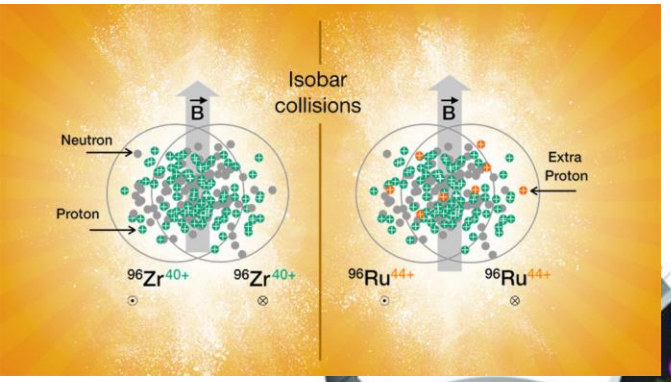
Baryon Junction: a new frontier



Zhangbu Xu
Kent State University
BNL

- baryon number carrier
- Three experimental approaches at RHIC (3+1)
- Flavor Independence of u,d,s,c,b
- Future Perspectives

Center for Nuclear Research
KENT STATE UNIVERSITY
Brookhaven National Laboratory
U.S. DEPARTMENT OF ENERGY | Office of Science

Google AI overview:

The **experimental discovery of the baryon junction** by the STAR Collaboration at the Relativistic Heavy Ion Collider (RHIC) represents a foundational shift in how we understand the basic building blocks of visible matter. Published in *Science*, the discovery provides the first definitive evidence that a proton's **"baryon number"**—the fundamental quantum property that marks it as matter rather than antimatter—is carried not by its individual quarks, but by a **Y-shaped topological arrangement of gluons** at its center. Phys.org +3

To grasp why this discovery is so momentous, it must be viewed within the historic arc of nuclear and particle physics over the last 60 years.

The Discovery: How the Paradox Was Solved

The STAR Collaboration tackled this by pushing protons to extreme environments where they could be violently stripped apart. They utilized two distinct types of high-energy interactions at RHIC: EurekAlert! ... +1

1. **Isobaric Collisions (Ruthenium vs. Zirconium):** They collided atoms of Ruthenium-96 and Zirconium-96. These ions have the same total mass but different numbers of protons (Ruthenium has more positive charge). If baryon number belonged to the valence quarks, the transport of baryon number and electric charge would be perfectly synchronized. Instead, they found that **baryon number moved independently of electric charge**, stopping more easily in the collision zone than the quarks did. ScienceAlert +2

NEWS AND VIEWS | 06 October 2026

Strong evidence that 'baryon junctions' give proton its identity

A conserved property of protons and neutrons is carried not by their constituent particles but by structures that mediate the force between them.

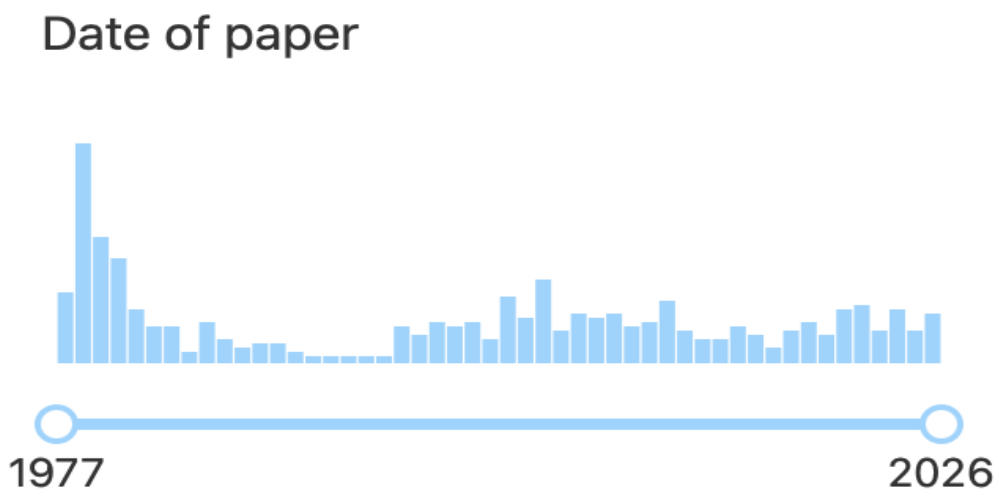
By José Guilherme Milhano & Néstor Armesto

A Possible Description of Baryon Dynamics in Dual and Gauge Theories #18

G.C. Rossi (CERN), G. Veneziano (CERN) (Mar, 1977)

Published in: *Nucl.Phys.B* 123 (1977) 507-545

pdf | DOI | cite | claim | reference search | 452 citations

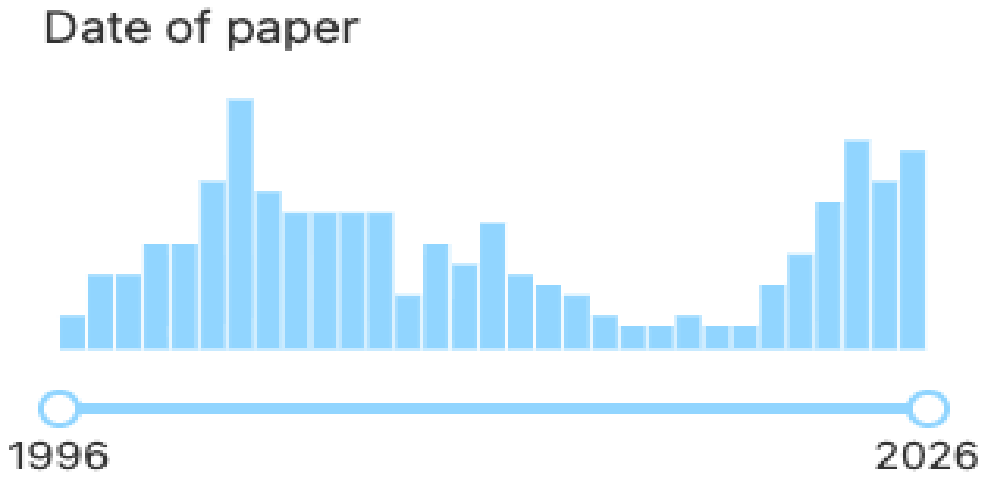


Can gluons trace baryon number? #1

D. Kharzeev (CERN and Bielefeld U.) (Feb, 1996)

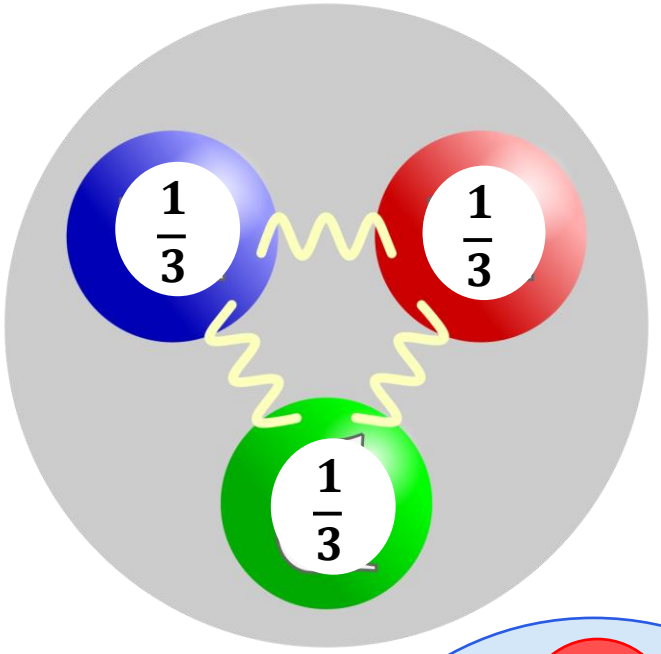
Published in: *Phys.Lett.B* 378 (1996) 238-246 • e-Print: nucl-th/9602027 [nucl-th]

pdf | DOI | cite | claim | reference search | 283 citations

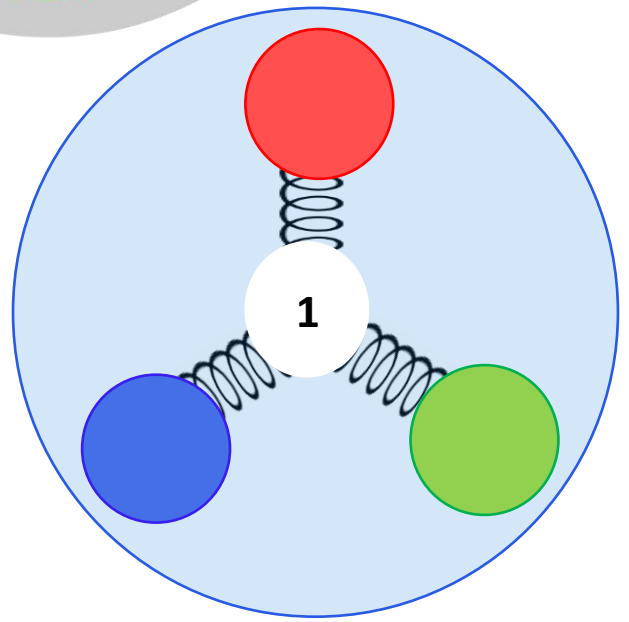


Baryon Number (B) Carrier

https://en.wikipedia.org/wiki/Quark



- Textbook picture of a proton
  - Lightest baryon with strictly conserved baryon number
  - Each valence quark carries 1/3 of baryon number
  - Proton lifetime >10^{34} years
  - Quarks are connected by gluons
- Alternative picture of a proton
  - Proposed at the Dawn of QCD in 1970s
  - A Y-shaped gluon junction topology carries baryon number (B=1)
  - The topology number is the strictly conserved number
  - Quarks do not carry baryon number
  - Valence quarks are connected to the end of the junction always
- Neither of these postulations has been verified experimentally



[1]: Artru, X.; String Model with Baryons: Topology, Classical Motion. Nucl. Phys. B 85, 442–460 (**1975**).
[2]: Rossi, G. C. & Veneziano, G. A; Possible Description of Baryon Dynamics in Dual and Gauge Theories. Nucl. Phys. B 123, 507–545 (**1977**)

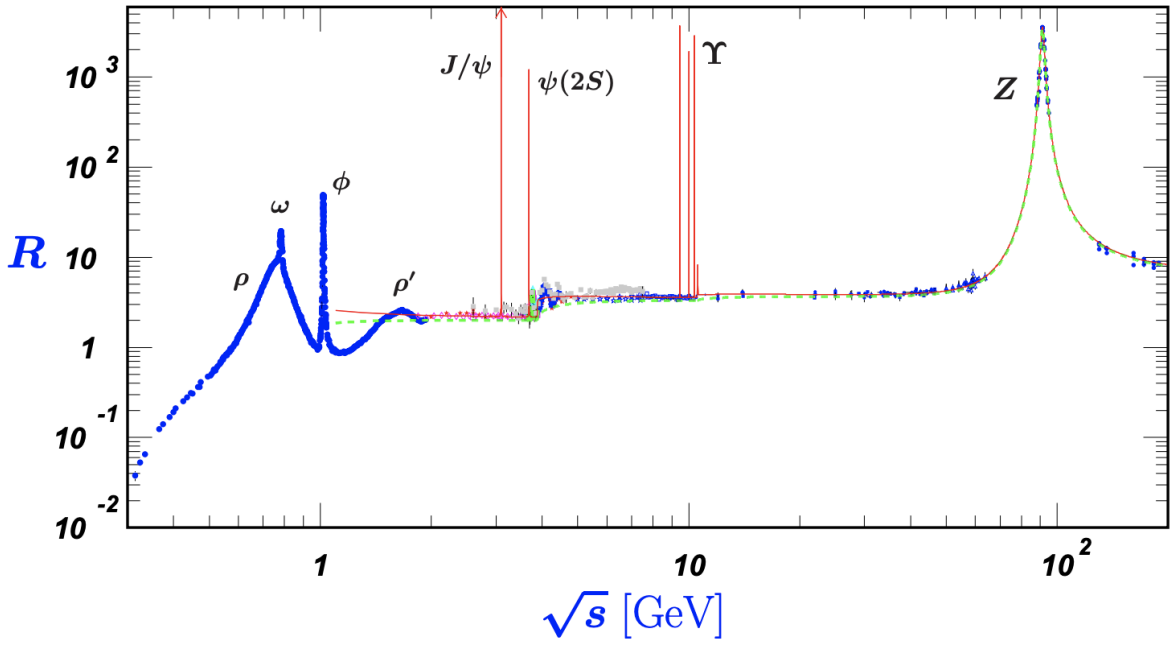
Measurements of quark electric charges

Scattering cross section $\sigma \propto e_q^2$

$(2/3)^2+(1/3)^2+(1/3)^2=2/3$

$(2/3)^2+(2/3)^2+(1/3)^2=1$

$(1/3)^2+(1/3)^2+(1/3)^2=1/3$



PDG

Figure 53.2: World data on the total cross section of $e^+e^- \to hadrons$ and the ratio $R(s) = \sigma(e^+e^- \to hadrons, s)/\sigma(e^+e^- \to \mu^+\mu^-, s)$. $\sigma(e^+e^- \to hadrons, s)$ is the experimental cross section corrected for initial state radiation and electron-positron vertex loops, $\sigma(e^+e^- \to \mu^+\mu^-, s) = 4\pi\alpha^2(s)/3s$. Data errors are total below 2 GeV and statistical above 2 GeV. The curves are an educative guide: the broken one (green) is a naive quark-parton model

Riordan, Science 1992

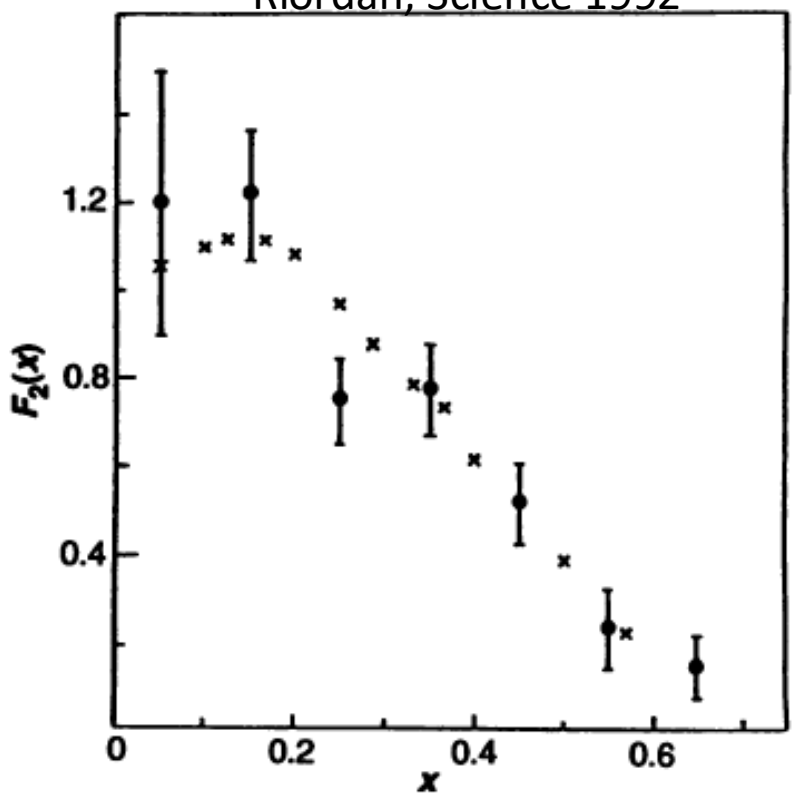
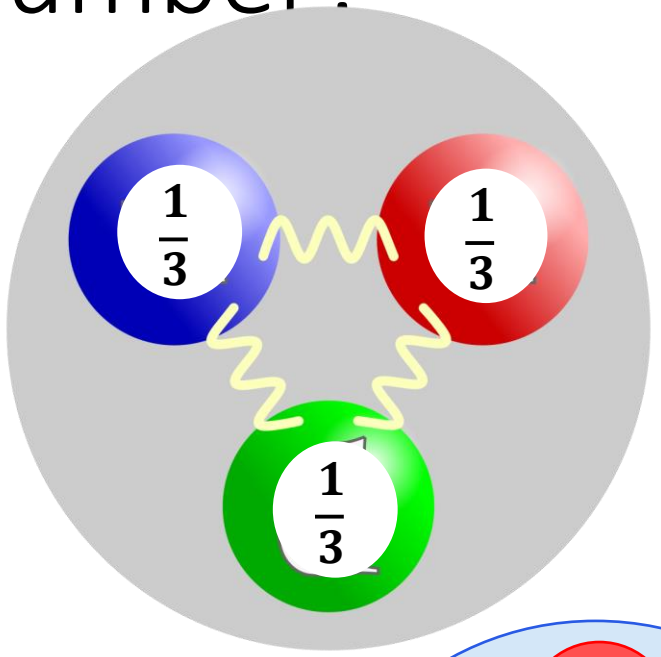
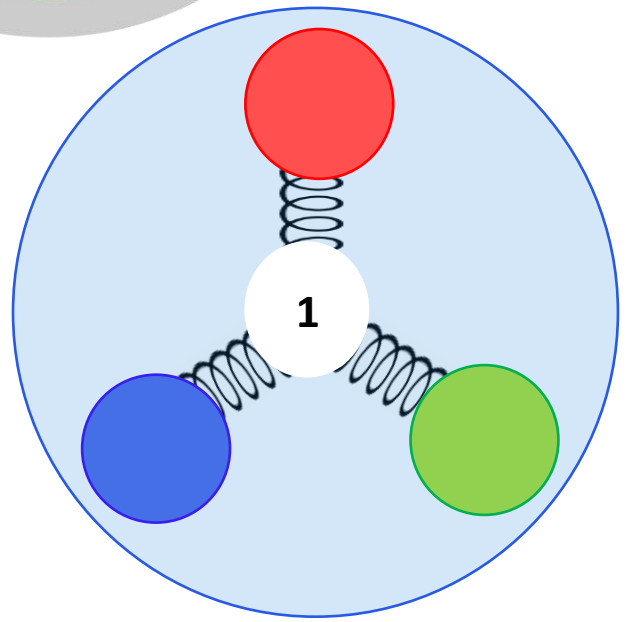


Fig. 8. Comparison of structure functions measured in deep inelastic neutrino-nucleon scattering experiments on the Gargamelle heavy-liquid bubble chamber with the MIT-SLAC data [(●), Gargamelle, $F_2^{\nu N}$; (×), MIT-SLAC, (18/5)F_2^{eN}]. When multiplied by 18/5, a number specified by the quark-parton model, the electron scattering data coincide with the neutrino data.

Measurements of quark baryon number?

- Textbook picture of a proton
  - Lightest baryon with strictly conserved baryon number
  - Each valence quark carries 1/3 of baryon number
  - Proton lifetime >10^{34} years
  - Quarks are connected by gluons
- Alternative picture of a proton
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Model implementations of baryons at RHIC

- Many of the models used for heavy-ion collisions at RHIC (HIJING, AMPT, UrQMD) have implemented a nonperturbative baryon stopping mechanism

  V. Topor Pop, *et al,* Phys. Rev. C **70**, 064906 (2004)

  Zi-Wei Lin, *et al*, Phys. Rev. C **72**, 064901 (2005)

  M. Bleicher, *et al,* J.Phys.G **25,** 1859-1896 (1999)

- Baryon Stopping
  - Theorized to be an effective mechanism of stopping baryons in pp and AA

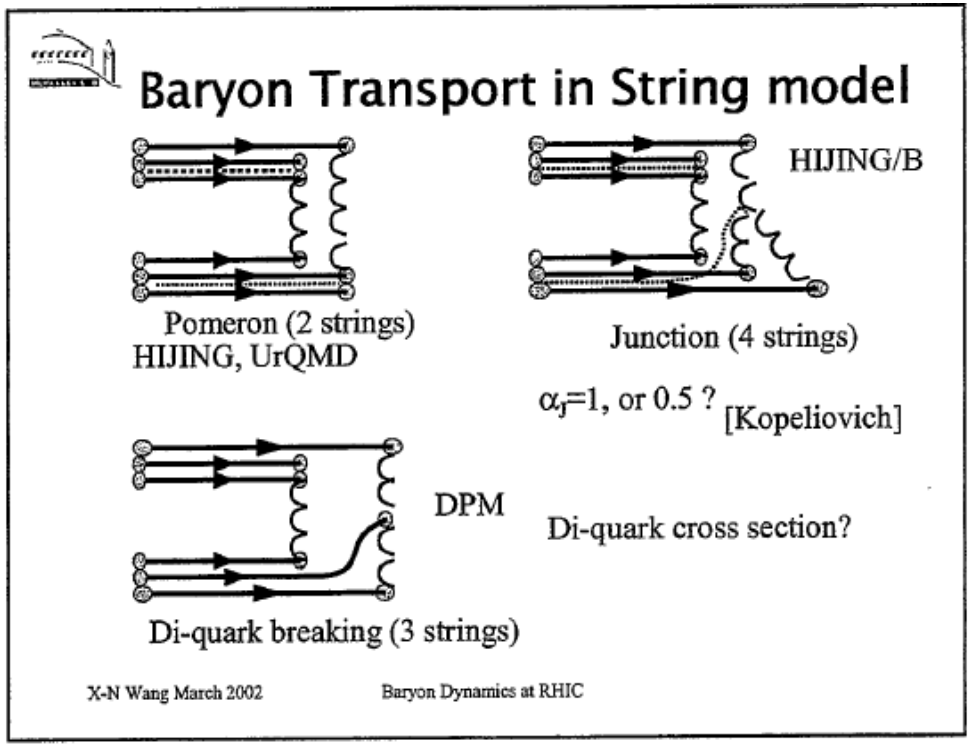
  D. Kharzeev, Physics Letters B **378**, 238-246 (1996)

- Specific rapidity dependence is predicted:

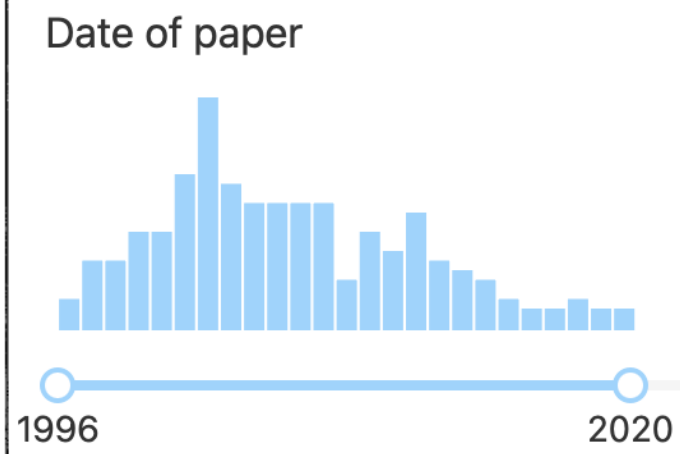
$$p = \sim e^{-\alpha_B y}$$

α_B ~=0.5

2003 RBRC Workshop on "Baryon Dynamics at RHIC"
Organized by D. Kharzeev, M. Gyulassy, N. Xu



D. Kharzeev, Physics Letters B **378**, 238-246 (1996)
"Can gluons trace baryon number?"



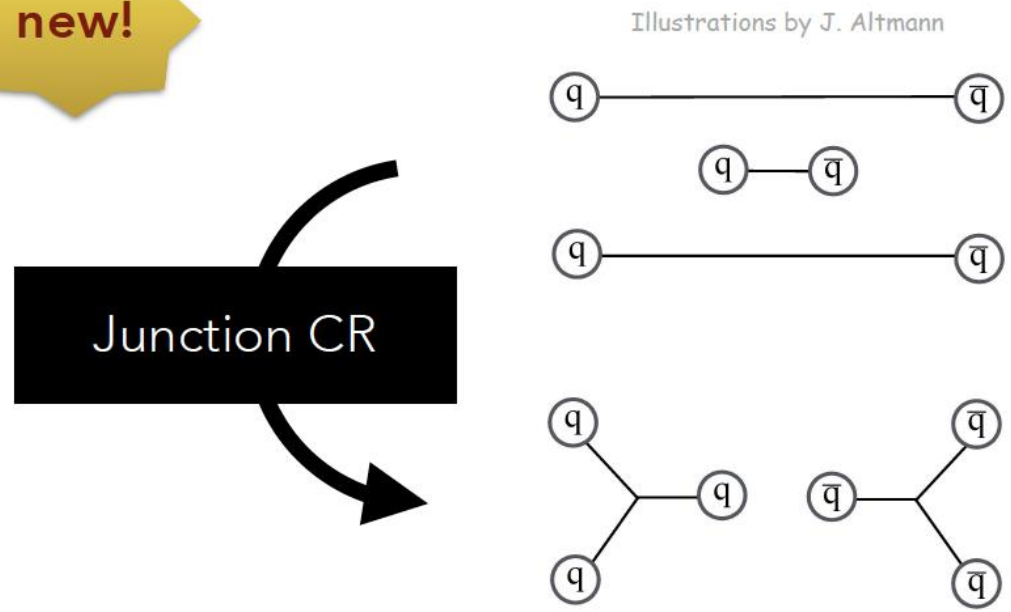
"Science, however, is never conducted as a popularity contest…" --- Michio Kaku

BUT citations ARE

“Final-State” baryon junction in PYTHIA 8.x

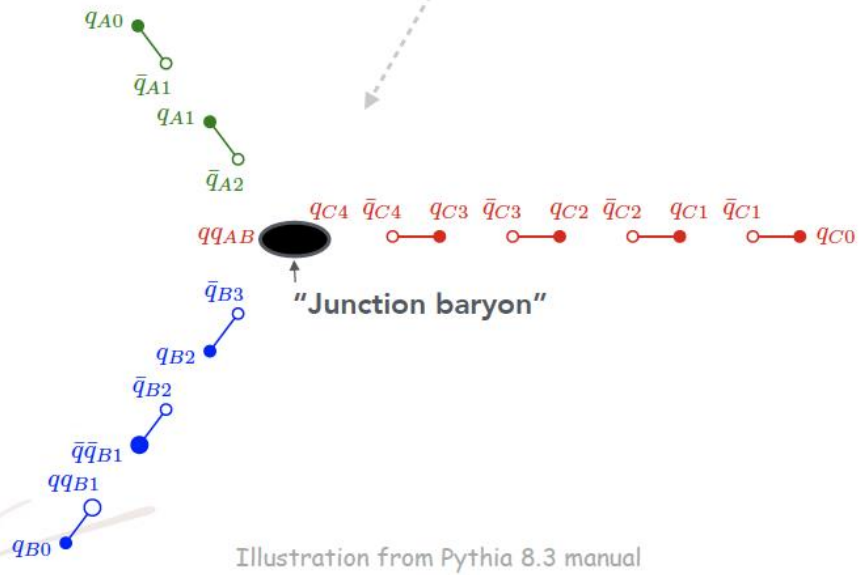
new!

Peter Skands, 2021



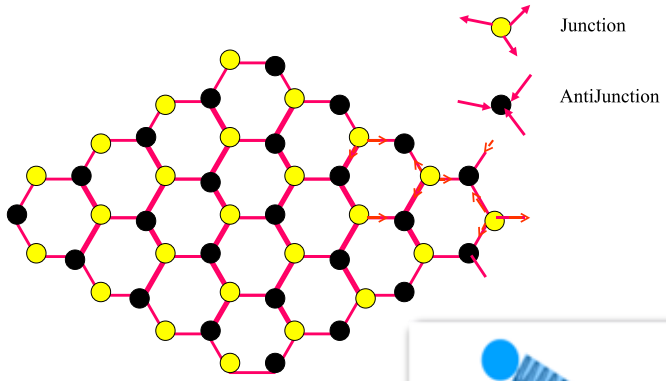
Junction treatment (PYTHIA MANUAL 8.x)

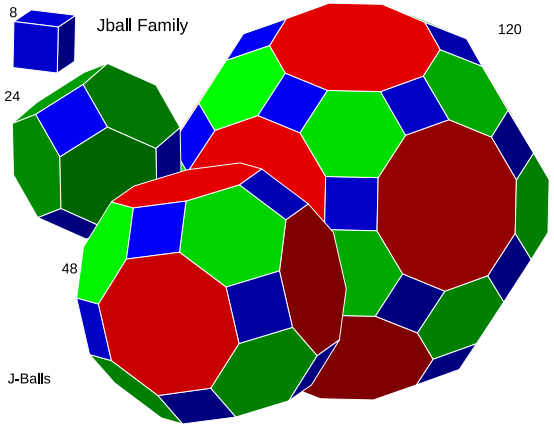
A junction topology corresponds to an Y arrangement of strings i.e. where three string pieces have to be joined up in a junction. Such topologies can arise if several valence quarks are kicked out from a proton beam, or in baryon-number-violating SUSY decays. Special attention is necessary to handle the region just around the junction, where the baryon number topologically is located. The junction fragmentation scheme is described in [Sjo03, 2003]. The parameters in this section should not be touched except by experts.

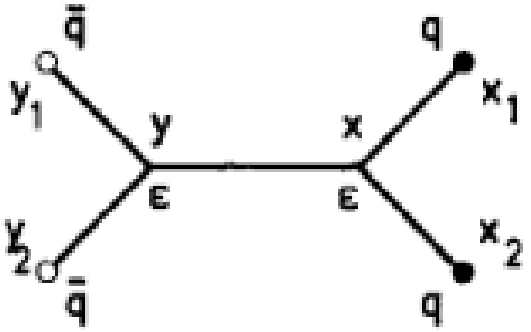


MCnet

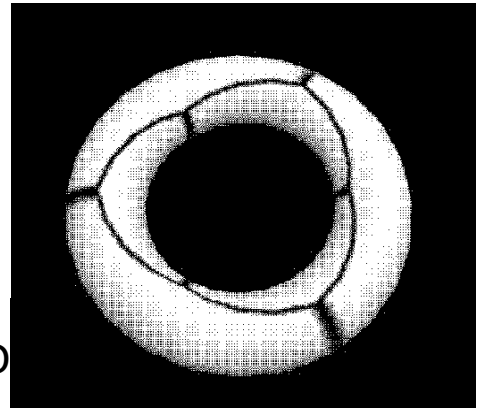
Junction anti Junction Gluon
"Graphite"



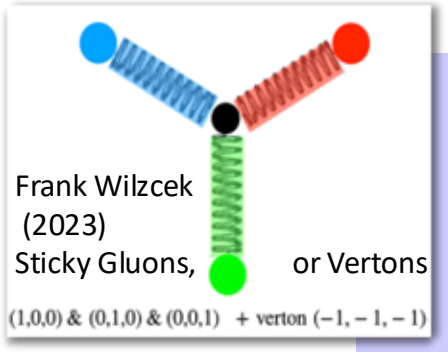




Veneziano, 50 years of QCD
arXiv:1603.05830

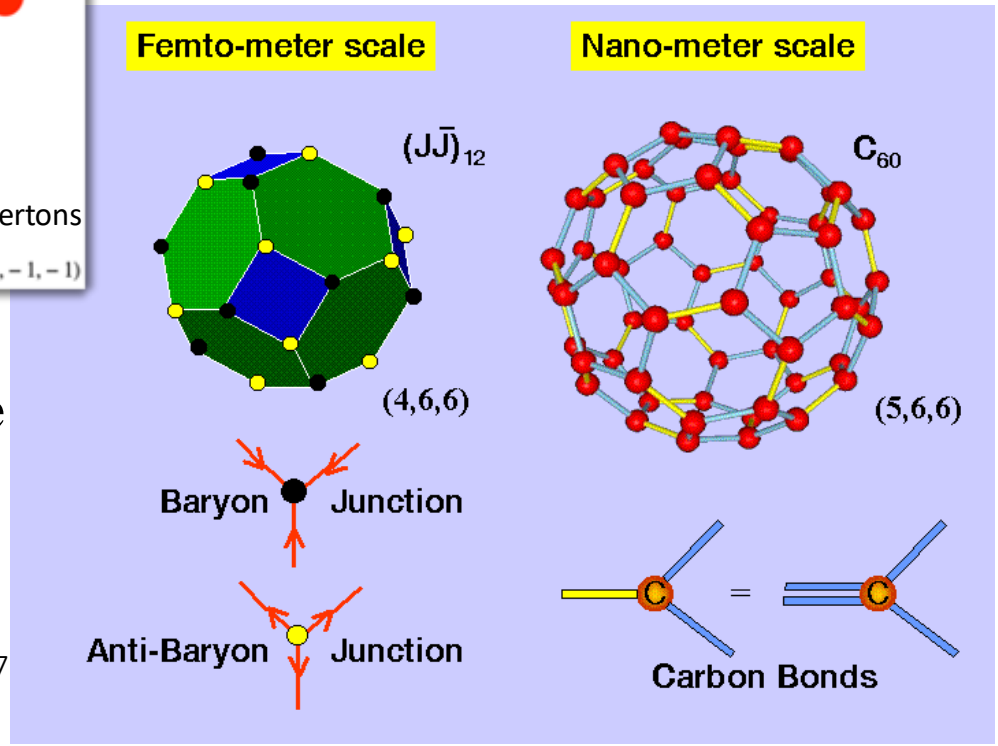


Baryonium Torus, O.I. Piskounova
hep-ph/1909.08536

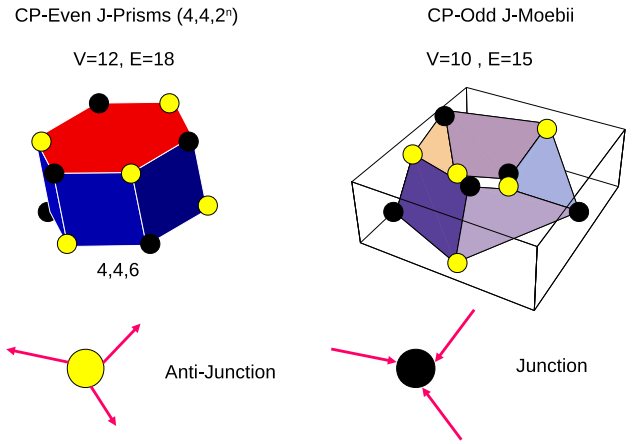


Buckyballs and gluon junction networks on the femtometre scale

D. Kharzeev, PLB 378 (96)
S. Vance, M. Gyulassy, XN Wang, PLB 443 (98)
T. Csorgo, M. Gyulassy, D. Kharzeev, JPG 30 (2004) L17



CP Odd vs Even J$\bar{J}$ Ribbons

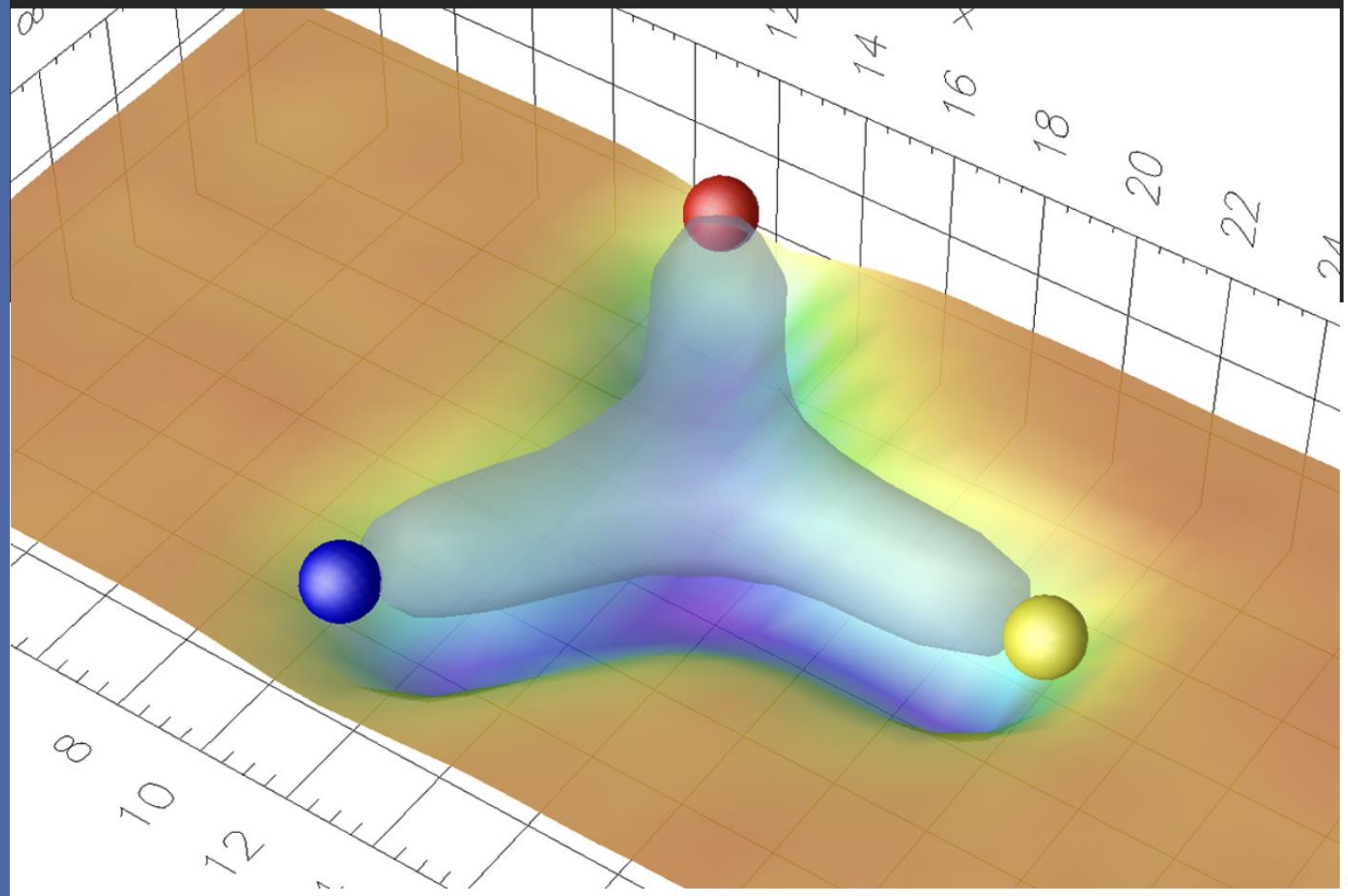


NEWS | PHYSICS

A new explanation of why the universe's supply of nuclear matter is fixed?

Experiments point to an alternative origin of a particle accounting tool called the baryon number

13 AUG 2026 · 2:00 PM ET · BY ADRIAN CHO



This simulation shows the baryon junction formed inside a proton or neutron by countless gluons. FRANCOIS BISSEY

in Lattice QCD

- Some lattice calculations have suggested the formation of a Y-shaped color flux tube among the three quarks at long distances

  T. T. Takahashi, *et al* Phys. Rev. Lett. **86**, 18 (2001).

  T. Takahashi, *et al*, Phys. Rev. D **65**, 114509 (2002)

  Takahashi, RBRC workshop 2003
- Still under investigation

Concentration of energy and mass in flux tubes connected at a junction

Baryon Transport w/o gluon junction

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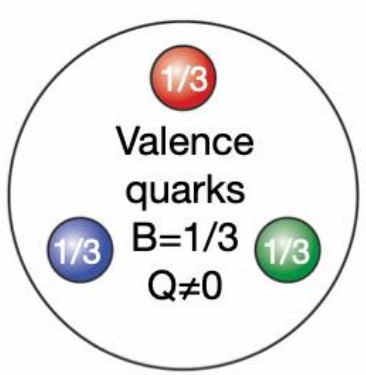
HOME > SCIENCE > VOL. 393, NO. 6812 > TRACKING THE BARYON NUMBER WITH NUCLEAR COLLISIONS

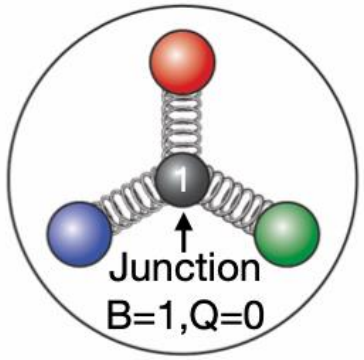
RESEARCH ARTICLE | PHYSICS

Tracking the baryon number with nuclear collisions

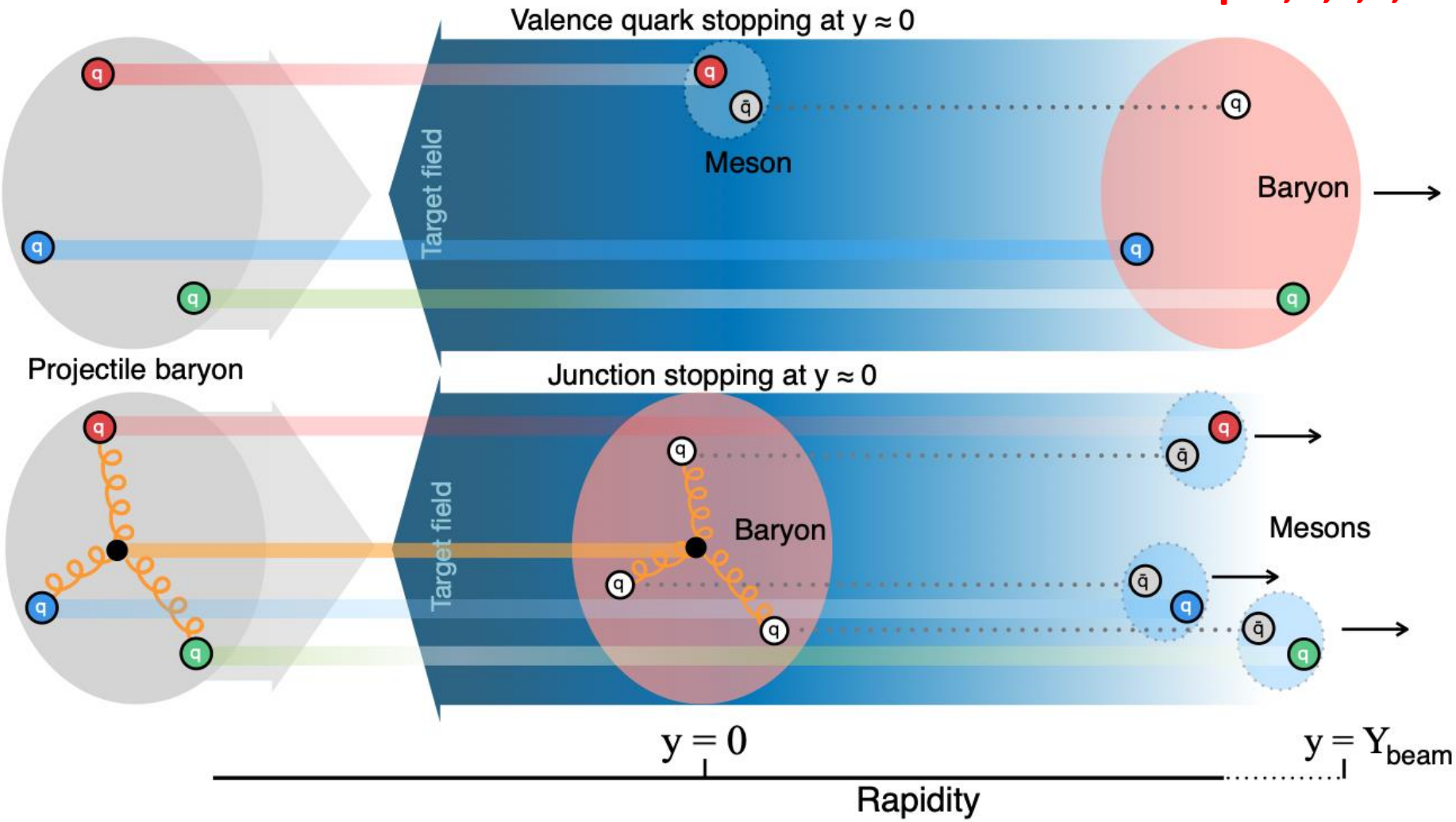
STAR COLLABORATION Authors Info & Affiliations

SCIENCE • 13 Aug 2026 • Vol 393, Issue 6812 • pp. 727-731 • DOI: 10.1126/science.ads5962





q=u,d,s,c,b



Three approaches toward tracking the origin of the baryon number

1. STAR Method:
   Charge (Q) stopping vs baryon (B) stopping:
   if valence quarks carry Q and B,
   Q=B at middle rapidity

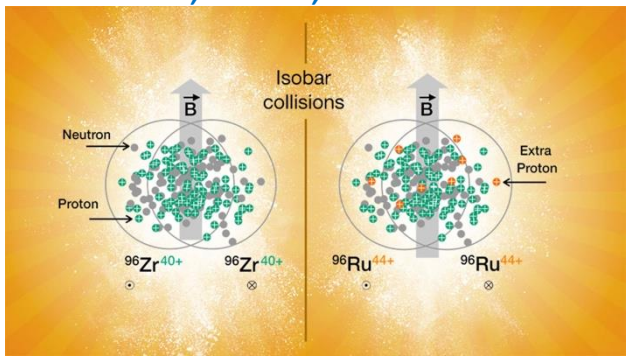
2. Kharzeev-STAR Method:
   If gluon topology (J) carries B as one unit, it should show scaling according to Regge theory

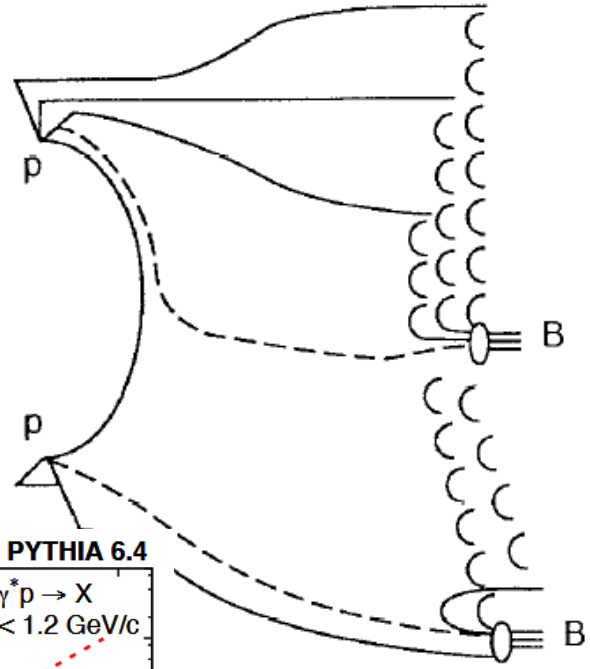
$$p = \sim e^{-\alpha_B y}$$

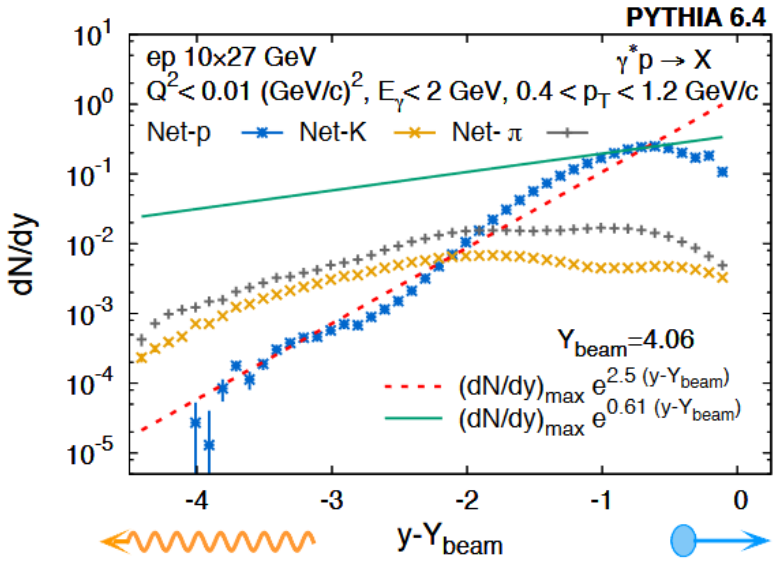
α_B ~=0.5

3. Artru Method:
   In γ+Au collision, rapidity asymmetry can reveal the origin

N. Lewis, et al., arXiv:2205.05685, *Eur.Phys.J.C* 84 (2024) 6, 590

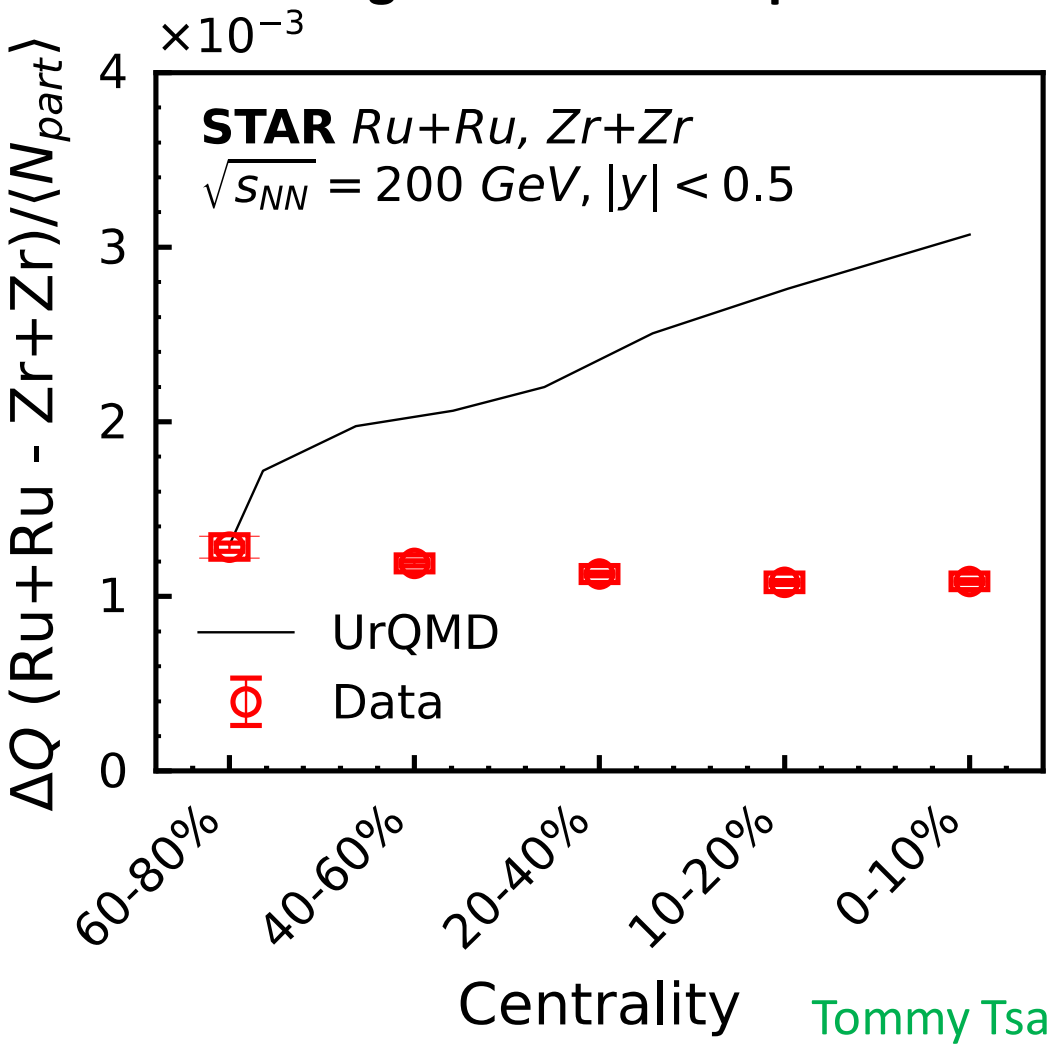






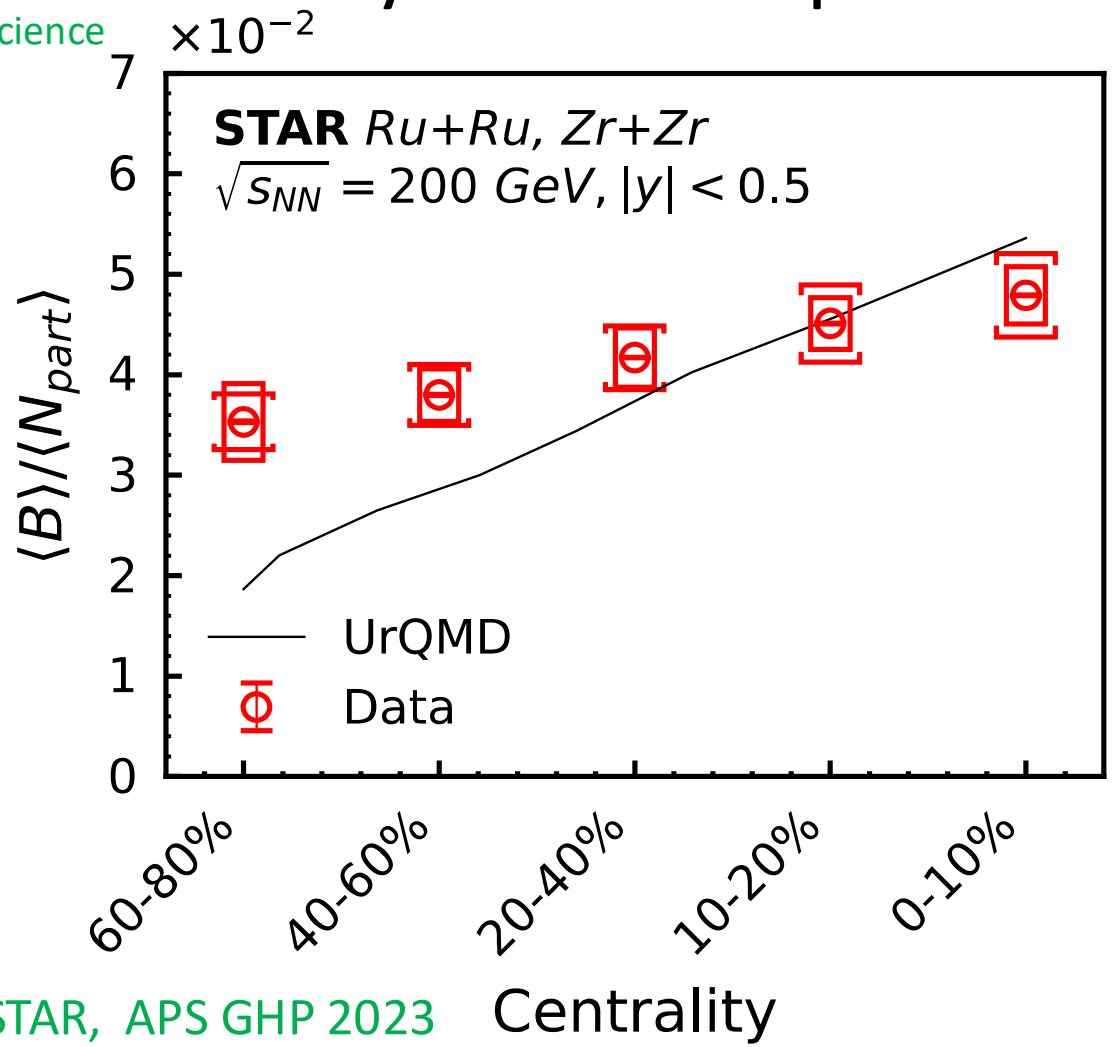
Separate charge and baryon transports

Charge number transport



STAR, arXiv:2408.15441
accepted by Science

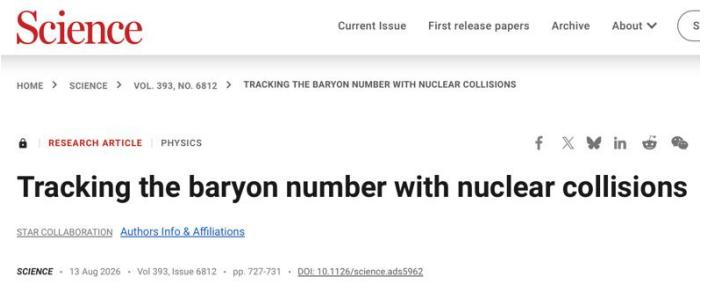
Baryon number transport



Tommy Tsang (KSU) for STAR, APS GHP 2023

UrQMD matches data on charge stopping better in peripheral; better on baryon stopping in central
overpredicts charge stopping in central; underpredicts baryon stopping in peripheral

Ratio of baryon over charge transports


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RESEARCH ARTICLE | PHYSICS

Tracking the baryon number with nuclear collisions

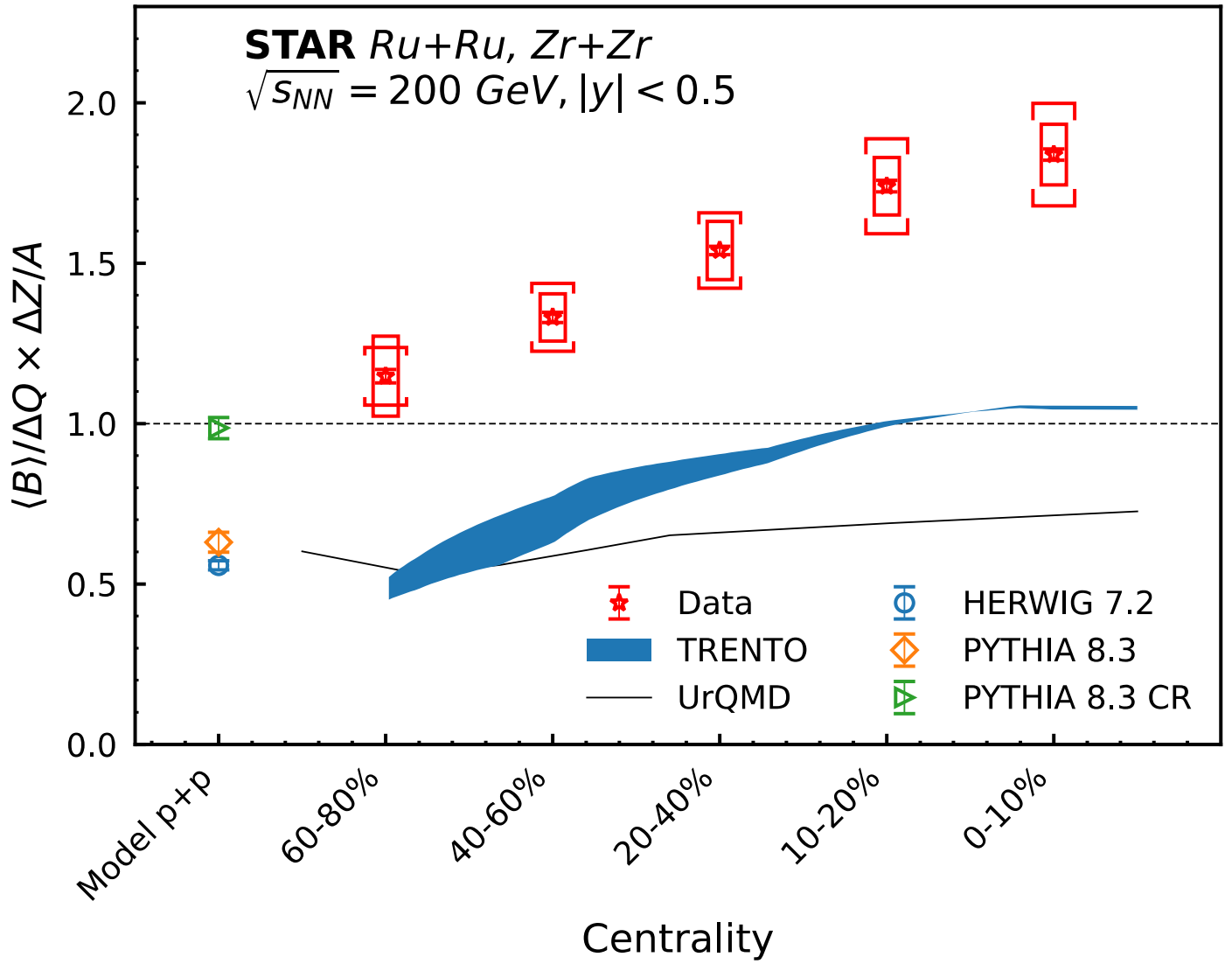
STAR COLLABORATION Authors Info & Affiliations

SCIENCE • 13 Aug 2026 • Vol 393, Issue 6812 • pp. 727-731 • DOI: 10.1126/science.ads5962

- **Experimental data**:
  More baryon transported to C.O.M than charge by about a factor of 2

- **Model simulations**:
  Less baryon transported to C.O.M frame than charge

- Pure geometry:
  with neutron skin predicts the right centrality dependence (Trento)

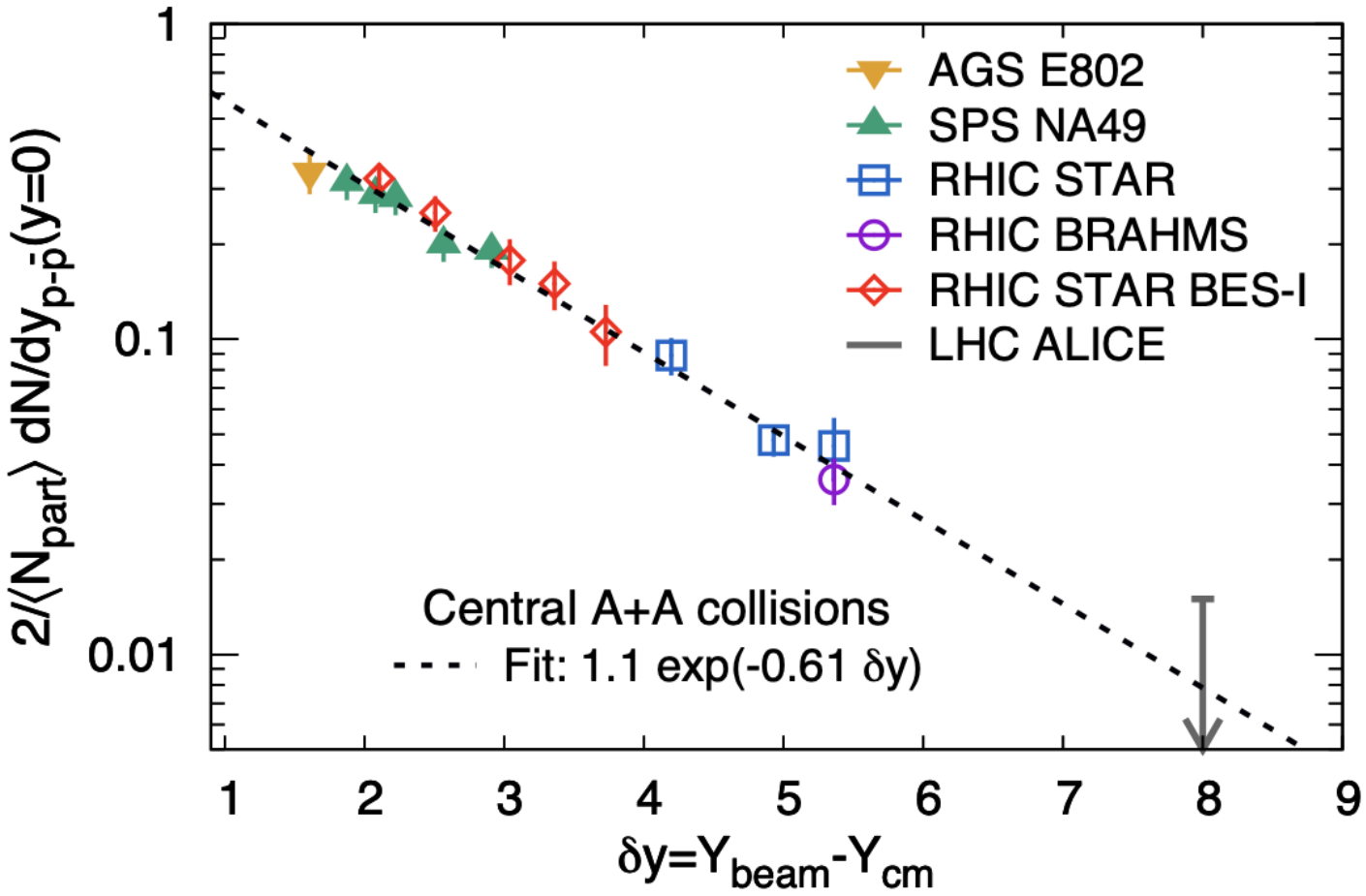


Quantifying baryon number transport

- RHIC Beam Energy Scan (BES-I) span large range of rapidity shift
- Exponential with slope of α_B =0.61±0.03
- Consistent with the baryon junction transport by gluons: α_B~=0.5+Δ Δ~=0.1

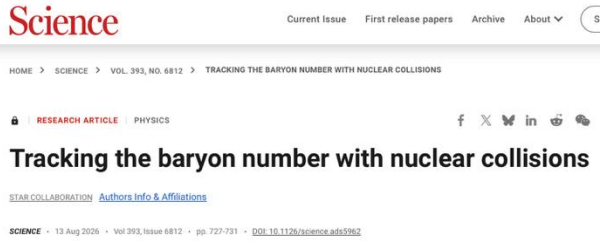
STAR, Phys. Rev. C **79** (2009) 34909; **96** (2017) 44904

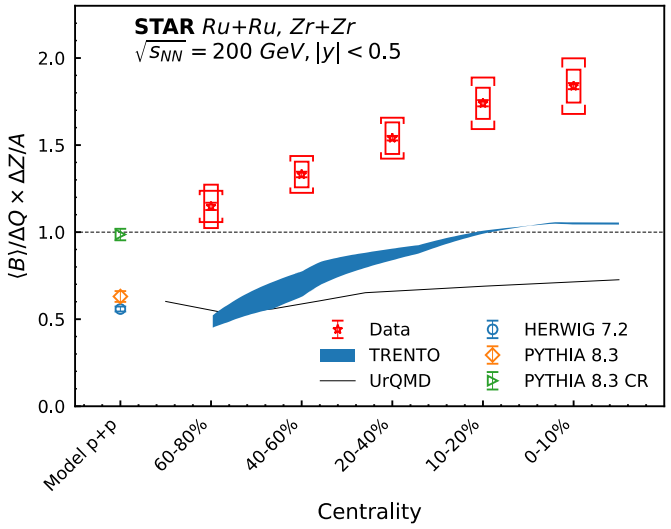
N. Lewis, et al., arXiv:2205.05685, *Eur.Phys.J.C* 84 (2024) 6, 590



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   B/Q=2



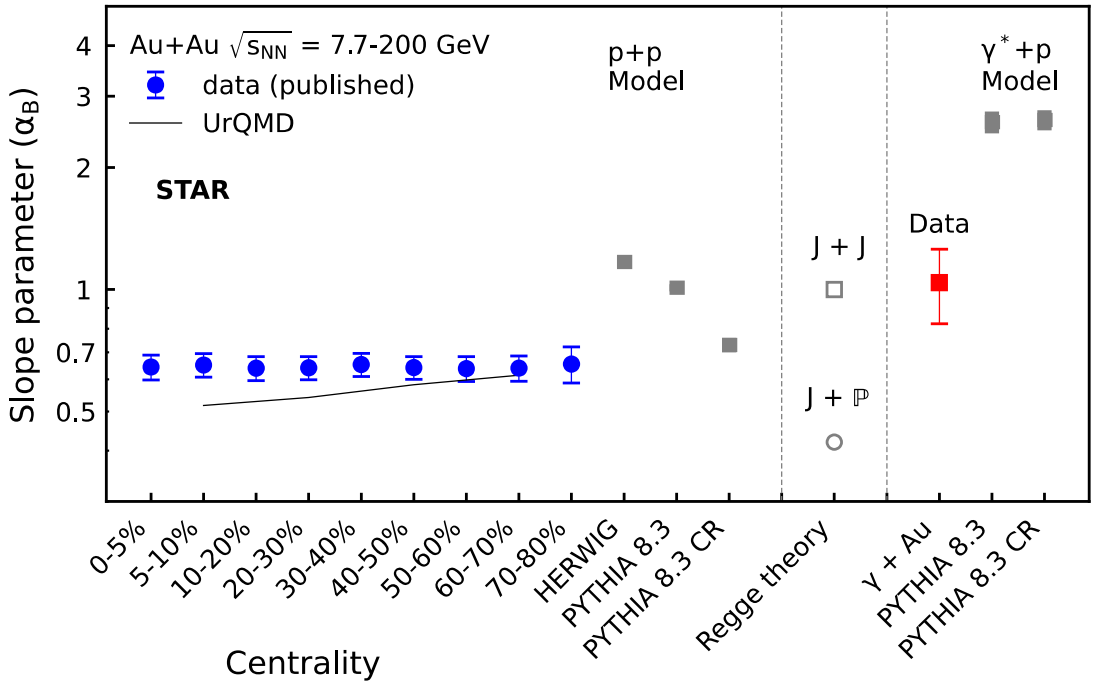


2. Kharzeev-STAR Method:
   If gluon topology (J) carries B as one unit, it should show scaling according to Regge theory
   α_B=0.61

$$p = \sim e^{-\alpha_B y}$$

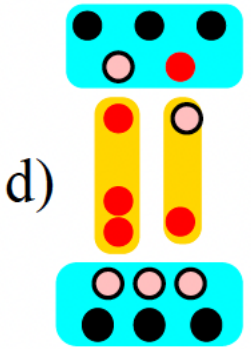
α_B ~=0.5

3. Artru Method:
   In γ+Au collision, rapidity asymmetry can reveal the origin
   α_B(A+A)=0.61< α_B(γ+A)=1.1< α_B(PYTHIA)

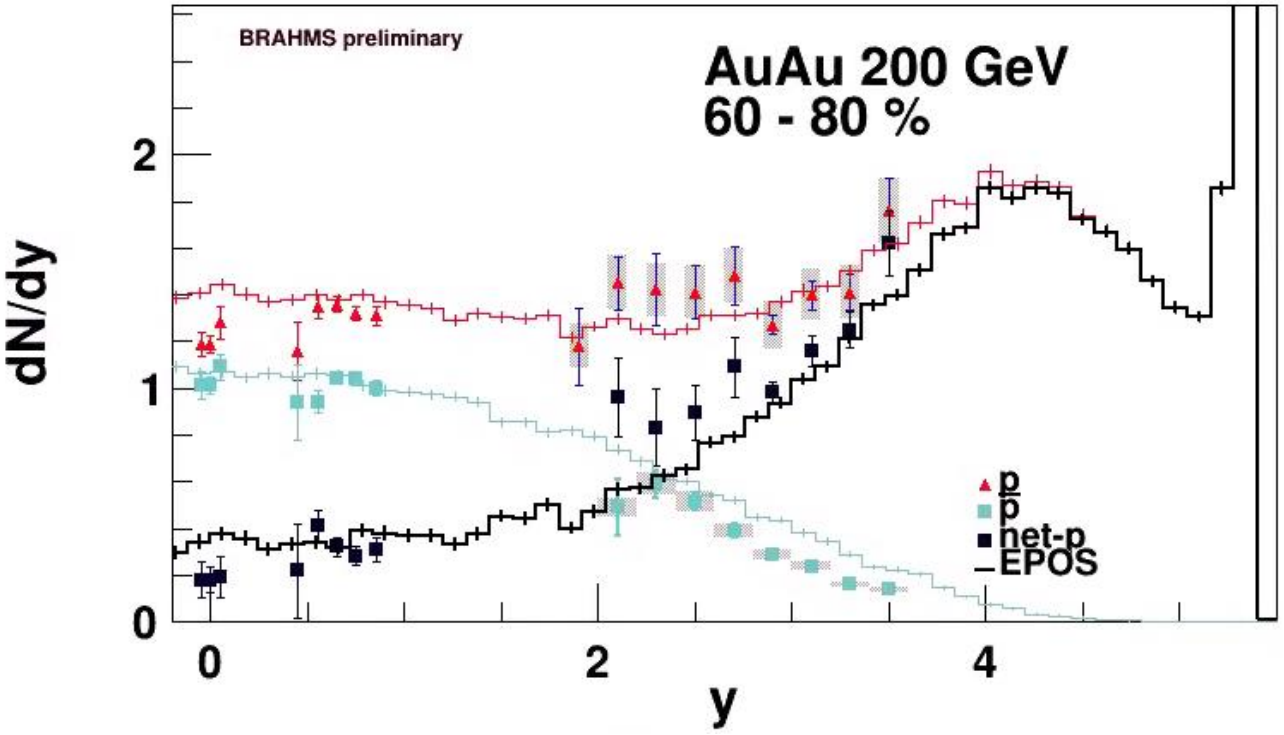


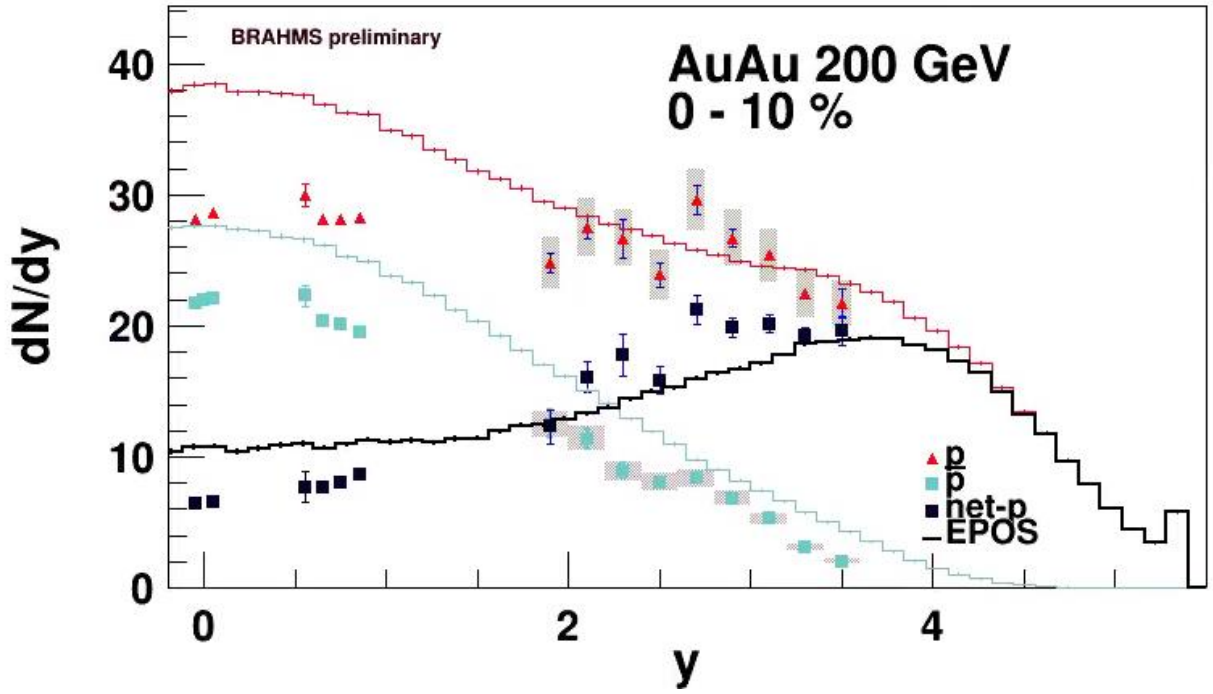
Baryon Transport in rapidity

Pierog/Werner
ISVHECRI 2008



F. Videbœk (BRAHMS) Baryon Dynamics 2024





EPOS 1.99 (similar results with EPOS-LHC):
reasonably well matched with peripheral data, but different in central collisions

Systematic Measurements of Identified Particle Spectra in pp, d^+ Au and Au+Au Collisions from STAR

STAR Collaboration • B.I. Abelev (Illinois U., Chicago) et al. (Aug, 2008)

Published in: *Phys.Rev.C* 79 (2009) 034909 • e-Print: 0808.2041 [nucl-ex]

pdf links DOI cite datasets claim
reference search 1,244 citations

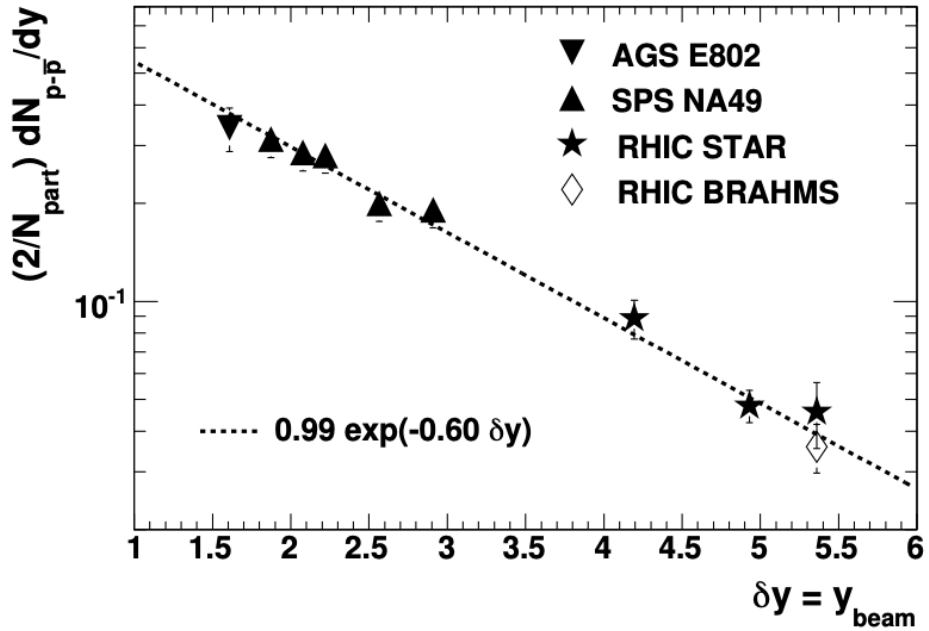


FIG. 29: The ratio of mid-rapidity inclusive net-protons to half of the number of participants in central heavy-ion collisions as a function of the rapidity shift. The AGS data is taken from Refs. [75, 86], SPS data from Refs. [87, 88, 89], and BRAHMS data from Ref. [90]. The published SPS data have already been corrected for weak-decays, the size of which is of the order 20-25% [88], so we have added 25% to the published net-proton yields to obtain the inclusive ones. Errors shown are total statistical and systematic uncertainties. The dashed line is an exponential fit to the data.

shift, obtained from central collisions at different energies, as a "measure" of the rapidity distribution of net-protons in central Au+Au collisions at the top RHIC energy. Since the net-protons shown in Fig. 29 contain equal contributions from the two colliding nuclei, the net-proton rapidity distribution in Au+Au collisions at the top RHIC energy is the data points in Fig. 29 multiplied by a factor varying between 1/2 and 1. At small $\delta y \sim 0$ the net-proton density should be close to 1/2 of those shown in Fig. 29, and at large δy (i.e. nearly mid-rapidity) the factor should be close to 1. Assuming an exponential variation in this factor between 1/2 and 1, i.e. a net-proton rapidity distribution of $\frac{dN_{p-\bar{p}}/dy}{N_{\rm part}/2} = 2^{\delta y/5.36-1} \times 0.99\exp(-0.60\delta y) = 0.50\exp(-0.47\delta y)$ in 200 GeV Au+Au collisions (where 5.36 is the beam rapidity for 100 GeV beams), we estimate a rapidity shift of $\langle\delta y\rangle = 1/0.47 \approx 2.1$. It is interesting to note that the integral of the above rapidity distribution between 0 and 5.36 comes out to be rather close to unity as required by proper normalization. Clearly the exponential form we used is a simplification. BRAHMS has measured the rapidity distribution of net-protons in the range $0 < y < 3$ in central Au+Au collisions at 200 GeV, and used a more sophisticated functional form to estimate the average rapidity shift to be approximately 2.06 ± 0.16 [90].

Confusing Evidence AGAINST junction

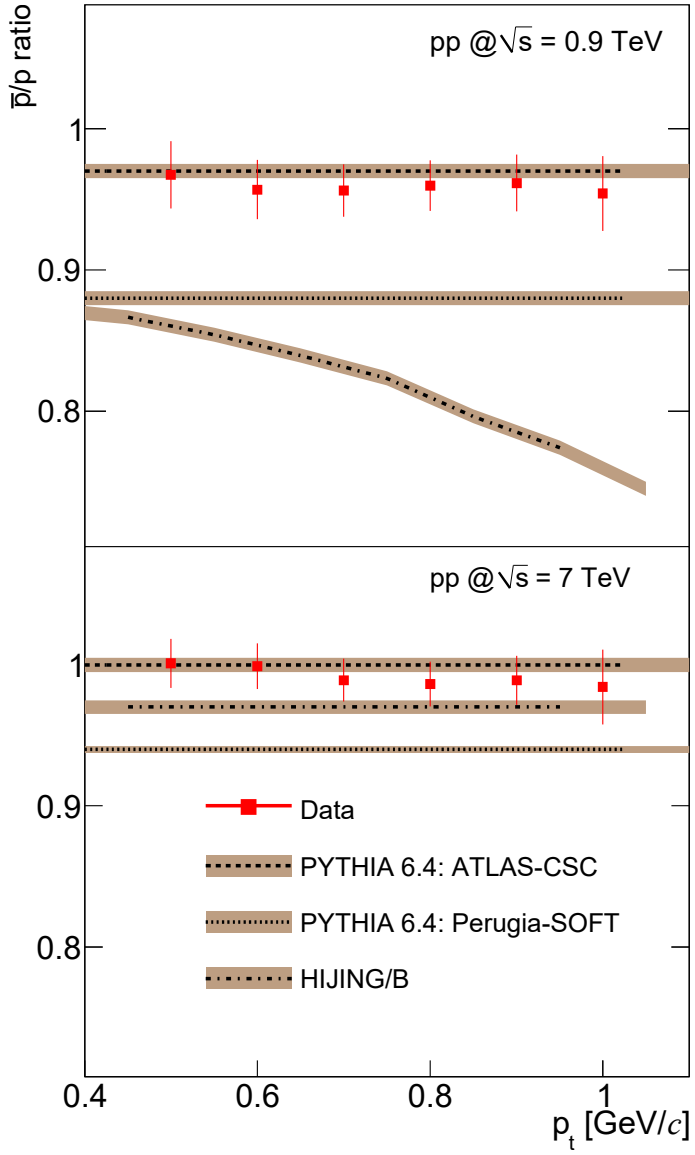
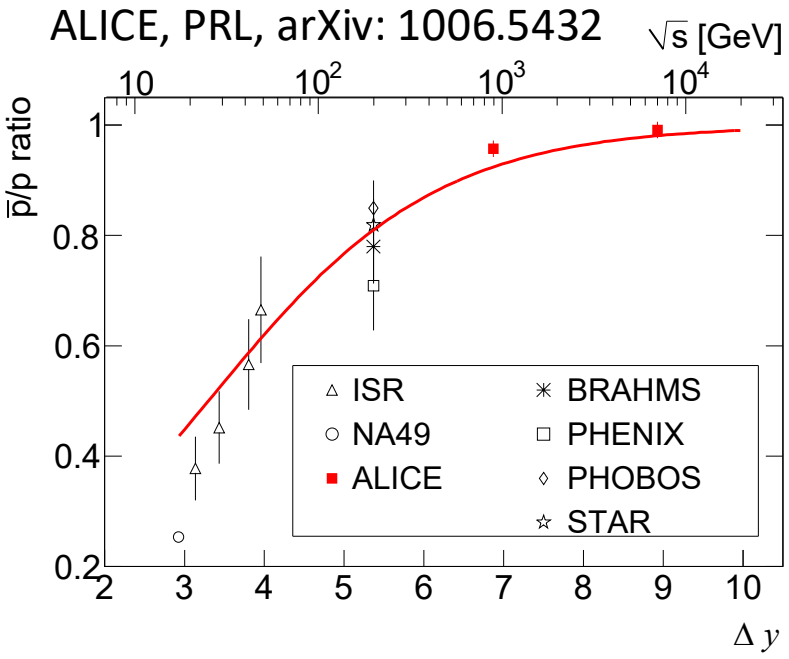


FIG. 3. (Color online) The p_t dependence of the $\bar{p}/p$ ratio integrated over $|y| < 0.5$ for pp collisions at $\sqrt{s} = 0.9$ TeV (top) and $\sqrt{s} = 7$ TeV (bottom). Only statistical errors are shown for the data; the width of the Monte Carlo bands indicates the statistical uncertainty of the simulation results.

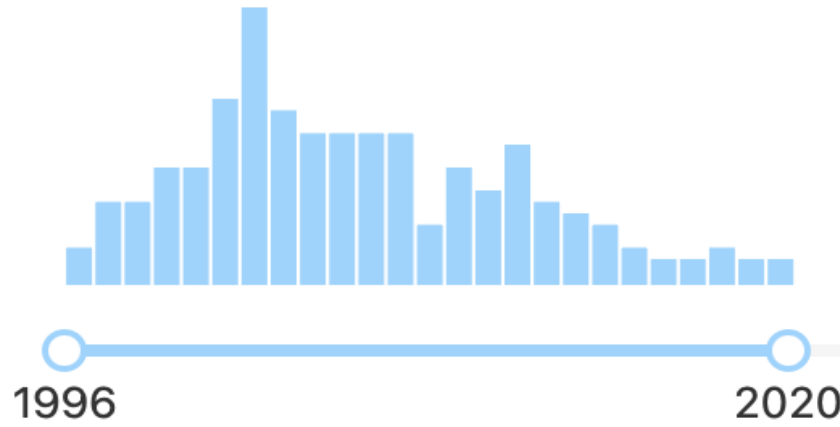
Abstract:
The results are consistent with the conventional model of baryon-number transport and set stringent limits on any additional contributions to baryon-number transfer over very large rapidity intervals in pp collisions.

It rules out α_B=0.5 + valence-quark transport

A rough approximation of the Δy dependence of the ratio R can be derived in the Regge model, where baryon pair production at very high energy is governed by Pomeron exchange and baryon transport by string-junction exchange [5]. In this case the $p/\bar{p}$ ratio takes the simple form $1/R = 1 + C\exp[(\alpha_J - \alpha_P)\Delta y]$. We have fitted such a function to the data, using as value for the Pomeron intercept $\alpha_P = 1.2$ [23] and $\alpha_J = 0.5$, whereas C, which determines the relative contributions of the two diagrams, is adjusted to the measurements from ISR, RHIC, and LHC. The fit, shown in Fig. 4, gives a reasonable description of the data with only one free parameter (C), except at lower energies, where contribu-

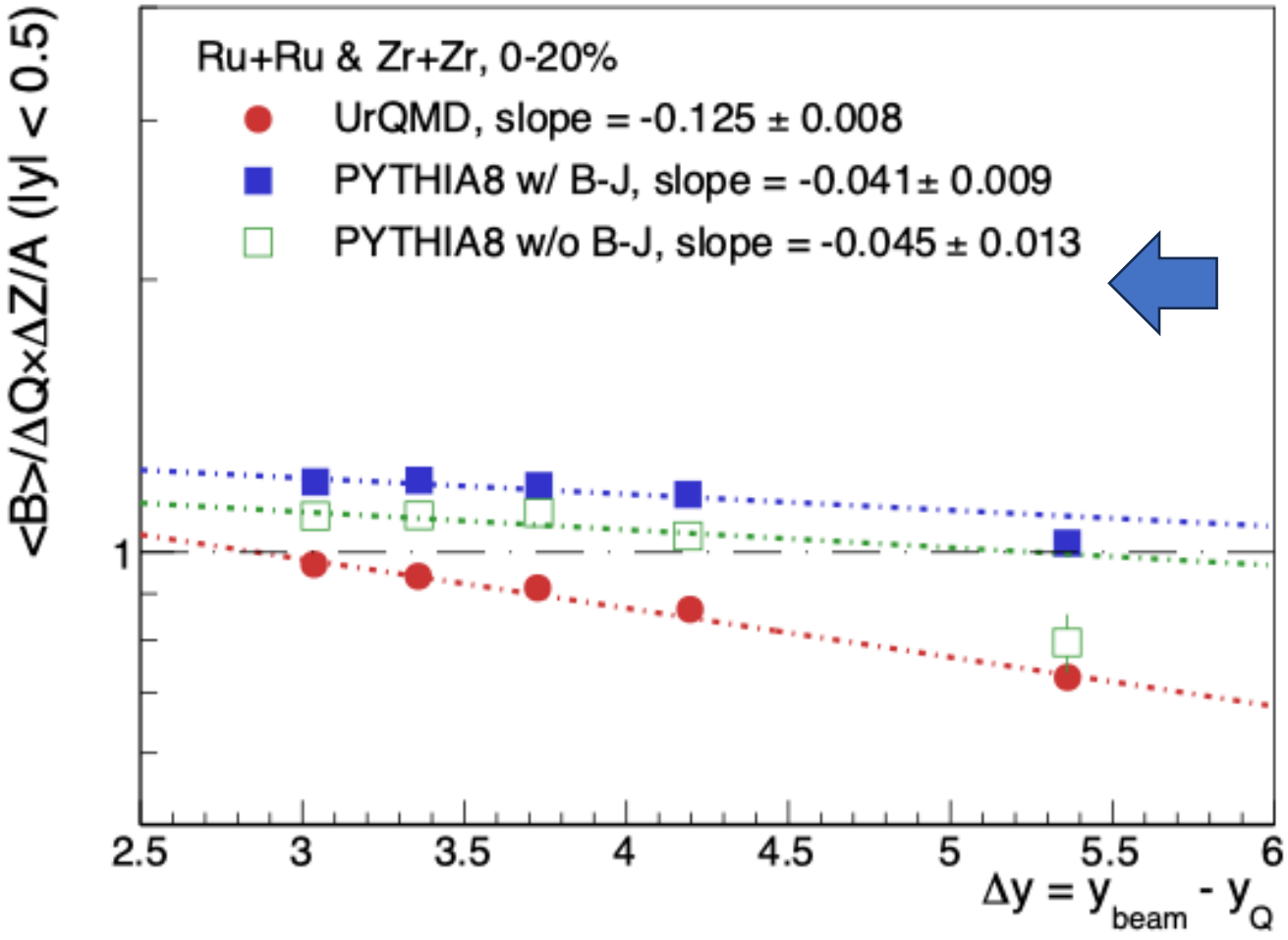


Date of paper



Charge vs baryon rapidity (transport) slope

STAR BUR 2025



Unfortunately, RHIC shut down before this was done;
LHCb Fixed target?

q=u,d

Measure charge transport in high-energy nuclear collisions with an energy scan of isobaric collisions

Wendi Lv, Niseem Magdy, Rongrong Ma, Zebo Tang, Prithwish Tribedy, Chun Yuen Tsang, Zhangbu Xu

We present a method to measure electric-charge transport in high-energy nuclear collisions using a beam-energy scan of isobaric systems. Comparing collisions of nuclei with identical mass number but different atomic number allows the charge difference (ΔQ) to be extracted with a double-ratio technique that suppresses most experimental systematic uncertainties. By varying the beam energy, the rapidity gap (Δy) over which electric charge is transported can be systematically scanned. Simulations of Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}}$=19.6–200GeV with UrQMD and PYTHIA Angantyr show that midrapidity ΔQ decreases exponentially with increasing Δy, with the slope parameter exhibiting strong model dependence. Comparisons with the baryon number transport reveal distinct patterns. In both UrQMD and PYTHIA Angantyr (with and without final-state baryon junctions), where baryon number is carried solely by valence quarks, the rapidity slope for baryon transport is larger than that for electric-charge transport. In contrast, scenarios that include baryon junctions in the initial state are expected to produce the opposite trend. This demonstrates that an isobar beam-energy scan provides a sensitive probe of electric-charge transport and offers new constraints on the microscopic mechanisms governing conserved-charge redistribution in QCD matter.

Comments: 8 pages, 7 figures
Subjects: **Nuclear Experiment (nucl-ex)**; High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:2604.02825 **[nucl-ex]**

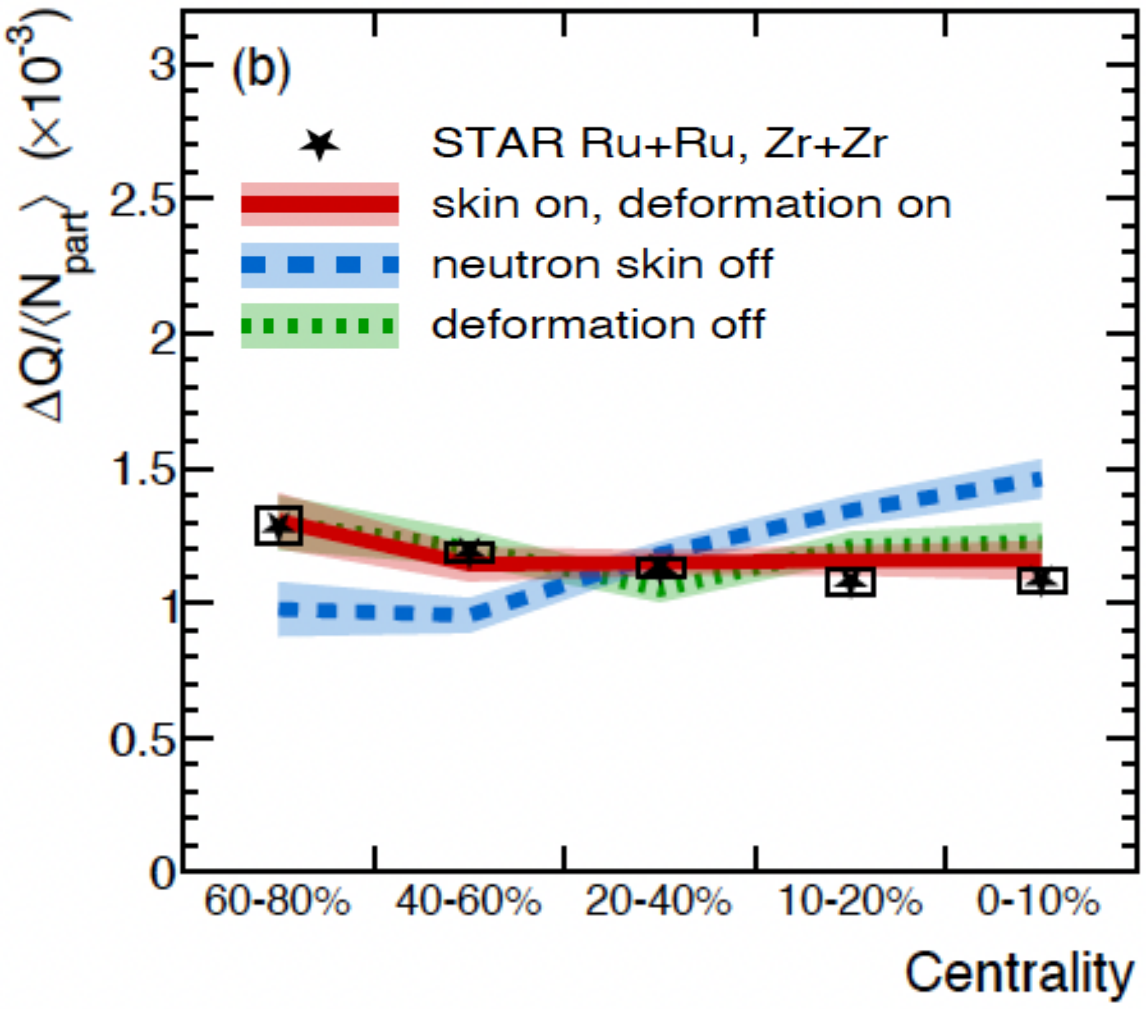
Lv et al., Eur.Phys.J.C 86 (2026) 9, 1044

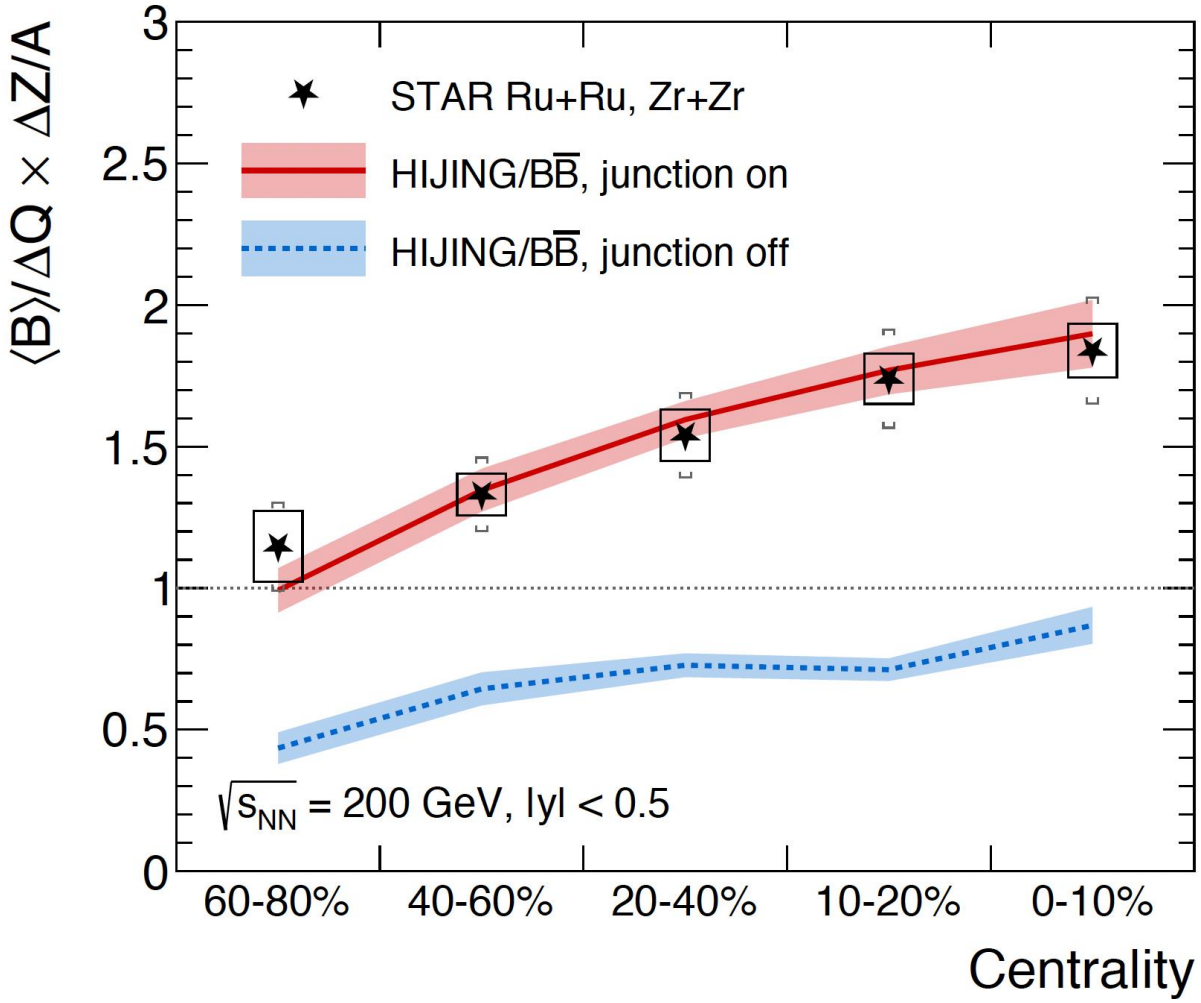
RHIC top energy data and baryon junction would predict a positive slope difference

> "This is one of the most significant results achieved by the RHIC program," says Dmitri Kharzeev, a physicist at Stony Brook University, who was not involved with the new paper but is mentioned in its acknowledgments. "It reshapes our understanding of baryon structure and how baryonic matter emerged."

https://www.scientificamerican.com/article/physicists-find-major-clue-to-matters-biggest-mystery/

Quantitative modeling using HIJING/B



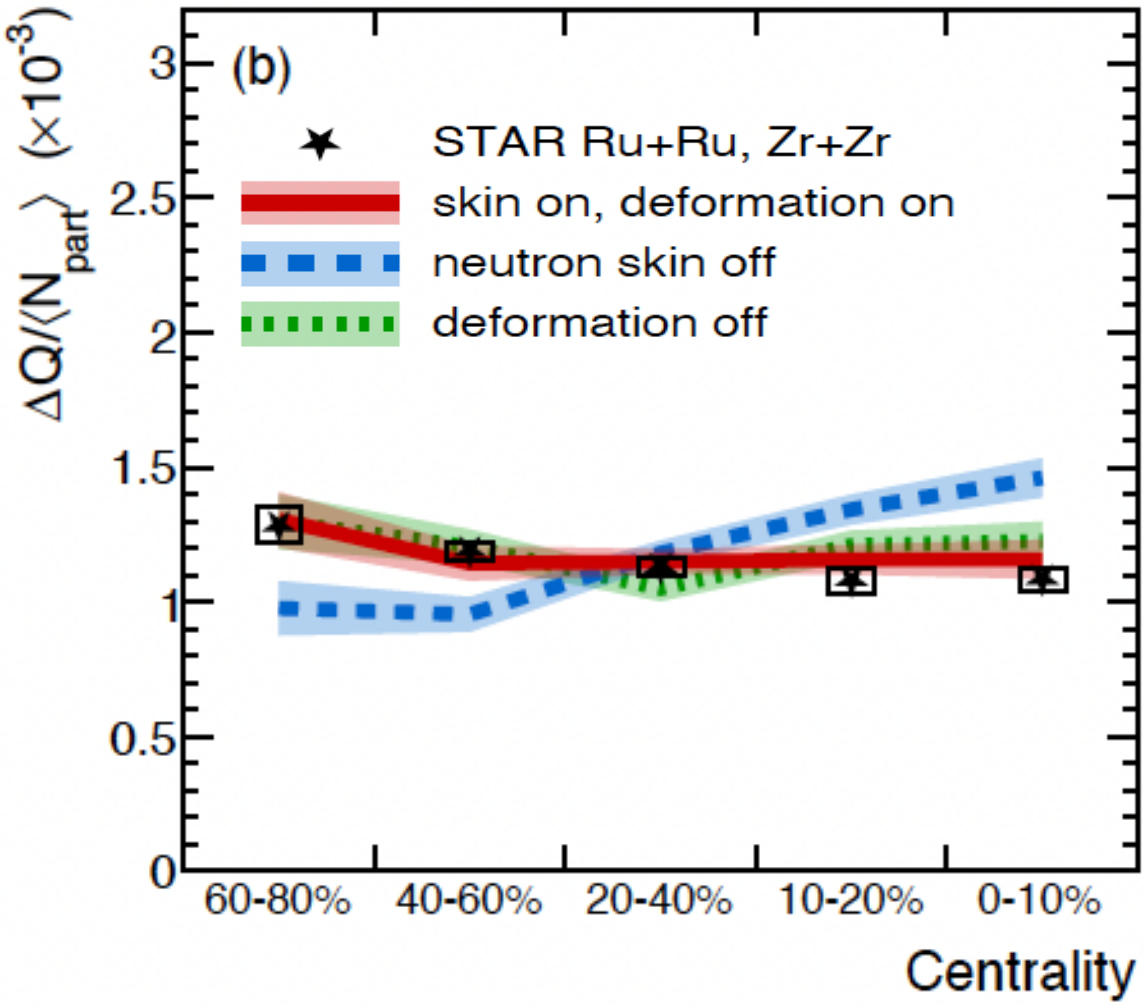


Centrality dependence of Q sensitive to neutron skin
Overall B/Q ratio sensitive to junction

A. Pandav, XZB, Mohanty, arXiv:2611.16977

O+O as baseline to determine neutron skins

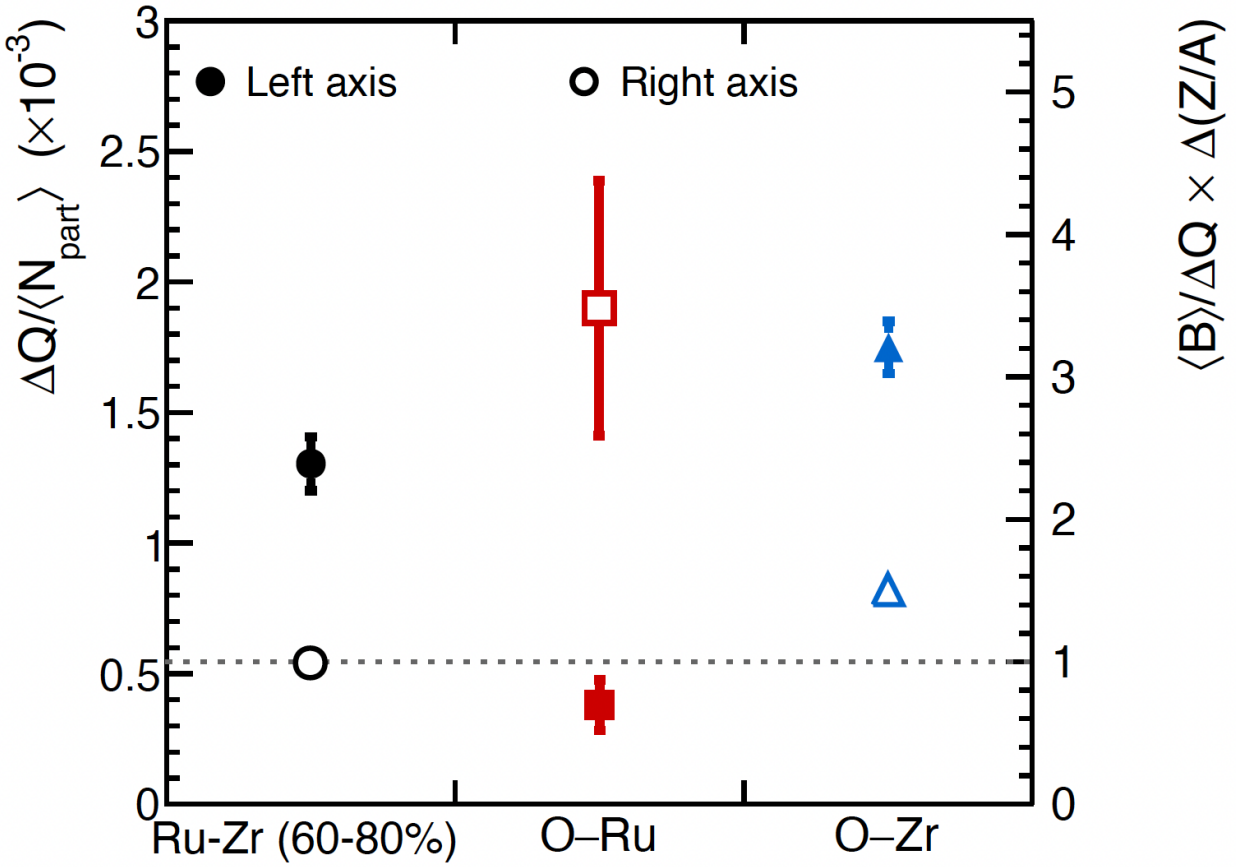
A. Pandav, XZB, Mohanty, arXiv:2611.16977



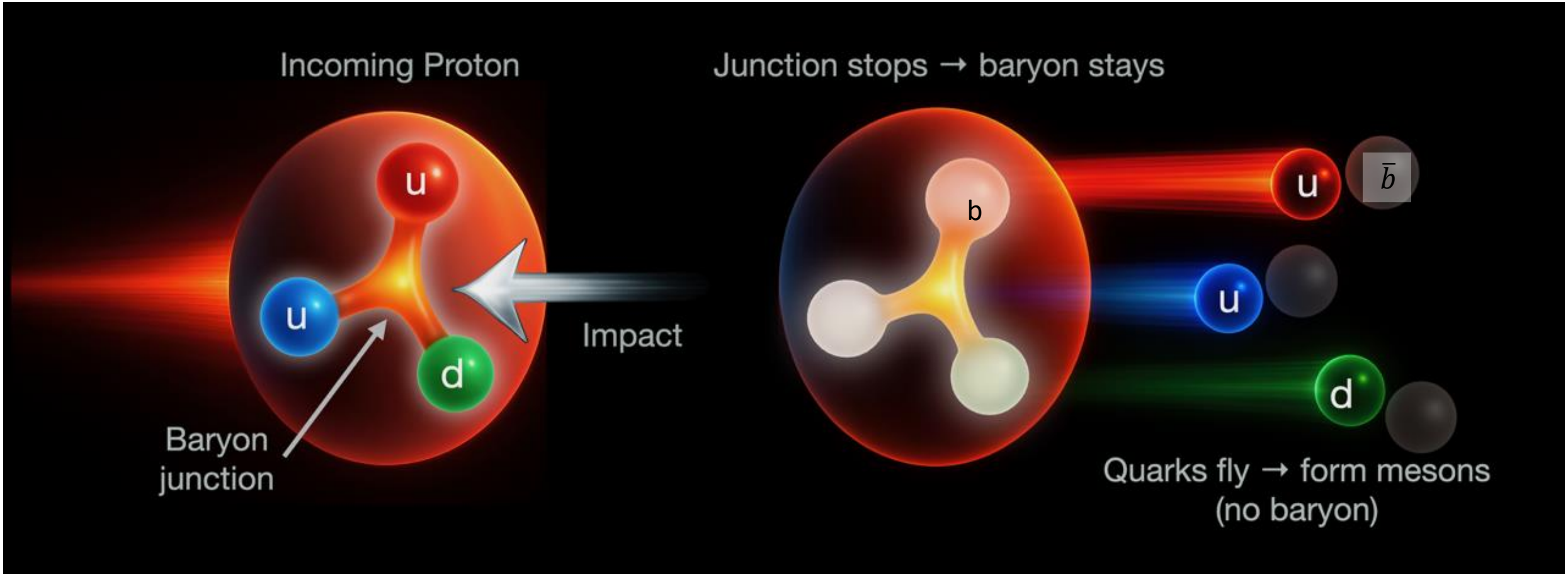
Ru+Ru, Zr+Zr 60-80% and O+O 20-30%

$\sqrt{s_{NN}}$ = 200 GeV, |y| < 0.5

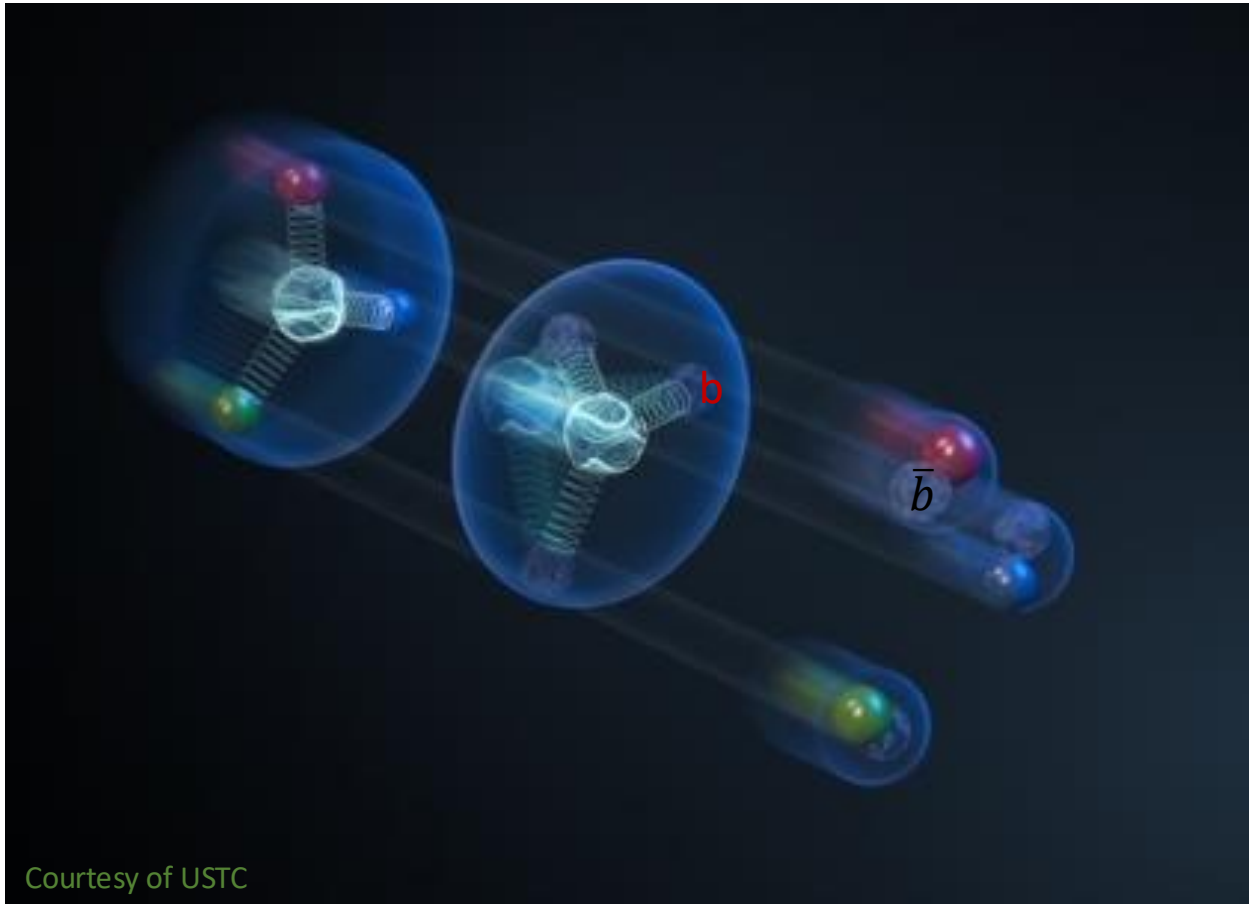
HIJING/B$\bar{B}$ v2.0, junction on



Flavor-Independent Baryon Transport



Flavor-Independent Baryon Transport

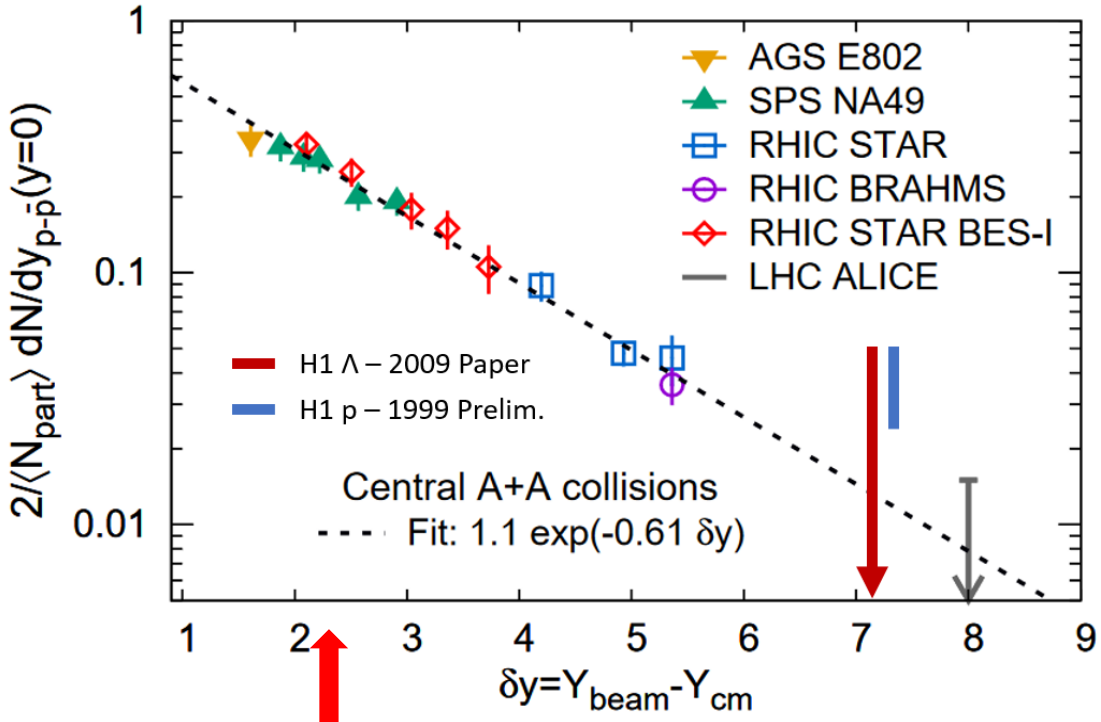


Pull heavy-flavor pairs from vacuum (c,b)

What do we know about e+p collisions

- LHC and HERA energy are too high with small baryon excess (<1%)
- Isobar collisions at EIC with low Q^2 and low-p_t PID to study the charge and baryon transports
- JLab Electron beam at exponential slope of baryon transport in baryon junction model

N. Lewis, et al., arXiv:2205.05685;
Henry Klest (ANL) HERA data



CLAS12 Kinematics
HIAF

Measurement of the Baryon-Antibaryon Asymmetry in Photoproduction at HERA
C. Adloff et al. (H1 Collaboration), ICHEP 1998

Baryon stopping at HERA: Evidence for gluonic mechanism
Boris Kopeliovich (Heidelberg, Max Planck Inst. and Dubna, JINR), Bogdan Povh (Heidelberg, Max Planck Inst.)
Published in: *Phys.Lett.B* 446 (1999) 321-325 • e-Print: hep-ph/9810530 [hep-ph]

What do we know about μ+p (d) collisions

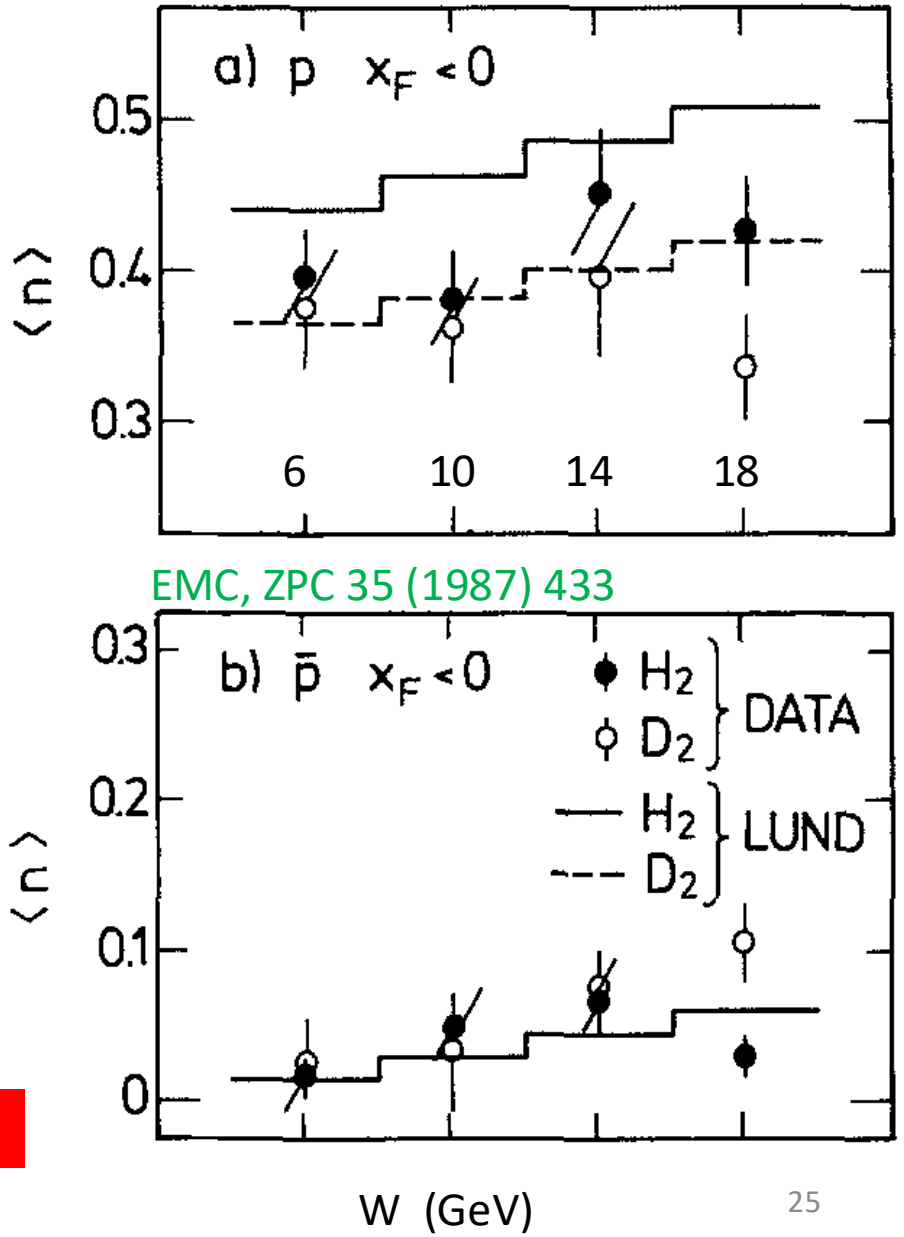
Diquark Lund model predicts a flavor dependence of backward proton production (20%) while data shows little-to-no dependence

Total citations: 19

Fig. 5a-d. Average multiplicities from the H_2 (full circles) and the D_2 target (open circles) vs. W for backward protons a, backward antiprotons b. The histograms show the Lund model predictions (full line: H_2 target, dashed line: D_2 target, full line only where both are the same)

the Lund model (JETSET62) predicts a higher yield of backward going protons from hydrogen than from deuterium, an effect which is less pronounced in the data.

Both proton and antiproton yields show independent on target flavor



EMC, ZPC 35 (1987) 433

Simulation at present day

Same kinematics as EMC, reproduce the simulation result

Next, using EIC kinematics,

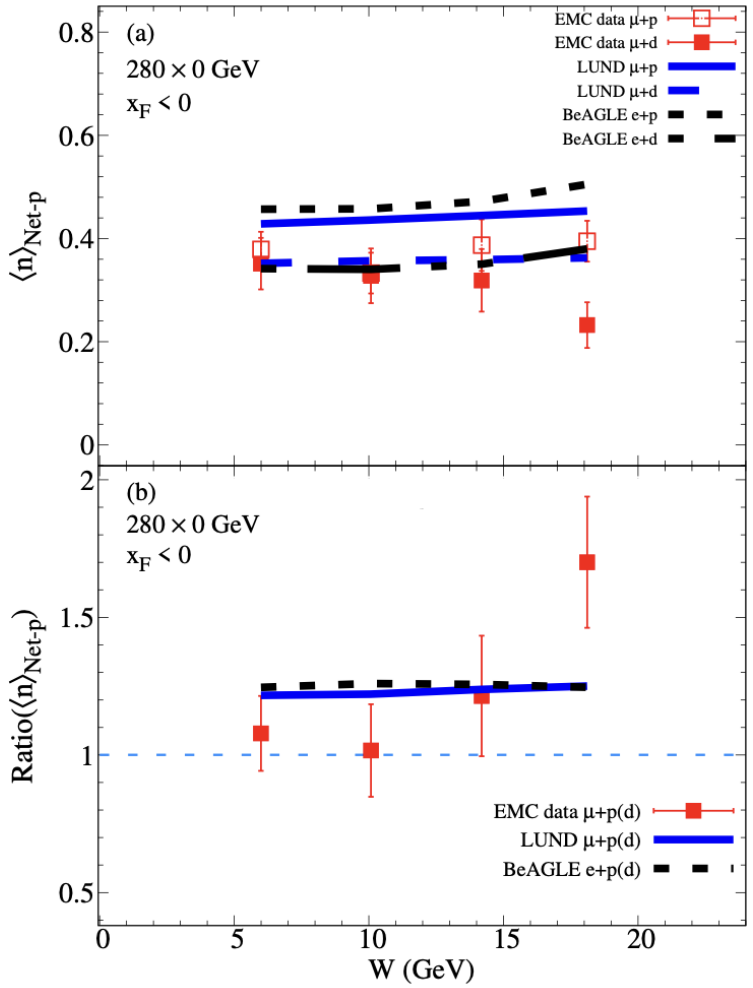


FIG. 7. The W dependence of the net-proton for μ+p and μ+d at 280-GeV muon on fixed targets are shown in panel (a). The ratios between μ+p and μ+d are presented in panel (b). Data and LUND model calculations are extracted from Ref. [15].

Niseem Magdy (SBU), arXiv:2408.08713

Does proton transport independent of target flavor

Xiaqing Li (SDU), Bill Li (MSU), Zhihong Ye (THU)

EIC simulation of baryon vs charge transports

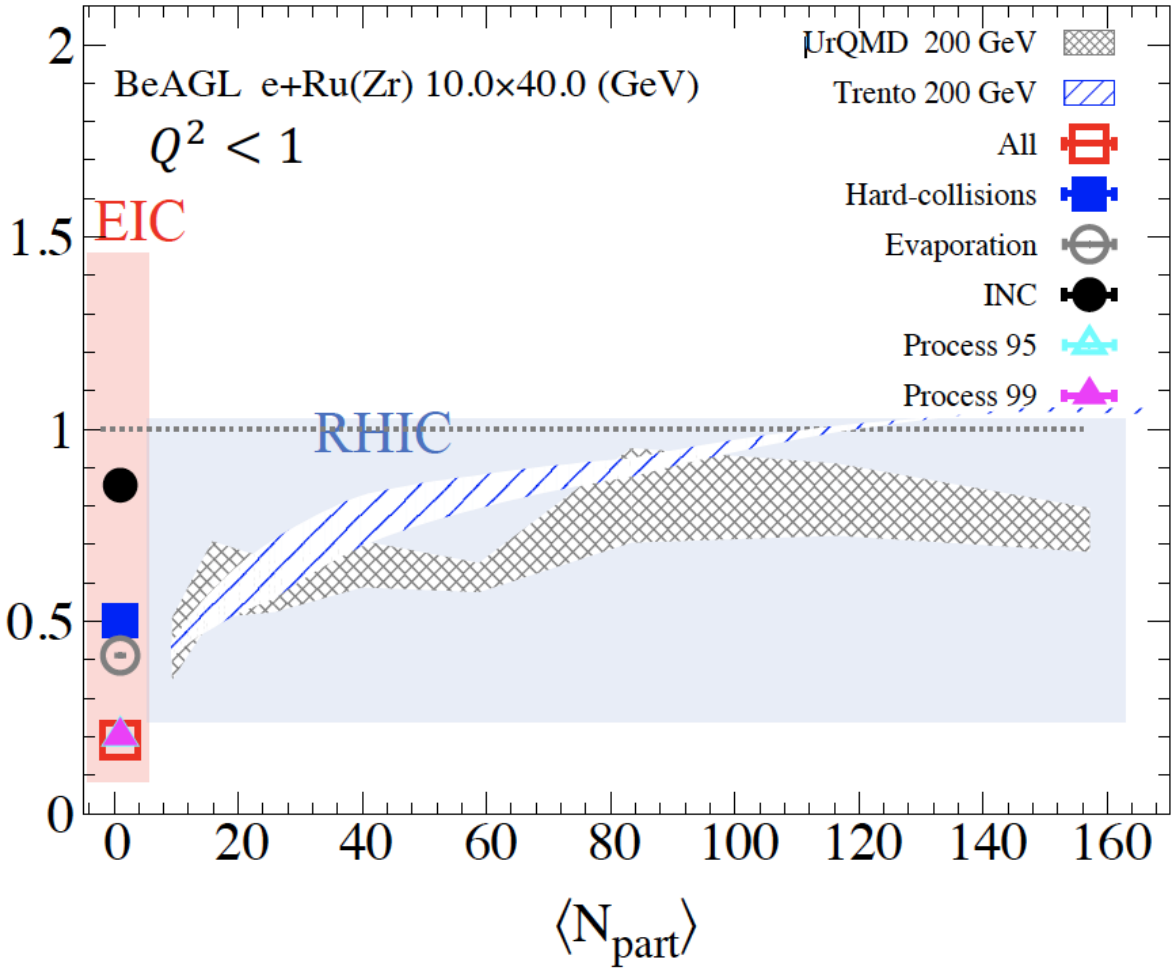
Summary of the 1st workshop on 2nd EIC detector (05/15/23)

Golden Channels Strawman

CHANNEL	PHYSICS	DETECTOR II OPPORTUNITY
Diffractive dijet	Wigner Distribution	detection of forward scattered proton/nucleus + detection of low p_T particles
DVCS on nuclei	Nuclear GPDs	High resolution photon + detection of forward scattered proton/nucleus
Baryon/Charge Stopping	Origin of Baryon # in QCD	PID and detection for low p_T pi/K/p
F_2 at low x and Q^2	Probes transition from partonic to color dipole regime	Maximize Q^2 tagger down to 0.1 GeV and integrate into IR.
Coherent VM Production	Nuclear shadowing and saturation	High resolution tracking for precision t reconstruction

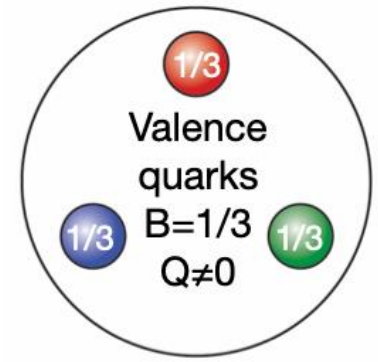
These channels are just a starting point, a way to initially focus activities within the group. Additional ideas and efforts are welcome!

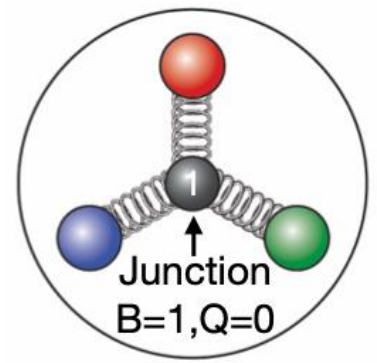
Niseem Magdy etal., *Eur.Phys.J.C* 84 (2024) 12, 1326

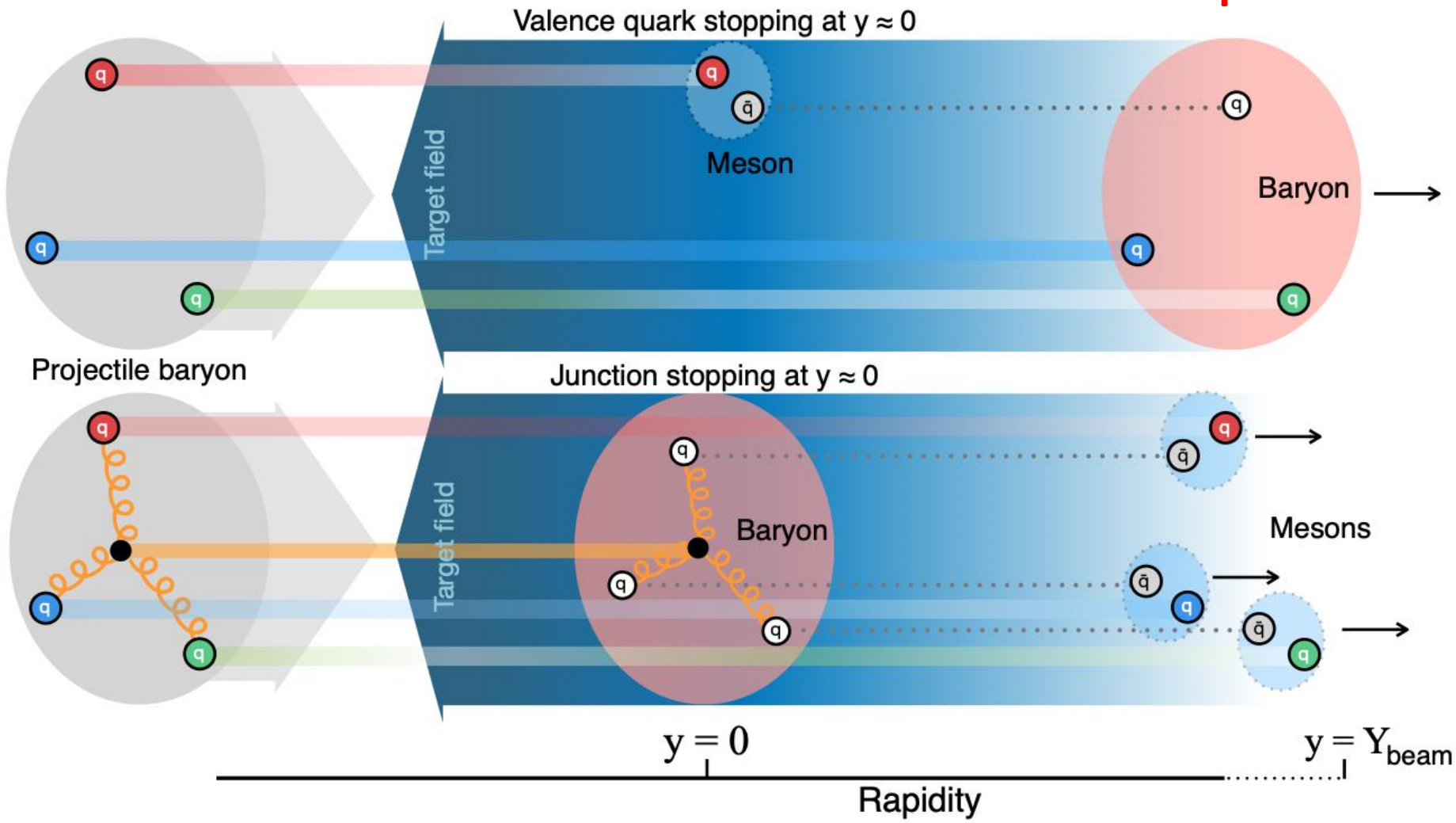


Flavor Independent Baryon Transport

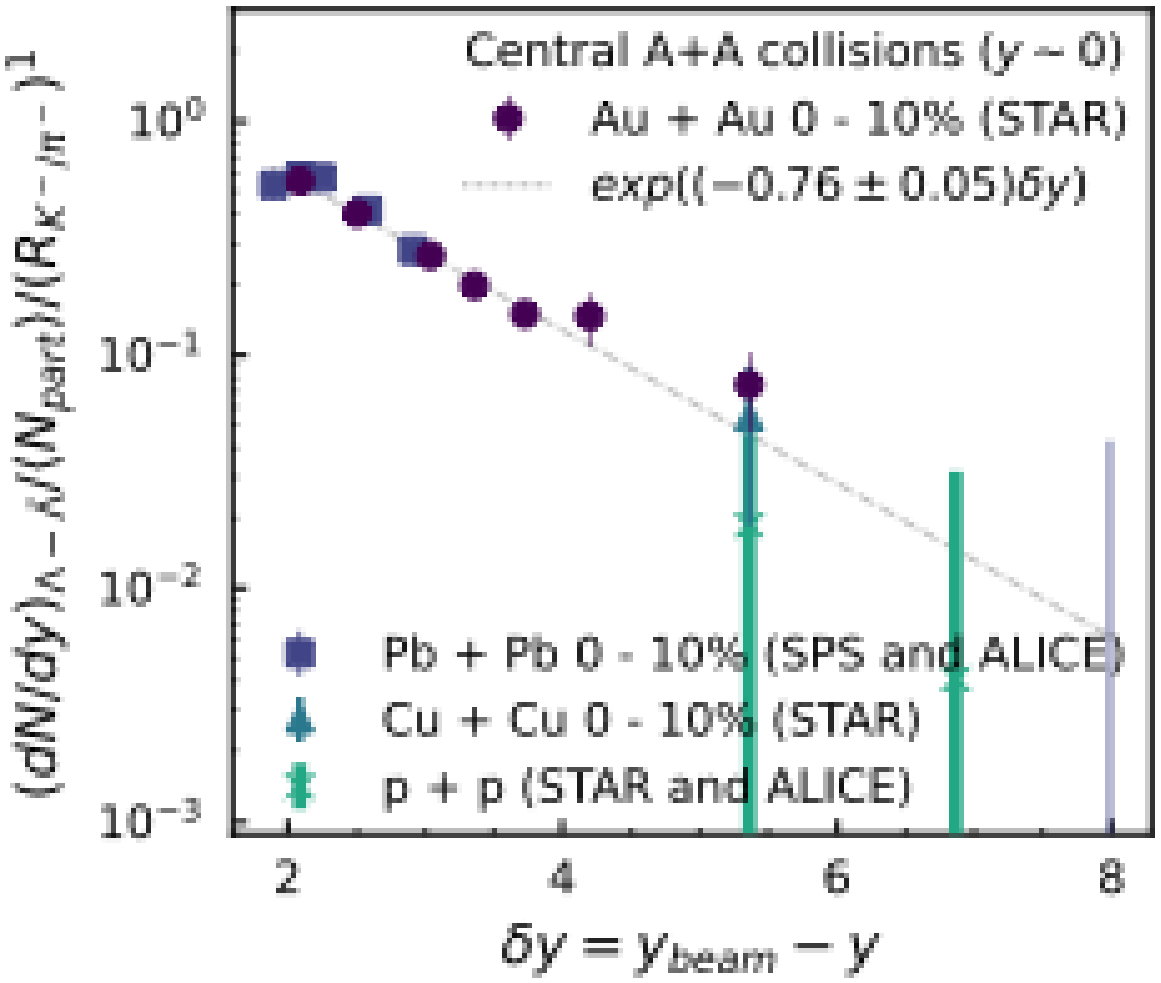


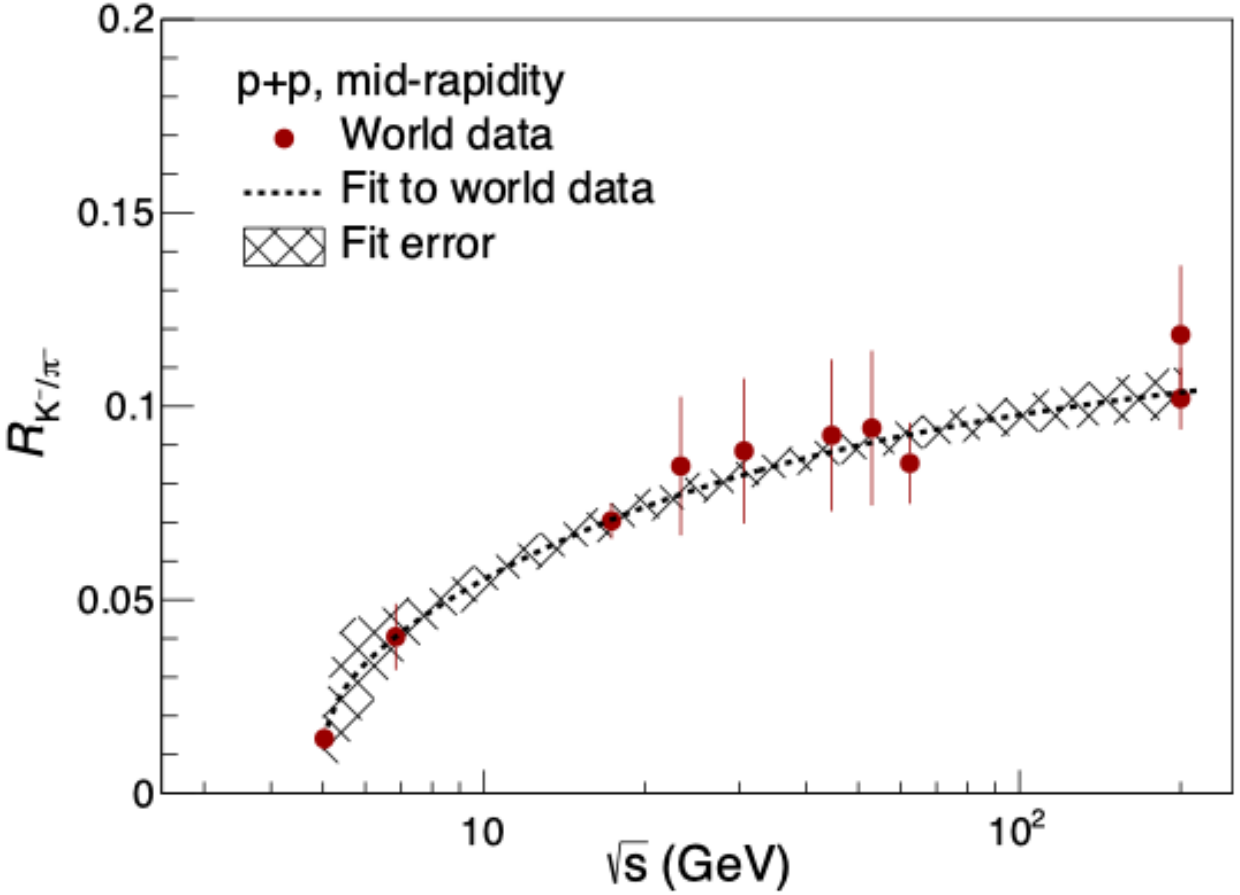




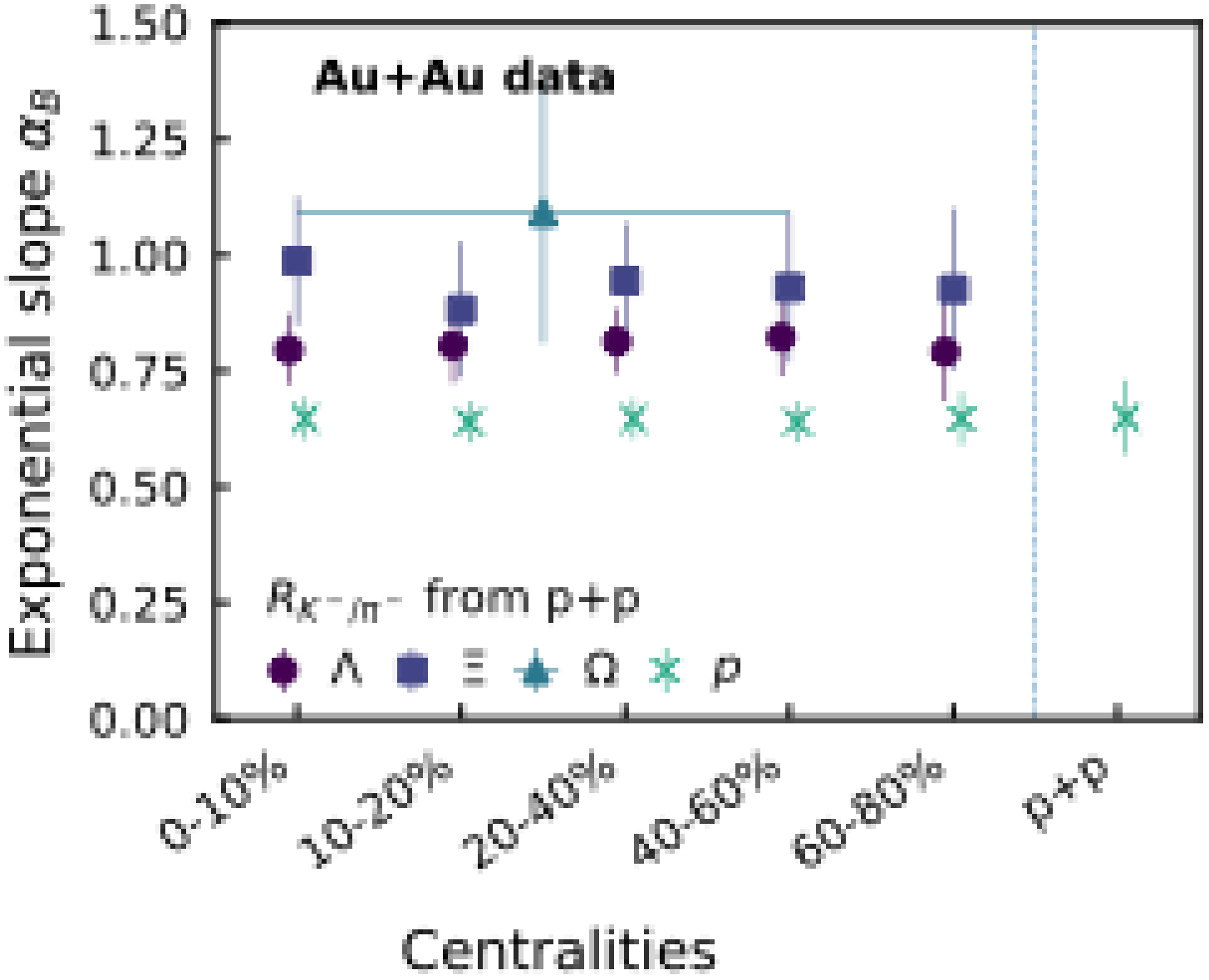


Hyperon Rapidity Slopes





Flavor independence of baryon transport

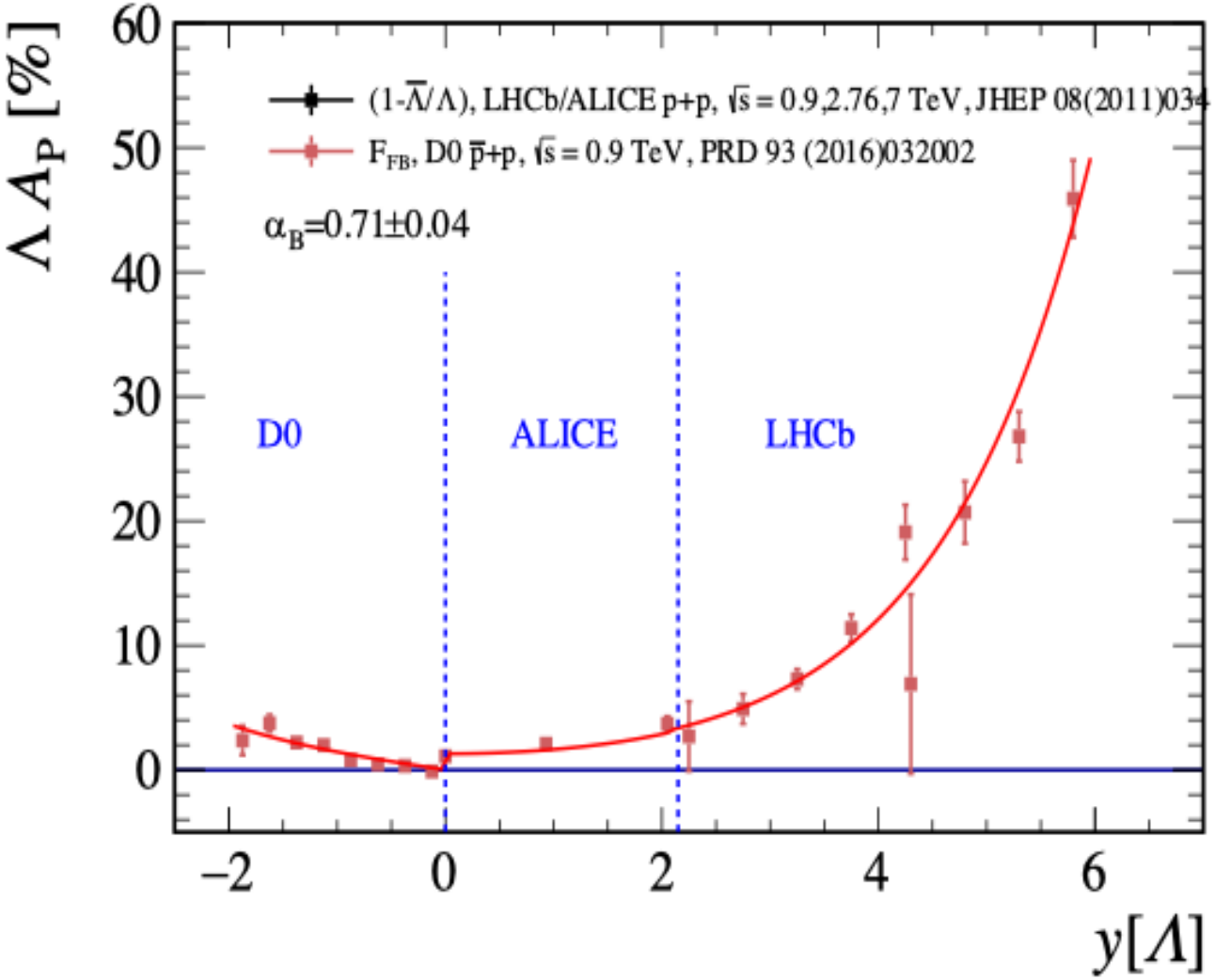


Beam energy dependence of net-hyperon yield and its implication on baryon transport mechanism

Chun Yuen Tsang (Kent State U. and Brookhaven), Rongrong Ma (Brookhaven), Prithwish Tribedy (Brookhaven), Zhangbu Xu (Kent State U. and Brookhaven) (Sep 10, 2024)

Published in: *Phys.Lett.B* 860 (2025) 139205 • e-Print: 2409.06492 [nucl-th]

Combined ALICE/LHCb/D0 $\bar{\Lambda}/\Lambda$



Eur. Phys. J. C (2013) 73:2496
DOI 10.1140/epjc/s10052-013-2496-5
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Experimental Physics

Mid-rapidity anti-baryon to baryon ratios in pp collisions at $\sqrt{s} = 0.9,\ 2.76$ and 7 TeV measured by ALICE

The ALICE Collaboration*
CERN, 1211 Geneva 23, Switzerland

Measurement of V^0 production ratios in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV

JHEP08(20

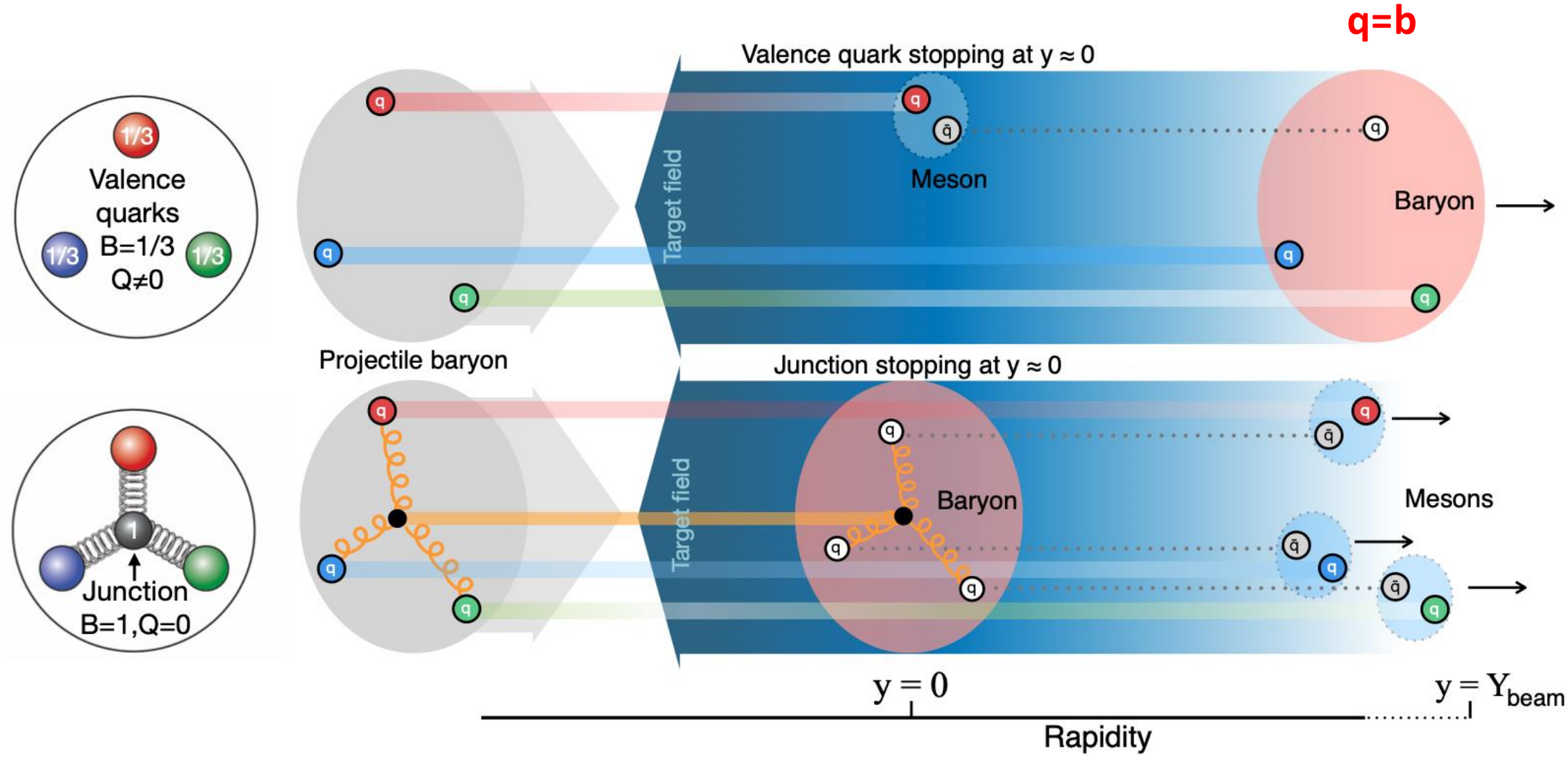
The LHCb collaboration

Measurement of the forward-backward asymmetry of Λ and $\bar{\Lambda}$ production in $p\bar{p}$ collisions

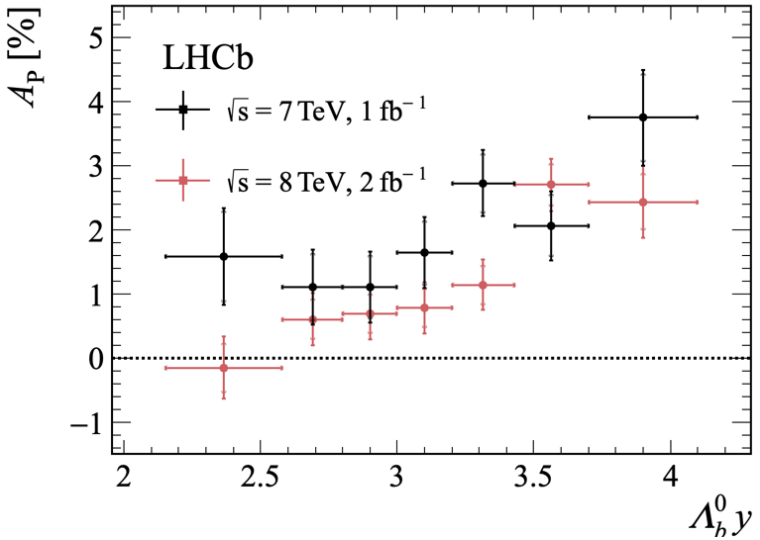
D0 Collaboration · Victor Mukhamedovich Abazov (Dubna, JINR) Show All(368)
Nov 16, 2015

- LHC p+p: $\frac{\bar{\Lambda}}{\Lambda} \propto (e^{-\alpha_B y} + e^{\alpha_B y})$
- Tevatron $\bar{p}$+p: $\frac{\bar{\Lambda}}{\Lambda} \propto (e^{-\alpha_B y} - e^{\alpha_B y})$

Flavor Independent Baryon Transport



LHCb Λ_b paper



JHEP

Published for SISSA by Springer

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Revised: September 6, 2021
Accepted: September 14, 2021
Published: October 7, 2021

Observation of a $\Lambda_b^0 - \overline{\Lambda}_b^0$ production asymmetry in proton-proton collisions at $\sqrt{s} = 7$ and 8 TeV

The LHCb collaboration

E-mail: sascha.stahl@cern.ch

Abstract: This article presents differential measurements of the asymmetry between Λ_b^0 and $\overline{\Lambda}_b^0$ baryon production rates in proton-proton collisions at centre-of-mass energies of $\sqrt{s} = 7$ and 8 TeV collected with the LHCb experiment, corresponding to an integrated luminosity of 3 fb^{-1}. The Λ_b^0 baryons are reconstructed through the inclusive semileptonic decay $\Lambda_b^0 \to \Lambda_c^+ \mu^- \overline{\nu}_\mu X$. The production asymmetry is measured both in intervals of rapidity in the range $2.15 < y < 4.10$ and transverse momentum in $2 < p_T < 27$ GeV/c. The results are found to be incompatible with symmetric production with a significance of 5.8 standard deviations for both $\sqrt{s} = 7$ and 8 TeV data, assuming no CP violation in the decay. There is evidence for a trend as a function of rapidity with a significance of 4 standard deviations. Comparisons to predictions from hadronisation models in Pythia and heavy-quark recombination are provided. This result constitutes the first observation of a particle-antiparticle asymmetry in b-hadron production at LHC energies.

Keywords: Hadron-Hadron scattering (experiments), Heavy quark production, proton-proton scattering, Hard scattering, B physics

ArXiv ePrint: 2107.09593

Open Access, Copyright CERN, for the benefit of the LHCb Collaboration. Article funded by SCOAP^3.

https://doi.org/10.1007/JHEP10(2021)060

JHEP10(2021)060

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2015-223
LHCb-PAPER-2015-032
25 January 2016

Study of the production of Λ_b^0 and $\overline{B}^0$ hadrons in pp collisions and first measurement of the $\Lambda_b^0 \to J/\psi p K^-$ branching fraction

The LHCb collaboration†

Abstract

The product of the Λ_b^0 ($\overline{B}^0$) differential production cross-section and the branching fraction of the decay $\Lambda_b^0 \to J/\psi p K^-$ ($\overline{B}^0 \to J/\psi \overline{K}^*(892)^0$) is measured as a function of the beauty hadron transverse momentum, p_T, and rapidity, y. The kinematic region of the measurements is $p_T < 20$ GeV/c and $2.0 < y < 4.5$. The measurements use a data sample corresponding to an integrated luminosity of 3 fb^{-1} collected by the LHCb detector in pp collisions at centre-of-mass energies $\sqrt{s} = 7$ TeV in 2011 and $\sqrt{s} = 8$ TeV in 2012. Based on previous LHCb results of the fragmentation fraction ratio, $f_{\Lambda_b^0}/f_d$, the branching fraction of the decay $\Lambda_b^0 \to J/\psi p K^-$ is measured to be

$$\mathcal{B}(\Lambda_b^0 \to J/\psi p K^-) = (3.17 \pm 0.04 \pm 0.07 \pm 0.34^{+0.45}_{-0.28}) \times 10^{-4},$$

where the first uncertainty is statistical, the second is systematic, the third is due to the uncertainty on the branching fraction of the decay $\overline{B}^0 \to J/\psi \overline{K}^*(892)^0$, and the fourth is due to the knowledge of $f_{\Lambda_b^0}/f_d$. The sum of the asymmetries in the production and decay between Λ_b^0 and $\overline{\Lambda}_b^0$ is also measured as a function of p_T and y. The previously published branching fraction of $\Lambda_b^0 \to J/\psi p \pi^-$, relative to that of $\Lambda_b^0 \to J/\psi p K^-$, is updated. The branching fractions of $\Lambda_b^0 \to P_c^+(\to J/\psi p) K^-$ are determined.

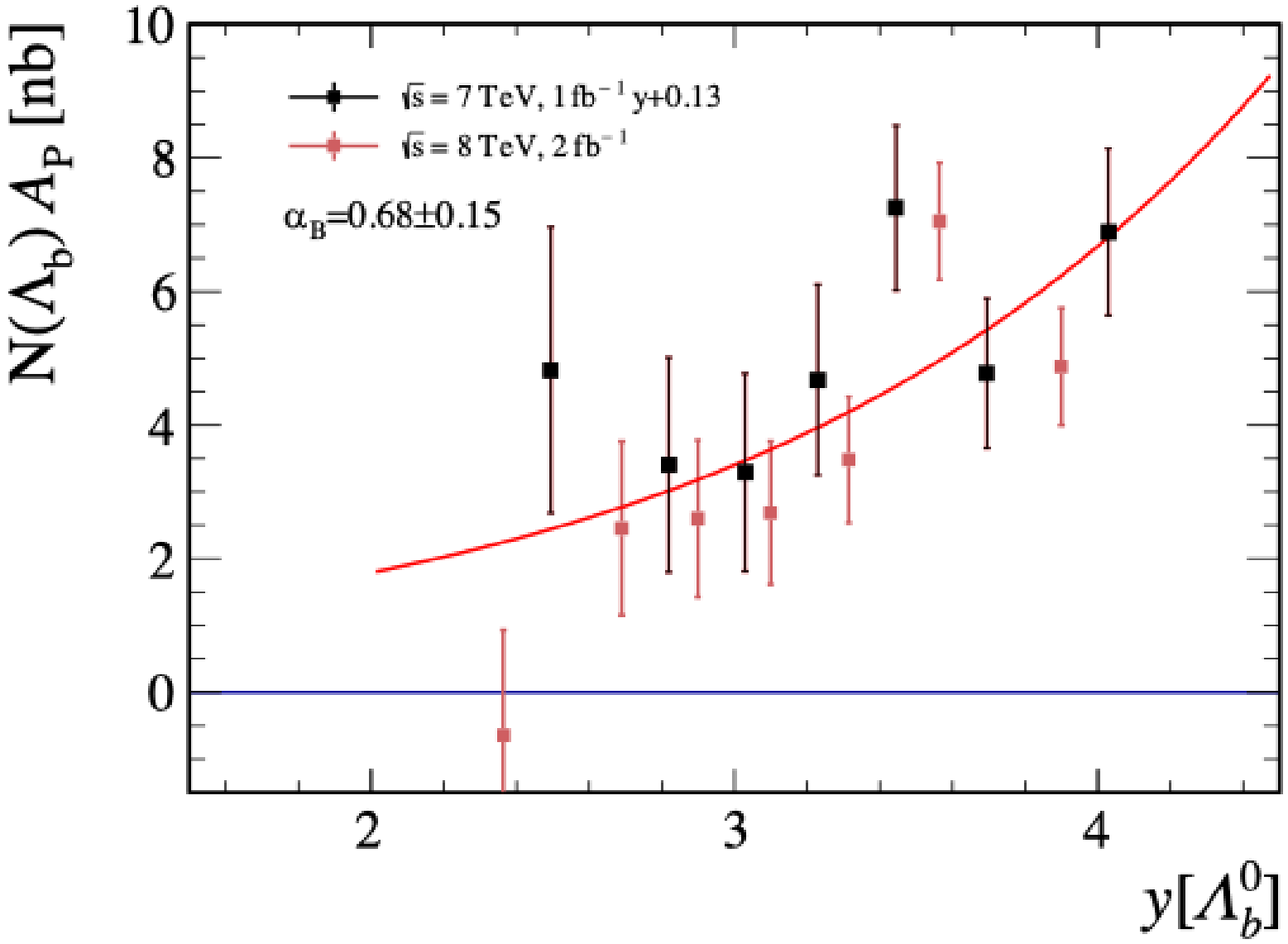
Published in Chin. Phys. C40 (2016) 011001

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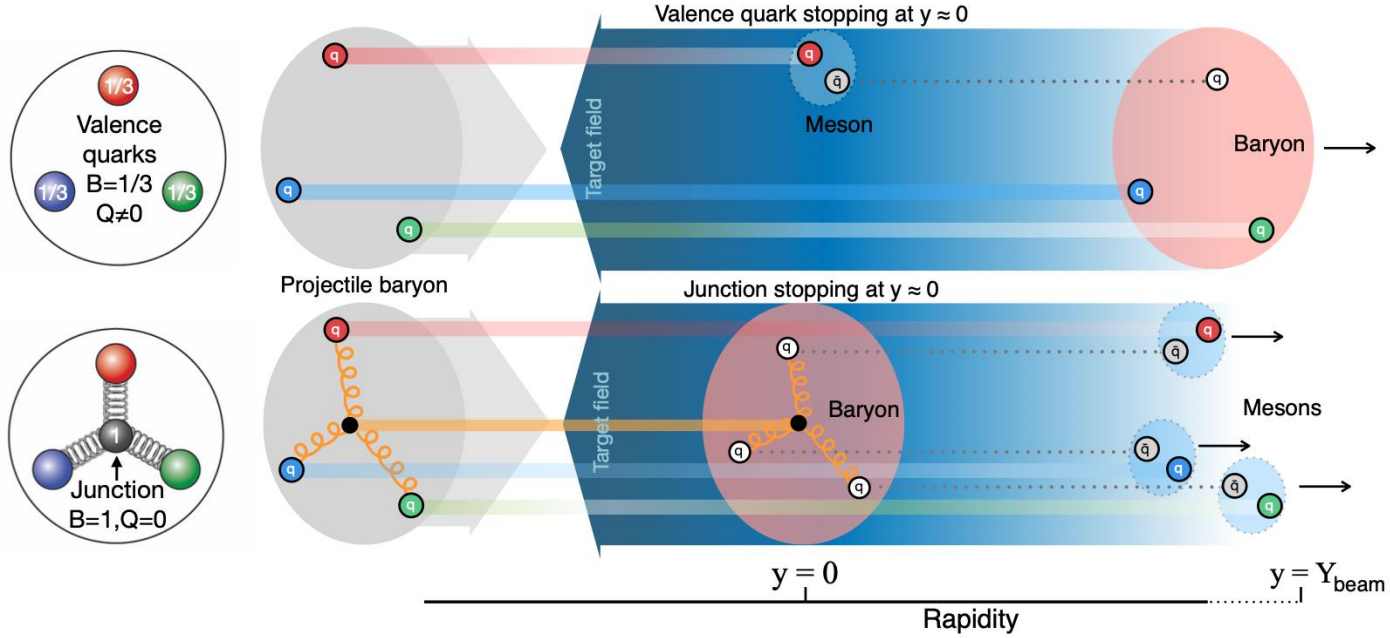
†Authors are listed at the end of this paper.

LHCb Λ_b

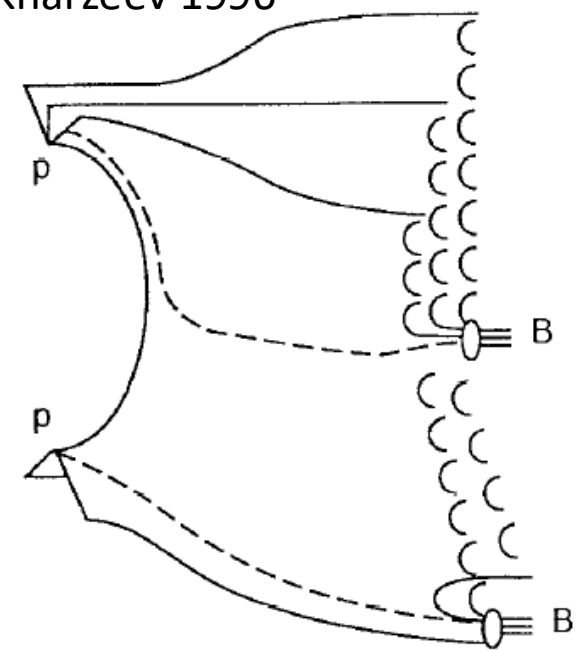
Existing high-statistic data at 13TeV



What can we do at FAIR & HIAF?



Kharzeev 1996



at high energies the associated multiplicities in the processes of single ($n^{(1)}$) and double ($n^{(2)}$) baryon stopping will be higher than in the average inelastic event, described by the cut of the Pomeron exchange diagram (see Fig. 6):

$$n^{(1)} \simeq \frac{5}{4} n^{\text{inel}}, \quad n^{(2)} \simeq \frac{3}{2} n^{\text{inel}}, \qquad (16)$$

as we already discussed above at the qualitative level. Also, since the baryon stopping and baryon pair production arise in our scheme from different kinds of t-channel exchange (M_0^J and the Pomeron, respectively), we expect a small correlation between the events with the pair production and stopping. Experimentally, it was found to be 0.16 ± 0.22 [8].

Artru&Mekhfi 1991



Proton energy ~=10--30 GeV

1. Multiplicity of forward rapidity events with stopped baryon = 3/2 inelastic
2. Correlation of pair production with stopped baryons weak (no) correlation
3. Spin Correlations between baryon pairs (p-pbar)

Separate baryon from quarks using heavy flavor in LQCD

$r_{baryon} << r_{bottom}$

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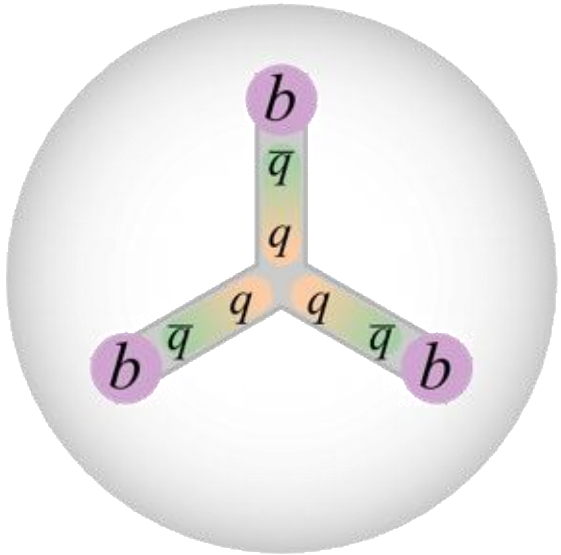
RESEARCH HIGHLIGHT

Separating baryon number from valence-quark charge

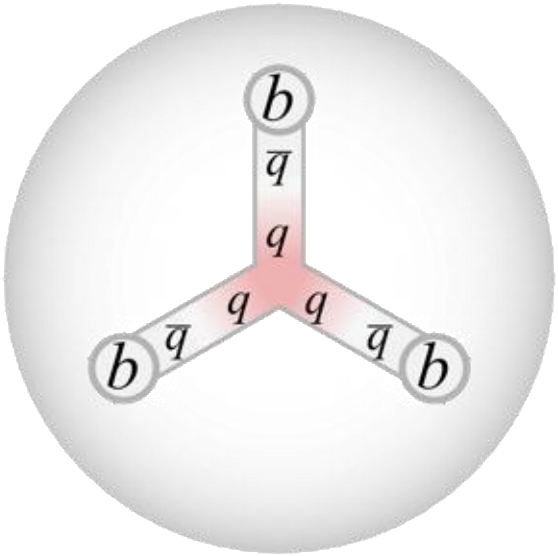
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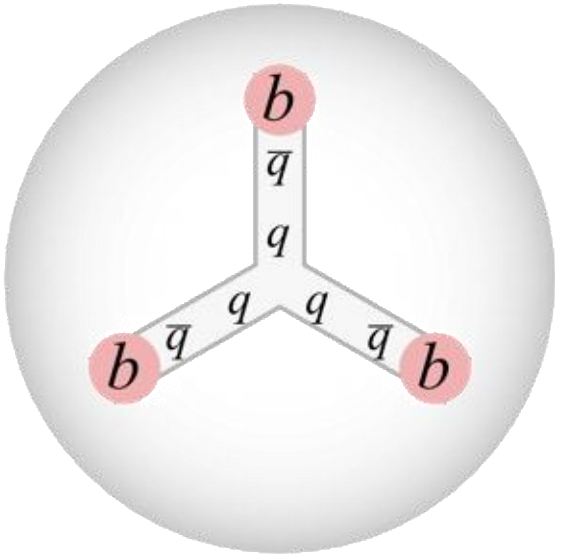
$$n_{\text{baryon}}(x) \equiv \sum_{f\in\{u,d,s,c,b,t\}} \langle \psi_f^\dagger(x)\psi_f(x)\rangle/3$$



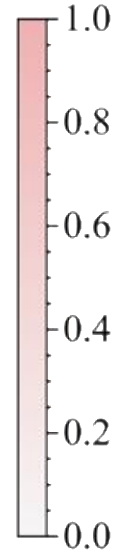
(a) structure



(b) $n_{\text{baryon}}(x)$



(c) $n_{\text{bottom}}(x)$



$n(x)$ [a.u.]

$$n_{\text{bottom}}(x) \equiv \langle \psi_b^\dagger(x)\psi_b(x)\rangle/3$$

$$r_{\text{bottom}} \equiv \left(\int r^2 n_{\text{bottom}}(x)\mathrm{d}^3x\right)^{1/2}$$

Conclusions and Perspectives

- Baryon number is a strictly conserved quantum number,
  keeps the Universe as is
- We did not know what its carrier is;
  It has not been experimentally verified one way or the other until now
- RHIC Beam Energy Scans provide unique opportunity in studying baryon number transport over large unit of rapidity
- RHIC Isobar collisions provide unique opportunity in studying charge and baryon transport
- Experimental verification of the simplest QCD topology

- Baryon junction is a non-perturbative object
- First measurement of Flavor Independence at JLab
- Future Isobar collisions to measure charge transport (quark transports),

  Zr/Ru; ^{7}Li/^{7}Be
- JLab and EIC can measure the baryon junction distribution function
- LHC has a unique position to measure Flavor-independent baryon transport
  q=u,d,s,c,b
- FAIR,HIAF could study the correlations

the simplest QCD topology

B=1

