Accessing the **real part** of the forward **elastic** Psi/Phi - p scattering amplitude close to threshold

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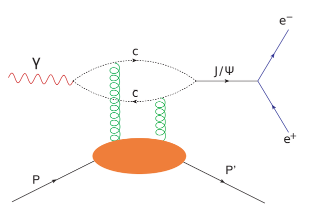
Motivation

- 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):

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

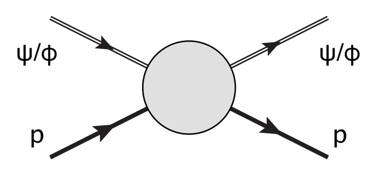
M. E. Luke, A. V. Manohar and M. J. Savage, Phys. Lett. B 288, 355 (1992)
S. J. Brodsky and G. A. Miller, Phys. Lett. B 412, 125 (1997)
S. H. Lee and C. M. Ko, Phys. Rev. C 67, 038202 (2003)
K. Tsushima, D. H. Lu, G. Krein and A. W. Thomas, Phys. Rev. C 83, 065208 (2011)

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

Forward ψ(ϕ) - p scattering

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

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



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 $a_{\psi p}$

parameterising cross section:

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

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

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

Vector meson dominance

Vector meson dominance (VMD) assumption:

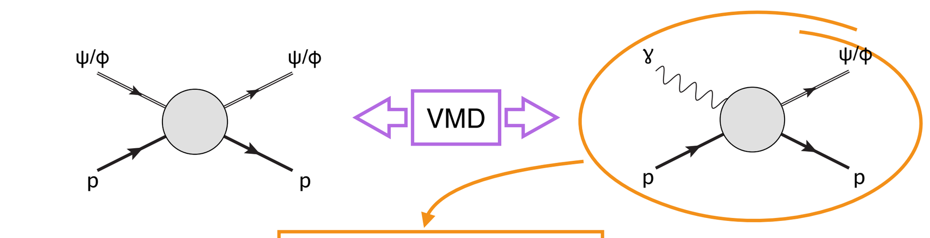
K. Redlich, H. Satz and G. M. Zinovjev, Eur. Phys. J. C 17, 461 (2000)
V. D. Barger and R. J. N. Phillips, Phys. Lett. B 58, 433 (1975)

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

$$\sigma^{inel}_{\psi p} = \left(\frac{M_\psi}{e f_\psi}\right)^2 \left(\frac{q_{\gamma p}}{q_{\psi p}}\right)^2 \sigma(\gamma p \to c\bar{c}X)$$

forward differential cross section:

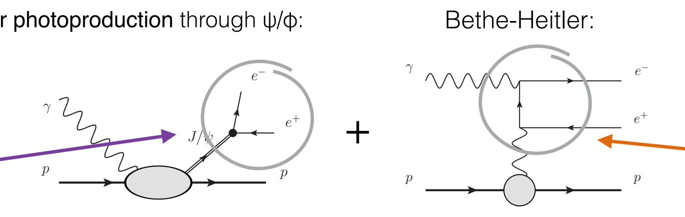
$$\left.\frac{d\sigma}{dt}\right|_{t=0}(\gamma p \to \psi p) = \left(\frac{e f_\psi}{M_\psi}\right)^2 \left(\frac{q_{\psi p}}{q_{\gamma p}}\right)^2 \left.\frac{d\sigma}{dt}\right|_{t=0}(\psi p \to \psi p)$$



lepton pair photoproduction: $\gamma p \;\to\; \psi/\phi\, p \;\to\; e^- e^+ p$

Lepton pair photoproduction

lepton pair photoproduction through ψ/ϕ: Bethe-Heitler:

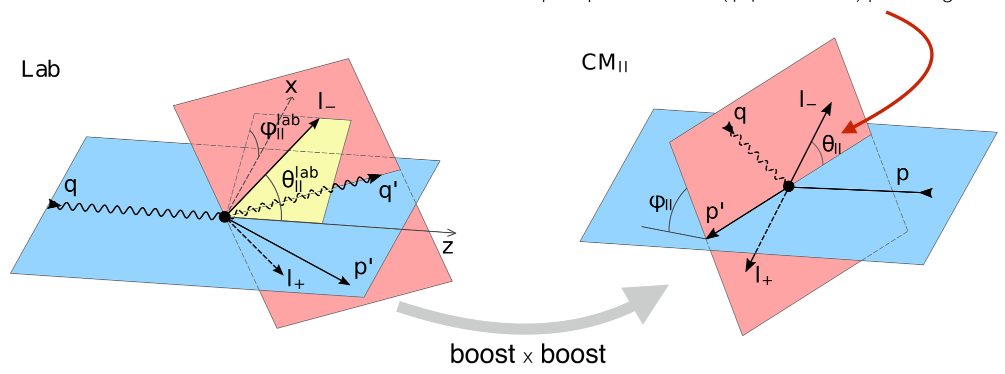


Observable:

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

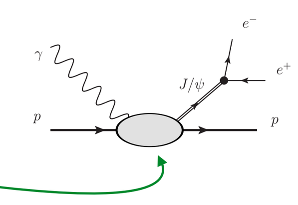
$l_+ \leftrightarrow l_-$: even, odd, even

lepton pair CM frame (ψ/ϕ rest frame) polar angle: θ_{ll}



$t \to 0$

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



Forward-backward asymmetry:

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

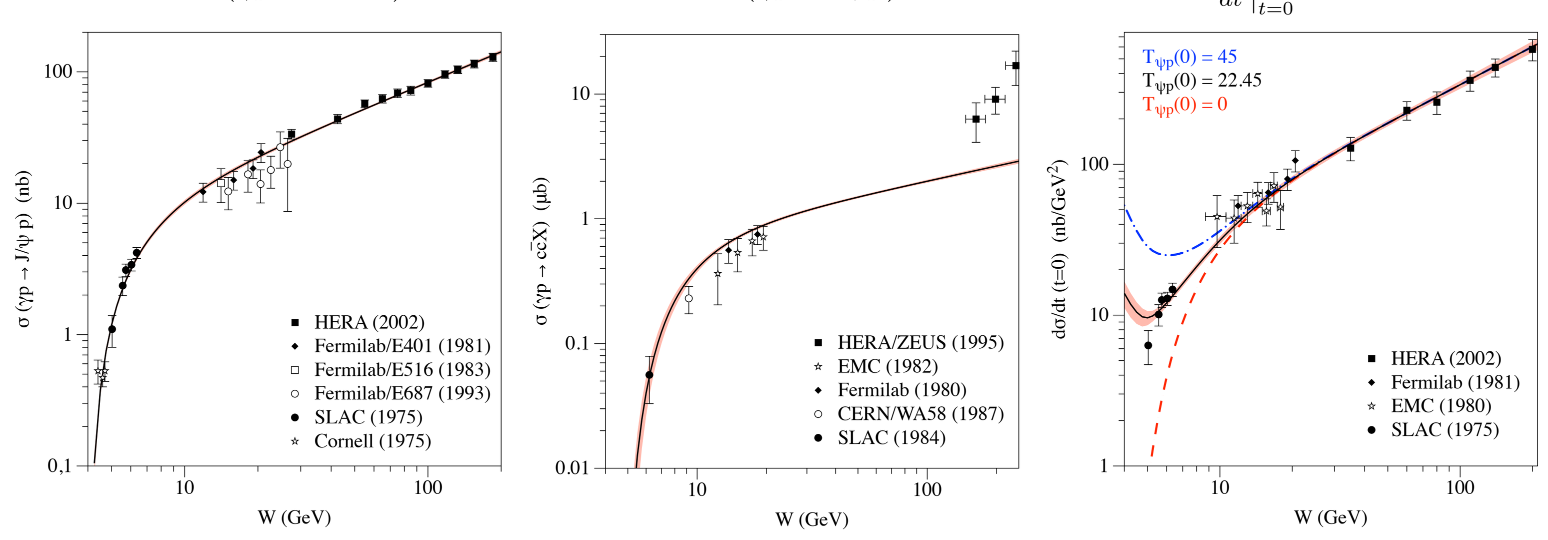
(interference term)

Psi

PRD **94**, 074001 (2016)

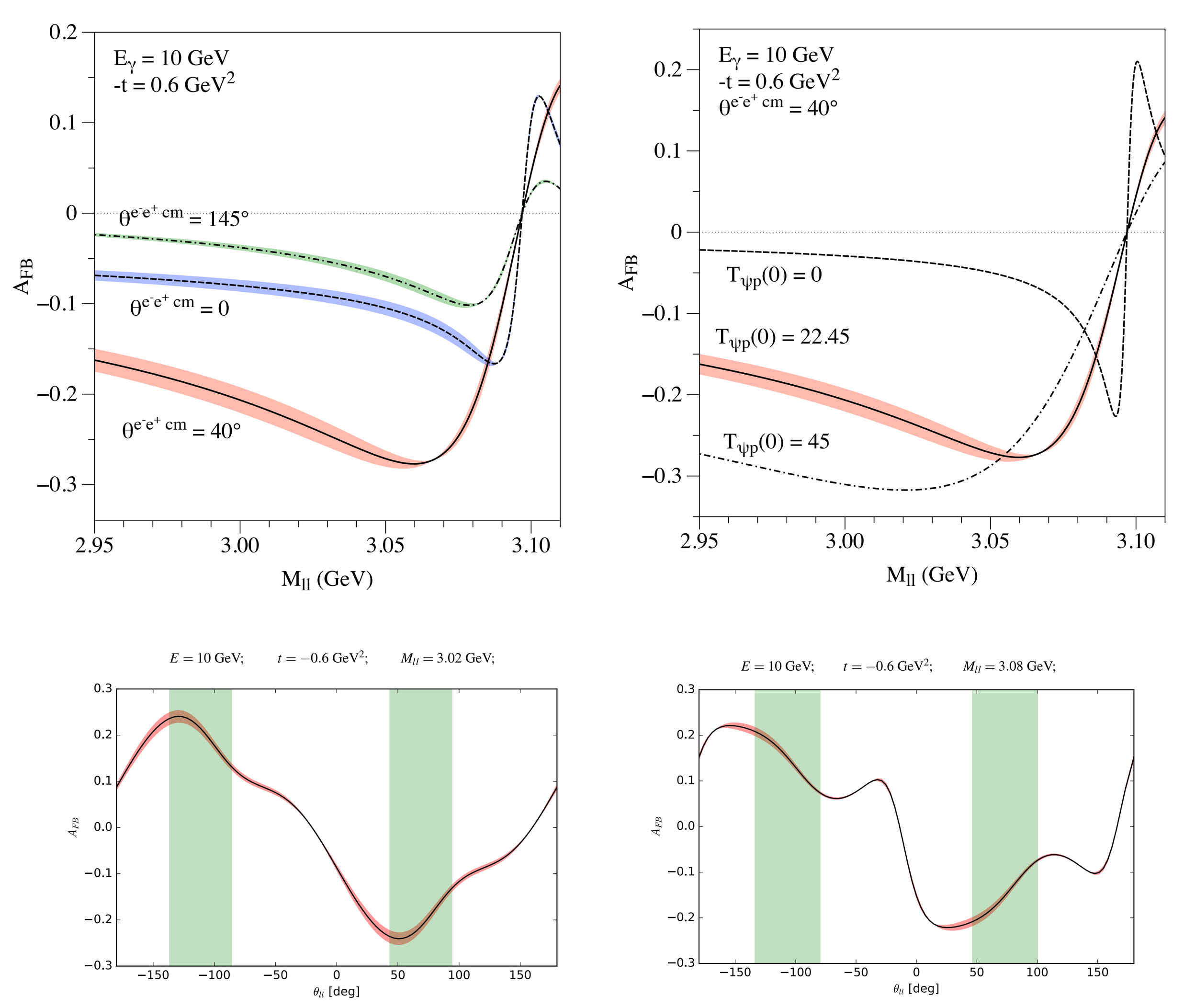
Fitting cross sections:

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



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

Forward-backward asymmetry:

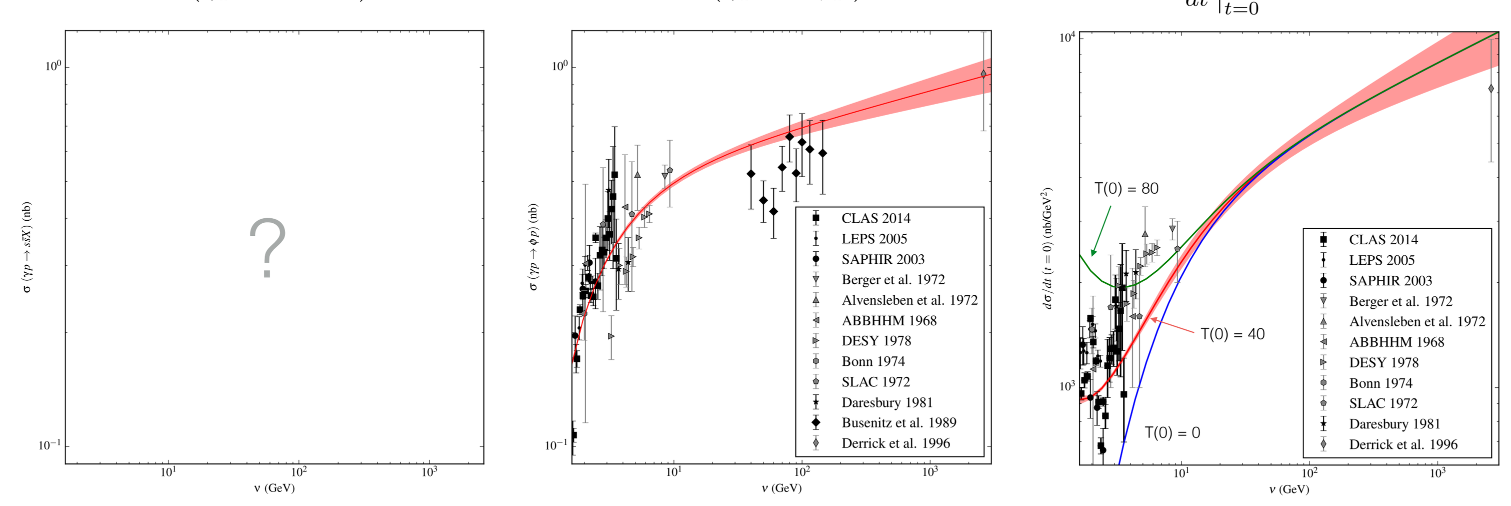


Phi

prospective study

Fitting cross sections:

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



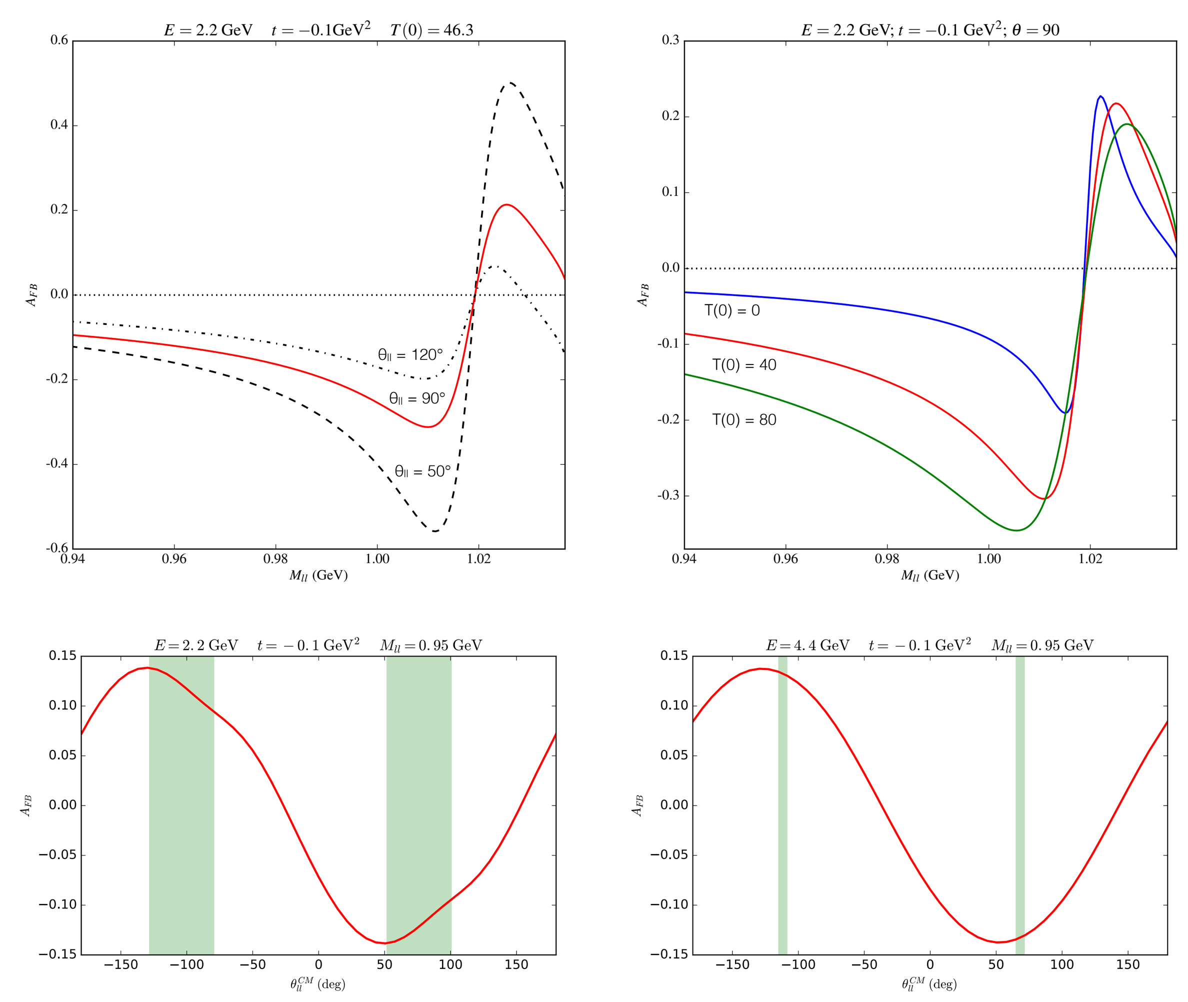
set Regge slope $\alpha_{el} = \alpha_{inel} \approx 1.092$ ⇒ $T(0) \approx 46.3$

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

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

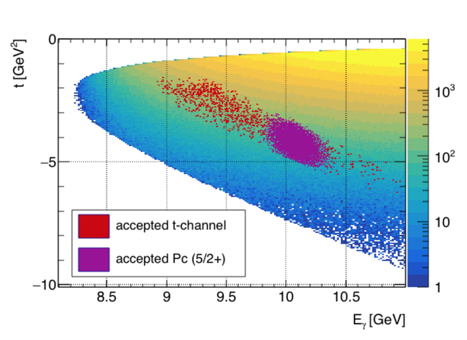
Forward-backward asymmetry:

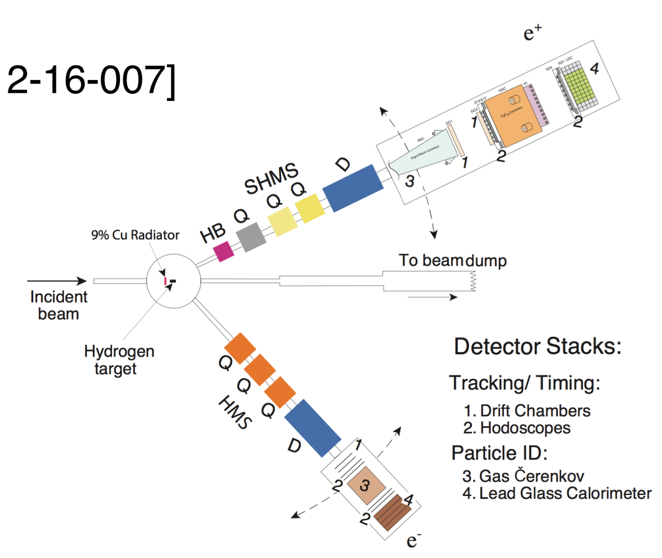
- smaller momentum transfer -t = 0.1 GeV²
- lepton pair mass M_{ll} = 0.95 GeV
- better precision for smaller beam energy E = 2.2, 4.4 GeV



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

kinematics:





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. **Hall D**, SOLID) are ongoing