Accessing the real part of the forward **Compton** & **elastic J/psi** scattering amplitudes off the proton

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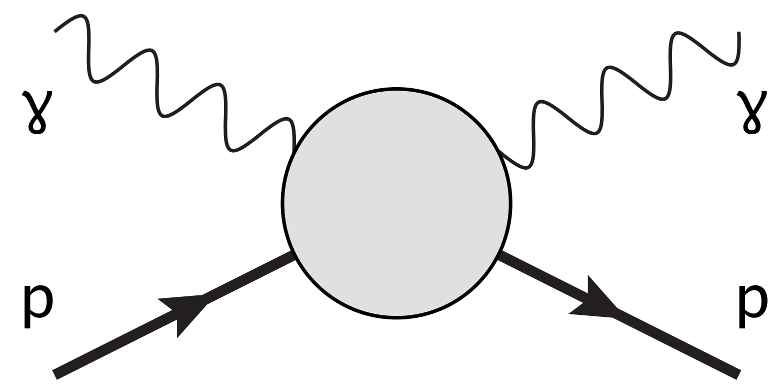
Outline

- Accessing the **real part** of the forward **Compton** scattering amplitude off the proton
- Accessing the **real part** of the forward elastic **J/psi - p** scattering amplitude
- Summary

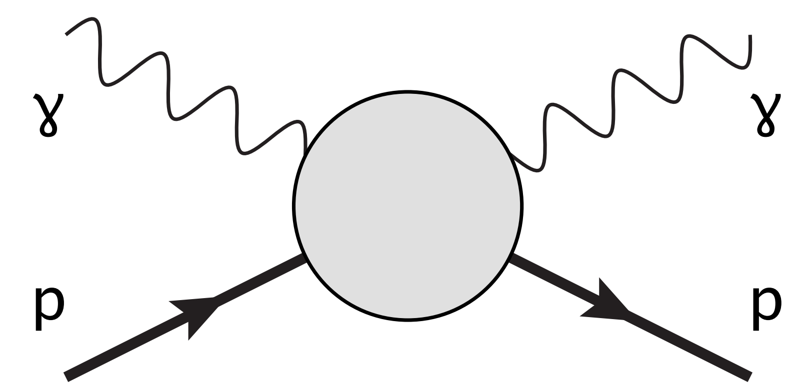
Forward **Compton** scattering off the proton



Forward **Compton** scattering off the proton

spin-averaged amplitude: $T_{\gamma p}(\nu)$

kinematic variable: $\frac{pq}{M_p} \equiv \nu = \frac{W^2 - M_p^2}{2M_p}$



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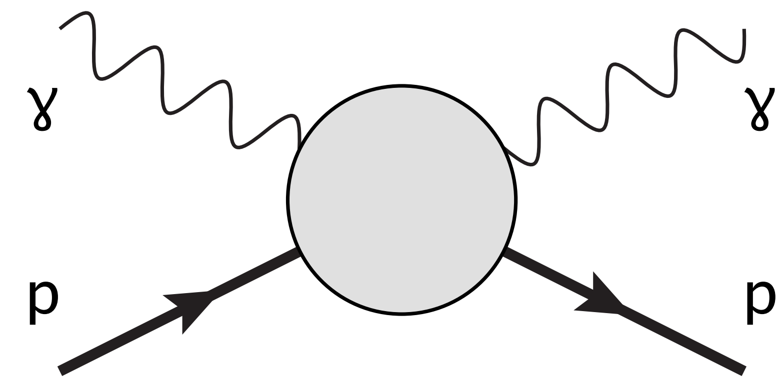

unitarity ⇒

$$\mathrm{Im}\, T_{\gamma p}(\nu) = \frac{\nu}{4\pi}\, \sigma^{\mathrm{tot}}_{\gamma p}(\nu)$$

Forward **Compton** scattering off the proton

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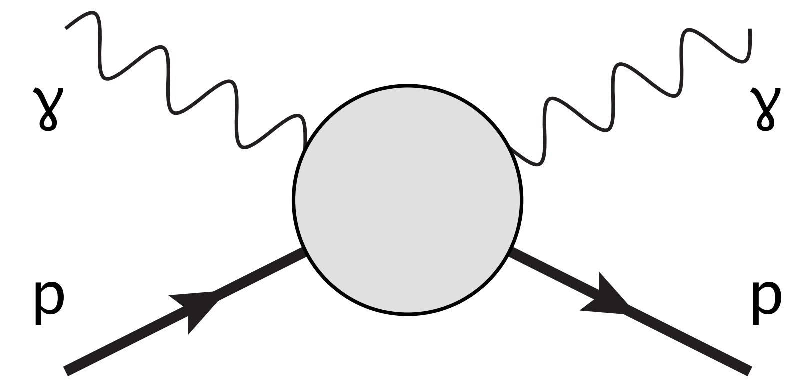


kinematic variable: $\frac{pq}{M_p} \equiv \nu = \frac{W^2 - M_p^2}{2M_p}$

unitarity ⇒ $\mathrm{Im}\, T_{\gamma p}(\nu) = \frac{\nu}{4\pi}\, \sigma_{\gamma p}^{\mathrm{tot}}(\nu)$

causality + crossing + low energy theorem

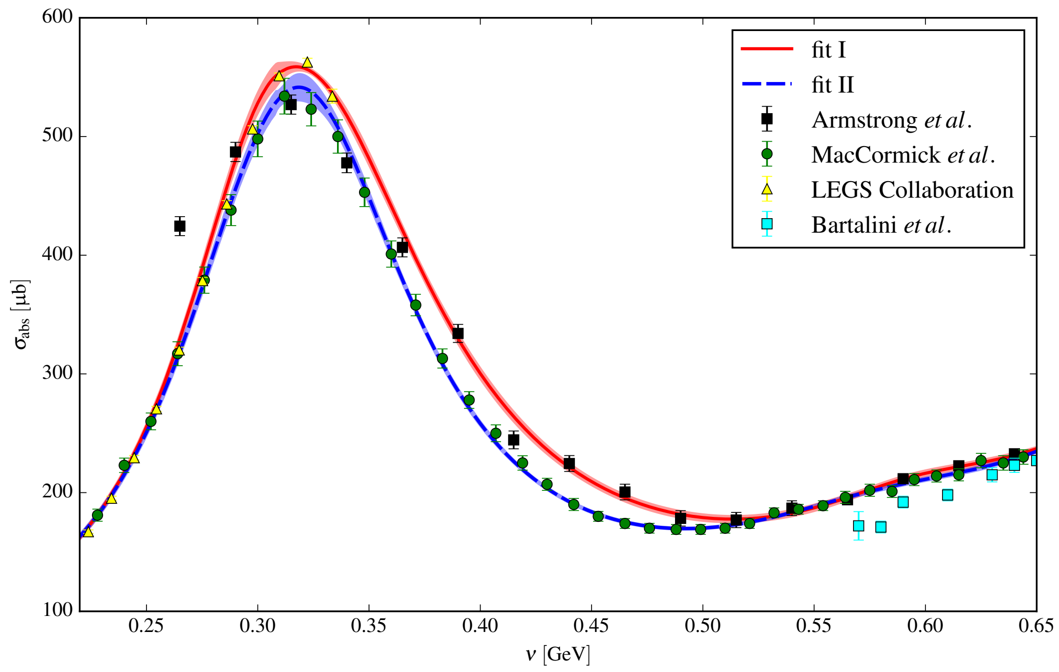
⇓

subtracted dispersion relation:

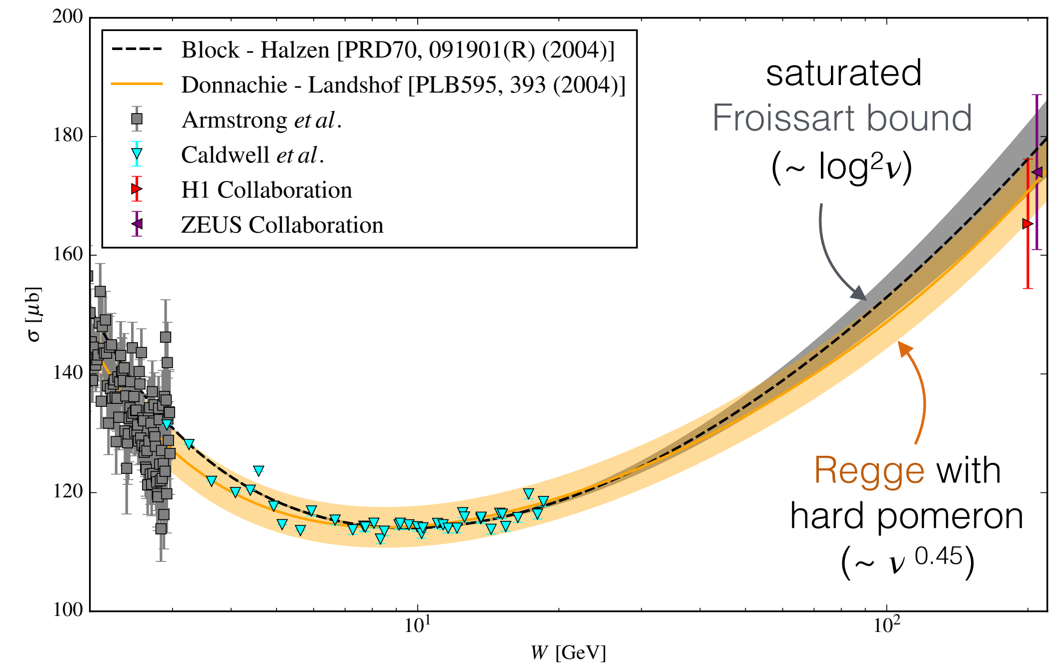
$$\mathrm{Re}\, T_{\gamma p}(\nu) = -\frac{\alpha}{M_p} + \frac{\nu^2}{2\pi^2} \int_0^\infty \frac{\sigma_{\gamma p}^{\mathrm{tot}}(\nu')}{\nu'^2 - \nu^2} d\nu'$$

Forward **Compton** scattering off the proton — motivation

resonance region



higher energies…

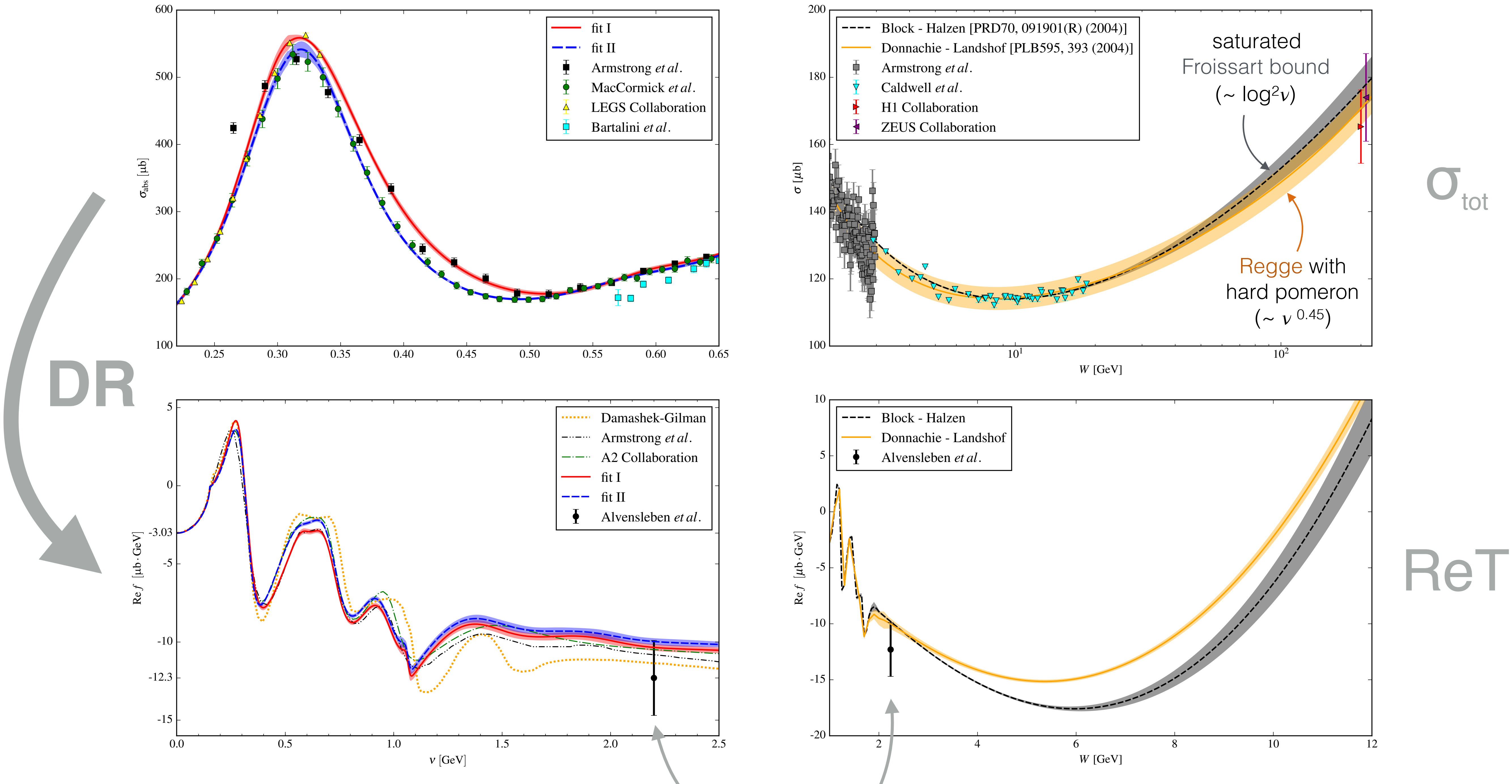


σ_{tot}

Forward **Compton** scattering off the proton — motivation

resonance region

higher energies…

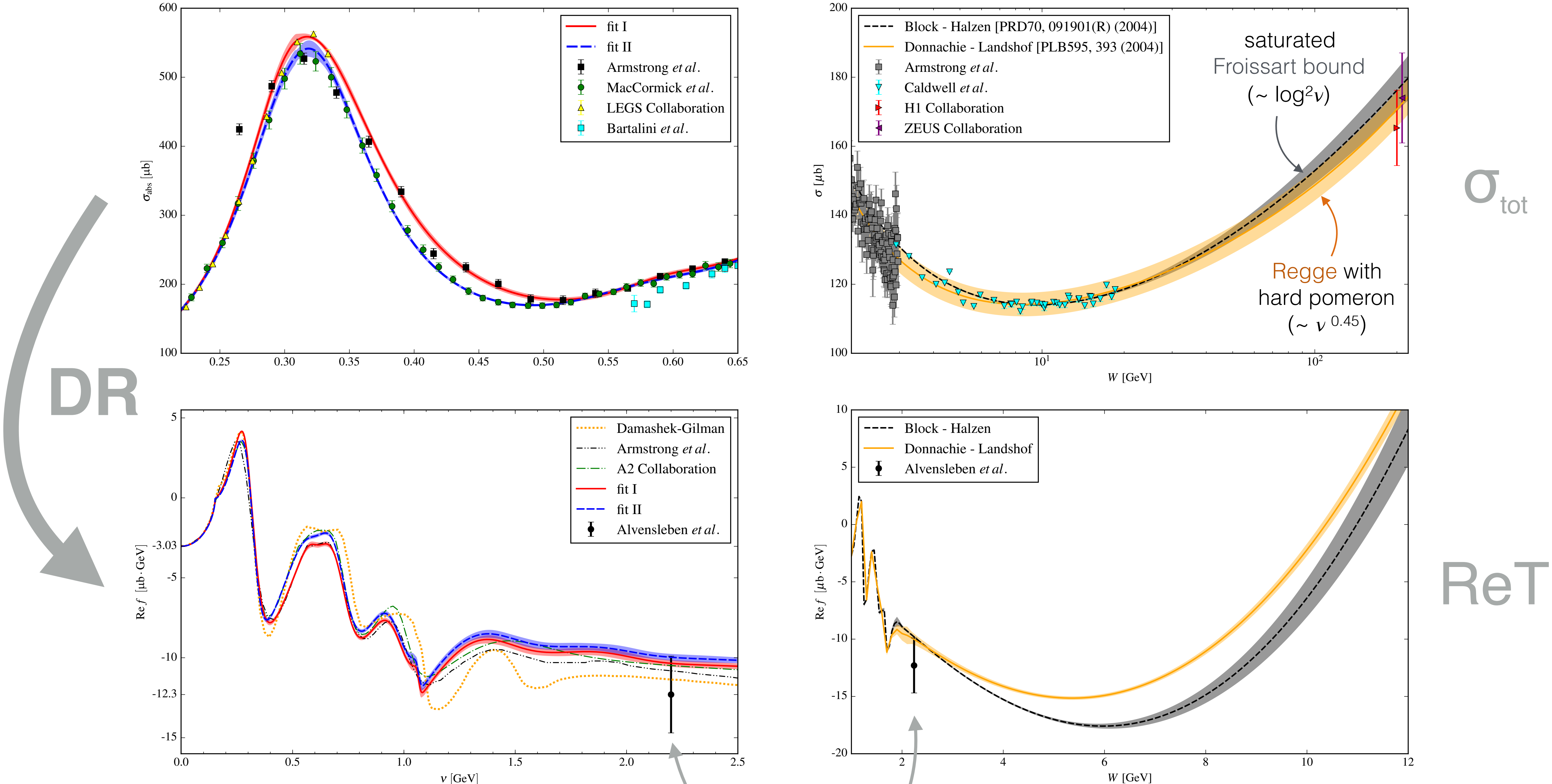


OG, F. Hagelstein, V. Pascalutsa,
PRD**92**, 074031 (2015)

a single existing **direct** experimental datapoint (1972)

Forward **Compton** scattering off the proton — motivation

resonance region / higher energies…



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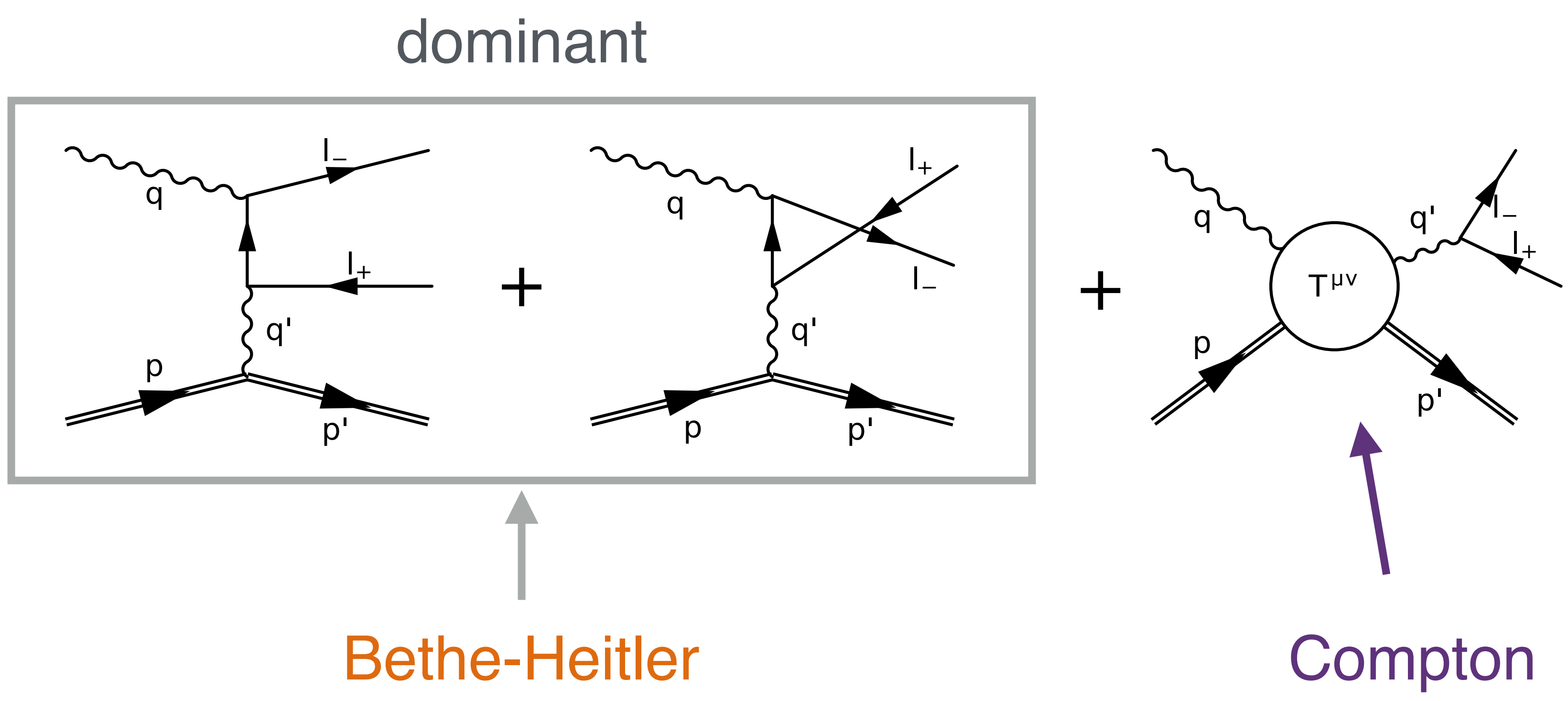
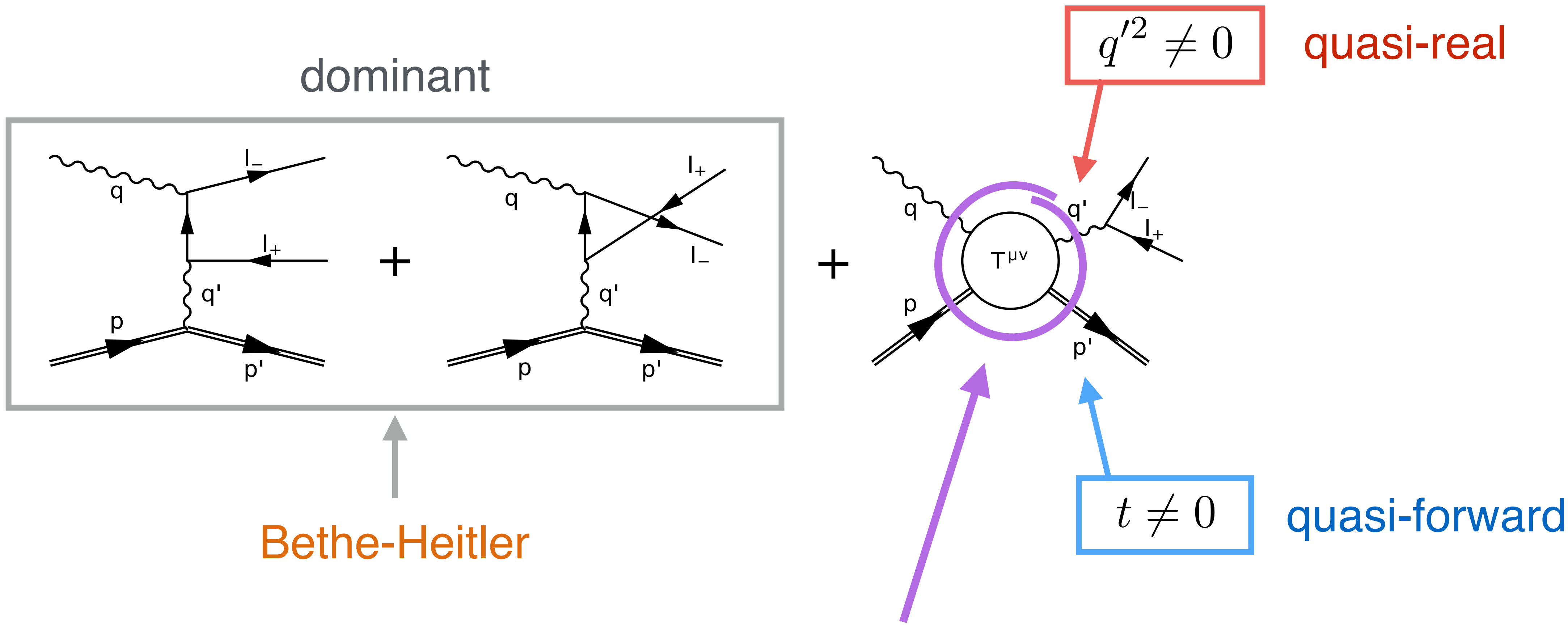
Let's redo the experiment at JLab!

Lepton pair photoproduction



Lepton pair photoproduction



quasi-forward-real Compton contribution: $q'^2 \to 0$

$t \to 0$

$$T^{\mu\nu}_{\text{unpoll}} \simeq \left(-g^{\mu\nu} + \frac{q'^\mu q^\nu}{qq'}\right) T_1$$

$$+ \frac{1}{M^2}\left(P^\mu - \frac{qP}{qq'}q'^\mu\right)\left(P^\nu - \frac{qP}{qq'}q^\nu\right) T_2$$

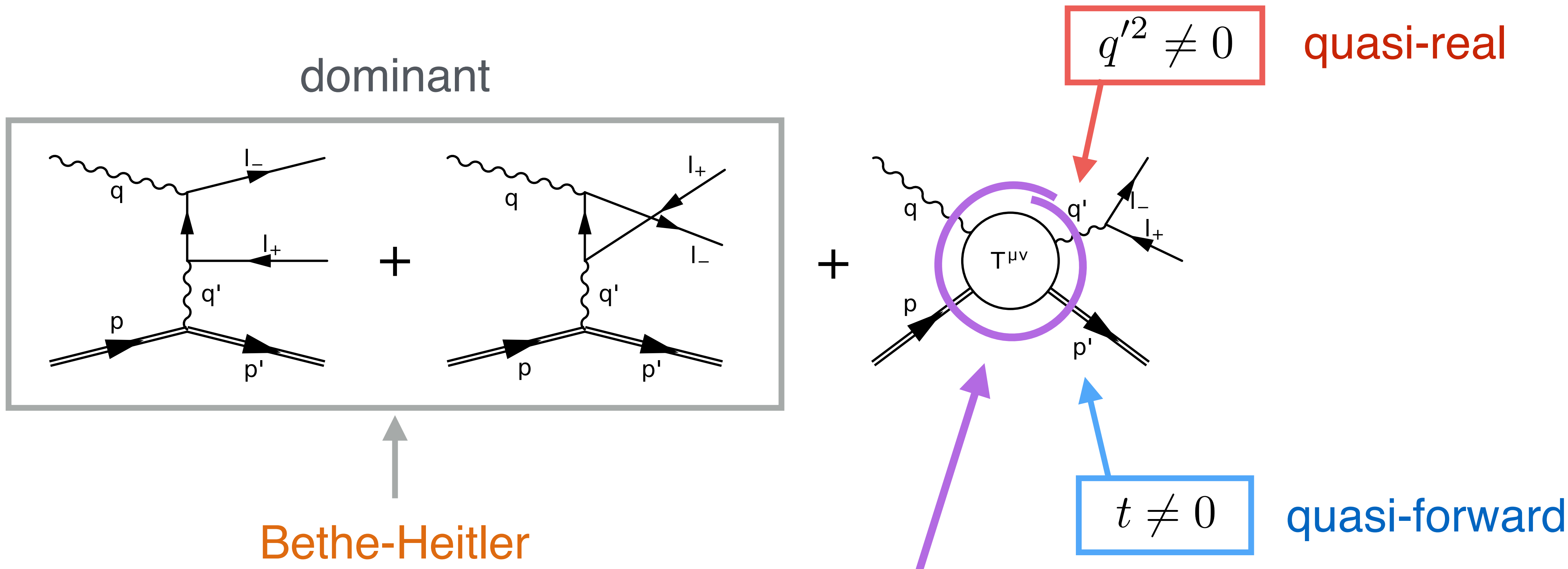
$$P = \frac{1}{2}(p + p') \qquad \tilde{\nu} = \frac{qP}{M}$$

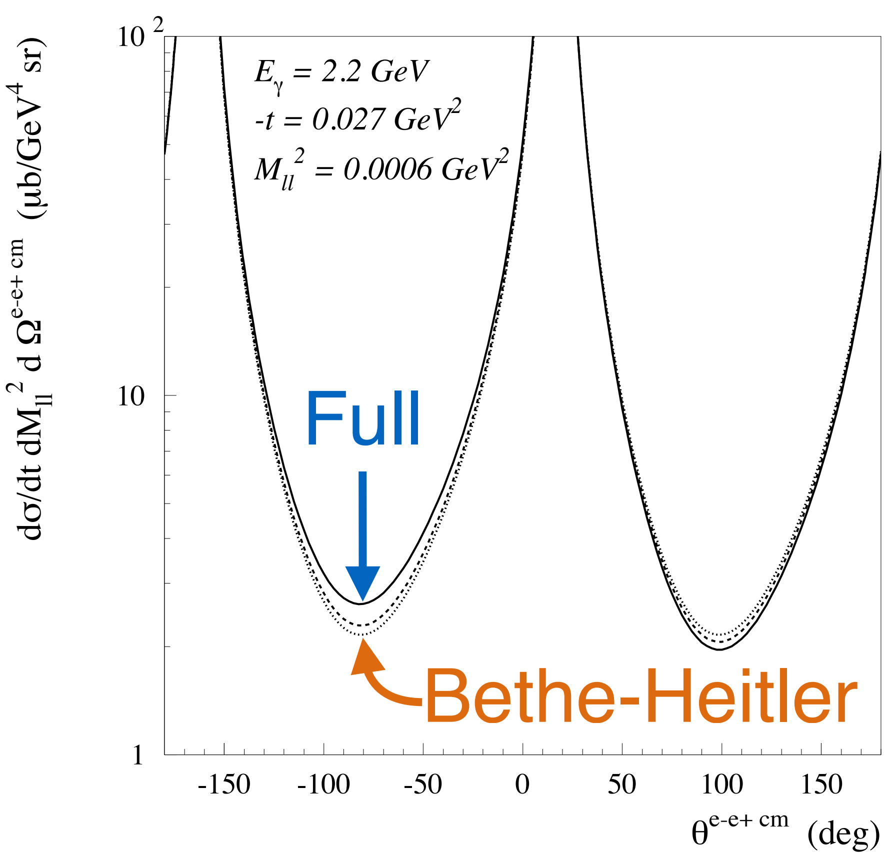
$$qq' = \frac{q'^2 - t}{2}$$

$$T_1(\tilde{\nu}, t, q'^2) \simeq T_1^{\text{FRCS}}(\tilde{\nu})$$

$$T_2(\tilde{\nu}, t, q'^2) \simeq -\frac{qq'}{\tilde{\nu}^2}\, T_1^{\text{FRCS}}(\tilde{\nu})$$

Lepton pair photoproduction





quasi-forward-real Compton contribution: $\quad q'^2 \to 0 \quad t \to 0$

$$T^{\mu\nu}_{\text{unpoll}} \simeq \left(-g^{\mu\nu} + \frac{q'^\mu q^\nu}{qq'}\right) T_1 + \frac{1}{M^2}\left(P^\mu - \frac{qP}{qq'} q'^\mu\right)\left(P^\nu - \frac{qP}{qq'} q^\nu\right) T_2$$

$$P = \frac{1}{2}(p + p') \qquad \tilde{\nu} = \frac{qP}{M} \qquad qq' = \frac{q'^2 - t}{2}$$

$$T_1(\tilde{\nu}, t, q'^2) \simeq T_1^{\text{FRCS}}(\tilde{\nu})$$

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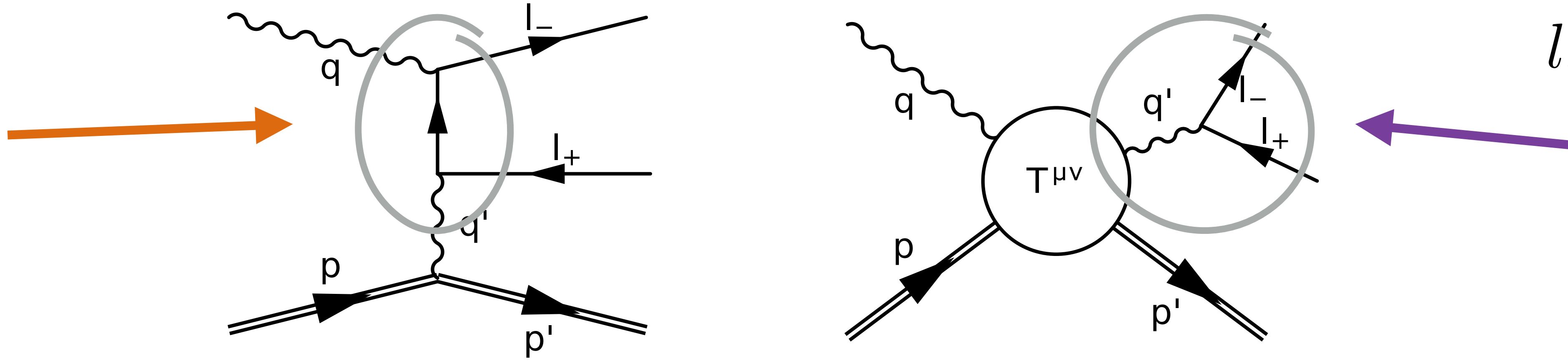
Interference term

$l_+ \leftrightarrow l_-$

Bethe-Heitler　　　　Compton

$l_+ \leftrightarrow l_-$:

odd



$l_+ \leftrightarrow l_-$:

even

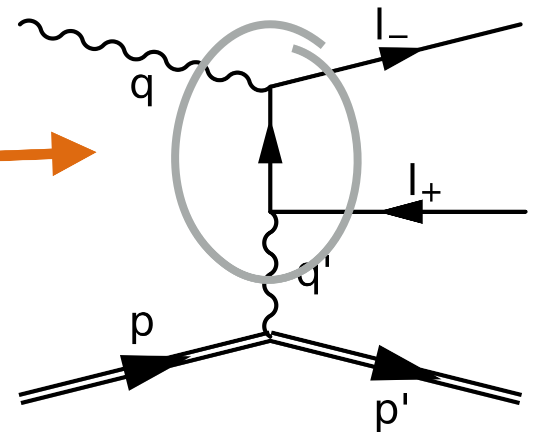
Interference term

$$l_+ \leftrightarrow l_-$$

Bethe-Heitler

$l_+ \leftrightarrow l_-$:

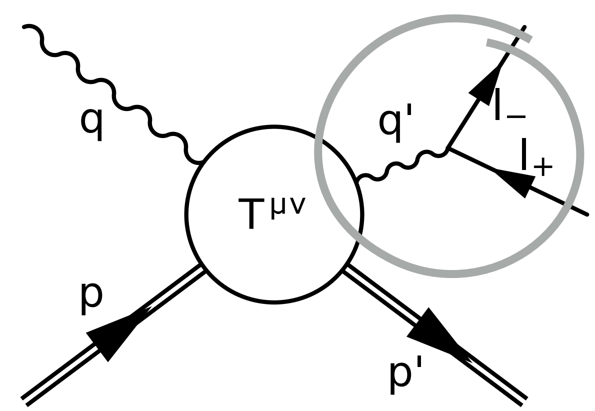
odd



Compton

$l_+ \leftrightarrow l_-$:

even



Observable:

$$|T_{\rm CS} + T_{\rm BH}|^2 = |T_{\rm CS}|^2 + 2\,{\rm Re}\,T_{\rm CS}\,T_{\rm BH} + |T_{\rm BH}|^2$$

even

odd

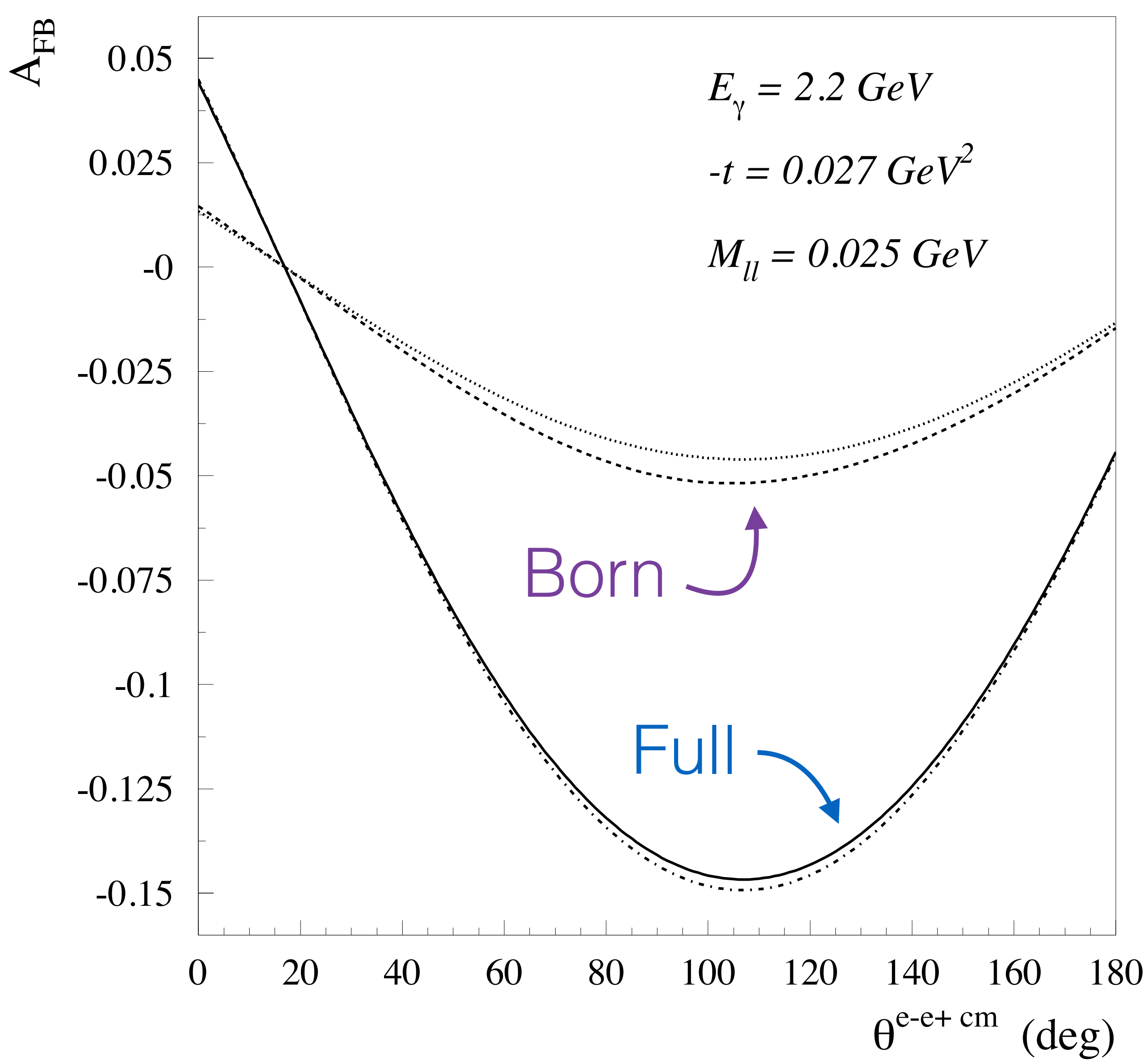
even

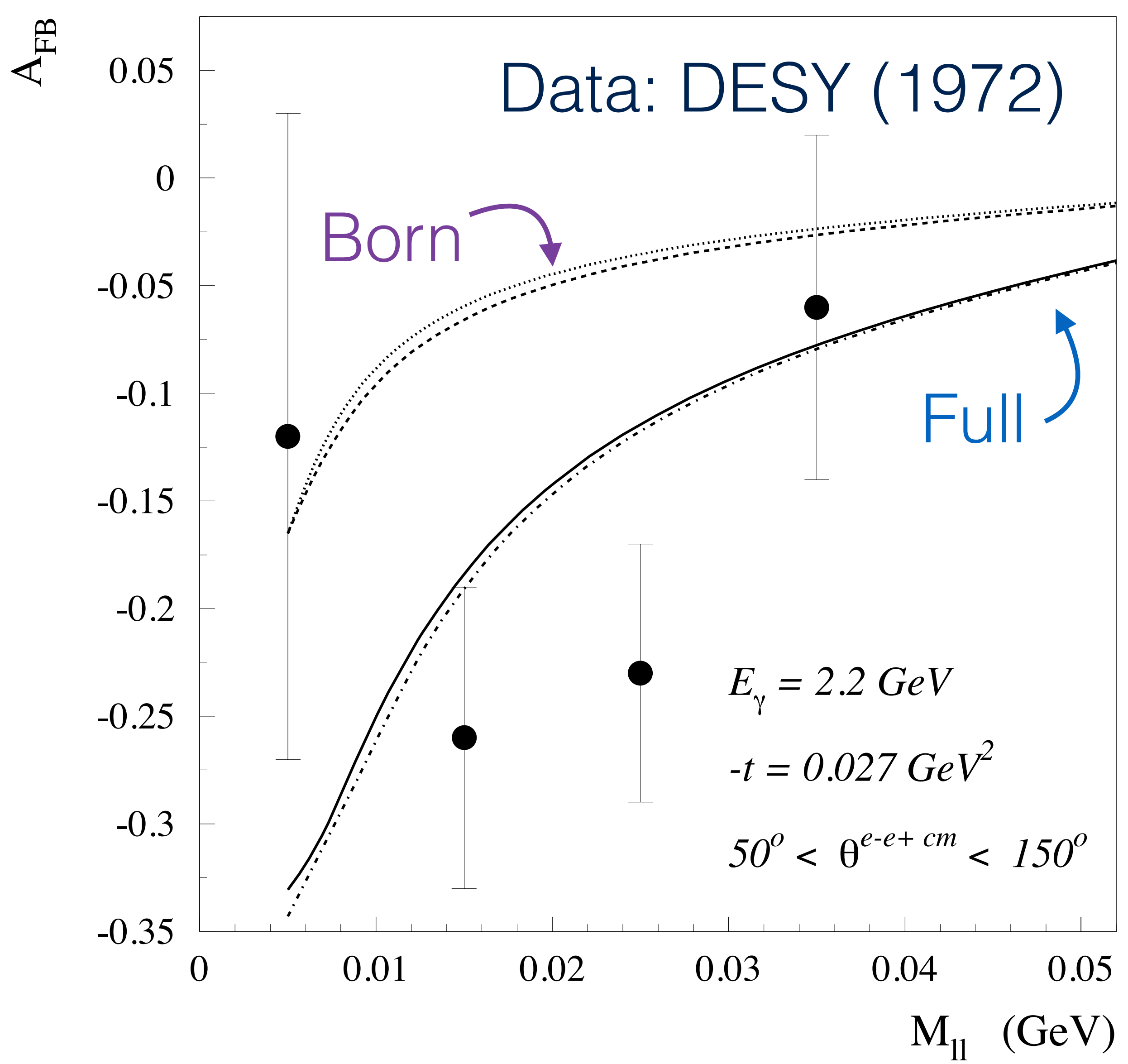
Forward-backward asymmetry

$$A_{\rm FB} \equiv \frac{\frac{d\sigma}{d\Omega}(\theta_{\rm cm}) - \frac{d\sigma}{d\Omega}(\theta_{\rm cm}-\pi)}{\frac{d\sigma}{d\Omega}(\theta_{\rm cm}) + \frac{d\sigma}{d\Omega}(\theta_{\rm cm}-\pi)} = \frac{2\,{\rm Re}\,T_{\rm CS}\,T_{\rm BH}}{|T_{\rm CS}|^2 + |T_{\rm BH}|^2}$$

interference

$\theta_{\rm cm}$ — scattering angle in a lepton pair CM frame

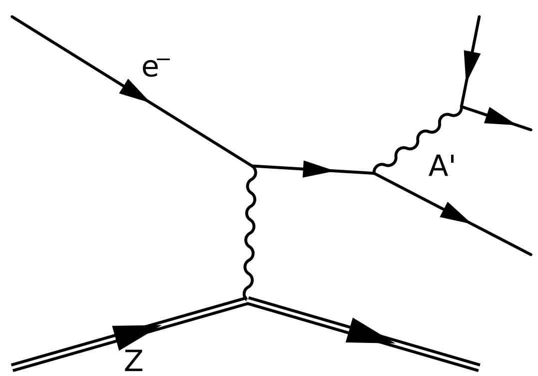




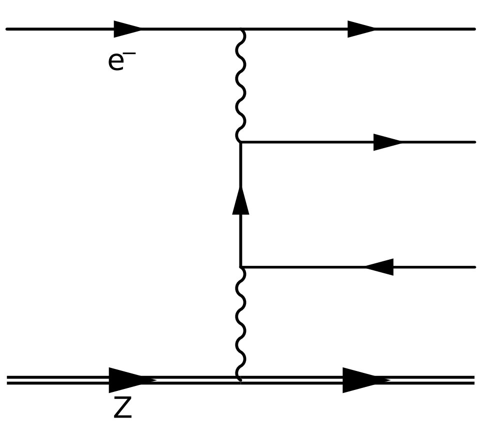
Future experiments at JLab

$$ep \to ep(e^- e^+)$$

initial process of interest:



background — of our interest:



HPS (Heavy Photon Search)

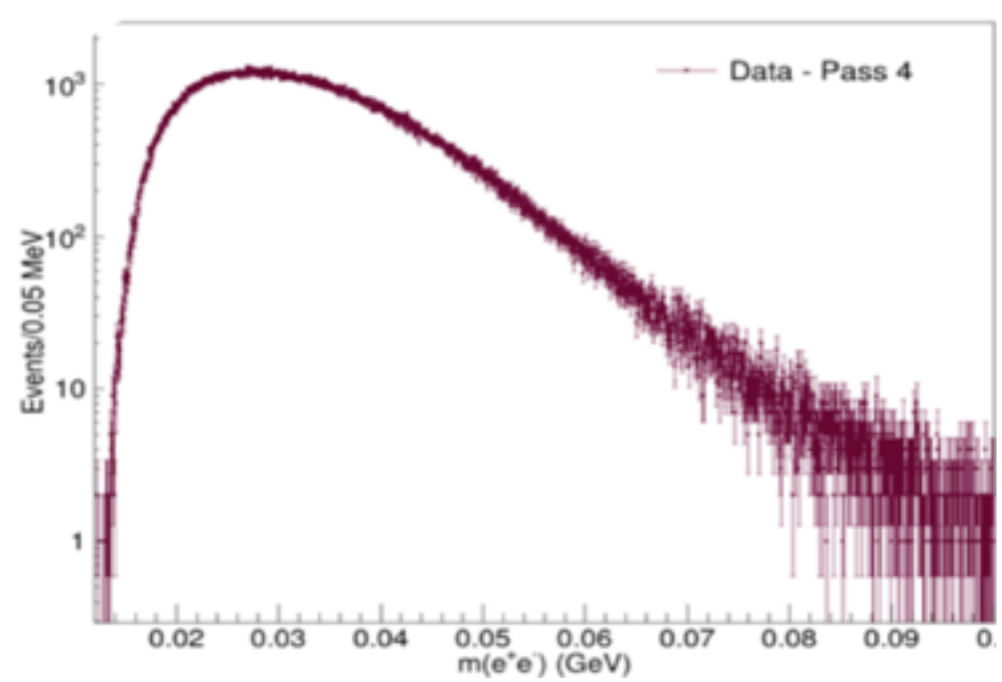
E12 - 11 - 006

beam energies: 1.1, 2.2, 4.4, **6.6** GeV

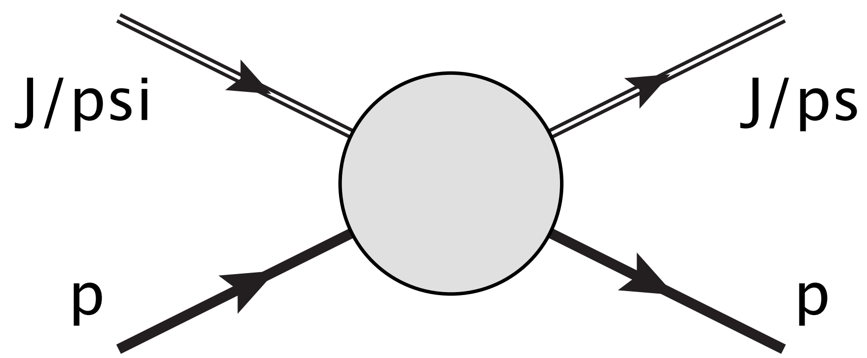
M_{ll} : 0.01 — 0.1 GeV

some preliminary results:

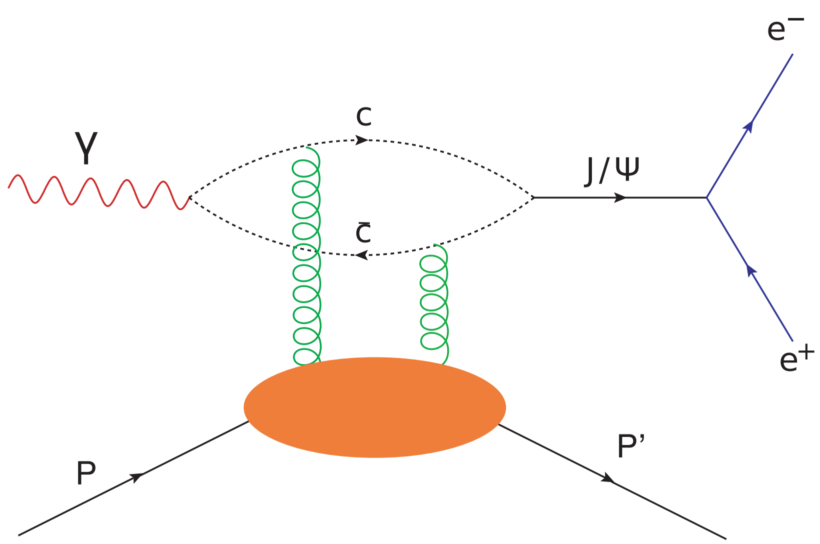
1.05 GeV beam



Forward **J/psi - p** scattering



Forward **J/psi - p** scattering — motivation



- probe of the colour deconfinement at high energies through the propagation of a J/Psi in a quark-gluon plasma

D. Kharzeev and H. Satz, Phys. Lett. B **334**, 155 (1994)

D. Kharzeev, H. Satz, A. Syamtomov and G. Zinovjev, Eur. Phys. J. C **9**, 459 (1999)

- is there a J/psi - nucleus bound state?

$$T_{\psi p}(\nu = \nu_{el}) = 8\pi(M + M_\psi)\, a_{\psi p}$$ ← J/psi - p s-wave scattering length

J/psi binding energy in a nuclear matter (linear density approximation):

$$B_\psi \simeq \frac{8\pi(M + M_\psi) a_{\psi p}}{4 M M_\psi}\, \rho_{nm}$$

M. E. Luke, A. V. Manohar and M. J. Savage, Phys. Lett. B **288**, 355 (1992)

S. J. Brodsky and G. A. Miller, Phys. Lett. B **412**, 125 (1997)

S. H. Lee and C. M. Ko, Phys. Rev. C **67**, 038202 (2003)

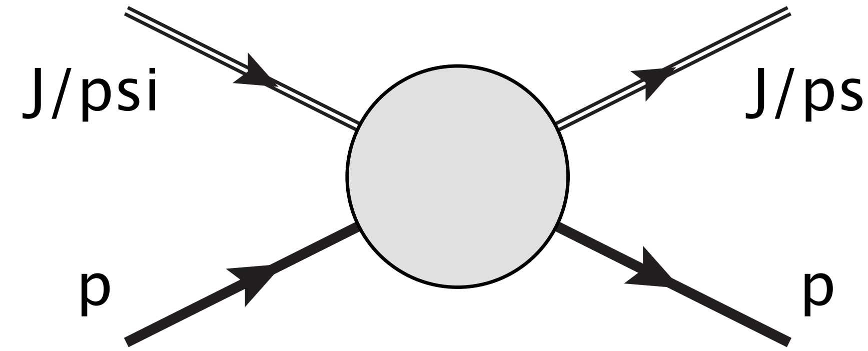
K. Tsushima, D. H. Lu, G. Krein and A. W. Thomas, Phys. Rev. C **83**, 065208 (2011)

...

Forward **J/psi - p** scattering

spin-averaged amplitude: $\boxed{T_{\psi p}(\nu)}$

kinematic variable: $\nu \equiv p\, q = \dfrac{s-u}{4}$



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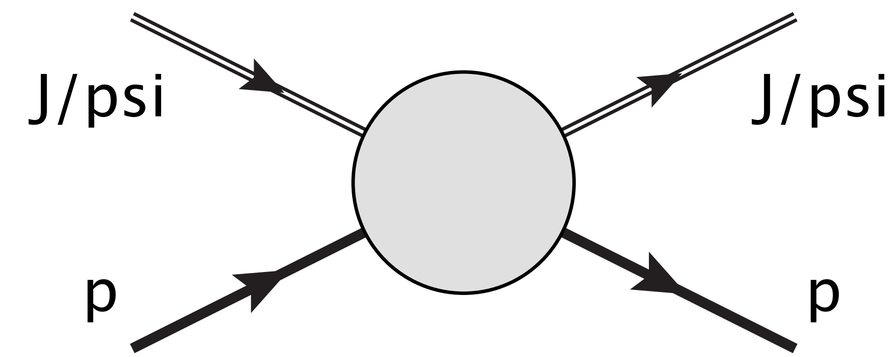

unitarity ⇒ $\mathrm{Im}\, T_{\psi p}(\nu) = 2\sqrt{s}\, q_{\psi p}\, \sigma^{tot}_{\psi p}(\nu)$

causality + crossing

subtracted dispersion relation:

$$\mathrm{Re}\, T_{\psi p}(\nu) = T_{\psi p}(0) + \frac{2}{\pi}\nu^2 \int_{\nu_{el}}^{\infty} d\nu' \frac{1}{\nu'} \frac{\mathrm{Im}\, T_{\psi p}(\nu')}{\nu'^{\,2} - \nu^2}$$

directly sensitive to $a_{\psi p}$

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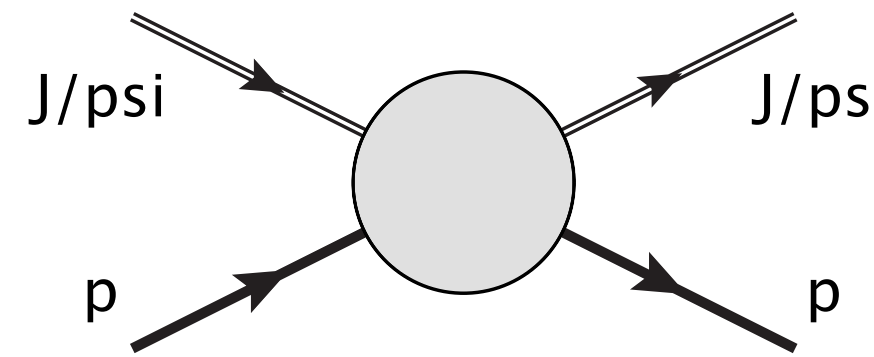

unitarity $\Rightarrow$ $\mathrm{Im}\, T_{\psi p}(\nu) = 2\sqrt{s}\, q_{\psi p}\, \sigma^{tot}_{\psi p}(\nu)$

parameterising cross section:

$$\sigma^{tot}_{\psi p} = \sigma^{el}_{\psi p} + \sigma^{inel}_{\psi p}$$

$$\sigma^{el}_{\psi p} \propto C_{el} \left(1 - \frac{\nu_{el}}{\nu}\right)^{b_{el}} \left(\frac{\nu}{\nu_{el}}\right)^{a_{el}}$$

$$\sigma^{inel}_{\psi p} \propto C_{in} \left(1 - \frac{\nu_{in}}{\nu}\right)^{b_{in}} \left(\frac{\nu}{\nu_{in}}\right)^{a_{in}}$$

causality + crossing

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directly sensitive to $a_{\psi p}$

Forward **J/psi - p** scattering

Vector meson dominance (VMD) assumption:

K. Redlich, H. Satz and G. M. Zinovjev, Eur. Phys. J. C **17**, 461 (2000)

V. D. Barger and R. J. N. Phillips, Phys. Lett. B **58**, 433 (1975)

$$\sigma_{\psi p}^{el} = \left(\frac{M_\psi}{ef_\psi}\right)^2 \left(\frac{q_{\gamma p}}{q_{\psi p}}\right)^2 \boxed{\sigma(\gamma p \to \psi p)}$$

$$\sigma_{\psi p}^{inel} = \left(\frac{M_\psi}{ef_\psi}\right)^2 \left(\frac{q_{\gamma p}}{q_{\psi p}}\right)^2 \boxed{\sigma(\gamma p \to c\bar{c}X)}$$

forward differential cross section:

$$\boxed{\left.\frac{d\sigma}{dt}\right|_{t=0}(\gamma p \to \psi p)} = \left(\frac{ef_\psi}{M_\psi}\right)^2 \left(\frac{q_{\psi p}}{q_{\gamma p}}\right)^2 \left.\frac{d\sigma}{dt}\right|_{t=0}(\psi p \to \psi p)$$

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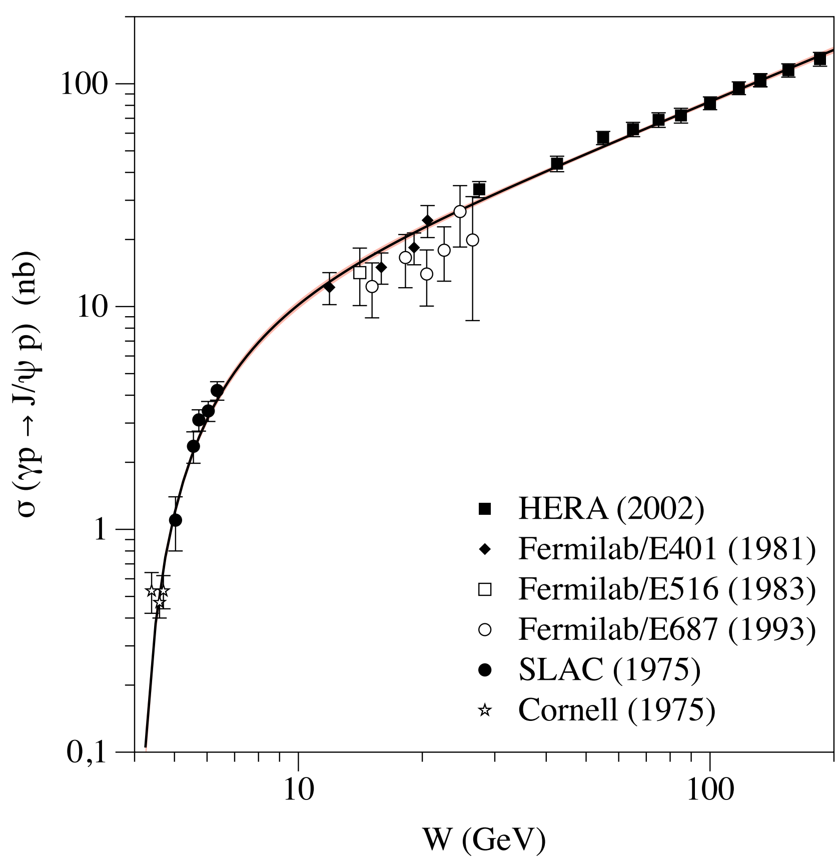

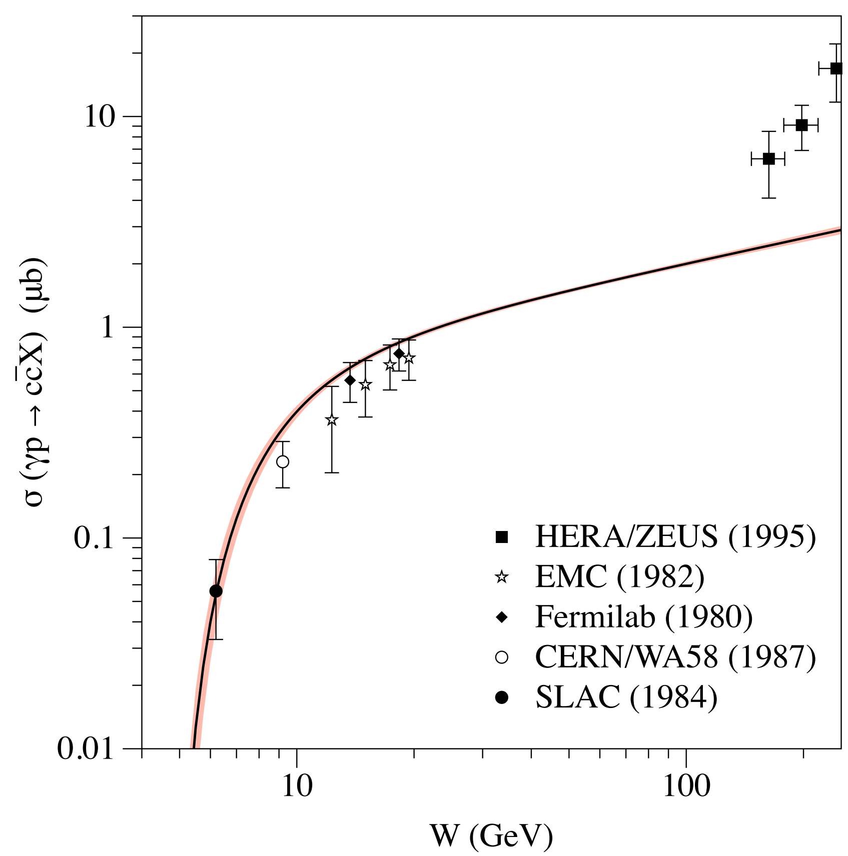

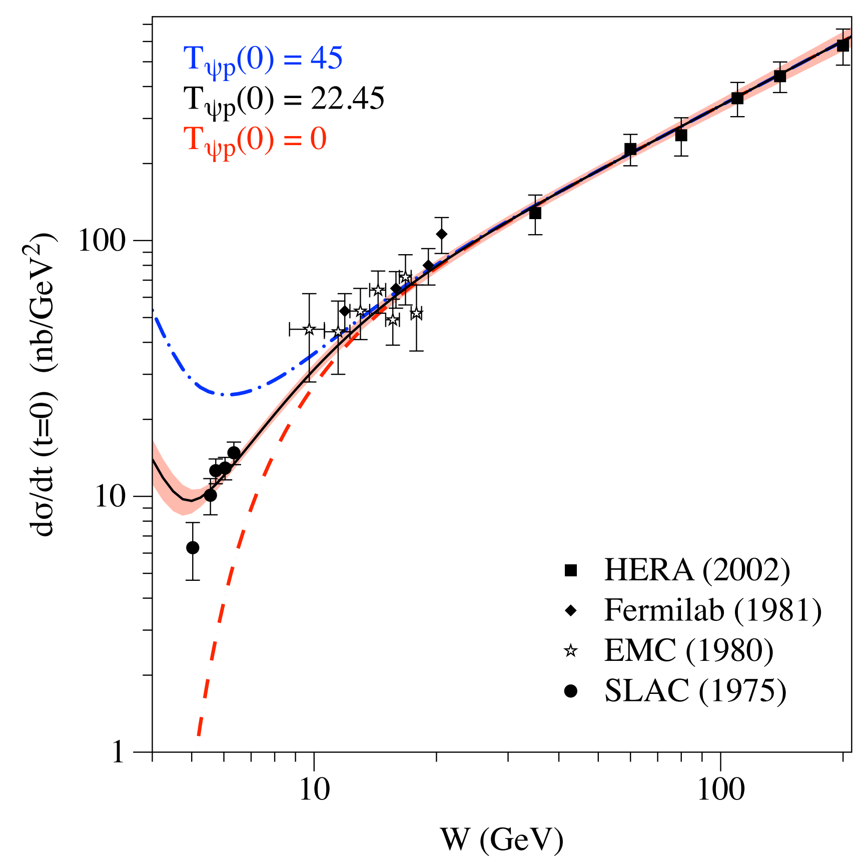

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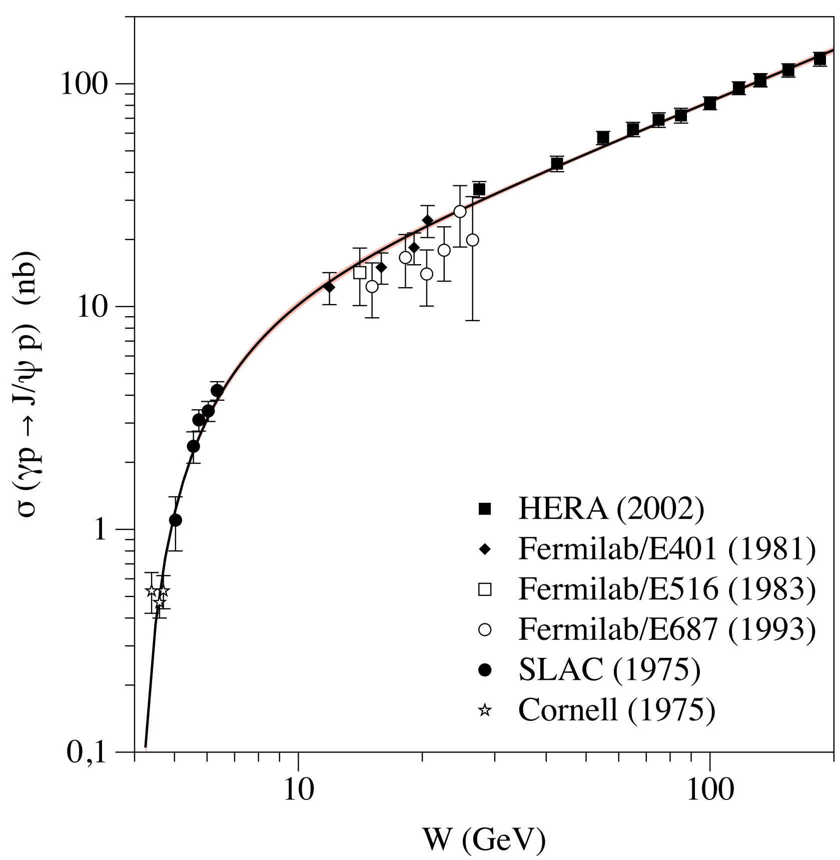
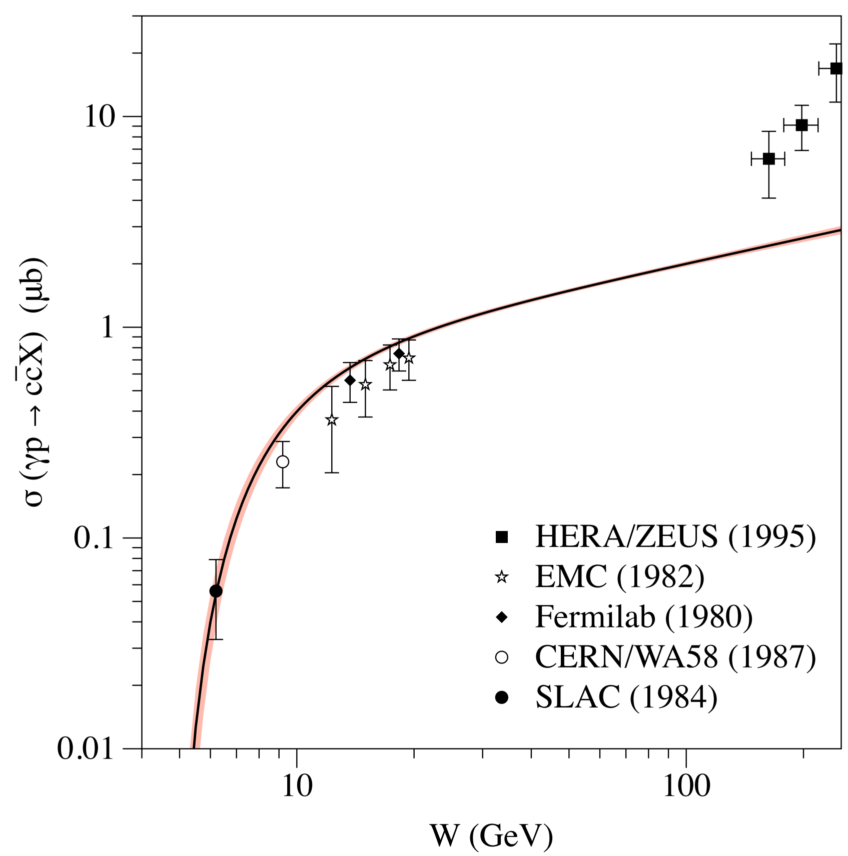
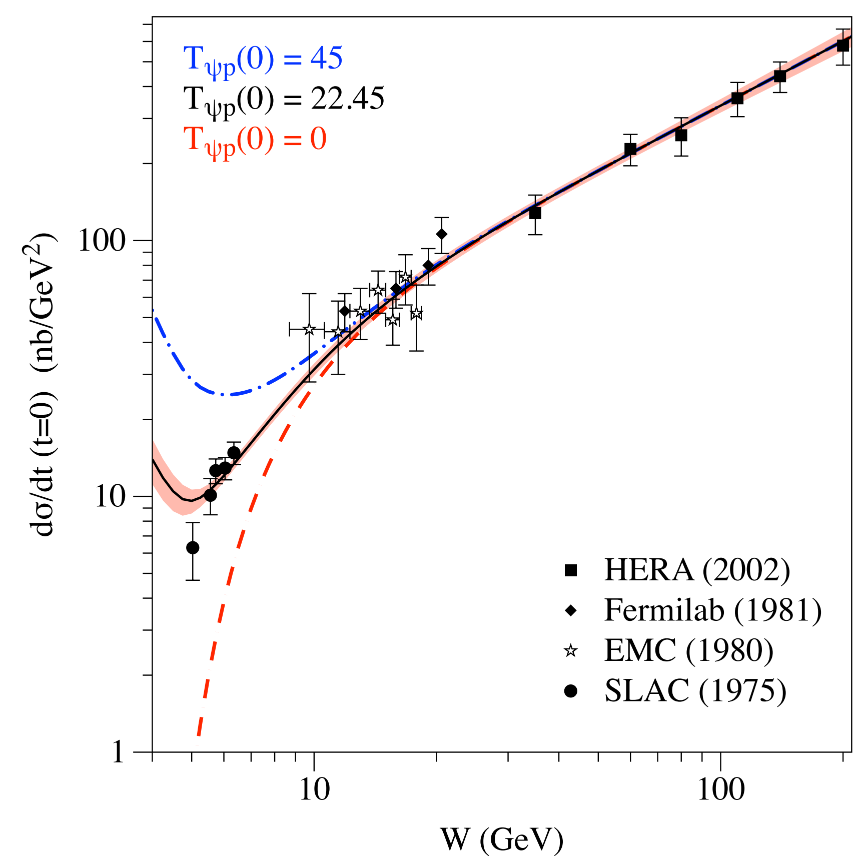
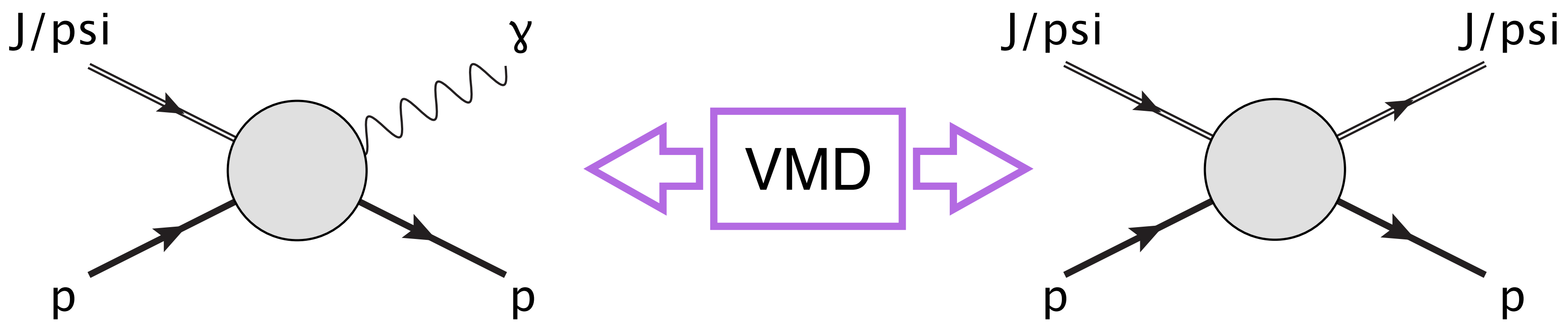






simultaneously fitting ⇨ $a_{\psi p} \sim 0.05$ fm $\quad B_\psi \sim 3$ MeV

Lepton pair photoproduction



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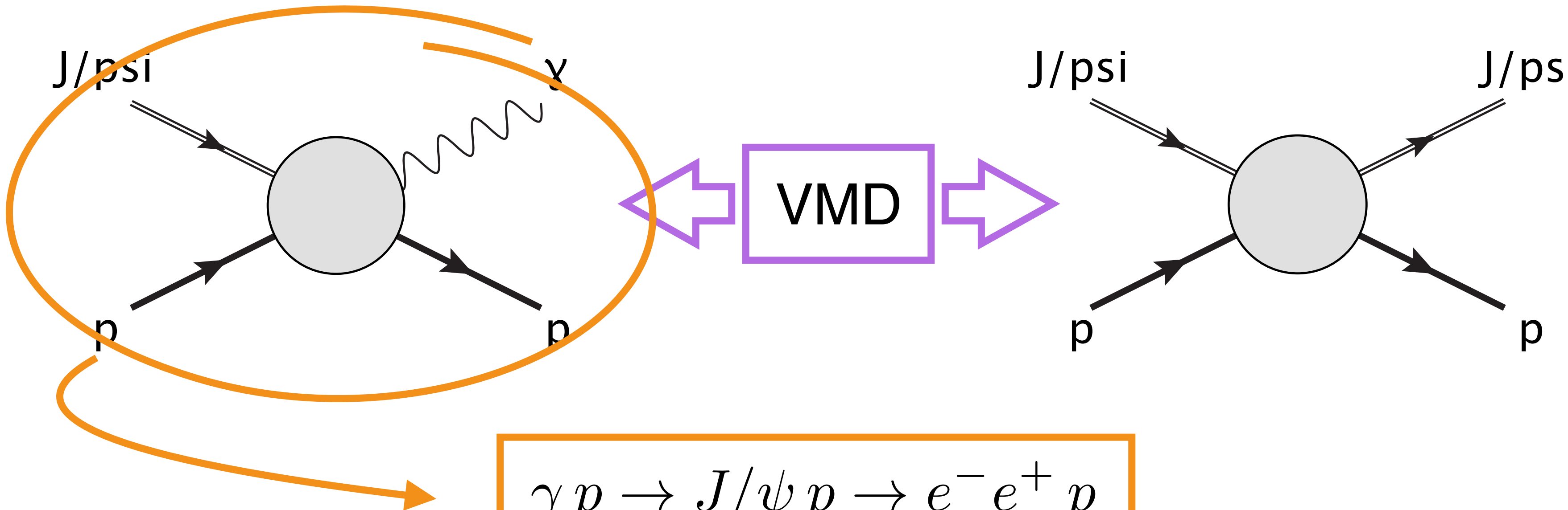
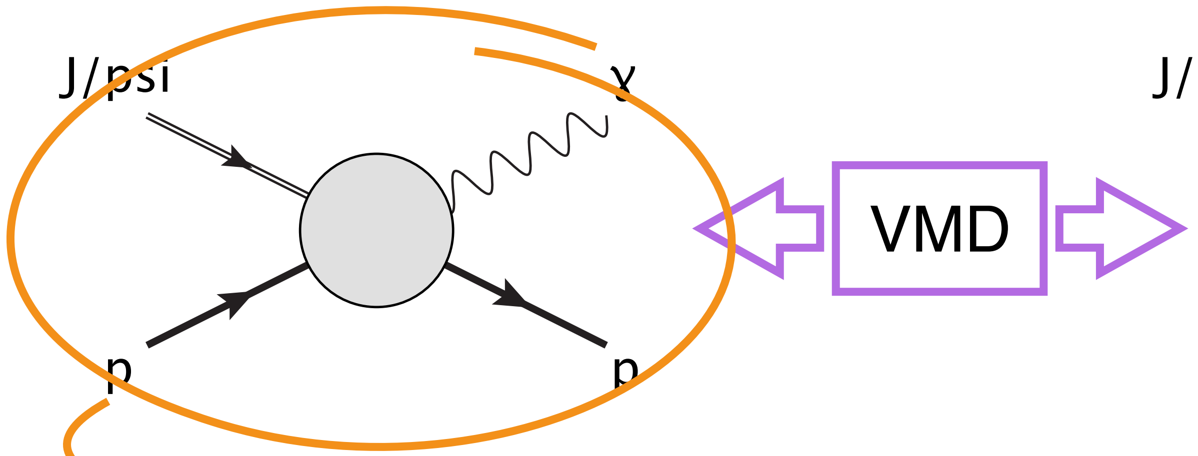


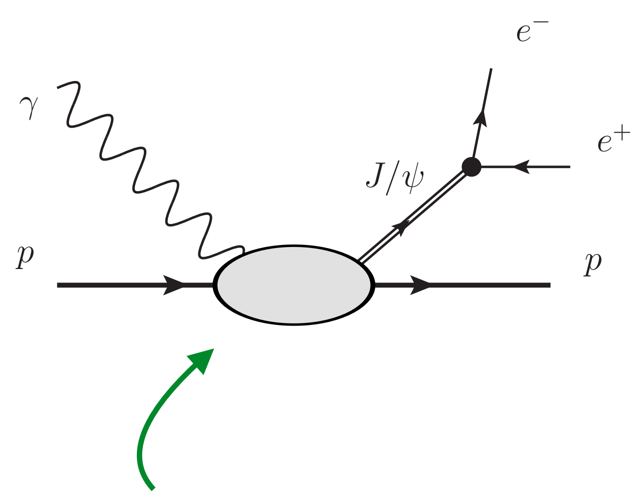
$$\gamma\, p \to J/\psi\, p \to e^- e^+\, p$$

Lepton pair photoproduction



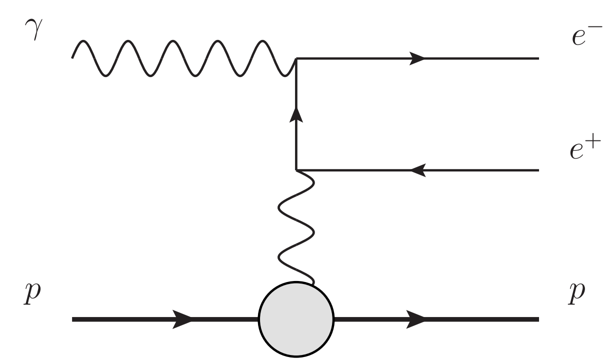
$$\gamma\, p \to J/\psi\, p \to e^- e^+\, p$$

dilepton photoproduction through J/psi:



+

Bethe-Heitler:

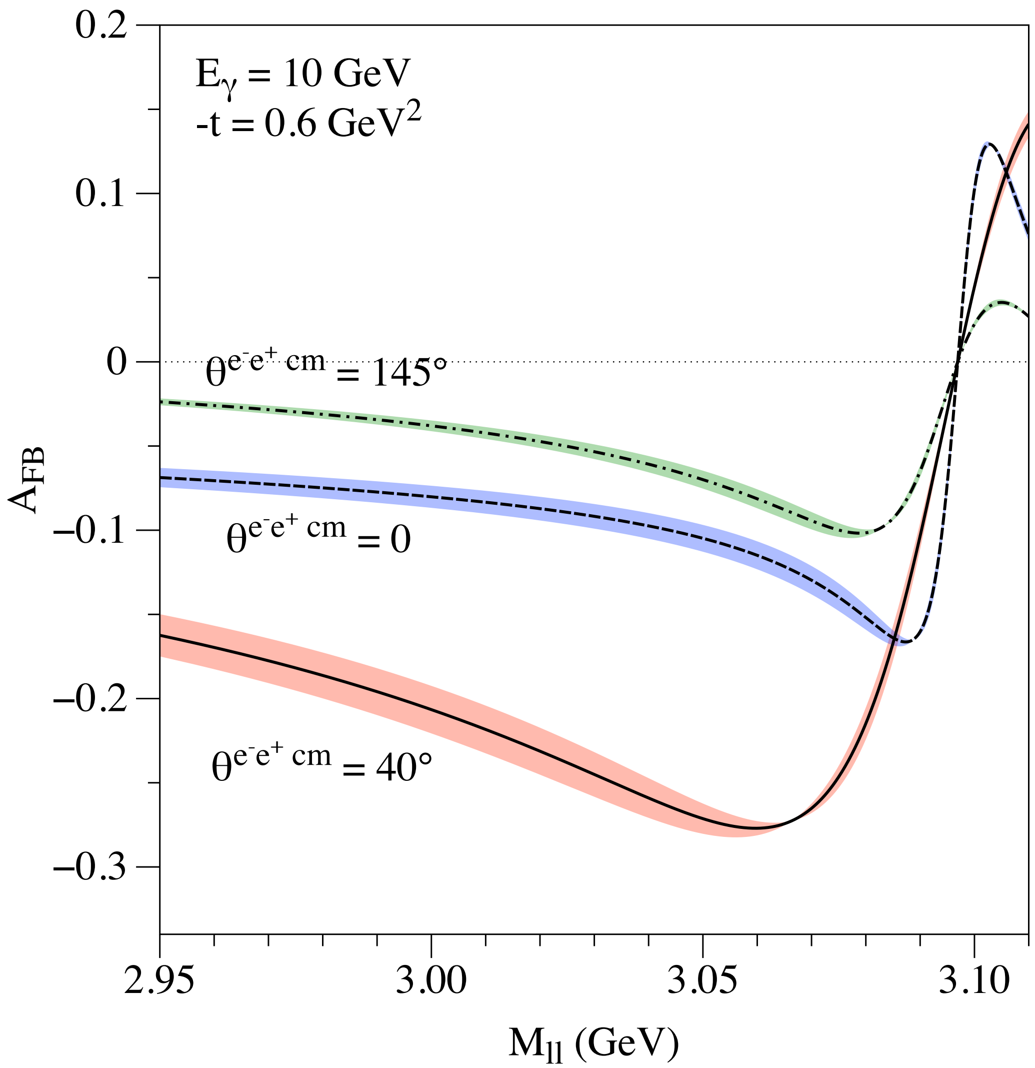


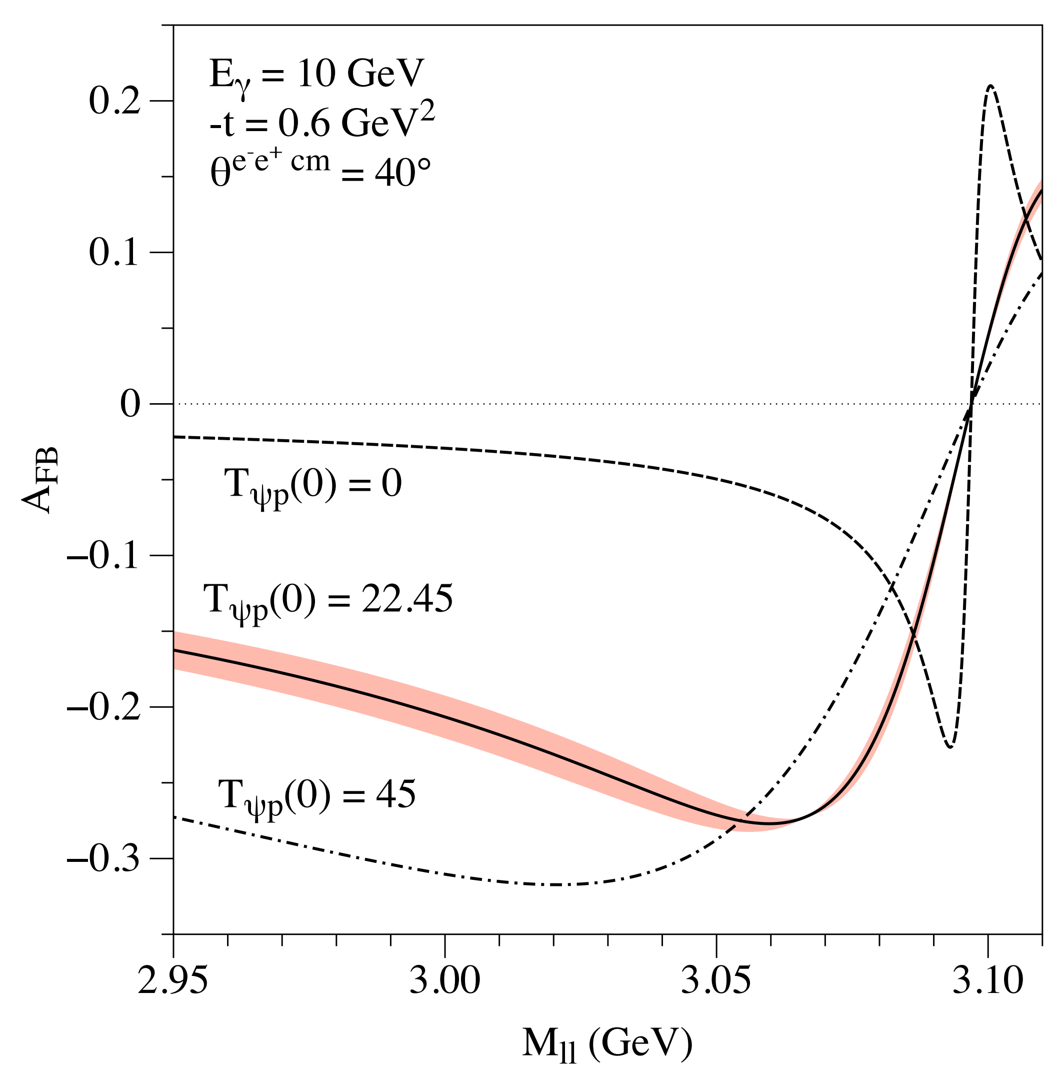
$t \to 0$

$$\mathcal{M}_\psi \simeq \frac{ie^3}{q'^2}\,\frac{f_\psi^2}{2M}\,\frac{1}{q'^2 - M_\psi^2 + iM_\psi\Gamma_\psi}\,T_{\psi p}\left(\nu = \frac{1}{2}(s - M_\psi^2 - M^2)\right)$$
$$\times\, \varepsilon_\mu(q,\lambda)\cdot \bar{u}(l_-, s_-)\gamma_\nu v(l_+, s_+)$$
$$\times\, \bar{N}(p', s_p')\left\{\left(g^{\mu\nu} - \frac{q'^\mu q^\nu}{q\cdot q'}\right) + \frac{q\cdot q'}{(q\cdot P)^2}\left(P^\mu - \frac{q\cdot P}{q\cdot q'}q'^\mu\right)\left(P^\nu - \frac{q\cdot P}{q\cdot q'}q^\nu\right)\right\} N(p, s_p)$$

Forward-backward asymmetry

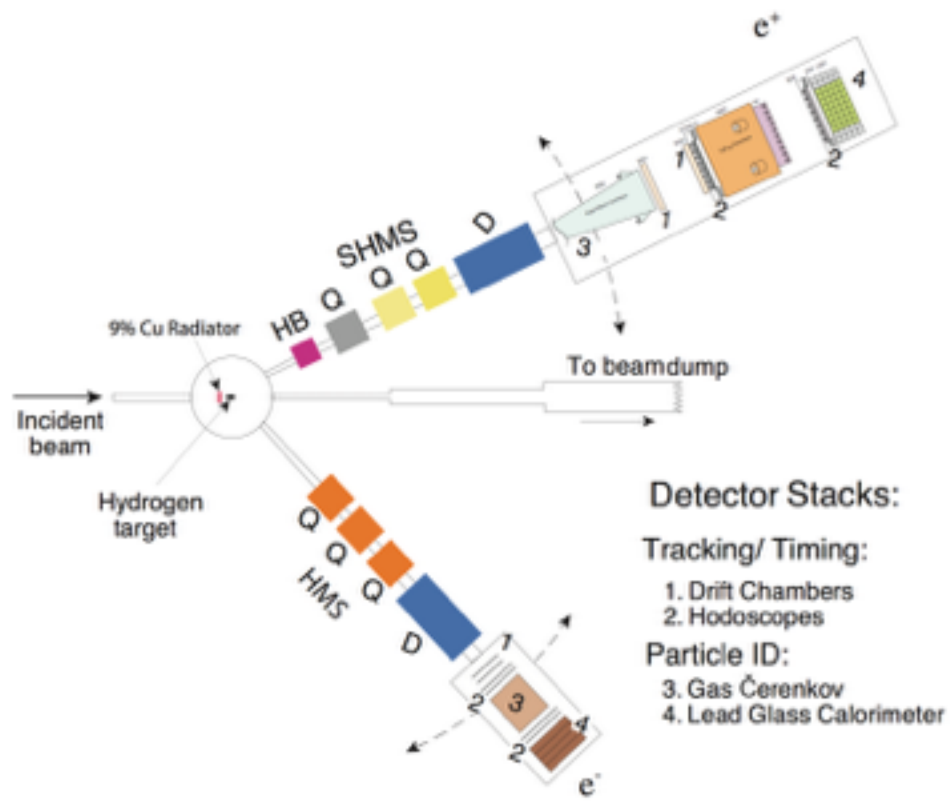
$$A_{\rm FB} = \frac{\frac{d\sigma}{d\Omega}(\theta_{\rm CM}) - \frac{d\sigma}{d\Omega}(\theta_{\rm CM} - \pi)}{\frac{d\sigma}{d\Omega}(\theta_{\rm CM}) + \frac{d\sigma}{d\Omega}(\theta_{\rm CM} - \pi)}$$



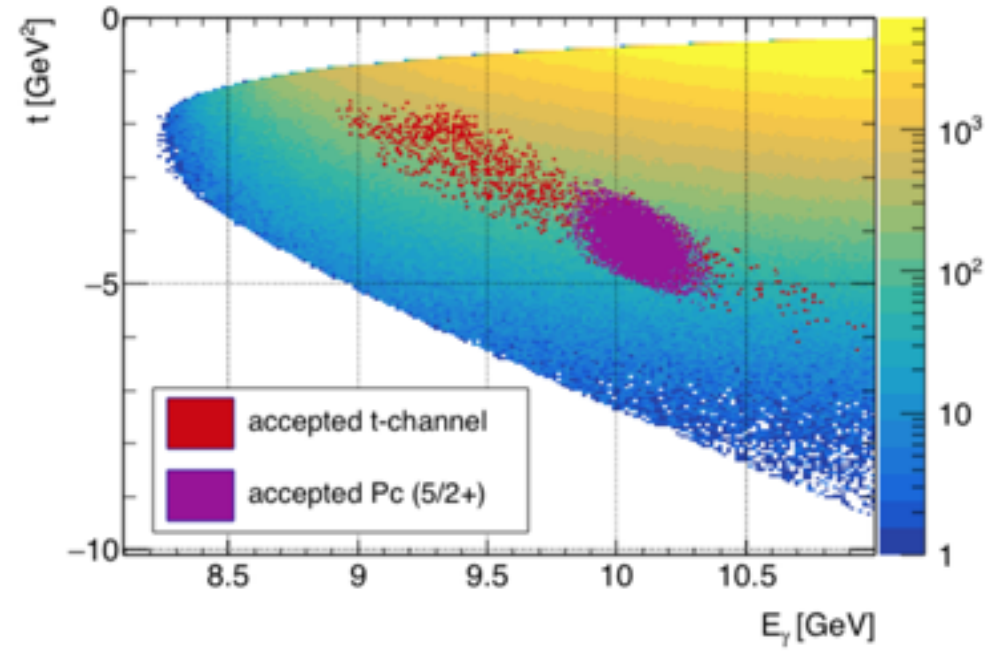


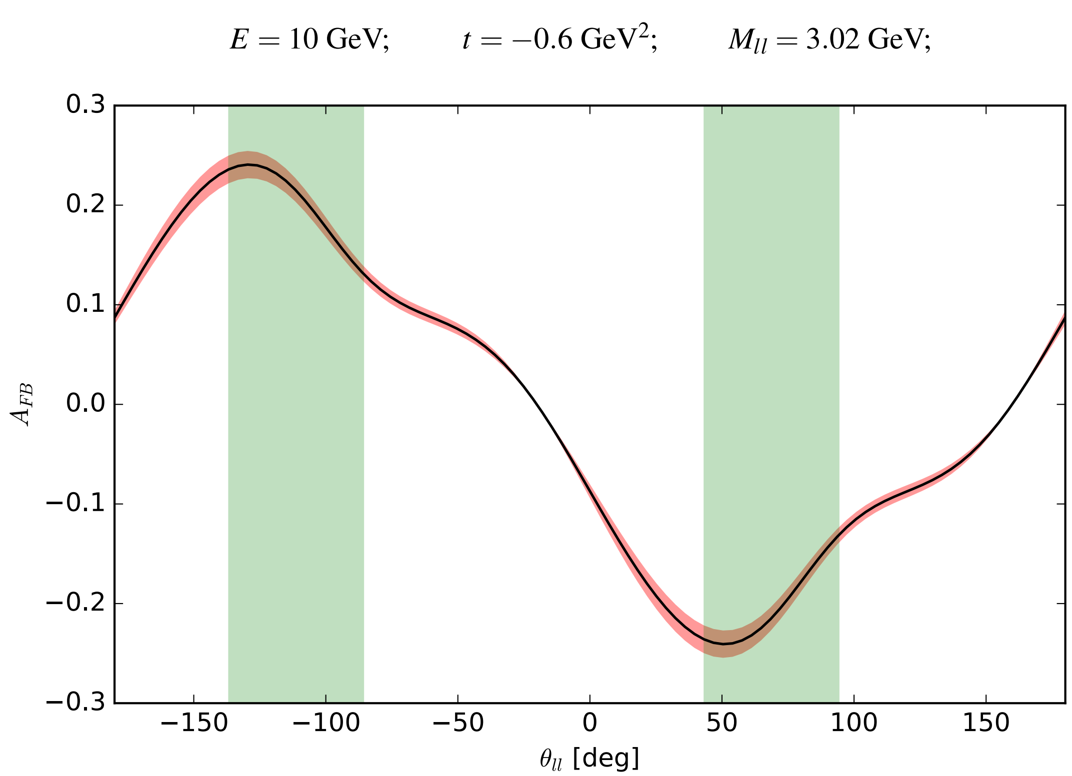
OG, M. Vanderhaeghen, PRD **94**, 074001 (2016)

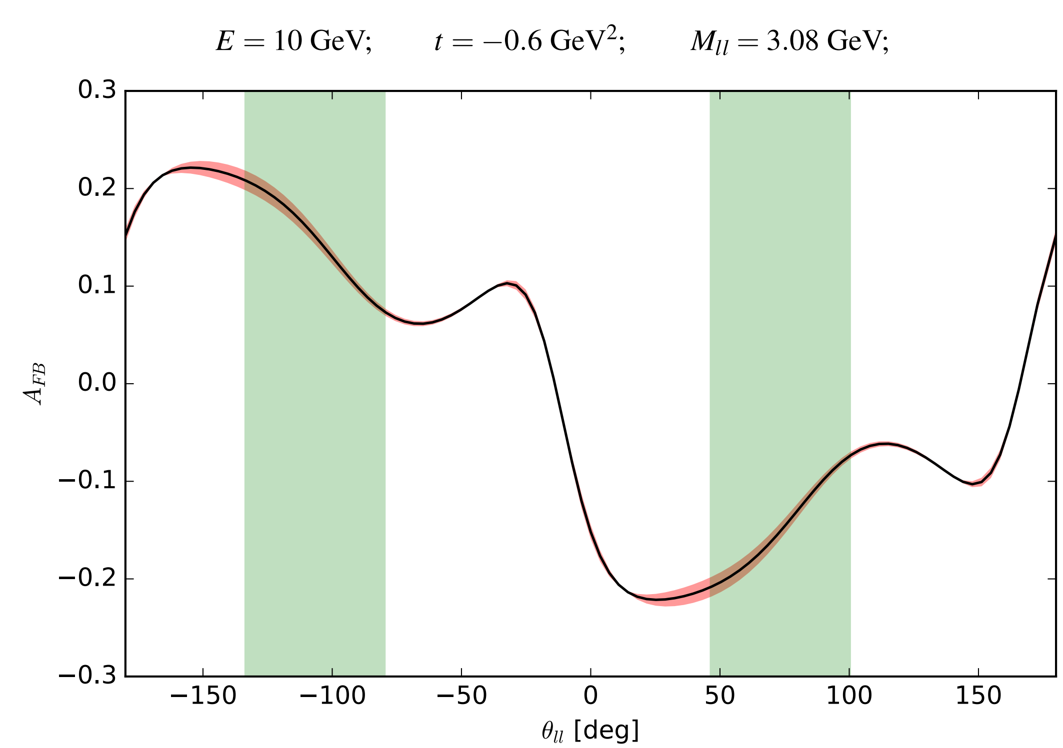
Upcoming experiment at JLab (Hall C) [PR12-16-007]



kinematic acceptance:







Summary

- probing the **real part** of the forward **Compton** and **elastic J/psi** scattering amplitudes at various kinematics **directly** appears to be a missing tool for a thorough study of the processes
- a dilepton photoproduction experiment is proposed to access the forward amplitudes **directly**
- some of the existing facilities are capable of carrying out the proposed experiment in the near future

Interference term

$$2\, T^*_{\mathrm{BH}} \cdot T_{\mathrm{qCS}} \;\simeq\; \frac{e^6\, G_E\, T_1}{L\, D\, M_{ll}^2\, t} \cdot \Big\{ \mathrm{I} \,-\, \mathrm{II} \,+\, \mathrm{III} \,-\, \mathrm{IV} \Big\},$$

$$D = 1 - \frac{t}{4M^2}$$

$$\mathrm{I} \;=\; \frac{1}{2M\nu^2}\, \left[a^2 - (2ME)^2\right]\, \left[t - M_{ll}^2\right]\, \Big\{ \left[t - M_{ll}^2\right]\, a + (2ME)\, b \Big\}$$

$$\mathrm{II} \;=\; \frac{2}{\nu}\, \left[a^2 - (2ME)^2\right]\, t\, b$$

$$\mathrm{III} \;=\; 4M\, \Big\{ \left[t - M_{ll}^2\right]^2 a \,-\, (2ME) \left[t + M_{ll}^2\right] b \Big\}$$

$$\mathrm{IV} \;=\; 16\, M\, m^2\, \Big\{ \left[t - M_{ll}^2\right] (Da + b) \,+\, (2ME)\, Db \Big\}$$