Photoproduction of multi-kaons in an effective Lagrangian approach

Huiyoung RYU

국가슈퍼컴퓨팅연구소
National Institute of Supercomputing and Networking

In Collaboration with
Atushi Hosaka (RCNP), A. I. Titov (JINR),
Hyun-Chul Kim (Inha Uni.) and Yongseok Oh (KNU)

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Bikal lake, 13 July, 2013
by Hee-Jung Lee

Contents

PART I. $\gamma p \to \phi p$

I. Introduction

Phi meson properties

$\phi(1020)$ $\quad I^G(J^{PC}) = 0^-(1^{--})$

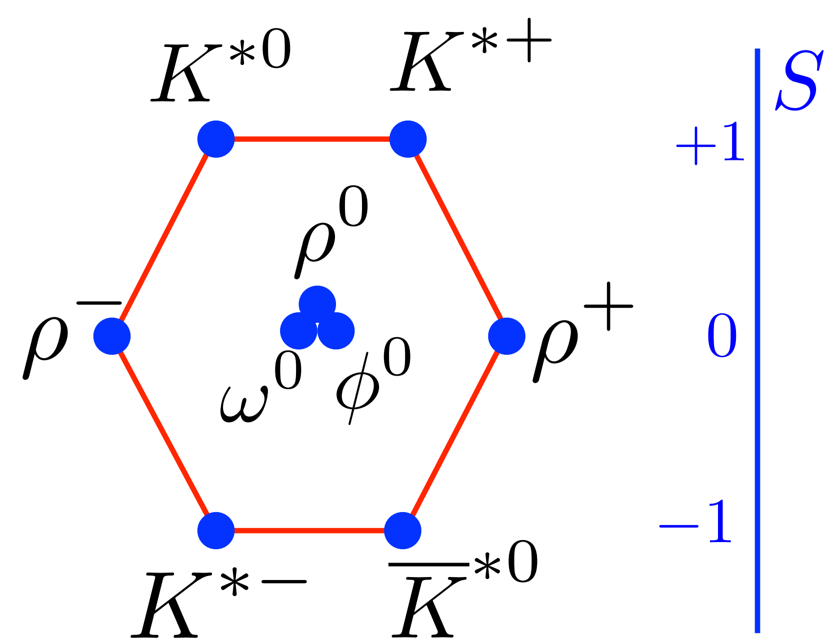
Mass $m = 1019.455 \pm 0.020$ MeV (S = 1.1)
Full width $\Gamma = 4.26 \pm 0.04$ MeV (S = 1.4)

$\phi(1020)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
K^+K^-	(48.9 ± 0.5) %	S=1.1	127
$K^0_L K^0_S$	(34.2 ± 0.4) %	S=1.1	110

$P = (-1)^J$
: natural parity

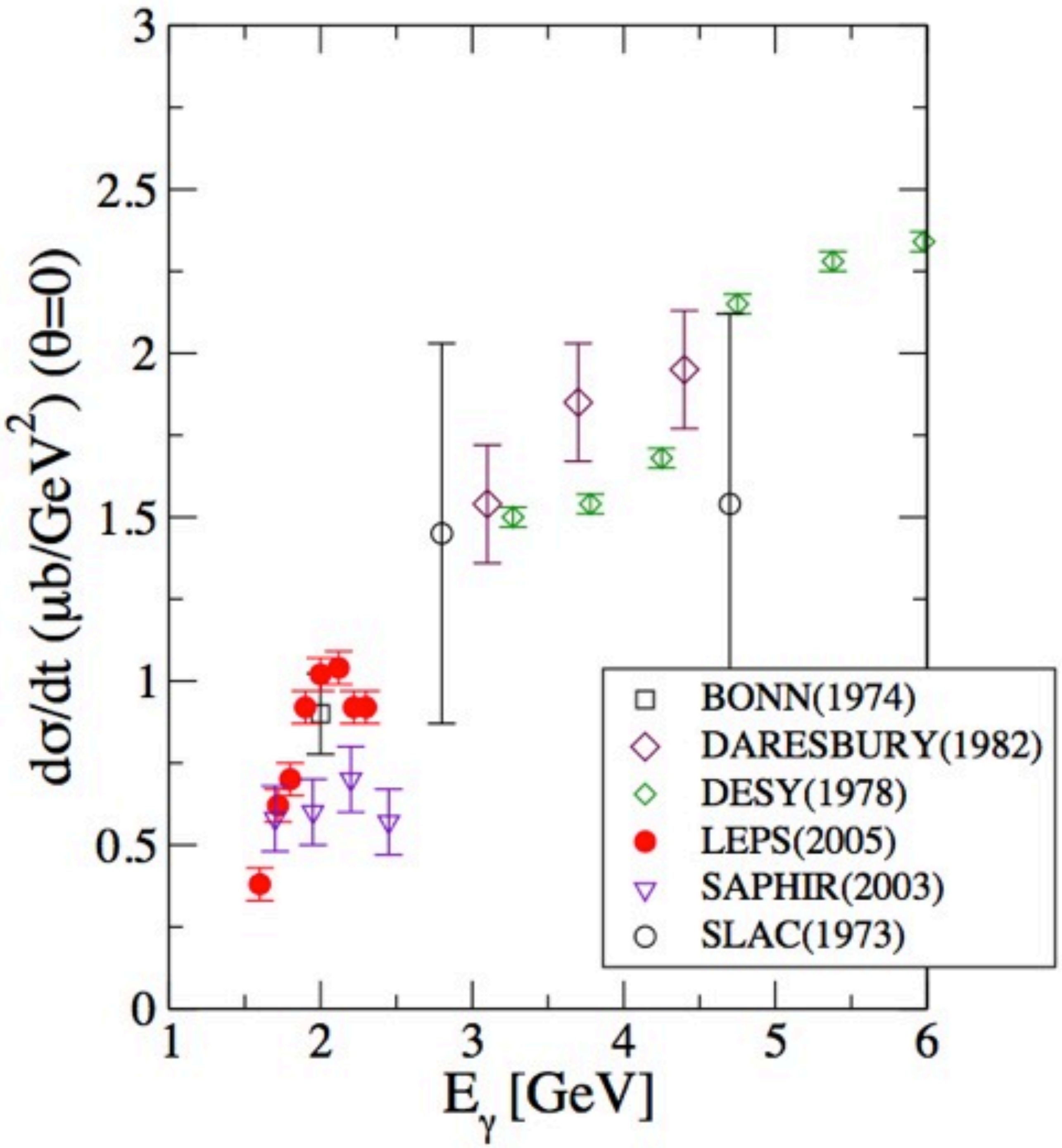
$P = (-1)^{J+1}$
: unnatural parity

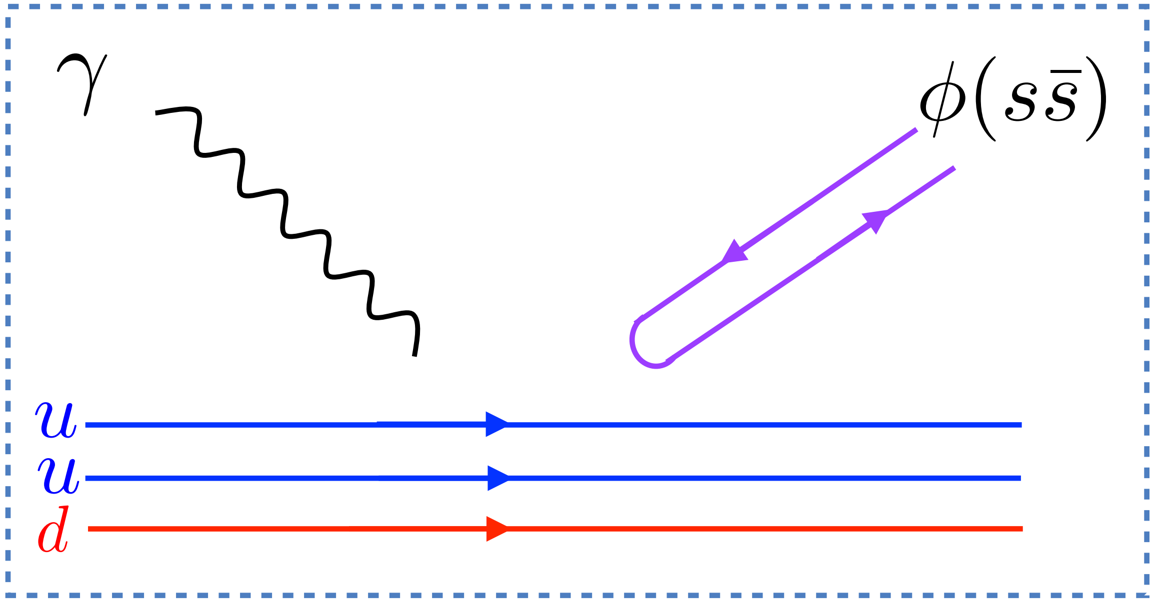
$$^{2S+1}L_J = {}^3S_1$$



$$\phi^0 = s\bar{s}$$

Phi meson photoproduction



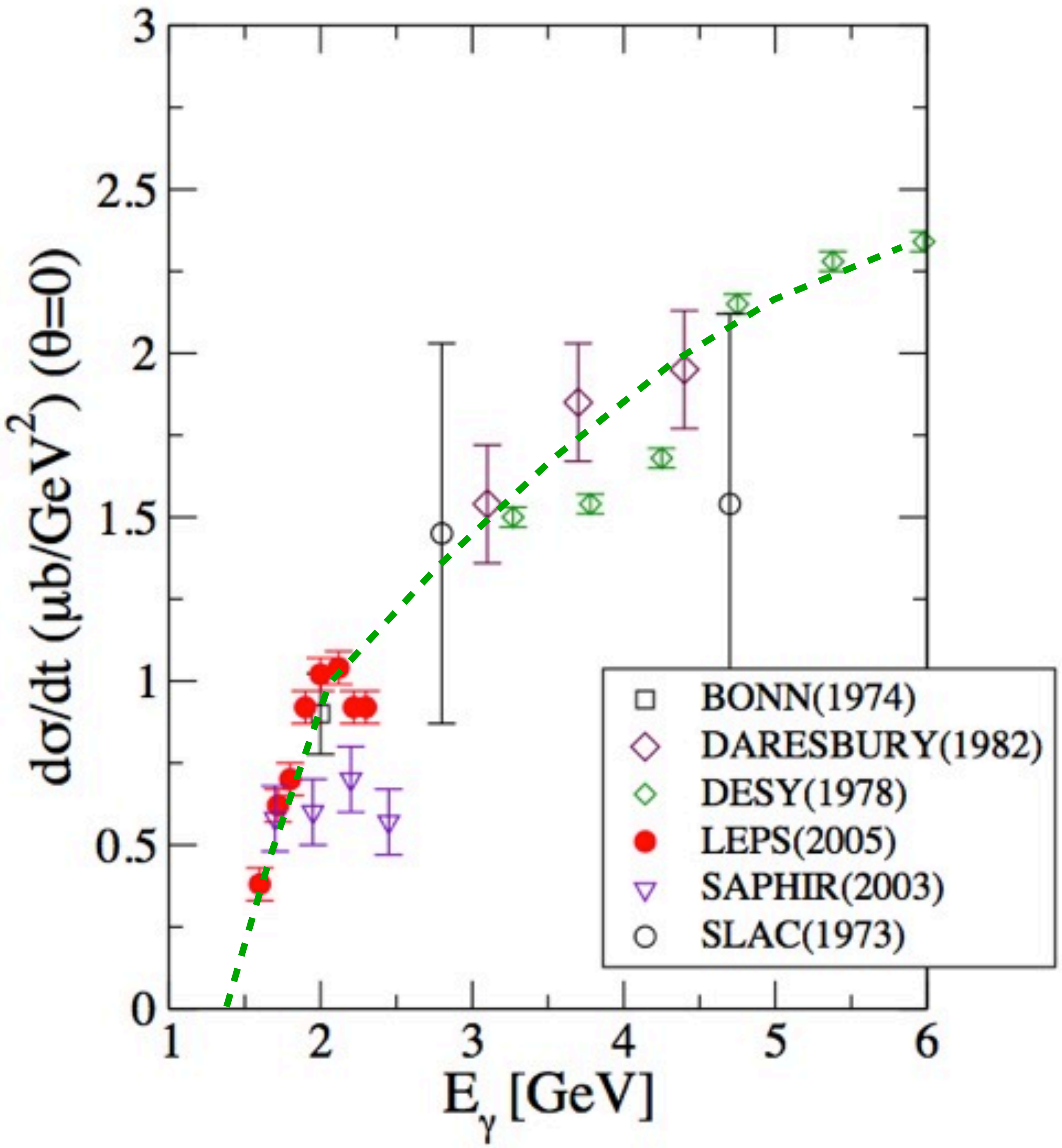


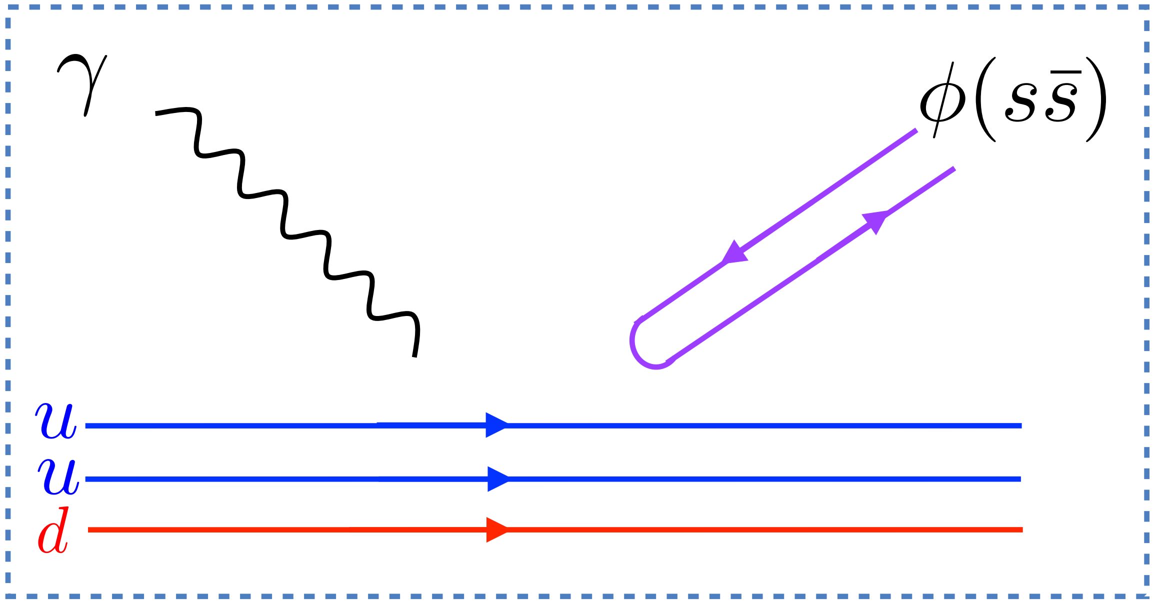
- OZI rule violation

- Gluonic dynamics (Pomeron)

- Hidden strangeness

Phi meson photoproduction





- OZI rule violation

- Gluonic dynamics (Pomeron)

- Hidden strangeness

Effective Lagrangian method

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

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

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

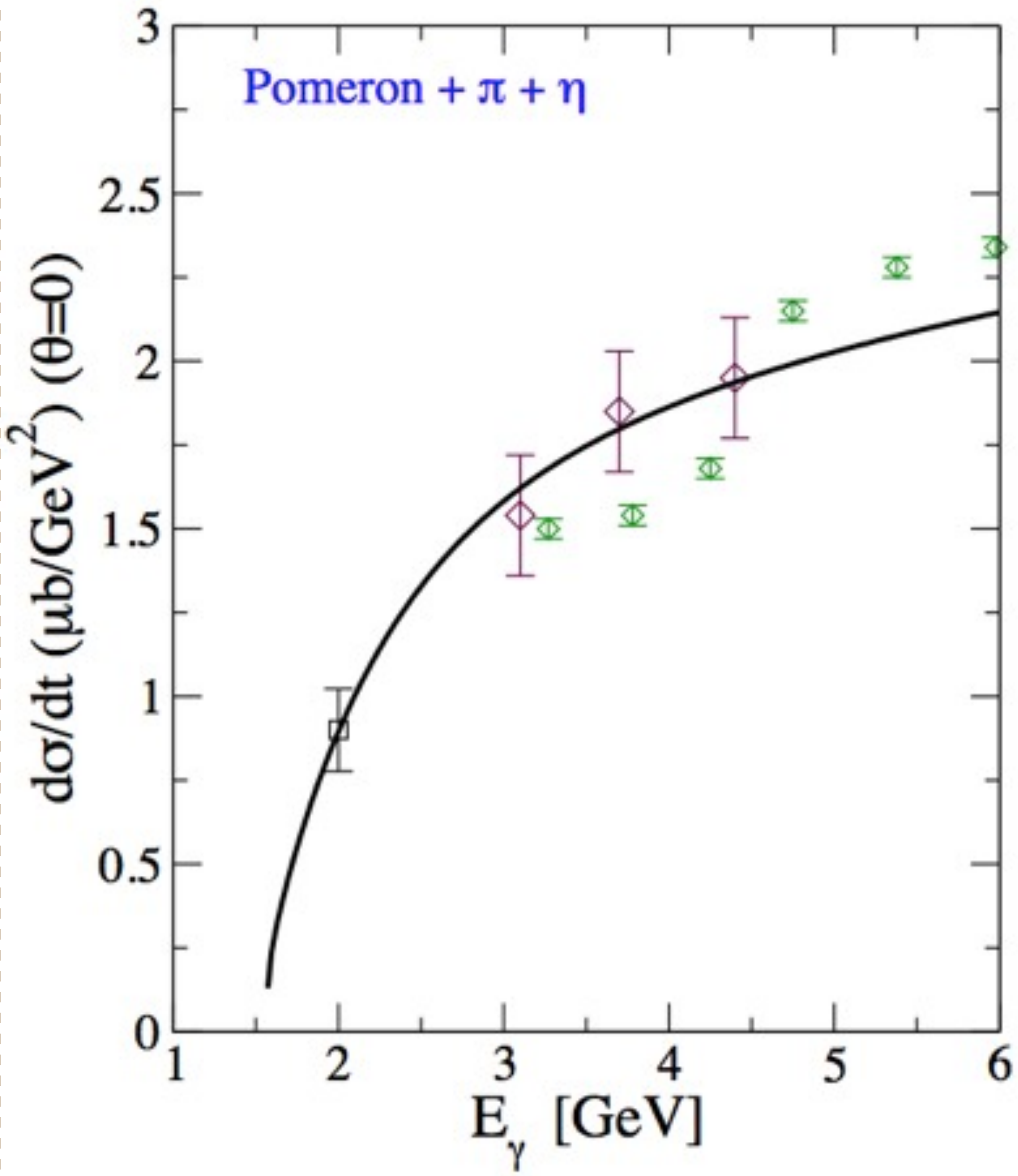
$$\exp[iZ] = \int \mathcal{D}q\ \mathcal{D}\bar{q}\ \mathcal{D}A\ \exp\left[i\int dx^4\ \mathcal{L}_{QCD}\right] = \int \mathcal{D}U\ \exp\left[i\int dx^4\ \mathcal{L}_{eff}\right]$$

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

II. Phi meson photoproduction

Previous works relevant to the present work

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 $\Lambda(1520)$
W. C. Chang *et al*	2010	Measurement of spin-density matrix elements for ϕ-meson photoproduction from protons and deuterons near threshold
A. Kiswandhi *et al*	2010	Is the nonmonotonic behavior in the cross section of ϕ photoproduction near threshold a signature of a resonance ?
H. Y. Ryu *et al*	2012	ϕ photoproduction with couple-channel effects



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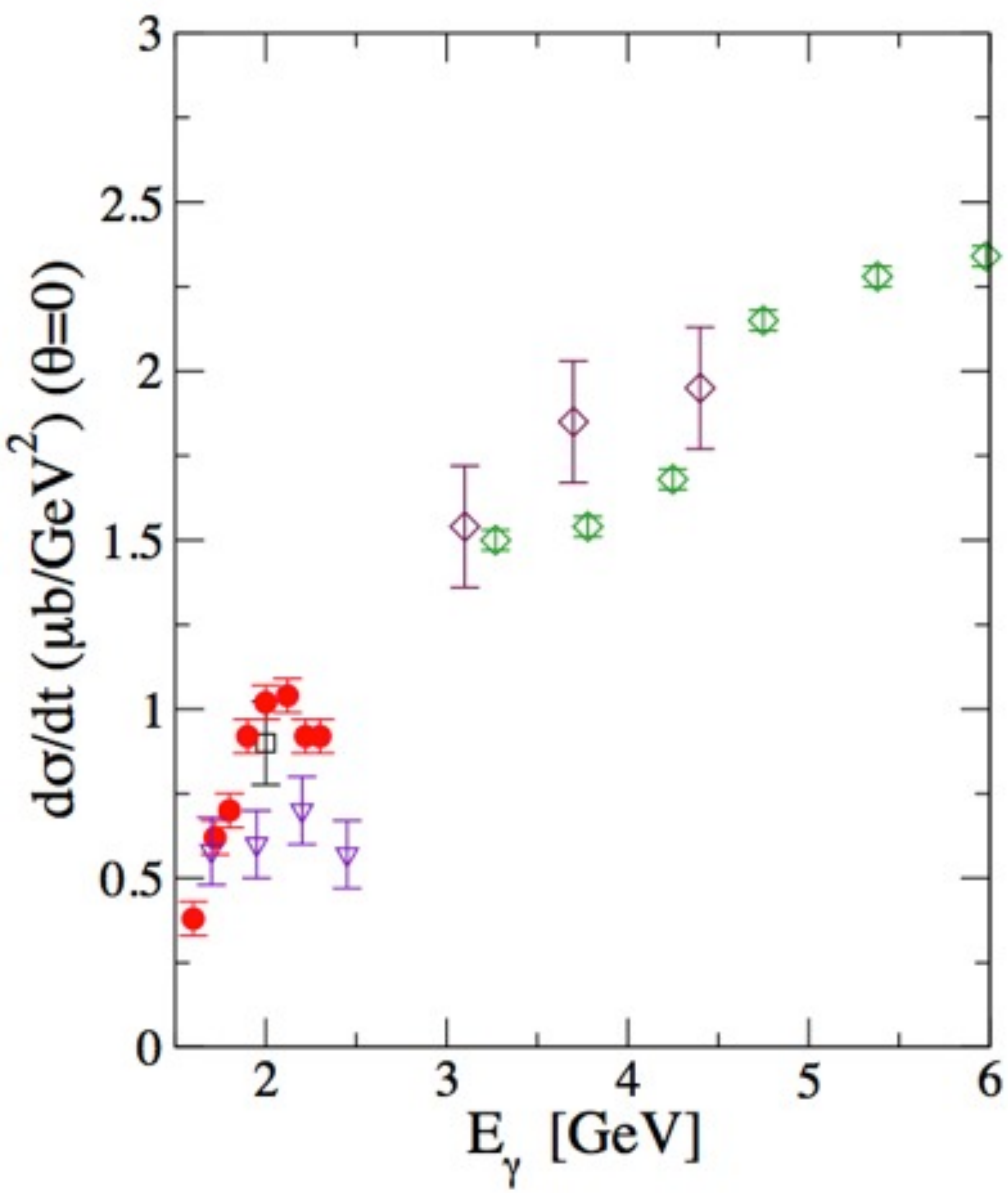

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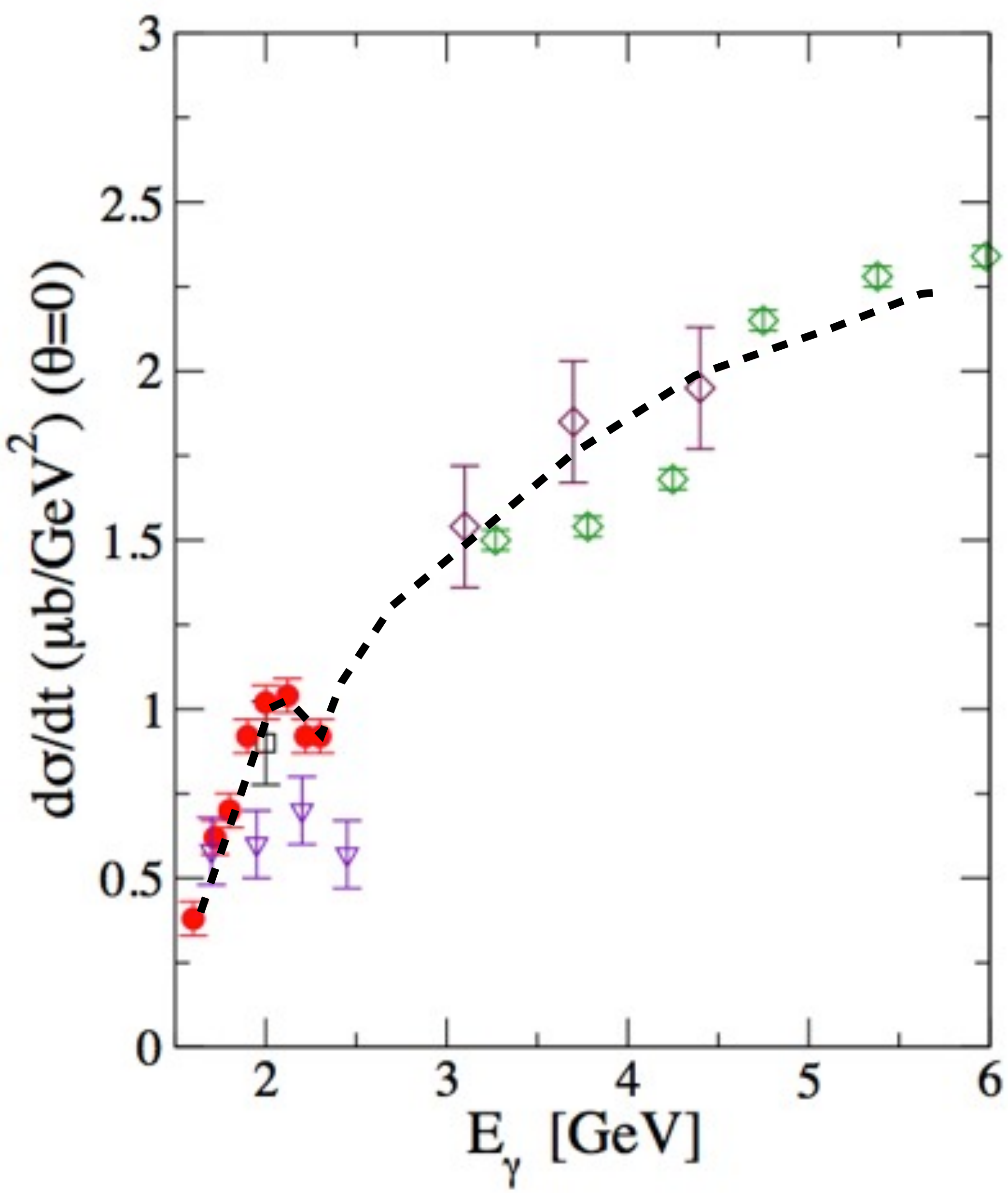

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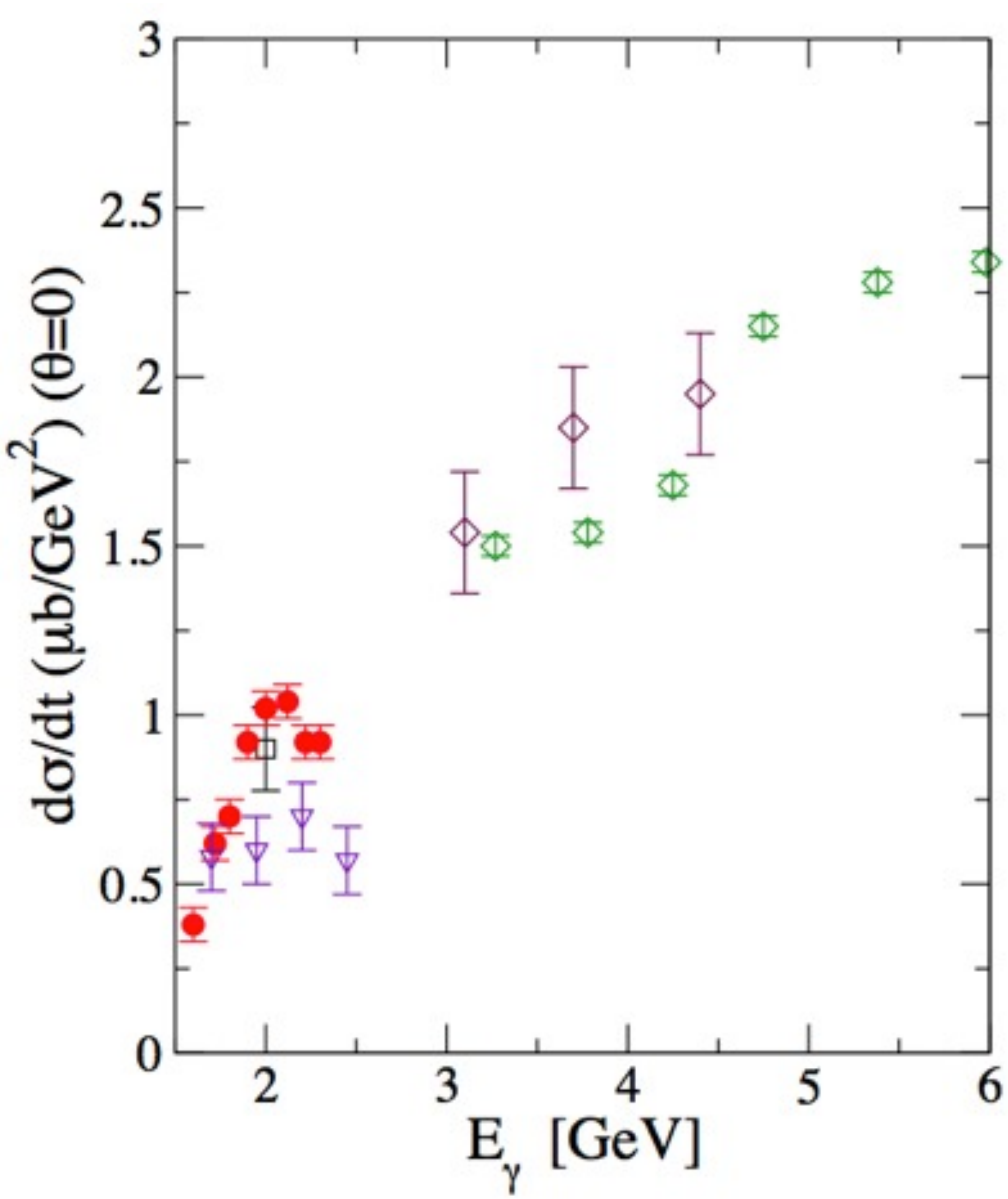

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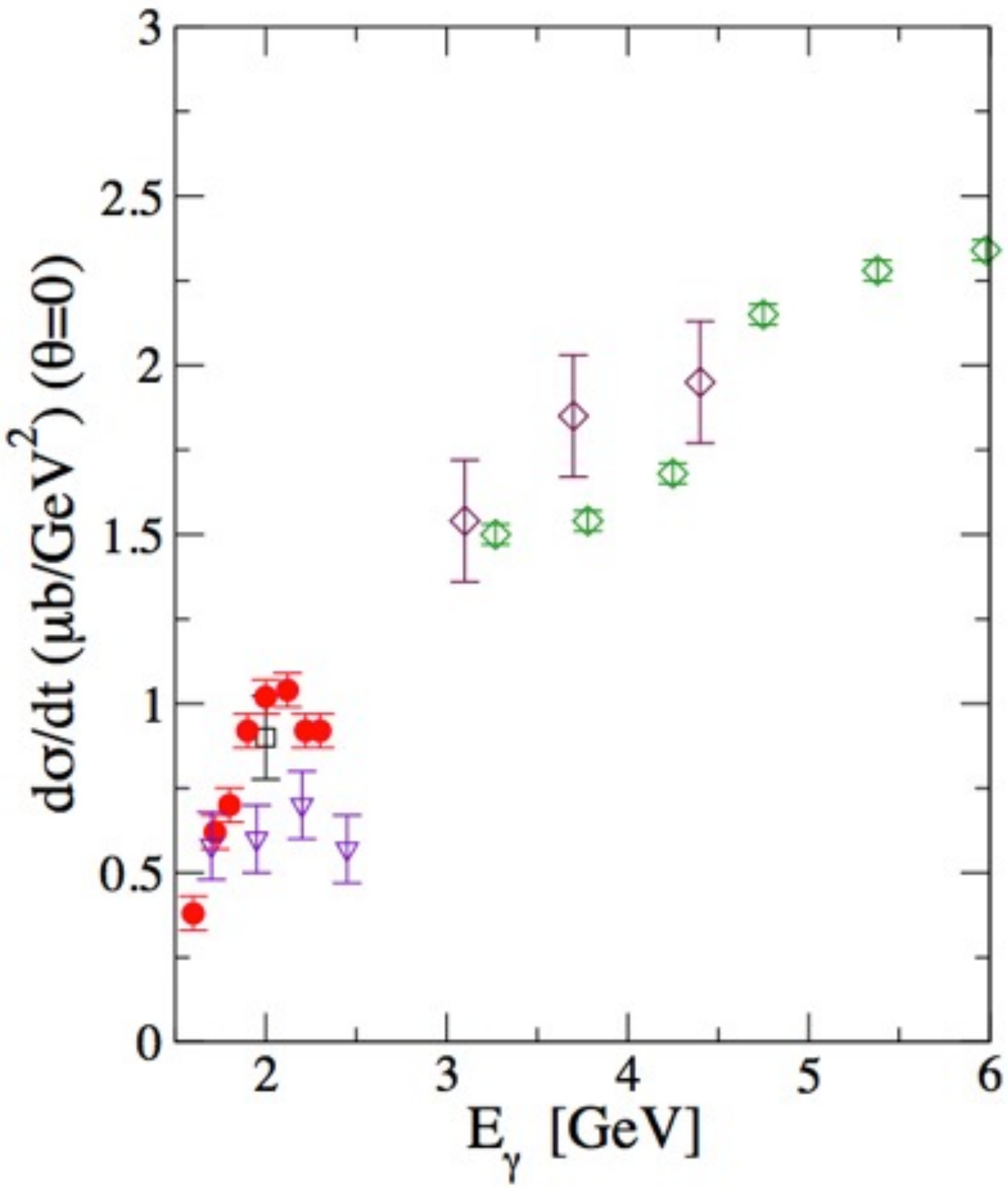
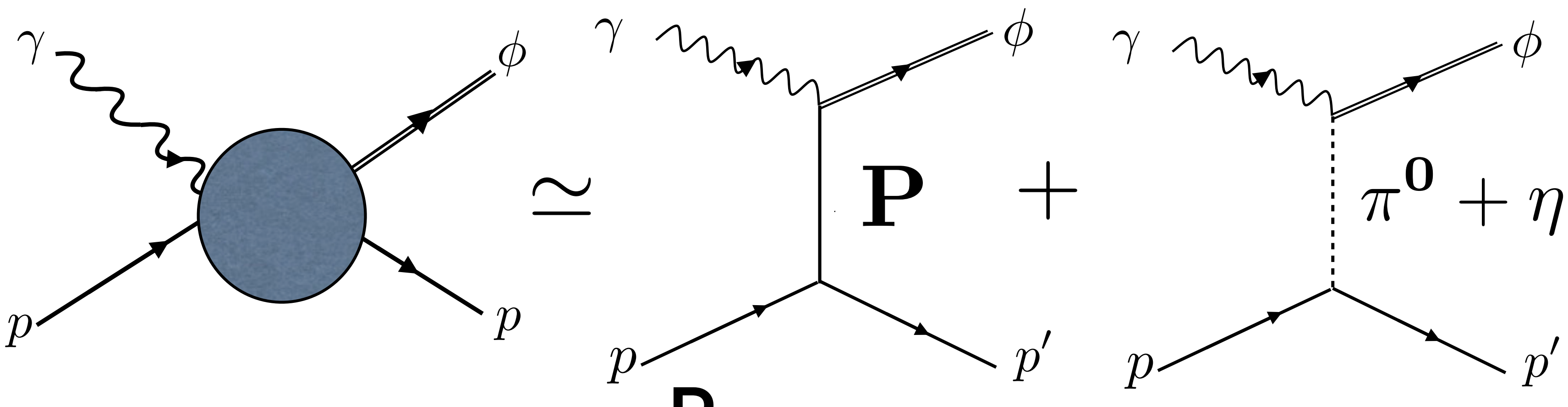


Mechanism for phi photoproduction

Conventional approach

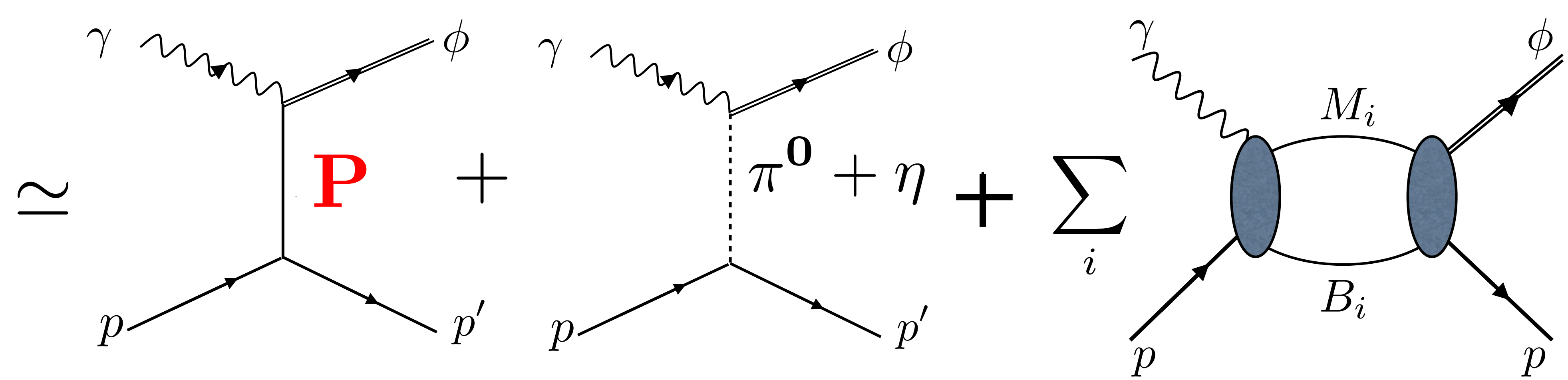
A. I. Titov et al. phys. rev. 60, 035205 (1999)



Pomeron

t-channel
hadron exchange

This work



hadron rescatterings

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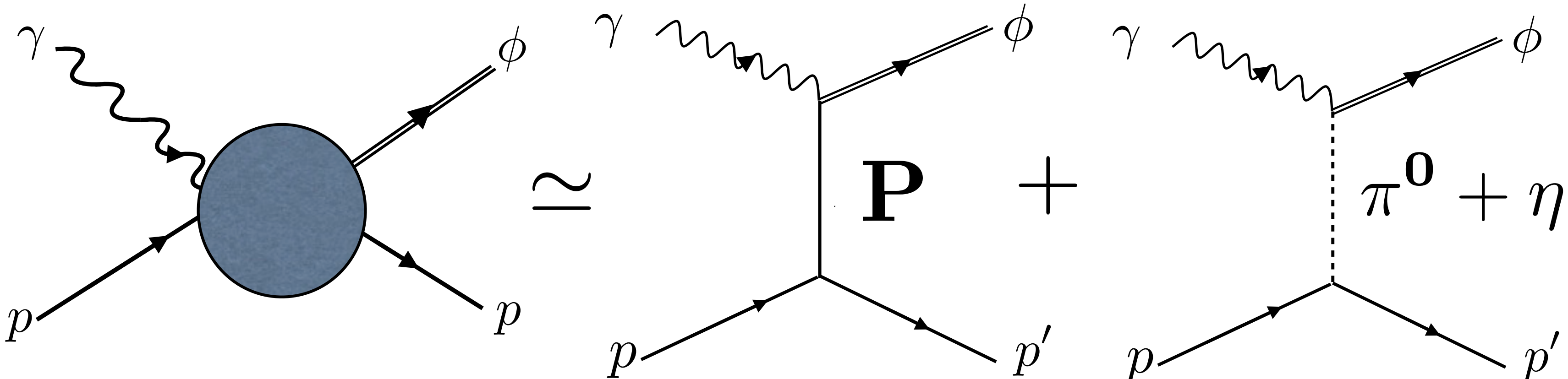

Pomeron

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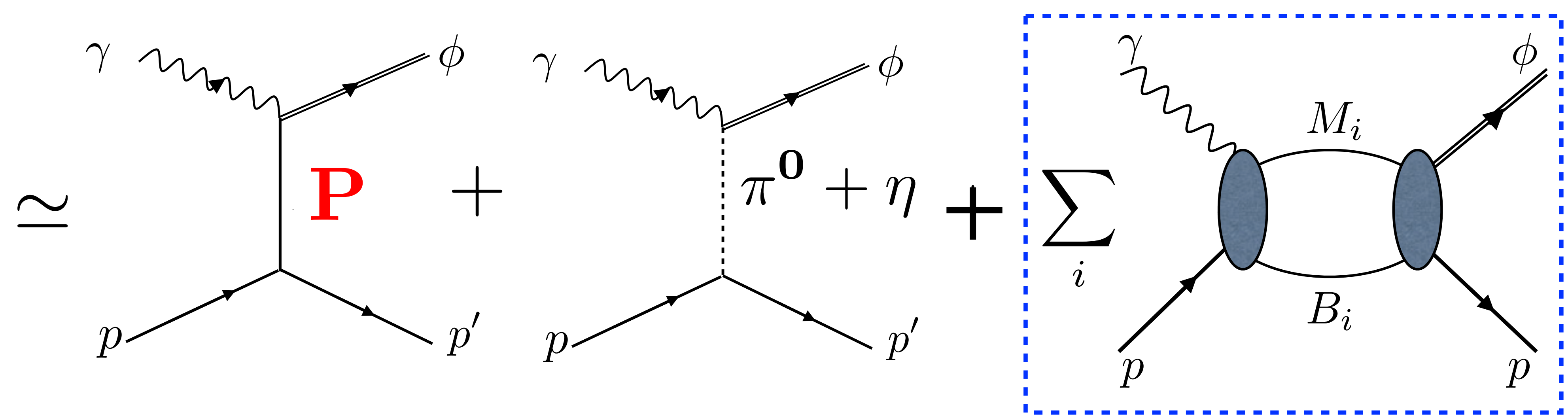
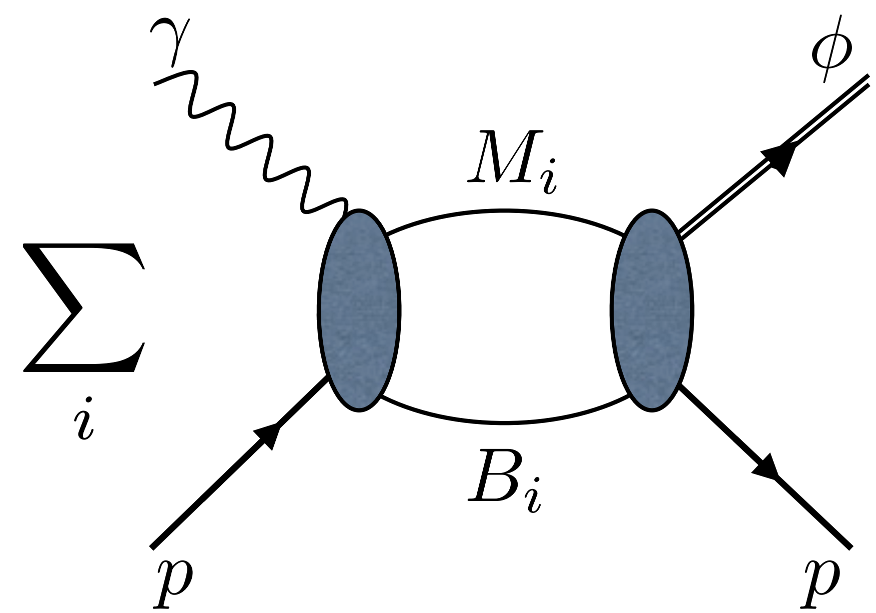


hadron rescatterings

Blankenbecler and Sugar Equation

R. Aaron, R. D. Amado and J. E. Young, phys. rev. 174, 5, 1968



$$T_{\gamma p\to\phi p} = V_{\gamma p\to\phi p} + \frac{1}{(2\pi)^3}\int \frac{dk^3}{2\omega_1\omega_2} T_{M_iB_i\to\phi p}\frac{(\omega_1+\omega_2)}{(\omega_1+\omega_2)^2 - s + i\epsilon} T_{\gamma p\to M_iB_i}$$

M	ρ	ω	σ	π	K	K^*	K
B	p	p	p	p	$\Lambda(1116)$	$\Lambda(1116)$	$\Lambda(1520)$

$$T_{\gamma p \to \phi p} = V_{\gamma p \to \phi p} + \frac{1}{(2\pi)^3} \int \frac{dk^3}{2\omega_1 \omega_2} T_{M_i B_i \to \phi p} \frac{(\omega_1 + \omega_2)}{(\omega_1 + \omega_2)^2 - s + i\epsilon} T_{\gamma p \to M_i B_i}$$

$$T_{\gamma p \to \phi p} = V_{\gamma p \to \phi p} + \frac{1}{(2\pi)^3} \int \frac{dk^3}{2\omega_1 \omega_2} T_{M_i B_i \to \phi p} \frac{(\omega_1 + \omega_2)}{(\omega_1 + \omega_2)^2 - s + i\epsilon} T_{\gamma p \to M_i B_i}$$

$$\frac{1}{(\omega_1 + \omega_2)^2 - s + i\epsilon} = \mathrm{P} \frac{1}{(\omega_1 + \omega_2)^2 - s} - i\pi\delta\left[(\omega_1 + \omega_2)^2 - s\right]$$

$$T_{\gamma p\to\phi p} = V_{\gamma p\to\phi p} + \frac{1}{(2\pi)^3}\int \frac{dk^3}{2\omega_1\omega_2} T_{M_iB_i\to\phi p}\frac{(\omega_1+\omega_2)}{(\omega_1+\omega_2)^2 - s + i\epsilon} T_{\gamma p\to M_iB_i}$$

$$\frac{1}{(\omega_1+\omega_2)^2 - s + i\epsilon} = \mathrm{P}\frac{1}{(\omega_1+\omega_2)^2 - s} - i\pi\delta\Big[(\omega_1+\omega_2)^2 - s\Big]$$

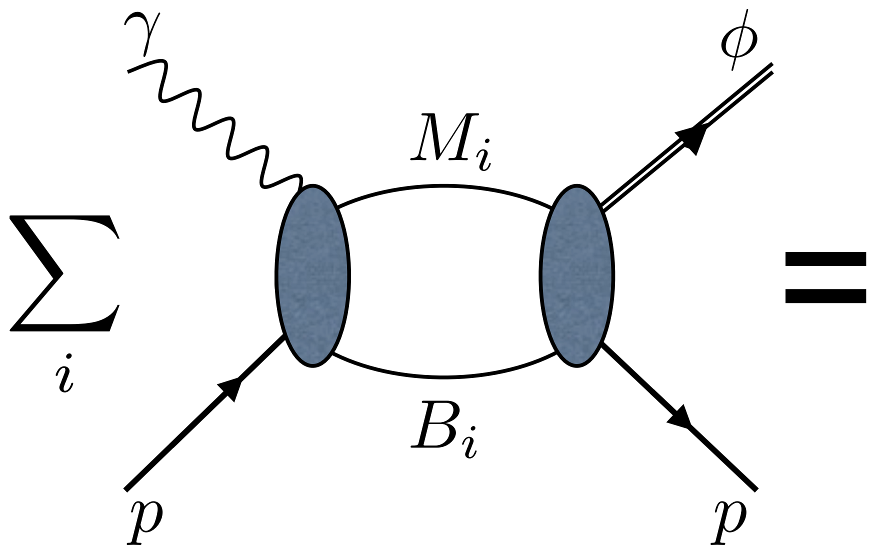
$$\mathrm{Im}\ T_{\gamma p\to\phi p} = -\frac{h}{32\pi^2\sqrt{s}}\int d\Omega\ T_{M_iB_i\to\phi p}T_{\gamma p\to M_iB_i}$$

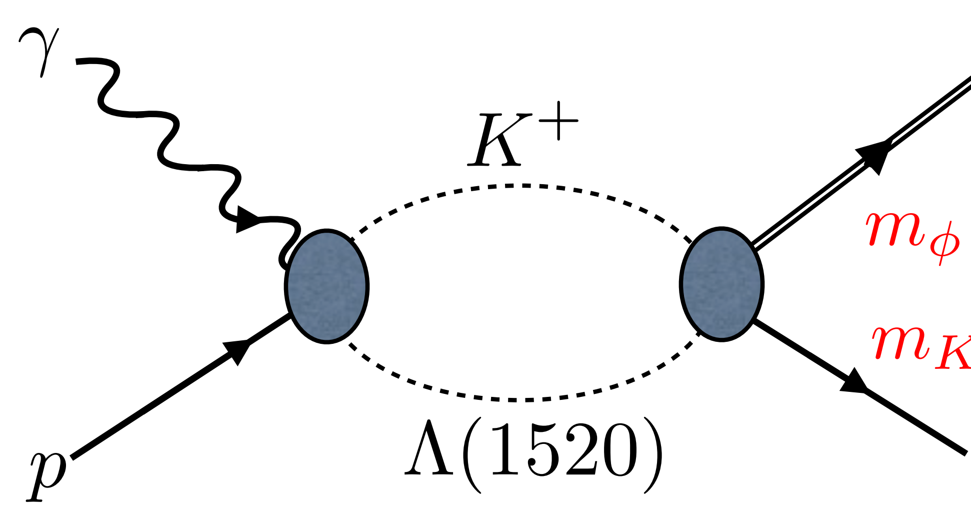
$$\omega_1(h) + \omega_2(h) - \sqrt{s} = 0\ ,$$

$$\omega_1(k) = \sqrt{M_{M_i}^2 + k^2}$$

$$\omega_2(k) = \sqrt{M_{B_i}^2 + k^2}$$

Detail of contents of hadronic rescattering



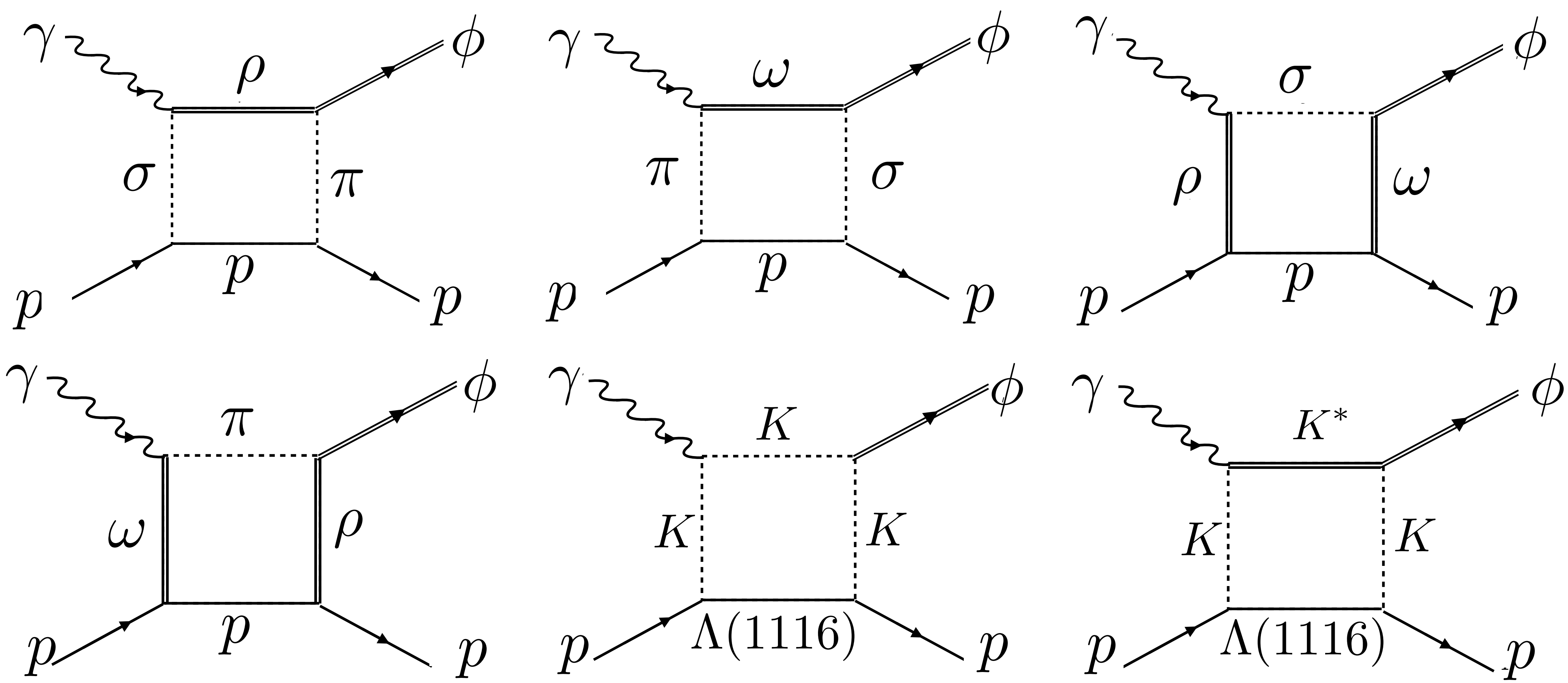


$m_\phi + m_p \simeq 1953$ MeV

$m_K + m_\Lambda \simeq 2013$ MeV

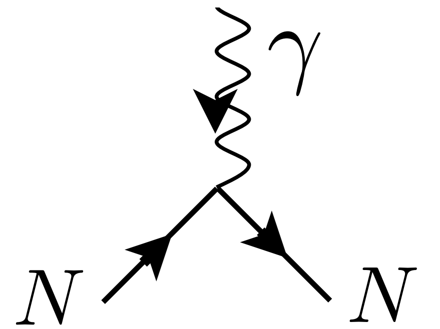
Most important term

\+

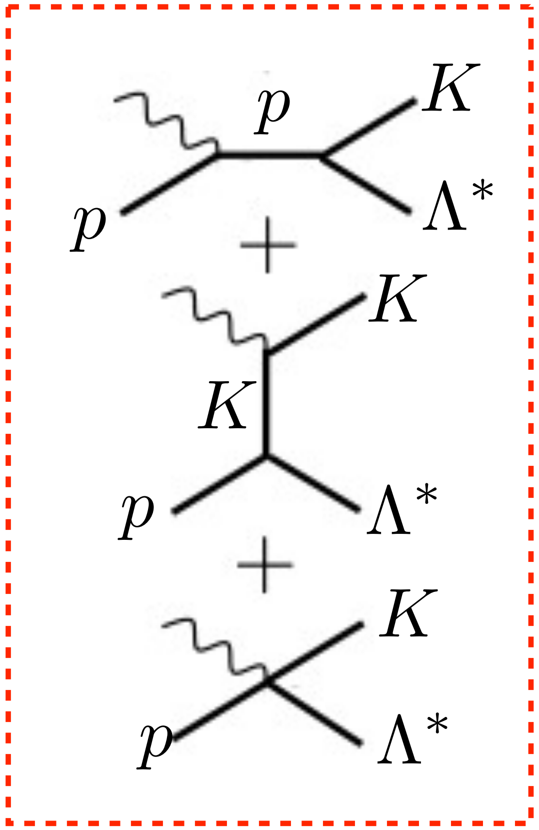


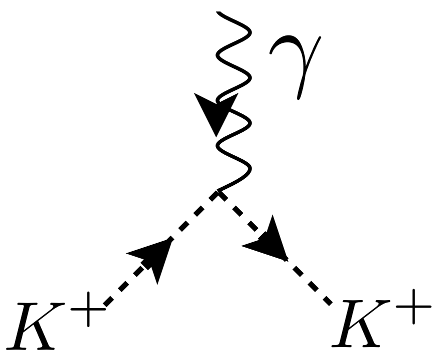
Effective Lagrangian

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

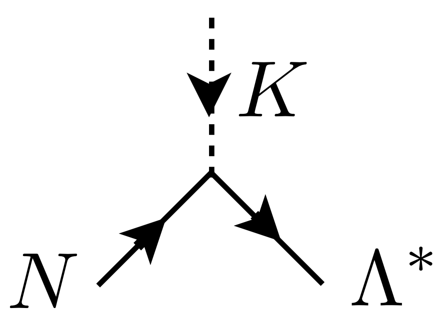


$$\mathcal{L}_{\gamma NN} = -e\overline{N}\left[\gamma^\mu - \frac{\kappa_N}{2M_N}\sigma_{\mu\nu}\partial_\nu\right]A_\mu N$$



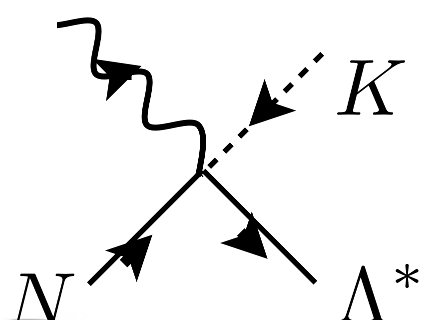


$$\mathcal{L}_{\gamma KK} = ie(\partial_\mu K^+ K^- - \partial_\mu K^- K^+)A^\mu$$



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

$$\partial_\mu \to \partial_\mu - ieA_\mu$$



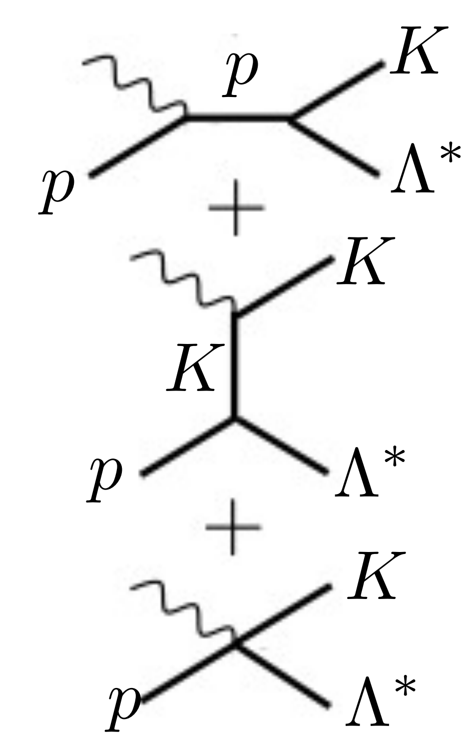
$$\mathcal{L}_{\gamma KN\Lambda^*} = -i\frac{eg_{KN\Lambda^*}}{m_K}\overline{N}\gamma_5 A_\mu K^+\Lambda^{*\mu}$$

Invariant amplitude

$$\mathcal{M}_{L,s} = \frac{e g_{KN\Lambda^*}}{M_K}\bar{u}^\mu k_{2\mu}\gamma_5 \frac{\not{k}_1 + \not{q} + M_N}{q^2 - M_N^2}\not{\epsilon}_\gamma u(p_1) + \frac{e\kappa_p g_{KN\Lambda^*}}{2M_N M_K}\bar{u}^\mu k_{2\mu}\gamma_5 \frac{\not{q} + M_N}{q^2 - M_p^2}\not{\epsilon}_\gamma \not{k}_1 u(p_1),$$

$$\mathcal{M}_{L,t} = -\frac{2e g_{KN\Lambda^*}}{M_K}\bar{u}^\mu \gamma_5 u(p_1)\frac{q_K^\mu}{t_K - M_K^2},$$

$$\mathcal{M}_{L,c} = \frac{e g_{KN\Lambda^*}}{M_K}\bar{u}^\mu \epsilon_\mu \gamma_5 u(p_1),$$

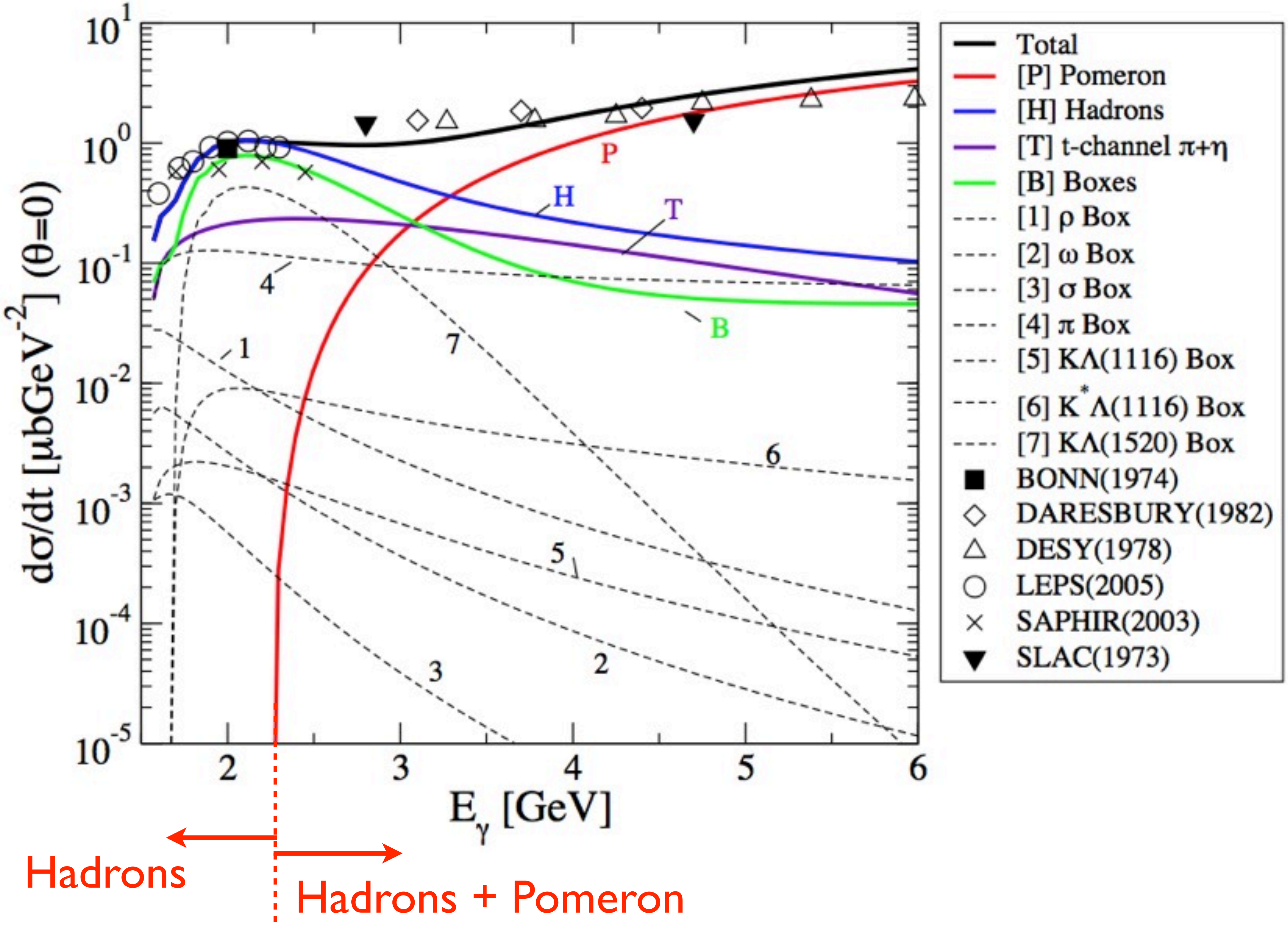


$$\mathcal{M}_L(\gamma p \to K^+\Lambda^*) = (\mathcal{M}_{L,s} + \mathcal{M}_{L,t} + \mathcal{M}_{L,c})F_L(s,t),$$
$$\mathcal{M}_R(K^+\Lambda^* \to \phi p) = (\mathcal{M}_{R,s} + \mathcal{M}_{R,t} + \mathcal{M}_{R,c})F_R(s,t),$$

$$F_R(s,t) = \left[\frac{n_1\Lambda_1^4}{n_1\Lambda_1^4 + (s - M_p^2)^2}\right]^{n_1}\left[\frac{n_2\Lambda_2^4}{n_2\Lambda_2^4 + t^2}\right]^{n_2}$$
$$F_L(s,t) = \left[\frac{n_3\Lambda_3^4}{n_3\Lambda_3^4 + (s - M_p^2)^2}\right]^{n_3}\left[\frac{n_4\Lambda_4^4}{n_4\Lambda_4^4 + t^2}\right]^{n_4}$$

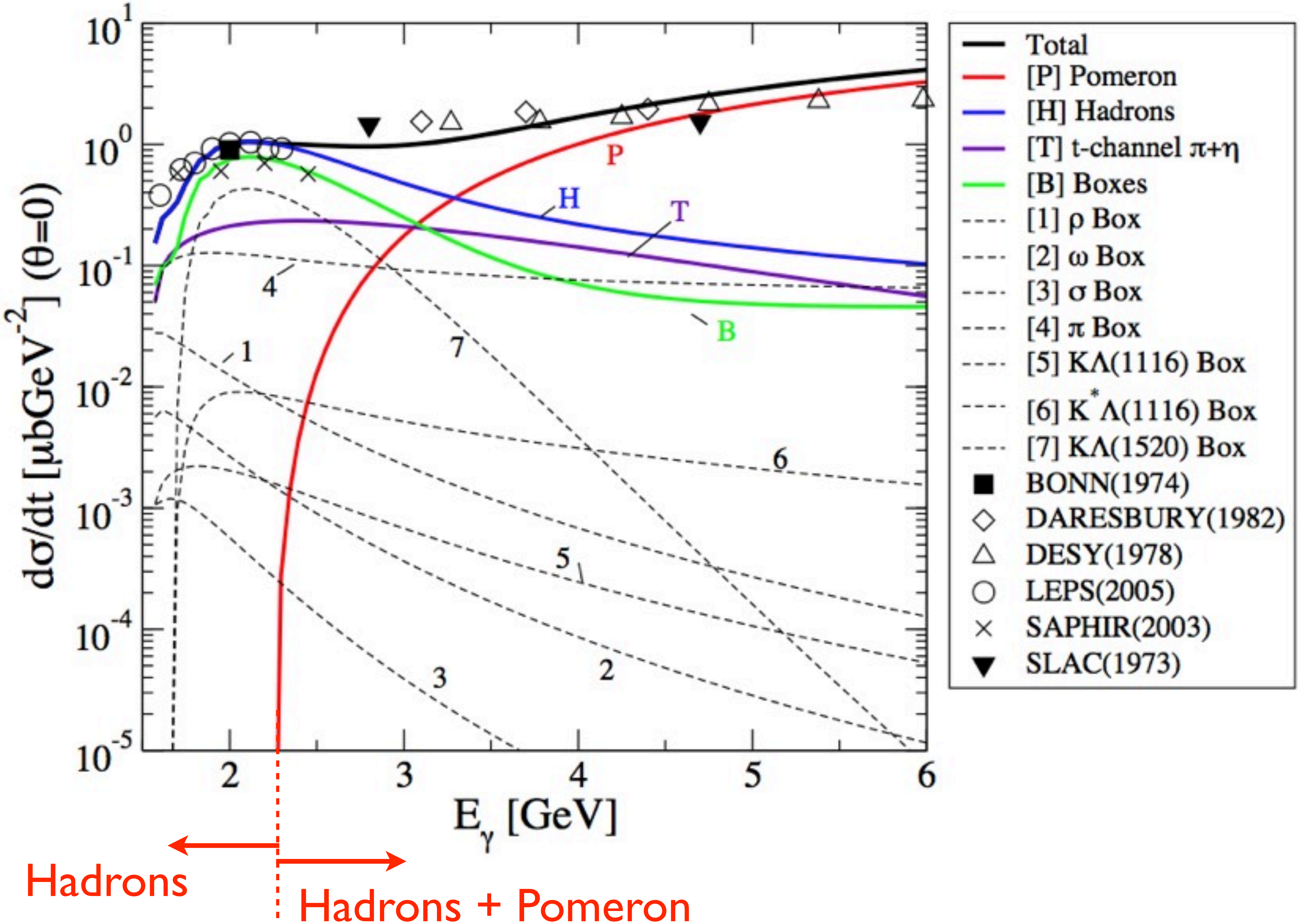
n_1	1
n_2	1
n_3	2
n_4	1
Λ_1	0.8 GeV
Λ_2	0.8 GeV
Λ_3	1.0 GeV
Λ_4	1.0 GeV

III. Numerical Result



III. Numerical Result

$$M(s,t) = C_p F_N(t) F_\phi(t) \frac{1}{s}\left(\frac{s-s_{\rm th}}{4}\right)^{\alpha_p(t)} \exp\left(-\frac{i\pi}{2}\alpha_p(t)\right)$$



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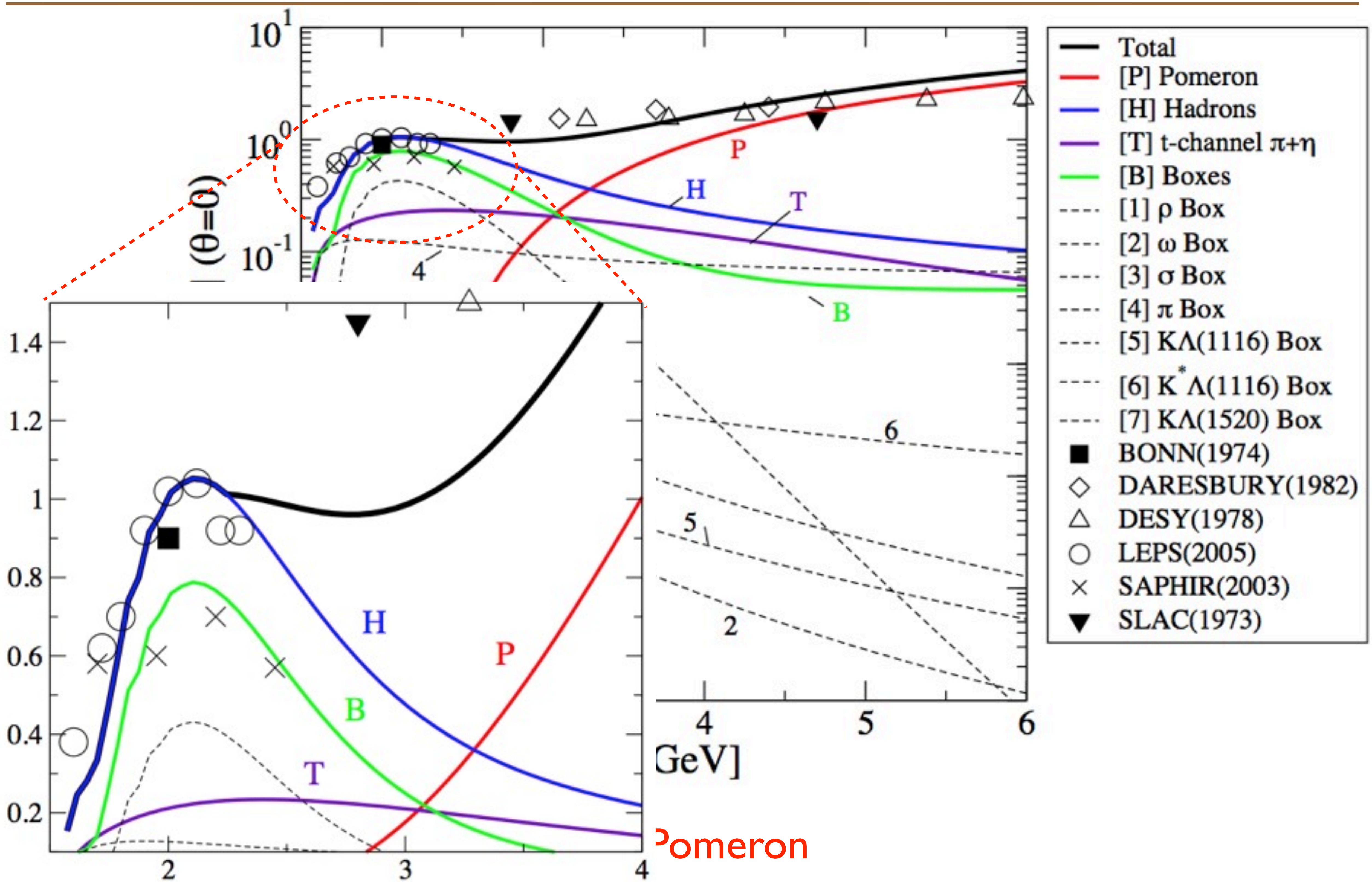
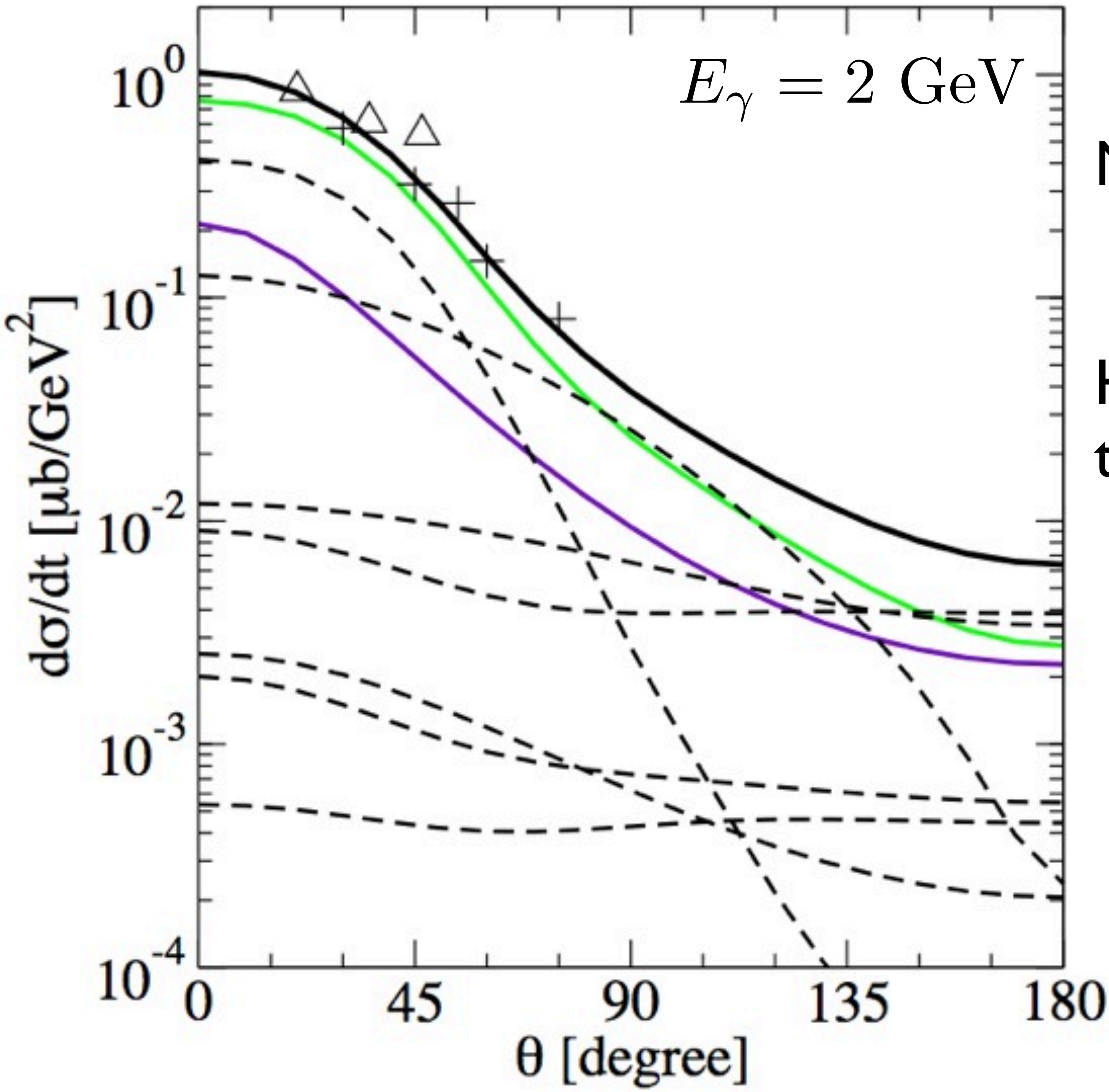


13년 7월 16일 화요일

Angular distribution



No Pomeron contribution.

Hadronic process can explain the angular distribution.

Spin density matrix and Decay angular distribution

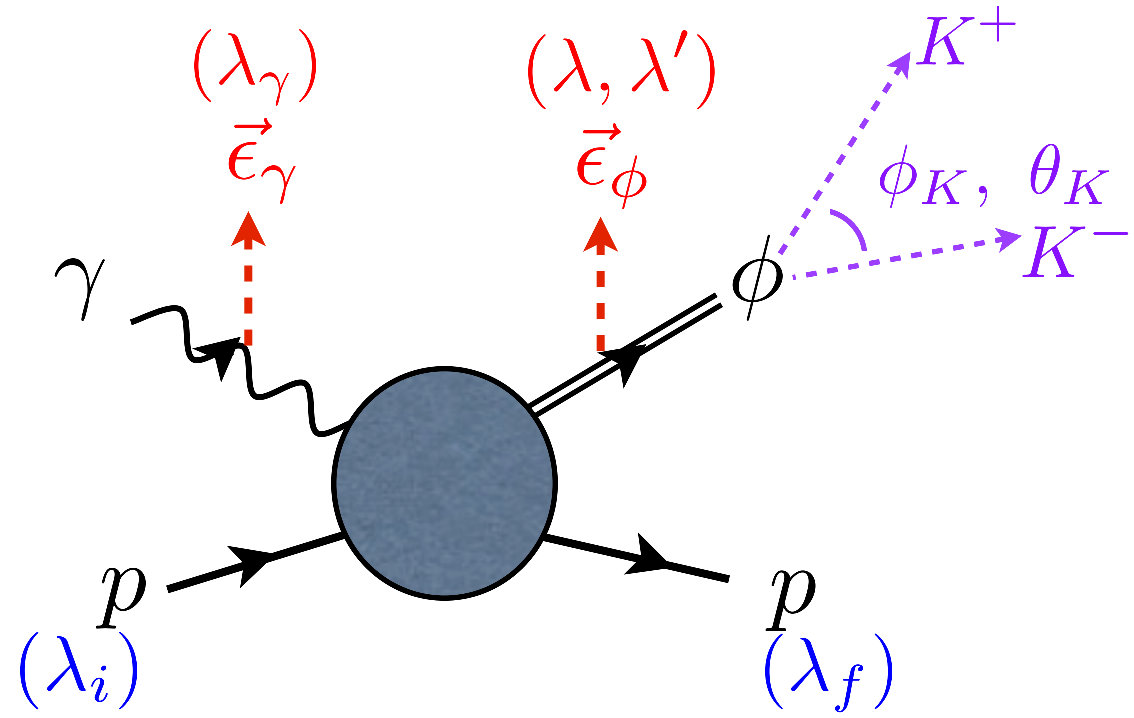
$$\rho^0_{\lambda\lambda'} = \frac{1}{N}\sum_{\lambda_\gamma,\lambda_i,\lambda_f} T_{\lambda_f,\lambda;\lambda_i,\lambda_\gamma} T^*_{\lambda_f,\lambda';\lambda_i,\lambda_\gamma}$$

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

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

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

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



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

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

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

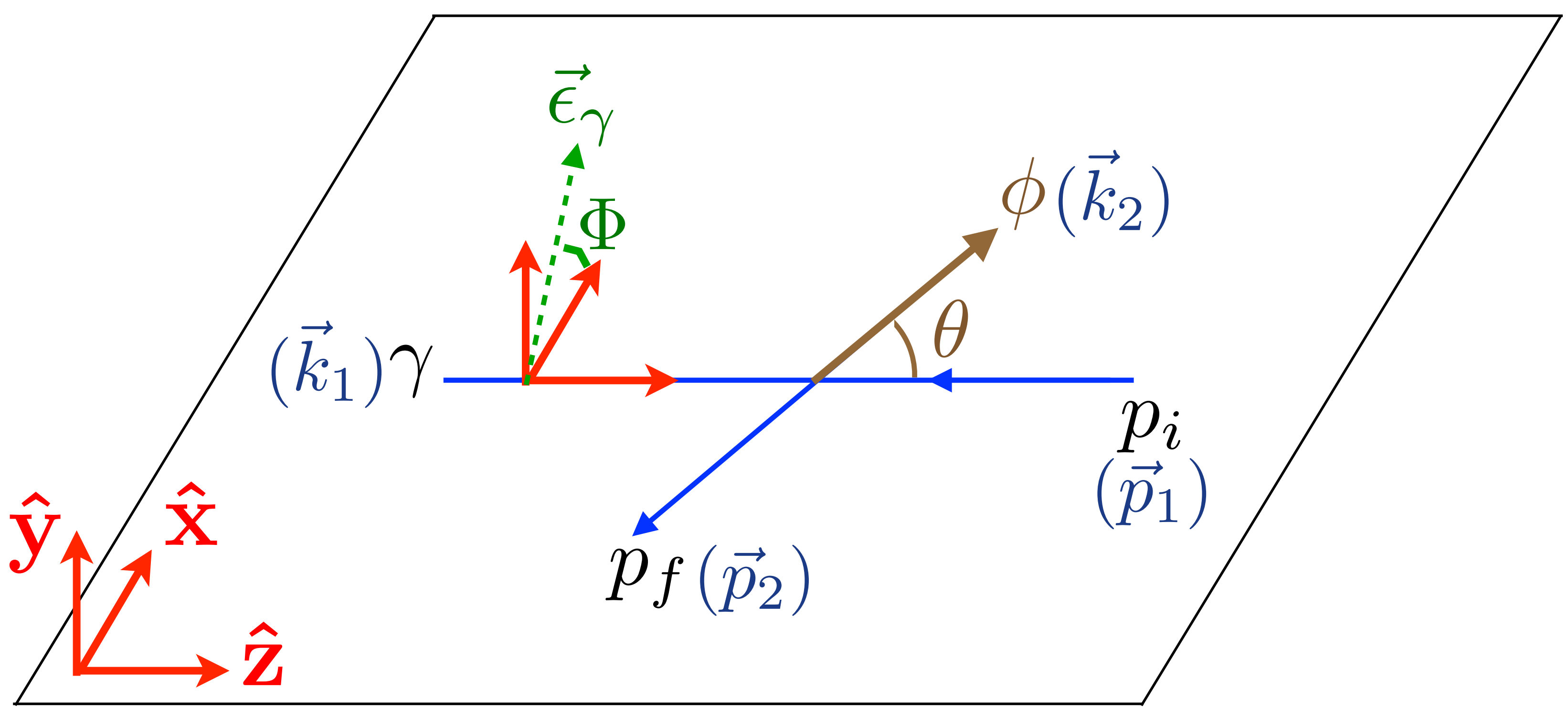
$$\bar{\rho}^1_{1-1} = \frac{1}{2}(\rho^1_{1-1} - \mathrm{Im}\rho^2_{1-1})$$

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

(p_γ : polarization strength $\simeq 0.95$)

Definition of angles

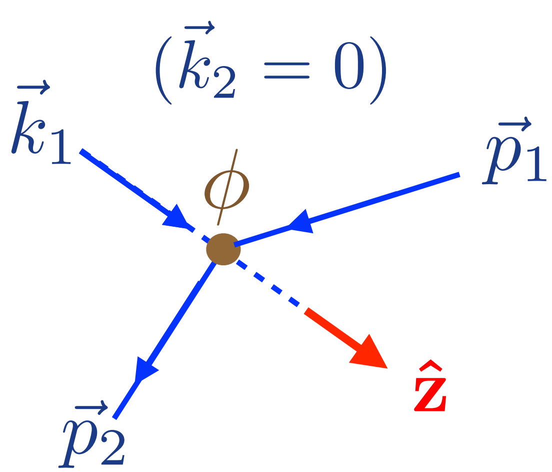
Φ: azimuthal angle for the reaction plane

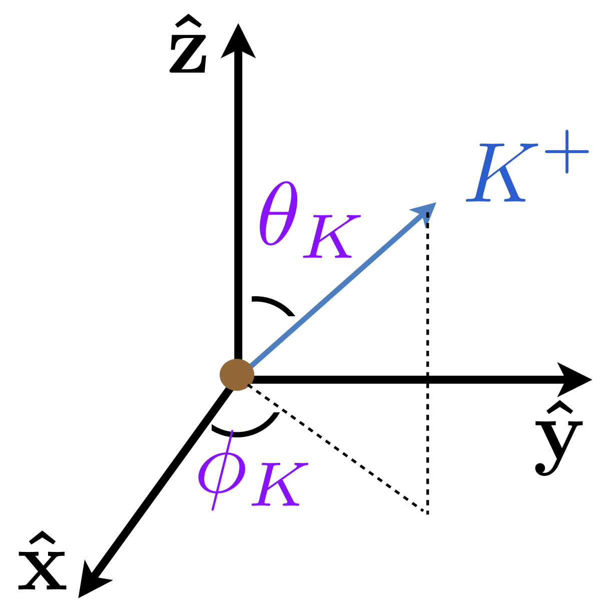


C.M. system

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

Rotation
Boost





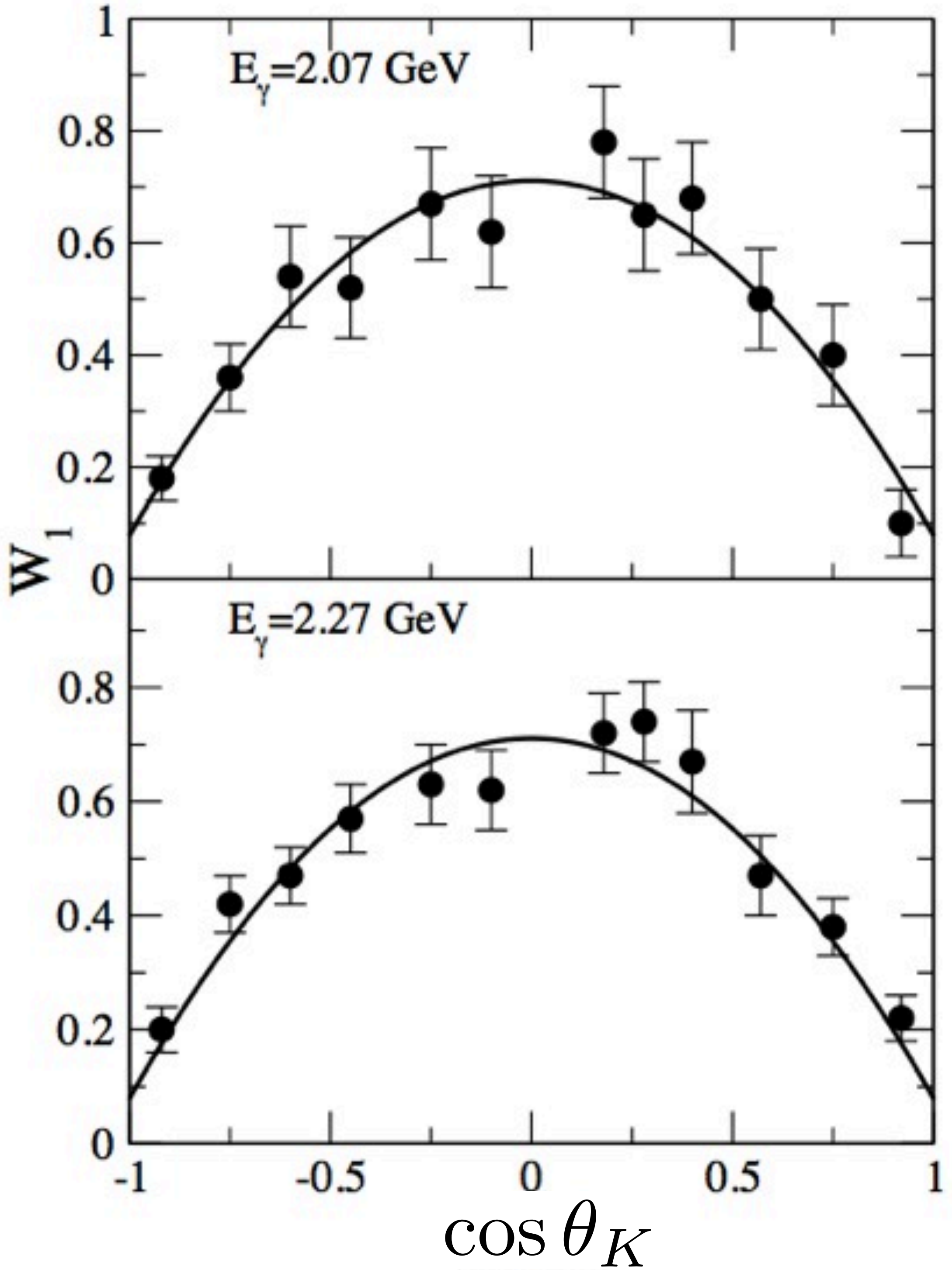
G.J. system

$$\vec{k}_2 = 0$$

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

13년 7월 16일 화요일

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



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

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

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

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

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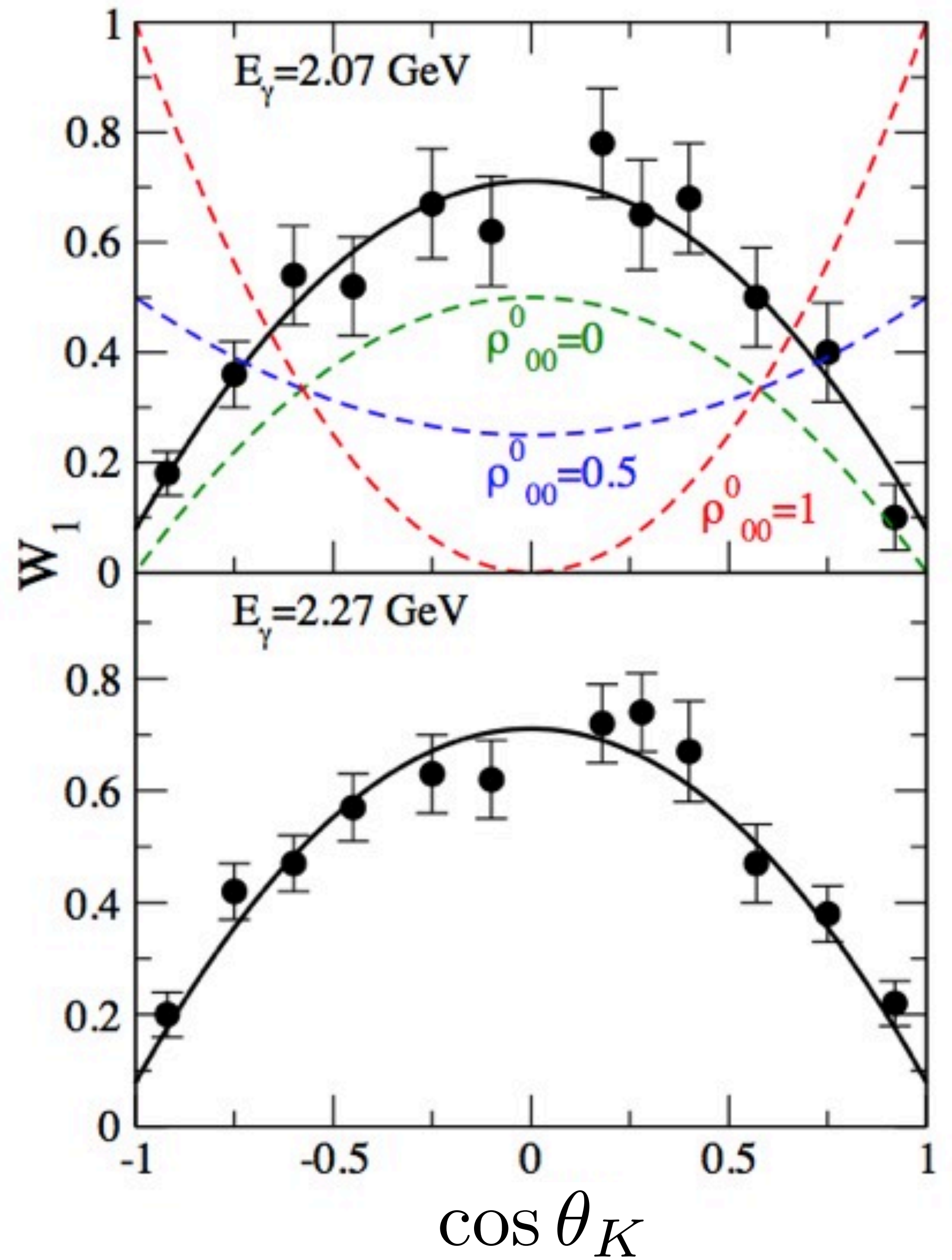
$$\rho^0_{00} = \frac{|T_{0,-1}|^2 + |T_{0,1}|^2}{|T_{-1,-1}|^2 + |T_{-1,1}|^2 + |T_{0,-1}|^2 + |T_{0,1}|^2 + |T_{1,-1}|^2 + |T_{1,1}|^2} \qquad (T_{\lambda_\phi \lambda_\gamma})$$



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

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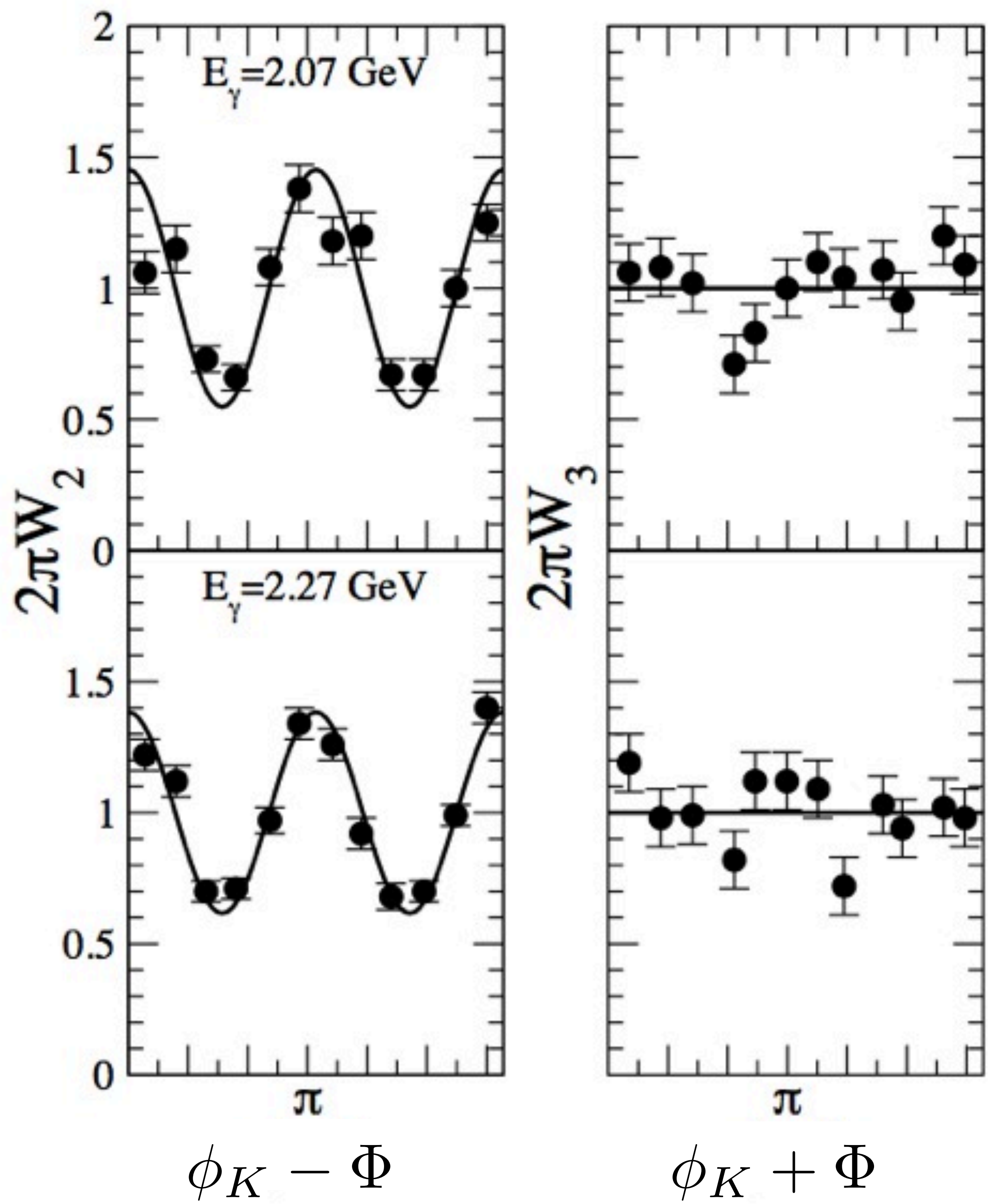


$$2\pi W_2(\phi_K - \Phi) = 1 + 2p_\gamma \bar{\rho}^1_{1-1} \cos 2(\phi_K - \Phi)$$
$$2\pi W_3(\phi_K + \Phi) = 1 + 2p_\gamma \Delta_{1-1} \cos 2(\phi_K + \Phi)$$

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

$$\rho^1_{1-1} = \frac{1}{N}\left[T_{11}T^*_{-1-1} + T_{1-1}T^*_{-11}\right]$$
$$\rho^2_{1-1} = \frac{i}{N}\left[-T_{11}T^*_{-1-1} + T_{1-1}T^*_{-11}\right]$$

$$T^{[N/U]}_{-\lambda-\lambda_\gamma} = \pm(-1)^{\lambda-\lambda_\gamma} T_{\lambda\lambda_\gamma} \text{ at high energy.}$$

$$\bar{\rho}^1_{1-1} = \frac{1}{N}|T_{11}|^2 \qquad \bar{\rho}^1_{1-1} = -\frac{1}{N}|T_{11}|^2$$

$$\Delta_{1-1} = \frac{1}{N}|T_{1-1}|^2 \qquad \Delta_{1-1} = -\frac{1}{N}|T_{1-1}|^2$$

(natural) (unnatural)

Real part calculation

$$\frac{1}{(2\pi)^3}\int \frac{dk^3}{2\omega_1\omega_2}\frac{(\omega_1+\omega_2)}{(\omega_1+\omega_2)^2-s}T_{M_iB_i\to\phi p}T_{\gamma p\to M_iB_i}$$

$$=\frac{1}{(2\pi)^3}\int d\Omega\int_0^\infty dk\frac{k(\omega_1+\omega_2)}{2\omega_1\omega_2}\left[\frac{kf(k)}{(\omega_1+\omega_2)^2-s}-\frac{hf(h)}{(\omega_1+\omega_2)^2-s}\right]$$

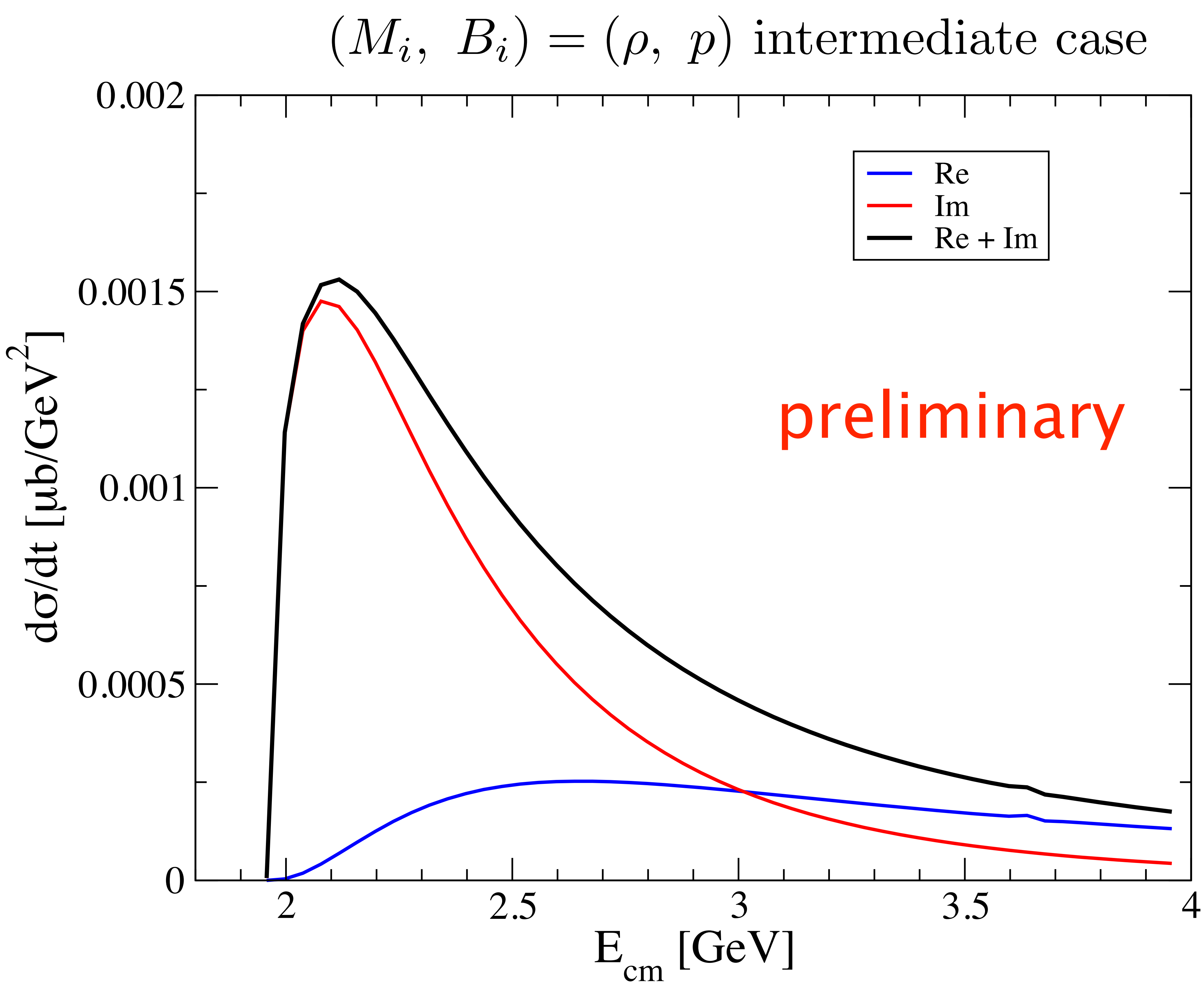
$$+\frac{1}{(2\pi)^3}\frac{hf(h)}{2\sqrt{s}}\int d\Omega\ \ln\left|\frac{\mu+\sqrt{s}}{\mu-\sqrt{s}}\right|$$

$$f(k)=T_{M_iB_i\to\phi p}T_{\gamma p\to M_iB_i}$$

$$(\omega_1(h)+\omega_2(h))^2-s=0$$

$$\mu=M_{M_i}+M_{B_i}$$

Real part calculation



Summary of part I

- ***What's new ?***

  - **Rescattering** contributions are essential to reproduce the bump structure near the threshold energy.

- ***What's questions ?***

  - Application of **Pomeron** at low energy is still in ambiguities. We would like to determine the range of threshold energy of **Pomeron** by calculating other scattering processes.

  - How to determine the parameters in form factors ?

- ***What's next ?***

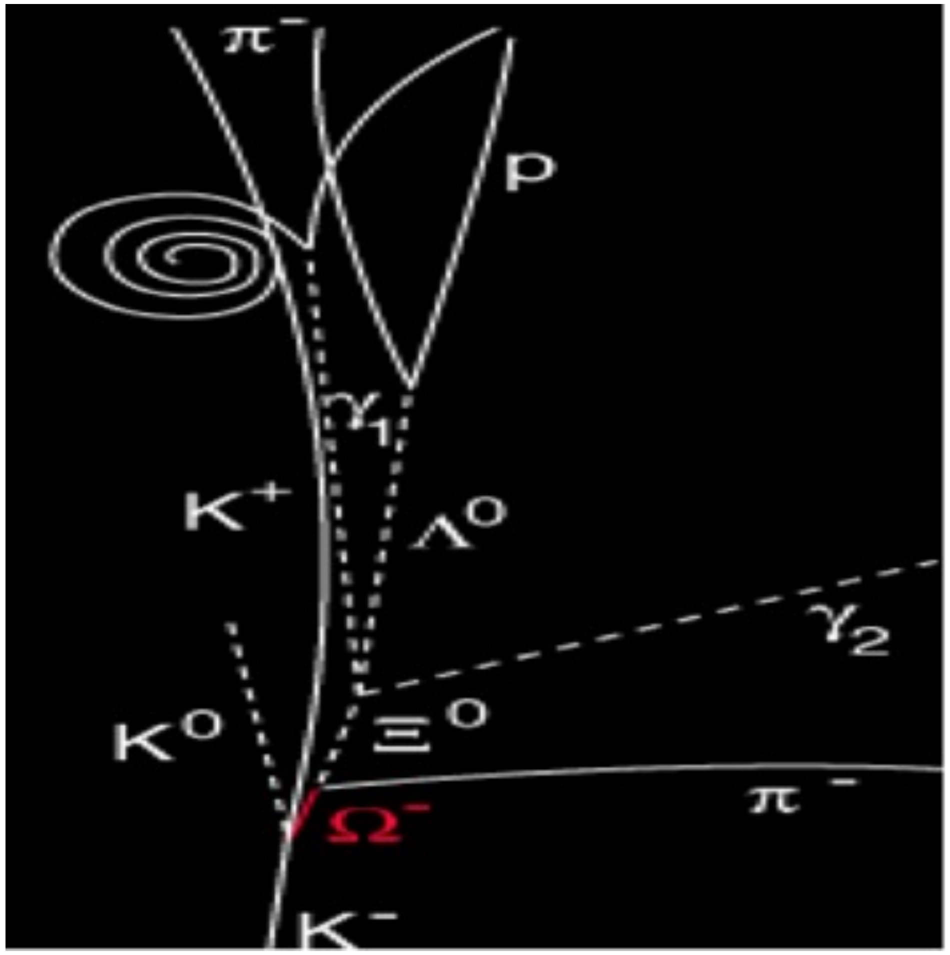
  - Real part calculation and beam-, target- **asymmetry** are next work.

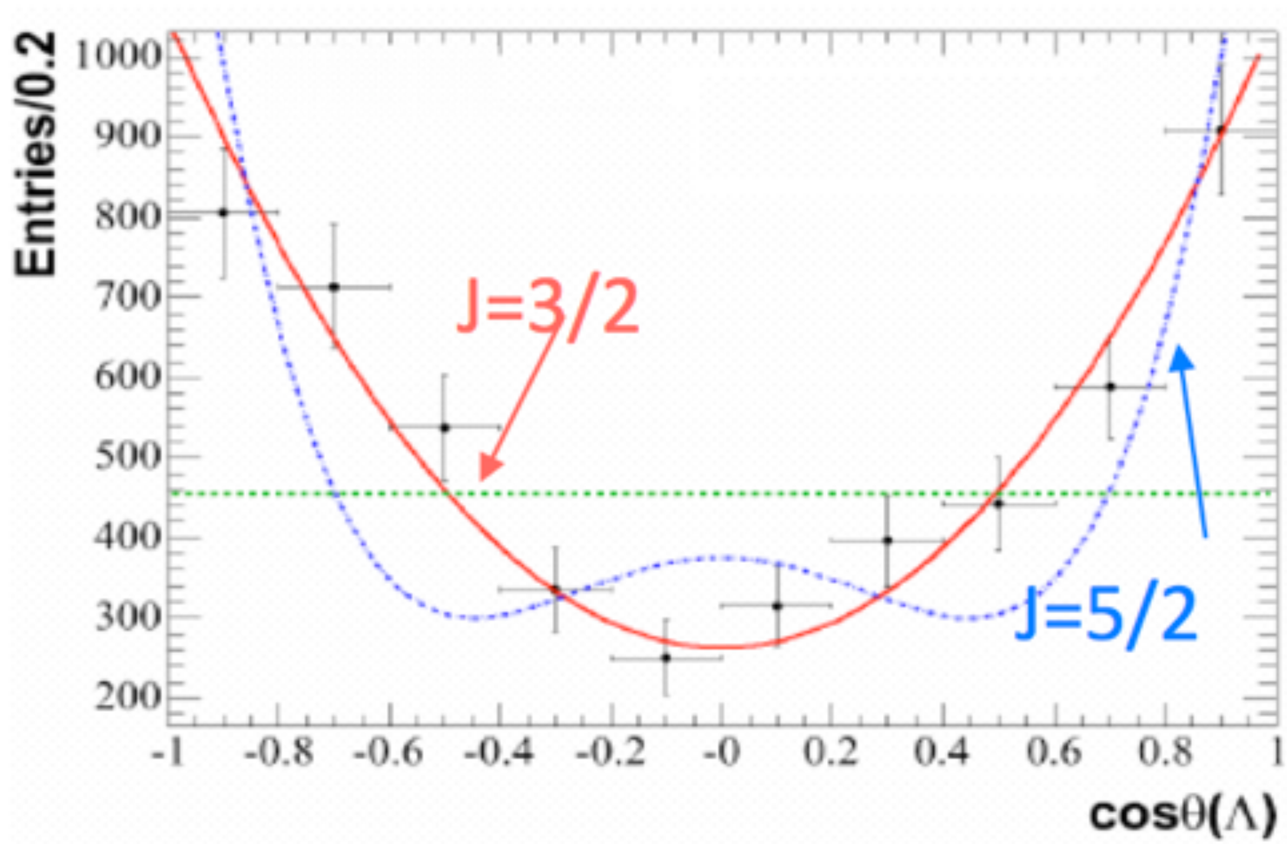
  - We are going to calculate the **neutron target** process via similar rescattering processes. This is next project.

PART II. $\gamma p \to K^+ K^+ K^0 \Omega^-$

Irkutsk, 13 July, 2013

Introduction





Barnes et al, PRL 12, 204 (1964)

Aubert et al, PRL.97, 112001 (2006)

$K^- p \to K^0 K^+ \Omega^-$

First measurement of $J(\Omega^-)$ at SLAC

$\Xi_c^0 \to \Omega^- K^+$, $\Omega^- \to \Lambda K^-$

Introduction

Photoproduction of the Very Strangest Baryons on a Proton Target in CLAS12

A. Afanasev, W.J. Briscoe, H. Haberzettl, I.I. Strakovsky*, and R.L. Workman
The George Washington University, Washington, DC 20052, USA

M.J. Amaryan, G. Gavalian, and M.C. Kunkel
Old Dominion University, Norfolk, VA 23529, USA

Ya.I. Azimov
Petersburg Nuclear Physics Institute, Gatchina, Russia 188300

⋮

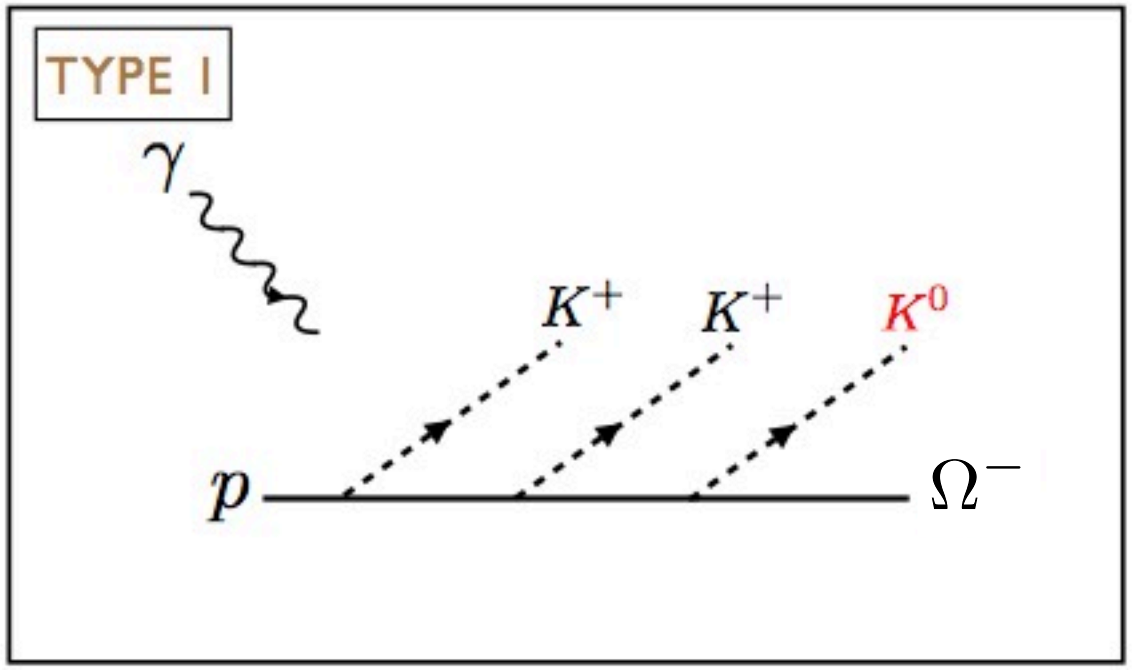
V. Shklyar
Giessen University, D-35392 Giessen, Germany

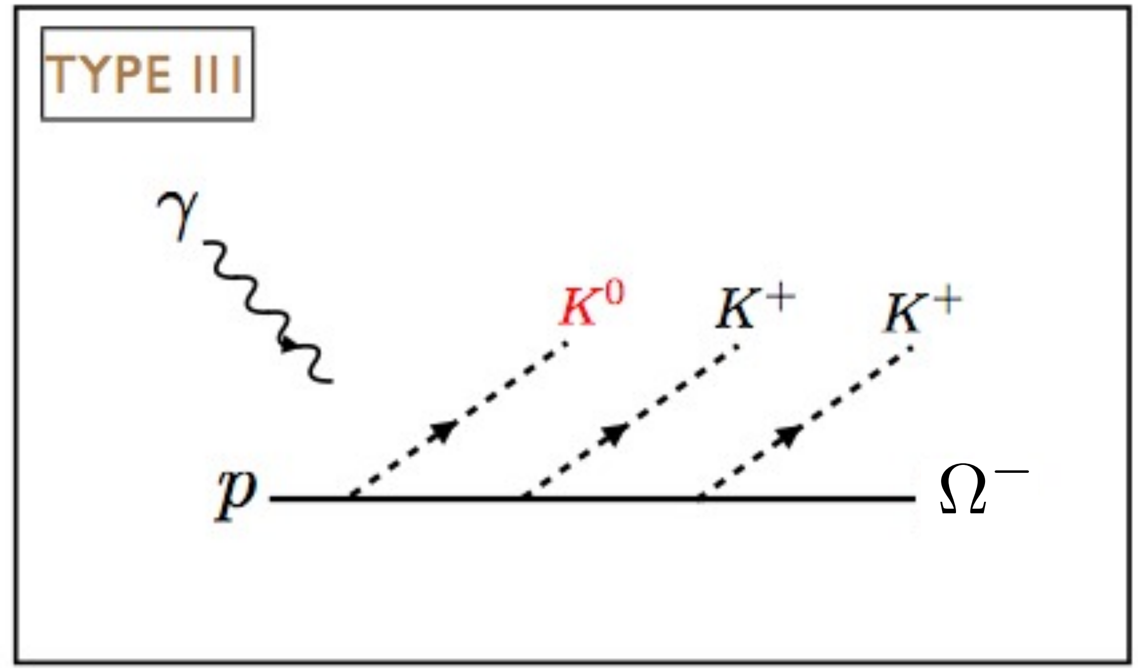
(The Very Strange Collaboration)

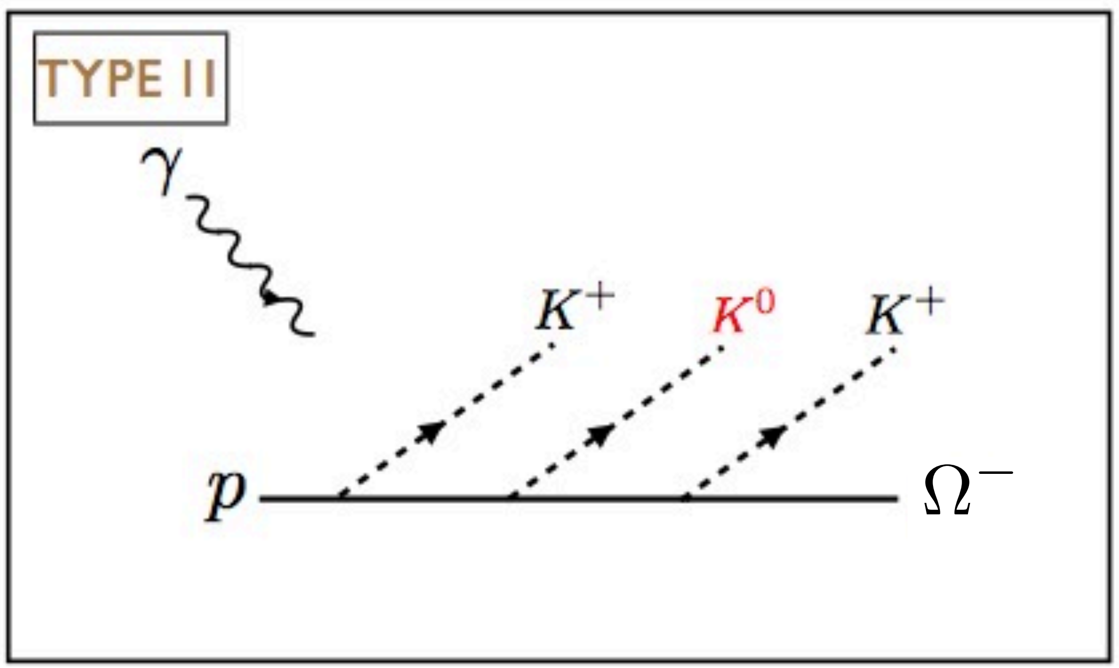
** - Contact person, * - Spokesperson

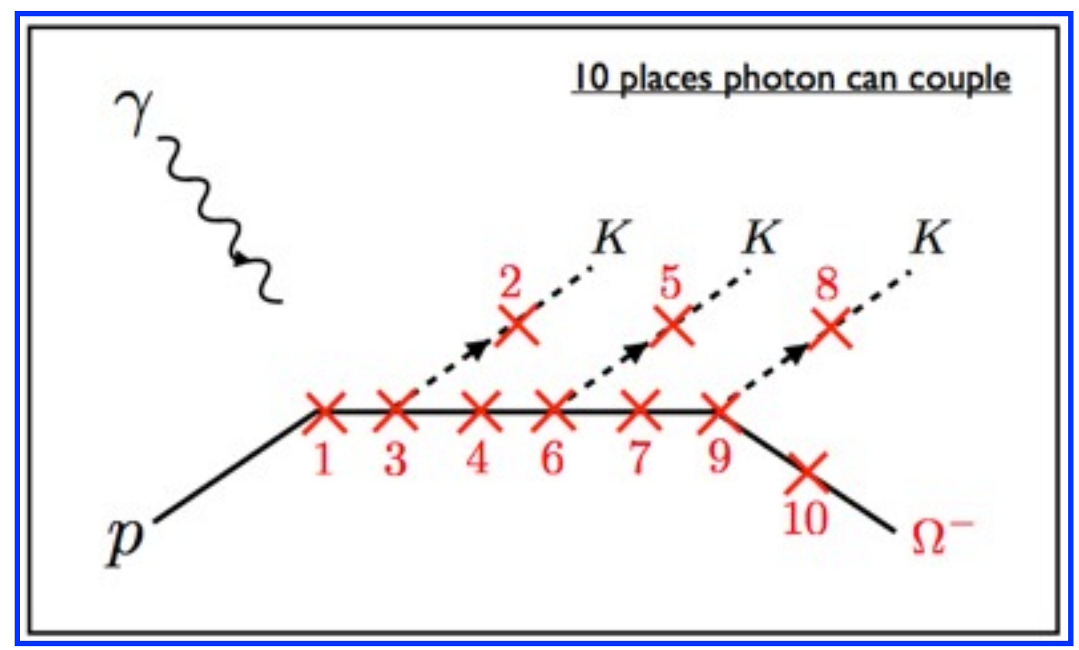
(Dated: May 4, 2012)

Diagrams

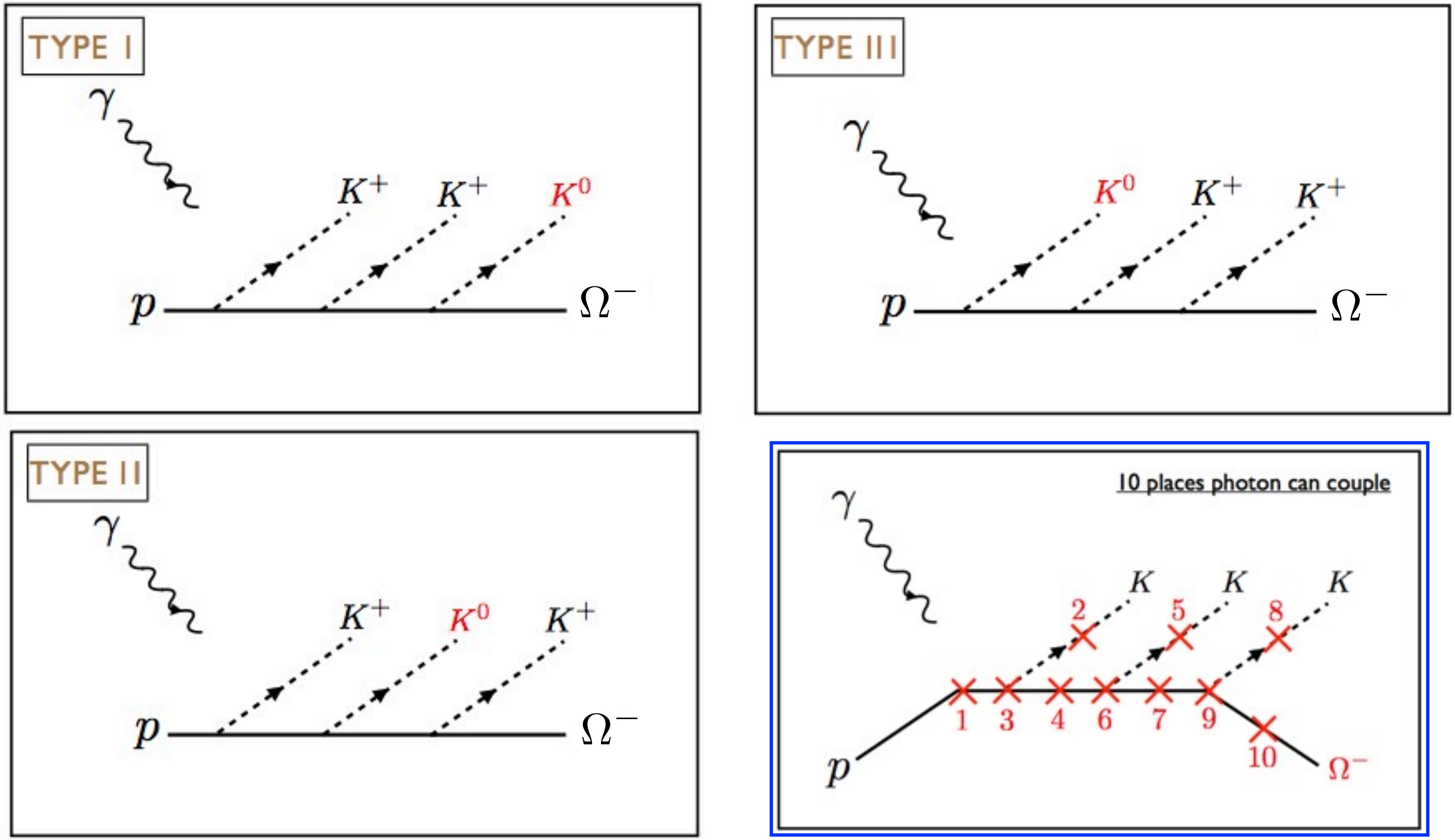

TYPE I
γ
K+ K+ K0
p
Ω−


TYPE III
γ
K0 K+ K+
p
Ω−


TYPE II
γ
K+ K0 K+
p
Ω−


10 places photon can couple
γ
K K K
2 5 8
1 3 4 6 7 9
10
p
Ω−

Diagrams



$$8 \times 3 = 24$$

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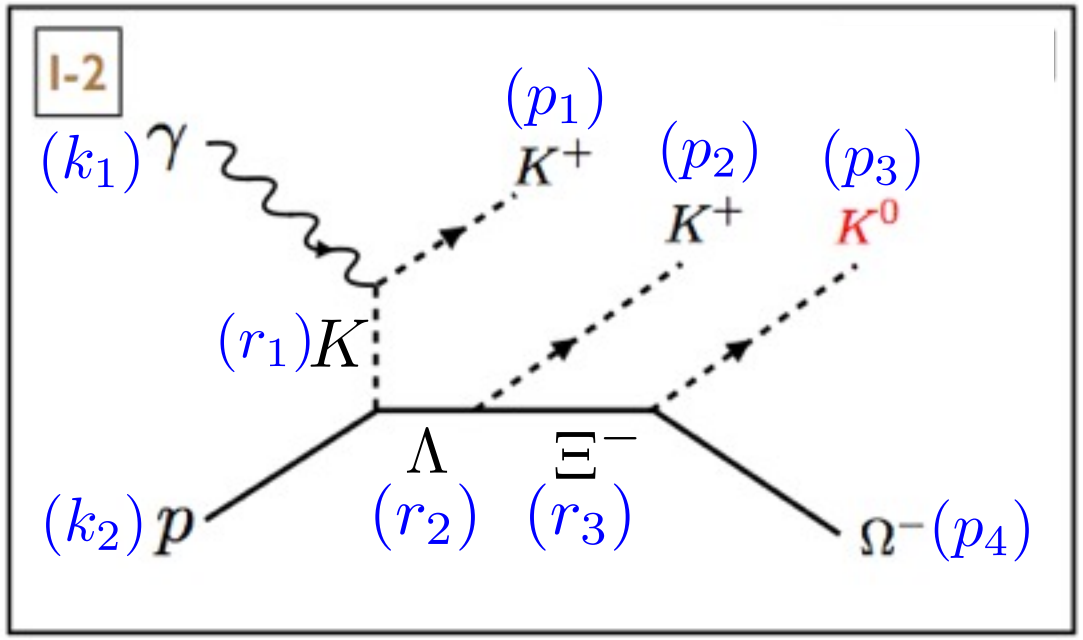
one example : the 2nd diagram of type I set



$$\mathcal{L}_{\gamma NN} = -e\bar{N}\left[\gamma_\mu - \frac{\kappa_N}{2M_N}\sigma_{\mu\nu}\partial^\nu\right]A^\mu N$$

$$\mathcal{L}_{\gamma KK} = -ie\left[(\partial K^+)K^- - \partial(K^-)K^+\right]$$

$$\mathcal{L}_{KN\Lambda} = g_{K^+N\Lambda}\bar{\Lambda}\gamma^\mu\gamma_5\partial_\mu K^- N$$

$$\mathcal{L}_{K\Lambda\Xi^-} = g_{K^+\Lambda\Xi^-}\bar{\Xi}^-\gamma^\mu\gamma_5\partial_\mu \bar{K}^-\Lambda$$

$$\mathcal{L}_{K^0\Xi^-\Omega^-} = g_{K^0\Xi^-\Omega^-}\bar{\Omega}^{-\mu}\partial_\mu\bar{K}^0\gamma_5\Xi^-$$

$$T_{\mathrm{I}-2} = ieg_{KN\Lambda}g_{K\Lambda\Xi}g_{K\Xi\Omega}\;\bar{u}^\mu(p_4)p_{3\mu}\frac{\not{r}_3 - M_{\Xi^-}}{r_3^2 - M_\Xi^2}\not{p}_2\frac{\not{r}_2 + M_\Lambda}{r_2^2 - M_\Lambda^2}\not{r}_1\gamma_5 u(k_2)\frac{2p_1\cdot\epsilon_\gamma}{r_1^2 - m_K^2} \times F_c$$

$$F_c = 1 - (1-F_1)(1-F_2)(1-F_3)(1-F_4)$$

$$T = T_1^{\mathrm{inv}}F_1 + (T_1^{\mathrm{viol}} + T_2 + T_3)F_c$$
$$+T_4F_4 + \cdots$$

$$F_2(r_1^2, r_2^2, r_3^2) = F_M(r_1^2)F_B(r_2^2)F_B(r_3^2)$$

$$F_M(r^2) = \frac{\Lambda_M^2 - m^2}{\Lambda_M^2 - r^2}$$

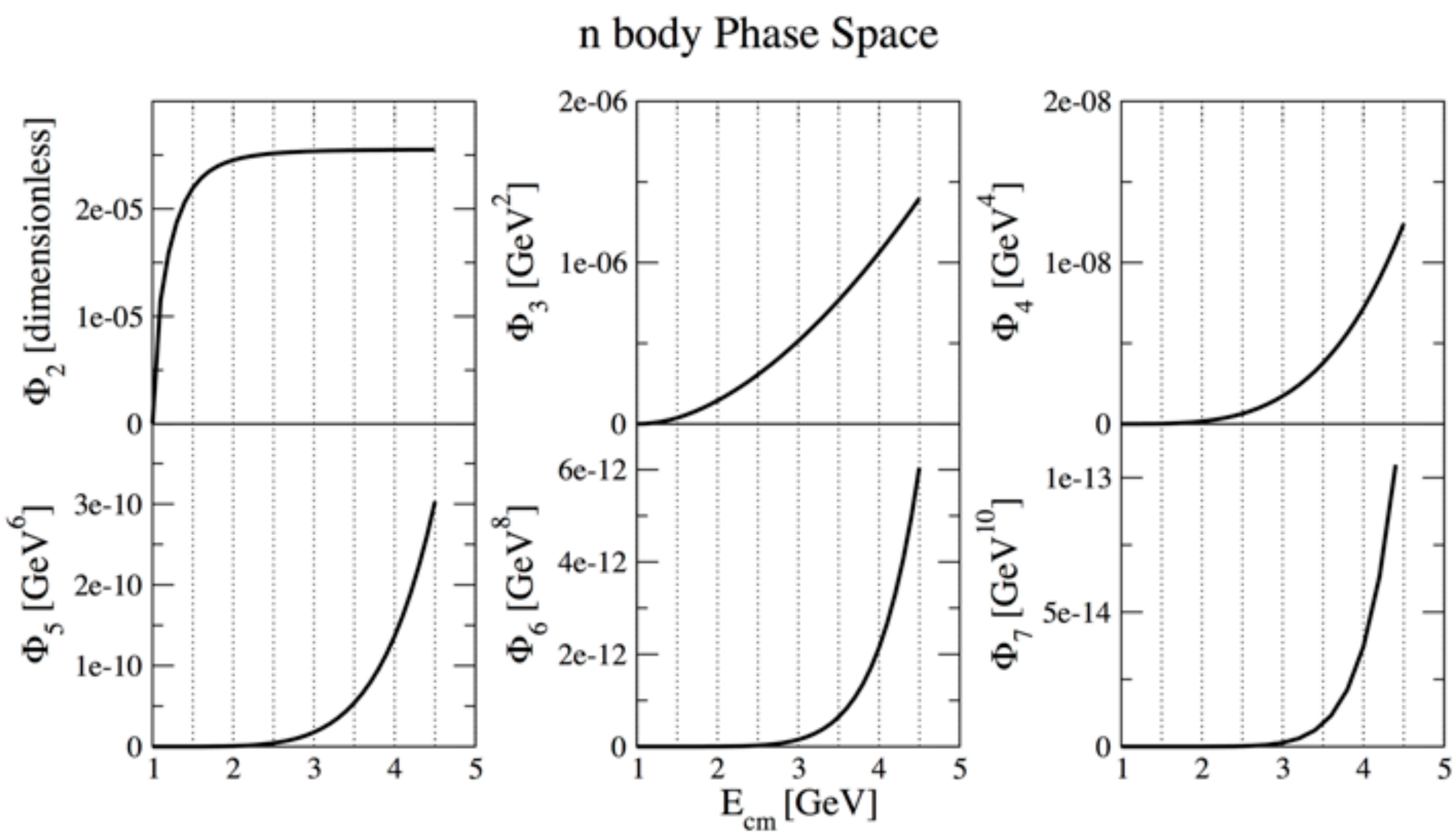
$$F_B(r^2) = \left[\frac{n\Lambda_B^4}{n\Lambda_B^2 + (r^2 - M^2)^2}\right]^n$$

Some comments on the numerical calculation

$$\Phi_n(P;p_1,\ldots,p_n) = \int_1 \cdots \int_n \delta^4(P - \sum_i^n p_i) \prod_{i=1}^n \frac{d^3p_i}{(2\pi)^3 2E_i}$$

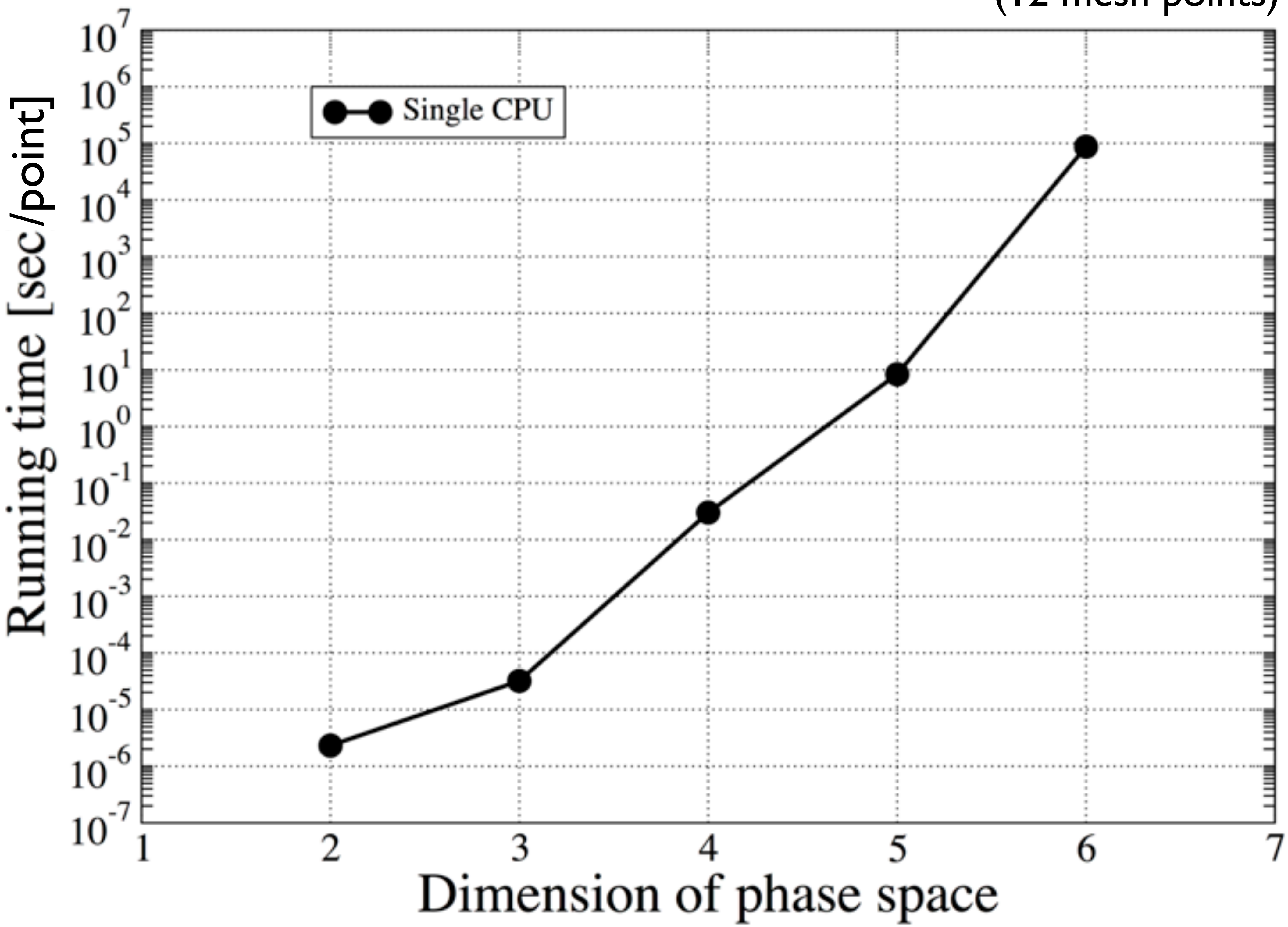
# of integration $= 3n - 5$

$(m_1 = m_2 = \cdots = m_n = 1\text{GeV}/n)$



Running time of one point calculation $(E_{\rm cm}, \Phi_n)$

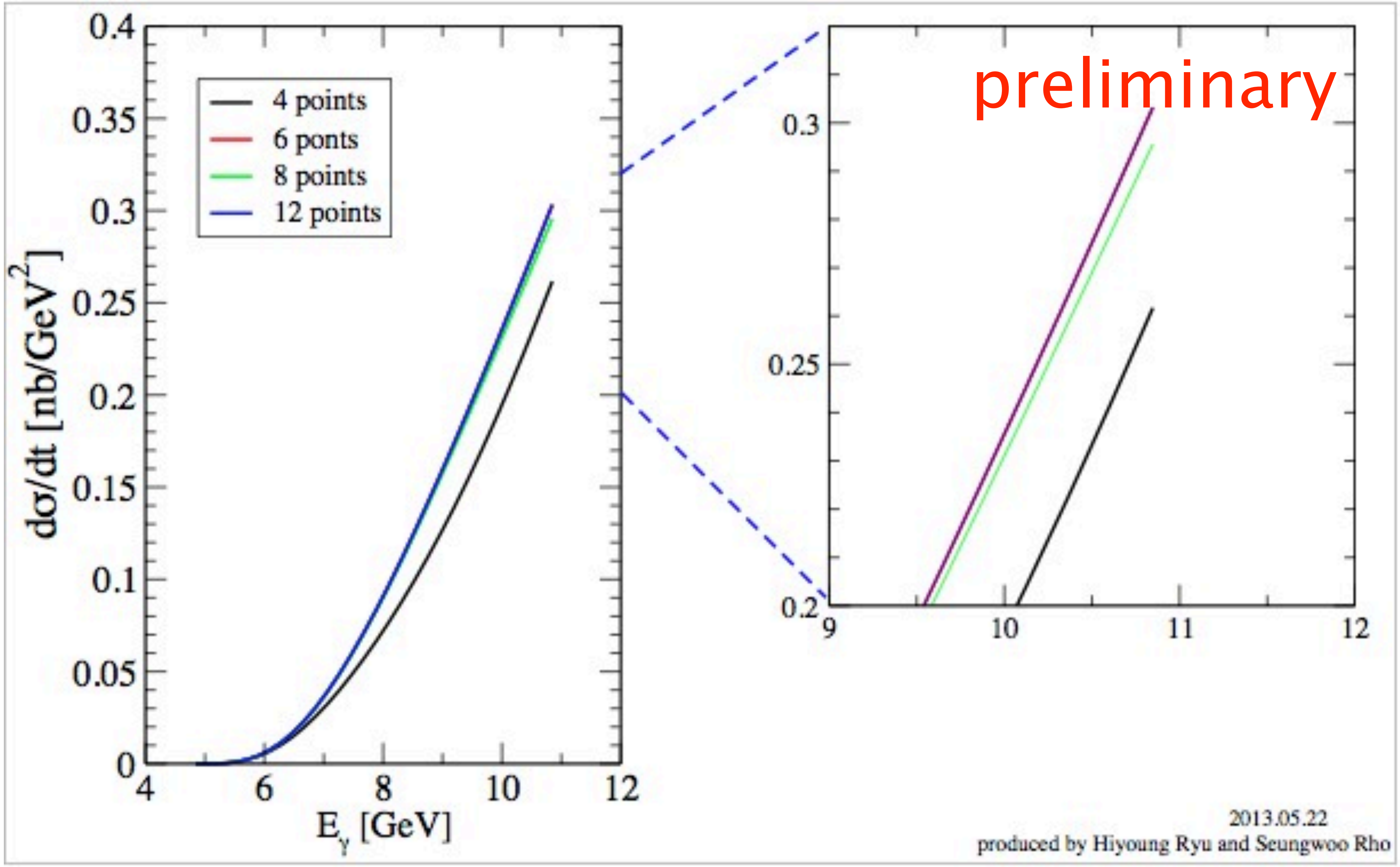
(12 mesh points)



Integration convergency check

STEP I : 4 mesh points calculation (single machine & HTCaaS with PLSI)

STEP II : convergency check for 6, 8 and 12 mesh points



Summary of part II

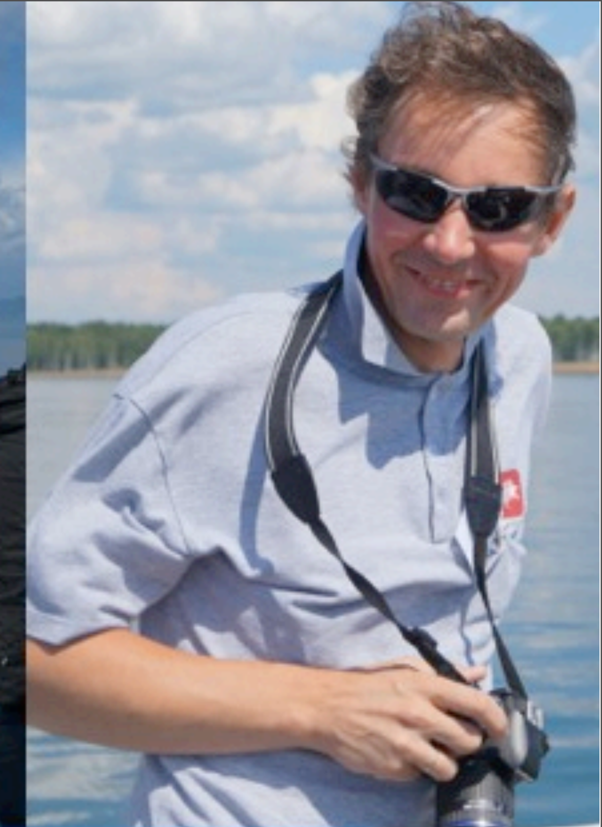
- ***What's new ?***
  - There is no published paper for the Omega- photoproduction.
  - We would like to suggest the minimum of the cross section.
  - 4 body phase space calculation with the supercomputing power.

- ***What's questions ?***
  - We are considering about which parameter we will use . (coupling constant/ cut-off in the form factor)
  - Are there other important diagrams ?

- ***What's next ?***
  - The differential cross section as a function of the invariant mass.

  ...





Thank you very much ~