SNP2017@Osaka E-C Univ., Mar 12-14, 2017

Baryon Spectroscopy with heavy flavors at J-PARC

Hiroyuki Noumi
RCNP, Osaka Univ./IPNS, KEK

Hadron and Nuclear Physics

Matter Evolution from Quark to Hadron, Nucleus, and Neutron Star

How QCD works in Hadron?

- Effective DoF (building blocks) to describe hadrons
- Change of Hadron Properties in Matter

How are nuclei formed?

- Extended Nuclear Force : Baryon-Baryon Int.
- Stability of Heavy Neutron Stars

Quark QCD

Effective DoF

Hadron

Q Q Q

BB Int.（2BF, 3BF）

Nucleus

Hypernuclei

Dense Baryonic Matter

Quark/Hyperon Matter

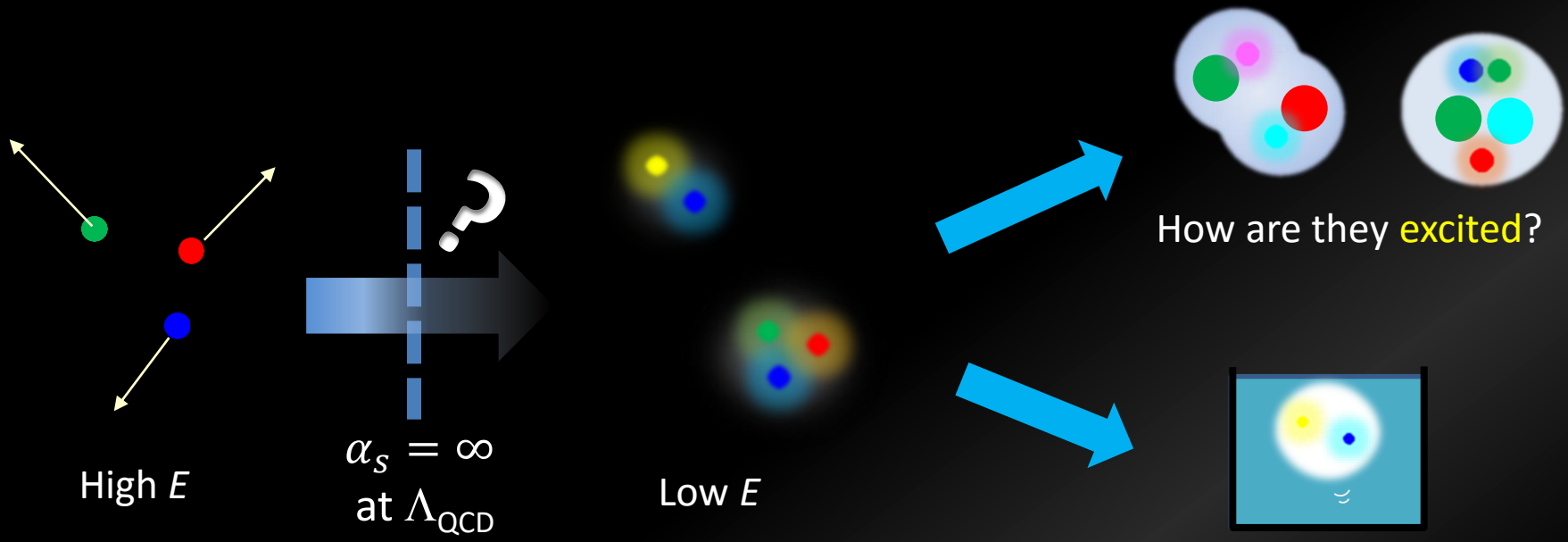
Mystery of Neutron Star

Atom→Molecule→Material,Human,Star,Universe

Content

- What can we learn through hadron spectroscopy with heavy flavors…
  - Why charmed baryon?
- How will we do it?
  - New Research Platform by means of a Missing Mass Technique
- What can we measure…
- Summary

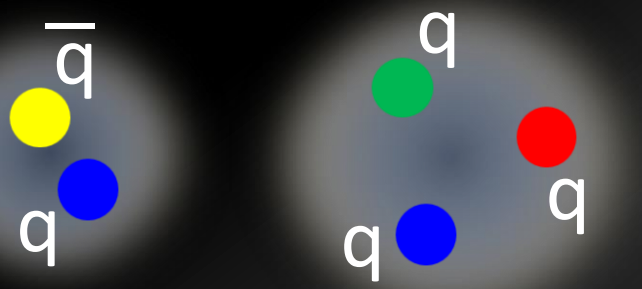
Hadron Physics at J-PARC

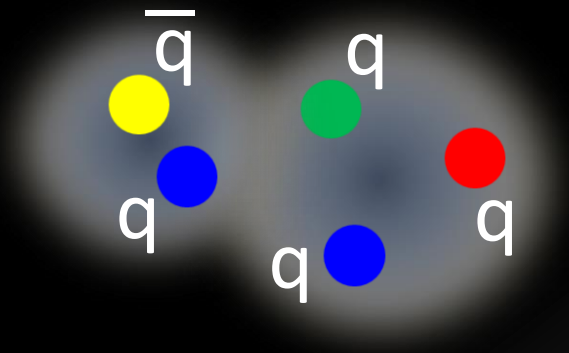


Quasi-Particles (= Effective DoF) emerging at Low E describe hadron properties effectively.

Quasi-Particles (Effective EoF) in Hadrons

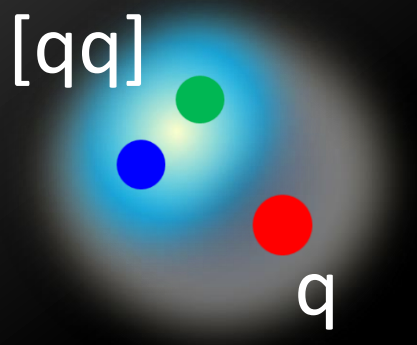
Constituent Quark





hadron (colorless cluster)

Diquark?
(Colored cluster)



Diquarks

Color-Magnetic Interaction of two quarks

$V_{CMI} \sim [\alpha_s/(m_i m_j)]^*(\lambda_i,\lambda_j)(\sigma_i,\sigma_j)$

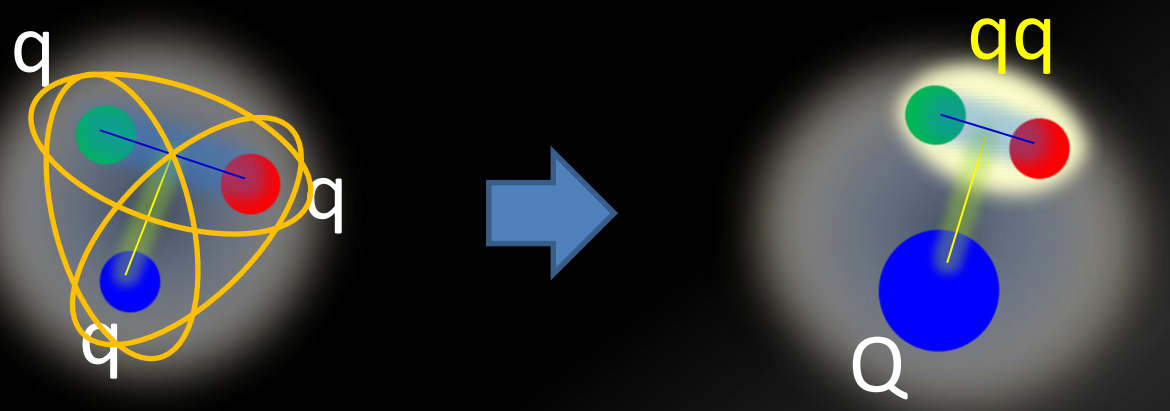
$\rightarrow 0$ if $m_{i,j} \rightarrow \infty$

"Good Diquark": Strong Attraction

$V_{CMI}(^1S_0, \bar{3}_c) = 1/2^* V_{CMI}(^1S_0, 1_c)$

[qq] [$\bar{q}$q]

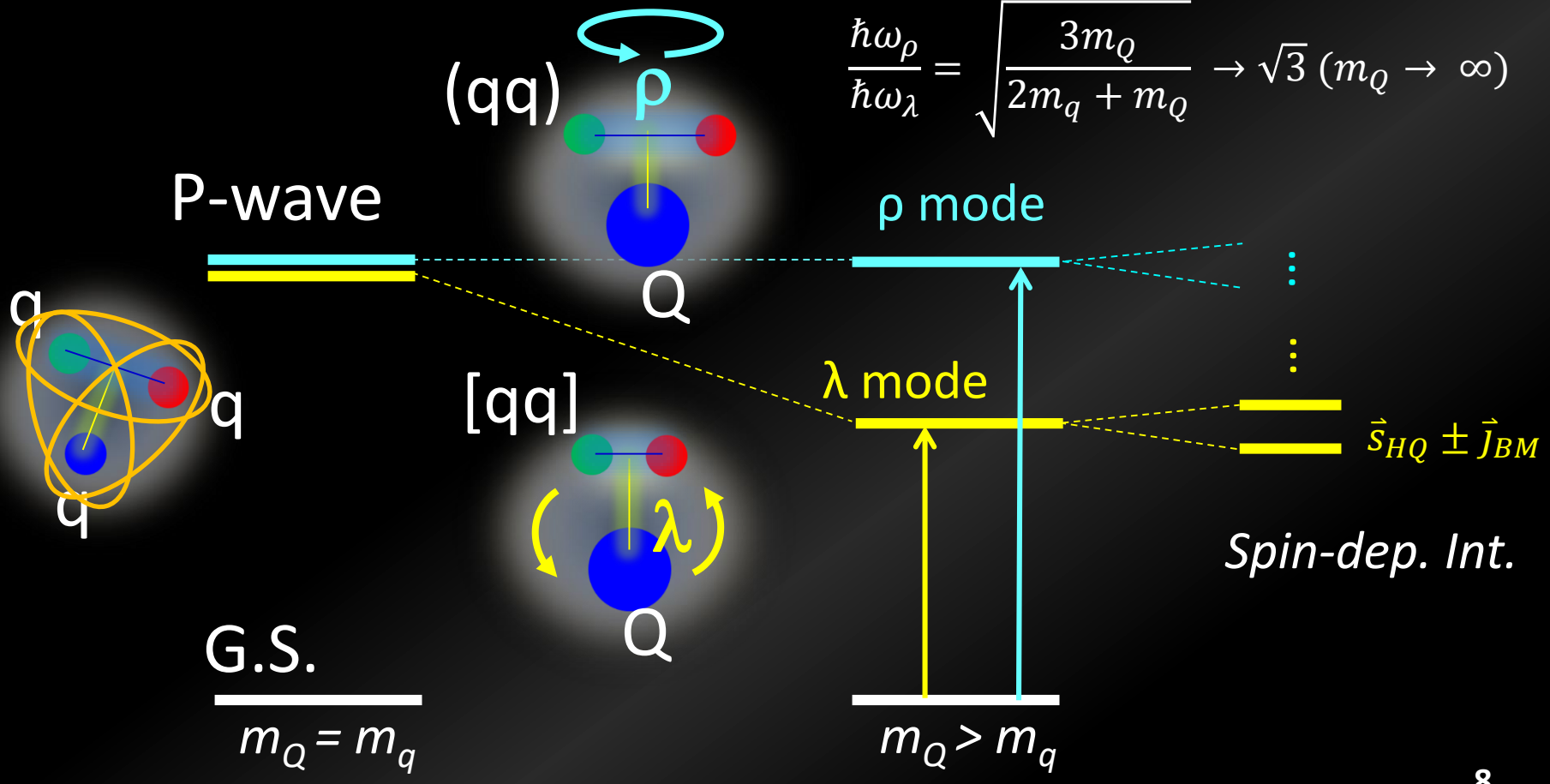
What we can learn from baryons with heavy flavors



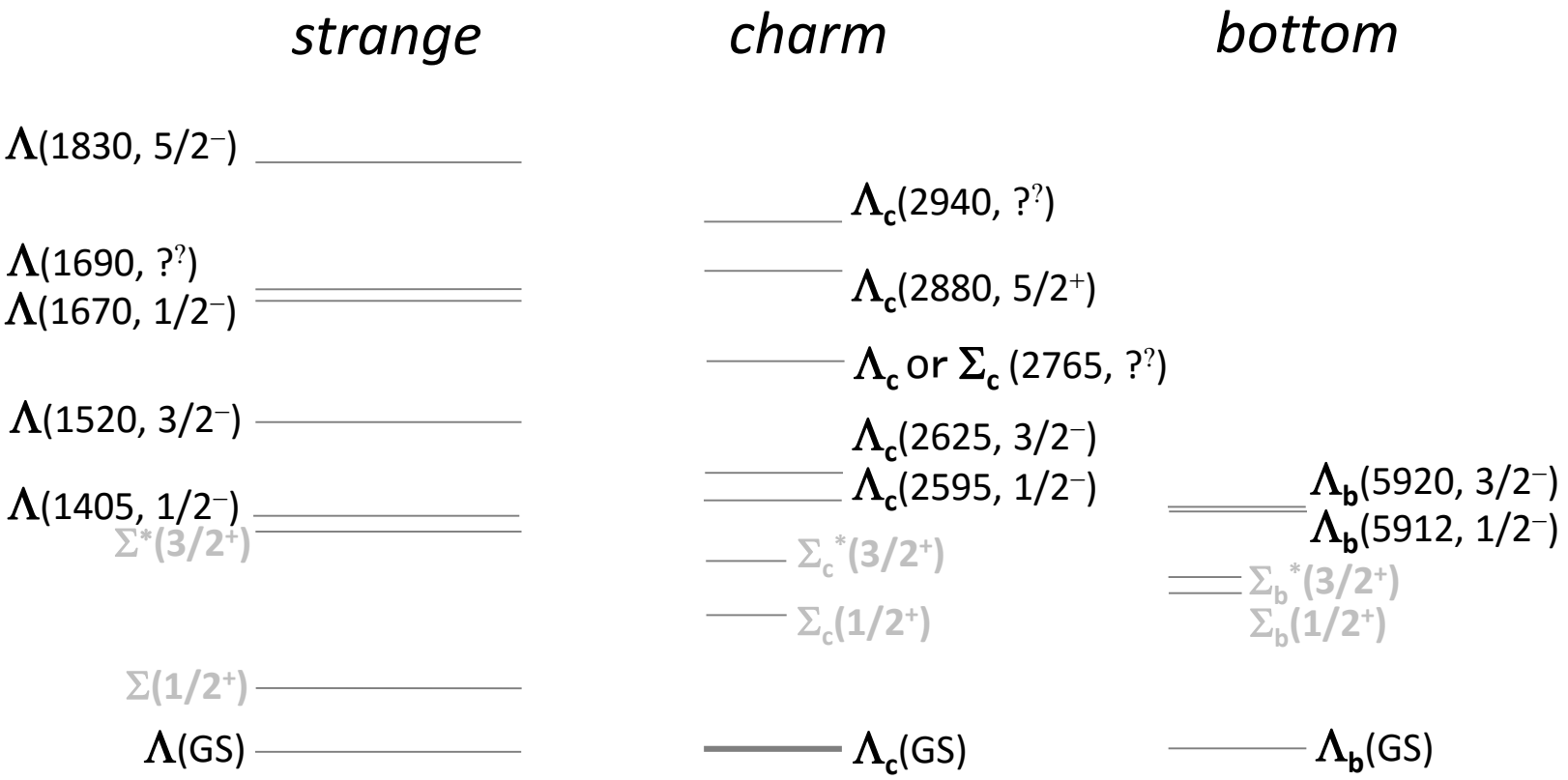
- Quark motion of “qq” is singled out by a heavy Q
  - Diquark correlation
- Level structure, Production rate, Decay properties
  - sensitive to the internal quark(diquark) WFs.
- Properties are expected to depend on a Q mass.

Baryon Spectroscopy w/ Heavy Quark

- Disentangle Quark Correlations in Baryon
  - λ and ρ motions split (Isotope Shift)



Lambda Baryons (P-wave)



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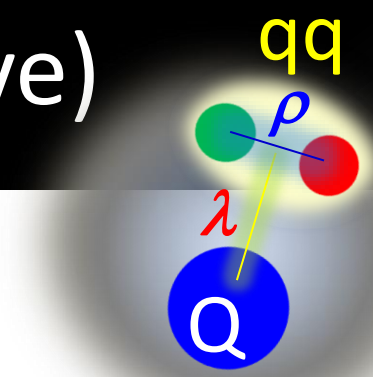
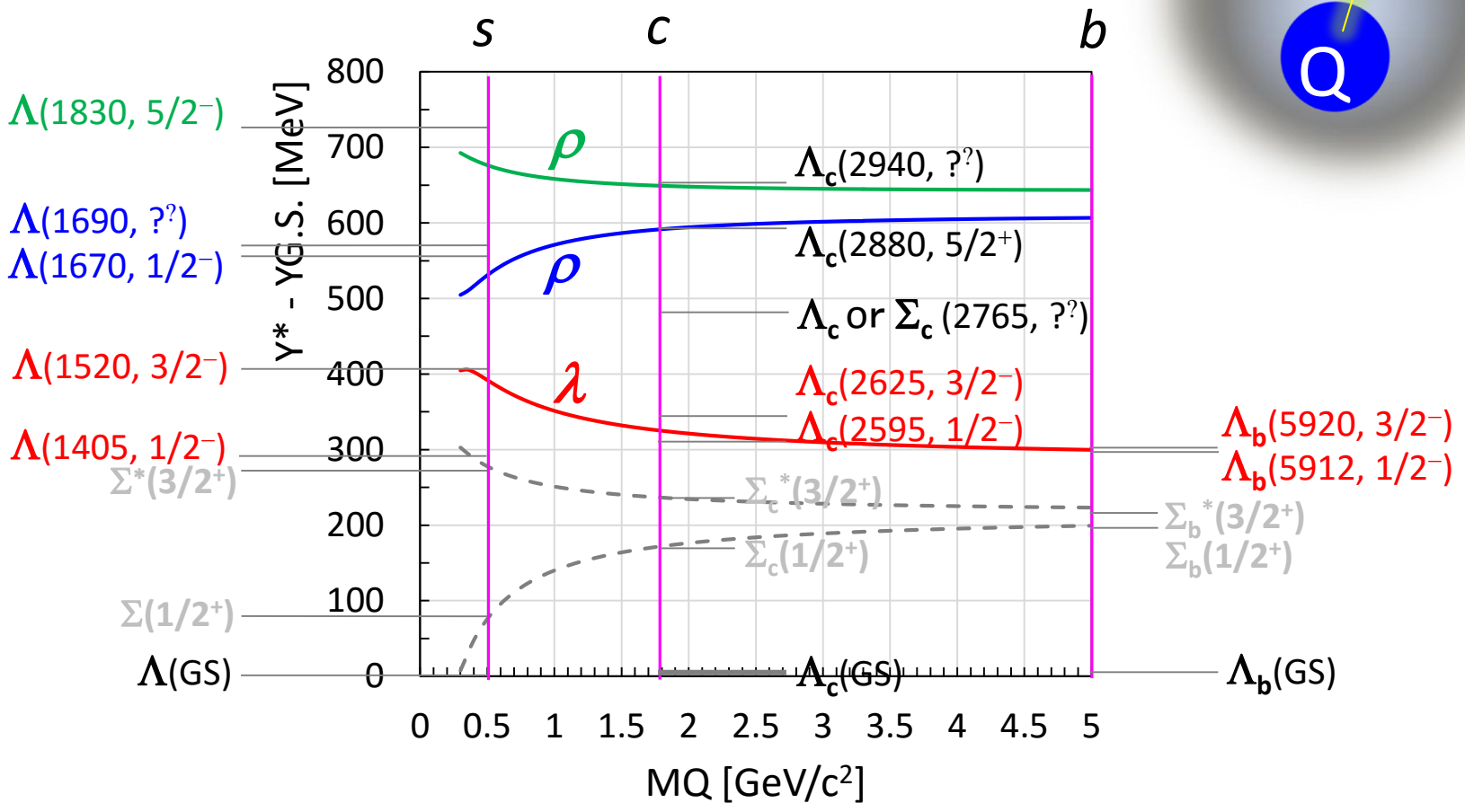
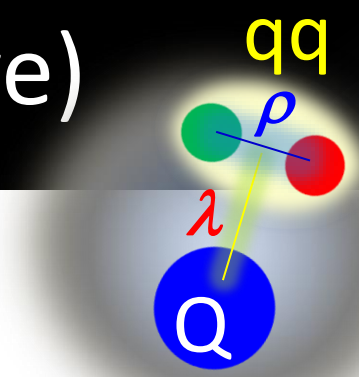
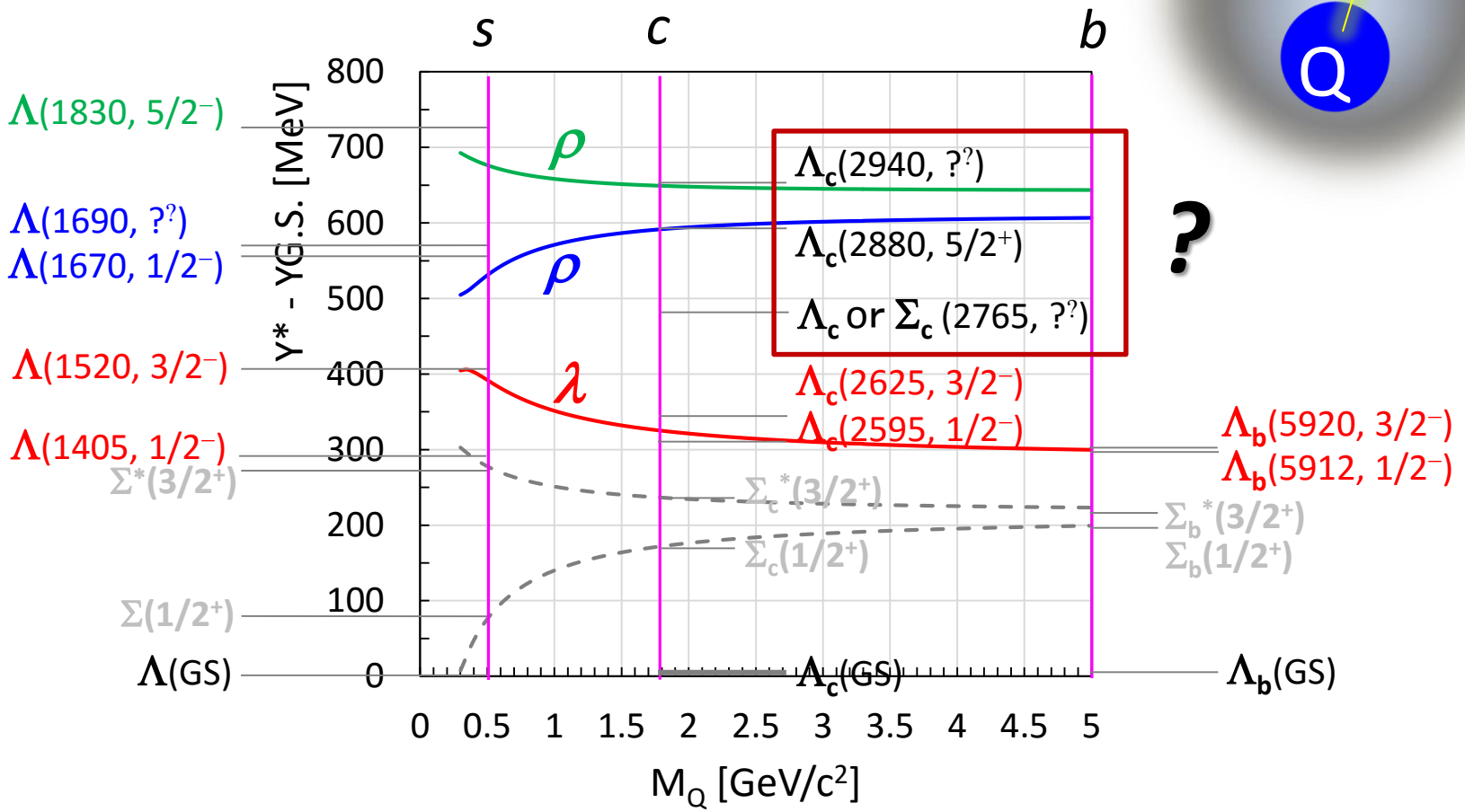




non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$
ρ–λ mixing (cal. By T. Yoshida)

Lambda Baryons (P-wave)





non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$
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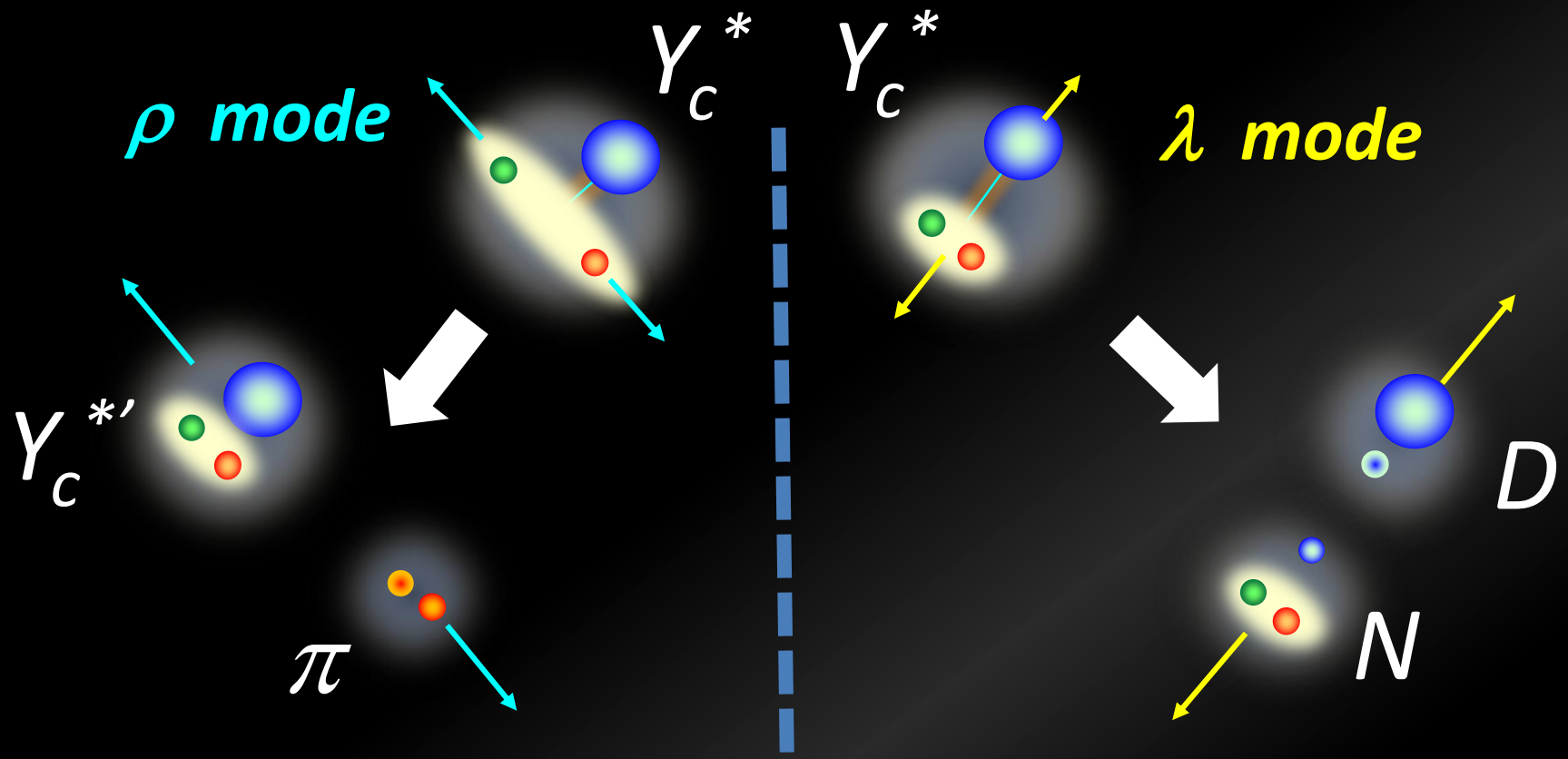
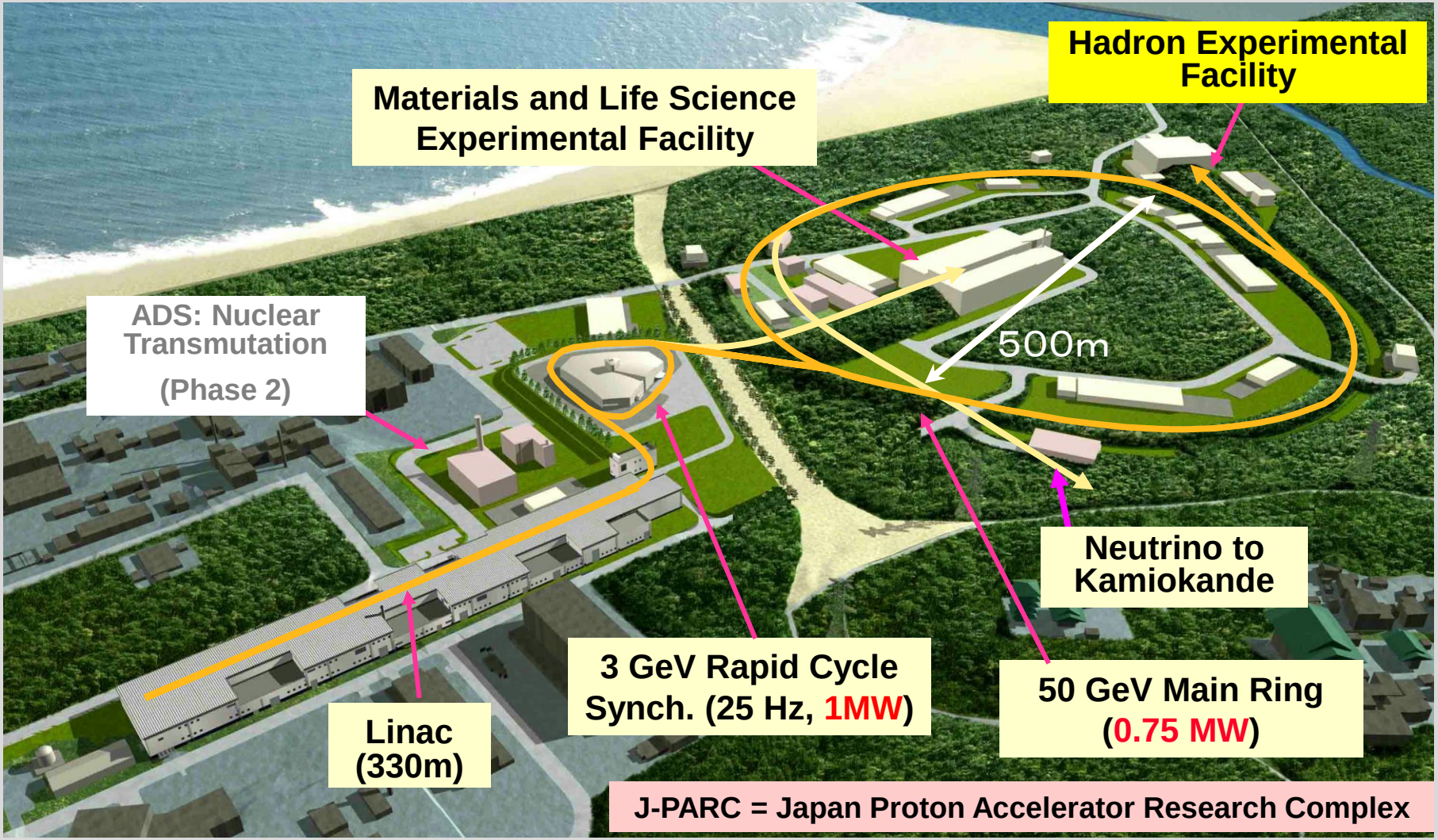
Y_c^* Decay Pattern



$\Gamma(Y\pi) > \Gamma(DN)$

$\Gamma(DN) > \Gamma(Y\pi)$

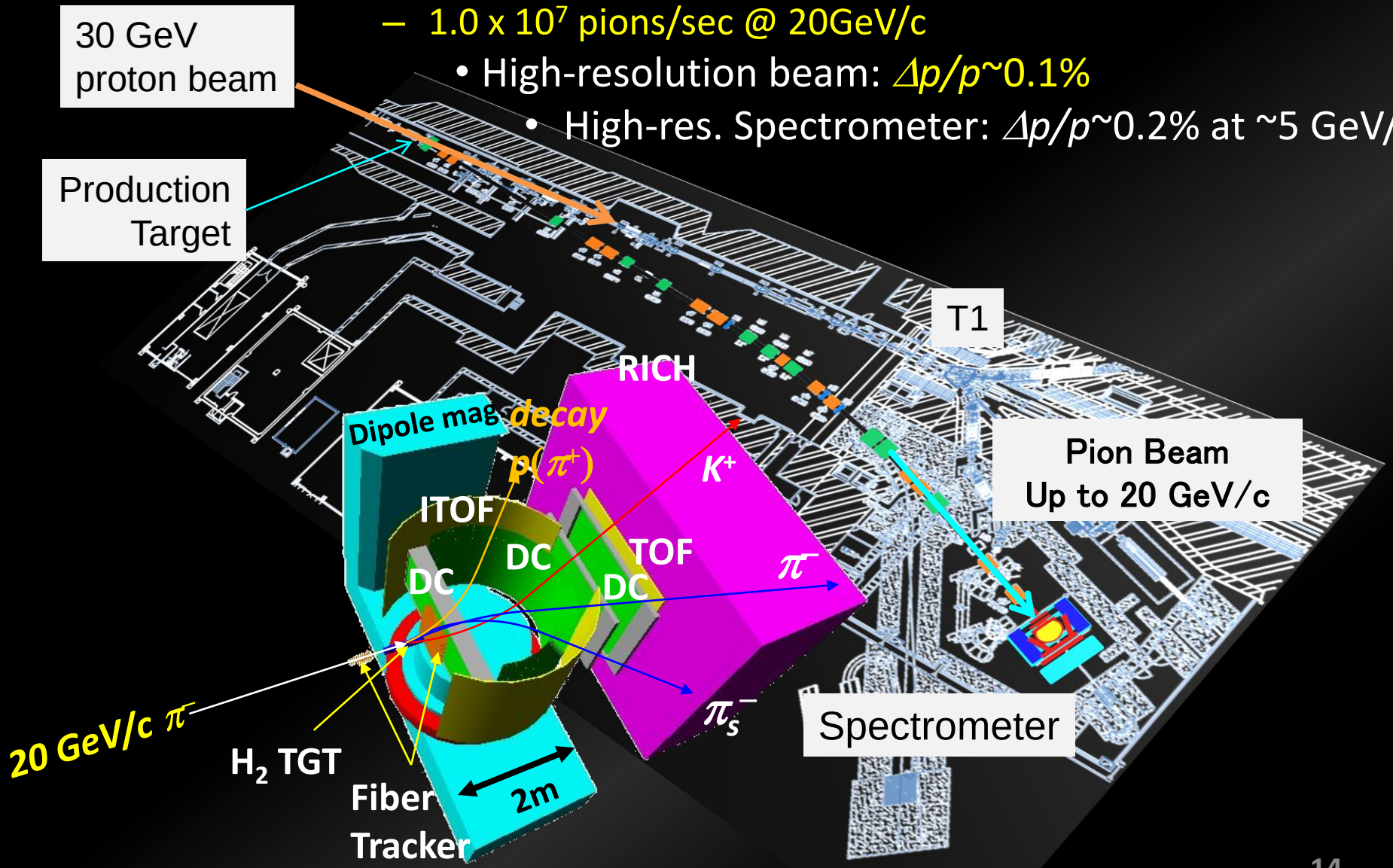
J-PARC Facility



Joint Project between KEK and JAEA since 2001

High-res., High-momentum Beam Line

- High-intensity secondary Pion beam (unseparated)
  - 1.0×10^7 pions/sec @ 20GeV/c
  - High-resolution beam: $\Delta p/p$~0.1%
  - High-res. Spectrometer: $\Delta p/p$~0.2% at ~5 GeV/c



New Platform for Hadron Physics

- Charmed Baryon Spectroscopy
  - Diquark motions
  - $p(\pi^-, D^{*-})Y_c^*$
  - Pentaquark
- Single/Double Strange Baryon Spectroscopy
  - $p(\pi^-, K^*)Y^*$, $p(K^-, K^*)\Xi^*$
- Hadron Tomography
  - Exclusive DY

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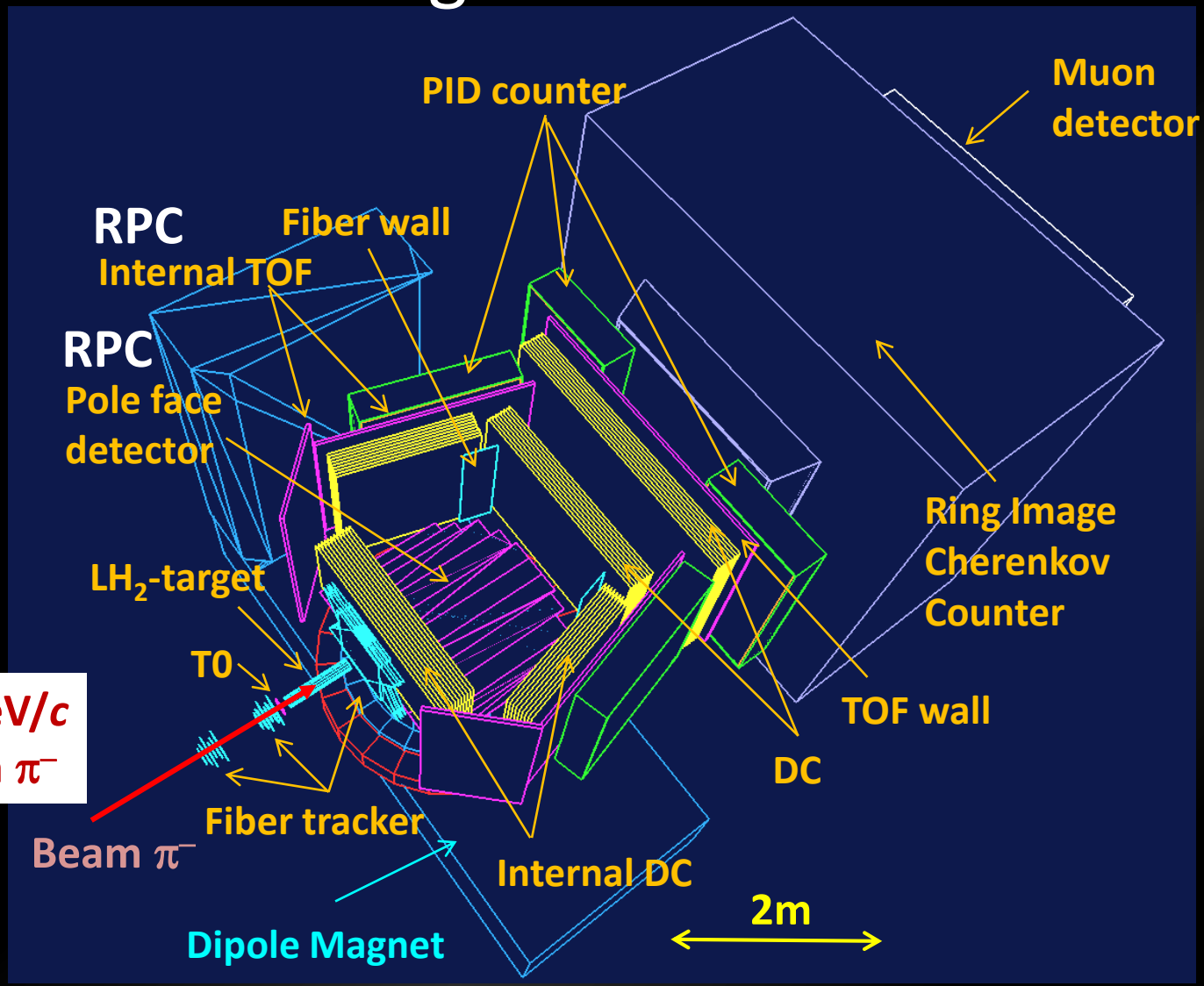
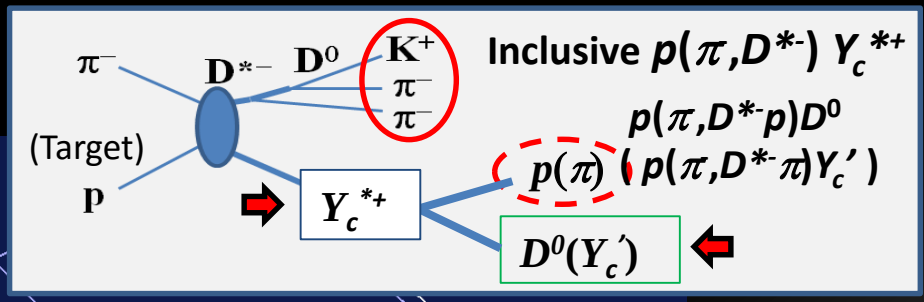
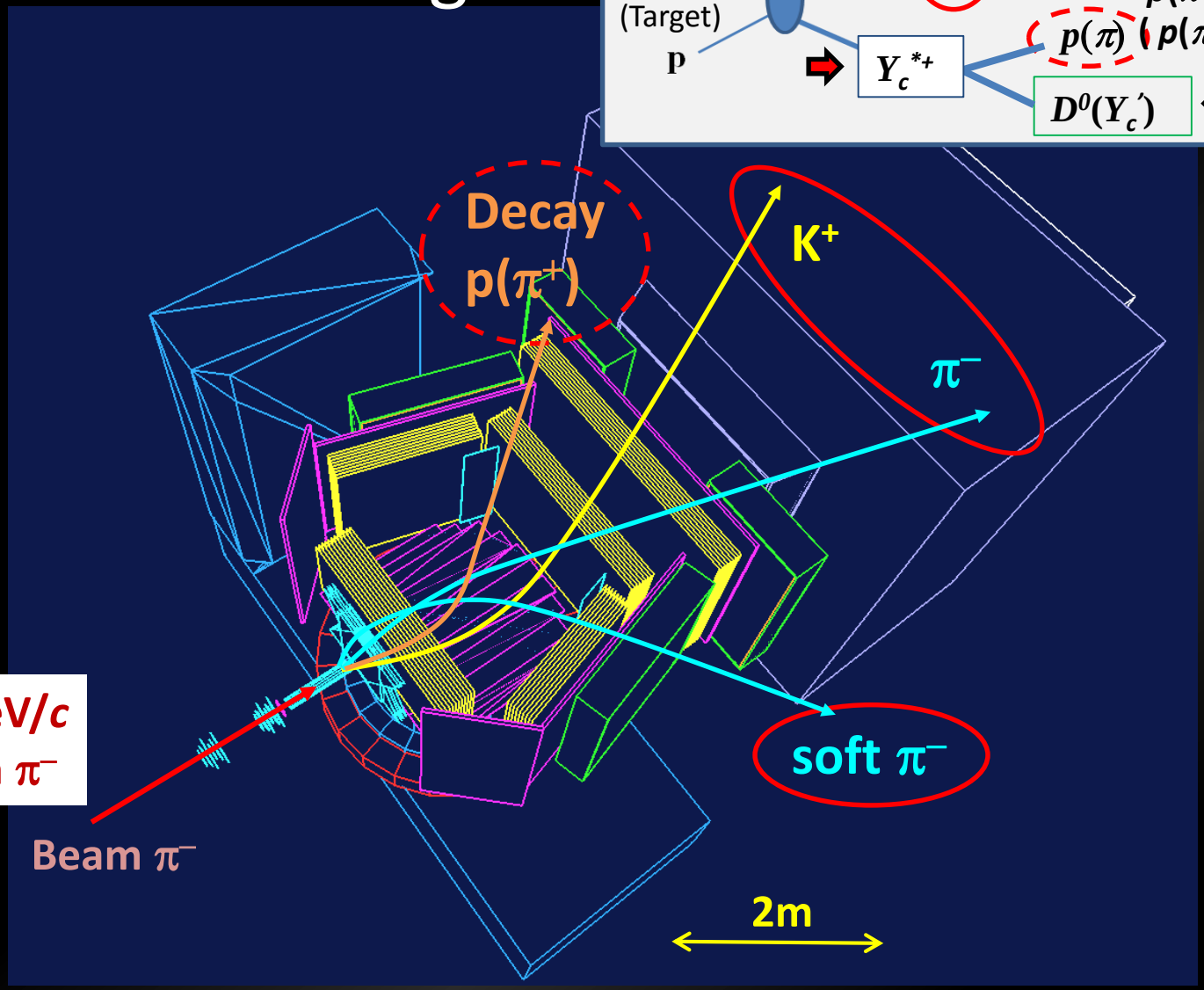
Spectrometer Design



Spectrometer Design

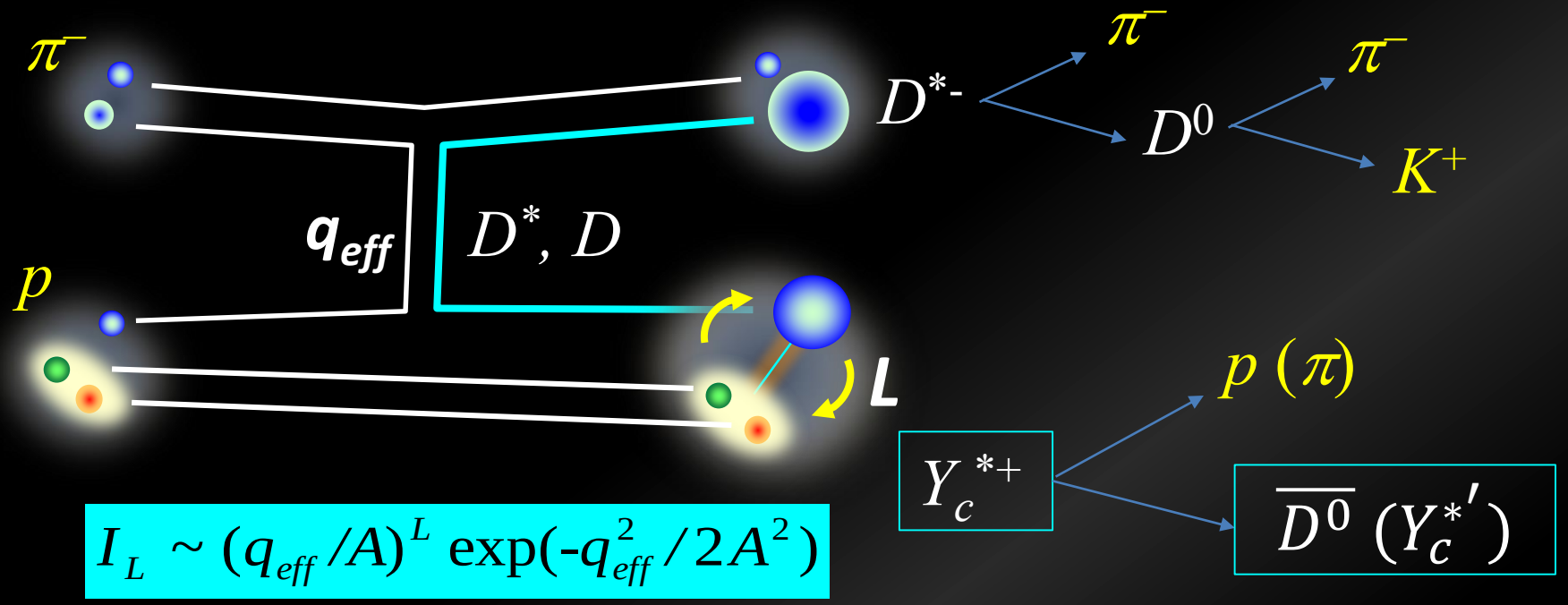




20 GeV/*c*
Beam π^-

Large acceptance ~ 60% (for *D), ~85% (for decay π^+)**
Good resolution: $\Delta p/p$~0.2% at ~5 GeV/*c*

Charmed Baryon Spectroscopy Using Missing Mass Techniques

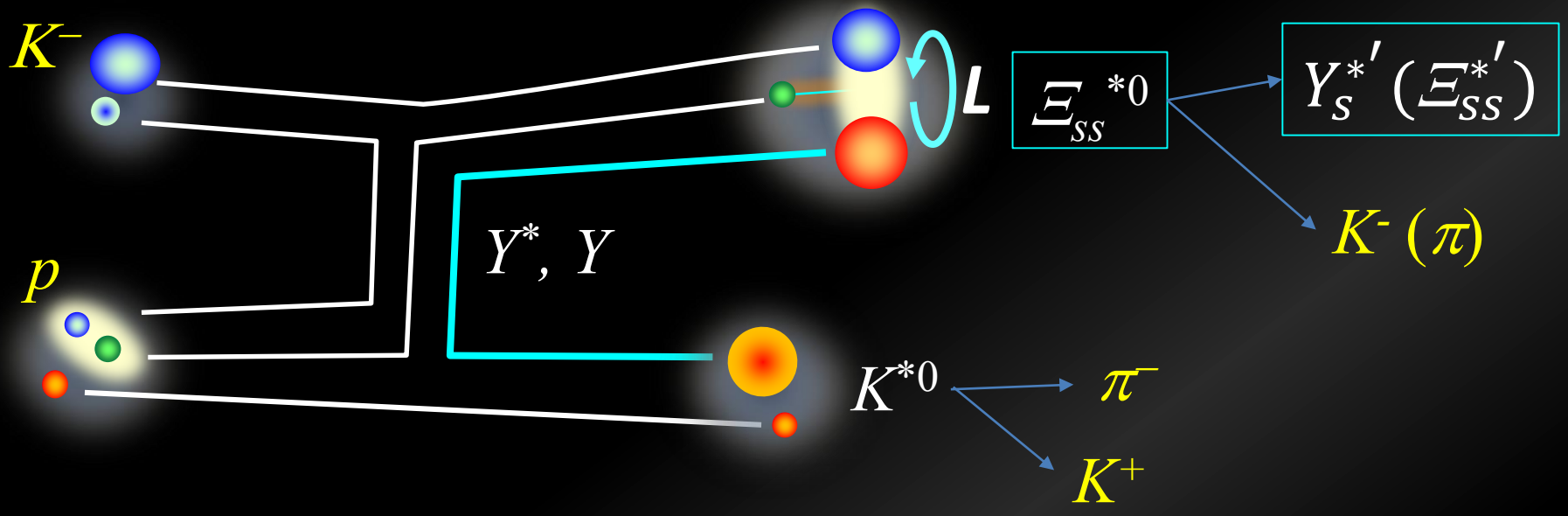


$$I_L \sim (q_{eff}/A)^L \exp(-q_{eff}^2/2A^2)$$

- ✓ Production and Decay reflect [qq] correlation in Excited Y_c^*
- ✓ C.S. DOES NOT go down at higher L when q_{eff} >1 GeV/c.

S.H. Kim, A. Hosaka, H.C. Kim, and HN, PTEP, (2014) 103D01,
S.H. Kim, A. Hosaka, H.C. Kim, and HN, Phys.Rev. D92 (2015) 094021

Double Strange Baryon Spectroscopy Using Missing Mass Techniques

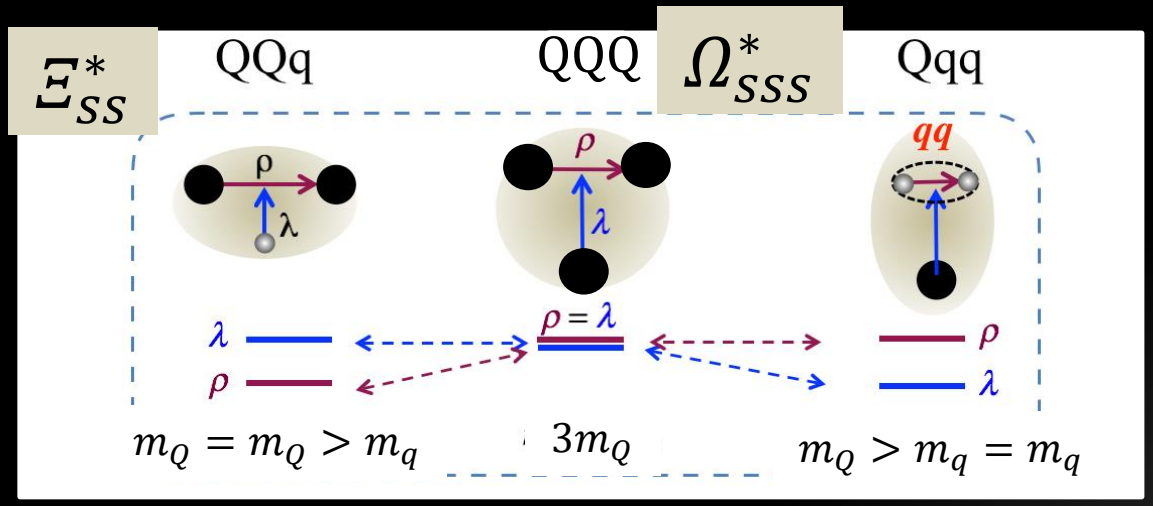


- ✓ Production and Decay reflect [QQ] correlation…
- ✓ *u-channel production plays a role in High-p…*
  - ✓ *ρ mode excitation may be favored*

    ⇔ $K_L p \rightarrow K^+ \Xi^{*0}$ *: contribution from s-channel in Low-p…*

Disentangle Quark Correlations in Baryon w/ HQ

- ρ/λ mode separation in excited states reveals quark correlations.

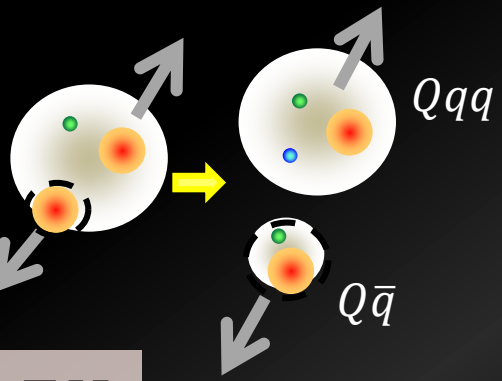


Level crossing between QQq and Qqq

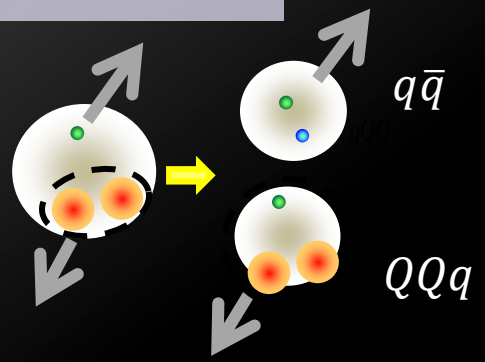
- Decay branches reflect the quark correlations.

$\Xi^* \to \Xi\pi$

ρ mode



λ mode

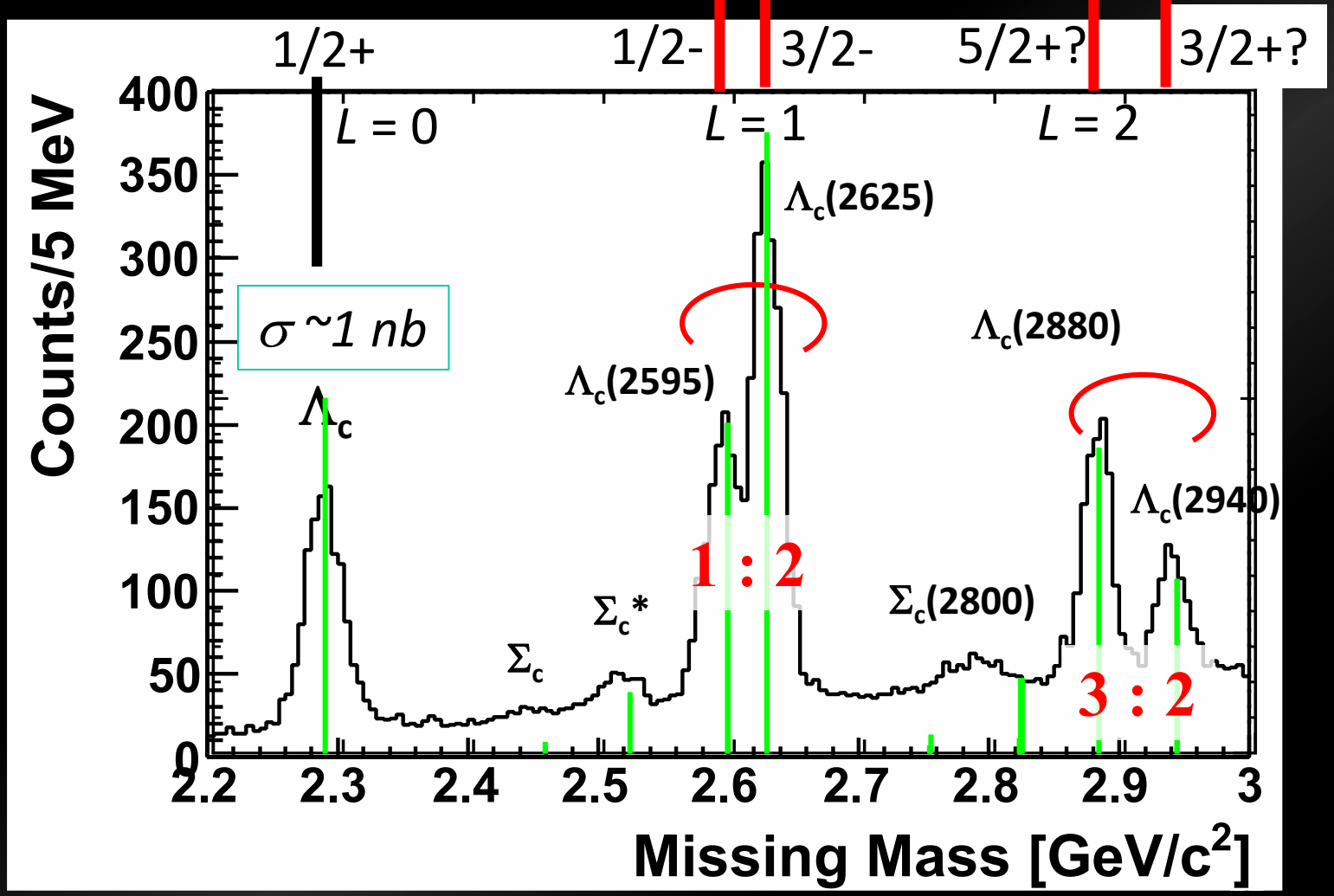


$\Xi^* \to \Lambda K, \Sigma K$

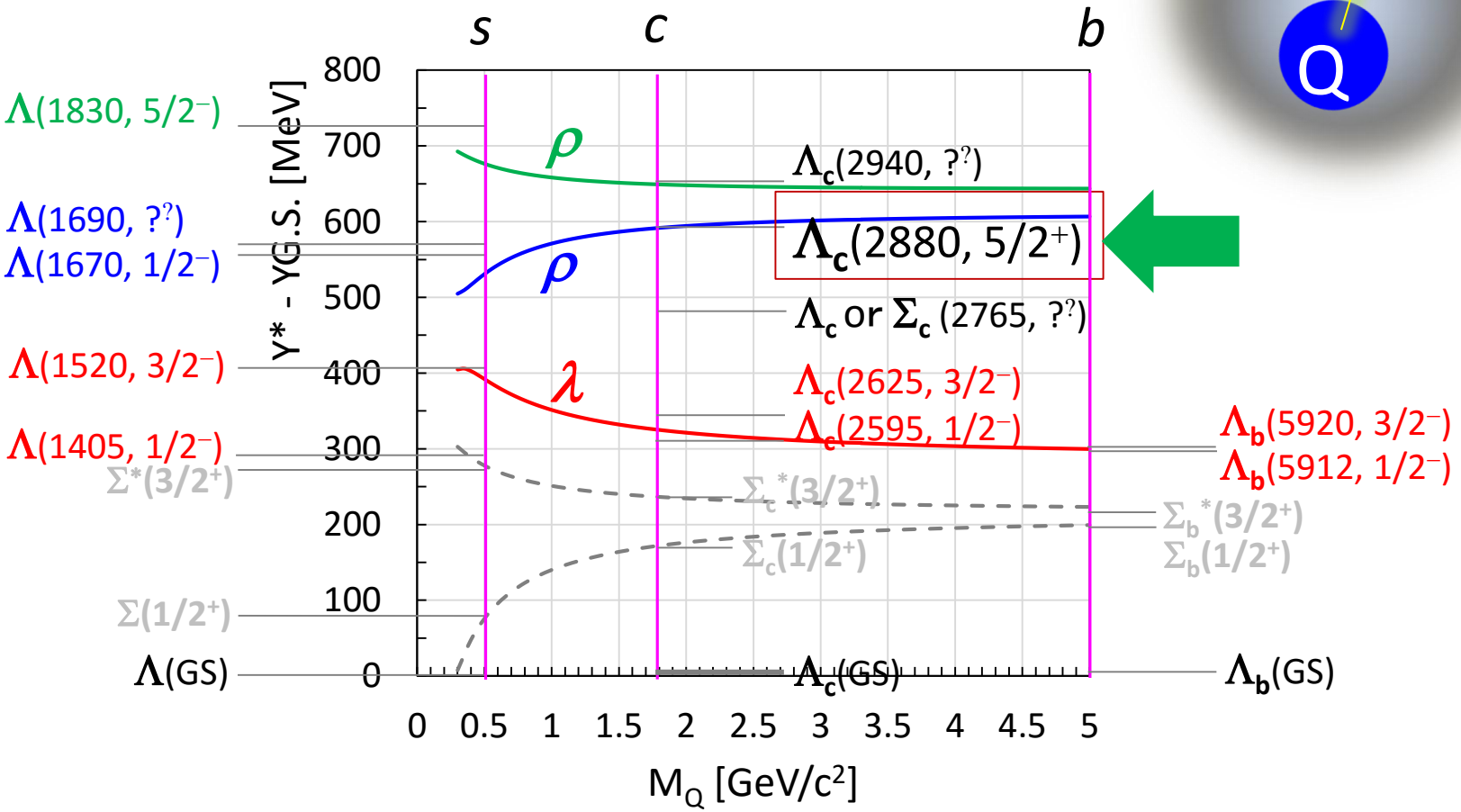
Different decay branches for different correlations

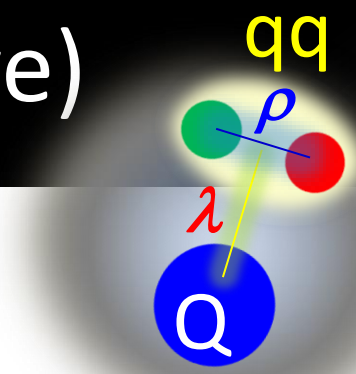
Missing Mass Spectrum (Sim.)

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



Lambda Baryons (P-wave)





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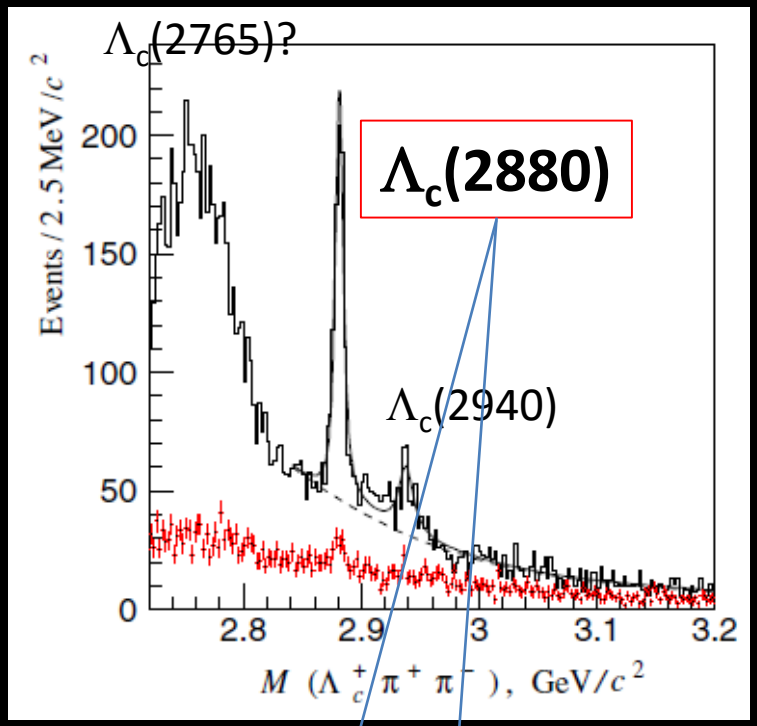
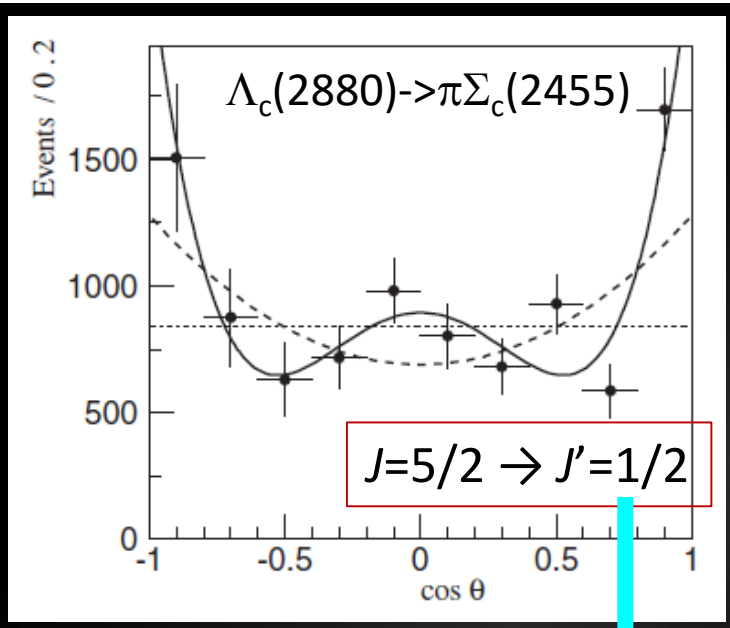
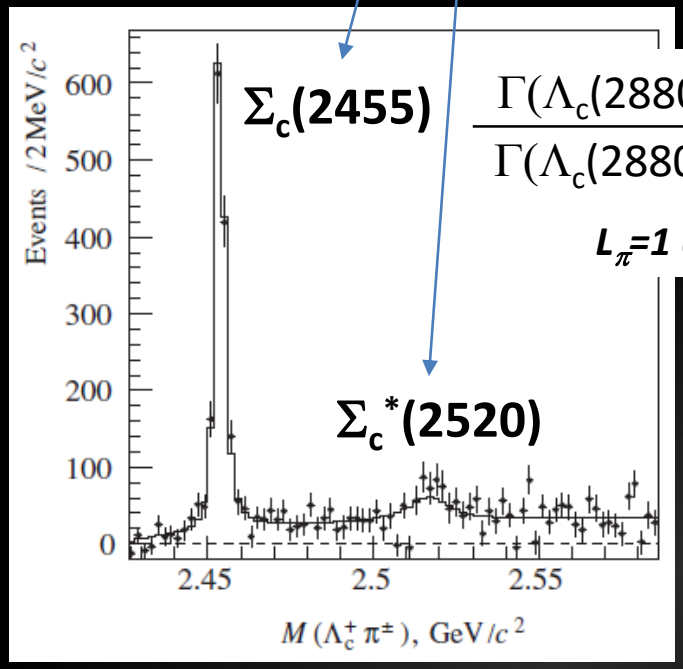


Lc(2880)Belle, PRL98, 262001('07)





$$\frac{\Gamma(\Lambda_c(2880)\to\pi\Sigma_c^*(2520))}{\Gamma(\Lambda_c(2880)\to\pi\Sigma_c(2455))} = 0.23$$

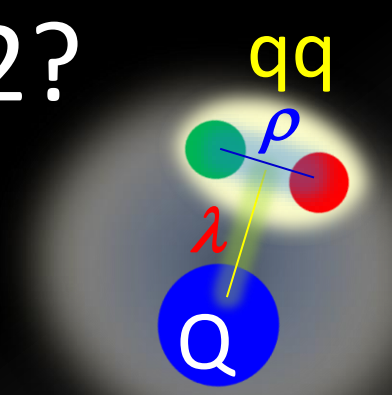
L_π=1 contribution may affect…

L_π=3 transition

J^P=5/2$^+$ for Λ_c(2880)

Is it a D-wave Lambda-c Baryon?
If so, where is a spin partner ?

Does $\Lambda(2880)$ have L=2?



- P-wave transition seems to be suppressed in $\Lambda_c(2880)^{\frac{5}{2}+} \to \Sigma_c^*(2520)^{\frac{3}{2}+} + \pi(0^-)$.
- It would be forbidden only in the case of $J^P_{BM} = 3^+$:
  - Negative party states "5/2-" have large widths.
    (H. Nagahiro et al., PRD95, 014023(2017))

Λ_c(2880) 5/2+	λλ	λρ	ρρ
color	Asymm.		
Isospin	Asymm. (I=0)		
Diquark spin Diquark orbit	Asymm. 0 Symm. 0	Symm. 1 Asymm. 1	Asymm. 0 Symm, 2
Lambda orbit	2	1	0
$J_{BM}{}^P$	2+	1+, 2+, **3+**	2+

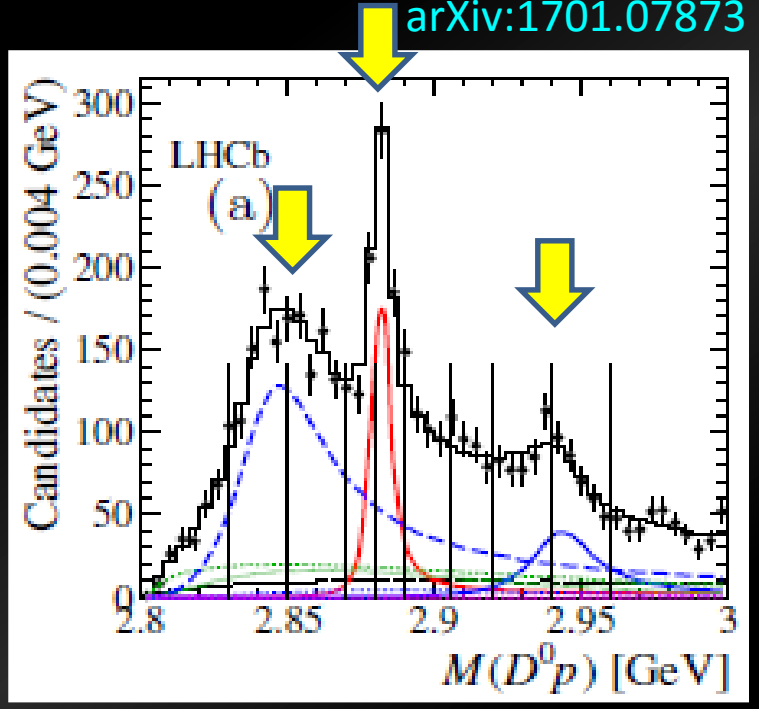
$\Sigma_c{}^*$(2520) 3/2+
Asymm
Symm. (I=1)
Symm. 1 Symm, 0
0
1+

- $\Lambda_c(2880)^{\frac{5}{2}+}$ is likely to be λρ mode (λ=1, ρ=1).
- This can be tested by measuring its production rate.

Λ_c^*'s from LHCb

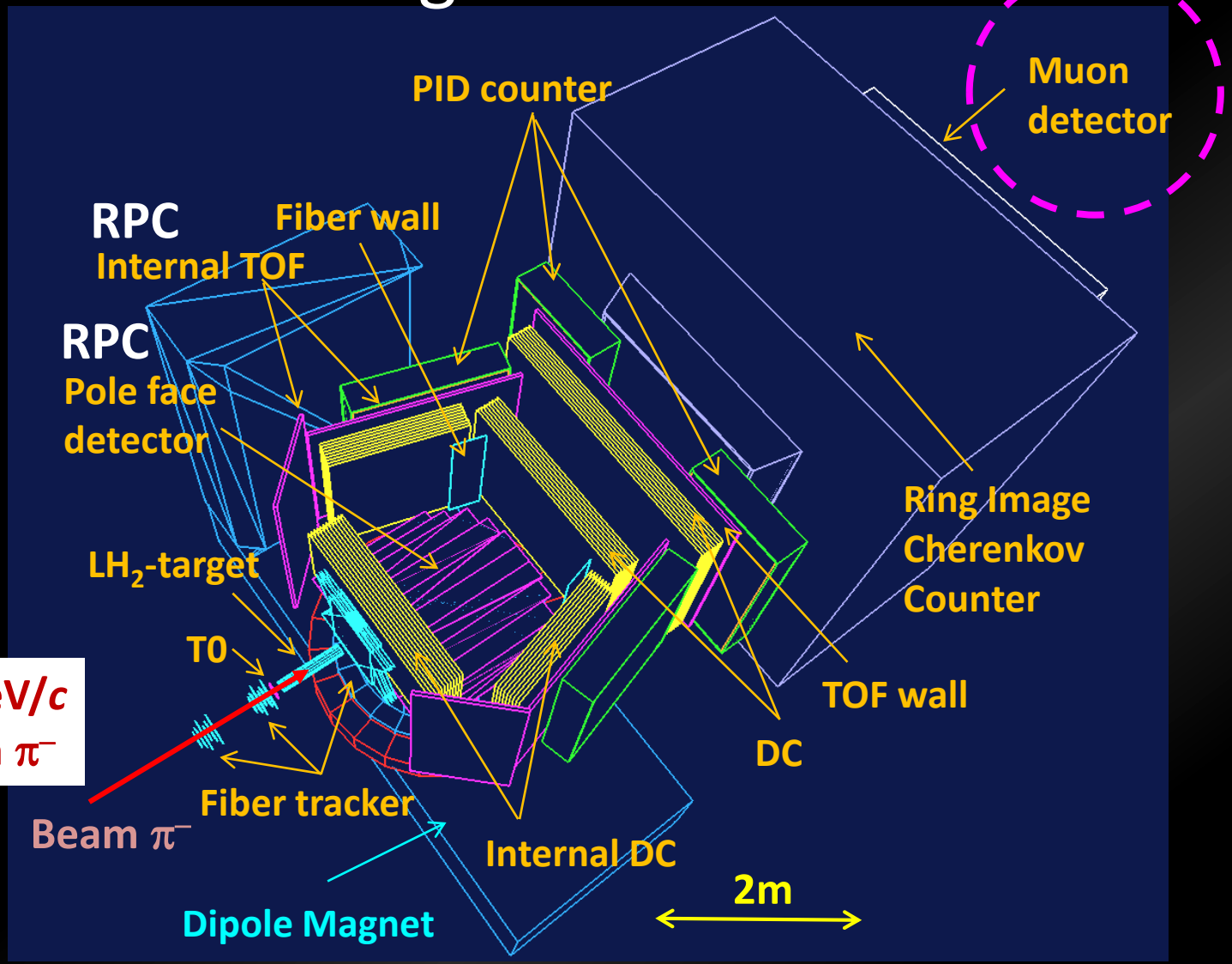
- D^0p invariant mass in $\Lambda_b \to D^0p\pi^-$
  - $\Lambda_c(2940)$
    - likely 3/2-, (acceptable 1/2, 7/2)
  - $\Lambda_c(2880)$
    - 5/2+ confirmed
  - $\Lambda_c(2860)$
    - likely 3/2+, new D-wave resonance?

arXiv:1701.07873



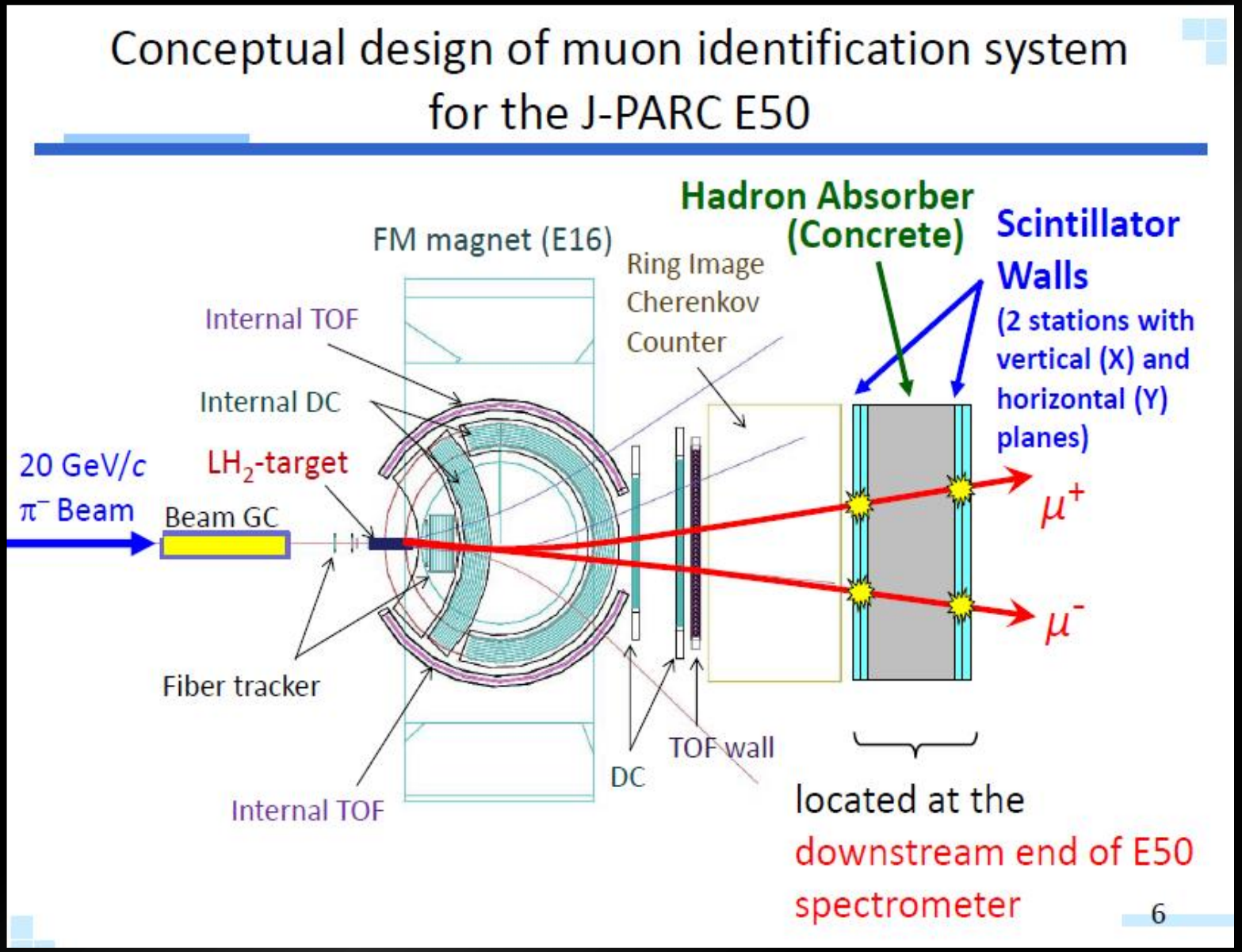
- Production rates of these states in p(π^-,D^{*-})Y_c^* tell us:
  - if $\Lambda_c(2940)$ is an *L*=3 state (λ mode).
  - if $\Lambda_c(2880)$ and $\Lambda_c(2860)$ are *LS* partners of *L*=2 (λ modes).

Spectrometer Design



Muon ID

By W.C. Chang, T. Sawada (Academia Sinica)

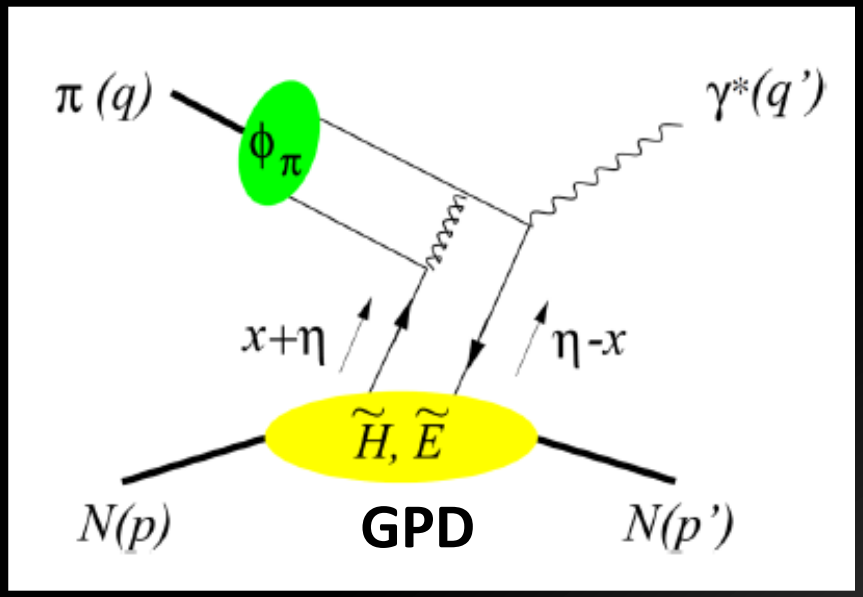


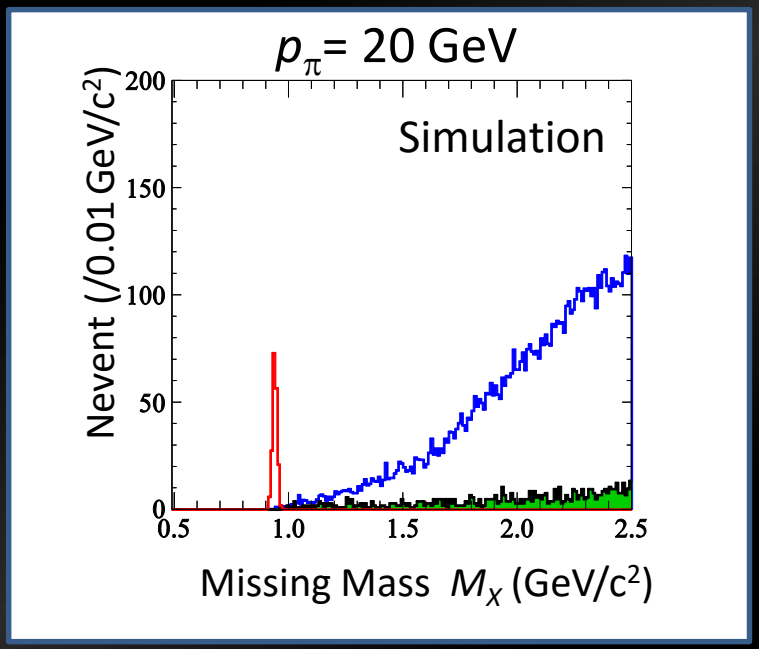
T. Sawada, W.C. Chang et al., PRD93, 114034(2016)

Hadron Tomography w/ Exclusive Drell-Yan

CHARM Spectrometer + Muon Detector at High-p BL

$$\pi^- + p \rightarrow \mu^+ + \mu^- + n$$





$$\pi^- + p \rightarrow \mu^+ + \mu^- + \Delta^0$$
$$K^- + p \rightarrow \mu^+ + \mu^- + Y^*$$

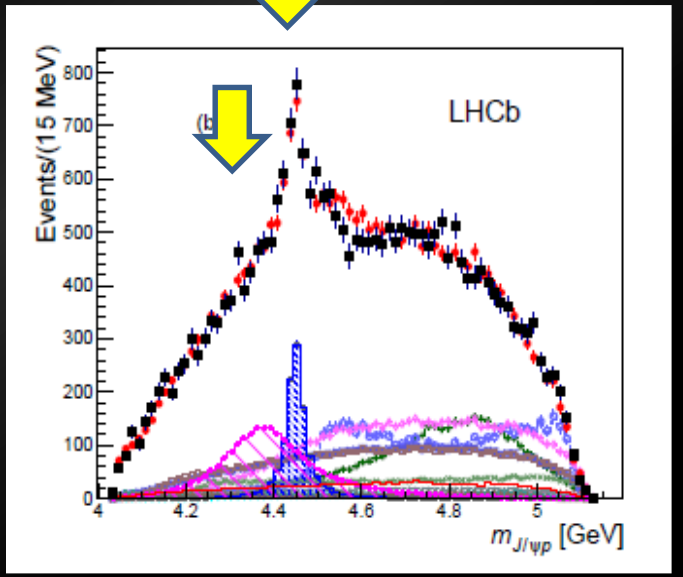
$N \rightarrow \Delta\,(Y^*)$ TDA

$P_c(4380), P_c(4450)$ *from LHCb*

- Found in $J/\psi p$ invariant mass in $\Lambda_b \to J/\psi p K^-$
  - $m_{4380} = (4380 \pm 8 \pm 29)\text{MeV},\ \Gamma = (205 \pm 18 + 86)\text{MeV}$

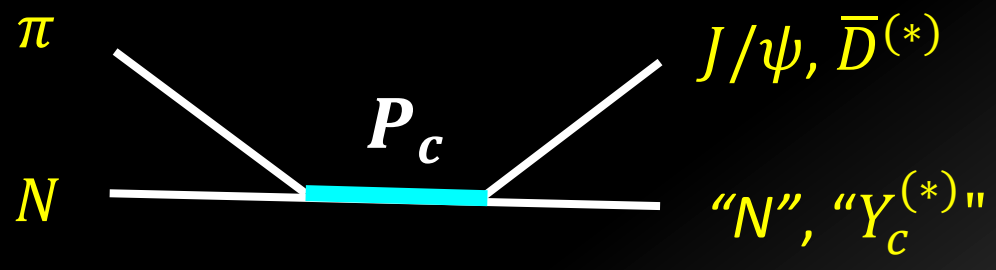
    $m_{4450} = (4449.8 \pm 1.7 \pm 2.5)\text{MeV},\ \ \Gamma = (39 \pm 5 + 19)\text{MeV}$
  - J^P: (3/2-, 5/2+) most likely, respectively
    - (3/2+, 5/2-), (5/2+,3/2-) are acceptable.
  - Hidden $c\bar{c}$ state, P_c^0 may exist.
- decay branch?
  - $J/\psi + N, \overline{D}^{(*)} + Y_c^{(*)}$
- Its spin family?

PRL 115, 072001 (2015)



$P_c(4380), P_c(4450)$ *at J-PARC*

- P_c^0 : s-channel formation with 10 GeV/c π^- on p



0.05

$P_c(4380), P_c(4450)$ *at J-PARC*

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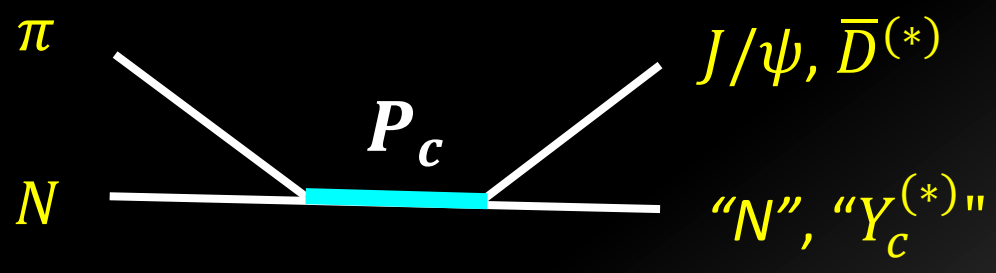
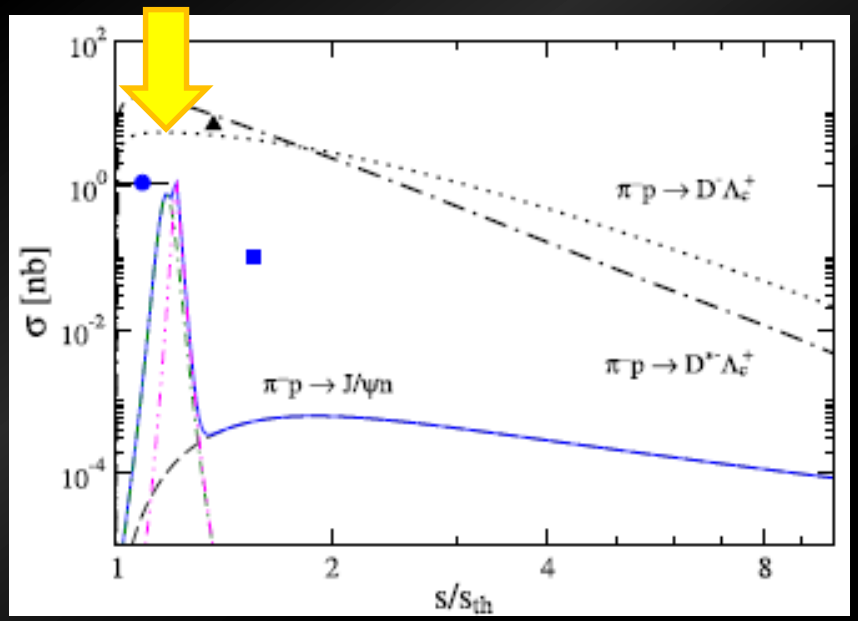


- Cross Section: <1 nb?
  - $\Gamma_{\pi N}/\Gamma_{tot}$~ 10^{-5}
  - $\Gamma_{j/\psi p}/\Gamma_{tot}$~0.05



S.H. Kim, H.C. Kim, A. Hosaka
PLB763, 358(2016)

$P_c(4380), P_c(4450)$

- $P_c^0 \to \pi N$: coupling strength is unknown.
- Estimation of $\Gamma_{\pi N} \sim 10^{-5}\Gamma_{tot} \sim 4 \times 10^{-4}$ [MeV] is comparable to:
  - $\Gamma\,(J/\psi \longrightarrow p\bar{p}\pi) = 1.19 \times 10^{-3} \times 0.093 \sim 10^{-4}$ [MeV],
  - while $\Gamma\,(\eta_c \longrightarrow p\bar{p}\pi) = 3.6 \times 10^{-3} \times 31.8 \sim 10^{-1}$ [MeV]!
- Spin configuration of $c\bar{c}$ in P_c may affect the production cross section drastically.
  - Coupling to $J/\psi p$ or $D^{(*)}Y_c^{(*)}$ is important as well.

$$\sigma_L = (2L+1)\frac{\pi}{k^2}\frac{\Gamma_{\pi N}\Gamma_{J/\psi p}}{(E-m)^2 + \Gamma_{tot}^2/4}$$

In Summary

1. Diquark correlation in baryons could be disentangled with heavy flavors
   - Mass spectrum, Production Rate, and Decay Branching ratio
   - Charmed, Strange, and Double Strange Baryons from the ground state up to high-spin states
   - Internal structure of exotic hadrons like P_c.
2. A general purpose spectrometer at the J-PARC High-p BL
   - open a new platform of hadron physics by means of missing mass technique
   - welcome to the High-p Collaboration for cooperative works on hadron physics