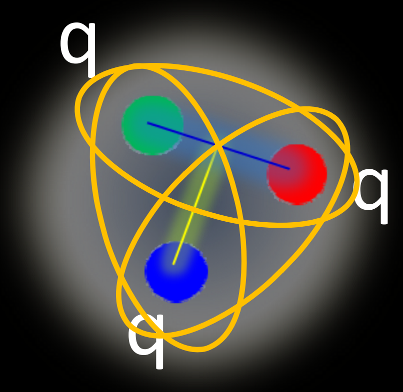
P50
Charmed Baryon Spectroscopy via the (π, D^{*-}) reactions

H. Noumi（RCNP, Osaka University）

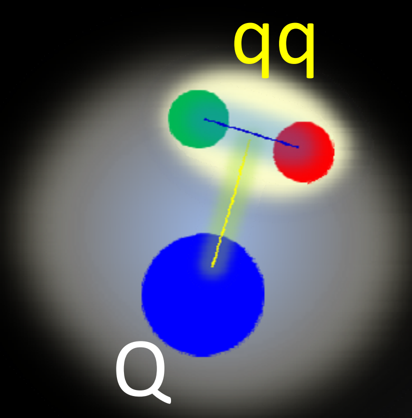
Outline:
1. Introduction
2. Signal Level
3. Background Estimate
4. Summary

What are essential D.o.F. of baryons?



- Most fundamental question
- Interaction btwn quarks

Diquark correlations



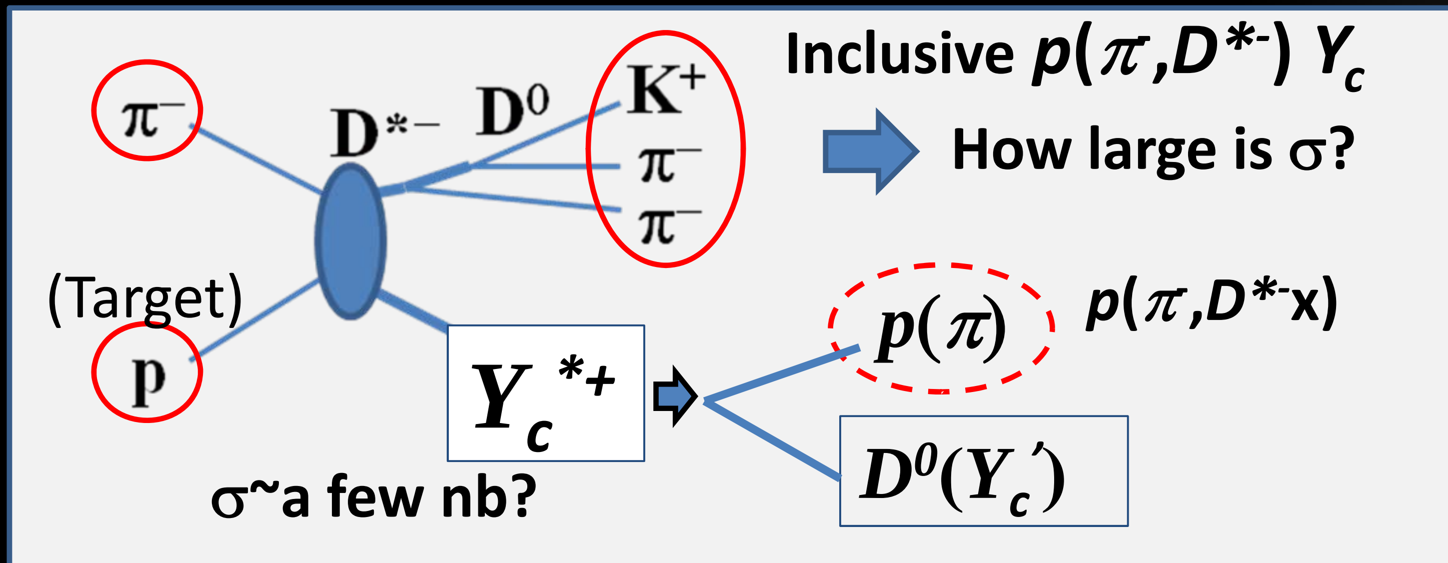
→ Charmed baryon

to close up diquark correlations

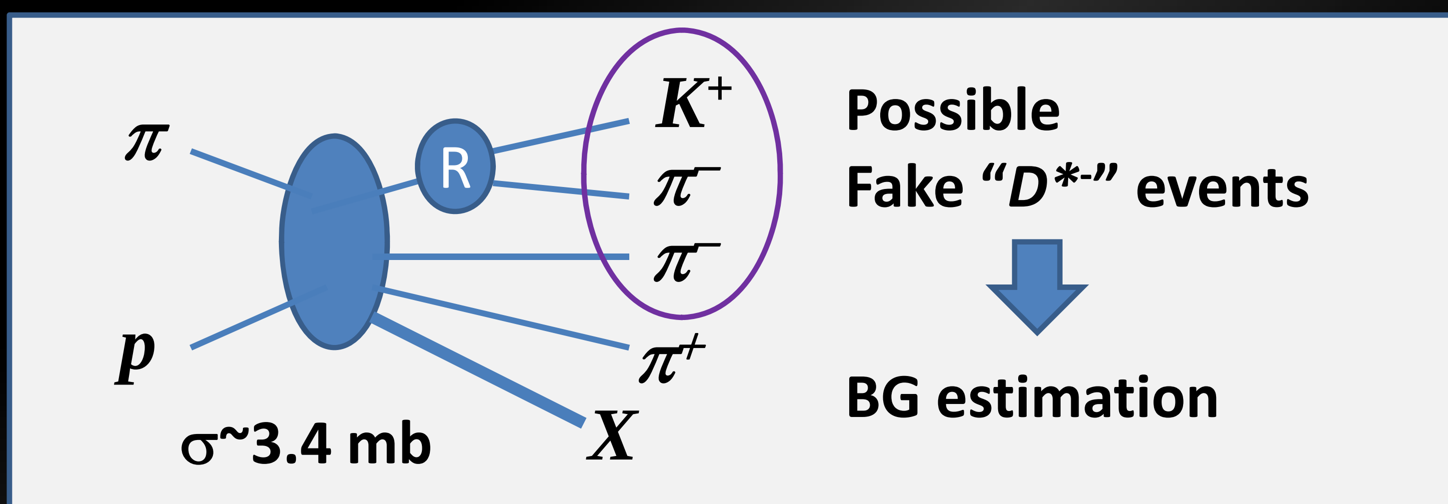
- Weak Color Magnetic Interaction with a heavy Quark

Charmed Baryon Spectroscopy Using Missing Mass Techniques

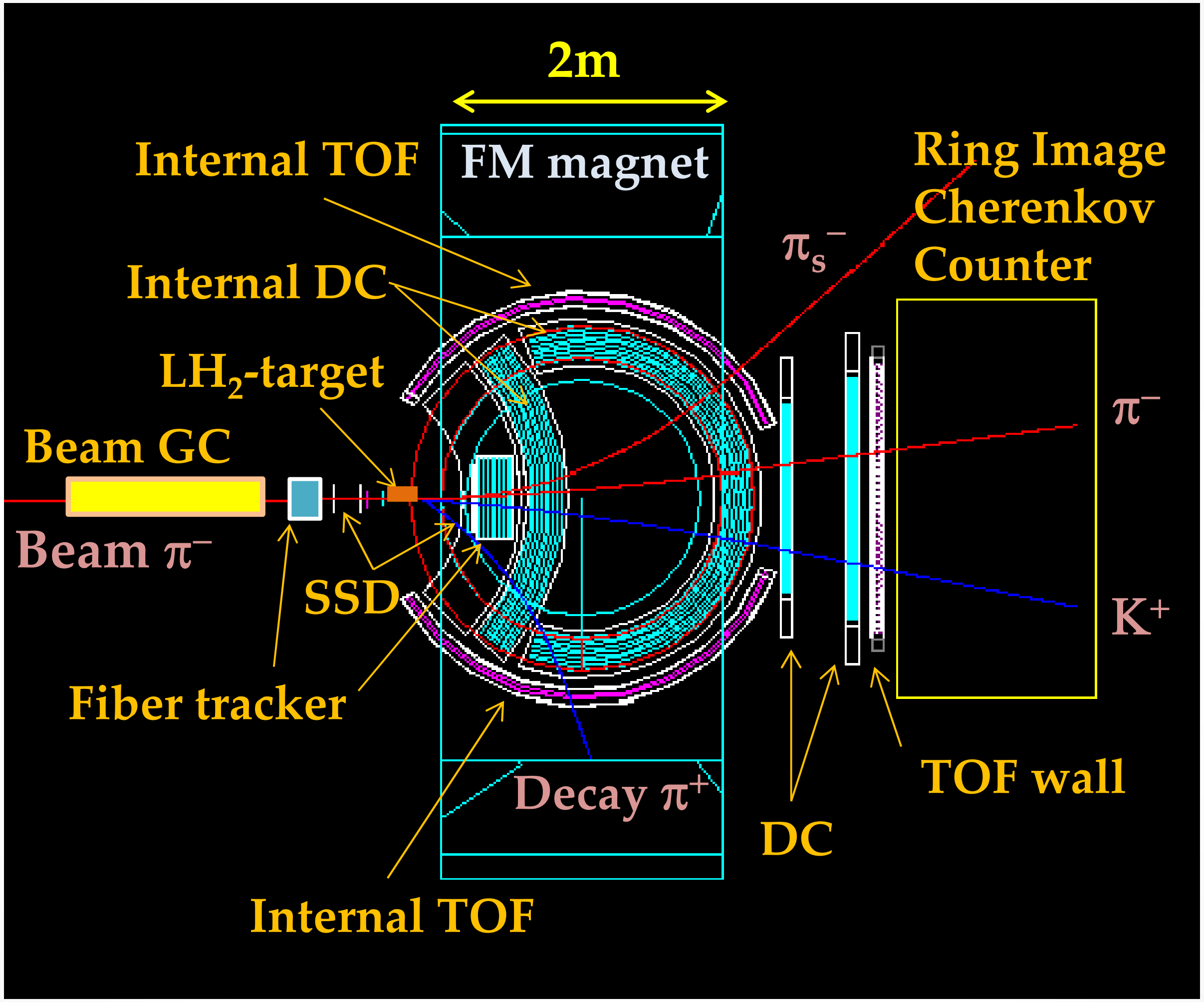
Signal



BG



Charmed baryon spectrometer



Large acceptance ~ 60% (for D^*), $\Delta p/p$~0.2% at ~5 GeV/c

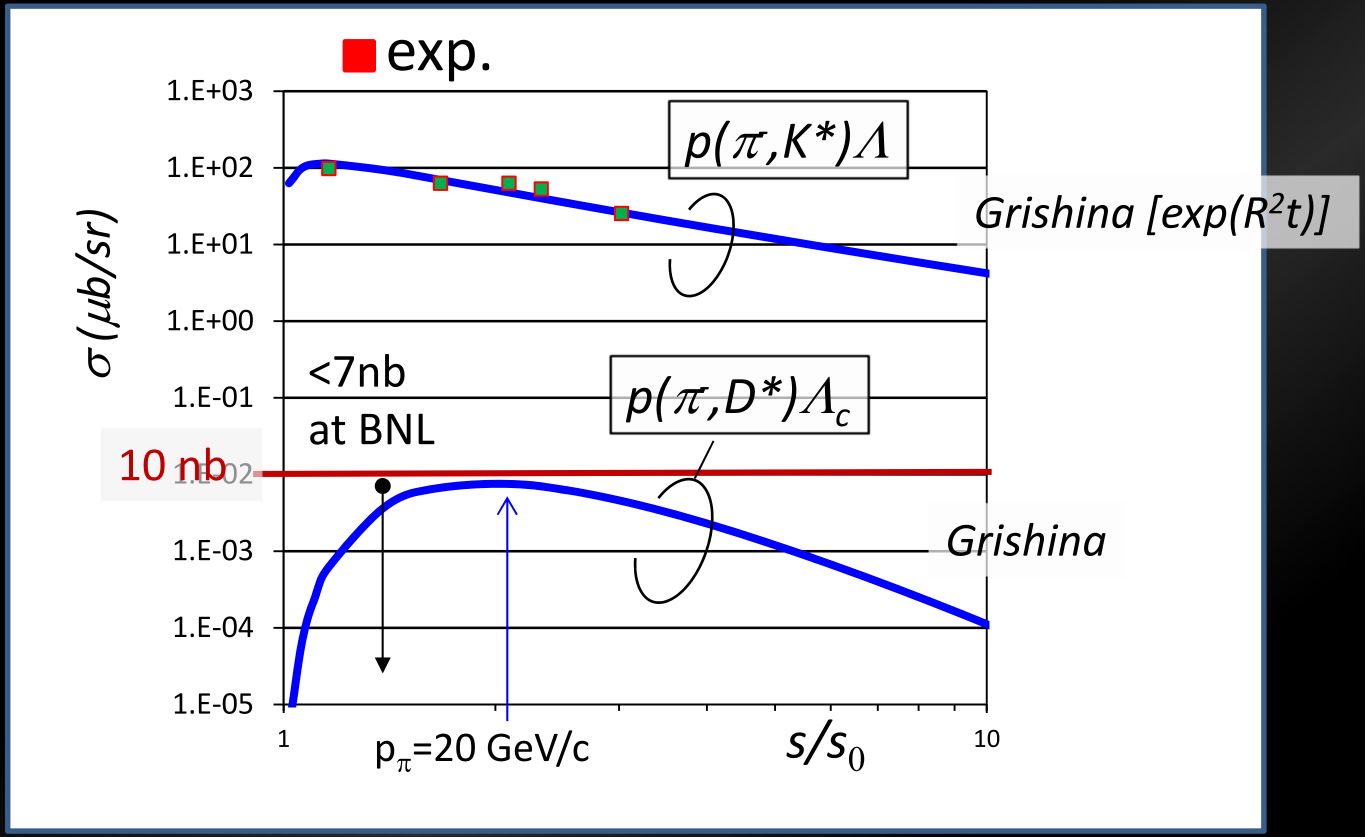
Estimation of cross sections

- Experiment
  - $\sigma(\pi p \rightarrow D^{*}\Lambda_c) < 7$ nb at $p_\pi = 13$ GeV/c [BNL, '85]
  - $\sigma(\pi N \rightarrow J/\psi X) = (3 \pm 0.6)$ nb at $p_\pi = 22$ GeV/c [BNL, '79]
  - $\sigma(\gamma p \rightarrow \Lambda_c D^{bar} X) = (44 \pm 7^{+11}_{-8})$ nb at $E_\gamma = 20$ GeV [SLAC, '86]
- Theory
  - Regge Model
    - Production rate of charm relative to strangeness
  - t-channel *D** exchange model
    - The model independent ratio of the production cross section

Ratios of Cross Section

- Normalized to strangeness production, $p(\pi^-,K^{*0})\Lambda$
- Charm production: ~10^{-4} of strangeness production

→ $\sigma(p(\pi^-,D^{*-})\Lambda_c)$ ~ a few nb at p_π=20 GeV/c



Cross Section Ratio

- Normalized to strangeness production, $p(\pi^-, K^{*0})\Lambda$
- Charm production: ~10^{-4} of strangeness production

→ $\sigma(p(\pi^-, D^{*-})\Lambda_c)$ ~ a few nb at p_π=20 GeV/c

Prob. of finding the fast quark of $q \sim M$ in a baryon

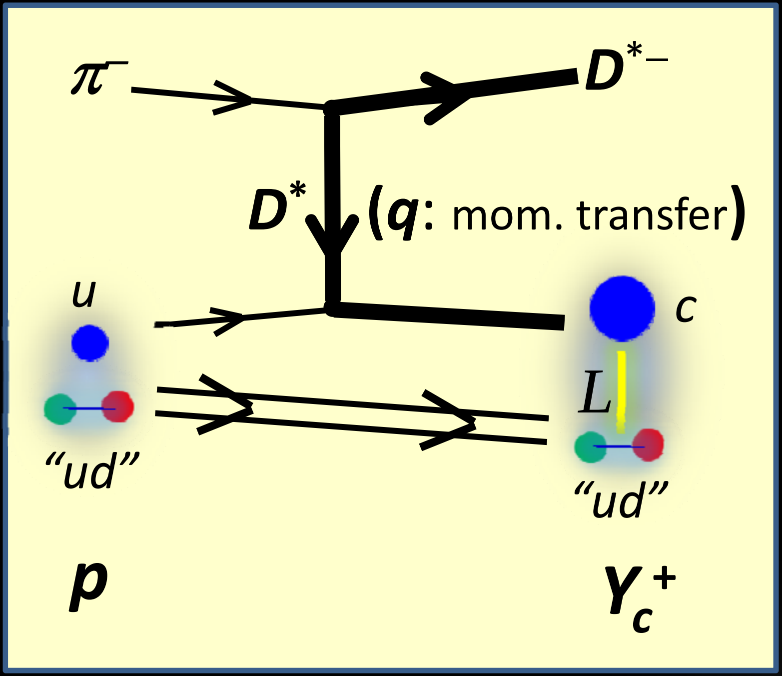
$$\sim \langle N(qd) | B(Qd) \rangle$$

$$P(M) \sim \left(\frac{\Lambda^2}{\Lambda^2 + M^2} \times \frac{\Lambda^2}{\Lambda^2 + M^2} \right)^2 \Rightarrow \frac{P(M_c)}{P(M_s)} \sim \frac{1}{1000}$$

per hadron

Typical suppression

Production Rate



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

Production Rates are determined by the overlap of WFs

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

and depend on:

1. Spin/Isospin Config. of Y_c
   Spin/Isospin Factor
2. Momentum transfer (q_{eff})

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

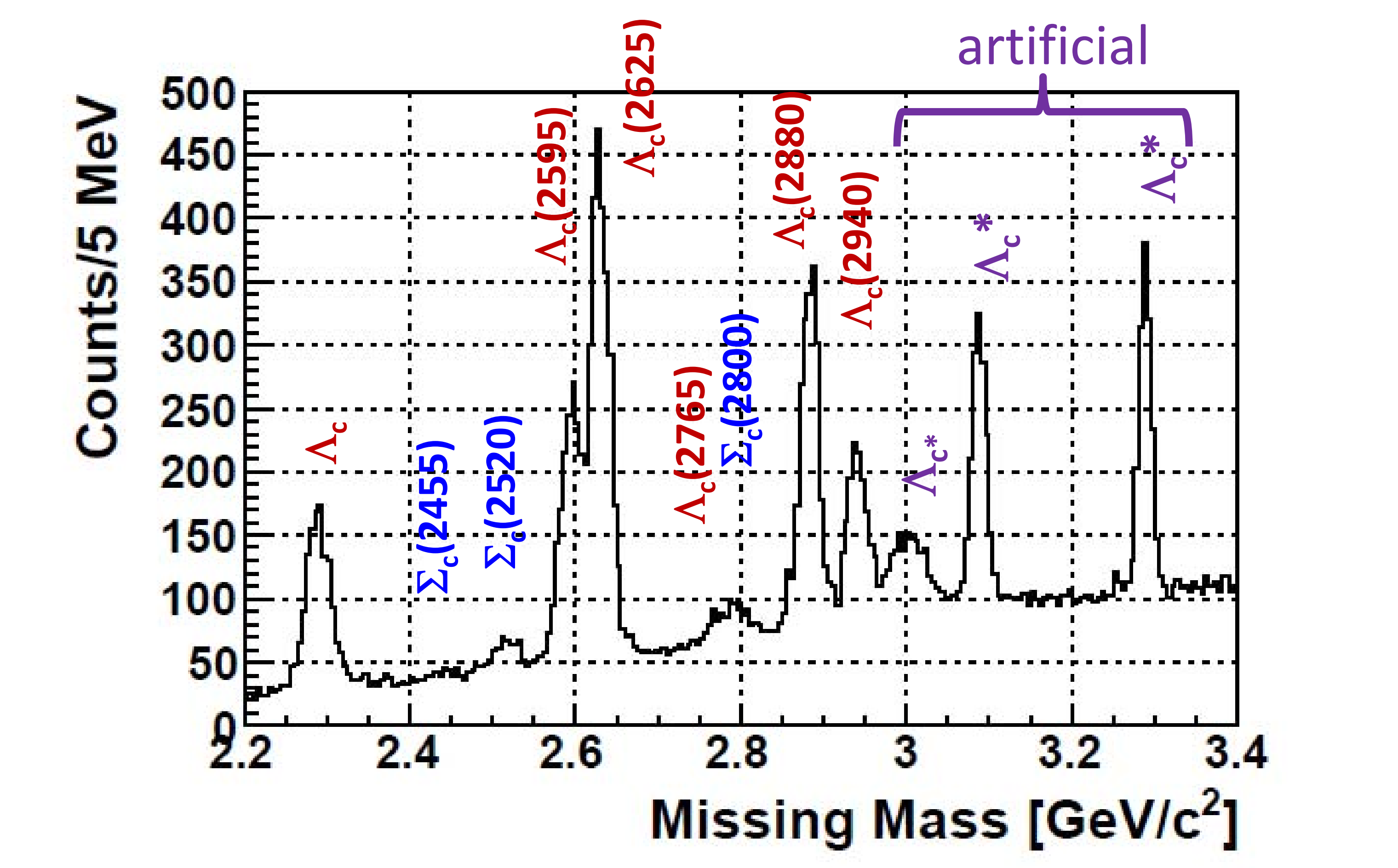
A: (baryon size parameter)$^{-1}$

Calculated production rates

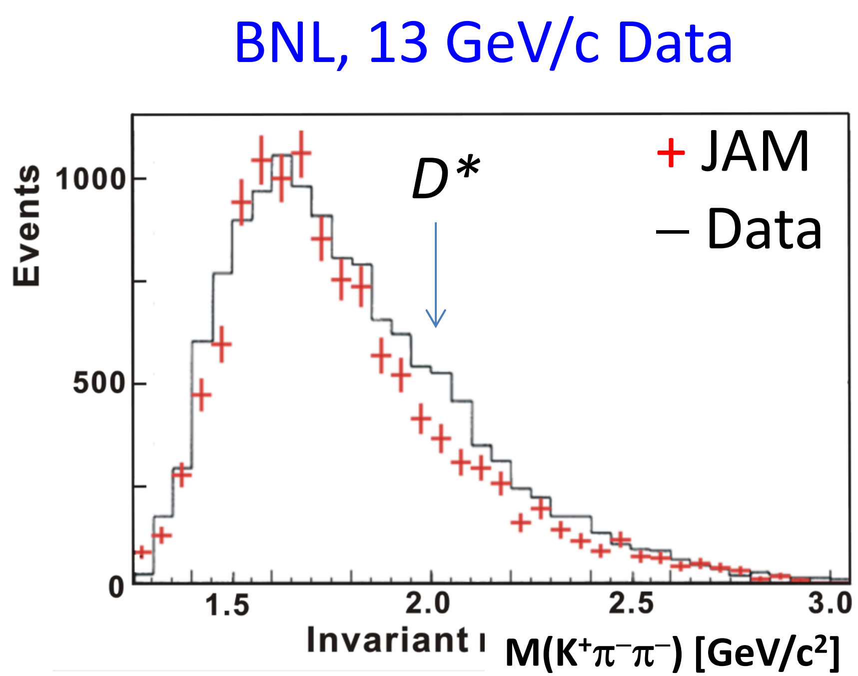
	p_π=20 GeV/c	Mass (GeV/c)	"ud" isospin factor	Y_c^* Spin factor	q_{eff} (GeV/c)	Rate (Relative)
L=0	$\Lambda_c^{1/2+}$	2286	1/2	1	1.33	1
	$\Sigma_c^{1/2+}$	2455	1/6	1/9	1.43	0.03
	$\Sigma_c^{3/2+}$	2520	1/6	8/9	1.44	0.20
L=1	$\Lambda_c^{1/2-}$	2595	1/2	1/3	1.37	1.17
	$\Lambda_c^{3/2-}$	2625	1/2	2/3	1.38	2.26
	$\Sigma_c^{1/2-}$	2750	1/6	1/27	1.49	0.03
	$\Sigma_c^{3/2-}$	2820	1/6	2/27	1.50	0.06
	$\Sigma_c^{1/2-\prime}$	2750	1/6	2/27	1.49	0.07
	$\Sigma_c^{3/2-\prime}$	2820	1/6	56/135	1.50	0.33
	$\Sigma_c^{5/2-\prime}$	2820	1/6	2/5	1.50	0.31
L=2	$\Lambda_c^{3/2+}$	2940	1/2	2/5	1.42	0.85
	$\Lambda_c^{5/2+}$	2880	1/2	3/5	1.41	1.55

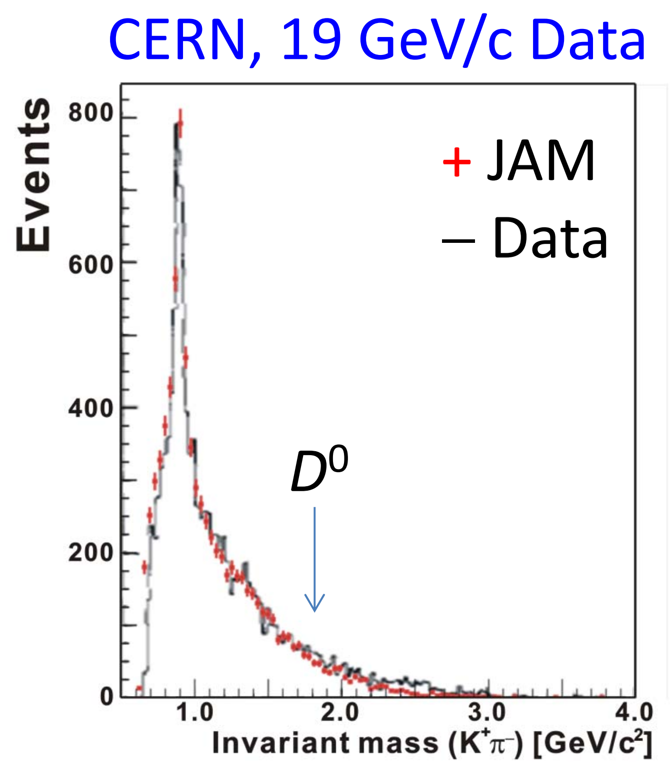
Expected spectra: σ_{GS} = 1 nb

N(Yc*)~1000 events/1nb/100 days
Sensitivity: ~0.1 nb (3σ, Γ~100 MeV)



Reliability of the BG simulation





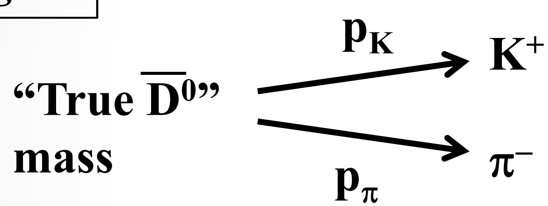
BGs of the past exp's were well reproduced.

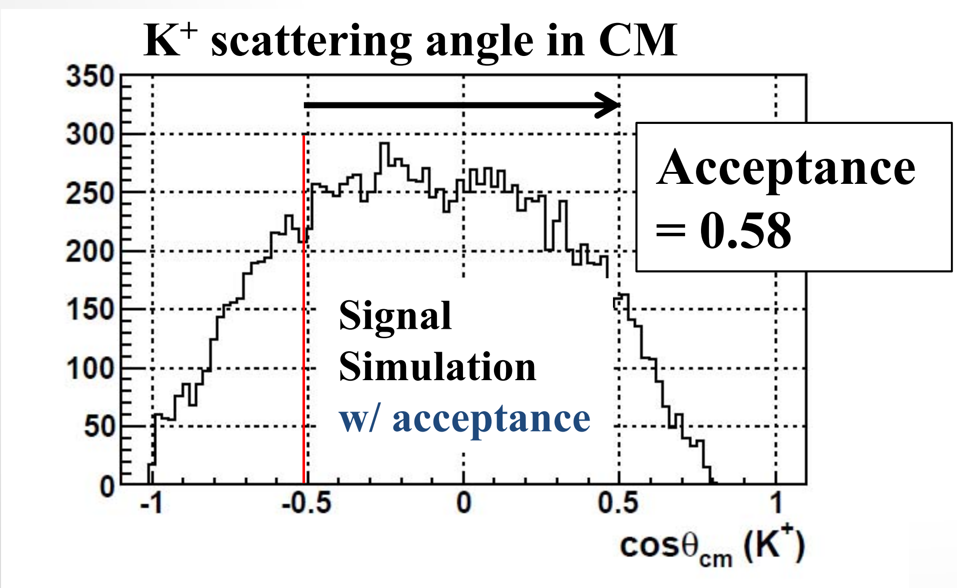
* Smooth BG shapes are seen in the D*/D mass region.

Background reduction

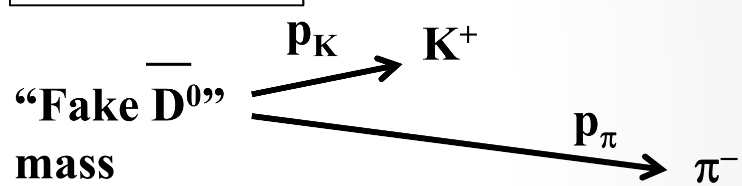
- **S/N improvement:**
  - Mass resolution: x4
  - Decay angle cut: x2
  - Production angle cut x4 (depends on $d\sigma/dt$)

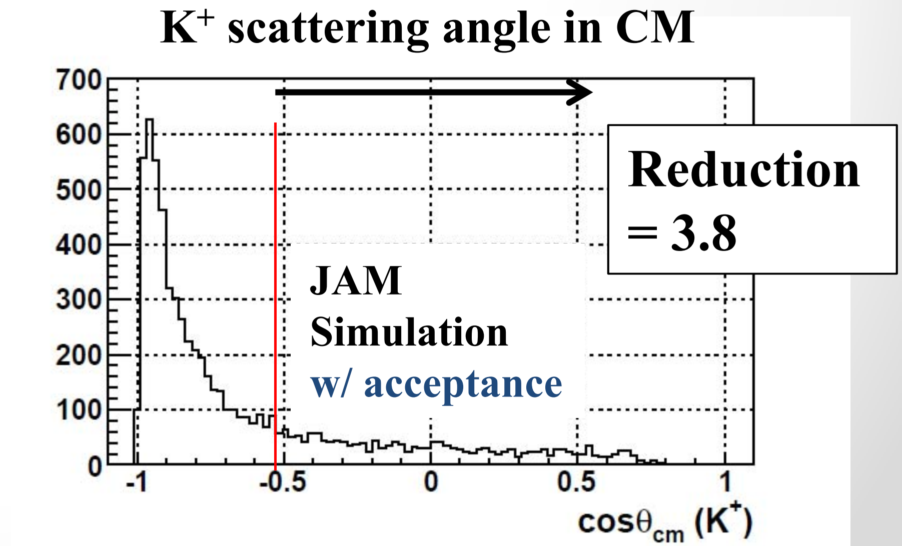
Signal





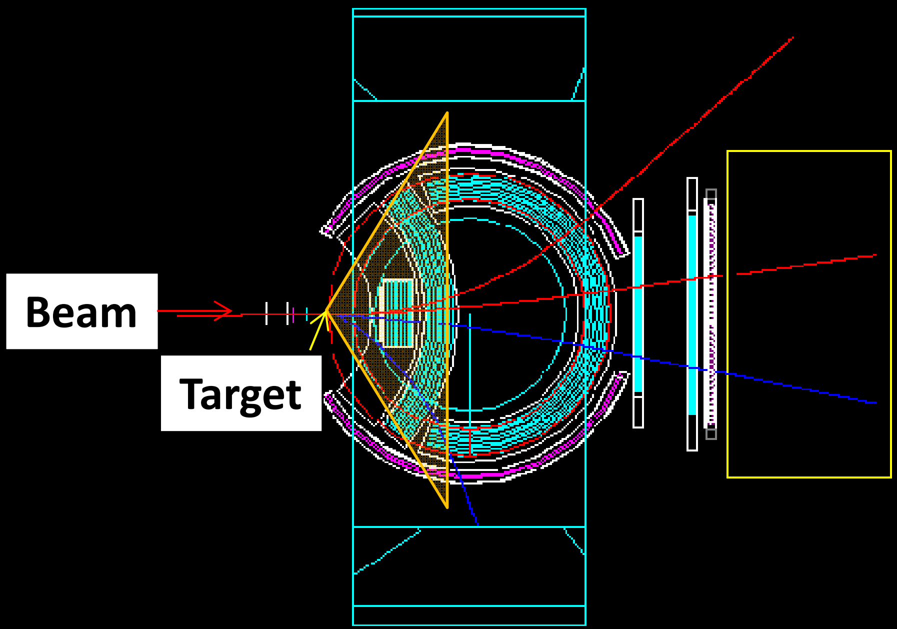
Background





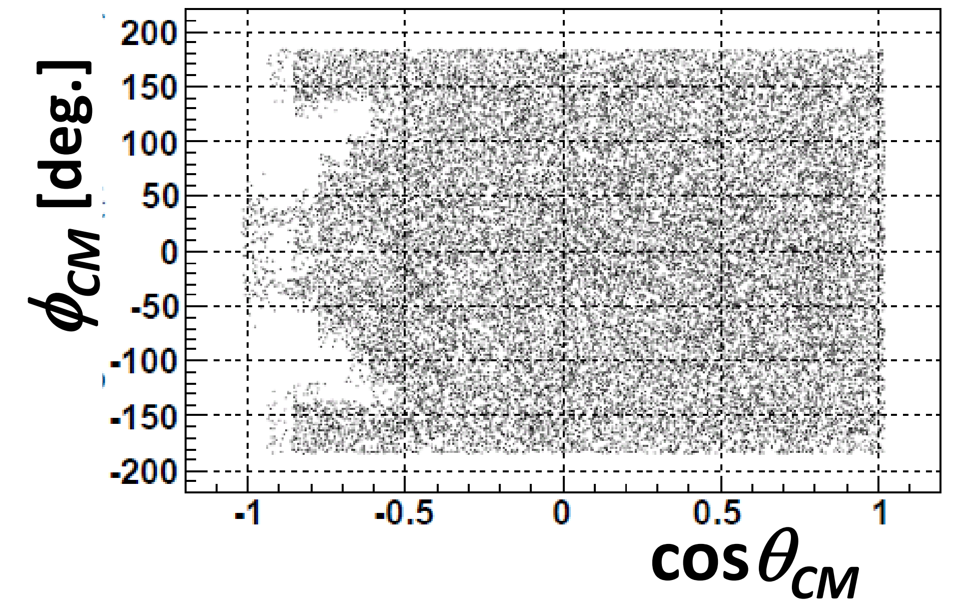
Acceptance for decay particles: ~85 %

a wide range of the azimuthal (ϕ_{CM}) and polar (θ_{CM}) angles



Coverage for decay π

$(\Lambda_c(2940) \to \Sigma_c^0\pi^+)$

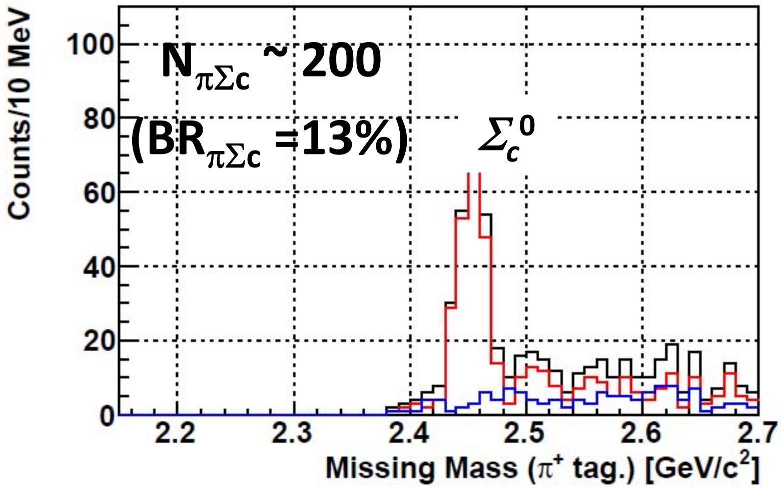


* Decay products can be measured efficiently.

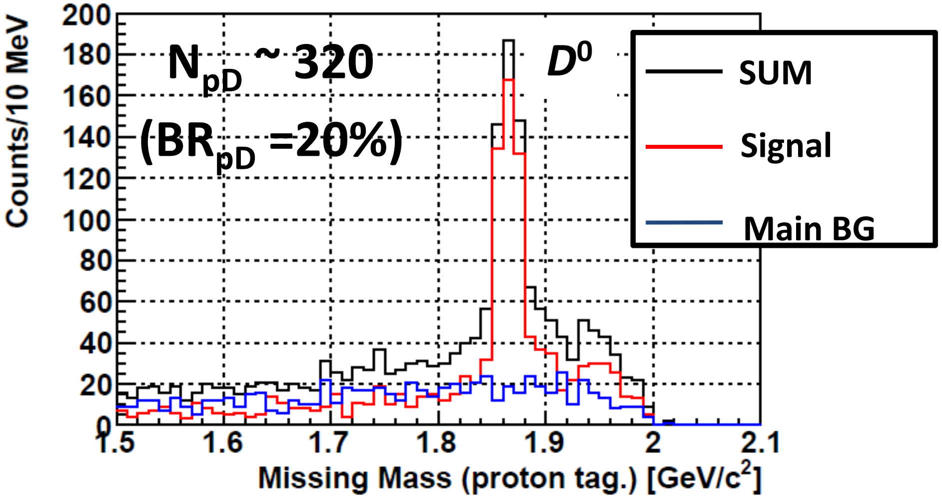
Decay Products

$\Lambda_c(2940)\text{->}\Sigma_c^0\,\pi^+$

with $\Lambda_c^+\,\pi^+\,\pi^-$ selected



$\Lambda_c(2940)\text{->}$ p D^0



* Decay products can be seen clearly owing to the large acceptance.

* Decay meas. strongly assists the missing mass spectroscopy.

- Branching ratios: Diquark corr. affects $\Gamma(\Lambda_c^*\text{->}pD)/\Gamma(\Lambda_c^*\text{->}\Sigma_c\pi)$.
- Angular distribution: Spin, Parity

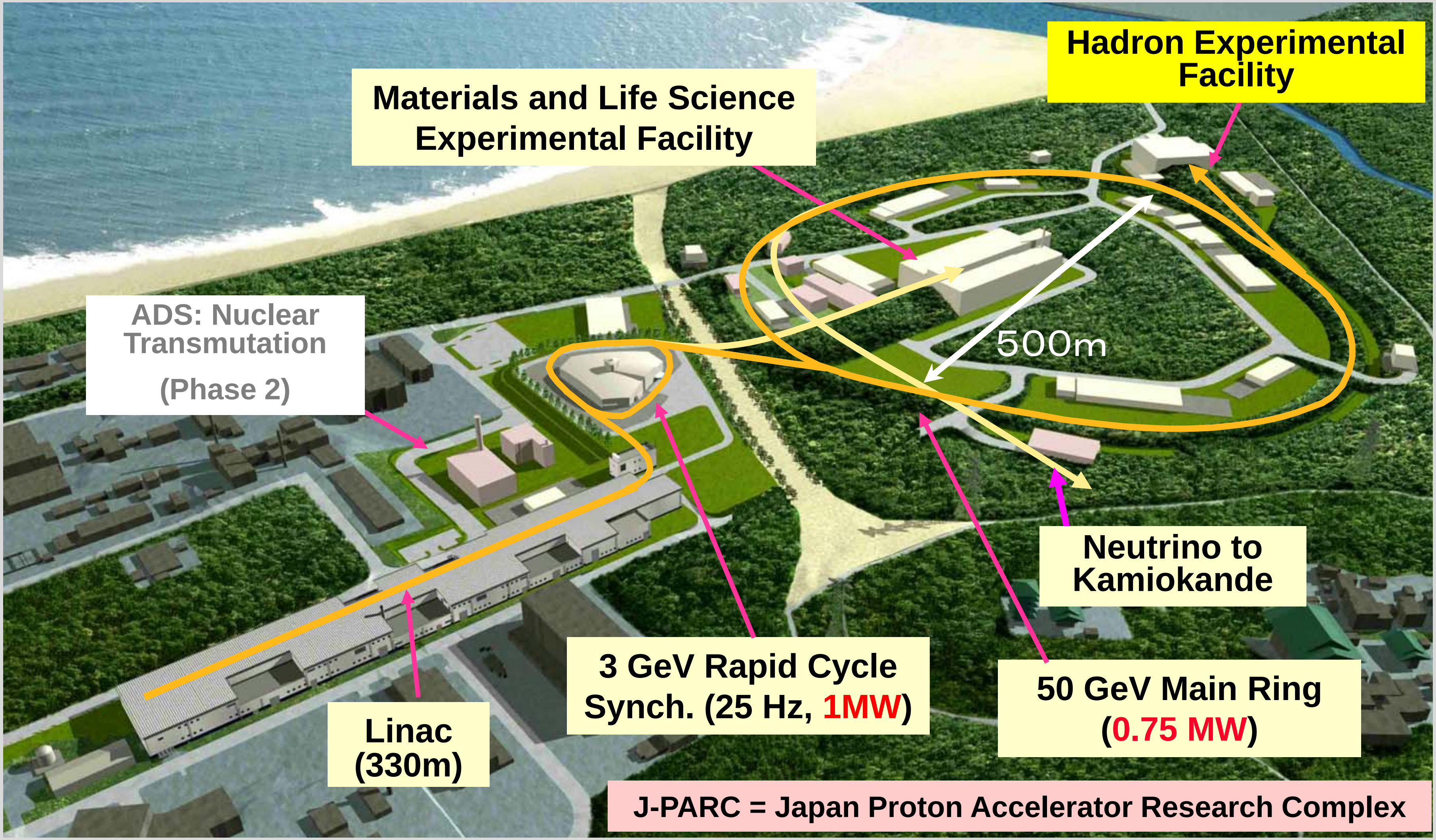
Summary

We have clarified the following features:

1. Signals
   - $\sigma(p(\pi^-,D^{*-})\Lambda_c)$ ~ a few nb seems plausible.
   - Higher *L* states are abundantly produced.
2. Background
   - The background level is well reproduced by JAM.
   - Background reduction is studied
   - Signal sensitivity of 0.1 nb for Γ~100 MeV is achieved.

Backup

J-PARC Facility

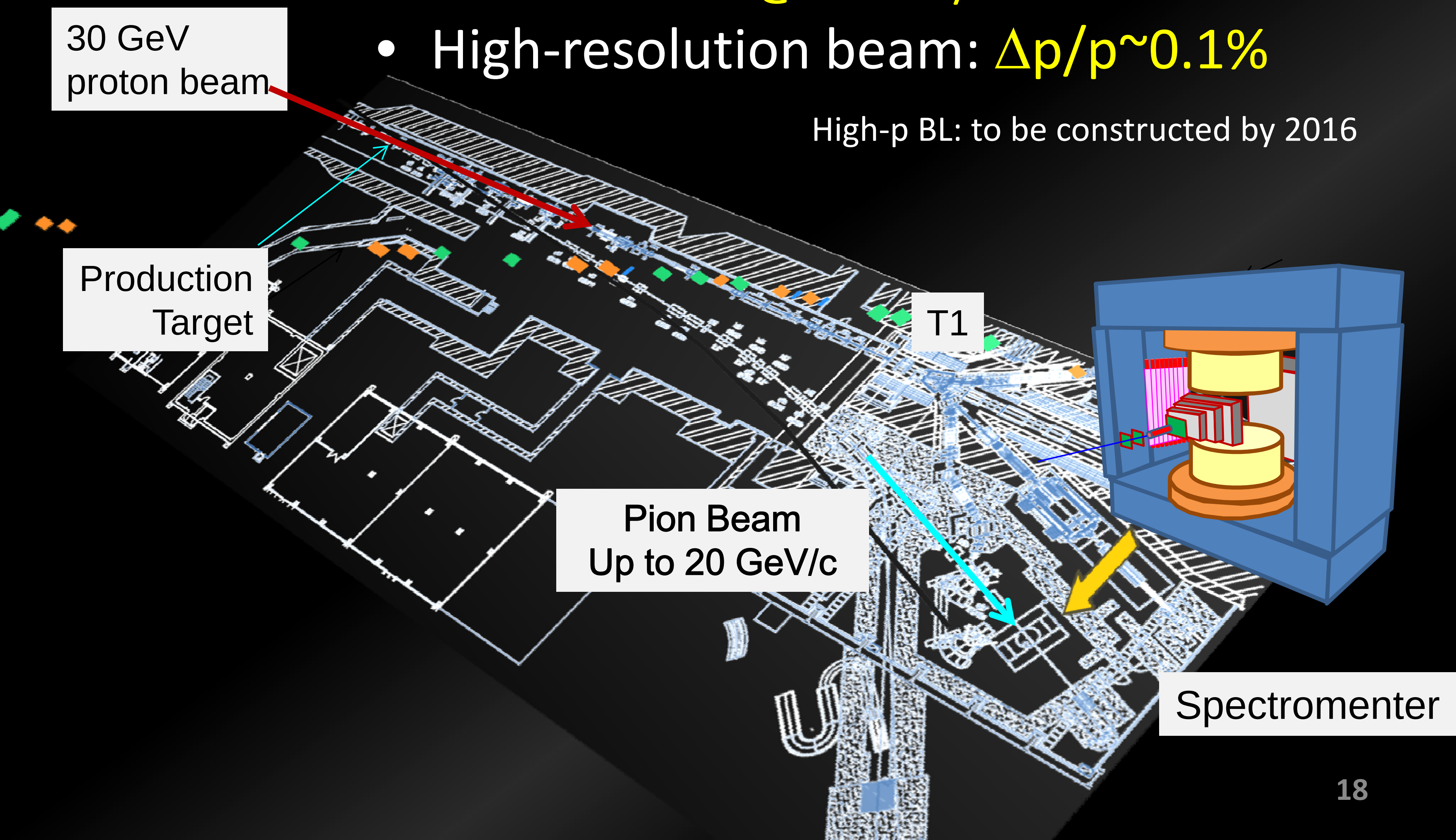


Joint Project between KEK and JAEA since 2001

High-res., High-momentum Beam Line

- High-intensity secondary Pion beam
  - 1.0 x 10^7 Hz @ 20GeV/c π
- High-resolution beam: $\Delta p/p$~0.1%

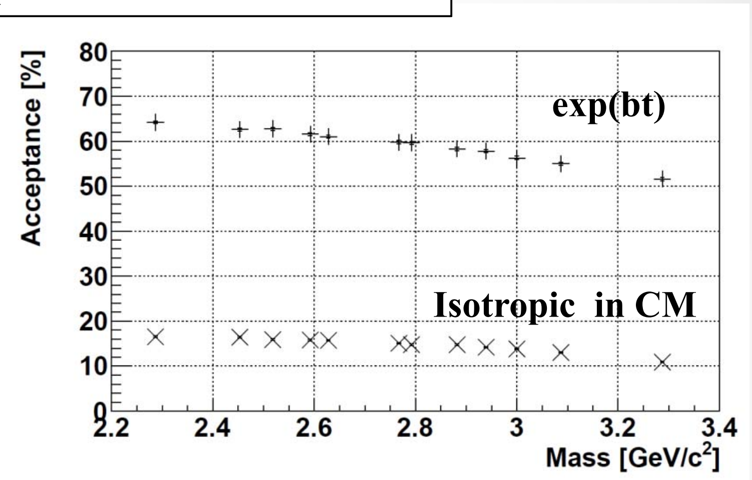
High-p BL: to be constructed by 2016



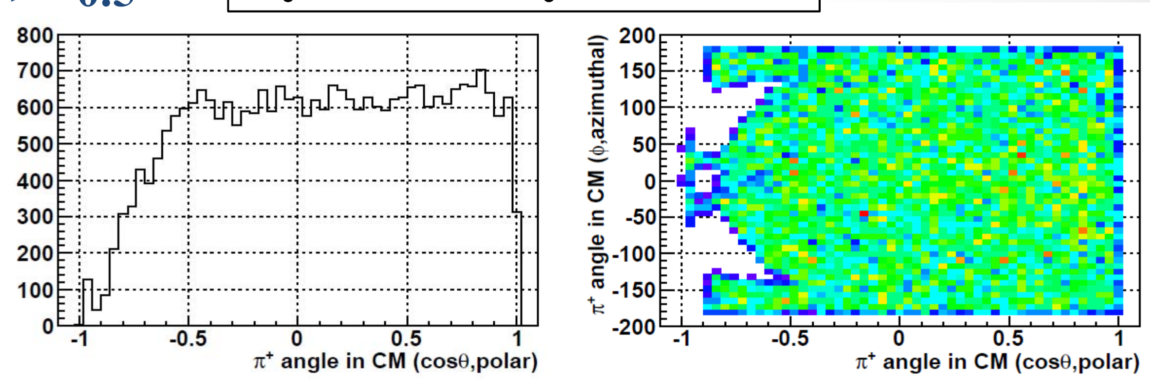
Basic performances

- **Resolution**
  - **Missing mass resolution**
    - Λ_c^+: 16.0 MeV
    - $\Lambda_c(2880)^+$: 9.0 MeV
- **Acceptance**
  - **for D^{*-} ($K^+p^-p^-$): 50–60%**
  - **for decay particles: ~85%**
    - * complete coverage $\cos\theta > -0.5$

Acceptance: D^{*-} detection

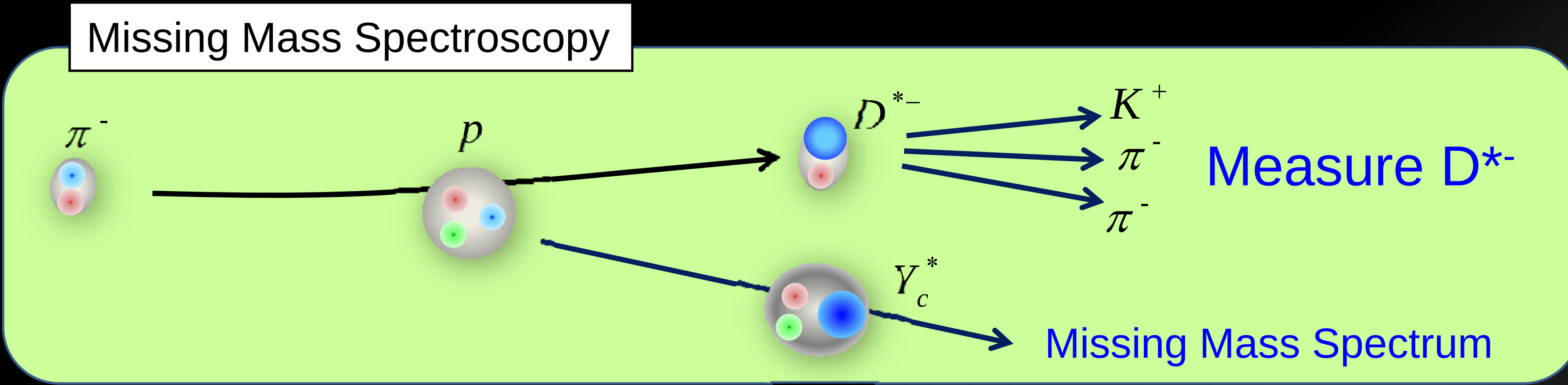


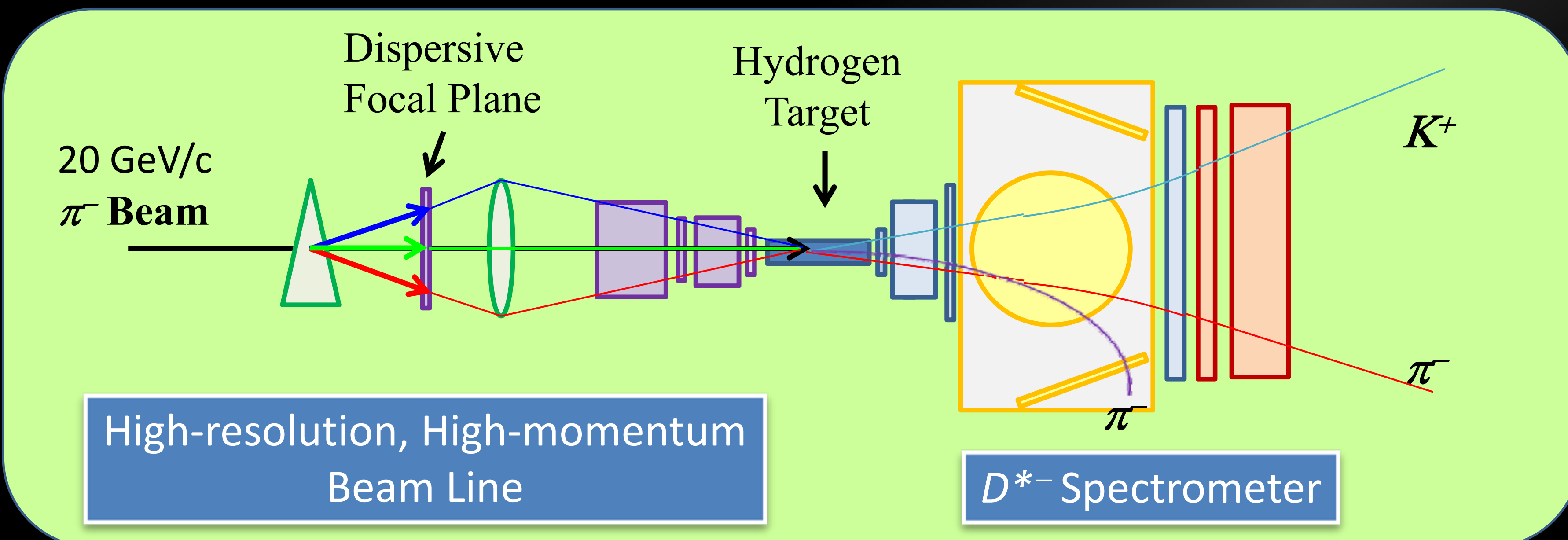
$\Lambda_c(2940)^+ \rightarrow \Sigma_c(2455)^0 + \pi^+$



Forward direction (Beam direction) →

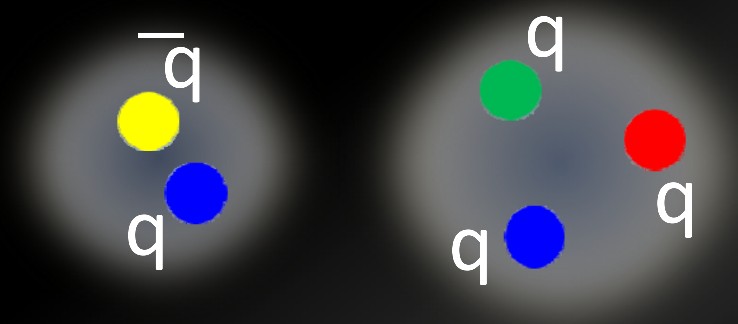
Charmed Baryon Spectroscopy





What are good building blocks of Hadrons?

Constituent Quark



Hadron properties

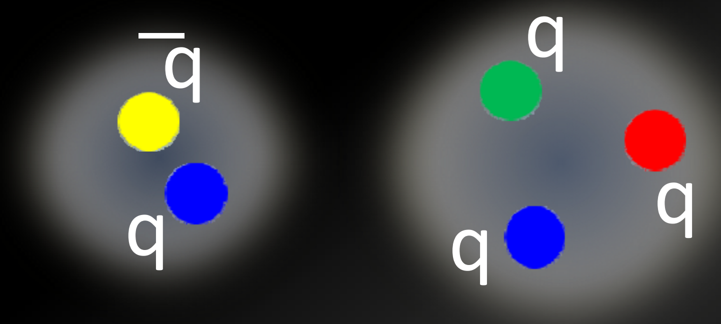
- Classification based on Spin/flavor symmetry
- Mass Relations, Magnetic Moments

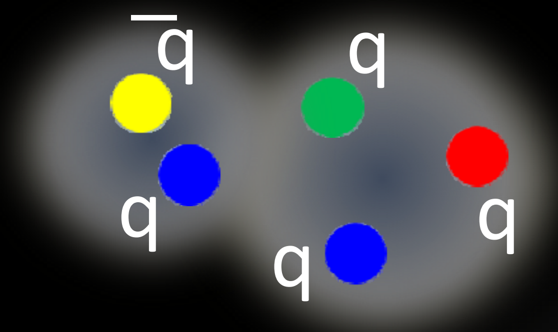
Failure in Resonant States

- Missing Resonances
- Exotics

What are good building blocks of Hadrons?

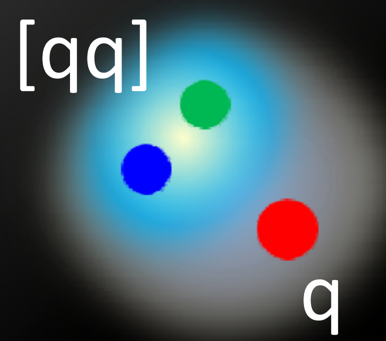
Constituent Quark





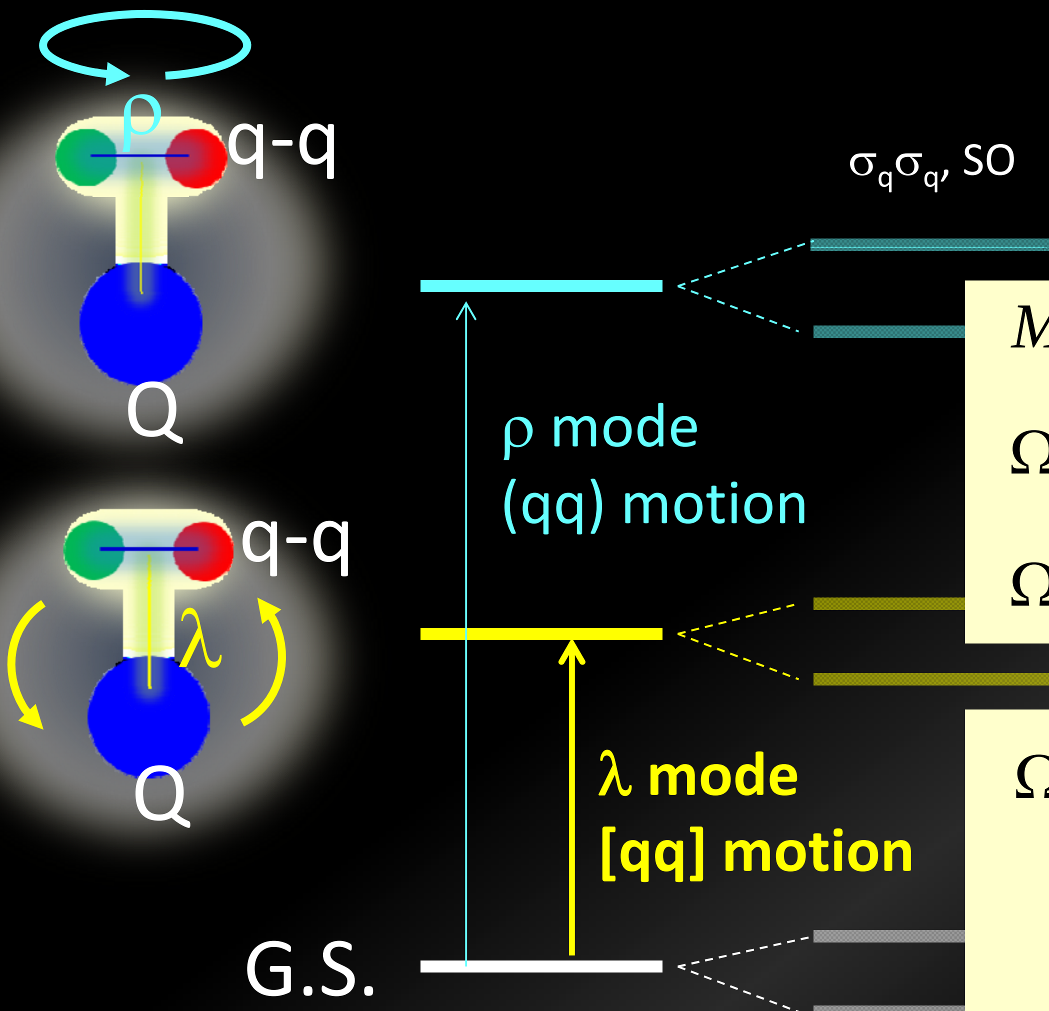
hadron (colorless cluster)

Diquark?
(Colored cluster)



Collective [qq] and relative (qq) motions

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



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

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

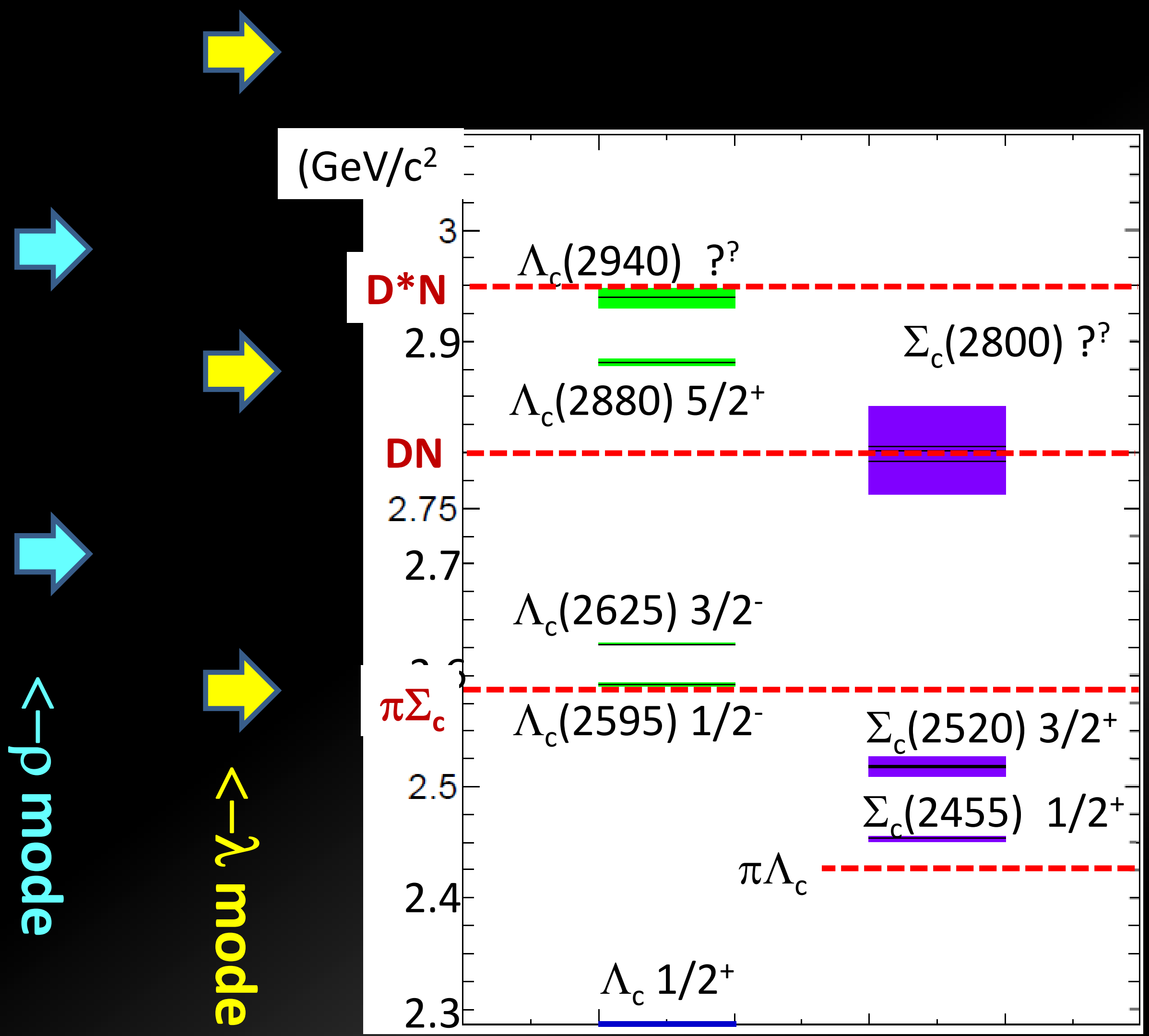
$$\Omega_\rho = 2\sqrt{3K(M_Q + 2m_q)^2/m_q}$$

$$\Omega_\lambda/\Omega_\rho = \sqrt{(M_Q + 2m_q)/3M_Q}$$

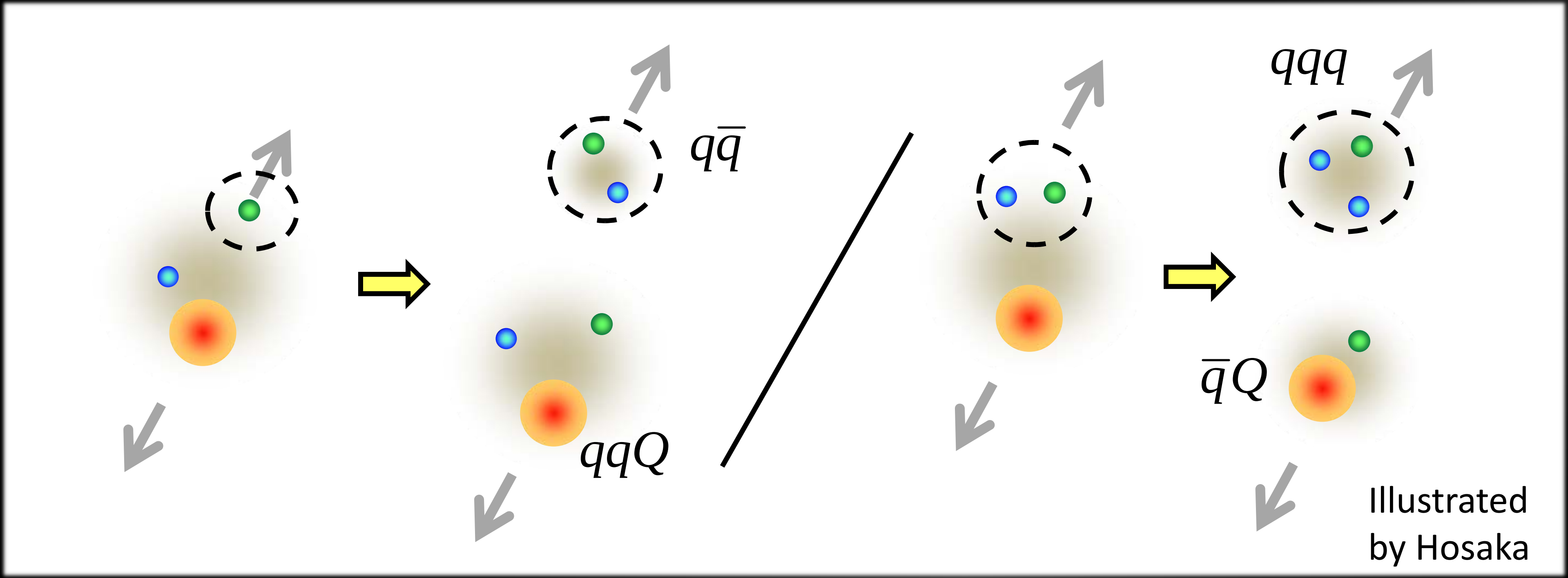
$$\to 1/\sqrt{3} \quad (M_Q >> m_q)$$

$$\to 1 \quad (M_Q = m_q)$$

Limited # of Charmed Baryons have been observed.



Structure and Decay Partial Width



Excited (qq) Good [qq]

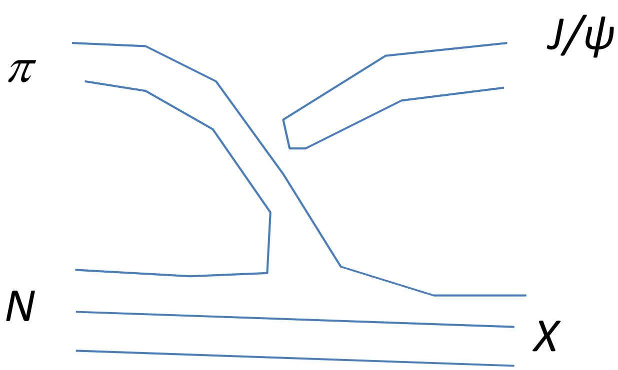
- Λ(1520) -> Γ(NK)>Γ($\pi\Sigma$), similarly Λ(1820), Λ(2100)
- Possible explanation of narrow widths of Charmed Baryons

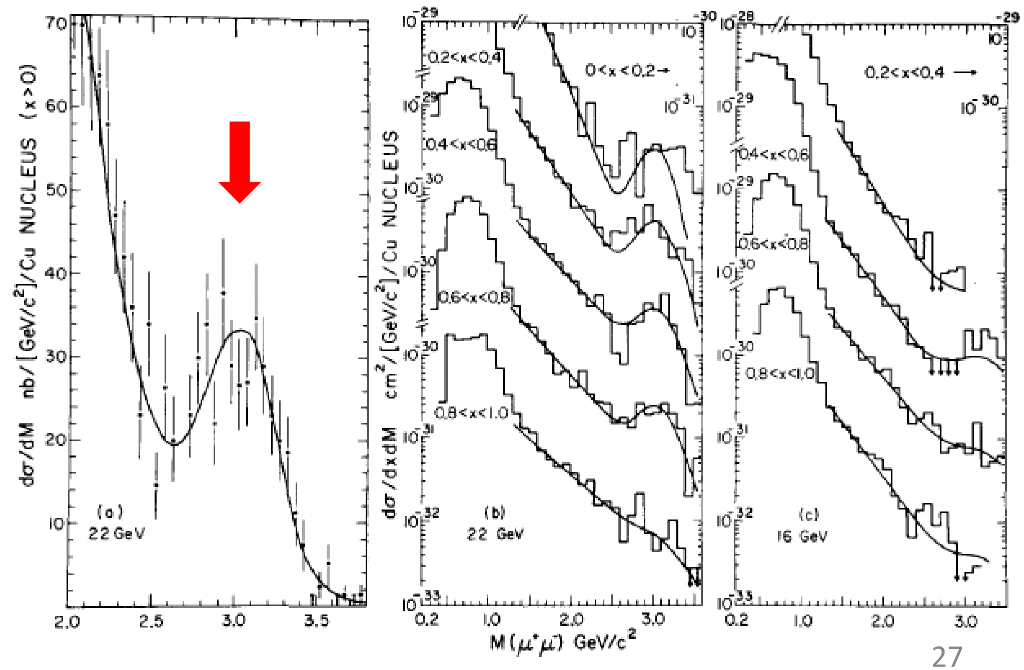
Backup slides for estimation of the production Cross Section

Charm production Cross Section

- $\sigma(\pi N \rightarrow J/\psi X) = (1 \pm 0.6)$ nb and (3.1 ± 0.6) nb at 16 GeV/c and 22 GeV/c.
  - OZI-suppressed process!

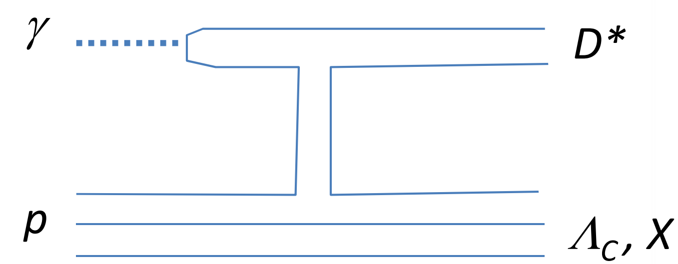
LeBritton et al., PLB81, 401(1979)





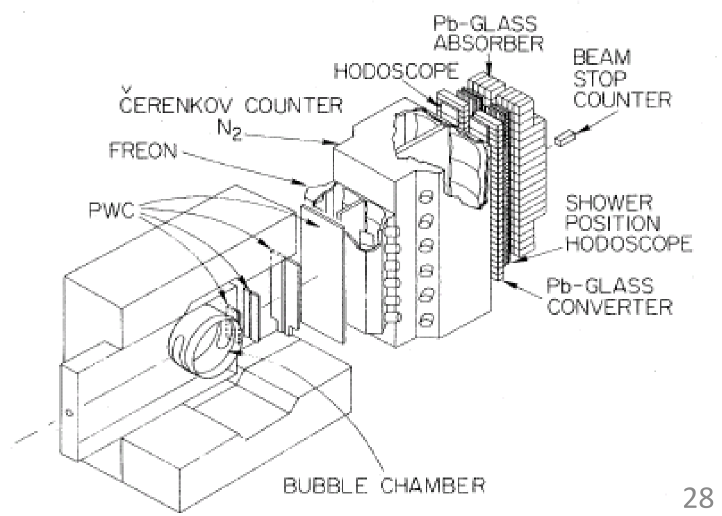
Charm production Cross Section

- Photoprod. of $\Lambda_c D^{*bar} X$ on p at E_γ=20 GeV.
  - $\sigma(\Lambda_c D^{bar} X) = 44 \pm 7^{+11}_{-8}$ nb
  - $\sigma(D^- X) = 29 \pm 5^{+7}_{-5}$ nb
  - $\sigma(D^{*-} X) = 12 \pm 2^{+3}_{-2}$ nb



$\sigma(\Lambda_c D^{*bar} X) \sim 18$ nb

- This seems sizable.



Abe et al., PRD33, 1(1986)

Comparison in strange sector

- OZI-suppressed process in Strange Sector
  - $\sigma(\pi^- p \to \phi n)$ = (1.66 ± 0.32) nb at 4 GeV/c.

    Avres et al., PRL32, 1463(1973)
  - $\sigma(\pi^+ p \to \phi \pi^+ p)$ = (9.5 ± 2.0) nb at 3.75 GeV/c

    Gidal et al., PRD17, 1256(1978)

    -> $\sigma(\pi N \to \phi N)/\sigma(\pi N \to \phi X)$~1/10?
- OZI-non-suppressed process
  - $\sigma(\pi^- p \to K^* \Lambda)$ = (53 ± 2) nb at 4.5 GeV/c

    Crennell et al., PRD6, 1220(1972)

    -> $\sigma(\pi^- p \to K^* \Lambda)/\sigma(\pi N \to \phi X)$~2?

    -> ??? $\sigma(\pi^- p \to D^* \Lambda_c)/\sigma(\pi N \to J/\psi X)$~2?

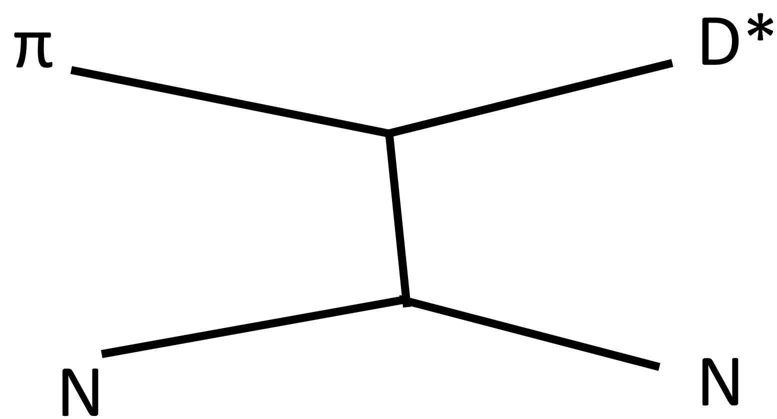
Effective Lagrangian

- Four possible processes; s, t, u and contact
- At high energies and forward region, t-dominates

  s: suppressed, no resonance above 3 GeV

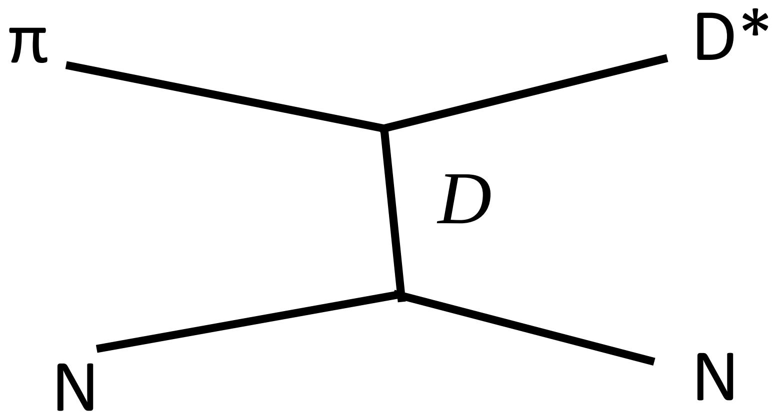
  u: suppressed kinematically

  c: unknown



- D, D* exchanges allowed, but scalar is not

D-exchange



$$L_{\pi D D^*} = f\,\pi\,\partial^\mu D\,D^*_\mu$$

$$L_{DNN} = g\bar{N}\gamma_5 N D$$

$$F(t) = \frac{\Lambda^4}{\Lambda^4 + \left(t - m_D^2\right)^2}$$

$$\frac{d\sigma}{d(\cos\theta)} = \frac{q}{8\pi\sqrt{s}}\frac{2G^2(E_N E_\Lambda - kq\cos\theta - m_N m_\Lambda)}{4\left[(pk)^2 - m_\pi^2 m_N^2\right]^{1/2}}\frac{k^2}{2} \times F(t)^{0,1,2}$$

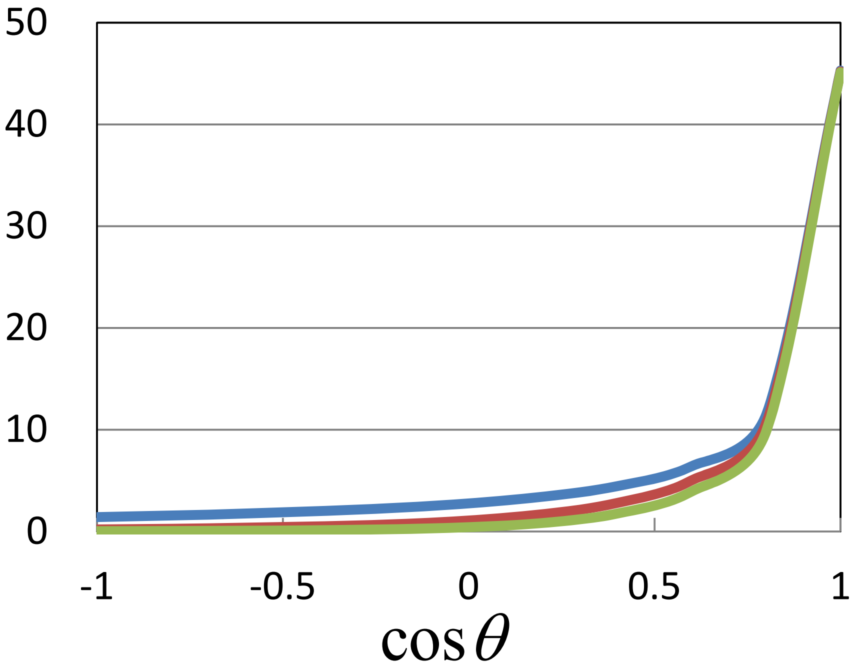
$$G = \frac{2fg}{t - m_D^2} = \frac{2gf}{m_\pi^2 + m_{D*}^2 - 2kq - m_D^2}, \quad t = (k-q)^2$$

Light flavor, u,d $\pi + P \rightarrow \rho + p$

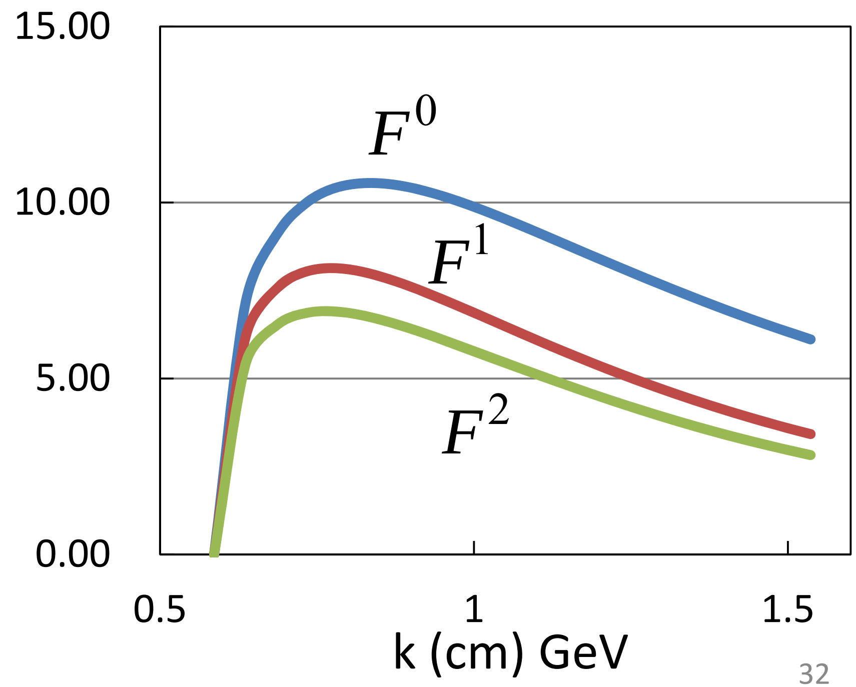
F^1: 8 mb

F^2: 7 mb

$$\frac{d\sigma}{d(\cos\theta)}\,[\mathrm{mb}]$$



$$\sigma_{tot}\,[mb]$$



Strangeness $\pi + P \rightarrow K^* + \Lambda(1116)$

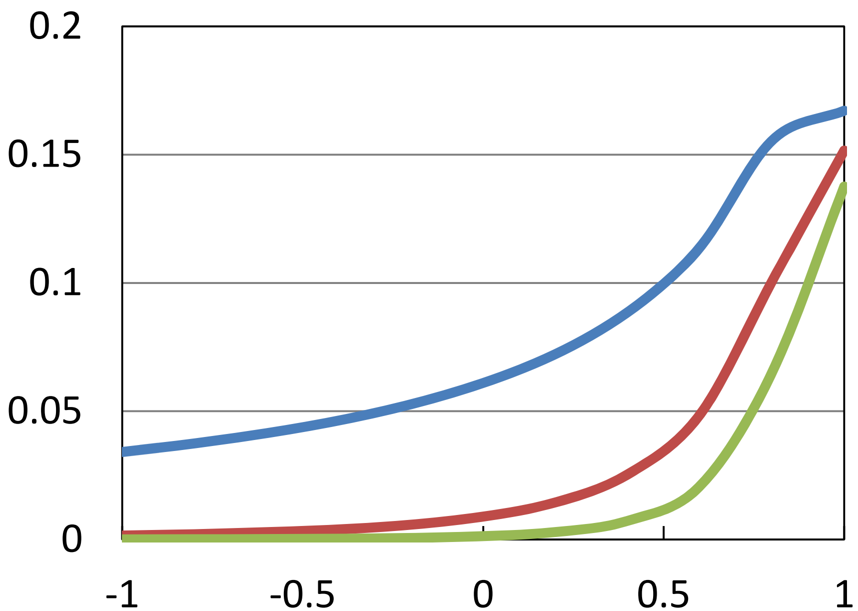
F^1: 8 mb ------> 0.07 mb

1/120

F^2: 7 mb ------> 0.04 mb

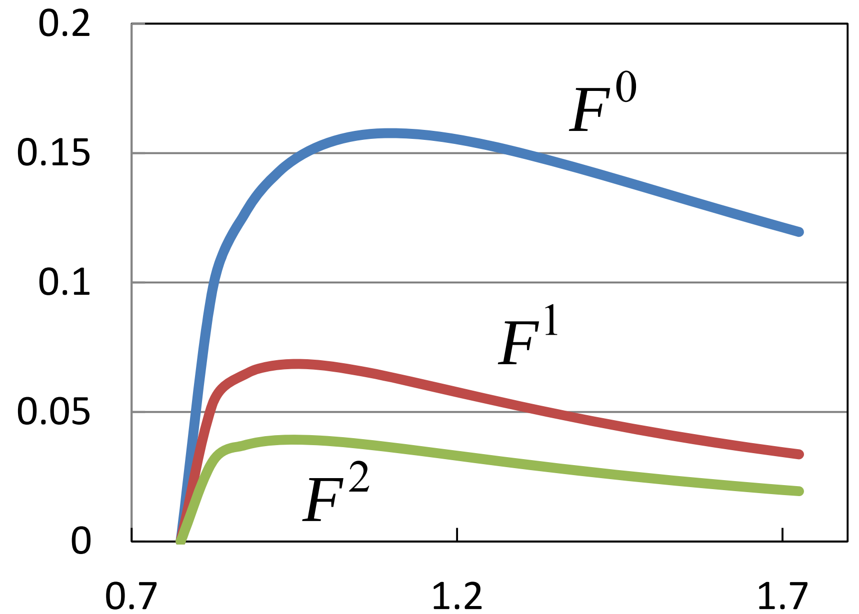
1/170

$$\frac{d\sigma}{d(\cos\theta)} [\text{mb}]$$



$\cos\theta$

$\sigma_{tot}\ [mb]$



k (cm) GeV

Charm $\pi+P \rightarrow D^*+\Lambda c(2226)$

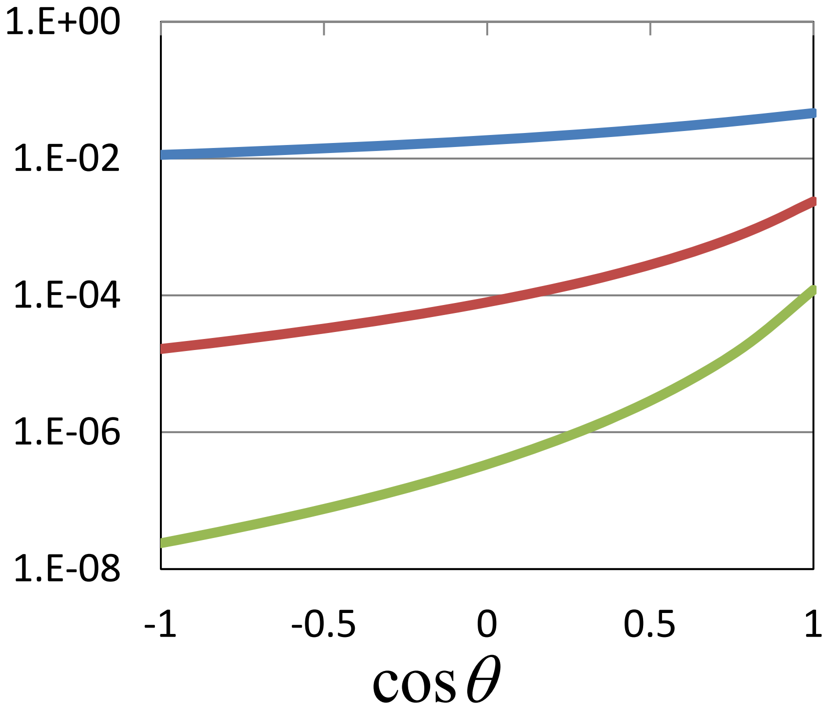
F^1: 8 mb ------> 0.07 mb ------> 0.0006 mb

1/120 **1/120**

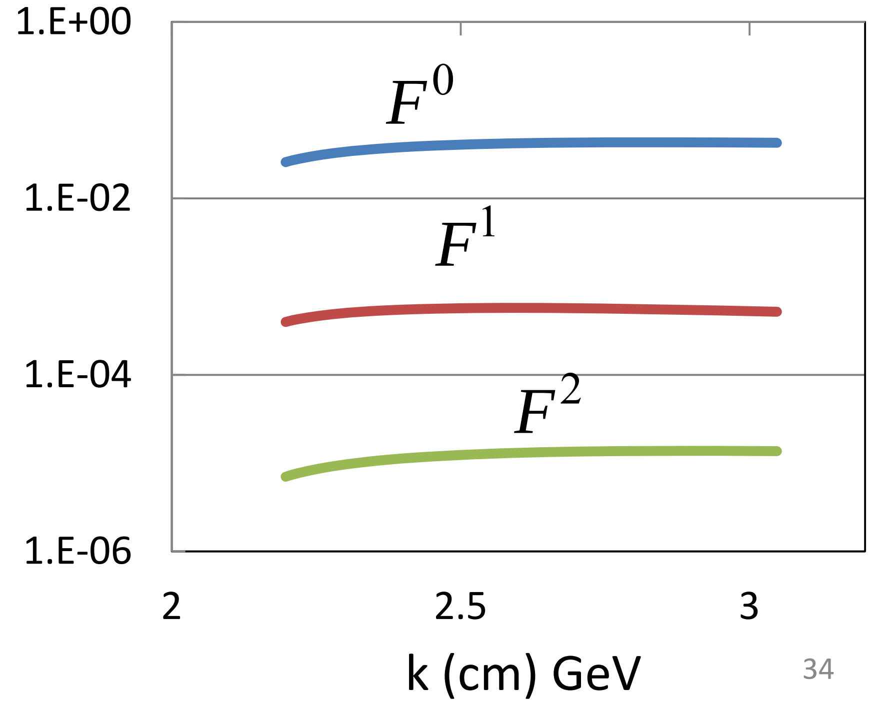
F^2: 7 mb ------> 0.04 mb ------> 0.00002mb = 20pb

1/170 **1/2000**

$\frac{d\sigma}{d(\cos\theta)}[mb]$



$\sigma_{tot}\,[mb]$



discussed with A. Hosaka

Revisit the Regge Theory

- shows the typical s-dependence of binary reaction cross sections at the large s region;

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s (p_\pi^{cm})^2} \left| \langle f | T | i \rangle \right|^2 \quad \langle f | T | i \rangle = g_1 g_2 \Gamma(-\alpha(t))(s/s_0)^{\alpha(t)}$$

  - Regge trajectory: $\alpha(t) = \alpha(0) - \gamma[\sqrt{T} - \sqrt{t - T}]$
  - scale parameter s_0 :

    s at the threshold energy of the reaction AB → CD

    (*In Kaidalov's Model: $s_0^{2(\alpha_{D^*}(0)-1)} = s_{CD}^{\alpha_\rho(0)-1} * s_{CD}^{\alpha_{J/\psi}(0)-1}$

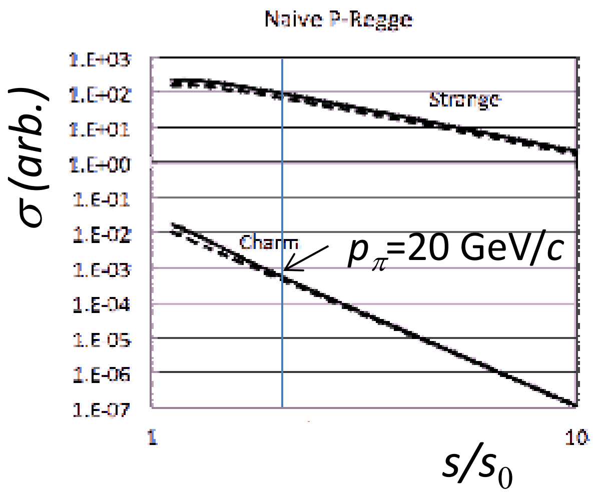
    $s_{AB}=(\Sigma m_i)_A*(\Sigma m_j')_B$, m_i:transversal masses of the consituent quark)

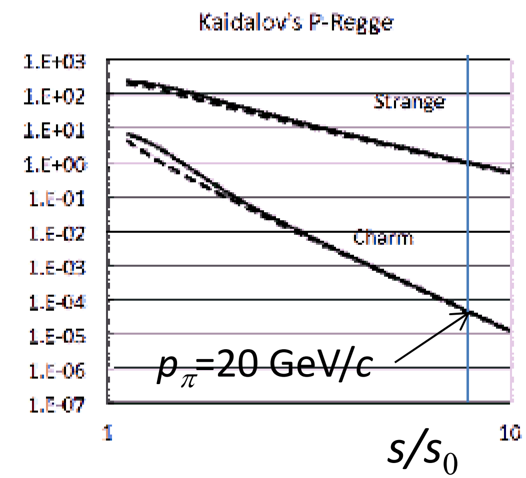
- Treatment of $\Gamma(-\alpha(t))$ to avoid possible singularities
  - Actually introduce phenomenological form factor
    - $\Gamma(-\alpha(t))$ → $\Gamma(1-\alpha(t_0))$: naïve Regge
    - → $\Gamma(1-\alpha(t_0))$: Kaidalov's Regge [Z. Phys. C12, 63(1982)]
    - → $\exp(R^2 t)$: Grishina's Regge [EPJ A25, 141(2005)]

calculated by A. Hosaka

Regge Theory

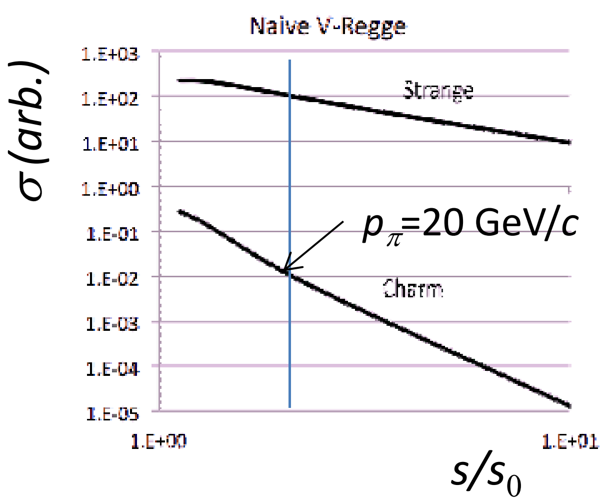
- PS(K,D)-Regge (Top): s/c-prod: ~10^{-5}(Naïve), ~3×10^{-5}(Kaidalov)
- V(K^*,D^*)-Regge (Bottom): s/c-prod.: ~10^{-4}(Naïve), ~3×10^{-5}(Kaidalov)

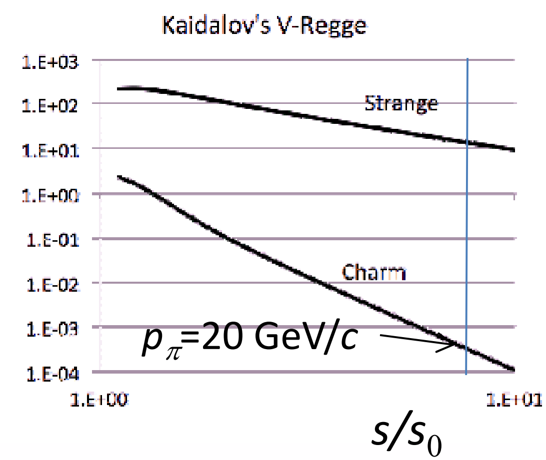




Scale Parameter

	s_0 (GeV^2)
Naïve $K^*\Lambda$	4.02
$K^*\Lambda_c$	18.46
Kaidalov $K^*\Lambda$	1.66
$K^*\Lambda_c$	4.75

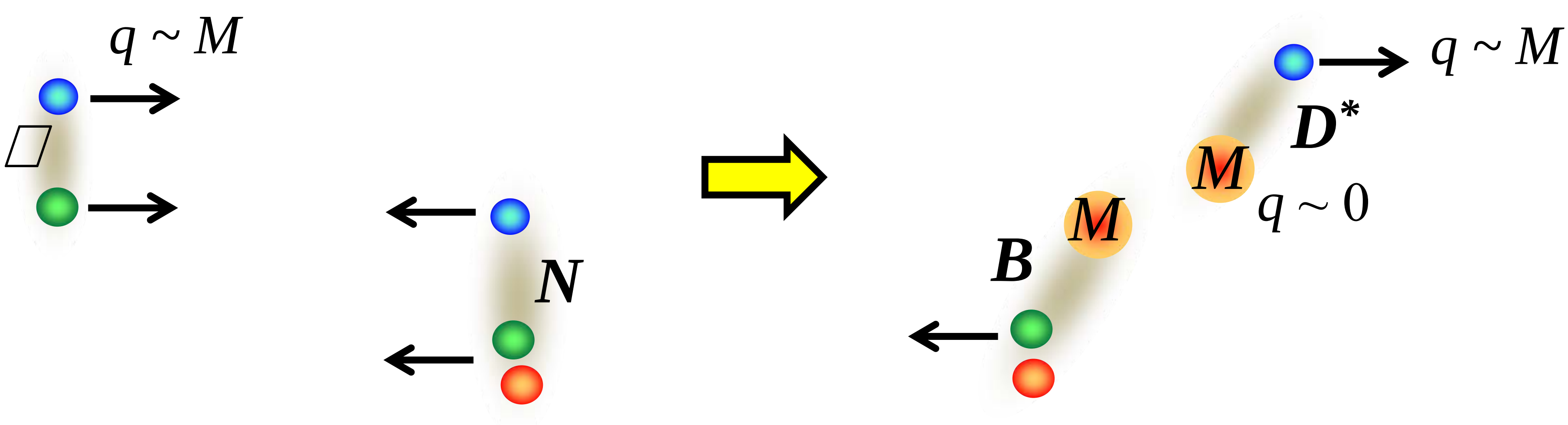




Regge Trajectory

	$\alpha(0)$	γ	$T^{1/2}$ (GeV)
K	-0.151	3.65	2.96
D	-1.611	3.65	4.16
K*	-0.414	3.65	2.58
D*	-1.020	3.65	3.91

Formation probability



Prob. of finding the fast quark of $q \sim M$ in a baryon $\sim \langle N(qd) | B(Qd) \rangle$

$$P(M) \sim \left(\underbrace{\frac{\Lambda^2}{\Lambda^2 + M^2}}_{\text{per hadron}} \times \frac{\Lambda^2}{\Lambda^2 + M^2} \right)^2 \Rightarrow \frac{P(M_c)}{P(M_s)} \sim \frac{\mathbf{1}}{\mathbf{1000}},$$

$M_s \sim 0.4 GeV, \Lambda = 0.5$

$M_c \sim 1.5 GeV$

Typical suppression

Comment on the Coupling Constant

- Comparison of $g_{D^*D^*\pi}/g_{K^*K^*\pi}$ and $g_{\Lambda cND}/g_{\Lambda NK^*}$
  - *Estimated by means of the Light Cone QCD Sum Rule*

$g_{K^*K^*\pi}$	$g_{D^*D^*\pi}$	$g_{D^*D^*\pi}/g_{K^*K^*\pi}$
3.5*	4.5	1.3
$g_{K^*K\pi}$	$g_{D^*D\pi}$	$g_{D^*D\pi}/g_{K^*K\pi}$
4.5*	7.5	1.7

M.E. Bracco et al.
Prog. Part Nucl. Phys. 67, 1019(2012)

$g_{\Lambda NK^*}$	$g_{\Lambda cND^*}$	$g_{\Lambda cND^*}/g_{\Lambda NK^*}$
$-6.1^{+2.1}_{-2.0}$	$-5.8^{+2.1}_{-2.5}$	$0.95^{+0.35}_{-0.28}$
$g_{\Lambda NK}$	$g_{\Lambda cND}$	$g_{\Lambda cND}/g_{\Lambda NK}$
$7.3^{+2.6}_{-2.8}$	$10.7^{+5.3}_{-4.3}$	$1.47^{+0.58}_{-0.44}$

A. Khodjamirian et al.
EJPA48, 31(2012)

  - *Exp. Data*

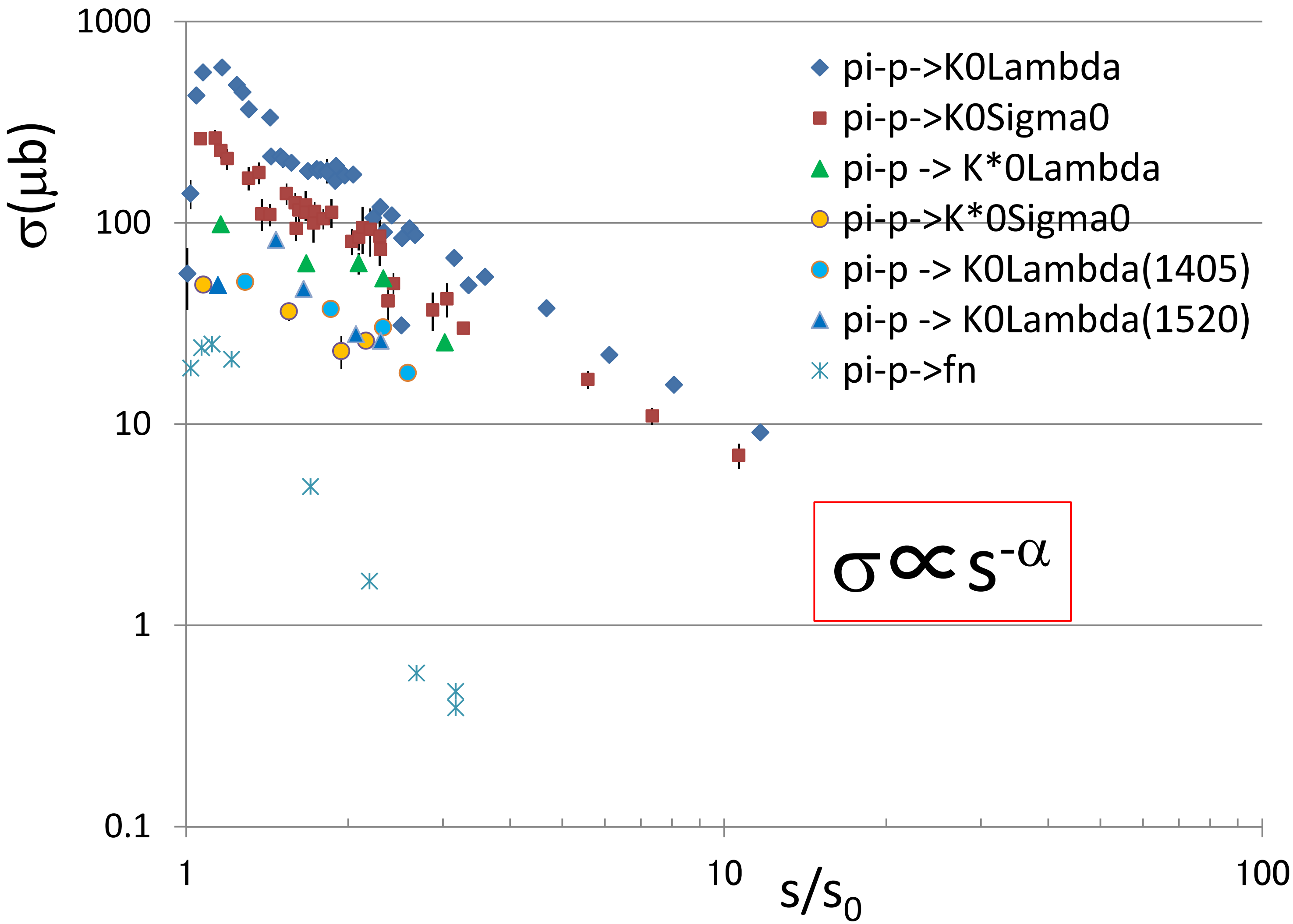
*note:g[Bracco]/2=g[Khodjamirian]

$g_{K^*K\pi}$	$g_{D^*D\pi}$	$g_{D^*D\pi}/g_{K^*K\pi}$
~4.5	8.95+-0.15+-0.9	~2+-0.2

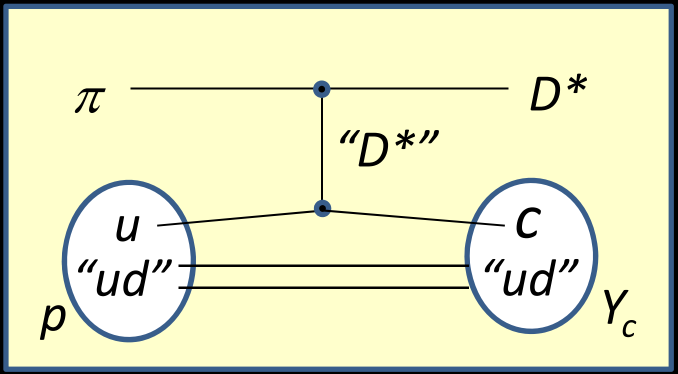
- Taking $g_{D^*D^*\pi}/g_{K^*K^*\pi} \sim 1$, $g_{\Lambda cND^*}/g_{\Lambda NK^*} \sim 0.67$

  → We still expect $\sigma(p(\pi,D^*)\Lambda_c) \sim$ a few nb.

Comparison in strange sector



Production Rate



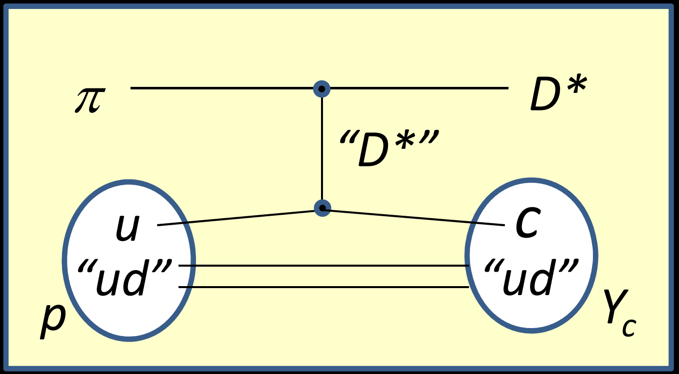
- t-channel D* EX
  at a forward angle
- quark-diquark picture

$$R \sim \gamma C \,|\, K \cdot I \,|^2 \; p_B$$

kinematicfactor× a propagator

$$K \sim k^0_{D*} k_\pi (|\,\vec{p}_B\,| / 2m_B - 1)/(q^2 - m^2_{D*})$$
$$\sim 0.9$$

The production rates depend on the spin/isospin configurations of baryons.

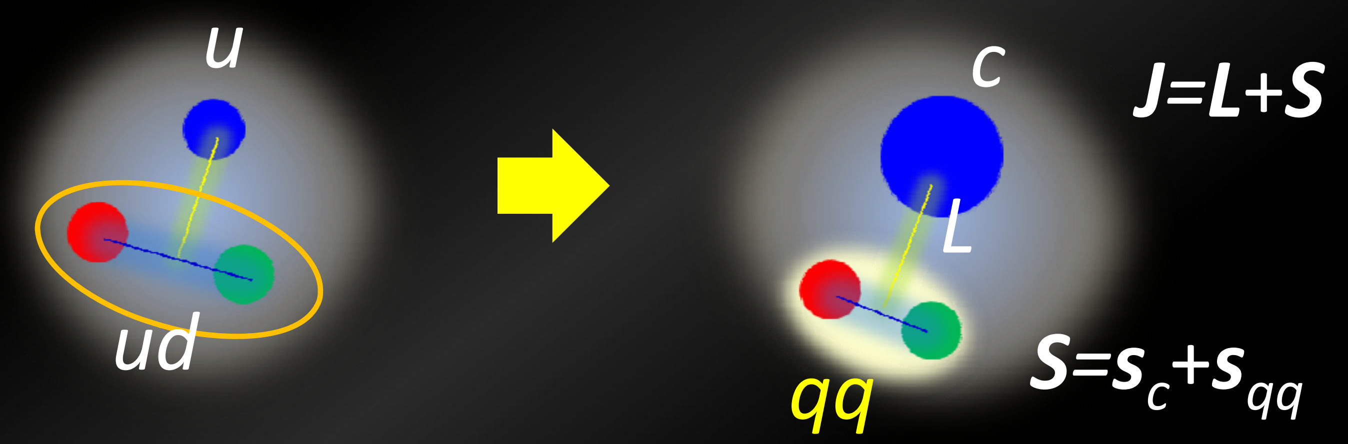


$$R \sim \gamma C \,|\, K \cdot I \,|^2 \; p_B$$

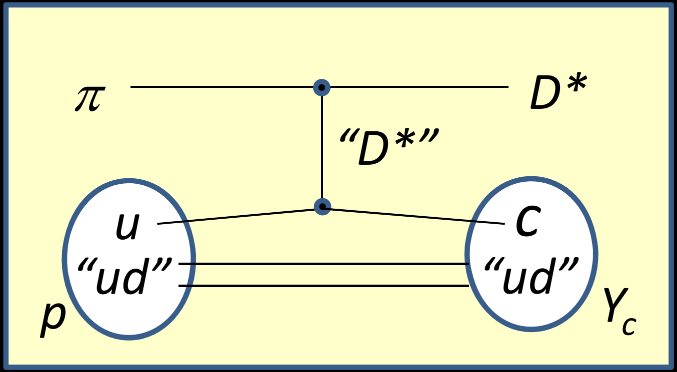
$$\gamma = \begin{cases} 1/2 \text{ for [ud]} : {}^1S_0, I = 0 \\ 1/6 \text{ for (ud)} : {}^3S_1, I = 1 \end{cases}$$

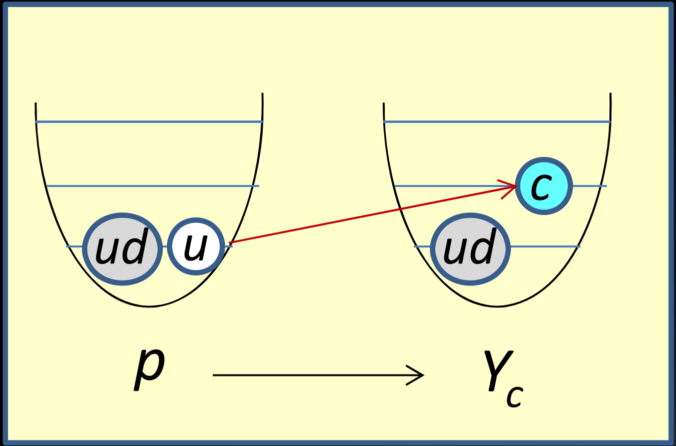
$$C = \left\langle [\varphi_{nL}, \chi^M]^J_{-1/2} \middle| \sqrt{2}\sigma_- \middle| \varphi_{000} \chi^\rho_{+1/2} \right\rangle$$

- t-channel *D** EX at a forward angle
- quark-diquark picture



The production rates do not go down at higher L states due to large q_{eff}





$$R \sim \gamma C \,|\, K \cdot I \,|^2 \; p_B$$

I : radial matrix element.

$$I \sim \int d\vec{r}[\varphi_f^*(\vec{r}) \exp(i\vec{q}_{eff}\vec{r})\varphi_i(\vec{r})]$$

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

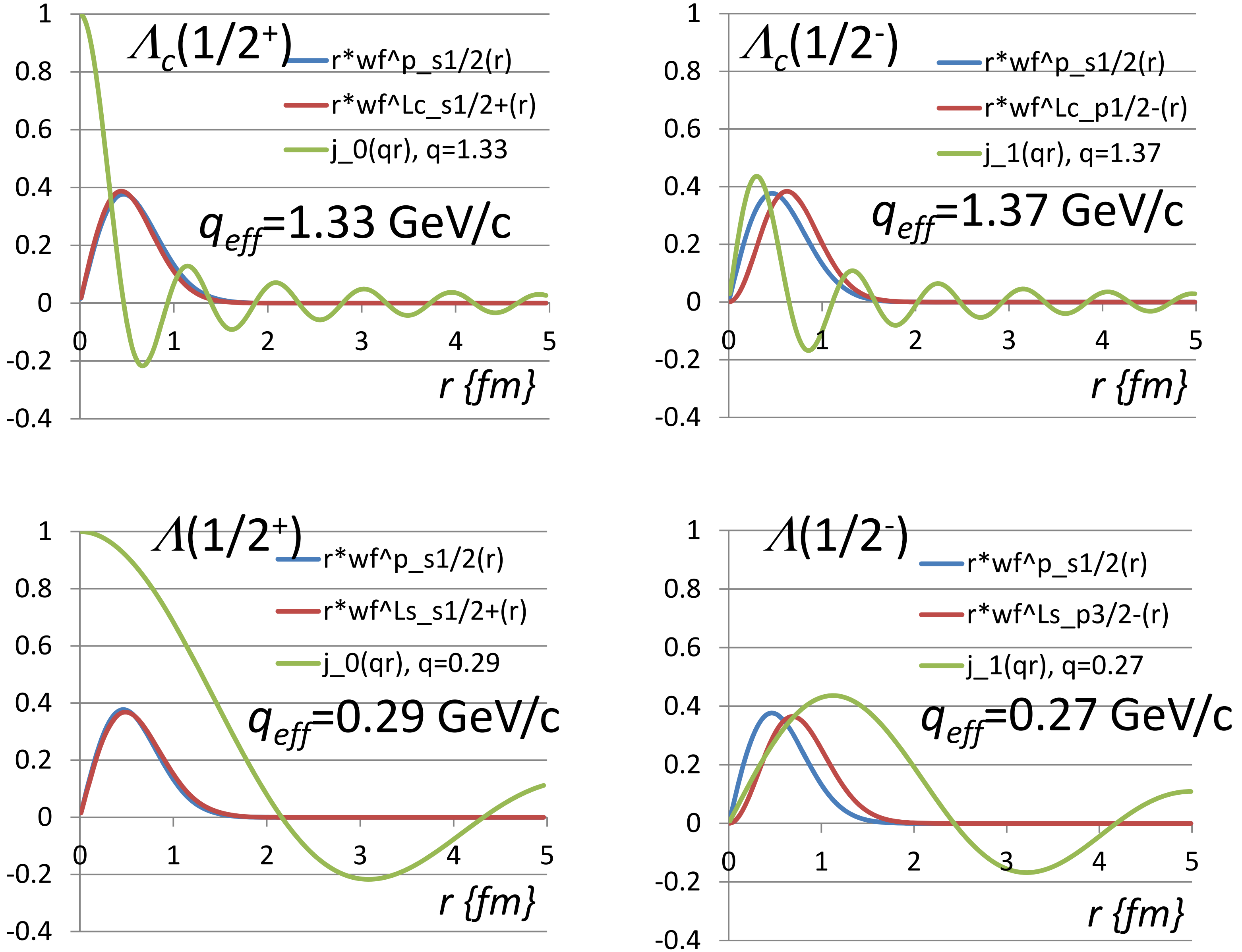
q_{eff} : effective recoil momentum ~ 1.4 GeV/c

A : oscillator parameter ~ 0.4 GeV

$$I_L / I_{L=0} \sim (q_{eff}/A)^L > 1$$

charm

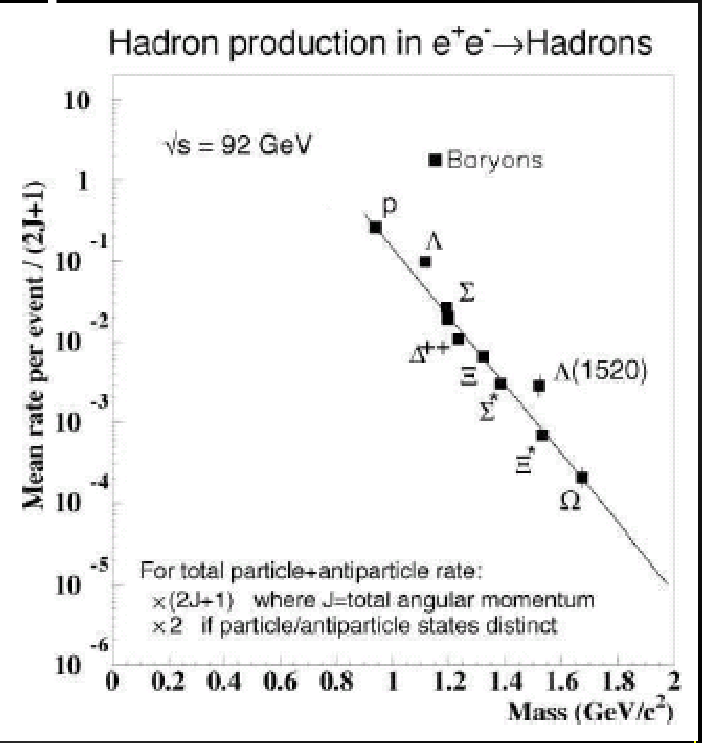
strange



L=0 *L*=1

The production rates provide

p_π=20 GeV/c	Mass (GeV/c)	γ	*C*	Q_{eff} (GeV/c)	*R* (Relative)	
$\Lambda_c^{1/2+}$	2286	1/2	1	1.33	1	*L=0*
$\Sigma_c^{1/2+}$	2455	1/6	1/9	1.43	0.03	
$\Sigma_c^{3/2+}$	2520	1/6	8/9	1.44	0.20	
$\Lambda_c^{1/2-}$	2595	1/2	1/3	1.37	1.17	*L=1*
$\Lambda_c^{3/2-}$	2625	1/2	2/3	1.38	2.26	*L=1*
$\Sigma_c^{1/2-}$	2750	1/6	1/27	1.49	0.03	
$\Sigma_c^{3/2-}$	2820	1/6	2/27	1.50	0.06	
$\Sigma_c^{1/2-\prime}$	2750	1/6	2/27	1.49	0.07	
$\Sigma_c^{3/2-\prime}$	2820	1/6	56/135	1.50	0.33	
$\Sigma_c^{5/2-\prime}$	2820	1/6	2/5	1.50	0.31	
$\Lambda_c^{3/2+}$	2940	1/2	2/5	1.42	0.85	*L=2*
$\Lambda_c^{5/2+}$	2880	1/2	3/5	1.41	1.55	*L=2*



No reduction at higher *L* states, depending on spin/isospin configuration of Quark-Diquark in Y_c.

Calculated by A. Hosaka

calculated by A. Hosaka

Estimated Relative Yield (strange sector)

p_π=4.5 GeV/c	$\Lambda^{1/2+}$ 1116	$\Sigma^{1/2+}$ 1192	$\Sigma^{3/2+}$ 1385	$\Lambda^{1/2-}$ 1405	$\Lambda^{3/2-}$ 1520
γ	1/2	1/6	1/6	1/2	1/2
C	1	1/9	8/9	1/3	2/3
K	1.02	1.23	1.17	0.99	0.97
q_{eff}	0.29	0.31	0.38	0.36	0.40
R (rel.)	1	0.05	0.29	0.09	0.17
Exp($\mu b/sr$)	318+-12	186+-28	29+-6	32+-7	60+-13

Exp.: $p(\pi^-,K_0)Y$, D.J. Crennell et al., PRD6, 1220(1972)

- The yield for $\Sigma^{1/2+}$ is suppressed due to γ and *C*.
- The estimation is not very far from the experimental data but for Σ's.
    - The measurement in charm sector provides valuable information on the reaction mechanism and structure of baryons.

Backup slides for the BG studies

Considered BG for BG reduction

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

     3.4 mb **JAM (**PRC61 (2000) 024901)
2. Wrong particle identification
   - Dominant cases: (π^+, π^-, π_s^-), (p, π^-, π_s^-)
     - PID miss-identification of *π/p* as *K^+*: ~3%
     - Productions of π and p are ~10 times higher than K.

     26 mb
   - Contribution of other combinations are negligible.
     - (K^+, K^-, π_s^-), (K^+, π^-, K_s^-), (π^+, K^-, π_s^-), (p, K^-, π_s^-), …
   - Semi-leptonic decay channels: (K^+, μ^-, π_s^-) (K^+, e^-, π_s^-)
     - D^0 mass cannot be reconstructed.
3. Associated charm production: Including D^{*-}
   - D^{**} production: $D^{**0,-} \rightarrow D^{*-} + \pi^{+,0}$
   - $D^{0,+} + D^{*-}$, $D^{*0,+} + D^{*-}$ pair production
   - Hidden charm meson (J/ψ, ψ, χ_c) production: Decay to D^{*-}

Very Small and No peak structure：shoulder at ~2.45 GeV/c^2

Main background

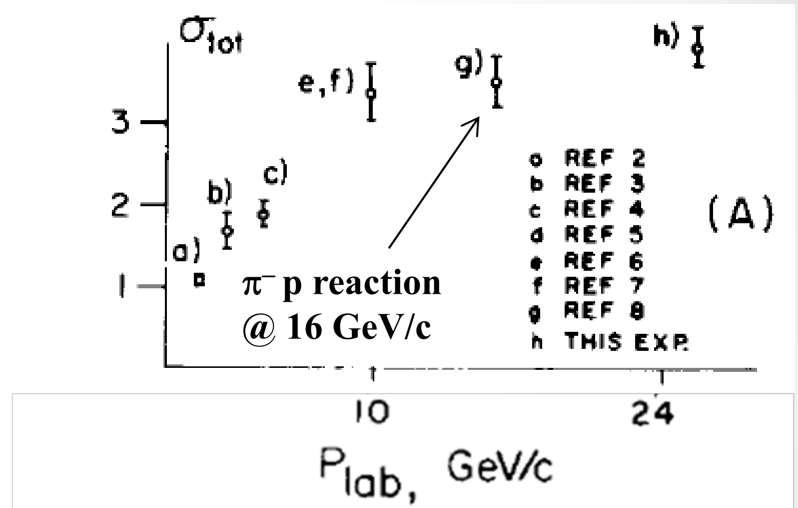
All events including K^+, π^-, π^-

- ∗ Less information from old experiments
- σ_{Total} of $\pi^- p$ @ 16 GeV/c : 25.7 mb
- ⇔ Strangeness production: 3.4 mb

⇒ **A few mb**

- More than 10^6 times higher than Y_c^* signals (1 nb)

Strangeness production C.S.



J. W. Waters et al, NPB17 (1970) 445

- **Background source**
  - $K^{*0}(\rightarrow K^+, \pi^-) + \pi^-$
  - KK_{bar} ($K^*K^*_{bar}$) production + π^-
  - $Y K^+ + \pi^-$
  - Non-resonant multi-meson production
  - ∗ No special channel contributes to background

- **Background generation** Y. Nara et.al. Phys. Rev. C61 (2000) 024901
  - JAM (Jet AA Microscopic transport model)
    - Use K^+ and π^- distribution from $\pi^- p$ reaction at 20 GeV/c
      - σ = 2.4 mb for (K^+, π^-, π^-)
    - ss_{bar} production multiplicity: ~1 (2 K^+event: ~3%)

String model for JAM

String model region in JAM: 4 GeV <$\sqrt{s}$ < 10 GeV (~6.2 GeV for 20 GeV/c)

- **String production by hadron-hadron collision**
  - String(hadron) + String(hadron)→st(qq_{bar}) + st(qqq) + st(qq_{bar}) + …
- **String collision**
  - Not considered: Hadronization at first ⇒ Hadron-hadron collisions
  - Color flux between strings was not also considered.

Hadronization model: Lund model

- **qqbar production rate: uu_{bar}: dd_{bar} : ss_{bar}: cc_{bar} = 1 : 1 : 0.3 : 10^{-11}**
- **Input of production rate not obeyed to the spin ($^3S_1$, $^1S_0$) statistics**
  - ρ/(π+ρ) = 0.5, K*/(K+K*)=0.6, D*/(D+D*)=0.75

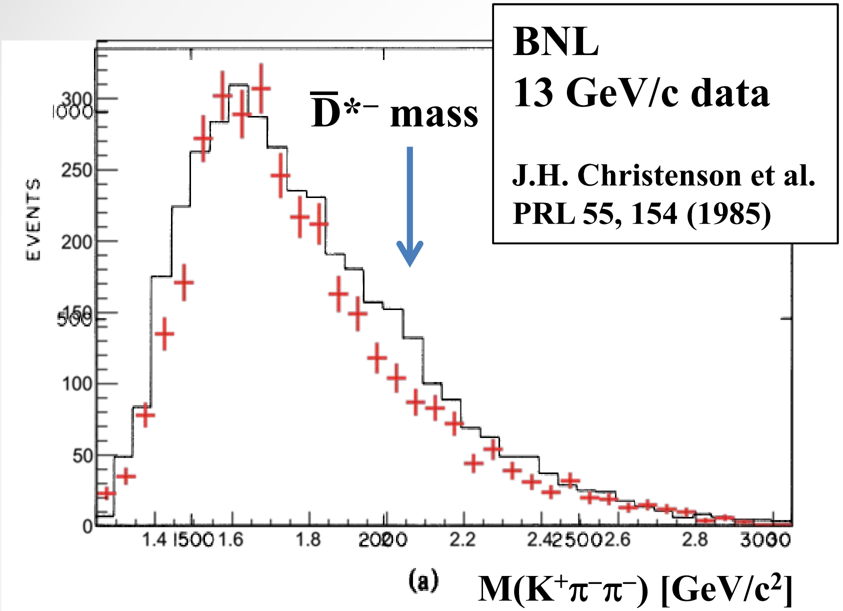
∗ Almost same as of PYTHIA

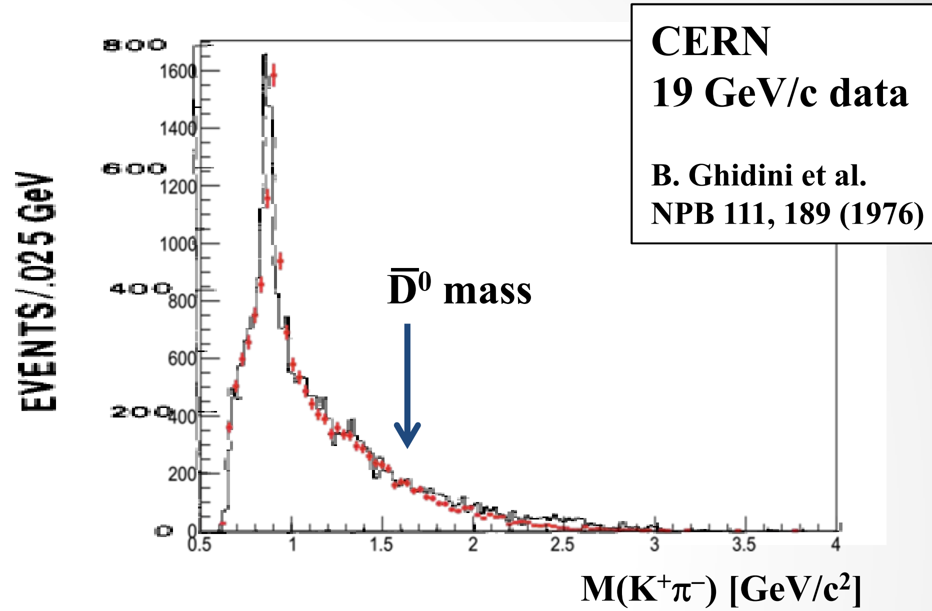
Difference from PYTHIA

- String collision: Used simplified input model
- Hadronization process: Input parameters of resonances are different.
- Hard process

⇒To be checked by experimental data

JAM simulation check





Data

JAM simulation

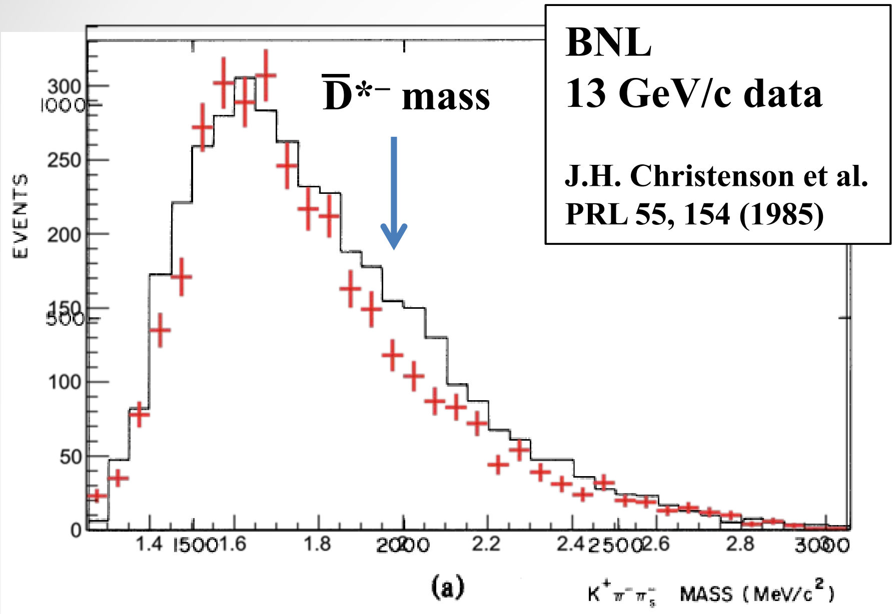
Old data by BNL & CERN:
Invariant mass: $M(K^+\pi^-\pi^-)$ & $M(K^+\pi^-)$

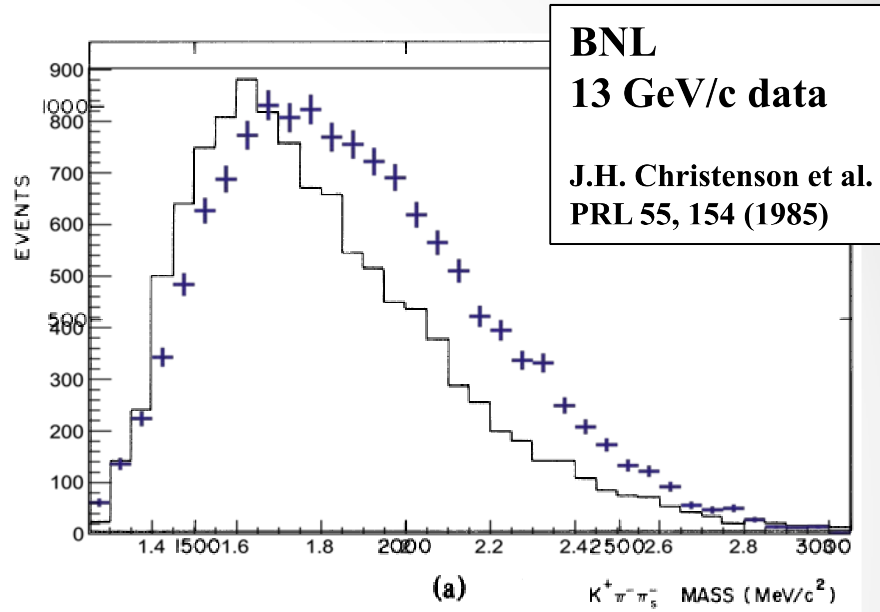
- $\pi^- + p \rightarrow Y_c^* + \bar{D}^{*-}$ @ 13 GeV/c, 19 GeV/c

- **Background shape: Reproduced**
- **D^{*-} mass region (±20 MeV) events (BNL: 13 GeV/c data)**
  - **Data: 230 ± 15 counts (stat.) ⇔ Simulation: 240 ± 50 counts (stat. + sys.)**

⇒ Old data background reproduced with small ambiguity (20-30%)

Compared with PYTHIA





Data
JAM simulation
PYTHIA simulation

Simulation results

∗ JAM simulation @ D^{*-} mass (±20 MeV)

⇒ 240±50 events (stat. + sys.)

∗ PYHIA simulation @ D^{*-} mass (±20 MeV)

⇒ 1000±110 events (stat. + sys.)

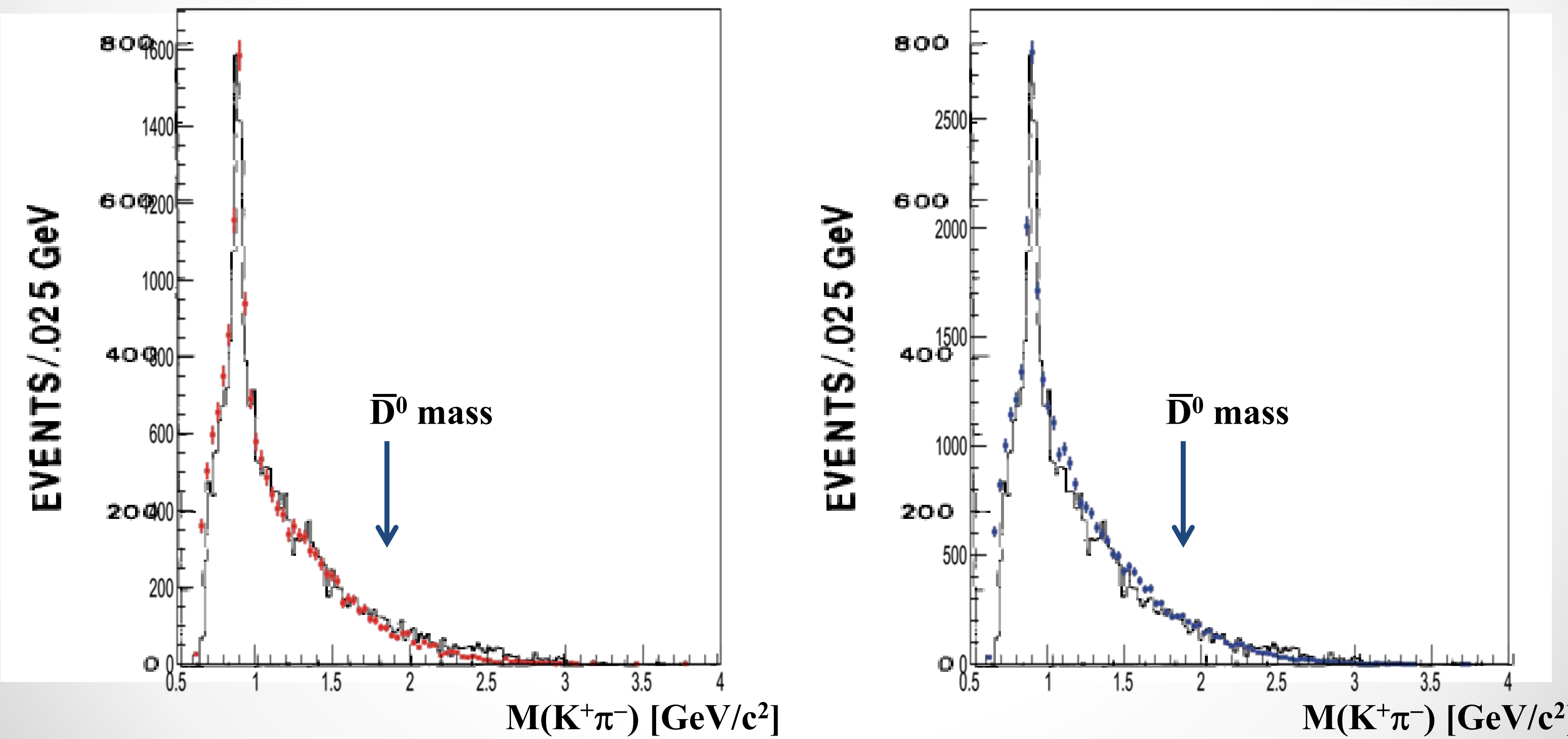
- **Background is overestimated at the higher mass region.**

JAM simulation check: M($K^+ \pi^-$)

Black line	Data
Red line	JAM simulation
Blue line	PYTHIA simulation

CERN
19 GeV/c data

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



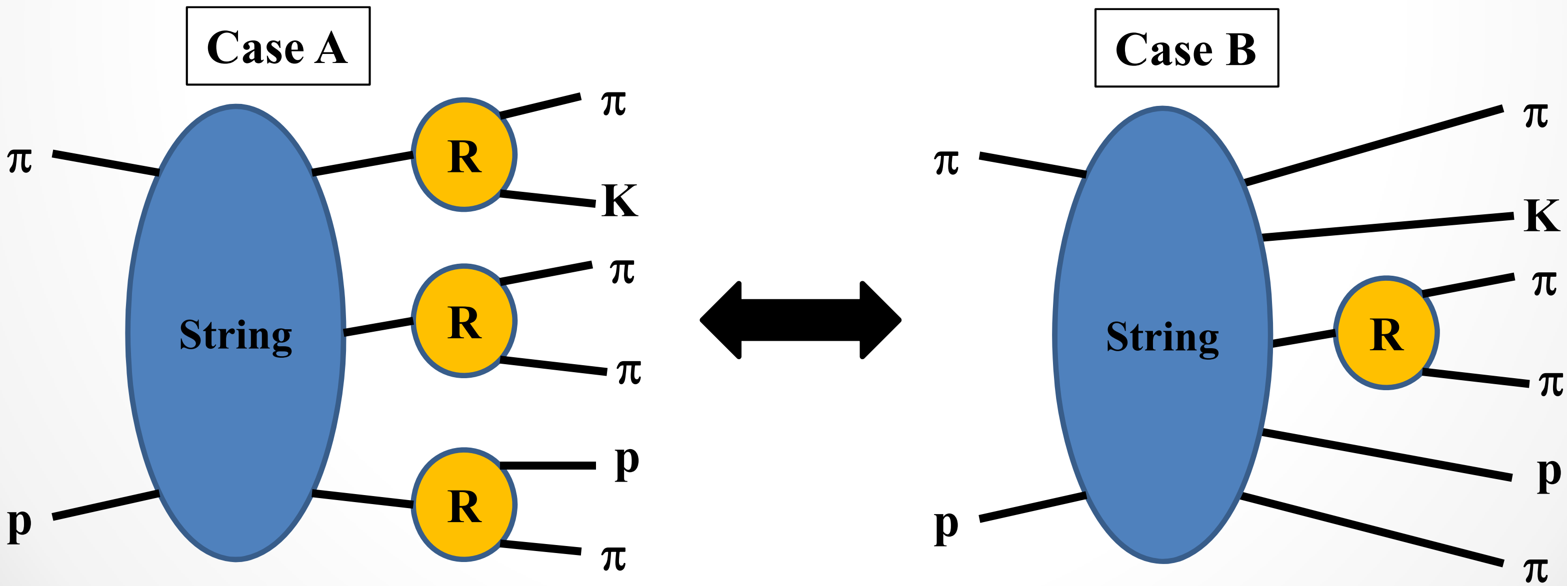
Peak position normalized

Possible difference

- **Model dependence**
  - JAM is tuned at BNL-AGS energy (E=14 GeV). This may be a reason why the BNL data is well reproduced by JAM…
  - Treatment for resonances is different in the case of PYTHIA.
    - $M(K^+\pi^-)$ at 19 GeV/c is reproduced better than $M(K^+\pi^-\pi^-)$

    ⇒ non-resonance-like production(closer to isotropic decays in N-body phase space)

    ⇒ contribution of resonances in Hadronization may be different
  - hard process is little contributed in both models.



$M=2E_1E_2(1-\cos\theta)$ ⇒ possibility to reconstruct "heavy particles": A < B

Comment

- Background shape
  - JAM
    - ○ Both BNL and CERN data were almost reproduced.
  - PYTHIA
    - ○ Higher mass side of BNL data simulated is different from data.

      ⇒Different treatment of hadronization process
      - Contribution of non-resonant multi-meson production is large.
    - ○ CERN data was almost reproduced.

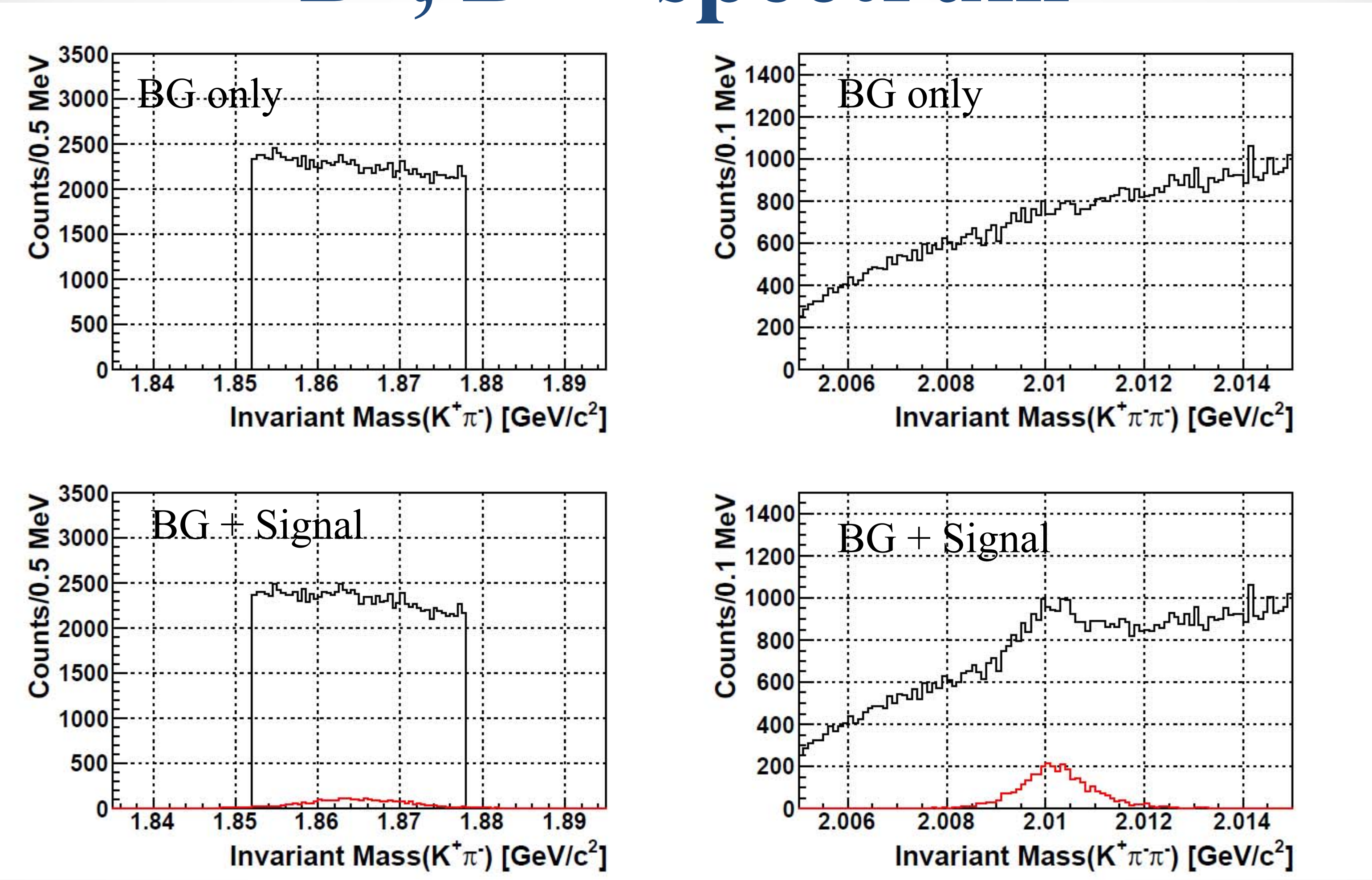
- Absolute value of the BNL data
  - JAM reproduced well.
  - PYTHIA data gave 4 times larger number of events.

  ＊There is no order difference of each simulator.

- Charged track multiplicity
  - Both JAM and PYTHIA reproduced well.

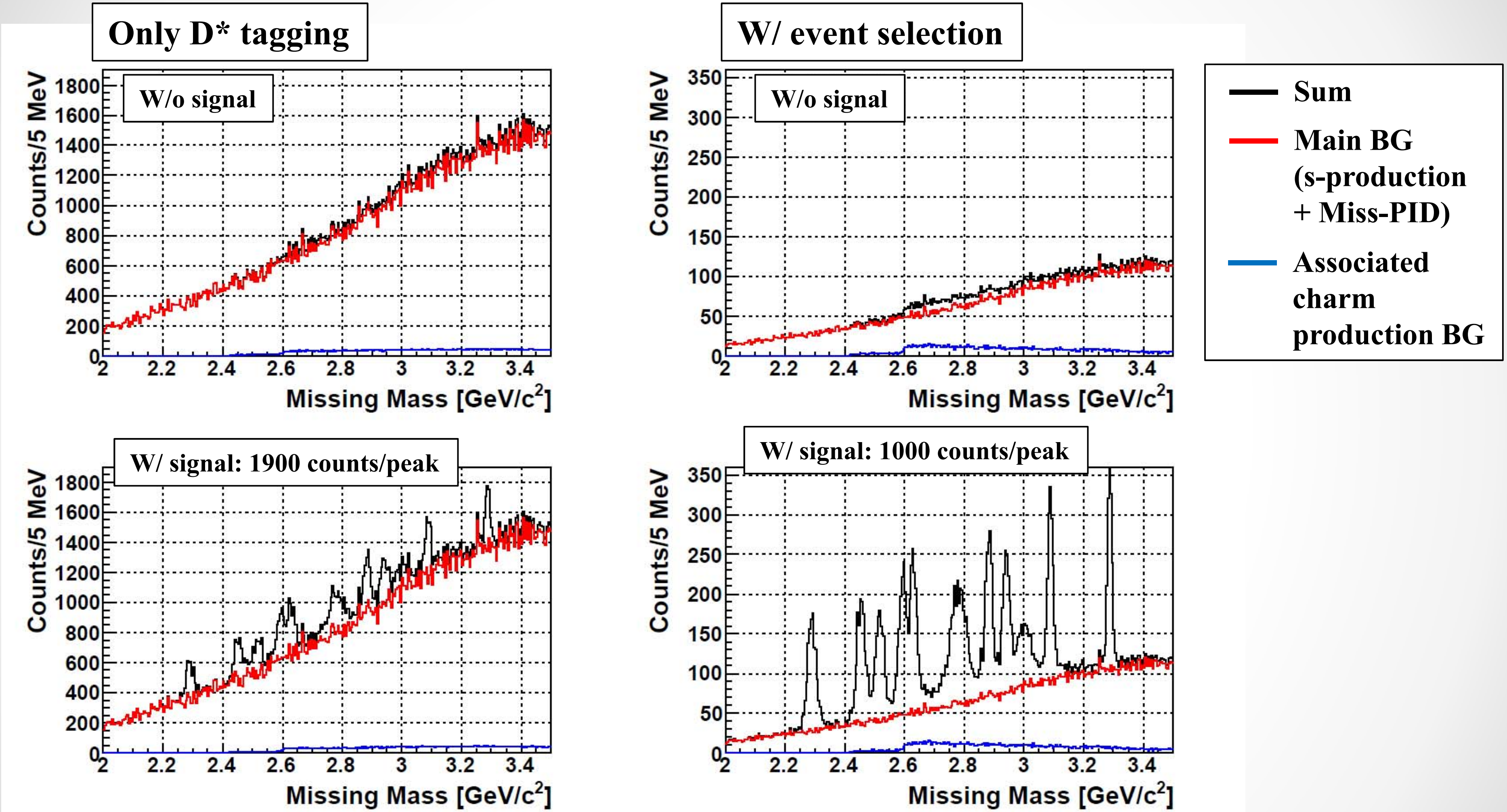
Backup slides for the BG reduction

D^0, D^{*-} spectrum



- **1/7 event, 12 nb in total: ~ 3200 events**
- **D^0 cutでD^{*-}のpeakが確認できる**

Background spectrum



Clear peak structure @ 1 nb/peak case

∗ Main background structure is dominant.

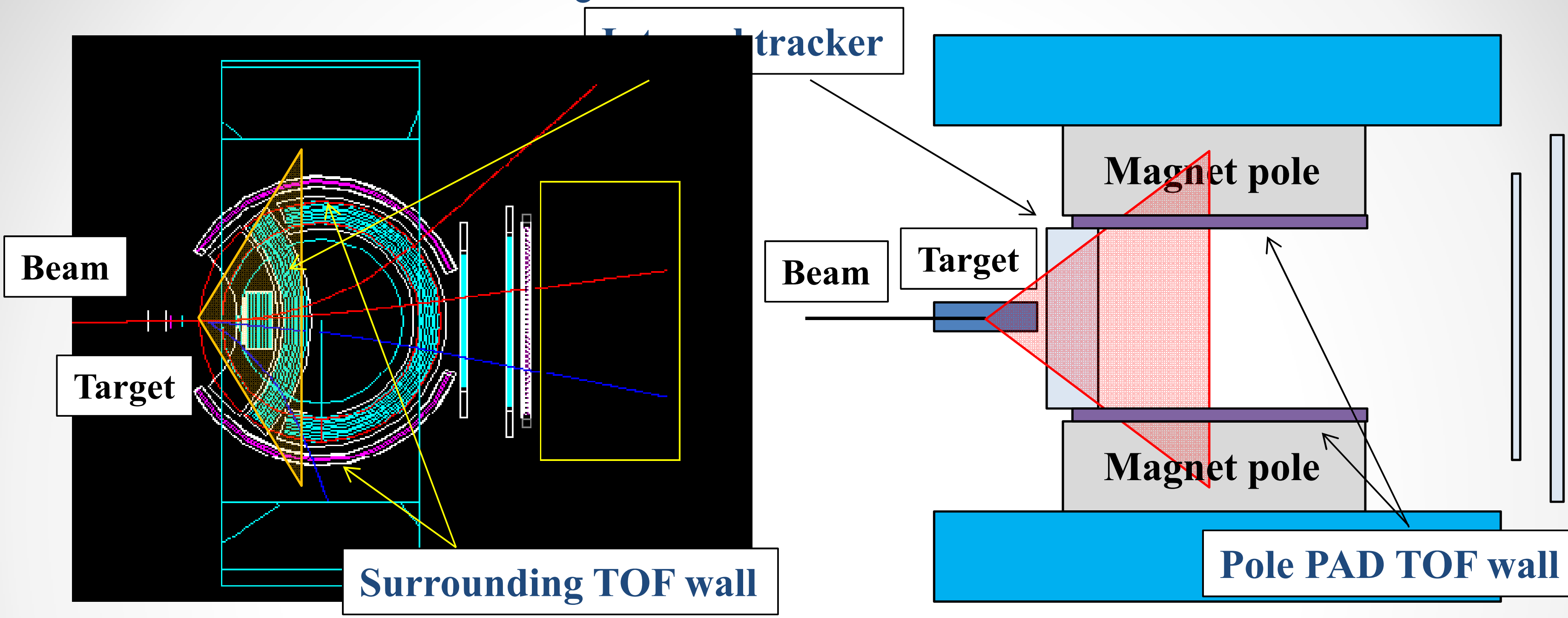
- ⇒ Achievable sensitivity: 0.1-0.2 nb (3σ level, Γ < 100 MeV)

Decay measurement

Setup modification

Performances

Decay measurement

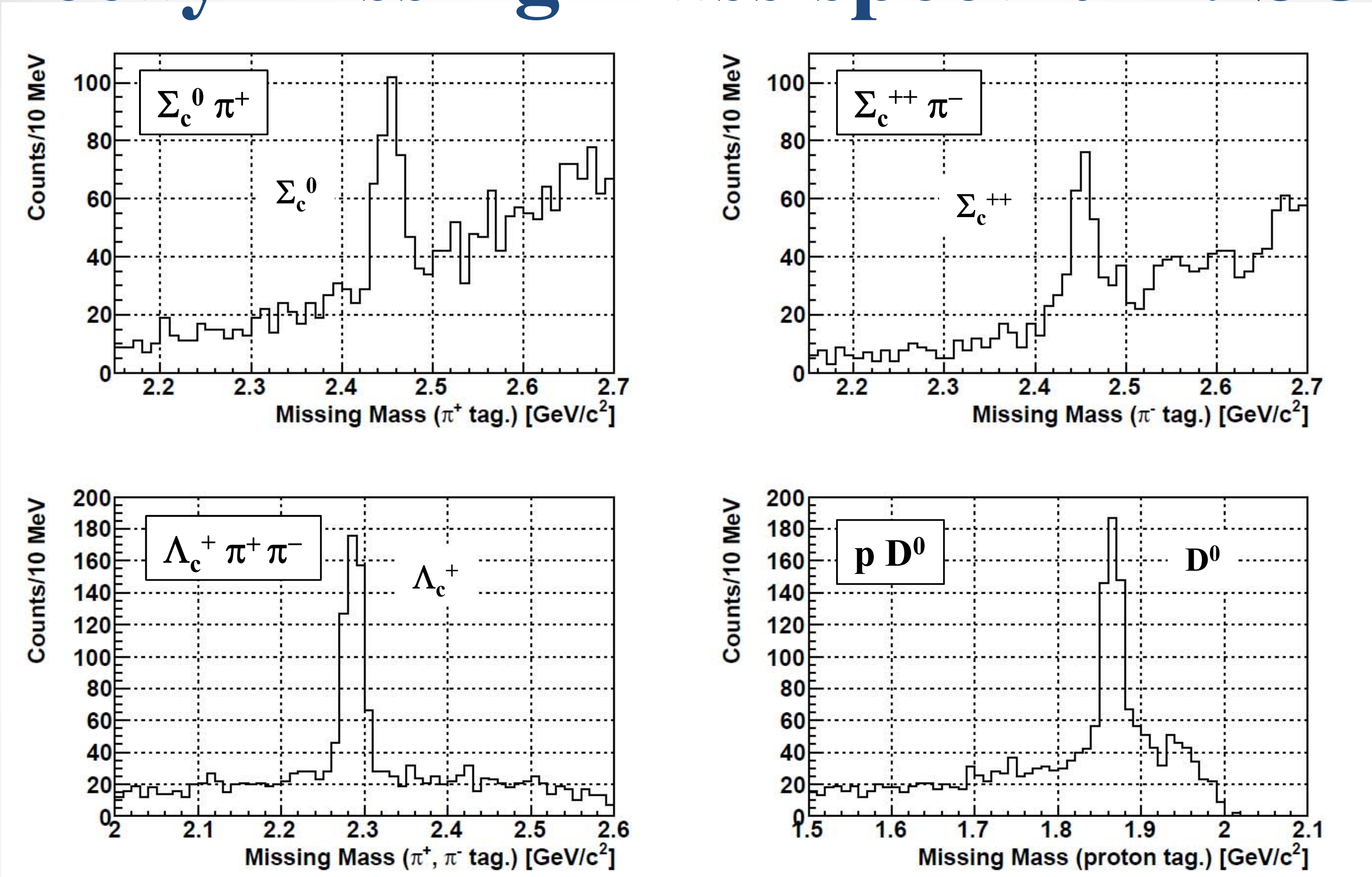


- **Method: Mainly Forward scattering due Lorentz boost (θ < 40°)**
  - **Horizontal direction: Internal tracker and Surrounding TOF wall**
  - **Vertical direction: Internal tracker and Pole PAD TOF detector**

- **Mass resolution: ~ 10 MeV(rms)**
  - **Only internal detector tracking at the target downstream**

- **PID requirement: TOF time difference (π & K) ⇒ ΔT > 500 ps**
  - **Decay particle has slow momentum: < 1.0 GeV/c**

Decay missing mass spectrum: SUM



∗ Full event w/ background/ No "$\Lambda_c^+\ \pi^+\pi^-$ gated"

- **Continuum background shape around Σ_c mass region**
- **Background events from Λ_c were the same as of ($K^+\pi^-\pi^-$)**
- **Better S/N of π^- tag. event than π^+ tag.**

Study condition

- **Assumed decay mode for $\Lambda_c^{*+}(J^P = 3/2^+, M = 2.94\ GeV/c^2)$**
  - **N + D: $\Gamma = 0.4 \Rightarrow$ $p\,D^0$: 0.2, $n\,D^+$:0.2**
  - **$\Sigma_c + \pi$: $\Gamma = 0.4 \Rightarrow$ $\Sigma_c^{++}\,\pi^-$: 0.4/3, $\Sigma_c^+\,\pi^0$: 0.4/3, $\Sigma_c^0\,\pi^+$: 0.4/3**
    - **Decay to $\Sigma_c(2455)$ assumed**
  - **$\Lambda_c + \pi + \pi$: $\Gamma = 0.2 \Rightarrow$ $\Lambda_c^+\,\pi^+\,\pi^-$: 0.1, $\Lambda_c^+\,\pi^0\,\pi^0$: 0.1**

- **Yield estimation @ 1 nb case (~1900 counts)**
  - **$p\,D^0$: 0.2 $\Rightarrow 1900 \times 0.2 \times 0.8 = \sim 300$**
  - **$\Sigma_c^{++,0}\,\pi^{-,+}$: 0.4/3 $\Rightarrow 1900 \times 0.4/3 \times 0.8 = \sim 200$**
    - **Forward scattering of protons**
    - **Wider scattering angle of pions**
    - **Combined with 4-body D^0 decay mode: 3 times larger yield**
      - **$D^0 \rightarrow K^+\,\pi^-$ (B.R.= 3.88%, acceptance = ~60%)**
      + $D^0 \rightarrow K^+\,\pi^-\,\pi^+\,\pi^-$ (B.R.= 8.07%, acceptance=~50%)
      - **Background level of 4-body case is larger. But, it can be combined.**

Comments

- **Decay measurement**
  - **Forward charged particle detection**
    - **Particles scattered to $\theta<40^\circ$ due to Lorentz boost**
  - **Enough acceptance and angular coverage**
    - **Pole PAD detector & internal TOF wall are used.**

- **Signal counts**
  - **Combine 2-body and 4-body D^0 decay channels**
    - **$\Sigma_c\ \pi$ mode: > 500 counts**
    - **p D mode: > 800 counts**
  - **Braining ratio obtained with ~5% statistical error**
    - **Assumed branching ratio @ 1 nb case & 100 days beam time**
  - **Angular distribution**
    - **S, P, D-wave can be measured.**
    - **Both polar and azimuthal angle can be measured.**

- **Other decay channels: Neutral channels**
  - **π^0 detection: Adding collimator**
  - **n D^+ mode: Downstream neutron counter**

3. Comment on the B-factories

iv. In order to establish the physics potential of this new proposal, P50 should provide a detailed comparison of the results expected on each Y_c state relative to those already available from the B factories.

Production

- fragmentation from e+e-/pp collision
  - Typical Reconstruction Rate:

    Belle:

    * $\Lambda_c(2880)$, $\Lambda_c(2940) \to \Sigma_c \pi \to \Lambda_c \pi\pi$: ~690, ~220/553fb^{-1} [PRL98, 262001('07)]

      c.f. :Babar($\Lambda_c(2880)$, $\Lambda_c(2940) \to Dp$: ~2800, ~2280/287fb^{-1} [PRL98, 012001('07)])

    * $\Sigma_c(2800)^{0,+,++} \to \Lambda_c \pi^{-,0,+}$: ~2240, ~1540, ~2810/281fb^{-1} [PRL94, 122002('05)]

    * Inclusively reconstructed Λ_c may be a several x10^4

    LHCb:

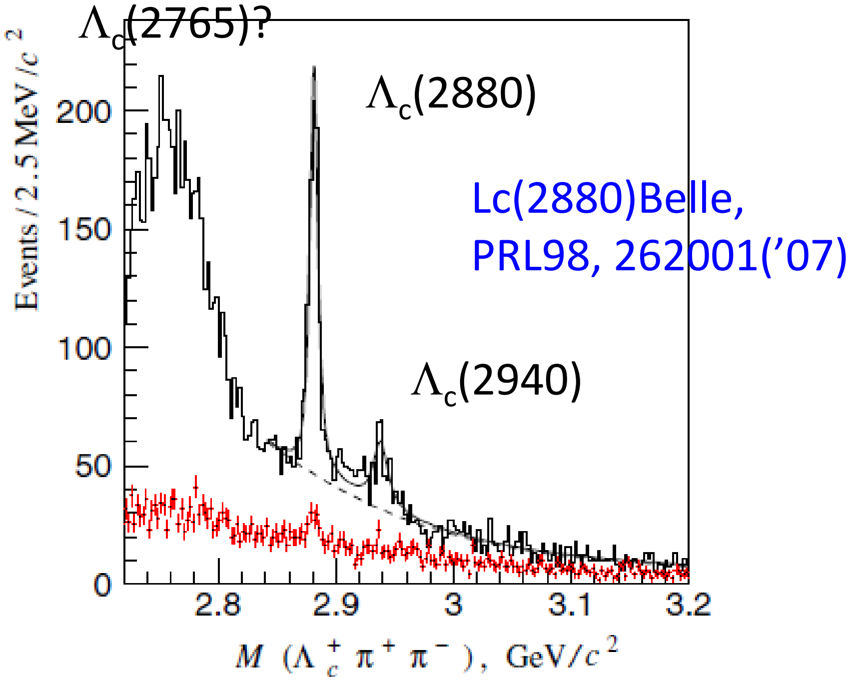
    ~70540$\Lambda_b \to \Lambda_c \pi$ /1fb^{-1} [PRL109, 172003('12)]
  - In Belle-II, they will increase 50 times in statistics.
- P50 provides unique information on:
  - **the level structure** of Y_c and
  - **the production rates** of Y_c over a wide mass up to higher L states.

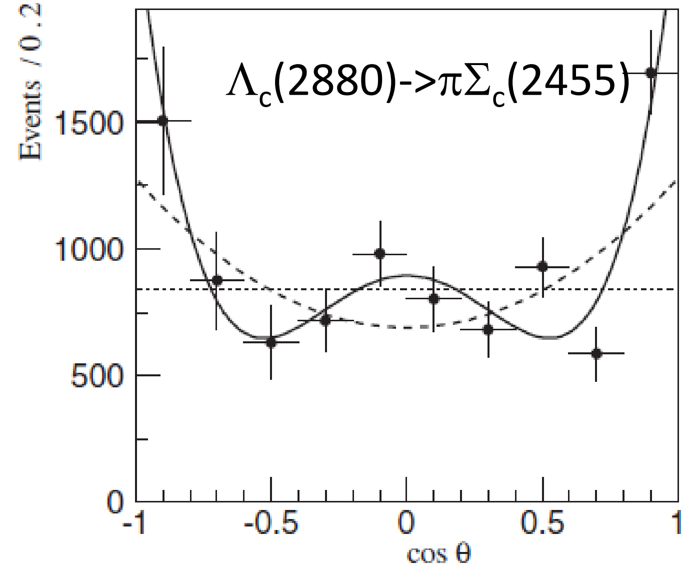
    → Complementary Roles

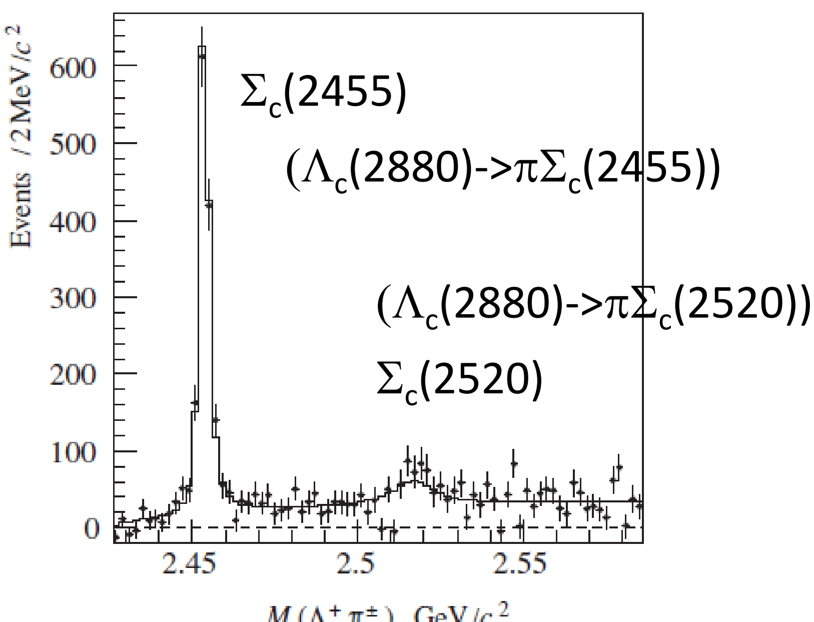
Complementary Roles

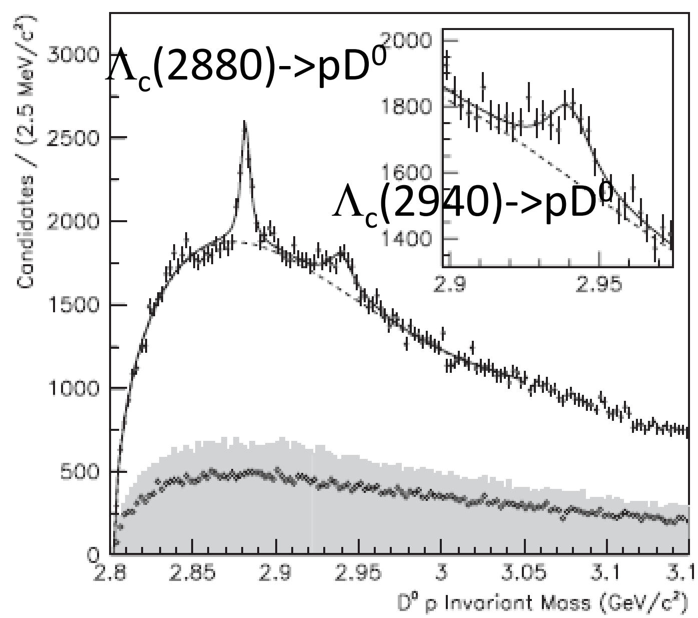
- Systematic study of Y_c* production
  - The production rate (ratio) is unique, reflecting the reaction mechanism.
    - $(q_{eff}\ /A)^L$ dependence

      ⇔ Exponential of the mass in fragmentation process after e+e- collision
    - Spin/Isospin dependence, Λ_c^*/Σ_c^*
  - The inclusive measurement provides unique/valuable information:
    - Spin/Isospin structure of Baryons
    - Spatial information of the wave functions
    - Coupling strength at the vertices
    - Exchange Bosons
- Decay measurement in coincidence w/ $p(\pi^-,D^{*-})$ assists the missing mass spectroscopy.
  - Decay Branches: diquark correlation affects $\Gamma(\Lambda_c^* \text{->} pD)/\Gamma(\Lambda_c^* \text{->} \Sigma_c\pi)$.
  - Angular Distribution: spin, parity





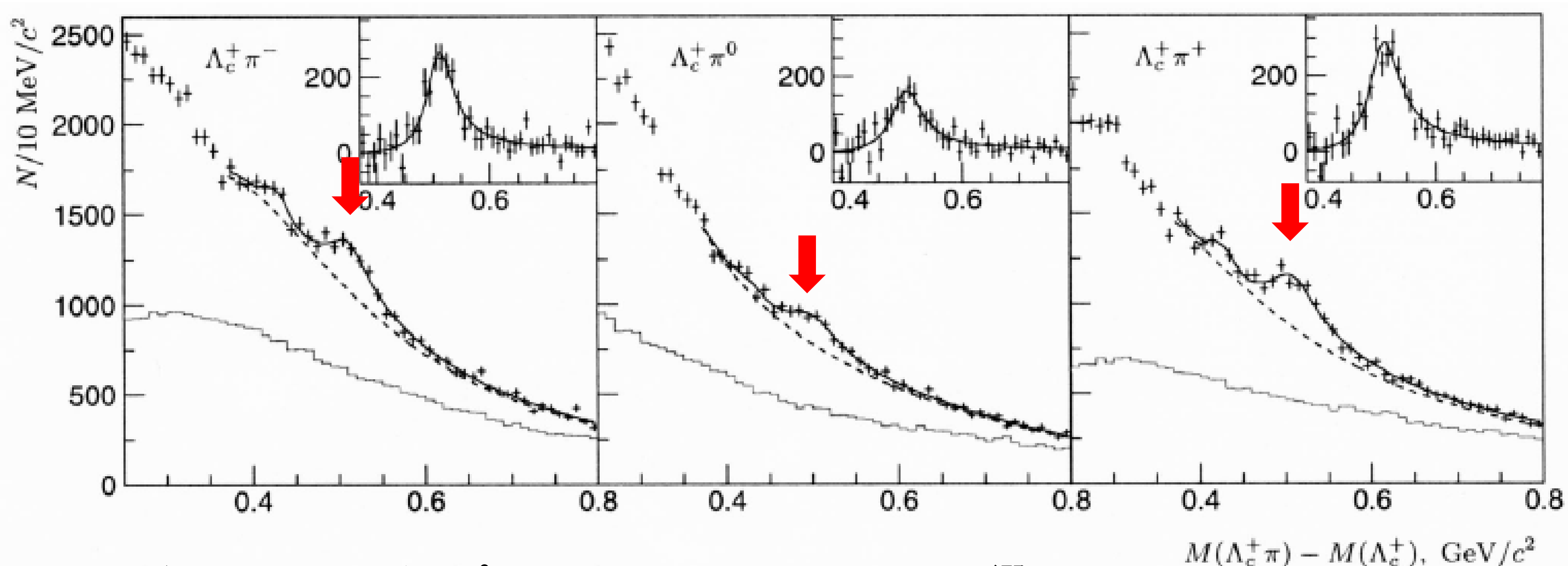




Babar, PRL98, 012001('07)

Σ_c (2800) -> Λ_c + π

Σ_c^0 Σ_c^+ Σ_c^{++}



注）0.4GeV付近のピークはΛ_c (2880) -> $\Lambda_c\pi\pi$の影響

Belle, PRL94, 122002('05)