Charmed-hadron experiments at J-PARC

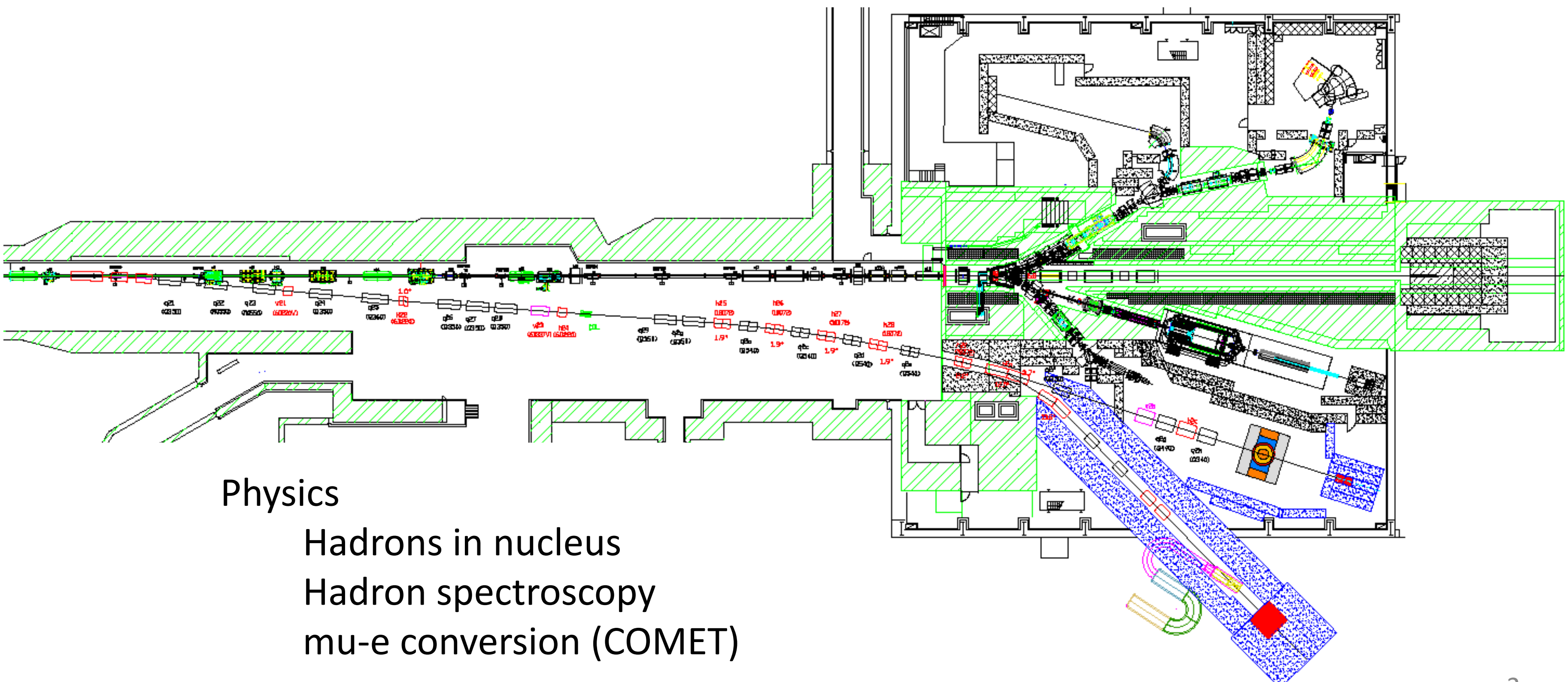
K. Ozawa (KEK), H. Noumi (RCNP)

Content

New High Momentum Beam Line

Construction of New Beam Line is proposed.
Characteristics of the beam line is following.

- Primary Proton Beam (30GeV), $10^{10\text{-}12}$ per spill
- High Momentum un-separated secondary beam ($\leq$15GeV/c), 10^{7} per spill
- Primary Proton Beam (8GeV) for COMET



Physics

- Hadrons in nucleus
- Hadron spectroscopy
- mu-e conversion (COMET)

Physics @ J-PARC high-p beam line

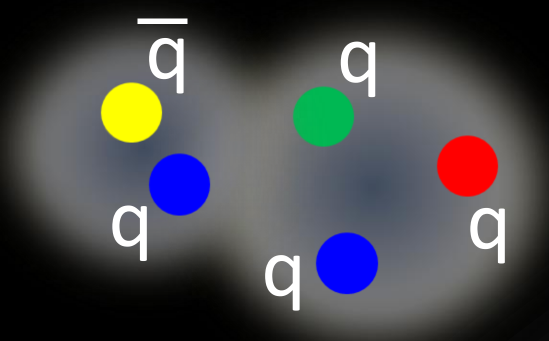
- **Hadrons in nucleus** -> Tomorrow
  - Hadron mass is dynamically generated and strongly related with medium properties.
  - **Experimental information of hadron mass in nucelus**

- **Hadron spectra**
  - Puzzles in hadron physics
    - States cannot be easily explained in simple manners
    - Unexpected states
  - **Internal structure of hadron** should be investigated.
    - Charmed baryon spectroscopy can provide essential information, especially for Di-quark correlations

CHARMED BARYON SPECTROSCOPY

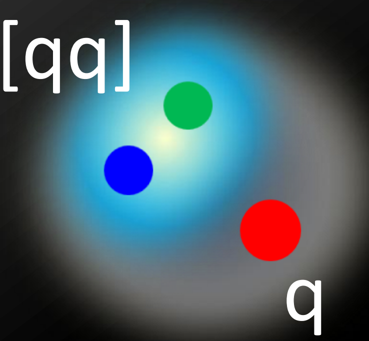
What are good building blocks of Hadrons?

Constituent Quark



hadron (colorless cluster)

Diquark?
(Colored cluster)



Diquarks

Color-Magnetic Interaction of two quarks

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

"Good Diquark": Strong Attraction

$$V_{CMI}(^1S_0, \bar{3}_c) = 1/2 * V_{CMI}(^1S_0, 1_c)$$

$[qq]$ $[\bar{q}q]$

Emergent Diquarks

Baryons as well as Mesons seem to be well described by a Rotating String Configuration with a universal string tension.

$$M^2 \sim \Omega * L$$

A distance of [qq]-q/$\bar{q}$-q increases as L increases.

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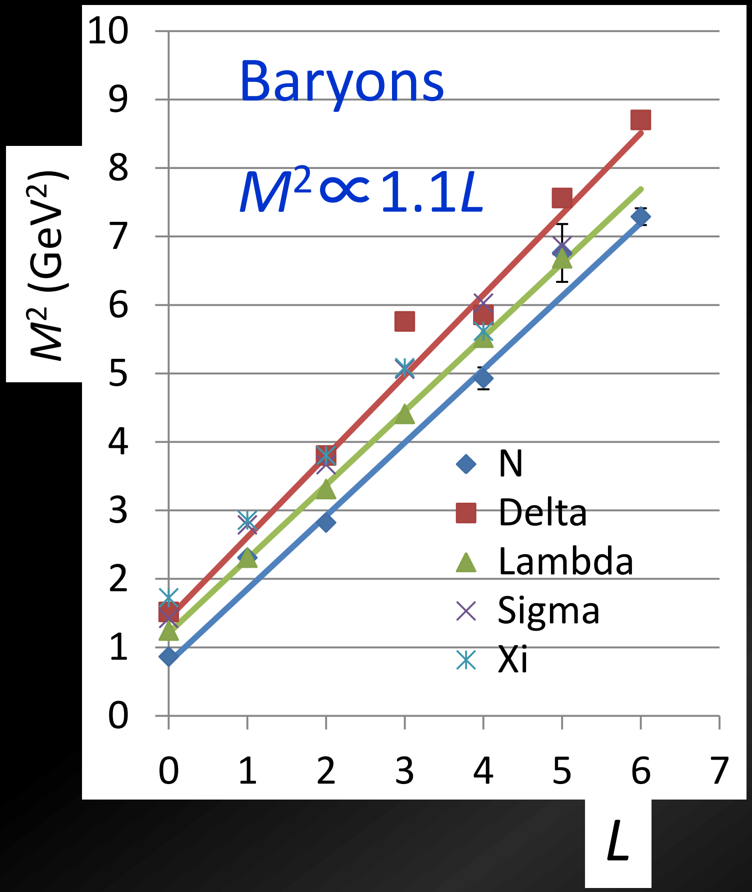

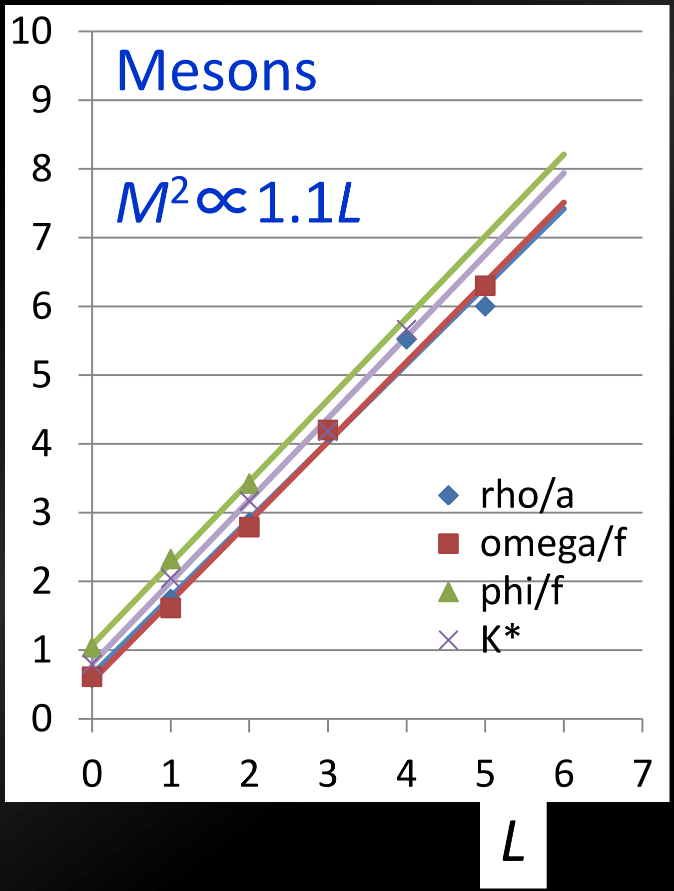

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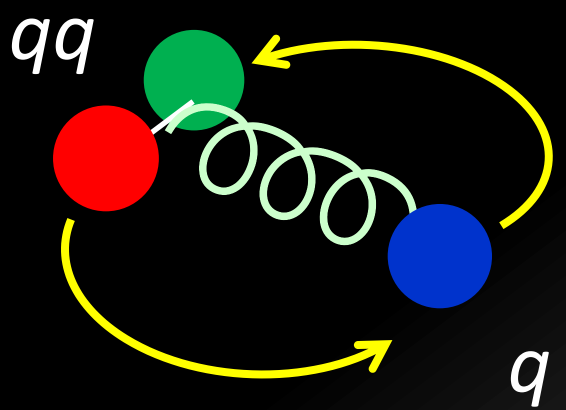
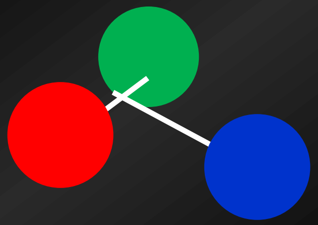
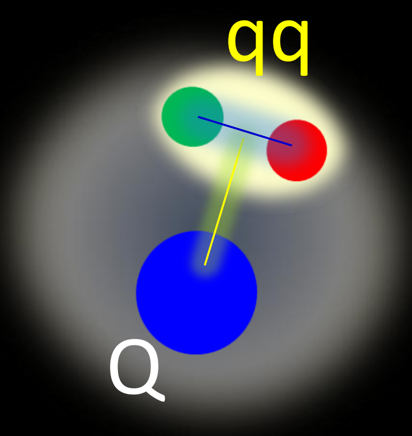


"diquark"
in low-lying modes



Charmed Baryon



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

Weak Color Magnetic Interaction
with a heavy Quark

- [qq] is well Isolated and developed

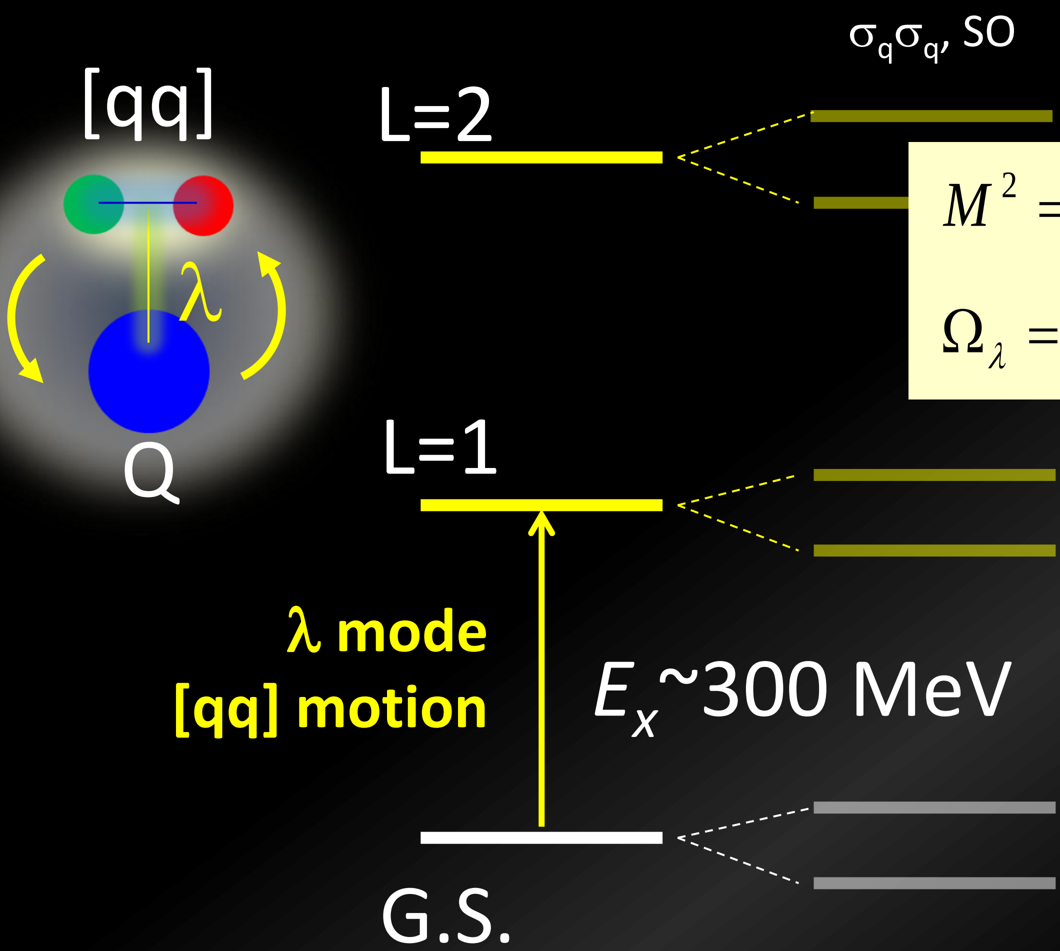
- Level structure of Y_c^* provides diquark properties
  - "diquark mass"

Precision measurement of collective [qq] orbital E_x gives a [qq] mass

Covariant Oscillator QM w/ Universal Spring [PTP 91, 775('94)]

$$M^2 = \Omega_\lambda L + \Omega_\rho L + M_0$$

$$\Omega_\lambda = 2K^{1/2}\sqrt{2(M_Q + m_{qq})^3/(M_Q m_{qq})}$$



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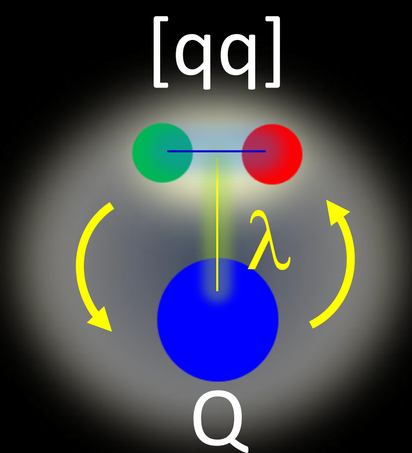
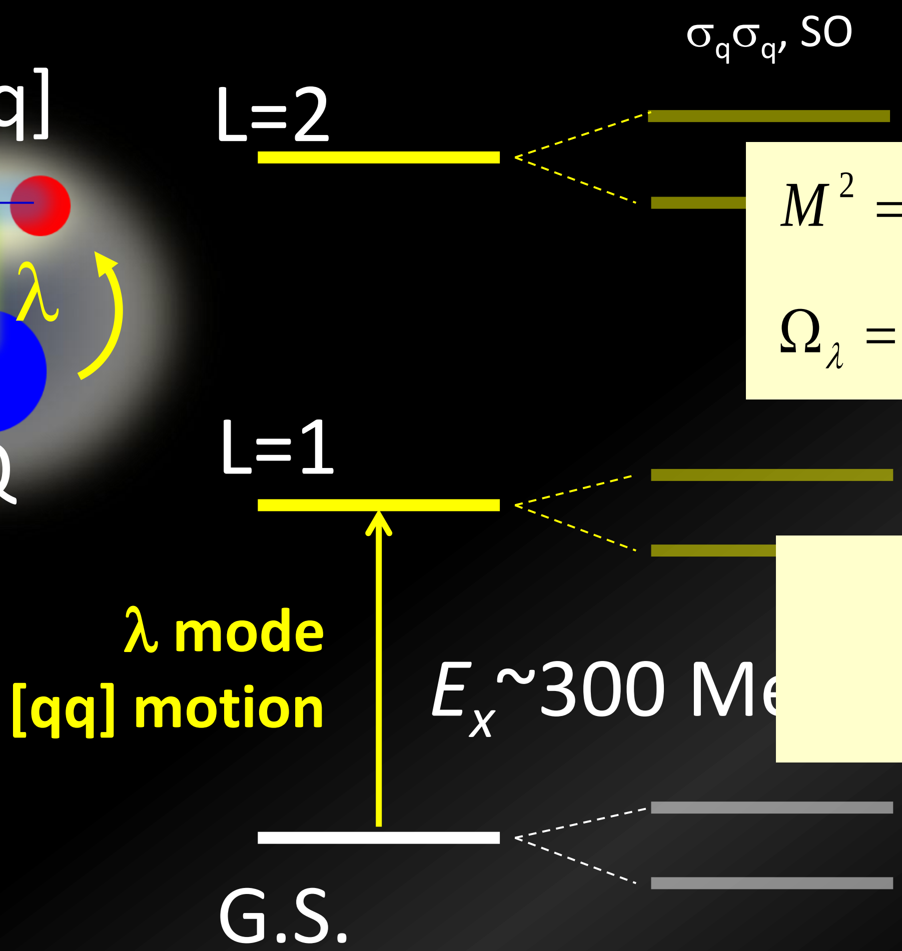


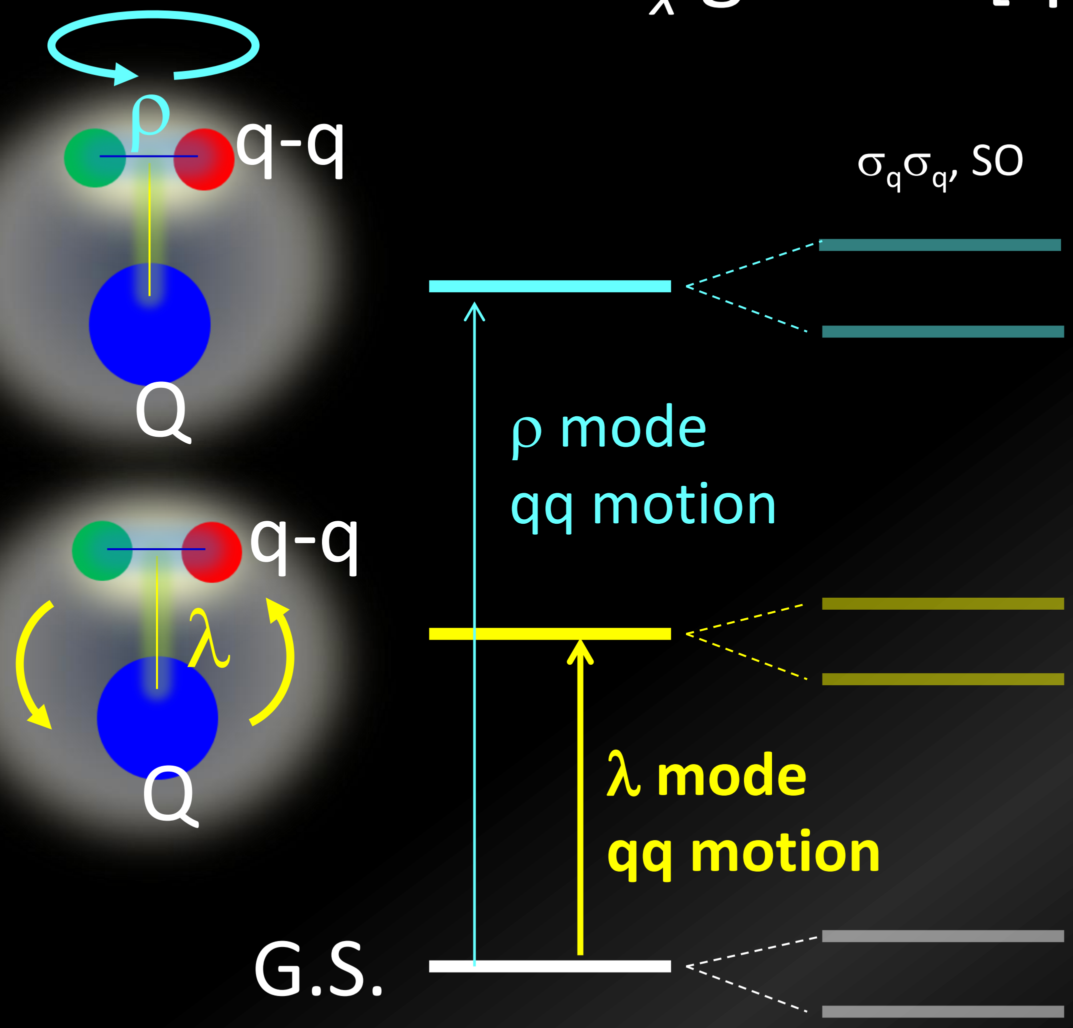


$$M^2 = \Omega_\lambda L + \Omega_\rho L + M_0$$

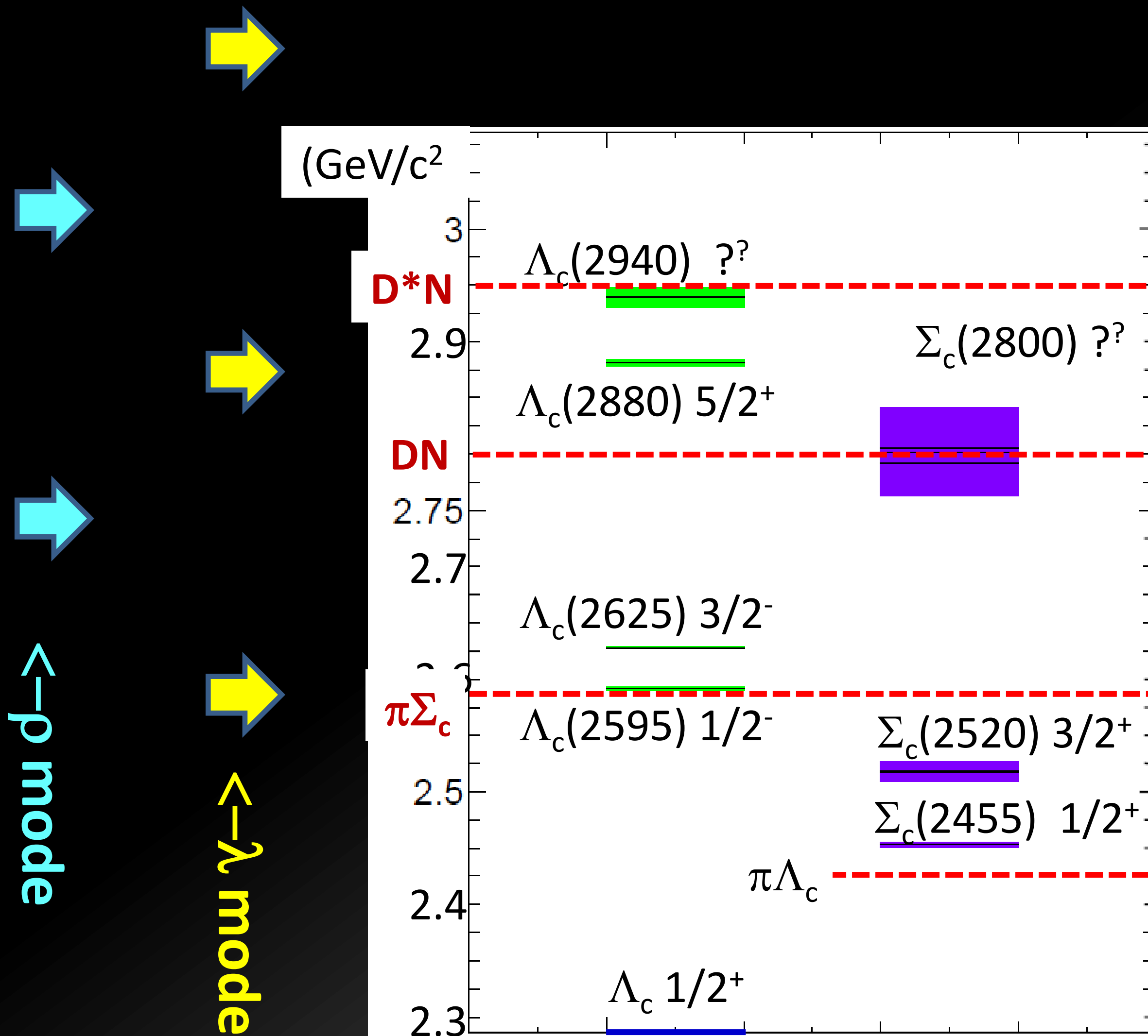
$$\Omega_\lambda = 2K^{1/2}\sqrt{2(M_Q + m_{qq})^3/(M_Q m_{qq})}$$

$$dE_x \sim dm_{qq}/30\,[\mathrm{MeV}]$$

Precision measurement of Collective [qq] orbital E_x gives a [qq] mass



Limited # of Charmed Baryons have yet been observed.



What we will measure…

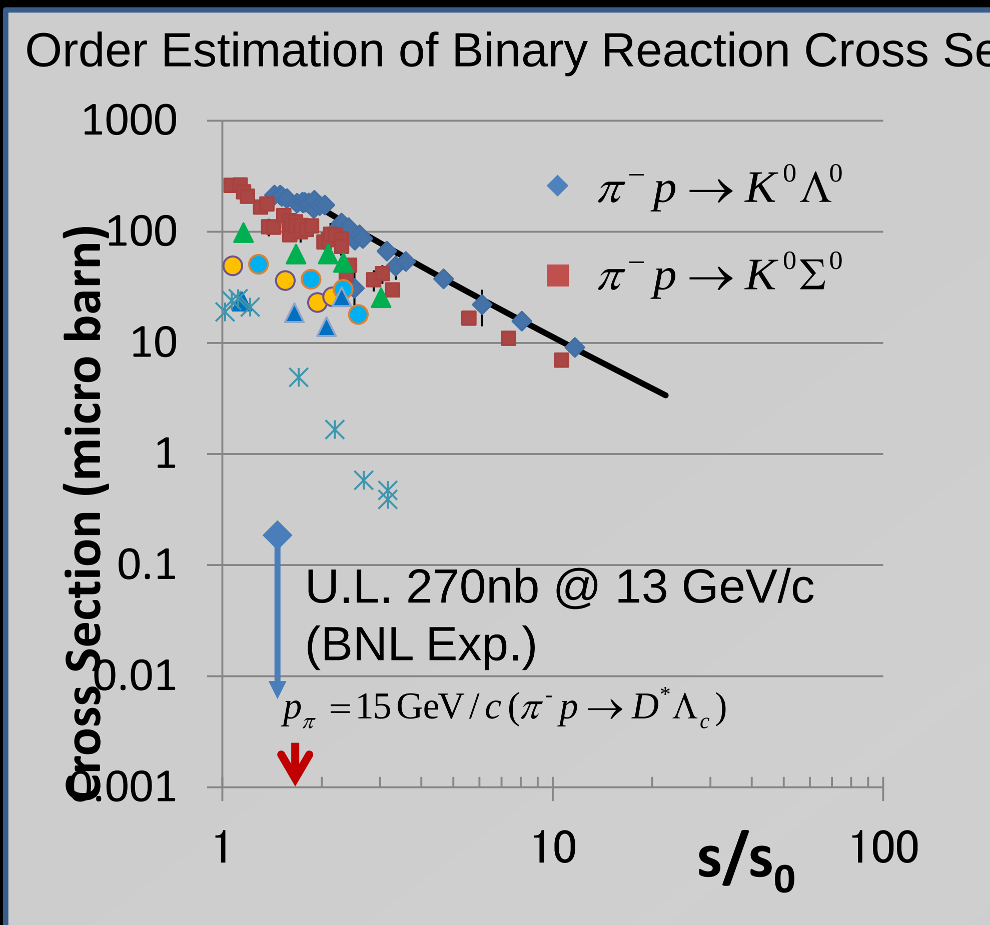
Missing mass spectroscopy via the (π,D*-) reactions.

- Excitation Energies and widths of charmed baryons
  - From the G.S. to highly E.S. of E_x>1 GeV w/ ~5.5 MeV res.
  - Independent of decay final states
- Decay properties of the populated states
  - Strong BG suppressions for the parent states
  - Decay branching ratios (Partial widths)
  - Possible assignment of spins

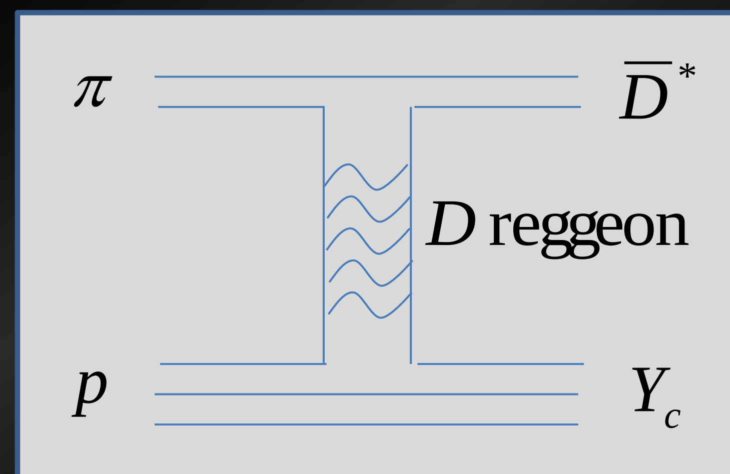
Production Cross Section

No exp. data : σ<270nb@13 GeV/c (PRL55, 154(1985))

Estimation: $10^{-4\sim-5}$ of $\sigma(\pi^{-}p \to K\Lambda, K\Sigma) \sim 1$ nb



Binary Reaction at High E is well described as quark planar diagram.



A.B. Kaidalov, ZPC12, 63(1982)

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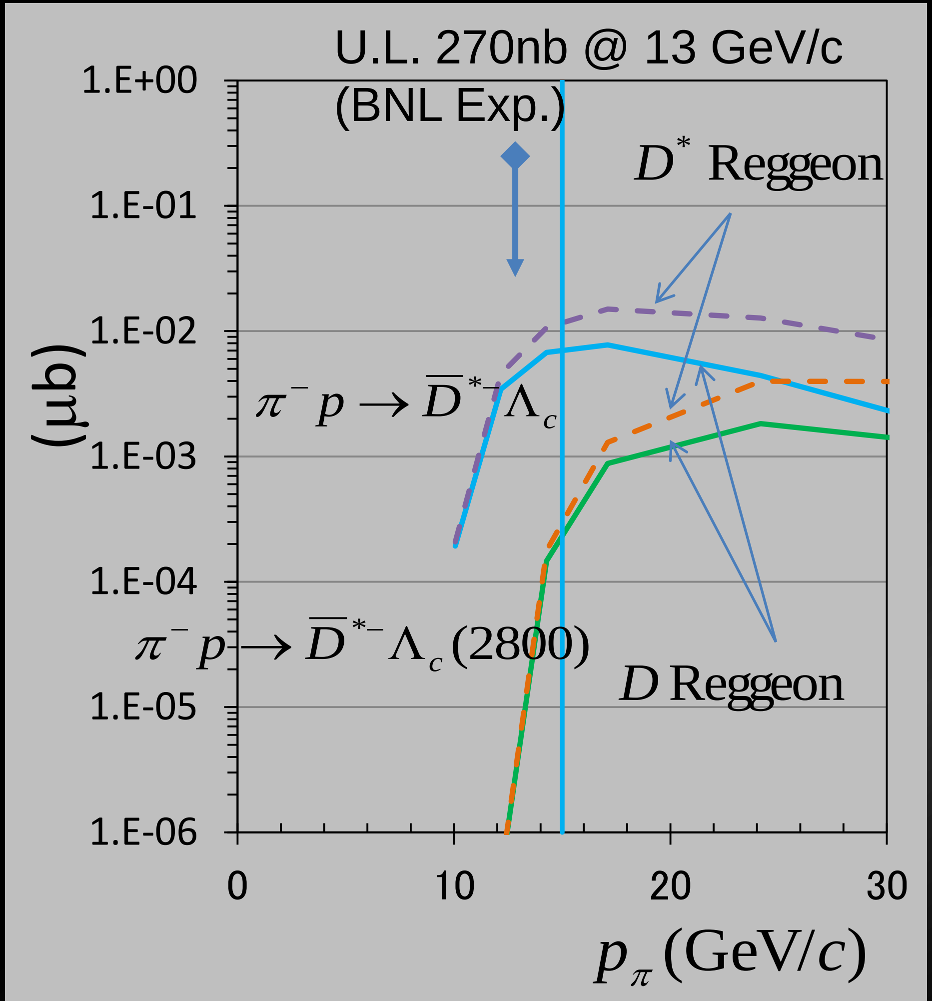

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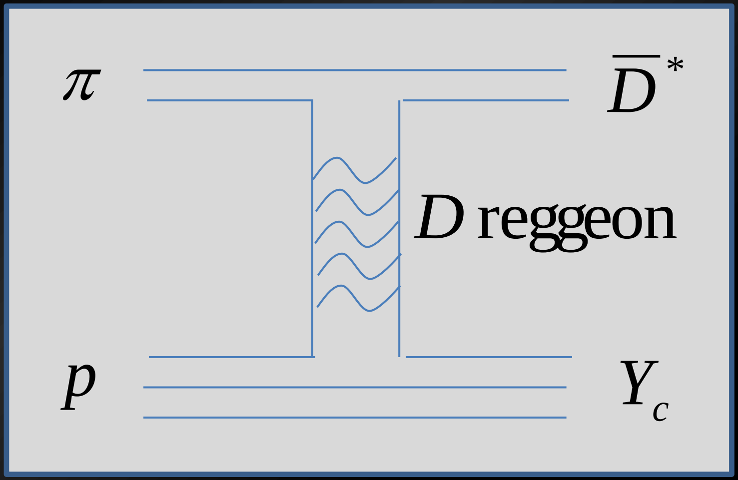

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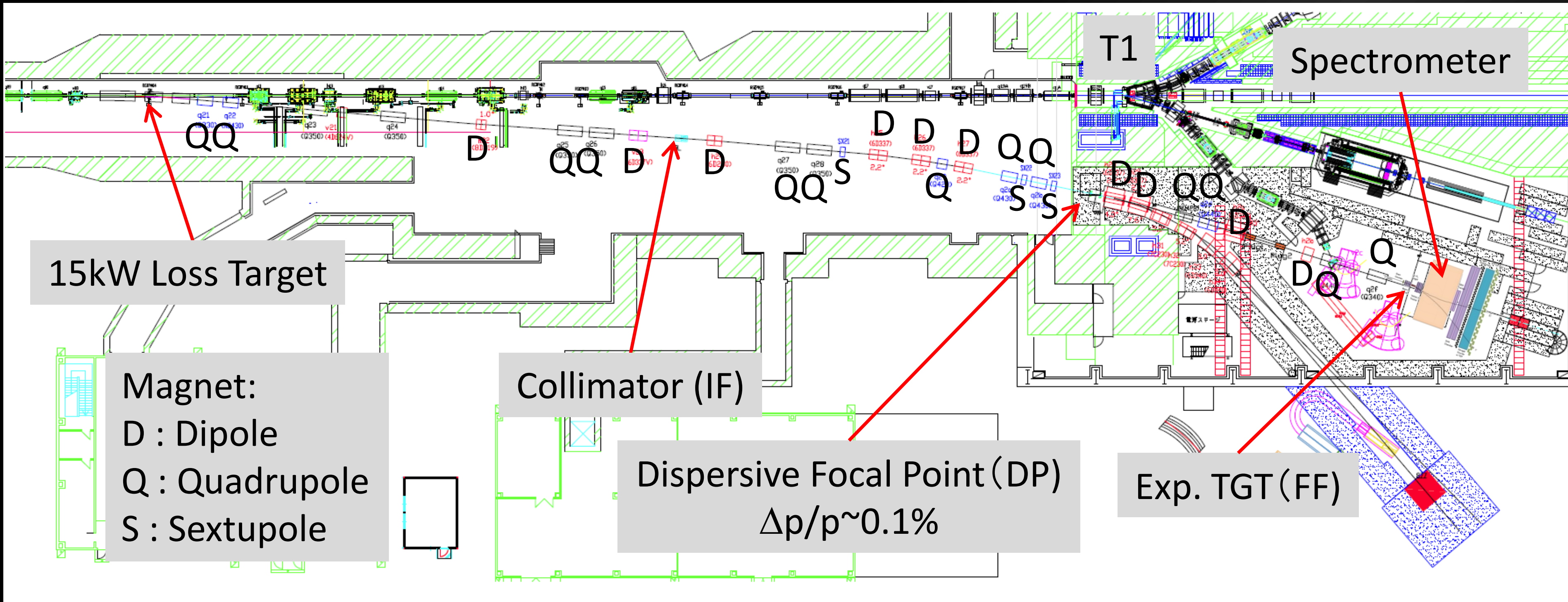
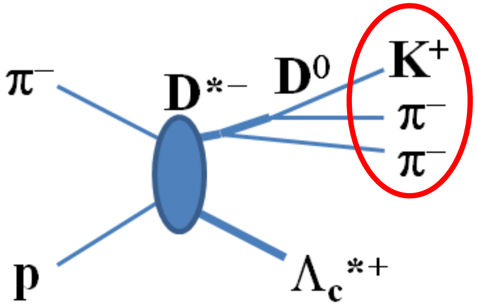
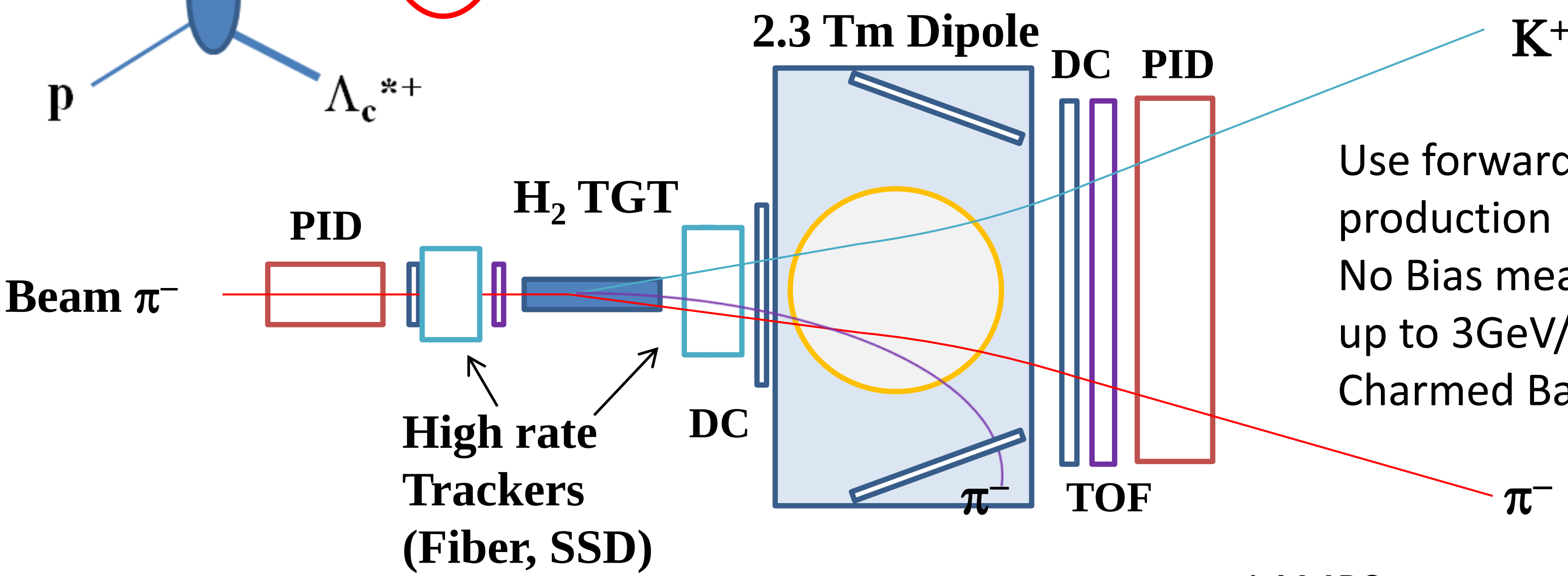
High-res., High-mom. Pion Beam

- High-intensity secondary Pion beam can be delivered.
  - 2 msr・%、1.0 x 10^7 Hz @ 15GeV/c π
- High-resolution beam: $\Delta p/p$~0.1%
  - Momentum dispersion and eliminate 2nd order aberrations

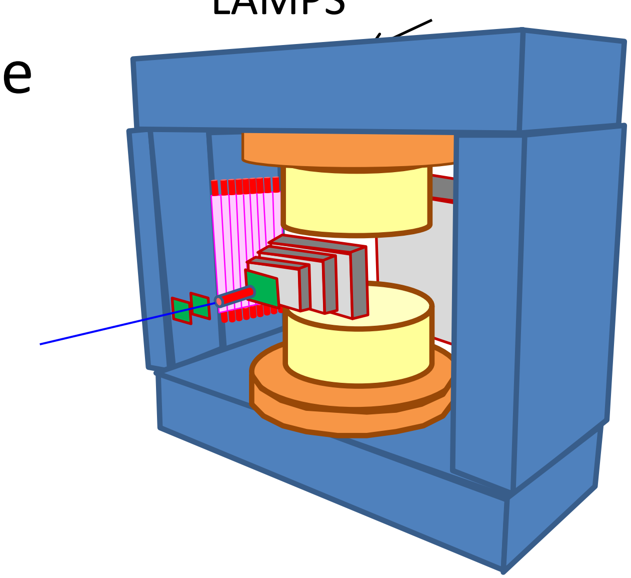


Missing mass Spectroscopy





Use forward D mesons production
No Bias measurements up to 3GeV/c^2 of Charmed Baryon mass



- Large Acceptance, Multi-Particle
  - *K*, π from D^0 decays
  - Soft π from D^{*-} decays
  - (Decay products from Y_c*)
- High Resolution
- High Rate
  - SFT/SSD op. >10M/spill at K1.8

Measurements methods

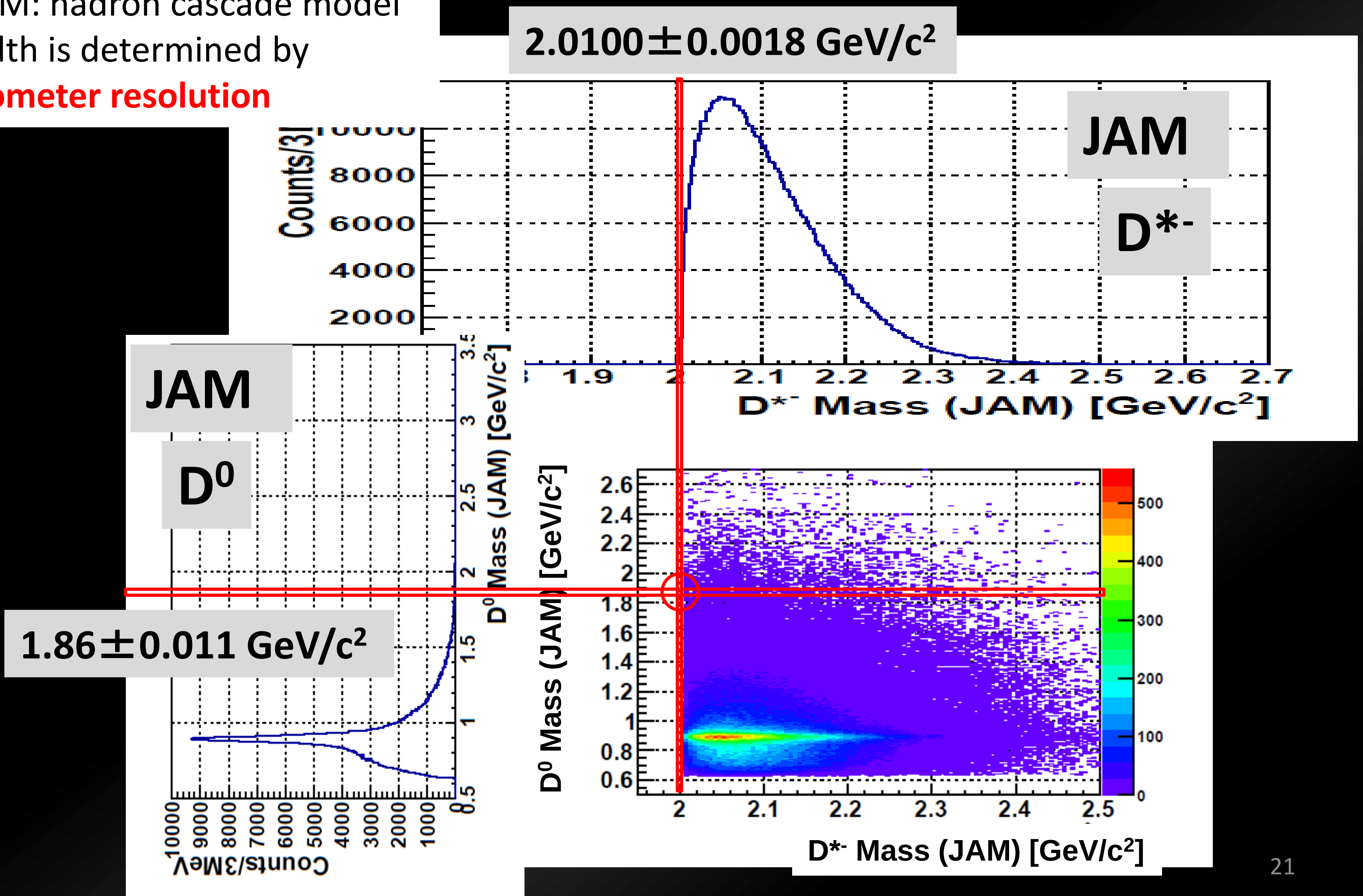
- Missing Mass method using forward D* meson
- Background is a large issue.
  - BG Production cross section of 1mb is expected.
- Background suppression without signal bias
  - D* meson tag instead of “easy” D meson tag
    - Additional correlation gives additional rejection power
      - Use D* -> Dπ decay mode
    - Large acceptance
  - Signal to Background ratio is determined by spectrometer resolution on D* and D meson measurements.
    - Good mass resolution is required
      - D^0 meson: 4.5 MeV, D* meson: 0.7 MeV

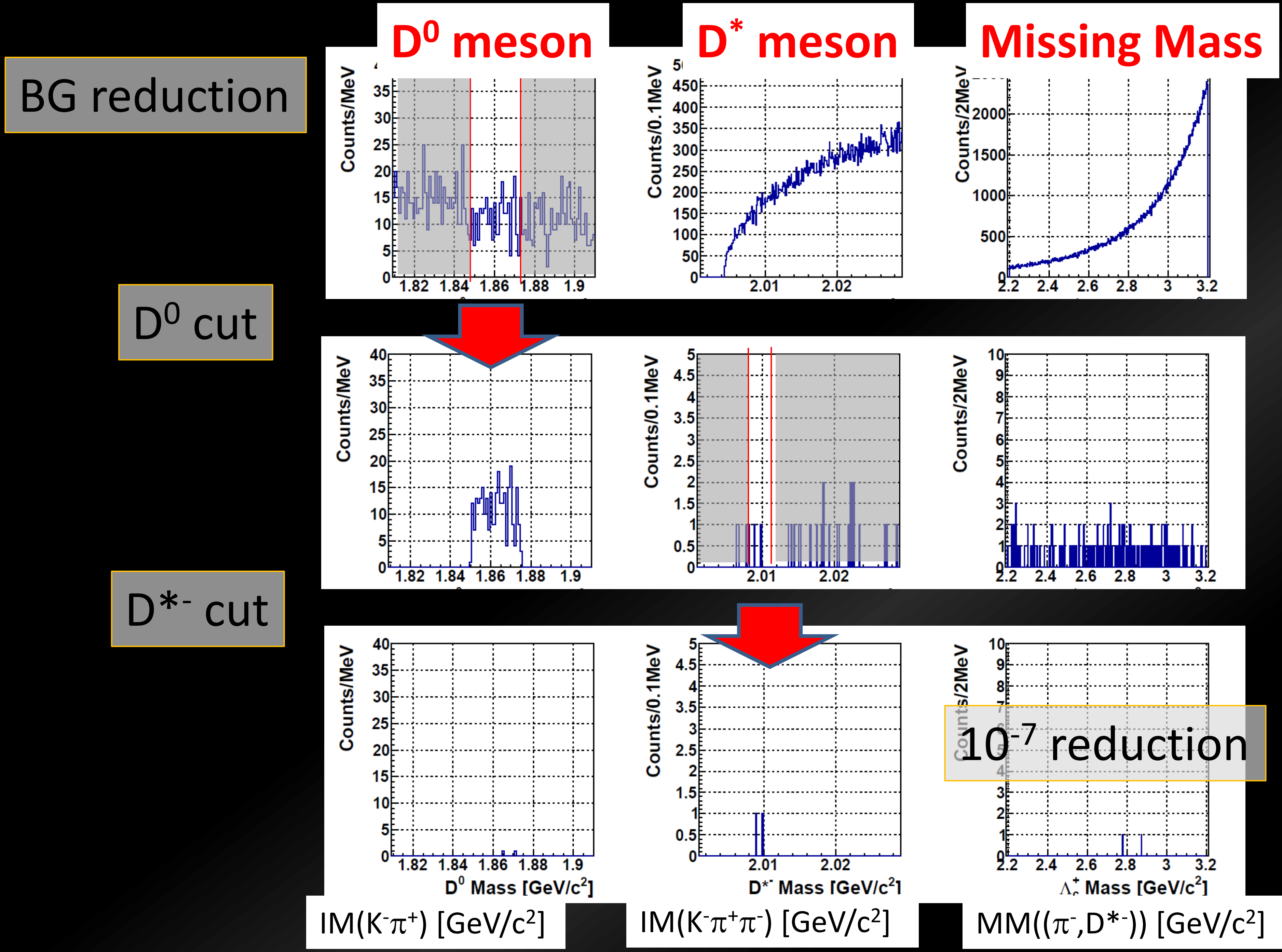
BG reduction by D^{*-} and D^0 mass cuts

Back Ground Only

JAM: hadron cascade model

Cut width is determined by **spectrometer resolution**

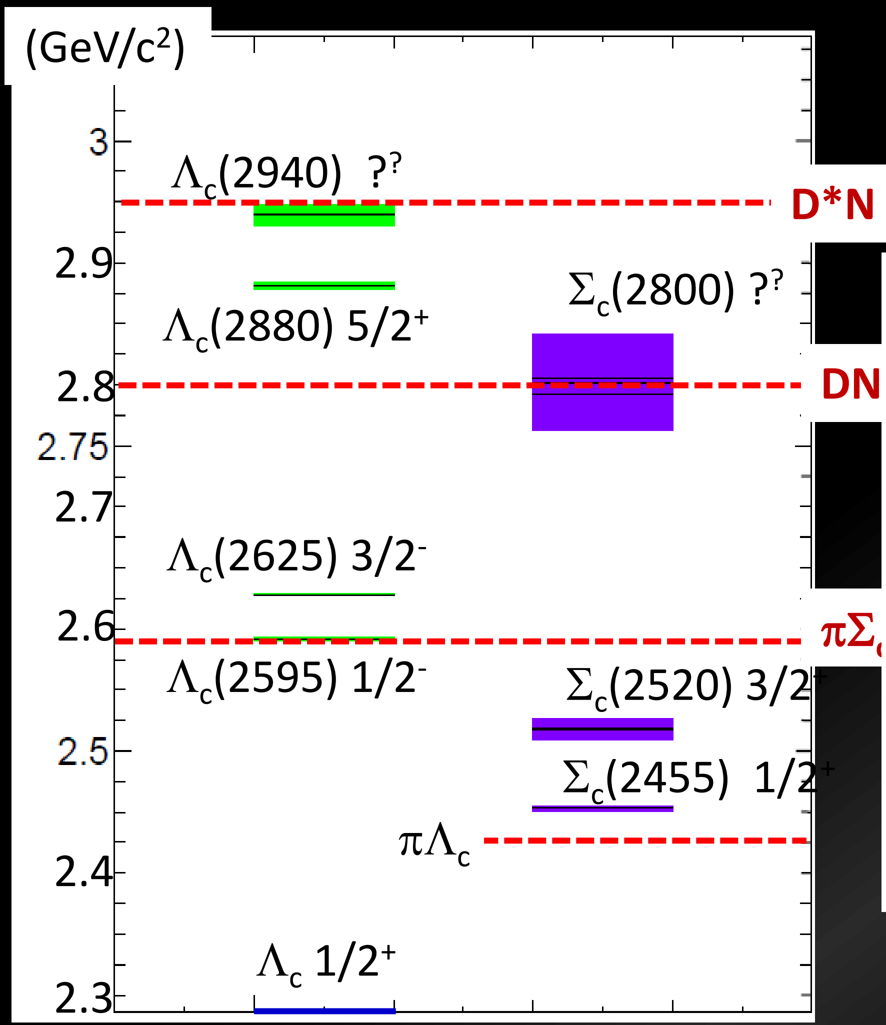


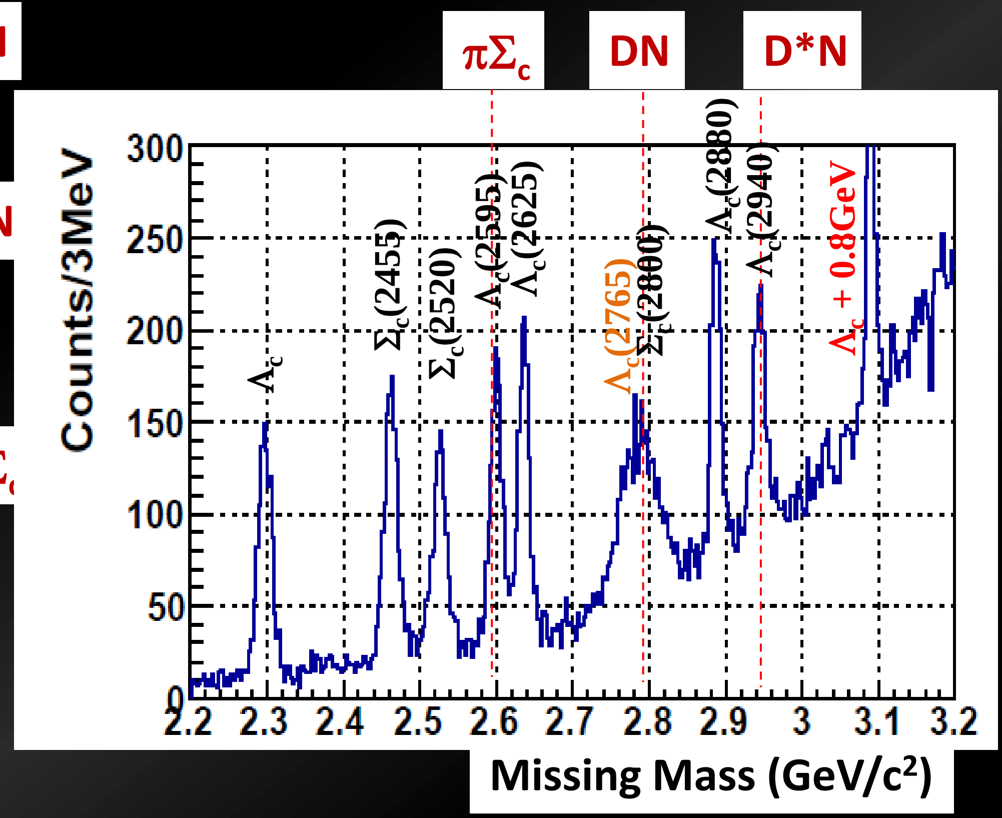


BG reduction
D0 cut
D*- cut
D0 meson
D* meson
Missing Mass
Counts/MeV
Counts/0.1MeV
Counts/2MeV
D0 Mass [GeV/c2]
D*- Mass [GeV/c2]
Λc+ Mass [GeV/c2]
10-7 reduction
IM(K-π+) [GeV/c2]
IM(K-π+π-) [GeV/c2]
MM((π-,D*-)) [GeV/c2]

Expected Spectrum in the (π,D*⁻) reaction

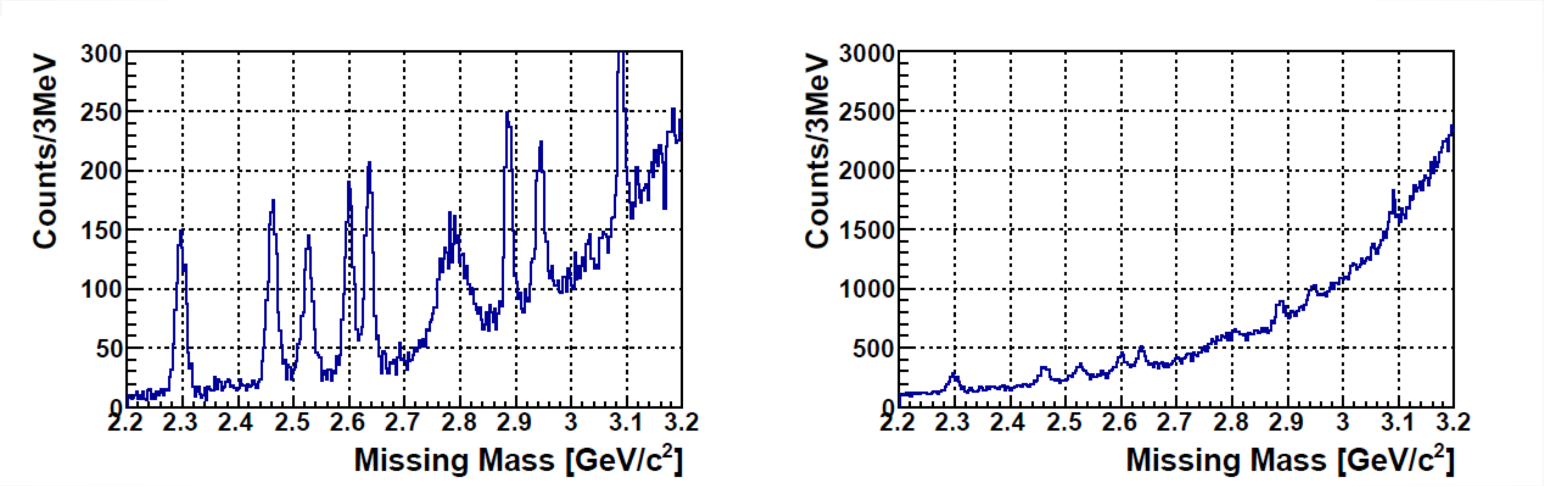
Signal: 1 nb/Yc* :~1000 events
BG: 1.8 mb (JAM)





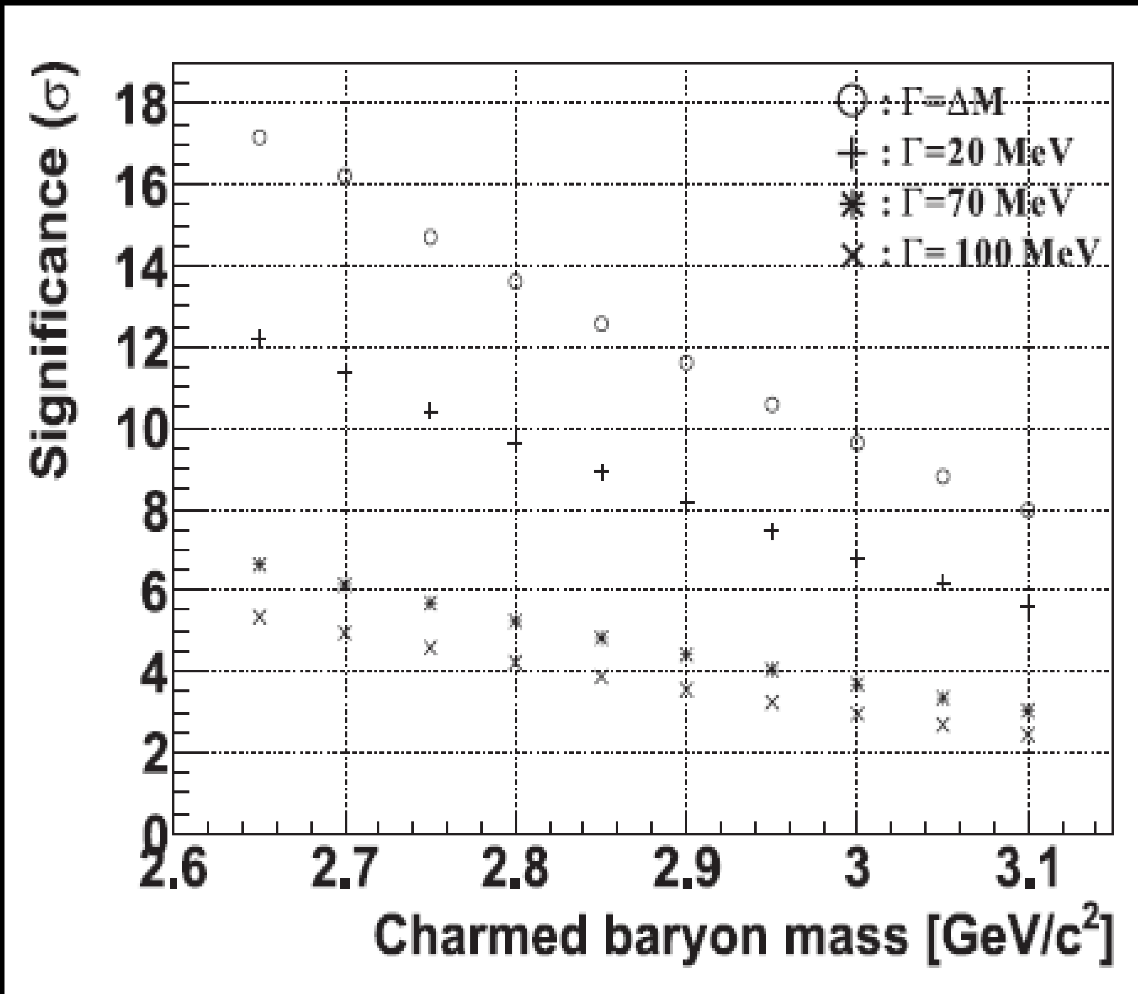
If 10 times more Background?

10^{-7} BG eduction → **IF 10 times more BG**



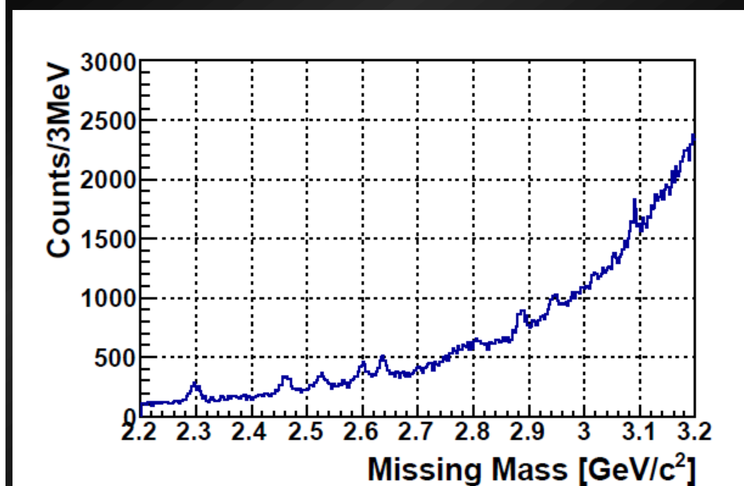
- **Assuming 10^{-7} and 10^{-6} BG reduction, generated by using the JAM code**
  - **BG: σ_{tot} = 1.8 mb**
- **For each Y_c*, production cross section of 1 nb, mass and width from PDG**
  - **~1000 counts for each Y_c***

Signal Sensitivity



Signal: 1000 events

BG: 10^{-6} reduction



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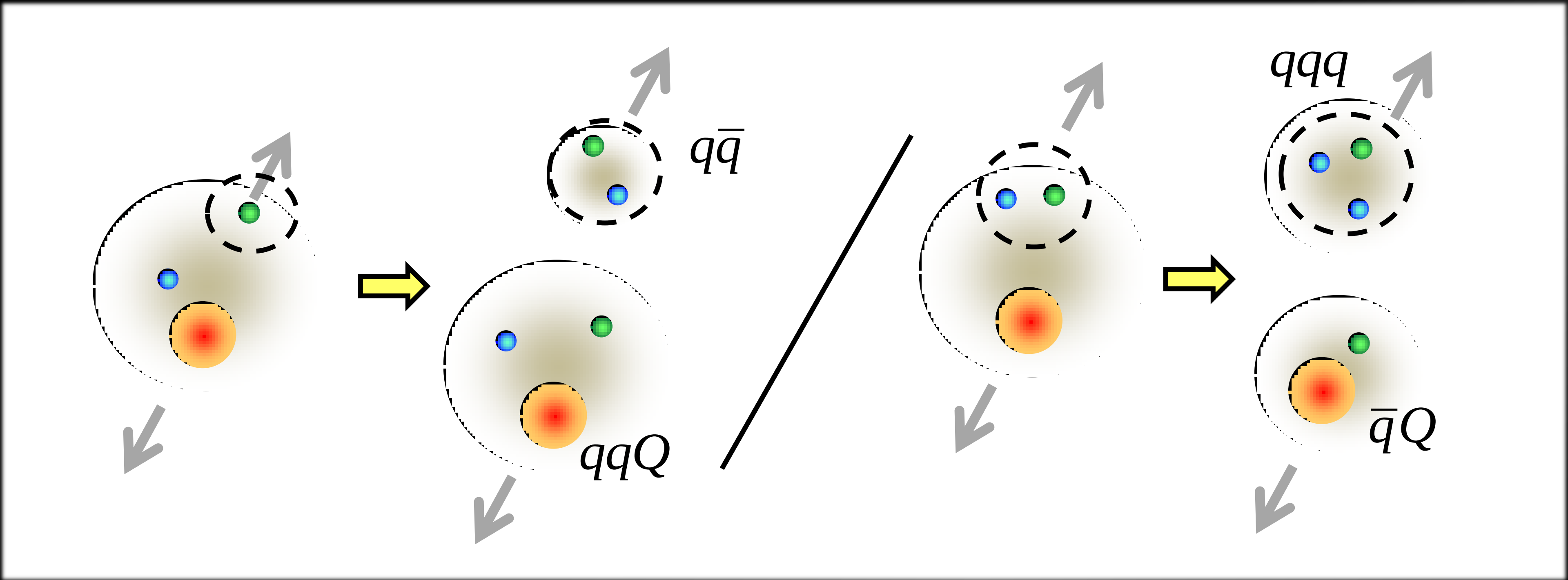
Structure and Decay Partial Width

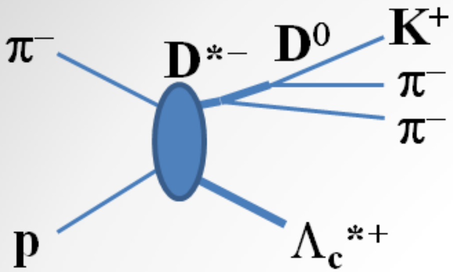


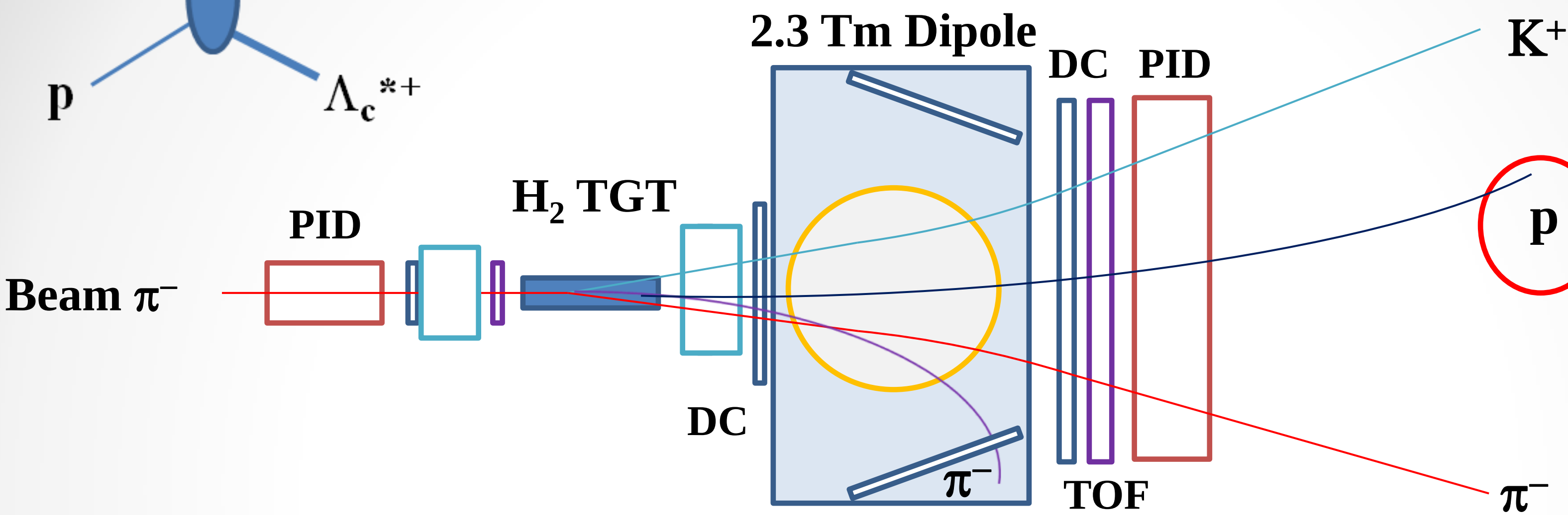
Excited (qq)

Good [qq]

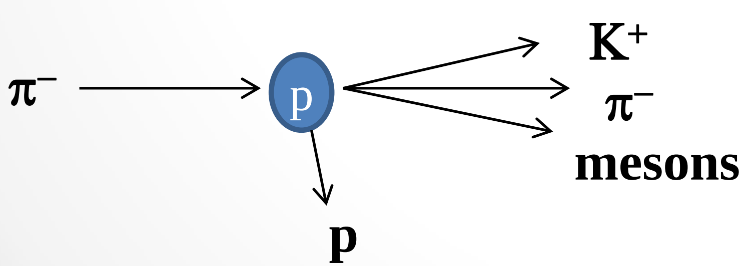
- Λ(1520) -> NK (D wave!)>πΣ , similarly Λ(1820), Λ(2100)
- Possible explanation of narrow widths of Charmed Baryons

Spectrometer Concept

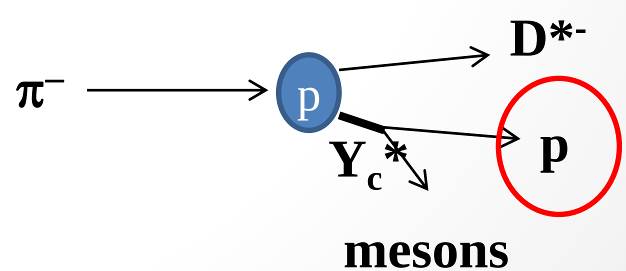




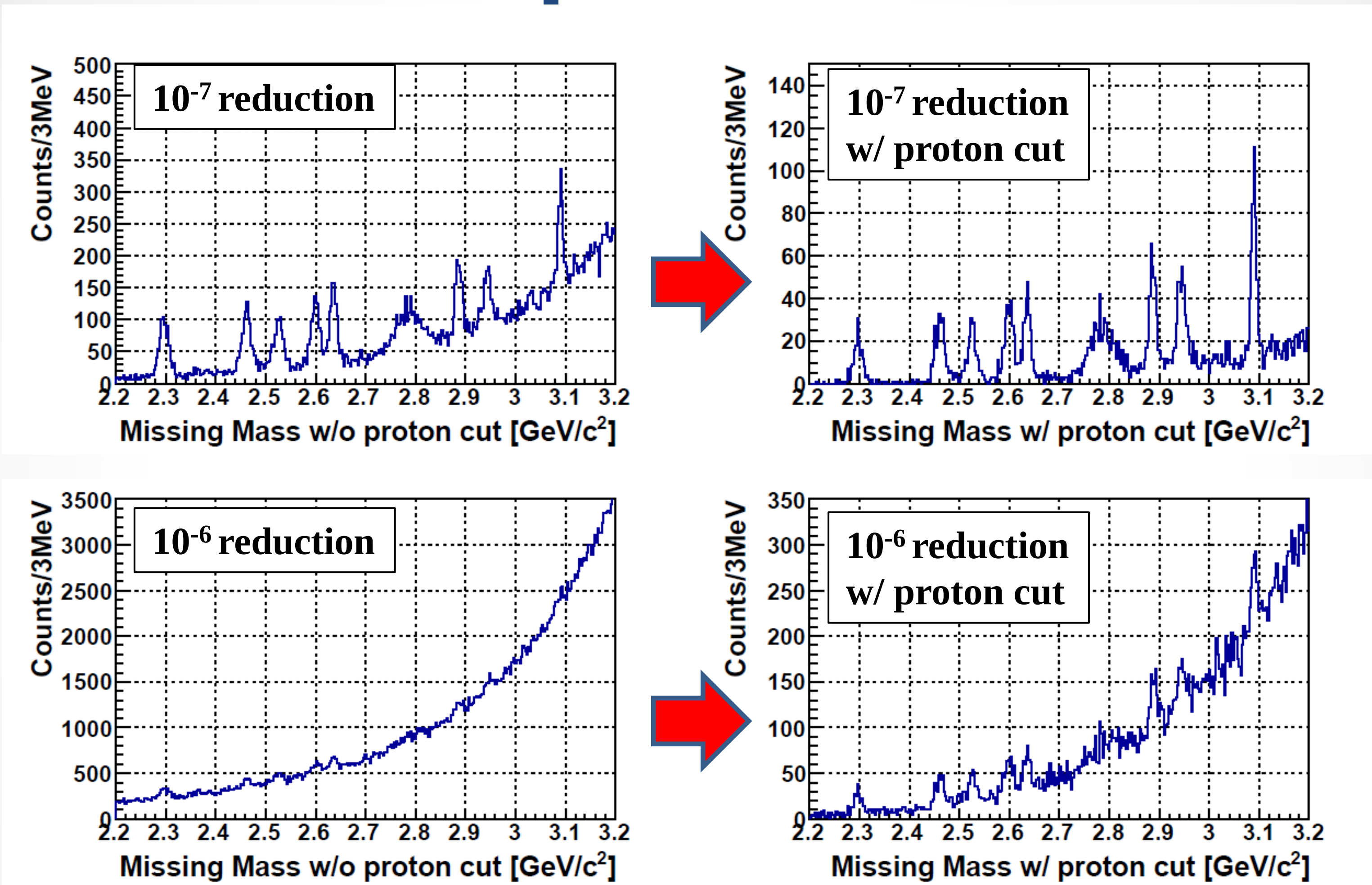
Multi-meson productions (BG)



Y_c* production (Signal)



Forward proton detection



- **Further BG reduction (significance ⇒ ×1.5)**
  - **Yied for Y_c* is reduced to be 1/4**
  - **S/N is improved from 1:15 ⇒ 1:6 @ Λ_c(2880)**

Summary for charmed baryon

- Charmed Baryon Spectroscopy via the (π,D*-) reactions
  - Shed light on "diquark": colored object in hadrons
  - Clarify a Level Structure of the charmed baryons
    - From the ground state to highly excited states of E_x~1 GeV
    - Independent of decay final states
  - Decay Branching Ratios (Partial Widths)
    - Suppressions of $[qq^{bar}]$-[qqQ] decays if "Good diquark" in Y_c*
    - Possible assignment of spins
- A New Project of Hadron Physics at J-PARC, High-p BL
  - High-res., High-intensity 2ndary Beam
  - Large Acceptance, Multi-Particle Spectrometer

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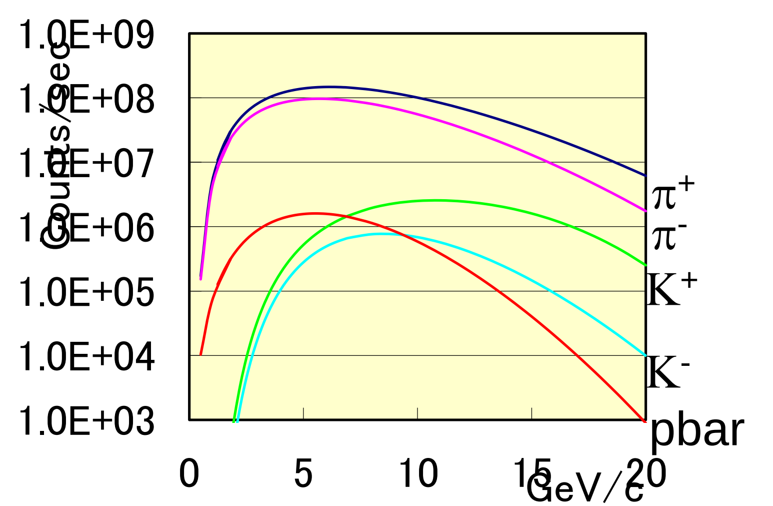
OTHER RELATED EXPERIMENTS

Basic Beam Specifications

- proton beam, E_{kin} = 30 GeV : $\sqrt{s}$ = 7.7 GeV
- proton beam, E_{kin} = 50 GeV : $\sqrt{s}$ = 9.8 GeV
  - proton target at rest
  - Beam intensity: up to 10^{12} per spil
  - Double Charmed (Ξ_{cc}) can be formed at 50GeV

- Secondary beam
  - Un-separated beam contains K and p.
  - Intensity depends on its momentum, however, we can have some intensity up to 20 GeV.



Sanford-Wang formula
production 2.5 degree, 15 kW loss Pt target
acceptance : 2 msr%, beam line length : 132 m

Physics with Kaon

- Un-separated secondary beam contains 1-10% Kaons. If a smart trigger system to select kaon is adopted, kaon physics can be done using a high momentum beam.
- Physics examples under discussions,
  - Ξ_c Spectroscopy
    - Investigate Strangeness and Charm sector
    - $K^- + p \rightarrow \Xi_c + D^-$ (Production Threshold: 10 GeV/*c*)
    - Use the same spectrometer with charm baryon spectroscopy. Experimental issues, such as yield, background, resolutions, are being evaluated.
  - Charmed exotic baryons
    - Θ_{cs} can be searched using a similar reaction.
    - $K^- + p \rightarrow \Theta_{cs} + D^+$

Charmed Deuteron: $\Lambda_c N$

- Production process candidate1: π + p -> Λ_c + D
  - Minimum momentum: 4 GeV /c @ 15 GeV/c beam
  - Target: ^{3}He or heavy nucleus?
    - Two step process and forward nucleon emission
    - Tiny probability. How much?

- Production process candidate2: pp-bar -> Λ_c + Λ_c-bar
  - Almost stopped Λ_c
  - Difficulties
    - How to make a bound state? Deuteron beam?

- Production process candidate2: Heavy ion collisions
  - Production + bound state with a spectator
  - Need an upgrade of accelerator

Summary

- New experiment using a high momentum beam line at J-PARC has been proposed to perform a charmed baryon spectroscopy.
- Other related experiments are also under discussions.
  - Double Charmed (Ξ_{cc}) at 50GeV
  - Ξ_c Spectroscopy
  - Charmed exotic baryons
  - $\Lambda_c N$ bound state