Hadrons and Hadron Interactions in QCD 2015 Symposium
2-6 Mar., 2015

Hadron spectroscopy at the J-PARC high-momentum beam line

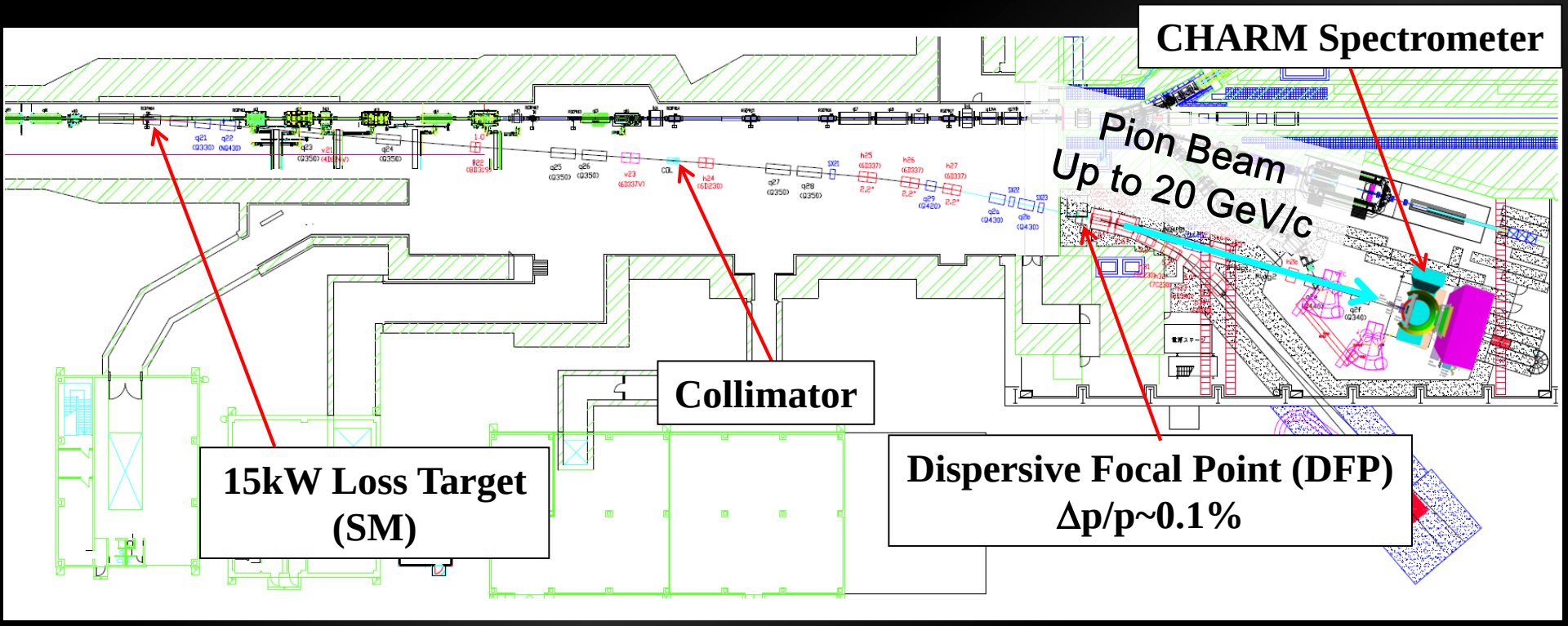
H. Noumi (RCNP, Osaka University)
2 March, 2015

Contents:

1. Charmed Baryon Spectroscopy
   - A new platform for hadron physics at J-PARC
   - Mass Spectrum, Production, and Decay
2. QQq system
3. Summary

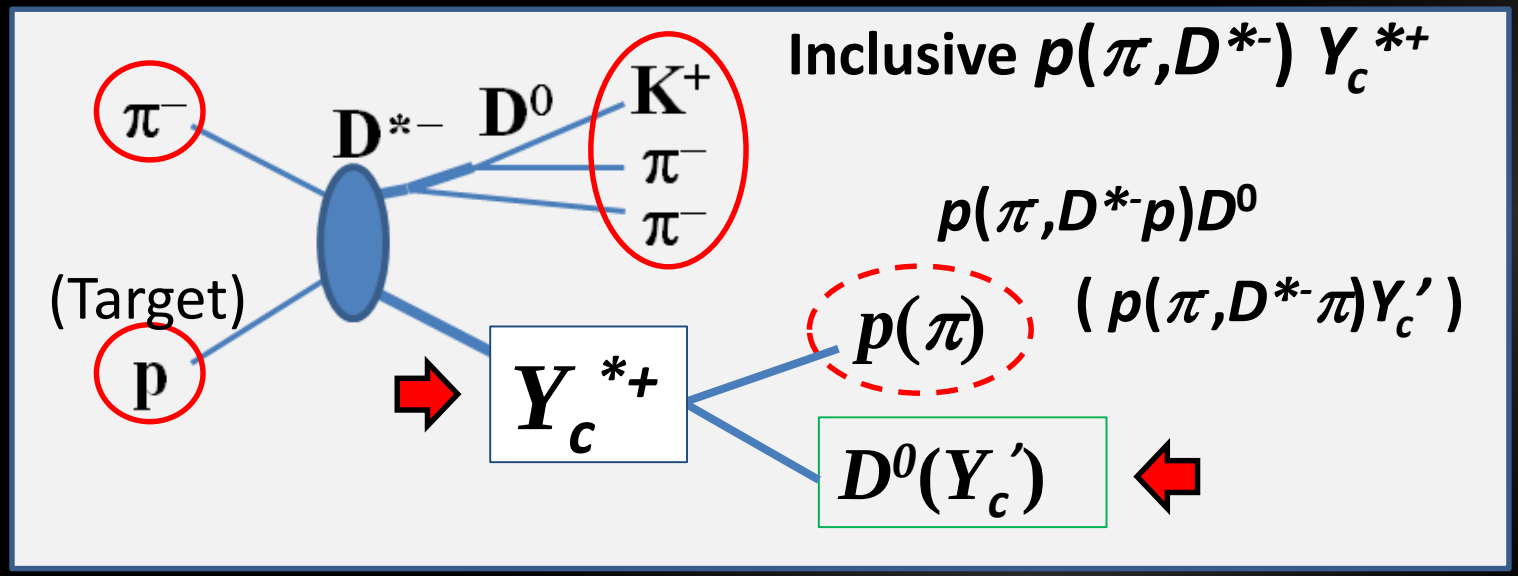
A New Platform for Hadron Physics at the High-momentum Beam Line

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



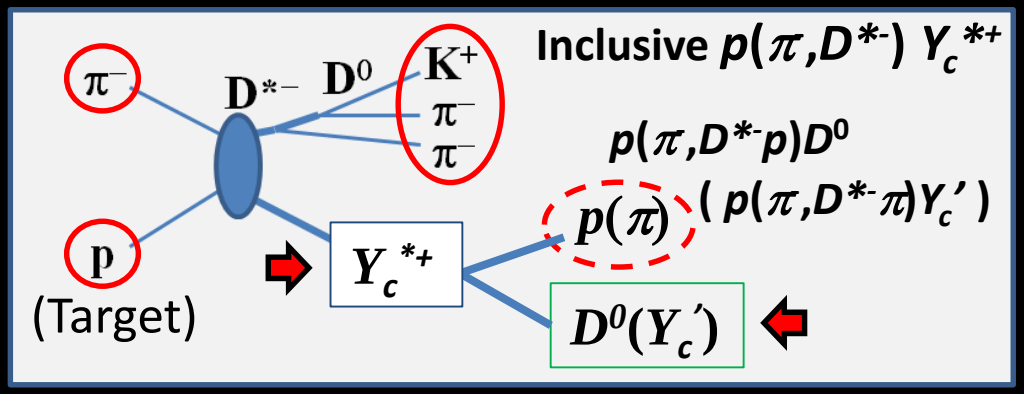
Charmed Baryon Spectroscopy

Using Missing Mass Techniques



Conducted by the E50 experiment at J-PARC

CHARM Spectrometer



Cross Section:

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

Acceptance:

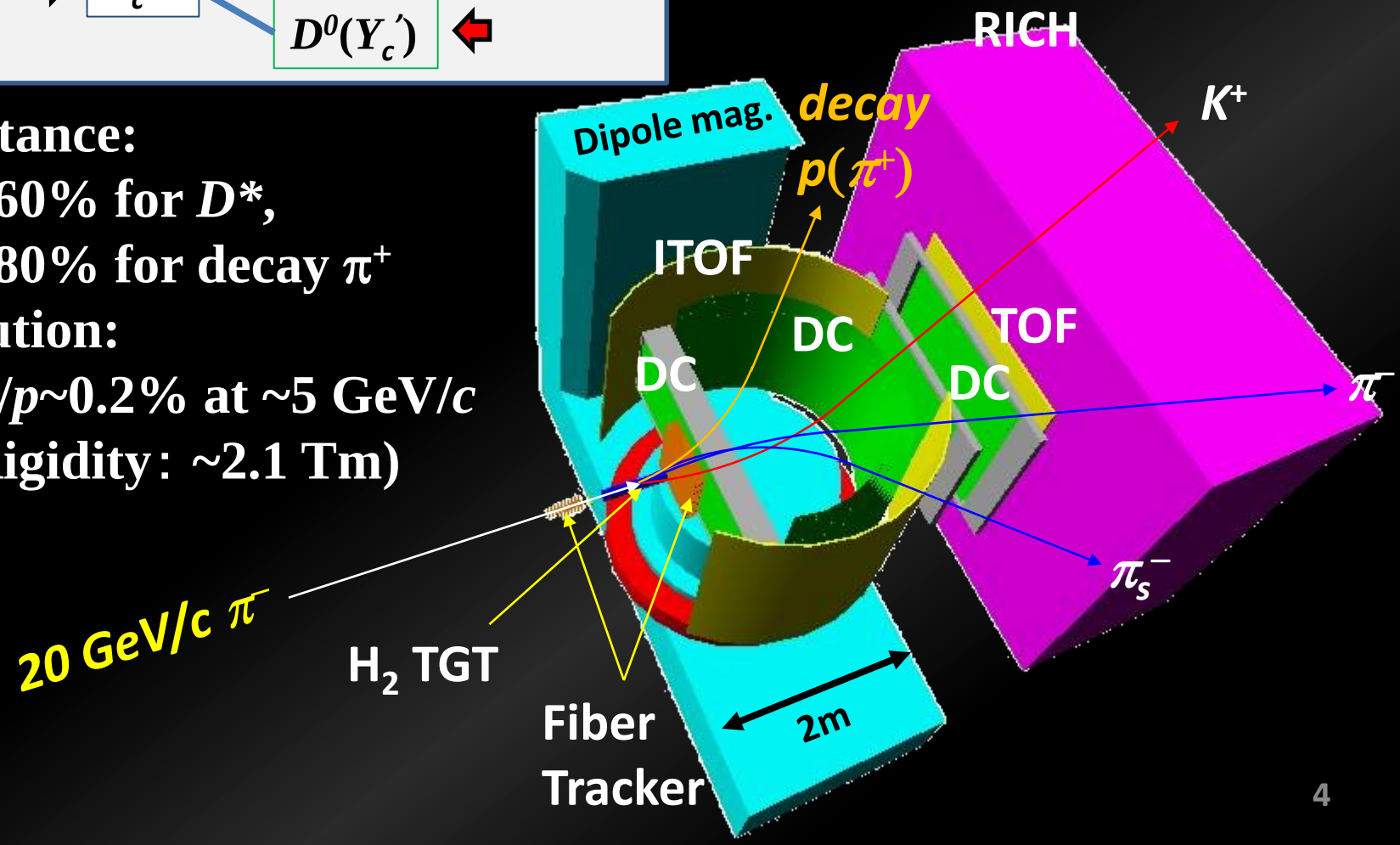
~ 60% for D^*,

~ 80% for decay π^+

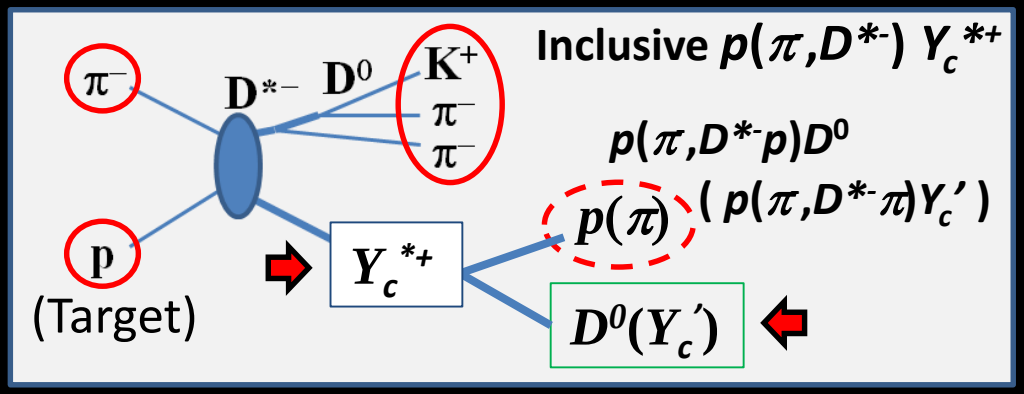
Resolution:

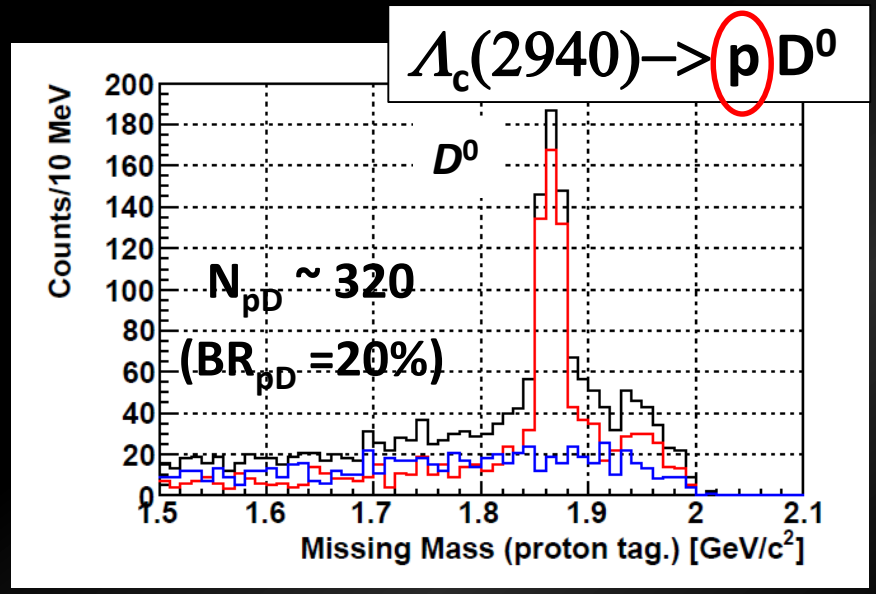
$\Delta p/p$~0.2% at ~5 GeV/c

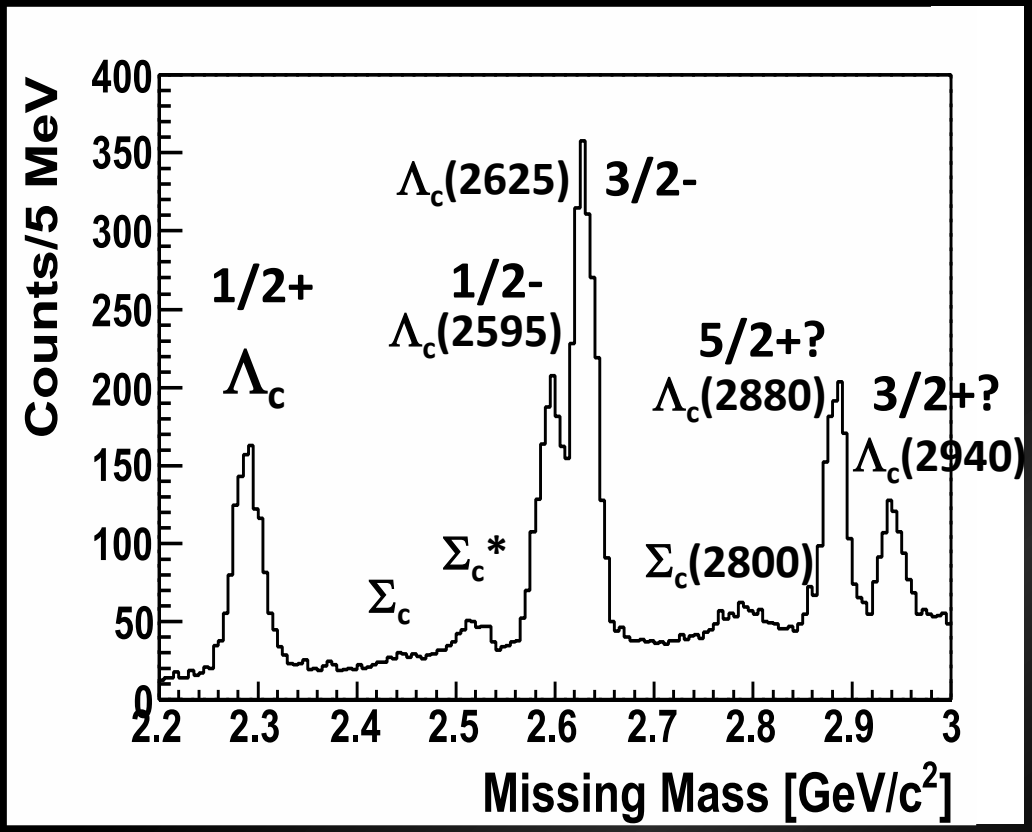
(Rigidity: ~2.1 Tm)

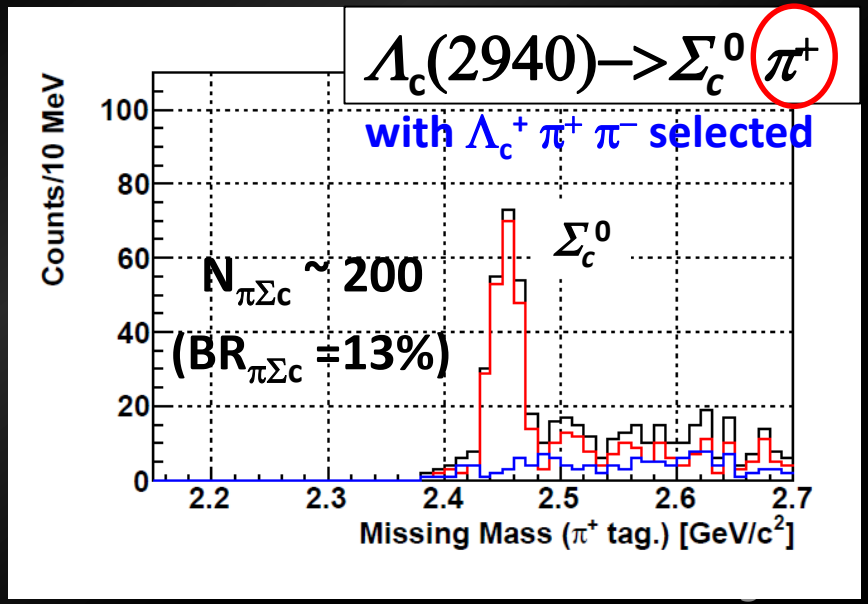


Inclusive Spectrum and Decay Mode ID (Sim.)





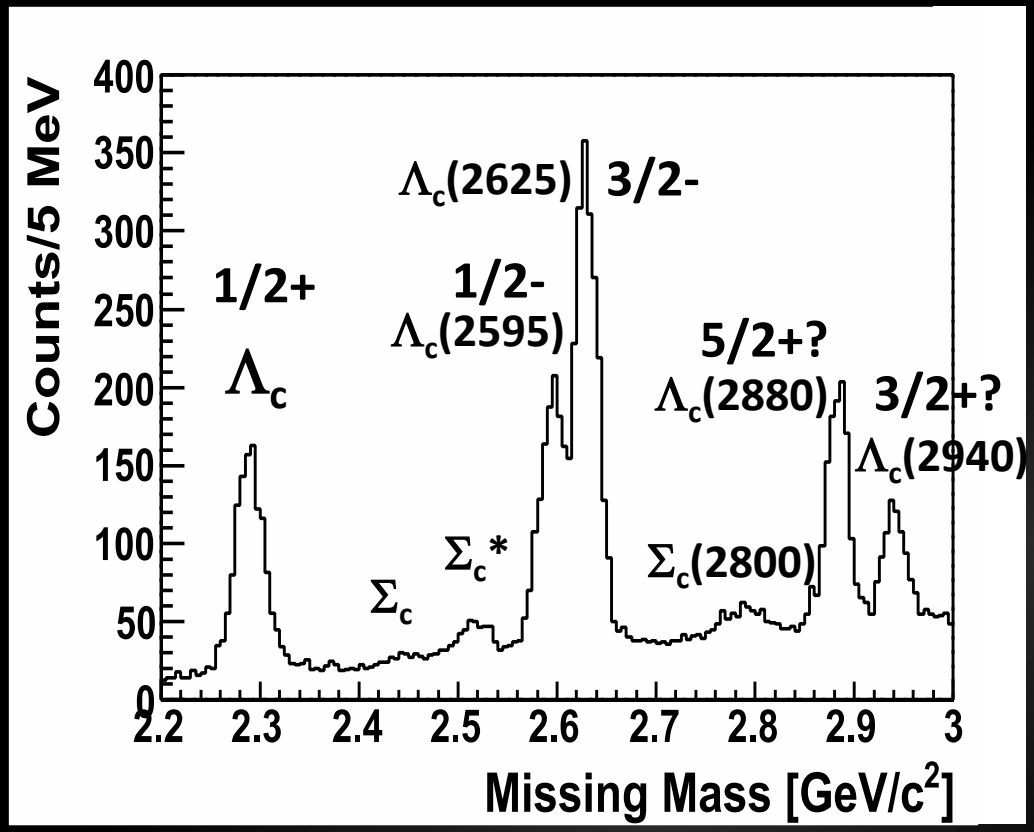


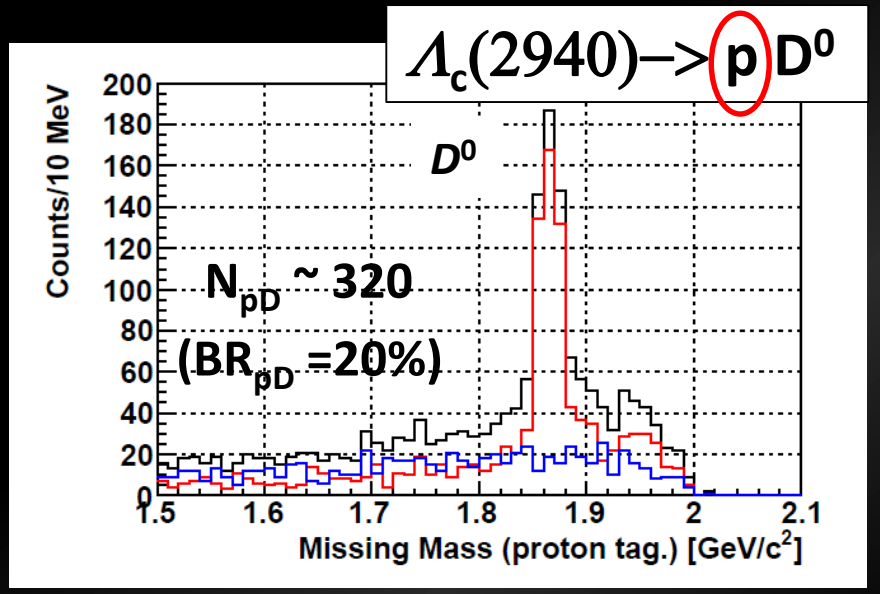


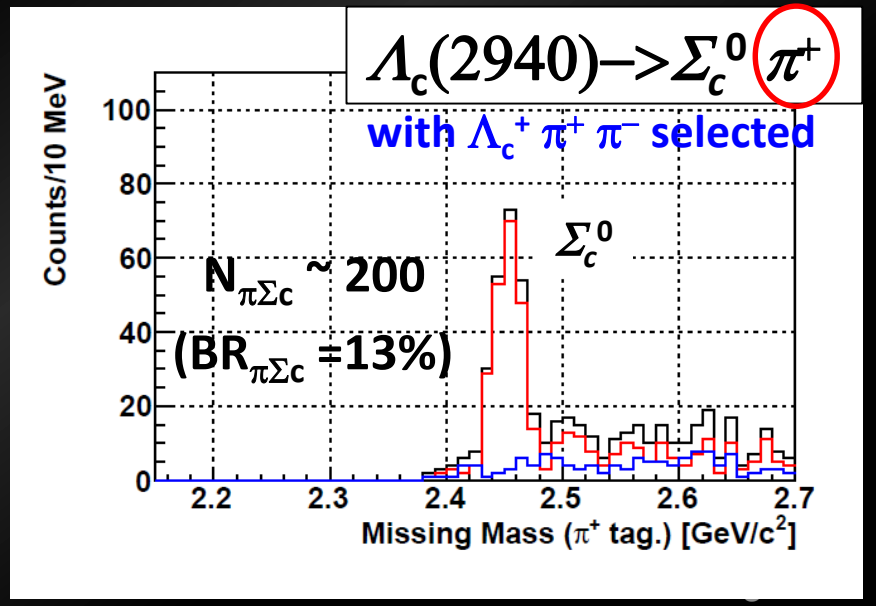
Inclusive Spectrum and Decay Mode ID (Sim.)

- Level Structure
- Production Rate
- Decay Branching Ratio

Yield: ~1000 Y_c^*/nb/100 day





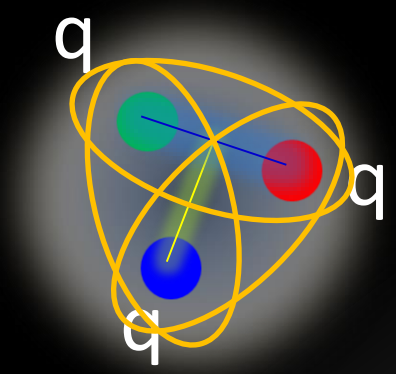


Hadron Spectroscopy at J-PARC

- Unique approach
  - Missing Mass Spectroscopy in M-B collisions.
  - $q\bar{q} + q[qq] \rightarrow q\bar{Q} + Q[qq]$

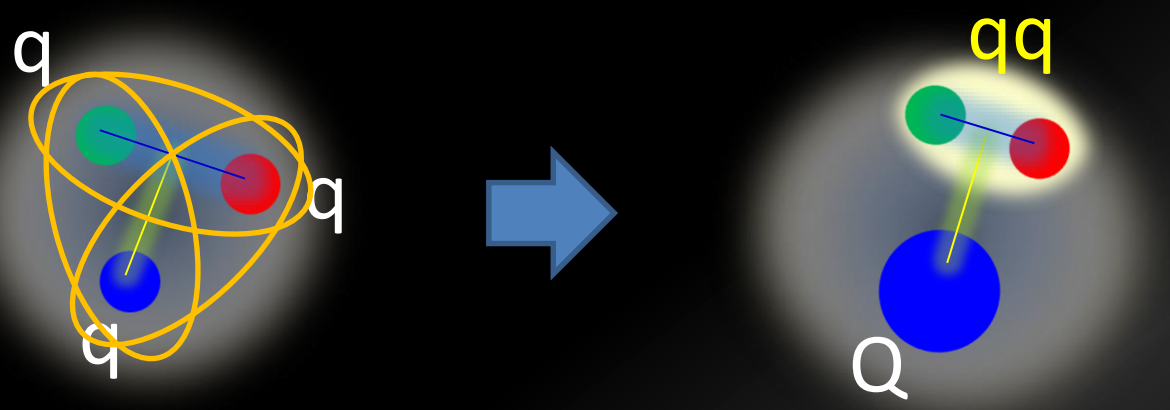
    in addition to mass, width, and spin/parity
    - Production Cross Section
    - Decay Property : Decay Branching Ratios
  - Study of Baryons with heavy flavors
    - Quark-Diquark config. of Baryons

What we can learn from baryons with heavy flavors



- Excited states of light baryons are complicated.
  - Easily coupled to light mesons. (Large Width)
  - Level structure and widths are hardly understood.

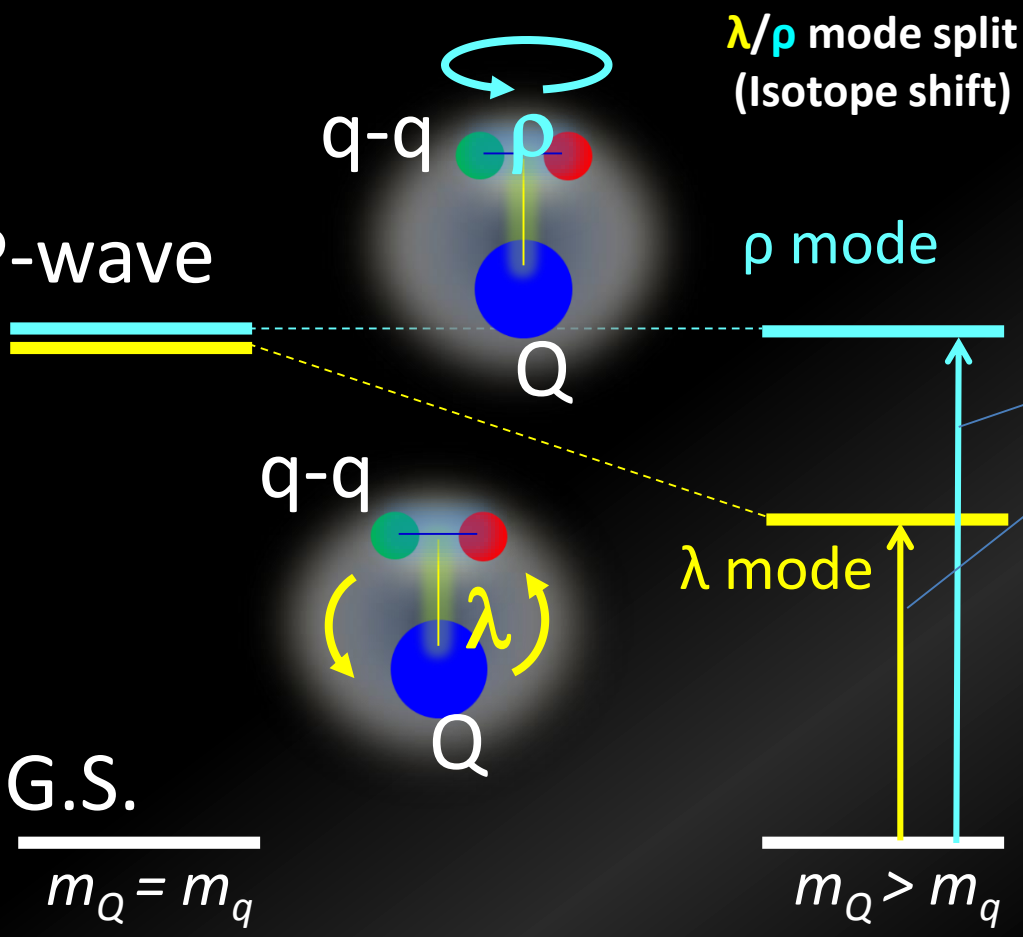
What we can learn from baryons with heavy flavors



- 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)
- Spin-dependent Int.



- $H = H_0 + V_{conf} \ldots$
- $V_{conf} = k/2 \sum r_i^2$

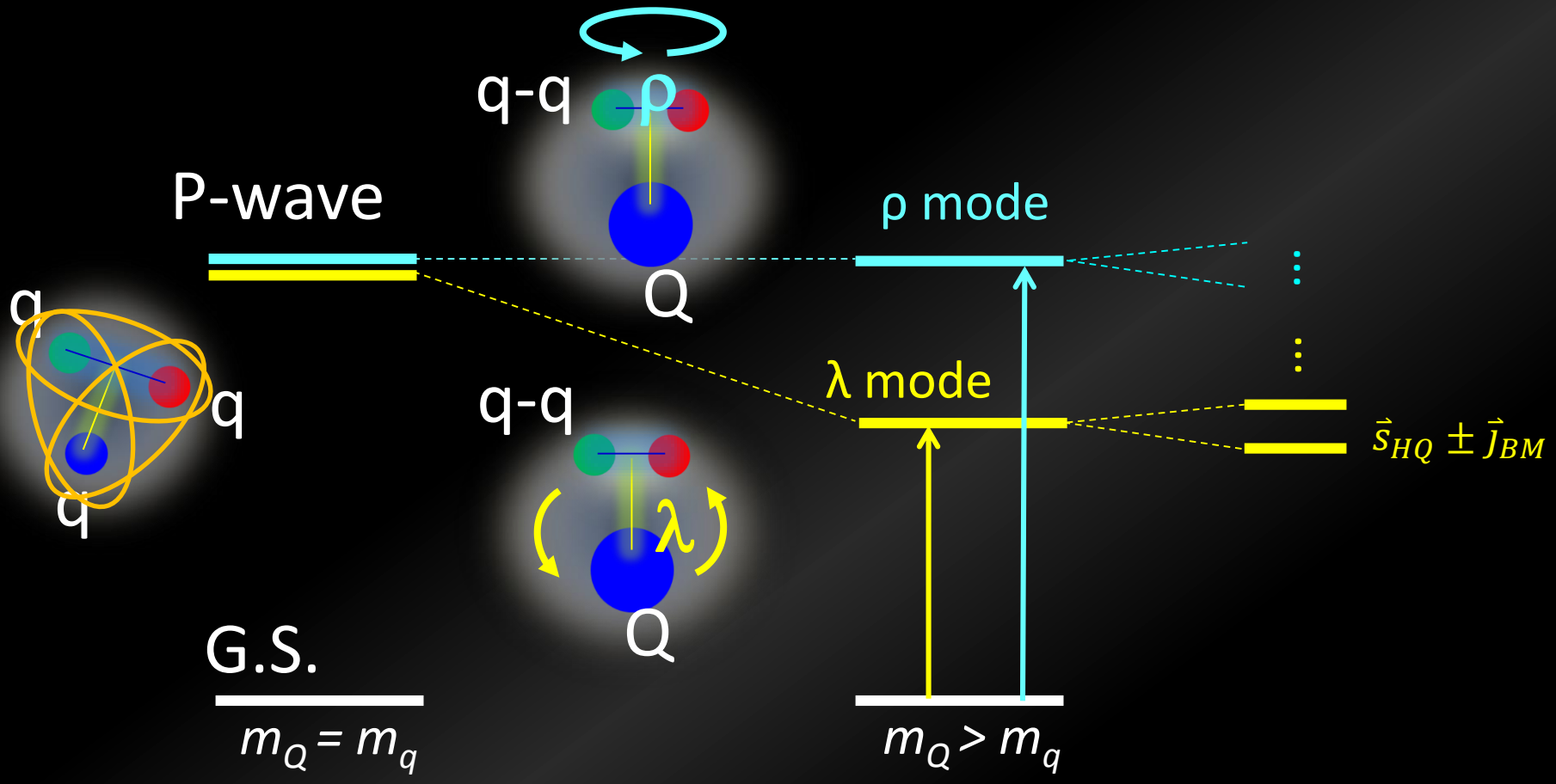
$$\omega_{\lambda,\rho} = \sqrt{3k/m_{\lambda,\rho}},$$

$$m_\lambda = \frac{3m_q m_Q}{2m_q + m_Q},$$

$$m_\rho = m_q$$

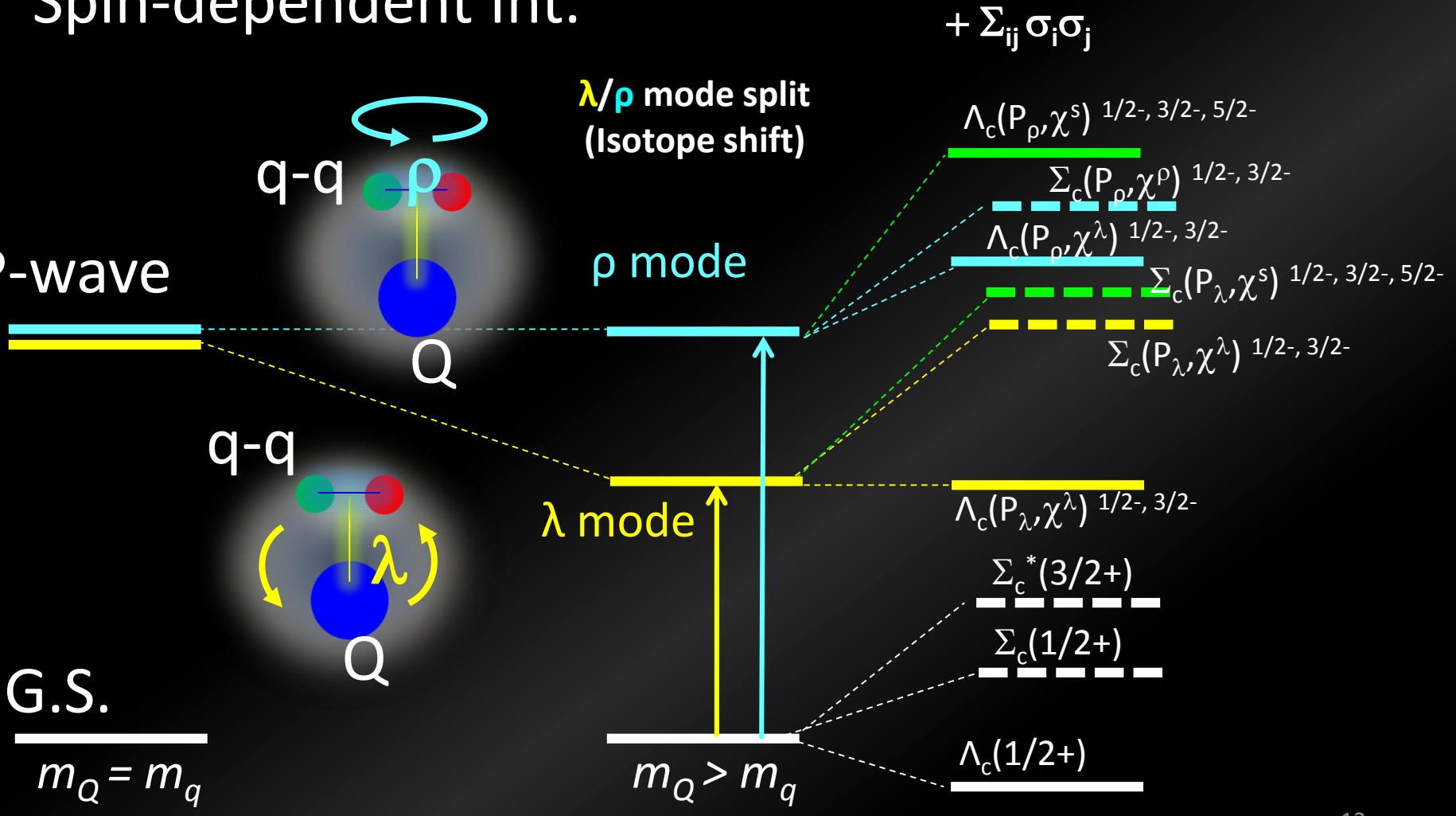
Schematic Level Structure of Heavy Baryons

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



"Schematic" Level Structure of Heavy Baryons

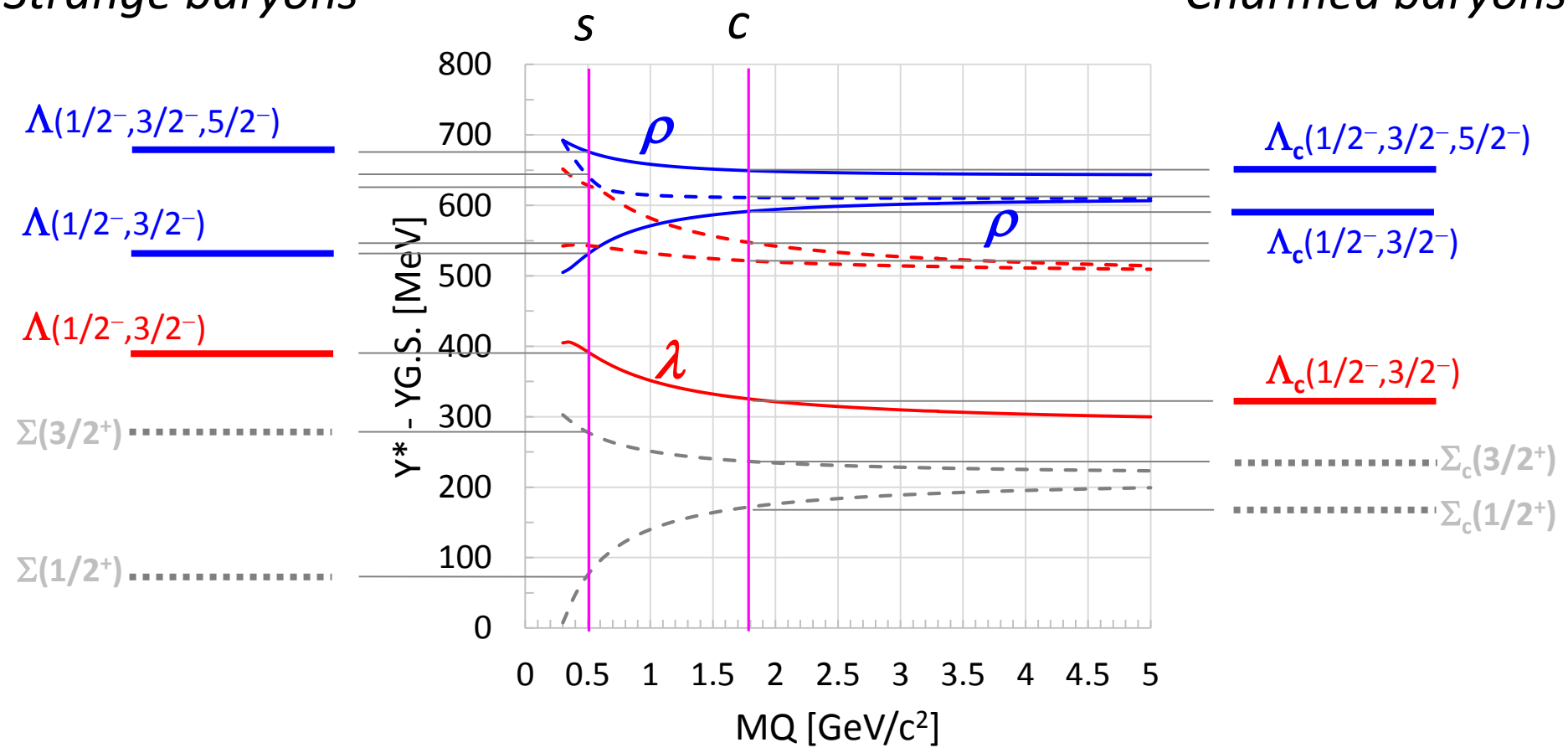
- λ and ρ motions split (Isotope Shift)
- Spin-dependent Int.



CQM calculation (Lambda)

Strange baryons

Charmed baryons



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

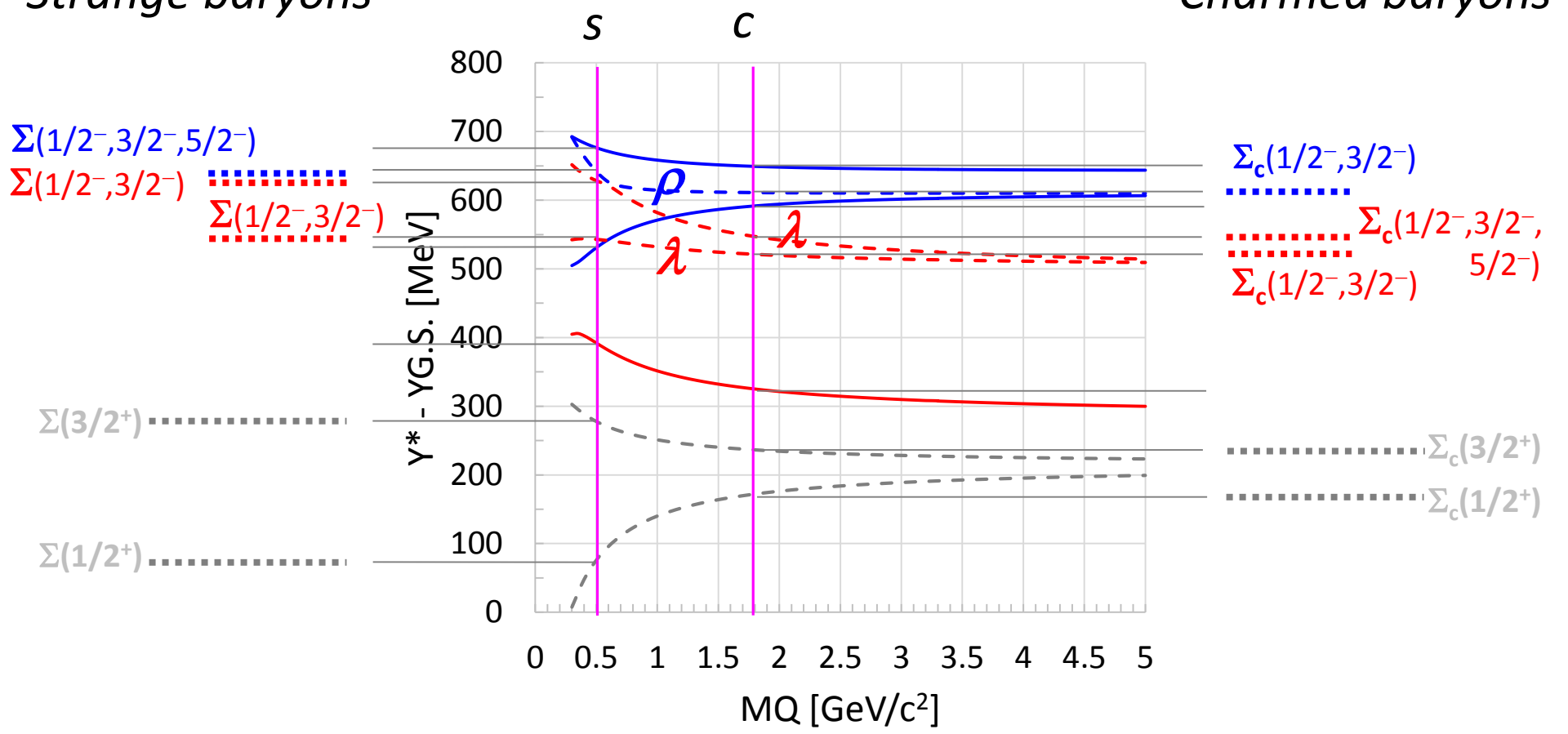
ρ–λ mixing (cal. By T. Yoshida)

→ POSTER SESSION

CQM calculation (Sigma)

Strange baryons

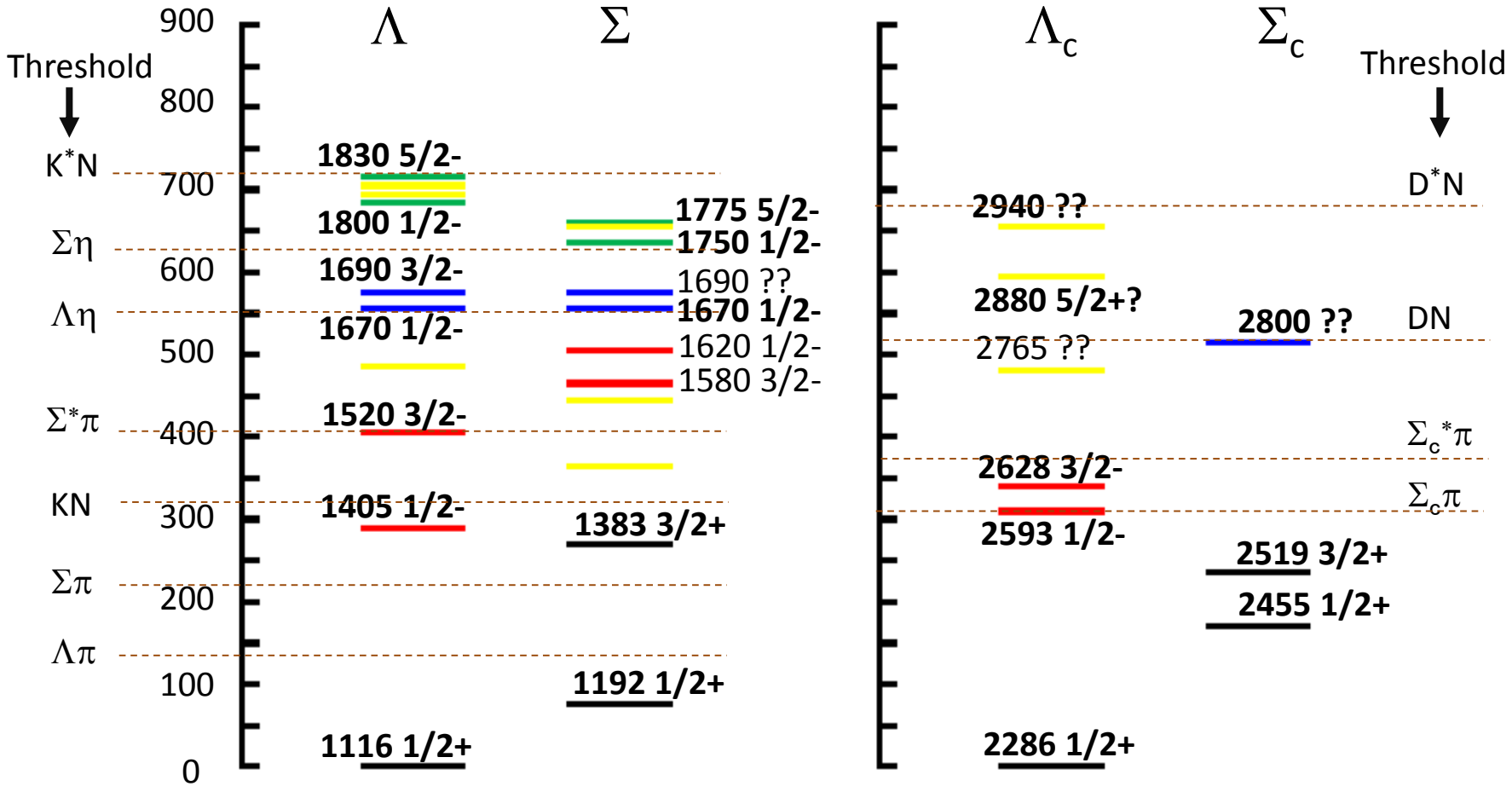
Charmed baryons



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

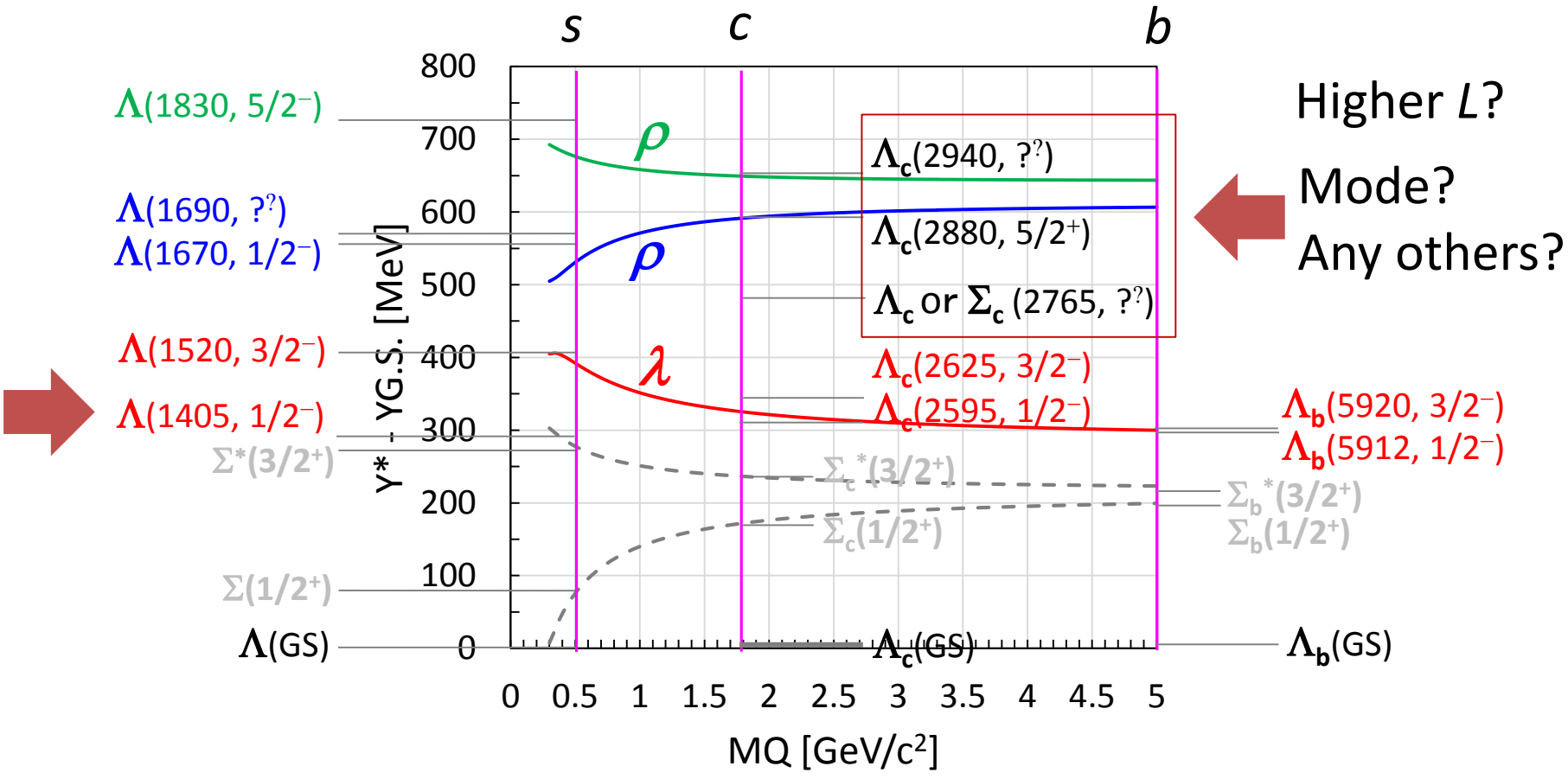
ρ–λ mixing (cal. By T. Yoshida)

Level structure (Exp.)



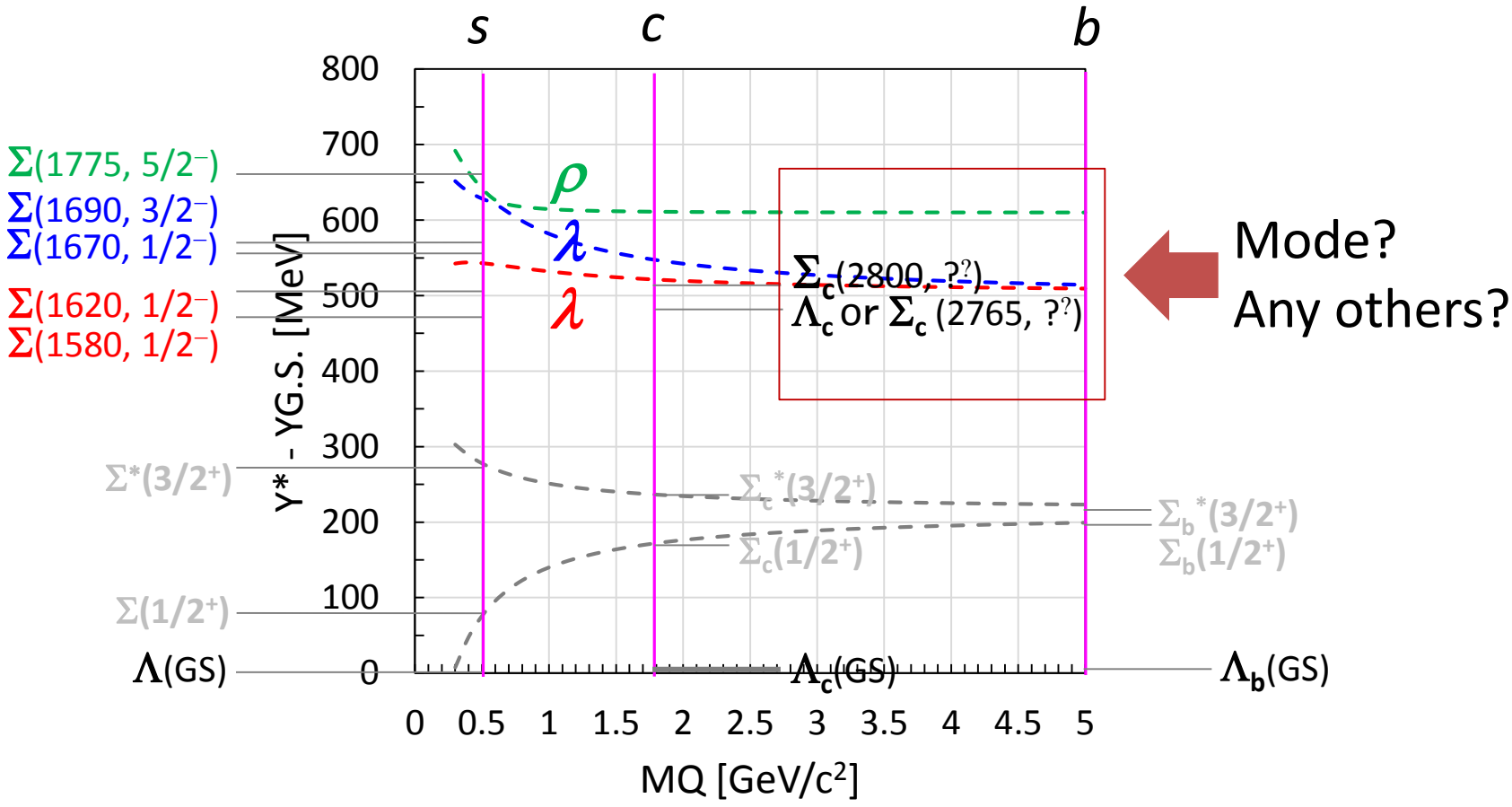
- ✓ λ / ρ mode assignment is not established yet.
- ✓ Level structure of Υ_c is little known.

Lambda Baryons



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

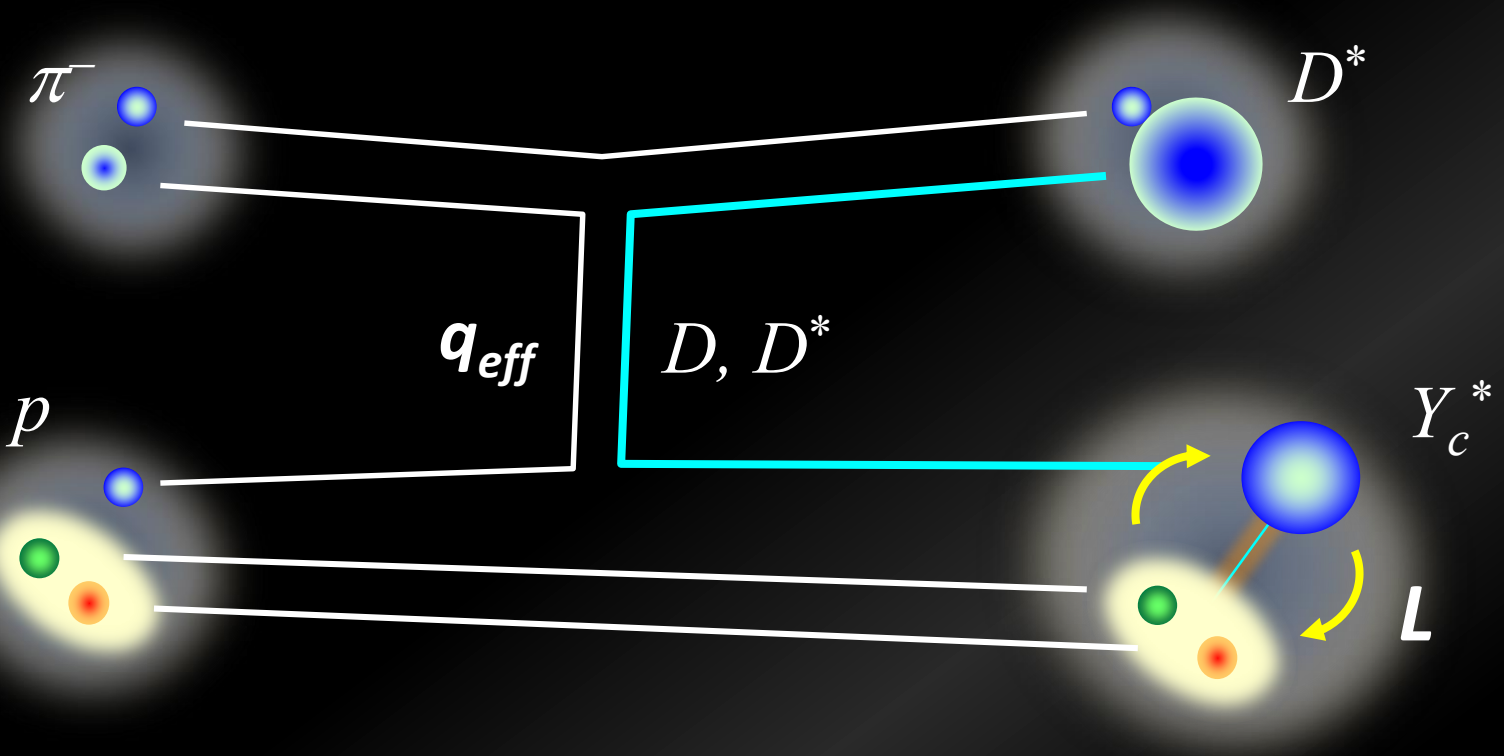
Sigma Baryons



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

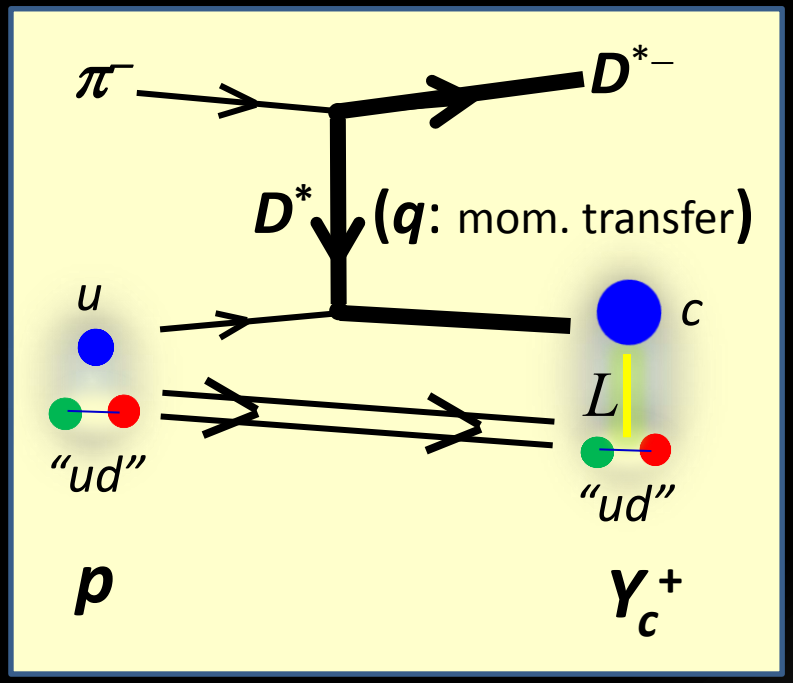
Production Rate

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

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

and depend on:

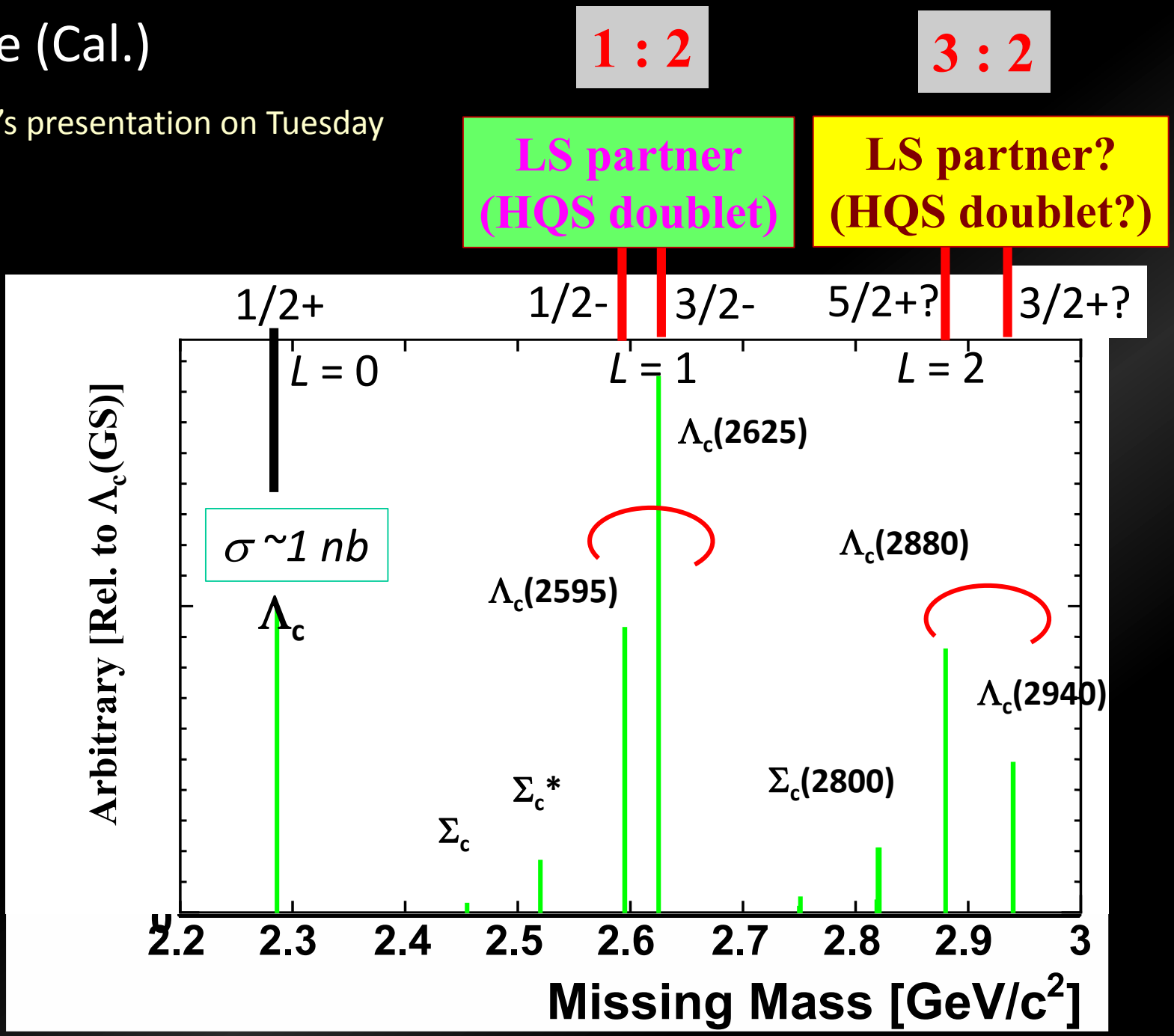
1. Spin/Isospin Config. of Y_c
   Spin/Isospin Factor
2. Momentum transfer (q_{eff})

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

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

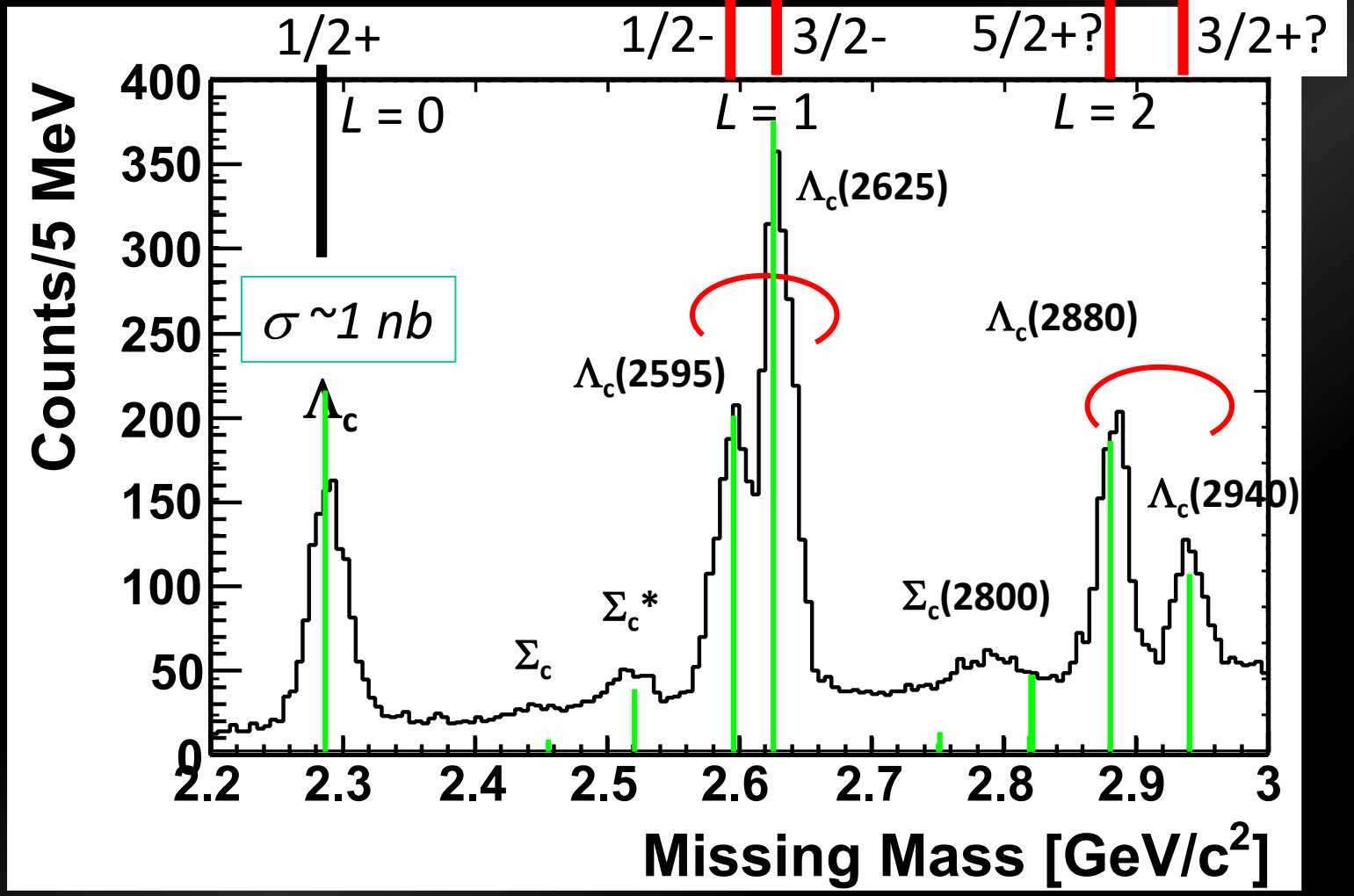
Prod. Rate (Cal.)

→ A. Hosaka's presentation on Tuesday



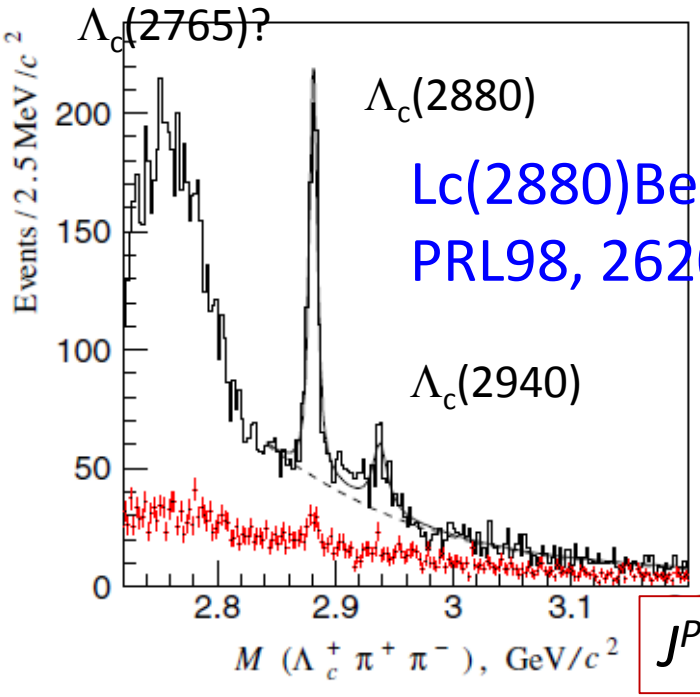
Missing Mass Spectrum (Sim.)

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

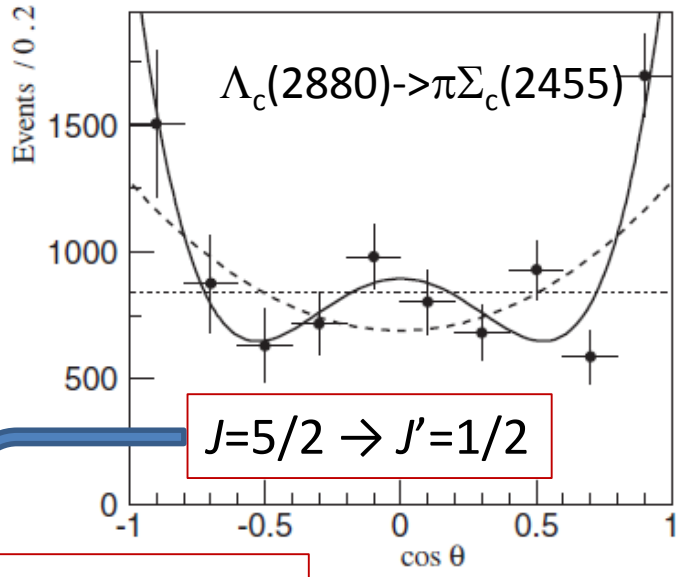


$\Lambda_c(2880)/\Lambda_c(2940)$

- Are $\Lambda_c(2880)/\Lambda_c(2940)$ *LS* partners?
- 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
  - *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. 60/35~5/3 !
- If NOT,
  - Prod. Rates give information on their structure…
  - new states corresponding to $L_{(\lambda)}=2$ should be observed

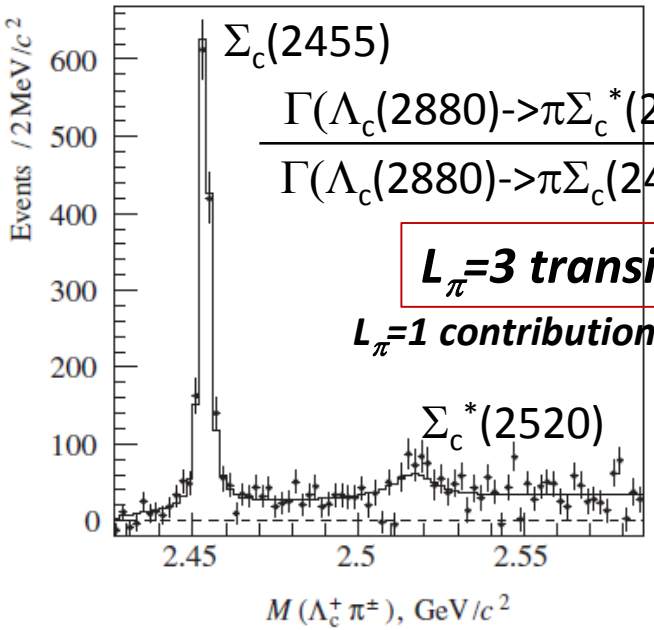


Lc(2880)Belle,
PRL98, 262001('07)



J=5/2 → J'=1/2

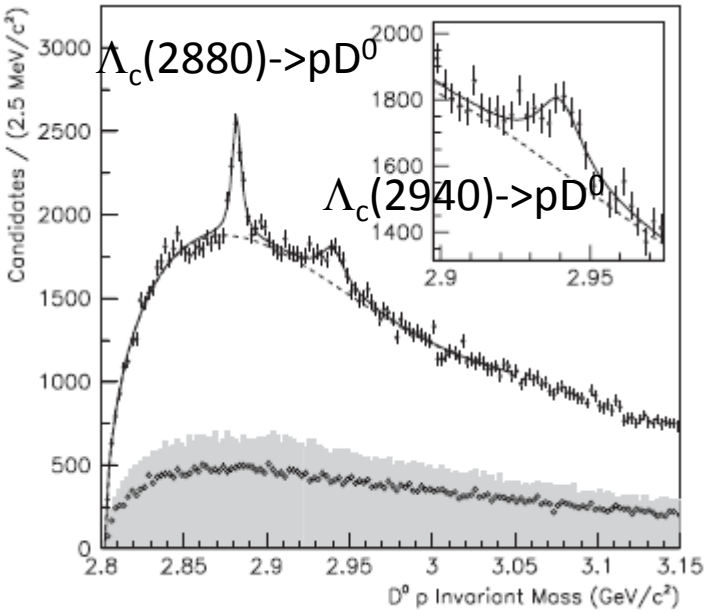
J^P=5/2$^+$ for Λ_c(2880)



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

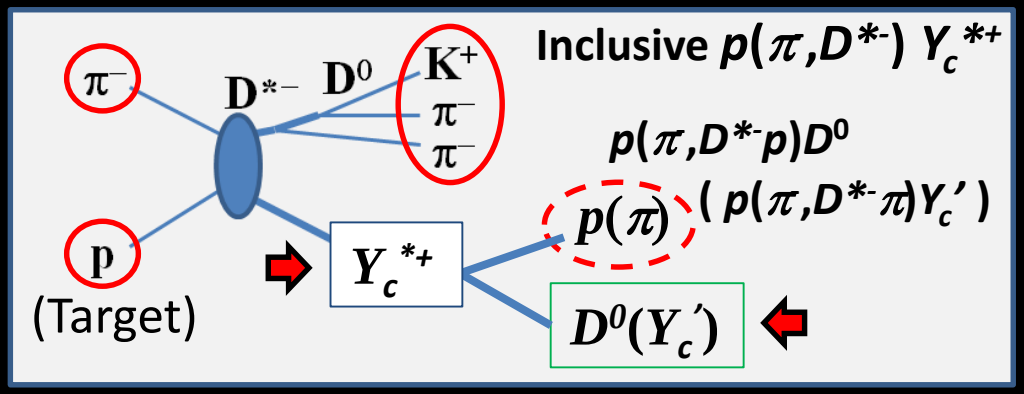
L_π=3 transition

L_π=1 contribution may affect…



Babar, PRL98, 012001('07)

CHARM Spectrometer



Cross Section:

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

Acceptance:

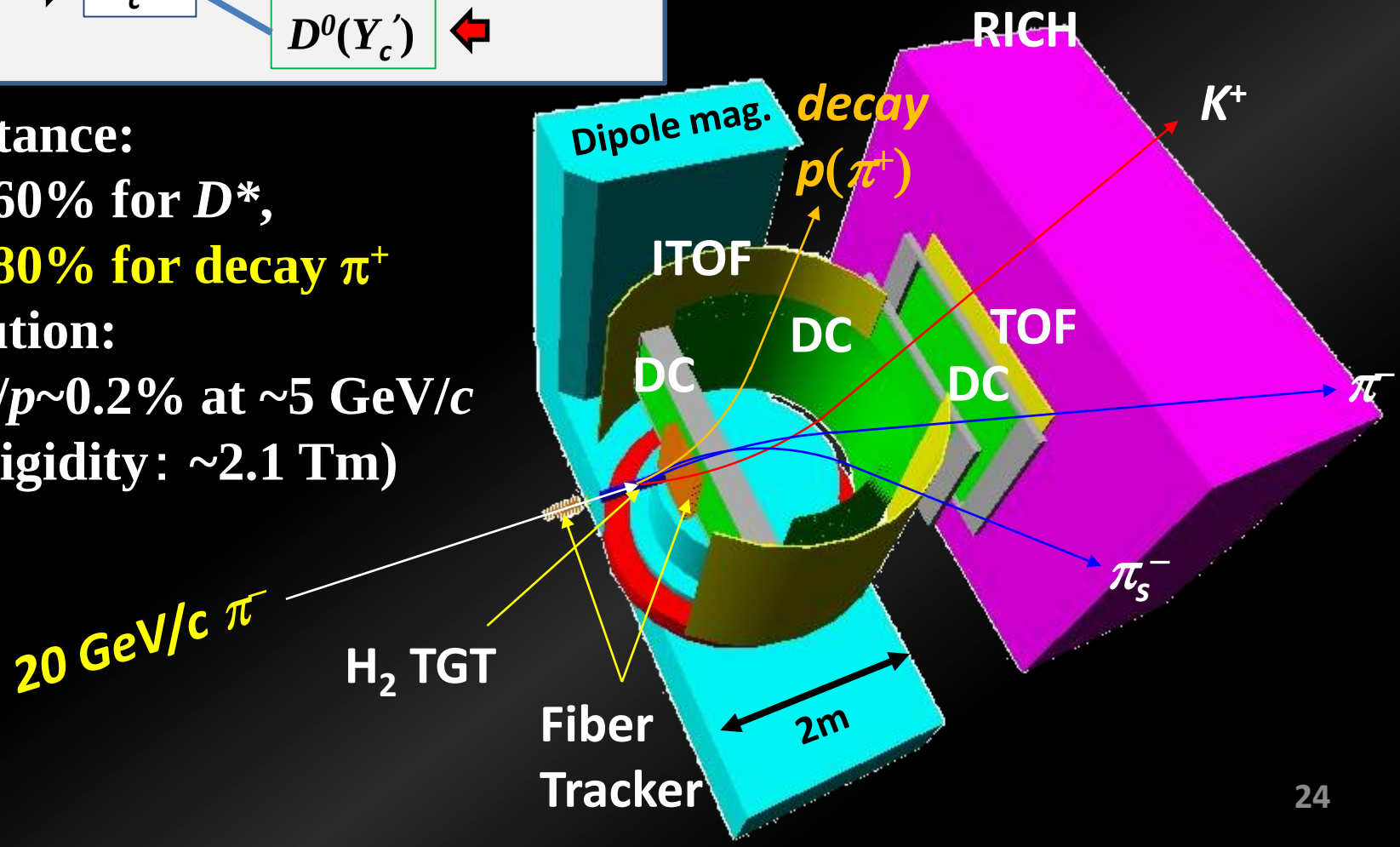
~ 60% for D^*,

~ 80% for decay π^+

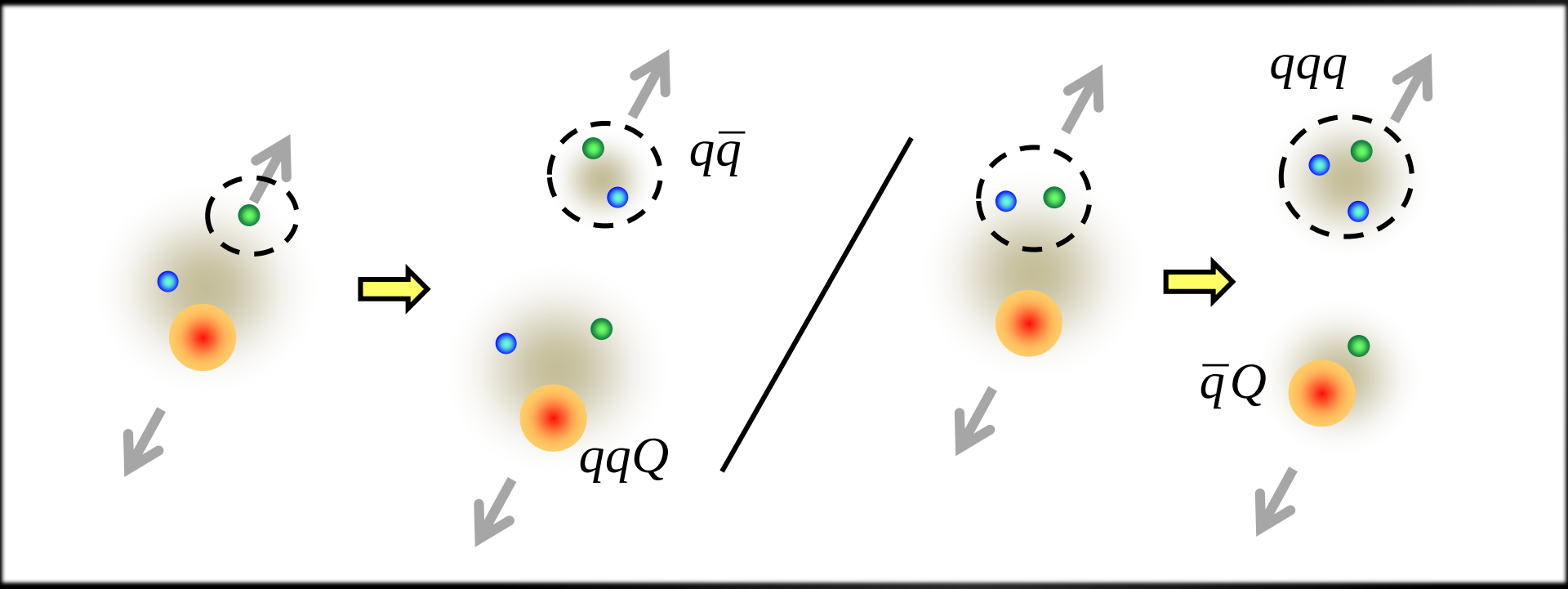
Resolution:

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

(Rigidity: ~2.1 Tm)



Decay Properties



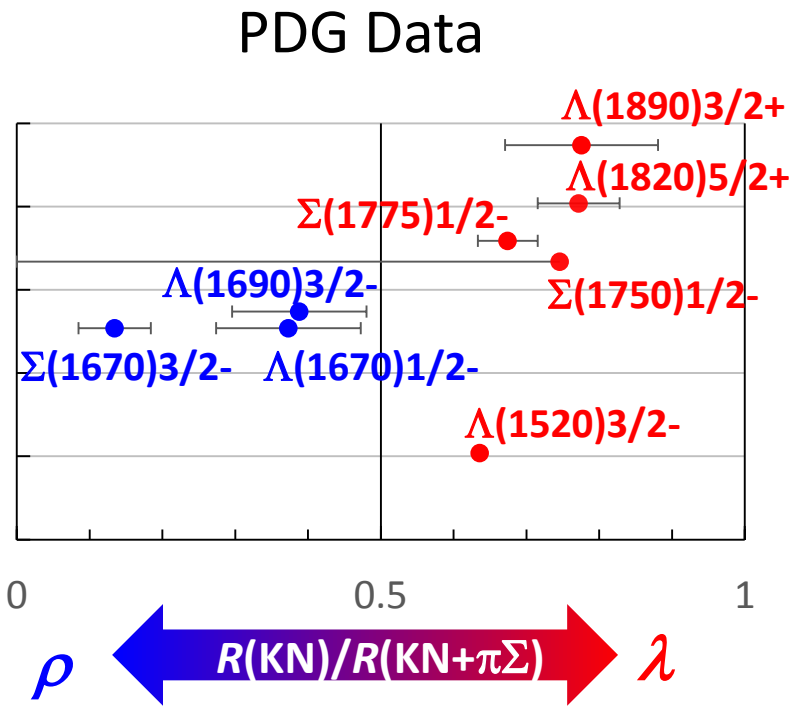
ρ mode (qq)

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

λ mode [qq]

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

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

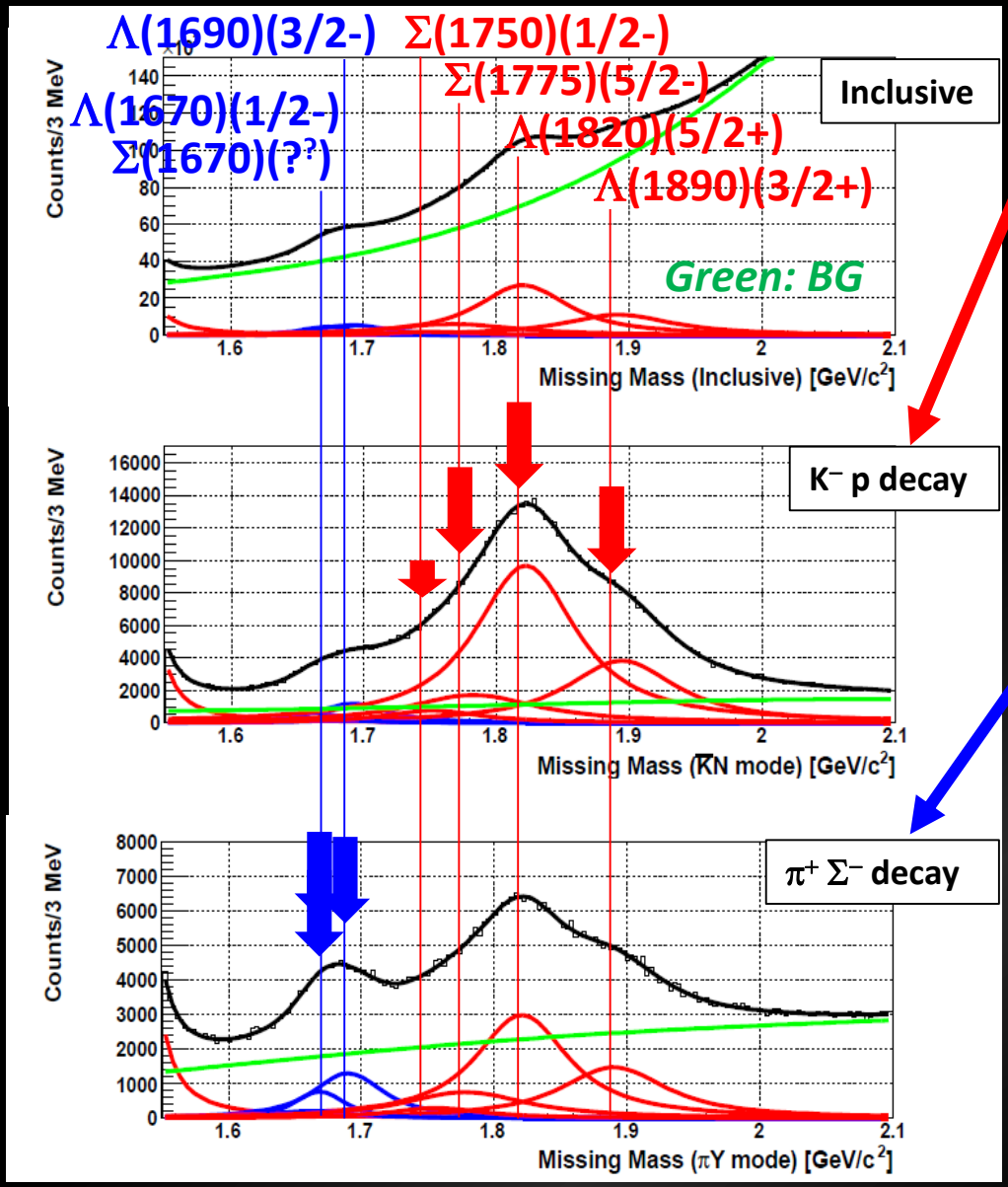


- Decay ratios in known hyperons SUGGEST the λ/ρ mode states
- λ/ρ mode ID by productions correlate w/ Decay Ratios
  → to be established

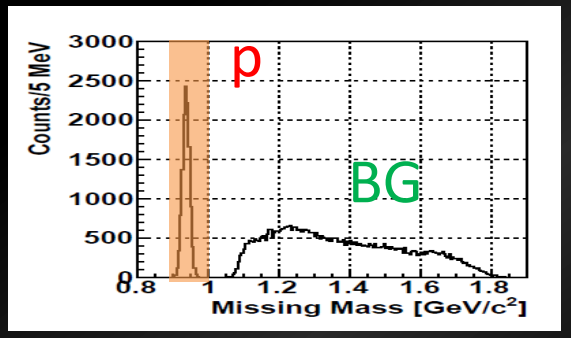
- Hyperon data indicate mode dependence
  → Errors should be improved.
- No data in charmed baryons

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

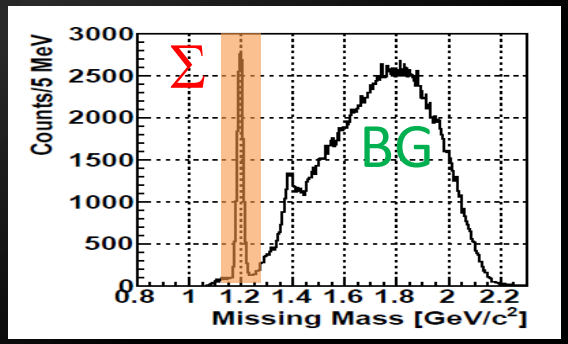
Simulation w/ 4×10^{11} pions (3 days)



- $X \rightarrow K^- p$ decay
  - K^- tagged, Missing "p" gated



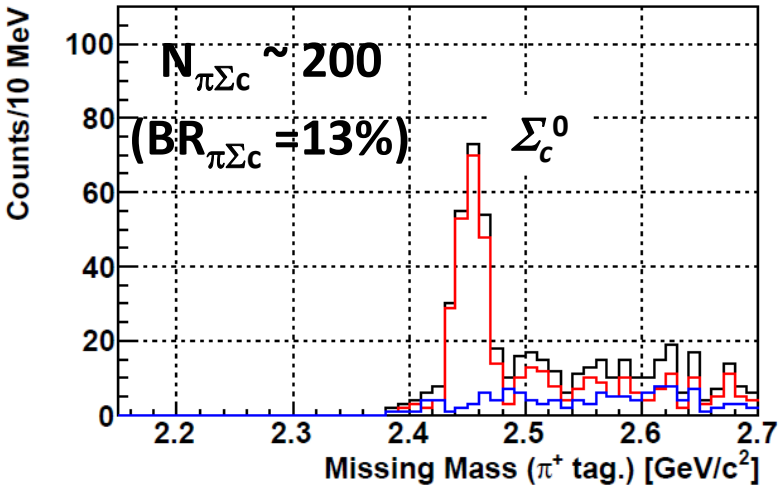
- $X \rightarrow \pi^+\Sigma^-$ decay
  - π^+ tagged, Missing "Σ" gated



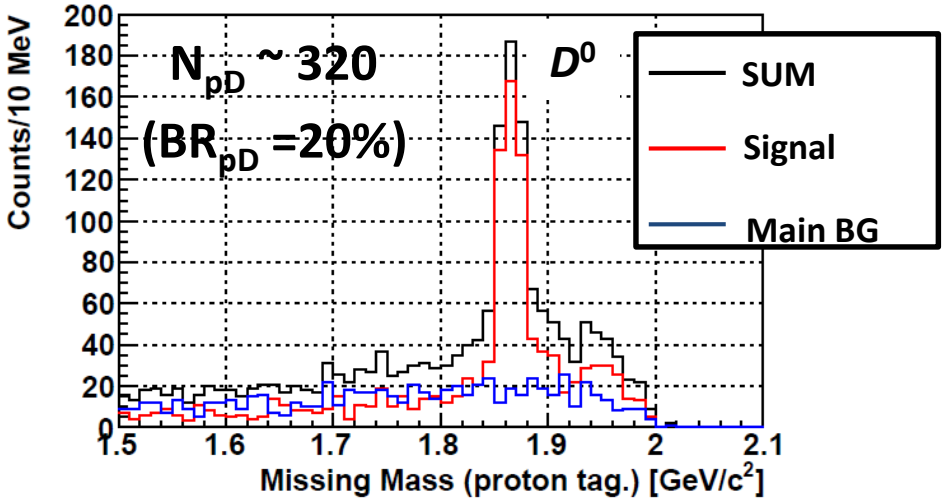
Decay Products

$\Lambda_c(2940) \rightarrow \Sigma_c^0 \pi^+$

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



$\Lambda_c(2940) \rightarrow p\ D^0$

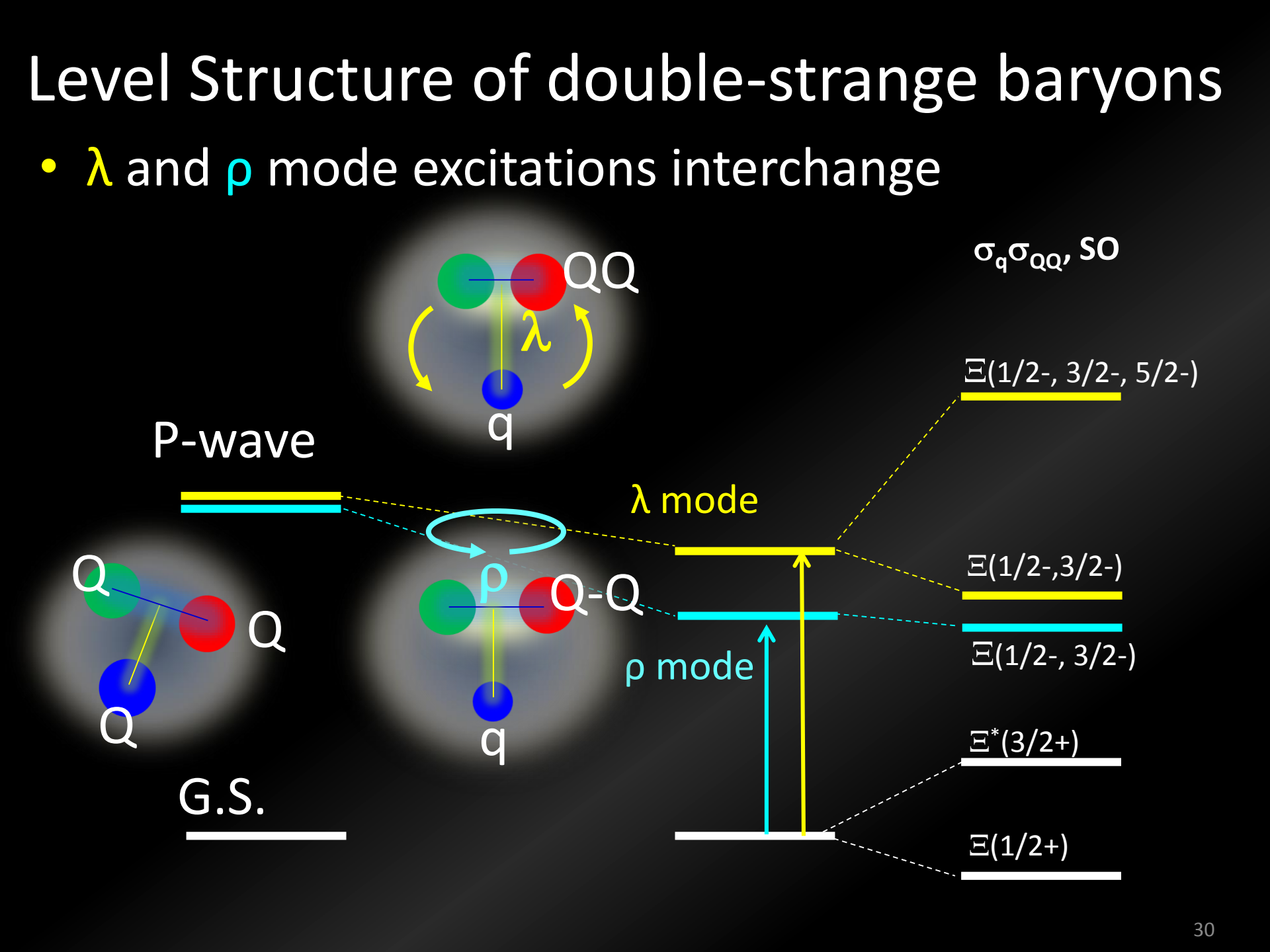


* Decay products can be seen clearly owing to the large acceptance.
* Decay meas. strongly assists the missing mass spectroscopy.
  - Branching ratios: Diquark corr. affects $\Gamma(\Lambda_c^* \rightarrow pD)/\Gamma(\Lambda_c^* \rightarrow \Sigma_c \pi)$.
  - Angular distribution: Spin, Parity

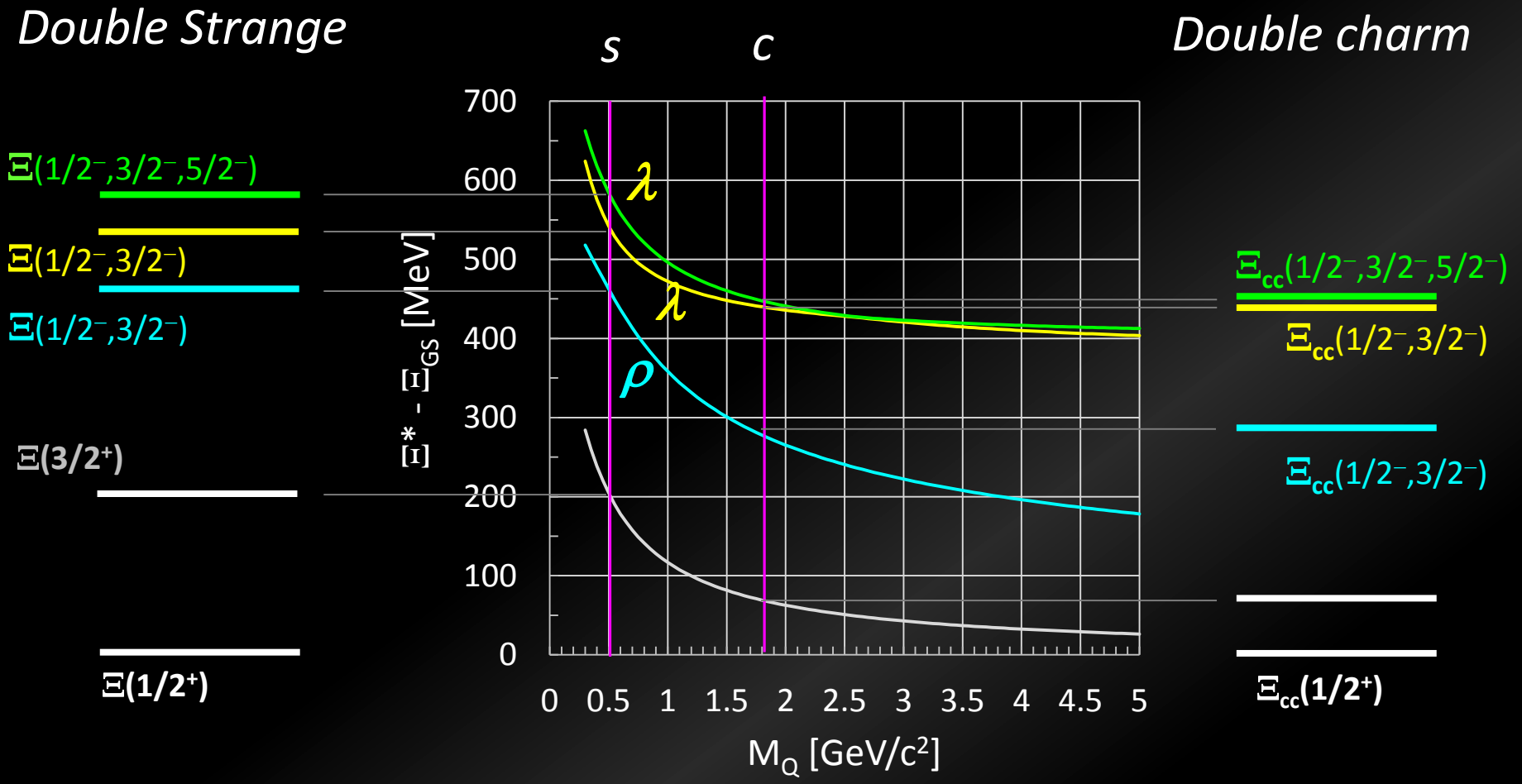
QQq system

Level Structure of double-strange baryons

- λ and ρ mode excitations interchange

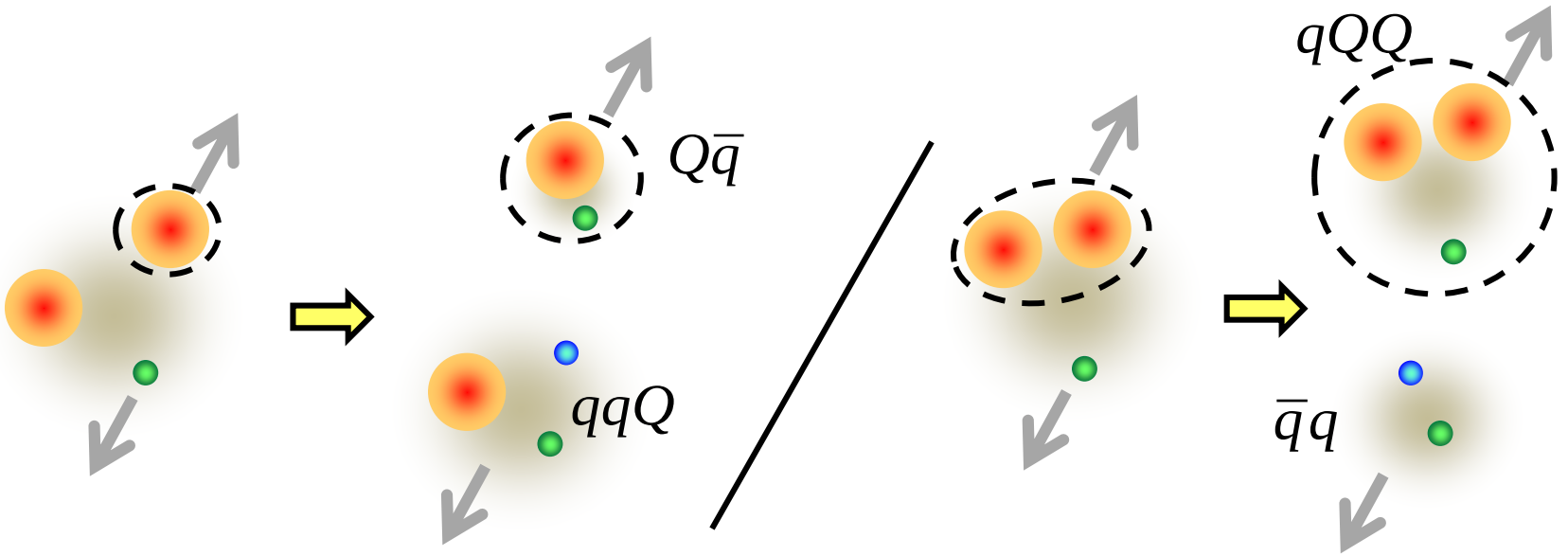


qQQ Baryon spectroscopy



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

Structure and Decay Partial Width



ρ mode (QQ)

λ mode [QQ] ?

Measured Ξ (PDG)

Threshold

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

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

$\Sigma^{*}\overline{K}(1878)$ $\Lambda\overline{K}^{*}(1908)$

$\Xi^{*}\pi(1665)$ $\Sigma\overline{K}(1685)$

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

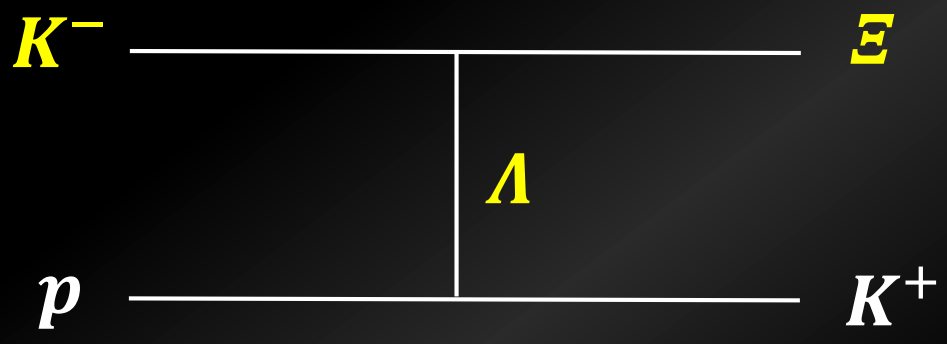
$\Xi\pi(1450)$

	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			

- ✓ *Spin/Parity is not determined yet.*
- ✓ *Why all the Ξ* states favor the ρ–mode like decays?*

$\Xi(1620)$ is $\Lambda(1405)$ analog?

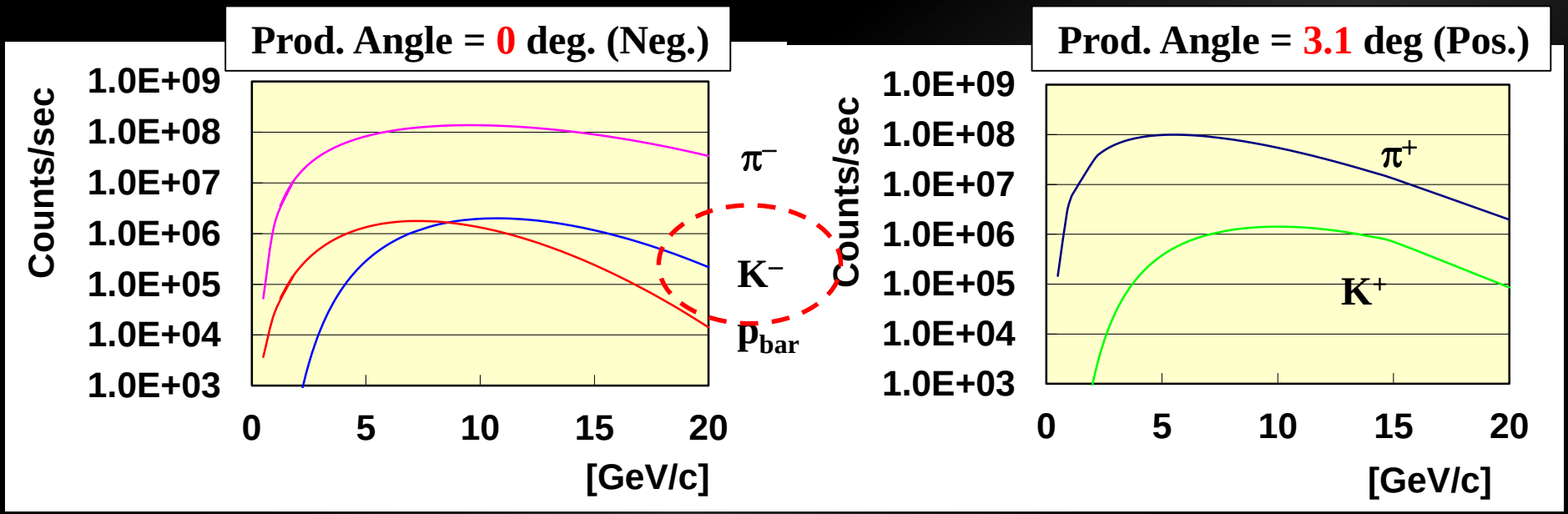
- u-channel prod. May be interesting to see $\Lambda\bar{K}$ coupled to Ξ
  - Large Acceptance Spectrometer



High-res., High-momentum Beam Line

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

Open a new platform for hadron physics



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

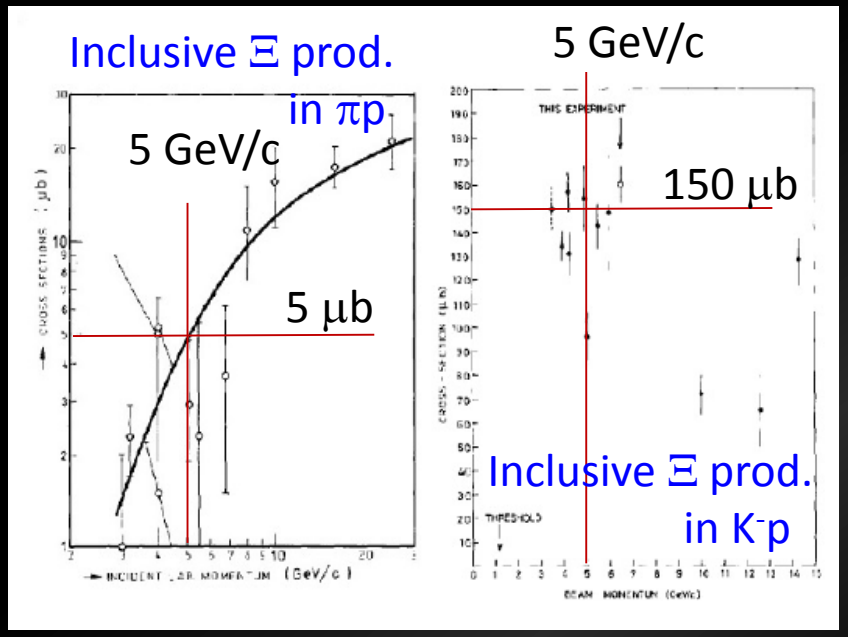
Ξ Baryon Spectroscopy w/ the High-p Secondary Beam

LoI submitted by M. Naruki and K. Shirotori

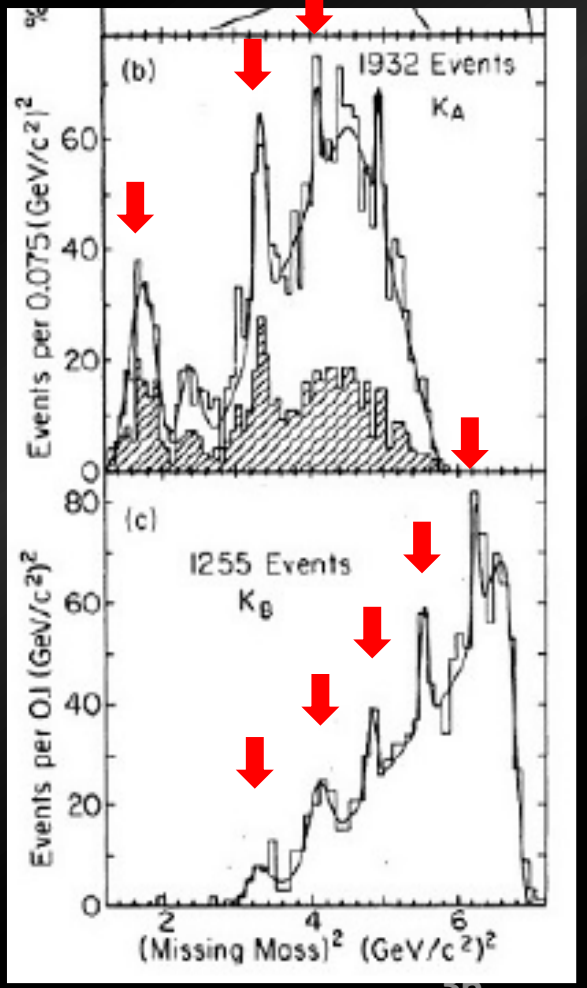
- Sizable yields are expected for a month.

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



Summary

- We can learn a lot from heavy baryons…
  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
     - Lighter system may be rather complicated…
       - Meson-baryon coupling may modify mass spectrum/width
         c.f. $\Lambda(1405)$
     - Charmed baryons are expected to be understood easier…
       - λ/ρ mode separation w/o mixing each other
       - Narrow width
  3. Hadron spectroscopy at the J-PARC High-p BL
     - will provide a new platform to study excited baryons w/ heavy quarks

backup

We welcome your join!

E50 collaboration:

Jung-Kun Ahn[1], Shuhei Ajimura[2], Kazuya Aoki[3], Johann Goetz[4], Ryotaro Honda[5], Takatsugu Ishikawa[6], Yue Ma[7], Koji Miwa[8], Yoshiyuki Miyachi[9], Yuhei Morino[3], Takashi Nakano[2], Megumi Naruki[10], Hiroyuki Noumi[2], Kyoichiro Ozawa[3], Fuminori Sakuma[7], Takahiro Sawada[11], Kotaro Shirotori[2], Yorihito Sugaya[2], Tomonori Takahashi[2], Kiyoshi Tanida[12], Wen-Chen Chang[11], and Takumi Yamaga[2]

[1] Physics Department, Korea University, Seoul 136-713, Korea

[2] Research Center for Nuclear Physics (RCNP), Osaka University, Osaka 567-0047, Japan

[3] Institute of Particle and Nuclear Studies (IPNS), High Energy Accelerator Research Organization (KEK), Ibaraki 305-0801, Japan

[4] Institute of Nuclear and Particle Physics, Ohio University, OH 45701, USA

[5] Department of Physics, Osaka University, Osaka 560-0043, Japan

[6] Research Center for Electron Photon Science (ELPH), Tohoku University, Miyagi 982-0826, Japan

[7] RIKEN Nishina Center, RIKEN, Saitama 351-0198, Japan

[8] Physics Department, Tohoku University, Miyagi 980-8578, Japan

[9] Physics Department, Yamagata University, Yamagata 990-8560, Japan

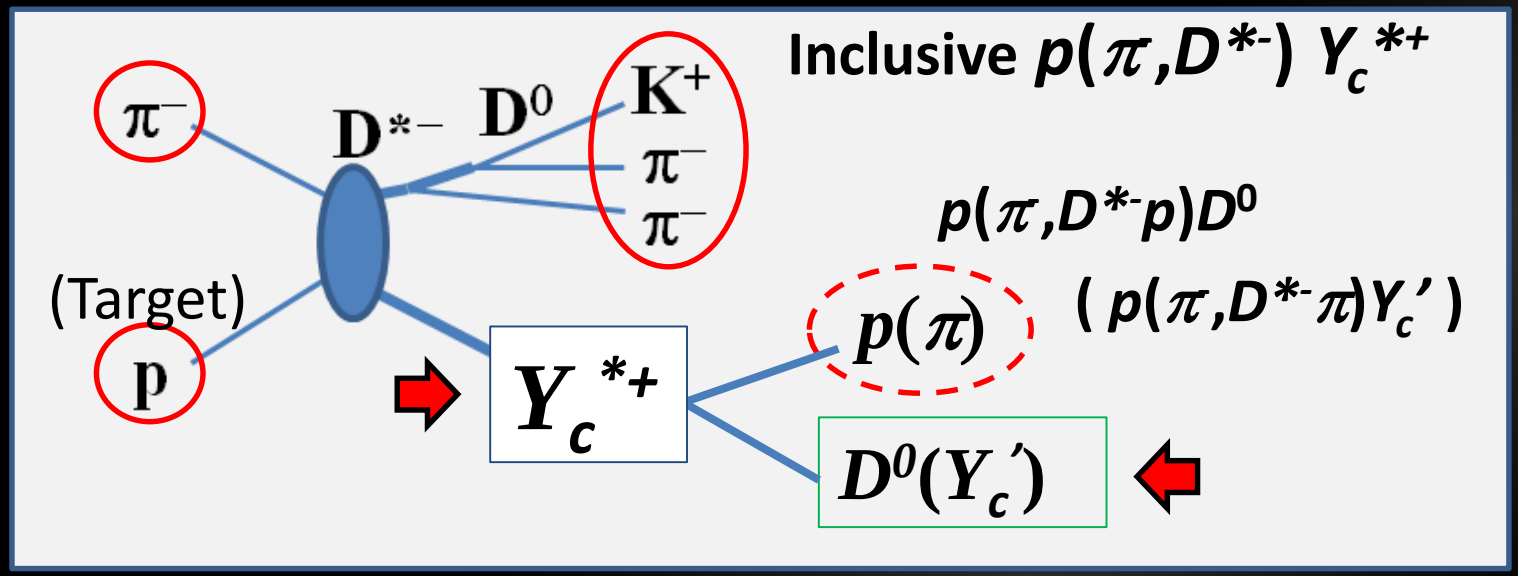
[10] Department of Physics, Kyoto University, Kyoto 606-8502, Japan

[11] Institute of Physics, Academia Sinica, Taipei 11529, Taiwan

[12] Department of Physics, Seoul National University, Seoul 151-747, Korea

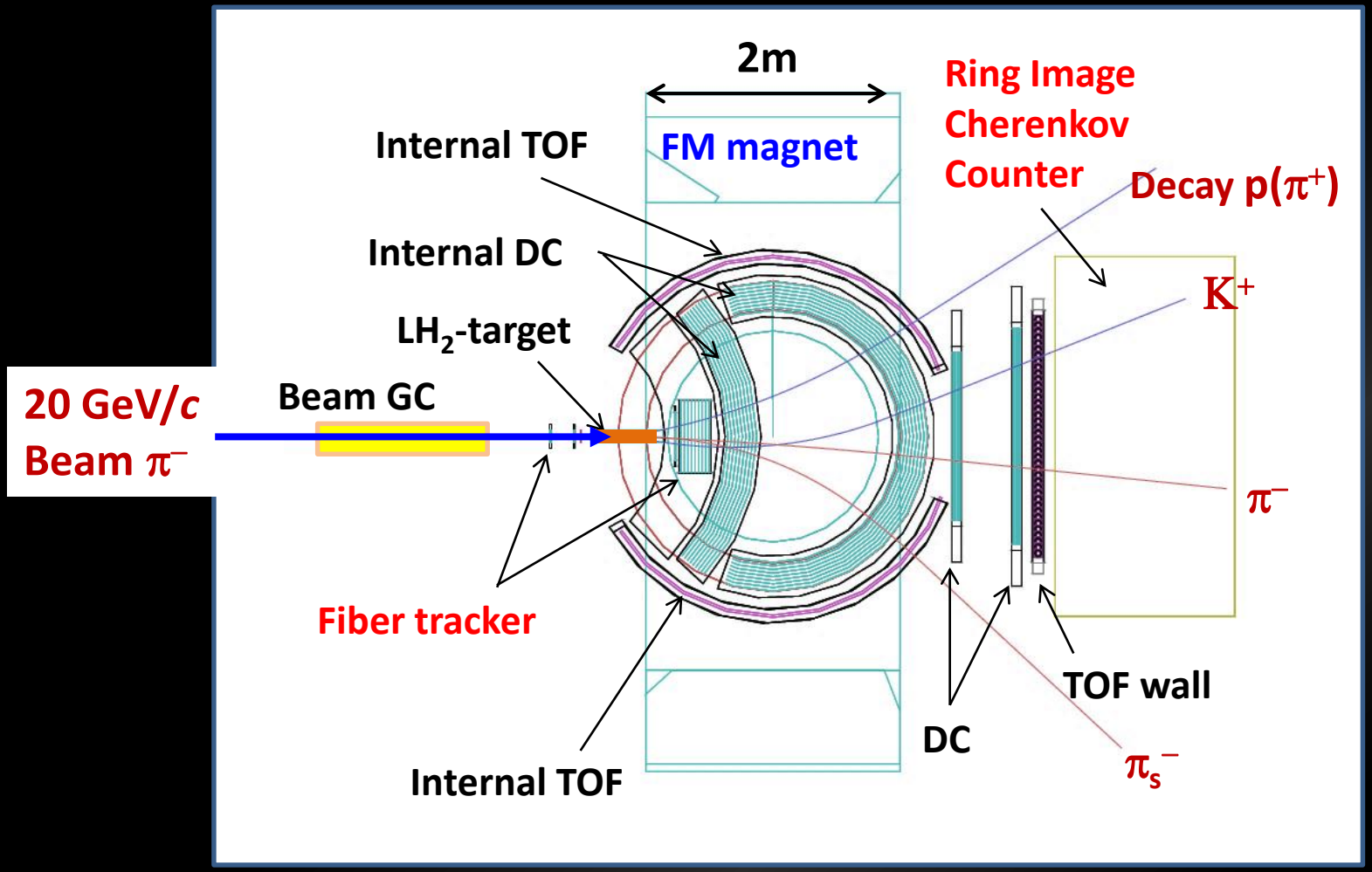
Charmed Baryon Spectroscopy

Using Missing Mass Techniques



Conducted by the E50 experiment at J-PARC

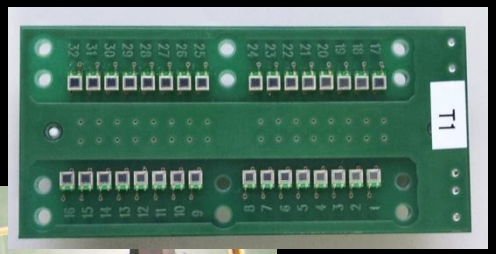
Detector R&D are issues…

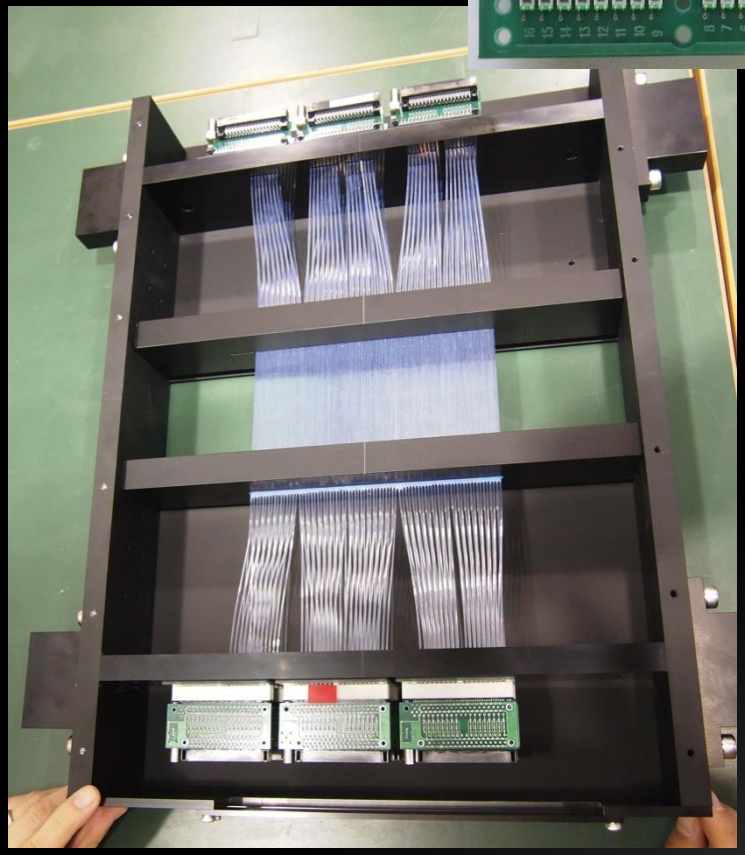


Acceptance: ~ 60% for D^*, ~80% for decay π^+

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

High rate BFT at K1.8



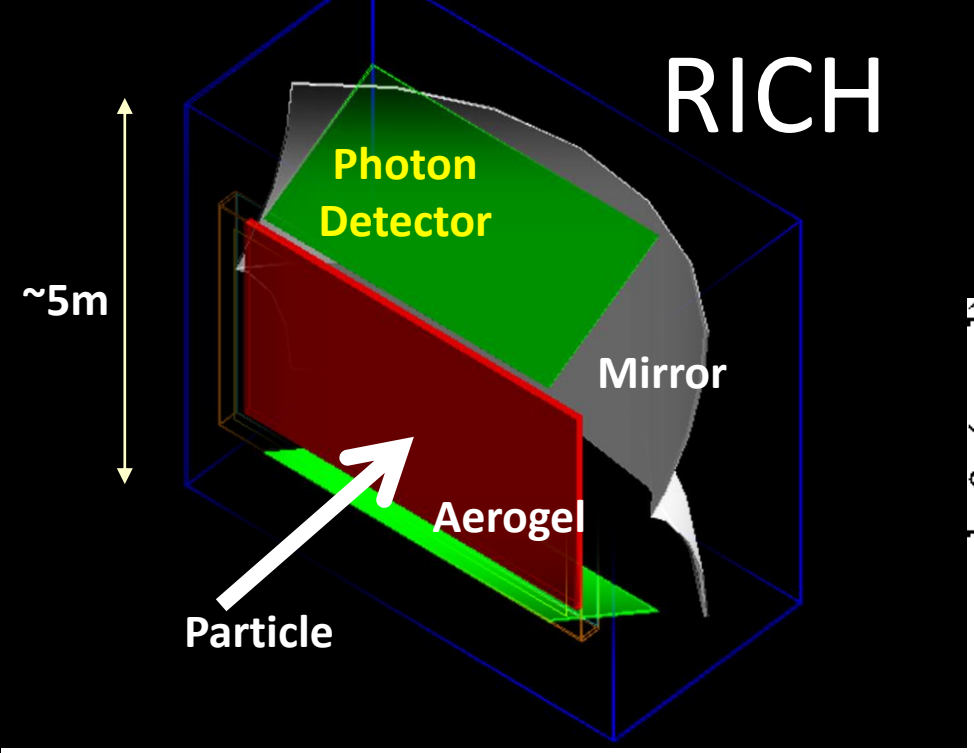


To be Enlarged for E50

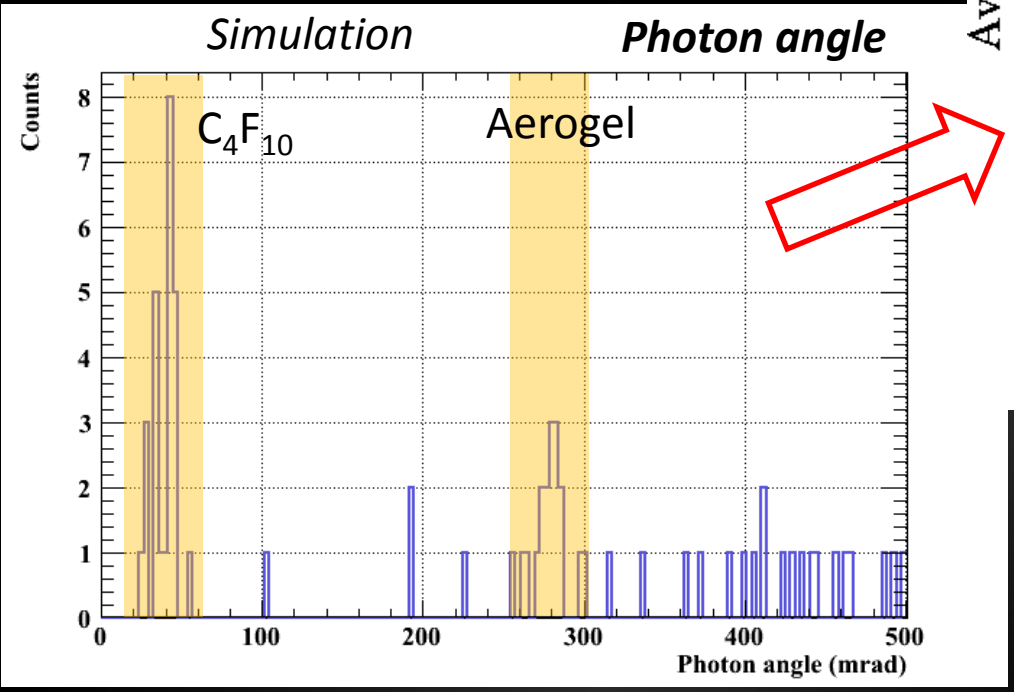
K. Miwa et al., Tohoku U.

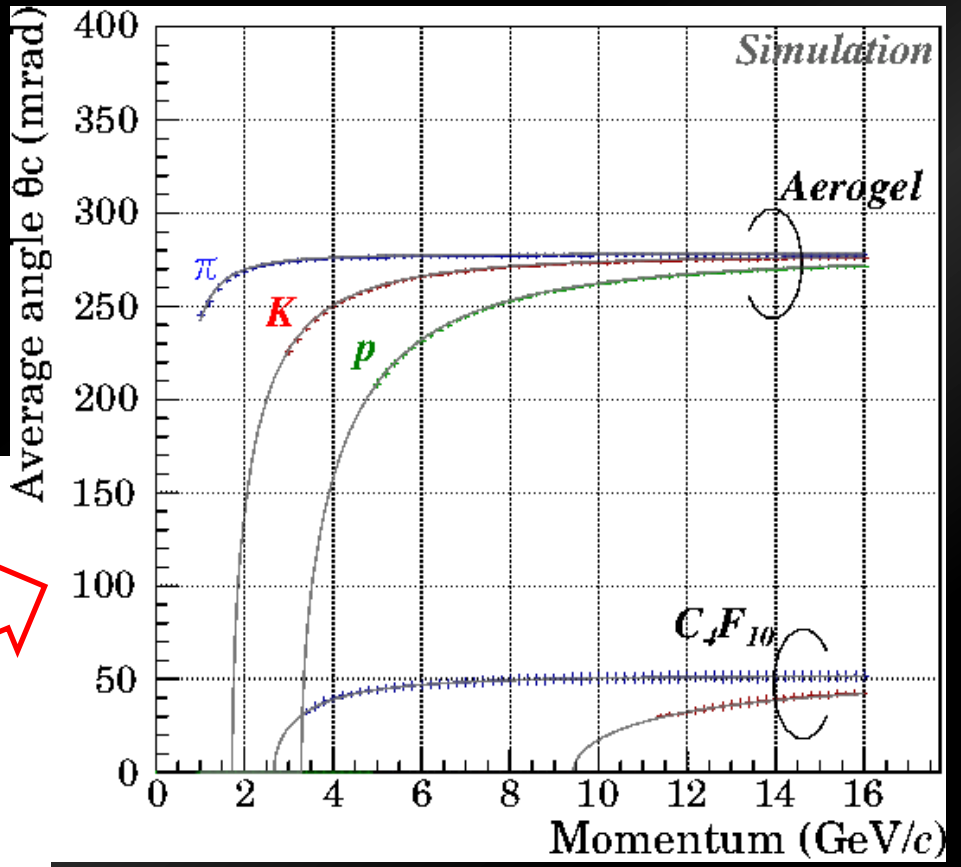
- Beamline Fiber Tracker
  - Can operate stably under a high intensity beam.
  - Structure
    - 320 ch of 1mm ϕ fibers
    - Two staggered layers
    - MPPC readout
      - We designed the high density MPPC PCB.
- We have finished the design. Detector and MPPC PCB are being produced now.
- We will use 10 EASIROC test board to operate 320 MPPCs, because we want to install this detector as soon as possible.

RICH



T. Yamaga
HUA Master Thesis Award 2014



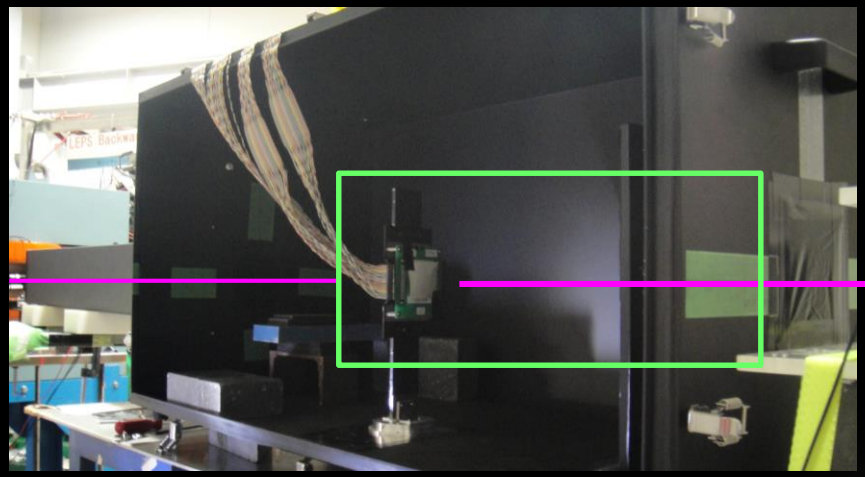


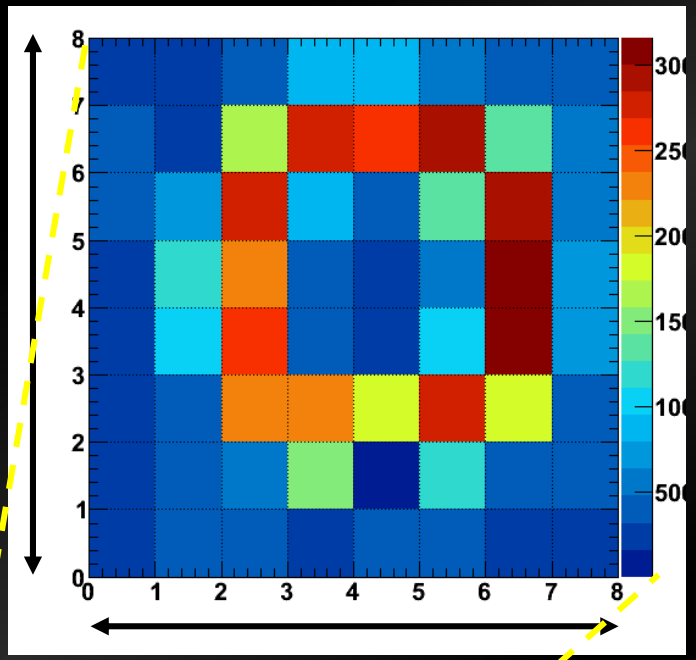
Conceptual Design: Done!
-> Test Experiment

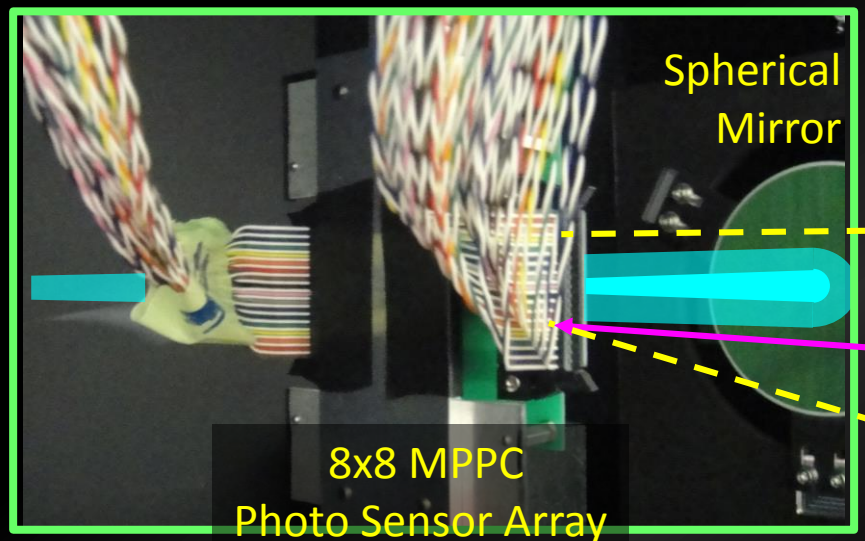
RICH R&D is in progress

Measured RING IMAGE
by 8x8 MPPC Array

Electron
0.75 GeV/c







Story

- L(2880)やL(2940)はλモードかρモードか。
- L=2のΛモード？
- L(2940) のSpinはわかっていない。
- →

  生成率

  崩壊分岐比

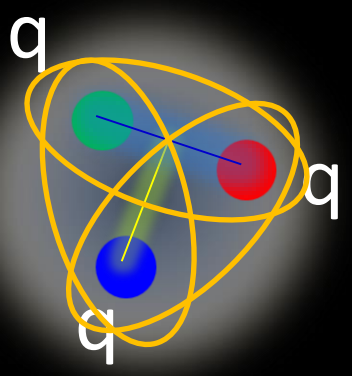
からわかることがある。

How to study CQP

- Mass Spectrum (mass, width, spin/parity)
  - Configuration of CQP
  - Motions of CQP in excited states
    - CQP orbital excitation
    - CQP internal excitation

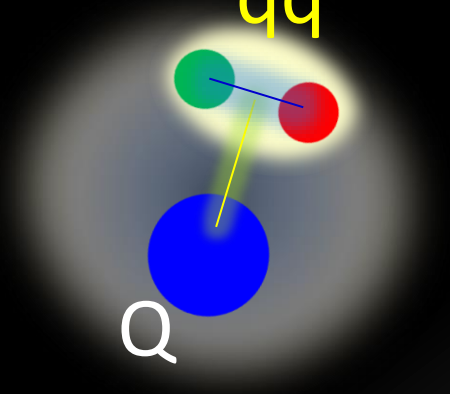
- Production rate
- Decay Branch

”qq” correlation in a heavy baryon



- How hadrons are formed?
- Quark dynamics in hadrons

to understand the low-E QCD



→ The heavy Q helps to isolate “qq” motion in baryons.

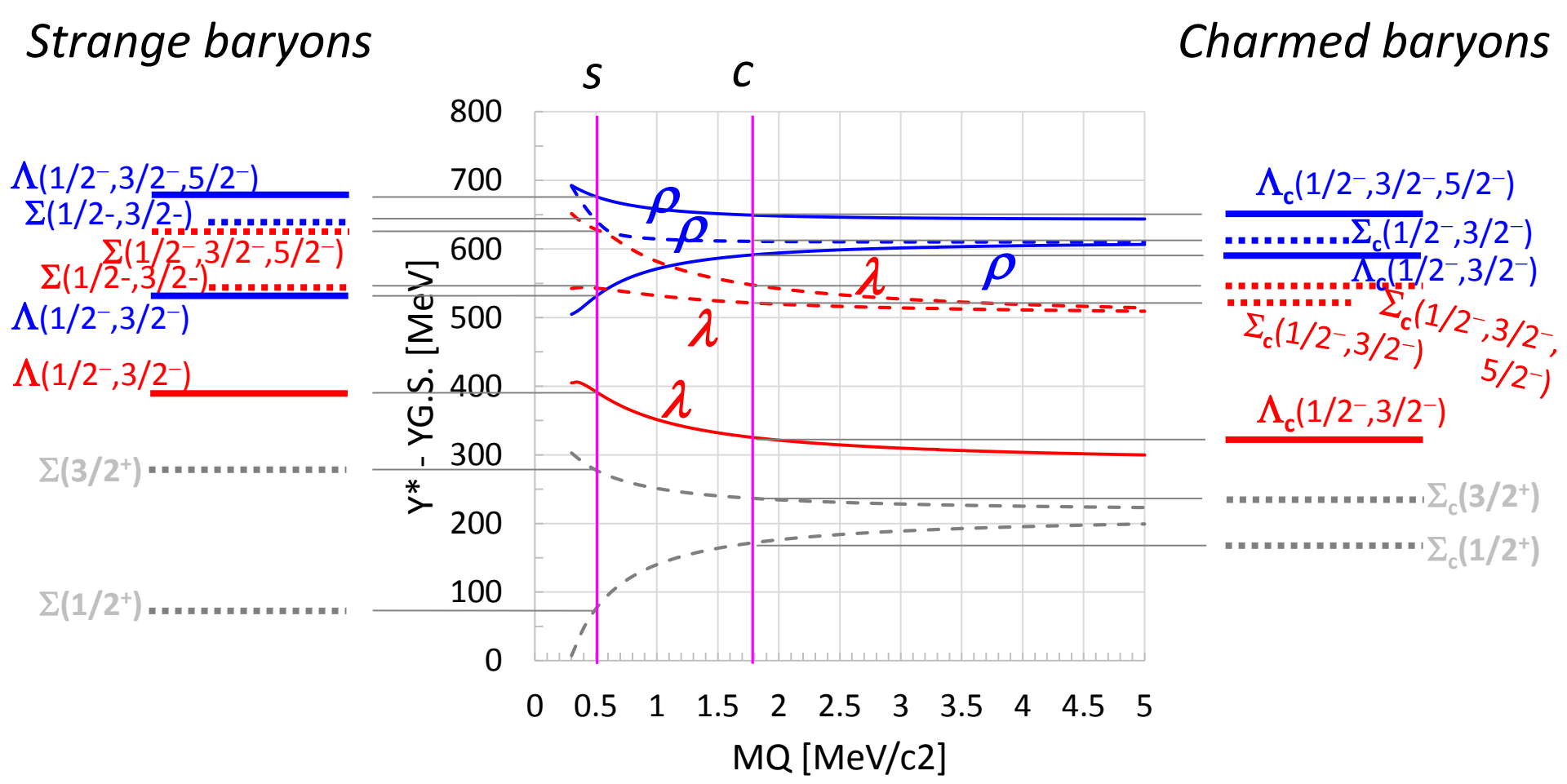
- HQ spin couples weakly to the rest.

→ HQ spin doublets ($\vec{S}_{HQ} \pm \vec{J}_{rest}$)

Level Structure, Production, and Decay

Threshold			JP	rating	Width [MeV]	→NK [%]	→Λπ [%]	→Σπ [%]	
		Σ(1940)	3/2-	4*	220	<20	seen	Seen	
		Σ(1915)	5/2+	3*	120	5-15	seen	Seen	
	Λ(1890)		3/2+	4*	95	20~35		3~10	
		Σ(1880)	1/2+	2*	220?				
		Σ(1840)	3/2+	1*	120?				
K*N(1830)	**Λ(1830)**		5/2-	4*	95	3~10		35~75	
	Λ(1820)		5/2+	4*	80	55~65		8~14	
	Λ(1810)		1/2+	3*	150	20~50		10~40	
	Λ(1800)		1/2-	3*	300	25~40		Seen	
		Σ(1775)	5/2-	4*	120	37~43	14-20	2-5	
Ση(1740)		**Σ(1750)**	1/2-	3*	90	10~40	seen	<8	(Ση)15~55
		Σ(1690)	??	2*					
	Λ(1690)		3/2-	4*	60	20~30		20~40	
Λη(1670)		**Σ(1670)**	3/2-	4*	60	7~13	5~15	30-60	
	Λ(1670)		1/2-	4*	35	20~30		25~55	
KN(1432) Σπ(1330)		Σ(1620)	1/2-	1*					
		Σ(1580)	3/2-	1*					
Σ*π(1520)	Λ(1520)			4*	19	45+-1		42+-1	

Recent QM calculation

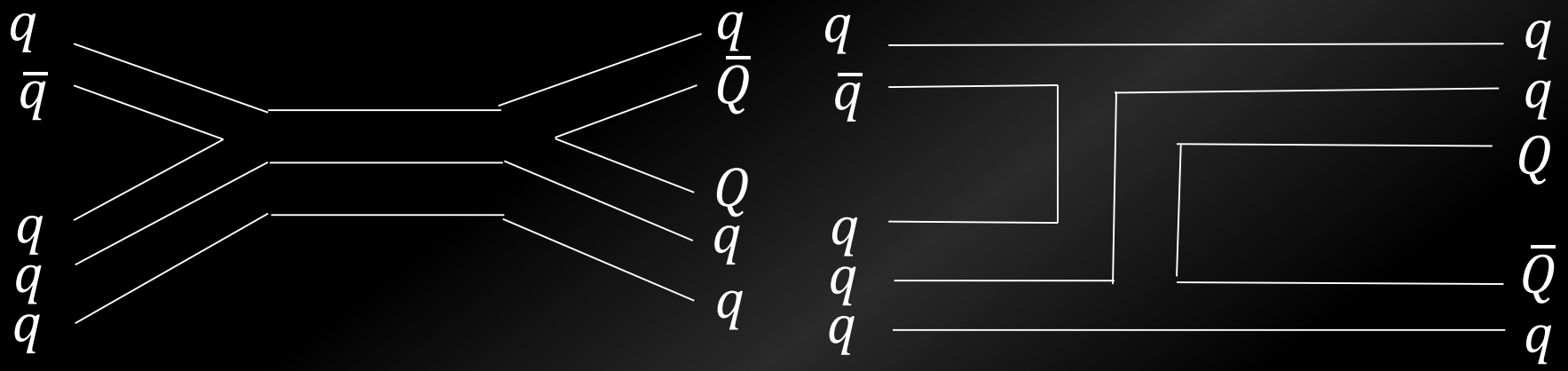


non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

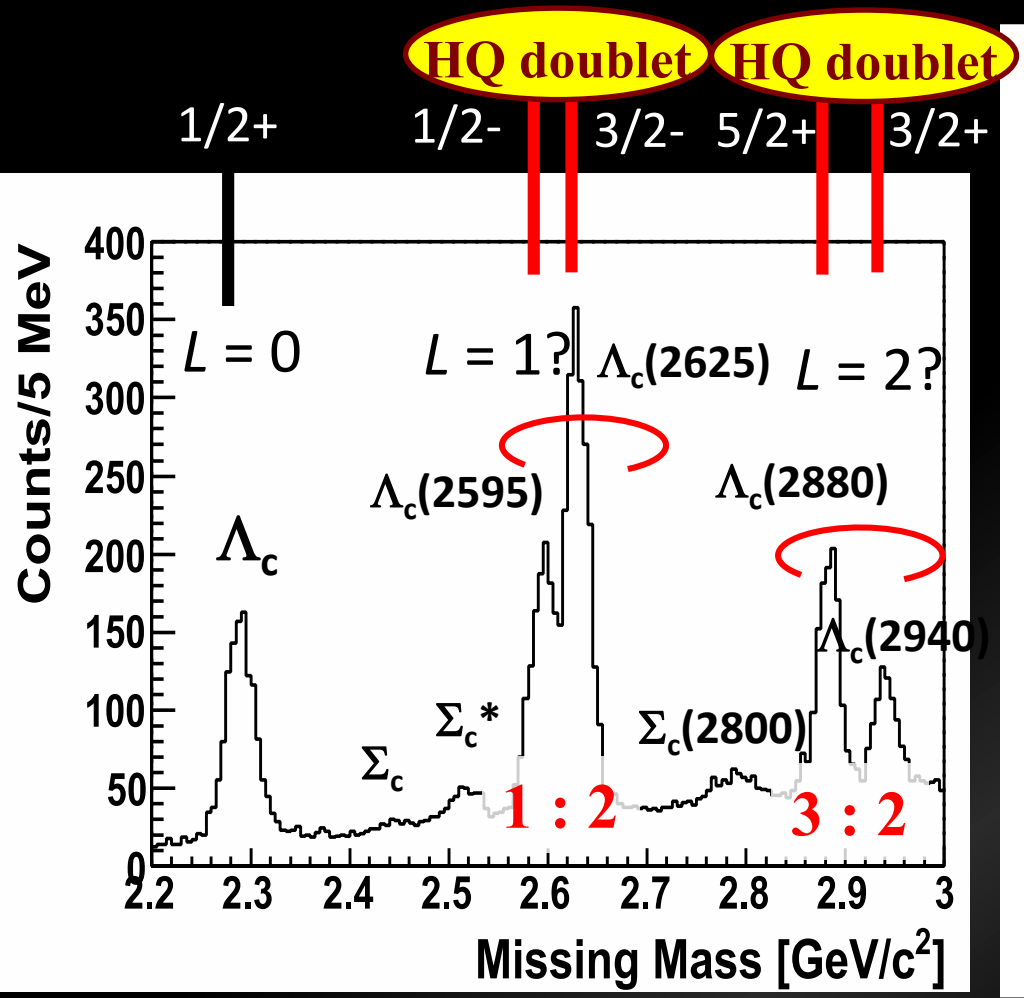
ρ–λ mixing (cal. By T. Yoshida)

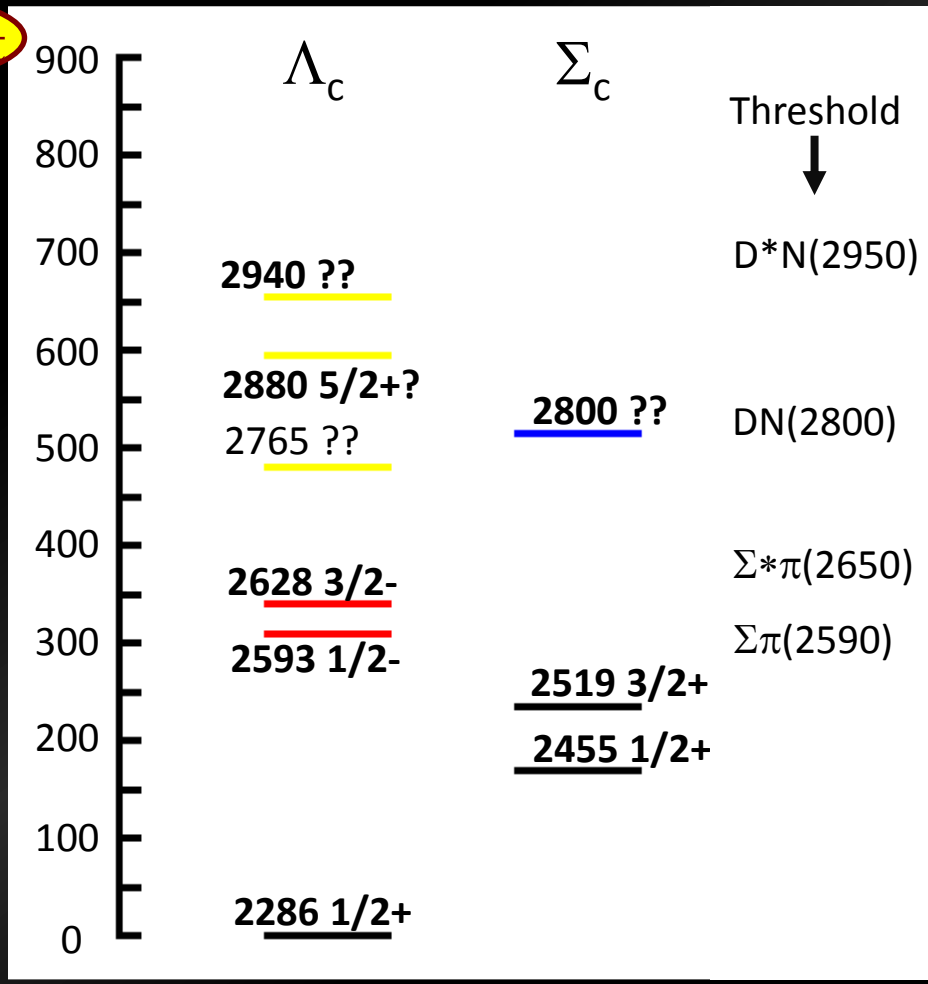
Production

- λ -mode excitation favor in t-channel Meson Exchange.
- *How about s*, *u*-ch., or Baryon (Reggeon) exchange?
  - ρ -mode excitation?



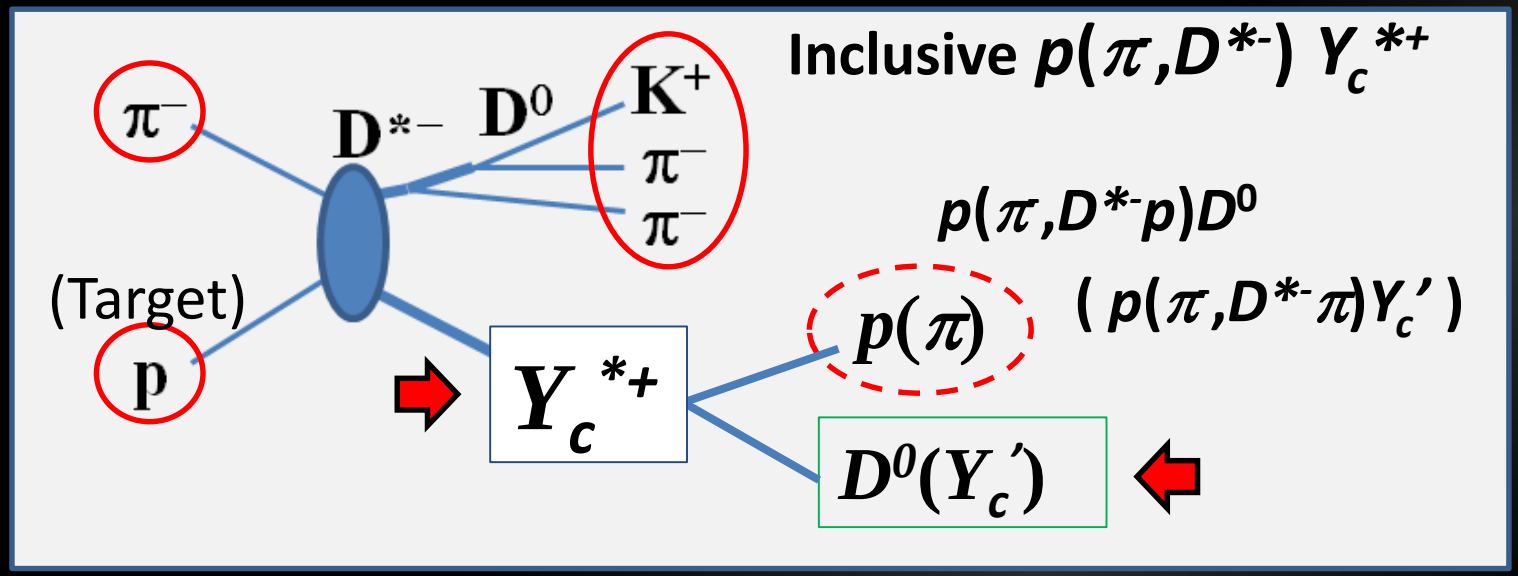
Level structure





Charmed Baryon Spectroscopy

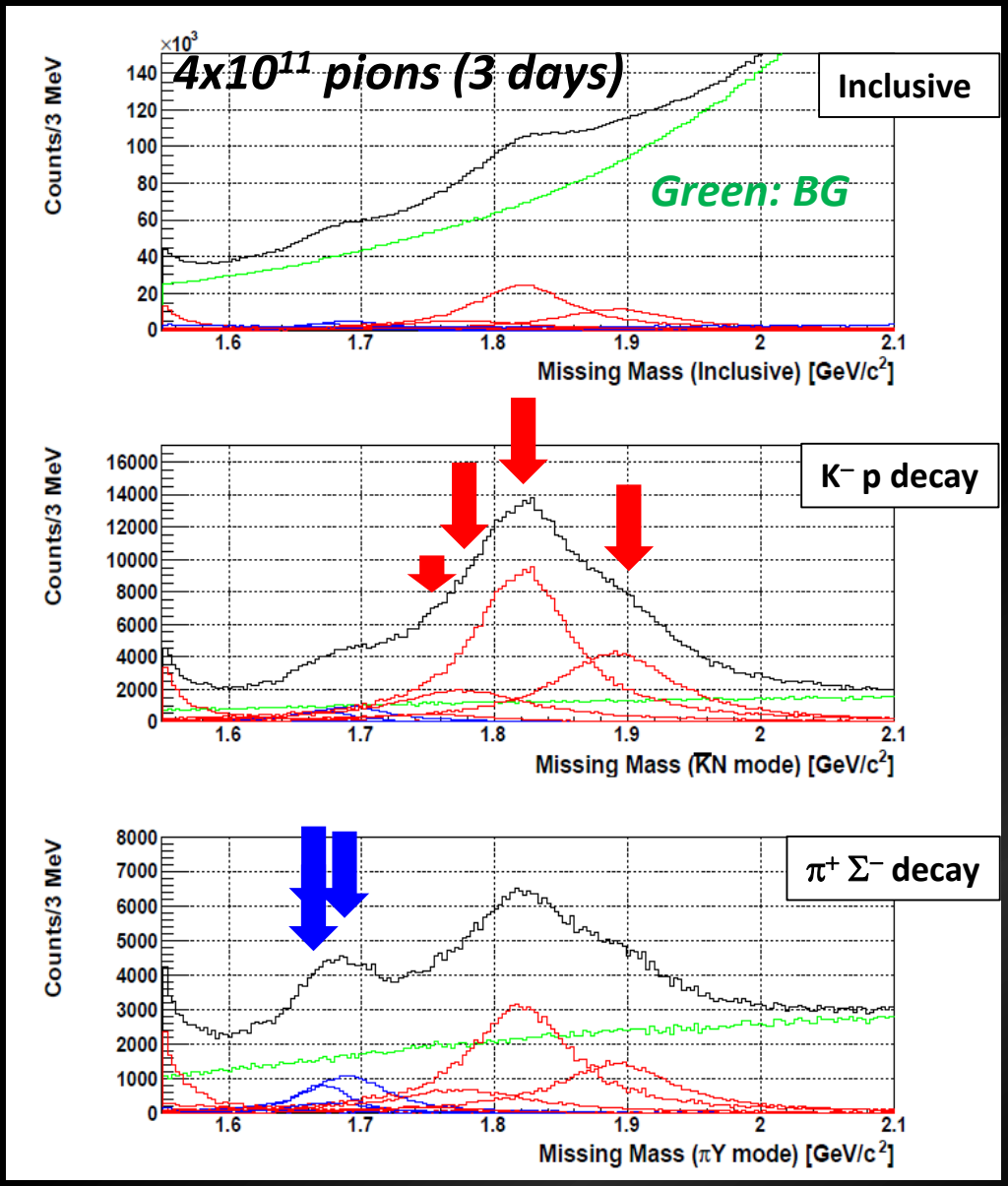
Using Missing Mass Techniques



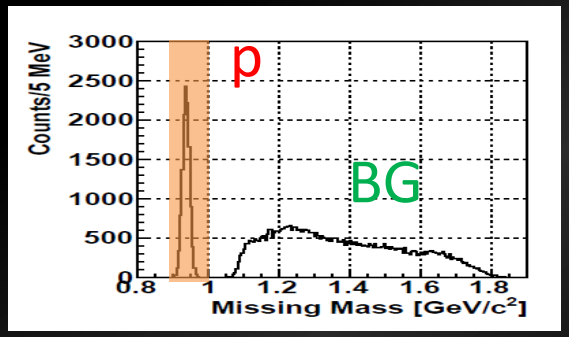
- S=-1 Hyperon *by* $p(\pi^-,K^*)$, $Y^*\rightarrow pK$, πY
- S=-2 Hyperon *by* $p(K^-,K^*)$, (K^-,K), (π,KK^*), $\Xi^*\rightarrow YK$, $\pi\Xi$

x1000~10000 better statistics than Y_c^*

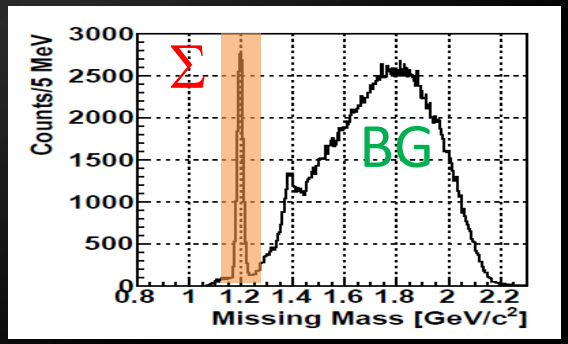
Hyperon production via $p(\pi^-,K^{*0})X$



- K^- p decay
  - K^- tagged, Missing "p" gated



- $\pi^+\Sigma^-$ decay
  - π^+ tagged, Missing "Σ" gated

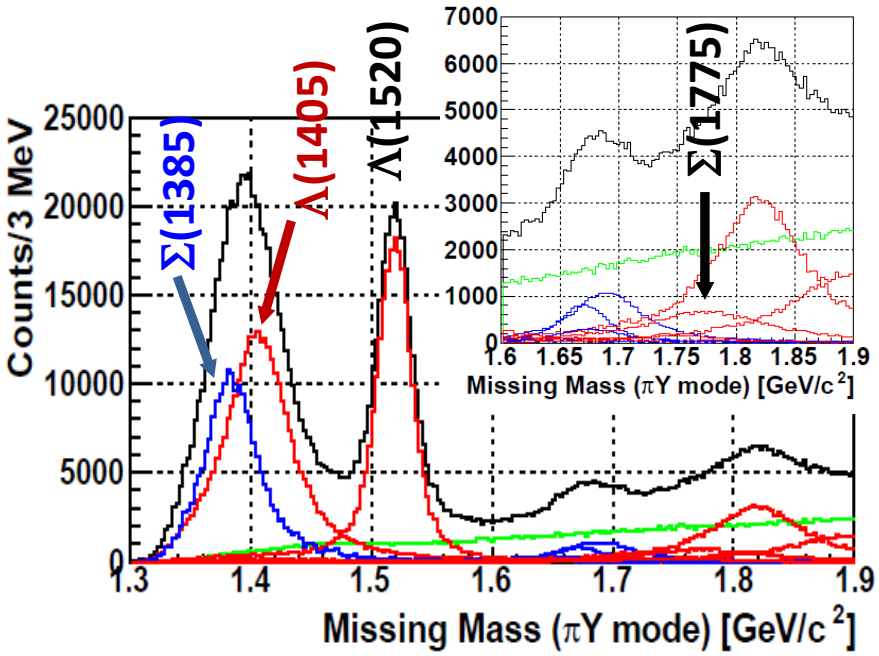


Strange Baryons

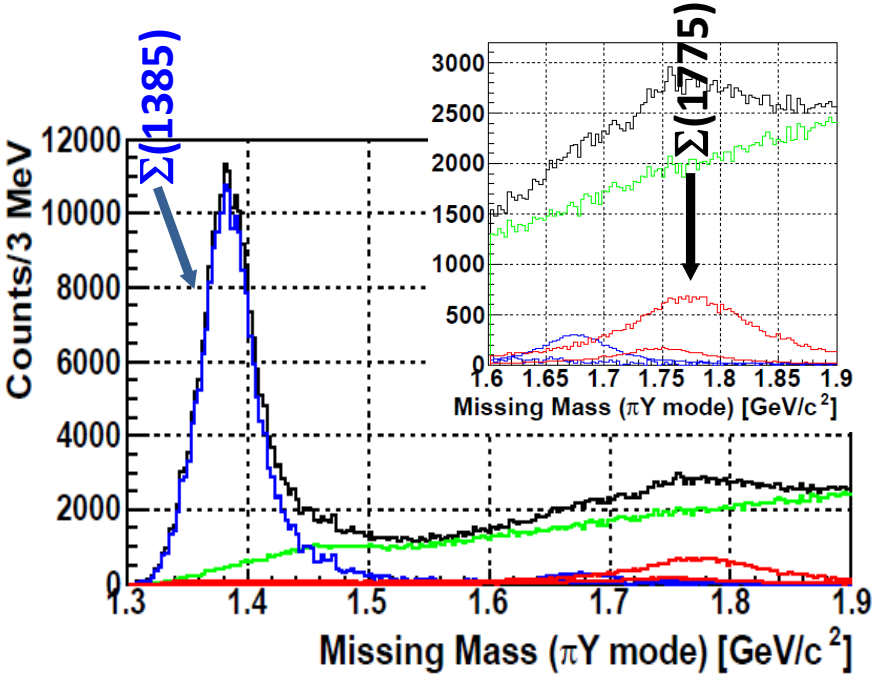
I = 0, 1

I = 1 only

(a)(π^-,K^{*0}) w/ $\pi\Sigma$ decay

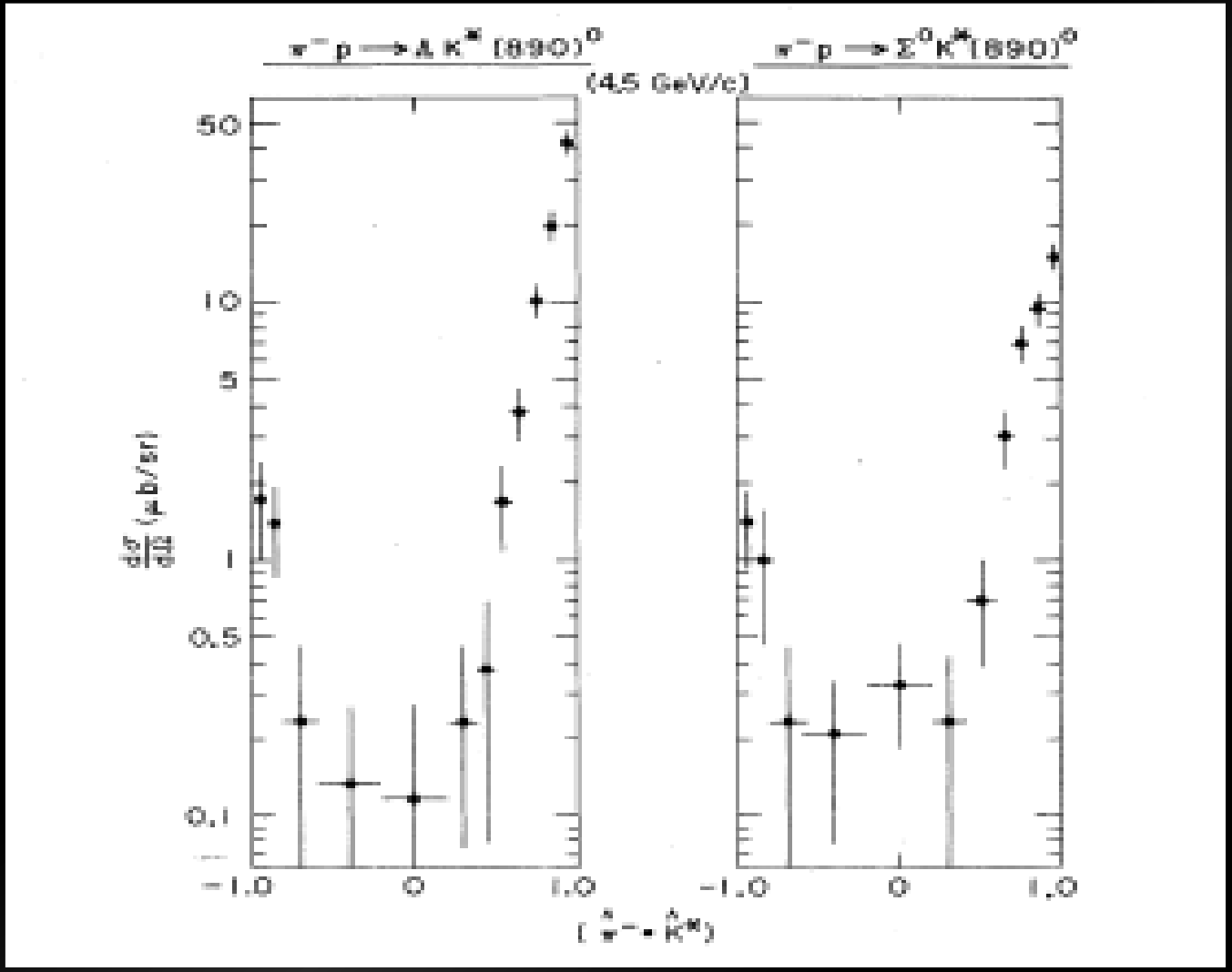


(b)(π^+,K^{*+}) w/ $\pi\Sigma$ decay



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

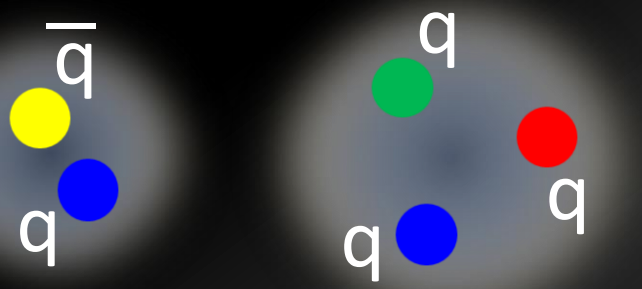
Production (π^-,K^{*0})

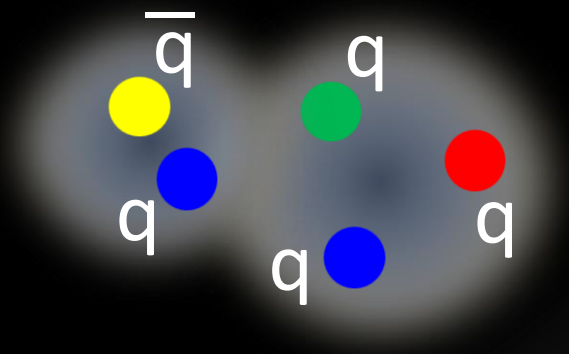


Baryon Spectroscopy w/ Heavy Quark

What are good building blocks of Hadrons?

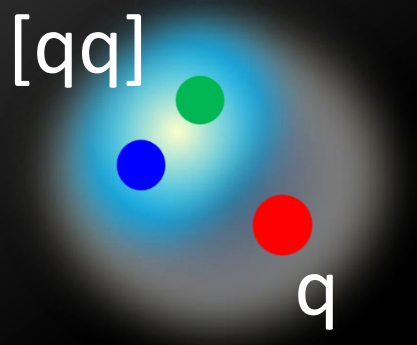
Constituent Quark





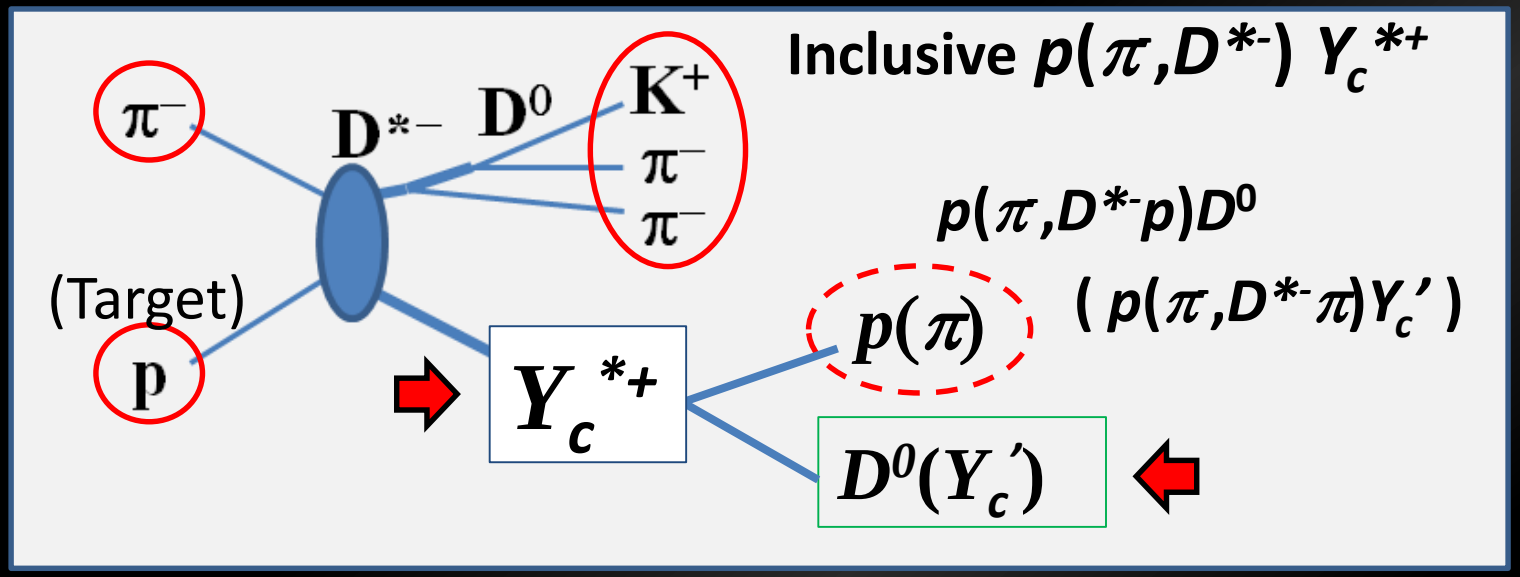
hadron (colorless cluster)

Diquark?
(Colored cluster)



Charmed Baryon Spectroscopy

Using Missing Mass Techniques



What we will measure
(What is the signature of diquark?)

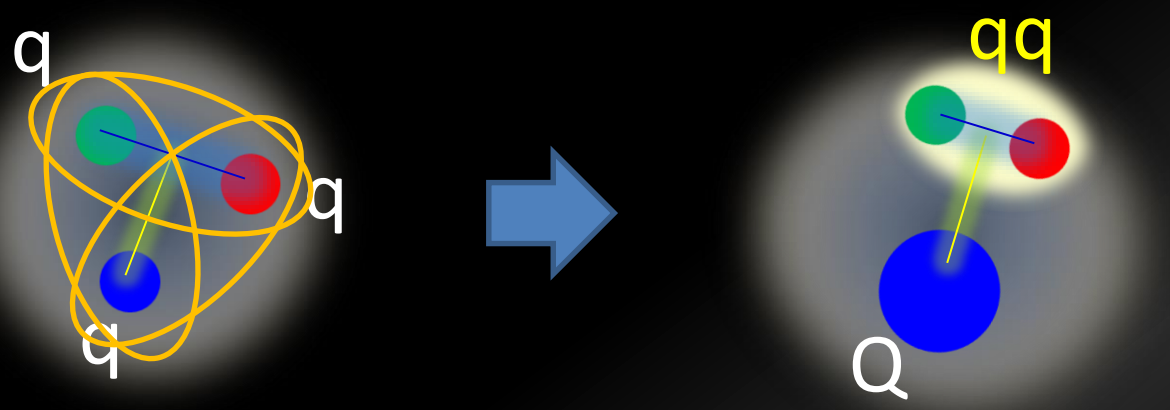
- Spectrum identified by productions:
  - ✓ Basic modes of diquark motions (λ/ρ modes)?
  - ✓ Heavy Quark Spin doublets ($\vec{S}_{HQ} \pm \vec{J}_{rest}$) ?

- Production Rate: reflect quark configuration
  Heavy quark + light diquark

- Decay properties:
  $M(Qq^{bar}) + N(qqq)$ / $m(qq^{bar}) + Y_c(Qqq)$

- any other else?

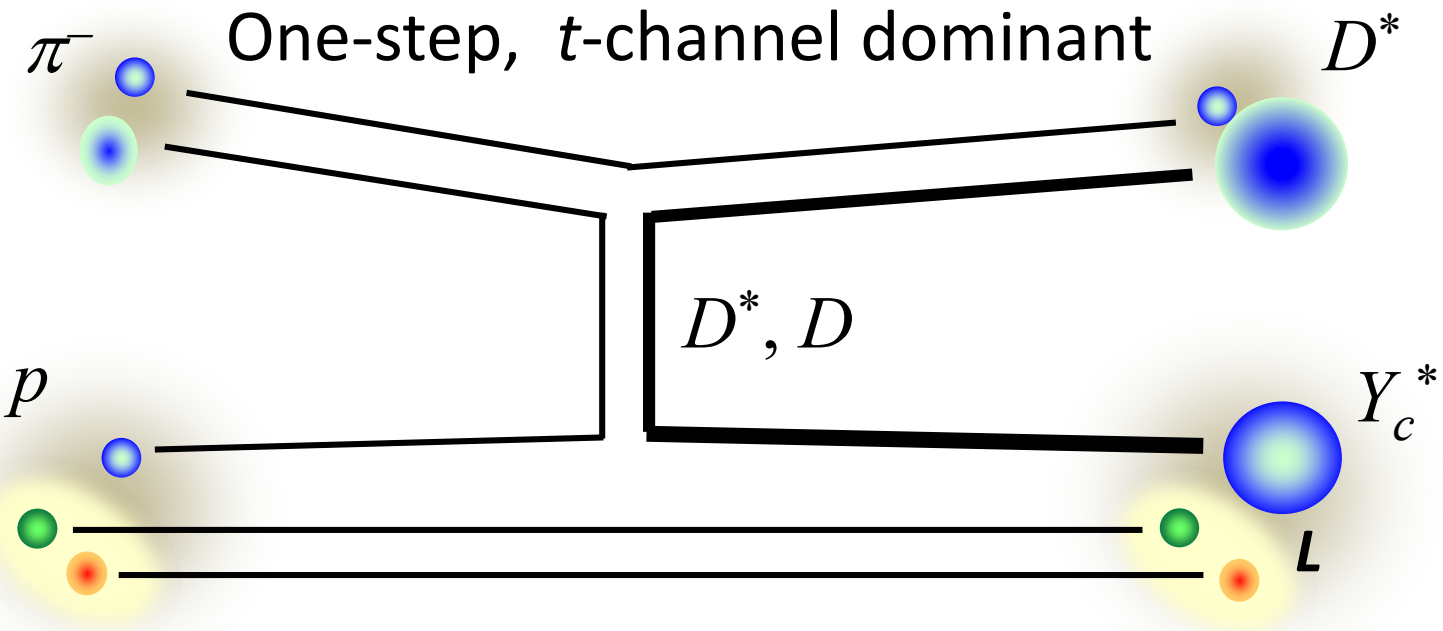
What we can learn from baryons with heavy flavors



- Quark motion of “qq” is singled out by a heavy Q
  - Diquark correlation
- Level structure, Production rate, Decay properties
- Properties are expected to depend on a Q mass.

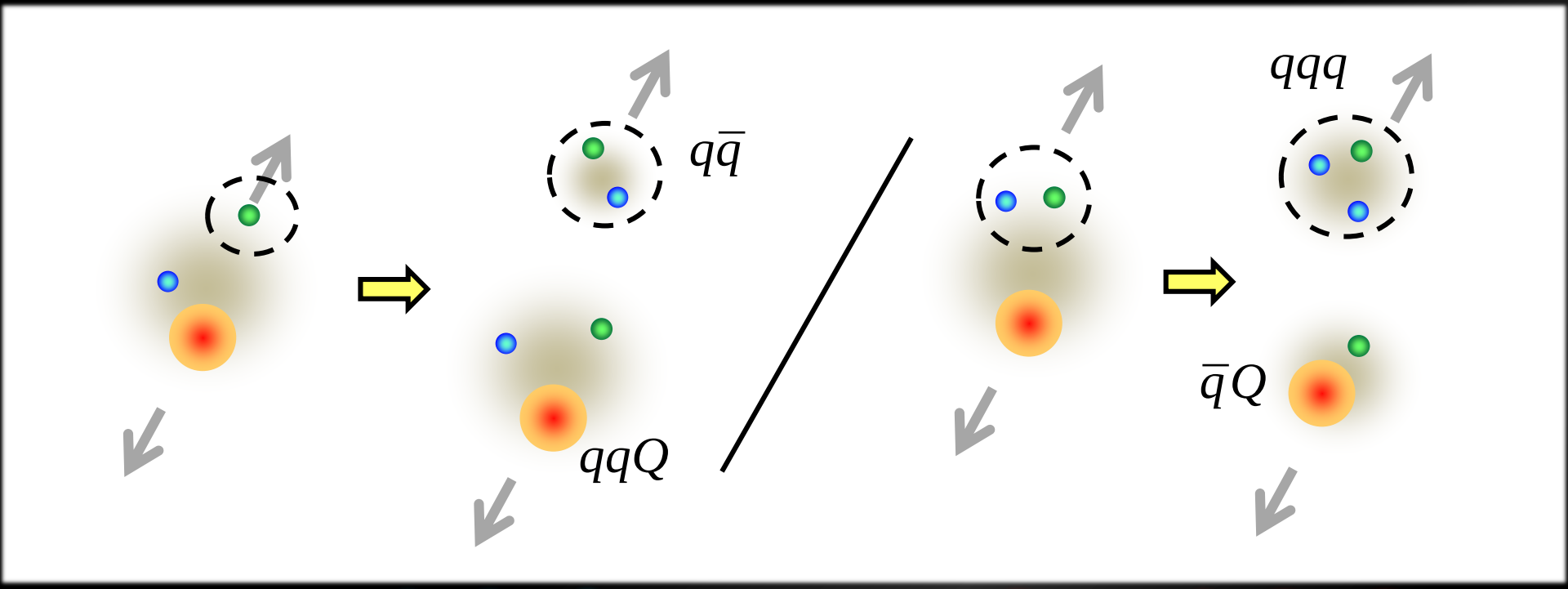
Production

S.H. Kim, A. Hosaka, H.C. Kim, HN, K. Shirotori, arXiv:1405.3445, 14 May, 2014.



- ✓ C.S. DOES NOT go down at higher *L* due to large q_{eff}
- ✓ λ modes are excited by a simple mechanism
  - *HQ spin doublet*
  - *Spin/Parity from Production Ratio*

Decay Properties



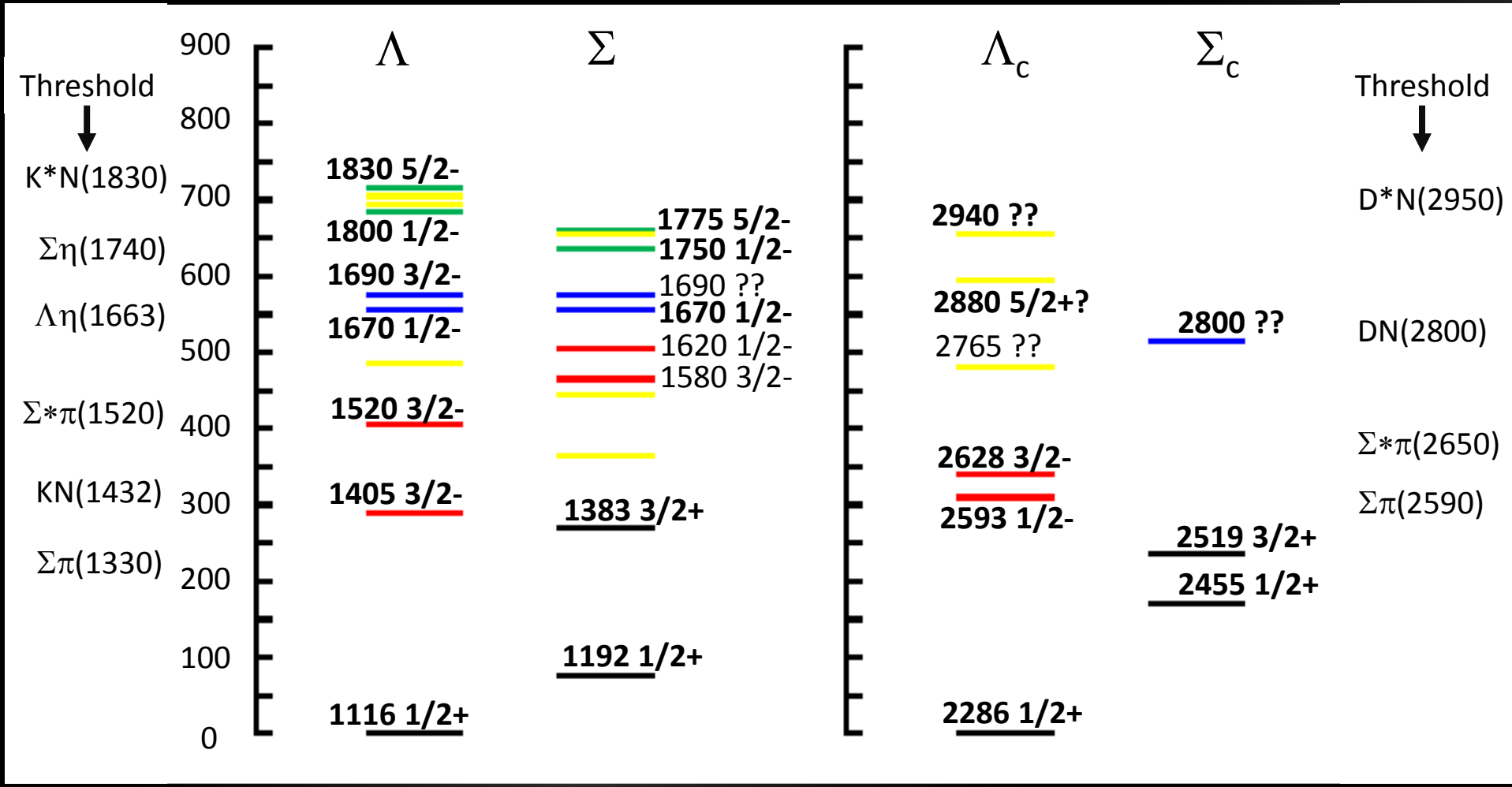
ρ mode (qq)

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

λ mode [qq]

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

Level structure (Exp.)



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

L		state	Rate (Rel.)
0		$\Lambda^{1/2+}(1116)$	1000
		$\Sigma^{1/2+}(1192)$	49
		$\Sigma^{3/2+}(1385)$	244
1	λ	$\Lambda^{1/2-}(1405)$	72
	λ	$\Lambda^{3/2-}(1520)$	127
	ρ	$\Lambda^{1/2-}(1670)$	7
	ρ	$\Sigma^{3/2-}(1690)$	4
	ρ	$\Lambda^{3/2-}(1690)$	13
	λ	$\Sigma^{1/2-}(1750)$	4
	λ	$\Sigma^{5/2-}(1775)$	18
2	λ	$\Lambda^{3/2+}(1890)$	25
	λ	$\Lambda^{5/2+}(1820)$	52

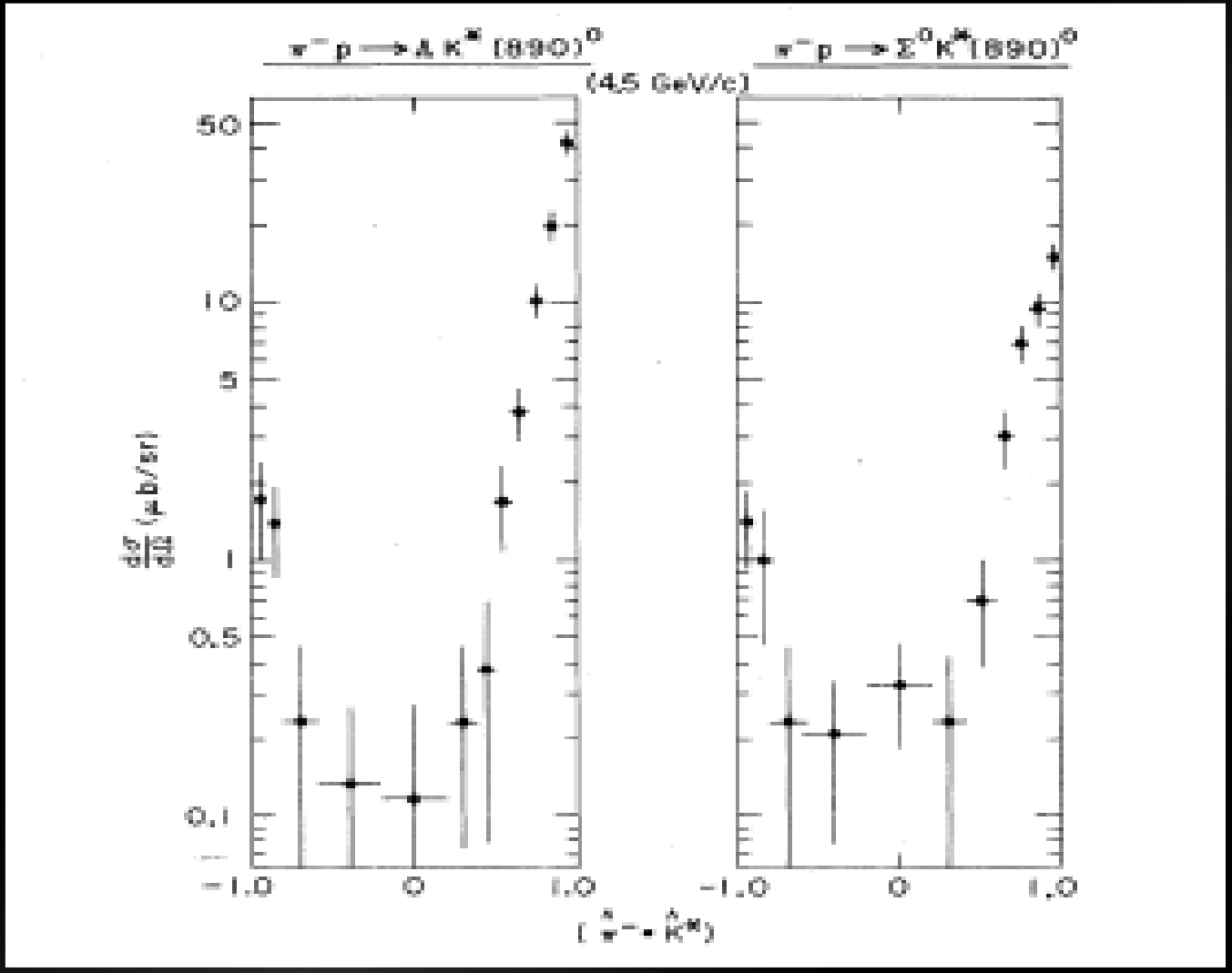
Cal. w/ t-channel K ex. reaction*
at $p_\pi = 5$ GeV/c

- λ mode states
  well populated
- ρ mode states
  excited through λ / ρ mixing (P_{mix})
  P_{mix}(*strange*) is given,
  P_{mix}(*charm*) could be deduced.

✓ $P_{mix}(strange) > P_{mix}(charm)$

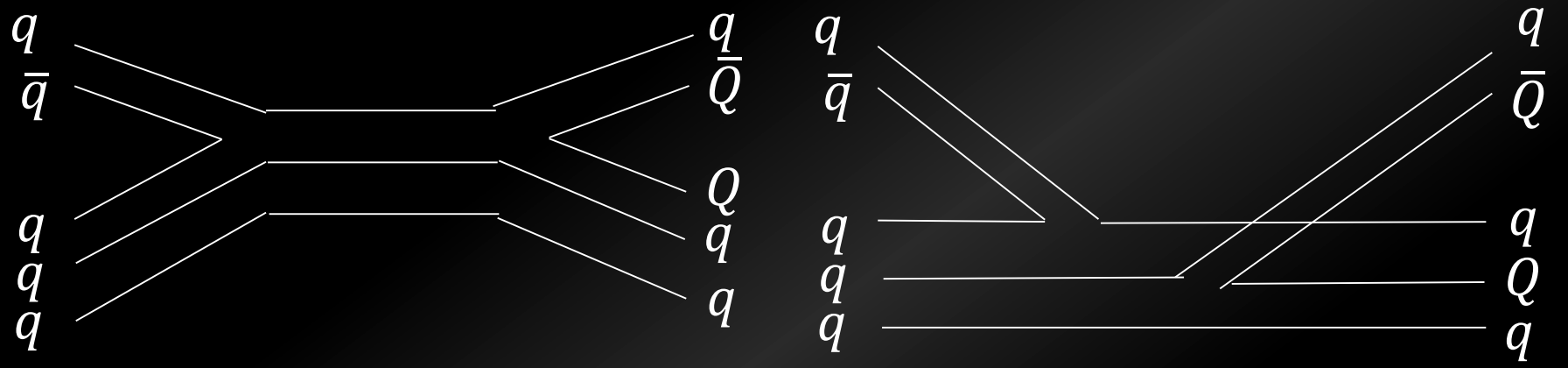
S.H. Kim, A. Hosaka, H.C. Kim, HN, K. Shirotori,
arXiv:submit/0978210, 14 May, 2014.

Production (π^-,K^{*0})



Production

- λ -mode excitation favor in t-channel Meson Exchange.
- *How about s*, *u*-ch., or Baryon (Reggeon) exchange?
  - ρ -mode excitation?

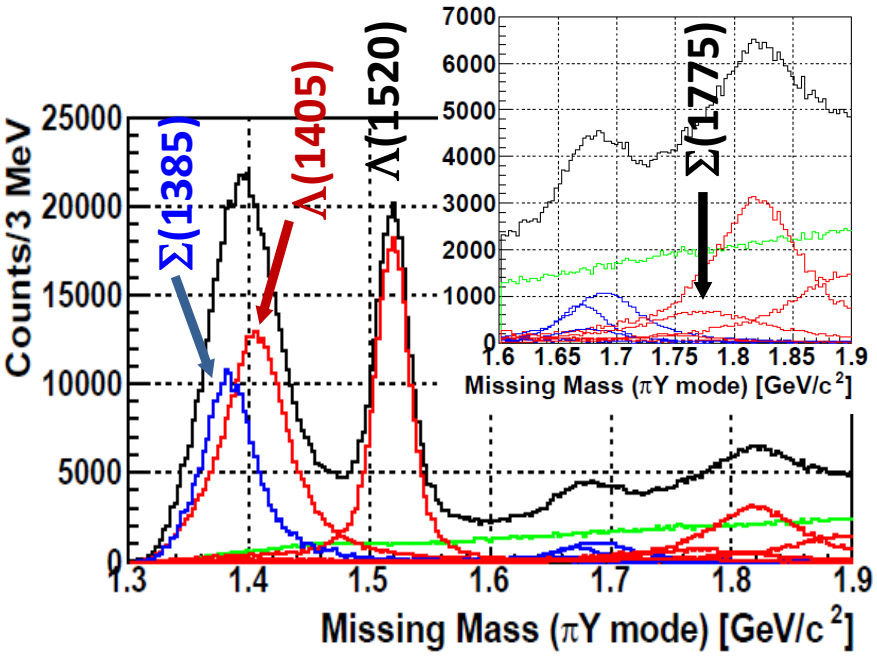


Strange Baryons

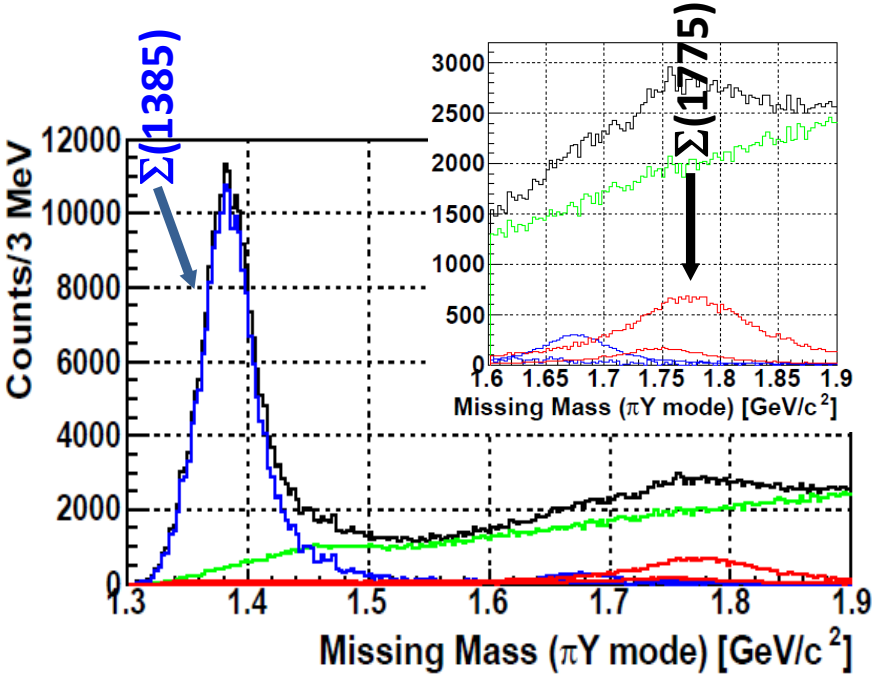
I = 0, 1

I = 1 only

(a)(π^-,K^{*0}) w/ $\pi\Sigma$ decay



(b)(π^+,K^{*+}) w/ $\pi\Sigma$ decay



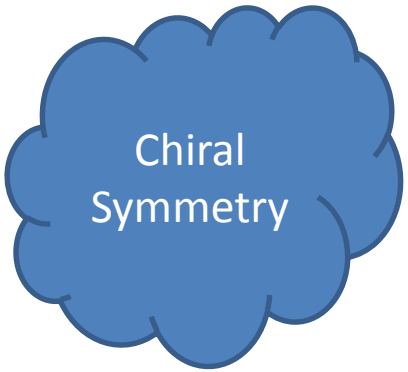
✓ Contribution of Σ(1385) can be subtracted to extract the Λ(1405) amplitude.

Last Meeting (11-13 Sep., 2013)

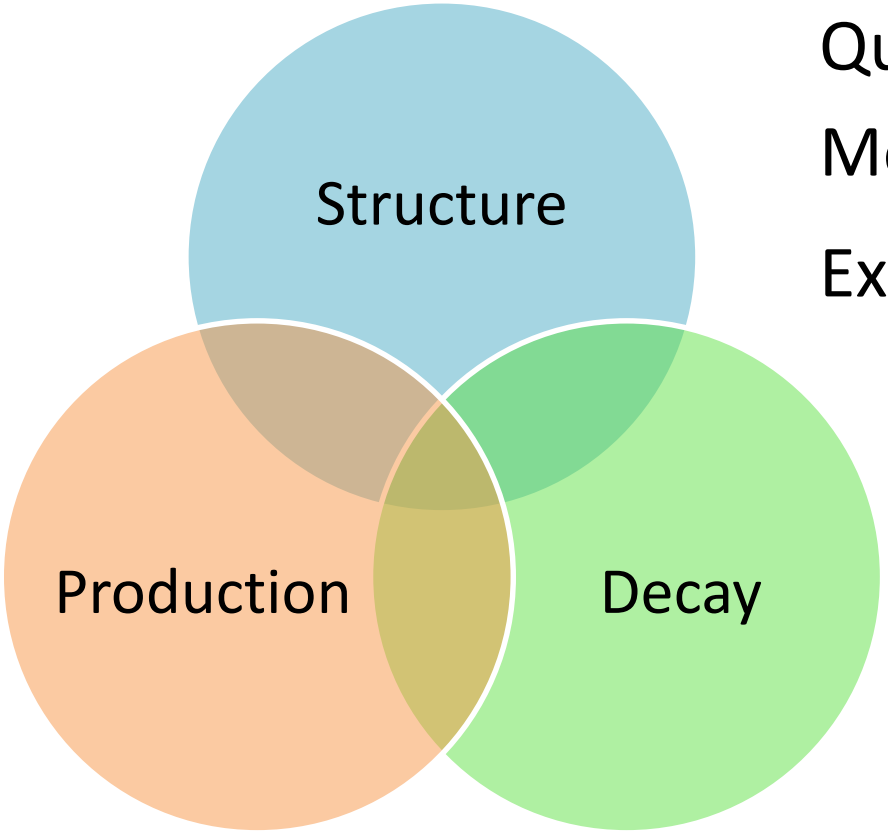
- Summary…

What We can Learn from Charm…

- What we want to see?
  - Di-quark in a baryon (colored object)
    - Wave function of a colored object
    - Flavor dependence
    - Chiral partner
  - Exotic state
  - Medium (c in matter)
  - Other
- Where can we see ? (Structure <->Observables)
  - Excitation Energy
  - Production Rate
  - Decay branch/partial width
    - $\Gamma(Y_c^* \to pD)/\Gamma(Y_c^* \to \pi\Sigma_c)$
  - Flavor difference/dependence



What We can Learn from Charm…



Quark-Diquark

Molecule

Exotic

Flavor Dependence

みんなでQ＆A

- QM: wave function
  - B>=qqq> +qqqqq^{bar}>+… 成分どう区別する？
- Charm in Medium
- DN Vρ+Vω<<0 <-> D^{bar}N/NN: Vρ-Vω~0
  - Cut off/ contact termの入れ方
- ModelとQCDの関連：意識
  - Constituent Quark（Diquark)の定義<-QCD
- LQCD：Q-qq　Qの部分を積分し、qqのPotentialをみるべき。
- Systematicに（collaborativeに）アタックすることの重要性
- 博物学的に始めても、普遍的なものを引き出す
- J-PARC理論センターの役割は重要

これから

- Production Rate: refine
- Decay：QHET
- CQM:　Wave function
- Medium
- Molecule
- $D^{bar}NN$
- DNN: Hadronの自由度とQuarkの自由度の観点（関連）

Still open question…

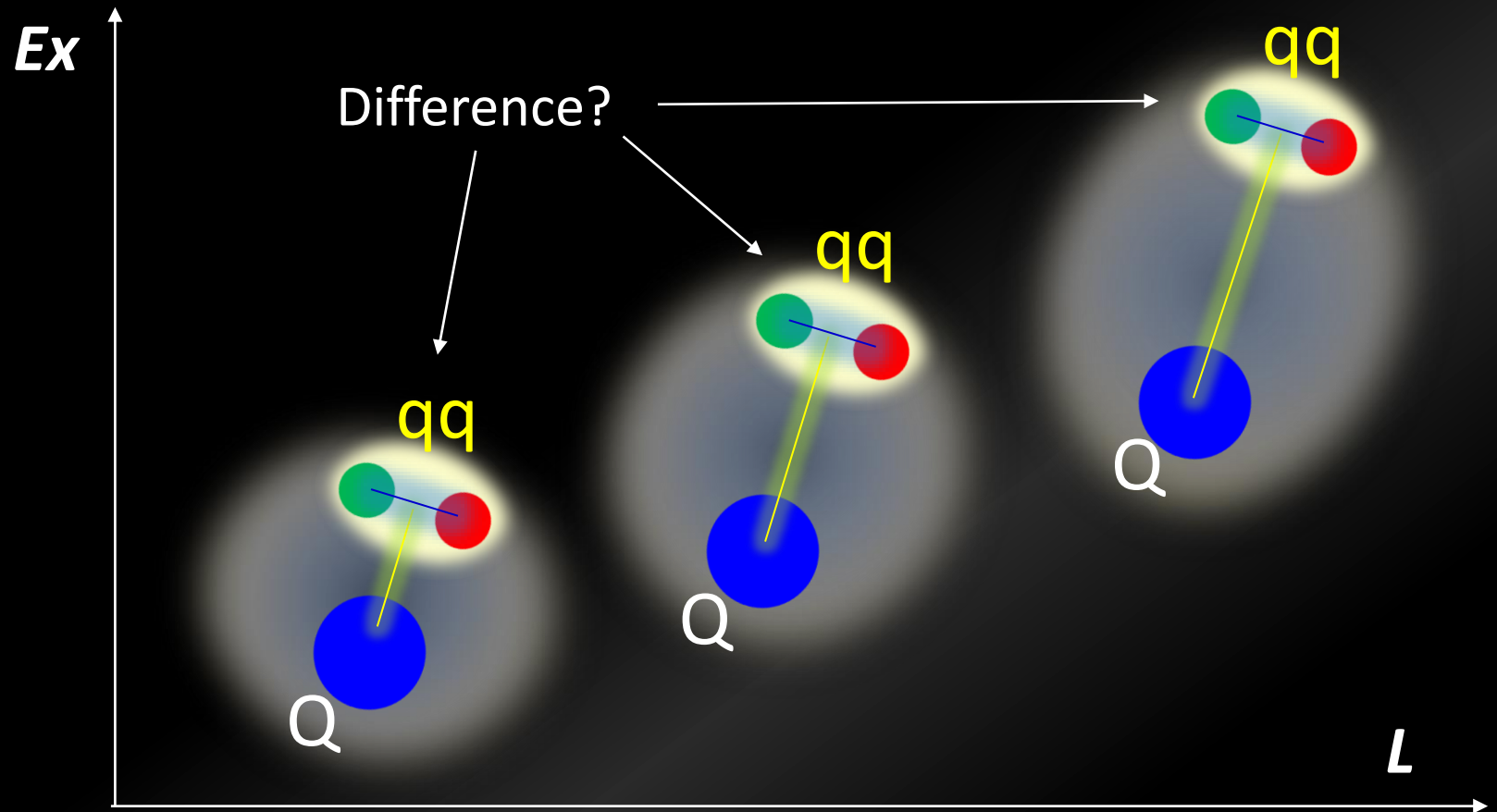
- Structure
- Production
- Decay

- Wave Function

What is essential DoF?
“Diquark”?

What is different from CQM?

- A diquark "mass" or $2m_q+\langle V_{qq}\rangle$

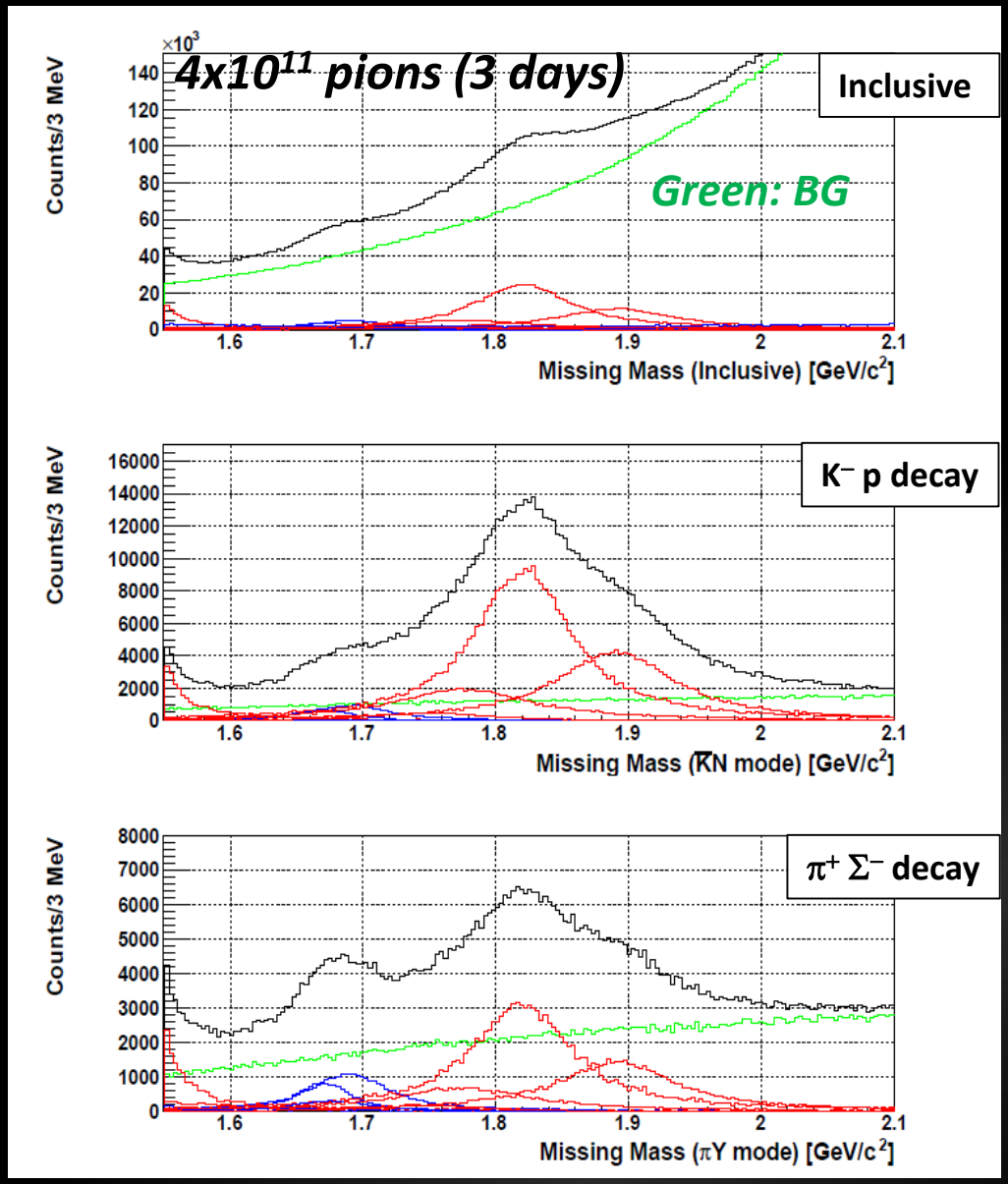


What is different from CQM?

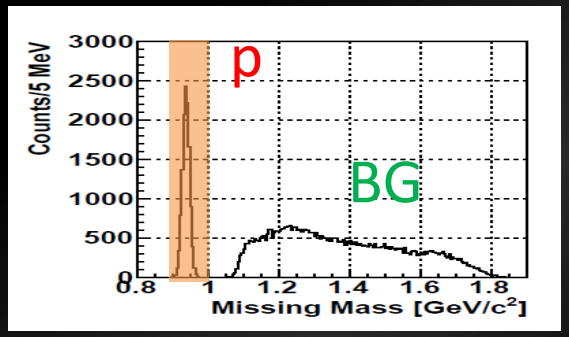
- A diquark "mass" or $2m_q+\langle V_{qq}\rangle$
- properties of diquark mode with higher L
  - Manner of λ/ρ –mode excitation
  - Narrower width is expected in Heavy Baryons
  - Need Decay Rate Calculations

Request to theorists…

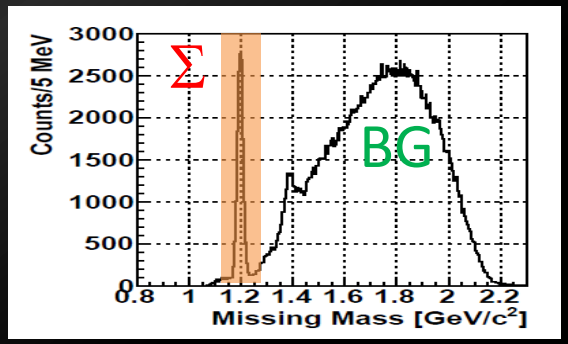
Hyperon production via $p(\pi^-,K^{*0})X$



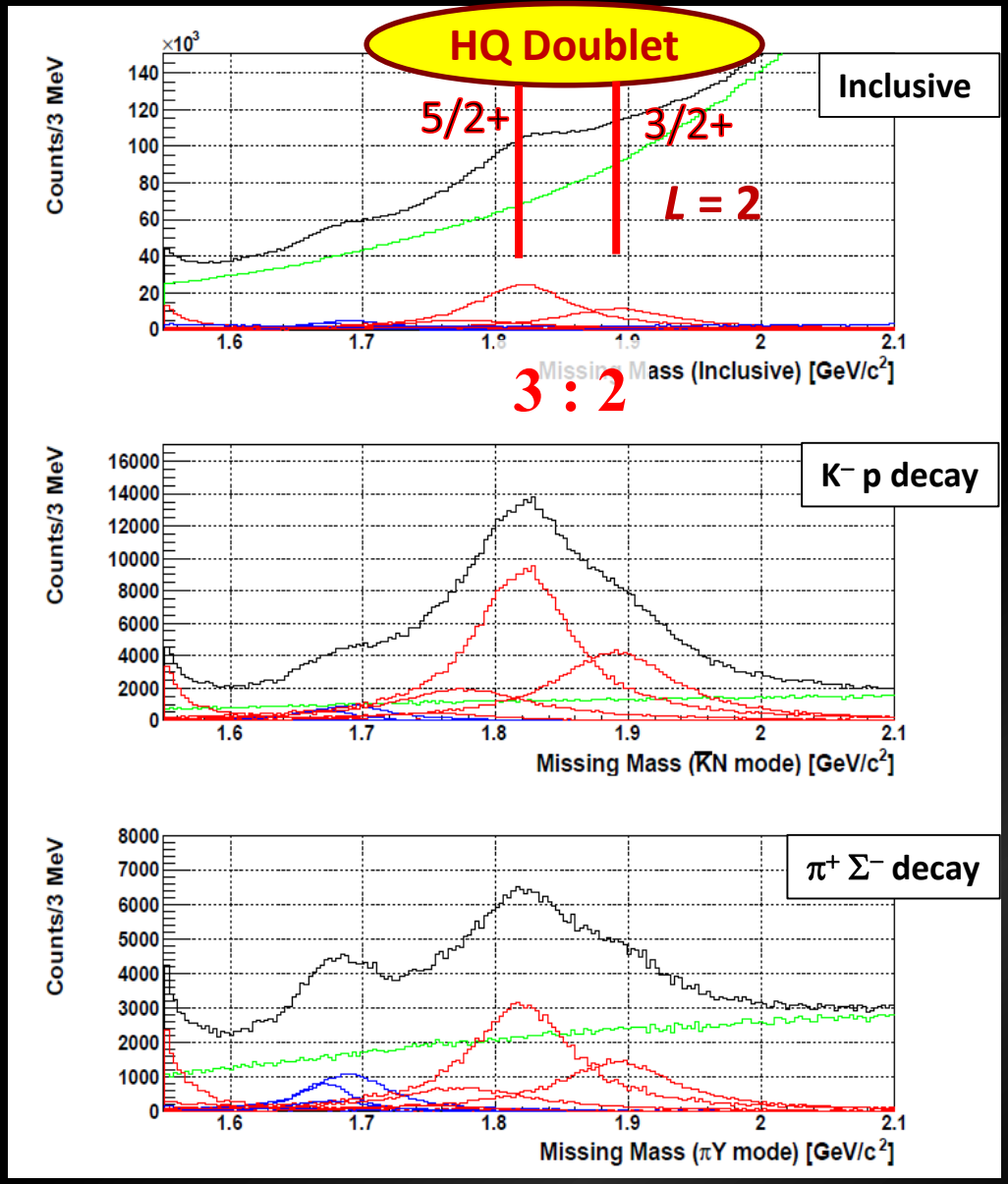
- K^- p decay
  - K^- tagged, Missing "p" gated



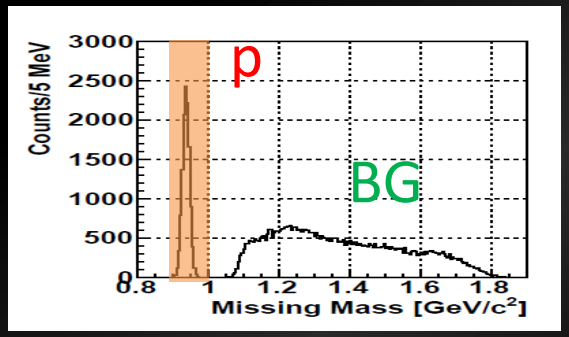
- $\pi^+\Sigma^-$ decay
  - π^+ tagged, Missing "Σ" gated



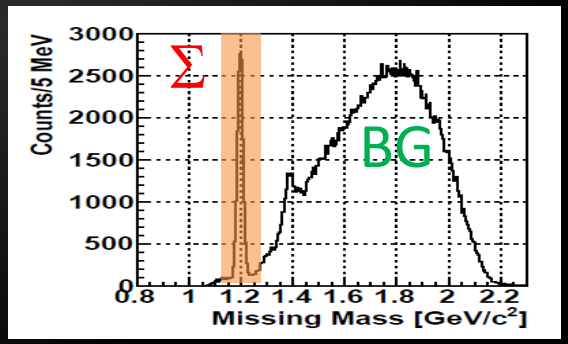
Hyperon production via $p(\pi^-, K^{*0})X$



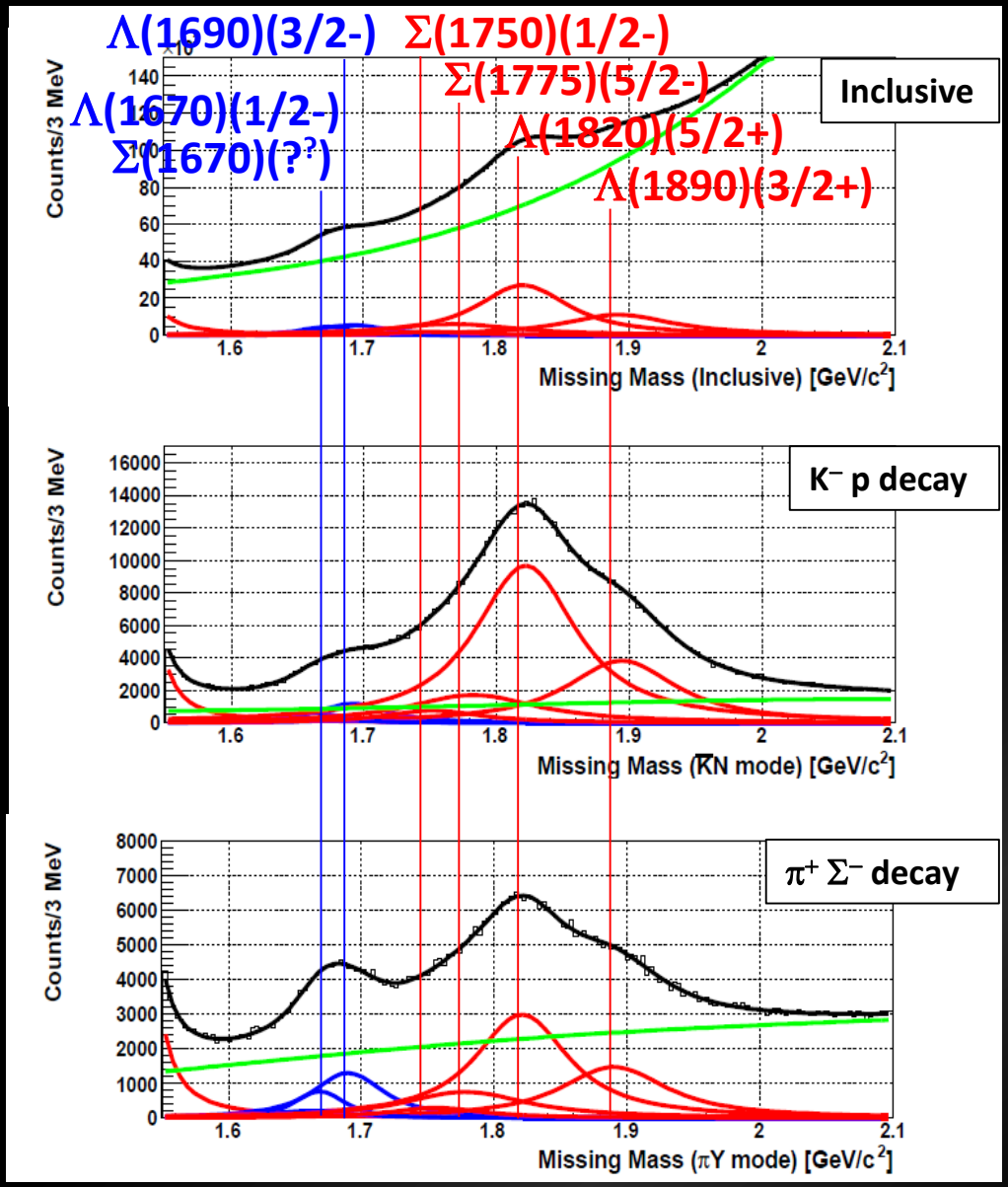
- K^- p decay
  - K^- tagged, Missing "p" gated



- $\pi^+\Sigma^-$ decay
  - π^+ tagged, Missing "Σ" gated



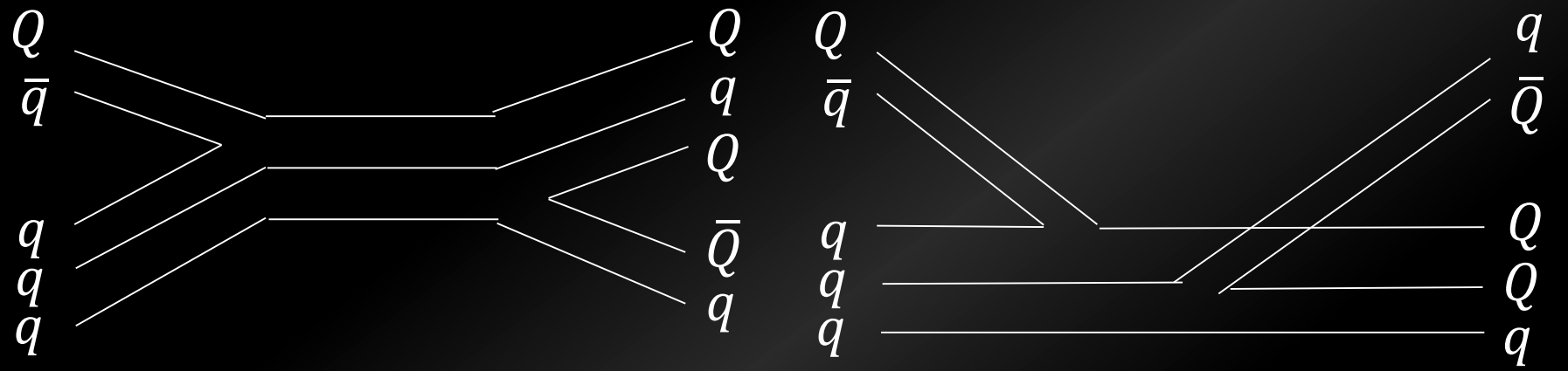
Hyperon Production (Fitting Results)



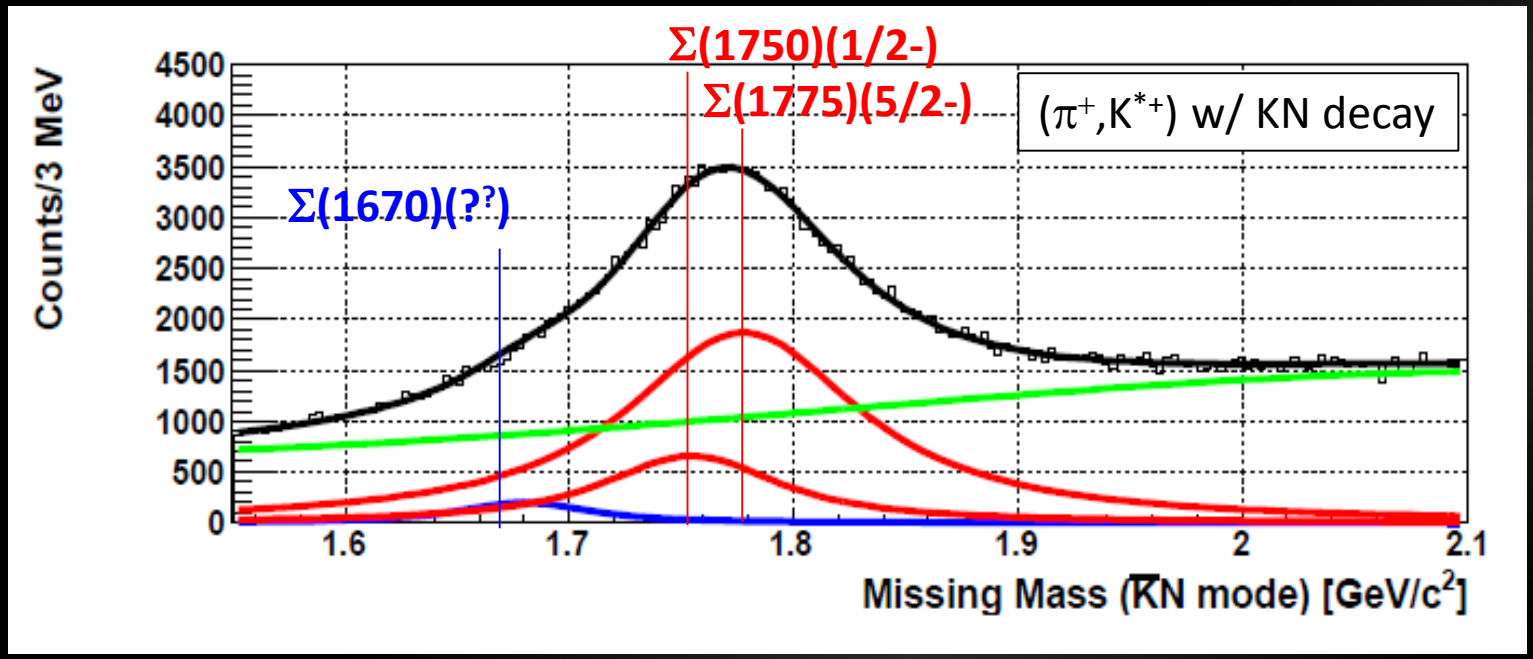
- Extract 7 states.
  - Constraint from known M & Γ
  - BG: 5th O. Polynomial F.
- Cross Section
  - λ / ρ mode ID
  - λ / ρ mixing: P_{mix}(*strange*) (ρ-mode C.S.)
  - *HQ spin multiplets*
- $\Gamma(KN)/\Gamma(\pi Y)$
  - λ / ρ mode ID

Production

- No one step, t-channel Meson Exchange.
  - *s*, *u*-ch., or Baryon (Reggeon) exchange?
  - No mode selectivity? <-> qqQ system



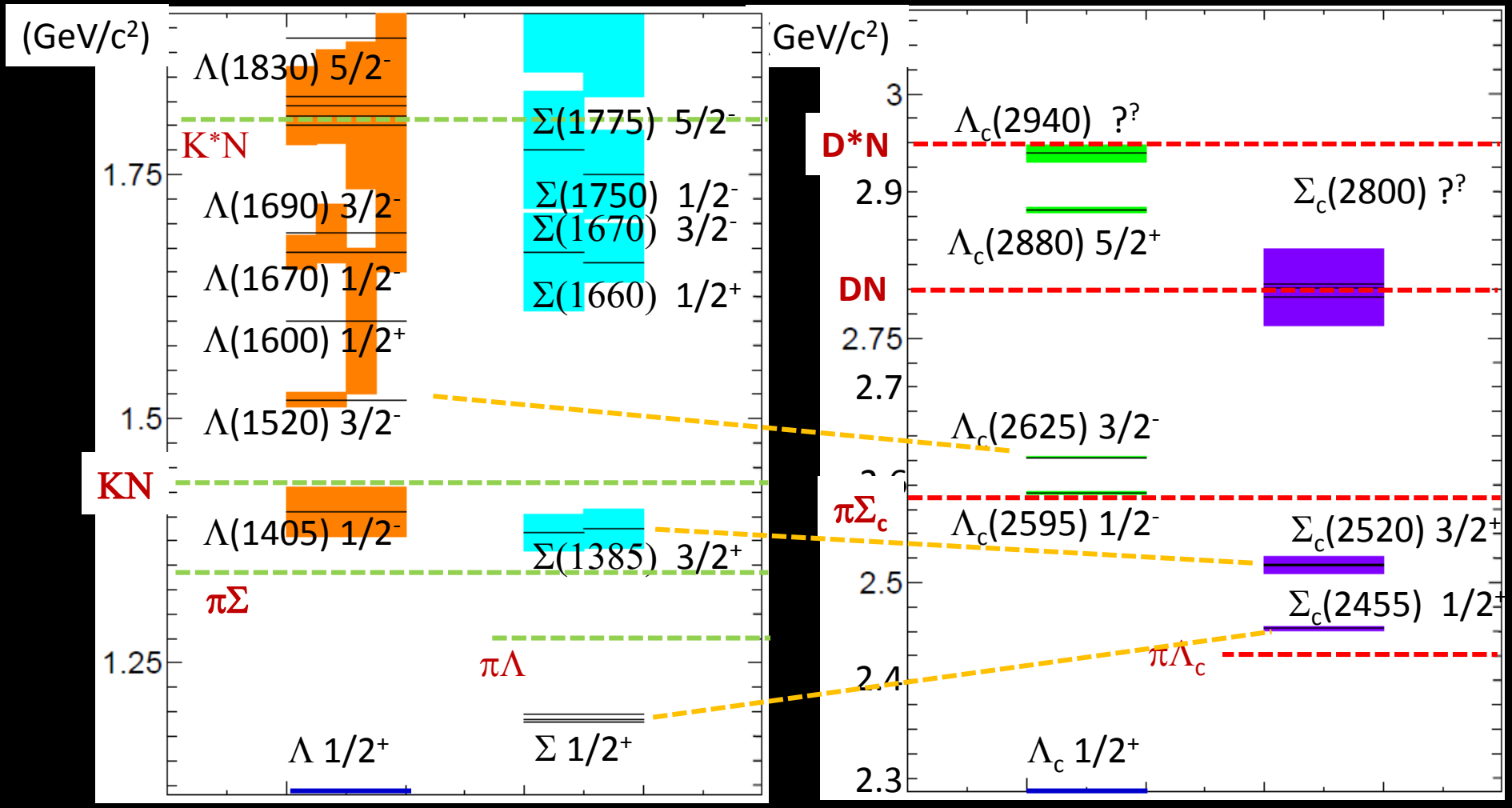
Peak fitting for $p(\pi^+,K^{*+})\Sigma^{*+}$



M and Γ of 3 Σ^{*+}'s are fixed first.

Strange Baryons

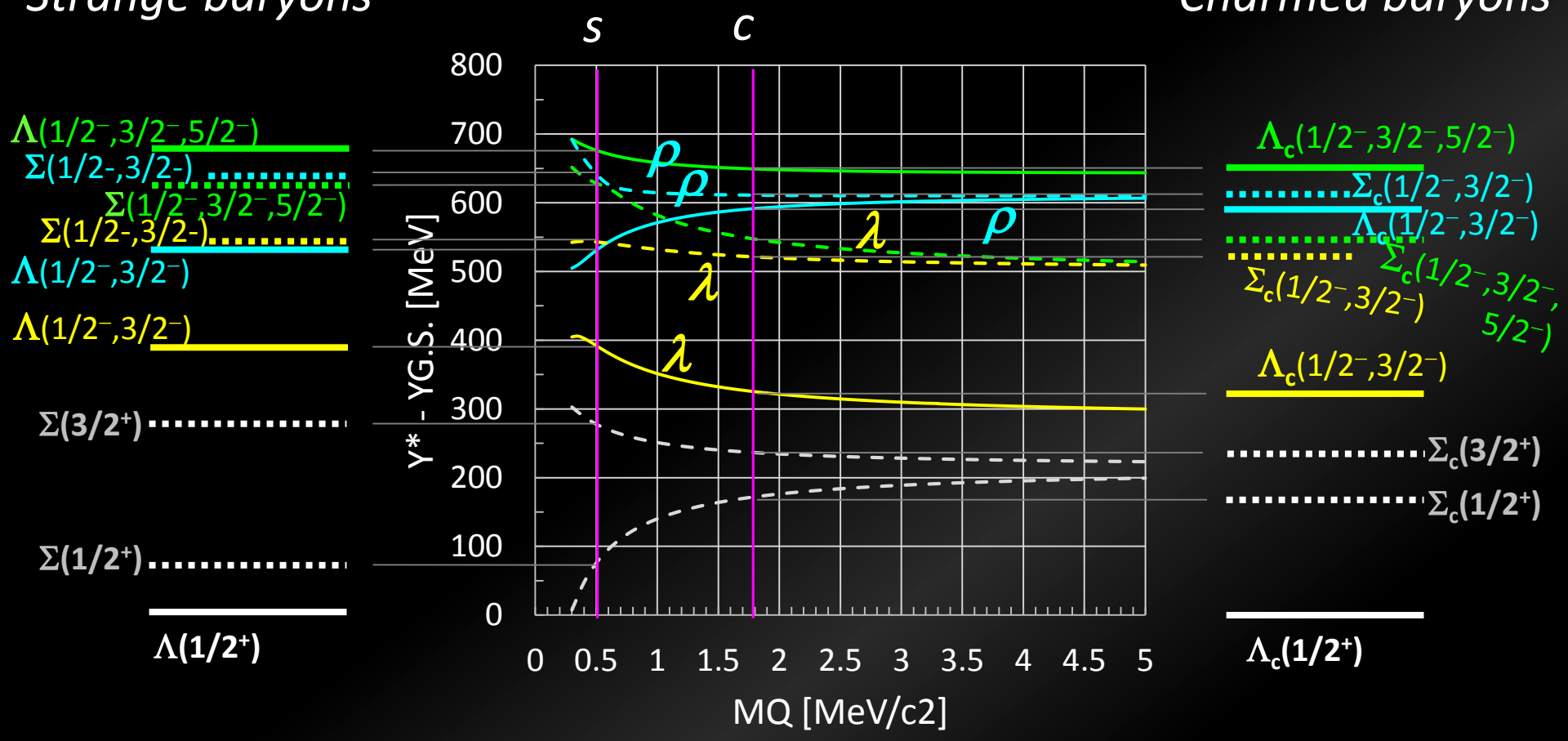
Charmed Baryons



Baryon spectroscopy in different flavors

Strange baryons

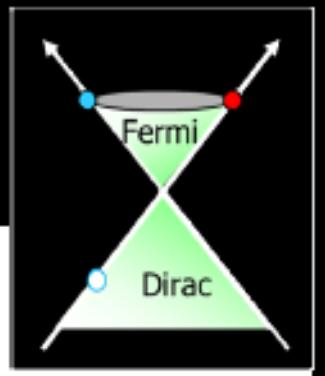
Charmed baryons



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

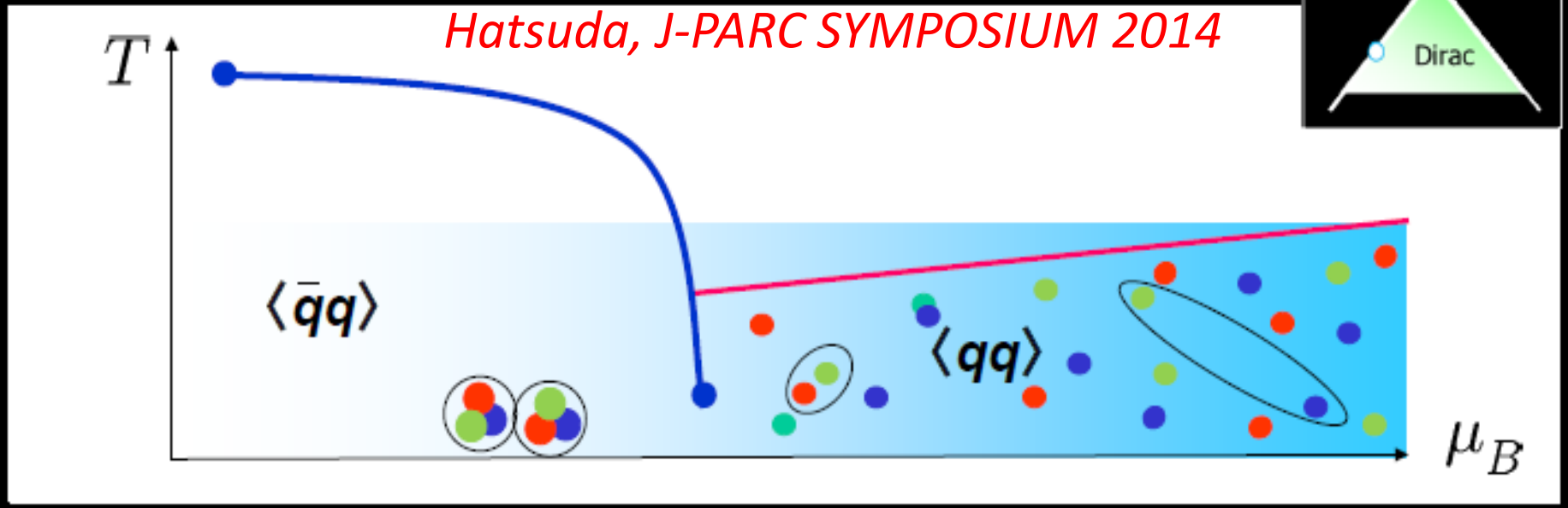
ρ–λ mixing (cal. By T. Yoshida)

"Diquark" as a bridge between hadrons and quarks



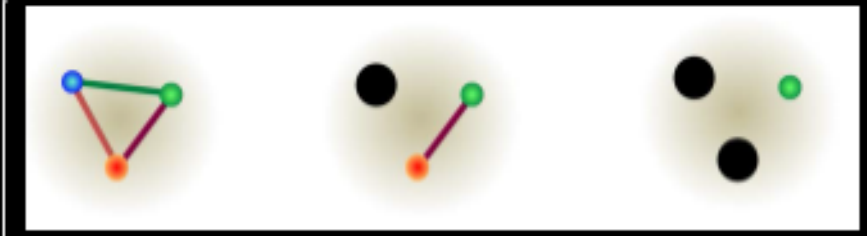
See e.g., Selem & Wilczek, hep-ph/0602128

Hatsuda, J-PARC SYMPOSIUM 2014



nucleon superfluidity ⇔ quark+"diquark" ⇔ colorsuperconductivity

Charmed baryons @J-PARC



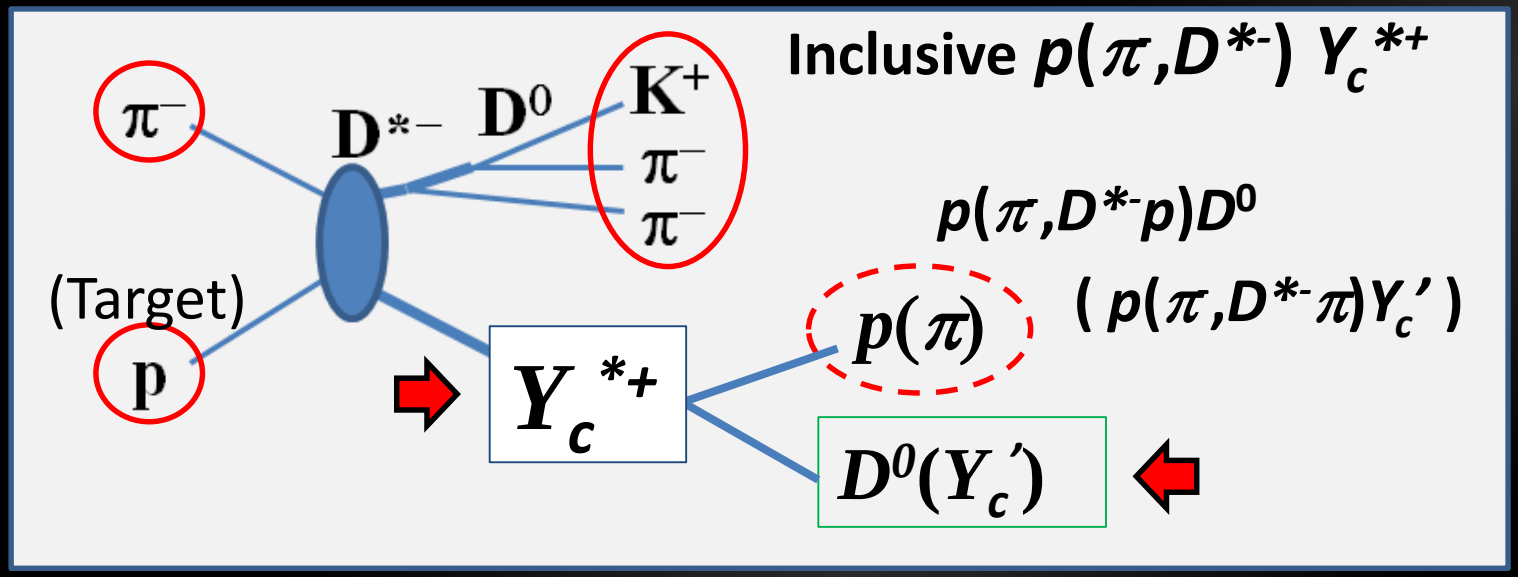
Noumi, Hosaka et al.

Quantum simulation by cold atoms

Maeda, Baym & Hatsuda, Phys.Rev.Lett. 103 ('09)

Charmed Baryon Spectroscopy

Using Missing Mass Techniques



What we will measure

- Spectrum identified by productions:
  - ✓ Basic modes of diquark motions (λ/ρ modes)
  - ✓ Heavy Quark Spin doublets ($\vec{S}_{HQ} \pm \vec{J}_{rest}$)

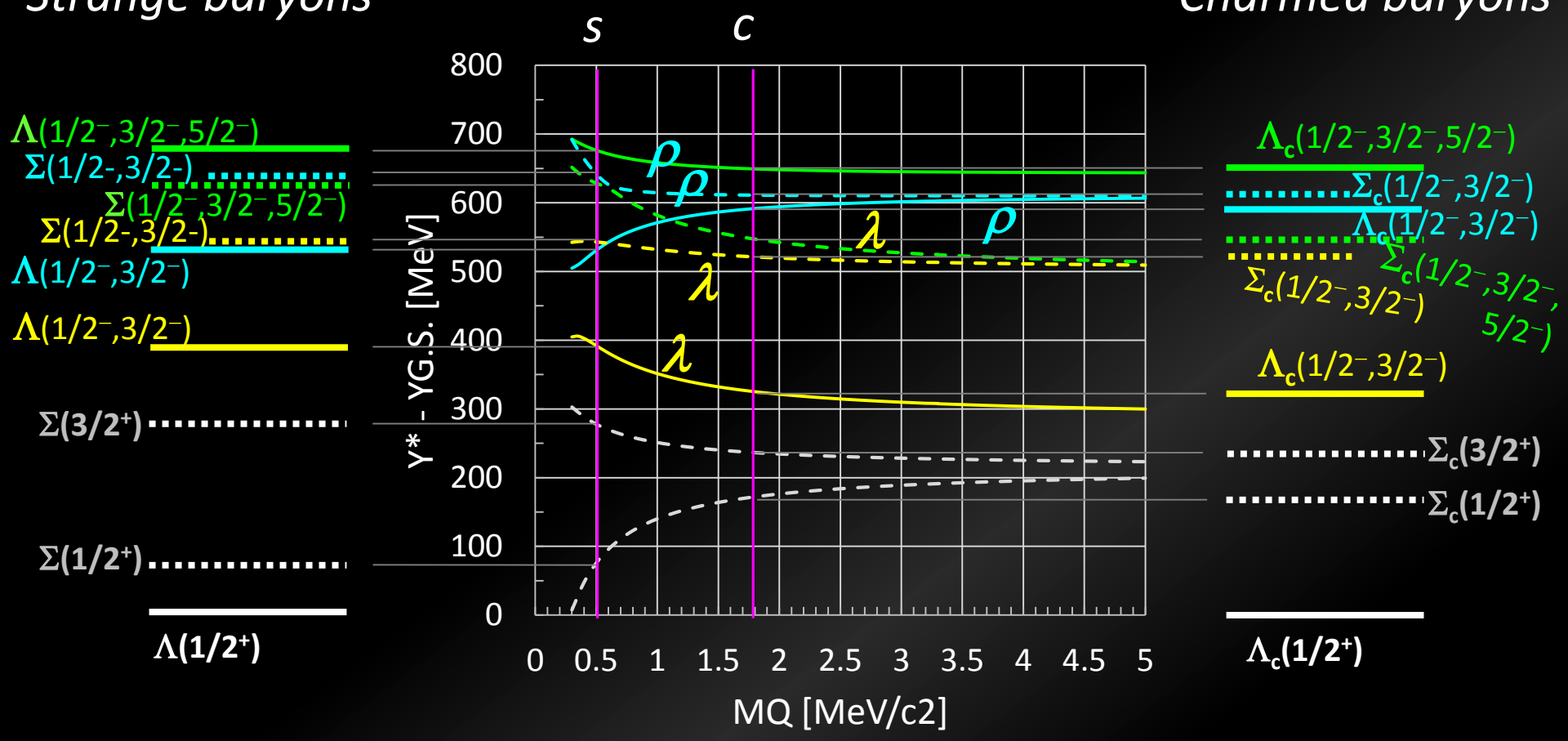
- Production Rate: reflect quark configuration
  Heavy quark + light diquark

- Decay properties:
  $M(Qq^{bar}) + N(qqq)$ / $m(qq^{bar}) + Y_c(Qqq)$

Baryon spectroscopy in different flavors

Strange baryons

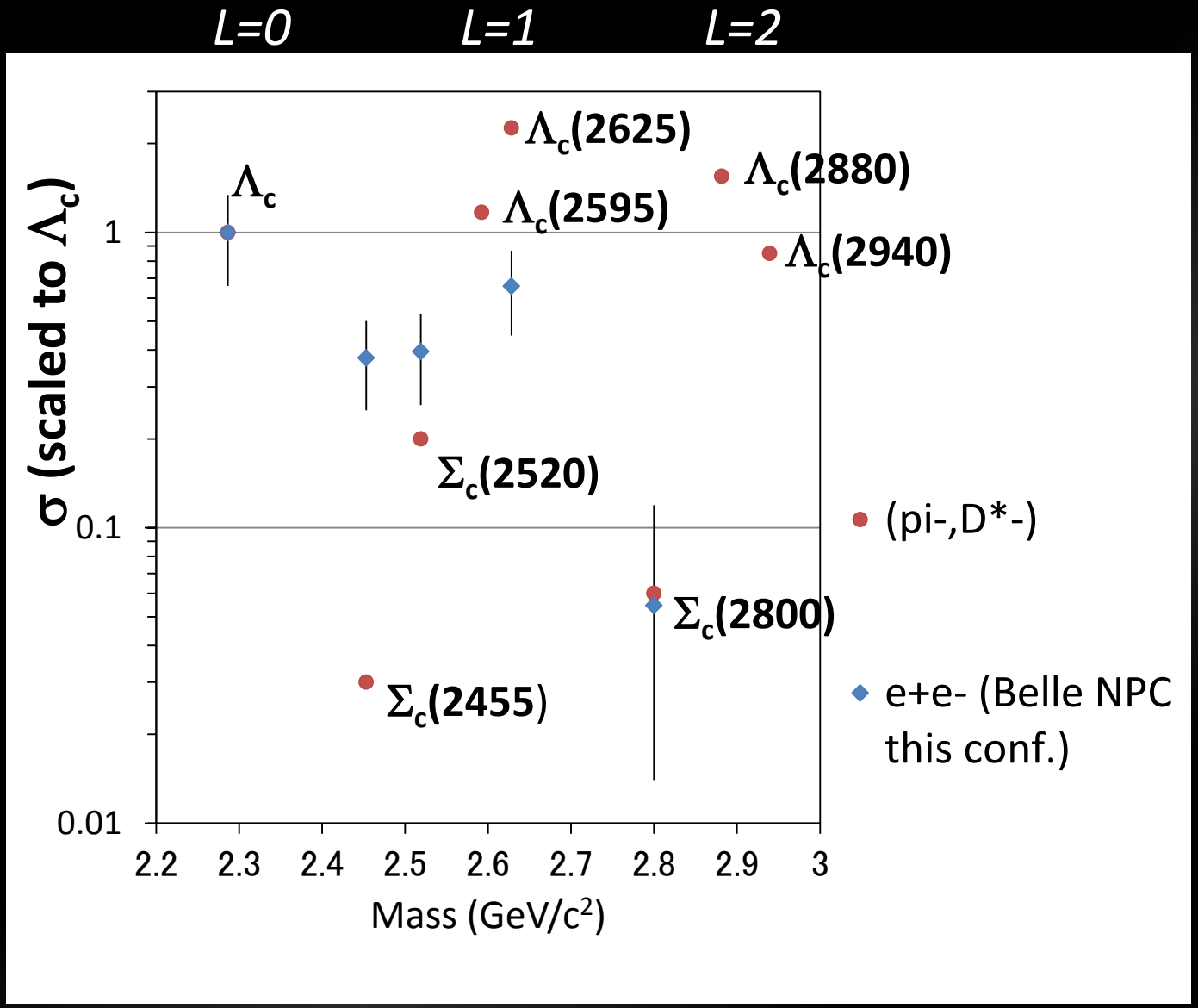
Charmed baryons



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

ρ–λ mixing (cal. By T. Yoshida)

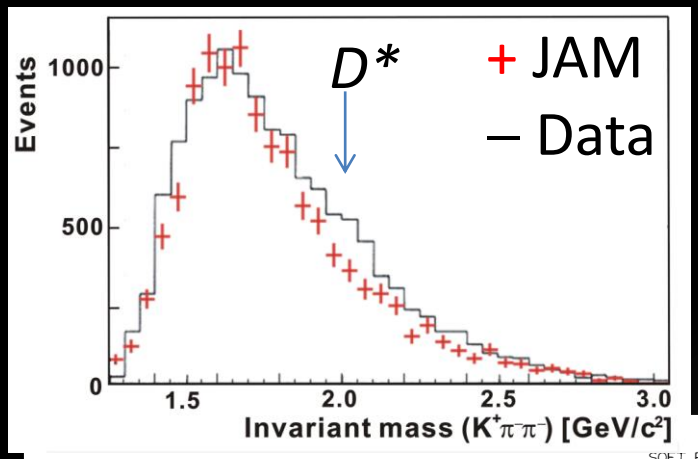
Calculated production rates

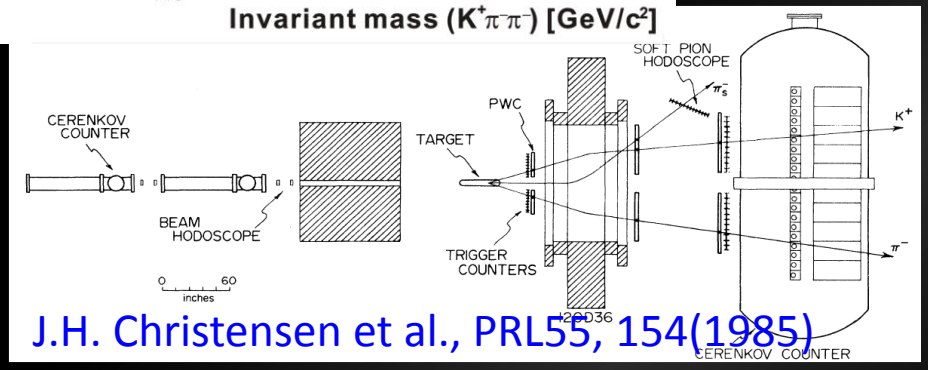


Production Cross Section

A. Hosaka et al., paper in preparation.

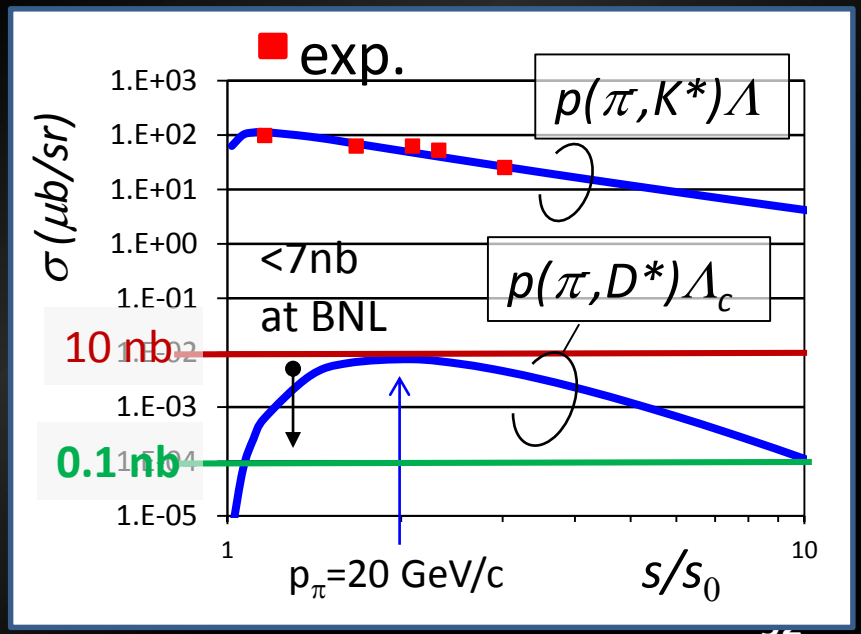
- Experimental data:
  - $\sigma(p(\pi^-,D^{*-})\Lambda_c)$ < 7 nb (68%CL) (BNL exp., 1985)
  - BG spectrum is well reproduced by a MC simulation w/ JAM
- Regge Theory suggests 10^{-4} of the hyperon production
  - $\sigma(p(\pi^-,D^{*-})\Lambda_c)$ ~ a few nb





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

Regge Theory



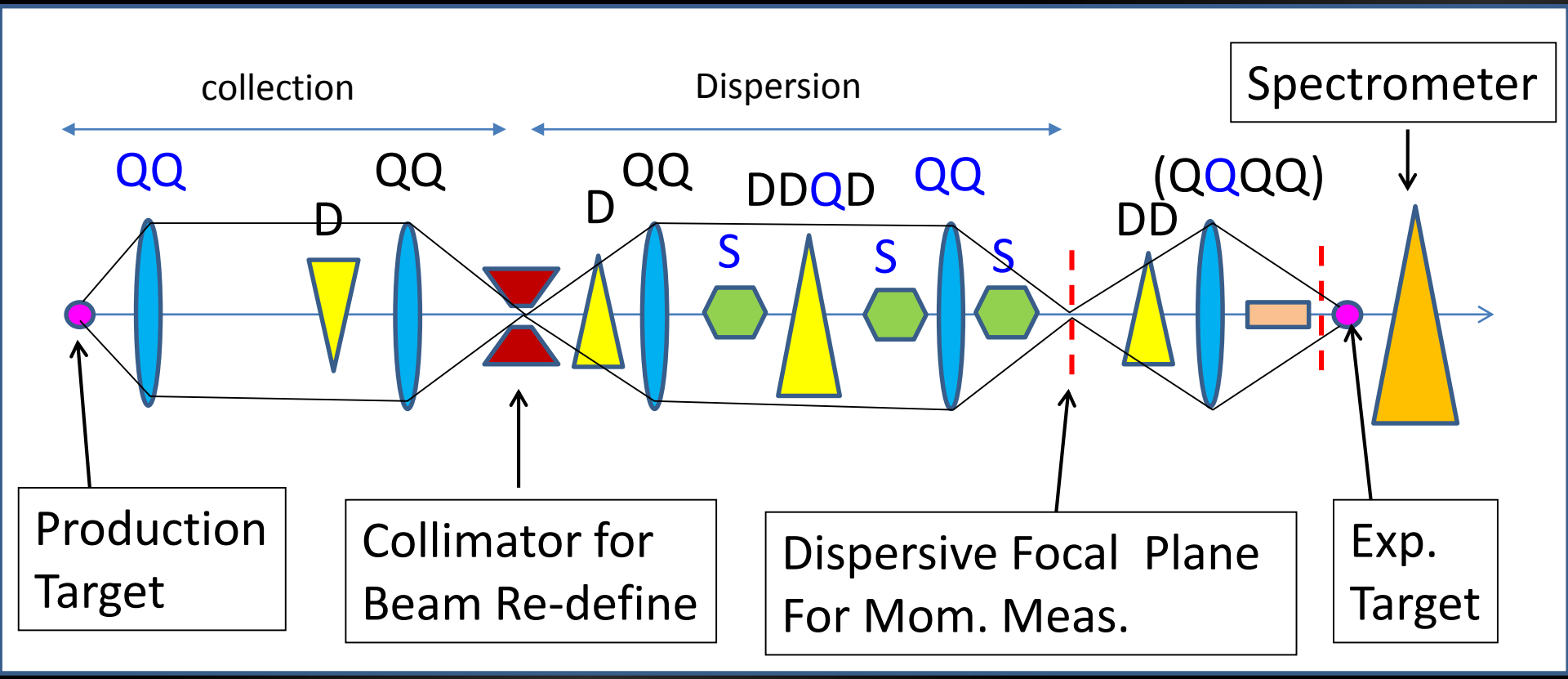
Calculated production rates

	p_π=20 GeV/c	Mass (GeV/c)	"ud" isospin factor	Y_c^* Spin factor	q_{eff} (GeV/c)	Rate (Relative)
L=0	$\Lambda_c^{1/2+}$	2286	1/2	1	1.33	1
	$\Sigma_c^{1/2+}$	2455	1/6	1/9	1.43	0.03
	$\Sigma_c^{3/2+}$	2520	1/6	8/9	1.44	0.17
L=1	$\Lambda_c^{1/2-}$	2595	1/2	1/3	1.37	0.93
	$\Lambda_c^{3/2-}$	2625	1/2	2/3	1.38	1.75
	$\Sigma_c^{1/2-}$	2750	1/6	1/27	1.49	0.02
	$\Sigma_c^{3/2-}$	2820	1/6	2/27	1.50	0.04
	$\Sigma_c^{1/2-'}$	2750	1/6	2/27	1.49	0.05
	$\Sigma_c^{3/2-'}$	2820	1/6	56/135	1.50	0.21
	$\Sigma_c^{5/2-'}$	2820	1/6	2/5	1.50	0.21
L=2	$\Lambda_c^{3/2+}$	2940	1/2	2/5	1.42	0.49
	$\Lambda_c^{5/2+}$	2880	1/2	3/5	1.41	0.86

Beam Line

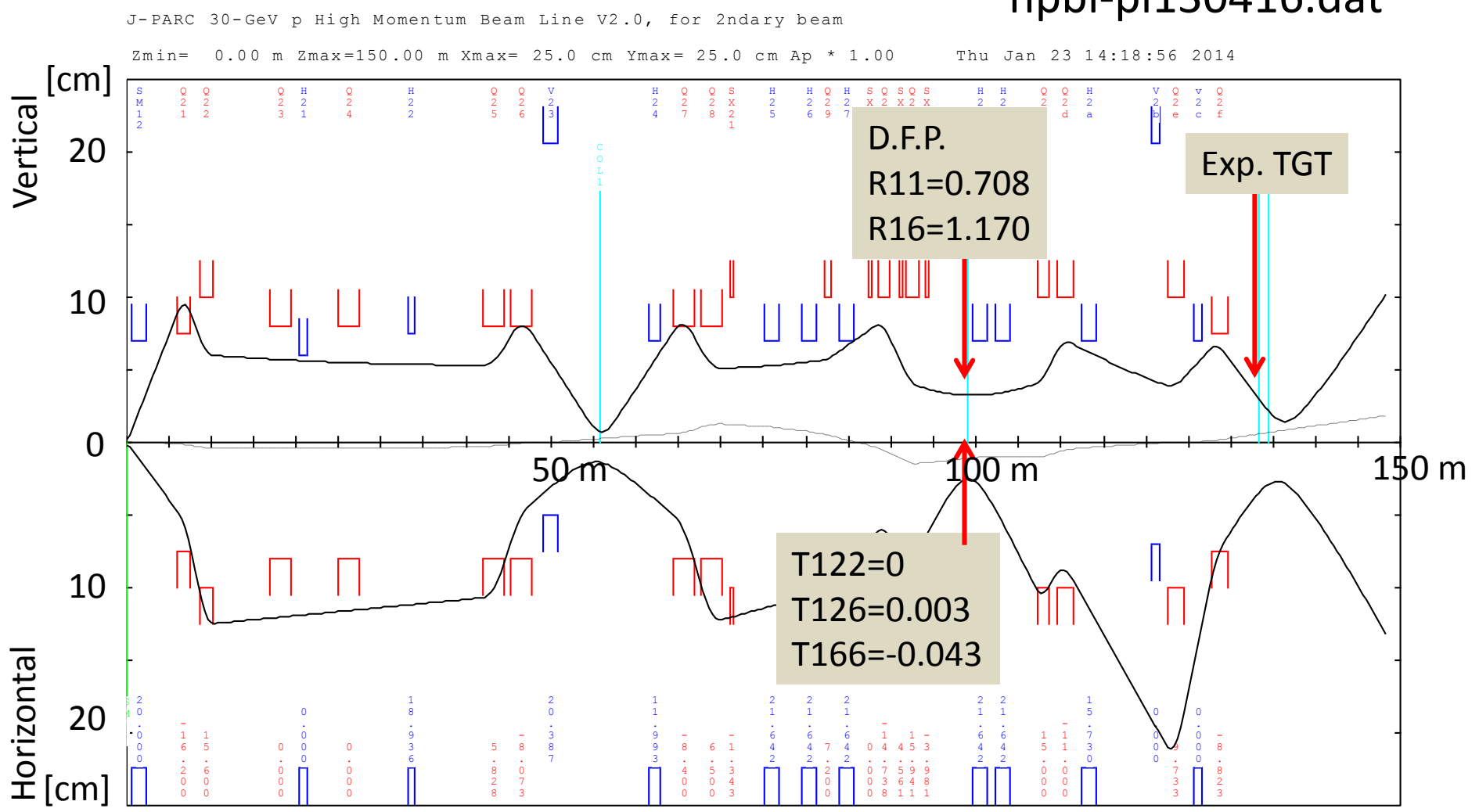
High-res., High-momentum Beam Line

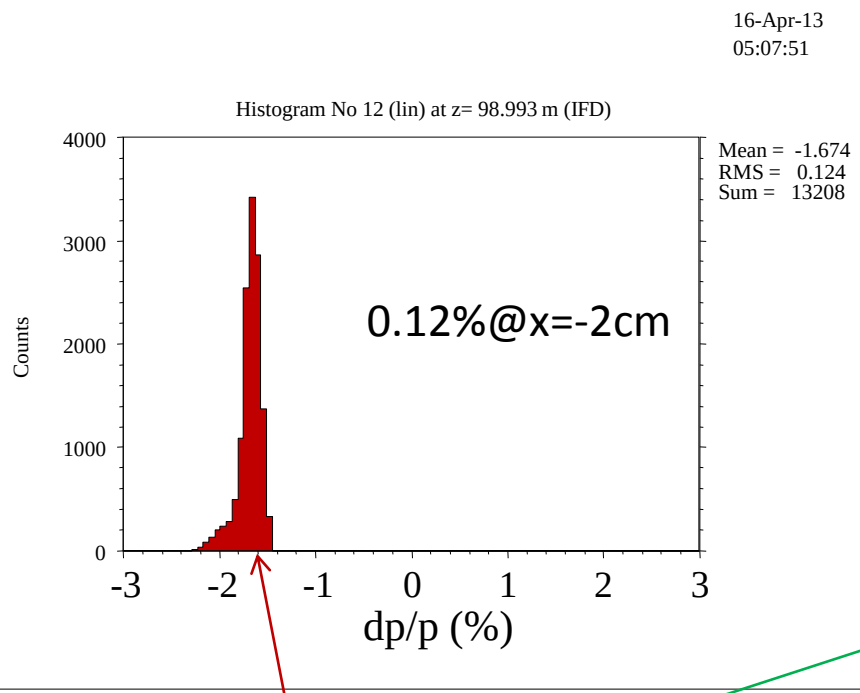
- High-intensity secondary Pion beam
- High-resolution beam: $\Delta p/p \sim 0.1\%$

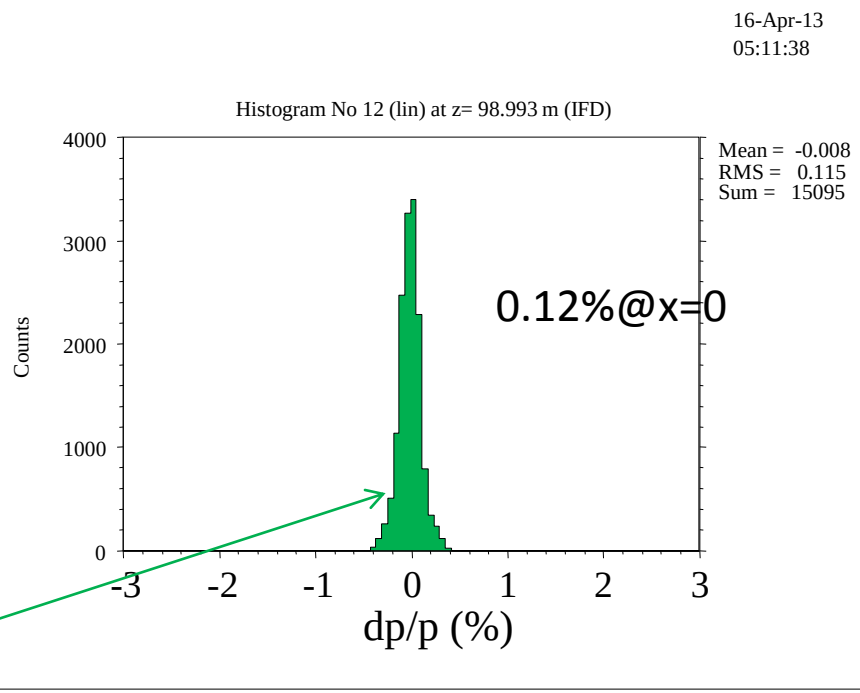


Beam Envelope (2nd order Transport)

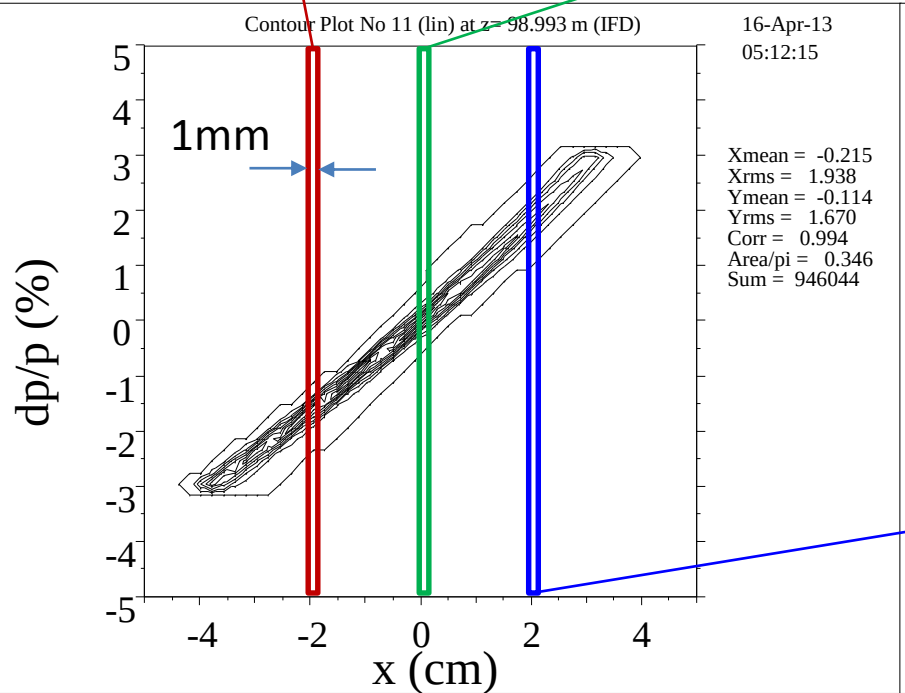
hpbl-pi130416.dat

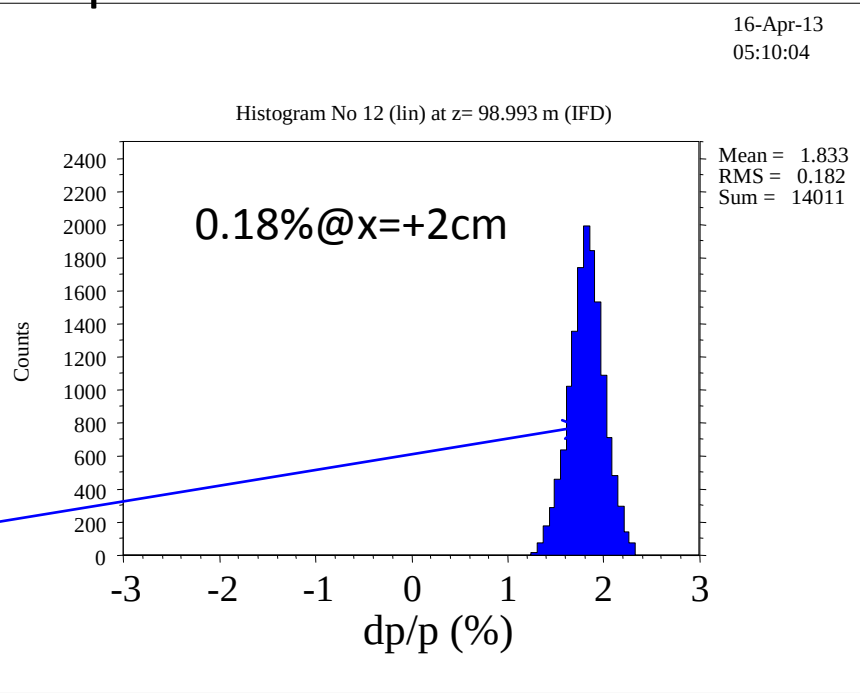






hpbl-pi130416tu.dat

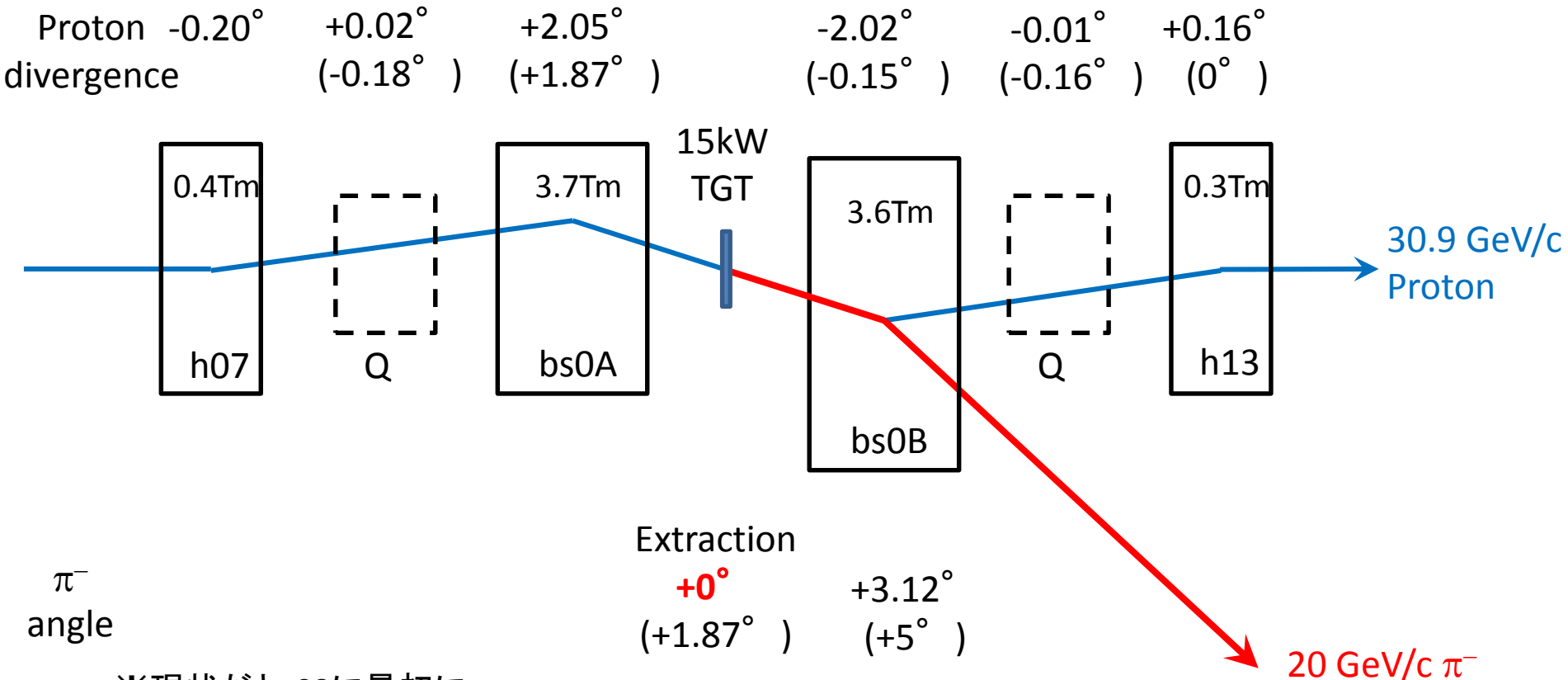




2013.02.19 H. Takahashi

π20 Beam Extraction

Beam Swinger



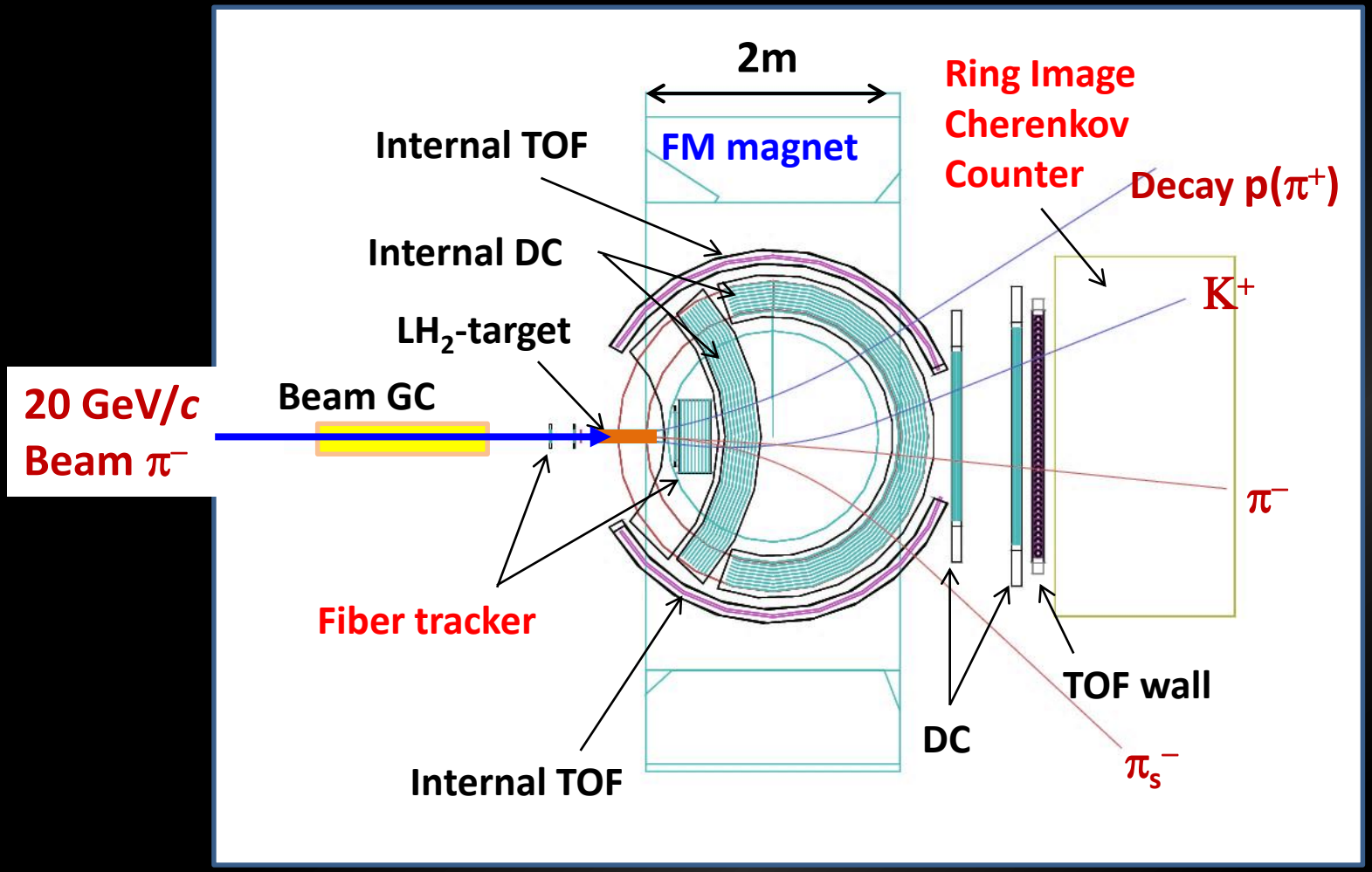
※現状だとv08に最初に当たり始めるが、それのギャップを広げれば(7D220V→7D420V)
全体でロスは0.1%以下

※標的位置: SM1-1m
bs0A偏向点: SM1-3m
bs0B偏向点: SM1+0.61m

※π^+の時は3.1°取り出しになる

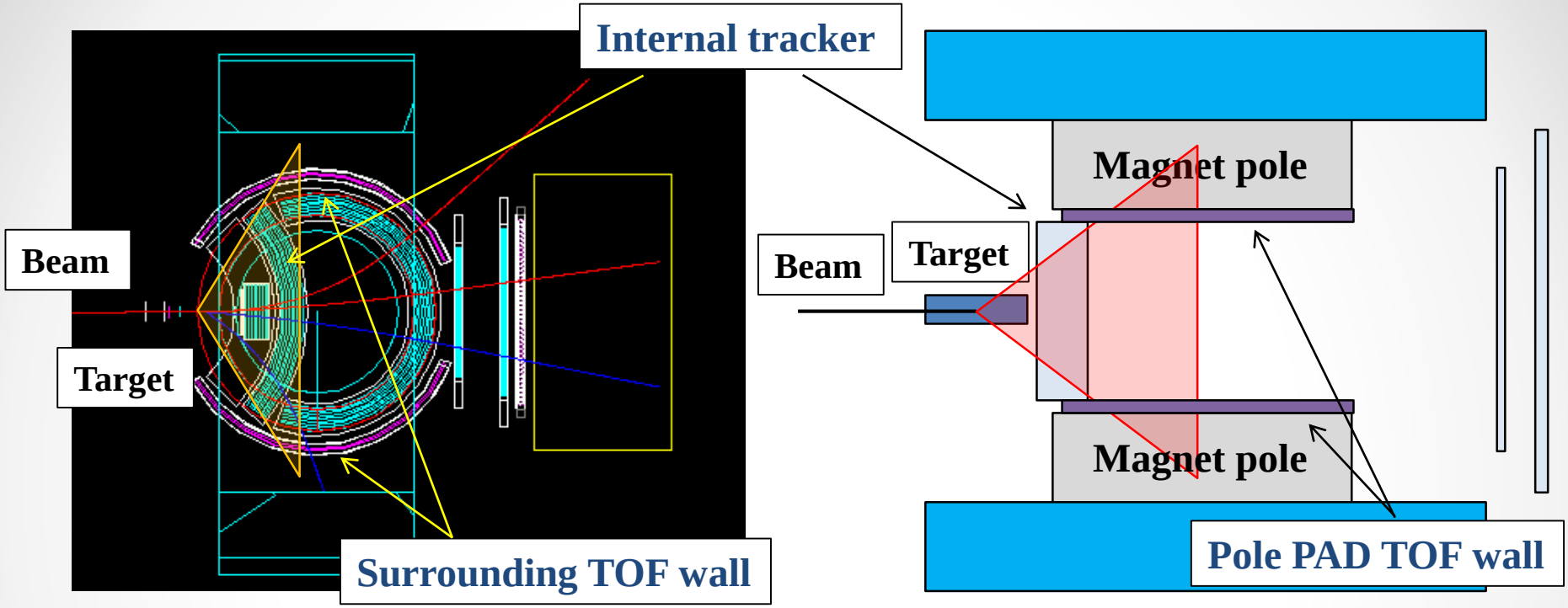
Detectors

Charmed Baryon Spectrometer



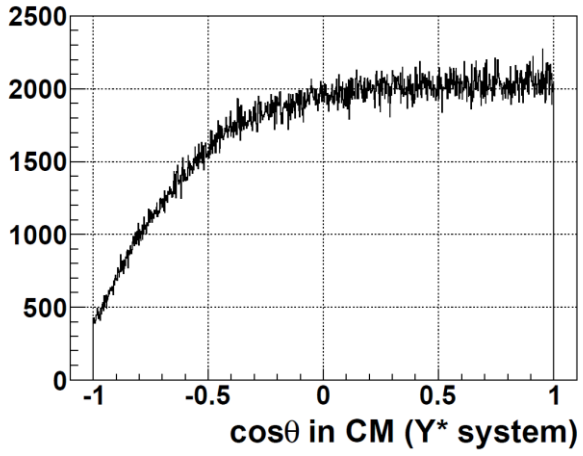
Large acceptance: ~ 60% for *D, ~80% for decay π^+**
Good resolution: $\Delta p/p$~0.2% at ~5 GeV/*c*

Acceptance



- **Method: Mainly Forward scattering due Lorentz boost ($\theta < 40^\circ$)**
  - **Horizontal direction**
    - **Internal tracker and Surrounding TOF wall**
  - **Vertical direction**
    - **Internal tracker and Pole PAD TOF detector**

  ⇒ ~70% acceptance for K* detection



- **Decay measurement: Angle in CM**

⇒ Both pole and azimuthal angles: $\cos\theta > -0.5$

- ✻ Minor change of detector system needed