Rescattering effects in Lambda(1520) photoproduction off the proton

Hui-Young RYU
Korea Institute of Science and Technology Information (KISTI)

In collaboration with Hyun-Chul Kim and A. Hosaka

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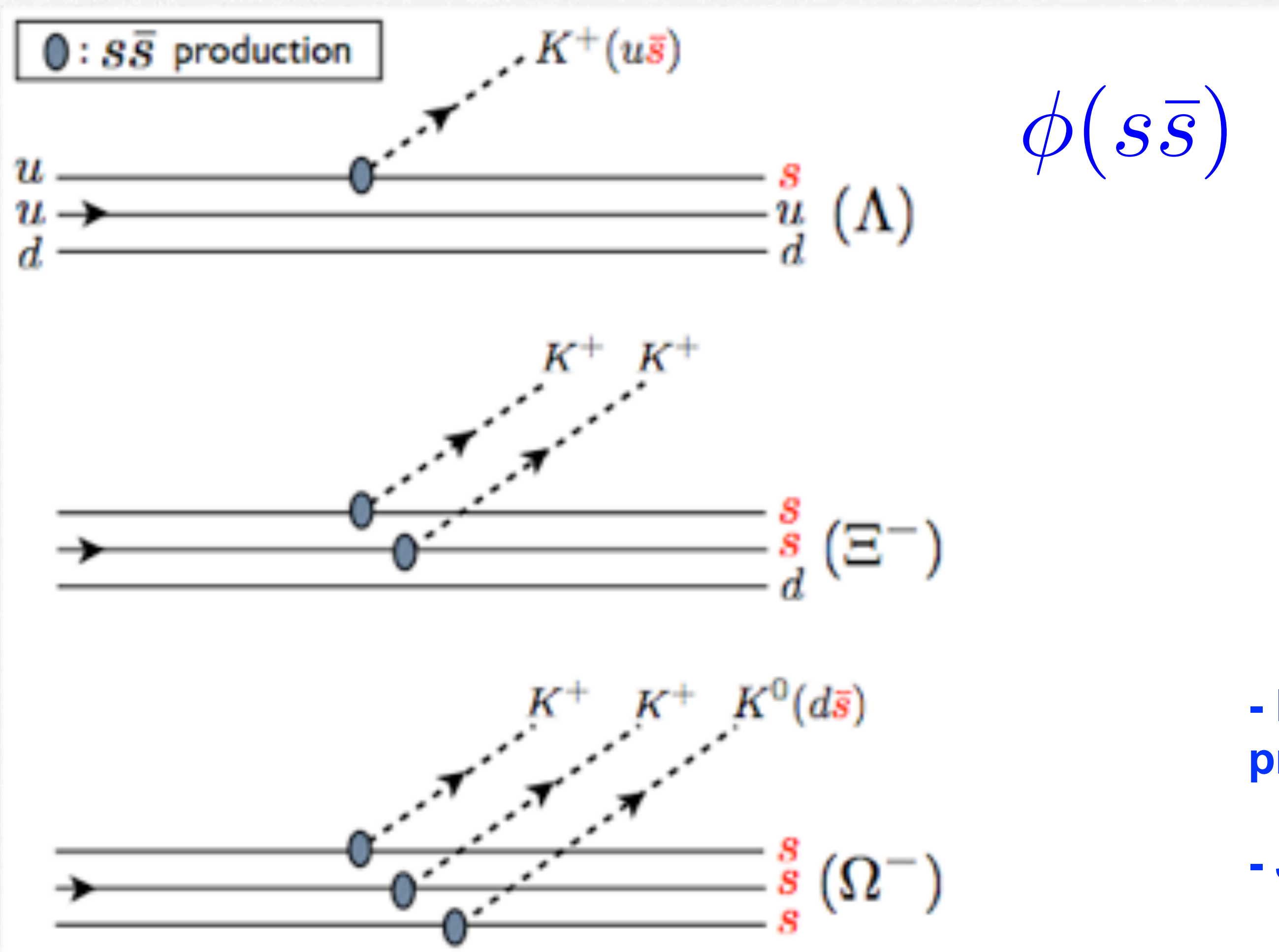
Content

- Introduction
- Formalism
- $\gamma\, p \to \phi\, p$
- $\gamma\, p \to K \Lambda(1520)$
- $\gamma\, p \to K K p$
- Summary and Outlook

Introduction I

□ Strangeness production



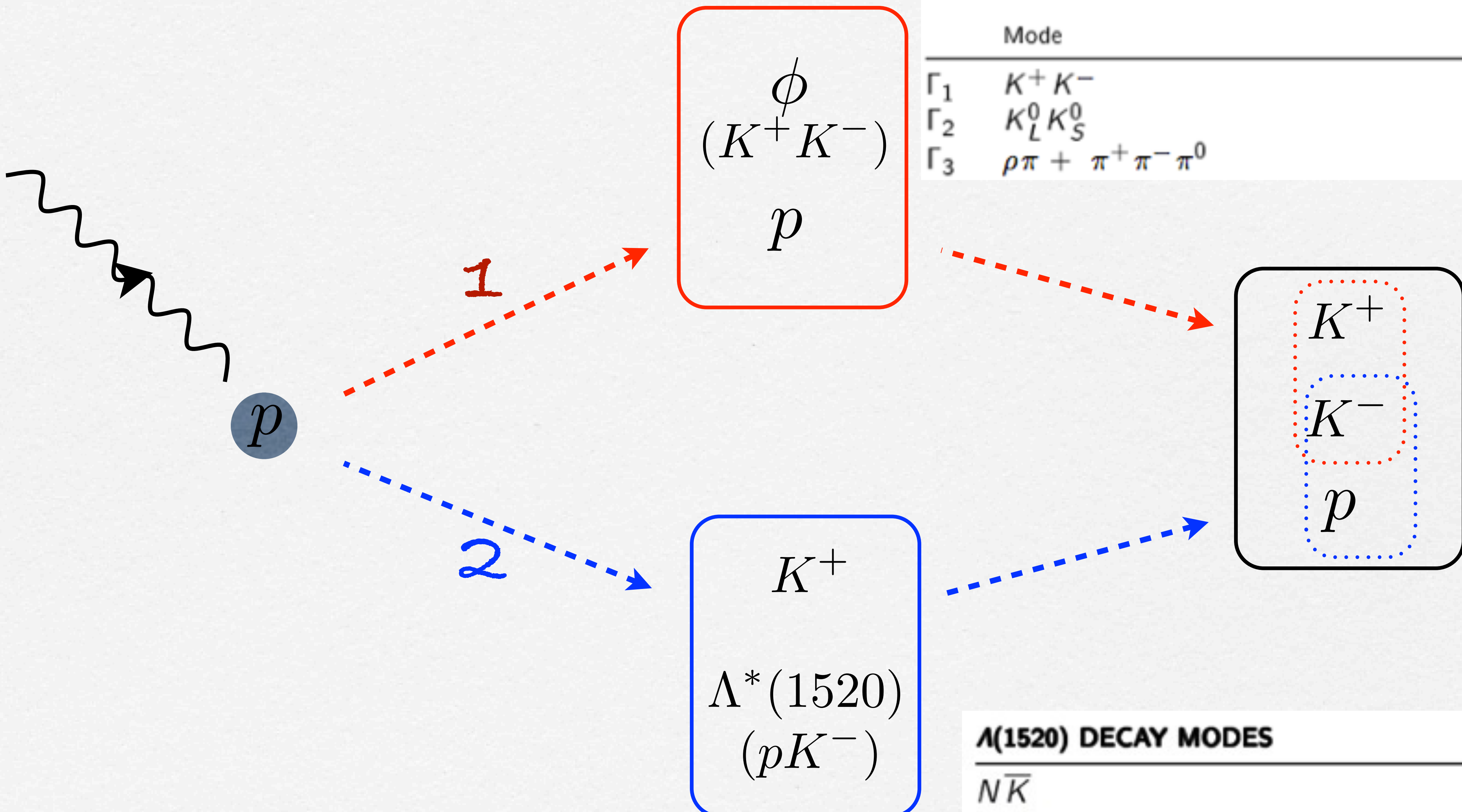
$\phi(s\bar{s})$

We are searching the systematic or consistent way to describe muti-strangeness production.

- Photoproduction of the very strangest baryons on the proton target in CLAS12 (M. Dugger, J. Goetz, L. Guo, ..)

- JLab Proposal E12-11-005a

Introduction II

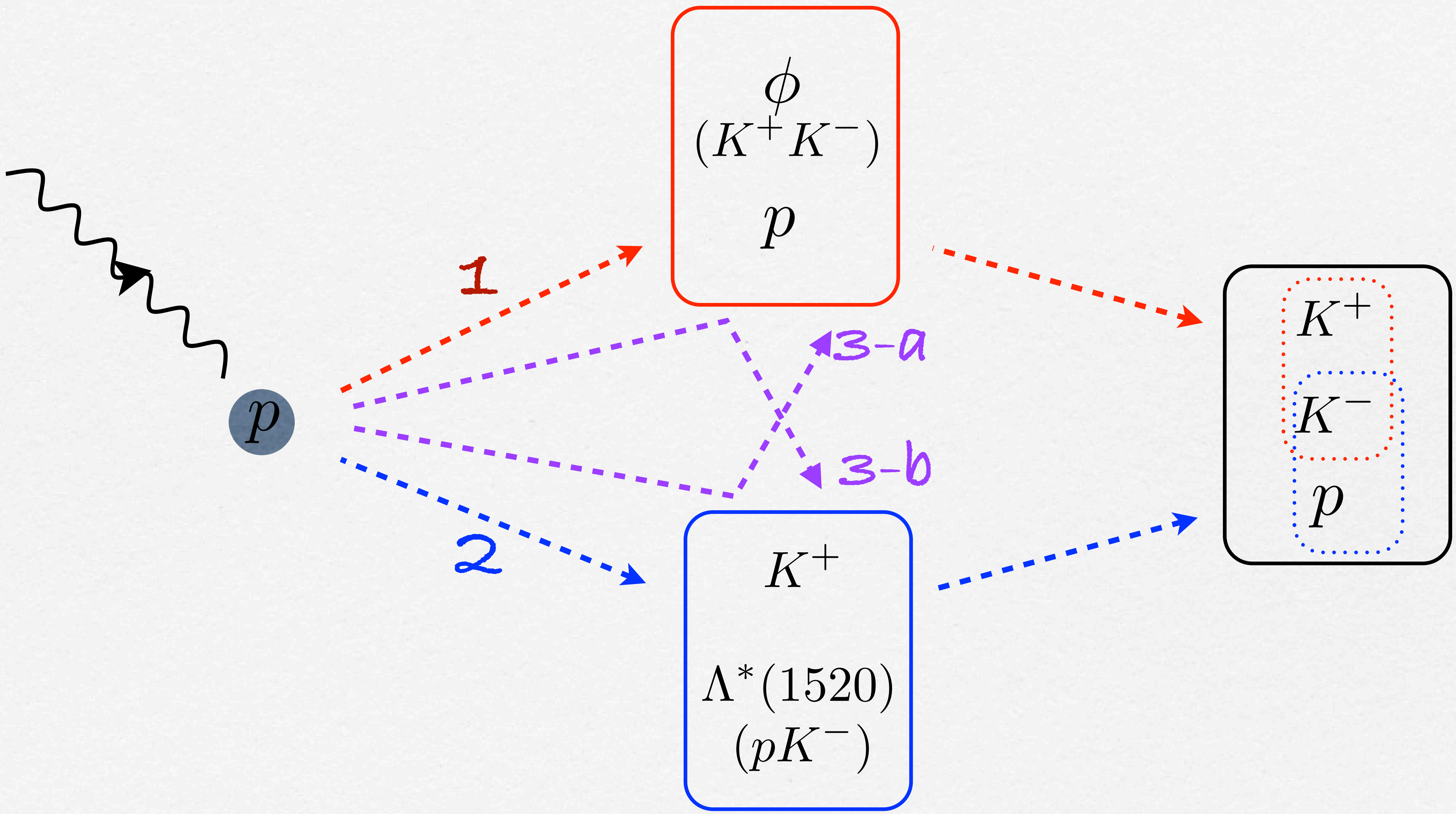


ϕ(1020) DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	K^+K^-	(48.9 ±0.5) %
Γ_2	$K^0_L K^0_S$	(34.2 ±0.4) %
Γ_3	$\rho\pi + \pi^+\pi^-\pi^0$	(15.32 ±0.32) %

Λ(1520) DECAY MODES	Fraction (Γ_i/Γ)
$N\overline{K}$	45 ± 1%
$\Sigma\pi$	42 ± 1%

☐ coupled-channel approach



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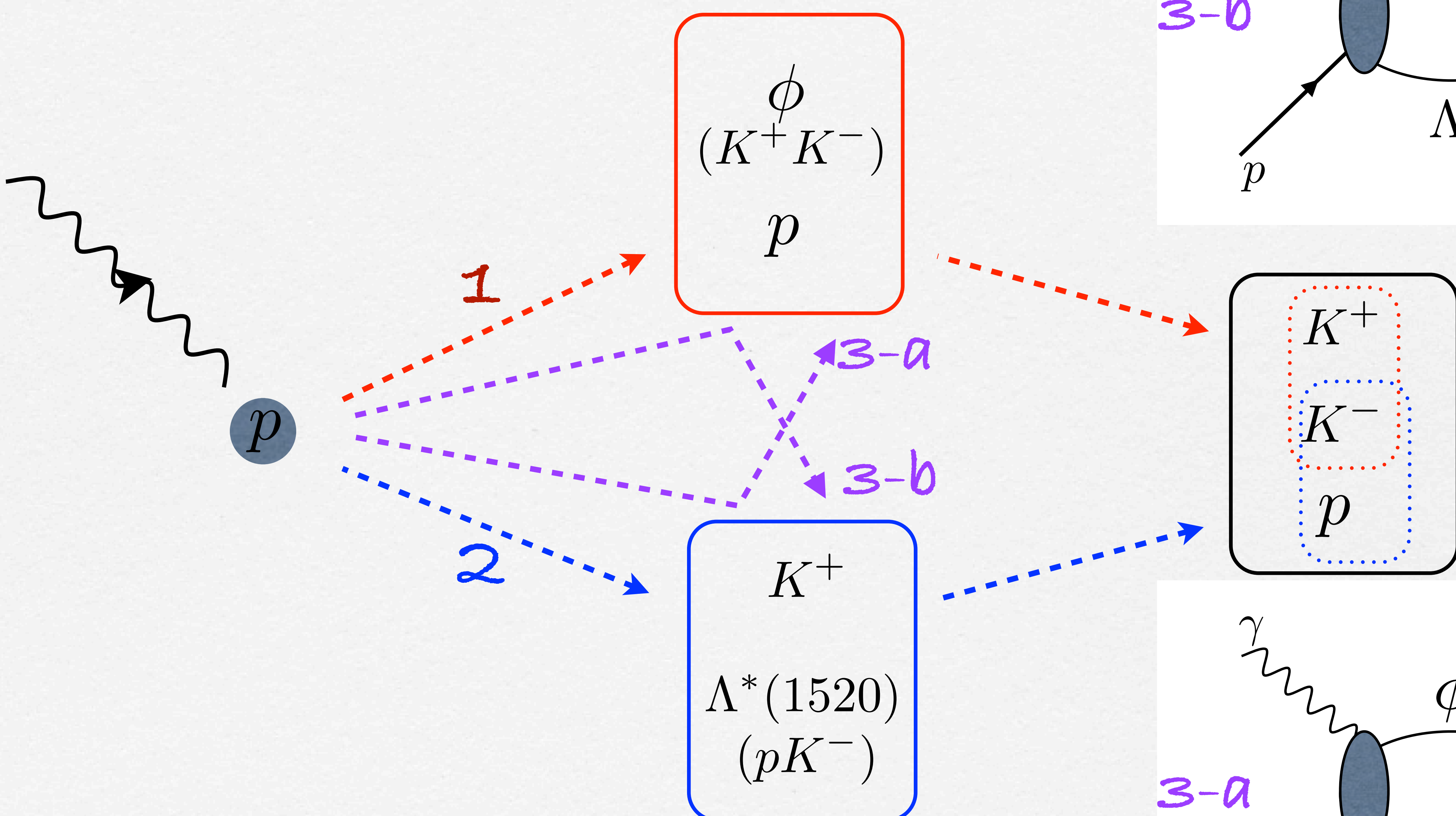
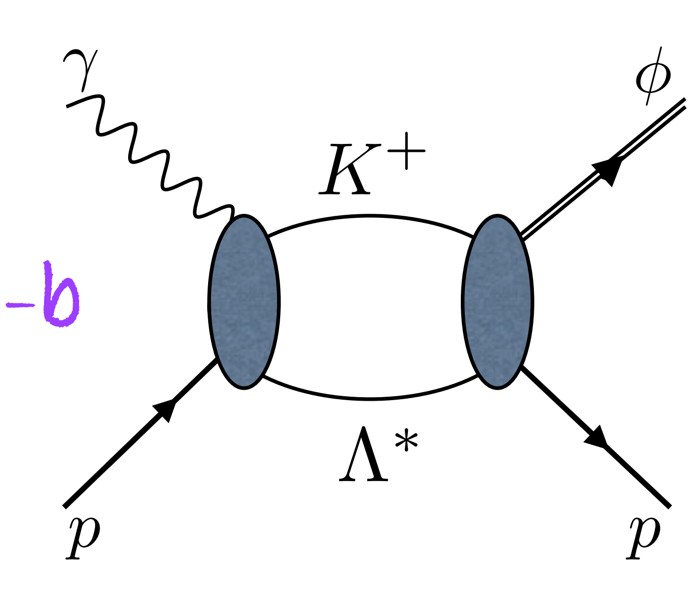


3-b



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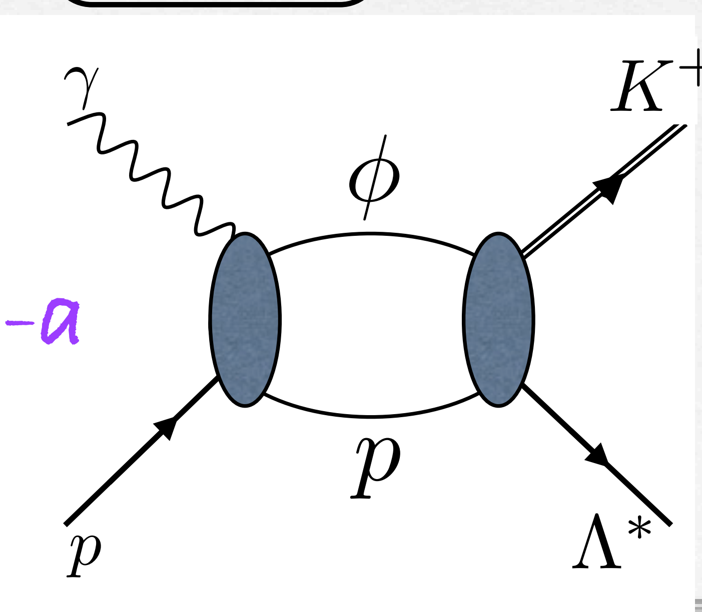
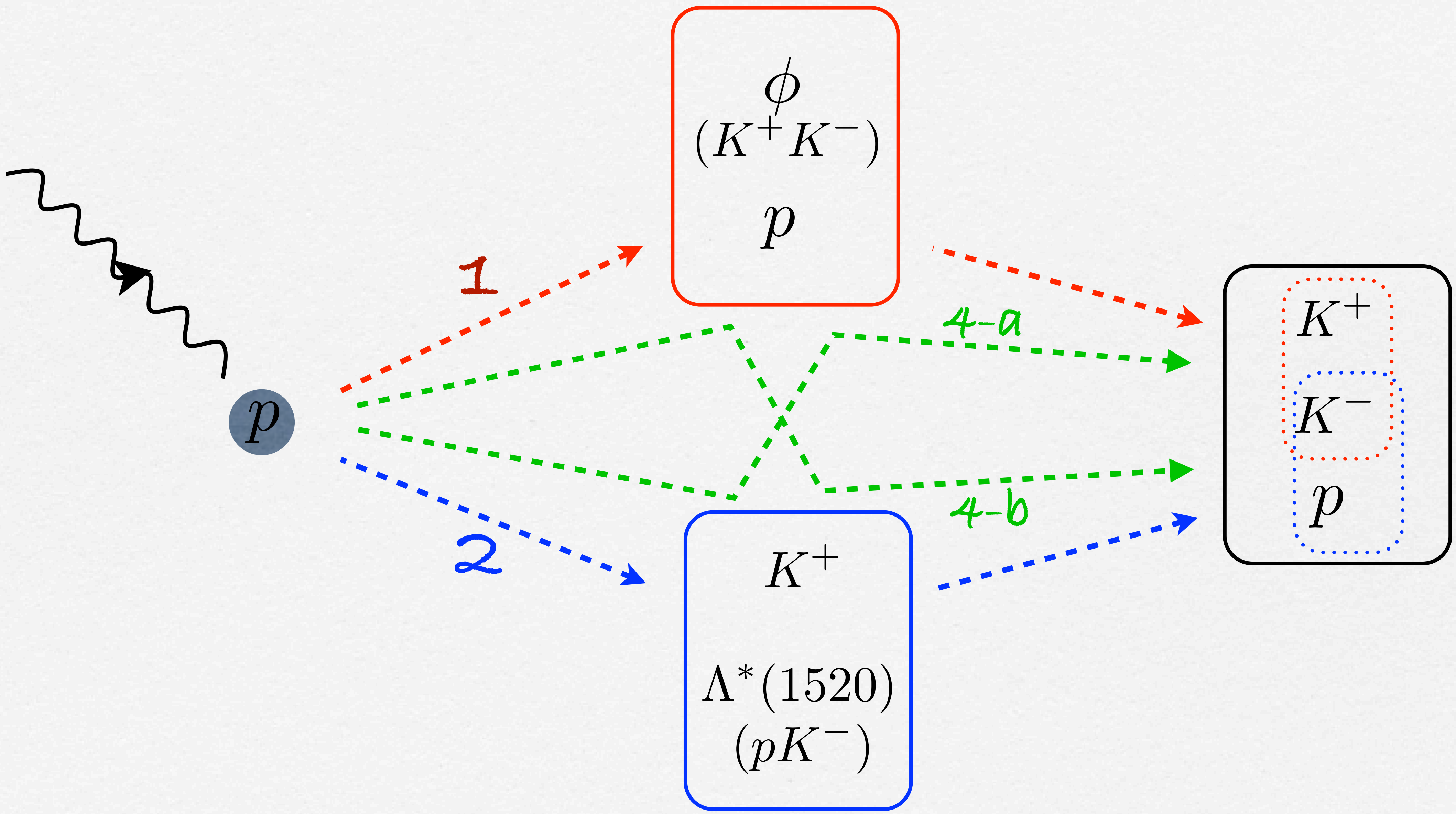
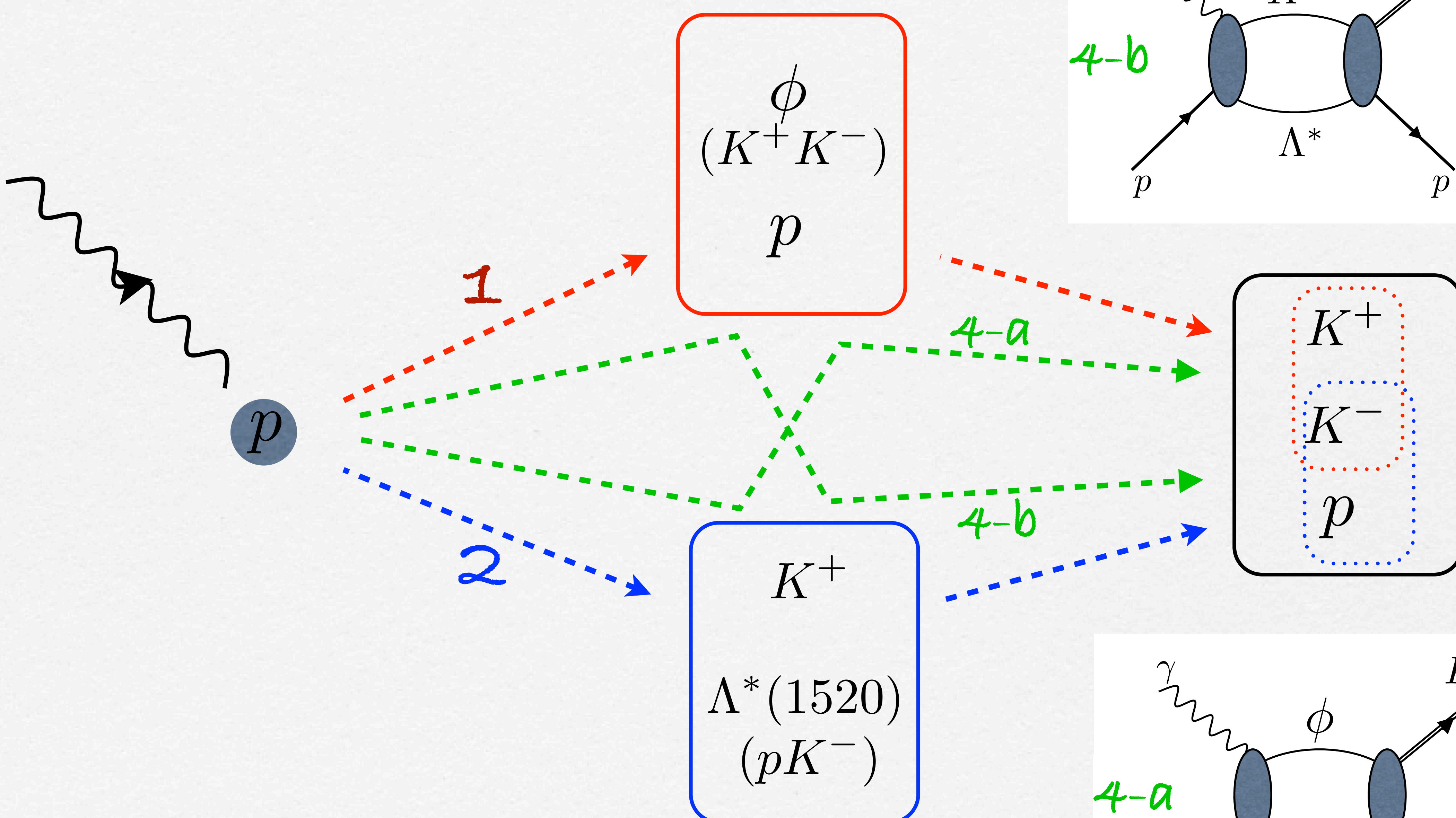
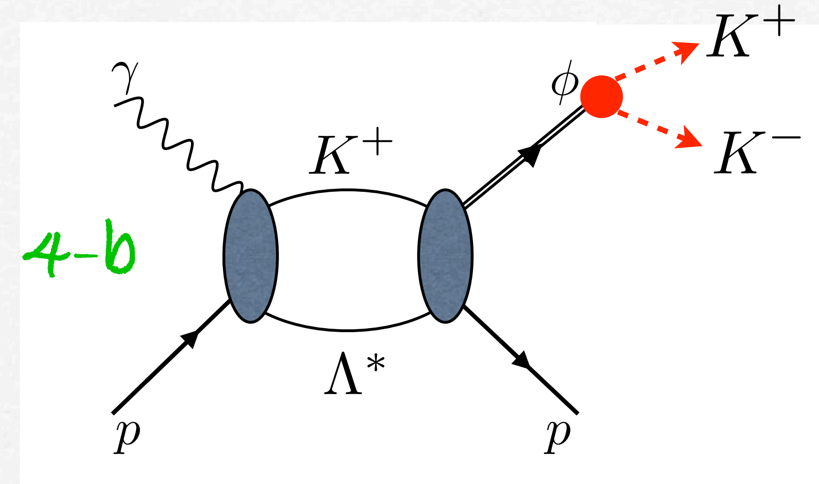
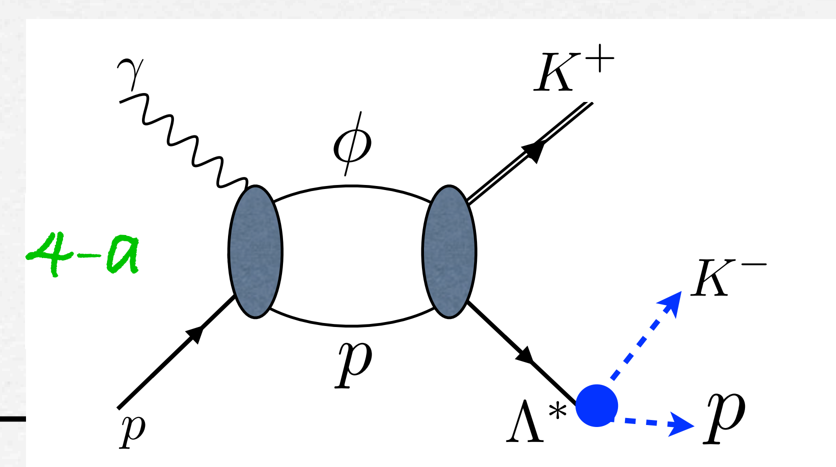



ϕ
(K^+K^-)
p
1
2
4-a
4-b
p
K^+
K^-
p
K^+
$\Lambda^*(1520)$
(pK^-)


p
1
2
φ
(K+K−)
p
K+
Λ*(1520)
(pK−)
4-a
4-b
K+
K−
p


4-b
γ
K+
φ
K+
K−
Λ*
p
p


4-a
γ
φ
K+
K−
p
p
Λ*
p

Formalism

□ Effective Lagrangian method

$$\mathcal{L}_{QCD} = -\frac{1}{2}\mathrm{tr}[G_{\mu\nu}G^{\mu\nu}] + \bar{q}i\gamma^\mu D_\mu q \;\; -\bar{q}\mathbf{m}q$$

$$G_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu - ig[A_\mu, A_\nu]\ , \quad D_\mu = \partial_\mu - igA_\mu, \quad A_\mu = \sum_a T^a A^a_\mu$$

$\mathcal{L}_{QCD}$	at low energy →	$\mathcal{L}_{eff}$
quark and gluon degree of freedom		hadronic degree of freedom

$$\exp[iZ] = \int \mathcal{D}q\,\mathcal{D}\bar{q}\,\mathcal{D}A\,\exp\left[i\int dx^4\ \mathcal{L}_{QCD}\right] = \int \mathcal{D}U\,\exp\left[i\int dx^4\ \mathcal{L}_{eff}\right]$$

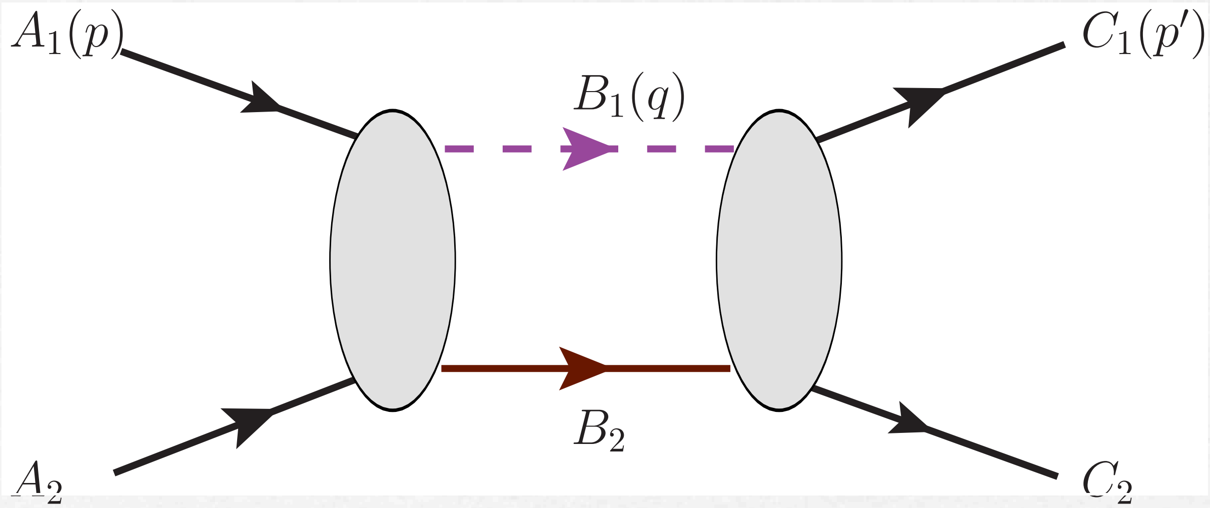
$$\mathcal{L}_{eff} = \mathcal{L}_{eff}(\underbrace{U, \partial_\mu U, V_\mu \cdots}_{Hadrons})\ , \quad U = \exp\left[\frac{i\sqrt{2}\Phi}{f}\right]$$

☐ Blankenbecler-Sugar (BbS) Equation

: 3-dim reduction of the Bethe-Salpeter equation

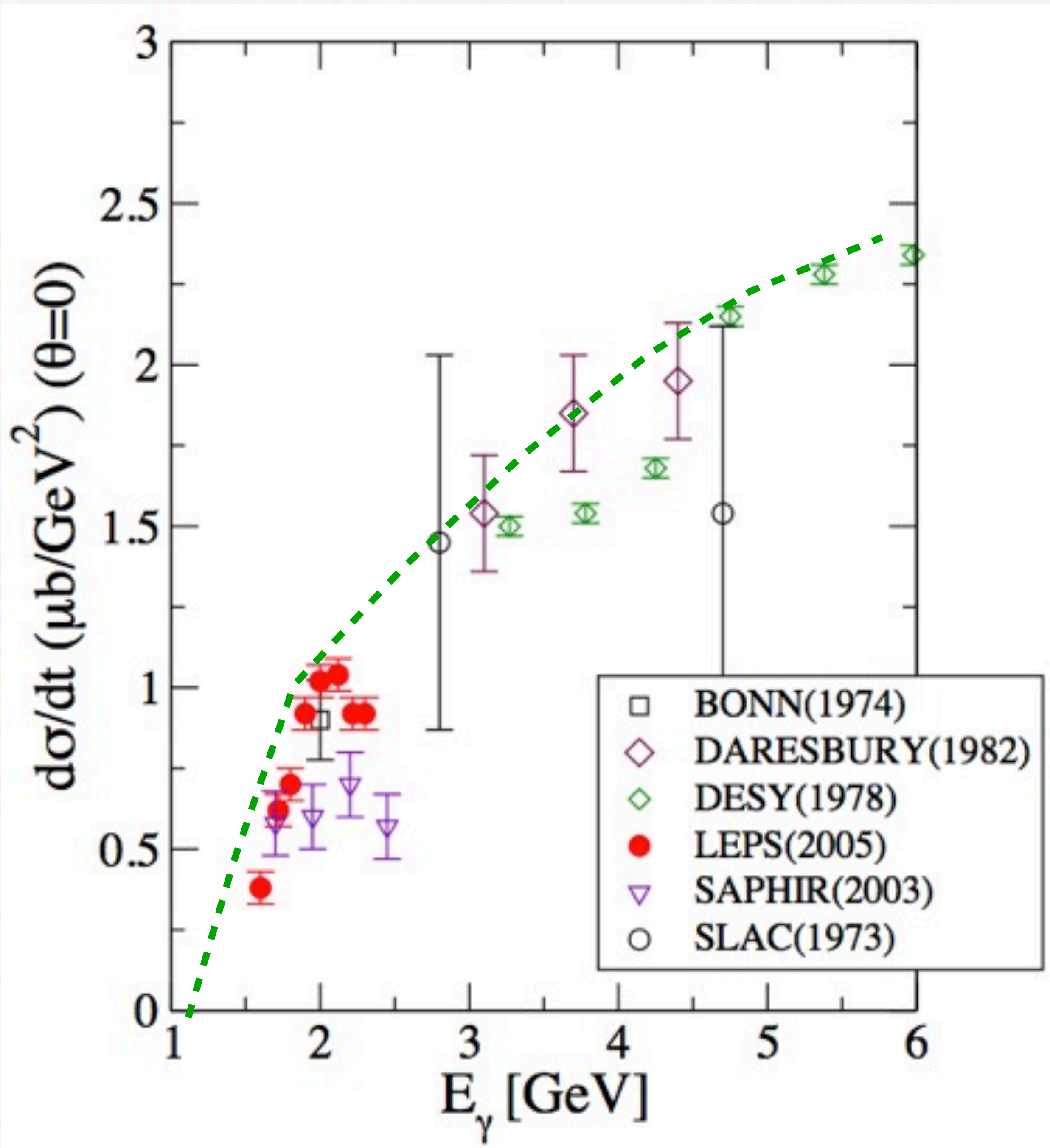
$$\mathcal{M}_{A_1A_2\to C_1C_2}(p,p';s) = \mathcal{M}^{\rm Born}_{A_1A_2\to C_1C_2}(p,p';s) + \int d^3q \frac{\omega+E}{(2\pi)^3 2\omega E}\mathcal{M}_{A_1A_2\to B_1B_2}(p,q;s)\frac{1}{s-(\omega+E)^2+i\epsilon}\mathcal{M}_{B_1B_2\to C_1C_2}(q,p';s)$$

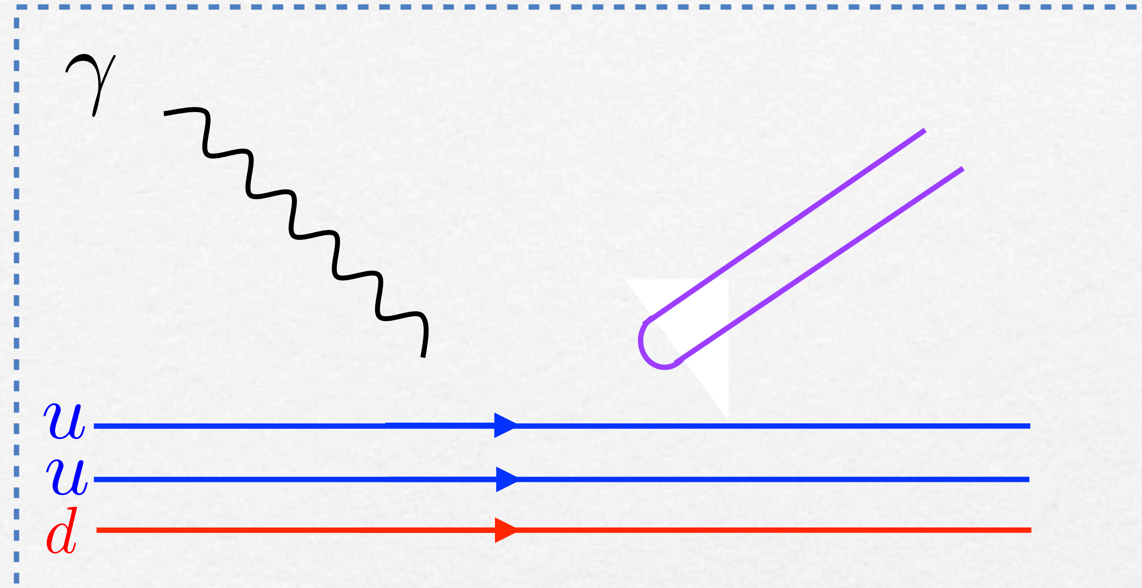
- $s=(E_{A_1}+E_{A_2})^2$
- $\omega=\sqrt{m^2_{B_1}+|\vec{q}|^2}$
- $E=\sqrt{m^2_{B_2}+|\vec{q}|^2}$



R. Blankenbecler and R. Sugar, Phys. Rev. 142, 1051 (1966)

γ p --> ϕ p





- OZI rule violation

- Gluonic dynamics (Pomeron)

- Hidden strangeness

□ Timeline of the recent study

Author	Date	Their work
Titov *et al*	1999	Structure of the ϕ photoproduction at a few GeV
T. Mibe *et al*	2005	Near-Threshold Diffractive ϕ-Meson Photoproduction from the proton
S. Ozki *et al*	2009	Coupled-channel analysis for ϕ photoproduction with $\Lambda(1520)$
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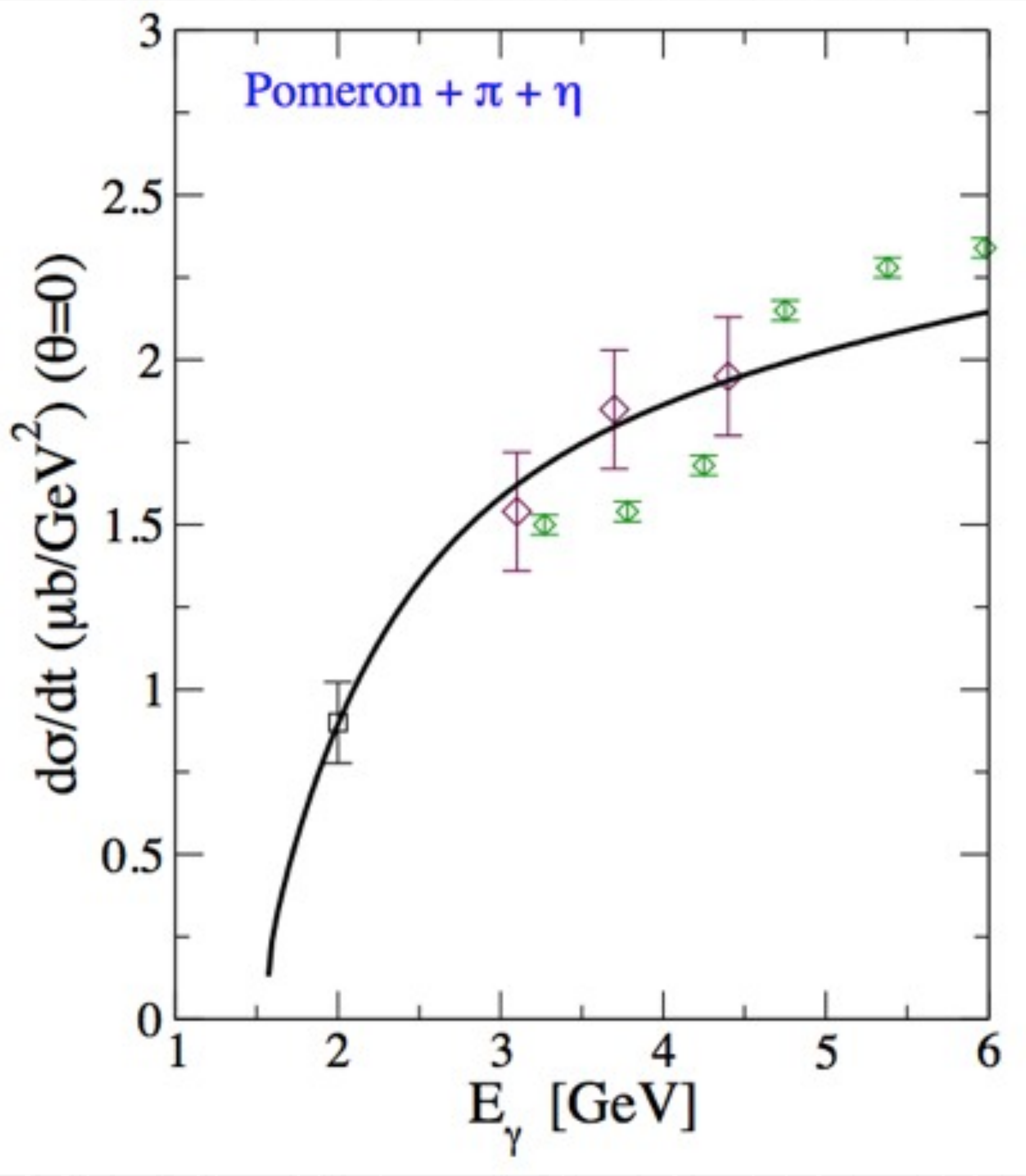

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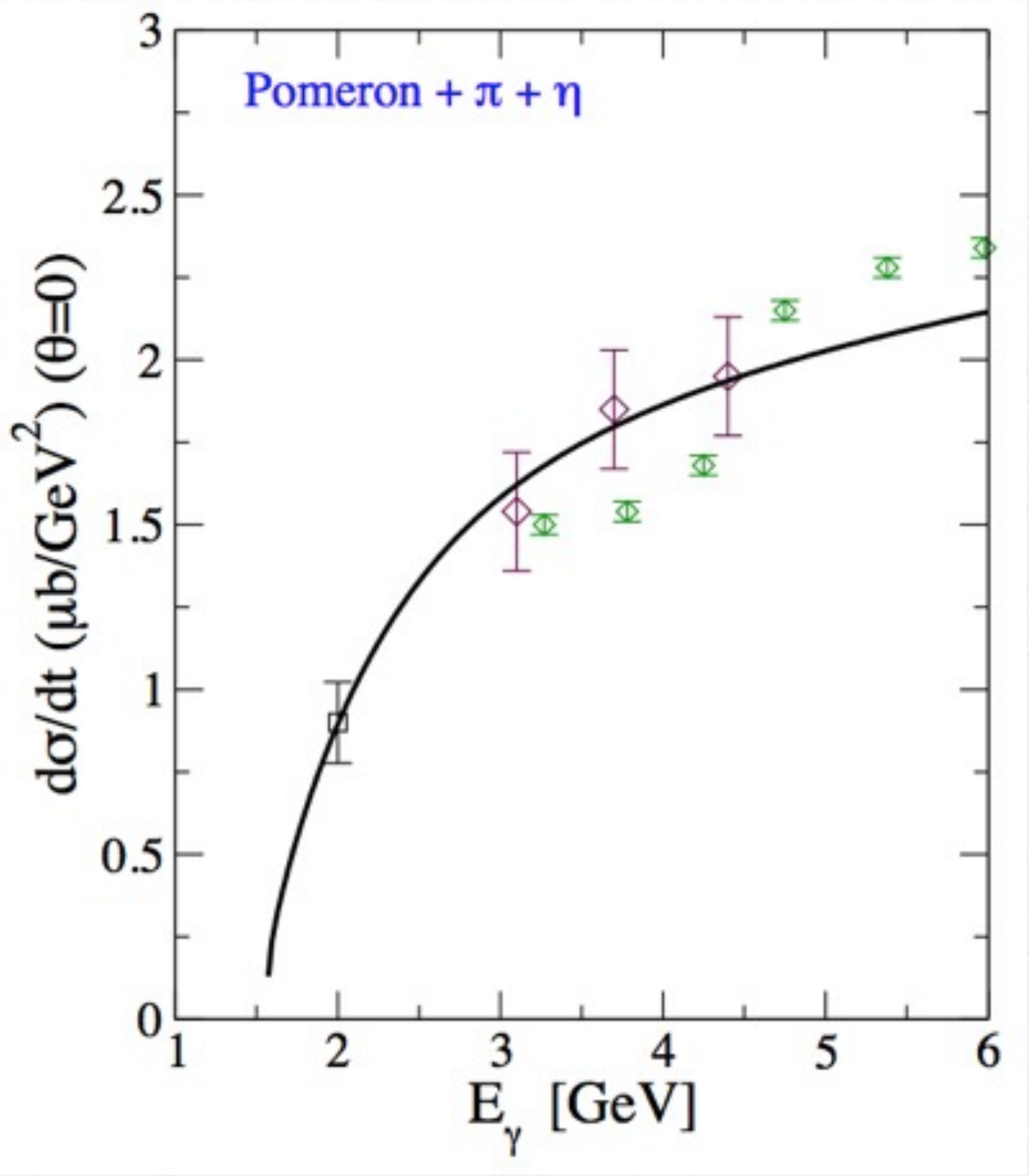

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S. Ozki *et al*	2009	Coupled-channel analysis for ϕ photoproduction with $\Lambda(1520)$ **S. Ozaki, A. Hosaka, H. Nagahiro and O. Scholten, Phys. Rev. C 80, 035201 (2009)**
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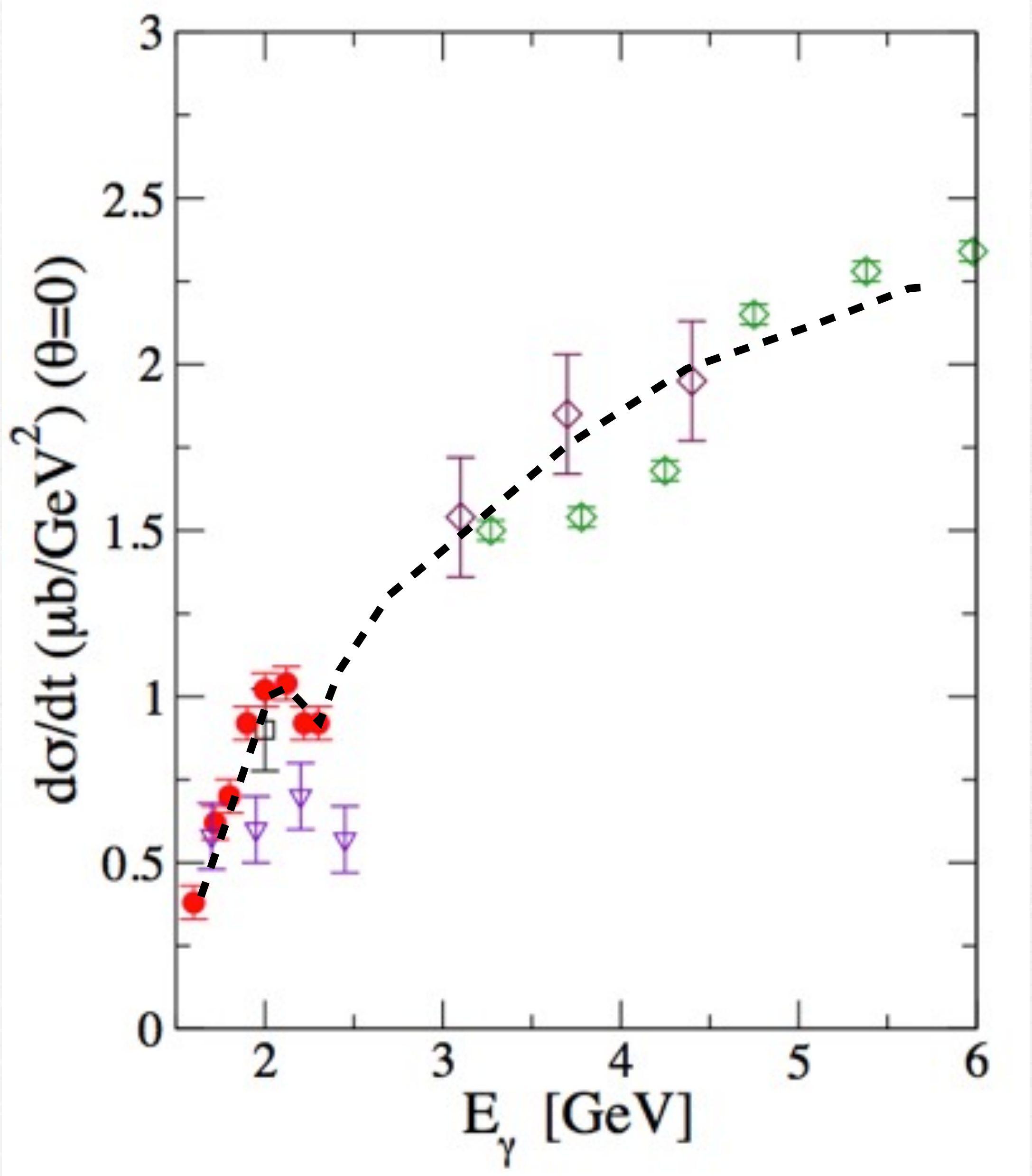

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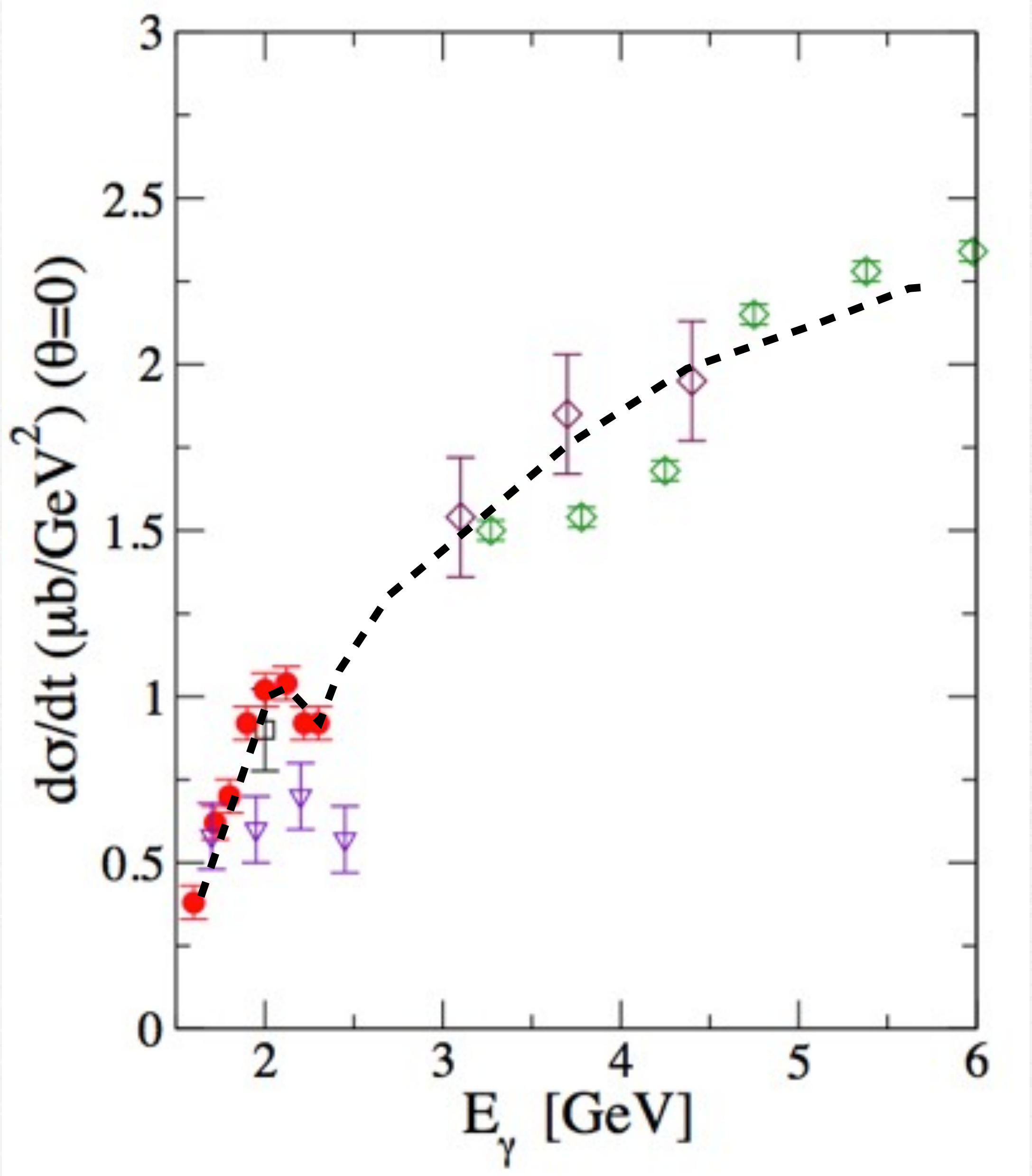

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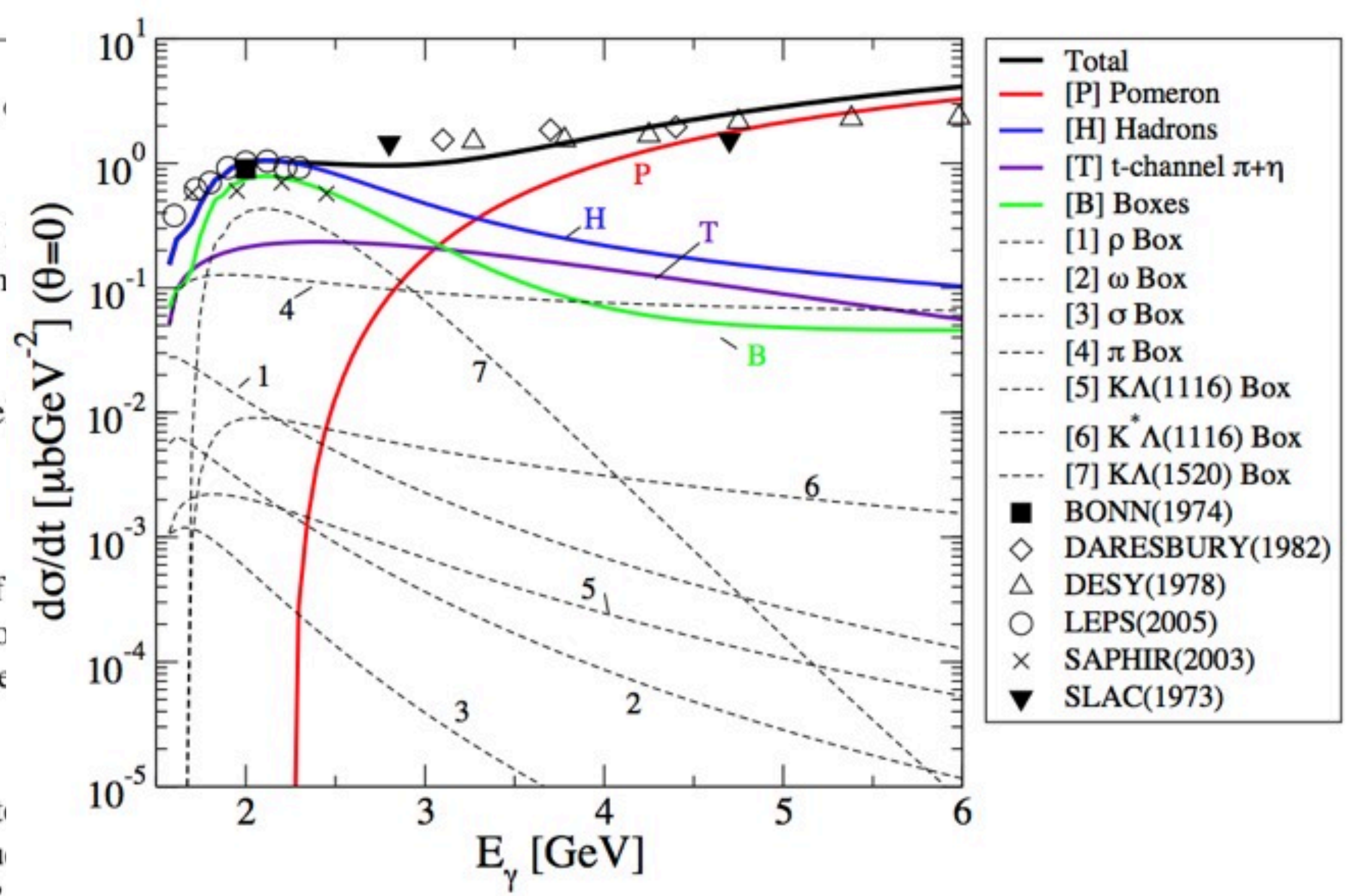

H. Y. Ryu, A. I. Titov, A. Hosaka, H. C. Kim, PTEP. 2014 (2014 023D03)(arxiv:1212.6075)

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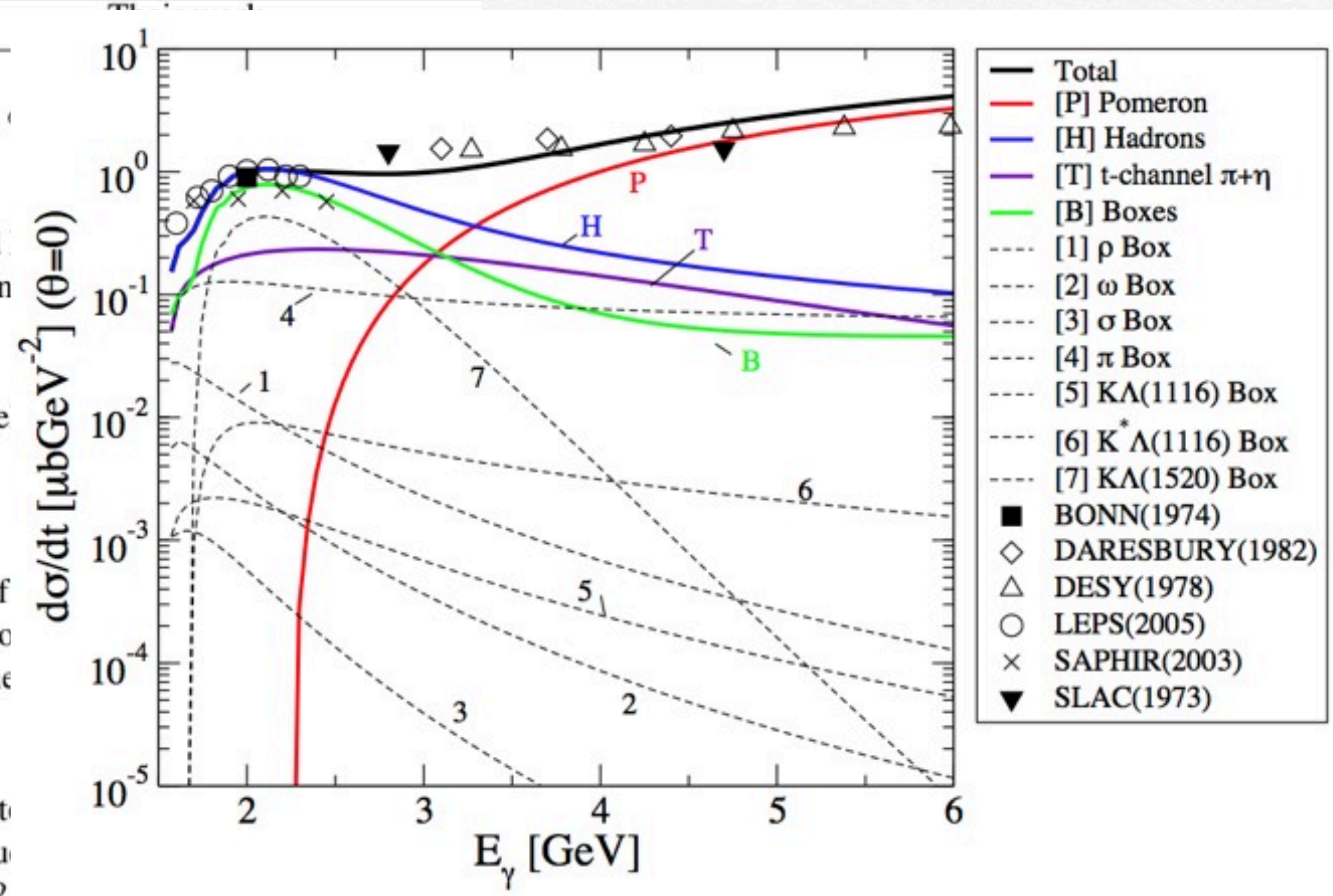

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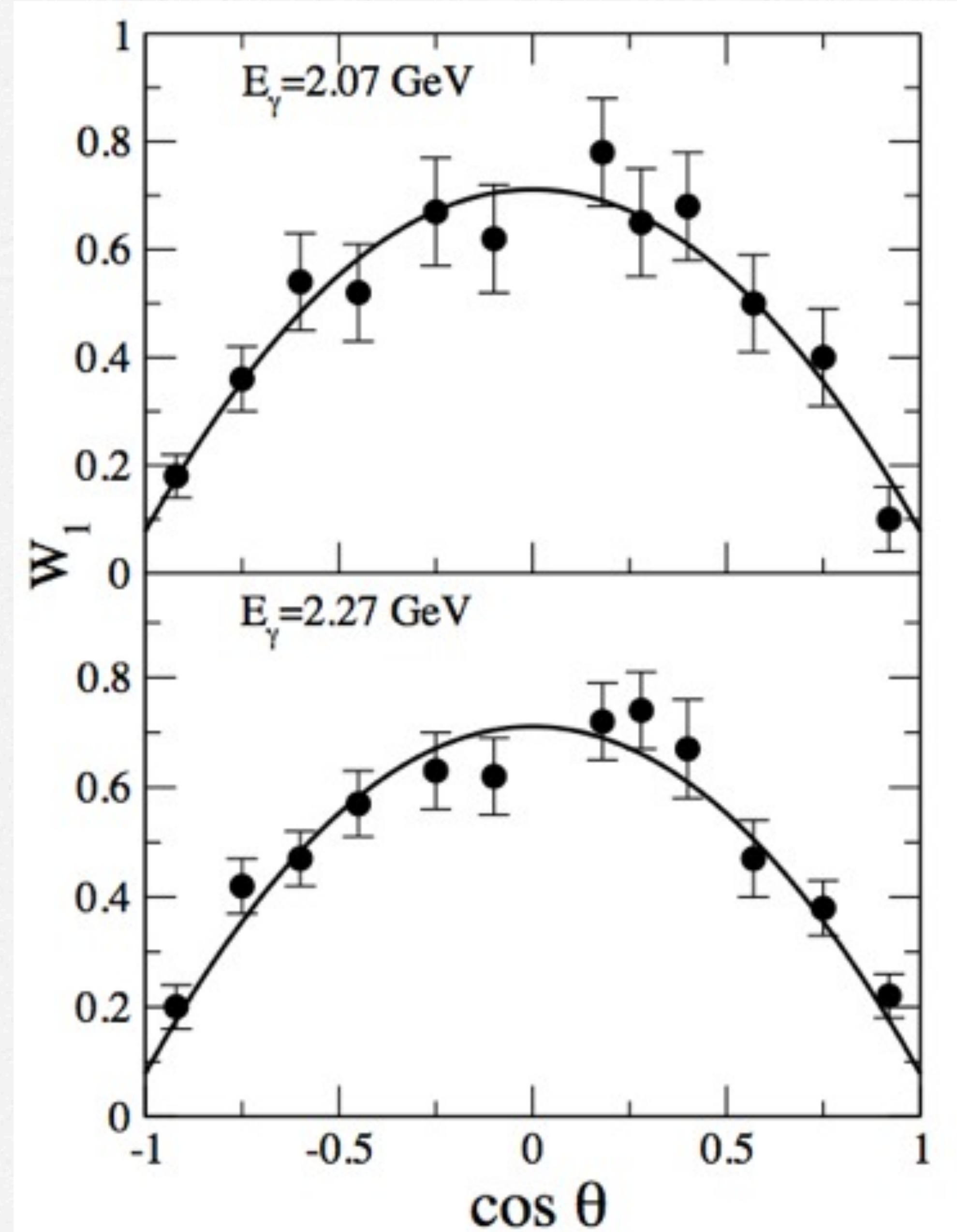
$$W_1(\cos\theta_K) = \frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\theta_K$$



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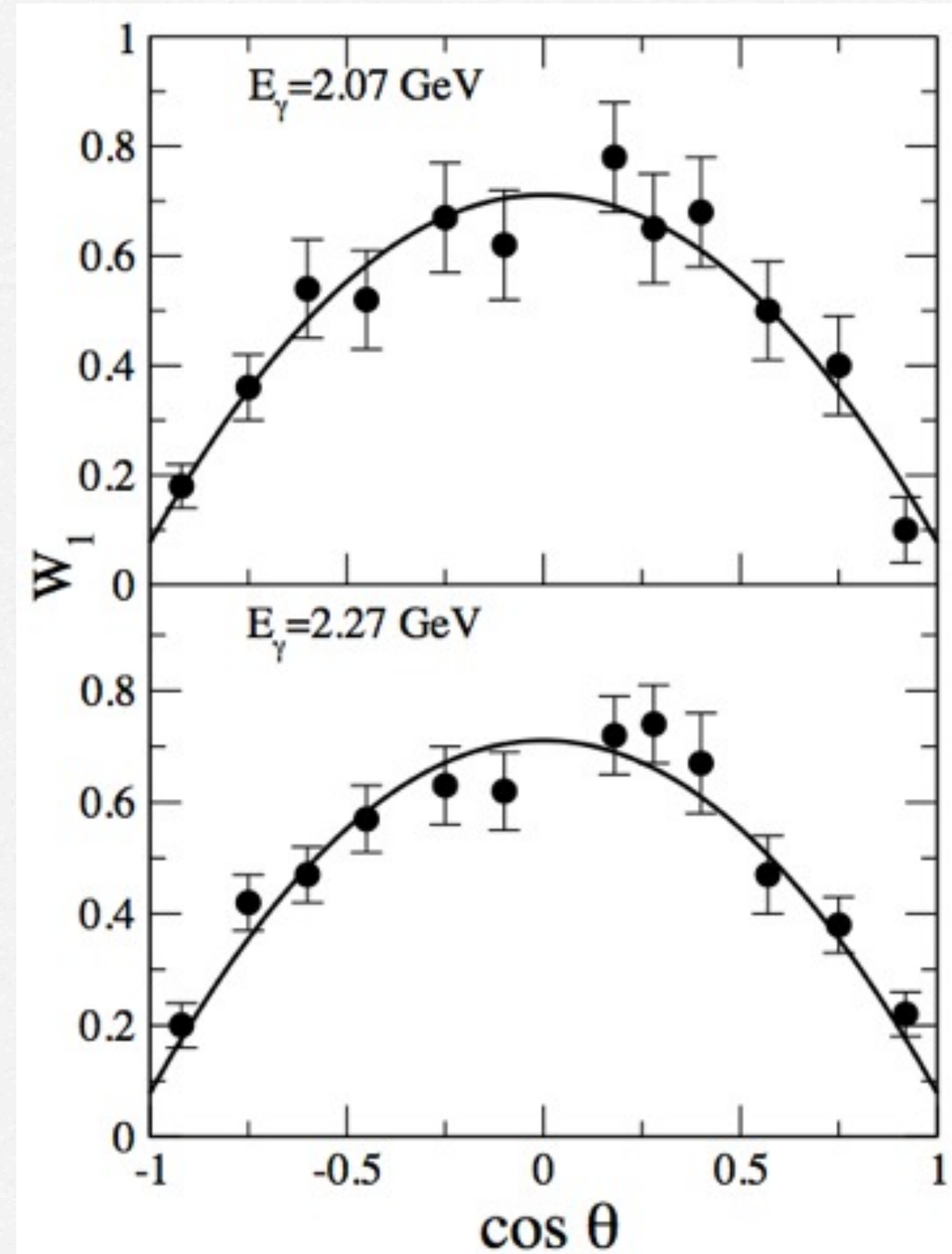

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H. Ch. Kim *et al*	2013	ϕN photoproduction coupled with the $K\Lambda^*$ channel.
B. Dey *et al*	2014 (Mar 9)	Data analysis techniques, differential cross sections, and spin density matrix elements for the reaction $\gamma p \to \phi p$.
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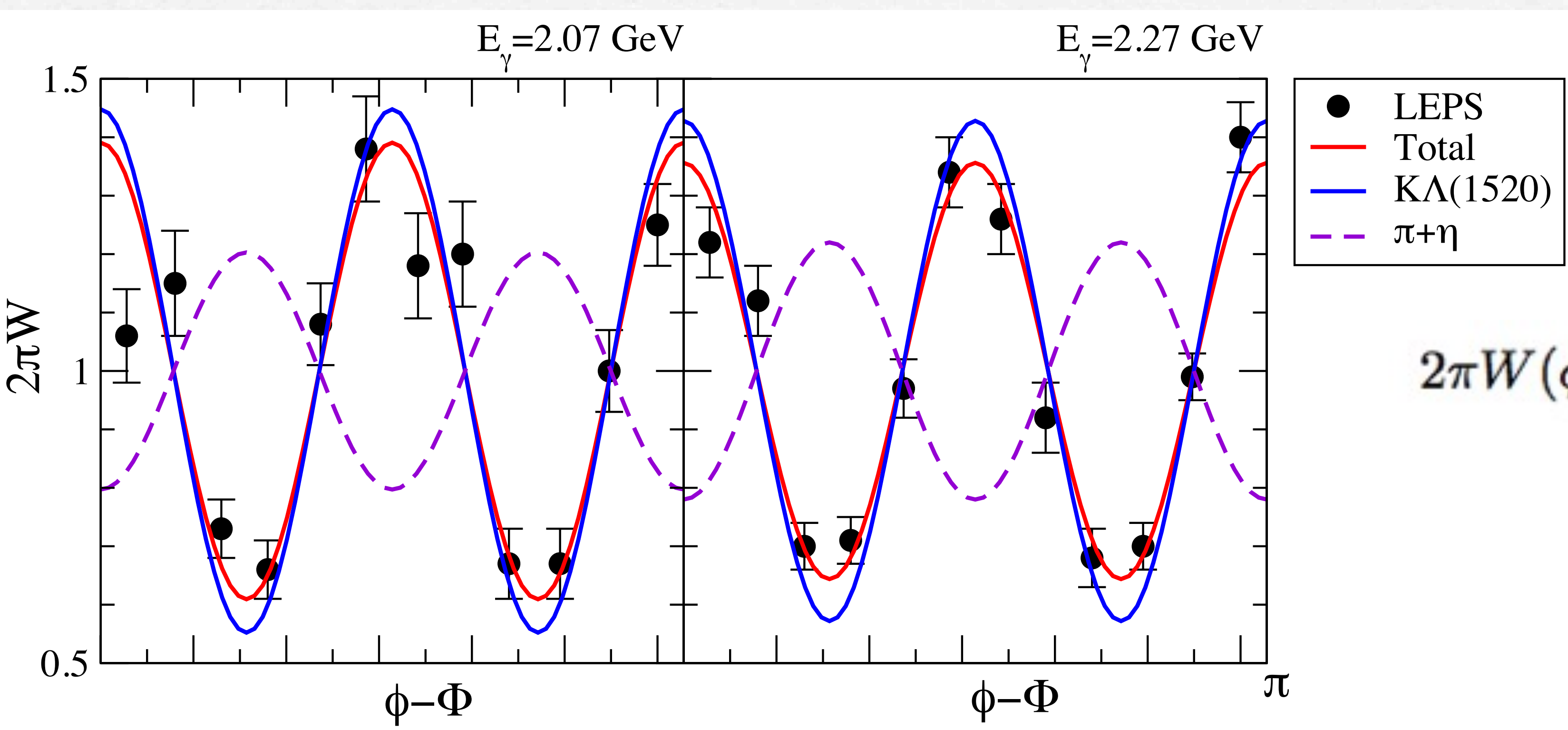

$$2\pi W(\phi - \Phi) = 1 + 2P_\gamma \bar{\rho}^1_{1-1} \cos 2(\phi - \Phi)$$

$$\bar{\rho}^1_{1-1} = \frac{1}{2}(\rho^1_{1-1} - \mathrm{Im}\rho^2_{1-1})$$

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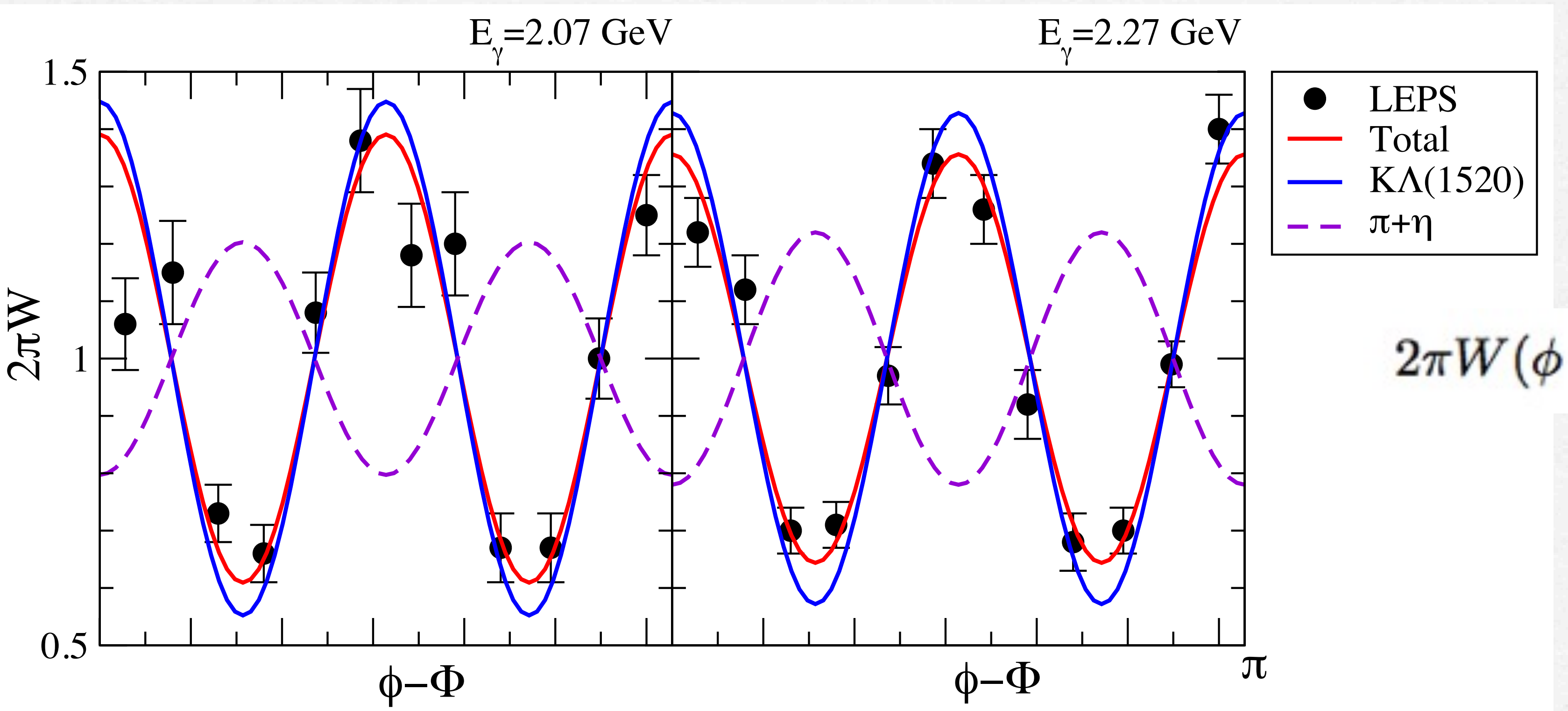

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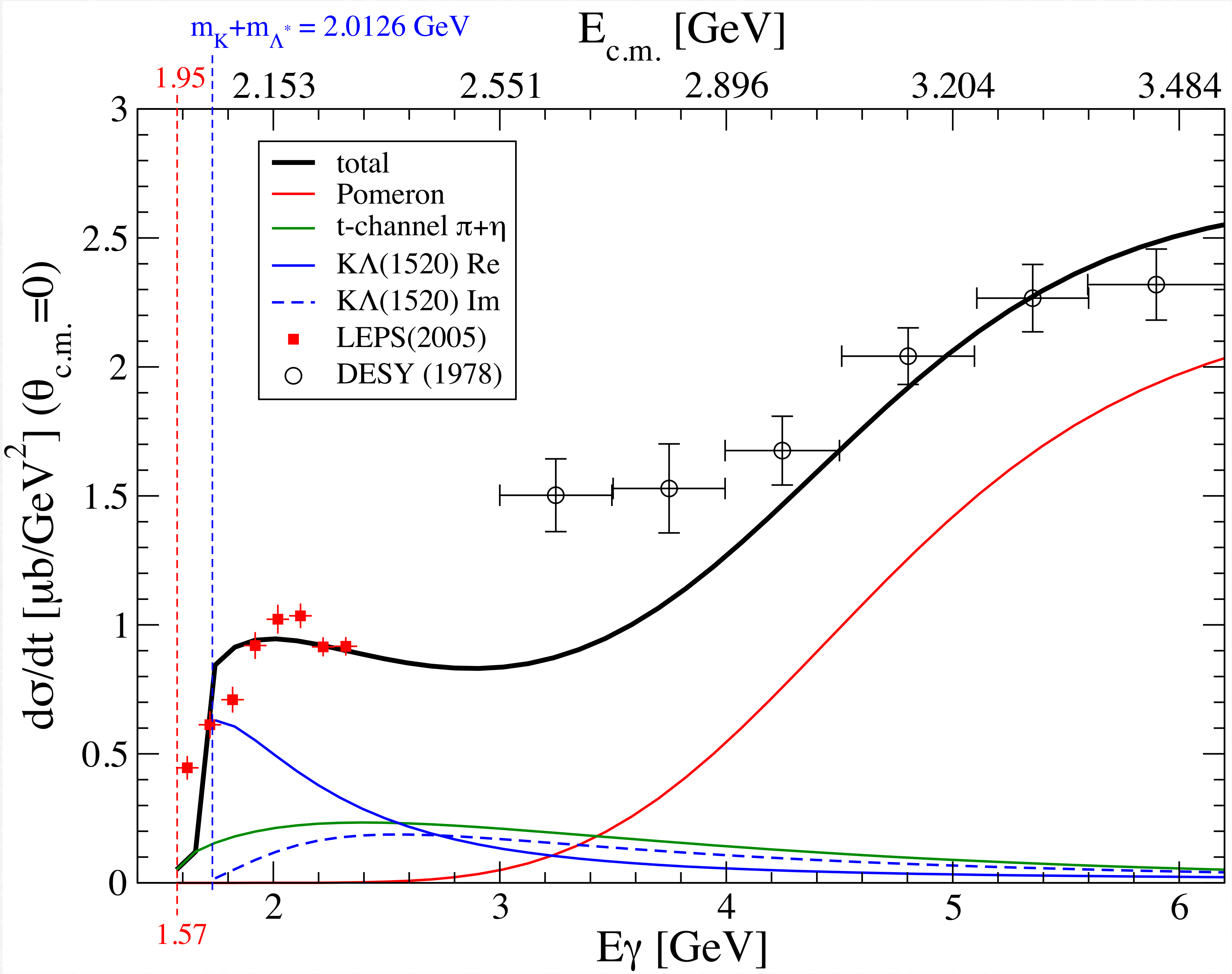
☐ Recent status



New data from CLAS

3. **Phenomenology of ϕ photoproduction from recent CLAS data at Jefferson Lab**
Biplab Dey. Mar 14, 2014.
e-Print: arXiv:1403.3730 [hep-ex] | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Detailed record

4. **Data analysis techniques, differential cross sections, and spin density matrix elements for the reaction $\gamma p \to \phi p$**
B. Dey, C.A. Meyer, M. Bellis, M Williams. Mar 9, 2014. 38 pp.
e-Print: arXiv:1403.2110 [nucl-ex] | PDF
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Detailed record - Cited by 1 record

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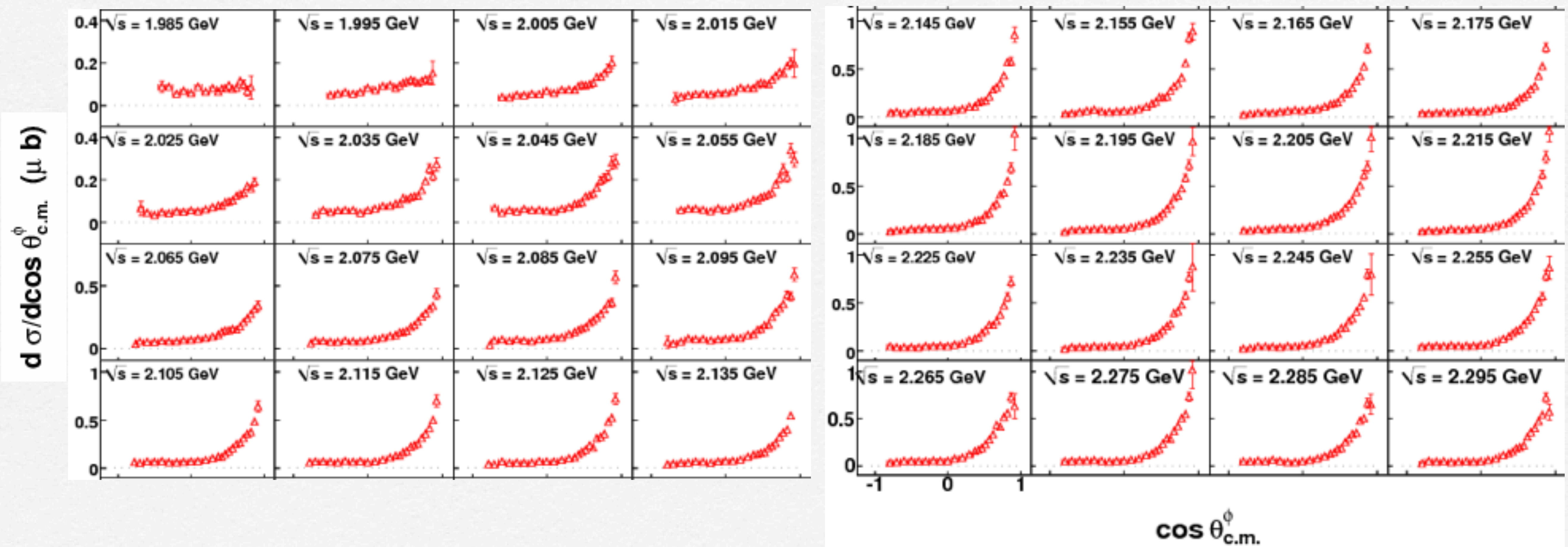
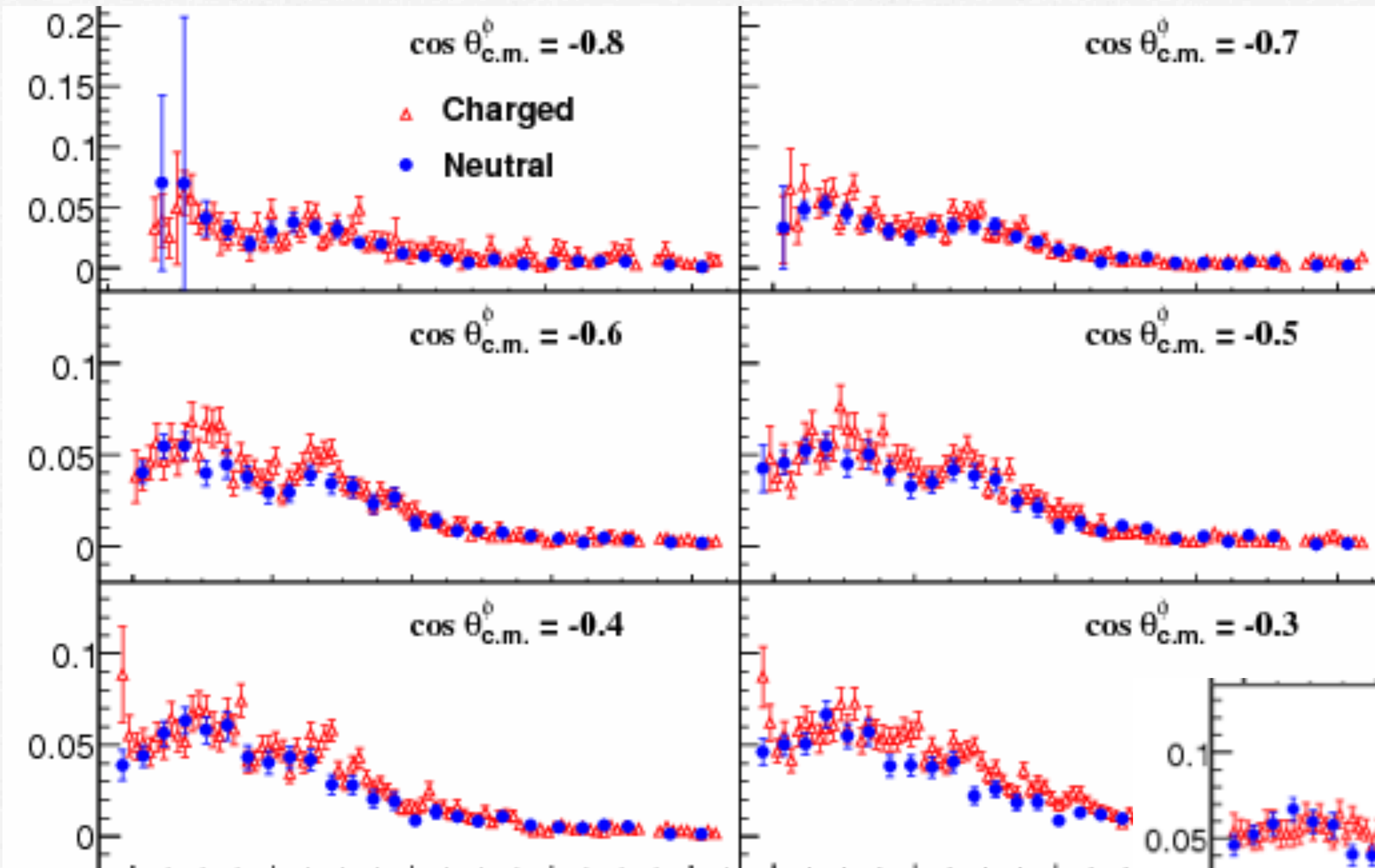
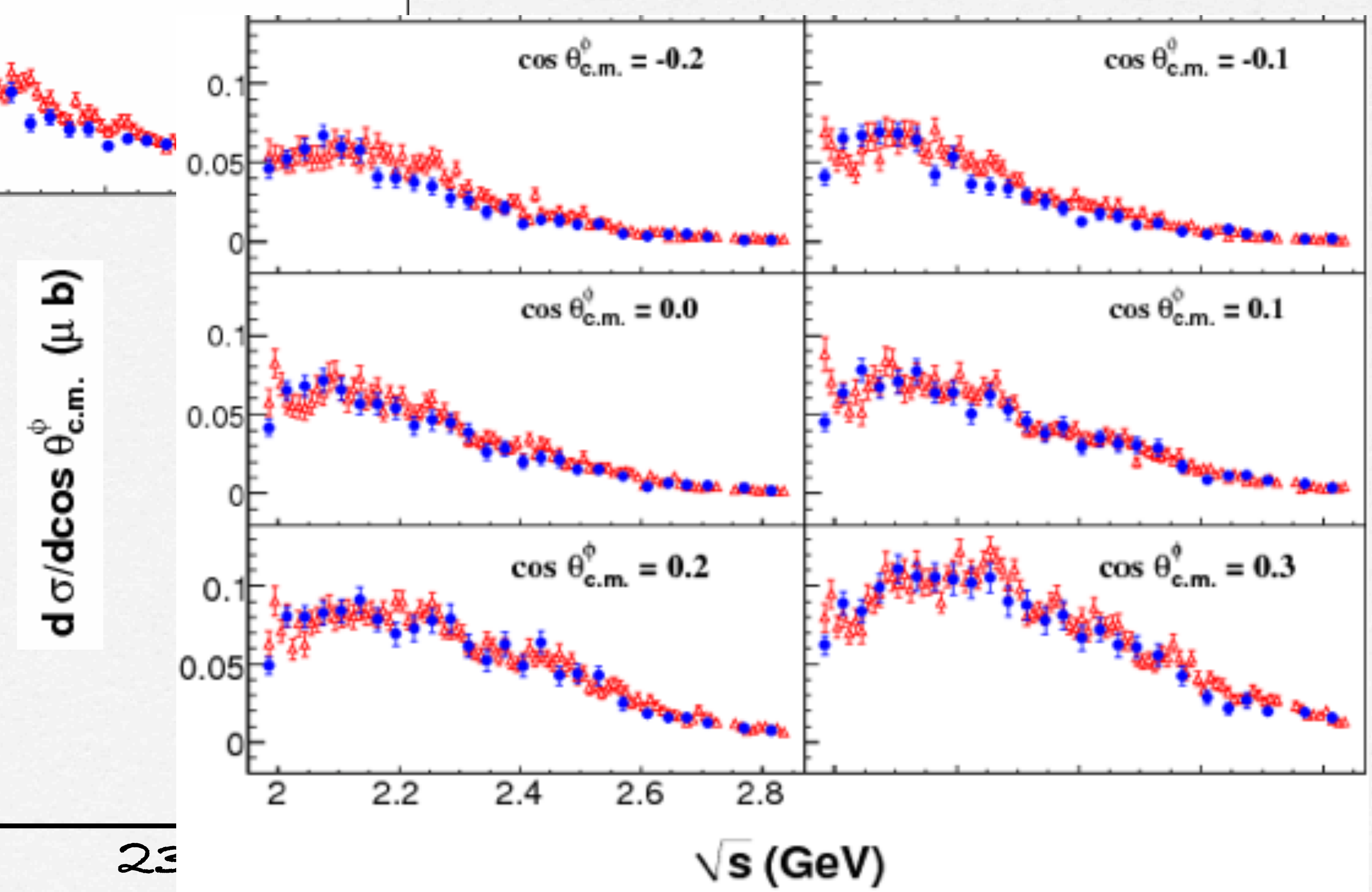
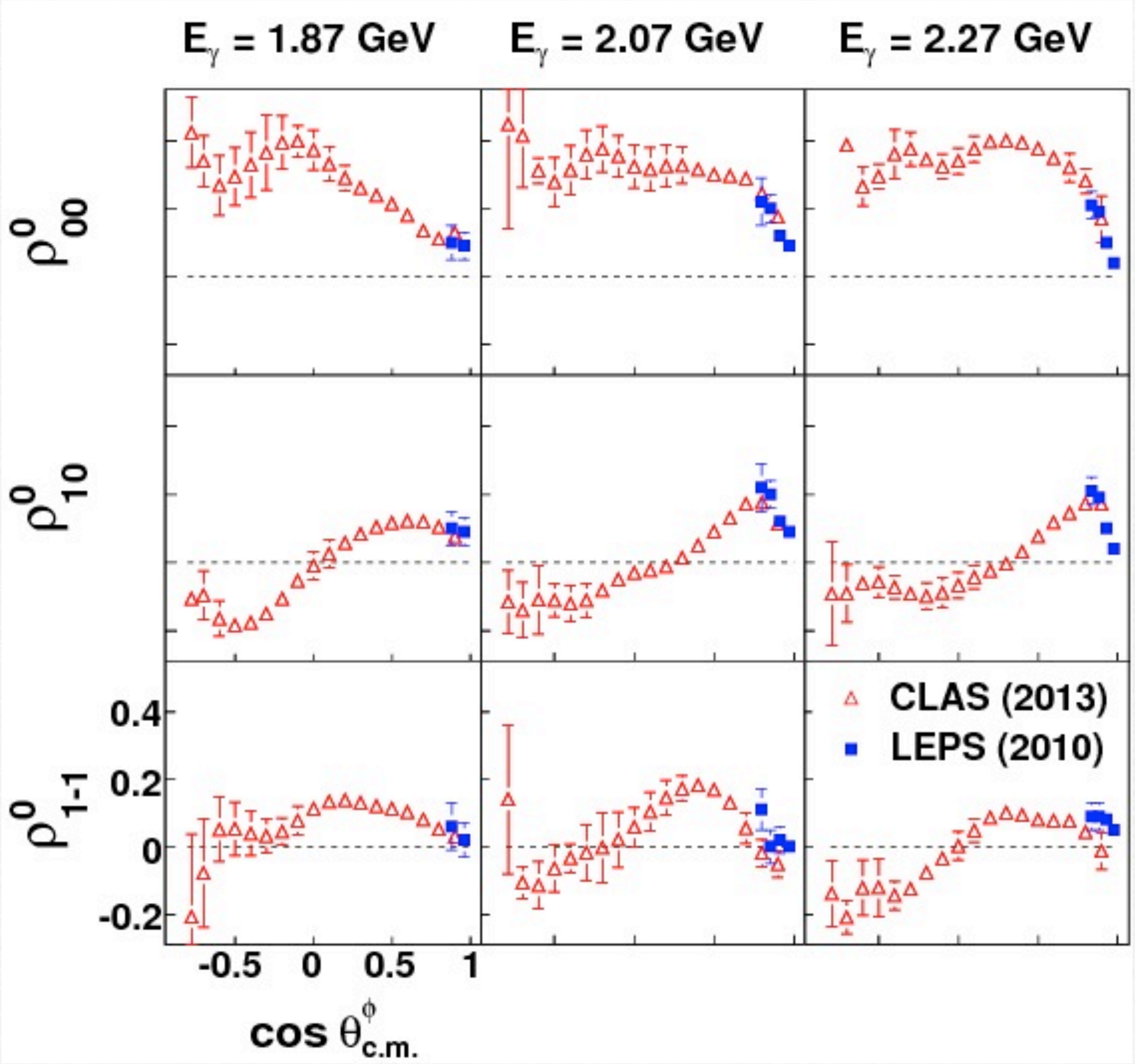




cos θ^φ_c.m. = -0.8
Charged
Neutral
cos θ^φ_c.m. = -0.7
cos θ^φ_c.m. = -0.6
cos θ^φ_c.m. = -0.5
cos θ^φ_c.m. = -0.4
cos θ^φ_c.m. = -0.3

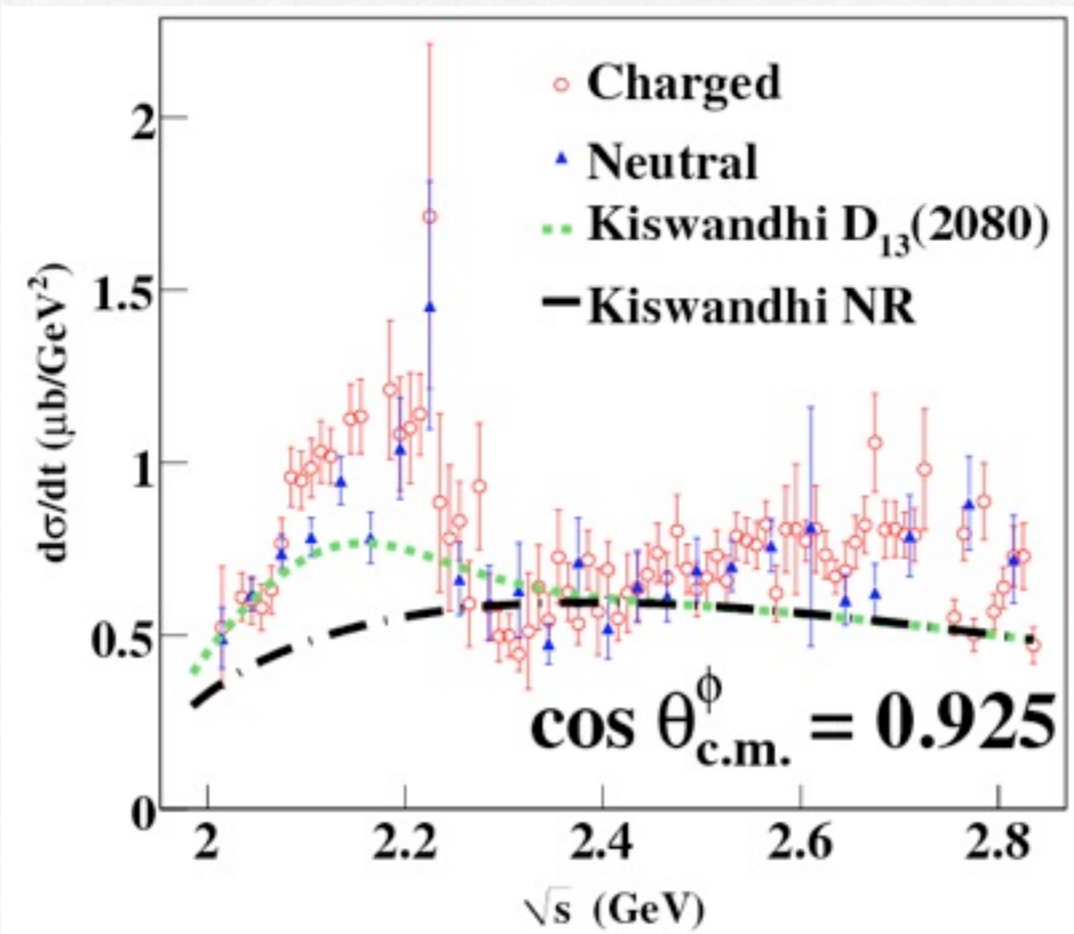


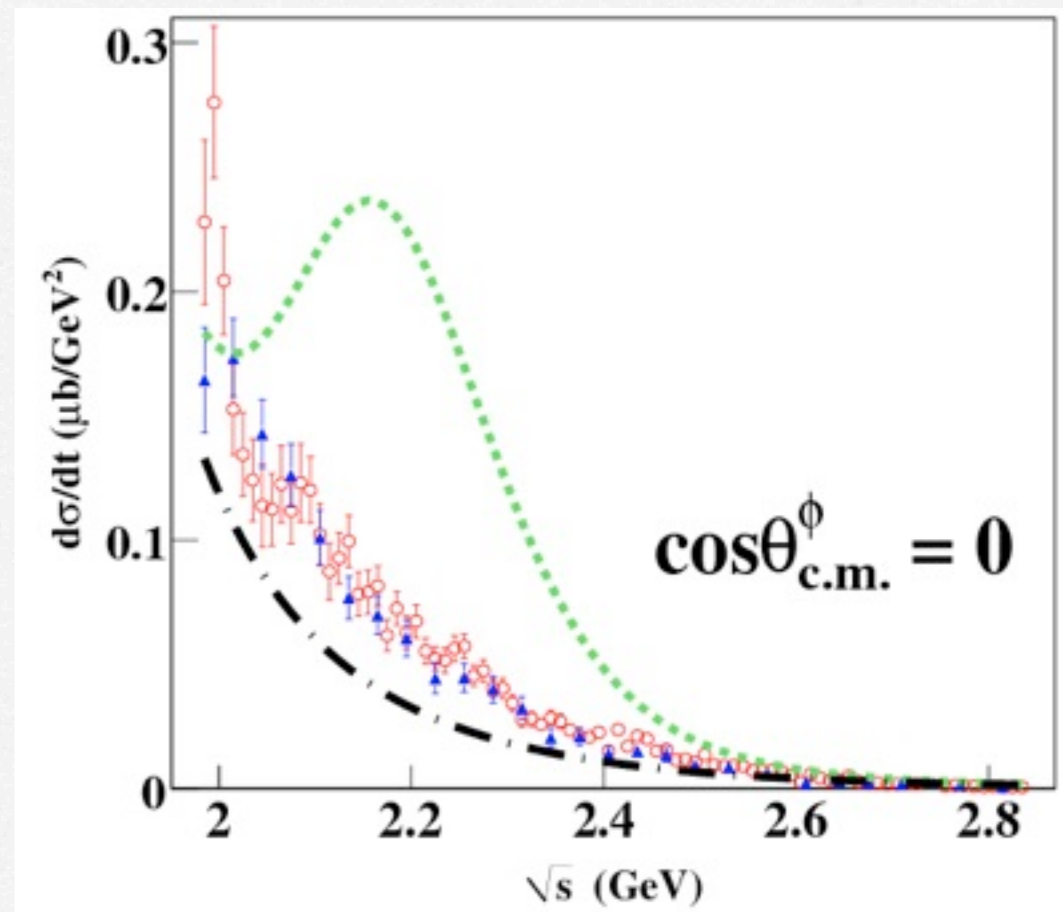
dσ/dcos θ^φ_c.m. (μ b)
cos θ^φ_c.m. = -0.2
cos θ^φ_c.m. = -0.1
cos θ^φ_c.m. = 0.0
cos θ^φ_c.m. = 0.1
cos θ^φ_c.m. = 0.2
cos θ^φ_c.m. = 0.3
√s (GeV)



E_γ = 1.87 GeV
E_γ = 2.07 GeV
E_γ = 2.27 GeV
ρ^0_{00}
ρ^0_{10}
ρ^0_{1-1}
0.4
0.2
0
-0.2
-0.5
0
0.5
1
$\cos\theta^{\phi}_{c.m.}$
CLAS (2013)
LEPS (2010)

3. **Phenomenology of ϕ photoproduction from recent CLAS data at Jefferson Lab**
Biplab Dey. Mar 14, 2014.
e-Print: **arXiv:1403.3730 [hep-ex]** | **PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Detailed record

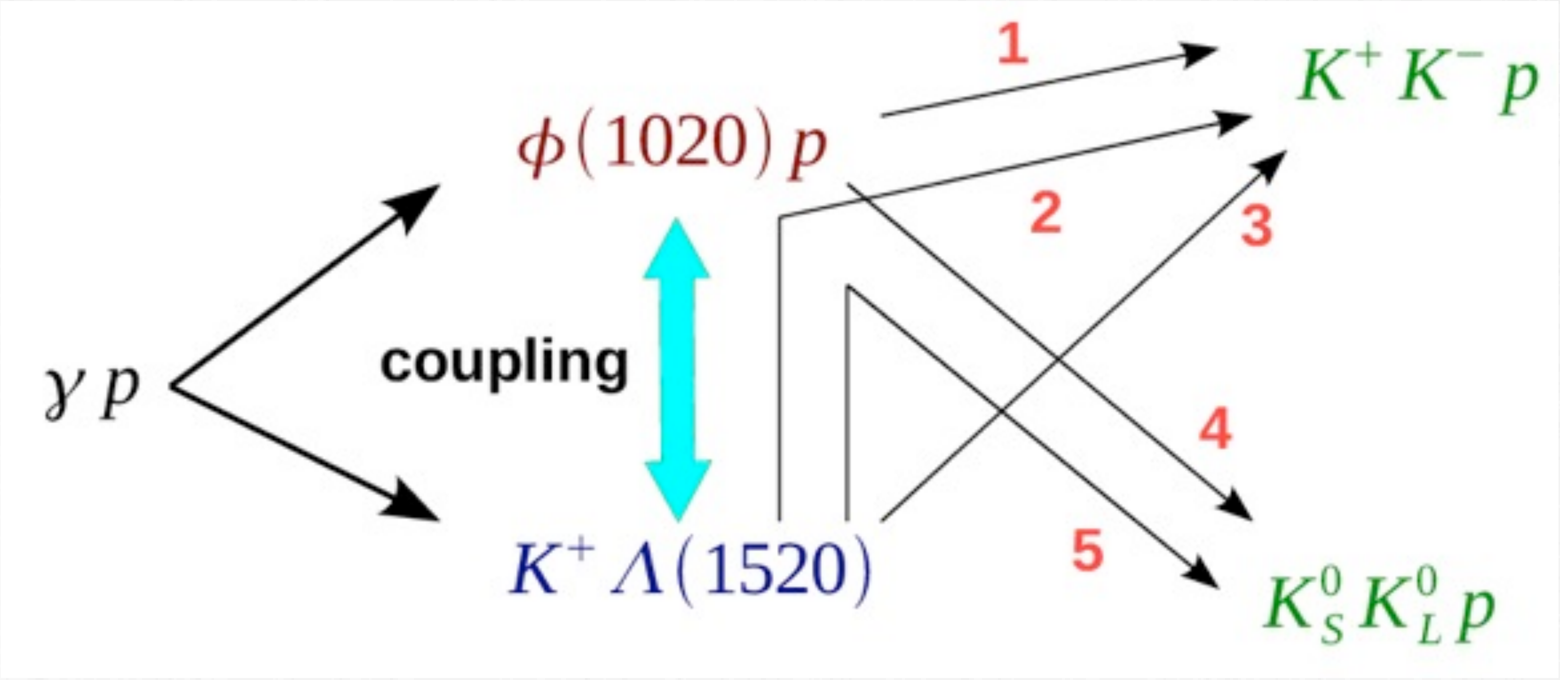




□ Summary for γ p-->ϕp

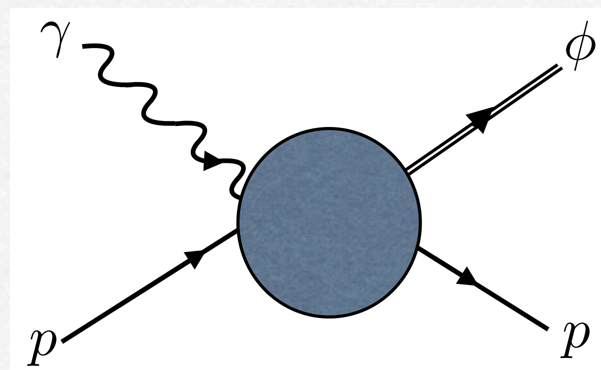
1. We found that the coupled-channel effect could be important

2. Resonances ?
   - good for LEPS data (2005/ 2010)
   - not enough for the new CLAS data



γ p --> KΛ(1520)

$$T_{\gamma p \to \phi p} =$$



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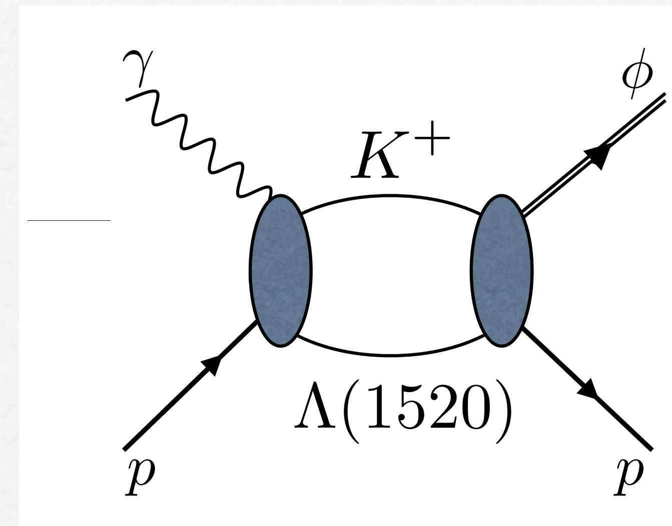
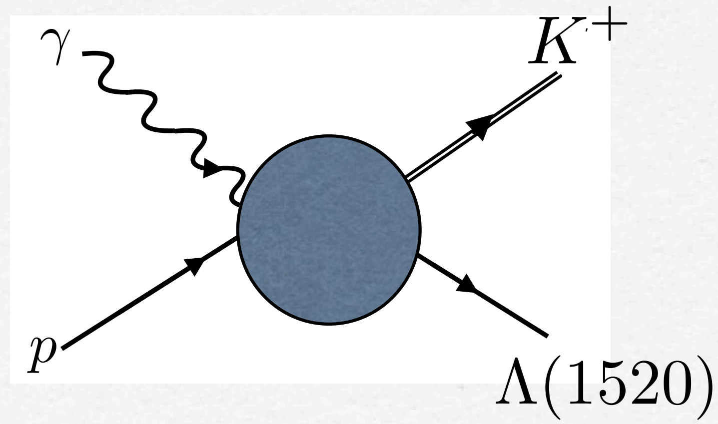


$$T_{\gamma p \to K^+ \Lambda^*} =$$



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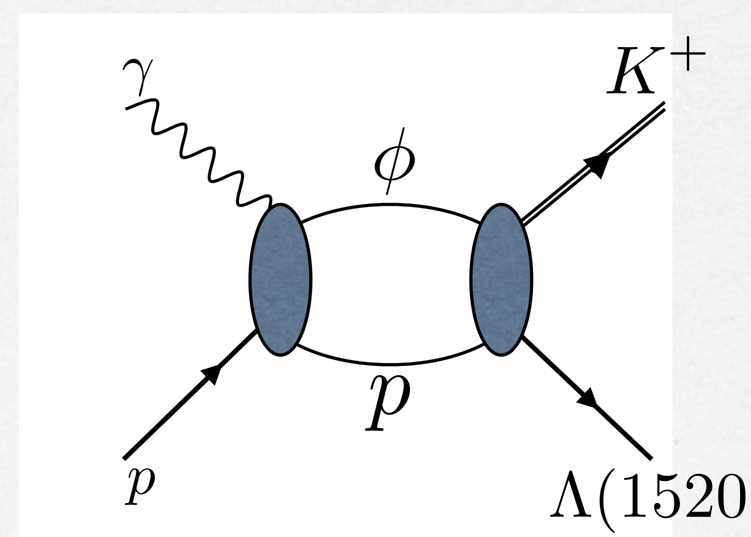
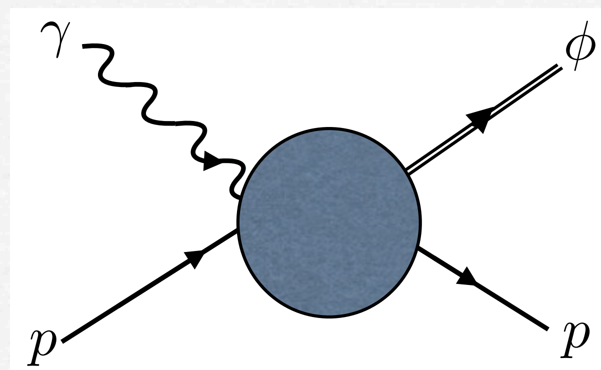


γ p --> KΛ(1520)

$(\Lambda^* = \Lambda(1520))$

$$T_{\gamma p \to \phi p} =$$ 

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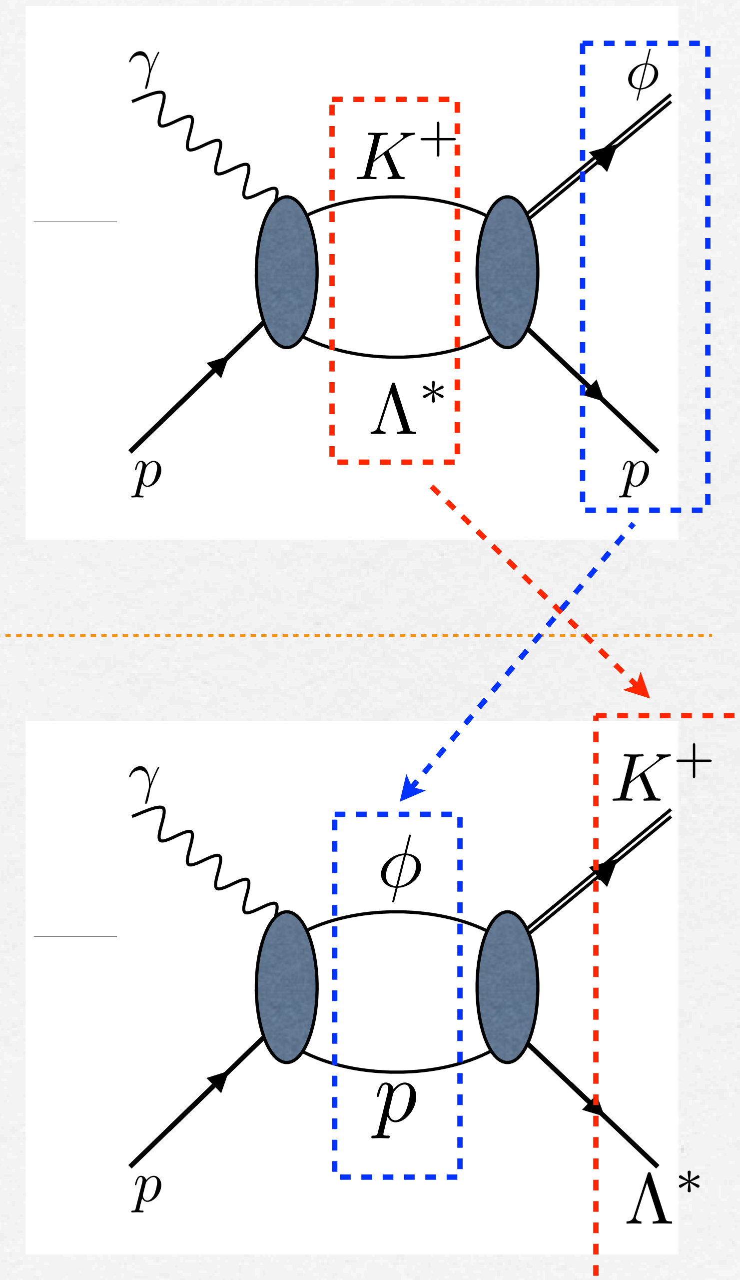
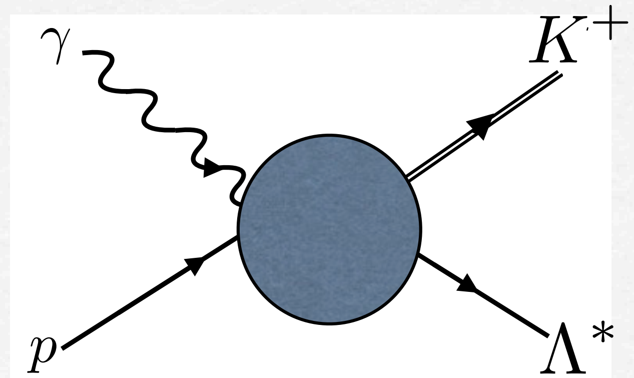


$$T_{\gamma p \to K^+ \Lambda^*} =$$ 

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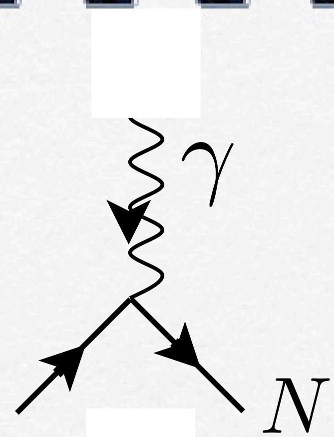
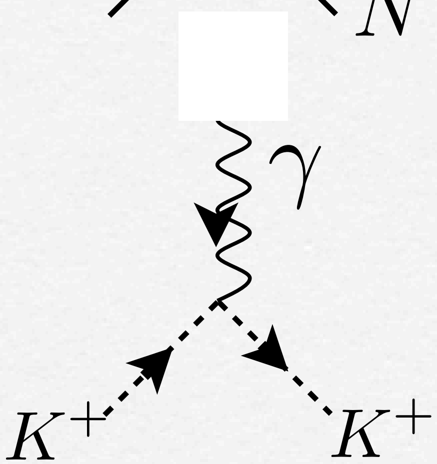
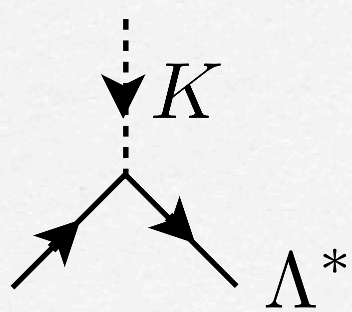


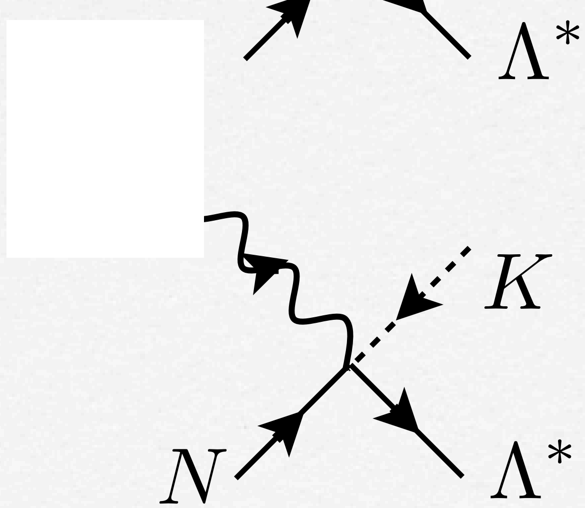
$$\mathcal{L}_{\gamma NN} = -e\overline{N}\left[\gamma^\mu - \frac{\kappa_N}{2M_N}\sigma_{\mu\nu}\partial_\nu\right]A_\mu N$$



$$\mathcal{L}_{\gamma KK} = ie(\partial_\mu K^+ K^- - \partial_\mu K^- K^+)A^\mu$$

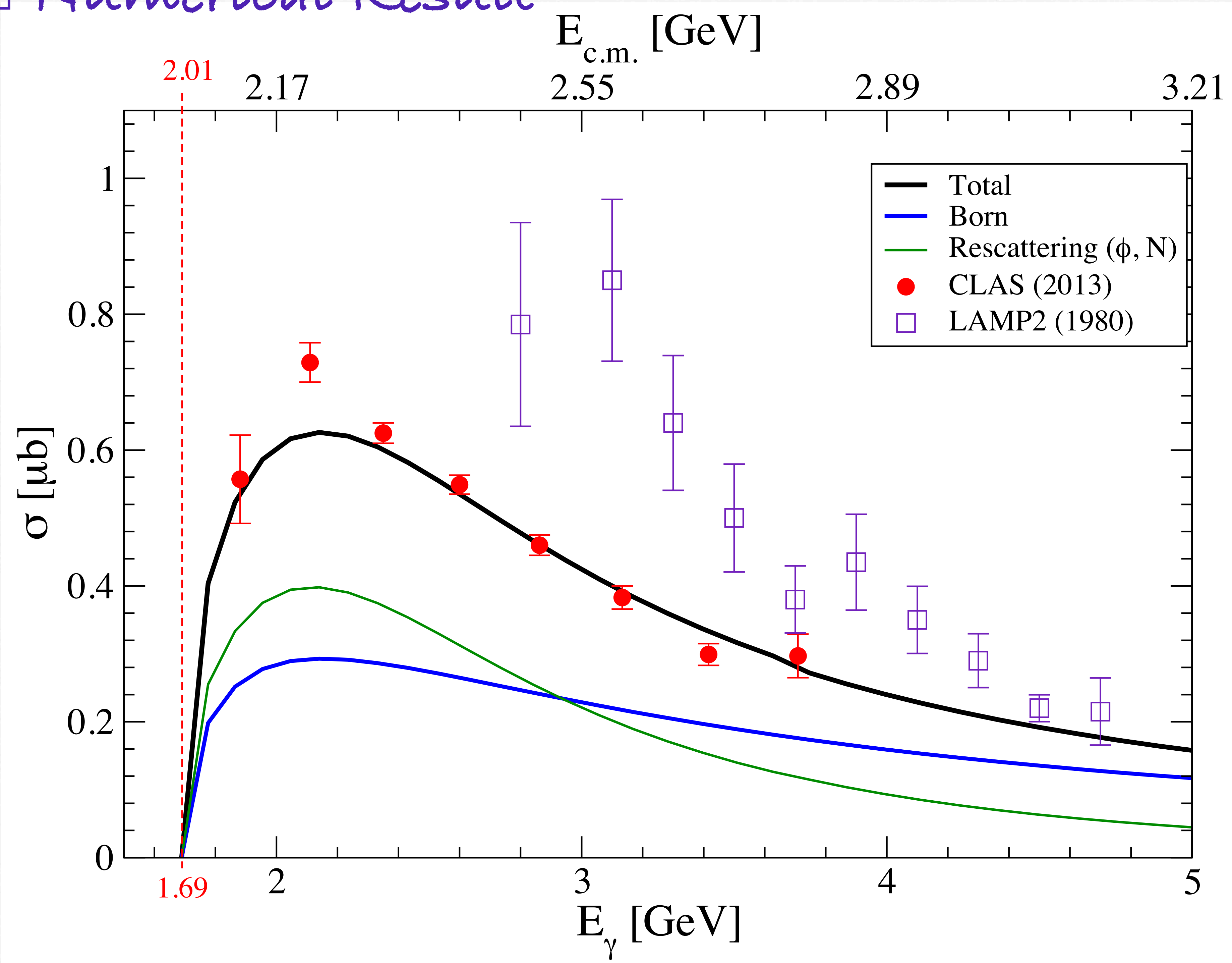


$$\mathcal{L}_{KN\Lambda^*} = \frac{g_{KN\Lambda^*}}{m_K}\overline{N}\gamma_5\partial_\mu K^+\Lambda^{*\mu}$$

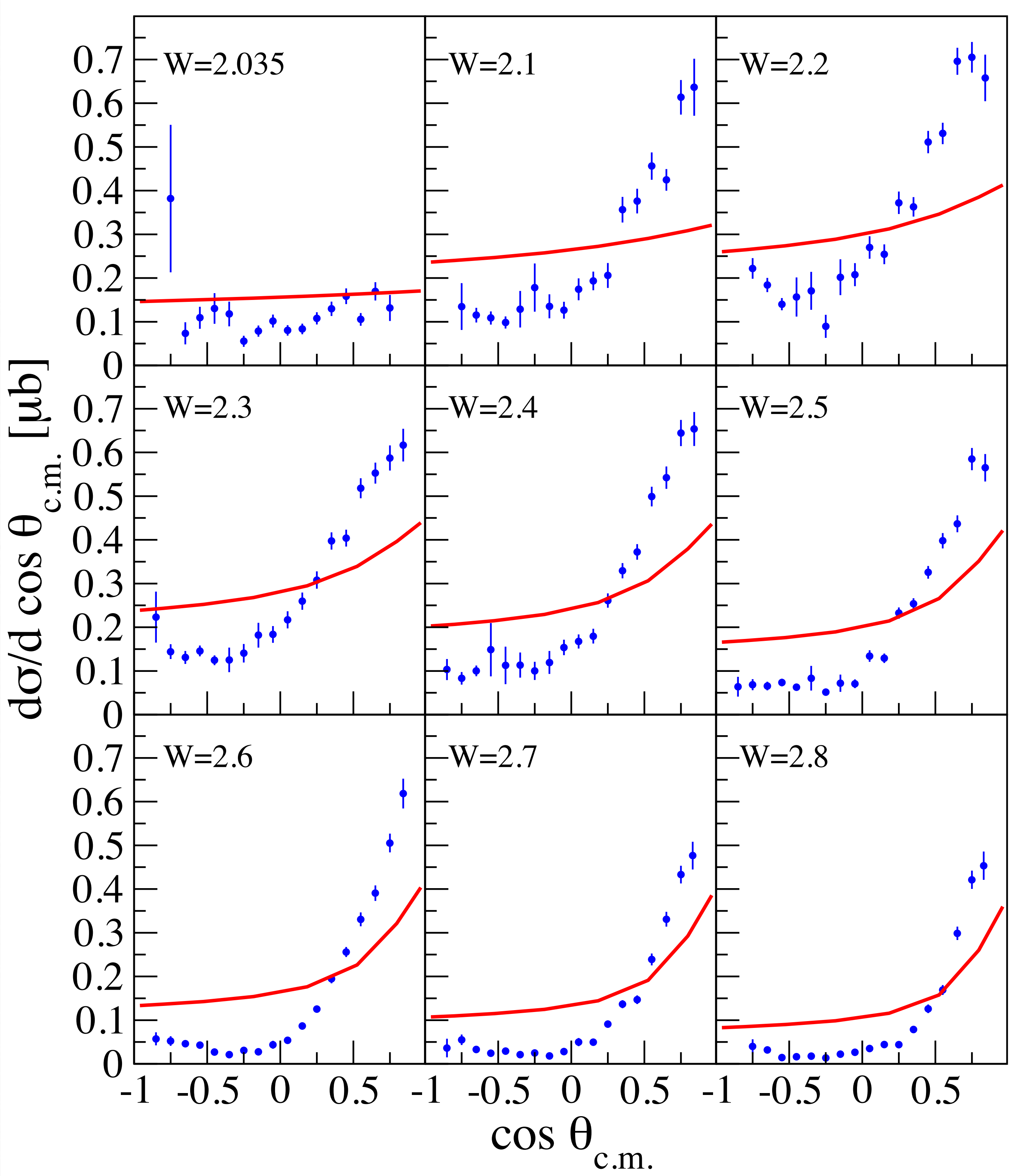


$$\mathcal{L}_{\gamma KN\Lambda^*} = -i\frac{eg_{KN\Lambda^*}}{m_K}\overline{N}\gamma_5 A_\mu K^+\Lambda^{*\mu}$$

Numerical Result



CLAS(2013): K. Moriya et al
Phys. Rev. C 88, 045201 (2013)



We need to consider
N* (s-channel)
and
u-channels
to improve this result.

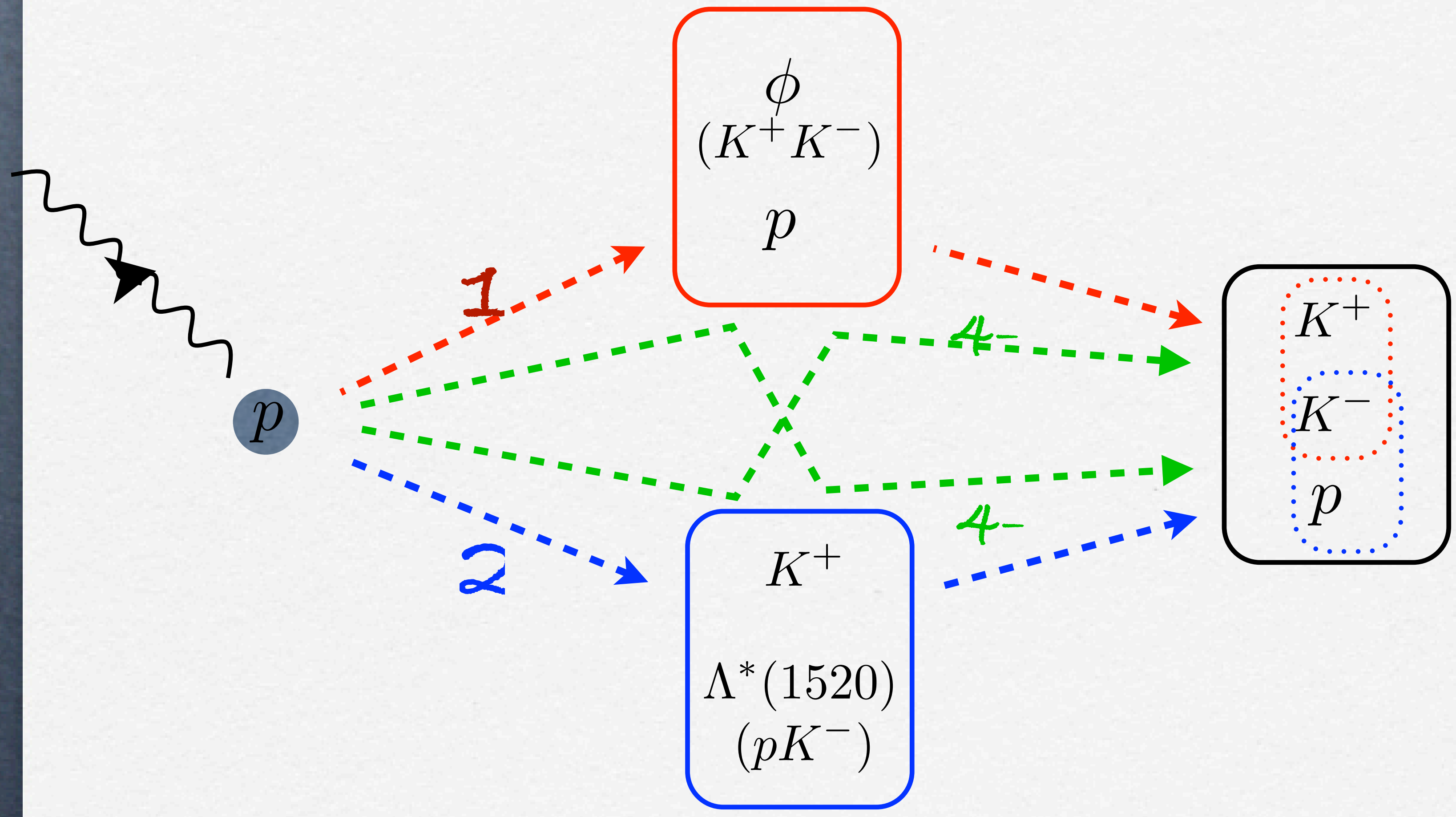
K. Moriya et al, Phys. Rev. C 88, 045201 (2013)

□ Summary for γ p-->KL(1520)

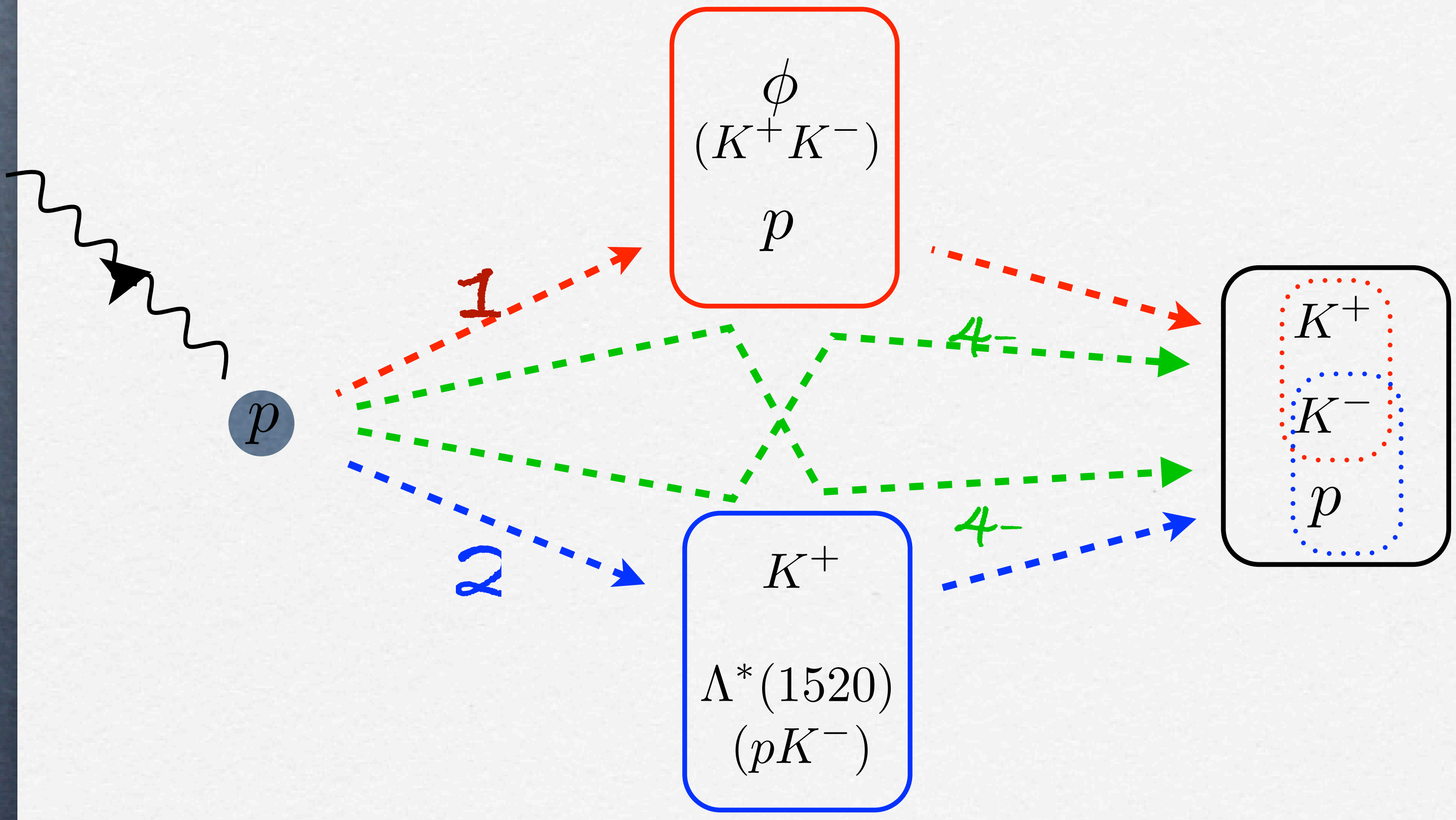
1. (Well tested) (ϕ, ρ) coupled-channel is applied and we found that it could be important here also.

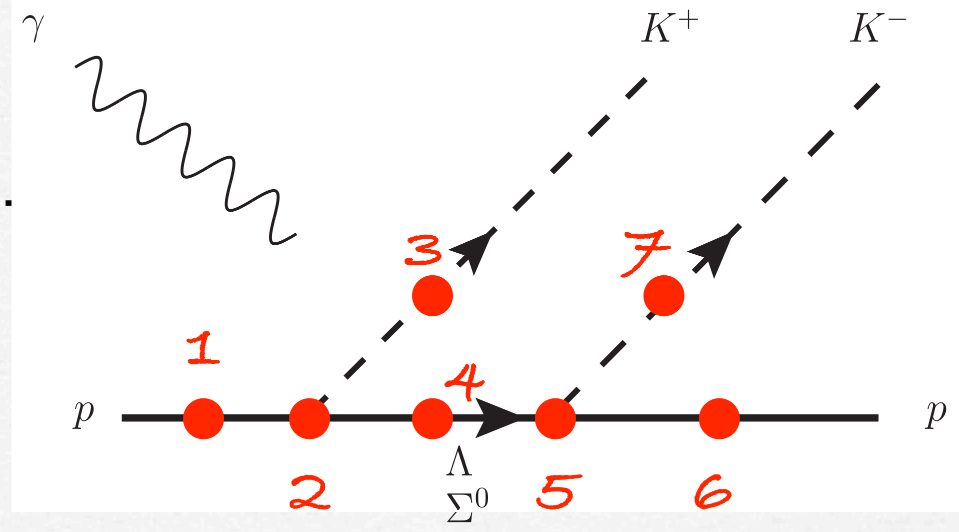
2. We need to consider s-channels(N*) and u-channels to explain the new data.

γ p --> K K p (Future work)

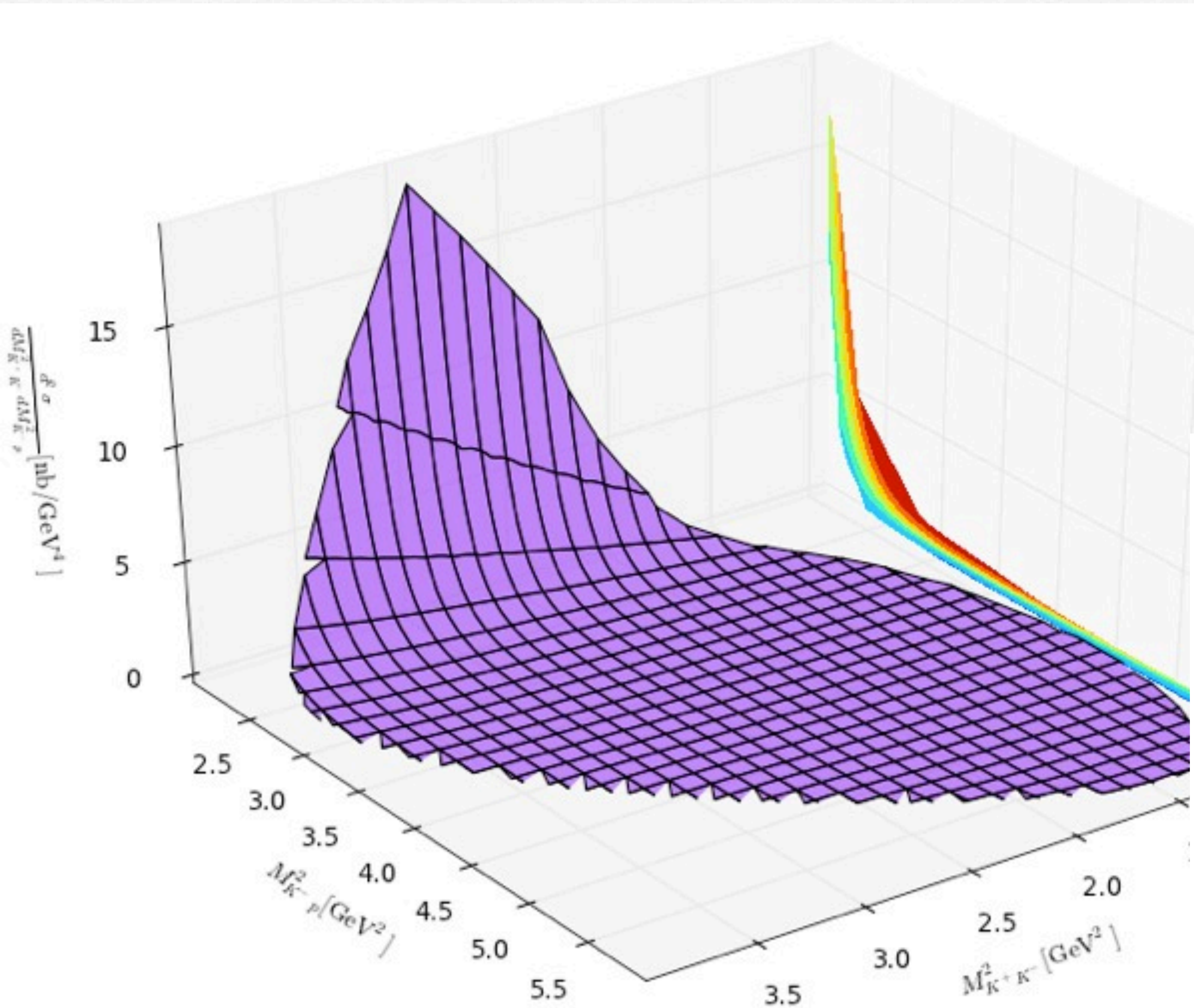


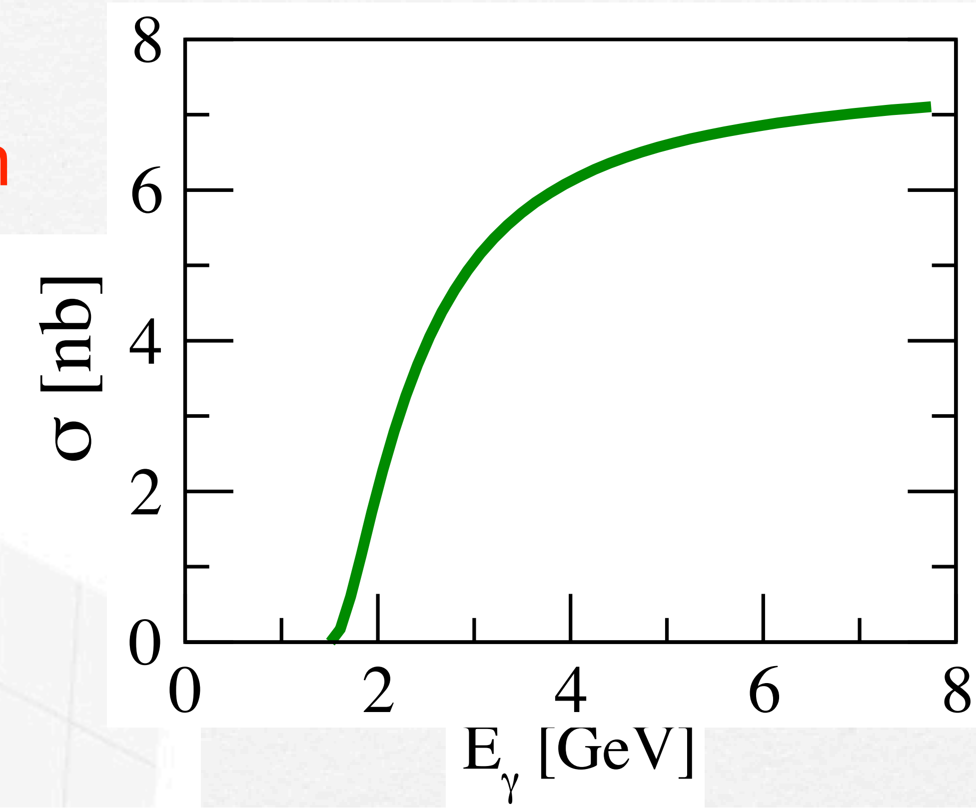
γ p --> K K p (Future work)

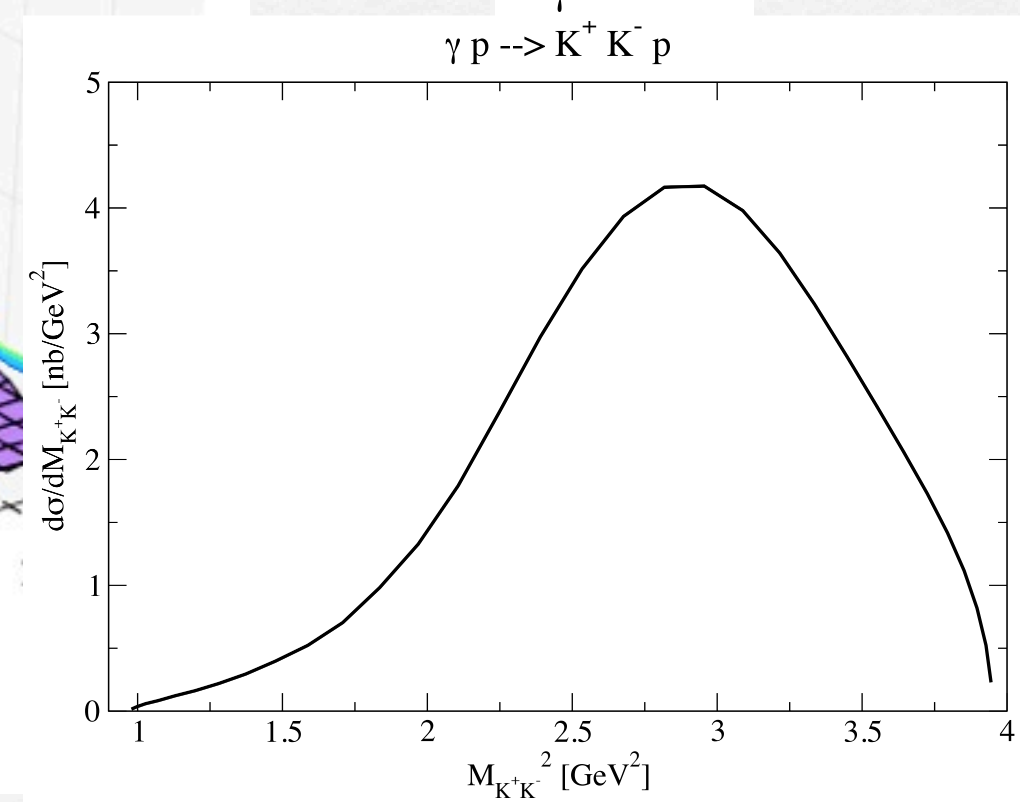




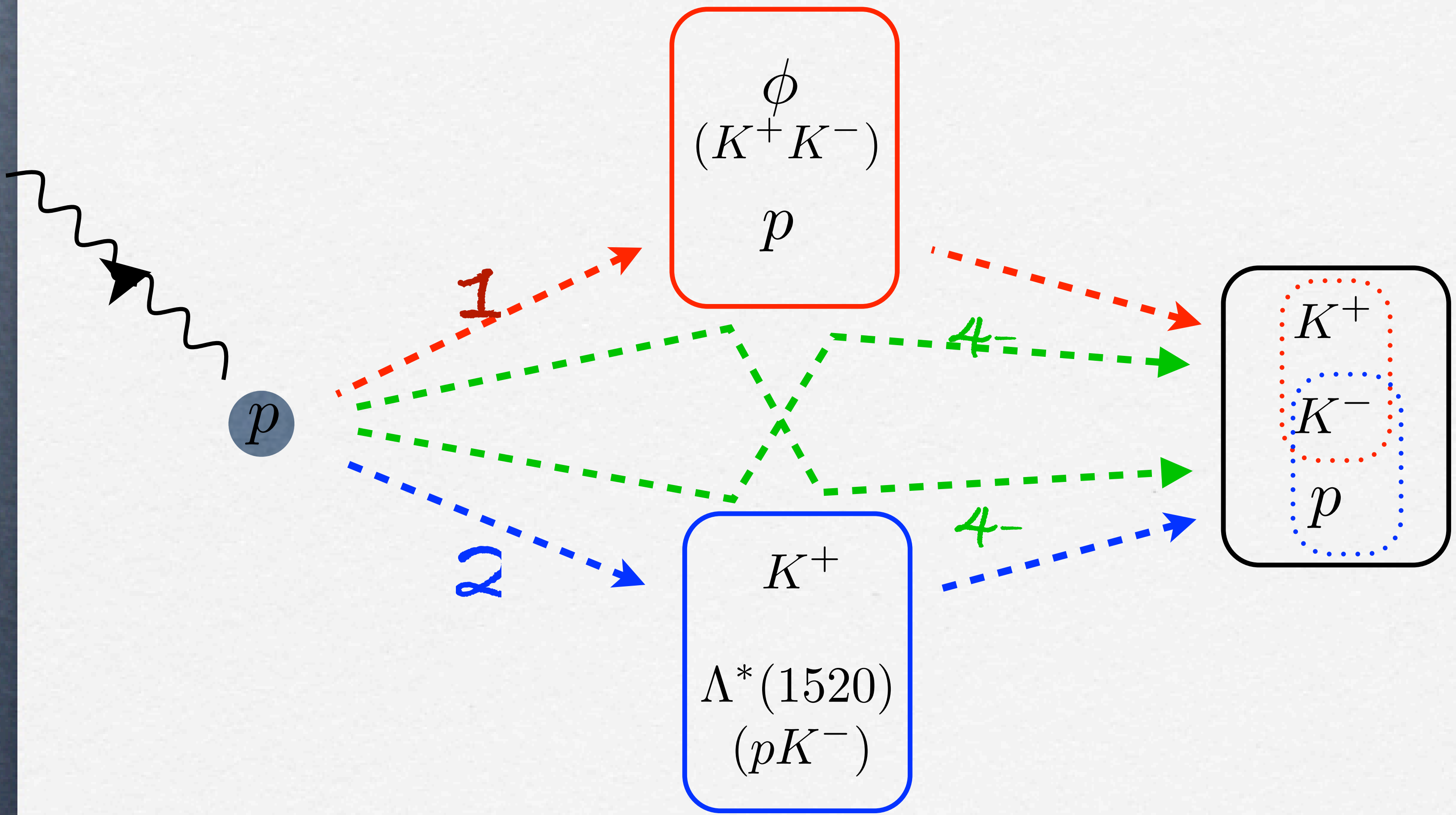
Only background contribution

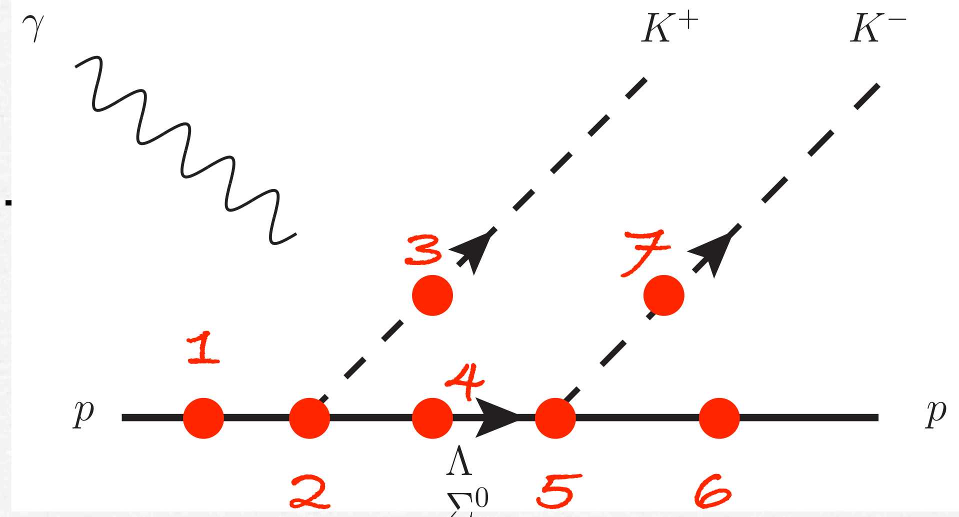






γ p --> K K p (Future work)





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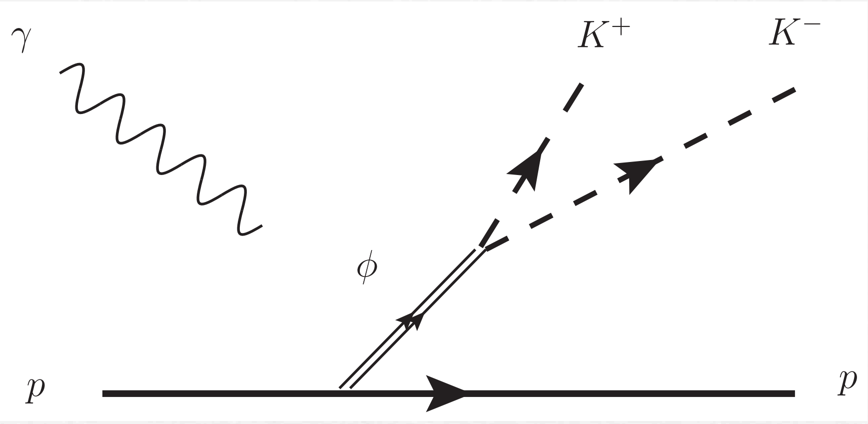

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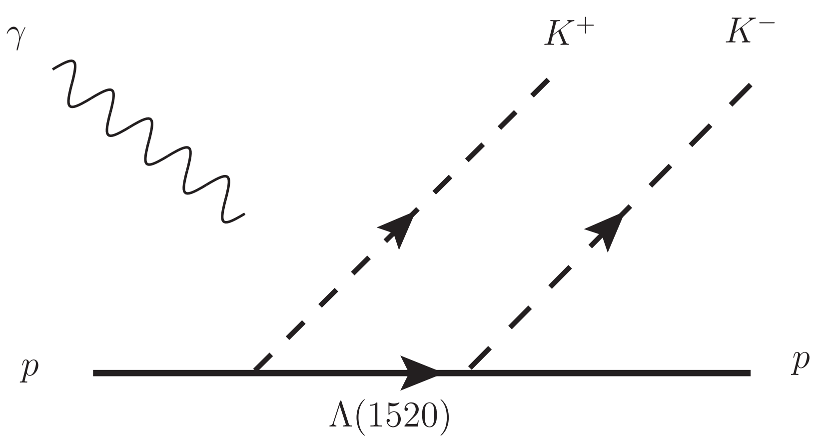
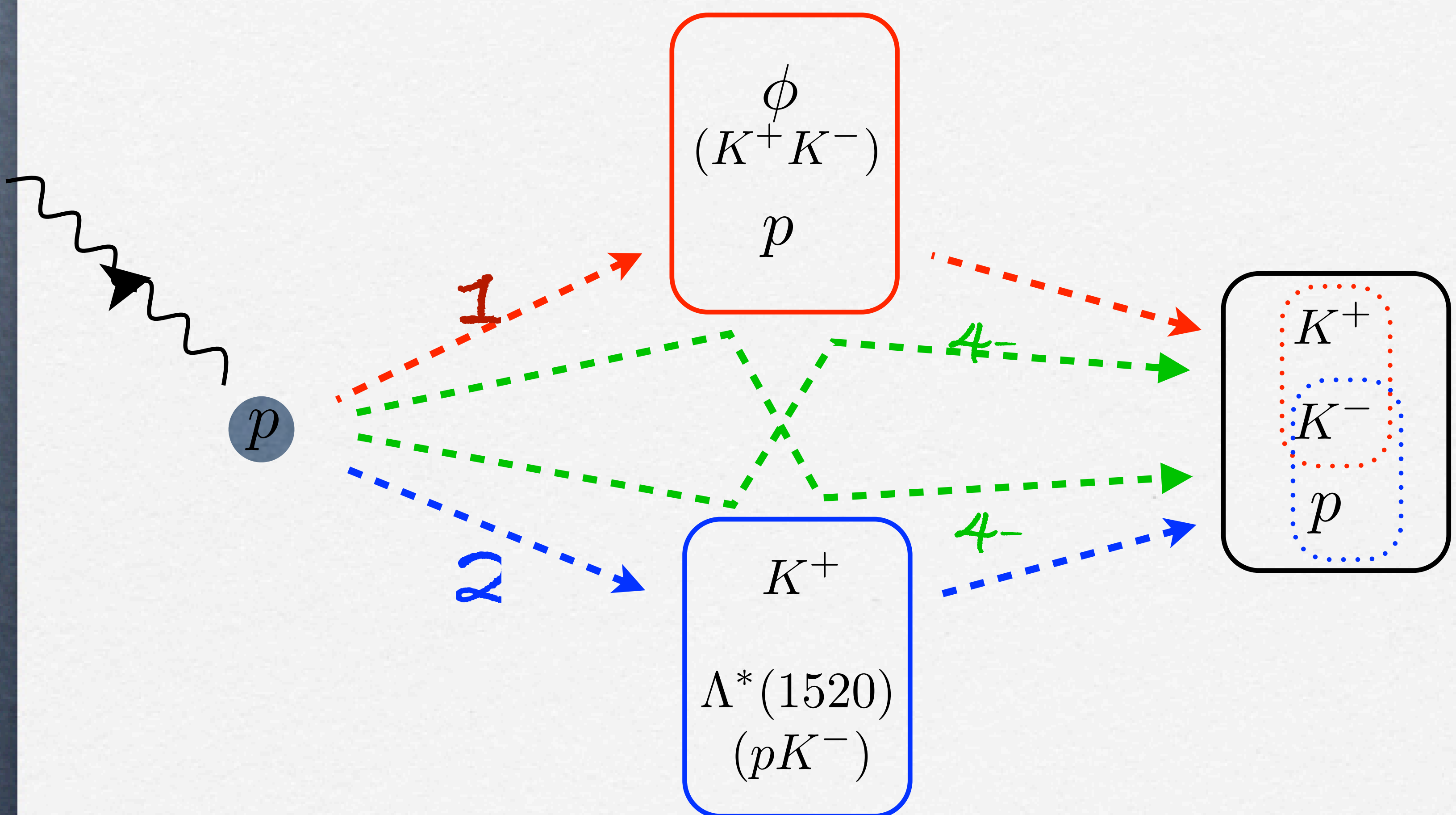
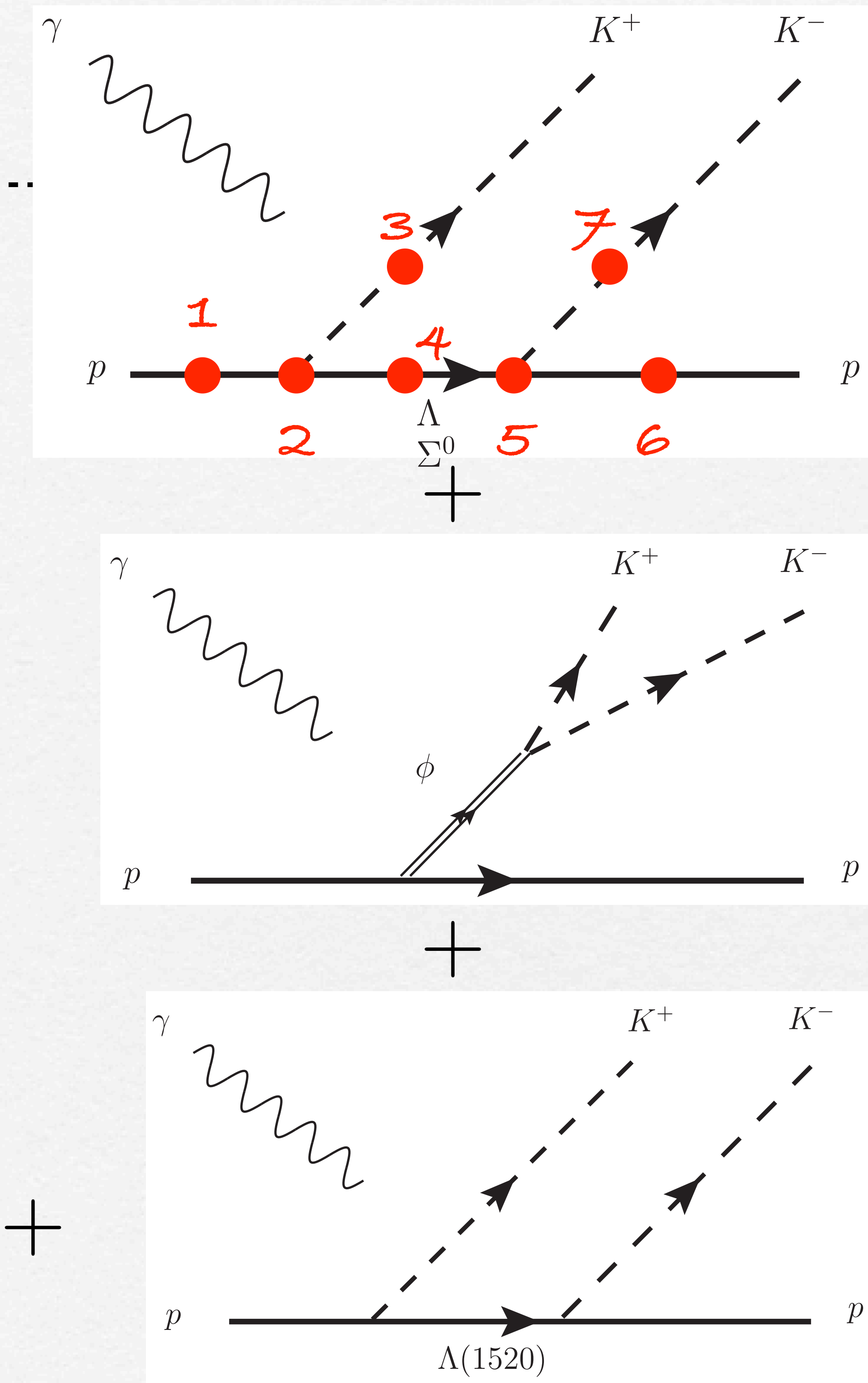
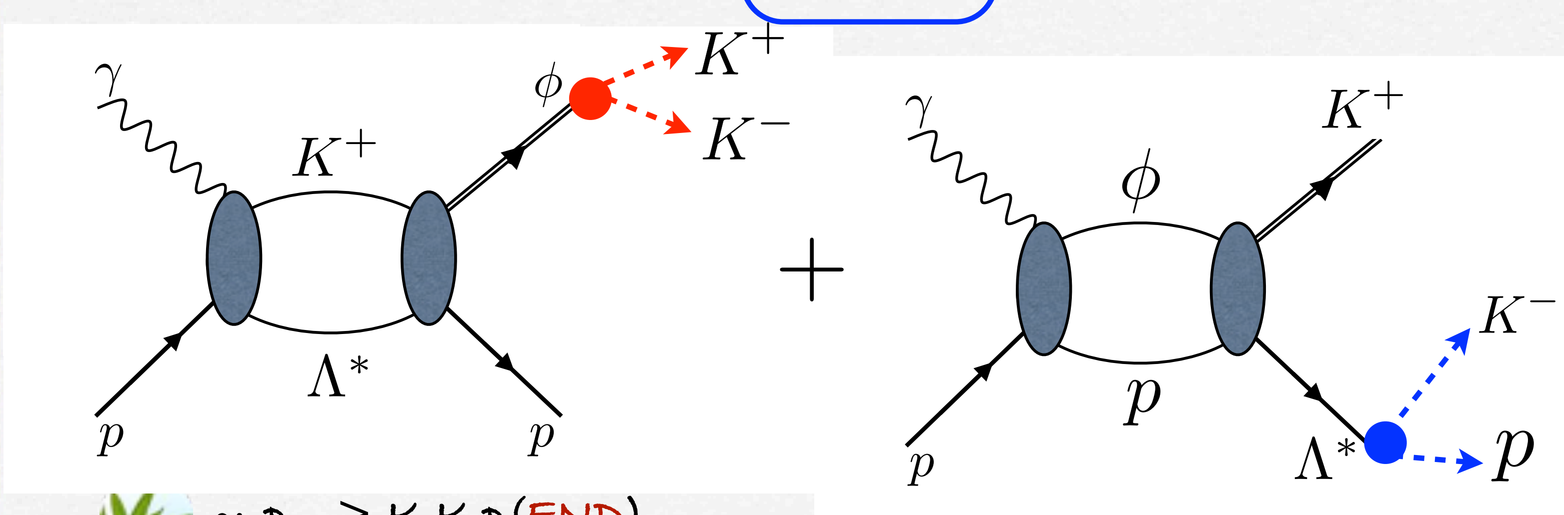


γ p --> K K p (Future work)





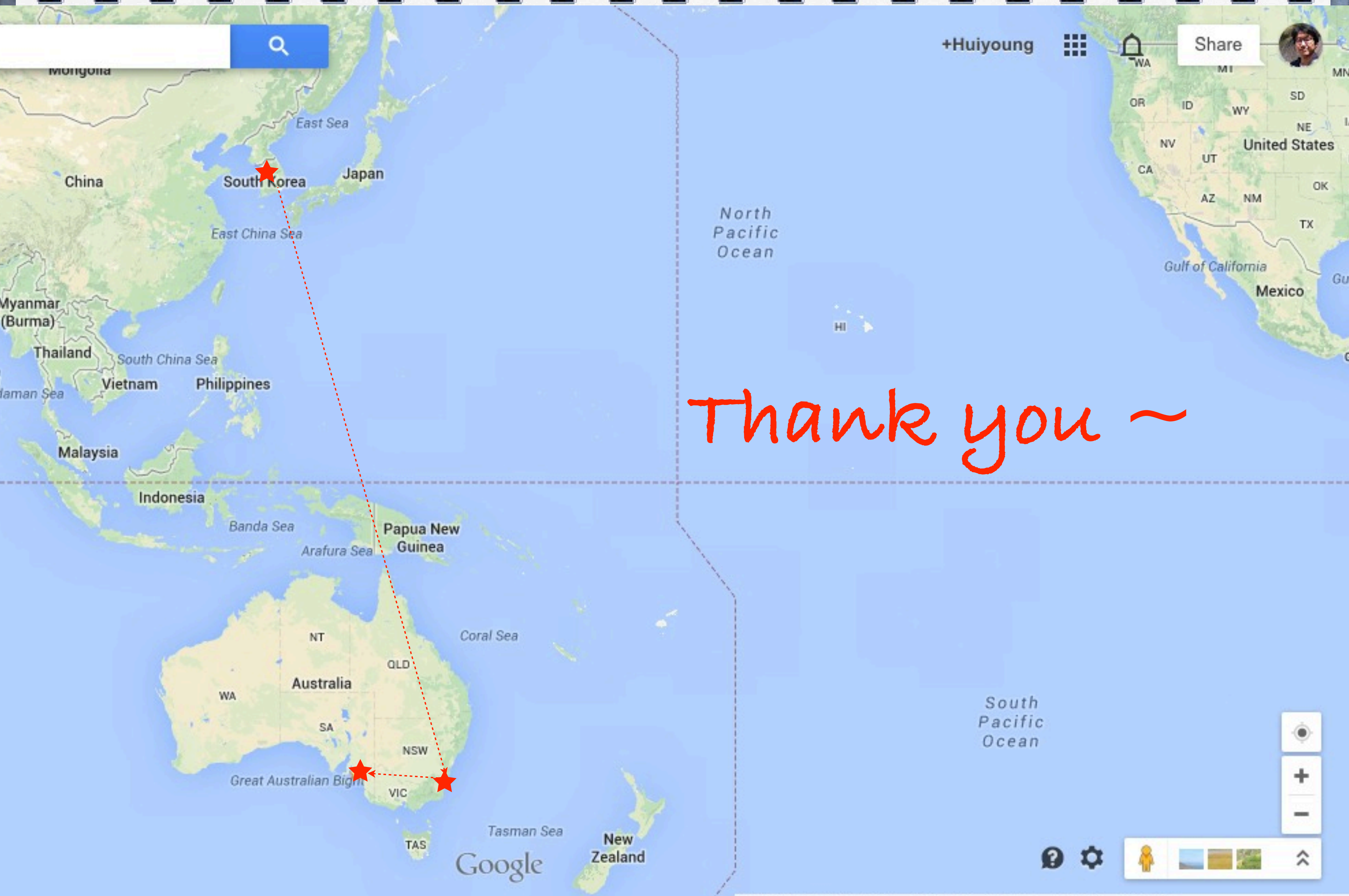


Summary and Outlook

1. We found that (ϕ, p)-(K,Λ*) coupled-channel could be important in (ϕ, p) and (K,Λ*) photoproduction process.

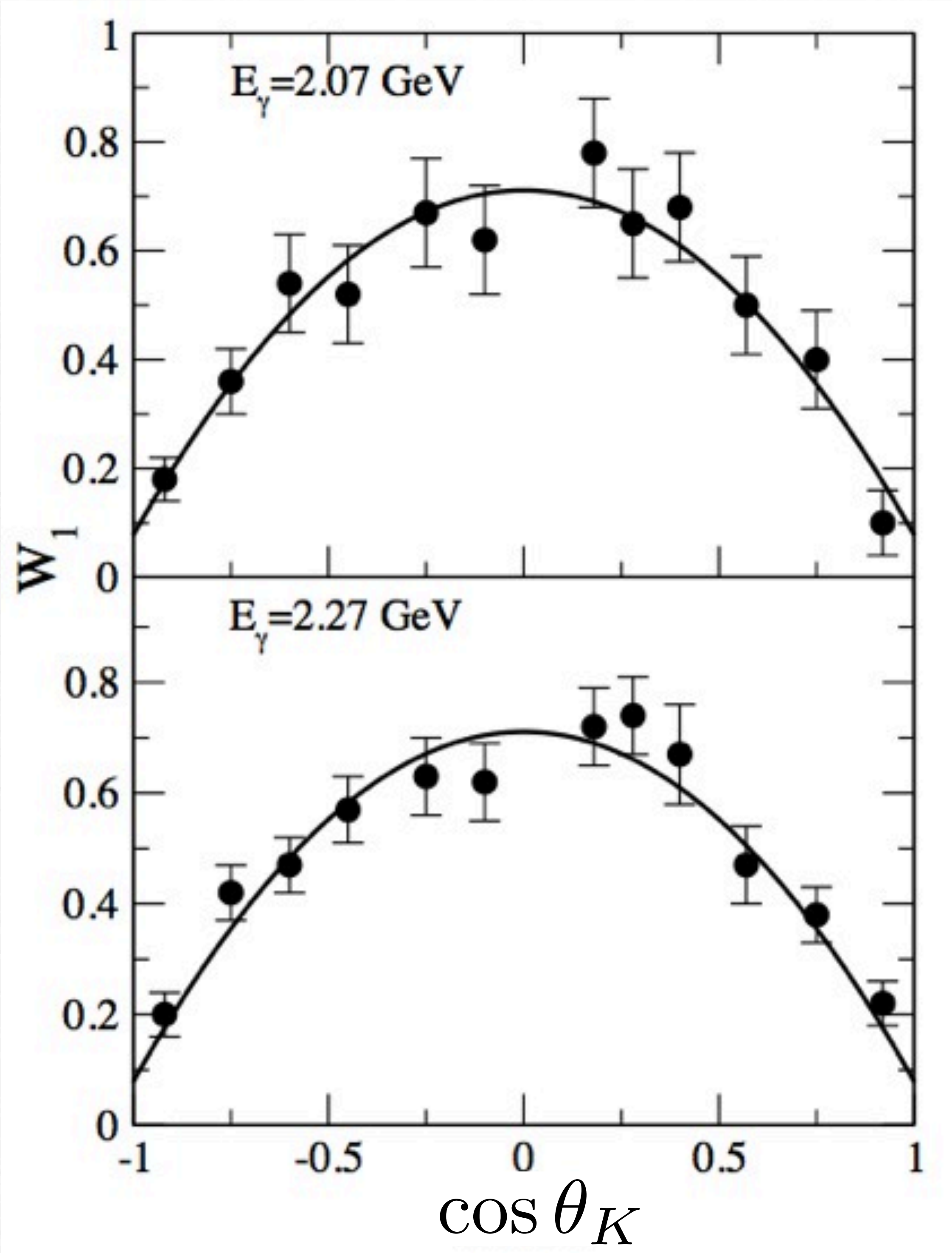
2. We can test this coupled-channel in the several decay channels.

3. Recent new data from CLAS (wide range data) would tell us that which process plays important role in each channels.


+Huiyoung
Share
Mongolia
East Sea
China
South Korea
Japan
East China Sea
North Pacific Ocean
Myanmar (Burma)
Thailand
South China Sea
Vietnam
Philippines
Andaman Sea
Malaysia
Indonesia
Banda Sea
Papua New Guinea
Arafura Sea
Coral Sea
NT
QLD
Australia
WA
SA
NSW
Great Australian Bight
VIC
TAS
Tasman Sea
New Zealand
South Pacific Ocean
HI
WA
MT
OR
ID
WY
SD
NE
NV
UT
United States
CA
AZ
NM
OK
TX
Gulf of California
Mexico
Google
Thank you ~

Backup

$$\rho^0_{00} = \frac{|T_{0,-1}|^2 + |T_{0,1}|^2}{|T_{-1,-1}|^2 + |T_{-1,1}|^2 + |T_{0,-1}|^2 + |T_{0,1}|^2 + |T_{1,-1}|^2 + |T_{1,1}|^2} \qquad (T_{\lambda_\phi \lambda_\gamma})$$



$$W_1(\cos\theta_K) = \frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\theta_K$$

If $\rho^0_{00} = 0$,

$$W_1(\cos\theta_K) = 0.5 + 0.5\cos^2\theta_K$$

If $\rho^0_{00} = 0.5$,

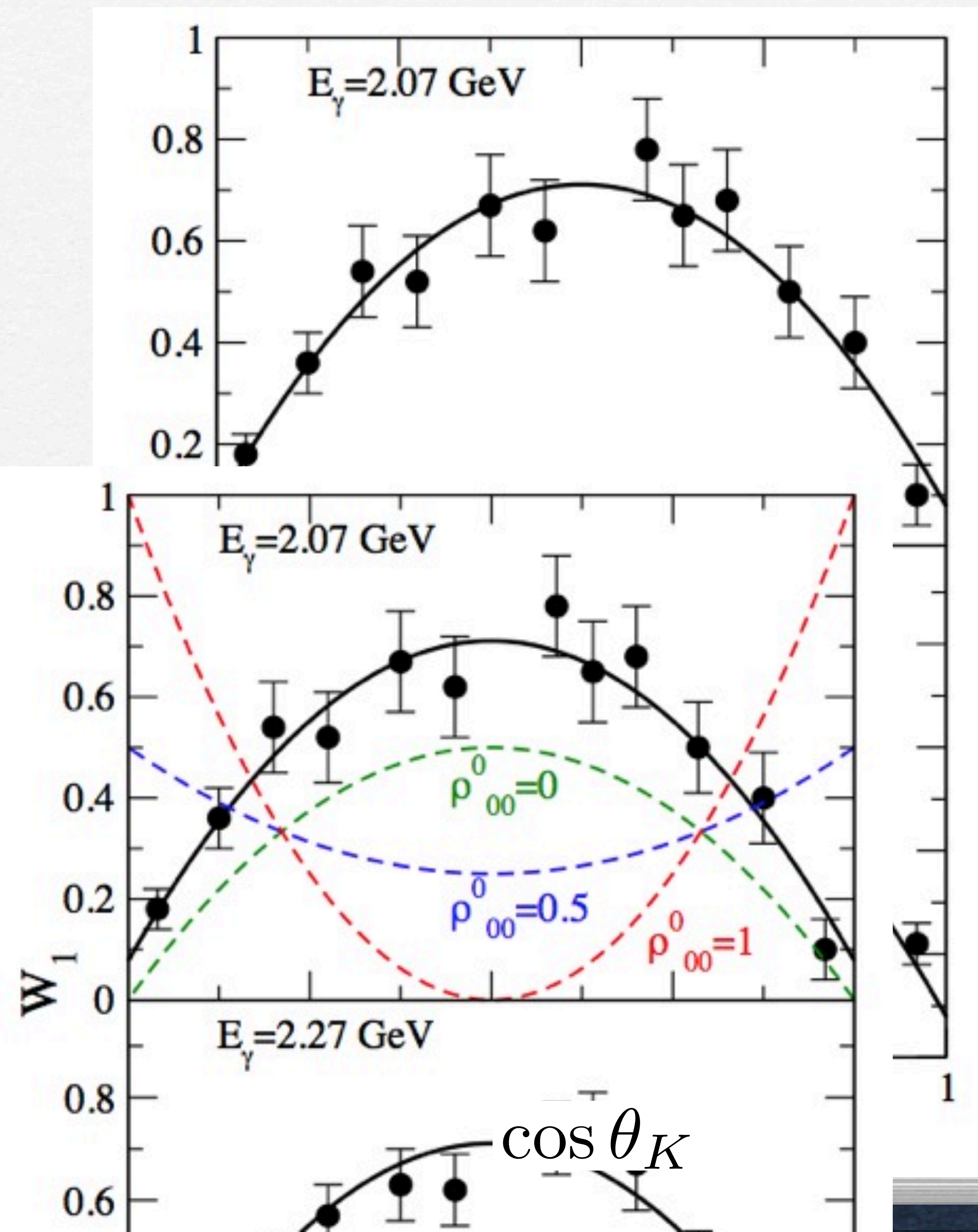
$$W_1(\cos\theta_K) = 0.25 + 0.25\cos^2\theta_K$$

If $\rho^0_{00} = 1$,

$$W_1(\cos\theta_K) = \cos^2\theta_K$$

T. Mibe *et al.* [LEPS Collaboration], Phys. Rev. Lett. **95**, 182001 (2005

$$\rho^0_{00} = \frac{|T_{0,-1}|^2 + |T_{0,1}|^2}{|T_{-1,-1}|^2 + |T_{-1,1}|^2 + |T_{0,-1}|^2 + |T_{0,1}|^2 + |T_{1,-1}|^2 + |T_{1,1}|^2} \qquad (T_{\lambda_\phi \lambda_\gamma})$$



$$W_1(\cos\theta_K) = \frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00} - 1)\cos^2\theta_K$$

If $\rho^0_{00} = 0$,

$$W_1(\cos\theta_K) = 0.5 + 0.5\cos^2\theta_K$$

If $\rho^0_{00} = 0.5$,

$$W_1(\cos\theta_K) = 0.25 + 0.25\cos^2\theta_K$$

If $\rho^0_{00} = 1$,

$$W_1(\cos\theta_K) = \cos^2\theta_K$$

T. Mibe *et al.* [LEPS Collaboration], Phys. Rev. Lett. **95**, 182001 (2005

Spin density matrix and Decay angular distribution

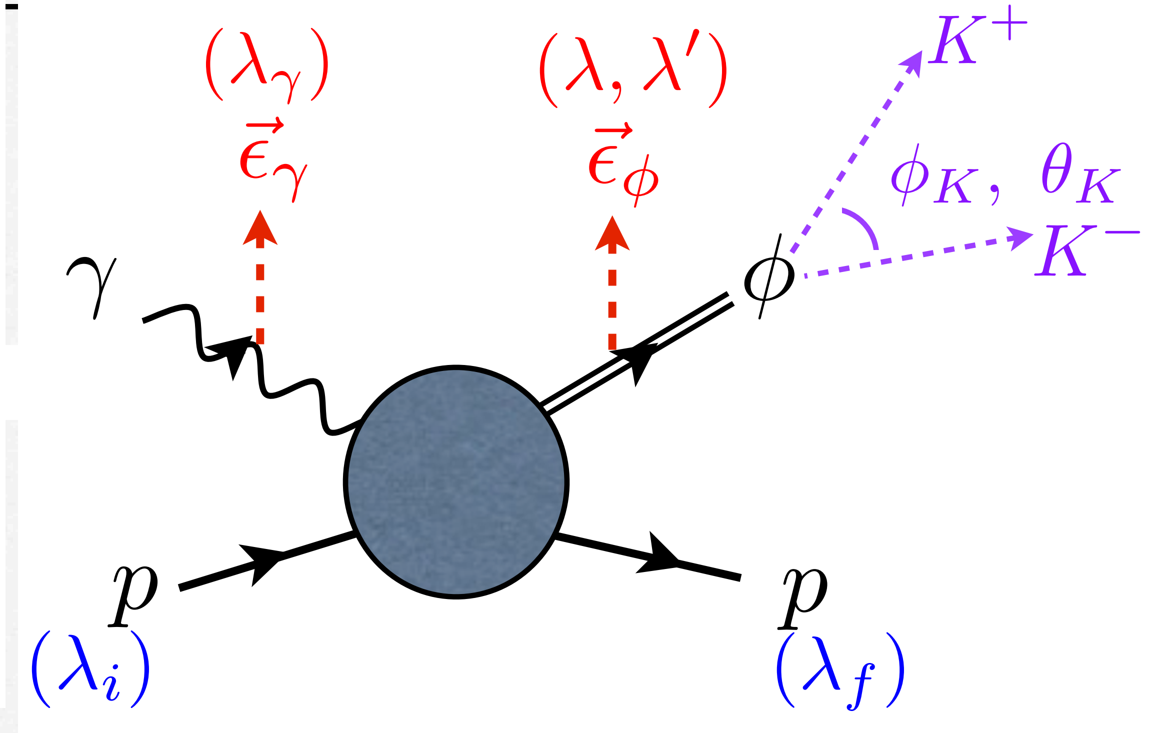
$$\rho^0_{\lambda\lambda'} = \frac{1}{N}\sum_{\lambda_\gamma,\lambda_i,\lambda_f} T_{\lambda_f,\lambda;\lambda_i,\lambda_\gamma} T^*_{\lambda_f,\lambda';\lambda_i,\lambda_\gamma}$$

$$\rho^1_{\lambda\lambda'} = \frac{1}{N}\sum_{\lambda_\gamma,\lambda_i,\lambda_f} T_{\lambda_f,\lambda;\lambda_i,-\lambda_\gamma} T^*_{\lambda_f,\lambda';\lambda_i,\lambda_\gamma}$$

$$\rho^2_{\lambda\lambda'} = \frac{i}{N}\sum_{\lambda_\gamma,\lambda_i,\lambda_f} \lambda_\gamma T_{\lambda_f,\lambda;\lambda_i,-\lambda_\gamma} T^*_{\lambda_f,\lambda';\lambda_i,\lambda_\gamma}$$

$$\rho^3_{\lambda\lambda'} = \frac{1}{N}\sum_{\lambda_\gamma,\lambda_i,\lambda_f} \lambda_\gamma T_{\lambda_f,\lambda;\lambda_i,\lambda_\gamma} T^*_{\lambda_f,\lambda';\lambda_i,\lambda_\gamma}$$

$$N = \sum |T_{\lambda_f,\lambda;\lambda_i,\lambda_\gamma}|^2$$



$$W_1(\cos\theta_K) = \frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\theta_K$$

$$2\pi W_2(\phi_K - \Phi) = 1 + 2p_\gamma \bar{\rho}^1_{1-1}\cos 2(\phi_K - \Phi)$$

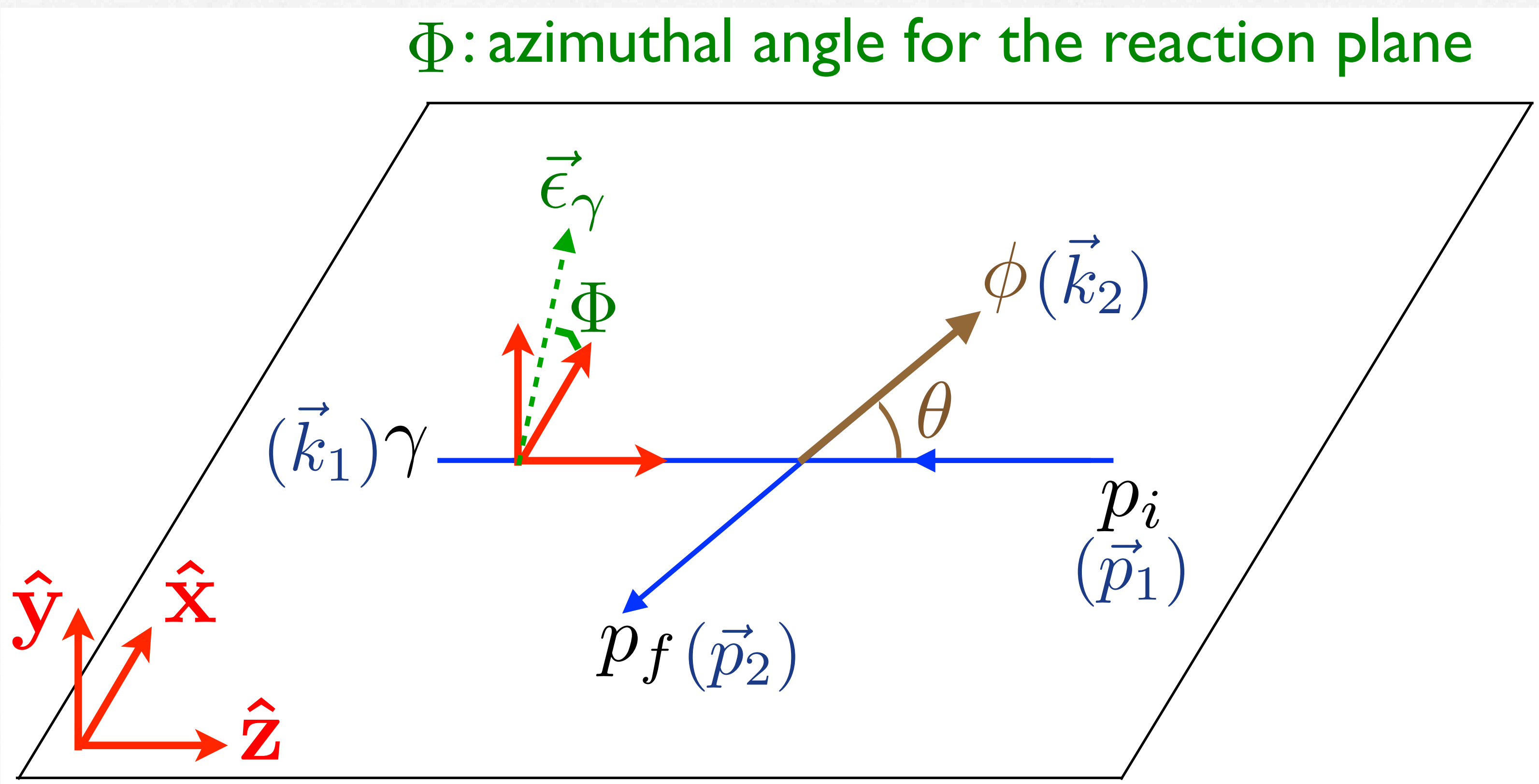
$$2\pi W_3(\phi_K + \Phi) = 1 + 2p_\gamma \Delta_{1-1}\cos 2(\phi_K + \Phi)$$

$$\bar{\rho}^1_{1-1} = \frac{1}{2}(\rho^1_{1-1} - \mathrm{Im}\rho^2_{1-1})$$

$$\Delta_{1-1} = \frac{1}{2}(\rho^1_{1-1} + \mathrm{Im}\rho^2_{1-1})$$

(p_γ : polarization strength $\simeq 0.95$)

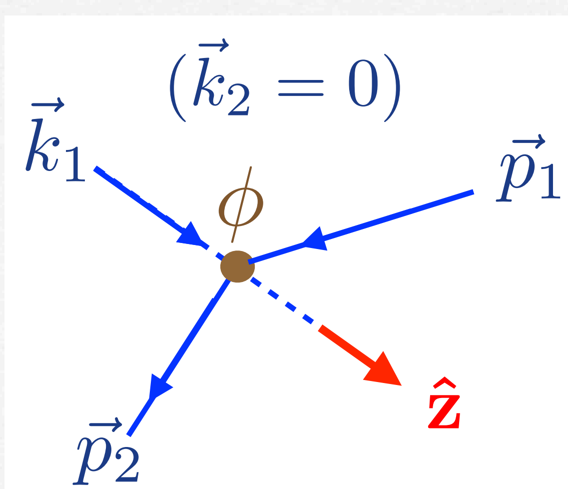
Definition of angles

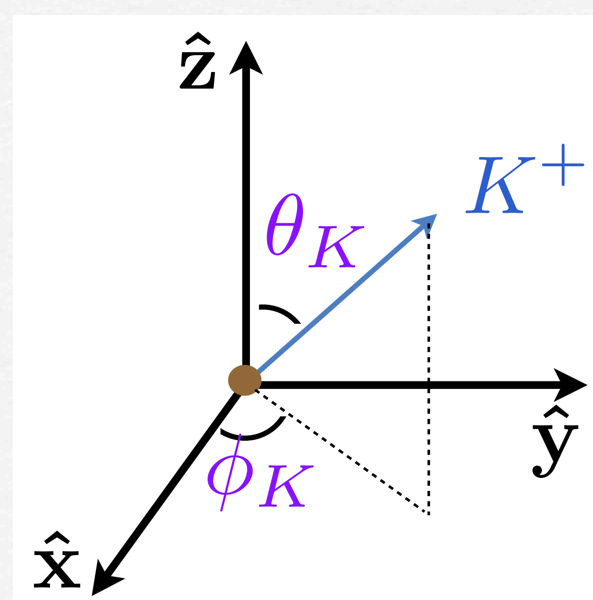


C.M. system

$\vec{k}_1 + \vec{p}_1 = 0$

Rotation
Boost





G.J. system

$\vec{k}_2 = 0$

$\vec{k}_1 \; // \; \hat{\mathbf{z}}$