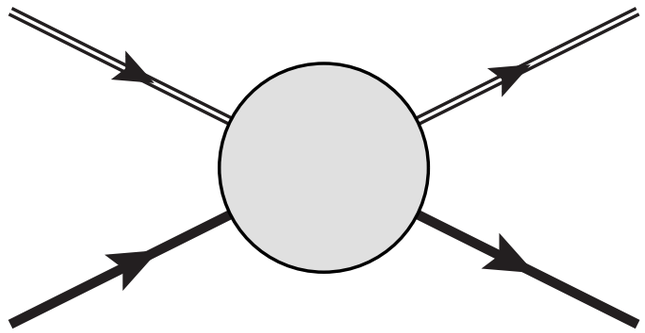


Accessing the **real part** of the forward **elastic J/ψ - p and ϕ - p** scatterings amplitudes close to threshold

Oleksii Gryniuk, Marc Vanderhaeghen

JGU, Mainz, Germany

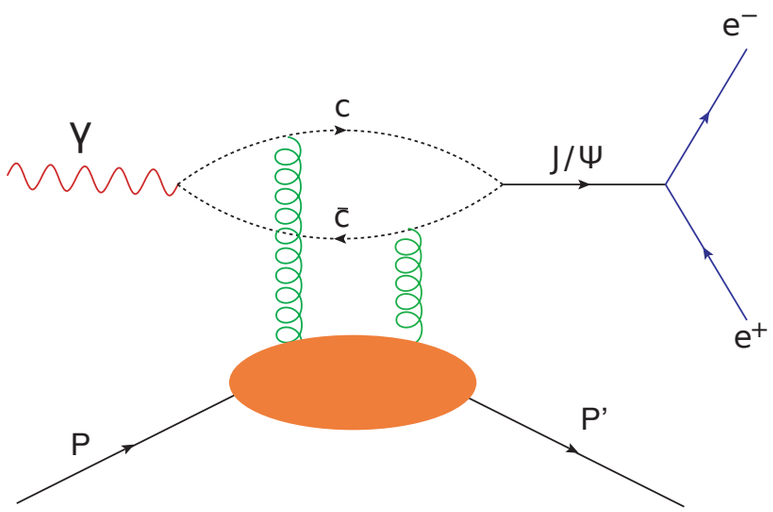
ECT Trento Workshop

April 4, 2017

Outline

- Motivation
- Accessing the **real part** of the forward elastic **J/ψ - p** scattering amplitude
- forward elastic **ϕ - p** scattering *(prospective study)*
- Summary

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



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

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

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

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

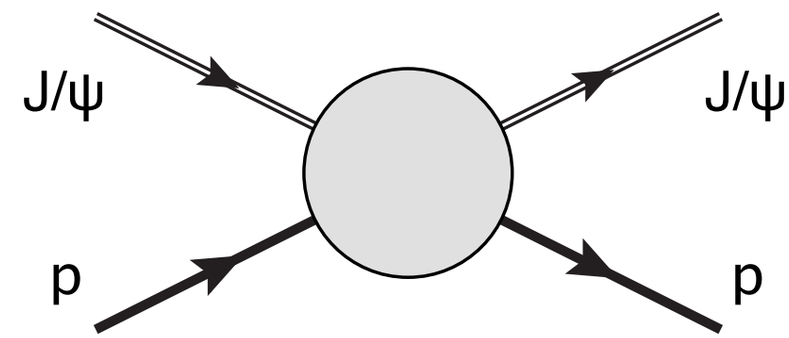
M. E. Luke, A. V. Manohar and M. J. Savage, Phys. Lett. B **288**, 355 (1992)
S. J. Brodsky and G. A. Miller, Phys. Lett. B **412**, 125 (1997)
. . .
S. H. Lee and C. M. Ko, Phys. Rev. C **67**, 038202 (2003)
K. Tsushima, D. H. Lu, G. Krein and A. W. Thomas, Phys. Rev. C **83**, 065208 (2011)

- connection of J/ψ scattering length (subtraction term) to QCD anomaly contribution to proton mass ?..

Forward J/ψ - p scattering

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

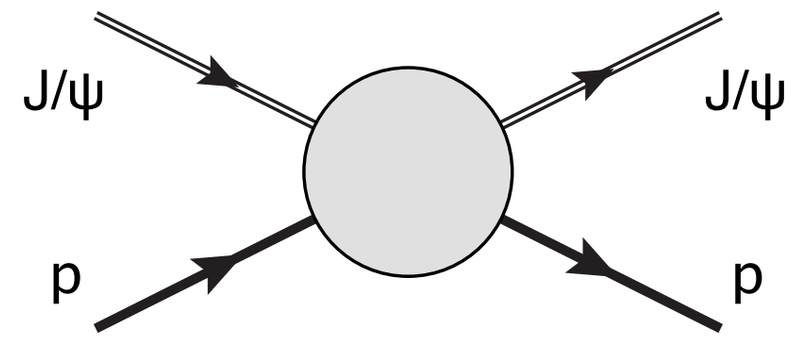
kinematic variable: $\nu \equiv p\,q = \dfrac{s-u}{4}$



Forward J/ψ - p scattering

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

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



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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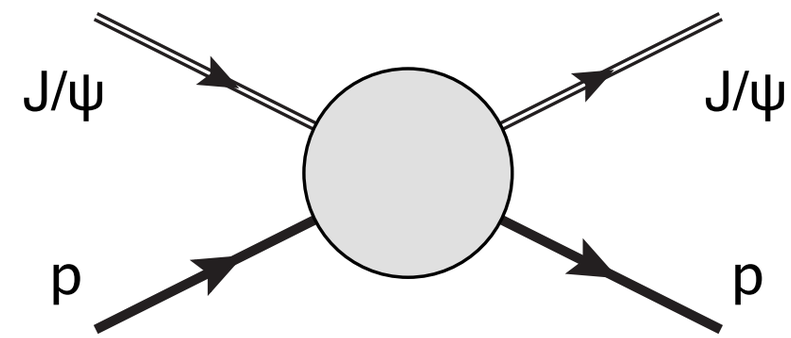

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directly sensitive to $a_{\psi p}$

parameterising cross section:

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

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

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

Forward J/ψ - 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)

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

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forward differential cross section:

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

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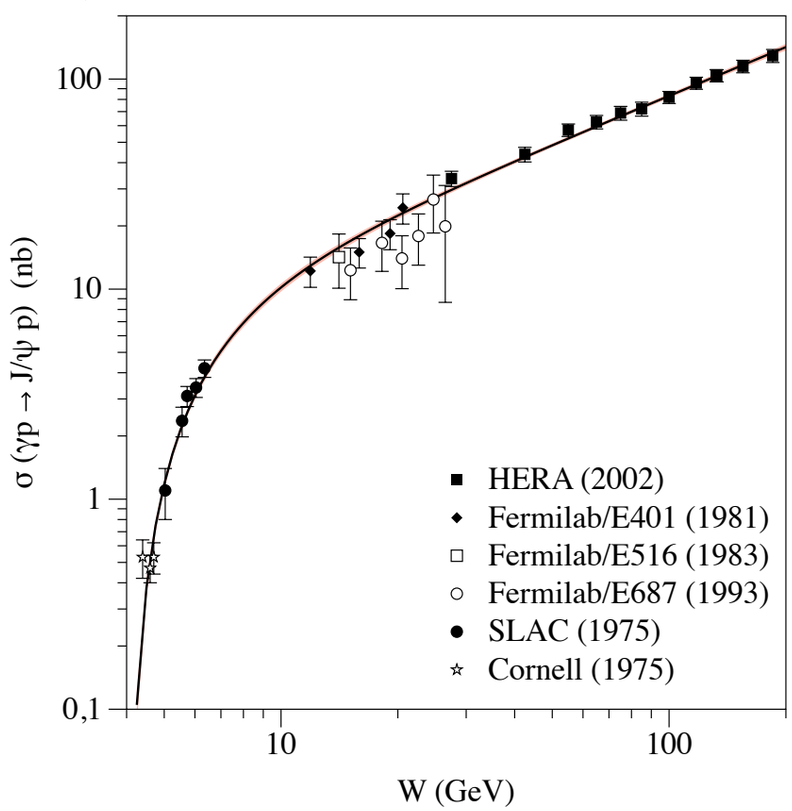

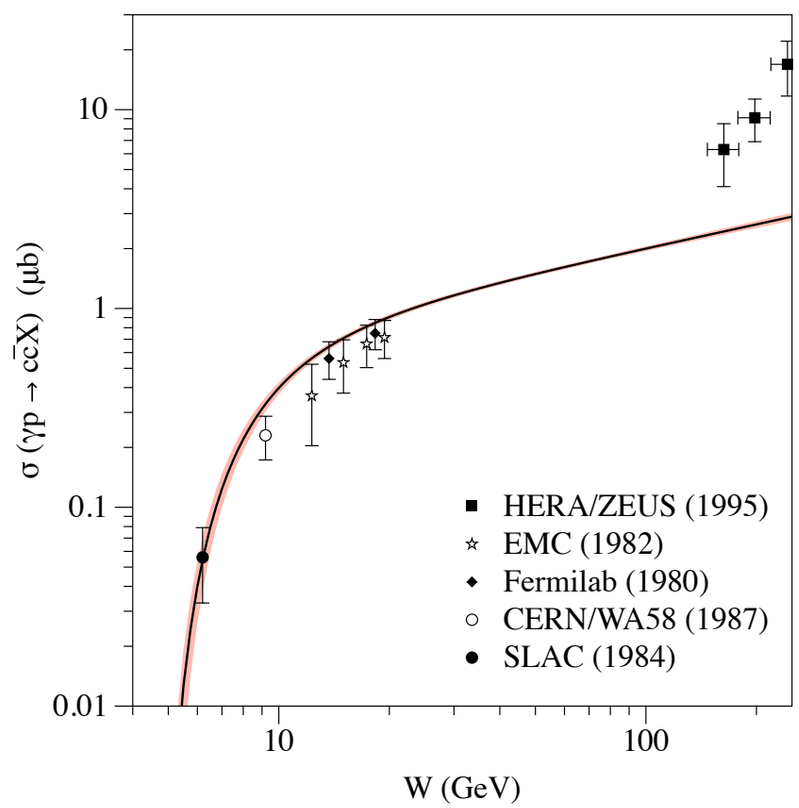

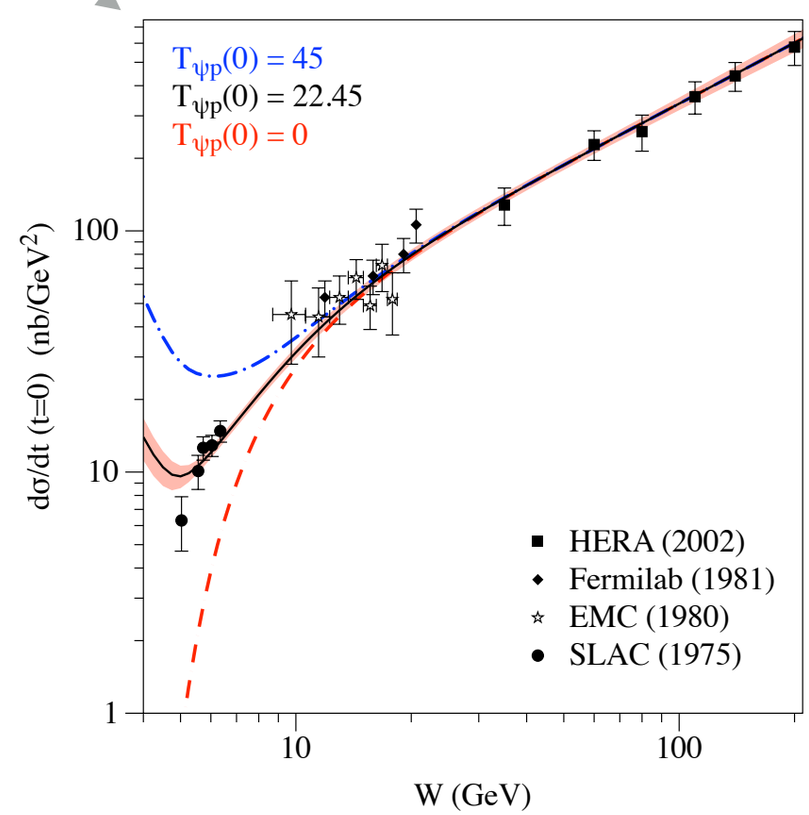

OG, M. Vanderhaeghen, PRD **94**, 074001 (2016)

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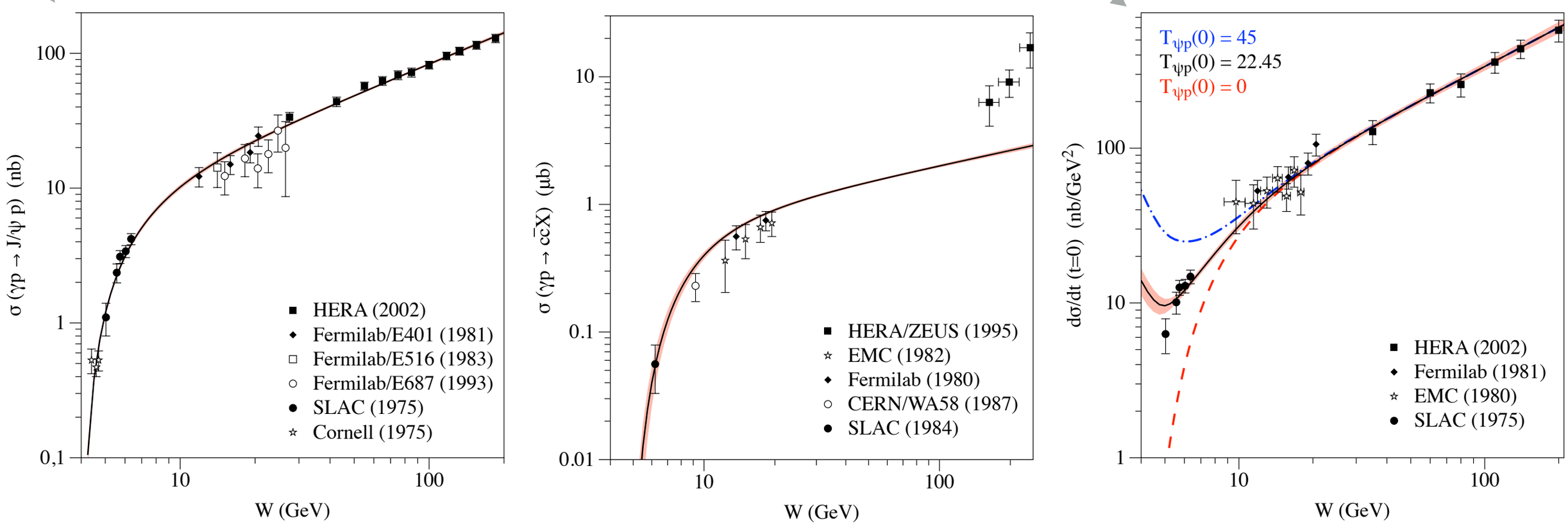


OG, M. Vanderhaeghen, PRD **94**, 074001 (2016)

simultaneously fitting ⇨ $T(0) = 22.5 \pm 2.5$ ⇨ $a_{\psi p} \sim 0.05$ fm $\quad B_\psi \sim 3$ MeV

Scattering length estimates

QCD sum rules:

A. Hayashigaki, Prog.Theor.Phys. **101**, 923 (1999) → $a_{\psi p} \approx 0.1 \text{ fm}$

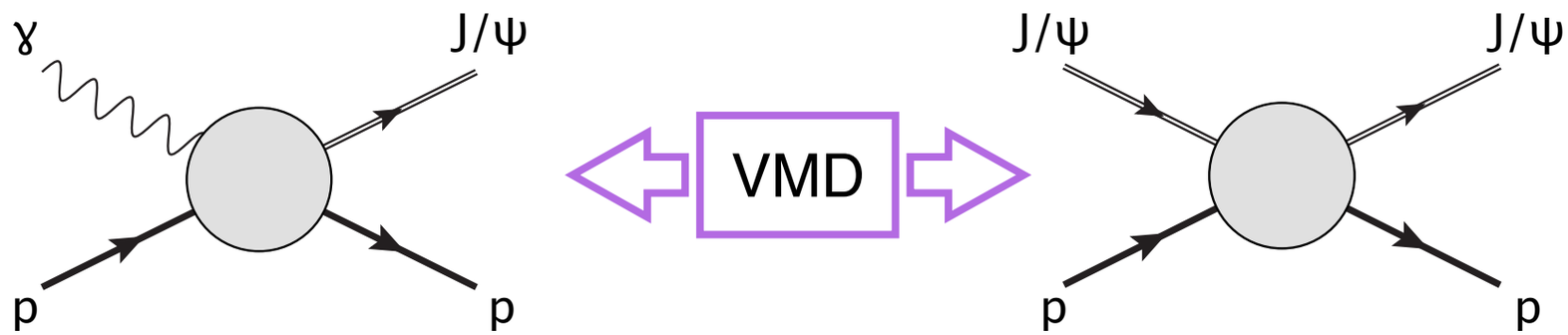
based on J/ψ chromo-electric polarisability:

A. B. Kaidalov and P. E. Volkovitsky, Phys. Rev. Lett. **69**, 3155 (1992) → $a_{\psi p} = 0.05 \text{ fm}$

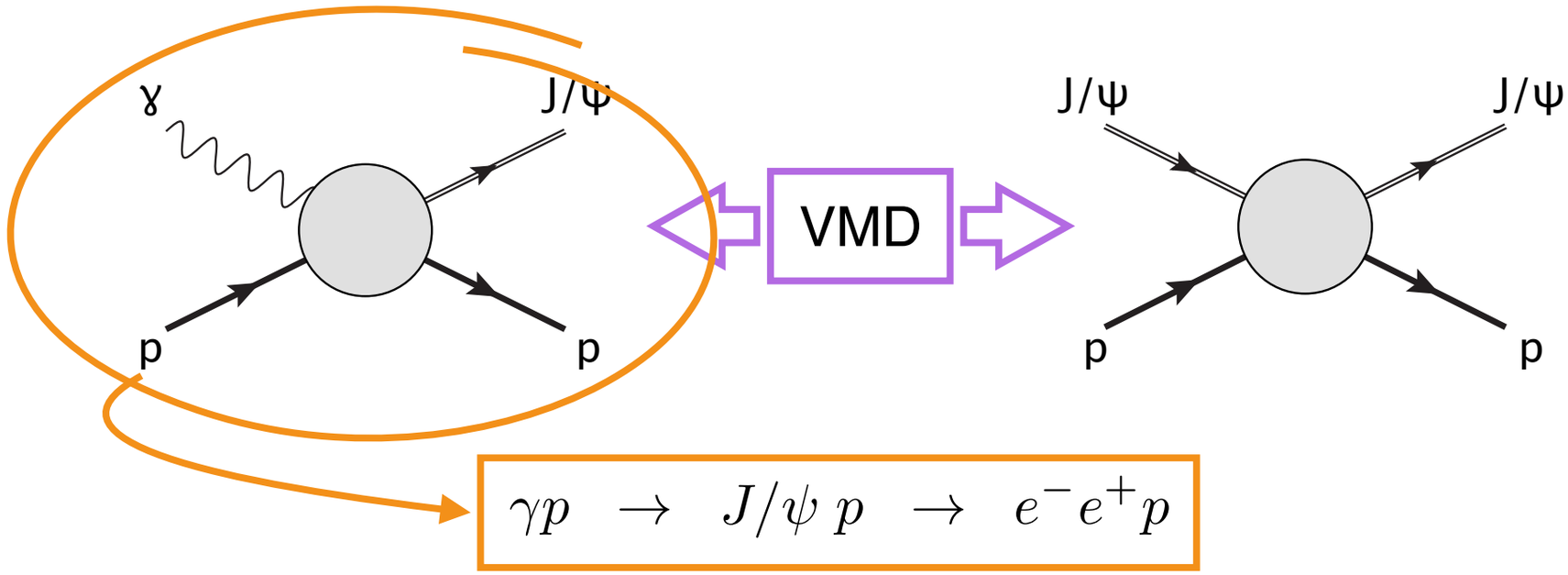
A. Sibirtsev and M. B. Voloshin, Phys. Rev. D **71**, 076005 (2005) → $a_{\psi p} = 0.37 \text{ fm}$

our estimate → $a_{\psi p} \approx 0.05 \text{ fm}$

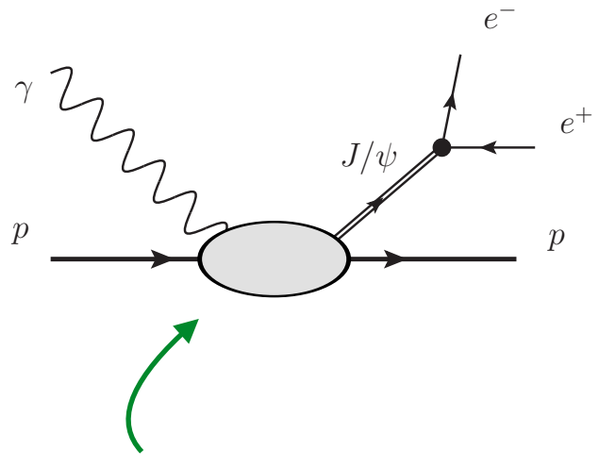
Lepton pair photoproduction



Lepton pair photoproduction

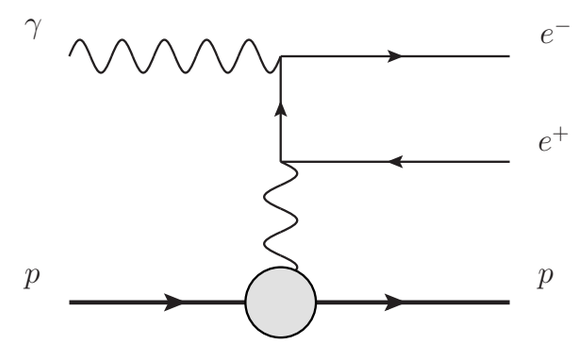


lepton pair photoproduction through J/ψ:



+

Bethe-Heitler:



$t \rightarrow 0$

$$\mathcal{M}_\psi \simeq \frac{ie^3}{q'^2}\frac{f_\psi^2}{2M}\frac{1}{q'^2 - M_\psi^2 + iM_\psi\Gamma_\psi} T_{\psi p}\left(\nu = \frac{1}{2}(s - M_\psi^2 - M^2)\right)$$

$$\times\, \varepsilon_\mu(q,\lambda)\cdot \bar{u}(l_-, s_-)\gamma_\nu v(l_+, s_+)$$

$$\times\, \bar{N}(p', s_p')\left\{\left(g^{\mu\nu} - \frac{q'^\mu q^\nu}{q\cdot q'}\right) + \frac{q\cdot q'}{(q\cdot P)^2}\left(P^\mu - \frac{q\cdot P}{q\cdot q'}q'^\mu\right)\left(P^\nu - \frac{q\cdot P}{q\cdot q'}q^\nu\right)\right\} N(p, s_p)$$

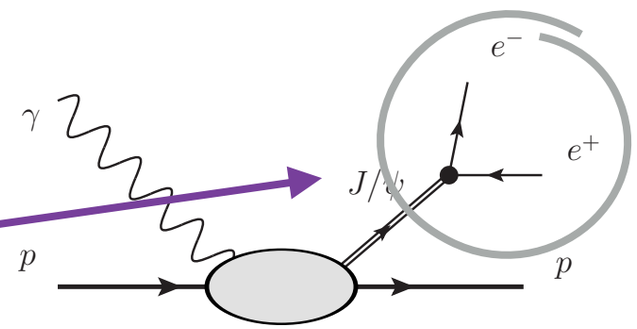
Lepton pair photoproduction

$l_+ \leftrightarrow l_-$

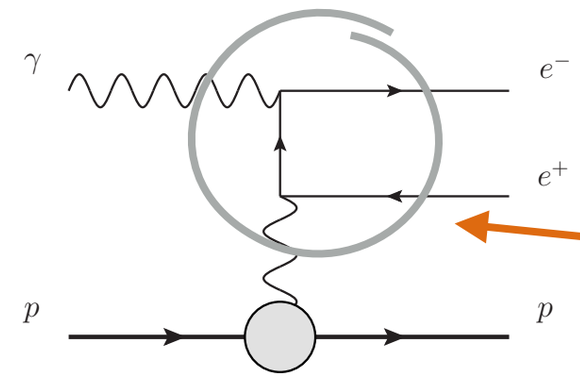
lepton pair photoproduction through J/ψ:

$l_+ \leftrightarrow l_- :$

odd



Bethe-Heitler:



$l_+ \leftrightarrow l_- :$

even

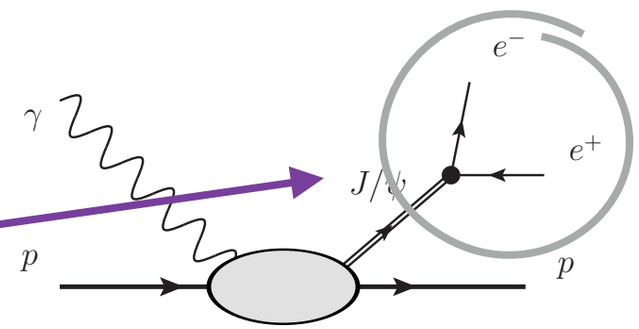
Lepton pair photoproduction

$l_+ \leftrightarrow l_-$

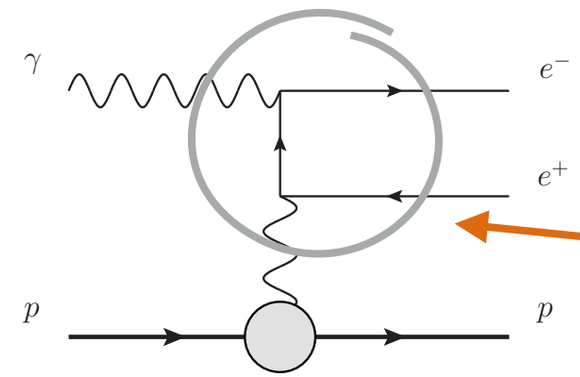
lepton pair photoproduction through J/ψ:

$l_+ \leftrightarrow l_- :$

odd



Bethe-Heitler:



$l_+ \leftrightarrow l_- :$

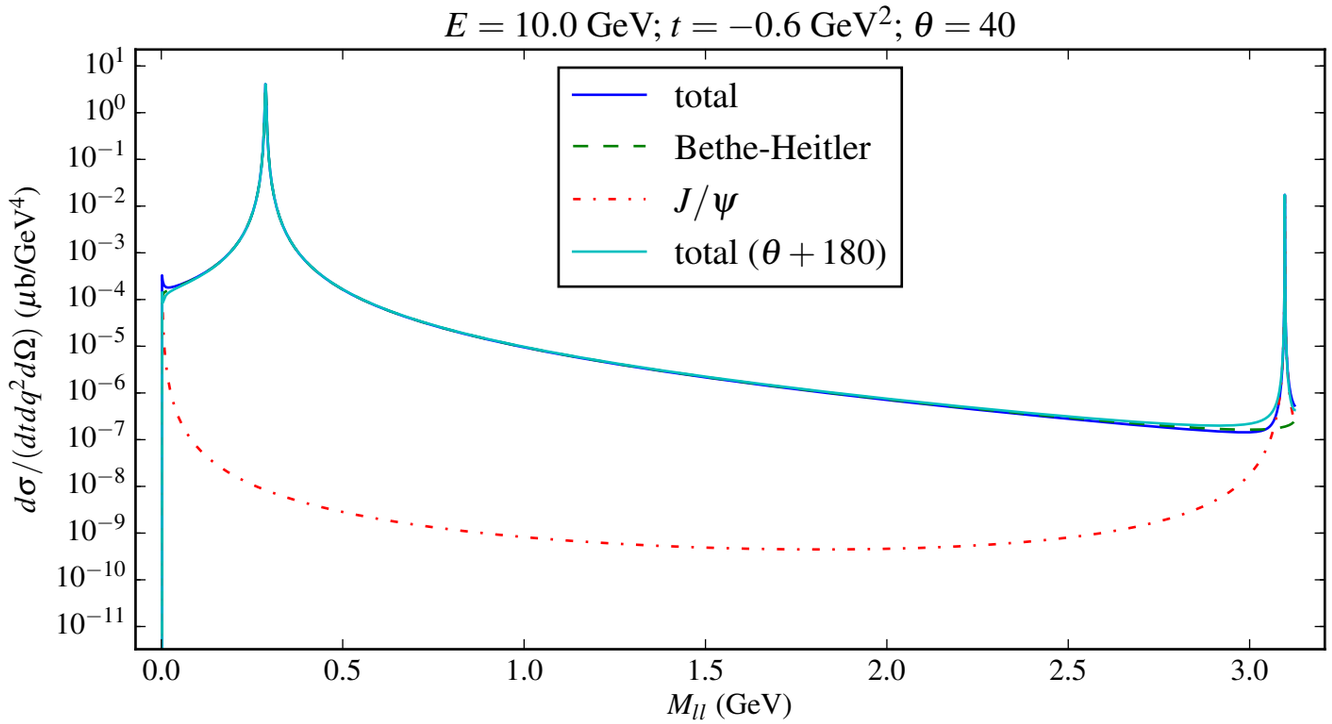
even

Observable:

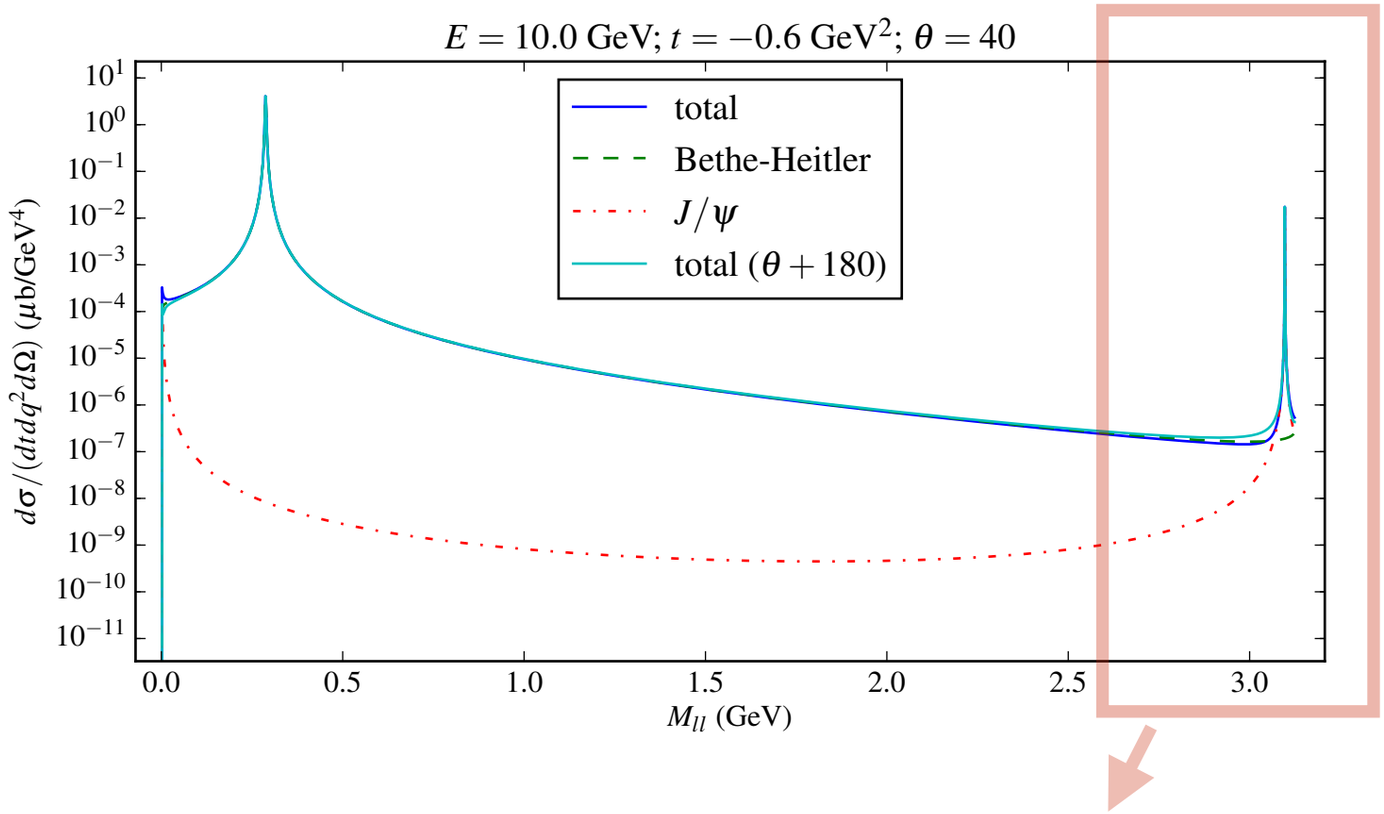
$$|T_\psi + T_{\rm BH}|^2 = |T_\psi|^2 + 2{\rm Re}T_\psi T_{\rm BH} + |T_{\rm BH}|^2$$

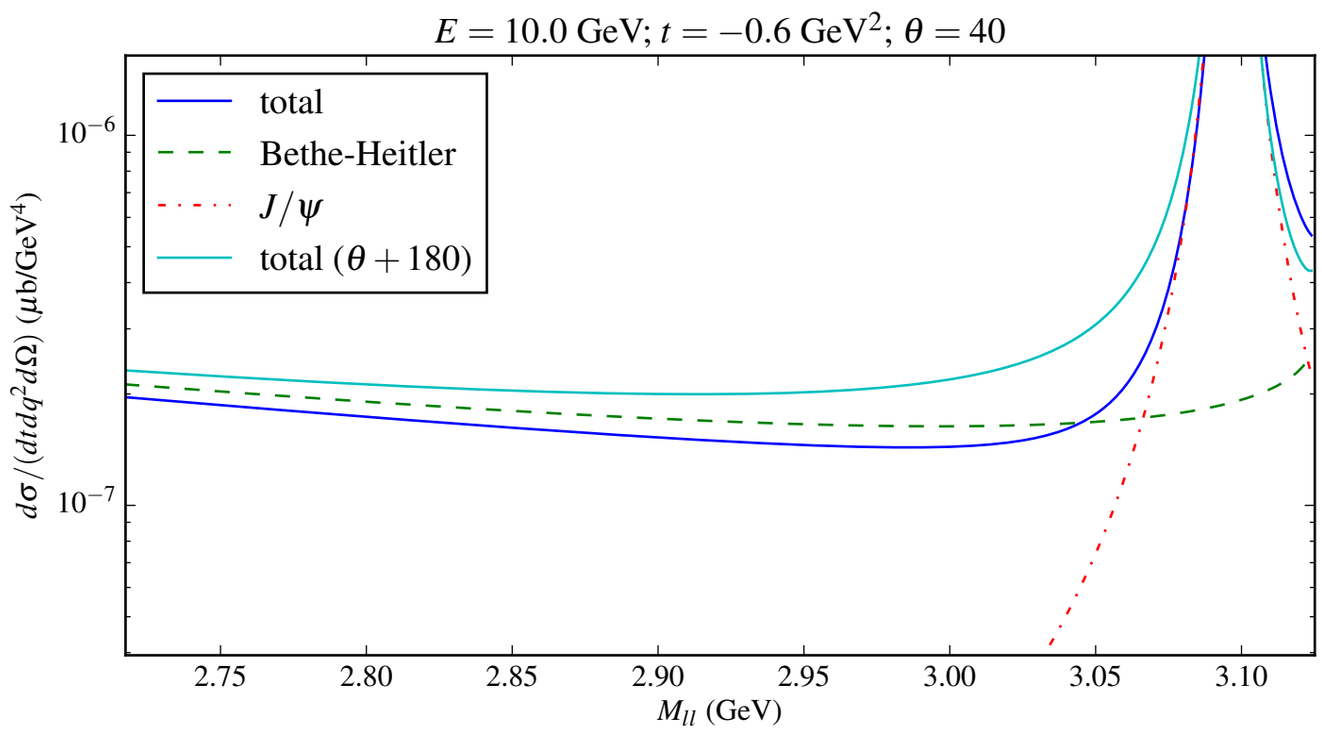
even odd even

J/ψ vs Bethe-Heitler cross sections



J/ψ vs Bethe-Heitler cross sections



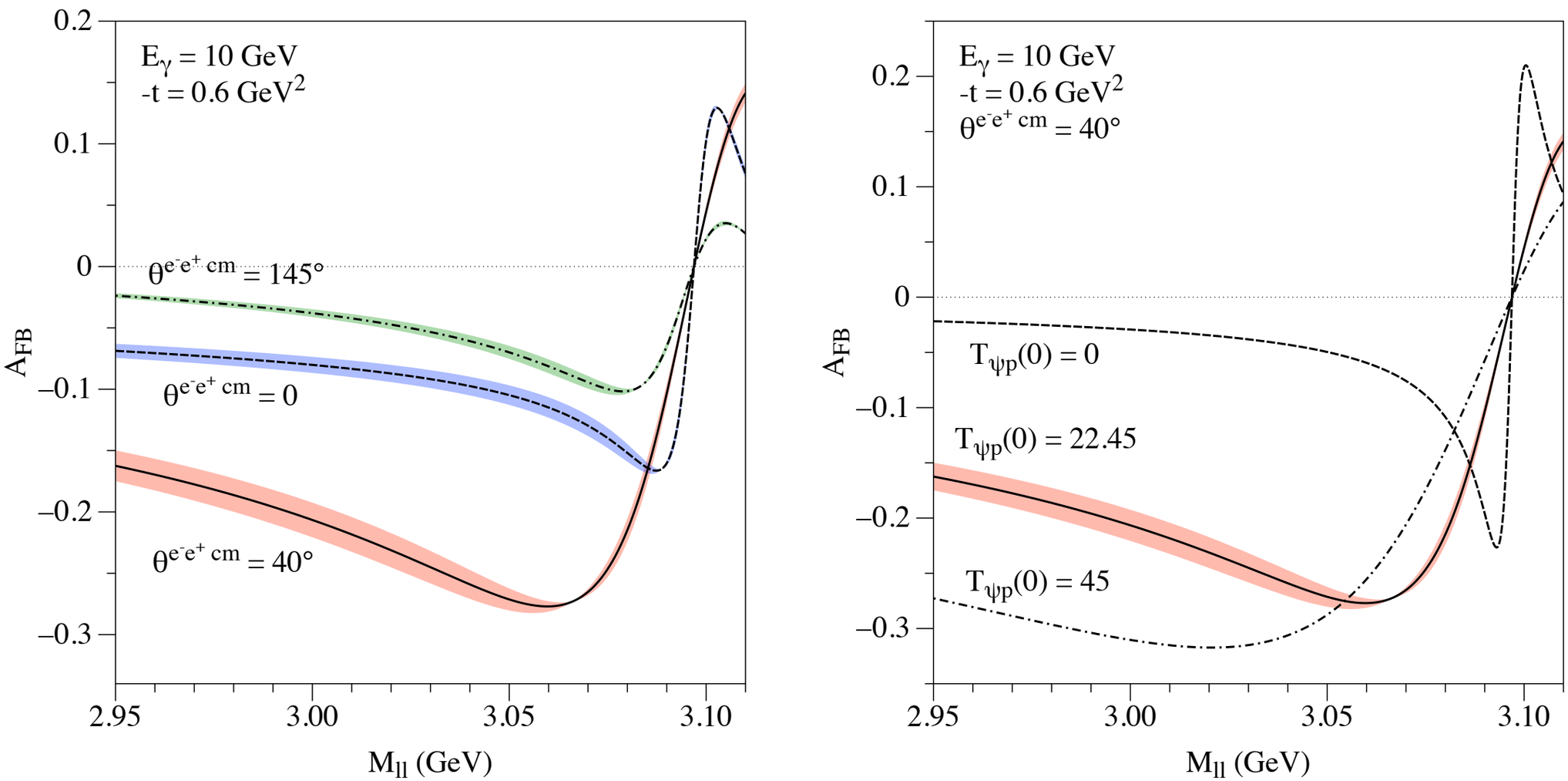


Forward-backward asymmetry (J/ψ - p)

interference term

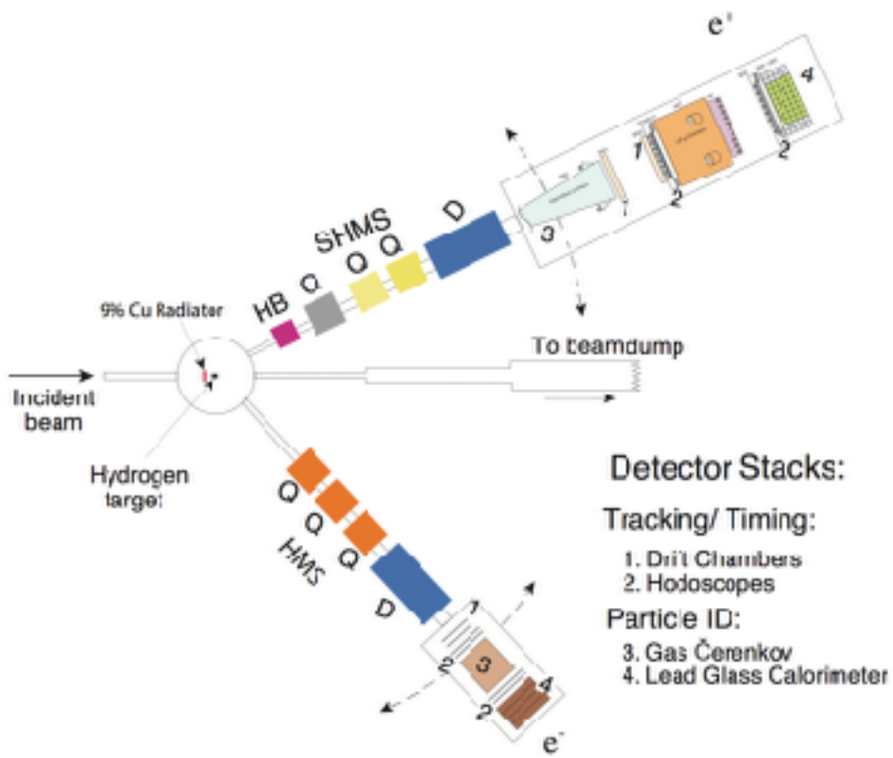
$$A_{\rm FB} \equiv \frac{\frac{d\sigma}{d\Omega}(\theta_{cm}) - \frac{d\sigma}{d\Omega}(\theta_{cm}-\pi)}{\frac{d\sigma}{d\Omega}(\theta_{cm}) + \frac{d\sigma}{d\Omega}(\theta_{cm}-\pi)} = \frac{\sum_s 2\,{\rm Re}T_\psi\, T_{BH}}{\sum_s |T_\psi|^2 + \sum_s |T_{BH}|^2}$$

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

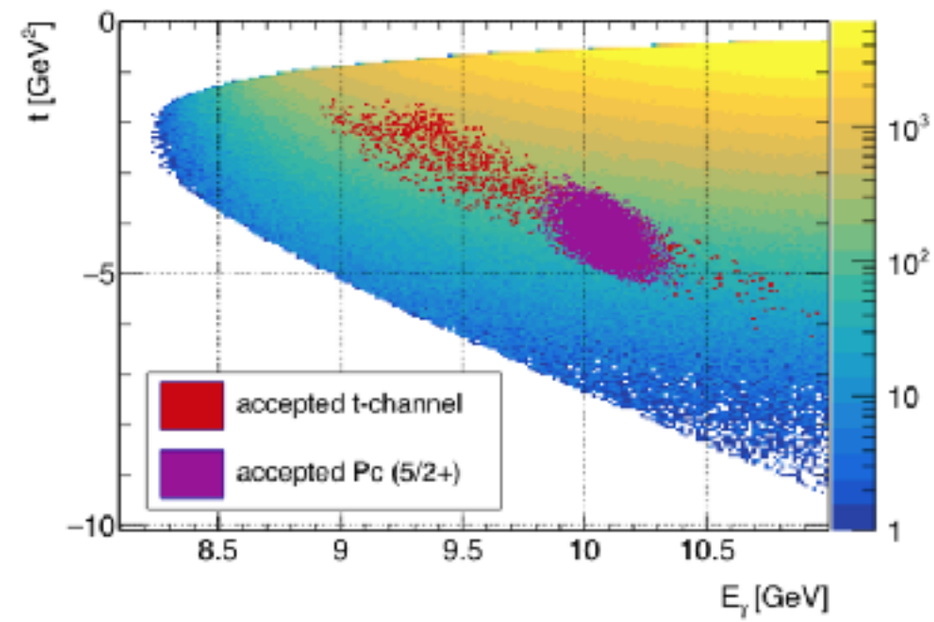


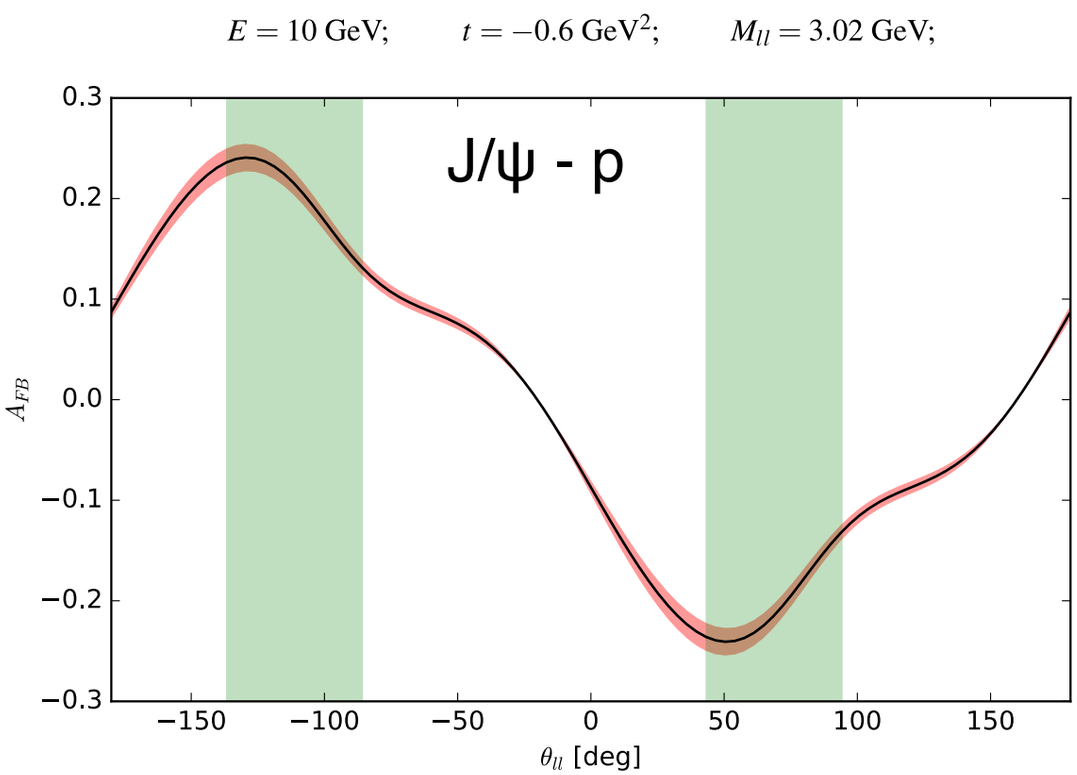
OG, M. Vanderhaeghen, PRD **94**, 074001 (2016)

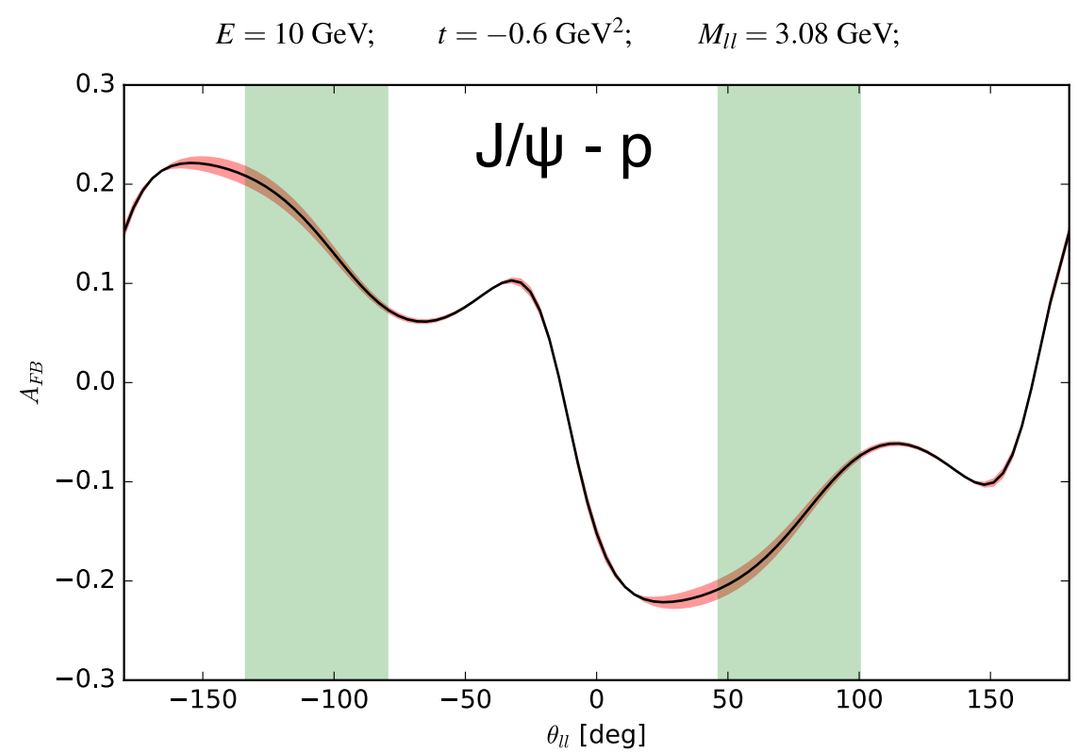
Upcoming experiment at JLab (Hall C) [PR12-16-007]



kinematics:

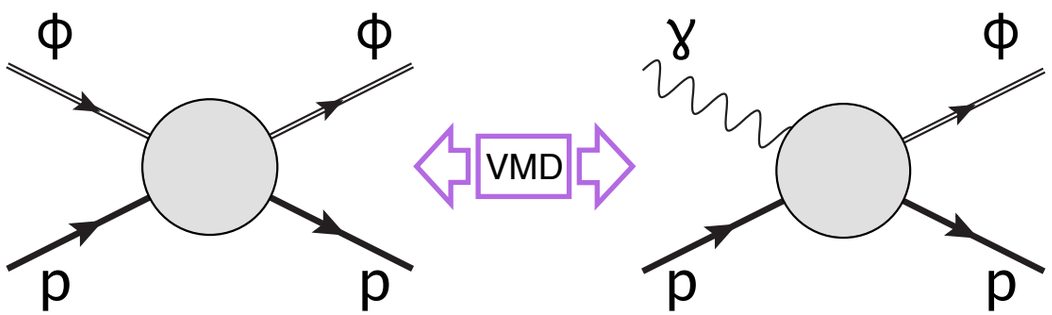






Forward ϕ - p scattering

prospective study



- lower threshold energy
- larger cross section
- **however:** lack of reliable cross section database / absence of *inelastic* cross section

Forward ϕ - p scattering

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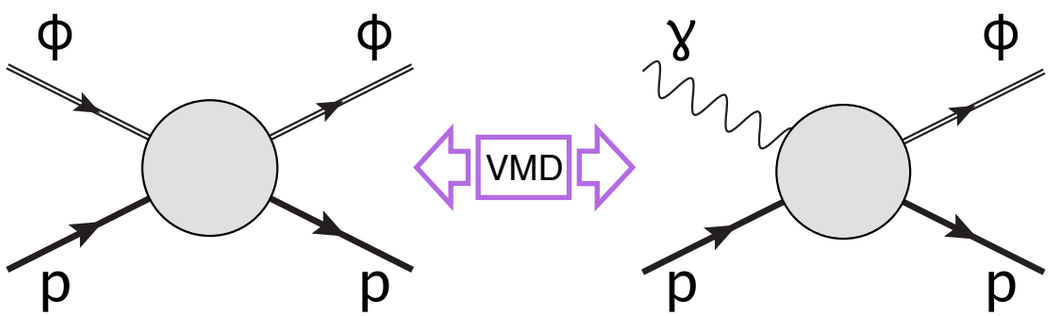

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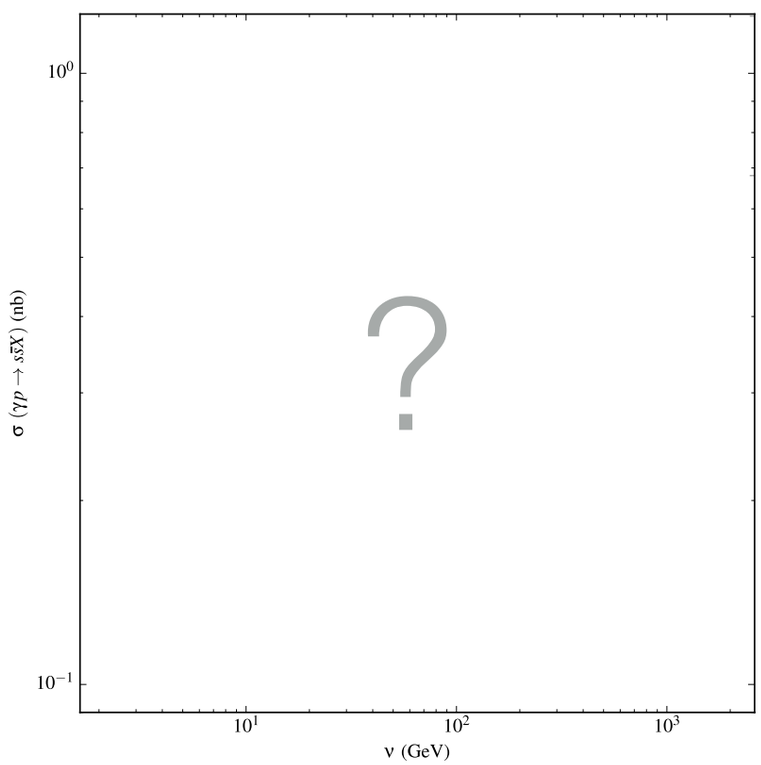
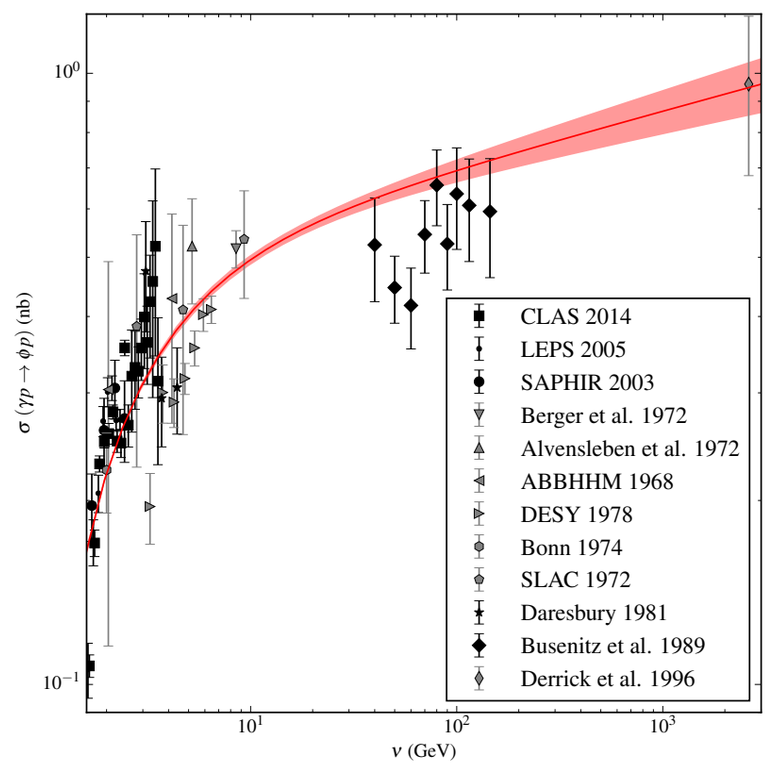
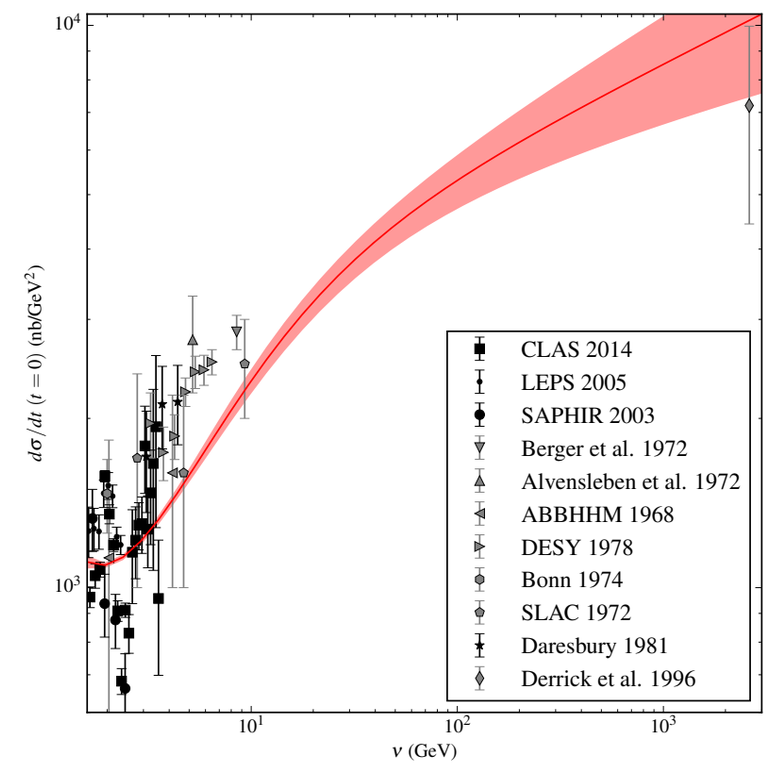
$\sigma(\gamma p \to s\bar{s}X)$



$\sigma(\gamma p \to \phi p)$



$\left.\frac{d\sigma}{dt}\right|_{t=0} (\gamma p \to \phi p)$



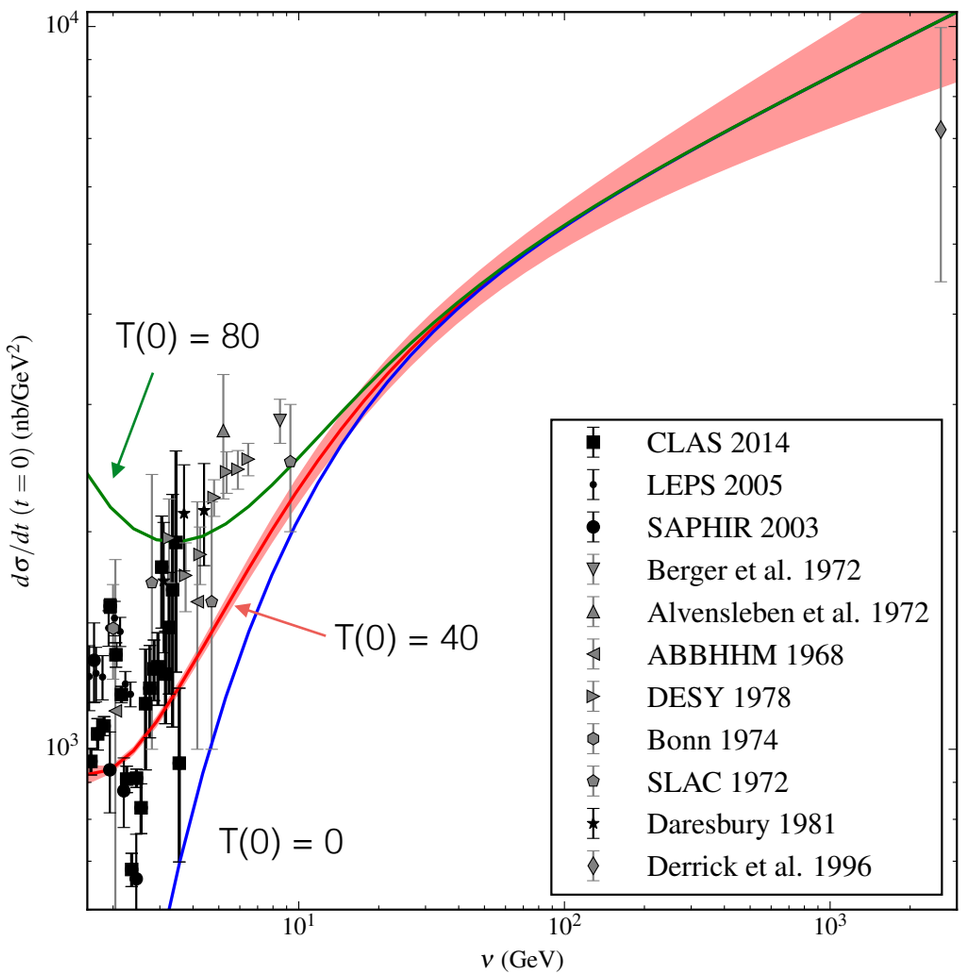
set Regge slope $\alpha_{el} = \alpha_{inel} \approx 1.092$

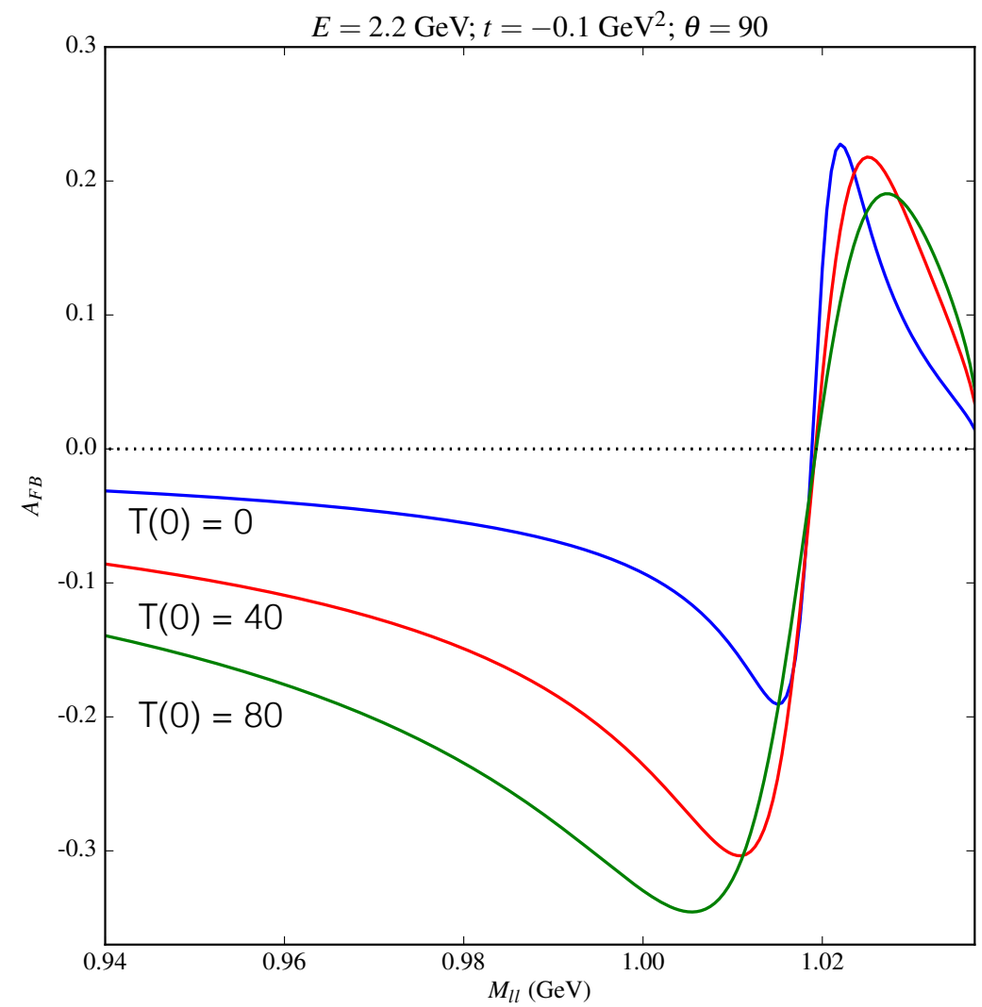
OG, F. Hagelstein, V. Pascalutsa, **PRD92**, 074031 (2015)

$T(0) \approx 46.3$

Forward-backward asymmetry (ϕ - p)

prospective study





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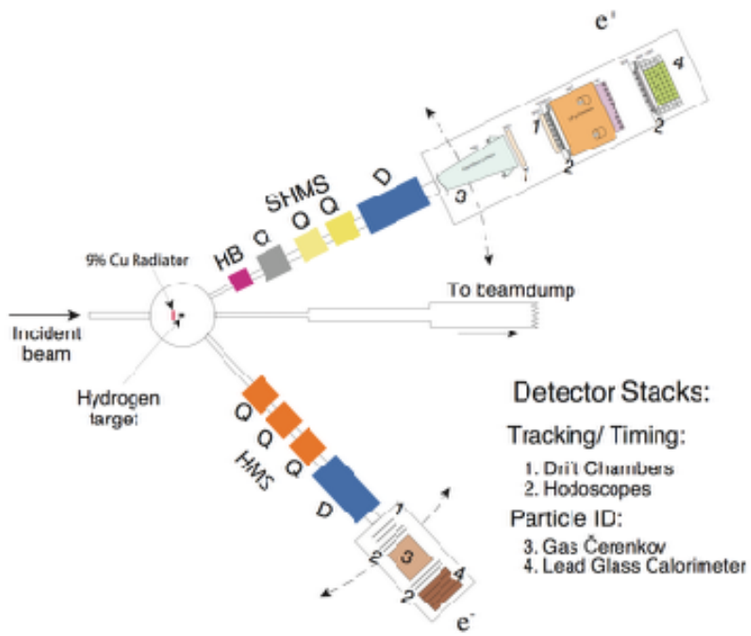
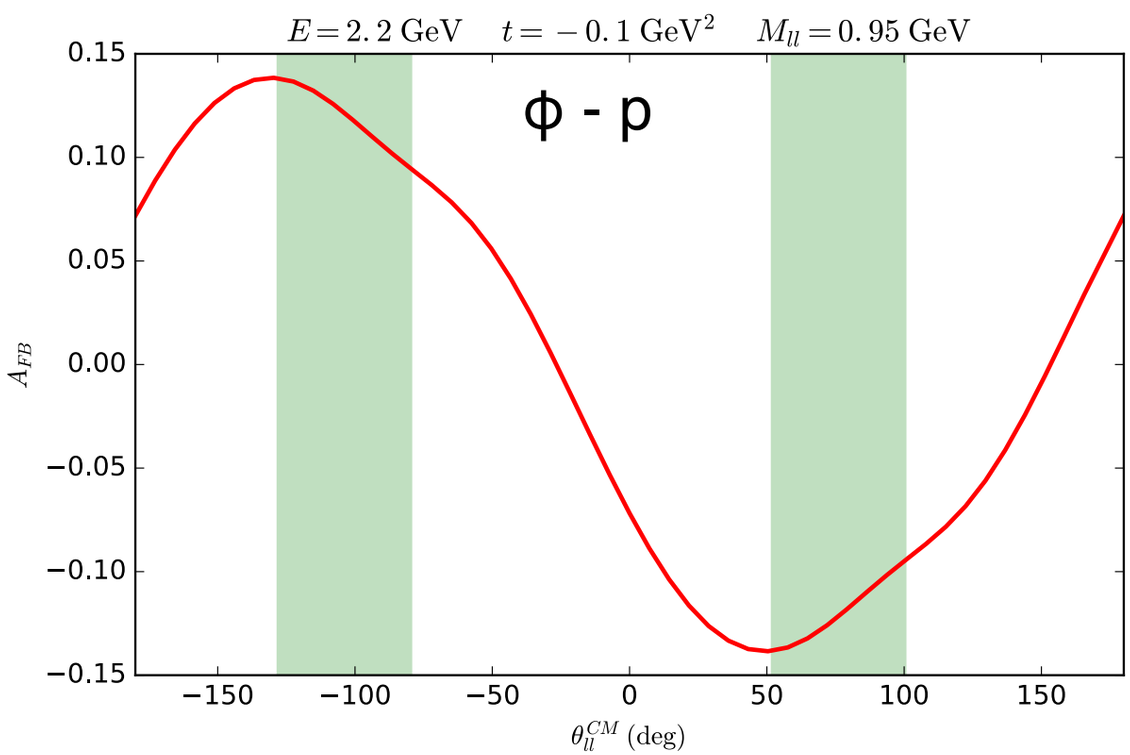
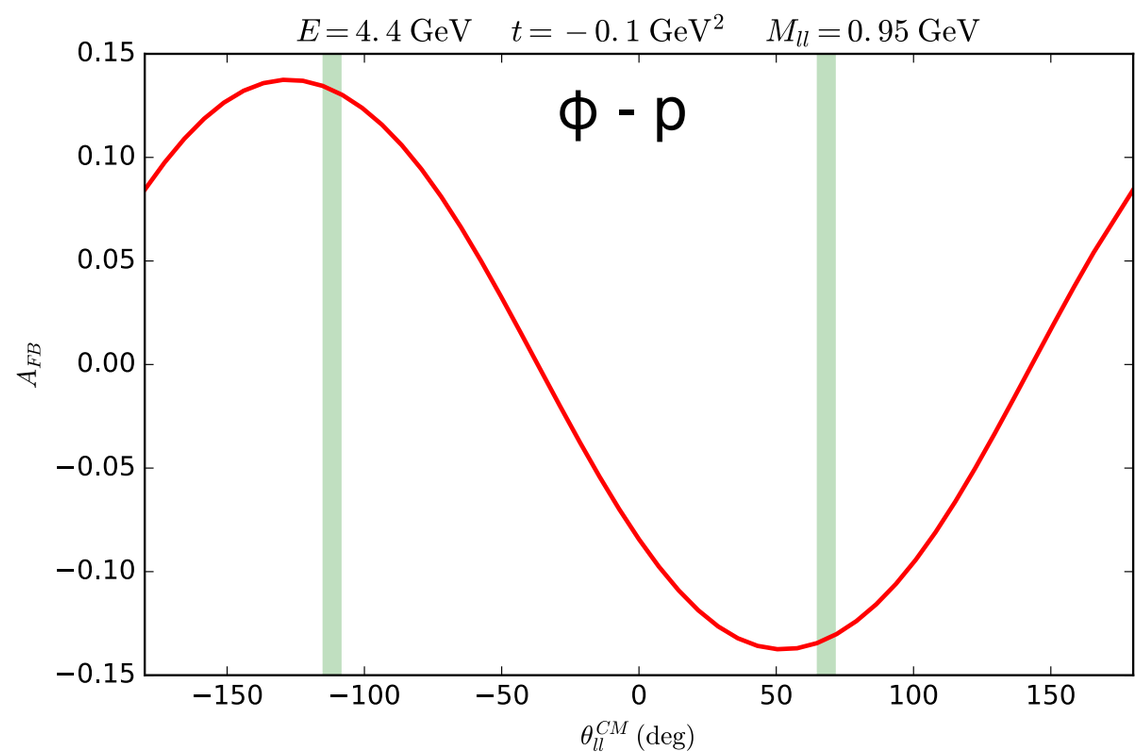


- smaller momentum transfer $-t = 0.1\ \mathrm{GeV}^2$
- lepton pair mass $M_{ll} = 0.95$ GeV
- better precision for smaller beam energy
  E = 2.2, 4.4 GeV





Summary

- probing the **real part** of the forward **elastic J/ψ (ϕ) - proton** scatterings amplitude at various kinematics **directly** is a crucial tool for a quantitative study of the interaction
- a dilepton photoproduction experiment is proposed to access the forward amplitude **directly**
- Hall C is capable of carrying out the proposed experiment
- study for other JLab experiments (e.g. SOLID) are ongoing