Studies on the $K^*\Sigma$ bound-state via $K^+ p \to K^+ \phi p$

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Contents based on

S.H.Kim and SiN, PRC100, 065208 (2019), PRC101, 065201 (2020)
SiN, PRD103, 054040 (2021)

Why is polarizations?

Hadron productions for understanding of low-E QCD.

New particle search, particle properties, new physics, etc..

How to single out what we want from various observables?

Symmetry and invariance: Gauge, chiral, charge, etc..

Dynamics: Coupling, structure, Regge, etc..

More constraints provide more definite information.

Polarizations of particle spin provide good testing grounds.

It can be achieved in experiments (beam, target, recoil, scattered).

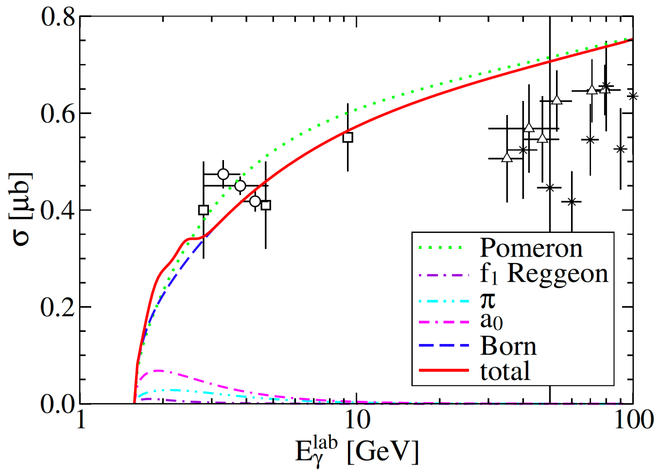
In this presentation, we will explore the followings for this purpose:

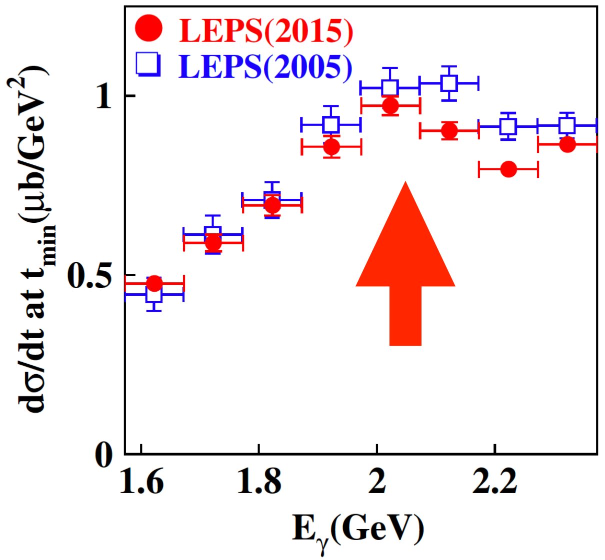
$\gamma^* p \to \phi p$ and $K^+ p \to K^+ \phi\, p$

Photo- and electro-productions of hadrons

S.H.Kim, SiN, PRC100 (2019) PRC101 (2020)

φ meson EM productions: Interesting physical contents





Diffractive Gluonic exchange via DL Pomeron
Donnachie-Landshoff (DL)

High-E behavior dominated by Pomeron.

Interferences between 1st and 2nd Pomerons?
Brodsky et al. PLB461 (1999)

Unidentified peak at 2.0~ 2.1 GeV. LEPS & CLAS

Resonance, bound state (ΣK*?), interference,

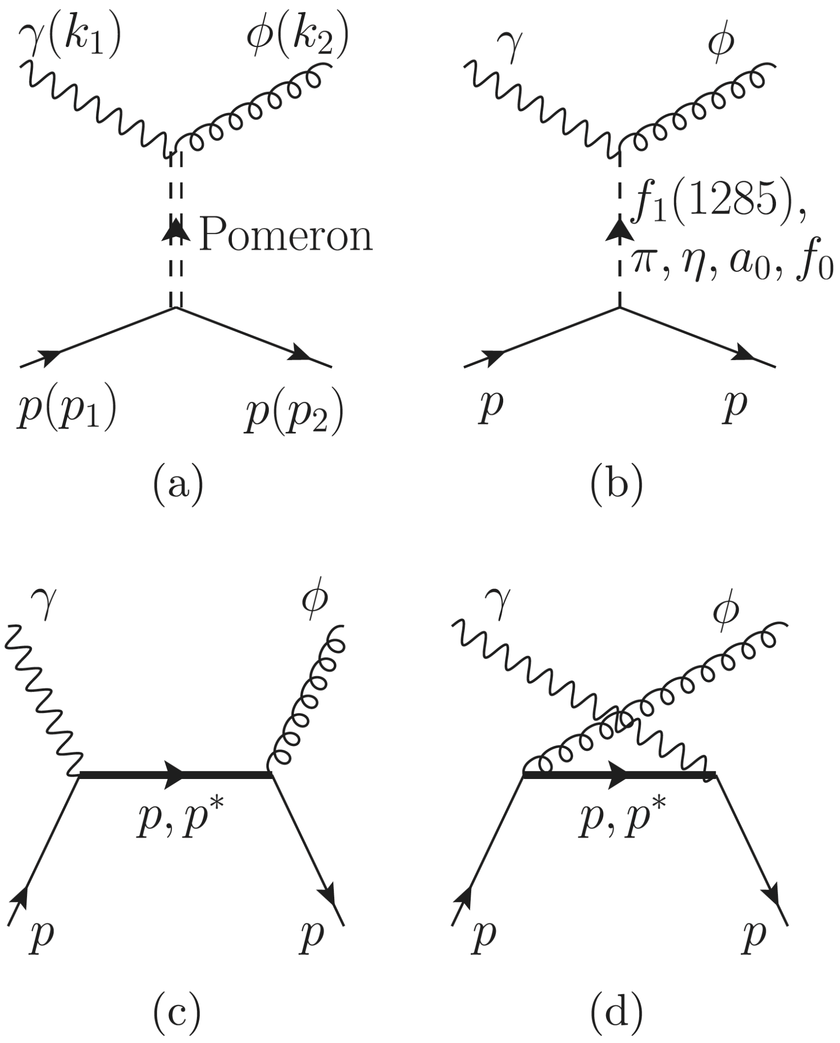
quantum fluctuation, channel-opening, etc?

Full polarizations of involved particles:

Various physical constraints.

Photo- and electro-productions of hadrons

How can we extract contributions other than Pomeon?: Polarizations



C=+1 vector-like (soft) Pomeron with

$$\alpha_{\mathbb{P}}(t) = 1 + \epsilon_{\mathbb{P}} + \alpha'_{\mathbb{P}} t,$$

$$\epsilon_{\mathbb{P}} = 0.08, \quad \alpha'_{\mathbb{P}} = 0.25\,\mathrm{GeV}^{-2}$$

PS, S (new), AV (new) mesons in t-channel with Regge trajectories.

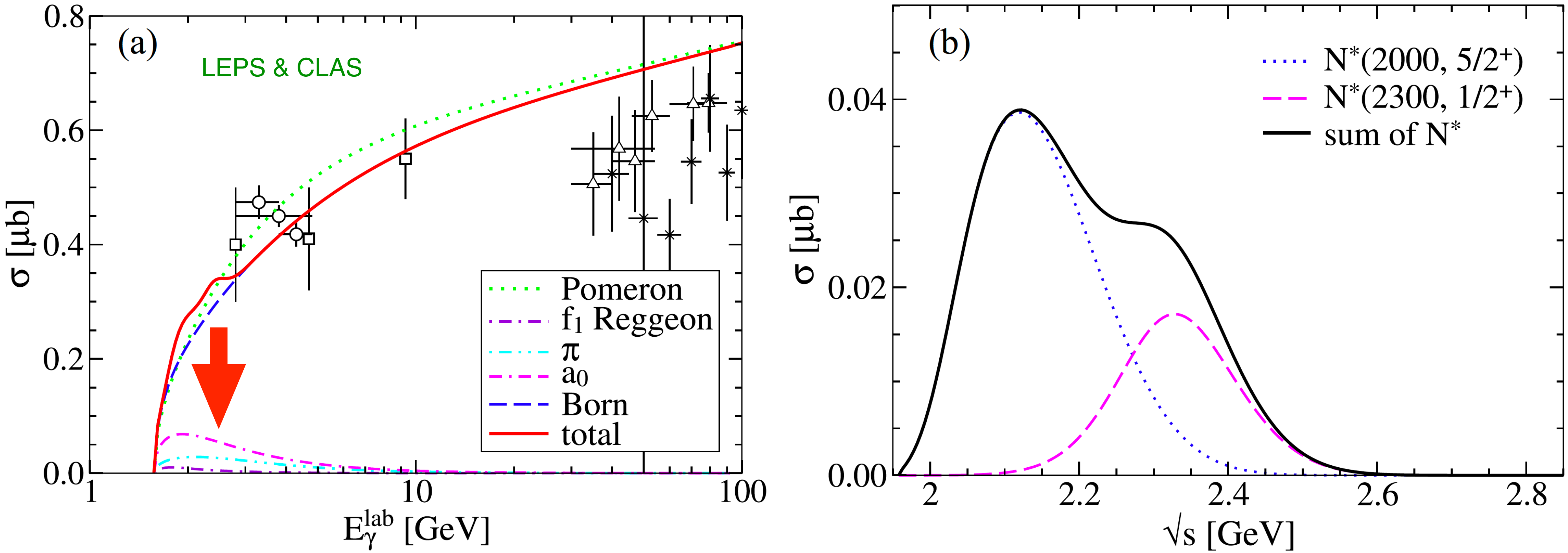
N* in s- and u-channels: N*(2000,5/2+) and N*(2300,1/2+).

cf) Pomeron+PS meson:

Conventional Donnachie-Landshoff (DL) model

Photo- and electro-productions of hadrons

Pomeron-dominated cross section for φ-meson EM production



In addition, various meson exchanges provide structure near E_{th}

N* contribution do not clearly seen.

The “Peak” or “Bump” is not reproduced.

Photo- and electro-productions of hadrons

Angular distributions

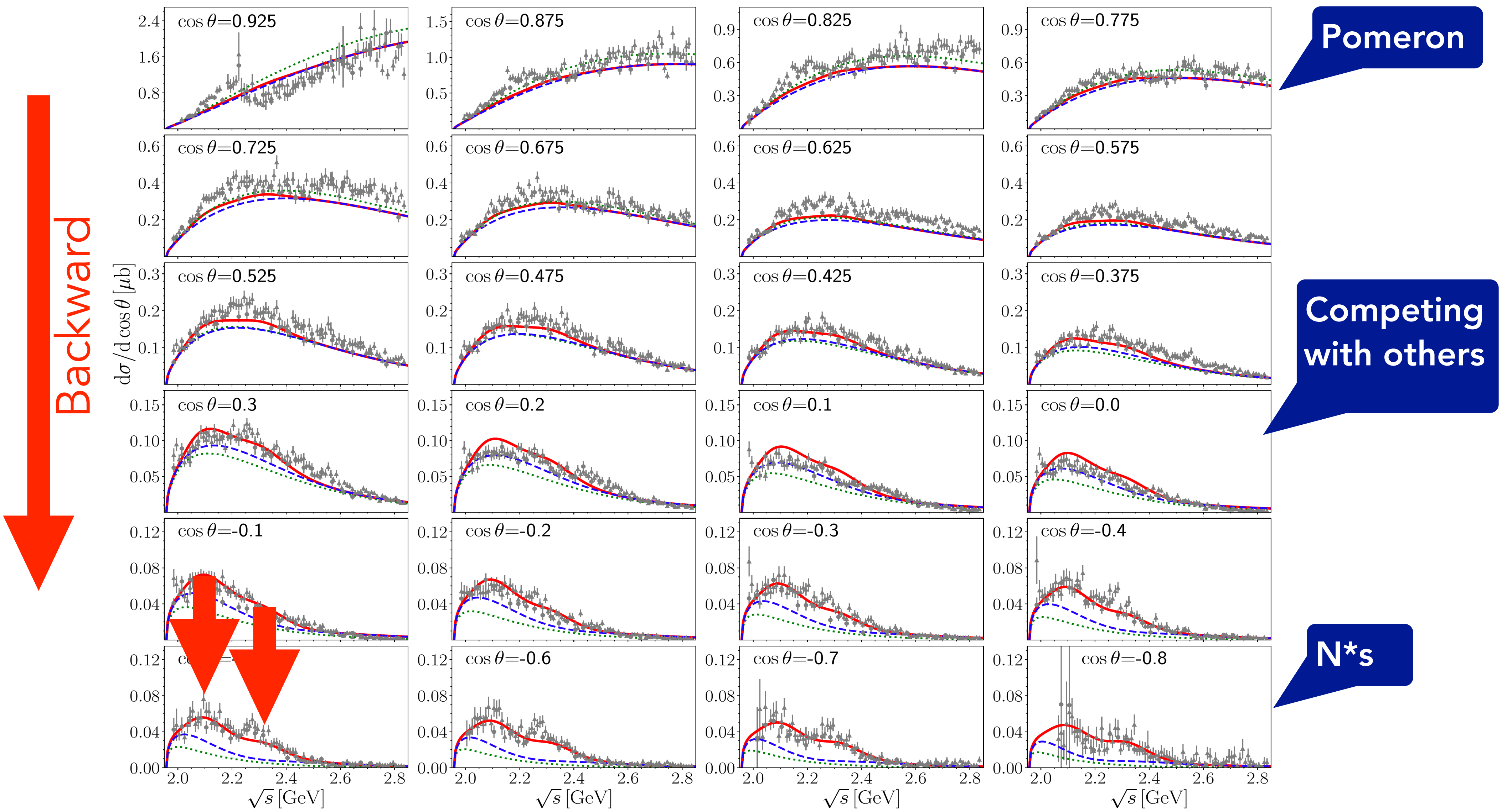
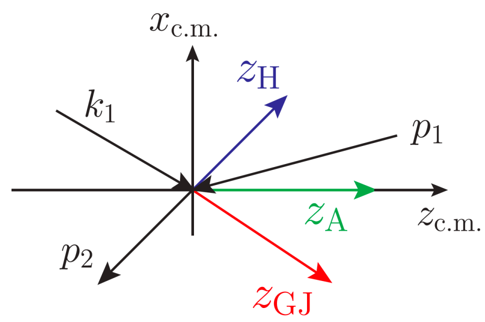


Photo- and electro-productions of hadrons

Non-zero SDME of (helicity, GJ) frame indicates breakdown of (SCHC,TCHC) (X-Channel Helicity Conservation)



$$\rho^0_{00} \propto \left|\mathcal{M}_{\lambda_\gamma=1,\lambda_\phi=0}\right|^2 + \left|\mathcal{M}_{\lambda_\gamma=-1,\lambda_\phi=0}\right|^2$$

Spin density: Manifesting S- & AV-meson contributions.

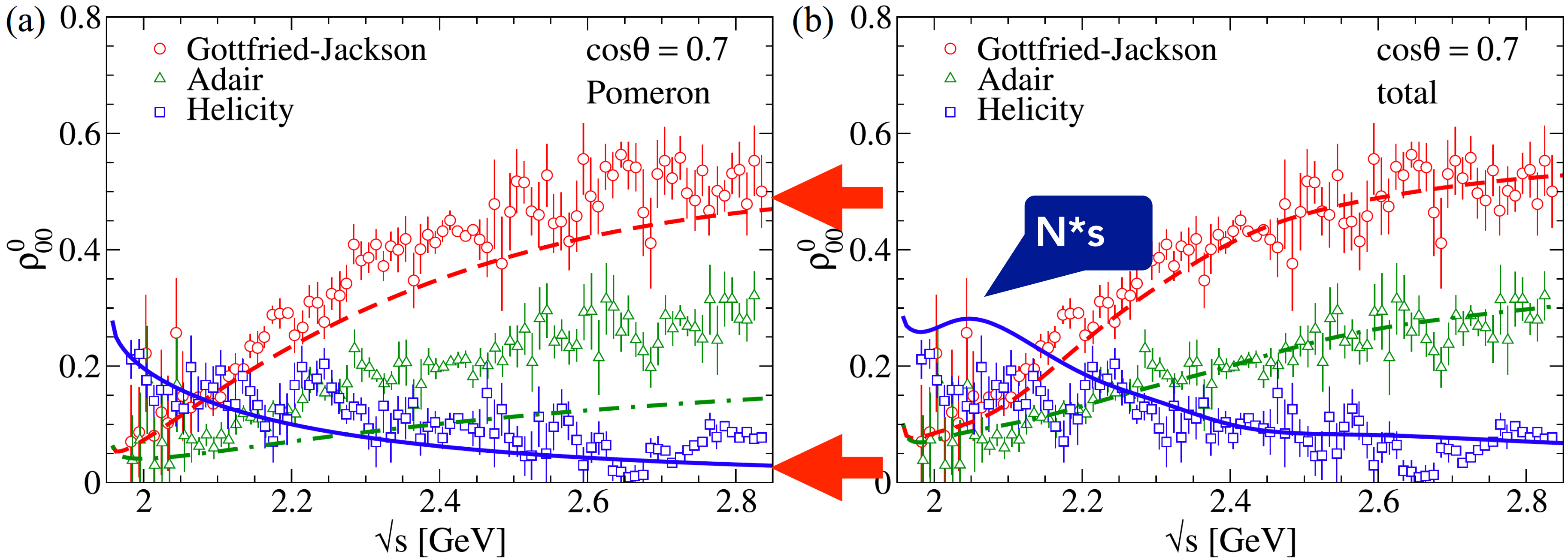
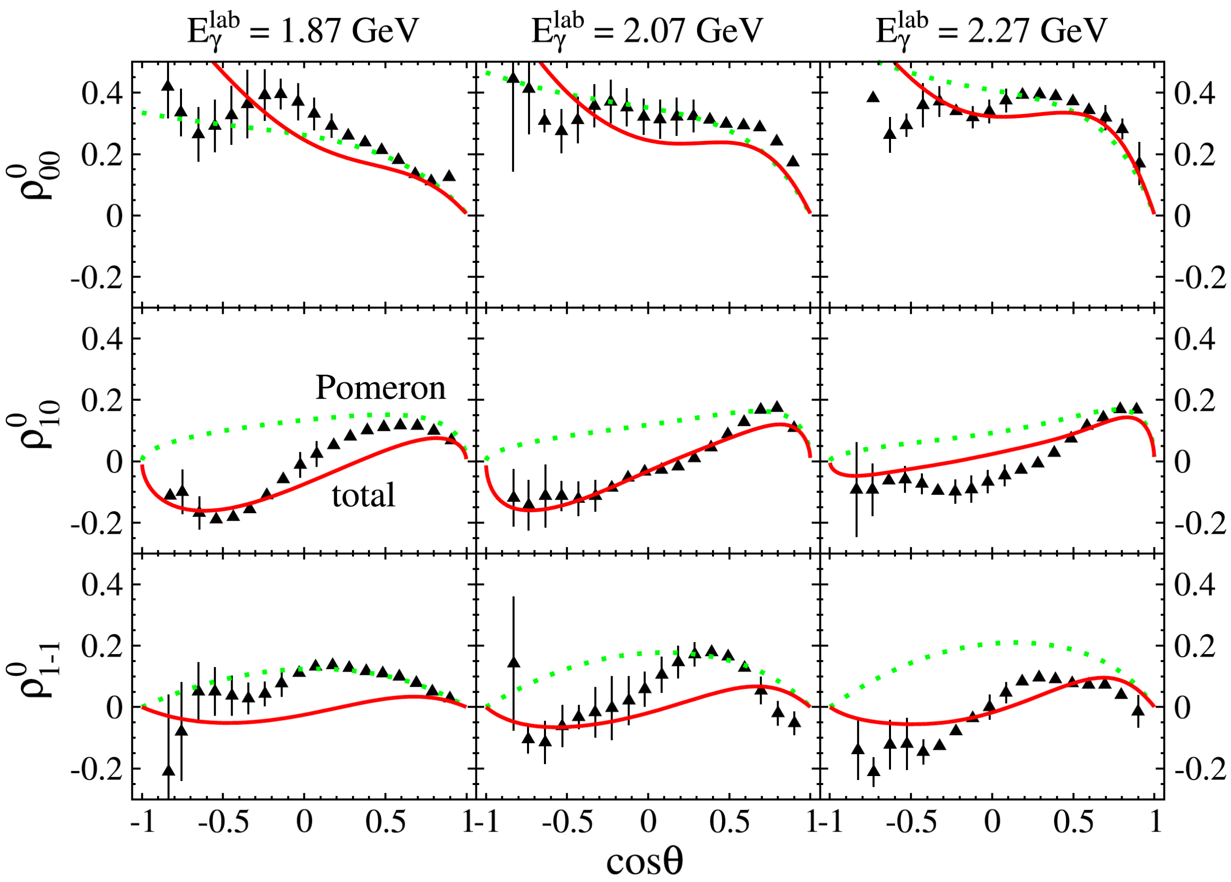


Photo- and electro-productions of hadrons

SDME: Manifesting other contributions (N*s) beyond Pomeron



Forward: Pomeron

Backward: u-channel N*s

In addition to mesons.

Green: Pomeron

Red: Total

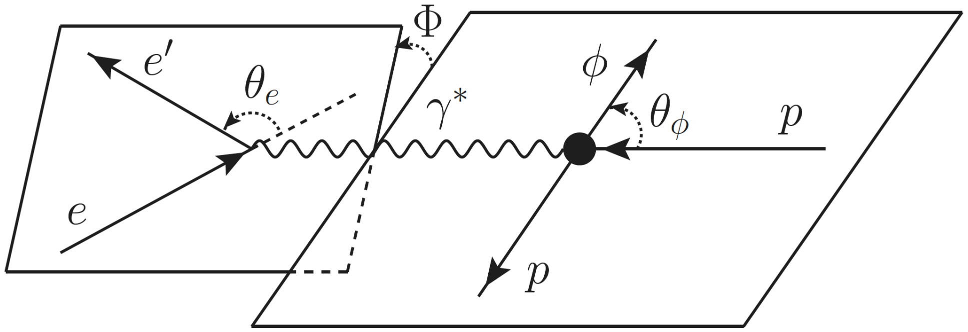
Destructive interference

between them.

G-J frame

Photo- and electro-productions of hadrons

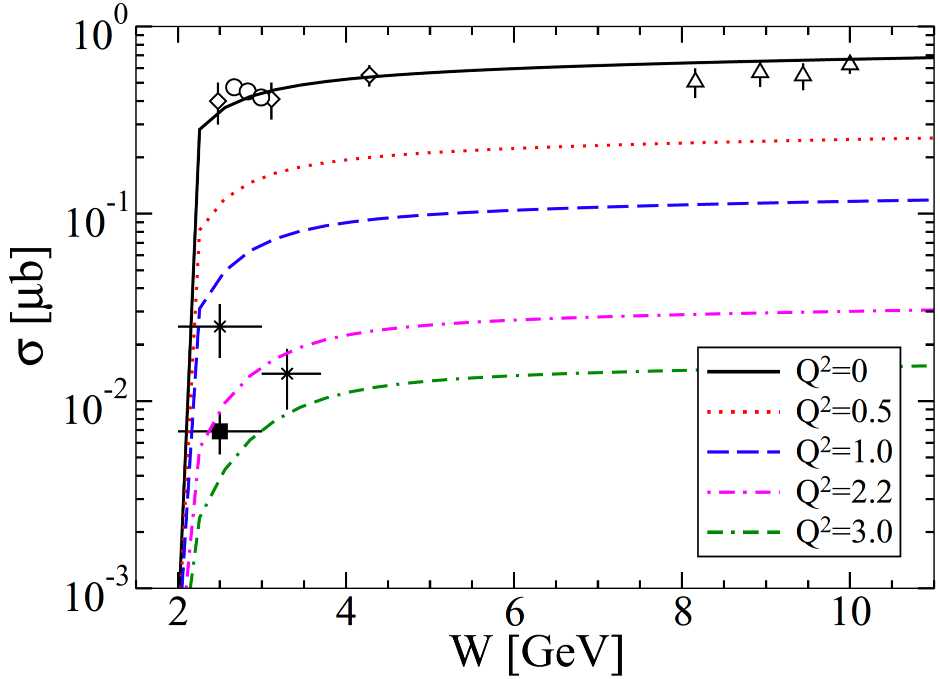
Scalar component of virtual photon in electro-production.



$$\frac{d\sigma}{d\Phi} = \frac{1}{2\pi}\left(\sigma + \varepsilon\sigma_{\mathrm{TT}}\cos 2\Phi + \sqrt{2\varepsilon(1+\varepsilon)}\sigma_{\mathrm{LT}}\cos\Phi\right)$$

$$\sigma = \sigma_{\mathrm{T}} + \varepsilon\sigma_{\mathrm{L}} \qquad \varepsilon = \left[1 + \frac{2k^2}{Q^2}\tan^2\frac{\theta_e}{2}\right]^{-1}$$

Virtual-photon polarization parameter



Theory reproduces data for

$Q^2 = 0$ and $Q^2 = 2.2$ GeV^2 .

Basically, EM form factor strongly

suppresses cross sections.

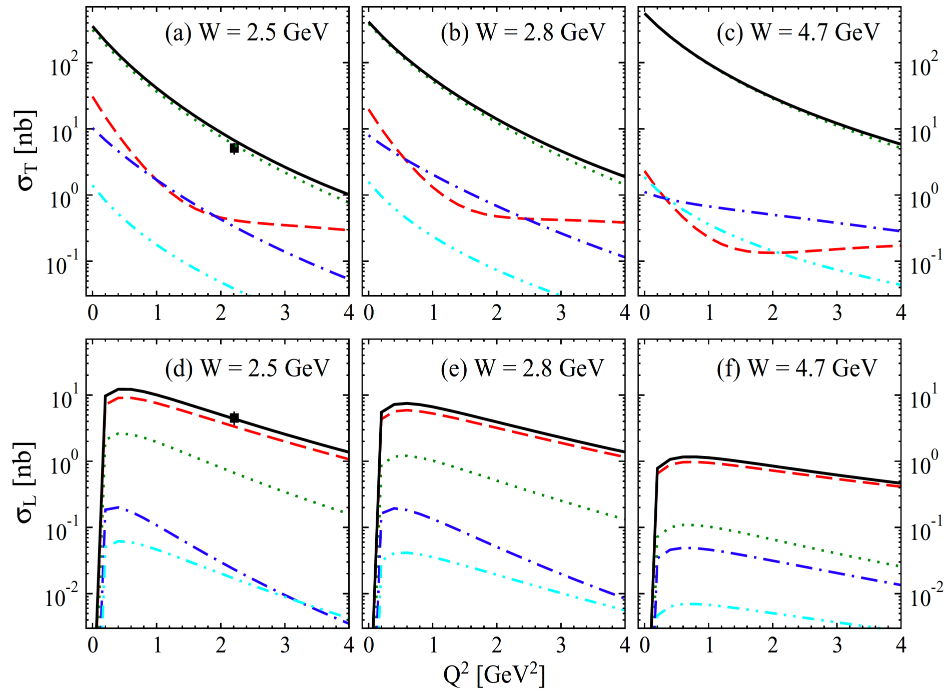
D. G. Cassel et al., PRD24, 2787 (1981)
J. P. Santoro et al. (CLAS Collaboration), PRC78, 025210 (2008).

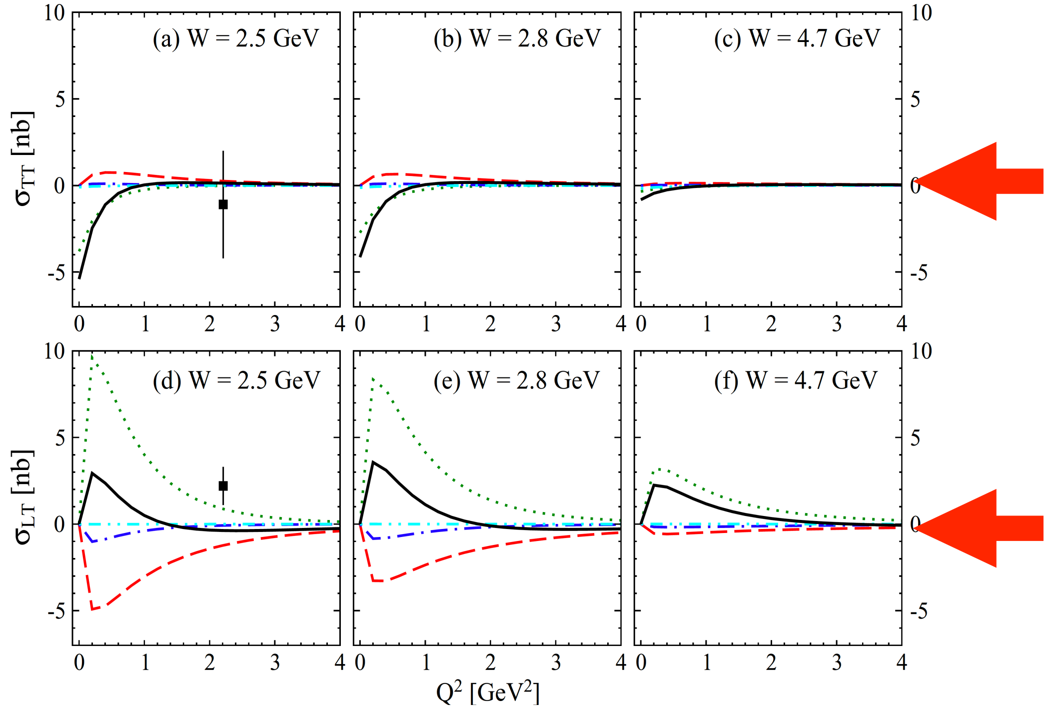
Photo- and electro-productions of hadrons

Longitudinal and transverse components

Green: Pomerol

Red: Scalar meson





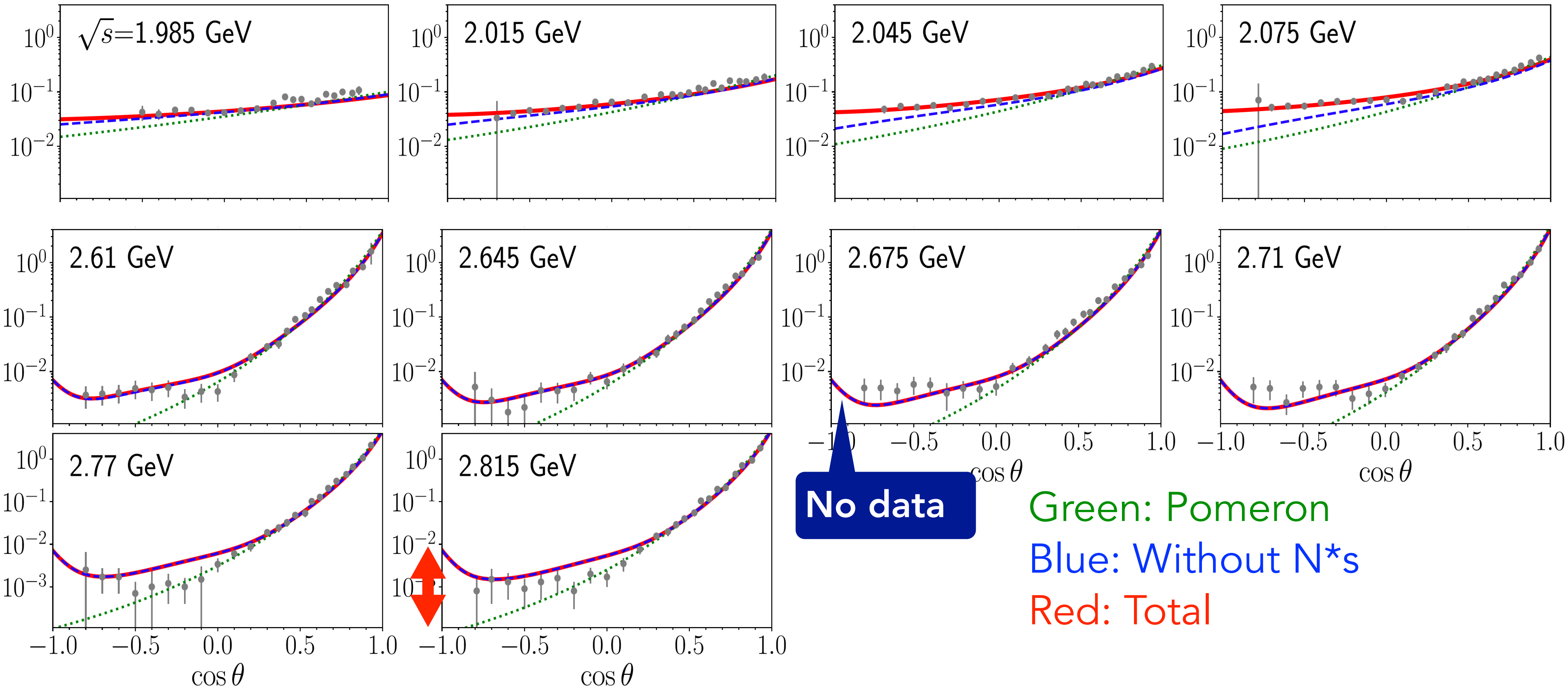
For $\sigma_{T,L}$, Pomeron and scalar meson interfere constructively,

and vice versa for $\sigma_{LT,TT}$, due to destructive interference, going to

zero as Q^2 increases.

Photo- and electro-productions of hadrons

As for higher energy, beyond-pomeron (BP) contributions prevails.

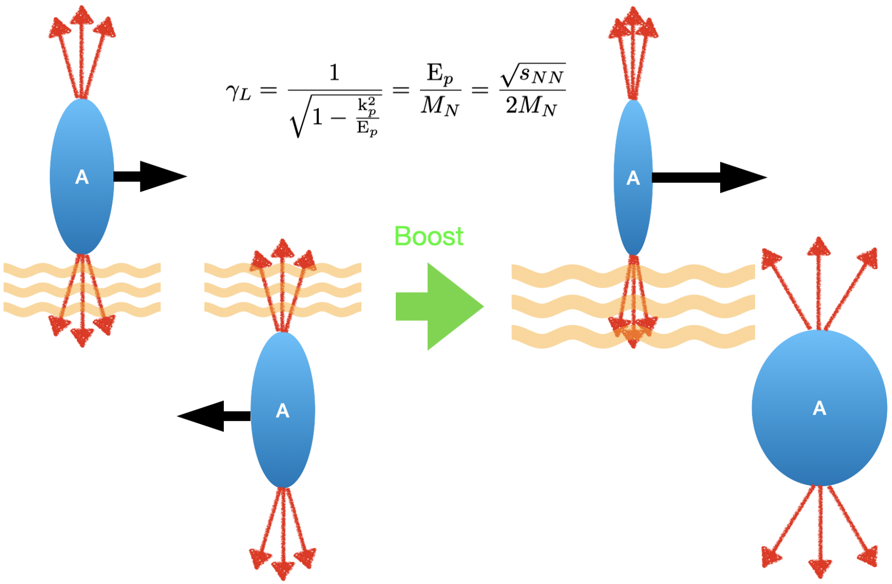


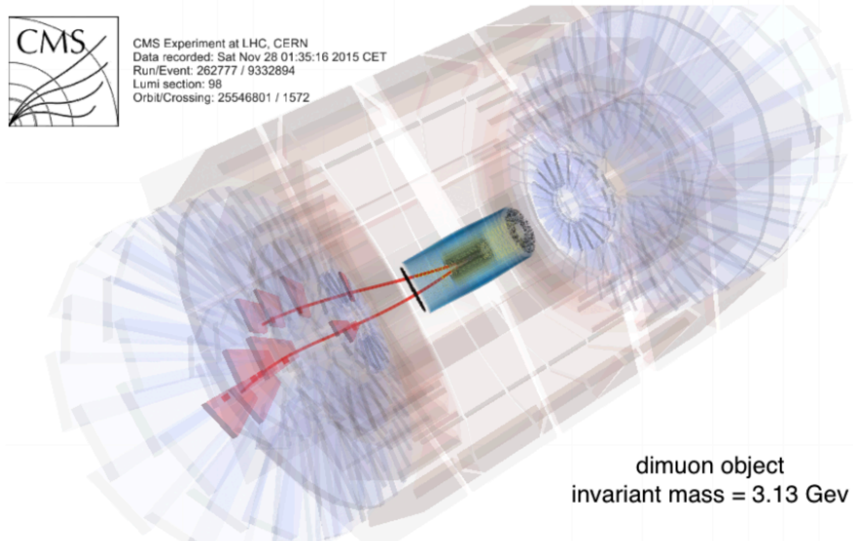
Where can we examine BP contributions at high-E?

UPC (Ultra-peripheral collision) at HIC and EIC for instance.

Photo- and electro-productions of hadrons

Physical observables in ultra-peripheral collision (UPC)





M.Walczak, Acta Phys. Pol. B 48

$$\sigma_{AA\to\phi AA} = \int_0^\infty d\omega \frac{dN_\gamma(\omega)}{d\omega} \sigma_{\gamma^* A\to\phi A}(\omega),$$

Photon flux

Elementary + Glauber model

Photo- and electro-productions of hadrons

In general UPC theories, equivalent-photon approx. (EPA) employed since meson produced parallel to the collision axis: $\theta_{13} \sim 0$

Highly relativistic charged fermion scattering: $m_{1,3}^2 \ll s_{NN}$.

EPA tells us:

1) Almost real photon

2) Transverse amplitude dominates

3) t-chanel amplitudę dominates

4) Collinear photon

$e^+e^- \rightarrow e^-\nu W^+$

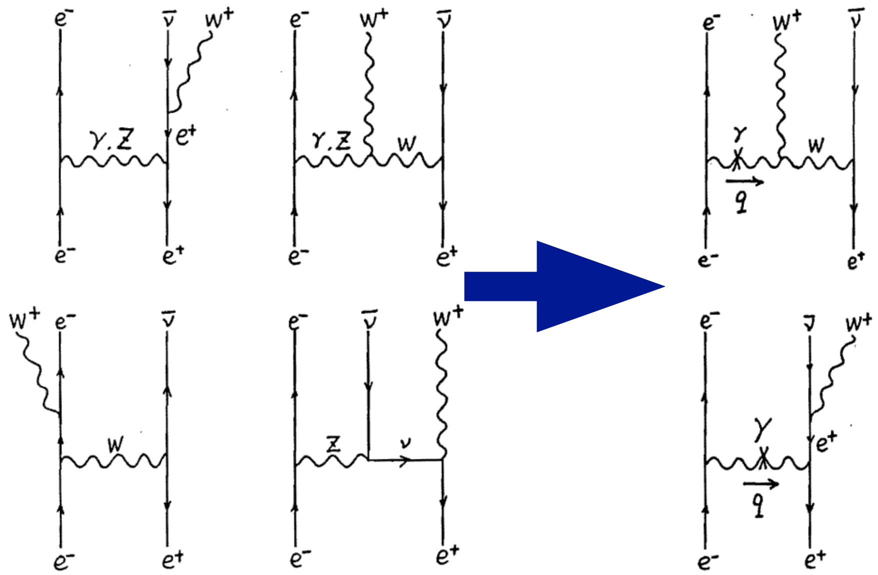
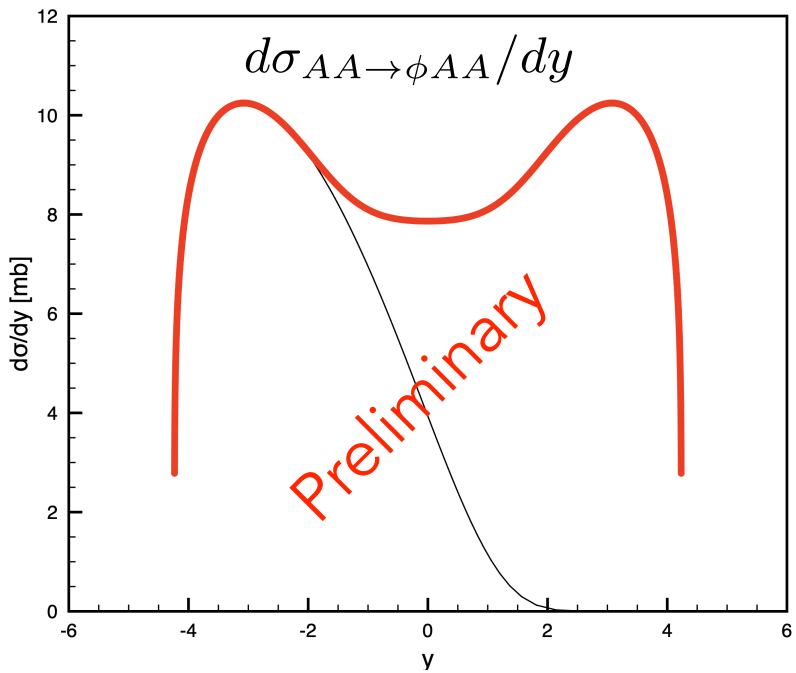


Photo- and electro-productions of hadrons

Traditionally, Pomeron is usually an only contribution in this game

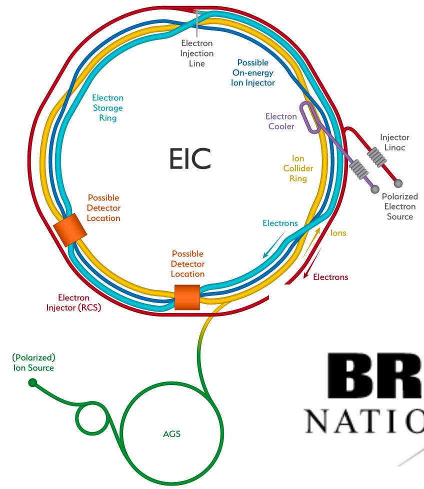
Pomeron+EPA is enough for UPC?

If we go beyond EPA, with non-collinear, longitudinal photon, and non-zero virtuality, we will see BP-contributions.



Also EIC may shed light on this.

Related works in progress.



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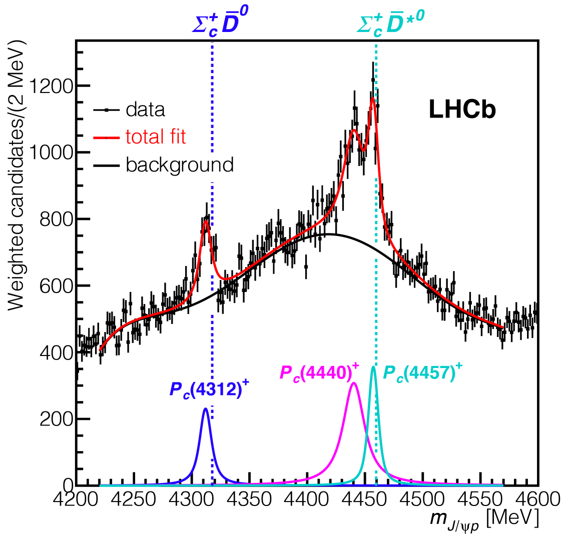
Hadron productions using meson beam

SiN, 2101.03317

Pentaquark bound states measured in hidden-charm ch. at LHCb



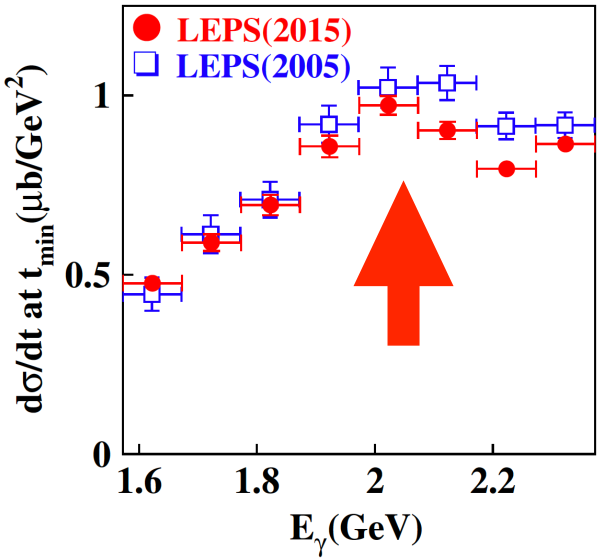
$$P_c^+[\bar{D}^*\Sigma_c] \to J/\psi[c\bar{c}]\,p.$$

Hidden-flavor channel is a key?

Then, what analogous to light-flavor sector?

$$P_s^+[K^*\Sigma] \to \phi[s\bar{s}]\,p.$$

~ 2.1 GeV



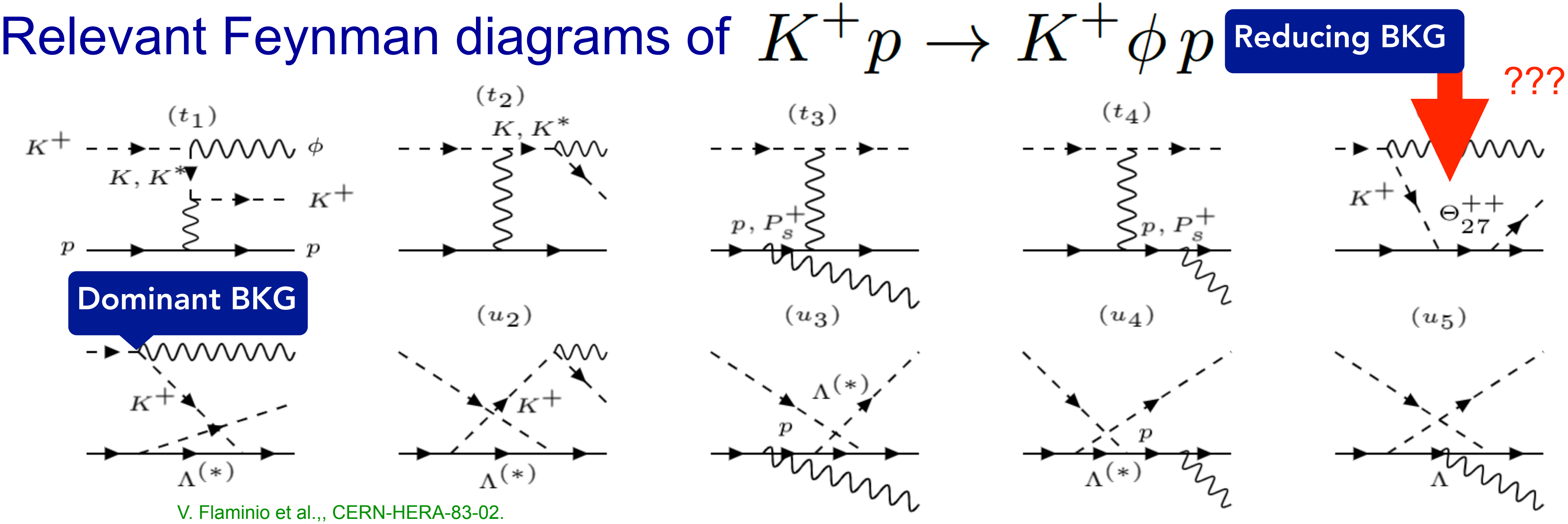
Mass 2.0 ~ 2.1 GeV peak-like structure.

Resonance, interference, higher-oder, etc

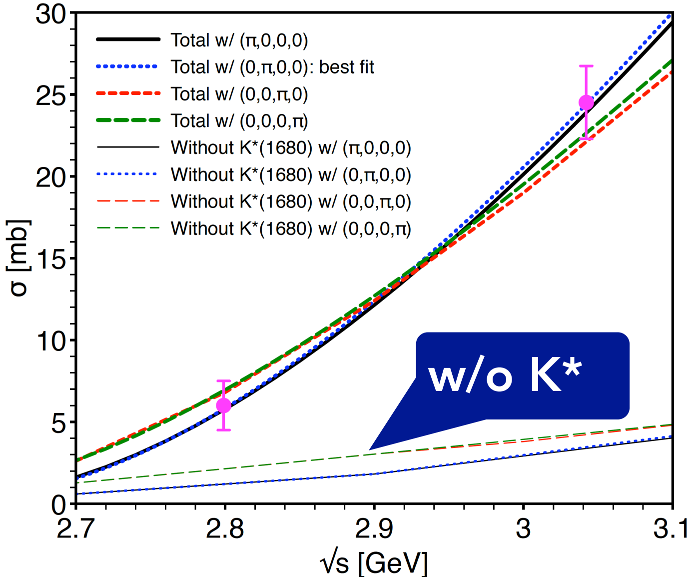
Isn't it a pentaquark-like molecular bound state? (WIP)

Hadron productions using meson beam

Relevant Feynman diagrams of $K^+ p \to K^+ \phi\, p$



V. Flaminio et al.,, CERN-HERA-83-02.



Model parameter determination.

Critical K*(1680) in high-E (LHCb).

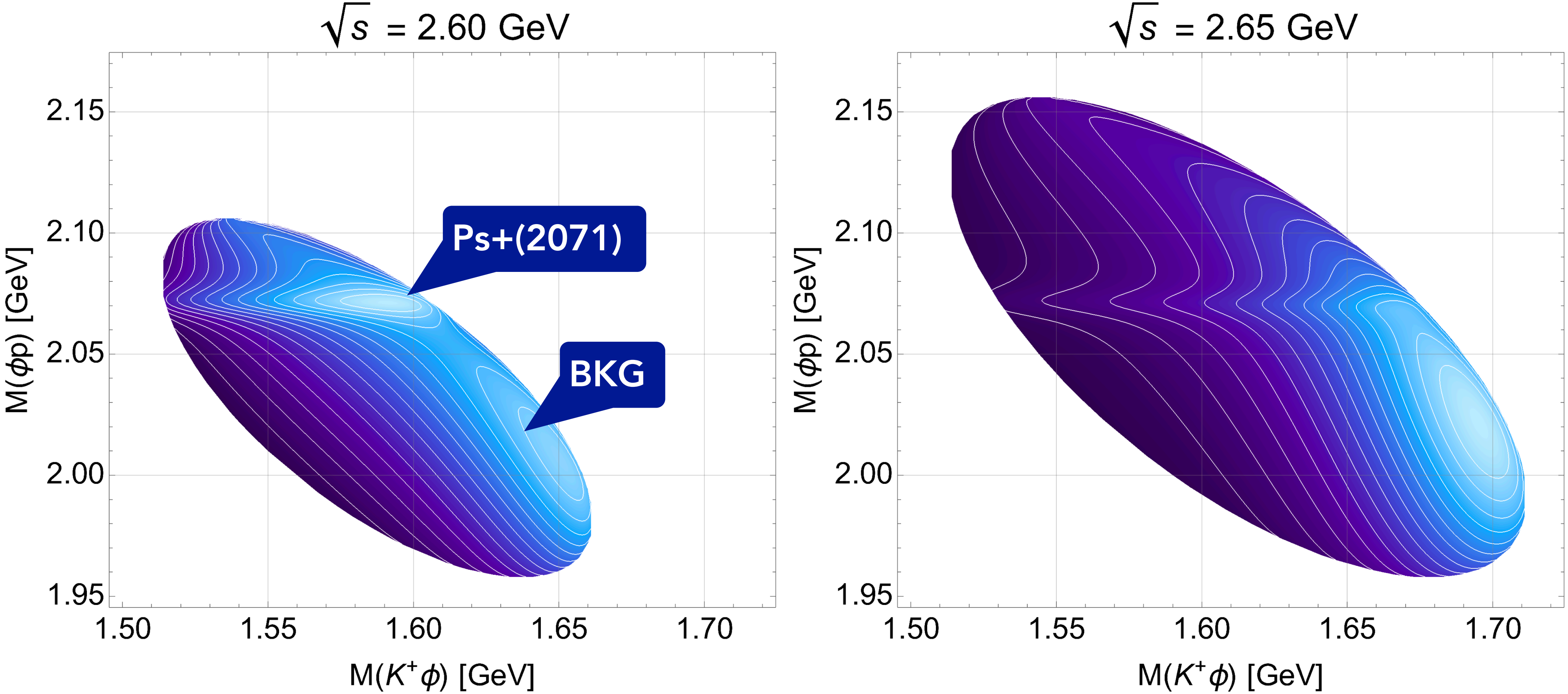
R. Aaij et al.[LHCb], PRL118 (2017)

Inputs for Ps+(2071,3/2-) from ChUM.

K. P. Khemchandani et al., PRD83 (2011)

Various interference combinations

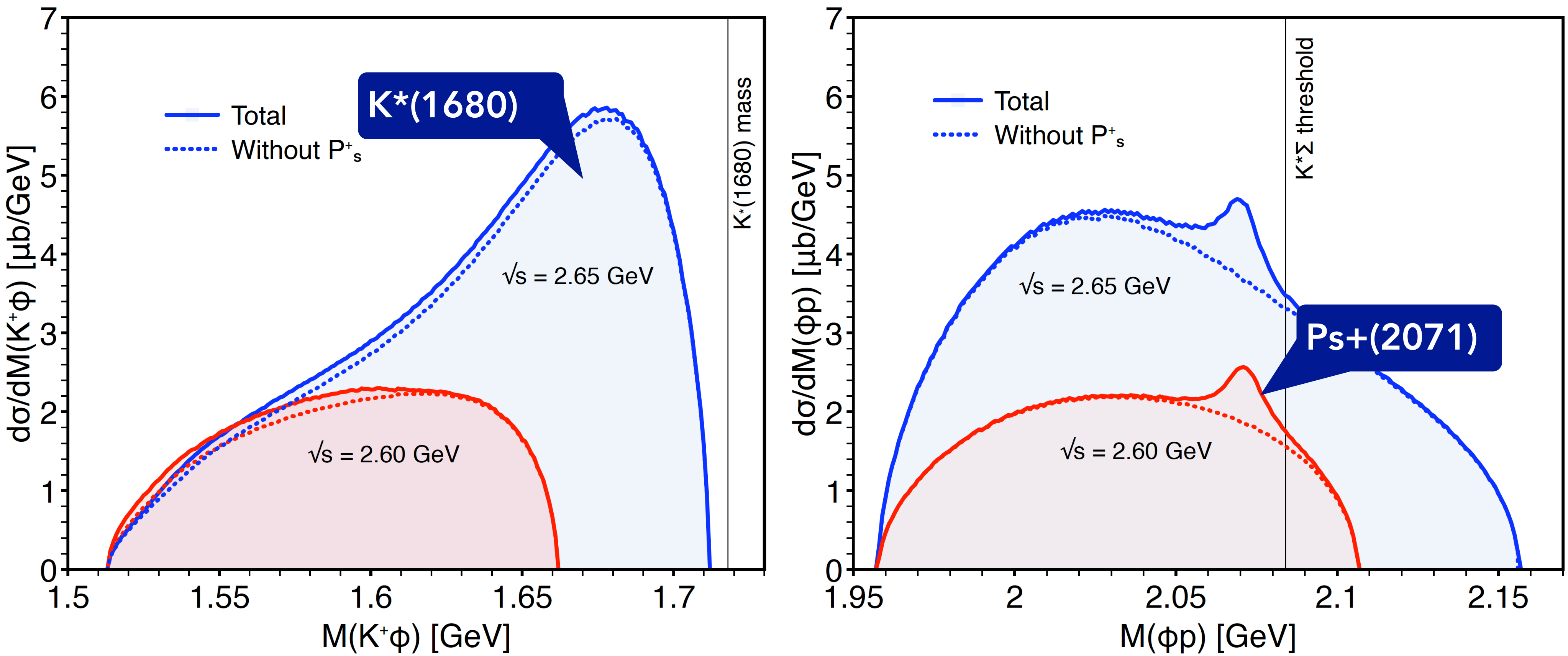
Hadron productions using meson beam



$g_{KK\phi}$ [35]	$g_{\phi NN}$ [30]	$g_{KK^*(1680)\phi}$	$g_{\phi P_s^+ P_s^+}$ [26]	$g_{KN\Theta_{27}^{++}}$ [36]	$g_{KN\Lambda}$ [30]	$g_{KN\Lambda(1405)}$ [35]	$g_{KN\Lambda(1520)}$ [35]
4.75	-1.47	1.6 (fit)	$0.14 + 0.2i$	$\lesssim 2.06$	-13.4	1.51	10.5
Γ_ϕ [35]		$\Gamma_{K^*(1680)}$ [35]	$\Gamma_{P_s^+}$ [26]	$\Gamma_{\Theta_{27}^{++}}$ [36]	–	$\Gamma_{\Lambda(1405)}$ [35]	$\Gamma_{\Lambda(1520)}$ [35]
4.249 MeV		322 MeV	14 MeV	$\lesssim 43$ MeV	–	50.5 MeV	15 MeV

Hadron productions using meson beam

SiN, 2101.03317



Significant K*(1680) contribution as Ecm increases

Ps+ peak is observed with S/N ~ 1.7%

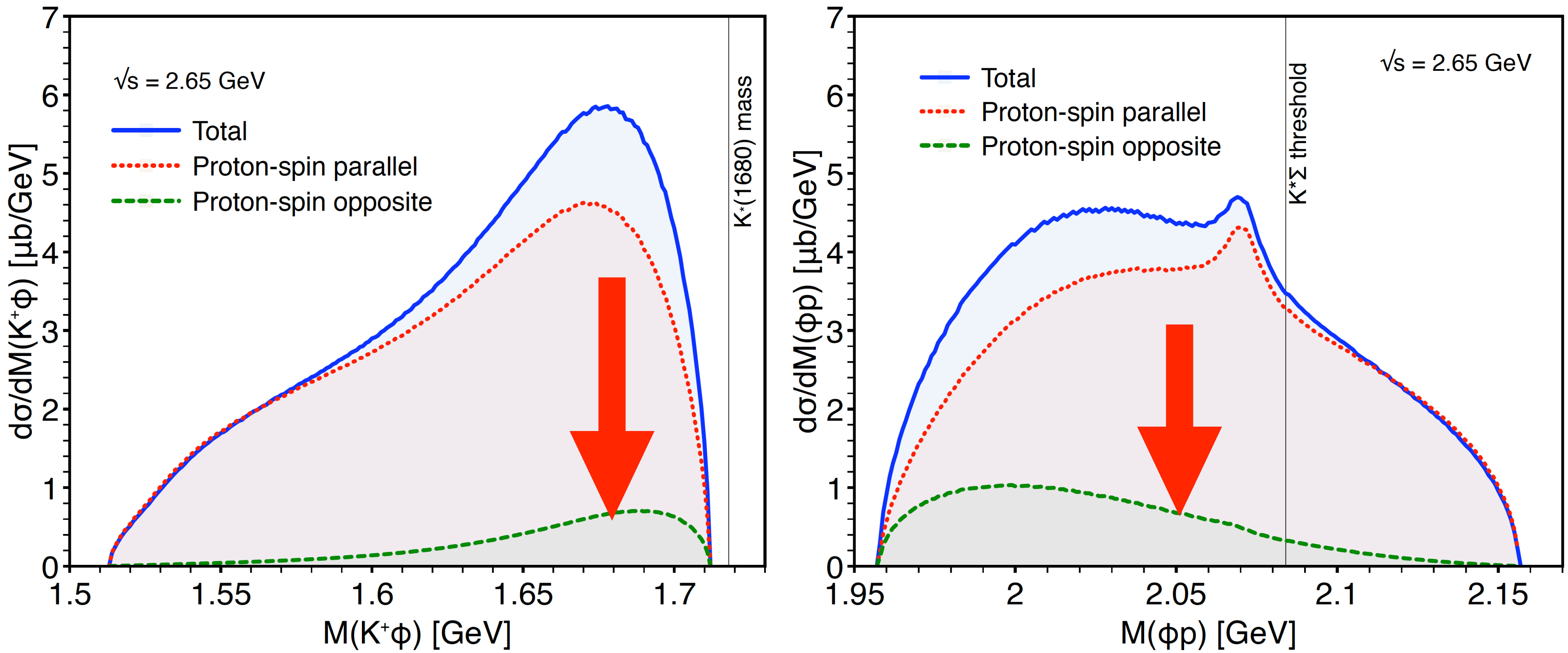
Possible measurements in the future J-PARC upgrade

Hadron productions using meson beam

Spin-polarizations of initial- and final-state protons

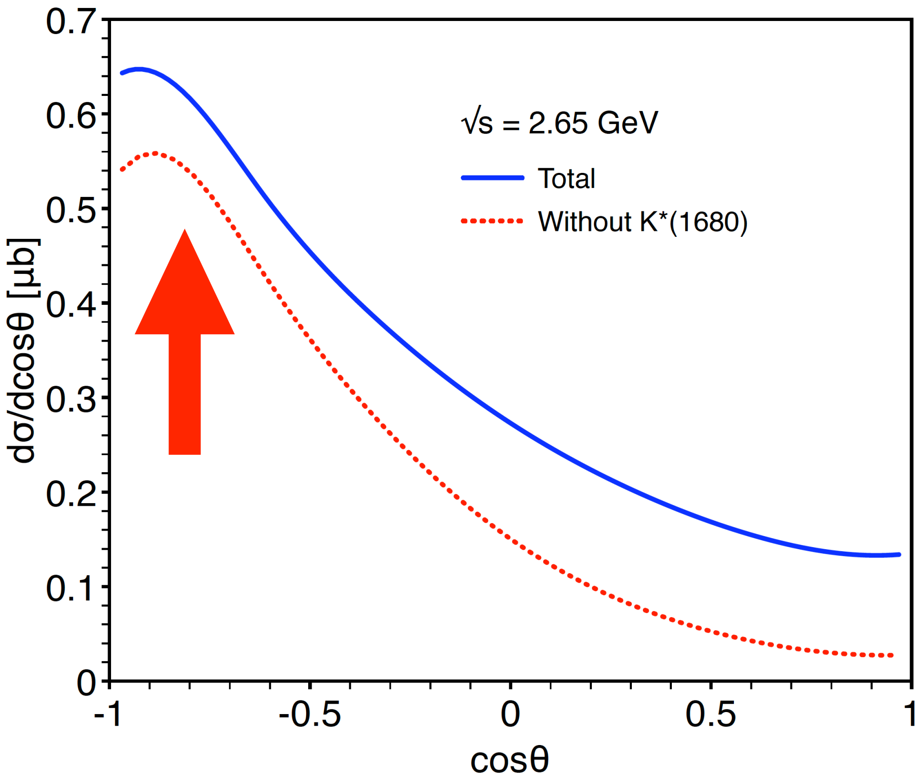
$$\sigma_{\rm parallel} \equiv \sigma(\uparrow\uparrow) + \sigma(\downarrow\downarrow), \quad \sigma_{\rm opposite} \equiv \sigma(\uparrow\downarrow) + \sigma(\downarrow\uparrow),$$

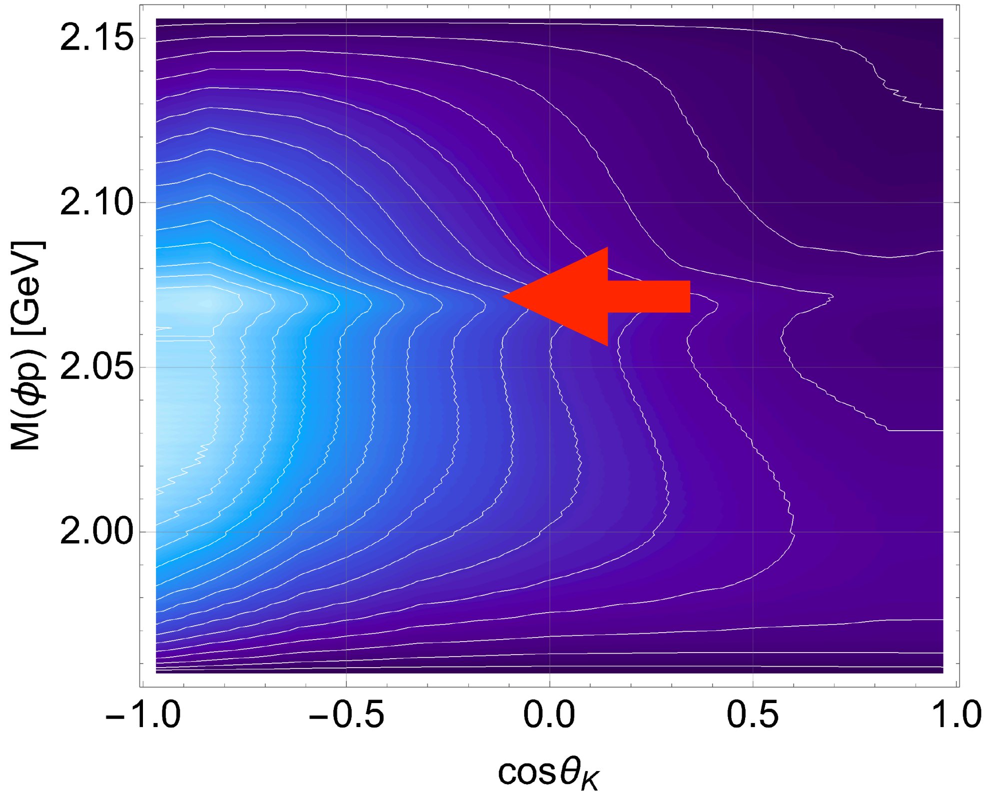
When opposite, largest BKG from Λ(1115) suppressed



Hadron productions using meson beam

Angular distributions





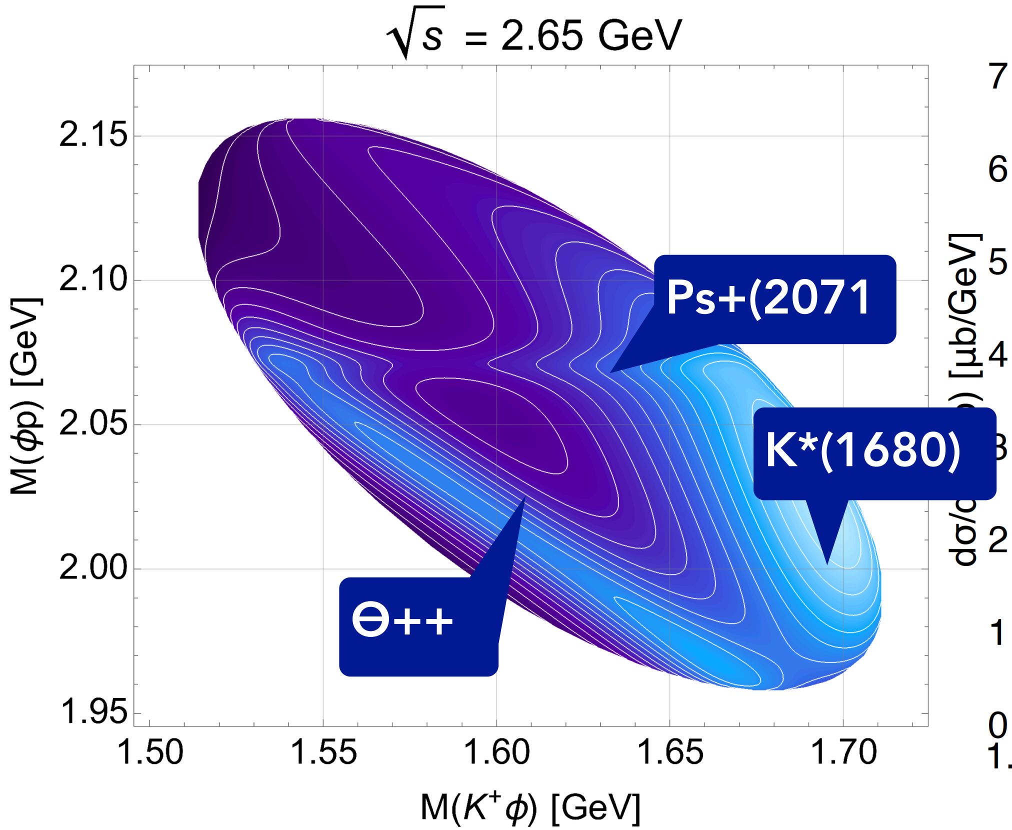
Dominant hyperon contributions in u-channel

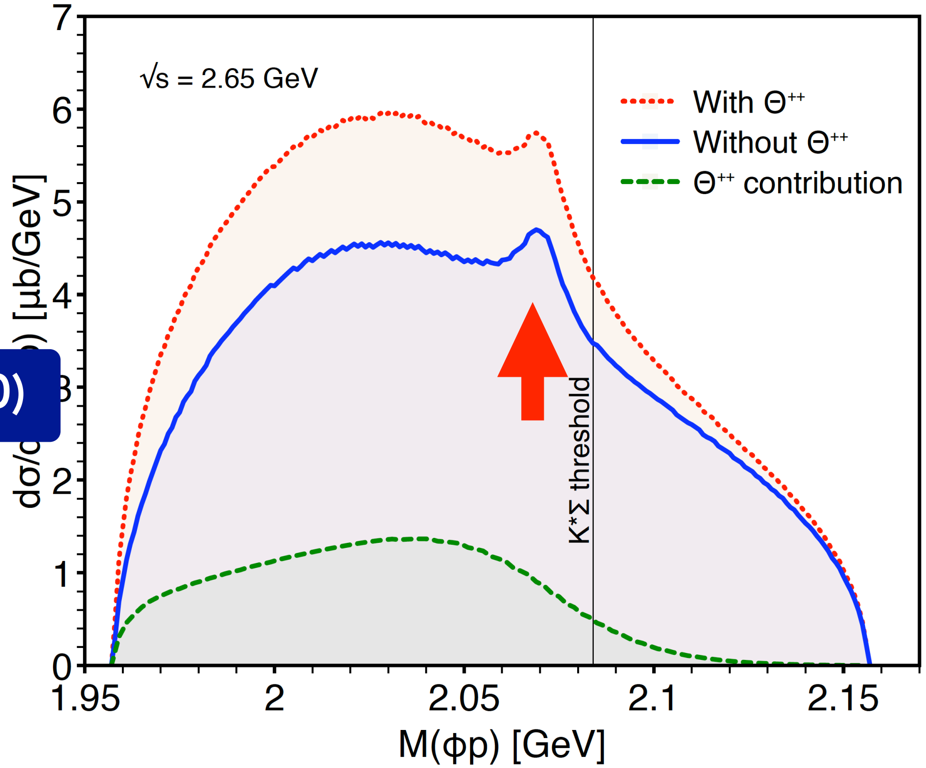
Ps+ also enhanced in the K+ backward scattering region

Hadron productions using meson beam

SiN, 2101.03317

If there is 27-plet pentaquark baryon?





Θ++(1600,3/2-) enhanced M(φp) ~ 2 GeV as BKG

Ps+ peak seen unaffected

B. Wu and B. Q. Ma, PLB 586 (2004)

Summary

Polarizations in hadron productions explored.

Beyond Pomeron-exchange picture in φ-meson EM productions.

Complicated interference between L and T photon polarizations.

In SDME, significant S- & AV-meson contributions in addition to N*s.

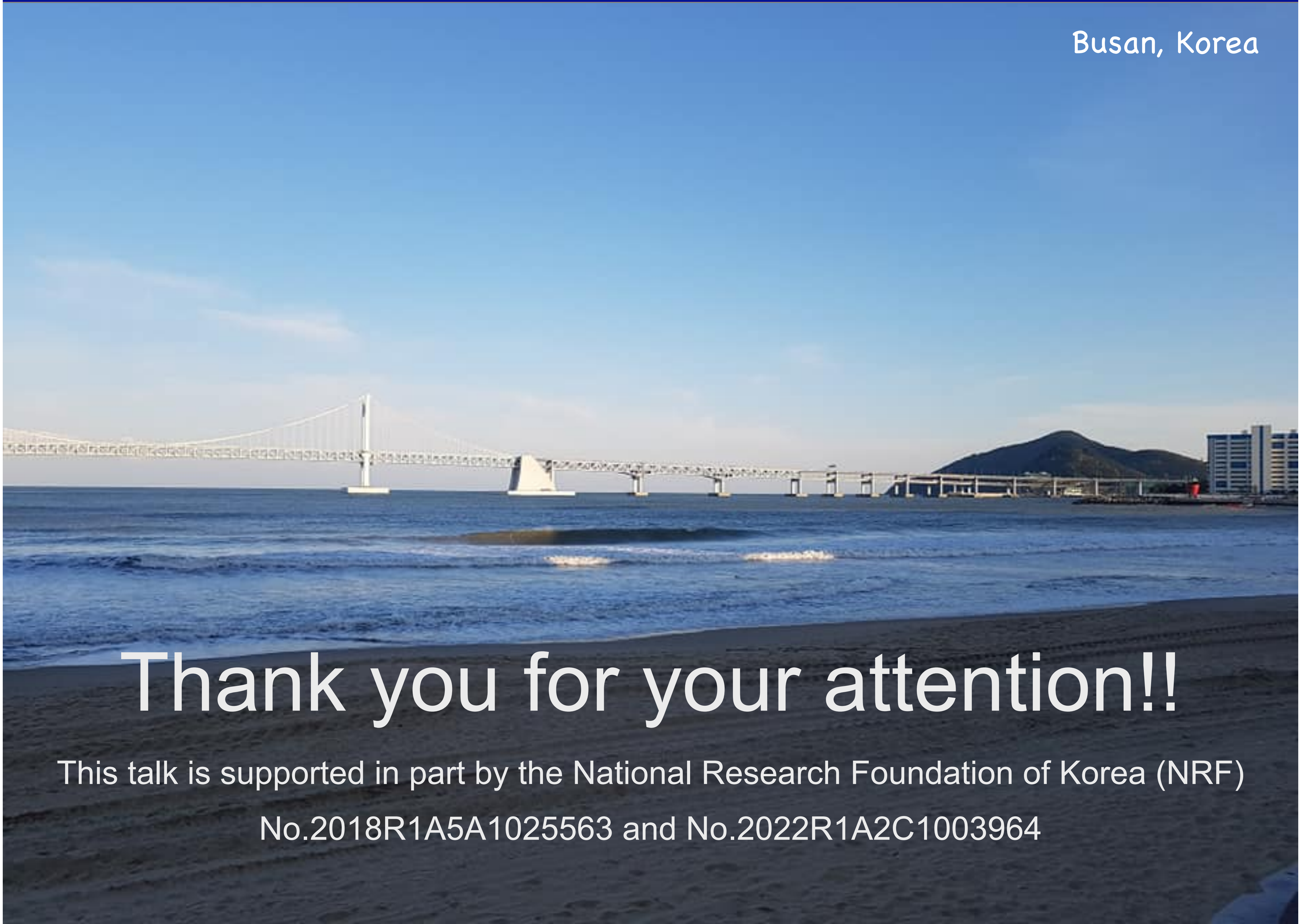
UPC and EIC will be the testing grounds for “beyond Pomeron”

A pentaquark molecular bound state of Ps+[ΣK*] with S/N~1.7%

Large BKG from K*(1680) decaying into K+ and φ.

By beam-target polarization, BKG is reduced considerably.

Is this Ps+(2071) responsible for the “Weird peak”?



Thank you for your attention!!

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