Hyperon-resonance productions with photon and meson beams

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Contents based on

S.i.N. PRD96, 076021 (2017)
J.K.Ahn, S.i.N. PRD98, 114012 (2018)
S.i.N., A.Hosaka arXiv:1902.09106 [hep-ph]
J.K.Ahn, S.B.Yang, K.S.Choi, S.i.N. In preparation

Internationalization
Cooperation
Synergy

What are we interested in?

Hyperons of terra incognita: Λ(1405) and Ξ(1690)

New types of hadrons

Structures seem different from others

Rarely known physical properties

How can we probe the puzzles via experiments?

Theoretical guides and estimations for Future

What are we interested in?

Λ(1405) at LEPS/SPring-8 and CLAS/JLab

$$\gamma^{(*)} p \to K^+ \pi^+ \Sigma^-$$

S.i.N. PRD96, 076021 (2017)

$$\gamma^{(*)} p \to K^{*+} \pi^0 \Sigma^0$$

S.i.N., A.Hosaka arXiv:1902.09106 [hep-ph]

Ξ(1690) at Hadron hall/J-PARC

$$K^- p \to K^+ K^- \Lambda$$

J.K.Ahn, S.i.N. PRD98, 114012 (2018)

S=0 and S=-1 resonances at Belle/KEK (Dr. S.B.Yang)

$$\Lambda_c^+ \to \pi \bar{K} p$$

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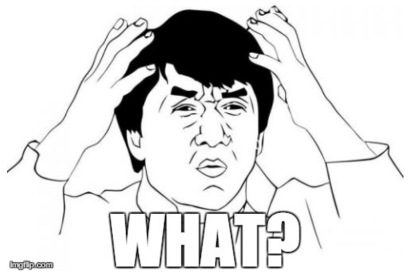
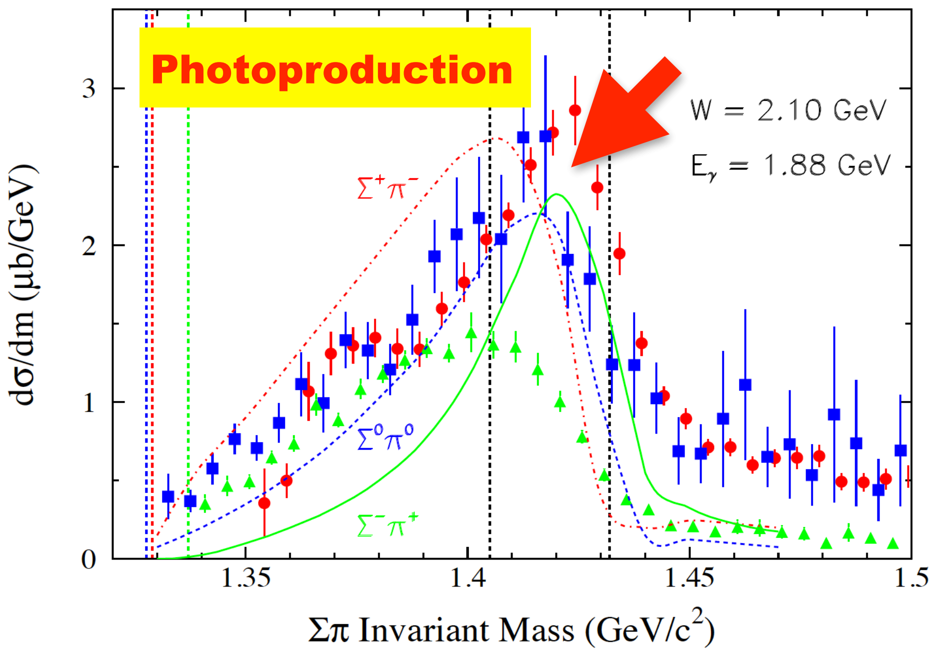
J.K.Ahn, S.B.Yang, K.S.Choi, S.i.N. In preparation

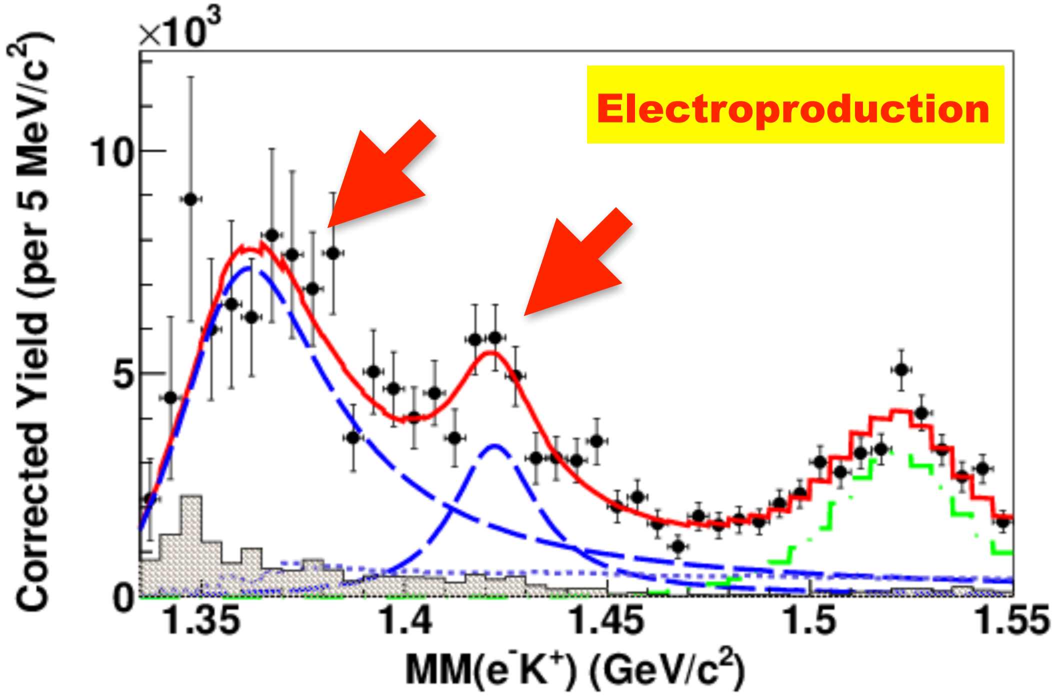
Motivation



Obvious difference between Λ(1405) invariant masses

from photo- and electro-production in experiments: Why??





K. Moriya et al. [CLAS], PRC87, no. 3, 035206 (2013)

H. Y. Lu et al. [CLAS], PRC88, 045202 (2013)

Single peak vs. Double peak

Possible explanations (real vs. virtual photon)

Virtual photon has scalar component → Increasing t-ch contribution?

In terms of strong interaction,
No differences for two poles
(even more, numerically small…)

Virtual photon probes Λ(1405) EM form factor → New EM excitation?

Hadron EM form factors play the roles
then, nontrivial interference occurs?

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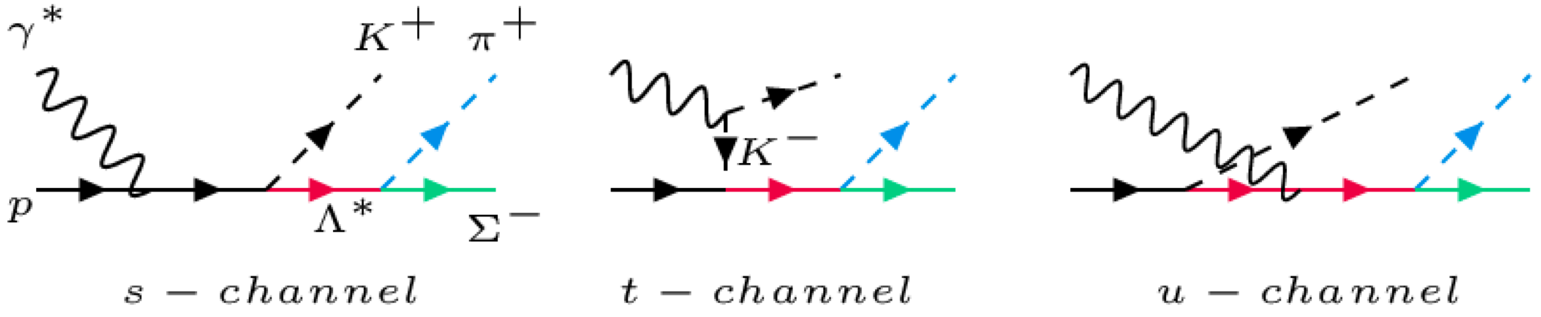
then, nontrivial interference occurs?

We will take this scenario!!!

Theoretical framework

Effective Lagrangian approach in Born approximation at tree level



+ Small far-off-shell contributions

Relevant strong couplings from ChUM

B	Mass	Width	g_{KNB}	$g_{\pi\Sigma B}$	κ_B
p	938.272 MeV	$\sim$ 0 MeV	–	–	2.79
L	1368 MeV	100 MeV	$1.2+1.7i$	$-2.5-1.5i$	0.30
H	1423 MeV	50 MeV	$-2.5+0.94i$	$0.42-1.4i$	0.41

T. Sekihara, T. Hyodo and D. Jido, PL669, 133 (2008).

Theoretical framework

Scattering amplitudes conserving WT identity for arb. Q^2 values

$$i\mathcal{M}_{\mathrm{total}} = \sum_{\Lambda^*=H,L}\sum_{x} i\mathcal{M}_x^{\Lambda^*},\quad i\mathcal{M}_x^{\Lambda^*} = ieg_{KN\Lambda^*}g_{\pi\Sigma\Lambda^*}\frac{\bar{u}(k_5)[\not{q}_{4+5}+M_{\Lambda^*}^2]\Gamma_x^{\Lambda^*}u(k_2)}{M_{\pi^+\Sigma^-}^2 - M_{\Lambda^*}^2 - i\Gamma_{\Lambda^*}M_{\Lambda^*}},$$

$$\Gamma_s^{\Lambda^*} = \frac{\not{k}_1+\not{k}_2+M_N}{s-M_N^2}\left[\not{\epsilon}+(F_1^p-1)\left[\not{\epsilon}+\frac{(\epsilon\cdot k_1)\not{k}_1}{Q^2+\delta}\right]-\frac{\kappa_p F_2^p}{2M_N}(\not{\epsilon}\not{k}_1-\epsilon\cdot k_1)\right]F_c,$$

$$\Gamma_t^{\Lambda^*} = \frac{1}{t-M_K^2}\left[\epsilon\cdot(2k_3-k_1)+(F_K-1)\left[\epsilon\cdot(2k_3-k_1)+\frac{(\epsilon\cdot k_1)[k_1\cdot(2k_3-k_1)]}{Q^2+\delta}\right]\right]F_c,$$

$$\Gamma_u^{\Lambda^*} = F_u\left[F_1^{\Lambda^*}\left[\not{\epsilon}+\frac{(\epsilon\cdot k_1)\not{k}_1}{Q^2+\delta}\right]-\frac{\kappa_{\Lambda^*}F_2^{\Lambda^*}}{2M_N}(\not{\epsilon}\not{k}_1-\epsilon\cdot k_1)\right]\frac{\not{k}_2-\not{k}_3+M_{\Lambda^*}}{u-M_{\Lambda^*}^2},$$

Strong form factors satisfying WT identity as well

$$i\mathcal{M}_{\mathrm{total}}^{\mathrm{dressed}} = (i\mathcal{M}_{Es}+i\mathcal{M}_{Et}+i\mathcal{M}_{Eu})F_c + i\mathcal{M}_{Ms}F_s + i\mathcal{M}_{Mt}F_t + i\mathcal{M}_{Mu}F_u.$$

$$F_c = 1-(1-F_s)(1-F_t).$$

S.i.N. et al., JKPS59, 2676 (2011).

Theoretical framework

Photon polarization in cm frame

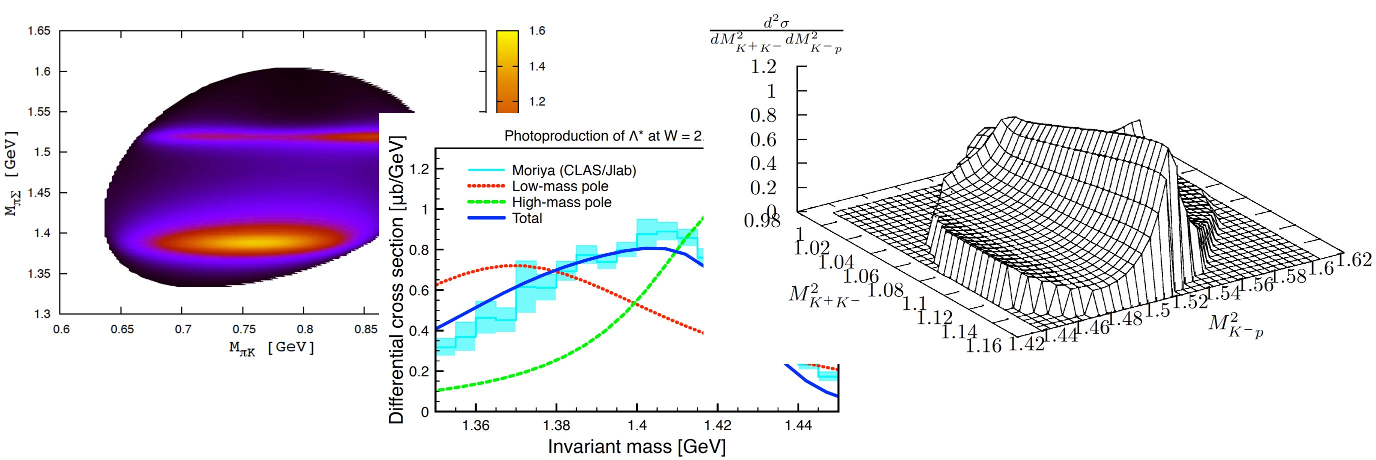
$$\varepsilon_x = \left(0, \sqrt{1+\varepsilon}, 0, 0\right), \quad \varepsilon_y = \left(0, 0, \sqrt{1-\varepsilon}, 0\right), \quad \varepsilon_z = \frac{\sqrt{2\varepsilon}}{\sqrt{|Q^2|}}\left(k, 0, 0, E_1\right).$$

Transverse-polarization parameter **ε** = (0.3~0.7) at CLAS, so that

we choose it **ε** = 0.5

We compute double differential cross section W=2.4 GeV

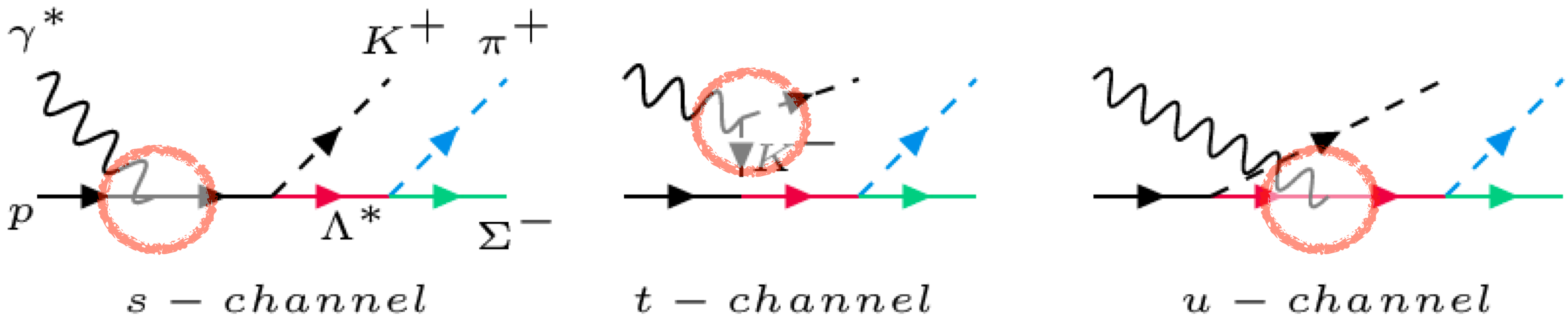
$$\frac{d^2\sigma_{\gamma^{(*)}p\to K^+\pi^+\Sigma^-}}{dM_{K^+\pi^+}dM_{\pi^+\Sigma^-}} = \frac{1}{4|\vec{k}_{\gamma^{(*)}}|\left|E_{\gamma^{(*)}} - E_N\right|}\frac{1}{128\pi^4 s}\int M_{K^+\pi^+}M_{\pi^+\Sigma^-}\, d\cos\theta_{K^+}\, d\phi_{\Sigma^-}\, \frac{1}{2n}\sum |\mathcal{M}_{\gamma^{(*)}p\to K^+\pi^+\Sigma^-}|^2$$



Theoretical framework

Hadron EM form factors for electroproduction

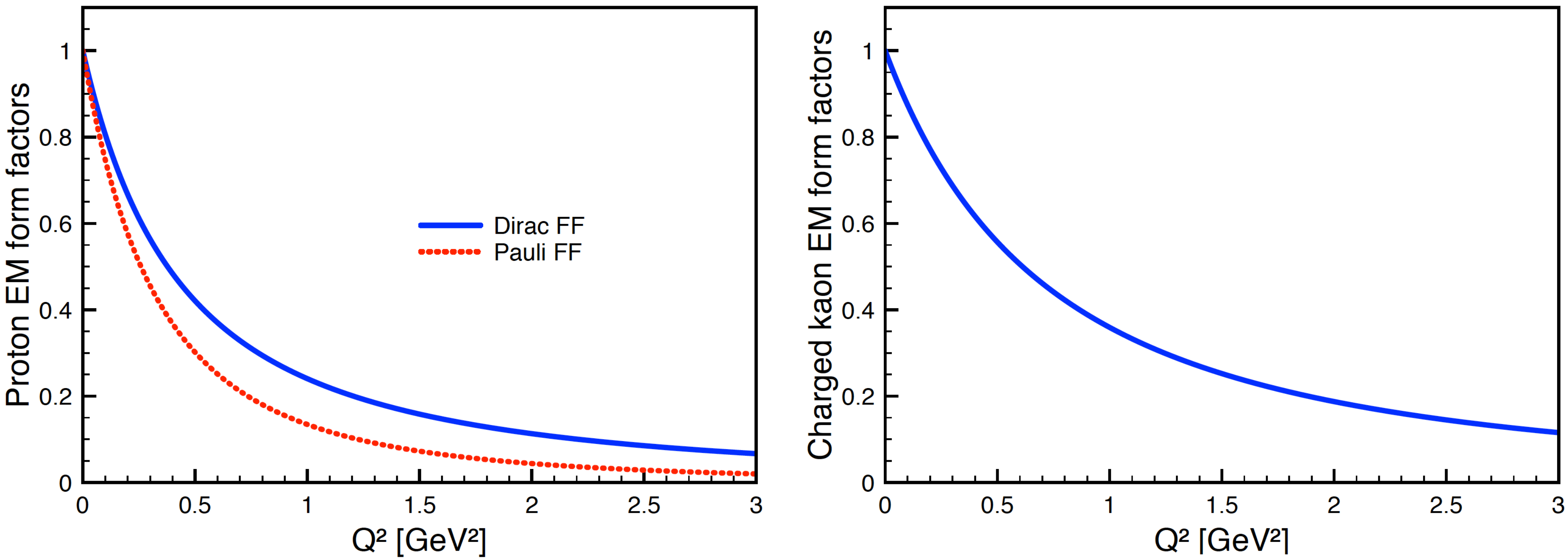
Where hadron EM form factors appear?



Proton, Kaon, and Λ(1405), three EM form factors necessary

Theoretical framework

EM form factors (FF) for proton and kaon: **Well known**



$$G_E^p(Q^2) \simeq G_D(Q^2), \quad G_M^p(Q^2) \simeq \mu_p G_D(Q^2), \quad G_D(Q^2) = \left[\frac{1}{1+Q^2\langle r^2\rangle_E^p/12}\right]^2,$$

J. J. Kelly, Phys. Rev. C 70, 068202 (2004).

$$F_K(Q^2) = \frac{1}{[1+Q^2/(0.845\,\mathrm{GeV})^2 + Q^4/(1.270\,\mathrm{GeV})^4]},$$

W. Jaus, Phys. Rev. D 44, 2851 (1991).

Theoretical framework

EMFF for Λ(1405): Less known so far. So How to model it?

How can we construct Λ(1405) EMFF???

1) It's neutral so possibly similar structure to neutron EMFF

2) EM charge rms radii relates to EMFF

cf) Galster parameterization

$$G_E^n(Q^2) \simeq -\frac{a\mu_n \tau}{1+b\tau} G_D(Q^2)$$

$$\langle r^2 \rangle_E^{H,L} = -6 \frac{dG_E^{H,L}(Q^2)}{dQ^2}\Big|_{Q^2=0}, \quad \langle r^2 \rangle_M^{H,L} = -\frac{6}{\mu_{H,L}} \frac{dG_M^{H,L}(Q^2)}{dQ^2}\Big|_{Q^2=0},$$

$$G_E^{H,L}(Q^2) = -\frac{\langle r^2 \rangle_E^{H,L}}{6} Q^2 F_K(Q^2) \left[\frac{1}{1+Q^2\langle r^2 \rangle_M^{H,L}/12}\right]^2, \quad G_M^{H,L}(Q^2) \approx \mu_{H,L} \left[\frac{1}{1+Q^2\langle r^2 \rangle_M^{H,L}/12}\right]^2$$

2) EM information of Λ(1405) from ChUM: EM charge rms radii

M.M.Kaskulov, P.Grabmayr, EPJA 19, 157 (2004).

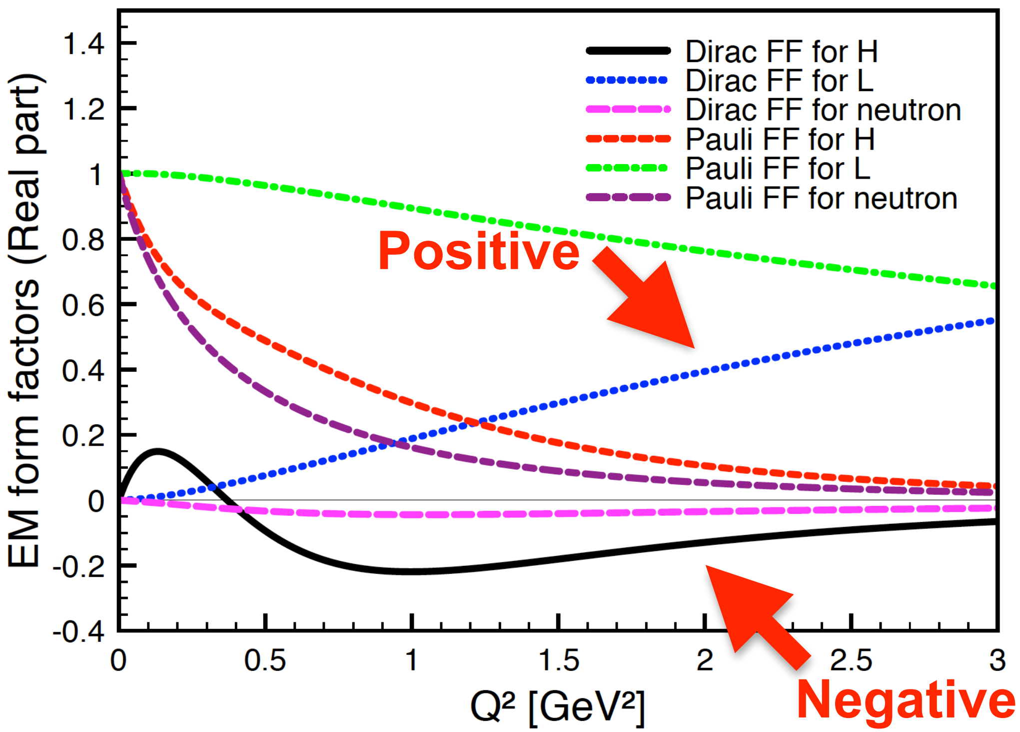
Neutron EMFF + Charge rms radii from ChUM ≈ Λ(1405) EMFF

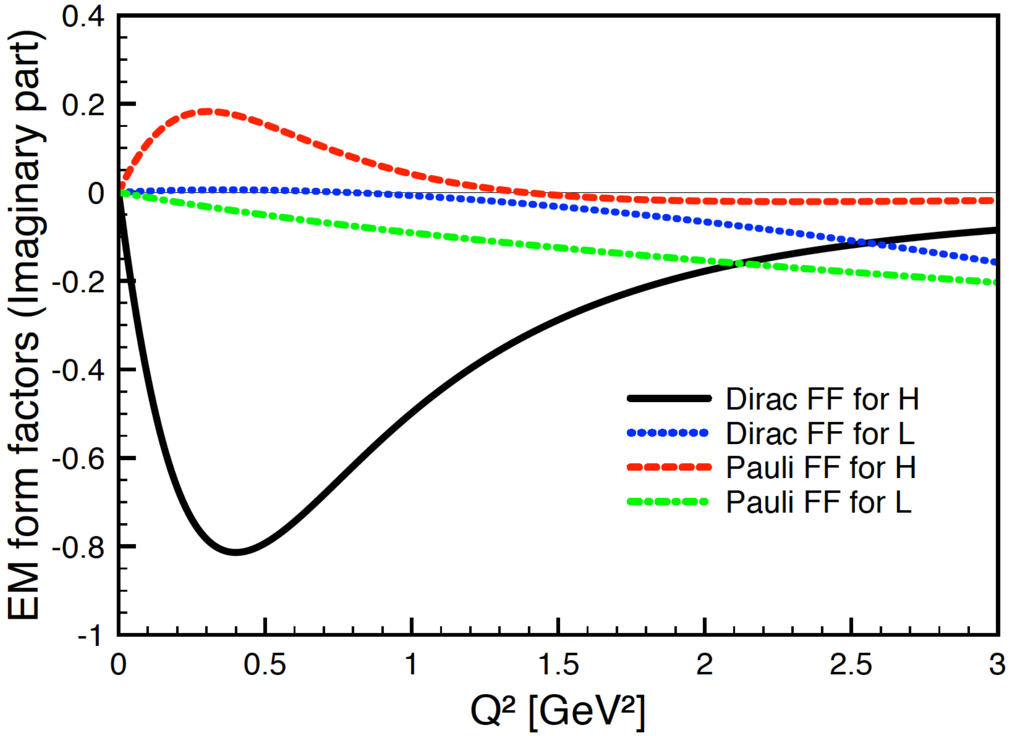
Theoretical framework

EMFF for Λ(1405): **Less known so far. So How to model it?**

T. Sekihara, T. Hyodo and D. Jido, Phys. Lett. B 669, 133 (2008).

$\langle r^2\rangle_E^H$	$\langle r^2\rangle_M^H$	$\langle r^2\rangle_E^L$	$\langle r^2\rangle_M^L$	$\langle r^2\rangle_E^n$
$-3.365+7.783i$	$6.859-10.455i$	$0.462-0.051i$	$-0.334+0.539i$	-2.877 ± 0.077



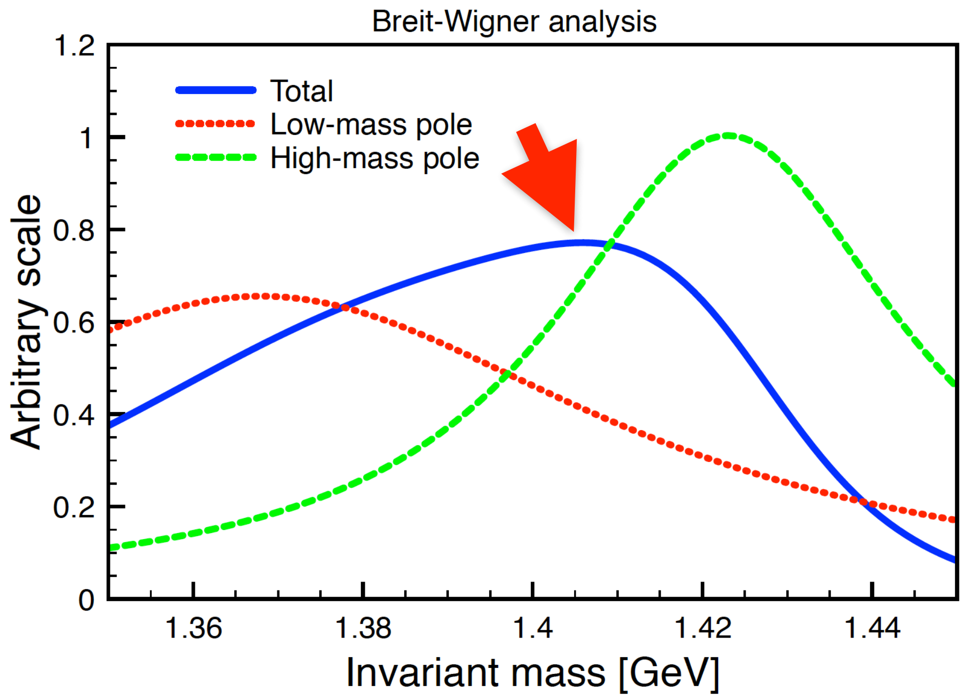


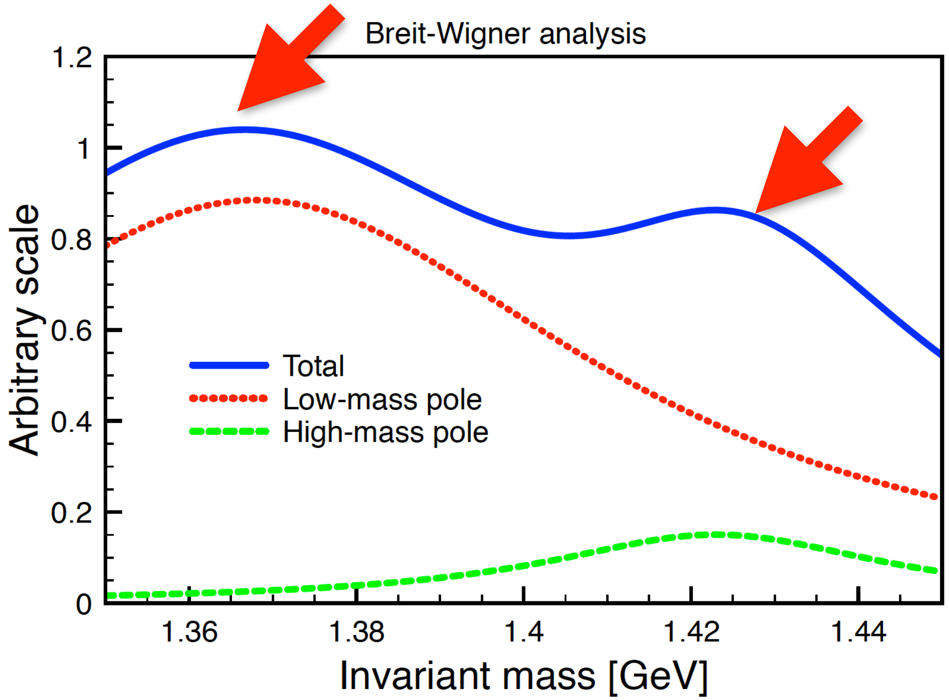
Theoretical framework

Invariant mass plots with Breit-Wigner type distributions (test)

$$i\mathcal{M}_H = \frac{g_{KNH}\, g_{\pi\Sigma H} A_H}{M^2_{\pi^+\Sigma^-} - M_H^2 - i\Gamma_H M_H}, \quad i\mathcal{M}_L = \frac{g_{KNL}\, g_{\pi\Sigma L} A_L}{M^2_{\pi^+\Sigma^-} - M_L^2 - i\Gamma_L M_L}.$$

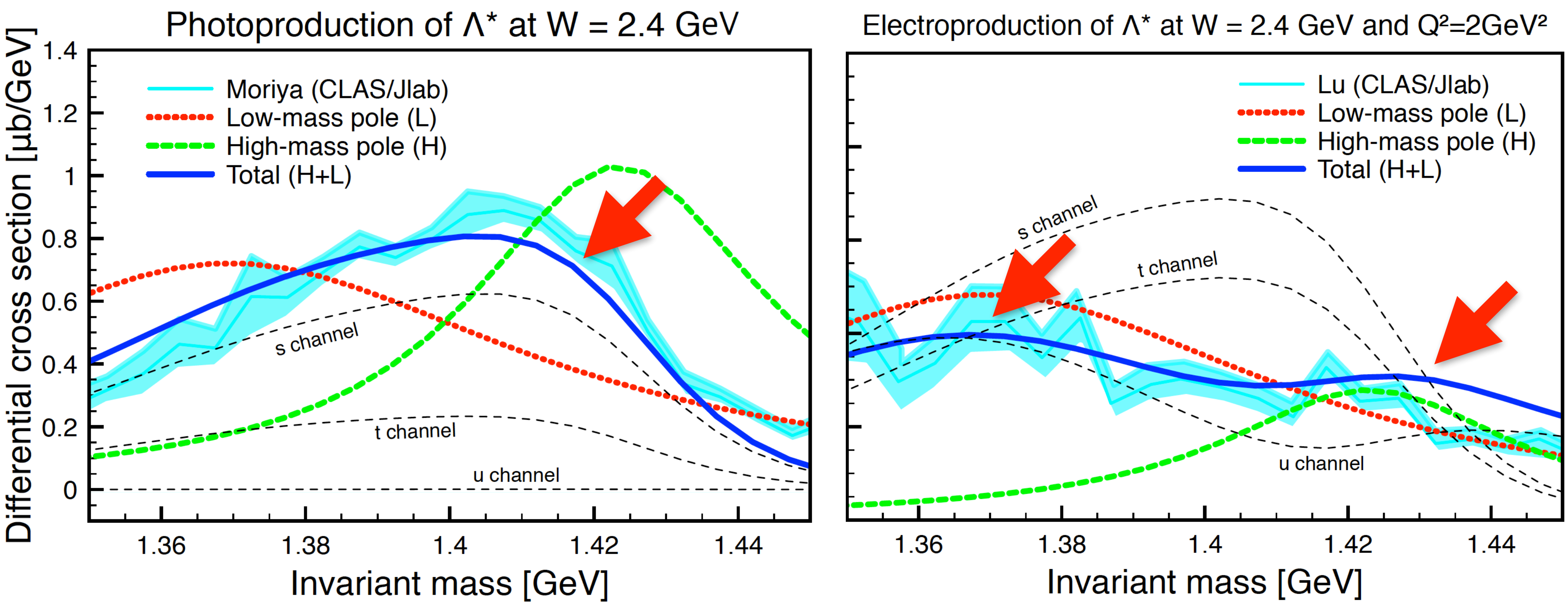
$$g_{KNL}\, g_{\pi\Sigma L}\, F_1^L = \underline{0.660} - 0.549i, \quad g_{KNH}\, g_{\pi\Sigma H}\, F_1^H = \underline{-0.583} - 2.363i.$$





Theoretical framework

Invariant mass plots: Full calculations



Destructive interference for photoproduction ⇒ Single pole

vs.

Constructive interference for electroproduction ⇒ Double pole

What are we interested in?

Λ(1405) at LEPS/SPring-8 and CLAS/JLab

$$\gamma^{(*)} p \to K^+ \pi^+ \Sigma^-$$

S.i.N. PRD96, 076021 (2017)

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Motivation

New questions and challenges

1) Is this observation universal for Λ(1405)?

2) Then, what about other meson productions?

3) Theoretically, K*NΛ(1405) coupling rarely known

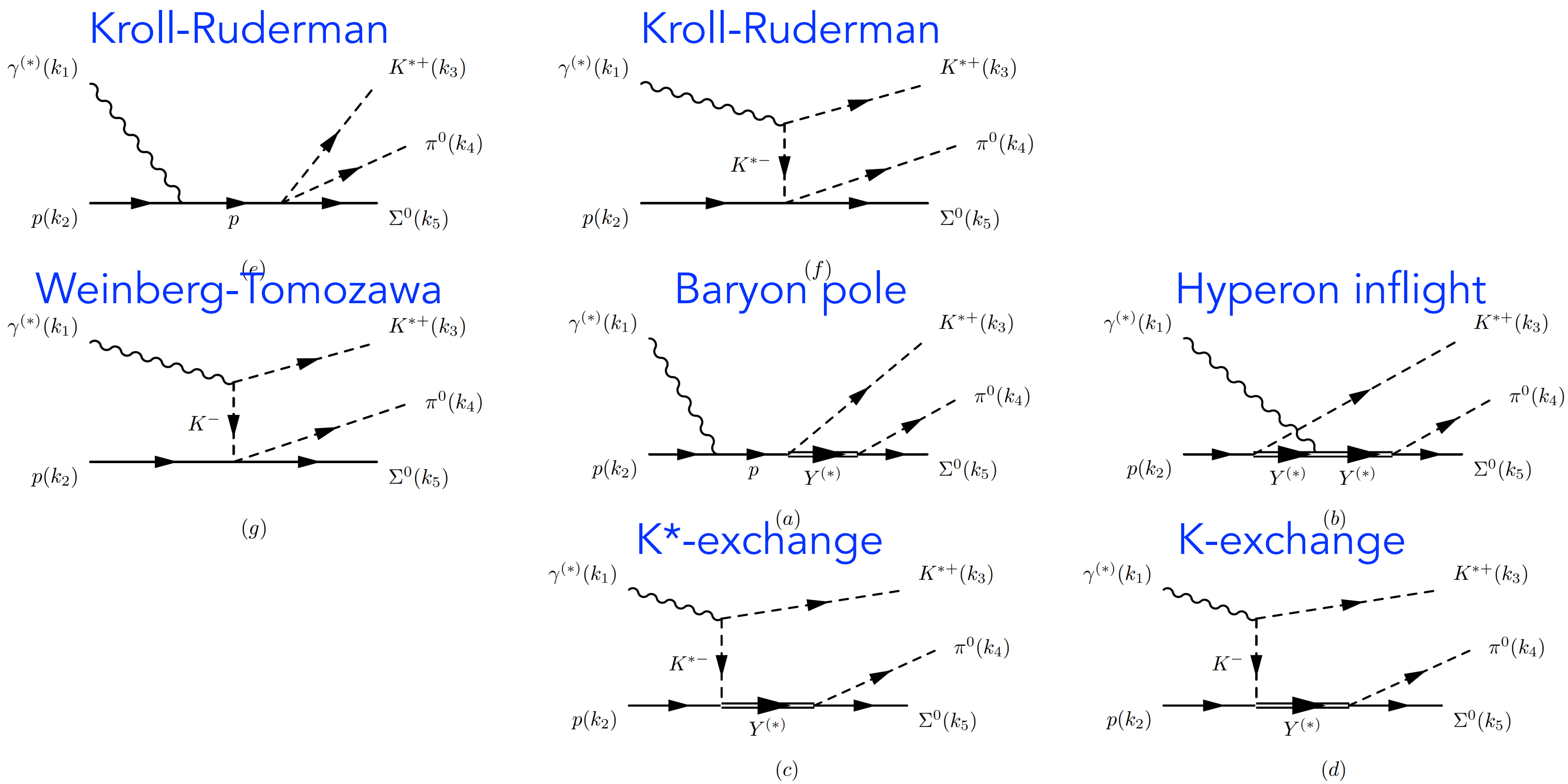
4) It is notorious for Λ(1405) reaction studies

5) Now is the time for $\gamma^{(*)} p \to K^{*+} \pi^0 \Sigma^0$

Theoretical framework

Effective Lagrangian approach at tree-level

Born approximation



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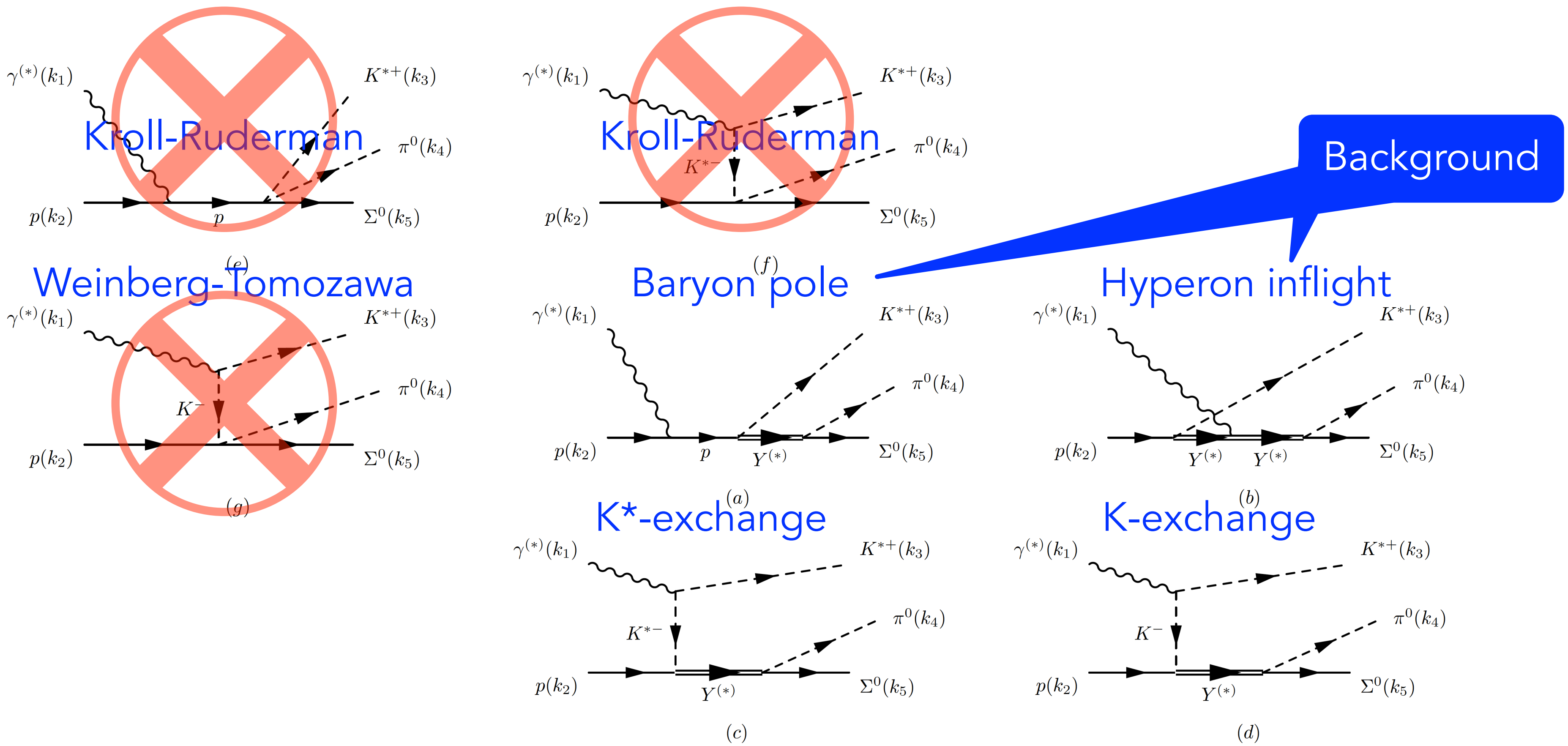
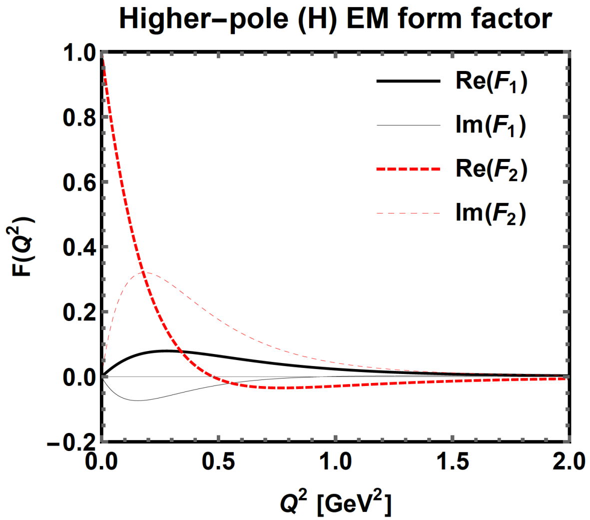
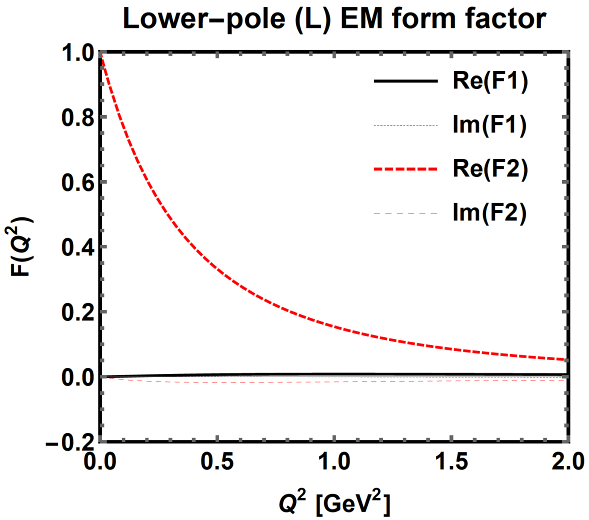


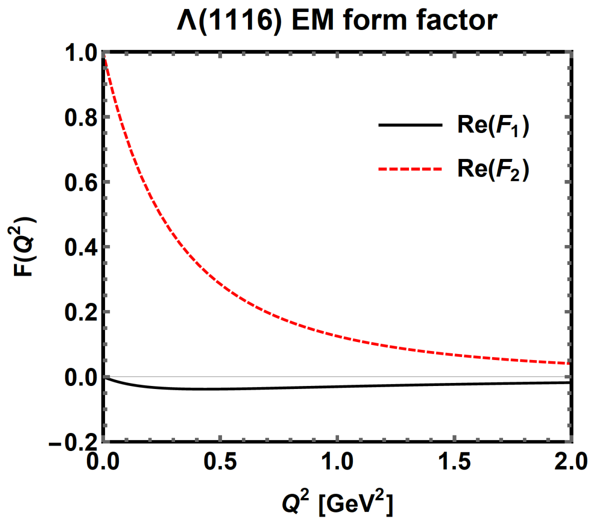
Theoretical framework

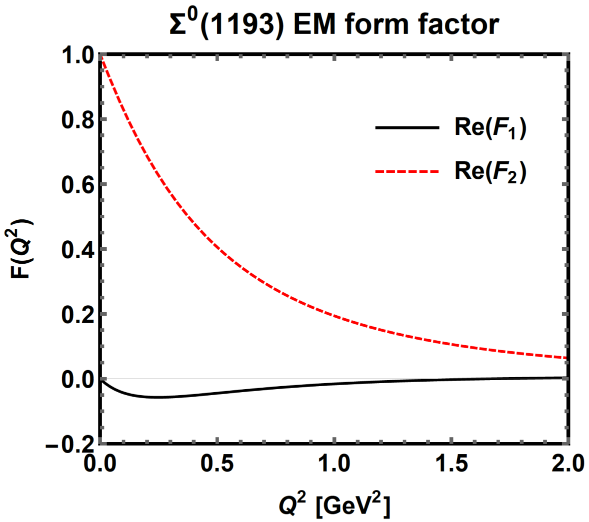
Hyperon EM form factors from exp. and theo.

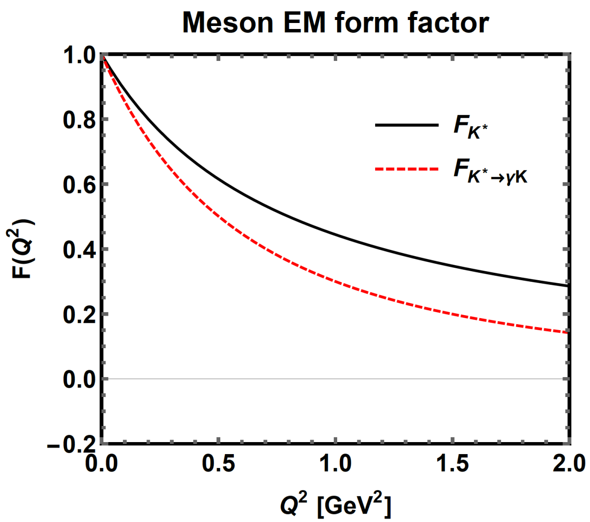
$\langle r_E^2 \rangle_H$	$\langle r_M^2 \rangle_H$	$\langle r_E^2 \rangle_L$	$\langle r_M^2 \rangle_L$
$-0.131 + 0.303i$	$0.267 - 0.407i$	$0.018 + 0.002i$	$-0.013 + 0.021i$









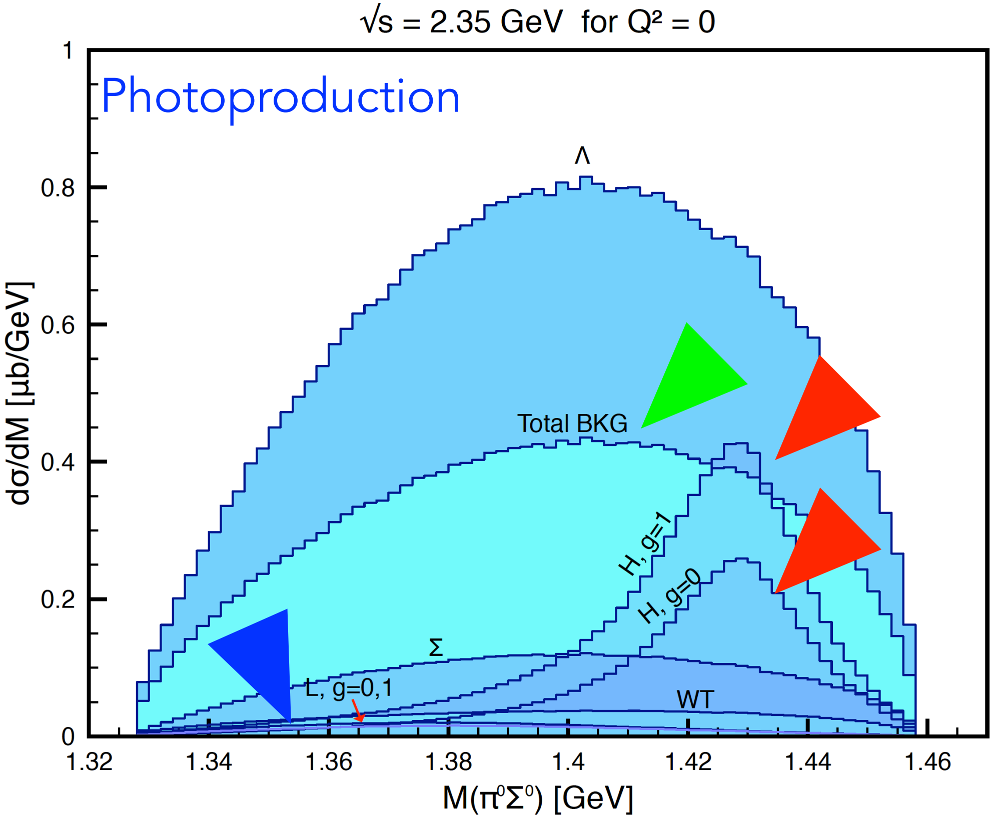


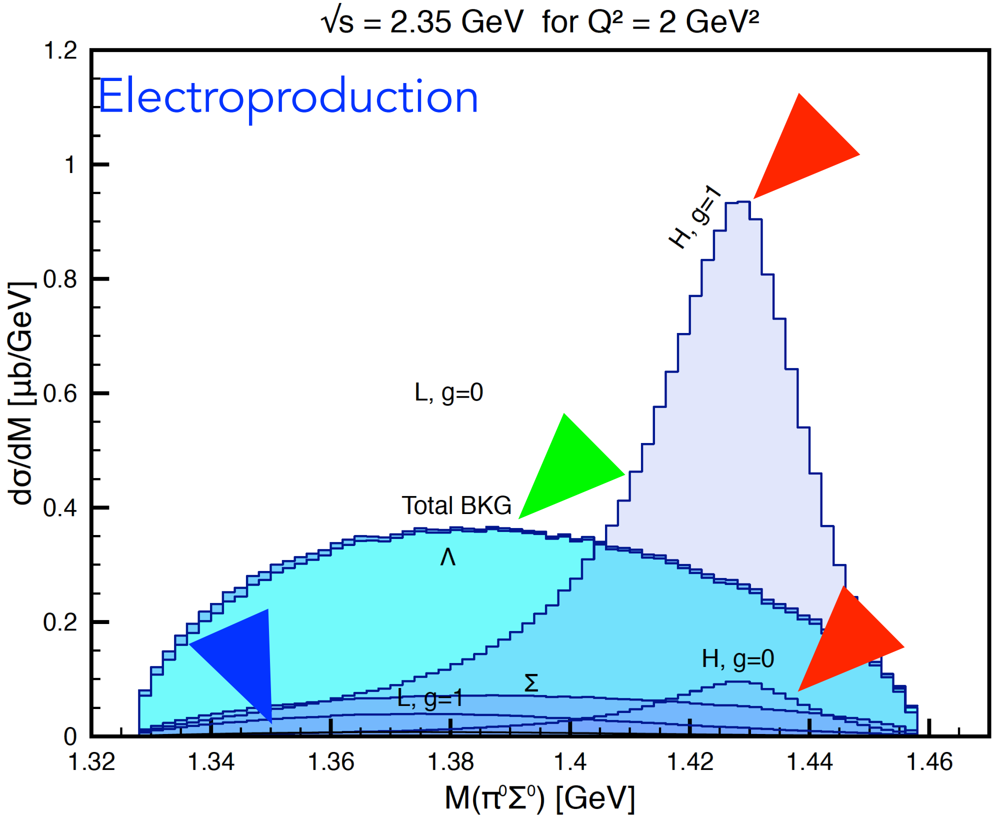
Numerical results

Each contribution for Q^2=0 and Q^2>0 GeV^2 at Ecm=2.35 GeV

	$g_{KN\Lambda_H}$	$g_{K^*N\Lambda_H}$	$g_{\pi\Sigma\Lambda_H}$	$g_{KN\Lambda_L}$	$g_{K^*N\Lambda_L}$	$g_{\pi\Sigma\Lambda_L}$
$g=0$	$2.4+1.1i$	$0.0+i0.0$	$-0.2-1.4i$	$1.4-1.6i$	$0.0+0.0i$	$-2.3+1.4i$
$g=1$	$2.4+1.1i$	$0.1-0.9i$	$-0.2-1.3i$	$1.4-1.6i$	$-0.4+0.1i$	$-2.3+1.5i$

M_H	Γ_H	M_L	Γ_L
1430 MeV	30 MeV	1376 MeV	126 MeV





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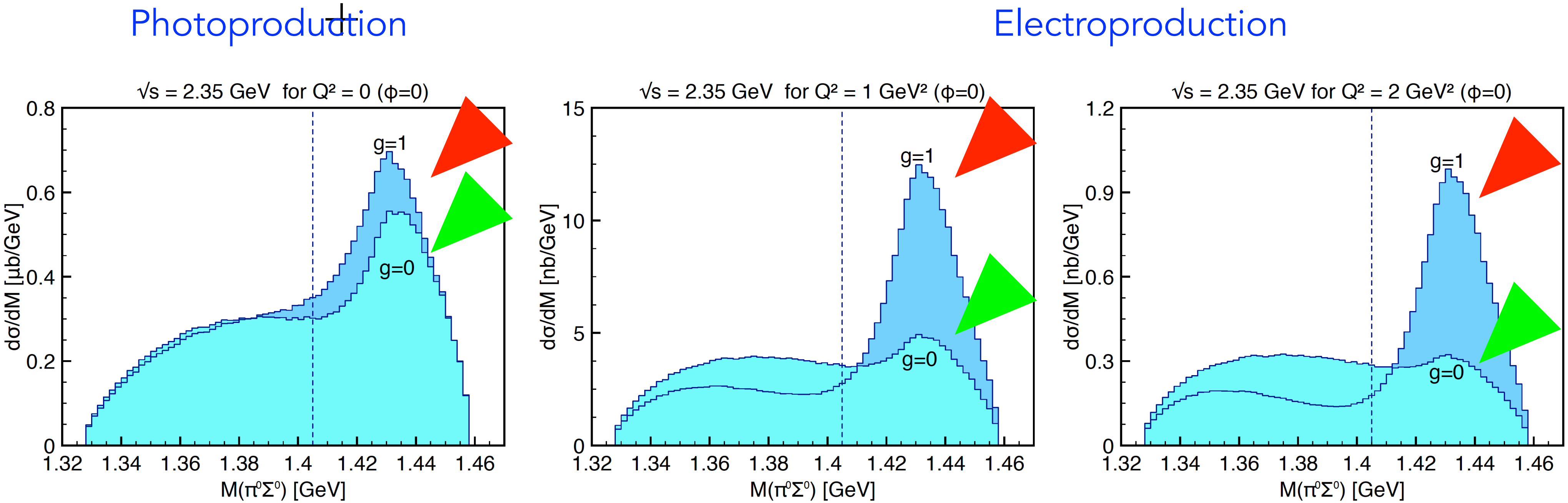


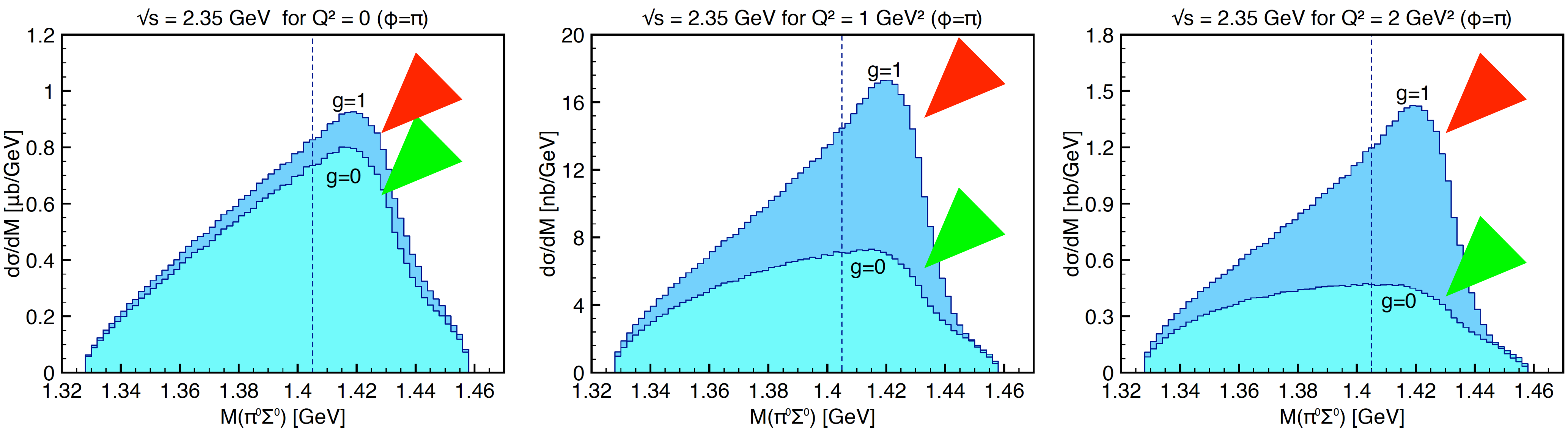
With K* exchange vs. Without K* exchange

Numerical results

Each contribution for Q^2=0 and Q^2>0 GeV^2 at Ecm=2.35 GeV

Photoproduction

Electroproduction



With K* exchange vs. Without K* exchange

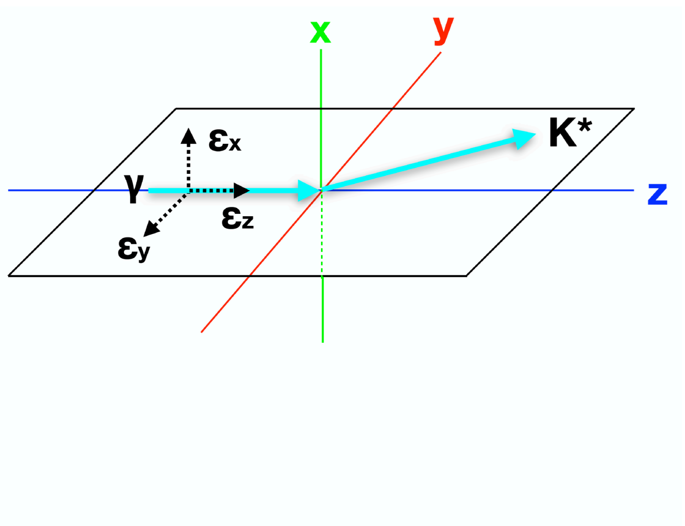
Numerical results

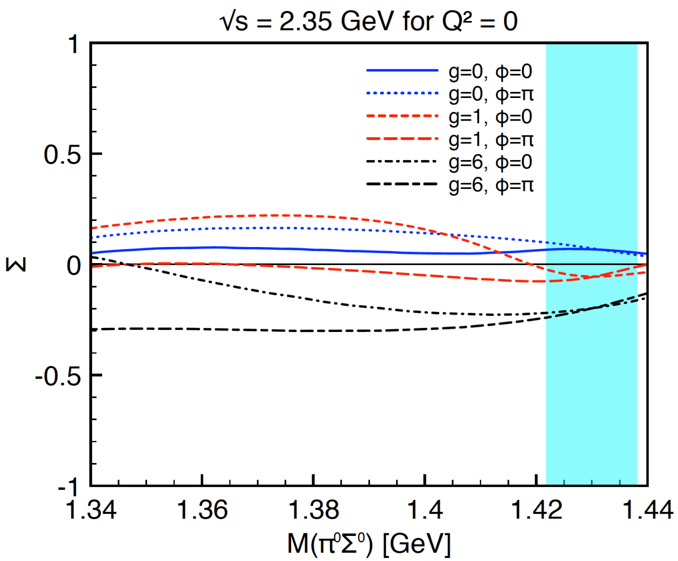
Each contribution for Q^2=0 and Q^2>0 GeV^2 at Ecm=2.35 GeV

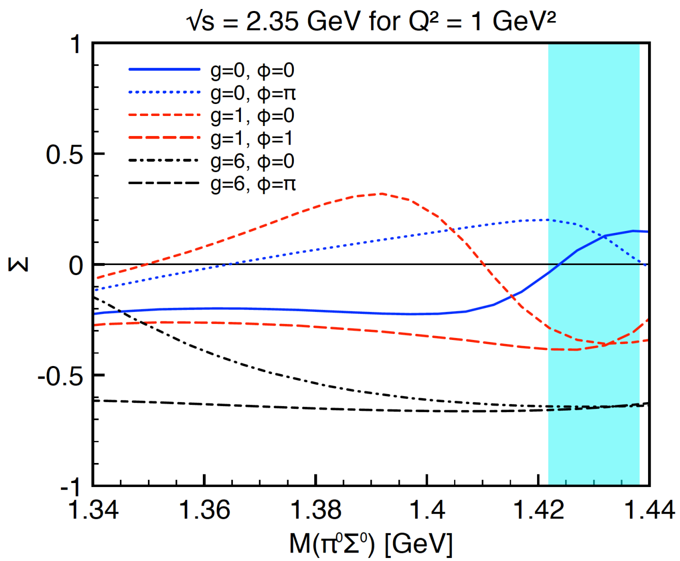
$$\Sigma(M_I) = \frac{d\sigma_x/dM_I - d\sigma_y/dM_I - d\sigma_z/dM_I}{d\sigma_x/dM_I + d\sigma_y/dM_I + d\sigma_z/dM_I},$$

Photoproduction

Electroproduction







Summary, conclusion, and perspectives

K* photo and electroproductions are studied

Higher-pole and BKG dominate:
No single or double bump observed in K productions

If K*N Λ* coupling is negligible, no peak observed in electroproduction, whereas photoproduction shows it at M_{INV} ~ 1430 MeV

If K*N Λ* coupling is sizable, similar invariant mass shapes observed in both at M_{INV} ~ 1430 MeV

Summary, conclusion, and perspectives

These observations based on ChUM, indicating that
Two-pole structure of Λ*

Furthermore, we can extract information of K*N Λ* coupling

How to pin down two-pole structure of Λ* from K* photoproduction?: LEPS2 experiment

Polarization will help!!!! (works in progress)

What are we interested in?

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S.i.N. PRD96, 076021 (2017)

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J.K.Ahn, S.B.Yang, K.S.Choi, S.i.N. In preparation

Motivation

S=-2 Ξ hyperon spectra have not been established

Theoretical contradictions such as Ξ(1620), Ξ(1690)

BaBar experiment assigned Ξ(1690,1/2-) and Ξ(1820,3/2-) almost confirmed: Ξ(1620,??)

N(1535,1/2-) ~ N(1530,3/2-): degenerated spin parter
Λ(1405,1/2-) < Λ(1520,3/2-): ~115 MeV difference
Ξ(1690,1/2-) < Ξ(1820,3/2-): ~ 130 MeV difference

Ξ(1690,1/2-) can be molecular?

Motivation

Ξ(1690,1/2-) from Λc → Λ K_s0 K+ in Belle/Belle-II, LHCb

Interference Ξ(1690,1/2-) and a0(980) unavoidable

K- p → K+ K- Λ can control interference by Ecm

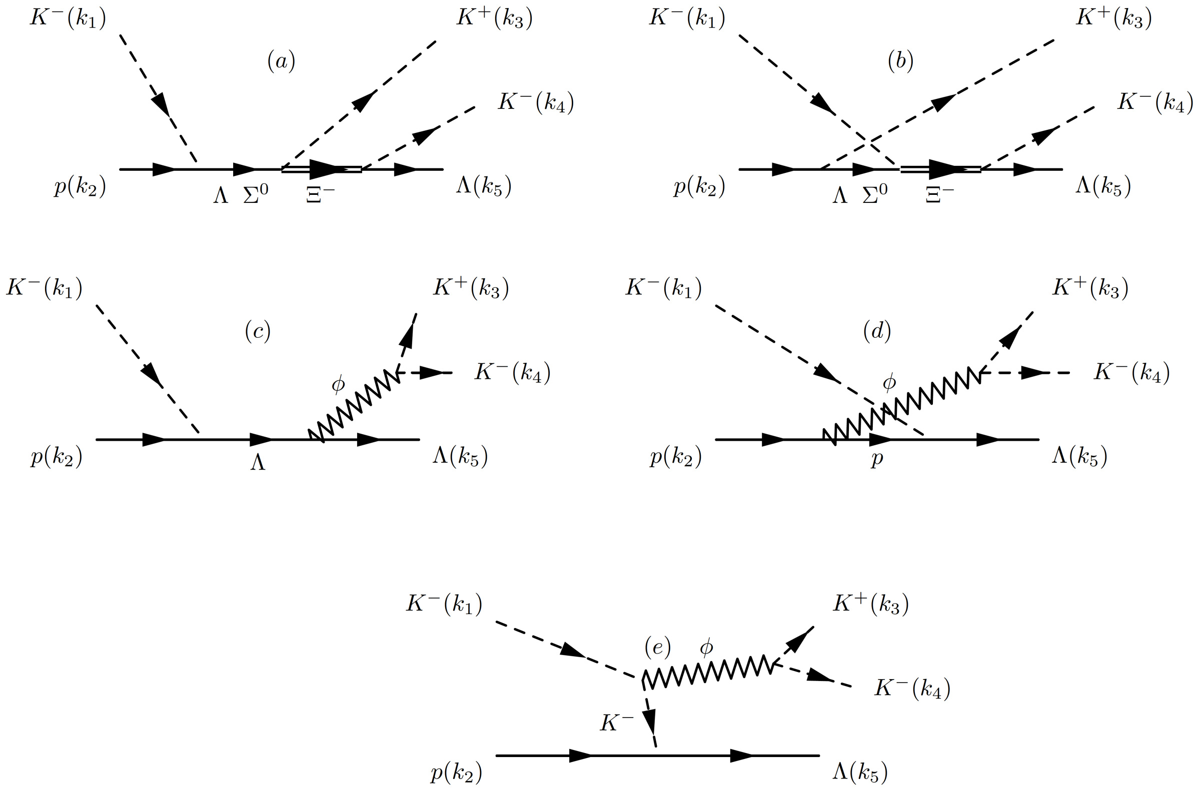
Narrow φ(1020) can be isolated easily

Old K- p → K+ K- Λ BC data focusing on Ξ(1820)

Experimental and theoretical guides for Ξ(1690,1/2-)
in K- p → K+ K- Λ at J-PARC

Theoretical framework

Effective Lagrangian approach at tree-level Born approx.



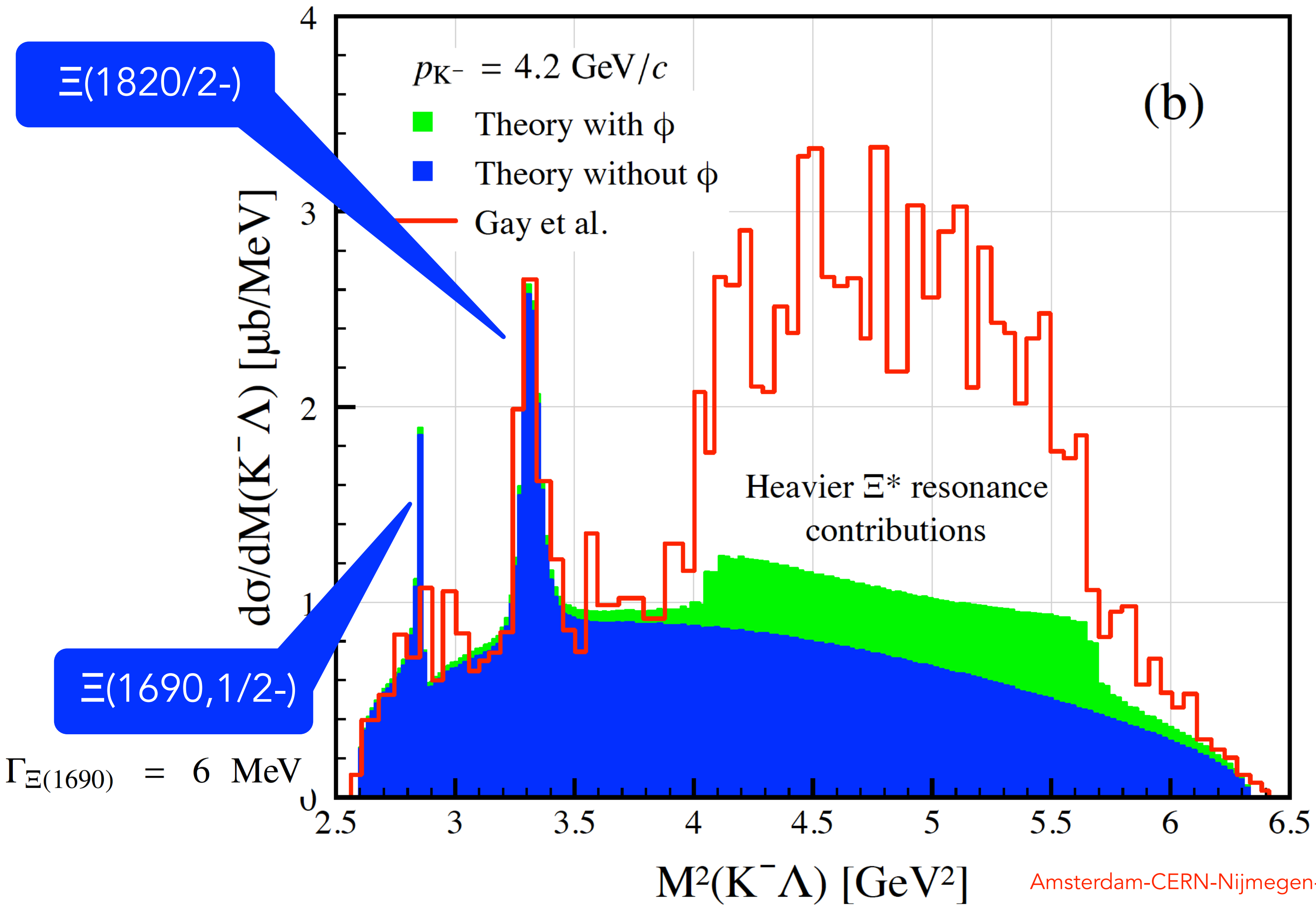
$$F_{\Xi,\phi}(x) = \frac{\Lambda^4_{\Xi,\phi}}{\Lambda^4_{\Xi,\phi} + (x - M_x^2)^2}, \quad \text{for} \quad x = (s,u,t),$$

$$i\mathcal{M}_{\text{total}} = ie^{i\pi/2}\mathcal{M}_{\Xi_{3/2}} + ie^{i3\pi/2}\mathcal{M}_{\Xi_{1/2}} + i\mathcal{M}_\phi$$

(M, J^P)	$\Lambda(1116, 1/2^+)$	$\Lambda(1405, 1/2^-)$	$\Lambda(1520, 3/2^-)$	$\Lambda(1670, 1/2^-)$	$\Sigma(1193, 1/2^+)$	$\Sigma(1385, 3/2^+)$
$N(938, 1/2^+)$	−13.24 [22]	0.91 [21]	−10.90 [1]	0.30 [20]	3.58 [22]	−3.22 [21]
$\Xi(1322, 1/2^+)$	3.52 [22]	0.91 [21]	3.27 [21]	−0.18 [20]	−13.26 [22]	−3.22 [21]
$\Xi(1532, 3/2^+)$	4.08	–	–	–	3.22	–
$\Xi(1690, 1/2^-)$	−0.3 [8]	–	–	–	1.8 [8]	–
$\Xi(1820, 3/2^-)$	6.10 [5]	–	–	–	8.00 [5]	–

Numerical results

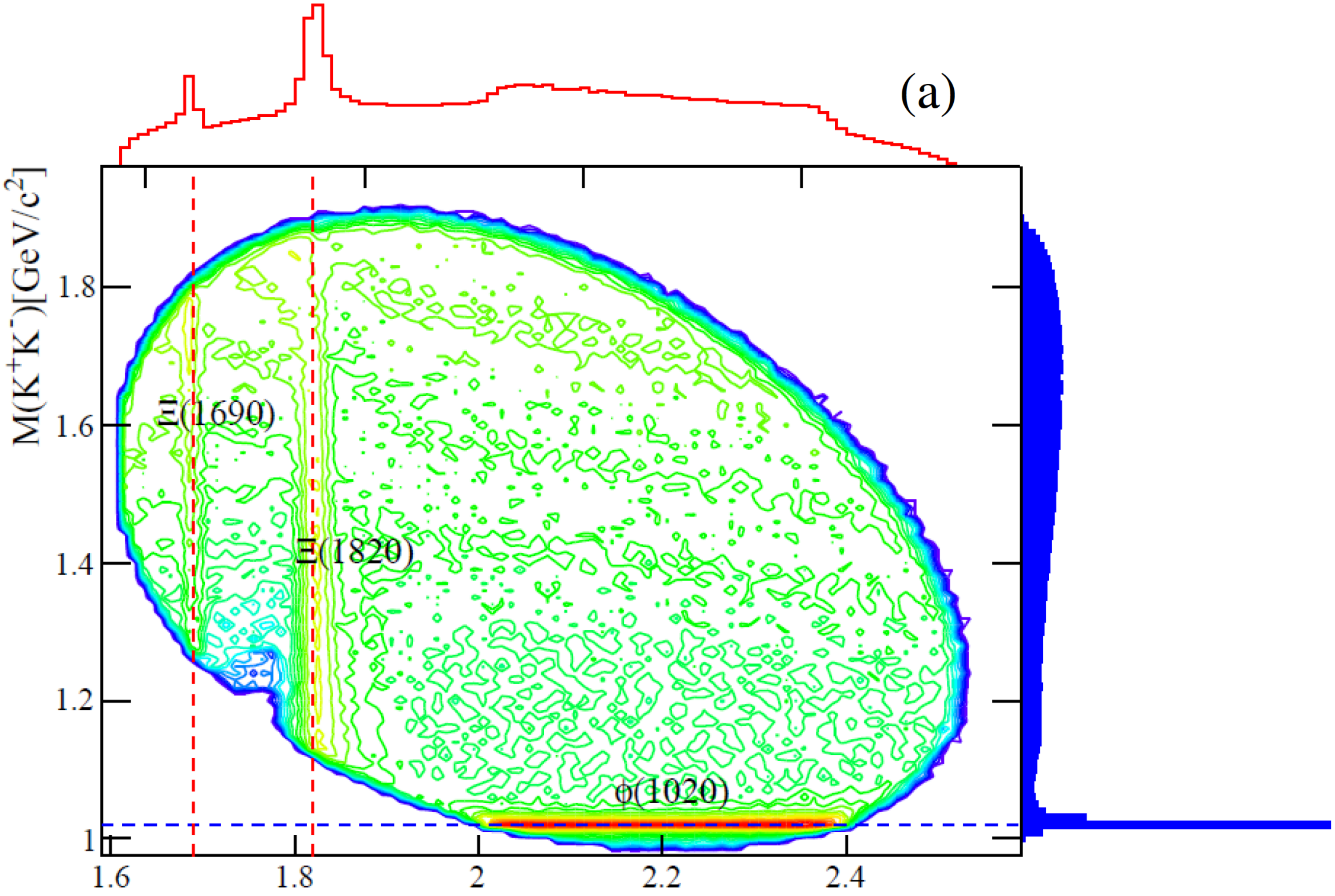
Invariant mass plot: Significant φ contribution



Amsterdam-CERN-Nijmegen-Oxford Collaboration

Numerical results

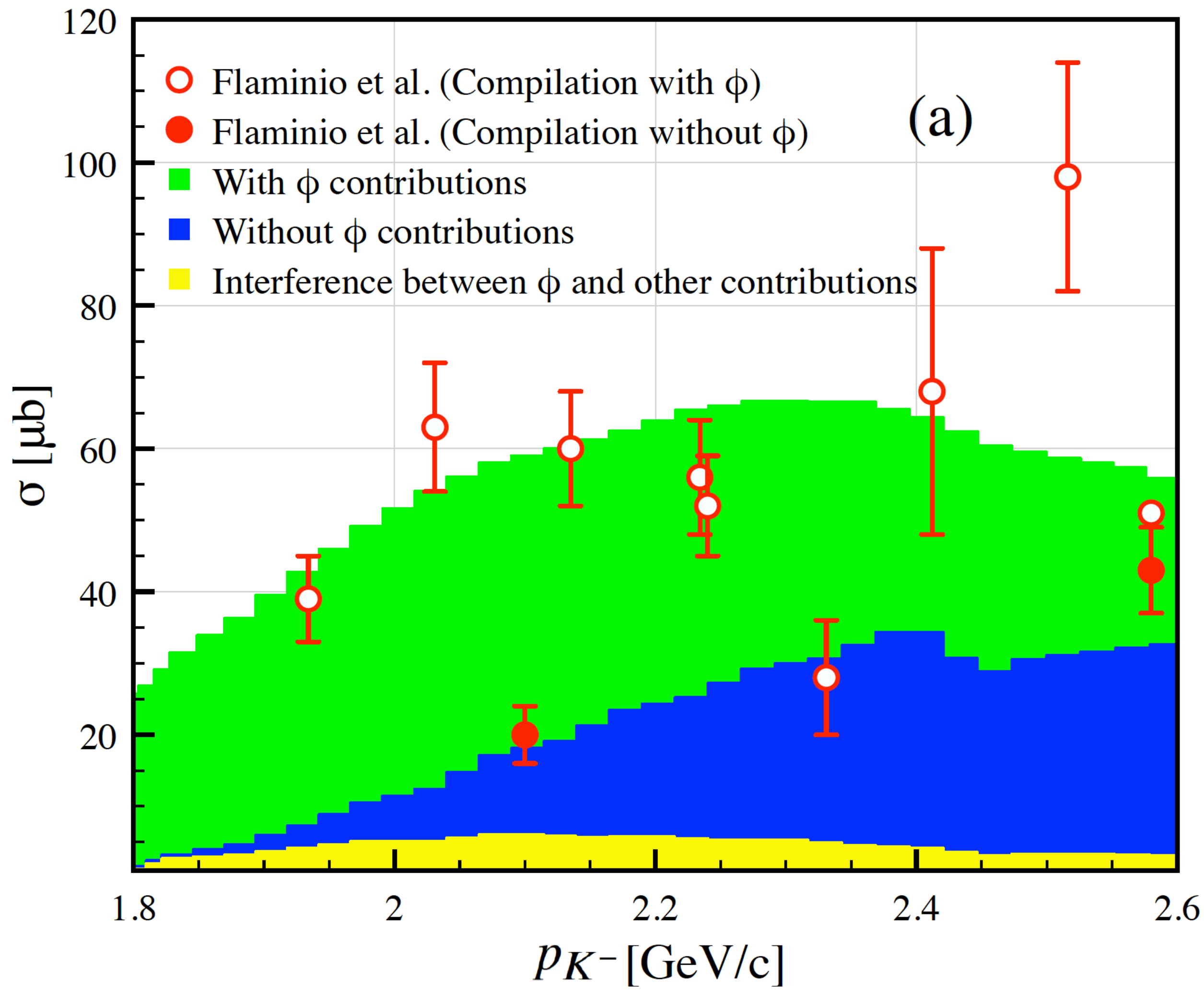
Dalitz plot: Negligible interference (merits of production)



Numerical results

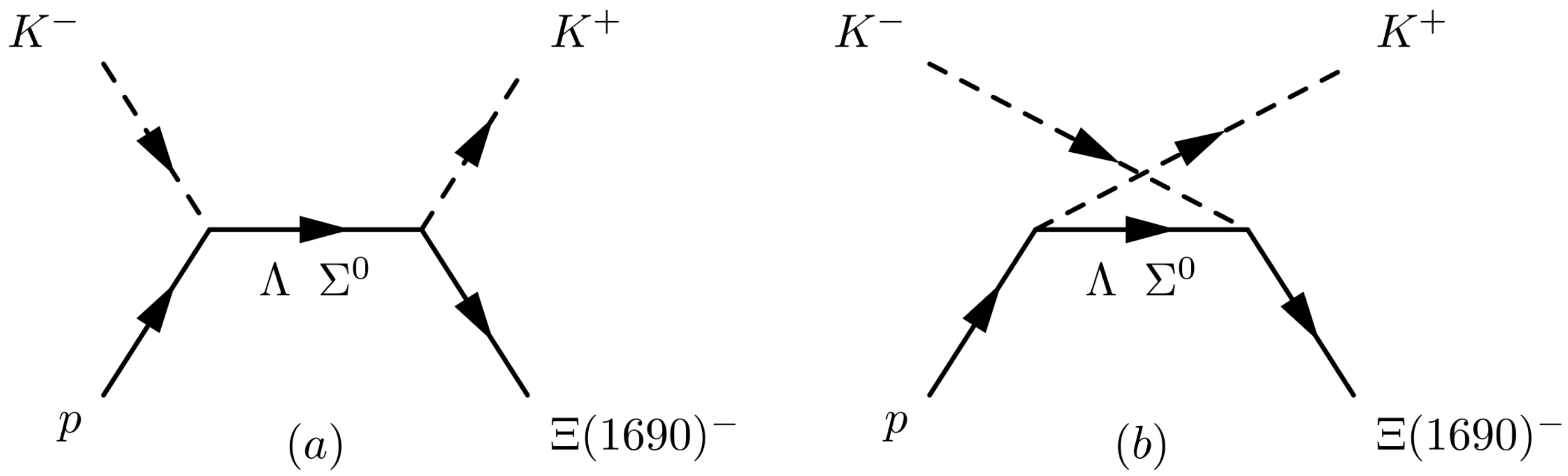
All the model parameters determined then…

Qualitative agreement with other data!!!



Numerical results

The model parameters applied to K- p → K+ Ξ-(1690)

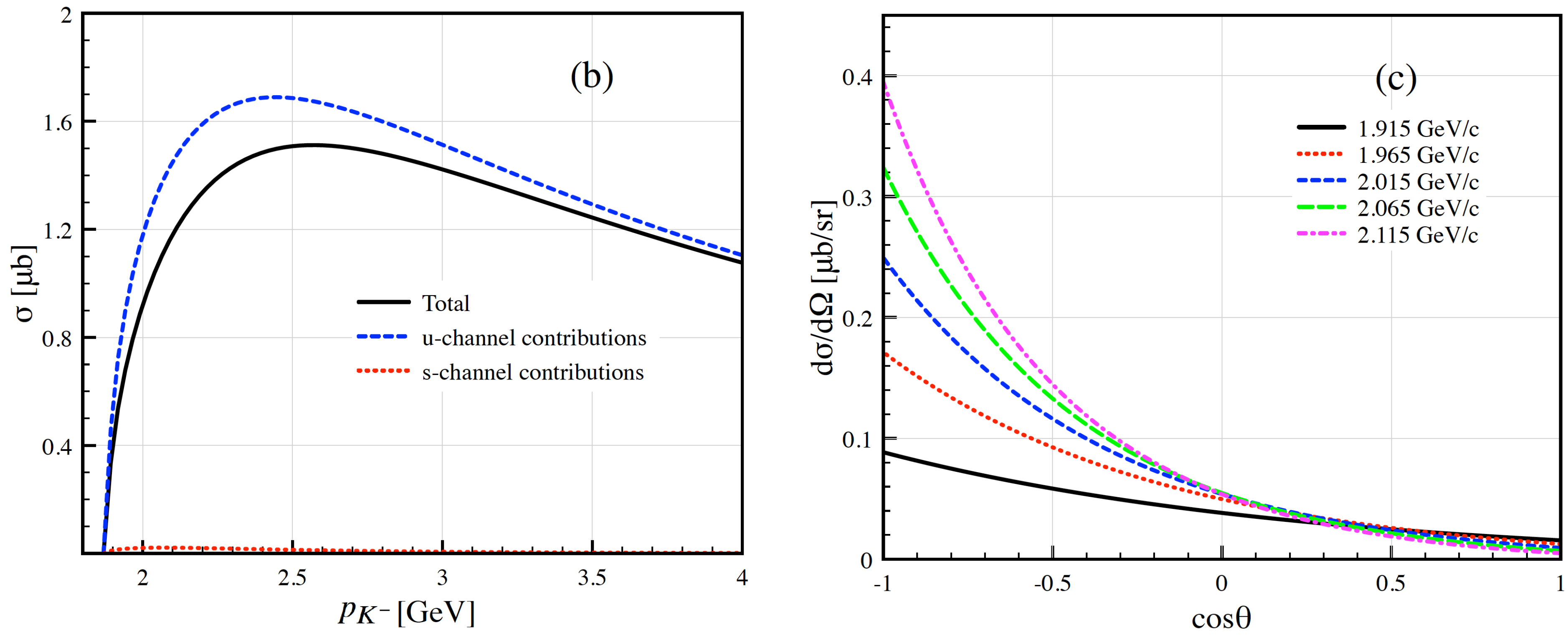


No S=-2 meson makes problem much easier

No hyperon Regge: Is it necessary?!?!

Numerical results

The model parameters applied to K- p → K+ Ξ-(1690)



u-channel dominates ~ 1 μb

Measurable at J-PARC: P_{K-} = 1.878 GeV at threshold

Numerical results

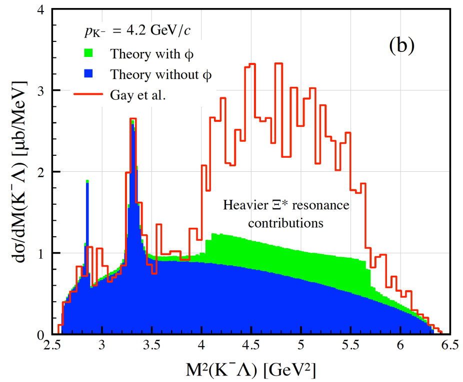
Strong backward scattering of K+ in cm frame due to u-channel dominance

Experimentally Ξ-(1690) decays into Σ- K0, Σ0 K-, Ξ- π0, Ξ0 π- : Only one neutral decay particle

Easy to reconstruct mass of Ξ-(1690)

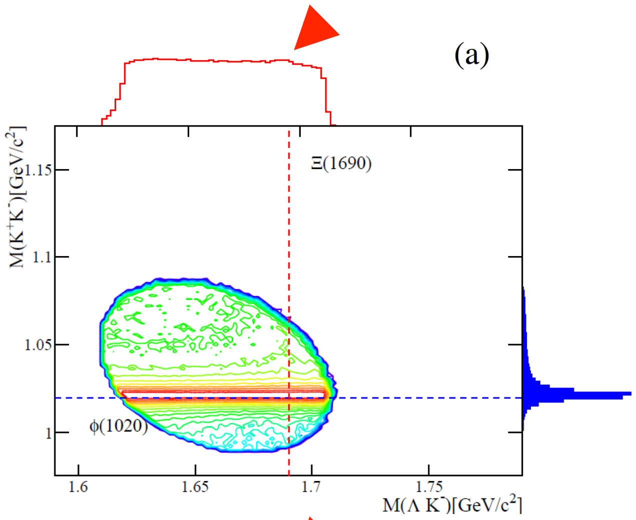
For future experiment at high-intensity K- beam at J-PARC, theory calculations for Dalitz plots are employed to simulate experiment via event generators

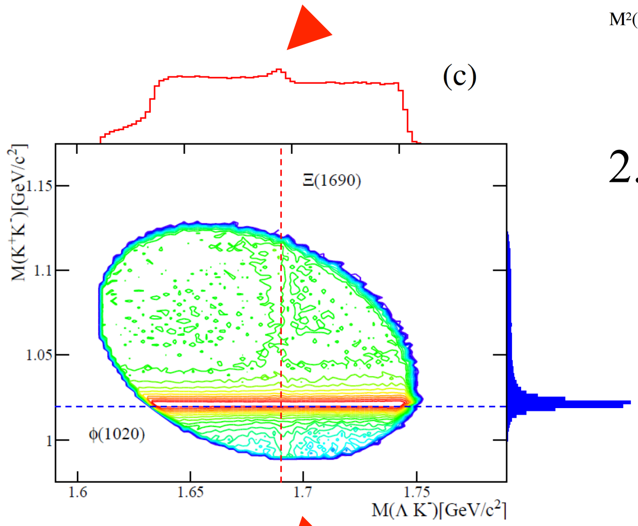
Numerical results



Simulated Dalitz plots based on theory

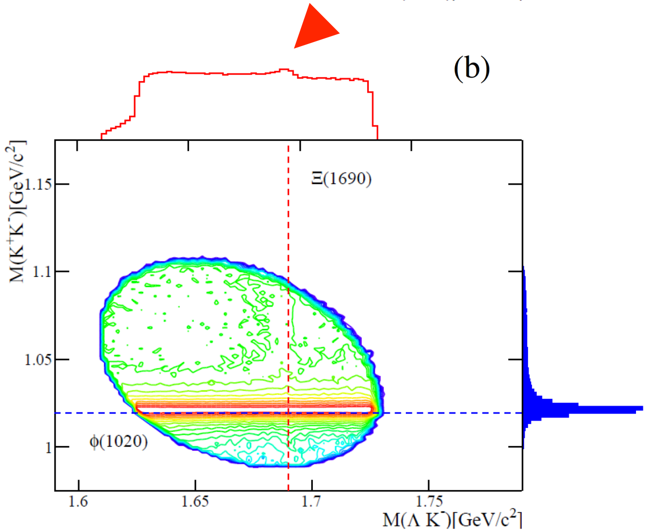
1.915 GeV

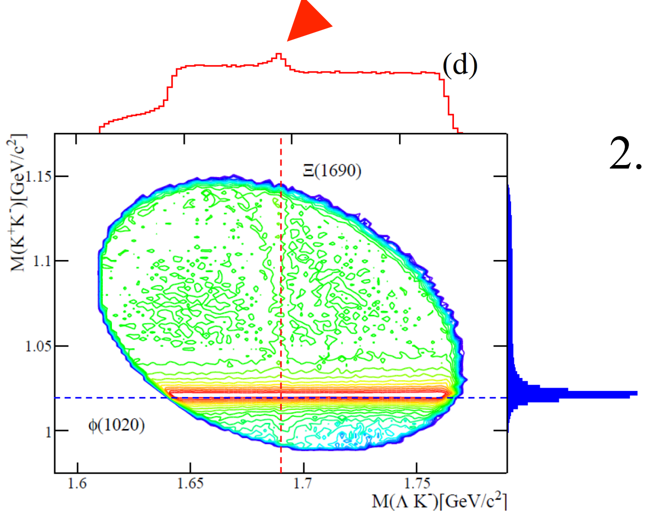




2.015 GeV

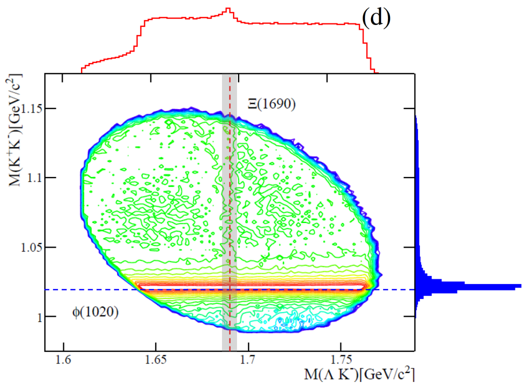
1.965 GeV



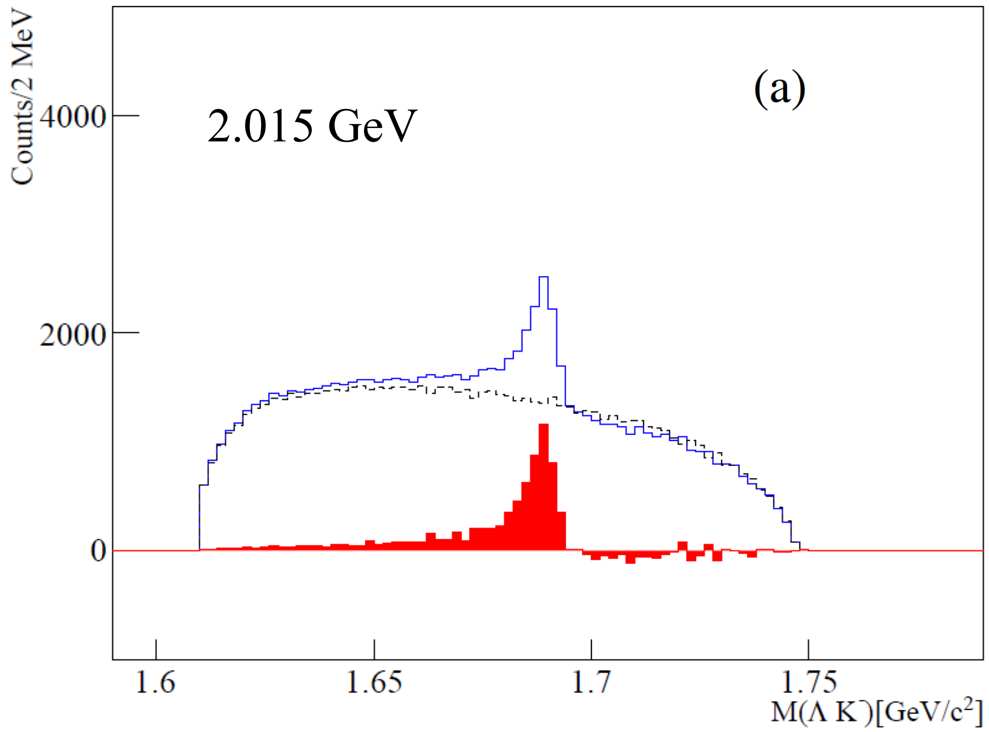


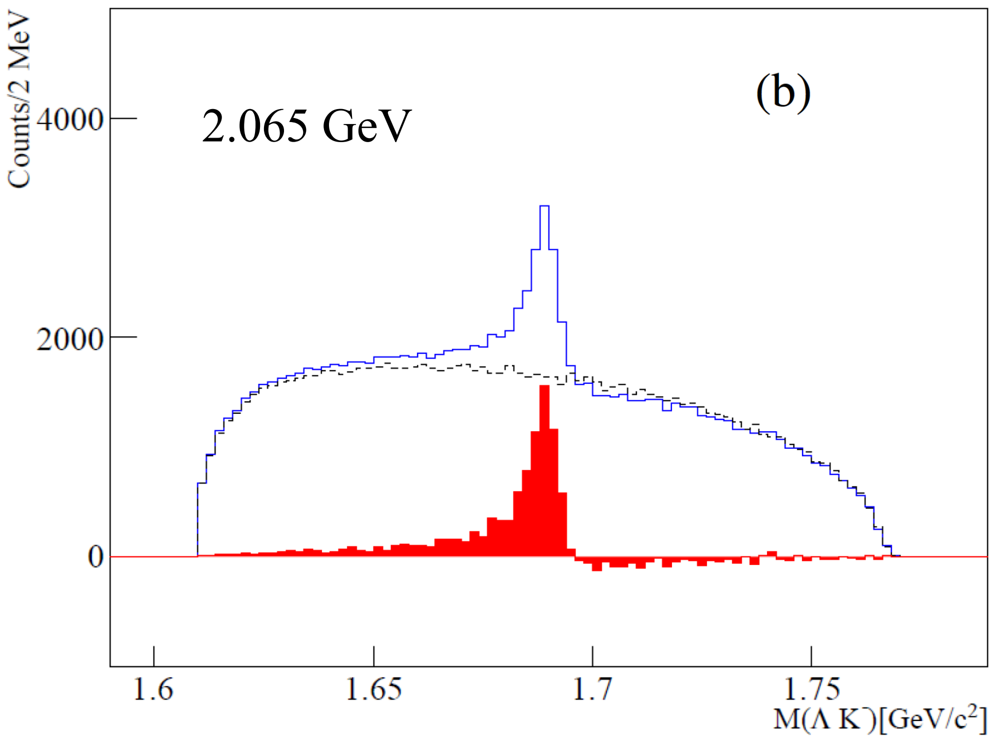
2.065 GeV

Numerical results



Simulated Dalitz plots excluding φ(1020)



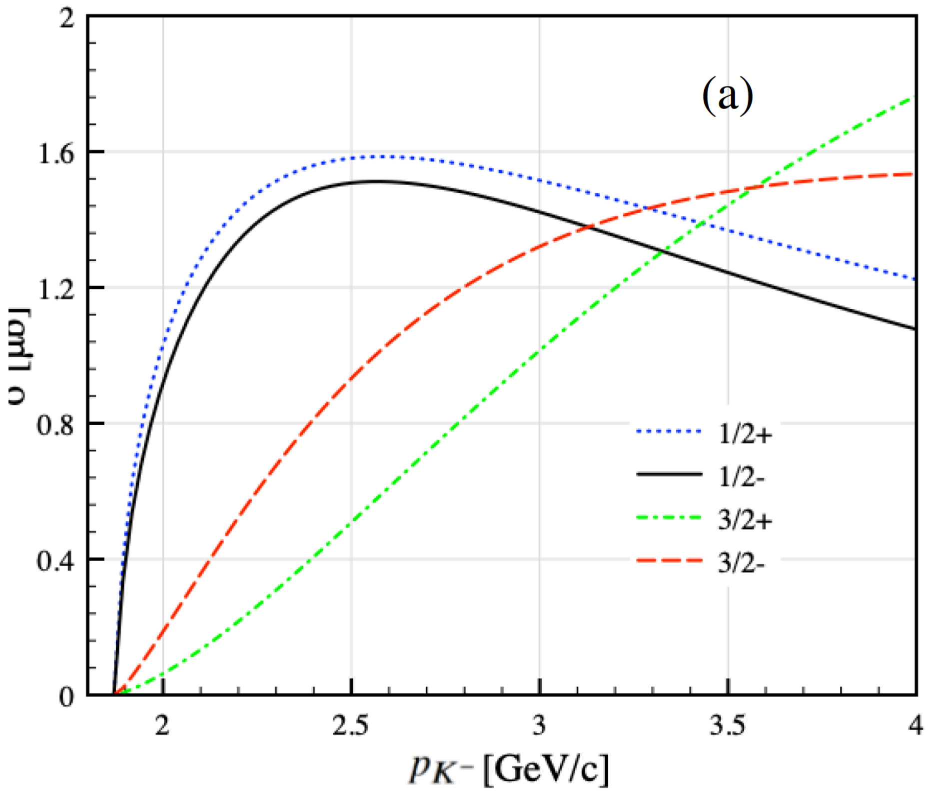


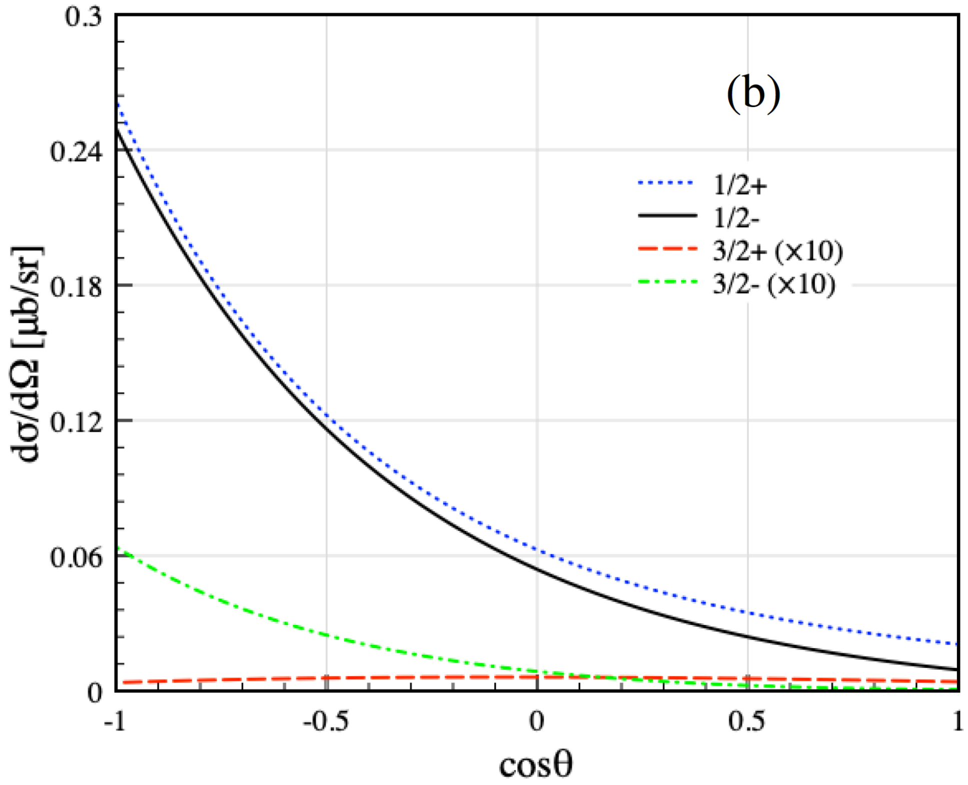
Clear peak with Ξ-(1690) and interference

Numerical results

Different spin-parity states of Ξ(1690)

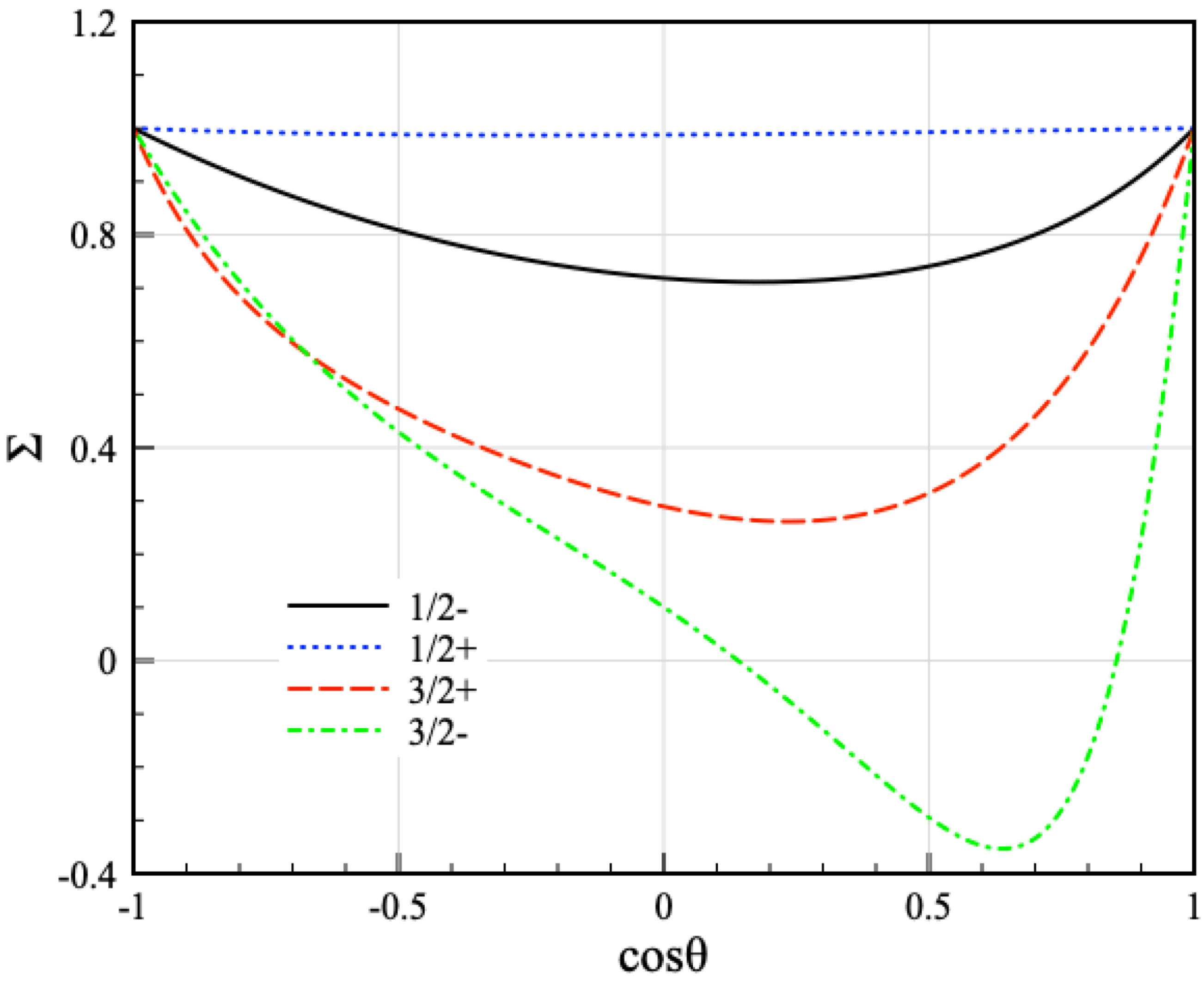
$$\frac{\Gamma_{\Xi(1690)\to\bar{K}\Lambda}}{\Gamma_{\Xi(1690)}} = 0.271, \quad \frac{\Gamma_{\Xi(1690)\to\bar{K}\Sigma}}{\Gamma_{\Xi(1690)}} = 0.533.$$





Numerical results

Double polarization asymmetry $\Sigma(s_R) = \frac{d\sigma_\uparrow/d\Omega - d\sigma_\downarrow/d\Omega}{d\sigma_\uparrow/d\Omega + d\sigma_\downarrow/d\Omega}.$



Summary, conclusion, and perspectives

Ξ-(1690) production with K- beam studied
Effective Lagrangian method at tree-level Born approx.
All the parameters determined by Dalitz process

K- p → K+ Ξ-(1690) shows **σ** ~ 1 μb and backward scattering enhancement due to u-channel contribution

Simulated Dalitz and invariant mass plot via event generators based on theory: Clean peak for Ξ-(1690) after **φ** exclusion

Reliable guides for future J-PARC experiments

Thank you for your attention!

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