Signatures of baryon junctions in semi-inclusive deep inelastic scattering

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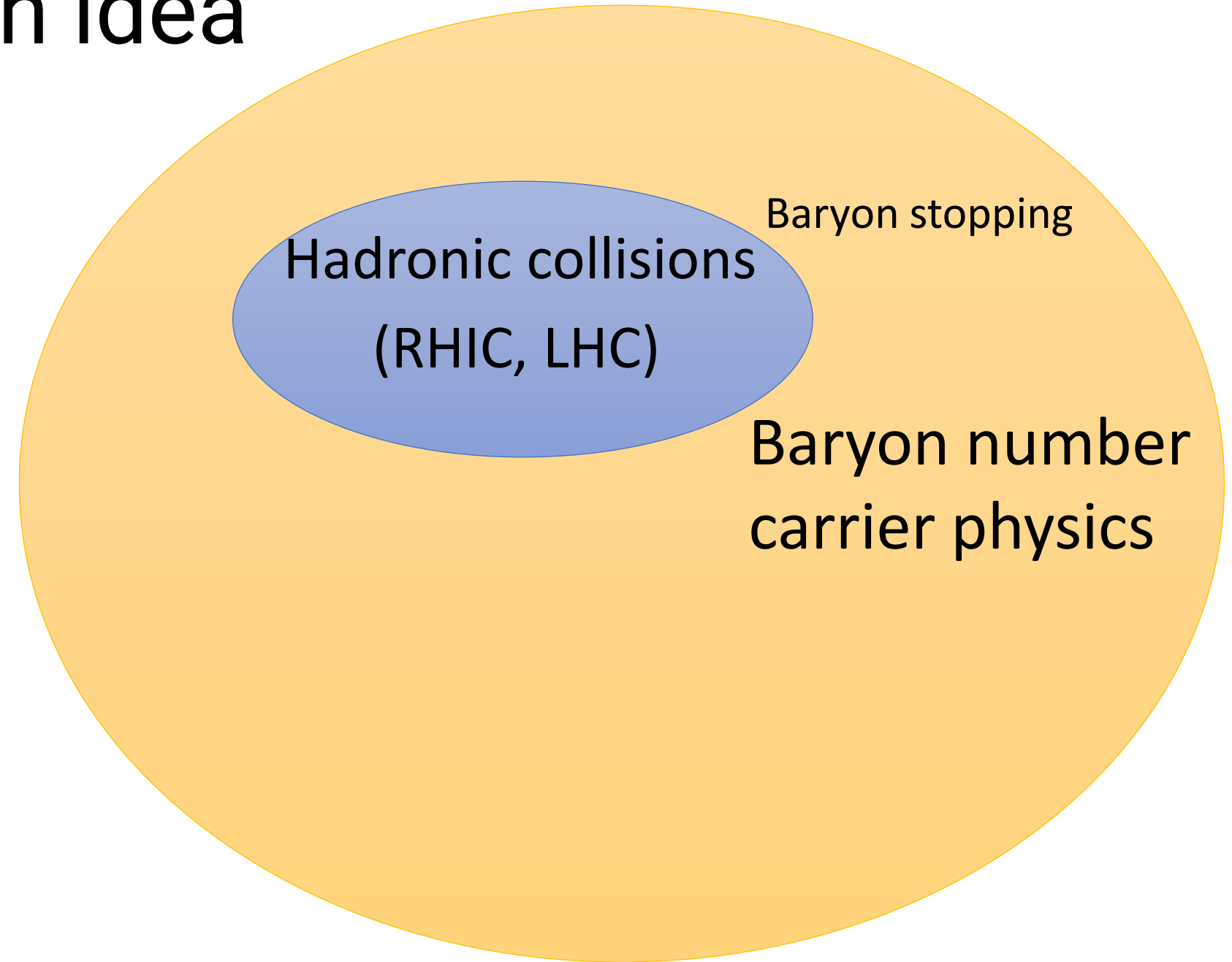
based on arXiv: 2312.15039 with D. Kharzeev

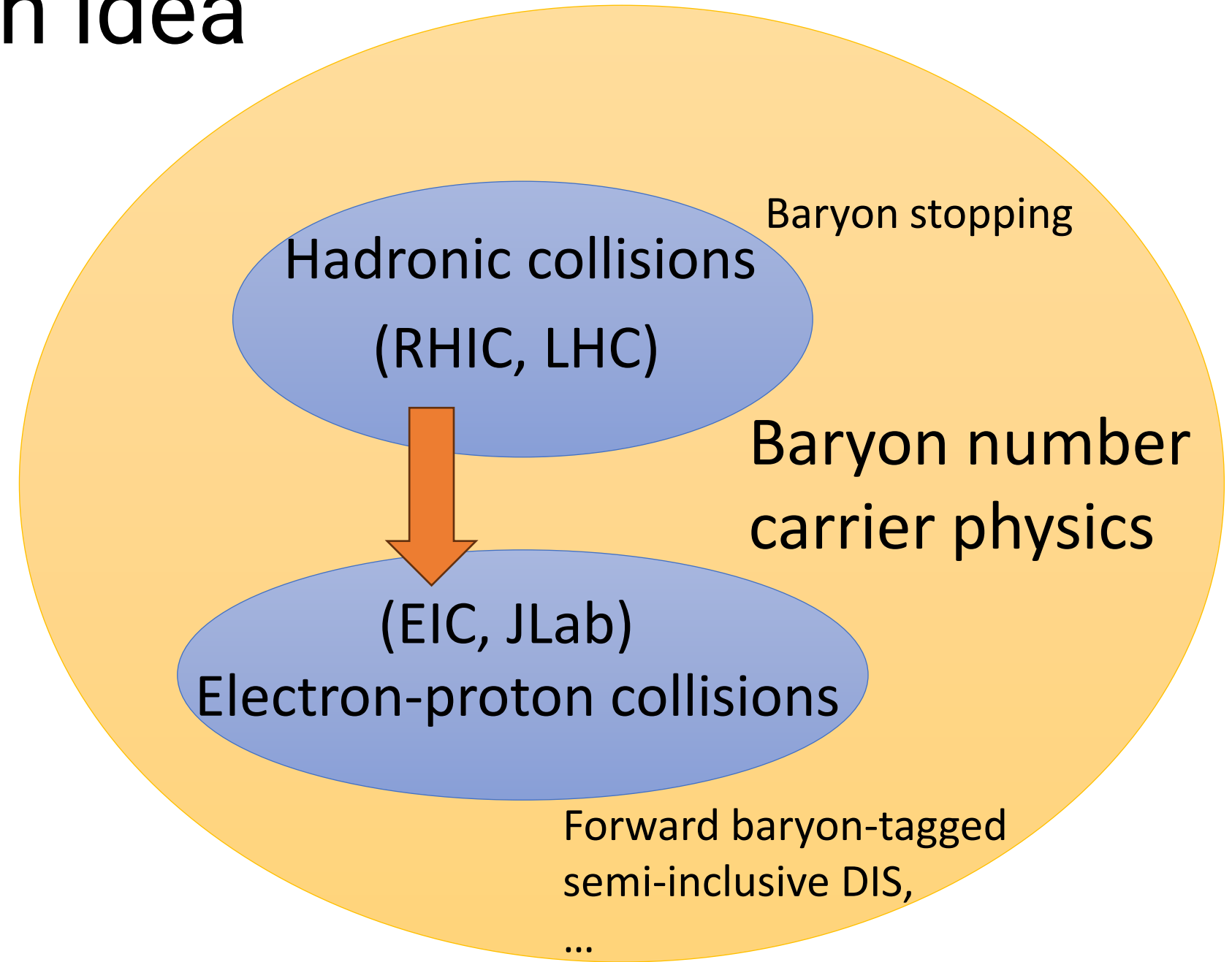
1st Workshop on Baryon dynamics from RHIC to EIC

January 22, 2024

Main idea


Baryon stopping
Hadronic collisions
(RHIC, LHC)
Baryon number
carrier physics

Main idea

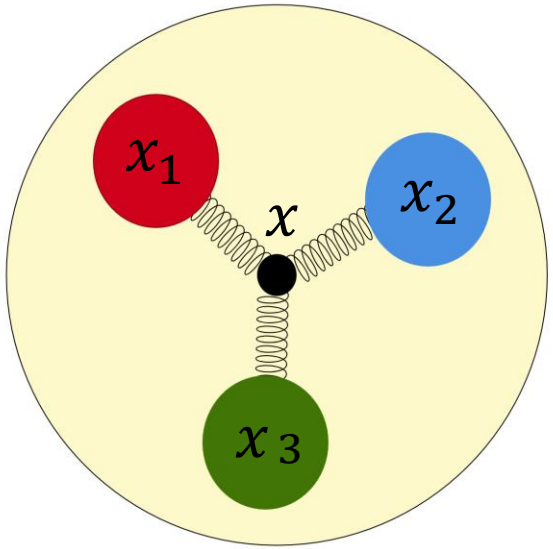

Baryon stopping
Hadronic collisions
(RHIC, LHC)
Baryon number
carrier physics
(EIC, JLab)
Electron-proton collisions
Forward baryon-tagged
semi-inclusive DIS,
…

Baryon junction

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

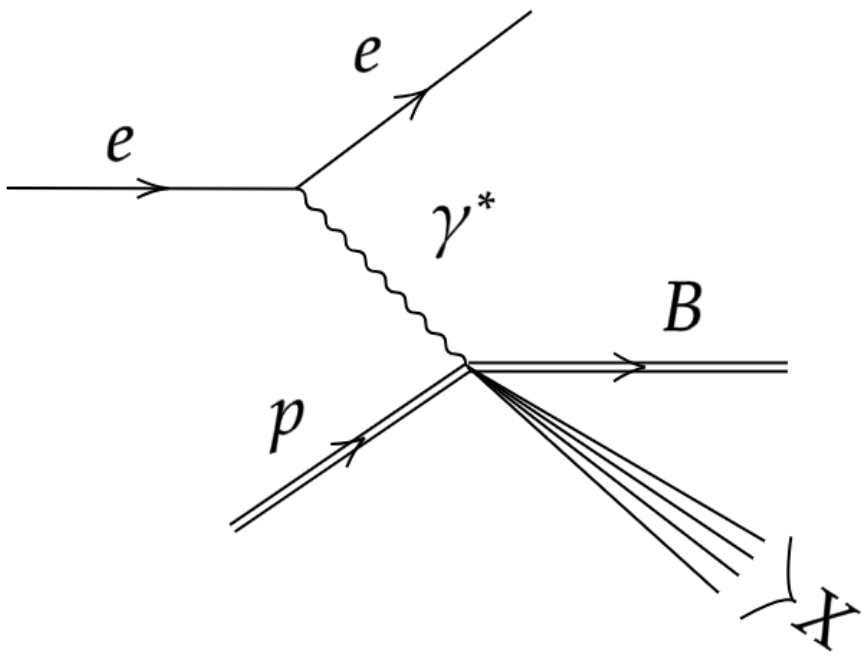
Gauge invariance

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



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

Deep inelastic scattering (DIS)



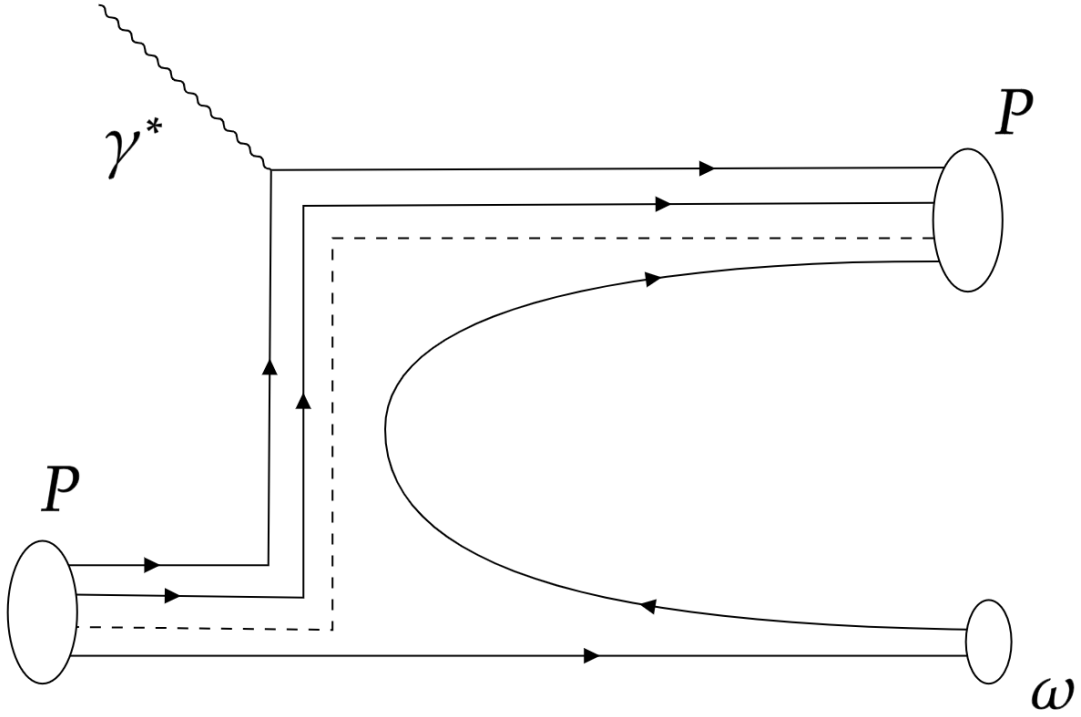
$\gamma^* p$ center of mass frame:

$$p_{\gamma^*} = (\frac{\sqrt{s}}{2}, \frac{\sqrt{s}}{2}, 0^\perp)$$

$$p_p = (\frac{\sqrt{s}}{2}, -\frac{\sqrt{s}}{2}, 0^\perp)$$

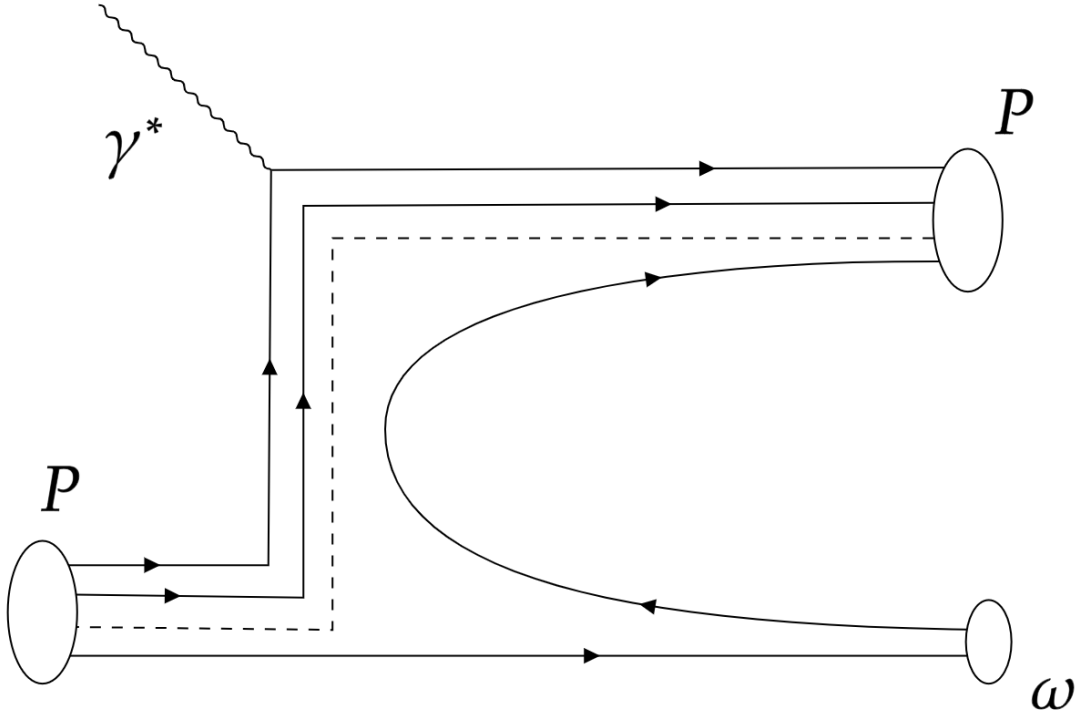
$$p_B = (m_t \cosh y^*, m_t \sinh y^*, p_B^\perp)$$

Initial motivation: exclusive ω production



Significant fraction of events have the proton in the photon fragmentation region

Initial motivation: exclusive ω production

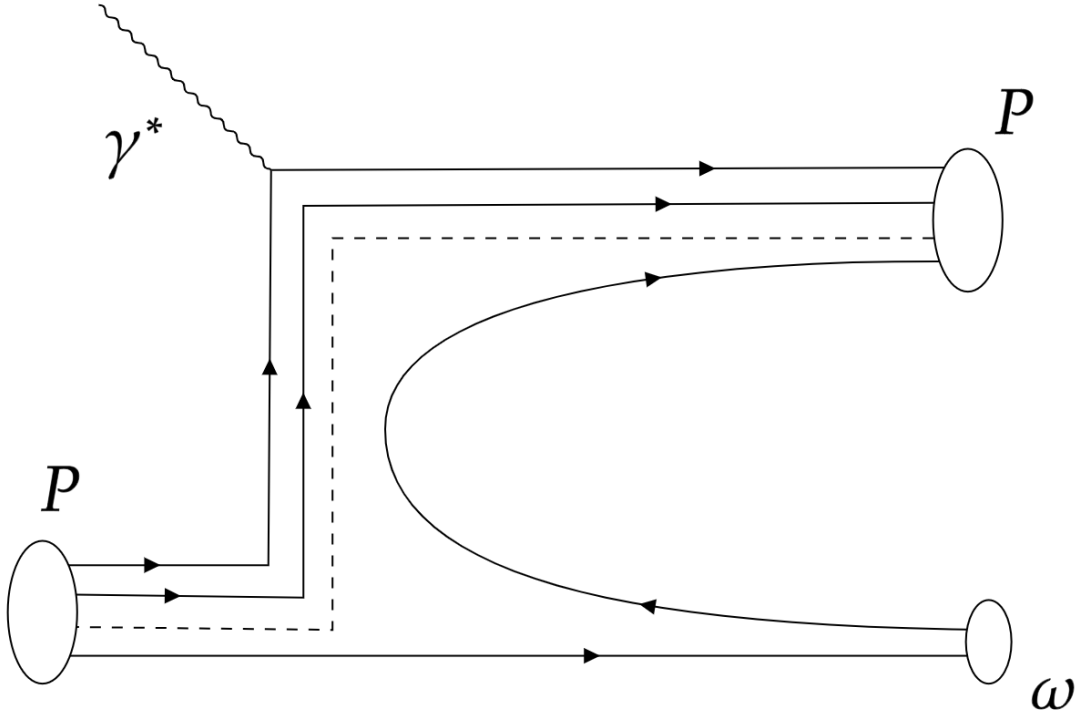


Significant fraction of events have the proton in the photon fragmentation region

Entire baryon is exchanged in the t-channel

Cannot separate the junction from valence quarks

Initial motivation: exclusive ω production



Significant fraction of events have the proton in the photon fragmentation region

Entire baryon is exchanged in the t-channel

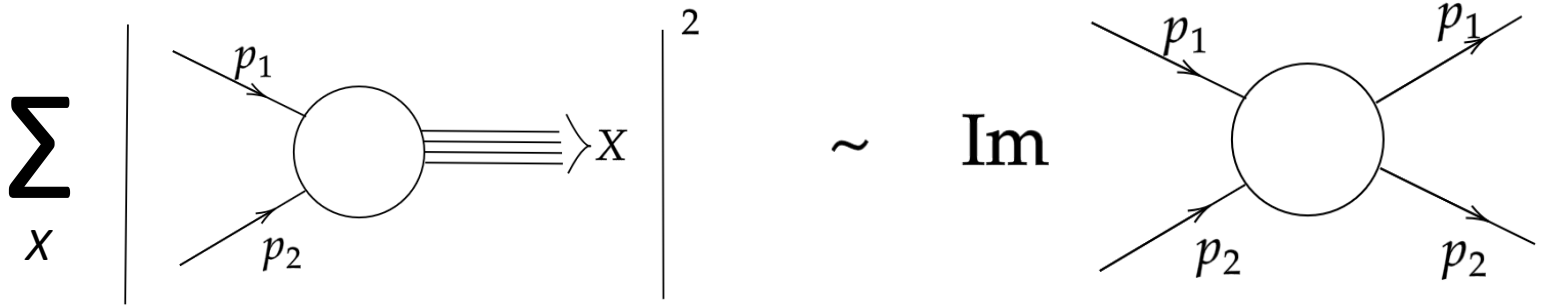
Cannot separate the junction from valence quarks

Need a semi-inclusive process

Mueller-Kancheli theorem

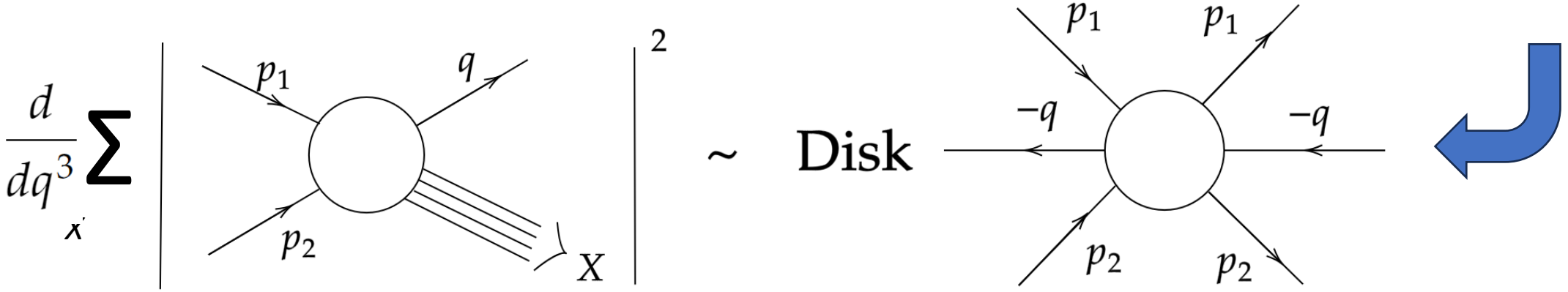
A.H. Mueller, Phys. Rev. D 2 (1970) 2963.
O.V. Kancheli, JETP Lett. 11 (1970) 397.

Optical theorem:

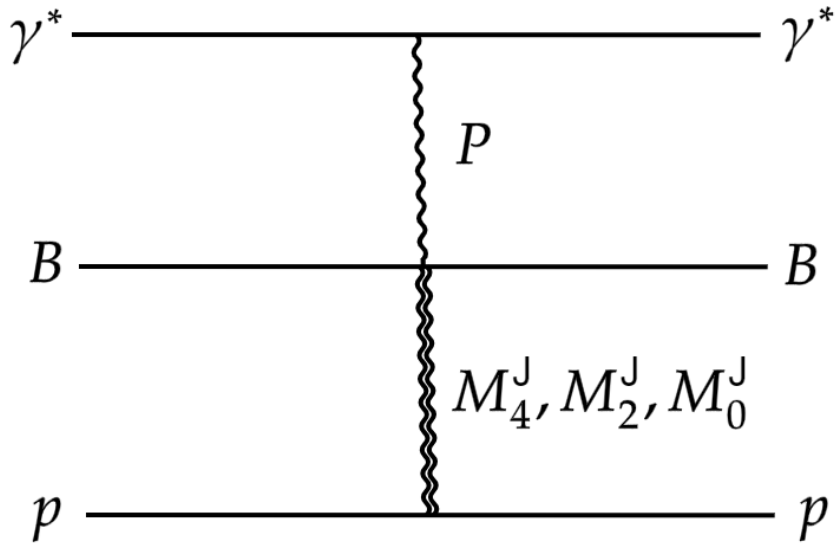


Generalized to semi-inclusive scattering:

Study in Regge theory



$3 \rightarrow 3$ forward scattering in Regge limit



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

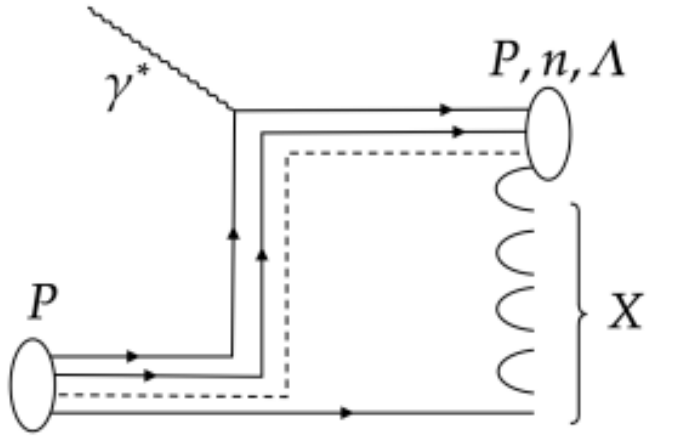
$$s_1 = (p_1 + p_B)^2 = \sqrt{s}\, m_t\, e^{-y^*}$$

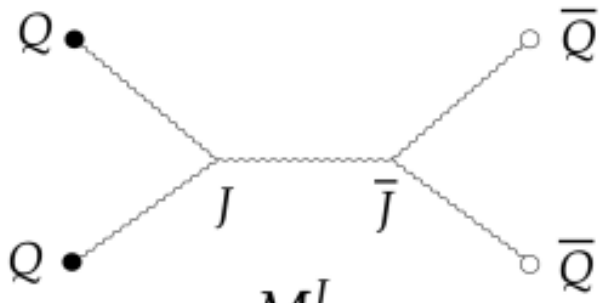
$$s_2 = (p_2 + p_B)^2 = \sqrt{s}\, m_t\, e^{y^*}$$

$$E_B \frac{d^3\sigma}{dp_B^3} \propto s_1^{\alpha_P(0)-1} s_2^{\alpha_M(0)-1}$$

The largest $\alpha_M(0)$ is leading

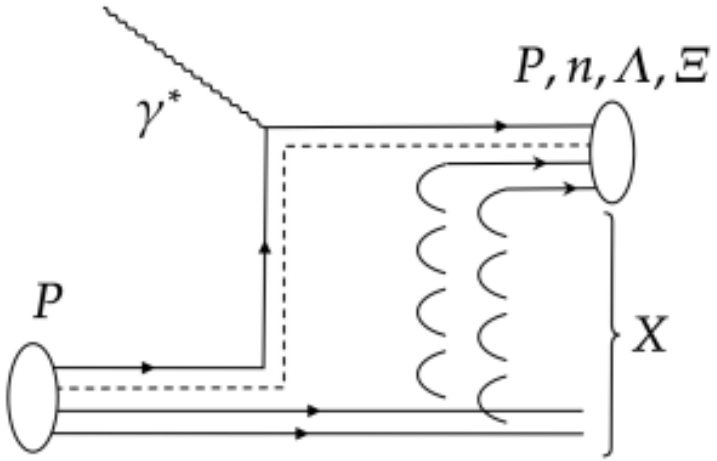
Possible processes





M_4^J

$$\alpha_4^J(0) \approx -\frac{1}{2}$$



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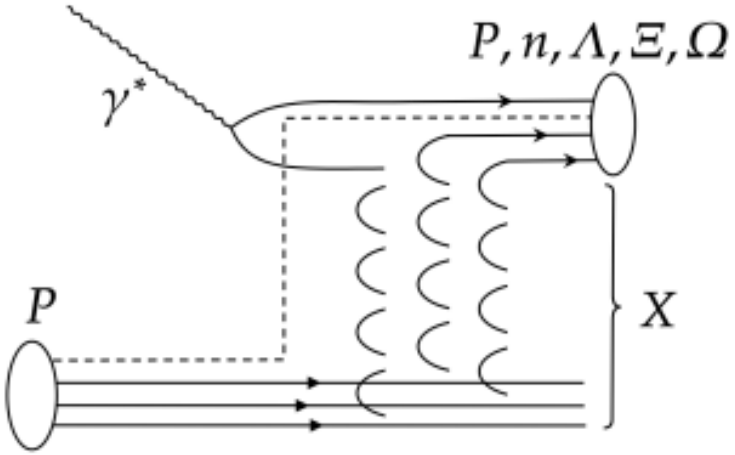
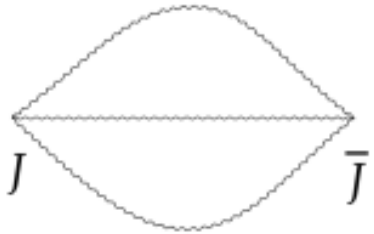


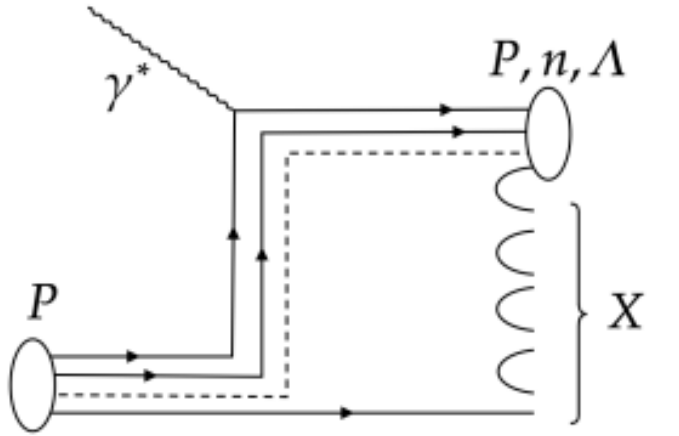


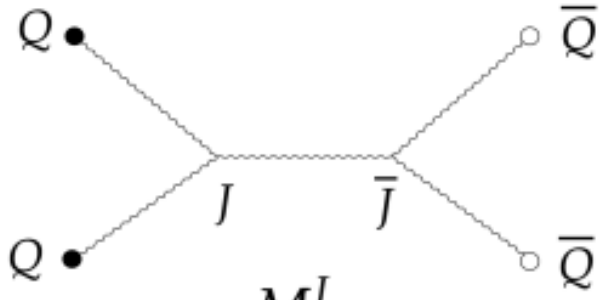
M_0^J

$$\alpha_0^J(0) \approx \frac{1}{2}$$

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

Possible processes





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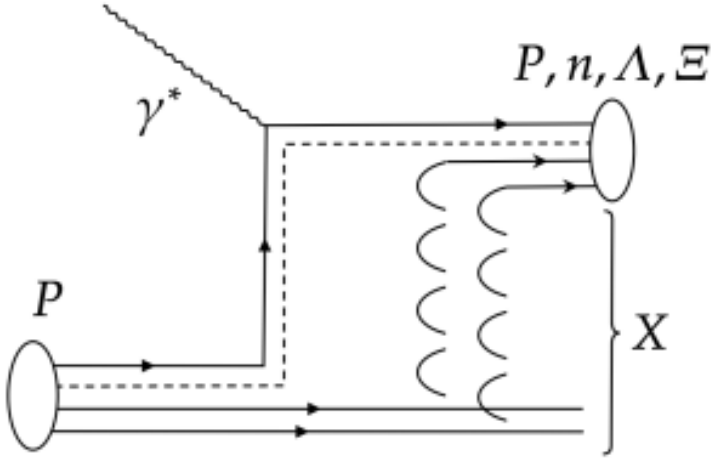
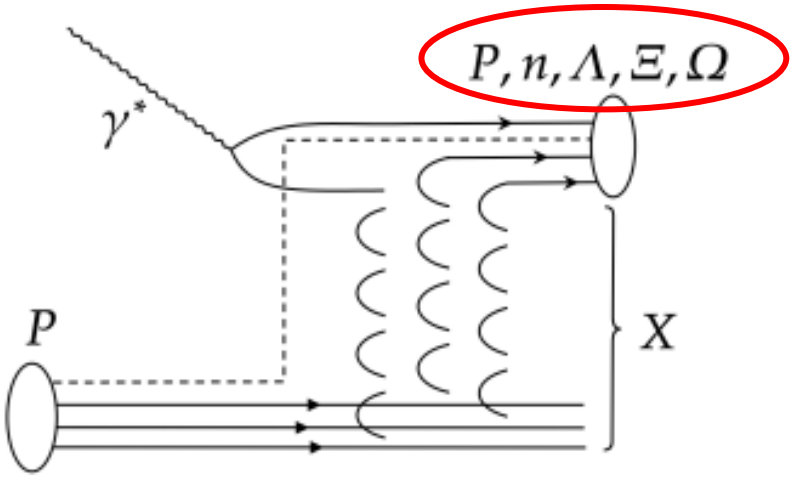
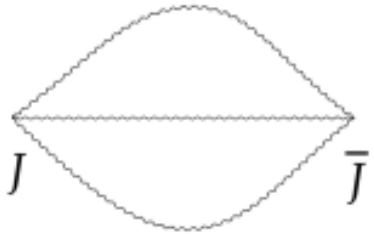


M_2^J

$$\alpha_2^J(0) \approx 0$$





M_0^J

$$\alpha_0^J(0) \approx \frac{1}{2}$$

Leading

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

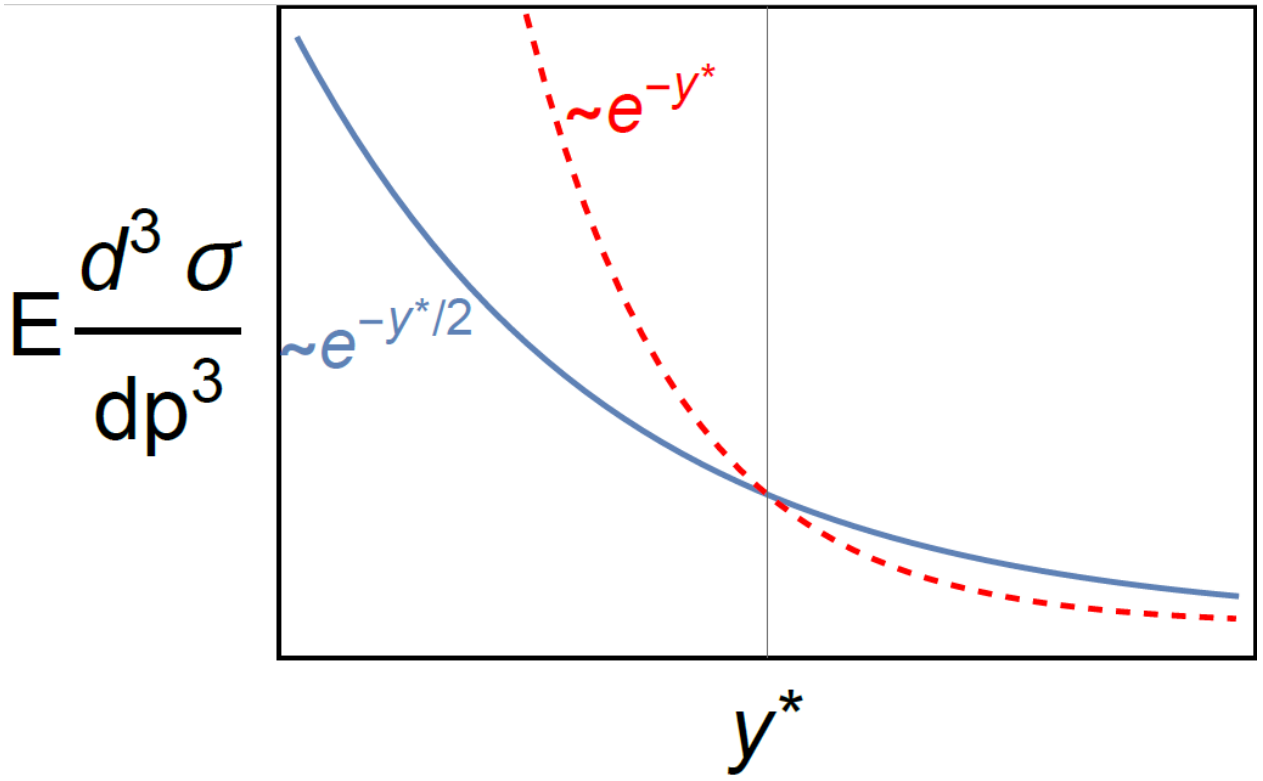
Rapidity distribution

$$E_B \frac{d^3\sigma}{dp_B^3} \propto s_1^{\alpha_P(0)-1} s_2^{\alpha_M(0)-1}$$

$$s_1 = \sqrt{s}\ m_t\ e^{-y^*}\ ,\ s_2 = \sqrt{s}\ m_t\ e^{y^*}$$

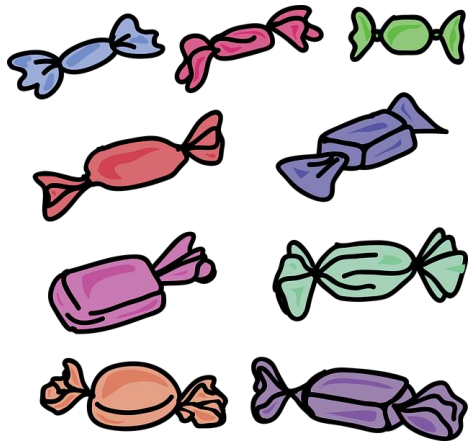
$$\alpha_P \approx 1, \alpha_M \approx \frac{1}{2}$$

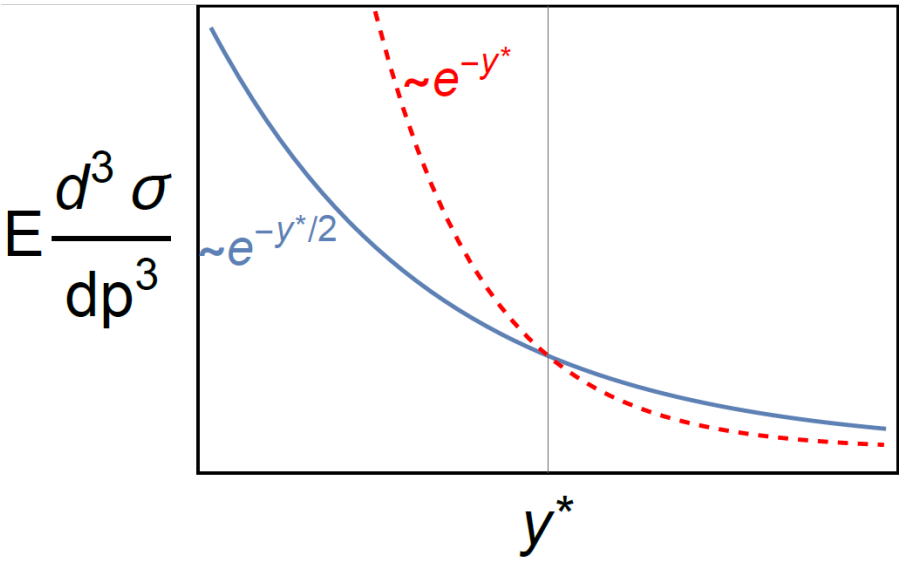
$$E_B \frac{d^3\sigma}{dp_B^3} \propto s^{-1/4} e^{-y^*/2}$$



Summary: observational consequences

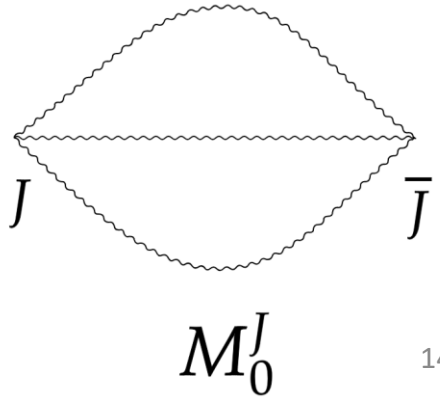
Flavor content of forward baryons: all flavors



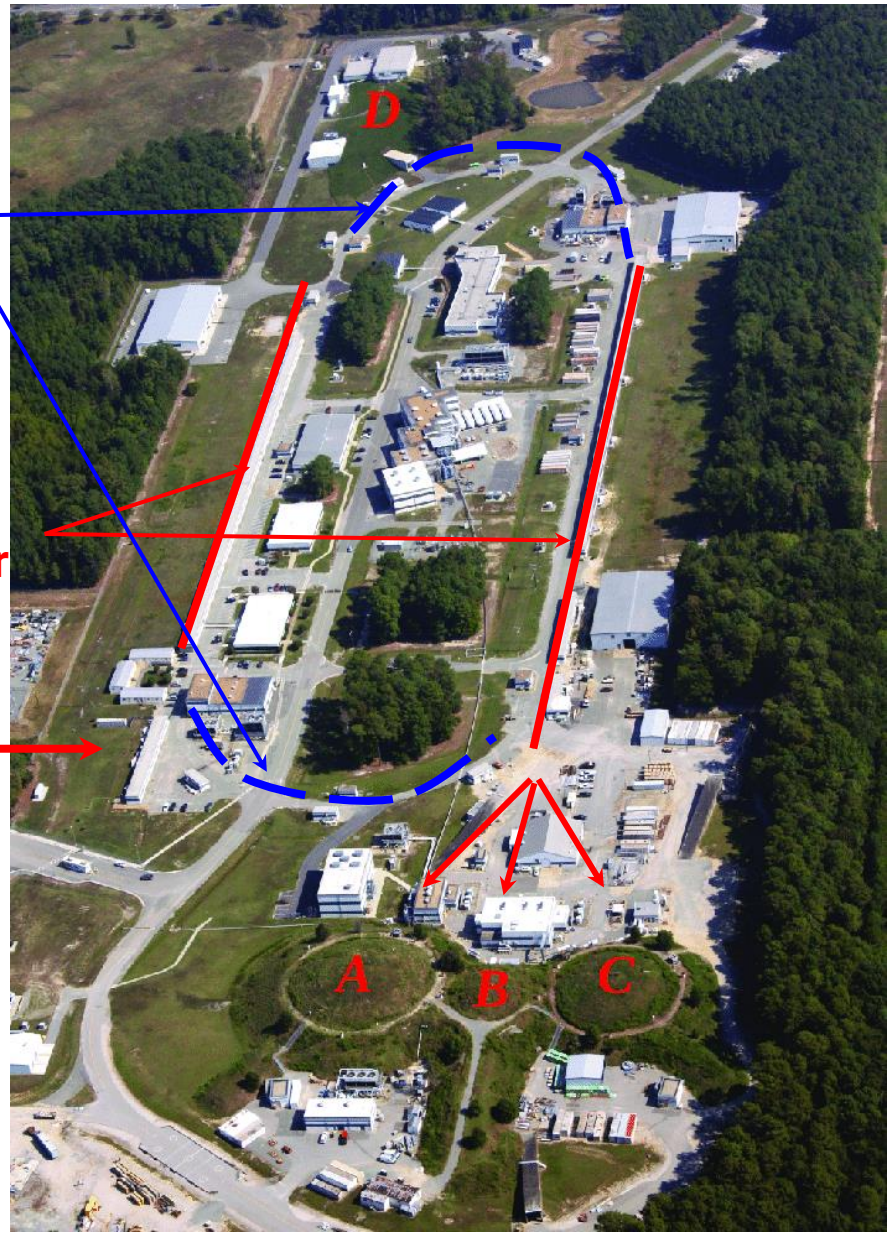


Rapidity dependence of forward baryon distribution

Large meson multiplicity from 3 fragmenting strings

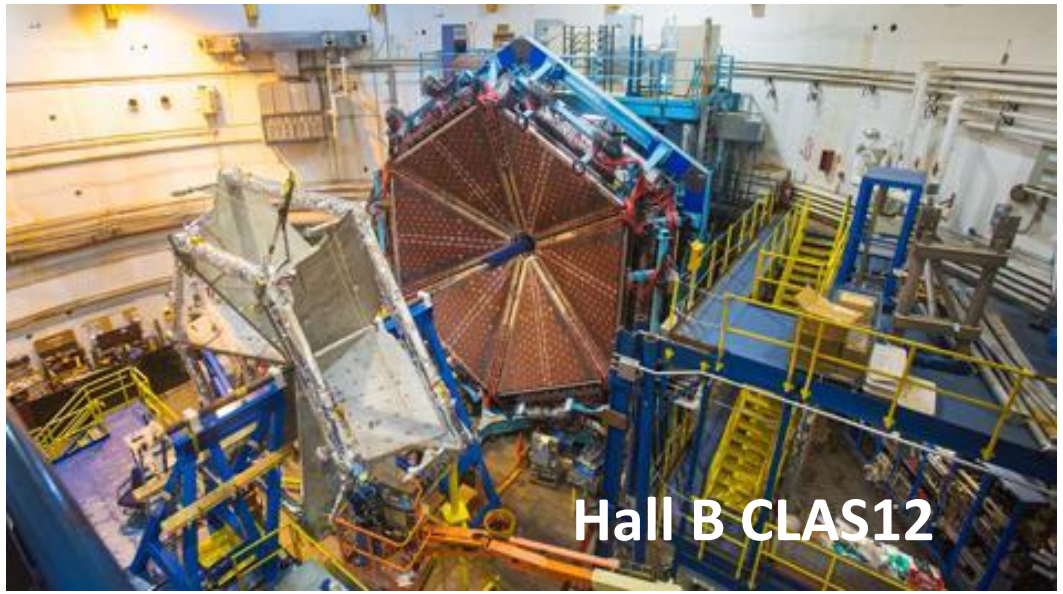


Jefferson Lab



- Continuous e beam upto 12 GeV
- CEBAF Accelerator:
  - Injector
  - 2 x Superconducting linear accelerator
  - Bending Arcs
  - Duty Factor: 100%
- 4 x experimental Halls
  - Hall A, B, C, and D
- Luminosity upto 10^{36} $cm^{-2}s^{-1}$

Jefferson Lab Experimental Halls at 12 GeV



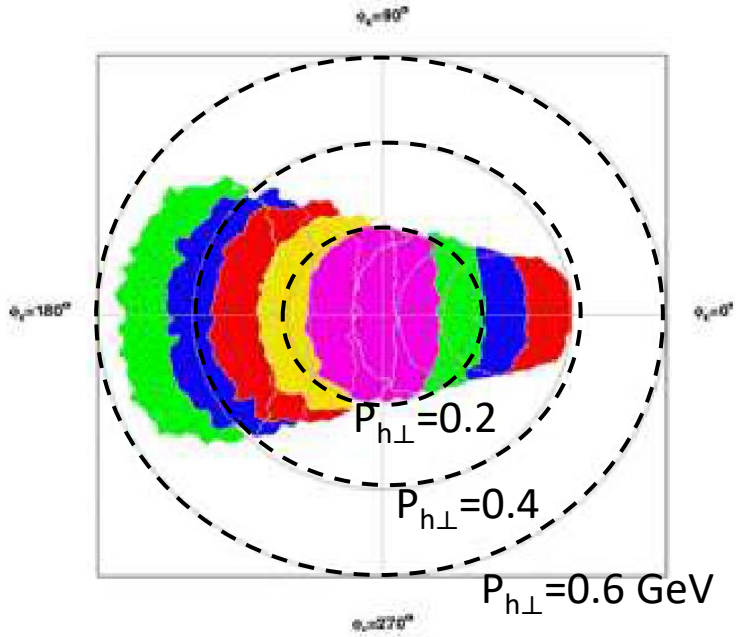
Each Experimental Hall carry unique scientific objectives:

- **Hall A: currently, not running SIDIS program.**
- **Hall B: CLAS 12 detector Stack. Low lumi. beam, large acceptance. Study multiple interactions simultaneously.**
- **Hall C: High Res. Spectrometers. High intensity beam. Study nucleon structure, LT separation.**
- **Hall D: photon beam. large acceptance, Study multiple interactions simultaneously.**

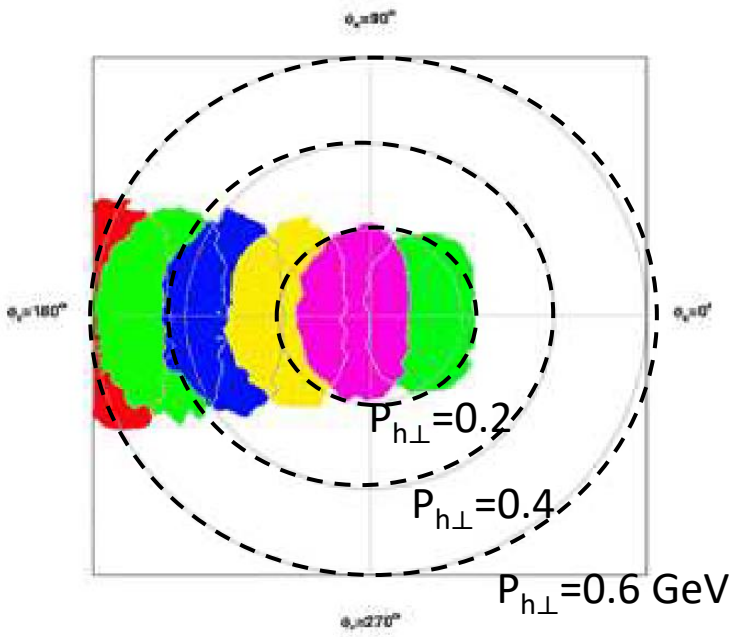
Recent Data from Hall C SIDIS Program

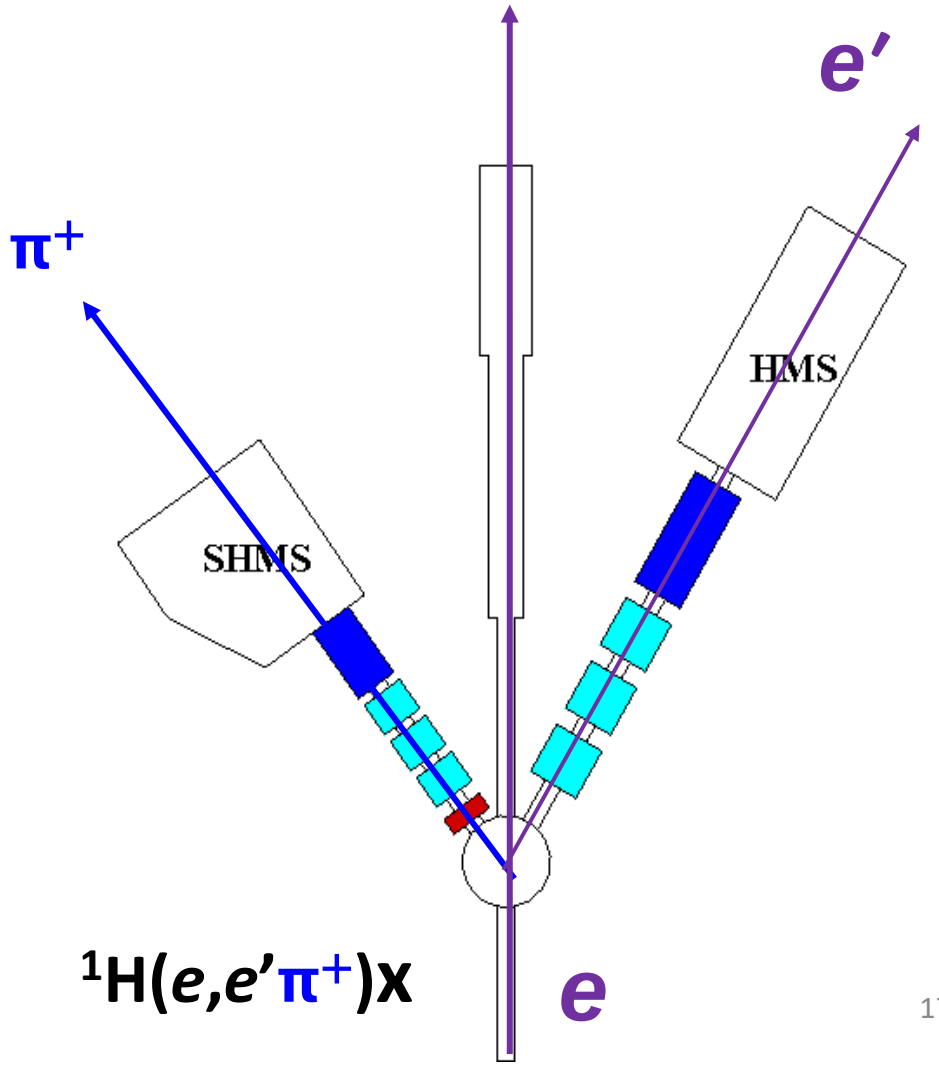
- **E12-09-017: Semi-Inclusive Pion and Kaon Production**
  - **Primary experiment observable:**
    e + p → e′ + π^+ + X

Q^2 = 3 GeV²



Q^2 = 4 GeV²

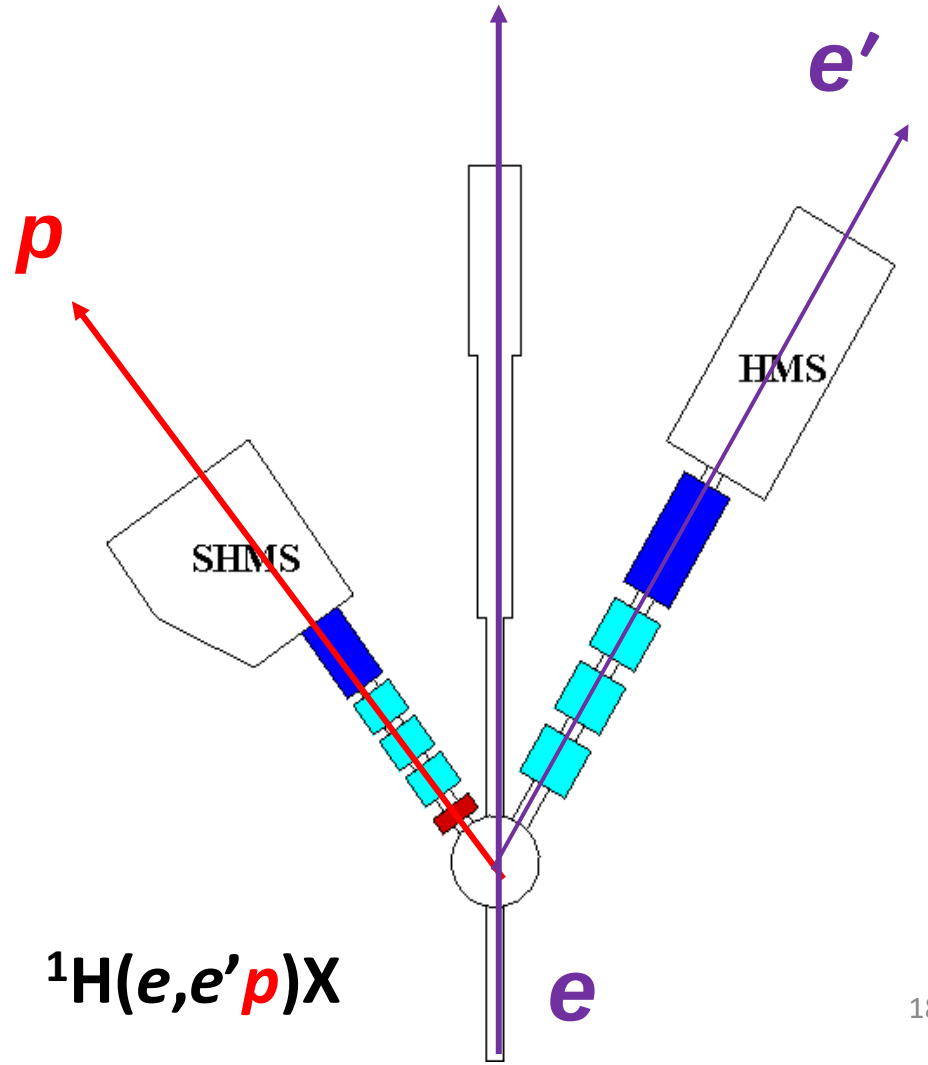




^{1}H(*e*,*e*′π^+)X

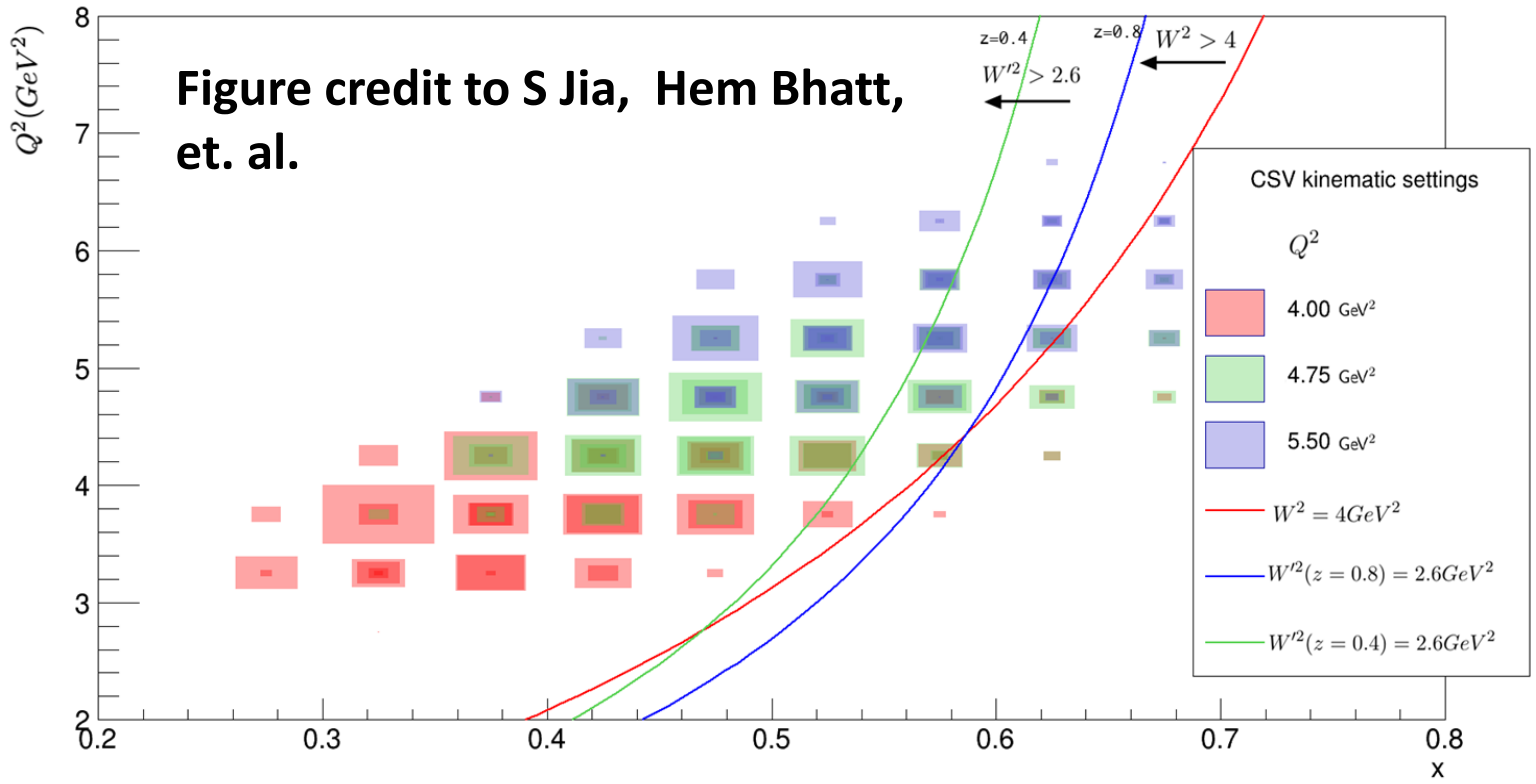
Recent Data from Hall C SIDIS Program

- **E12-09-017: Semi-Inclusive Pion and Kaon Production**
  - Primary experiment observable:
    e + p → e′ + π^+ + X
  - **Unexpected 2nd secondary experiment observable:**
    e + p → e′ + *p* + X
  - ep SIDIS data is 30% of the overall data set!



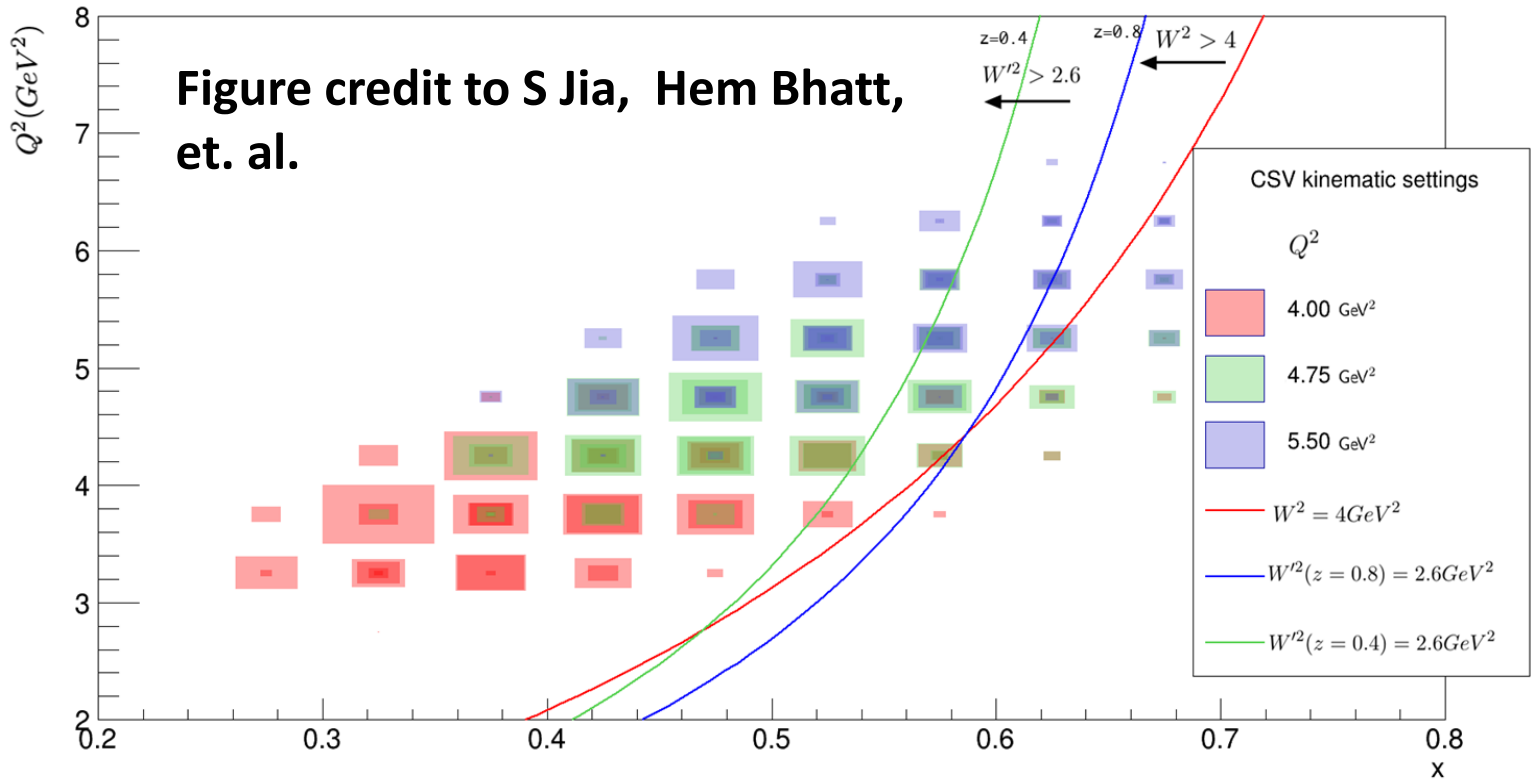
^{1}H(*e*,*e*′*p*)X

Recent Data from Hall C SIDIS Program



- **Kinematic of the ep data set on tape**
  - Q^2 Setting: 4.00, 4.75, 5.5 GeV^2
  - z coverage: $z < 0.8$
  - $P_{h\perp}$ coverage: $P_{h\perp} < 0.6$
- **Cross section extraction of the $P_{h\perp}$ dependence is under preparation**

Recent Data from Hall C SIDIS Program



$$z = \frac{E_{\text{Proton}}}{E_{\gamma^*}}$$

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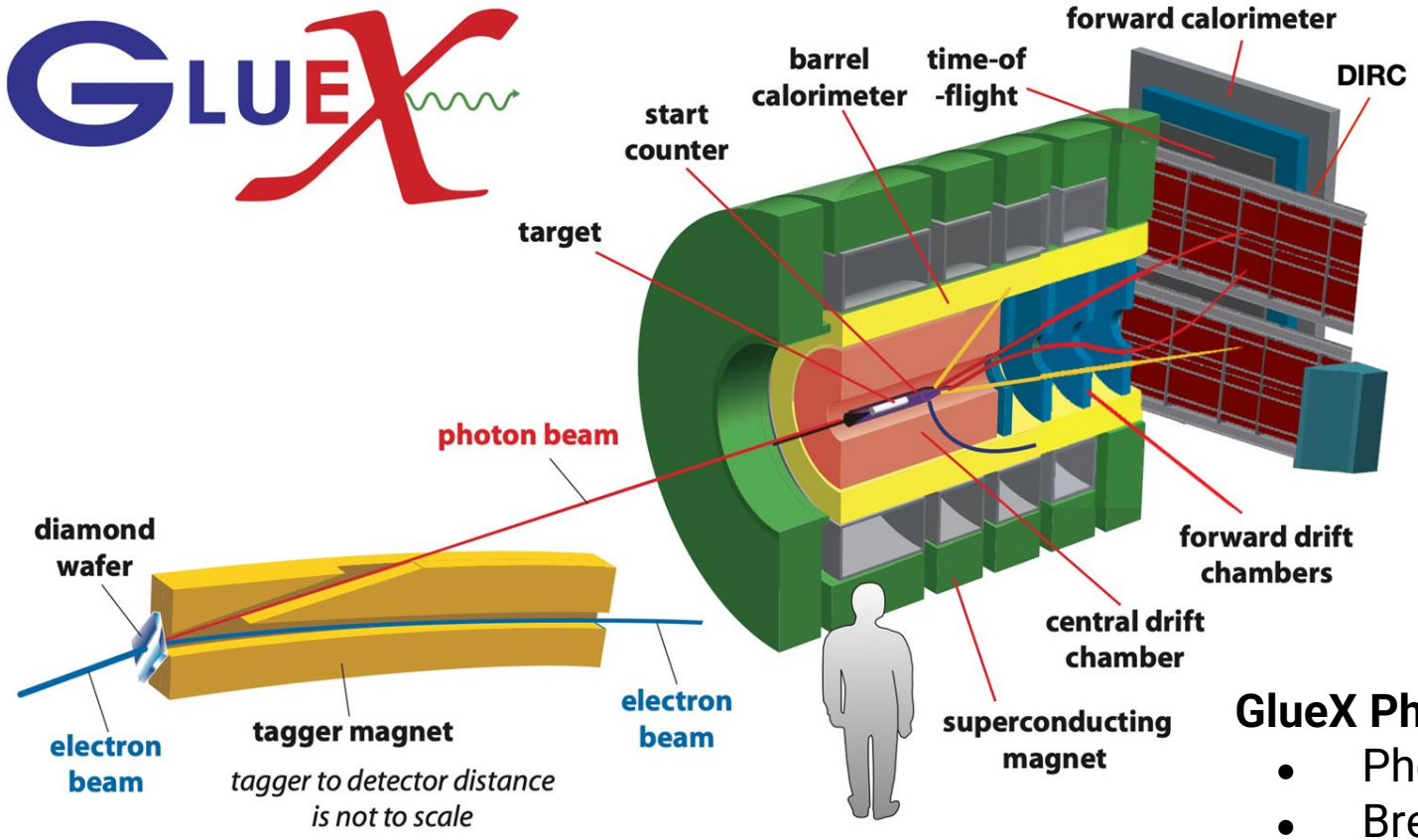
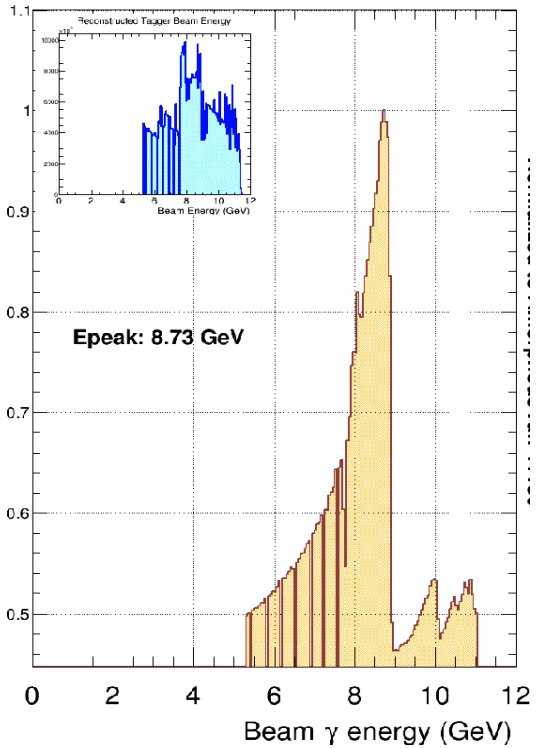
GlueX Experiment Hall D: Real Photon Scattering





GlueX Photon Hall D

- Photon beam, large acceptance.
- Bremsstrahlung photon: 5.5 - 12 GeV (peak edge at 8.8 GeV)
- Near 4π coverage
- **Capable of detecting final state:**
  γ + p →[p, n, Λ, …] + X
- Baryon Multiplicity studies could be carried out.
  - **Λ-Λbar production is a potential candidate**

Conclusion Remarks

- **Despite valence quark kinematics, JLab experiments accumulated data un-intentionally via SIDIS observable**

- **These data set might shed some light on supporting the existence of baryon junction, and inspire more studies in the near future**