THE McDIPPER

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

Based on 2308.11713

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CRC-TR 211
Strong-interaction matter under extreme conditions

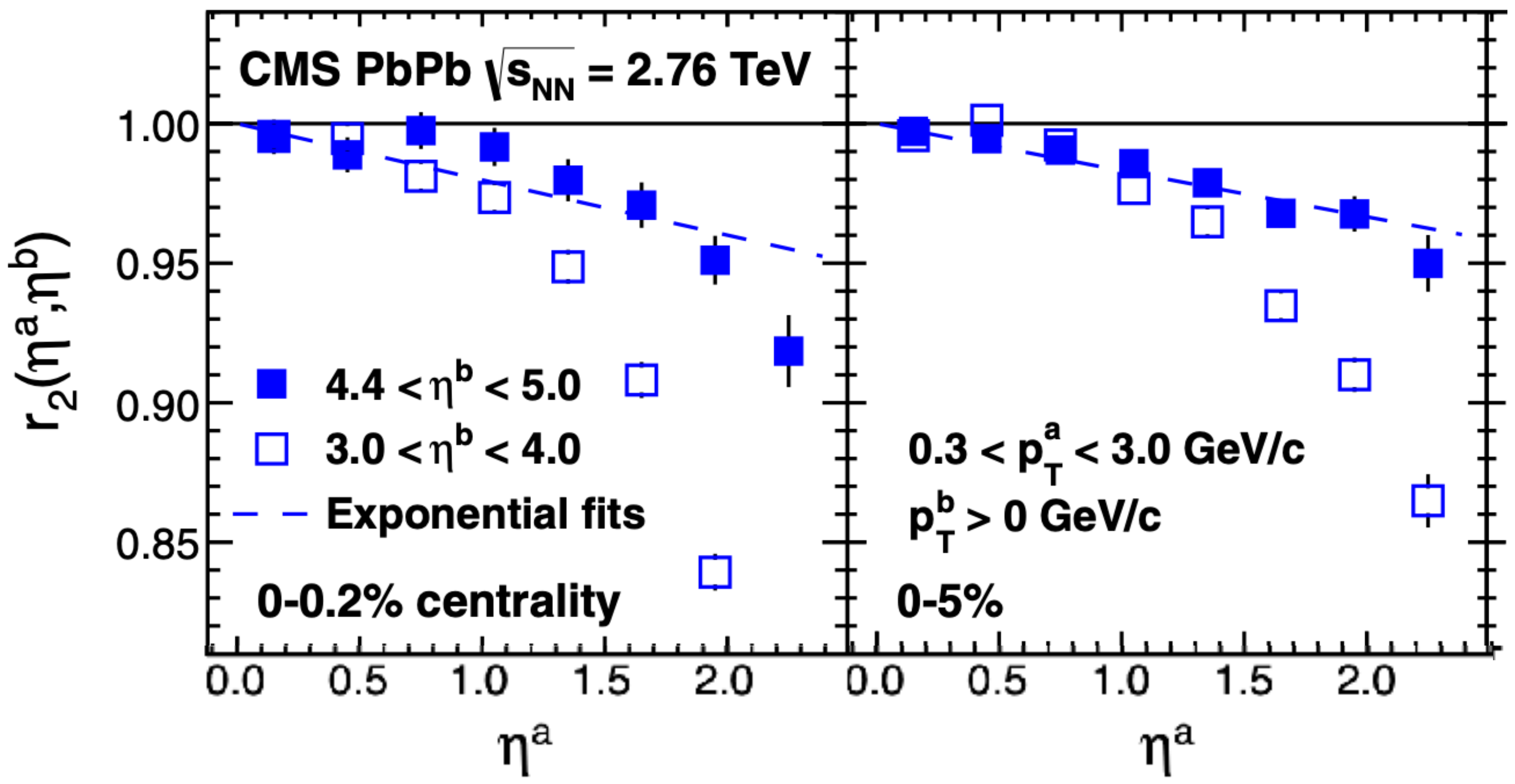
UNIVERSITÄT BIELEFELD

FSP ALICE
Erforschung von Universum und Materie

MOTIVATION

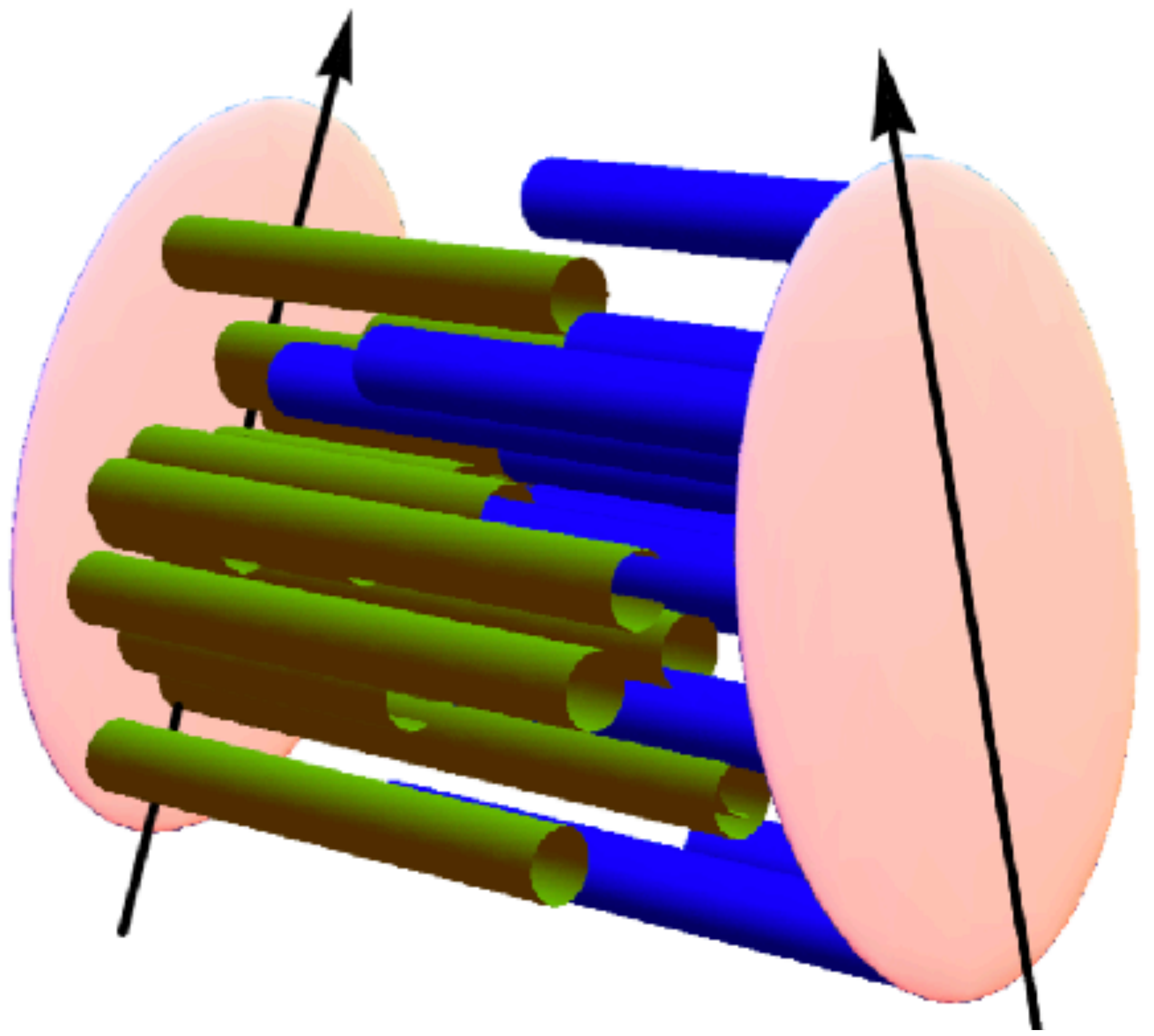
- New experimental and theoretical insights towards the forward/backward rapidity window
  - Long. Correlations (multiplicity and geometry)

[*Phys.Rev.C* 92 (2015) 3, 034911]



- 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]

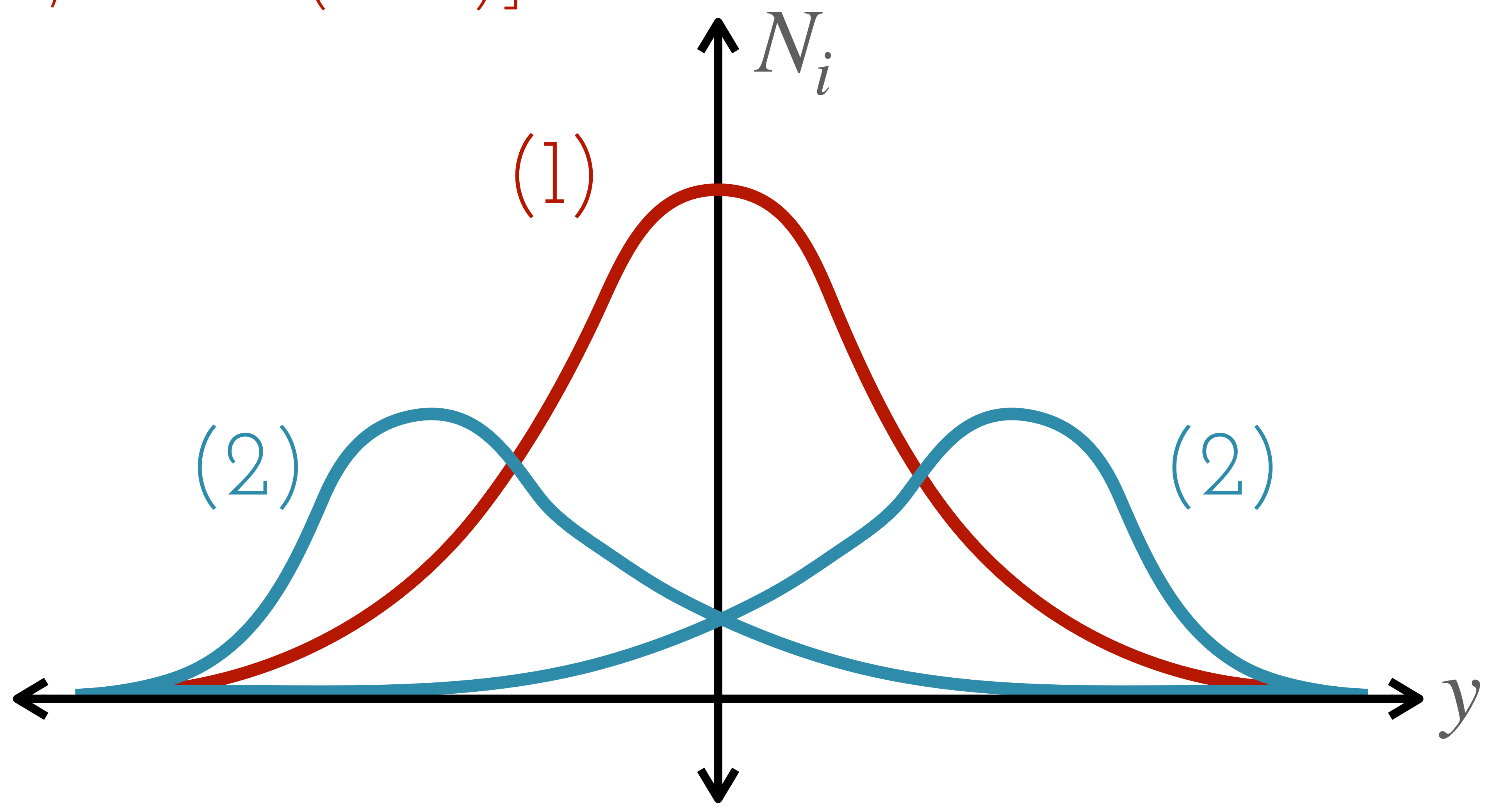


- Needed: A first-principles inspired framework to compute and compare Event-by-Event ICs in Heavy Ion Collisions

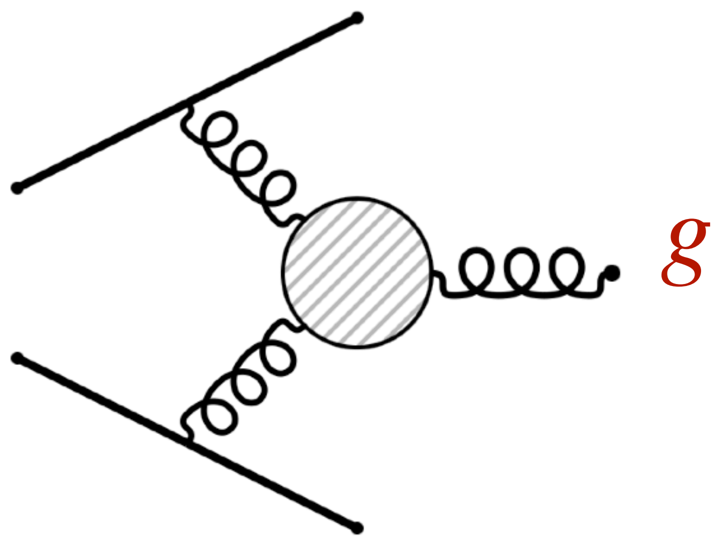
THE INITIAL STATE OF A HIC

- Energy deposition in high-energy collisions dominated by small-x gluons
  - MC-KLN, IP-Glasma...

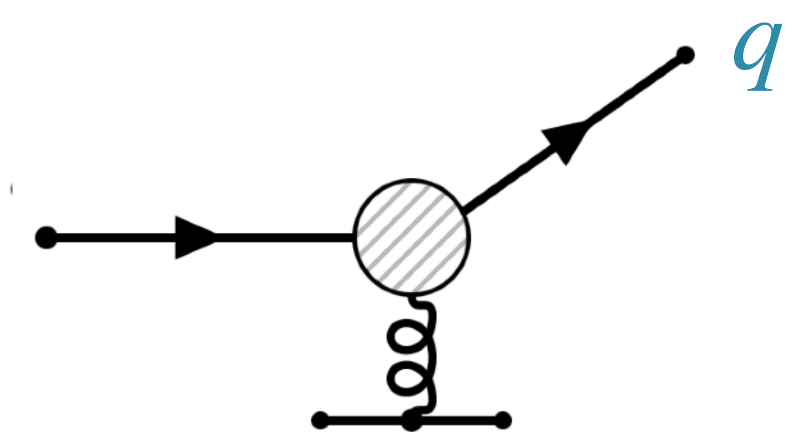
[PRC 76, 041903 (2007)]
[PRC 94,no.4,044907(2016)]



- 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:

(1) 

Single Gluon Production

(2) 

Baryon Stopping

THE McDIPPER

Monte-Carlo Dipole Parallel Event GeneRator

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

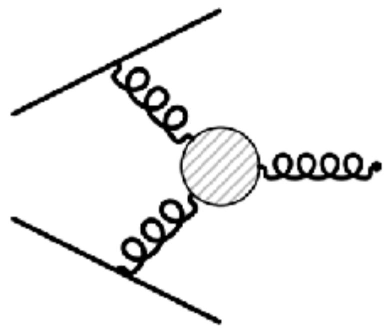
HOW DOES IT WORK?

- 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

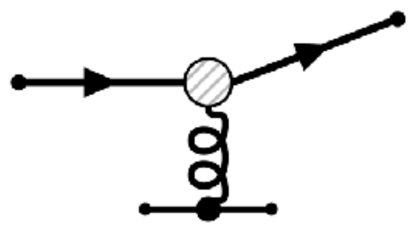
- Low-x gluons dominate the midrapidity region

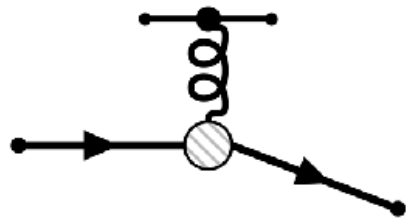
$$\frac{dN_g}{d^2\mathbf{x}d^2\boldsymbol{p}dy} = \frac{g^2}{8\pi^5 C_F\, \boldsymbol{p}^2}\int \frac{d^2\boldsymbol{q}}{(2\pi)^2}\frac{d^2\boldsymbol{k}}{(2\pi)^2}(2\pi)^2\delta(\boldsymbol{p}+\boldsymbol{q}-\boldsymbol{p}) \times \Phi_1(x_1,\boldsymbol{x},\boldsymbol{q})\ \Phi_2(x_2,\boldsymbol{x},\boldsymbol{k})$$



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

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





THE INPUT

Low-x gluons

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

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

- 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

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

FROM MICRO TO MACRO

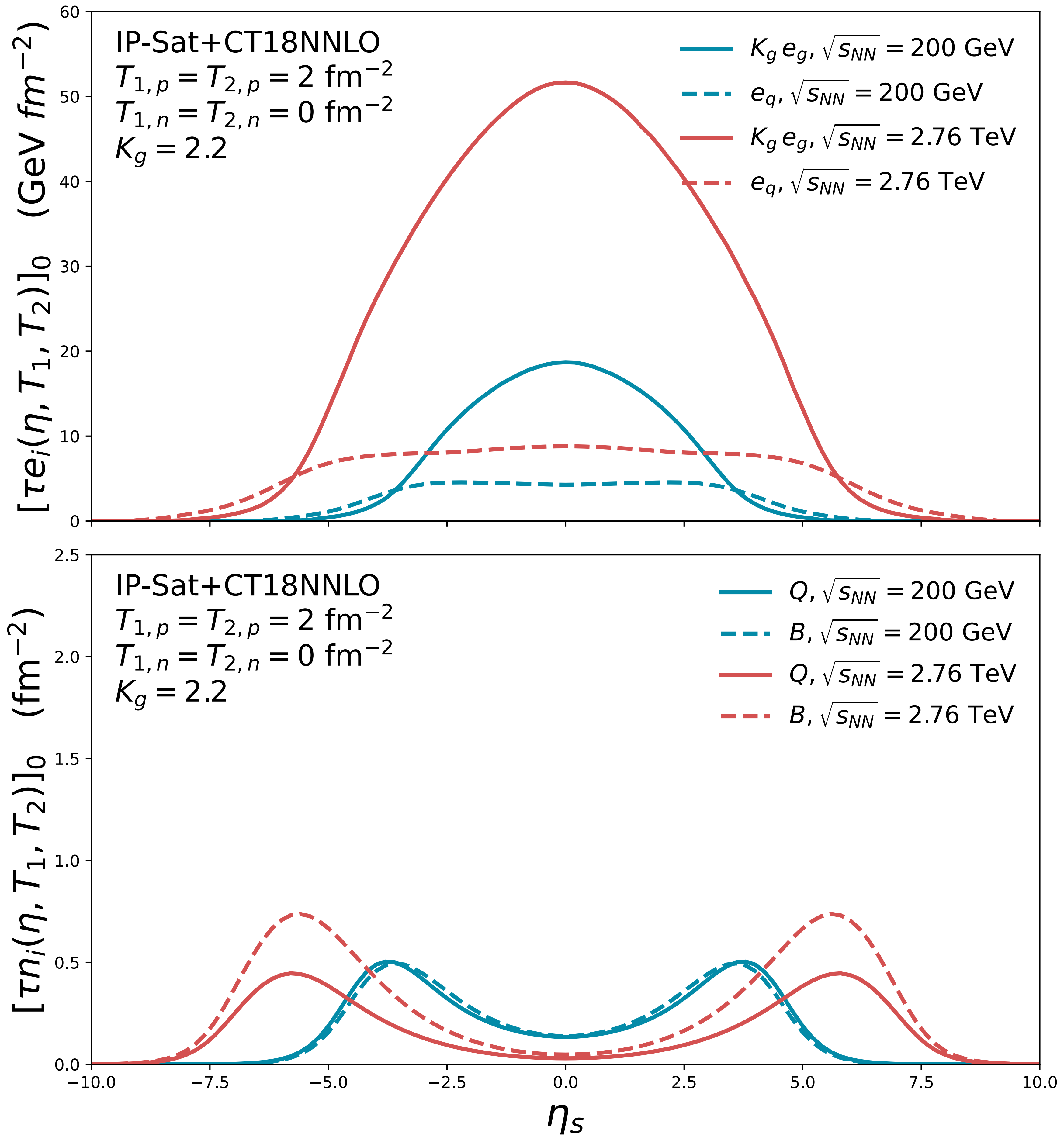
- Macroscopic quantities (energy, charges) are computed as moments of the single particle distributions
  - Total energy deposition

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

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

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

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



TUNING

FIXING THE K-FACTOR

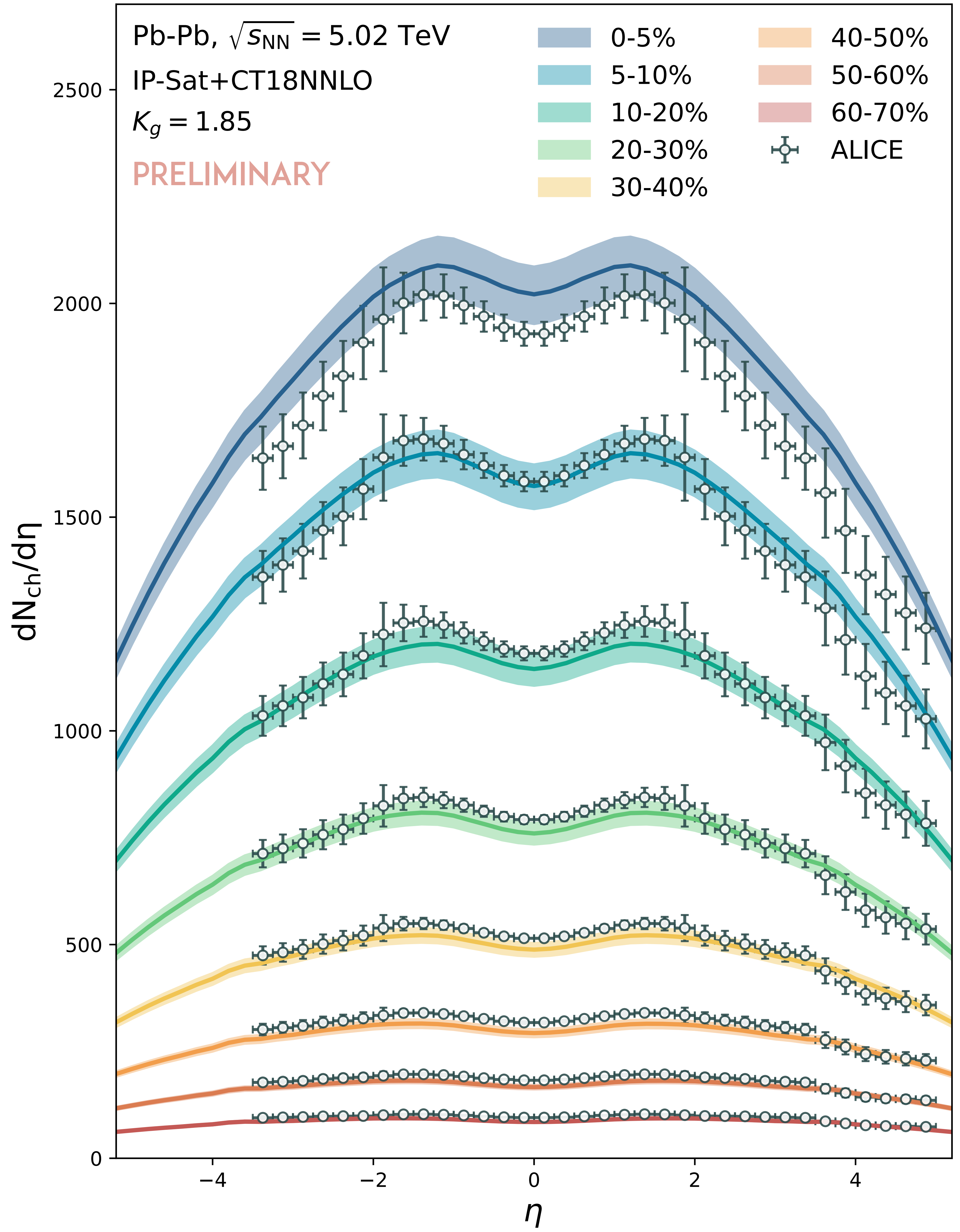
- Input model parameters can be fixed by other experiments e.g. DIS (e+p)
- Overall normalisation of $(e_g\tau)_0$ treated as a free parameter, K_g, to account for perturbative corrections
- Tune K_g using $E_\perp$ in pp min. bias collisions at $\sqrt{s_{NN}} = 5.02\,\mathrm{TeV}$

$K_g = 1.25$ {GBW} $\quad$ $K_g = 1.85$ {IP-Sat}

- Multiplicity can be then estimated using

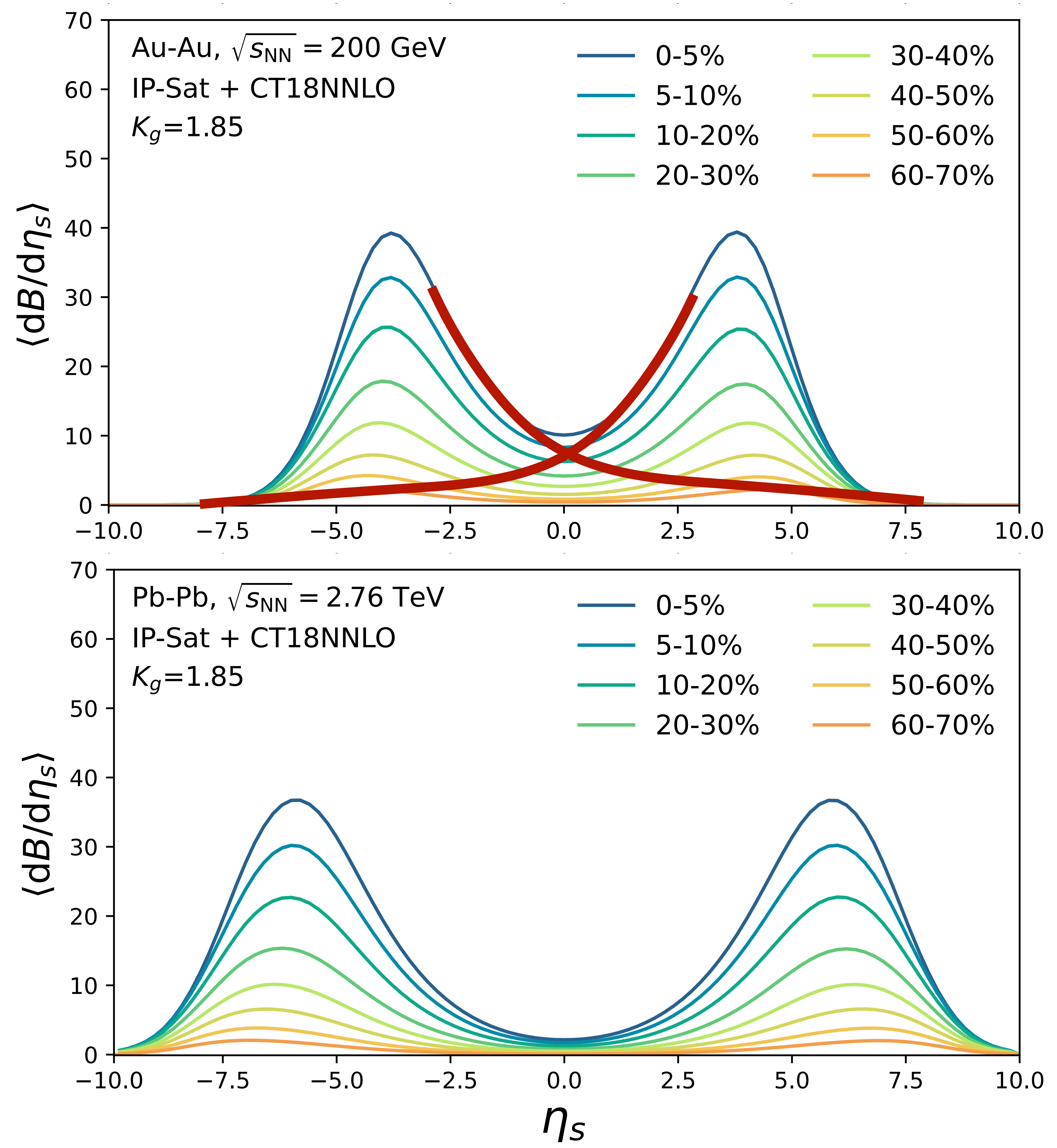
$$\left\langle \frac{dN_{ch}}{dy} \right\rangle = \frac{4}{3}\frac{N_{ch}}{S} C_\infty^{3/4} \left(4\pi \frac{\eta}{s}\right)^{1/3} \left(\frac{\pi^2}{30}\nu_{\mathrm{eff}}\right)^{1/3} \int d^2\mathbf{x} \left[\tau e(y,\mathbf{x})\right]_0^{2/3}$$

[PRL. 123, 262301]



CHARGE DEPOSITION

- Non-trivial interaction between x-dependence of gluon uGDs and quark PDFs gives tails in the charge deposition
- Even at higher rapidities, non-zero baryon stopping is found!



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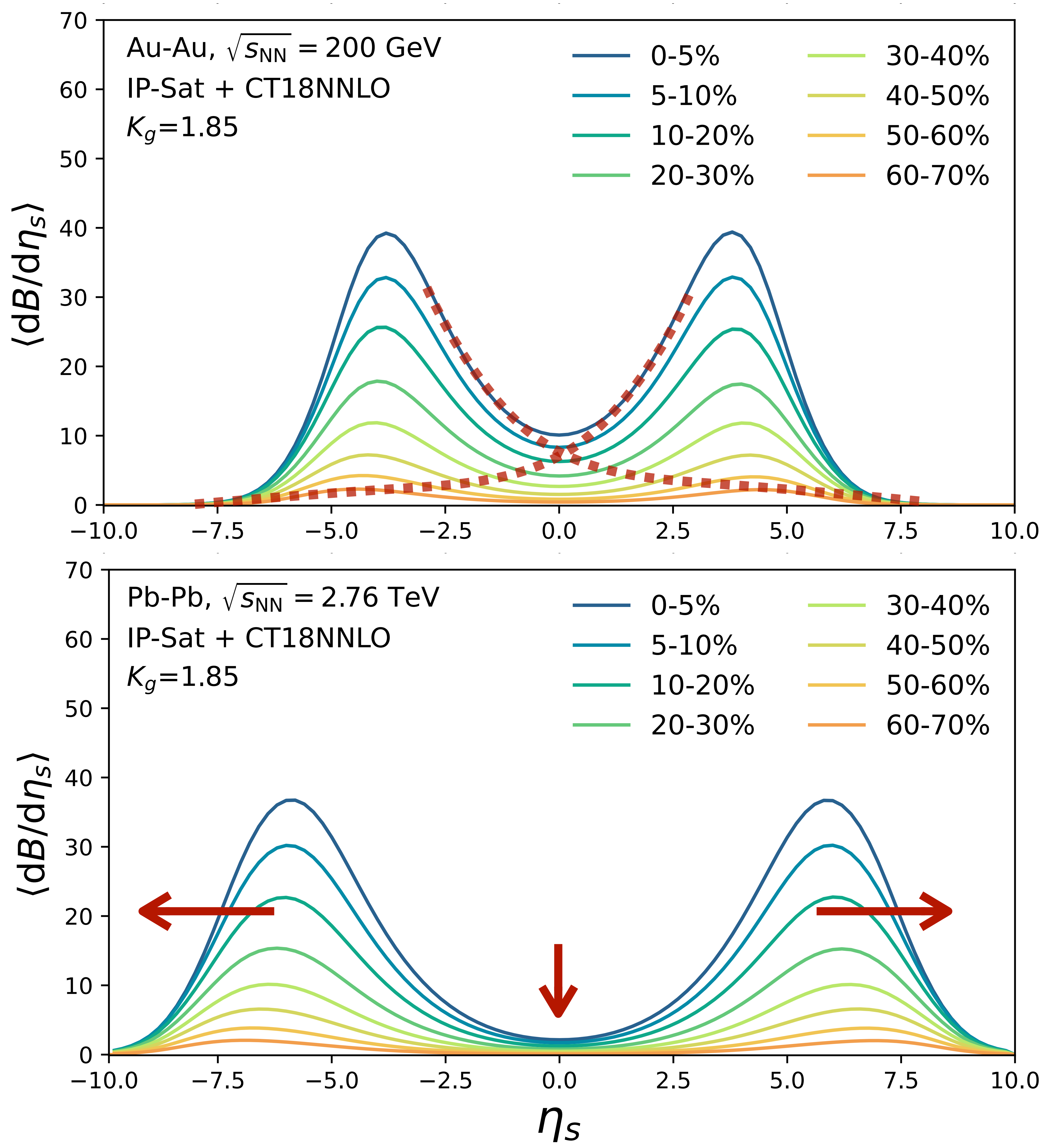
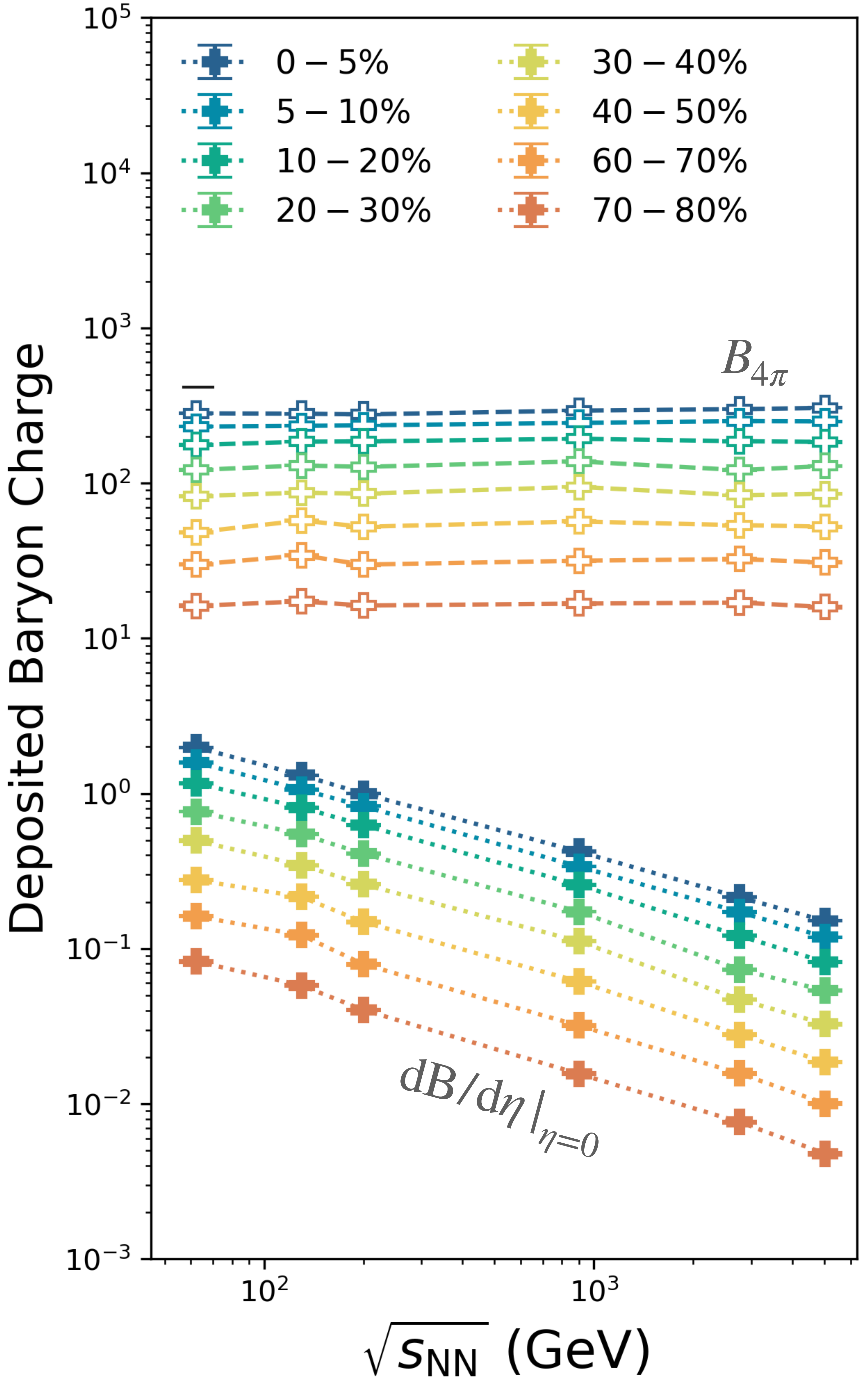


CHARGE DEPOSITION

- Non-trivial interaction between x-dependence of gluon uGDs and quark PDFs gives tails in the charge deposition
- Even at higher rapidities, non-zero baryon stopping is found!
- Midrapidity baryon charge deposition follows a power-law trend

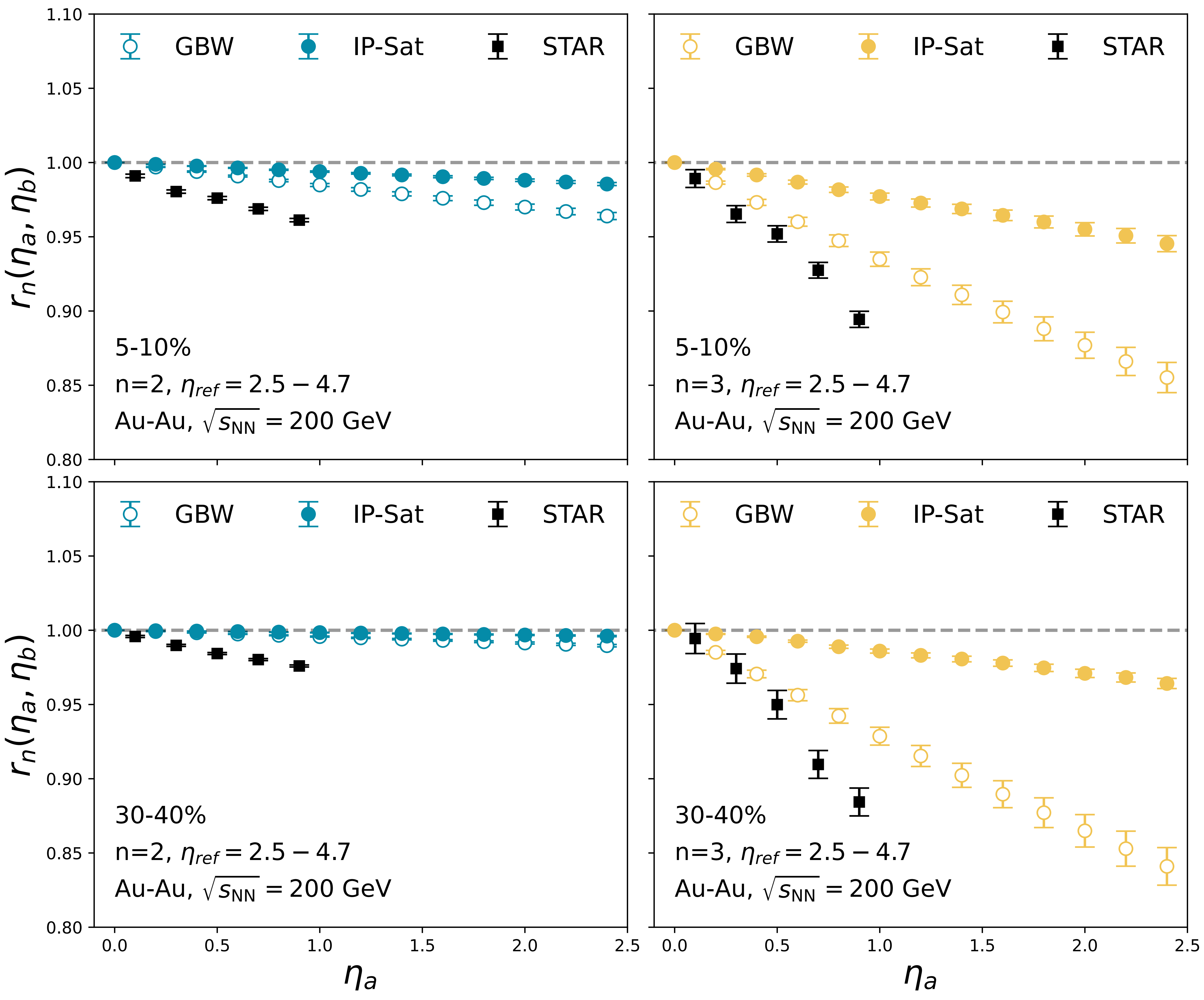
$$\left.\frac{\mathrm{dB}}{\mathrm{d}\eta}\right|_{\eta=0} \sim \left(\sqrt{s_{NN}}\right)^{\alpha}$$



LONGITUDINAL CORRELATIONS

- Decorrelation due to non-trivial *x*-dependence of uGHs and PDFs
- Additional fluctuations needed to explain flow decorrelation. Charge fluctuations in the valence sector?

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



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: explore phenomenology by
including into a 3+1D evolution hybrid model