9 th APCTP-BLTP JINR Joint WS at Kazakhstan
28 June - 3 July, 2015

New Platform for Hadron Physics at RCNP

H. Noumi (RCNP, Osaka University)

29 June, 2015

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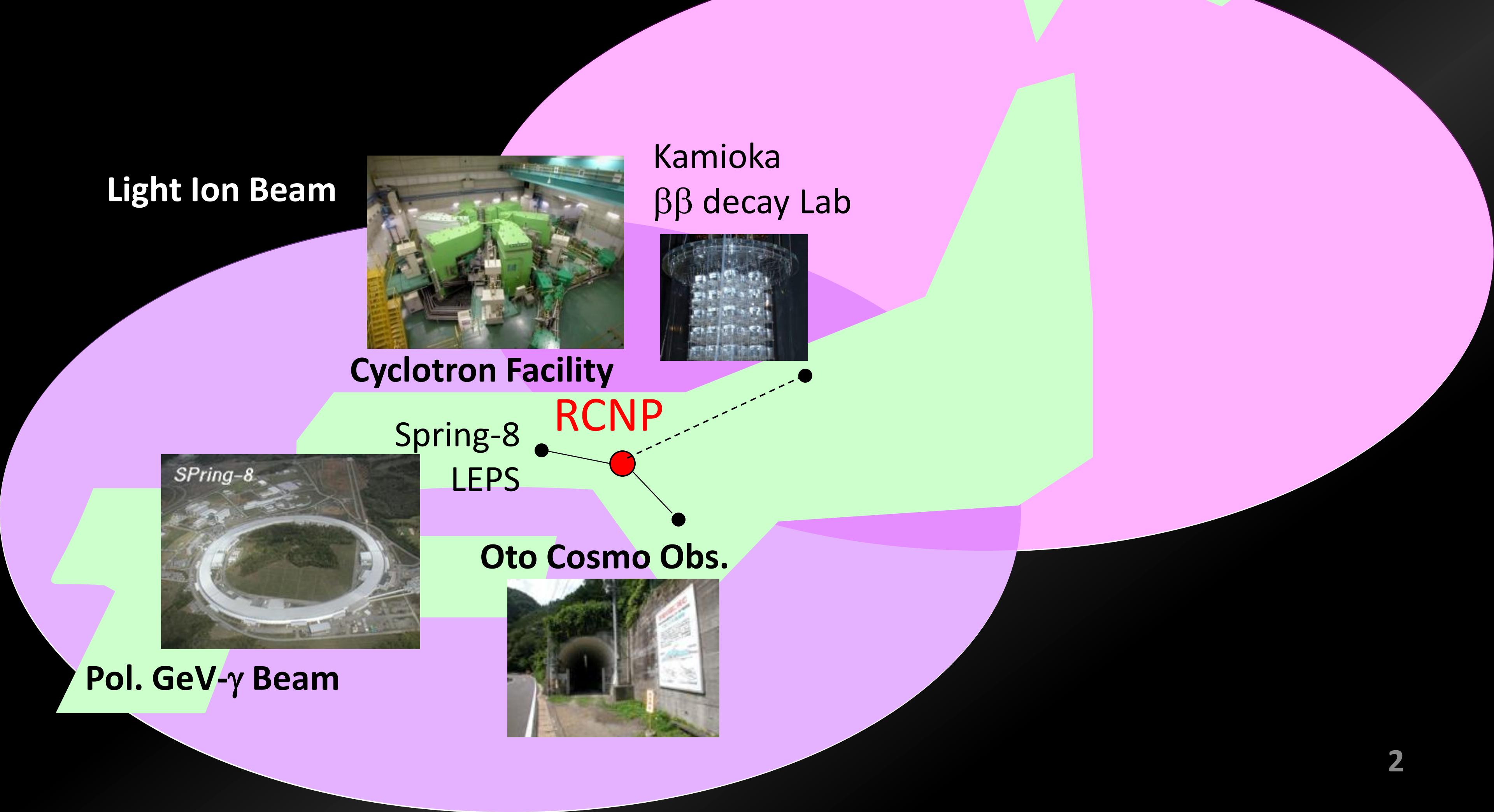
4. Summary

RCNP：User Based Research Center for Nuclear Physics

Founded in 1971

- Cyclotron Facility（AVF, RING・G-RAIDEN)
- Laser Electron Photon Facility at SPring-8（LEPS)
- Oto Cosmo Observatory (Science under the ground)
- Kamioka ββ Lab (Science under the ground)



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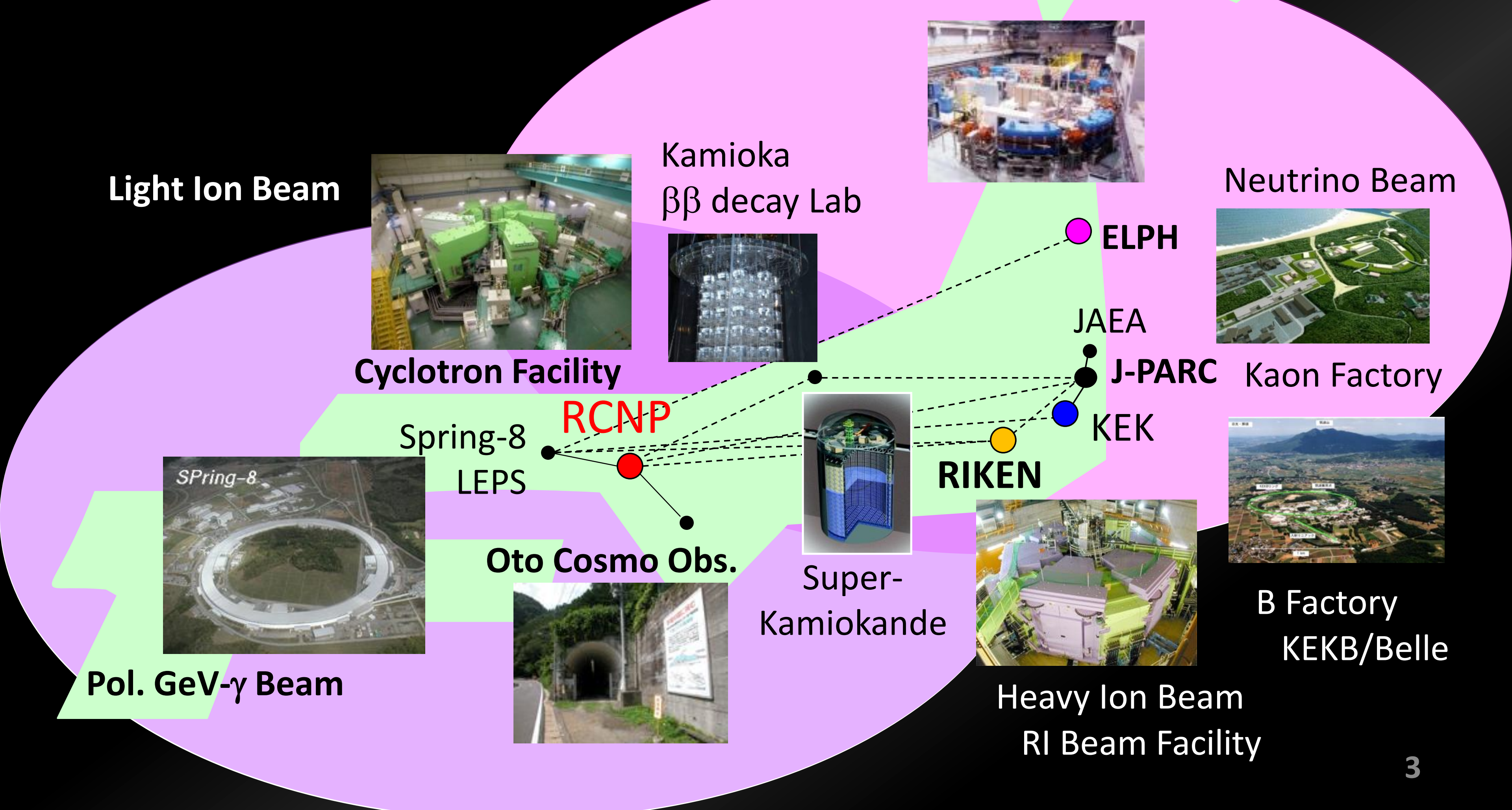
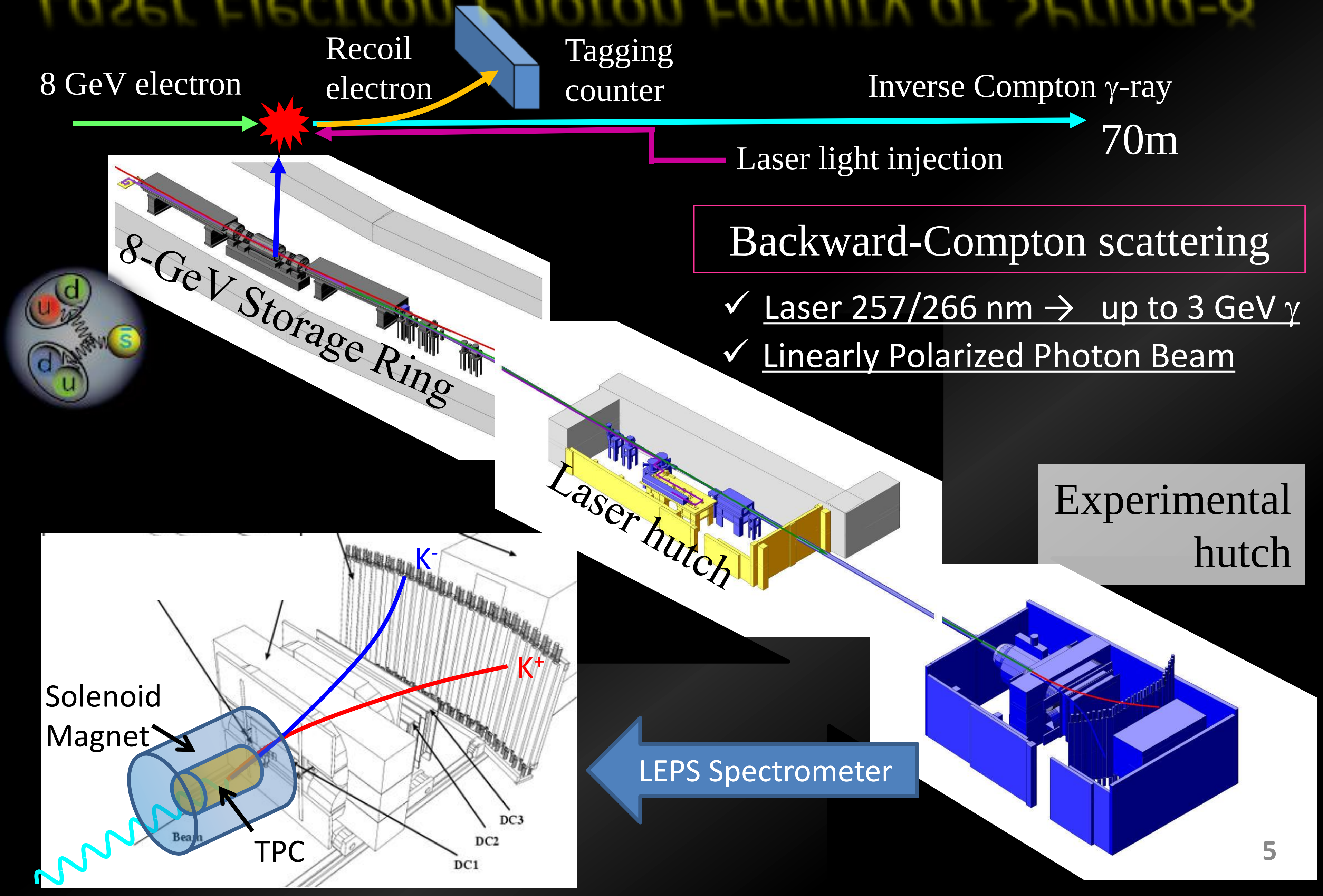
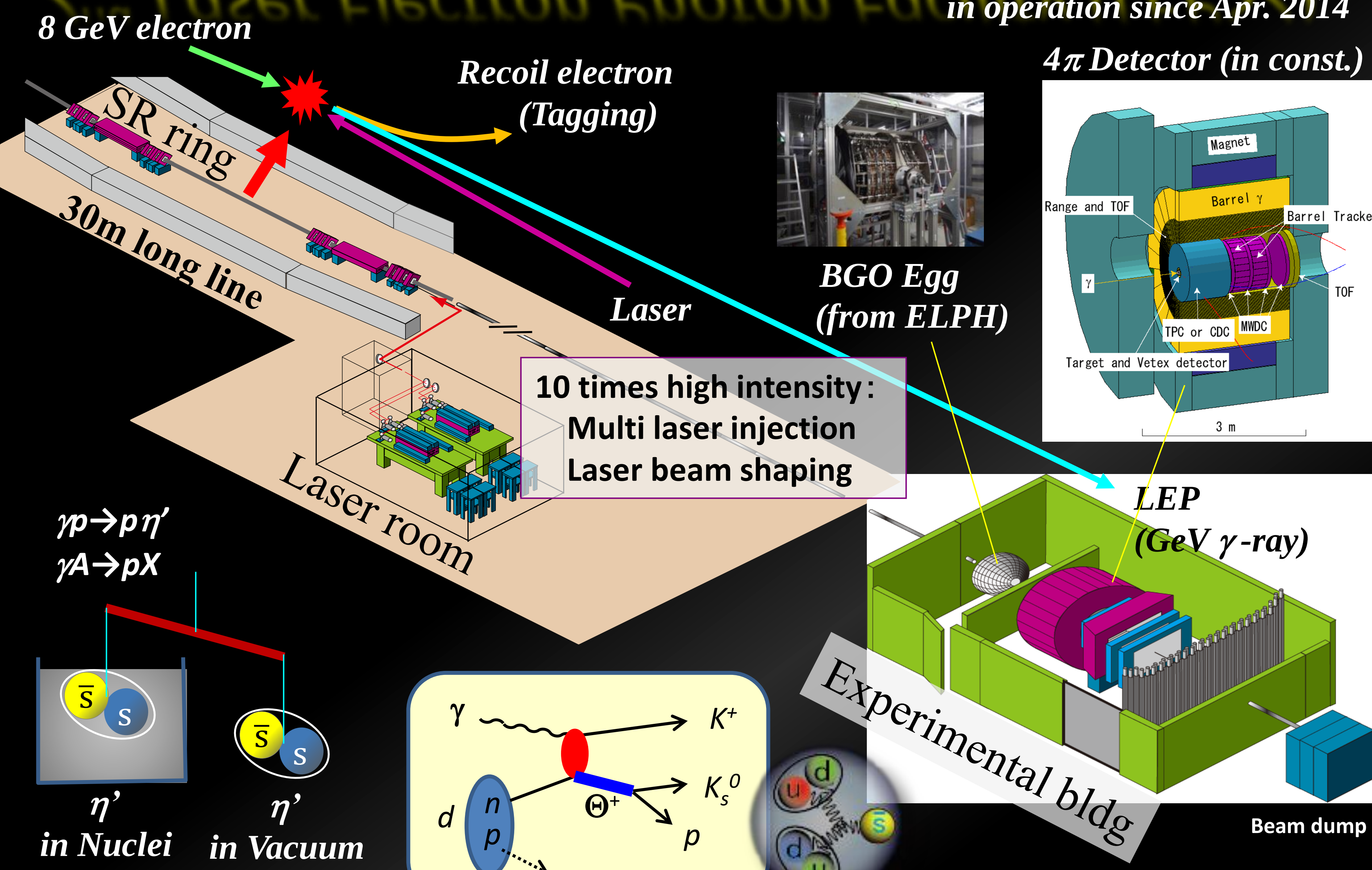


RCNP CYCLOTRON FACILITY

Laser Electron Photon Facility at SPring-8



2nd Laser Electron Photon Facility (LEPS2)



RCNP Activity

Cyclotron
High-res. Nuclear Spectroscopy
MuSIC
UCN

LEPS/LEPS2
Hadron Spectroscopy w/ pol. GeV-γ

J-PARC
A new platform of RCNP for hadron physics

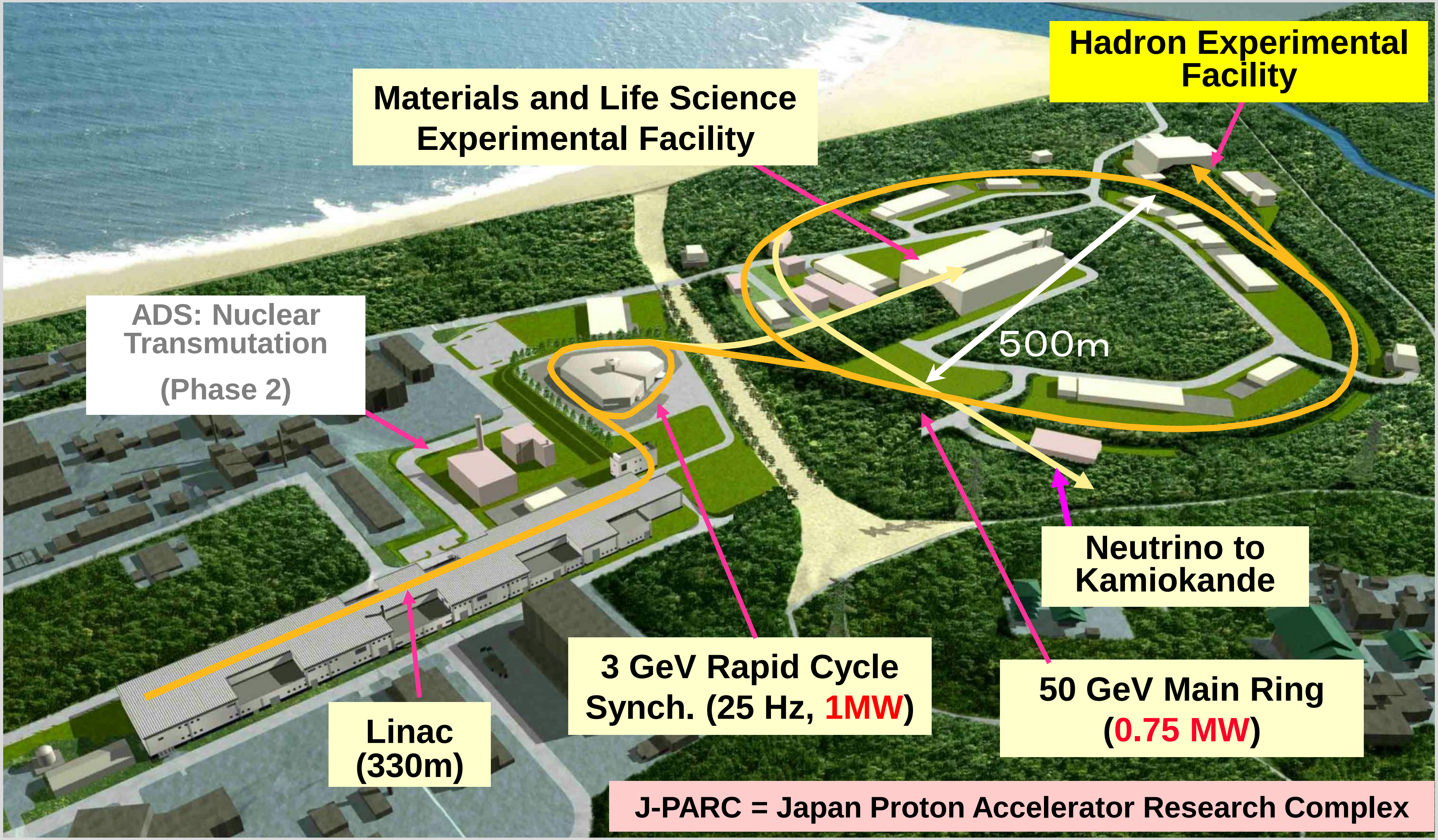
CANDLES
$\beta\beta$ decay of ^{48}Ca

Facility
Accelerator Tech.
Medical App.
Electronics/DAQ

Theory
Hadron Physics
Nuclear Physics
Computational Phys

A new platform of RCNP for hadron physics at J-PARC

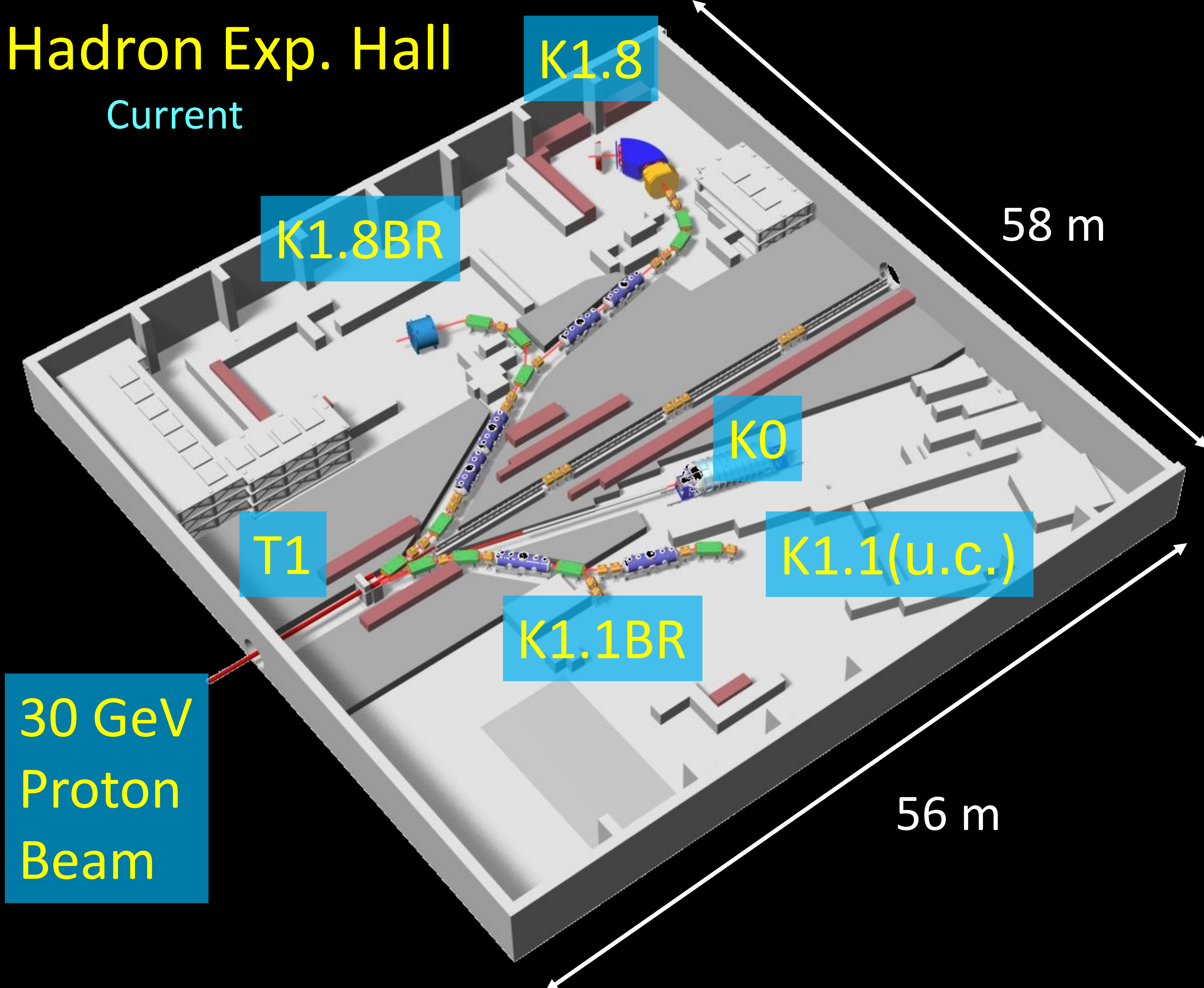
J-PARC Facility



Joint Project between KEK and JAEA since 2001

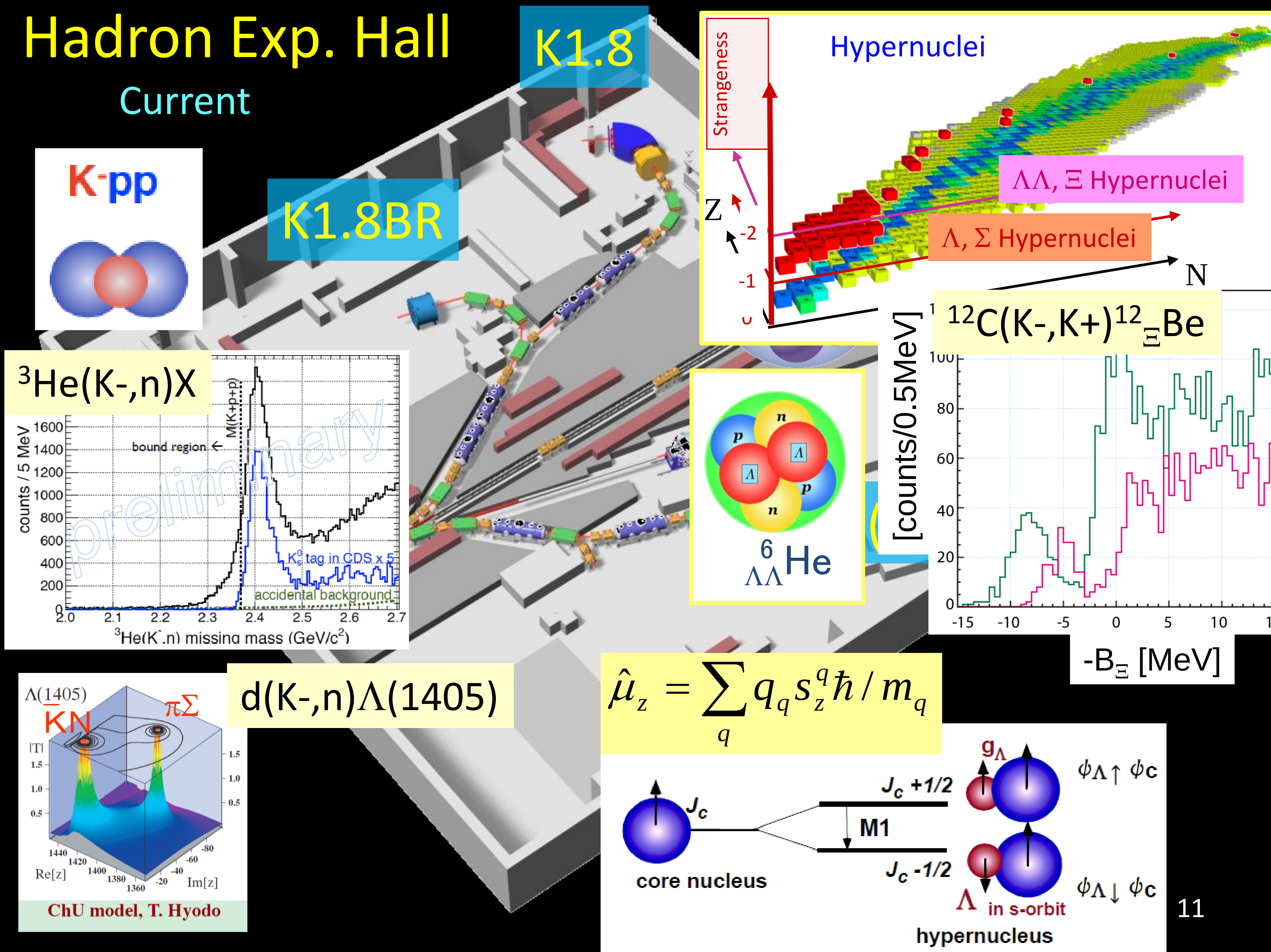
Hadron Exp. Hall

Current



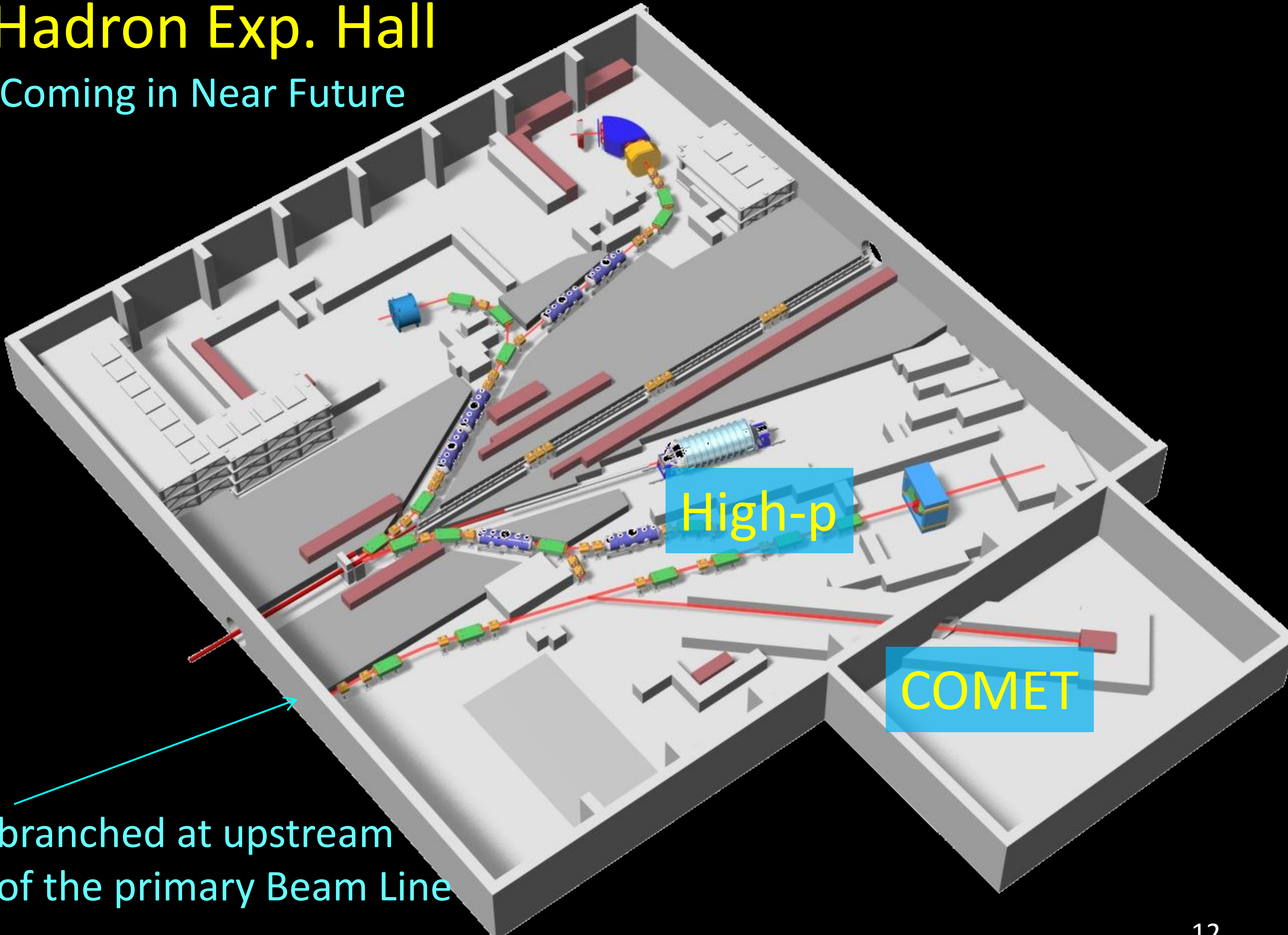
Hadron Exp. Hall

Current



Hadron Exp. Hall

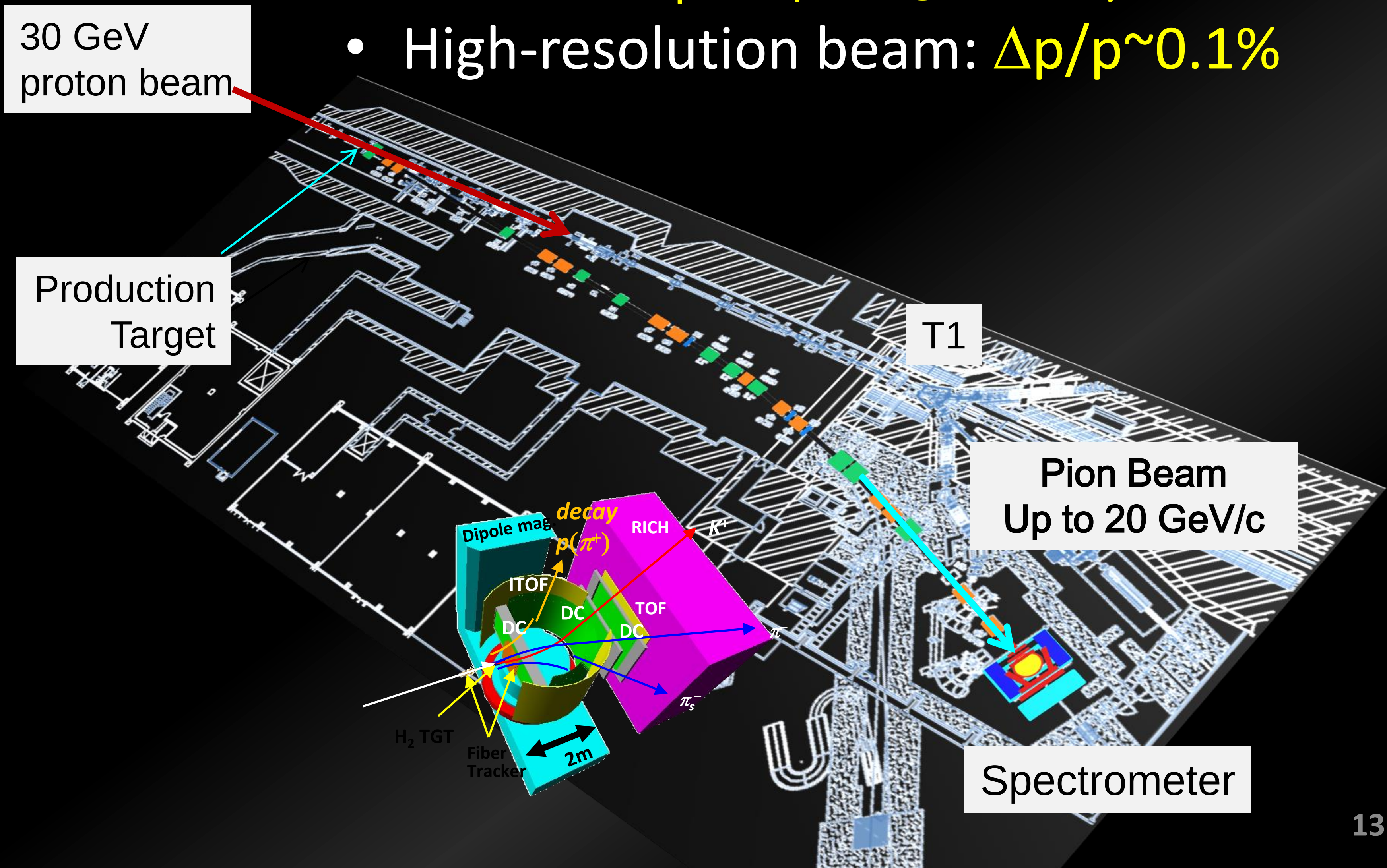
Coming in Near Future



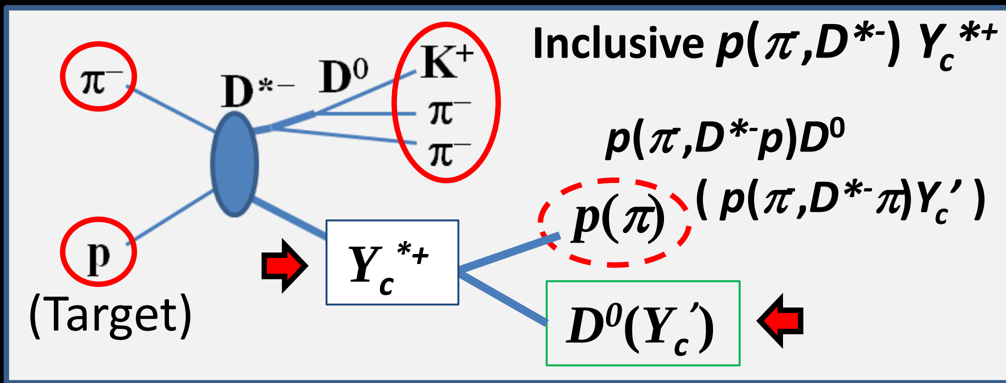
branched at upstream
of the primary Beam Line

High-res., High-momentum Beam Line

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



CHARM Spectrometer Design



Cross Section:

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

Acceptance:

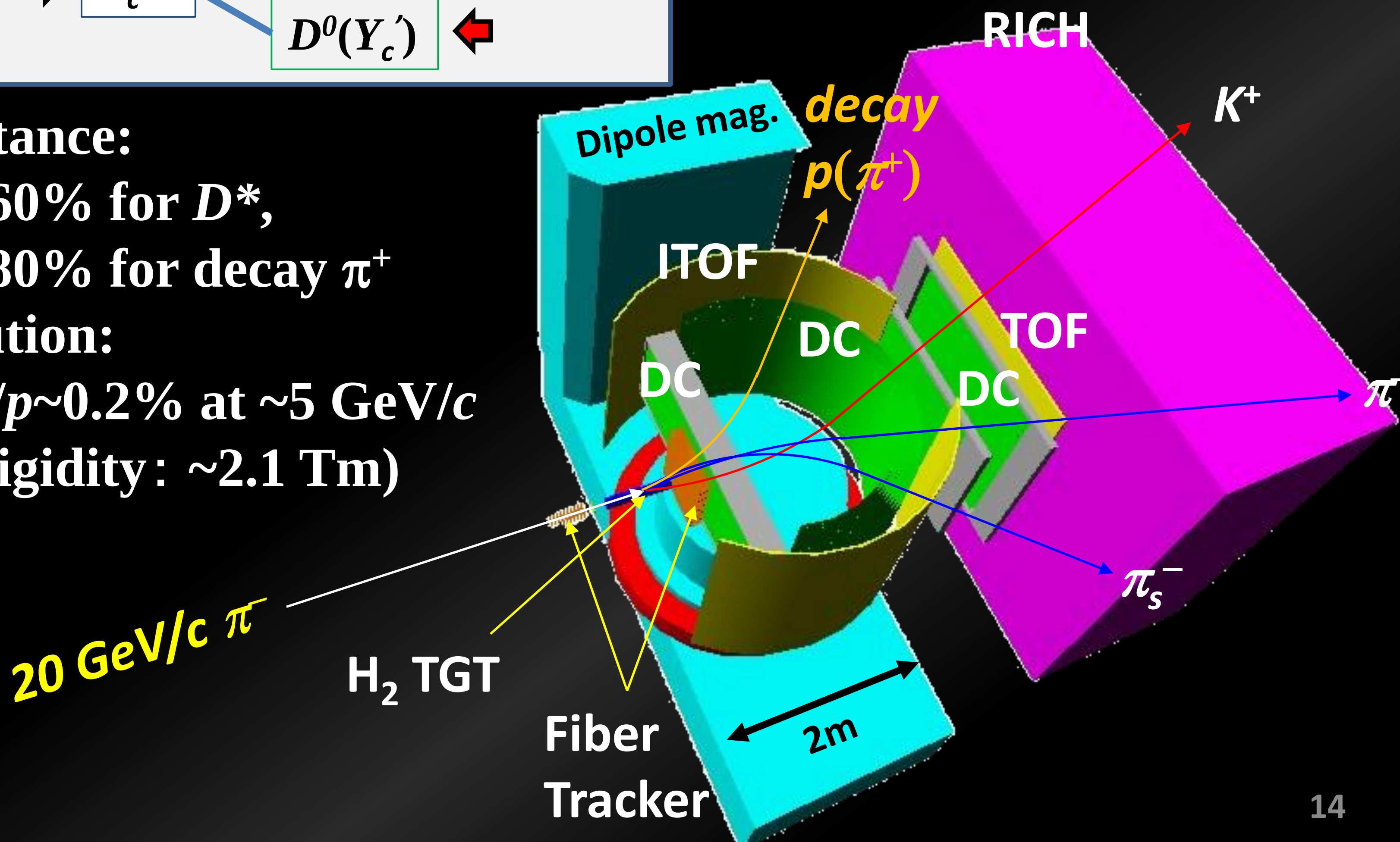
~ 60% for D^*,

~ 80% for decay π^+

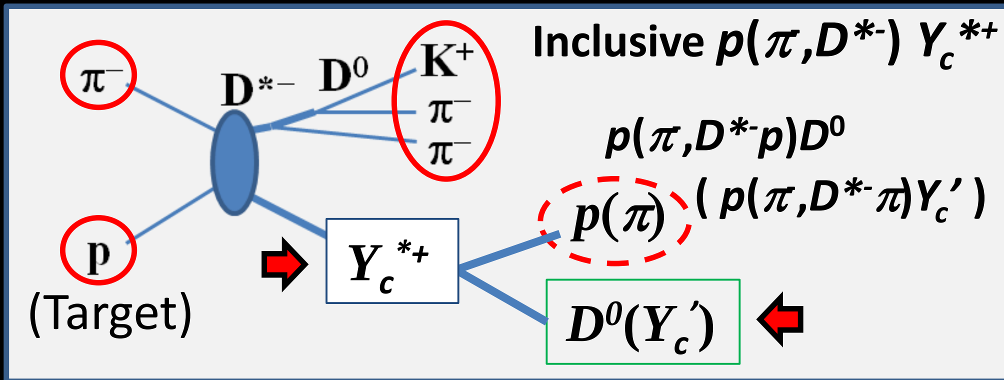
Resolution:

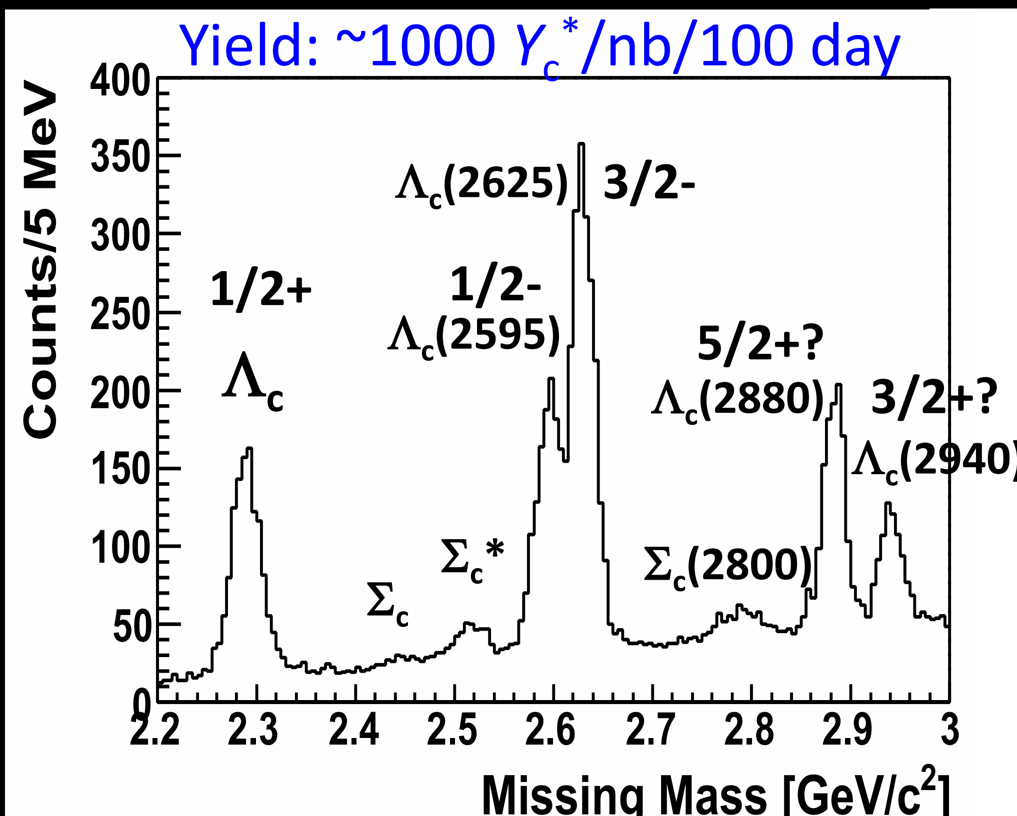
$\Delta p/p$~0.2% at ~5 GeV/c

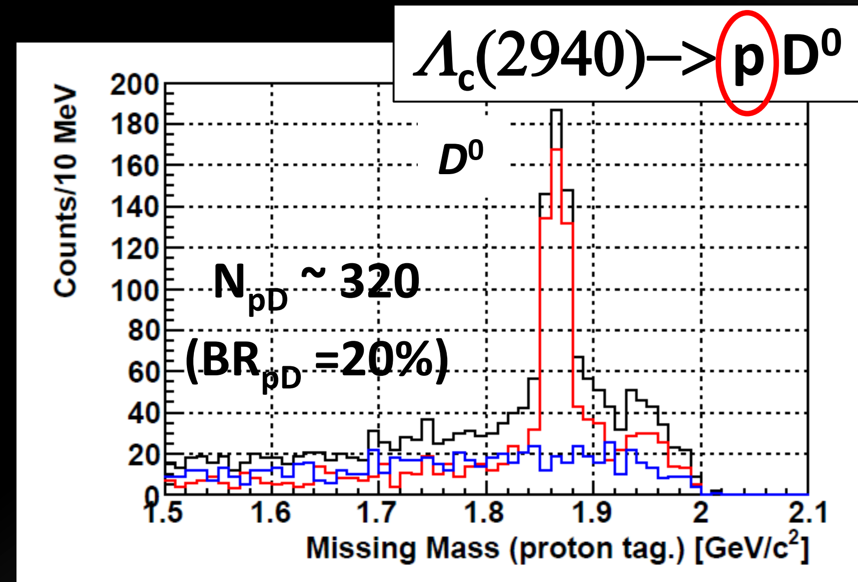
(Rigidity: ~2.1 Tm)

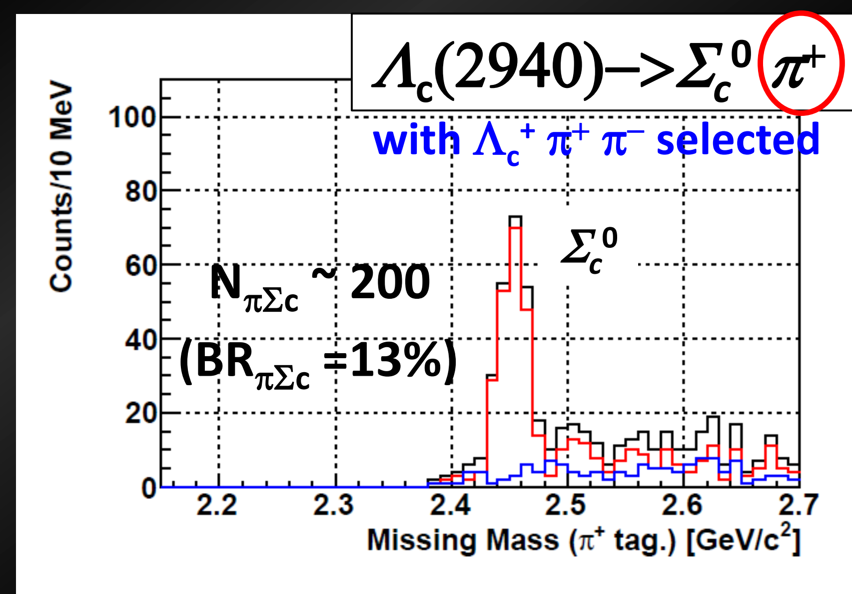


Inclusive Spectrum and Decay Mode ID (Sim.)









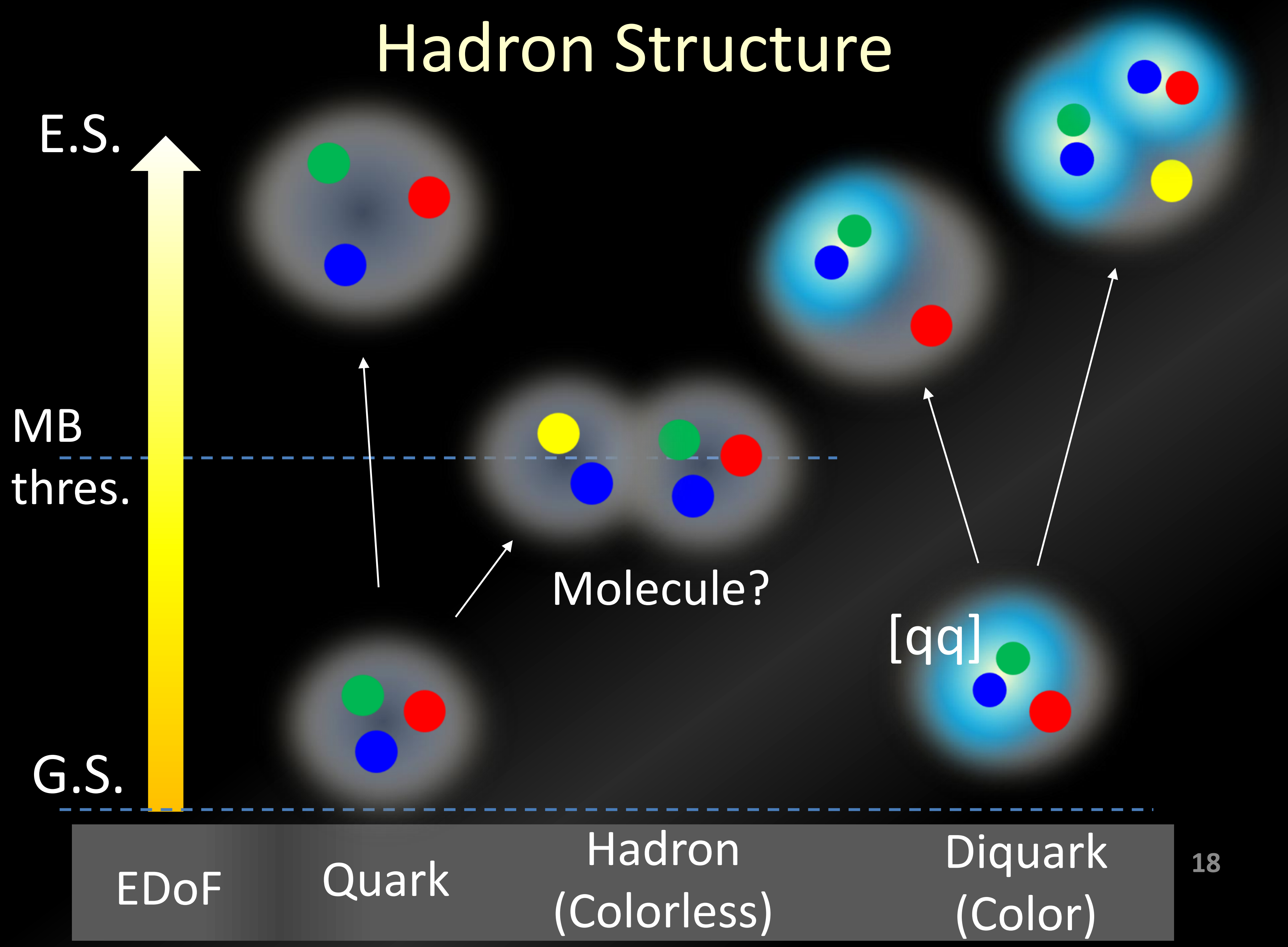
A new research project in High-res., High-p Beam Line at J-PARC

- MOU on research cooperation btwn RCNP, IPNS/KEK, and the J-PARC Center
- RCNP conducts in cooperation w/ J-PARC:
  - collection of research ideas and collaborators
  - introduction of new methods/techniques
    - High-resolution, high-p Secondary Beam Line
    - Multi-particle Spectrometer
- Proposal E50: “Charmed Baryon Spectroscopy via the (π^-,D^{*-}) reaction”, stage-1 approval in the 18^{th} PAC (May, 2014)

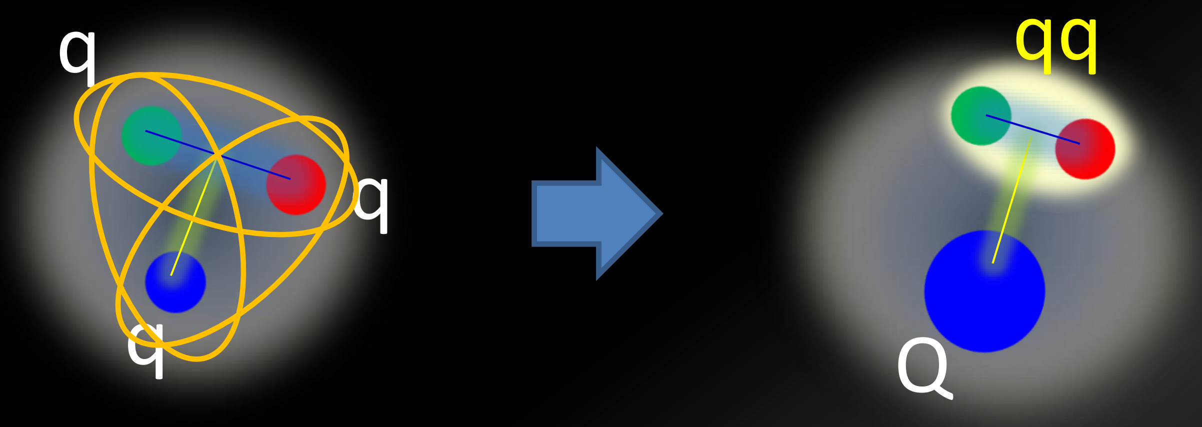
http://www.j-parc.jp/researcher/Hadron/en/Proposal_e.html#1301

Baryon Spectroscopy with Heavy Flavors

Hadron Structure



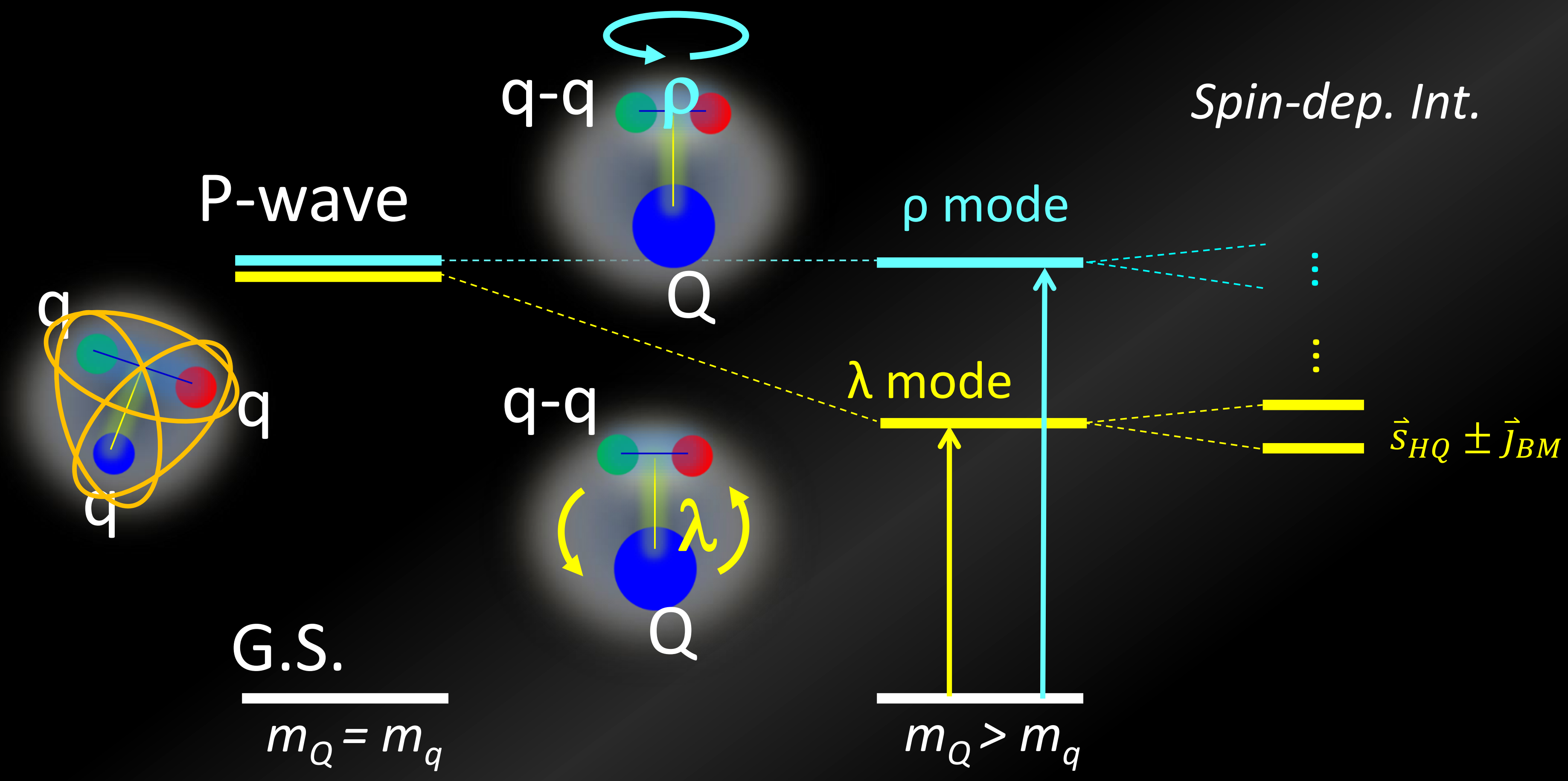
What we can learn from baryons with heavy flavors



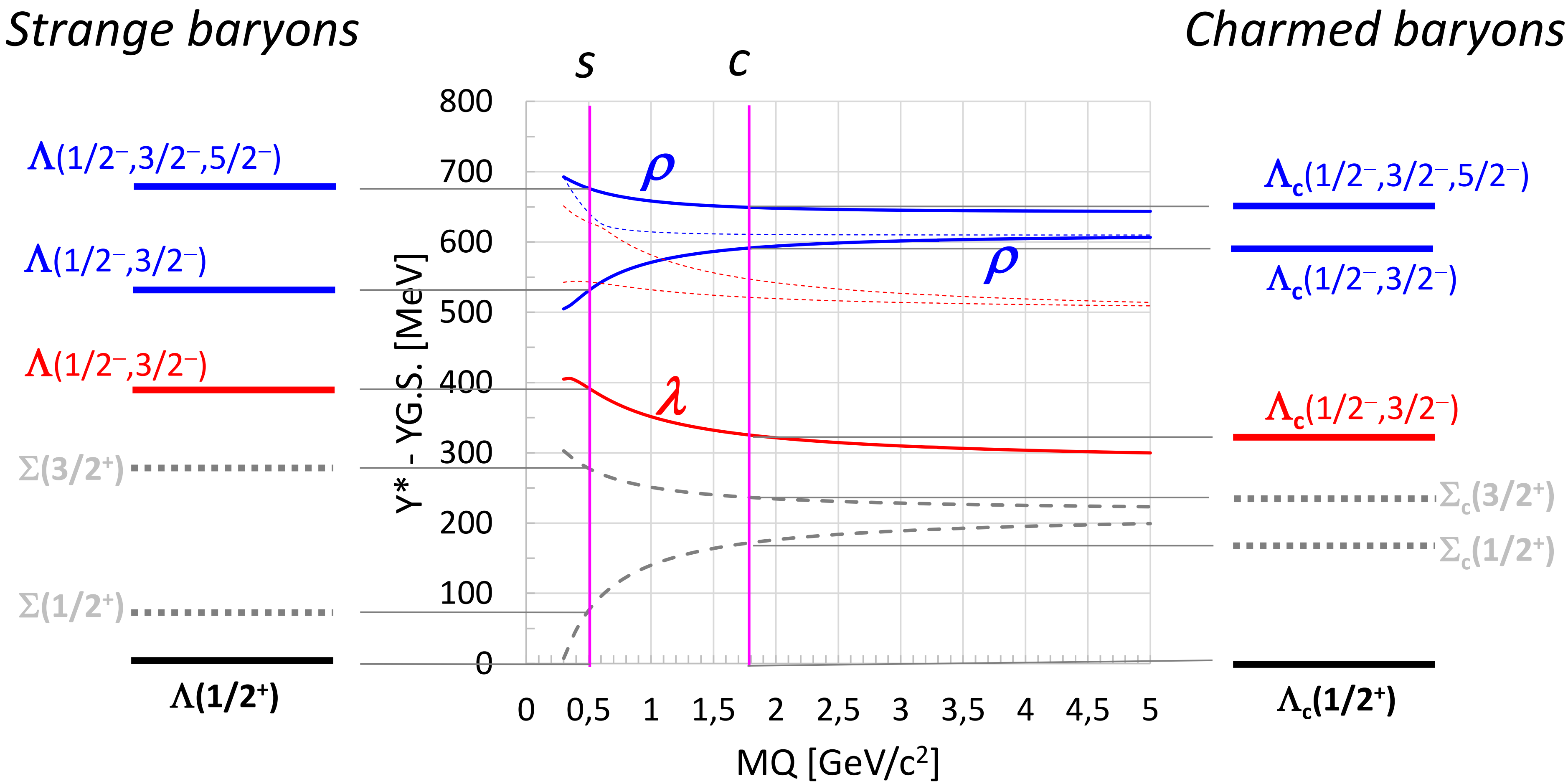
- Quark motion of "qq" is singled out by a heavy Q
  - Diquark correlation
- Level structure, Production rate, Decay properties
  - sensitive to the internal quark(diquark) WFs.
- Properties are expected to depend on a Q mass.

Schematic Level Structure of Heavy Baryons

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



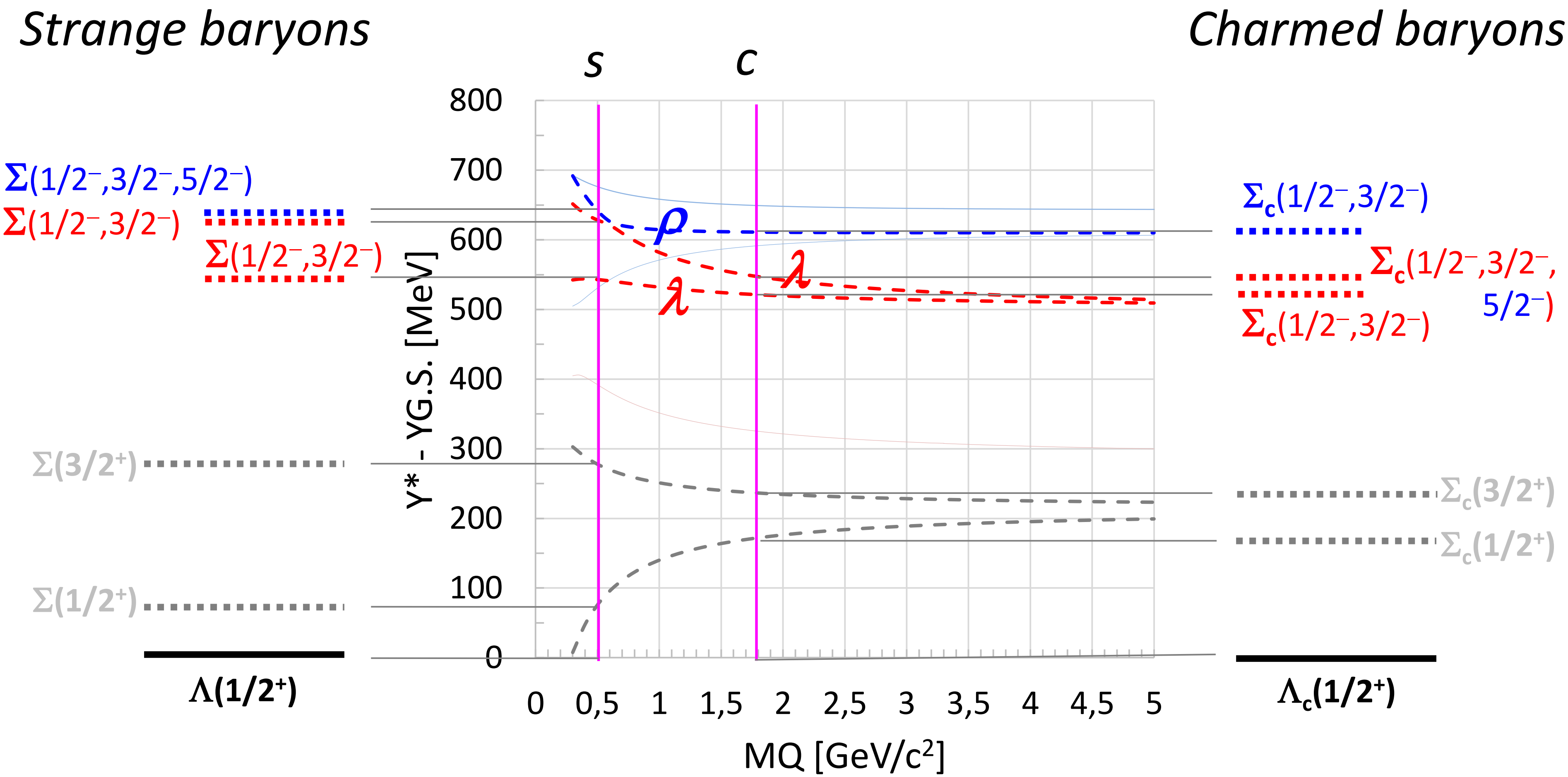
CQM calculation (P-wave Lambda)



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

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

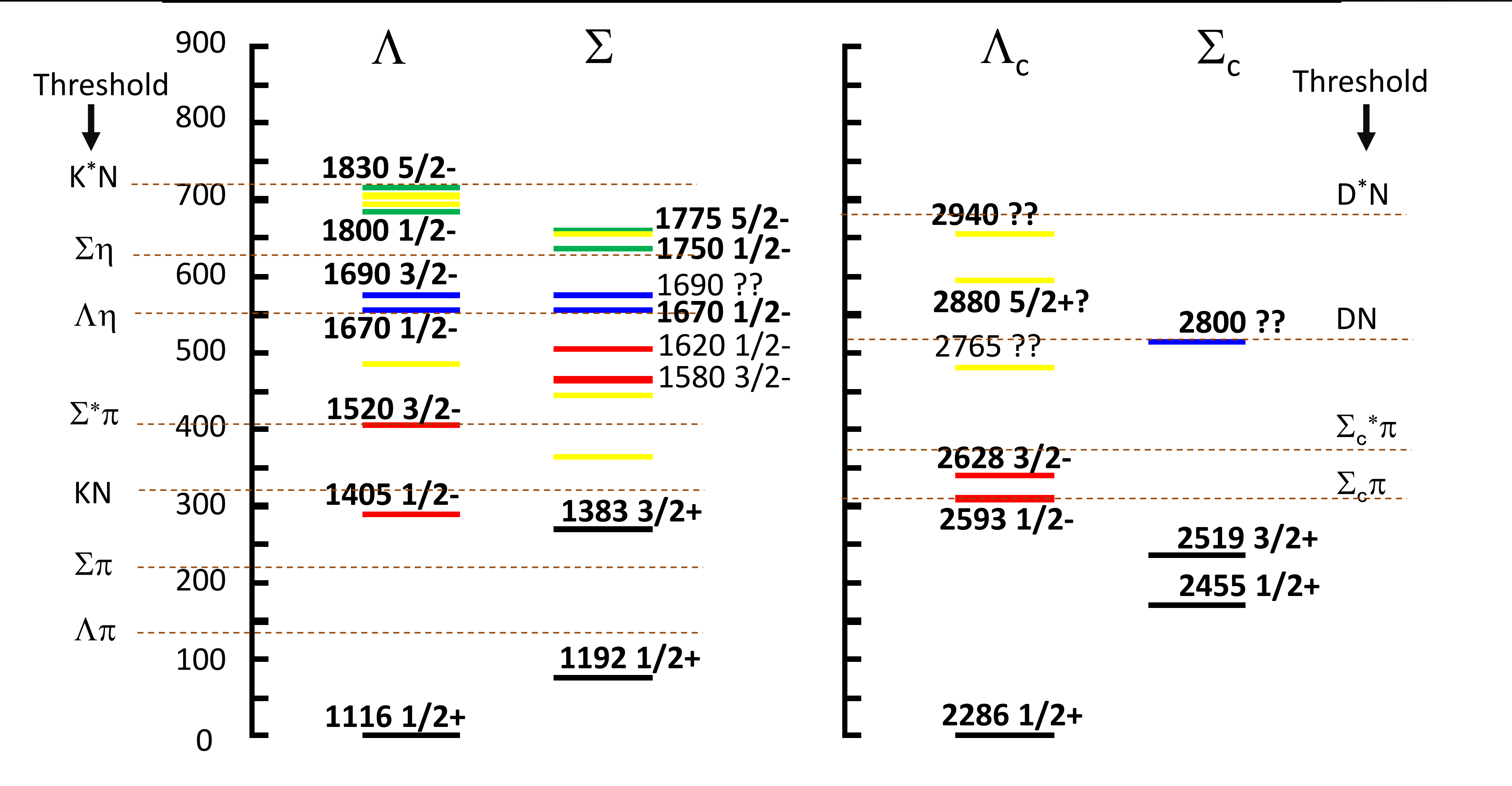
CQM calculation (P-wave Sigma)



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

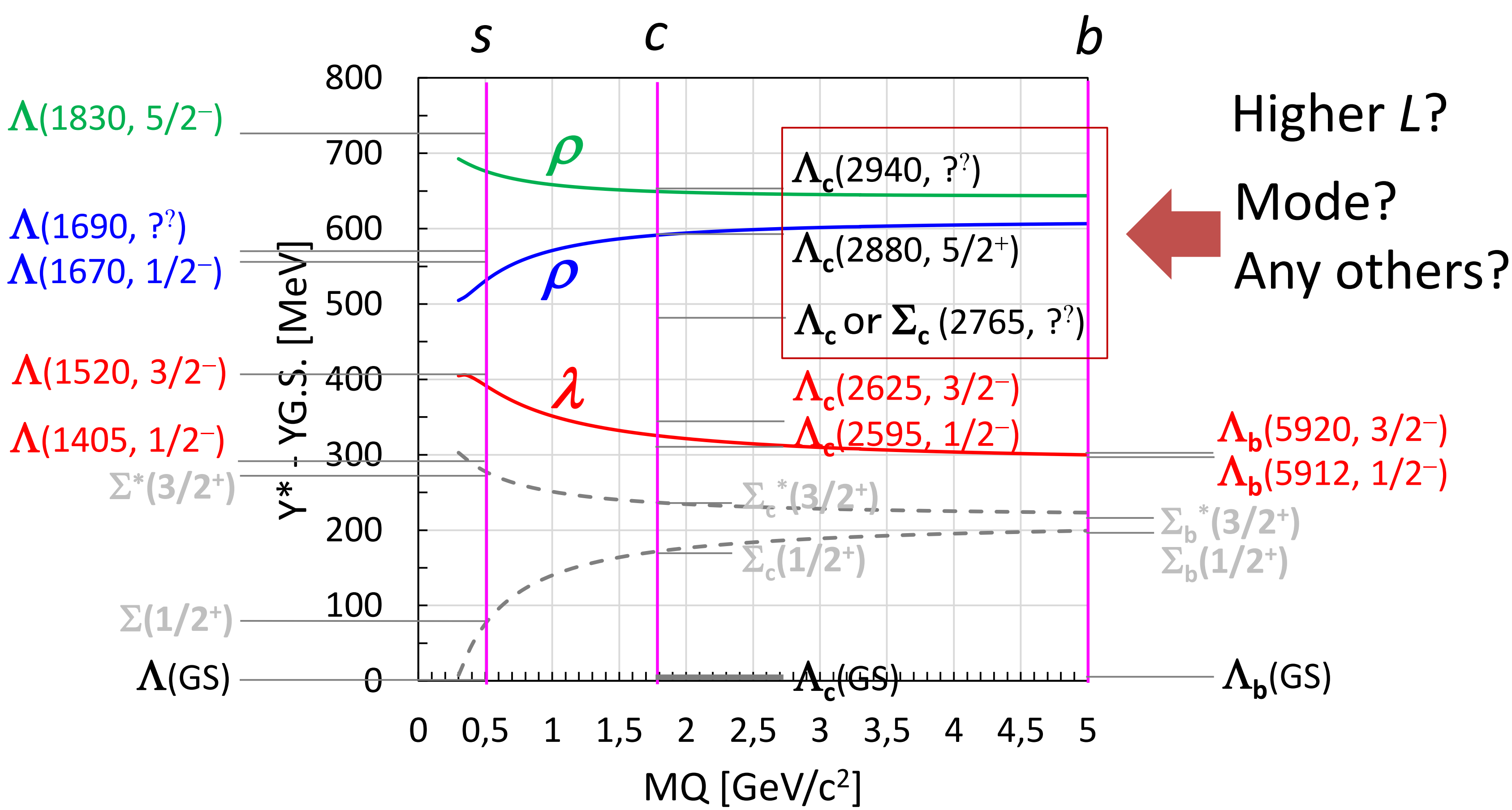
ρ–λ mixing (cal. By T. Yoshida)

Level structure (Exp.)



- ✓ Classification based on λ / ρ mode has yet to be established.
- ✓ Little of Y_c is known.

Lambda Baryons

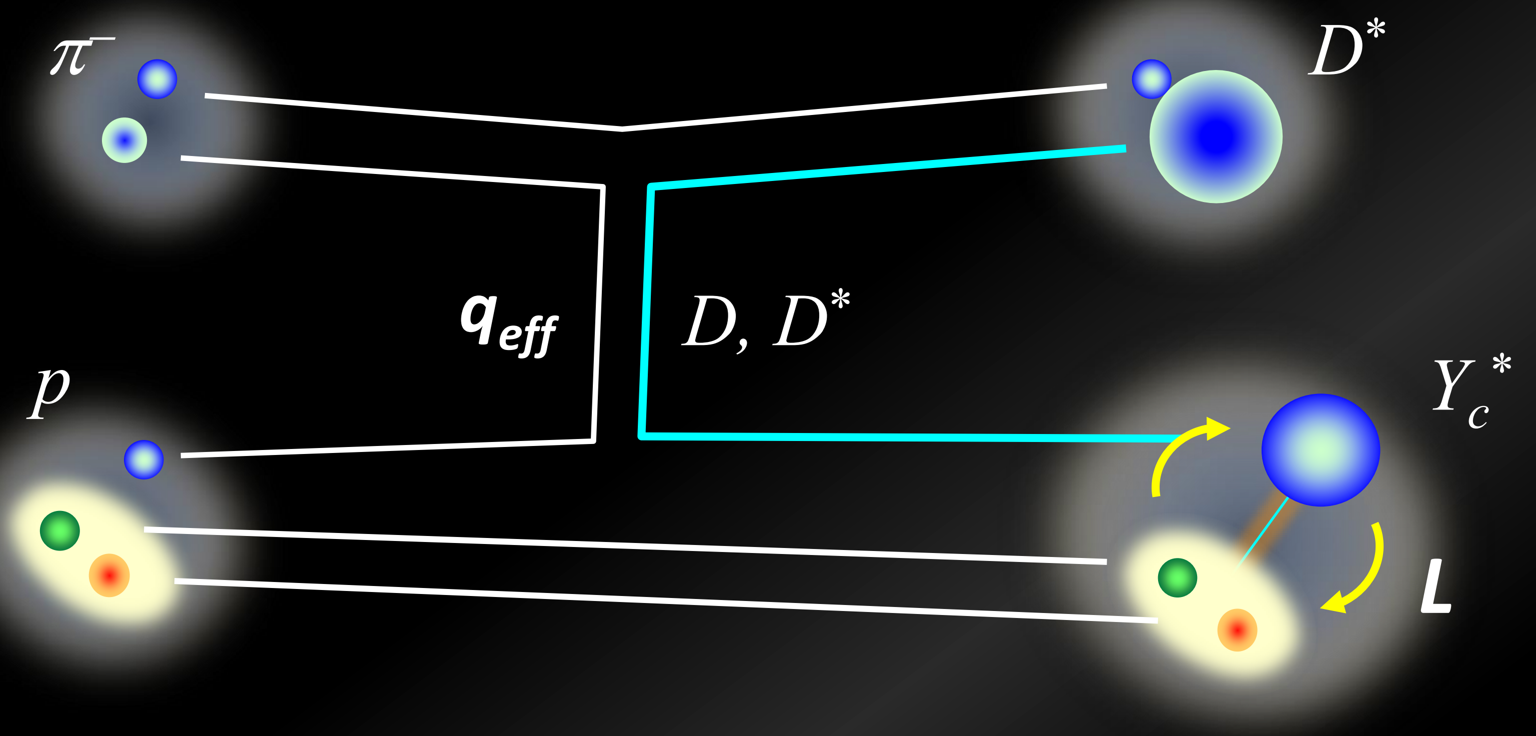


non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

ρ–λ mixing (cal. By T. Yoshida)

Production Rate

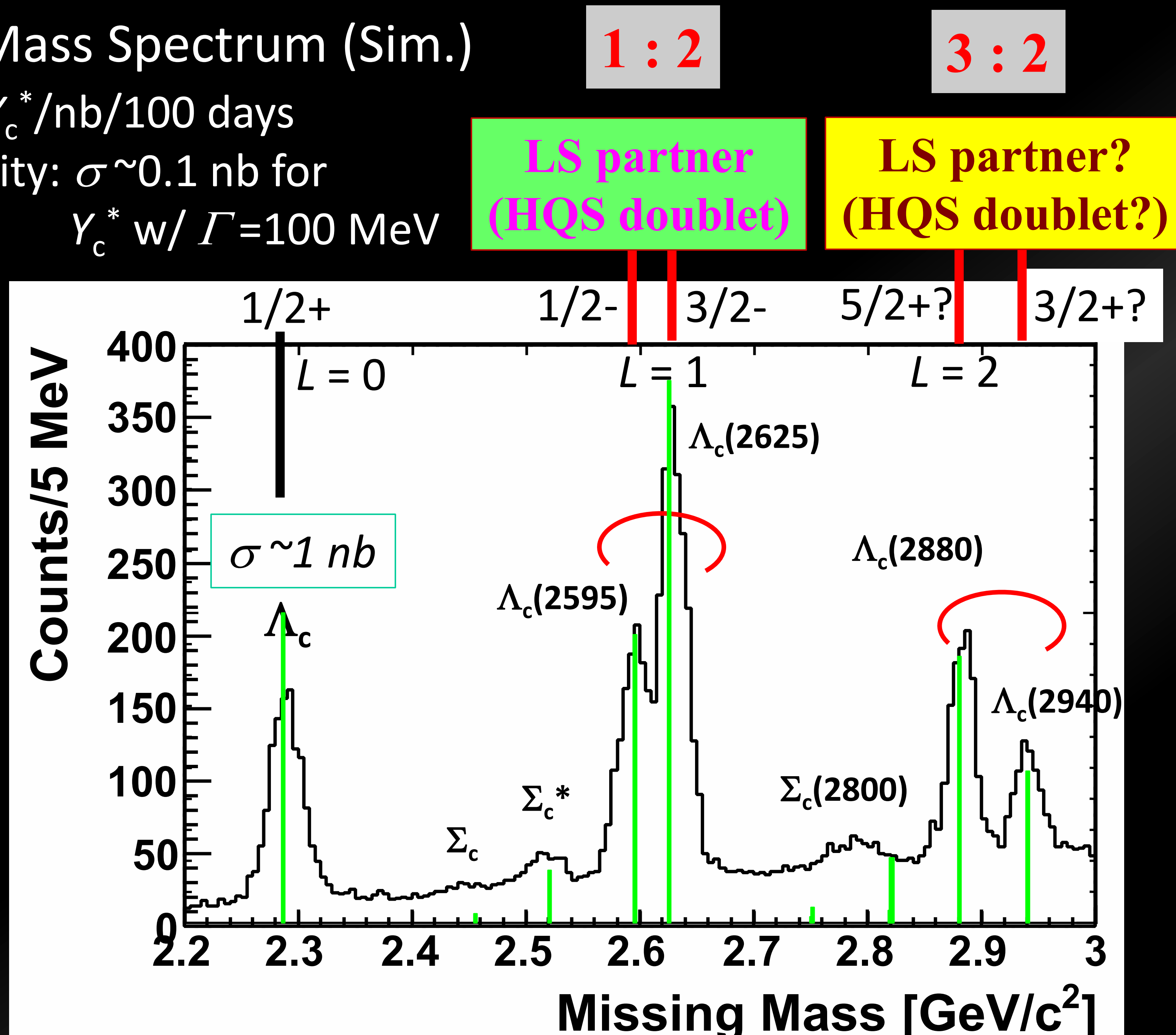
S.H. Kim, A. Hosaka, H.C. Kim, HN, K. Shirotori, PTEP, 103D01, 2014.



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

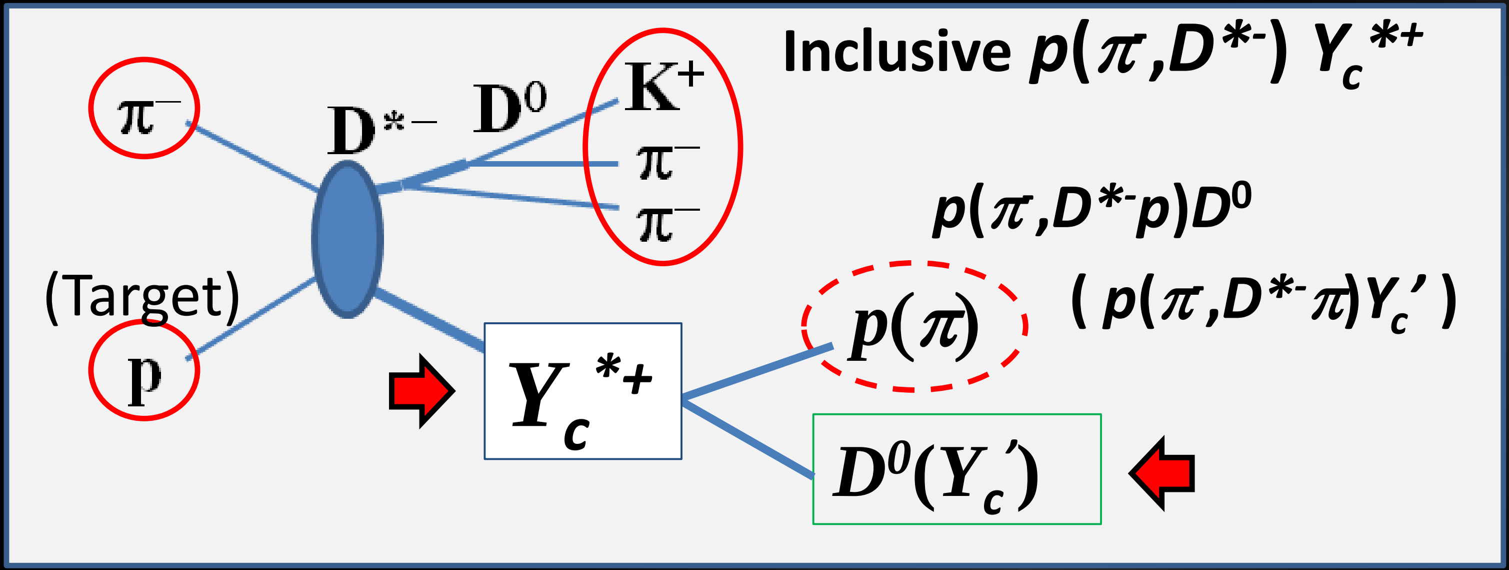
Missing Mass Spectrum (Sim.)

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



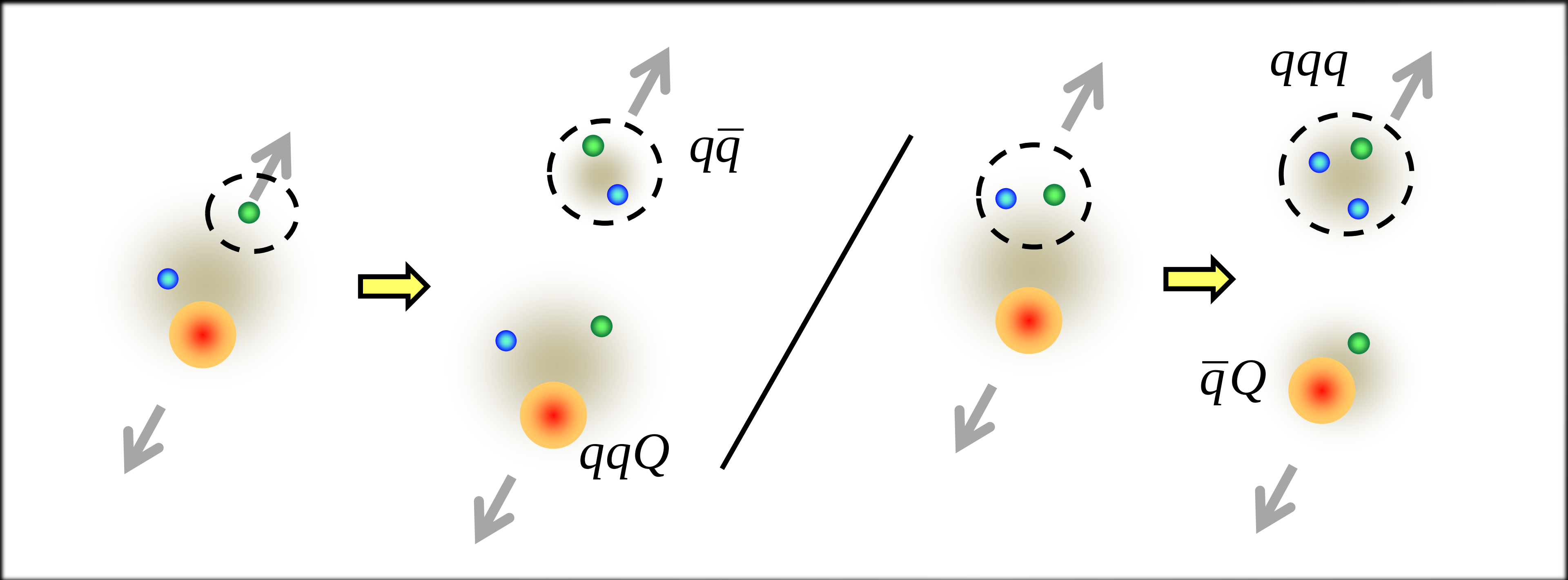
Charmed Baryon Spectroscopy

Using Missing Mass Techniques



Conducted by the E50 experiment at J-PARC

Decay Properties



ρ mode (qq)

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

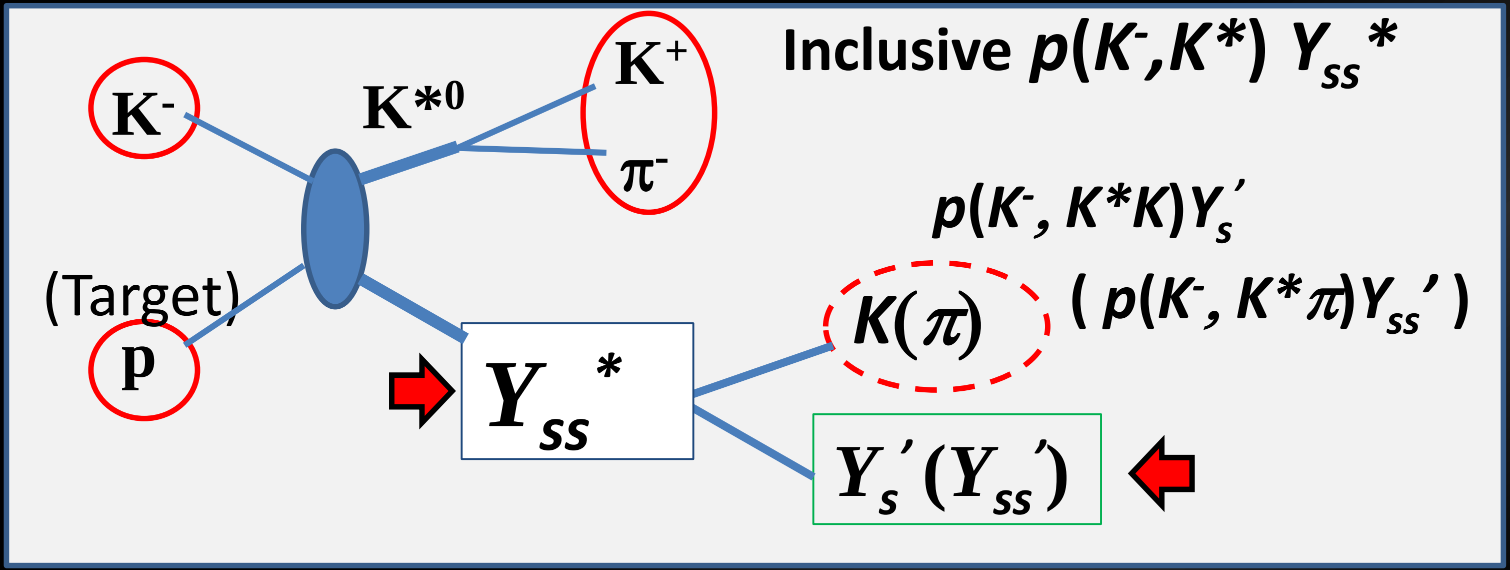
λ mode [qq]

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

Strange Hyperons

Double-Strange Baryon Spectroscopy

Using Missing Mass Techniques



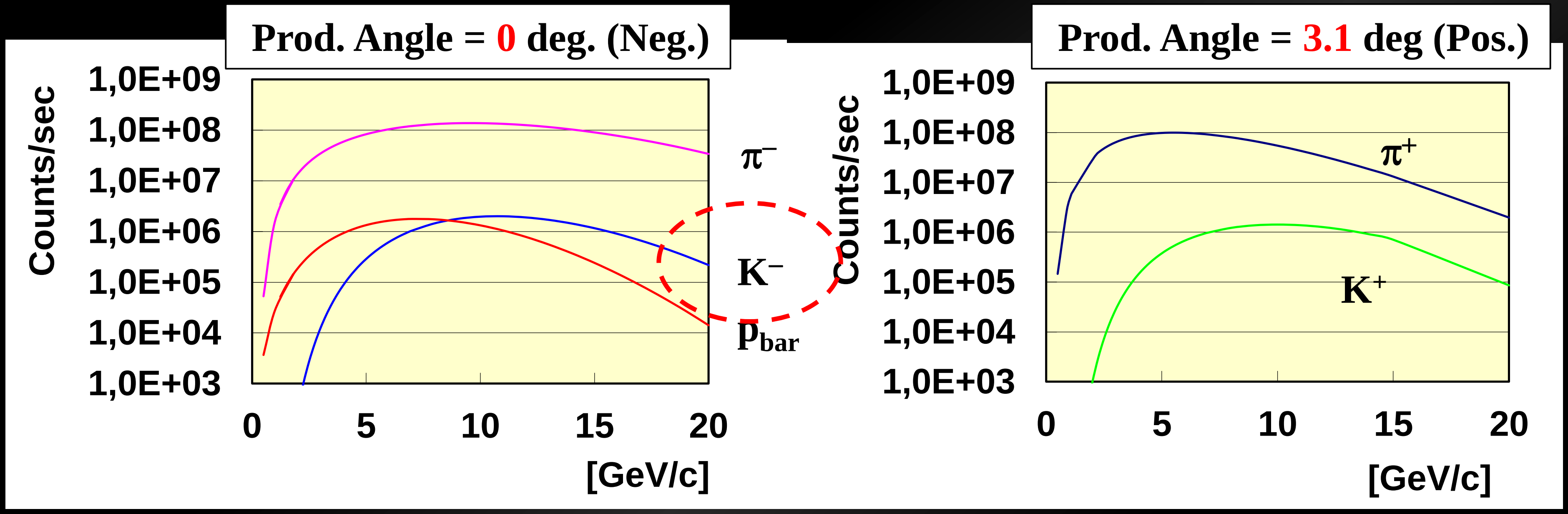
- S=-1 Hyperon *by* $p(\pi^-,K^*)$, $Y^*\to pK,\ \ \pi Y$
- S=-2 Hyperon *by* $p(K^-,K^*)$, (K^-,K), (π^-,KK^*), $\Xi^*\to YK,\ \pi\Xi$

x1000~10000 better statistics than Y_c^*

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%

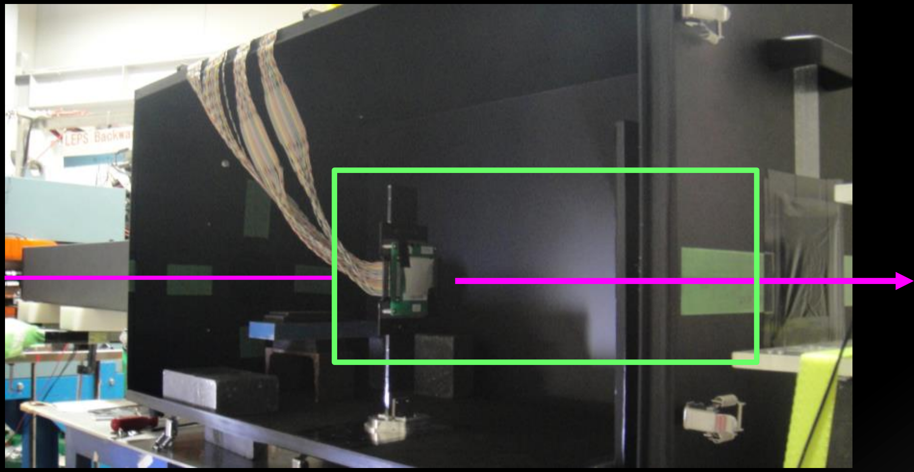
Intense K beams are available w/ a good KID counter.



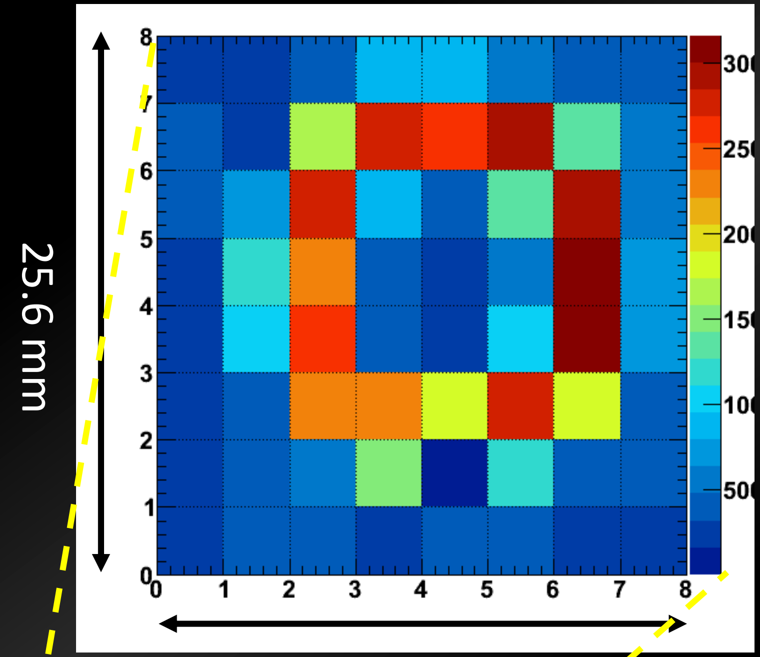
* Sanford-Wang:15 kW Loss on Pt, Acceptance :1.5 msr%, 133.2 m

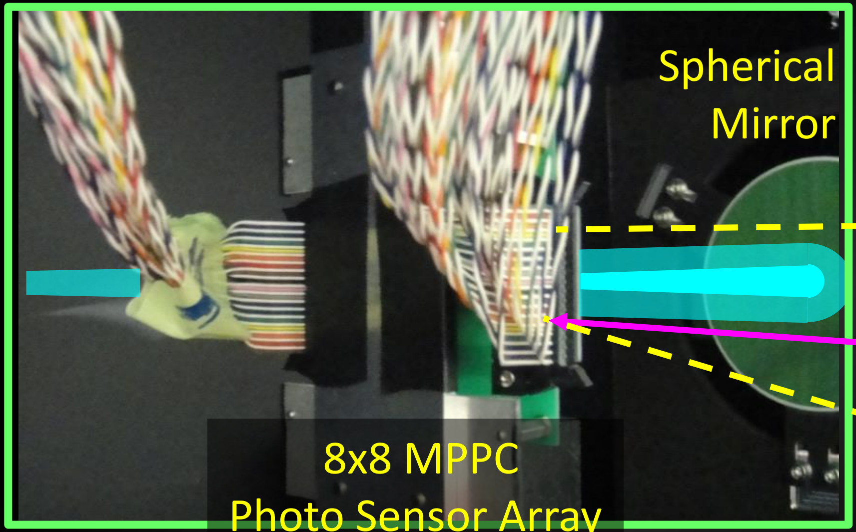
RICH R&D is in progress

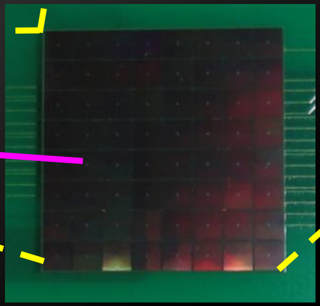
Electron
0.75 GeV/c



Measured RING IMAGE
by 8x8 MPPC Array



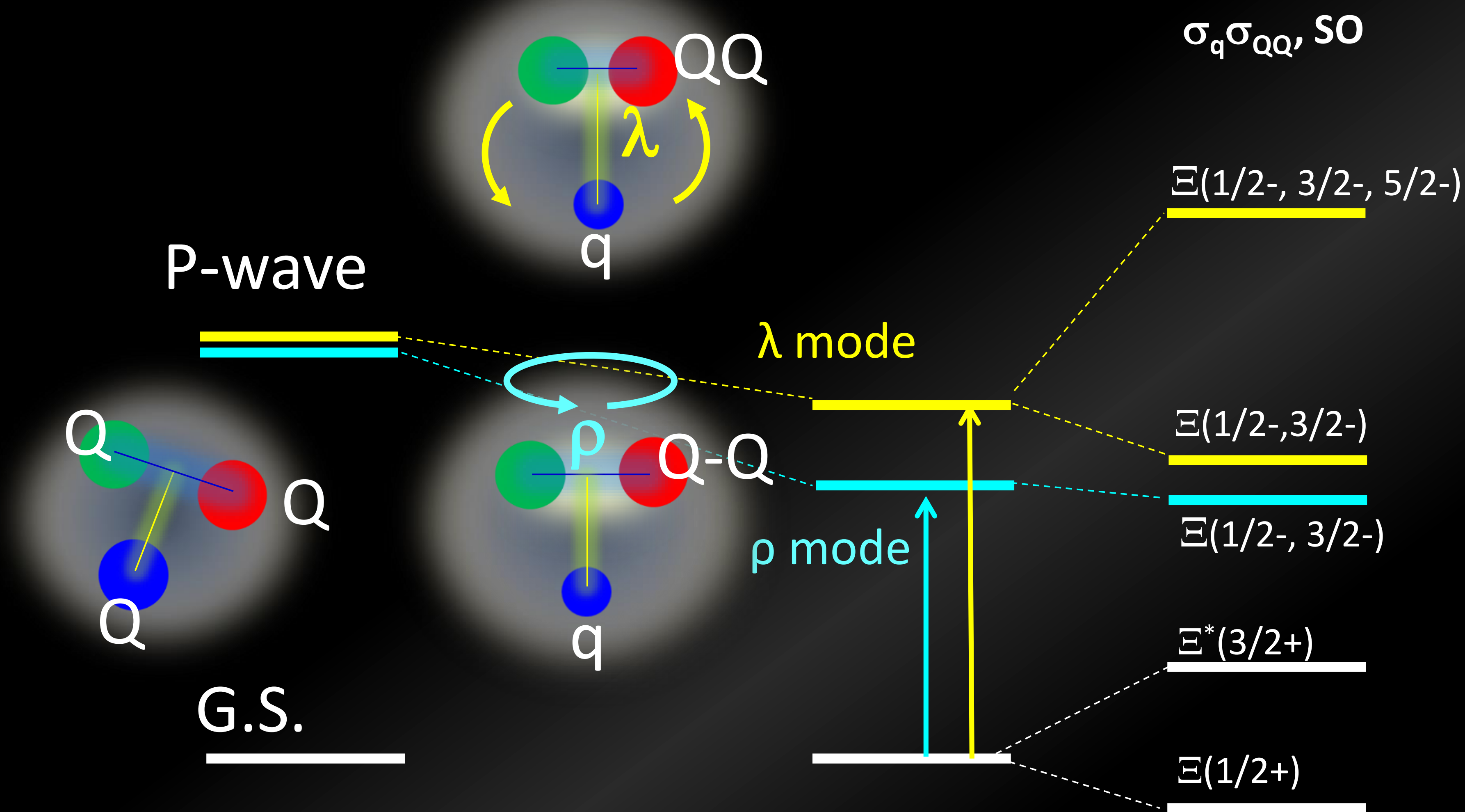




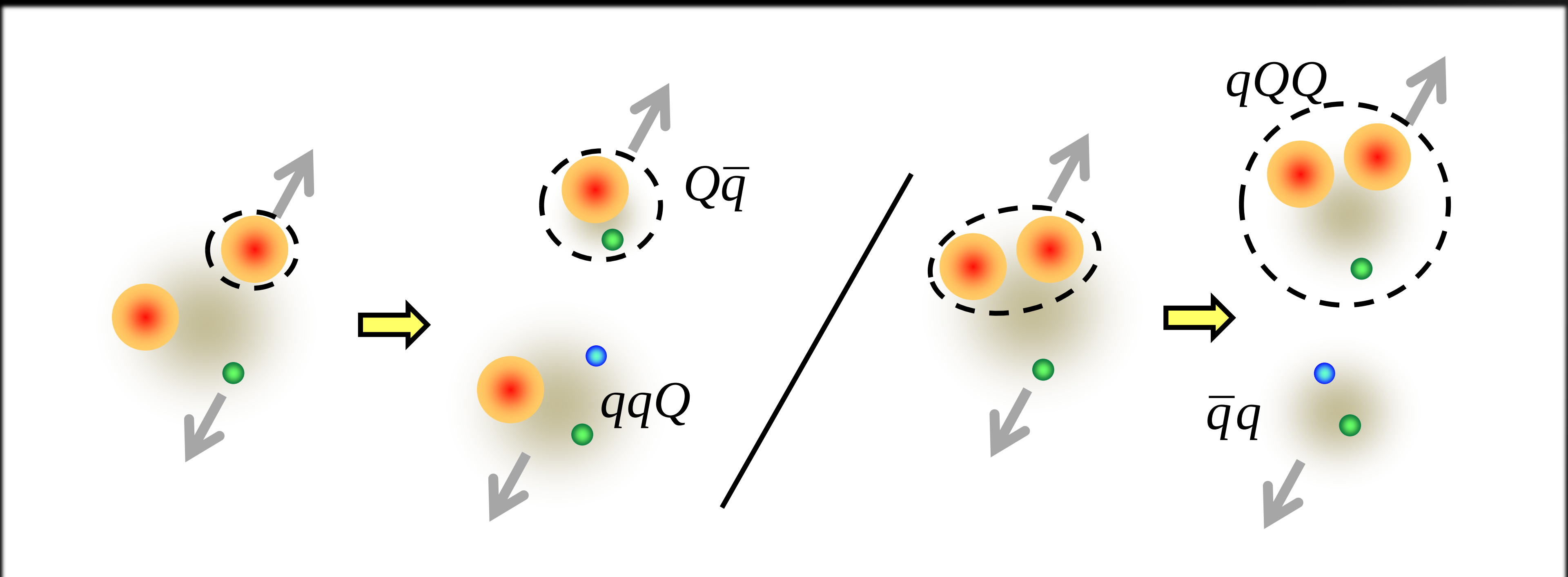
2014.11.30

Level Structure of double-strange baryons

- λ and ρ mode excitations interchange



Structure and Decay Partial Width



ρ mode (QQ)

$\Gamma(\Xi\pi) < \Gamma(YK^{bar})$

λ mode [QQ]

$\Gamma(\Xi\pi) > \Gamma(YK^{bar})$

Measured Ξ (PDG)

Threshold

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

$\Sigma\bar{K}$

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

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

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

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

$\Xi^*\pi(1665)$

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

$\Xi\pi(1450)$

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

✓ *Most of spins/parities have NOT been determined yet.*

✓ *Why the* Ξ^* -> $\pi\Xi$ decay seems to be suppressed?

✓ expected to reflect QQq configuration.

RCNP Activity

Cyclotron
High-res. Nuclear Spectroscopy
MuSIC
UCN

LEPS/LEPS2
Hadron Spectroscopy w/ pol. GeV-γ

J-PARC
A new platform of RCNP for hadron physics

CANDLES
$\beta\beta$ decay of ^{48}Ca

Facility
Accelerator Tech.
Medical App.
Electronics/DAQ

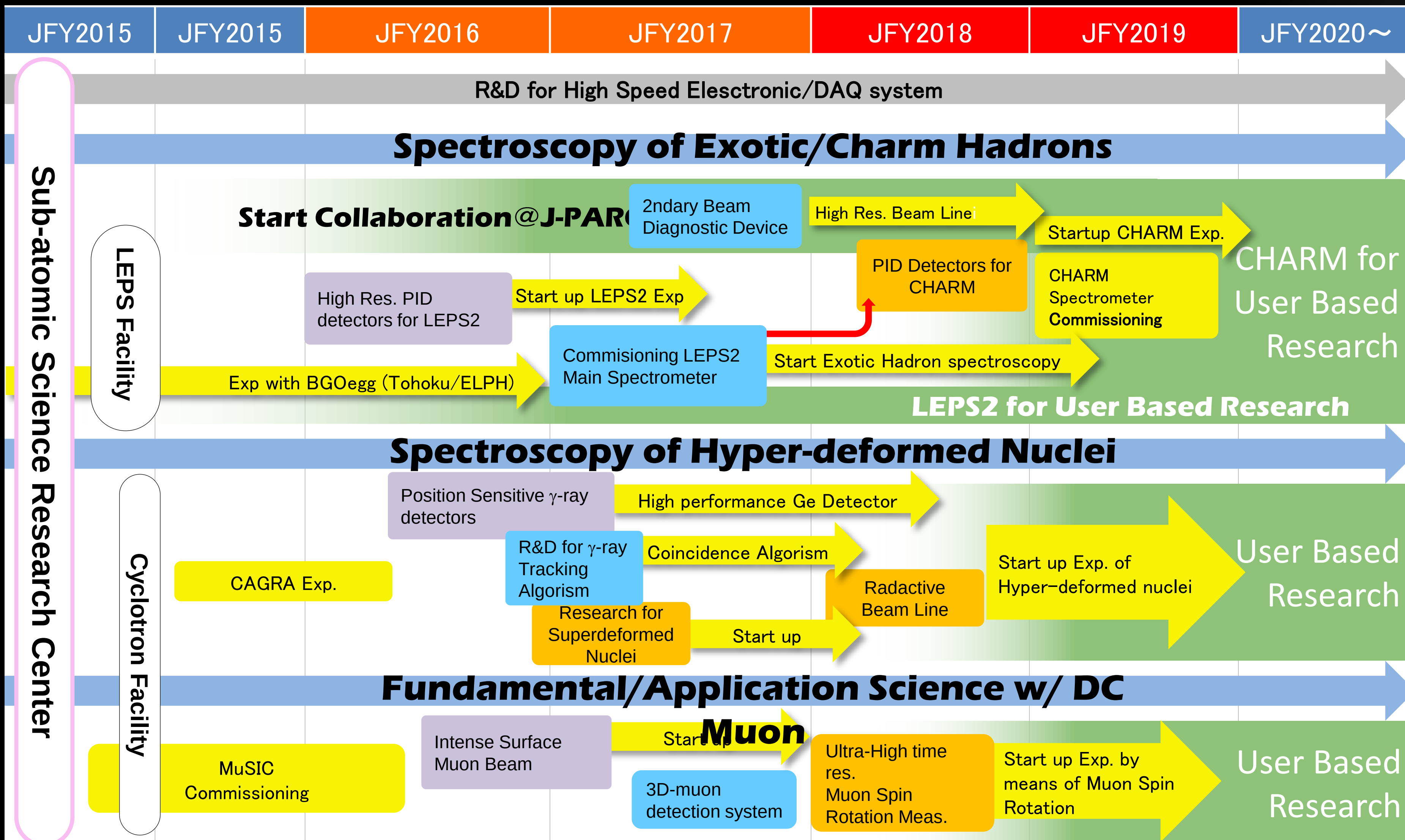
Theory
Hadron Physics
Nuclear Physics
Computational Phys

Summary

- RCNP will conduct a new platform for hadron physics at the High-p Beam Line of J-PARC.
  - Hadron beam and γ-beam
  - Strangeness and charm
- Strong collaborations of experiment and theory are important to attack problems on hadron physics
- RCNP can provide a lot of opportunities to study nuclear hadron physics in Japan.
  - APCTP are expected to play an important role to strengthen mutual collaborations.

backup

PLAN



JFY2015
JFY2015
JFY2016
JFY2017
JFY2018
JFY2019
JFY2020～
Sub-atomic Science Research Center
R&D for High Speed Elesctronic/DAQ system
Spectroscopy of Exotic/Charm Hadrons
LEPS Facility
Start Collaboration@J-PARC
2ndary Beam Diagnostic Device
High Res. Beam Line
Startup CHARM Exp.
PID Detectors for CHARM
CHARM Spectrometer Commissioning
CHARM for User Based Research
High Res. PID detectors for LEPS2
Start up LEPS2 Exp
Commisioning LEPS2 Main Spectrometer
Start Exotic Hadron spectroscopy
Exp with BGOegg (Tohoku/ELPH)
LEPS2 for User Based Research
Spectroscopy of Hyper-deformed Nuclei
Cyclotron Facility
Position Sensitive γ-ray detectors
High performance Ge Detector
R&D for γ-ray Tracking Algorism
Coincidence Algorism
CAGRA Exp.
Radactive Beam Line
Start up Exp. of Hyper−deformed nuclei
User Based Research
Research for Superdeformed Nuclei
Start up
Fundamental/Application Science w/ DC Muon
Intense Surface Muon Beam
Start up
Ultra-High time res. Muon Spin Rotation Meas.
Start up Exp. by means of Muon Spin Rotation
User Based Research
MuSIC Commissioning
3D-muon detection system

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*

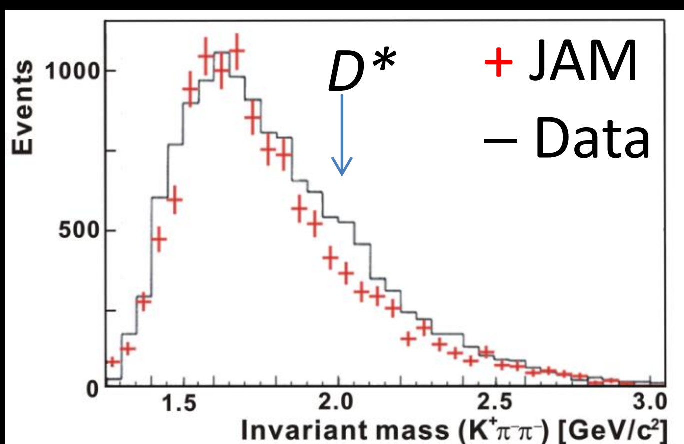
[11] *Institute of Physics, Academia Sinica, Taipei 11529, Taiwan*

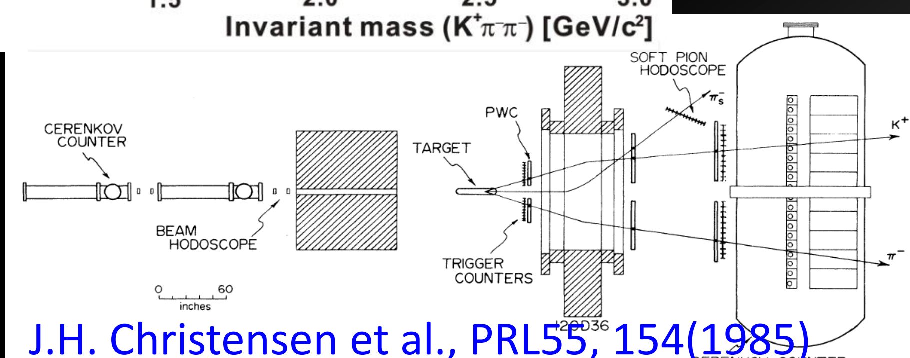
[12] *Department of Physics, Seoul National University, Seoul 151-747, Korea*

Production Cross Section

A. Hosaka et al.

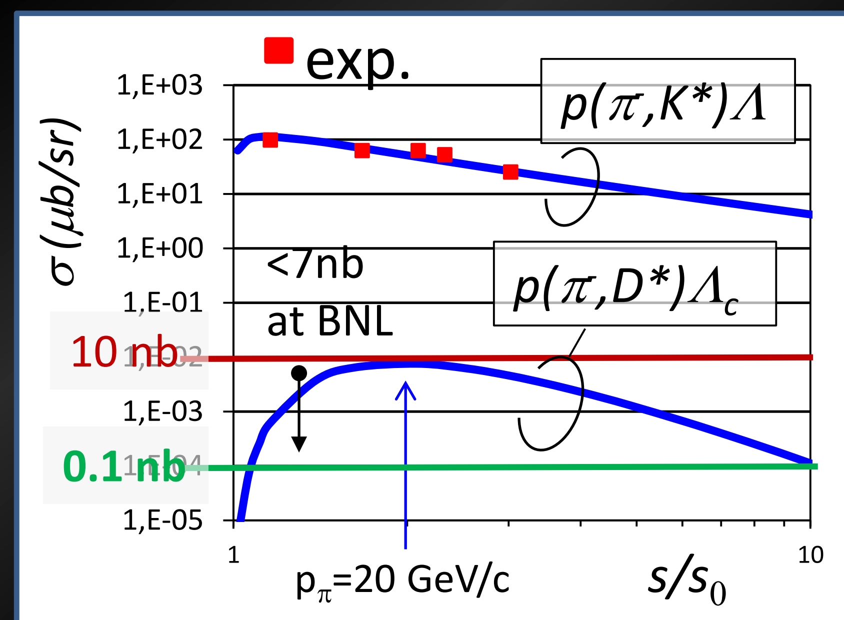
- Experimental data:
  - $\sigma(p(\pi^-, D^{*-})\Lambda_c) <$ 7 nb (68%CL) (BNL exp., 1985)
  - BG spectrum is well reproduced by a MC simulation w/ JAM
- Regge Theory suggests 10^{-4} of the hyperon production
  - $\sigma(p(\pi^-, D^{*-})\Lambda_c) \sim$ a few nb





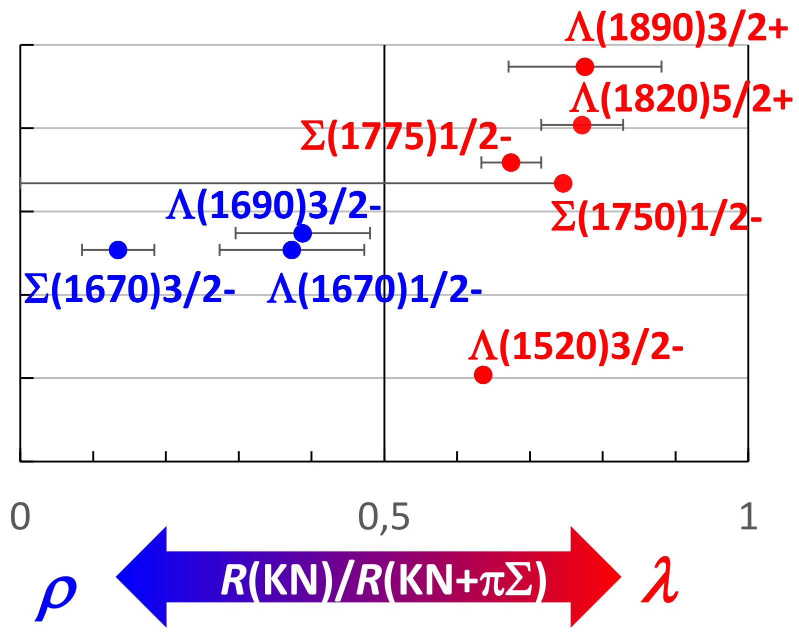
J.H. Christensen et al., PRL55, 154(1985)

Regge Theory



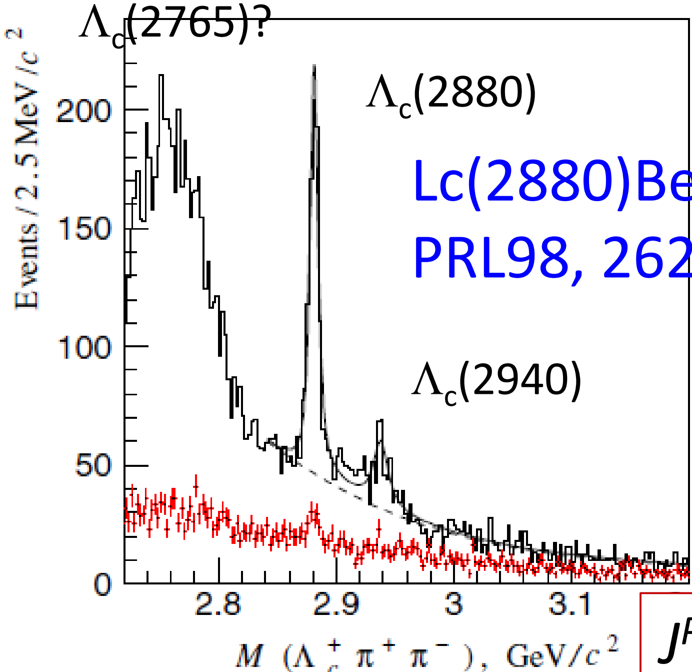
Hint in $R(NK)/R(\pi\Sigma)$

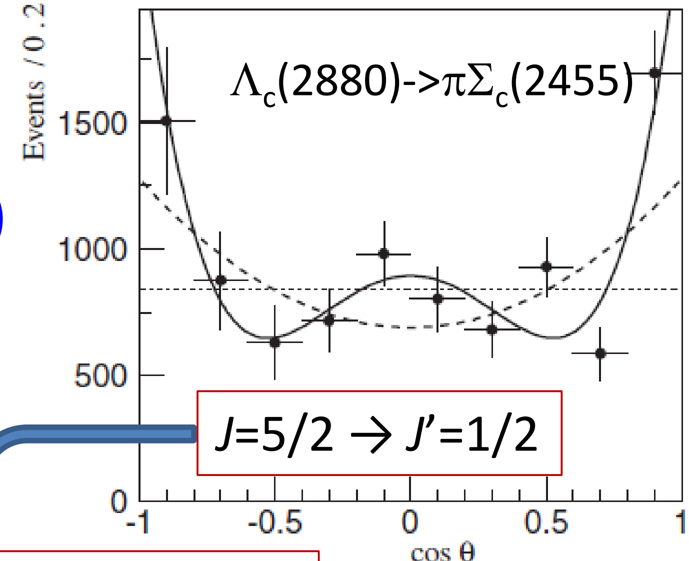
PDG Data



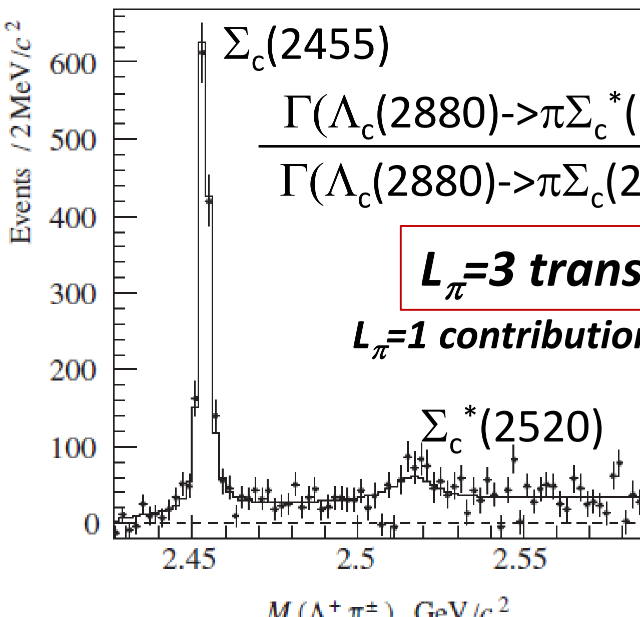
- Decay ratios in known hyperons SUGGEST the λ/ρ mode states
- λ/ρ mode ID by productions correlate w/ Decay Ratios
  → to be established

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



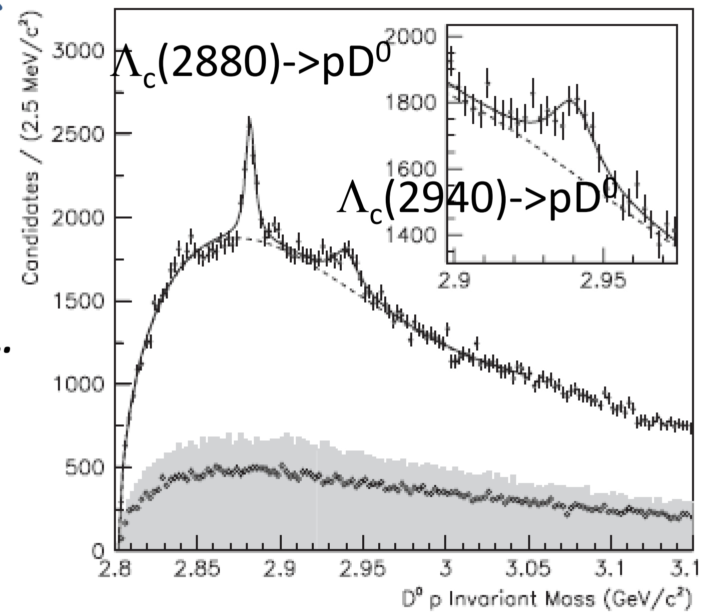


J^P=5/2$^+$ for Λ_c(2880)



L_π=3 transition

L_π=1 contribution may affect…



Babar, PRL98, 012001('07)

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

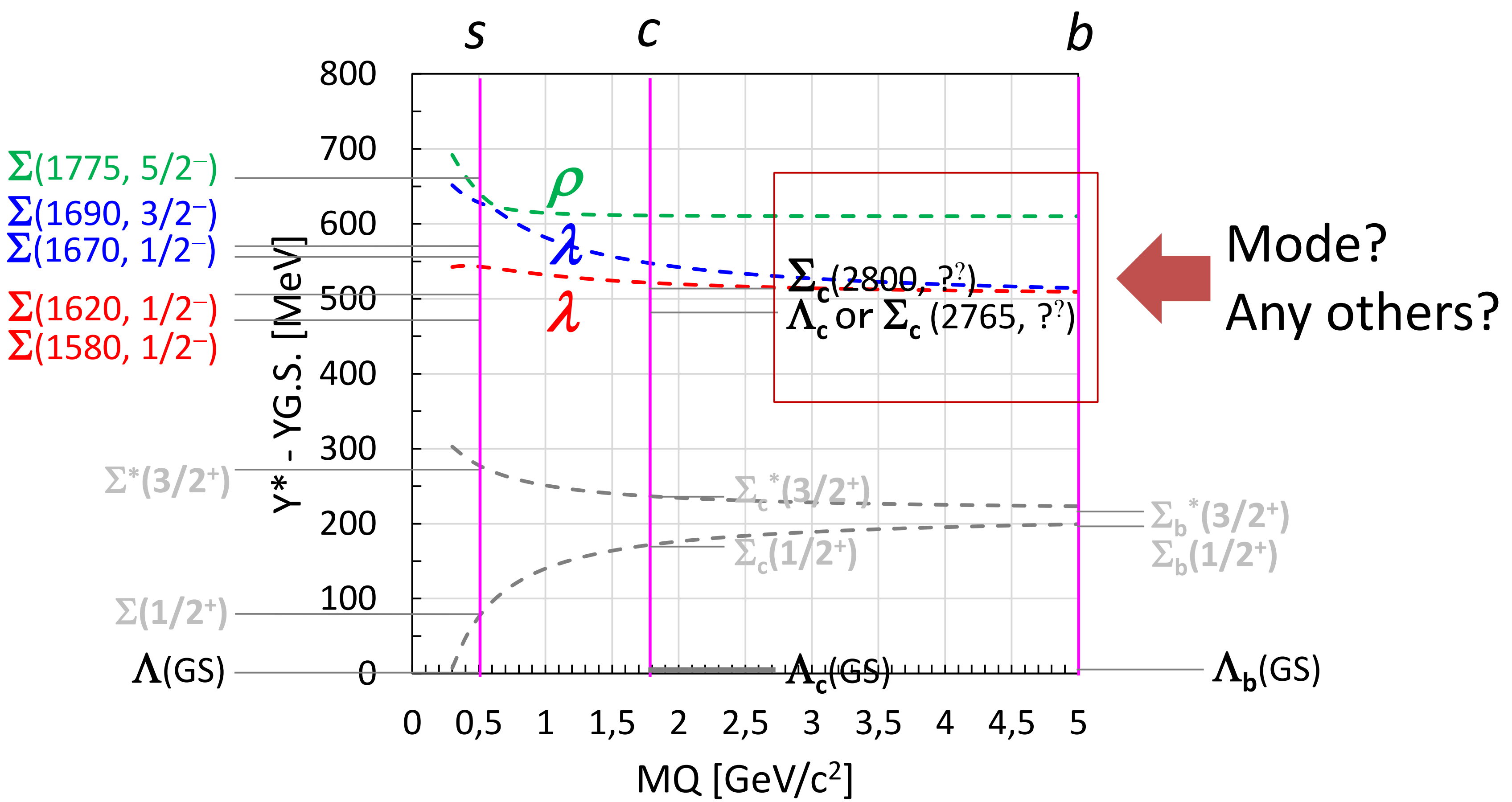
- Are $\Lambda_c(2880)/\Lambda_c(2940)$ *LS* partners?
  - *LS* splitting; $\Delta E(J^{\wedge},J_{\vee}) \sim (2L+1)/2$
    - $\Delta E(5/2^+,3/2^+)/\Delta E(3/2^-,1/2^-)=5/3$

      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?
  - $\sigma(5/2^+;2880):\sigma(3/2^+;2940)=3:2$ ($\sigma(J^{\wedge}):\sigma(J_{\vee})=L+1:L$)

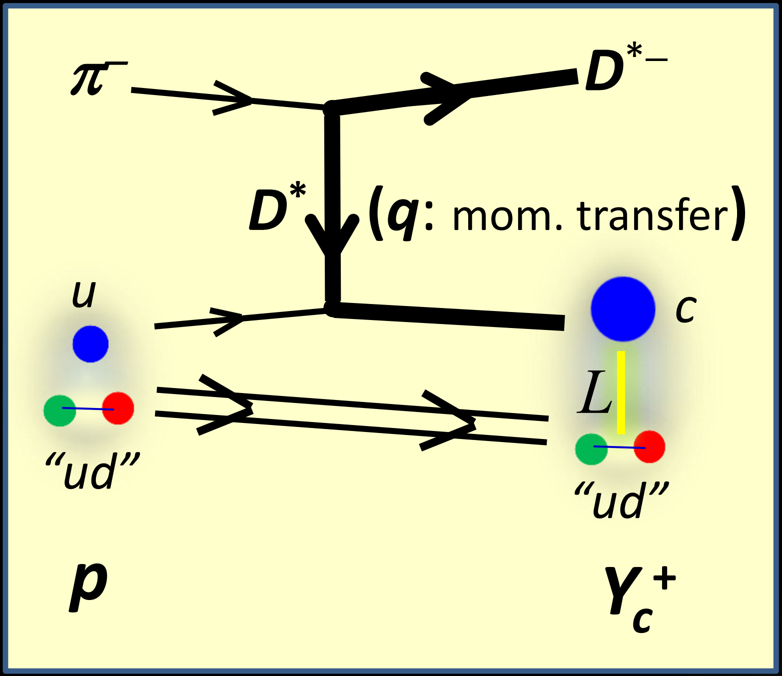
    c.f. $\sigma(3/2^-;2625):\sigma(1/2^-;2595)=2:1$ for
- If NOT,
  - Prod. Rates give information on their structure...
  - new states corresponding to $L_{(\lambda)}=2$ should be observed

Sigma Baryons



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

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:

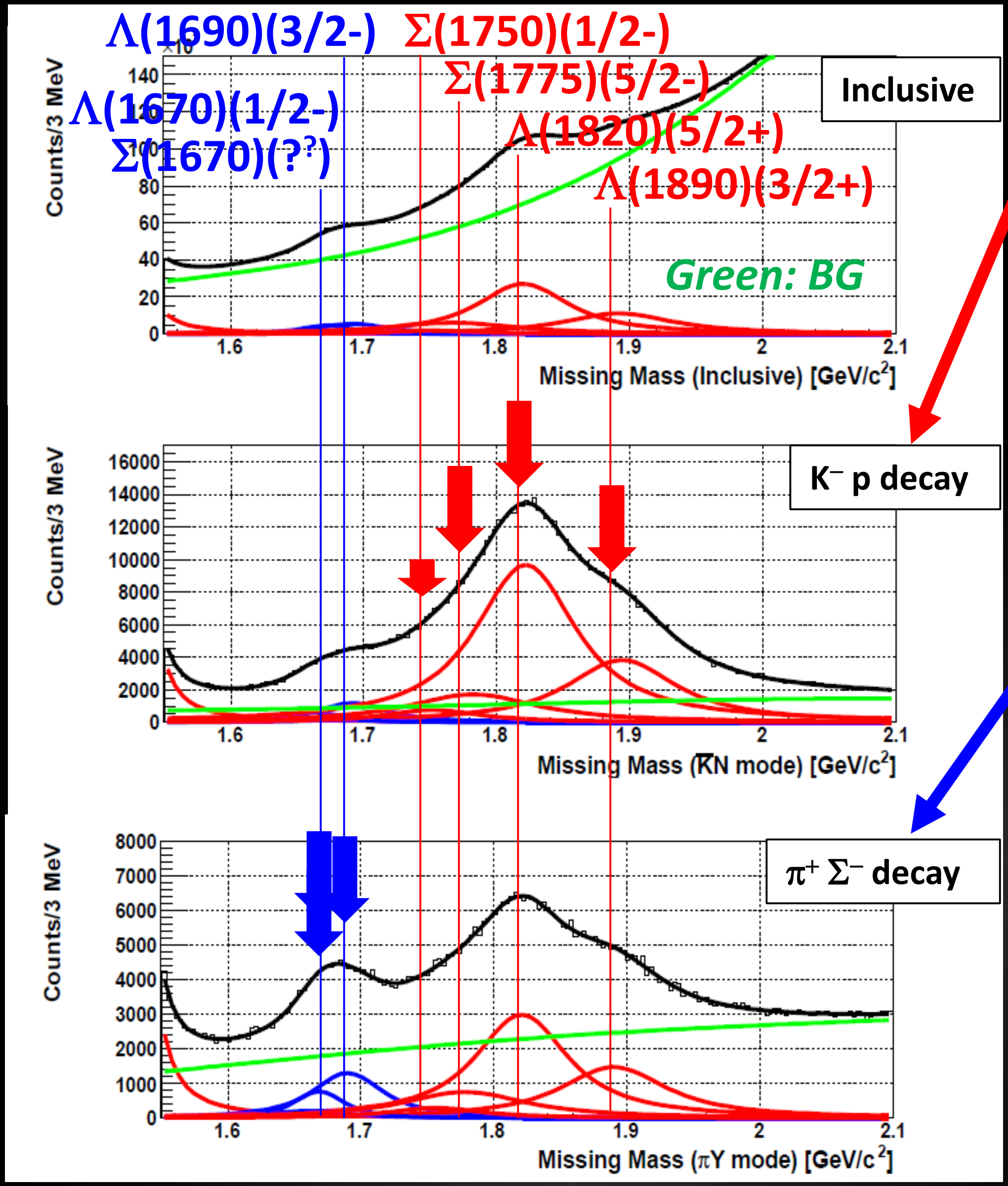
1. Spin/Isospin Config. of Y_c
   Spin/Isospin Factor
2. Momentum transfer (q_{eff})

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

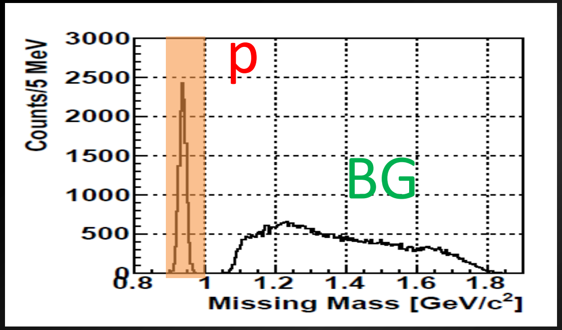
A: (baryon size parameter)$^{-1}$

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

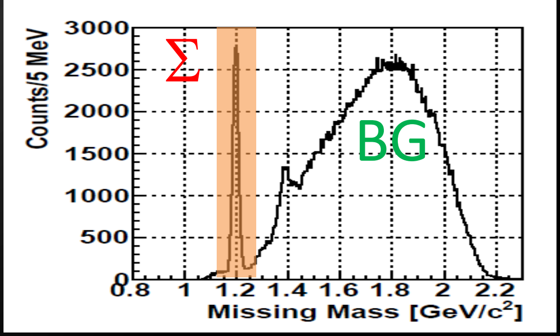
Simulation w/ 4×10^{11} pions (3 days)



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

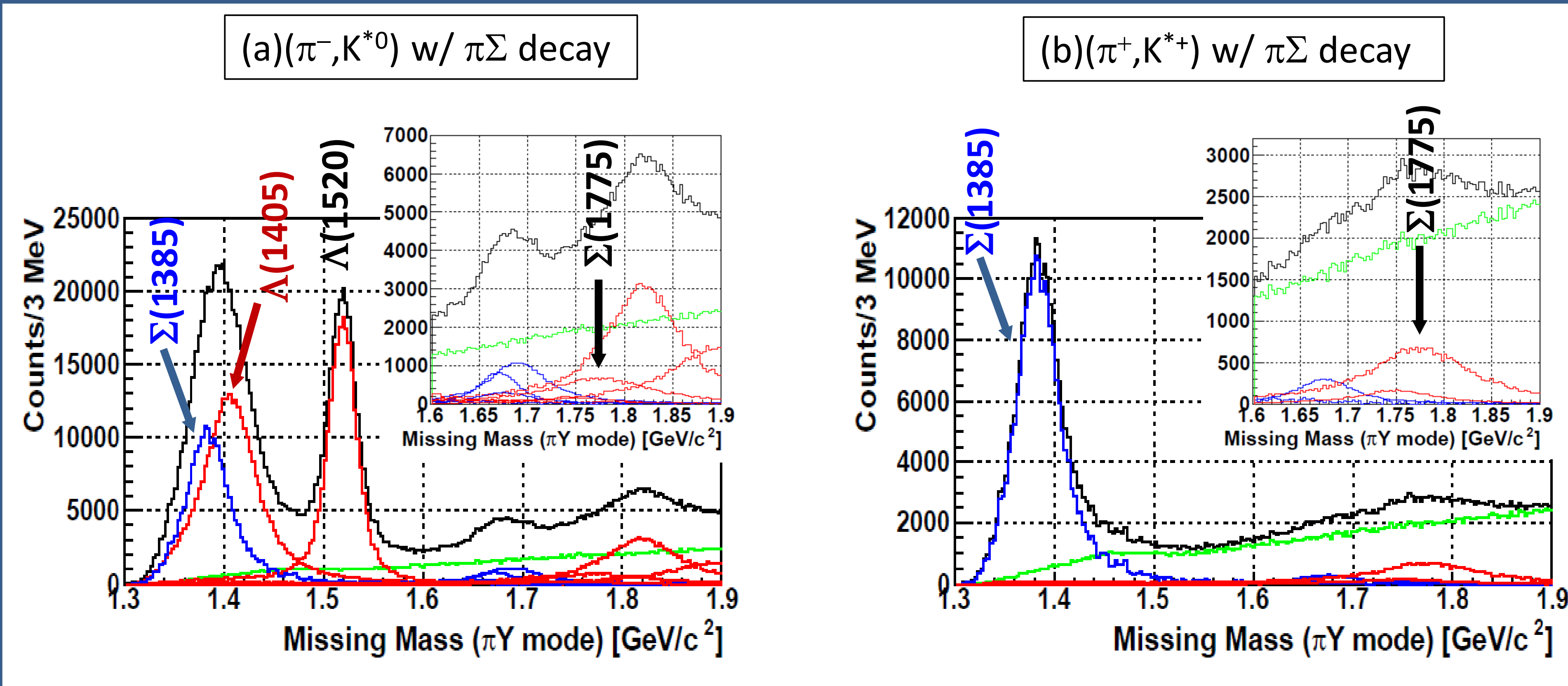


- *X* → $\pi^+\Sigma^-$ decay
  - π^+ tagged, Missing "Σ" gated



Strange Baryons

I = 0, 1 *I* = 1 only

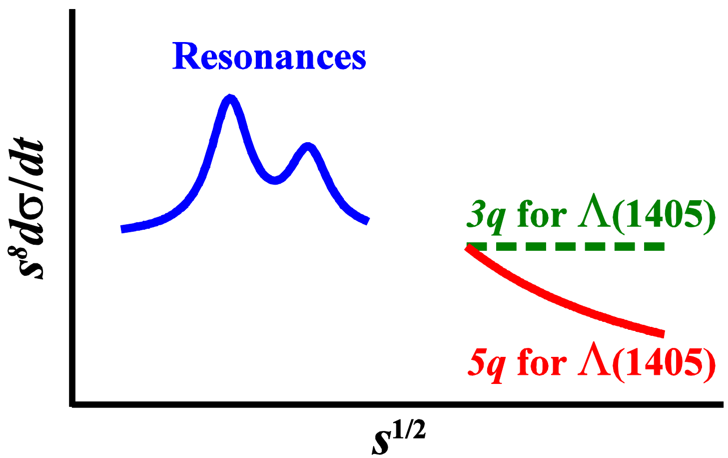


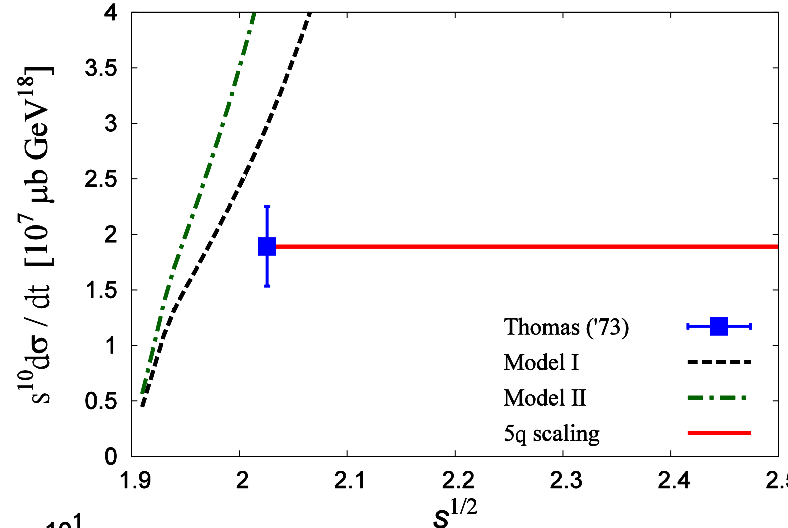
✓ Contribution of $\Sigma(1385)$ can be subtracted to extract the $\Lambda(1405)$ amplitude.

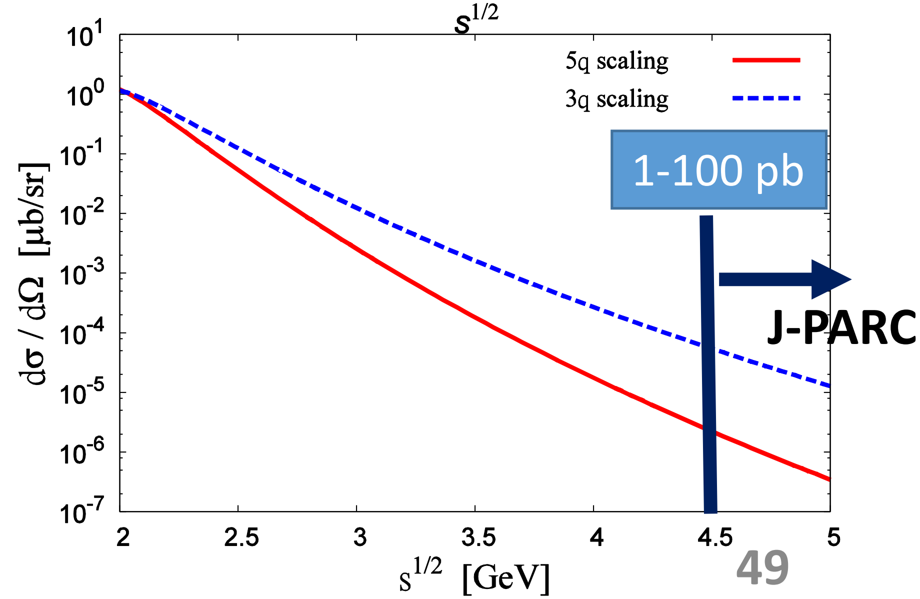
Quark Degrees of $\Lambda(1405)$

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

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







Takayasu Sekihara (March 15)

Ξ Baryon Spectroscopy w/ the High-p Secondary Beam

LoI submitted by M. Naruki and K. Shirotori

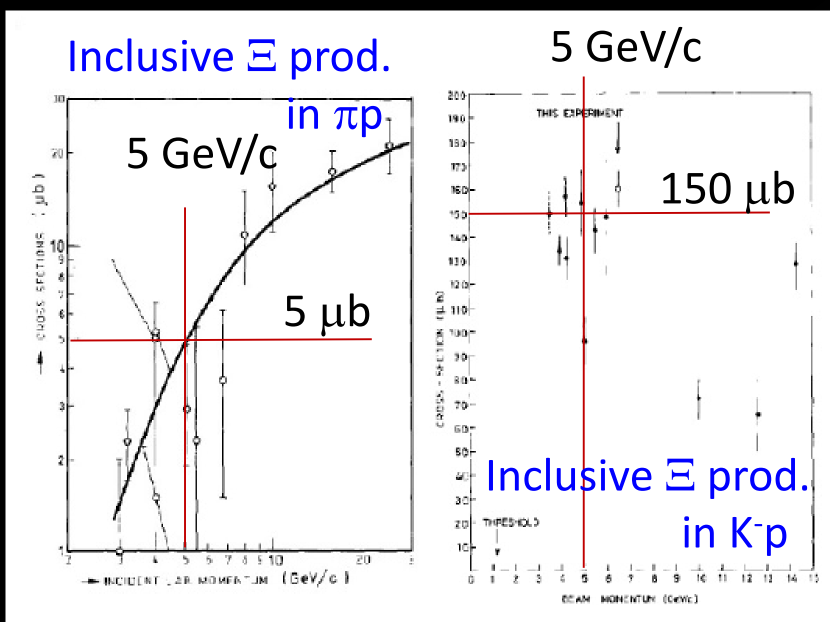
- Sizable yields are expected for a month.

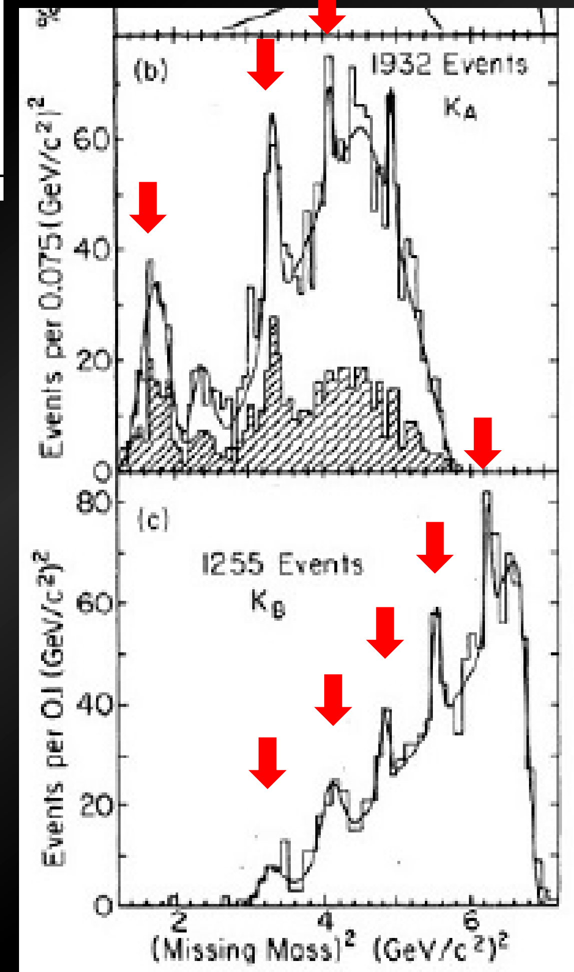
Reaction	σ [μb]	Beam [/spill]	B.R.	Acceptance [%]	Y_{Total}	$Y_{Decay/bin}$
$K^-p \to \Xi^{*-}K^+$	1.0	10^6	1.0	50	3.1×10^5	2500
$K^-p \to \Xi^{*-}K^{*+}$	1.0	10^6	0.23	50	0.7×10^5	580
$K^-p \to \Xi^{*0}K^{*0}$	1.0	10^6	0.67	50	2.1×10^5	1700
$\pi^-p \to \Xi^{*-}K^{*0}K^+$	0.1	10^7	0.67	50	3.1×10^5	2500

p(K-,K+) spectra

- Past exp.

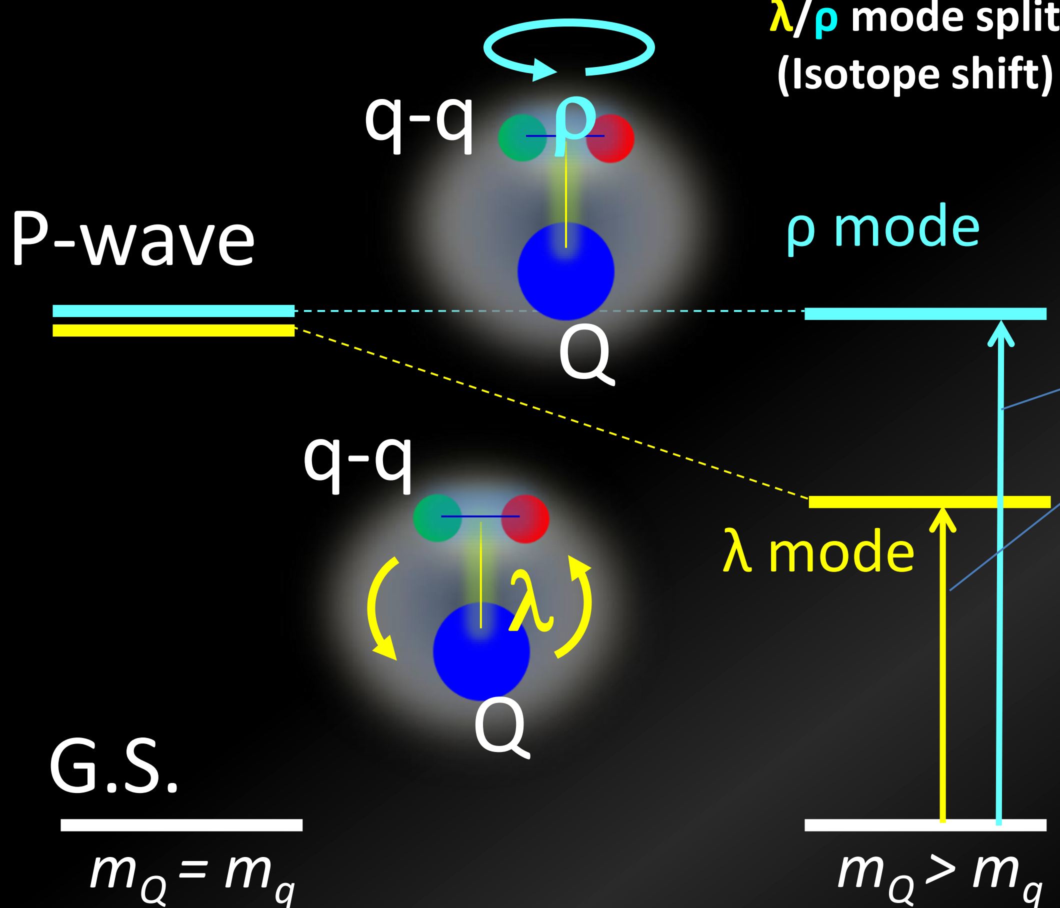
C.M. Jenkins et al., PRL51, 951(1983) →





“Schematic” Level Structure of Heavy Baryons

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



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

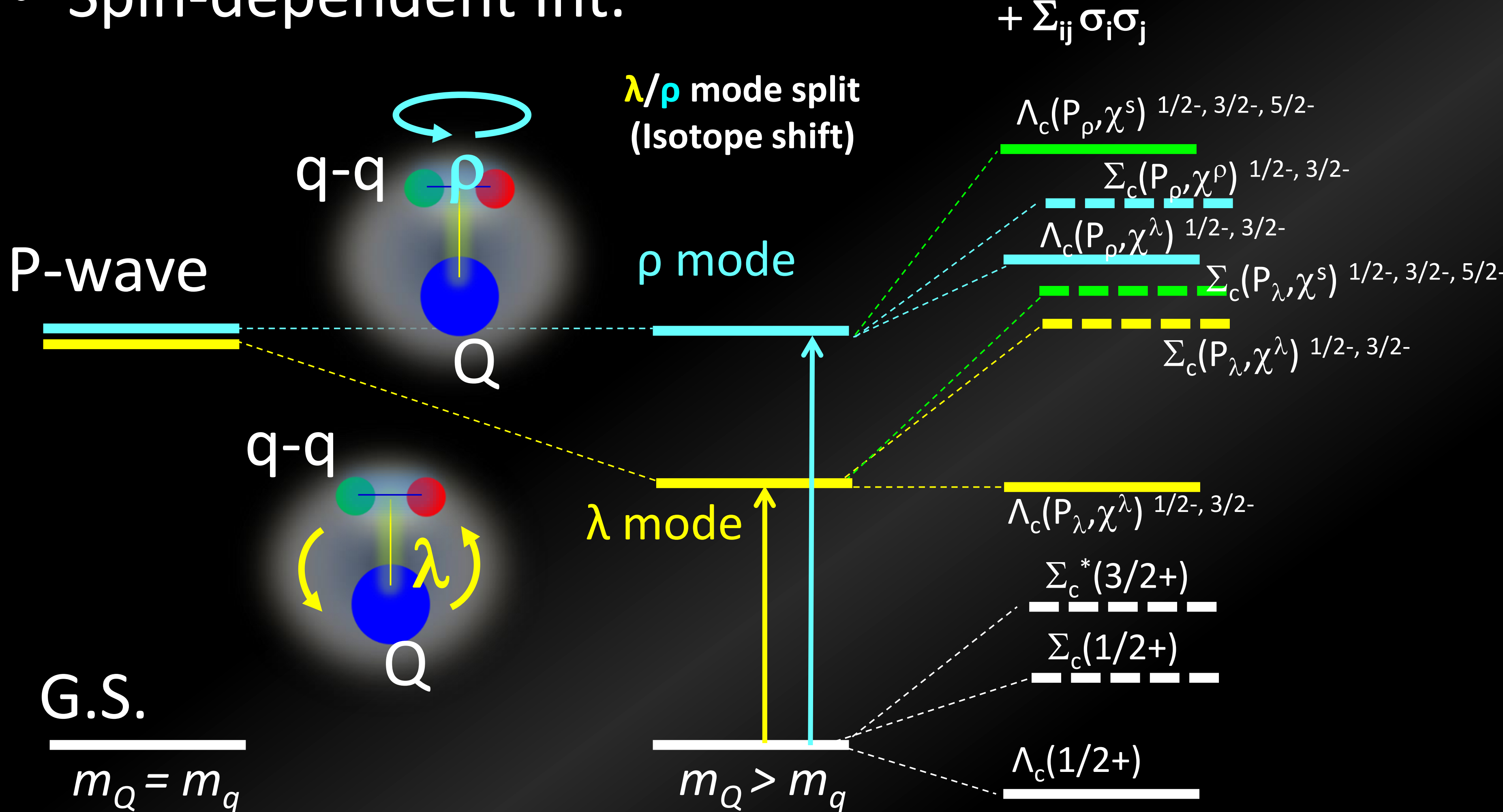
$$\omega_{\lambda,\rho} = \sqrt{3k/m_{\lambda,\rho}},$$

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

$$m_\rho = m_q$$

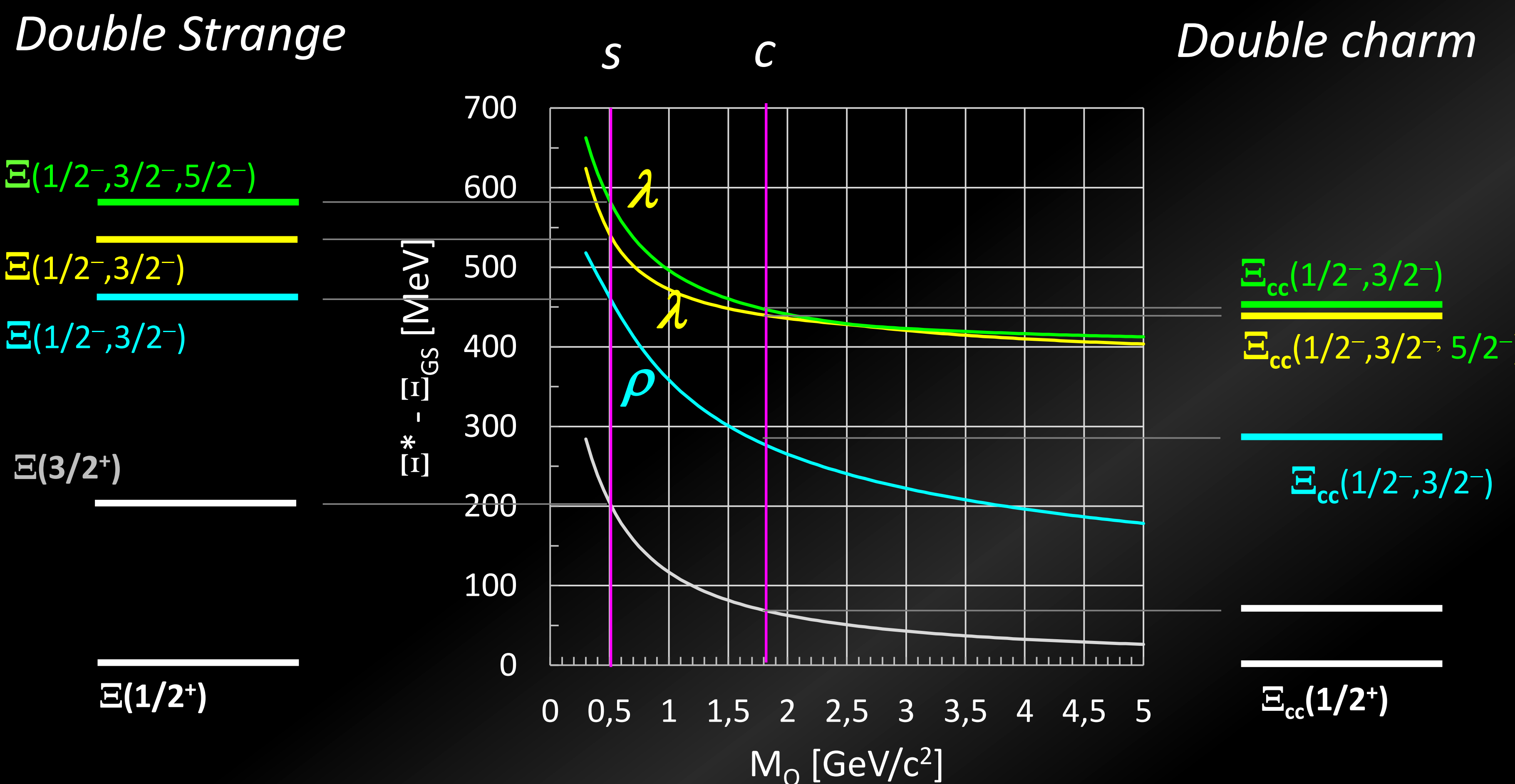
“Schematic” Level Structure of Heavy Baryons

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



Ξ Hyperons

qQQ Baryon spectroscopy



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

$\rho-\lambda$ mixing (cal. By T. Yoshida)

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	
KN(1432)	**Λ(1670)**		1/2-	4*	35	20~30		25~55	
Σπ(1330)		Σ(1620)	1/2-	1*					
		Σ(1580)	3/2-	1*					
Σ*π(1520)	Λ(1520)			4*	19	45+-1		42+-1	

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
		$\Lambda^{3/2-}(1520)$	127
	ρ	$\Lambda^{1/2-}(1670)$	7
		$\Sigma^{3/2-}(1690)$	4
		$\Lambda^{3/2-}(1690)$	13
	λ	$\Sigma^{1/2-}(1750)$	4
		$\Sigma^{5/2-}(1775)$	18
2		$\Lambda^{3/2+}(1890)$	25
		$\Lambda^{5/2+}(1820)$	52

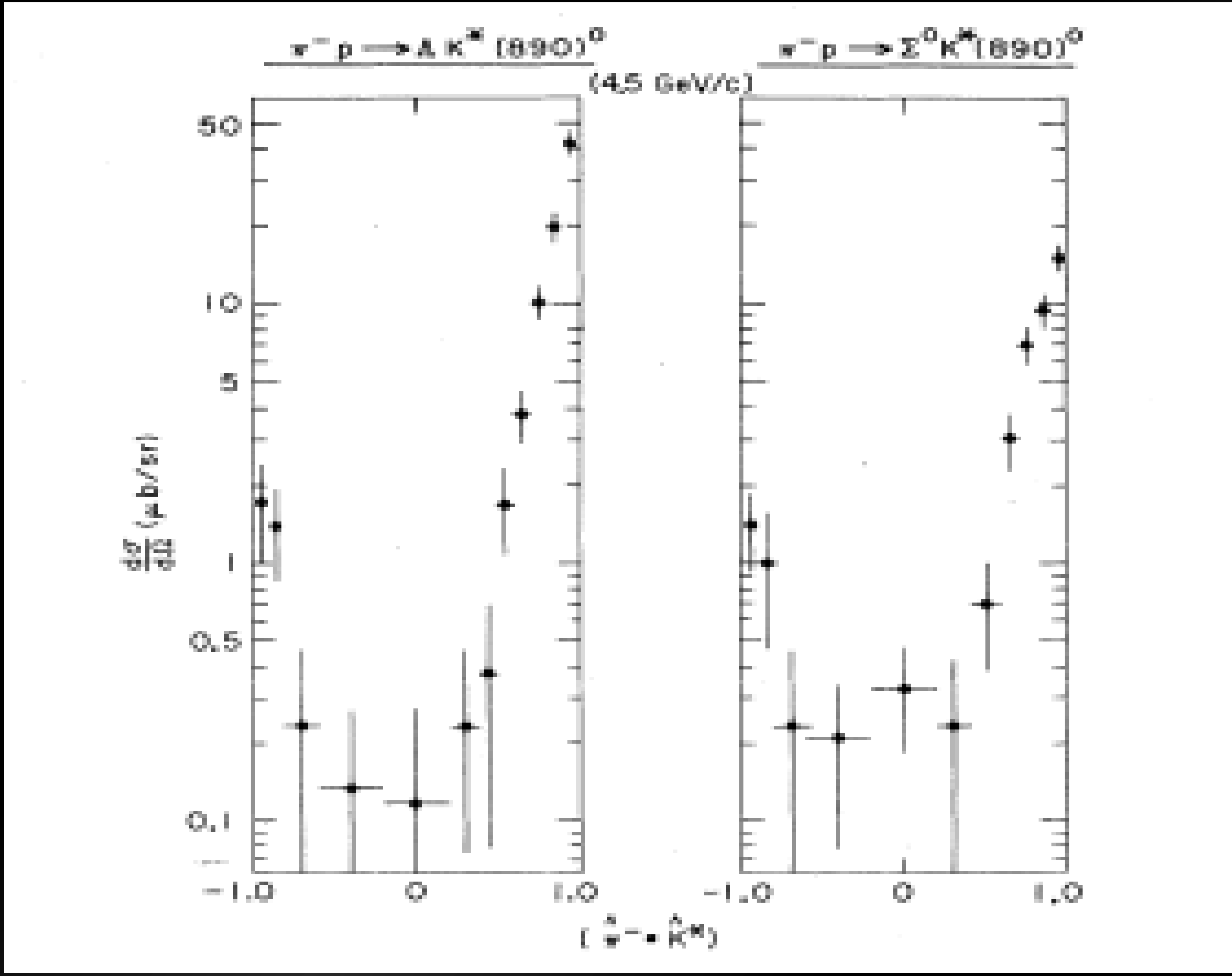
Cal. w/ t-channel K ex. reaction*
at p_π = 5 GeV/c

- 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.

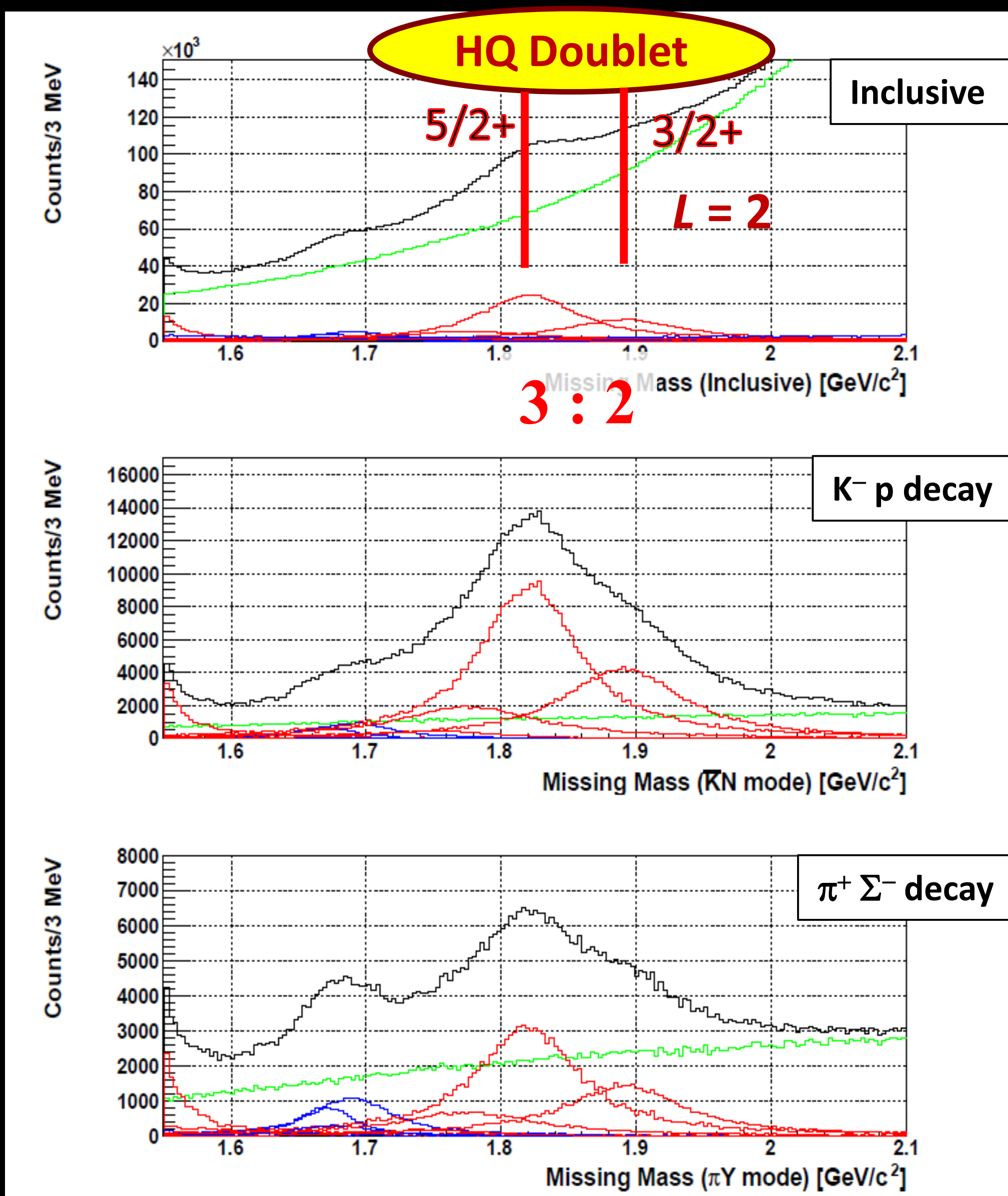
✓ $P_{mix}(strange) > P_{mix}(charm)$

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

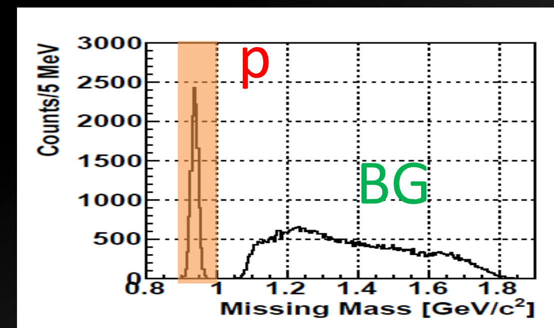
Production (π^-,K^{*0})



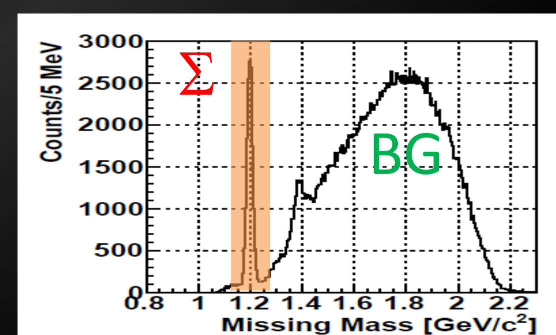
Hyperon production via $p(\pi^-,K^{*0})X$



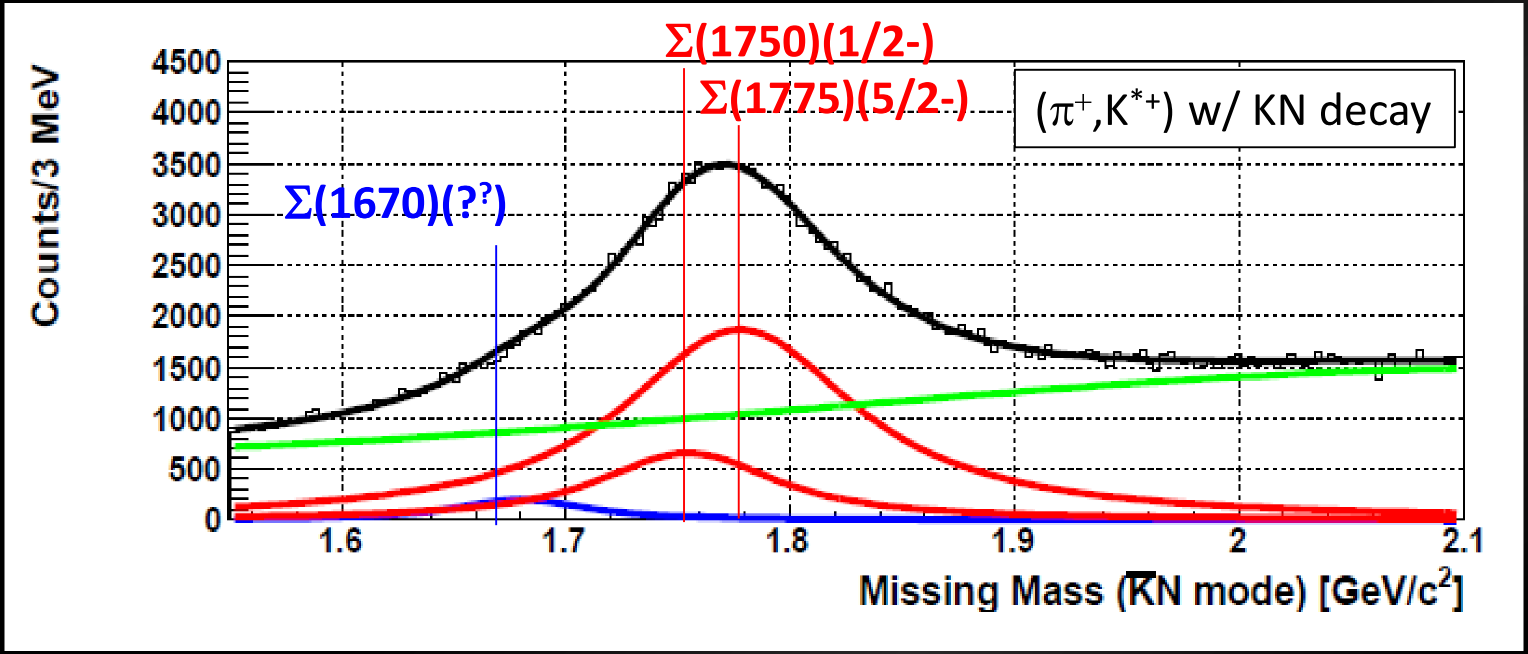
- K^- p decay
  - K^- tagged, Missing "p" gated



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

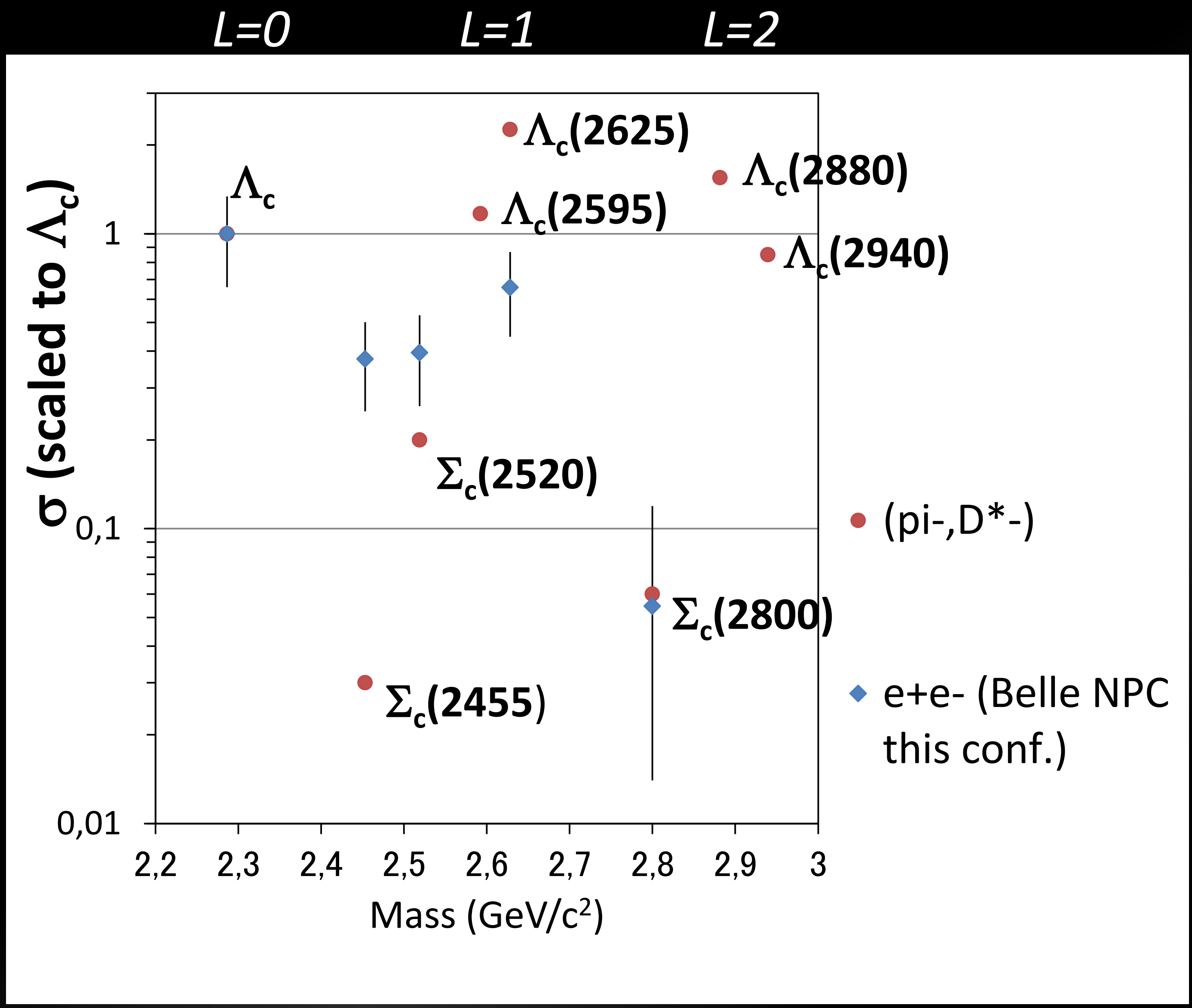


Peak fitting for $p(\pi^+, K^{*+})\Sigma^{*+}$



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

Calculated production rates



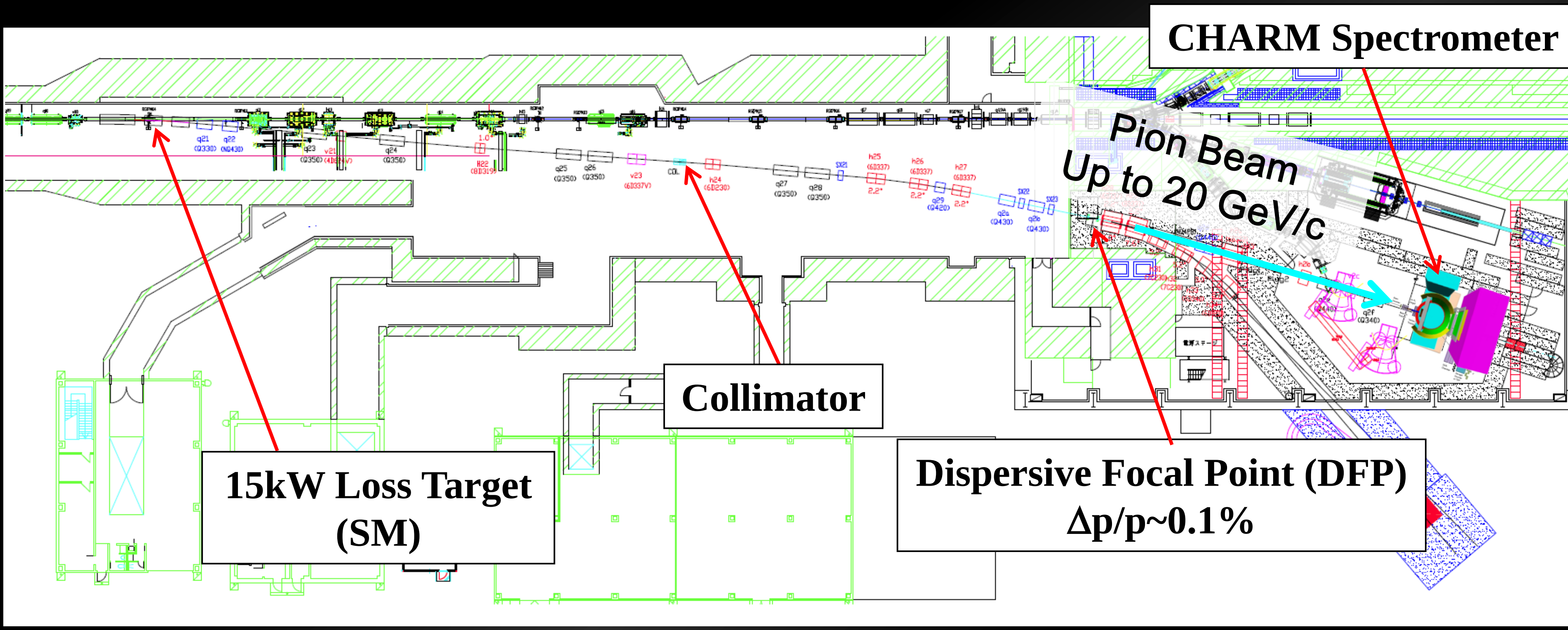
Calculated production rates

	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
	$\Sigma_c^{1/2-\prime}$	2750	1/6	2/27	1.49	0.05
	$\Sigma_c^{3/2-\prime}$	2820	1/6	56/135	1.50	0.21
	$\Sigma_c^{5/2-\prime}$	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

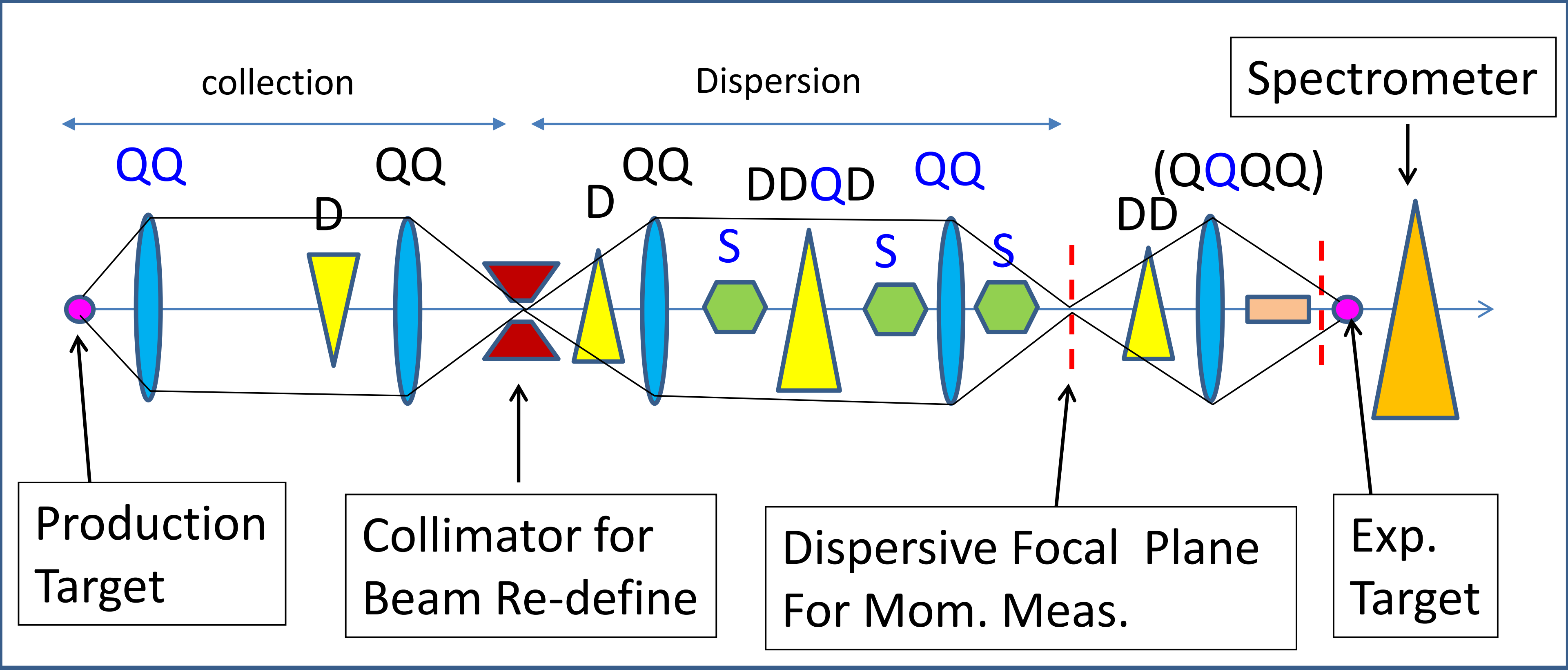
A New Platform for Hadron Physics at the High-momentum Beam Line

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



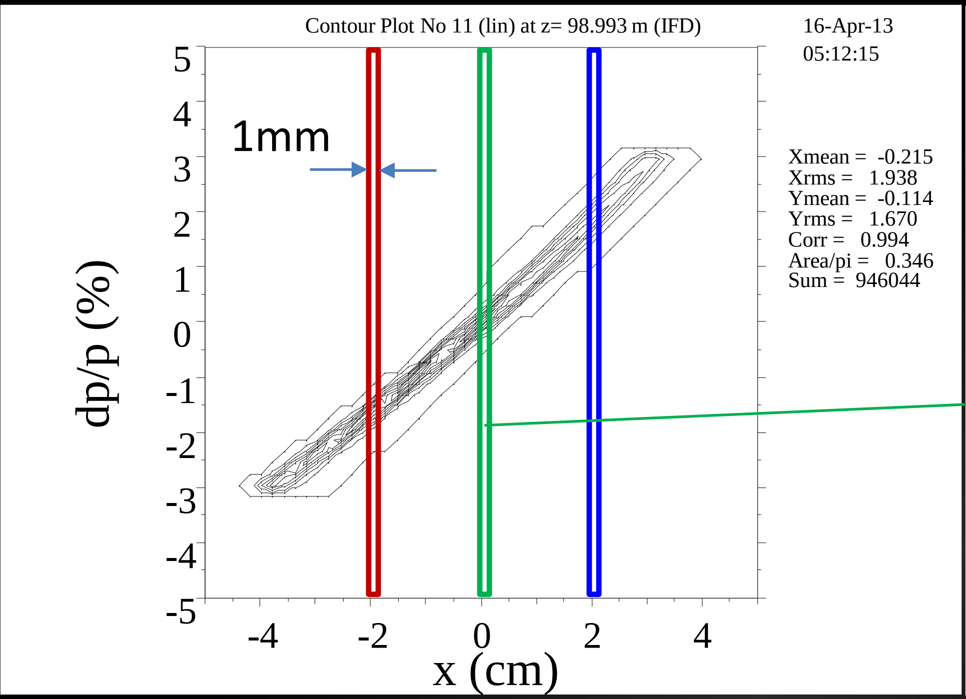
High-res., High-momentum Beam Line

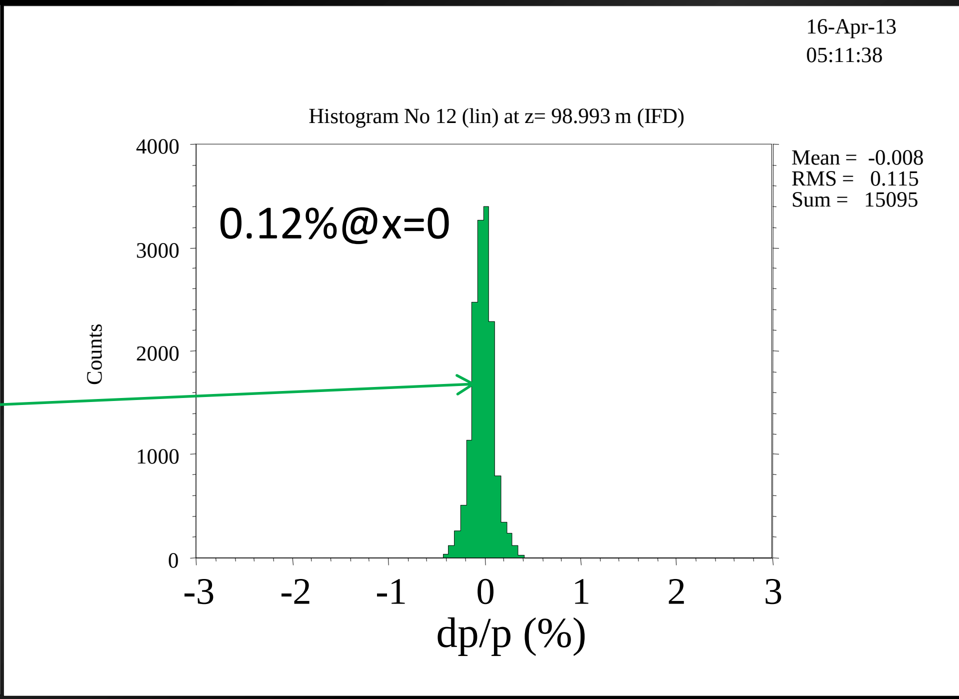
- High-intensity secondary Pion beam
- High-resolution beam: Δp/p~0.1%



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

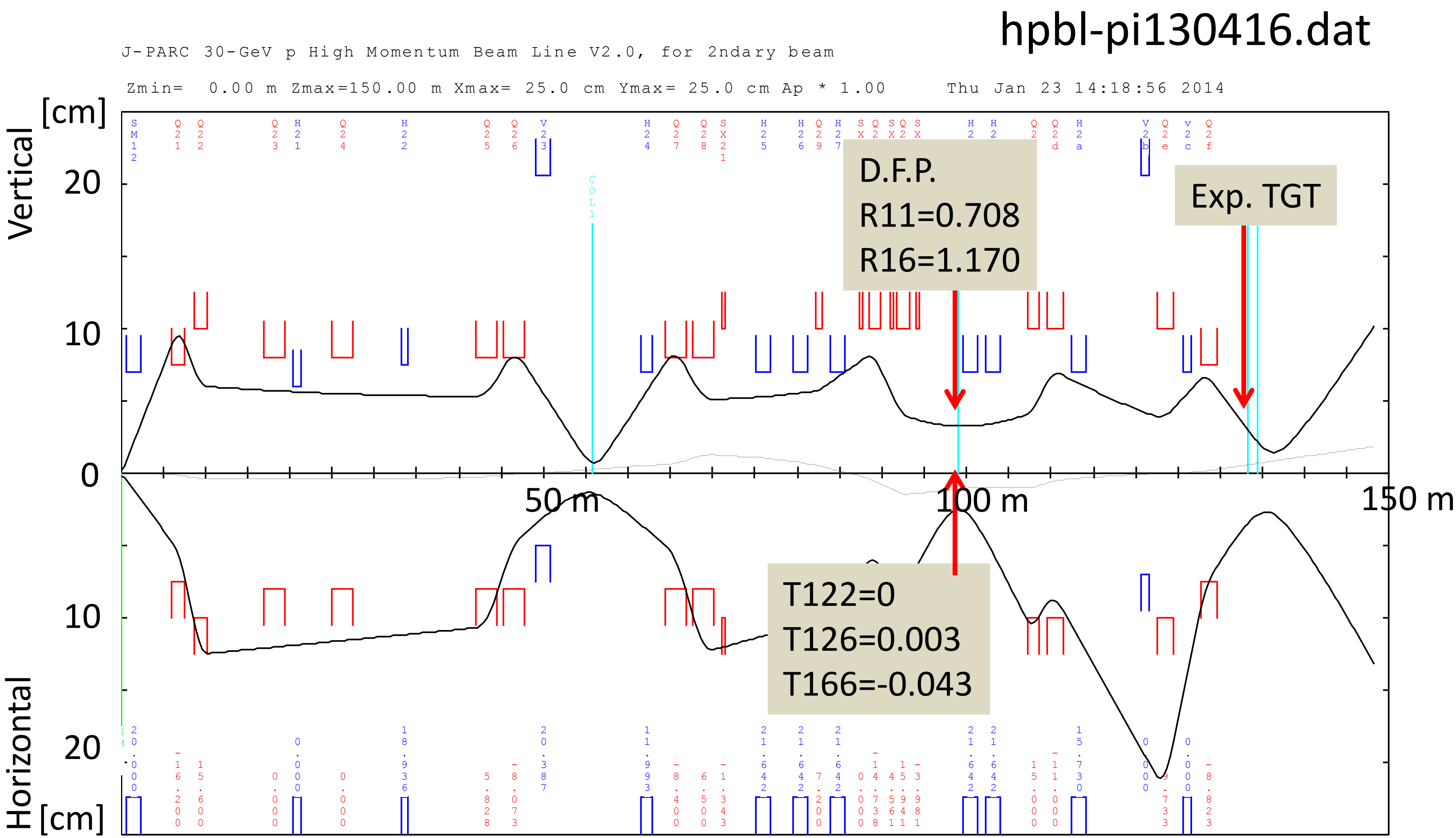
- High-intensity secondary Pion beam
  - >1.0 x 10^7 pions/sec @ 20GeV/c
- High-resolution beam: $\Delta p/p$~0.1%





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

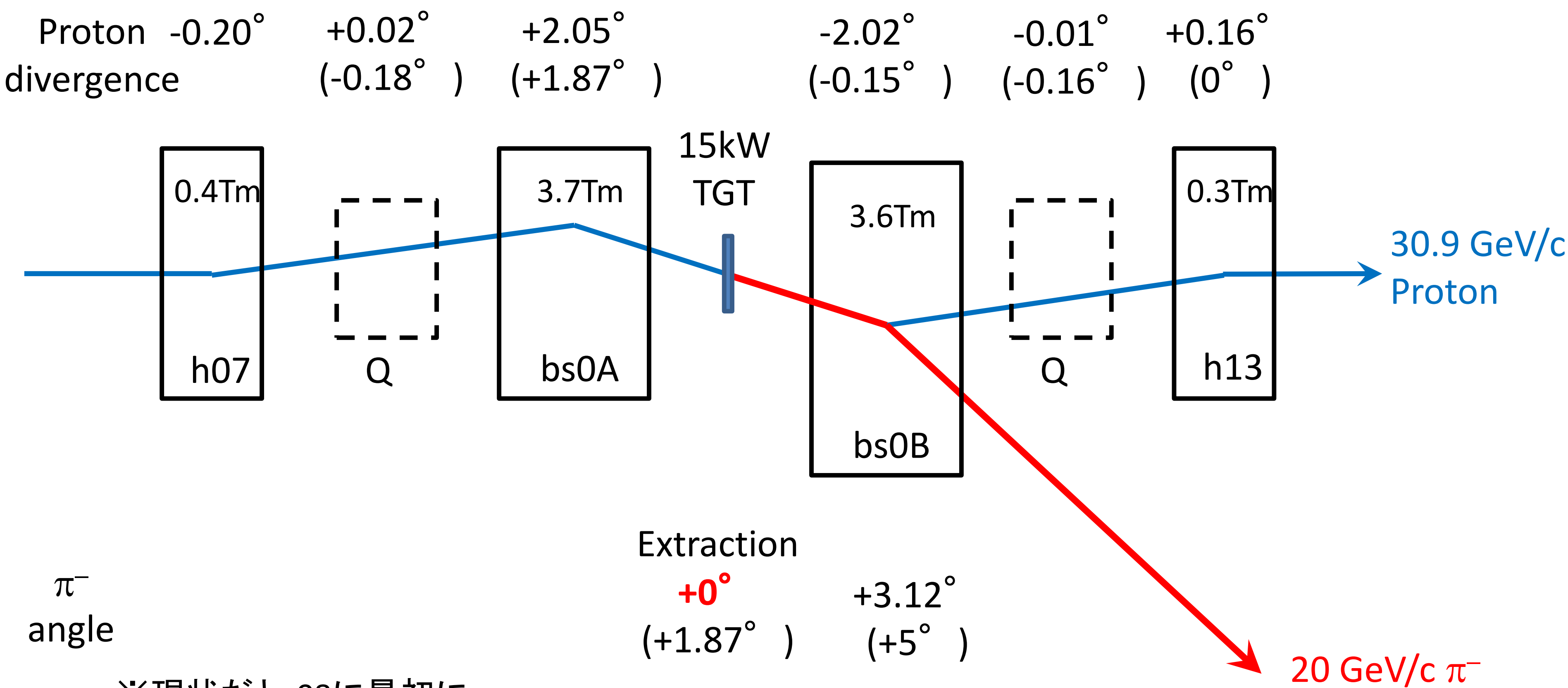
Beam Envelope (2nd order Transport)



2013.02.19 H. Takahashi

π20 Beam Extraction

Beam Swinger



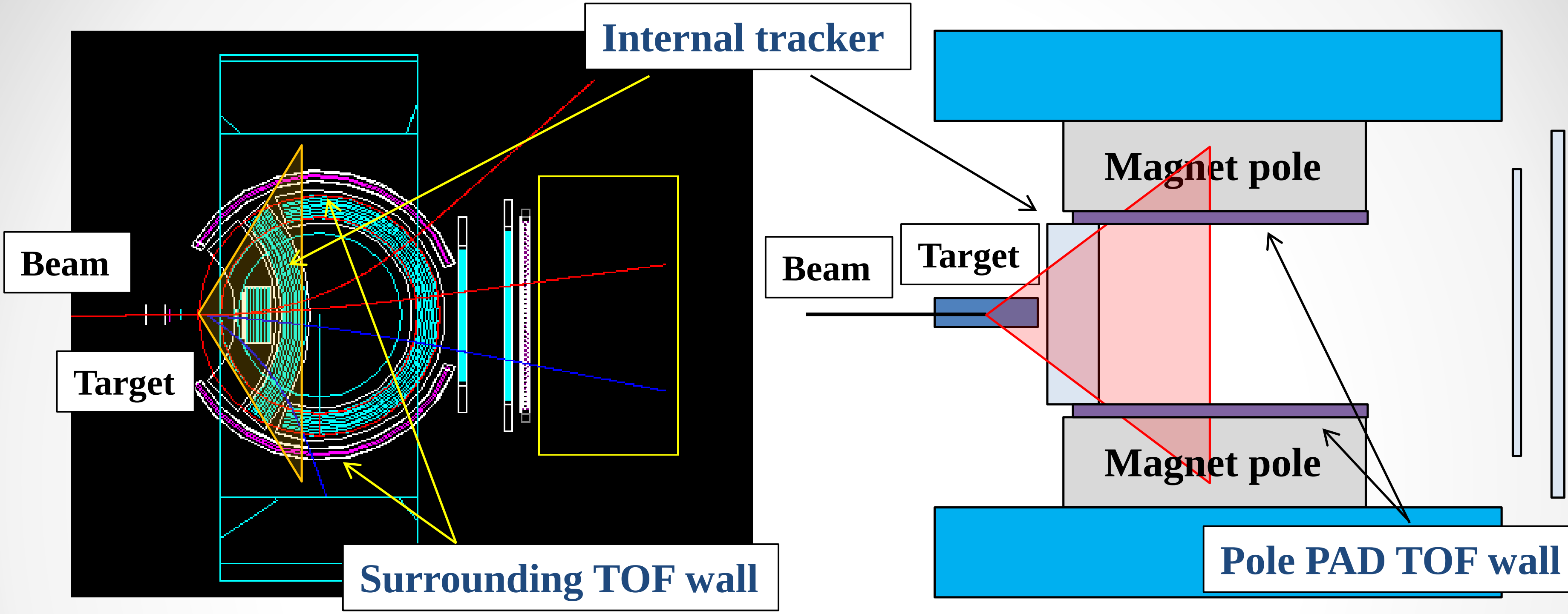
※現状だとv08に最初に当たり始めるが、それのギャップを広げれば
(7D220V→7D420V)
全体でロスは0.1%以下

※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

Acceptance



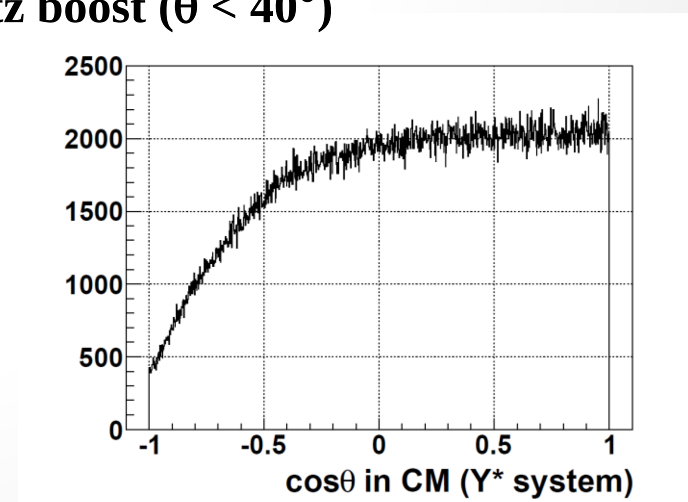
- **Method: Mainly Forward scattering due Lorentz boost (θ < 40°)**
  - **Horizontal direction**
    - **Internal tracker and Surrounding TOF wall**
  - **Vertical direction**
    - **Internal tracker and Pole PAD TOF detector**

  ⇒ ~70% acceptance for K* detection

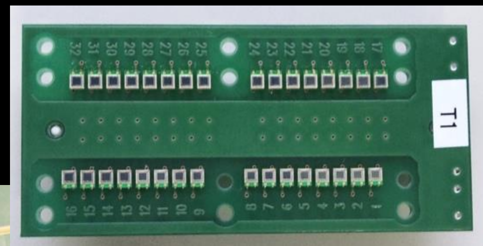
- **Decay measurement: Angle in CM**

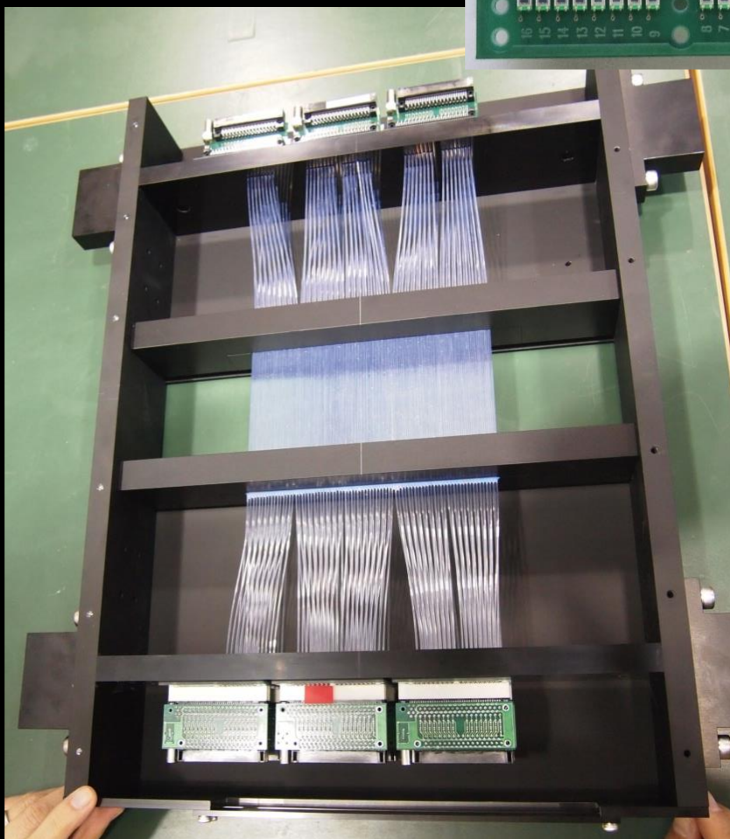
⇒ Both pole and azimuthal angles: cosθ > –0.5

- **∗ Minor change of detector system needed**



High rate BFT at K1.8





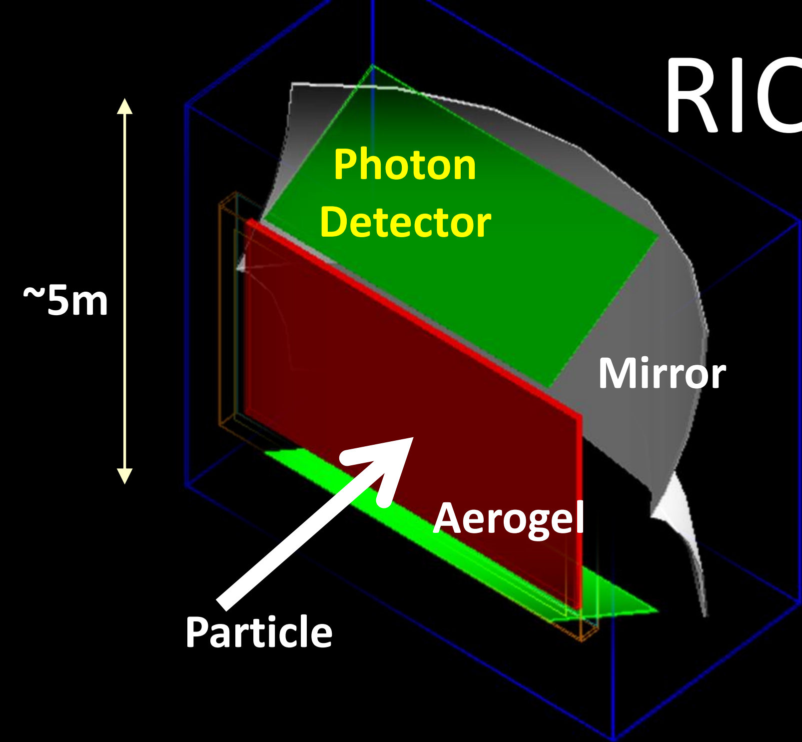
K. Miwa et al., Tohoku U.

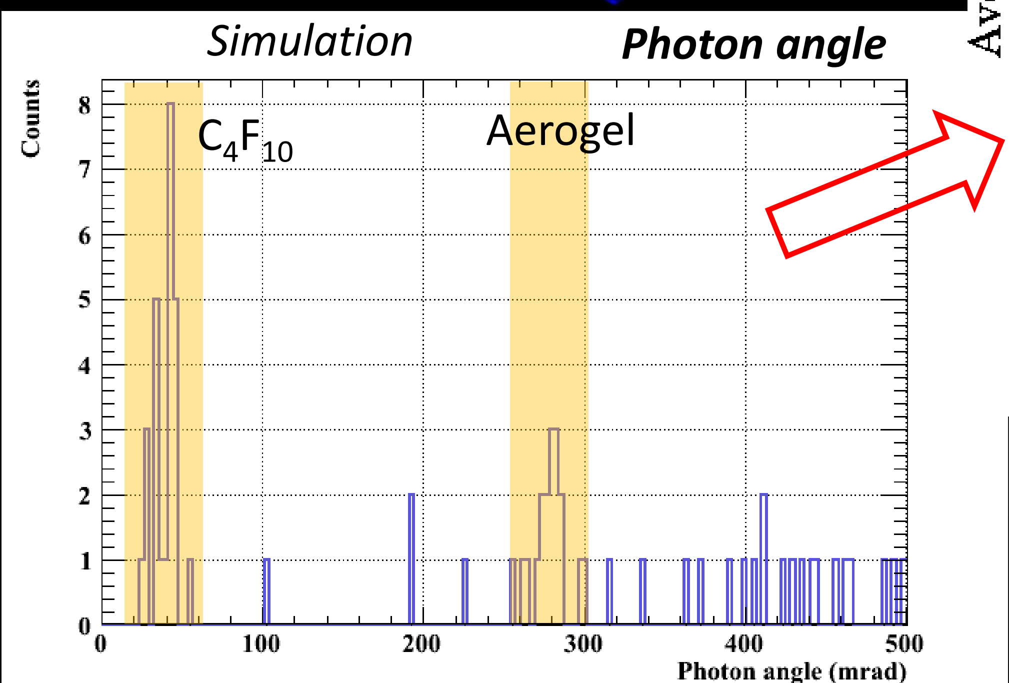
- Beamline Fiber Tracker
  - Can operate stably under a high intensity beam.
  - Structure
    - 320 ch of 1mm ϕ fibers
    - Two staggered layers
    - MPPC readout
      - We designed the high density MPPC PCB.
- We have finished the design. Detector and MPPC PCB are being produced now.
- We will use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

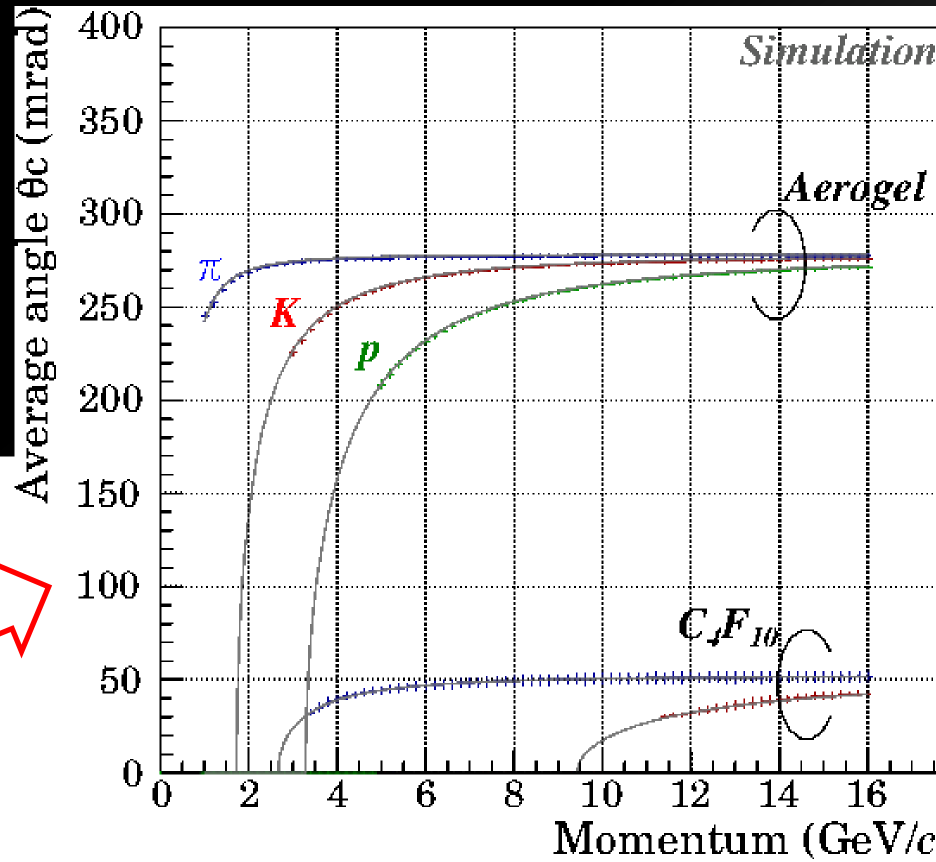
To be Enlarged for E50

RICH

T. Yamaga
HUA Master Thesis Award 2014







Conceptual Design: Done!
-> Test Experiment