Experimental investigation for diquark degrees of freedom in a charmed baryon at J-PARC

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MENU2016 at Kyoto

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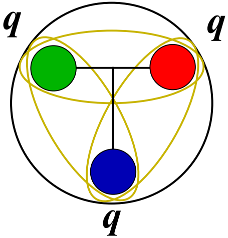
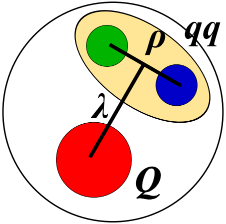
Physics motivation

- Fundamental building blocks of QCD = quarks and gluons
- Hadron dynamics : constituent quark
  - ground state
  - nuclear force
- excited states, exotic resonance
  - not well described by constituent quark model
- diquark as effective degrees of freedom

Quark correlation





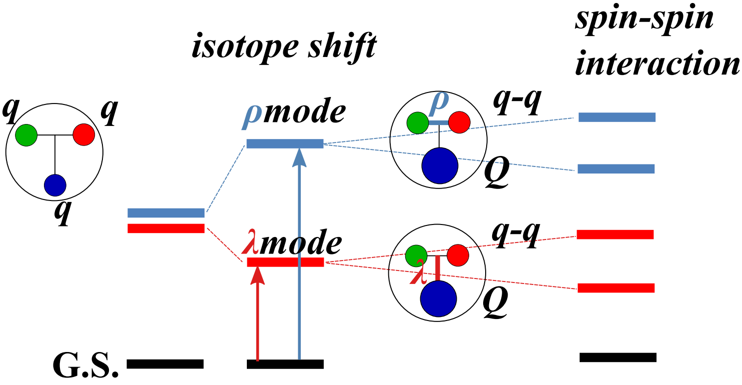
- color-spin interaction between quarks $\propto 1/m_i m_j$
- 3 light diquark pairs ⇒ difficult to distinguish
- Heavy Q ⇒ separate to Q and $q - q$

We will investigate the diquark correlation by measurement of charmed baryon's properties

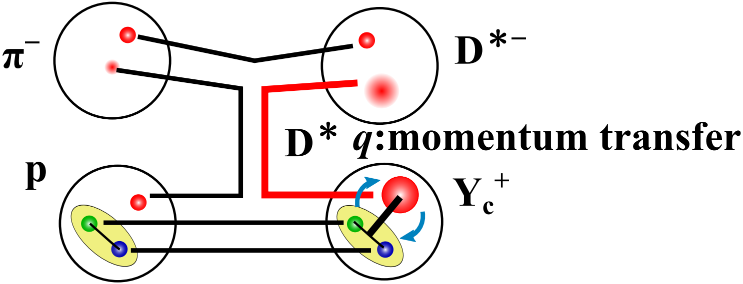
- Level structure
- Production rate
- Decay branching ratio

Schematic level structure of heavy baryons

- λ/ρ modes
- Heavy quark spin doublet ($\vec{s}_{HQ} \pm \vec{j}_{\rm rest}$) for $j_{\rm rest}$>0
  - Heavy quark symmetry ⇒ smaller mass splitting (or degeneracy) of doublet

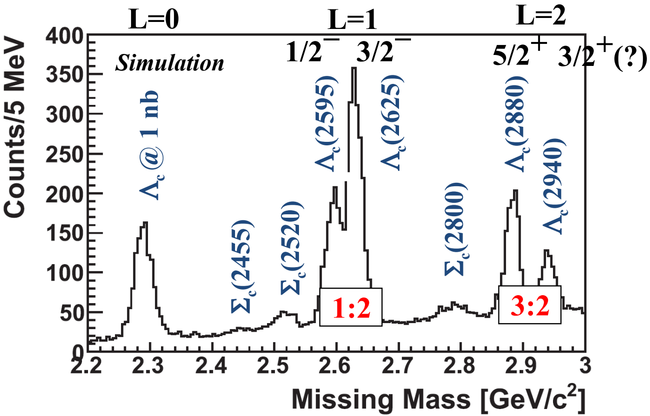


Production



- t-channel dominant
- λ mode excitation at forward angles
- one-step reaction

Production (2)



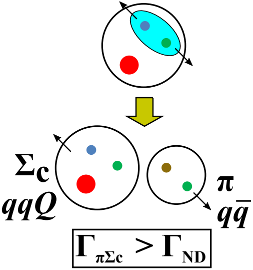
- The production rates are determined by the overlap of the wave function of initial and final states.
- momentum transfer ⇒ orbital excitation
- Heavy quark doublet
  - spin/parity ⇒ relative ratio

Y_c^* Decay pattern

Two decay patterns for two-body decay

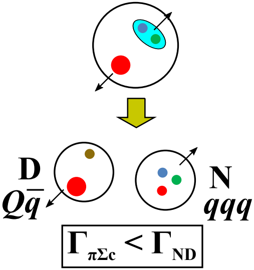
- $Y_c^* \to \pi + Y_c$
- $Y_c^* \to D + N$

ρ mode



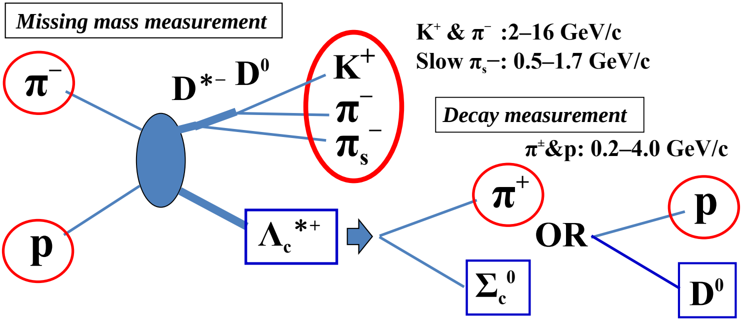
- $\pi^- + \Sigma_c^{++}$
- $\pi^+ + \Sigma_c^0$

λ mode



- $p + D^0$

J-PARC E50 experiment



$\pi^- + p \to Y_c^{*+} + D^{*-}$ reaction
@ 20 GeV/c

- Missing mass spectroscopy
  - $D^{*-} \to \overline{D}^0 \pi_s^-$ (67.7%)
  - $\overline{D}^0 \to K^+\pi^-$ (3.93%)
- Decay measurement
  - $\pi^{\pm}, p$ from Y_c^*

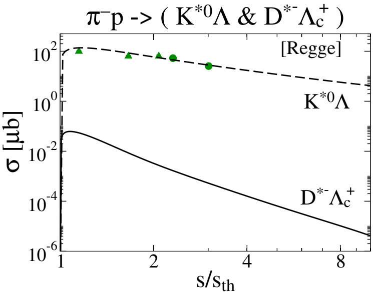
Systematic measurement

- Excited states search
- Excitation energy
- Production cross section
- Decay property

⇒ Diquark correlation

Estimation of production cross section

- High energy 2-body reaction based on the Regge theory
- Normalized to strangeness production
  $\Rightarrow$ Charm production: $\sim 10^{-4}$

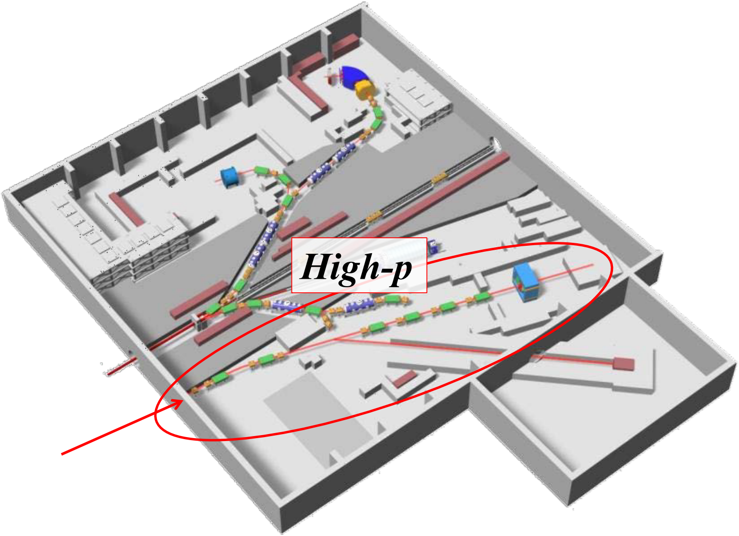


No old data @ 10–20 GeV/c

- Assumed production cross section: $\sigma \sim 1$ nb
- c.f. σ < 7 nb (BNL data)

Small production cross section (expected)
$\Rightarrow$ We need high-rate beam & multi-porpose spectrometer system.

J-PARC hadron hall

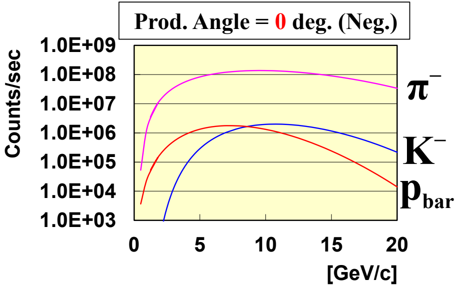


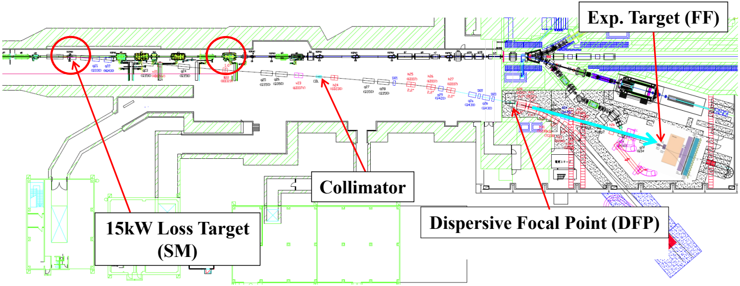
High momentum beam line for secondary beam

- High intensity
  - > 1.0×10^7 Hz π (< 20 GeV/c)
    - 6×10^7 π^-/spill on E50 experimental target
  - Unseparated beam
- High resolution
  - $\Delta p/p$ ~0.1% (rms)
  - Momentum dispersive optics method

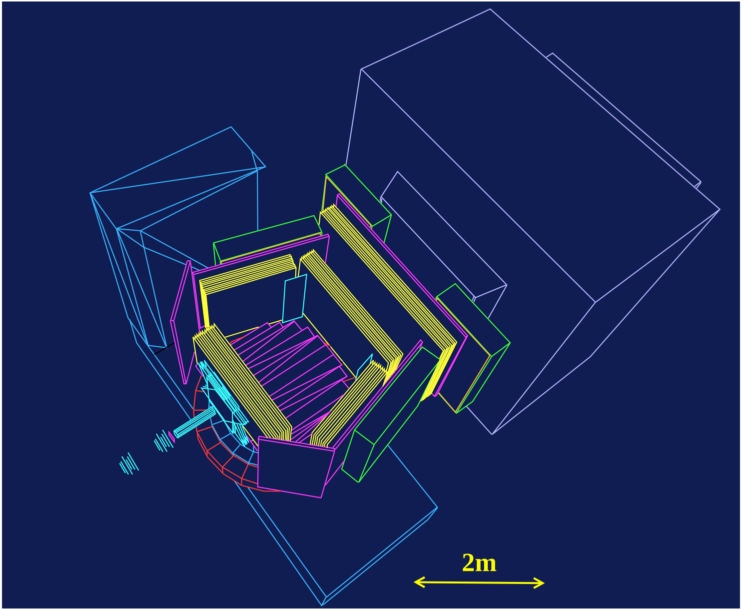
Sanford-Wang

acceptance: 2 msr%, 132 m

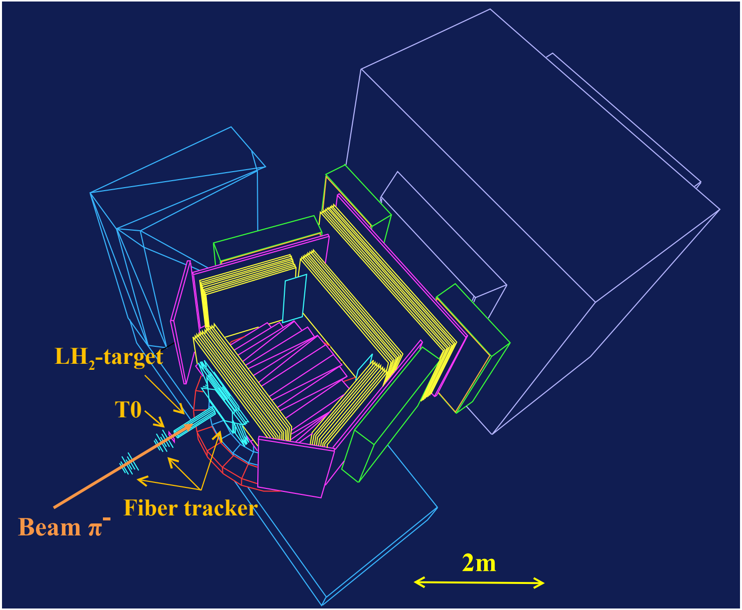




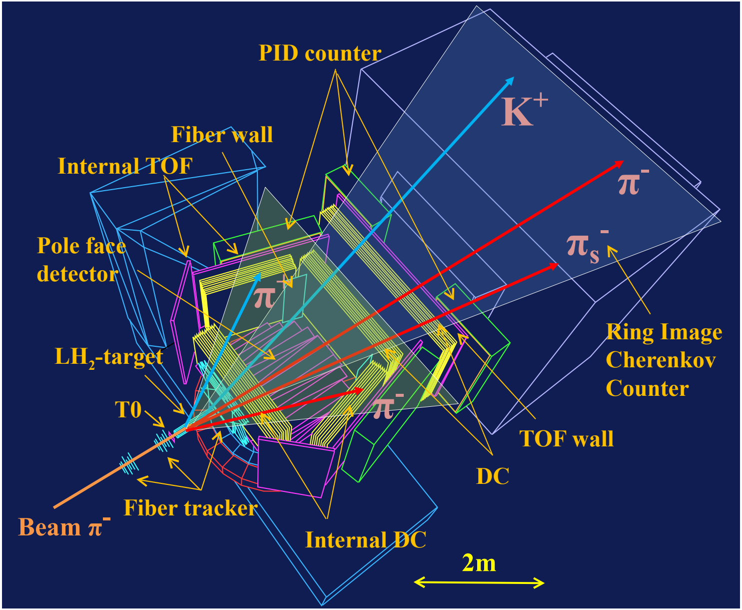
Spectrometer (Realistic design is ongoing.)



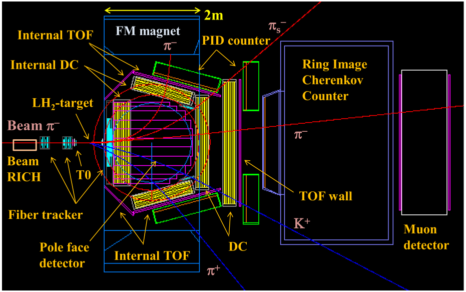
Spectrometer (High-rate detectors)



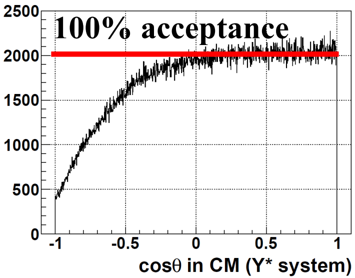
Spectrometer (Charmed baryon prod. and decay)



Spectrometer performance

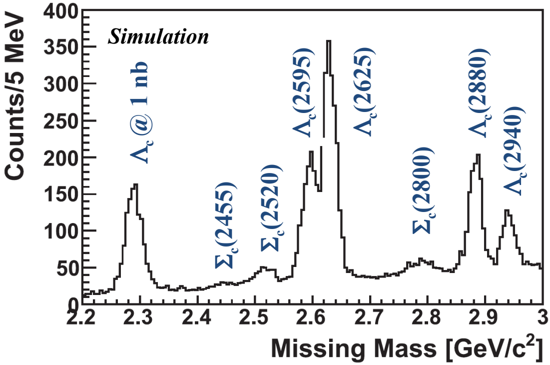


Decay angle: $\Lambda_c(2940)^+ \to \Sigma_c(2455)^0 + \pi^+$



- Acceptance
  - Momentum: 0.2–20 GeV/c
  - Anale: < 40° $\Rightarrow D^*$: 50–60%
  - Decay particle~80%
- Resolution
  - $\Delta p/p = 0.2\%$ @ 5 GeV/c
  - $\Delta M_{\Lambda_c^*} = 10$ MeV @ 2.8 GeV/c^2

Expected spectra



- ~2,000 counts @ N_{pot} = 8.64×10^{13} (100 days, $\varepsilon_{total} = 0.5$)
- Λ_c (g.s.): 1 nb production cross section
  - Production ratio for excited states
- Background: simulated by JAM code.
  - D^* tagging reduces B.G. by a factor of 2×10^6.
- Achievable sensitivity of 0.1 – 0.2 nb (3σ level, Γ < 100 MeV)

Many physics channels

Main channel: Charmed baryons ($Q + qq$)

- $\pi^- + p \rightarrow Y_c^+ + D^{*-}$

Data rate: < 0.1 kHz

Byproducts

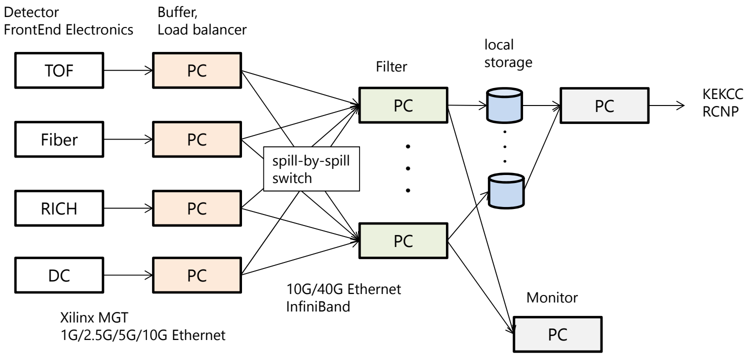
- Ξ_c baryons
  - $\pi^- + p \rightarrow \Xi_c^0 + D^{*-} + K^+$
- Y baryons: yield $= Y_c \times 10^4$
  - $\pi^- + p \rightarrow Y^0 + K_s^0$
  - $\pi^- + p \rightarrow Y^0 + K^{*0}$
  - $\pi^- + p \rightarrow Y^- + K^{*+}$
  - $\pi^- + p \rightarrow \Theta^+ + K^{*-}$
- Ξ baryons: yield $= Y_c \times 10^3$
  - $K^- + p \rightarrow \Xi^0 + K^{*0}$
  - $K^- + p \rightarrow \Xi^- + K^{*+} : (K_s^0 + \pi^+)$
  - $\pi^- + p \rightarrow \Xi^- + K_s^0 + K^+$
  - $\pi^- + p \rightarrow \Xi^- + K^{*0} + K^+$
- Ω baryons : yield $= Y_c \times 10^2$
  - $K^- + p \rightarrow \Omega^- + K_s^0 + K^+$
  - $K^- + p \rightarrow \Omega^- + K^{0*} + K^+$
- Drell-Yan channels
  - $\pi^- + p \rightarrow n + \mu^+ + \mu^-$
  - $K^- + p \rightarrow Y^0 + \mu^+ + \mu^-$

$*$ K beam rate ~1/100

Strangeness

- Yield: 10^4–10^5/day @ 1 μb
  - 4 g/cm^2, 6×10^7/spill ($\sim 10^6$/spill for K beam)
  - 50% acceptance, 50% efficiency (DAQ, PID, analysis)
- Y: $qq + Q$ system @ strangeness sector
  - $\pi^- p \to Y^* + K^{*0}$ reaction
  - Production ratio: qq excitation mode
  - Decay branching ratio: $\Gamma(N\overline{K})/\Gamma(\pi\Sigma)$
- Ξ: $a + QQ$ system
  - $K^- + p \to \Xi^* + K/K^*$ and $\pi^- + p \to \Xi^* + K/K^* + K$ reactions
  - Heavier diquark ($q - s$, $s - s$) system ?
  - λ and ρ mode excitation interchange
- Ω: QQQ system
  - $K^- + p \to \Omega^* + K/K^* + K$ reaction
  - Much simpler system: Diquark less system ?

Data acquisition system : free-streaming DAQ



Frontend modules

- Self or periodic trigger
- ~30,000 ch

Buffer PCs

- Data accumulation ~50 GB/spill (~250 Gbps, 2 sec.)
- Derandomized → ~10GB/sec

Filter PCs

- Event reconstruction using CPUs and/or GPUs

Storage

(<0.5 GB/spill)

- Local storage
- Transferred to KEKCC/RCNP

Ongoing R&D works

- High speed and/or high performance detectors
  - Scintillating fiber tracker
  - T0 timing counter
  - Large RPC for TOF measurement (collaboration with LEPS2)
- High speed DAQ
  - Front-end electronics for trigger-less readout
  - Test bench for free-streaming DAQ
    - Load-balancing of CPU/GPU (collaboration with ALICE O2 project)
    - Fast on-line track reconstruction

J-PARC High-p collaboration

- J-PARC E16 (talk by Y. Komatsu, 26-MNI-2-2)
- J-PARC E50
- future Heavy Ion project at J-PARC

Summary

- Charmed baryon spectroscopy
  - Essential way to understand hadron structure
  - Diquark correlation: λ and ρ mode excitation
- Experiment at the J-PARC high-p beam line
  - Inclusive measurements by missing mass spectroscopy with multi-purpose spectrometer system
  - Unique information from the production measurement
  - Data taking of many reaction channels by high-speed DAQ
- Systematic study of baryons at J-PARC
  - Excitation energy, production, decay with strangeness sector: $qq + Q$, $q + QQ$, QQQ
  - pilot studies for the K10 beam line
  - Systematics to understand hadron structure

J-PARC E50 collaboration

- RCNP
  - S. Ajimura, H. Asano, T. Nakano, H. Noumi, K. Shirotori, Y. Sugaya, T.N. Takahashi, T. Yamaga
- KEK
  - K. Aoki, Y. Morino, K. Ozawa
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- Tohoku U
  - K. Miwa
- Academia Sinica
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- Korea U
  - J.K. Ahn
- Osaka U
  - R. Honda
- Yamagata U
  - Y. Miyachi
- JLab
  - J.T. Goetz

Spectrometer (Drell-Yan)