WS on J-PARC hadron physics, 10-12 Feb., 2014

Charmed Hadron Experiments at J-PARC

H. Noumi（RCNP, Osaka University）

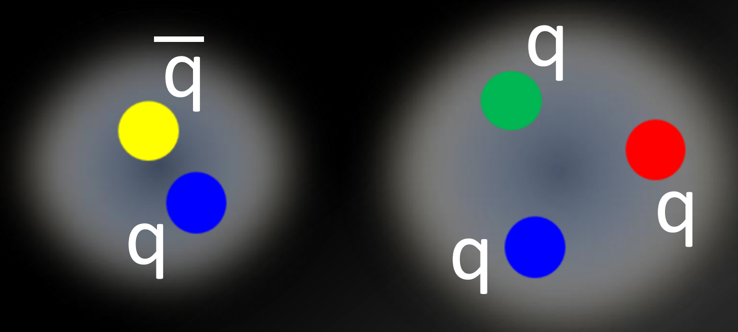
Outline:

1. Spectroscopic study of charmed baryons
2. Proposed Experiment at J-PARC
3. Summary

Spectroscopic study of Charmed Baryons

Understanding of Hadrons

Constituent Quark



Hadron properties

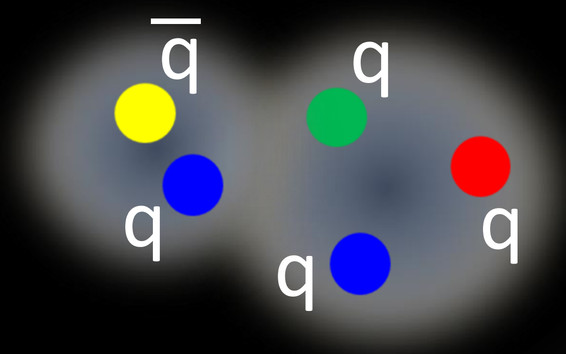
- Classification based on Spin/flavor symmetry
- Mass Relations, Magnetic Moments

Failure in Resonant States

- Missing Resonances
- Exotics

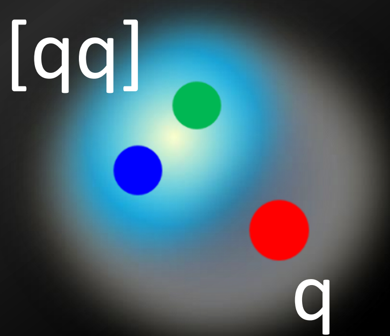
What are essential D.o.F. of baryons?

Constituent Quark

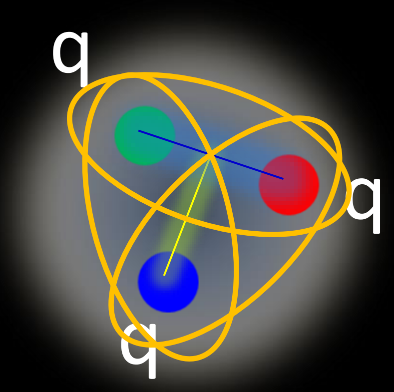


hadron (colorless cluster)

Diquark?
(Colored cluster)



How to form baryons?



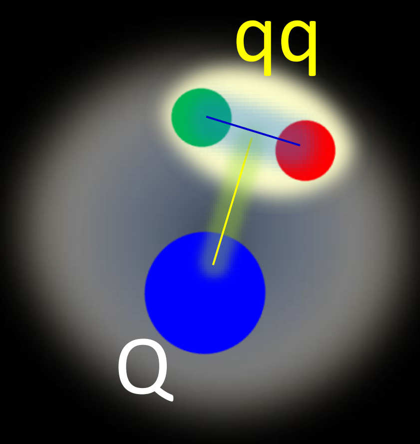
- Most fundamental question
- Interaction btwn quarks

Diquark correlations

- 3 [qq]-pairs in a Light Baryon

How to close up diquark correlations

Charmed Baryon



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

Weak CMI with a heavy Quark

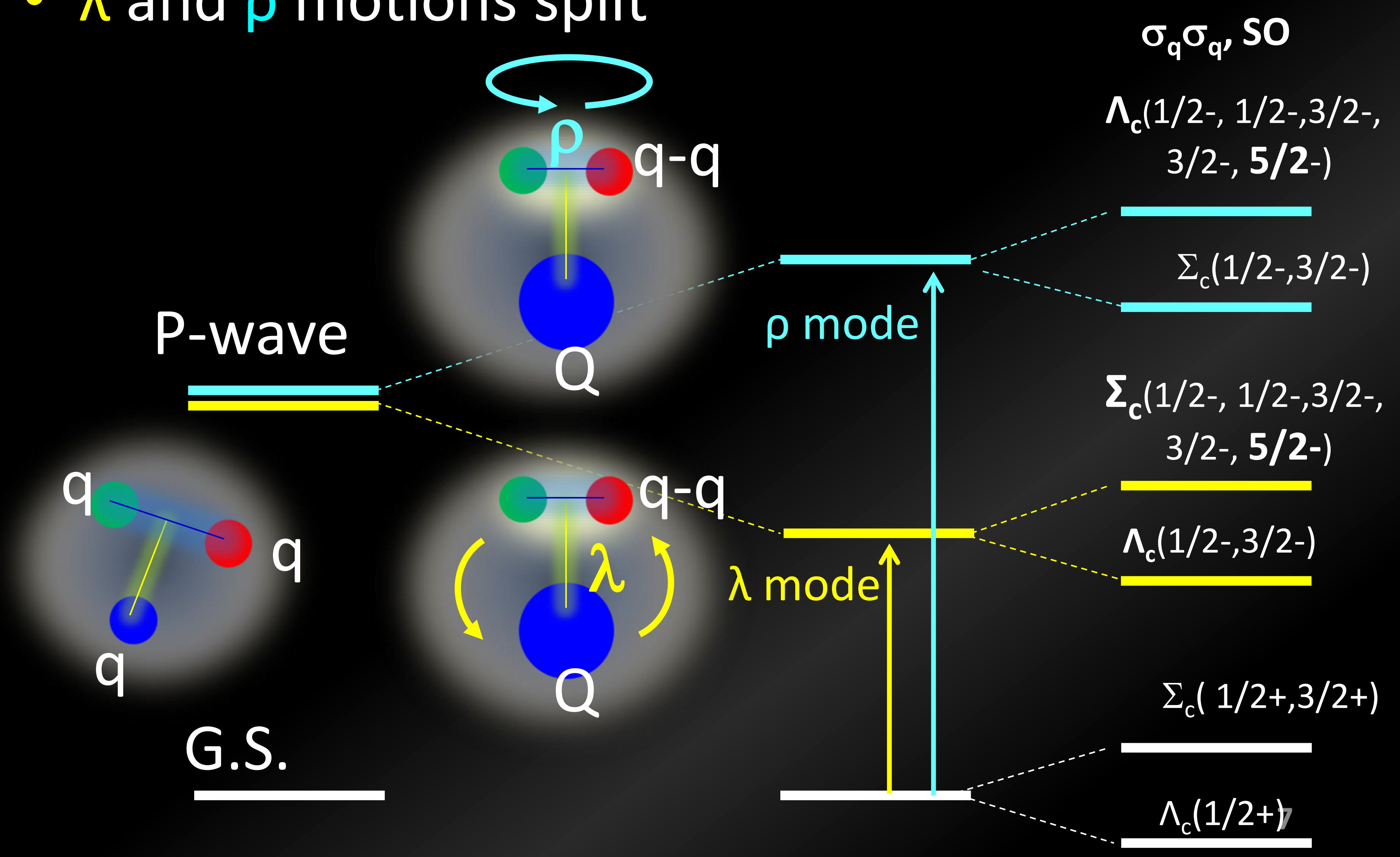
- A "qq" correlation could be singled out.

- Level structure of Y_c*
- Decay Widths/Decay Branching Ratios
  - Spin, Parity

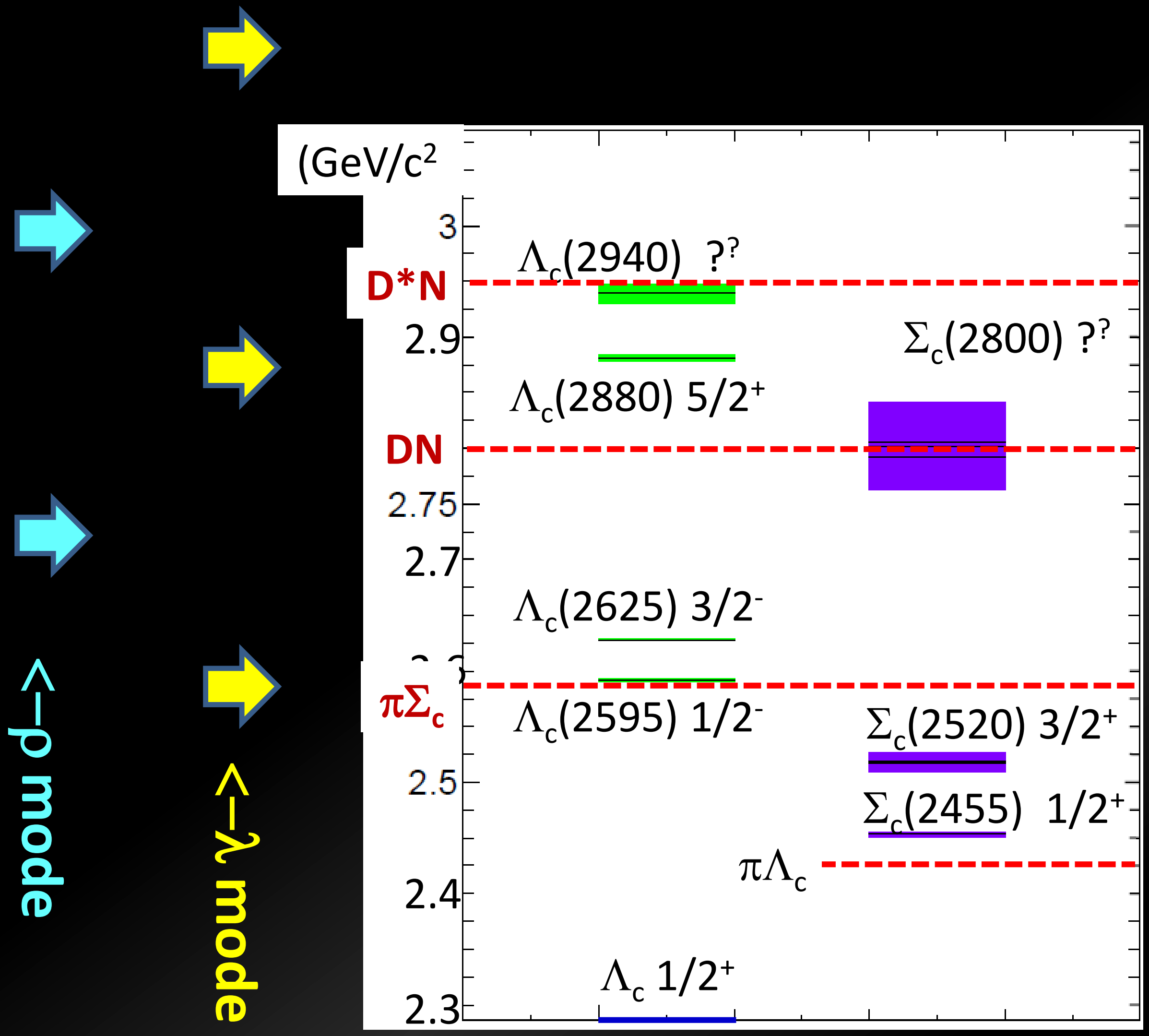
- Production Rate

Level Structure of charmed baryons

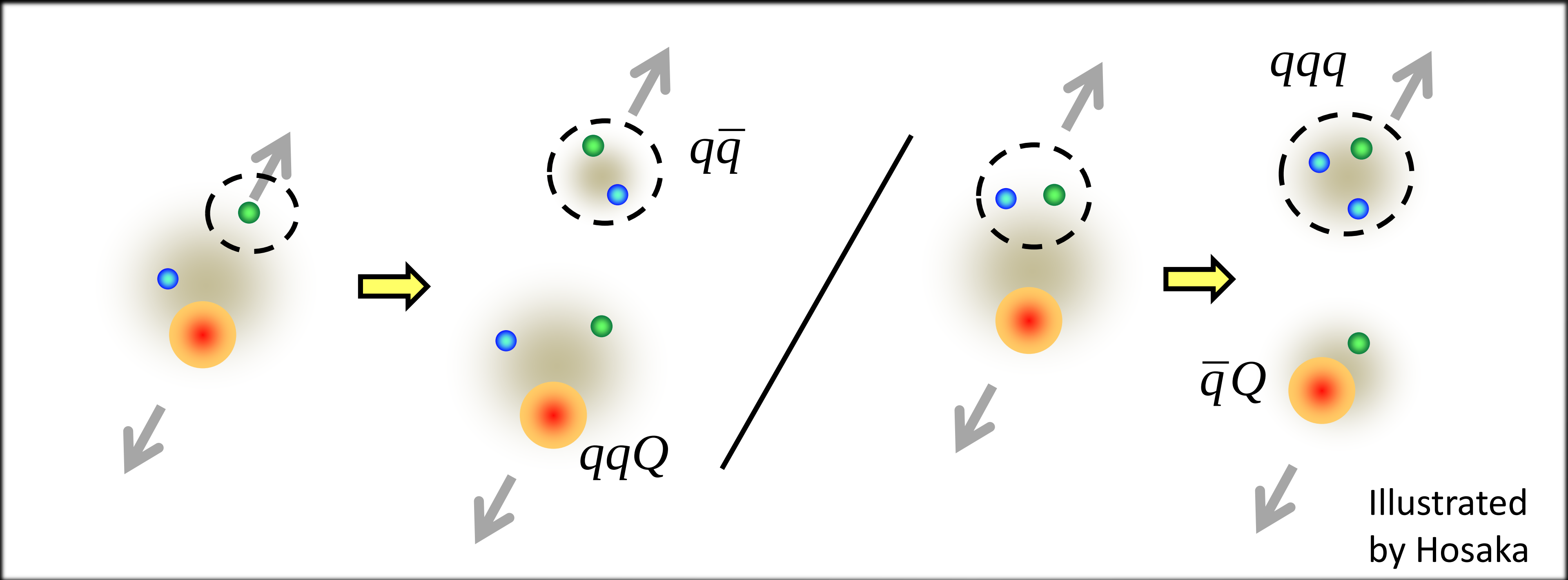
- λ and ρ motions split



Limited # of Charmed Baryons have been observed.



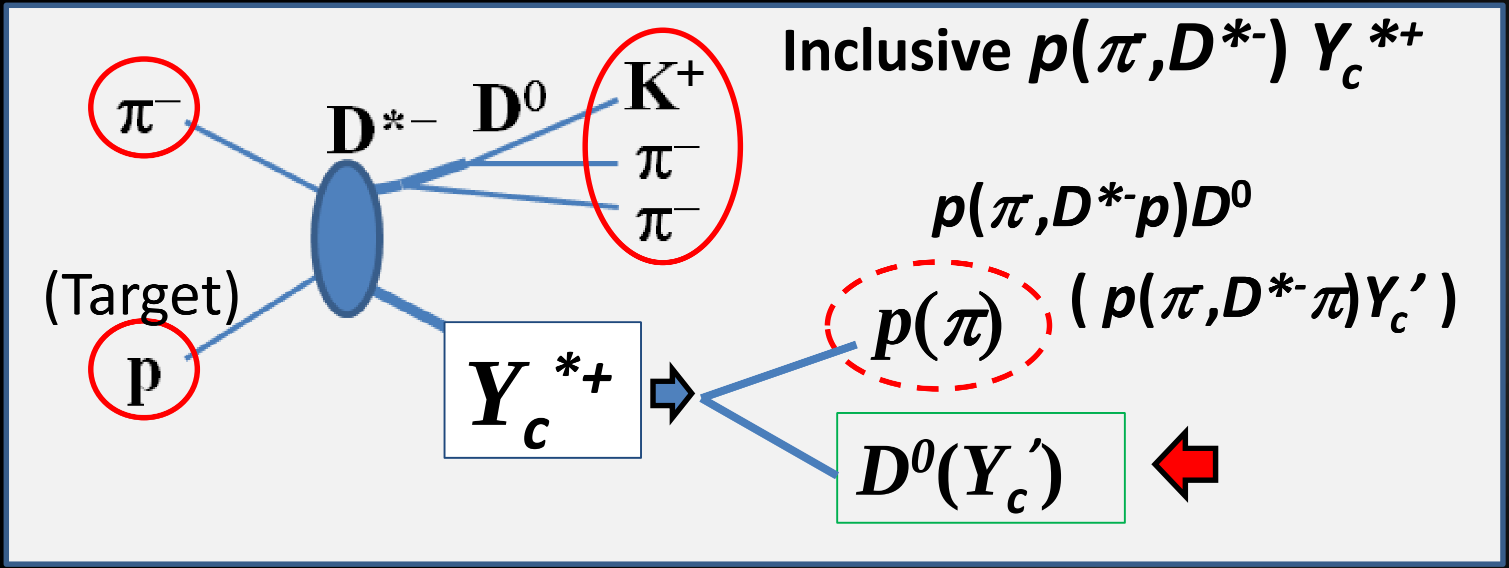
Structure and Decay Partial Width



ρ mode (qq)

λ mode [qq]

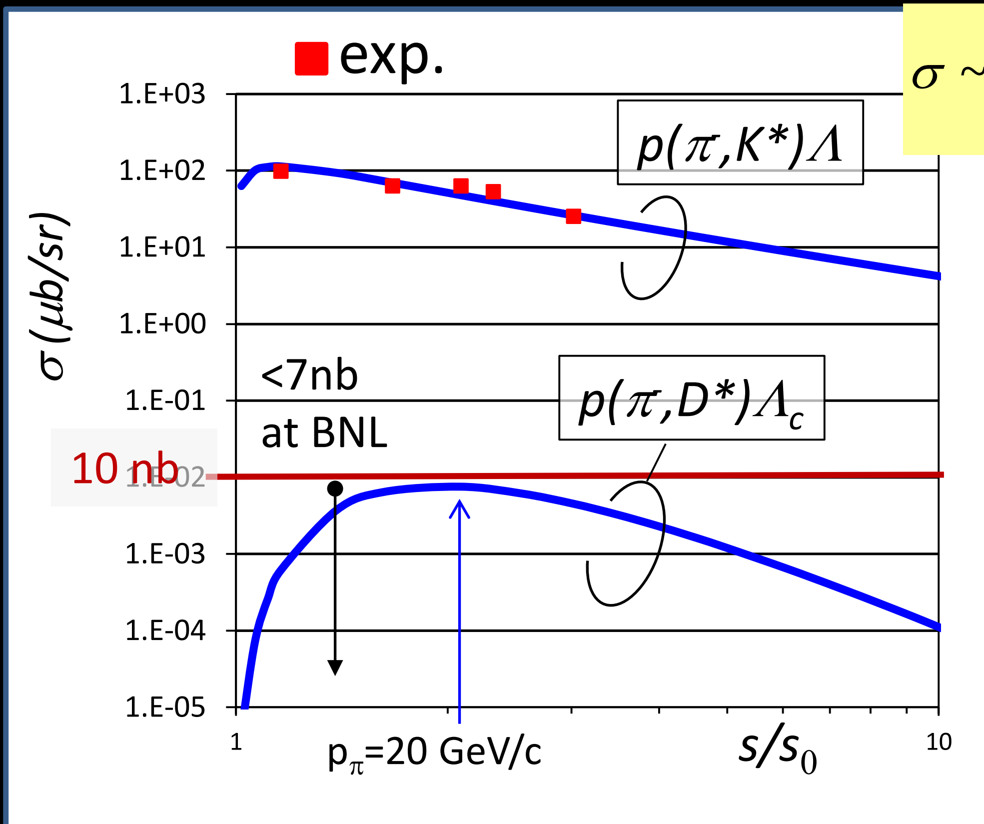
Charmed Baryon Spectroscopy Using Missing Mass Techniques



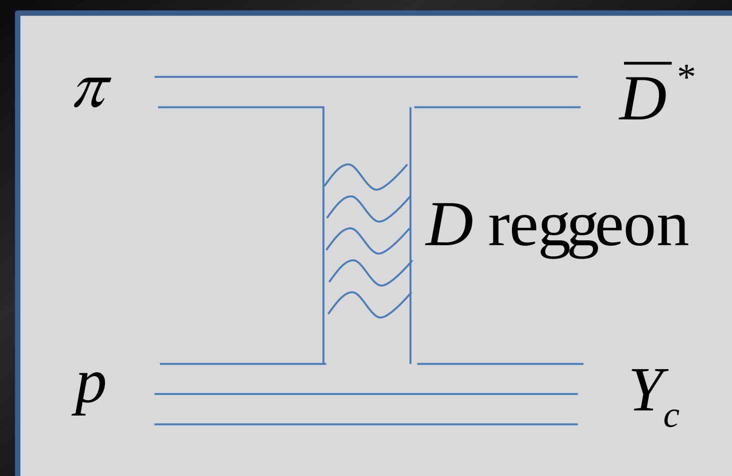
- inclusive (π^-,D^{*-}) spectrum
  - Level structure of Y_c^*
  - Production Rate
- Decay Particles
  - Decay Width/Decay Branching Ratios
  - Spin, Parity (Angular correlation)

Production Cross Section

- Regge Theory: Binary Reaction at High E is well described
- 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



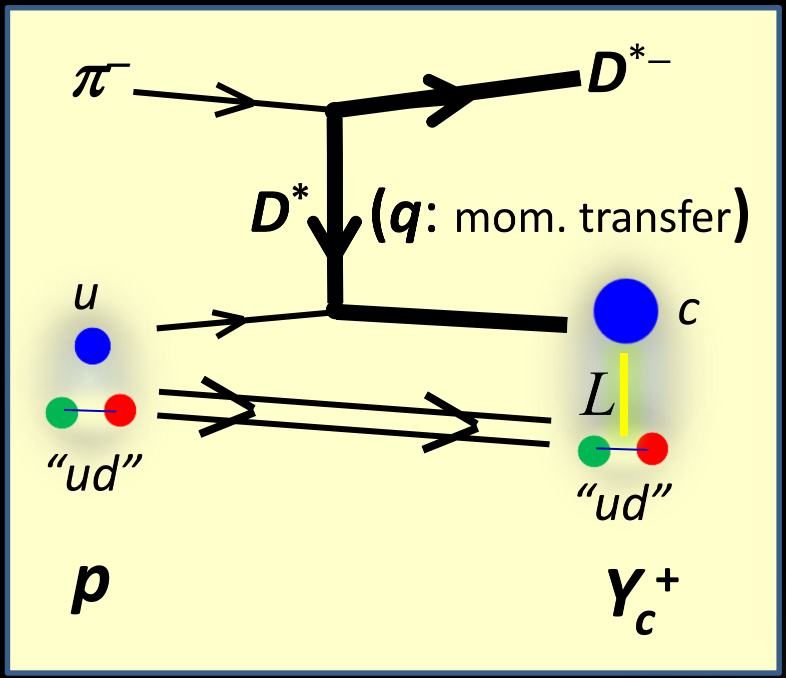
$$\sigma \sim C \int \frac{1}{64\pi s (p_\pi^{cm})^2} \exp(2R^2 t)(s/s_0)^{2\alpha(t)} dt$$



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

V.Yu. Grishina et al., EPJA25, 141(2005)

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})

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

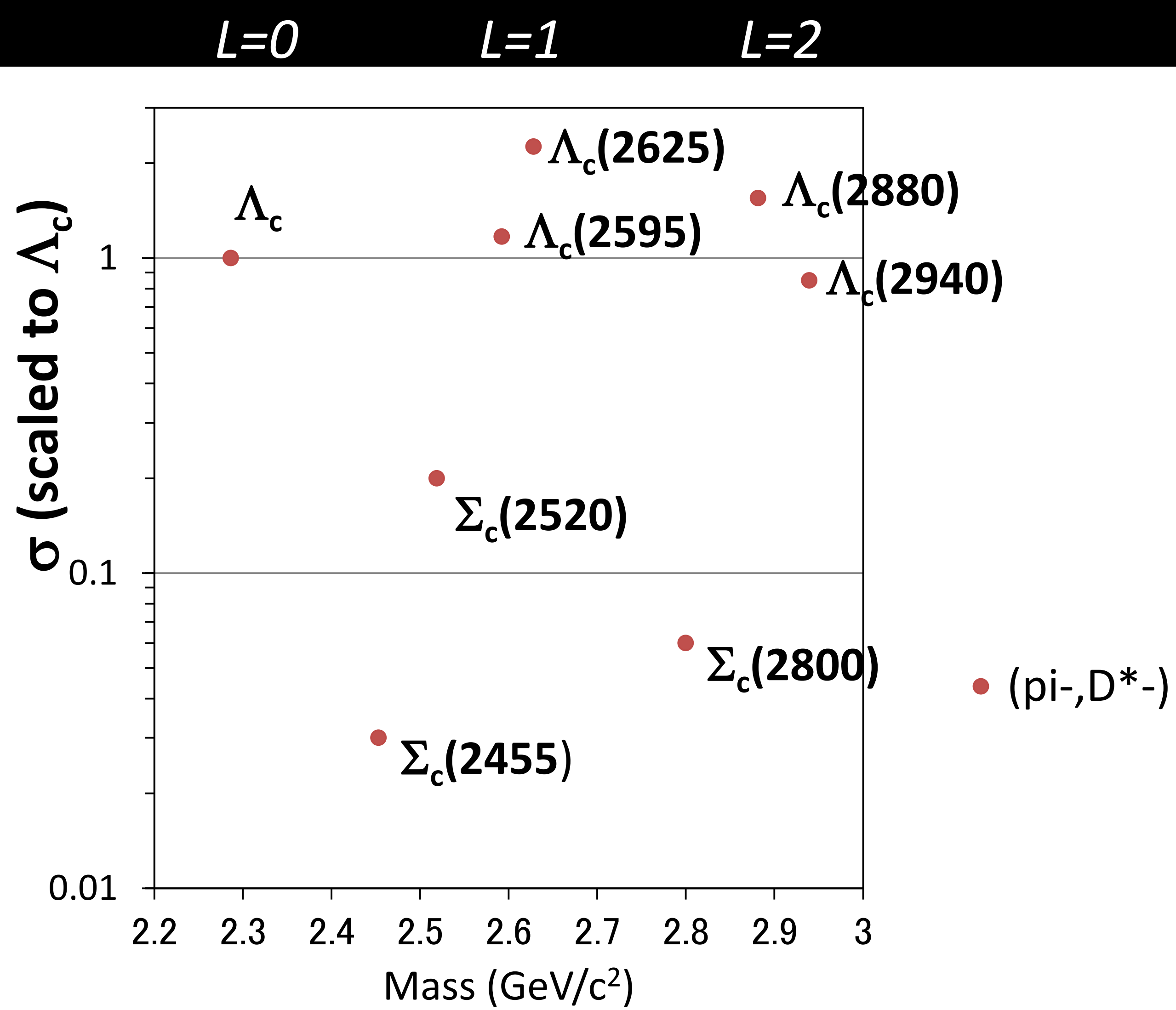
A~0.42 GeV ([Baryon size]$^{-1}$)
q_{eff}~1.4 GeV/c

Calculated production rate

	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**

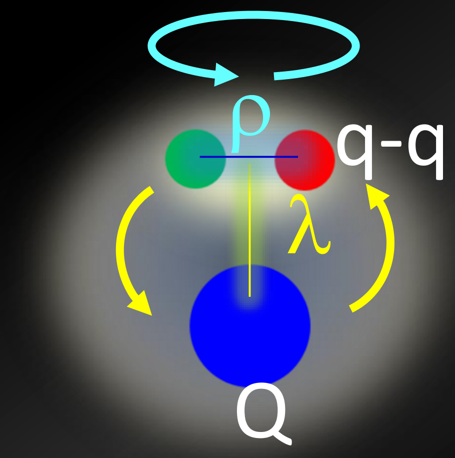
$p(\pi, D^{*-})Yc^*$ (t-channel D^* ex.) A. Hosaka, private comm. (2013)

Calculated production rate



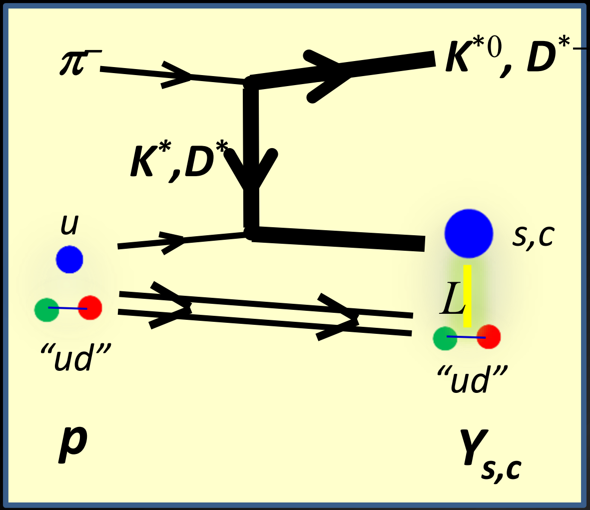
$p(\pi^-, D^{*-})Yc^*$ (t-channel D^* ex.)

A Heavy quark in a baryon



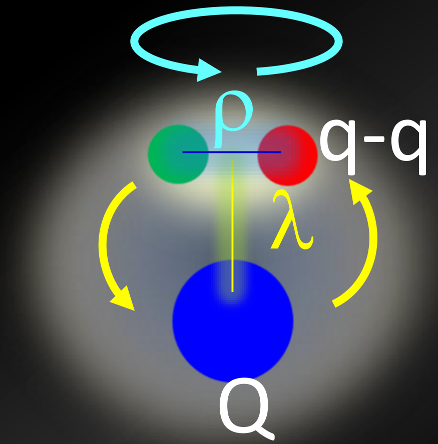
- λ and ρ mode excitations split
- Spin interactions btwn quarks …
  - Mix the λ and ρ modes
  - Mixing is weaken as increase of m_Q.
  - Mixing depends on the Spin conf. of "qq". (Λ/Σ)
- These affect …
  - Level structure: excitation energy
  - Decays: $\Gamma(Y_c{}^*\text{->}DN)/\Gamma(Y_c{}^*\text{->}\pi Y_c{}')$
  - Production rate

$p(\pi^-, D^{*-})Y_c^*$



- Picks up the structure of proton
  - Spin config. of "residual ud"
  - Naïve CQM: Good [qq]/Bad (qq) ~1
  - Suggested as G/B>1
- Favors λ mode excitations
  - Mixing effect populates the ρ mode excitations
- Systematic Studies are necessary ...
  - Level structure, decay, and Production rate
  - Details of the baryon WF (spatial/spin/isospin)

A Heavy quark in a baryon



- λ and ρ mode excitations split
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  - Production rate

Flavor dependence

Neg. Parity Hyperons (L=1)

Threshold

$\Sigma\eta$(1790)

$\Lambda\eta$(1710)

		rat ing	Width [MeV]	Br(-> NK) [%]	Br(->Yπ) [%]
Λ(1830) 5/2-		4*	95	3~10	35~75
Λ(1800) 1/2-		3*	300	25-40	seen
	Σ(1775) 5/2-	4*	120	37~43	16-25
	Σ(1750) 1/2-	3*	90	10~40	($\Sigma\eta$)15~55
	Σ(1690) ??	2*			
Λ(1690) 3/2-		4*	60	20~30	20~40
	Σ(1670) 3/2-	4*	60	7~13	35~75
Λ(1670) 1/2-		4*	35	20~30	25~55
	Σ(1620) 1/2-	1*			
	Σ(1580) 3/2-	1*			
Λ(1520) 3/2-		4*	19	45+-1	42+-1

KN(1432)

$\Sigma\pi$(1330)

Calculated production rate (Strange sector)

$p(\pi^-, K^{*-})Y^*$ reaction (t-channel K^* exchange)

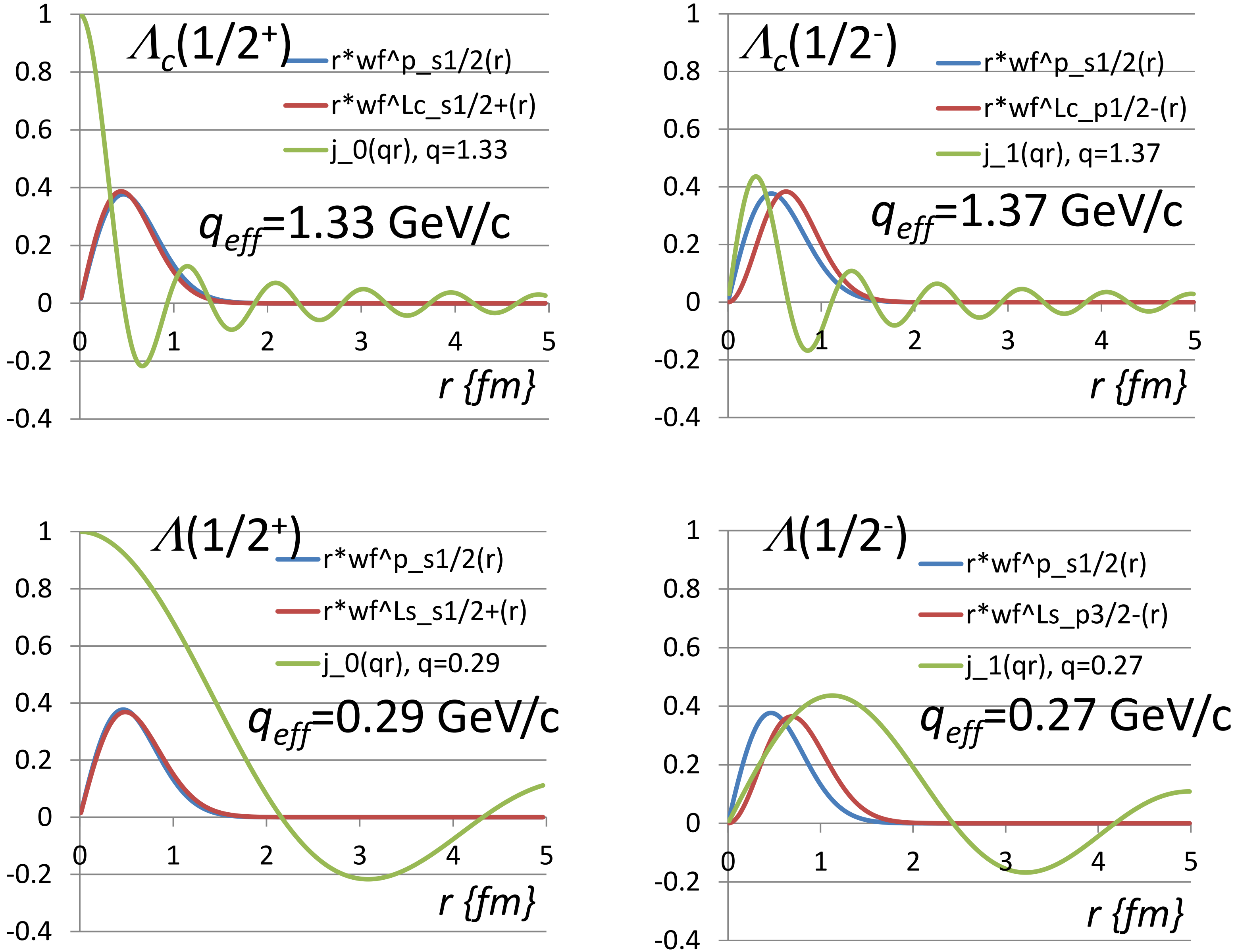
p_π=4.5 GeV/c	$\Lambda^{1/2+}$ 1116	$\Sigma^{1/2+}$ 1192	$\Sigma^{3/2+}$ 1385	$\Lambda^{1/2-}$ 1405	$\Lambda^{3/2-}$ 1520
γ	1/2	1/6	1/6	1/2	1/2
C	1	1/9	8/9	1/3	2/3
K	1.02	1.23	1.17	0.99	0.97
q_{eff}	0.29	0.31	0.38	0.36	0.40
R (rel.)	1	0.05	0.29	0.09	0.17

calculated by A. Hosaka

Mass dependence is different from that in charm sector.

charm

strange



L=0 *L*=1

Exp.: $p(\pi^-,K^{*0})Y$, D.J. Crennell et al., PRD6, 1220(1972)

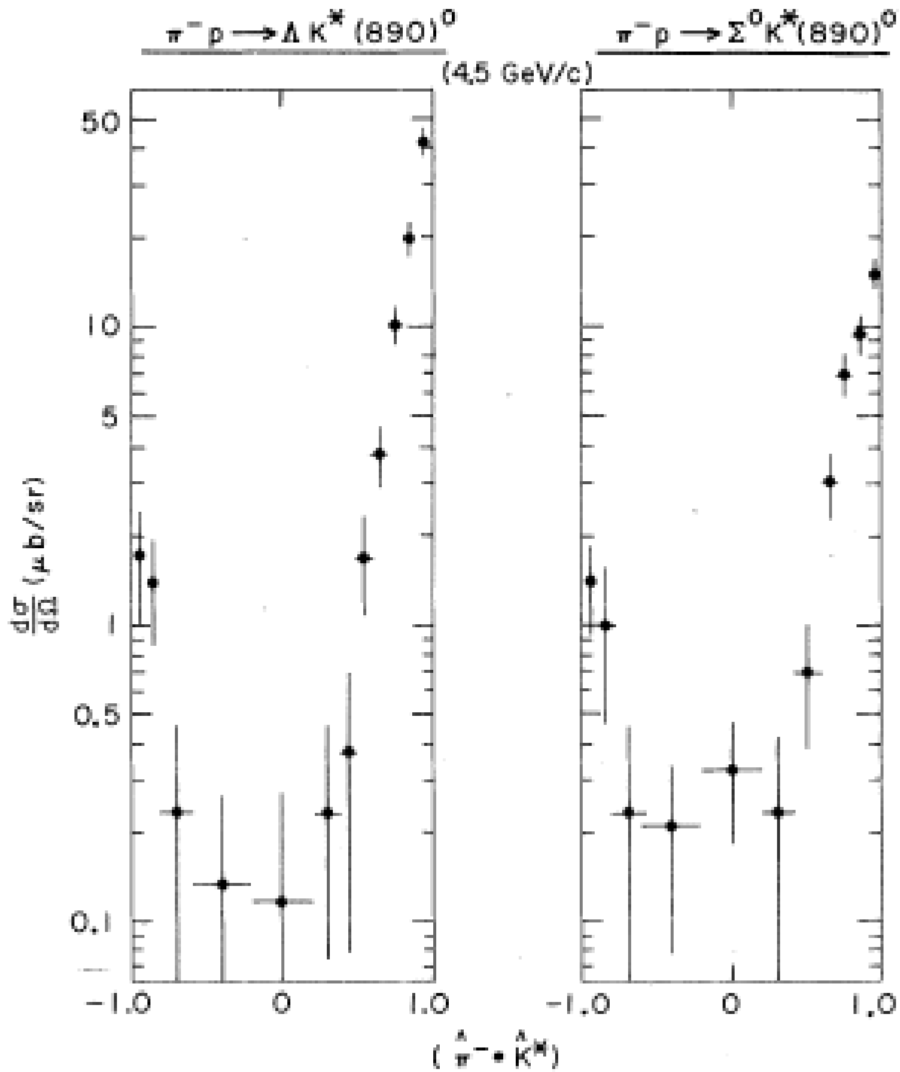
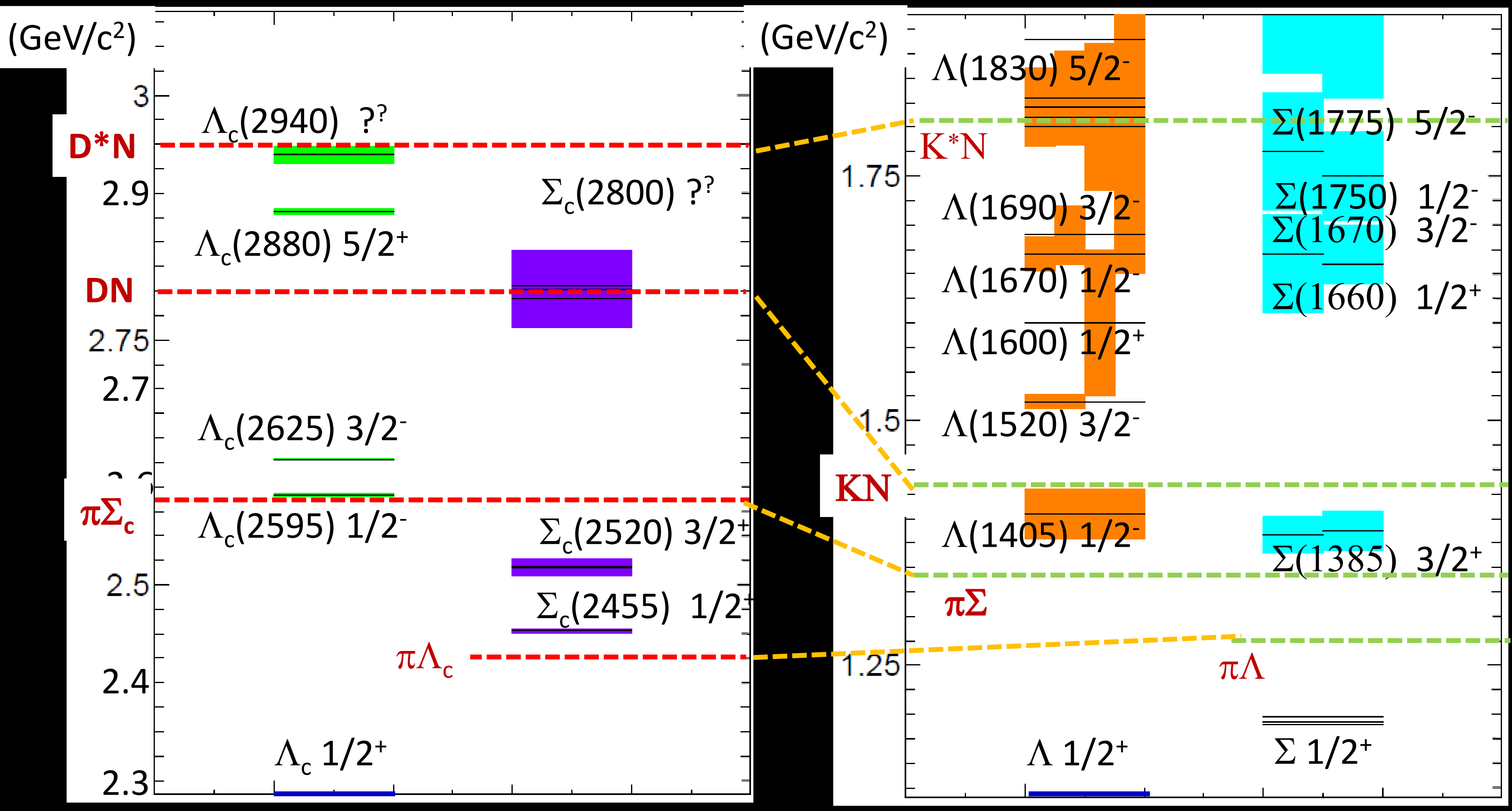


FIG. 21. Differential cross sections vs center-of-mass production angle [$\hat{\pi}^- \cdot \hat{K}^*(890)^0$] for reactions (2a) and (2b) at 4.5 GeV/c.

Systematic data are little available …

Charmed Baryons　　Strange Baryons

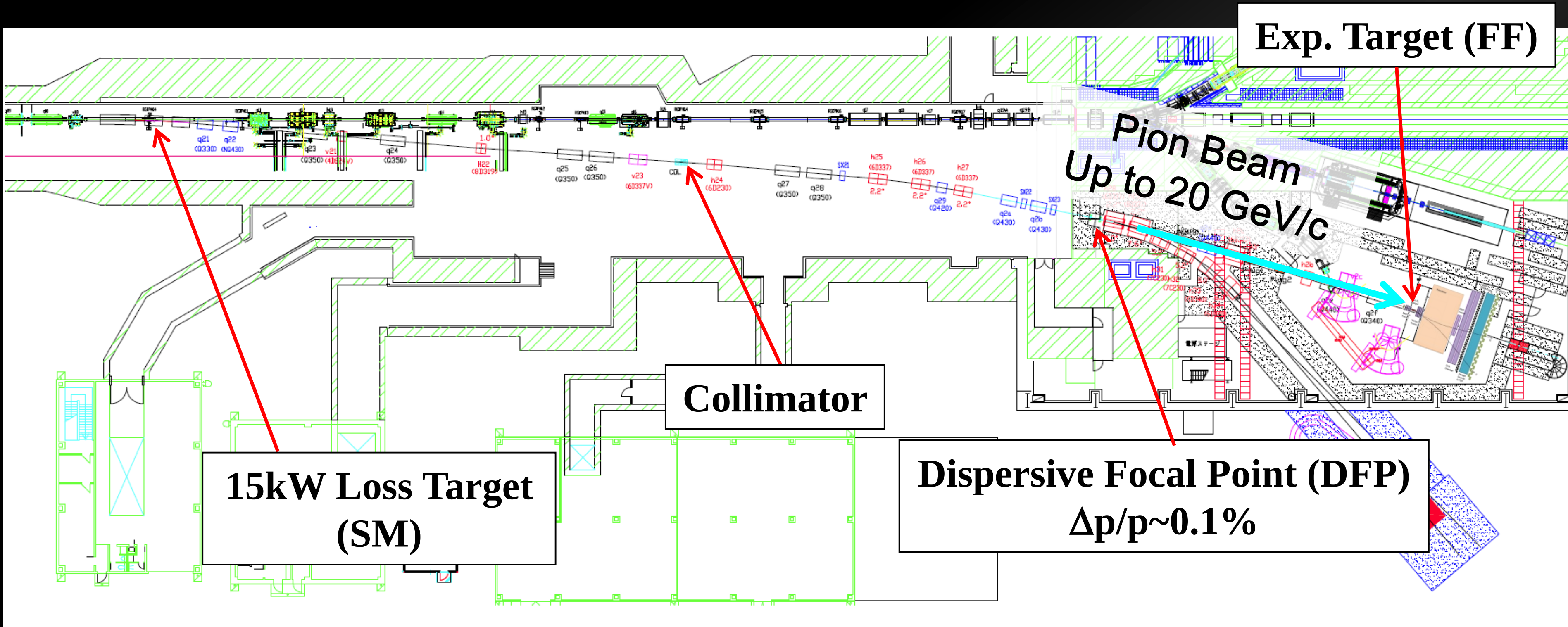


- Difference and Similarity in different flavor sectors
  - Level structure (spin/parity), Decay width
  - State population

Proposed Experiment at J-PARC

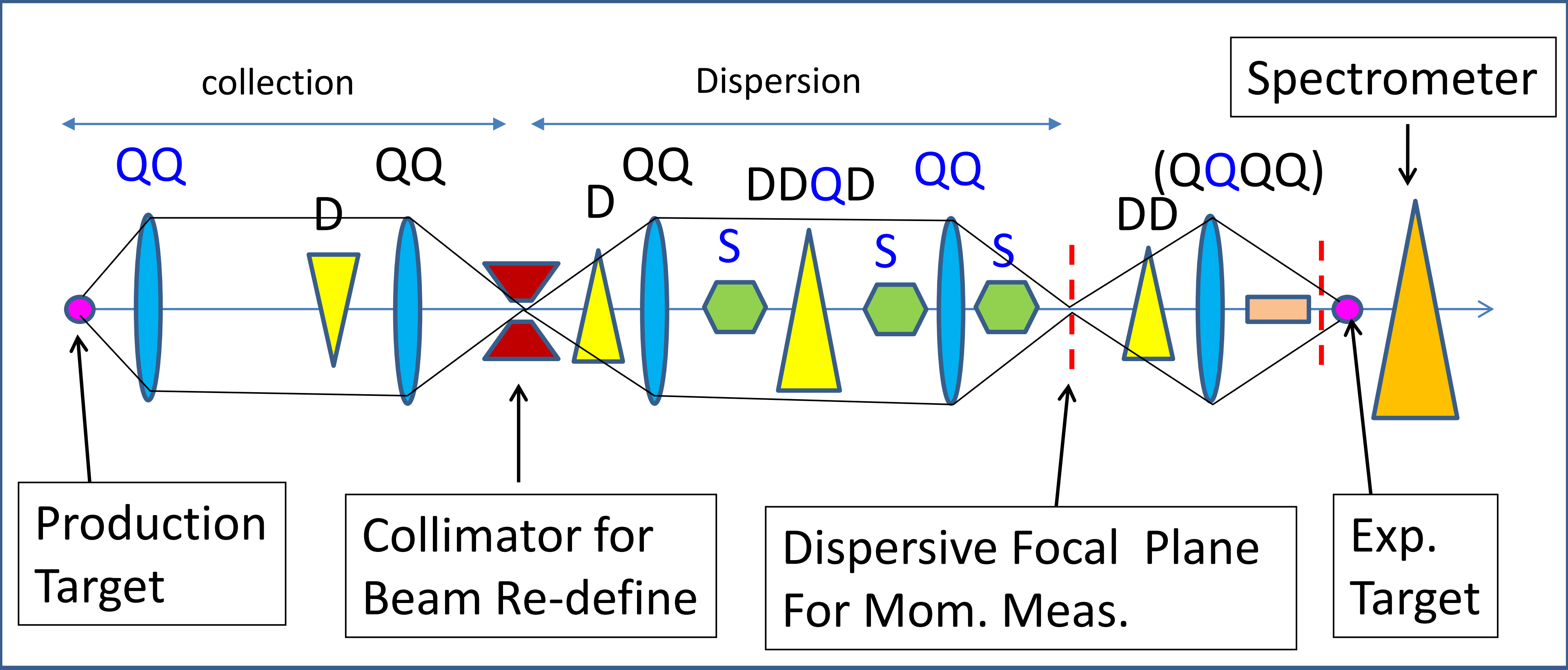
High-res., High-momentum Beam Line

- High-intensity secondary Pion beam
- High-resolution beam: Δp/p~0.1%



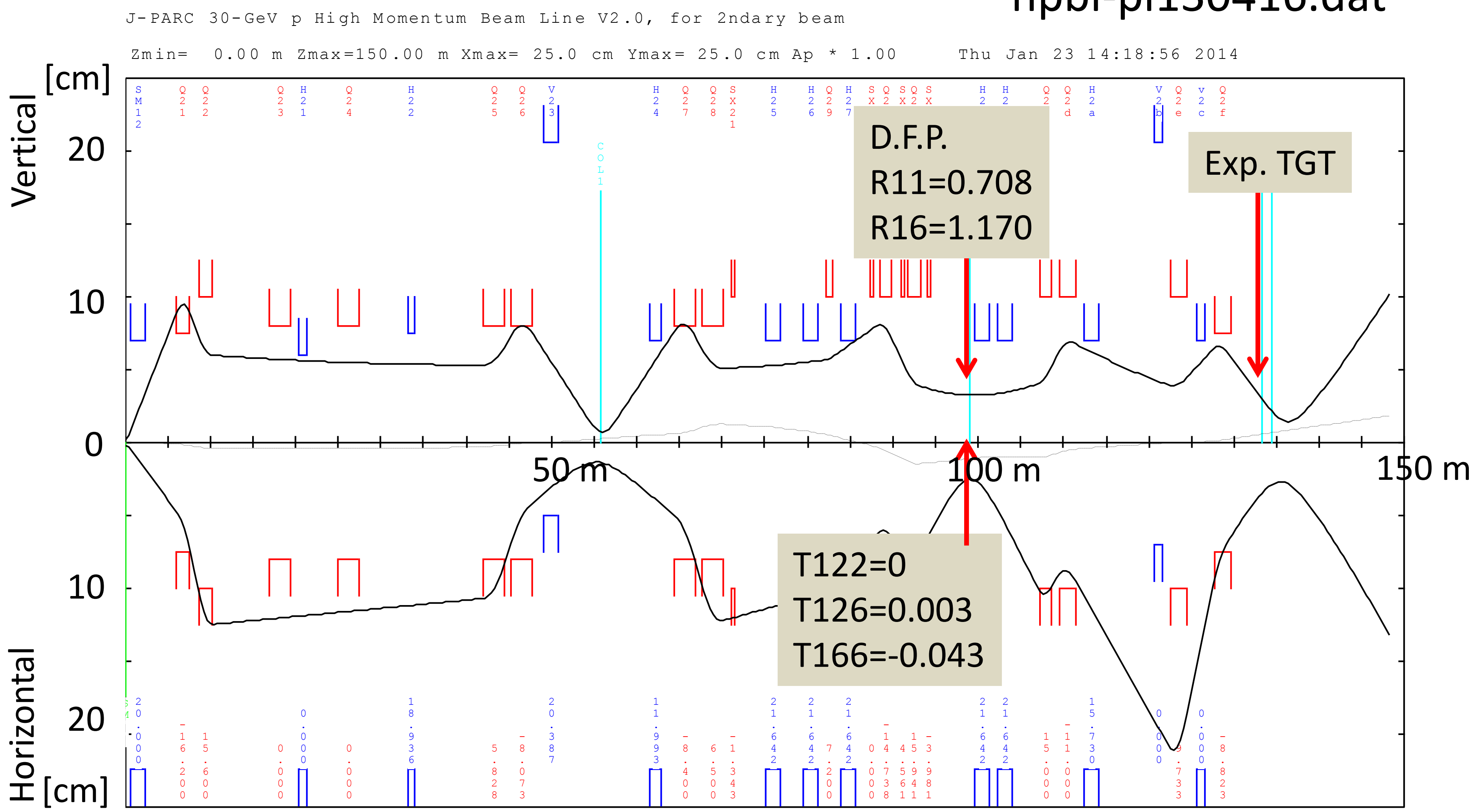
High-res., High-momentum Beam Line

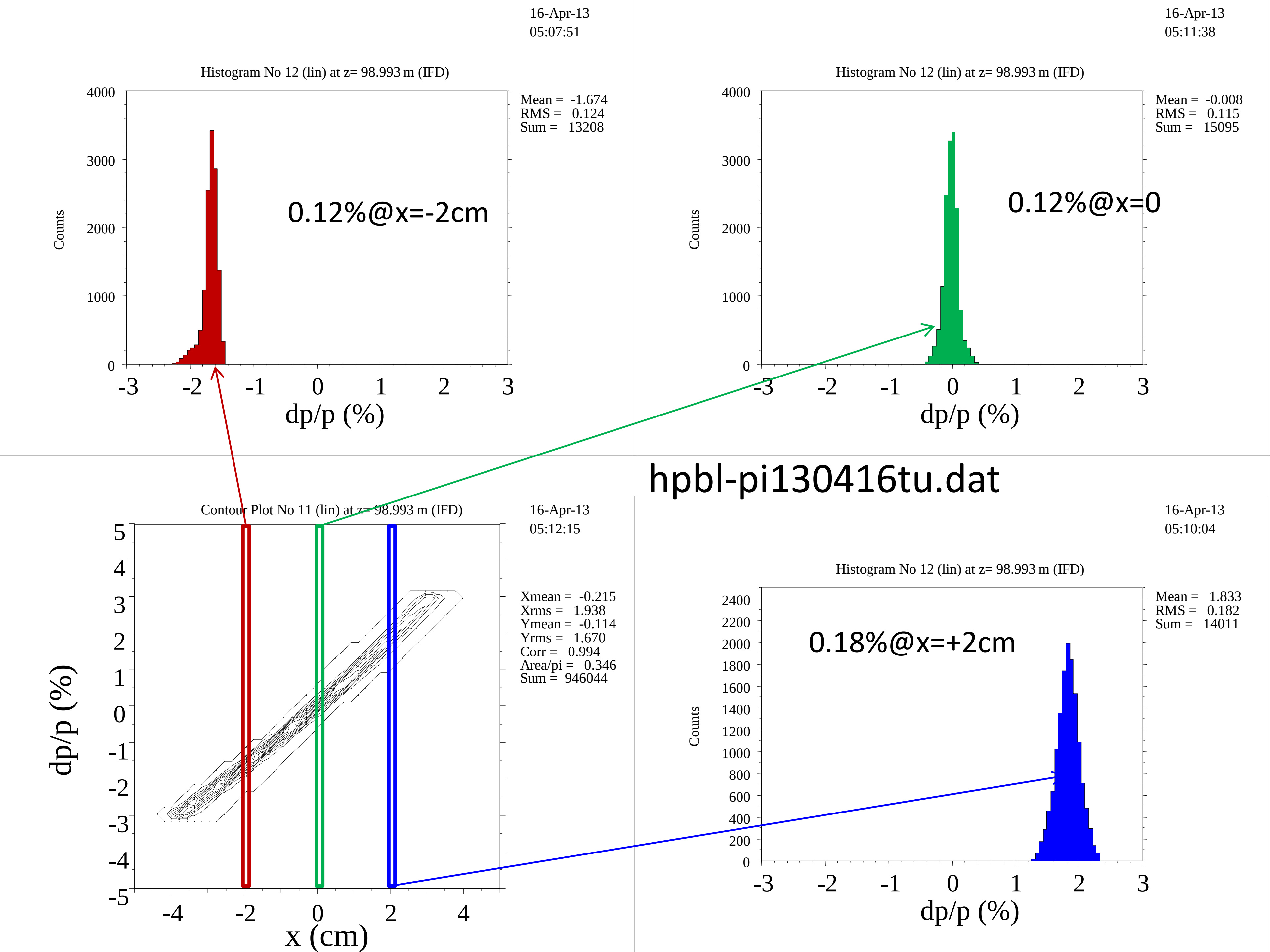
- High-intensity secondary Pion beam
- High-resolution beam: $\Delta p/p \sim 0.1\%$



Beam Envelope (2nd order Transport)

hpbl-pi130416.dat

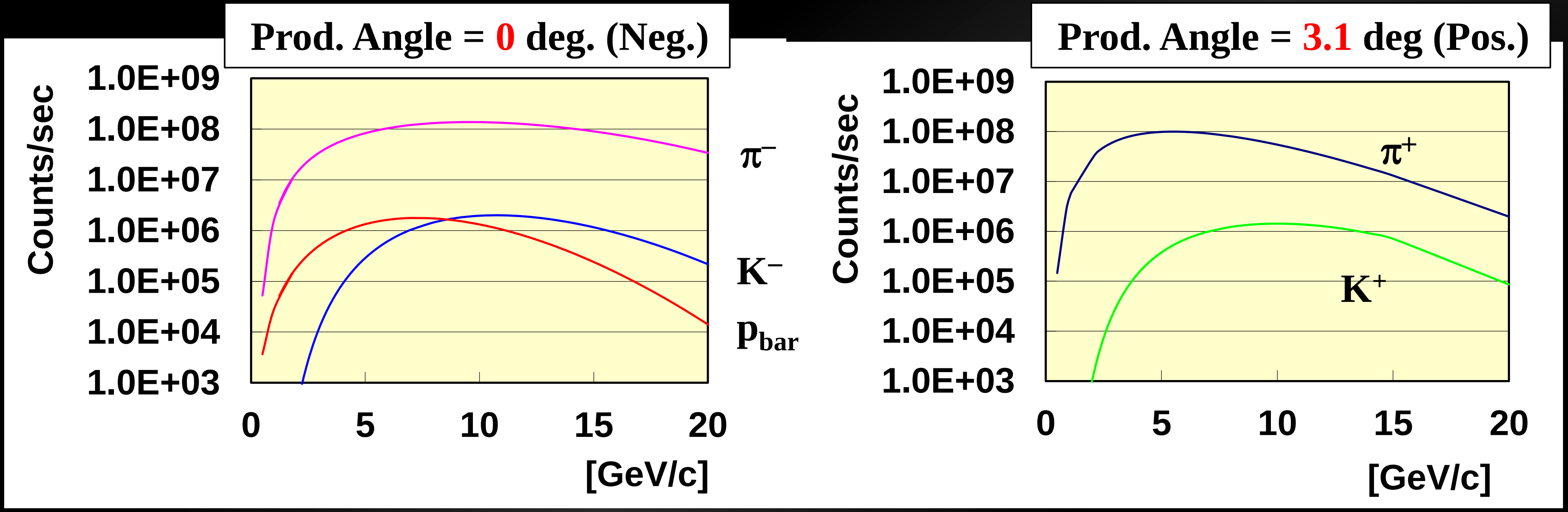



16-Apr-13
05:07:51
Histogram No 12 (lin) at z= 98.993 m (IFD)
Mean = -1.674
RMS = 0.124
Sum = 13208
0.12%@x=-2cm
Counts
dp/p (%)
16-Apr-13
05:11:38
Histogram No 12 (lin) at z= 98.993 m (IFD)
Mean = -0.008
RMS = 0.115
Sum = 15095
0.12%@x=0
Counts
dp/p (%)
hpbl-pi130416tu.dat
Contour Plot No 11 (lin) at z= 98.993 m (IFD)
16-Apr-13
05:12:15
Xmean = -0.215
Xrms = 1.938
Ymean = -0.114
Yrms = 1.670
Corr = 0.994
Area/pi = 0.346
Sum = 946044
dp/p (%)
x (cm)
16-Apr-13
05:10:04
Histogram No 12 (lin) at z= 98.993 m (IFD)
Mean = 1.833
RMS = 0.182
Sum = 14011
0.18%@x=+2cm
Counts
dp/p (%)

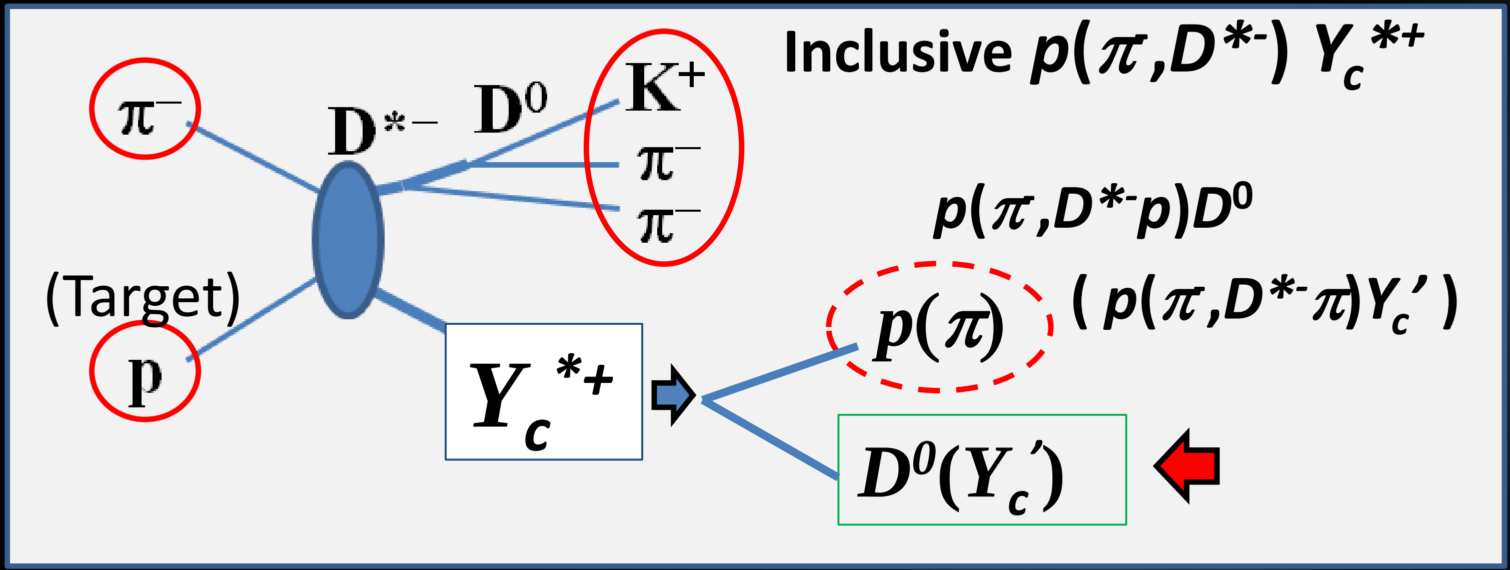
High-res., High-momentum Beam Line

- High-intensity secondary Pion beam
  - 1.0 x 10^7 pions/sec @ 20GeV/c
- High-resolution beam: $\Delta p/p$~0.1%
  - → charmed baryon spectroscopy

Sanford-Wang
15 kW Loss on Pt
Acceptance :1.5 msr%, 133.2 m

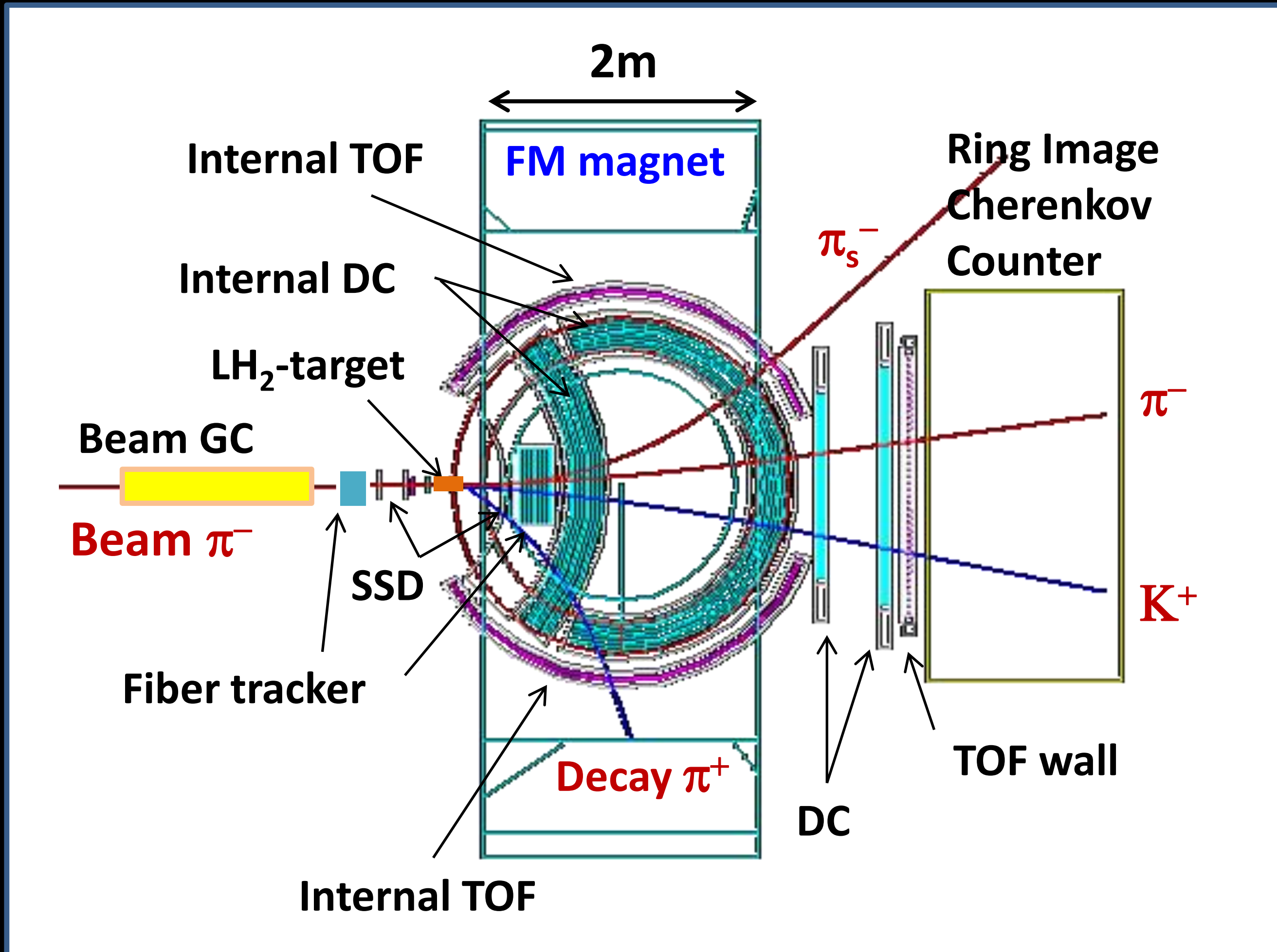


Charmed Baryon Spectroscopy Using Missing Mass Techniques



- inclusive (π^-,D^{*-}) spectrum
  - Level structure of Y_c*
  - Production Rate
- Decay Particles
  - Decay Width/Decay Branching Ratios
  - Spin, Parity

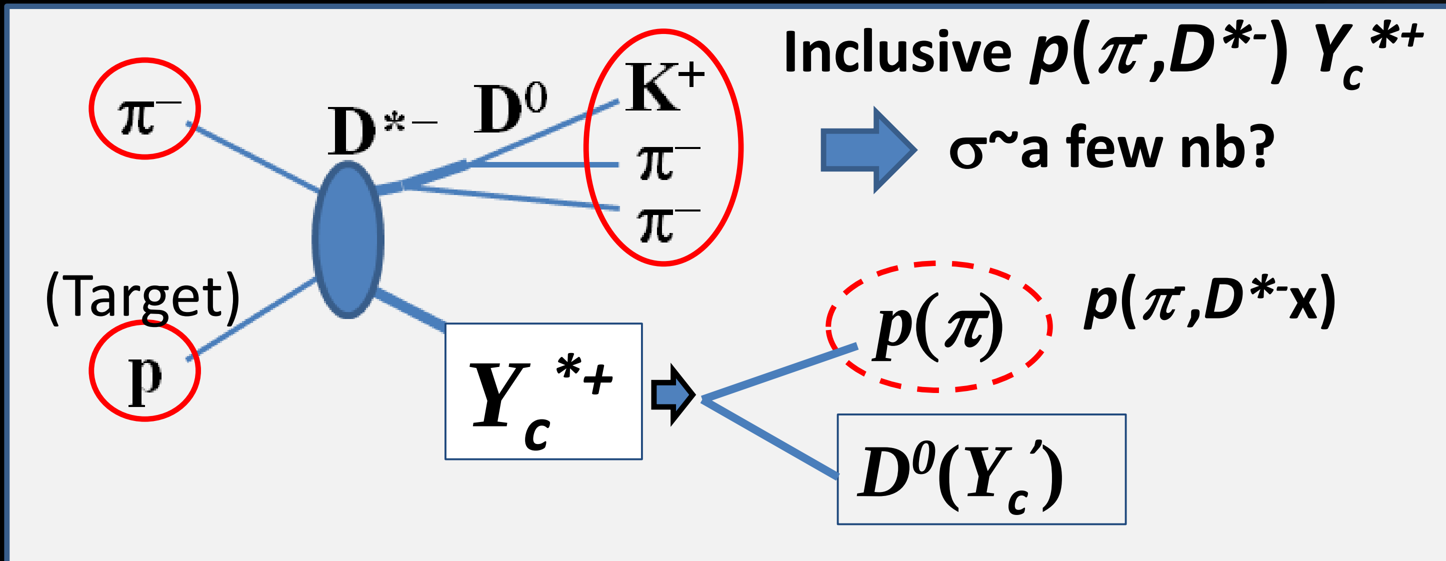
Charmed Baryon Spectrometer



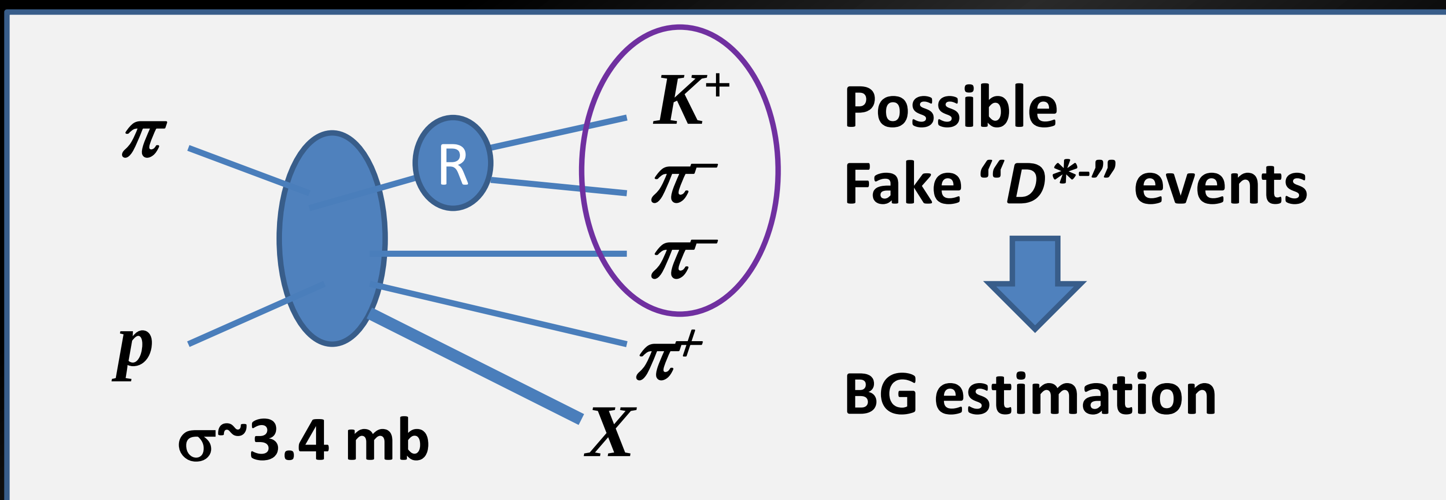
Large acceptance ~ 60% (for *D), $\Delta p/p$~0.2% at ~5 GeV/*c***

Charmed Baryon Spectroscopy Using Missing Mass Techniques

Signal

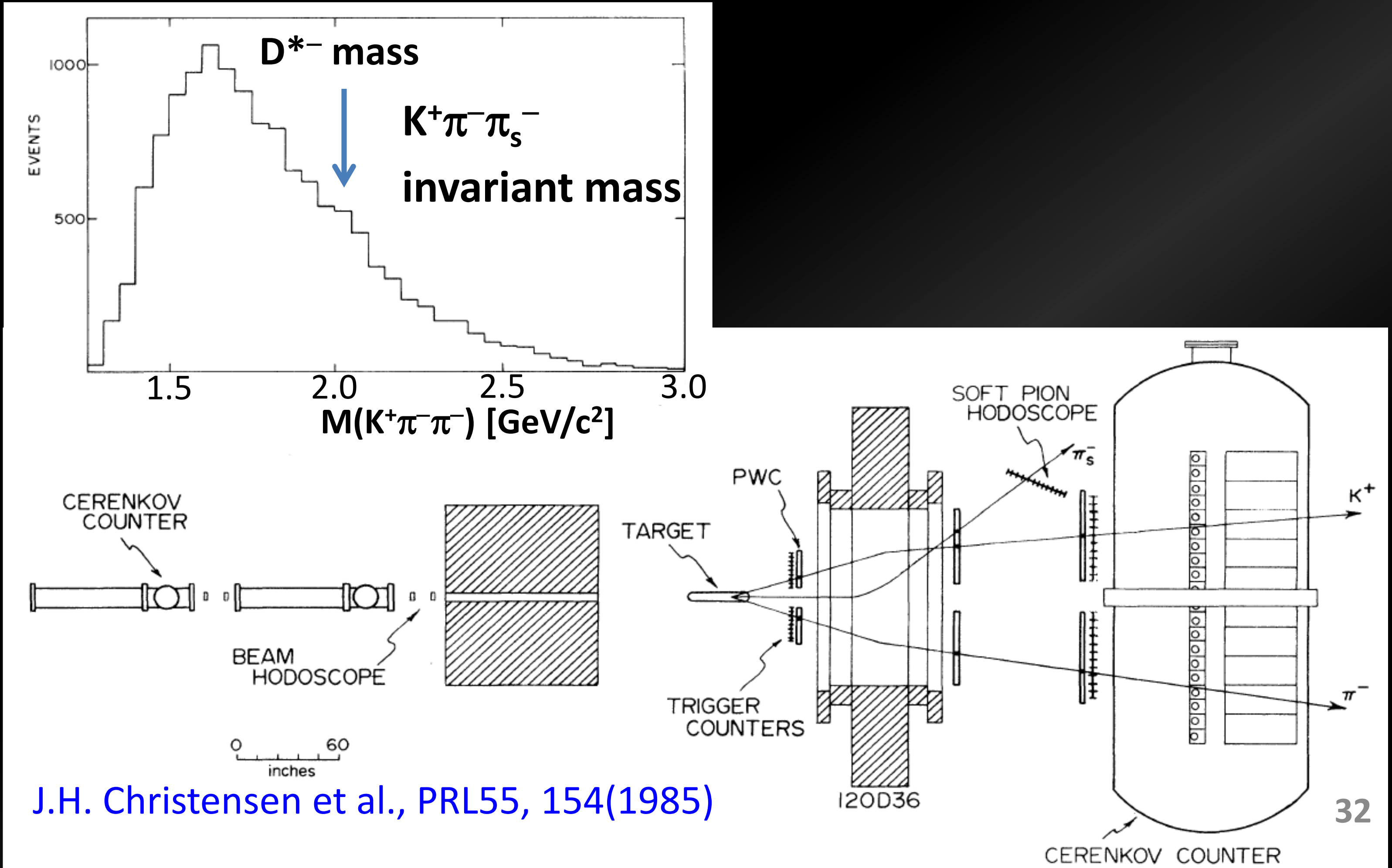


BG



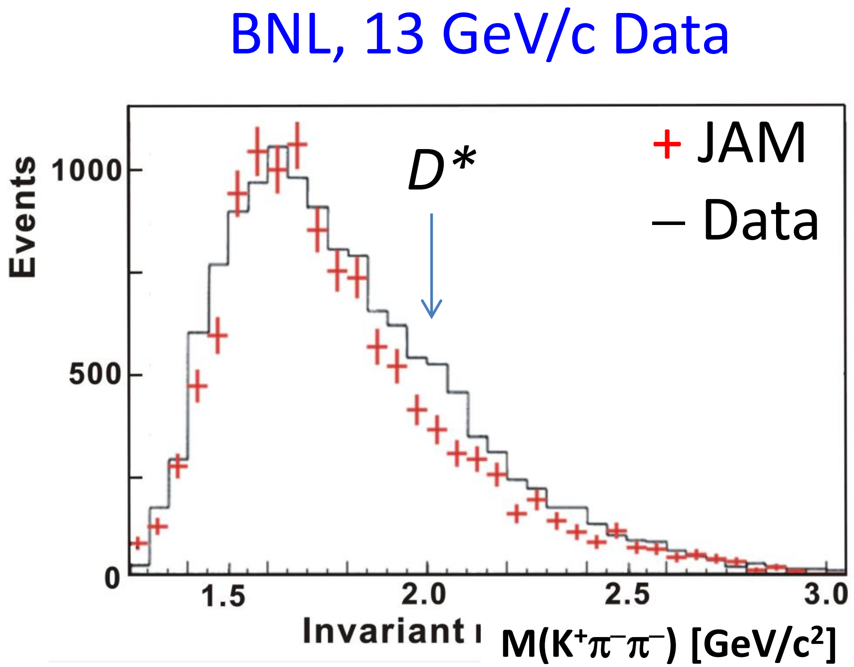
charmed baryon meas. by $p(\pi^-,D^{*-})Y_c$

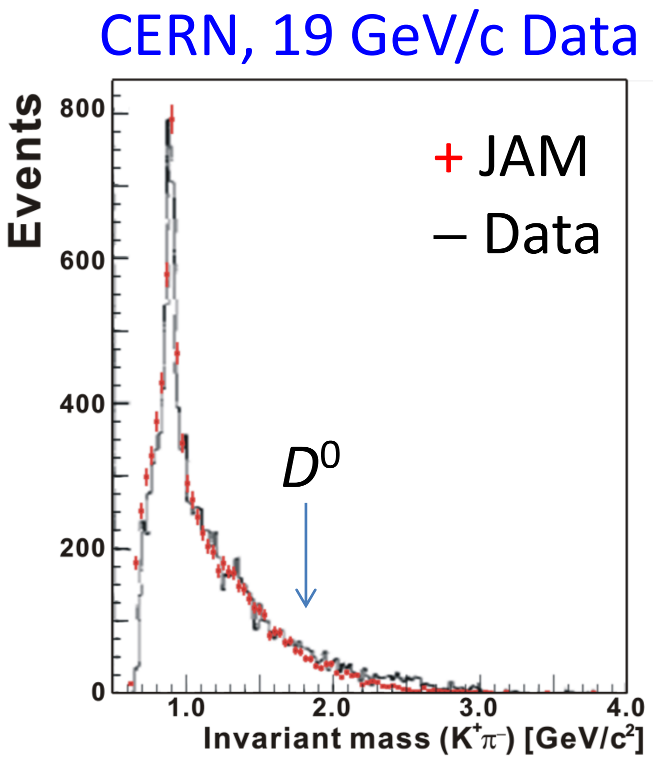
- No exp. data for the $p(\pi^-,D^{*-})\Lambda_c$ is available
  but σ<7nb at p_π=13 GeV/c at BNL (1985)



J.H. Christensen et al., PRL55, 154(1985)

BG simulation by JAM





BGs of the past exp's were well reproduced.

What we improve …

	Beam [GeV/c]	Beam [/spill]	PoT	Acceptance	High rate	HS DAQ	PID	Beam Resol.	Mass Resol.	D* detection	S/N method
J-PARC	15–20	○	○	○	○	○	○	○	○	○	○
BNL 1	13	○	△	×	×	×	×	○	○	○	×
BNL 2	16	×	×	○	×	×	×	×	△	○	×
CERN 1	19	×	×	○	×	×	×	×	×	×	×

- Yield ⇔ Cross section: level of nb
  - Both beam & acceptance
  - High-rate detectors & High-speed DAQ
  - High performance PID system

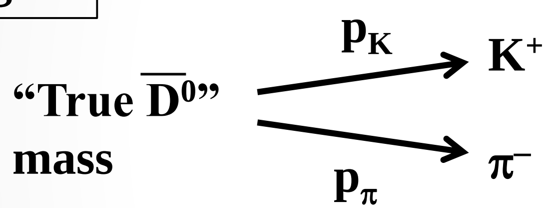
- Experimental techniques
  - Beam & D mass resolution
  - Background reduction: D* detection
  - Study for good S/N

✱ Design of experiment with proper conditions needed

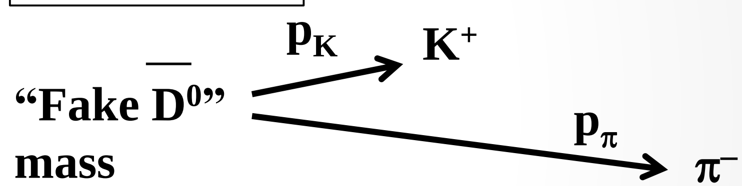
Background reduction

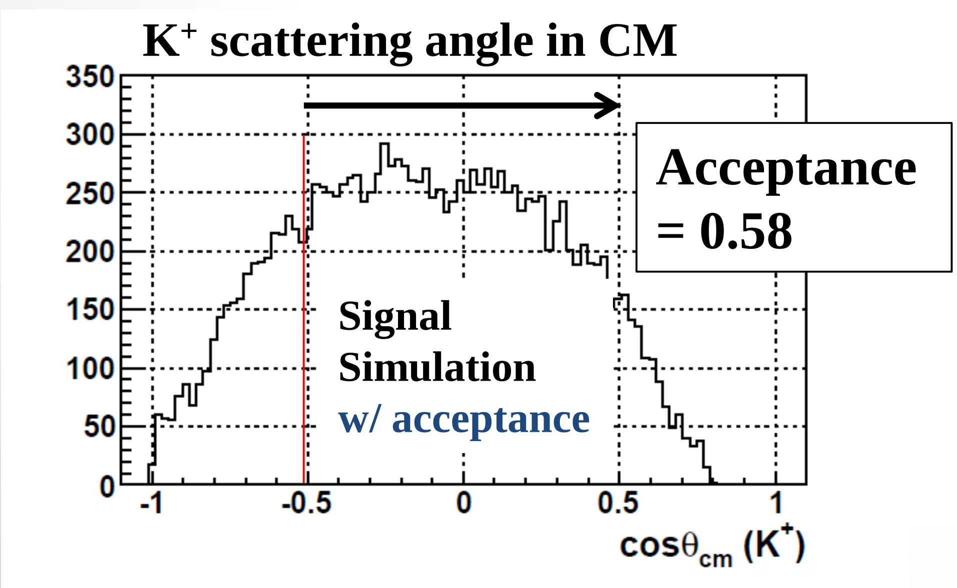
- **S/N improvement:**
  - Mass resolution: x4
  - Decay angle cut: x2
  - Production angle cut x4 (depends on $d\sigma/dt$)

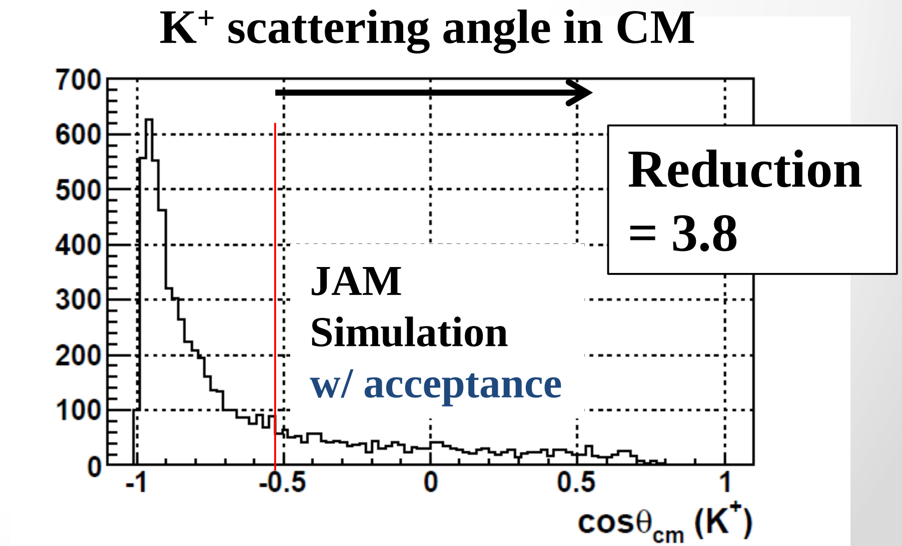
Signal



Background





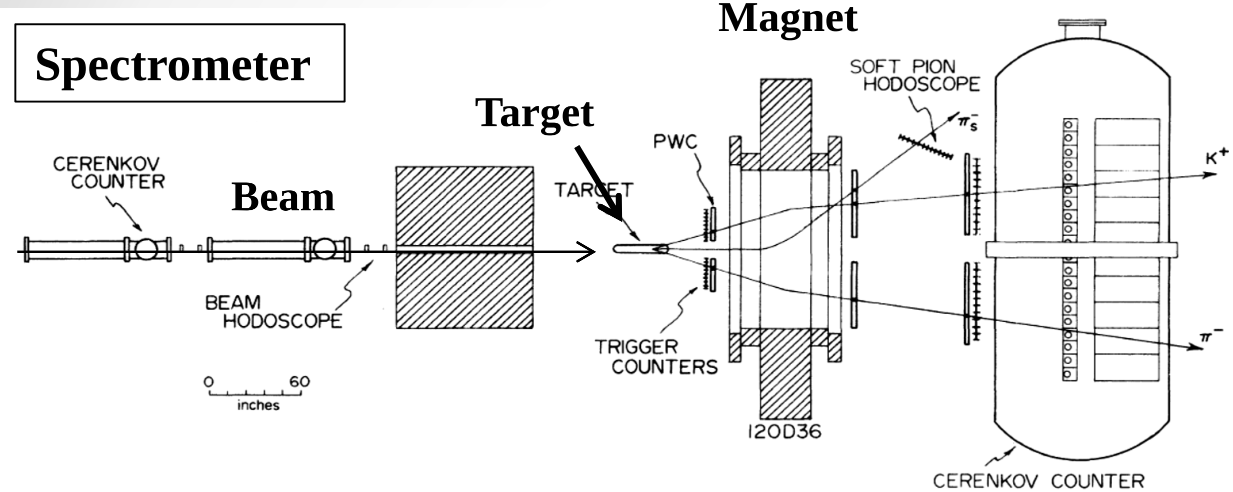


BG Sources

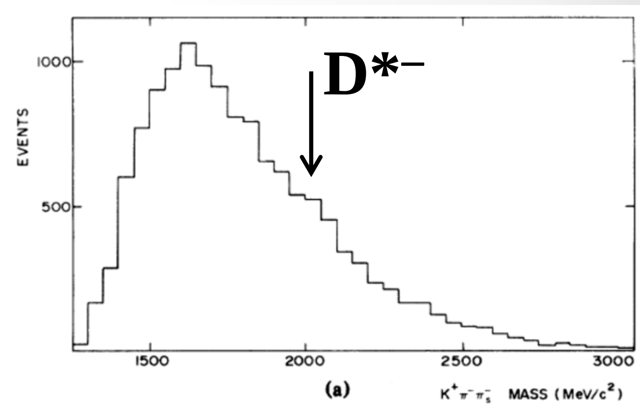
1. Main background
   - Strangeness production including the **(K^+, π^-, π_s^-)** final state
     3.4 mb **JAM (**PRC61 (2000) 024901）
2. Wrong particle identification
   - (π^+, π^-, π_s^-), (p, π^-, π_s^-) : Dominant **26 mb**
     - PID misidentification of π/p as K^+: ~3%
   - Contribution of other 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 makes in the MM spectrum

BNL experiment



$K^+\pi^-\pi_s^-$ invariant mass



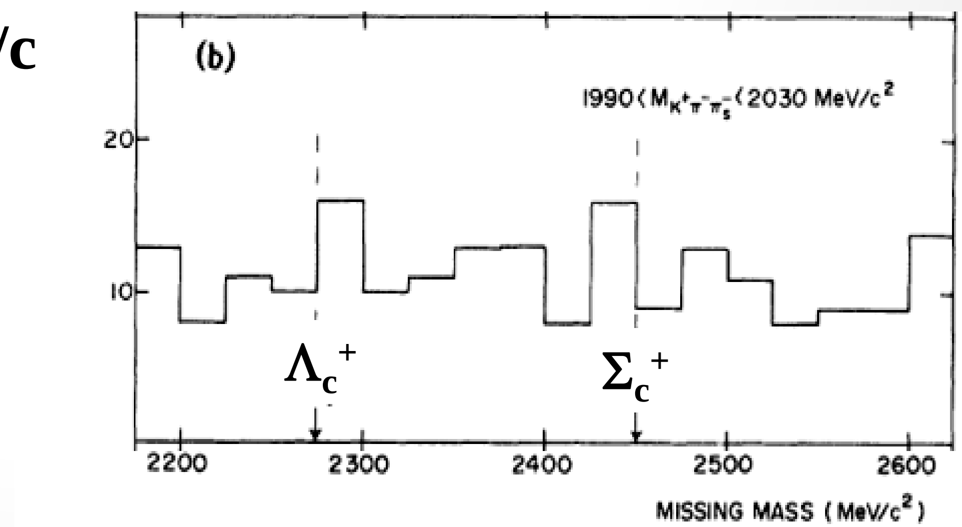
BNL experiment in 1983

- $\pi^- p \rightarrow \Lambda_c^+ D^{*-}$ @ 13 GeV/c
  - $N_\pi = 3 \times 10^{12}$
  - $\Delta M = 20$ MeV

✱ No peak structure

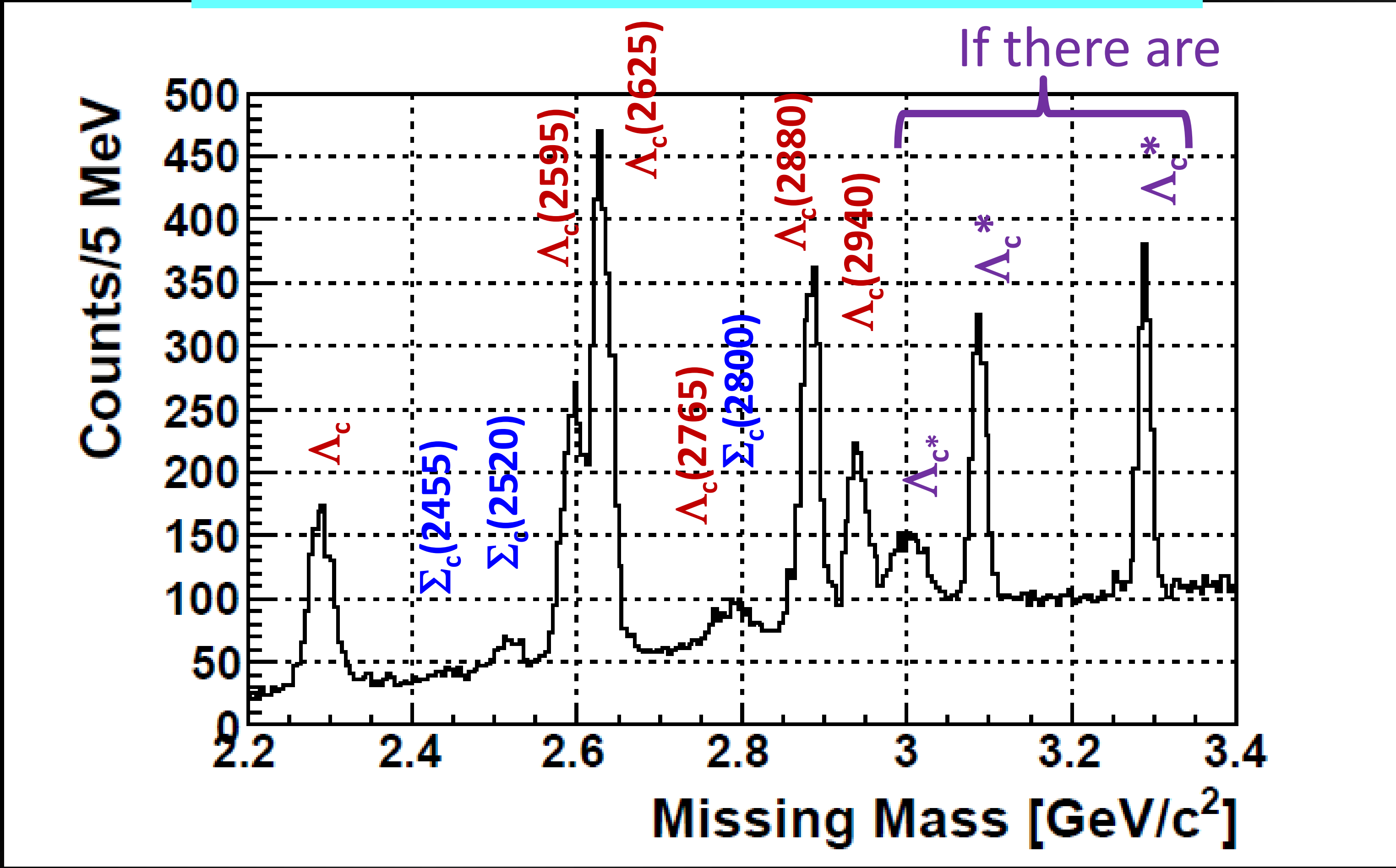
⇒ Upper limit: $\sigma = 7$ nb

Missing mass spectrum

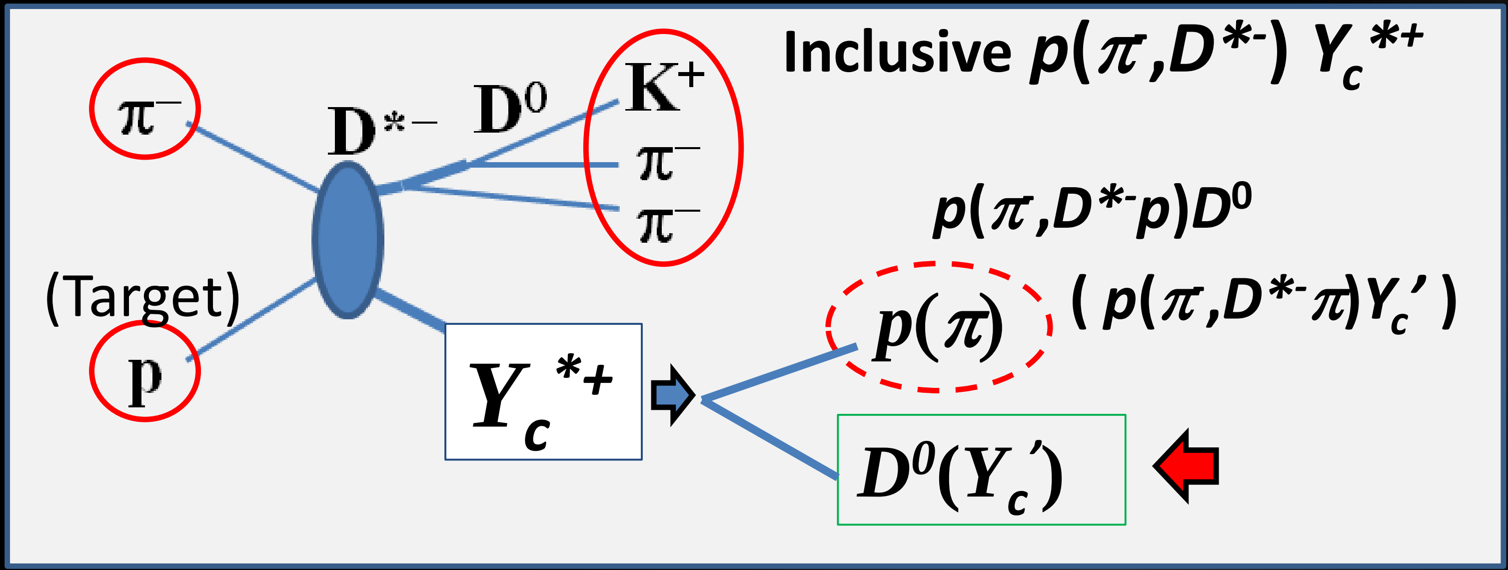


Expected spectrum: σ_{GS} = 1 nb

N(Yc*)~1000 events/1nb/100 days
Better mass resolution: ~10 MeV/c^2
Sensitivity: ~0.1 nb (3σ, Γ~100 MeV)



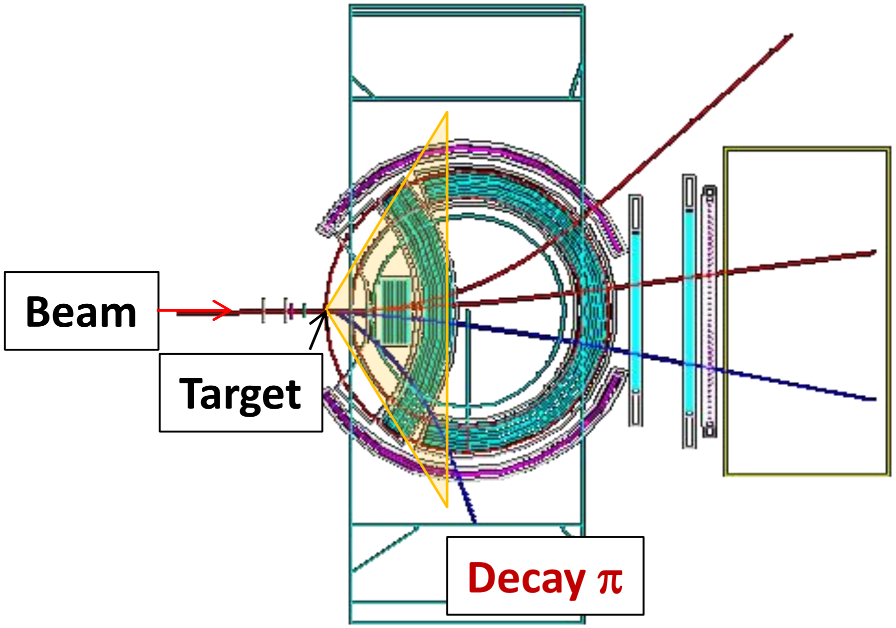
Charmed Baryon Spectroscopy Using Missing Mass Techniques



- inclusive (π^-,D^{*-}) spectrum
  - Level structure of Y_c^*
  - Production Rate
- Decay Particles
  - Decay Width/Decay Branching Ratios
  - Spin, Parity

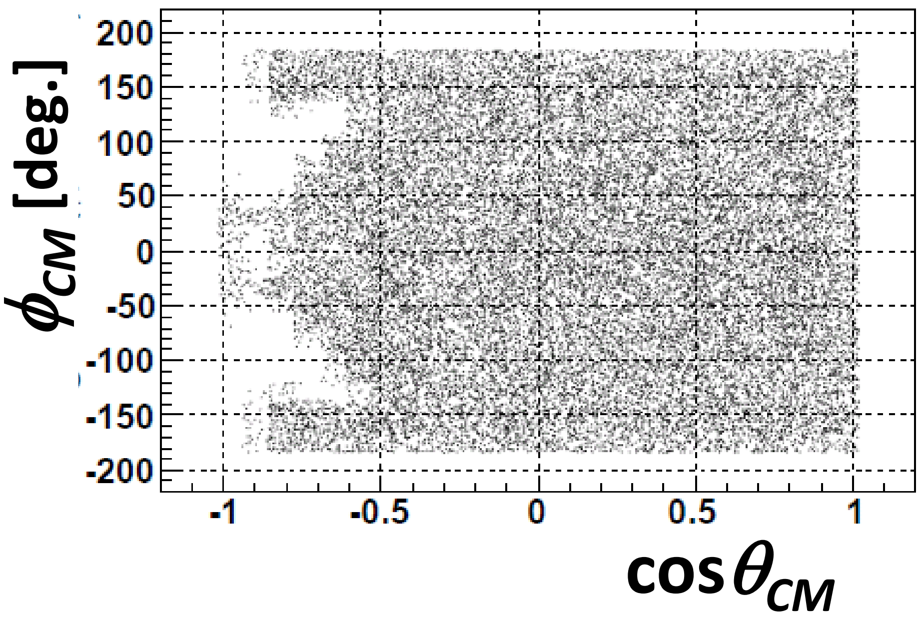
Acceptance for decay particles: ~85 %

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



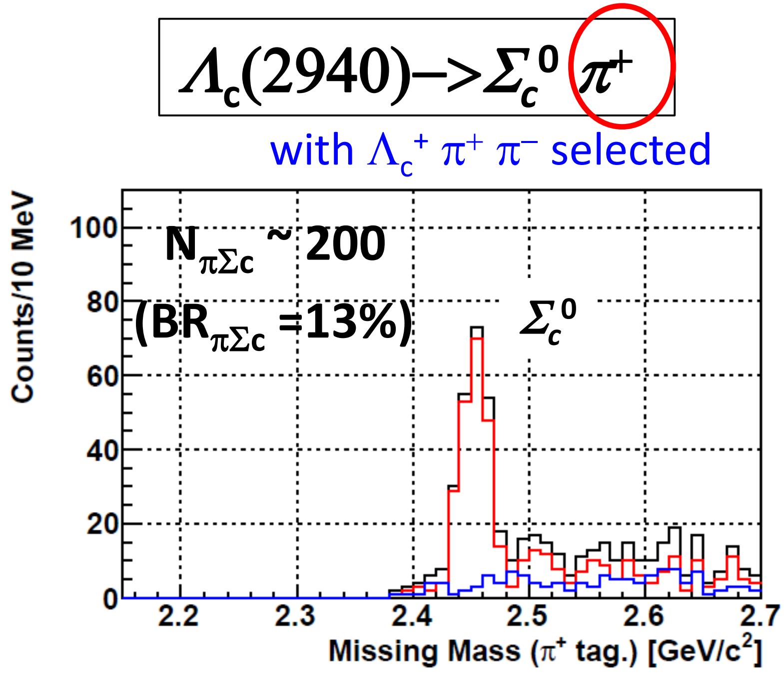
Coverage for decay π

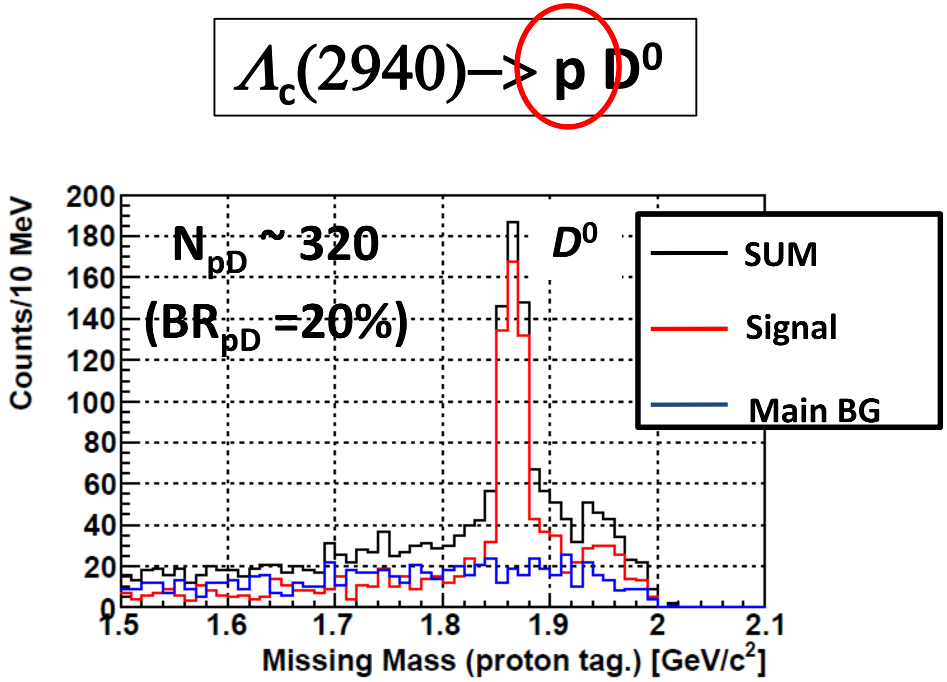
($\Lambda_c(2940) \to \Sigma_c^0\pi^+$)



* Decay products can be measured efficiently.

Decay Products





* Decay meas. strongly assists the missing mass spectroscopy.
  - Branching ratios: Diquark corr. affects $\Gamma(\Lambda_c^* \to pD)/\Gamma(\Lambda_c^* \to \Sigma_c \pi)$.
  - Angular distribution: Spin, Parity

Summary

- A new project for charmed baryon spectroscopy at the J-PARC High-p Beam Line
  - Under research cooperation btwn RCNP, IPNS/KEK, and the J-PARC Center
  - Proposal P50 are submitted:

    "Charmed Baryon Spectroscopy via the (π^-,D^{*-}) reaction"

    http://www.j-parc.jp/researcher/Hadron/en/Proposal_e.html#1301

- Opens new opportunities to study hadron physics