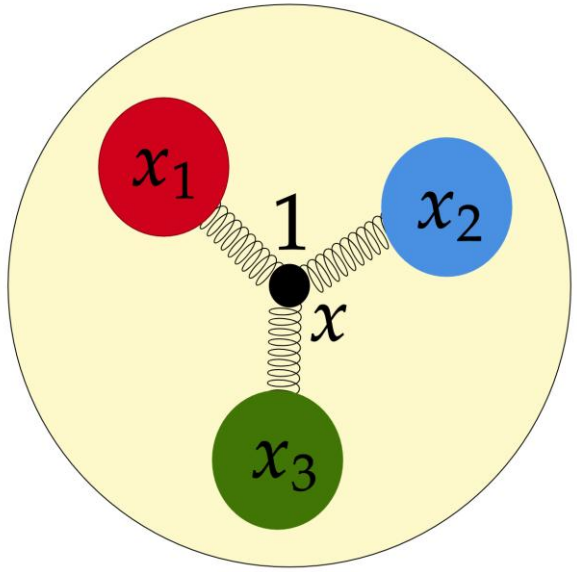
Baryon number dynamics from RHIC to the EIC

David Frenklakh

Brookhaven National Laboratory



2312.15039 (PLB) with D. Kharzeev and W. Li
2405.04569 (JHEP) with D. Kharzeev, G. Rossi, G. Veneziano

Physics Opportunities at an Electron-Ion Collider XI

Florida International University February 24, 2025

In memory of

Giancarlo Rossi

Motivation: what carries the baryon number?

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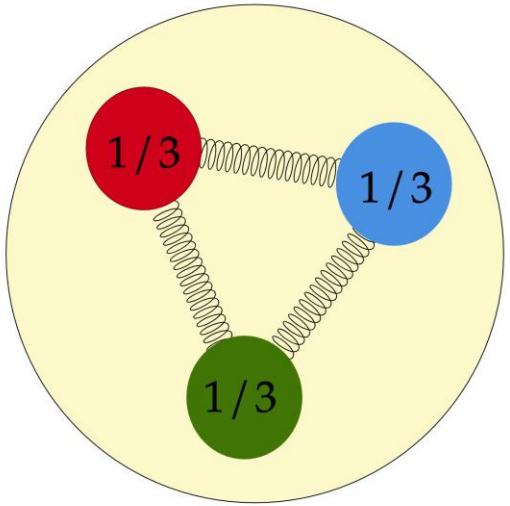
$$B(x_1, x_2, x_3) = \epsilon^{ijk} q(x_1)_i \; q(x_2)_j q(x_3)_k$$



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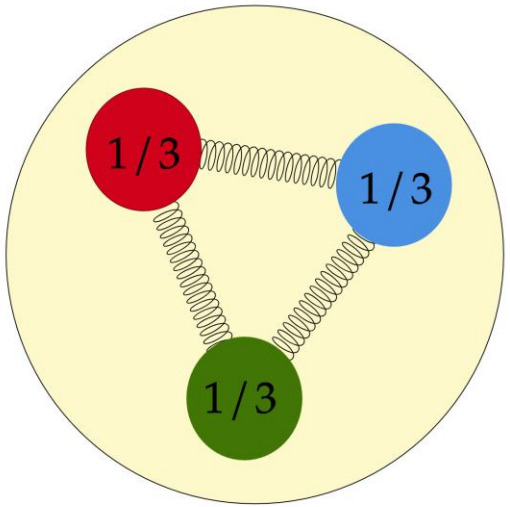
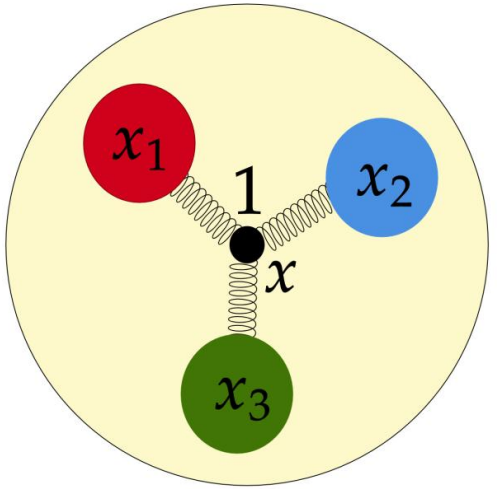


Gauge invariance

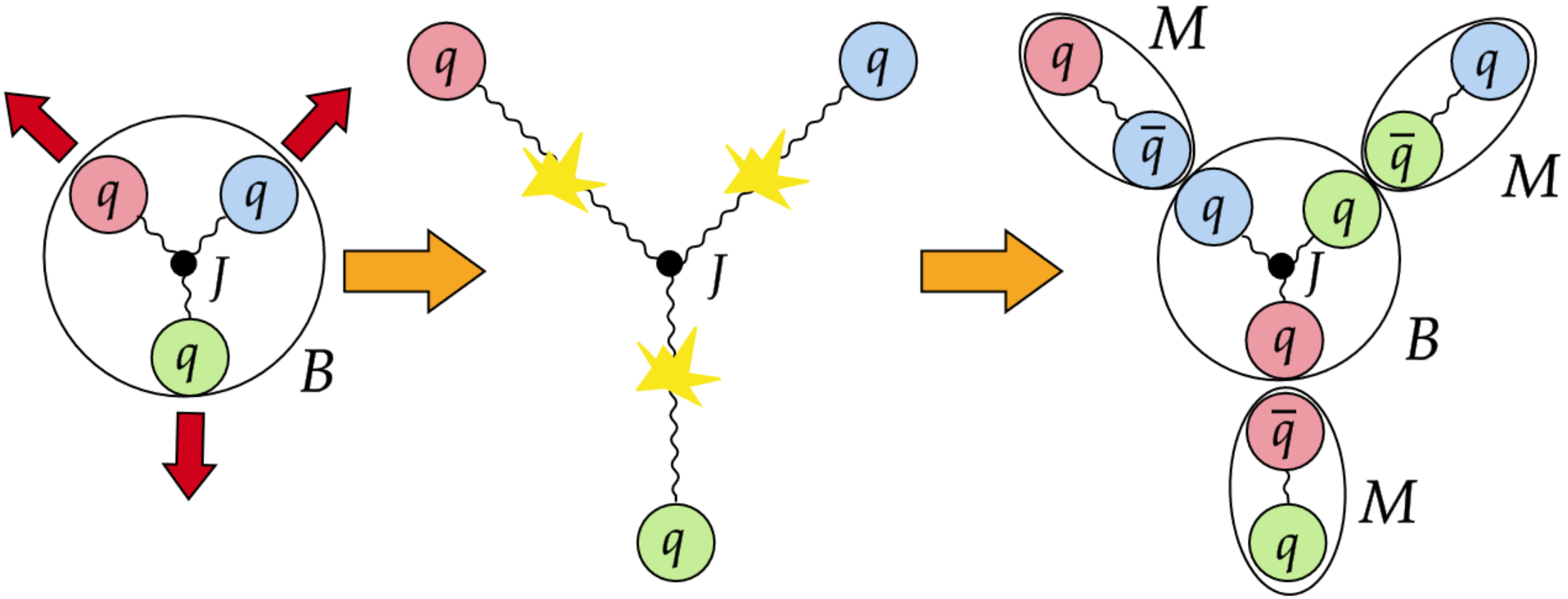
$$B(x_1, x_2, x_3, x) = \epsilon^{ijk} \; [P(x_1, x) \; q(x_1)]_i \; [P(x_2, x) \; q(x_2)]_j \, [P(x_3, x) \; q(x_3)]_k$$

$$P(x_n, x) \equiv \mathcal{P} \exp\left(ig \int_{x_n}^{x} A_\mu dx^\mu \right)$$

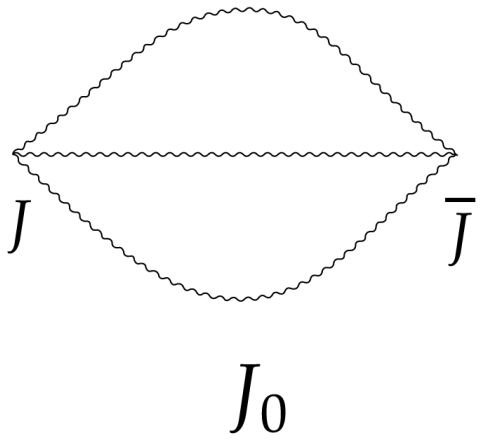


G.C. Rossi and G. Veneziano, Nucl. Phys. B 123 (1977)

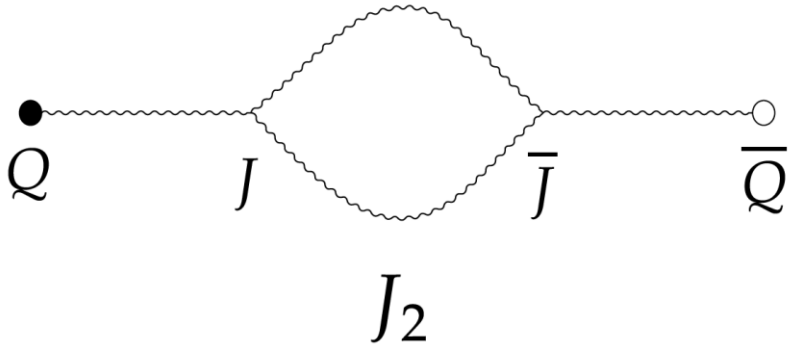
Can baryon junction carry the baryon number?



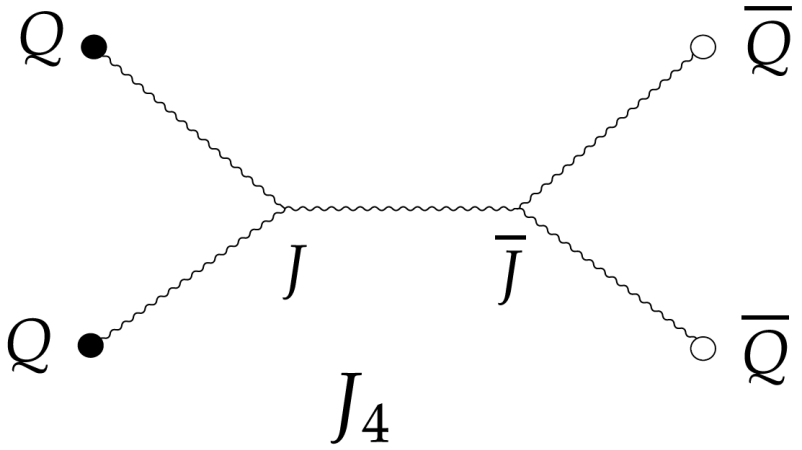
Baryonium



Glueball



Meson



Tetraquark

G.C. Rossi and G. Veneziano, Nucl. Phys. B 123 (1977)

Baryon stopping in pp and AA

Can gluons trace baryon number?

D. Kharzeev

Physics Letters B 378 (1996) 238–246

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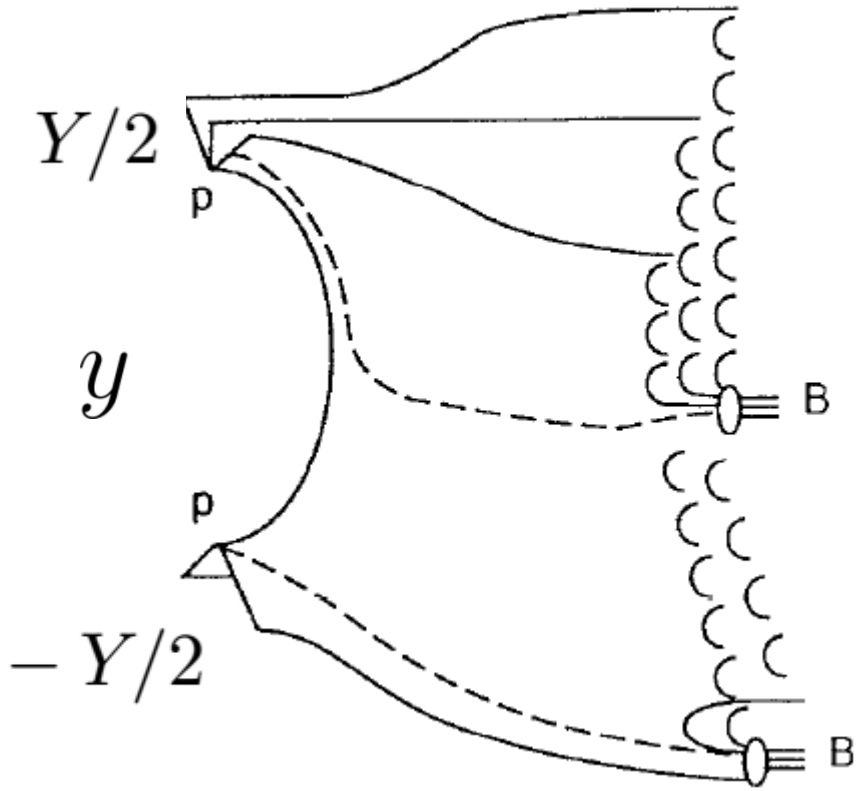
$$\left(\frac{dN_B}{dy}\right)_{net} \propto e^{(\alpha_{\mathbb{P}}+\alpha_{\mathbb{J}_0}-2)Y/2}\left[e^{(\alpha_{\mathbb{P}}-\alpha_{\mathbb{J}_0})y} + e^{(\alpha_{\mathbb{J}_0}-\alpha_{\mathbb{P}})y}\right]$$



Dashed lines denote junctions

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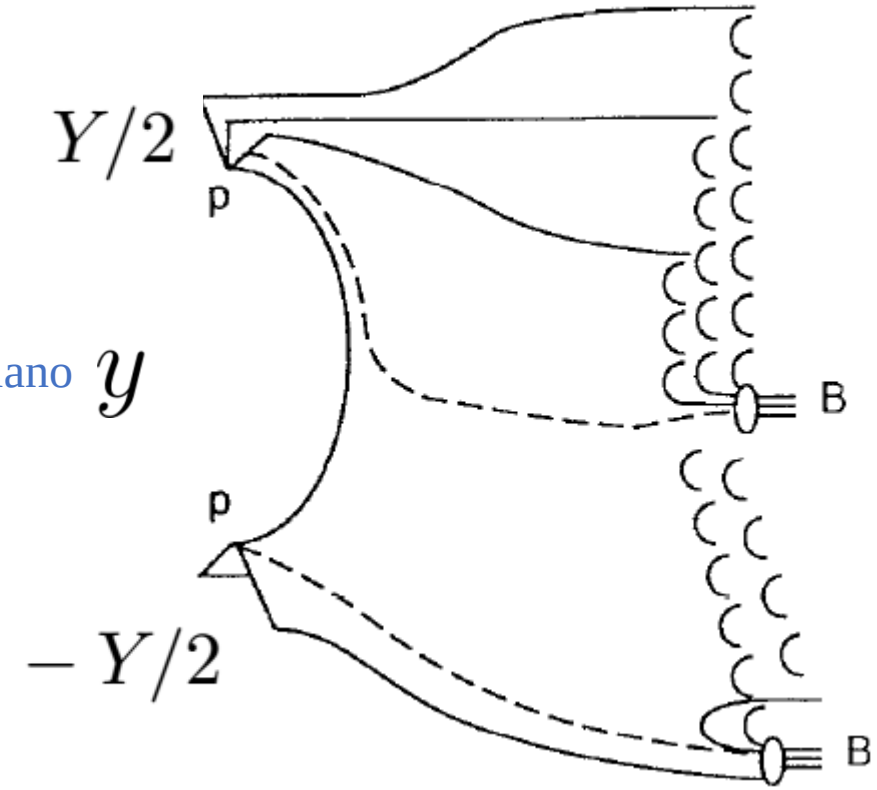
$$\alpha_{\mathbb{P}} = 1 + \Delta \approx 1.08$$

$$\alpha_{\mathbb{J}_0} \approx 0.26$$

2405.04569

DF, Kharzeev, Rossi, Veneziano



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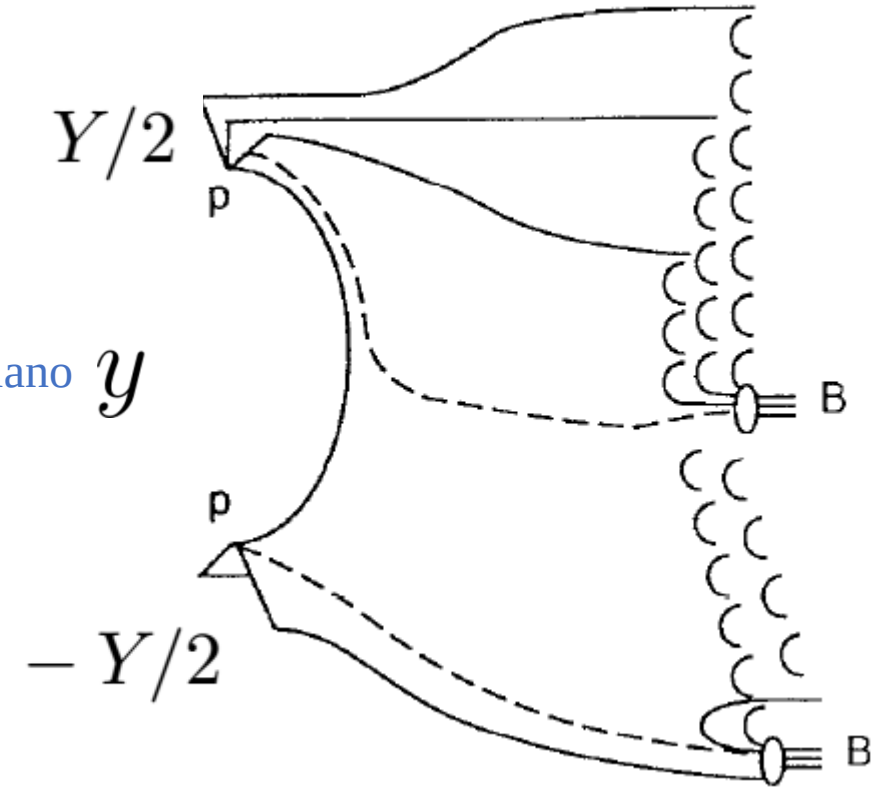
$$\left(\frac{dN_B}{dy}\right)_{net} \propto e^{-0.66Y/2}\left[e^{(0.82y} + e^{-0.82y}\right]$$



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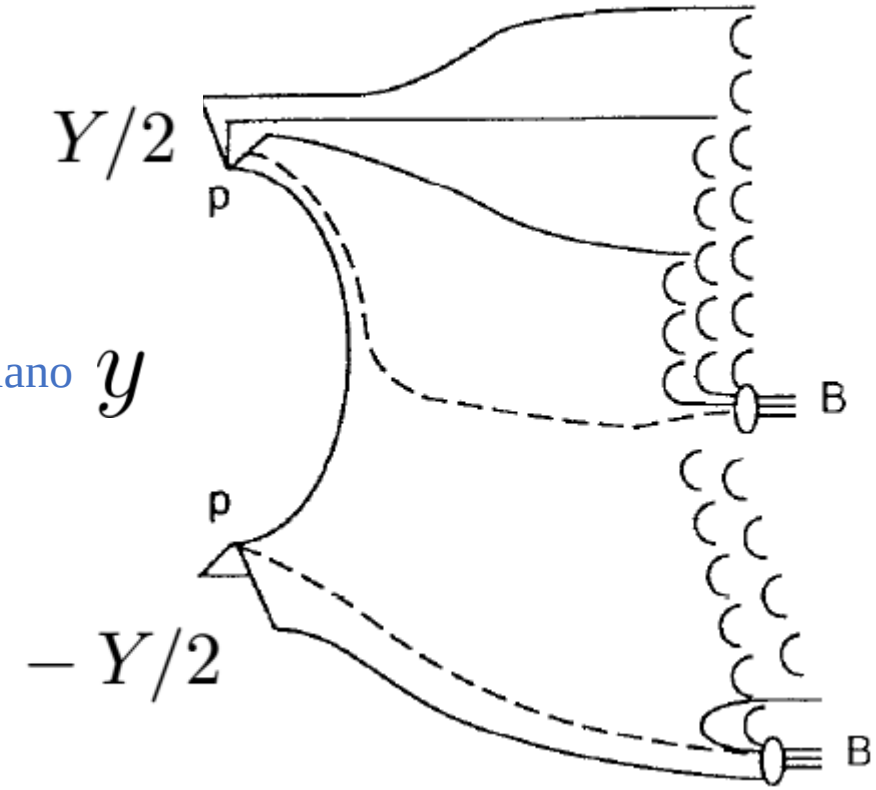
$$\left(\frac{dN_B}{dy}\right)_{net} \propto e^{-0.66Y/2}\left[e^{(0.82y} + e^{-0.82y}\right]$$

$$\left(\frac{dN_B}{dy}\right)_{net}\Big|_{y=0} \propto e^{(-0.65\pm0.1)y_b}$$



Dashed lines denote junctions

From RHIC Beam Energy Scan by STAR collaboration, 2205.05685

Recent experimental results

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

2205.05685

Nicole Lewis[1], Wendi Lv[2], Mason Alexander Ross[3], Chun Yuen Tsang[4], James Daniel Brandenburg[5], Zi-Wei Lin[3], Rongrong Ma[1], Zebo Tang[2], Prithwish Tribedy[1,a], Zhangbu Xu[4]

2309.06445

Correlations of baryon and charge stopping in heavy ion collisions*

Wendi Lv (吕文棣)[1], Yang Li (李洋)[1], Ziyang Li (李子阳)[1], Rongrong Ma (马荣荣)[2], Zebo Tang (唐泽波)[1], Prithwish Tribedy[2], Chun Yuen Tsang[3], Zhangbu Xu (许长补)[2] and Wangmei Zha (查王妹)[1]

Tracking the baryon number with nuclear collisions

2408.15441

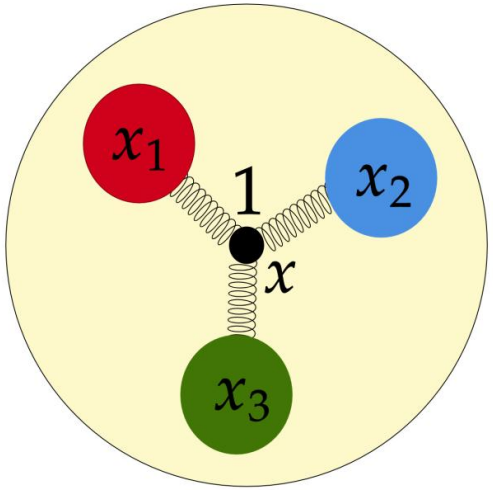
STAR Collaboration

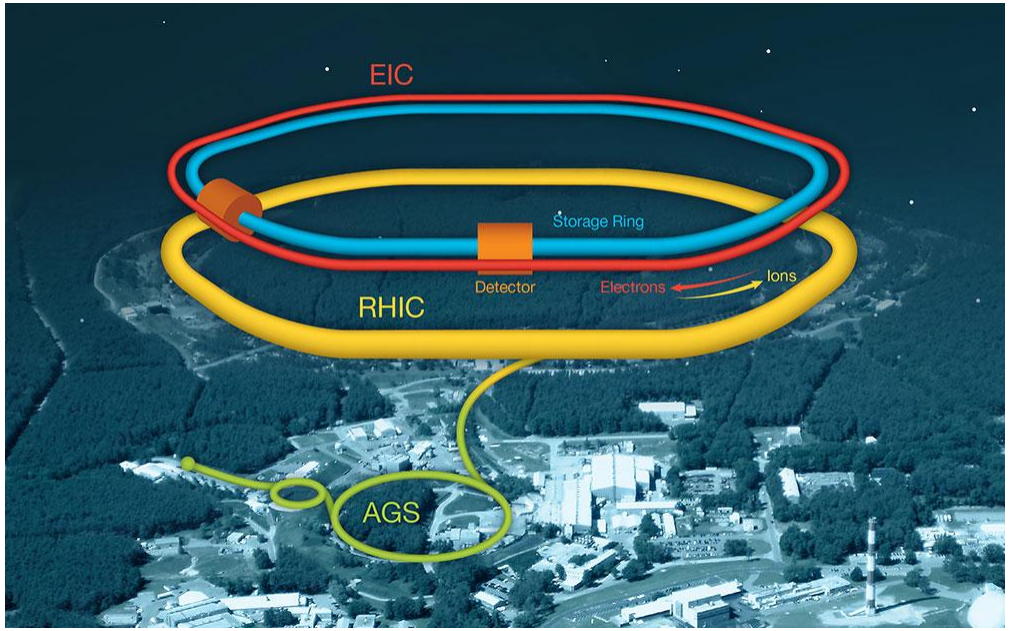
Beam energy dependence of net-hyperon yield and its implication on baryon transport mechanism

2409.06492

Chun Yuen Tsang[a,b], Rongrong Ma[b], Prithwish Tribedy[b], Zhangbu Xu[a,b]

DIS to probe the carrier of baryon number?

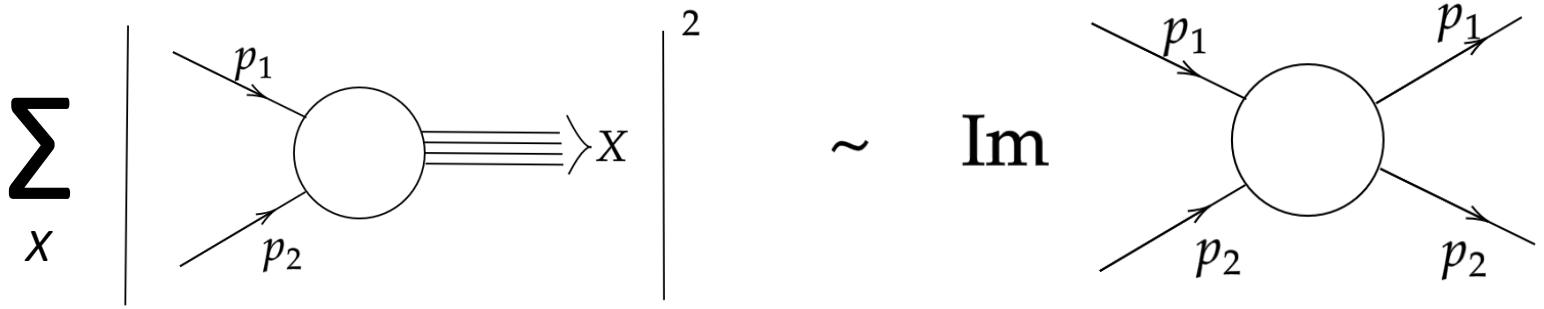




Mueller-Kancheli theorem

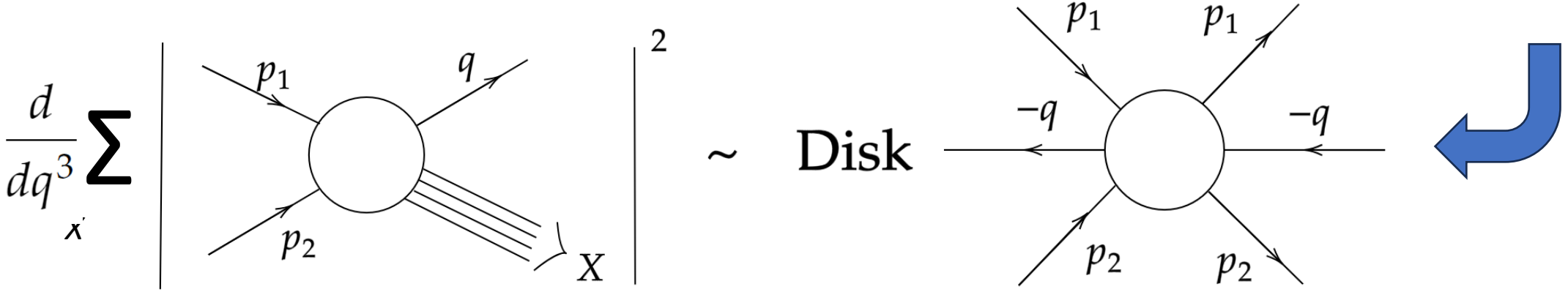
A.H. Mueller, Phys. Rev. D 2 (1970) 2963.
O.V. Kancheli, JETP Lett. 11 (1970) 397.

Optical theorem:

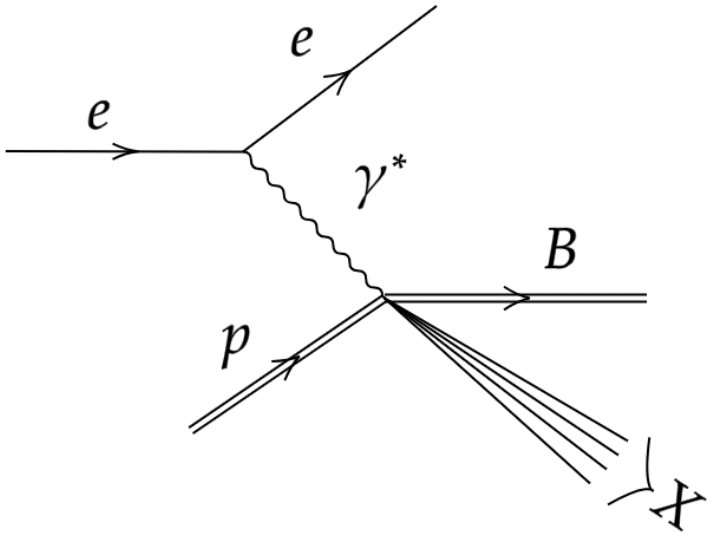


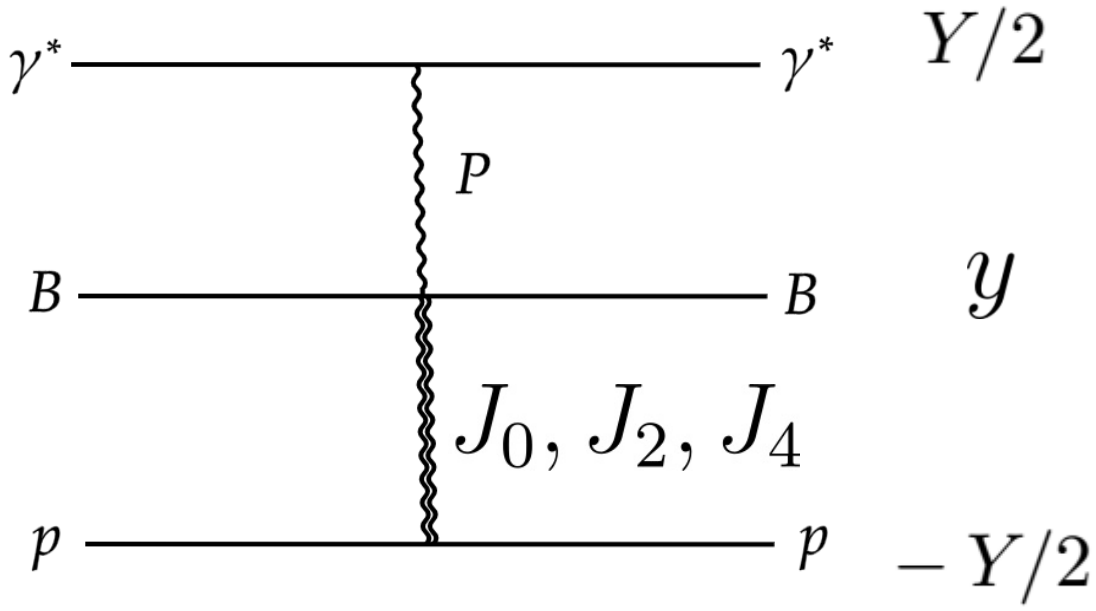
Generalized to semi-inclusive scattering:

Study in Regge theory



SIDIS as $3 \to 3$ forward scattering





$$\mathcal{A}(s,t) \propto s^{\alpha(t)}, s \to \infty$$

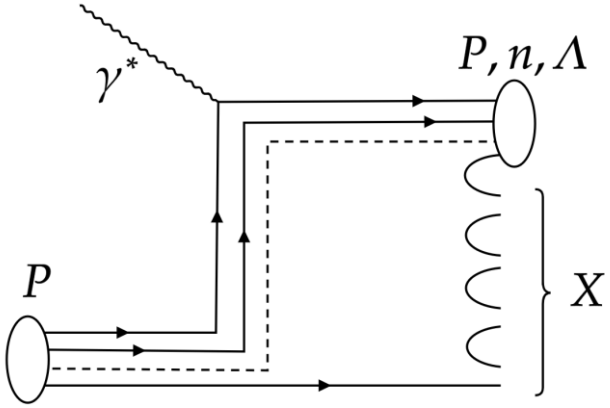
$$s_1 = (p_1 + p_B)^2 = \sqrt{s}\, m_t\, e^{-y^*}$$

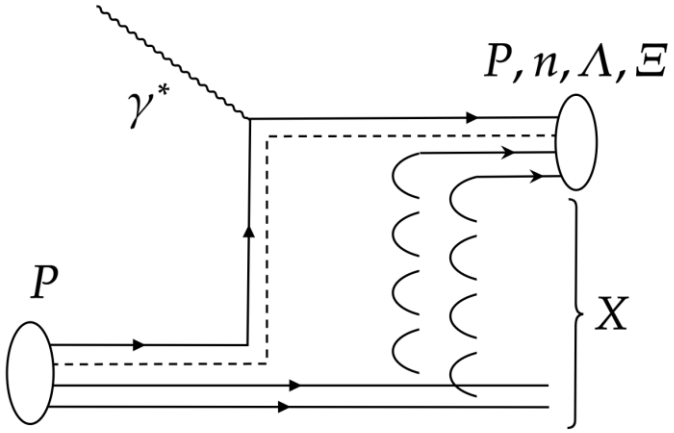
$$s_2 = (p_2 + p_B)^2 = \sqrt{s}\, m_t\, e^{y^*}$$

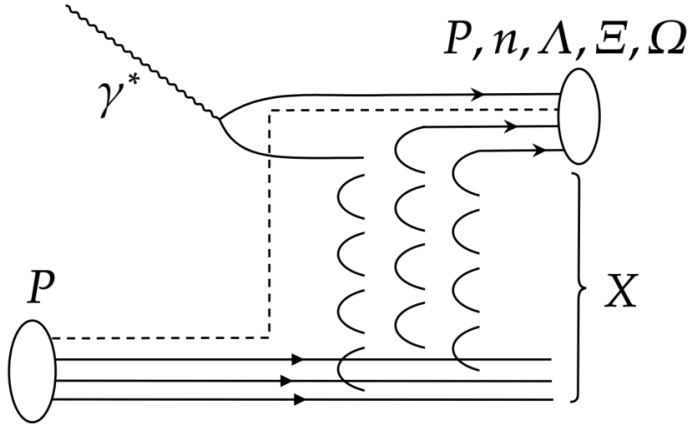
$$\left(\frac{dN_B}{dy}\right)_{net} \propto s_1^{\alpha_{\mathbb{P}}(0)-1} s_2^{\alpha_{\mathbb{J}}(0)-1}$$

The largest $\alpha_{\mathbb{J}}(0)$ is leading

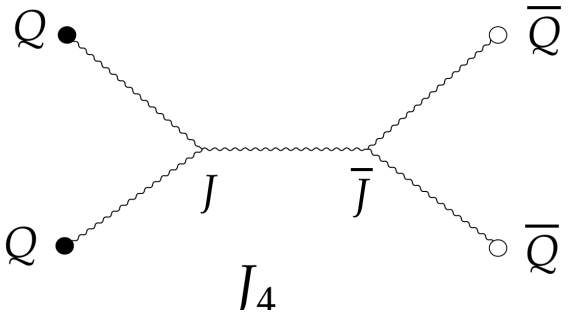
Three possible processes





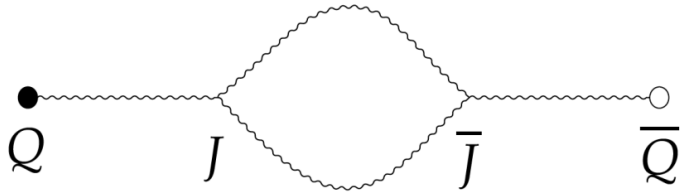


Mueller-Kancheli t-channel exchanges:



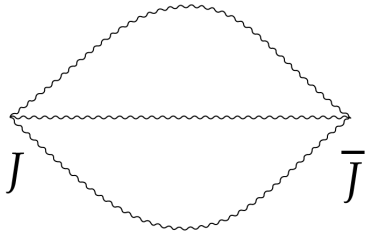
I_4

$\alpha_{\mathbb{J}_4} \approx -0.66$



J_2

$\alpha_{\mathbb{J}_2} \approx -0.24$



J_0

$\alpha_{\mathbb{J}_0} \approx 0.26$

Intercept estimates: Topological expansion+ Feynman-Wilson gas model

2405.04569 DF, Kharzeev, Rossi, Veneziano

Three possible processes

Mueller-Kancheli t-channel exchanges:

J_4

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J_2

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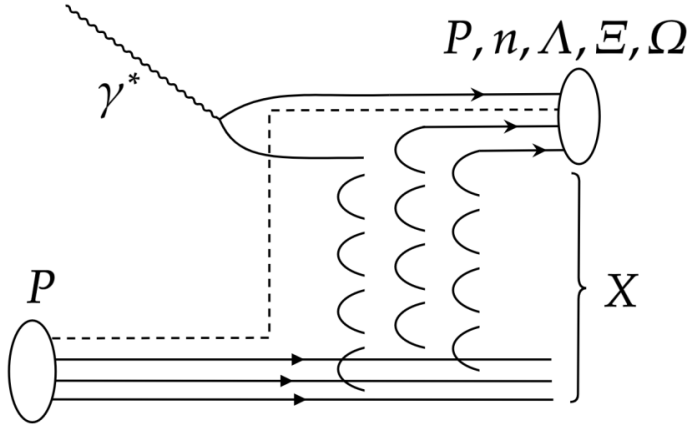
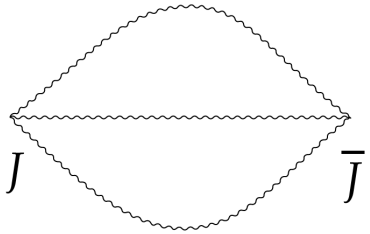
Leading





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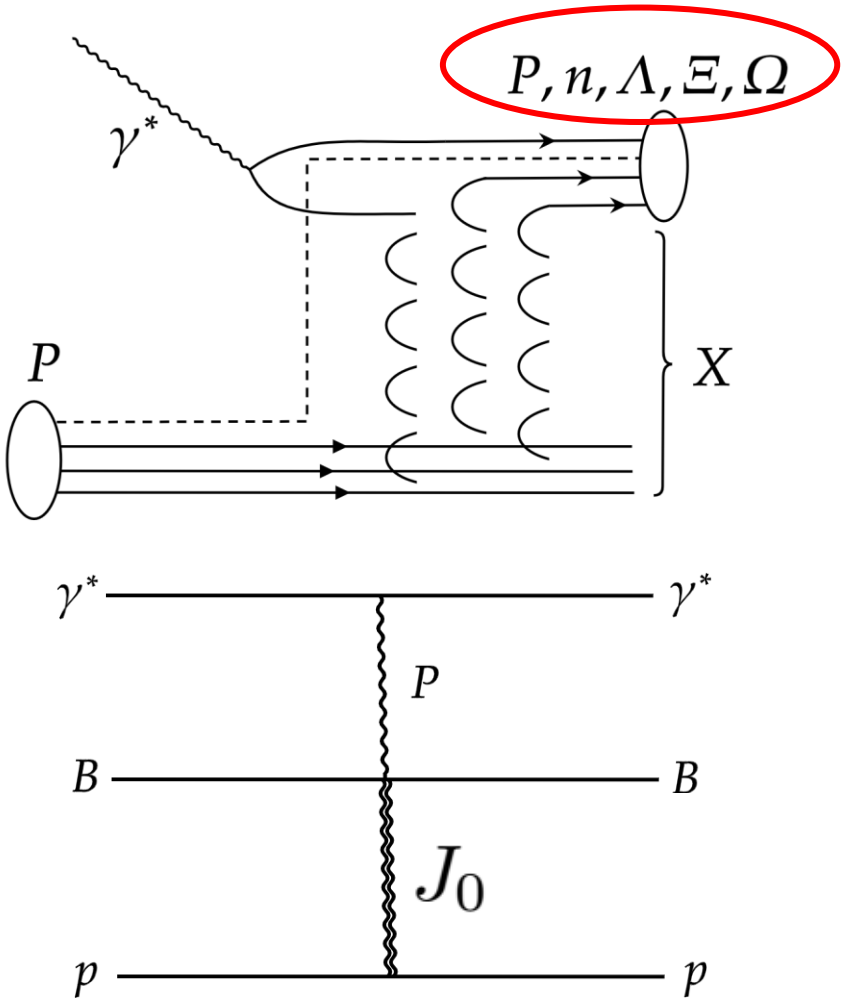
Rapidity distribution of baryons in DIS

$$\left(\frac{dN_B}{dy}\right)_{net} \propto s_1^{\alpha_{\mathbb{P}}-1} s_2^{\alpha_{\mathbb{J}_0}-1}$$

$$s_1 \propto e^{Y/2-y} \qquad s_2 \propto e^{Y/2+y}$$

$$\left(\frac{dN_B}{dy}\right)_{net} \propto e^{(\alpha_{\mathbb{P}}+\alpha_{\mathbb{J}_0}-2)Y/2} e^{(\alpha_{\mathbb{J}_0}-\alpha_{\mathbb{P}})y}$$



Wide rapidity acceptance at the EIC will make it possible to measure both *Y/2* and *y* dependence.

Summary

- Accounting for inter-species correlations in Feynman-Wilson gas improves agreement with the baryon stopping data from RHIC

- Signatures of baryon junctions in semi-inclusive DIS for the EIC:
  - ❑ characteristic rapidity dependence
  - ❑ baryon flavor content
  - ❑ relation between meson multiplicities in rapidity intervals