Search for strange partners of P_c states from γp reactions

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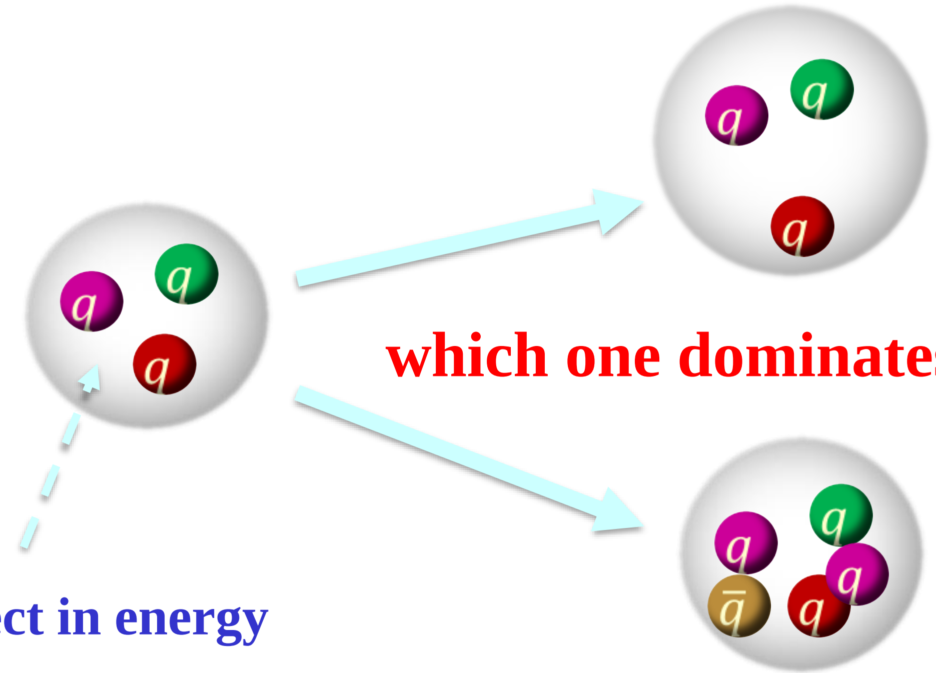
1) S.M.Wu, F.Wang, B.S.Zou, Phys. Rev. C108 (2023) 045201
2) Di Ben, A.C.Wang, F.Huang, B.S.Zou, Phys. Rev. C108 (2023) 065201

Outline

- **Key point for N* internal structure**
- **Strange partners of P_c states from γp reactions**
- **Conclusion and prospect**

1. Key point for N* internal structure

Unquenching dynamics: gluons → $\bar{q}q$



Classic quark model:
3q excited states

which one dominates？

New view:
Pentaquark excitation
dominates already for
the lowest ½- SU(3) nonet

inject in energy

Pentaquark crucial for baryon spectroscopy and structure !

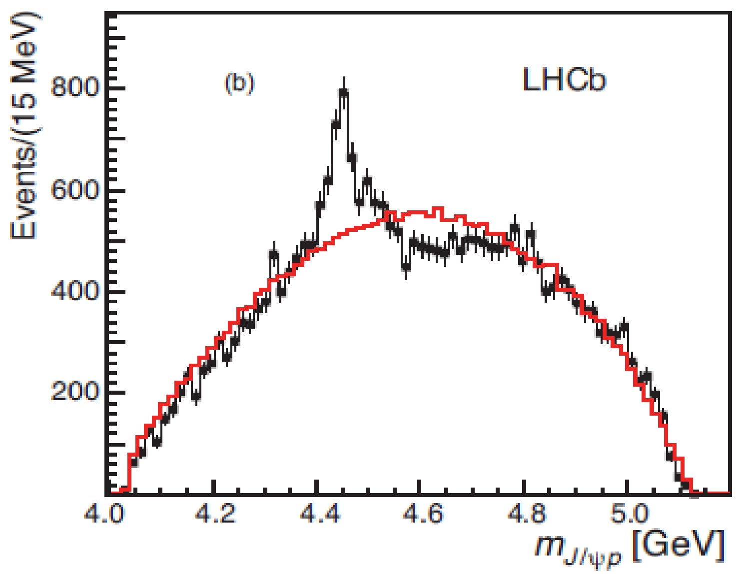
LHCb → 3 narrow P_c states 1757 cites

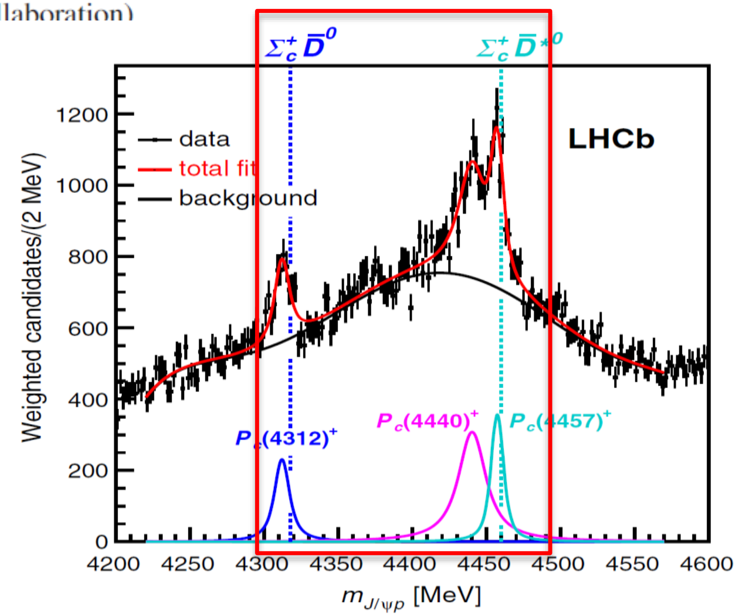
Selected for a Viewpoint in *Physics*
PRL **115,** 072001 (2015) PHYSICAL REVIEW LETTERS week ending 14 AUGUST 2015

Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_b^0 \to J/\psi K^- p$ Decays

R. Aaij *et al.**
(LHCb Collaboration)

PRL 122 (2019) 222001



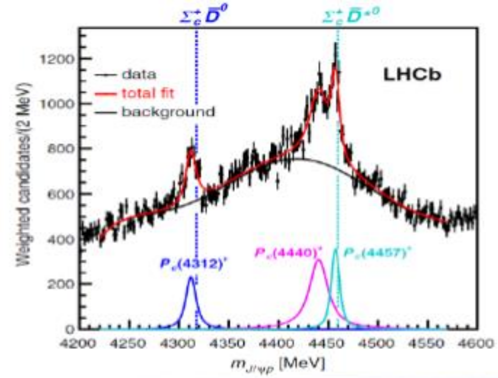


A milestone for pentaquark search

Top cited paper on QCD physics in last 10 yrs

P_c states: observation vs predictions

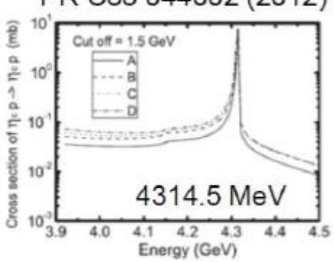
LHCb, PRL122 (2019) 222001



Comparison to numerical predictions

- Many theoretical predictions for $\Sigma_c^+ \bar{D}^{(*)0}$ published before 2015, **some in quantitative agreement with the LHCb data**
  - Wu,Molina,Oset,Zou, PRL105, 232001 (2010),
  - **Wang,Huang,Zhang,Zou, PR C84, 015203 (2011),**
  - **Yang,Sun,He,Liu,Zhu, Chin. Phys. C36, 6 (2012),**
  - **Wu,Lee,Zou, PR C85 044002 (2012),**
  - Karliner,Rosner, PRL 115, 122001 (2015)

PR C85 044002 (2012)



ΔE – binding energy

Example:

Nucleon resonances with hidden charm in coupled-channels models

Jia-Jun Wu, T.-S. H. Lee, and B. S. Zou

Phys. Rev. C **85**, 044002 – Published 17 April 2012

arXiv:1202.1036

TABLE III: The pole position $(M - i\Gamma/2)$ and "binding energy" $(\Delta E = E_{thr} - M)$ for different cut-off parameter Λ and spin-parity J^P. The threshold E_{thr} is 4320.79 MeV of $\bar{D}\Sigma_c$ in PB system and 4462.18 MeV of $D^*\Sigma_c$ in VB system. The unit for the listed numbers is MeV.

		PB System		VB System	
$J^P = \frac{1}{2}^-$	Λ	$M - i\Gamma/2$	ΔE	$M - i\Gamma/2$	ΔE
	650	-	-	-	-
	800	-	-	4462.178 − 0.002i	0.002
	1200	4318.964 − 0.362i	1.826	4459.513 − 0.417i	2.667
	1500	4314.531 − 1.448i	6.259	4454.088 − 1.662i	8.092
	2000	4301.115 − 5.835i	19.68	4438.277 − 7.115i	23.90
$J^P = \frac{3}{2}^-$					
	650	-	-	-	-
	800	-	-	4462.178 − 0.002i	0.002
	1200	-	-	4459.507 − 0.420i	2.673
	1500	-	-	4454.057 − 1.681i	8.123
	2000	-	-	4438.039 − 7.268i	23.14

$\Delta E(4312) = 5.8^{+1.0}_{-6.8}$ MeV

$\Delta E(4457) = 2.5^{+4.3}_{-4.1}$ MeV

$\Delta E(4440) = 19.5^{+4.9}_{-4.3}$ MeV

Λ - cut off on exchanged meson mass.

Hadronic molecular picture

Guo, Hanhart, Meissner,Wang,Zhao,Zou, Rev.Mod.Phys.90 (2018)015004

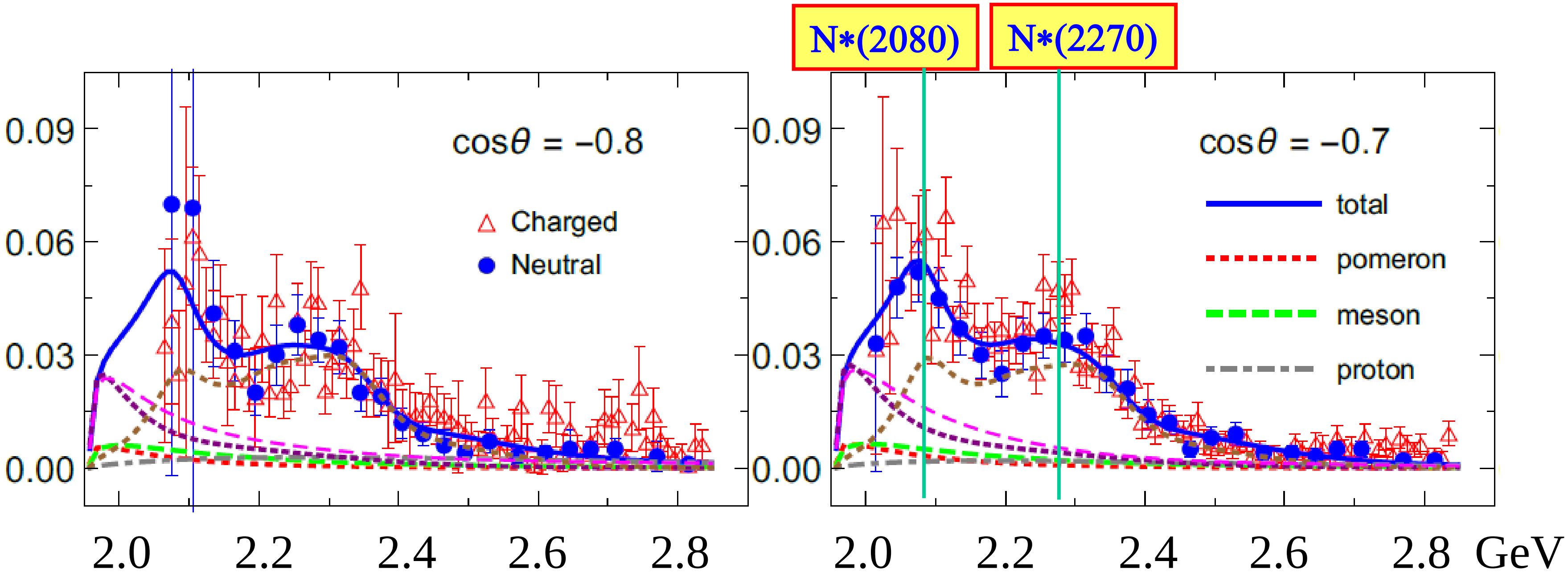
P_c states	relevant thresholds	
$P_c(4312)$	$\bar{D}\Sigma_c$	4317 MeV
$P_c(4380)$	$\bar{D}\Sigma_c^*$	4382 MeV
$P_c(4440)$/ $P_c(4457)$	$\bar{D}^*\Sigma_c$	4459 MeV

How about strange partners of P_c states ?

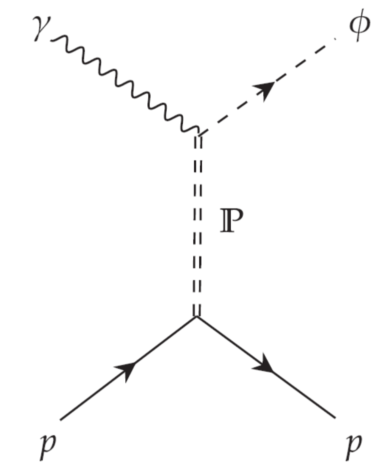
KΣ ~1686	KΣ* ~1880	K*Σ ~ 2086	K*Σ* ~ 2280
N*(1535)	N*(1875)	N*(2080)	N*(2270)
1/2-	3/2-	1/2-, 3/2-	1/2-, 3/2-, 5/2-

2. Strange partners of P_c state from γp reactions

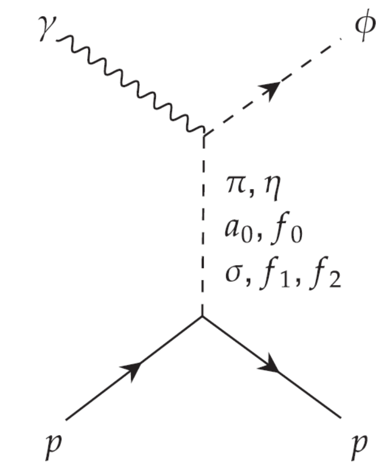
$\gamma p \to \phi p$ CLAS, PRC89(2014)019901



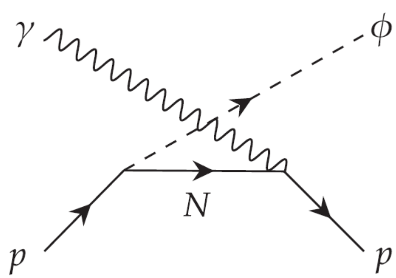
S.M.Wu, F.Wang, B.S.Zou, PRC108 (2023) 045201



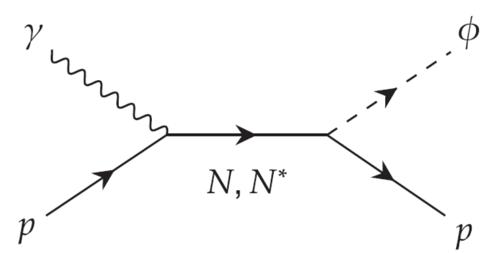
(a) t-channel Pomeron exchange



(b) t-channel mesons exchange



(c) u-channel proton exchange



(d) s-channel nucleon exchange

Relevant Feynman diagrams for $\gamma p \to \phi p$.

Our fit with N*(2080)3/2- & N*(2270)3/2-

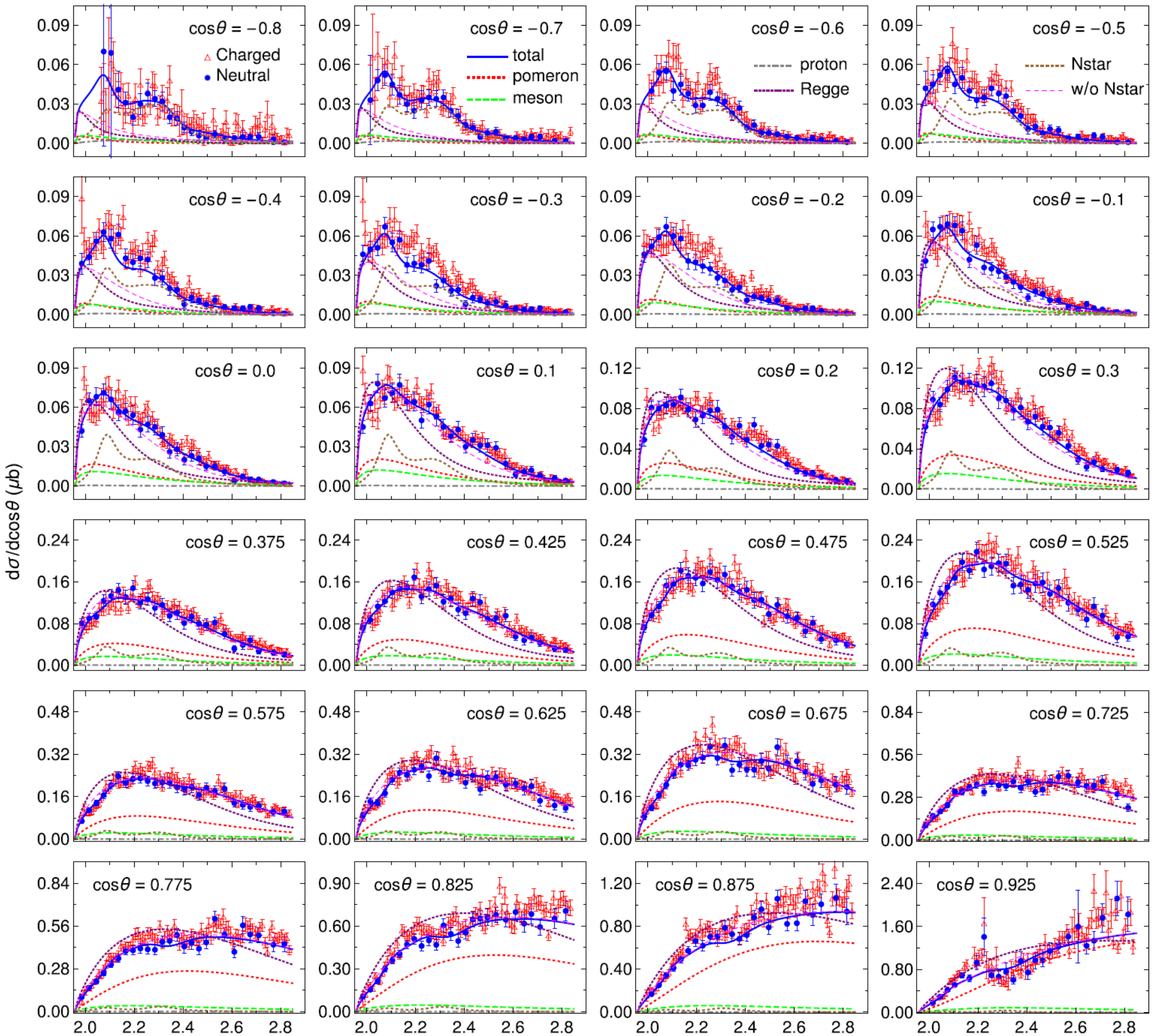
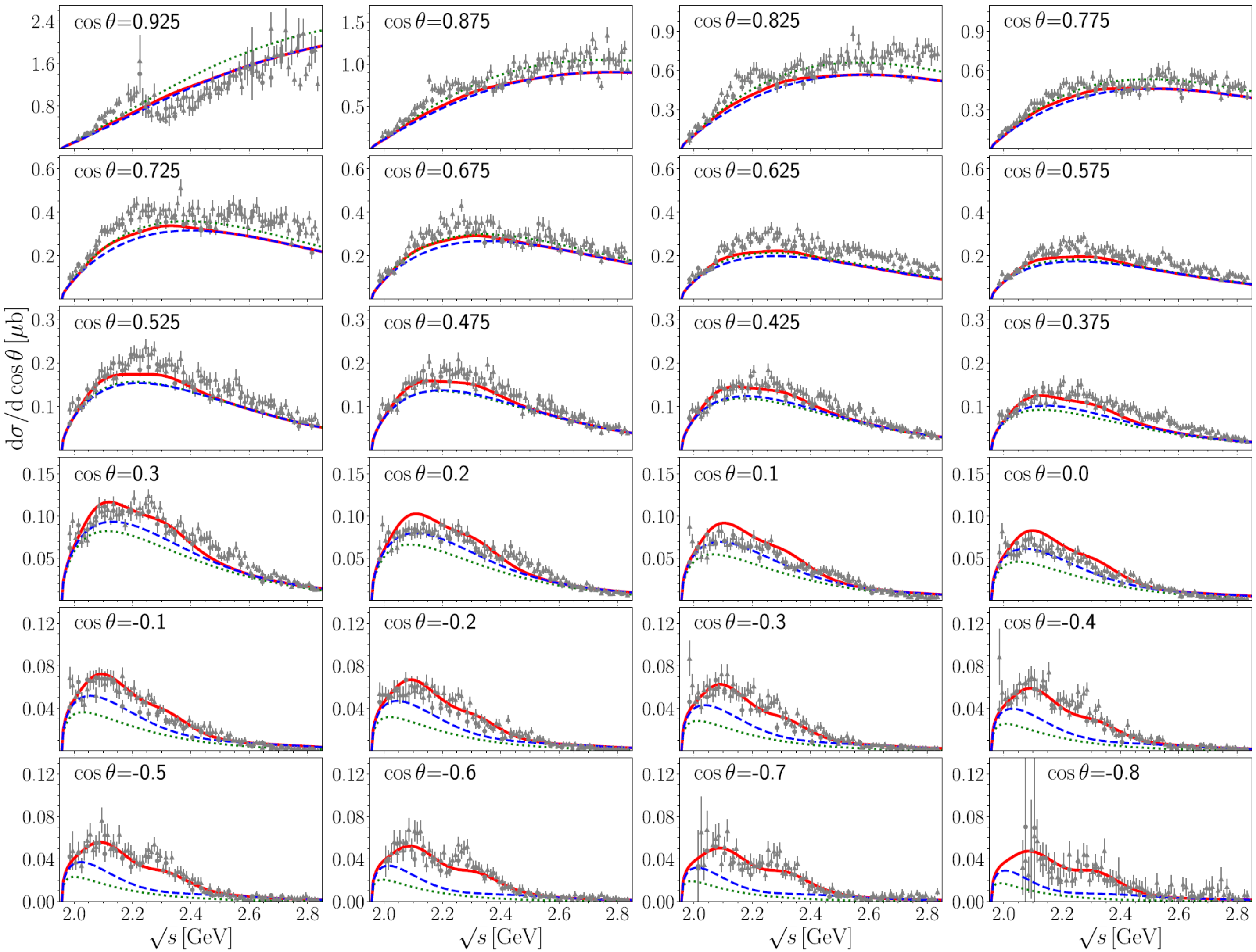


FIG. 3. Differential cross sections $d\sigma/d\cos\theta(\mu b)$ as a function of W(GeV) at different $\cos\theta$.

Previous fit with N*(2000)5/2+ & N*(2300)1/2+

S. H. Kim and S. I. Nam, Phys. Rev. C **100**, 065208 (2019).



Our fit with N*(2080)3/2- & N*(2270)3/2-

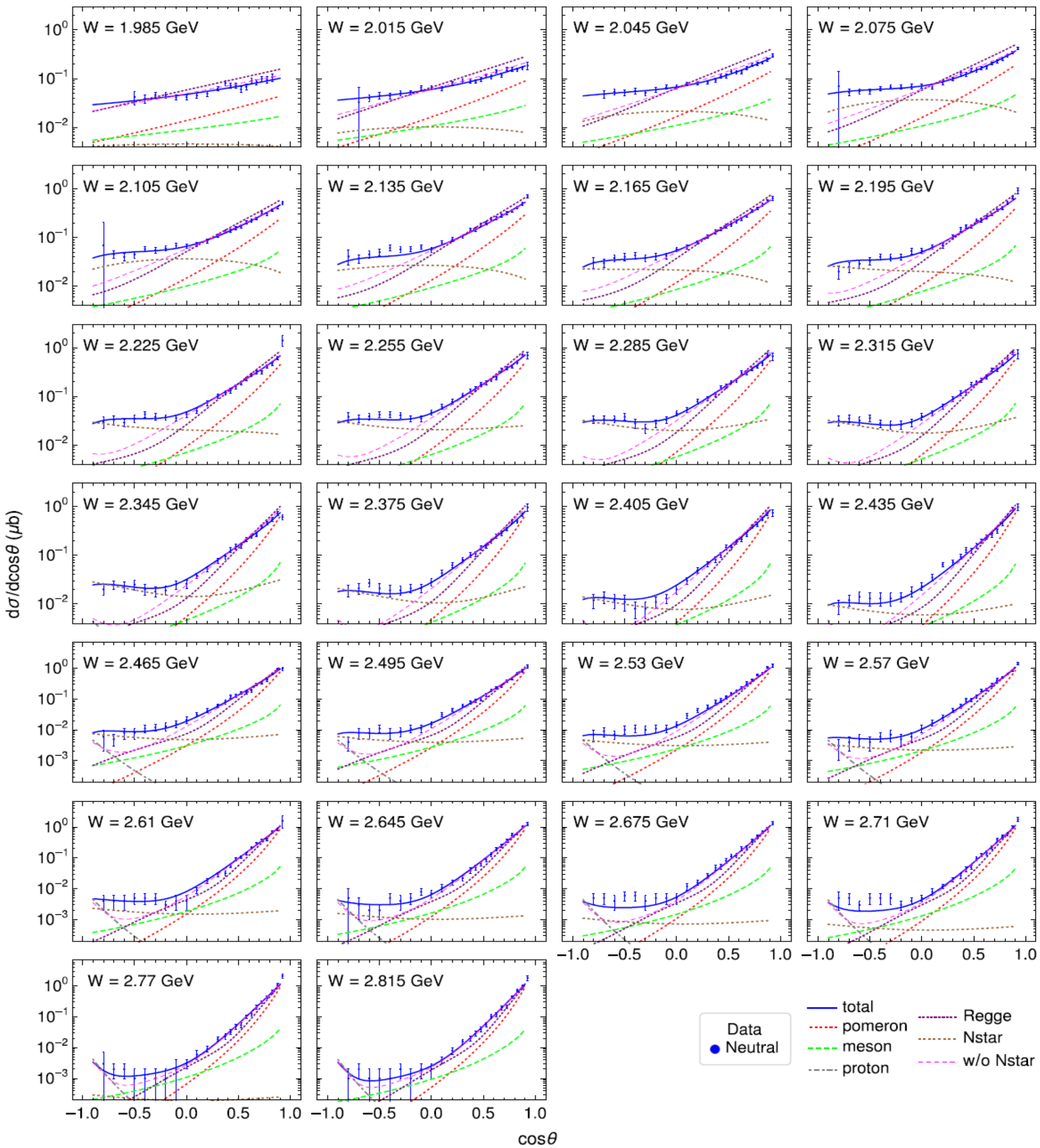
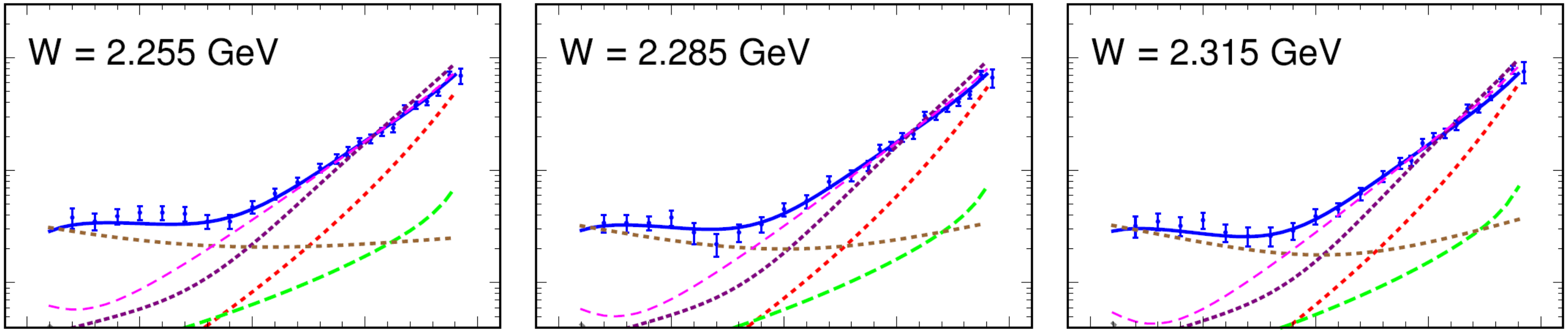
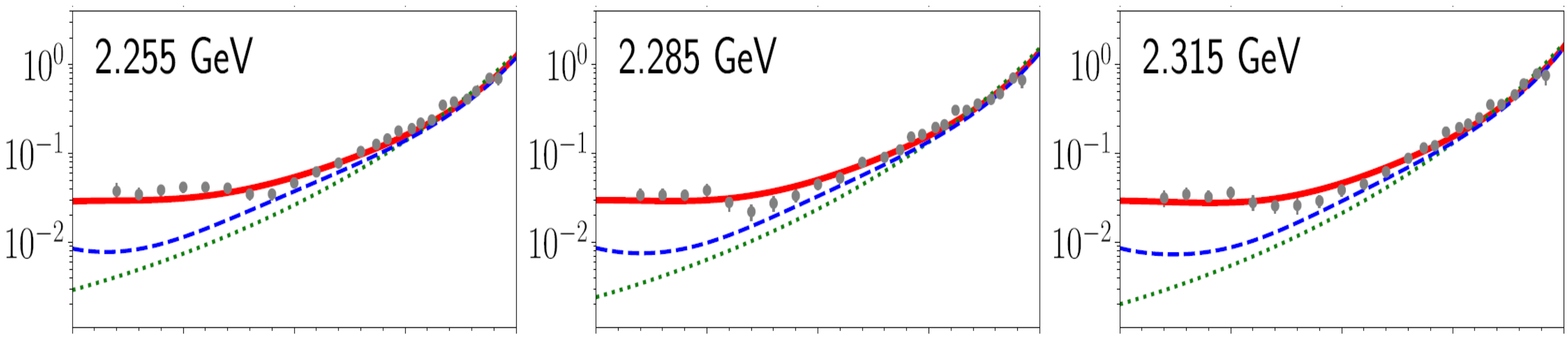


FIG. 4. Differential cross sections $d\sigma/d\cos\theta$ (μb) as a function of $\cos\theta$ at different W(GeV). The marks are the same as in Fig. 3.

Our fit with N*(2080)3/2- & N*(2270)3/2-



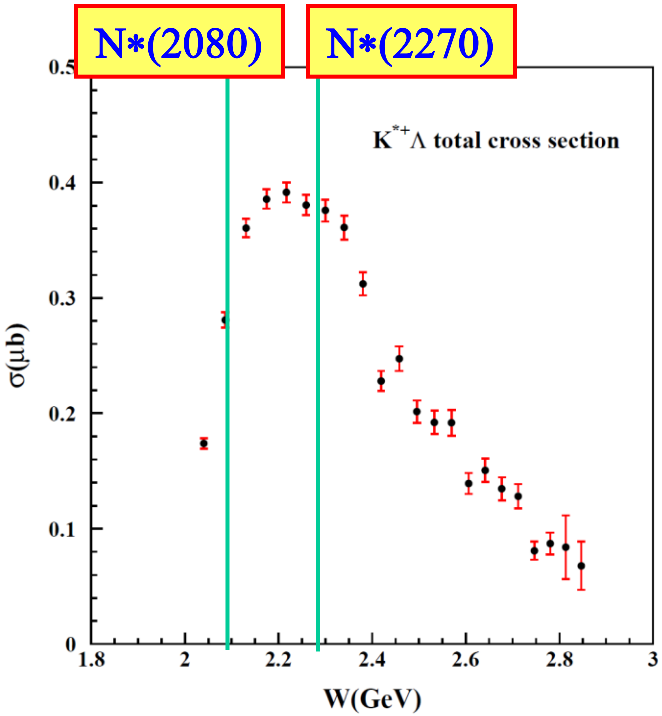


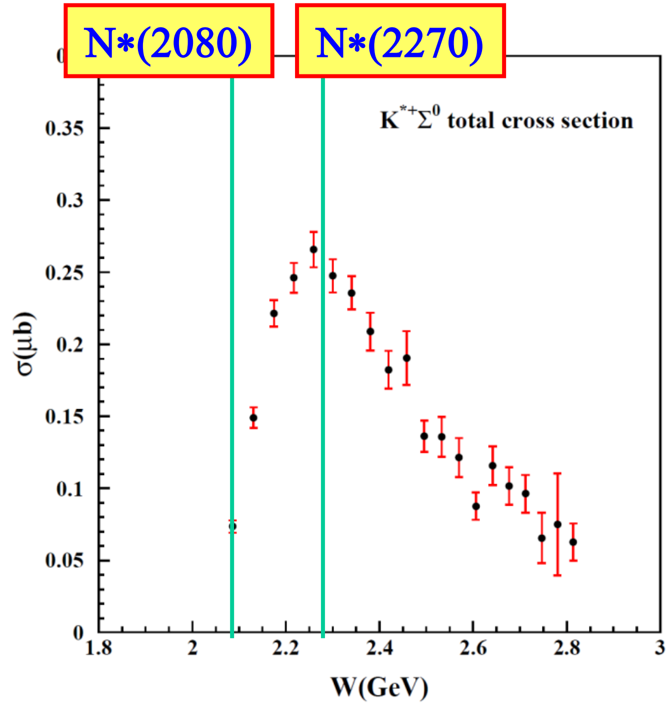
Previous fit with N*(2000)5/2+ & N*(2300)1/2+

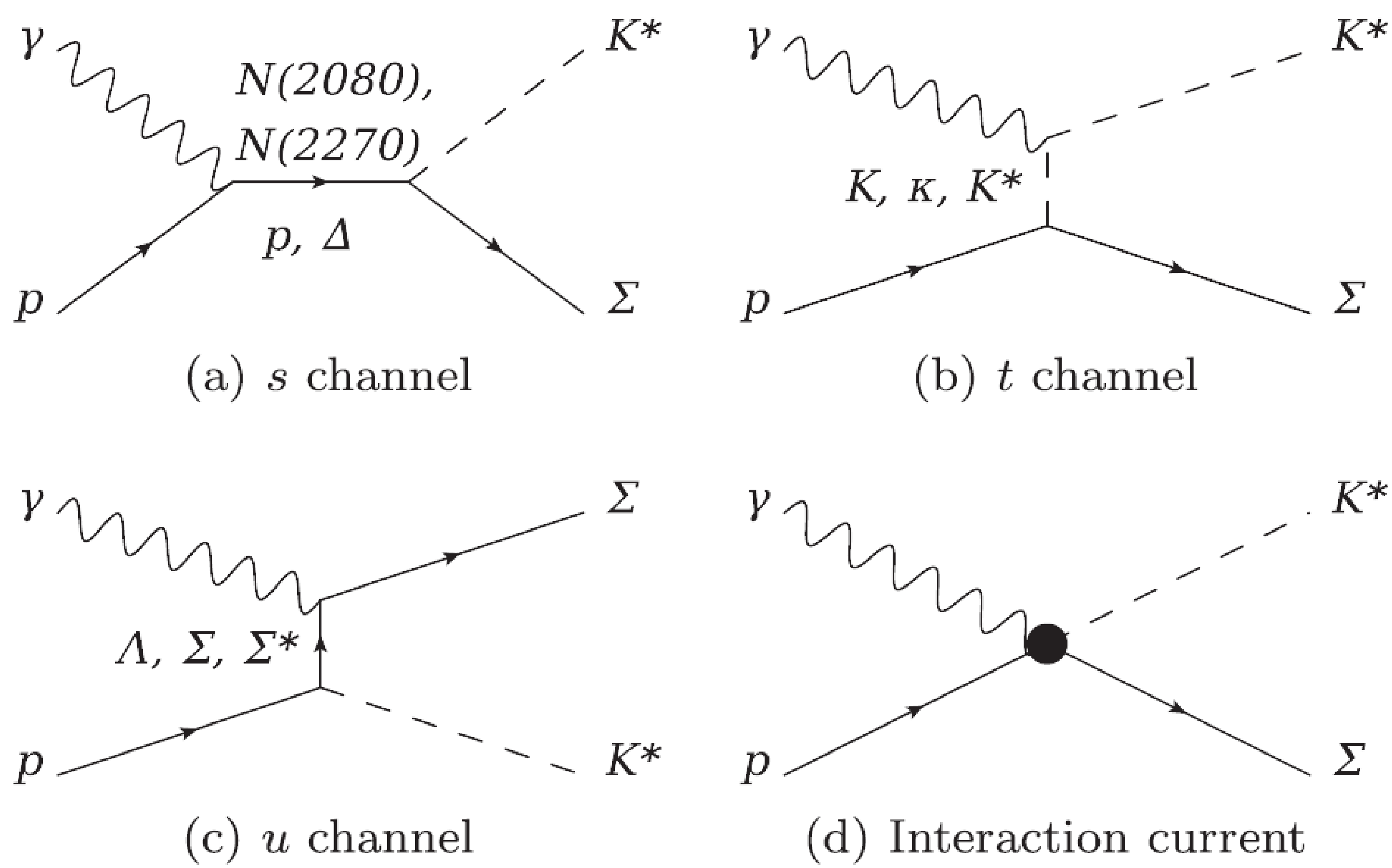
S. H. Kim and S. I. Nam, Phys. Rev. C **100**, 065208 (2019).

Total cross sections of the reaction $\gamma p \to K^{*+}\Lambda$ (left) and $\gamma p \to K^{*+}\Sigma^0$ (right)

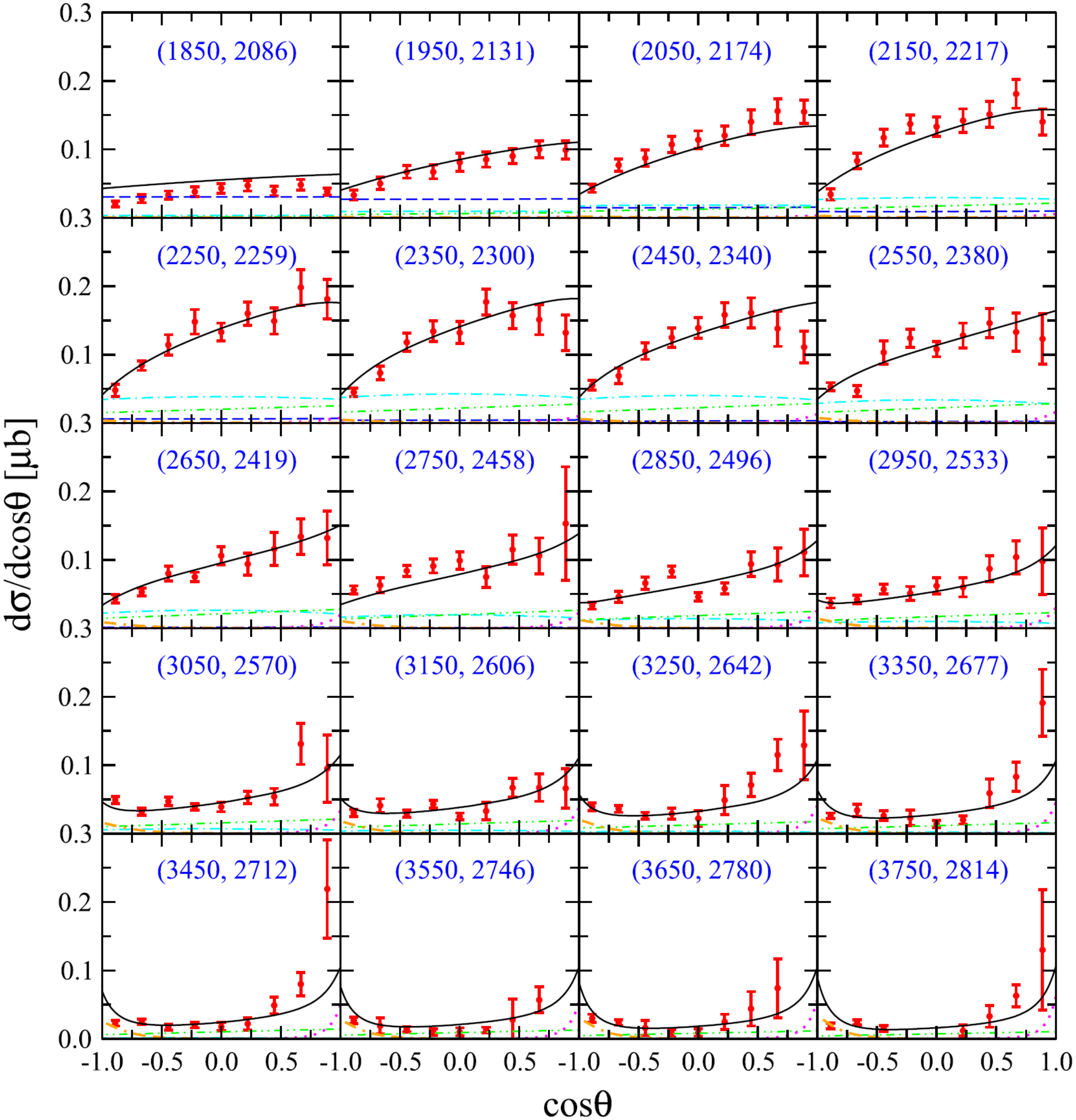
CLAS, PRC 87(2013)065204







Di Ben, A.C.Wang, F.Huang, B.S.Zou, PRC 108 (2023) 065201



Di Ben, A.C.Wang, F.Huang, B.S.Zou, PRC 108 (2023) 065201

Di Ben, A.C.Wang, F.Huang, B.S.Zou, PRC 108 (2023) 065201

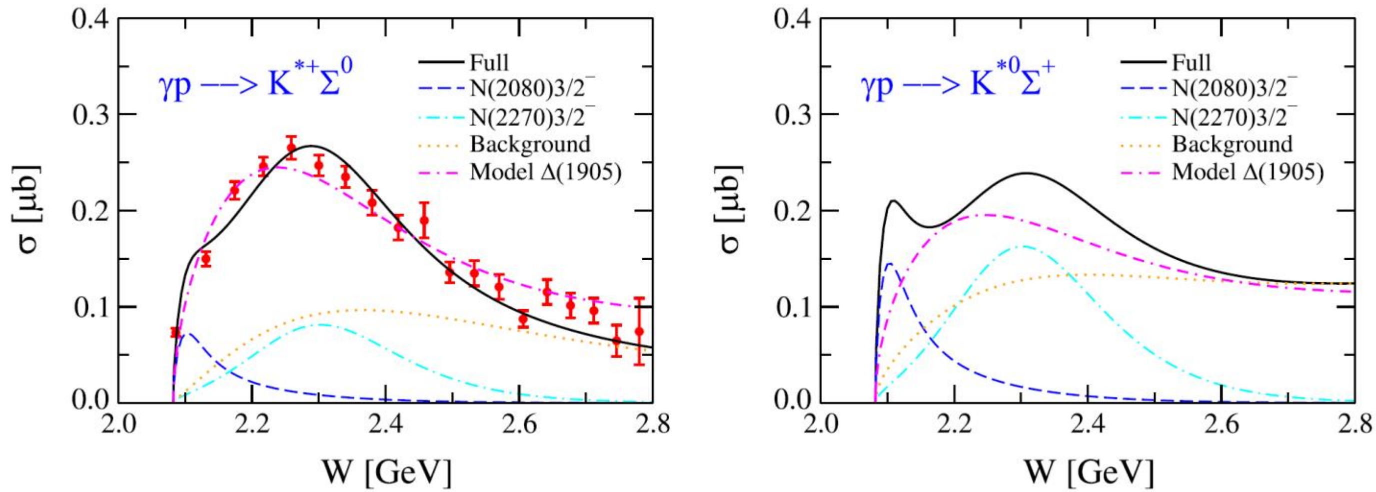


FIG. 7. Total cross sections for $\gamma p \to K^{*+}\Sigma^0$ (left) and $\gamma p \to K^{*0}\Sigma^+$ (right). The black solid lines represent the full results. The blue dashed lines and cyan dash-dotted lines represent the individual contributions from the s-channel $N(2080)3/2^-$ and $N(2270)3/2^-$ exchanges, respectively. The orange dotted lines represent the results calculated by switching off the contributions from the $N(2080)3/2^-$ and $N(2270)3/2^-$ exchanges. The magenta double-dash-dotted lines represent the full results of Ref. [25]. The scattered symbols are data from CLAS Collaboration [19].

[25] A.C.Wang, W.L.Wang, F.Huang, Phys. Rev. C 98 (2018) 045209 with Δ(1905)5/2+

Single spin asymmetries may help to distinguish the two solutions

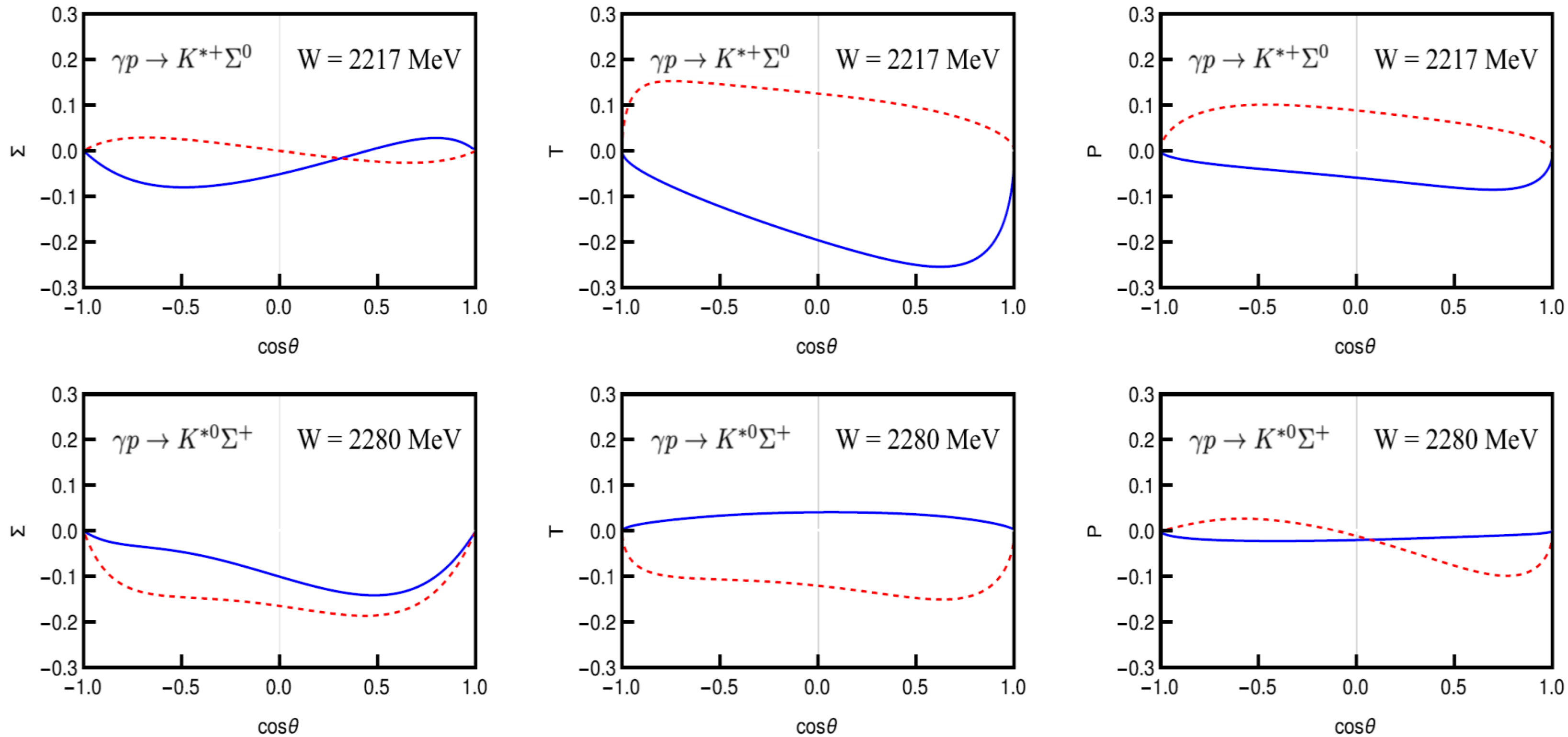
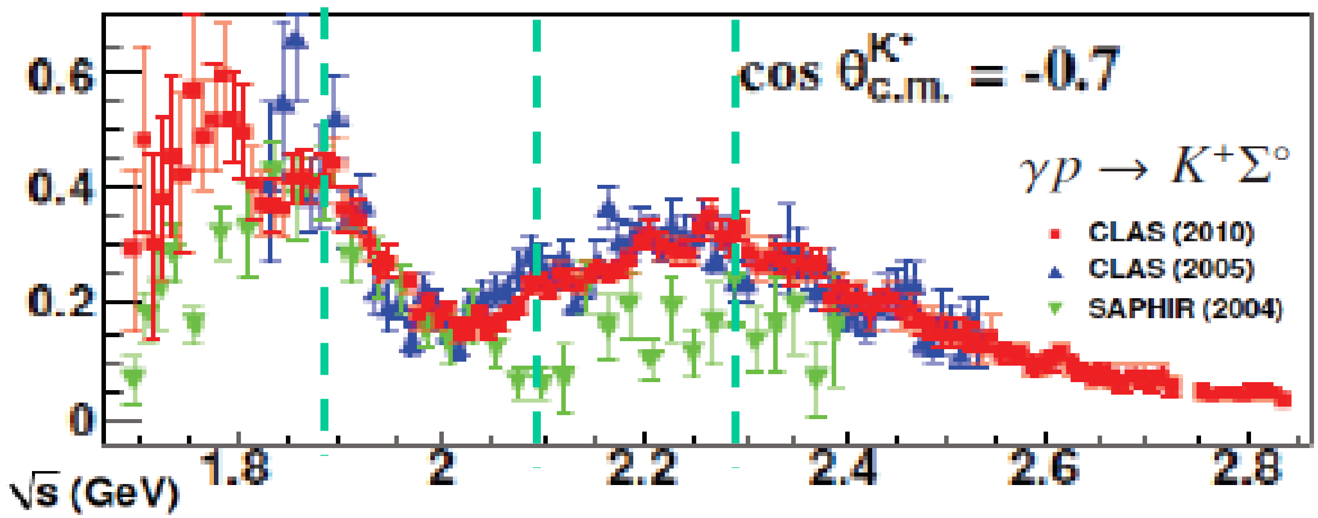
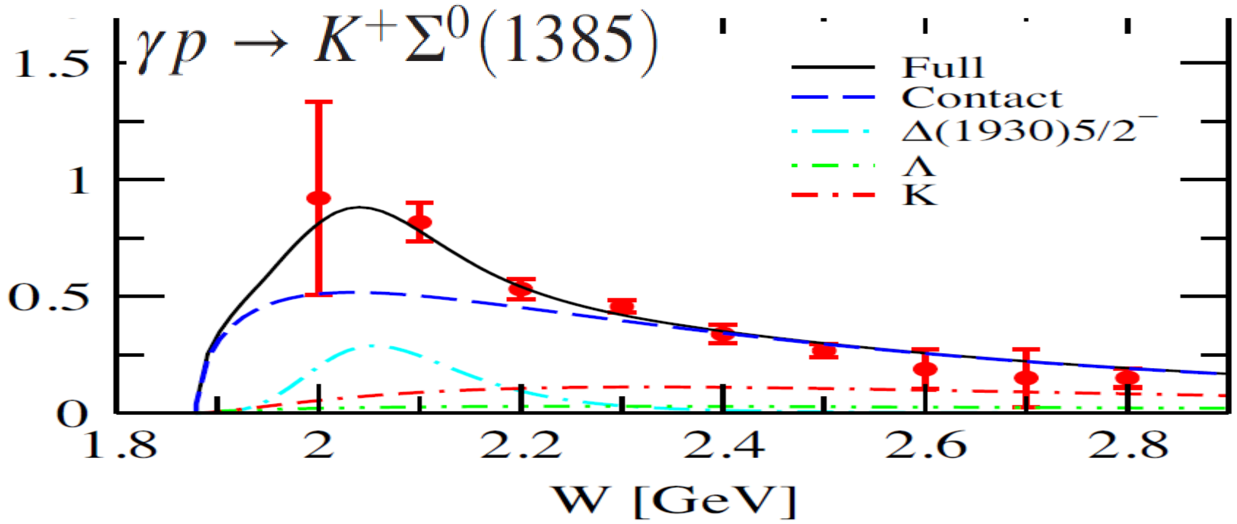


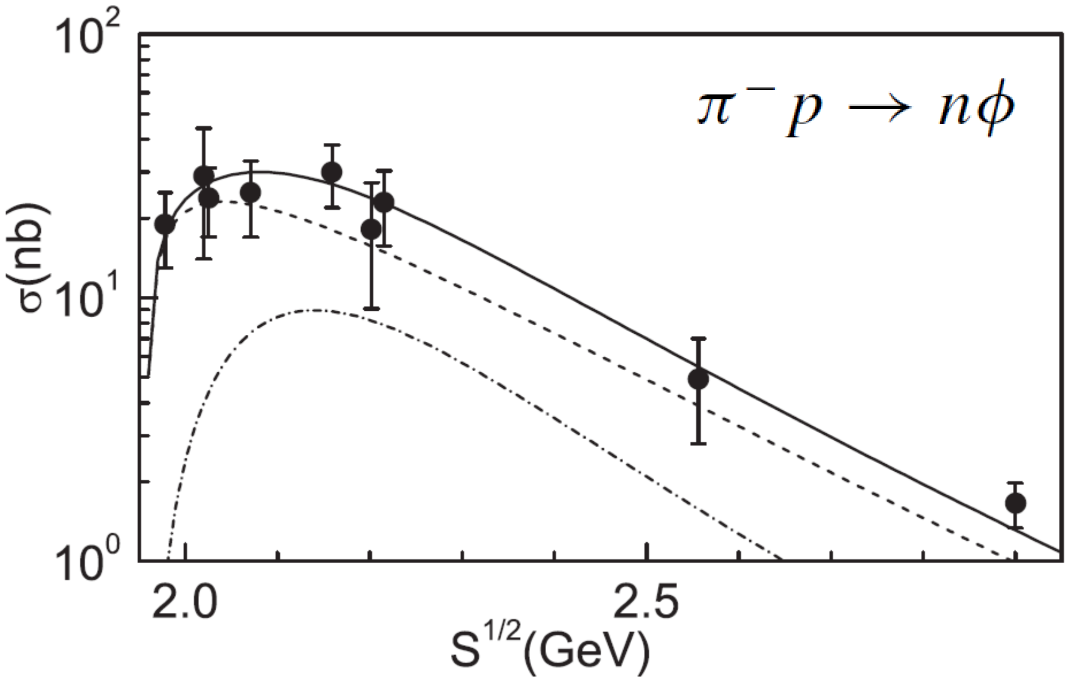
FIG. 8. Single spin asymmetries Σ (left), T (middle), and P (right) predicted at $W = 2217$ MeV for $\gamma p \to K^{*+}\Sigma^0$ (the upper row) and $W = 2280$ MeV for $\gamma p \to K^{*0}\Sigma^+$ (the lower row). The blue solid lines represent the results from the present work, and the red dashed lines denote the results from Ref. [25].

Further evidence of N*(1875), N*(2080) & N*(2270) ?





J.J.Xie, B.S.Zou, H.C.Chiang, PRC77(2008)015206



N*(1535) + N*(1900) ½+ or N*(1875)+N*(2080)+N*(2270) ?

More data with angular distribution and polarization information are needed !

Conclusion and prospect

- strange partners of P_c states are expected to exist
- strong evidence for their existence in γp reactions
- higher statistics and polarization info are needed
- CEBAF, ELSA, πp@JPARC, EIC&EicC may play an important role here:

  $\pi^- p \rightarrow n\phi, K\Lambda, K\Sigma, K^*\Lambda, K^*\Sigma, K\Sigma^*, \ldots$

  $\gamma^{(*)} p \rightarrow p\phi, K^+\Lambda, K\Sigma, K^{*+}\Lambda, K^*\Sigma, K\Sigma^*, \ldots$

Thank you for your attention !

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EicC@HIAF

Complementary to CBM and PANDA at FAIR etc.

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2) ECT*, Trento, Italy
3) FIAS, Frankfurt, Germany
4) YITP, Kyoto, Japan
5) …

① Nuclear Structure

- Super Heavy Element
- New Isotopes
- Collision Dynamics
- Nuclear-astrophysics

② Nuclear Matter Structure

- QCD phase boundary, critical point
- Hyper-nuclear production
- EOS at high baryon density
- CEE, CBM, NICA, STAR

③ Nucleon Structure

- Hadron spectroscopy
- 3D Imaging
- Origin of mass and spin
- EicC, EIC, BESIII, PANDA

④ Neutrino

Weak interactions in Nucl. Phys.

- Dirac or Majorana?
- Beyond SM physics
- Nuclear structure with neutrino
- NνDEx, NEXT

You are welcome to SCNT to participate its activities!

Spin "crisis" , $\bar{d} - \bar{u} \sim 0.12$, $\bar{s}(x) \neq s(x)$ puzzles →

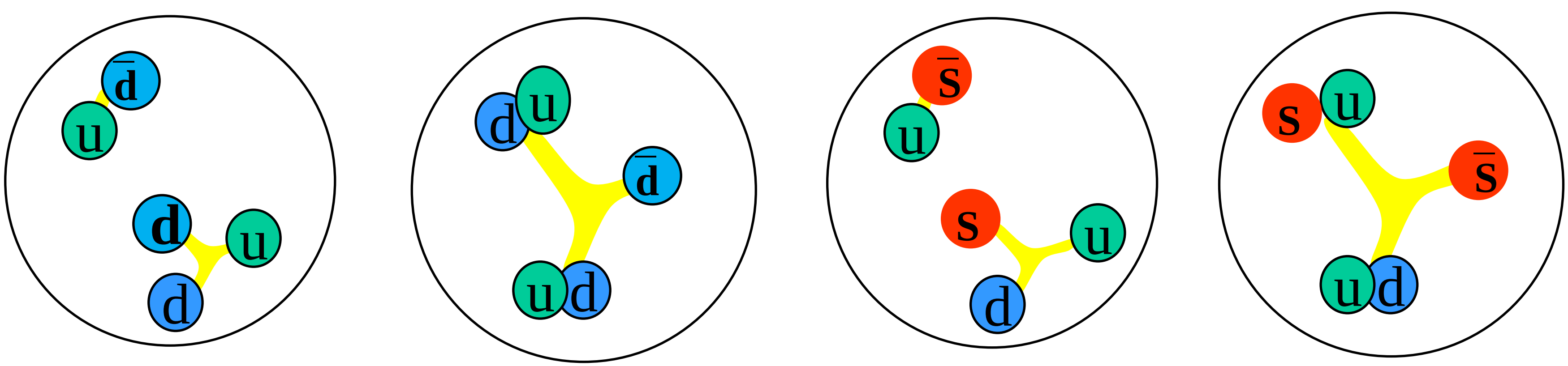
two possible solutions:

Meson clouds: **Thomas, Speth, Weise, Oset, Brodsky, Ma, …**

$$| p > \sim | uud > + \varepsilon_1 | n\,(udd)\,\pi^+ (\bar{d}u) >$$
$$+ \varepsilon_2 | \Delta^{++} (uuu)\,\pi^- (\bar{u}d) > + \varepsilon' | \Lambda\,(uds)\,K^+ (\bar{s}u) > \ldots$$

diquarks: **Riska, Zou, Zhu, …**

$$| p > \sim | uud > + \varepsilon_1 | [ud][ud]\,\bar{d} > + \varepsilon' | [ud][us]\,\bar{s} > + \ldots$$



$1/2^-$ baryon nonet with strangeness

- **Mass pattern : quenched or unquenched ?**

uds (L=1) $1/2^-$ ~ $\Lambda^*(1670)$ ~ $[us][ds]\bar{s}$ $\bar{K}\Xi - \eta\Lambda$

uud (L=1) $1/2^-$ ~ $N^*(1535)$ ~ $[ud][us]\bar{s}$ $\bar{K}\Sigma - \bar{K}\Lambda - \eta N$

uds (L=1) $1/2^-$ ~ $\Lambda^*(1405)$ ~ $[ud][su]\bar{u}$ $\bar{K}N - \pi\Sigma$

uus (L=1) $1/2^-$ ~ $\Sigma^*(1390)$ ~ $[us][ud]\bar{d}$ $\bar{K}N - \pi\Sigma - \pi\Lambda$

Zou et al, NPA835 (2010) 199 ; CLAS, PRC87(2013)035206

- **Strange decays of N*(1535) : PDG → large $g_{N^*N\eta}$**

$J/\psi \rightarrow \bar{p}N^* \rightarrow \bar{p}\,(K\Lambda)$ / $\bar{p}\,(p\eta)$ → large $g_{N^*K\Lambda}$

Liu&Zou, PRL96 (2006) 042002; Geng,Oset,Zou&Doring, PRC79 (2009) 025203

$\gamma p \rightarrow p\eta'$ & $pp \rightarrow pp\eta'$ → large $g_{N^*N\eta'}$

M.Dugger et al., PRL96 (2006) 062001; Cao&Lee, PRC78(2008) 035207

$\pi^- p \rightarrow n\phi$ & $pp \rightarrow pp\phi$ & $pn \rightarrow d\phi$ → large $g_{N^*N\phi}$

Xie, Zou & Chiang, PRC77(2008)015206; Cao, Xie, Zou & Xu, PRC80(2009)025203

- **Strange decays of Λ*(1670) : PDG → large $g_{\Lambda^*\Lambda\eta}$**

narrower width (35MeV) than Λ*(1405)

$\bar{s}suud \rightarrow \bar{c}cuud$

- prediction of three P_c pentaquark states → J/ψ-p :
  1 $\bar{D}\Sigma_c$ molecule + 2 $\bar{D}^*\Sigma_c$ molecules

  J.J.Wu, R.Molina, E.Oset, B.S.Zou, PRL 105 (2010) 232001
  W.L.Wang, F.Huang, Z.Y.Zhang, B.S.Zou, PRC 84 (2011) 015203
  J.J.Wu, T.H.Lee, B.S.Zou, PRC 85 (2012) 044002

- 4 more broader P_c states with $\Sigma_c \rightarrow \Sigma_c^*$:
  1 $\bar{D}\Sigma_c^*$ molecule + 3 $\bar{D}^*\Sigma_c^*$ molecules

  C.W.Xiao, J.Nieves, E.Oset, PRD 88 (2013) 056012

Due to limitation of energy range, luminosity and detectors at COSY, not much observations on N* with hidden strangeness from pp yet.

HIAF + CEE @ Huizhou may play a important role

$pp \rightarrow pK^+\Lambda$, $nK^+\Sigma^+$, $pK^+\Sigma^0$, $Ks\Sigma^+p$, $pp\phi$, $pp\eta$, $pp\eta'$, ppK^+K^-, pnK^+Ks, $p\Lambda Ks\,\pi^+$, $p\Lambda K^+\eta$, $p\Lambda K^+\phi$, $p\Xi^-K^+K^+$, ……

→ strange partners of P_c and P_{cs} states

\+ more reliable input for studying K production in HIC

How about pp at JPARC ?