Charmed baryon spectroscopy experiment at J-PARC high-p beam line

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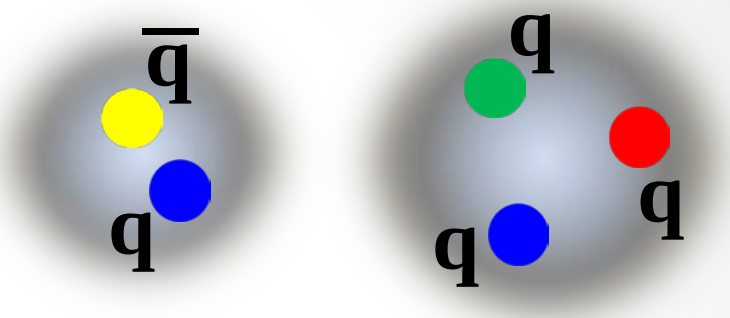
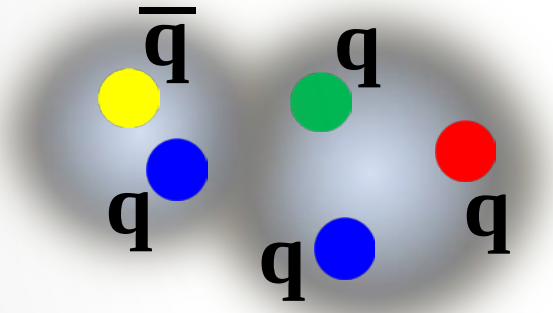
- **Summary**

Physics motivation

What is a building block of hadrons ?

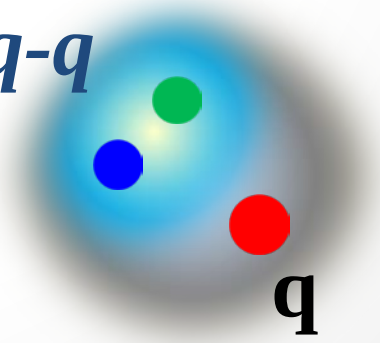
Constituent Quark





Exotic hadron

q-q correlation (diquark)

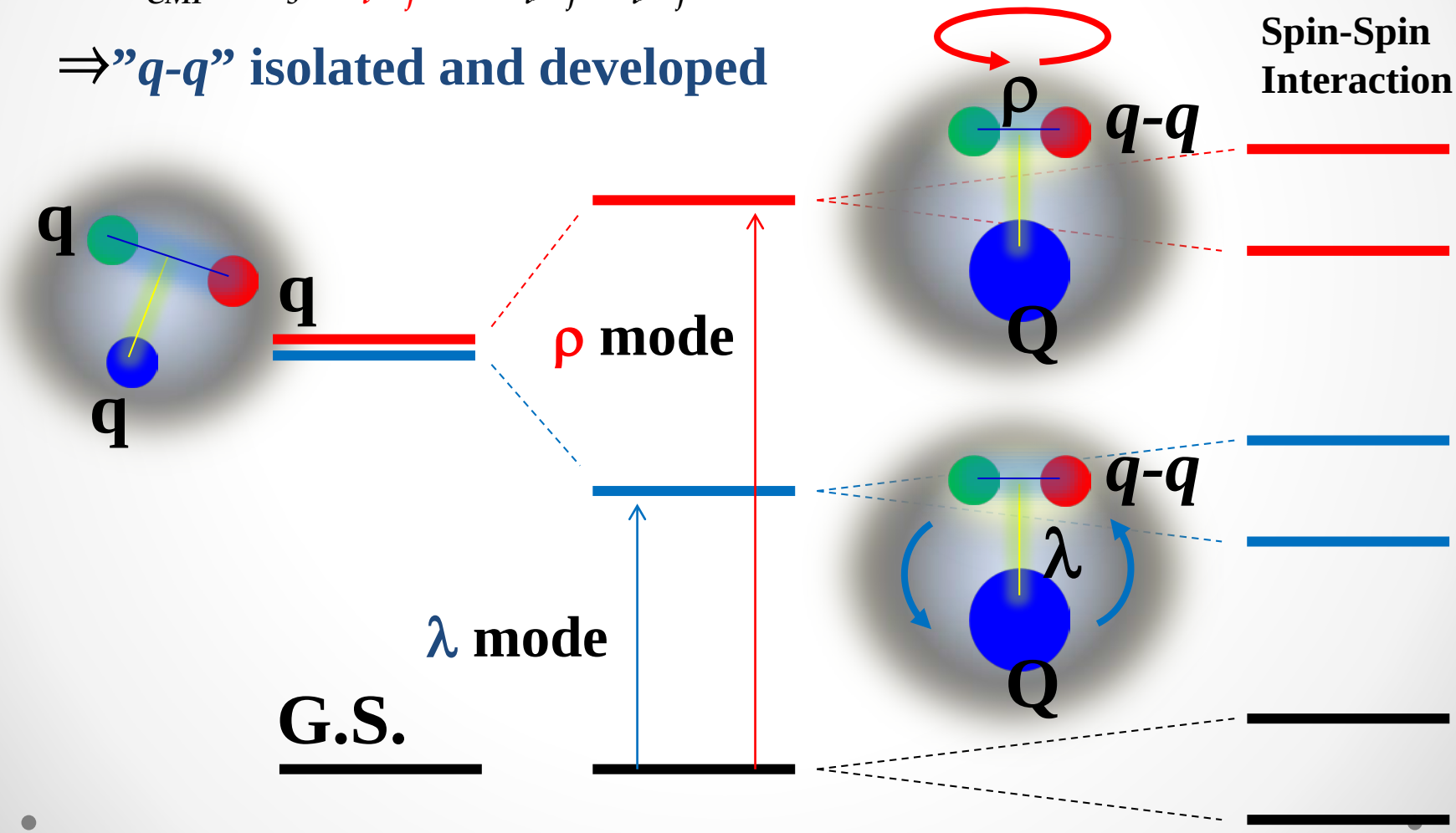


Charmed baryon spectrum

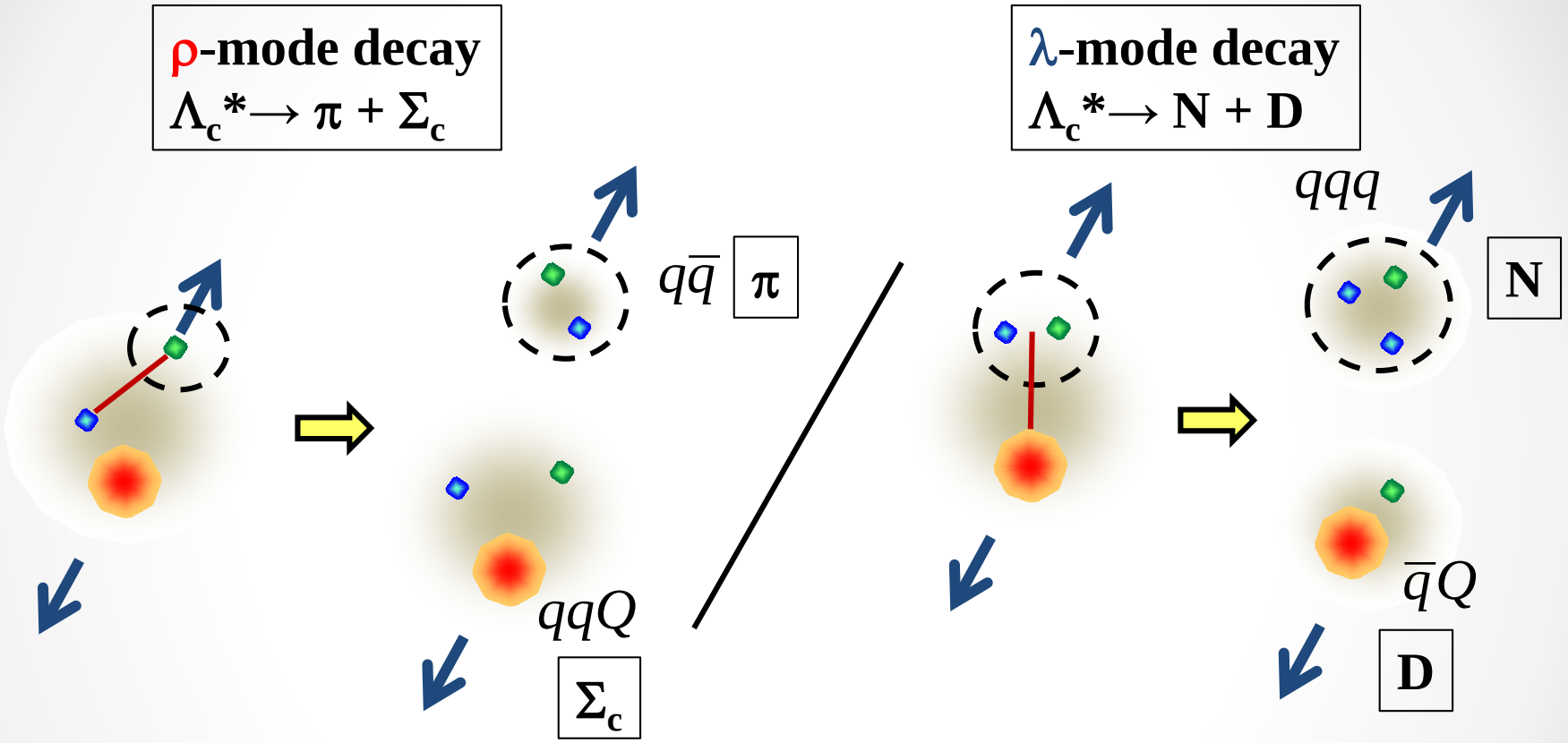
Heavy Quark: Weak color-magnetic interaction

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

$\Rightarrow$ *"q-q" isolated and developed*



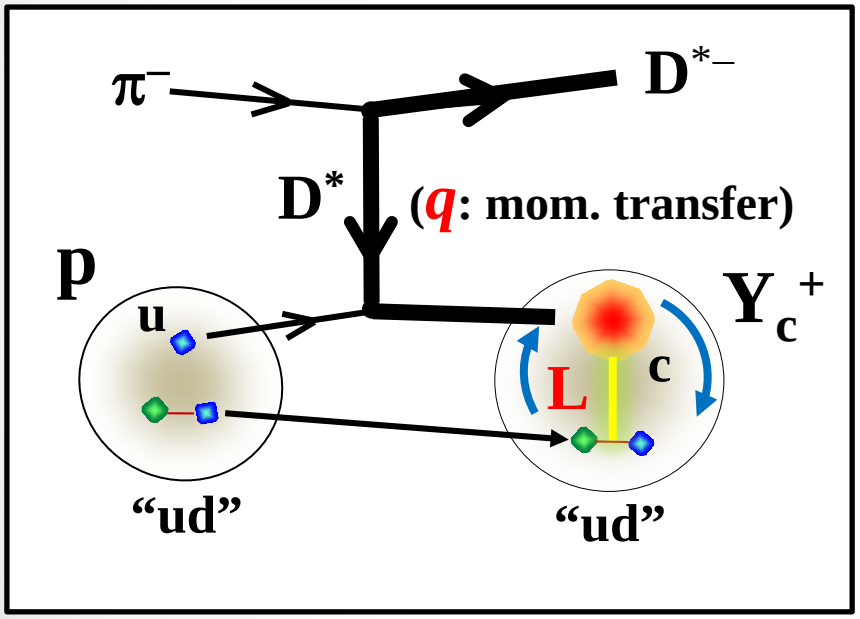
Decay property



- **Decay measurement: $\Gamma_{\pi\Sigma c} \Leftrightarrow \Gamma_{ND}$**
  - $\pi^- + \Sigma_c^{++}$, $\pi^+ + \Sigma_c^0$
  - $p + D^0$

Production cross section

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



*D** exchange at a forward angle

Production cross section

⇒ Overlap of wave function

∗ charm and q-q (spectator)

1. Spin/Isospin of Y_c^*

2. Momentum transfer (q_{eff})

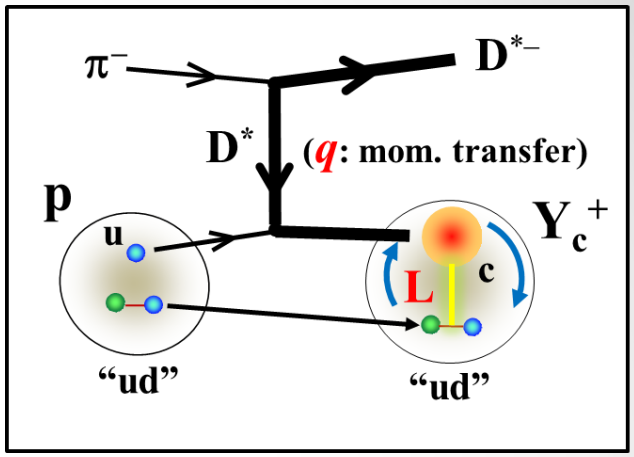
$$I_L \sim (q_{eff}/A)^L \exp(-q_{eff}^2/2A^2)$$

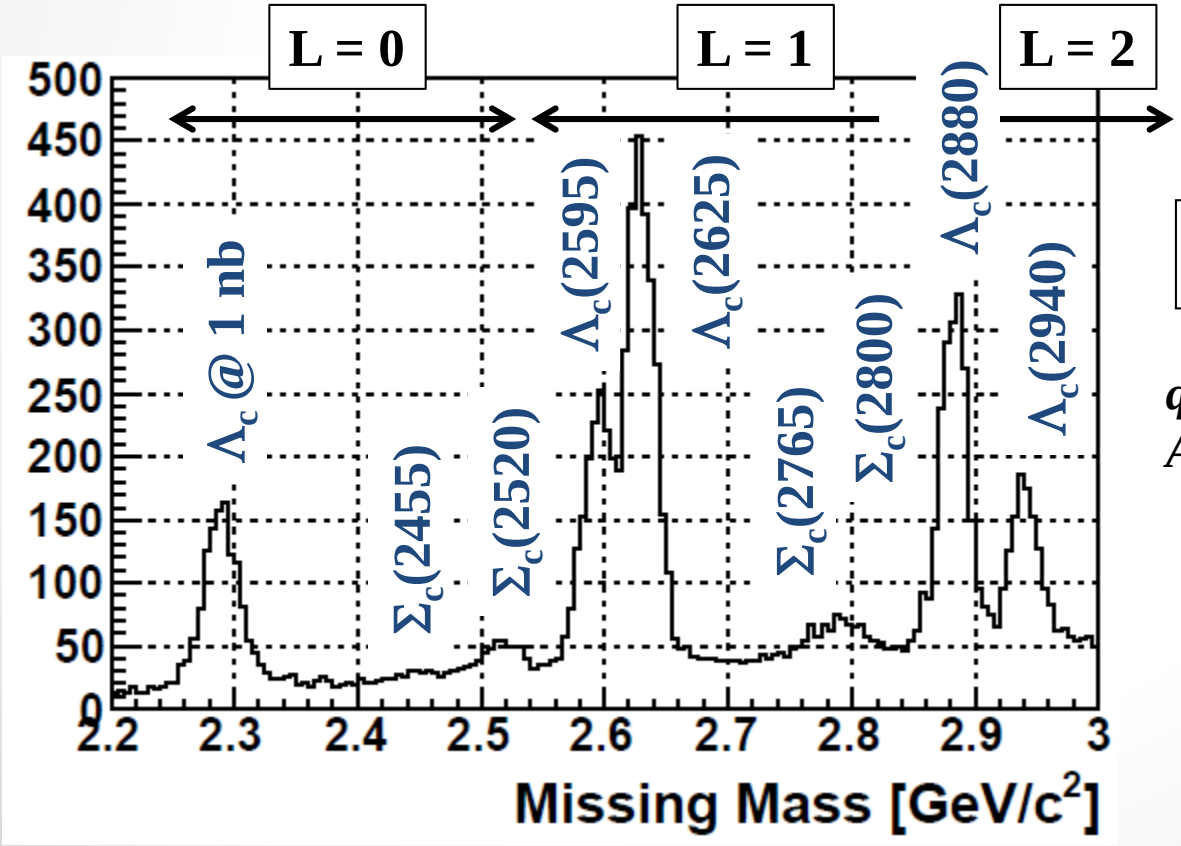
***A*: (baryon size parameter)$^{-1}$**

Production cross section

Production rate: Excitation mode

- Forward: λ-mode (Λ*)
- (Backward: ρ-mode (Σ*) ?)





$$I_L / I_{g.s.} \sim (q_{eff}/A)^L$$

q_{eff}: Momentum transfer
A: (baryon size parameter)$^{-1}$

Charmed baryon spectroscopy

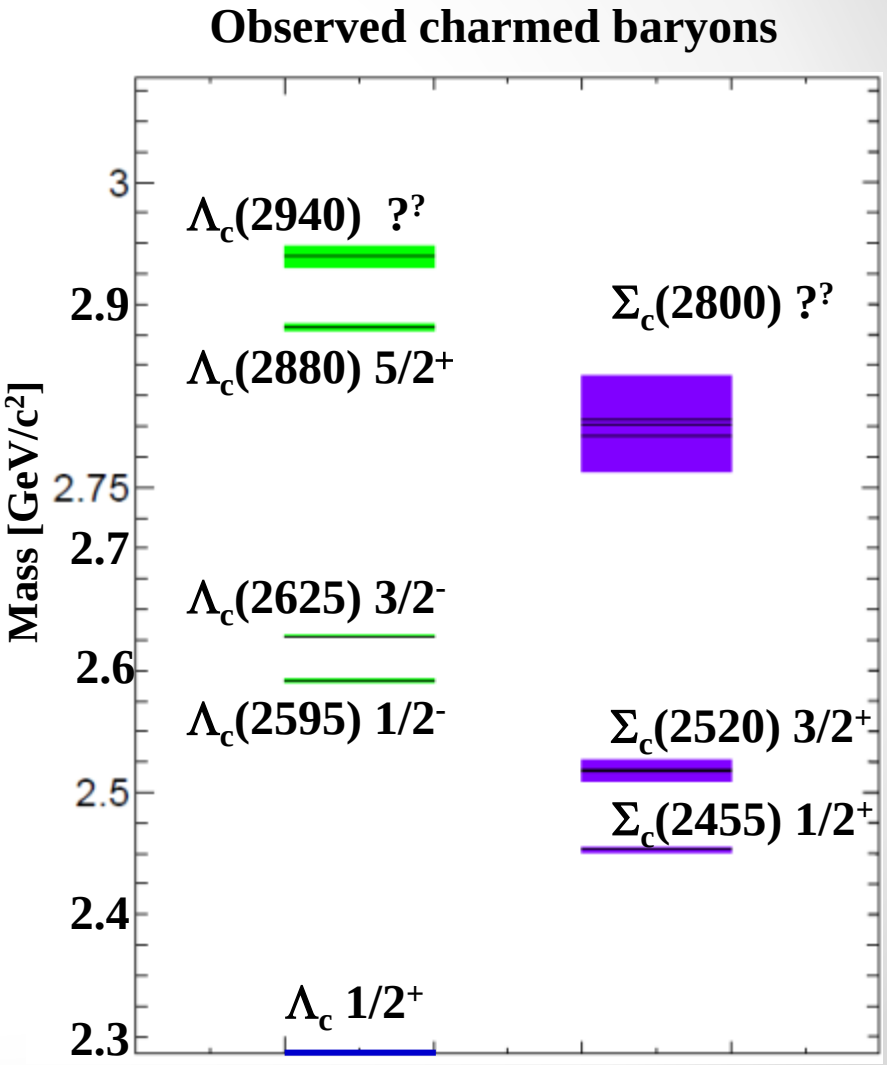
Propose

- **Investigate charmed baryons**

⇒ Missing mass spectroscopy

- **Systematic measurement**
  - **Excited states search**
  - **Excitation energy**
  - **Decay property**
  - **Production cross section**

⇒ Diquark correlation
  - **Excitation mode**



Experiment

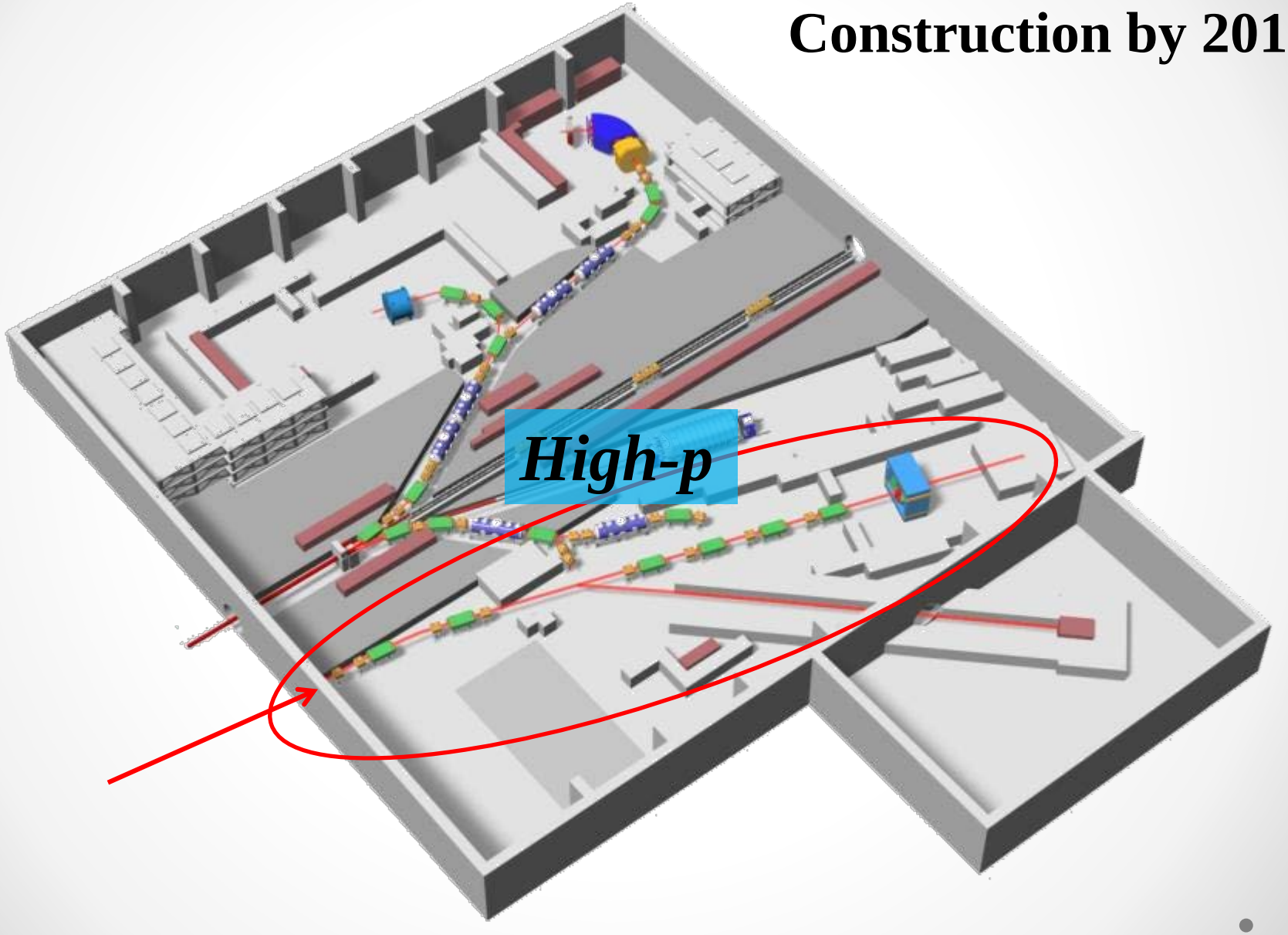
High-momentum beam line

Spectrometer system

Simulations

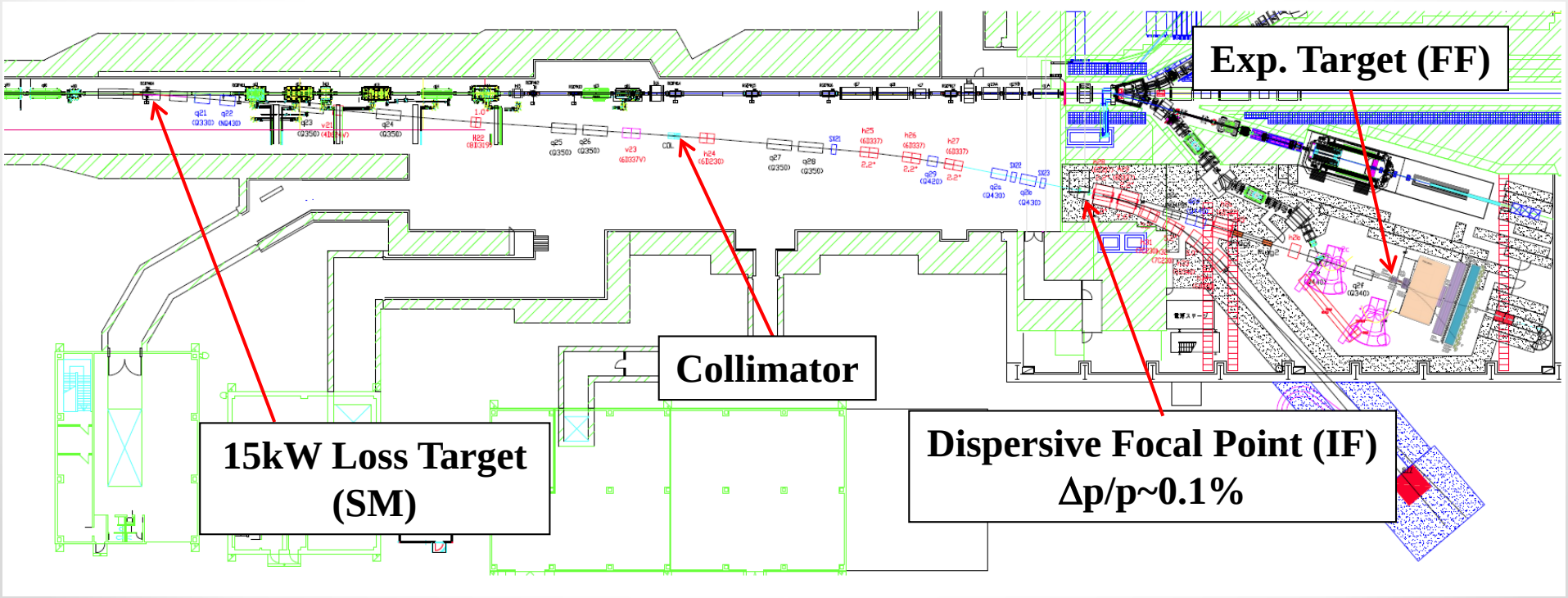
High-momentum beam line

Construction by 2015



High-momentum beam line for 2ndary beam

- **High-intensity beam:** > 1.0×10^7 Hz π (< 20 GeV/c)
  - Unseparated beam
- **High-resolution beam:** Δp/p ~ 0.1%(rms)
  - Dispersive optics method



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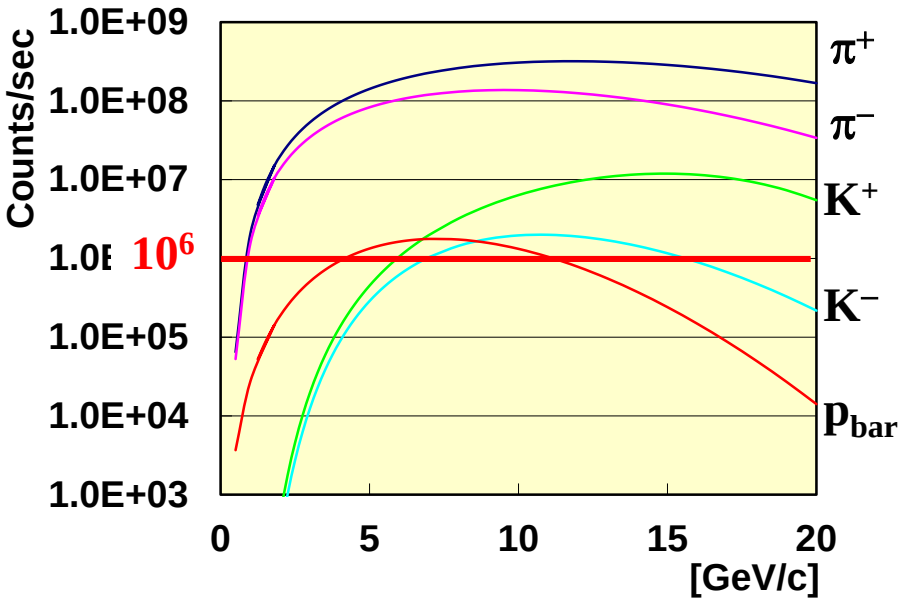
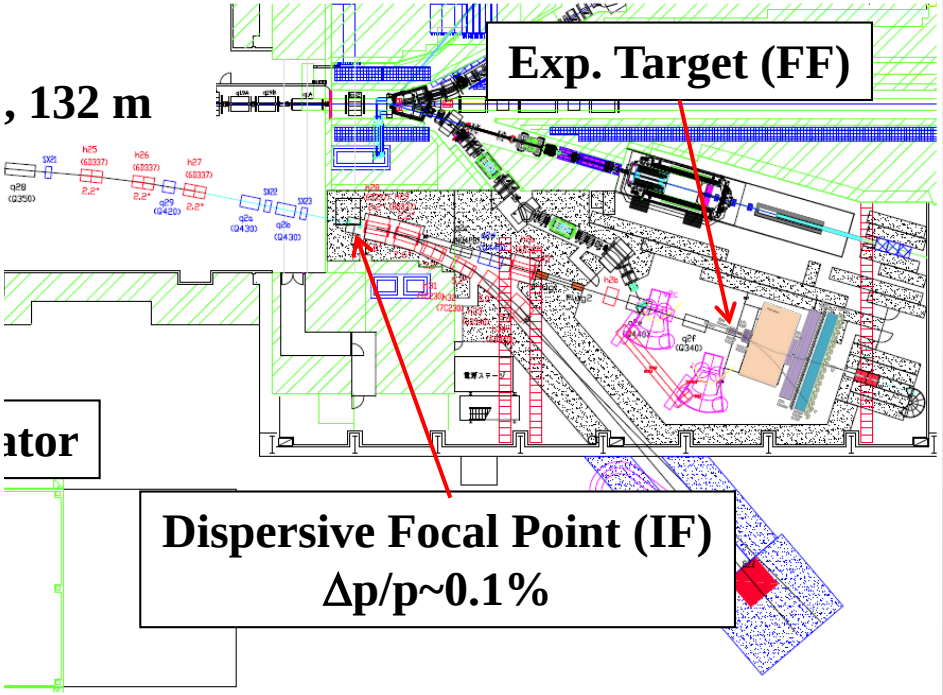
Sanford-Wang

Prod. Angle =0 degrees

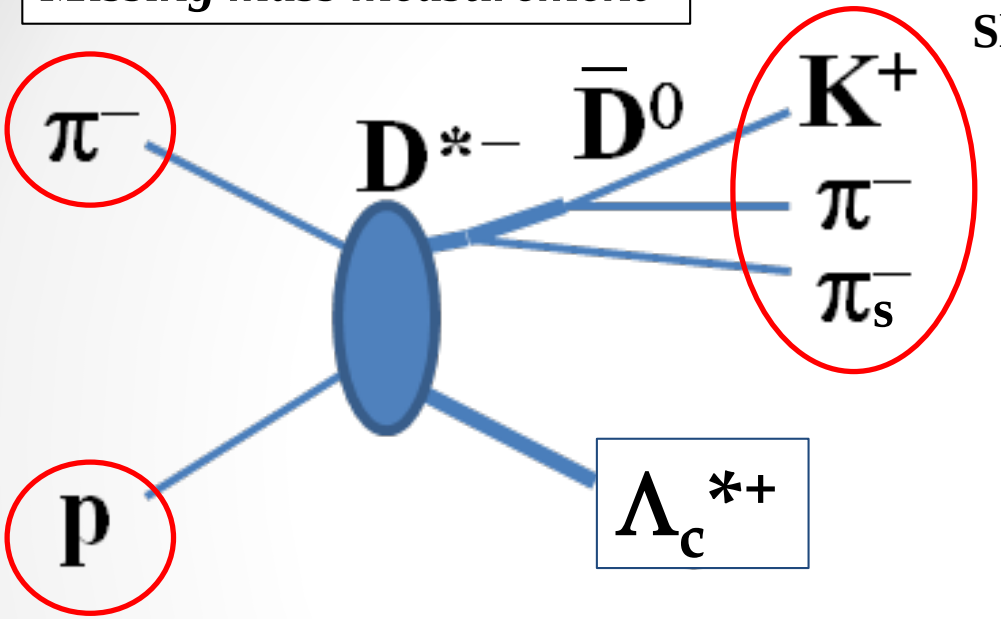
15 kW Loss on Pt, Acceptance :2 msr%, 132 m





Experiment

Missing mass measurement



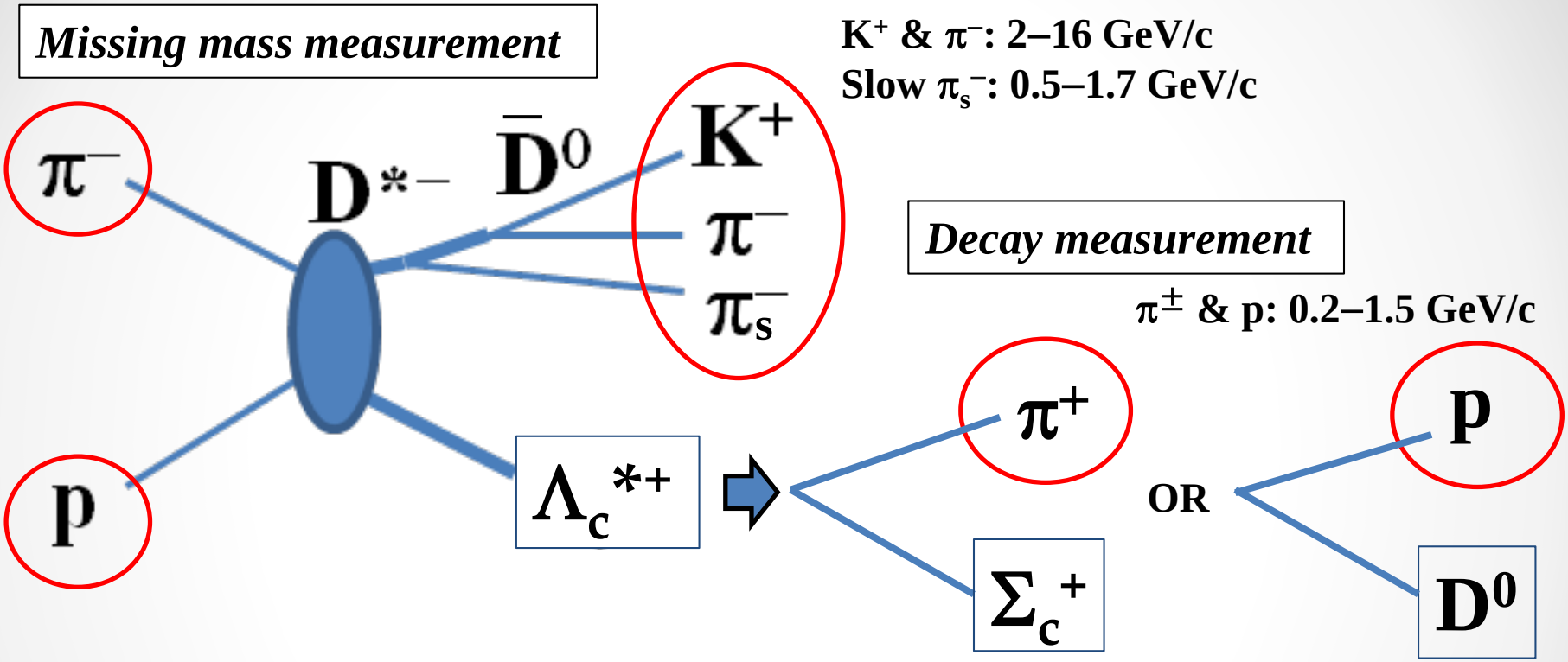
K^+ & π^-: 2–16 GeV/c
Slow π_s^-: 0.5–1.7 GeV/c

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



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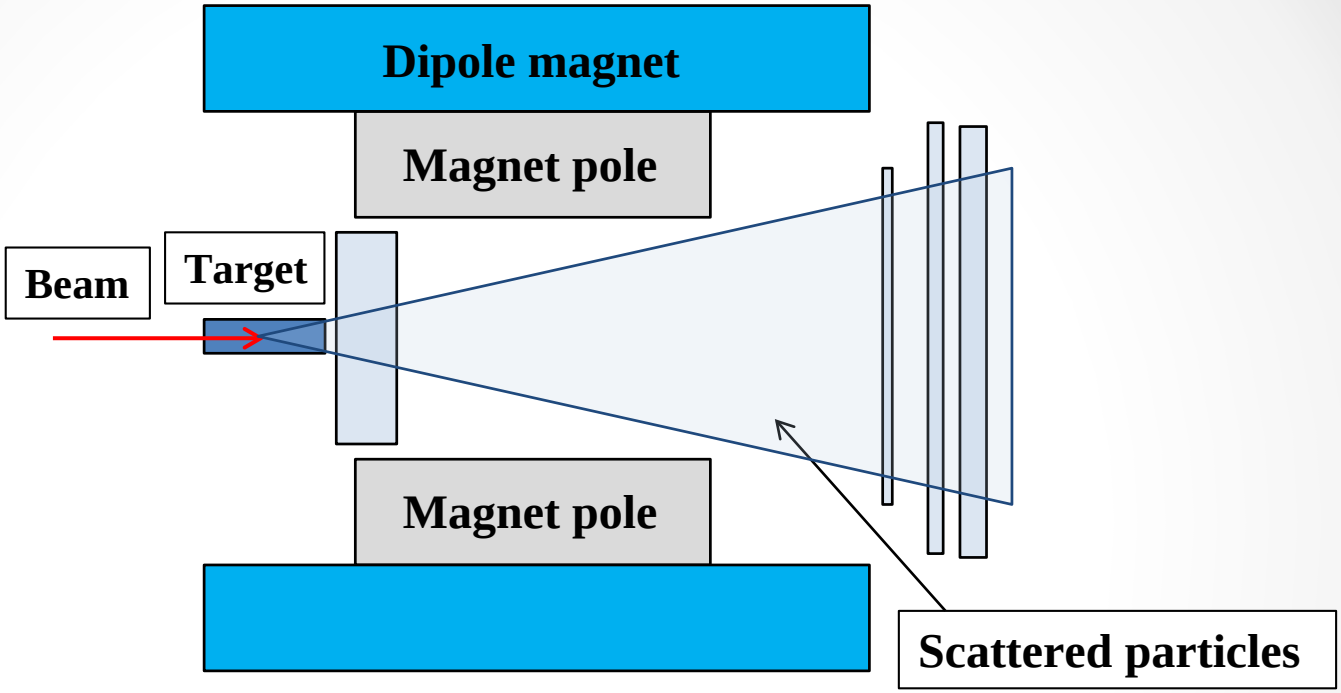
2) Decay measurement
   - Decay particles ($\pi^{\pm}$& proton) from Y_c^*

Experimental design

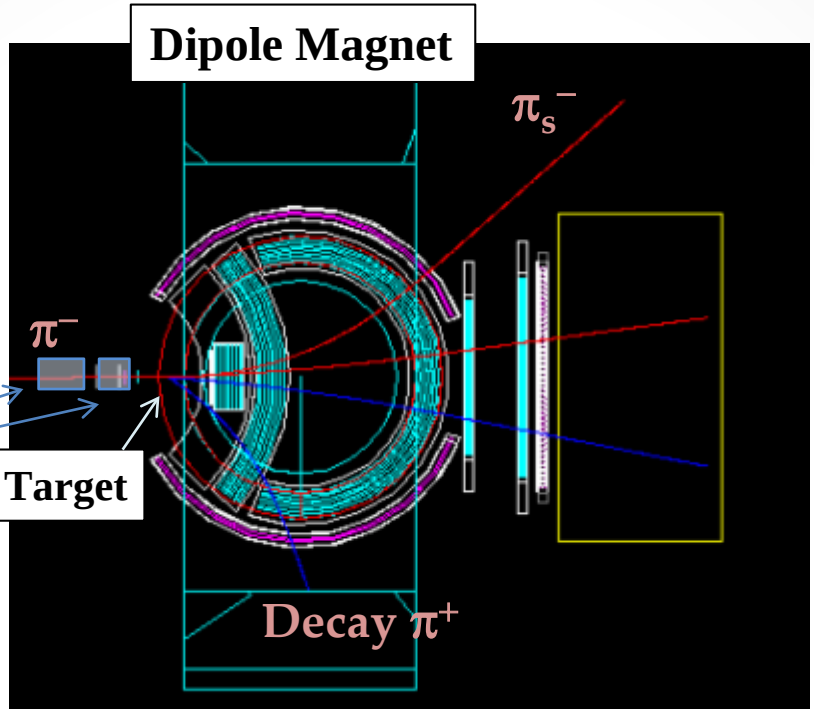


✻ **Assumed production cross section: σ ~ 1 nb**

- $\pi^- + p \rightarrow \Lambda_c^+ + D^{*-}$ reaction @ 13 GeV/c: σ < 7 nb (BNL data)

- **Dipole-magnet spectrometer**
  - **High-resolution: Δp/p < 1%**
- **High-rate beam & High-rate detector system**
  - **Beam intensity: 6×10^7 /2.0 sec spill (~1 MHz/mm)**

Experimental design



Beam measurement
- Fiber trackers
- Beam Cherenkov

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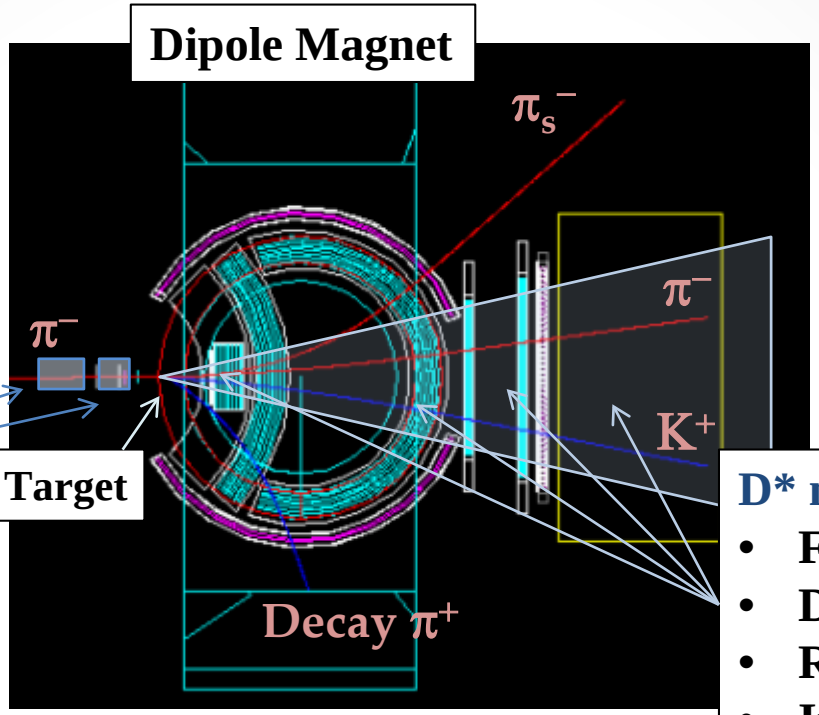

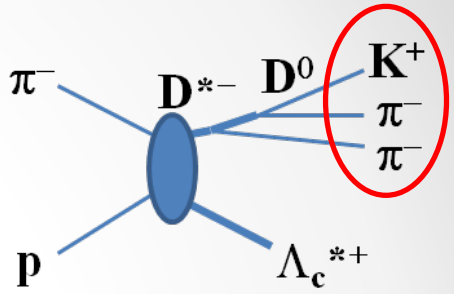

Beam measurement
- Fiber trackers
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D* measurement
- Fiber trackers
- Downstream DC, TOF
- Ring Image Cherenkov
- Internal DCs

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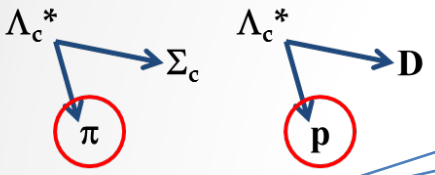
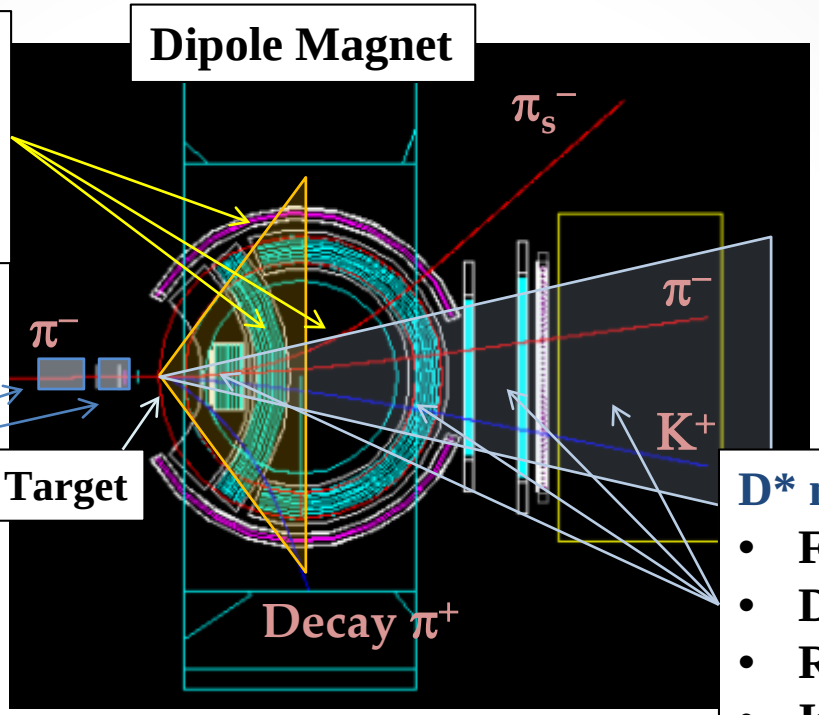
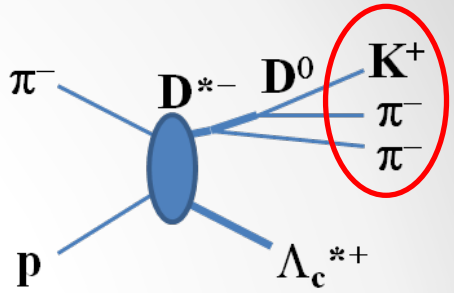
Experimental design

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







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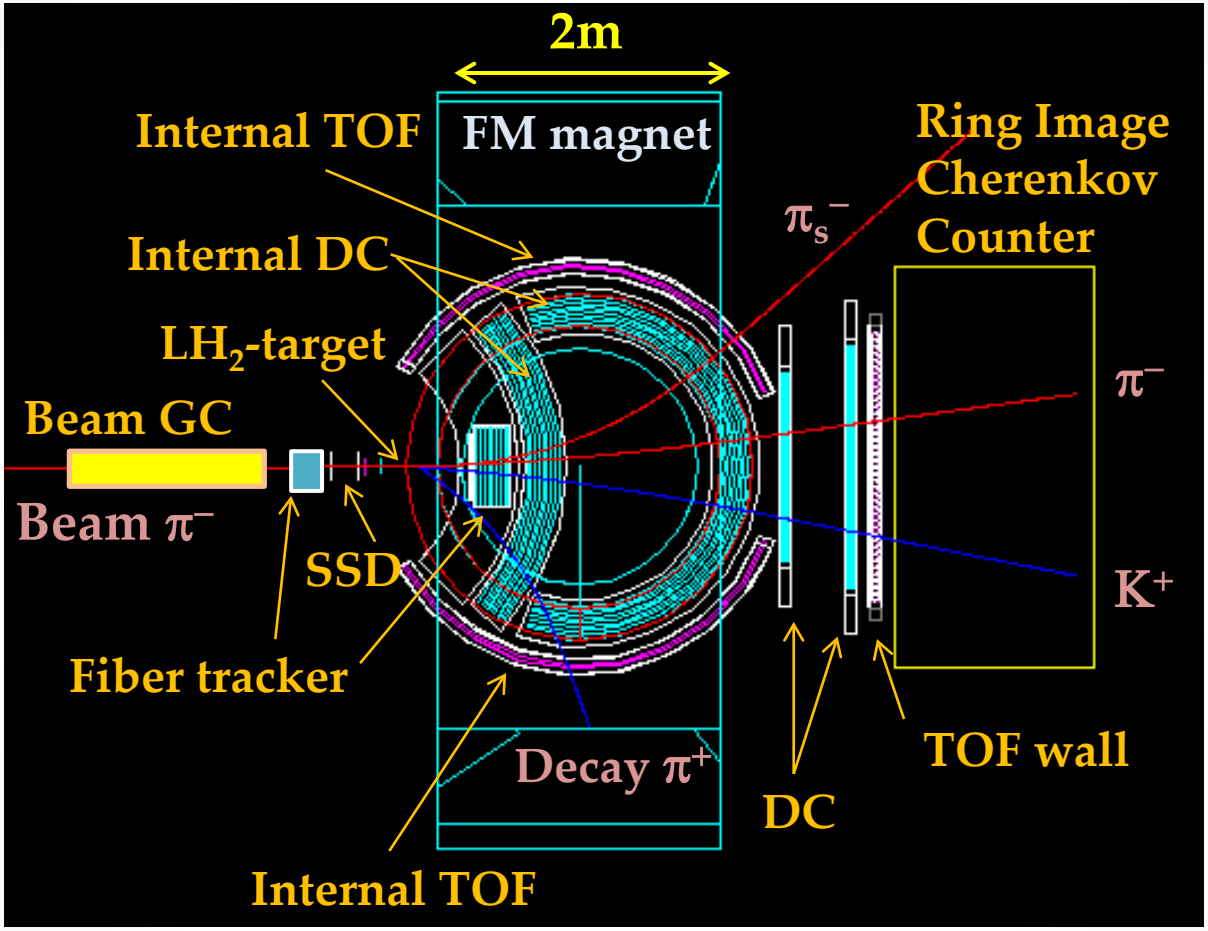
Charmed baryon spectrometer

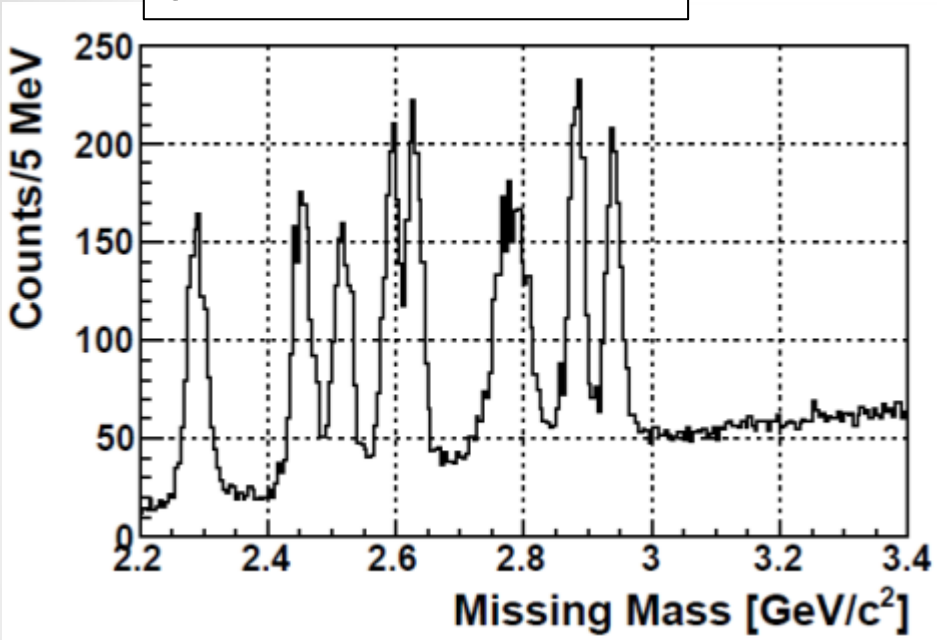


Large Acceptance Multi-Particle Spectrometer

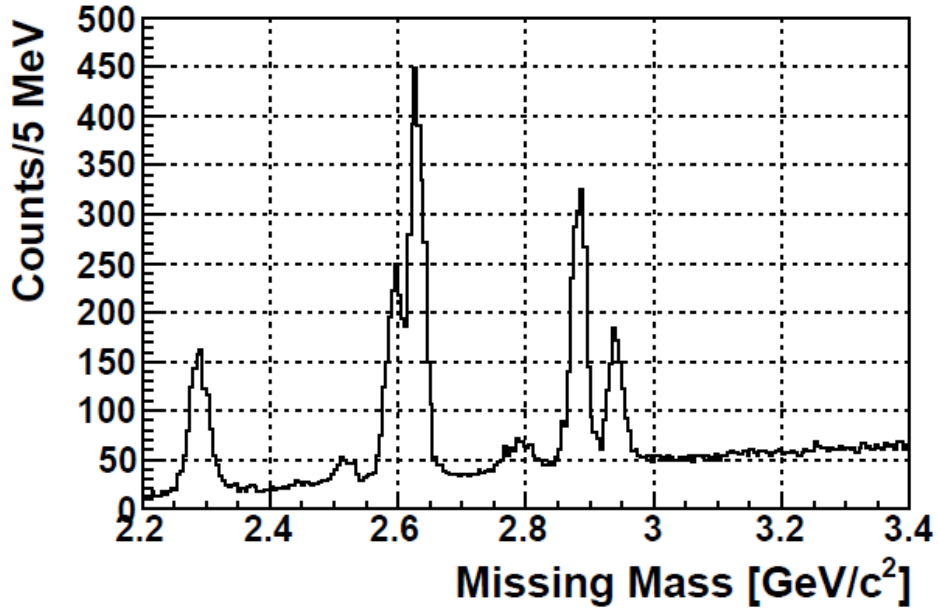
- **Acceptance: ~50% for D***
- **Mass resolution: $M_{\Lambda c^*}$ = 10 MeV(rms) @ 2.7 GeV/c^2**

Expected spectra: σ = 1 nb

σ = 1 nb case for each state



G.S. = 1 nb & production ratio



Known Mass & Width in PDG

- Background study by the JAM code

⇒ Reduction by D* tagging + Event selections

  - $D^0 \rightarrow K^+ \pi^-$ decay angle cut, production angle cut

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

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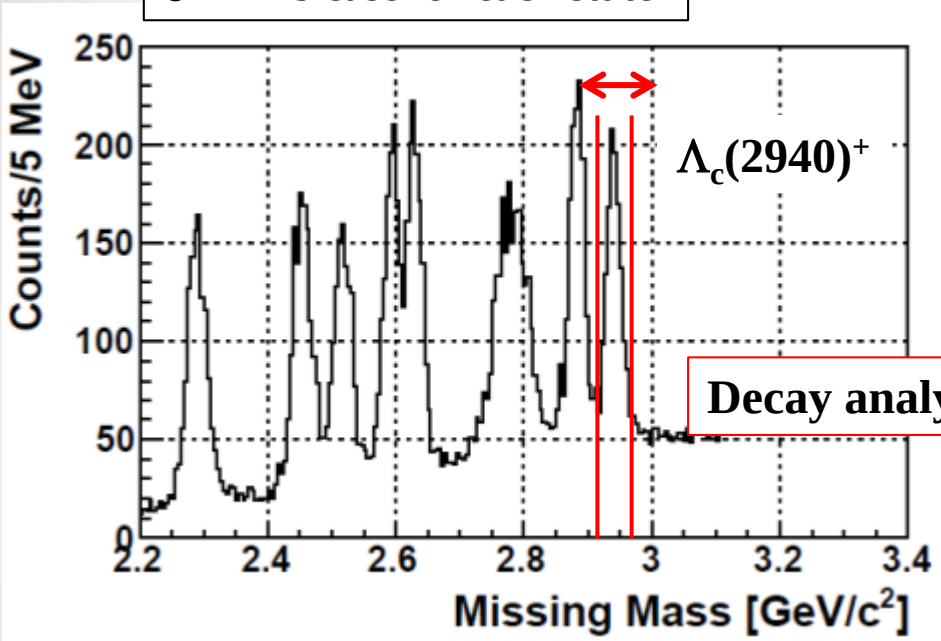
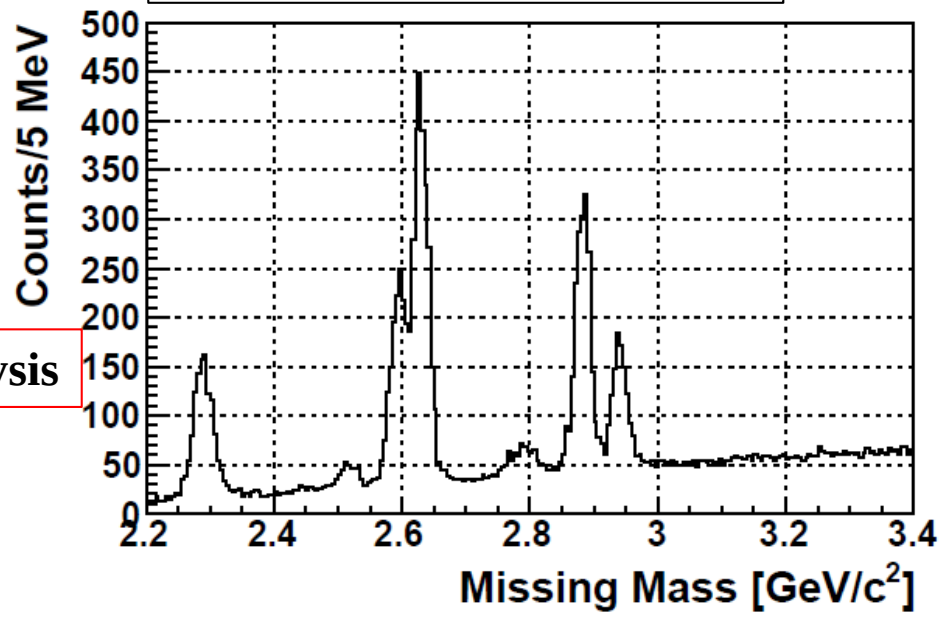


Decay analysis

G.S. = 1 nb & production ratio



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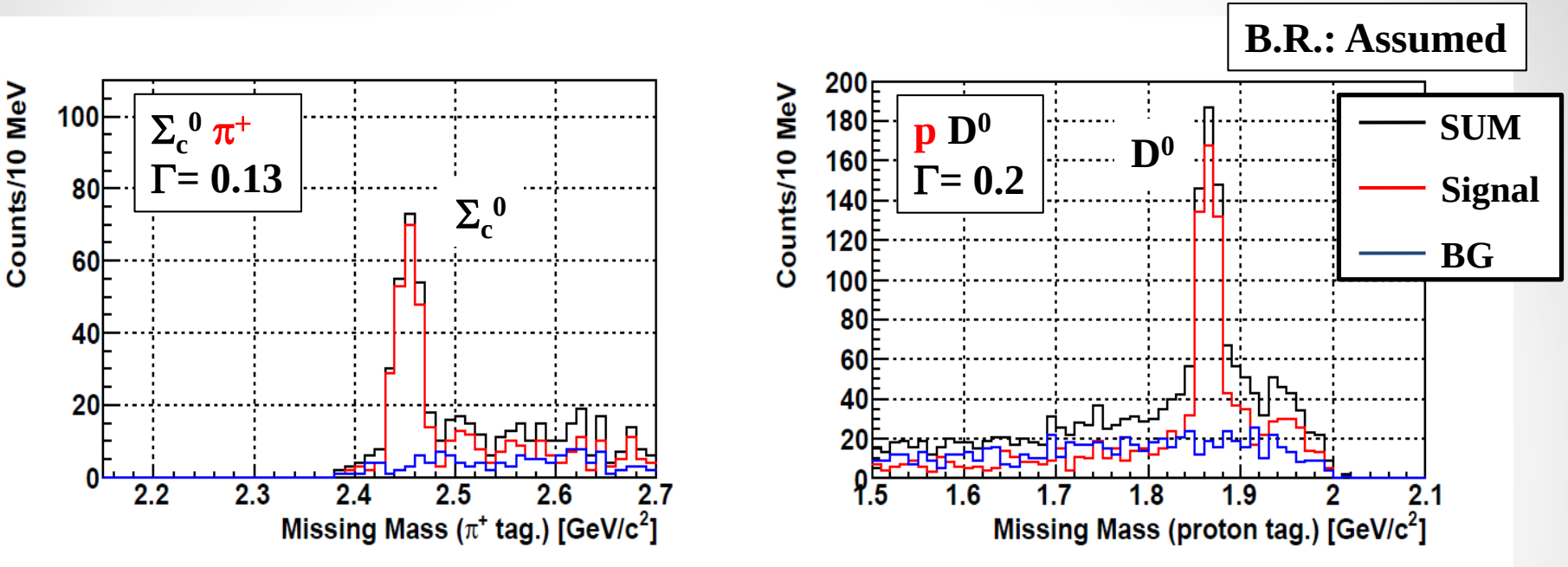
Decay measurement



Decay measurement

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

- **$D^0 \rightarrow K^+\ \pi^-$ (3.88%): Main mode**
  + $D^0 \rightarrow K^+\ \pi^-\ \pi^+\ \pi^-$ (8.07%), $D^0 \rightarrow K_S^0\ \pi^+\ \pi^-$ (2.82%) modes
  - **~4 time more statistics**

Systematic study

Charm and Strange

Strangeness sector: Production

Yield: 10^5–10^6 /day @ 1 μb

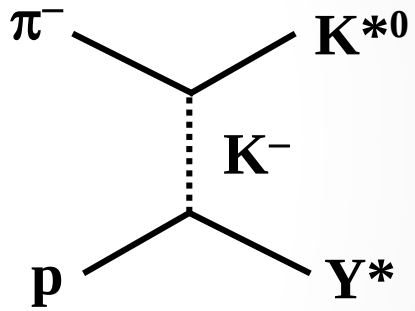
- π beam of a few 10 M/spill
- Mass resolution: 10–20 MeV @ 5–10 GeV/c beam
- K beam = 10^6: ~10^4 /day @ 1 μb

∗ Missing mass & decay analysis

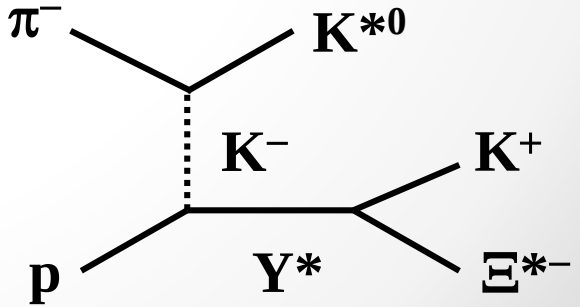
- **Λ*, Σ* states**
  - $\pi^- + p \rightarrow \Lambda^*(\Sigma^*) + K^{*0}$: σ ~ 1–10 μb
- **Ξ* and Ω* search**
  - $K^- + p \rightarrow \Xi^* + K\ (K^*)$: σ ~ 1–10 μb
  - $\pi^- + p \rightarrow \Xi^* + K + K$: σ ~ 0.1–1 μb
    - Both K and π beam
  - $K^- + p \rightarrow \Omega^* + K + K$: σ ~ 0.1–1 μb

∗ K^+ or K^{*0} detections are important for strangeness tagging.

π-induced Y* production



π-induced Ξ* production



Excitation mode

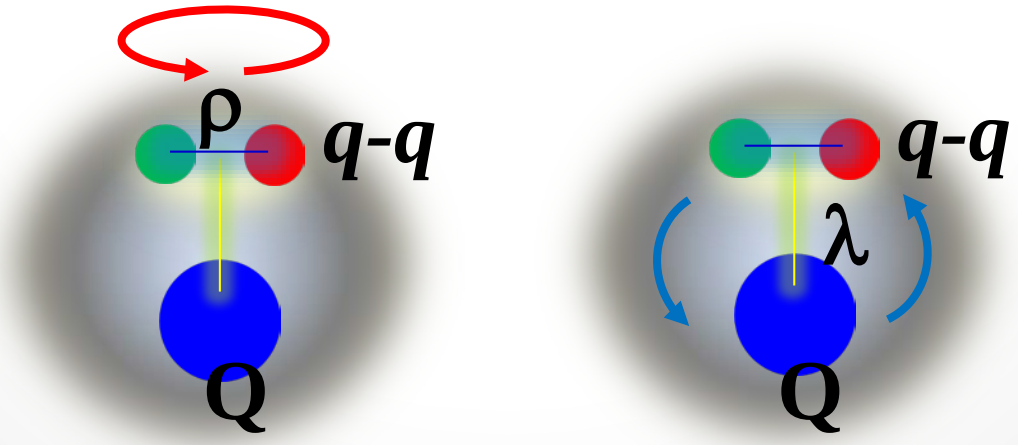
- **Heavy Q: λ and ρ-mode**

⇒ M_Q dependence of excitation spectrum

- **Charmed baryons: Y_c***
- **Hyperons: Y***

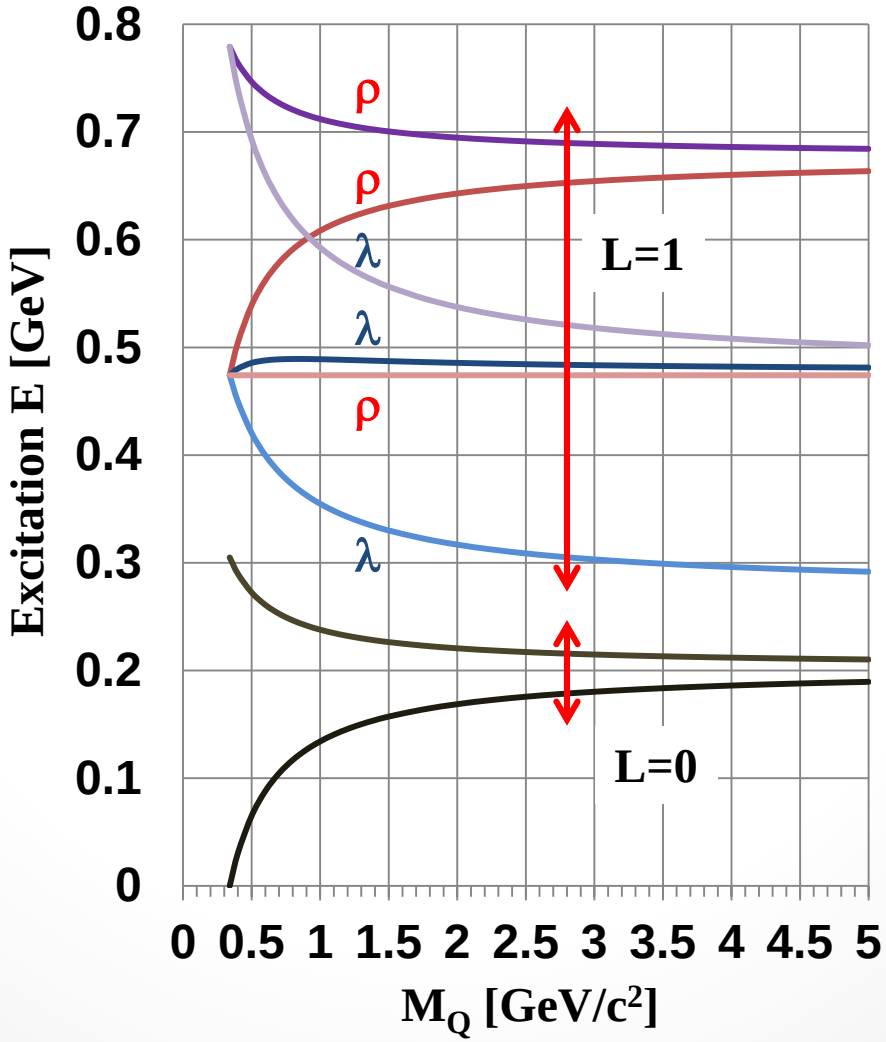
*** spin-spin: $H = H_0 + V_c + V_{ss}$**

- $V_c = k/2 \sum r_i^2$
- $V_{ss} = c_s \sum \frac{\sigma_i \cdot \sigma_j}{m_i m_j} \delta(r_{ij})$



Excitation spectrum

- **L=1 excited states: spin-spin interaction**



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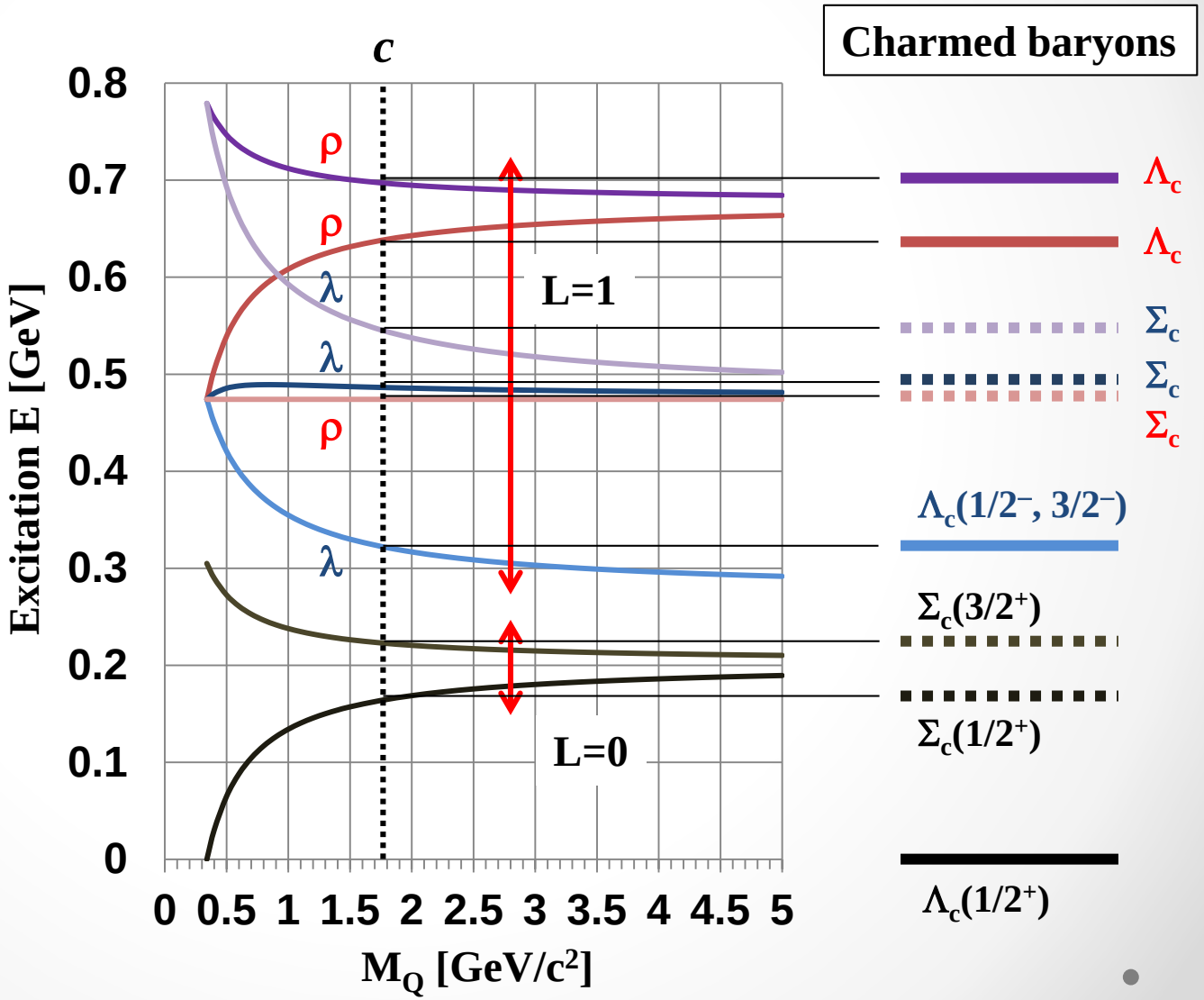

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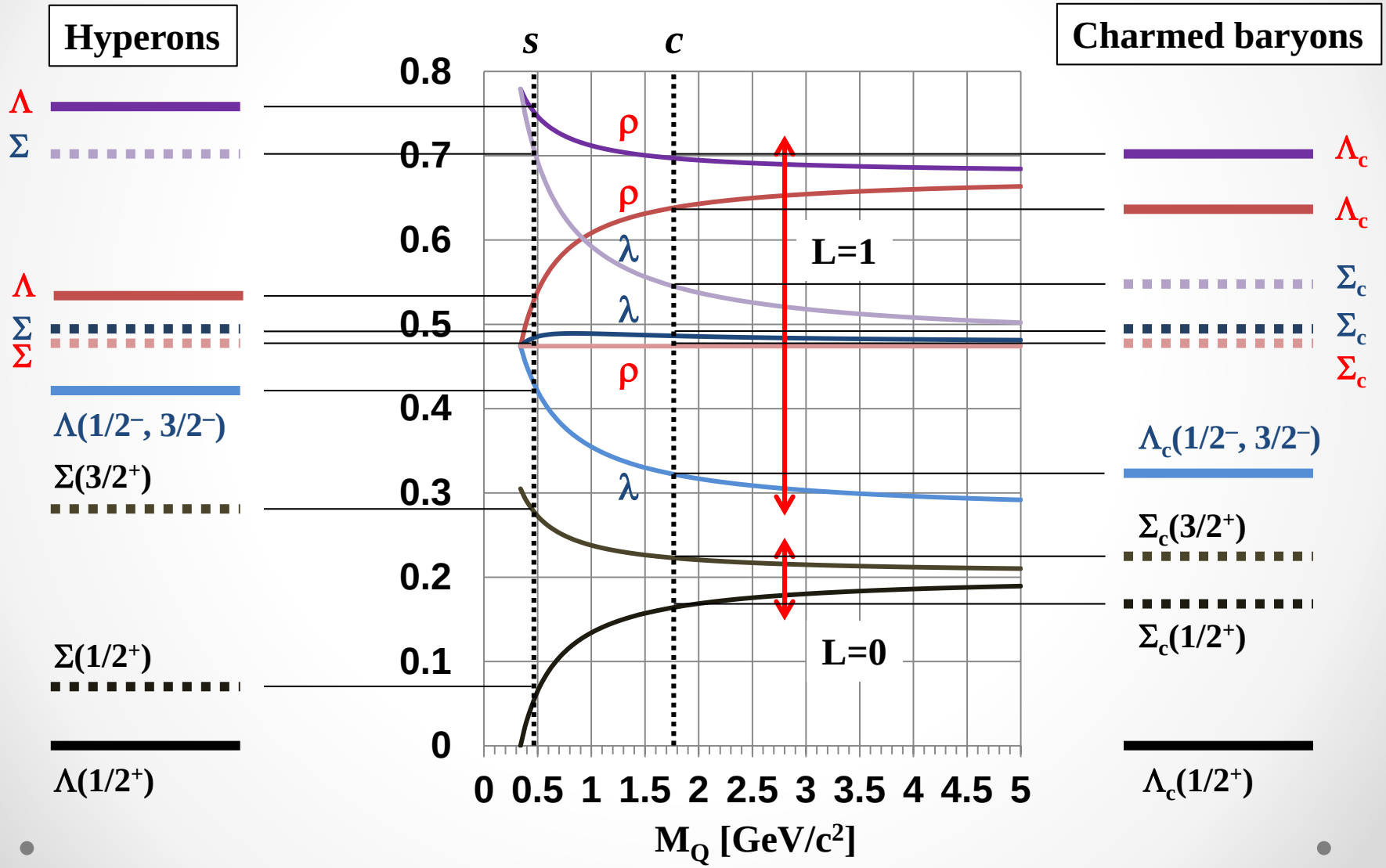


Systematic study

- **Excited state measurements**

Hyperons

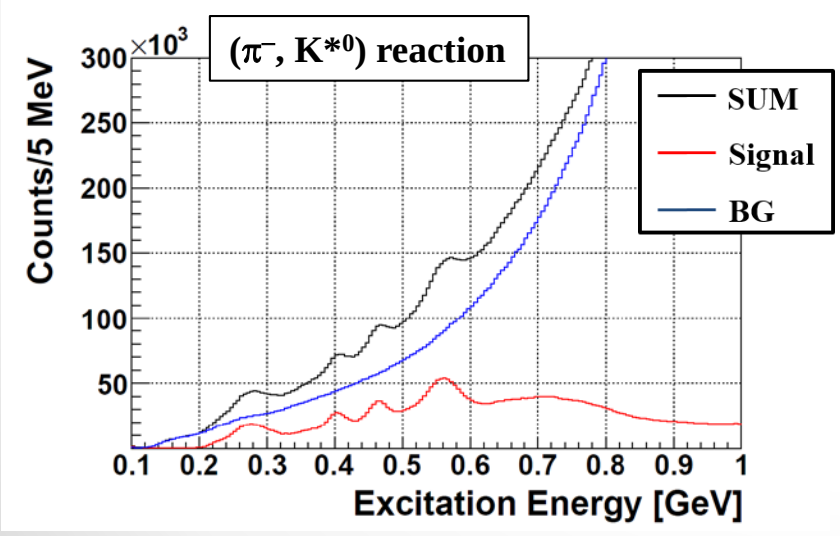
- **Decay property: $\pi\Sigma/K_{bar}N$**
- **Production angle/rate**

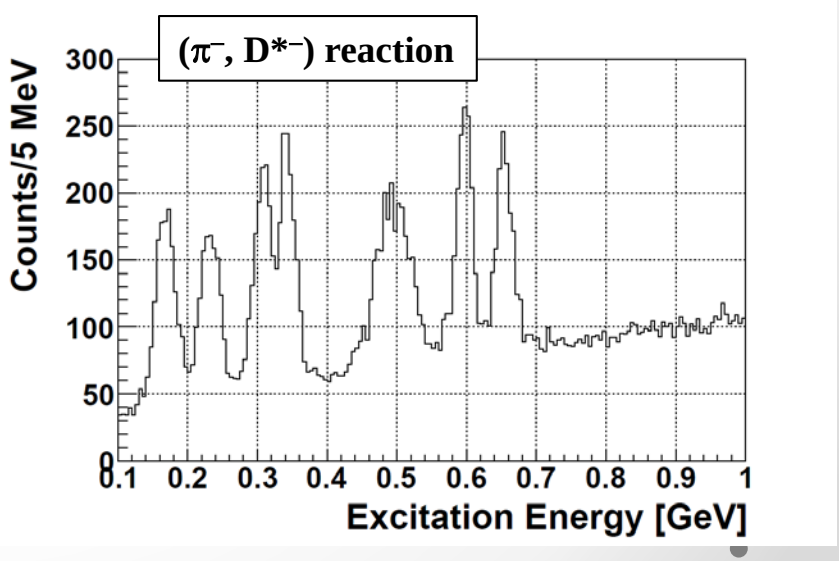
Wider width states: ~100 MeV
⇒ Decomposition needed
Huge statistics: ~10^6 /day

Charmed baryons

- **Decay property: $\pi\Sigma_c/DN$**
- **Production angle/rate**

Narrower width states
⇒ Clear separation
Better S/N (1 nb case)





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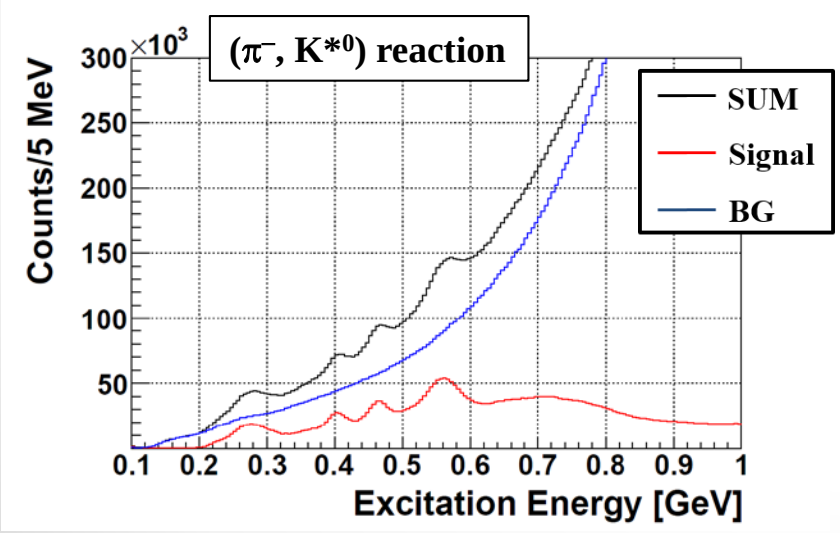

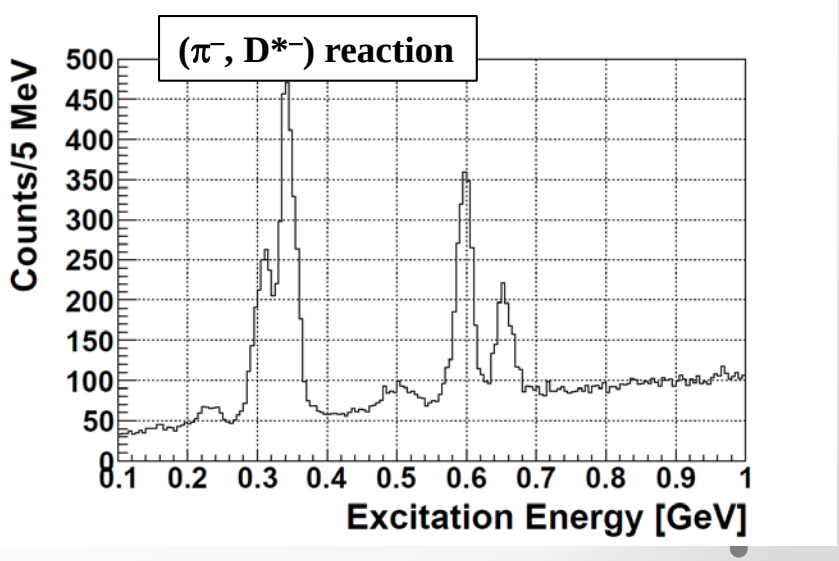

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Proper degree of freedom = Rule to understand structure

- **Connection to QCD**

⇒ How to describe differences (corrections) ?

e.g. Diquark: Just correlation between two constituent quarks ?
or Quasi-particle object of two quarks ?

＊ Essential step to understand low energy QCD nature

Summary

- **Charmed baryon spectroscopy**
  - **Diquark correlation: λ and ρ excitation mode**
  - **Inclusive measurements by missing mass spectroscopy**

- **Experiment at the J-PARC high-p beam line**
  - **Spectrometer**
    - **High resolution & Lager acceptance spectrometer**
  - **Experimental feasibility being checked by simulation**
    - **Mass resolution**
    - **Background study**
    - **Decay measurement to help missing mass measurement**

- **Systematic study of charmed baryons at J-PARC**
  - **Excitation energy, production, decay**
    - **With strange sector**

New project at J-PARC

New Hadron Experiment
at the J-PARC High-p beam line

Let's join us !

Thank you for your attention