

QCD and the Strange Baryon Spectrum

M. Niiyama (Kyoto Sangyo Univ.)



2024 QP
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IWHS COMPASS
Yerevan Armenia

Yerevan, Armenia
30 September – 4 October, 2024

The banner features a scenic view of Yerevan, Armenia, with the snow-capped Mount Ararat in the background. The text is overlaid on the top left and right of the image. The '2024' is in large yellow and orange numbers, with a globe icon for the '0'. 'QP' is in large pink and blue letters. The workshop titles are in white text. 'IWHS COMPASS' is in blue and red letters with a compass icon. 'Yerevan Armenia' is in blue and yellow text with a key icon. The dates and location are in red text.

QCD and the Strange Baryon Spectrum

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Review

QCD and the strange baryon spectrum

Tetsuo Hyodo^{a,*}, Masayuki Niiyama^b

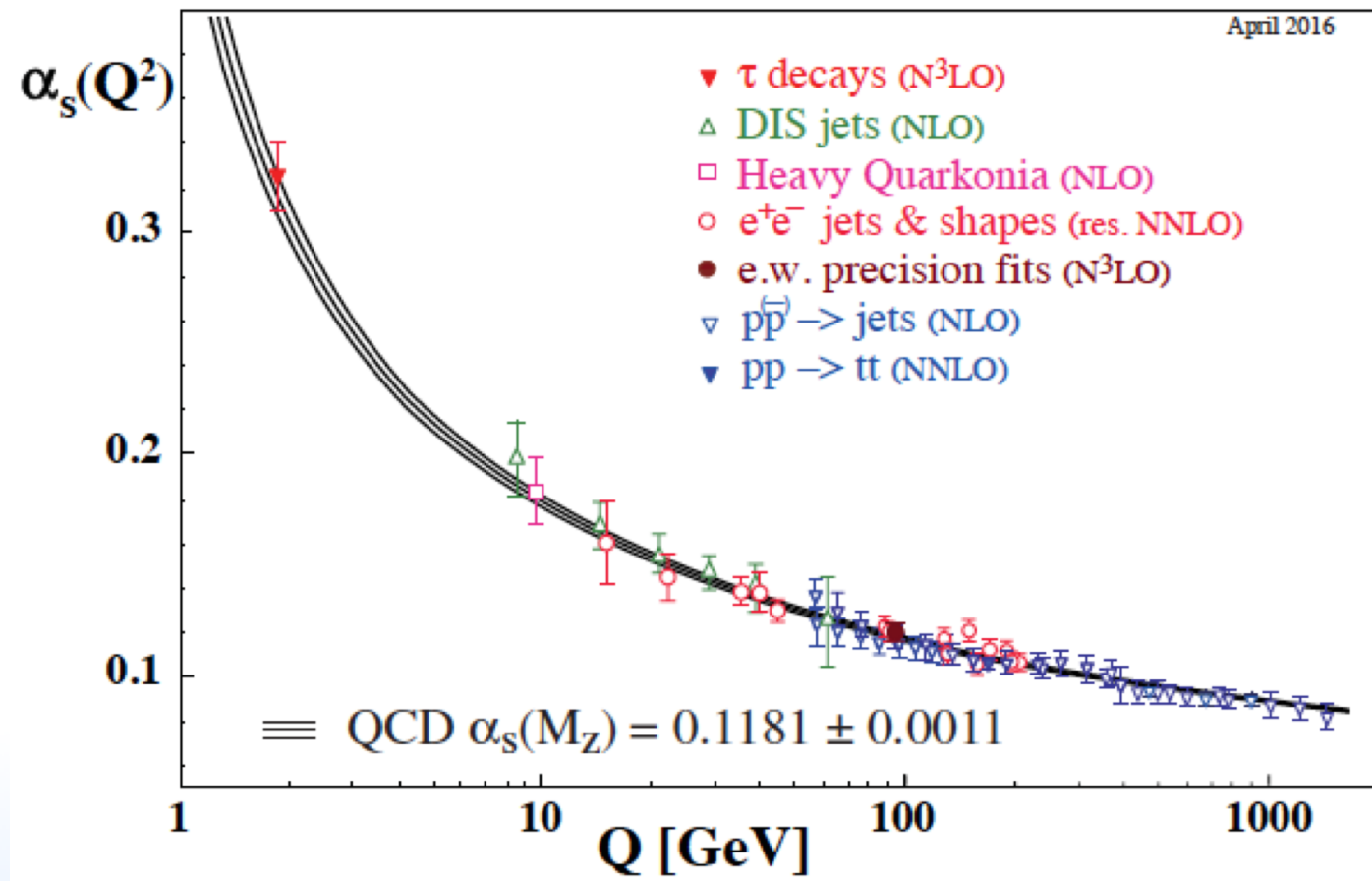
^a Department of Physics, Tokyo Metropolitan University, Hachioji 192-0397, Japan

^b Department of Physics, Kyoto Sangyo University, Kyoto 603-8555, Japan



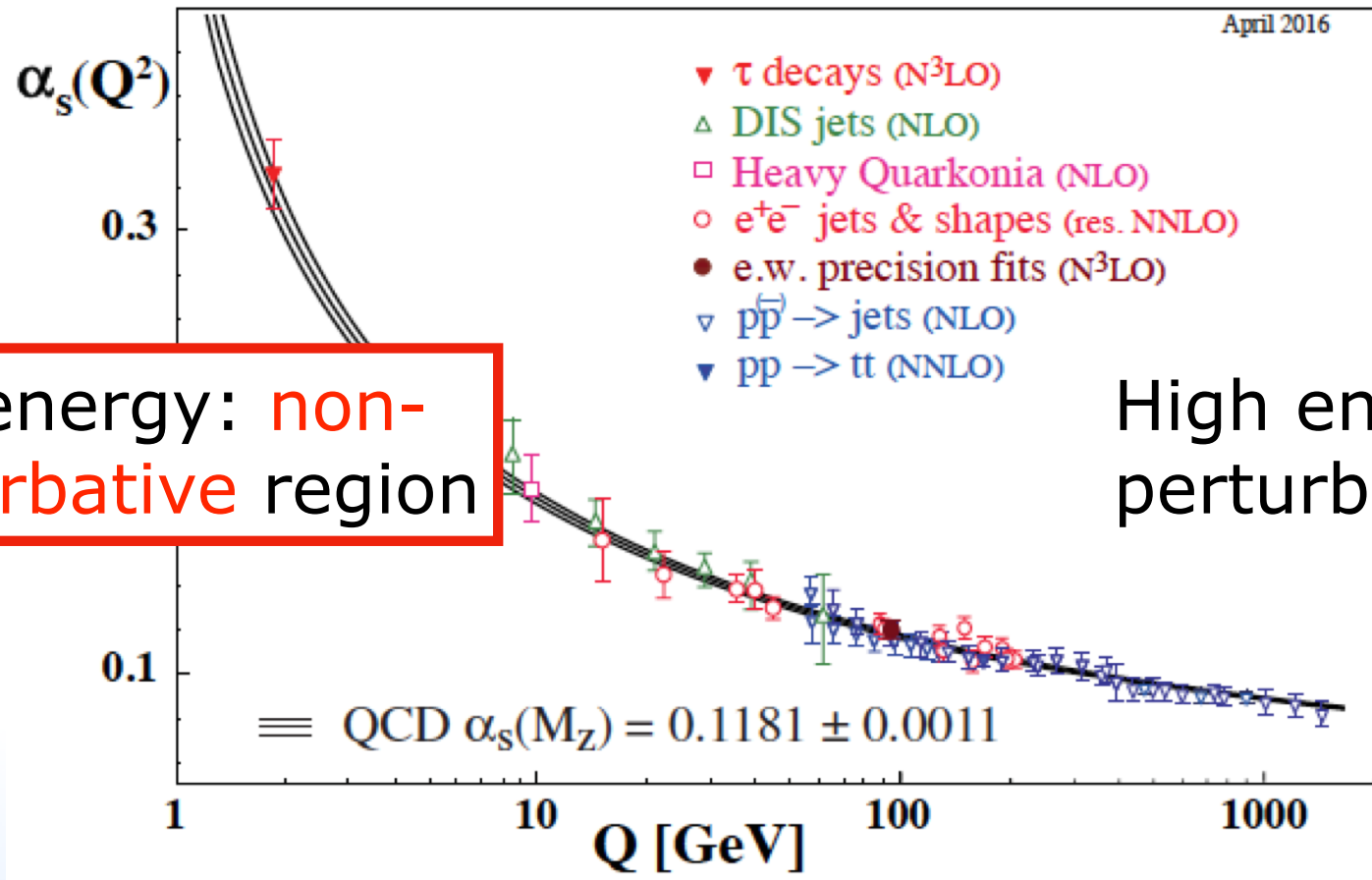
Quantum Chromo-Dynamics (QCD) and hadron physics

Running coupling constant of strong interaction



Quantum Chromo-Dynamics (QCD) and hadron physics

Running coupling constant of strong interaction

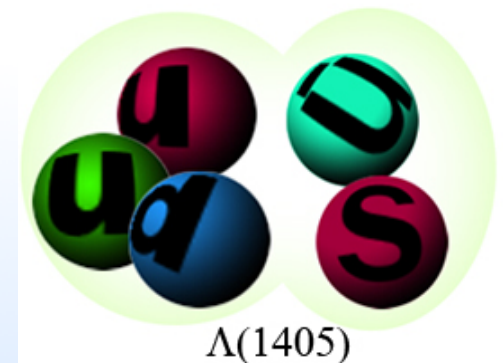


Low energy: **non-perturbative** region

High energy: perturbative region

Degrees-of-freedom for hadron

- Constituent quark model
 - guiding principle
- “Exotic” non- $3q/q\bar{q}$ hadrons
- Hadronic molecules
 - hadrons as building blocks of a hadron
 - most candidates appear near the threshold
 - $\Lambda(1405):\bar{K}N$, $X(3872):\bar{D}D^*$, $P_{c\bar{c}}:\bar{D}\Sigma_c$, $\bar{D}^*\Sigma_c$
- Compact exotic hadron
 - $3 <$ quarks in a confinement bag
 - diquark DOF may appear



Spectroscopy of hyperon resonances

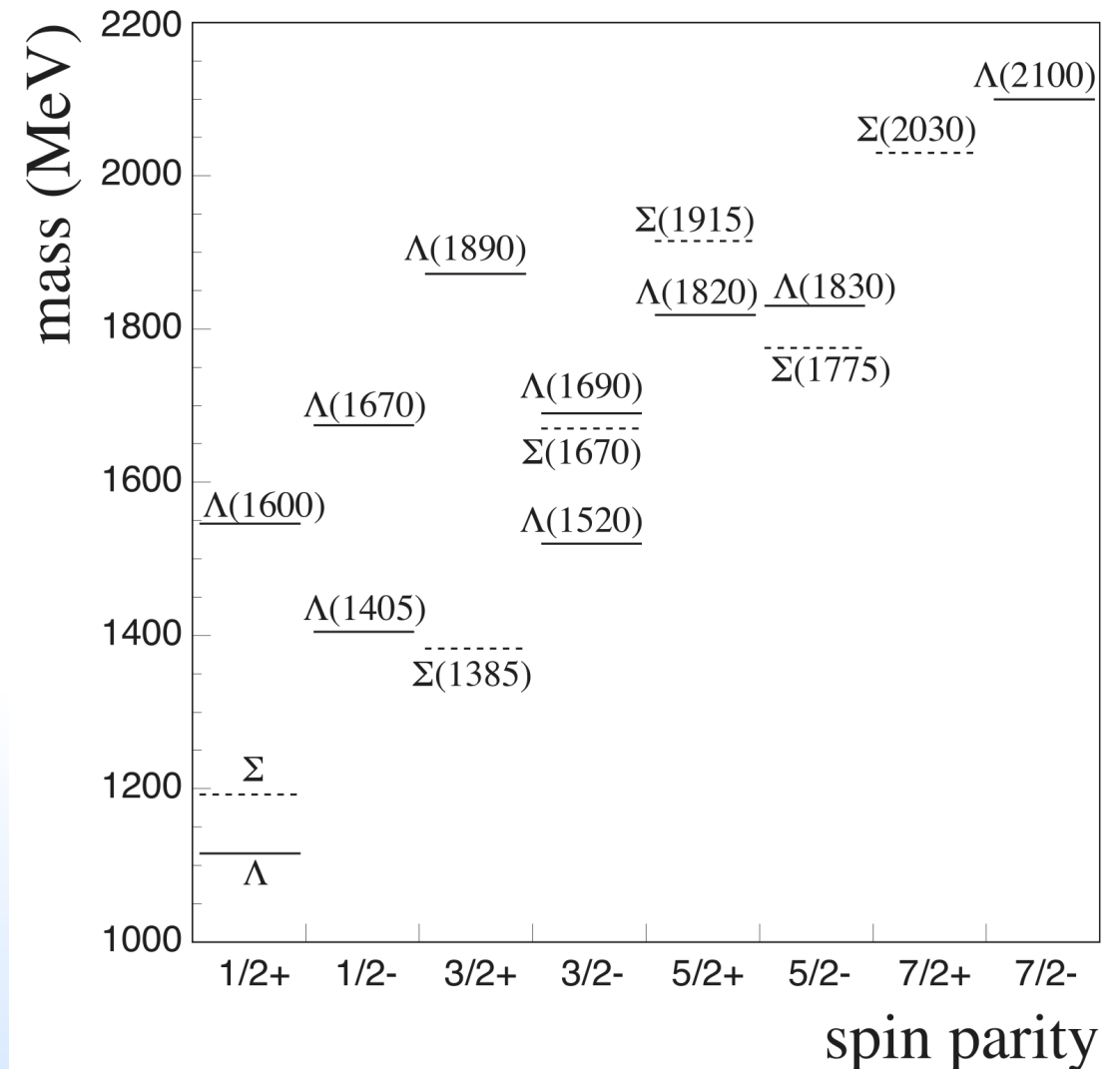
4 star (★) rating by PDG

$S = -1$

- 10 Λ states, 6 Σ states : ★★★★★

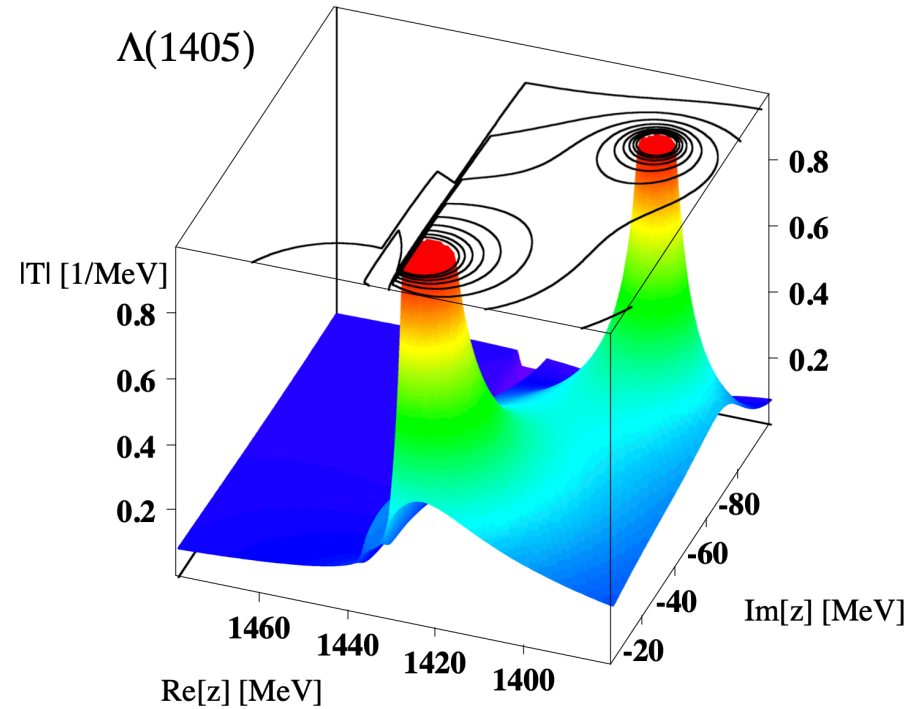
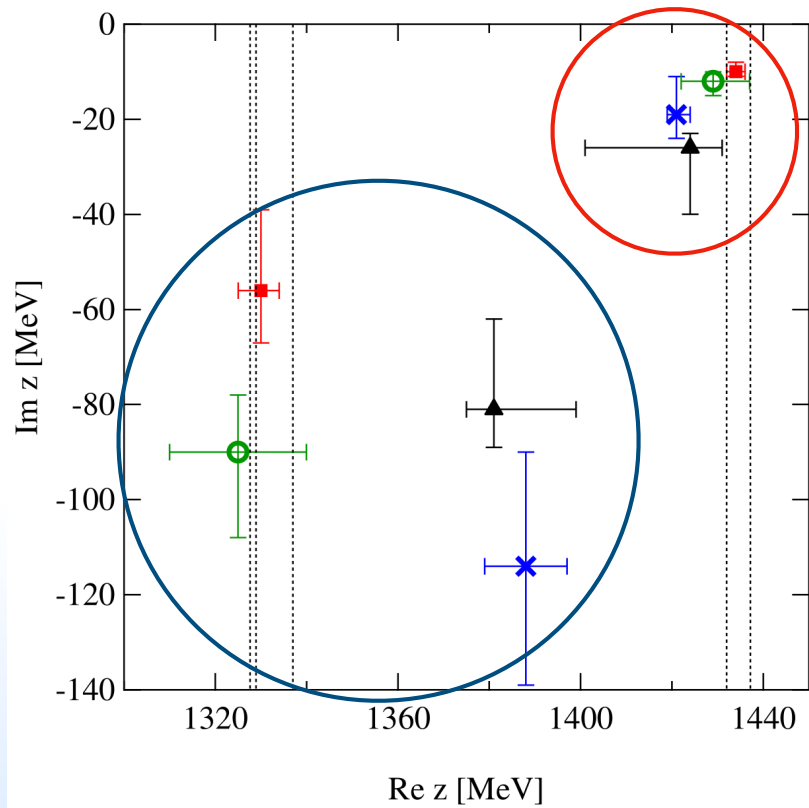
Several exotic candidates

- $\Lambda(1380)/\Lambda(1405)$
 - $\bar{K}N, \pi\Sigma$
- Λ 's around 1.67 GeV
- and more ...



$\Lambda(1380)/\Lambda(1405)$

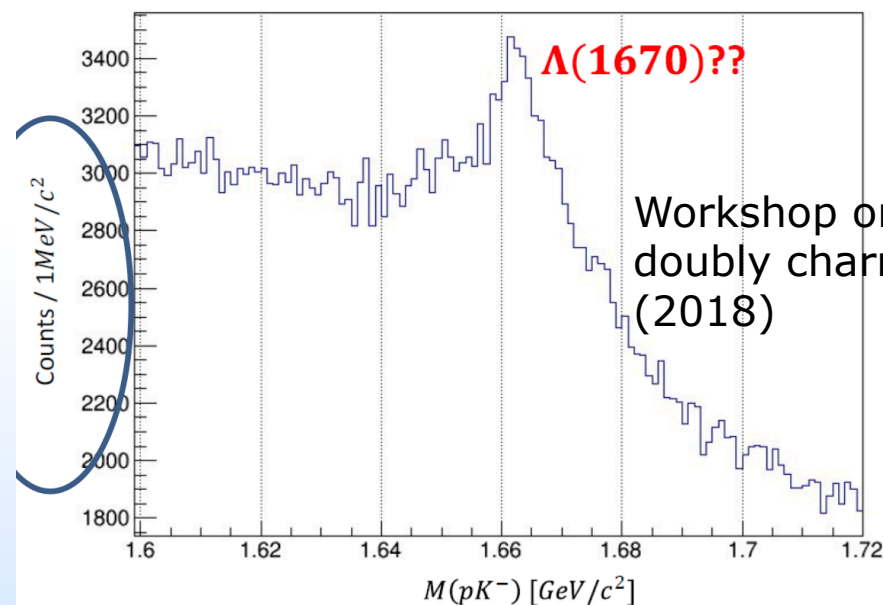
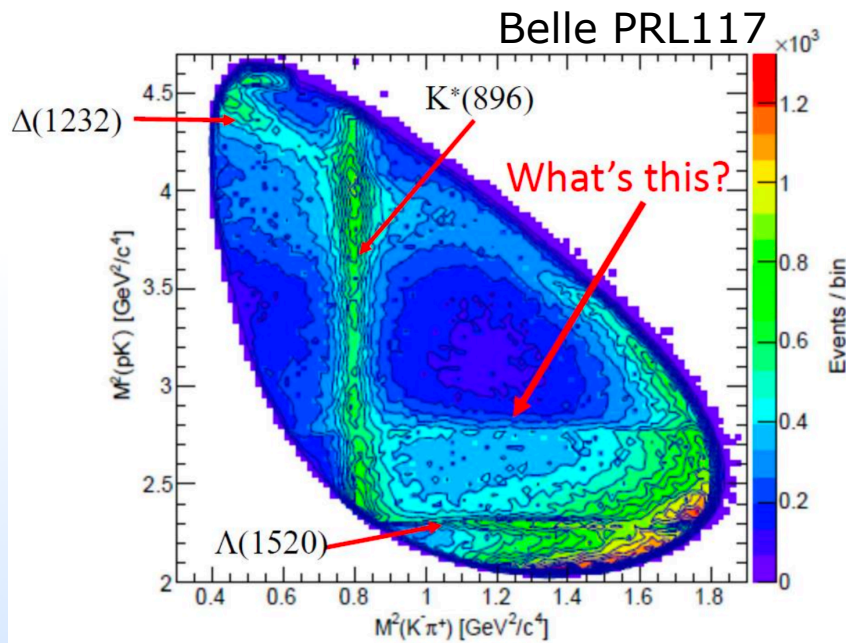
- Two pole structure for Λ below KN threshold
- $\Lambda(1405)$: ★ ★ ★ ★
 - pole ~ 1420 MeV (Kaonic Hydrogen)
- $\Lambda(1380)$: ★ ★
 - newly assigned state



T. Hyodo, D. Jido,
Prog. Part. Nucl. Phys. 67, 55 (2012)

Λ 's around 1.67 GeV

- Belle observed narrow peaking structure in $M(K^- p)$ of $\Lambda_c \rightarrow p K^- \pi^+$ around 1663 MeV ($\Lambda_\eta = 1663.5 \text{ MeV}$)
(PRL117,011801, Workshop on singly and doubly charmed baryons)
- $\sim 10 \text{ MeV}$ width: narrower than known resonances (25~200 MeV).
- Two groups claim narrow resonances from $K^- p \rightarrow \Lambda \eta$ data
 - $J^P = 3/2^+$, $M = 1671^{+2}_{-8} \text{ MeV}$, $\Gamma = 10^{+22}_{-4} \text{ MeV}$ (Kamano et al., PRC90.065204, PRC92.025205)
 - $J^P = 3/2^-$, $M = 1668.5 \pm 0.5 \text{ MeV}$, $\Gamma = 1.5 \pm 0.5 \text{ MeV}$ (Liu&Xie, PRC85.038201, PRC86.055202)
- New experiment at J-PARC (E72)



Workshop on singly and doubly charmed baryons (2018)

Spectroscopy of hyperon resonances

$S = -2$

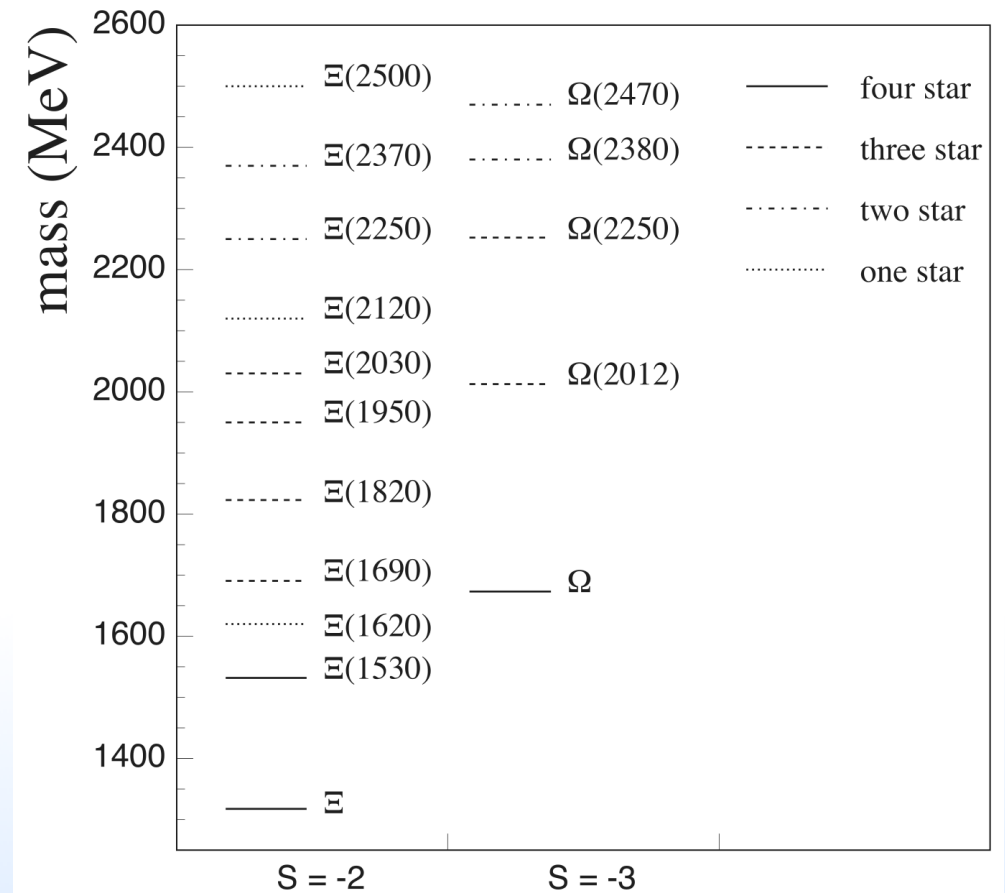
- Ξ , $\Xi(1530)$: ★★★★★
- $\Xi(1690)$, $\Xi(1820)$, $\Xi(1950)$, $\Xi(2030)$: ★★★

$S = -3$

- only 5 states in PDG
- $\Omega(2012)$, $\Omega(2250)$: ★★★

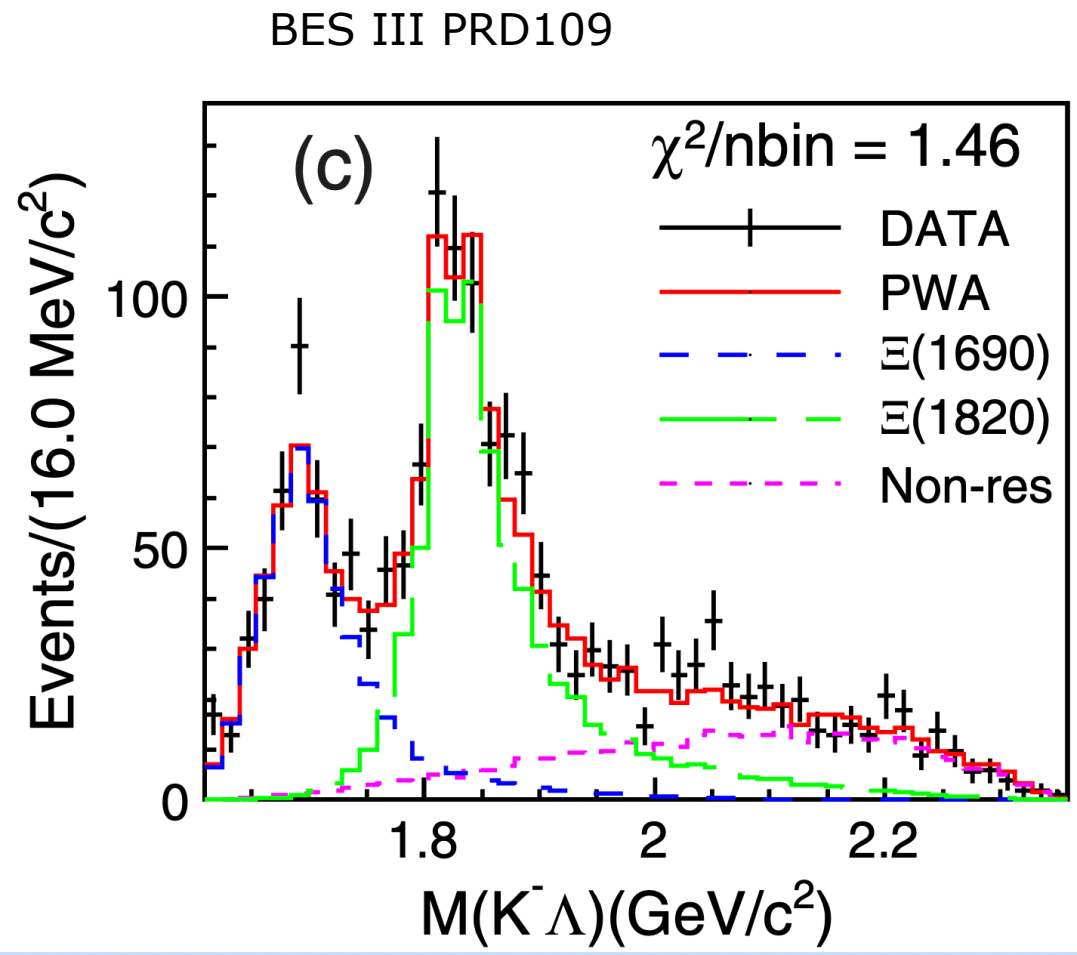
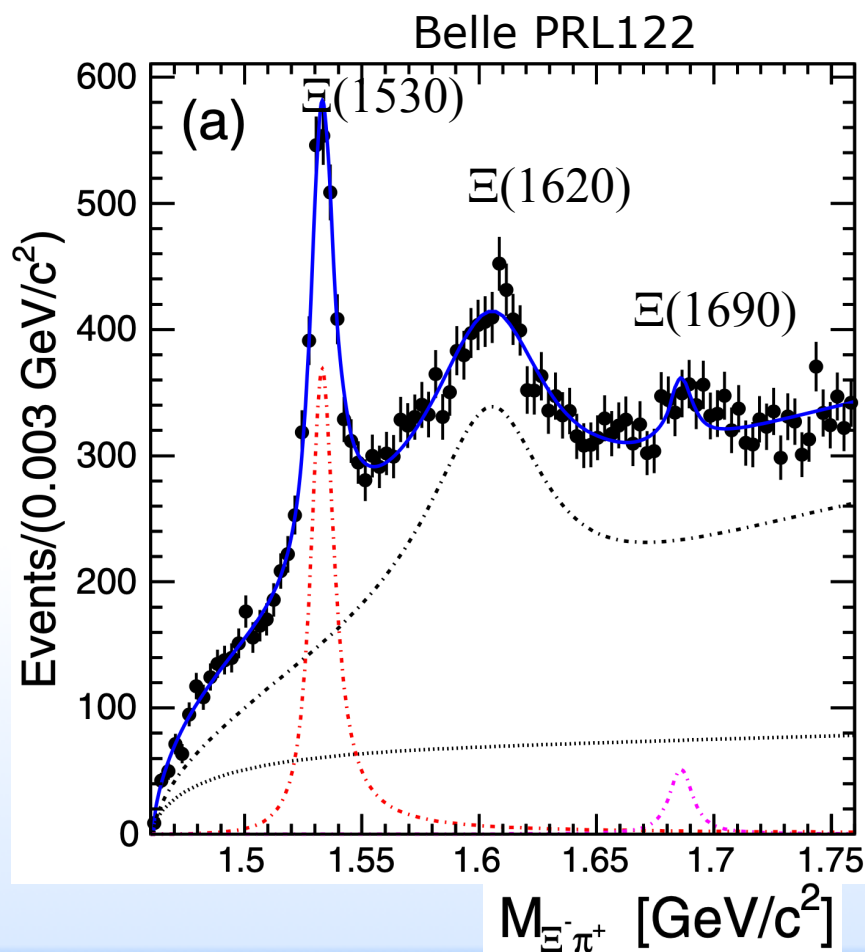
Exotic candidates

- $\Xi(1620)$, $\Xi(1690)$,
 $\Xi(1820)$
- $\Omega(2012)$...



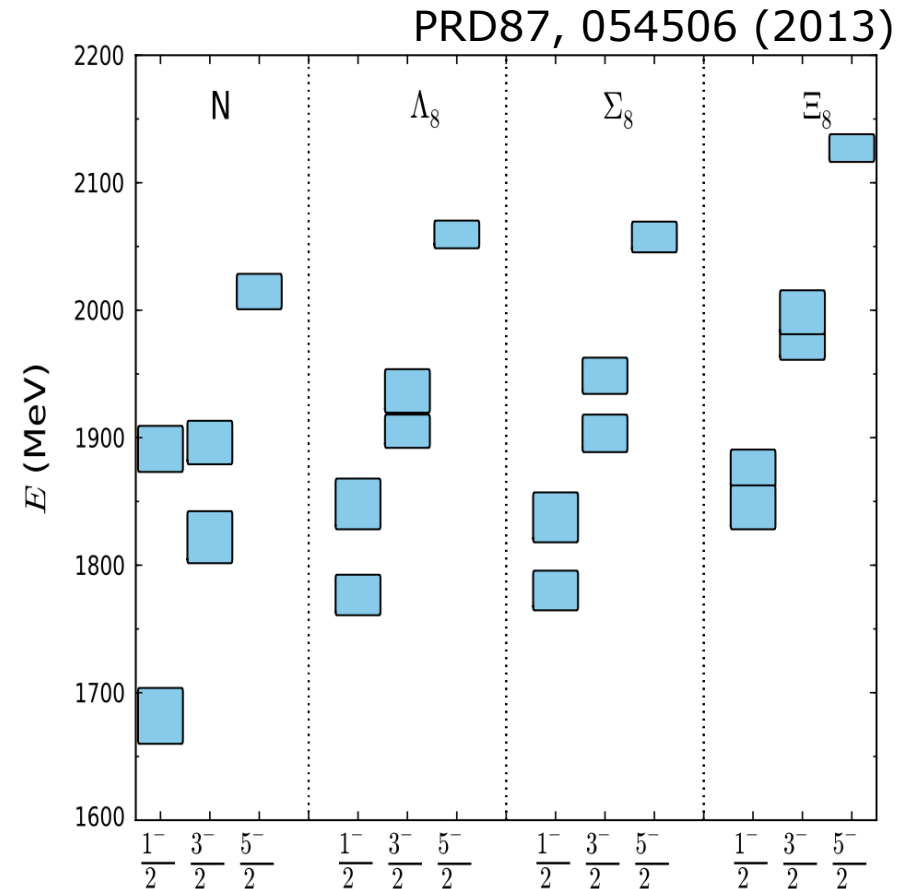
Excited Ξ states

- Belle : $\Xi(1620)$, $\Xi(1690)$ in $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$, (PRL122, 072501 (2019))
 - $\Xi(1620)$ @ $1610.4 \pm 6.0^{+6.1}_{-4.2}$ MeV , $\Gamma \sim 60$ MeV
- BES III : $\Xi(1690)$, $\Xi(1820)$ in $\psi(3686) \rightarrow K^- \Lambda \Xi^+$ (PRD 91, 092006 (2015), PRD 109, 072008 (2024))
 - $\Xi(1690)$ 1/2- @ $1685^{+3.2}_{-2} \pm 12$ MeV, $\Gamma \sim 81$ MeV
 - $\Xi(1820)$ 3/2- @ $1821^{+2.3}_{-3} \pm 3$ MeV, $\Gamma \sim 73$ MeV



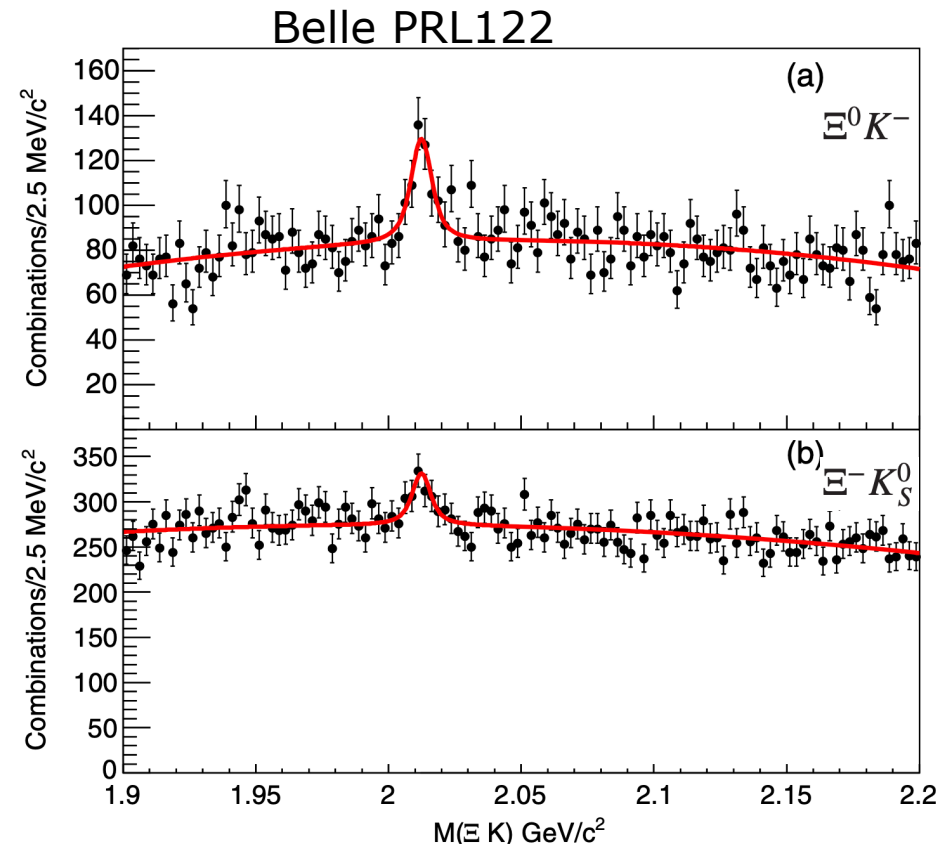
Excited Ξ states

- Low-lying states, $\Xi(1620)$, $\Xi(1690)$ $1/2^-$
- Constituent quark model predicts heavier states
- Lattice QCD also predicts heavier states
R.G. Edwards et al., PRD87, 054506 (2013)
- Discussions on the internal structure, mostly based on meson-baryon molecular picture ($\pi\Xi$, $\bar{K}\Lambda$, $\bar{K}\Sigma$)
 - K.Miyahara et al., PRC 95, 035212 (2017)
 - H.P.Li et al., Eur. Phys. J. C (2023) 83:954
 - and ...
- Large width of $\Xi(1820)$, $\Gamma = 73^{+6}_{-5} \pm 9$ MeV
 - two states may overlap? M.Y. Duan et al., Eur. Phys. J. C (2024) 84:947



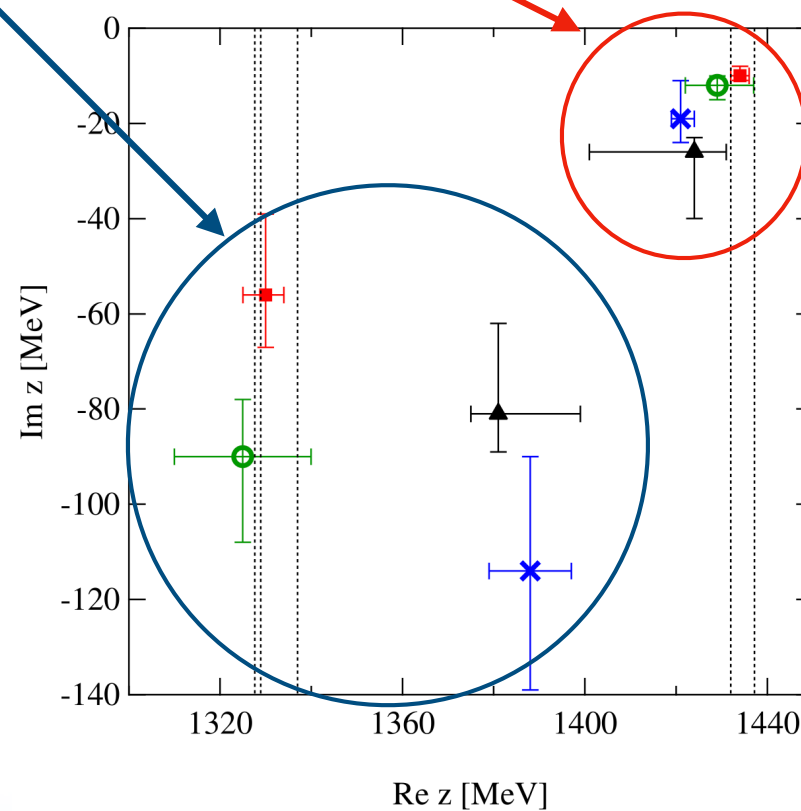
Excited Ω state

- Belle: $\Omega(2012)$ in $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ decay
(PRL121, 052003 (2018), arXiv:2207.03090)
and $\Omega_c \rightarrow \pi^+(\bar{K}\Xi)^-$ (PRD 104, 052005 (2021))
 - $M = 2012.4 \pm 0.7$ (stat) ± 0.6 (syst),
 - $\Gamma \sim 6.4$ MeV
- Lattice : 3/2-
(R.J. Hudspith et al., (arXiv:2404.02769))
1/2- or 3/2-
(L. Hockley et al., (arXiv:2408.16281))
- QCD sum rule : 1/2- or 3/2-
(N. Su et al., (NPPP 347 (2024)))
- meson-baryon ($\bar{K}\Xi(1530)$, $\eta\Omega$, $\bar{K}\Xi$)
molecular picture
 - J.X Lu et al., (EPJ C (2020) 80:361)
 - N. Ikeno et al., (PRD 101, 094016 (2020))
 - and ...



$\Lambda(1380)/\Lambda(1405)$

- Meson baryon molecule?
- Two pole structure?

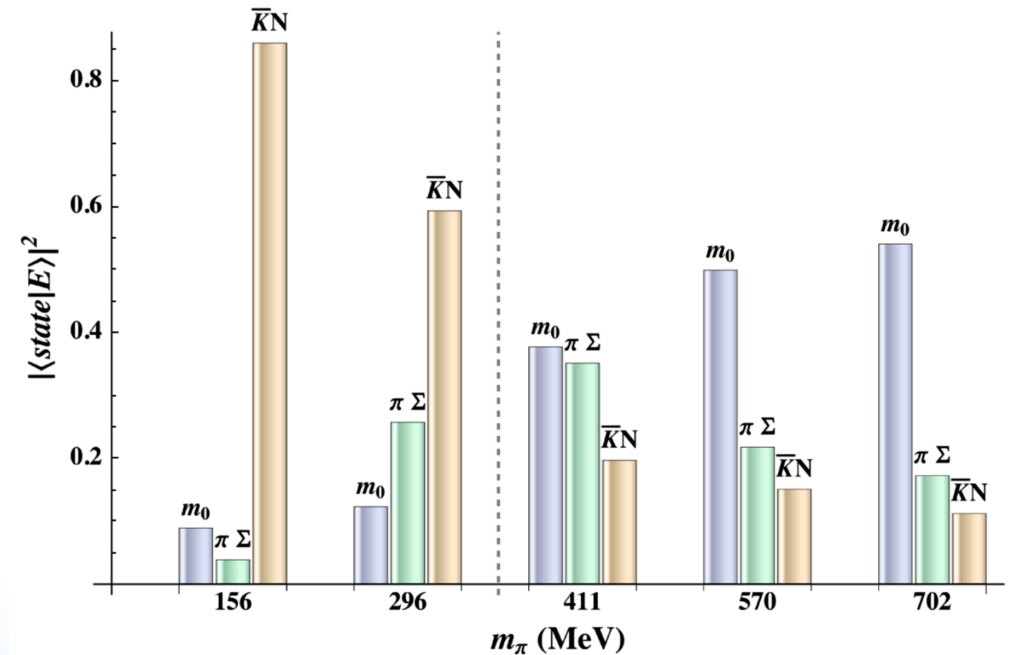
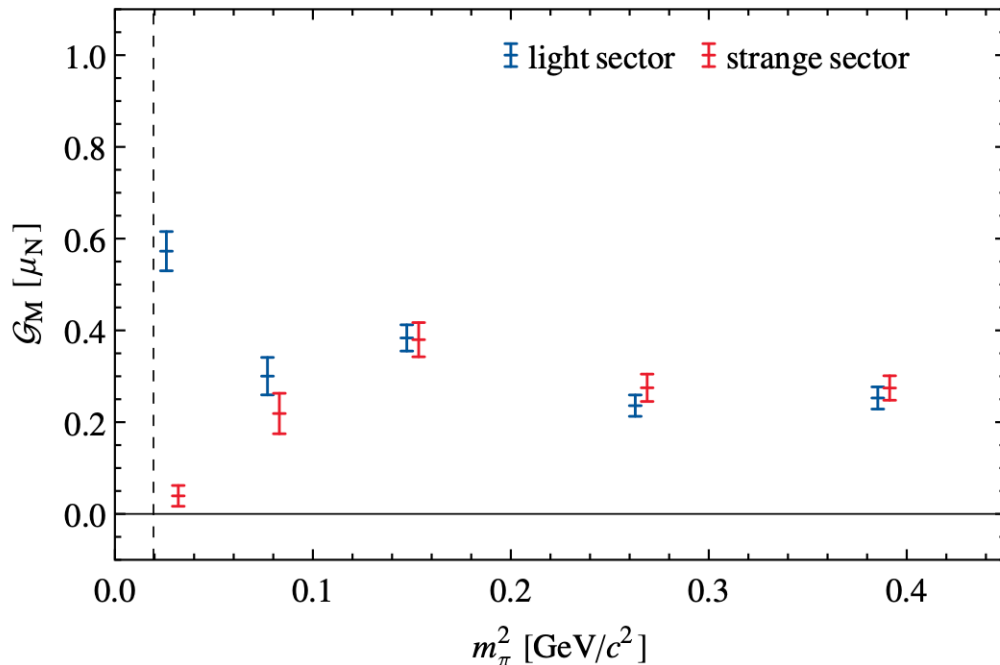
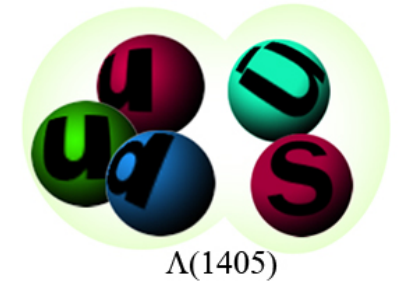


T. Hyodo, M. Niiyama, PPNP 120, 103868 (2021)

3 quark or hadron molecule? (I)

Lattice QCD

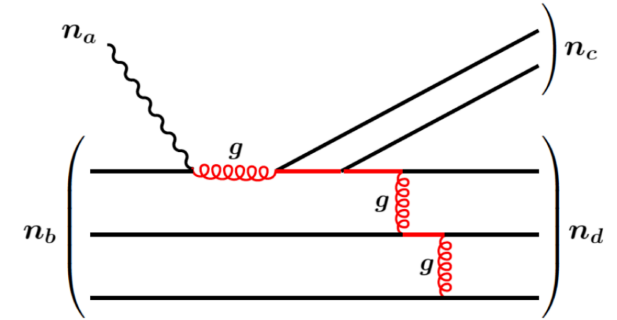
- Magnetic form factor (J.M.M. Hall et al., PRL 114, 132002 (2015))
 - contribution from strange quark vanish
 - strange quark spin is hidden in the kaon
→ evidence as $\bar{K}N$ molecule



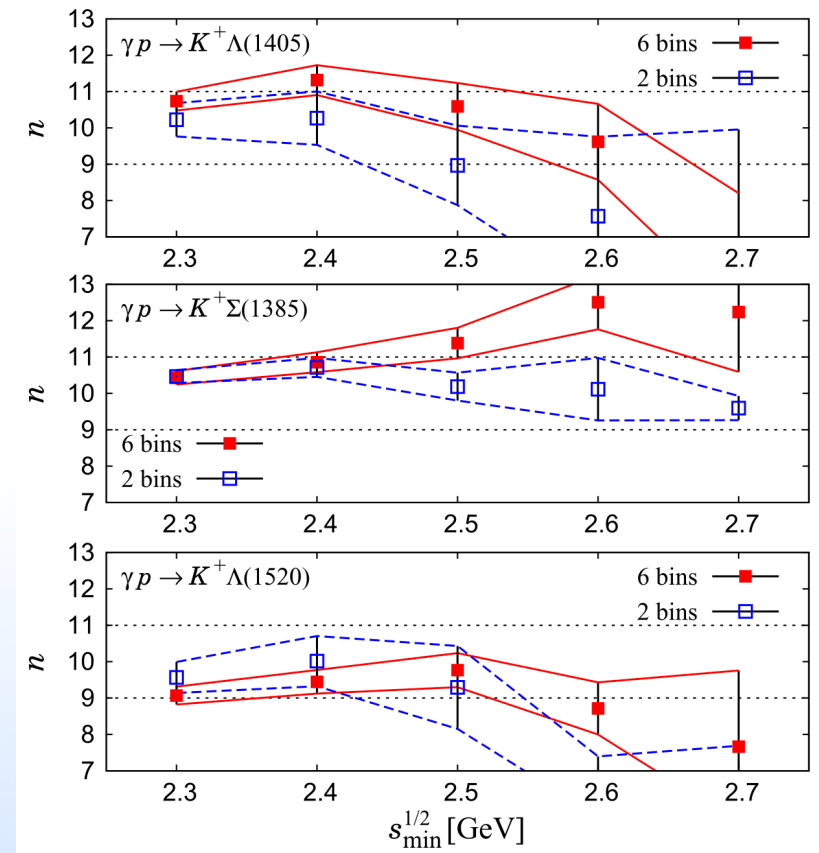
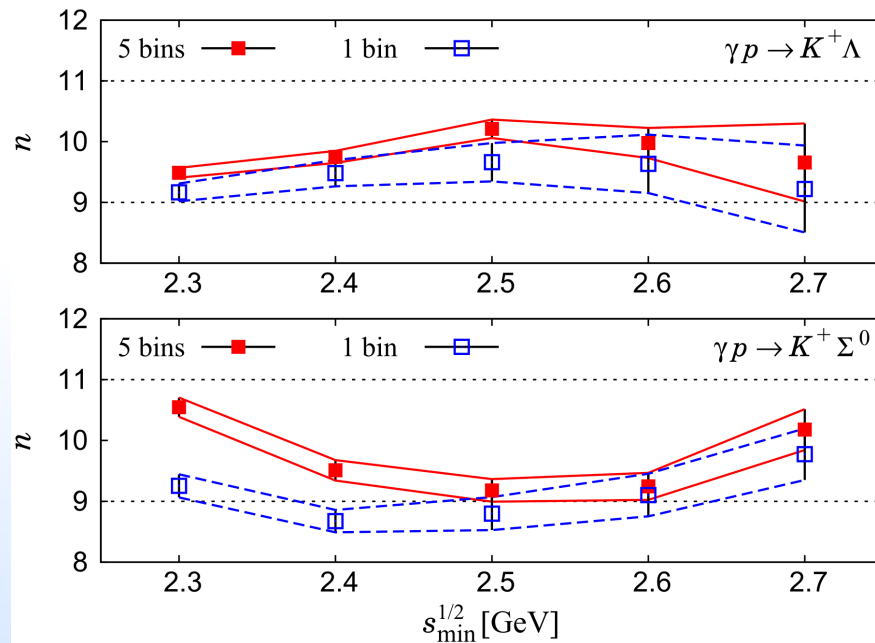
3 quark or hadron molecule? (II)

- Constituent quark counting rule for hard exclusive reaction
 - $\gamma p \rightarrow K^+ Y$ reactions (J-Lab CLAS) (W.C.Chang et al. PRD93 034006)

$$\frac{d\sigma}{dt} = \frac{1}{s^{n-2}} f(t/s) \quad n = n_\gamma + n_b + n_c + n_d$$

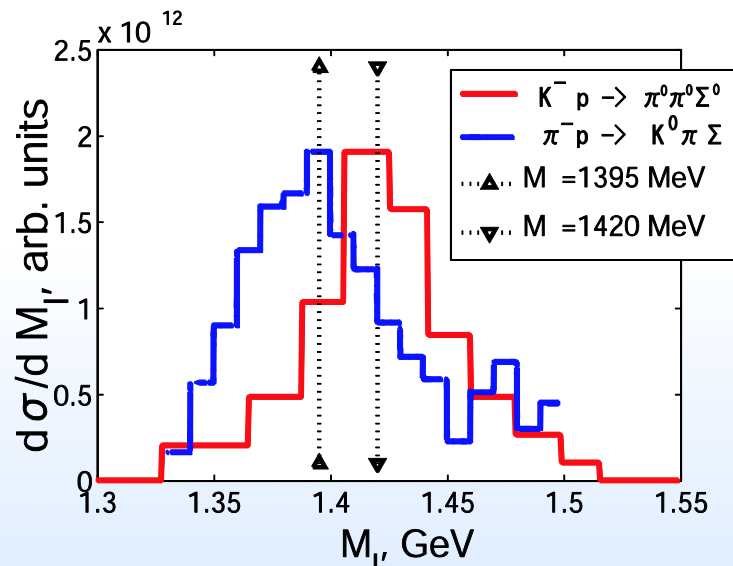
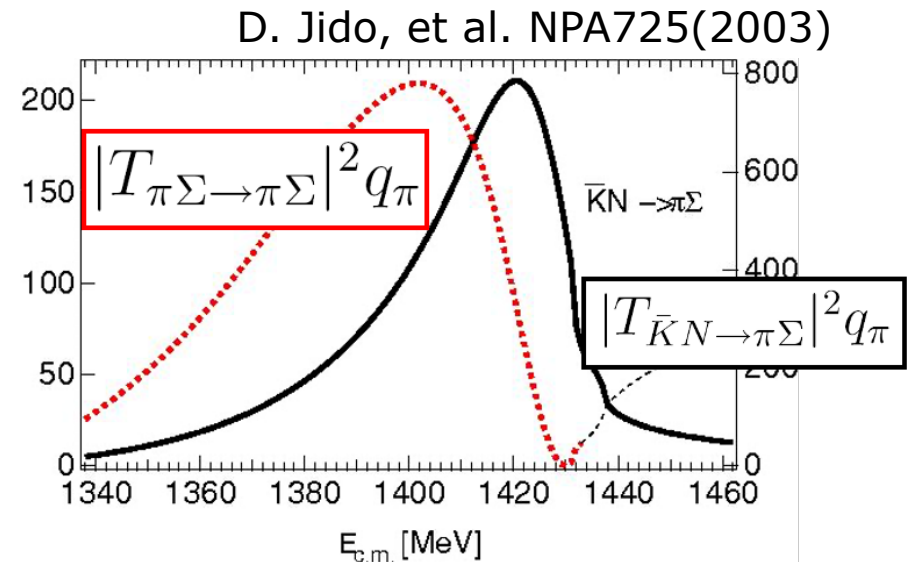


- $n=9$ for 3q hyperons
 - $n=9$ for ground state Λ, Σ
 - not conclusive for excited states
- higher energy data, J-LAB, J-PARC?

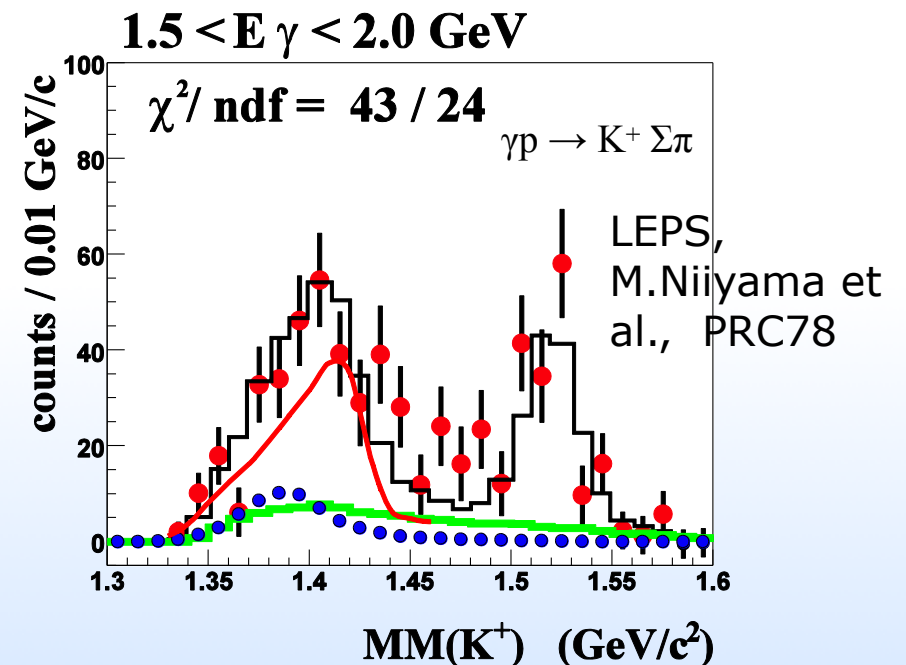


Two pole structure

- $\Lambda(1405)$: ★ ★ ★ ★
 - pole ~ 1420 MeV
 - strongly couples to $\bar{K}N$
- $\Lambda(1380)$: ★ ★
 - newly assigned state
 - $\pi\Sigma$ resonance?

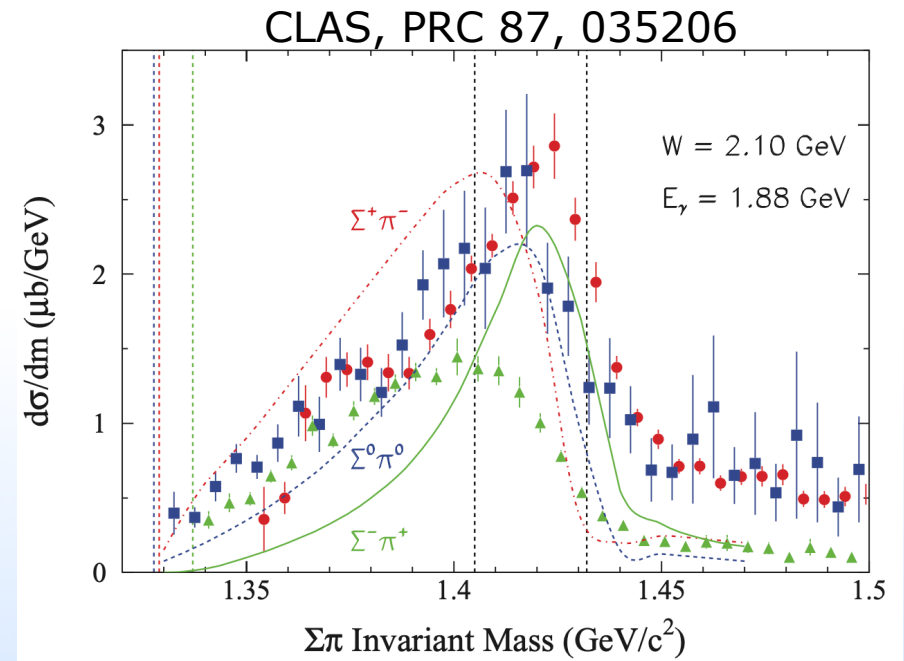
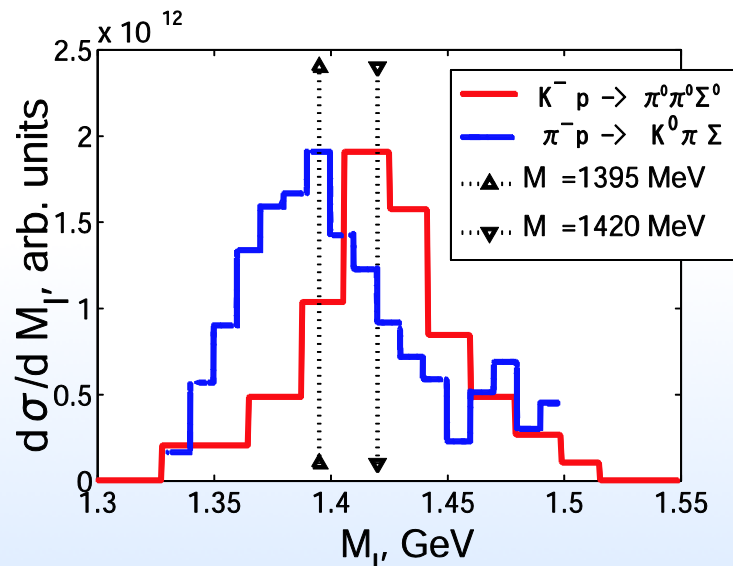
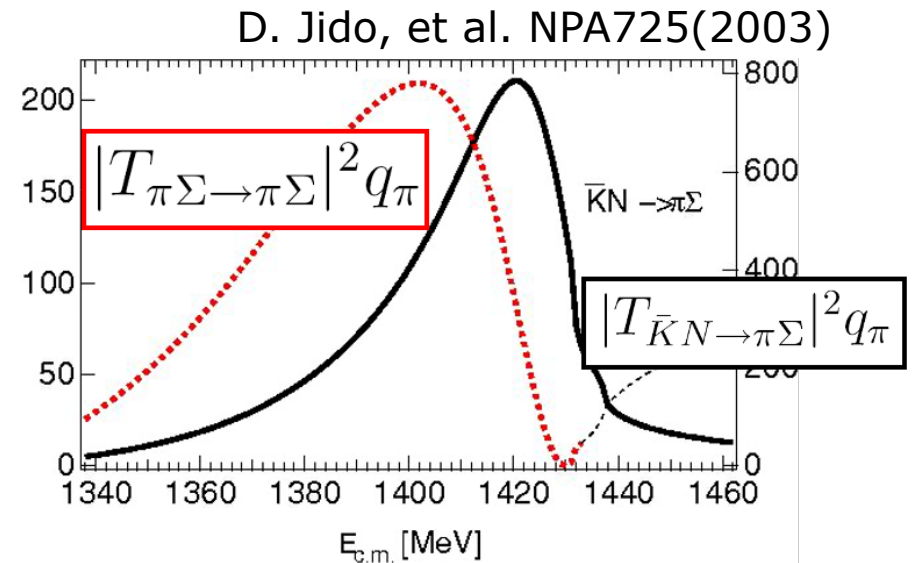


V.K. Magas, E. Oset and A. Ramos, PRL 95



Two pole structure

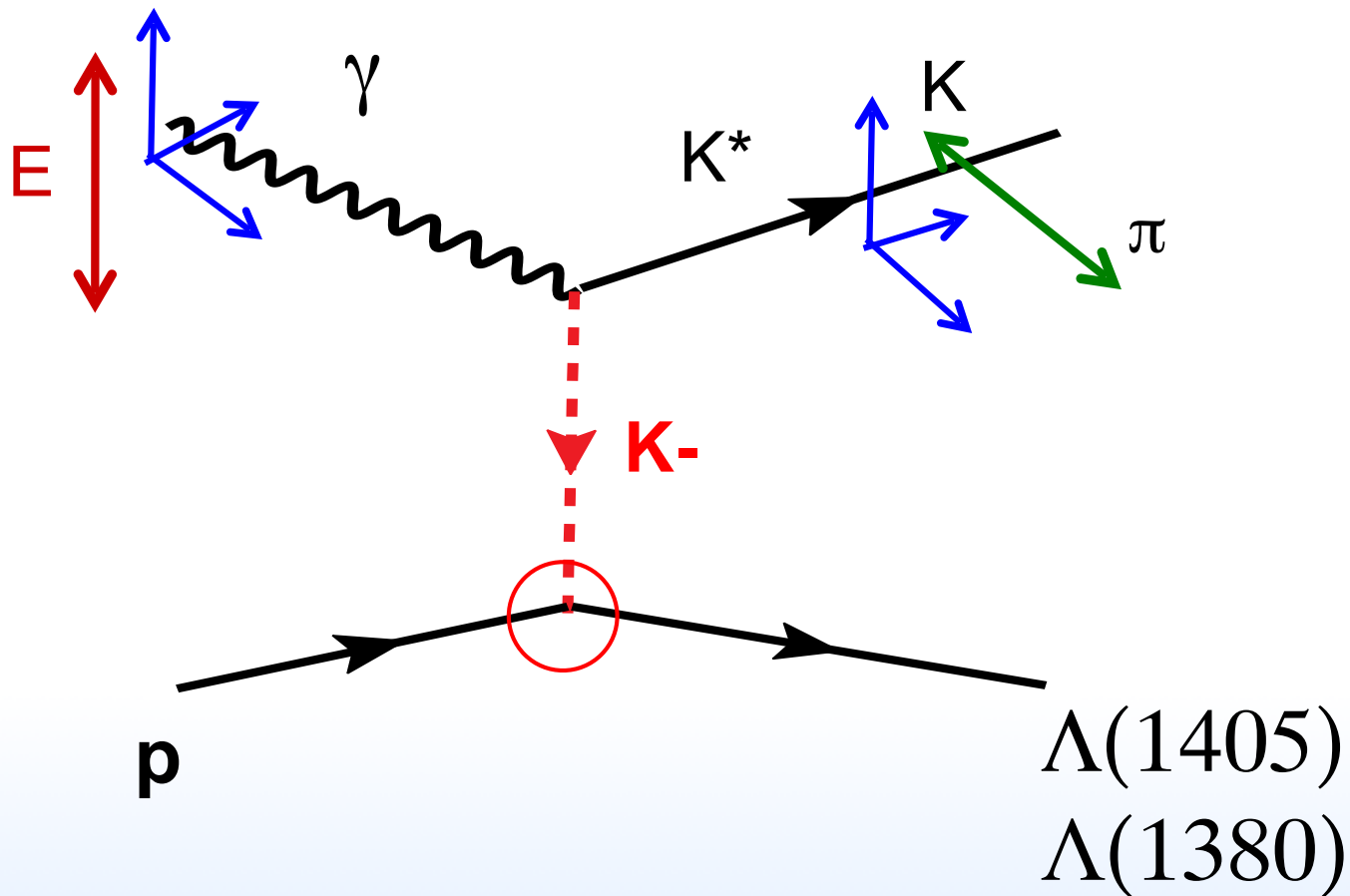
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 - newly assigned state
 - $\pi\Sigma$ resonance?



$\Lambda(1405)/\Lambda(1380)$ using linearly polarized photon beam

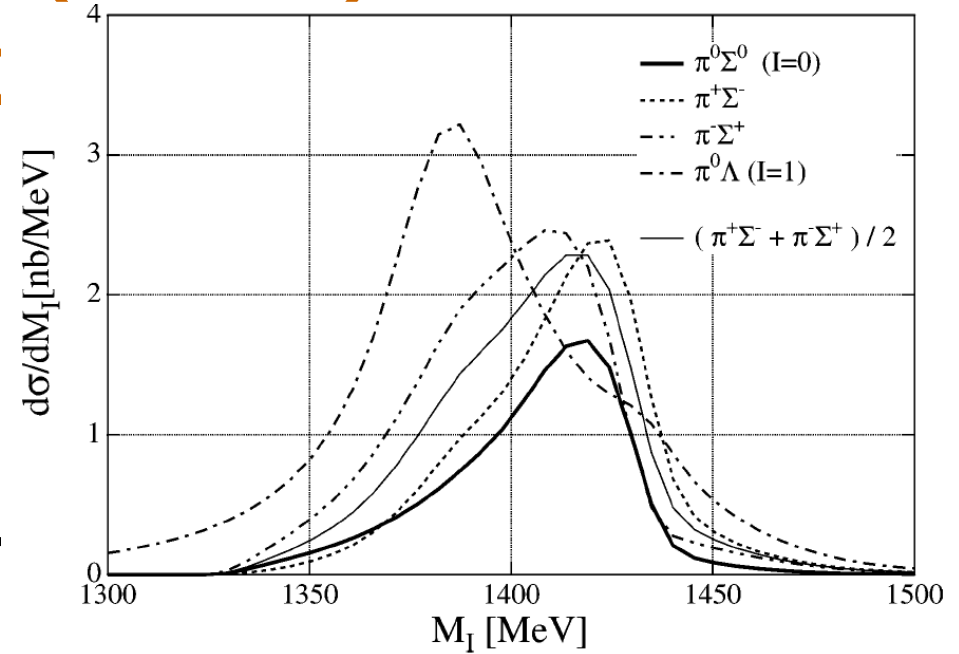
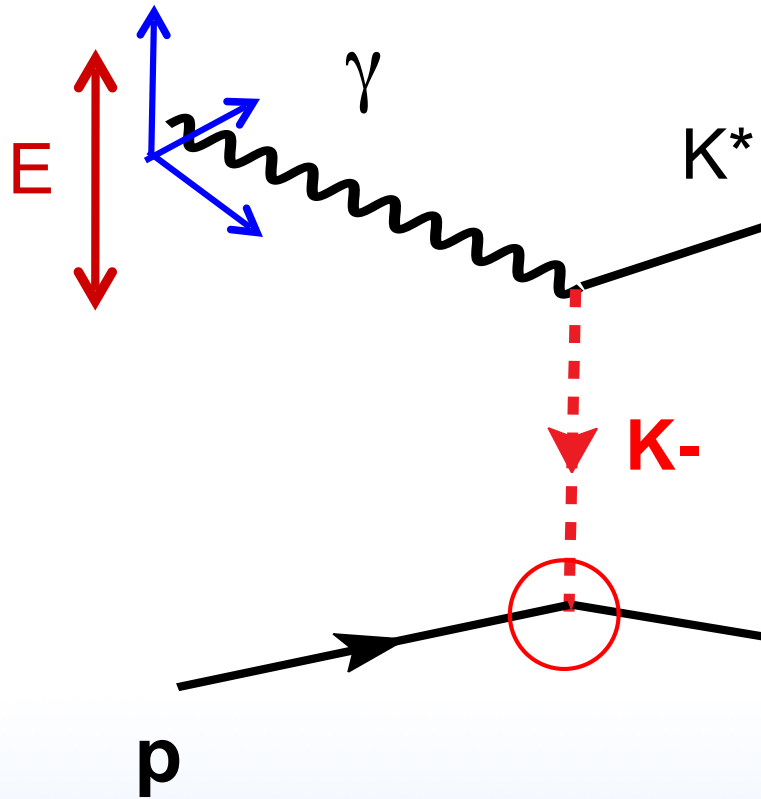
Linear pol γ + vector K^* meson : Parity filter

$$\gamma p \rightarrow K(890)^+ \Lambda^*$$



$\Lambda(1405)/\Lambda(1380)$

using linearly polarized

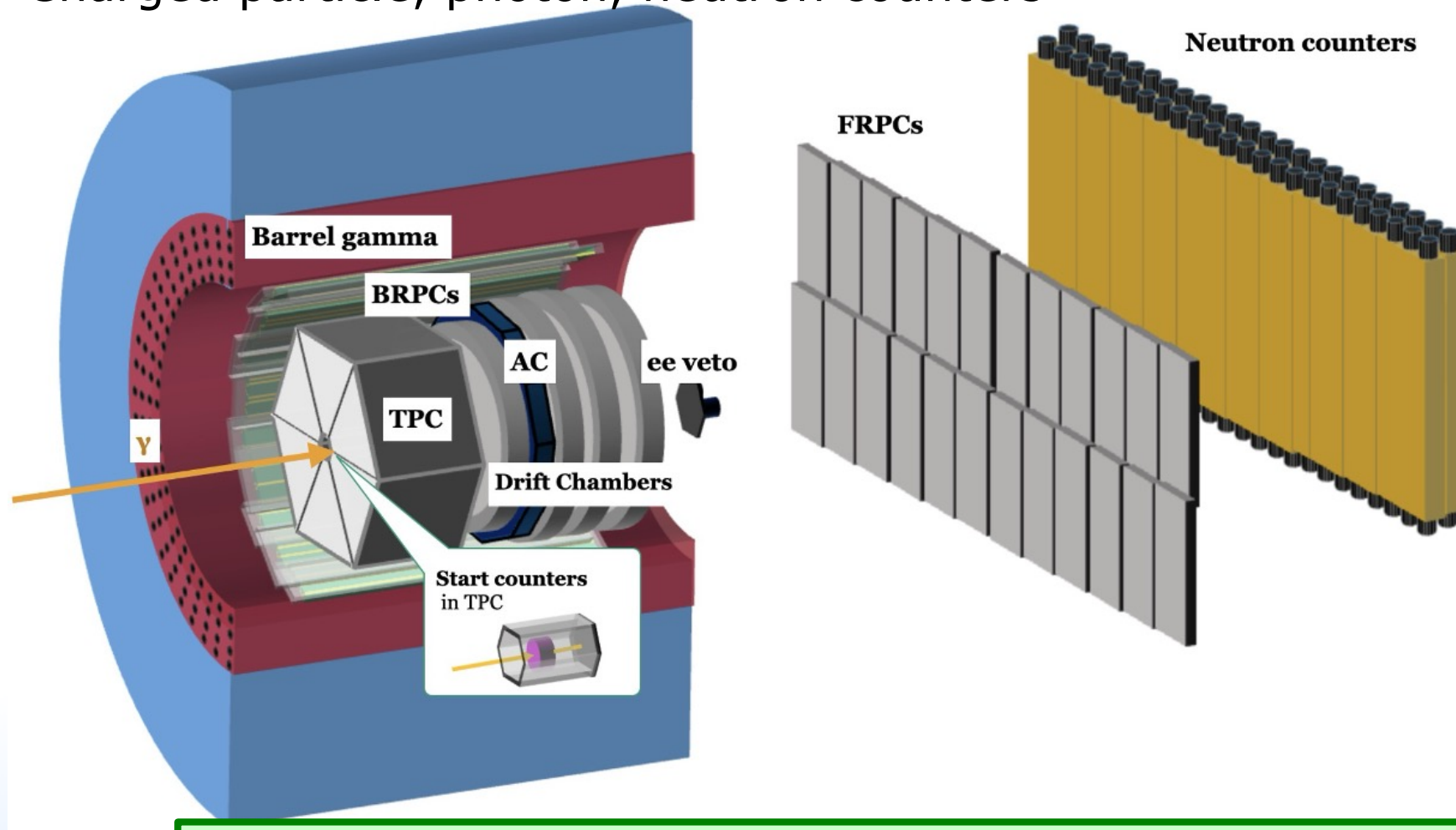


T.Hyodo et. al, PLB593

$\Lambda(1405)$
 $\Lambda(1380)$

Solenoid spectrometer at LEPS2/SPring-8 in Japan

- 1.4-2.9 GeV photon beam with 1 Mcps
- Charged particle, photon, neutron counters



Commissioning of forward tracking system in this autumn, start physics data taking in next year

Summary

- Many new measurements of strange baryons
 - $S=-1$, $\Lambda(1380)$, $\Lambda(1405)$, Λ 's around 1.67 GeV
 - $S=-2$, $\Xi(1620)$, $\Xi(1690)$, $\Xi(1820)$
 - $S=-3$, $\Omega(2012)$
- non-3q exotic candidates
 - meson-baryon picture
- $\Lambda(1405)$
 - magnetic FF from lattice : $\bar{K}N$ molecule
 - constituent quark counting
- $\Lambda(1380)/\Lambda(1405)$
 - Parity filter using linear pol. γ and K^* associate production using solenoid spectrometer at SPring-8 in Japan