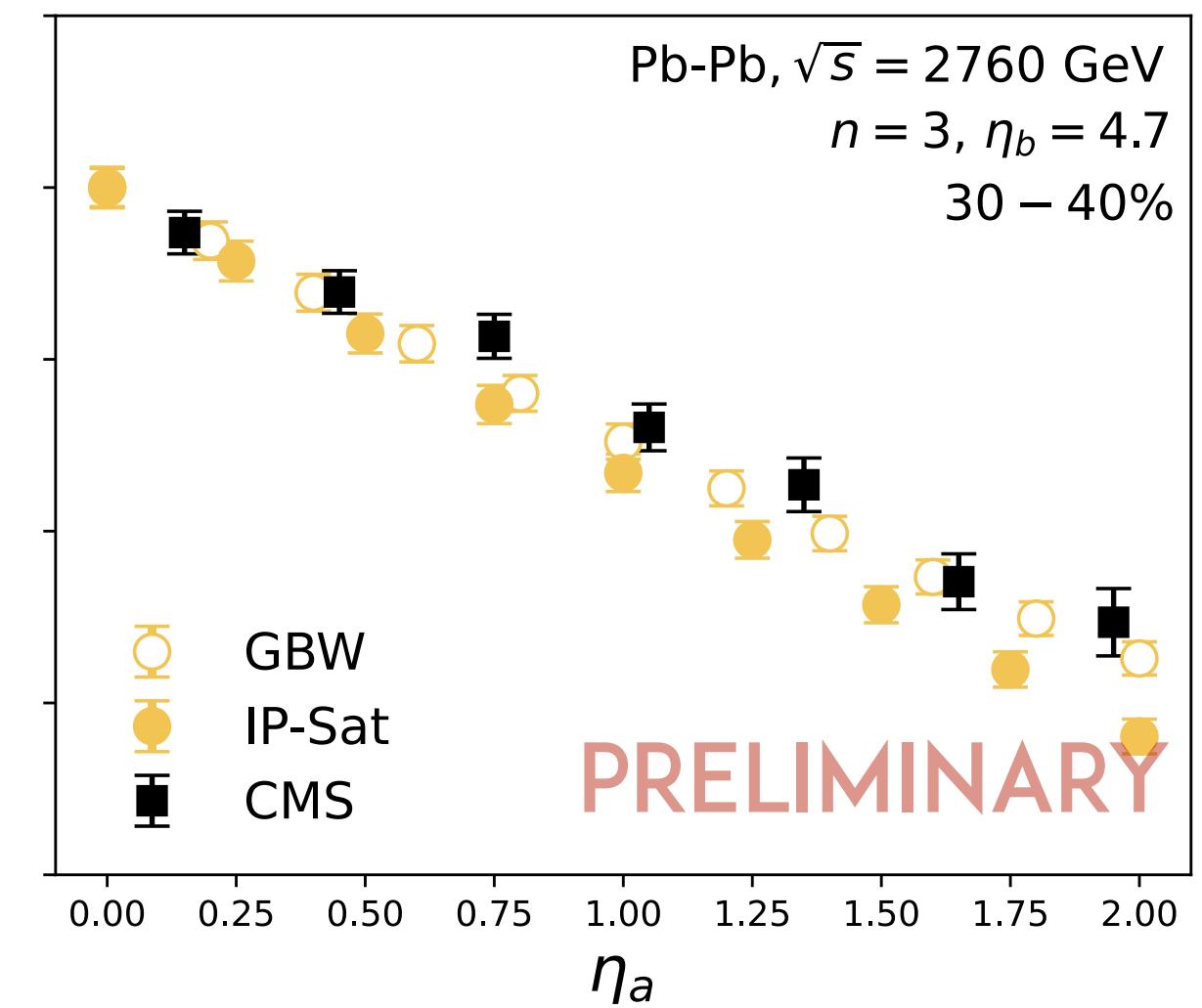
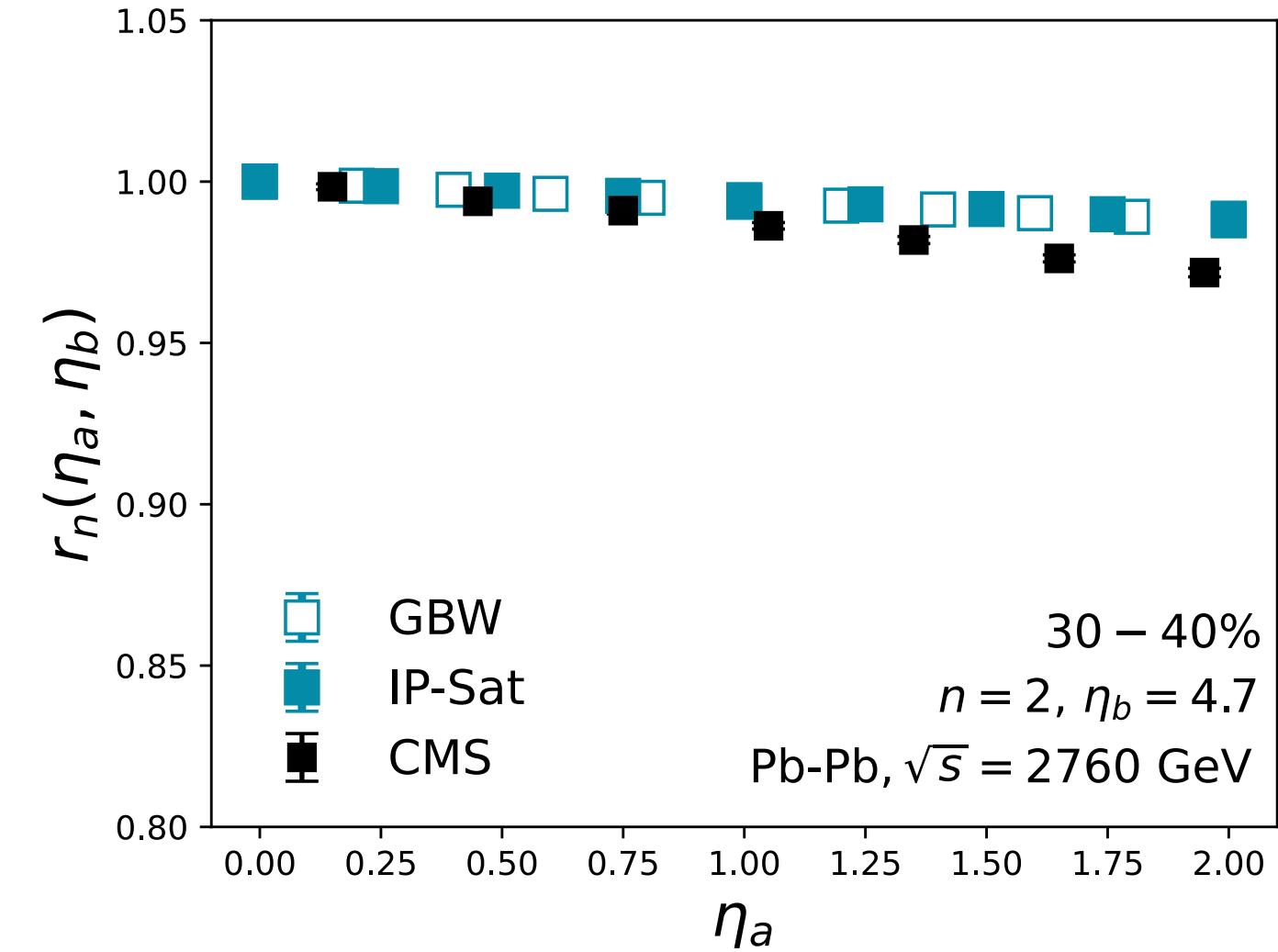
Decorrelation due to non-trivial x-dependence of uGDs and PDFs



[CMS data from *PRC* 92 (2015) 3, 034911]



Energy dependence (RHIC/LHC)
naturally reproduced within the
McDIPPER framework



SUMMARY + OUTLOOK



We have developed a **3D Initial state model** using the principles of High Energy QCD,
– for **all conserved charges** –



Only one free parameter. Rest is fixed by other experiments.

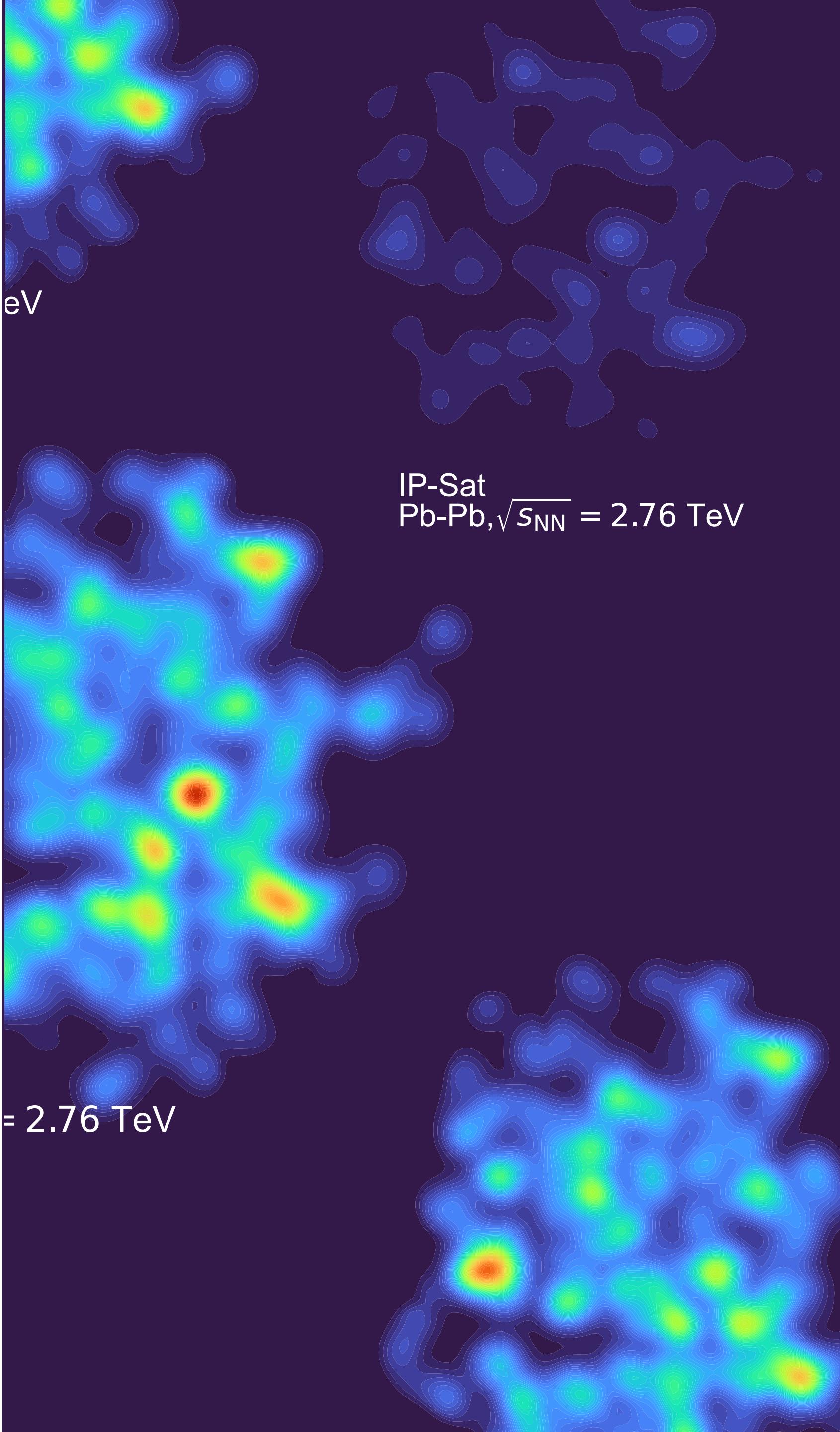


Systematically improvable: Fluctuations, extensions to lower energies....

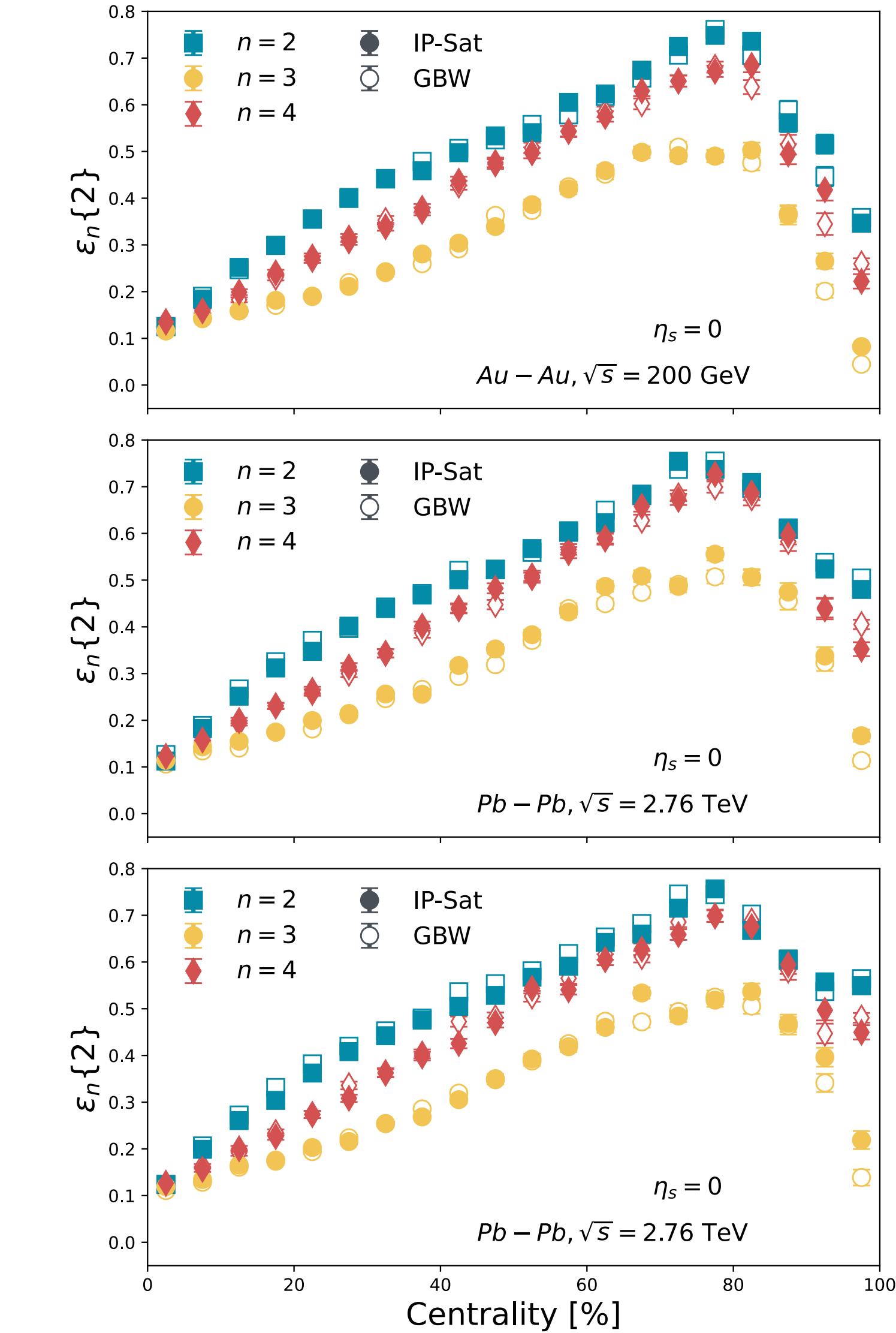
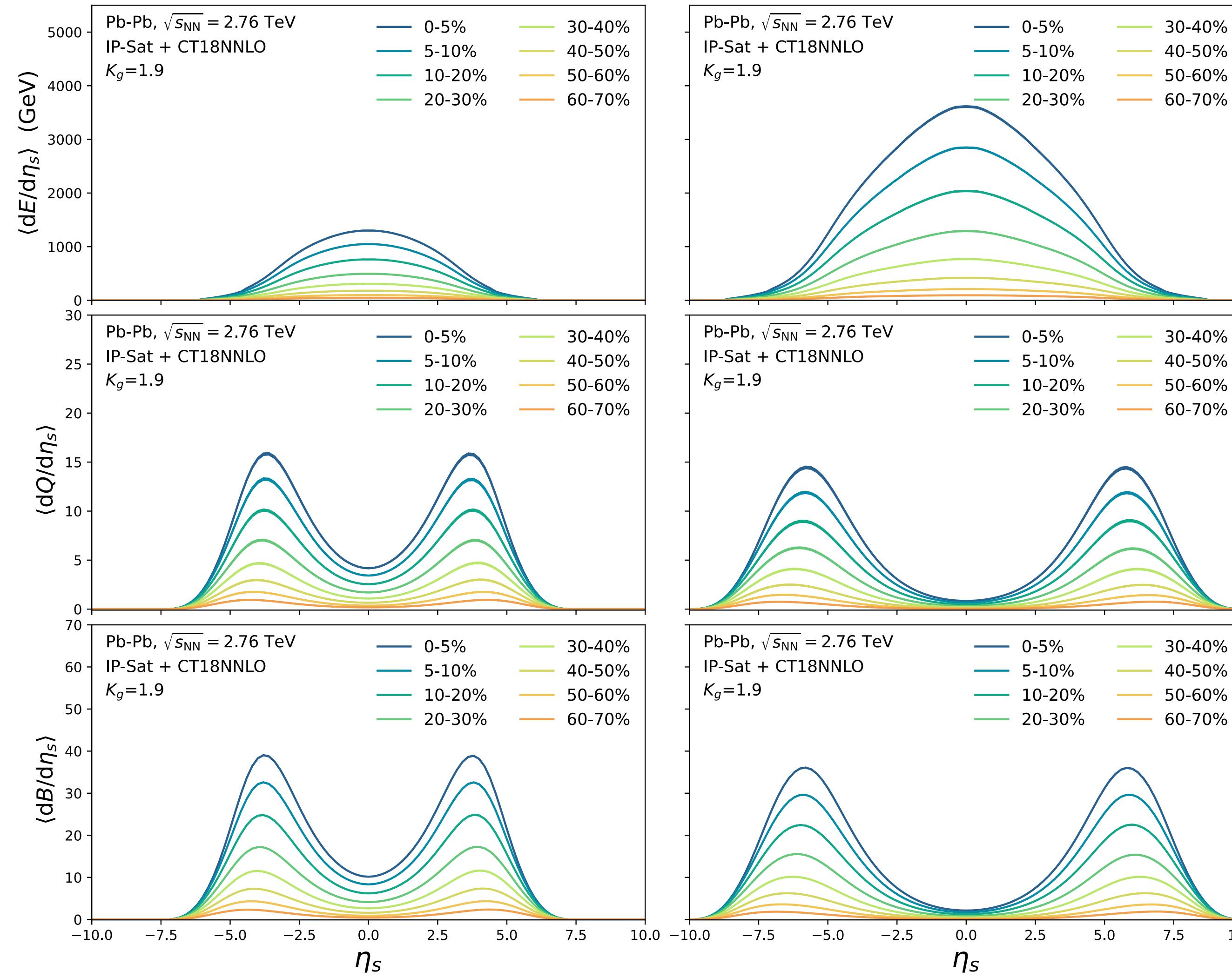


Future plans: use it as analysis suite for saturation physics.
Comprehensive comparisons across models.

CUT FOR TIME:
**BACKUP
SLIDES**



YIELDS AND ECCENTRICITIES



LONGITUDINAL CORRELATIONS

