Search for baryon junctions in heavy-ion and electron-ion collisions

Daniel Brandenburg, Nicole Lewis, Prithwish Tribedy, Zhangbu Xu

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High Energy Physics – Phenomenology

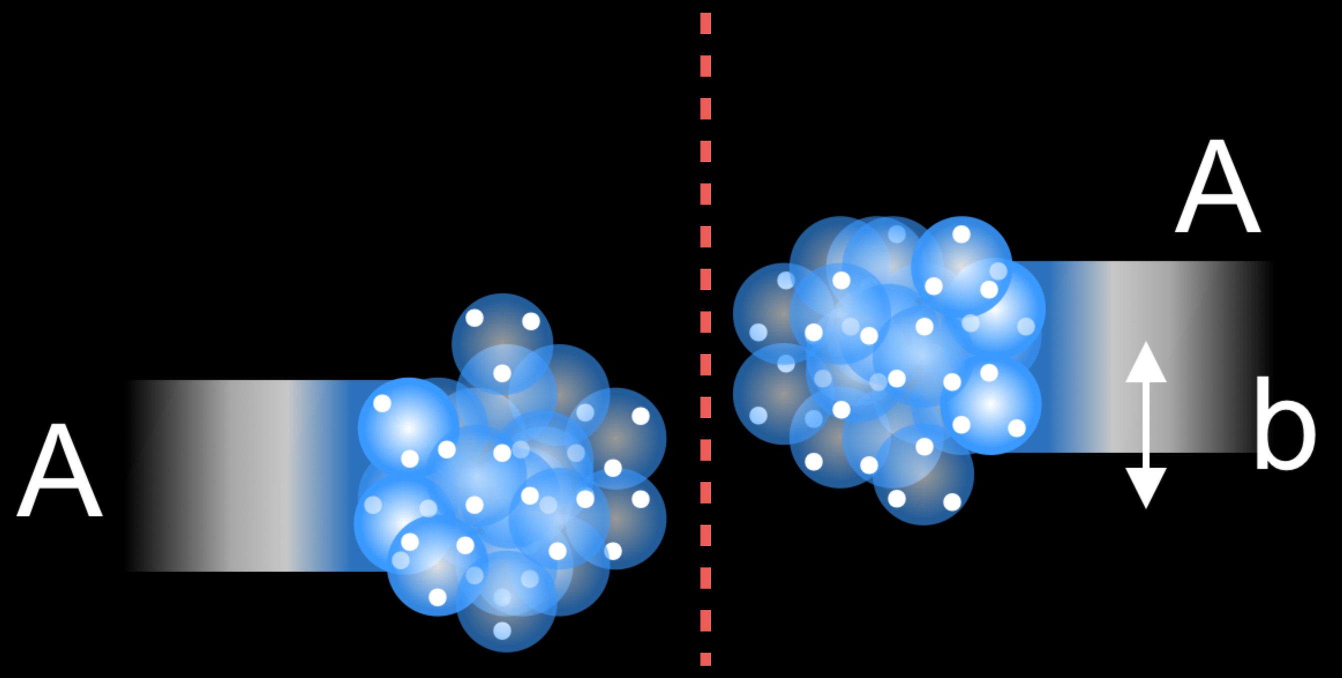
[Submitted on 12 May 2022 (v1), last revised 13 May 2022 (this version, v2)]

Search for baryon junctions in photonuclear processes and isobar collisions at RHIC

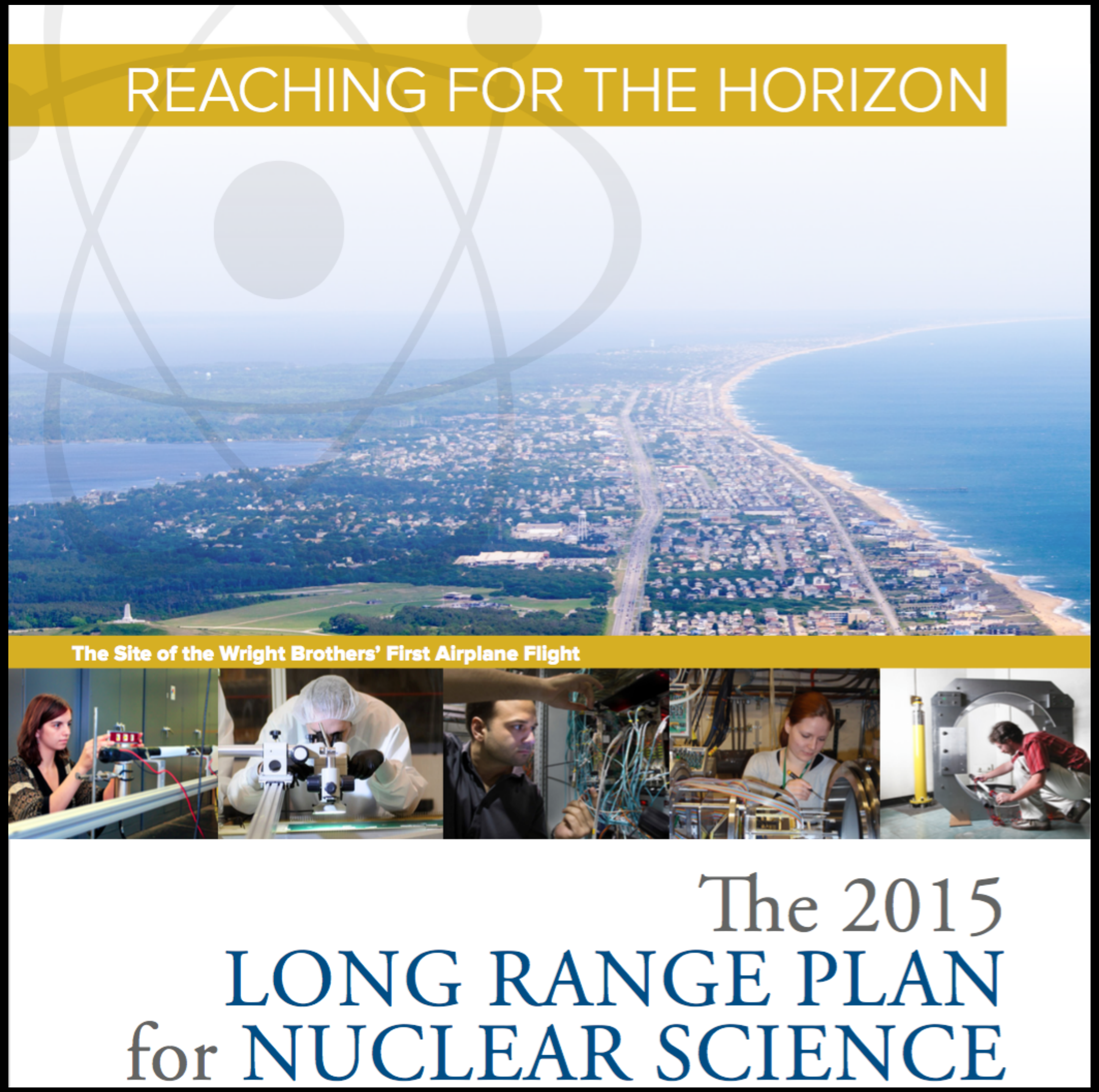
James Daniel Brandenburg, Nicole Lewis, Prithwish Tribedy, Zhangbu Xu

A puzzling feature of ultra-relativistic nucleus-nucleus collisions is the apparent substantial baryon excess in the midrapidity region. It was proposed that baryon number could be carried by a non-perturbative Y-shaped topology of gluon fields, called the baryon junction, rather than by the valence quarks. The stopping of baryon junctions is predicted to lead to a characteristic exponential distribution of net-baryon density with rapidity and could resolve the puzzle. In this context we point out that the rapidity density of net-baryons near midrapidity indeed follows an exponential distribution with a slope of -0.61 ± 0.03 as a function of beam rapidity in the existing global data from A+A collisions at AGS, SPS and RHIC energies. To further test if quarks or gluon junction carry the baryon quantum number, we propose to study the absolute magnitude of the baryon vs. charge stopping in isobar collisions at RHIC. We also argue that semi-inclusive photon-induced processes ($\gamma + p$/A) at RHIC kinematics provide an ideal opportunity to search for the signatures of the baryon junction and to shed light onto the mechanisms of observed baryon excess in the mid-rapidity region in ultra-relativistic nucleus-nucleus collisions. Such measurements can be further validated in $e + p$/A collisions at the EIC.

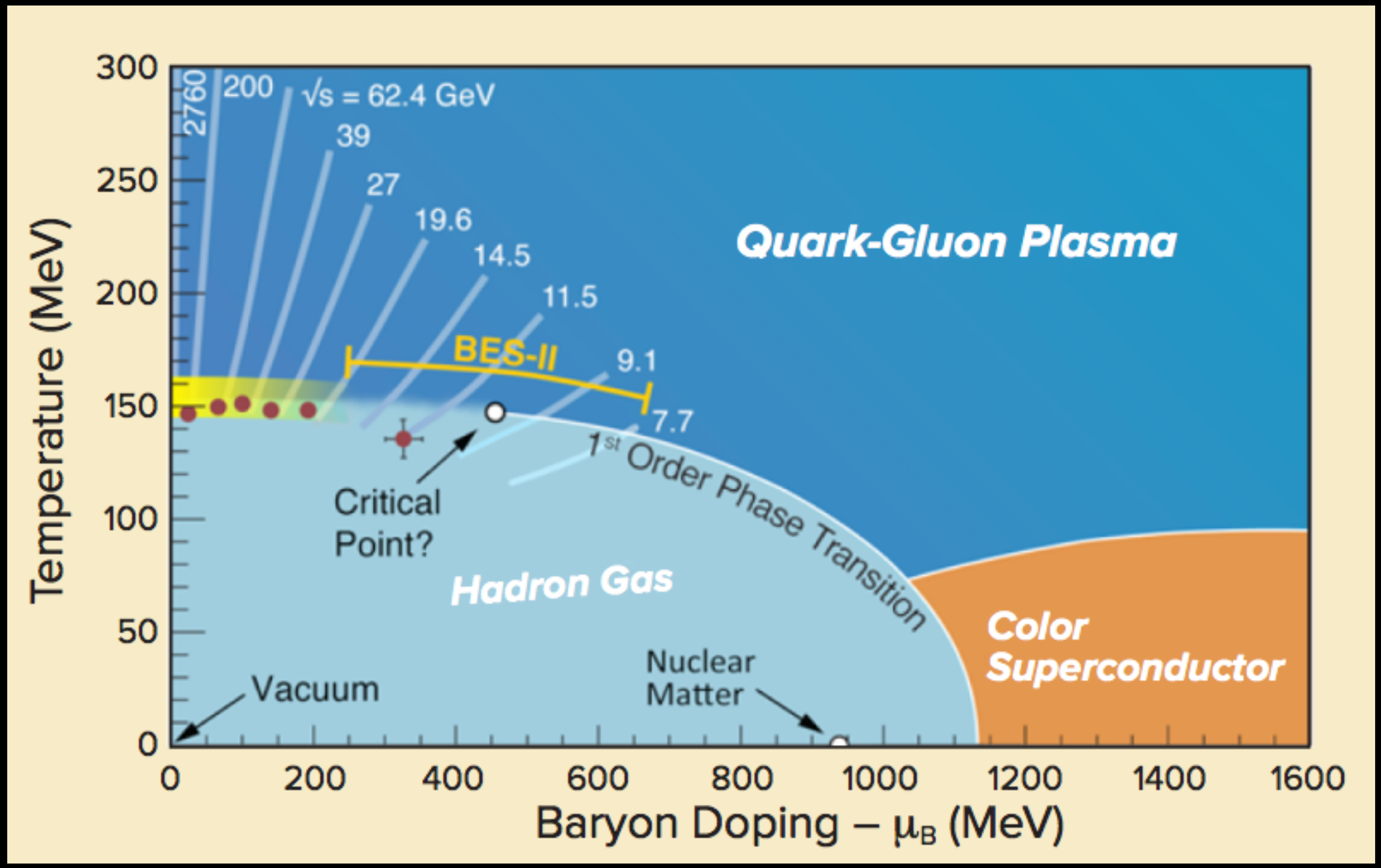
From the last NSAC LRP 2015

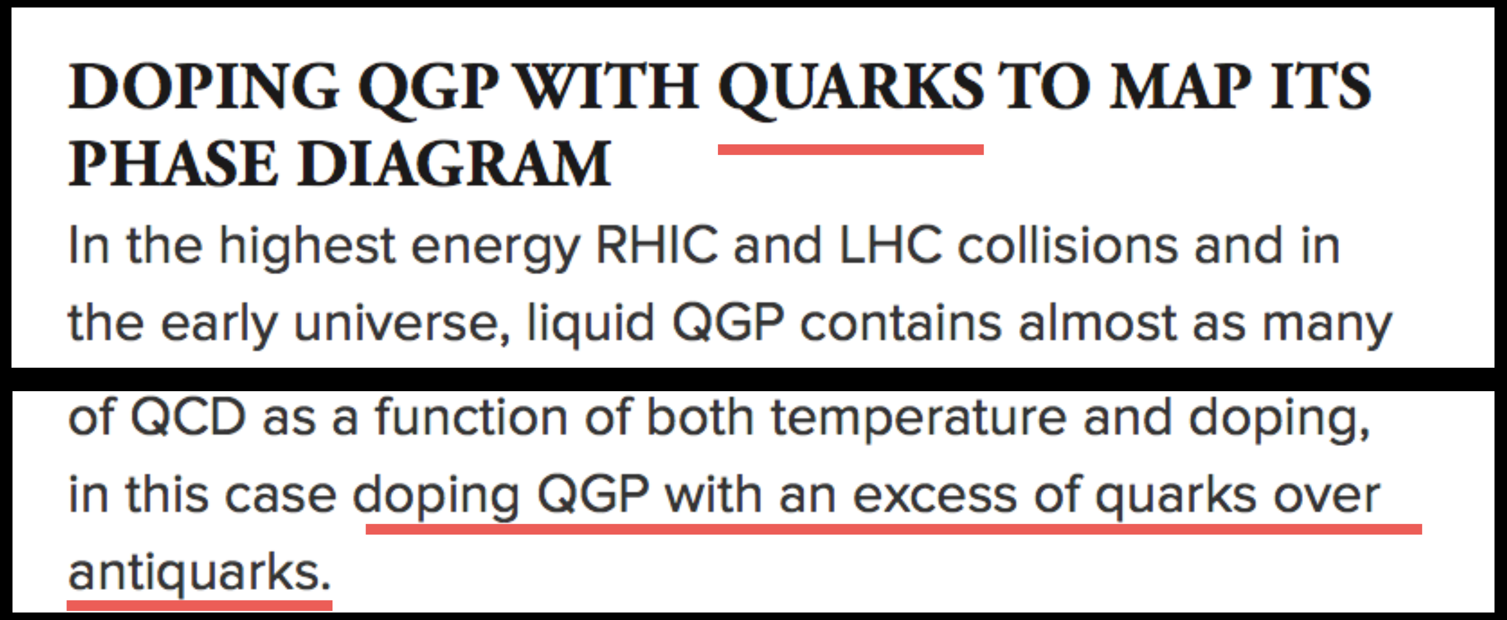


Excess baryon near central rapidity is a puzzle



A primary goal : map QCD phase diagram and discover the QCD critical point





DOPING QGP WITH QUARKS TO MAP ITS PHASE DIAGRAM

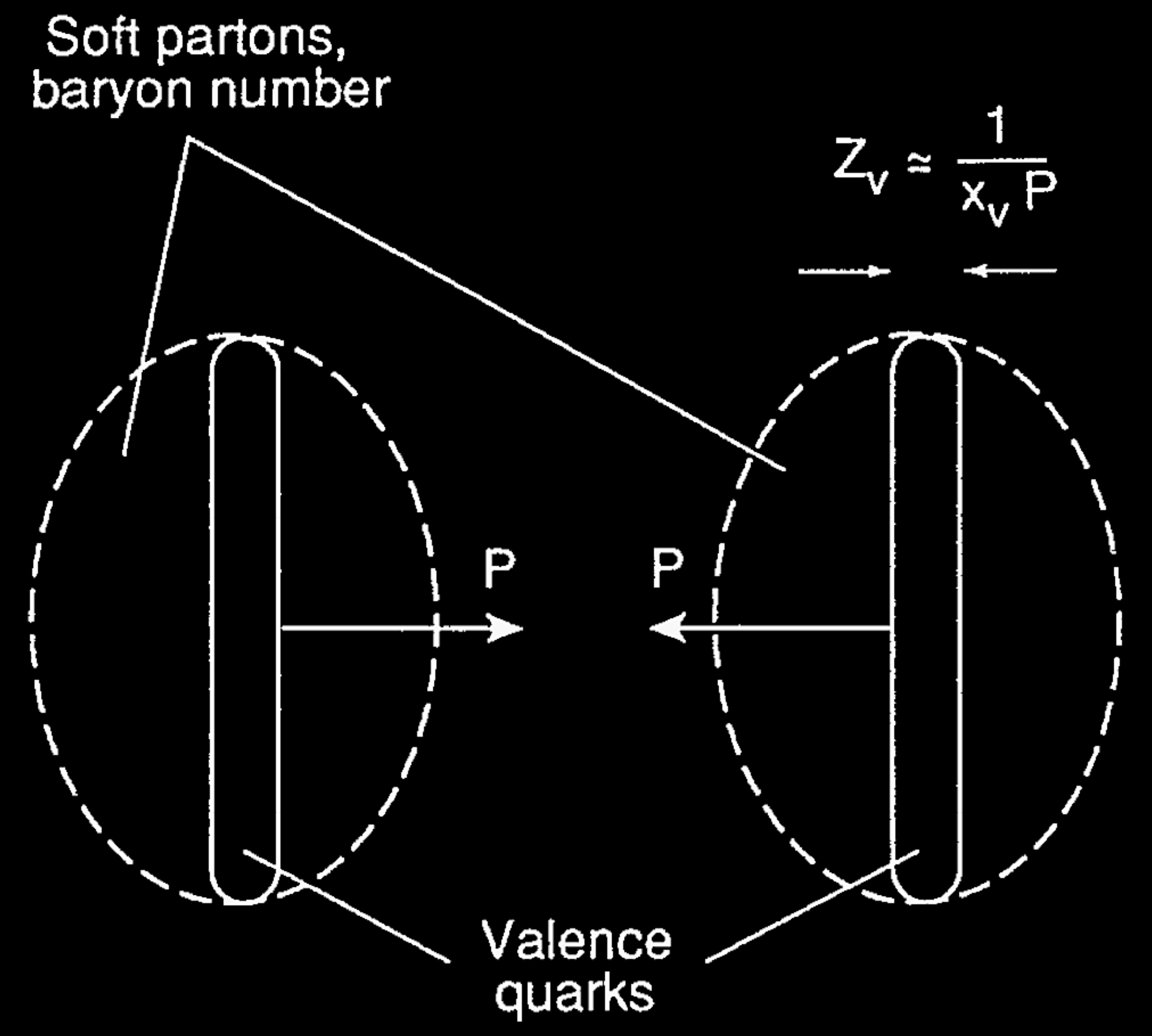
In the highest energy RHIC and LHC collisions and in the early universe, liquid QGP contains almost as many

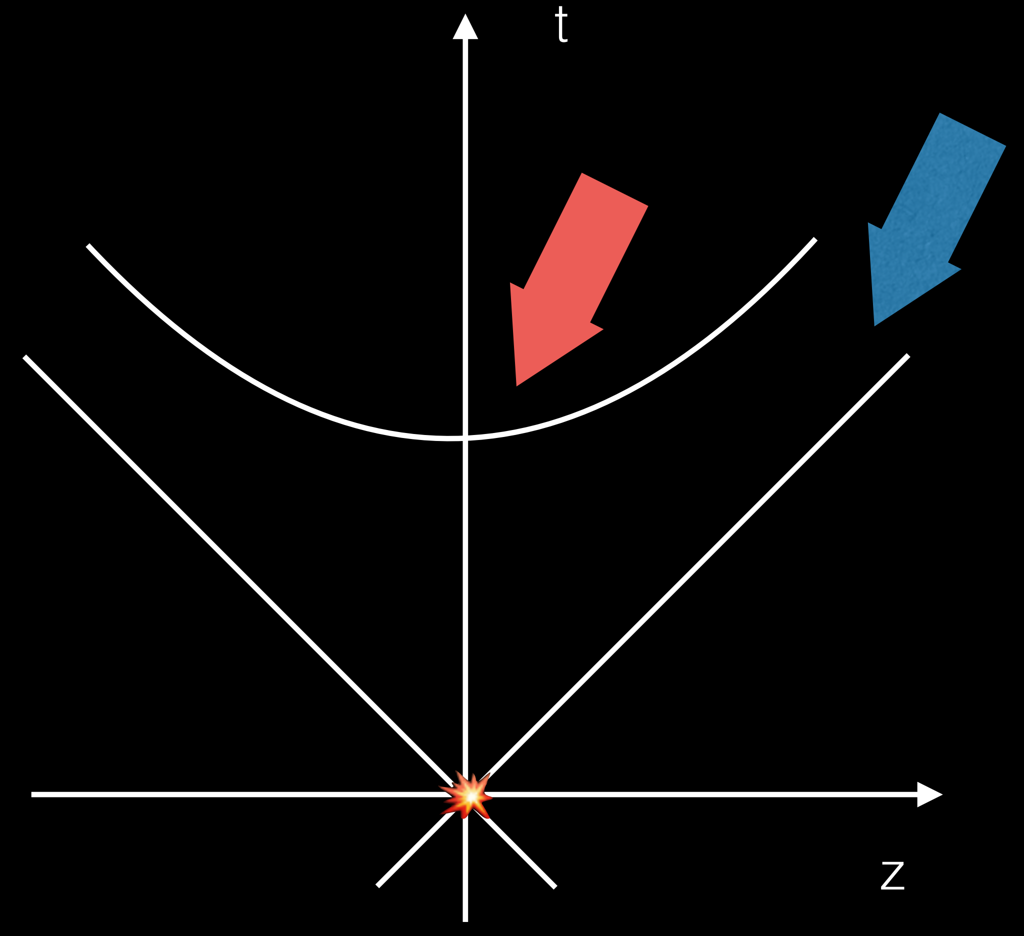
of QCD as a function of both temperature and doping, in this case doping QGP with an excess of quarks over antiquarks.

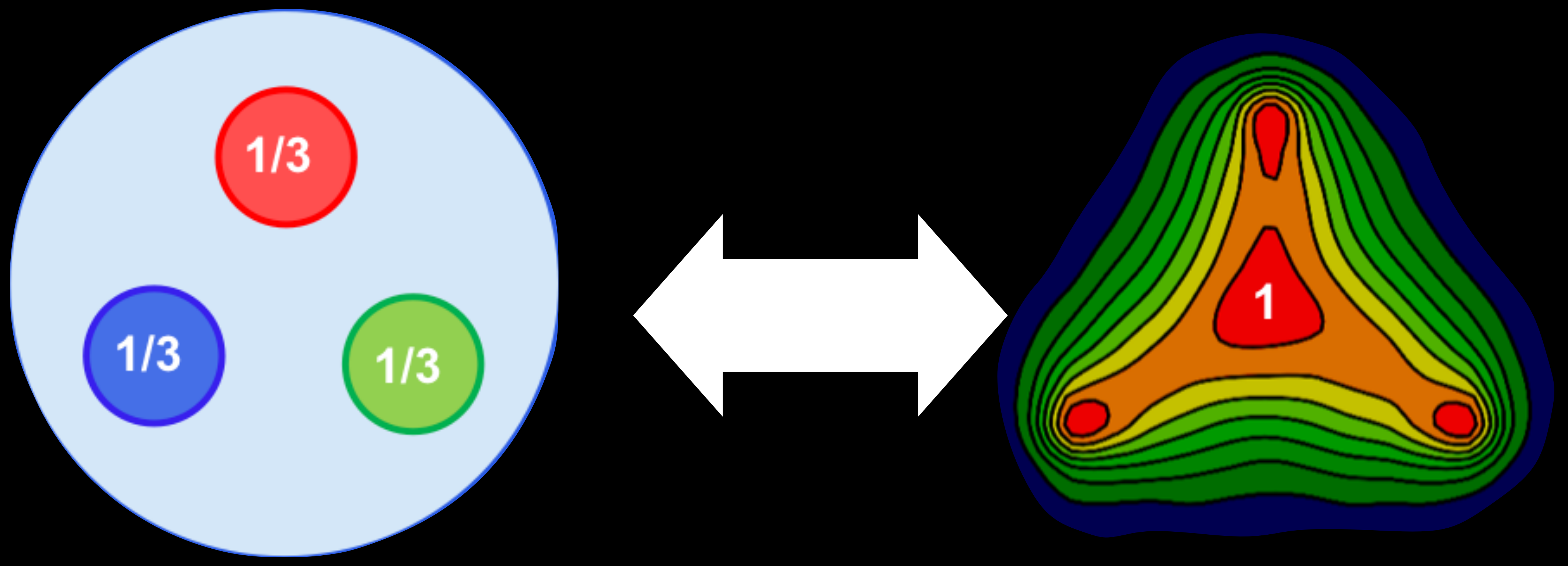
How the baryon doping happens in QGP at the microscopic level is not known

What carries the baryon number? How is it stopped ?

In the conventional picture valence quarks carry it but this has been never proven



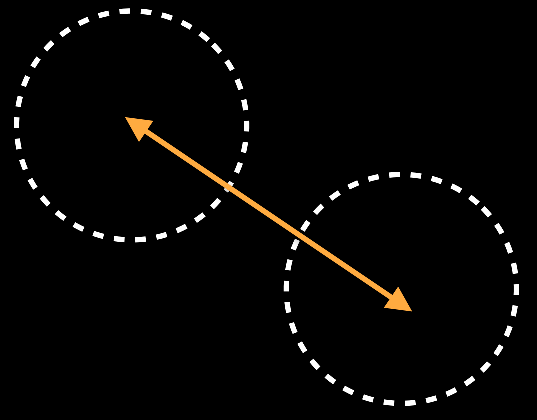




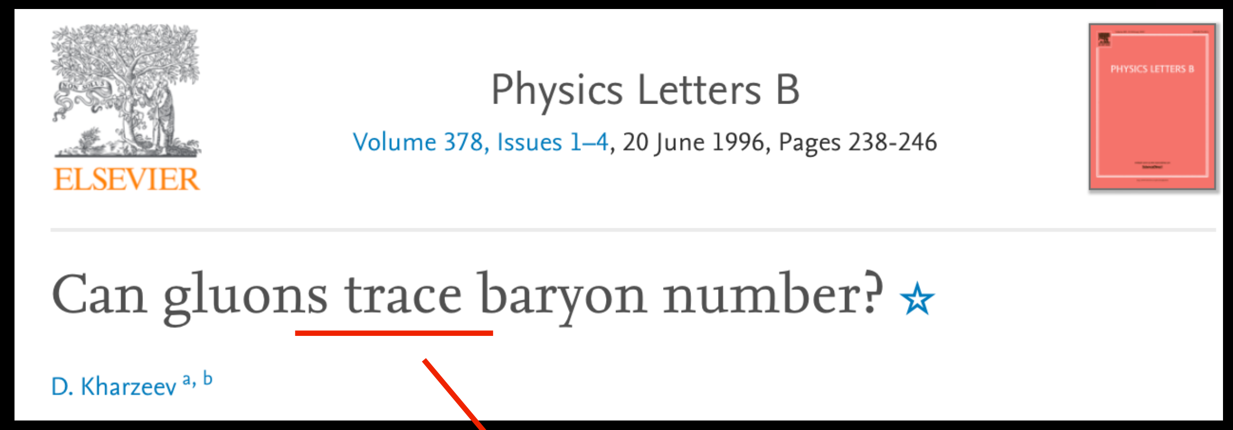
G.C. Rossi and G. Veneziano, Nucl. Phys.B123(1977) 507; Phys. Rep.63(1980) 149
Kharzeev, Phys. Lett. B, 378 (1996) 238-246

$$t_{\text{coll}} \sim (x_V P)^{-1} = (1/3 \times 100)^{-1}\ \text{GeV}^{-1} = 0.006\ \text{fm}$$

$$t_{\text{int}} \sim \mathcal{O}(1)\ \text{fm}$$



The time available for valence quarks is too short to be stopped in collisions



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Physics Letters B
Volume 378, Issues 1–4, 20 June 1996, Pages 238-246

Can gluons trace baryon number? ☆

D. Kharzeev [a, b]

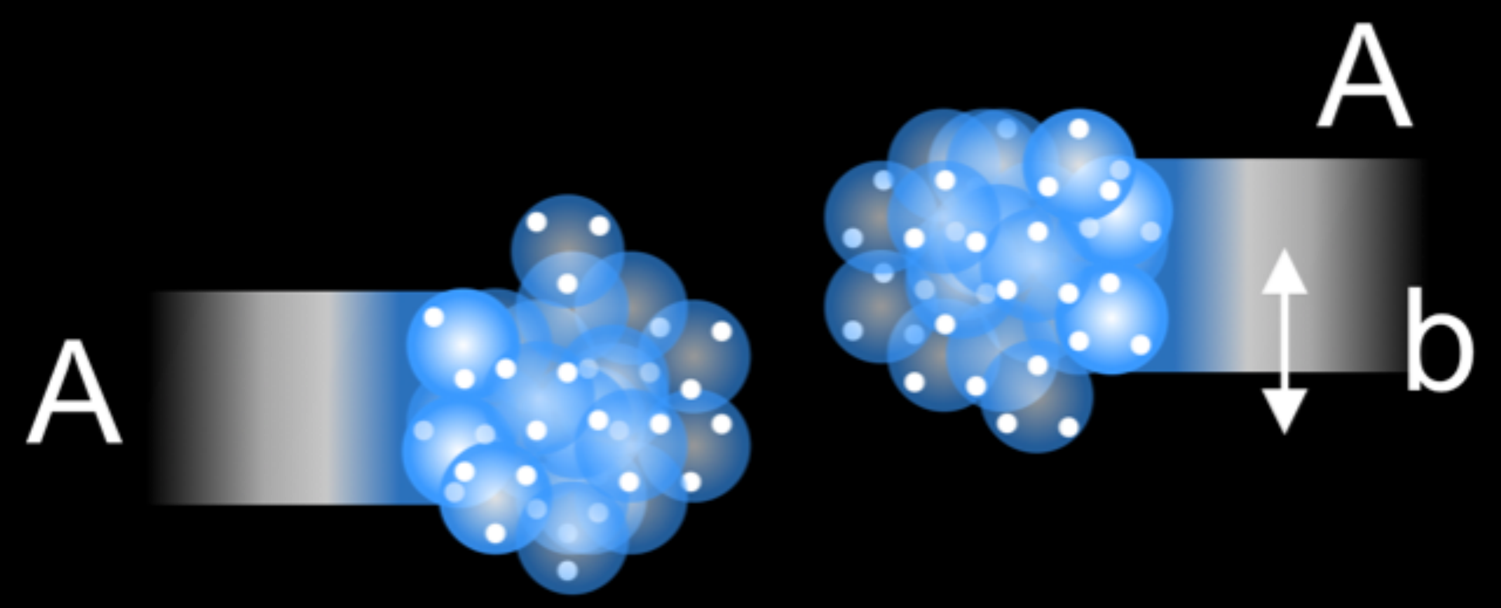
carry

$$B = \epsilon^{ijk}\left[P\exp\left(ig\int_{x_1}^{x} A_\mu dx^\mu\right)q(x_1)\right]_i \times \left[P\exp\left(ig\int_{x_2}^{x} A_\mu dx^\mu\right)q(x_2)\right]_j \times \left[P\exp\left(ig\int_{x_3}^{x} A_\mu dx^\mu\right)q(x_3)\right]_k$$

Isobars collisions: most controlled HIC systems

Brandenburg, Lewis, Tribedy, Xu, arXiv:2205.05685

Scenario 1: Valence quarks carry electric charge & baryon number

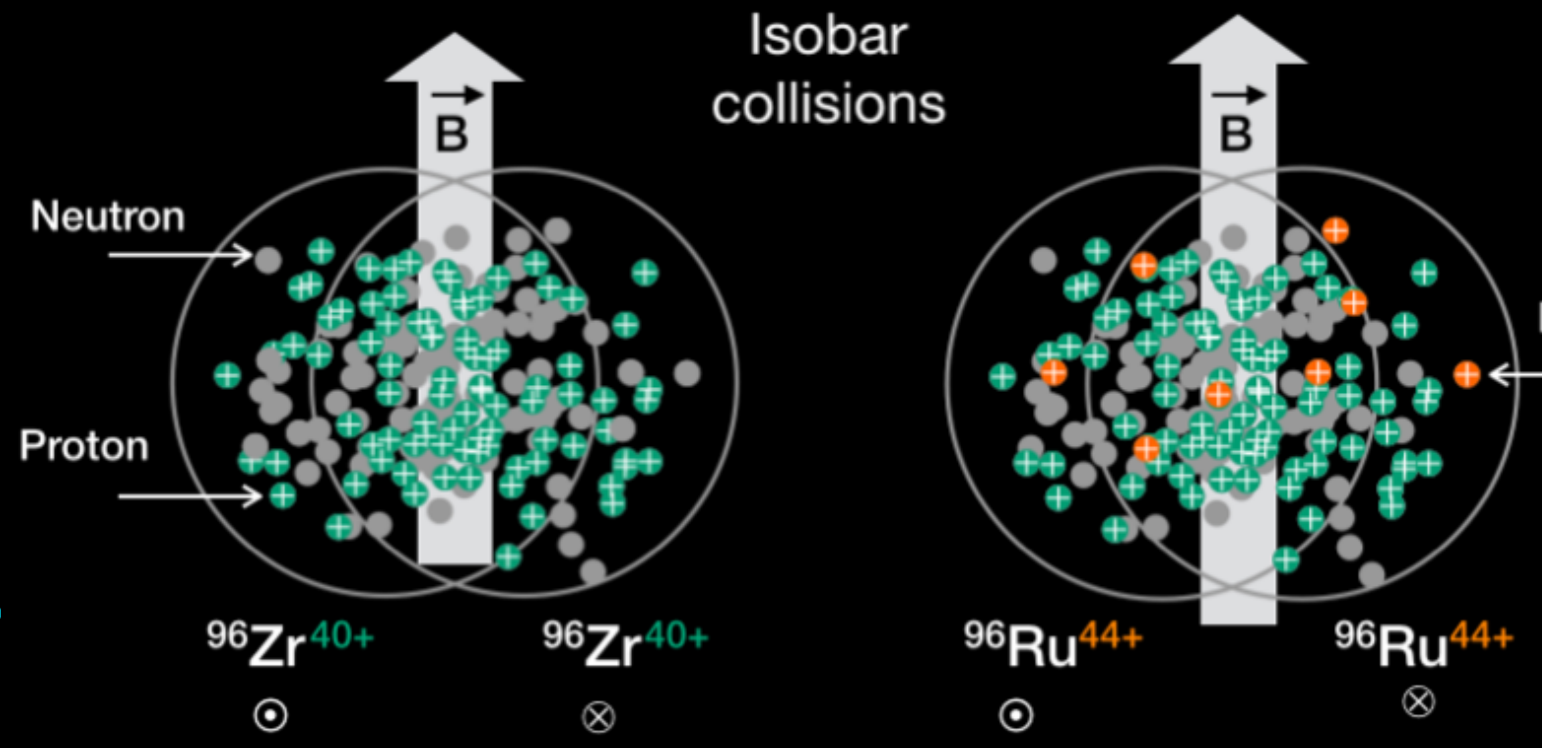


A=Mass number = Baryon number
Z=Atomic number = Electric charge

Charge stopping $\simeq \frac{Z}{A} \times$ Baryon stopping

Scenario 2: Valence quarks carry electric charge & junctions cary baryon number

Charge stopping $< \frac{Z}{A} \times$ Baryon stopping



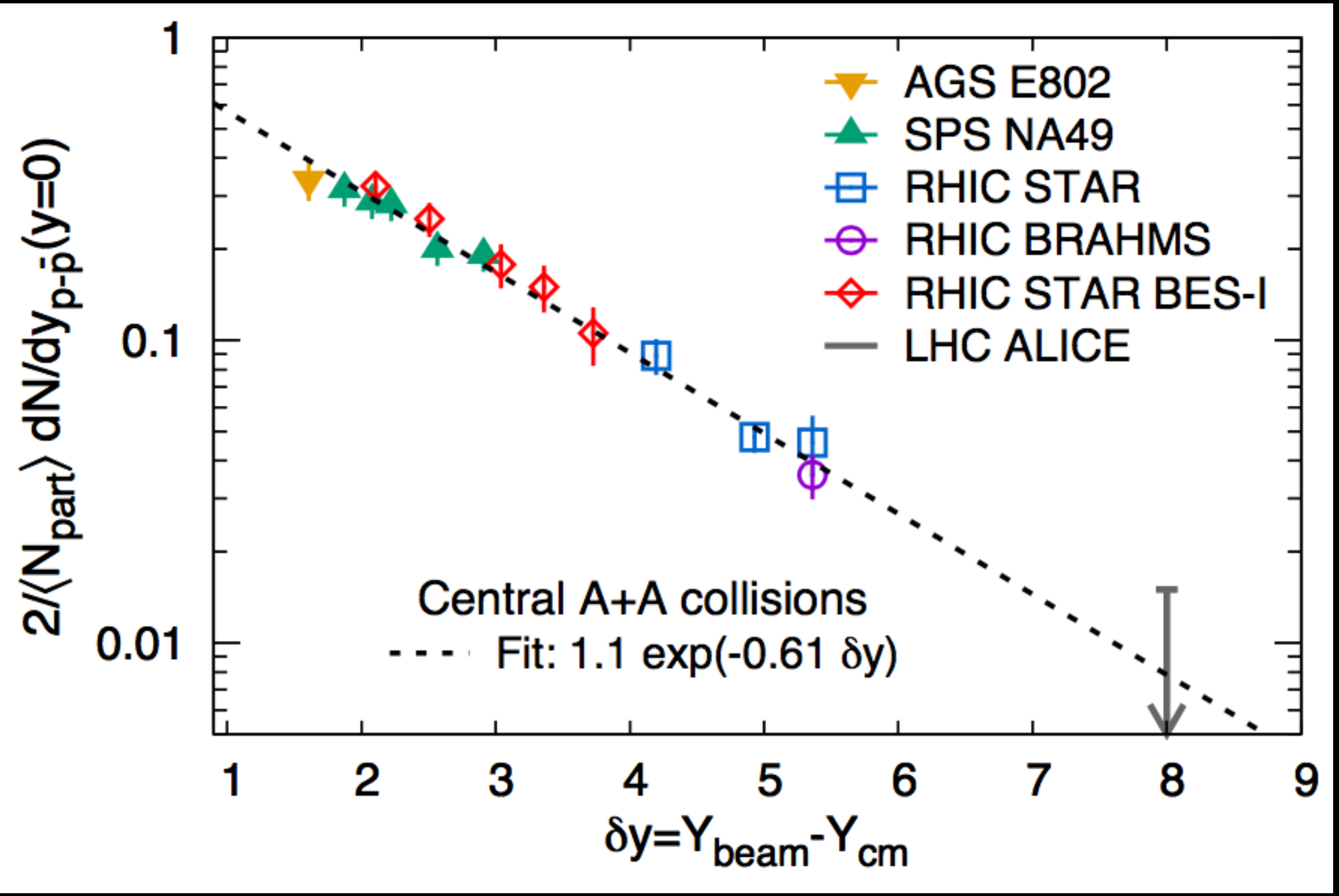
Zirconium:
A=96 (Total baryon)
Z=40 (Total charge)

Ruthenium:
A=96 (Total baryon)
Z=44 (Total charge)

$$\Delta Q \leftrightarrow \frac{\Delta Z}{A} \times B$$

Midrapidity baryon production in A+A collisions

Brandenburg, Lewis, Tribedy, Xu, arXiv:2205.05685



Kharzeev, Phys. Lett. B, 378 (1996) 238-246

Fit to global data on central A+A:

$$\frac{2}{N_{\rm part}} \frac{dN_{\rm p-\bar{p}}}{dy}\bigg|_{A+A} = N_B \, e^{-\alpha_B (Y_{\rm beam} - Y_{\rm cm})}$$

$$\alpha_B = 0.61 \pm 0.03$$

Predictions form Regge theory & baryon junction picture:

$$0.42 \leq \alpha_B \leq 1$$

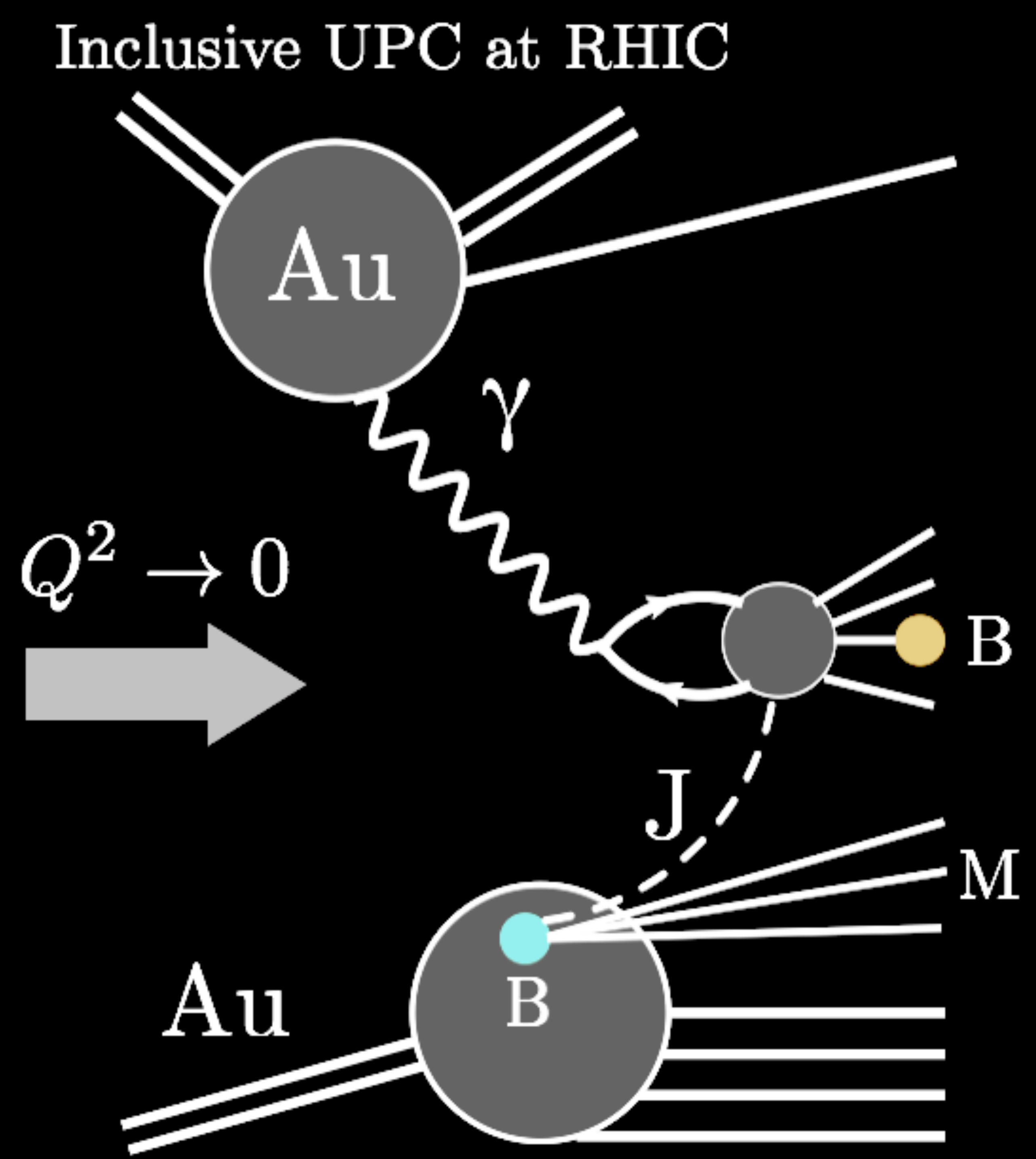
Consistent but more tests are needed

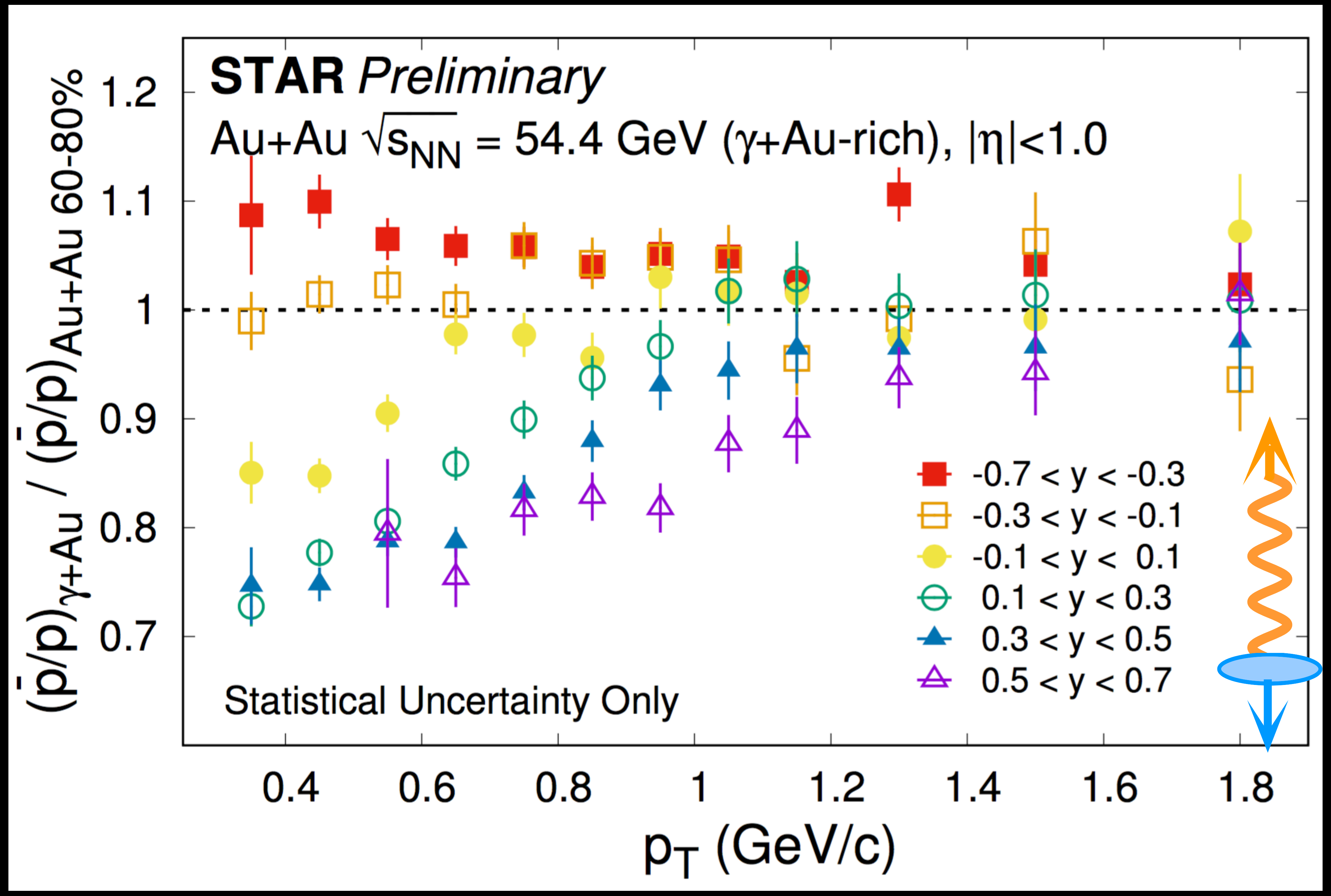
Baryon free projectile: photon-induced processes

Brandenburg, Lewis, Tribedy, Xu, arXiv:2205.05685

Nicole Lewis (STAR collaboration), QM 2022

First look at photonuclear events: stronger rapidity dependent stopping in γ+Au » Au+Au





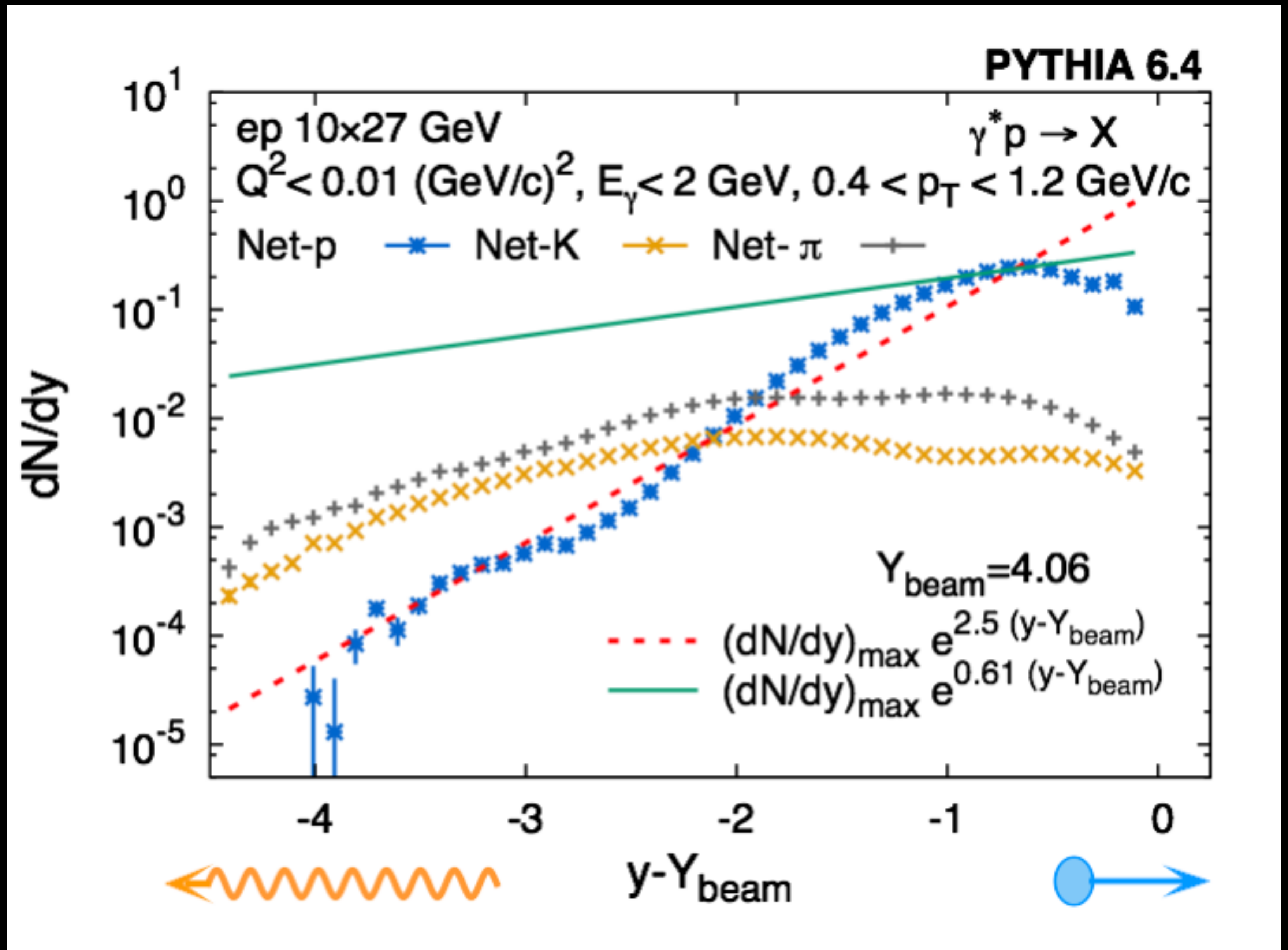
Triggering photonuclear processes using Au+Au UPCs

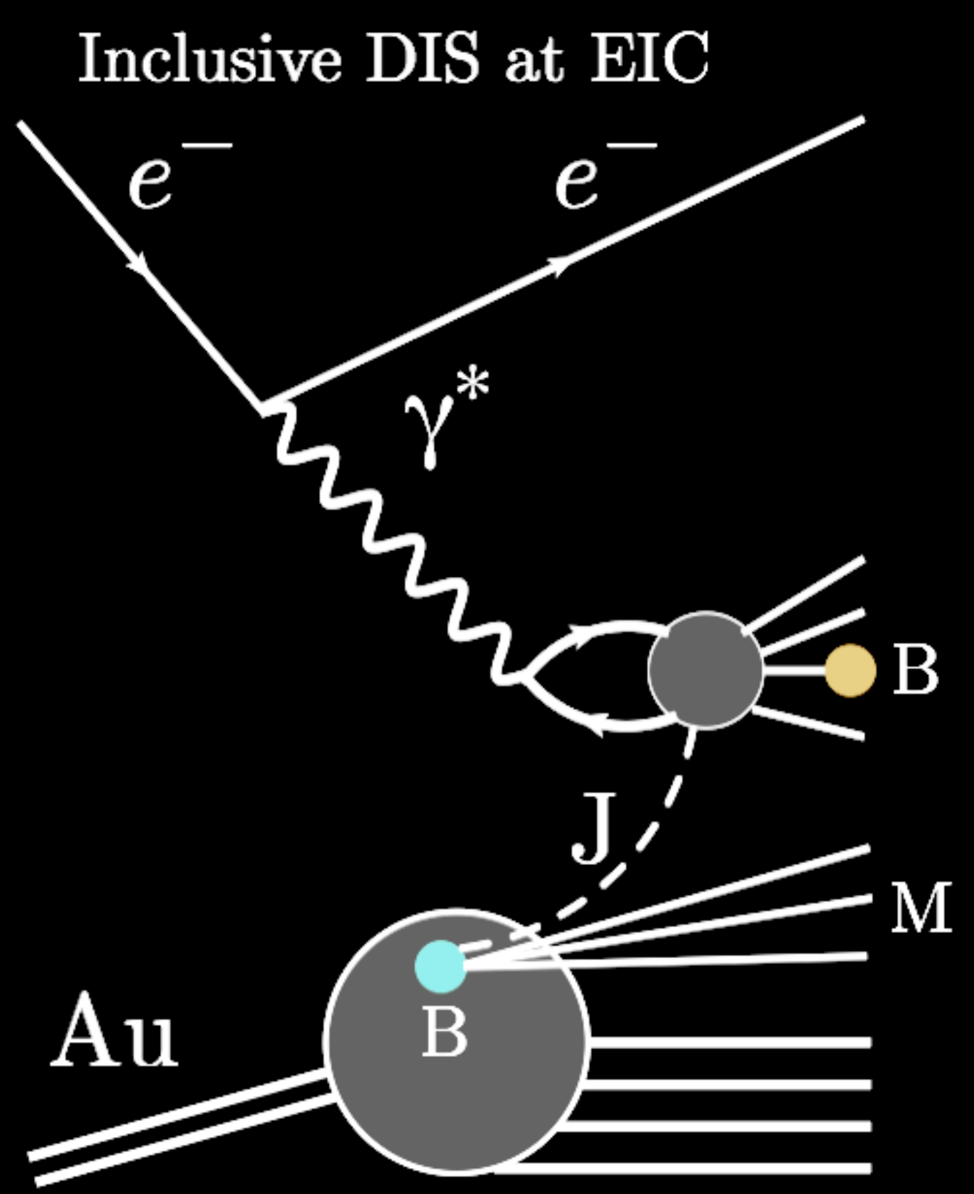
Interesting rapidity dependence of soft baryon stopping observed in RHIC photonuclear events

Low momentum PID (TOF) @ EIC needed to perform these measurements

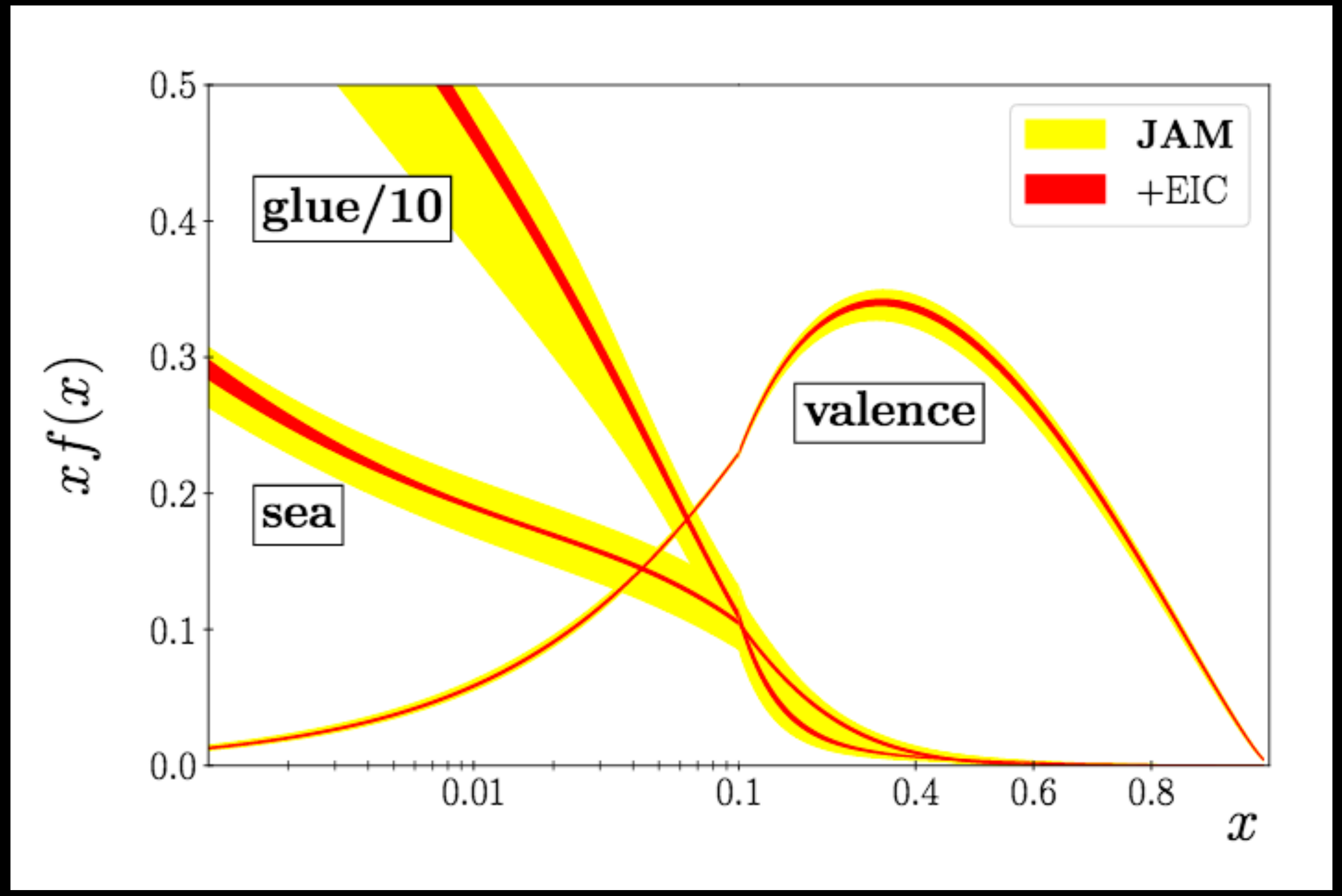
Baryon Distributions in x & Q^2: cleaner environment at EIC

Brandenburg, Lewis, Tribedy, Xu, arXiv:2205.05685

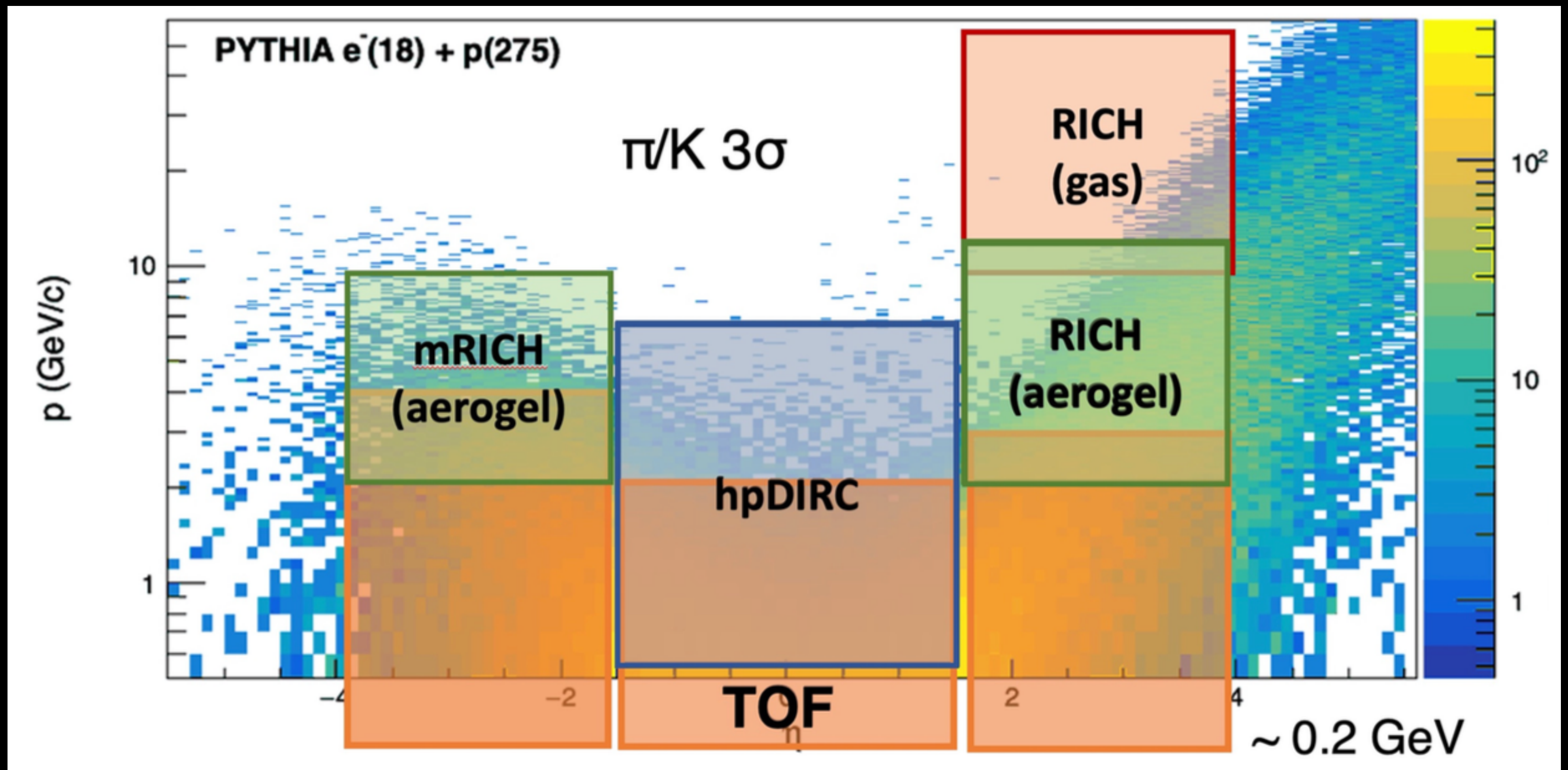


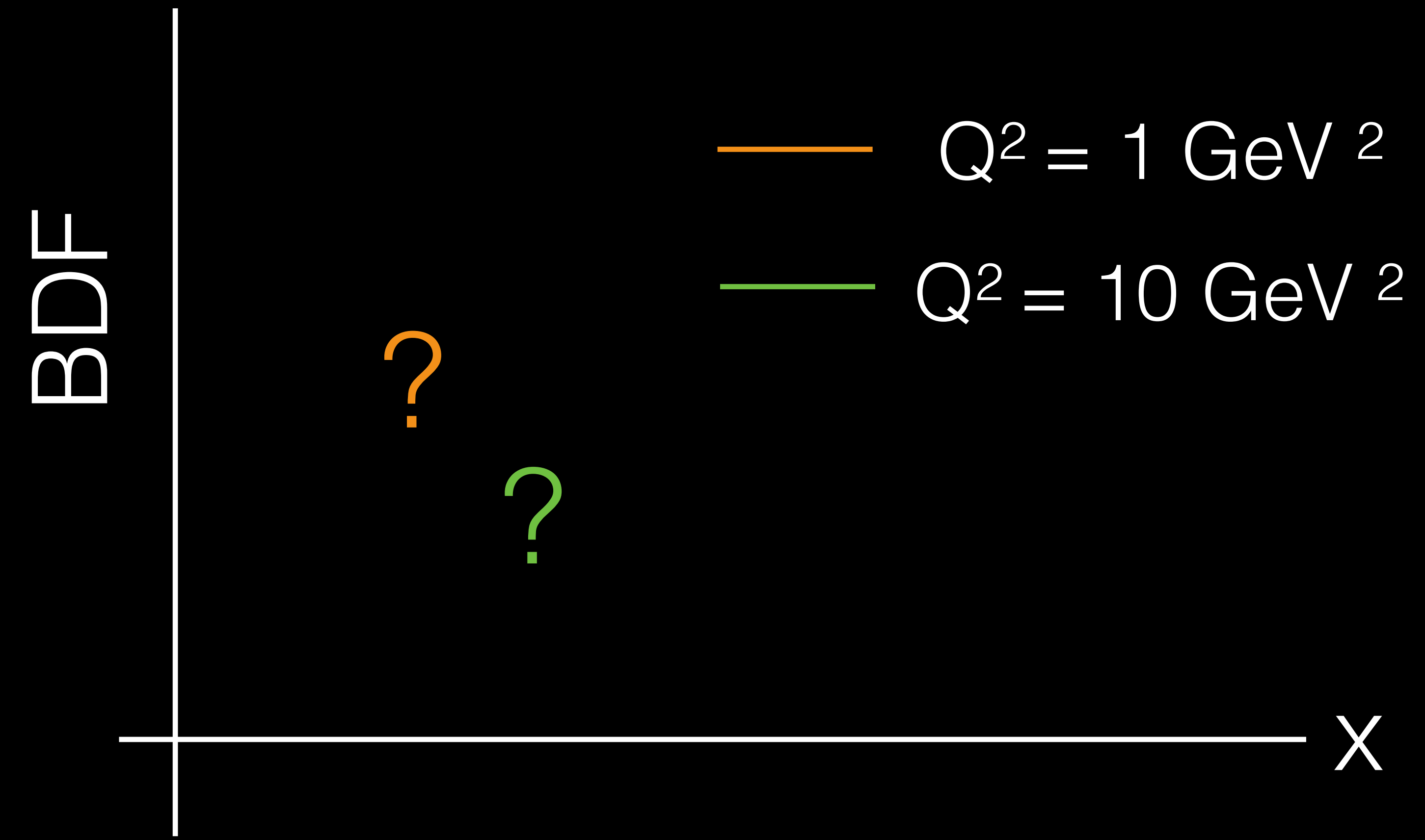


EIC yellow report, arXiv:2103.05419



What is the PDF equivalent of baryons ?





Low momentum PID capable detectors (TOF) at EIC will provide unique opportunity