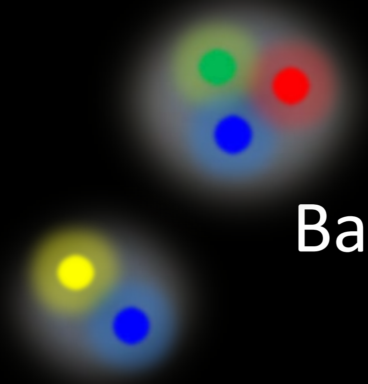
Reimei Symposium on “Synergies in Hadron Physics between J-PARC and JLab”@JLab
5 Nobember, 2019

High-momentum pion beamline at J-PARC and Open Charm Production

Hiroyuki NOUMI
Research Center for Nuclear Physics, Osaka University
Institute of Particle and Nuclear Studies, KEK

Form of Hadrons

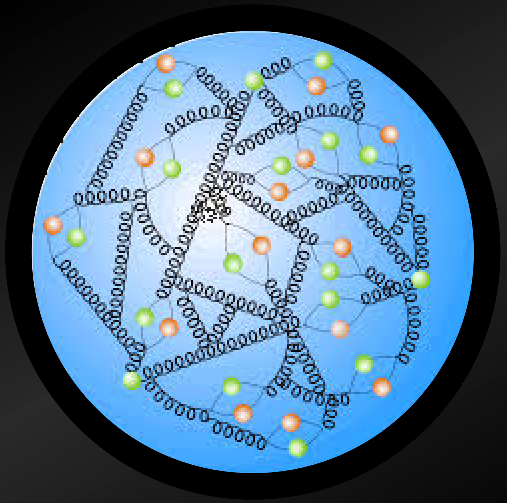
Low E ← High E



Baryon

Meson

$\alpha_s = \infty$
at Λ_{QCD}



Effective DoF

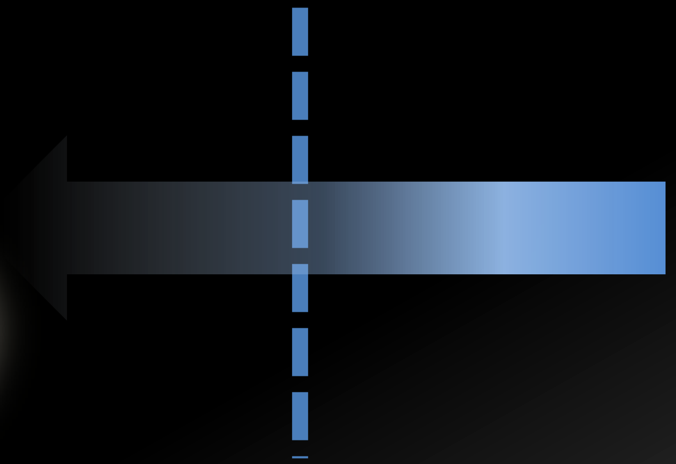
Quark-Gluon

Form of Hadrons

Low E ← High E

Tetraquark?

Pentaquark?



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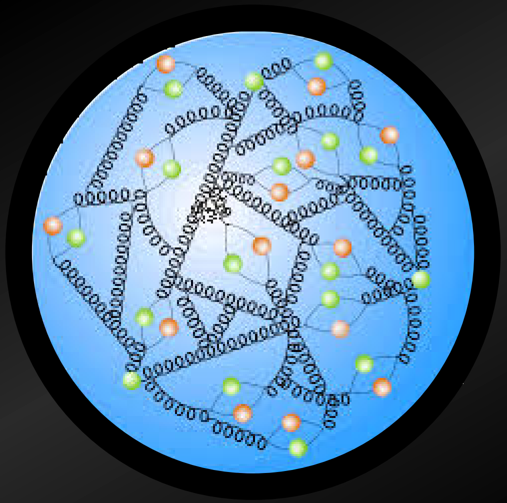
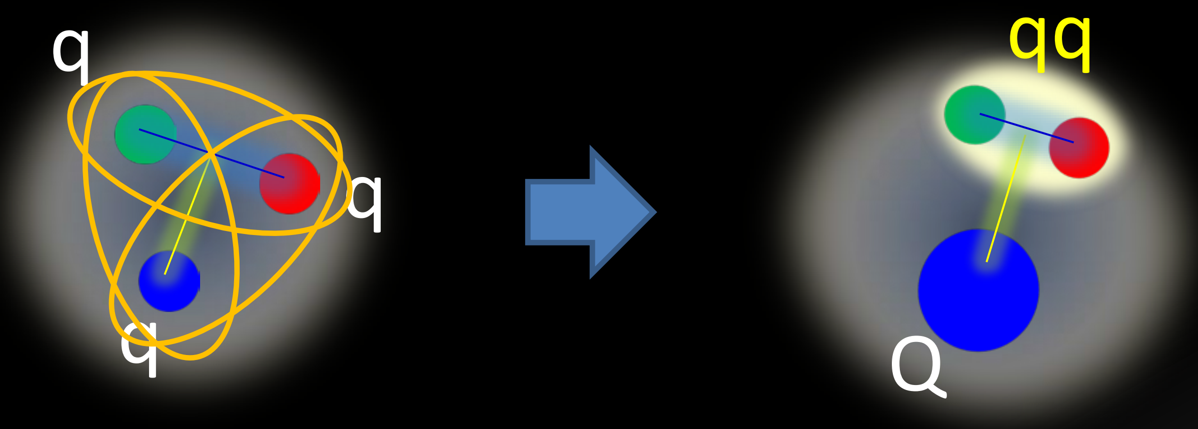


Effective DoF

Quark-Gluon

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

Roles of Heavy Flavors



$$V_{CMI} \sim [\alpha_s/(m_i m_j)]*(\lambda_i,\lambda_j)(\sigma_i,\sigma_j)$$
$$\rightarrow 0 \text{ if } m_{i,j} \rightarrow \infty$$

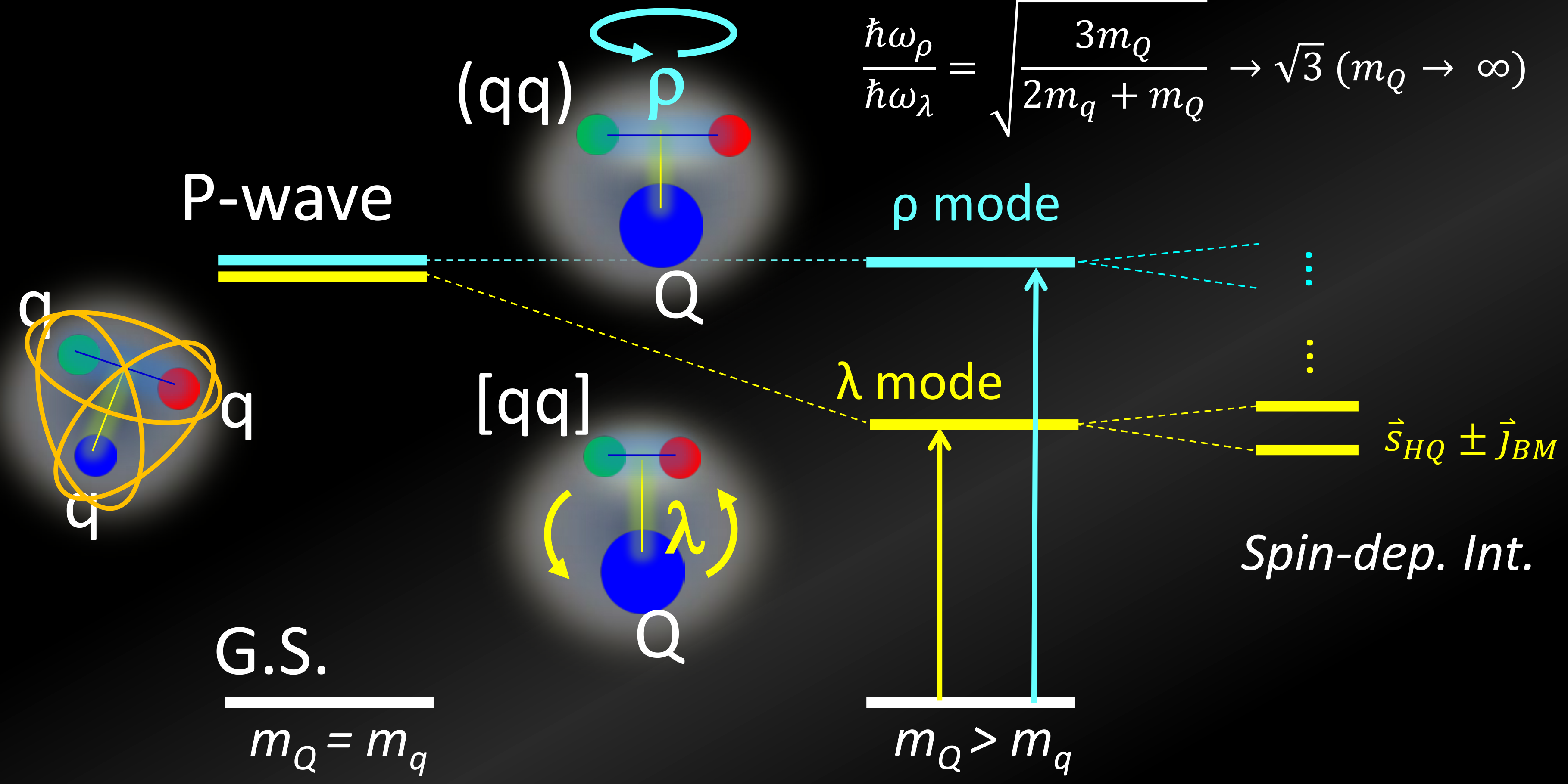
$$V_{CMI}(^1S_0, \bar{3}_c) = 1/2 * V_{CMI}(^1S_0, 1_c)$$
[qq] $\qquad$ [$\bar{q}$q]

- 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.

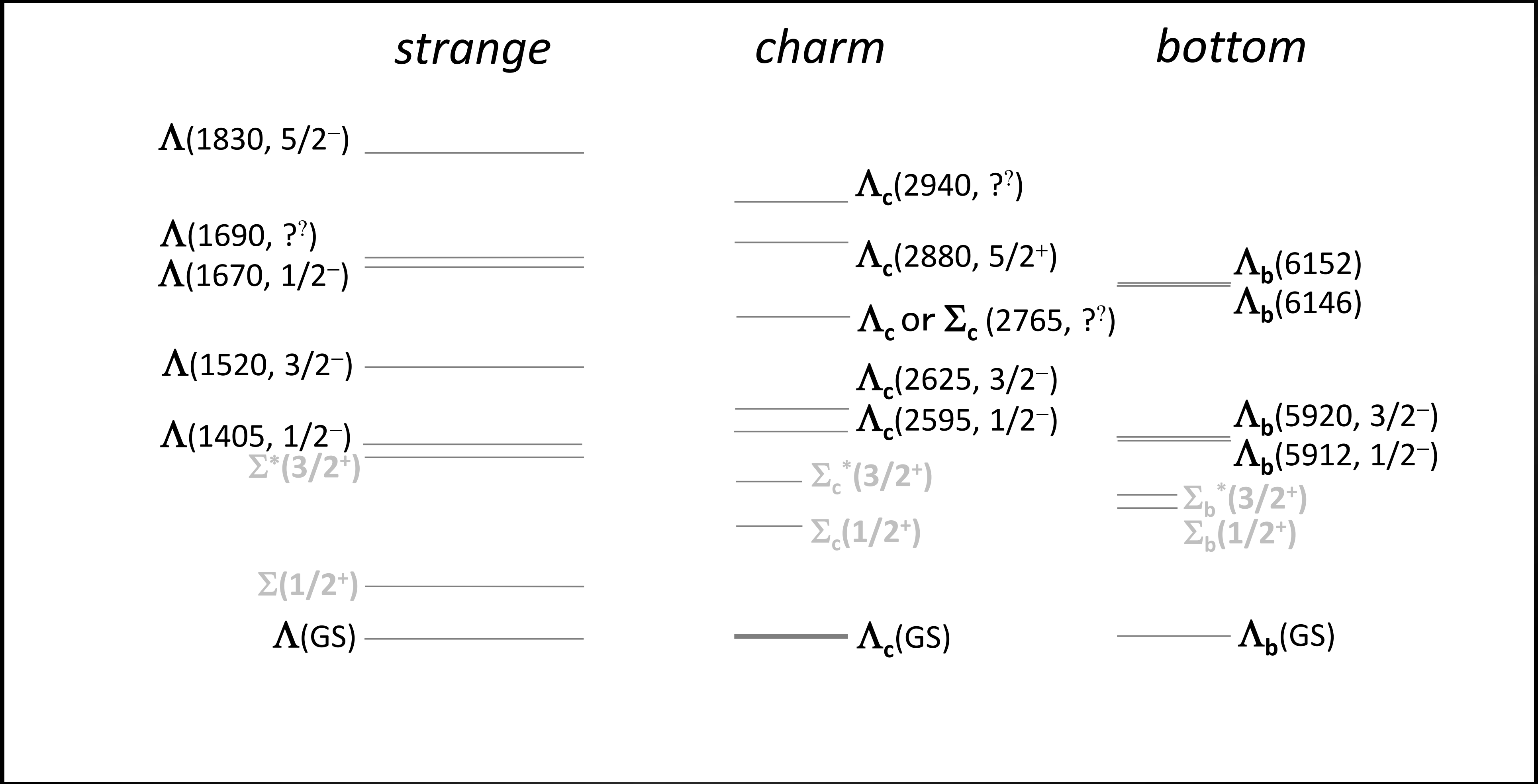
Schematic Level Structure of Heavy Baryons

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

$$\frac{\hbar\omega_\rho}{\hbar\omega_\lambda} = \sqrt{\frac{3m_Q}{2m_q + m_Q}} \to \sqrt{3}\ (m_Q \to \infty)$$



Lambda Baryons



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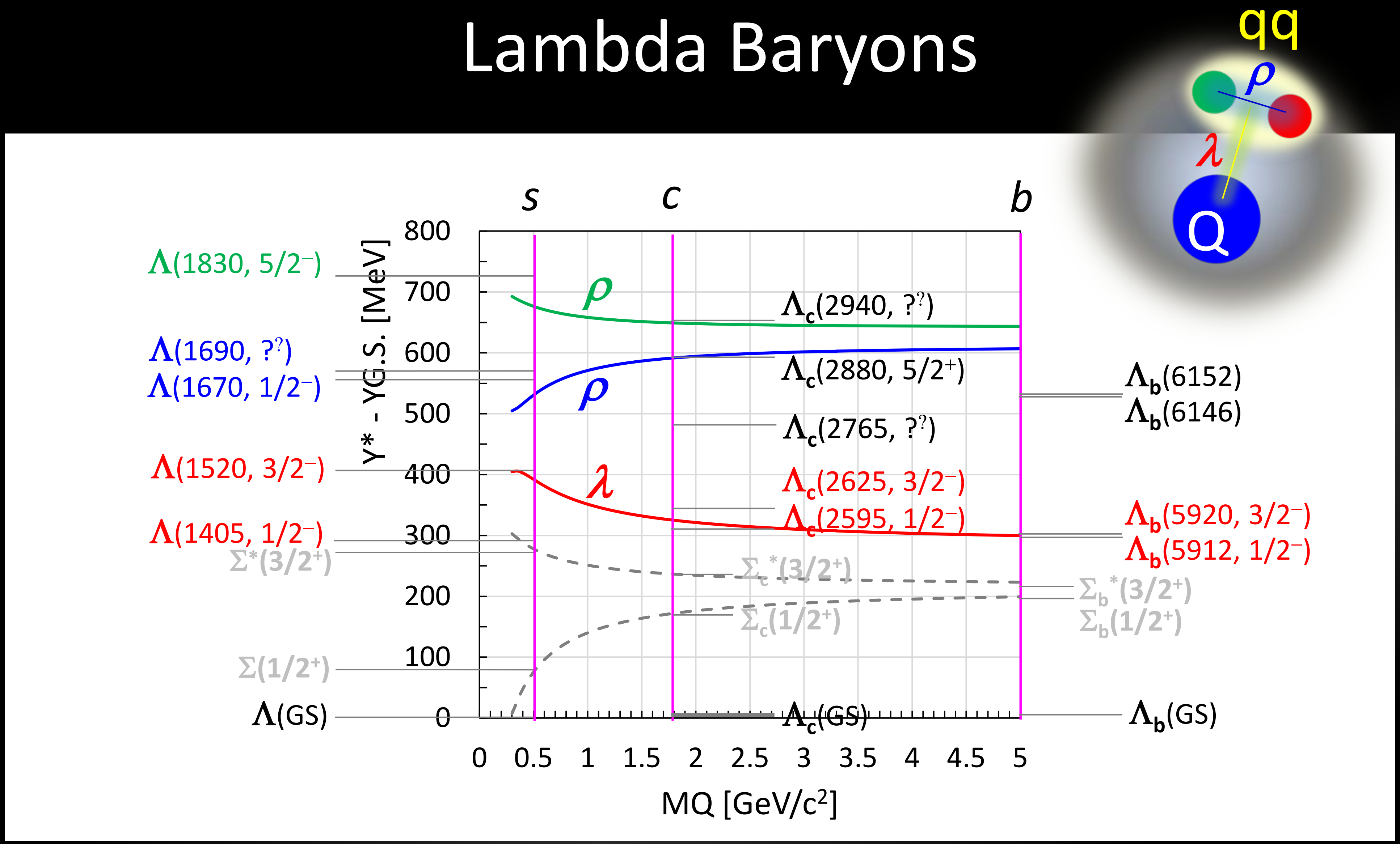
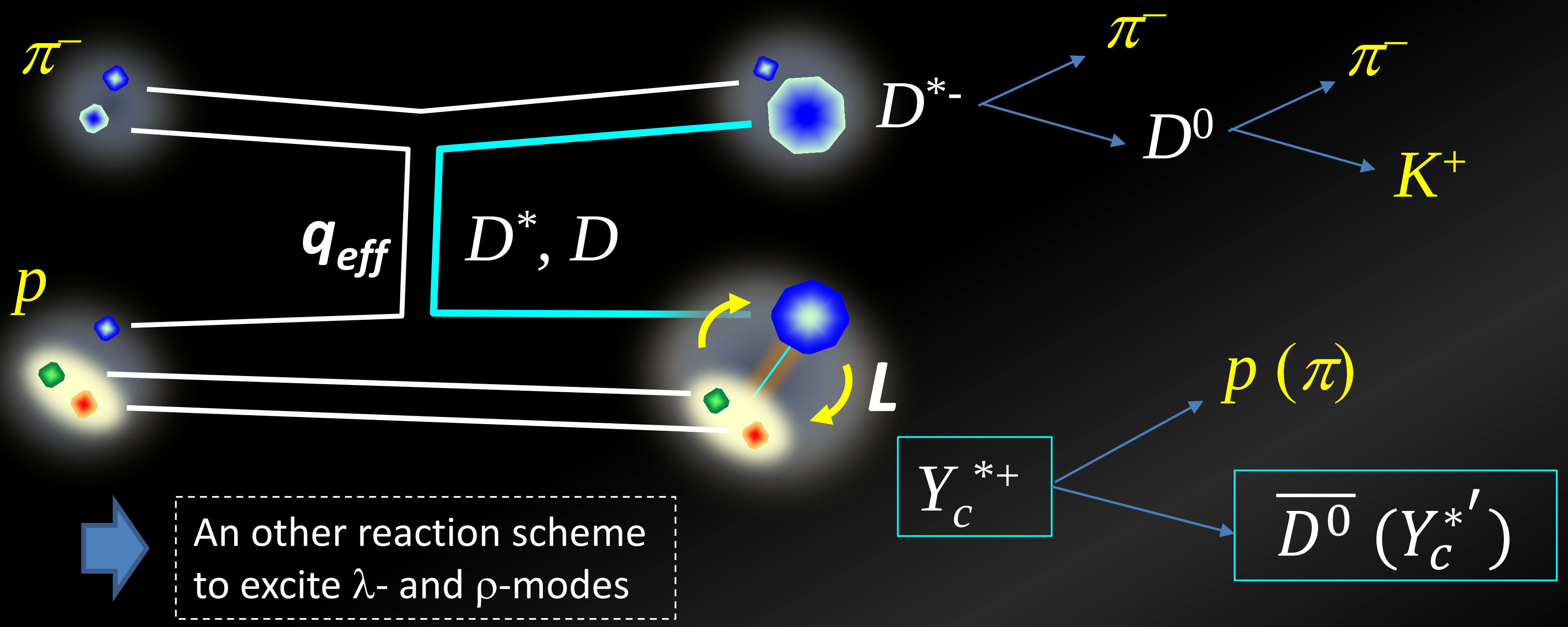


non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$
ρ–λ mixing (cal. By T. Yoshida)

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

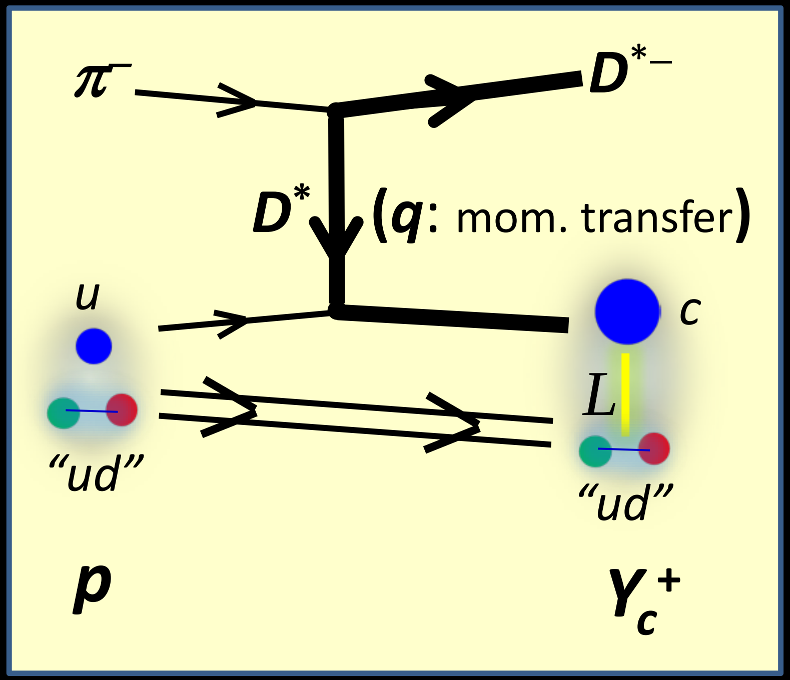
Charmed Baryon Spectroscopy Using Missing Mass Techniques



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



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

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

1. Momentum transfer (q_{eff})

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

q_{eff}~1.4 GeV/c A~0.4 GeV ([Baryon size]$^{-1}$)

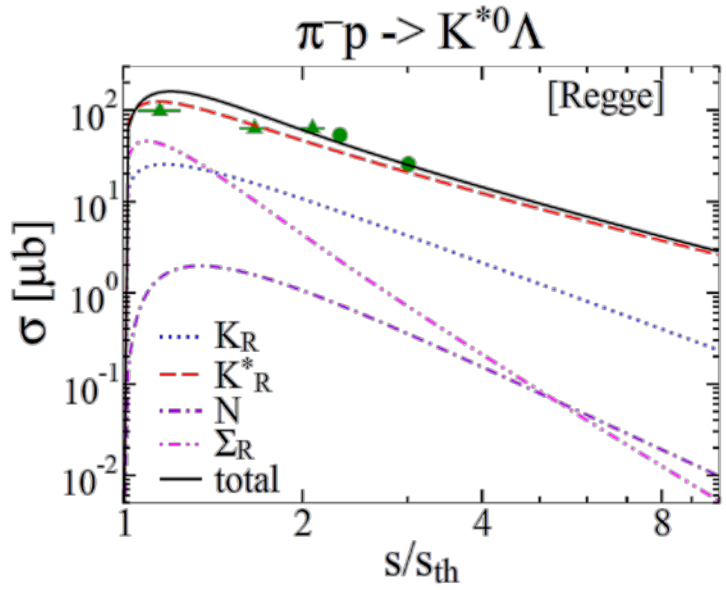
2. Population shared among HQ-spin multiplet

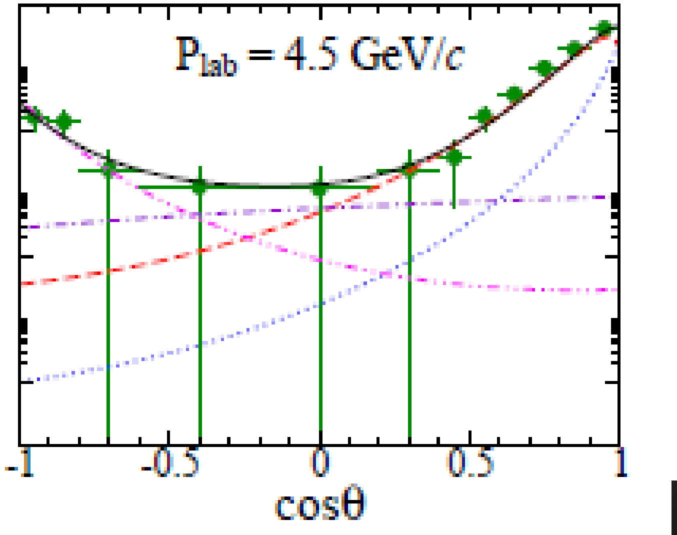
$$J_{BM} - s_{HQ} : J_{BM} + s_{HQ} = L : L+1$$

3. Spectroscopic Factor ("ud" configulation)

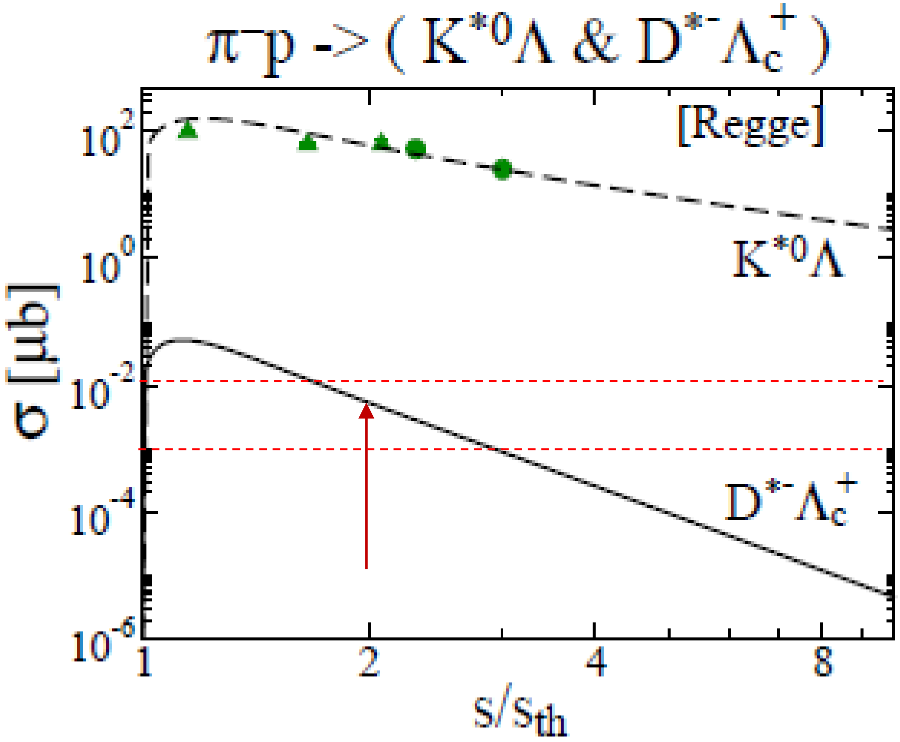
γ=1/2 for Λ_c's, =1/6 for Σ_c's

Production Cross Section



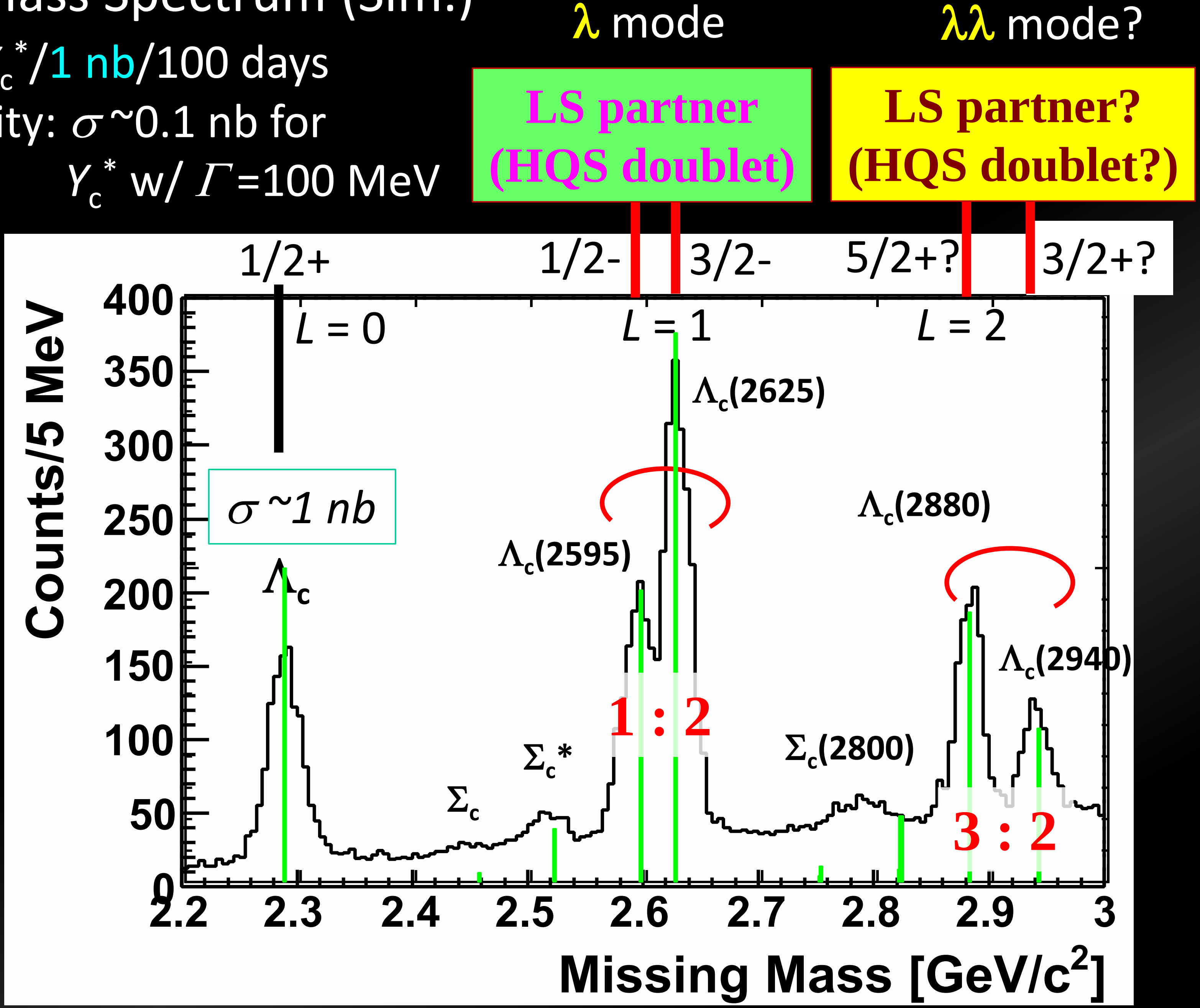


S.H. Kim, A. Hosaka, H.C. Kim, and HN
PRD92, 094021(2015)



Missing Mass Spectrum (Sim.)

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



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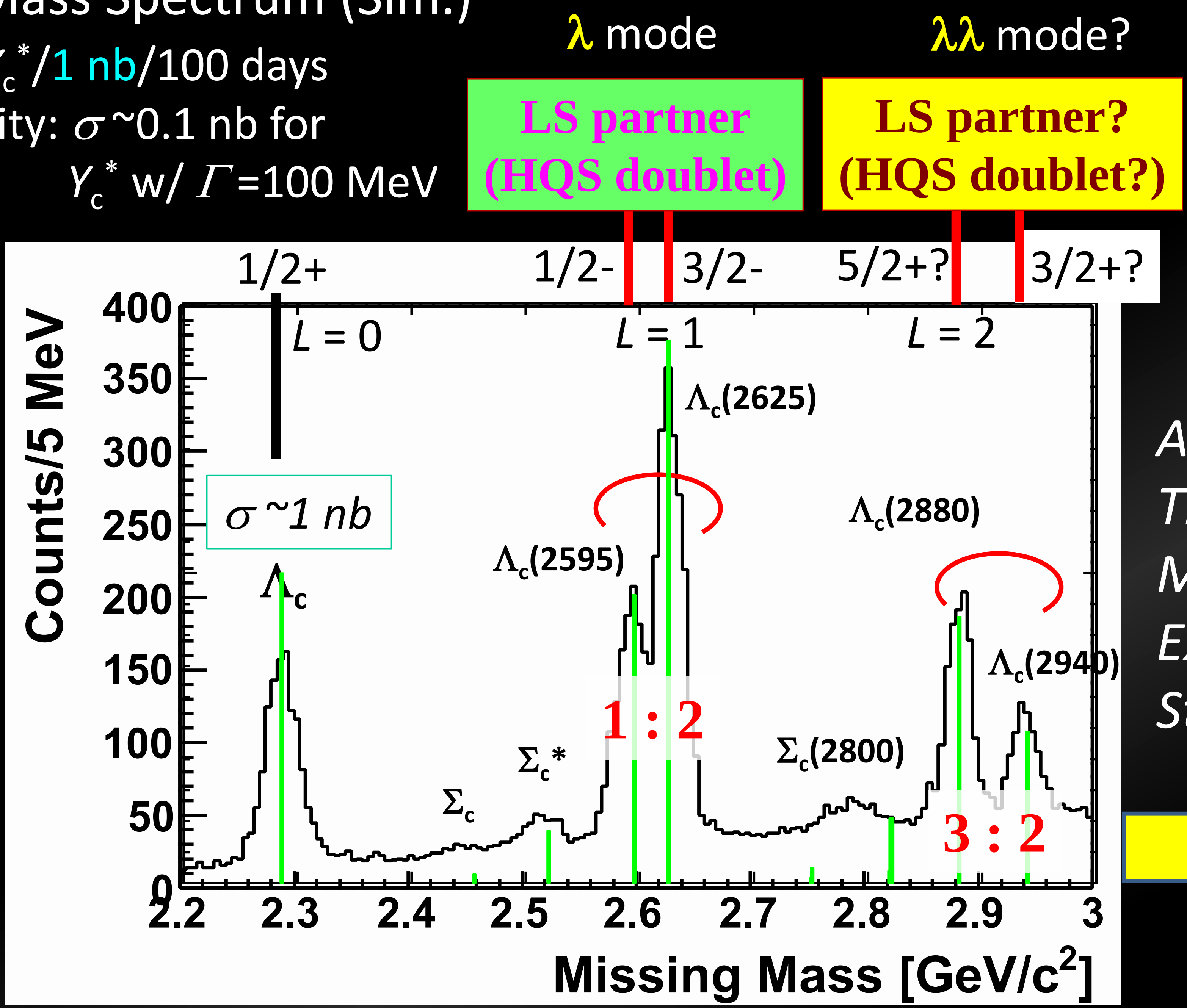
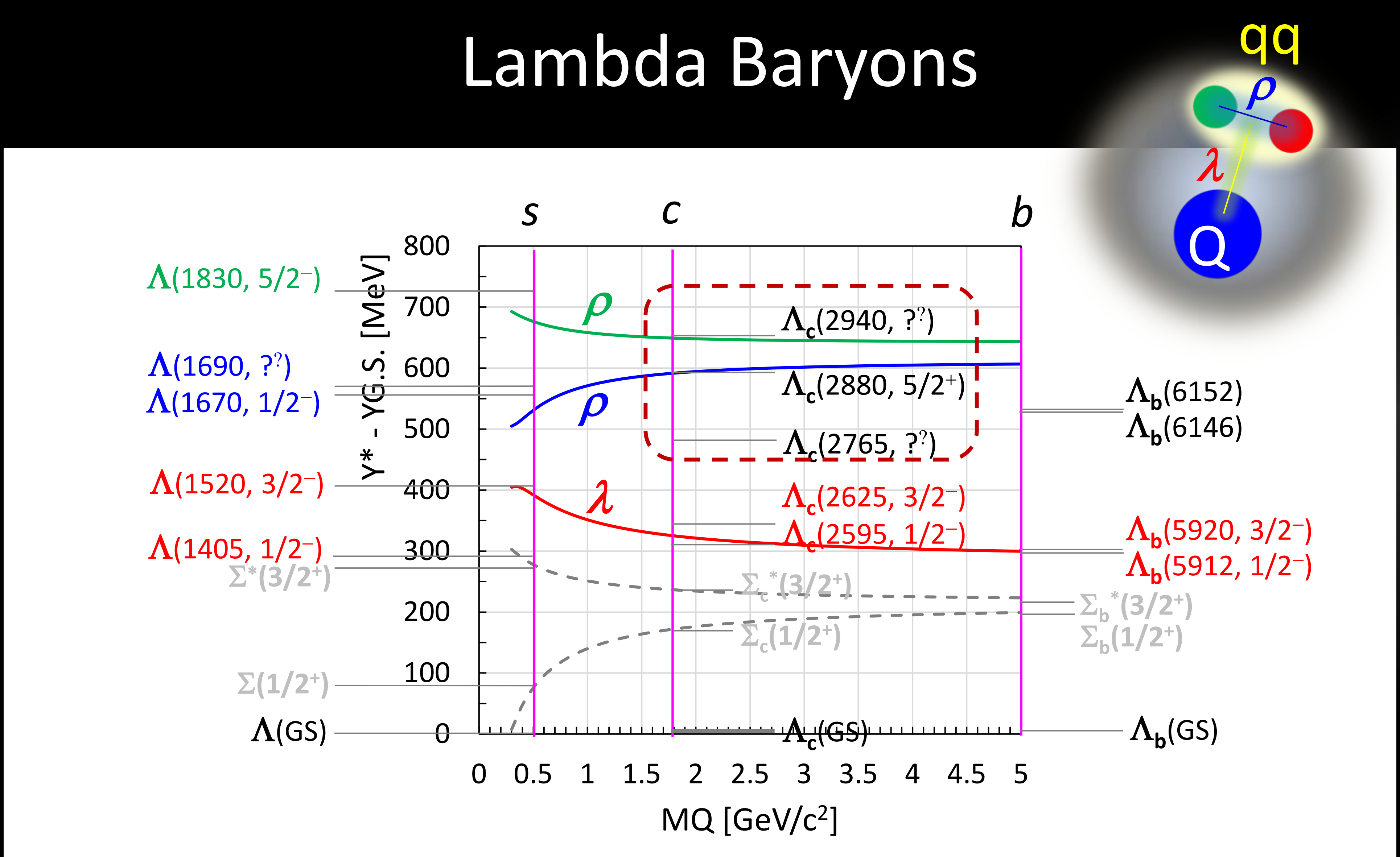


Are There More Excited States?

Lambda Baryons



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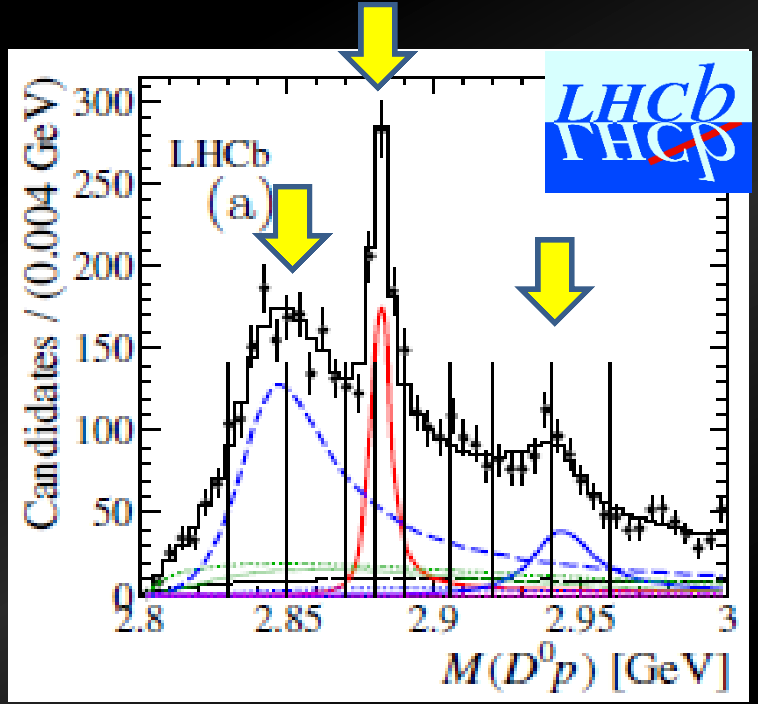
T. Yoshida et al., Phys. Rev. D**92**, 114029(2015)

New data from LHCb

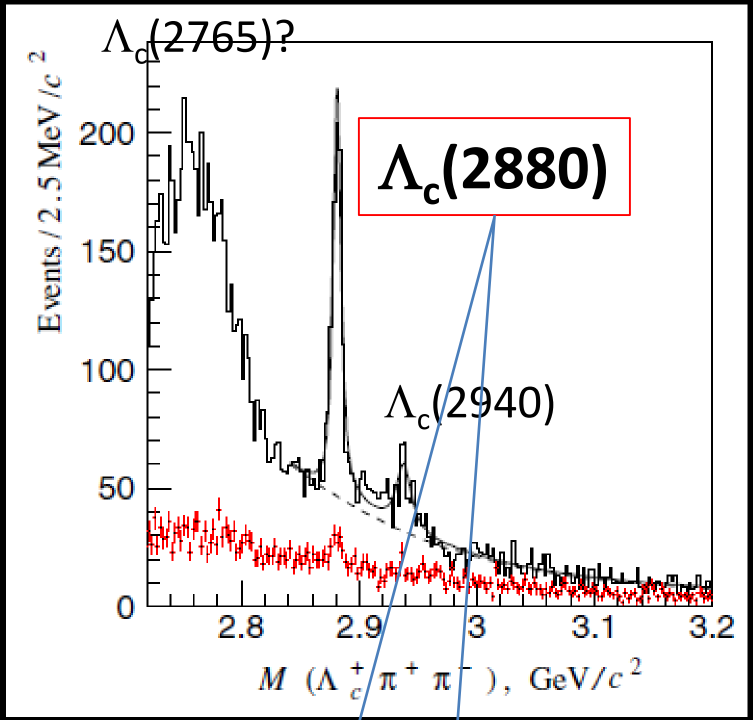
J. High Energ. Phys. (2017) 2017

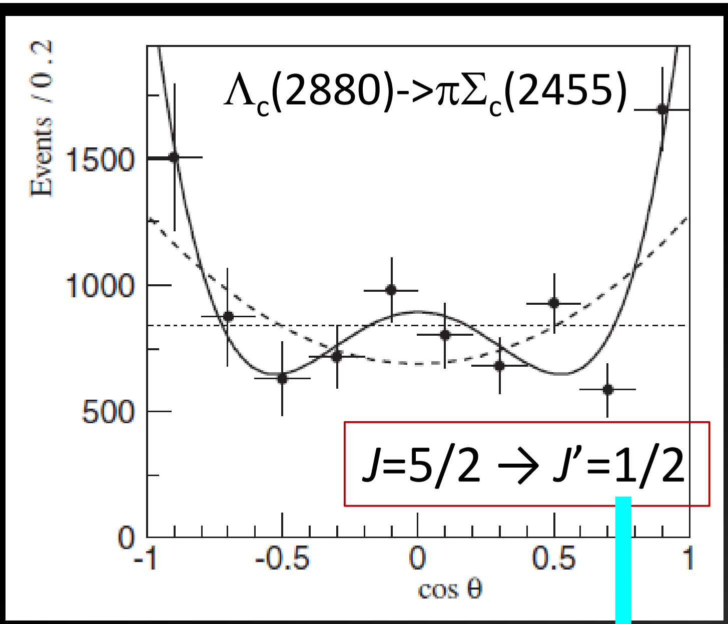
- $D^0 p$ invariant mass in $\Lambda_b \to D^0 p \pi^-$
  - $\Lambda_c(2940)$: known
    - likely 3/2-, (acceptable 1/2, 7/2)
  - $\Lambda_c(2880)$: known
    - 5/2+ confirmed
  - $\Lambda_c(2860)$: new
    - likely 3/2+, D-wave (L=2) resonance?

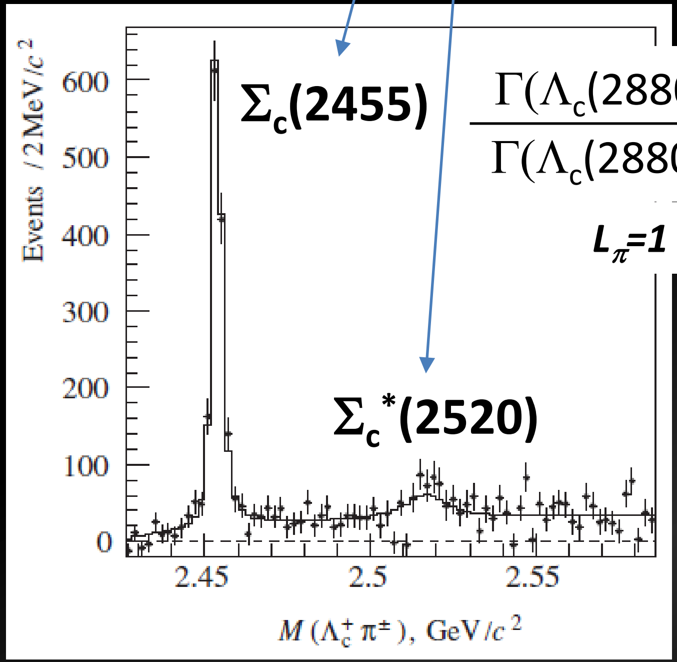


- Questions arise;
  - Is $\Lambda_c(2940)$ an L=3 state (λ mode)?
  - Are $\Lambda_c(2880)$ and $\Lambda_c(2860)$ *LS* partners of L=2 (λ modes)?
- Production rates in p(π^-,D^{*-})Y_c^* will give answer.

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…

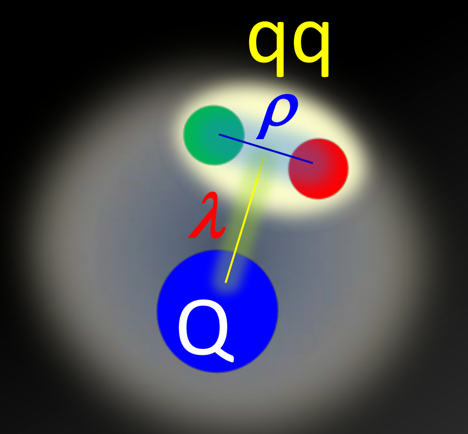
L_π=3 transition

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

Is it a D-wave Lambda-c Baryon?

If so, where is a spin partner ?

Λ(2880) likely to be λρ mode?



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

- P-wave transition seems to be suppressed in

$$\Lambda_c(2880)\frac{5}{2}^+ \to \Sigma_c^*(2520)\frac{3}{2}^+ + \pi(0^-).$$

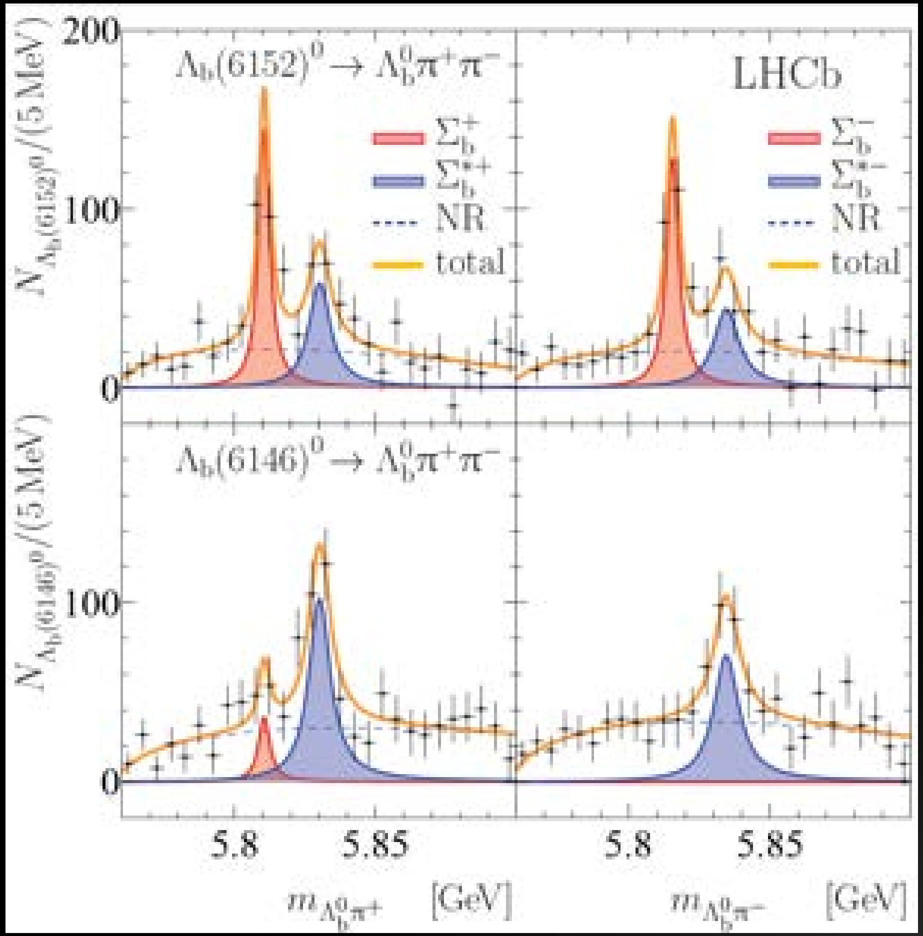
- It would be forbidden only in the case of $J_{BM}^P = 3^+$: "5/2-" state have large widths.
- $\Lambda_c(2880)\frac{5}{2}^+$ is likely to be a λρ mode (λ=1, ρ=1) state.

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+

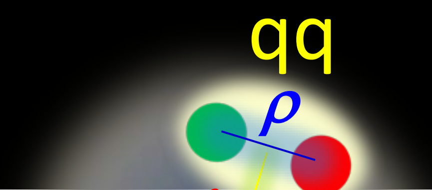
Q: Is it true? Where are λλ mode states?

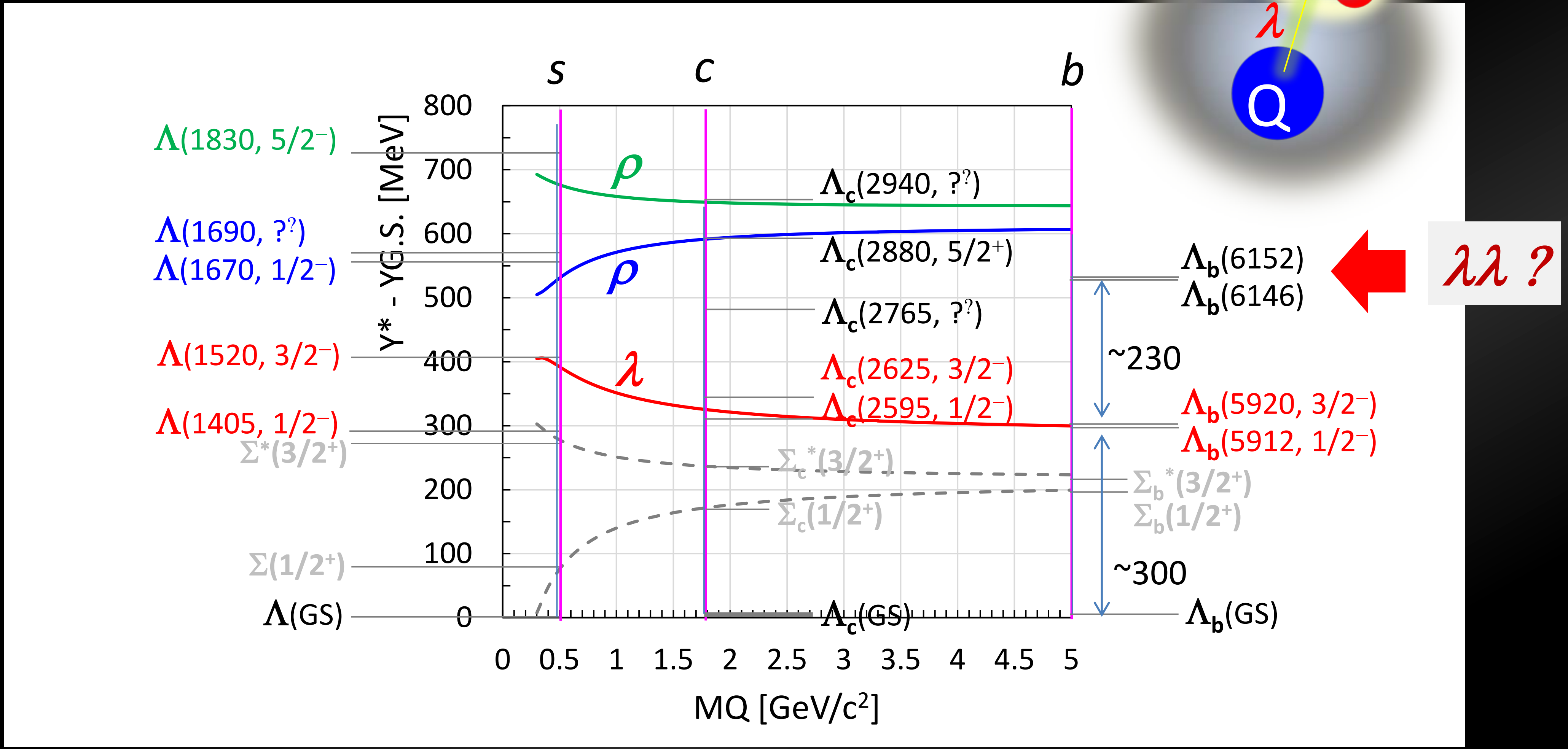
Lambda_b(5146/5152) Phys. Rev. Lett. 123, 152001



- A new doublet Λ_b^* states decaying into $\Lambda_b\pi^+\pi^-$ have been observed.
  - $M_{\Lambda_b(6146)} = 6146.17 \pm 0.33 \pm 0.22 \pm 0.16$ MeV
  - $M_{\Lambda_b(6152)} = 6152.51 \pm 0.26 \pm 0.22 \pm 0.16$ MeV
  - $\Gamma_{\Lambda_b(6146)} = 2.9 \pm 1.3 \pm 0.3$ MeV
  - $\Gamma_{\Lambda_b(6146)} = 2.1 \pm 0.8 \pm 0.3$ MeV
- They are likely to be λ-mode with L=2…
- $\Lambda_b(6146)$ dominantly decays to Σ_b?
  - Similar to the case of $\Lambda_c(2880, 5/2^+)$

Lambda Baryons





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T. Yoshida et al.,
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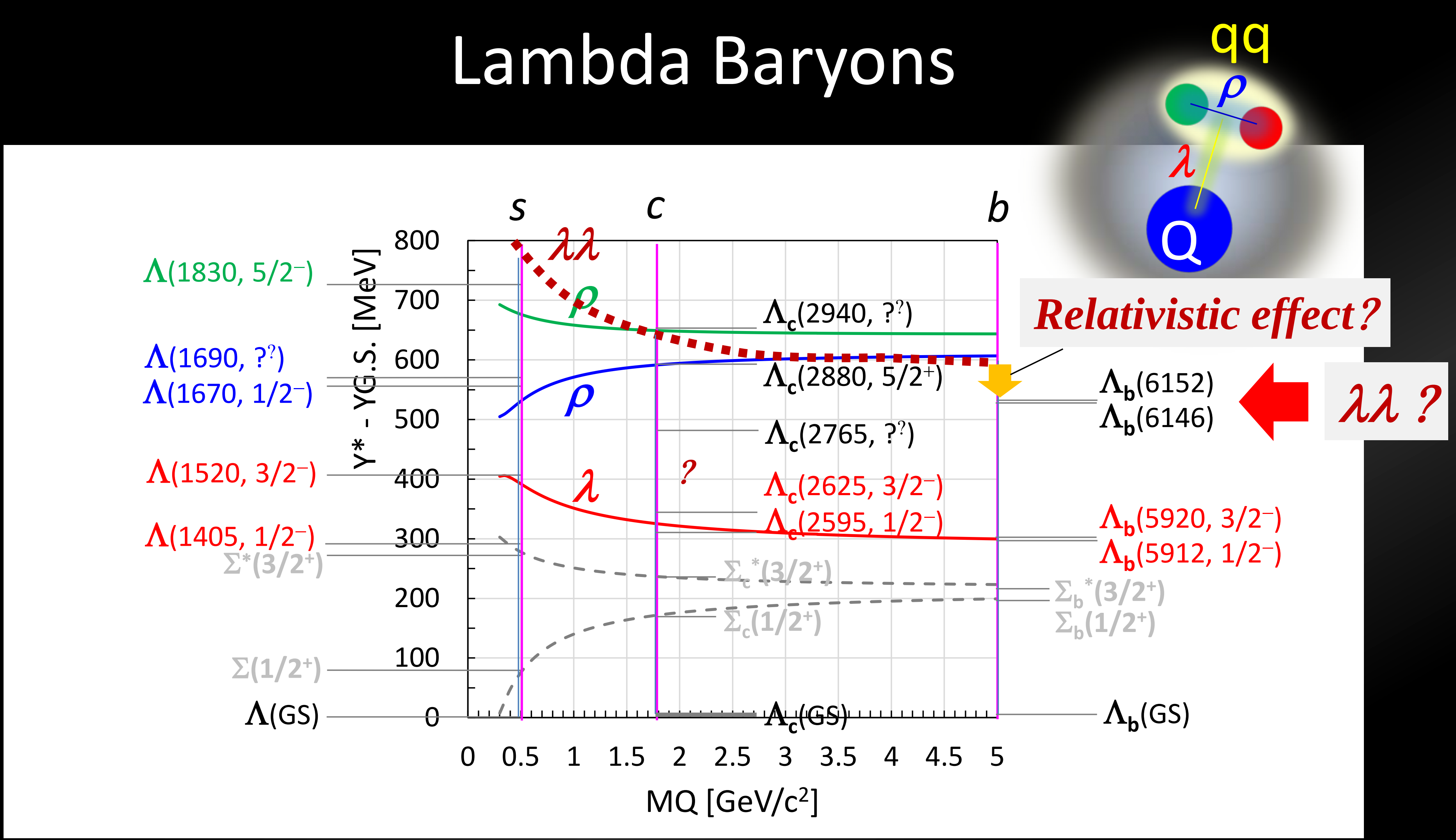

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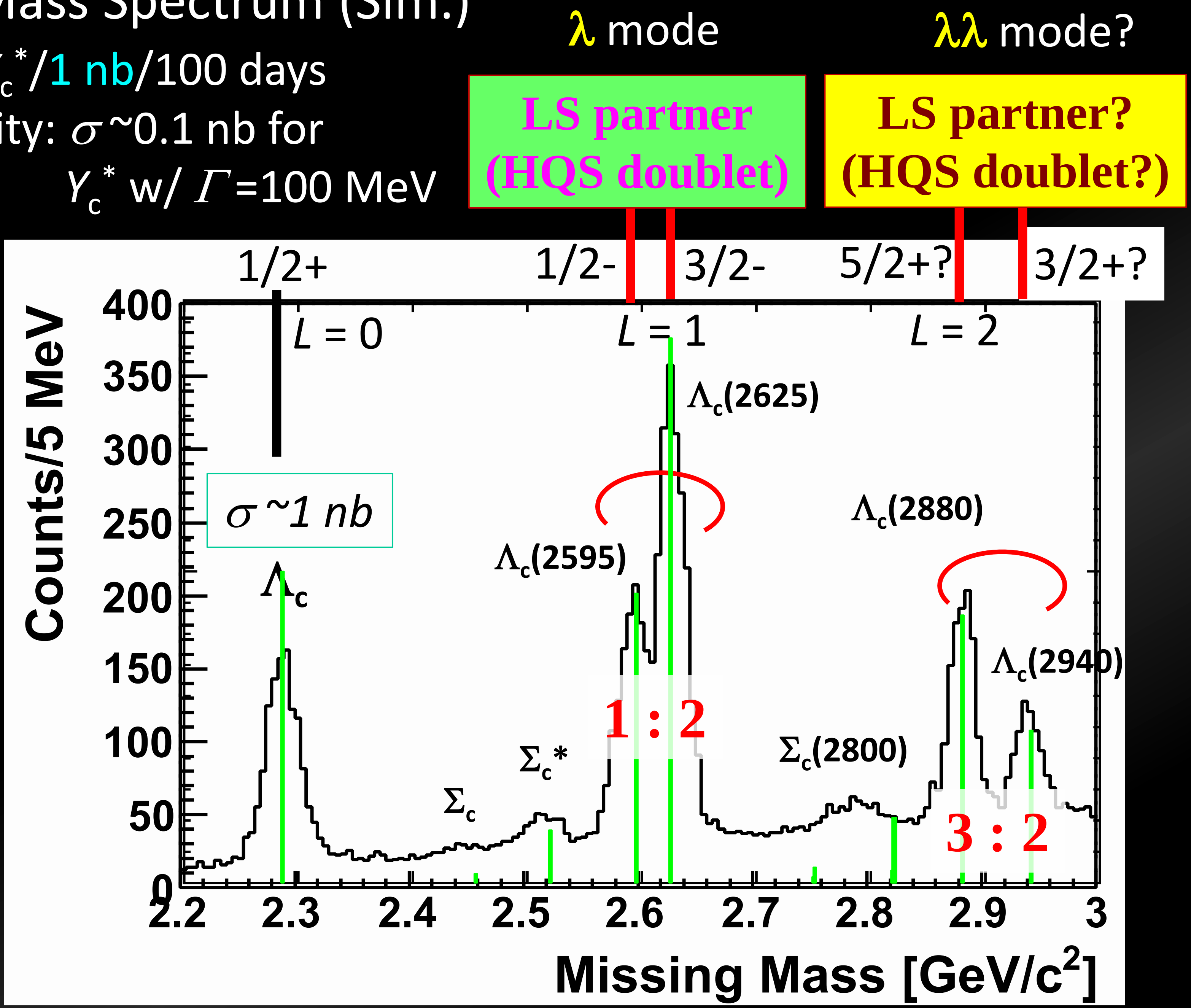
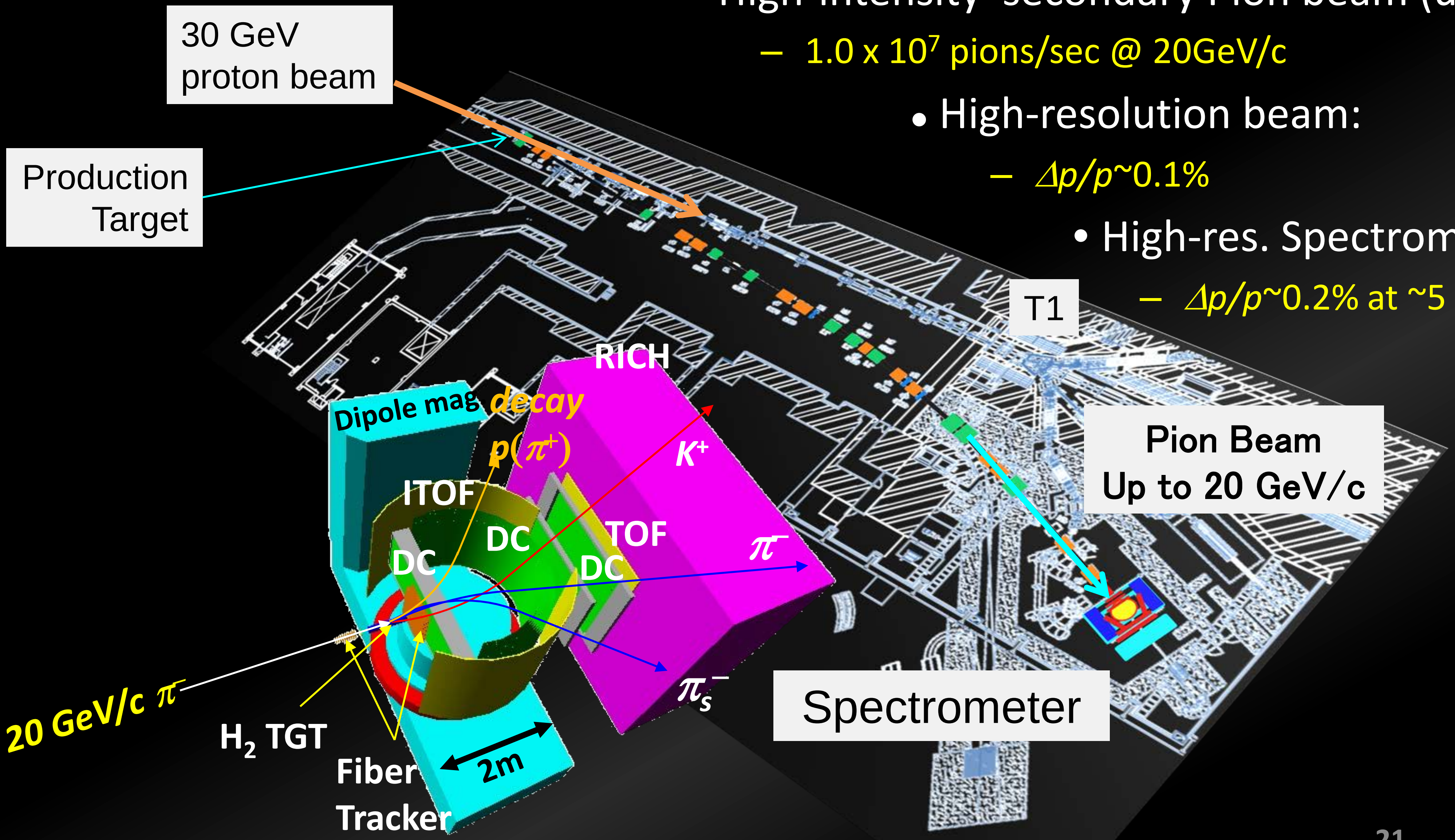
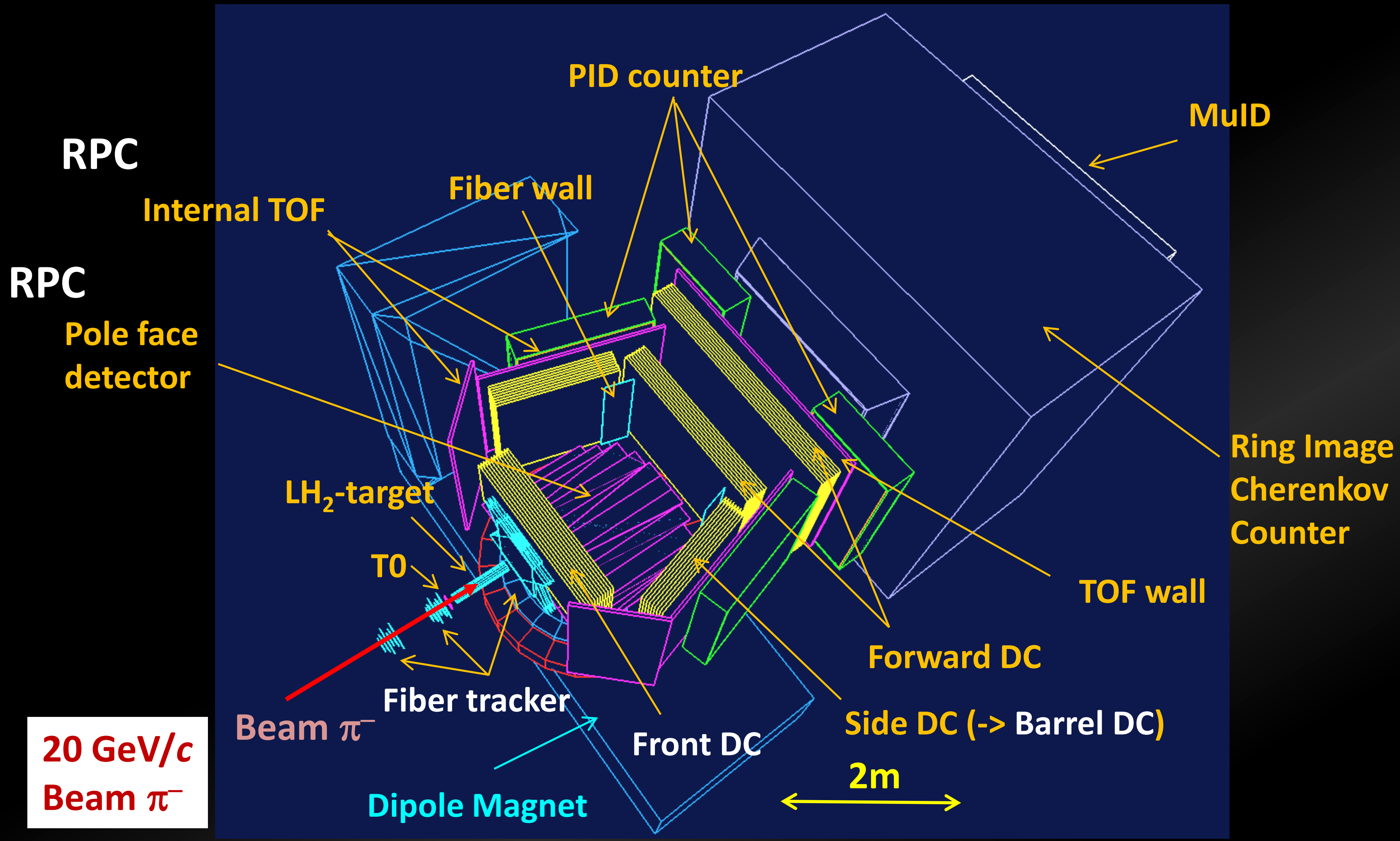


High-res., High-momentum Beam Line at J-PARC

- 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



Spectrometer Design



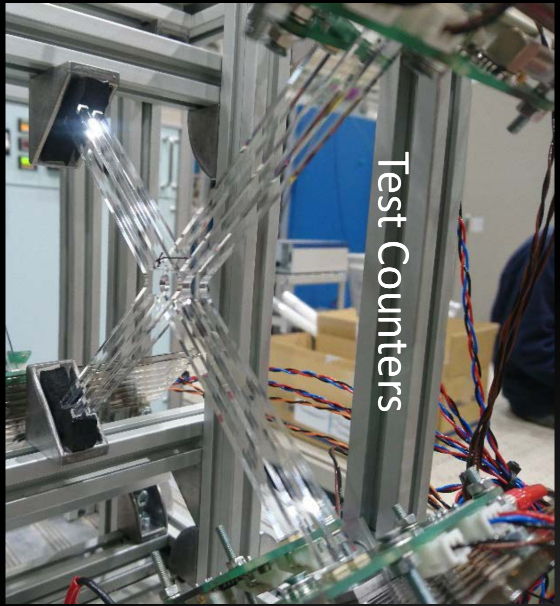
R&D Works

- Particle Identification (Osaka/Kyoto/Tohoku/RIKEN…)
  - Timing counters
    - T-Zero (Osaka): Cherenkov type ~50 ps
    - Resistive Plate Chamber (LEPS2/ELPH/Taiwan/JAEA/Tsukuba): Large Size~60 ps
  - Ring Image Cherenkov Detector
    - BeamRICH/RICH (Kyoto/Osaka/RIKEN/…)
  - Muon ID (Academia Sinica)
- Trackers (Tohoku/RCNP/RIKEN…)
  - SciFi Tracker (Focal Plane/Beam/Scattered particle)
  - DC (Forward, Barrel)
- High-speed DAQ system (RCNP/Tohoku/Taiwan/KEK…)
  - PC cluster-based DAQ scheme
    - Flexible "trigger": not only (π^-,D*) but also (K^-,K*),…

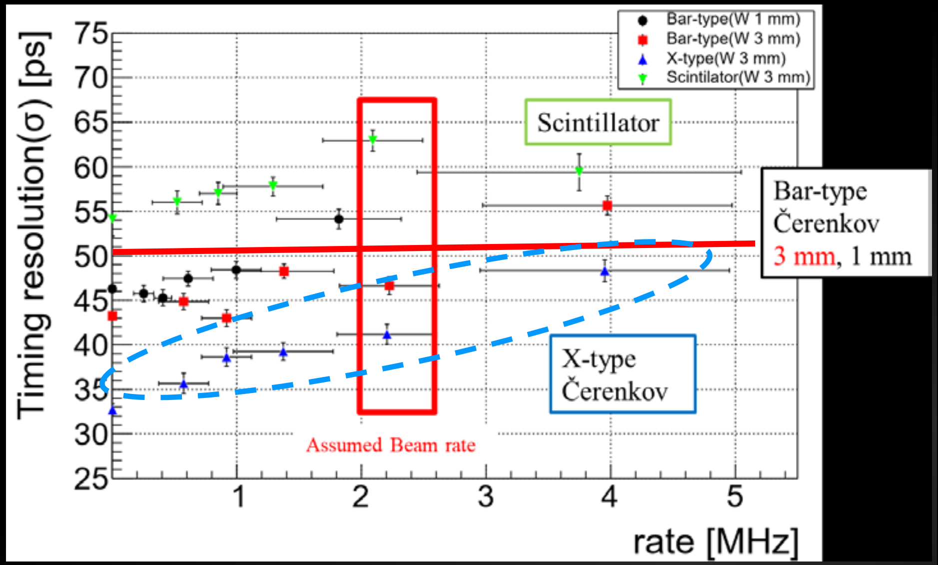
Time Zero Counter

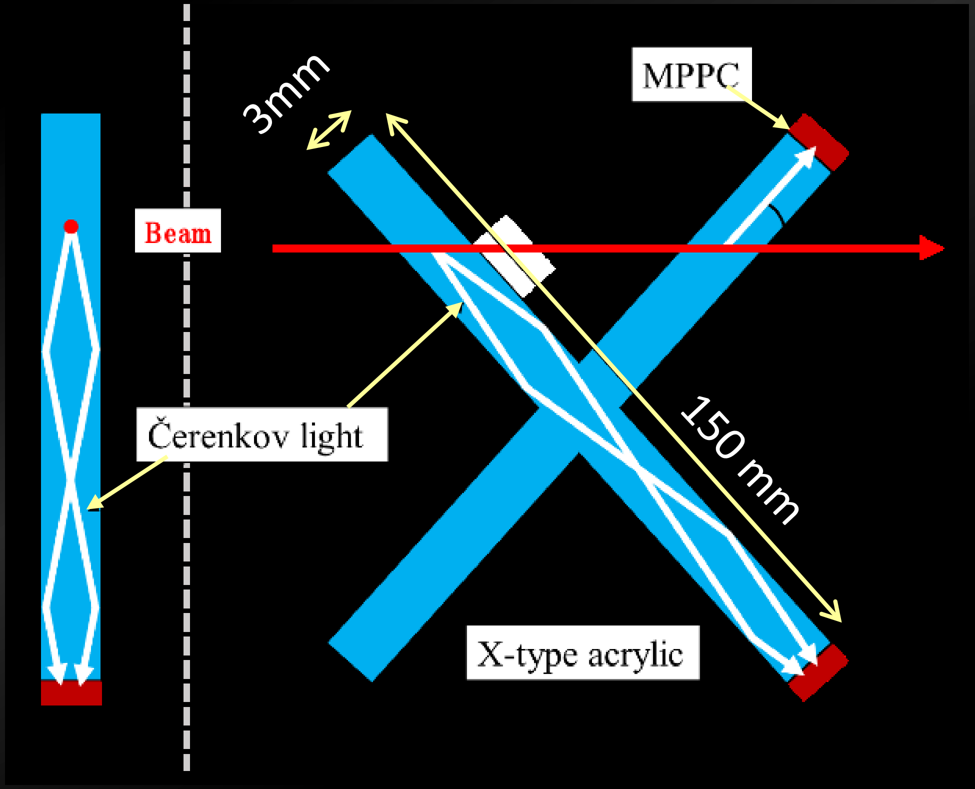
- Hodoscope w/ Cherenkov Radiator for a Beam Rate: 60 M/spill (30 MHz)
  - X-shape to cancel position dependence by taking mean time
  - σ<50 ps at 3-5 MHz

By T. Akaishi, K. Shirotori et al.



Measured Performance for MIPs



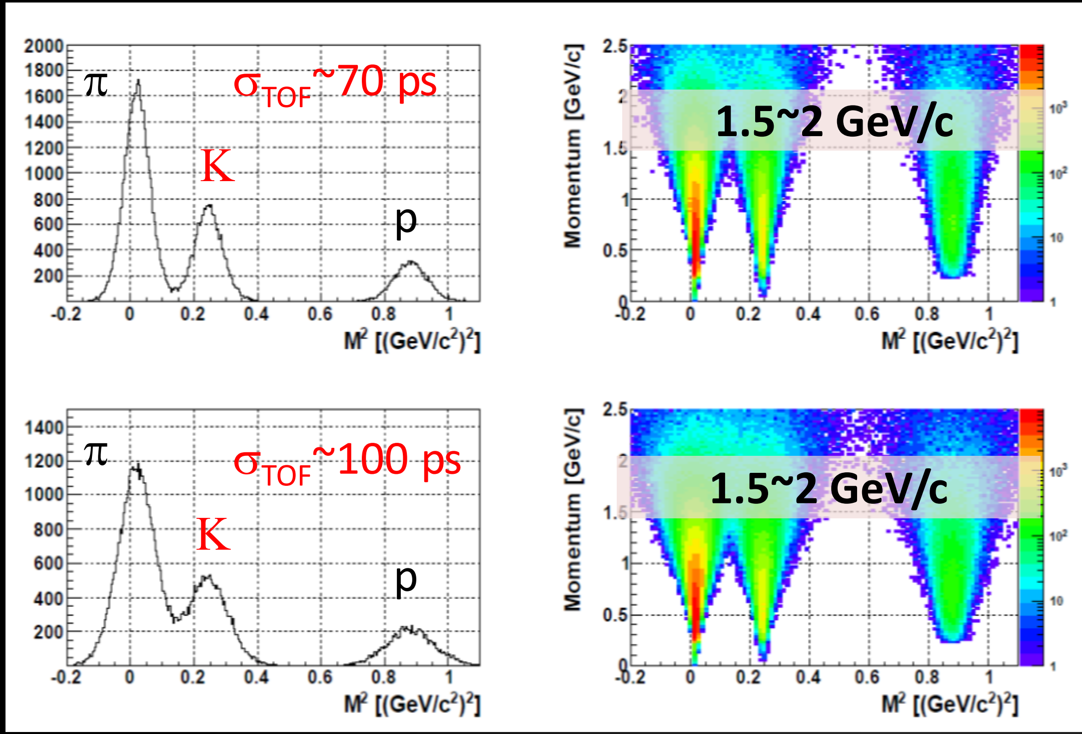


Resistive Plate Chamber

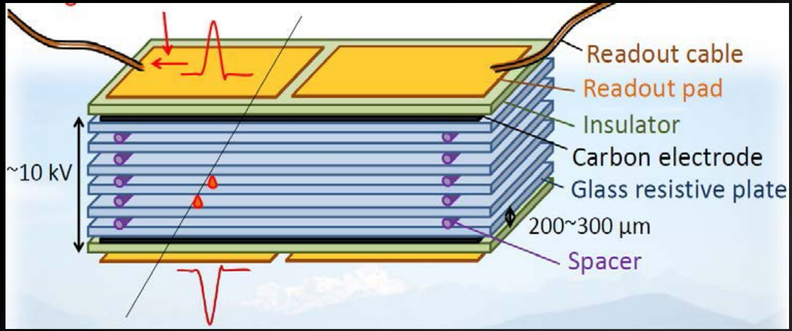
- TOF meas. for Scattered Particles
  - Developed in LEPS
  - σ~60 ps

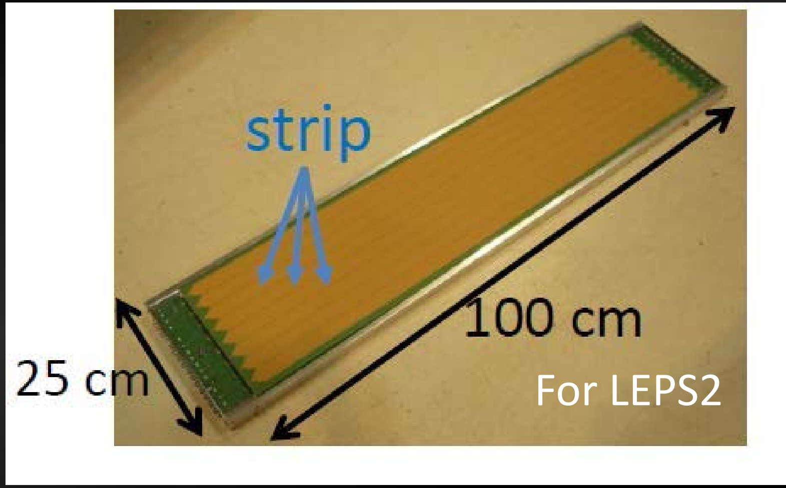
By N. Tomida, H. Ohnishi et al.

Simulation



Expected PID performance w/ TOF vs Mom.

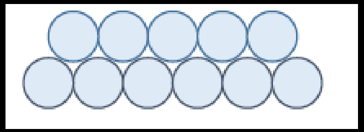


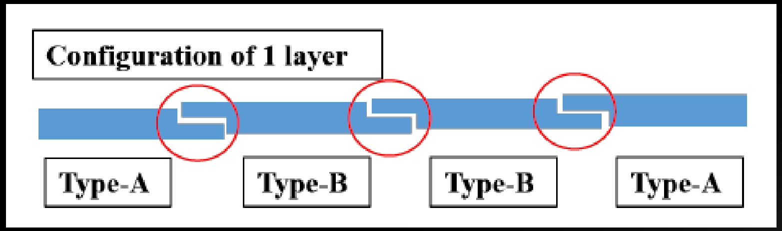


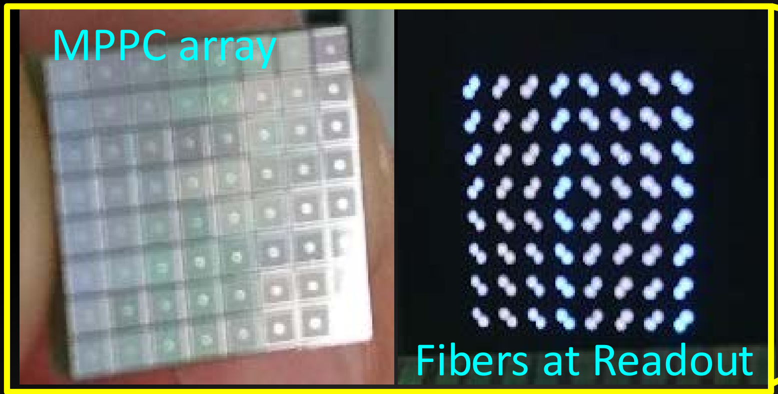
Fiber Tracker

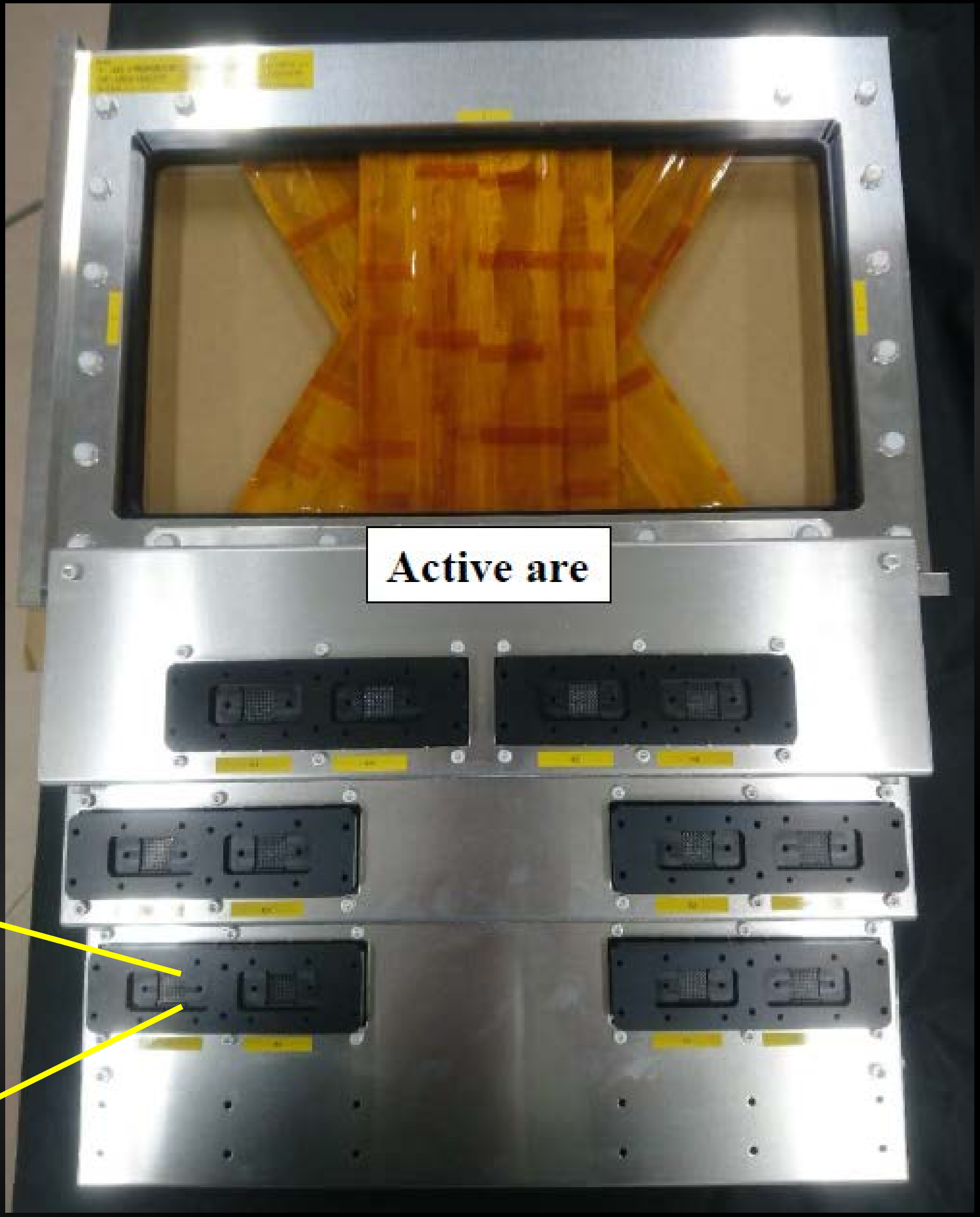
By K. Shirotori et al.

- Faster Responding Trackers are needed for a Beam Rate: 60 M/spill (30 MHz)
  - Focal plane: XUV 1 set w/ ϕ1mm fiber
  - Beam Trackers: XUV 2 sets w/ ϕ0.5mm fiber
  - Scattered Particle Trackers : in Fabrication



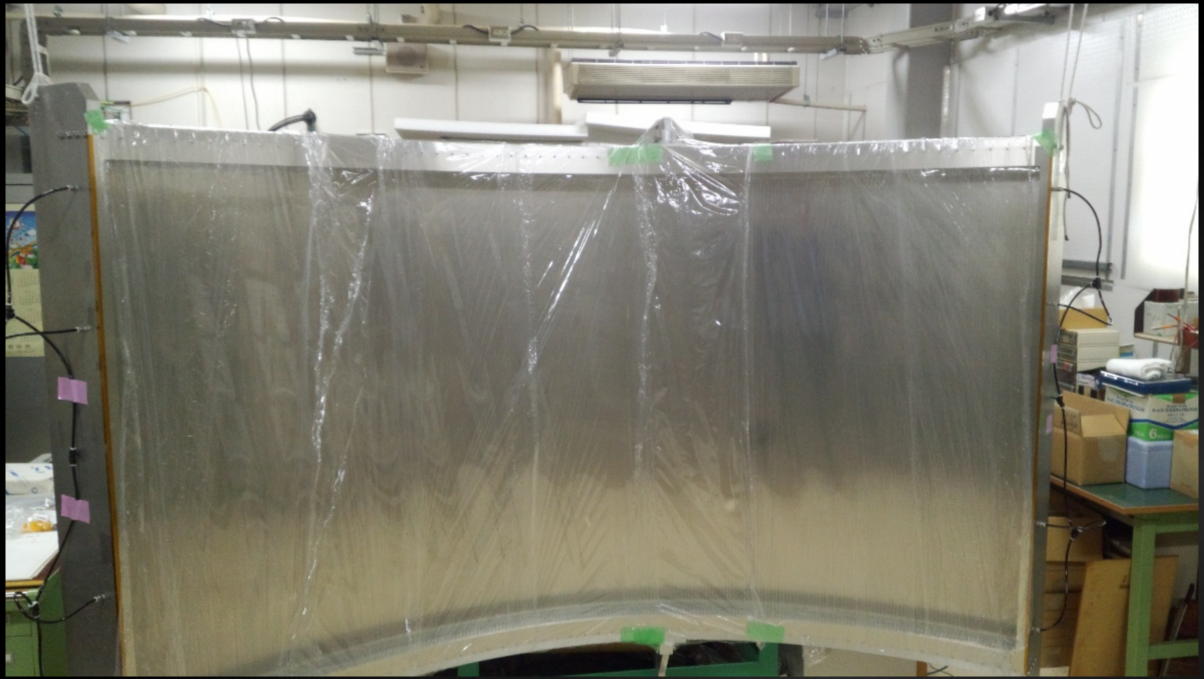






Drift Chamber

- Barrel DC (Side DC) for backward-emitted, low mom. particles
  - Two arms are ready and waiting for FEEs.
- Front/Forward DC for Forward-emitted particles
  - To be prepared
  - still missing pieces for better redundancy



High-speed DAQ system

Streaming DAQ(~50 GB/spill)

Frontend modules
- ＊Signal digitalization
  - Pipelined system

Buffer PCs
- ＊Data accumulation
  - Several 10 GB memories

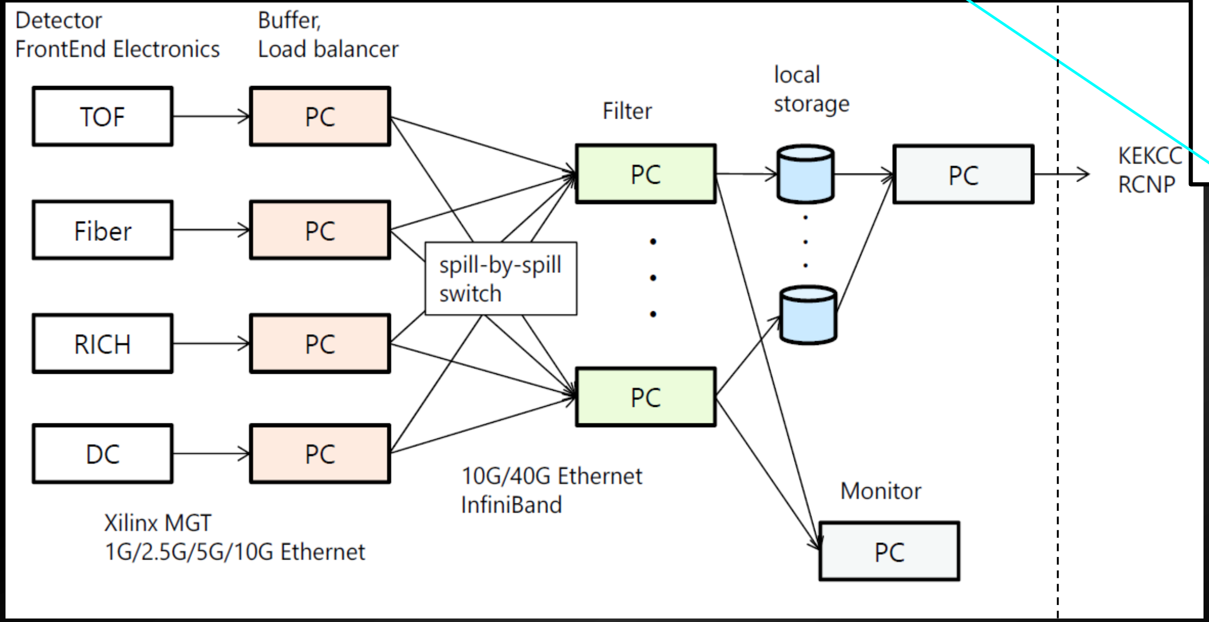
＊High-speed data link (Local)

~50 GB/spill

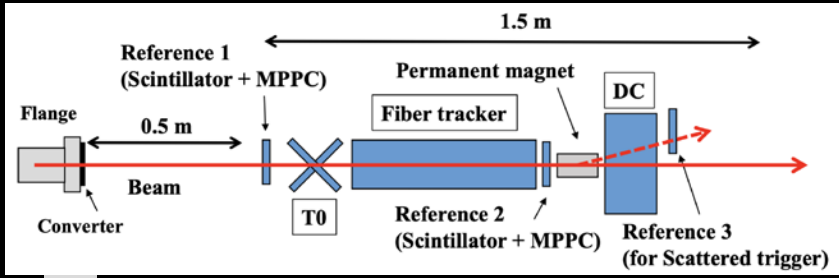
Filter PCs
- ＊Event reconstruction
  - 100–200 CPUs

<0.5 GB/spill

Storage
- Local storage
- Transferred to KEKCC/RCNP



Demonstration of High-speed DAQ



under the Highest Throughput (SiTCP: GbE)

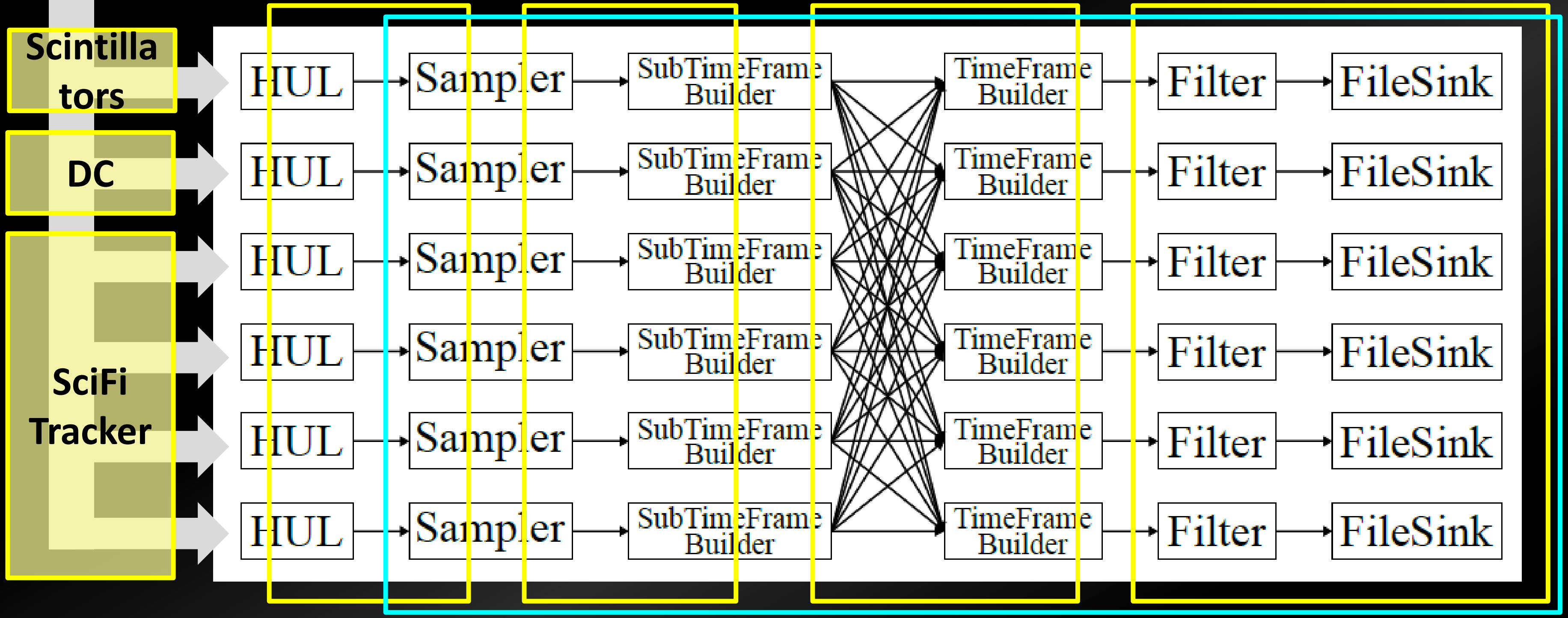
R. Honda, Y. Igarashi, Y. Ma, T.N. Takahashi et al. (paper in preparation)

Data Flow
1Gbps x 6

Data Slice in a time window

Recombine data w/ the time window

Data storage w/ Event Filtering



40 CPUs and 256 GB Memories

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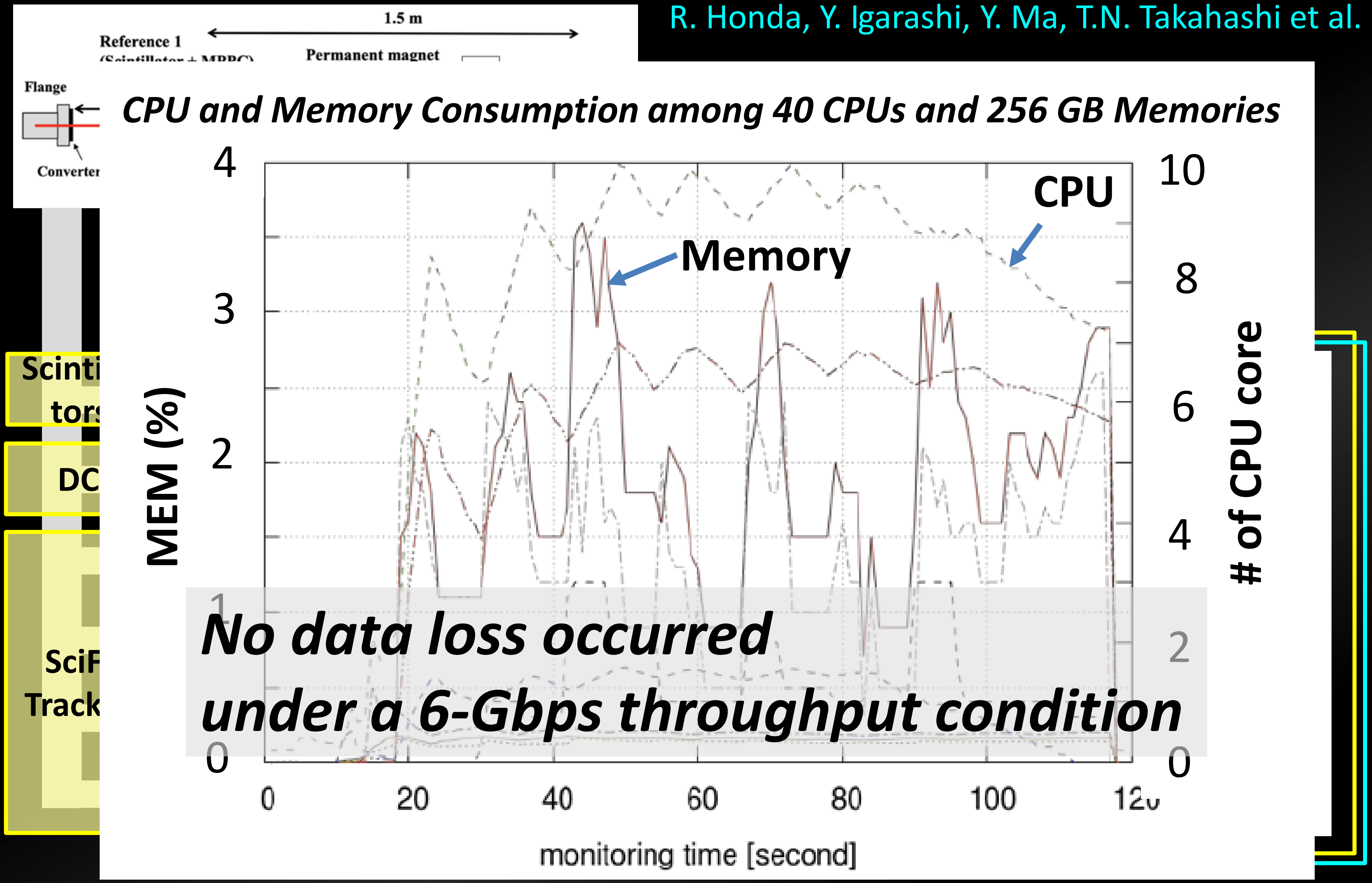
R. Honda, Y. Igarashi, Y. Ma, T.N. Takahashi et al.



40 CPUs and 256 GB Memories

New Platform for Hadron Physics

- Baryon Spectroscopy with Heavy Flavors
  - $p(\pi^-, D^{*-})Y_c^*$, $p(\pi^-, K^*)Y^*$ (E50)
  - $p(K^-, K^*)\Xi^*$, $p(K^-, K^+K^*)\Omega^*$ (LoI)
  - $\pi^- p \to P_c \to J/\psi n$, $D^-\Lambda_c$, $D^-\Sigma_c$
- Hadron Tomography
  - Exclusive DY in $\pi^- p \to \mu^+ \mu^- n$ (LoI)

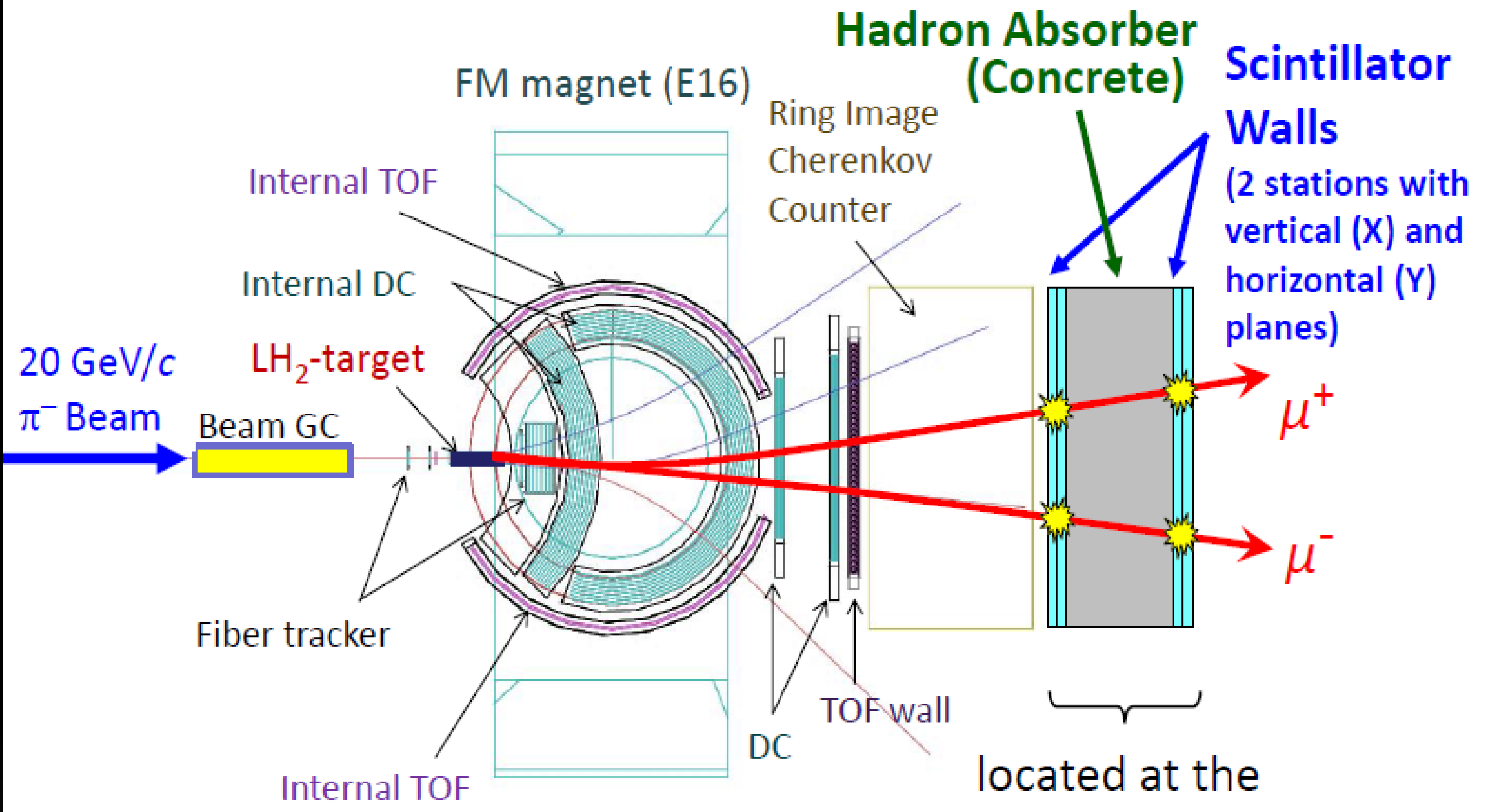
J.C. Peng's talk?

- For Strangeness Nuclear Physics
  - Hyperon-Nucleon Interaction
  - Kaonic Nuclei
  - Vector Mesons in Nuclei
- For Neutrino Physics
  - Hadron Production for neutrino beams

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

Remark

– Synergies between J-PARC and JLab –

We have many items in Hadron Physics and R&D works for detectors/electronics/DAQ

to collaborate between J-PARC and JLab.