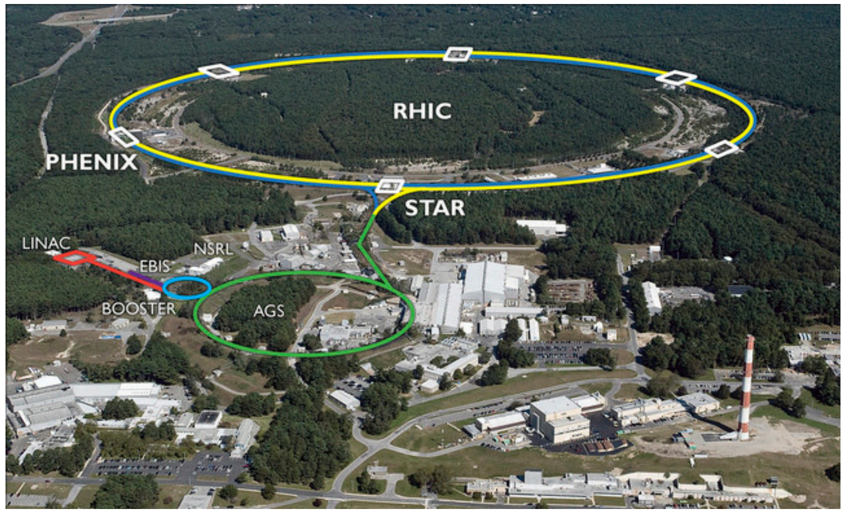
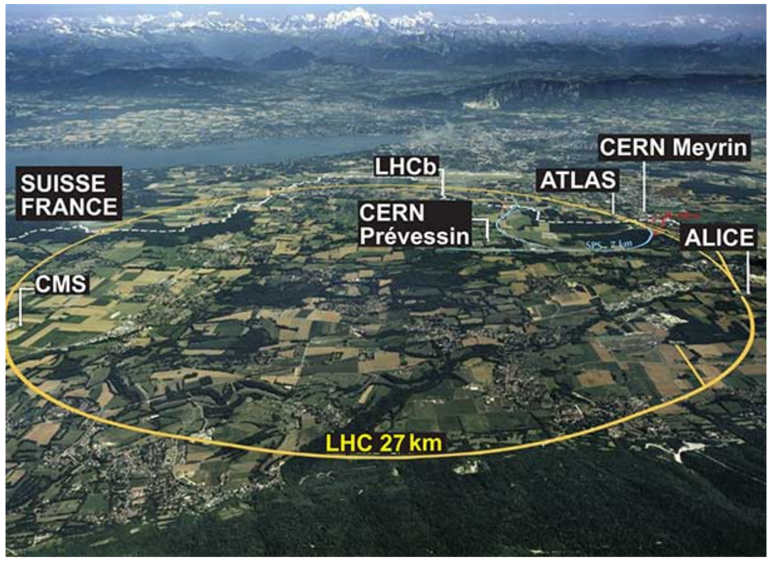
Overview of measurements of hard exclusive processes

Charlotte Van Hulse
University College Dublin – UCD

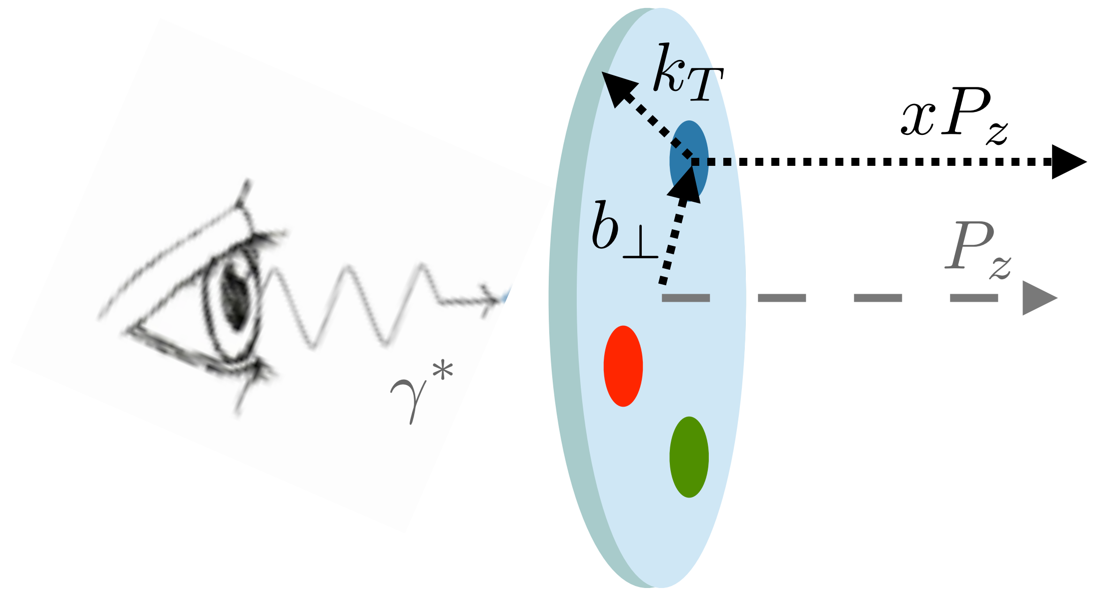




Spectroscopy program at EIC and future accelerators
19-21 December, 2018
ECT*, Trento

Structure of the nucleon

Wigner distributions $W(x, \vec{k}_T, \vec{b}_\perp)$



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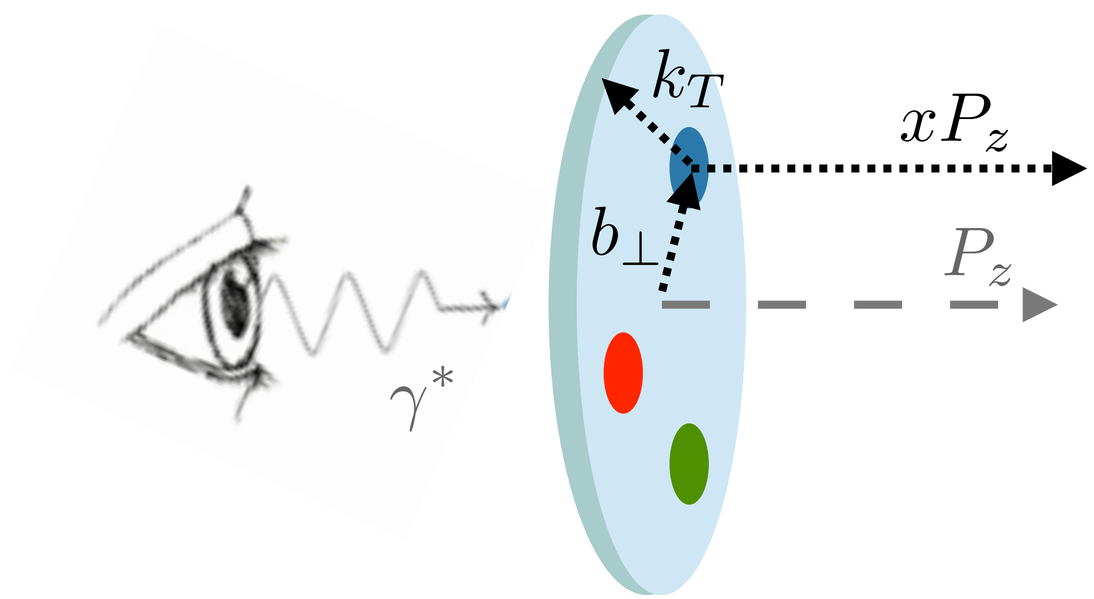
$\int d^2\vec{k}_T$

impact-parameter distributions



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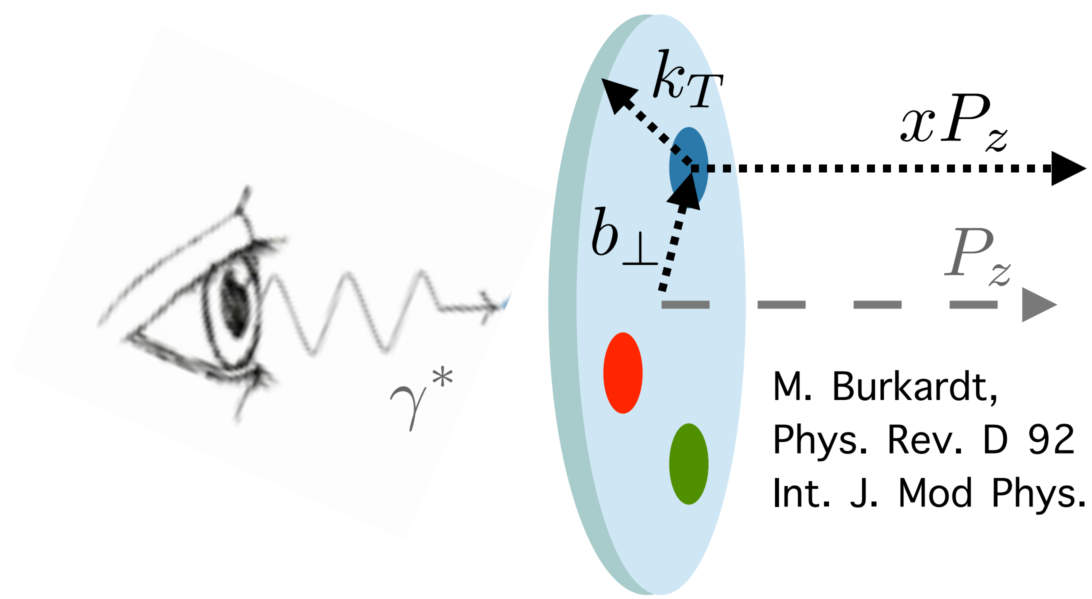

impact-parameter distributions

M. Burkardt,
Phys. Rev. D 92 (2000) 071503
Int. J. Mod Phys. A 18 (2003) 173

Fourier transform

generalized parton distributions (GPDs)

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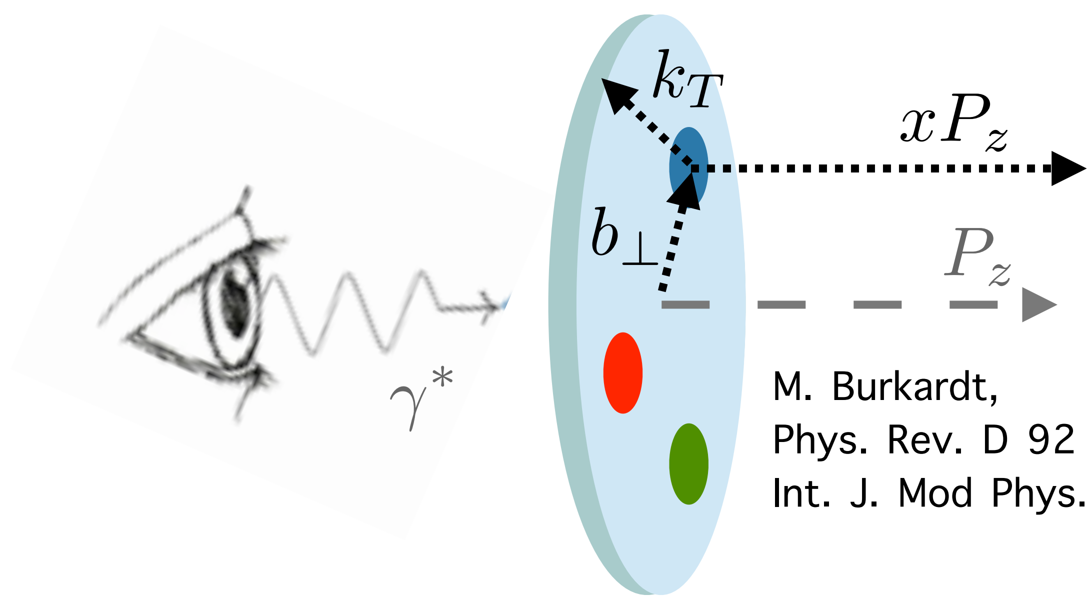

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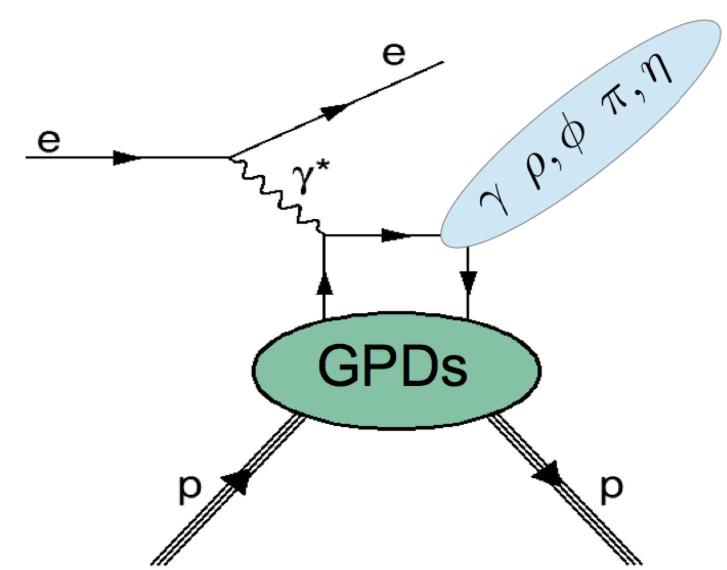
$\int d^2\vec{k}_T$

impact-parameter distributions

Fourier transform

generalized parton distributions (GPDs)

hard exclusive reactions



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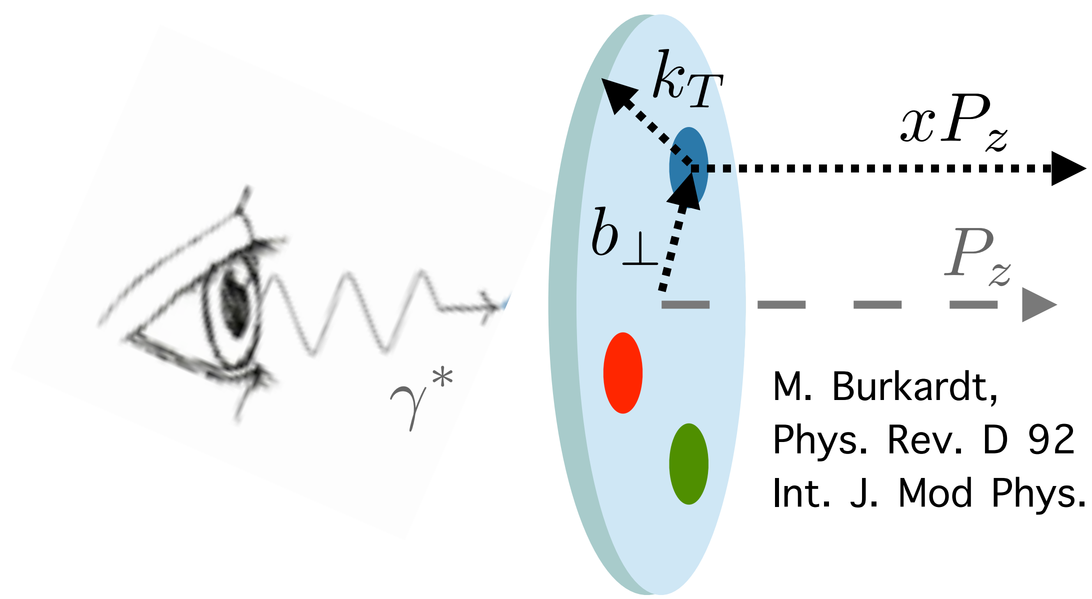

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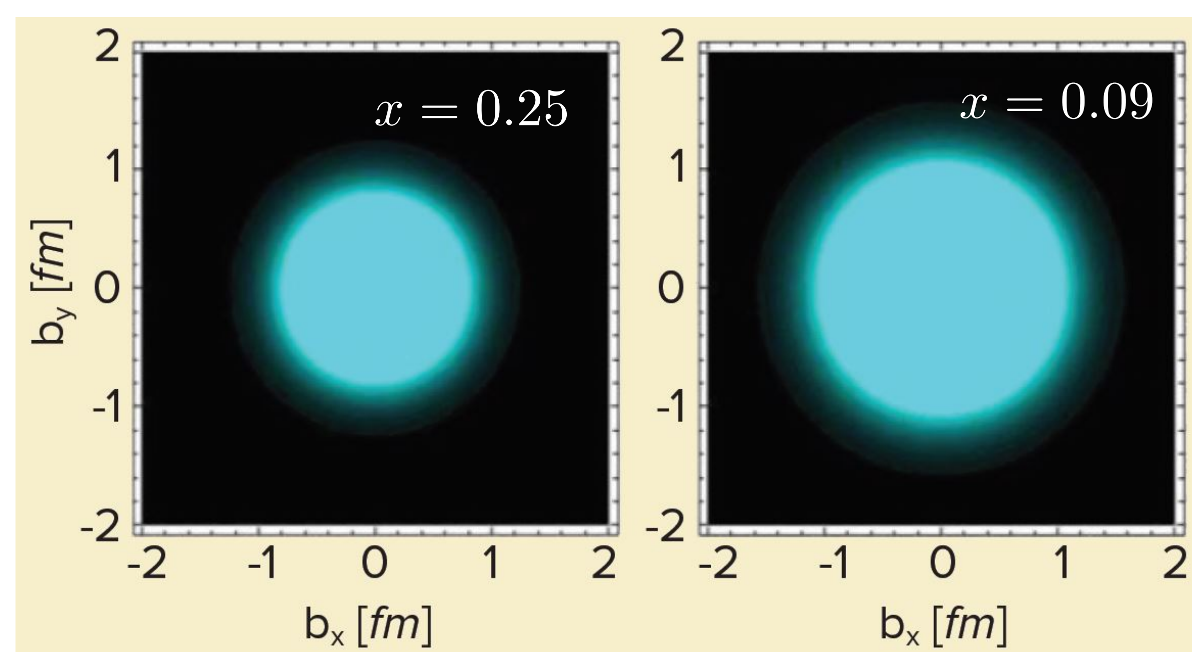

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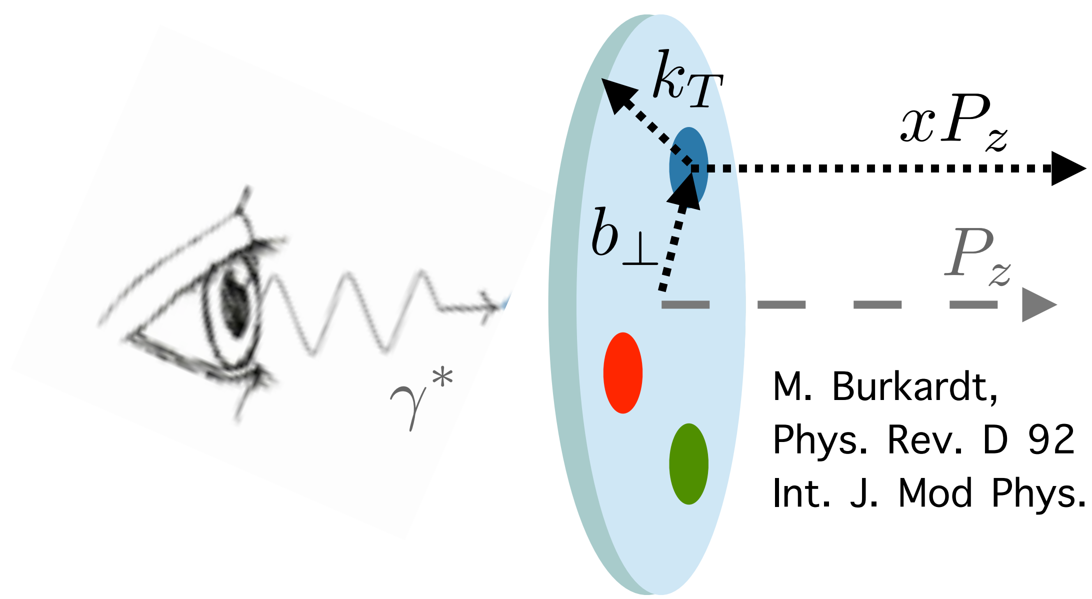

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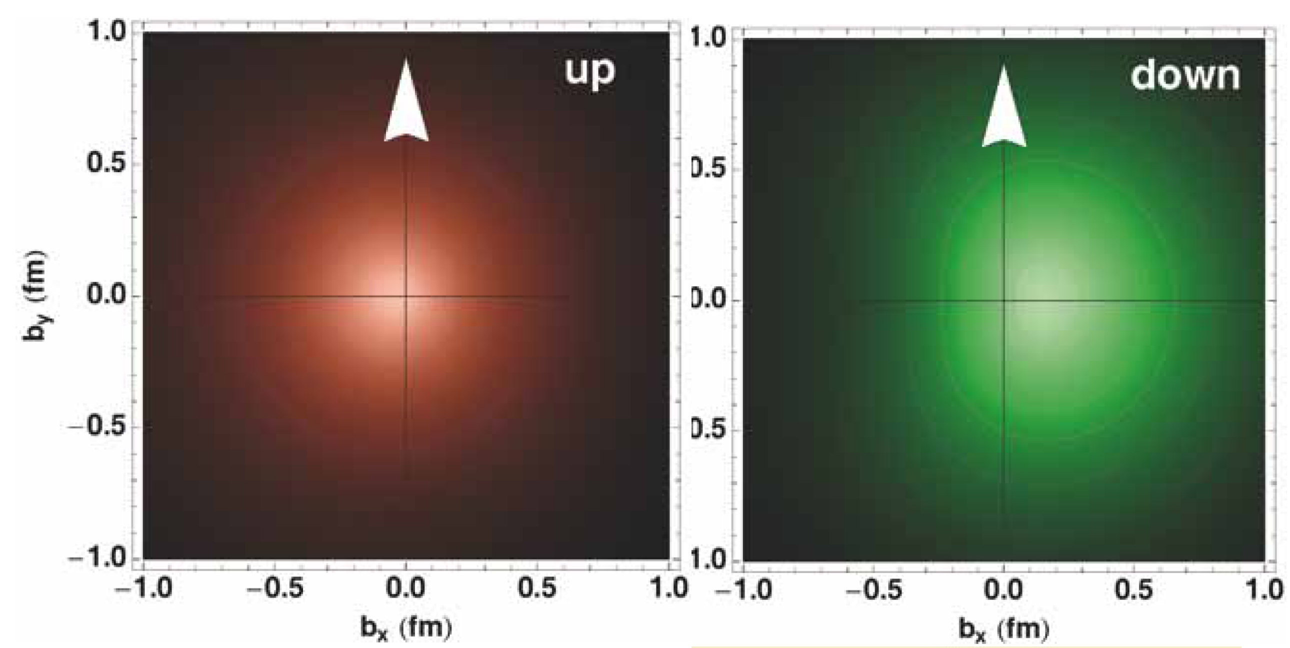
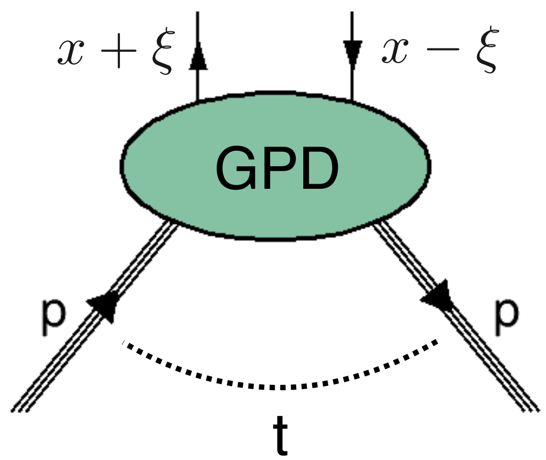


Generalized parton distributions (GPDs)

See e.g. M. Diehl, Phys. Rept. 388 (2003) 41



- x=average longitudinal momentum fraction
- 2ξ= longitudinal momentum transfer: $\xi \approx \frac{x_B}{2-x_B}$
- t=squared momentum transfer to nucleon

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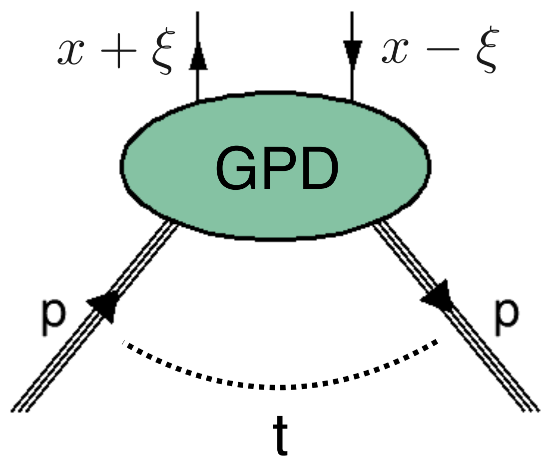

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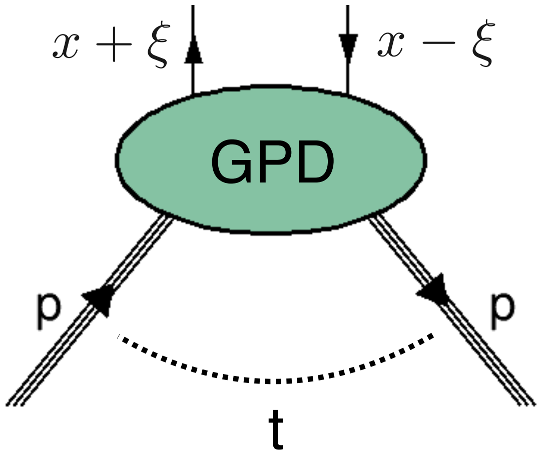
Four quark helicity-conserving twist-2 GPDs

$H(x,\xi,t)$	$E(x,\xi,t)$	spin independent
$\tilde{H}(x,\xi,t)$	$\tilde{E}(x,\xi,t)$	spin dependent
proton helicity non flip	proton helicity flip	

Four quark helicity-flip twist-2 GPDs = transversity GPDs

$H_T(x,\xi,t)$	$E_T(x,\xi,t)$
$\tilde{H}_T(x,\xi,t)$	$\tilde{E}_T(x,\xi,t)$

GPDs and deeply virtual Compton scattering (DVCS)



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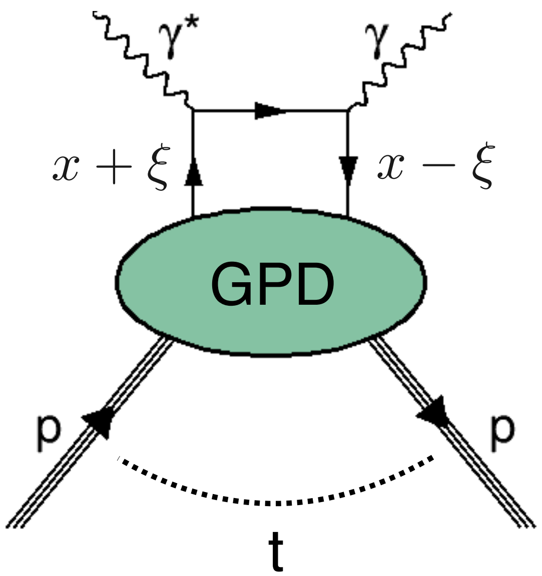

DVCS

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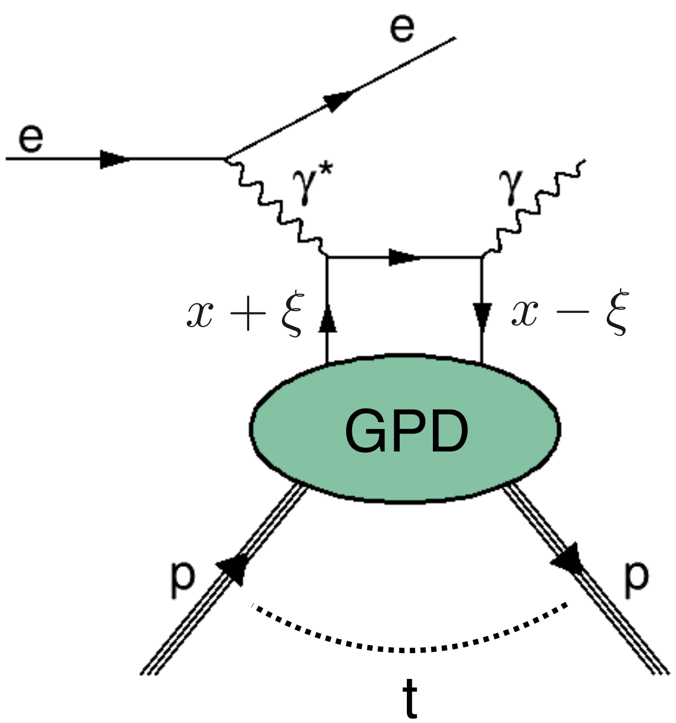

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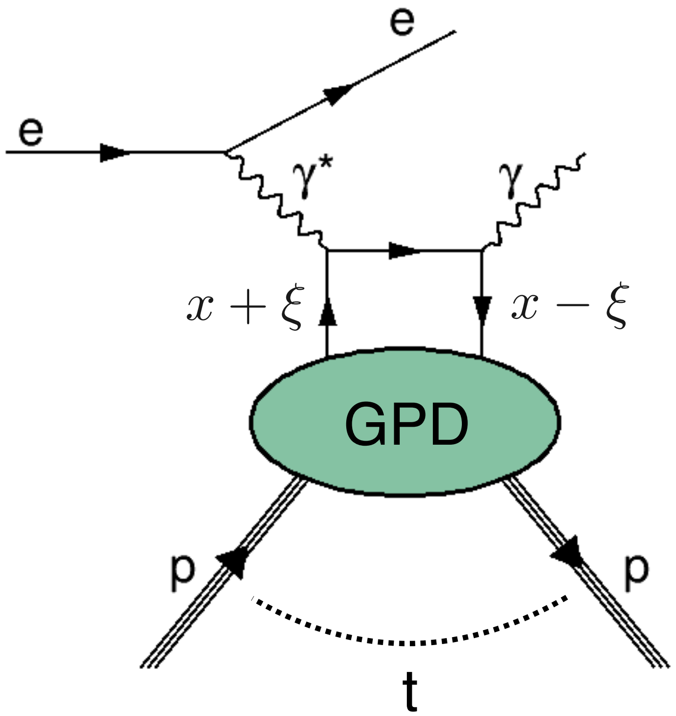
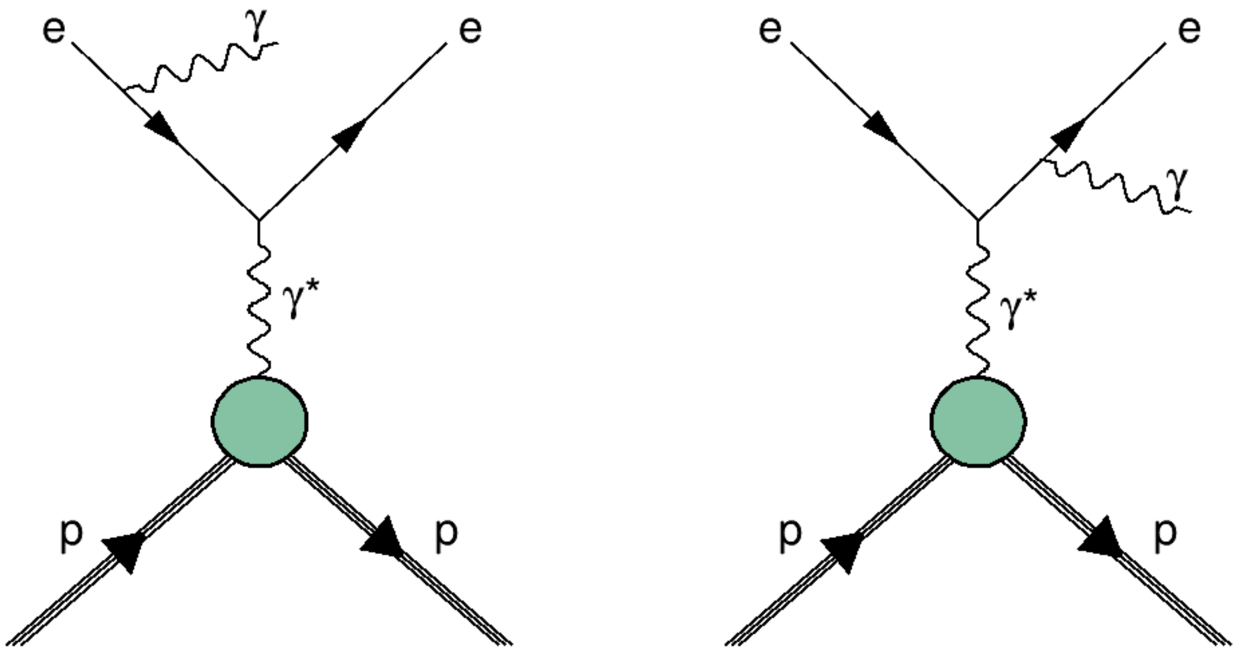
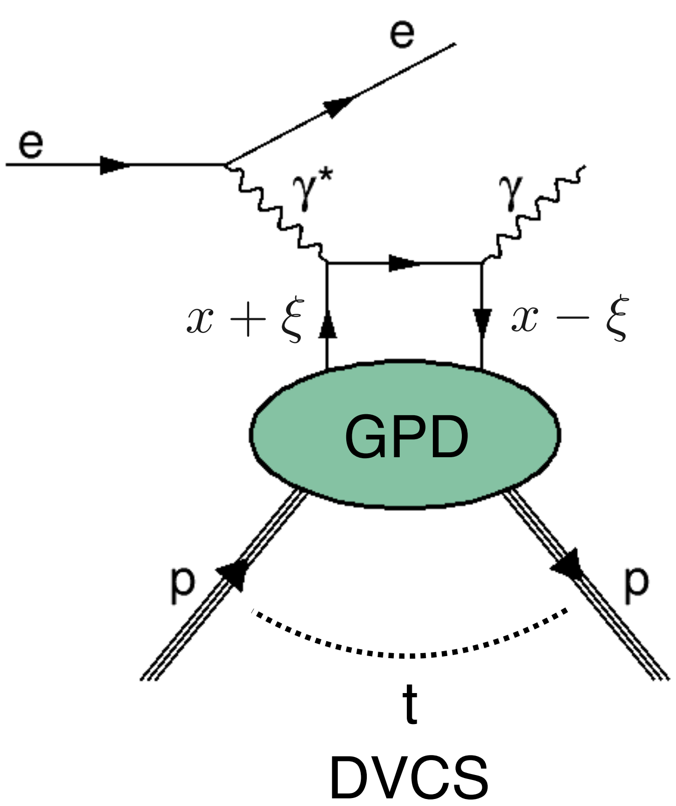


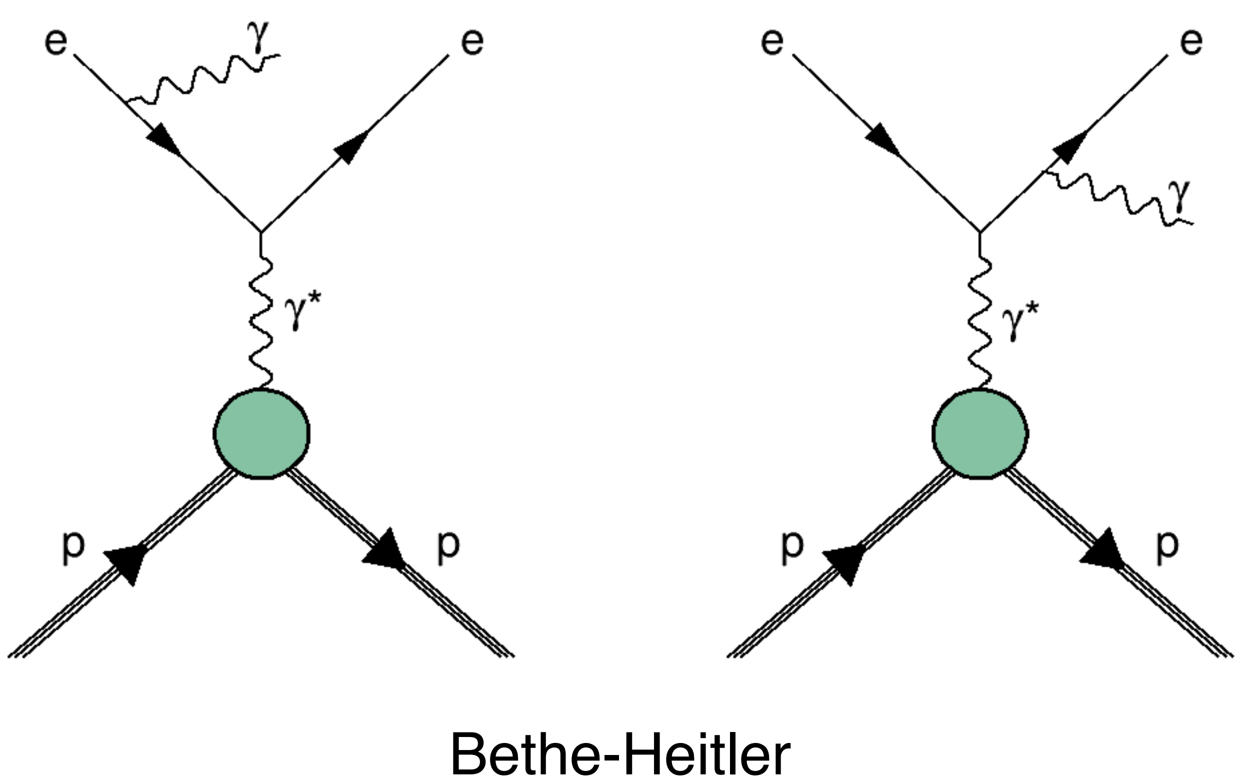
DVCS



Bethe-Heitler

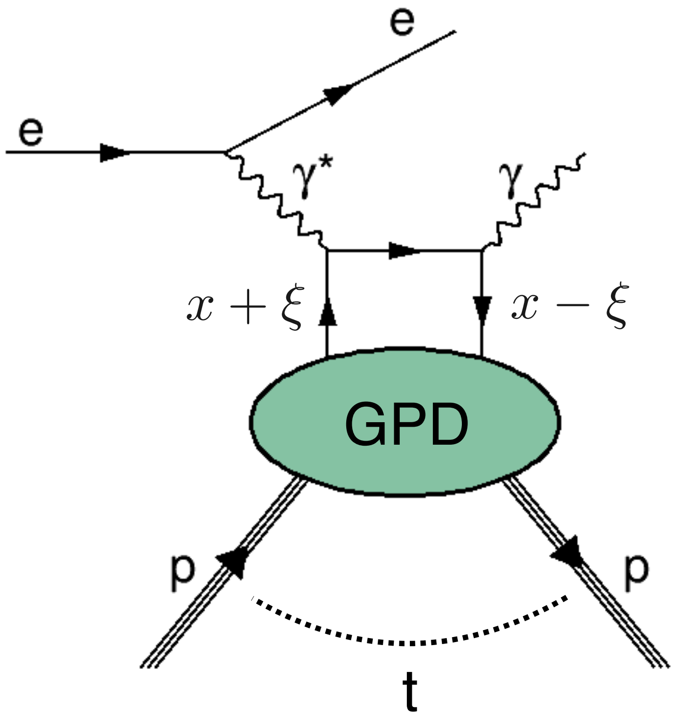
GPDs and deeply virtual Compton scattering (DVCS)



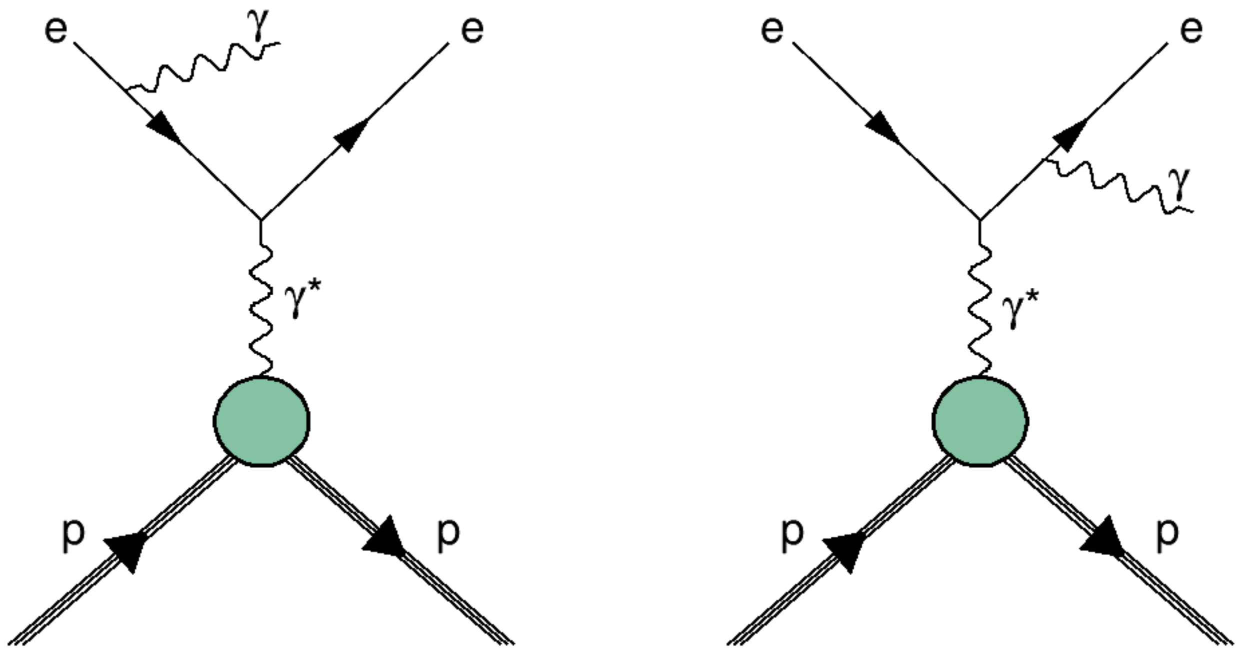


$$d\sigma \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \tau_{DVCS}\tau_{BH}^* + \tau_{DVCS}^*\tau_{BH}$$

GPDs and deeply virtual Compton scattering (DVCS)



DVCS



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CLAS – PRC 80 ('09) 035206; PRL 87 ('01) 182002; 100 ('08) 162002

COMPASS – arXiv:1702.06315

JLab Hall A Collaboration – PRL 99 ('07) 242501; PRC 92 ('15) 055202

H1 – PLB 681 ('09) 391; 659 ('07) 796; EPJ C 44 ('05) 1

HERMES – JHEP 10 ('12) 042; PLB 704 ('11) 15; NPB 842 ('11) 265

ZEUS – PLB 573 (2003) 46; JHEP 05 ('09) 108

DVCS cross section

$$d\sigma \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \tau_{DVCS}\tau^*_{BH} + \tau^*_{DVCS}\tau_{BH}$$

Unpolarized nucleon
Longitudinally polarized lepton beam

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Unpolarized nucleon
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$$|\tau_{BH}|^2 = \frac{K_{BH}}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{2} c_n^{BH} \cos(n\phi) \right\}$$

calculable with knowledge Pauli & Dirac form factors

$$|\tau_{DVCS}|^2 = \frac{1}{Q^2} \left\{ \sum_{n=0}^{2} c_n^{DVCS} \cos(n\phi) + \lambda\, s_1^{DVCS} \sin(\phi) \right\}$$

coefficients: bilinear in GPDs

$$\mathcal{I} = \frac{-e_l\, K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{3} c_n^{\mathcal{I}} \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi) \right\}$$

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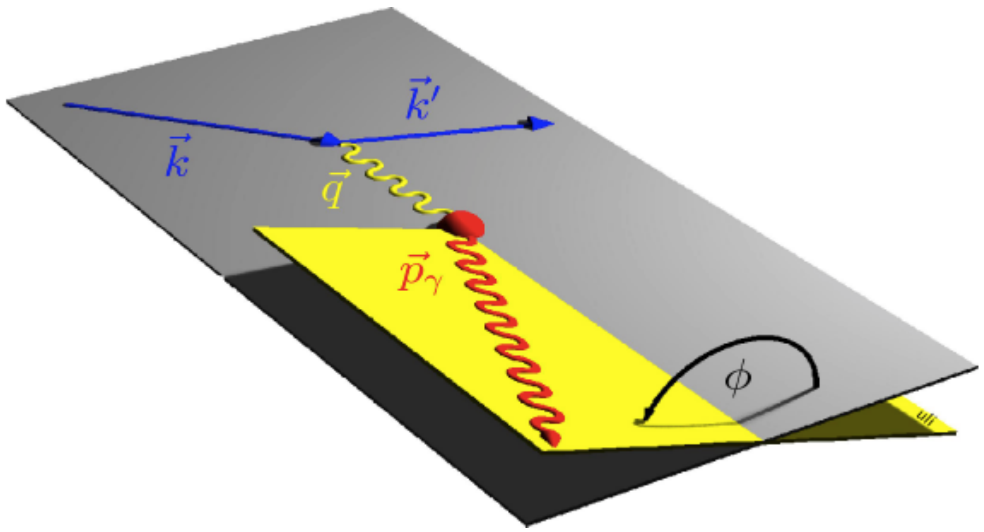

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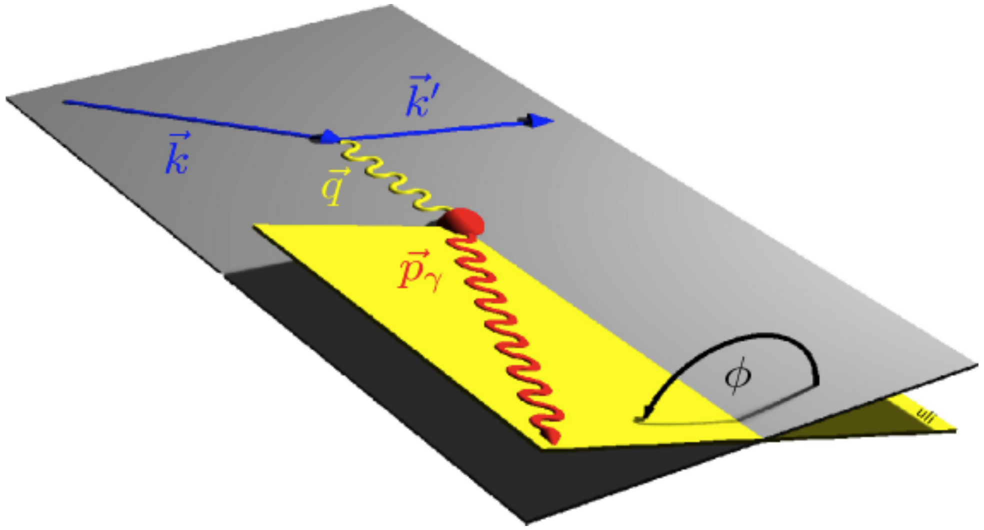

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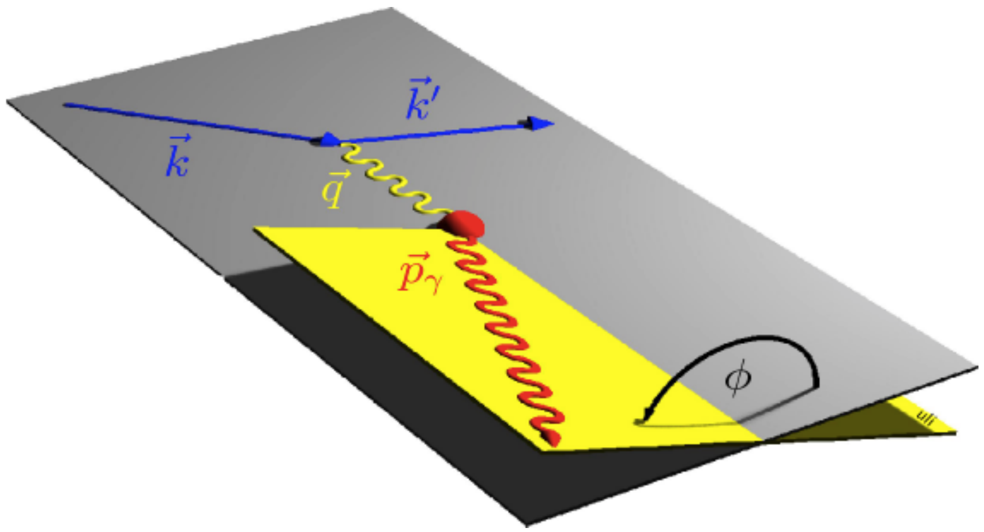
beam charge

beam polarization



DVCS cross section

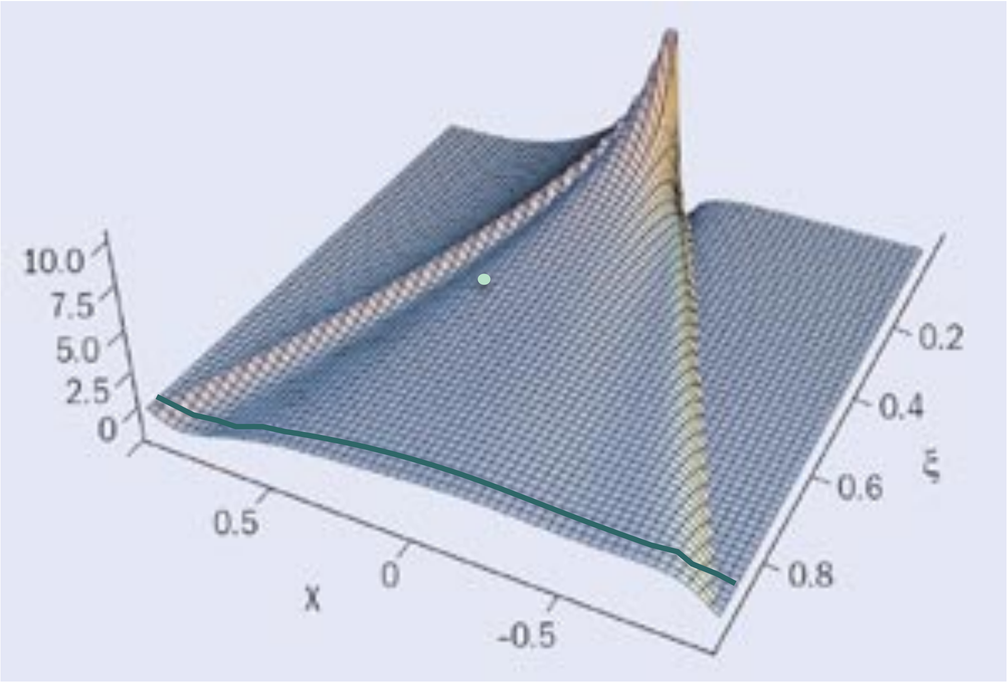
$$\mathcal{I} = \frac{-e_l K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{3} c_n^{\mathcal{I}} \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi) \right\}$$

$c_1^{\mathcal{I}} \propto \Re M^{1,1}$ $s_1^{\mathcal{I}} \propto \Im M^{1,1}$

$$M^{1,1} = F_1(t)\,\mathcal{H}(\xi,t) + \frac{x_B}{2-x_B}(F_1(t)+F_2(t))\,\tilde{\mathcal{H}}(\xi,t) - \frac{t}{4M_p^2}\,F_2(t)\mathcal{E}(\xi,t)$$

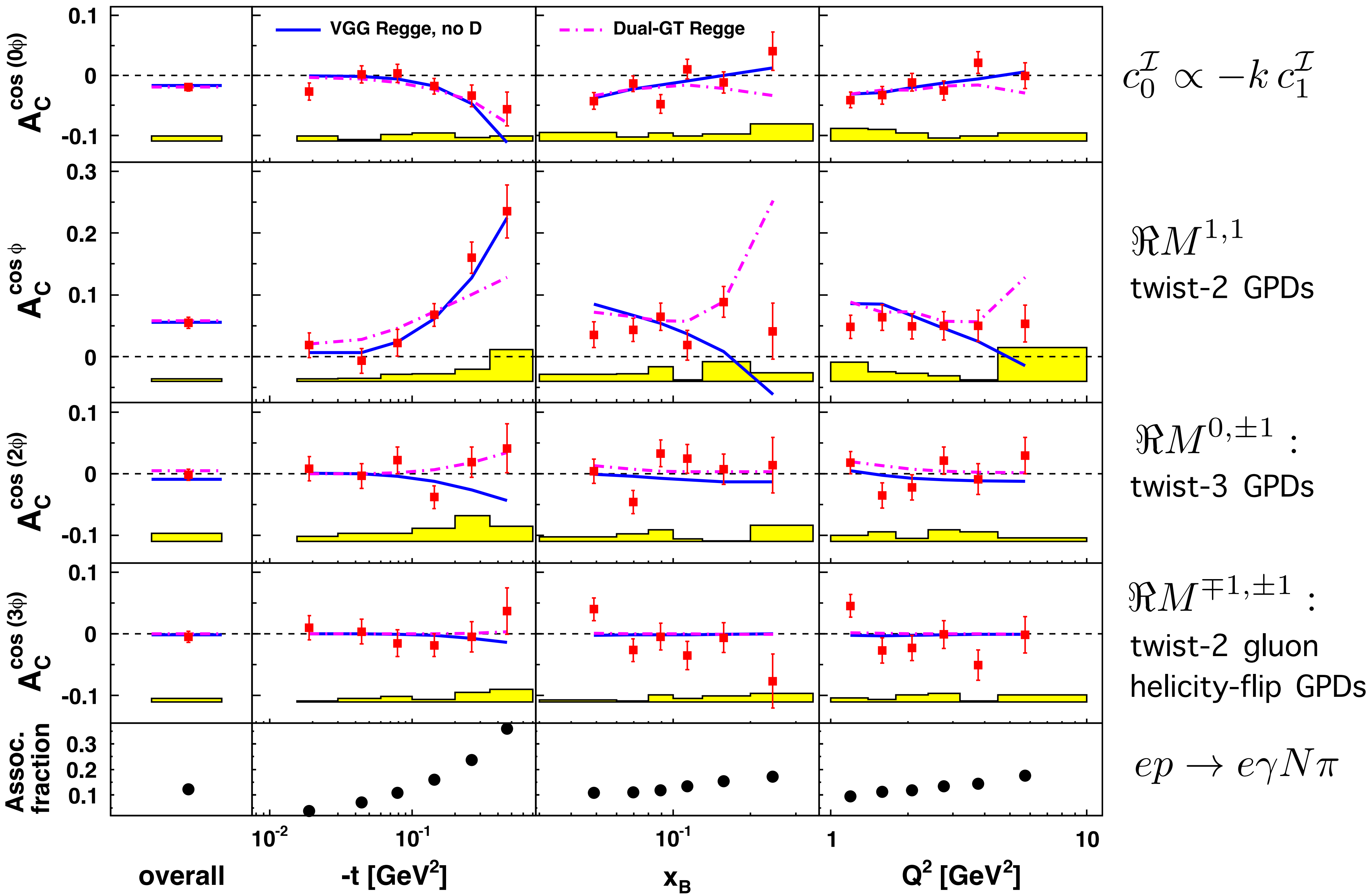
CFF $\mathcal{H}, \tilde{\mathcal{H}}, \mathcal{E}$ =convolution GPD x hard scattering amplitude

At LO: $\Im$ direct access to GPDs at $x = \pm\xi$
$\Re$ convolution integral over x
+ access to D-term



Beam-charge asymmetry

HERMES, JHEP **11** (2009) 083



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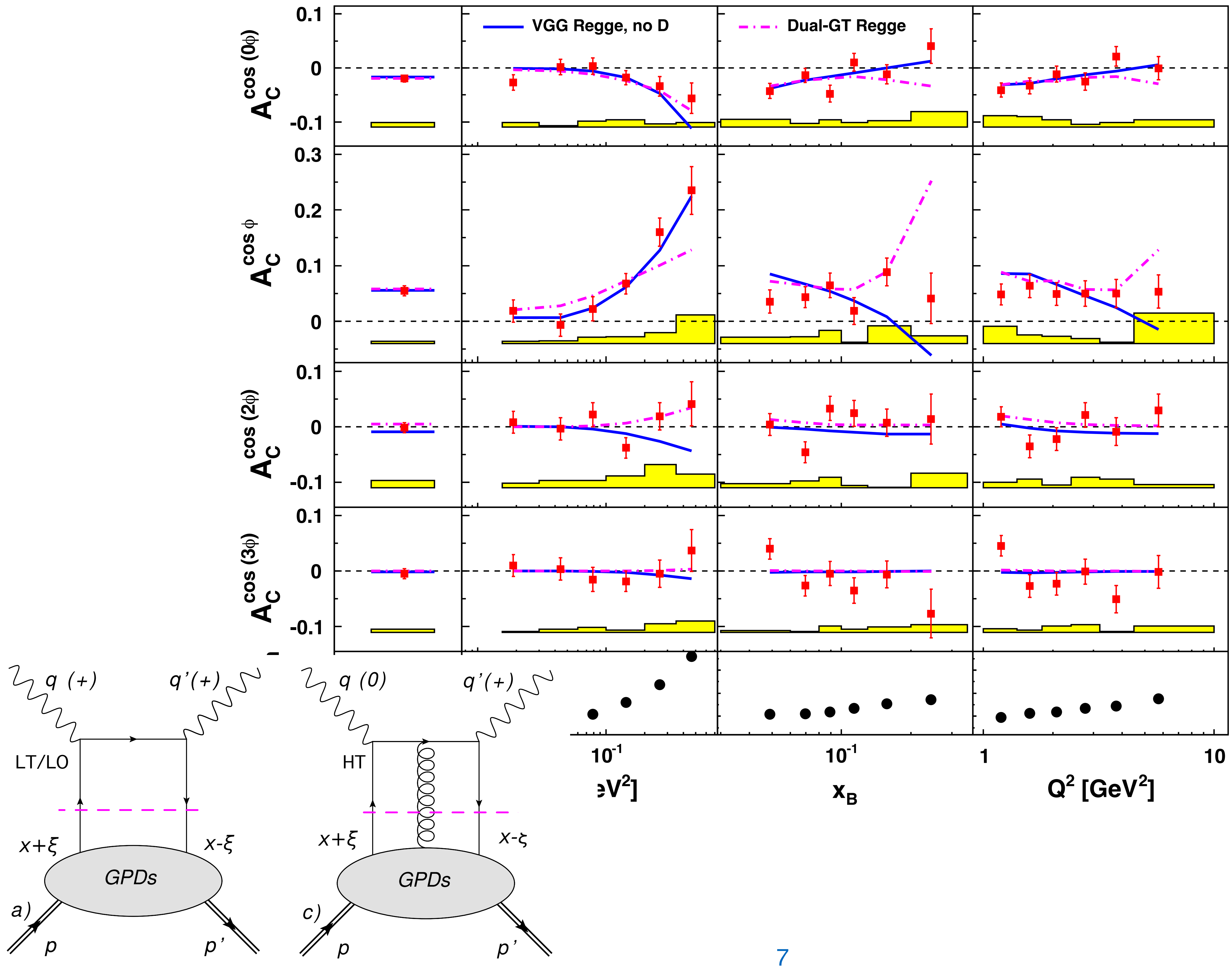

$c_0^{\mathcal{I}} \propto -k\, c_1^{\mathcal{I}}$

$\Re M^{1,1}$

twist-2 GPDs

$\Re M^{0,\pm 1}$:

twist-3 GPDs

$\Re M^{\mp 1,\pm 1}$:

twist-2 gluon helicity-flip GPDs

$ep \to e\gamma N\pi$

courtesy of M. Defurne

Beam-helicity asymmetry

Unpolarised nucleon
Longitudinally polarised lepton beam

$$|\tau_{BH}|^2 = \frac{K_{BH}}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{2} c_n^{BH} \cos(n\phi) \right\}$$

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coefficients: linear in GPDs

beam charge

beam polarisation

Beam-helicity asymmetry

$$\mathcal{A}_{\mathrm{LU}}(\phi, e_\ell) \equiv \frac{d\sigma^{\rightarrow} - d\sigma^{\leftarrow}}{d\sigma^{\rightarrow} + d\sigma^{\leftarrow}}$$

$$= \frac{-e_\ell \frac{K_{\mathrm{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[\sum_{n=1}^{2} s_n^{\mathrm{I}} \sin(n\phi)\right] + \frac{1}{Q^2} s_1^{\mathrm{DVCS}} \sin\phi}{\frac{1}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left[K_{\mathrm{BH}} \sum_{n=0}^{2} c_n^{\mathrm{BH}} \cos(n\phi) - e_\ell K_{\mathrm{I}} \sum_{n=0}^{3} c_n^{\mathrm{I}} \cos(n\phi)\right] + \frac{1}{Q^2} \sum_{n=0}^{2} c_n^{\mathrm{DVCS}} \cos(n\phi)}$$

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- suppressed as $1/Q^2$

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calculable

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calculable

twist-2 $c_0^{\rm I}, c_1^{\rm I} \neq 0$

- suppressed as $1/Q^2$

Beam-helicity asymmetry

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Cross section differences

Beam-helicity asymmetries

Charge-difference beam-helicity asymmetry

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{I}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

$$= \frac{-\frac{K_{\mathrm{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left[\sum_{n=1}^{2} s_n^{\mathrm{I}} \sin(n\phi)\right]}{\frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\sum_{n=0}^{2} c_n^{\mathrm{BH}}\cos(n\phi) + \frac{1}{Q^2}\sum_{n=0}^{2} c_n^{\mathrm{DVCS}}\cos(n\phi)}$$

Beam-helicity asymmetries

Charge-difference beam-helicity asymmetry

linear access to GPDs

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{I}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

$$= \frac{-\frac{K_{\mathrm{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left[\sum_{n=1}^{2} s_n^{\mathrm{I}} \sin(n\phi)\right]}{\frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\sum_{n=0}^{2} c_n^{\mathrm{BH}} \cos(n\phi) + \frac{1}{Q^2}\sum_{n=0}^{2} c_n^{\mathrm{DVCS}} \cos(n\phi)}$$

Beam-helicity asymmetries

Charge-difference beam-helicity asymmetry

linear access to GPDs

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{I}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

$$= \frac{-\frac{K_{\mathrm{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left[\sum_{n=1}^{2} s_n^{\mathrm{I}} \sin(n\phi)\right]}{\frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\sum_{n=0}^{2} c_n^{\mathrm{BH}}\cos(n\phi) + \frac{1}{Q^2}\sum_{n=0}^{2} c_n^{\mathrm{DVCS}}\cos(n\phi)}$$

Charge-averaged beam-helicity asymmetry

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

$$= \frac{\frac{1}{Q^2}\, s_1^{\mathrm{DVCS}} \sin\phi}{\frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\sum_{n=0}^{2} c_n^{\mathrm{BH}}\cos(n\phi) + \frac{1}{Q^2}\sum_{n=0}^{2} c_n^{\mathrm{DVCS}}\cos(n\phi)}$$

Beam-helicity asymmetries

Charge-difference beam-helicity asymmetry

linear access to GPDs

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{I}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) - (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

$$= \frac{-\frac{K_{\mathrm{I}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left[\sum_{n=1}^{2} s_n^{\mathrm{I}} \sin(n\phi)\right]}{\frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\sum_{n=0}^{2} c_n^{\mathrm{BH}} \cos(n\phi) + \frac{1}{Q^2}\sum_{n=0}^{2} c_n^{\mathrm{DVCS}} \cos(n\phi)}$$

Charge-averaged beam-helicity asymmetry

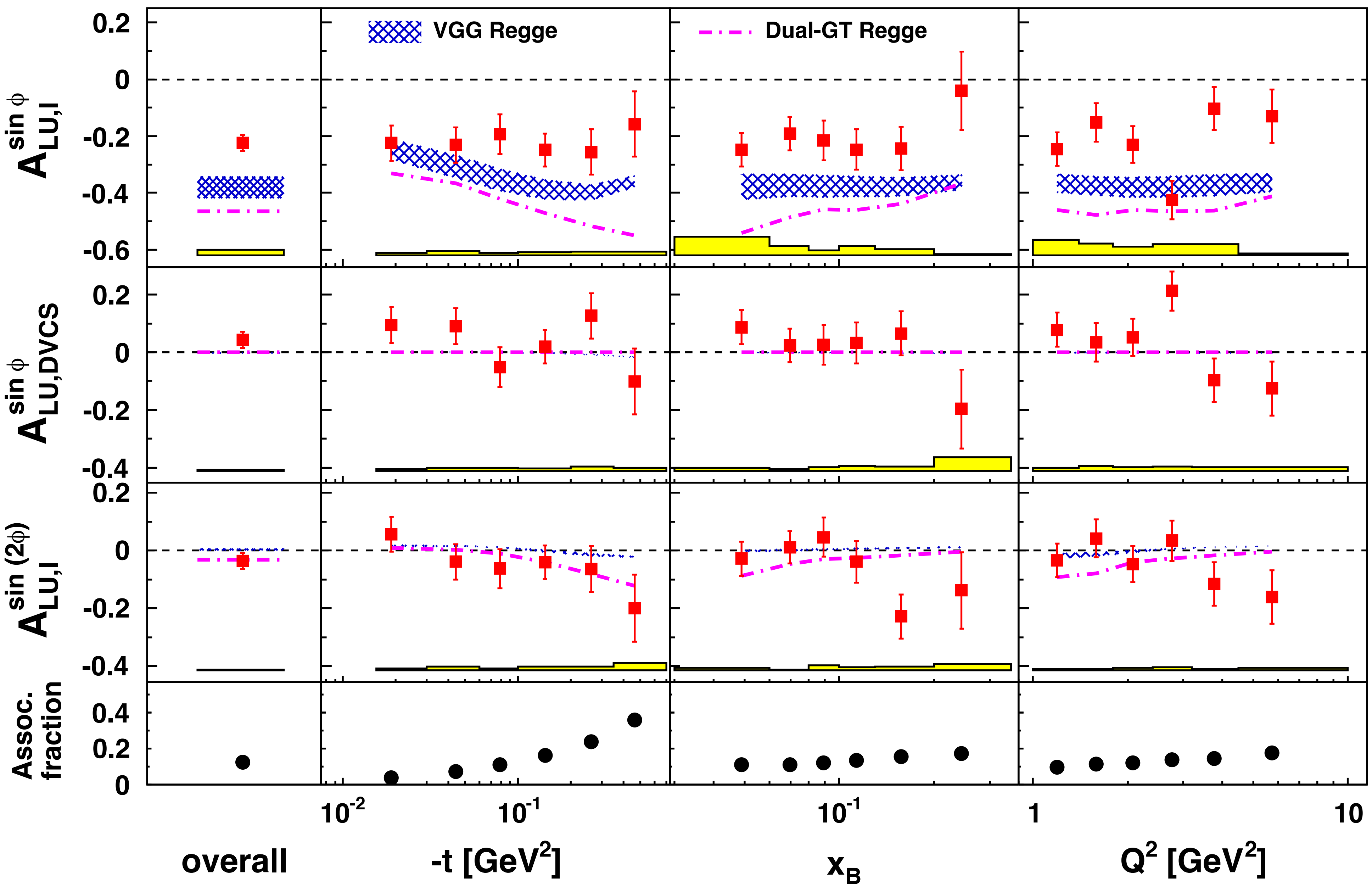
bilinear access to GPDs

$$\mathcal{A}_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) \equiv \frac{(d\sigma^{+\rightarrow} - d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} - d\sigma^{-\leftarrow})}{(d\sigma^{+\rightarrow} + d\sigma^{+\leftarrow}) + (d\sigma^{-\rightarrow} + d\sigma^{-\leftarrow})}$$

$$= \frac{\frac{1}{Q^2}\, s_1^{\mathrm{DVCS}} \sin\phi}{\frac{K_{\mathrm{BH}}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\sum_{n=0}^{2} c_n^{\mathrm{BH}} \cos(n\phi) + \frac{1}{Q^2}\sum_{n=0}^{2} c_n^{\mathrm{DVCS}} \cos(n\phi)}$$

Charge-difference and charge-average beam-helicity asymmetry

HERMES, JHEP **11** (2009) 083



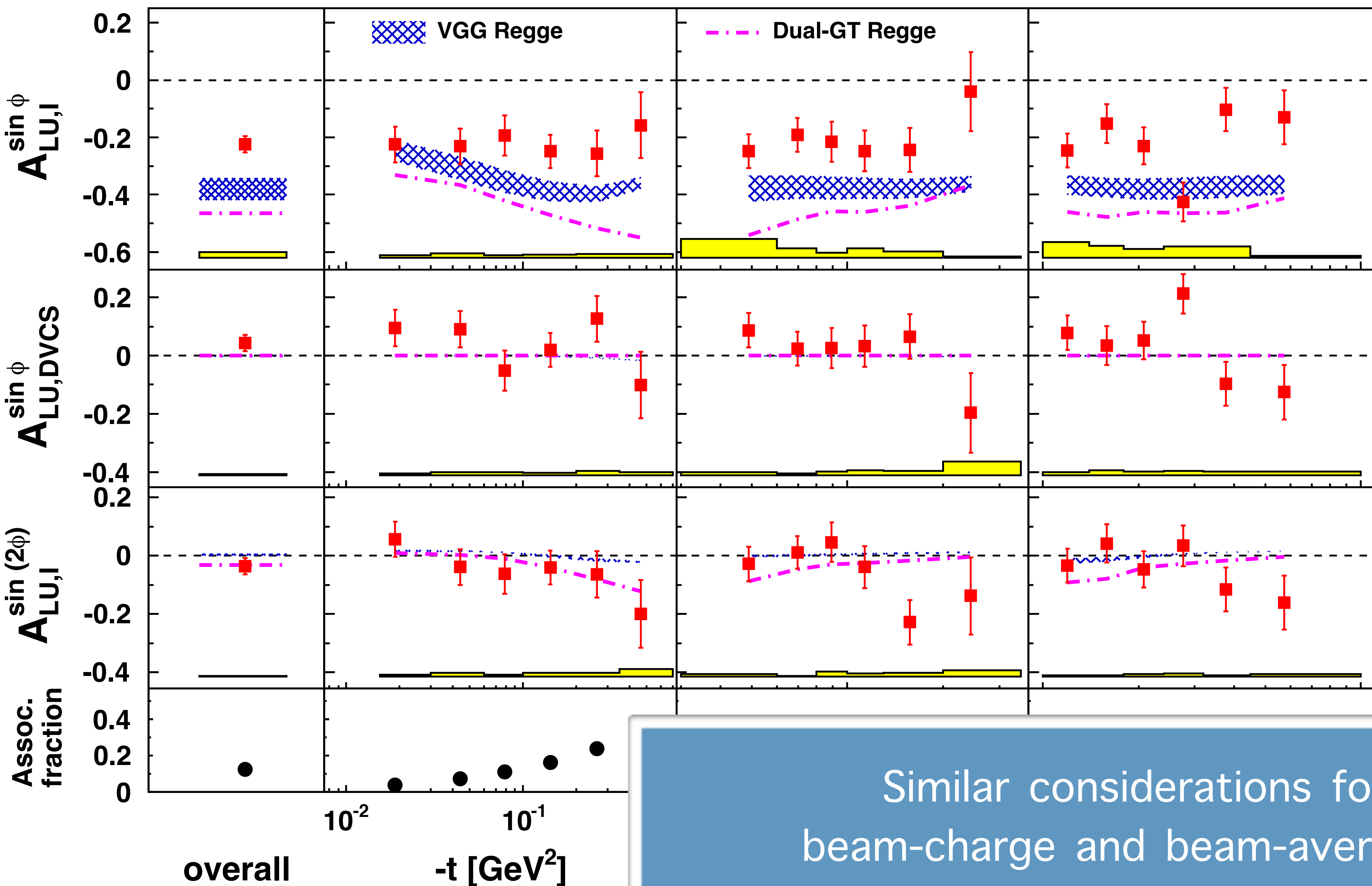
$\Im M^{1,1}$
twist-2 GPDs

twist-3 GPDs

$\Im M^{0,\pm1}$
twist-3 GPDs

Charge-difference and charge-average beam-helicity asymmetry

HERMES, JHEP **11** (2009) 083



$\Im M^{1,1}$
twist-2 GPDs

twist-3 GPDs

$\Im M^{0,\pm 1}$
twist-3 GPDs

Similar considerations for
beam-charge and beam-averaged
target-spin asymmetries
(JHEP 06 (2008) 066, Phys. Lett. B 704 (2011) 15-23)

Disentangling interference and DVCS contributions

$$d\sigma \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + \tau_{DVCS}\tau_{BH}^* + \tau_{DVCS}^*\tau_{BH}$$

Unpolarised nucleon
Longitudinally polarised lepton beam

$$|\tau_{BH}|^2 = \frac{K_{BH}}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{2} c_n^{BH} \cos(n\phi) \right\}$$

calculable with knowledge Pauli & Dirac form factors

$$|\tau_{DVCS}|^2 = \frac{1}{Q^2} \left\{ \sum_{n=0}^{2} c_n^{DVCS} \cos(n\phi) + \lambda\, s_1^{DVCS} \sin(\phi) \right\}$$

coefficients: bilinear in GPDs

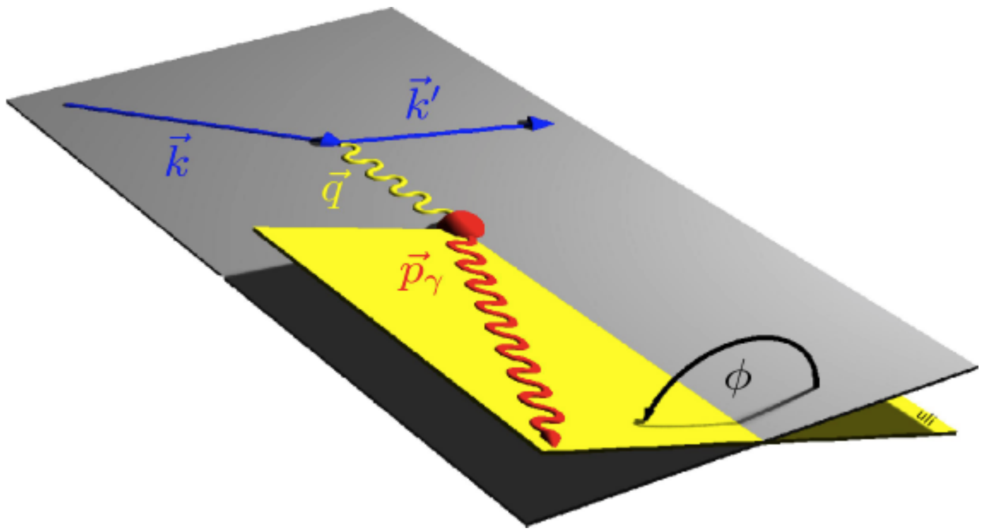
$$\mathcal{I} = \frac{-e_l K_{\mathcal{I}}}{\mathcal{P}_1(\phi)\,\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{3} c_n^{\mathcal{I}} \cos(n\phi) + \lambda \sum_{n=1}^{2} s_n^{\mathcal{I}} \sin(n\phi) \right\}$$

coefficients: linear in GPDs

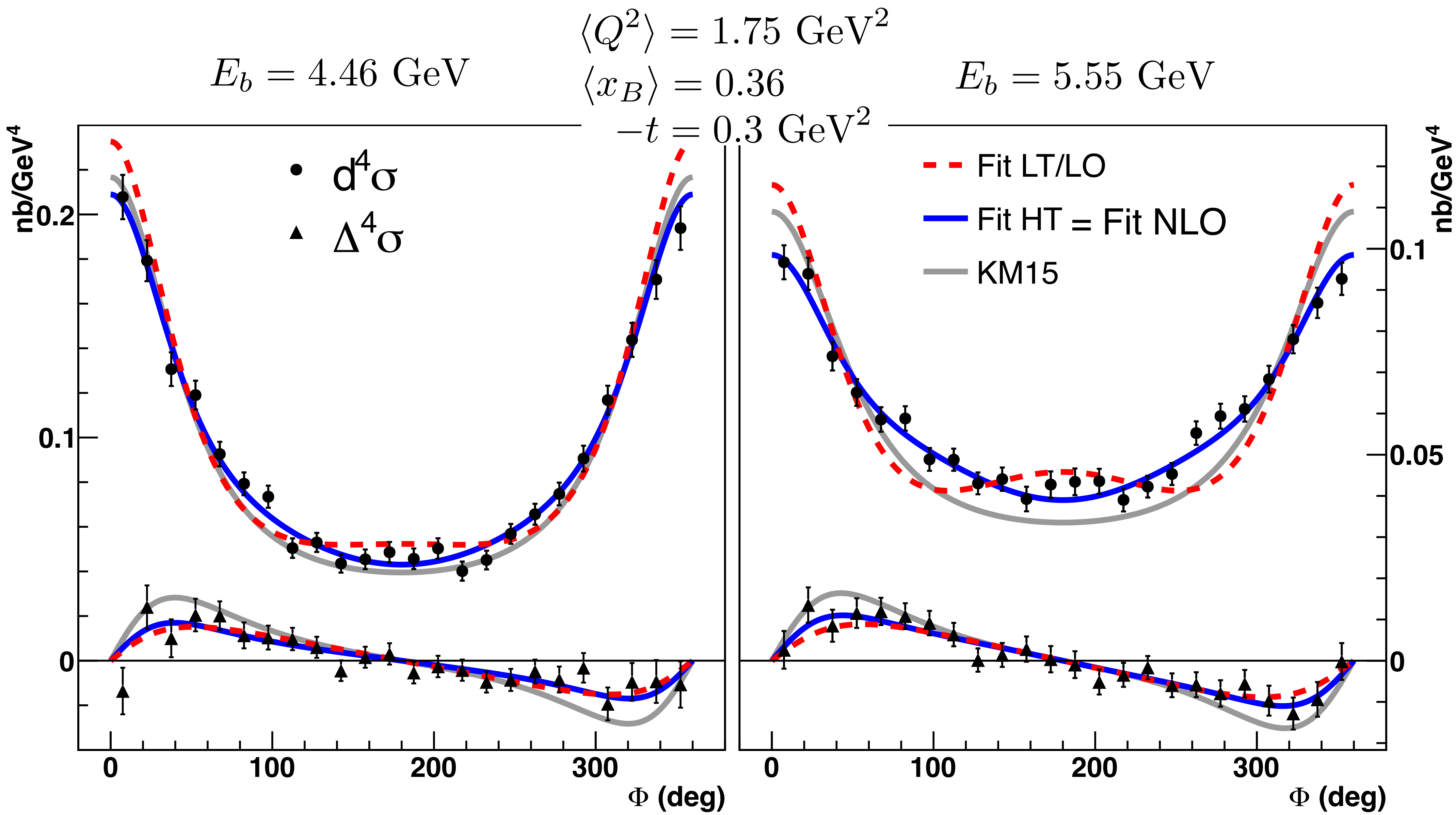
beam charge

beam polarisation

$s_1^{\mathcal{I}}$ and s_1^{DVCS} have different beam energy dependence: exploited at Jefferson Lab Hall A

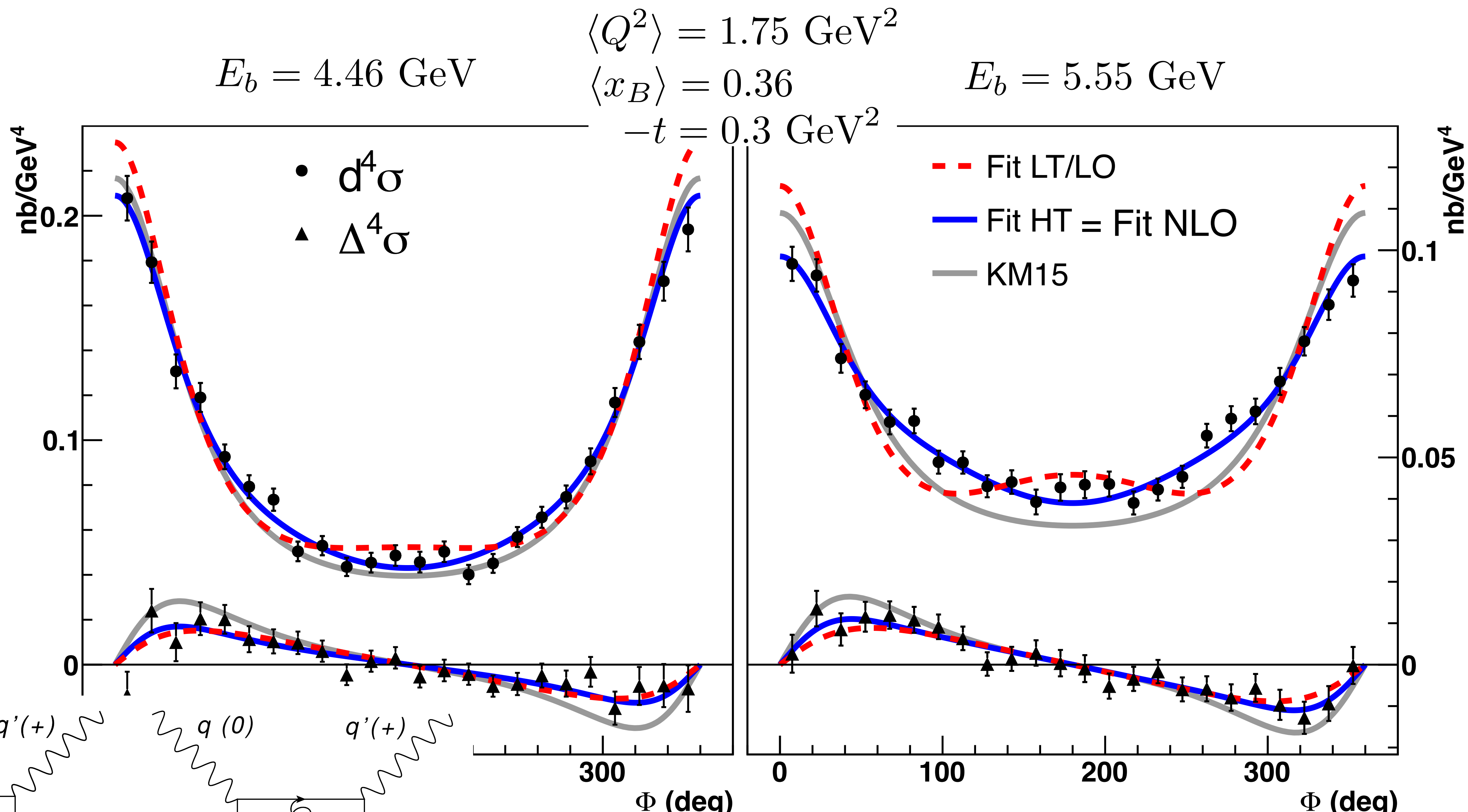


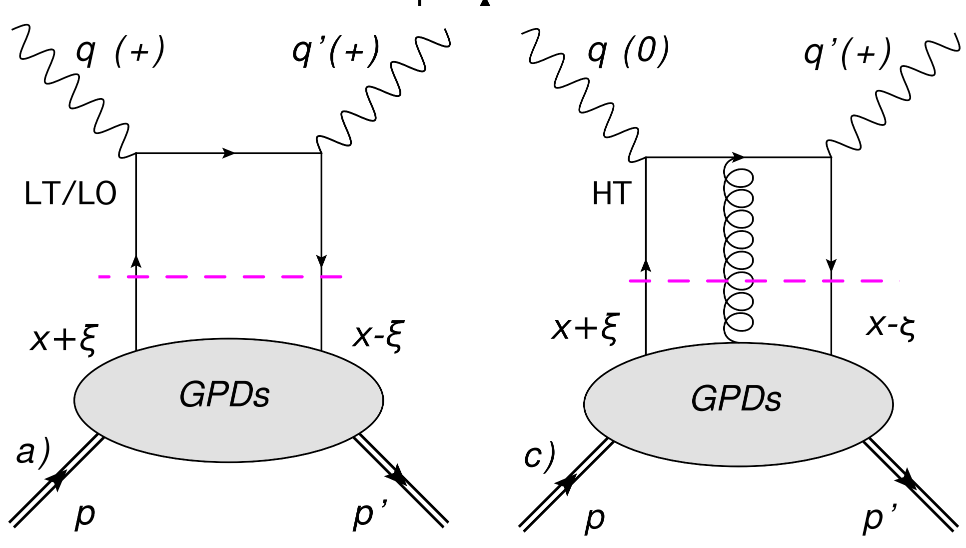
Disentangling interference and DVCS contributions



Jefferson Lab Hall A, Nat. Com. 8 (2017) 1408

Disentangling interference and DVCS contributions

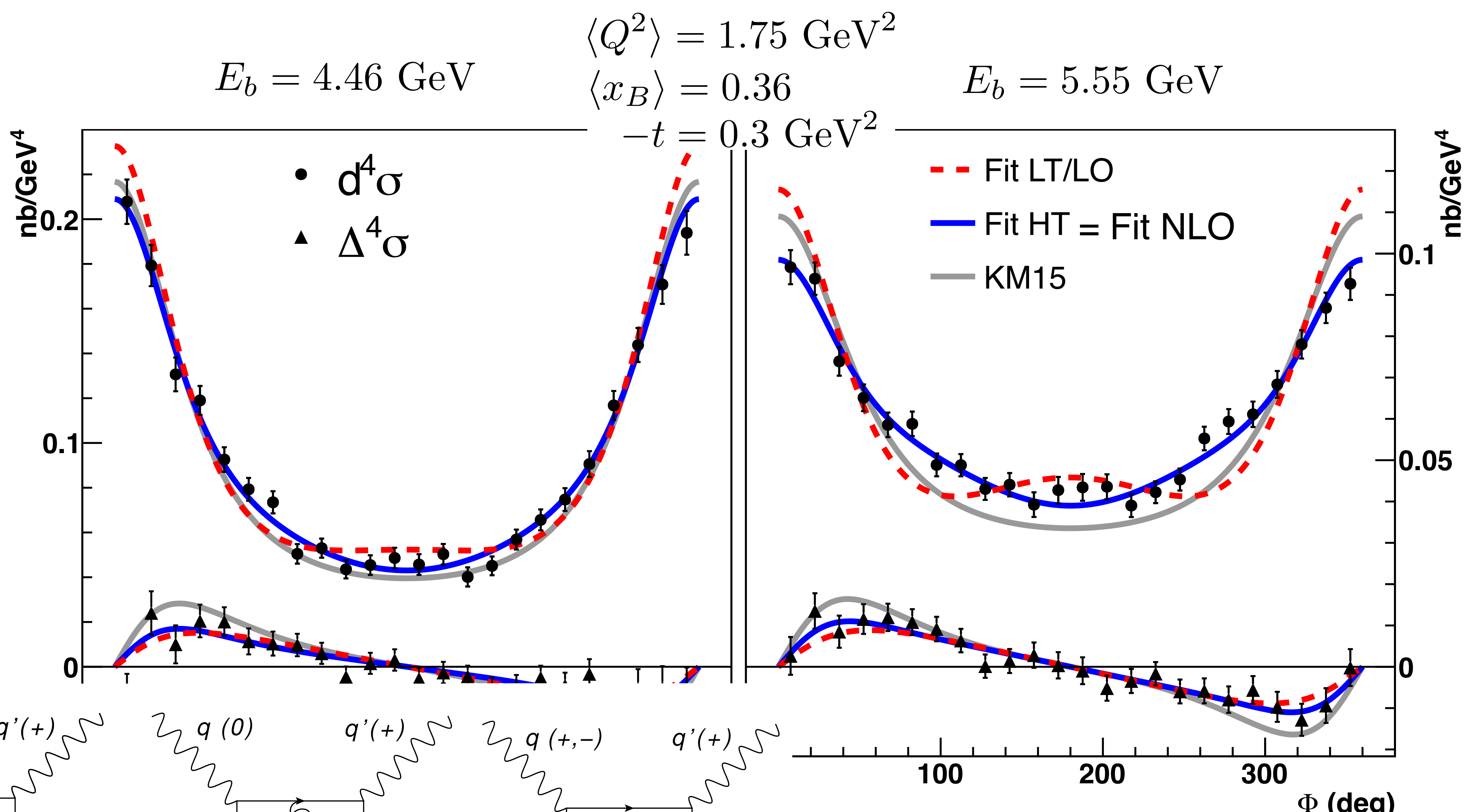


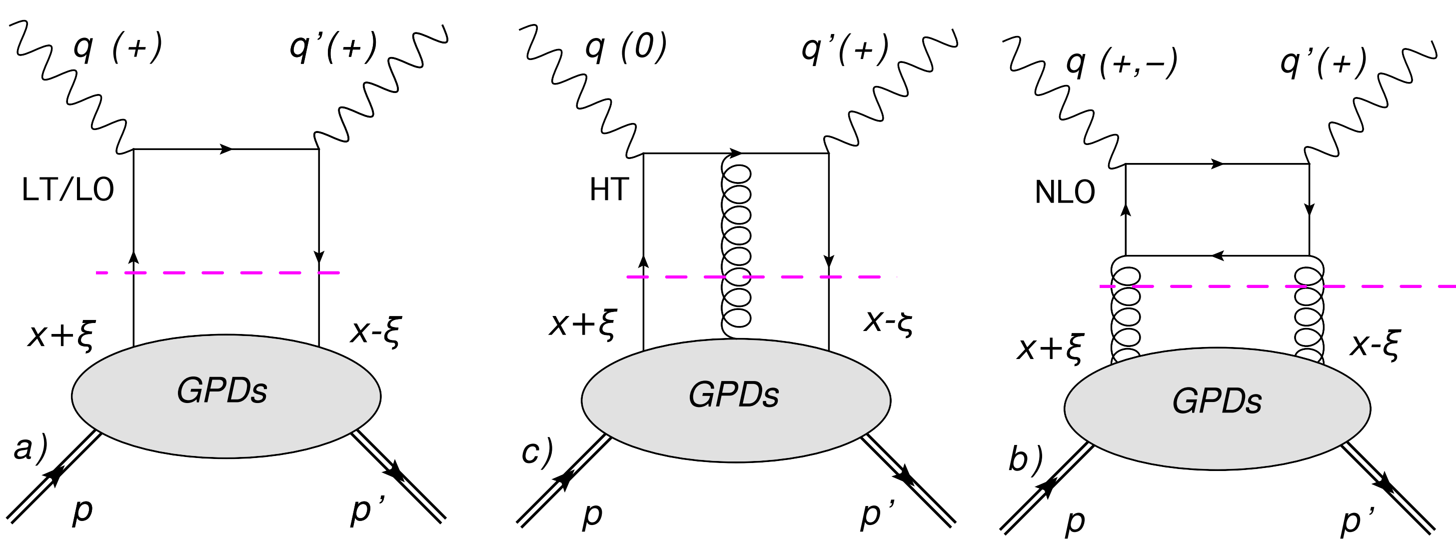


Jefferson Lab Hall A, Nat. Com. 8 (2017) 1408

courtesy of M. Defurne

Disentangling interference and DVCS contributions



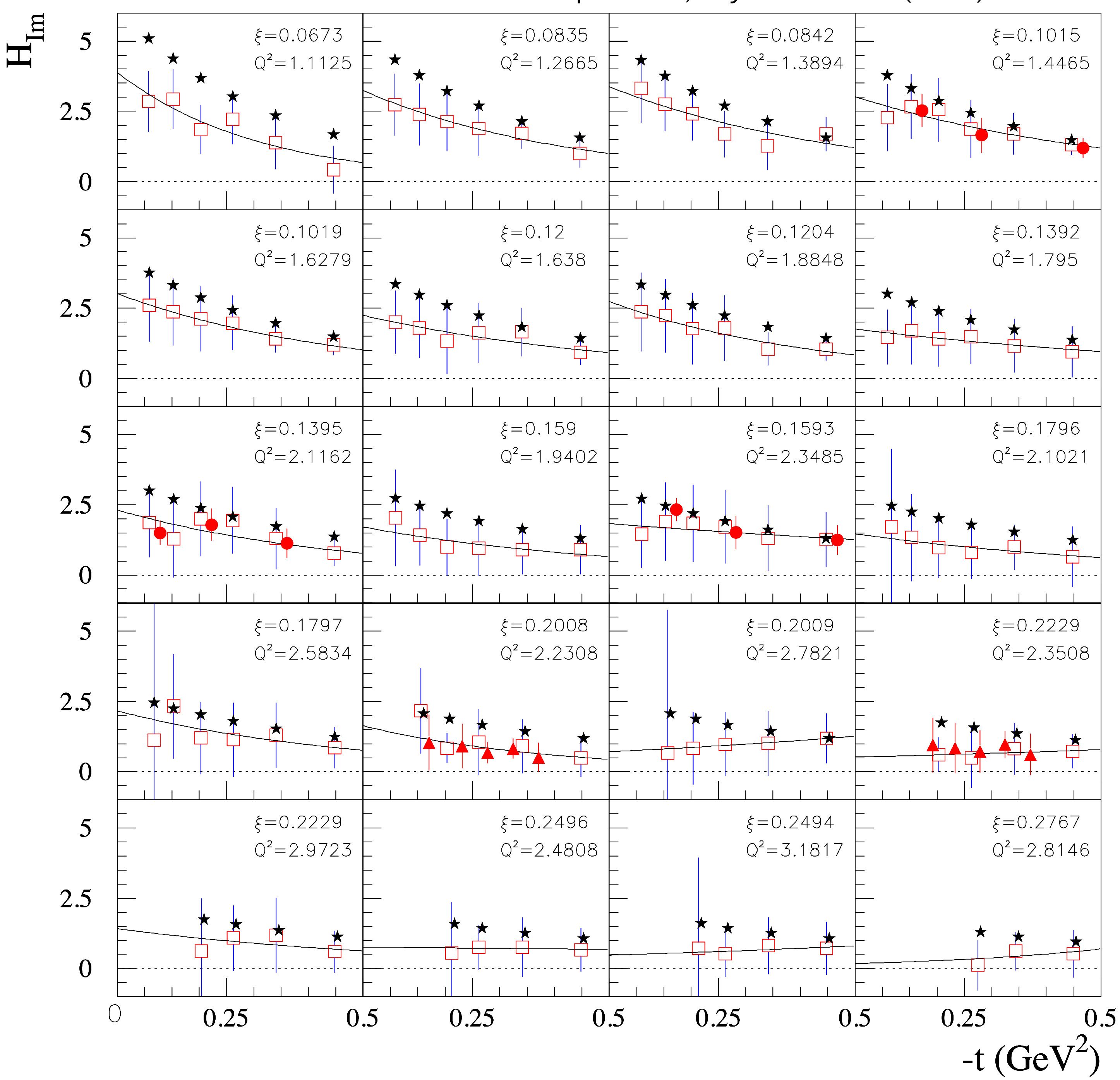


Jefferson Lab Hall A, Nat. Com. 8 (2017) 1408

courtesy of M. Defurne

Multi-dimensional binning present @ JLab

Dupre et al., Phys. Rev. D 95 (2017) 011501



- Longitudinal target-spin asymmetry – CLAS
  Phys. Rev. Lett. 114 (2015) 032001
  Phys. Rev. D 91 (2015) 052014
- Unpolarized and beam-polarized cross sections – CLAS
  Phys. Rev. Lett. 115 (2015) 212003
- Unpolarized and beam-polarized cross sections – Hall A
  Phys. Rev. C 92 (2015) 055202

↓

Fit of $\Im\mathcal{H}(\xi,t)$

Dupre et al., Phys. Rev. D 95 (2017) 011501
Dupre et al., Eur. Phys. J. A 53 (2017) 171

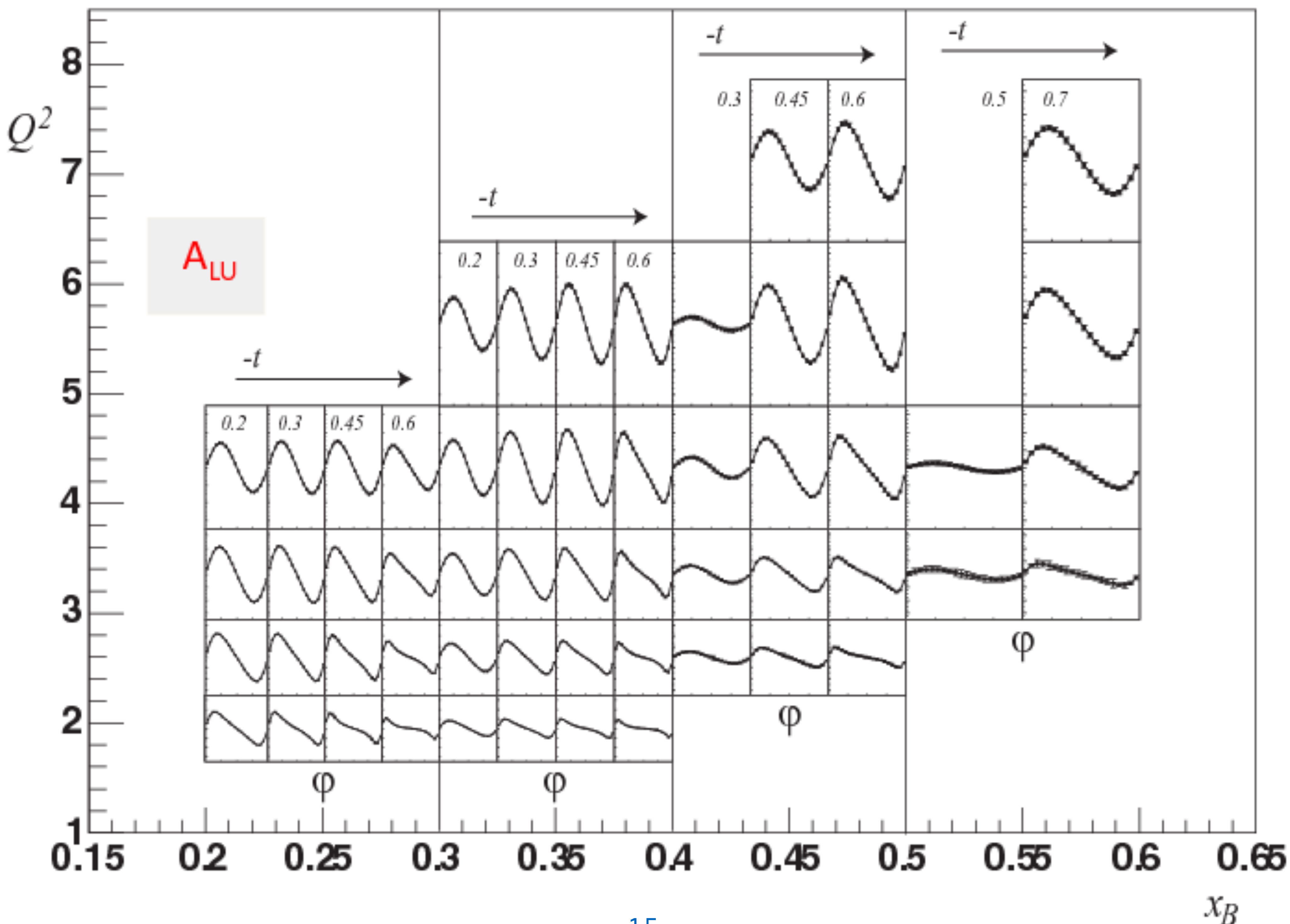
fit results:

- □ CLAS unpolarized and beam-polarized cross section
- ● CLAS all data
- △ Hall A
- ★ VGG model (Phys. Rev. Lett. 80 5064 (1998))
- — fit $\Im\mathcal{H}(\xi,t) = A(\xi)e^{B(\xi)t}$

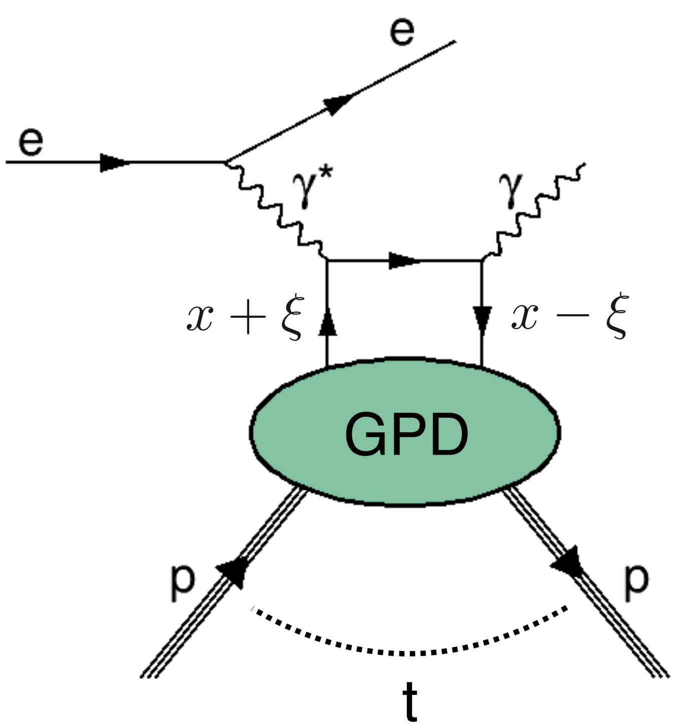
- Increase of t-slope with decreasing ξ
- Increase of $\Im\mathcal{H}(\xi,t)$ amplitude with decreasing ξ

Multi-dimensional binning: JLab 12GeV

JLab experiment E12-06-119, CLAS12

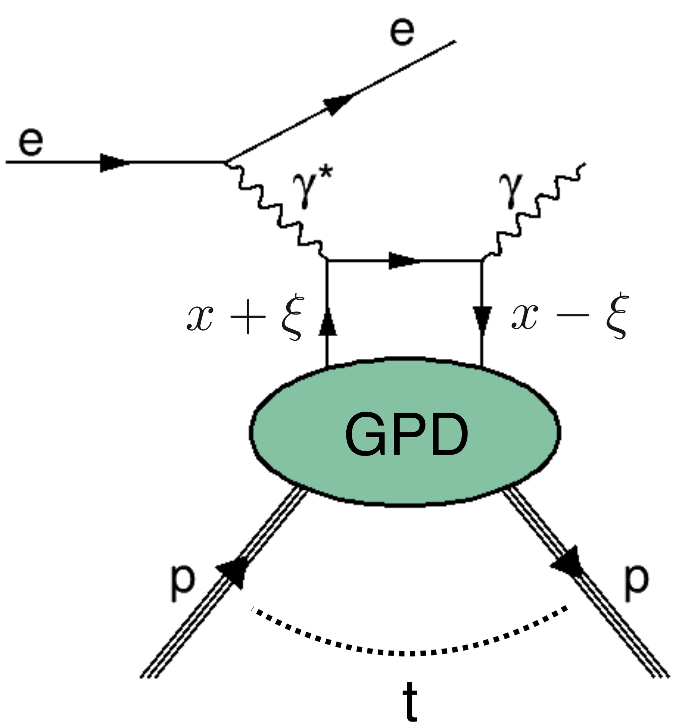


GPDs and exclusive meson production

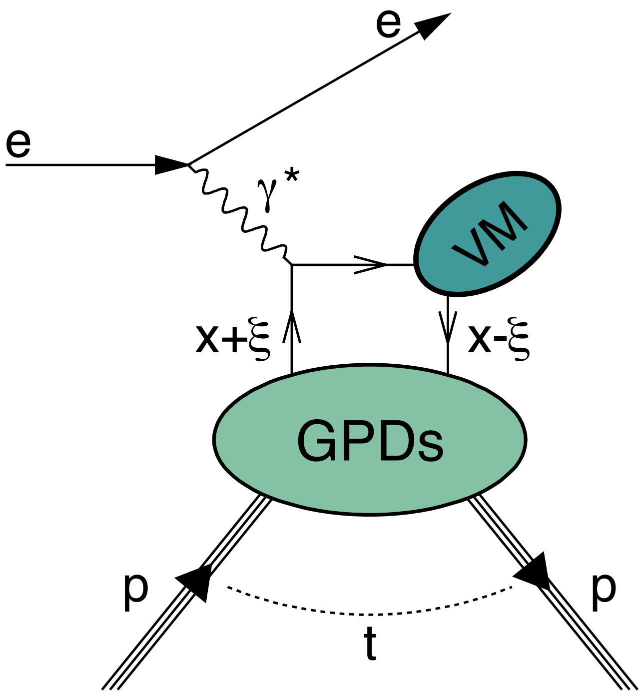


DVCS

GPDs and exclusive meson production

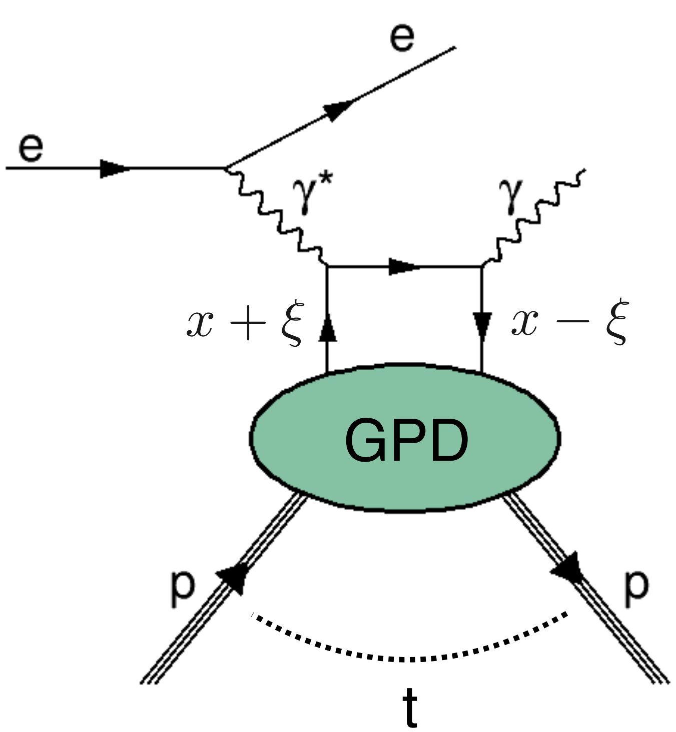


DVCS

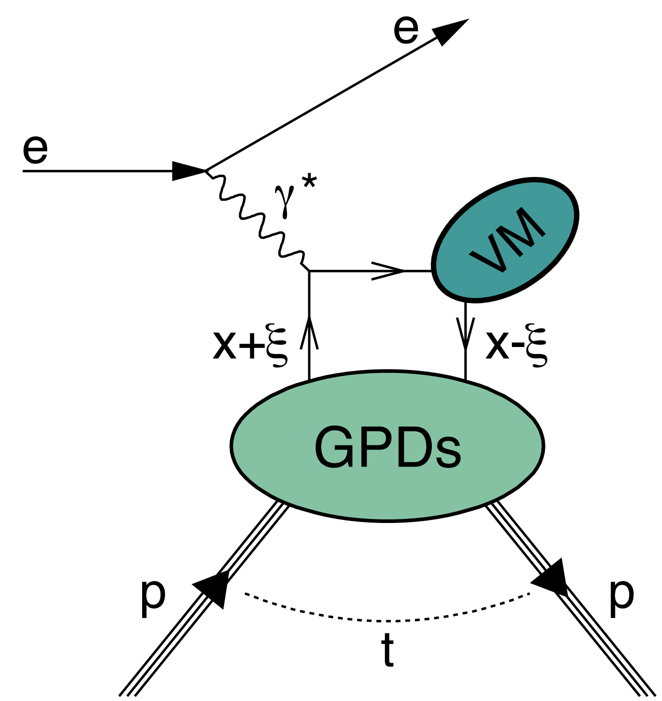


Exclusive meson production

GPDs and exclusive meson production



DVCS



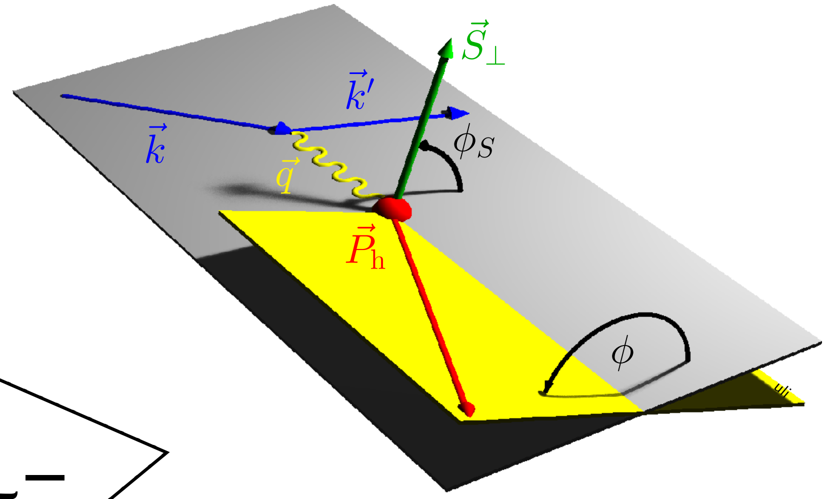
Exclusive meson production

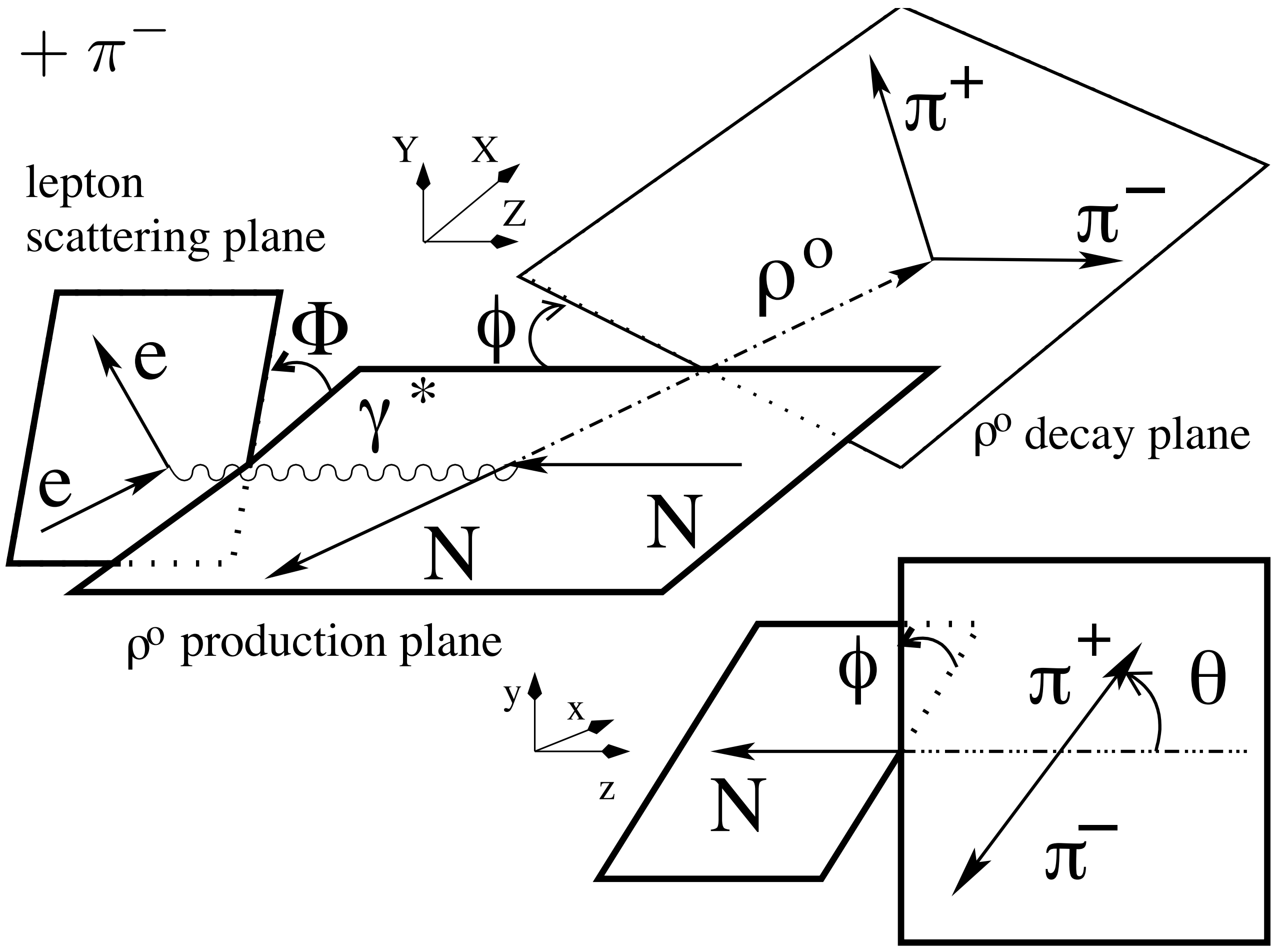
- complementary access to GPDs
- sensitive to different flavour combinations
- different sensitive to different types of GPDs, including transversity GPDs

Angular distributions

$$e + N \rightarrow e + N + \rho^0$$

$$\rho^0 \rightarrow \pi^+ + \pi^-$$

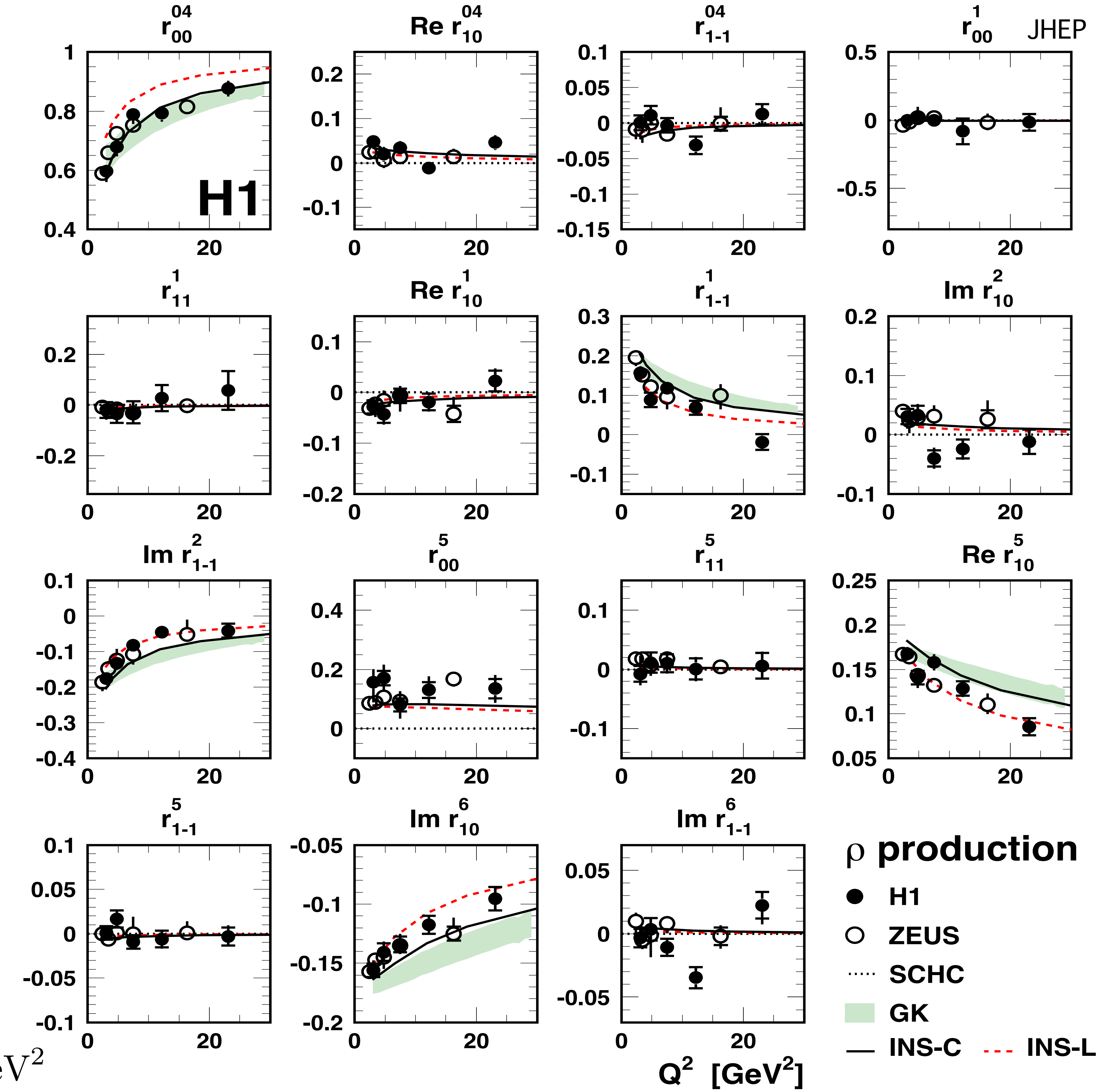




Fit angular distribution of decay pions $\mathcal{W}(\Phi, \phi, \Theta, \phi_S)$ and extract either Spin Density Matrix Elements (SDMEs) or helicity amplitude ratios

ρ^0 SDMEs: Q^2 dependence

JHEP 1005(2010)032

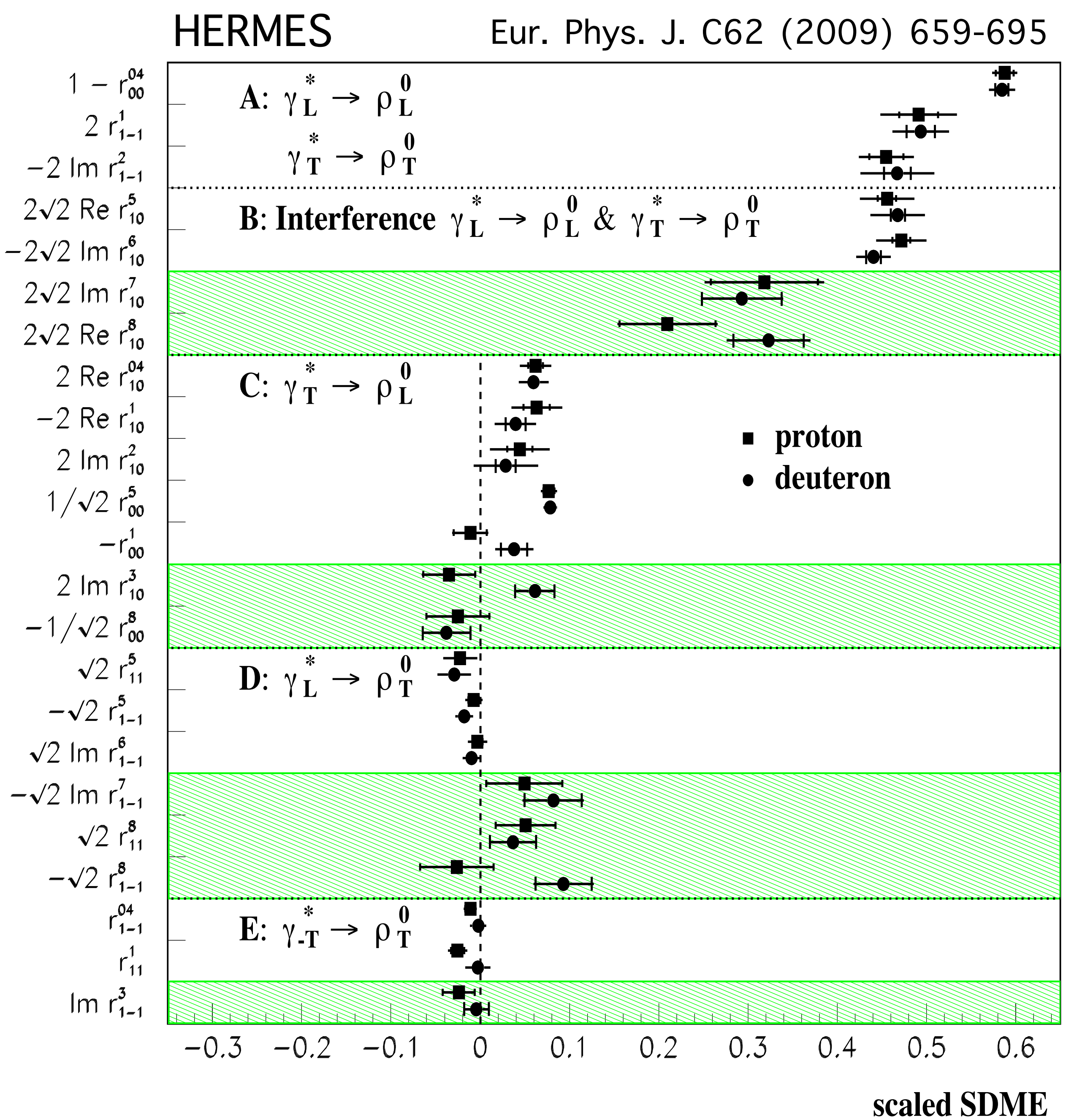


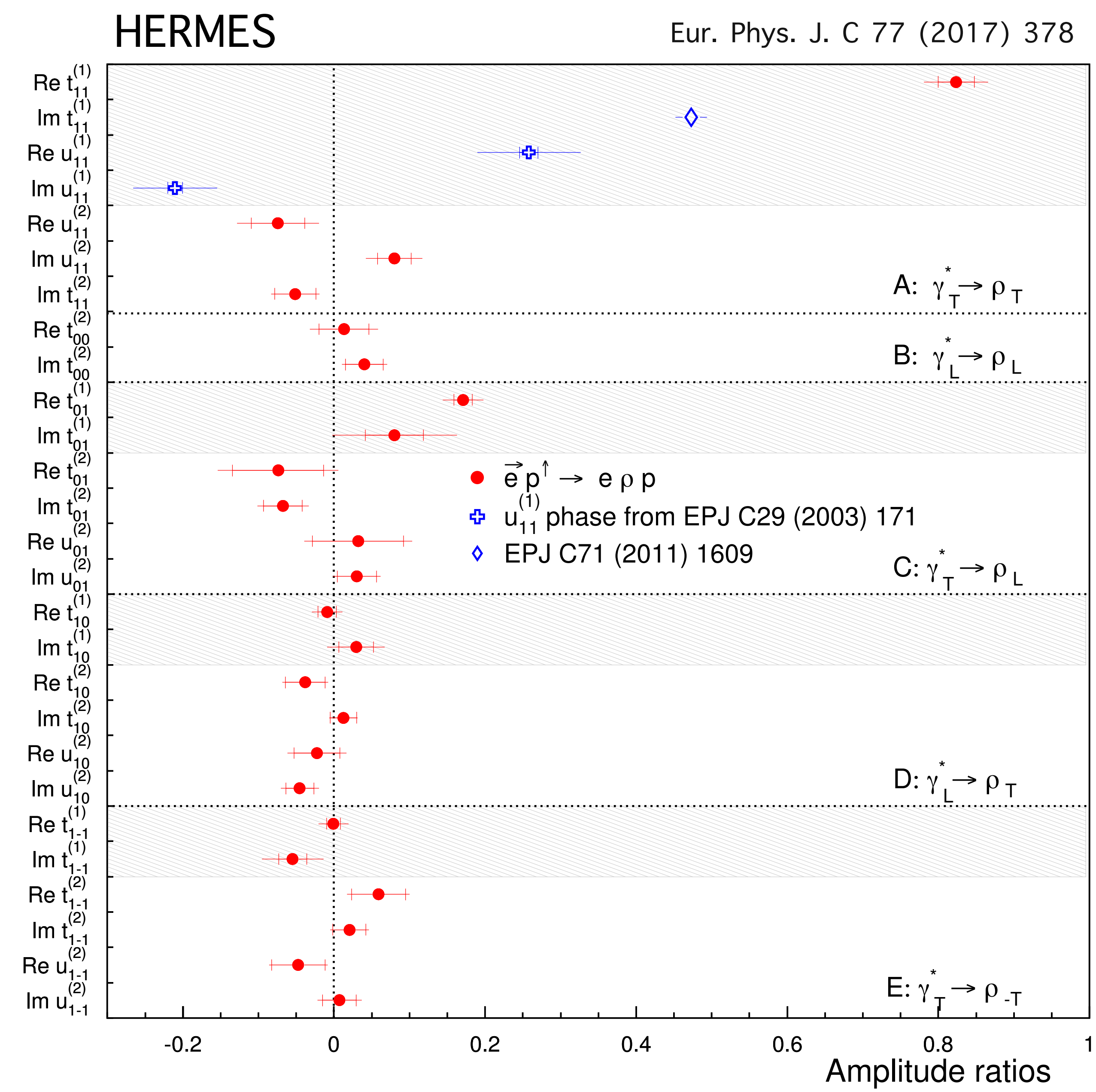
$10^{-4} \le x_B \le 10^{-2}$

$2\ \mathrm{GeV}^2 \le Q^2 \le 100\ \mathrm{GeV}^2$

$30\ \mathrm{GeV} \le W \le 300\ \mathrm{GeV}$

Polarisation





unpolarised and polarised SDMEs

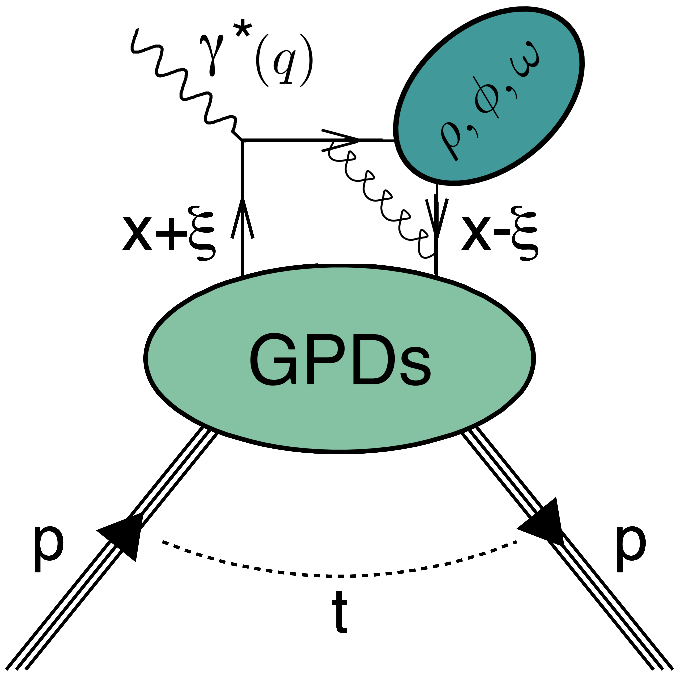
longitudinally polarised beam

unpolarised p and d target

unpolarised target

transversely polarised target

Exclusive meson production



Hard exclusive meson production

hard scale = large Q^2 (Q^2=-q^2)

CLAS – PRC 95 ('17) 035207; 95 (2017) 035202

COMPASS – PLB 731 ('14) 19; NPB 915 ('17) 454

JLab Hall A Collaboration – PRC 83 ('11) 025201

HERMES – EPJ C 74 ('14) 3110; 75 ('15) 600; 77 ('17) 378

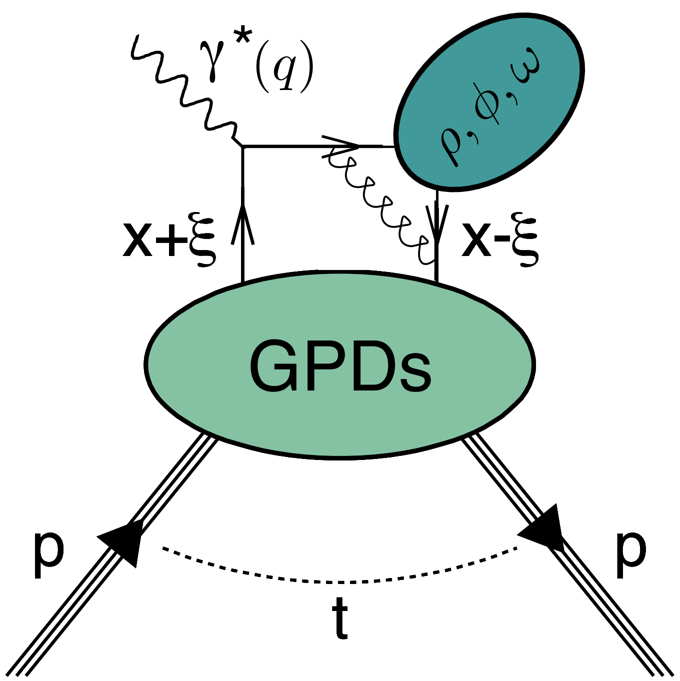
H1 – JHEP 05('10)032; EPJ C 46 ('06) 585

ZEUS – PMC Phys. A1 ('07) 6; NPB 695 ('04) 3

colliders, small x_B, gluons

fixed target: medium/large x_B , quarks

Exclusive meson production



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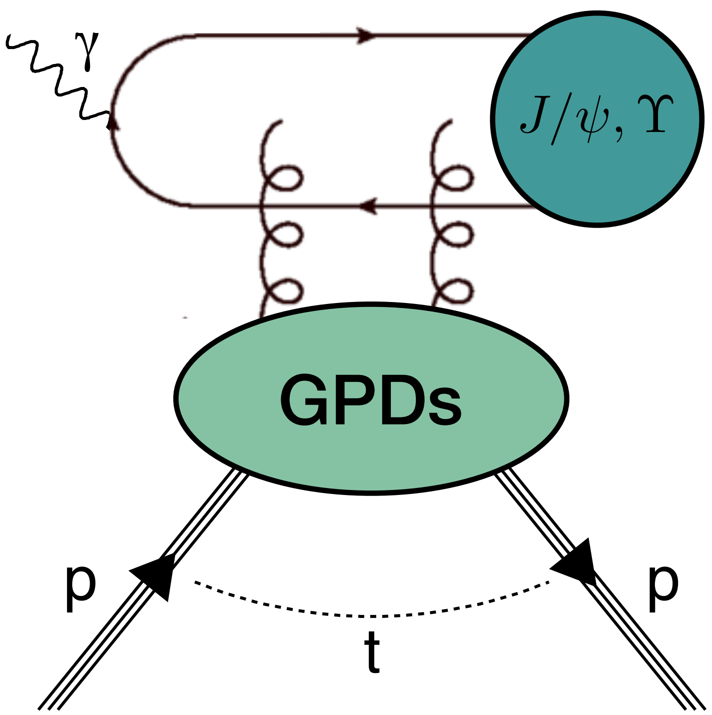

Exclusive meson photoproduction

hard scale = large vector meson mass

CLAS – PRC 95 ('17) 035207; 95 (2017) 035202

COMPASS – PLB 731 ('14) 19; NPB 915 ('17) 454

JLab Hall A Collaboration – PRC 83 ('11) 025201

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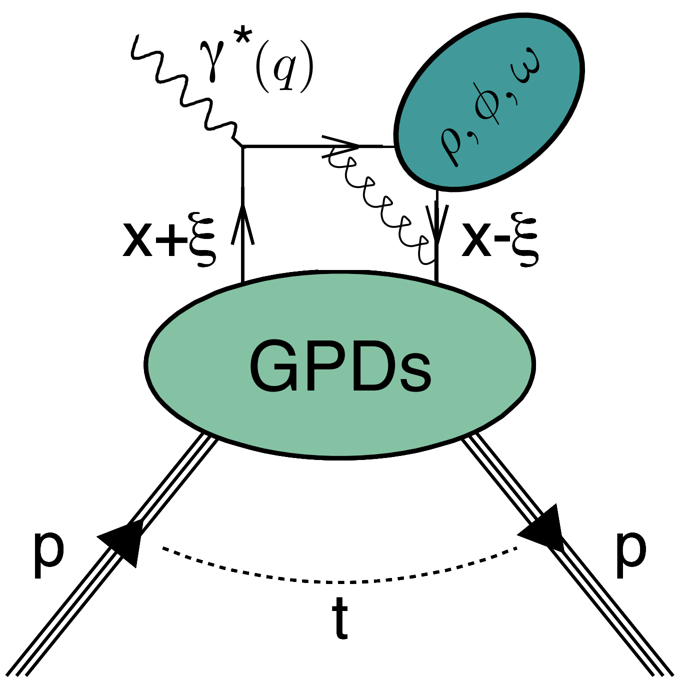
Exclusive meson production



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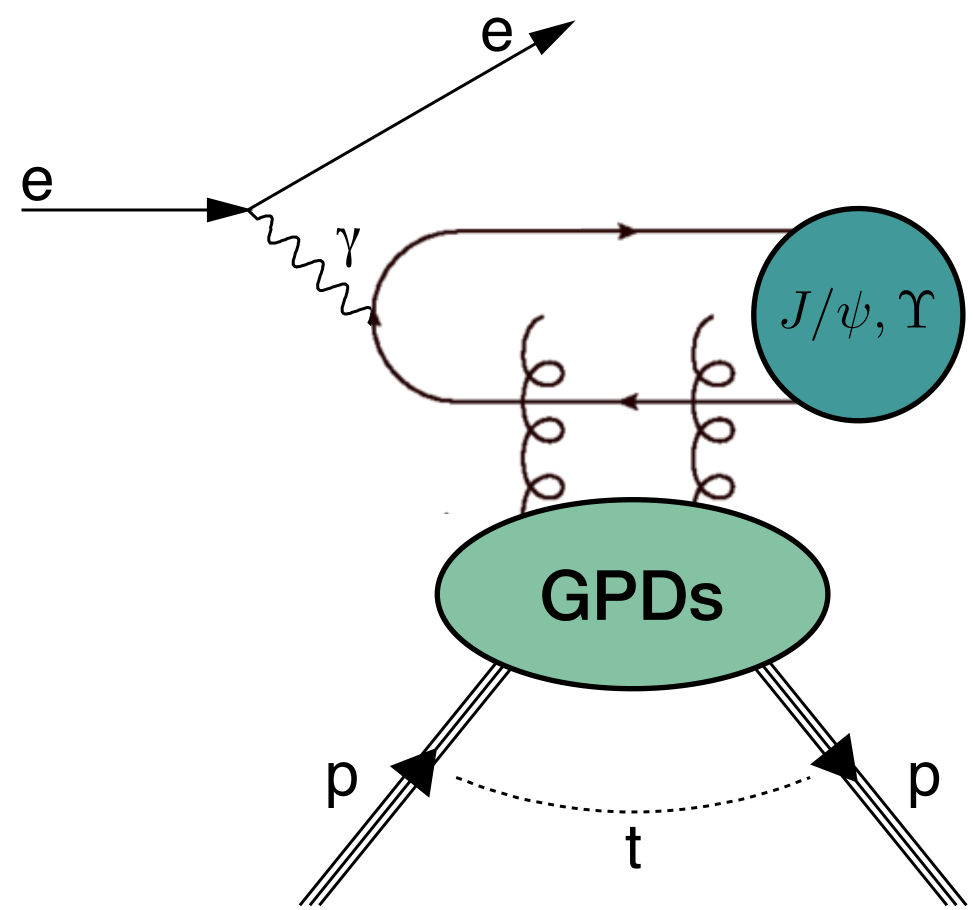

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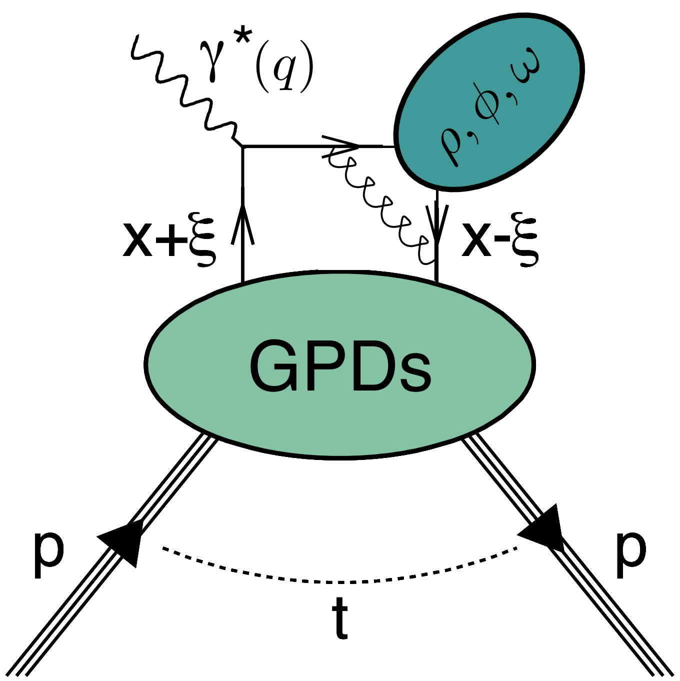

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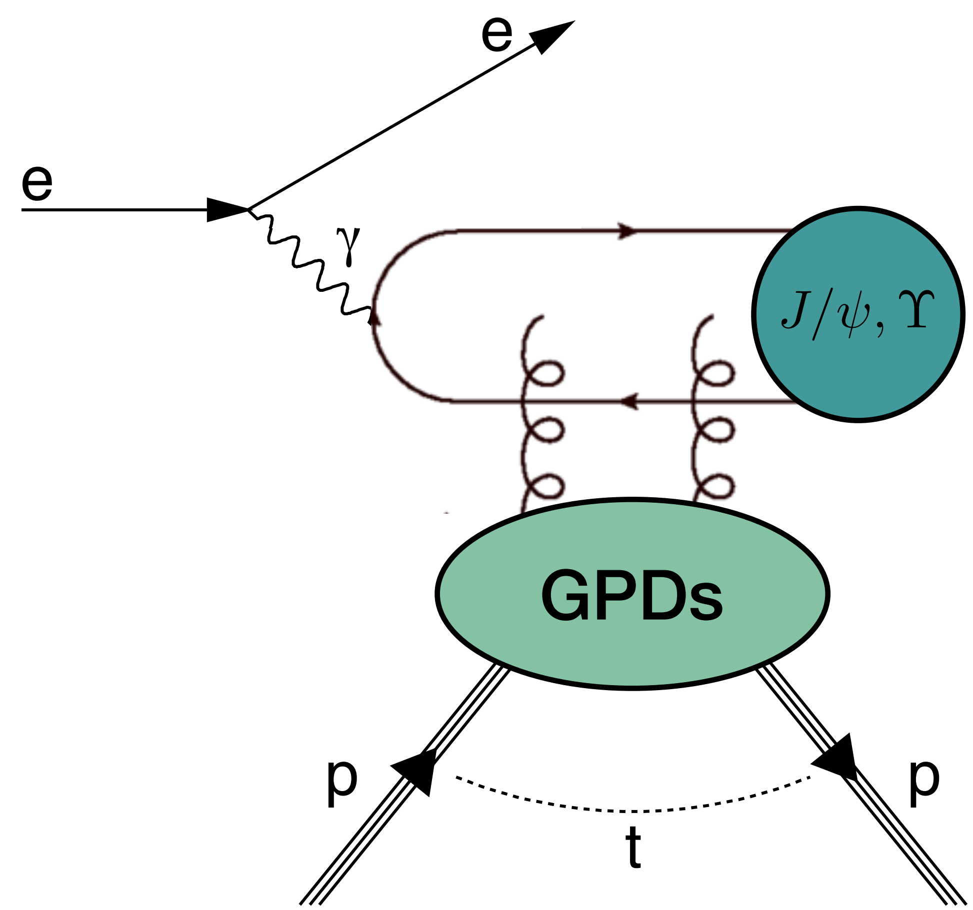

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COMPASS – PLB 731 ('14) 19; NPB 915 ('17) 454

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colliders, small x_B, gluons

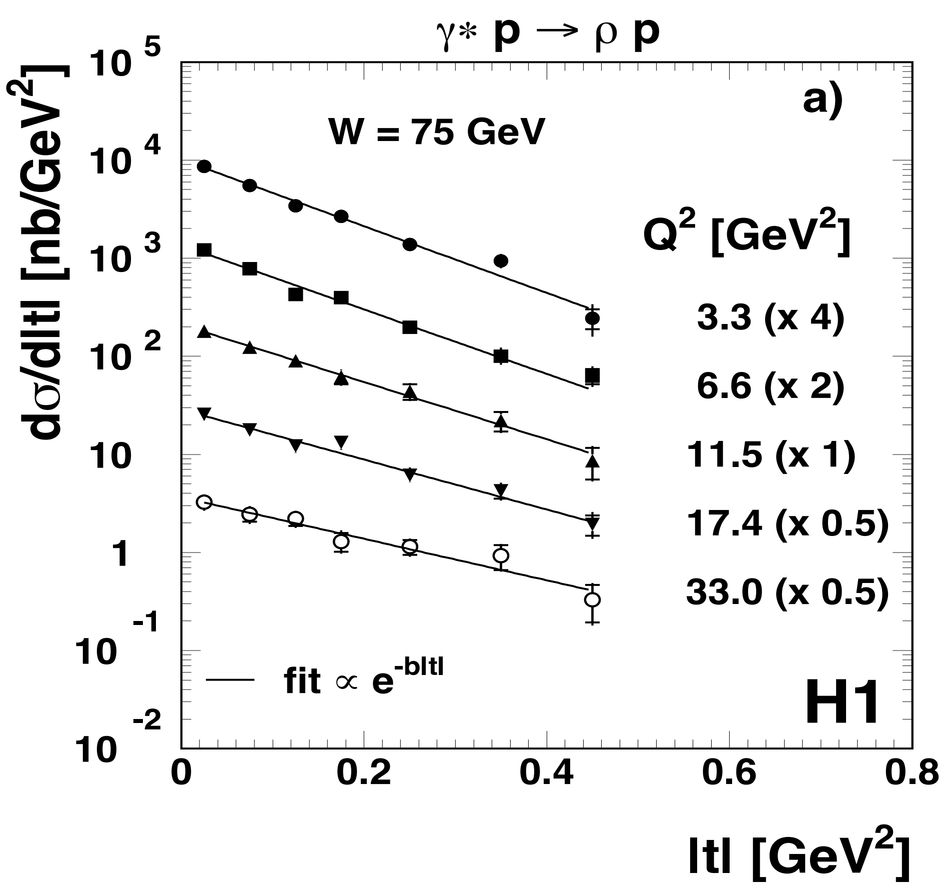
fixed target: medium/large x_B , quarks

H1 – EPJ C 46 ('06) 585; 73 ('13) 2466; PLB 541 ('02) 251

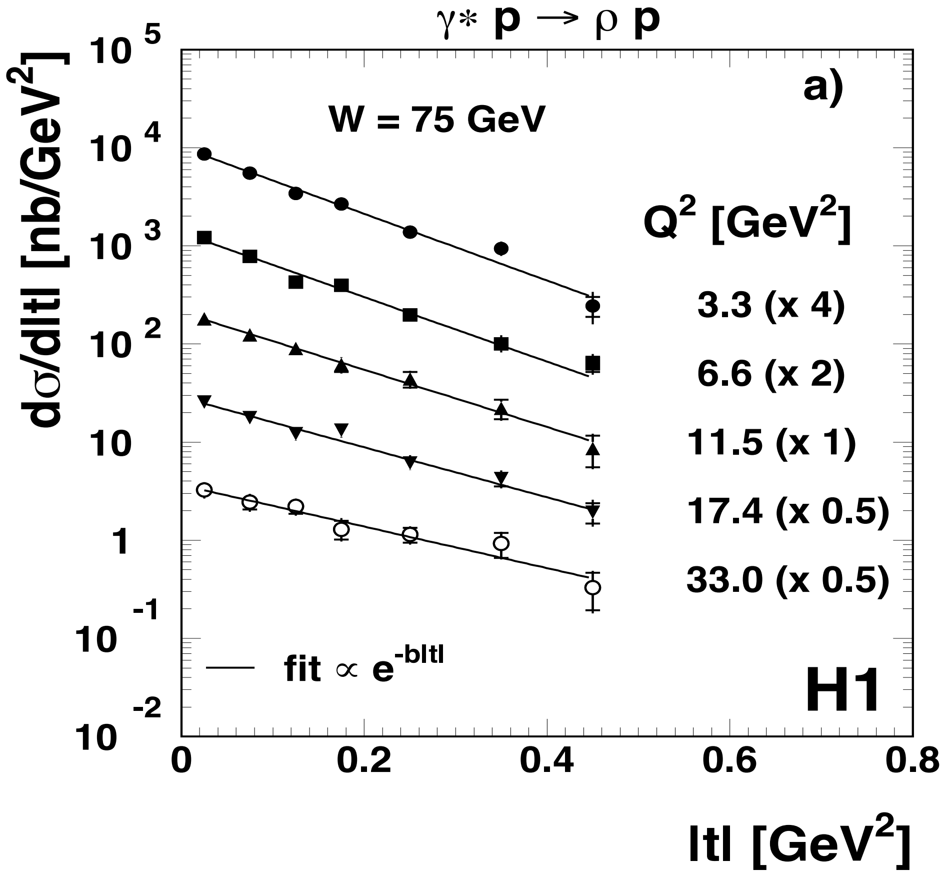
ZEUS – Nucl. Phys. B 695 ('04) 3; PLB 680 ('09) 4

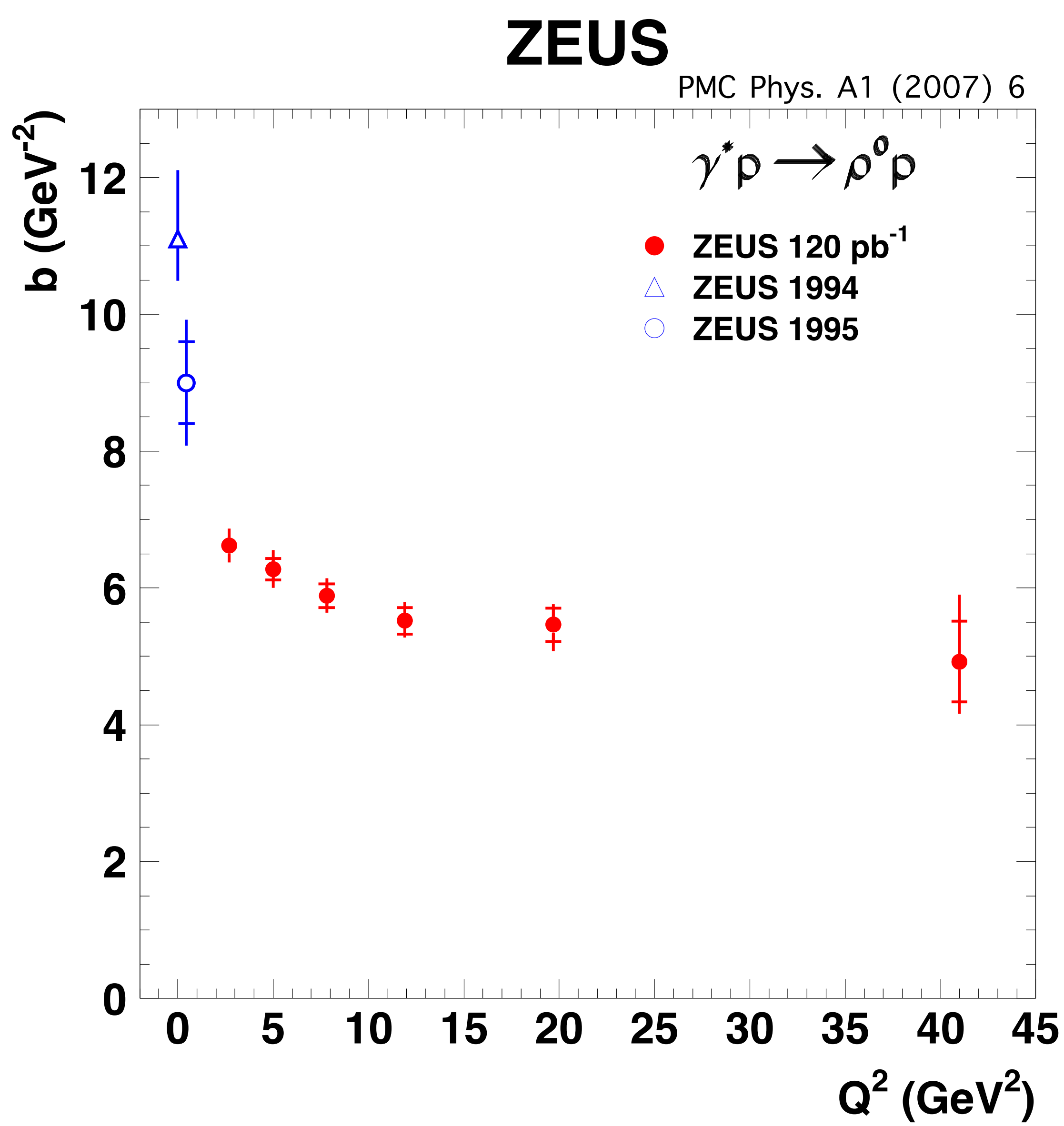
$$W_{\gamma p} = [30, 300] \text{ GeV}$$

t dependence

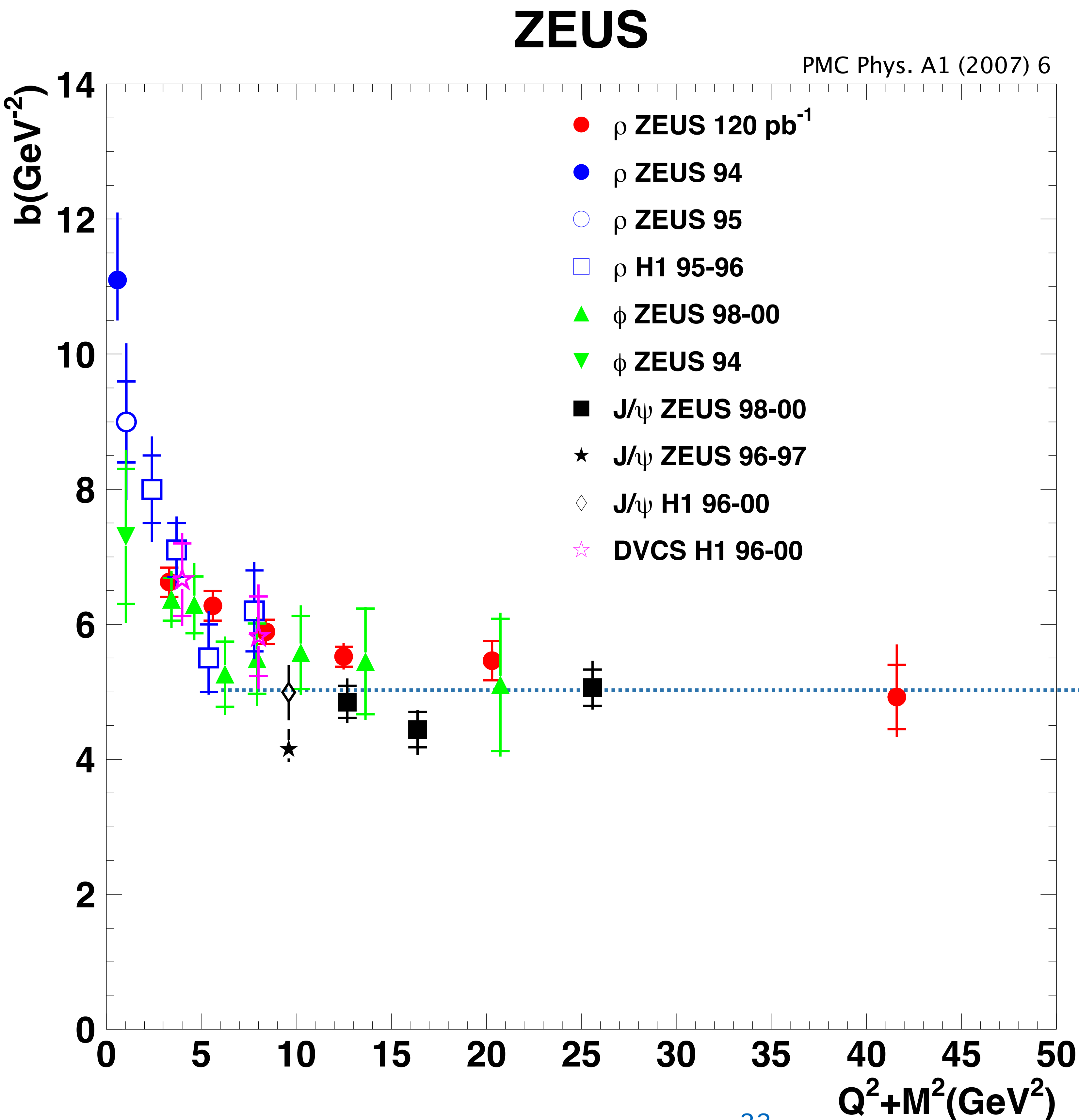


t dependence



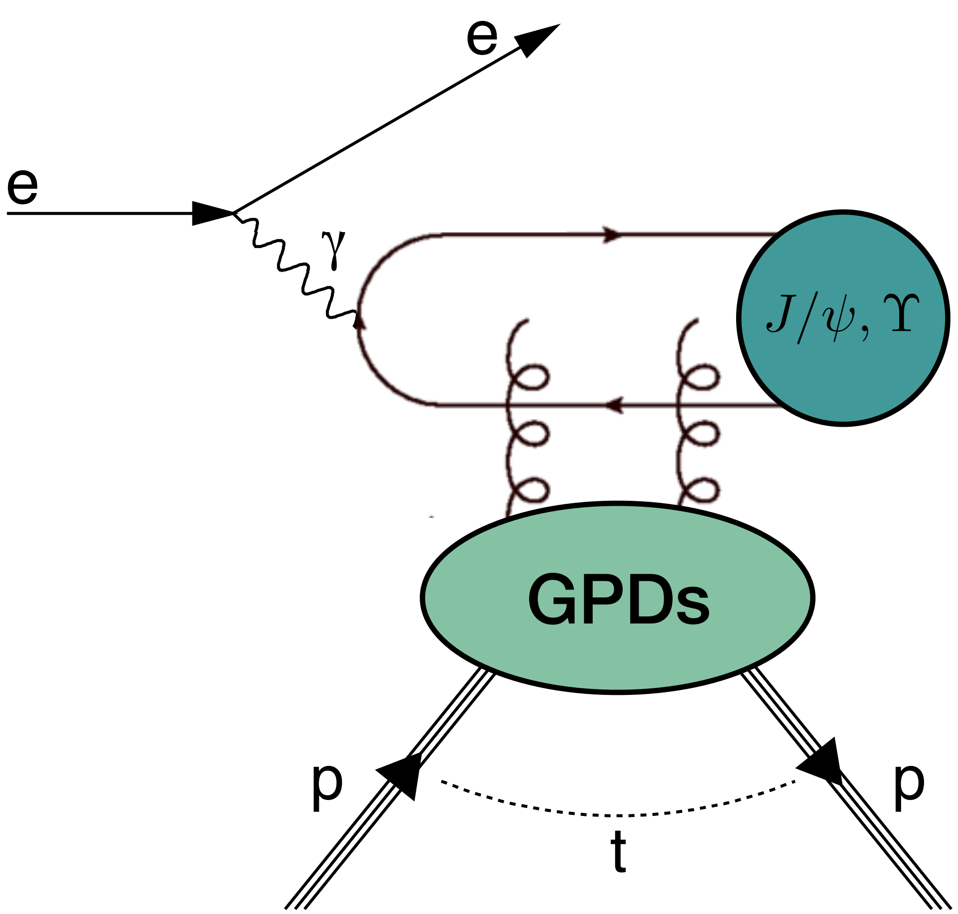


Q^2+M^2 dependence of b



$5\ \mathrm{GeV}^2:\ \langle r\rangle_g \sim 0.6\ \mathrm{fm}$

Exclusive meson production: ultra-peripheral collisions



Exclusive meson photoproduction

hard scale = large vector meson mass

H1 – EPJ C 46 ('06) 585; 73 ('13) 2466; PLB 541 ('02) 251

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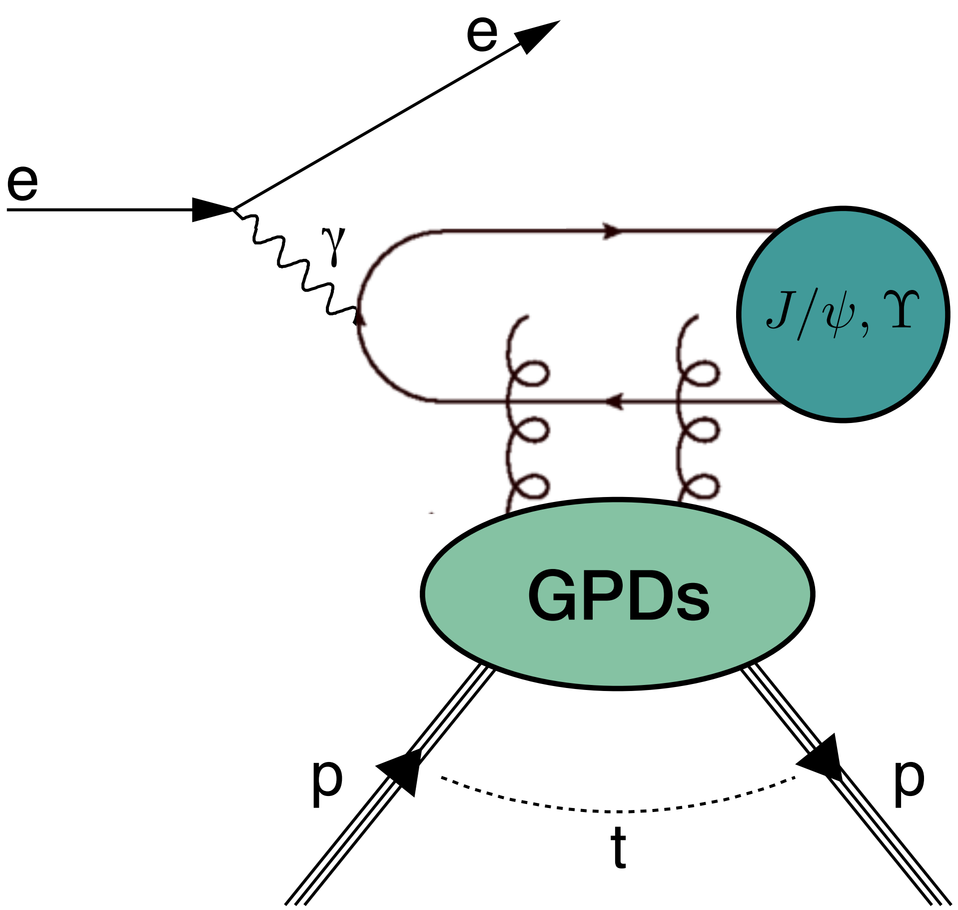
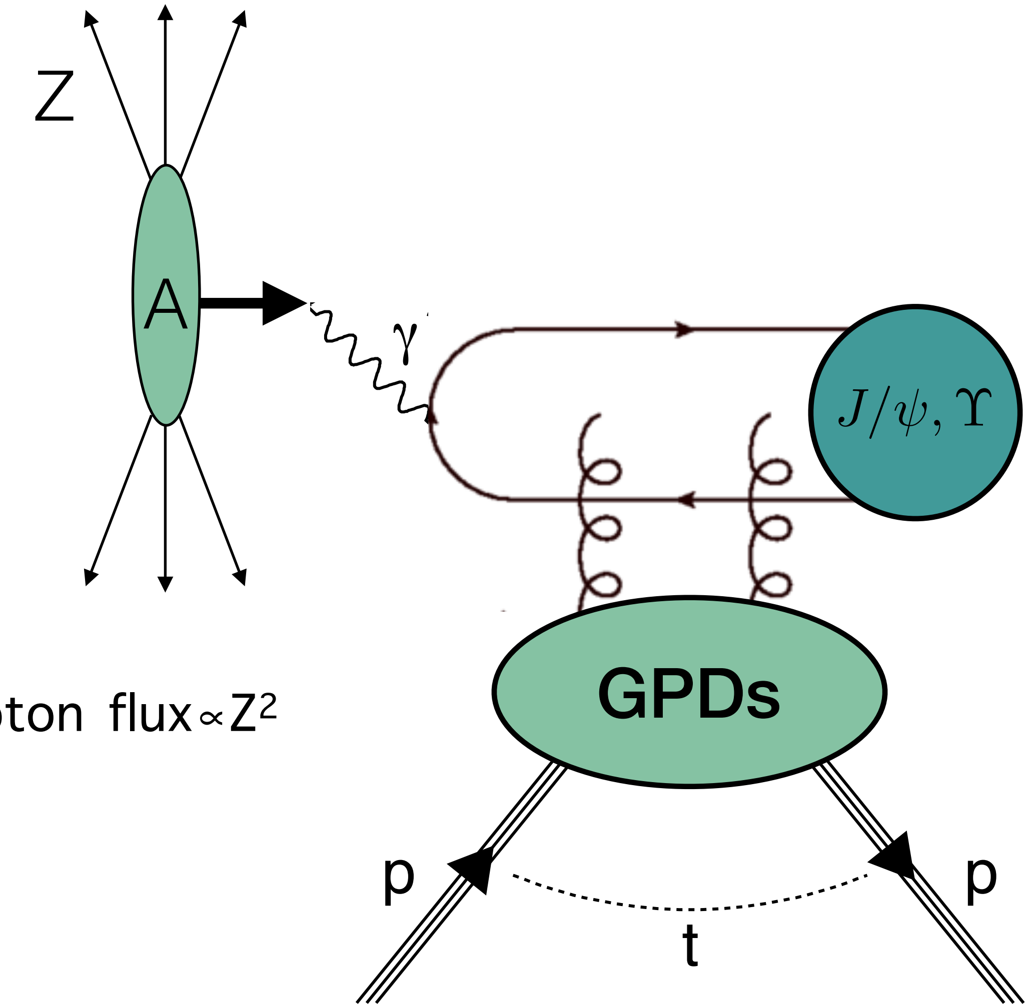
Exclusive meson production: ultra-peripheral collisions





photon flux ∝ Z^2

Exclusive meson photoproduction

hard scale = large vector meson mass

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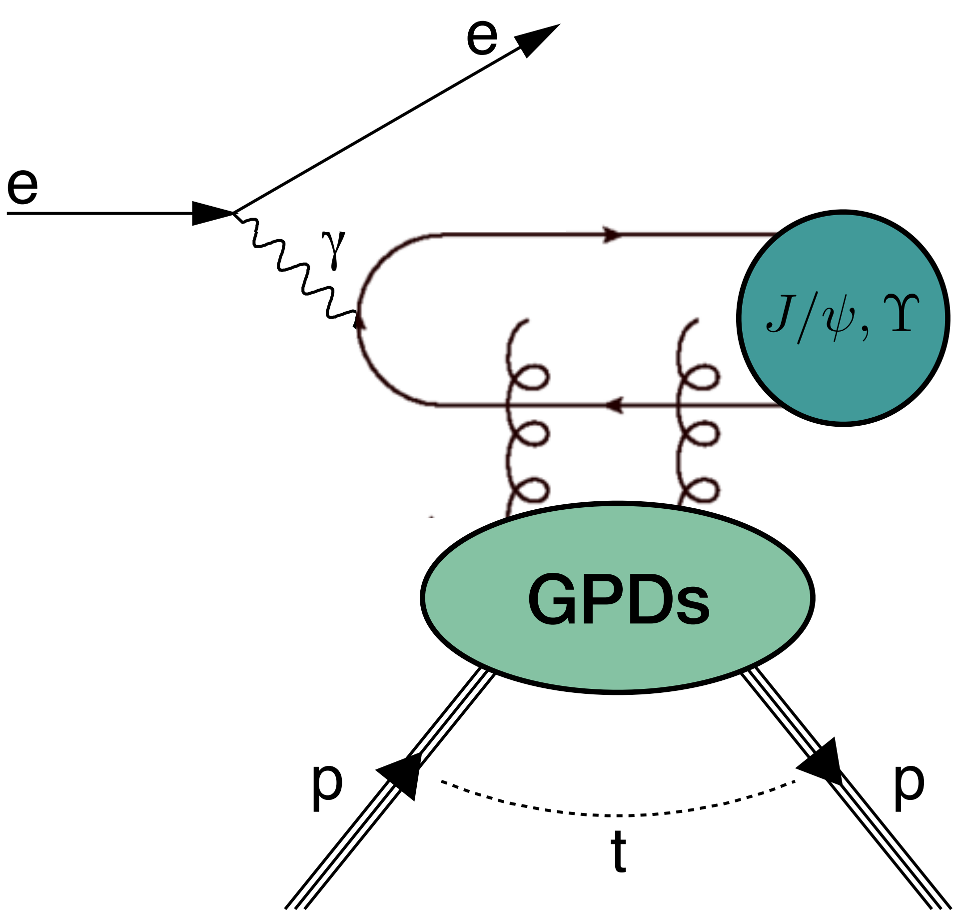

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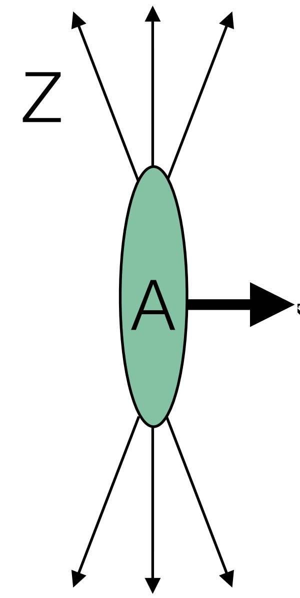
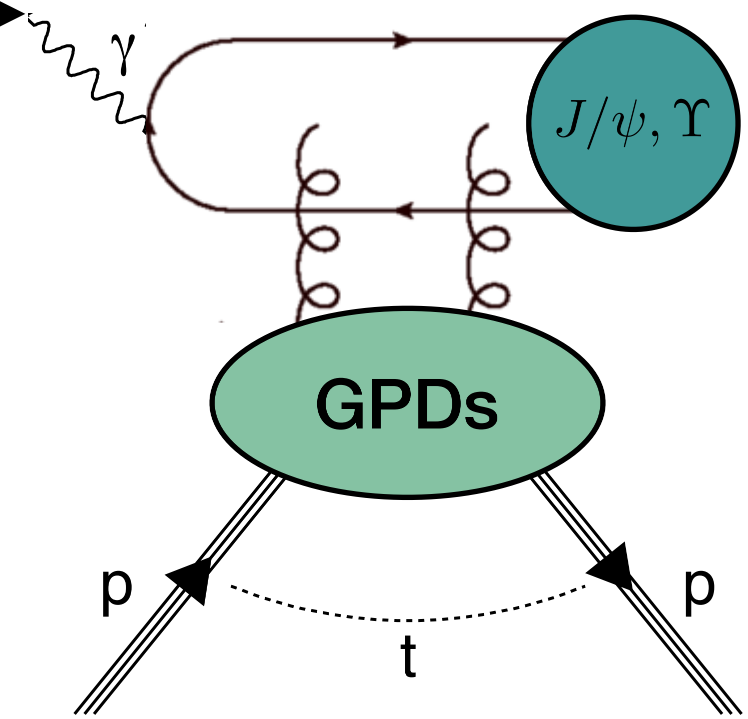


photon flux ∝ Z^2



$$W^{\max}_{\gamma N} = 34\ \mathrm{GeV}$$

PHENIX: Au-Au – Phys. Lett. B 679 ('09) 321.

CDF: p-p̄ – Phys. Rev. Lett. 102 ('09) 242001.

ALICE: Pb-Pb –
Eur. Phys. J. C 73 ('13) 2617; Phys. Lett. B 718 ('13) 1273.

ALICE: p-Pb – Phys. Rev. Lett. 113 ('14) 232504.

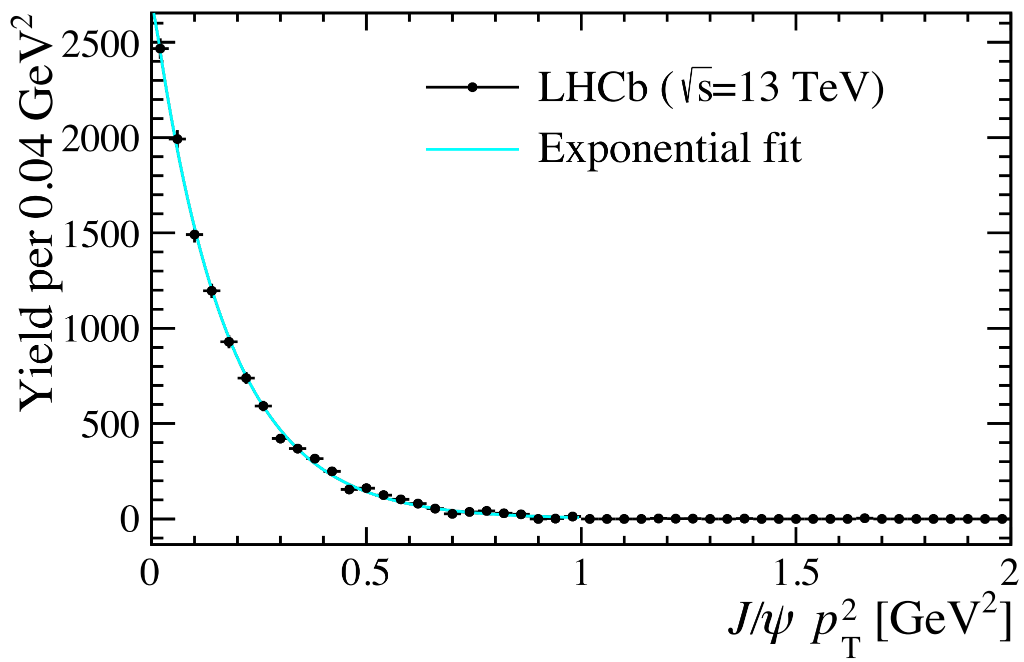
LHCb: pp – J. Phys. G: Nucl. Part. Phys. 40 ('13) 045001; 41 ('14) 055002, arXiv:1806.04079, JHEP 1509 (2015) 084).

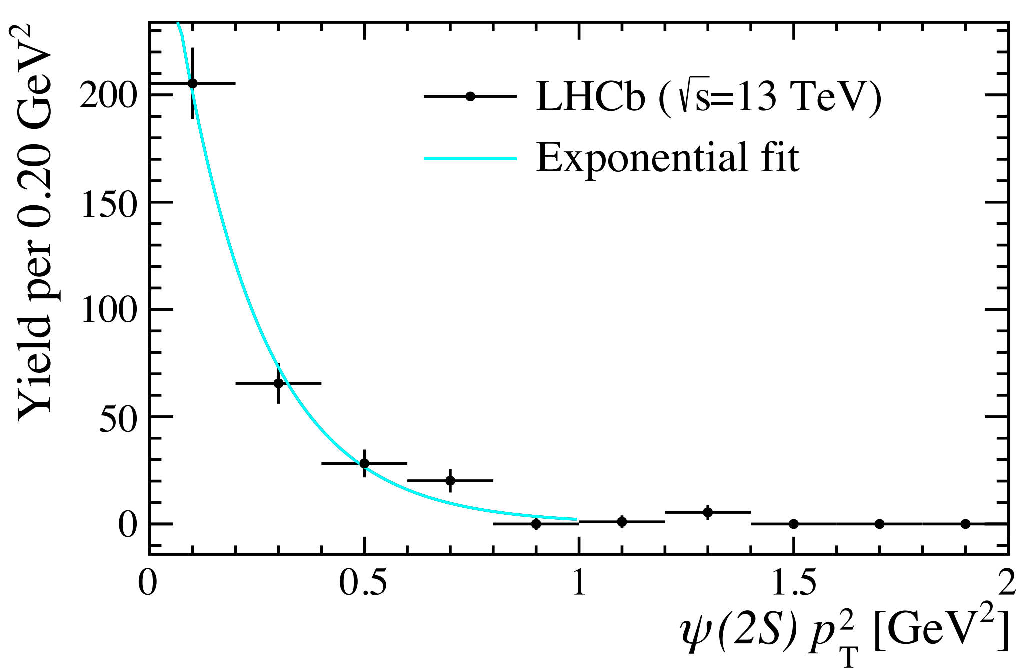
LHCb: PbPb – CERN-LHCb-CONF-2018-003

$$W^{\max}_{\gamma p} = 1.5\ \mathrm{TeV}$$

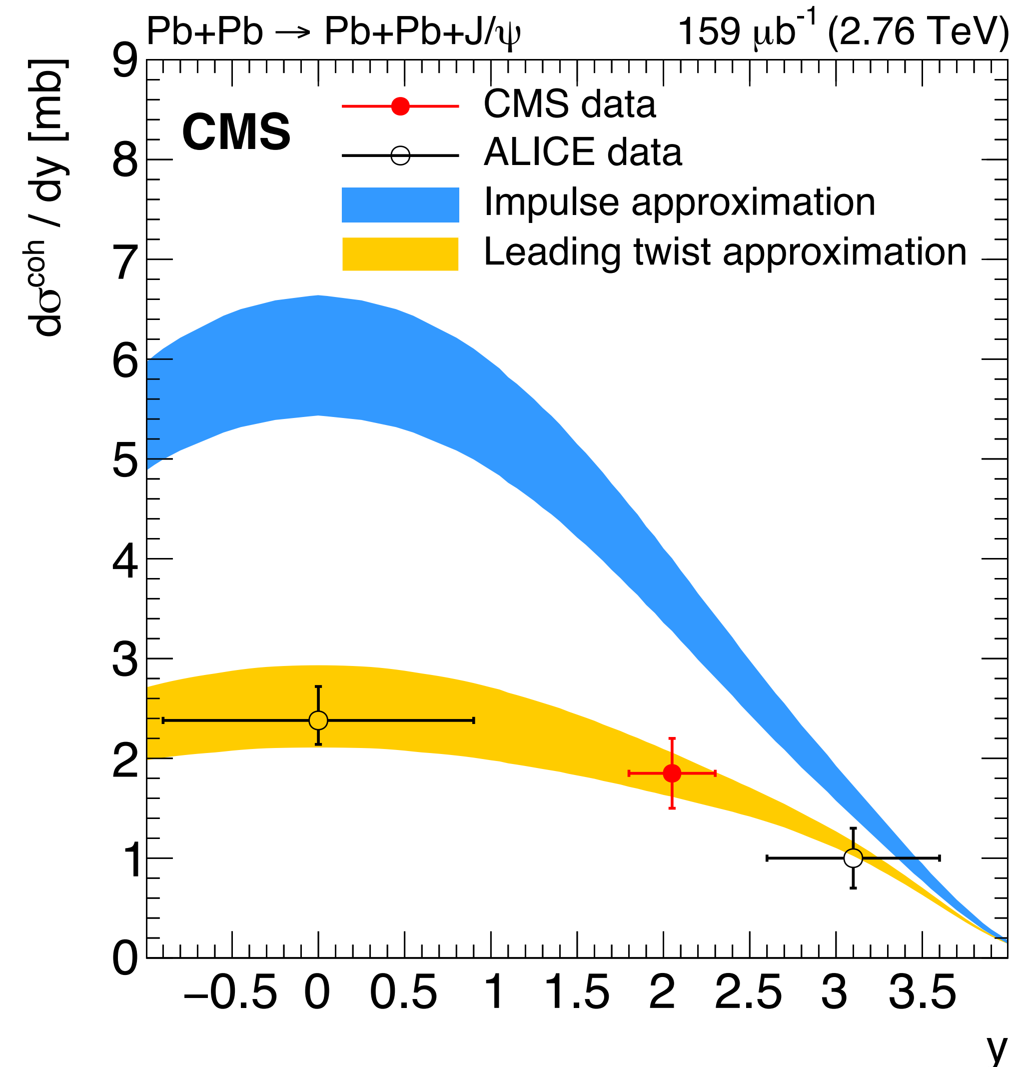
Ultra-peripheral collisions

LHCb, JHEP 10 (2018) 167





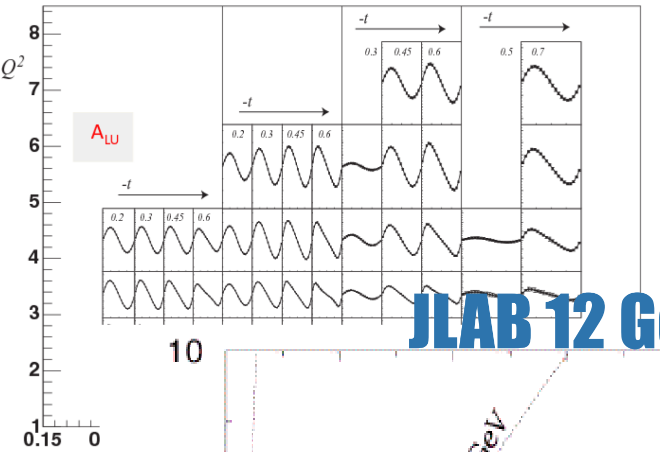
Phys. Lett. B 772 (2017) 489



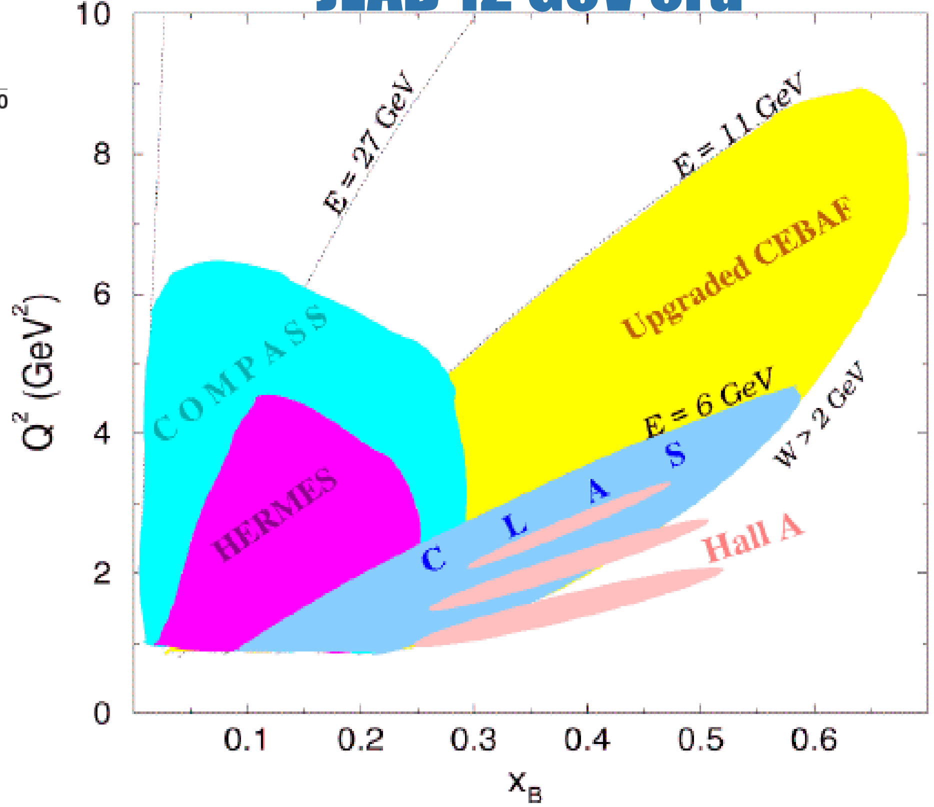
High energy of LHC

→ extend gluon GPDs, down to $x_B = 10^{-5}$!

Outlook



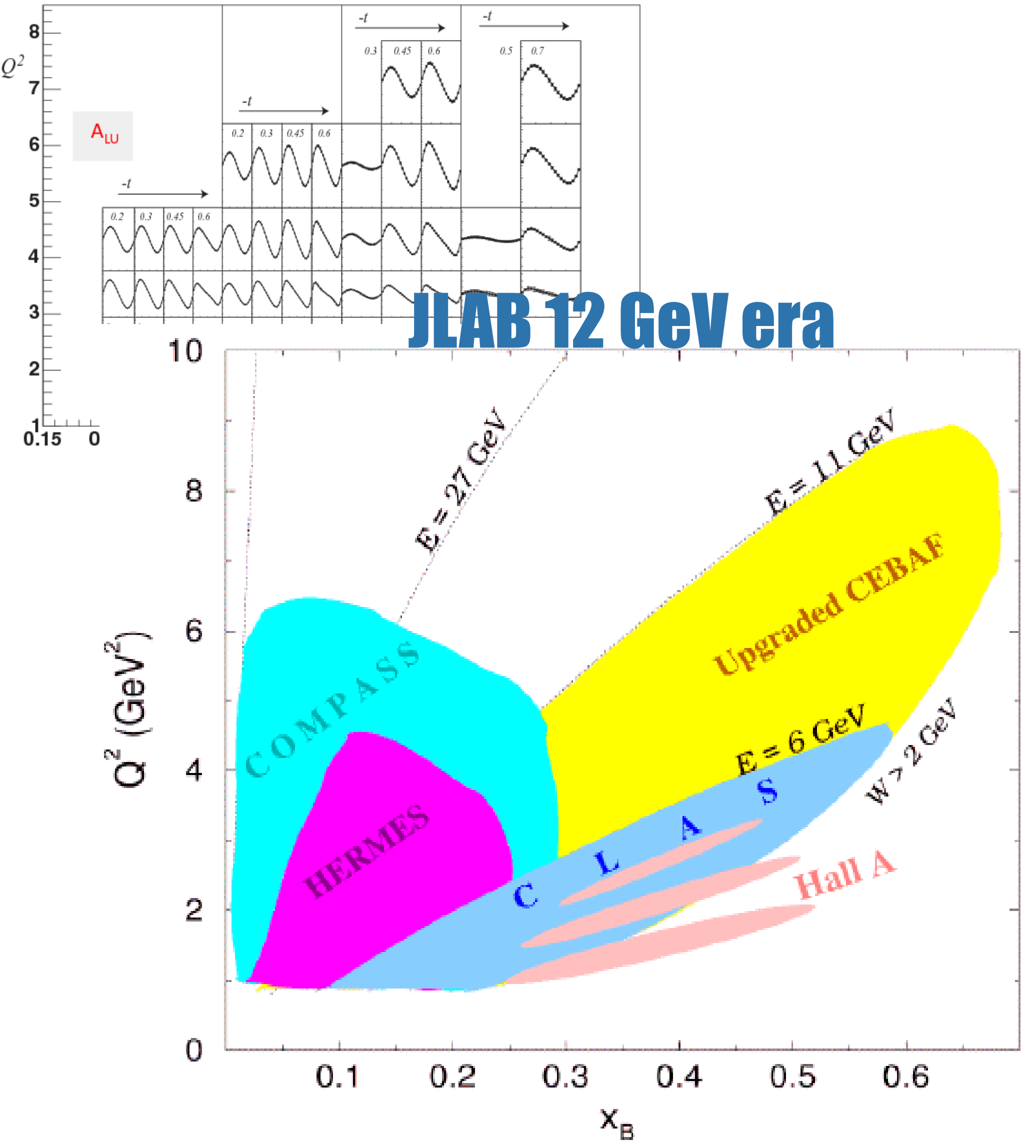
JLAB 12 GeV era

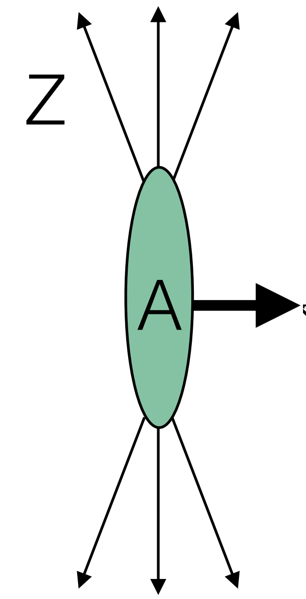


NOW!

Outlook

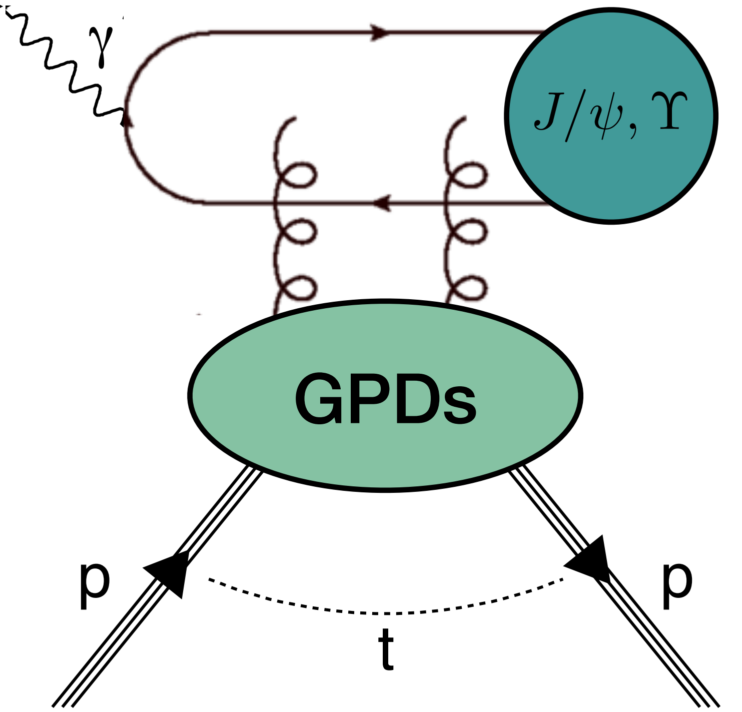
JLAB 12 GeV era





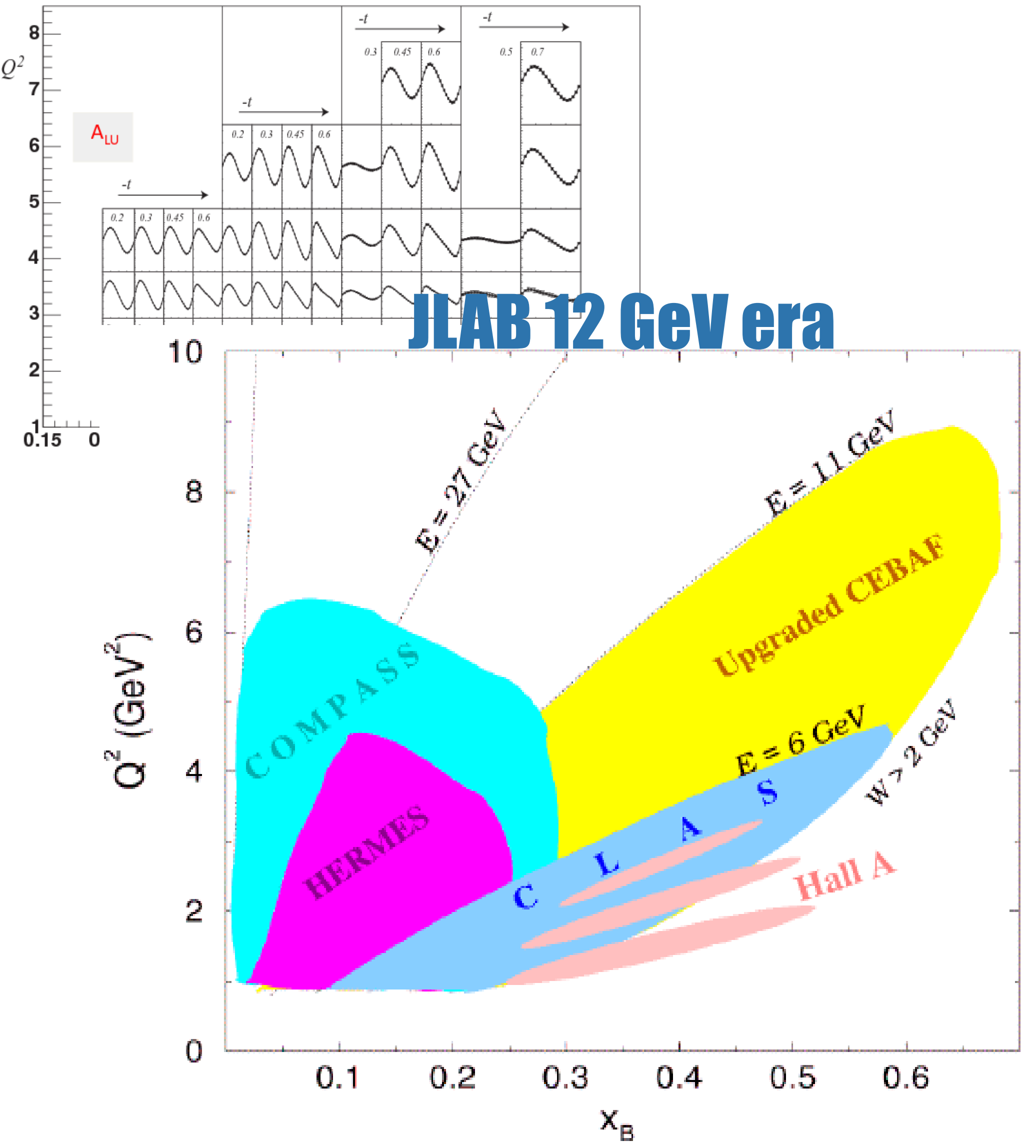
photon flux $\propto Z^2$

UPCs

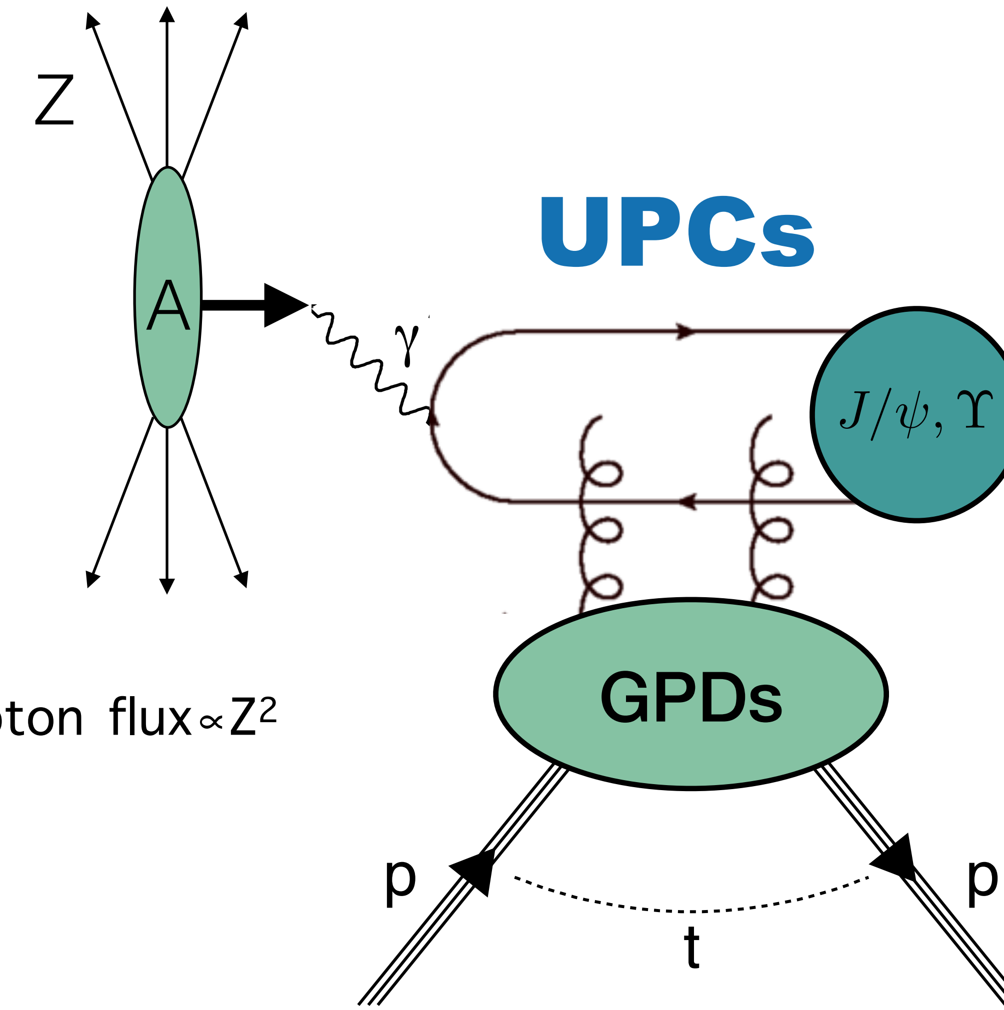


NOW!

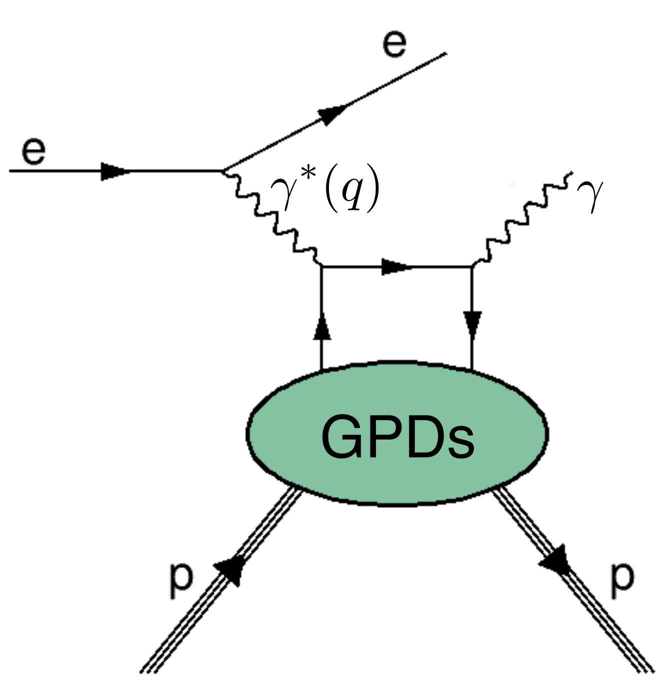
Outlook



NOW!

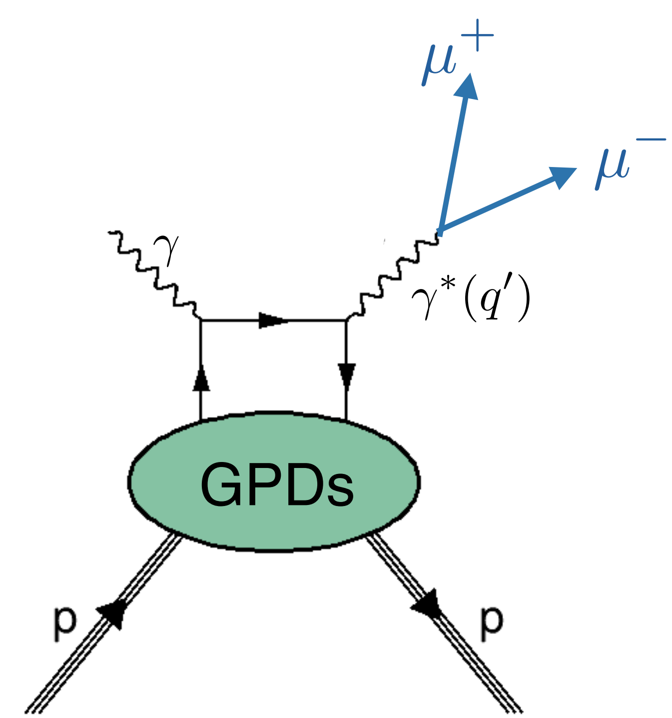


photon flux ∝ Z^2



Deeply virtual Compton scattering

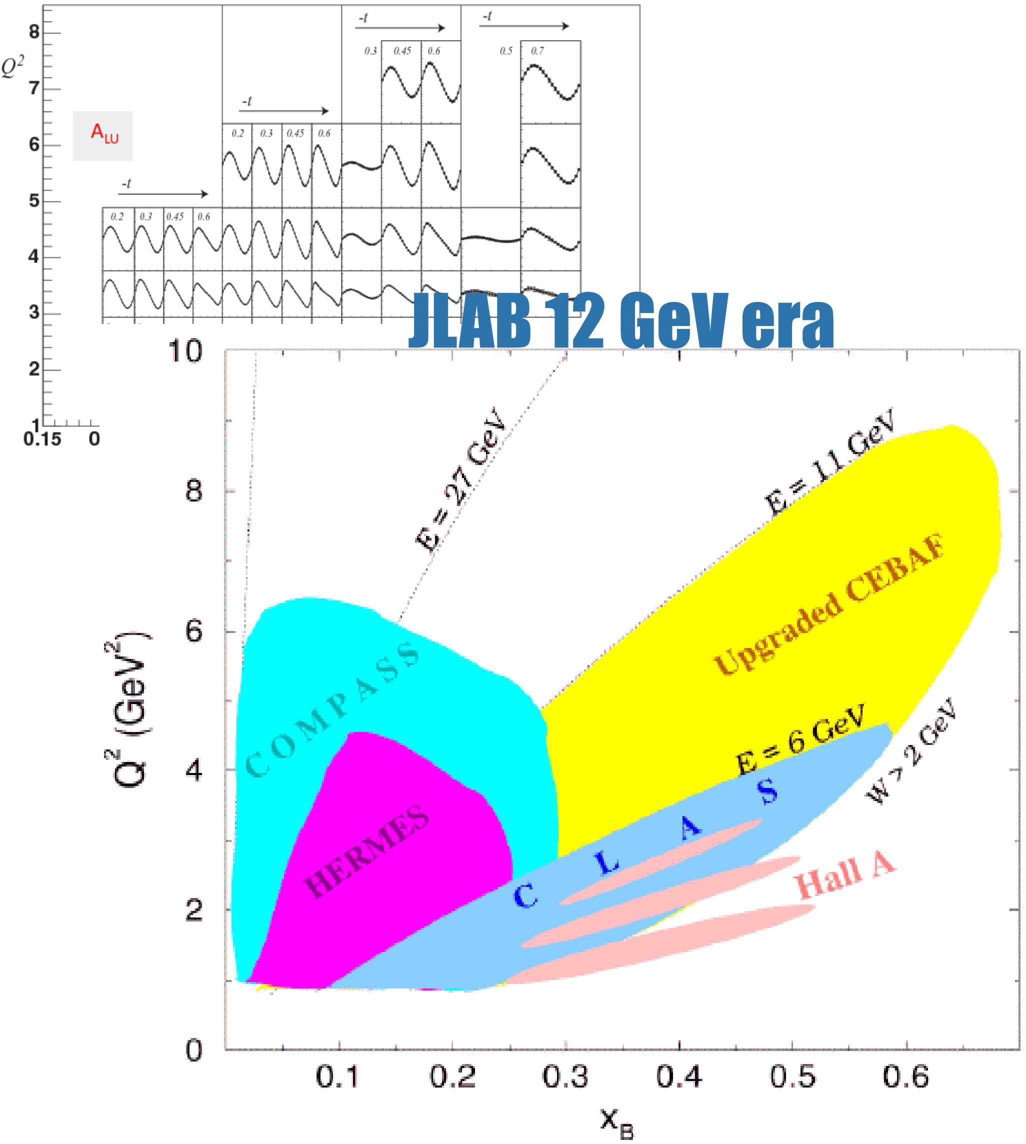
hard scale = large Q^2



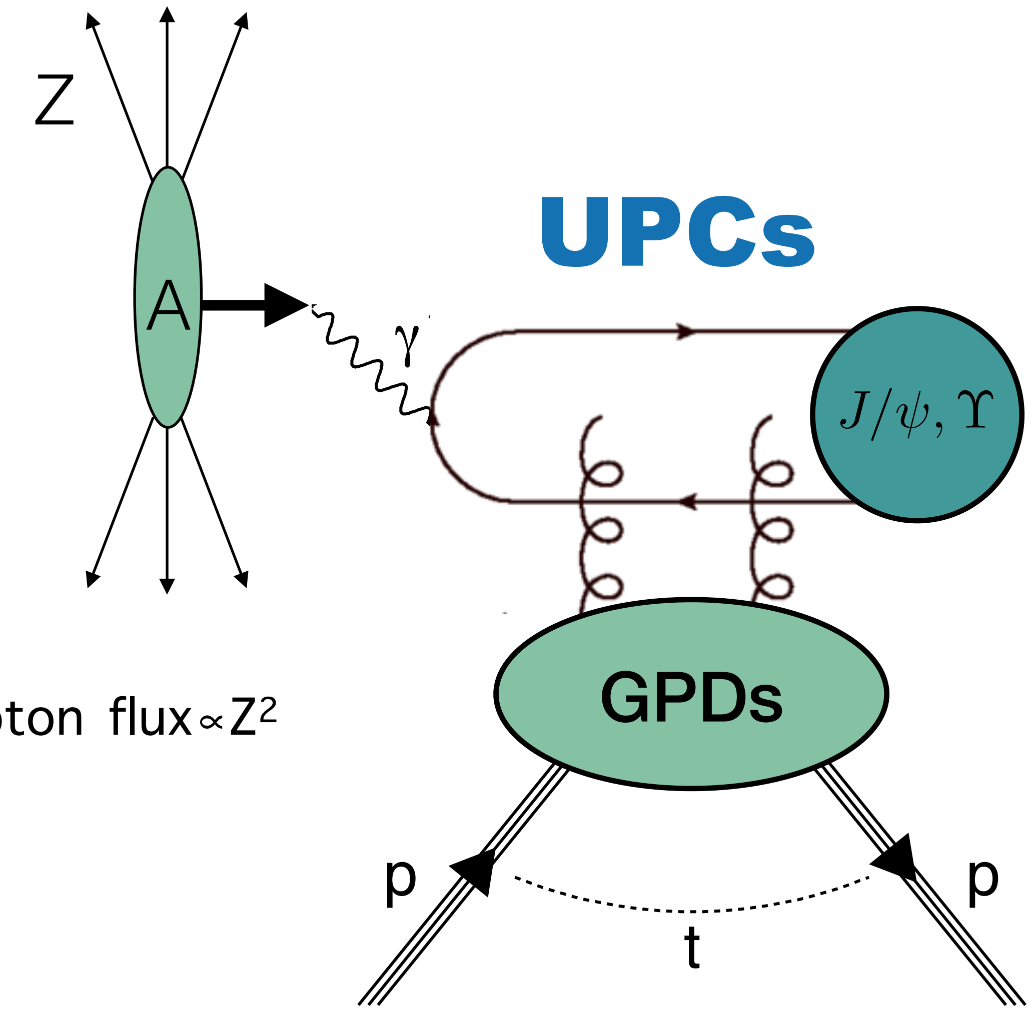
Timelike Compton scattering

hard scale = large Q'^2

Outlook

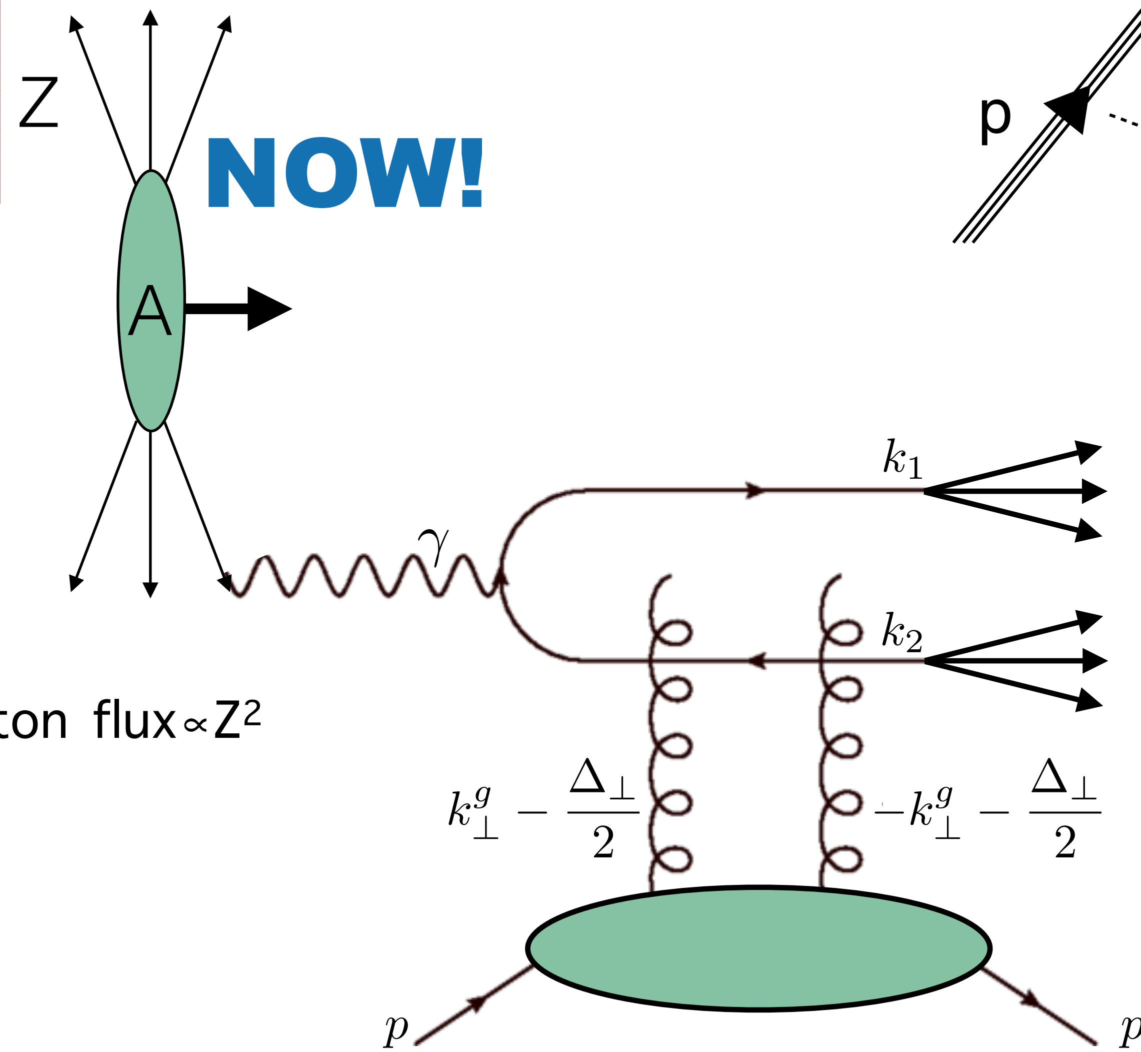


UPCs



photon flux∝Z^2

NOW!



photon flux∝Z^2

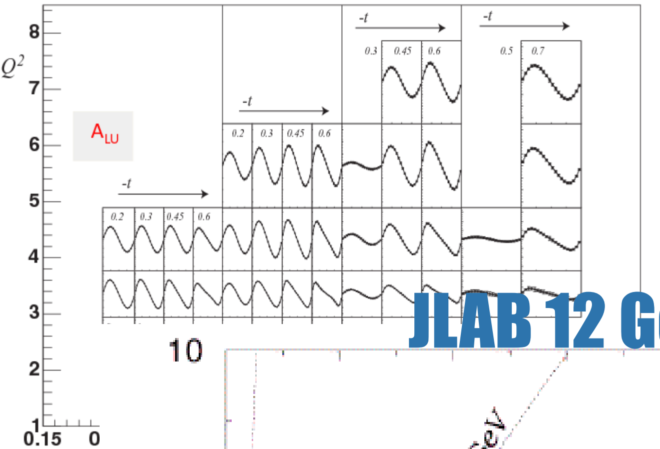
Wigner distributions

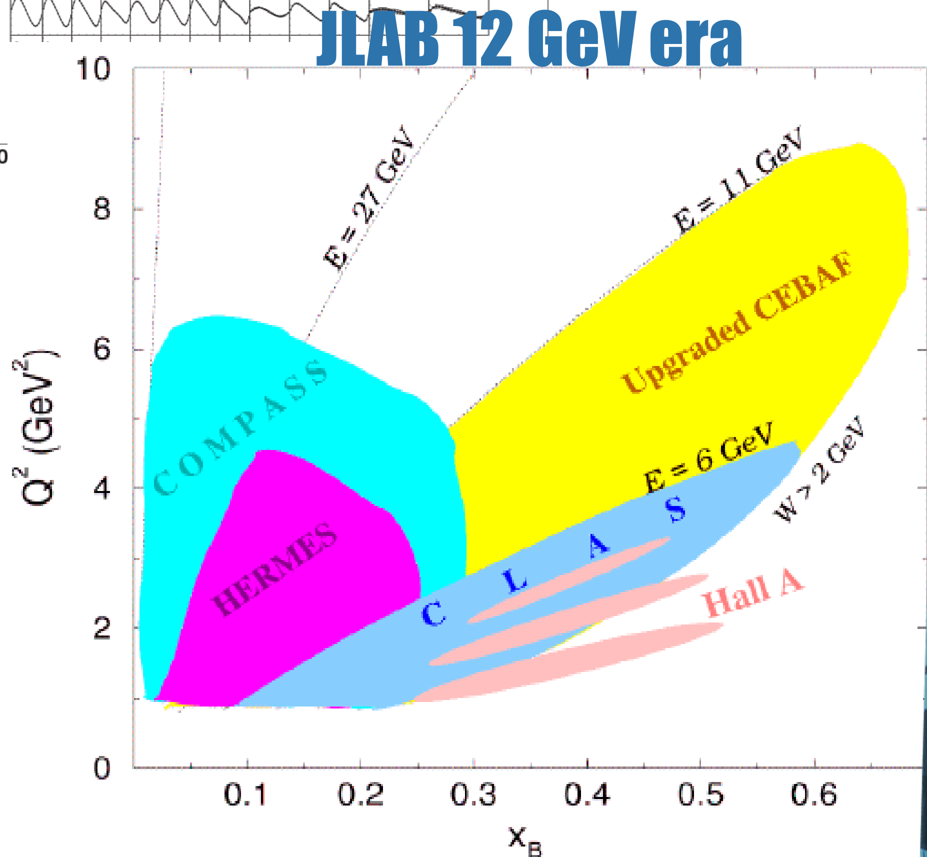
$$W(x, \vec{k}_T, \vec{b}_\perp)$$

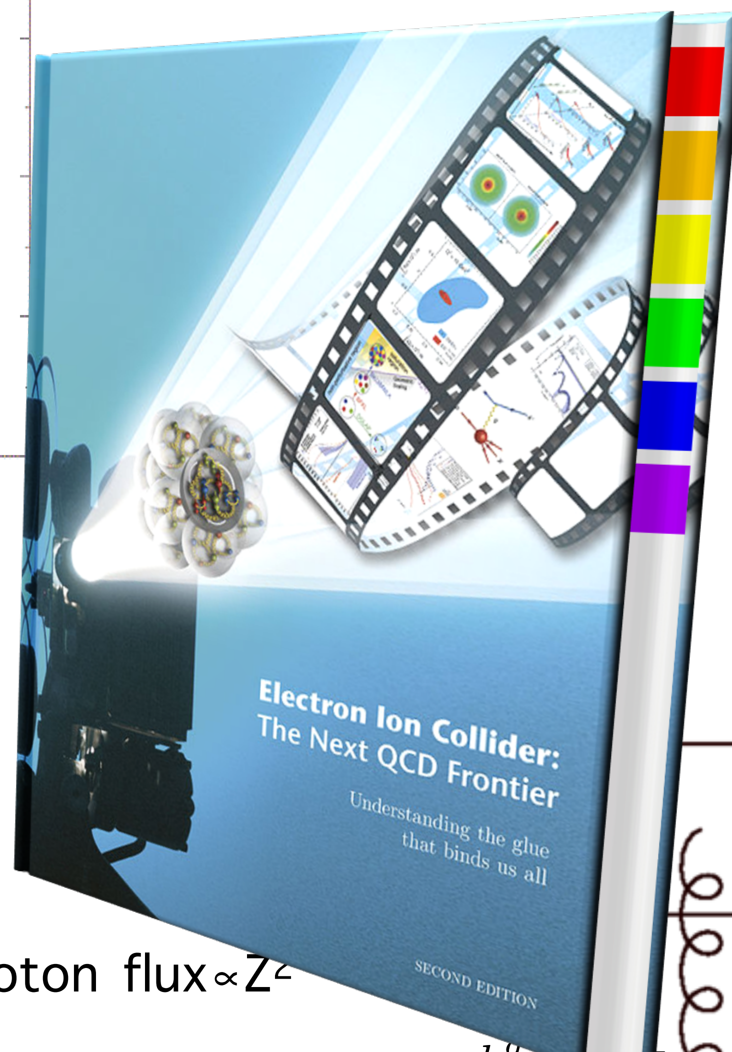
Exclusive production of dijets or heavy di-mesons

Y. Hatta et al., PRL 116 (2016) 202301
Y. Hagiwara et al., PRD 96 (2017) 034009
M. Pelicer et al., arXiv: 1811.12888

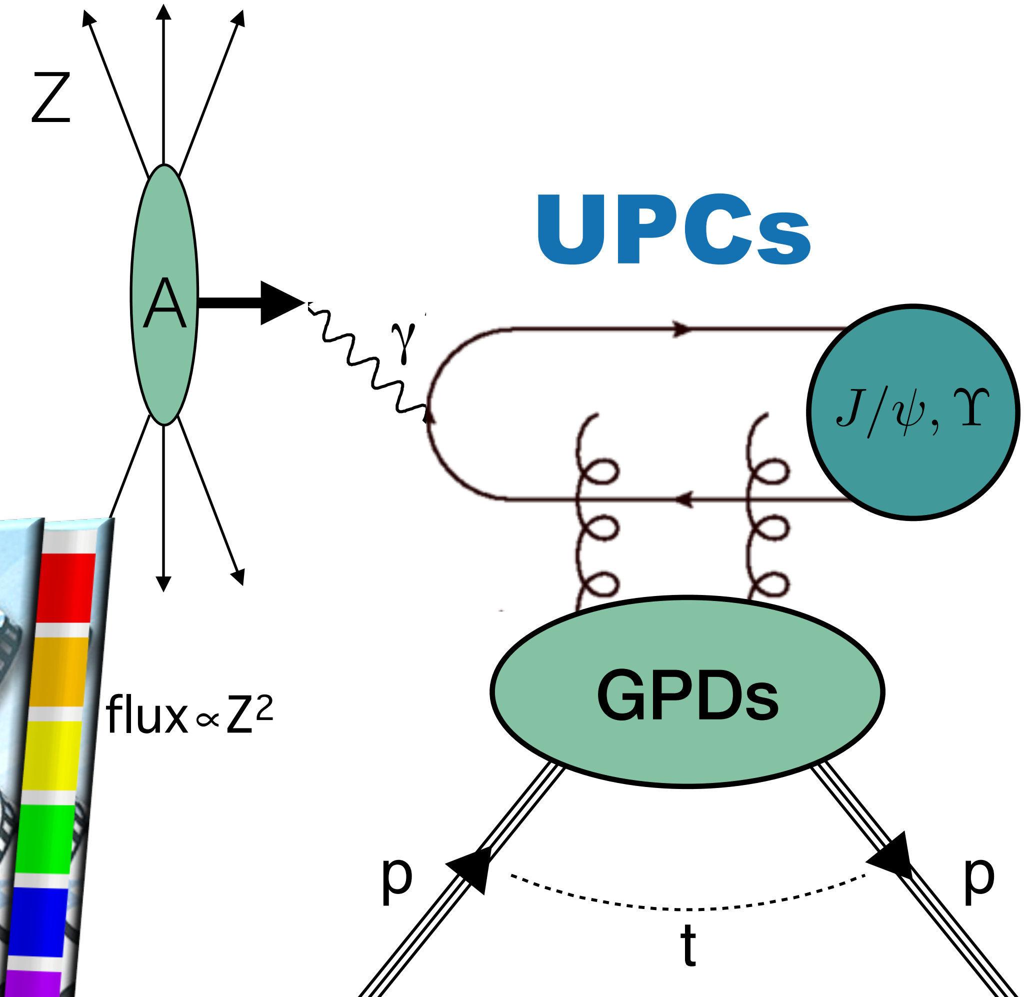
Outlook

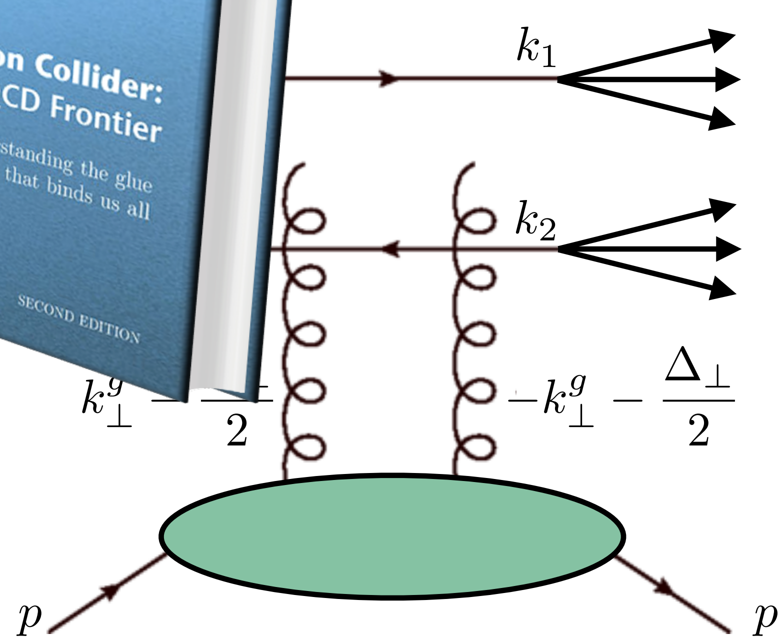






UPCs





photon flux ∝ Z²

Wigner distributions

$W(x, \vec{k}_T, \vec{b}_\perp)$

Exclusive production of dijets or heavy di-mesons

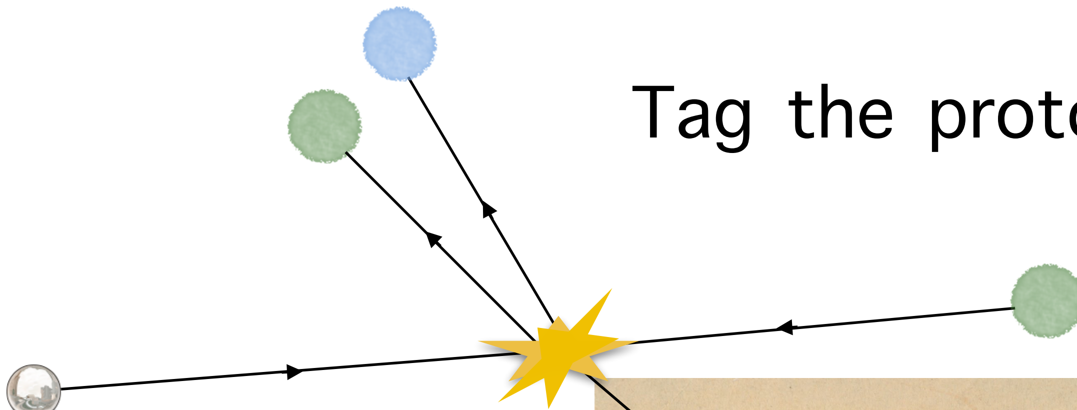
Y. Hatta et al., PRL 116 (2016) 202301
Y. Hagiwara et al., PRD 96 (2017) 034009
M. Pelicer et al., arXiv: 1811.12888

JLAB 12 GeV era

UPCs

EIC

Tag the proton if you can!



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