WS on Hadron Physics with high-momentum hadron beams at J-PARC
13-16 March, 2015

Charmed Hadron Experiments at J-PARC

H. Noumi (RCNP, Osaka University)

15 March, 2015

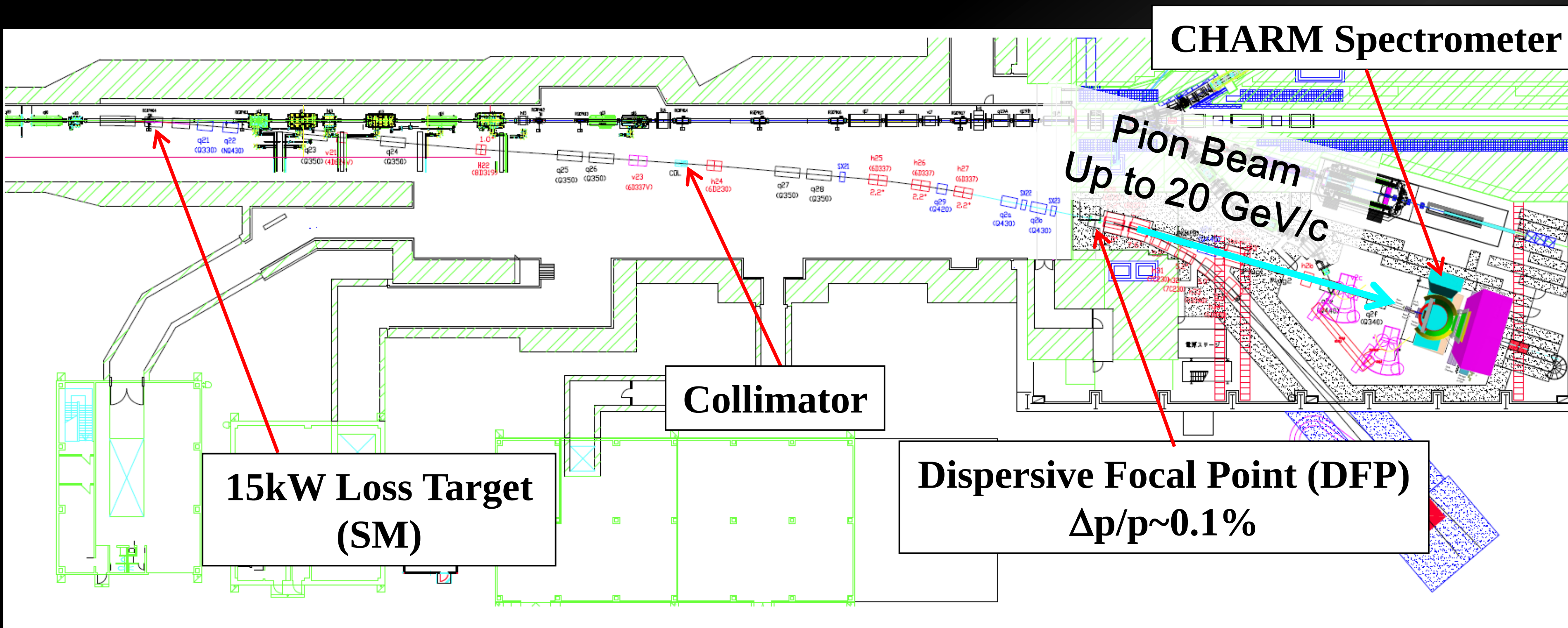
Contents:

1. A new platform for hadron physics at J-PARC
2. Charmed Baryon Spectroscopy
   - Study of Hadron Structure
   - Mass Spectrum, Production, and Decay
3. Strange Hyperon System
4. Summary

A New Platform for Hadron Physics at the High-momentum Beam Line

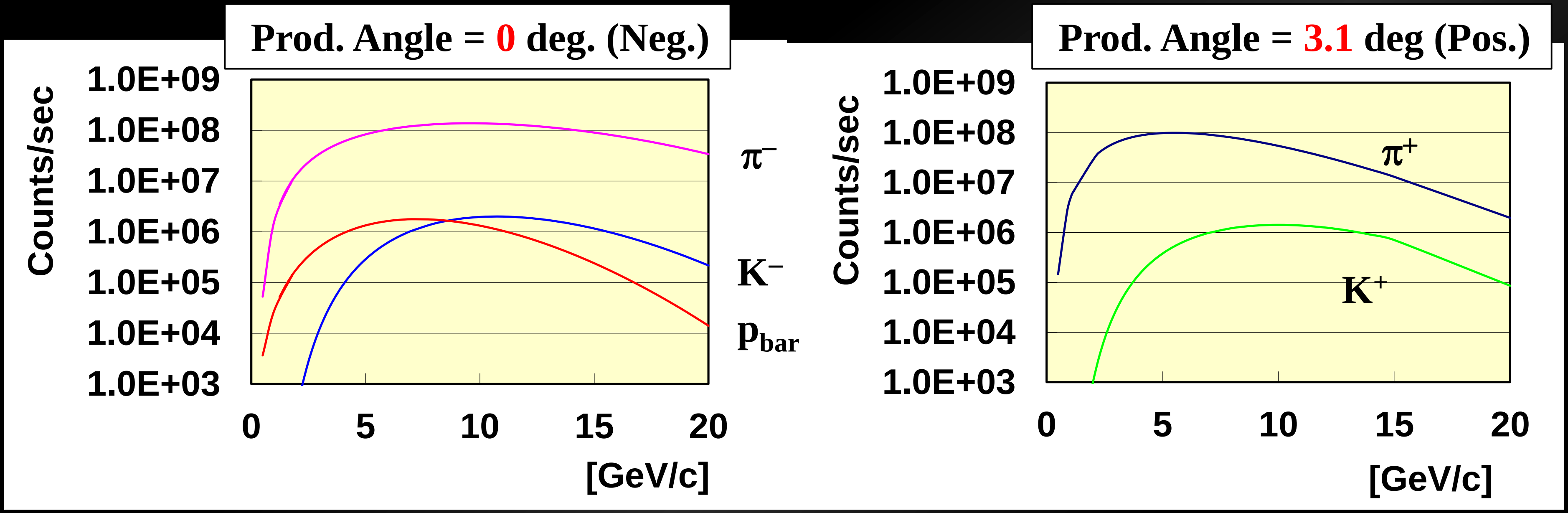
- High-intensity secondary Pion beam

- High-resolution beam:



A New Platform for Hadron Physics at the High-momentum Beam Line

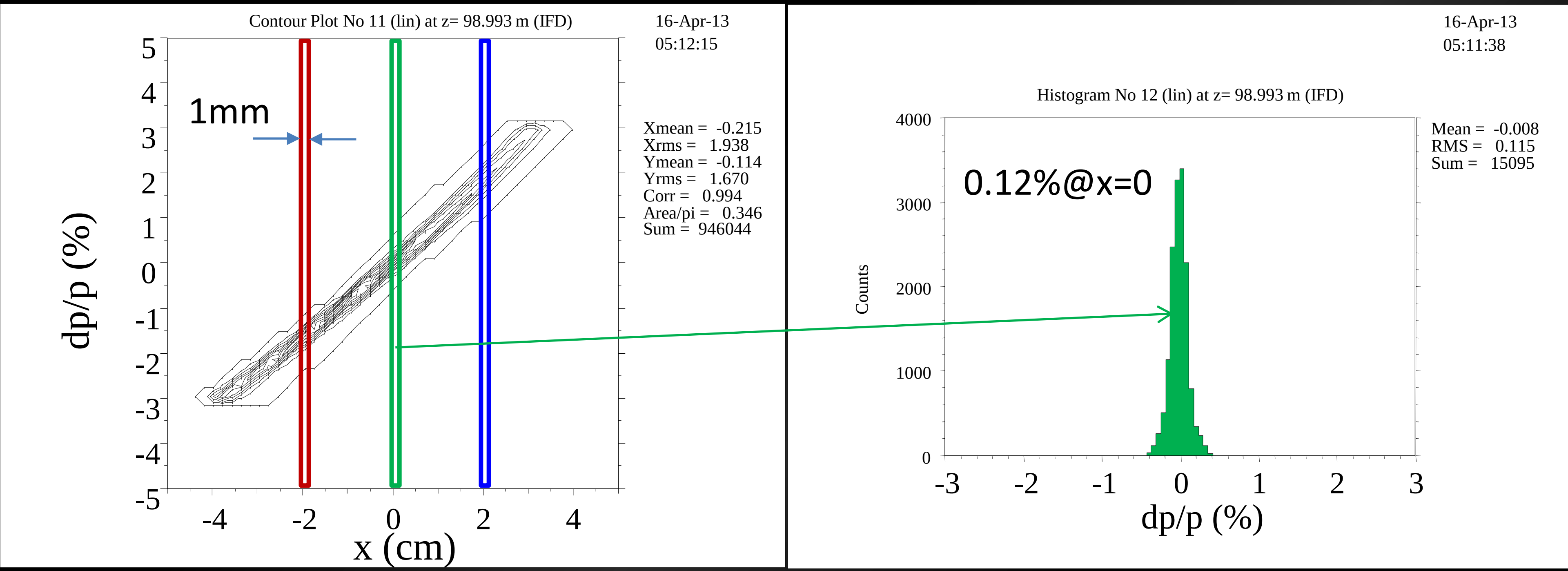
- High-intensity secondary Pion beam
  >1.0 x 10^7 pions/sec @ 20GeV/c
- High-resolution beam:



* Sanford-Wang:15 kW Loss on Pt, Acceptance :1.5 msr%, 133.2 m

A New Platform for Hadron Physics at the High-momentum Beam Line

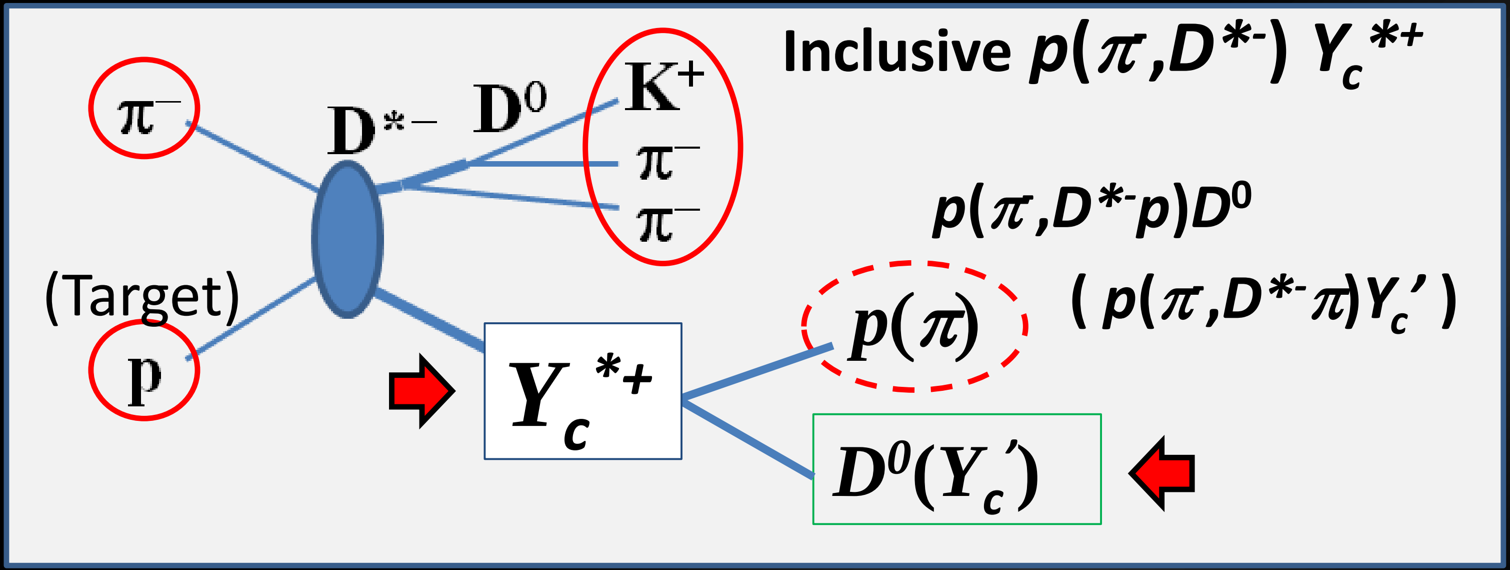
- High-intensity secondary Pion beam
  - >1.0 x 10^7 pions/sec @ 20GeV/c
- High-resolution beam: $\Delta p/p$~0.1%



Beam correlation btw *p* vs *x* at DFP

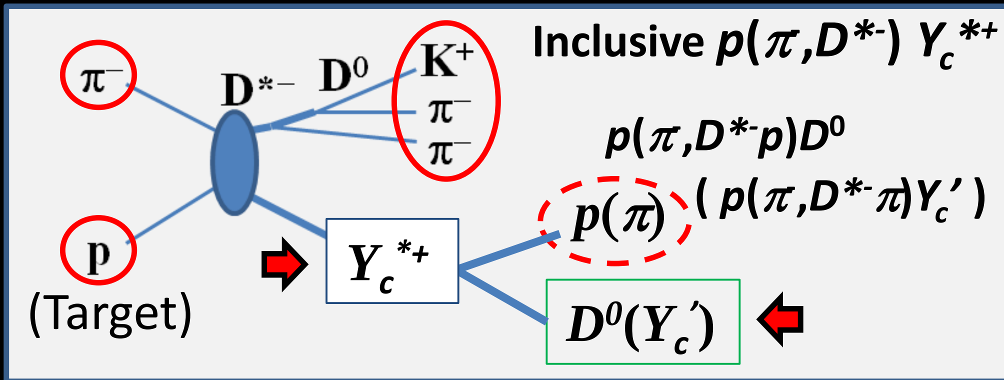
Charmed Baryon Spectroscopy

Using Missing Mass Techniques



Conducted by the E50 experiment at J-PARC

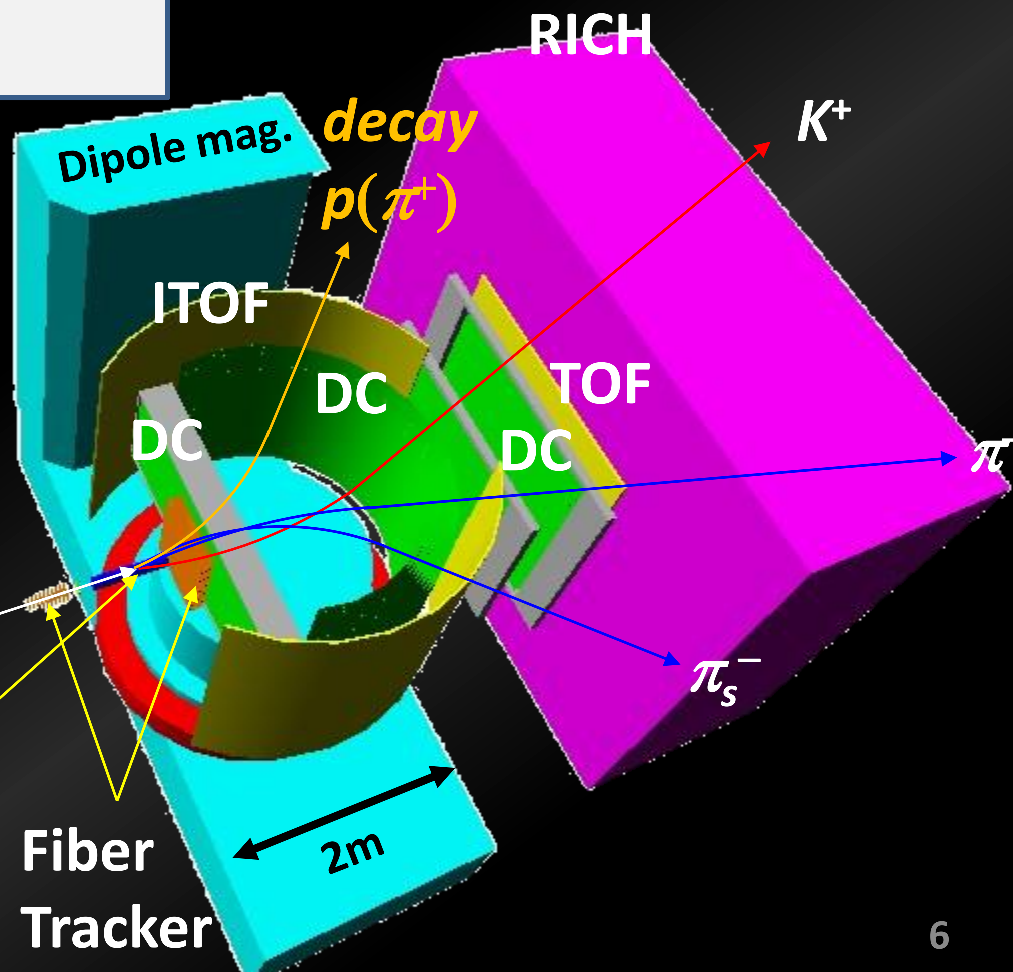
CHARM Spectrometer



Cross Section:
$\sigma\ (\Lambda_c)$ ~ 1 nb (no meas.)

Acceptance:
~ 60% for D^*,
~ 80% for decay π^+

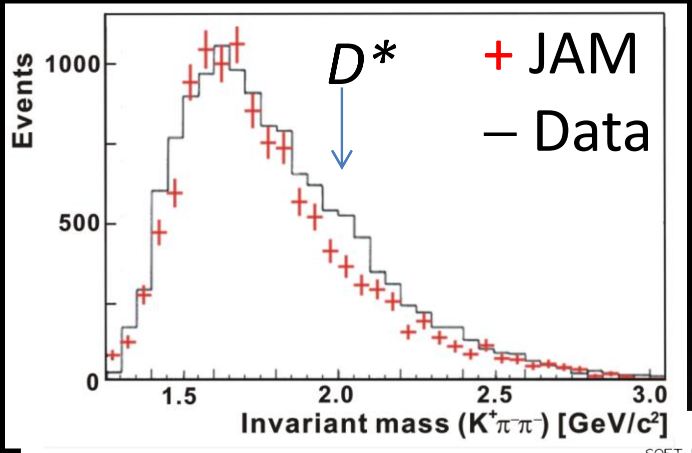
Resolution:
$\Delta p/p$~0.2% at ~5 GeV/c
(Rigidity: ~2.1 Tm)

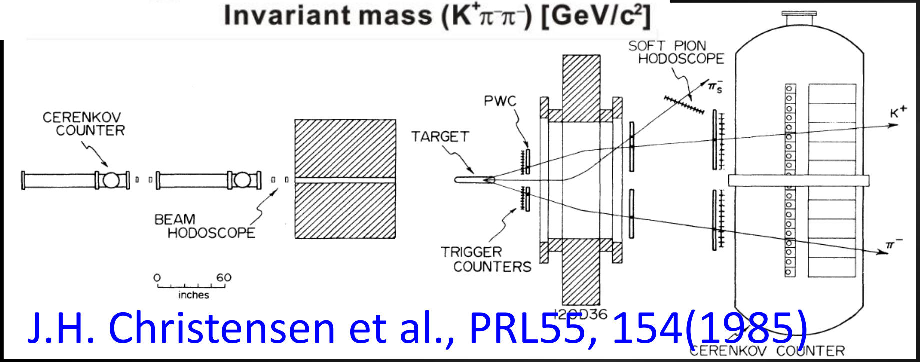


Production Cross Section

A. Hosaka et al.

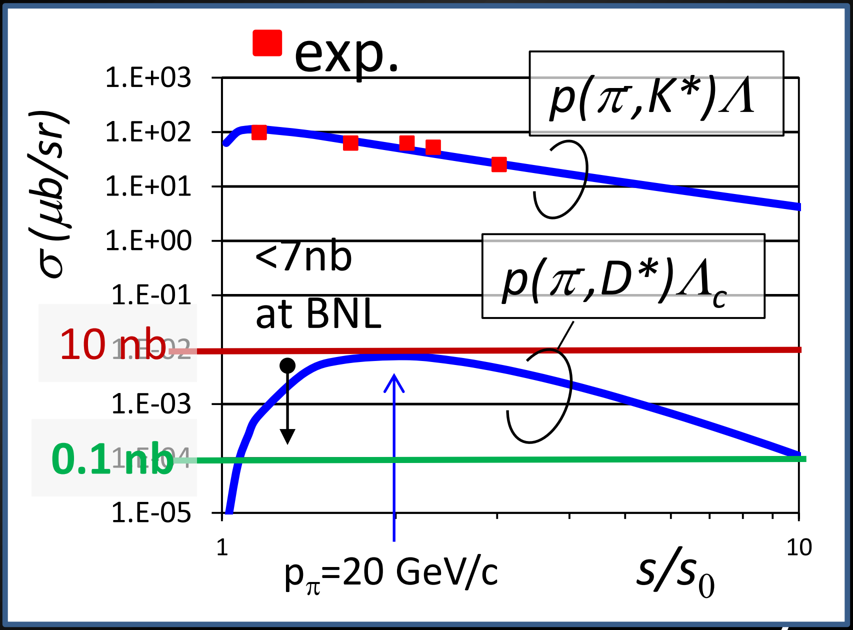
- Experimental data:
  - $\sigma(p(\pi^-,D^{*-})\Lambda_c) <$ 7 nb (68%CL) (BNL exp., 1985)
  - BG spectrum is well reproduced by a MC simulation w/ JAM
- Regge Theory suggests 10^{-4} of the hyperon production
  - $\sigma(p(\pi^-,D^{*-})\Lambda_c) \sim$ a few nb



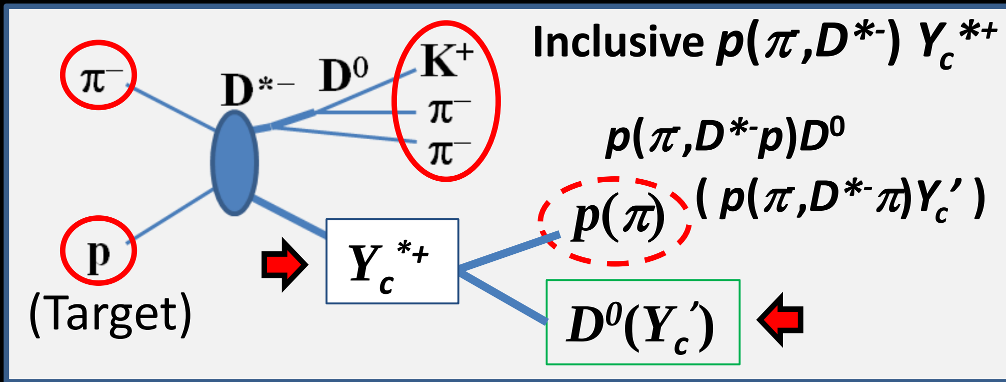


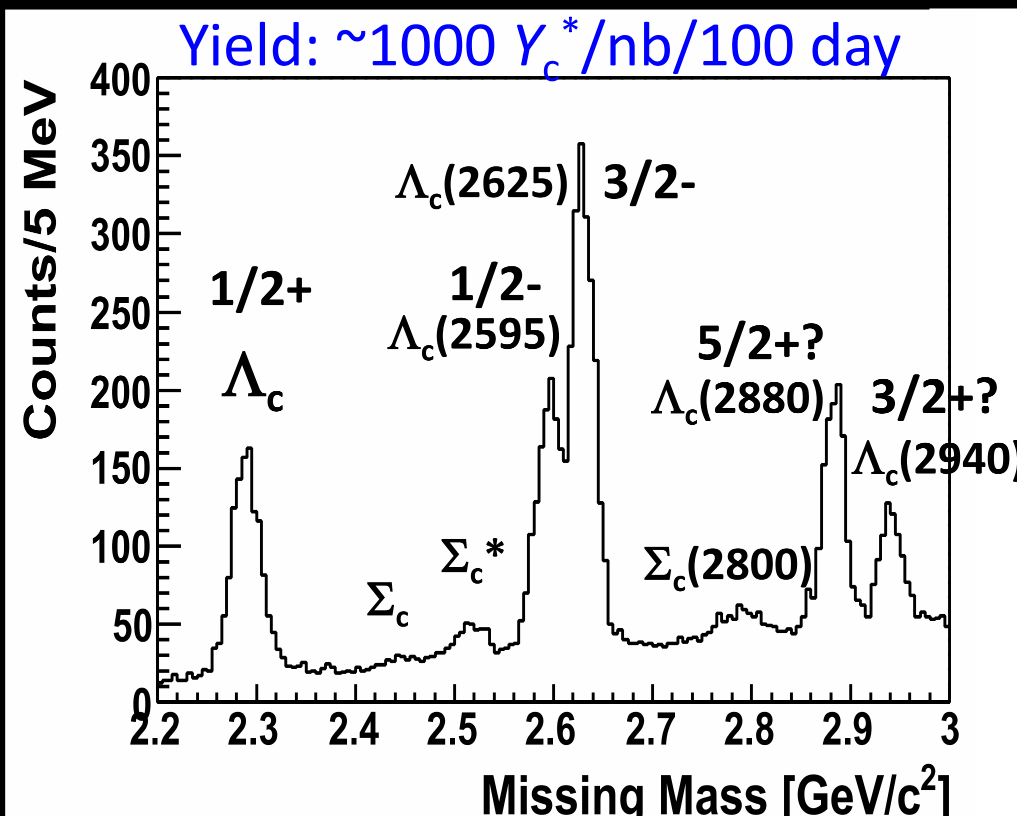
J.H. Christensen et al., PRL55, 154(1985)

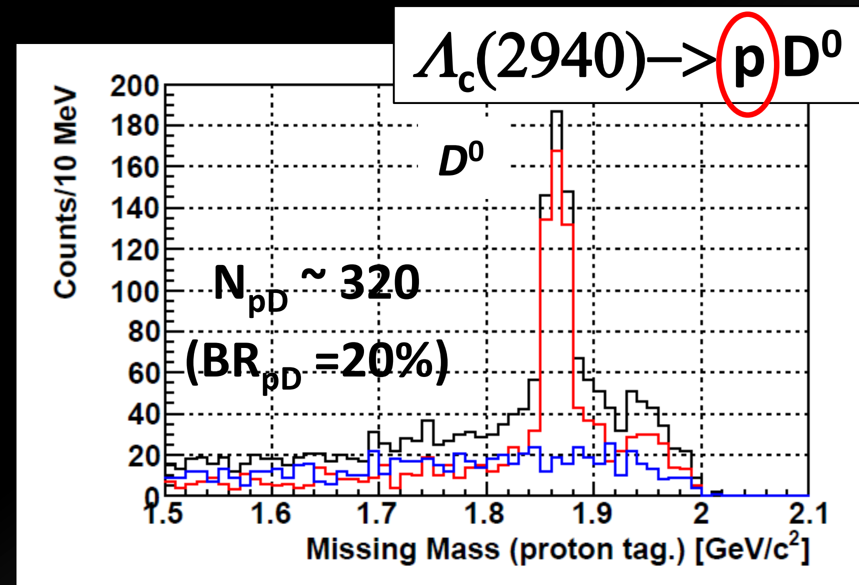
Regge Theory

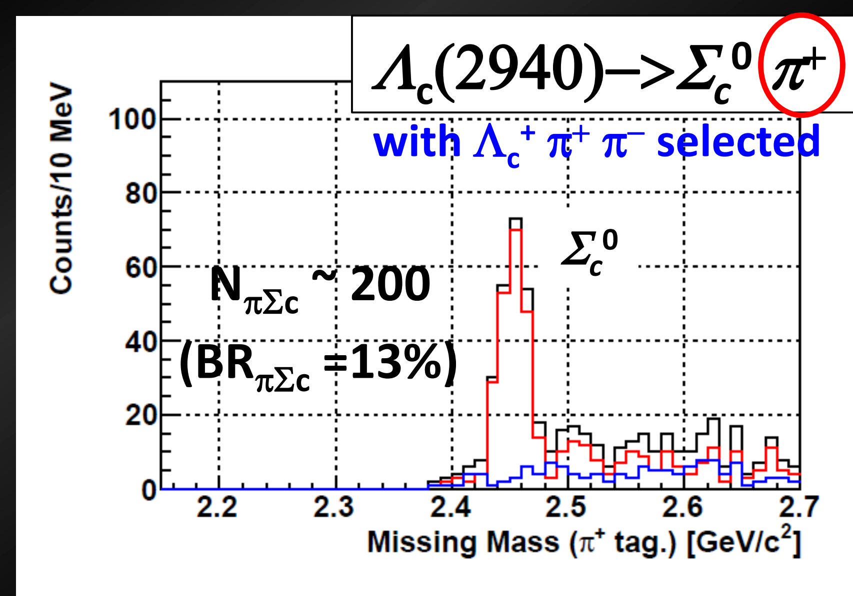


Inclusive Spectrum and Decay Mode ID (Sim.)





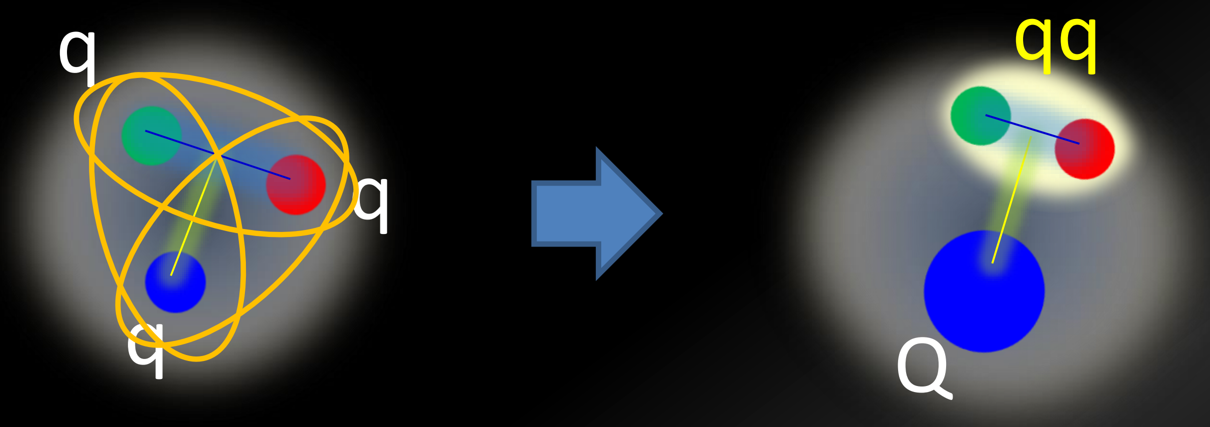




Hadron Structure

- Tomography
  - Distribution Function of Q and G in hadron (N)
  - How to approach hadrons other than N?
- Spectroscopy
  - Effective DOF (quark, diquark, hadron, …) and correlations among them
  - Why they appear and form hadrons?
    - Current quark <-> EDOF <-> Hadrons?
- Hadrons as objects in the non-perturbative region of QCD
  - Relation btw “Distribution” and “Correlation ”

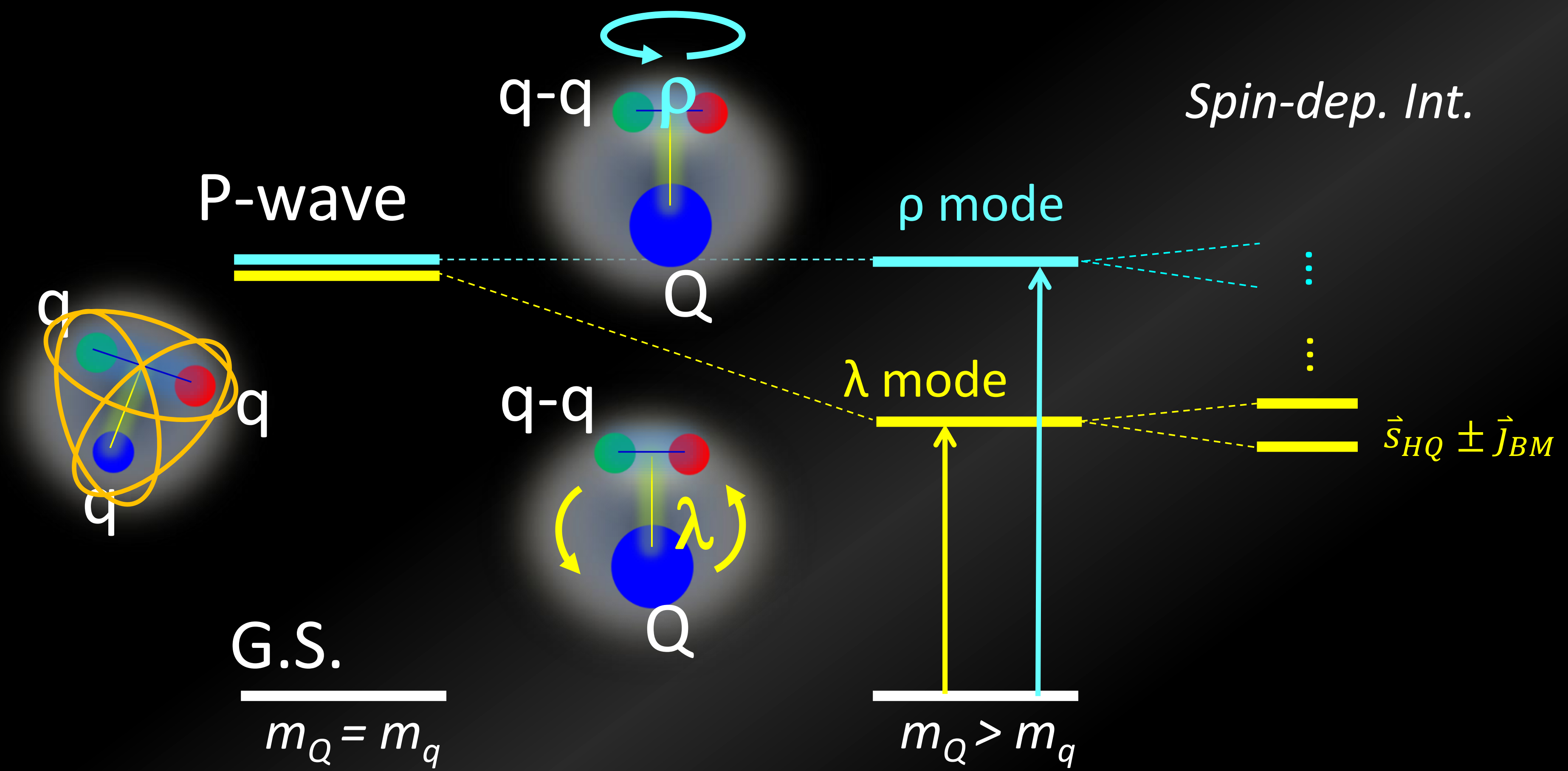
What we can learn from baryons with heavy flavors



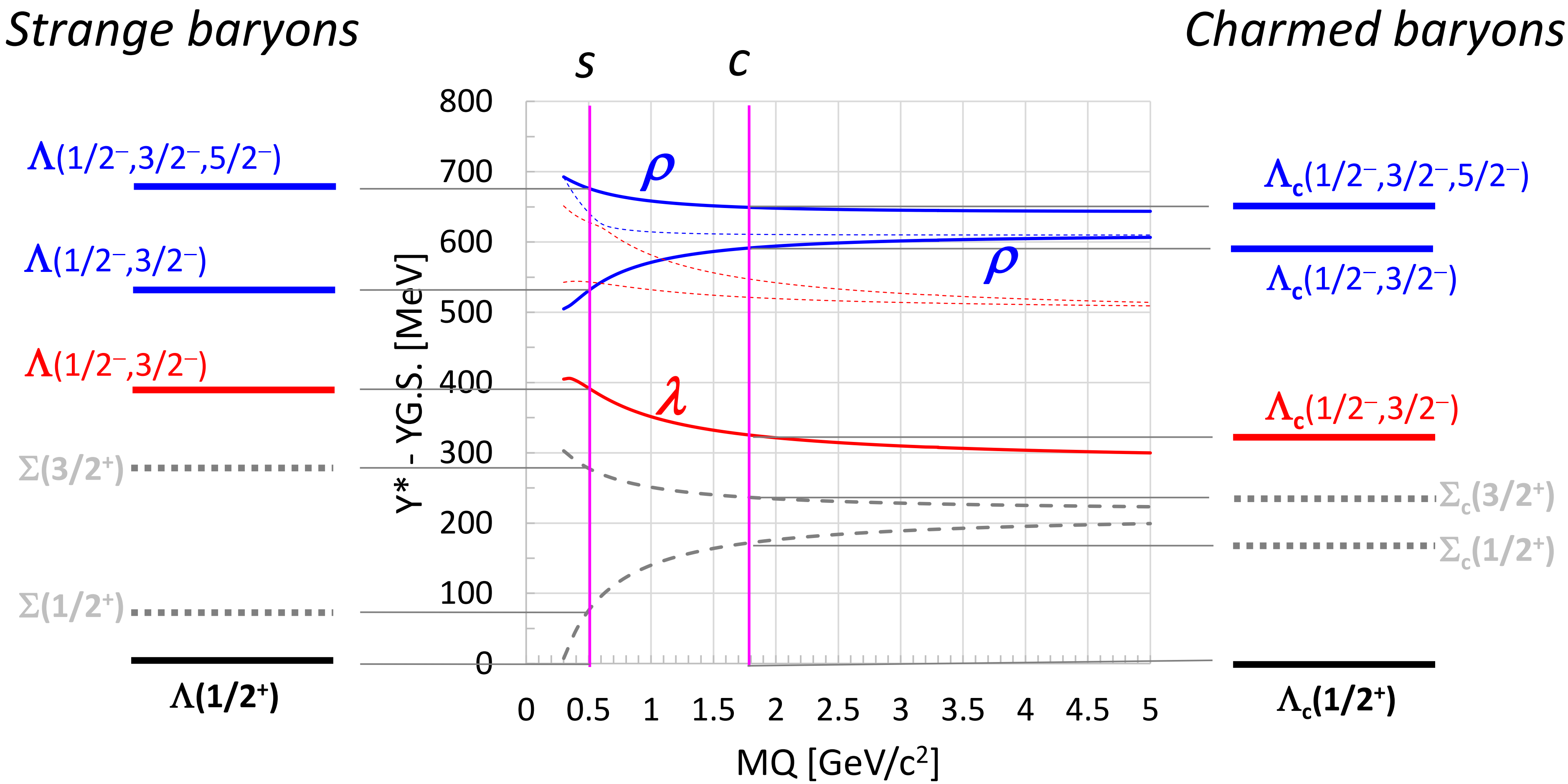
- Quark motion of "qq" is singled out by a heavy Q
  - Diquark correlation
- Level structure, Production rate, Decay properties
  - sensitive to the internal quark(diquark) WFs.
- Properties are expected to depend on a Q mass.

Schematic Level Structure of Heavy Baryons

- λ and ρ motions split (Isotope Shift)
- HQ spin multiplet $(\vec{s}_{HQ} \pm \vec{J}_{Brown\ Muck})$



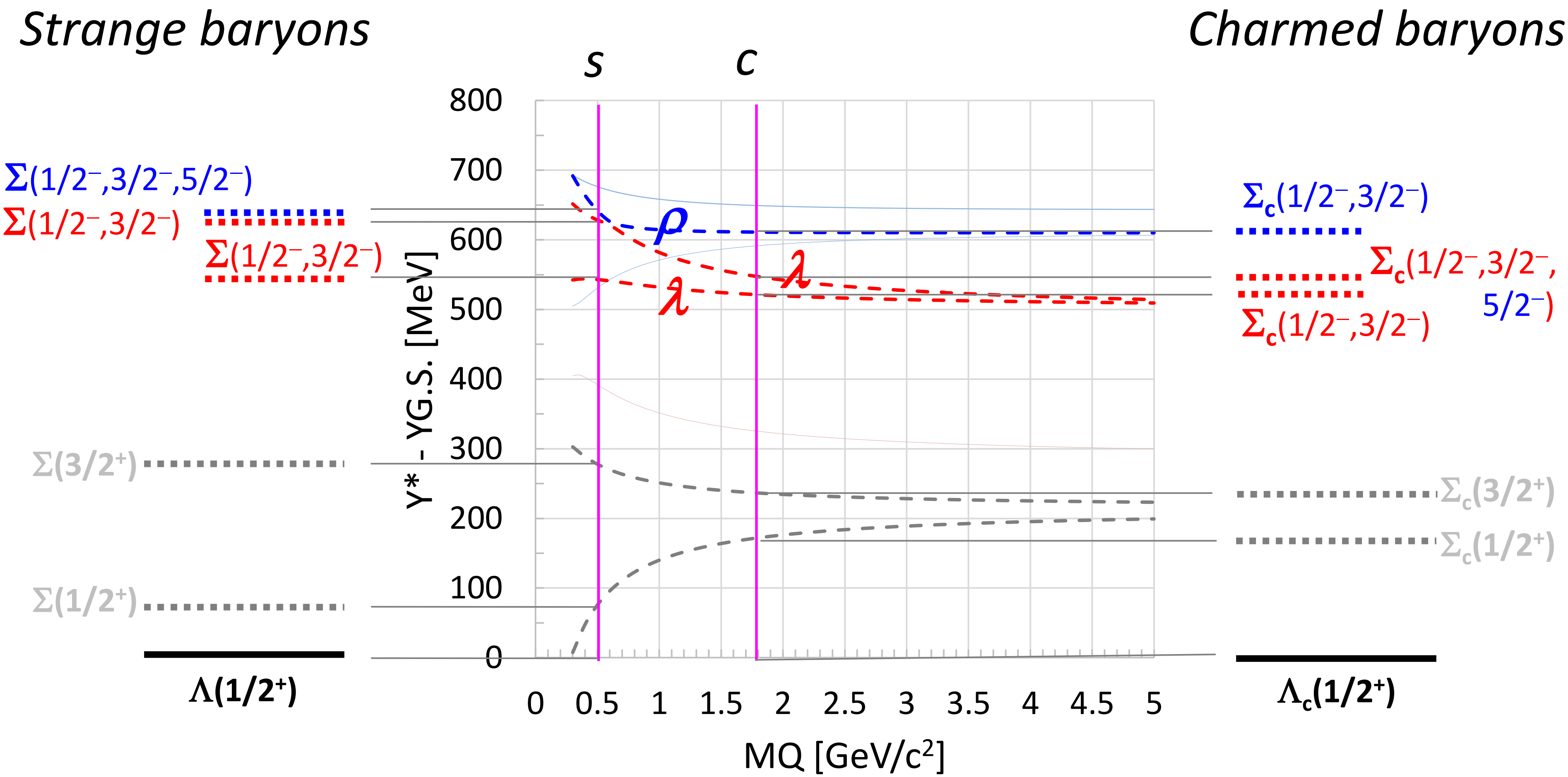
CQM calculation (Lambda)



non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

ρ–λ mixing (cal. By T. Yoshida (Tokyo I. Tech.)

CQM calculation (Sigma)



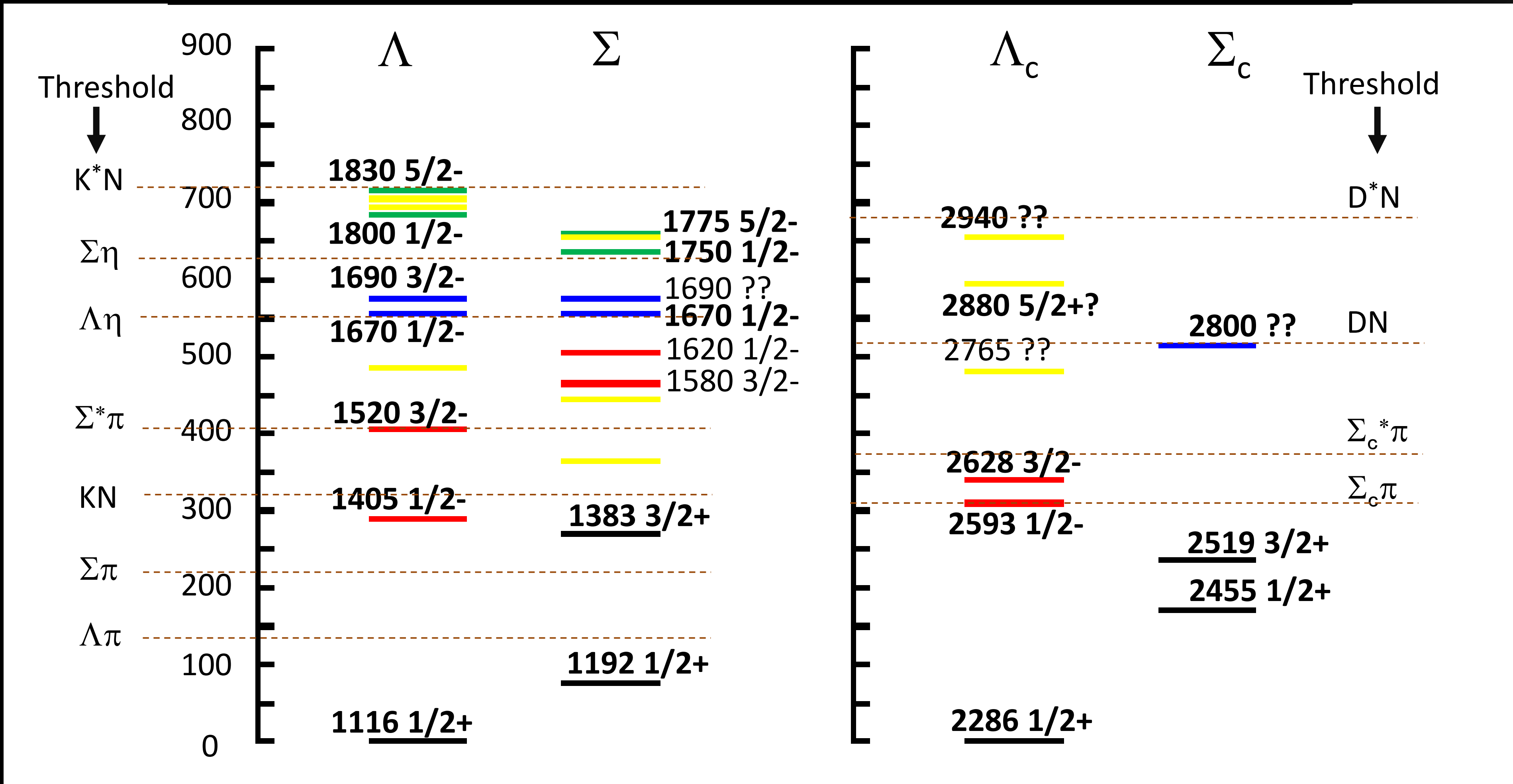
non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

ρ–λ mixing (cal. By T. Yoshida)

Little is known about charmed baryons

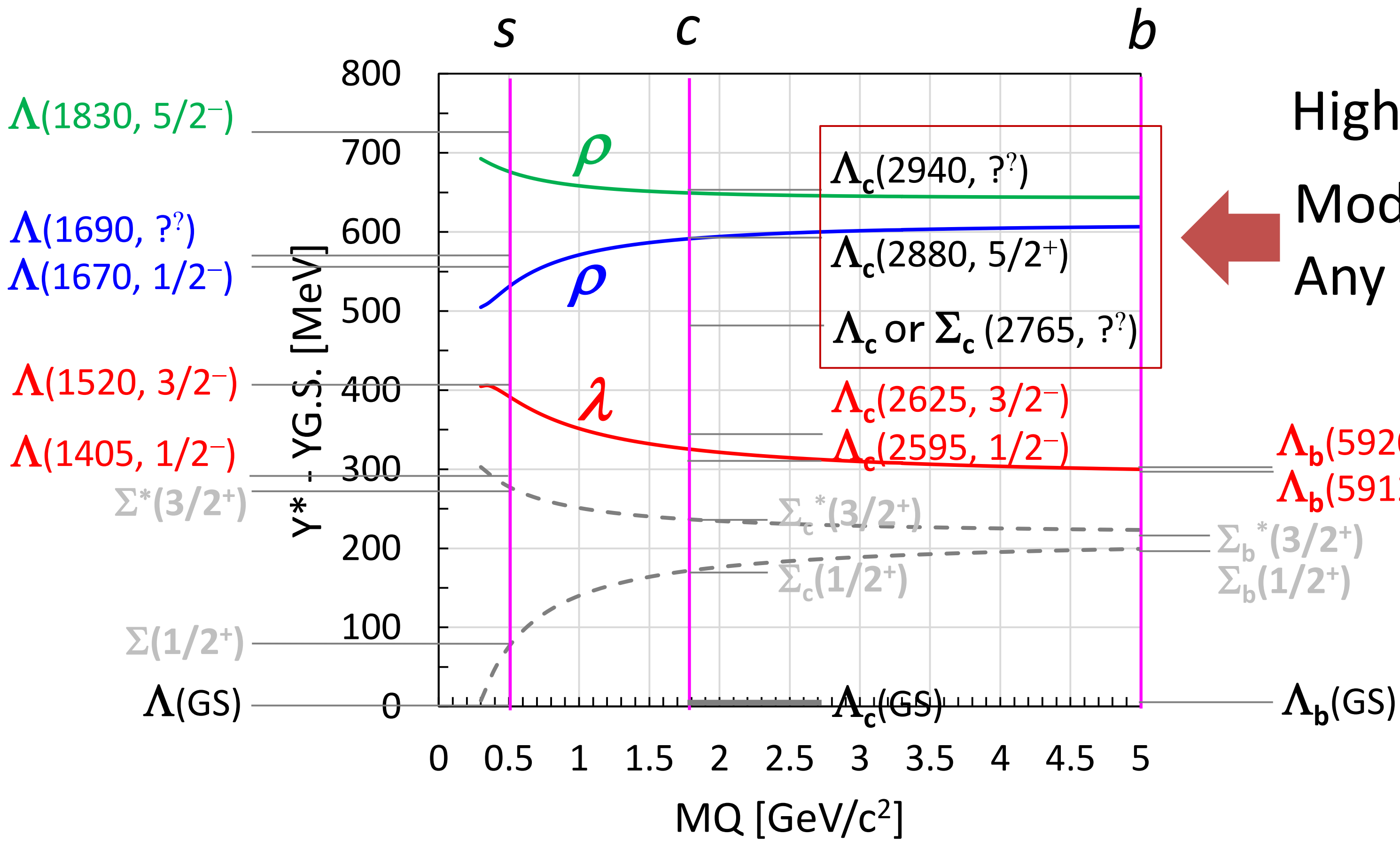
- Limited # of excited states are reported.
- Most of Spins/Parties are not determined.
- Partial Decay Width are not measured.

Level structure (Exp.)



- ✓ λ / ρ mode assignment is not established yet.
- ✓ Little of Y_c is known.

Lambda Baryons



Higher L?

Mode?

Any others?

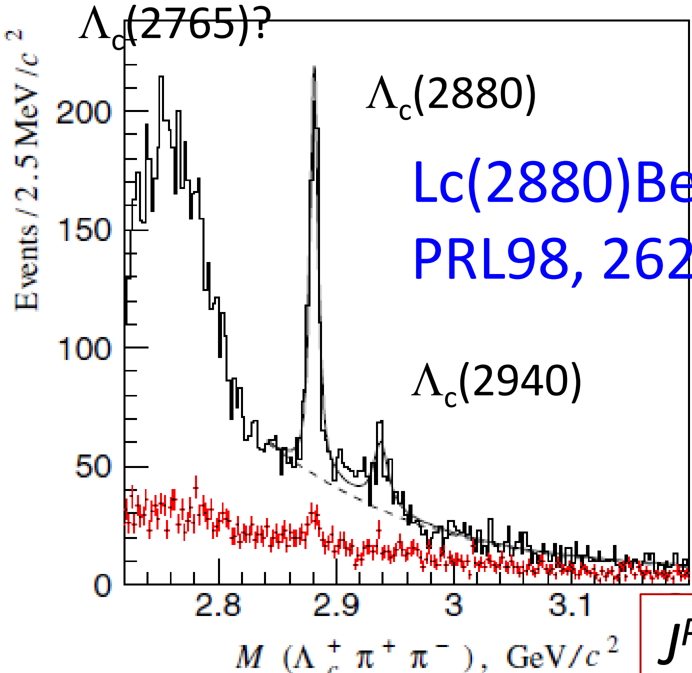
non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

ρ–λ mixing (cal. By T. Yoshida)

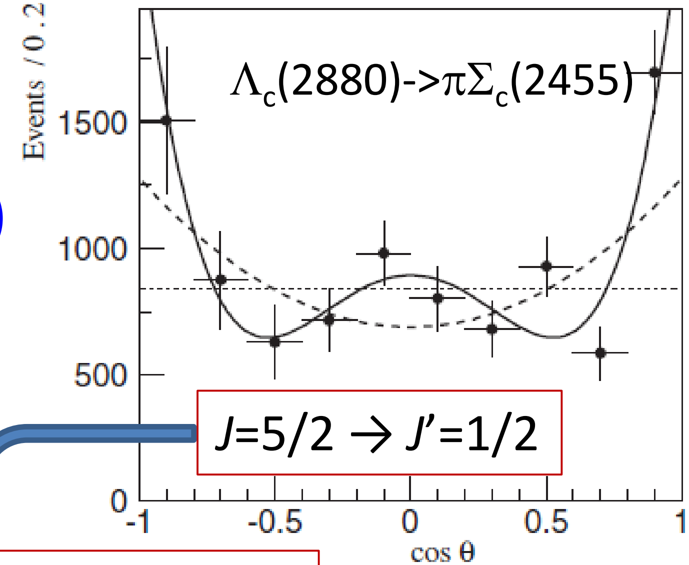
$\Lambda_c(2880)/\Lambda_c(2940)$

- Are $\Lambda_c(2880)/\Lambda_c(2940)$ *LS* partners?
  - *LS* splitting; $\Delta E(J^{\wedge},J_{v})\sim(2L+1)/2$
    - $\Delta E(5/2^{+},3/2^{+})/\Delta E(3/2^{-},1/2^{-})=5/3$

      c.f. exp. 60 MeV/35 MeV~5/3 seems consistent?

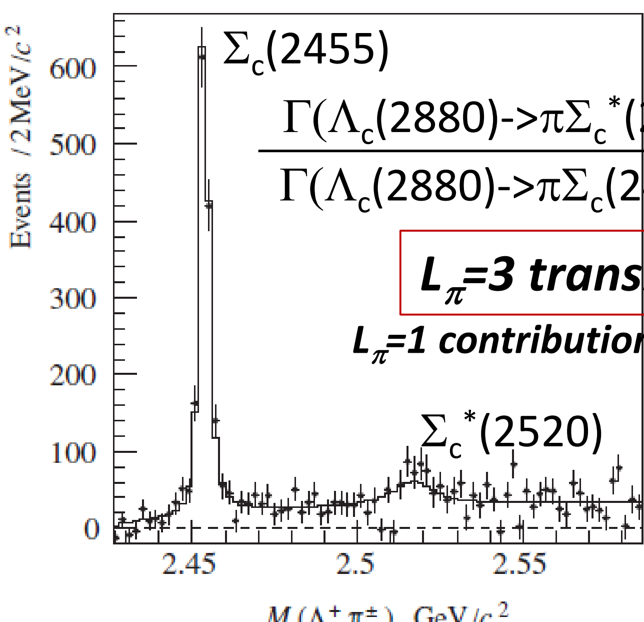


Lc(2880)Belle, PRL98, 262001('07)



$J=5/2 \rightarrow J'=1/2$

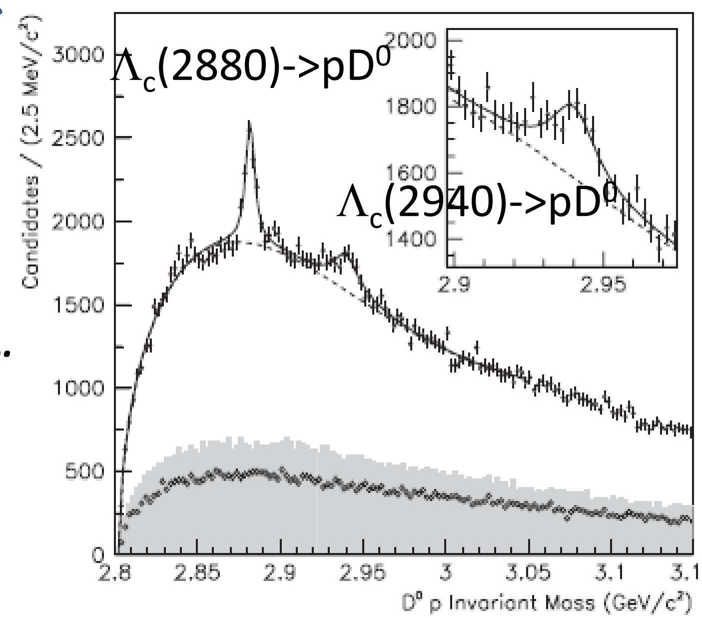
$J^P=5/2^+$ for $\Lambda_c(2880)$



$$\frac{\Gamma(\Lambda_c(2880) \to \pi\Sigma_c^*(2520))}{\Gamma(\Lambda_c(2880) \to \pi\Sigma_c(2455))}$$

$L_\pi=3$ transition

$L_\pi=1$ contribution may affect…



Babar, PRL98, 012001('07)

$\Lambda_c(2880)/\Lambda_c(2940)$

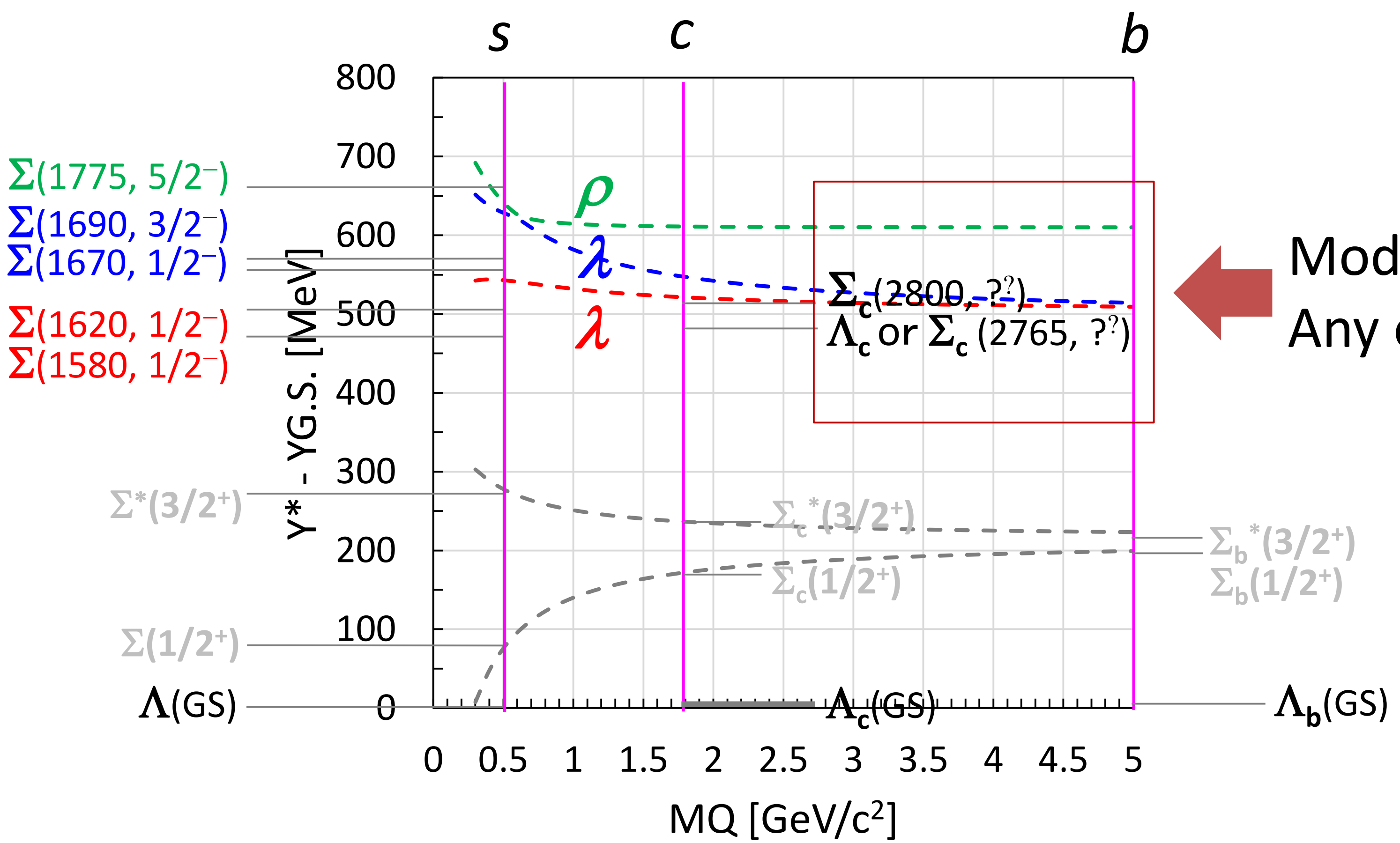
- Are $\Lambda_c(2880)/\Lambda_c(2940)$ *LS* partners?
  - *LS* splitting; $\Delta E(J^{\wedge},J_{v})\sim(2L+1)/2$
    - $\Delta E(5/2^{+},3/2^{+})/\Delta E(3/2^{-},1/2^{-})=5/3$

      c.f. exp. 60 MeV/35 MeV~5/3 seems consistent?
- If they are λ mode excited states w/ $L_{(\lambda)}=2$...
  - $\Lambda_c(2880):5/2^{+}$, $\Lambda_c(2940):3/2^{+}$, possibly

    → [HQ($1/2^{+}$) + Brown Muck(2^{+})]; HQS doublet?
  - $\sigma(5/2^{+};2880):\sigma(3/2^{+};2940)=3:2$ ($\sigma(J^{\wedge}):\sigma(J_{v})=L+1:L$)

    c.f. $\sigma(3/2^{-};2625):\sigma(1/2^{-};2595)=2:1$ for
- If NOT,
  - Prod. Rates give information on their structure...
  - new states corresponding to $L_{(\lambda)}=2$ should be observed

Sigma Baryons

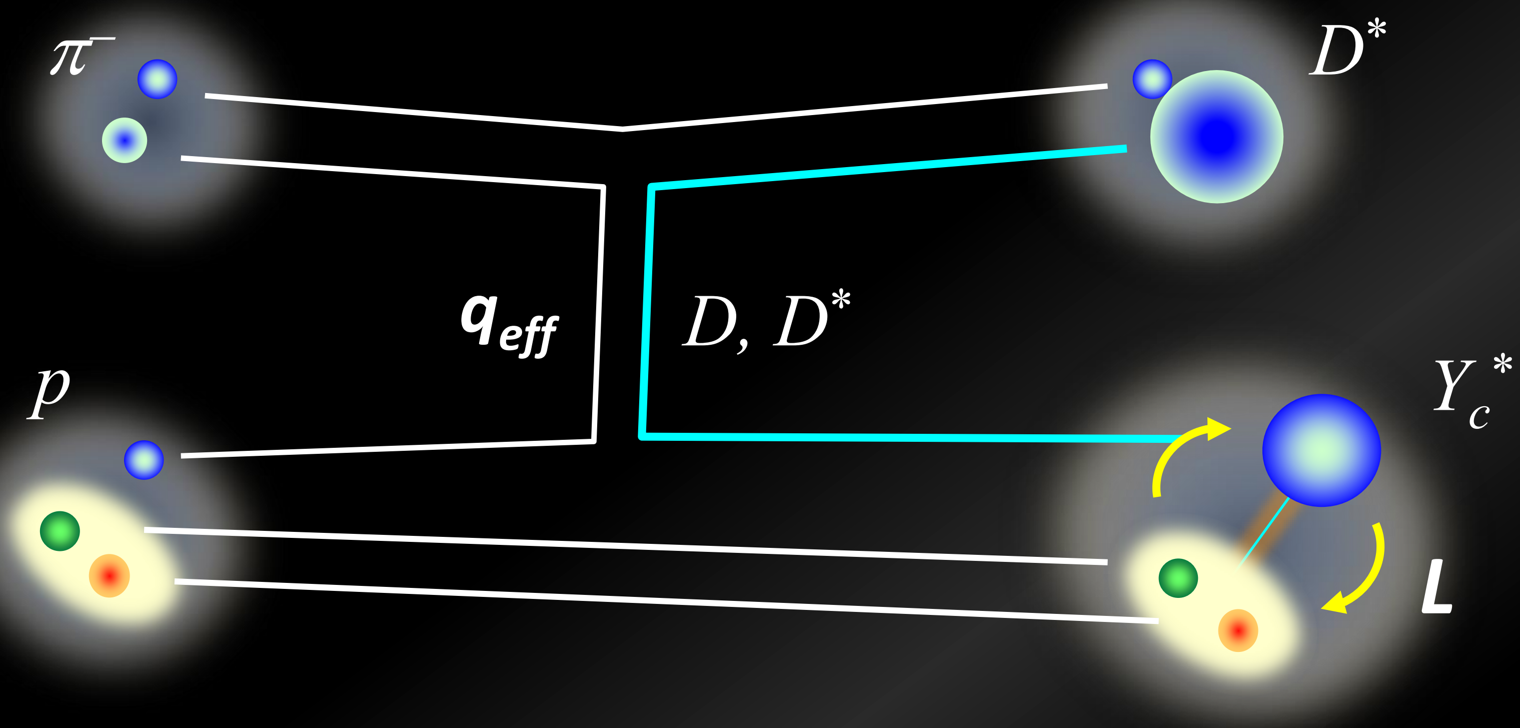


Mode?
Any others?

non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$
ρ–λ mixing (cal. By T. Yoshida)

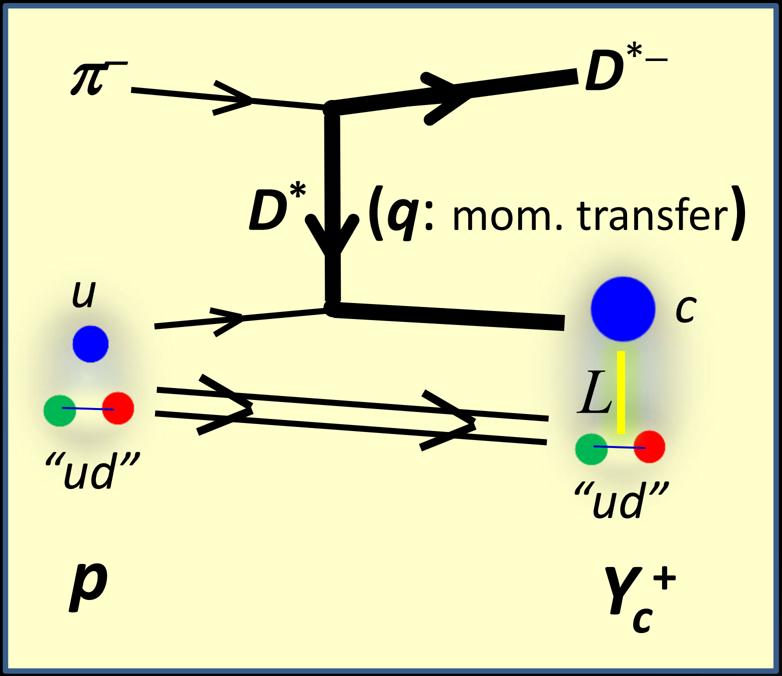
Production Rate

S.H. Kim, A. Hosaka, H.C. Kim, HN, K. Shirotori, PTEP, 103D01, 2014.



- ✓ C.S. DOES NOT go down at higher *L* when q_{eff}>1 GeV/c
- ✓ λ modes are excited by a simple mechanism

Production Rate



- t-channel D^* EX at a forward angle

Production Rates are determined by the overlap of WFs

$$R \sim \langle \varphi_f | \sqrt{2}\sigma_- \exp(i\vec{q}_{eff}\vec{r}) | \varphi_i \rangle$$

and depend on:

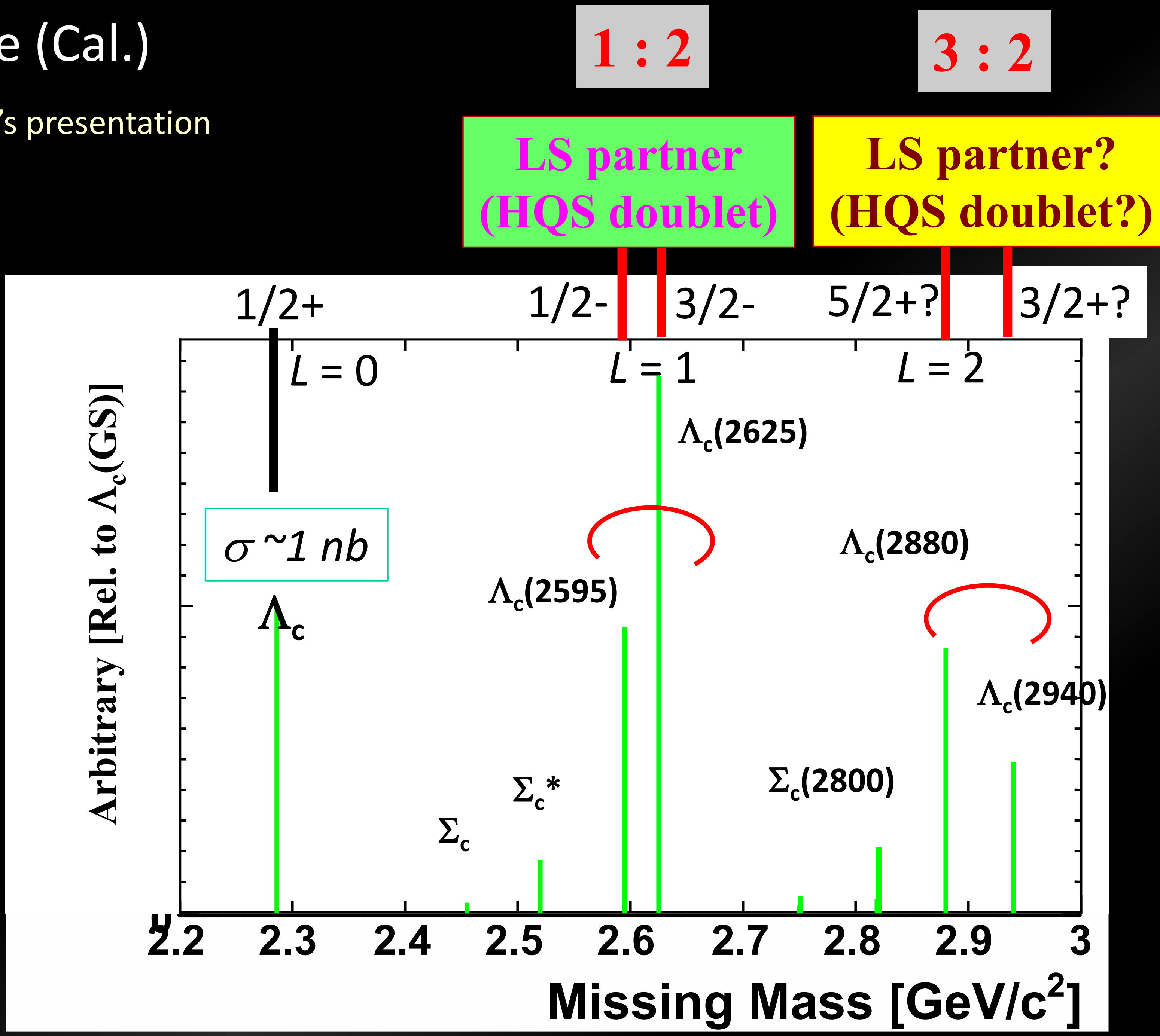
1. Spin/Isospin Config. of Y_c
   Spin/Isospin Factor
2. Momentum transfer (q_{eff})

$$I_L \sim (q_{eff}/A)^L \exp(-q_{eff}^2/2A^2)$$

A: (baryon size parameter)$^{-1}$

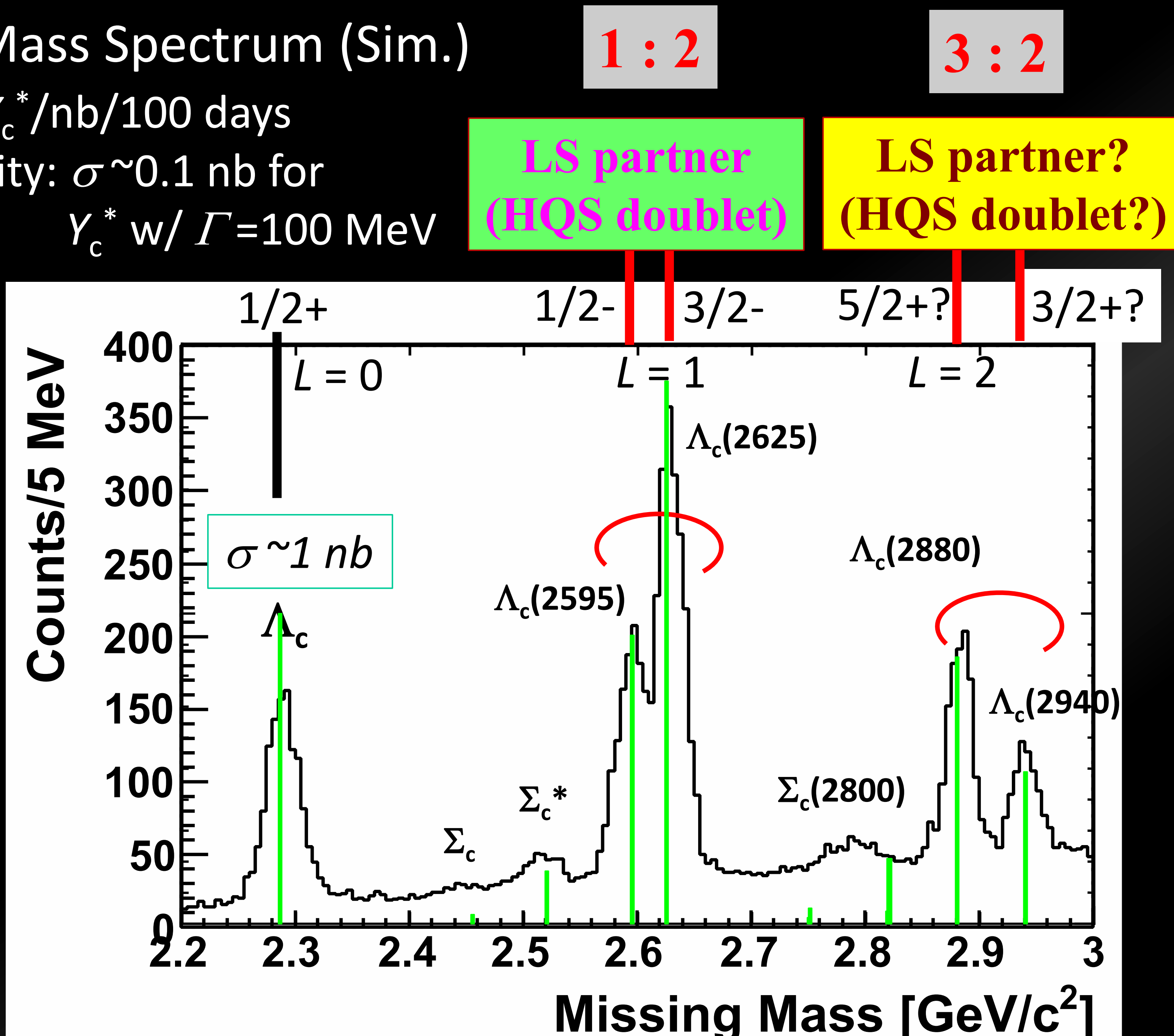
Prod. Rate (Cal.)

→ A. Hosaka's presentation

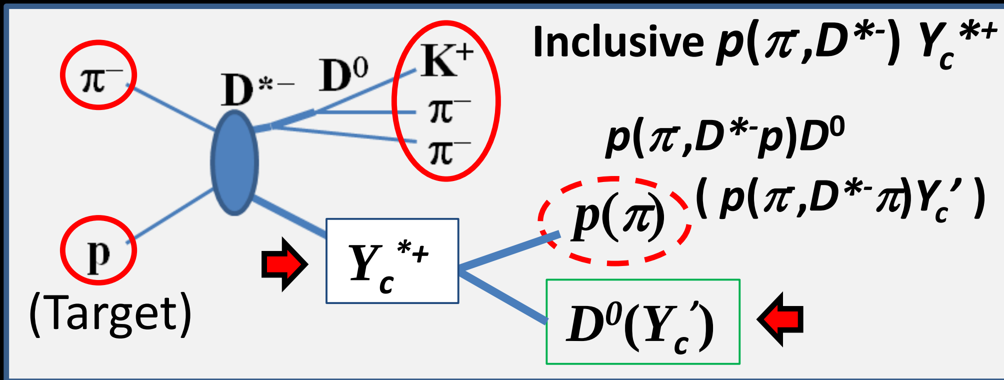


Missing Mass Spectrum (Sim.)

- ~1000 Y_c^*/nb/100 days
- Sensitivity: σ~0.1 nb for Y_c^* w/ Γ=100 MeV



CHARM Spectrometer



Cross Section:

$\sigma\ (\Lambda_c) \sim 1$ nb (no meas.)

Acceptance:

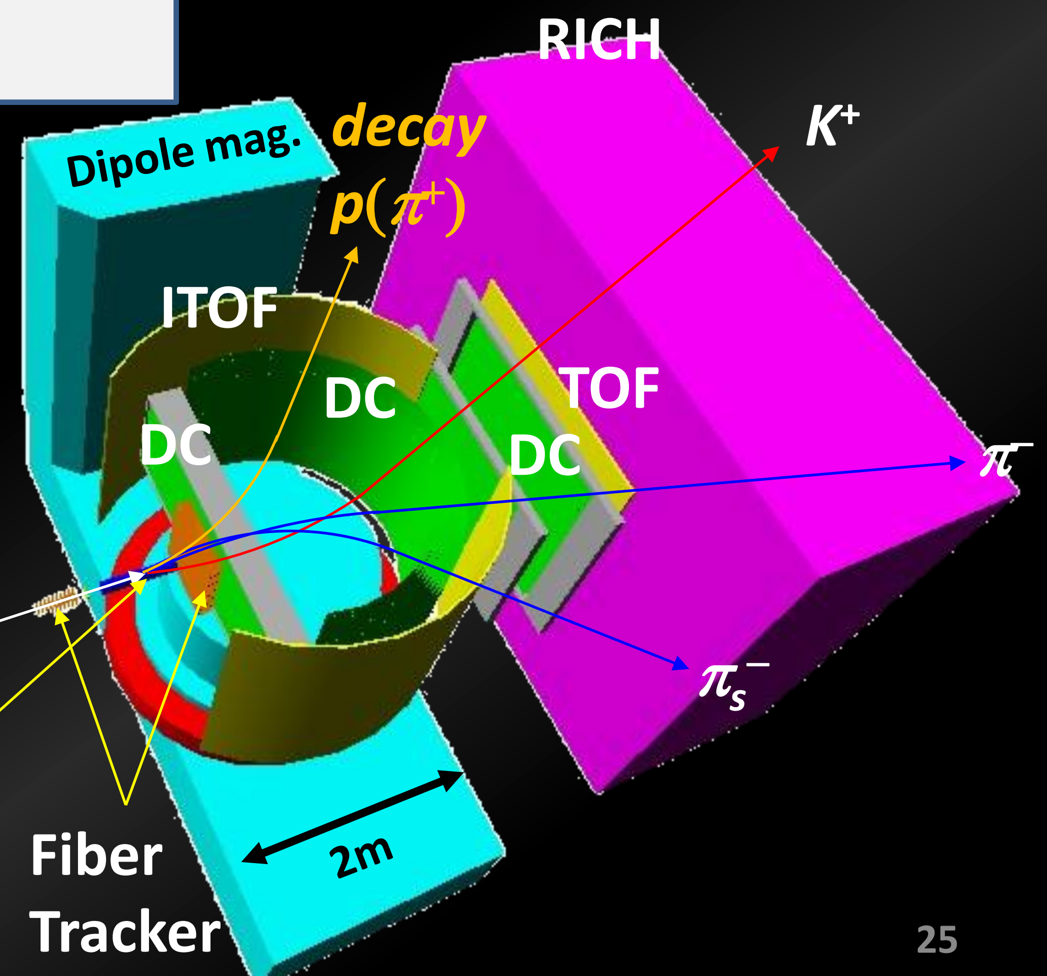
~ 60% for D^*,

~ 80% for decay π^+

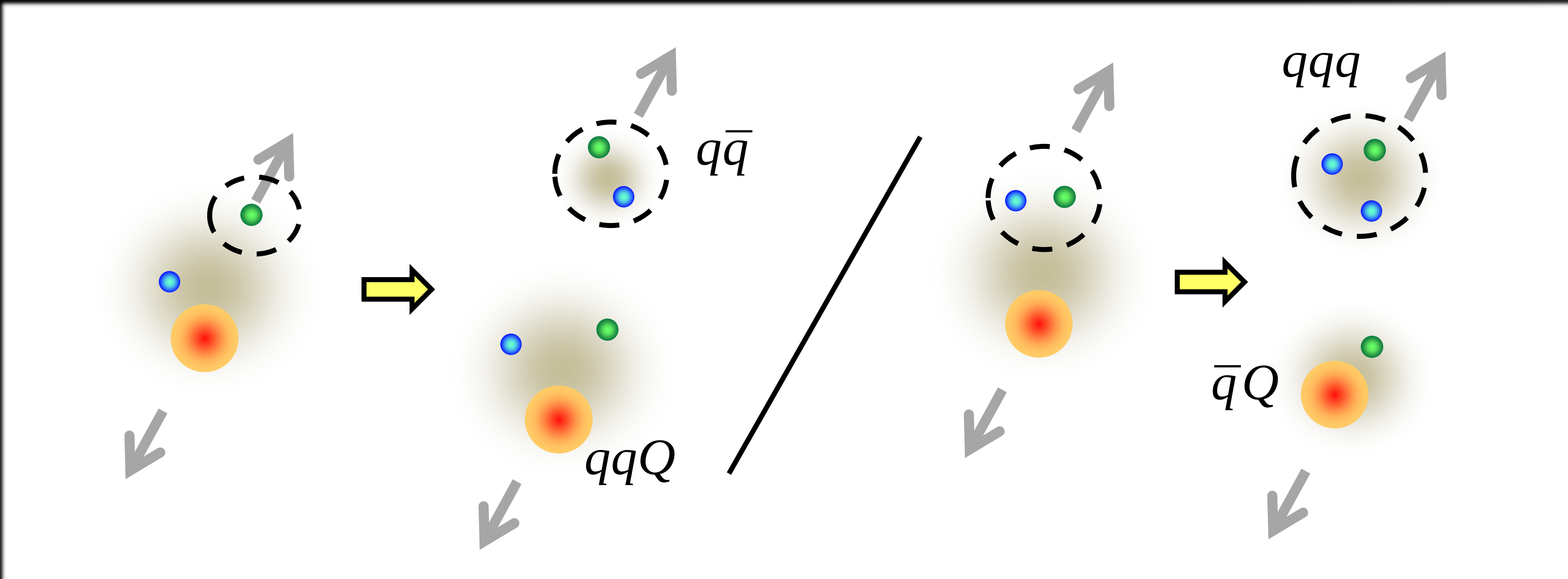
Resolution:

$\Delta p/p$~0.2% at ~5 GeV/c

(Rigidity: ~2.1 Tm)



Decay Properties



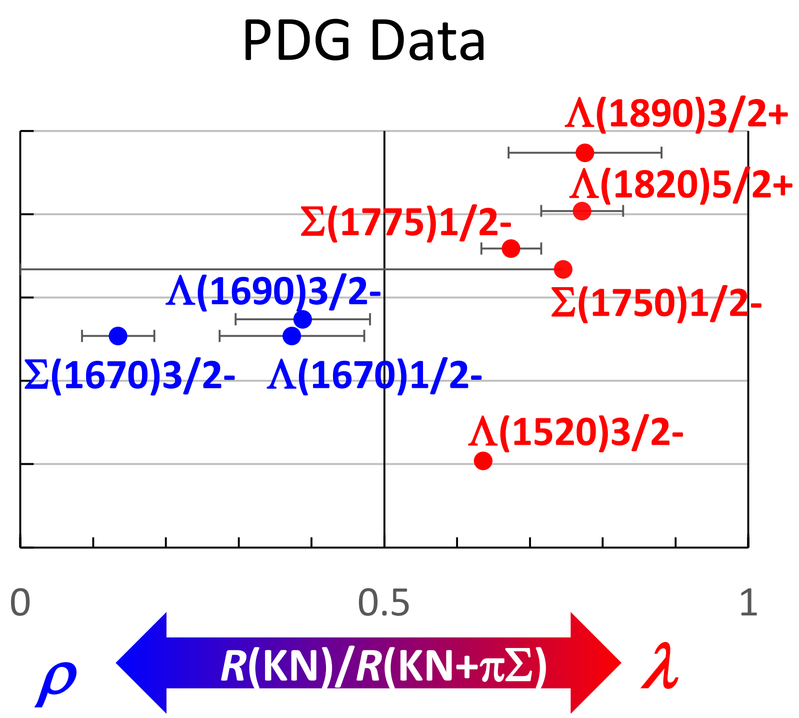
ρ mode (qq)

$\Gamma(\Sigma_c\pi) > \Gamma(pD)$

λ mode [qq]

$\Gamma(\Sigma_c\pi) < \Gamma(pD)$

Hint in $R(NK)/R(\pi\Sigma)$



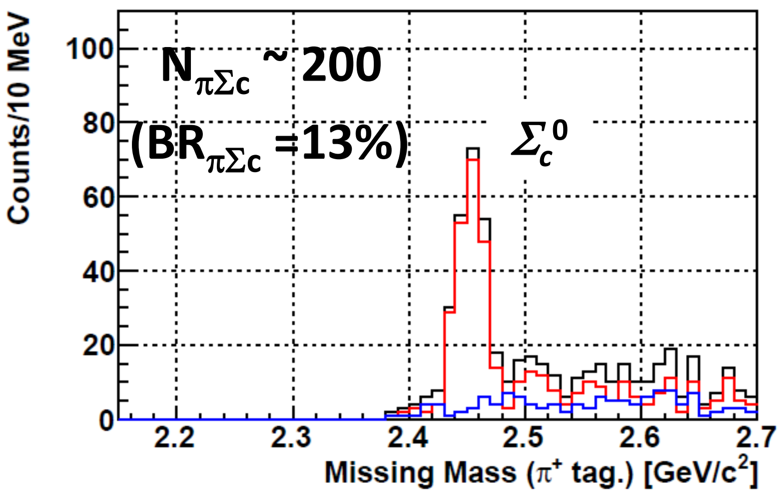
- Decay ratios in known hyperons SUGGEST the λ/ρ mode states
- λ/ρ mode ID by productions correlate w/ Decay Ratios
  → to be established

- Hyperon data indicate mode dependence
  → Errors should be improved.
- No data in charmed baryons

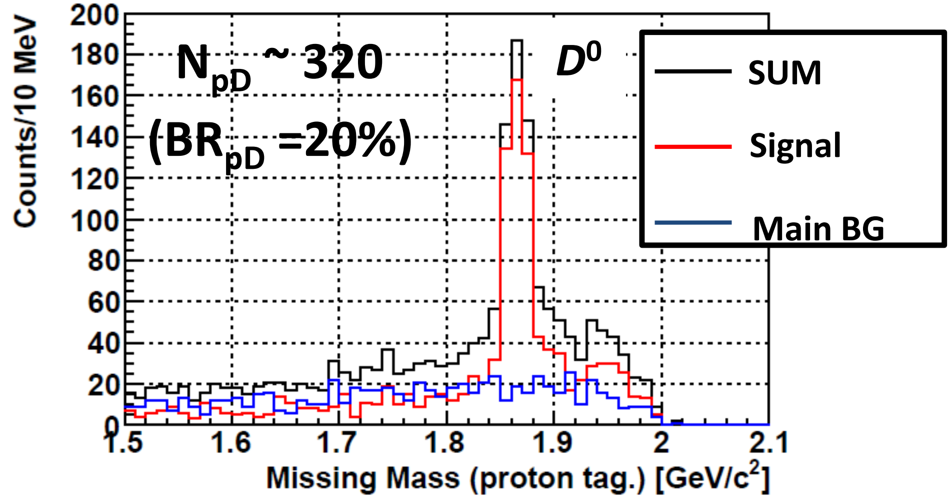
Decay Products

$\Lambda_c(2940) \to \Sigma_c^0\,\pi^+$

with $\Lambda_c^+\,\pi^+\,\pi^-$ selected



$\Lambda_c(2940) \to p\,D^0$



* Decay products can be seen clearly owing to the large acceptance.

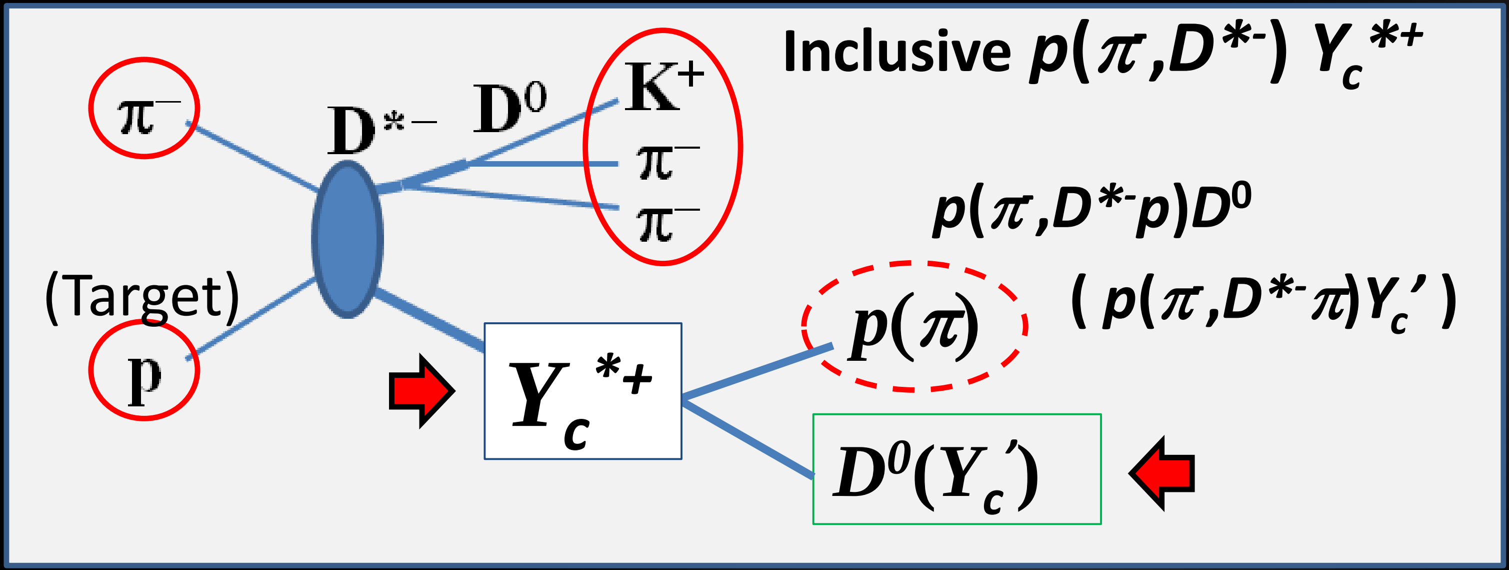
* Decay meas. strongly assists the missing mass spectroscopy.

- Branching ratios: Diquark corr. affects $\Gamma(\Lambda_c^* \to pD)/\Gamma(\Lambda_c^* \to \Sigma_c \pi)$.
- Angular distribution: Spin, Parity

Strange Hyperons

Strange Baryon Spectroscopy

Using Missing Mass Techniques

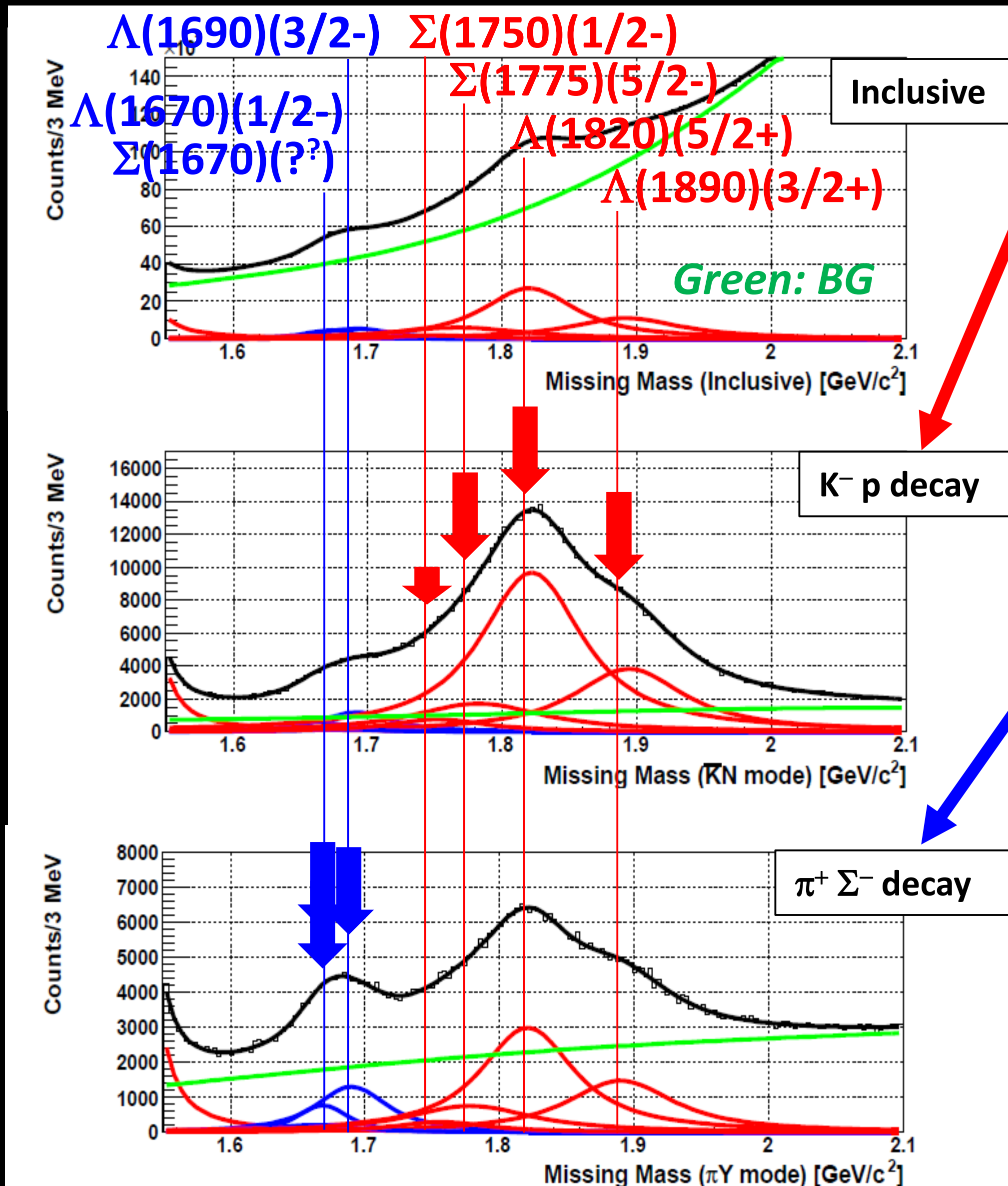


- S=-1 Hyperon *by p(π^-,K*), Y*→pK, πY*
- S=-2 Hyperon *by p(K^-,K*), (K^-,K), (π^-,KK*), Ξ*→YK, πΞ*

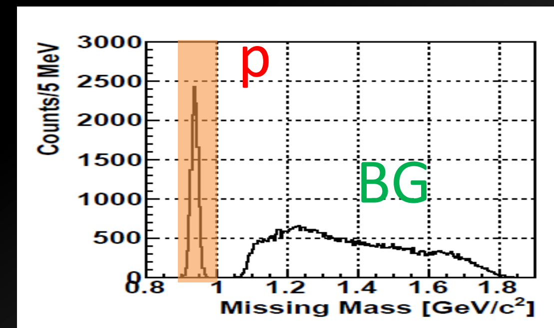
x1000~10000 better statistics than Y_c^*

Hyperon production via $p(\pi^-, K^{*0})X$

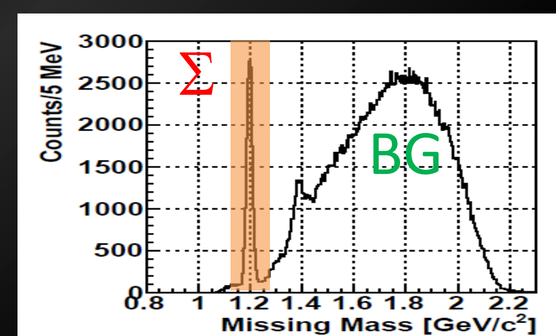
Simulation w/ 4×10^{11} pions (3 days)



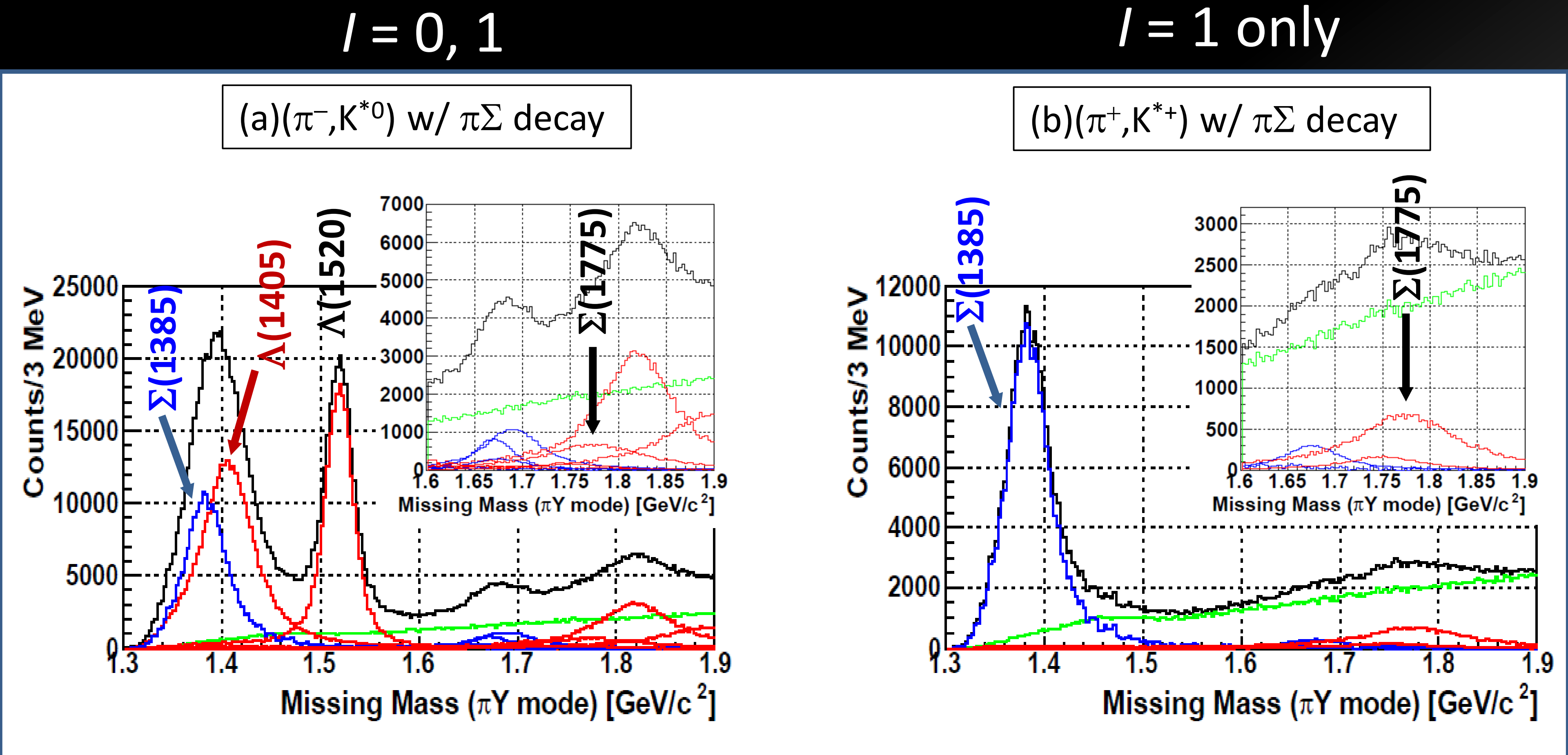
- *X → K⁻ p* decay
  - K⁻ tagged, Missing "p" gated



- *X* → π⁺Σ⁻ decay
  - π⁺ tagged, Missing "Σ" gated



Strange Baryons

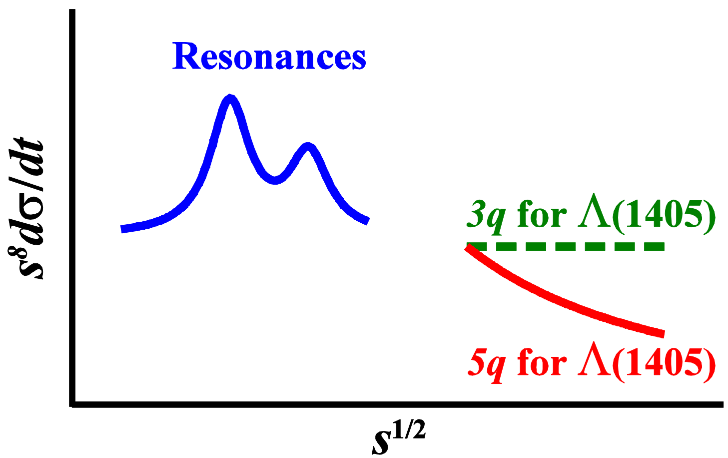


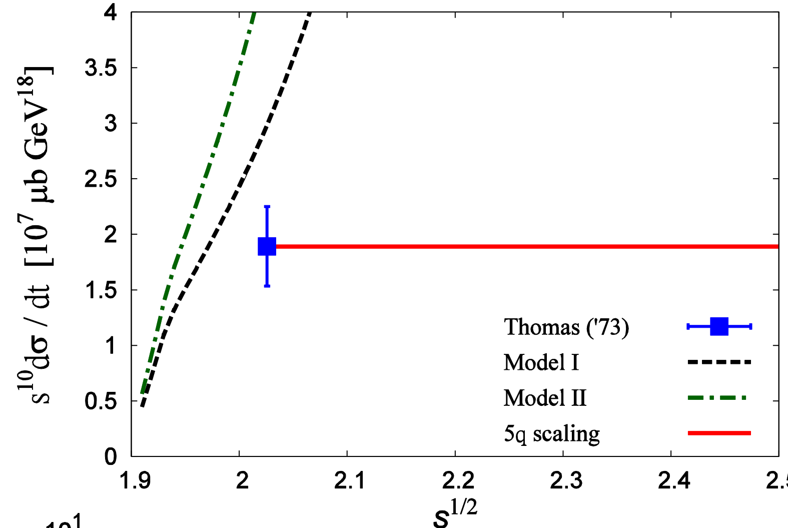
✓ Contribution of $\Sigma(1385)$ can be subtracted to extract the $\Lambda(1405)$ amplitude.

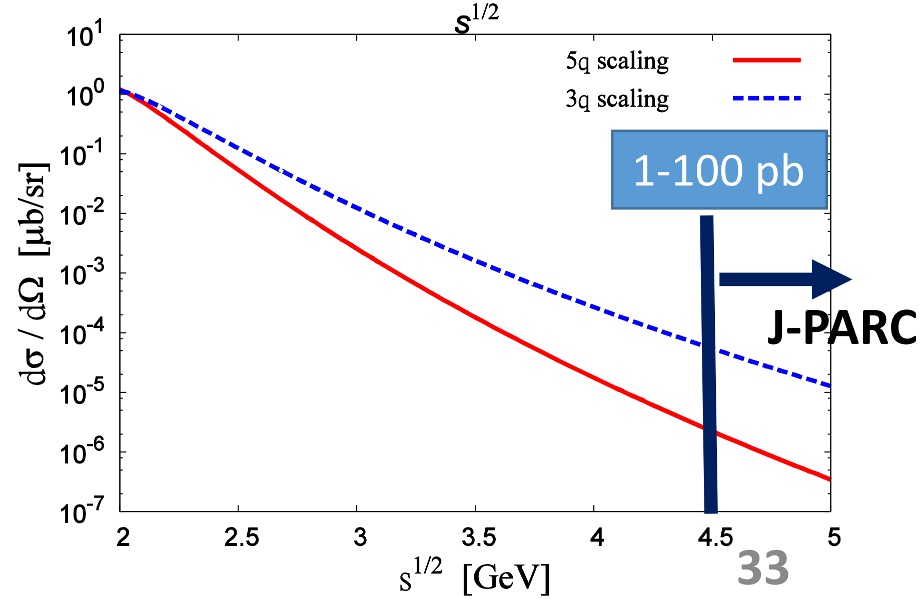
Quark Degrees of Λ(1405)

Kawamura et al., PRD 88, 034010 (2013)

$$\pi^- + p \to \mathrm{K}^0 + \Lambda(1405)$$





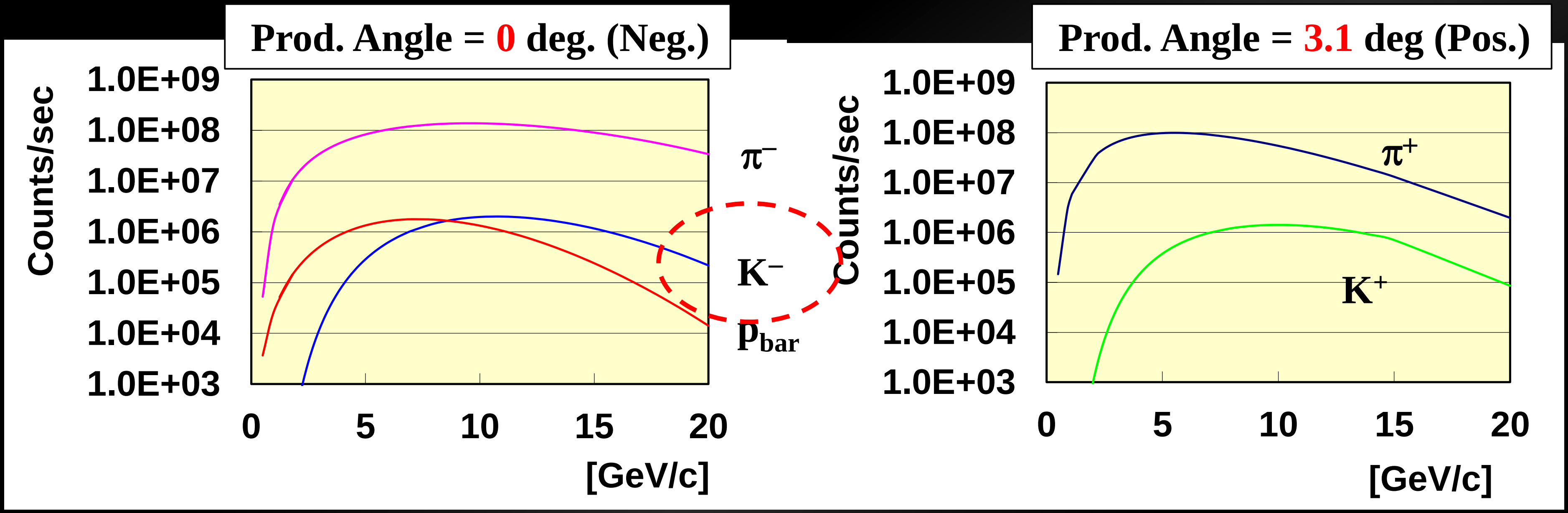


Takayasu Sekihara (March 15)

High-res., High-momentum Beam Line

- High-intensity secondary Pion beam
  - >1.0 x 10^7 pions/sec @ 20GeV/c
- High-resolution beam: $\Delta p/p \sim 0.1\%$

Intense K beams are available w/ a good KID counter.



* Sanford-Wang:15 kW Loss on Pt, Acceptance :1.5 msr%, 133.2 m

Ξ Baryon Spectroscopy w/ the High-p Secondary Beam

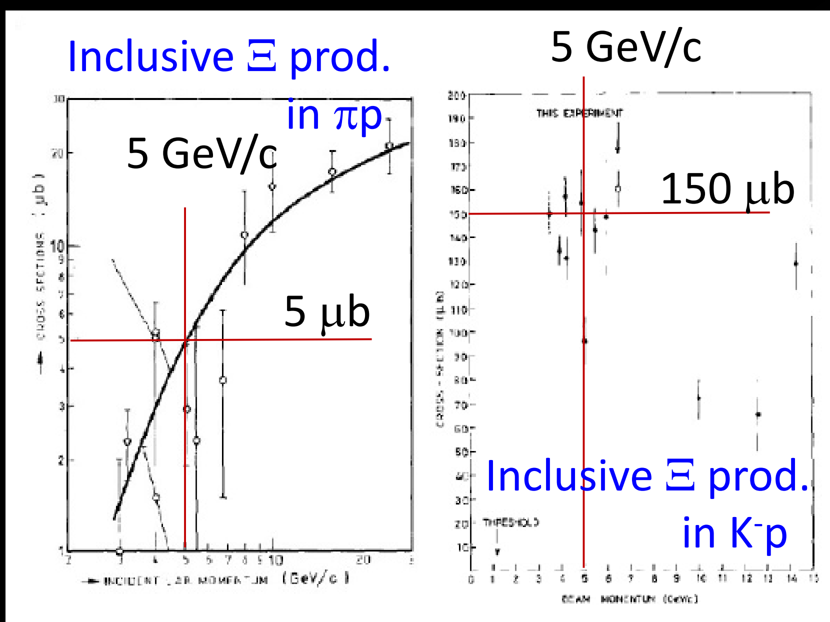
LoI submitted by M. Naruki and K. Shirotori

- Sizable yields are expected for a month.

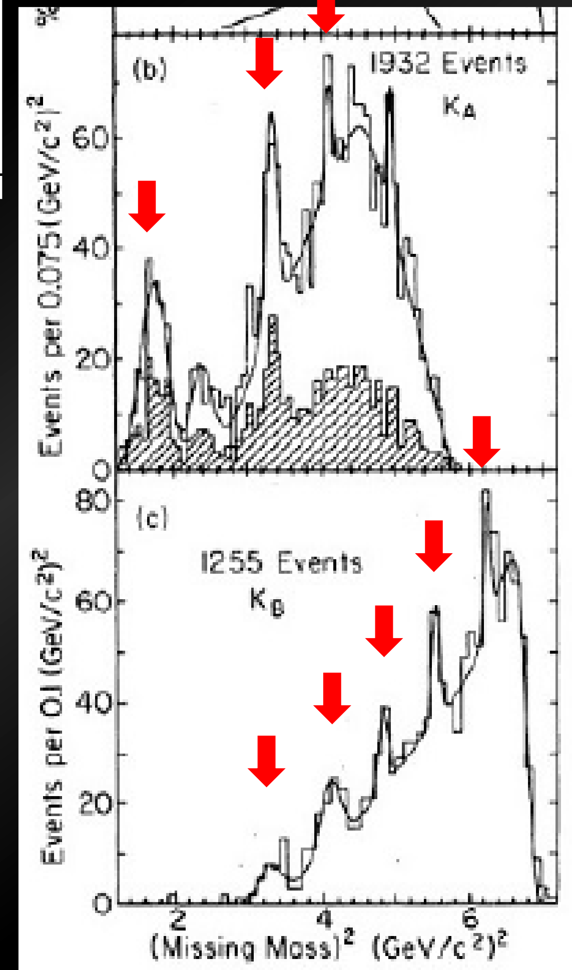
Reaction	σ [μb]	Beam [/spill]	B.R.	Acceptance [%]	Y_{Total}	$Y_{Decay/bin}$
$K^-p \to \Xi^{*-}K^+$	1.0	10^6	1.0	50	3.1×10^5	2500
$K^-p \to \Xi^{*-}K^{*+}$	1.0	10^6	0.23	50	0.7×10^5	580
$K^-p \to \Xi^{*0}K^{*0}$	1.0	10^6	0.67	50	2.1×10^5	1700
$\pi^-p \to \Xi^{*-}K^{*0}K^+$	0.1	10^7	0.67	50	3.1×10^5	2500

- Past exp.

C.M. Jenkins et al., PRL51, 951(1983) →



p(K-,K+) spectra



Measured Ξ (PDG)

Threshold

$\Omega\bar{K}(2166)$

$\Sigma\bar{K}$

$\Sigma\bar{K}^*(1983)$

$\Lambda\bar{K}^*(1908)$

$\Sigma^*\bar{K}(1878)$

$\Sigma\bar{K}(1685)$

$\Xi^*\pi(1665)$

$\Lambda\bar{K}(1610)$

$\Xi\pi(1450)$

	JP	rating	Width [MeV]	→Ξπ [%]	→ΛK [%]	→ΣK [%]	
Ξ(2500)	??	1*	150?				
Ξ(2370)	??	2*	80?				ΩK~9±4
Ξ(2250)	??	2*	47+-27?				
Ξ(2120)	??	1*	25?				
Ξ(2030)	>=5/2?	3*	20^{+15}_{-5}	small	~20	~80	Why ΣK?
Ξ(1950)	??	3*	60+-20	seen	seen		
Ξ(1820)	3/2-	3*	24^{+15}_{-10}	small	Large	Small	
Ξ(1690)	??	3*	<30	seen	seen	seen	
Ξ(1620)	??	1*	20~40?				
Ξ(1530)	3/2+	4*	19	100			

- ✓ *Most of spins/parities have NOT been determined yet.*
- ✓ *Why the* Ξ^* -> $\pi\Xi$ decay seems to be suppressed?
  - ✓ expected to reflect QQq configuration.

Summary

1. Quark-diquark structure of heavy baryons
   - Mass spectrum, Production Rate, and Decay Branching ratio
   - Information to access “wave function” of quark/diquark in baryons
2. Systematic studies with different flavors may help to understand the light baryon system
   - Meson-baryon coupling may modify mass spectrum/width
   - Relation btw charmed and strange baryons are useful.
3. A general purpose spectrometer at the J-PARC High-p BL
   - CHARM spectrometer will open a new platform to study hadron physics.
   - Cooperative efforts of potential users at the High-p BL are of essential importance to push forward this field.