Dilepton Production with Meson and Antiproton Beams, ECT*
6-10 November, 2017

Charm Physics with Meson Beam at J-PARC

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1. Introduction
2. Charm Baryon Spectroscopy
3. Dilepton Production

Hadron Nuclear Physics at J-PARC

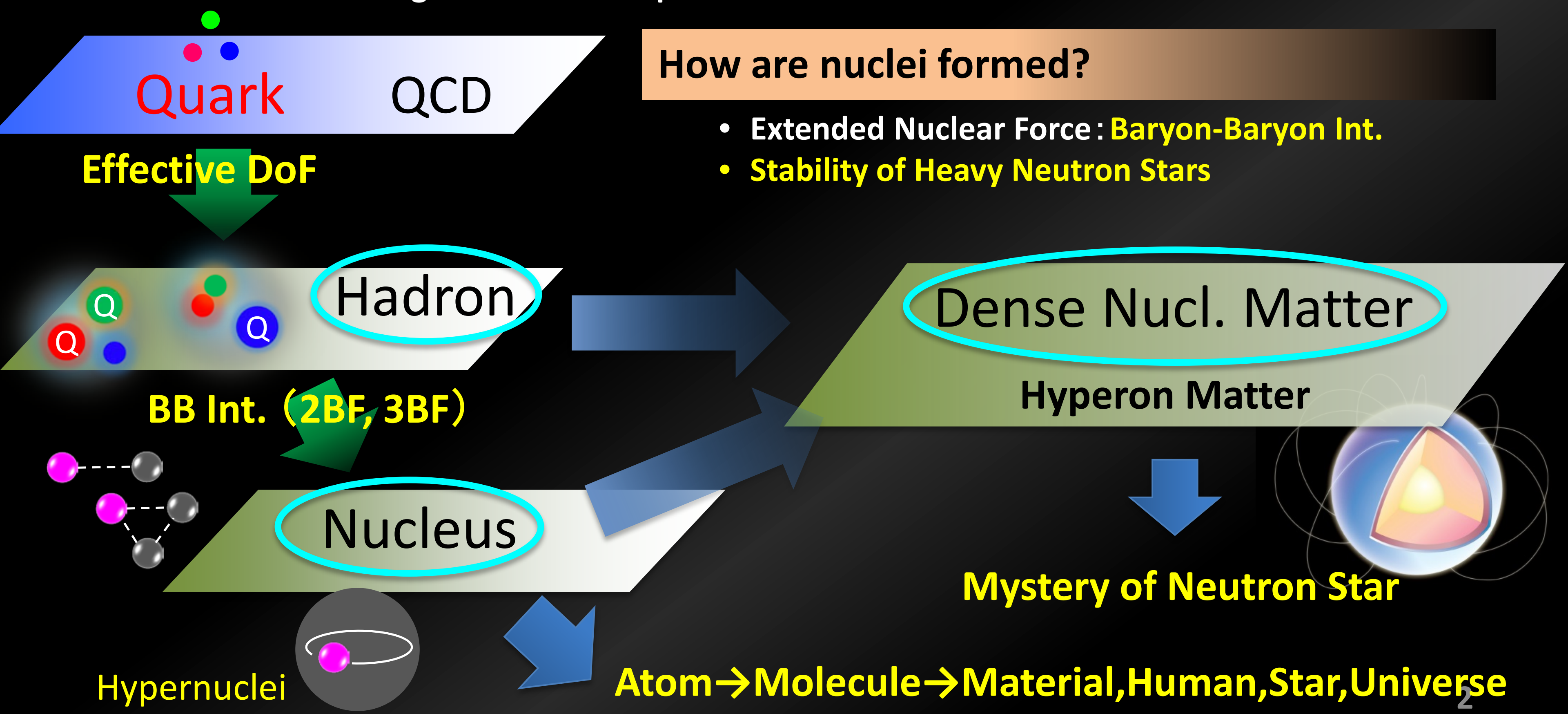
Matter Evolution from Quark to Hadron, Nucleus, and Neutron Star

How QCD works in Hadron?

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

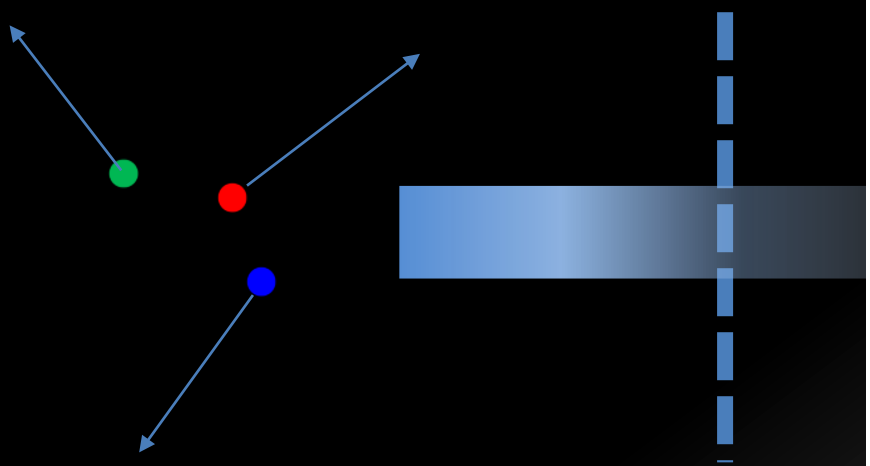
How are nuclei formed?

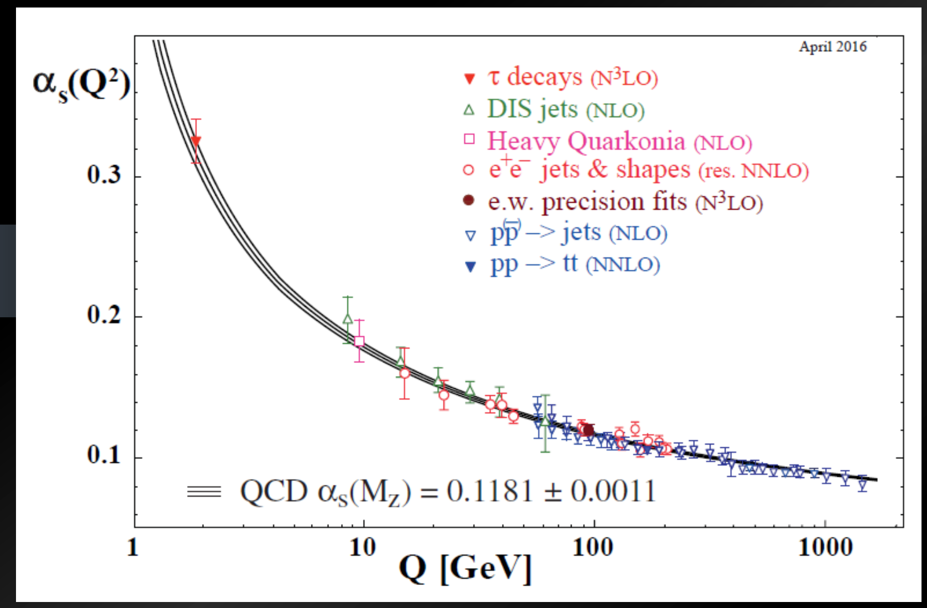
- Extended Nuclear Force : Baryon-Baryon Int.
- Stability of Heavy Neutron Stars



How Hadrons are formed?

High E → Low E



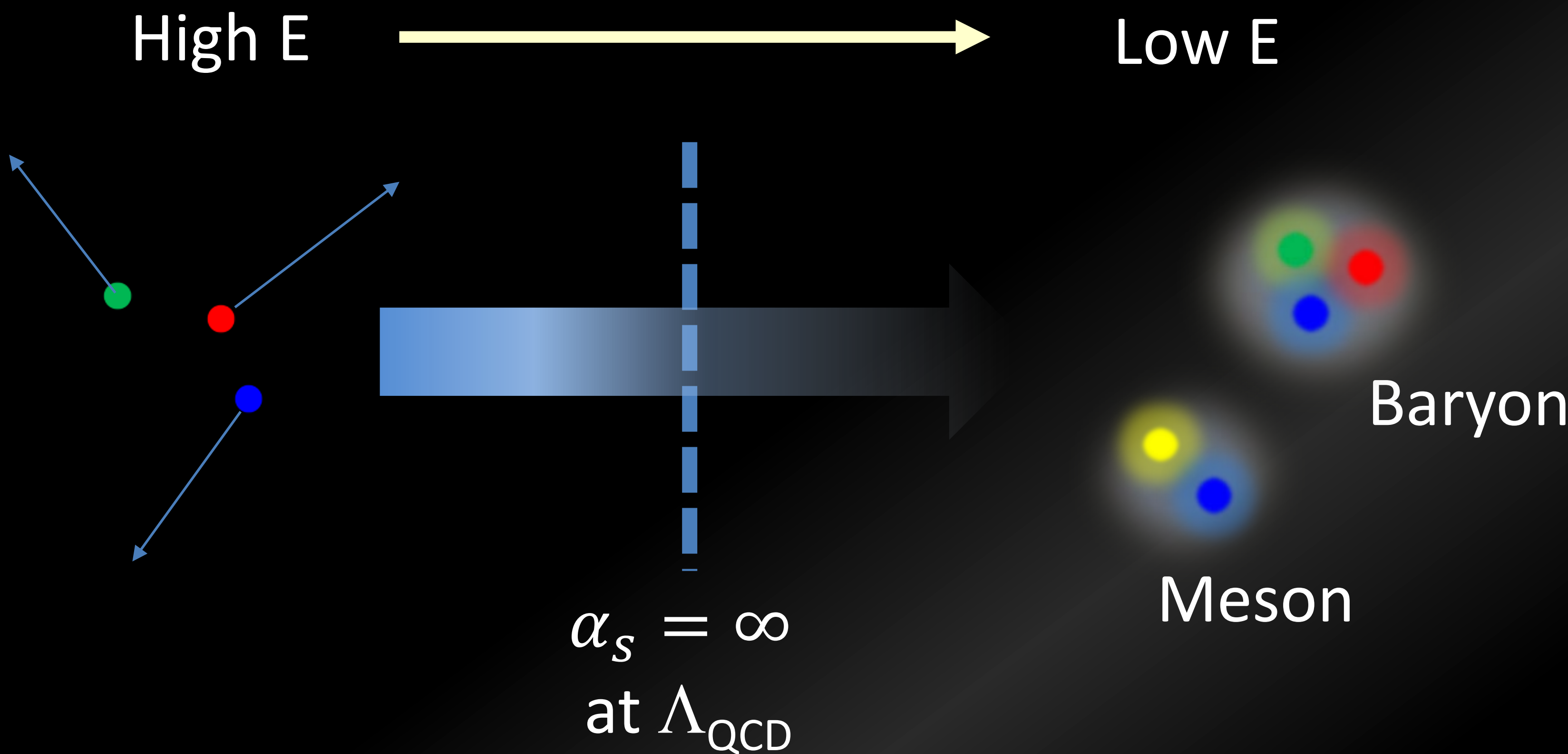


$\alpha_s = \infty$

at Λ_{QCD}

Quarks drastically change themselves below Λ_{QCD}.

How Hadrons are formed?



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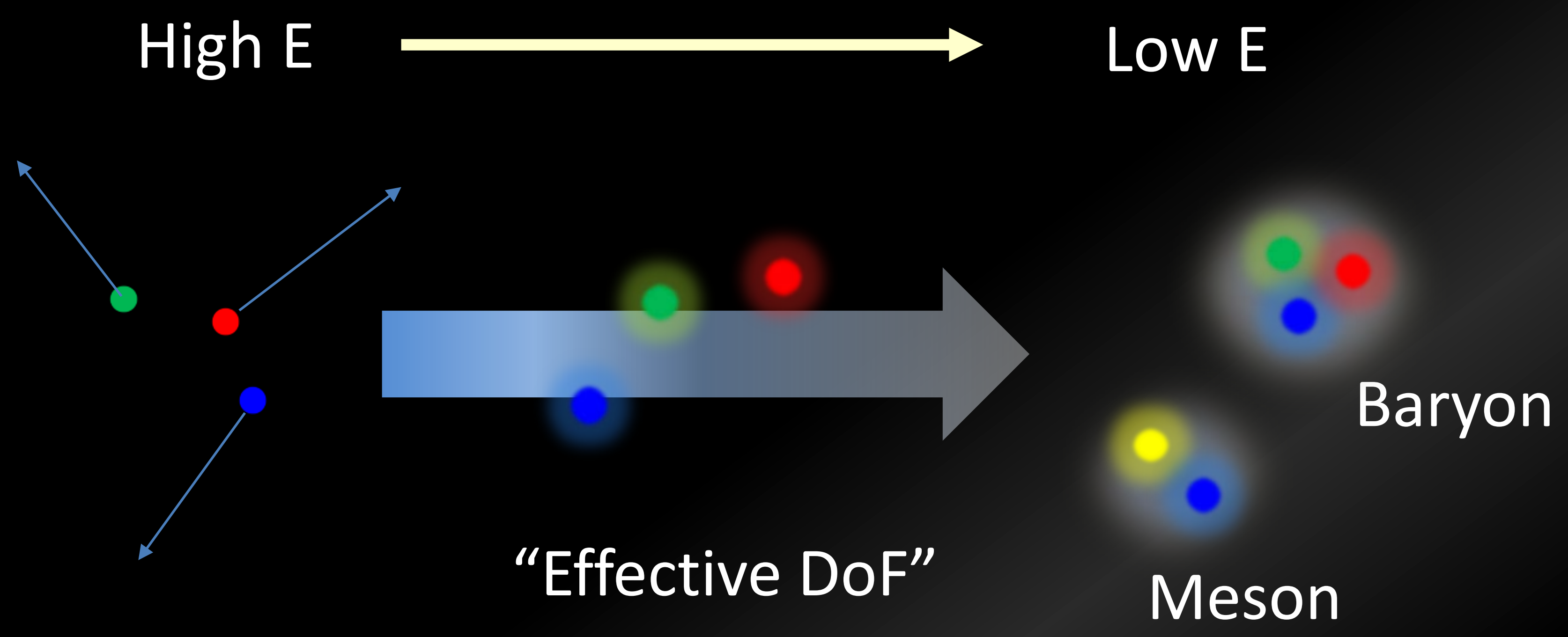
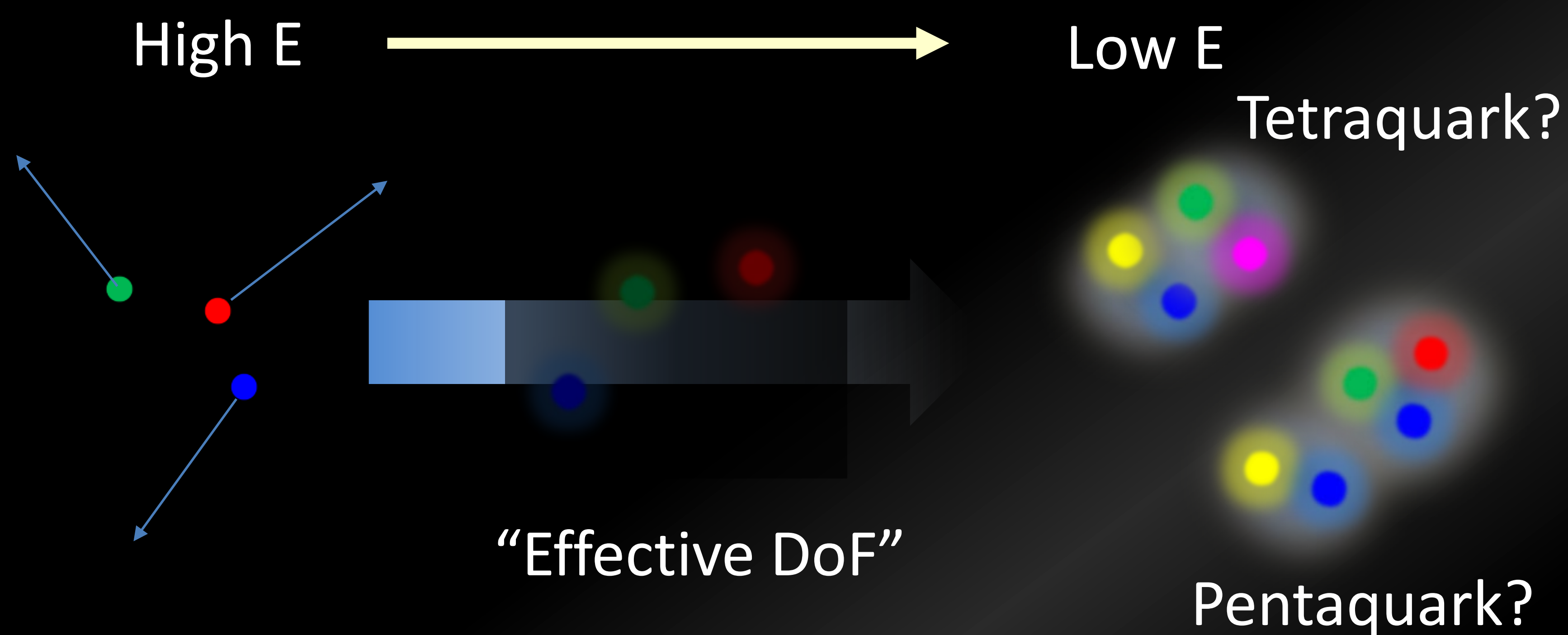
How Hadrons are formed?



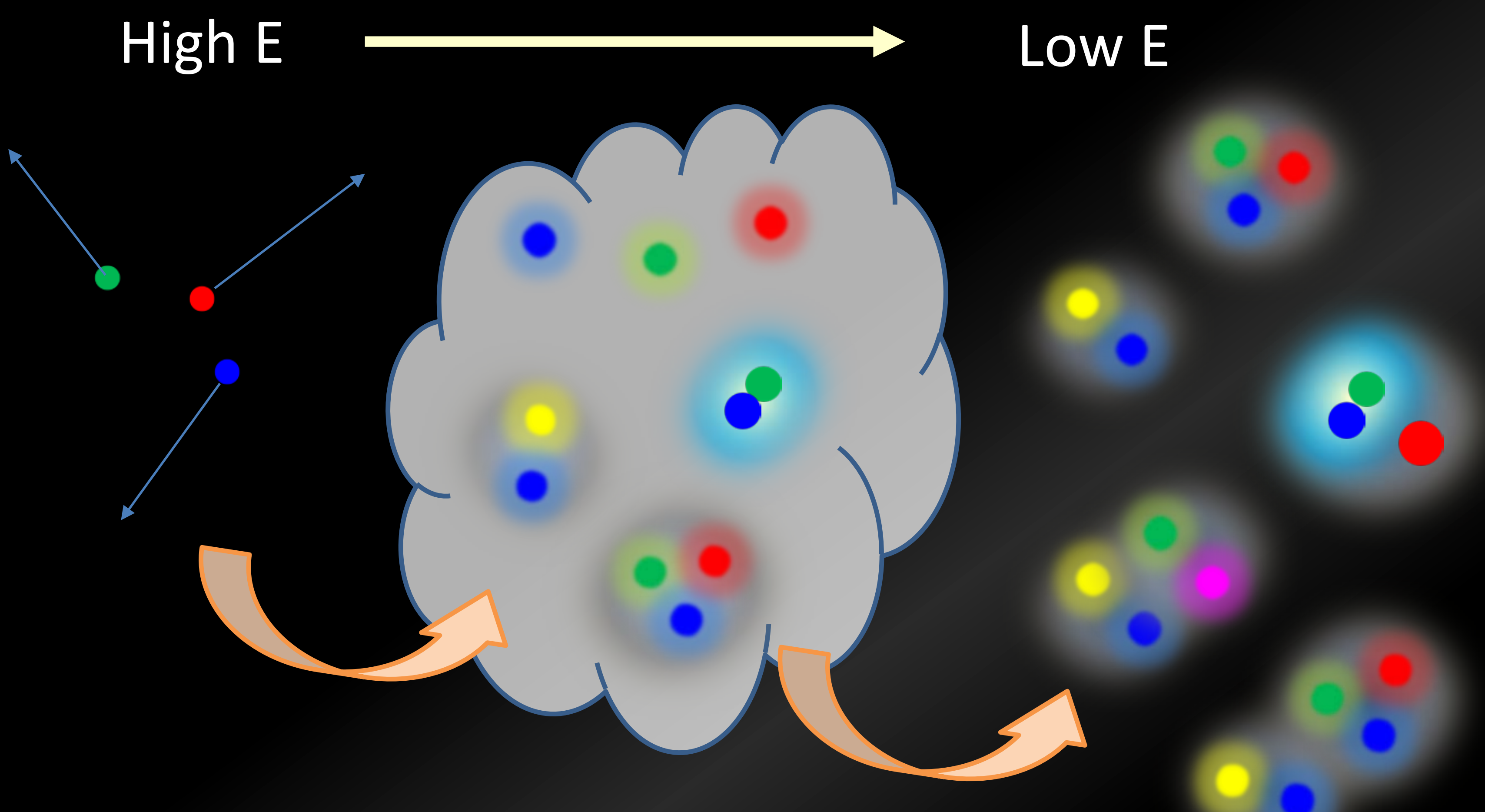
"Constituent Quarks" seem to work rather well
as good building blocks of hadrons...

How Hadrons are formed?



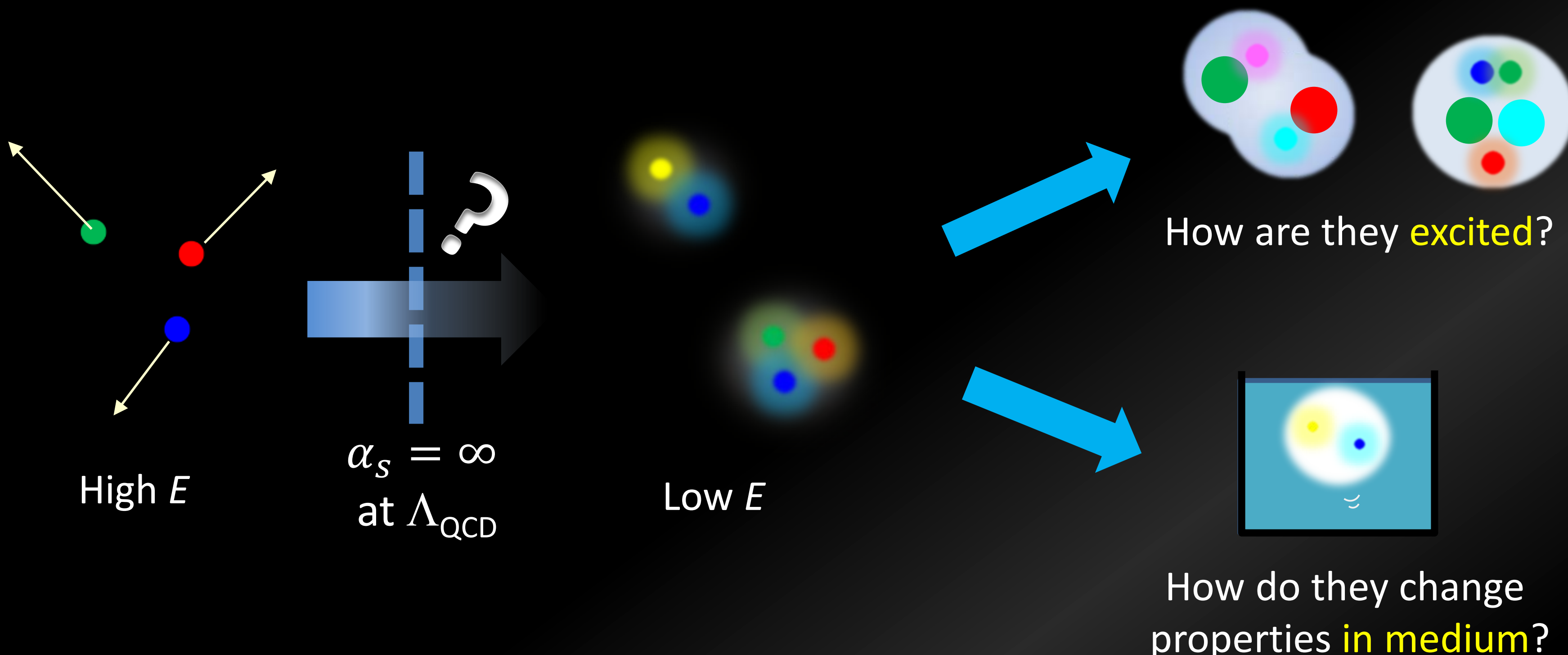
"Exotic hadrons" require a new aspect
in describing hadrons beyond the "standard picture".

How Hadrons are formed?



"Composite (or Colored) Quasi-Particle?"

Hadron Physics at J-PARC

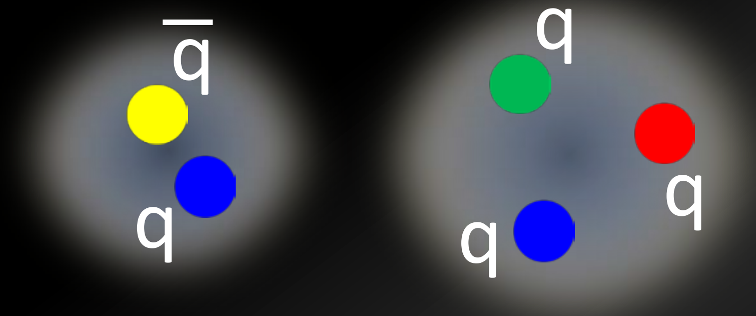


Quasi-Particles (= Effective DoF) emerging at Low E describe hadron properties effectively.

Charm Baryon Spectroscopy

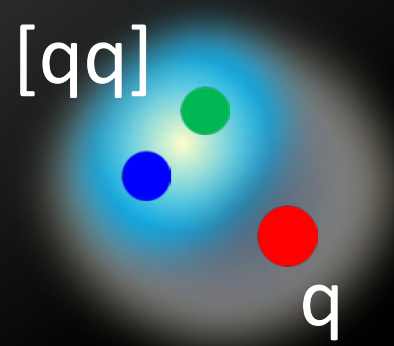
What are good building blocks of Hadrons?

Constituent Quark



hadron (colorless cluster)

Diquark?
(Colored cluster)



Diquarks

Color-Magnetic Interaction of two quarks

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

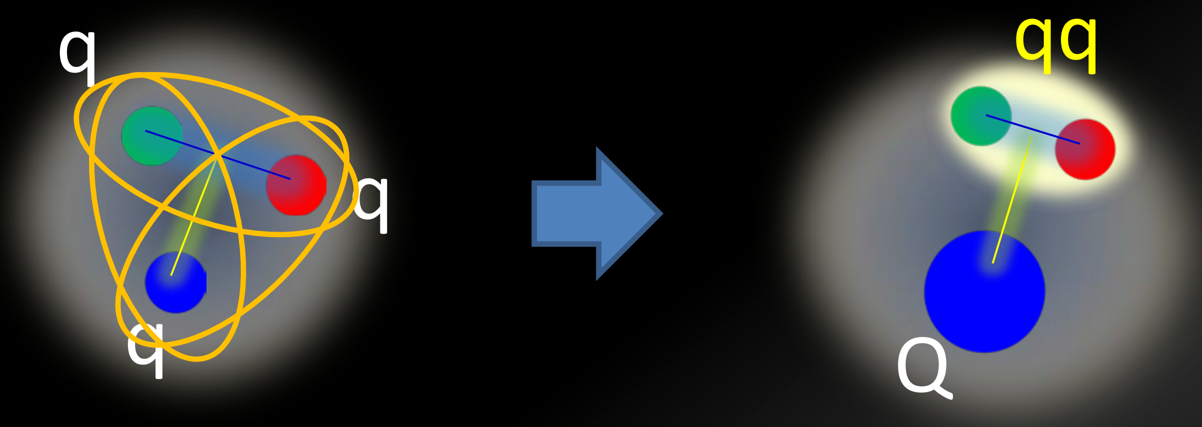
$\rightarrow 0$ if $m_{i,j} \rightarrow \infty$

"Good Diquark": Strong Attraction

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

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

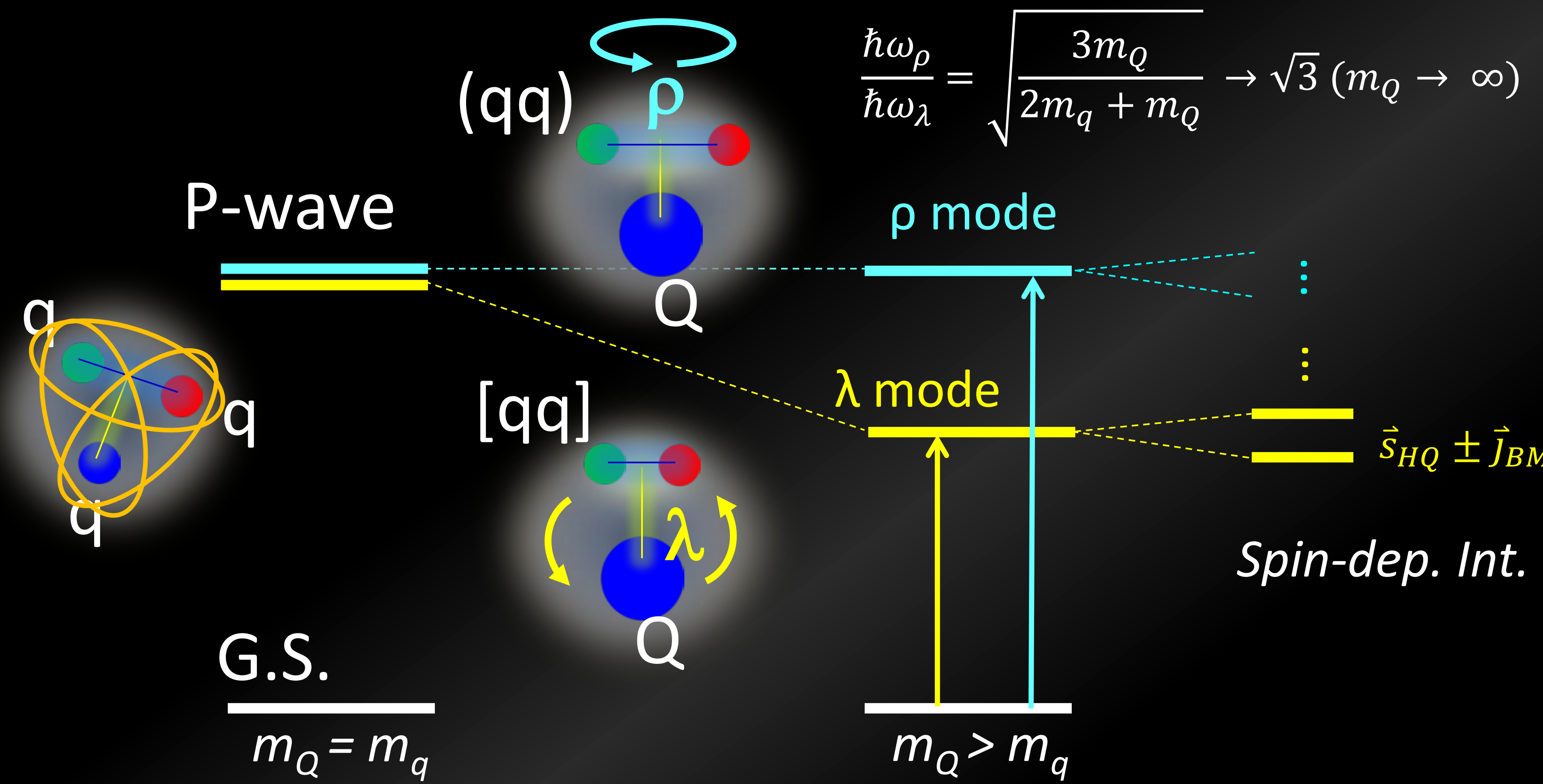
What we can learn from baryons with heavy flavors



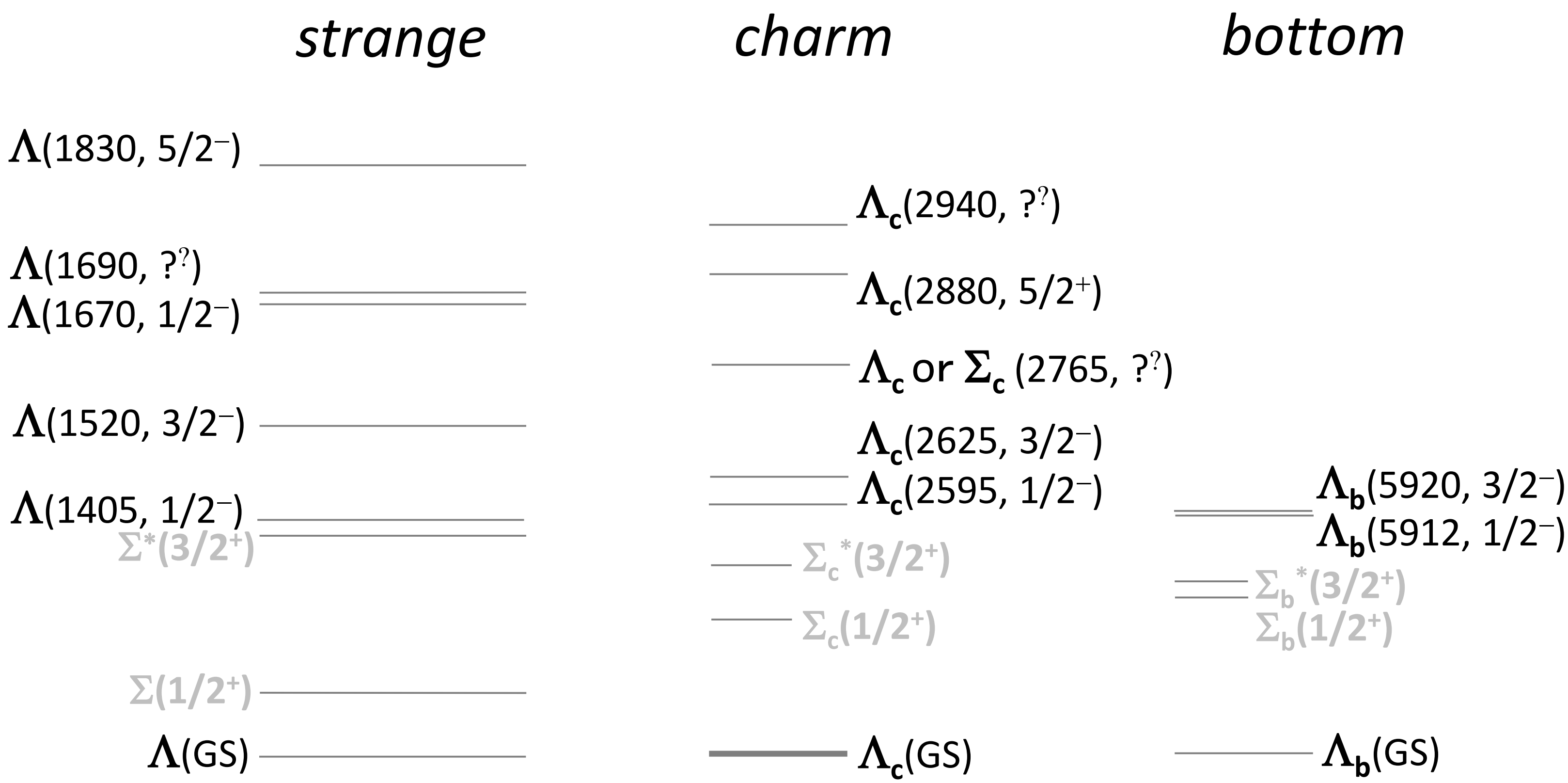
- Quark motion of “qq” is singled out by a heavy Q
  - Diquark correlation
- Level structure, Production rate, Decay properties
  - sensitive to the internal quark(diquark) WFs.
- Properties are expected to depend on a Q mass.

Schematic Level Structure of Heavy Baryons

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



Lambda Baryons (P-wave)



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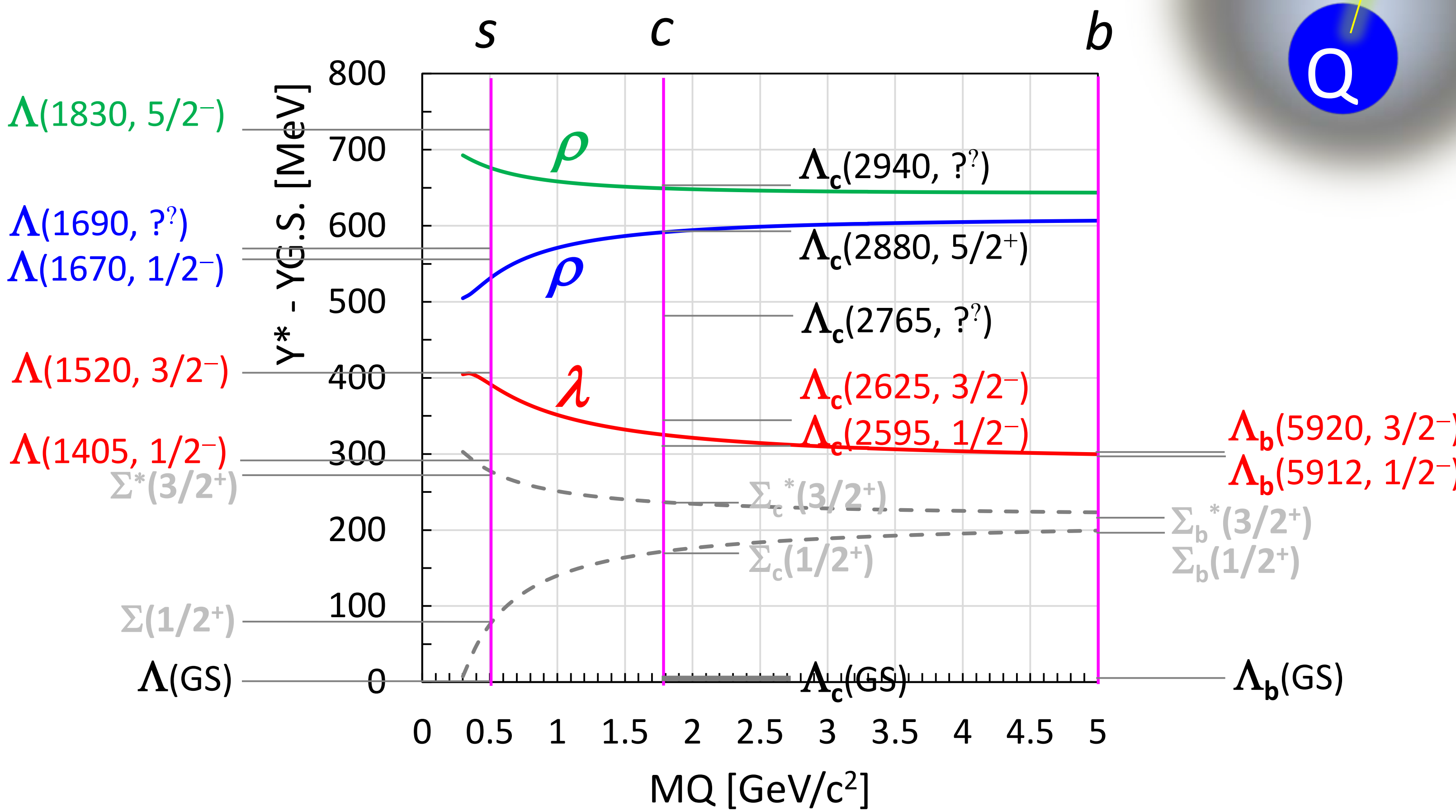
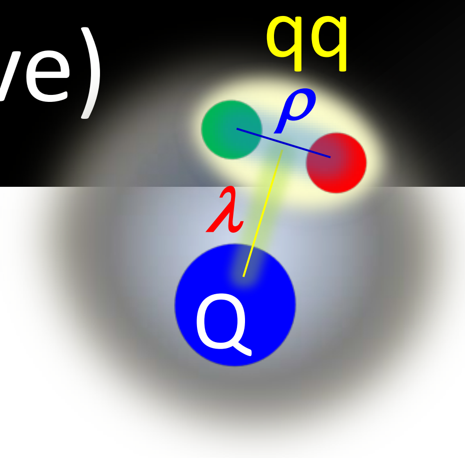
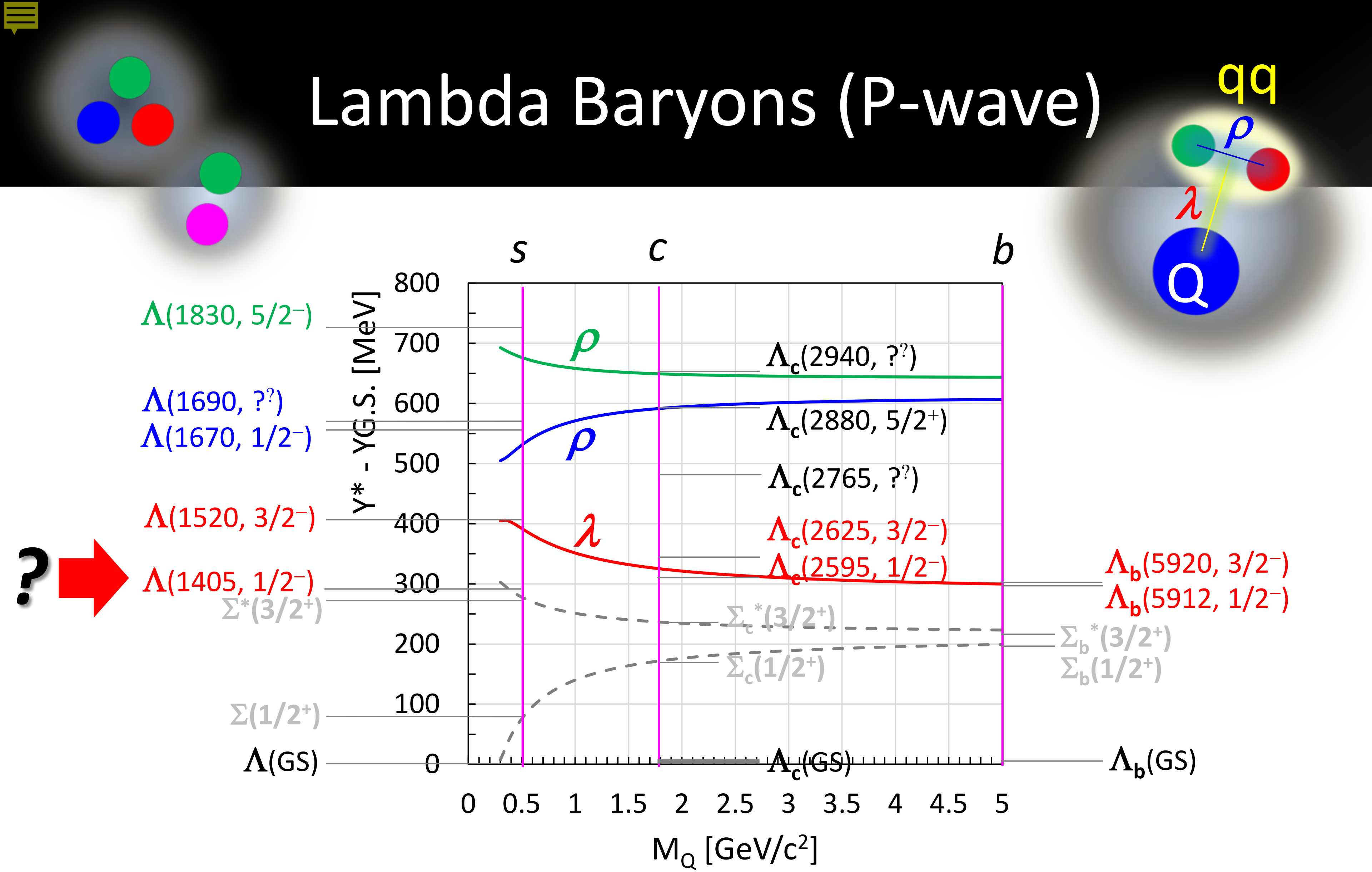




non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$
$\rho-\lambda$ mixing (cal. By T. Yoshida)

Lambda Baryons (P-wave)

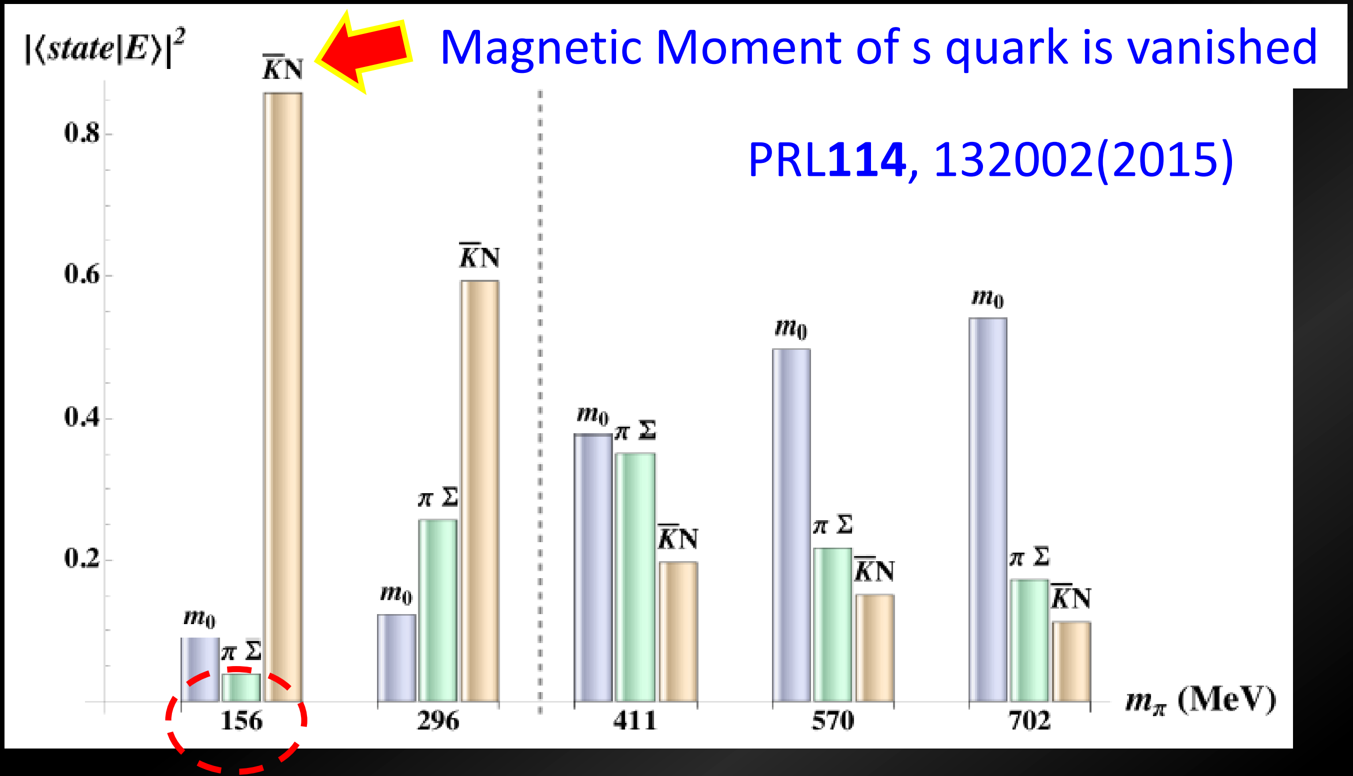


non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

ρ–λ mixing (cal. By T. Yoshida)

T. Yoshida et al., Phys. Rev. D**92**, 114029(2015)

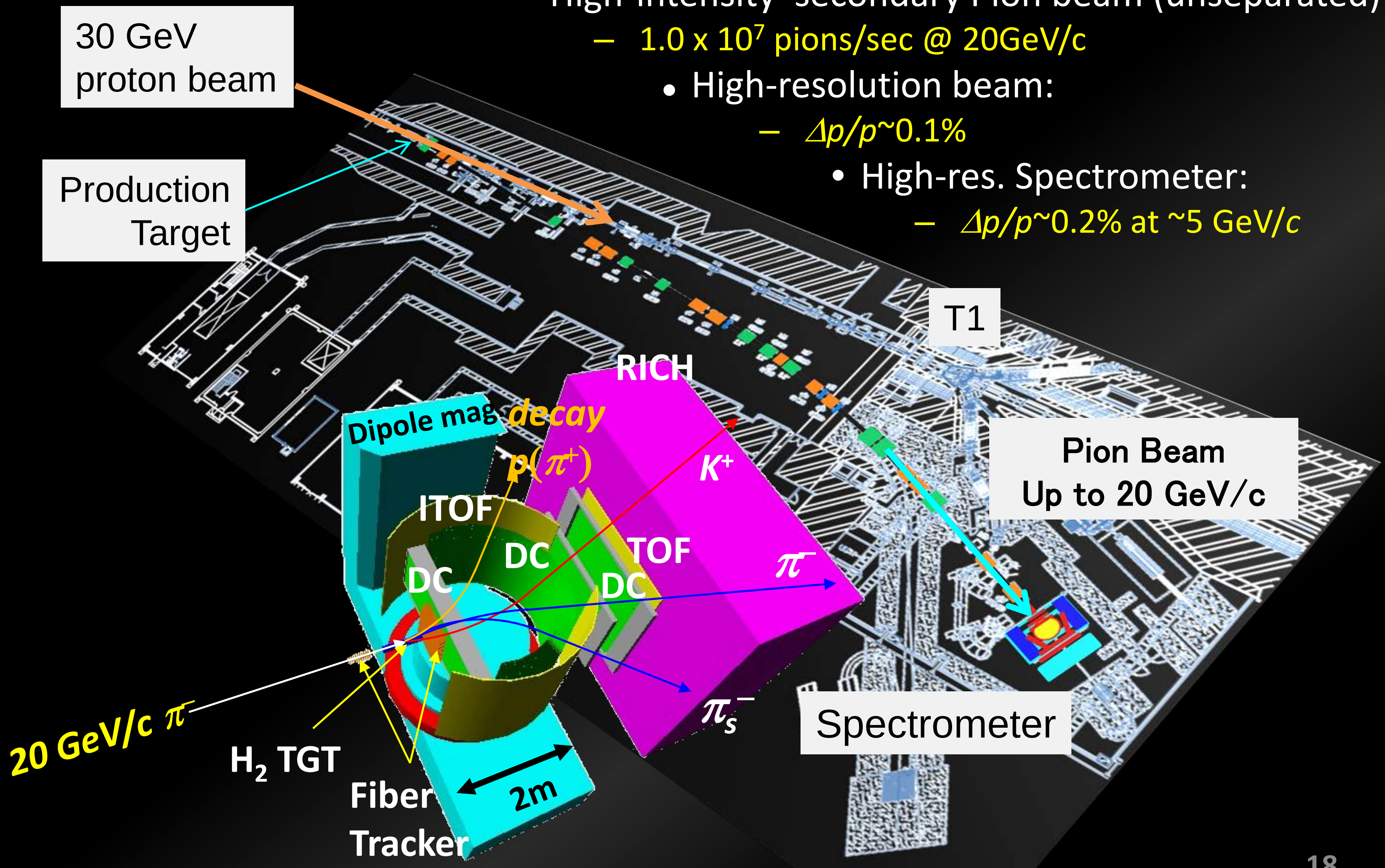
LQCD Evidence that Λ(1405) is a $K^{bar}N$ molecule



- Study of $K^{bar}N$ scattering below the $K^{bar}N$ thres. are important.

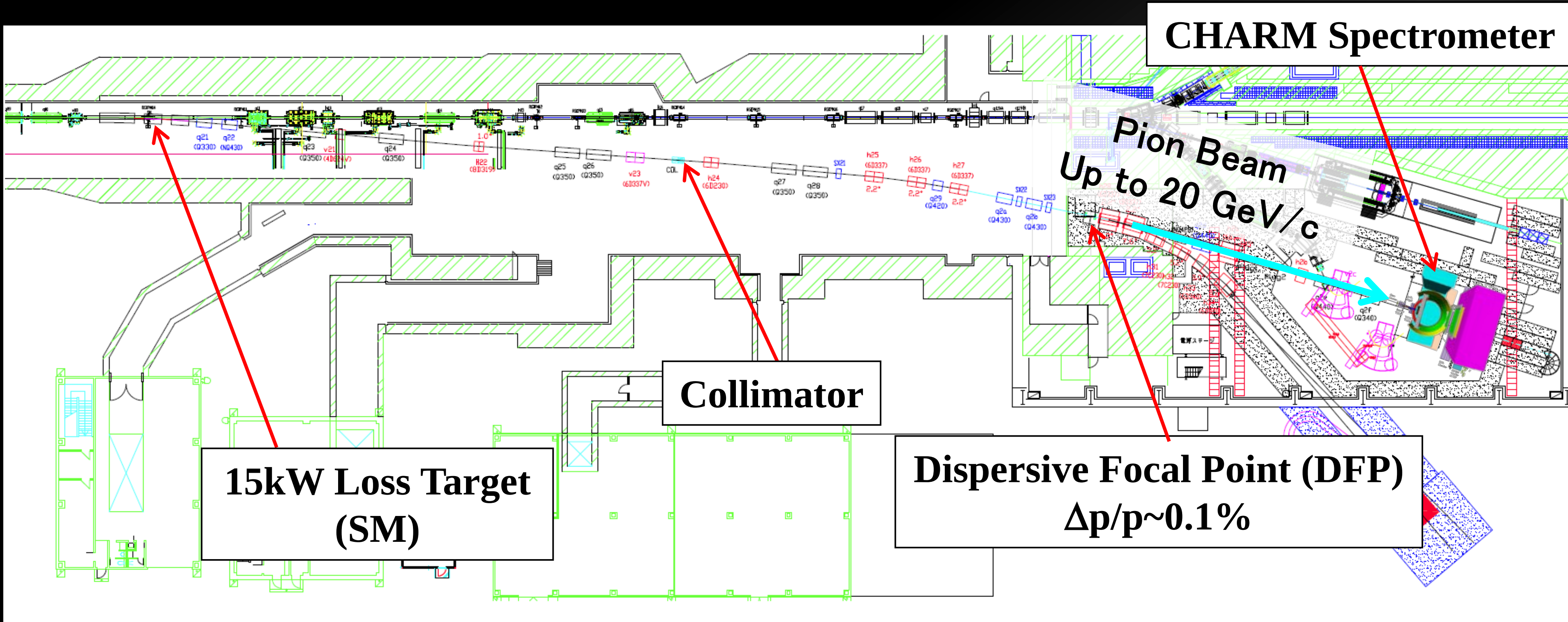
High-res., High-momentum Beam Line

- High-intensity secondary Pion beam (unseparated)
  - 1.0 x 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



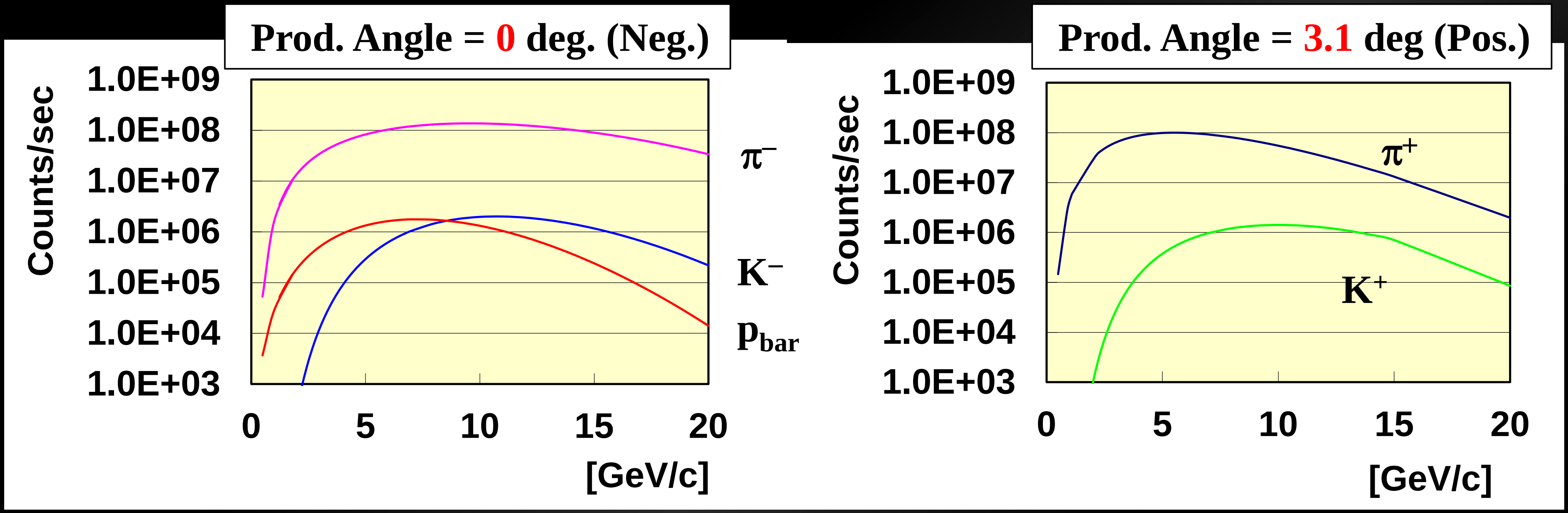
A New Platform for Hadron Physics at the High-momentum Beam Line

- 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

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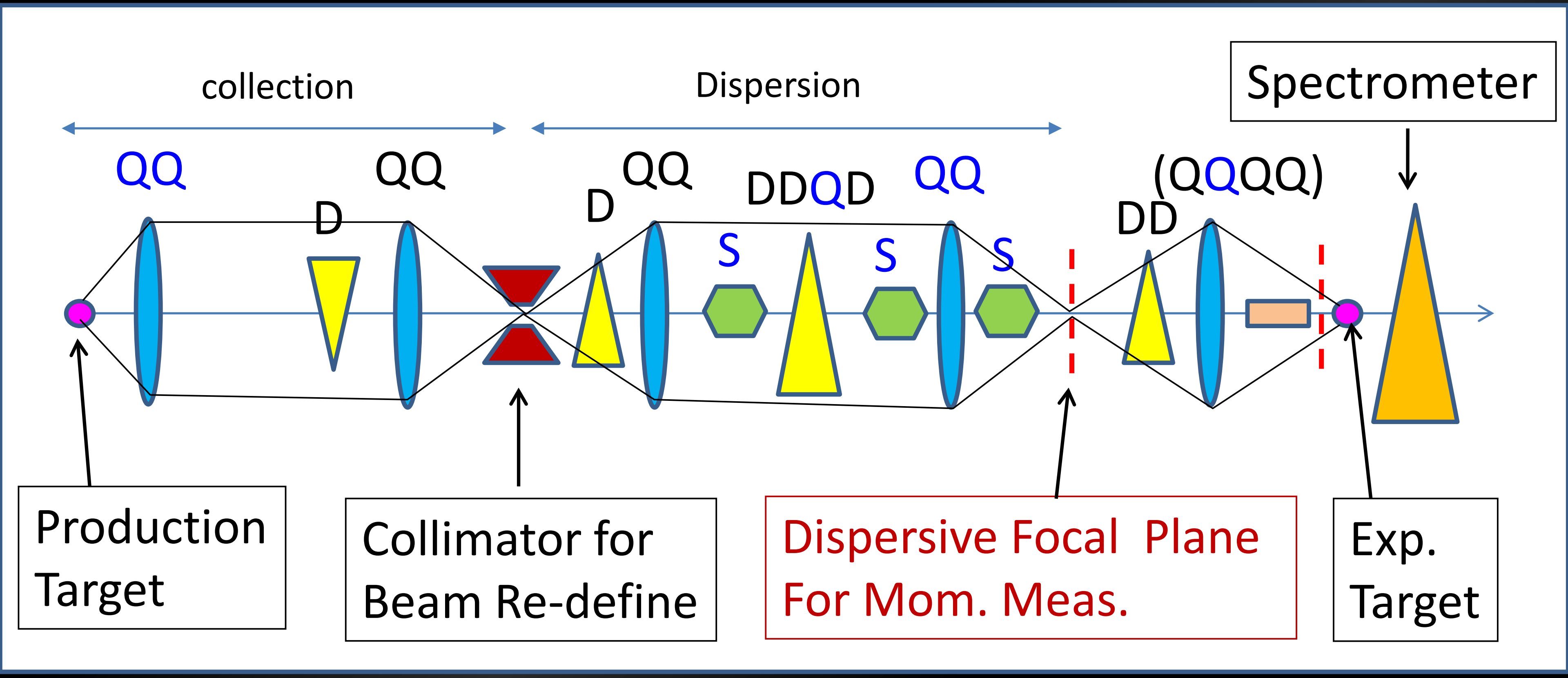
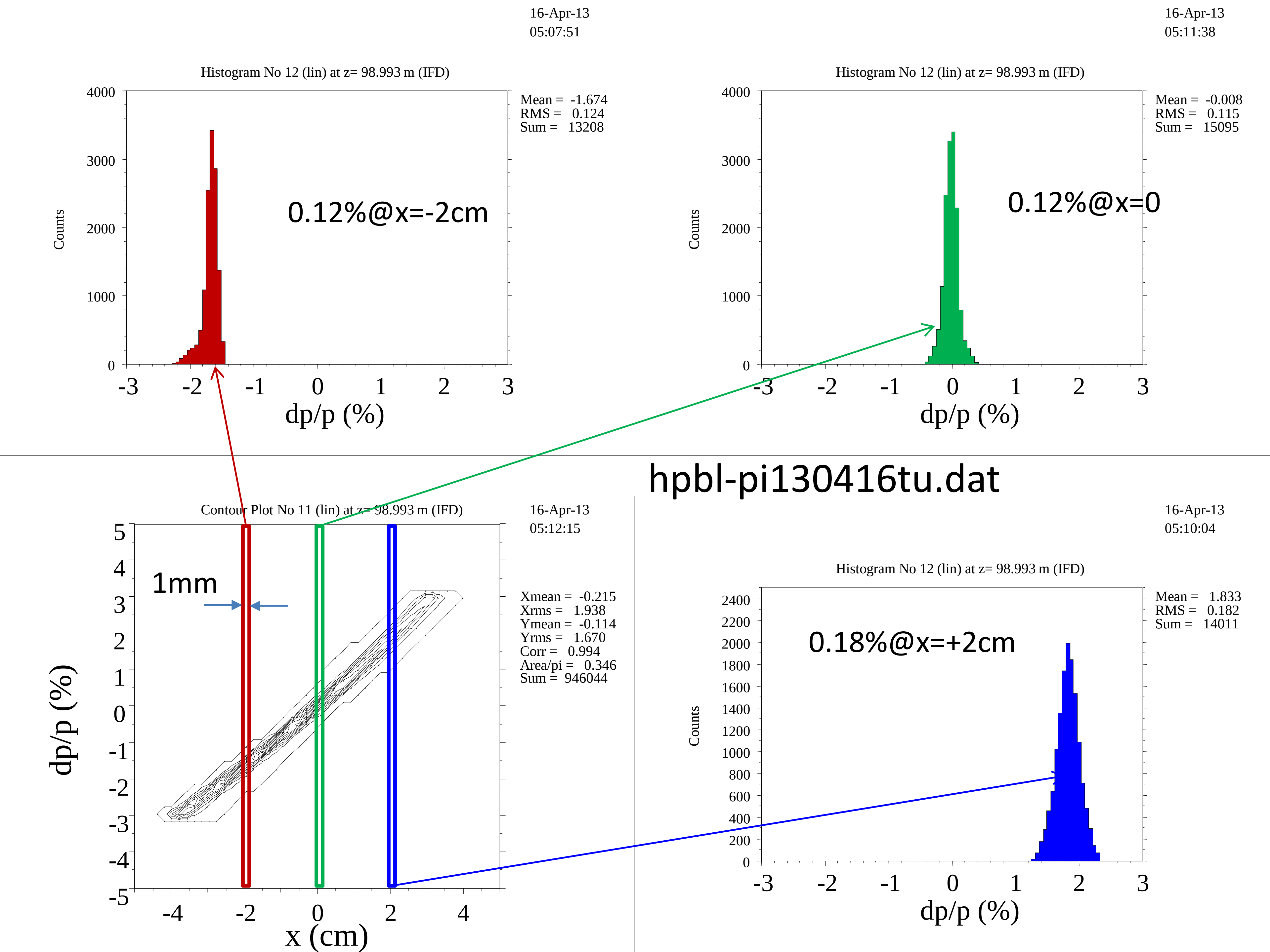
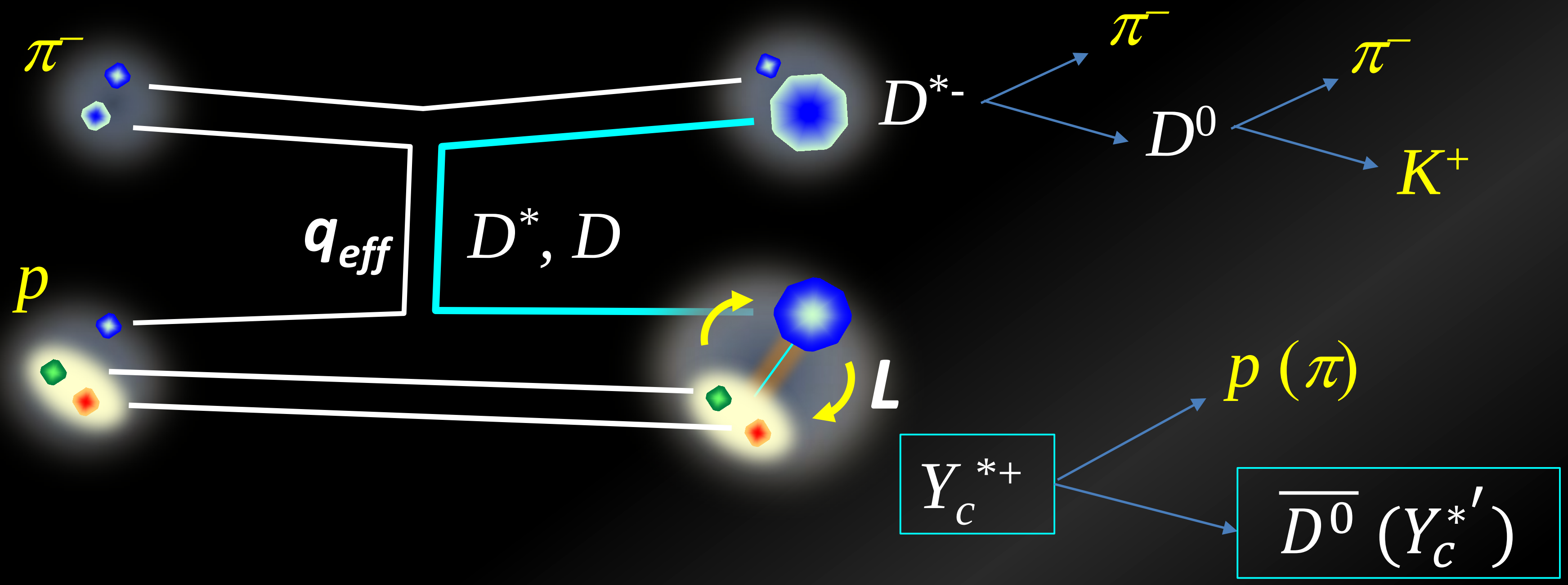
- High-resolution beam: $\Delta p/p$~0.1%



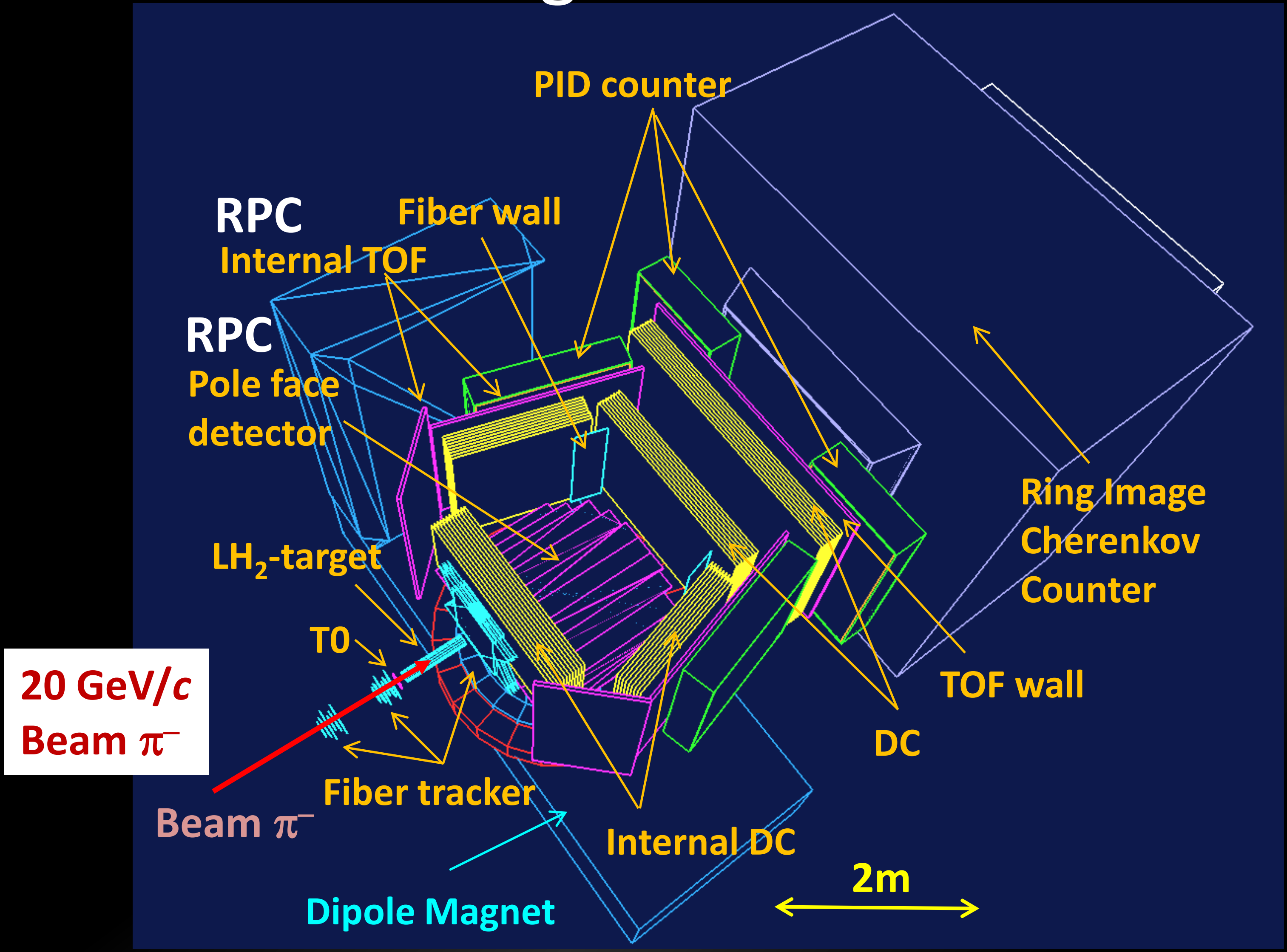


16-Apr-13
05:07:51
Histogram No 12 (lin) at z= 98.993 m (IFD)
Counts
dp/p (%)
Mean = -1.674
RMS = 0.124
Sum = 13208
0.12%@x=-2cm
16-Apr-13
05:11:38
Histogram No 12 (lin) at z= 98.993 m (IFD)
Counts
dp/p (%)
Mean = -0.008
RMS = 0.115
Sum = 15095
0.12%@x=0
hpbl-pi130416tu.dat
Contour Plot No 11 (lin) at z= 98.993 m (IFD)
16-Apr-13
05:12:15
1mm
dp/p (%)
x (cm)
Xmean = -0.215
Xrms = 1.938
Ymean = -0.114
Yrms = 1.670
Corr = 0.994
Area/pi = 0.346
Sum = 946044
16-Apr-13
05:10:04
Histogram No 12 (lin) at z= 98.993 m (IFD)
Counts
dp/p (%)
Mean = 1.833
RMS = 0.182
Sum = 14011
0.18%@x=+2cm

Charmed Baryon Spectroscopy Using Missing Mass Techniques



Spectrometer Design



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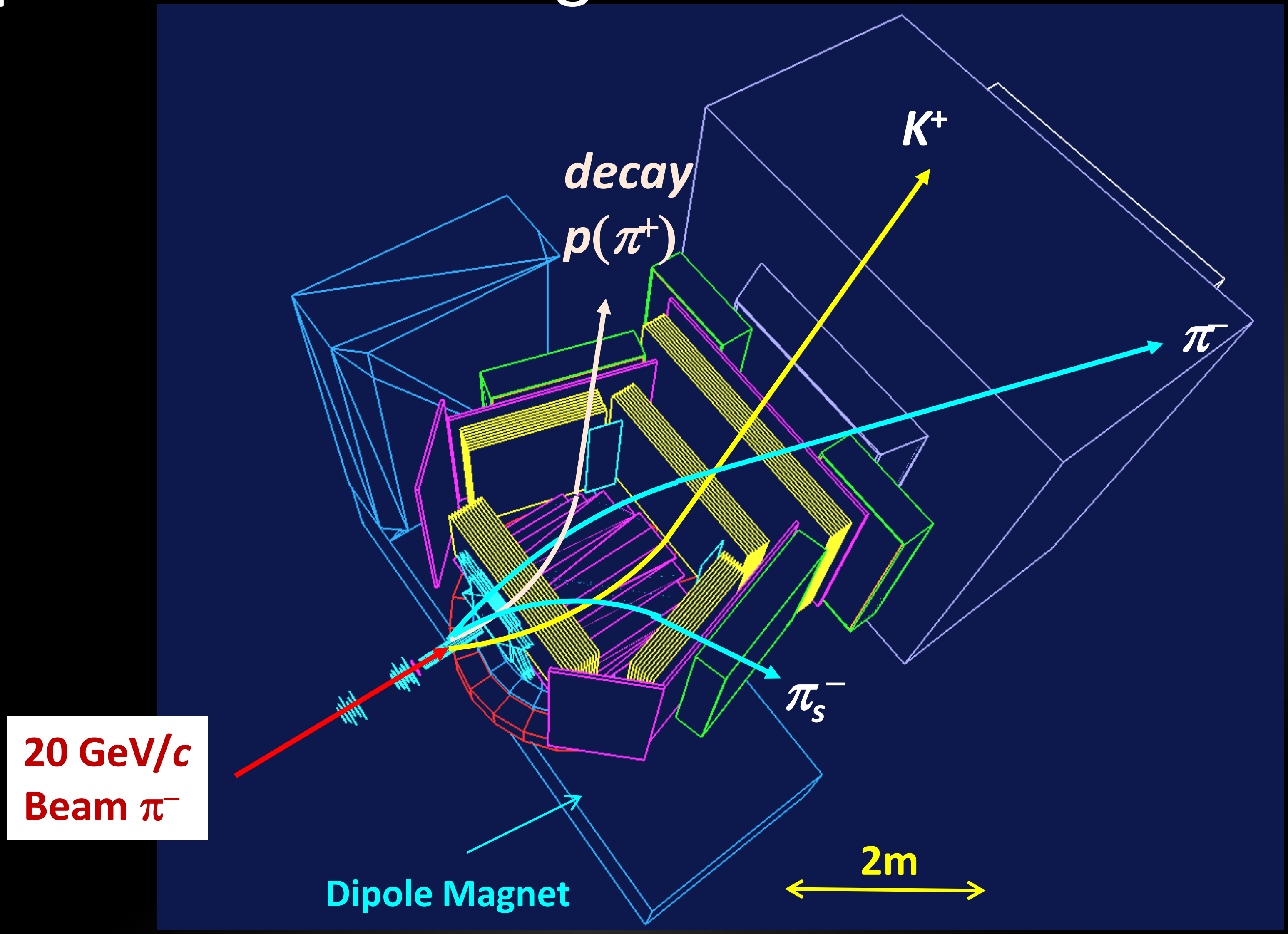
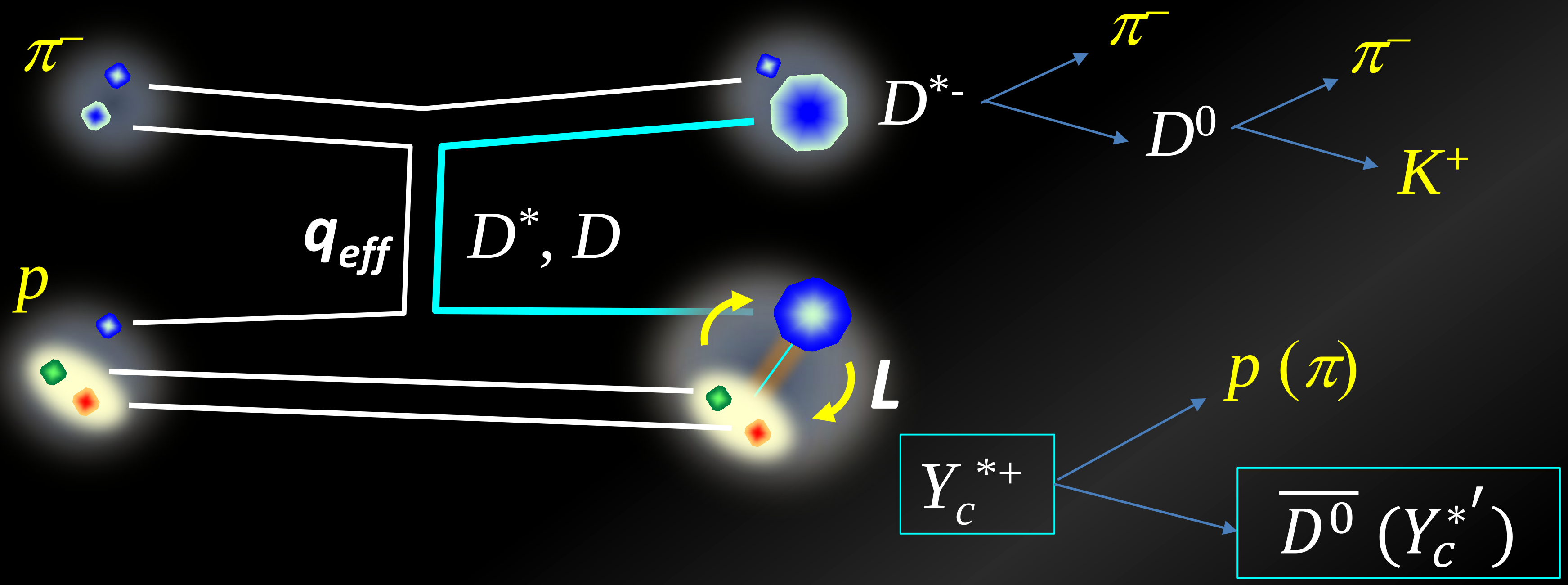


Acceptance: ~ 60% for D^*, ~ 80% for decay π^+

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

Charmed Baryon Spectroscopy Using Missing Mass Techniques

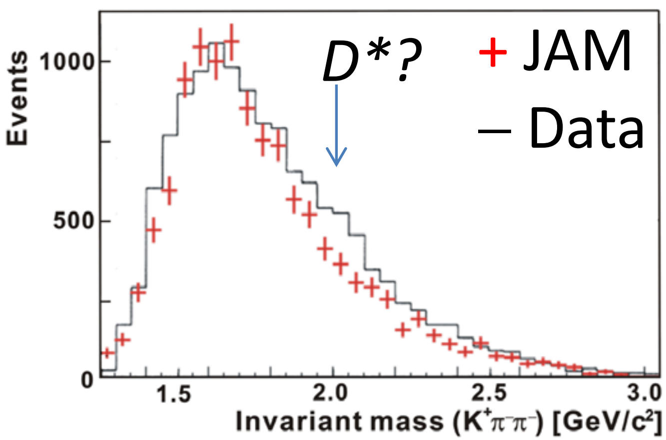


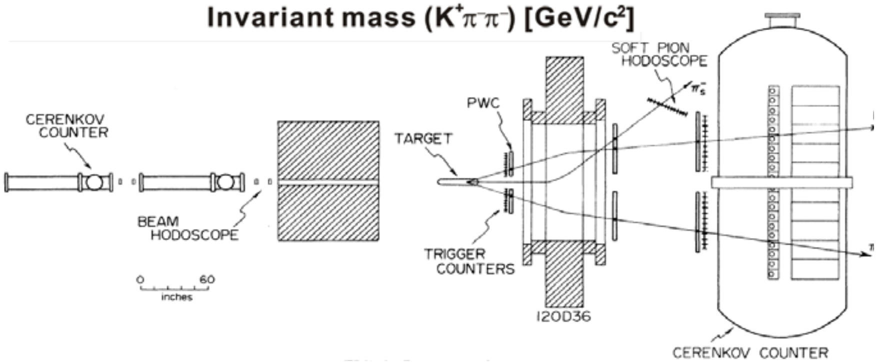
- ✓ Production and Decay reflect [qq] correlation in Excited Y_c*
- ✓ C.S. DOES NOT go down at higher *L* when q_{eff}>1 GeV/c.

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

Production Cross Section

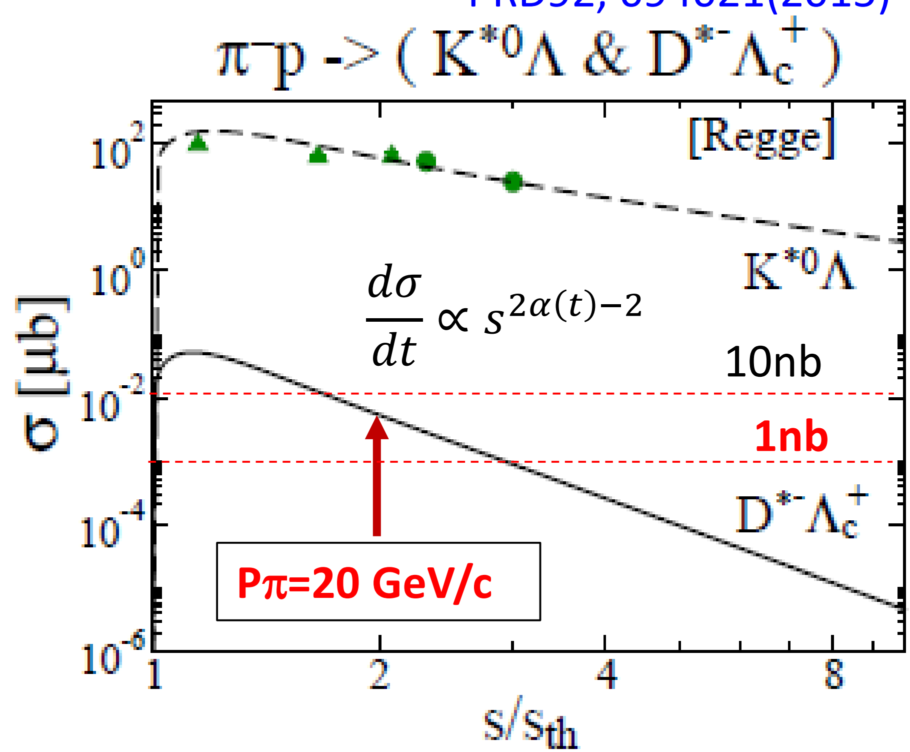
- Experimental data:
  - $\sigma(p(\pi^-,D^{*-})\Lambda_c) < 7$ nb (68%CL) (BNL exp., 1985)
  - BG spectrum is well reproduced by a MC simulation w/ JAM
- Regge Theory suggests 10^{-4} of the hyperon production
  - $\sigma(p(\pi^-,D^{*-})\Lambda_c) \sim$ a few nb



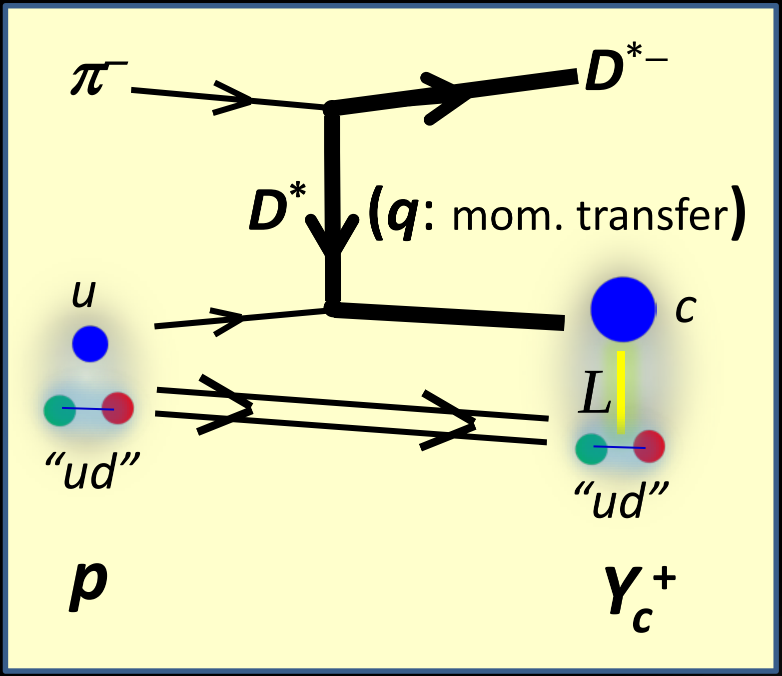


J.H. Christensen et al., PRL55, 154(1985)

S.H. Kim, A. Hosaka, H.C. Kim, and HN
PRD92, 094021(2015)



Production Rate



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

S. H. Kim, et al., PTEP, 2014, 103D01(2014)

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

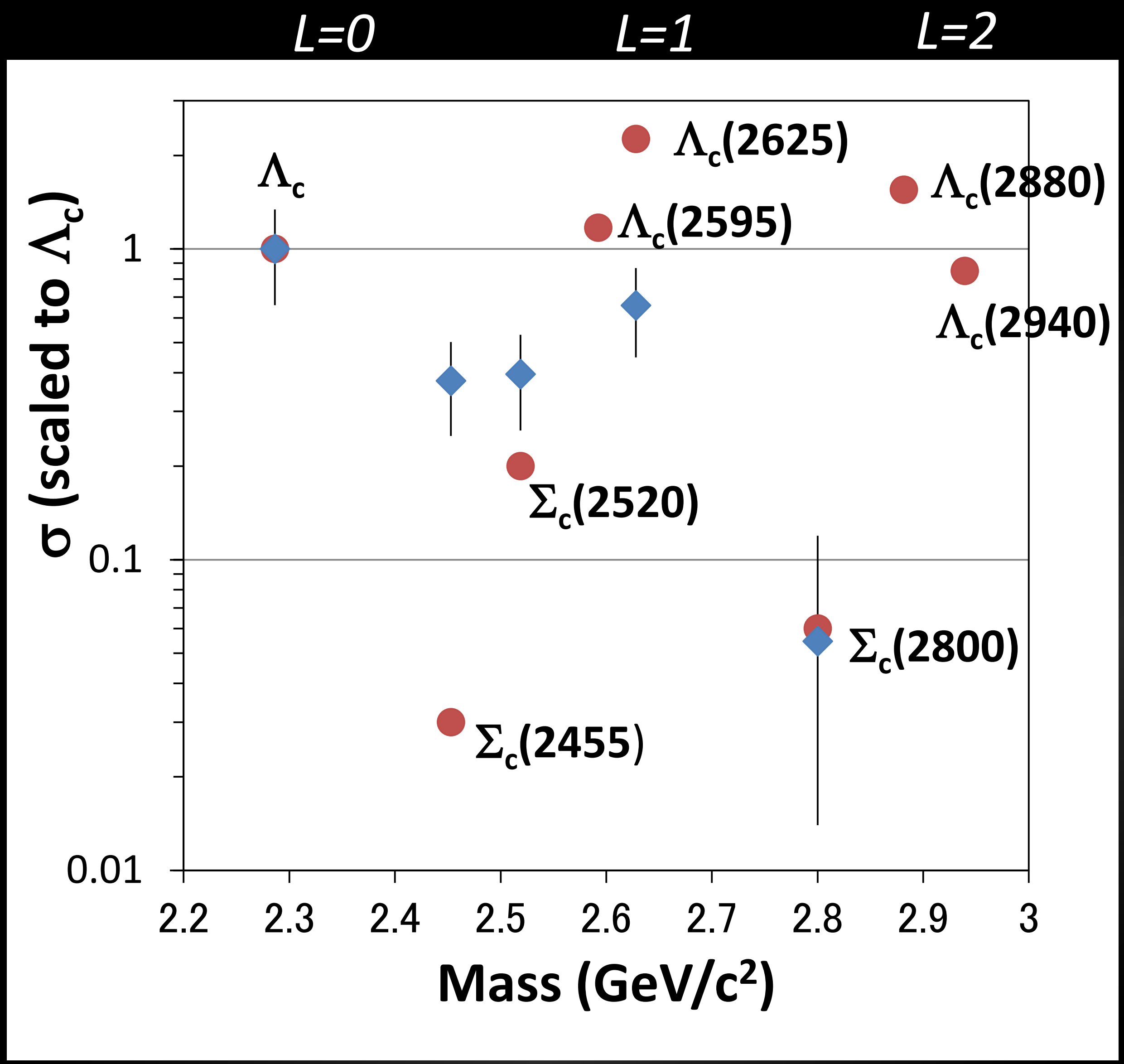
2. Momentum transfer (q_{eff})

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

A~0.42 GeV ([Baryon size]$^{-1}$)

q_{eff}~1.4 GeV/c

Comparison of production rates

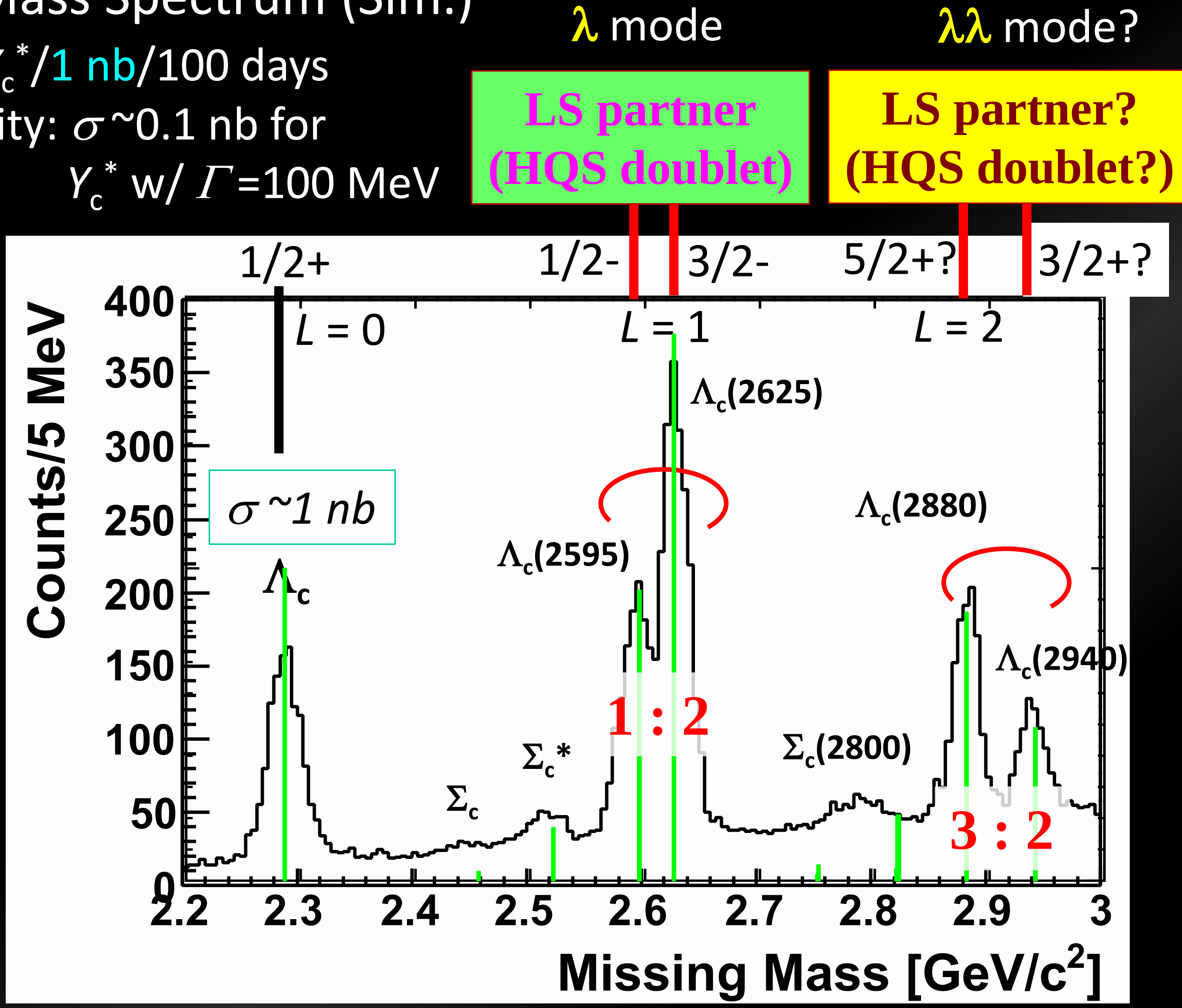


$p(\pi^-, D^{*-})Y_c^*$ (Calculation)

e^+e^- *Belle Data* (Hadron2013)

Missing Mass Spectrum (Sim.)

- ~1000 Y_c^*/1 nb/100 days
- Sensitivity: σ~0.1 nb for Y_c^* w/ Γ=100 MeV

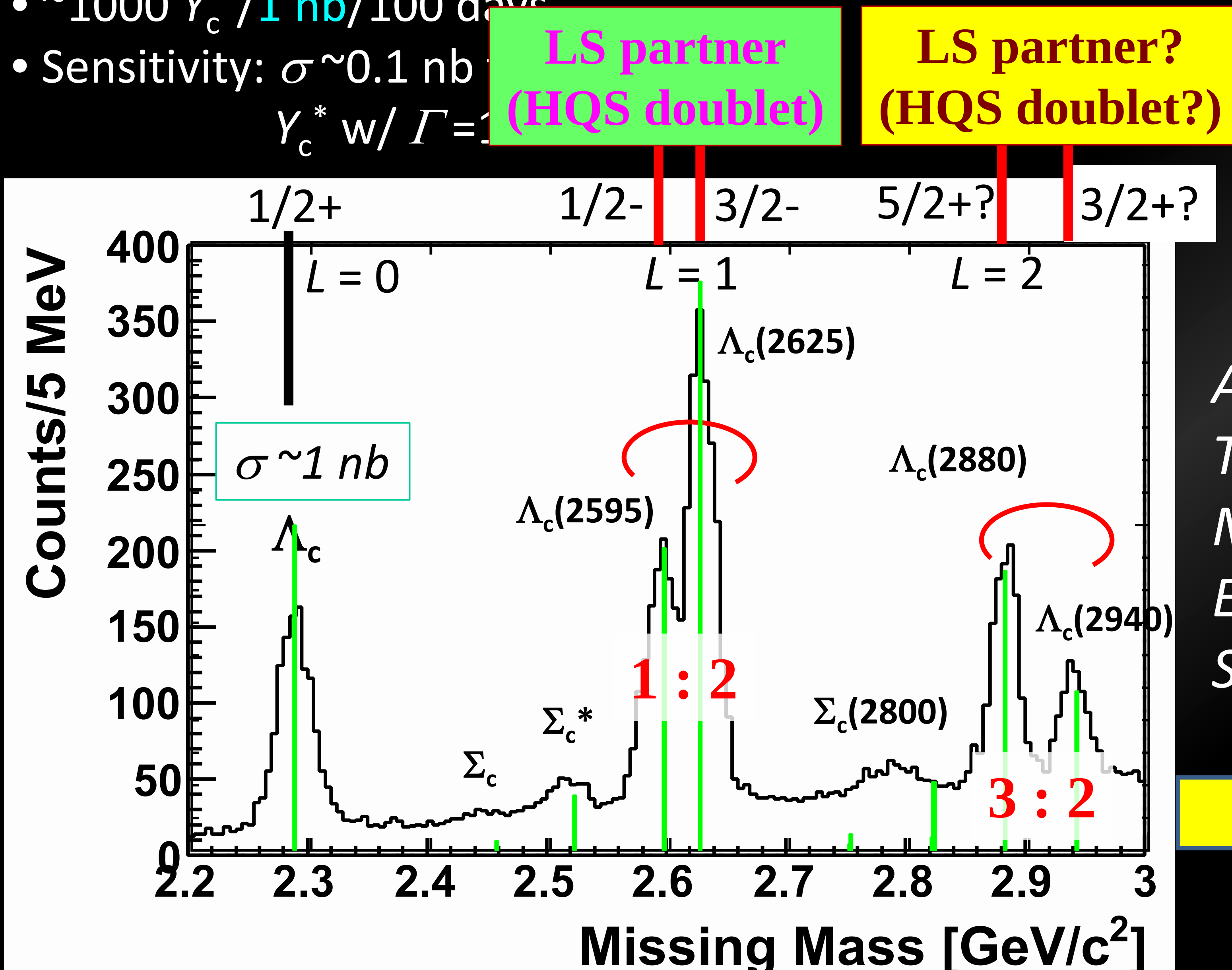


Missing Mass Spectrum (Sim.)

- ~1000 Y_c^*/1 nb/100 da
- Sensitivity: σ~0.1 nb
  Y_c^* w/ Γ=1

λ mode

λλ mode?

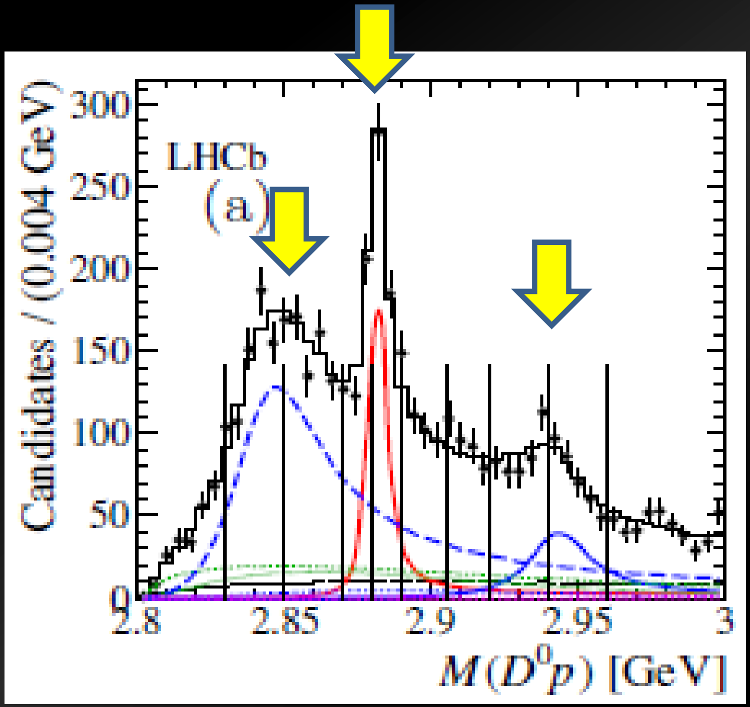


Are There More Excited States?

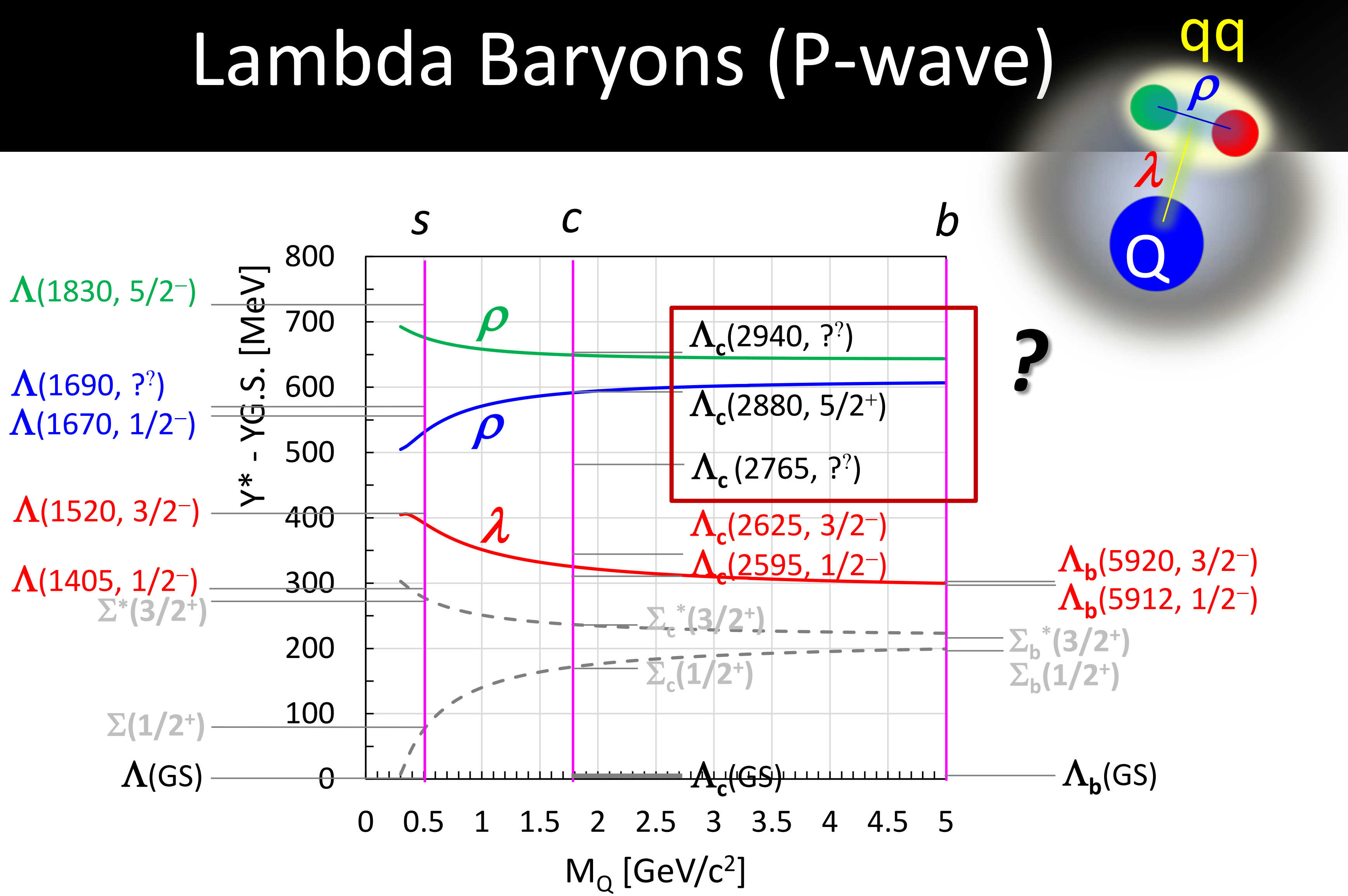
New data from LHCb

J. High Energ. Phys. (2017) 2017

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



Lambda Baryons (P-wave)



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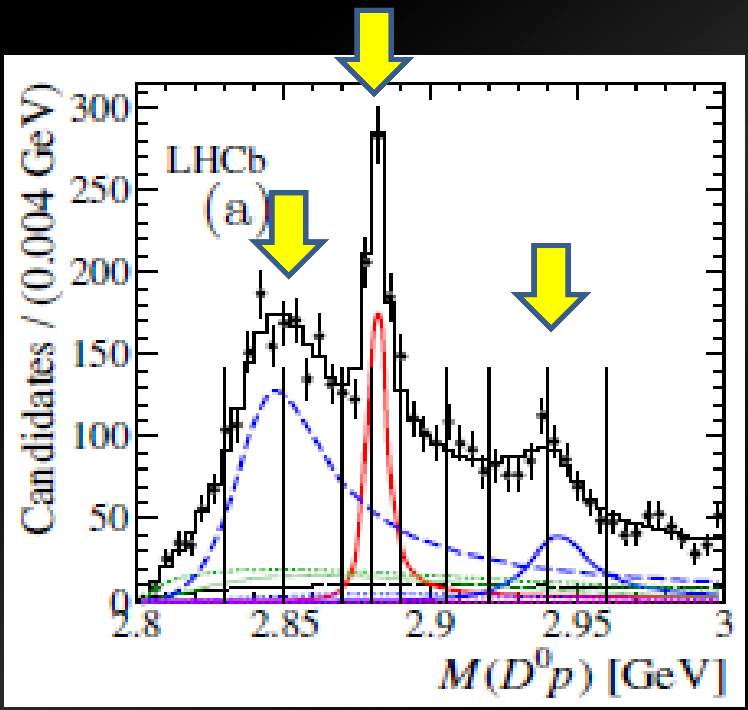
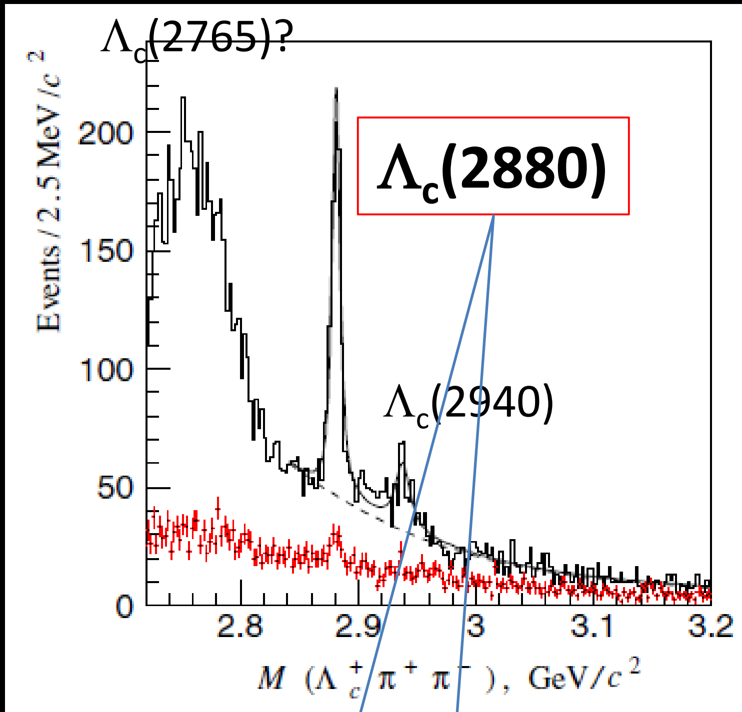
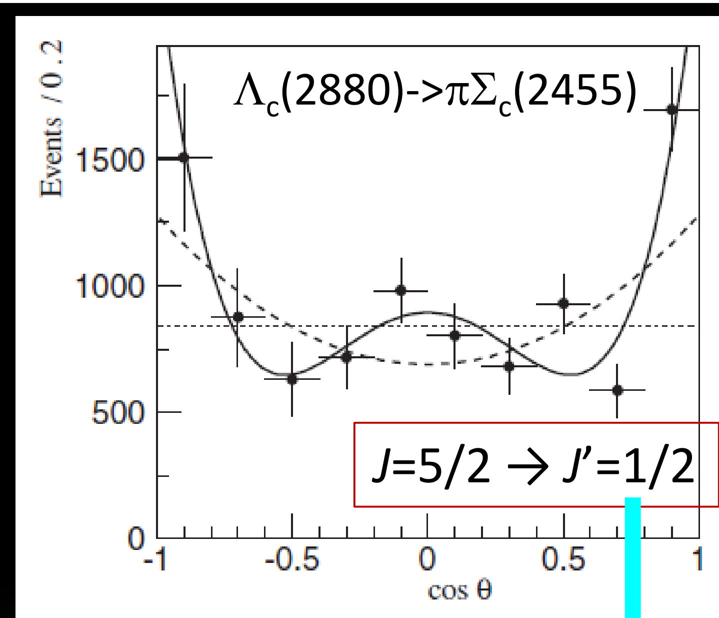
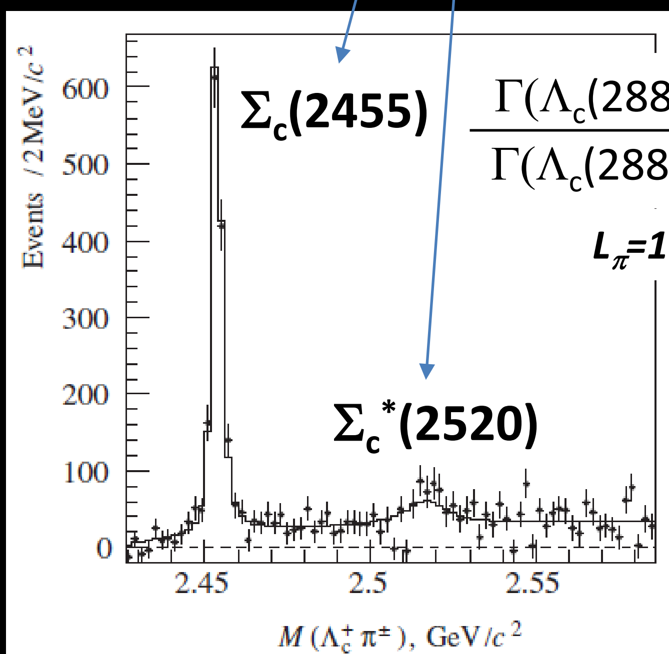


- Questions arise;
  - Is $\Lambda_c(2940)$ an *L*=3 state (λ mode)?
  - Are $\Lambda_c(2880)$ and $\Lambda_c(2860)$ *LS* partners of *L*=2 (λ modes)?
- Production rates in $p(\pi^-, D^{*-})Y_c^*$ will give answer.

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







$$\frac{\Gamma(\Lambda_c(2880)\text{->}\pi\Sigma_c^*(2520))}{\Gamma(\Lambda_c(2880)\text{->}\pi\Sigma_c(2455))} = \mathbf{0.23}$$

L_π=3 transition

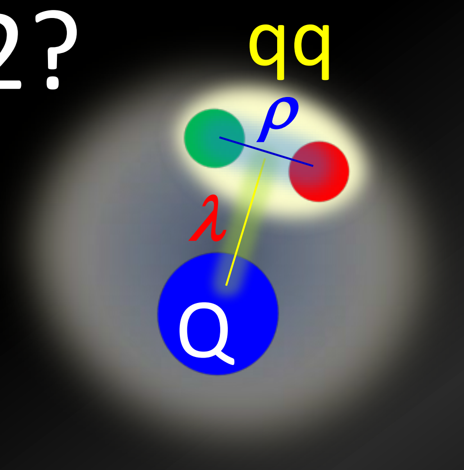
L_π=1 contribution may affect…

J^P=5/2⁺ for Λ_c(2880)

Is it a D-wave Lambda-c Baryon?

If so, where is a spin partner ?

Does Λ(2880) have L=2?



- P-wave transition seems to be suppressed in $\Lambda_c(2880)^{\frac{5}{2}+} \rightarrow \Sigma_c^*(2520)^{\frac{3}{2}+} + \pi(0^-)$.
- It would be forbidden only in the case of $J_{BM}^P = 3^+$:
  - Negative party states "5/2-" have large widths.

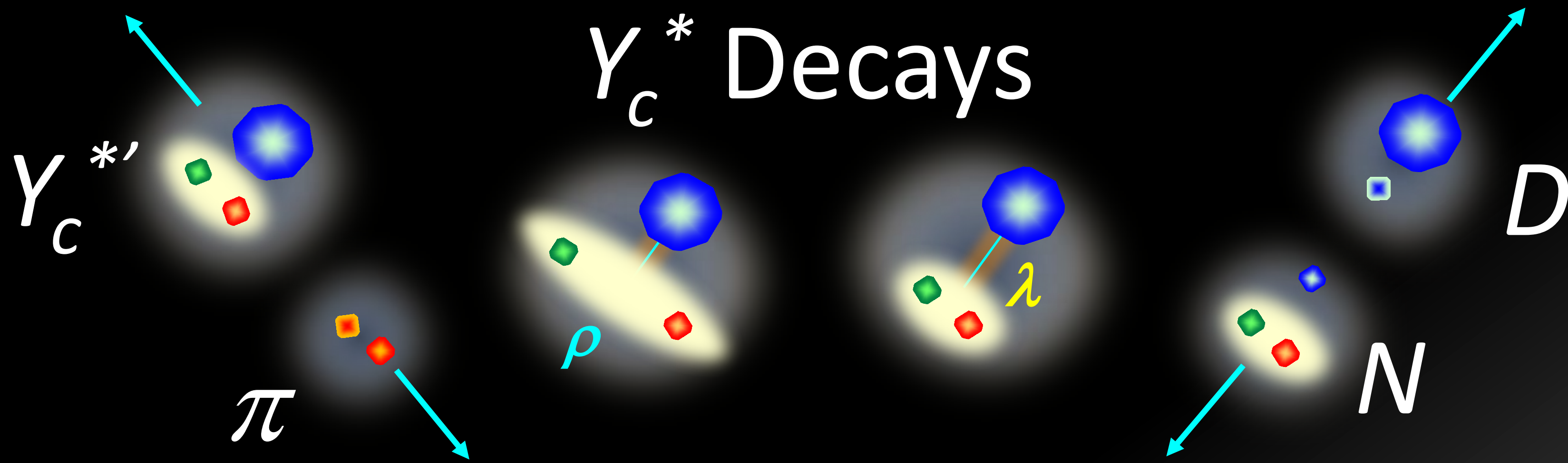
    (H. Nagahiro et al., PRD95 (2017) no.1, 014023)

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+

Σ_c^*(2520) 3/2+
Asymm
Symm. (I=1)
Symm. 1 Symm, 0
0
1+

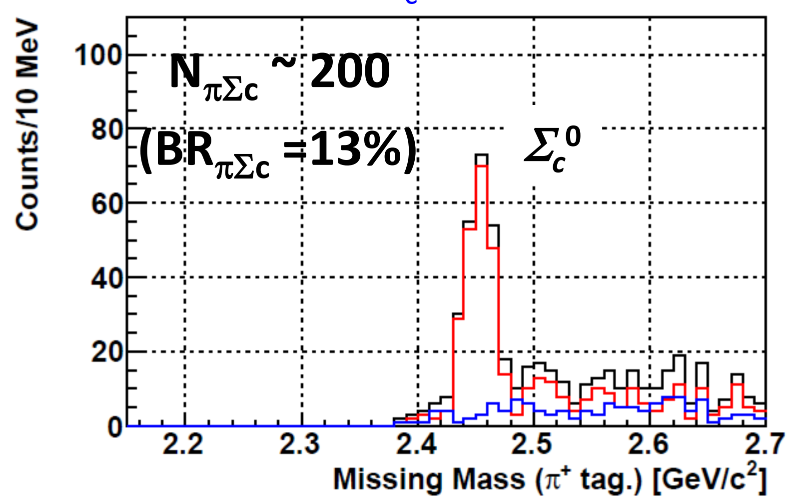
- $\Lambda_c(2880)^{\frac{5}{2}+}$ is likely to be λρ mode (λ=1, ρ=1).
  - Since, Naively, Ex(λλ)<Ex(λρ), Ex(2880) is too low if it is a λρ state.
- This can be tested by measuring its production rate.

$Y_c{}^*$ Decays

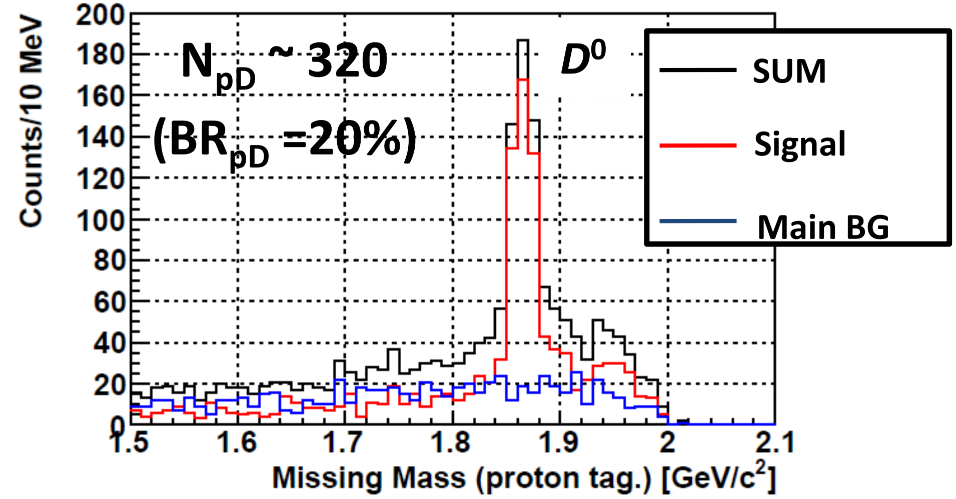


$\Lambda_c(2940) \to \Sigma_c{}^0\,\pi^+$

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

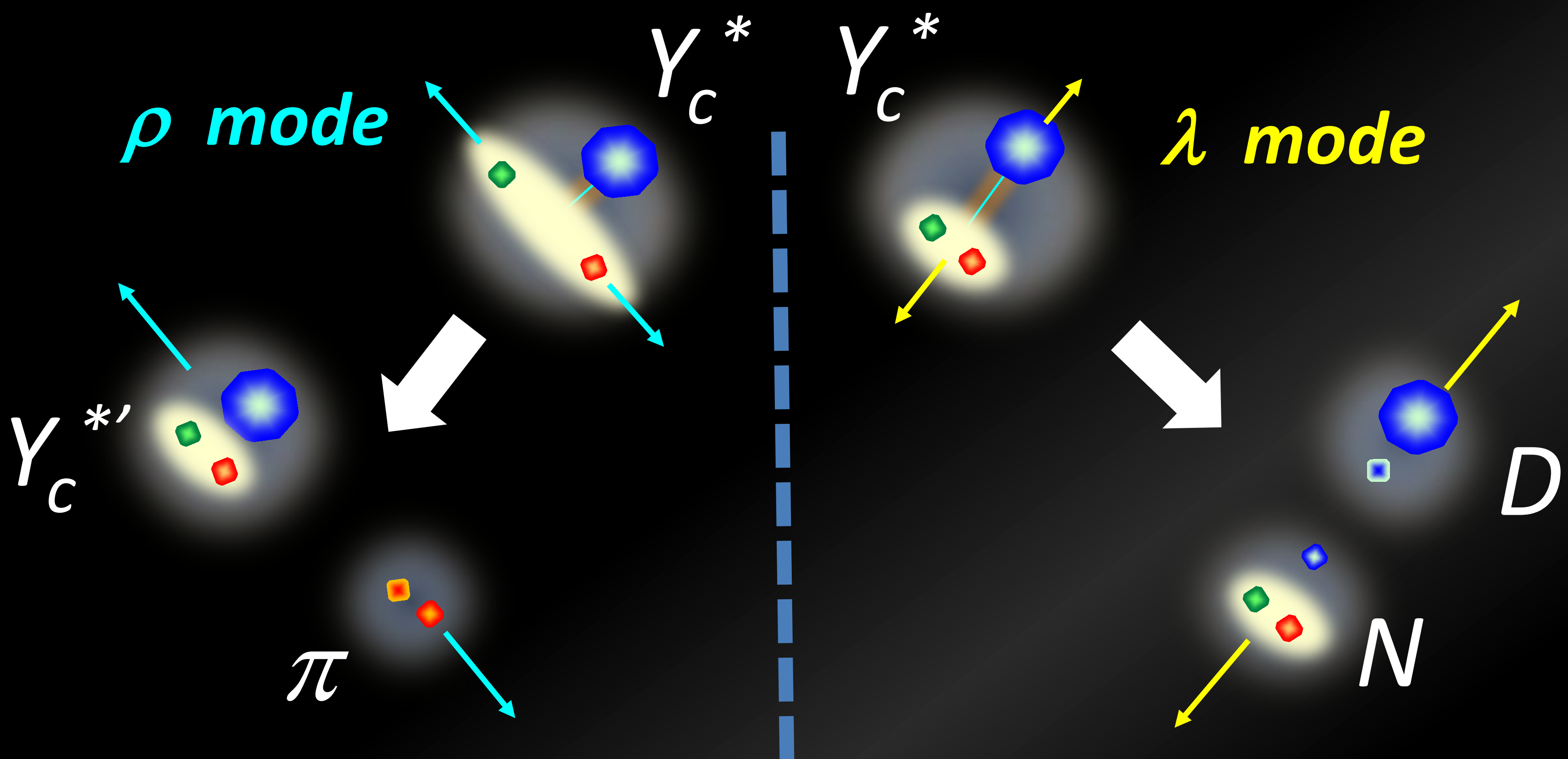


$\Lambda_c(2940) \to$ p D^0



* Branching ratios: Diquark corr. affects $\Gamma(\Lambda_c{}^* \to pD)/\Gamma(\Lambda_c{}^* \to \Sigma_c\pi)$.

Y_c^* Decay Branching Ratio

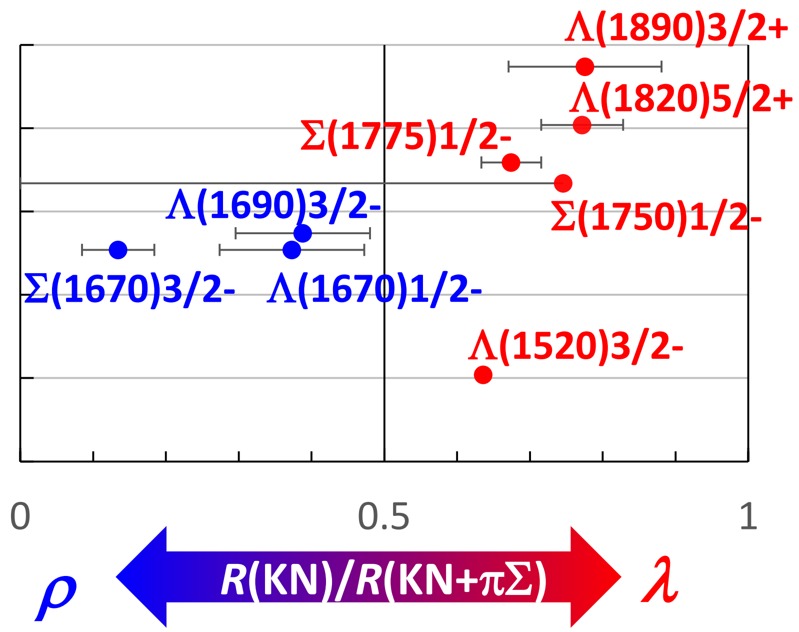


$\Gamma(Y\pi) > \Gamma(DN)$

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

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

PDG Data

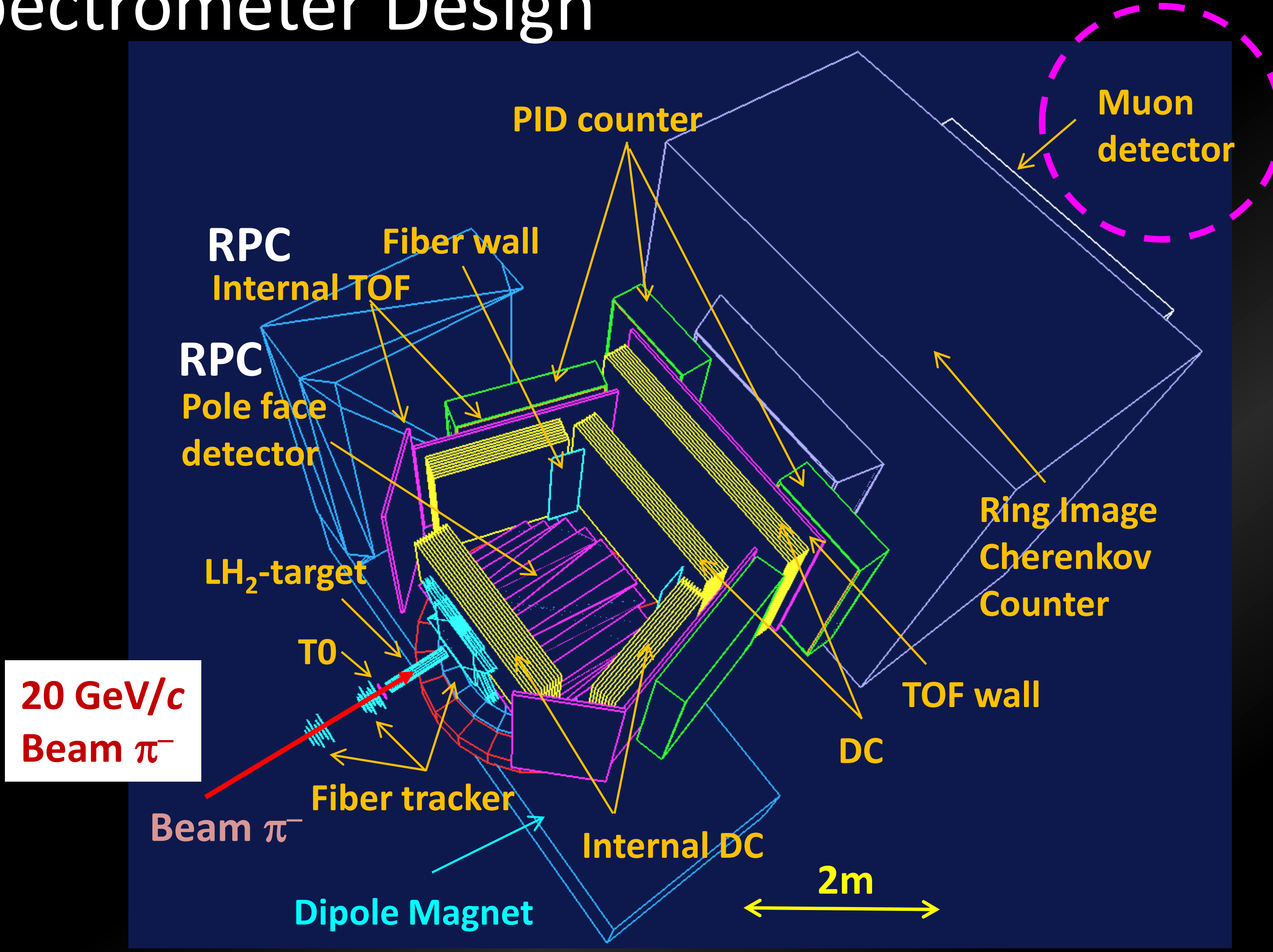


- Decay ratios in known hyperons SUGGEST the λ/ρ mode states
- λ/ρ mode ID by productions correlate w/ Decay Ratios
  → to be established

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

Dilepton Production

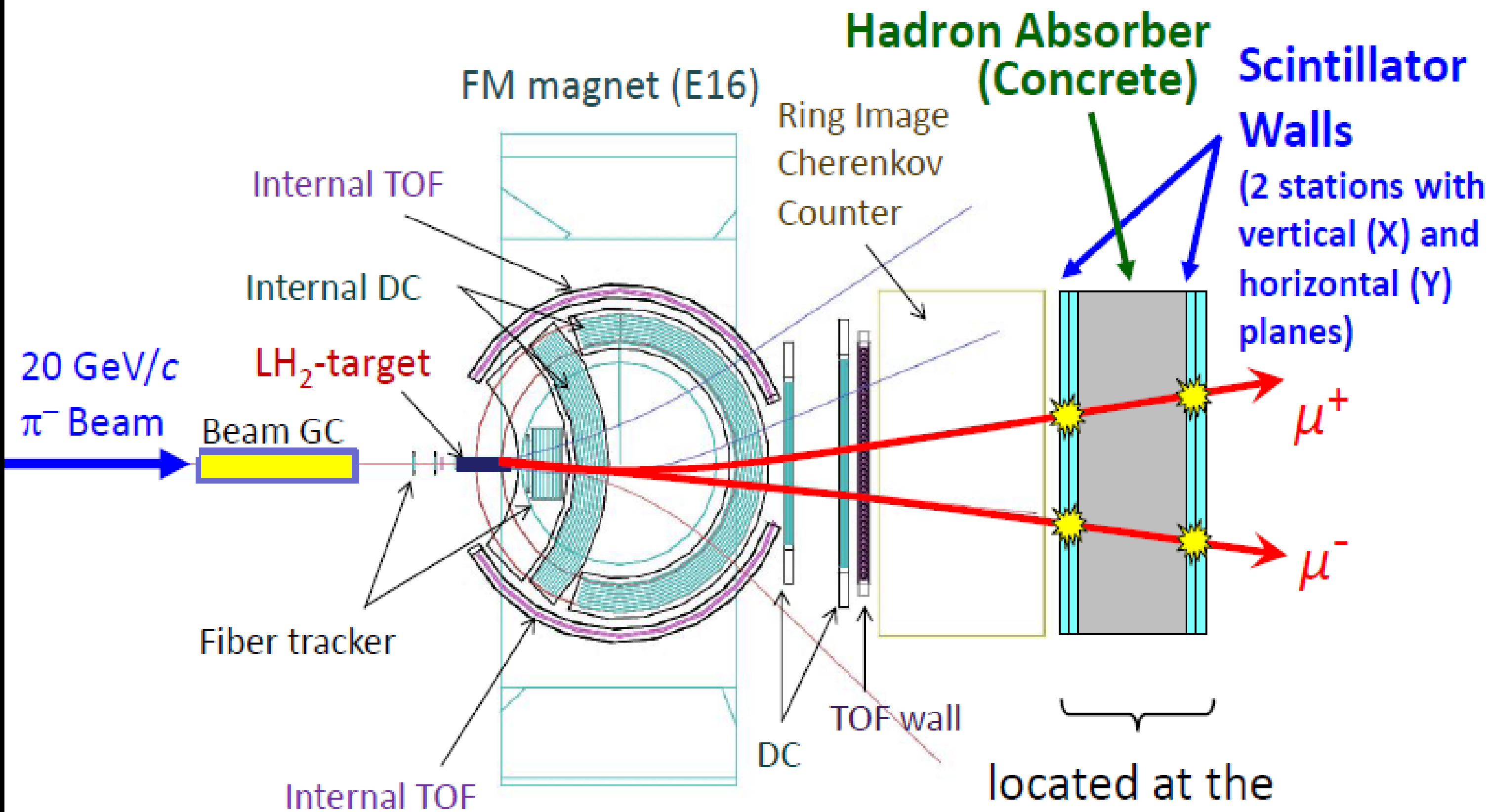
Spectrometer Design



Muon ID

T. Sawada, W.C. Chang, et al.

Conceptual design of muon identification system for the J-PARC E50



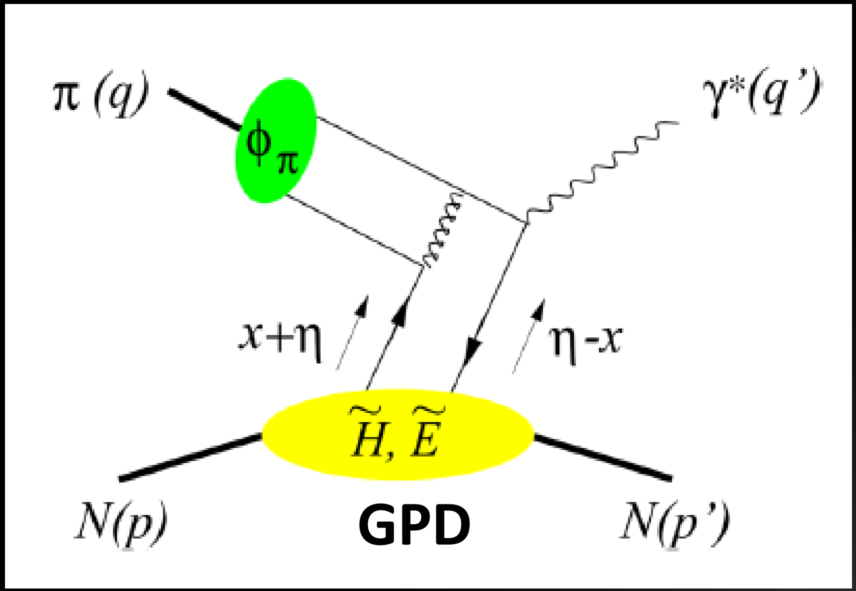
located at the downstream end of E50 spectrometer

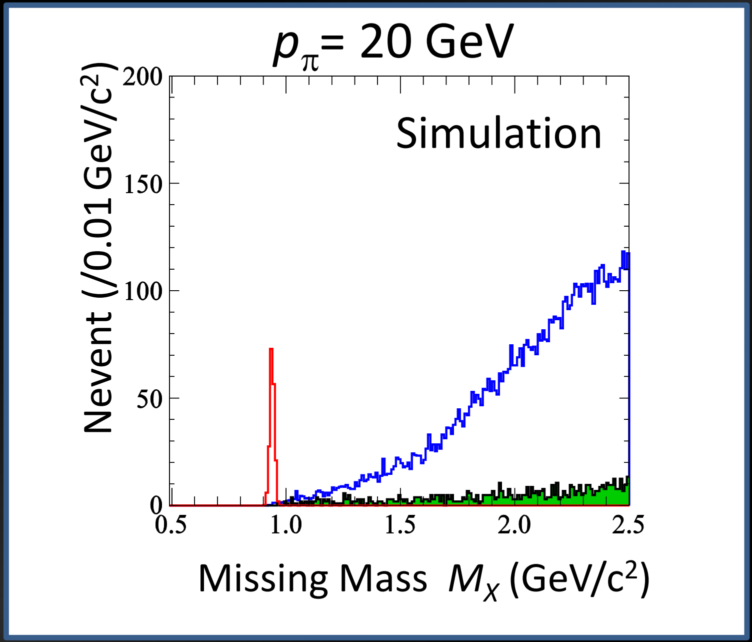
T. Sawada, W.C. Chang et al., PRD93, 114034(2016)

Hadron Tomography w/ Exclusive Drell-Yan

CHARM Spectrometer + Muon Detector at High-p BL

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



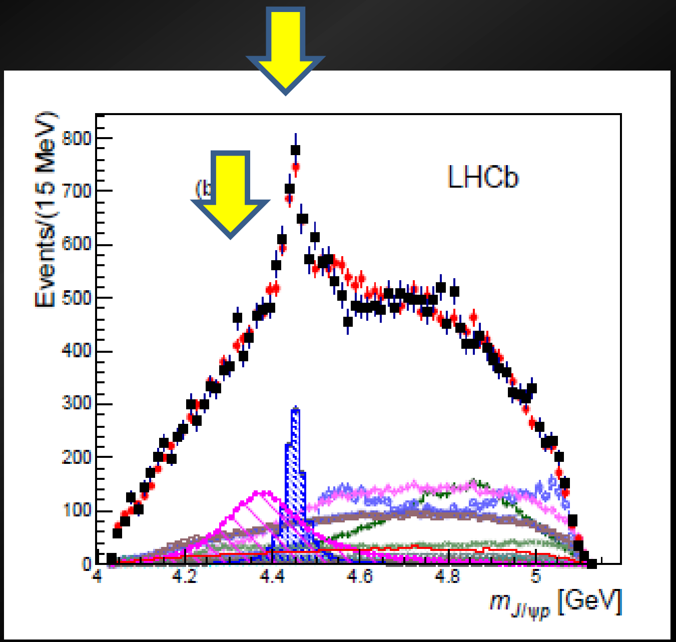


$$\pi^- + p \rightarrow \mu^+ + \mu^- + \Delta^0$$
$$K^- + p \rightarrow \mu^+ + \mu^- + Y^*$$

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

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

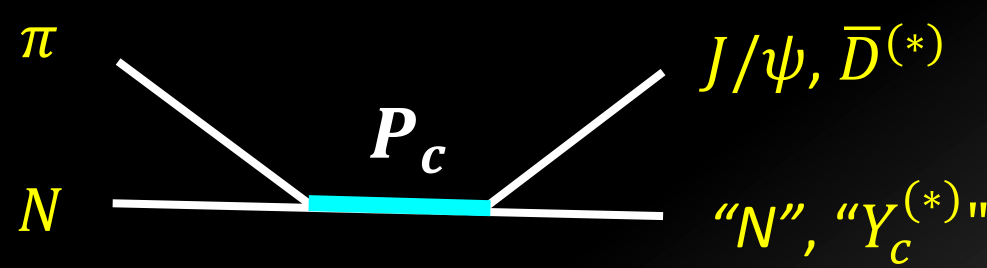
- Found in $J/\psi p$ invariant mass in $\Lambda_b \to J/\psi p K^-$
  - $m_{4380} = (4380 \pm 8 \pm 29)\text{MeV},\ \Gamma = (205 \pm 18 + 86)\text{MeV}$
    $m_{4450} = (4449.8 \pm 1.7 \pm 2.5)\text{MeV},\ \ \Gamma = (39 \pm 5 + 19)\text{MeV}$
  - J^P: (3/2-, 5/2+) most likely, respectively
    - (3/2+, 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?



R. Aaij et al.
PRL 115, 072001 (2015)

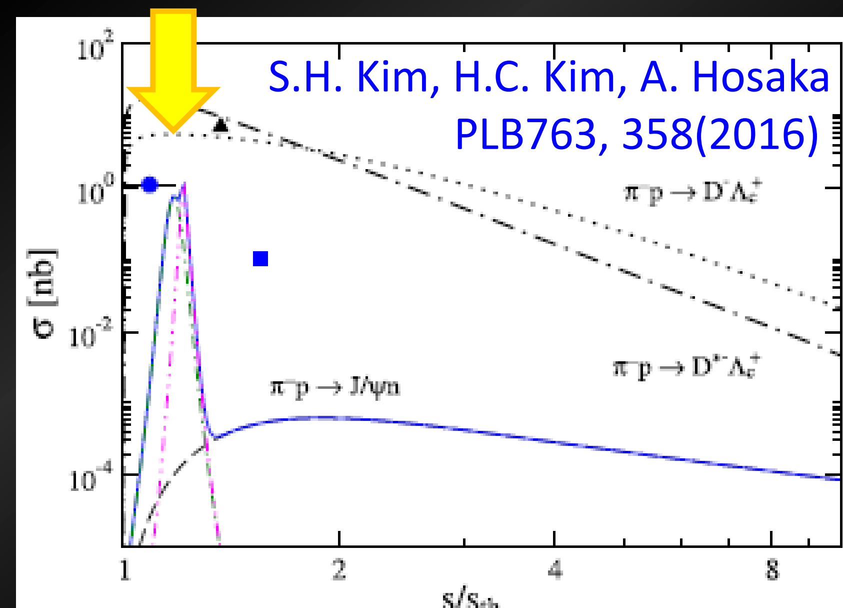
$P_c^0(4380), P_c^0(4450)$ *at J-PARC*

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



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

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



Summary

1. Diquark correlation in baryons could be disentangled with heavy flavors
   – Mass spectrum, Production Rate, and Decay Branching ratio
   – Charmed Baryons from the ground state up to high-spin states
2. A general purpose spectrometer will be constructed at the J-PARC High-p BL
   – open a unique platform of hadron physics by means of missing mass technique