The 2nd Workshop on Jets for 3D Imaging at the EIC

Spin Asymmetries with Electron-Jet Production at the EIC

arXiv:2106.15624

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In collaboration with Zhong-Bo Kang,
Kyle Lee and Ding Yu Shao

29 Sep 2021

Overview

- Motivation

- Part I: $ep \to e + \text{jet} + X$

  Theoretical framework
  Example 1: Electron-jet production

- Part II: $ep \to e + \text{jet}(h) + X$

  Theoretical framework
  Example 2: Unpolarized $\pi^{\pm}$ in jet
  Example 3: Transversely polarized Λ in jet

- Summary & Outlook

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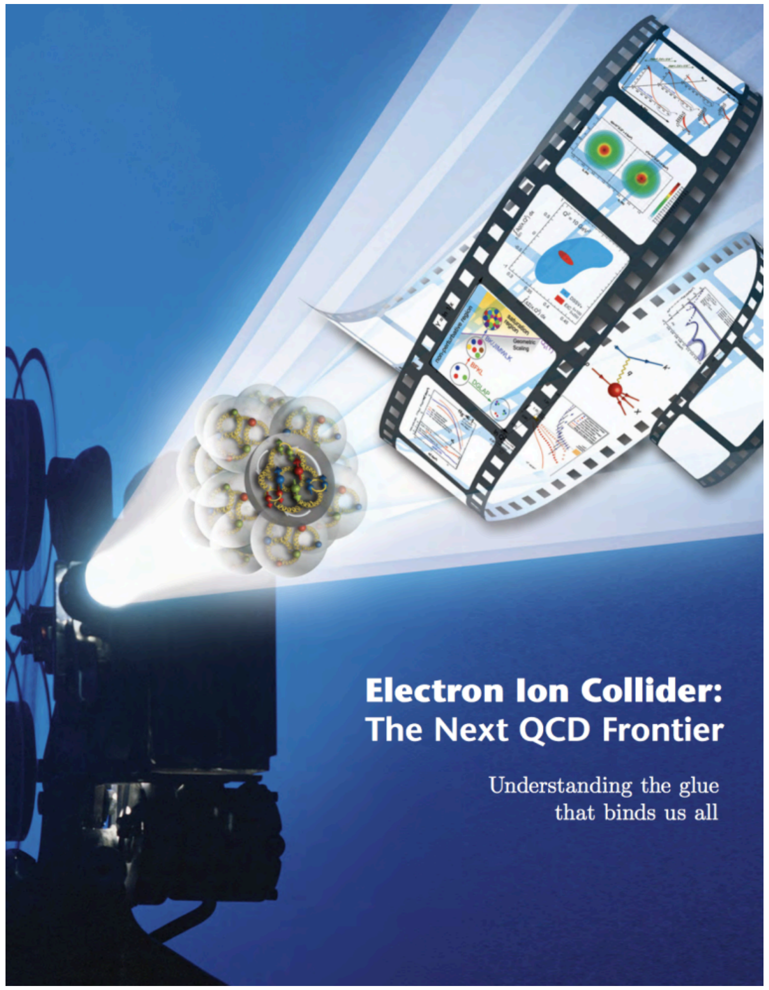
- Summary & Outlook

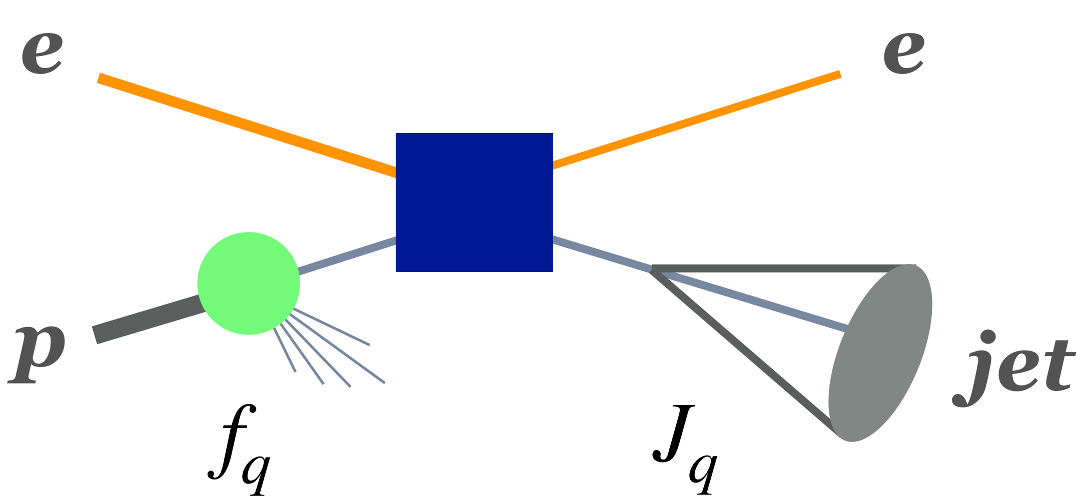
- Studies of jets have been used as an important probe to test the fundamental properties of hadrons.
- The advent of the Electron-Ion Collider (EIC) with polarized beams unlock the full potential of jets for probing 3D structure of the nucleon and nuclei (encoded in **TMDPDFs**).



Motivation

- In the process of $ep \to e + \text{jet} + X$, the 3D structure of hadrons (encoded in **TMDPDFs**) correlate with quark jet functions J_q.

$$ep \to e + \text{jet} + X$$



$$\sigma \sim f_q \otimes J_q$$

J_q: Perturbative

Sum over all hadrons in the jet.

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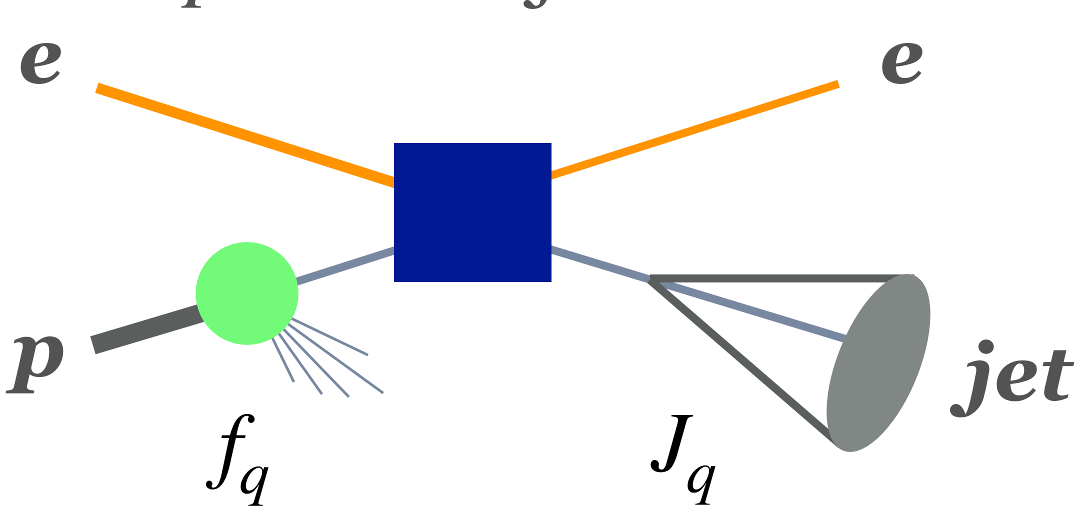

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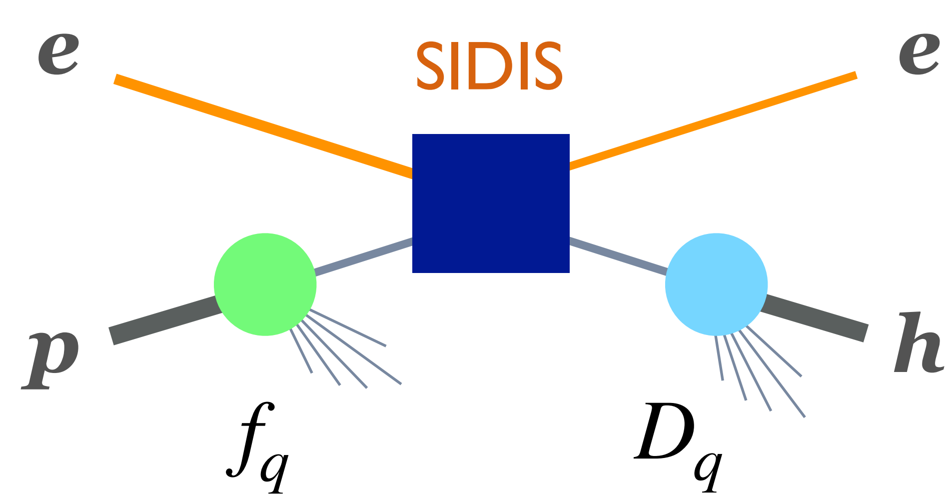
Sum over all hadrons in the jet.

$$ep \to e + h + X$$



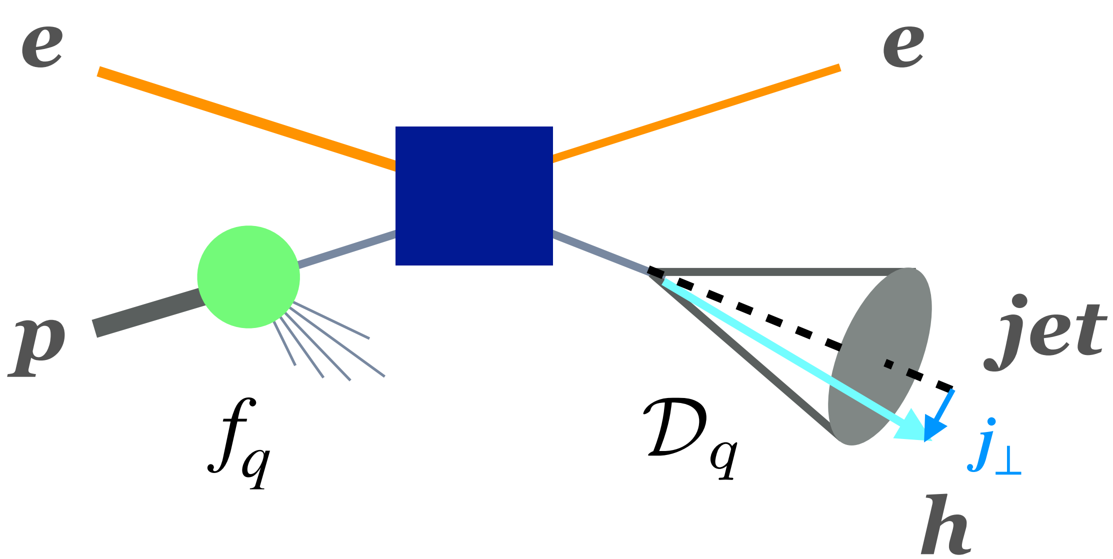
$$\sigma \sim f_q \otimes D_q$$

D_q: Non-perturbative

Hadrons are identified.

- In the process of $ep \to e + \text{jet}(h) + X$, the hadron's distribution inside jet (**TMDJFFs**) correlate with the parton distribution functions (**TMDPDFs**) of the initial proton

$$ep \to e + \text{jet}(h) + X$$



$$\sigma \sim f_q \otimes \mathcal{D}_q$$

$\mathcal{D}_q$: Match to TMDFFs with a perturbative coefficient function

Factorization: $j_\perp \ll p_T R \ll Q$

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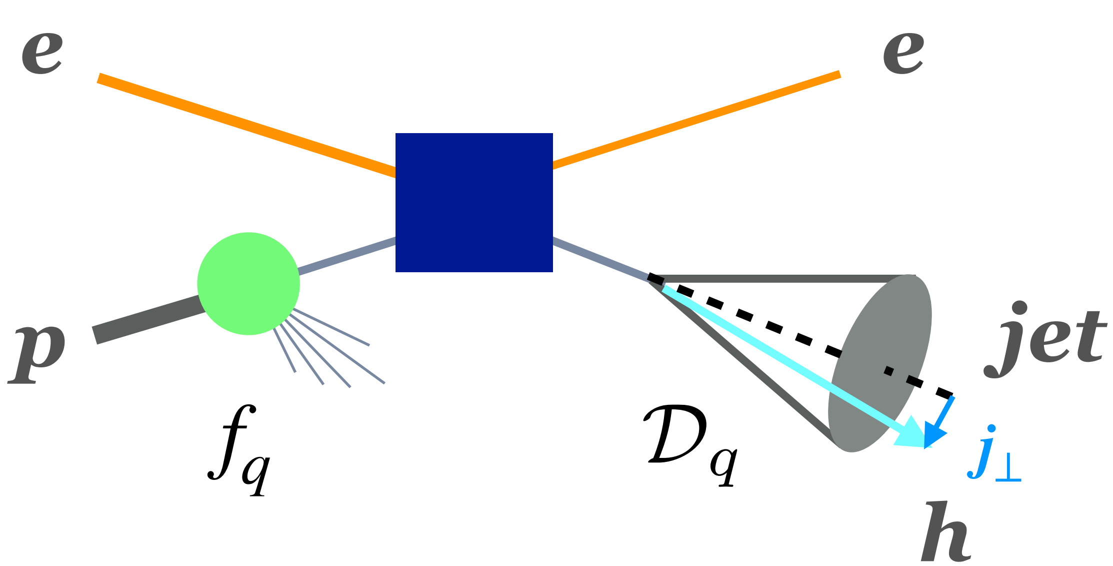

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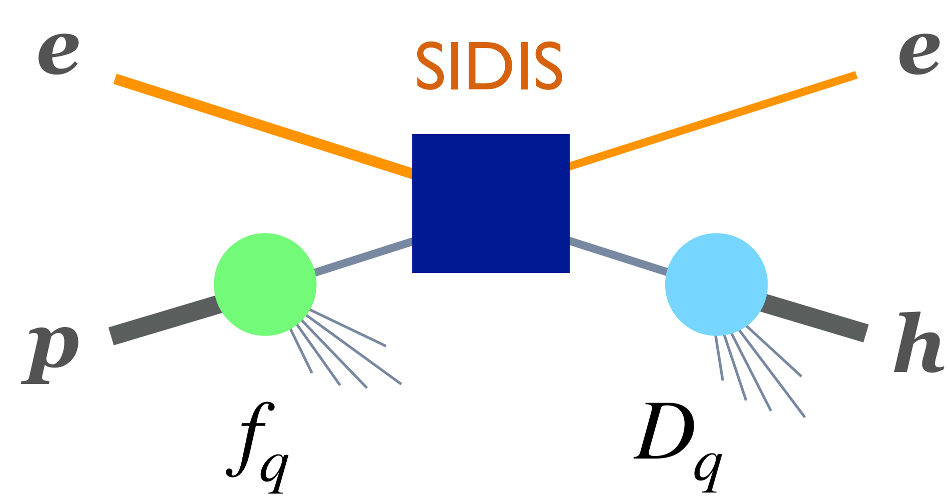

$$\sigma \sim f_q \otimes D_q$$

D_q: Non-perturbative

Factorization: $P_{hT} \ll Q$

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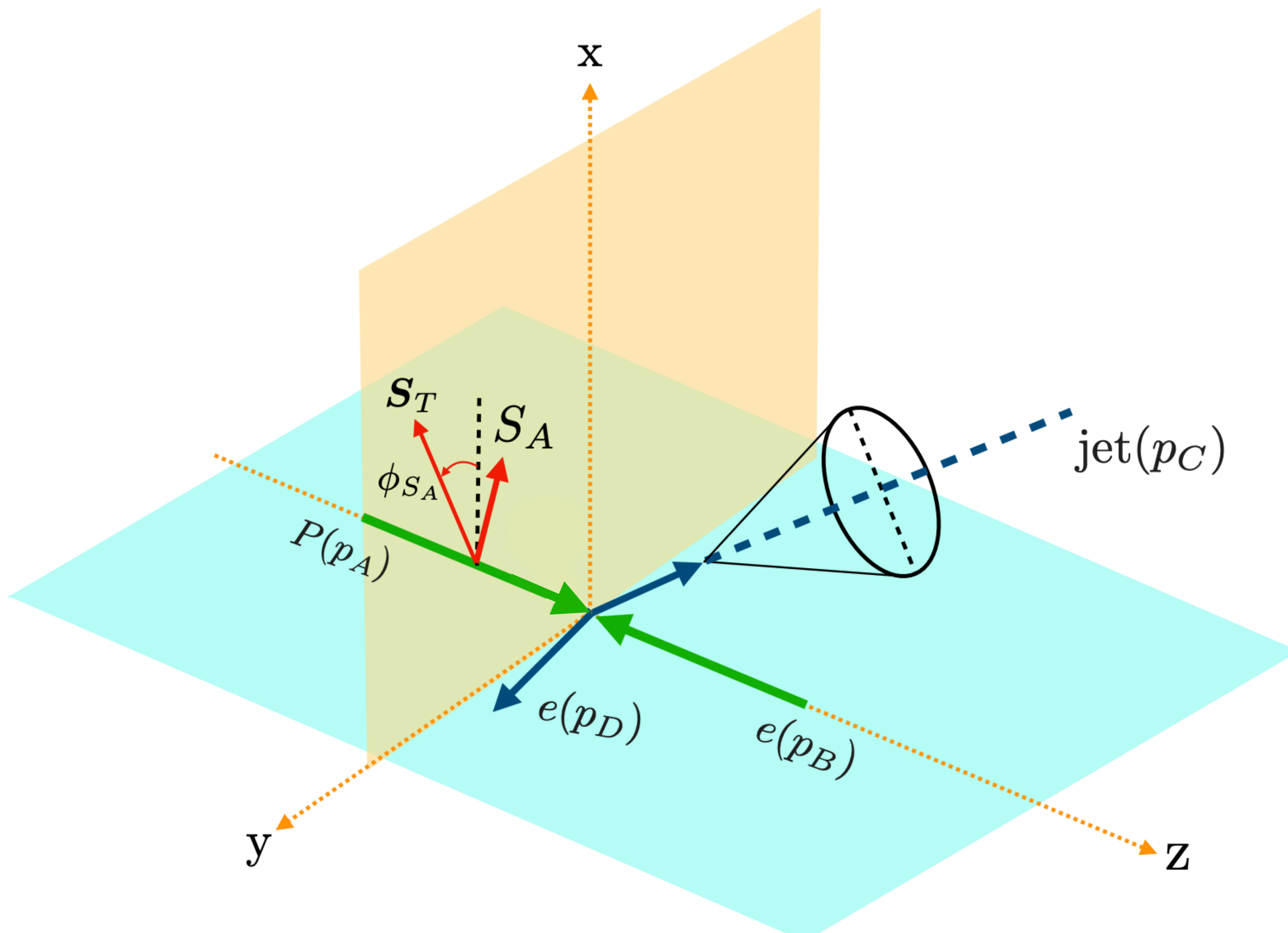
- All the possible spin asymmetries in back-to-back electron-jet production, $ep \to e + \text{jet} + X$, at the EIC



$$ep \to e + \text{jet} + X$$

- All the possible spin asymmetries in back-to-back electron-jet production, $ep \to e + \text{jet} + X$, at the EIC

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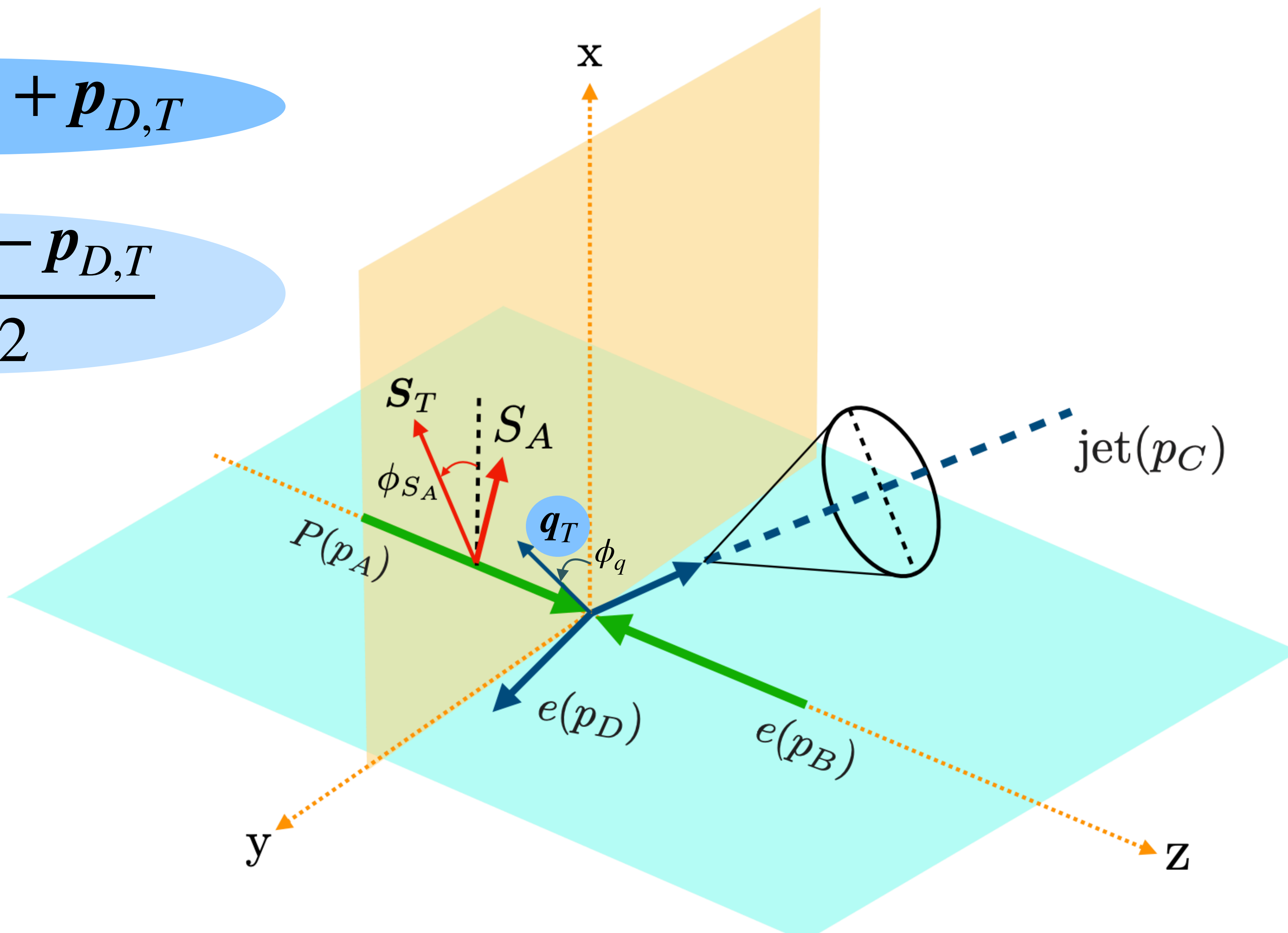
$$\boldsymbol{p}_T = \frac{\boldsymbol{p}_{C,T} - \boldsymbol{p}_{D,T}}{2}$$



$$ep \to e + \text{jet} + X$$

incoming proton

incoming electron

$$\frac{d\sigma^{p(S_A)+e(\lambda_e)\to e+\text{jet}+X}}{dp_T^2 dy_J d^2\boldsymbol{q}_T} = F_{UU} + \lambda_p \lambda_e F_{LL}$$

$$+ S_T \left\{ \sin(\phi_q - \phi_{S_A}) F_{TU}^{\sin(\phi_q - \phi_{S_A})} + \lambda_e \cos(\phi_q - \phi_{S_A}) F_{TL}^{\cos(\phi_q - \phi_{S_A})} \right\}$$

y_J : the rapidity of the jet

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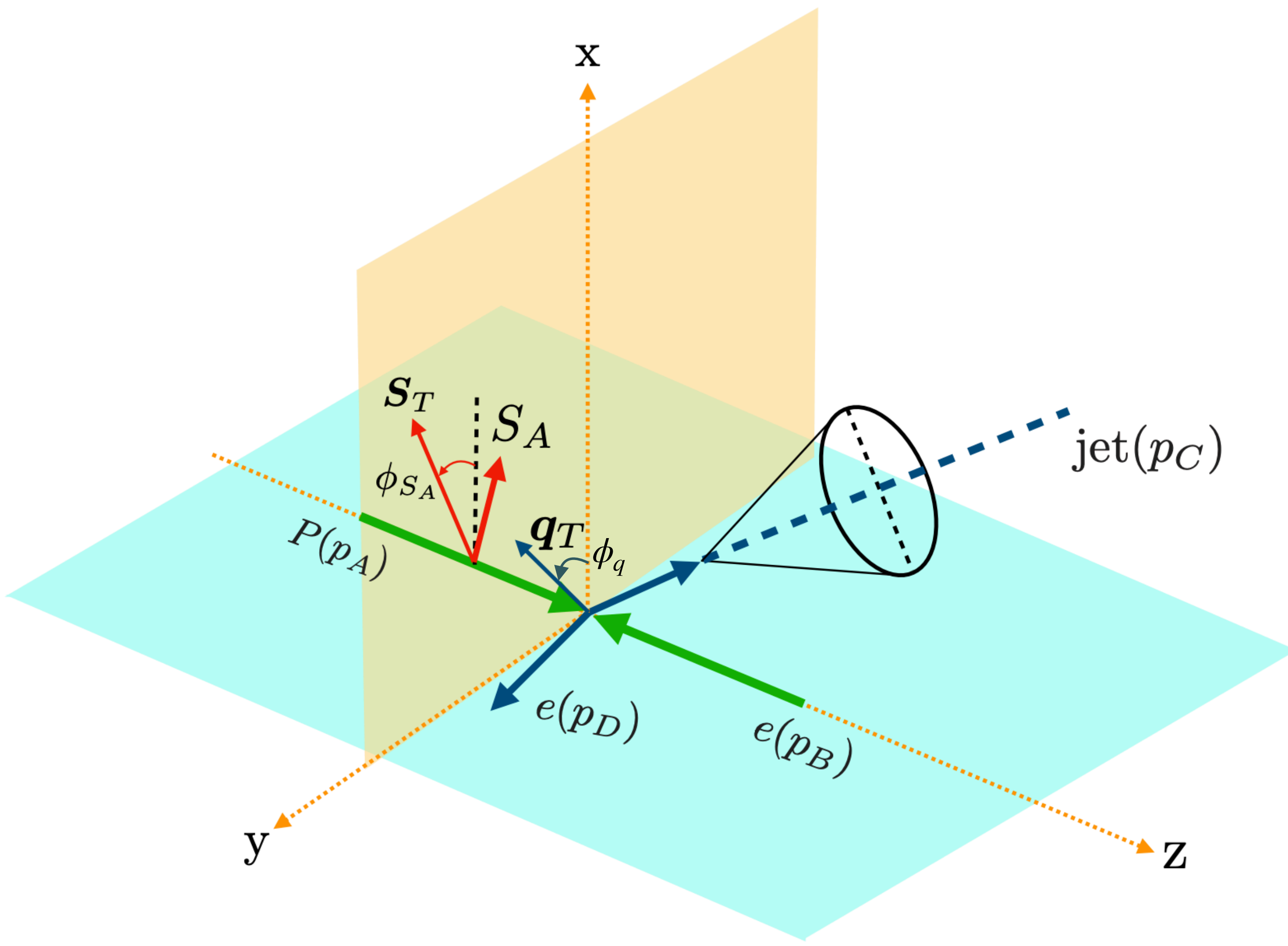

Theoretical framework (part I)

incoming proton

incoming electron

$$\frac{d\sigma^{p(S_A)+e(\lambda_e)\to e+\text{jet}+X}}{dp_T^2 dy_J d^2\boldsymbol{q}_T} = F_{UU} + \lambda_p\lambda_e F_{LL}$$

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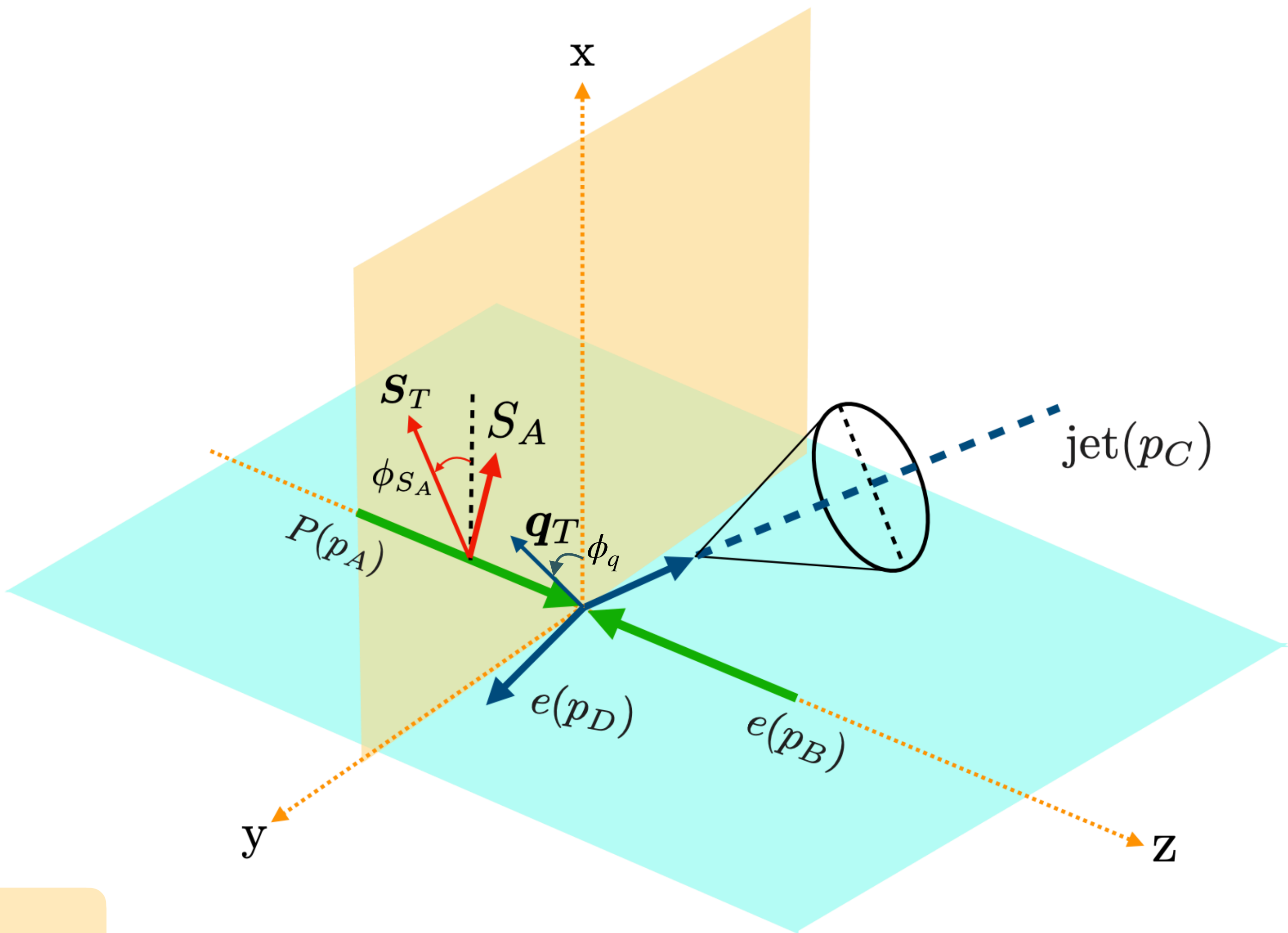

H \ q	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1,\ h_{1T}^\perp$

$$F_{UU} \sim f_1^q \otimes J_q$$

$$ep \to e + \text{jet} + X$$

$$\frac{d\sigma^{p(S_A)+e(\lambda_e)\to e+\text{jet}+X}}{dp_T^2\, dy_J\, d^2\boldsymbol{q}_T} = F_{UU} + \lambda_p \lambda_e F_{LL}$$

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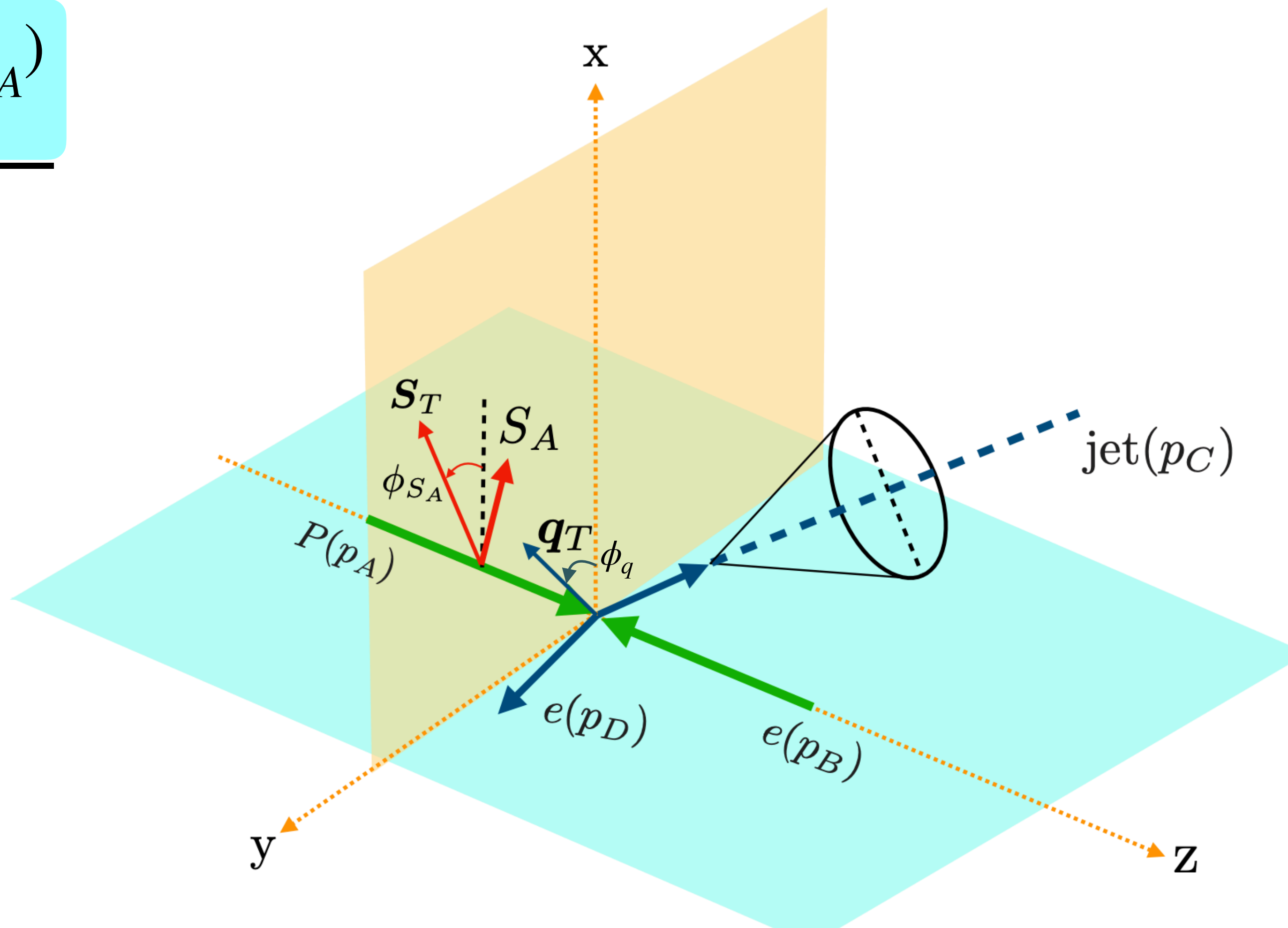
$$A_{TL}^{\cos(\phi_q-\phi_{S_A})} = \frac{F_{TL}^{\cos(\phi_q-\phi_{S_A})}}{F_{UU}}$$

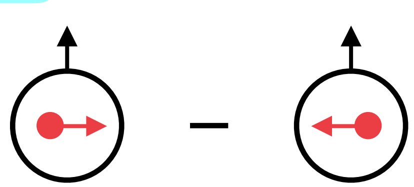
incoming proton

incoming electron



$$F_{UU} \sim f_1^q \otimes J_q$$

$$F_{TL}^{\cos(\phi_q-\phi_{S_A})} \sim g_{1T}^q \otimes J_q$$

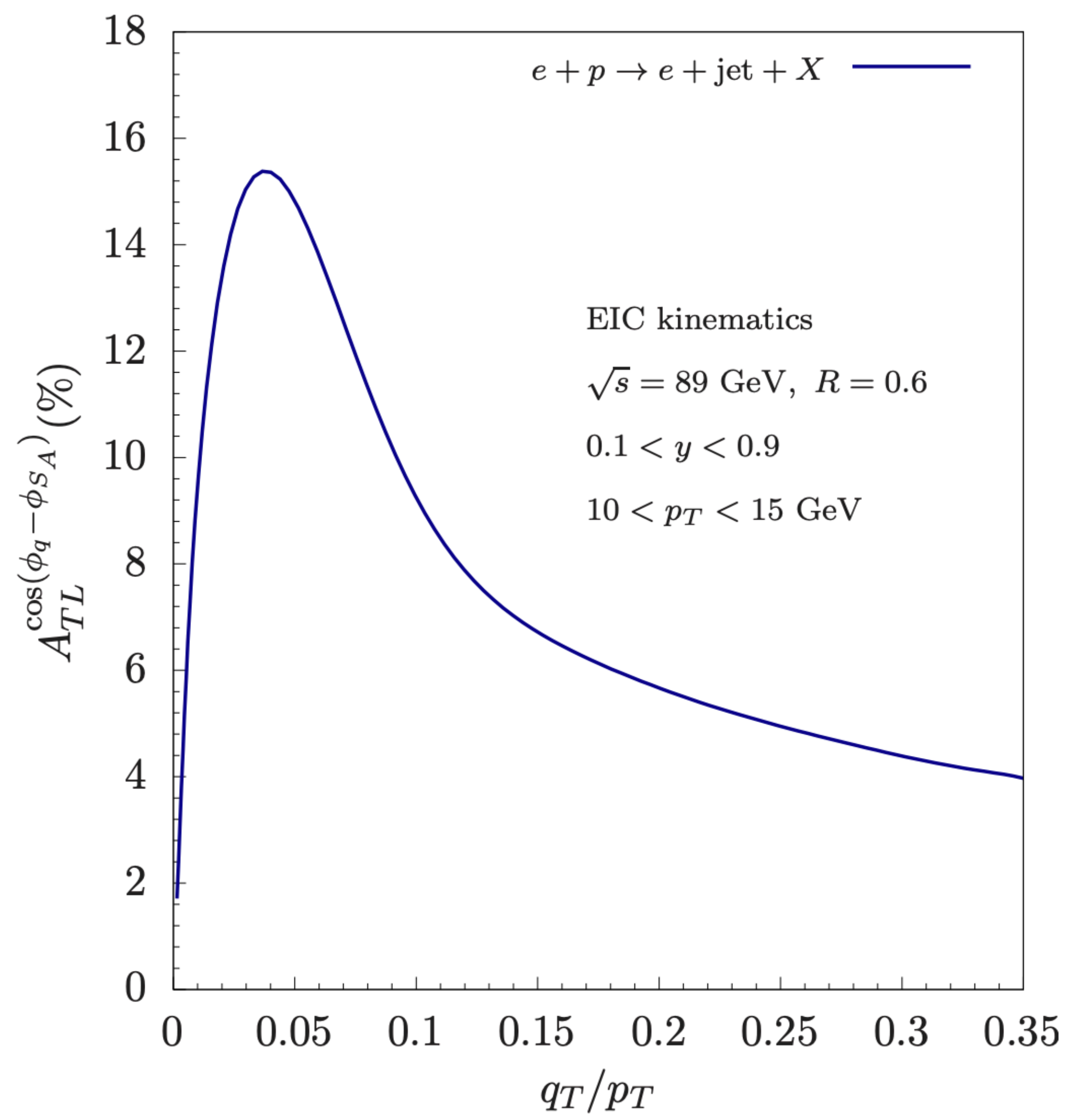


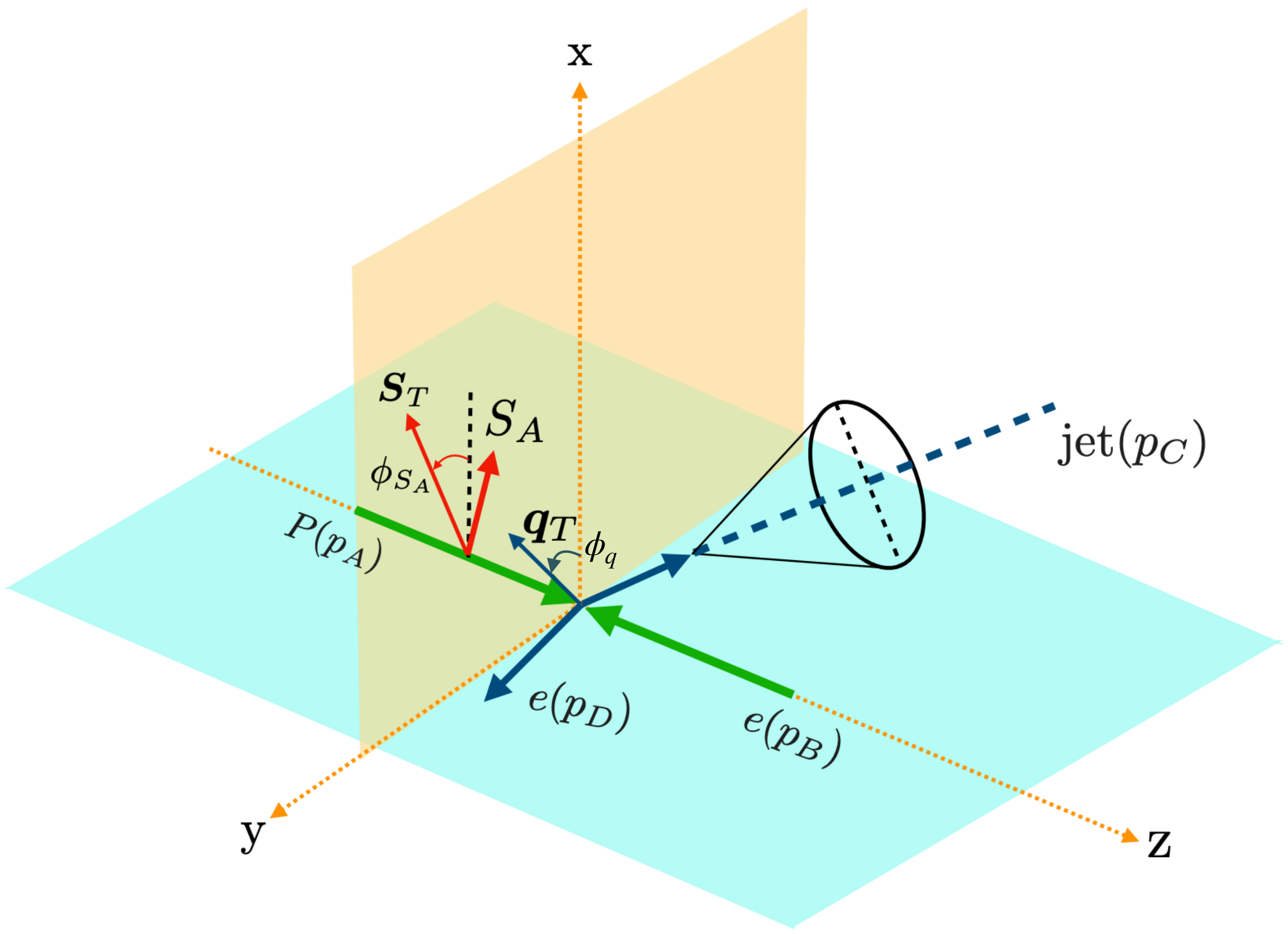
$$ep \to e + \text{jet} + X$$

$$A_{TL}^{\cos(\phi_q-\phi_{S_A})} = \frac{F_{TL}^{\cos(\phi_q-\phi_{S_A})}}{F_{UU}}$$

$$F_{UU} \sim f_1^q \otimes J_q$$

$$F_{TL}^{\cos(\phi_q-\phi_{S_A})} \sim g_{1T}^q \otimes J_q$$





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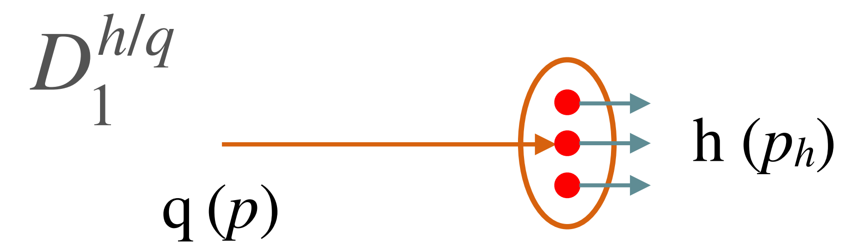
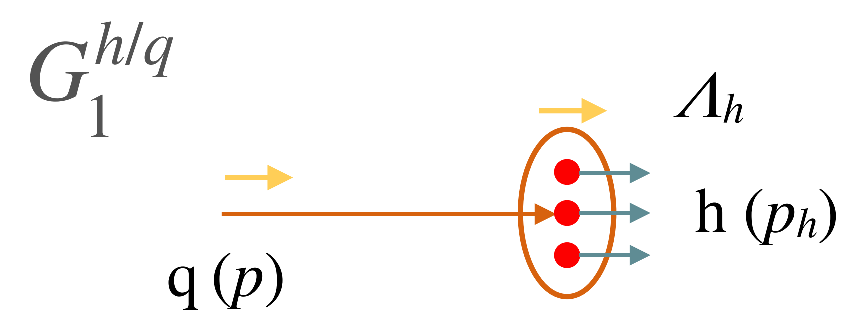
TMDJFFs

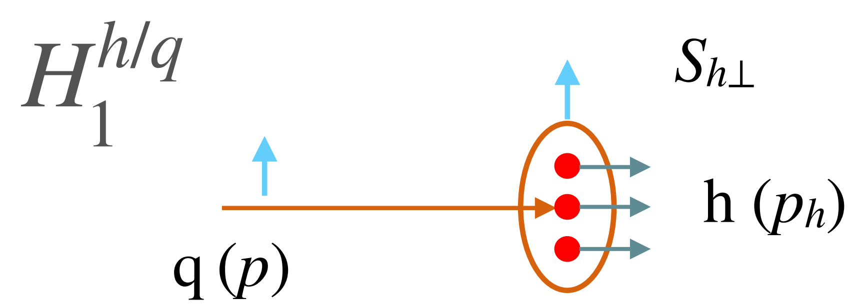
$$ep \to e + \text{jet}(h) + X$$



Collinear FFs



h\ q	U	L	T
U	$D_1^{h/q}$		
L		$G_1^{h/q}$	
T			$H_1^{h/q}$



Collinear FFs for quarks. Here U, L, and T represent unpolarized, longitudinally, and transversely polarized state

TMDJFFs

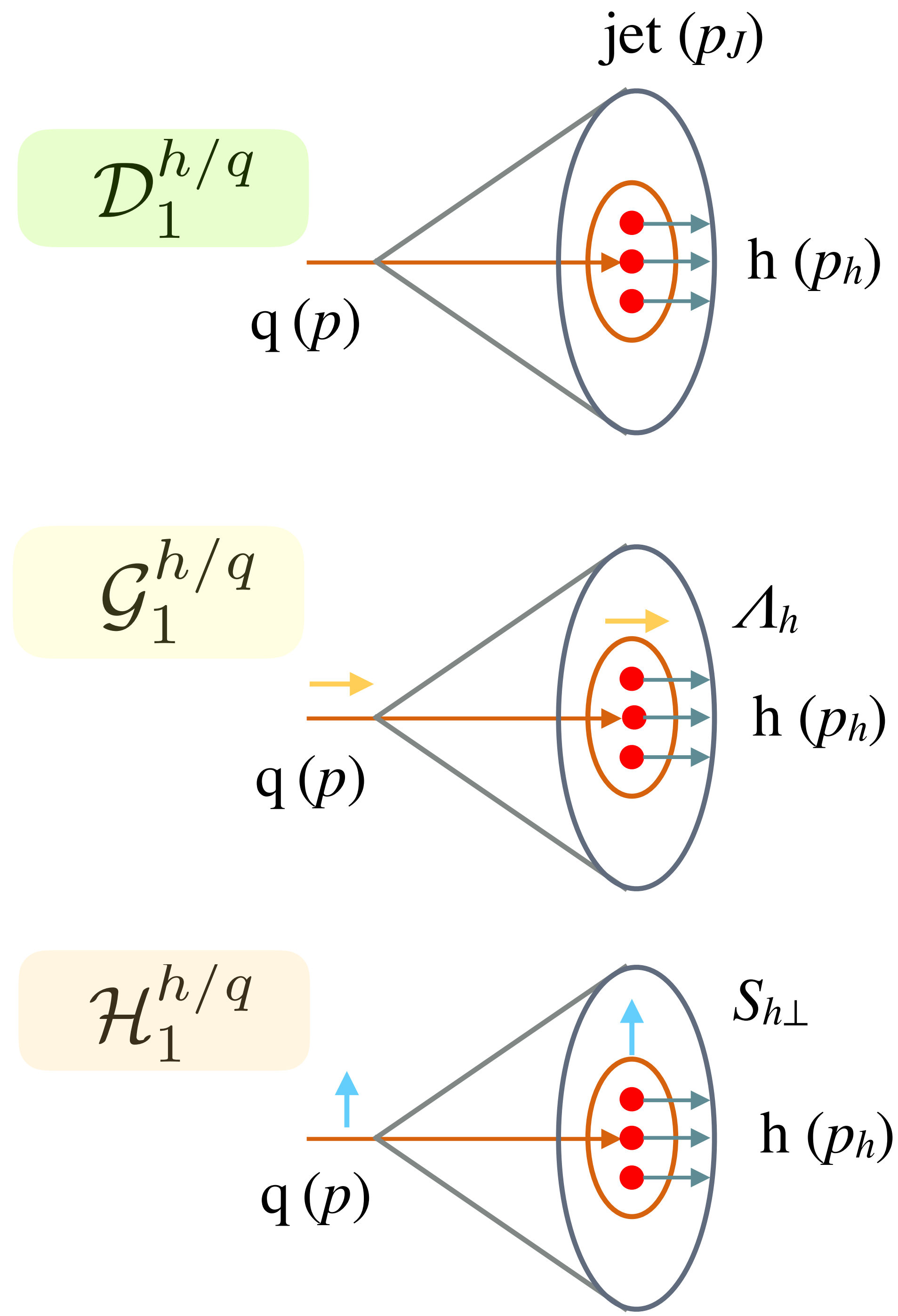
$$ep \to e + \text{jet}(h) + X$$

Collinear JFFs

$$z = \frac{p_J^-}{p^-}, \qquad z_h = \frac{p_h^-}{p_J^-},$$

h\ q	U	L	T
U	$\mathcal{D}_1^{h/q}$		
L		$\mathcal{G}_1^{h/q}$	
T			$\mathcal{H}_1^{h/q}$

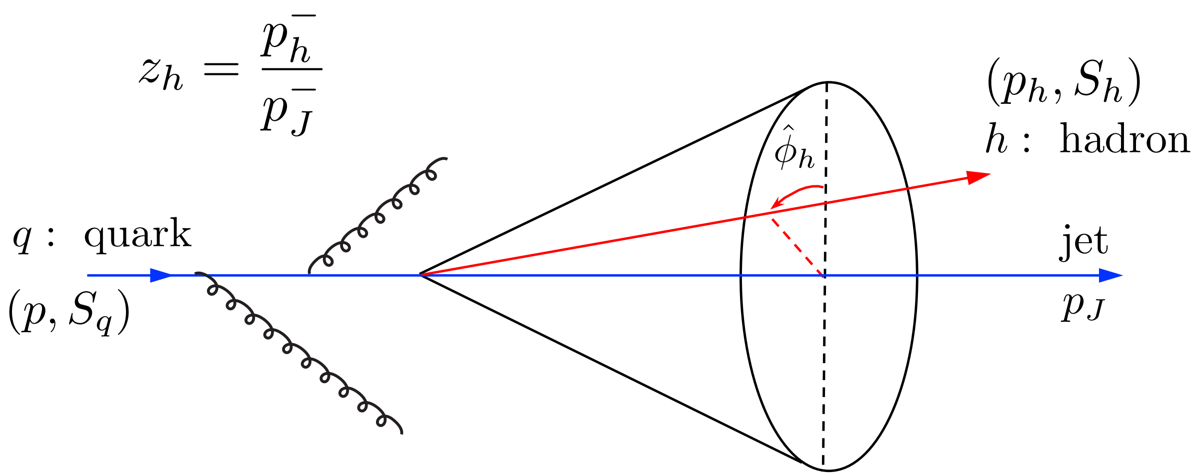
Collinear JFFs for quarks. Here U, L, and T represent unpolarized, longitudinally, and transversely polarized state



Theoretical framework (part II)

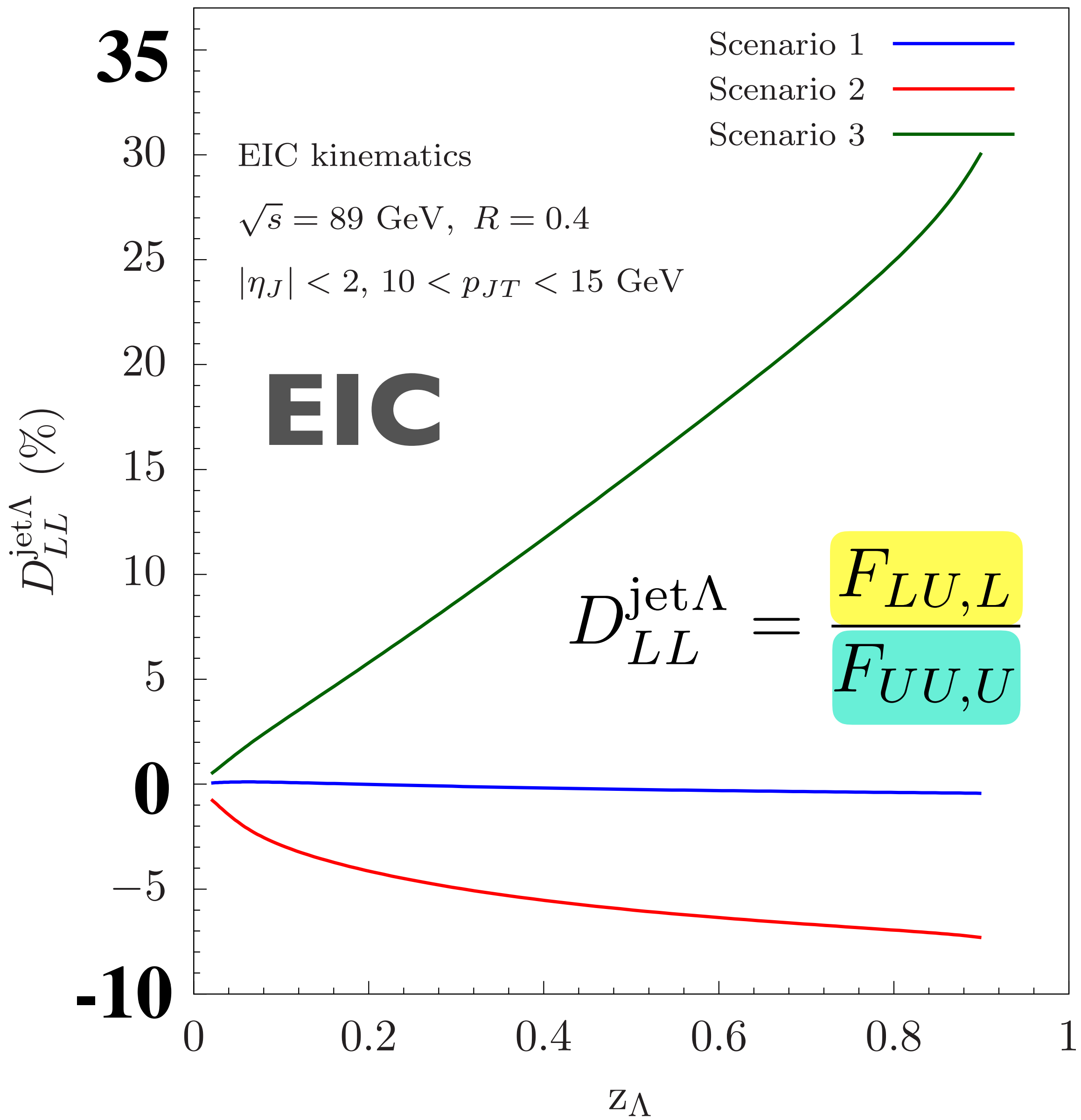
Collinear JFFs

$$p(p_A, S_A) + e(p_B) \to (\text{jet}(\eta_J, p_{JT}, R)\ h(z_h, S_h)) + e(p_D) + X$$



$$F_{UU,U} \sim f_a \otimes \mathcal{D}_1^{\Lambda/c}$$
$$F_{LU,L} \sim g_a \otimes \mathcal{G}_1^{\Lambda/c}$$

h\ q	U	L	T
U	$\mathcal{D}_1^{h/q}$		
L		$\mathcal{G}_1^{h/q}$	
T			$\mathcal{H}_1^{h/q}$



Kang, Lee, Zhao `20

TMDJFFs

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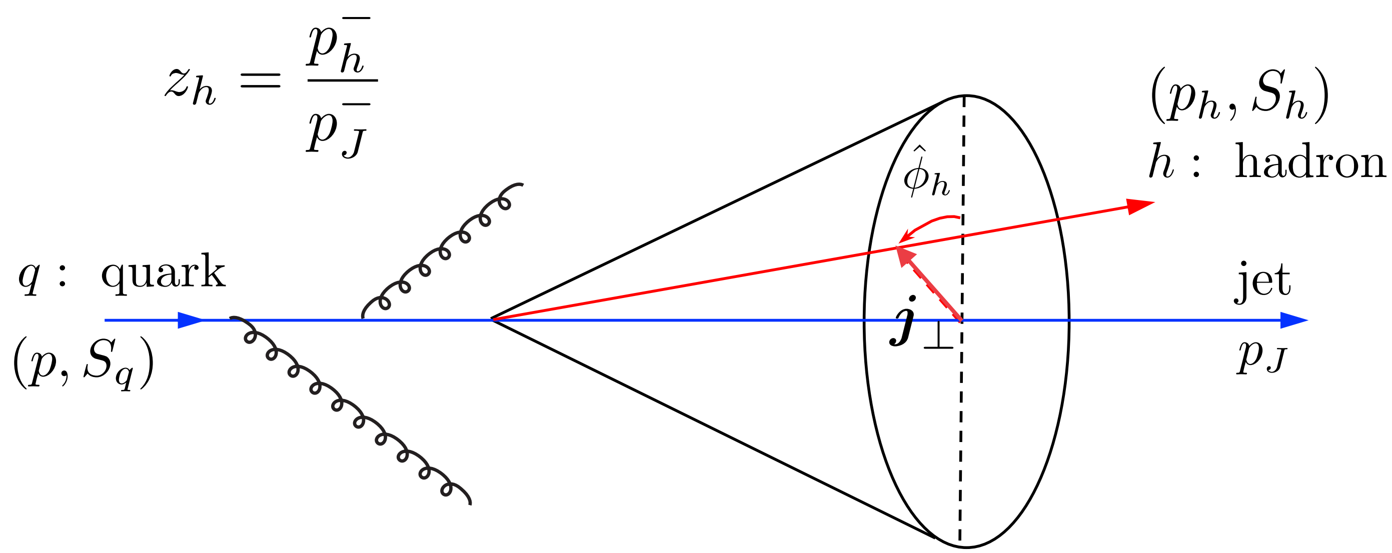


Leading TMDFFs

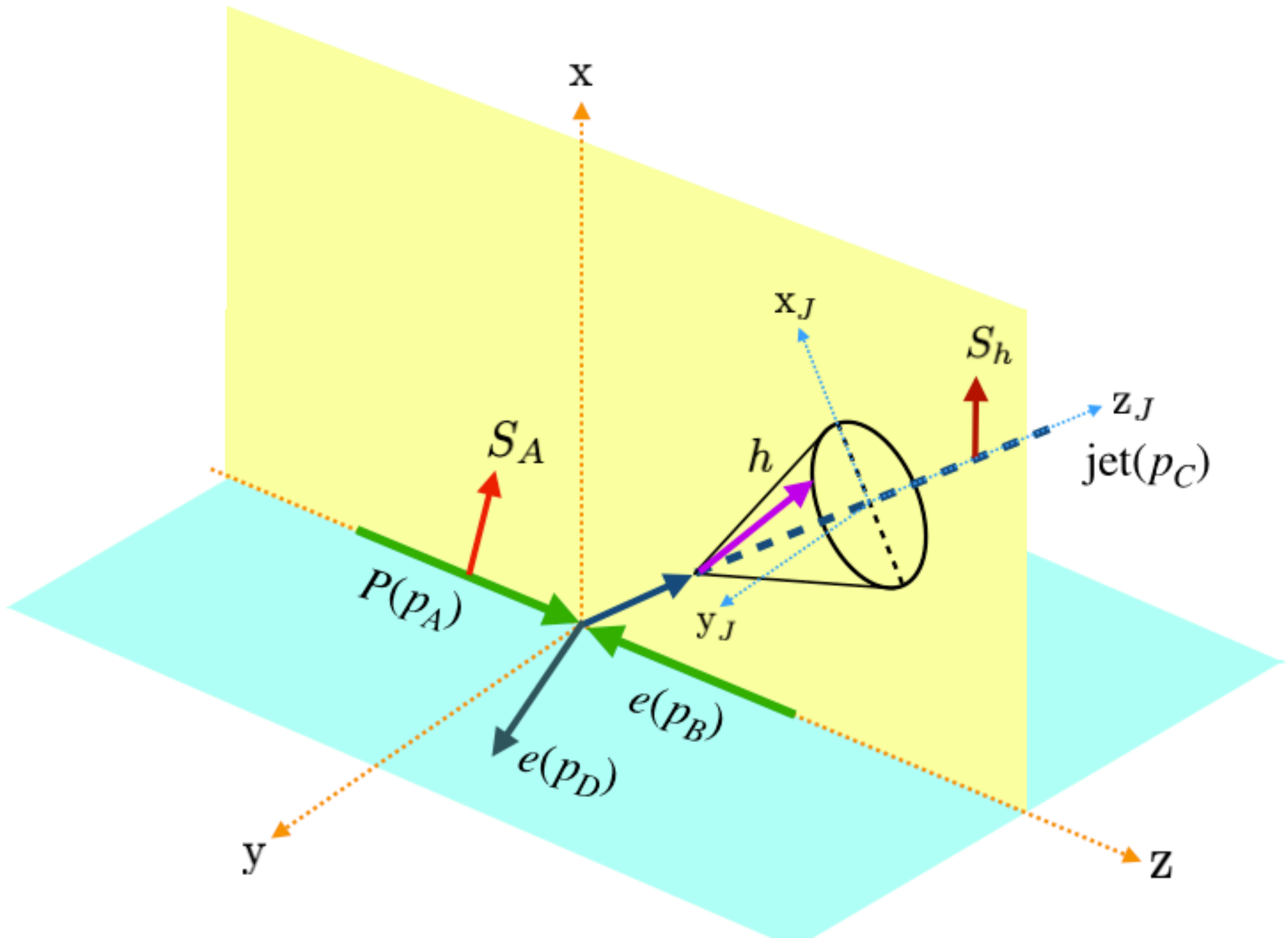
h/q	U	L	T
U	D_1		$H_1^\perp$
L		G_{1L}	$H_{1\mathrm{L}}^\perp$
T	$D_{1\mathrm{T}}^\perp$	$G_{1\mathrm{T}}$	$H_1, H_{1\mathrm{T}}^\perp$

Leading TMDJFFs

h\ q	U	L	T
U	$\mathcal{D}_1^{h/q}$		$\mathcal{H}_1^{\perp\, h/q}$
L		$\mathcal{G}_{1L}^{h/q}$	$\mathcal{H}_{1L}^{h/q}$
T	$\mathcal{D}_{1T}^{\perp\, h/q}$	$\mathcal{G}_{1T}^{h/q}$	$\mathcal{H}_1^{h/q}, \mathcal{H}_{1T}^{\perp\, h/q}$

Transverse momentum dependent FFs/JFFs for quarks. Here U, L, and T represent unpolarized, longitudinally, and transversely polarized state

- All the possible spin asymmetries in back-to-back electron-jet production with jet fragmentation process, $ep \to e + \text{jet}(h) + X$, at the future electron ion collider (EIC)



$$ep \to e + \text{jet}(h) + X$$

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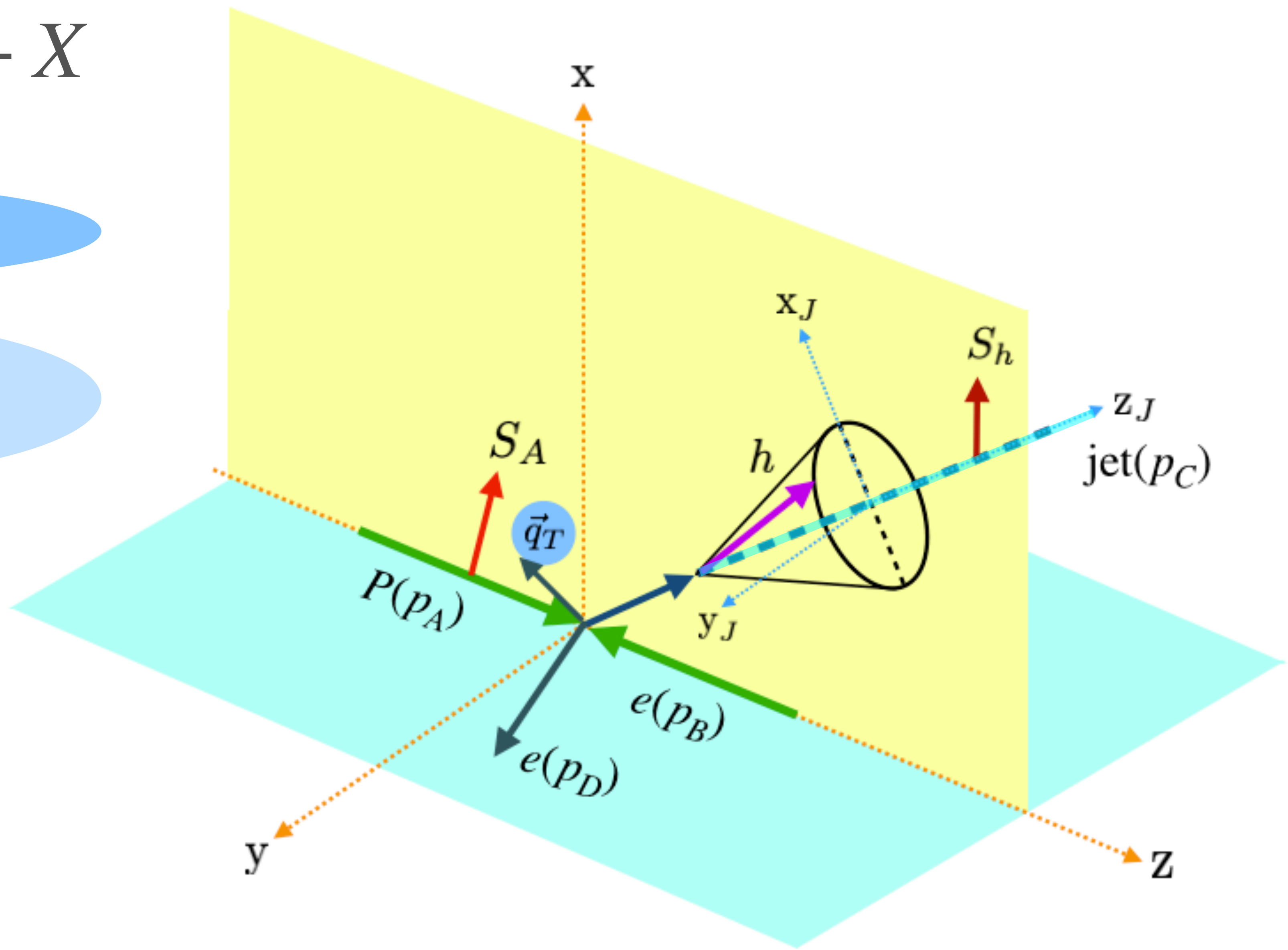
$$\boldsymbol{p}_T = \frac{\boldsymbol{p}_{C,T} - \boldsymbol{p}_{D,T}}{2}$$

$$z_h = \frac{p_h^-}{p_J^-}$$

$$\boldsymbol{j}_\perp$$

$$\boldsymbol{S}_{h\perp}$$

$$\boldsymbol{S}_T$$



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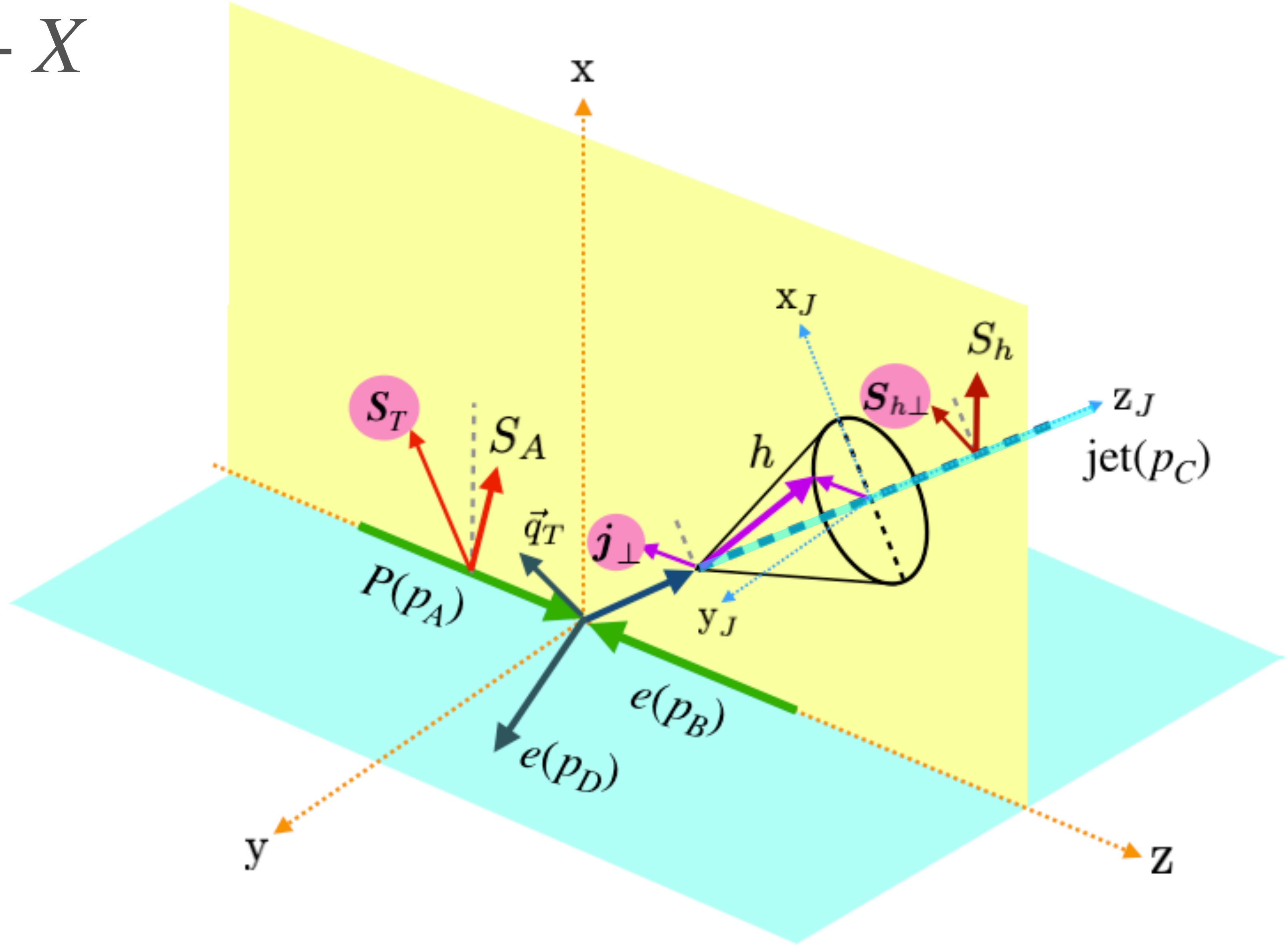

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$$ep \to e + \text{jet}(h) + X$$

$$\boldsymbol{q}_T = \boldsymbol{p}_{C,T} + \boldsymbol{p}_{D,T} \quad \phi_q$$

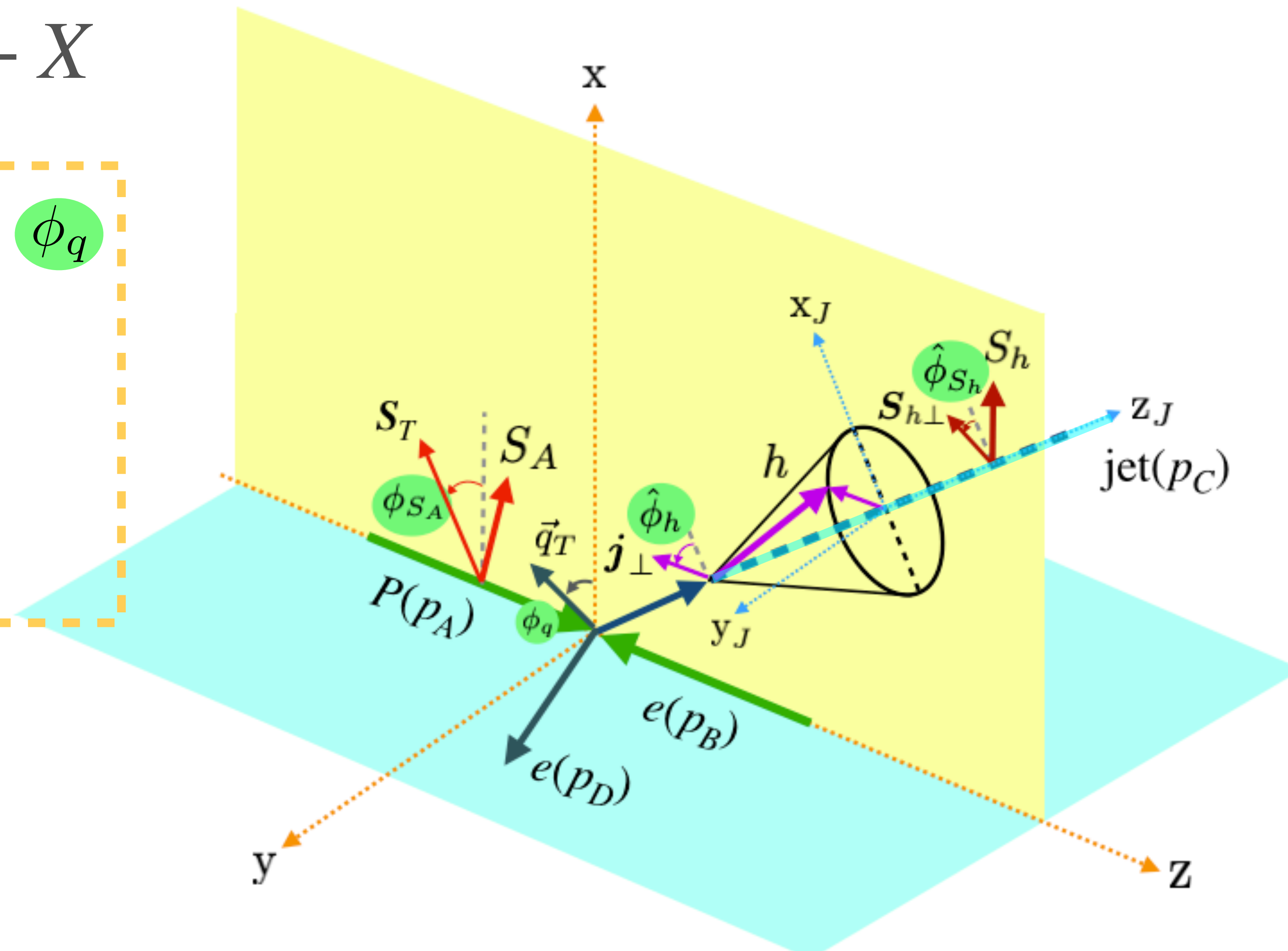
$$\boldsymbol{p}_T = \frac{\boldsymbol{p}_{C,T} - \boldsymbol{p}_{D,T}}{2}$$

$$\boldsymbol{S}_T \quad \phi_{S_A}$$

$$z_h = \frac{p_h^-}{p_J^-}$$

$$\boldsymbol{j}_\perp \quad \hat{\phi}_h$$

$$\boldsymbol{S}_{h\perp} \quad \hat{\phi}_{S_h}$$



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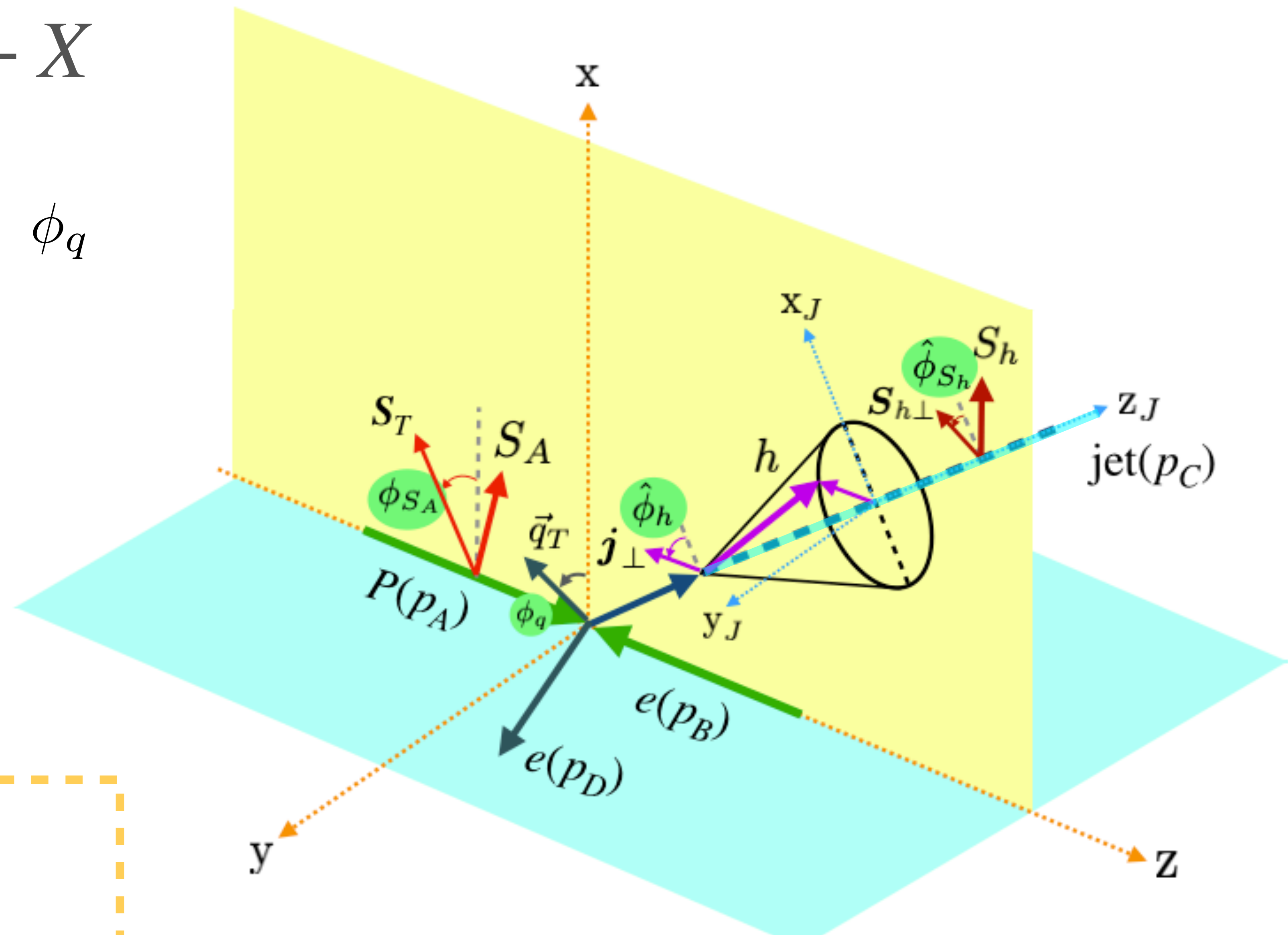

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TMDPDFs

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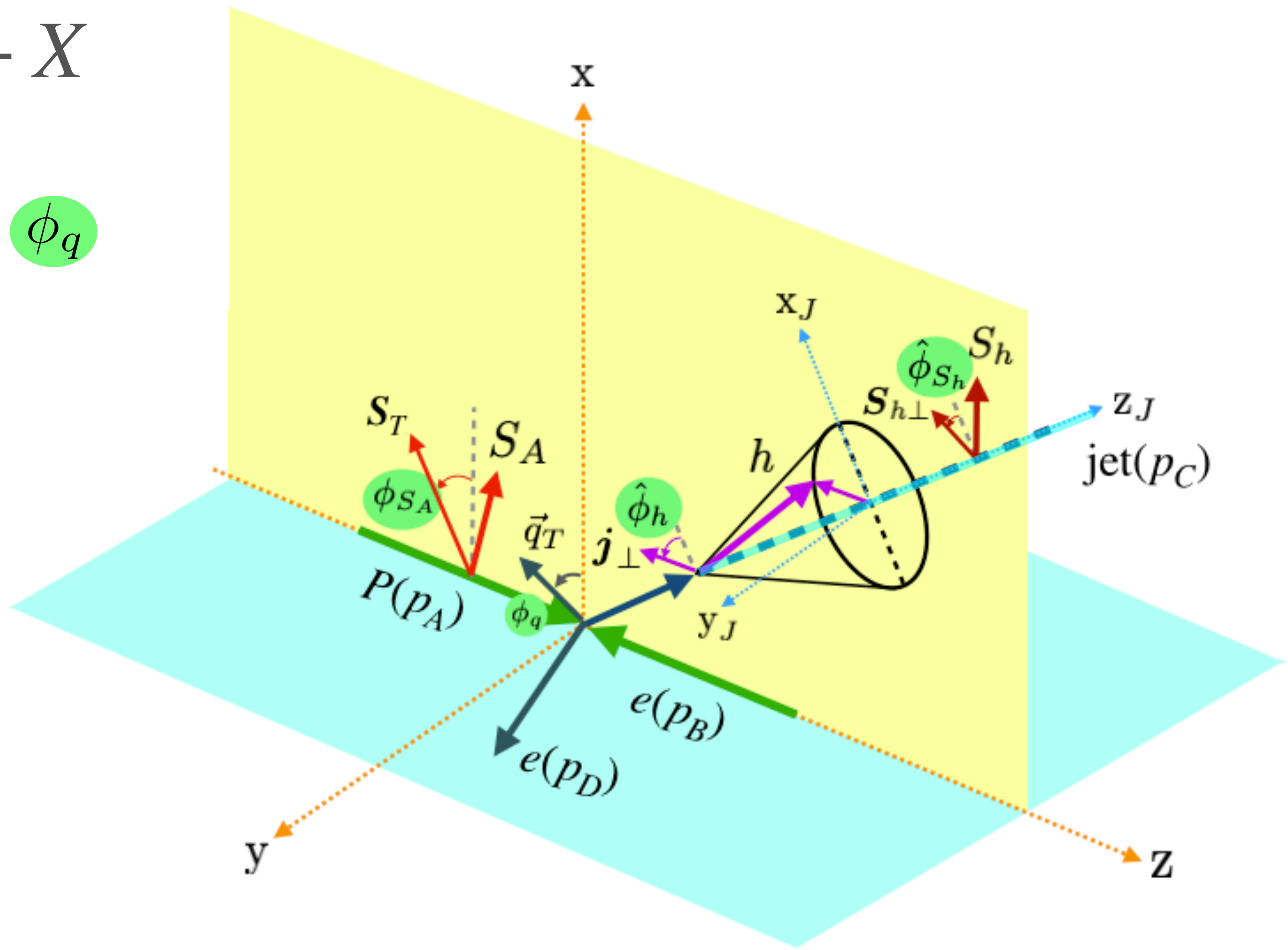
TMDJFFs $\boldsymbol{j}_\perp$ $\hat{\phi}_h$

$$\boldsymbol{S}_{h\perp} \quad \hat{\phi}_{S_h}$$



Different from SIDIS!

$$\frac{d\sigma}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cos(\phi_q - \hat{\phi}_h) F_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)} + \cdots$$

(Total 32 terms.)

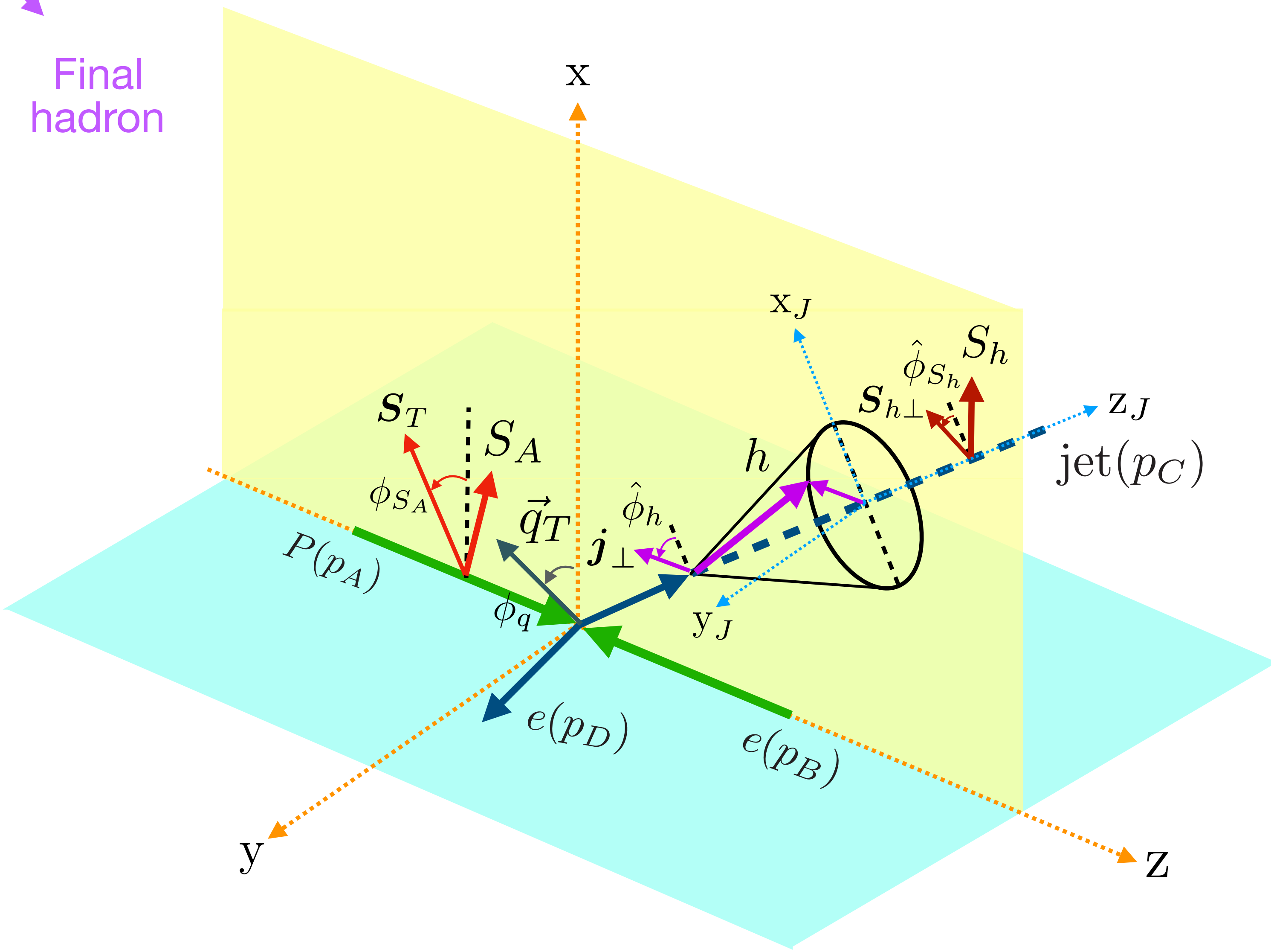
$$A_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)} = \frac{F_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)}}{F_{UU,U}}$$

$$ep \to e + \mathrm{jet}(h) + X$$

incoming proton

incoming electron

Final hadron



$$\frac{d\sigma}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cos(\phi_q - \hat{\phi}_h) F_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)}$$

$$A_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)} = \frac{F_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)}}{F_{UU,U}}$$

$$F_{UU,U} \sim f_1 \otimes \mathcal{D}_1^{h/q}$$

$$F_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)} \sim h_1^\perp \otimes \mathcal{H}_1^{\perp\, h/q}$$

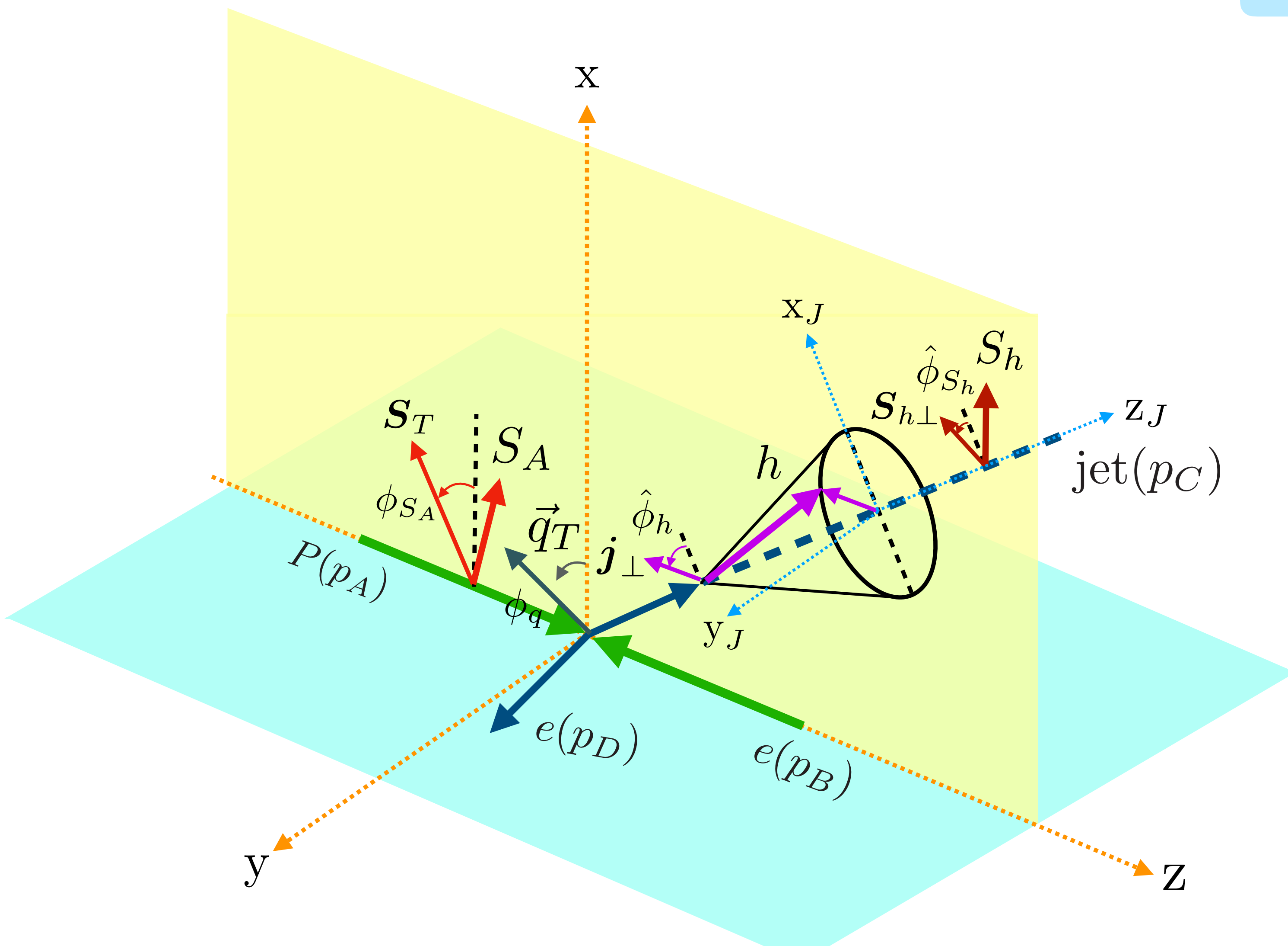
match to

Boer-Mulders function

Collins function

arXiv: [0912.5194]

arXiv: [1505.05589]



$$ep \to e + \text{jet}(h) + X$$

h\ q	U	L	T
U	$\mathcal{D}_1^{h/q}$		$\mathcal{H}_1^{\perp\, h/q}$
L		$\mathcal{G}_{1L}^{h/q}$	$\mathcal{H}_{1L}^{h/q}$
T	$\mathcal{D}_{1T}^{\perp\, h/q}$	$\mathcal{G}_{1T}^{h/q}$	$\mathcal{H}_1^{h/q}$, $\mathcal{H}_{1T}^{\perp\, h/q}$

TMDJFFs for quarks.

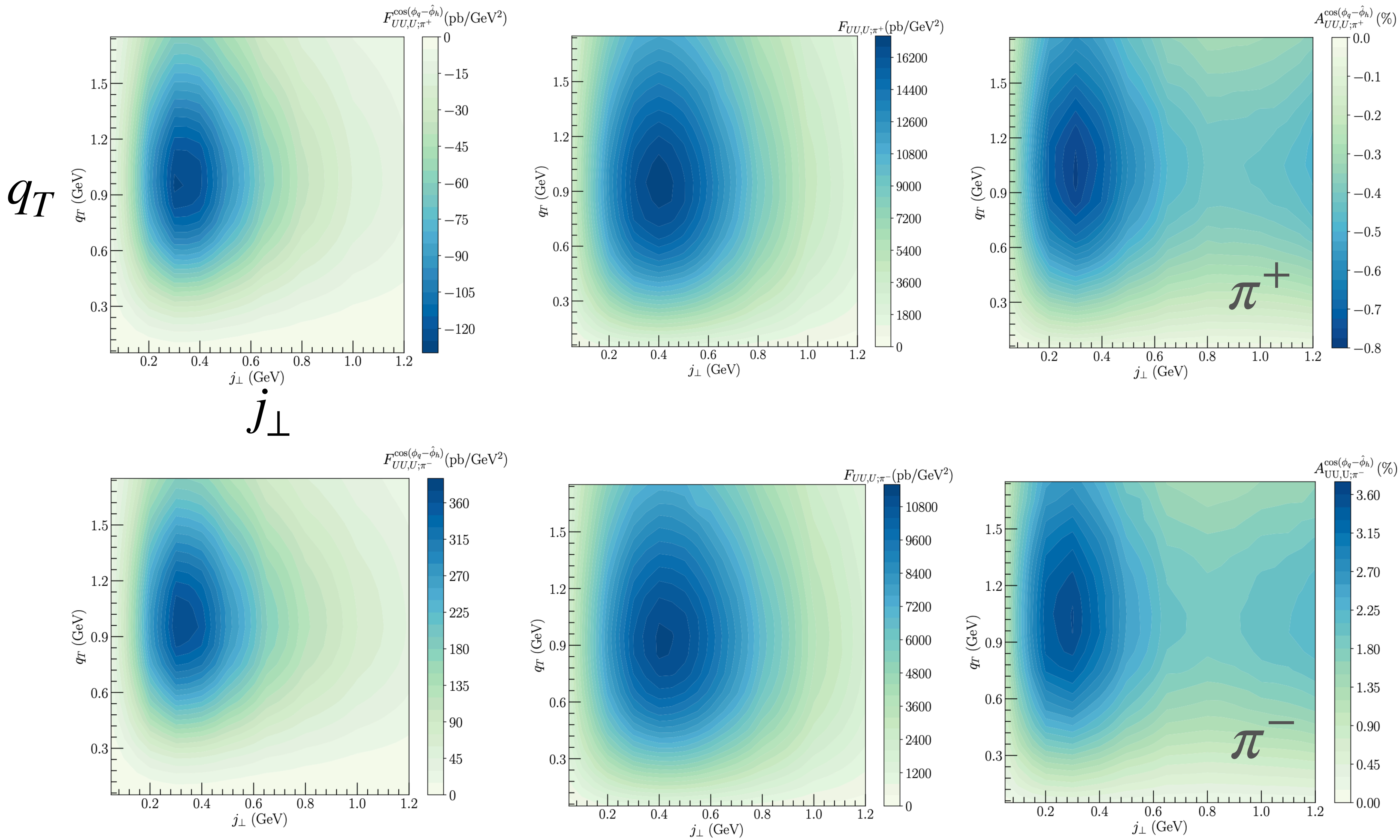
Example 2

$$\frac{d\sigma}{dp_T^2\, dy_J\, d^2\boldsymbol{q}_T\, dz_h\, d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cos(\phi_q - \hat{\phi}_h) F_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)}$$

$$F_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)} \sim h_1^\perp \otimes \mathcal{H}_1^{\perp\; h/q}$$

$$F_{UU,U} \sim f_1 \otimes \mathcal{D}_1^{h/q}$$

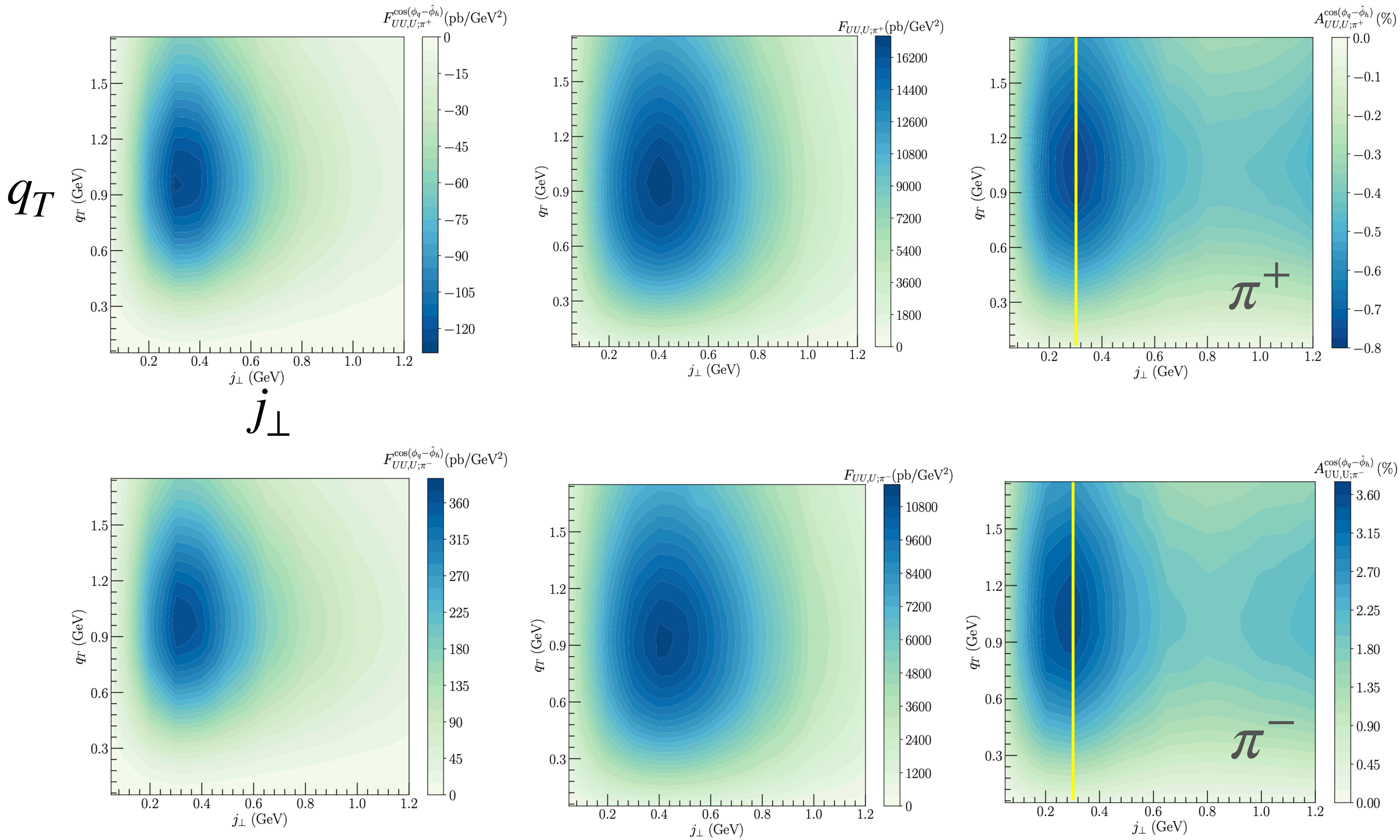
$$A_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)} = \frac{F_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)}}{F_{UU,U}}$$



Example 2

$$\frac{d\sigma}{dp_T^2\,dy_J\,d^2\boldsymbol{q}_T\,dz_h\,d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cos(\phi_q - \hat{\phi}_h)\,F_{UU,U}^{\cos(\phi_q-\hat{\phi}_h)}$$

$$F_{UU,U}^{\cos(\phi_q-\hat{\phi}_h)} \sim h_1^\perp \otimes \mathcal{H}_1^{\perp\ h/q} \qquad F_{UU,U} \sim f_1 \otimes \mathcal{D}_1^{h/q} \qquad A_{UU,U}^{\cos(\phi_q-\hat{\phi}_h)} = \frac{F_{UU,U}^{\cos(\phi_q-\hat{\phi}_h)}}{F_{UU,U}}$$



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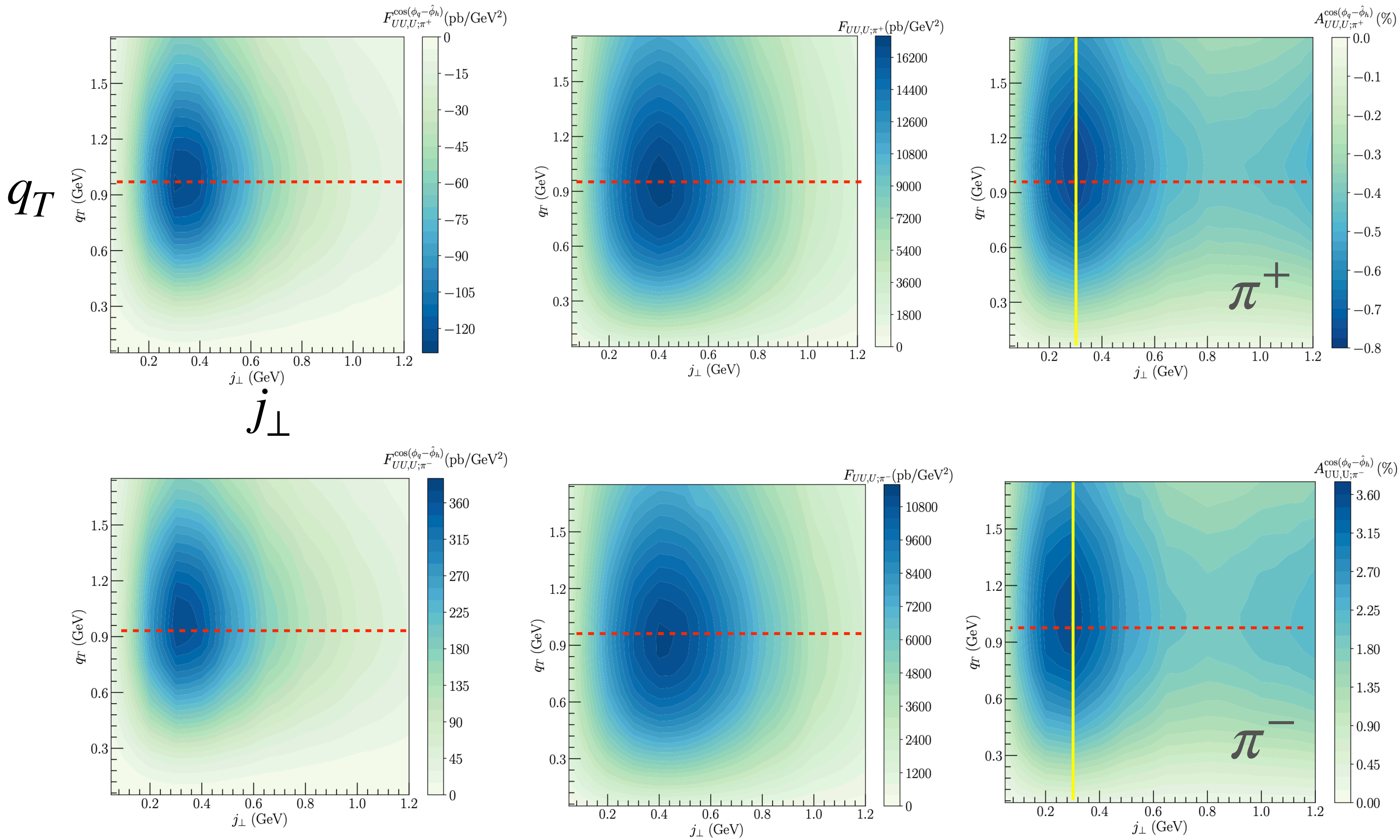

Example 2

$$\frac{d\sigma}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cos(\phi_q - \hat{\phi}_h) F_{UU,U}^{\cos(\phi_q - \hat{\phi}_h)}$$

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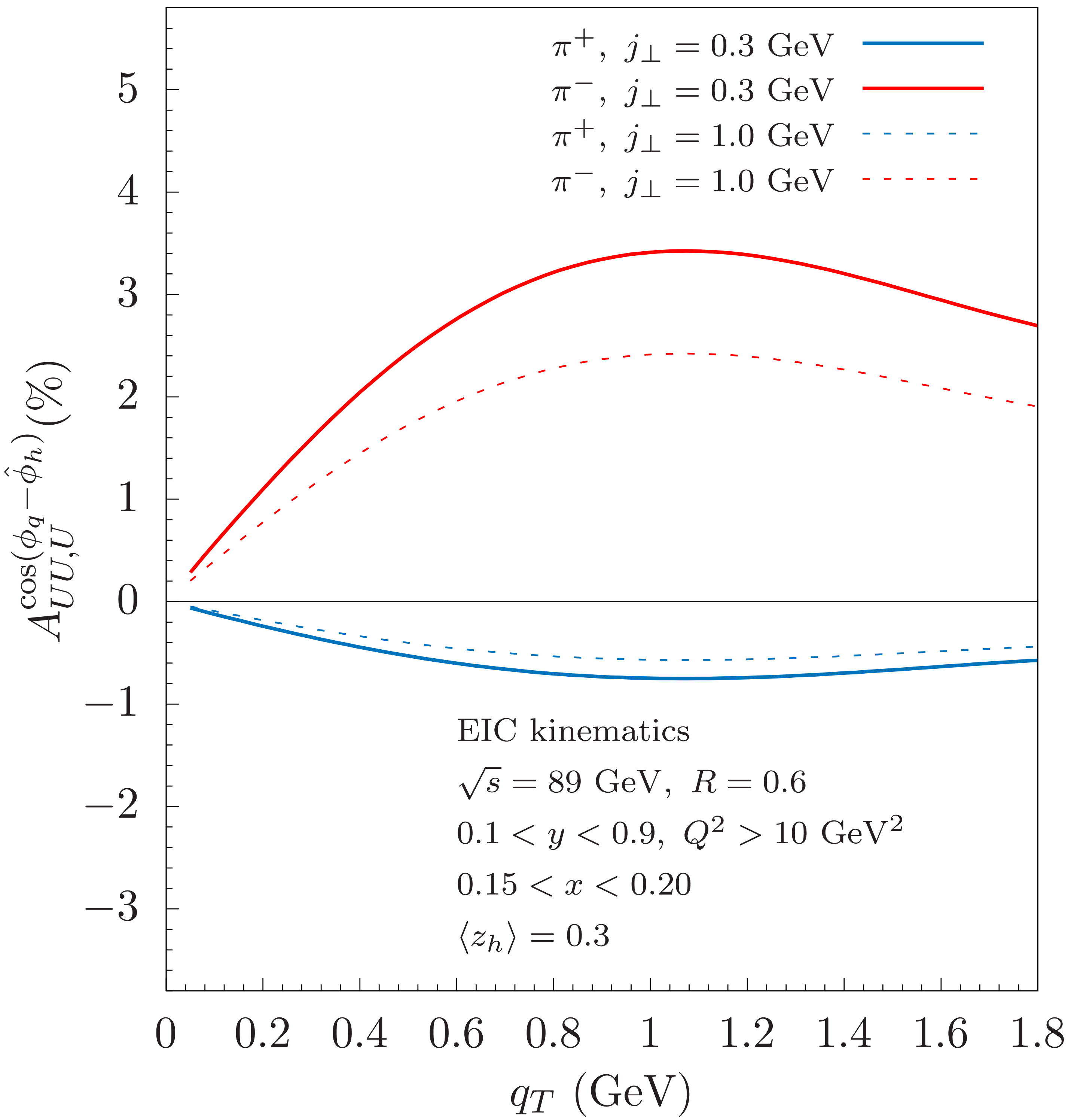

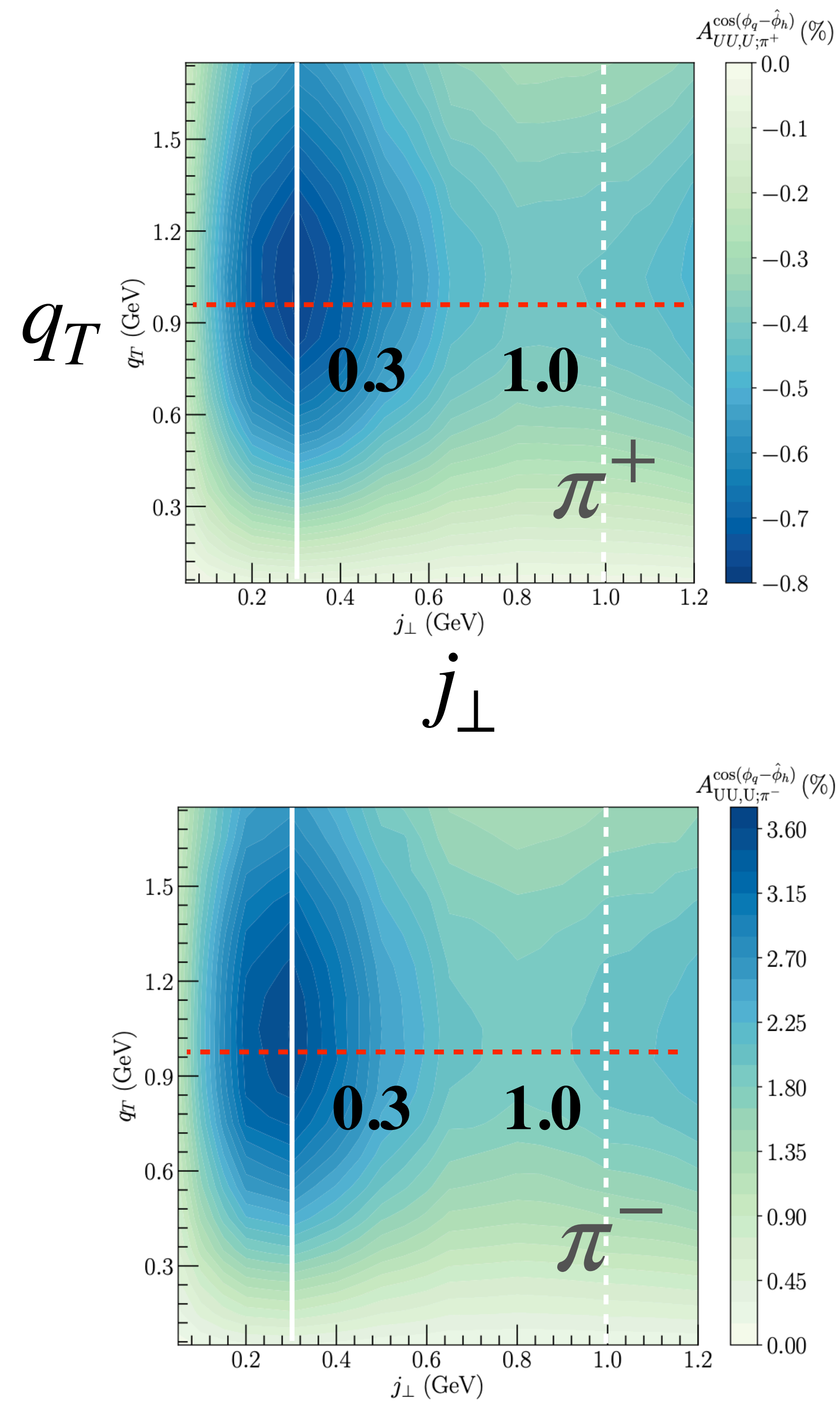

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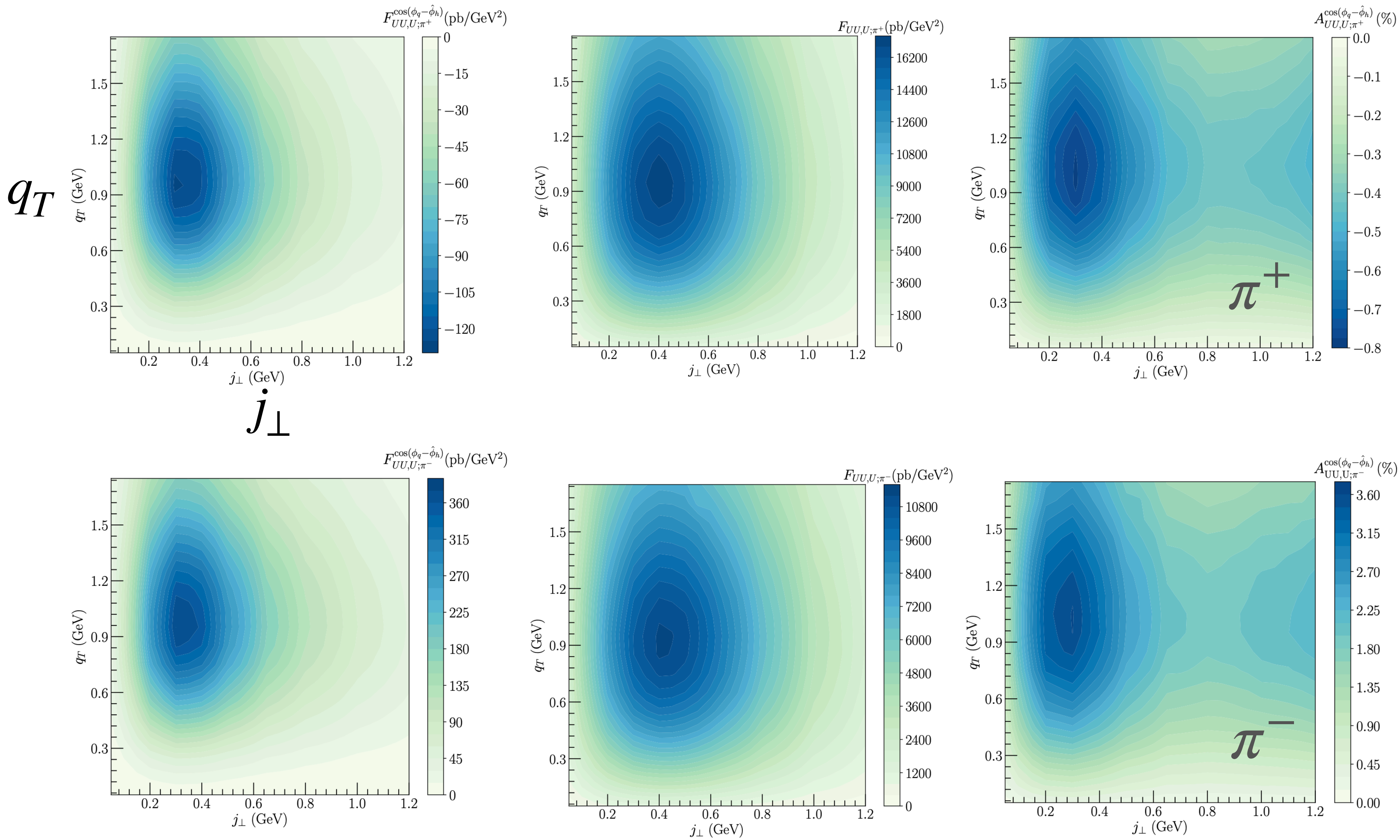

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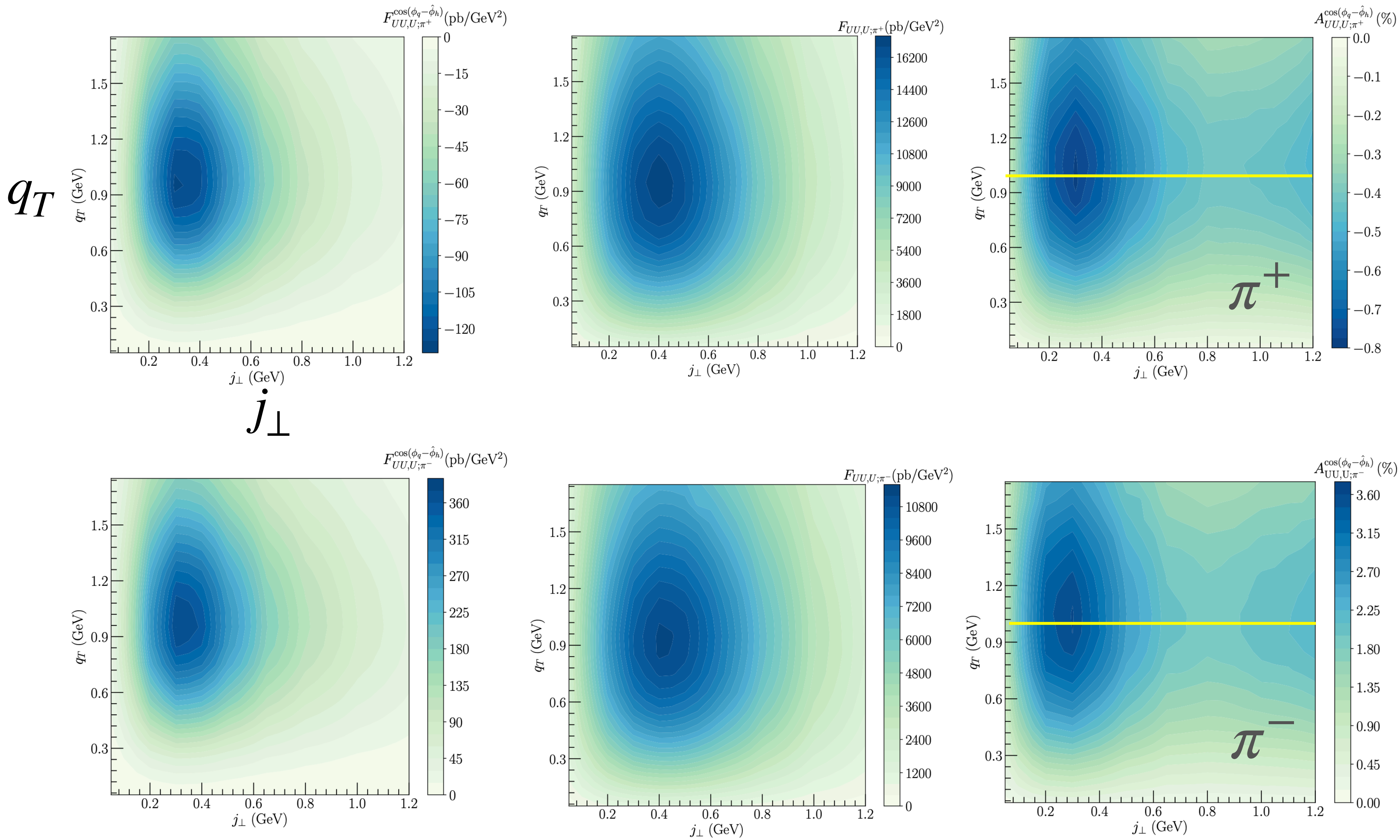

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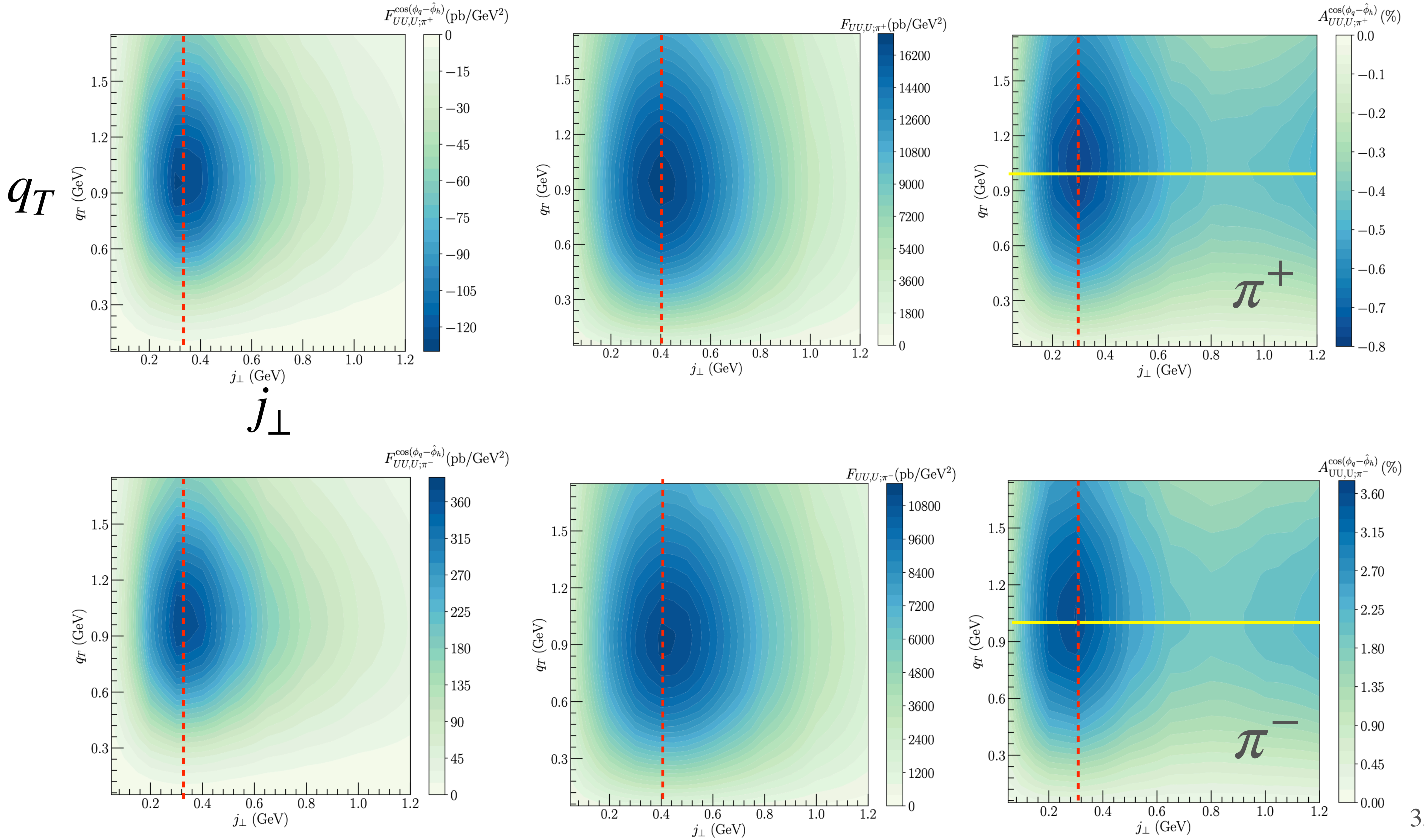

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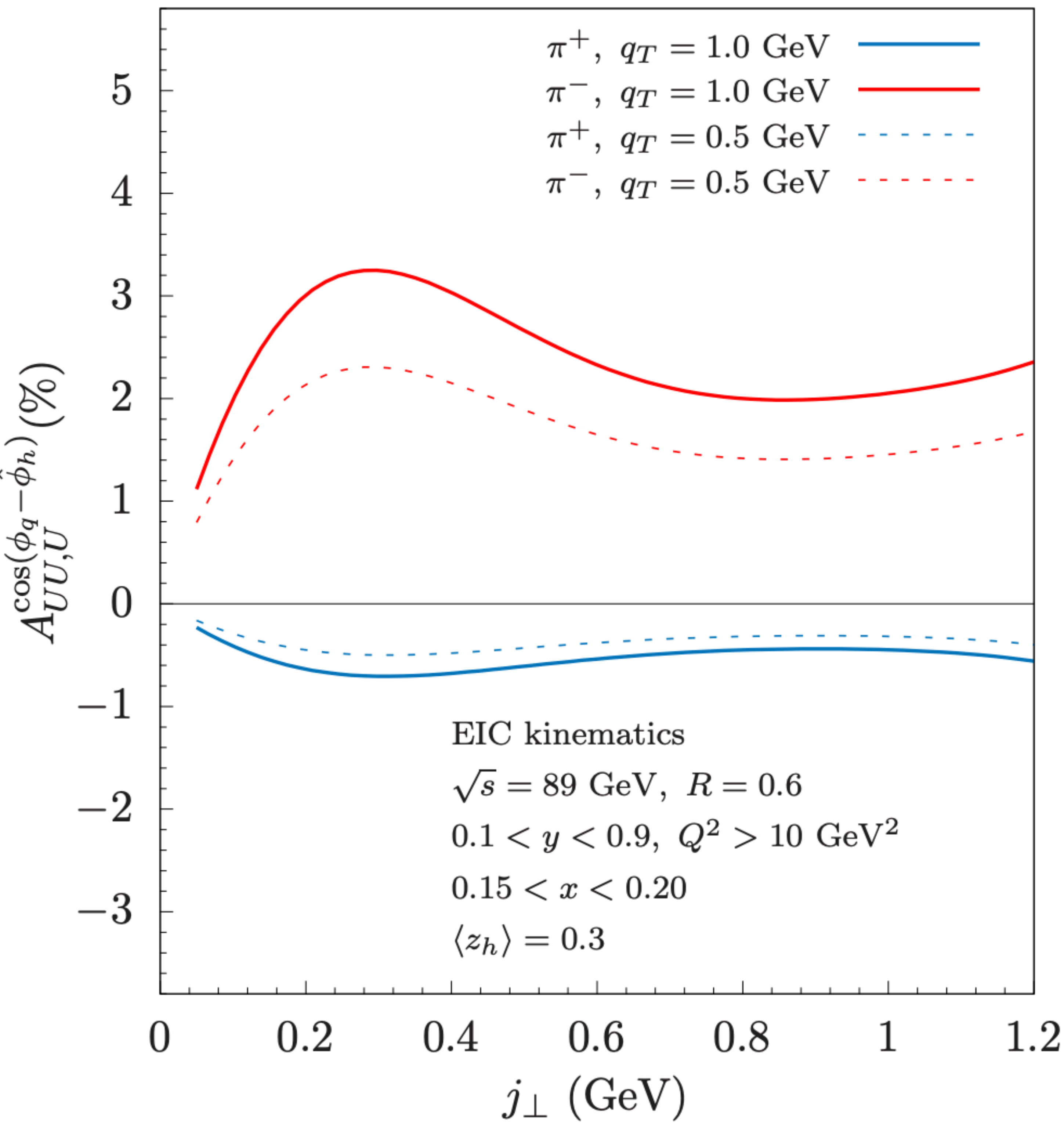
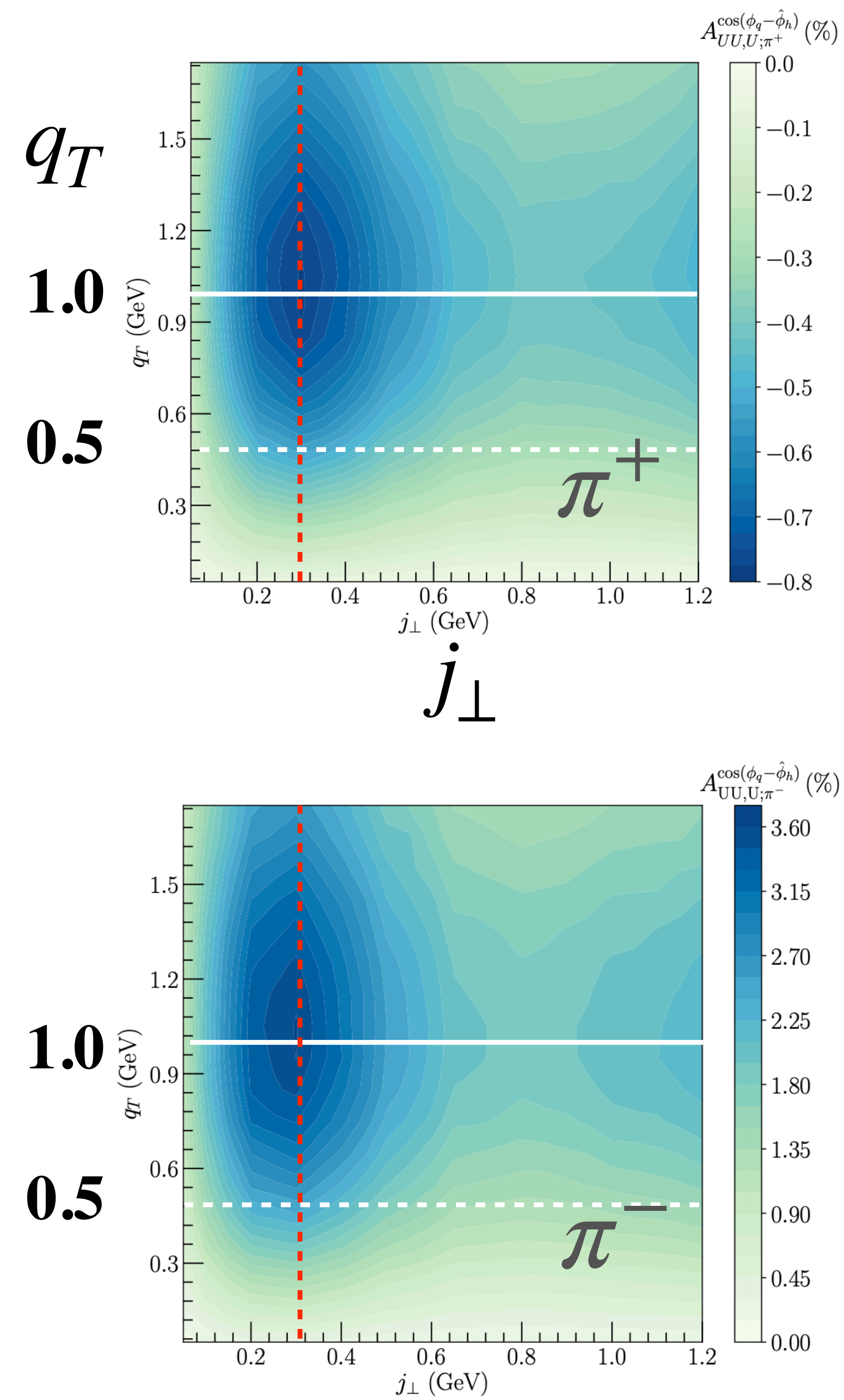




Overview

- Motivation
- Part I: $ep \to e + \text{jet} + X$

  Theoretical framework
  Example 1: Electron-jet production

- Part II: $ep \to e + \text{jet}(h) + X$

  Theoretical framework

  Example 2: Unpolarized $\pi^{\pm}$ in jet

  Example 3: Transversely polarized Λ in jet

- Summary & Outlook

Example 3

$$\frac{d\sigma}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cdots + S_{h\perp}\left\{\sin(\hat\phi_h - \hat\phi_{S_h}) F_{UU,T}^{\sin(\hat\phi_h - \hat\phi_{S_h})} + \cdots\right.$$

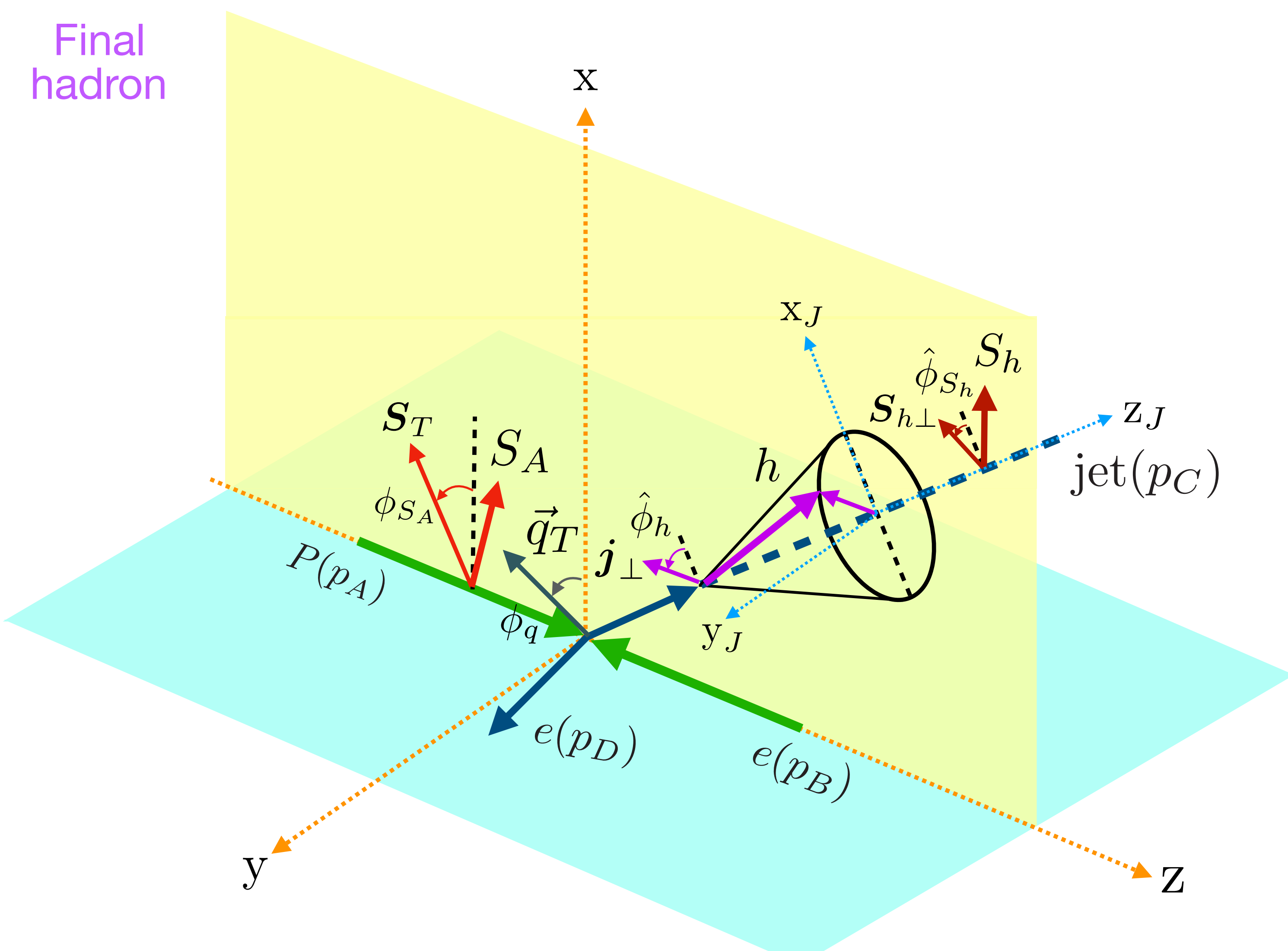
$$A_{UU,T}^{\sin(\hat\phi_h - \hat\phi_{S_h})} = \frac{F_{UU,T}^{\sin(\hat\phi_h - \hat\phi_{S_h})}}{F_{UU,U}}$$

$$ep \to e + \mathrm{jet}(h^\uparrow) + X$$

incoming proton

incoming electron

Final hadron



$$\frac{d\sigma}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cdots + S_{h\perp}\left\{ \sin(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})} + \cdots \right.$$

$$A_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})} = \frac{F_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})}}{F_{UU,U}}$$

$$F_{UU,U} \sim f_1 \otimes \mathcal{D}_1^{h/q}$$

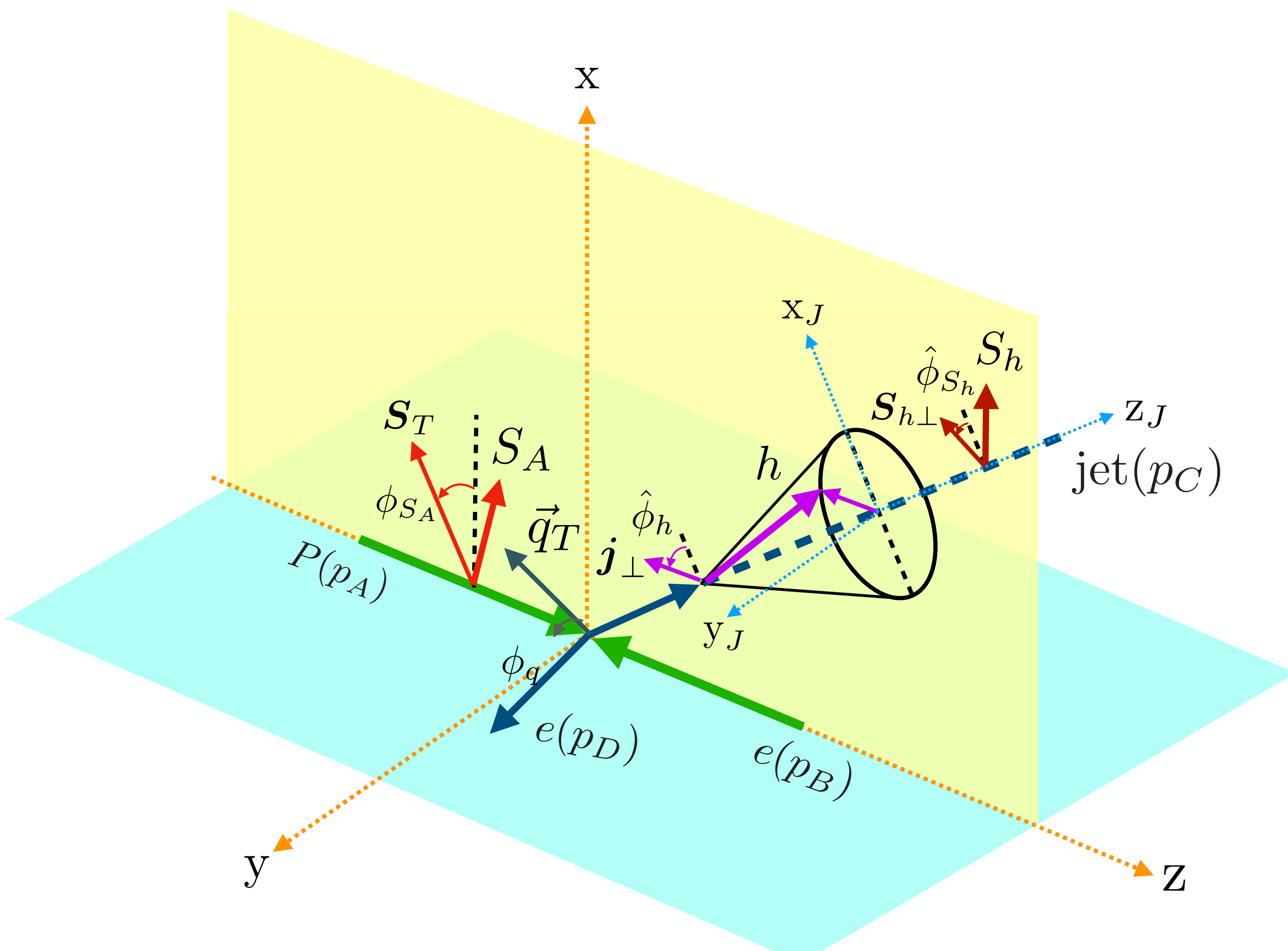
$$F_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})} \sim f_1 \otimes \mathcal{D}_{1T}^{\perp\, h/q}$$

match to

Unpolarized TMDPDF

Polarizing TMDFF

arXiv: [2003.04828]



$$ep \to e + \text{jet}(\Lambda^\uparrow) + X$$

h\ q	U	L	T
U	$\mathcal{D}_1^{h/q}$		$\mathcal{H}_1^{\perp\, h/q}$
L		$\mathcal{G}_{1L}^{h/q}$	$\mathcal{H}_{1L}^{\perp\, h/q}$
T	$\mathcal{D}_{1T}^{\perp\, h/q}$	$\mathcal{G}_{1T}^{h/q}$	$\mathcal{H}_1^{h/q}$, $\mathcal{H}_{1T}^{\perp\, h/q}$

TMDJFFs for quarks.

$$\frac{d\sigma}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cdots + S_{h\perp}\left\{\sin(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})} + \cdots\right.$$

$$F_{UU,U} \sim f_1 \otimes \mathcal{D}_1^{h/q}$$

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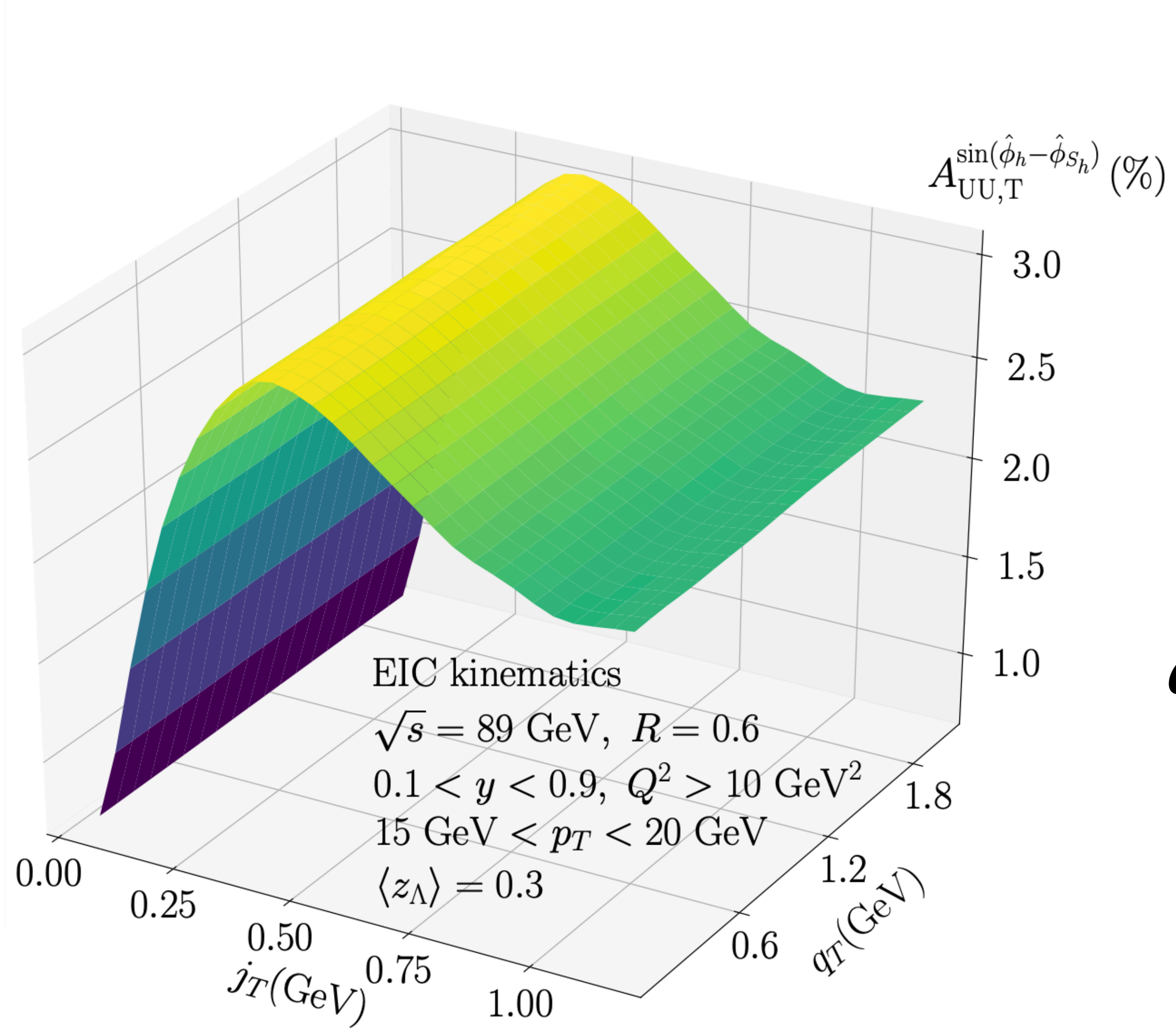
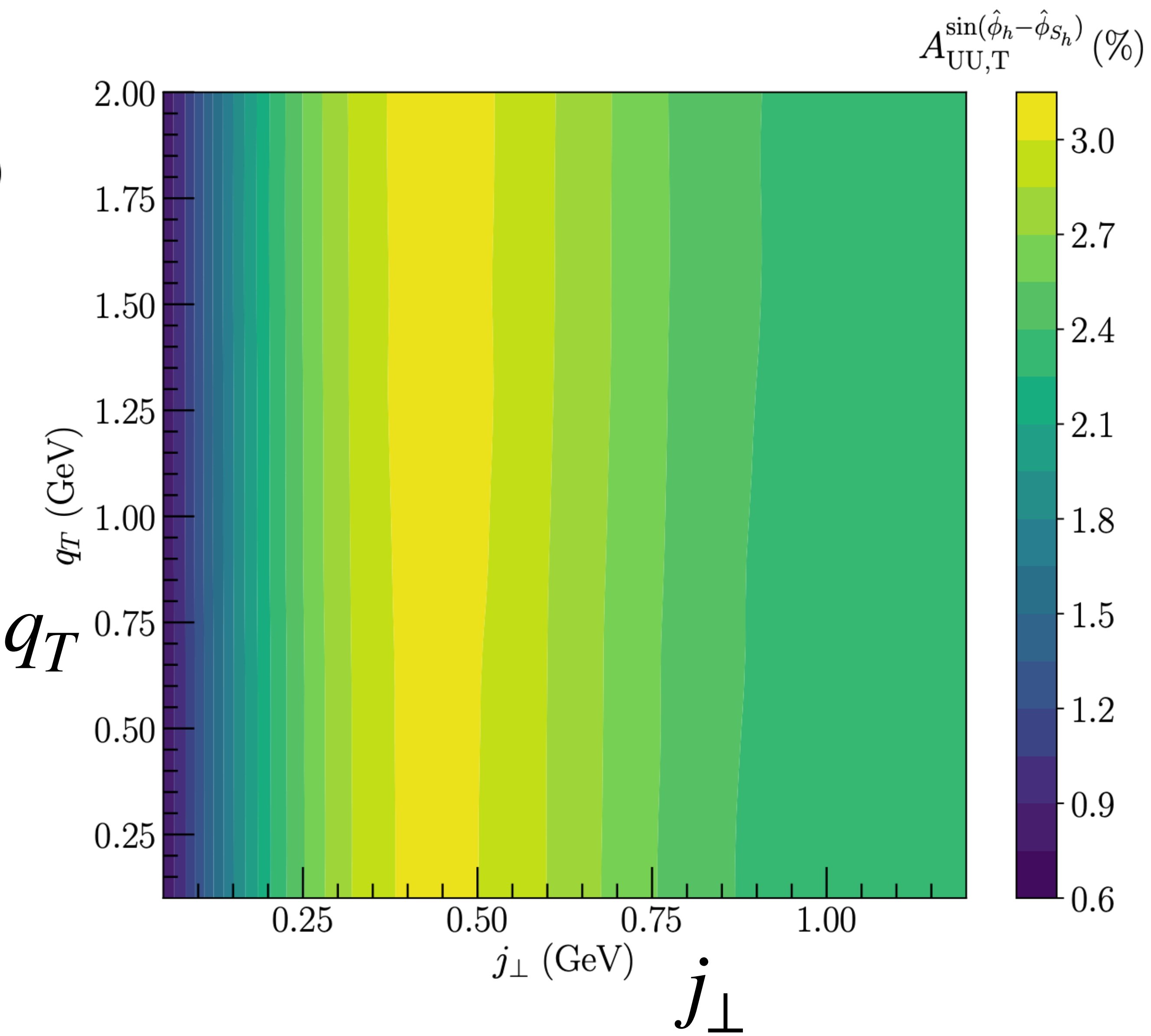


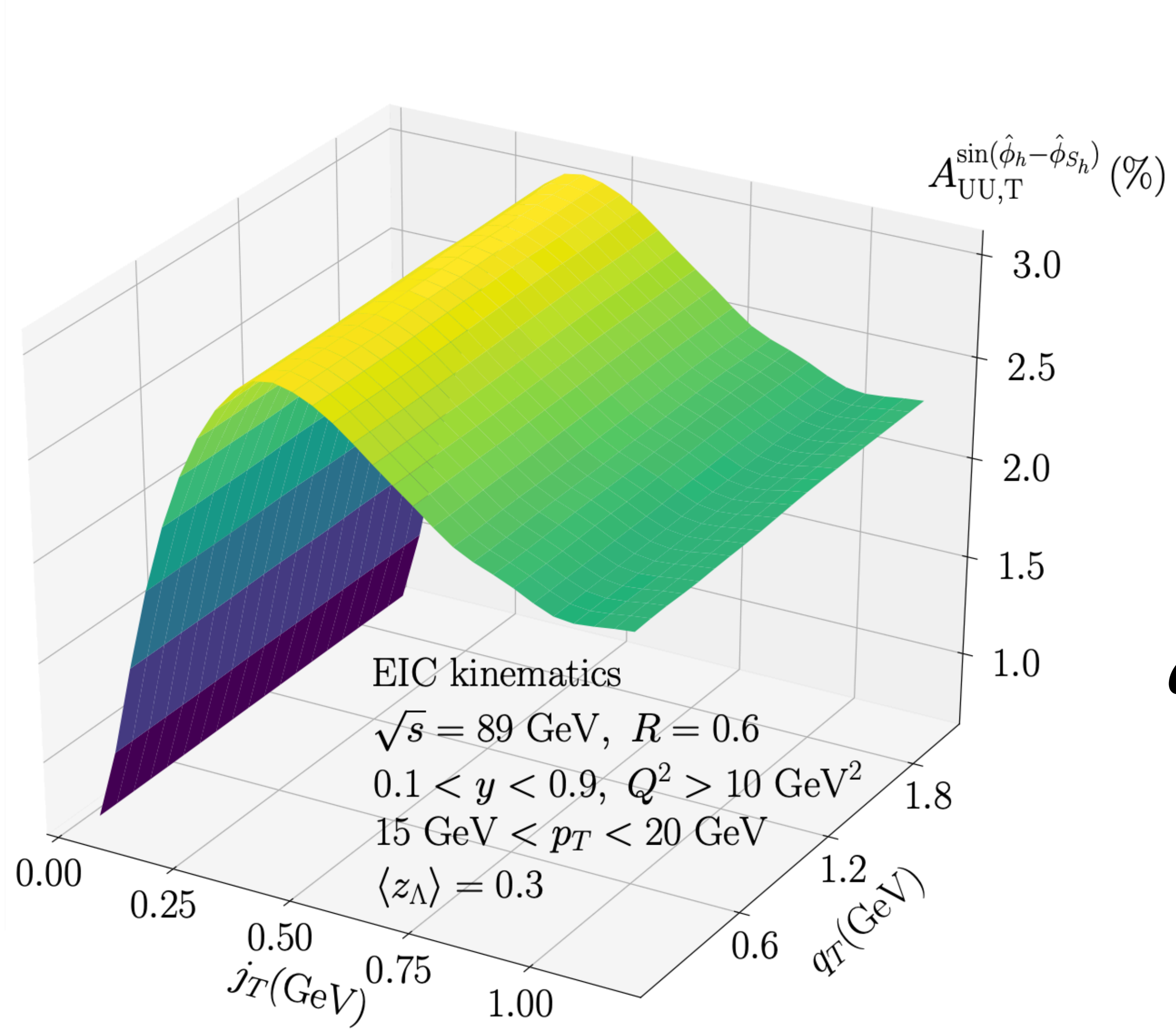


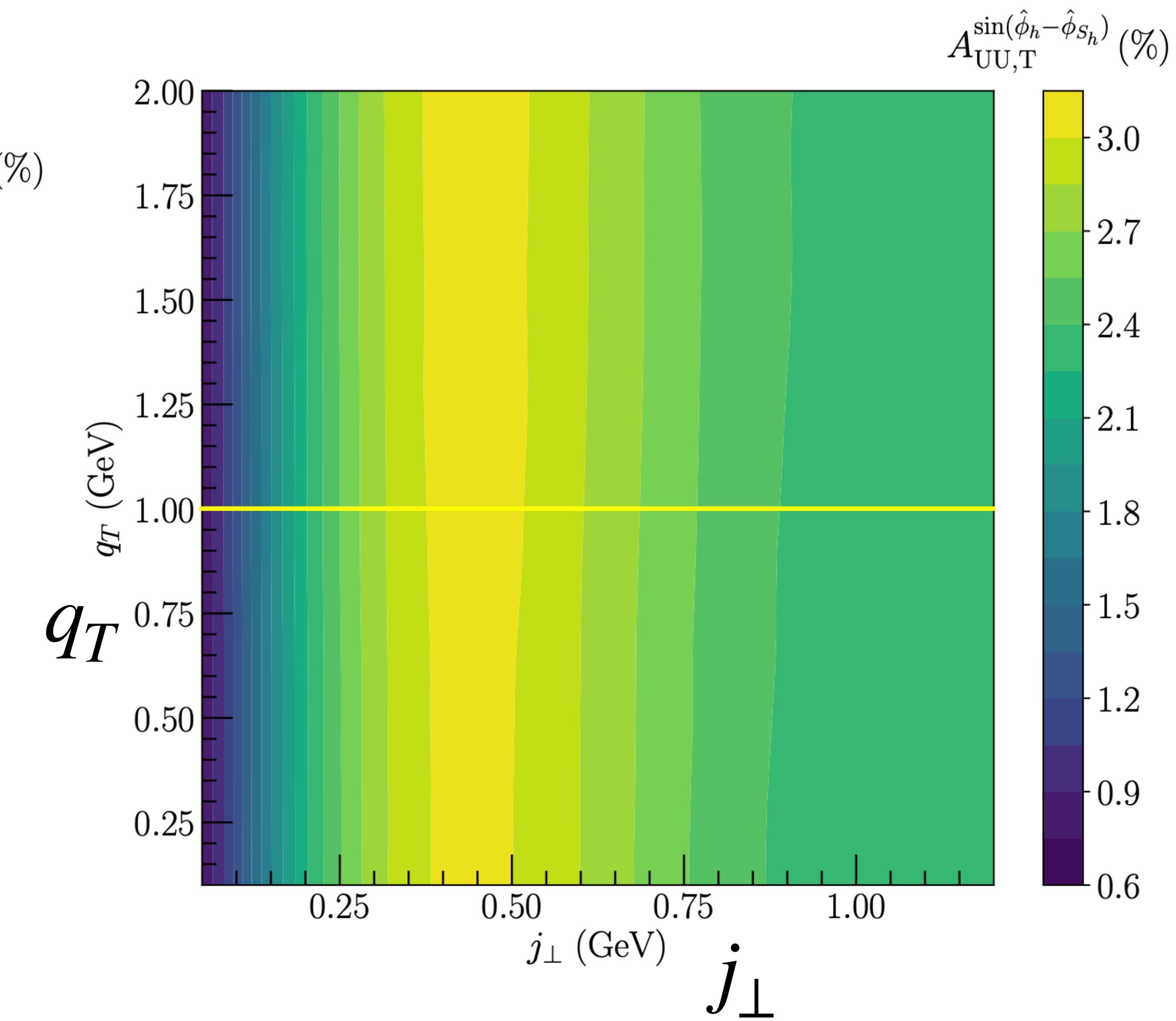
$$\frac{d\sigma}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cdots + S_{h\perp}\left\{\sin(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})} + \cdots\right.$$

$$F_{UU,U} \sim f_1 \otimes \mathcal{D}_1^{h/q}$$

$$F_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})} \sim f_1 \otimes \mathcal{D}_{1T}^{\perp\, h/q}$$

$$A_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})} = \frac{F_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})}}{F_{UU,U}}$$





Example 3

$$\frac{d\sigma}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cdots + S_{h\perp}\left\{\sin(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{UU,T}^{\sin(\hat{\phi}_h - \hat{\phi}_{S_h})} + \cdots\right.$$

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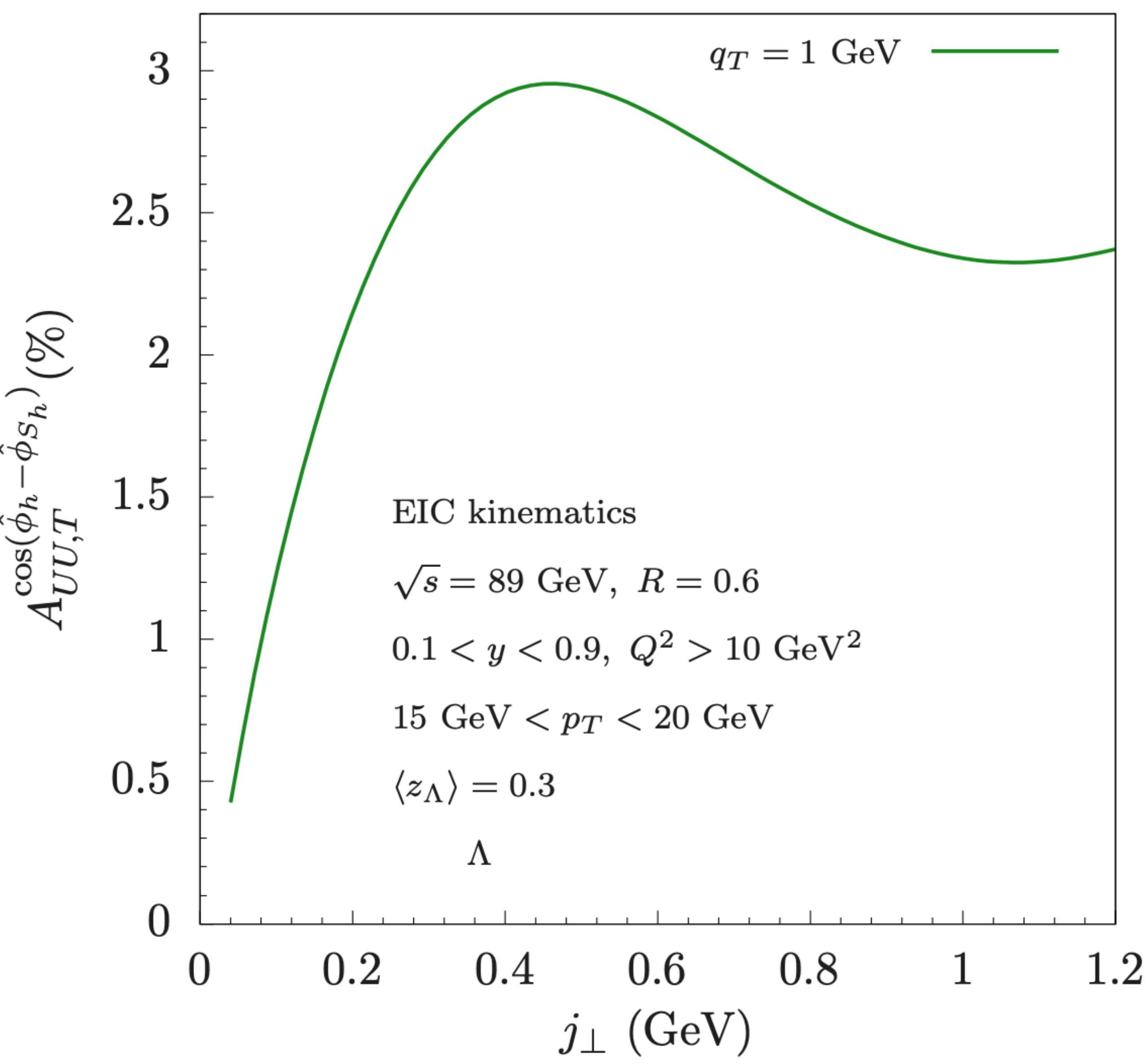
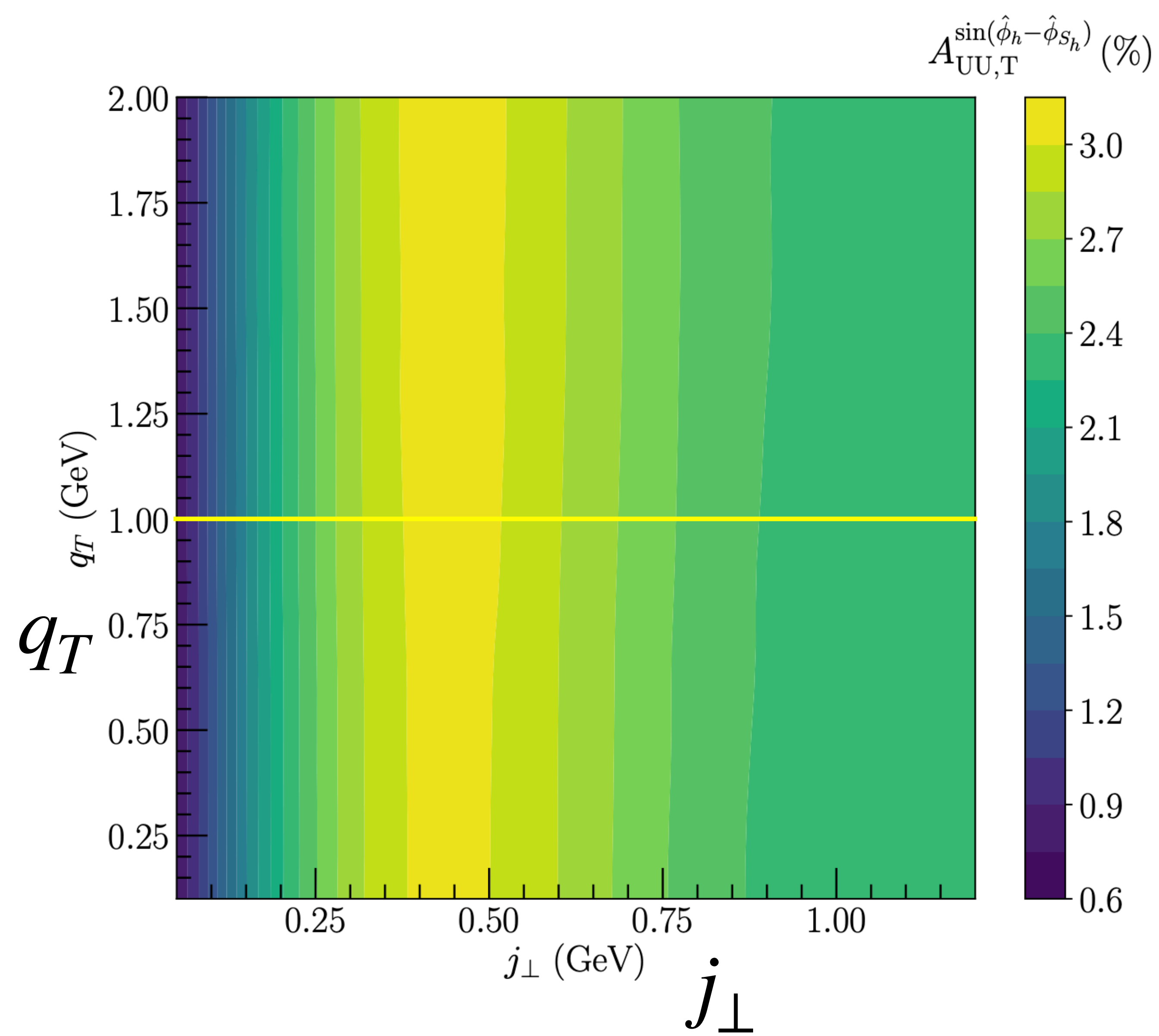
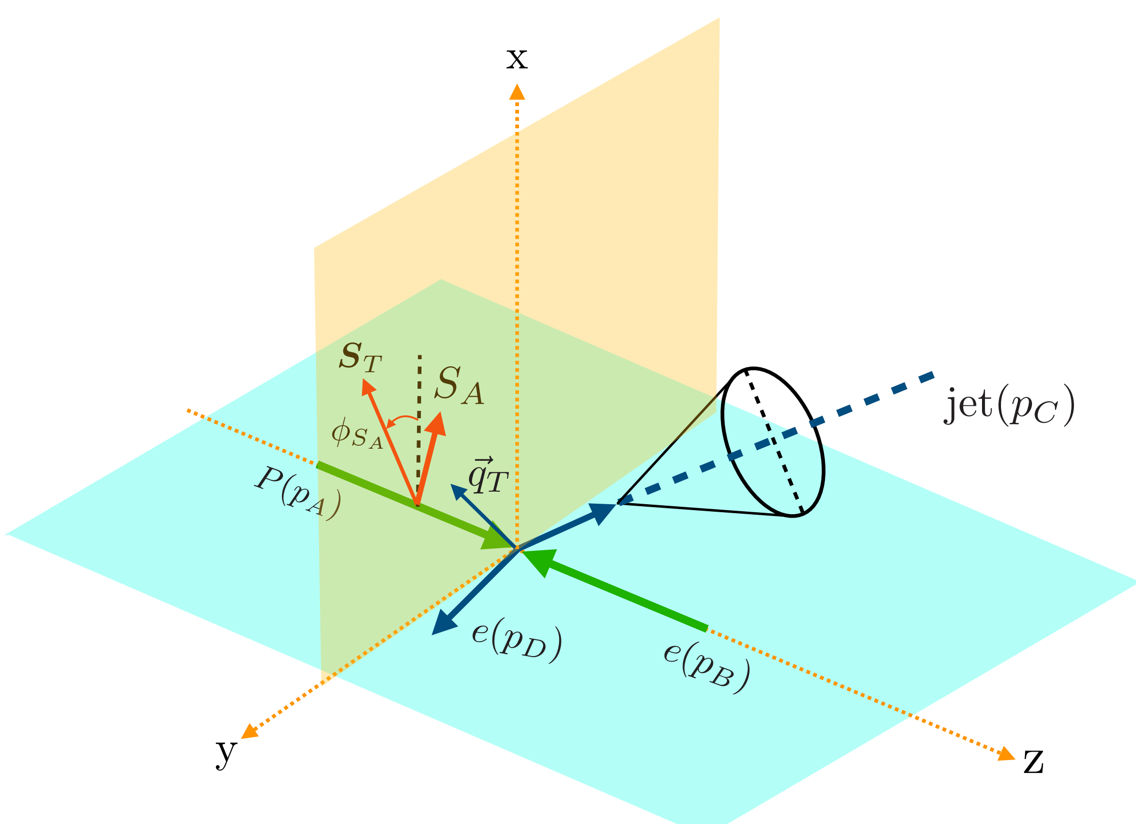
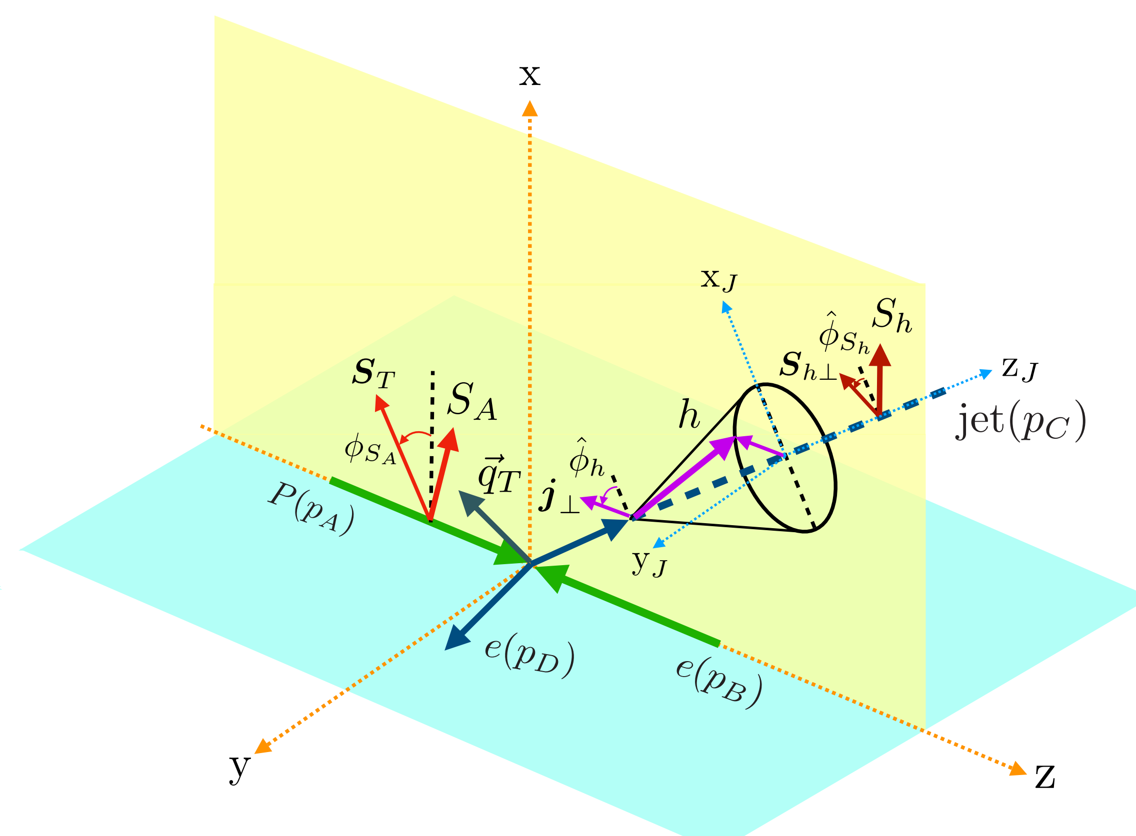




Summary & Outlook

- In summary, we have developed the theoretical framework for all spin asymmetries in back-to-back $e+\text{jet}$ and $e+\text{jet}(h)$ productions.
- Sizable asymmetry can be measured with EIC kinematics.
- Open new and exciting opportunities in the direction of studying spin-dependent hadron structures





$$\frac{d\sigma^{p(S_A)+e(\lambda_e)\to e+(\text{jet}\,h(S_h))+X}}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cos(\phi_q - \hat{\phi}_h) F_{UU,U}^{\cos(\phi_q-\hat{\phi}_h)}$$

$$+ \Lambda_p \Big\{ \lambda_e F_{LL,U} + \sin(\phi_q - \hat{\phi}_h) F_{LU,U}^{\sin(\phi_q-\hat{\phi}_h)} \Big\}$$

$$+ S_T \Big\{ \sin(\phi_q - \phi_{S_A}) F_{TU,U}^{\sin(\phi_q-\phi_{S_A})} + \lambda_e \cos(\phi_q - \phi_{S_A}) F_{TL,U}^{\cos(\phi_q-\phi_{S_A})}$$

$$+ \sin(\phi_{S_A} - \hat{\phi}_h) F_{TU,U}^{\sin(\phi_{S_A}-\hat{\phi}_h)} + \sin(2\phi_q - \hat{\phi}_h - \phi_{S_A}) F_{TU,U}^{\sin(2\phi_q-\hat{\phi}_h-\phi_{S_A})} \Big\}$$

$$+ \Lambda_h \Big\{ \lambda_e F_{UL,L} + \sin(\hat{\phi}_h - \phi_q) F_{UU,L}^{\sin(\hat{\phi}_h-\phi_q)} + \Lambda_p \Big[F_{LU,L} + \cos(\hat{\phi}_h - \phi_q) F_{LU,L}^{\cos(\hat{\phi}_h-\phi_q)} \Big]$$

$$+ S_T \Big[\cos(\phi_q - \phi_{S_A}) F_{TU,L}^{\cos(\phi_q-\phi_{S_A})} + \lambda_e \sin(\phi_q - \phi_{S_A}) F_{TL,L}^{\sin(\phi_q-\phi_{S_A})}$$

$$+ \cos(\phi_{S_A} - \hat{\phi}_h) F_{TU,L}^{\cos(\phi_{S_A}-\hat{\phi}_h)} + \cos(2\phi_q - \phi_{S_A} - \hat{\phi}_h) F_{TU,L}^{\cos(2\phi_q-\phi_{S_A}-\hat{\phi}_h)} \Big] \Big\}$$

$$+ S_{h\perp} \Big\{ \sin(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{UU,T}^{\sin(\hat{\phi}_h-\hat{\phi}_{S_h})} + \lambda_e \cos(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{UL,T}^{\cos(\hat{\phi}_h-\hat{\phi}_{S_h})}$$

$$+ \sin(\hat{\phi}_{S_h} - \phi_q) F_{UU,T}^{\sin(\hat{\phi}_{S_h}-\phi_q)} + \sin(2\hat{\phi}_h - \hat{\phi}_{S_h} - \phi_q) F_{UU,T}^{\sin(2\hat{\phi}_h-\hat{\phi}_{S_h}-\phi_q)}$$

$$+ \Lambda_p \Big[\cos(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{LU,T}^{\cos(\hat{\phi}_h-\hat{\phi}_{S_h})} + \cos(\phi_q - \hat{\phi}_{S_h}) F_{LU,T}^{\cos(\phi_q-\hat{\phi}_{S_h})}$$

$$+ \cos(2\hat{\phi}_h - \hat{\phi}_{S_h} - \phi_q) F_{LU,T}^{\cos(2\hat{\phi}_h-\hat{\phi}_{S_h}-\phi_q)} + \lambda_e \sin(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{LL,T}^{\sin(\hat{\phi}_h-\hat{\phi}_{S_h})} \Big]$$

$$+ S_T \Big[\cos(\phi_{S_A} - \hat{\phi}_{S_h}) F_{TU,T}^{\cos(\phi_{S_A}-\hat{\phi}_{S_h})} + \cos(2\hat{\phi}_h - \hat{\phi}_{S_h} - \phi_{S_A}) F_{TU,T}^{\cos(2\hat{\phi}_h-\hat{\phi}_{S_h}-\phi_{S_A})}$$

$$+ \sin(\hat{\phi}_h - \hat{\phi}_{S_h}) \sin(\phi_q - \phi_{S_A}) F_{TU,T}^{\sin(\hat{\phi}_h-\hat{\phi}_{S_h})\sin(\phi_q-\phi_{S_A})}$$

$$+ \cos(\hat{\phi}_h - \hat{\phi}_{S_h}) \cos(\phi_q - \phi_{S_A})) F_{TU,T}^{\cos(\hat{\phi}_h-\hat{\phi}_{S_h})\cos(\phi_q-\phi_{S_A})}$$

$$+ \cos(2\phi_q - \phi_{S_A} - \hat{\phi}_{S_h}) F_{TU,T}^{\cos(2\phi_q-\phi_{S_A}-\hat{\phi}_{S_h})}$$

$$+ \cos(2\hat{\phi}_h - \hat{\phi}_{S_h} + 2\phi_q - \phi_{S_A}) F_{TU,T}^{\cos(2\hat{\phi}_h-\hat{\phi}_{S_h}+2\phi_q-\phi_{S_A})}$$

$$+ \lambda_e \cos(\hat{\phi}_h - \hat{\phi}_{S_h}) \sin(\phi_{S_A} - \phi_q) F_{TL,T}^{\cos(\hat{\phi}_h-\hat{\phi}_{S_h})\sin(\phi_{S_A}-\phi_q)}$$

$$+ \lambda_e \sin(\hat{\phi}_h - \hat{\phi}_{S_h}) \cos(\phi_{S_A} - \phi_q)) F_{TL,T}^{\sin(\hat{\phi}_h-\hat{\phi}_{S_h})\cos(\phi_{S_A}-\phi_q)} \Big] \Big\}$$

Thank you

Back up

TMDJFFs

$$
\begin{aligned}
&\frac{d\sigma^{p(S_A)+e(\lambda_e)\to e+(\mathrm{jet}\,h(S_h))+X}}{dp_T^2 dy_J d^2\boldsymbol{q}_T dz_h d^2\boldsymbol{j}_\perp} = F_{UU,U} + \cos(\phi_q - \hat{\phi}_h) F_{UU,U}^{\cos(\phi_q-\hat{\phi}_h)} \\
&+ \Lambda_p \Big\{ \lambda_e F_{LL,U} + \sin(\phi_q - \hat{\phi}_h) F_{LU,U}^{\sin(\phi_q-\hat{\phi}_h)} \Big\} \\
&+ S_T \Big\{ \sin(\phi_q - \phi_{S_A}) F_{TU,U}^{\sin(\phi_q-\phi_{S_A})} + \lambda_e \cos(\phi_q - \phi_{S_A}) F_{TL,U}^{\cos(\phi_q-\phi_{S_A})} \\
&\quad + \sin(\phi_{S_A} - \hat{\phi}_h) F_{TU,U}^{\sin(\phi_{S_A}-\hat{\phi}_h)} + \sin(2\phi_q - \hat{\phi}_h - \phi_{S_A}) F_{TU,U}^{\sin(2\phi_q-\hat{\phi}_h-\phi_{S_A})} \Big\} \\
&+ \Lambda_h \Big\{ \lambda_e F_{UL,L} + \sin(\hat{\phi}_h - \phi_q) F_{UU,L}^{\sin(\hat{\phi}_h-\phi_q)} + \Lambda_p \Big[F_{LU,L} + \cos(\hat{\phi}_h - \phi_q) F_{LU,L}^{\cos(\hat{\phi}_h-\phi_q)} \Big] \\
&\quad + S_T \Big[\cos(\phi_q - \phi_{S_A}) F_{TU,L}^{\cos(\phi_q-\phi_{S_A})} + \lambda_e \sin(\phi_q - \phi_{S_A}) F_{TL,L}^{\sin(\phi_q-\phi_{S_A})} \\
&\quad + \cos(\phi_{S_A} - \hat{\phi}_h) F_{TU,L}^{\cos(\phi_{S_A}-\hat{\phi}_h)} + \cos(2\phi_q - \phi_{S_A} - \hat{\phi}_h) F_{TU,L}^{\cos(2\phi_q-\phi_{S_A}-\hat{\phi}_h)} \Big] \Big\} \\
&+ S_{h\perp} \Big\{ \sin(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{UU,T}^{\sin(\hat{\phi}_h-\hat{\phi}_{S_h})} + \lambda_e \cos(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{UL,T}^{\cos(\hat{\phi}_h-\hat{\phi}_{S_h})} \\
&\quad + \sin(\hat{\phi}_{S_h} - \phi_q) F_{UU,T}^{\sin(\hat{\phi}_{S_h}-\phi_q)} + \sin(2\hat{\phi}_h - \hat{\phi}_{S_h} - \phi_q) F_{UU,T}^{\sin(2\hat{\phi}_h-\hat{\phi}_{S_h}-\phi_q)} \\
&\quad + \Lambda_p \Big[\cos(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{LU,T}^{\cos(\hat{\phi}_h-\hat{\phi}_{S_h})} + \cos(\phi_q - \hat{\phi}_{S_h}) F_{LU,T}^{\cos(\phi_q-\hat{\phi}_{S_h})} \\
&\qquad + \cos(2\hat{\phi}_h - \hat{\phi}_{S_h} - \phi_q) F_{LU,T}^{\cos(2\hat{\phi}_h-\hat{\phi}_{S_h}-\phi_q)} + \lambda_e \sin(\hat{\phi}_h - \hat{\phi}_{S_h}) F_{LL,T}^{\sin(\hat{\phi}_h-\hat{\phi}_{S_h})} \Big] \\
&\quad + S_T \Big[\cos(\phi_{S_A} - \hat{\phi}_{S_h}) F_{TU,T}^{\cos(\phi_{S_A}-\hat{\phi}_{S_h})} + \cos(2\hat{\phi}_h - \hat{\phi}_{S_h} - \phi_{S_A}) F_{TU,T}^{\cos(2\hat{\phi}_h-\hat{\phi}_{S_h}-\phi_{S_A})} \\
&\quad + \sin(\hat{\phi}_h - \hat{\phi}_{S_h}) \sin(\phi_q - \phi_{S_A}) F_{TU,T}^{\sin(\hat{\phi}_h-\hat{\phi}_{S_h})\sin(\phi_q-\phi_{S_A})} \\
&\quad + \cos(\hat{\phi}_h - \hat{\phi}_{S_h}) \cos(\phi_q - \phi_{S_A})) F_{TU,T}^{\cos(\hat{\phi}_h-\hat{\phi}_{S_h})\cos(\phi_q-\phi_{S_A})} \\
&\quad + \cos(2\phi_q - \phi_{S_A} - \hat{\phi}_{S_h}) F_{TU,T}^{\cos(2\phi_q-\phi_{S_A}-\hat{\phi}_{S_h})} \\
&\qquad + \cos(2\hat{\phi}_h - \hat{\phi}_{S_h} + 2\phi_q - \phi_{S_A}) F_{TU,T}^{\cos(2\hat{\phi}_h-\hat{\phi}_{S_h}+2\phi_q-\phi_{S_A})} \\
&\quad + \lambda_e \cos(\hat{\phi}_h - \hat{\phi}_{S_h}) \sin(\phi_{S_A} - \phi_q) F_{TL,T}^{\cos(\hat{\phi}_h-\hat{\phi}_{S_h})\sin(\phi_{S_A}-\phi_q)} \\
&\quad + \lambda_e \sin(\hat{\phi}_h - \hat{\phi}_{S_h}) \cos(\phi_{S_A} - \phi_q)) F_{TL,T}^{\sin(\hat{\phi}_h-\hat{\phi}_{S_h})\cos(\phi_{S_A}-\phi_q)} \Big] \Big\},
\end{aligned}
$$

$$ep \to e + \mathrm{jet}(h) + X$$

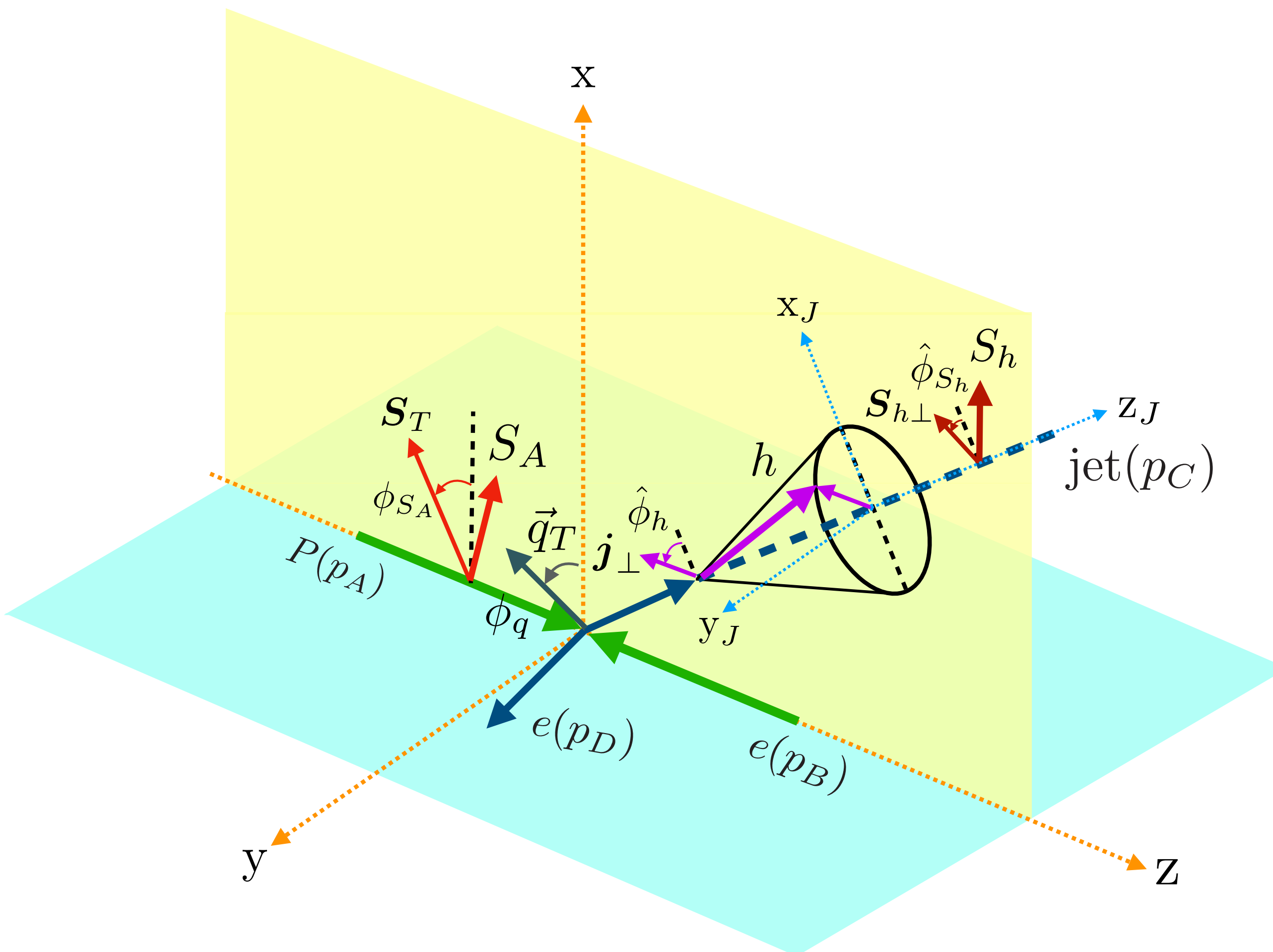


Illustration for the distribution of hadrons inside jets produced with an electron in the collisions of a polarized proton and en electron.