Spectrometer for charmed baryon spectroscopy experiment at the J-PARC high-momentum beam line

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for the J-PARC P50 collaboration

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- **Physics motivation**
- **Experiment at J-PARC**
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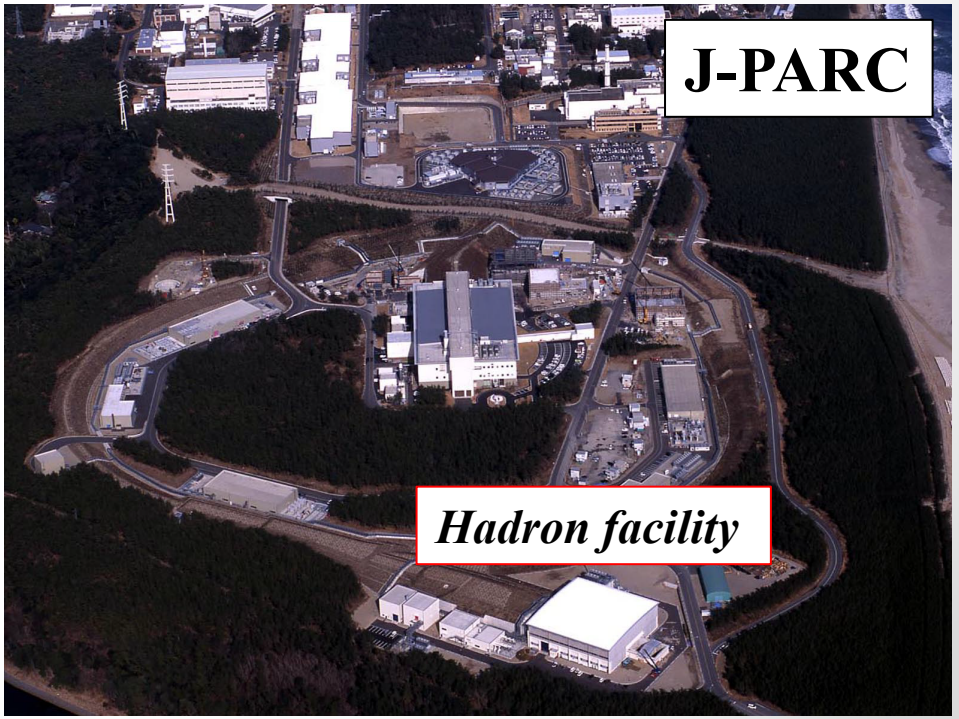
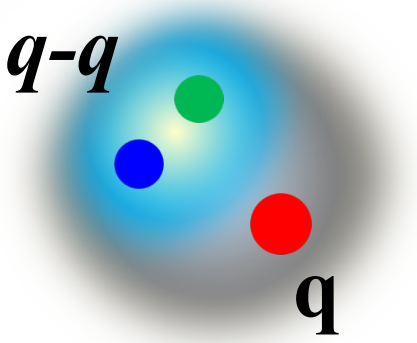
- **Summary**



Charmed baryon spectrum

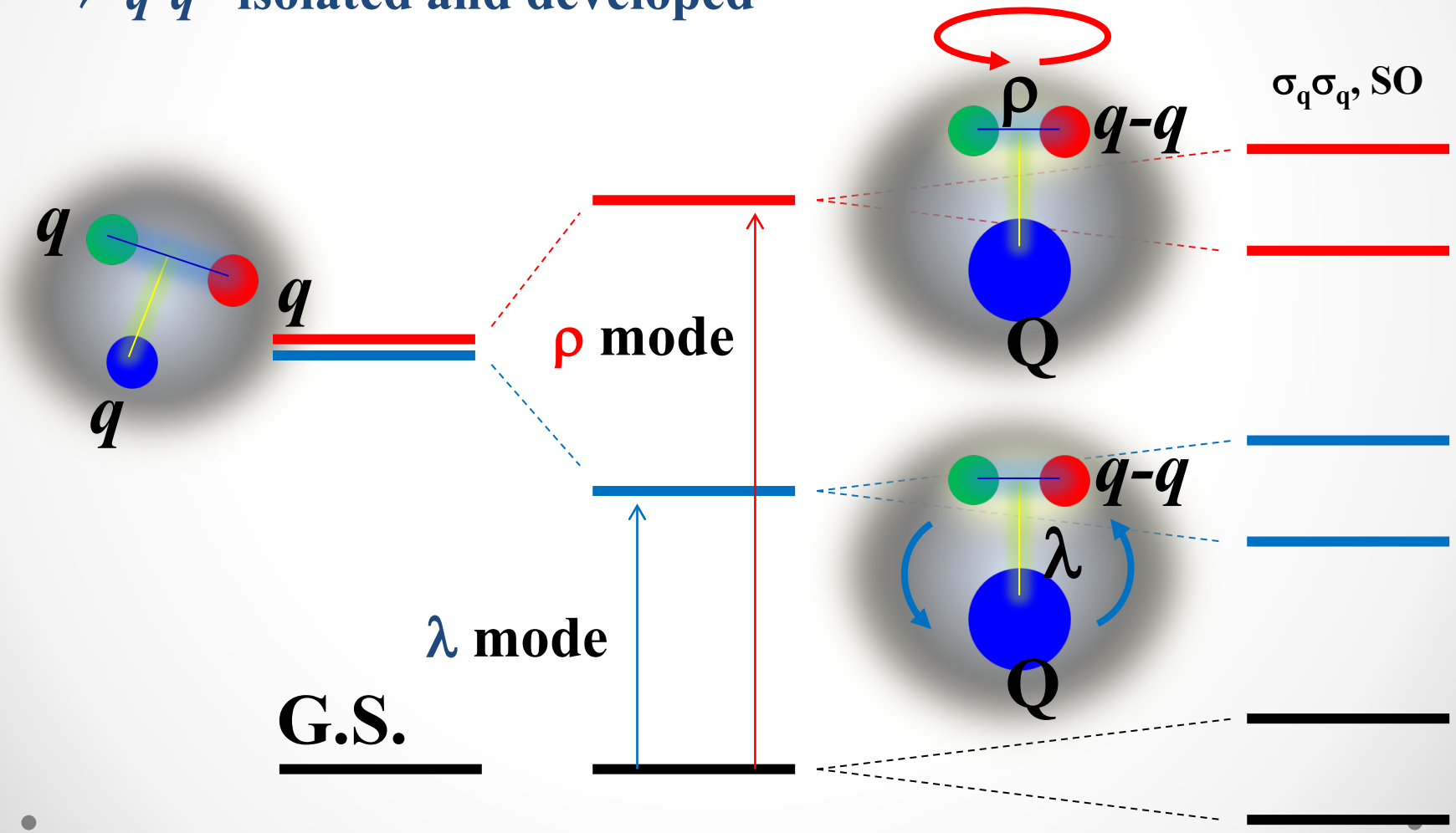
Diquark 

$\Rightarrow$ *Charmed baryon*

Charmed baryon spectrum

Heavy Quark: Weak color-magnetic interaction

⇒"*q*-*q*" isolated and developed



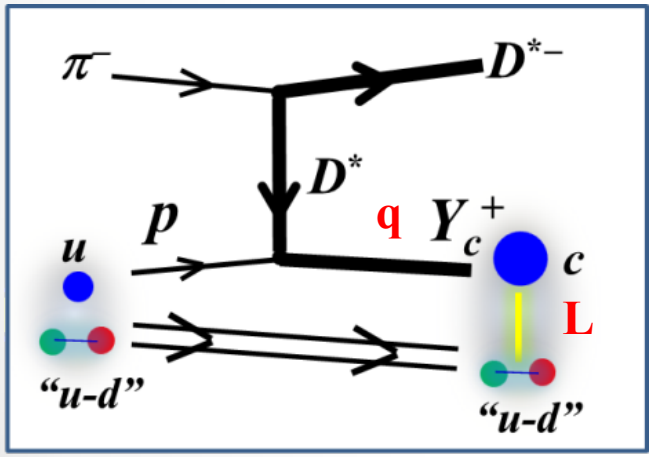
Production cross section

Measurement

⇒ Missing mass spectroscopy: $\pi^- + p \rightarrow Y_c^{*+} + D^{*-}$

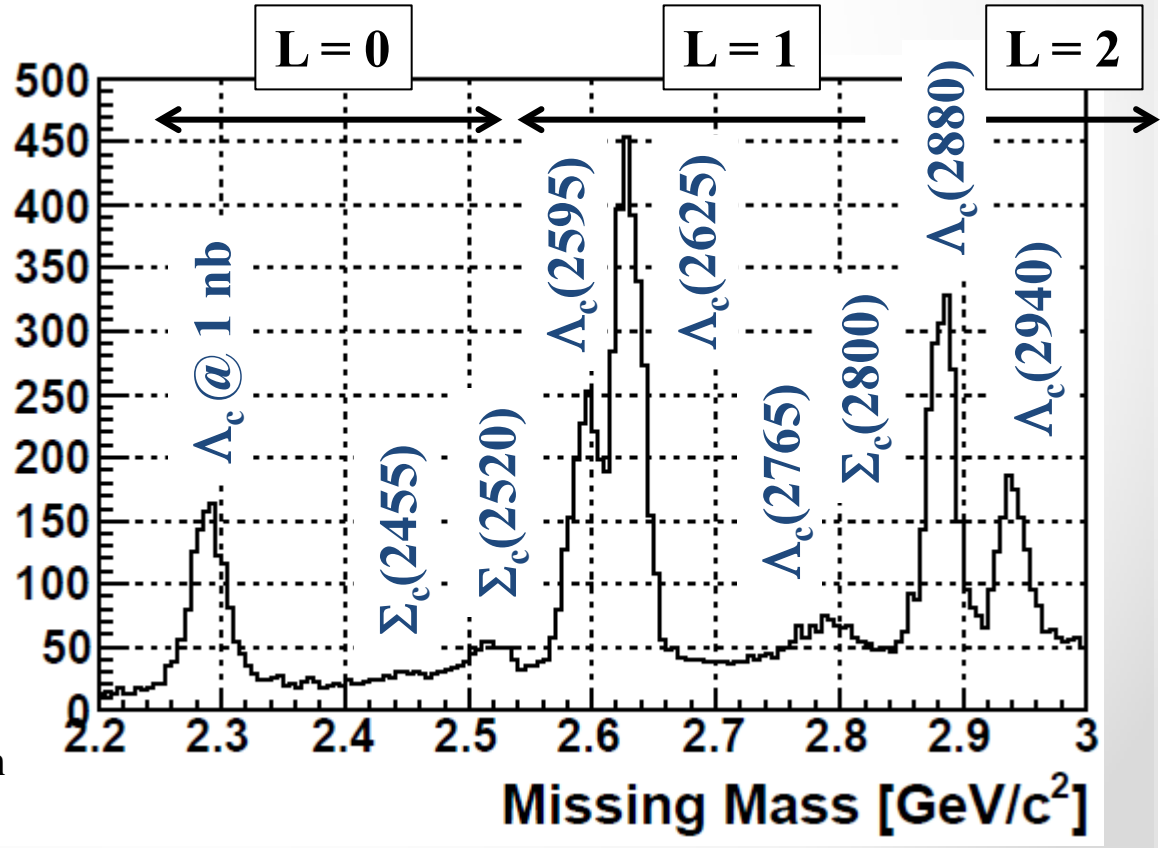
∗ Production rate: Spin/Isospin & Momentum transfer

⇒ Structure: Diquark configuration



$$R \propto C_{q\text{-}q} \times C_J \times q^L$$

A. Hosaka, private communication



Charmed baryon spectroscopy

Propose

∗ Investigate charmed baryons

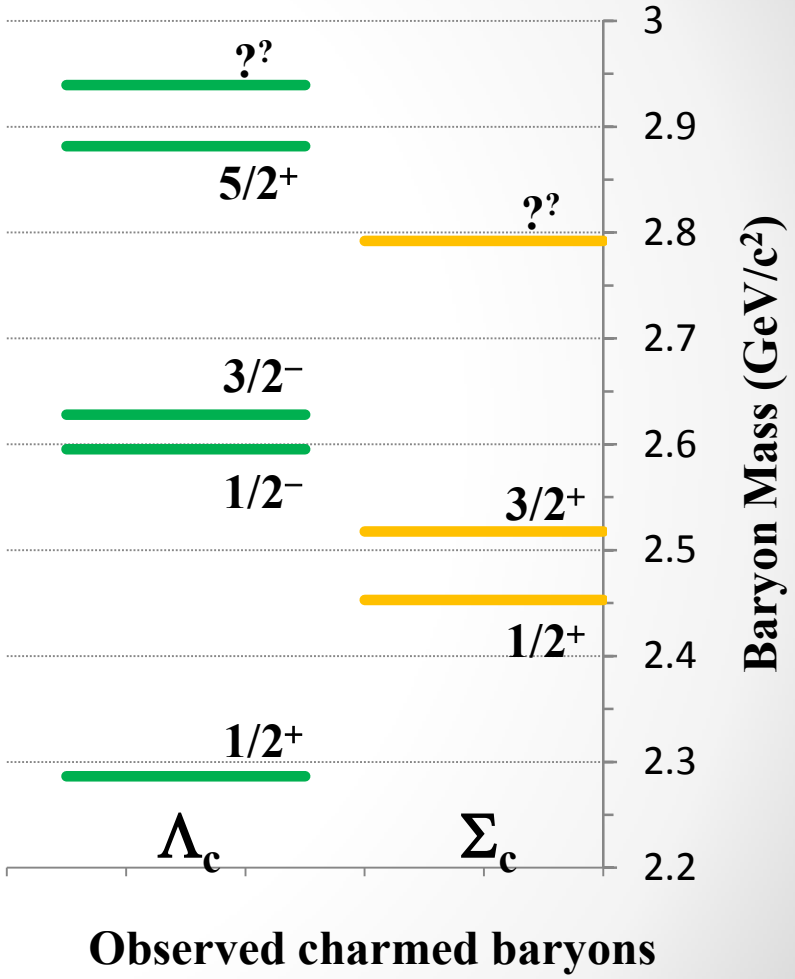
⇒ Missing mass spectroscopy

∗ Systematic measurement

- **Excitation energy**
- **Production cross section**
- **Decay branching ratio**

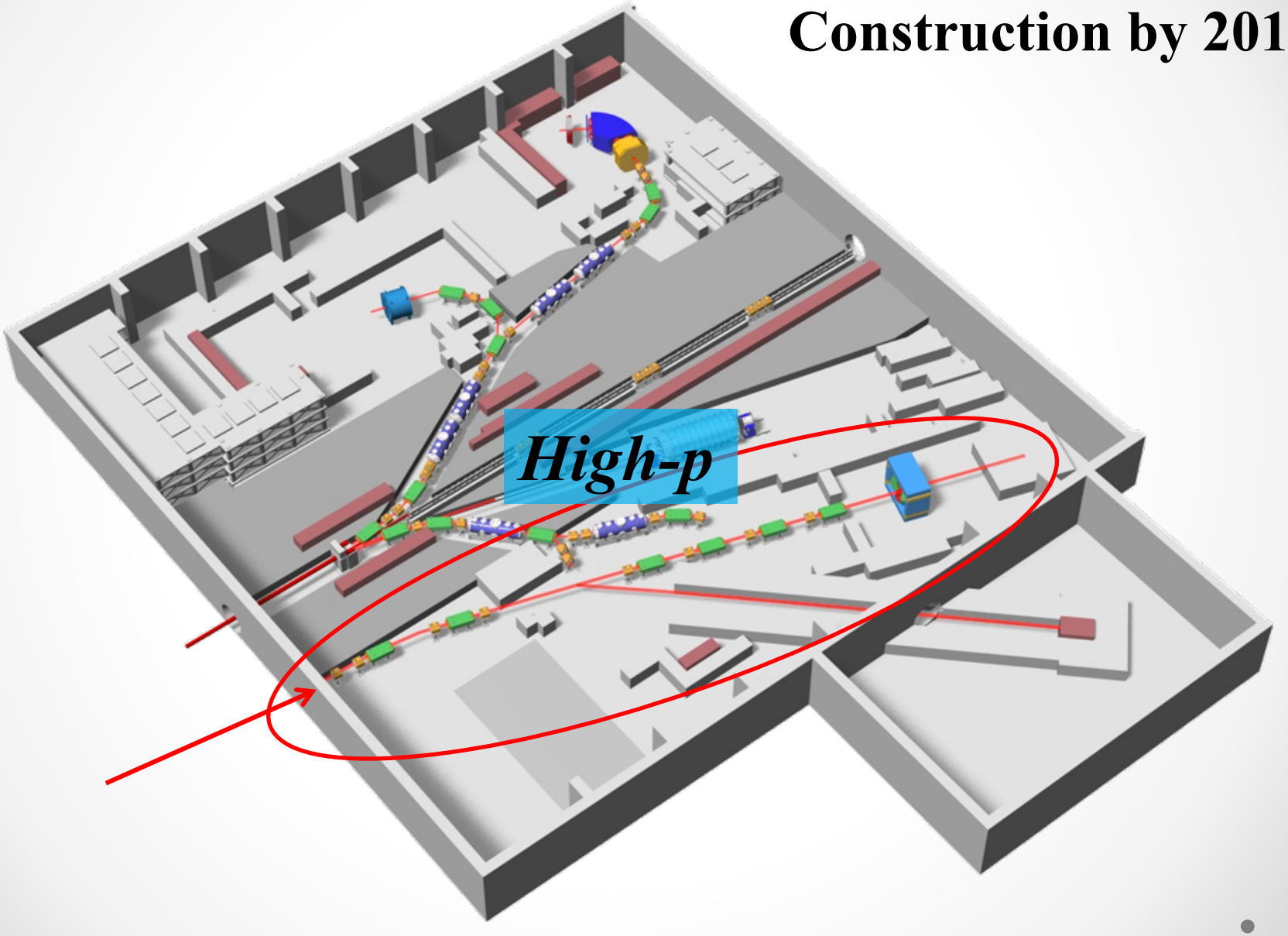
⇒ *Diquark*

- **No old experiments using hadron beams with 10-20 GeV/c observed charmed baryons.**



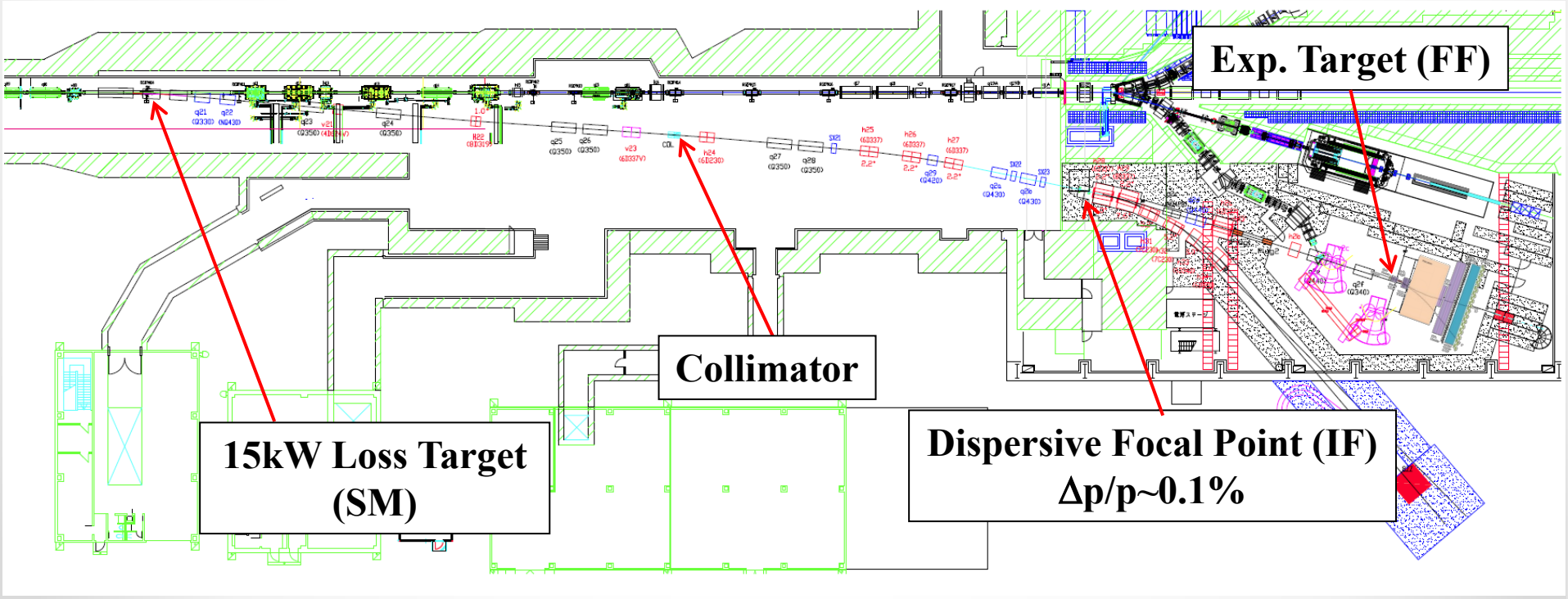
High-momentum beam line

Construction by 2015



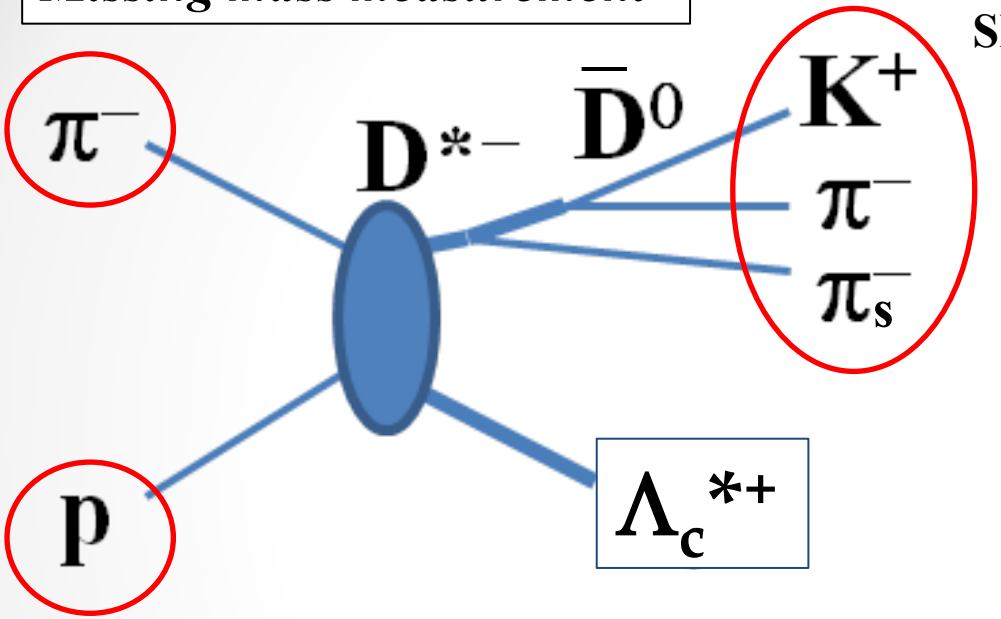
High-momentum beam line for 2ndary beam

- **High-intensity beam:** $> 1.0 \times 10^7$ Hz π (< 20 GeV/c)
- **High-resolution beam:** $\Delta p/p \sim 0.1\%$
  - **Momentum dispersion and eliminate 2nd order aberrations**



Experiment

Missing mass measurement



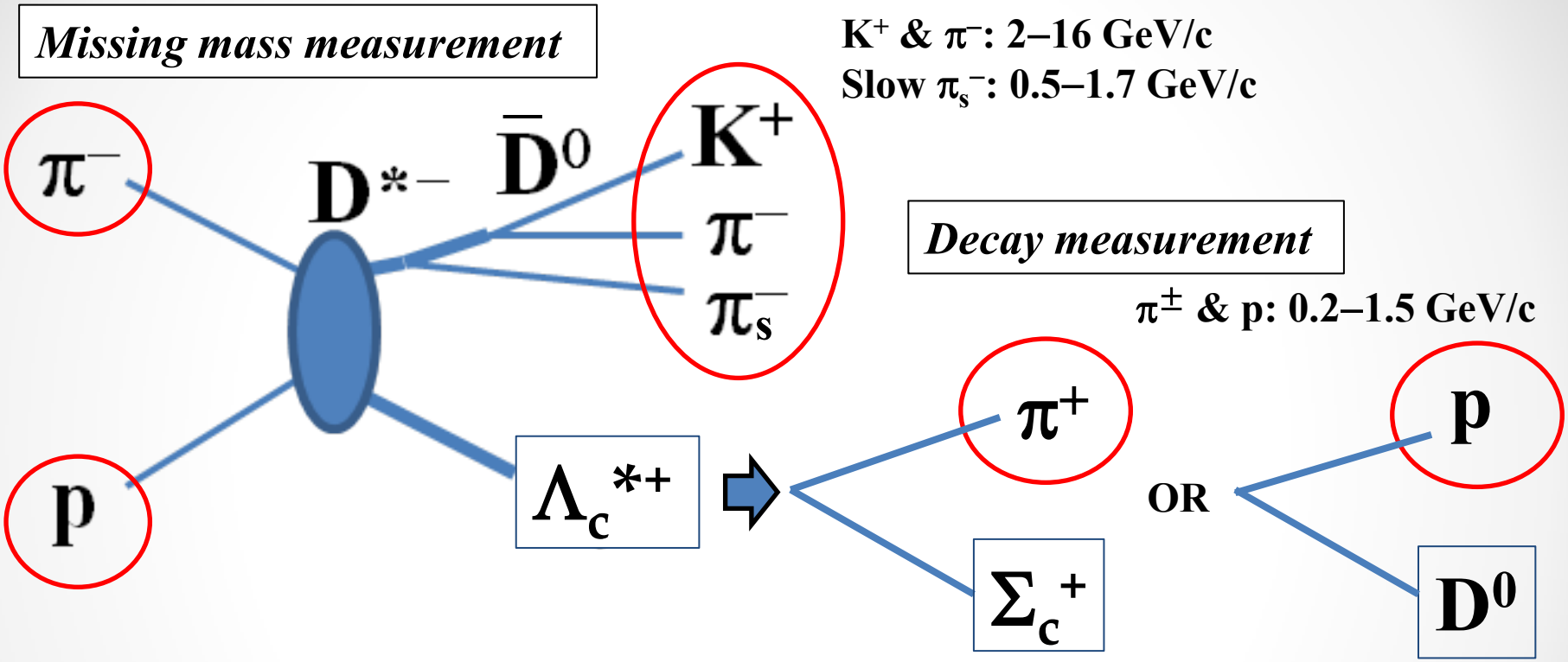
K^+ & π^-: 2–16 GeV/c
Slow π_s^-: 0.5–1.7 GeV/c

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

1) Missing mass spectroscopy

– $D^{*-} \rightarrow \bar{D}^0 \pi_s^- \rightarrow K^+ \pi^- \pi_s^-$: $D^{*-} \rightarrow \bar{D}^0 \pi_s^-$ (67.7%), $\bar{D}^0 \rightarrow K^+ \pi^-$ (3.88%)

Experiment



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

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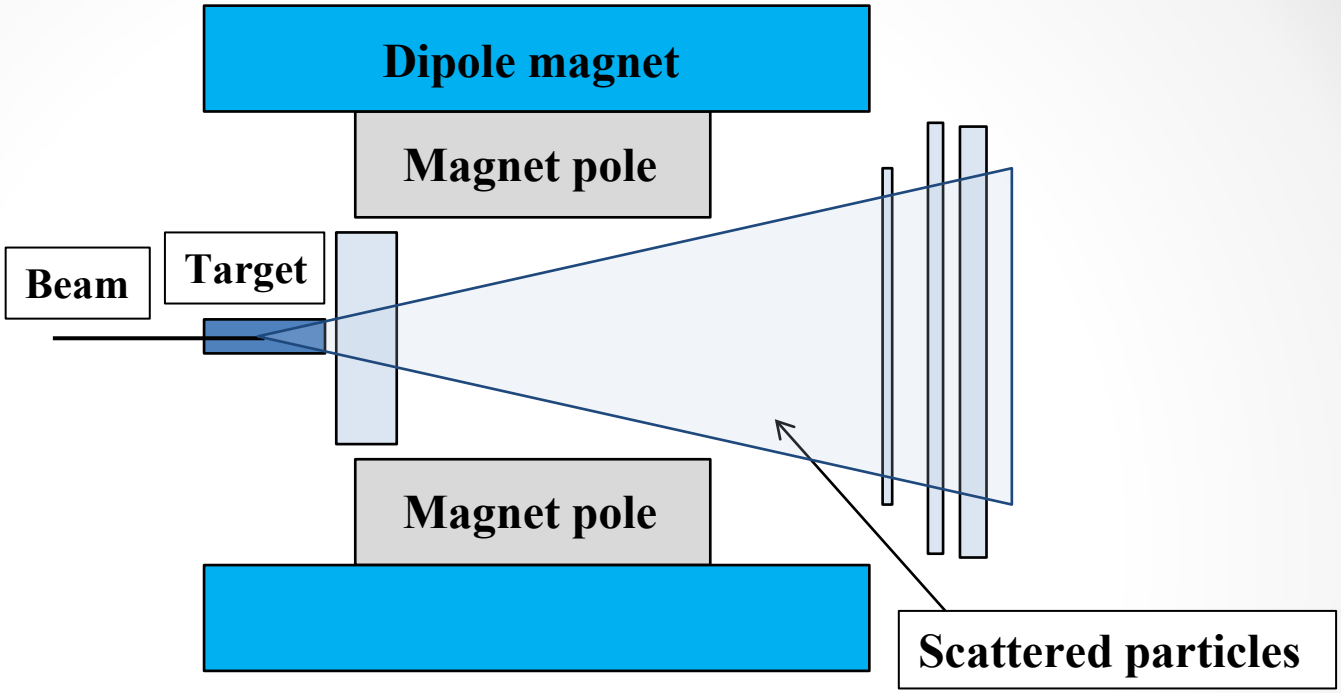
2) Decay measurement

- Decay particles ($\pi^{\pm}$& proton) from Y_c^*

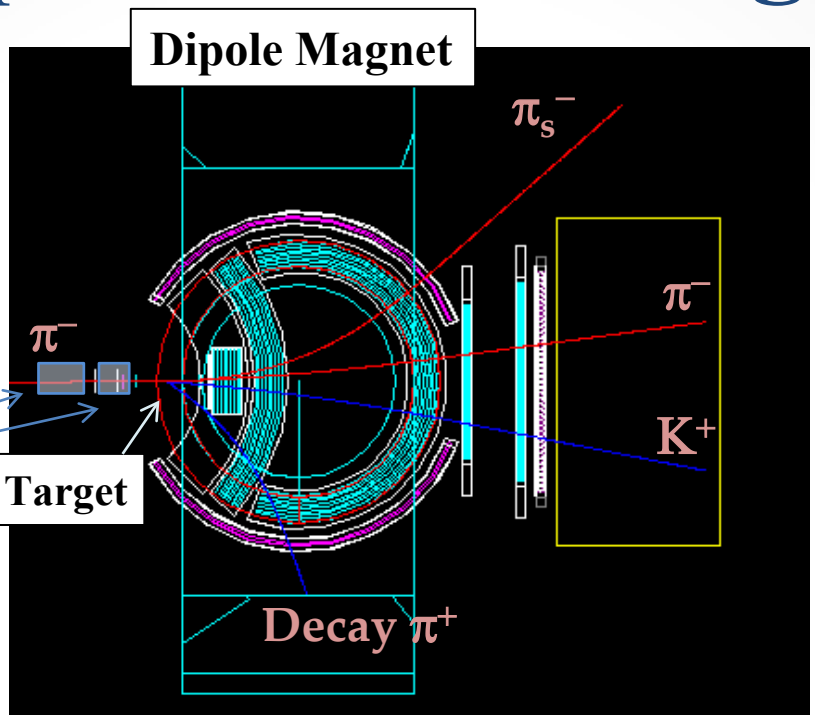
Experimental design



- **High sensitivity experiment: $\sigma \sim 1$ nb (10^{-4} of strangeness production)**
  - $\pi^- + p \rightarrow \Lambda_c^+ + D^{*-}$ reaction @ 13 GeV/c: $\sigma < 7$ nb

- **Dipole-magnet spectrometer**
  - **High-resolution: $\Delta p/p < 1\%$**

Experimental design



Beam measurement
- Fiber trackers
- Beam Cherenkov
- Focal plane

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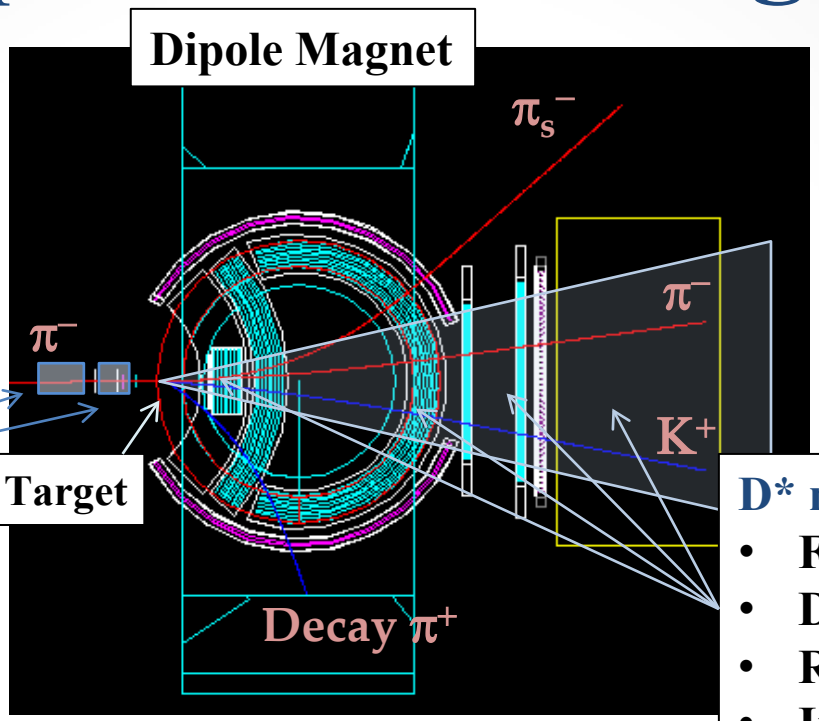
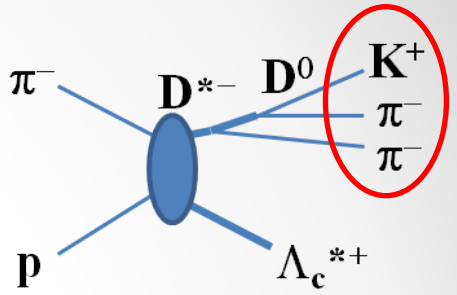
- **Dipole-magnet spectrometer**
  - High-resolution: $\Delta p/p < 1\%$
- **High-rate beam & high-rate detector system**
  - Beam intensity: 6×10^7 /2.0 sec spill (~1 MHz/mm)
  - Event rate: 3 M/spill (Multiplicity = 4)

Experimental design





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D* measurement
- Fiber trackers
- Downstream DC, TOF
- Ring Image Cherenkov
- Internal DCs

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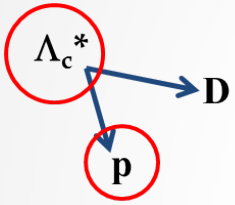
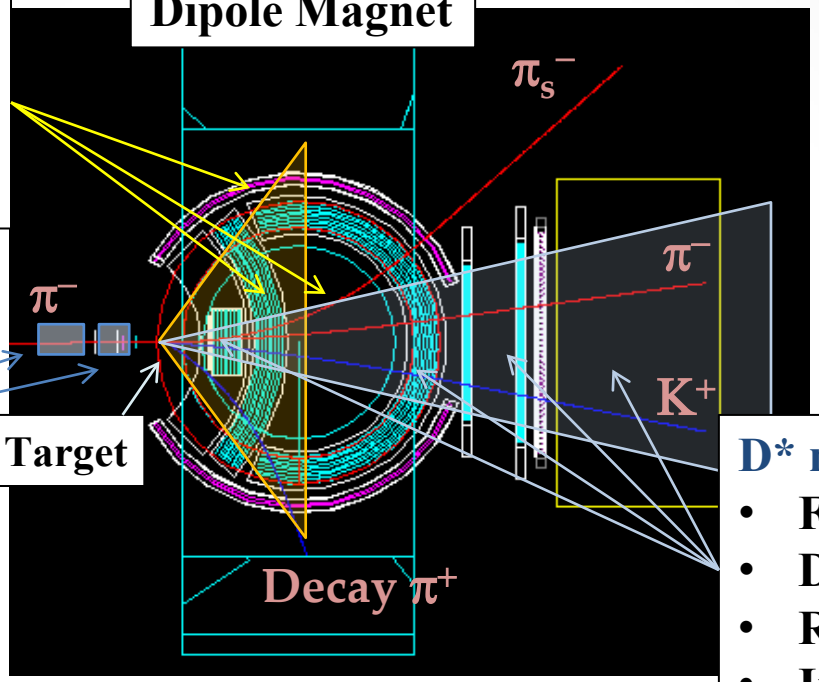
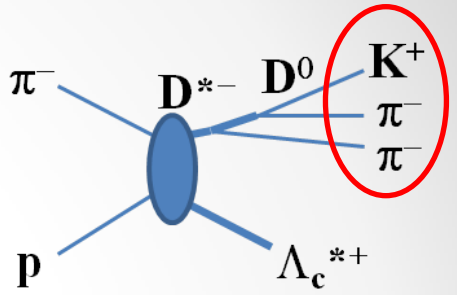
Experimental design

Λ_c* decay measurement
- Internal DC
- Internal TOF
- Pole face TOF detector







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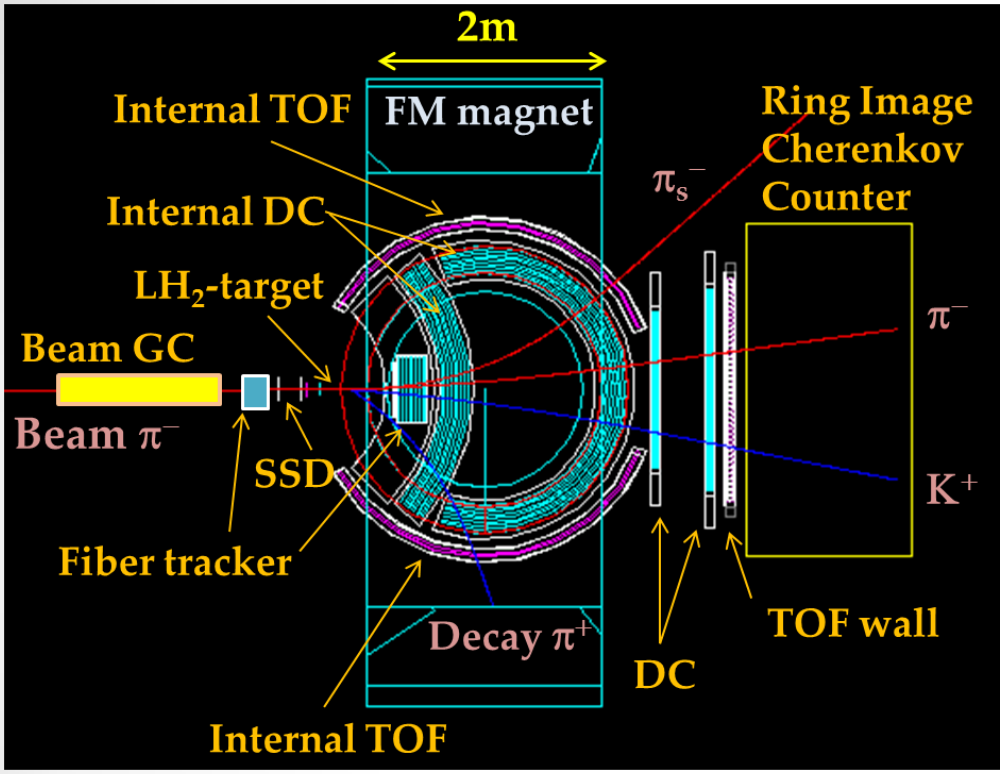
Charmed baryon spectrometer



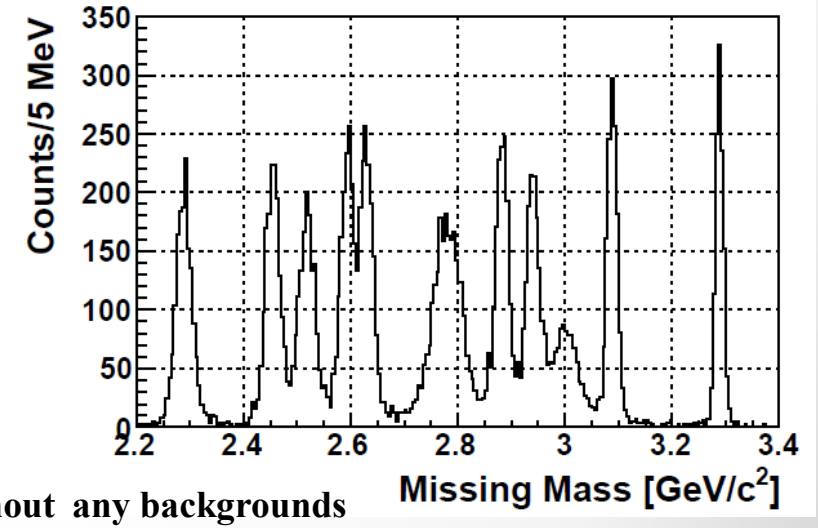
- **Acceptance**
  - D*: 50–60%
  - Decay particle: > 80%
    - Wide angular coverage
- **Resolution**
  - $\Delta p/p = 0.2\%$ @ 5 GeV/c

High-speed DAQ system

∗ **Trigger: Mass trigger**

- Momentum analysis by DCs and fiber tracker

Simulated excitation spectrum @ 1 nb



∗ Without any backgrounds

Backgrounds

1. **Main background**
   - **Strangeness production: (K^+, π^-, π_s^-) in final state**

2. **Wrong particle identification**
   - **Dominant cases: (π^+, π^-, π_s^-), (p, π^-, π_s^-)**
     - **Miss-identification of K^+**

3. **Associated charm production: D^{*-}**
   - **Highly excited D***
   - **DD_{bar} pair**
   - **Charmonium**

Backgrounds

1. **Main background**
   - **Strangeness production: (K^+, π^-, π_s^-) in final state**

2. **Wrong particle identification: 30% of Main BG**
   - **Dominant cases: (π^+, π^-, π_s^-), (p, π^-, π_s^-)**
     - **Miss-identification of K^+**

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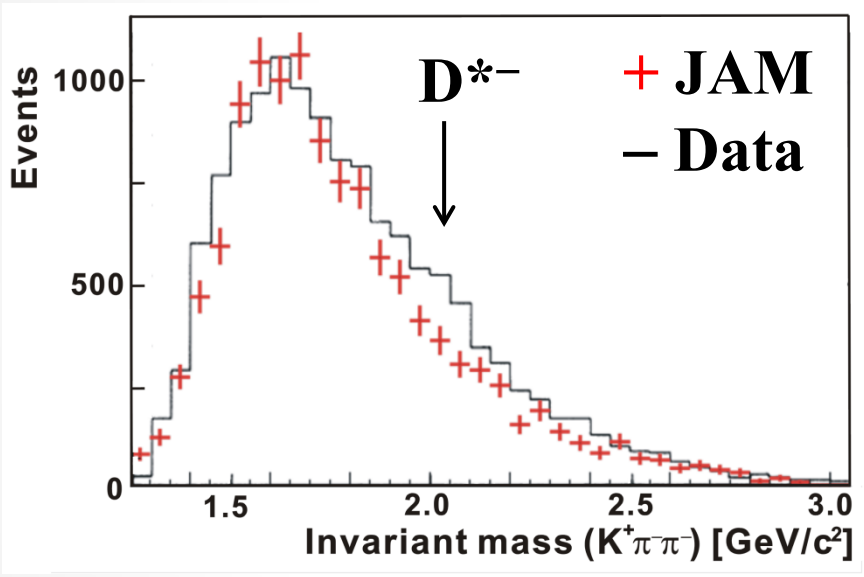
Contribution (peaking or not) checked by analysis

Reliability of the BG simulation

BNL 13 GeV/c data
J.H. Christenson et al., PRL 55, 154 (1985)



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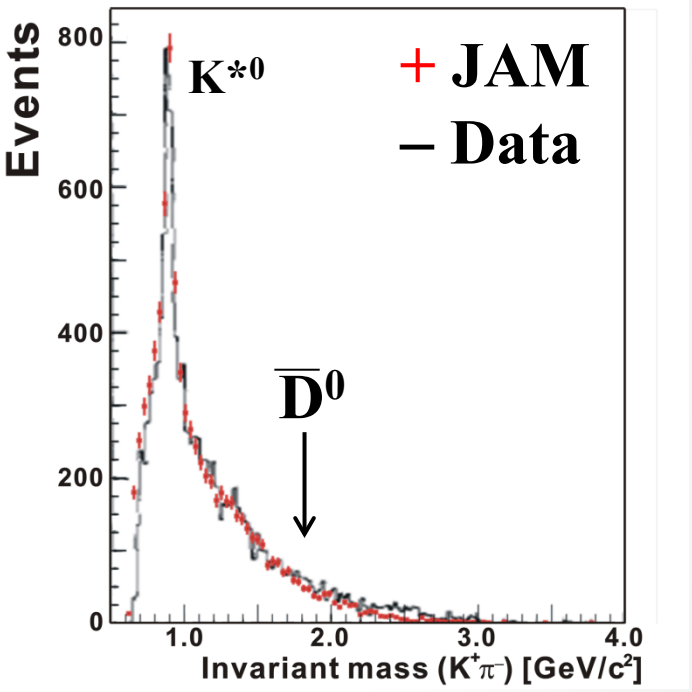
B. Ghidini et al., NPB 111, 189 (1976)



- **Background simulation by JAM (PYTHIA)**

⇒ **Shapes and yields were well reproduced.**

Y. Nara et.al., Phys. Rev. C61 (2000) 024901

– Event counts in D* mass and K^{*0} cross section: ~30% ambiguity

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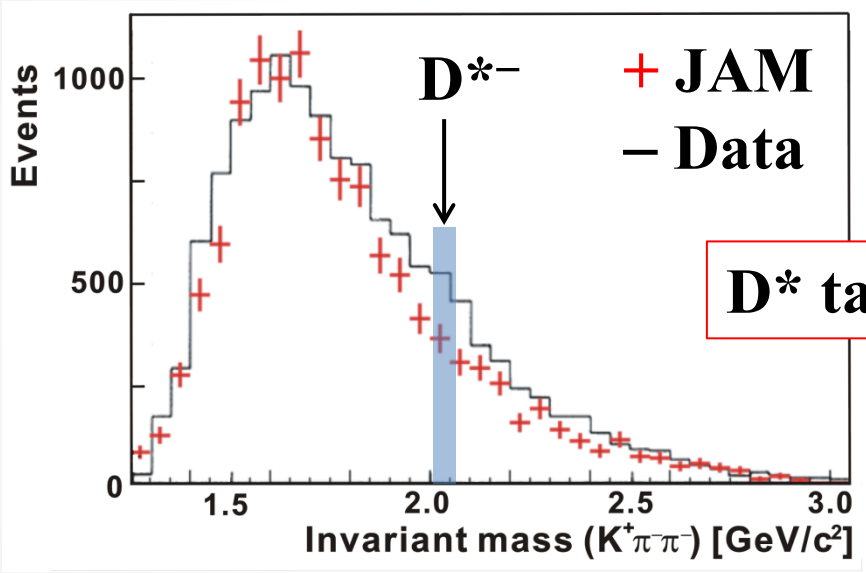

D* tagging

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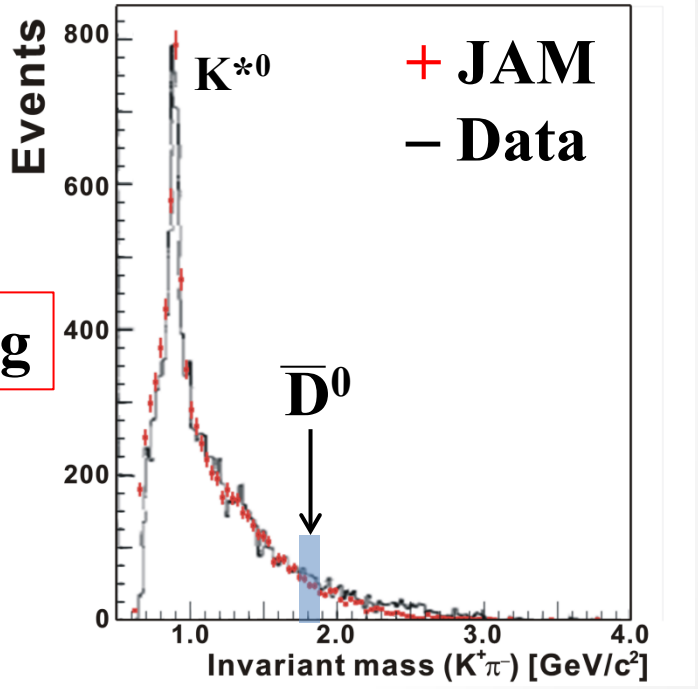

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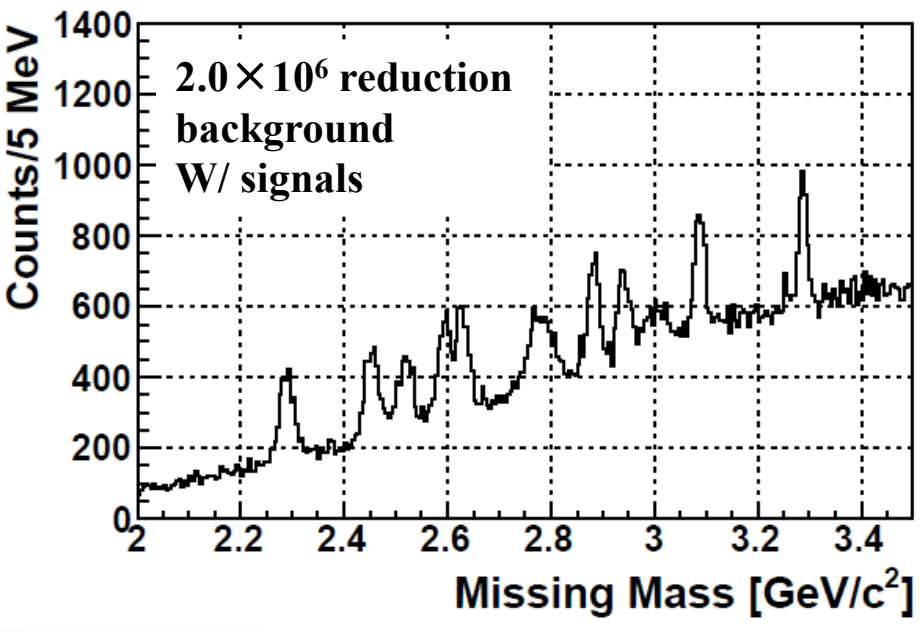
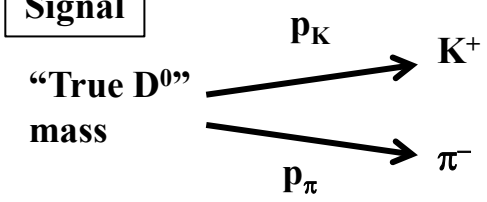
Background reduction

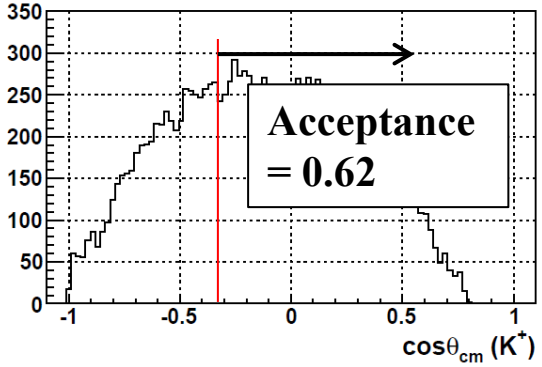


S/N improvement

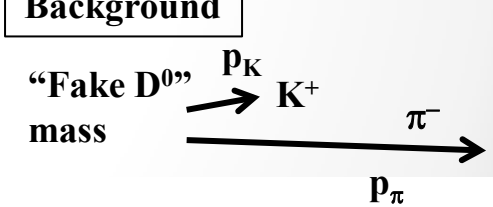
- **D* tagging**
  - Mass resolution: × 4
- **Event selections**
  - Decay angle cut: ×2
  - Production angle cut ×4 (depends on $d\sigma/dt$)

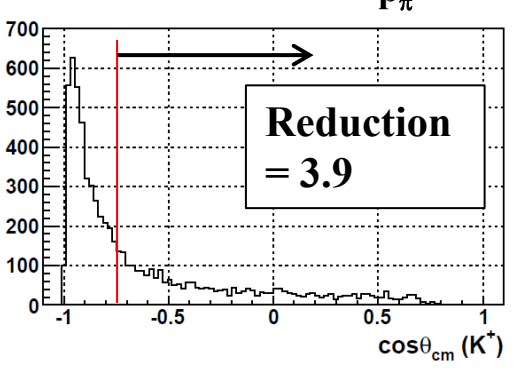
Signal





Background

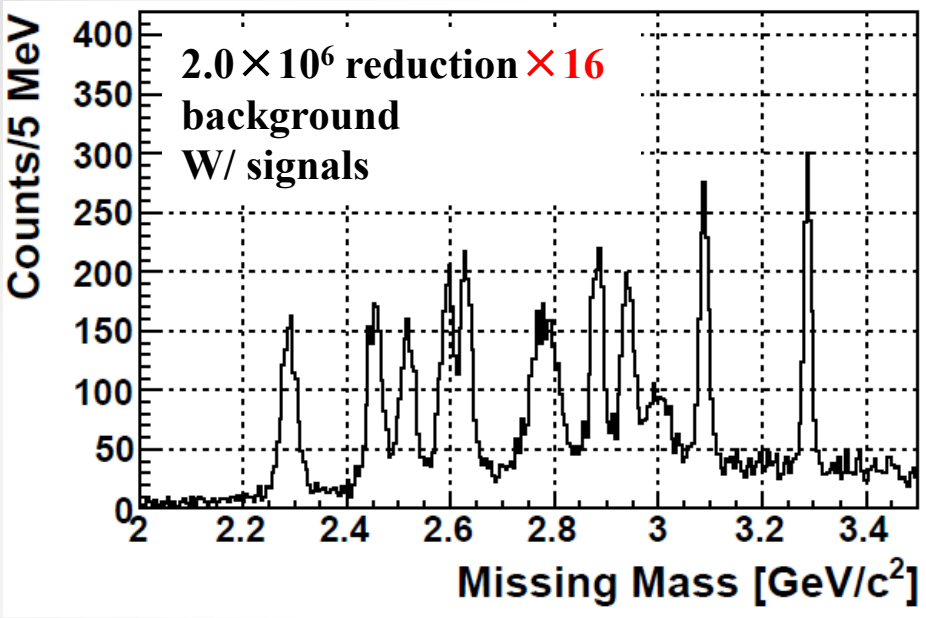




K^+ scattering angel in CM
- **Simulation**

w/ spectrometer acceptance

Background reduction



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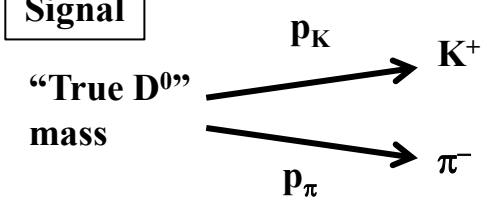

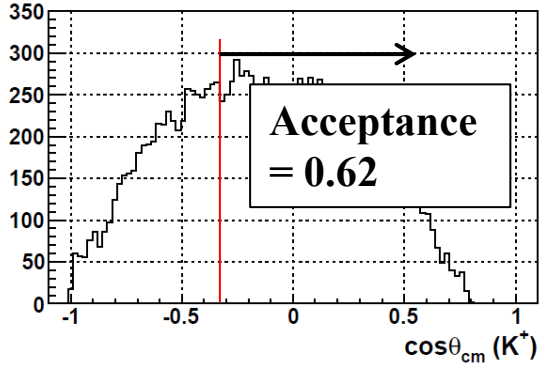

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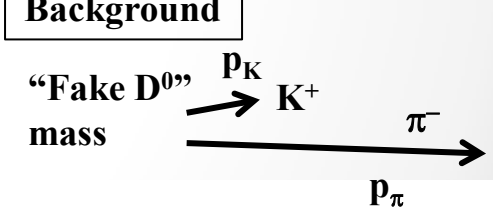
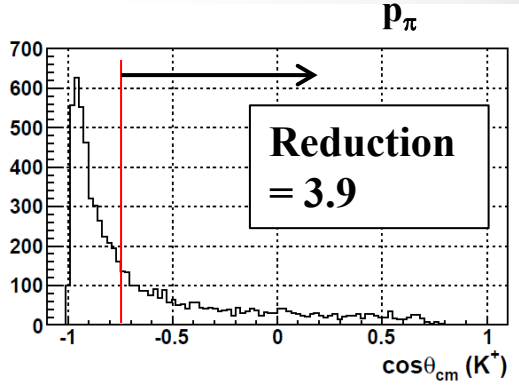


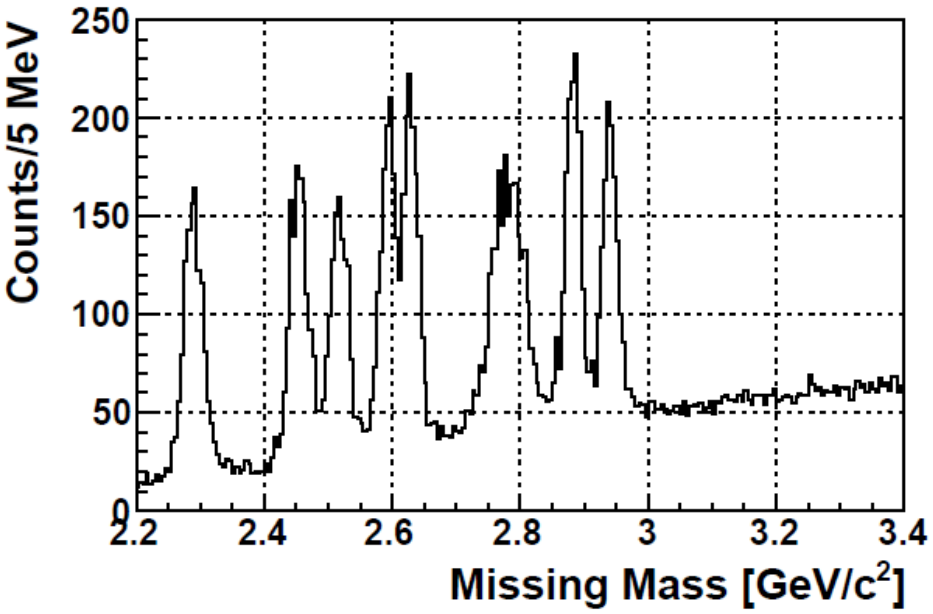


K^+ scattering angel in CM
- Simulation

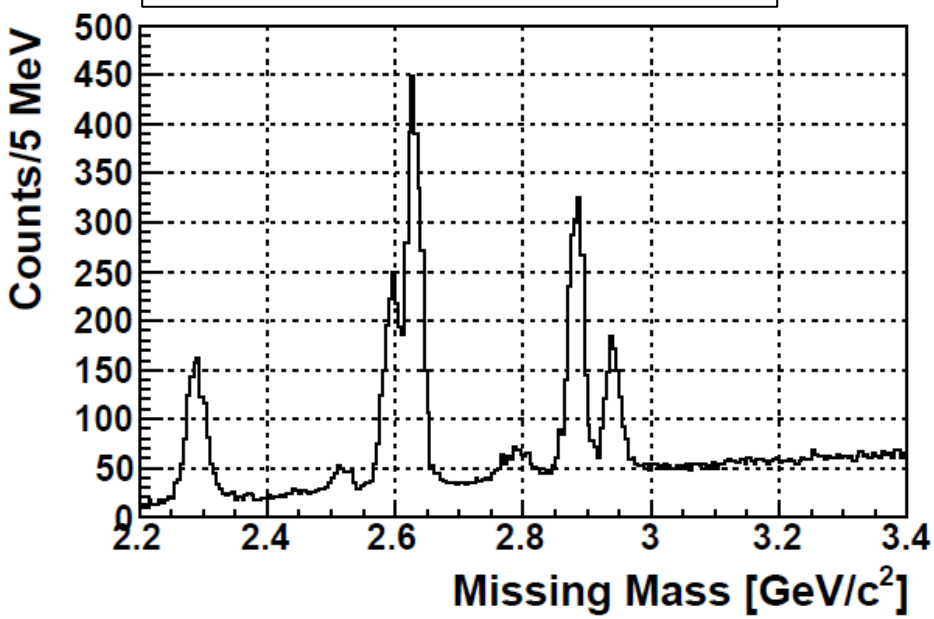
w/ spectrometer acceptance

Expected spectra: σ = 1 nb

σ = 1 nb case for each state



G.S. = 1 nb & production ratio



Known Mass & Width in PDG

✱Sum background
- Main BG
- Miss-PID
- Charm prod.

Achievable sensitivity of 0.1-0.2 nb: (3σ level, Γ < 100 MeV)

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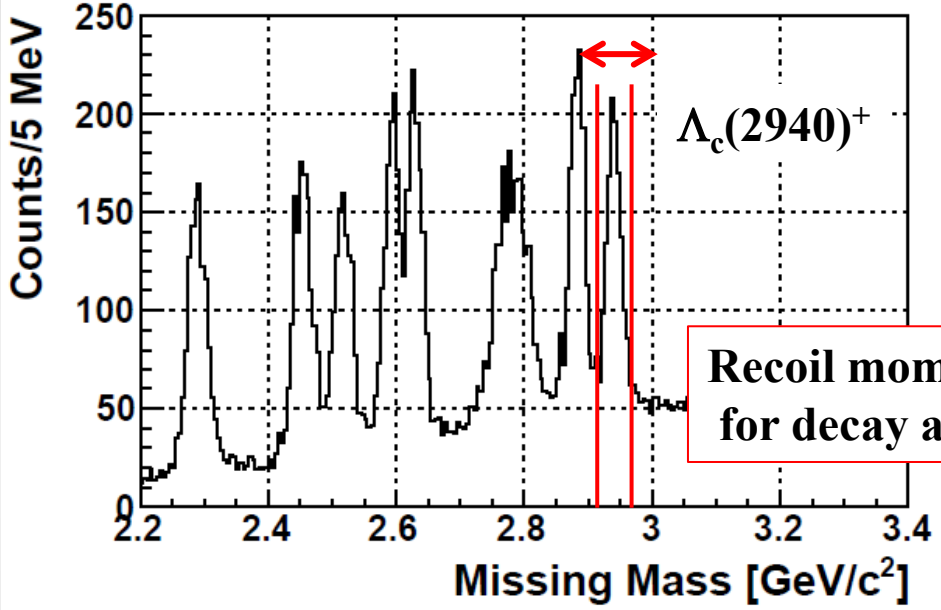
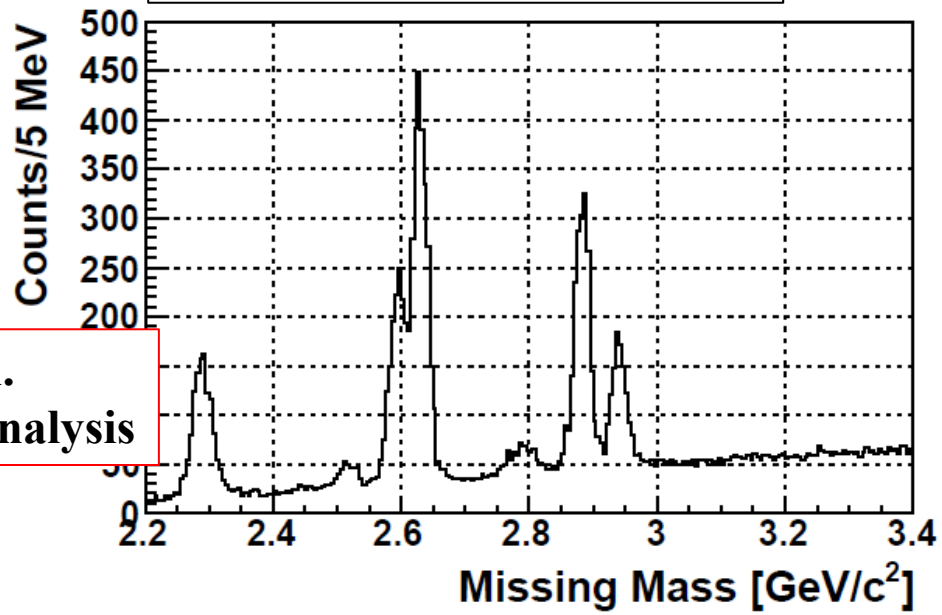


Recoil mom.
for decay analysis

G.S. = 1 nb & production ratio



Known Mass & Width in PDG

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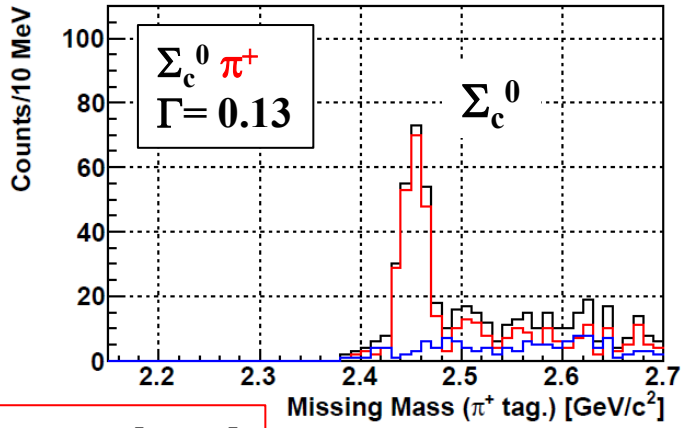
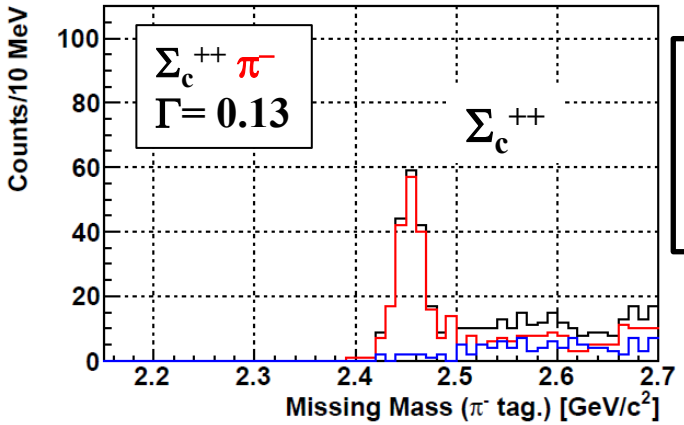
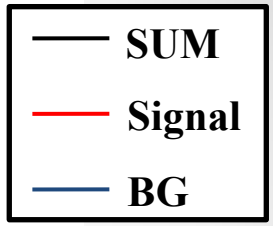
Decay measurement

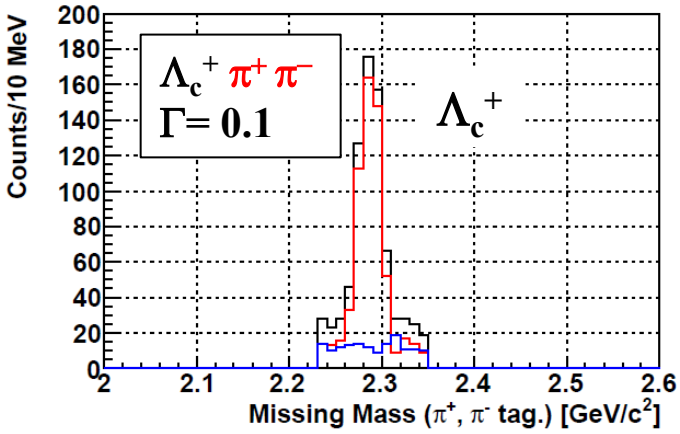
B.R.: Assumed

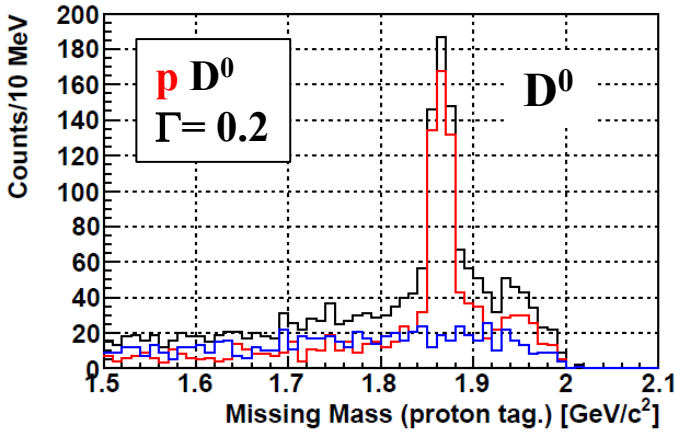






W/ $\Lambda_c^+ \pi^+ \pi^-$ selected





Decay measurement strongly assists the missing mass spectroscopy.

- **Branching ratios: $\Gamma(\Lambda_c^* \rightarrow p\ D)/\Gamma(\Lambda_c^* \rightarrow \Sigma_c \pi)$**
- **Angular distribution**

*** Both $\bar{D}^0 \rightarrow K^+ \pi^-$ (3.88%) & $\bar{D}^0 \rightarrow K^+ \pi^- \pi^+ \pi^-$ (8.07%) can be used.**

Summary

- **Investigation of internal structure of hadron from charmed baryon spectroscopy**
  - **What is the building block of hadron ? : Diquark**

  ⇒ Systematic study of excited charmed baryons

  ∗ Missing mass spectroscopy

- **Experiment at the J-PARC high-momentum beam line**
  - **Spectrometer**
    - **High resolution & Lager acceptance spectrometer**
  - **Experimental feasibility being checked by simulation**
    - **Enough mass resolution**
    - **Background study: D* tagging & Event selections**

      ⇒ Level of 0.1 nb
    - **Decay measurement to help missing mass measurement**

∗ Systematic study of charmed baryons at J-PARC

– Excitation energy, production, decay