Ultraperipheral collisions: new isights on collectivity & baryons

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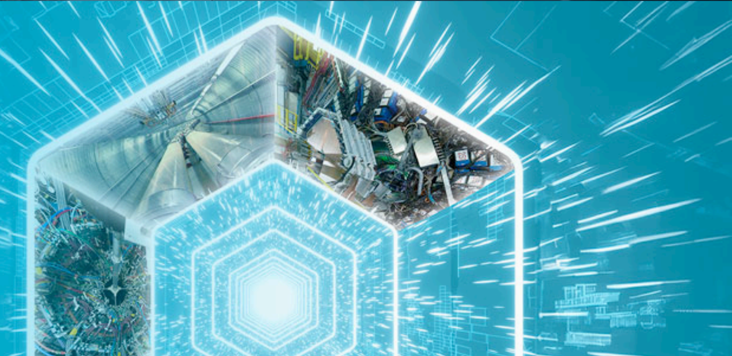
2024 RHIC/AGS ANNUAL USERS' MEETING

A New Era of Discovery
Guided by the New Long Range Plan for Nuclear Science

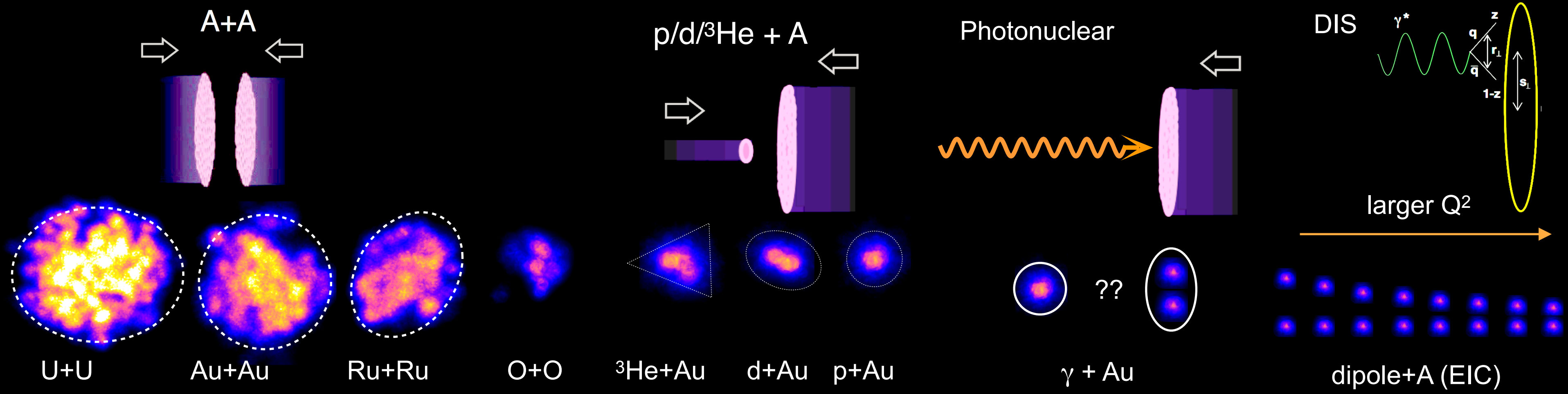
June 11–14, 2024



Ultraperipheral collisions: new isights on ~~collectivity~~ & baryons

Disclaimer: I've informed the organizers I will not be able to cover the collectivity part

See talk by Wenbin



RHIC system scan: using a target heavy ion to study the imprints of the shape of another

UPCs: continue the system scan to extreme & maybe image a photon?

New insights on baryons

50 years of puzzles with baryon production in high energy collisions

1970s

Nuclear Physics B
Volume 85, Issue 2, 27 January 1975, Pages 442-460

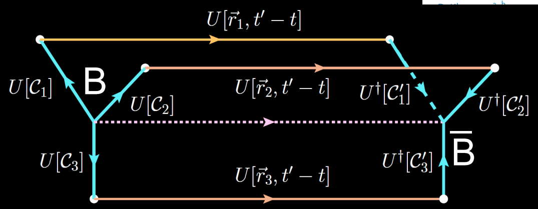
String model with baryons: Topology; classical motion

X. Artru

Nuclear Physics B
Volume 123, Issue 3, 30 May 1977, Pages 507-545

A possible description of baryon dynamics in dual and gauge theories

G.C. Rossi, G. Veneziano



G. Veneziano, 1st workshop on baryon dynamics, SBU, 2024

1990s

Nuclear Physics A532 (1991) 351c–358c
North-Holland, Amsterdam

NUCLEAR PHYSICS A

What can we learn from unpolarized and polarized electroproduction of fast baryons?

X. Artru[a] and M. Mekhfi[b]

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

Can gluons trace baryon number? ☆

Physics Letters B
Volume 443, Issues 1–4, 10 December 1998, Pages 45-50

Baryon number transport via gluonic junctions

Stephen E. Vance a, Miklos Gyulassy a, Xin-Nian Wang b

Antihyperon Enhancement through Baryon Junction Loops

Stephen E. Vance and Miklos Gyulassy
Phys. Rev. L

Baryon junction loops and the baryon-meson anomaly at high energies

V. Topor Pop, M. Gyulassy, J. Barrette, C. Gale, X. N. Wang, and N. Xu
Phys. Rev. C **70**, 064906 – Published 21 December 2004

2022-

Backward-angle (u-channel) production at an electron-ion collider

Daniel Cebra, Zachary Sweger, Xin Dong, Yuanjing Ji, and Spencer R. Klein
Phys. Rev. C **106**, 015204 – Published 15 July 2022

arXiv > hep-ph > arXiv:2205.05685

High Energy Physics – Phenomenology

[Submitted on 12 May 2022 (v1), last revised 2 Dec 2023 (this version, v4)]

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

Nicole Lewis, Wendi Lv, Mason Alexander Ross, Chun Yuen Tsang, James Daniel Brandenburg, Zi-Wei Lin, Rongrong Ma, Zebo Tang, Prithwish Tribedy, Zhangbu Xu

arXiv > nucl-th > arXiv:2309.06445

Nuclear Theory

[Submitted on 12 Sep 2023 (v1), last revised 20 Nov 2023 (this version, v2)]

Correlations of Baryon and Charge Stopping in Heavy Ion Collisions

Wendi Lv, Yang Li, Ziyang Li, Rongrong Ma, Zebo Tang, Prithwish Tribedy, Chun Yuen Tsang, Zhangbu Xu, Wangmei Zha

arXiv > hep-ph > arXiv:2312.15039

High Energy Physics – Phenomenology

[Submitted on 22 Dec 2023]

Signatures of baryon junctions in semi-inclusive deep inelastic scattering

David Frenklakh, Dmitri E. Kharzeev, Wenliang Li

arXiv > nucl-th > arXiv:2312.12376

Nuclear Theory

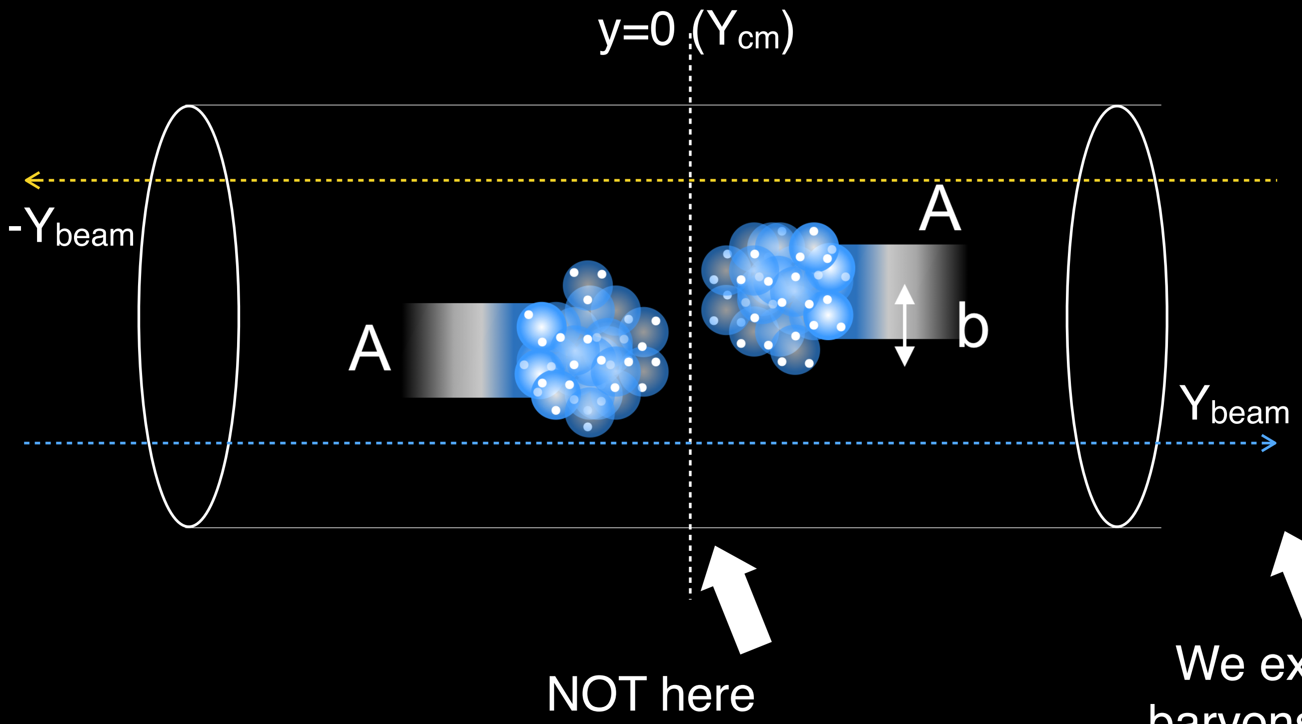
[Submitted on 19 Dec 2023]

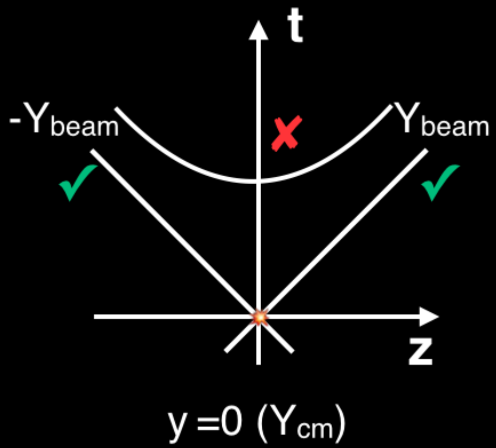
Tracing baryon and electric charge transport in isobar collisions

Gregoire Pihan, Akihiko Monnai, Björn Schenke, Chun Shen

And many more…

Puzzles with baryons appearing in the central rapidity





If baryon number flows with valence quarks, then they should end up near beam rapidity Y_{beam} and not near y=0 or Y_{cm}

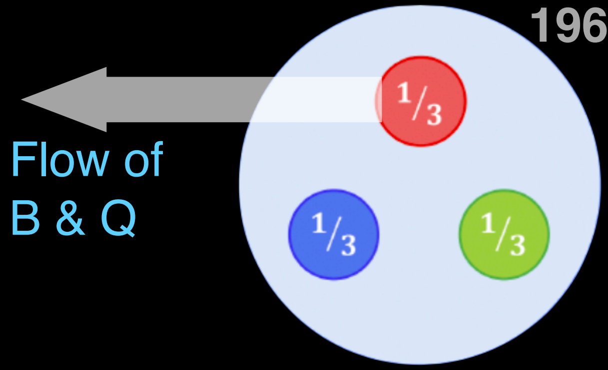
What traces the baryon number?

In particle physics, the **baryon number** is a strictly conserved additive quantum number of a system.

Baryons, along with mesons, are hadrons, particles composed of quarks. Quarks have baryon numbers of $B = \frac{1}{3}$ and antiquarks have baryon numbers of $B = -\frac{1}{3}$. The term "baryon" usually refers to *triquarks*—baryons made of three quarks ($B = \frac{1}{3} + \frac{1}{3} + \frac{1}{3} = 1$).

https://en.wikipedia.org/wiki/Proton
https://en.wikipedia.org/wiki/Baryon

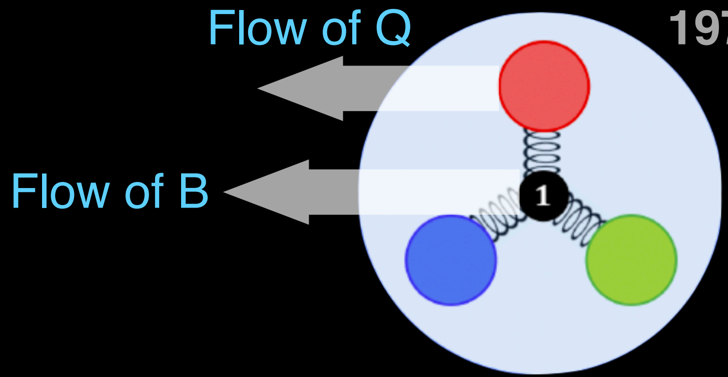
1963-70



In conventional picture, baryon number is assumed to be carried by the valence quarks each carrying 1/3

Goldberg and Y. Ne'eman, Nuovo Cimento 27 (1963) 1
Gell-Mann, Zweig, 1964, SLAC 1970
Review: hep-ph/9301246

1975-

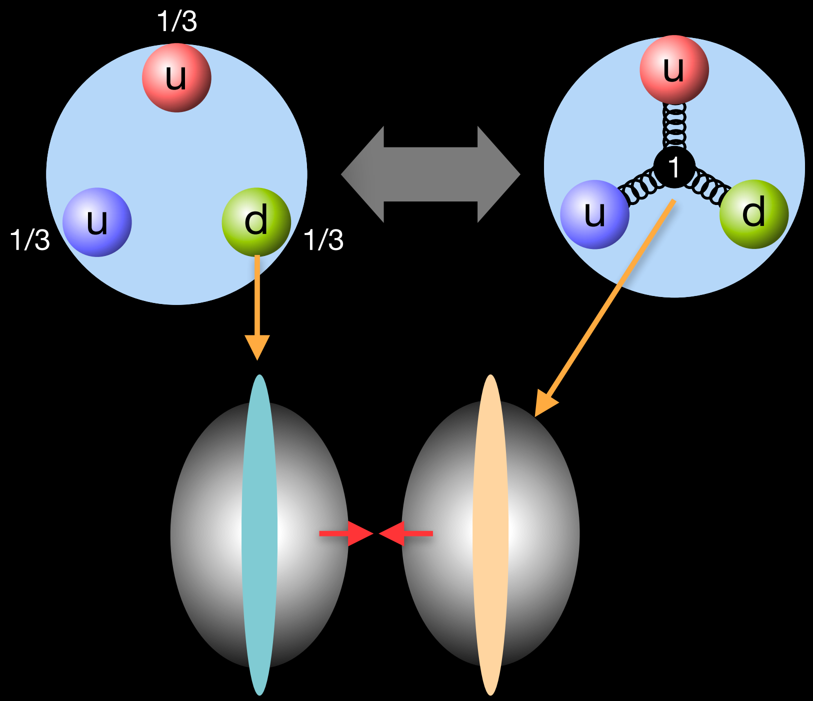


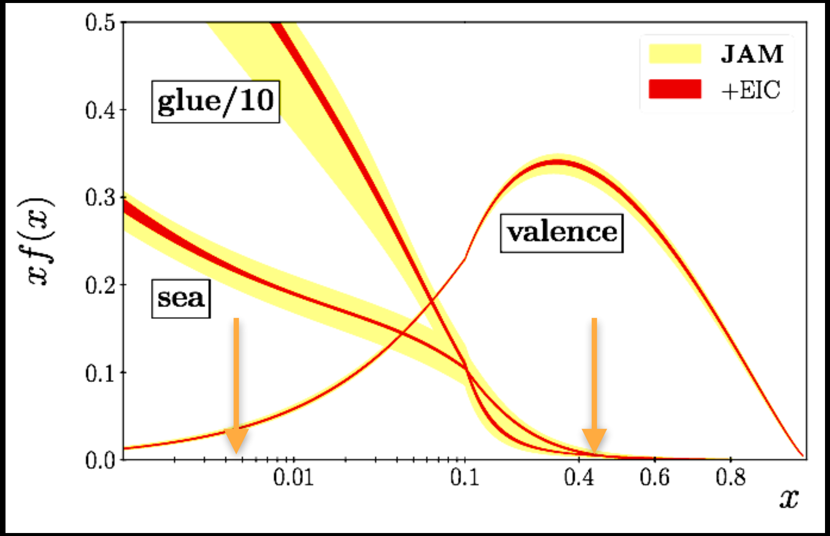
Baryon number may flow with the flow of the Y-shaped string junction (QCD topology)

X. Artru, Nucl. Phys. B 85, 442–460 (1975), G.C. Rossi and G. Veneziano, Nucl. Phys.B123(1977) 507; Phys. Rep.63(1980) 149
Kharzeev, Phys. Lett. B, 378 (1996) 238-246

No experiment has conclusively established either scenarios

Quarks vs. gluonic junction tracing the baryon number





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

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

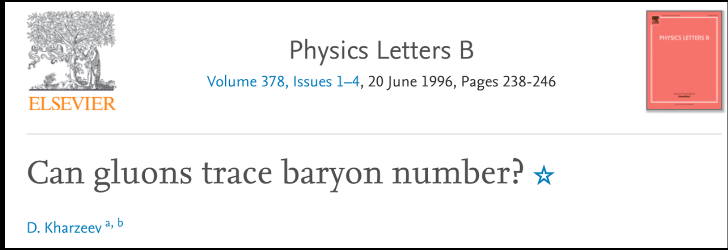
If junction traces the baryon number, means it is traced by small-x objects

Junction is made of infinite low-x gluons so they have enough time to be stopped

$$x_J \ll x_V \qquad ((x_J P)^{-1} \gg (x_V P)^{-1})$$

Gluonic junction as a carrier of baryon number

Kharzeev, Phys. Lett. B, 378 (1996) 238-246, Lewis et. al, arXiv:2205.05685

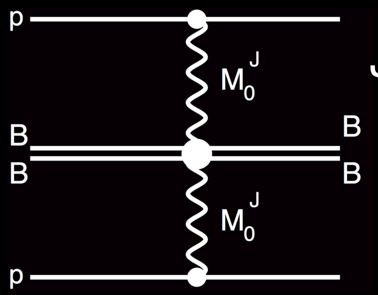


Physics Letters B
Volume 378, Issues 1–4, 20 June 1996, Pages 238-246

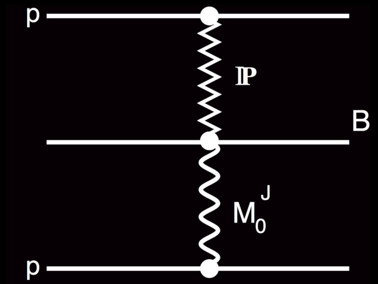
Can gluons trace baryon number? ☆

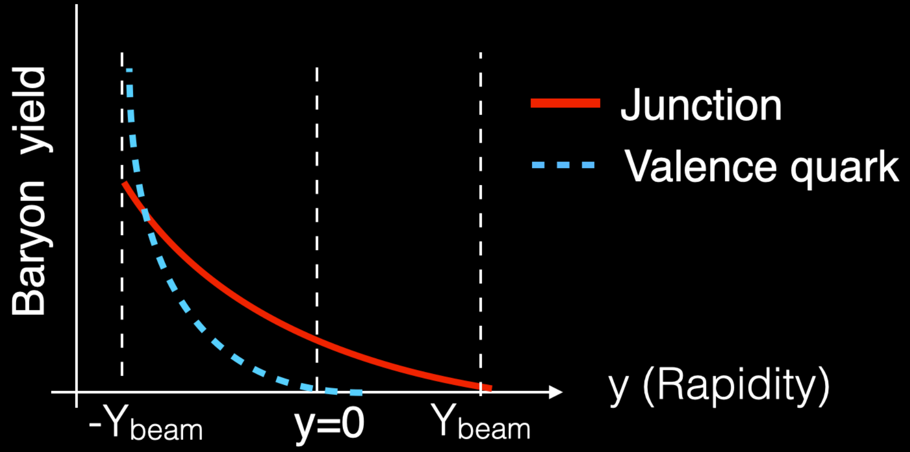
D. Kharzeev [a, b]

Junction-Junction



Junction-Pomeron





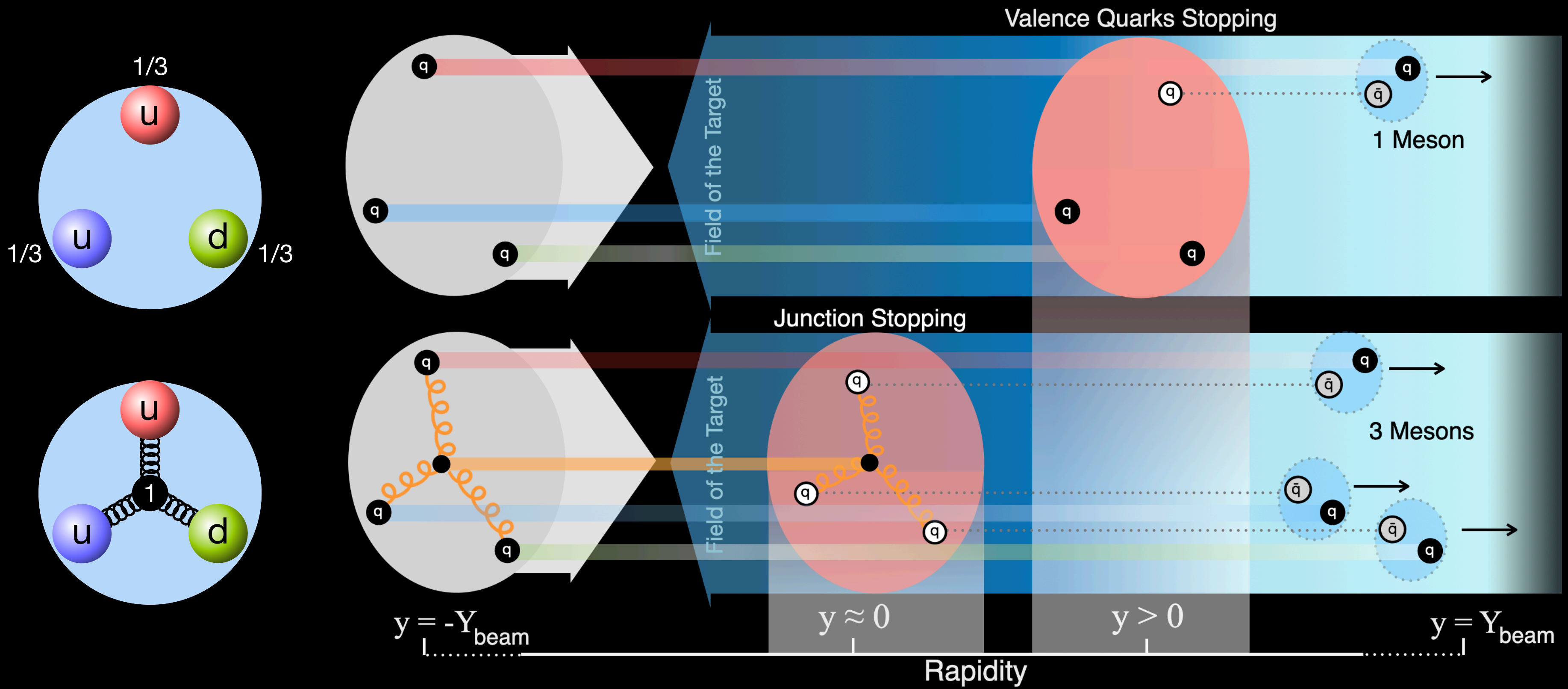
Baryon junction: $e^{-\alpha_B(y-Y_{\rm beam})}$ $0.42 \leq \alpha_B \leq 1$

PYTHIA 6 (Quarks): $e^{-2.5(y-Y_{\rm beam})}$

Regge theory can predict rapidity dependence of baryon stopping for junctions

Larger transport to mid-rapidity for gluonic junction than valence quarks as baryon carrier

How a baryon is transported at midrapidity?

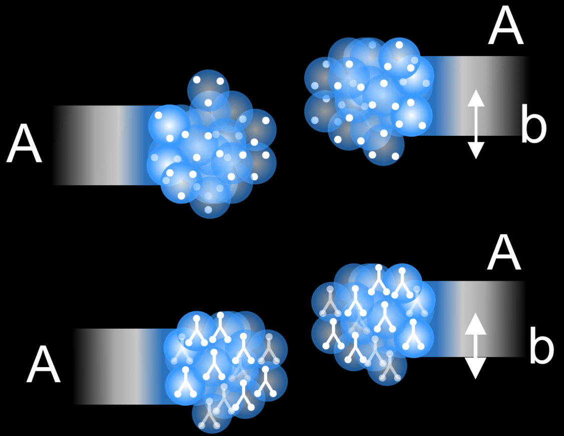


Valence quarks: difficult to stop near y~0 & associated with electric charge stopping

Baryon junction: easier to stop near y~0 & NOT associated electric charge stopping

Strategies for tracing the baryon carrier

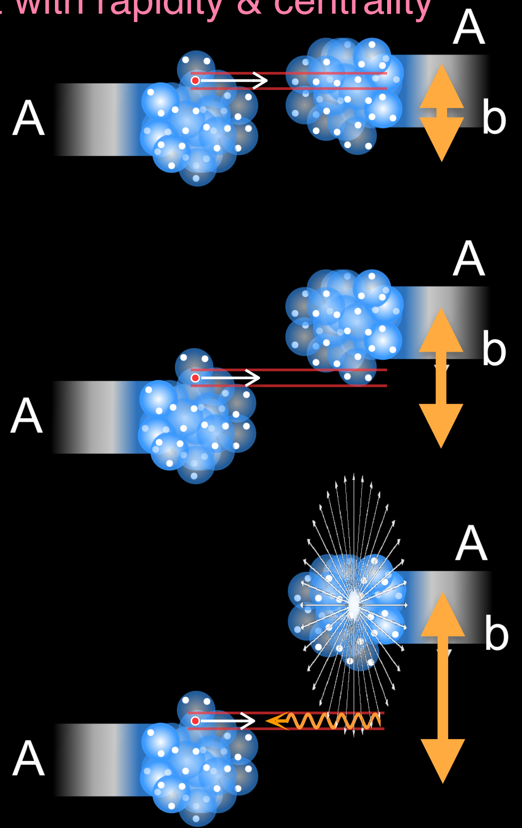
Check if charge and baryon are carried by the same object



Compare electric-charge with baryon transport

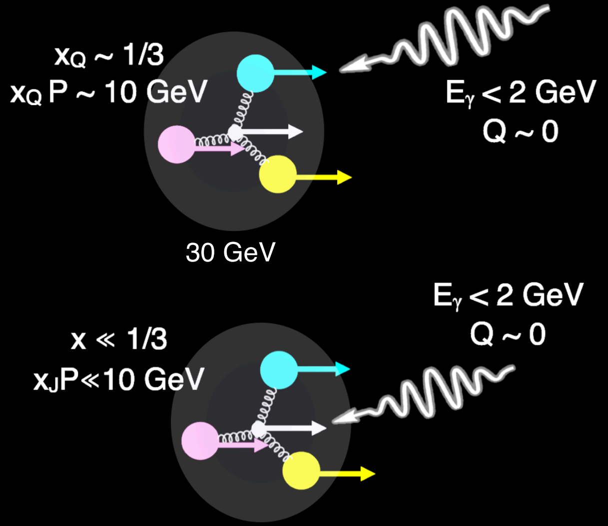
Q <-> Z/A x B

Test expectations for valence quark transport with rapidity & centrality



Centrality dependence of dN/dy(B) vs. $y\text{-}Y_{beam}$

Test if the baryon carrier is a gluonic object by colliding with a photon of very small stopping power

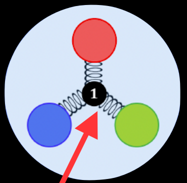


Rapidity dependence of dN/dy(B) in γ+A collisions

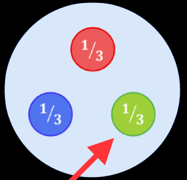
Baryon vs. electric charge transport & rapidity slope of baryon stopping

Measurements in isobar collisions: different carriers for Q & B?

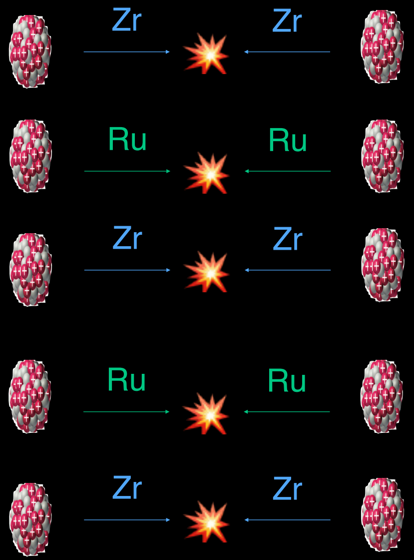
Talk by Rongrong Ma (Mon, 11 am)



B=1,
Q=0



B=1/3
Q≠0

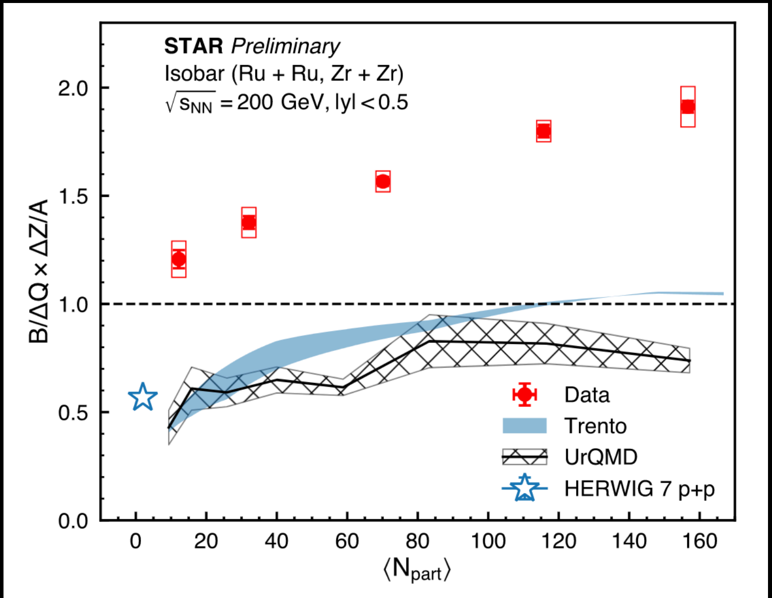


Zirconium:
A=96 (Total baryon)
Z=40 (Total charge)

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

Goal is to test:

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



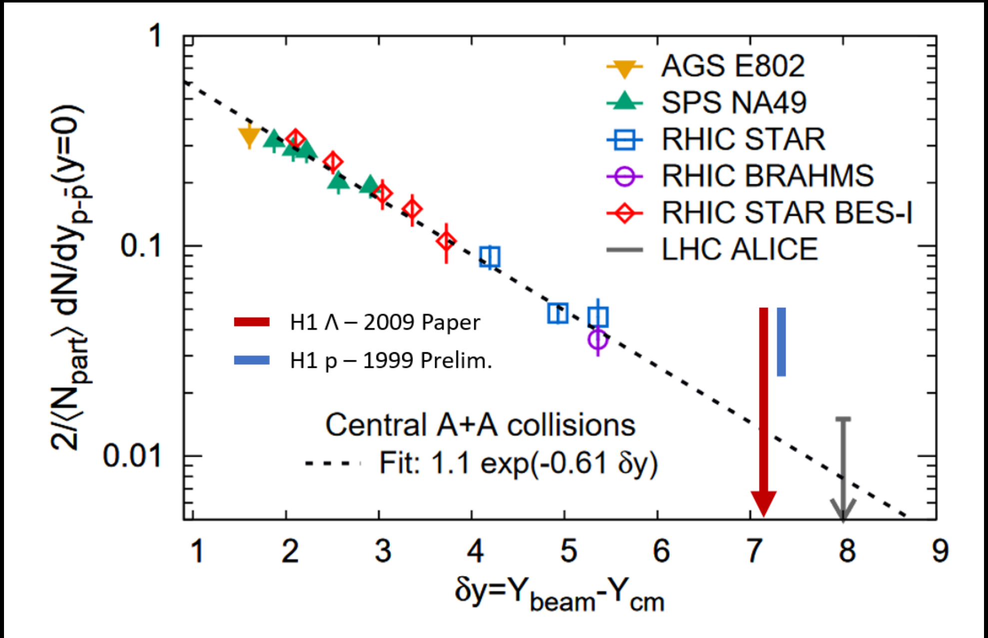
$$R2_\pi = \frac{(N_{\pi^+}/N_{\pi^-})^{\text{Ru}}}{(N_{\pi^+}/N_{\pi^-})^{\text{Zr}}}$$

$$\Delta Q = N_\pi \left[(R2_\pi - 1) + \frac{N_K}{N_\pi}(R2_K - 1) + \frac{N_p}{N_\pi}(R2_p - 1) \right]$$

STAR data: stronger baryon vs net-electric charge transport at mid-rapidity: hints different carriers for baryon & electric charge

Rapidity distribution of baryon production:

Lewis et al., arXiv:2205.05685 Henry Klest (SBU) HERA data



Fit to global data on central A+A:

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

$$\alpha_B = 0.61 \pm 0.03$$

Predictions form Regge theory & baryon junction picture:

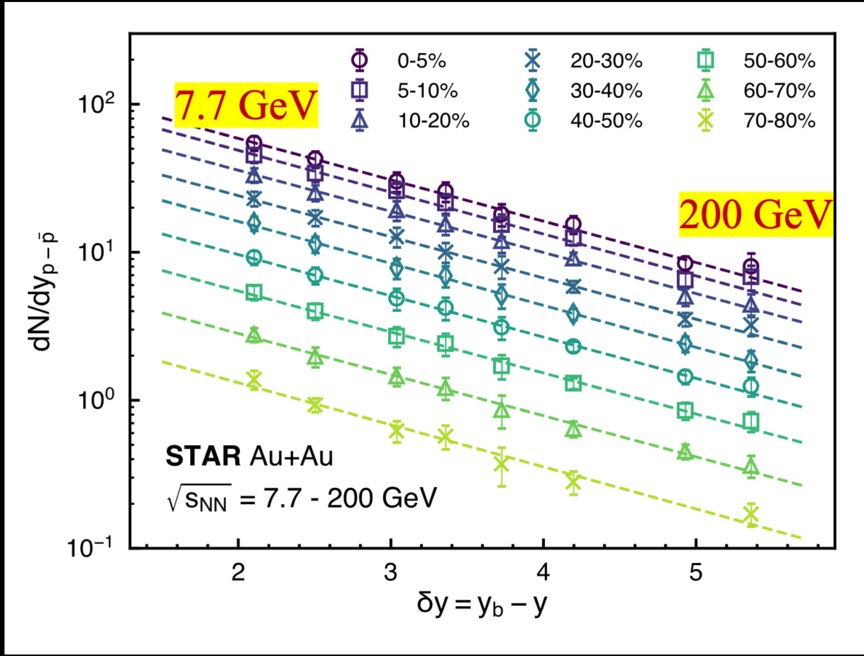
$$0.42 \leq \alpha_B \leq 1$$

Midrapidity baryon density slope is consistent with baryon junction prediction

Rapidity distribution of baryon production: Global data

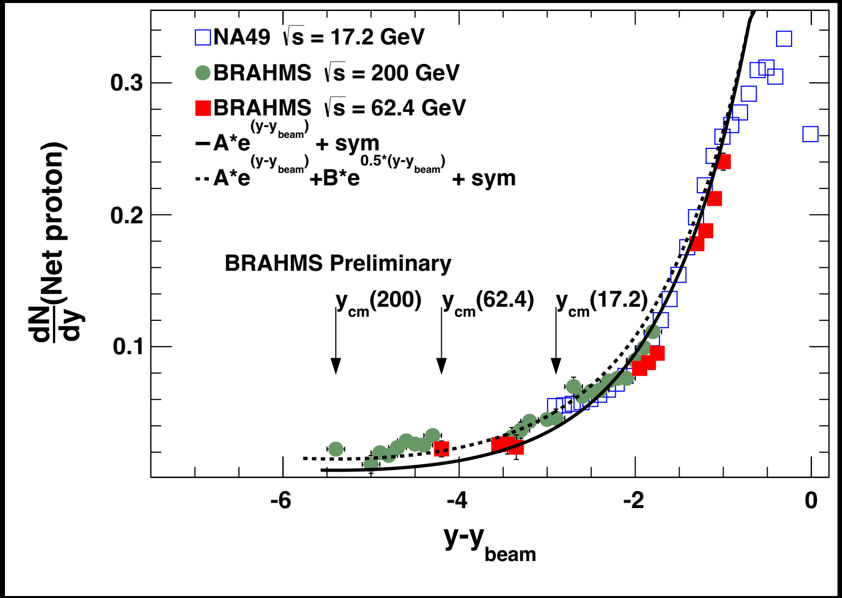
STAR data: N. Lewis, et. al., arXiv:2205.05685, BRAHMS+NA49: F. Videbaek, 1st workshop on baryon dynamics, SBU, 2024

Baryon transport with rapidity loss ($y-Y_{beam}$)



Exponential with slope 0.63±0.2, no change with centrality for $2 < Y_{beam} < 5.5$

BRAHMS + NA49 data (wider $y-Y_{beam}$)

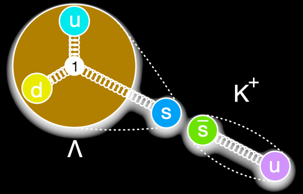


At higher energy rapidity slope closer to~0.5 lower energy ($|y-Y_{beam}|<2$) rapidity slope ~1

Rapidity slope of baryon density: centrality independent, depends on $|y-Y_{beam}|$ range

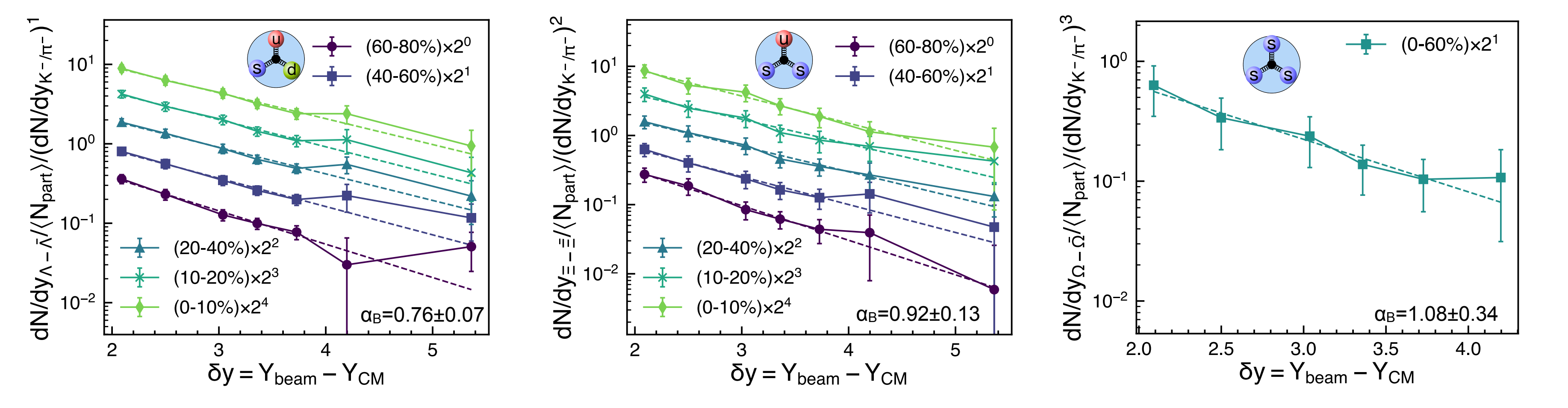
Rapidity distribution of strange baryons

Strange baryon production requires replacing incoming quark(s) in p &n through s-$\bar{s}$ production



STAR data for BES-I: G. Agakishiev Phys. Rev. Lett. 98, 062301 (2007),108, 072301 (2012), J. Adam Phys. Rev. C 102, 034909 (2020), Adamczyk et al, Phys. Rev. C 96, 044904 (2017), T. Sang, 1st workshop on baryon dynamics, SBU, 2024

More details: https://indico.cfnssbu.physics.sunysb.edu/event/113/contributions/750/



Net yield is scaled by $(\bar{K}/\bar{\pi})^n$ to compensate for difficulty in "n" s-quark production

Exponential slope for different net-strange baryons (Λ,Ξ,Ω) seem similar to net-proton

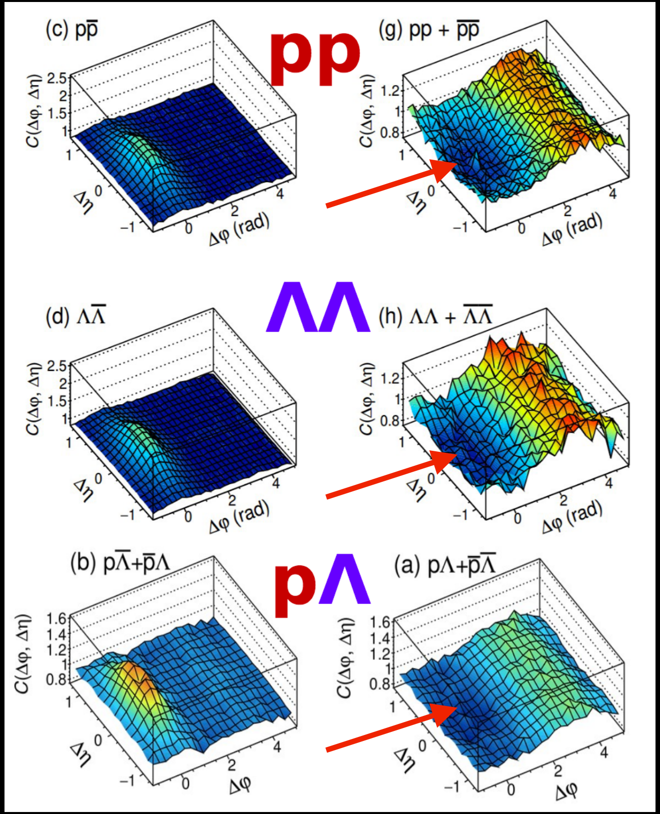
Rapidity slope of baryon density has no strong flavor dependence

B-$\bar{B}$ correlation: Flavor independence

Talk by Adam Kisiel WPCF 2022

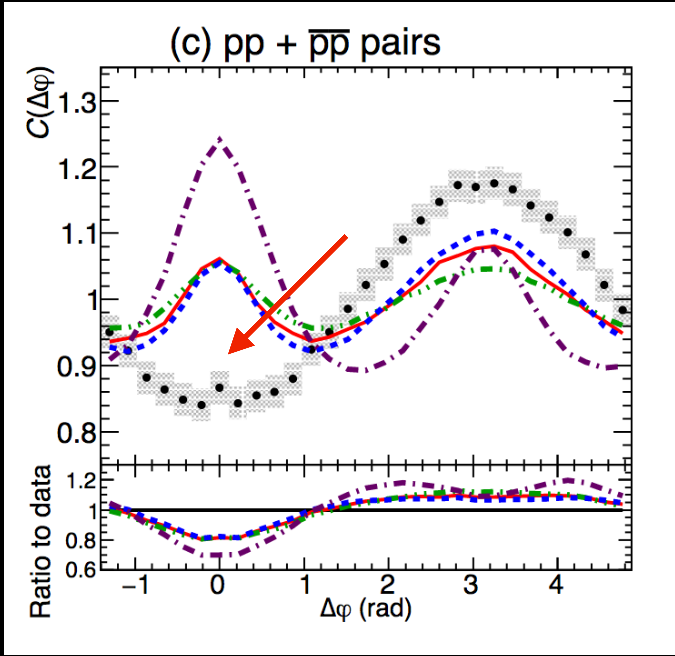
Baryon-baryon correlation functions in p+p collisions at 7 TeV

ALICE Collb. Eur. Phys. J. C77 (2017) 8, 569



Two baryons are not produced in close proximity

Effect does not depend on charge or strangeness content – purely baryon effect



MC-models can't explain despite a lot of effort

Baryon-anti-baryon correlations nearly flavor independent

Baryon transport in photon-induced process

Using photon-induced processes to identify the baryon carrier

Nuclear Physics A532 (1991) 351c–358c
North-Holland, Amsterdam

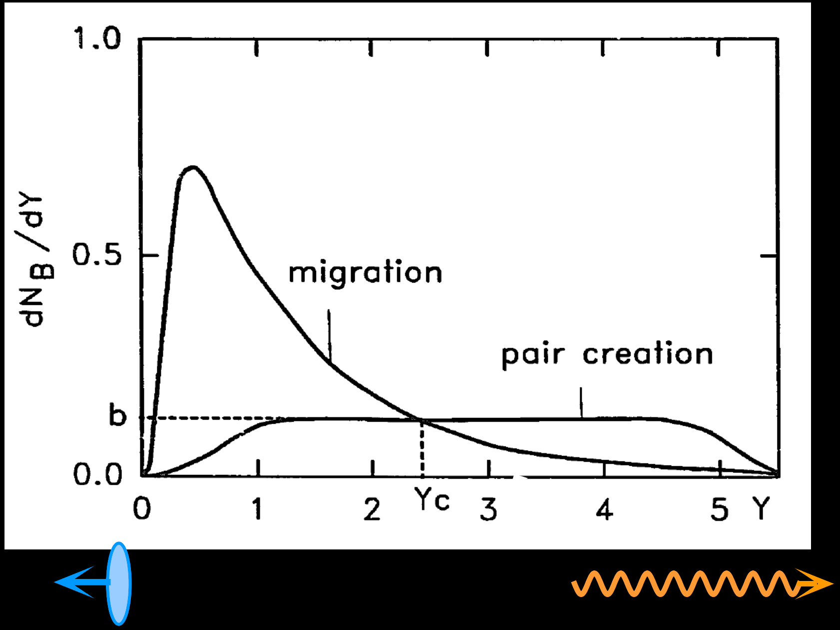
NUCLEAR PHYSICS A

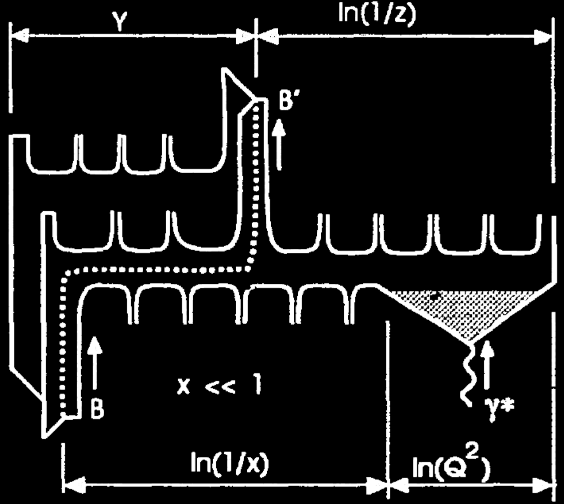
What can we learn from unpolarized and polarized electroproduction of fast baryons?

X. Artru[a] and M. Mekhfi[b]

Photon is a baryon-free projectile, baryon distribution in γ+p/A —> cleanest way to identify baryon carrier

$$dN_B/dY \simeq \beta\,(2p\cdot p'/m^2)^{-\beta} \simeq \beta\,\exp(-\beta Y)$$



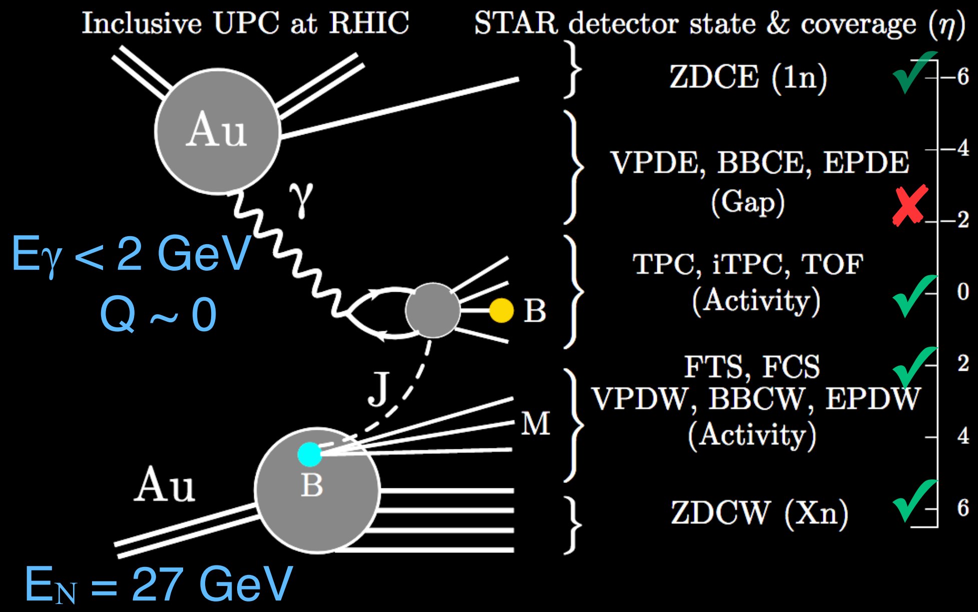


Rapidity asymmetry from colliding a source of photon at various energies on baryon —> reveal the junction-like structure of a baryon

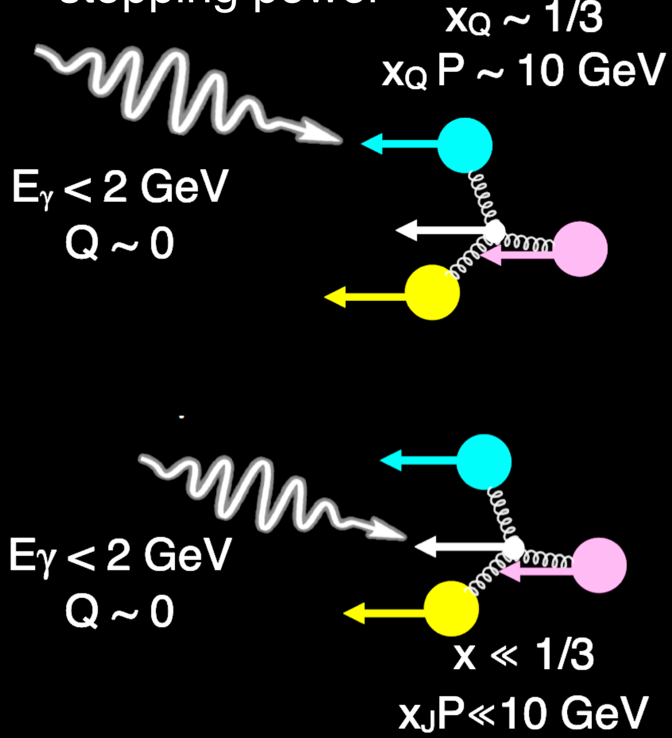
Probing baryon structure with photon-induced processes

Fig: Lewis et. al, arXiv: 2205.05685, Sweger, CA EIC consortia meet

We trigger on γ+Au events in Ultra-peripheral collisions of Au+Au at 54.4 GeV
Approximate γ+Au $\sqrt{s_{\gamma N}}$~10 GeV



UPC photons have very low stopping power

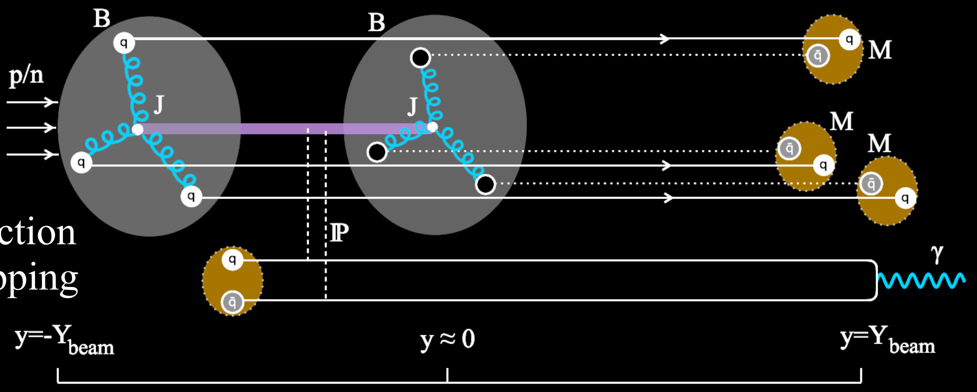


Search for non-zero net-baryon in photon-ion collisions near central-rapidity

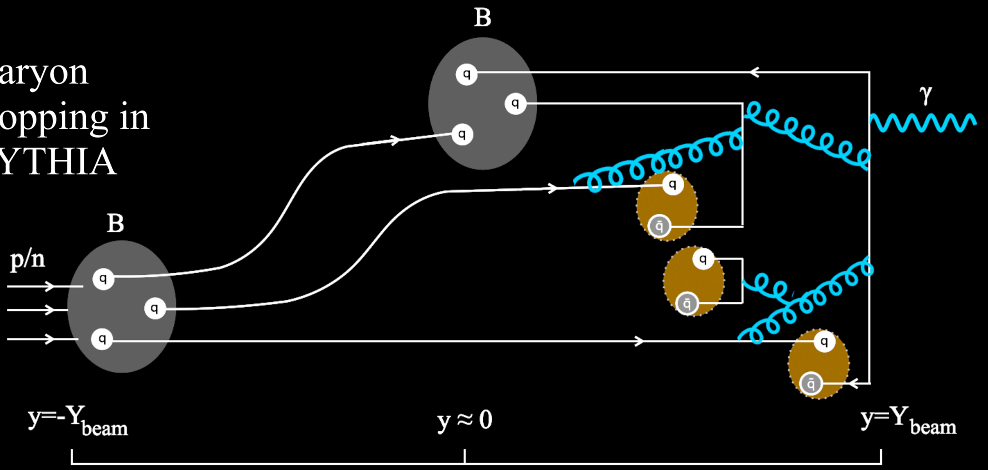
Probing baryon structure with photon-induced processes

Lewis et. al, arXiv:2205.05685
Dumitru, CFNS workshop on target fragmentation, 2022

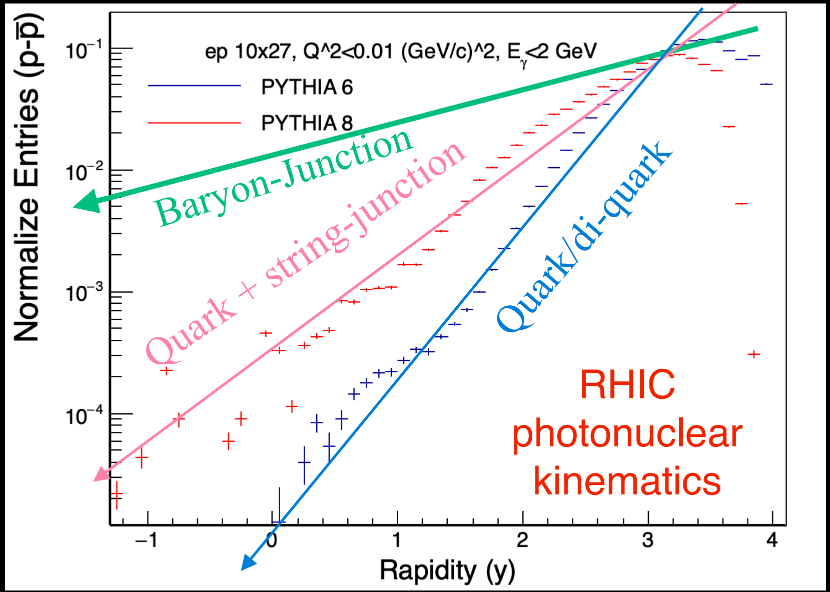
Junction stopping



Baryon stopping in PYTHIA



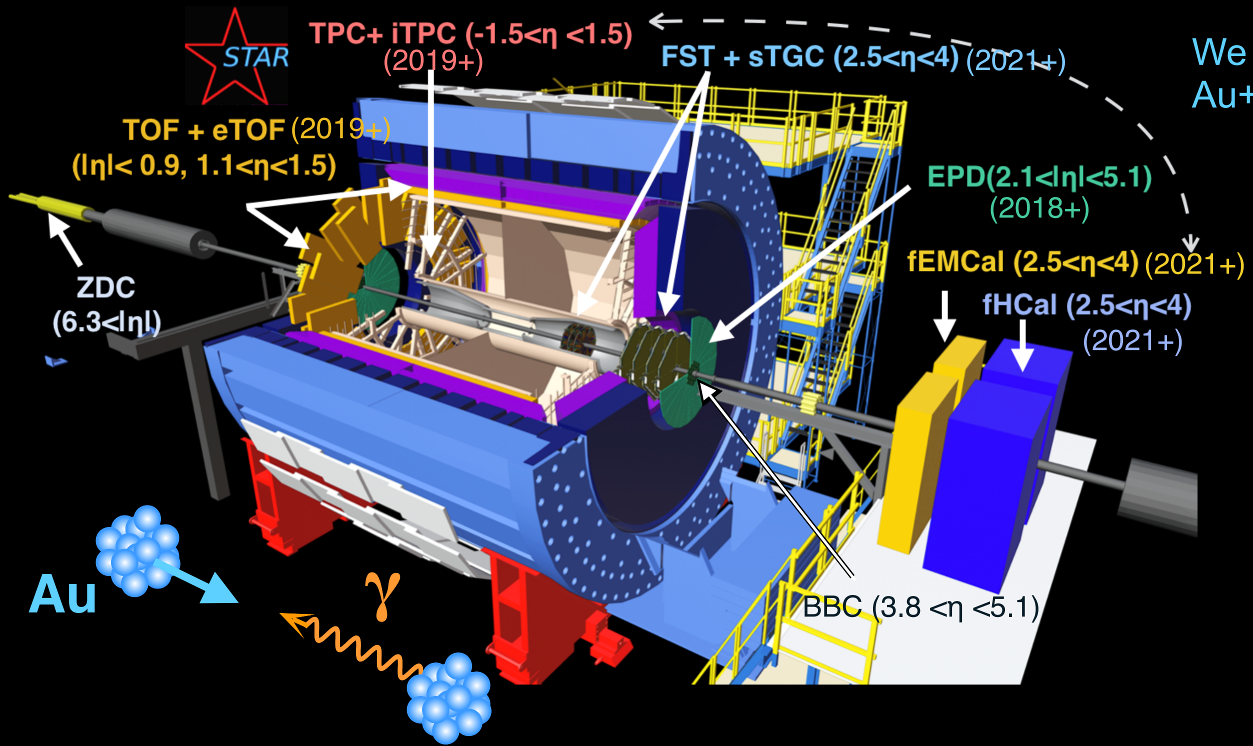
PYTHIA 6: Quark carries baryon
PYTHIA 8: Quark + mimic string-junction



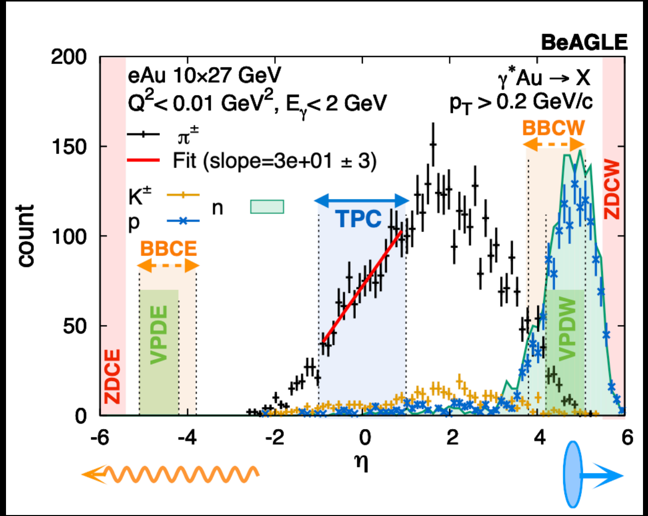
Models with various different carriers predict different rapidity dependence of net-proton yield

Triggering inclusive photon-induced processes by the STAR detector

Lewis et. al, arXiv: 2205.05685, BeAGLE:
W. Chang, et al PRD 106, 012007 (2022)



We trigger γ+Au events in ultra-peripheral Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV



Use characteristic asymmetric particle production to trigger inclusive γ+Au events with help of:

- Beam-Beam counter (BBC),
- Zero-Degree Calorimeter (ZDC),
- Vertex Position Detector (VPD)

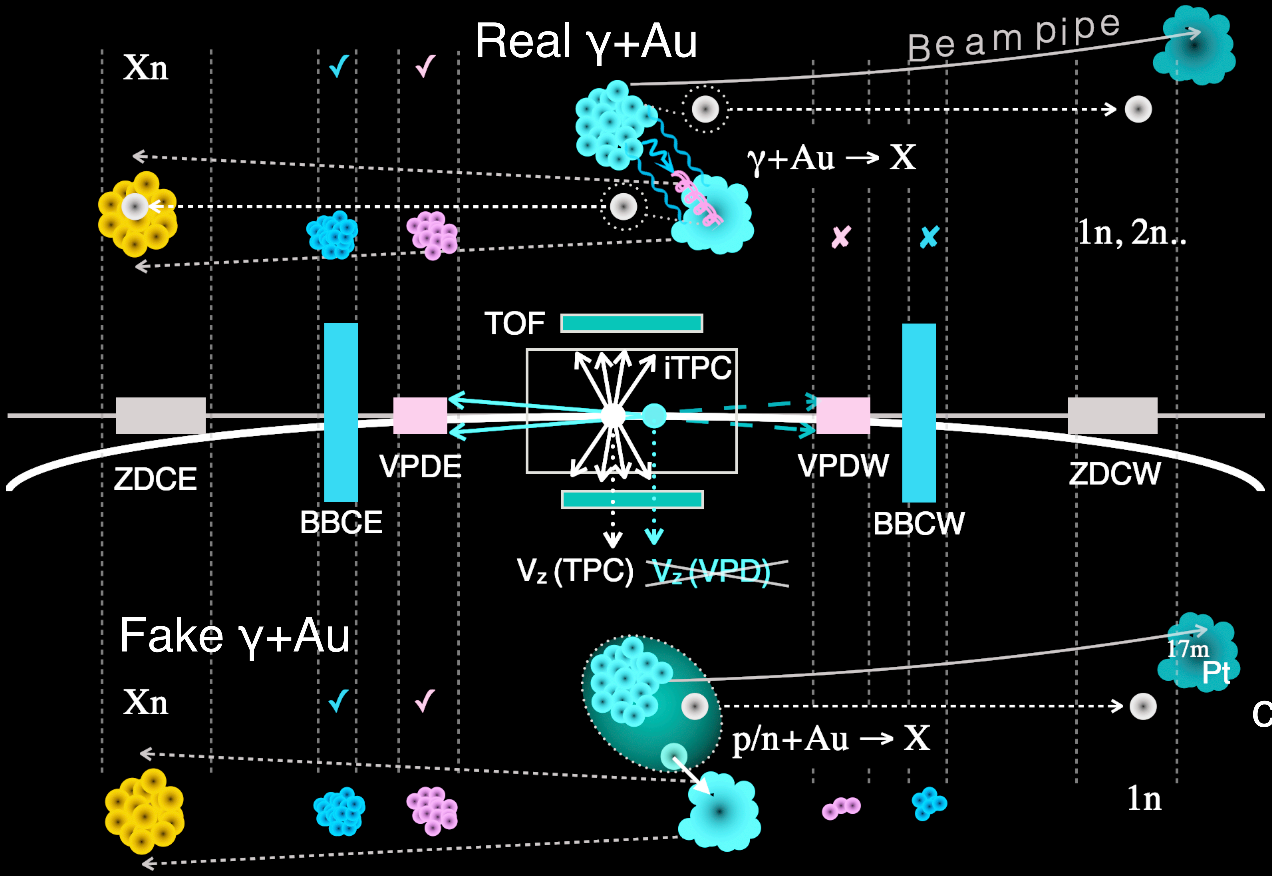
Time Projection Chamber (TPC)

- Track reconstruction
- Identify particles using dE/dx

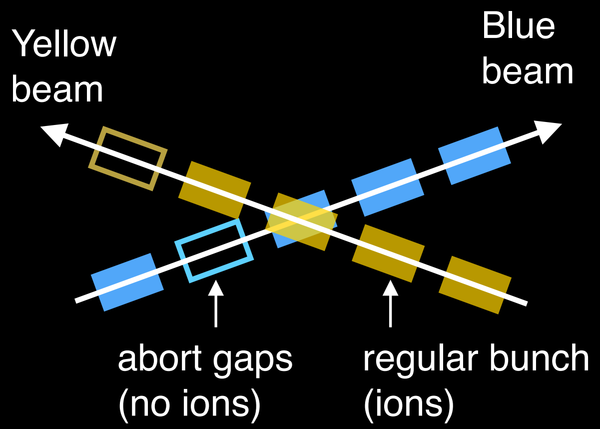
Time-Of-Flight detector (TOF)

- Extend particle identification to high pT
- Pile-up rejection

Triggering inclusive photon-induced processes by the STAR detector



Background from beam-gas

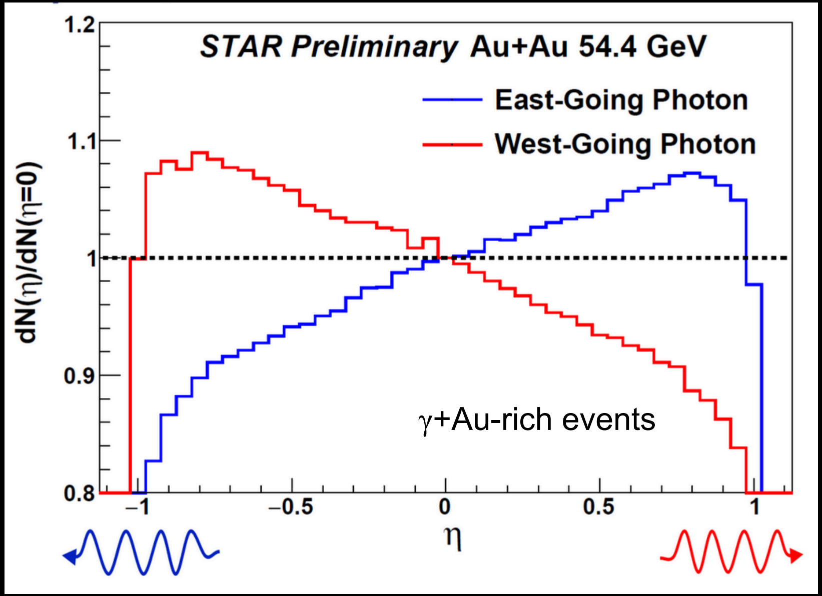


We estimate background contamination from peripheral heavy-ion collisions and beam-gas events

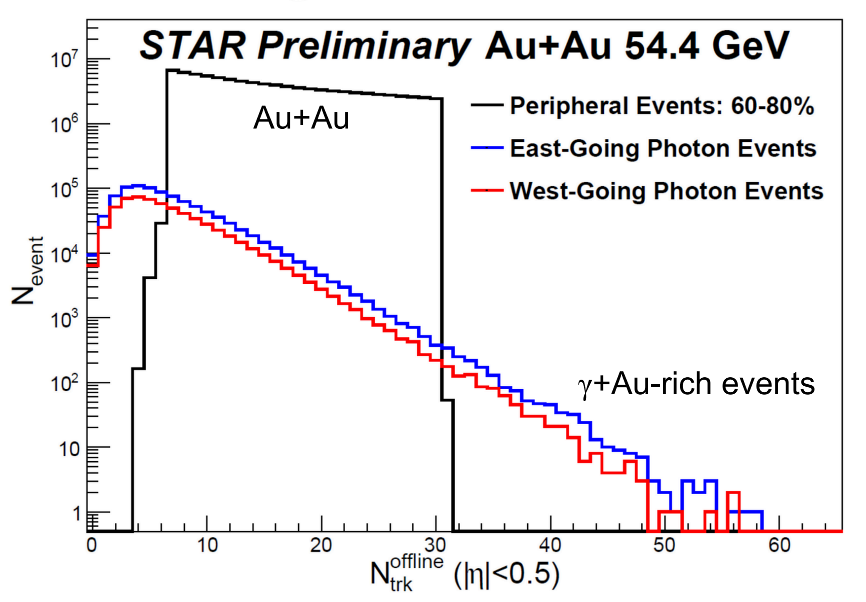
1nXn conditions on ZDCs largely suppress beam-gas background

Results: characteristic features of γ+Au events

Model calculations:
Lewis et. al, arXiv: 2205.05685



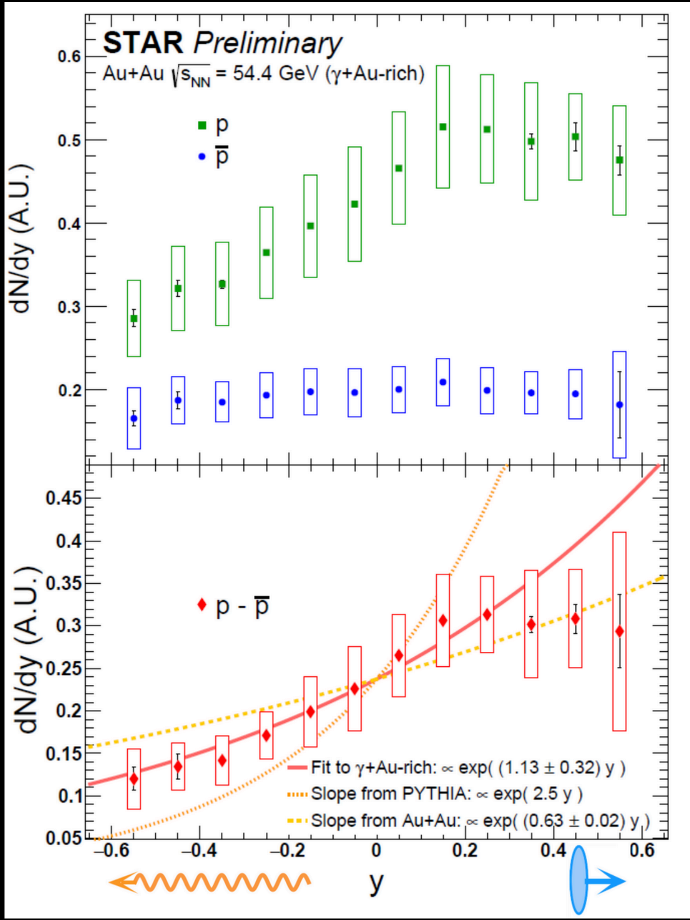
γ+Au events produce rapidity asymmetry that is expected from model predictions



Most photonuclear events have low multiplicity, consistent with very peripheral Au+Au collisions

Bulk features of γ+Au events are consistent with expectations from models

Results: Rapidity distribution of net-proton in γ+Au events



p and net-proton dN/dy with y described by an exponential with slope: 1.13 ± 0.32

Anti-proton distribution is near constant with y

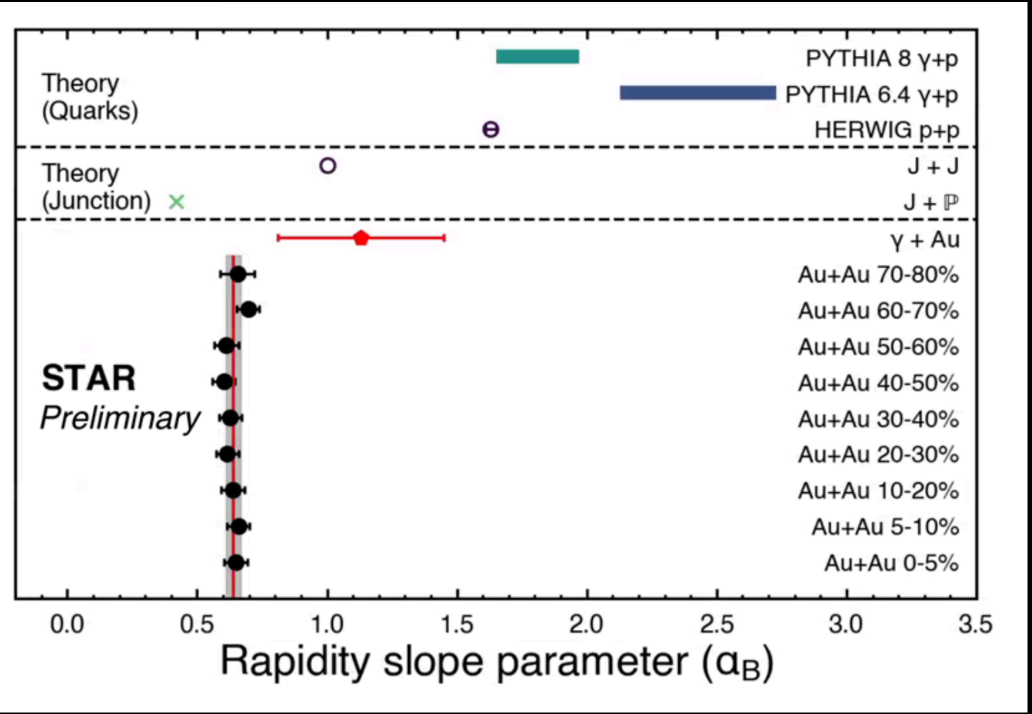
Compared Au+Au slope: 0.63 ± 0.02 ($2 < Y_{beam} < 5.5$)

Compared to PYTHIA, which does not include a baryon junction mechanism, predicts a slope of 2.5

Exponential slope of rapidity dependence of net-proton lower than PYTHIA predictions

Rapidity slope of net-proton: Global data

X. Artru, M. Mekhfi, Nucl. Phys. A 532 (1991) 351
BRAHMS+NA49: Videbaek, 1st workshop on baryon dynamics, SBU 2024



Au+Au slope same for all centrality

Slope γ+Au >~ Slope Au+Au:

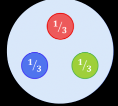
Closer to the fit to BRAHMS + NA49 data slope to ~1 for $Y_{beam} < 2$ (NA49 energy ~17 GeV closer to γ+Au cm energy ~ 10 GeV)

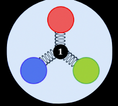
Slope has Y_{beam} (energy) dependence $\alpha_B = \alpha_B(|y-Y_{beam}|)$

Consistent with Regge theory baryon-junction prediction but smaller than PYTHIA/HERWIG

Rapidity dependence of net-proton in γ+Au collisions compatible with junction picture

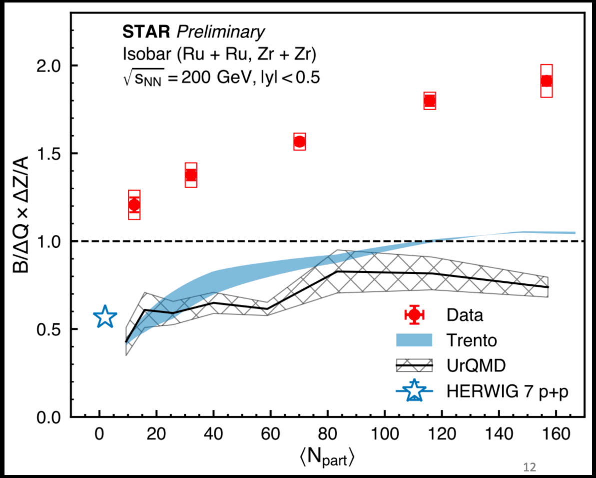
Summary

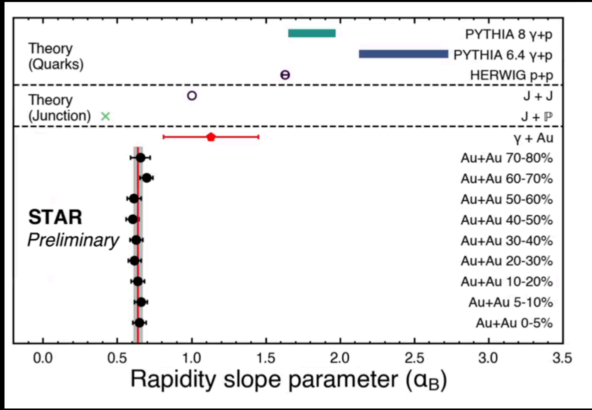




- Baryon number carrier and transport are of fundamental interest:
- STAR@RHIC advantage: BES & Isobar program, low-p_T PID capability, triggering capability for inclusive γ+Au events with low photons energy
- Three approaches to test the carrier of baryon number & transport:
  - Isobar data: less electric-charge transport than baryon transport
  - Au+Au BES/global data: exponential rapidity dependence with slope showing no centrality dependence, flavor blind
  - Significant net-proton in γ+Au at midrapidity: exponential rapidity slope compatible with prediction of Regge theory on baryon junction
- Quark-based models fail to provide simultaneous description of all features of STAR data, seems to be viable in baryon junction picture

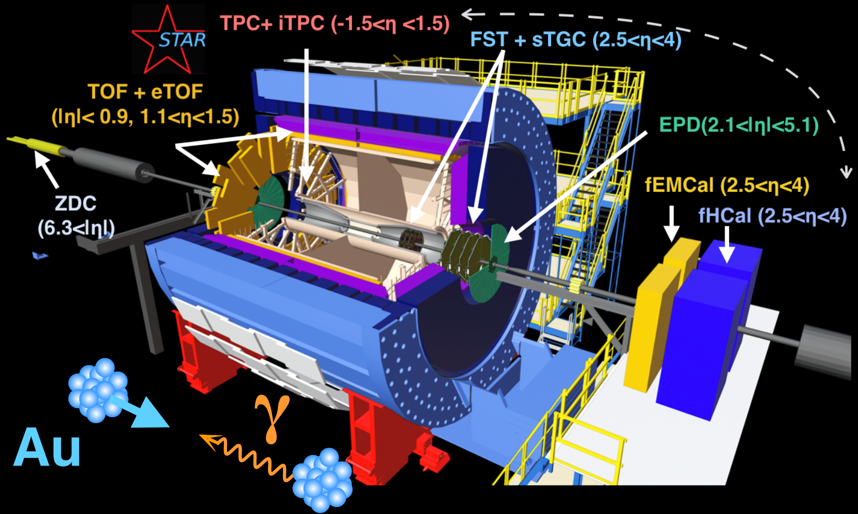
Outlook: Future RHIC, EIC, other experiments can further probe baryon carrier and transport mechanisms with controlled photon/ion kinematics





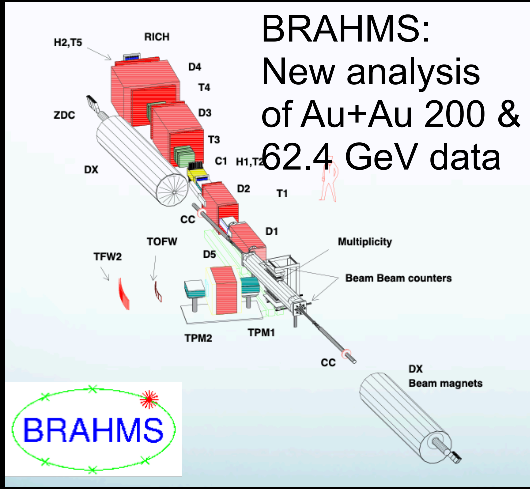
Future experiments on baryon carrier search

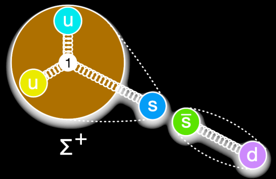
Huber, Klein, Videbaek, Magdy, 1st workshop on baryon dynamics, SBU 2024



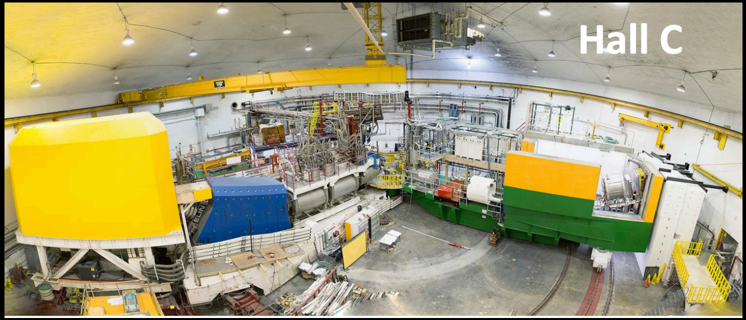
STAR: RHIC Run 23-25
high statistics γ+Au collisions using Au+Au 200 GeV UPC, p/d/He3+Au, strange baryon production

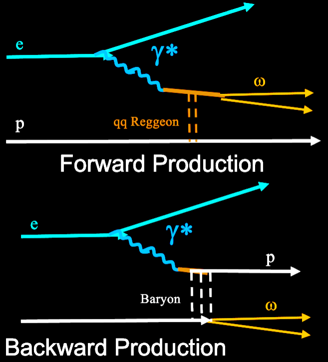
BRAHMS:
New analysis of Au+Au 200 & 62.4 GeV data



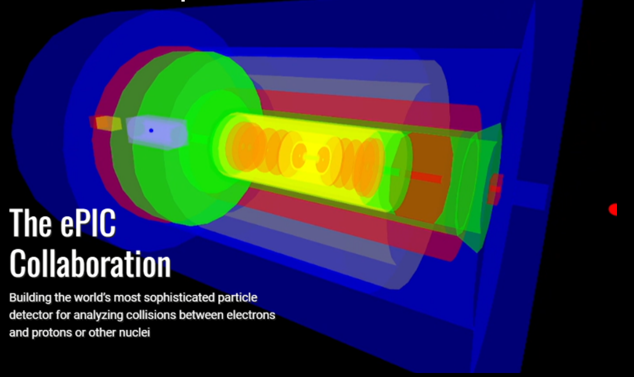


JLab e+p, u-channel backward production





HERA & EIC: Baryon spectra in DIS, possible e+Isobar

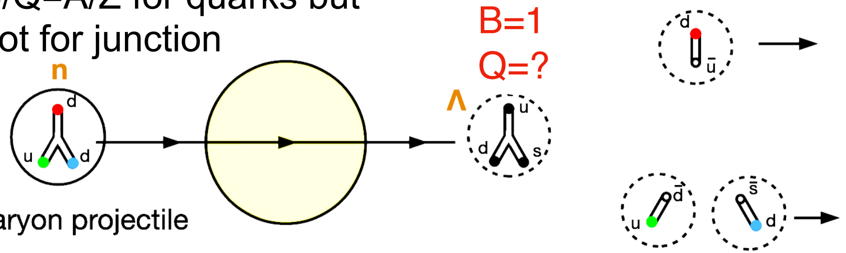


Recent dedicated workshop on baryon dynamics https://indico.cfnssbu.physics.sunysb.edu/event/113/

Backup slides

B/Q=A/Z for valence quarks, what about junction ?

B/Q=A/Z for quarks but not for junction



Baryon projectile

Field of target (Junction or Pomeron)

Junction is stopped at y~0

Quarks fragment as mesons at large y

The junction is flavor-blind, so when it is stopped, it will acquire any three quarks from vacuum

If a junction (flavor-blind) is stopped, we can estimate how much electric charge will be stopped depends on no. of flavors

No of flavors	Quarks	Combinations $\binom{n+r-1}{r}$	$\langle Q \rangle$	$\langle B \rangle$
2	u d	4	1/2	1
3	u d s	10	0	1
4	u d s c	20	1/2	1
5	u d s c b	35	1/5	1
6	u d s c b t	56	1/2	1

B/Q >= 2
(Independent of A/Z)

No of flavors: 2
(u)(2/3) + (u)(2/3) + (u)(2/3) = 2
(u)(2/3) + (u)(2/3) + (d)(-1/3) = 1
(u)(2/3) + (d)(-1/3) + (d)(-1/3) = 0
(d)(-1/3) + (d)(-1/3) + (d)(-1/3) = -1

No of flavors: 3
(u)(2/3) + (u)(2/3) + (u)(2/3) = 2
(u)(2/3) + (u)(2/3) + (d)(-1/3) = 1
(u)(2/3) + (u)(2/3) + (s)(-1/3) = 1
(u)(2/3) + (d)(-1/3) + (d)(-1/3) = 0
(u)(2/3) + (d)(-1/3) + (s)(-1/3) = 0
(u)(2/3) + (s)(-1/3) + (s)(-1/3) = 0
(d)(-1/3) + (d)(-1/3) + (d)(-1/3) = -1
(d)(-1/3) + (d)(-1/3) + (s)(-1/3) = -1
(d)(-1/3) + (s)(-1/3) + (s)(-1/3) = -1
(s)(-1/3) + (s)(-1/3) + (s)(-1/3) = -1

Stopping power in γ+Au and photon energy dependence