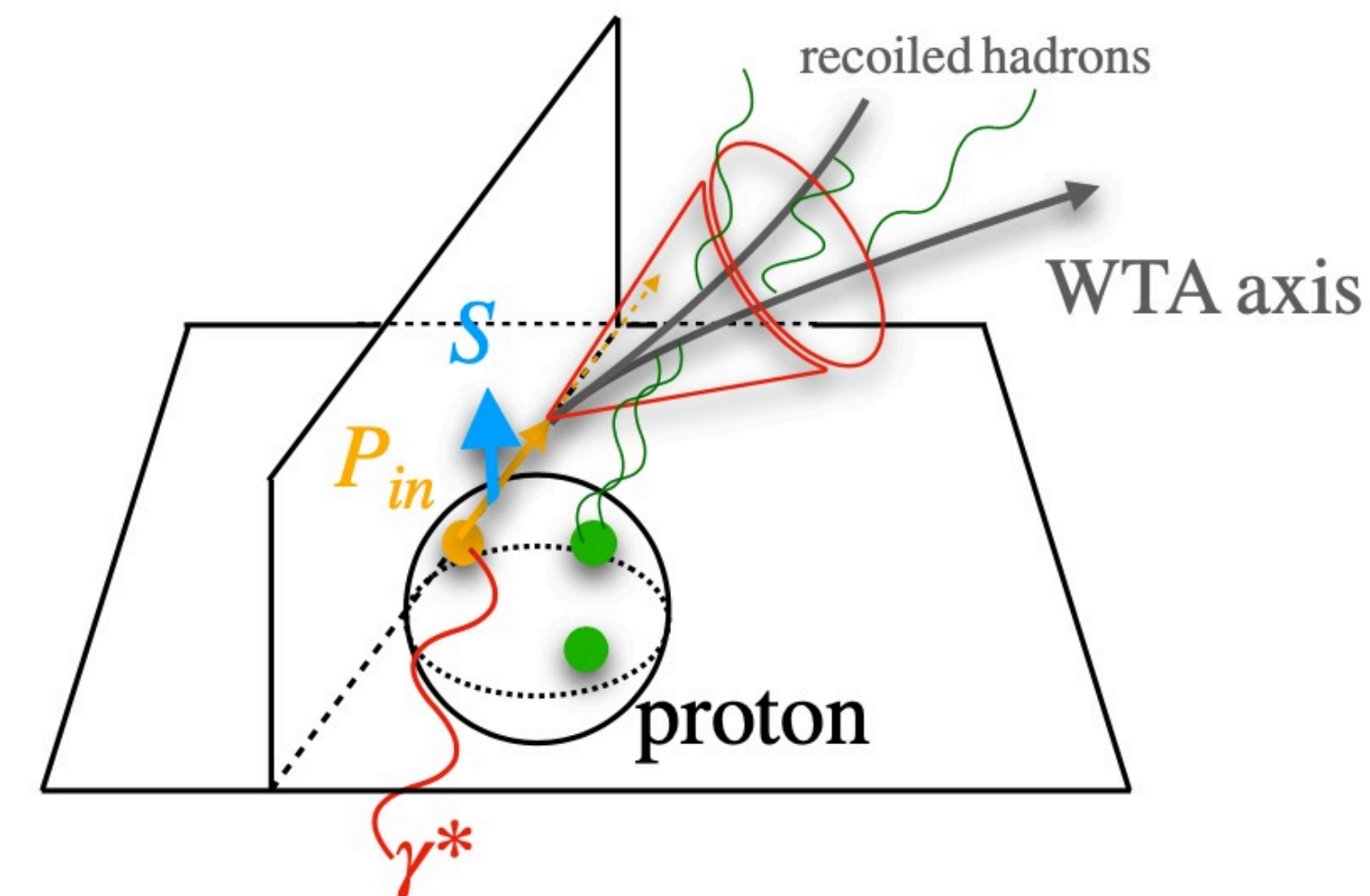




The time reversal odd side of a jet

Hongxi Xing

(South China Normal University)



QCD Evolution 2021, ZOOM@UCLA

Outline

- Motivation - the role of jets
- The T-odd jet in DIS and e^+e^- collisions
- Summary

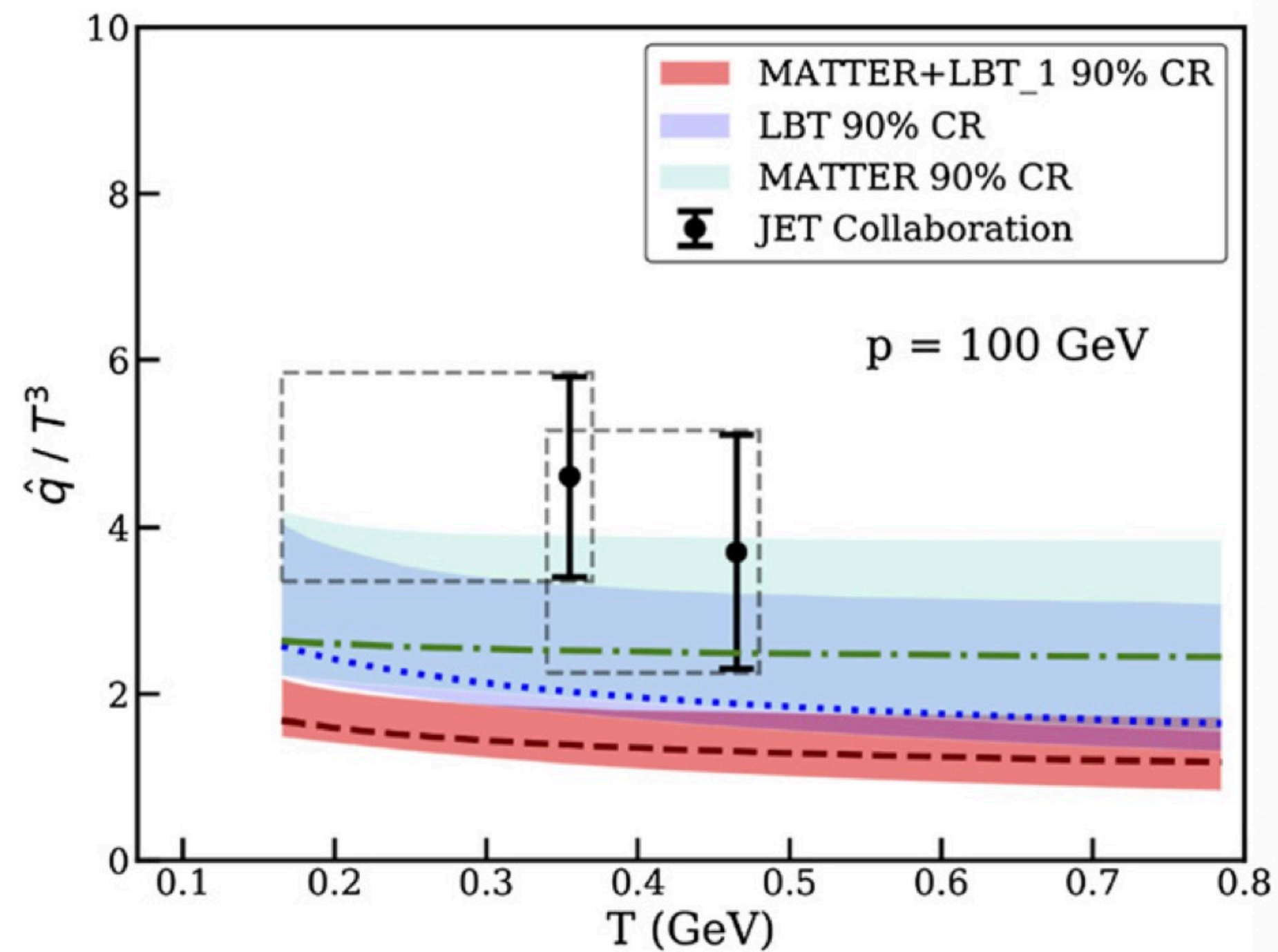
Liu, [HX](#), 2104.03328, 2021

Liu, [HX](#), Zhang, 2021

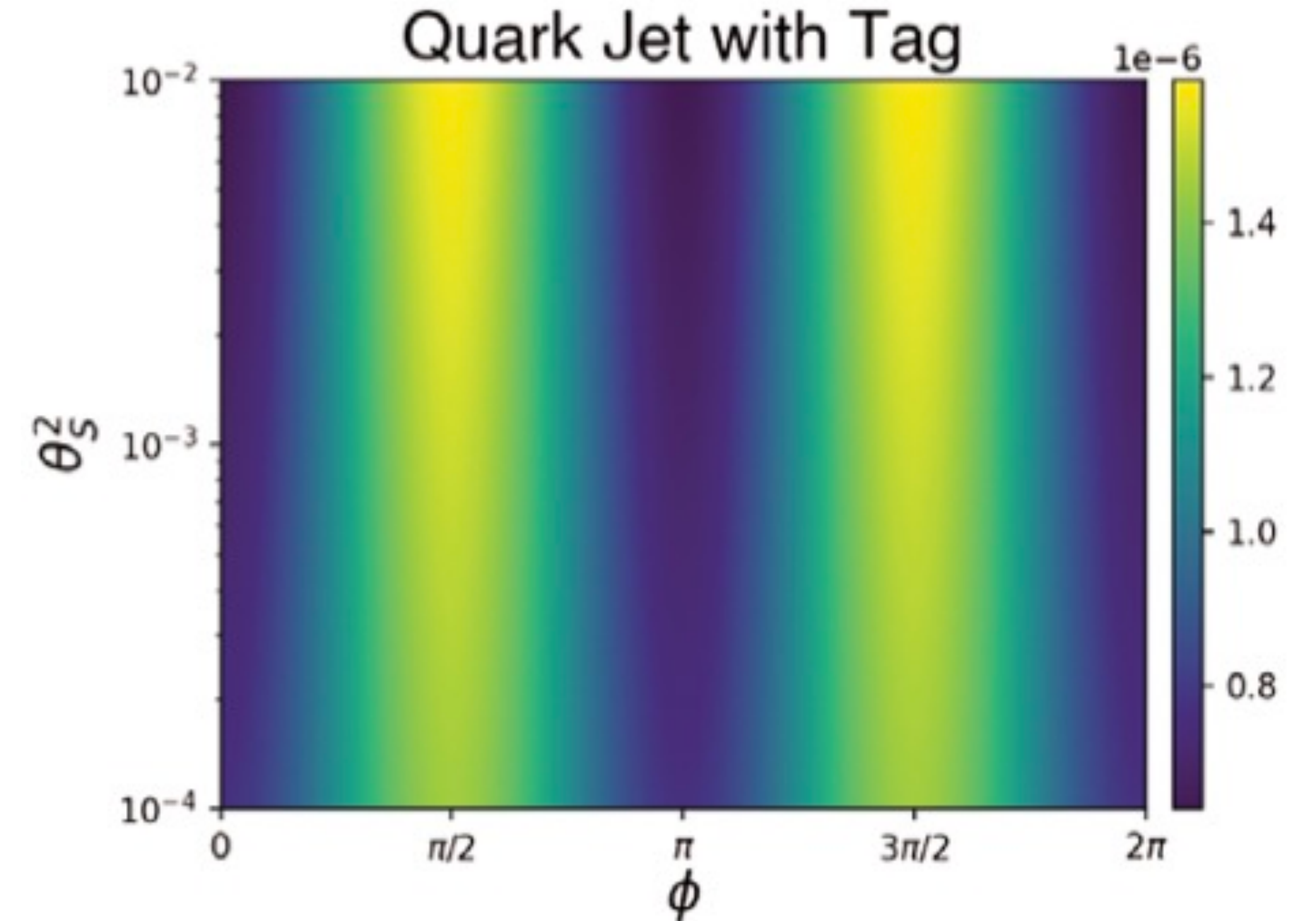
Lai, Liu, Wang, [HX](#), 2021

Motivation - jet is powerful in many fields

- Jet as a tool for QGP tomography
- Quantum interference in jet substructure



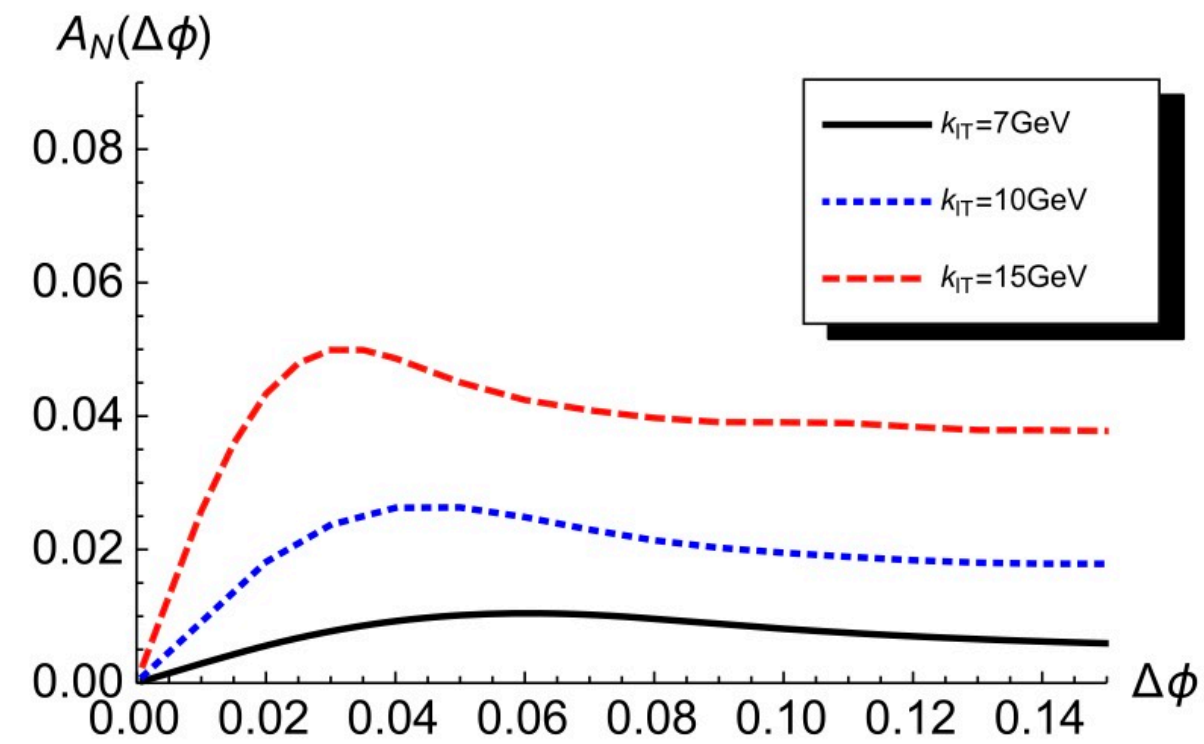
See e.g., review by Cao, Wang, Rept.Prog.Phys 2021



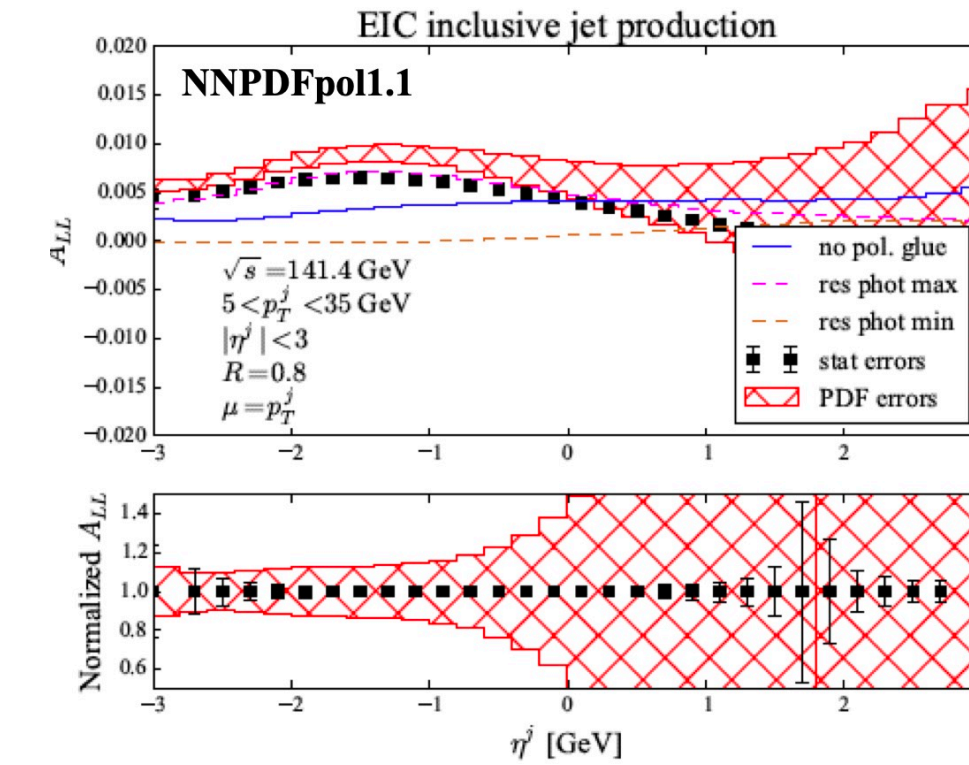
Chen, Moul, Zhu, PRL 2021
talk by I. Moul

Jet for spin related physics

- Jet in DIS for Sivers and helicity distributions

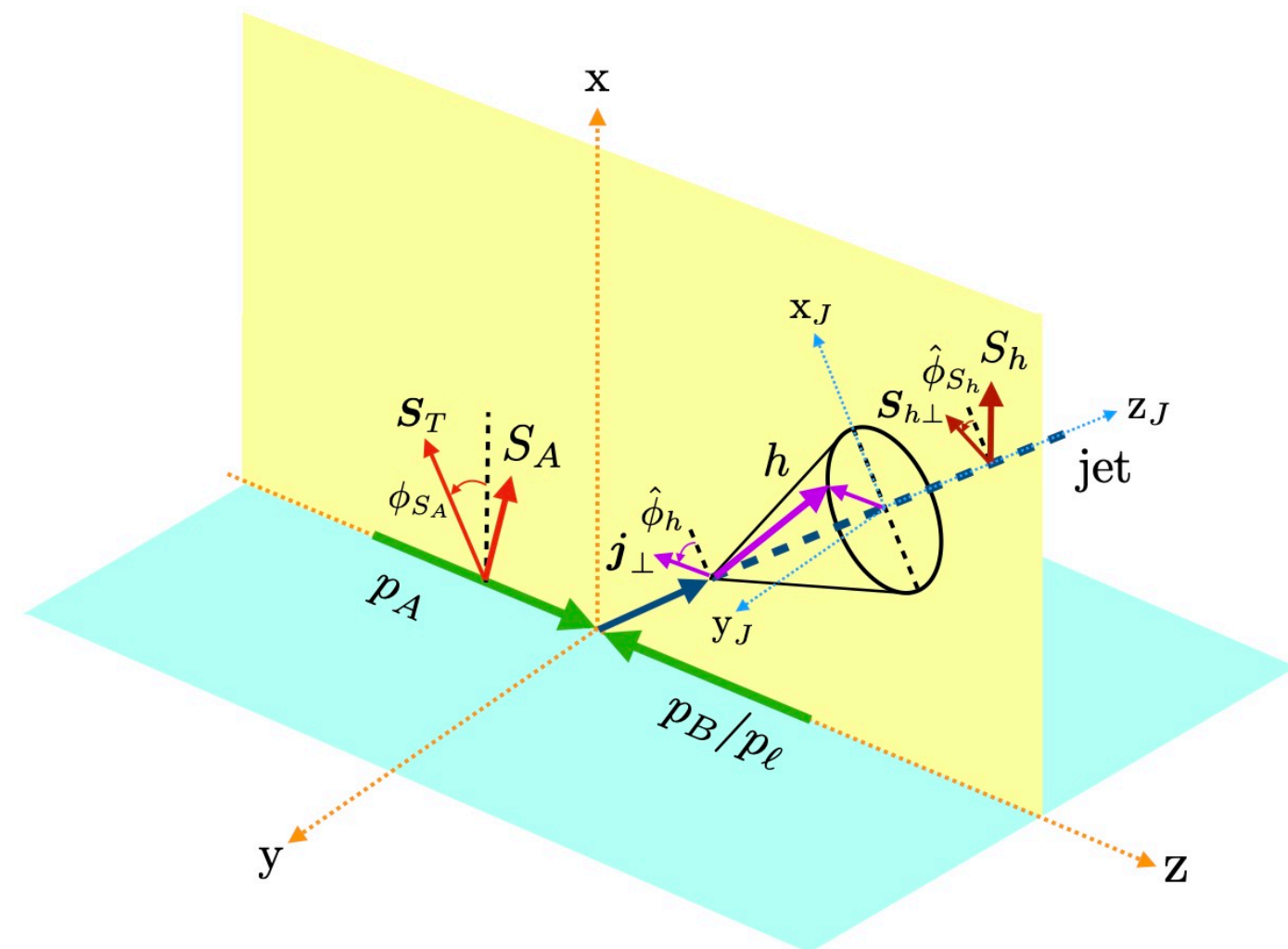


Liu, Ringer, Vogelsang, Yuan, PRL 2019 talk by F. Yuan



Boughezal, Petriello, **HX**, PRD 2017 talk by R. Boughezal

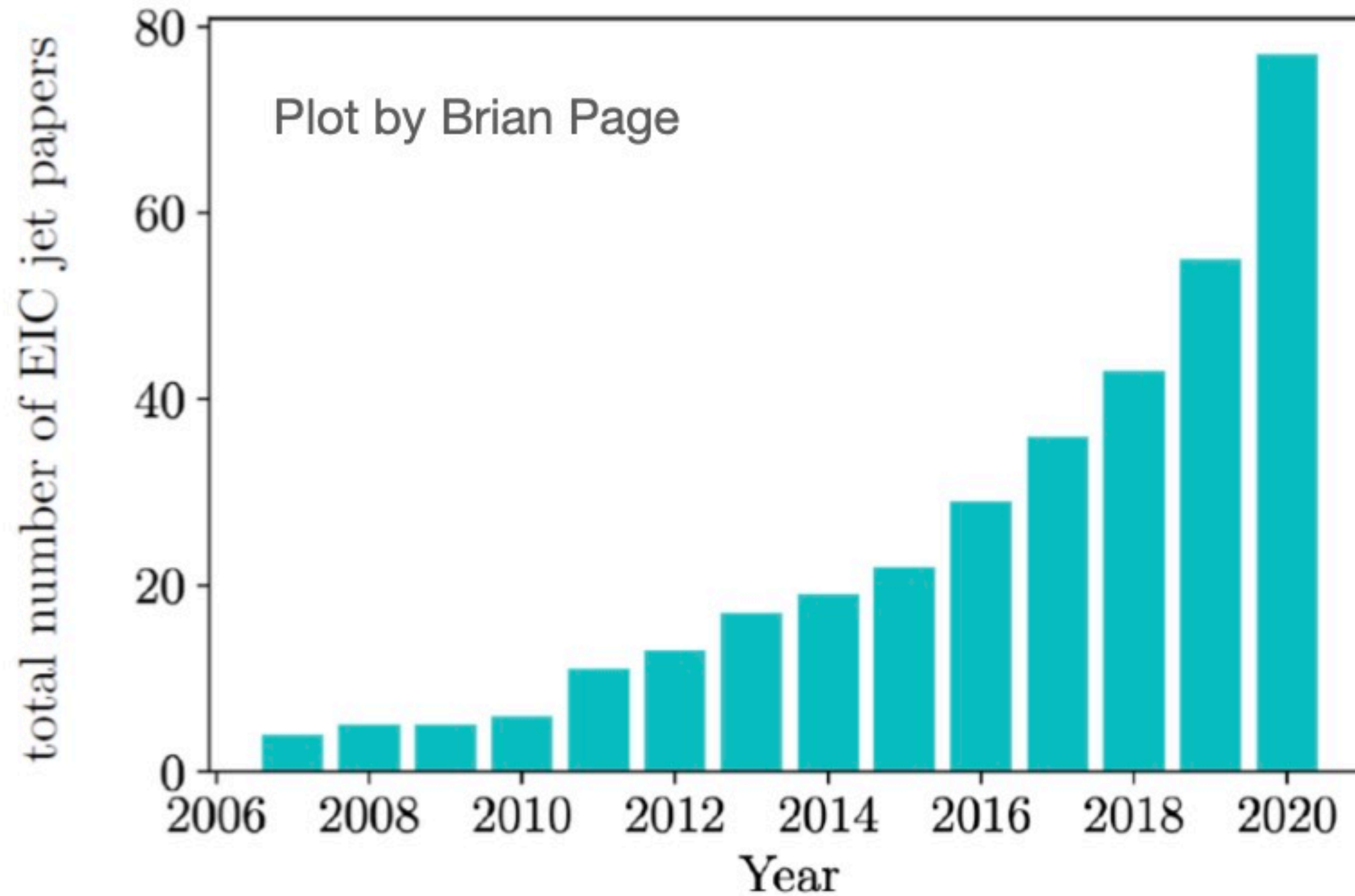
- Jet fragmentation -> polarized fragmentation functions (J/ψ , Λ)



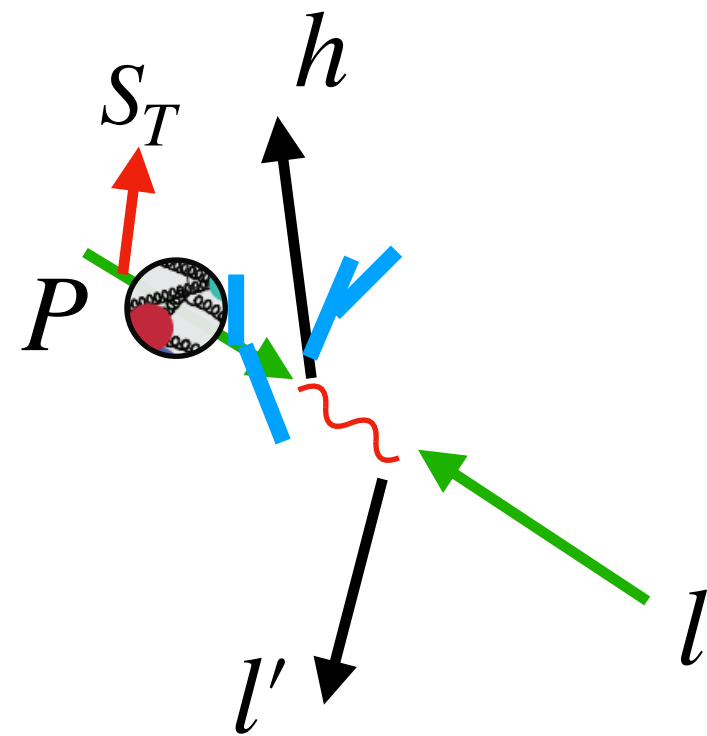
Kang, Qiu, Ringer, **HX**, Zhang, PRL 2017

Kang, Lee, Zhao, PLB 2020

Rapid growing interests for jets @ EIC



Jet vs hadron

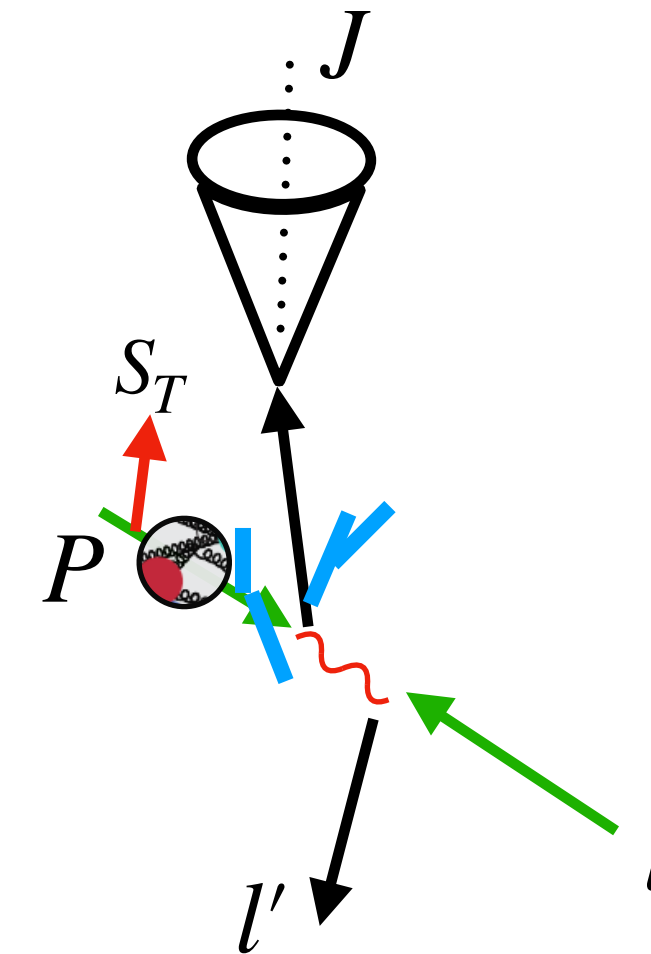


- Semi-inclusive DIS

$$\sigma^h \sim \sum_{i,j} \hat{\sigma}_{ei \rightarrow e'j} f_{i/p}(x, k_T) \otimes D_{j/h}(z, k'_T) \otimes S(k_T)$$

👎 The nonperturbative fragmentation functions -> extra uncertainty

👍 Identified hadrons can be used as flavor separation



- Jet production in DIS

$$\sigma^J = \sum_{i,j} \hat{\sigma}_{ei \rightarrow e'j} f_{i/p}(x, k_T) \otimes J(p_T, R) \otimes S(k_T, p_T R)$$

👍 Jet functions can be calculated perturbatively -> controllable uncertainty

👎 Sum all hadrons within jet, hard for flavor separation

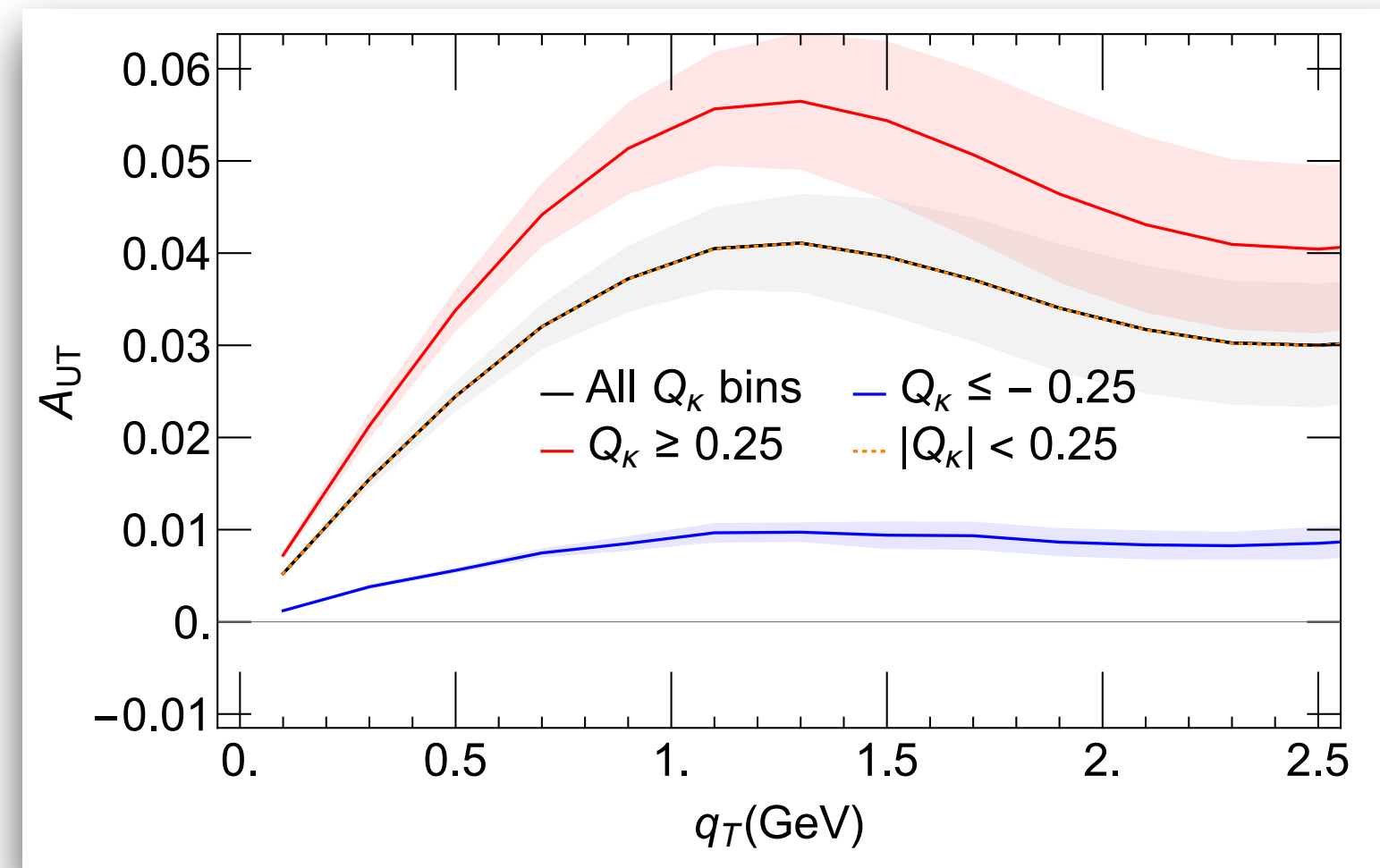
Jet charge for nucleon/nucleus flavor separation

Definition:

$$Q_\kappa = \sum_h \left(\frac{p_{h,T}}{p_J} \right)^\kappa Q_h$$

Field, Feynman, 1978

Krohn, Schwartz, Lin, Waalewijn, 2013

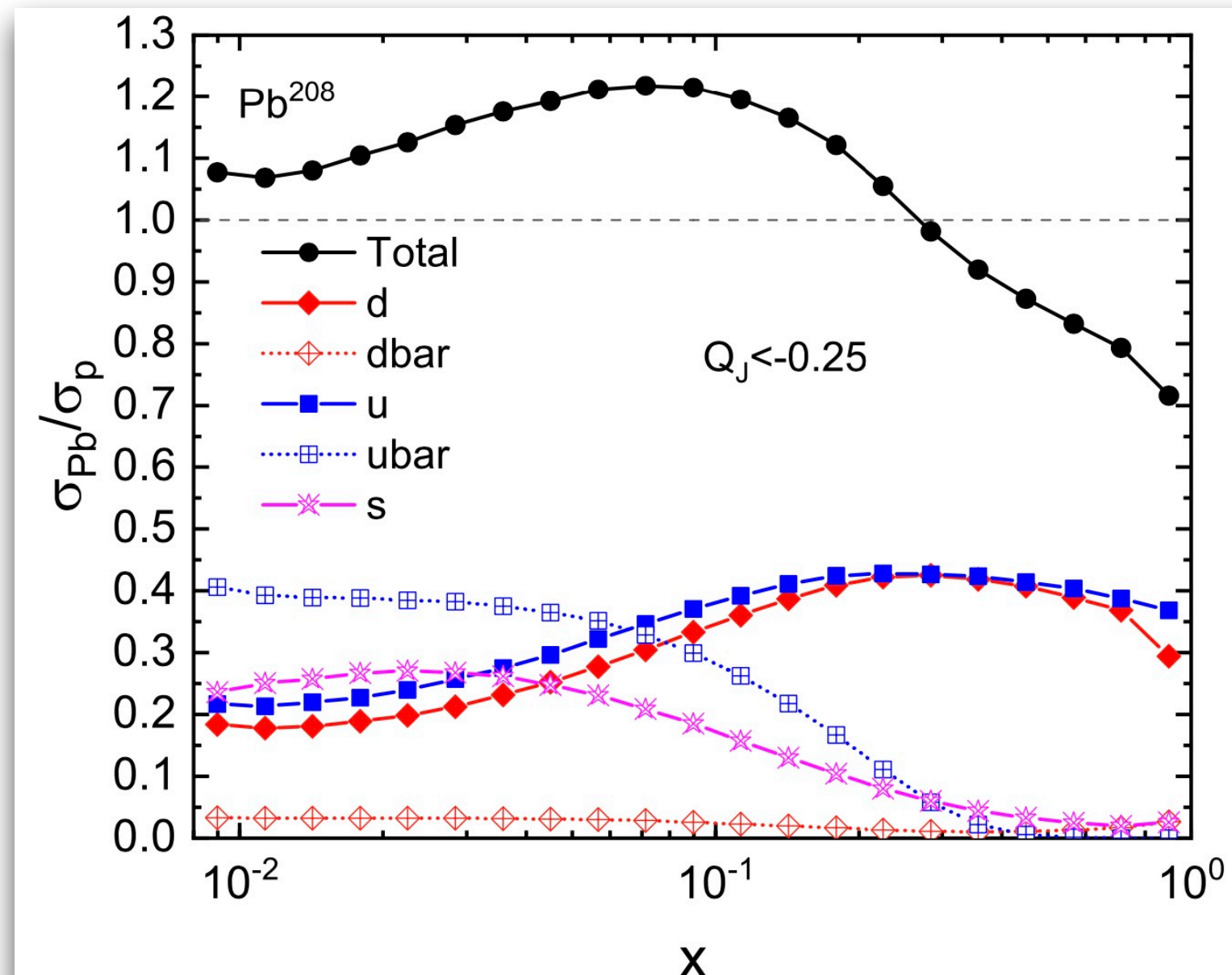
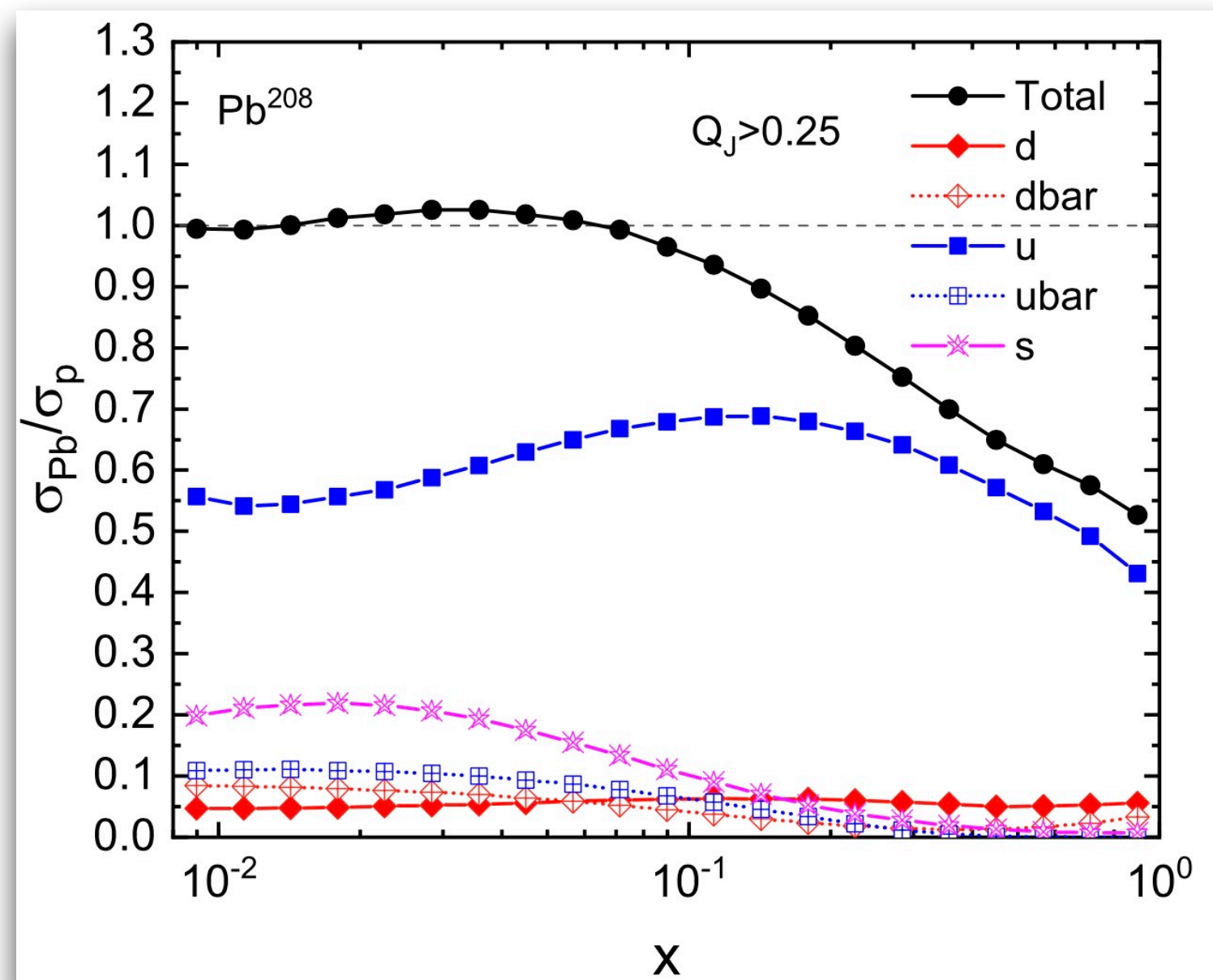


Flavor dependent Sivers effect

Positive charge: u

Negative charge: d

Kang, Liu, Mantry, Shao, PRL 2020



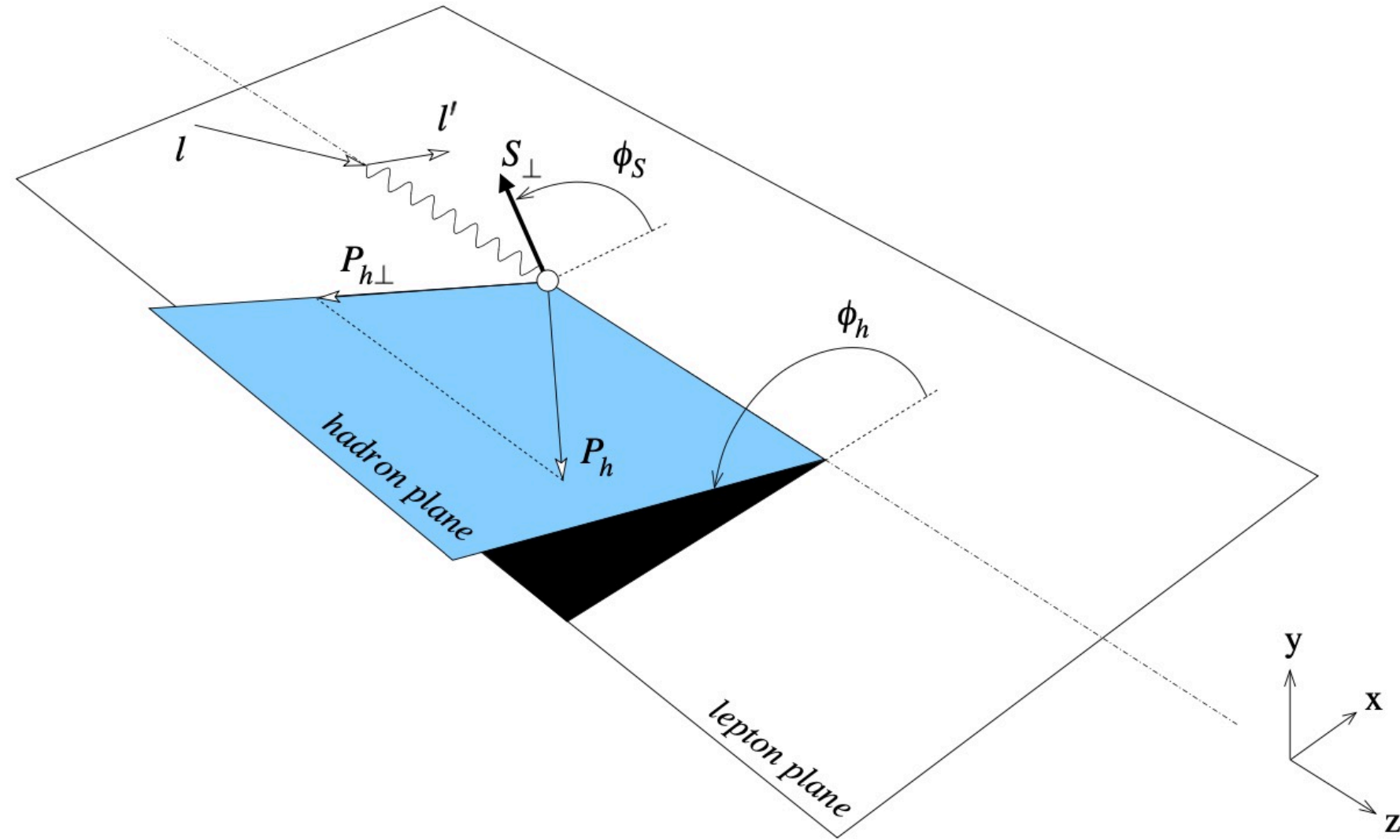
Flavor dependent nuclear PDFs

Positive charge: u

Negative charge: u, d, sea

Liu, HX, Zhang, in preparation, 2021

The role of T-odd fragmentation functions



$$\begin{aligned}
 \sigma(\phi, \phi_S) &\equiv \frac{d^6\sigma}{dx dy dz d\phi d\phi_S dP_{hT}^2} = \frac{\alpha^2}{xyQ^2} \frac{y^2}{2(1-\epsilon)} \left(1 + \frac{\gamma^2}{2x}\right) \\
 &\left\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)} \cos\phi F_{UU}^{\cos\phi} + \epsilon \cos(2\phi) F_{UU}^{\cos(2\phi)} + \lambda_e \left[\sqrt{2\epsilon(1-\epsilon)} \sin\phi F_{LU}^{\sin\phi} \right] + \right. \\
 &+ S_L \left[\sqrt{2\epsilon(1+\epsilon)} \sin\phi F_{UL}^{\sin\phi} + \epsilon \sin(2\phi) F_{UL}^{\sin(2\phi)} \right] + S_L \lambda_e \left[\sqrt{1-\epsilon^2} F_{LL} + \sqrt{2\epsilon(1-\epsilon)} \cos\phi F_{LL}^{\cos\phi} \right] \\
 &+ |S_T| \left[\sin(\phi - \phi_S) \left(F_{UT,T}^{\sin(\phi - \phi_S)} + \epsilon F_{UT,L}^{\sin(\phi - \phi_S)} \right) + \epsilon \sin(\phi + \phi_S) F_{UT}^{\sin(\phi + \phi_S)} + \epsilon \sin(3\phi - \phi_S) F_{UT}^{\sin(3\phi - \phi_S)} \right. \\
 &\left. + \sqrt{2\epsilon(1+\epsilon)} \sin\phi_S F_{UT}^{\sin\phi_S} + \sqrt{2\epsilon(1+\epsilon)} \sin(2\phi - \phi_S) F_{UT}^{\sin(2\phi - \phi_S)} \right] \\
 &\left. - |S_T| \lambda_e \left[\sqrt{1-\epsilon^2} \cos(\phi - \phi_S) F_{LT}^{\cos(\phi - \phi_S)} + \sqrt{2\epsilon(1-\epsilon)} \cos\phi_S F_{LT}^{\cos\phi_S} + \sqrt{2\epsilon(1-\epsilon)} \cos(2\phi - \phi_S) F_{LT}^{\cos(2\phi - \phi_S)} \right] \right\},
 \end{aligned}$$

The diagram shows the decomposition of the cross-section into various fragmentation function (FF) terms. The terms are grouped into boxes indicating their physical origin:

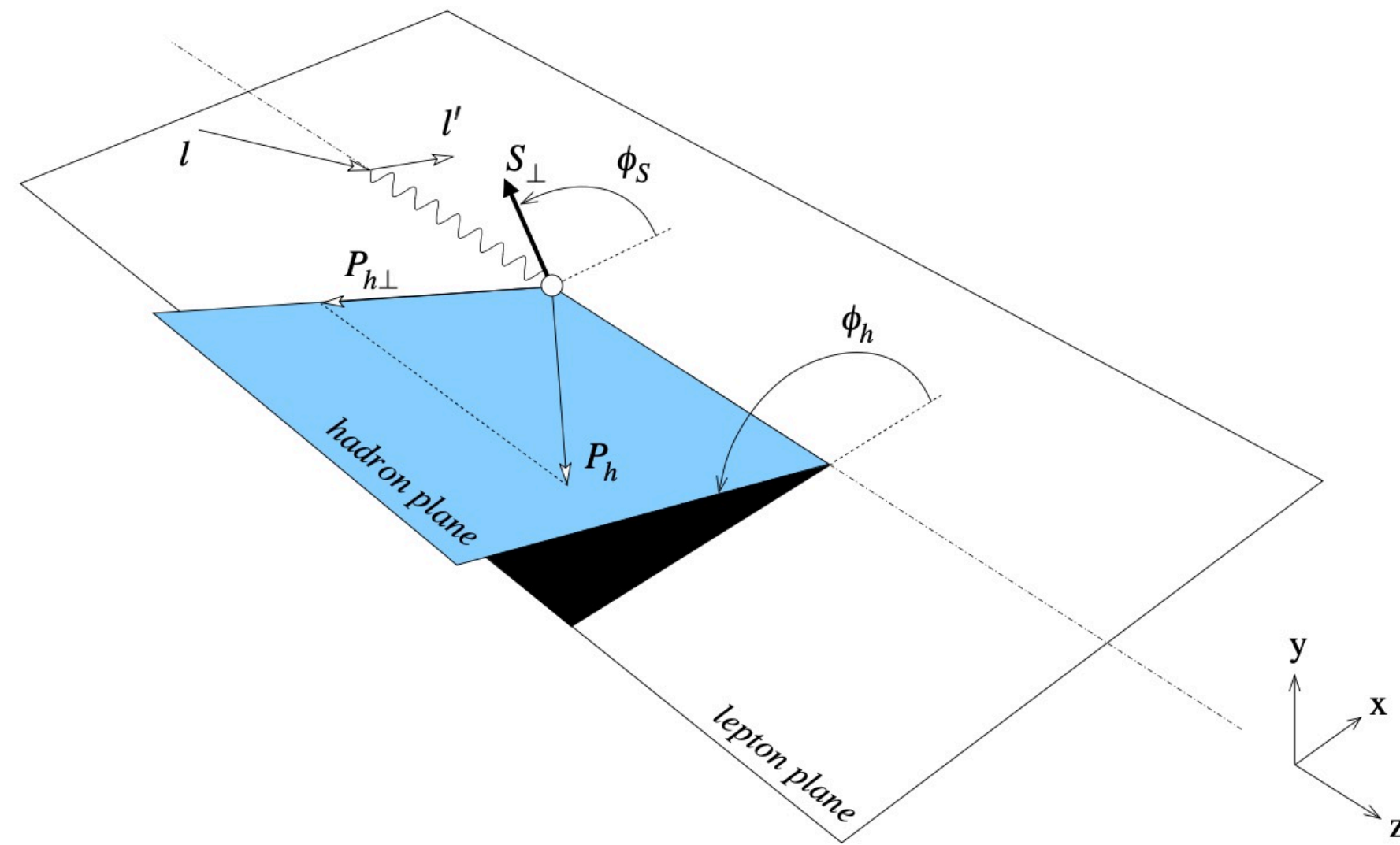
- Cahn-effect + BM $\otimes$ Collins**: Points to the first term in the curly braces.
- Worm-gear (Kotzinian-Mulders) $\otimes$ Collins**: Points to the second term in the curly braces.
- BM $\otimes$ Collins**: Points to the third term in the curly braces.
- Sivers $\otimes$ D1**: Points to the fourth term in the curly braces.
- Worm-gear $\otimes$ D1**: Points to the fifth term in the curly braces.
- Transversity $\otimes$ Collins**: Points to the sixth term in the curly braces.
- Pretzelosity $\otimes$ Collins**: Points to the seventh term in the curly braces.

Bacchetta, Diehl, Goeke, Metz, Mulders, Schlegel, JHEP 2007

QCD requires all physical observables should preserve time reversal invariance!

The T-odd FFs provide us abundant opportunities to probe nucleon structure.

Limited power of jet probing - conventional wisdom



$$\sigma(\phi, \phi_S) \equiv \frac{d^6\sigma}{dx dy dz d\phi d\phi_S dP_{KT}^2} = \frac{\alpha^2}{xyQ^2} \frac{y^2}{2(1-\epsilon)} \left(1 + \frac{\gamma^2}{2x}\right)$$

$$\left\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)} \cos(\phi - \phi_S) F_{UT}^{\sin(\phi - \phi_S)} + \epsilon \cos(2\phi) F_{UU}^{\cos(2\phi)} + \sqrt{2\epsilon(1-\epsilon)} \sin\phi F_{LU}^{\sin\phi} \right\} +$$

$$+ S_L \left[\sqrt{2\epsilon(1+\epsilon)} \sin\phi F_{UL}^{\sin\phi} + \epsilon \sin(2\phi) F_{UU}^{\cos(2\phi)} \right] + S_L \lambda_e \left[\sqrt{1-\epsilon^2} \cos(\phi - \phi_S) F_{LT}^{\cos(\phi - \phi_S)} + \sqrt{2\epsilon(1-\epsilon)} \cos\phi_S F_{LT}^{\cos\phi_S} + \sqrt{2\epsilon(1-\epsilon)} \cos(2\phi - \phi_S) F_{LT}^{\cos(2\phi - \phi_S)} \right] +$$

$$+ |S_T| \left[\sin(\phi - \phi_S) \left(F_{UT}^{\sin(\phi - \phi_S)} + \epsilon F_{UT,L}^{\sin(\phi - \phi_S)} \right) + \epsilon \sin(\phi + \phi_S) F_{UT}^{\sin(\phi + \phi_S)} + \epsilon \sin(3\phi - \phi_S) F_{UT}^{\sin(3\phi - \phi_S)} \right] +$$

$$+ \sqrt{2\epsilon(1+\epsilon)} \sin\phi_S F_{UT}^{\sin\phi_S} + \sqrt{2\epsilon(1+\epsilon)} \sin(2\phi - \phi_S) F_{UT}^{\sin(2\phi - \phi_S)} \right] +$$

$$+ |S_T| \lambda_e \left[\sqrt{1-\epsilon^2} \cos(\phi - \phi_S) F_{LT}^{\cos(\phi - \phi_S)} + \sqrt{2\epsilon(1-\epsilon)} \cos\phi_S F_{LT}^{\cos\phi_S} + \sqrt{2\epsilon(1-\epsilon)} \cos(2\phi - \phi_S) F_{LT}^{\cos(2\phi - \phi_S)} \right] \Big\} ;$$

Diagram illustrating the geometry of jet probing. The lepton plane (blue) and hadron plane (black) are shown. The lepton plane is defined by the lepton momentum l and the virtual photon momentum l' . The hadron plane is defined by the hadron momentum P_h and the virtual photon momentum l' . The angle between the lepton plane and the hadron plane is ϕ_h . The angle between the lepton plane and the virtual photon momentum l' is ϕ_S . The angle between the hadron plane and the virtual photon momentum l' is ϕ_S . The angle between the lepton plane and the hadron plane is ϕ_h .

Diagram illustrating the geometry of jet probing. The lepton plane (blue) and hadron plane (black) are shown. The lepton plane is defined by the lepton momentum l and the virtual photon momentum l' . The hadron plane is defined by the hadron momentum P_h and the virtual photon momentum l' . The angle between the lepton plane and the hadron plane is ϕ_h . The angle between the lepton plane and the virtual photon momentum l' is ϕ_S . The angle between the hadron plane and the virtual photon momentum l' is ϕ_S . The angle between the lepton plane and the hadron plane is ϕ_h .

In conventional wisdom, perturbative jet is T-even, thus many spin structures vanish.

✗ T-odd distributions involved
But Perturbative Jet is (almost) T-even

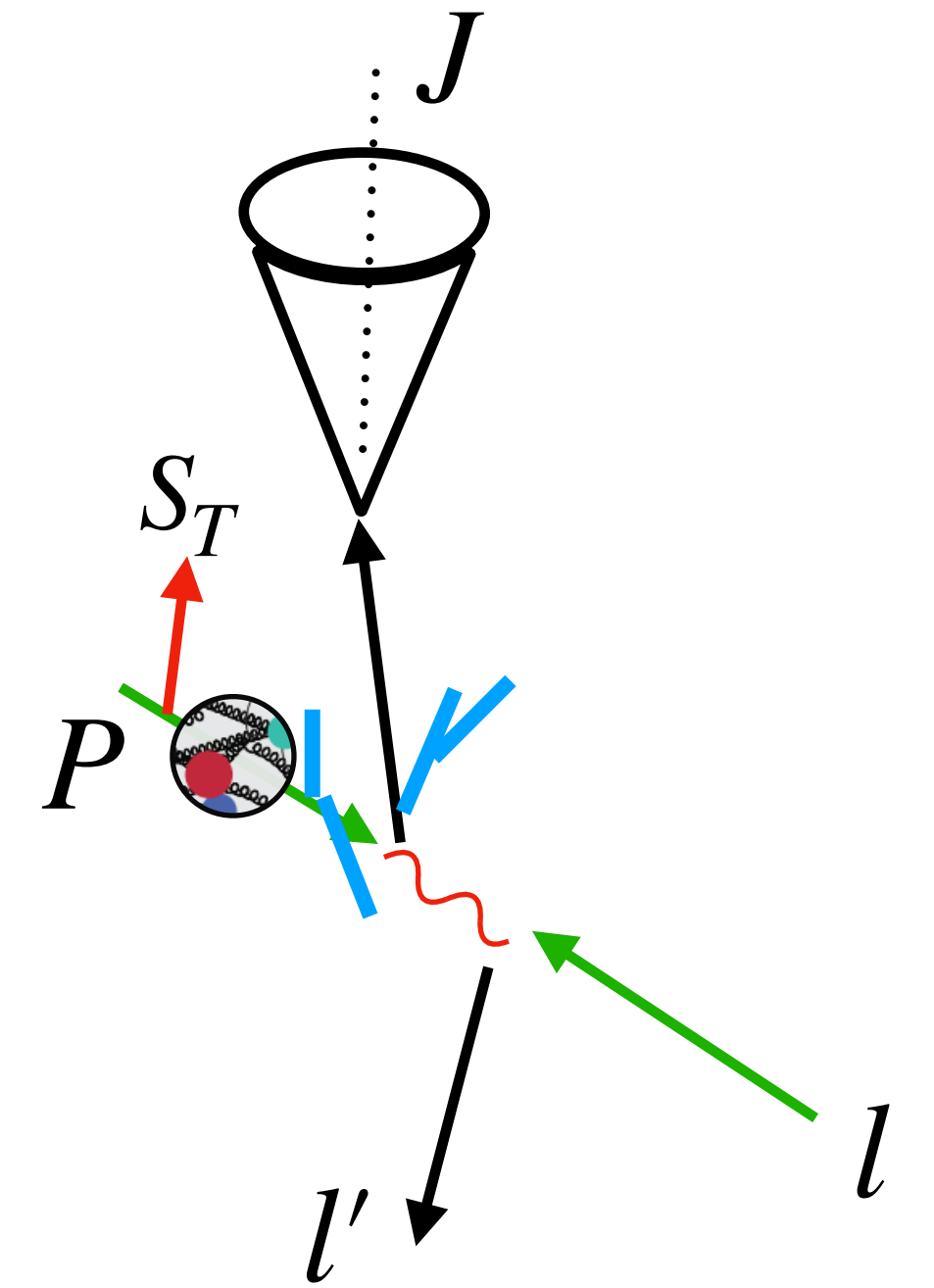
Revisit jet production in DIS

$$l p(P, s_T) \rightarrow \gamma^*(q) \rightarrow l' J(P_J) + X$$

- Factorization frame

$$P^\mu = \frac{P^-}{2}(1, 0, 0, 1) = \frac{P^-}{2}n^\mu \quad P_J^\mu = \frac{P_J^+}{2}(1, 0, 0, -1) = \frac{P_J^+}{2}\bar{n}^\mu$$

$$q_T = q - \frac{q \cdot n}{2}\bar{n} - \frac{q \cdot \bar{n}}{2}n \quad q_T \ll Q$$



- Winner-take-all jet

$$\text{SJA : } E_{(12)} = E_1 + E_2, \quad \vec{p}_{(12)} = \vec{p}_1 + \vec{p}_2,$$

$$\text{WTA : } E_{(12)} = E_1 + E_2, \quad \vec{p}_{(12)} = E_{(12)} \left[\frac{\vec{p}_1}{|\vec{p}_1|} \theta(E_1 - E_2) + \frac{\vec{p}_2}{|\vec{p}_2|} \theta(E_2 - E_1) \right]$$

WTA jet TMD has the same RG as TMD FFs

Bertolini, Chan, Thaler, JHEP 2014

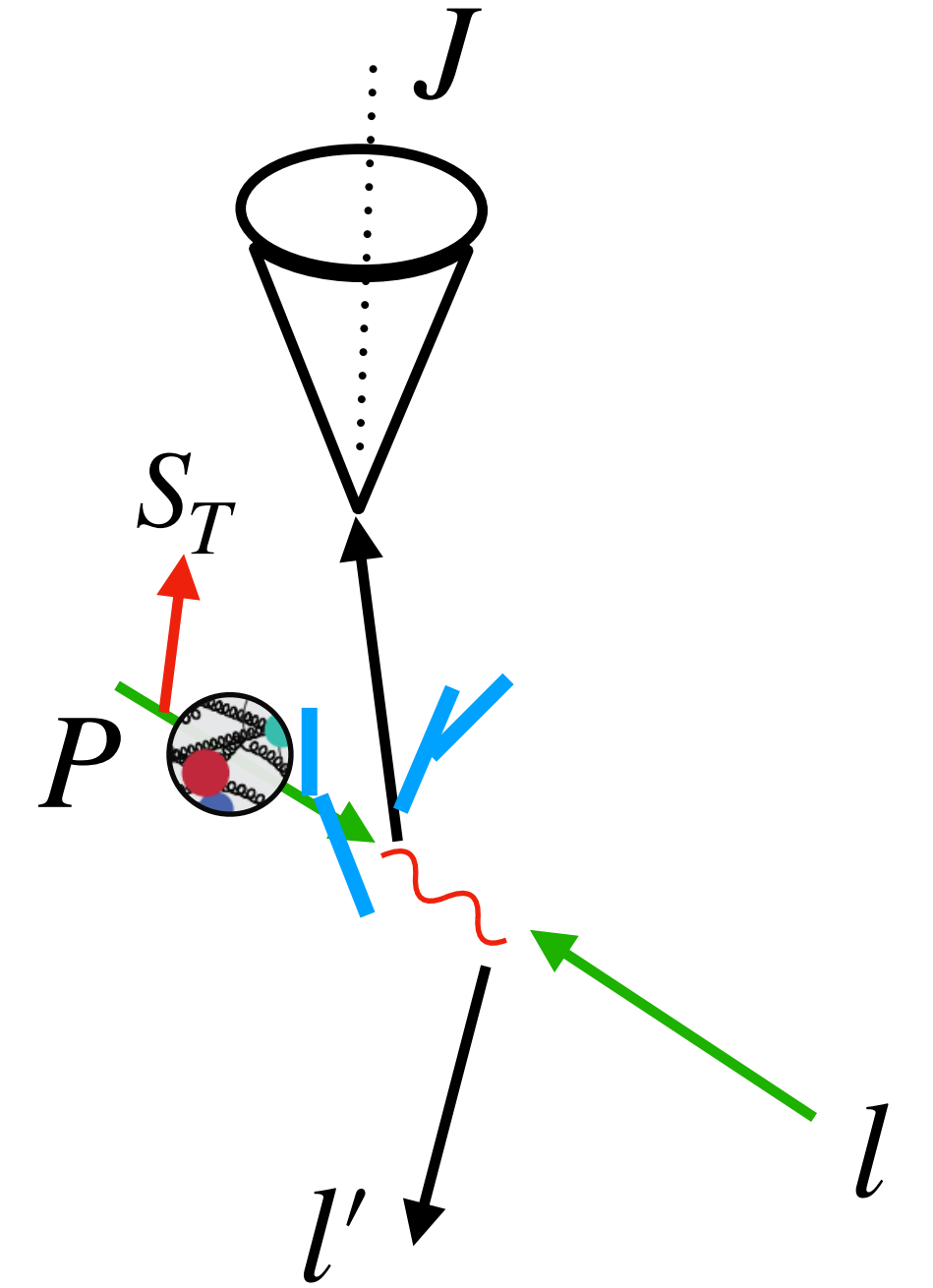
Reyes, Scimemi, Waalewijn, Zoppi, PRL 2018

Revisit jet production in DIS

$$l p(P, s_T) \rightarrow \gamma^*(q) \rightarrow l' J(P_J) + X$$

In small q_T limit

$$\begin{aligned} \sigma &= \frac{1}{2s} \int [dl'] \frac{e^4 e_q^2}{Q^4} \frac{1}{2} L_{\mu\nu} \frac{1}{2N_c} \int d^2 x_T e^{iq_T \cdot x_T} \gamma_{\alpha\beta}^\mu \gamma_{\beta'\alpha'}^\nu \\ &\times \int dx^- e^{iq^+ x^-} \langle P, s_T | \xi_n(0) \xi_n^\dagger(x^-, x_T) | P, s_T \rangle_{\alpha'\alpha} \\ &\times \int [dP_J] \int dx^+ e^{iq^- x^+} \langle 0 | \xi_{\bar{n}}(x^+, x_T) | J X_{\bar{n}} \rangle_\beta \langle J X_{\bar{n}} | \xi_{\bar{n}}^\dagger(0) | 0 \rangle_{\beta'} \end{aligned}$$

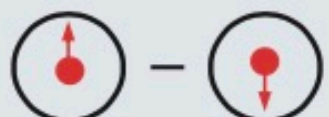
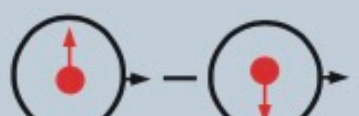


- Only consider photon exchange
- $L_{\mu\nu}$ is leptonic tensor

SCET quark field: $\xi_{n(\bar{n})} = W_{n(\bar{n})}^\dagger \chi_{n(\bar{n})}$

Decomposition Φ into different Dirac structures

$$\Phi(\zeta, p_T) = \frac{1}{2} \left\{ f_1 \not{n} - f_{1T}^\perp \frac{\epsilon_T^{\rho\sigma} p_{T\sigma} s_{T\sigma}}{M} \not{n} + g_{1s} \gamma_5 \not{n} \right. \\ \left. + h_{1T} \frac{[s_T, \not{n}] \gamma_5}{2} + h_{1s}^\perp \frac{[p_T, \not{n}] \gamma_5}{2M} + i h_1^\perp \frac{[p_T, \not{n}]}{2M} \right\} + \dots$$

TMDs		Quark polarization		
		Unpolarized (U)	Longitudinally polarized (L)	Transversely polarized (T)
Nucleon polarization	U	f_1  Unpolarized		$h_1^\perp$  Boer-Mulders
	L		g_{1L}  Helicity	$h_{1L}^\perp$  Longi-transversity
	T	$f_{1T}^\perp$  Sivers	g_{1T}  Trans-helicity	h_1  Transversity $h_{1T}^\perp$  Pretzelosity

Decomposition of Δ into different Dirac structures

For single hadron production:

Collins function $\rightarrow$ T-odd

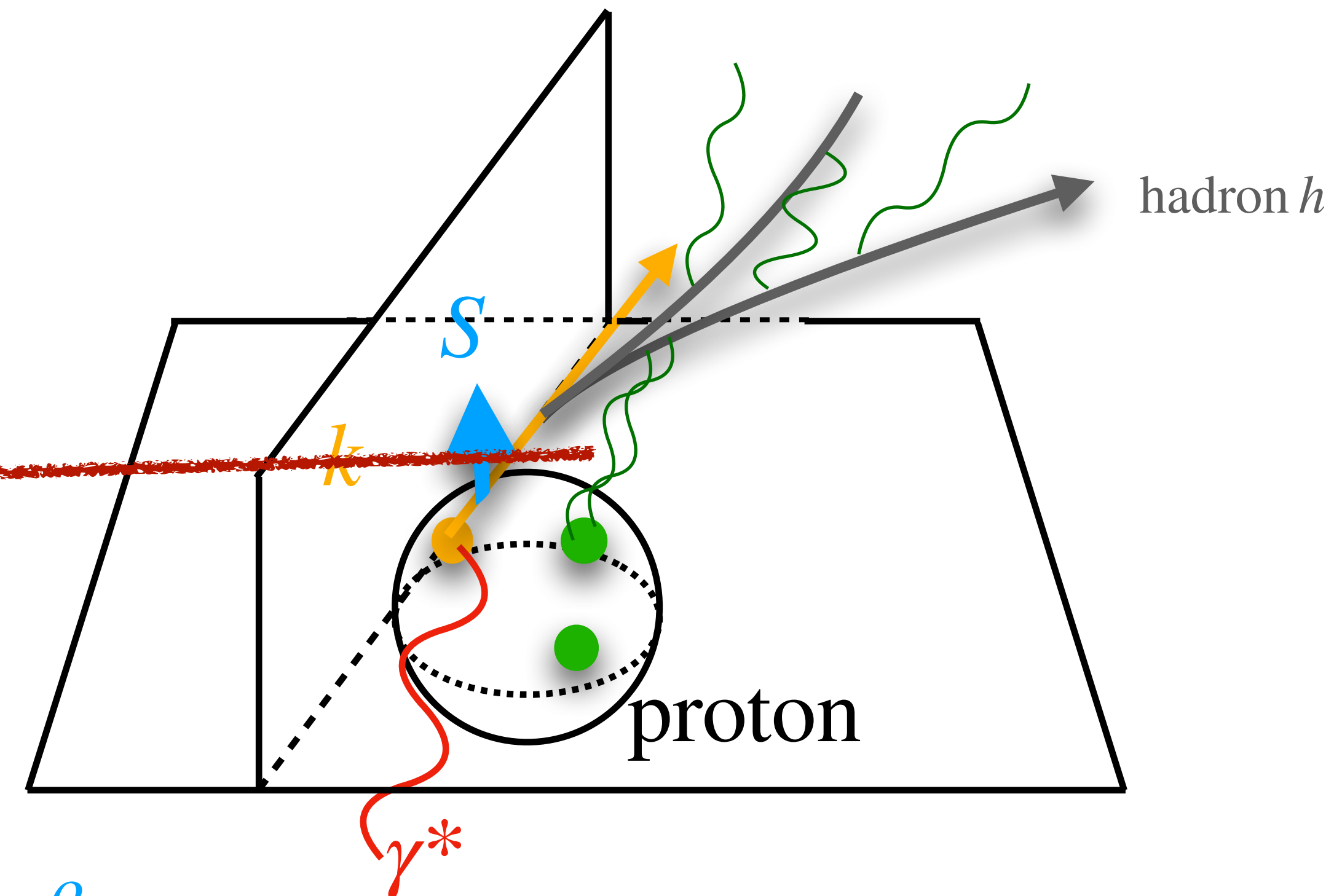
$$\Delta(z, k_T) = \frac{1}{2} \left\{ D_1 \vec{n} + i H_1^\perp \frac{[k_T^\perp, \vec{n}]}{2M_h} \right\} + \dots$$

Final state interactions generate an asymmetry

To observe the asymmetry (Collins 2002):

- h is not in the k - S plane
- Non-perturbative

$$\propto \epsilon_{\alpha\beta\mu\nu} k_\perp^\alpha s_\perp^\beta P_h^\mu n^\nu$$



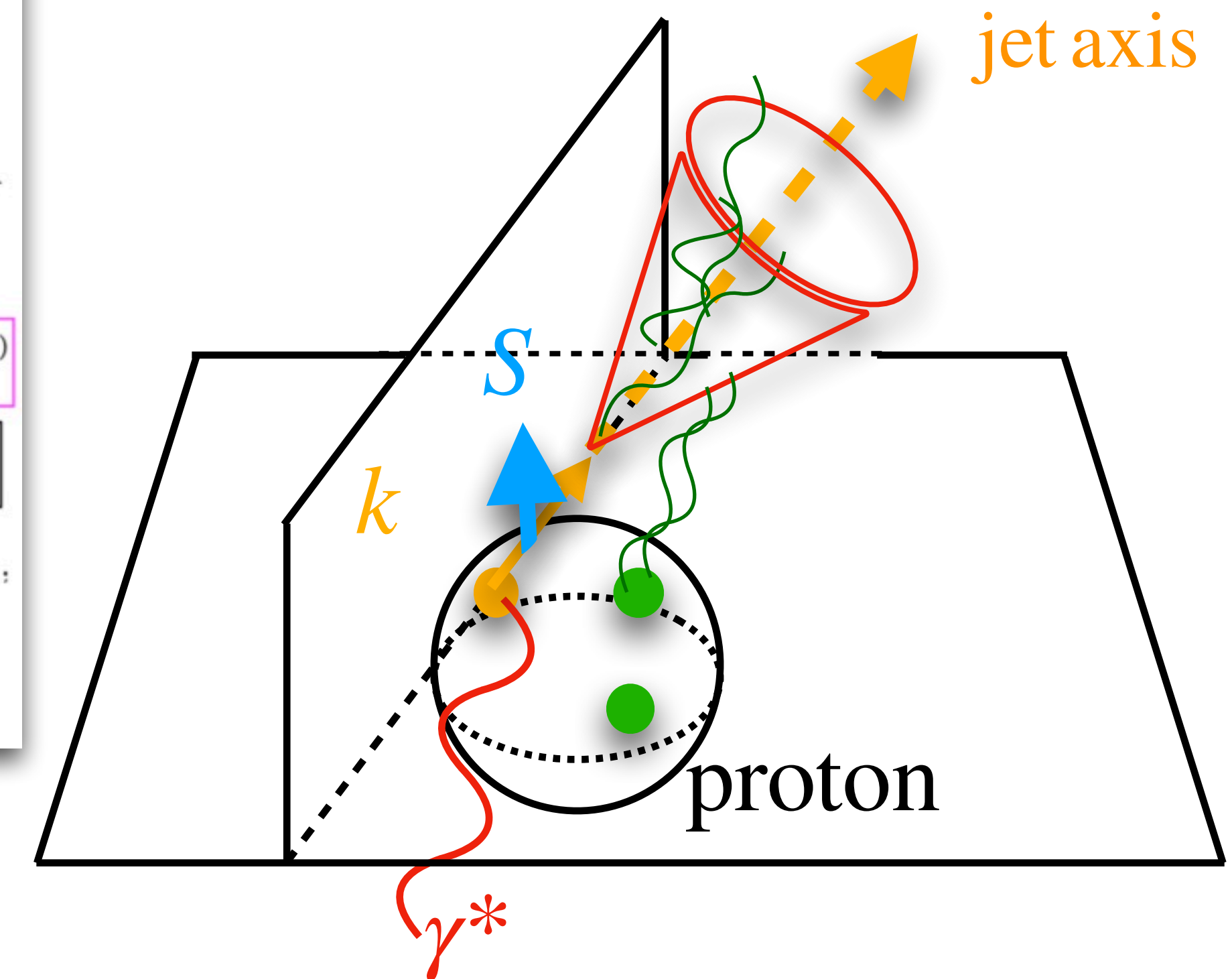
Decomposition of $\mathcal{J}$ into different Dirac structures

$$\mathcal{J}(z, k_T) = \frac{1}{4} \left\{ J_1 \not{n} + i J_T \frac{[k_T, \not{n}]}{2M_h} \right\} + \dots$$

$$\begin{aligned} & \sigma(\phi, \phi_S) \equiv \frac{d^6 \sigma}{dx dy dz d\phi d\phi_S dP_{KT}^2} = \frac{\alpha^2}{xy Q^2} \frac{y^2}{2(1-\epsilon)} \left(1 + \frac{\gamma^2}{2x} \right) \\ & \left\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)} \cos(\phi - \phi_S) F_{UT}^{\sin(\phi - \phi_S)} + \epsilon \cos(2\phi) F_{UU}^{\cos(2\phi)} + \sqrt{2\epsilon(1-\epsilon)} \sin\phi F_{LU}^{\sin\phi} \right\} \\ & + S_L \left[\sqrt{2\epsilon(1+\epsilon)} \sin\phi F_{UL}^{\sin\phi} + \epsilon \sin(2\phi) F_{LL}^{\sin(2\phi)} \right] + S_L \lambda_e \left[\sqrt{1-\epsilon^2} \cos\phi F_{LL}^{\cos\phi} + \sqrt{2\epsilon(1-\epsilon)} \cos\phi F_{LL}^{\cos\phi} \right] \\ & + |S_T| \left[\sin(\phi - \phi_S) \left(F_{UT}^{\sin(\phi - \phi_S)} + \epsilon F_{UT,L}^{\sin(\phi - \phi_S)} \right) + \epsilon \sin(\phi + \phi_S) F_{UT}^{\sin(\phi + \phi_S)} + \epsilon \sin(3\phi - \phi_S) F_{UT}^{\sin(3\phi - \phi_S)} \right. \\ & \quad \left. + \sqrt{2\epsilon(1+\epsilon)} \sin\phi_S F_{UT}^{\sin\phi_S} + (1+\epsilon) \sin(2\phi - \phi_S) F_{UT}^{\sin(2\phi - \phi_S)} \right] \\ & + |S_T| \lambda_e \left[\sqrt{1-\epsilon^2} \cos(\phi - \phi_S) F_{LT}^{\cos(\phi - \phi_S)} + \sqrt{2\epsilon(1-\epsilon)} \cos\phi_S F_{LT}^{\cos\phi_S} + \sqrt{2\epsilon(1-\epsilon)} \cos(2\phi - \phi_S) F_{LT}^{\cos(2\phi - \phi_S)} \right] \Big\} : \end{aligned}$$

Diagram illustrating the decomposition of the cross-section into different Dirac structures. The structures are categorized into boxes with labels and arrows indicating their contribution to the cross-section terms. Red 'X' marks indicate structures that are not present or are crossed out.

- Cahn-effect + BM $\otimes$ Collins** (Blue checkmark)
- Worm-gear (Kotzinian-Mulders) $\otimes$ Collins** (Blue checkmark)
- BM $\otimes$ Collins** (Red 'X')
- Sivers $\otimes$ D1** (Blue checkmark)
- Worm-gear** (Blue checkmark)
- Transversity $\otimes$ Collins** (Blue checkmark)
- Pretzelosity $\otimes$ Collins** (Red 'X')



- Jet is in the k - S plane
- perturbative

T-even jets limit the power of jet probe!

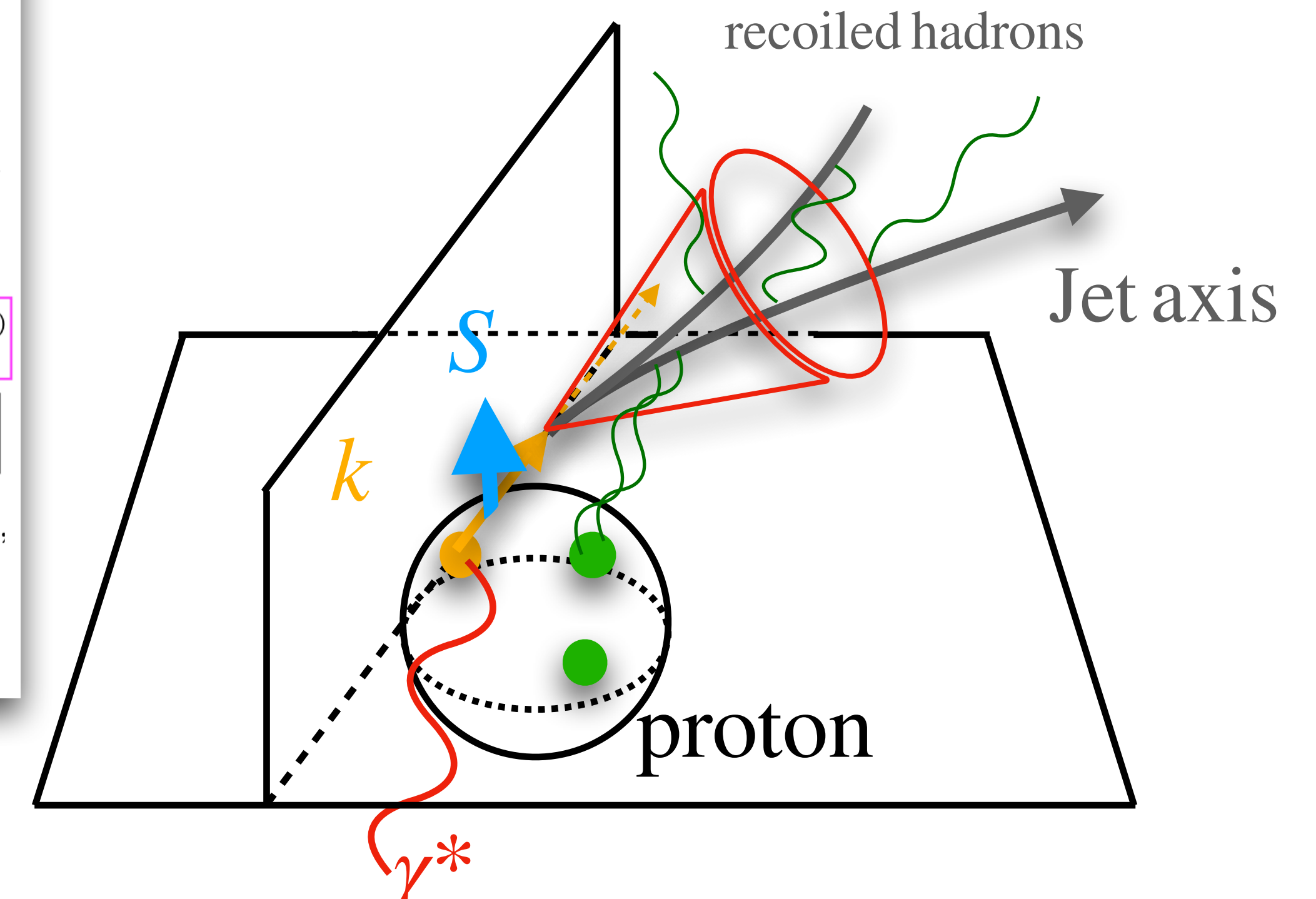
Decompose quark field correlation functions into different Dirac structures

$$\mathcal{J}(z, k_T) = \frac{1}{4} \left\{ J_1 \not{n} + i J_T \frac{[k_T, \not{n}]}{2M_h} \right\} + \dots \quad \text{Not true} \rightarrow \text{existence of T-odd jet component}$$

$$\begin{aligned} \sigma(\phi, \phi_S) \equiv \frac{d^6\sigma}{dx dy dz d\phi d\phi_S} = & \frac{\alpha^2}{xyQ^2} \frac{y^2}{2(1-\epsilon)} \left(1 + \frac{\gamma^2}{2x} \right) \\ & \left\{ F_{UU} F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)} \cos\phi F_{UU}^{\cos\phi} + \epsilon \cos(2\phi) F_{UU}^{\cos(2\phi)} + \sqrt{2\epsilon(1-\epsilon)} \sin\phi F_{LU}^{\sin\phi} \right\} + \\ & + S_L \left[\sqrt{2\epsilon(1-\epsilon)} \sin\phi F_{UL}^{\sin\phi} + \epsilon \sin(2\phi) F_{UL}^{\sin(2\phi)} \right] + S_L \lambda_e \left[\sqrt{1-\epsilon^2} F_{LL} + \sqrt{2\epsilon(1-\epsilon)} \cos\phi F_{LL}^{\cos\phi} \right] \\ & + |S_T| \left[\sin(\phi - \phi_S) \left(F_{UT,L}^{\sin(\phi - \phi_S)} + \epsilon F_{UT,L}^{\sin(\phi - \phi_S)} \right) + \epsilon \sin(\phi + \phi_S) F_{UT,L}^{\sin(\phi + \phi_S)} + \epsilon \sin(3\phi - \phi_S) F_{UT,L}^{\sin(3\phi - \phi_S)} \right] \\ & + \sqrt{2\epsilon(1+\epsilon)} \sin\phi_S F_{UT}^{\sin\phi_S} + \sqrt{2\epsilon(1+\epsilon)} \sin(2\phi - \phi_S) F_{UT}^{\sin(2\phi - \phi_S)} + \sqrt{2\epsilon(1-\epsilon)} \cos\phi_S F_{LT}^{\cos\phi_S} \\ & + \sqrt{2\epsilon(1-\epsilon)} \cos(2\phi - \phi_S) F_{LT}^{\cos(2\phi - \phi_S)} \left. \right\}, \end{aligned}$$

Labels and annotations in the diagram:

- Cahn-effect + BM ⊗ Collins** (points to F_{UU})
- Worm-gear (Kotzinian-Mulders) ⊗ Collins** (points to $F_{UU,L}$)
- BM ⊗ Collins** (points to $F_{UU}^{\cos\phi}$)
- Sivers ⊗ D1** (points to $F_{UL}^{\sin\phi}$)
- Worm-gear ⊗ D1** (points to $F_{UL}^{\sin(2\phi)}$)
- Transversity ⊗ Collins** (points to F_{LL})
- Pretzelosity ⊗ Collins** (points to $F_{LL}^{\cos\phi}$)



Lai, Liu, Wang, **HX**, 2021

Jet axes can be different with different artificial algorithms

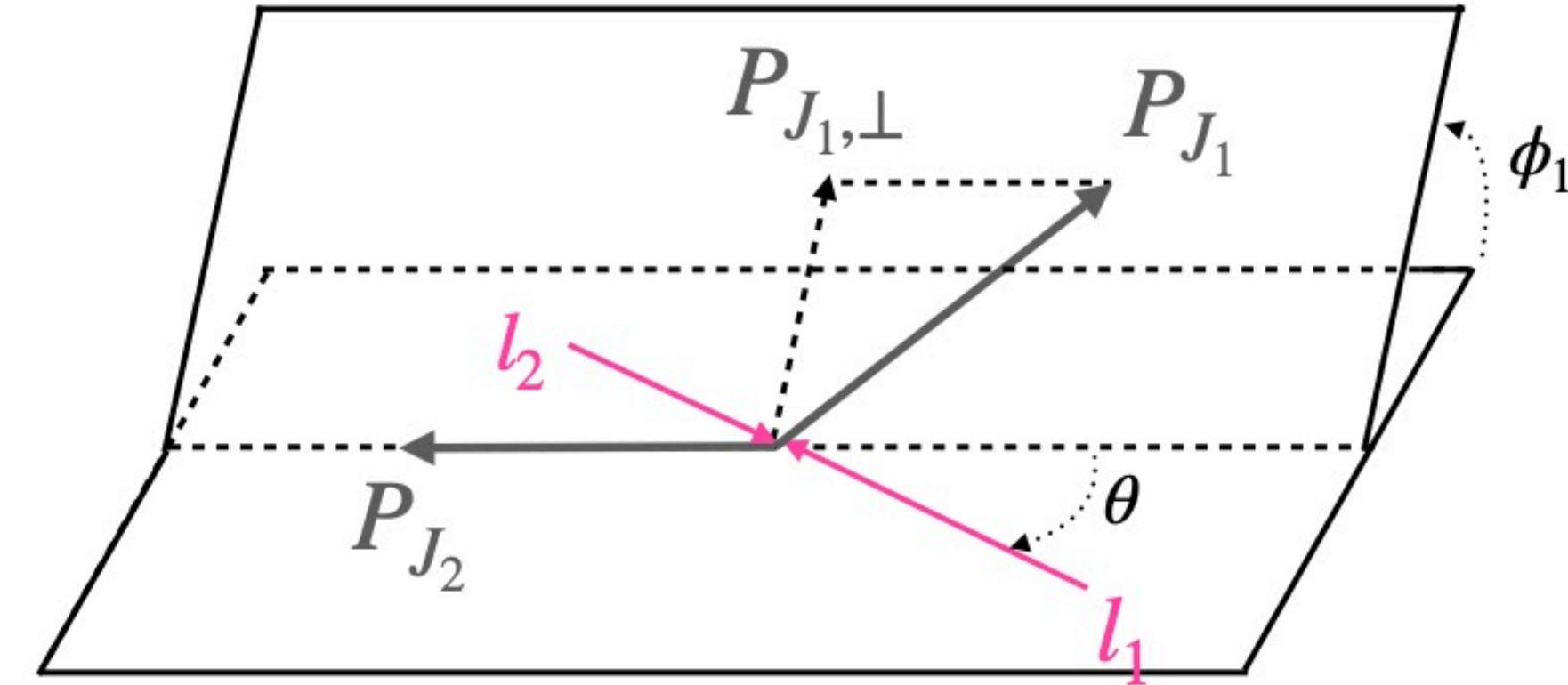
Cal, Neill, Ringer, Waalewijn, JHEP 2020

- Jet is not in the k - S plane
- Can be non-perturbative

Constrain T-odd jet in e^+e^- collisions

Azimuthal asymmetry:

$$R^{J_1 J_2} = 1 + \cos(2\phi_1) \frac{\sin^2 \theta}{1 + \cos^2 \theta} \frac{F_T(q_T)}{F_U(q_T)}$$



Factorization for WTA jet $\mathcal{J}_{\beta\beta'}^q(z, k_T, R) = \delta(1 - z)J_{\beta\beta'}^q(k_T) + \mathcal{O}\left(\frac{k_T^2}{p_J^2 R^2}\right)$

$$F_U = q_T \sum_q e_q^2 \int \frac{db b}{2\pi} J_0(q_T b) J^q(b) \bar{J}^q(b)$$

Reyes, Scimemi, Waalewijn, Zoppi, PRL 2018

$$F_T = q_T \sum_q e_q^2 \int \frac{d^2 b}{(2\pi)^2} e^{-iq_T \cdot b} \left(2 \frac{q_T^\alpha}{q_T} \frac{q_T^\beta}{q_T} + g^{\alpha\beta} \right) \partial_{b^\alpha} J_T^q(b) \partial_{b^\beta} \bar{J}_T^q(b)$$

Azimuthal asymmetry in e^+e^-

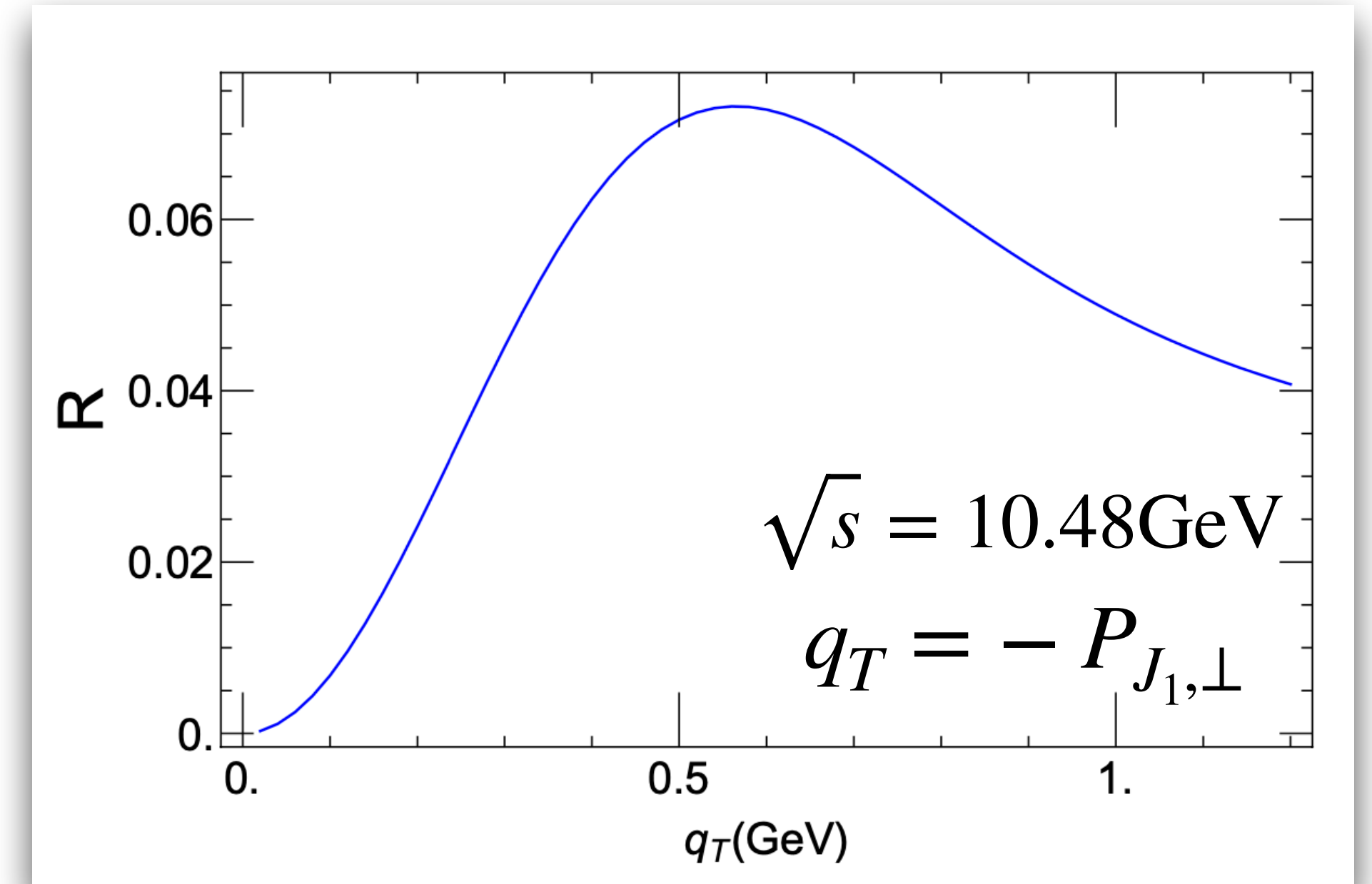
$$R = 2 \int d\cos\theta \frac{d\phi_1}{\pi} \cos(2\phi_1) R^{J_1 J_2}$$

$$J(b)\bar{J}(b) = e^{-S_{pert.} - S_{NP}^J} (1 + \mathcal{O}(\alpha_s)) r_q(Q_{J_{h_1}}) r_{\bar{q}}(Q_{J_{h_2}})$$

$$S_{pert.} = \int_{\mu_b^2}^s \frac{d\mu^2}{\mu^2} \left(A \log \frac{s}{\mu^2} + B \right)$$

$$\partial_{b^\alpha} J_T^q \partial_{b^\beta} \bar{J}_T^{\bar{q}} = e^{-S_{pert.} - S_{NP}^T} \frac{b^\alpha b^\beta}{4} \mathcal{N}_q^h(b) \mathcal{N}_{\bar{q}}^h(b)$$

- Follow the parametrization for Collins TMD (Kang, Prokudin, Sun, Yuan, 2015)
- This is for illustration only, because the non-perturbative T-odd jet functions are yet to be determined.



Can be extracted directly from BELLE or BaBar data

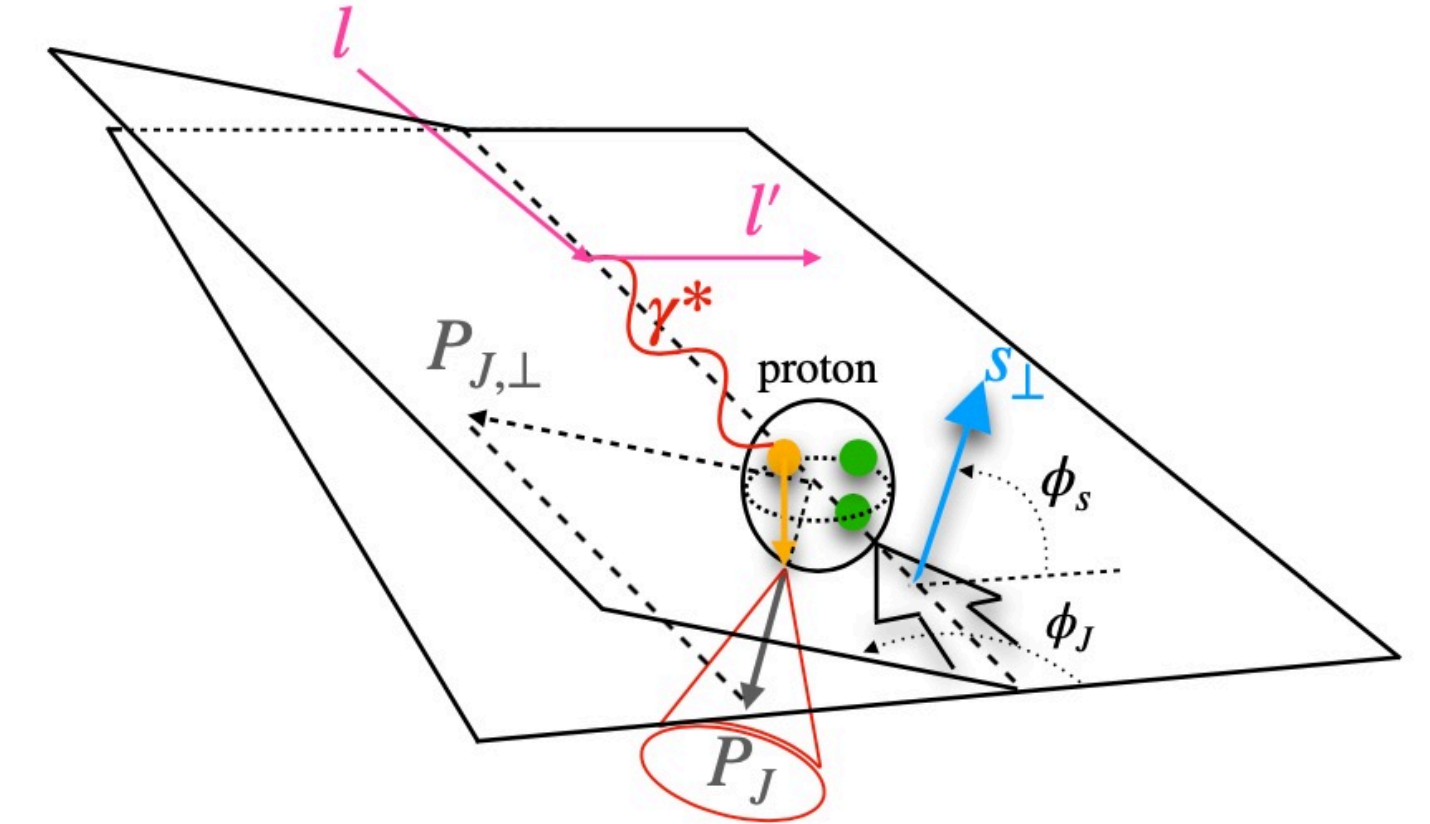
The lower the jet energy the better (if statistics guaranteed)

Using T-odd jets to constrain the nucleon tensor charge

Factorization in DIS

$$A(\zeta, y, \phi_s, \phi_J, P_{J\perp}) = 1 + \epsilon |s_\perp| \sin(\phi_J + \phi_s) \frac{F_{UT}}{F_{UU}}$$

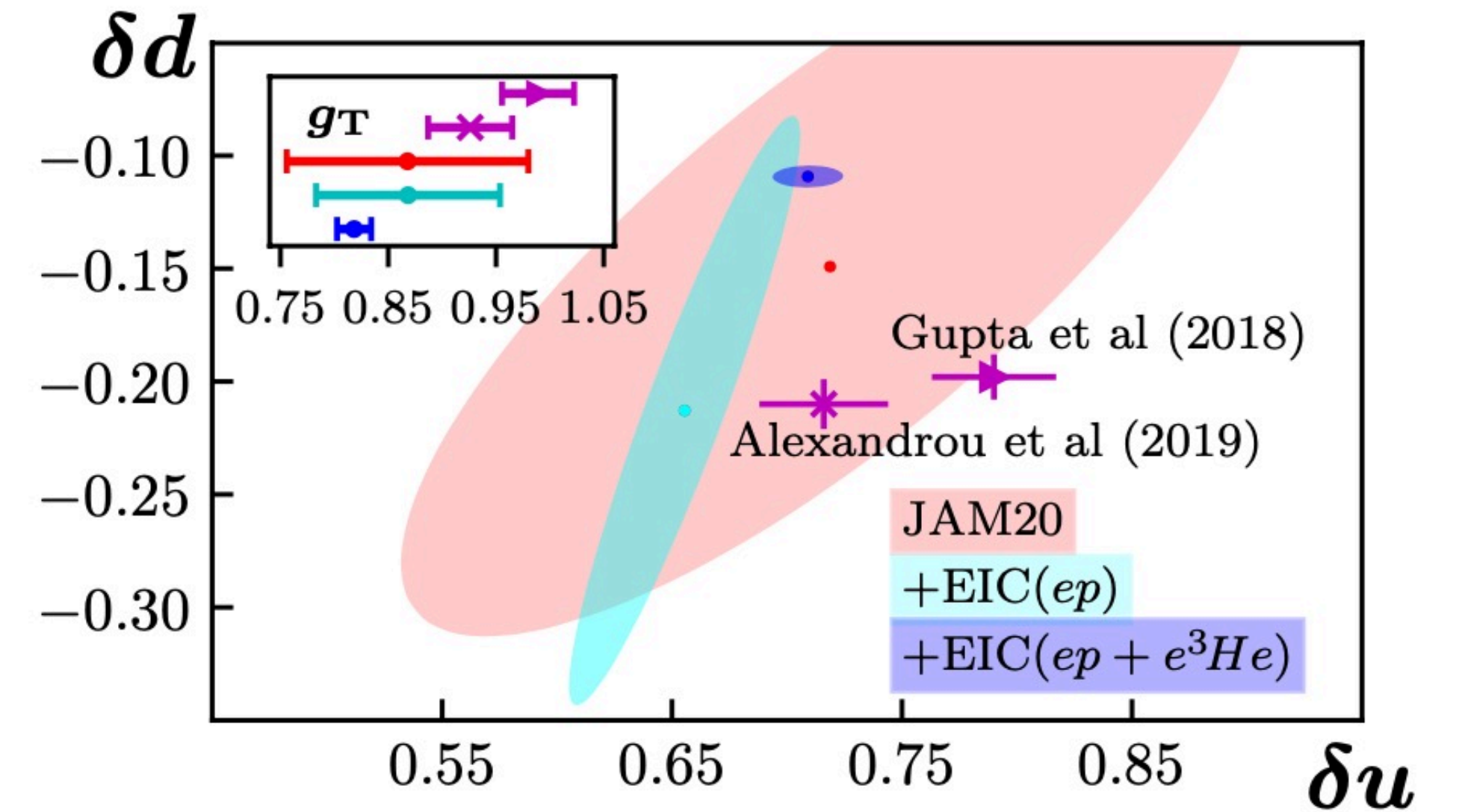
$$F_{UT} = \sum_q e_q^2 \int \frac{d^2b}{4\pi^2} e^{-iP_{J\perp} \cdot b} i \frac{P_{J\perp}^\alpha}{P_{J\perp}} \zeta h_1^q(\zeta, b) \partial_{b^\alpha} J_T^q(b)$$



Nucleon tensor charge: $g_T = \delta u - \delta d$

$$\delta u = \int_0^1 dx (h_1^u(x) - h_1^{\bar{u}}(x)), \quad \delta d = \int_0^1 dx (h_1^d(x) - h_1^{\bar{d}}(x))$$

T-odd jet with jet charge measurement can serve as a fantastic probe for nucleon tensor charge.



Gamberg, Kang, Pitonyak, Prokudin, Sato, PLB 2021

Conclusion

- Jet is a powerful tool in many fields.
- Two fundamental difficulties in conventional jet

Flavor separation -> Jet charge

Limited power of jet probing on nucleon spin structure -> T-odd jet

- More comprehensive and precise analyses will come soon - stay tuned!