JPS Annual Meeting in Waseda University
22 March, 2015

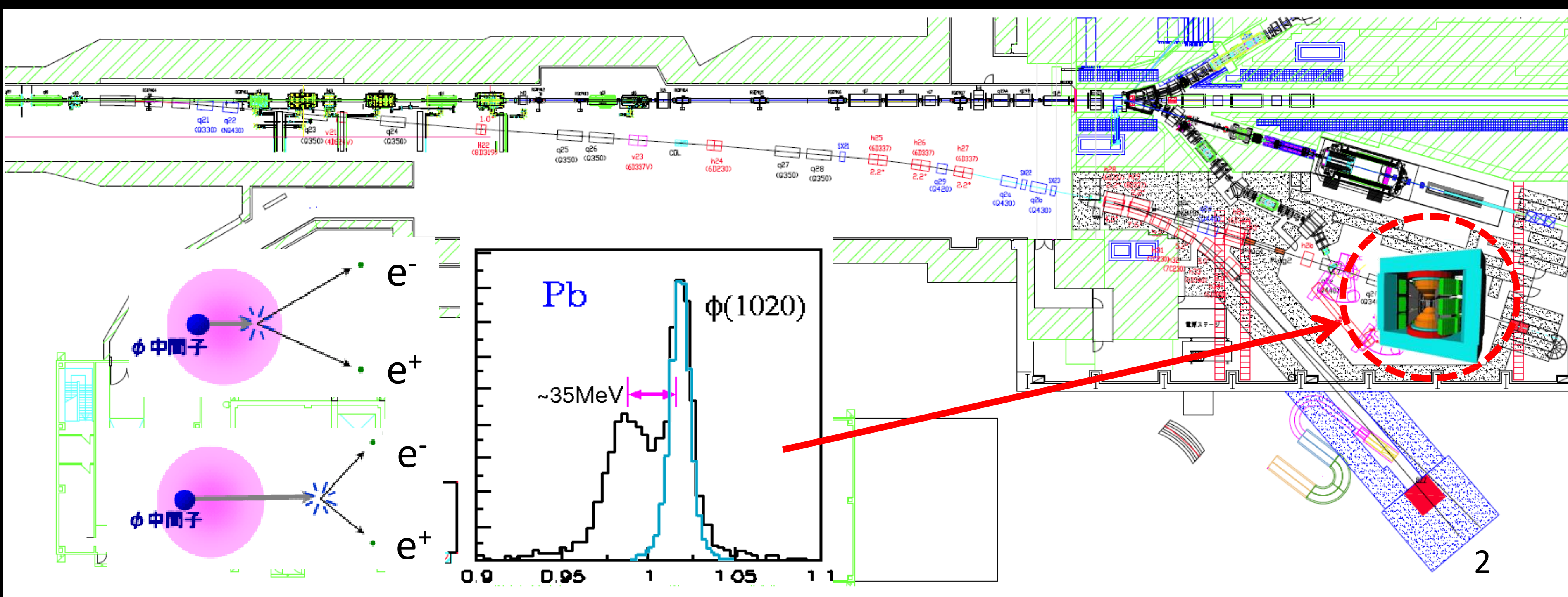
J-PARC高運動量ハドロンビームで探るハドロンダイナミクス

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

Contents:

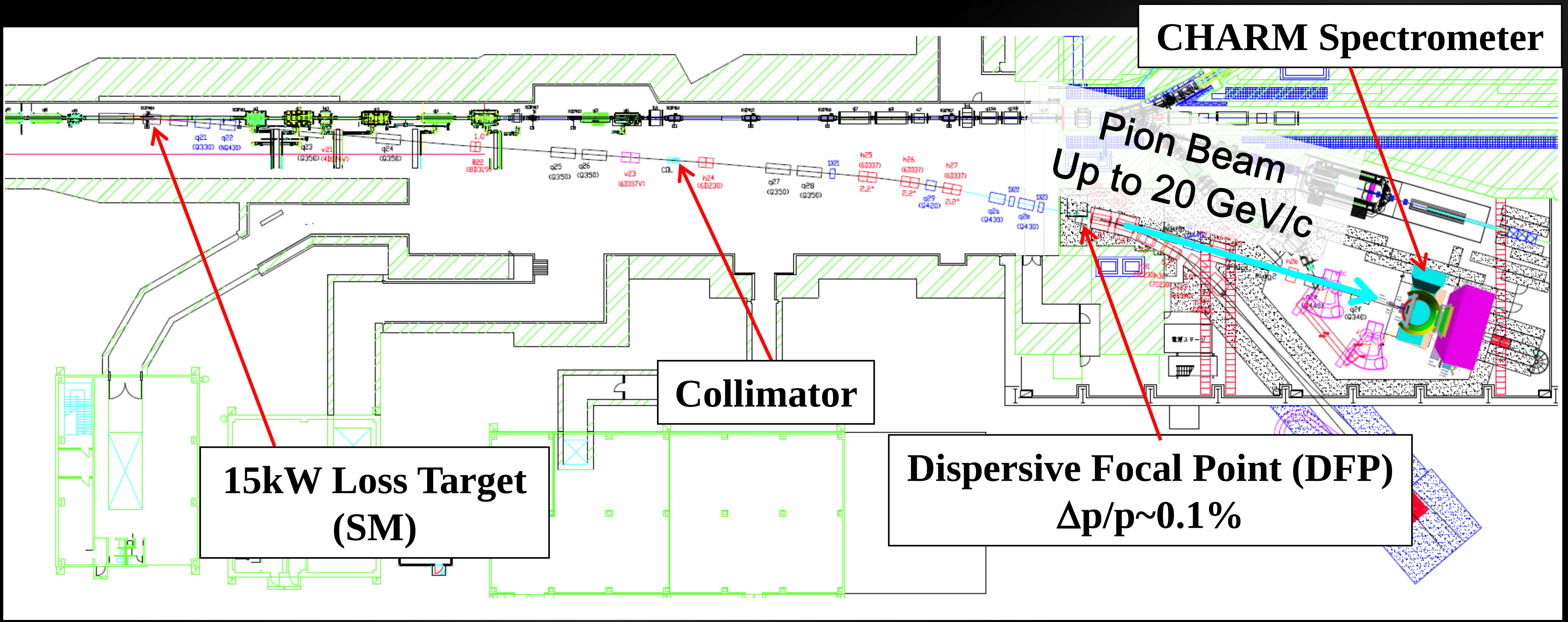
A New Platform for Hadron Physics at the High-momentum Beam Line

- Branch from the main primary BL-A line
  10^{10} primary proton at 30 GeV
- Commissioning will start in FY2016



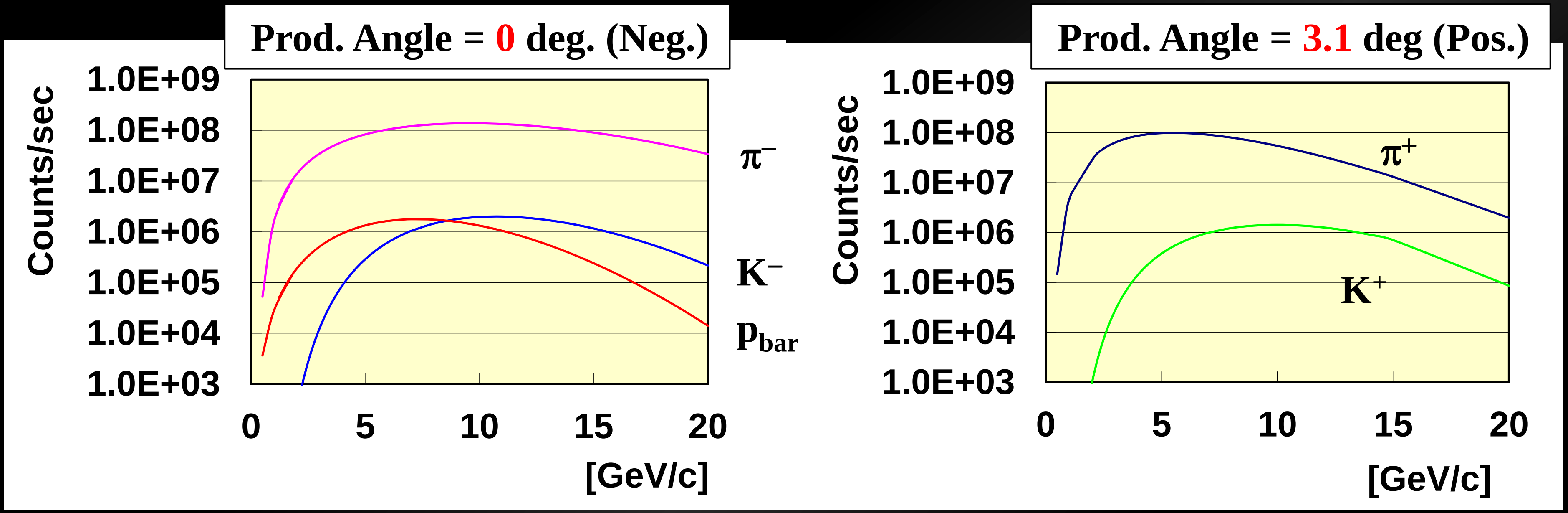
A New Platform for Hadron Physics at the High-momentum Beam Line

- High-intensity secondary Pion beam
- High-resolution beam:



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

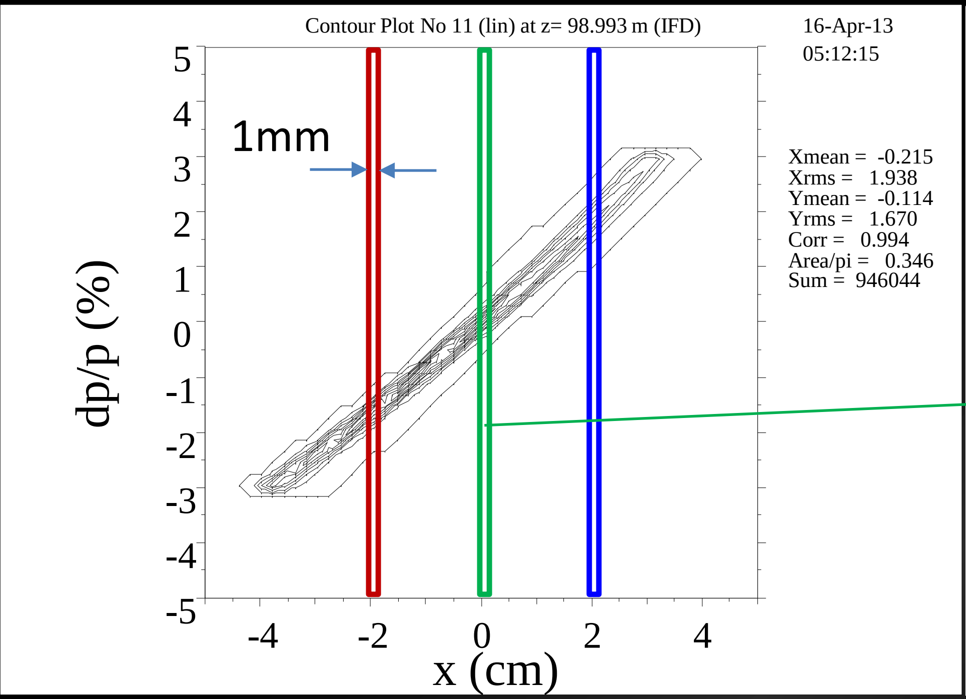
- High-intensity secondary Pion beam
  >1.0 x 10^7 pions/sec @ 20GeV/c
- High-resolution beam:

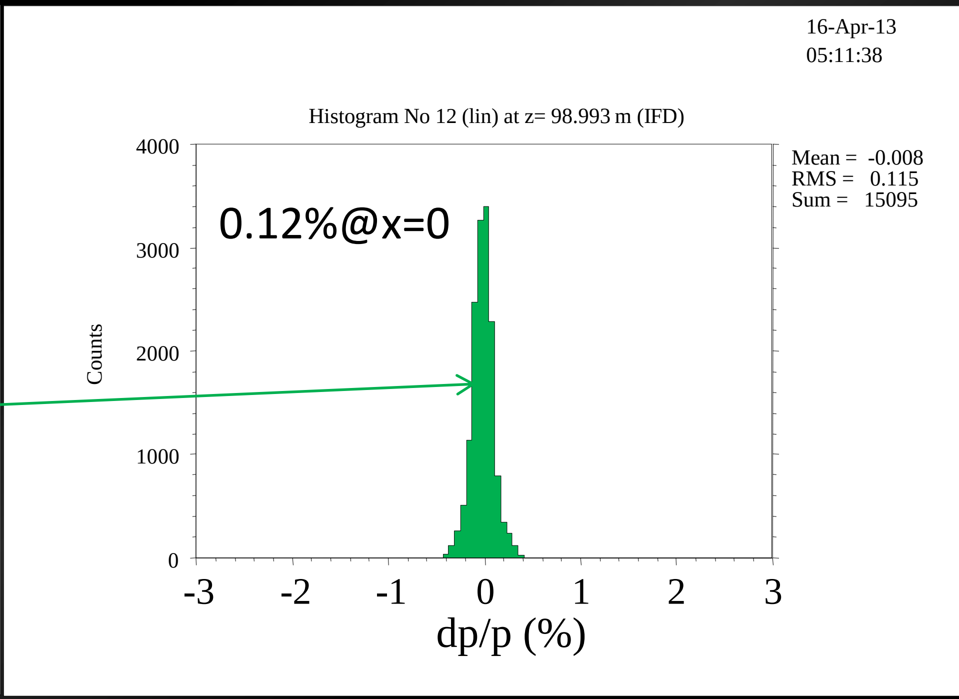


* Sanford-Wang:15 kW Loss on Pt, Acceptance :1.5 msr%, 133.2 m

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%



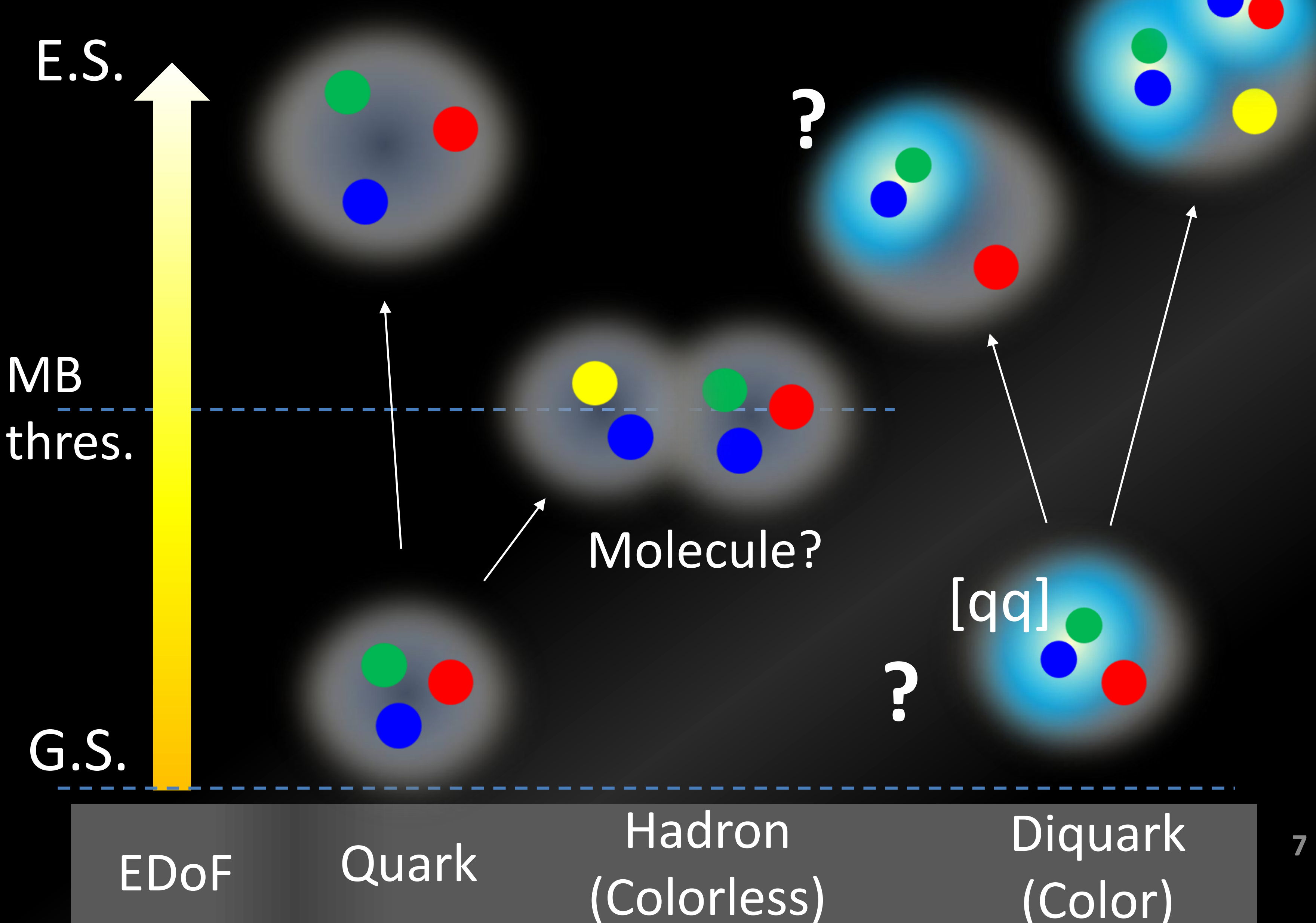


Beam correlation btw *p* vs *x* at DFP

Question in Hadron Physics

- How hadrons form from quarks (and gluons)
  - Non-perturbative nature of QCD
    - Chiral symmetry breaking and Confinement
  - Property of Hadron: mass, width, EM moments, …
  - Property of Hadronic matter: QCD phase diagram
- Spectroscopy
  - Effective DOF (quark, diquark, hadron, …) and correlations among them
  - Why they appear and form hadrons?
    - Current quark <-> EDOF <-> Hadrons?
  - How hadron properties change in matter
    - With respect to the environmental temperature and density

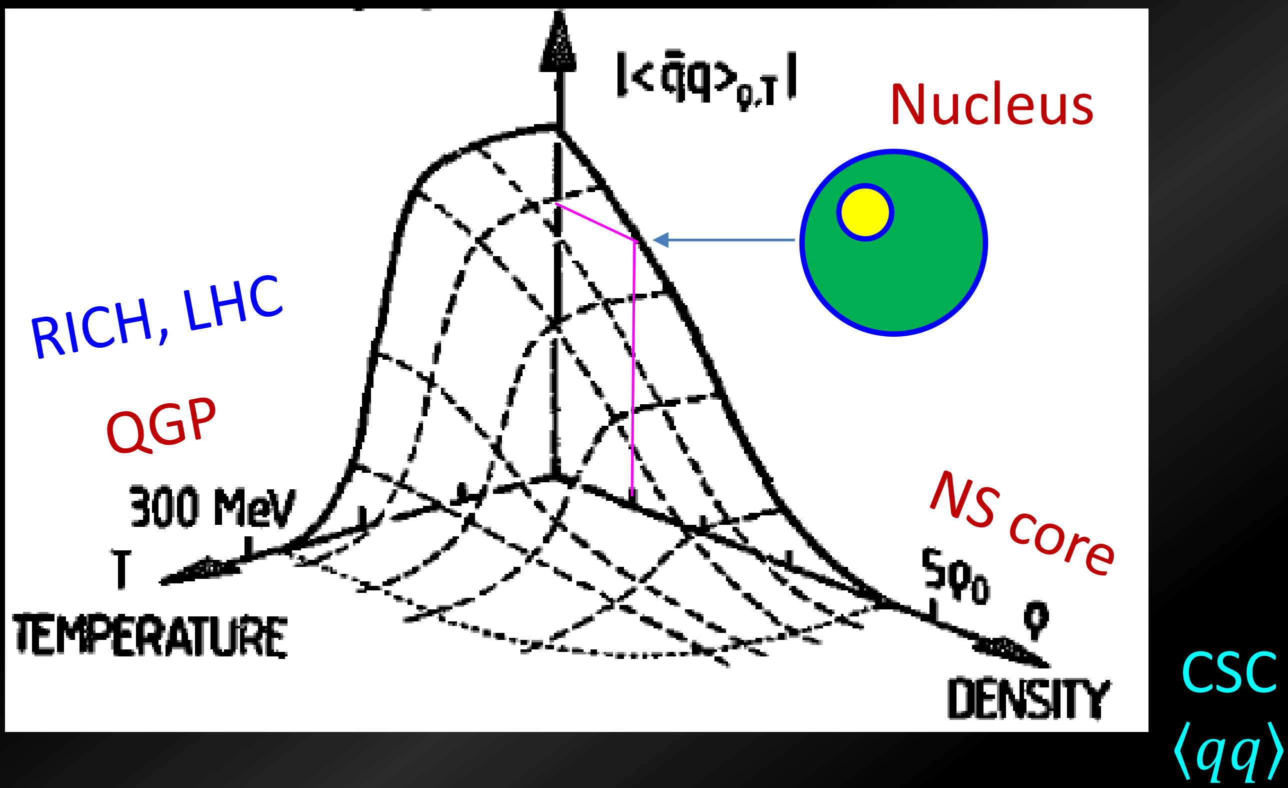
Hadron Structure



Spontaneous Chiral Symmetry Breaking

- Qualitative impression how $\langle \bar{q}q \rangle$ behaves with ρ and T.

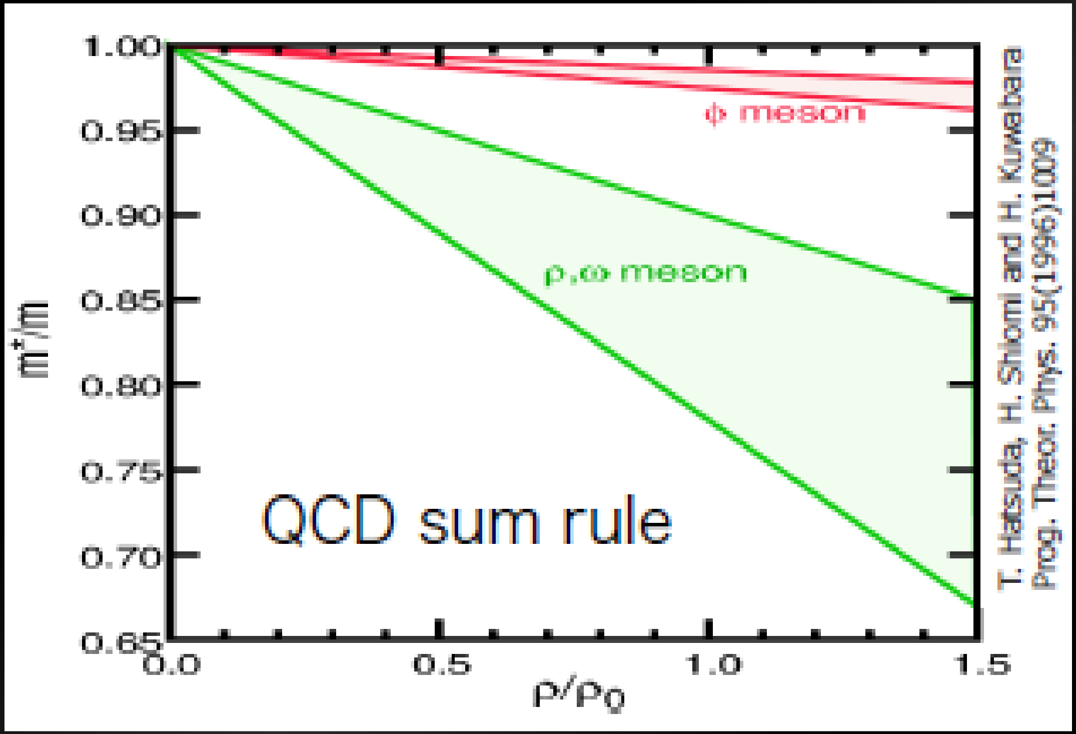
W. Weise, NPA553, 59(1996)



Spontaneous Chiral Symmetry Breaking

- Spectral changes of vector mesons in nuclear matter

  T. Hatsuda, H. Shiomi, and H. Kuwabara, PTP95, 1009(1996)

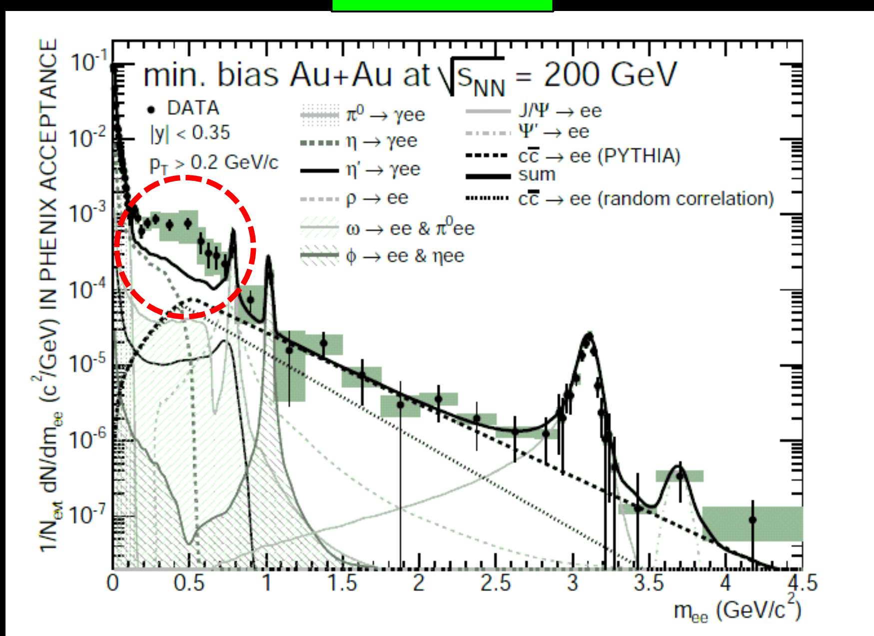


Hadrons in Nuclear Media

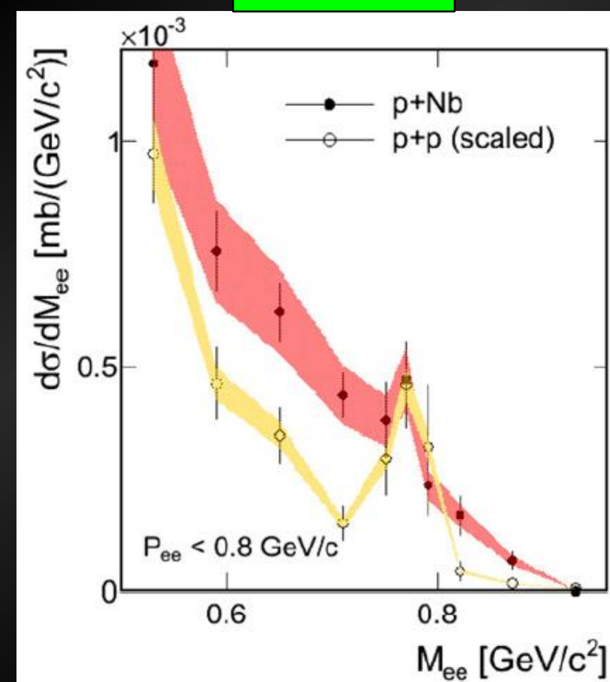
Meson in Nuclear Medium

- Dilepton decays of vector mesons in HIC/pA
  - Yield excesses are observed below ω

PHENIX



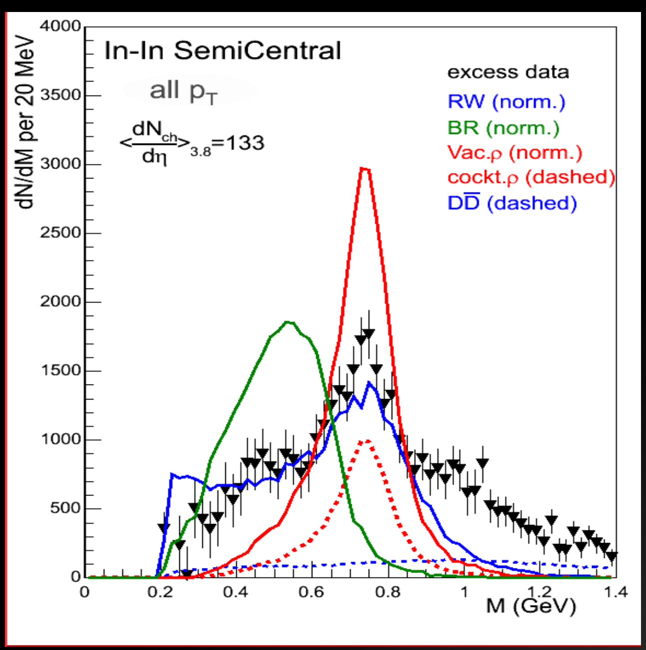
HADES



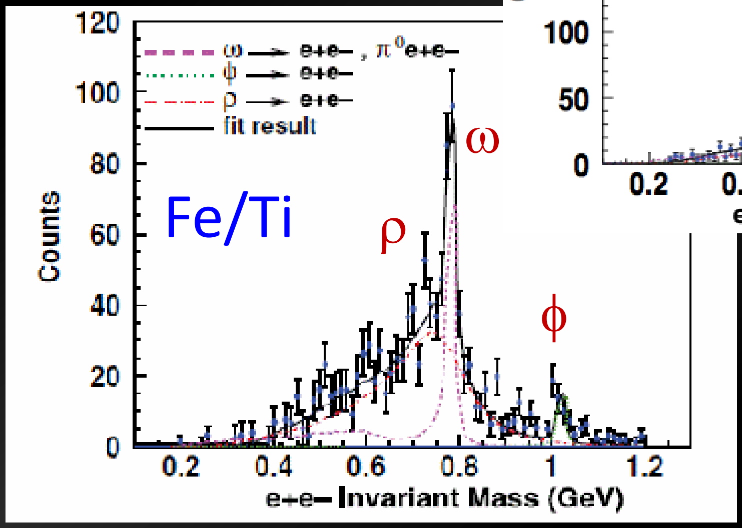
Meson in Nuclear Medium

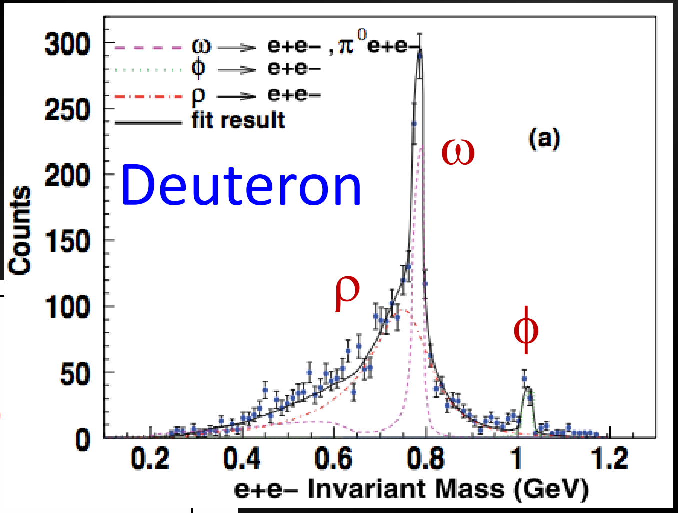
- Dilepton decays of vector mesons in HIC/γA
  - No mass shifts for ω/ϕ, collisional broadening for ρ

NA60



CLAS

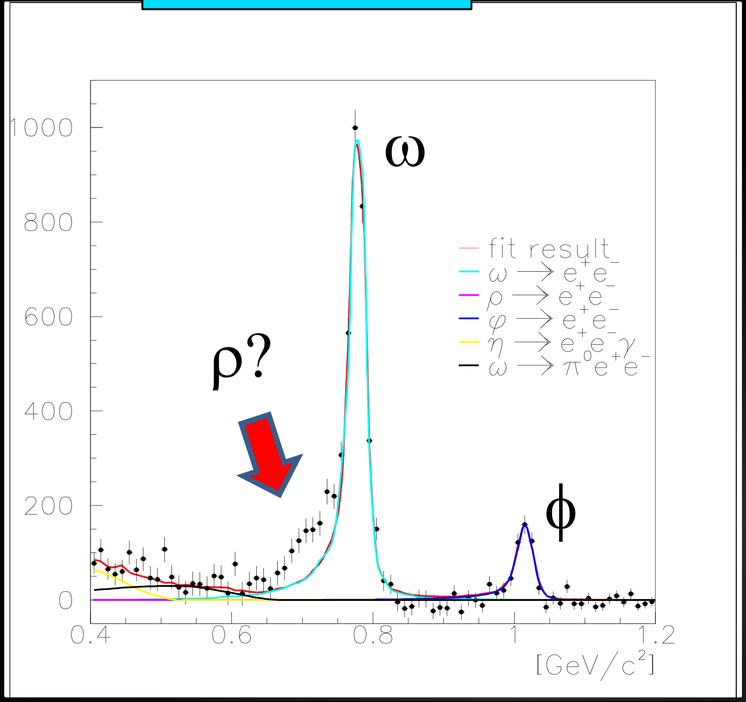




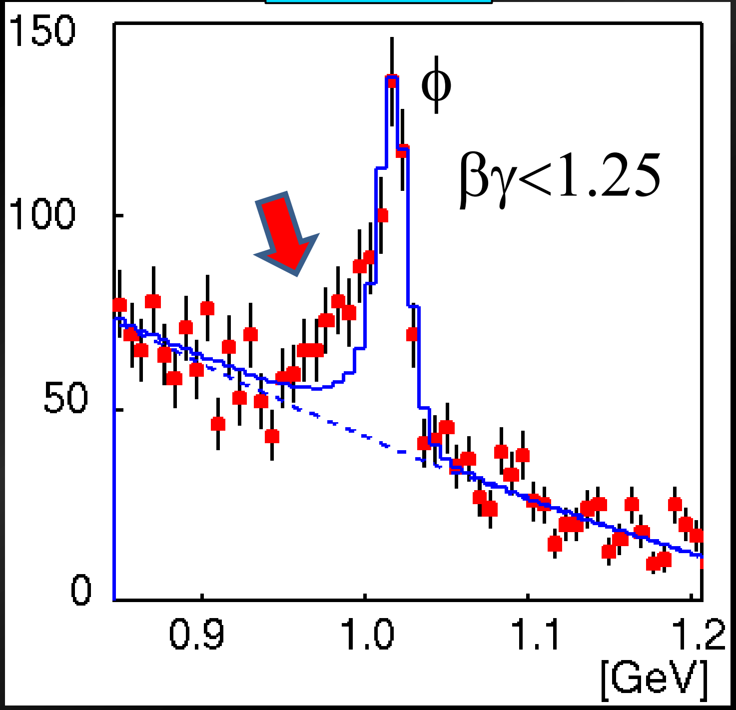
Meson in Nuclear Medium

- Dilepton decays of vector mesons in pA
  - Yield excesses are observed below ω/ϕ

E325 ρ/ω



E325 ϕ



Meson in Nuclear Medium

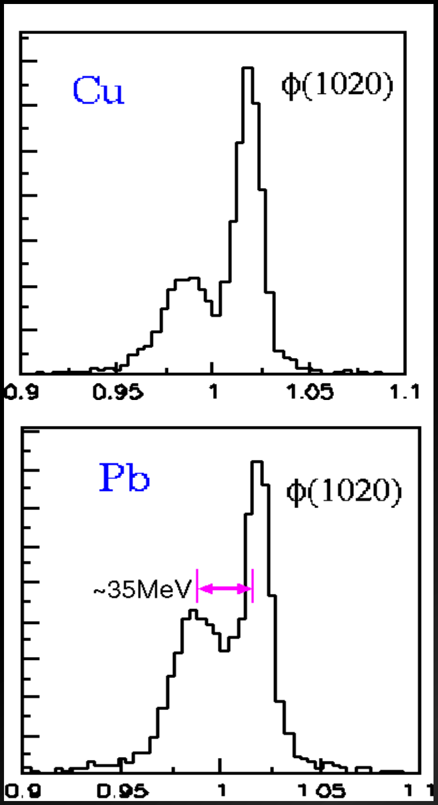
- Dilepton decays of vector mesons in AA/pA/γA
  - Yield excesses are observed below ω
  - No mass shifts for ω/ϕ, collisional broadening for ρ
- Dilepton decays of vector mesons in E325
  - Yield excesses are observed below ω/ϕ

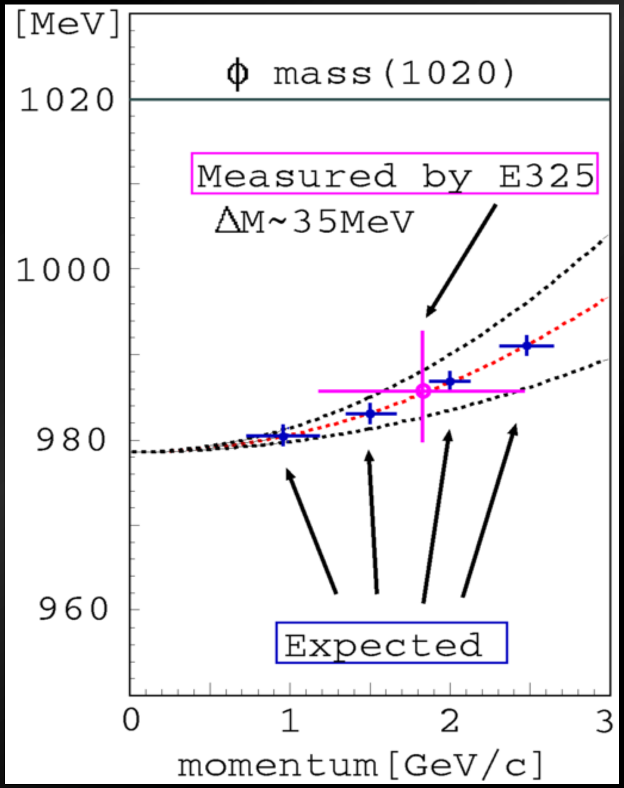
Controversial?

Need a precise experiment

J-PARC E16 Experiment

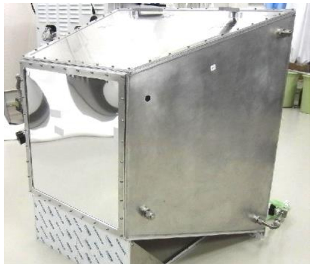
- pA → ϕ(ρ/ω)X, ϕ(ρ/ω)→e+e-
  - High resolution: 5 MeV (world best)
  - High statistics: x100 of E325 (100000ϕ's)

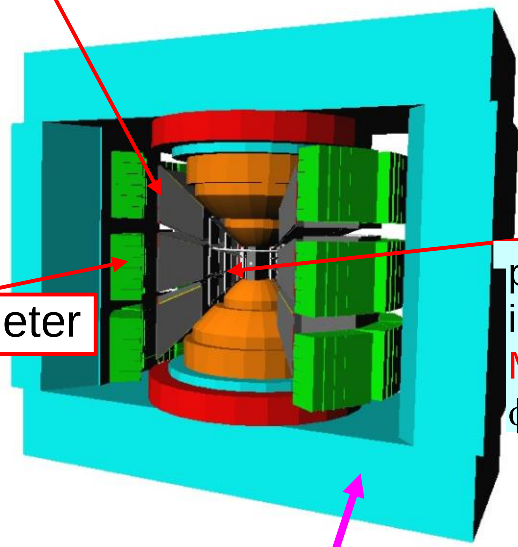


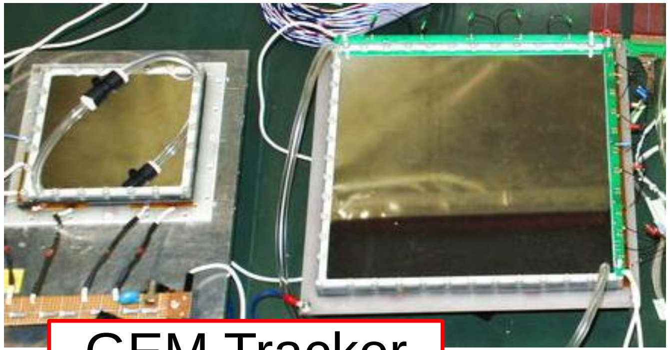


E16 : development & achieved performance

Hadron Blind Cherenkov Detector (HBD)

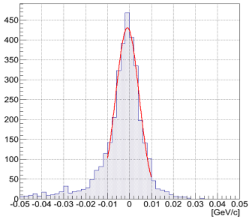






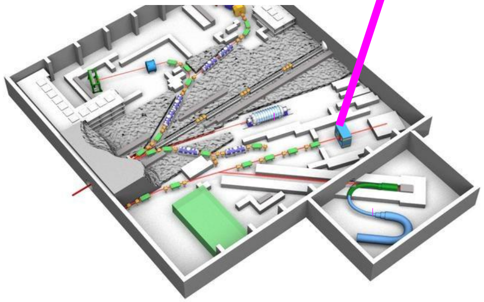
GEM Tracker

position resolution 100 μm is achieved to keep the ~5 MeV mass resolution for the ϕ mesons.



Lead-Glass EM Calorimeter

pion suppression down to ~0.1% is achieved with the combination of the two stage of electron-ID counters; HBD & LG

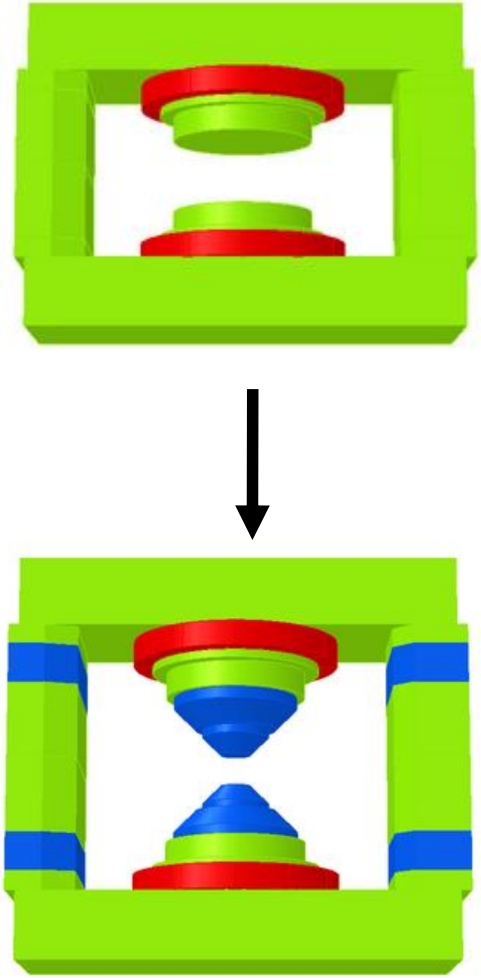


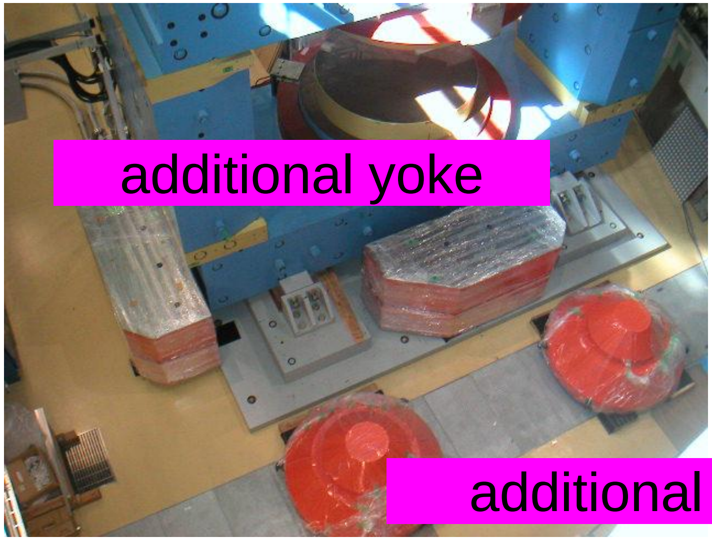
The spectromter magnet should be re-constructed and located at the new High-momentum beam line, which is under construction and completed in JFY 2016.

Experiment will start in early 2017.

Spectrometer Magnet

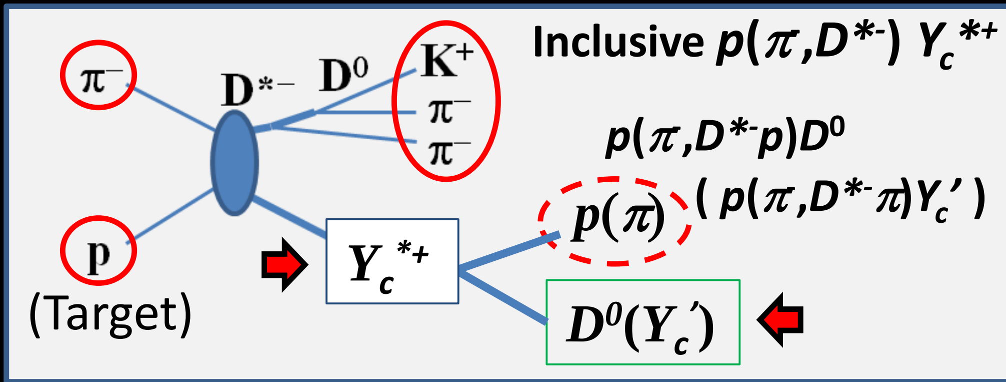
delivered in 2012
(by R. Muto)





Charmed Baryons

CHARM Spectrometer



Cross Section:

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

Acceptance:

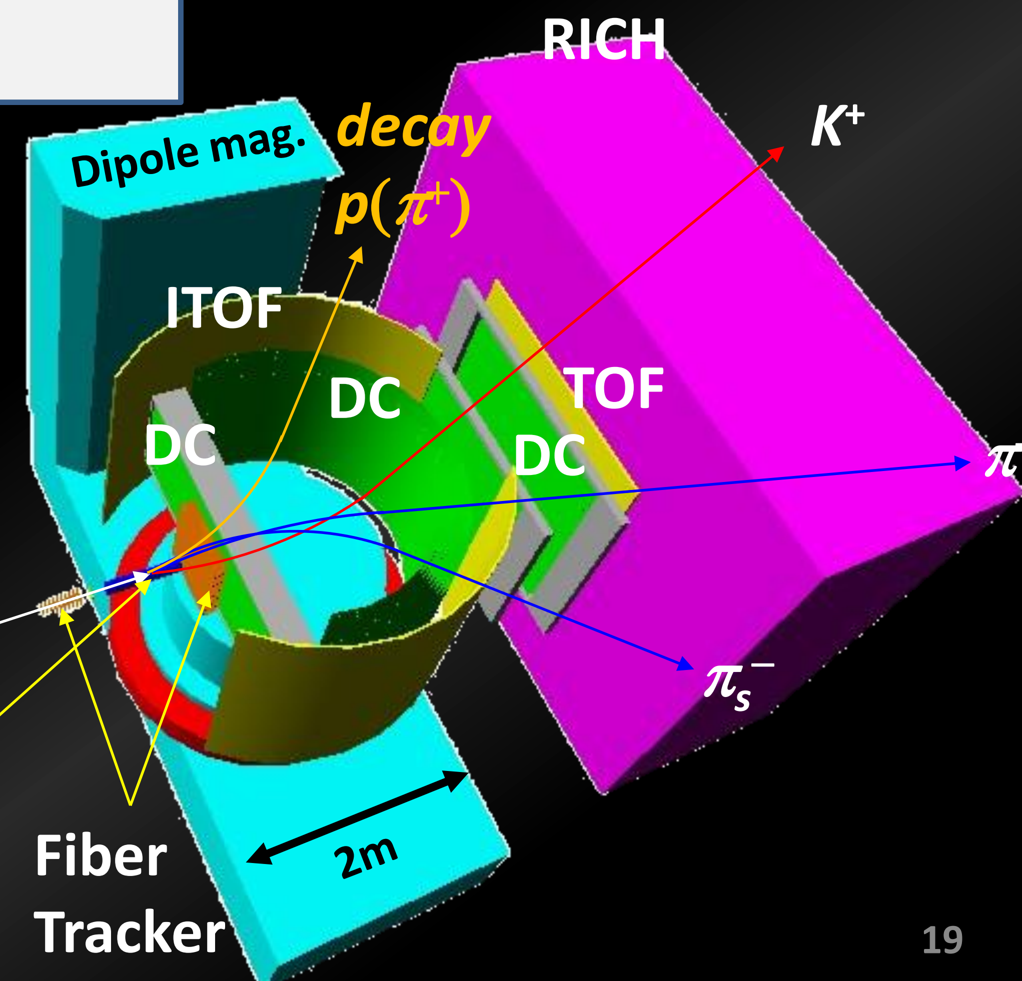
~ 60% for D^*,

~ 80% for decay π^+

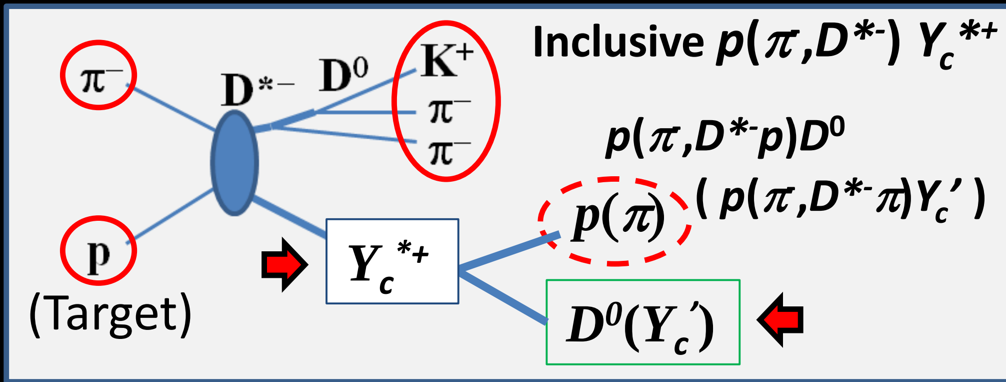
Resolution:

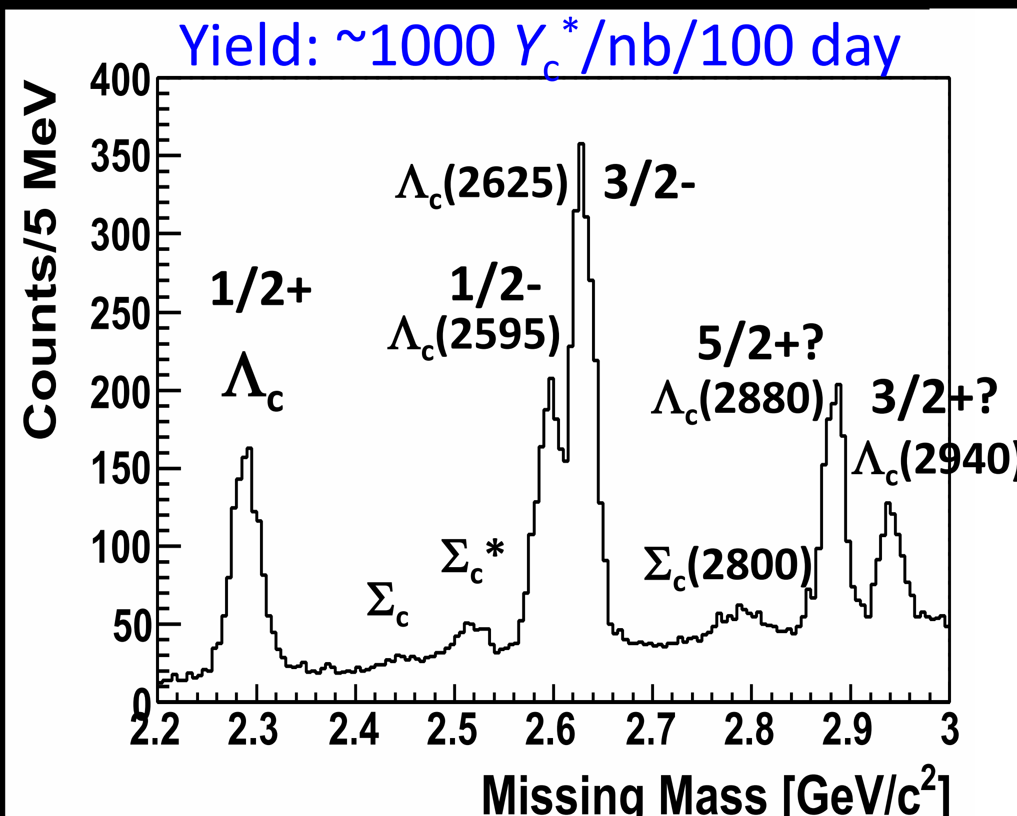
$\Delta p/p \sim 0.2\%$ at ~5 GeV/c

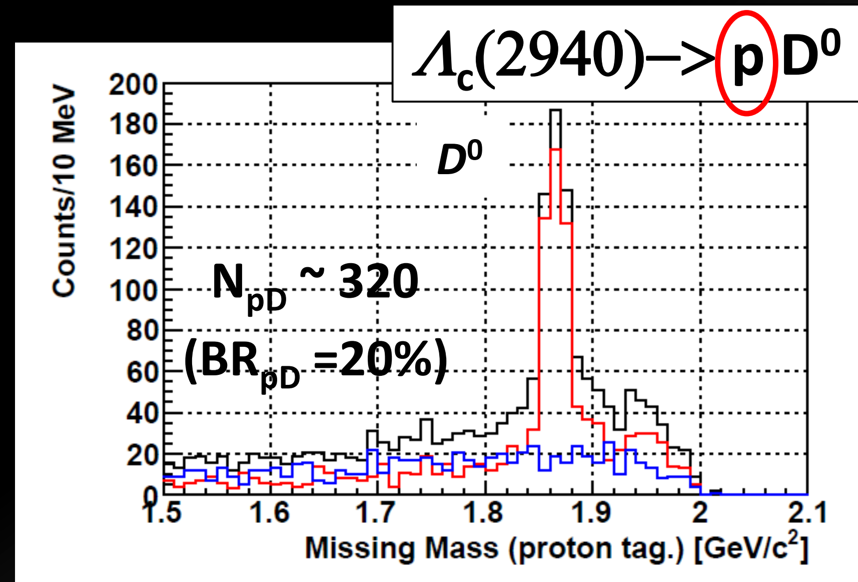
(Rigidity: ~2.1 Tm)

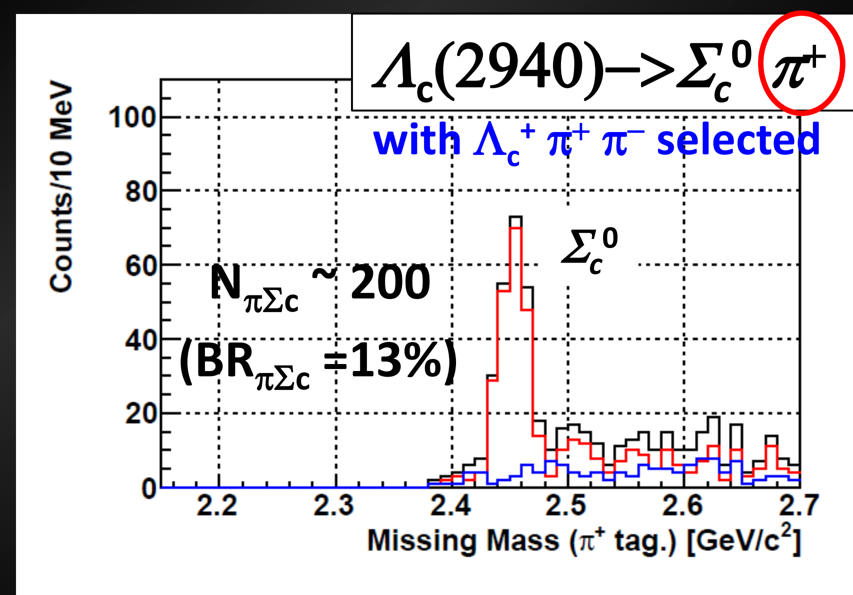


Inclusive Spectrum and Decay Mode ID (Sim.)

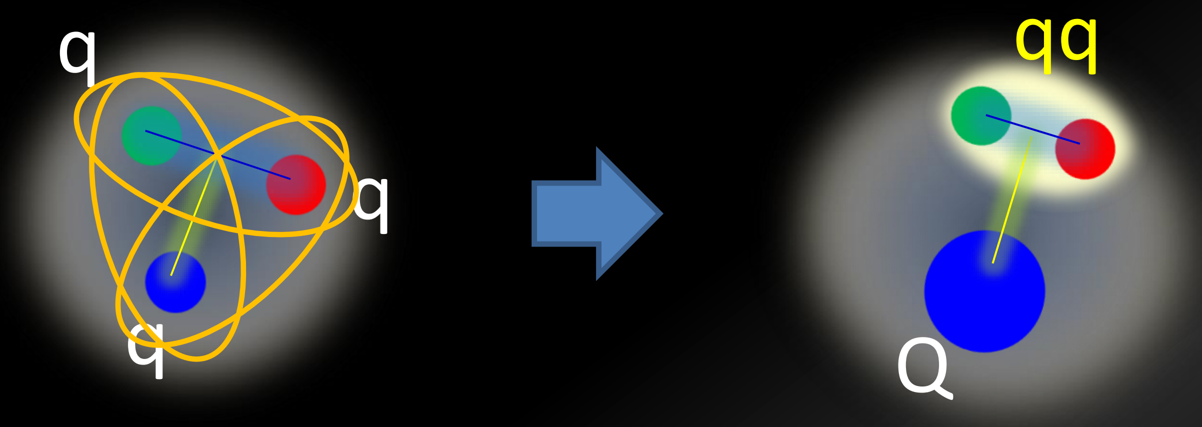








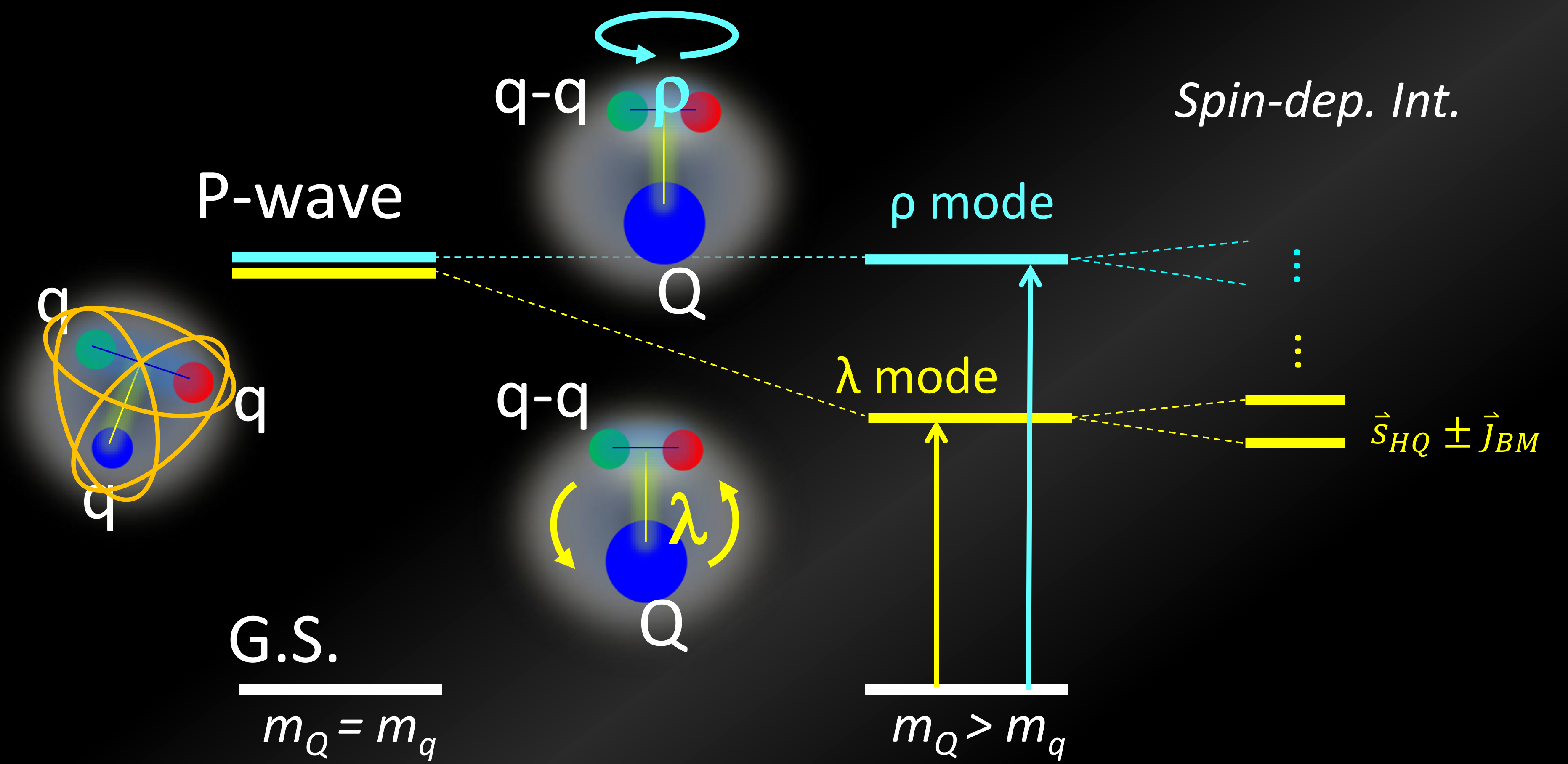
What we can learn from baryons with heavy flavors



- 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.

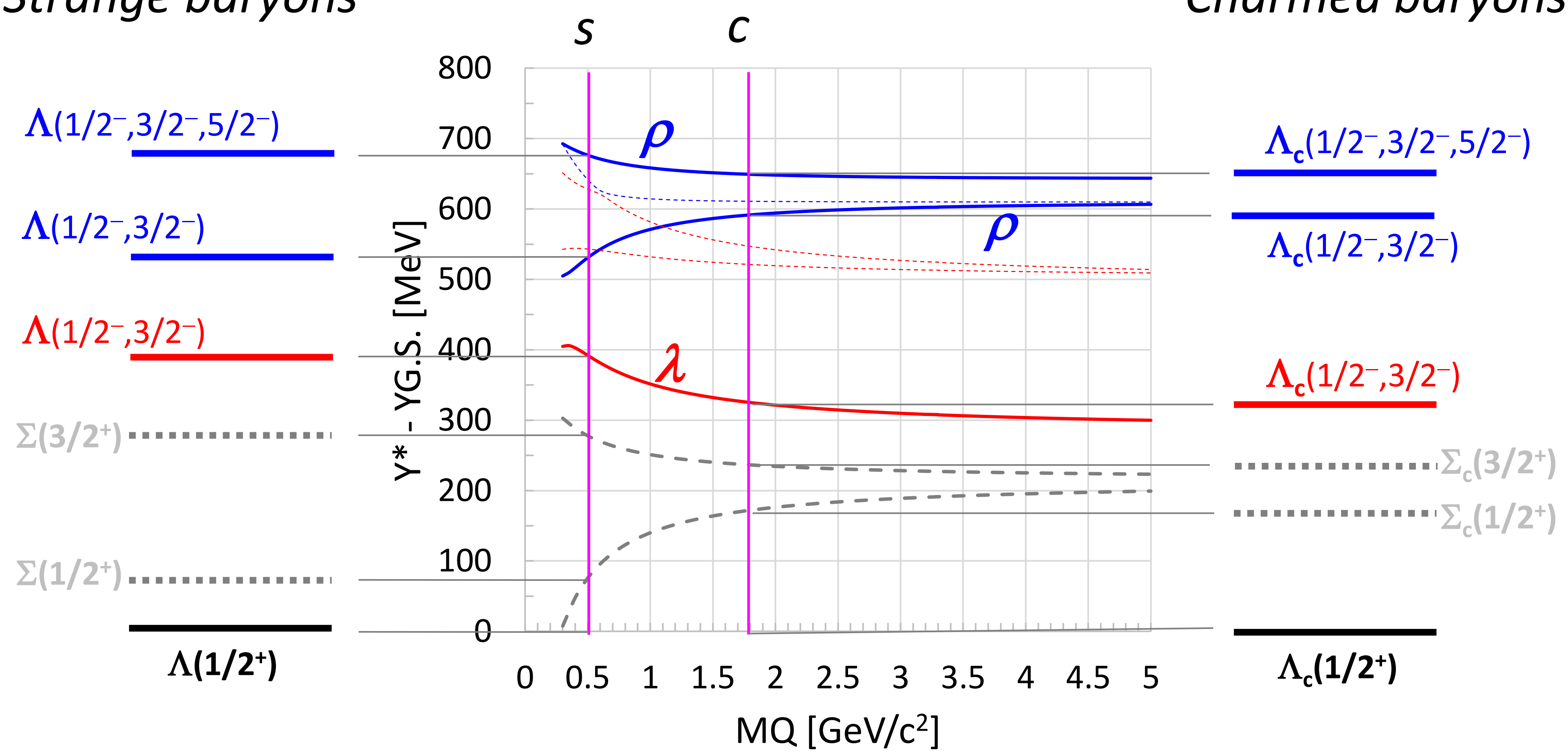
Schematic Level Structure of Heavy Baryons

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



CQM calculation (Lambda)

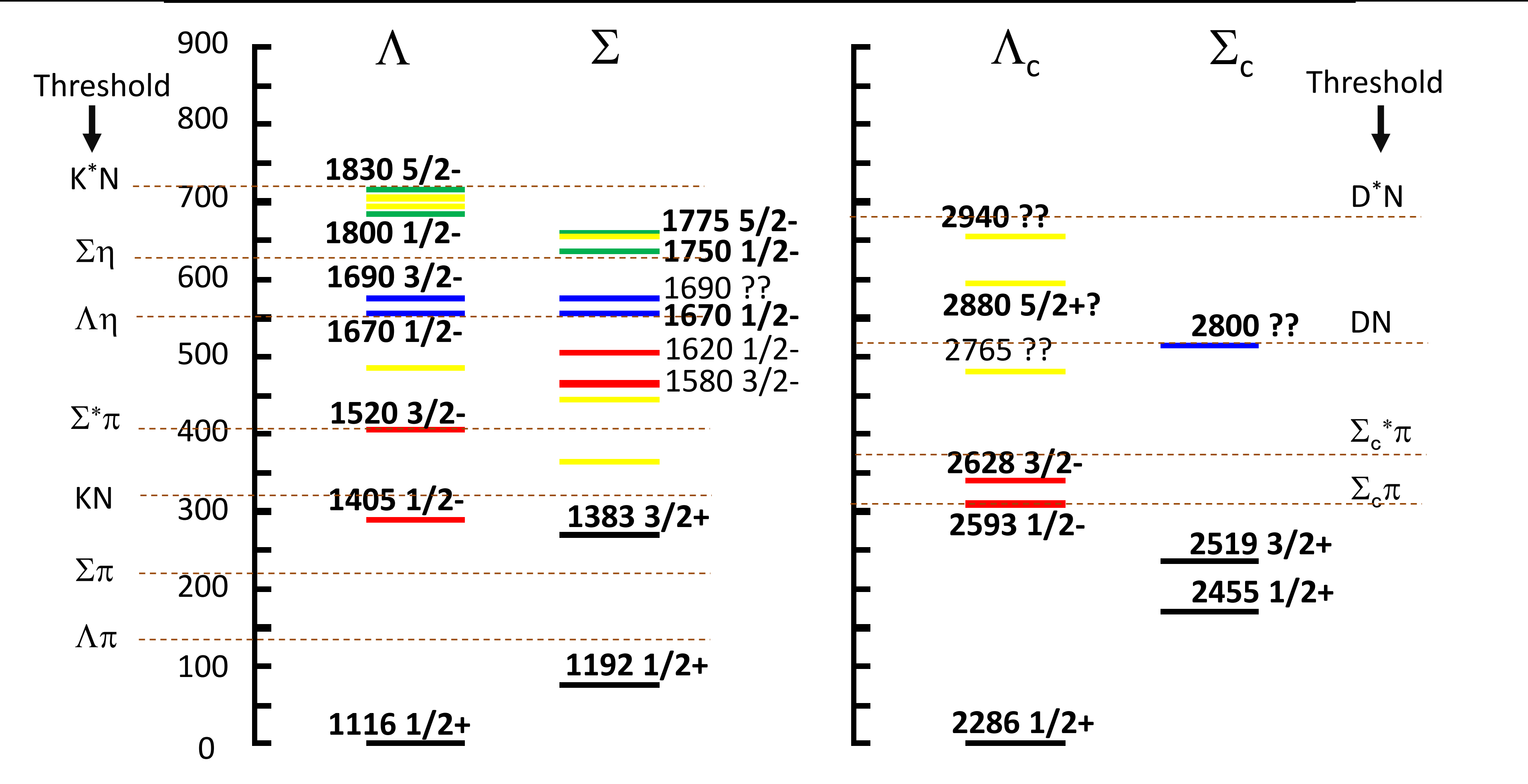
Strange baryons *Charmed baryons*



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

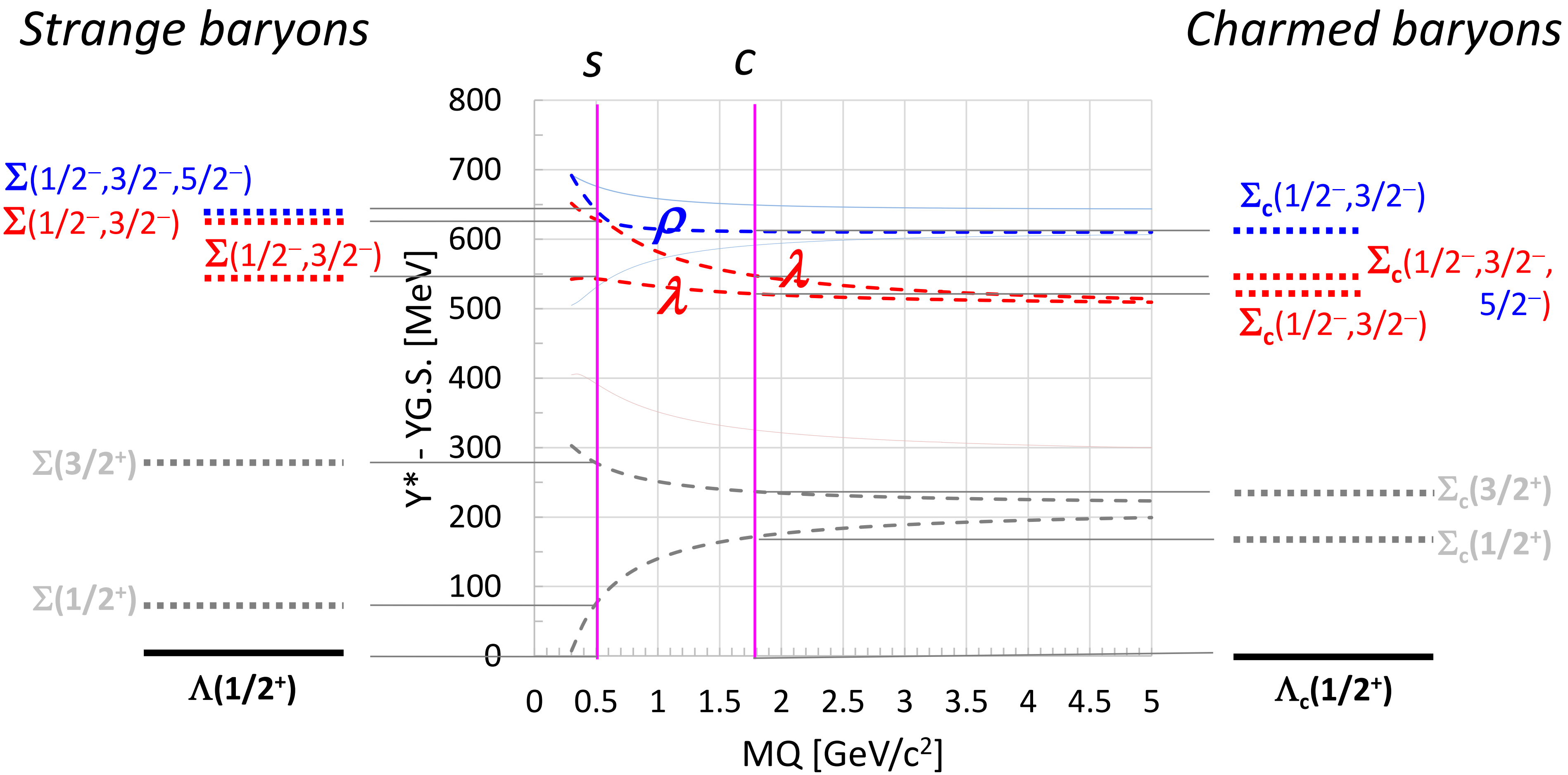
ρ–λ mixing (cal. By T. Yoshida (Tokyo I. Tech.)

Level structure (Exp.)



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

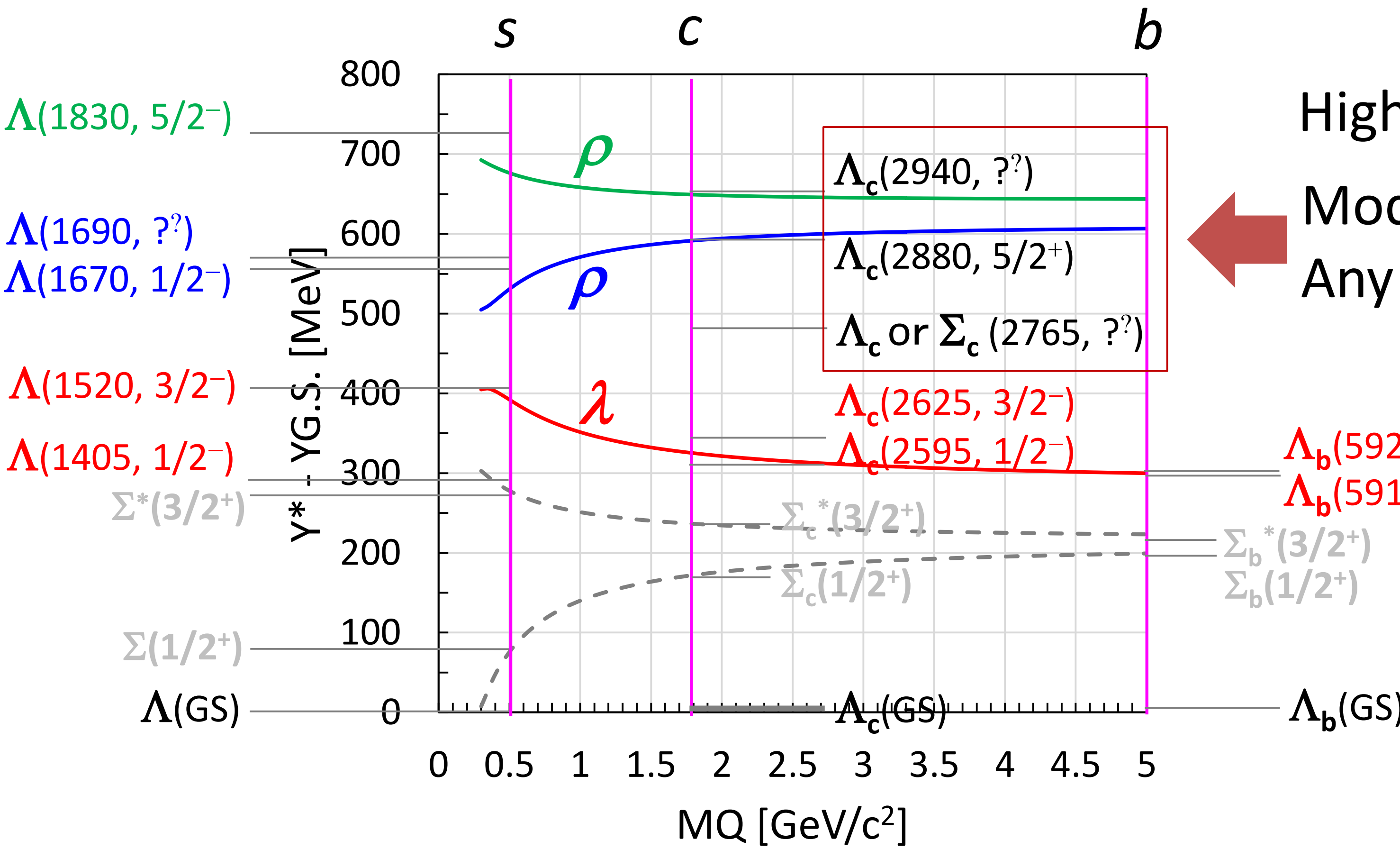
CQM calculation (Sigma)



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

ρ–λ mixing (cal. By T. Yoshida)

Lambda Baryons



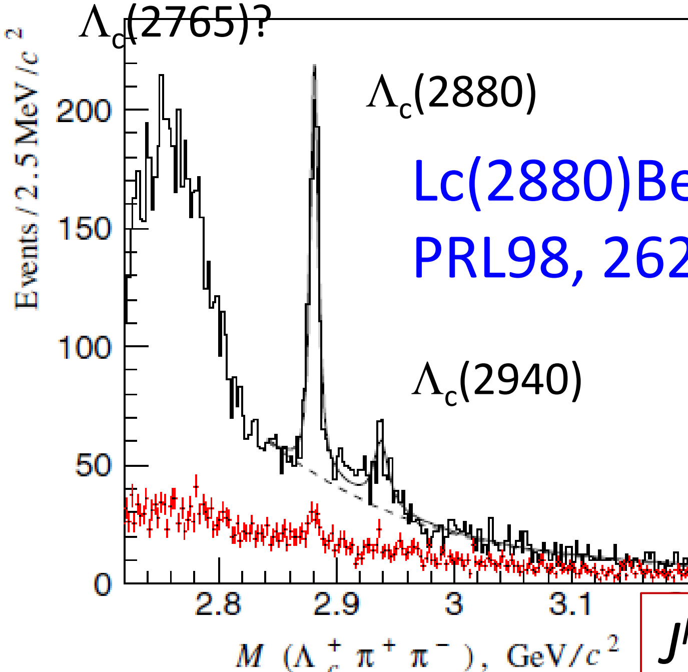
Higher L?

Mode?

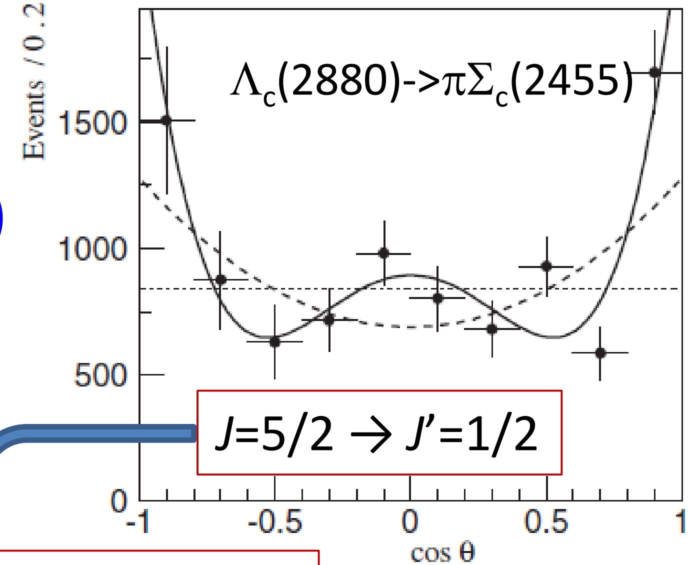
Any others?

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

ρ–λ mixing (cal. By T. Yoshida)

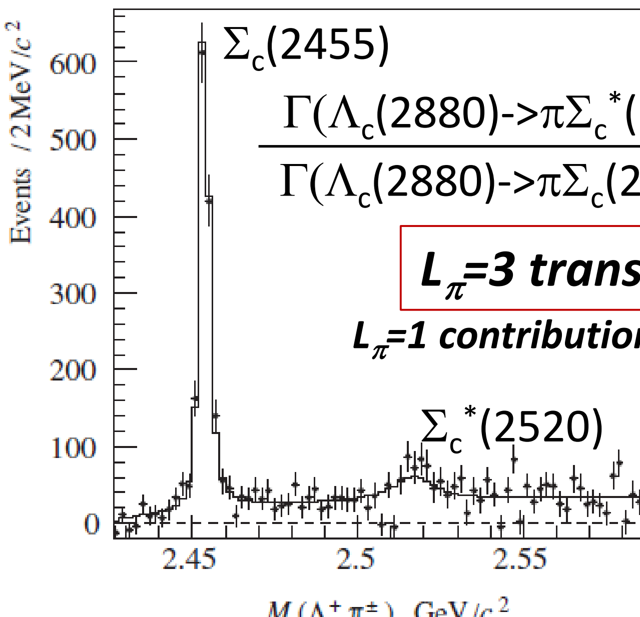


Lc(2880)Belle,
PRL98, 262001('07)



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

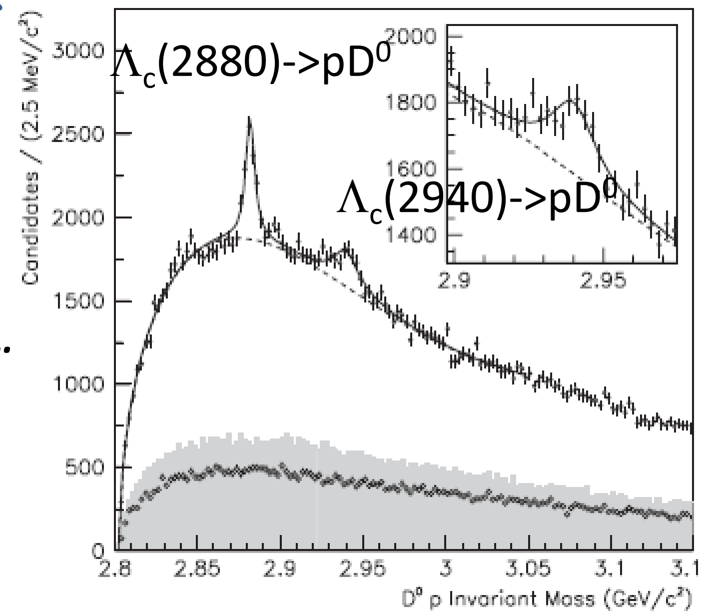
$J^P=5/2^+$ for $\Lambda_c(2880)$



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

L_π=3 transition

L_π=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; $\Delta E(J^{\wedge},J_{v}) \sim (2L+1)/2$
    - $\Delta E(5/2^+,3/2^+)/\Delta E(3/2^-,1/2^-)=5/3$

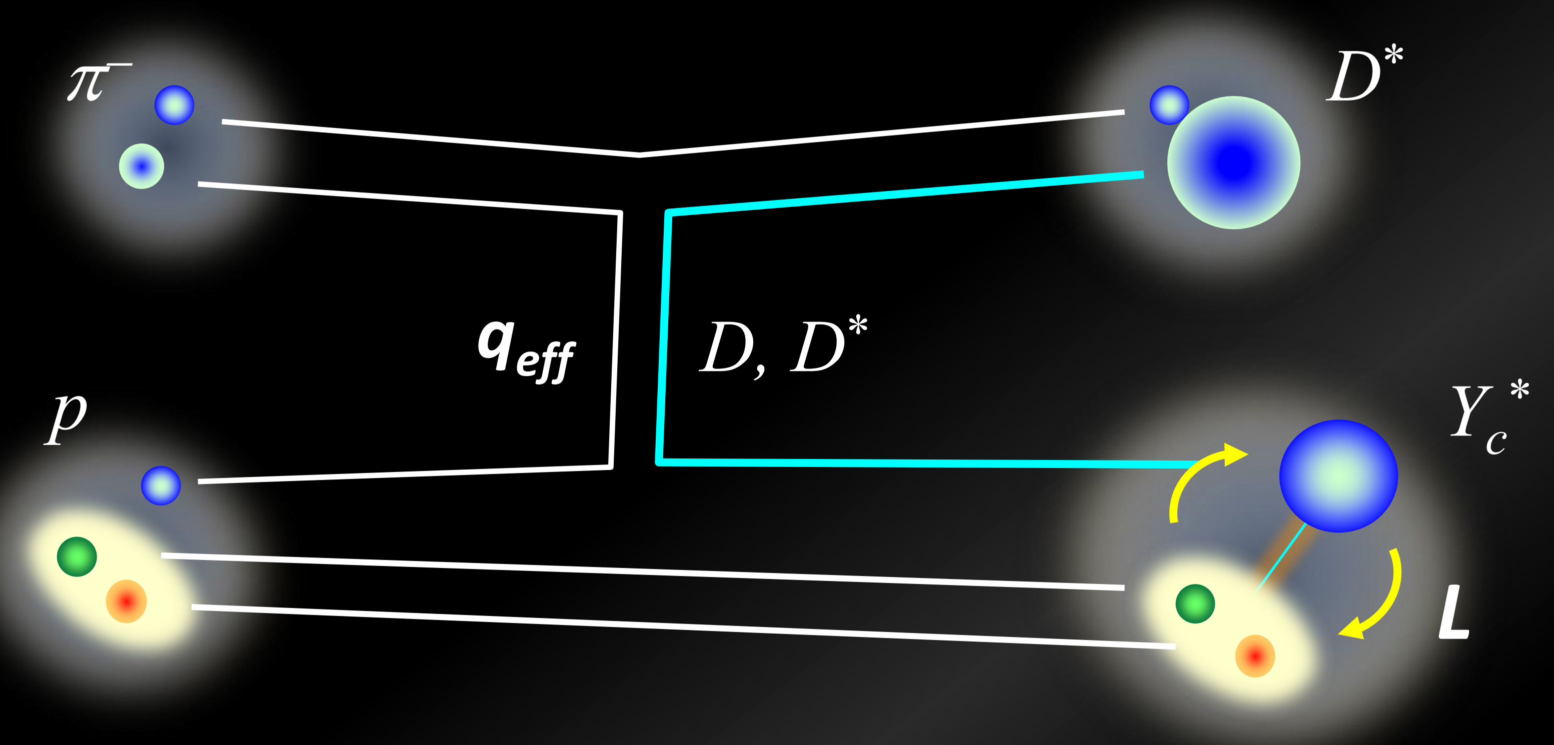
      c.f. exp. 60 MeV/35 MeV~5/3 seems consistent?
- If they are ***λ*** mode excited states w/ $L_{(\lambda)}=2$...
  - $\Lambda_c(2880)$:$5/2^+$, $\Lambda_c(2940)$:$3/2^+$, possibly

    → [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

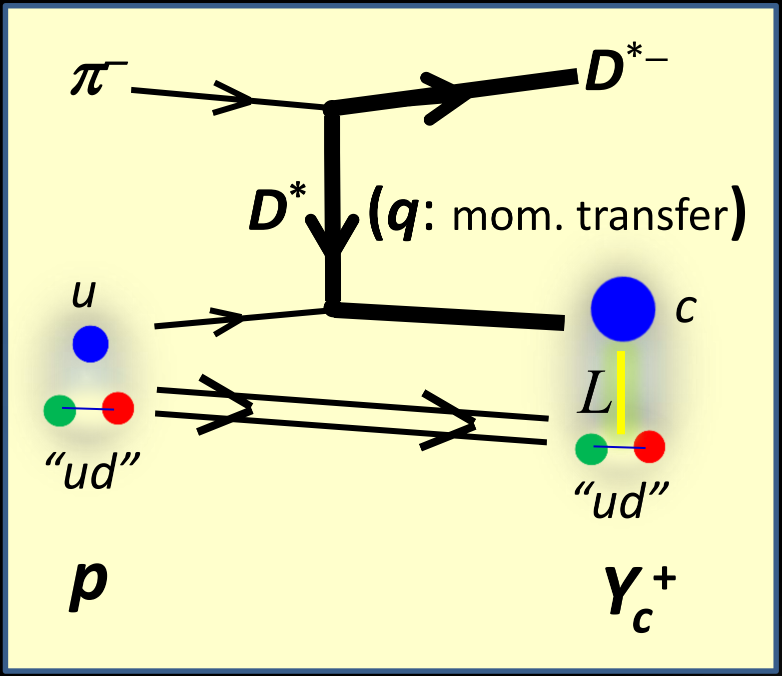
Production Rate

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

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

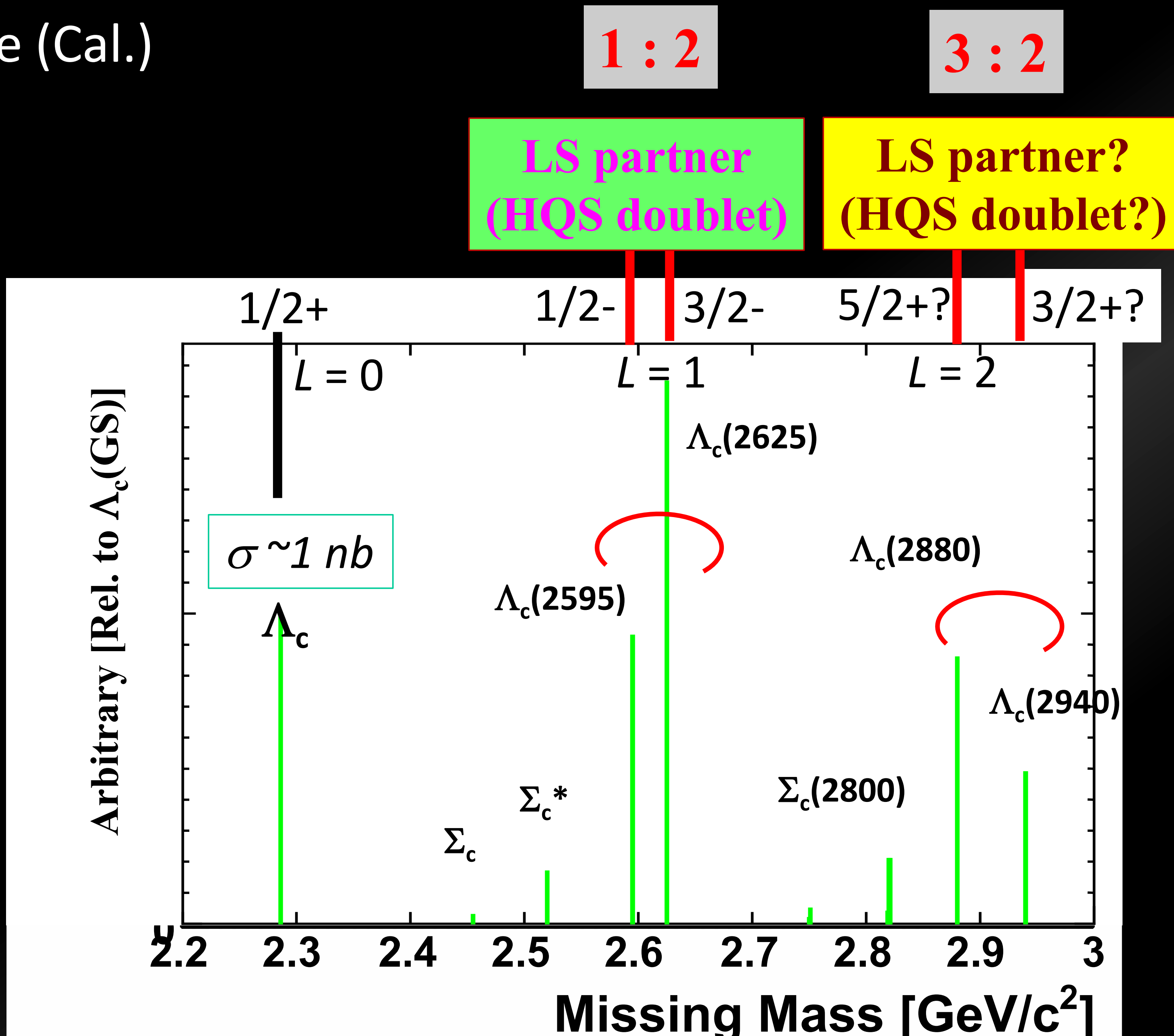
and depend on:

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

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

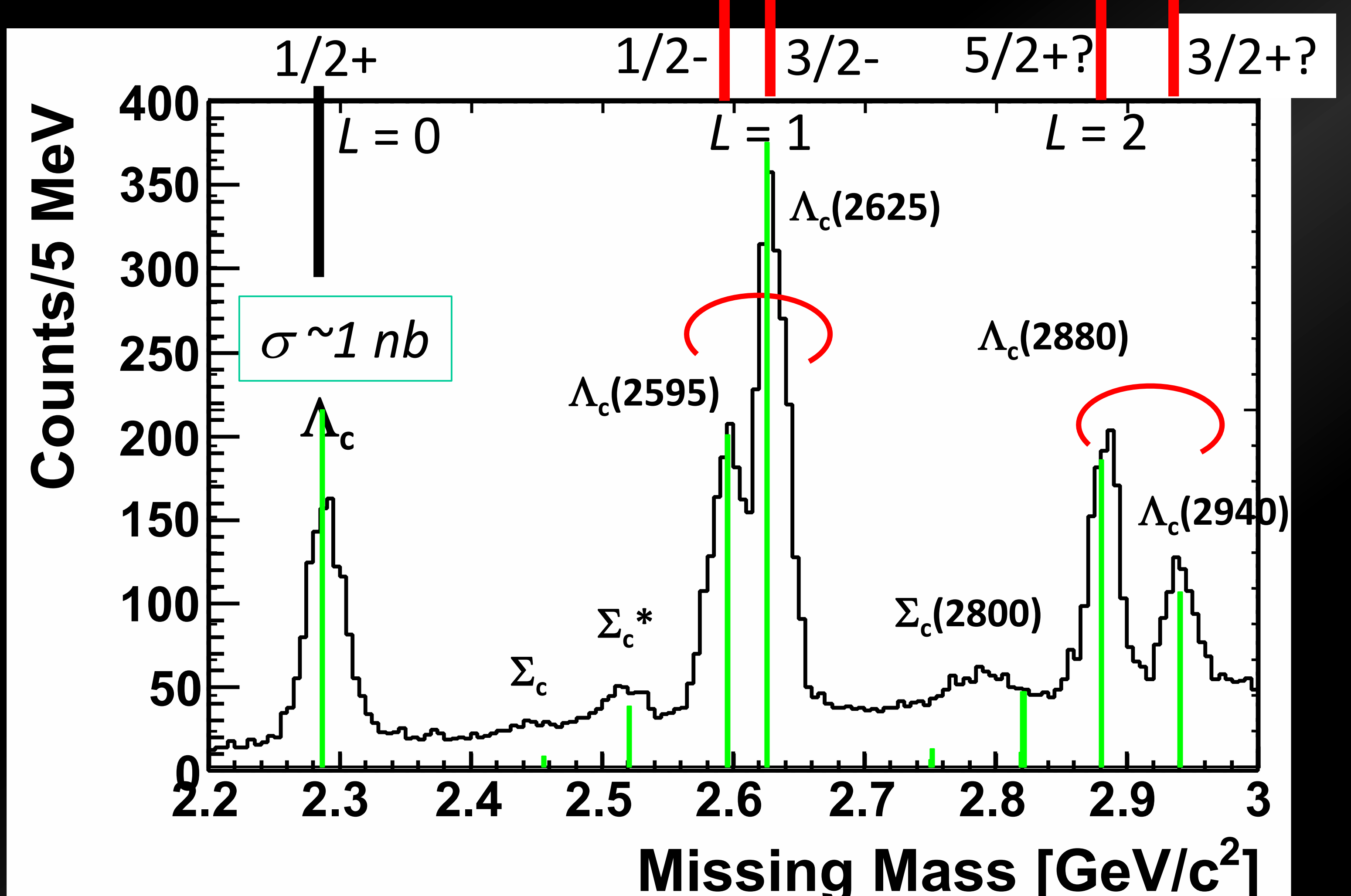
A: (baryon size parameter)$^{-1}$

Prod. Rate (Cal.)



Missing Mass Spectrum (Sim.)

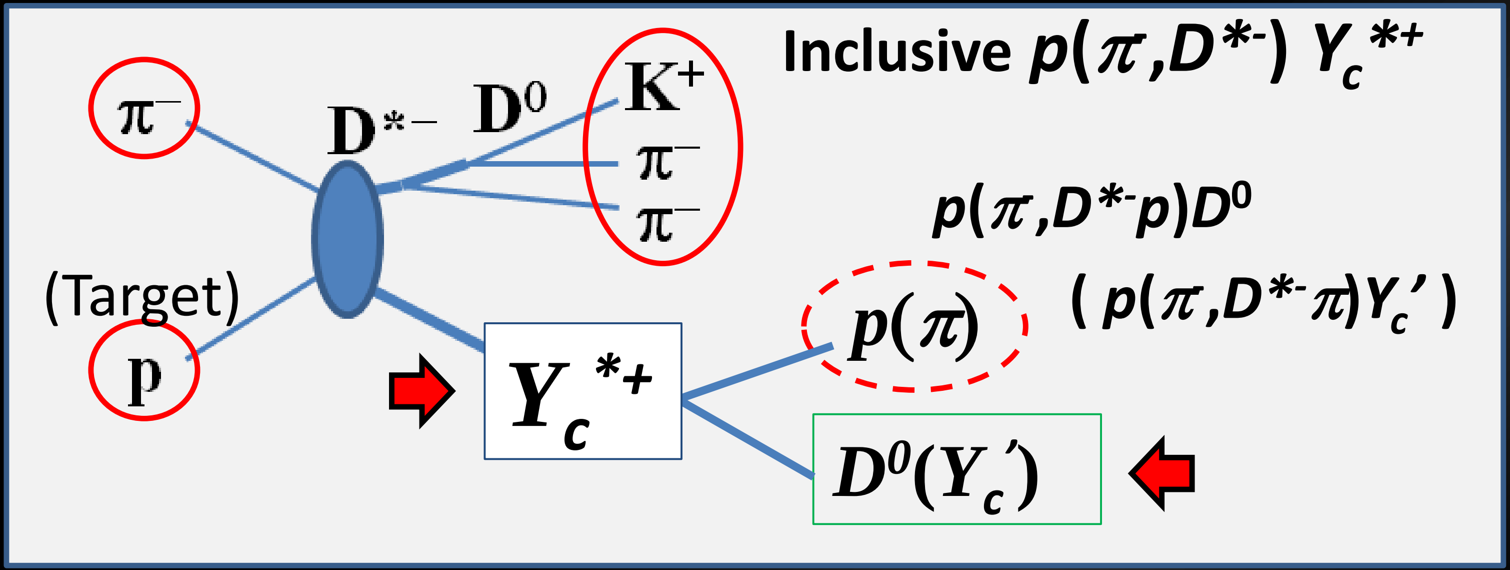
- ~1000 Y_c^*/nb/100 days
- Sensitivity: σ ~0.1 nb for Y_c^* w/ Γ=100 MeV



Strange Hyperons

Strange Baryon Spectroscopy

Using Missing Mass Techniques

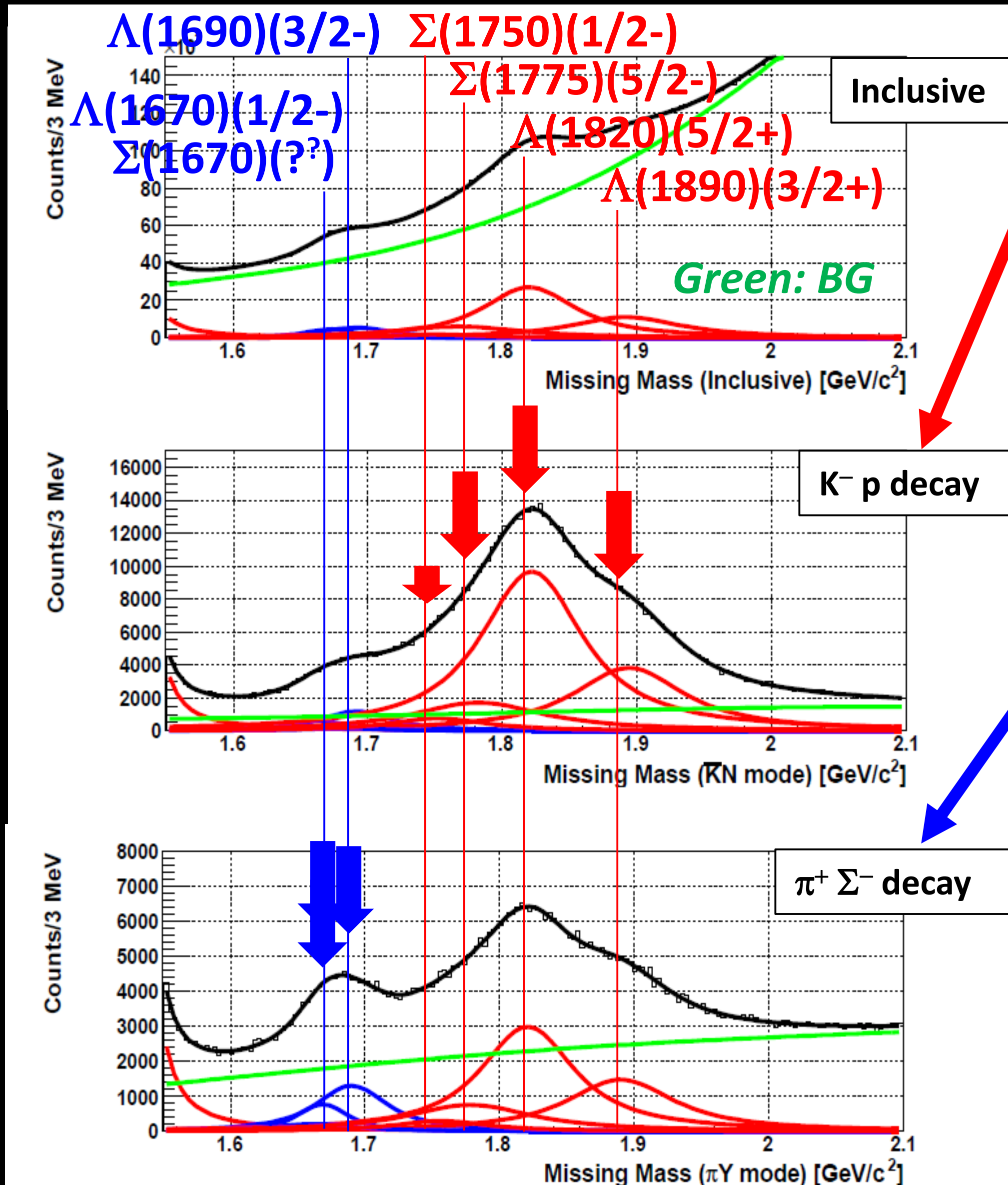


- S=-1 Hyperon *by* $p(\pi^-, K^*)$, $Y^* \to pK$, πY
- S=-2 Hyperon *by* $p(K^-, K^*)$, (K^-, K), (π^-, KK^*), $\Xi^* \to YK$, $\pi\Xi$

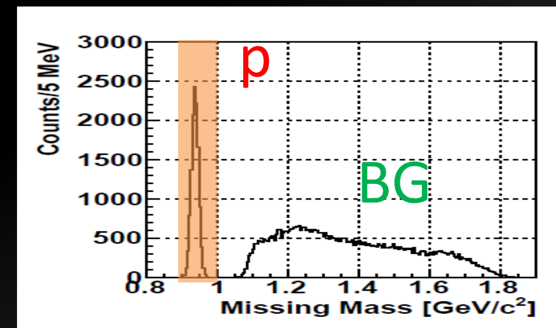
x1000~10000 better statistics than Y_c^*

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

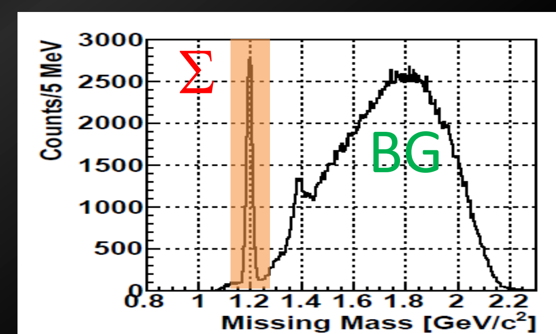
Simulation w/ 4×10^{11} pions (3 days)



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



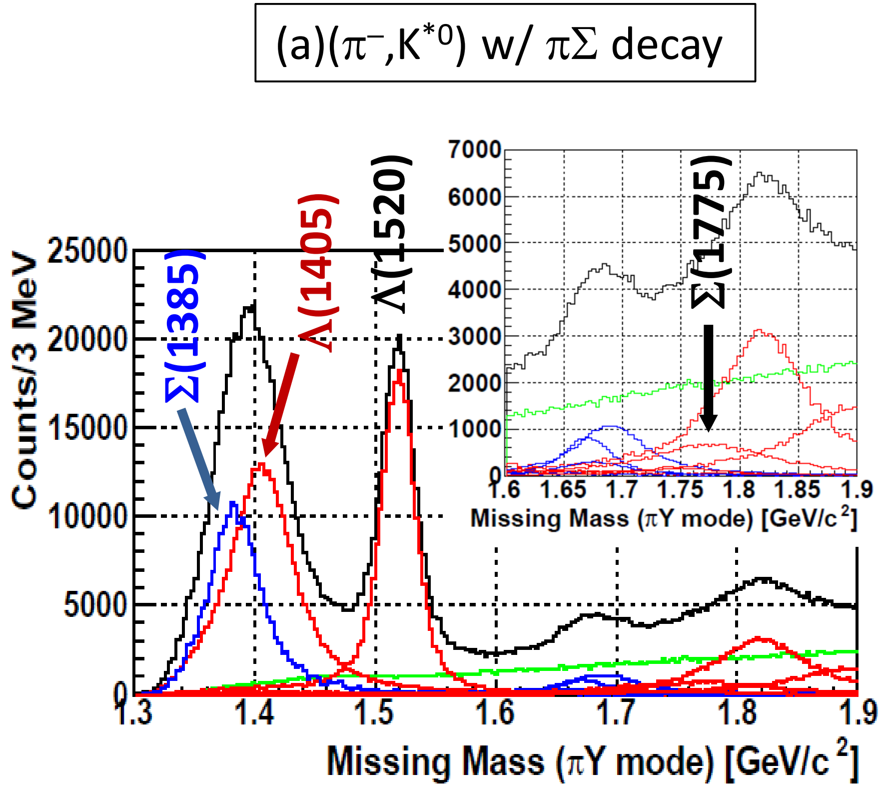
- *$X \rightarrow \pi^+\Sigma^-$* decay
  - π^+ tagged, Missing "Σ" gated

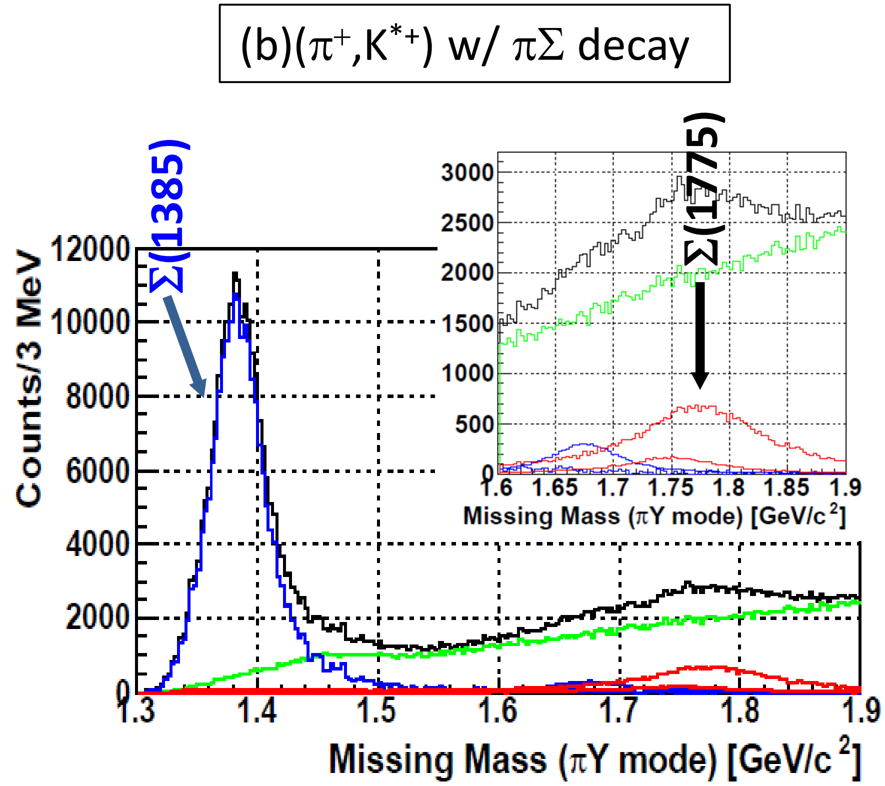


Strange Baryons

I = 0, 1

I = 1 only





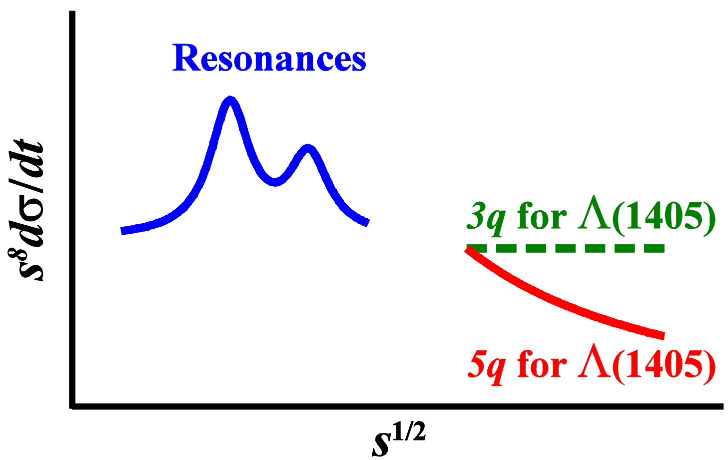
✓ Contribution of $\Sigma(1385)$ can be subtracted to extract the $\Lambda(1405)$ amplitude.

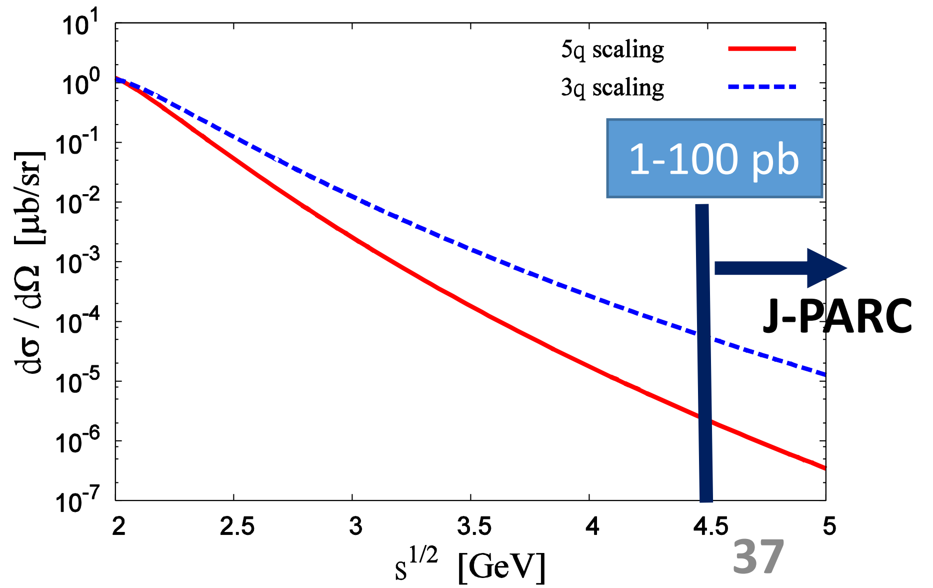
Quark Degrees of $\Lambda(1405)$

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

- Quark counting rule
- $d\sigma/d\Omega(90^o) \propto 1/s^{n-2}$

$$\pi^- + p \rightarrow K^0 + \Lambda(1405)$$

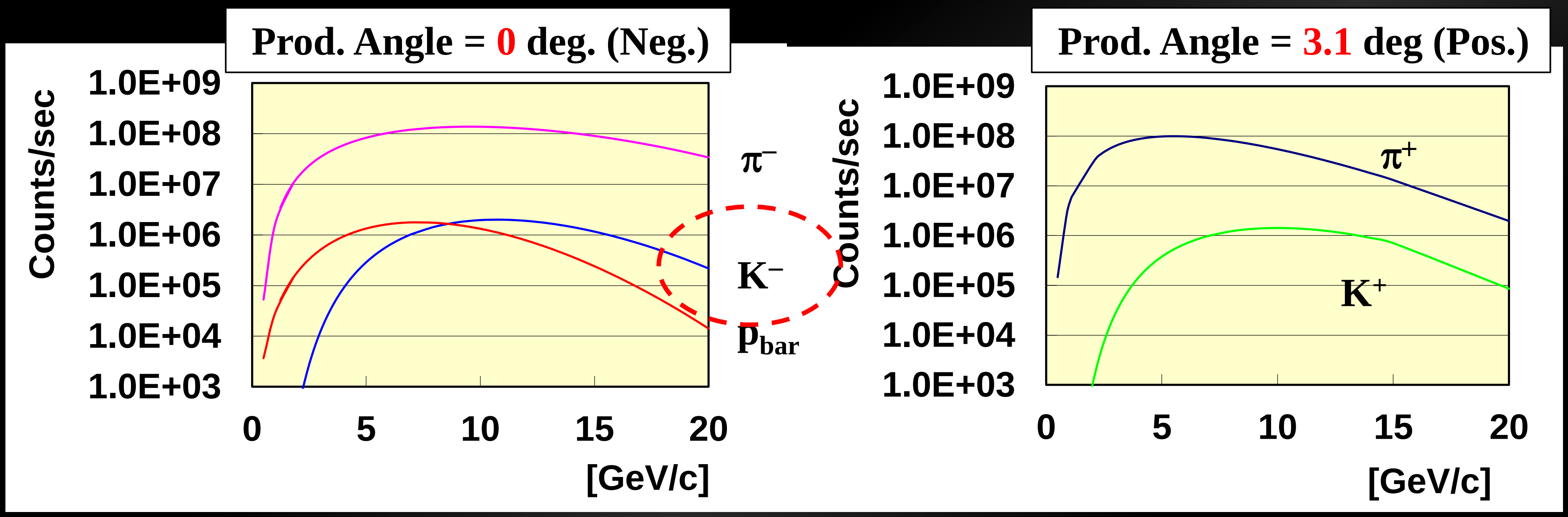




High-res., High-momentum Beam Line

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

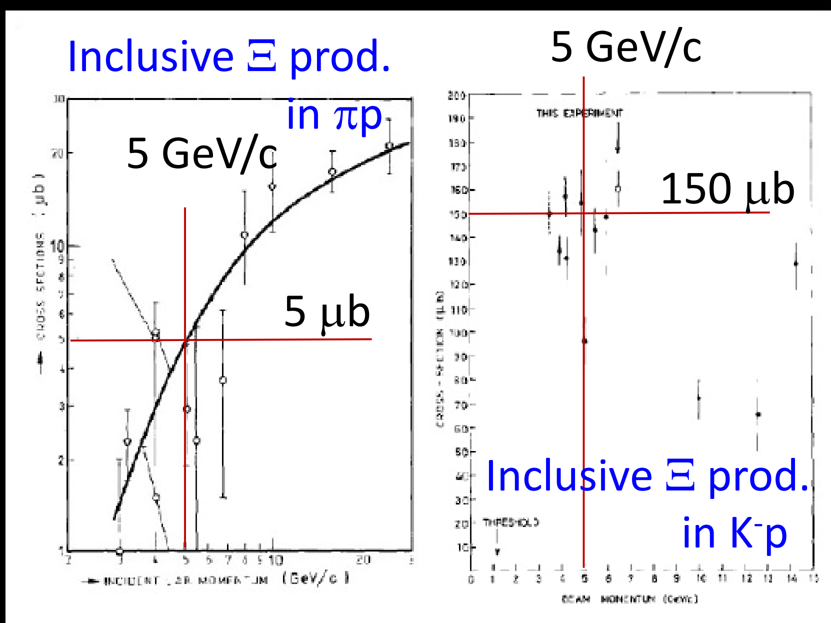
LoI submitted by M. Naruki and K. Shirotori

- Sizable yields are expected for a month.

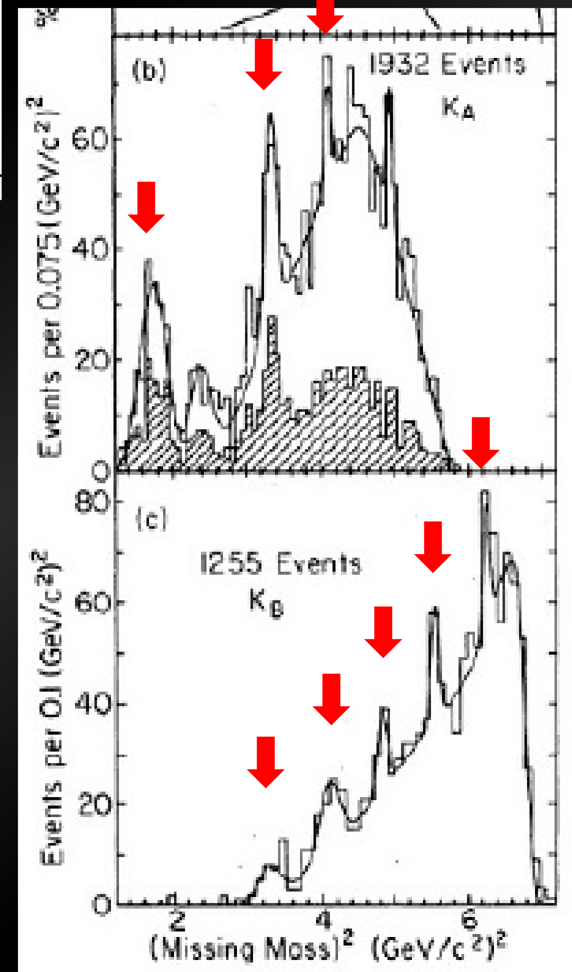
Reaction	σ [μb]	Beam [/spill]	B.R.	Acceptance [%]	Y_{Total}	$Y_{Decay/bin}$
$K^-p \to \Xi^{*-}K^+$	1.0	10^6	1.0	50	3.1×10^5	2500
$K^-p \to \Xi^{*-}K^{*+}$	1.0	10^6	0.23	50	0.7×10^5	580
$K^-p \to \Xi^{*0}K^{*0}$	1.0	10^6	0.67	50	2.1×10^5	1700
$\pi^-p \to \Xi^{*-}K^{*0}K^+$	0.1	10^7	0.67	50	3.1×10^5	2500

- 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)

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

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

$\Xi^*\pi$(1665)

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

Ξπ(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* -> πΞ* decay seems to be suppressed?
  - ✓ expected to reflect QQq configuration.

Summary

New platform for hadron physics w/ High-p Had. Beams

1. Hadron modification in nuclear medium
   - Precise measurement of invariant mass spectra in dilepton decays of vector mesons in nuclear media
     - σ ~ 5 MeV at m_{ϕ}, x100 statistics (100000ϕ)
2. Charmed baryons spectroscopy
   - Quark-diquark structure of heavy baryons
     - Mass spectrum, Production Rate, and Decay Branching ratio
     - Information to access “wave function” of quark/diquark in baryons
3. Strange hyperons
   - 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.