CHIRAL2013, 27-31 Oct., 2013

Future Project at J-PARC

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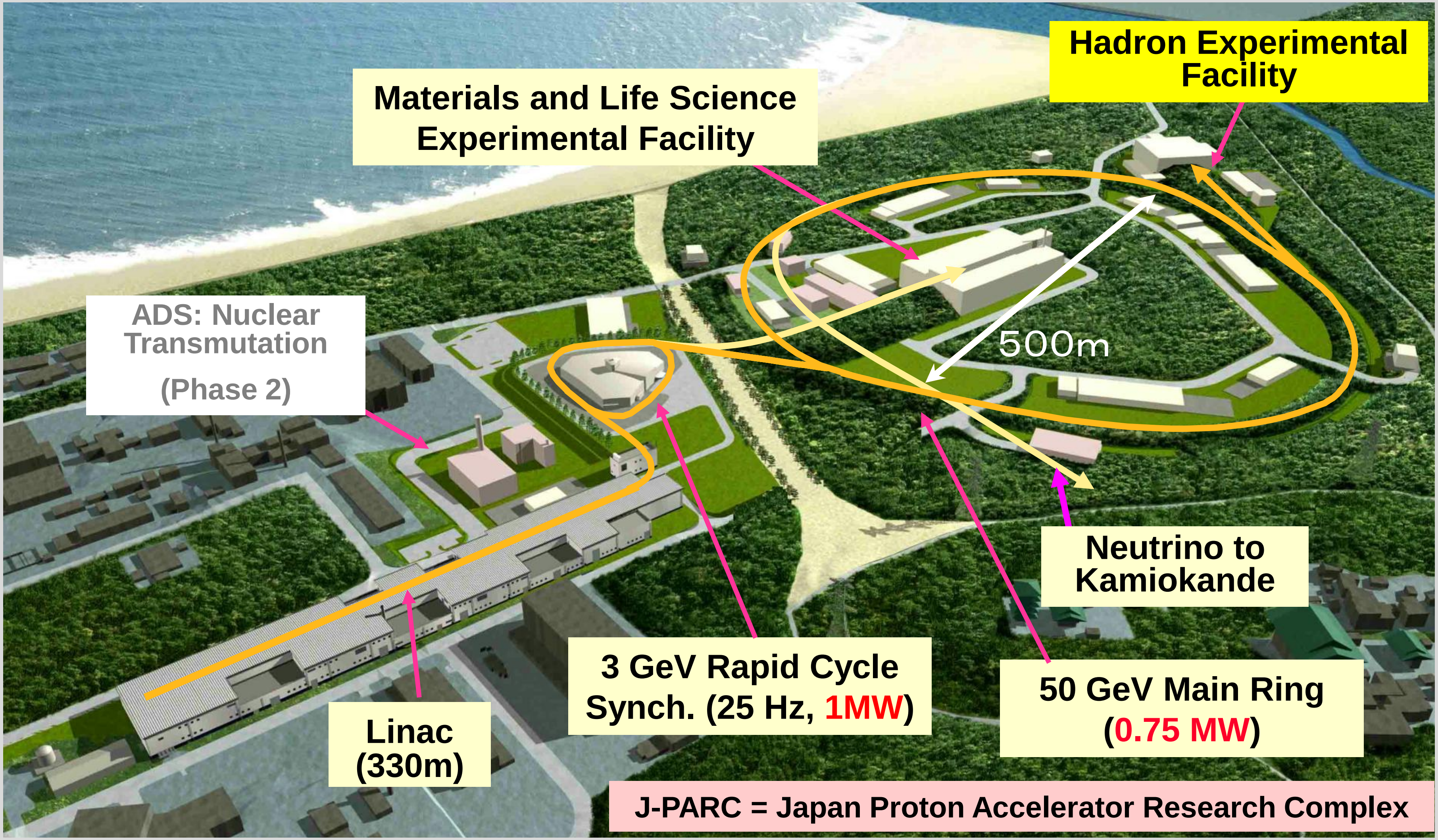
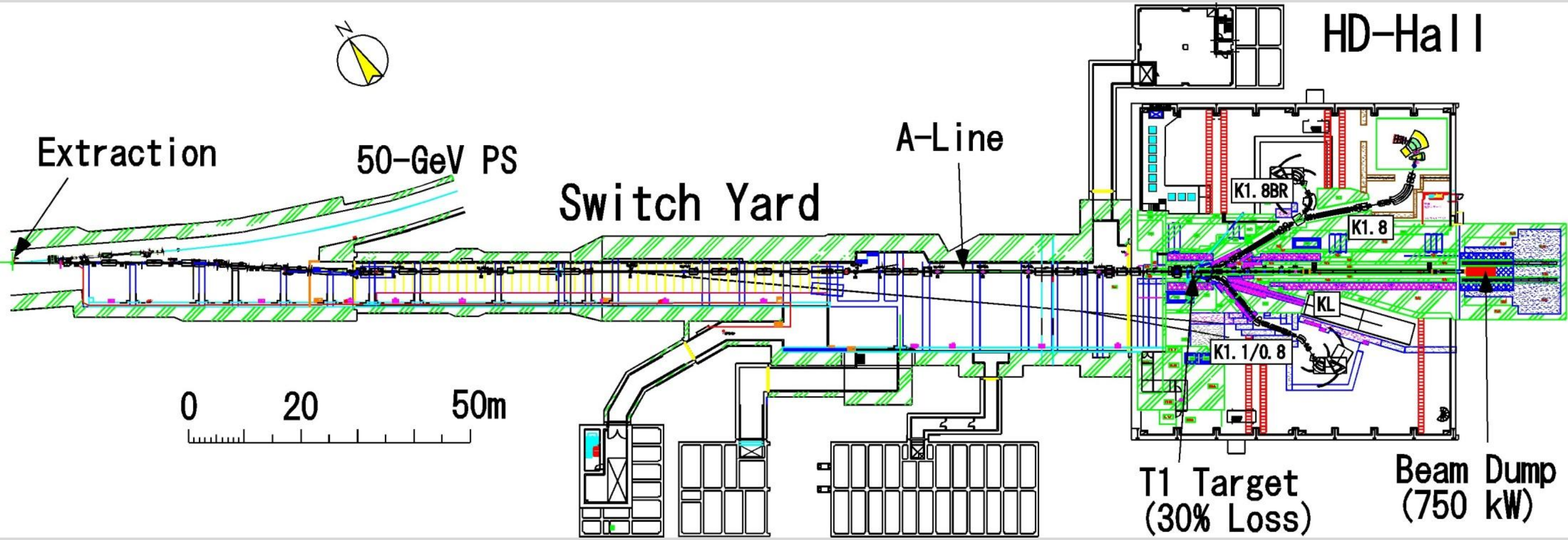
Outline:
1. J-PARC Hadron Exp. Facility
2. High Momentum Beam Line (New)
3. Charmed Baryon Spectroscopy at J-PARC
4. Summary

J-PARC Facility



Joint Project between KEK and JAEA since 2001

HADRON BEAM LINE FACILITY



- Slow Extraction (SX) Beam :
  - Currently, the accelerator is operated at 30 GeV.
  - 1st phase: A design goal is 9μA (270 kW, 3.4×10^{14} /6s spill)

    SX Beam: step by step operation to increase extracted power

    1st Beam in 2009.

    ~3 kW (Feb. 2011)

    ~6 kW (June, 2012)

    ~15 kW in 2012

    >30 kW in 2013

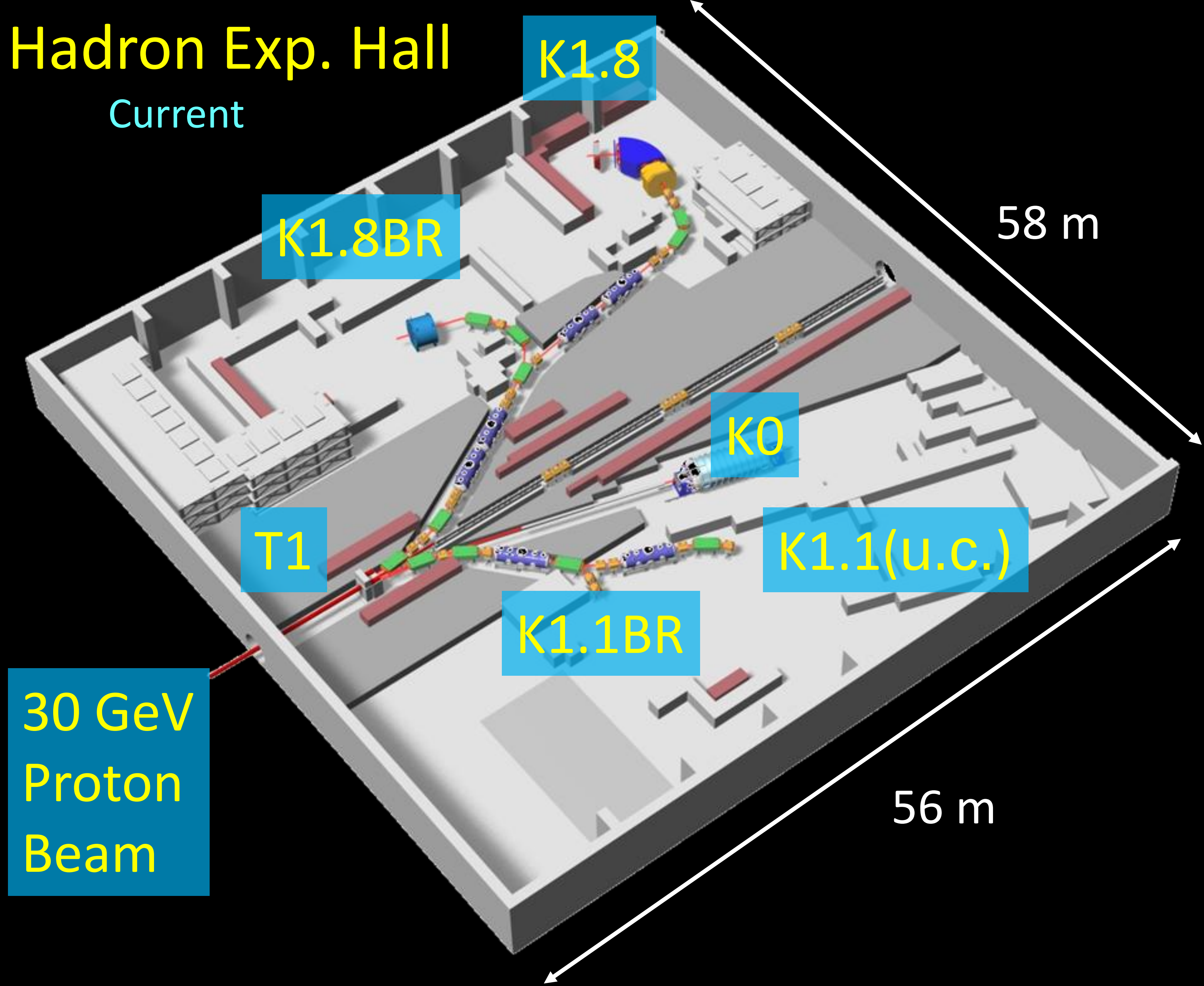
    ~100 kW

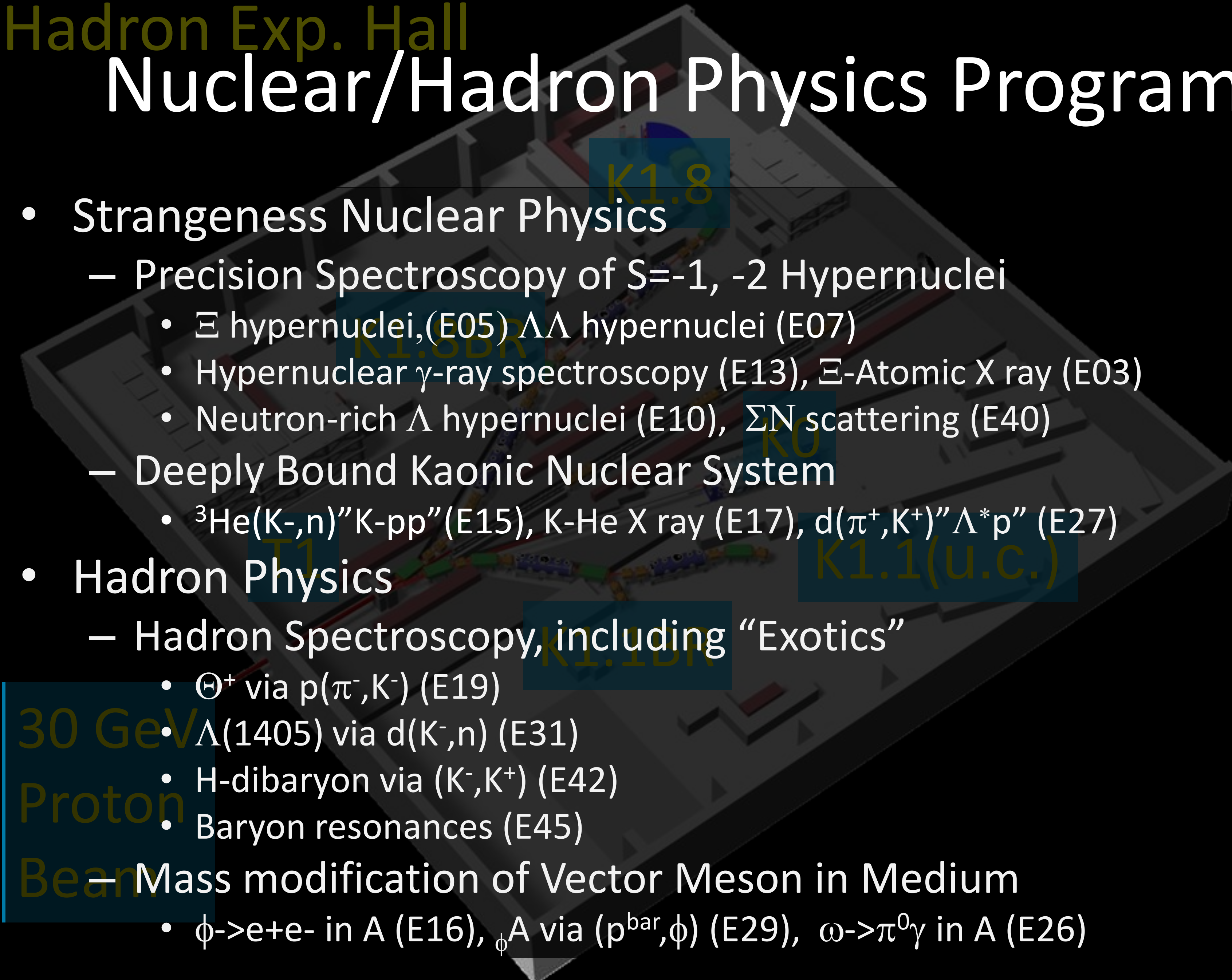
99.6% Extraction efficiency is achieved!
- The World Highest Score -

T1 accident at 24 kW

Hadron Exp. Hall

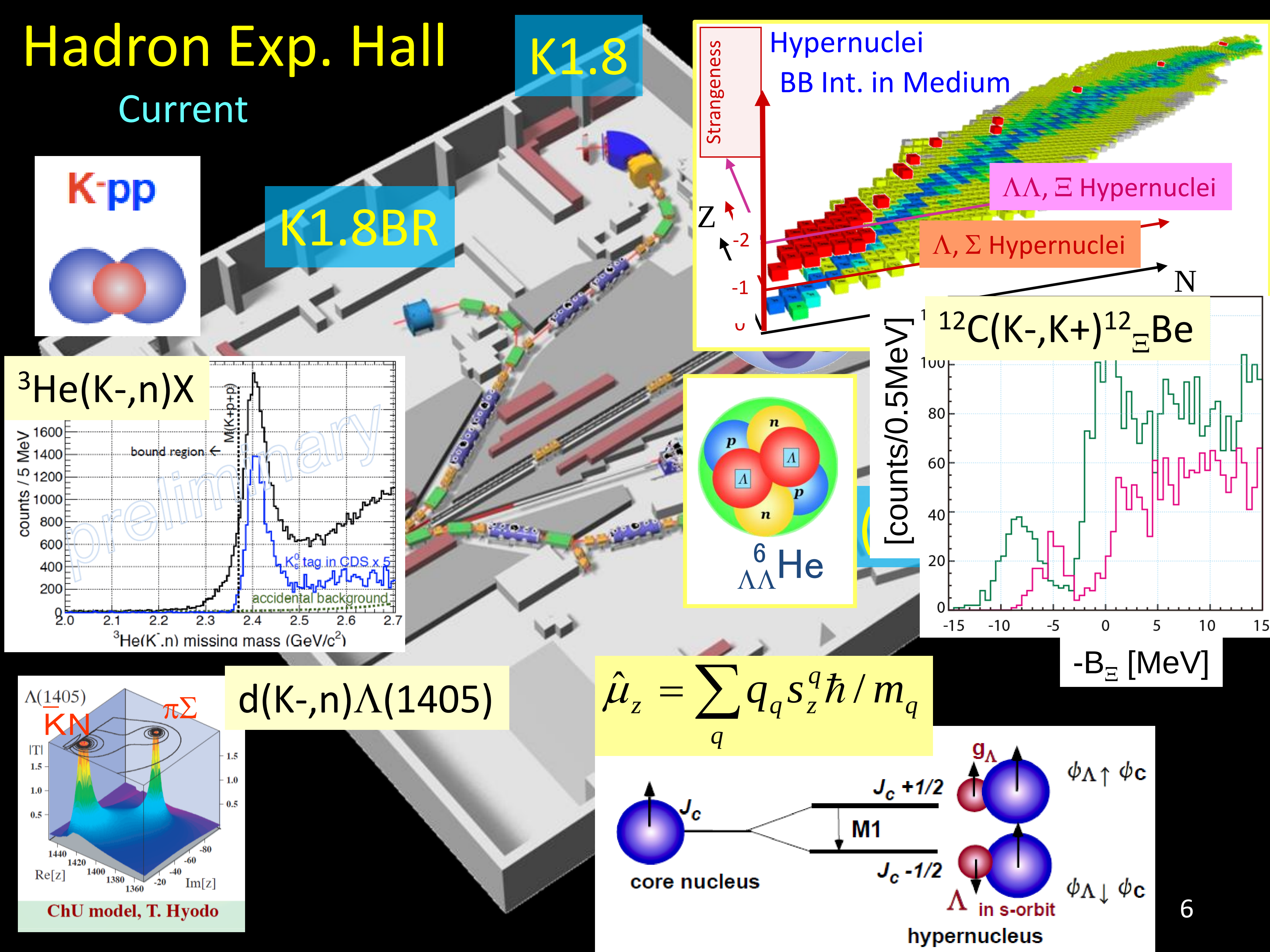
Current





Nuclear/Hadron Physics Programs

- Strangeness Nuclear Physics
  - Precision Spectroscopy of S=-1, -2 Hypernuclei
    - Ξ hypernuclei,(E05) $\Lambda\Lambda$ hypernuclei (E07)
    - Hypernuclear γ-ray spectroscopy (E13), Ξ-Atomic X ray (E03)
    - Neutron-rich Λ hypernuclei (E10), ΣN scattering (E40)
  - Deeply Bound Kaonic Nuclear System
    - ^{3}He(K-,n)"K-pp"(E15), K-He X ray (E17), d(π^+,K^+)"Λ^*p" (E27)
- Hadron Physics
  - Hadron Spectroscopy, including "Exotics"
    - Θ^+ via p(π^-,K^-) (E19)
    - Λ(1405) via d(K^-,n) (E31)
    - H-dibaryon via (K^-,K^+) (E42)
    - Baryon resonances (E45)
  - Mass modification of Vector Meson in Medium
    - ϕ->e+e- in A (E16), $_{\phi}$A via (p^{bar},ϕ) (E29), ω->$\pi^0\gamma$ in A (E26)

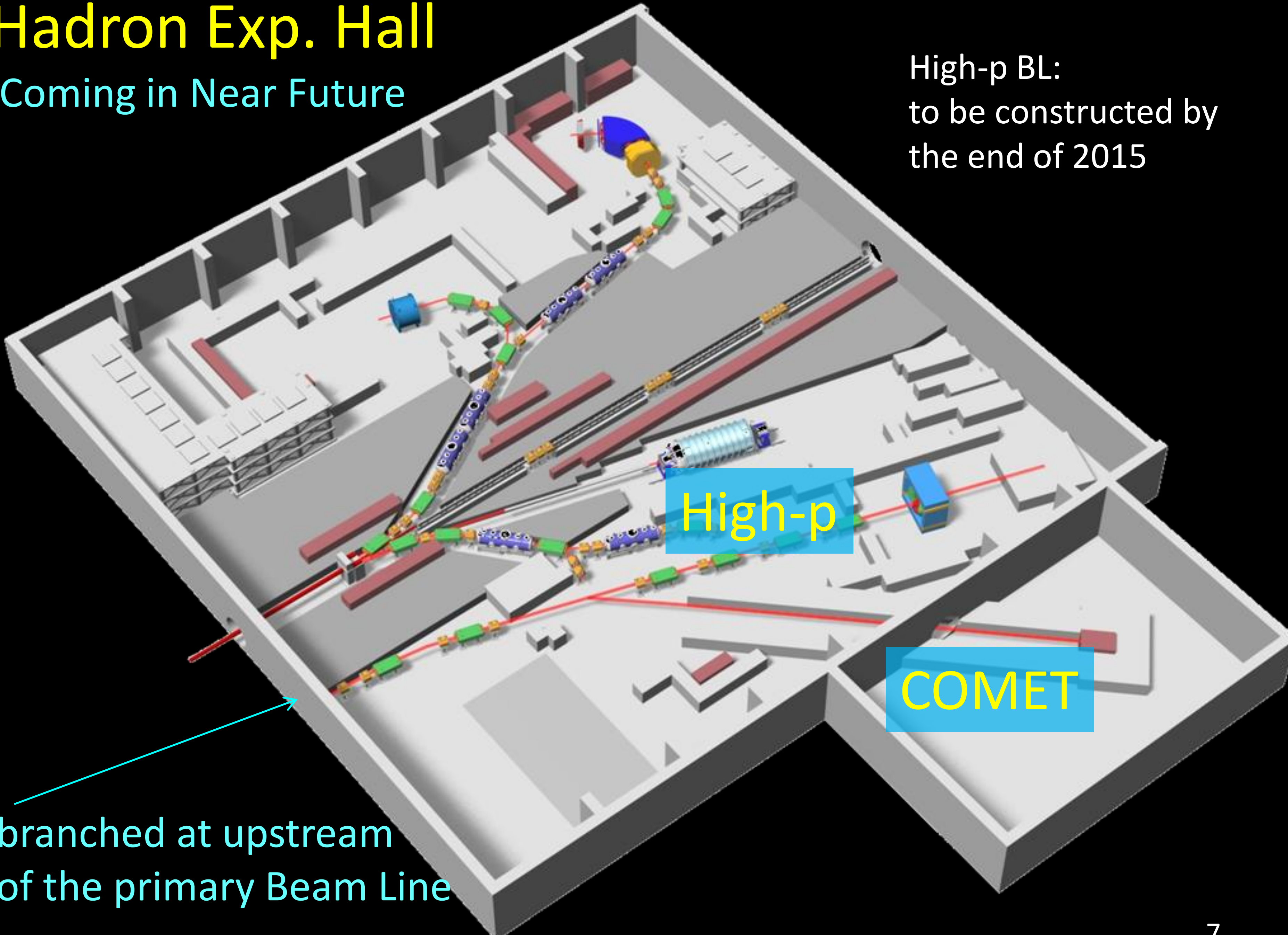


Hadron Exp. Hall
Current
K1.8
K1.8BR
K-pp
Hypernuclei
BB Int. in Medium
Strangeness
ΛΛ, Ξ Hypernuclei
Λ, Σ Hypernuclei
Z
N
-2
-1
$^{12}C(K-,K+)^{12}_{\Xi}Be$
[counts/0.5MeV]
-B$_{\Xi}$ [MeV]
$^{3}He(K-,n)X$
counts / 5 MeV
bound region
M(K+p+p)
preliminary
accidental background
$^{3}He(K^{-},n)$ missing mass (GeV/c^{2})
$^{6}_{\Lambda\Lambda}He$
d(K-,n)Λ(1405)
Λ(1405)
KN
πΣ
Re[z]
Im[z]
ChU model, T. Hyodo
$$\hat{\mu}_z = \sum_q q_q s_z^q \hbar / m_q$$
core nucleus
J_c
J_c +1/2
J_c -1/2
M1
g_Λ
Λ in s-orbit
hypernucleus
6

Hadron Exp. Hall

Coming in Near Future

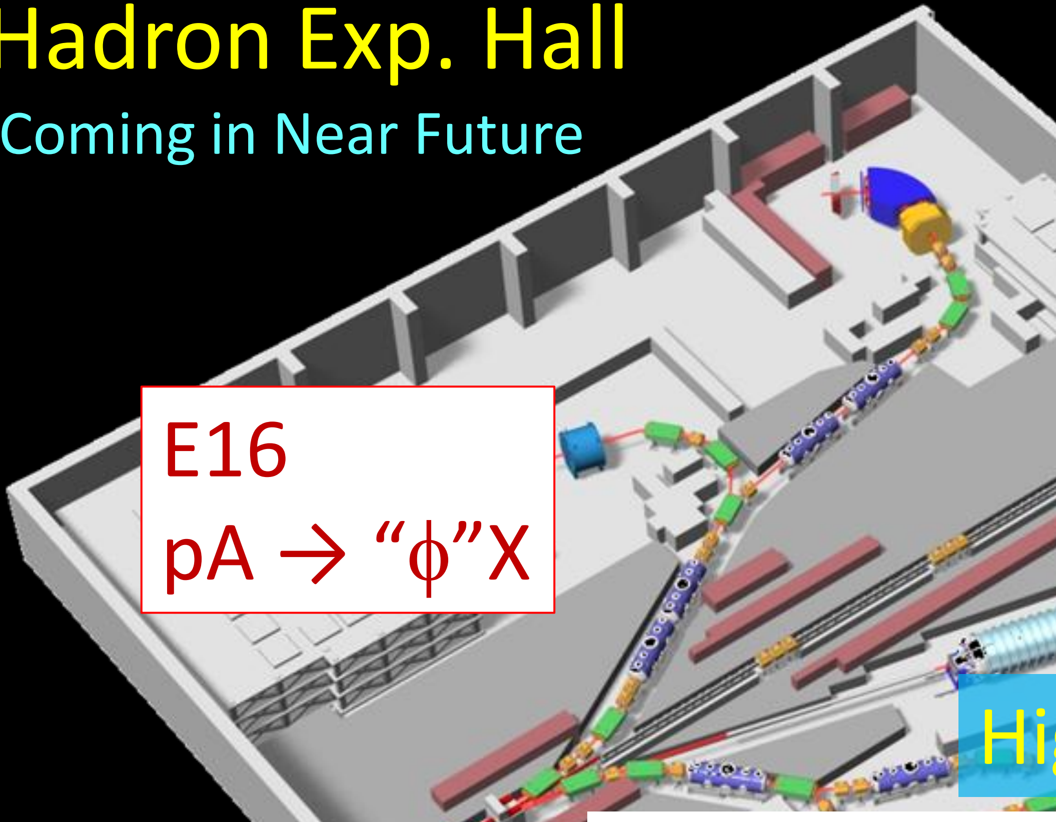
High-p BL:
to be constructed by
the end of 2015



branched at upstream
of the primary Beam Line

Hadron Exp. Hall

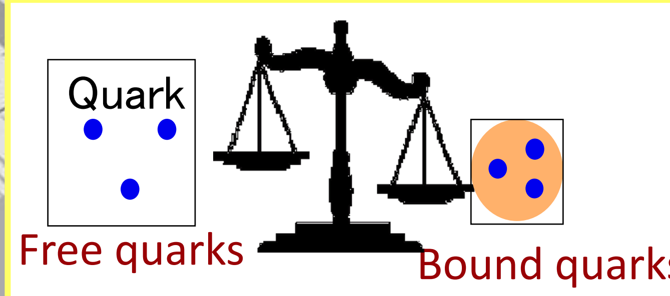
Coming in Near Future



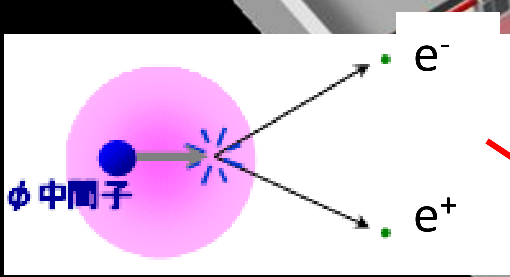
E16

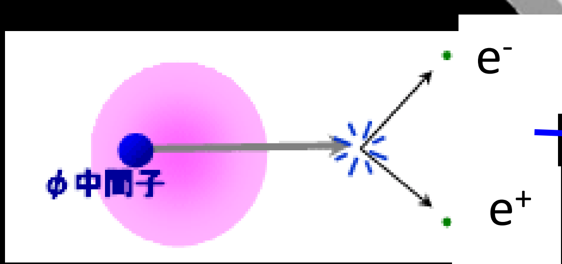
pA → "φ"X

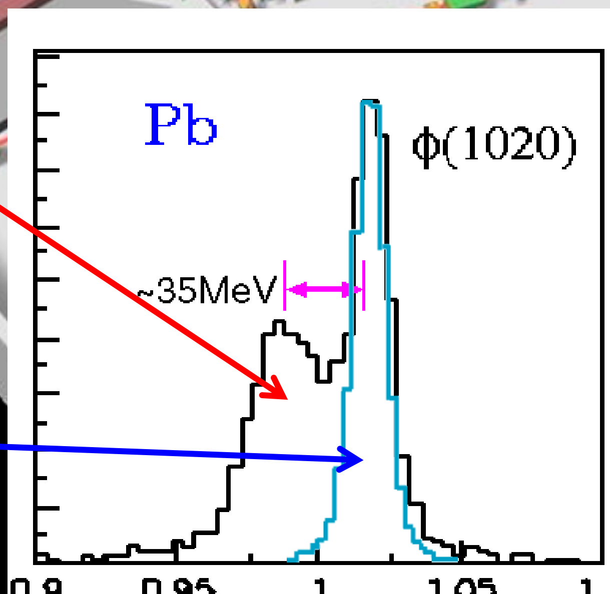
Origin of Mass

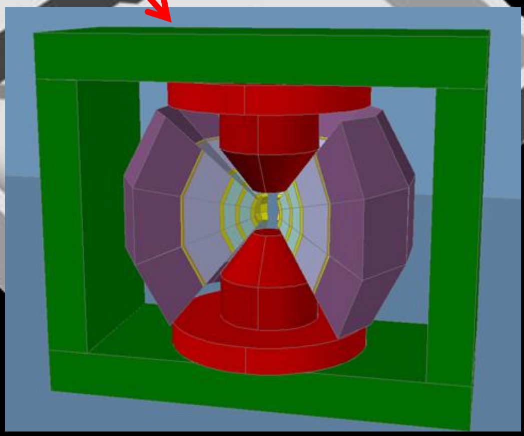


Why are bound quarks heavier？







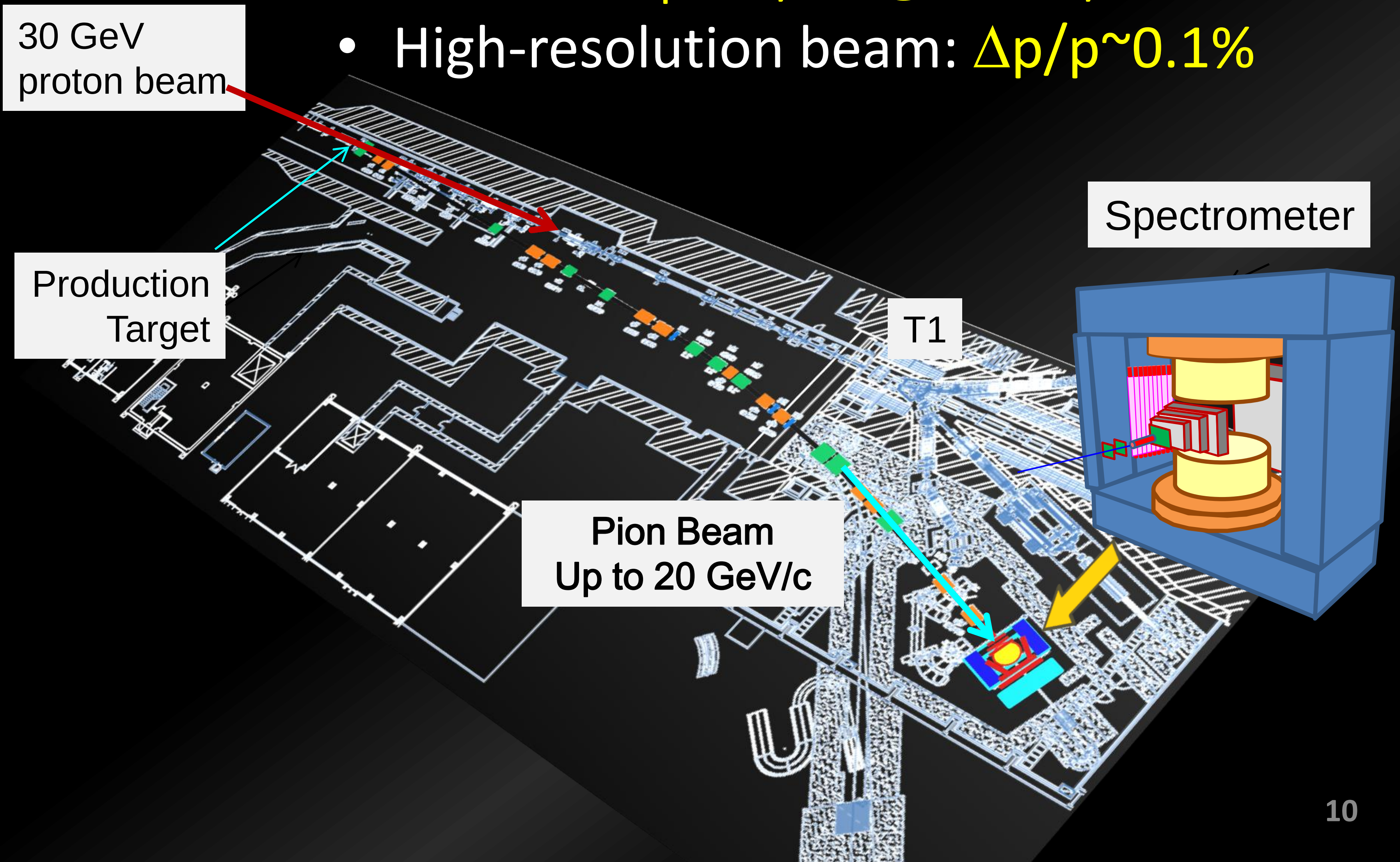


A New project
at the High-Momentum Beam Line

Charmed Baryon Spectroscopy

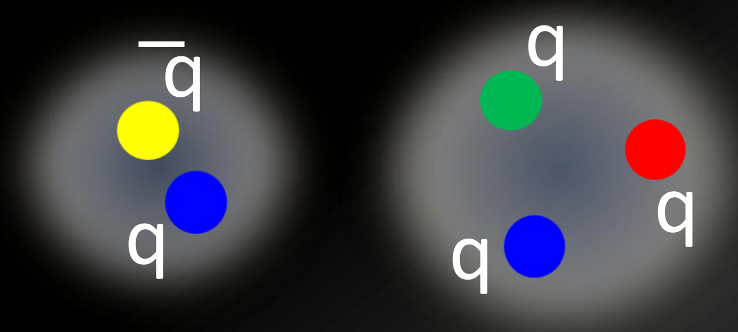
High-res., High-momentum Beam Line

- High-intensity secondary Pion beam
  - 1.0×10^7 pions/sec @ 20GeV/c
- High-resolution beam: $\Delta p/p \sim 0.1\%$



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

Constituent Quark



Hadron properties

– Classification based on Spin/flavor symmetry

– Mass Relations, Magnetic Moments

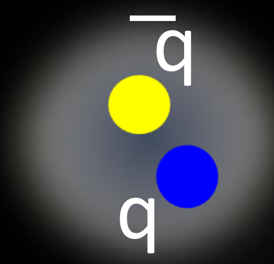
Failure in Resonant States

– Missing Resonances

– Exotics

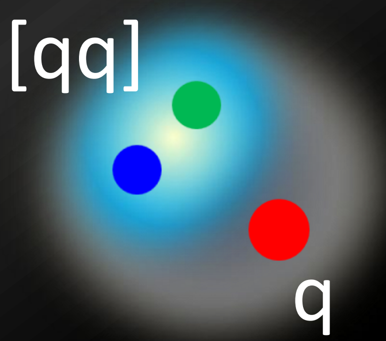
What are essential D.o.F. of baryons?

Constituent Quark

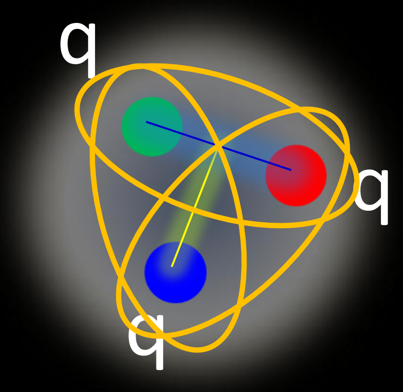


hadron (colorless cluster)

Diquark?
(Colored cluster)

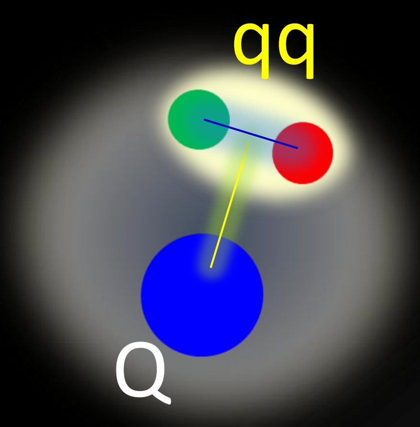


What are essential D.o.F. of baryons?



- Most fundamental question
- Interaction btwn quarks

Diquark correlations



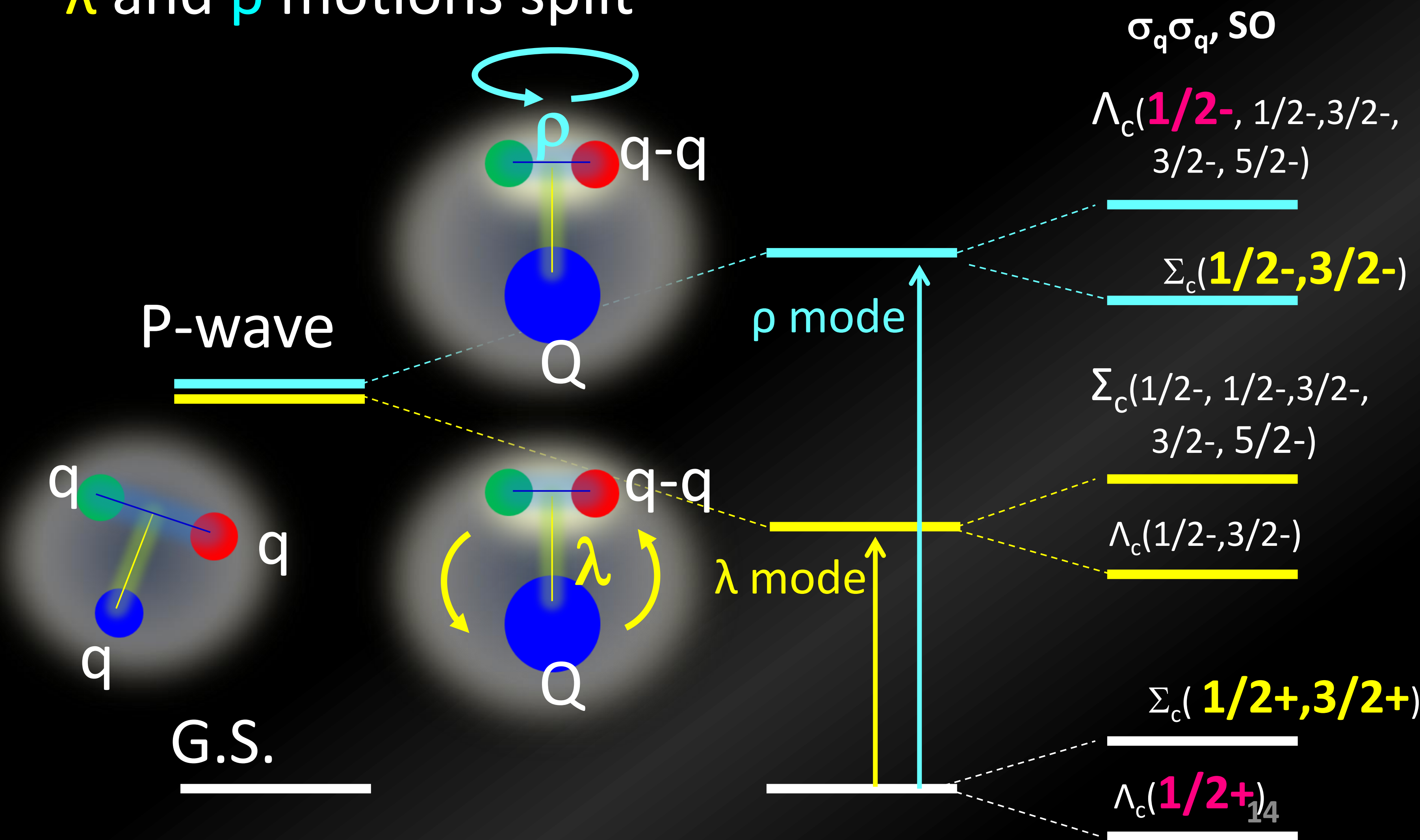
→ Charmed baryon

to close up diquark correlations

- Weak Color Magnetic Interaction with a heavy Quark

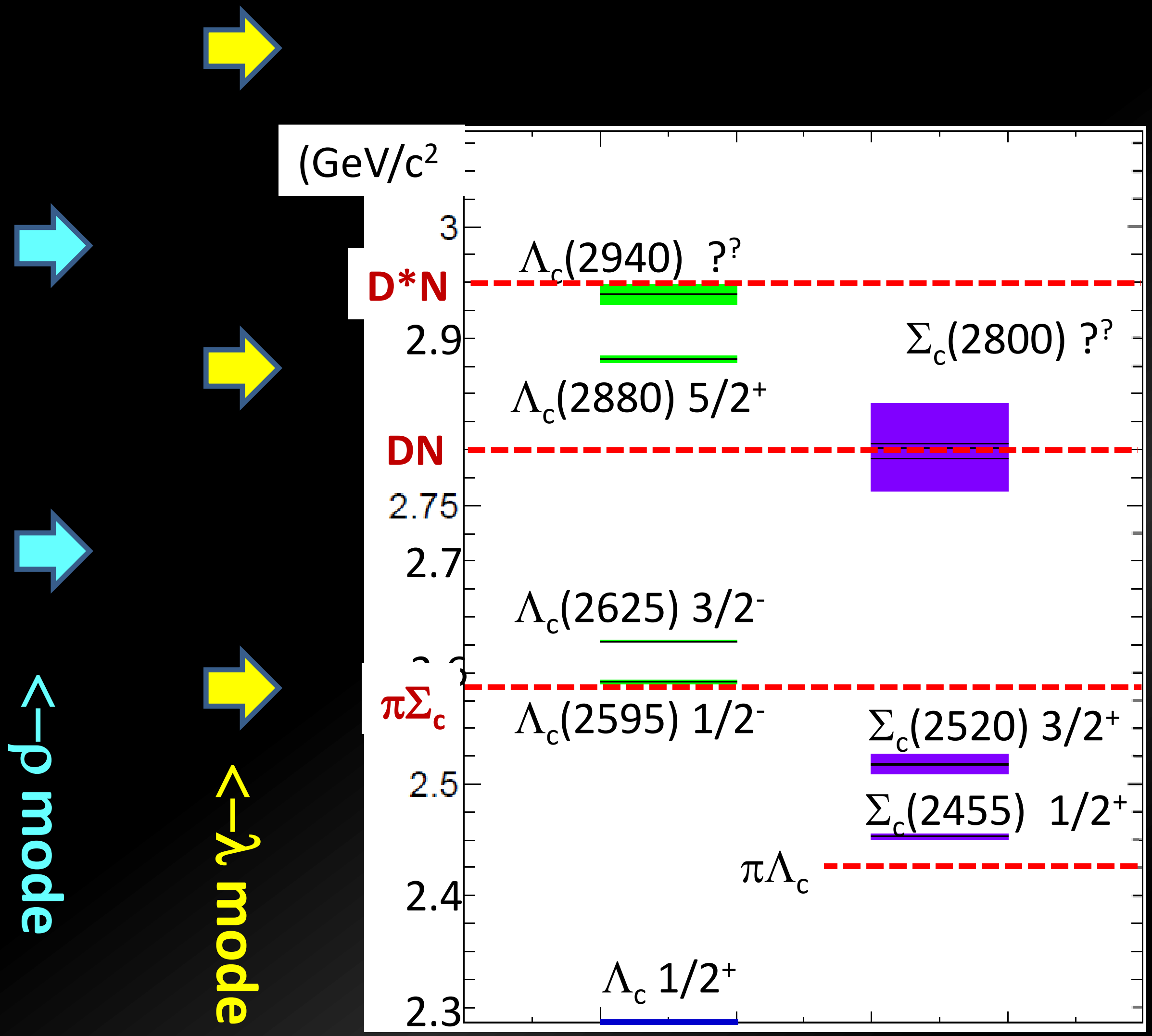
Level Structure of charmed baryons

- λ and ρ motions split

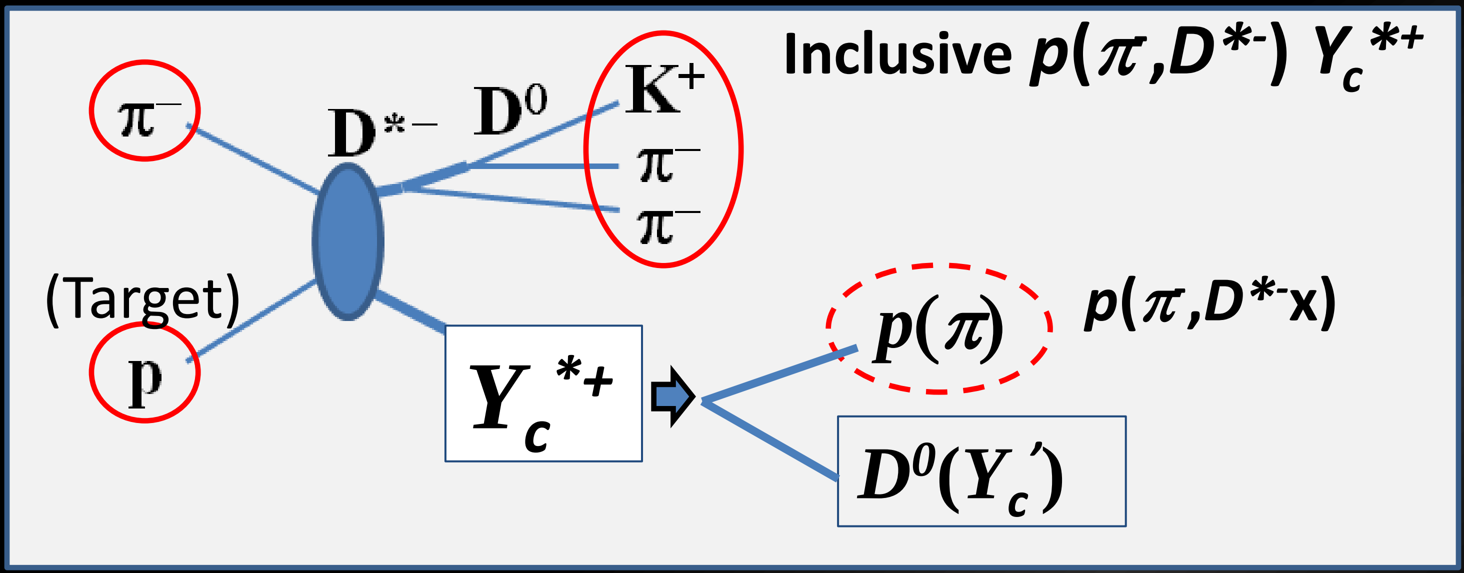


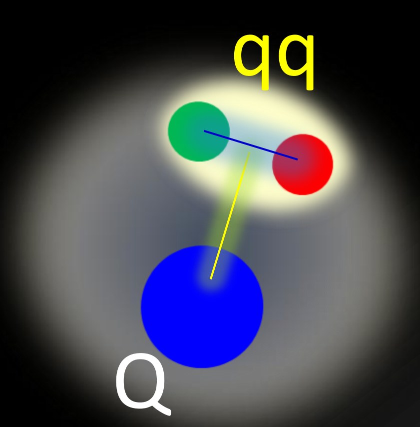
- chiral partners of “qq” states appear.

Limited # of Charmed Baryons have been observed.



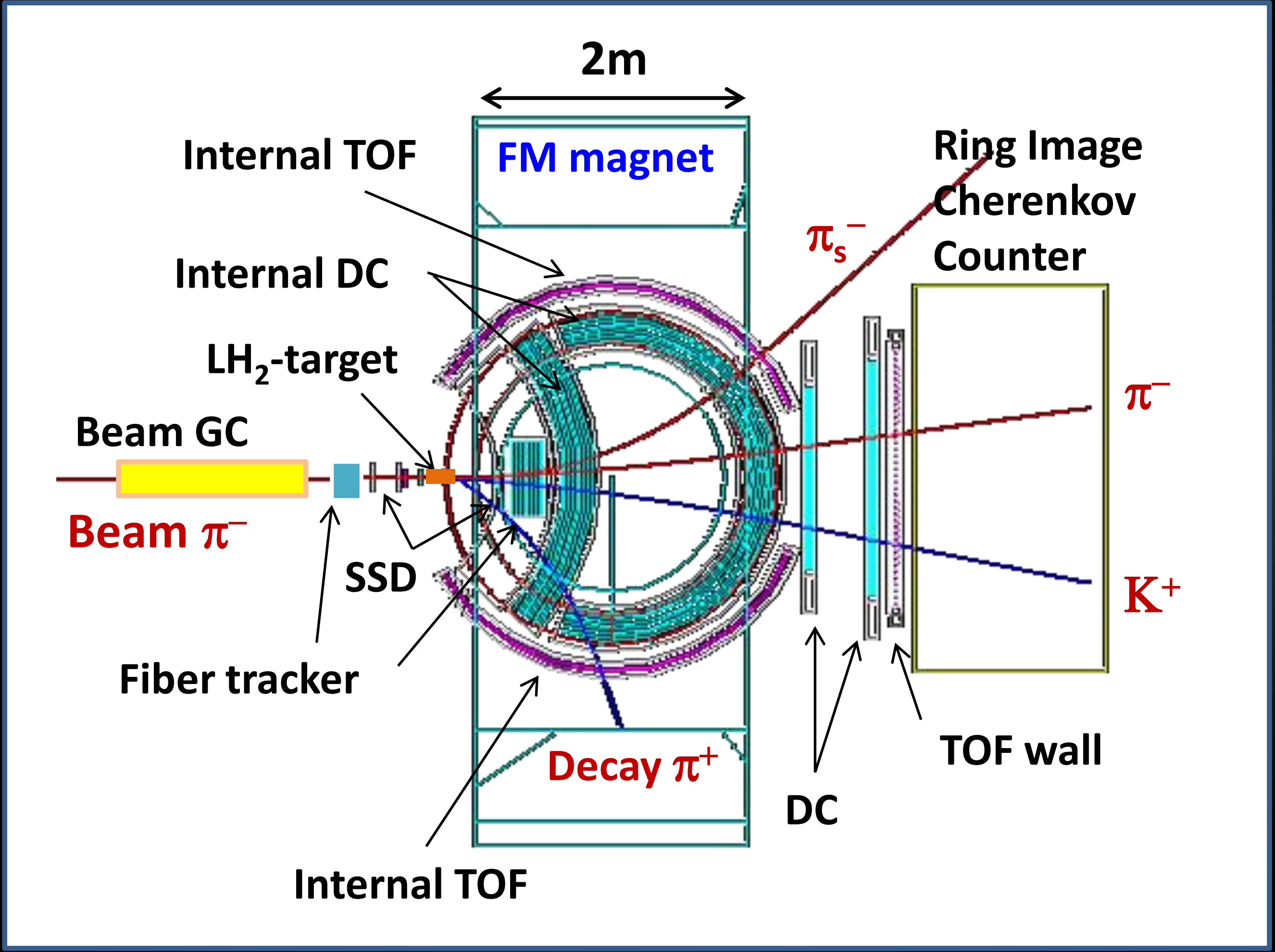
Charmed Baryon Spectroscopy Using Missing Mass Techniques





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

Charmed Baryon Spectrometer

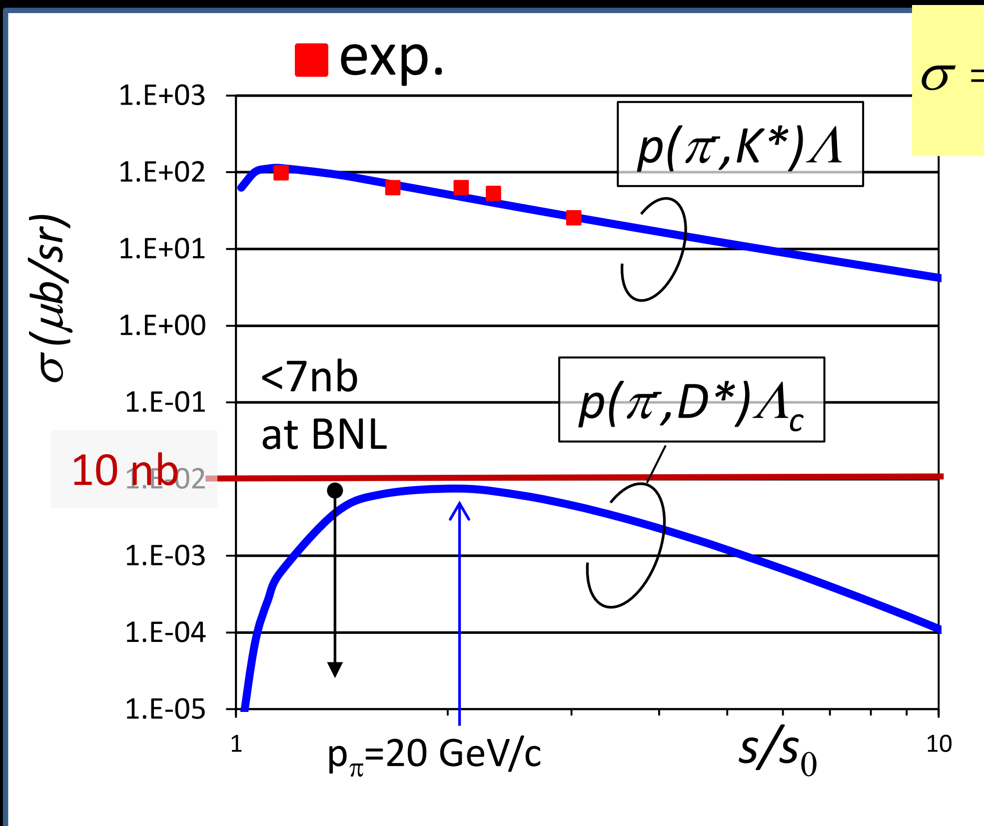


Large acceptance ~ 60% (for D^*), $\Delta p/p$~0.2% at ~5 GeV/c

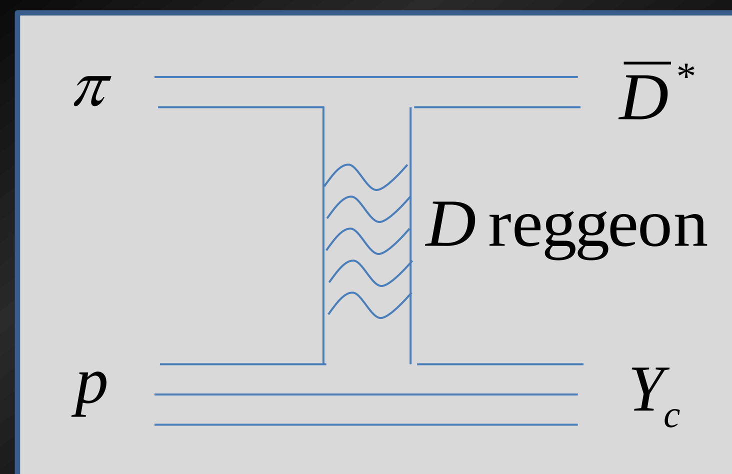
Production Cross Section

- 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



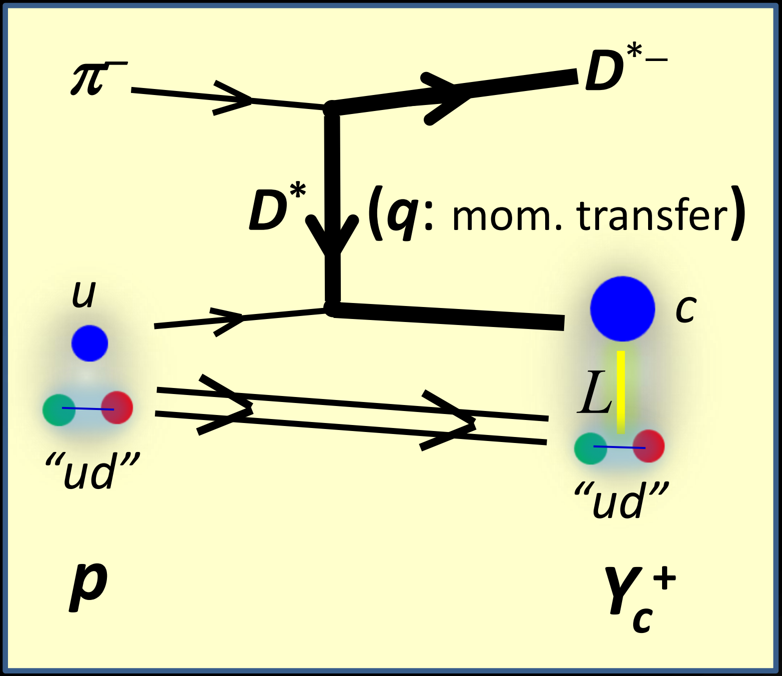
$$\sigma = \int \frac{1}{64\pi s(p_\pi^{cm})^2} \exp(2R^2 t)(s/s_0)^{2\alpha(t)}\, dt$$



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})

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

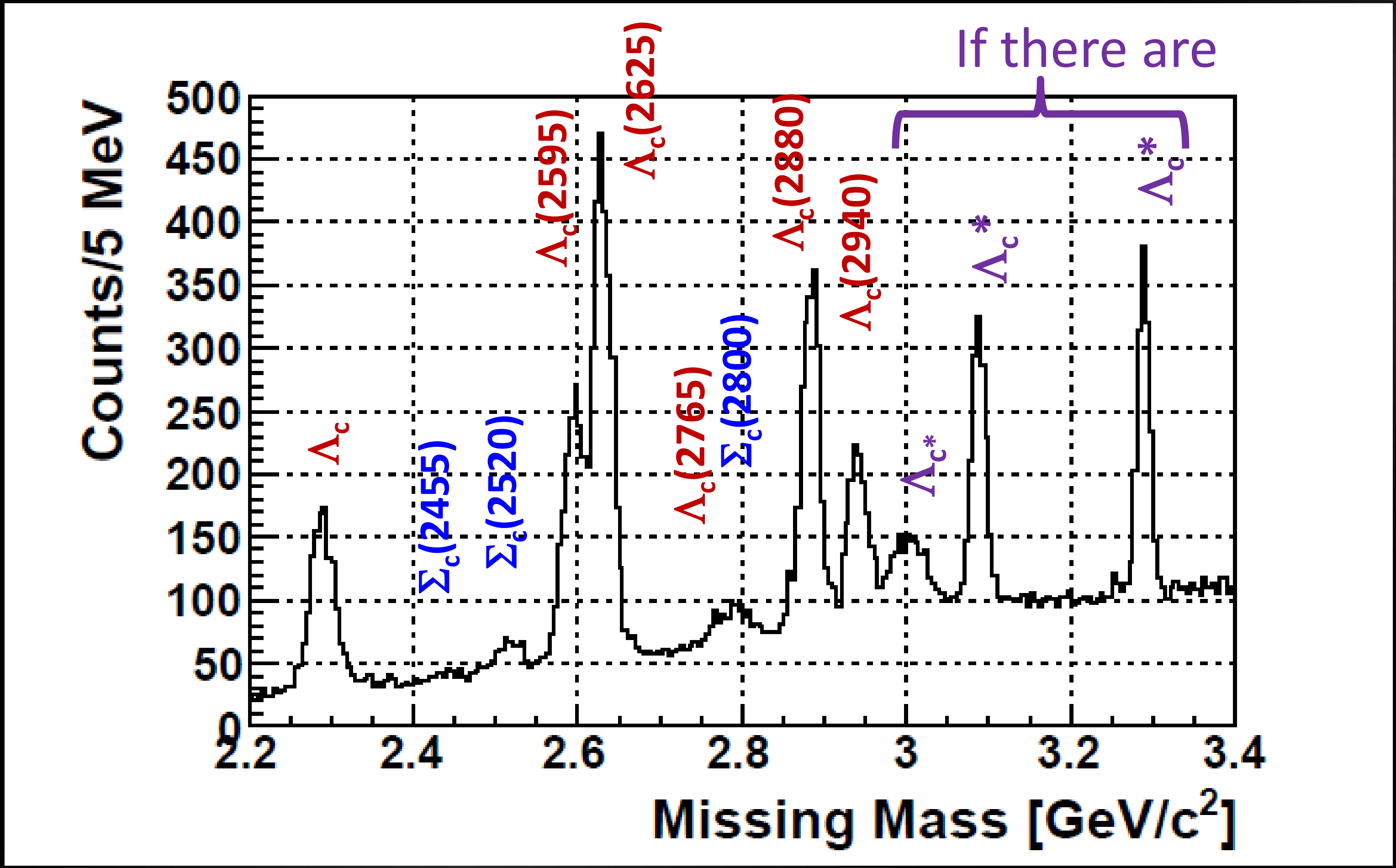
A: (baryon size parameter)$^{-1}$

Calculated production rates

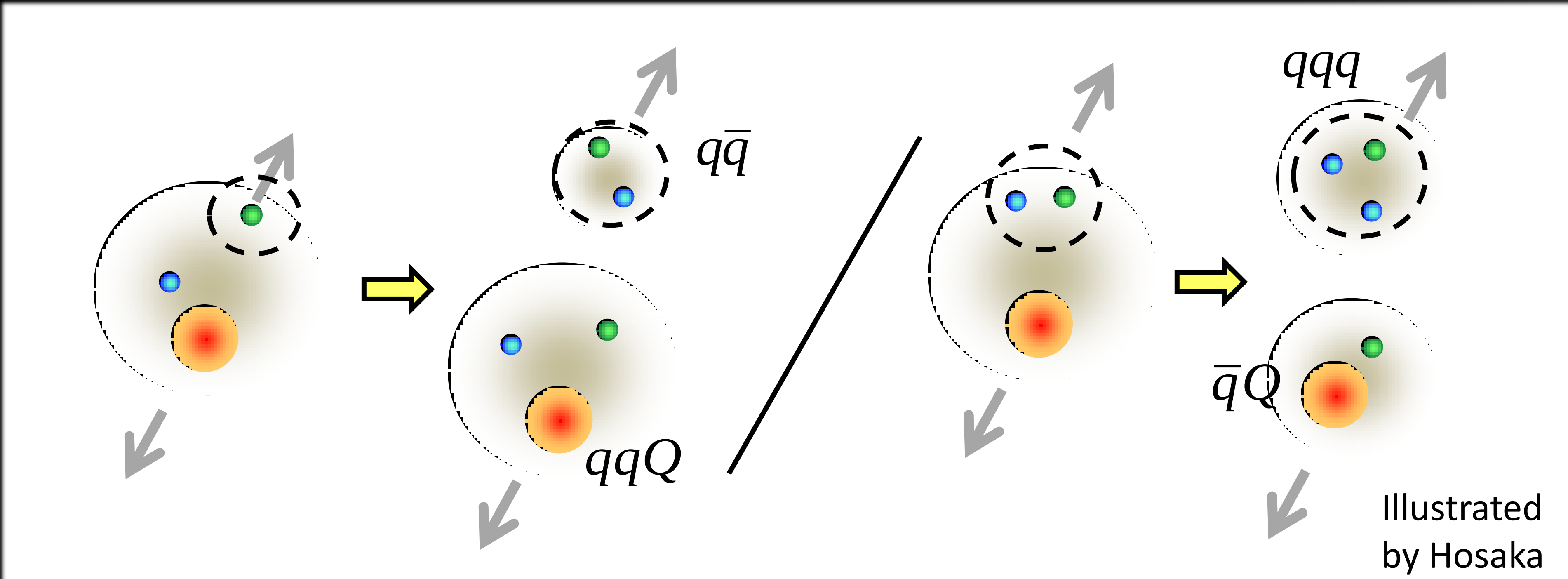
	p_π=20 GeV/c	Mass (GeV/c)	"ud" isospin factor	Y_c^* Spin factor	q_{eff} (GeV/c)	Rate (Relative)
L=0	$\Lambda_c^{1/2+}$	2286	1/2	1	1.33	1
	$\Sigma_c^{1/2+}$	2455	1/6	1/9	1.43	0.03
	$\Sigma_c^{3/2+}$	2520	1/6	8/9	1.44	0.20
L=1	$\Lambda_c^{1/2-}$	2595	1/2	1/3	1.37	1.17
	$\Lambda_c^{3/2-}$	2625	1/2	2/3	1.38	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)



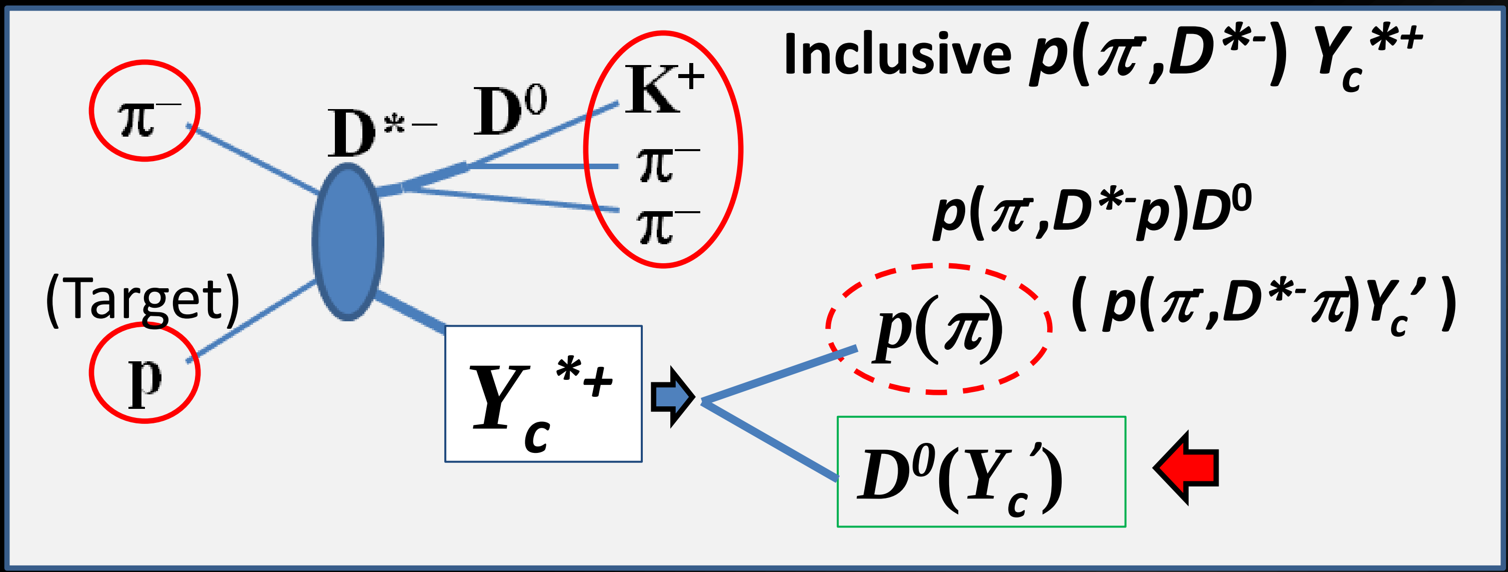
Structure and Decay Partial Width



ρ mode (qq) λ mode [qq]

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

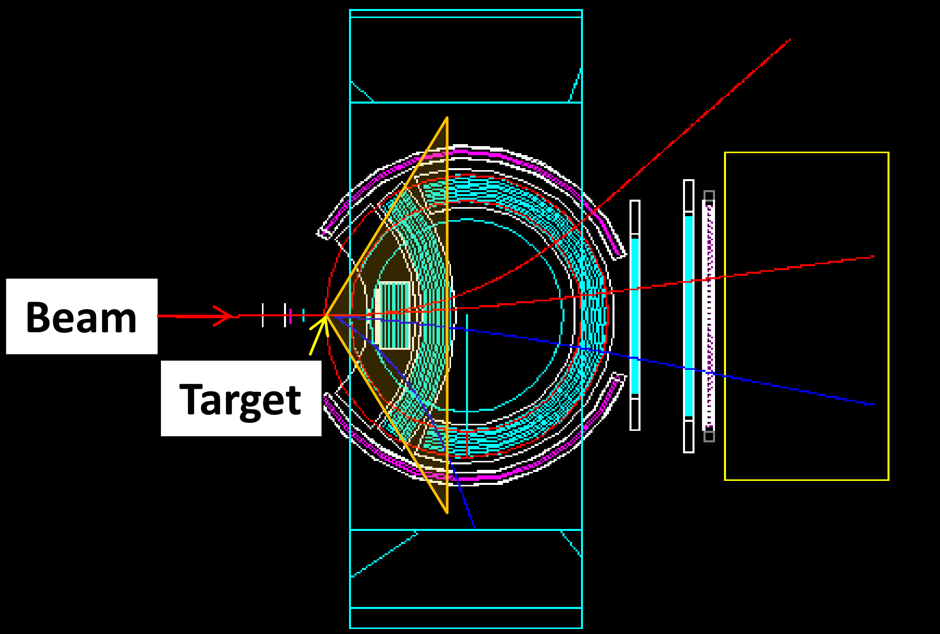
Decay Products



* Decay products can be measured by means of missing mass tech..

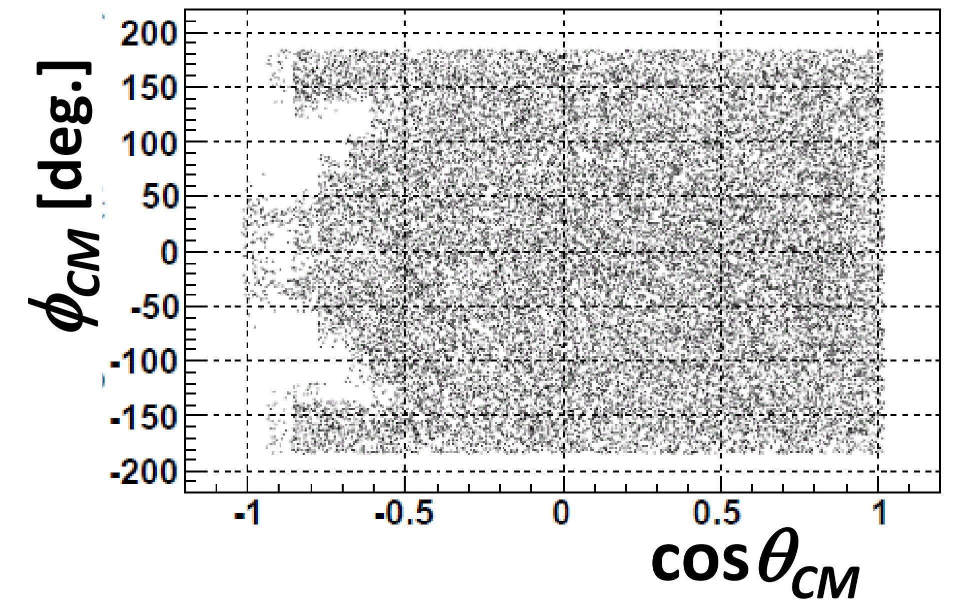
Acceptance for decay particles: ~85 %

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



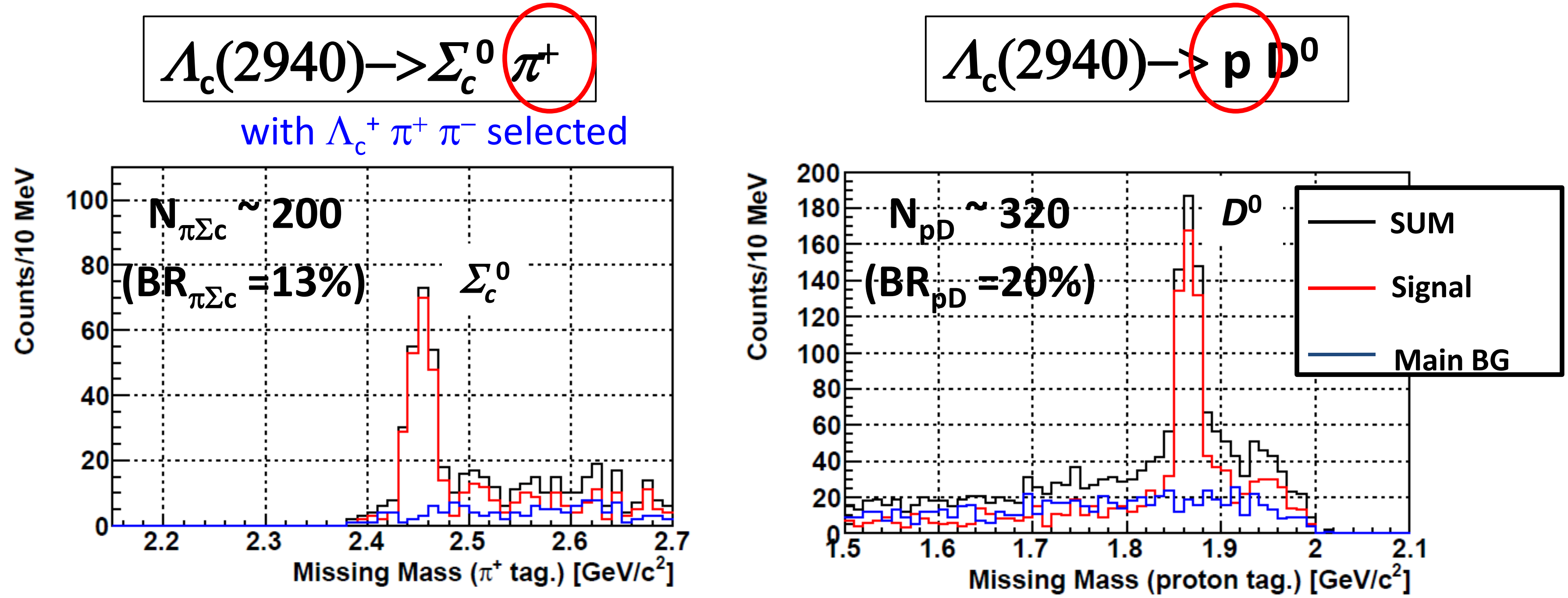
Coverage for decay π

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



* Decay products can be measured efficiently.

Decay Products



* Decay meas. strongly assists the missing mass spectroscopy.

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

Summary

- J-PARC Hadron Facility provides opportunities to study Hadron and Nulcear Physics.
- Upgrade plans of the Hadron Facility:
  - A high-momentum beam line is under construction.
  - Extension of the Hadron Hall is planning.
- A project of charmed baryon spectroscopy via the (π^- ,D^{*-}) reaction:
  - Systematic studies on charmed baryon spectrum, production rate, and decays provide information on quark-quark dynamics in baryons.

Backup

Hadron Exp. Hall

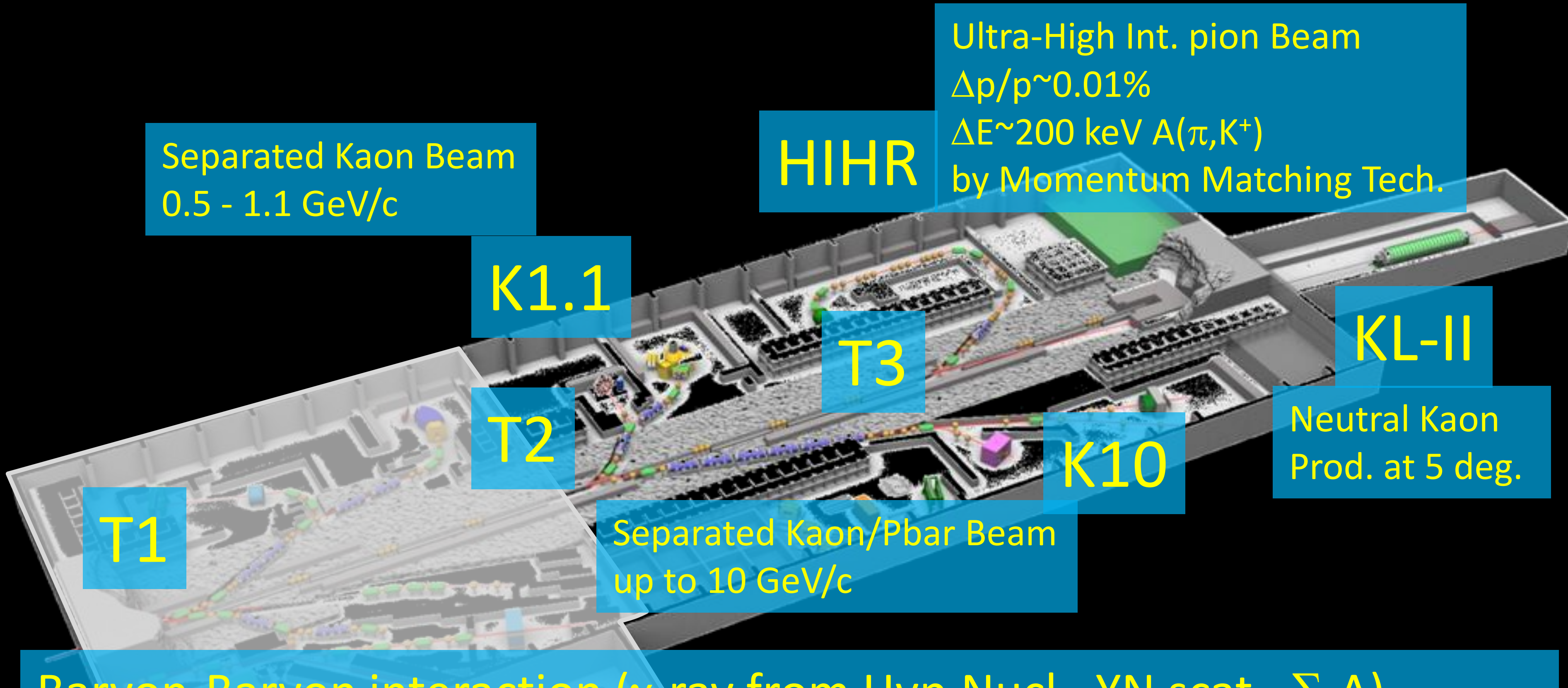
	K1.8	K1.8BR	K1.1	K1.1BR	KL
Design					
Max. p (GeV/c)	2.0	1.1	1.1	1.1	~2 (#) (0~5)
Prod. angle	-6 deg.	-6 deg.	+6 deg.	+6 deg.	+16 deg.
Length	45.8 m	31.4 m	27.9 m	21.5 m	20.6 m
Acceptance	1.5 msr・%	2.0 msr・%	1 msr*%	5.0 msr・%	7.8 μsr
Separator Max. Field	6 m x 2 80 kV/cm	6m x 1 80 kV/cm	2 m x 2 50 kV/cm	2 m x 1 50 kV/cm	-
Measured performance	ES1:50kV/cm ES2:40kV/cm	ES1:50kV/cm	Under Const'n	ES1:40kV/cm	
Kaon Intensity $/10^{14}$ proton on Pt 6cm	K- (1.8GeV/c) 1.3E+6 ($)	K- (1GeV/c) 8.1E+5	-	K+ (1 GeV/c) 1.6E+6	KL: 2.1E+7
K/all	0.15	0.23	-	0.47	

($) Mass Slits was closed about half of designed.

(#) typical mean value

Extension of Hadron Exp. Hall (in planning)

increase of new physics opportunities w/ unique beam lines



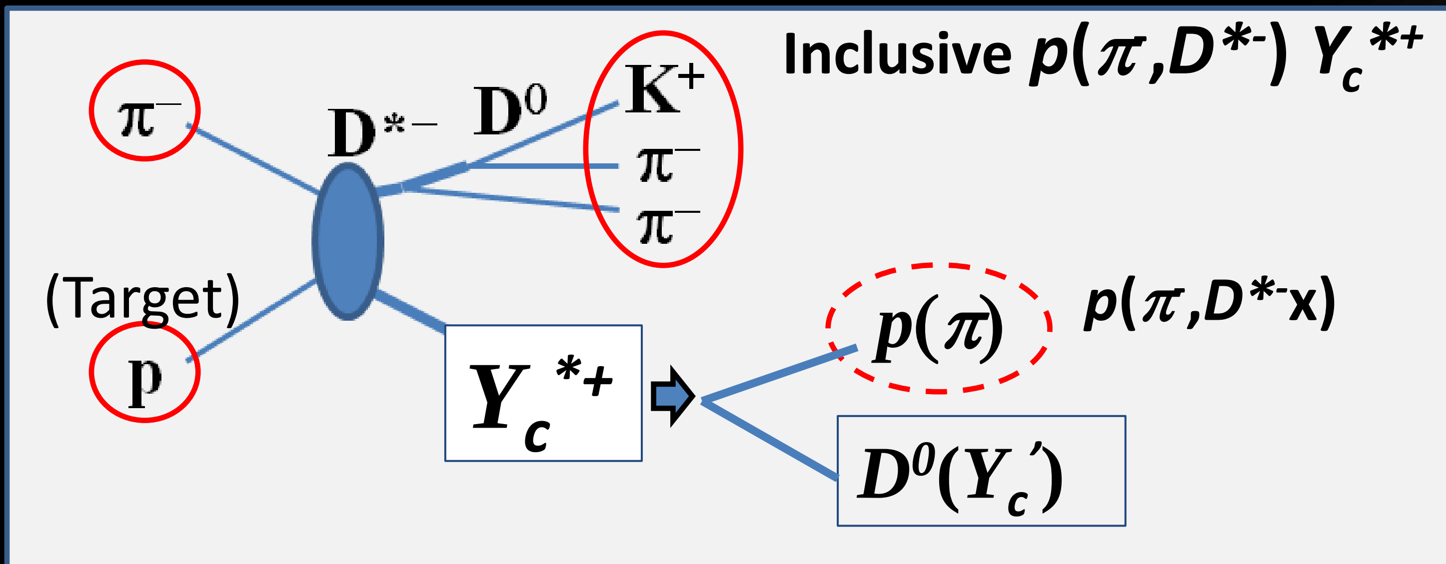
Baryon-Baryon interaction (γ-ray from Hyp.Nucl., YN scat., Σ-A)
Hadron Property in Nuclear Medium (Λ Mag. Moment in A)
Quark-Gluon Dynamics in Hadron/Medium (Ξ^*, Ω^*, Exotics, D off A)
Mechanism of Dynamical mass generation (σ, ϕ, η', J/ψ, multi-K in A)

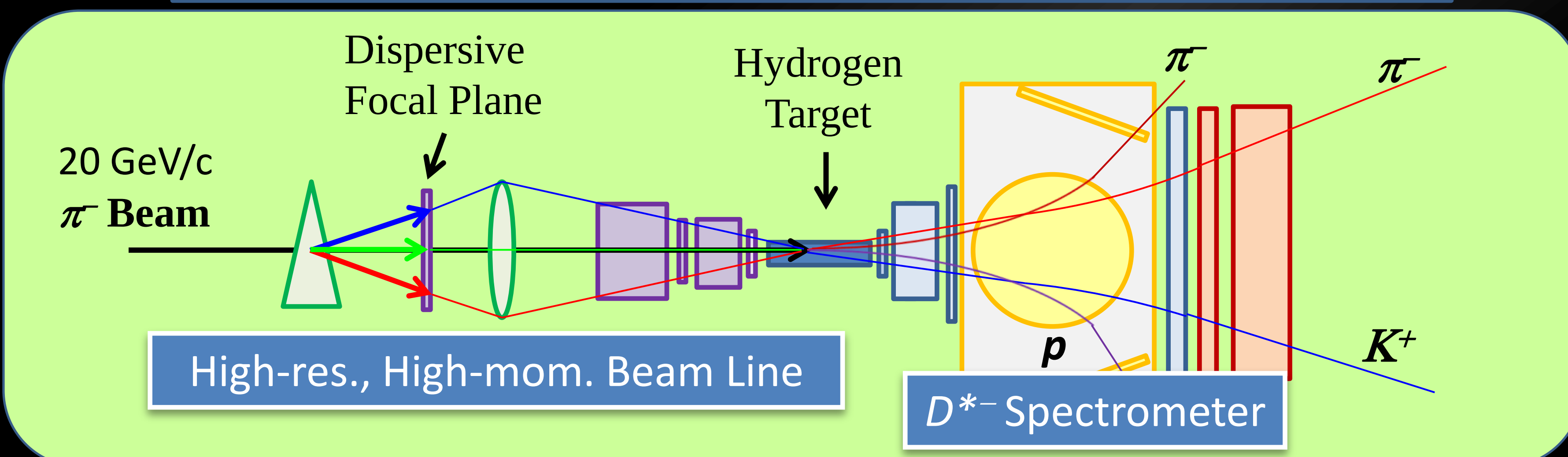
Summary

We have clarified the following features:

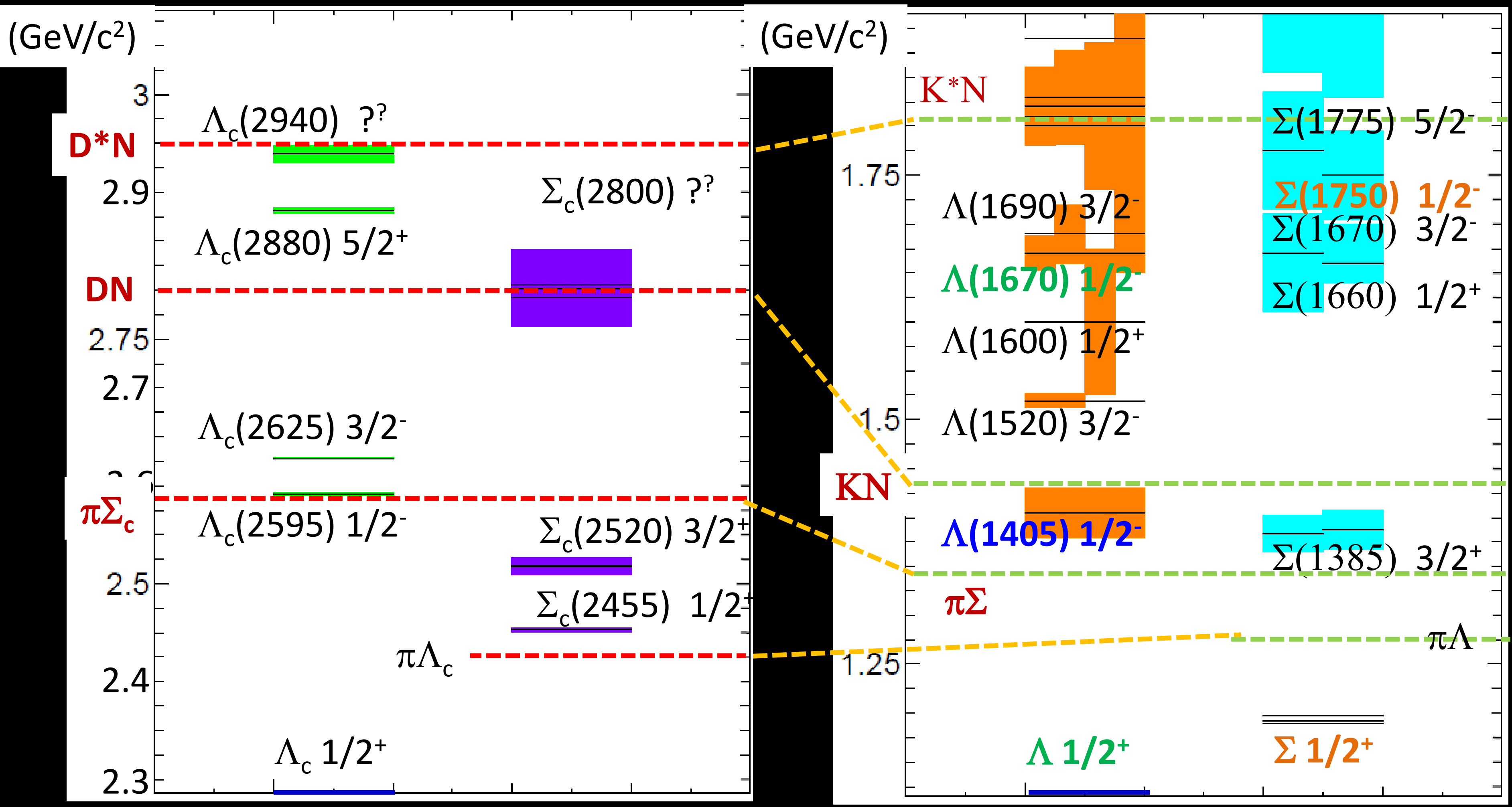
1. Signals
   - $\sigma(p(\pi^{-},D^{*-})\Lambda_c)$ ~ a few nb seems plausible.
   - Higher *L* states are abundantly produced.
2. Background
   - The background level is well reproduced by JAM.
   - Background reduction is studied
   - Signal sensitivity of 0.1 nb for Γ~100 MeV is achieved.

Charmed Baryon Spectroscopy Using Missing Mass Techniques





Baryon Spectra upto ~1 GeV Excitation Energy



- Difference and Similarity in s- and c-sector are of interest

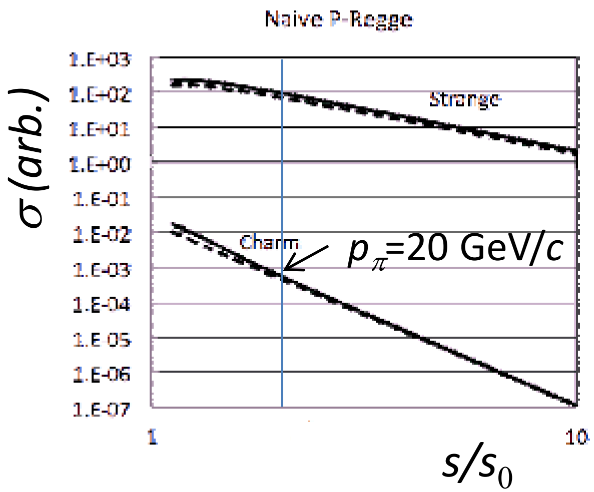
Estimation of cross sections

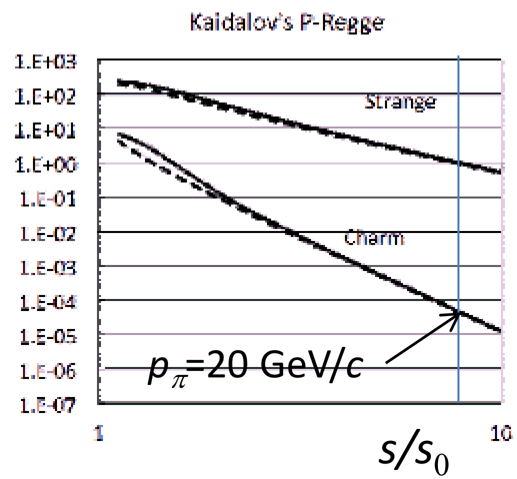
- Experiment
  - $\sigma(\pi p \rightarrow D^* \Lambda_c) < 7$ nb at $p_\pi = 13$ GeV/c [BNL, '85]
  - $\sigma(\pi N \rightarrow J/\psi X) = (3 \pm 0.6)$ nb at $p_\pi = 22$ GeV/c [BNL, '79]
  - $\sigma(\gamma p \rightarrow \Lambda_c D^{bar} X) = (44 \pm 7^{+11}_{-8})$ nb at $E_\gamma = 20$ GeV [SLAC, '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

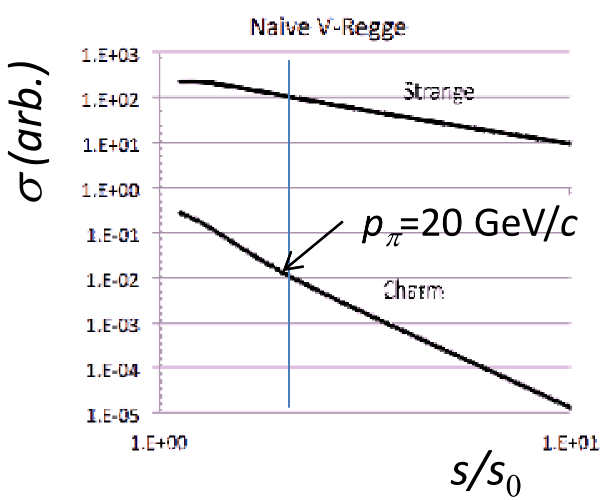
calculated by A. Hosaka

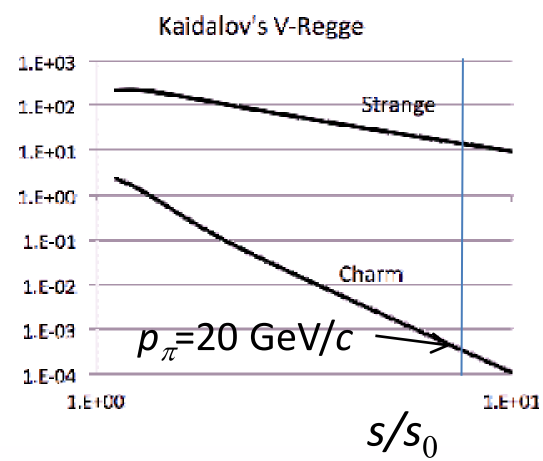
Regge Theory

- PS(*K*,*D*)-Regge (Top): s/c-prod: ~10^{-5}(Naïve), ~3x10^{-5}(Kaidalov)
- V(*K**,*D**)-Regge (Bottom): s/c-prod.: ~10^{-4}(Naïve), ~3x10^{-5}(Kaidalov)









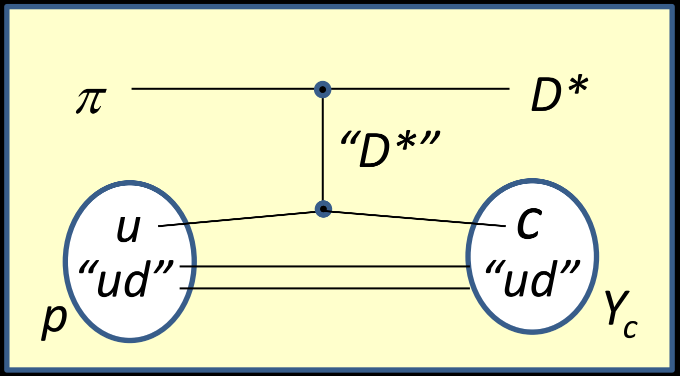
Scale Parameter

	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

Production Rate



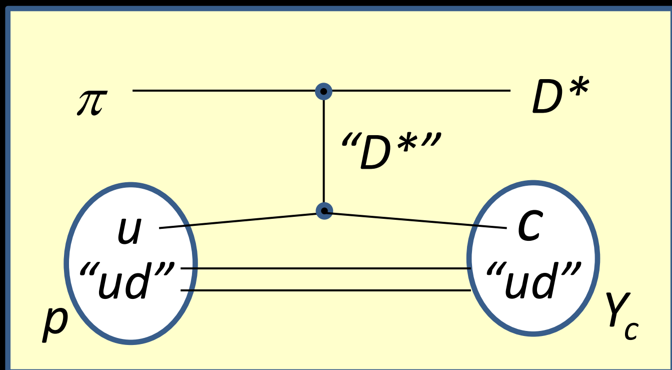
- t-channel D* EX at a forward angle
- quark-diquark picture

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

kinematic factor × 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.

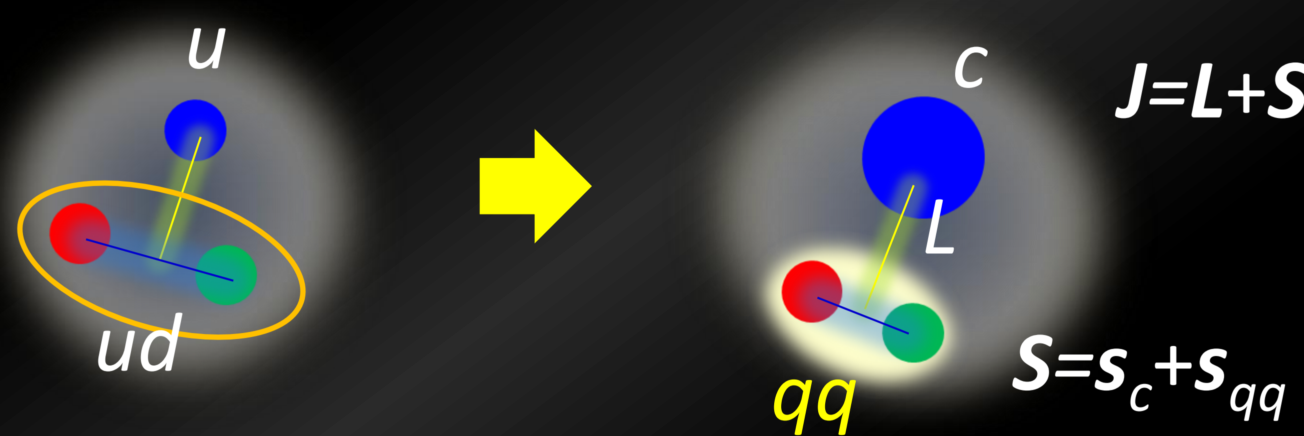


$$R \sim \gamma C \,|\, K \cdot I \,|^2 \; p_B$$

$$\gamma = \begin{cases} 1/2 \text{ for } [\text{ud}] : {}^1\text{S}_0,\, I = 0 \\ 1/6 \text{ for } (\text{ud}) : {}^3\text{S}_1,\, I = 1 \end{cases}$$

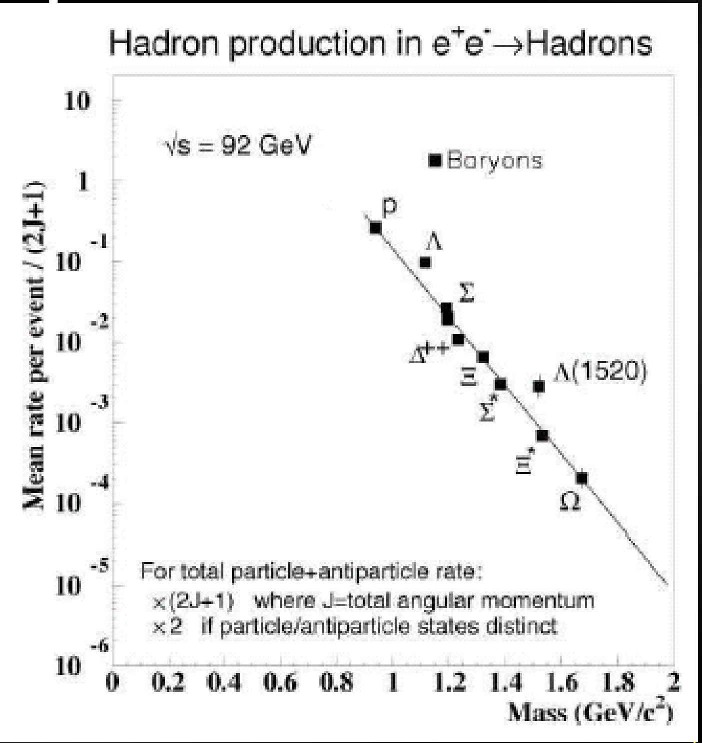
$$C = \left\langle [\varphi_{nL}, \chi^M]^J_{-1/2} \middle| \sqrt{2}\sigma_- \middle| \varphi_{000}\, \chi^\rho_{+1/2} \right\rangle$$

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



The production rates 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	
$\Sigma_c^{1/2-}$	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	

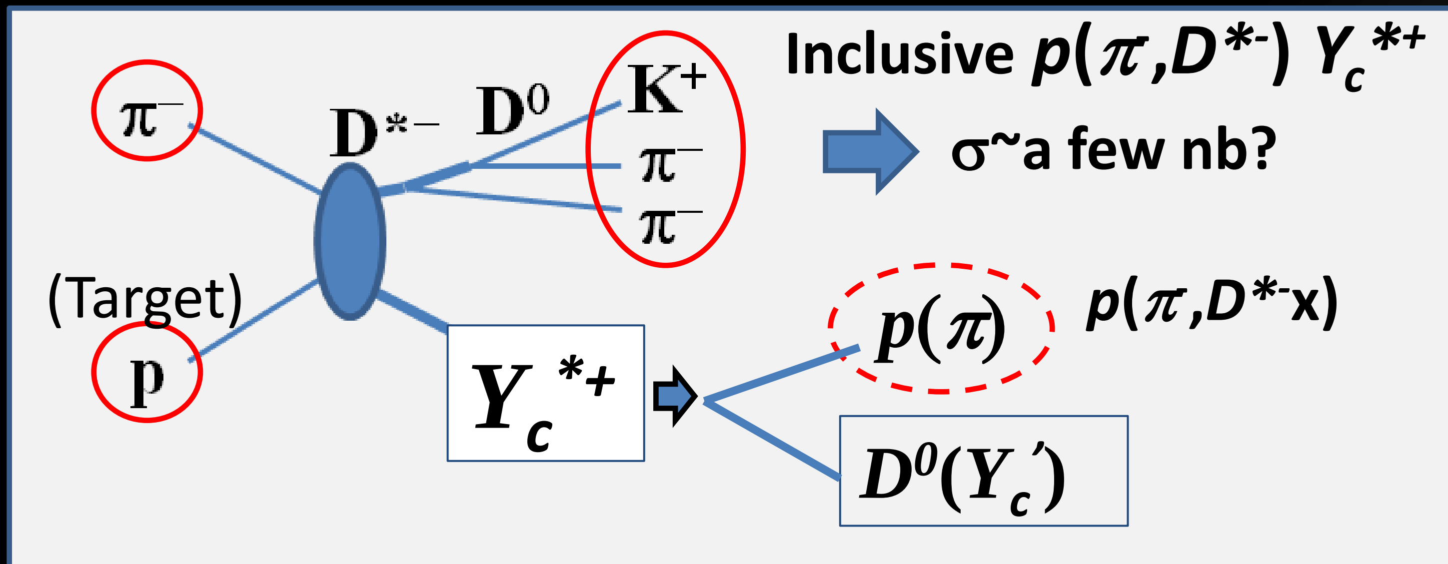


No reduction at higher *L* states, depending on spin/isospin configuration of Quark-Diquark in Y_c.

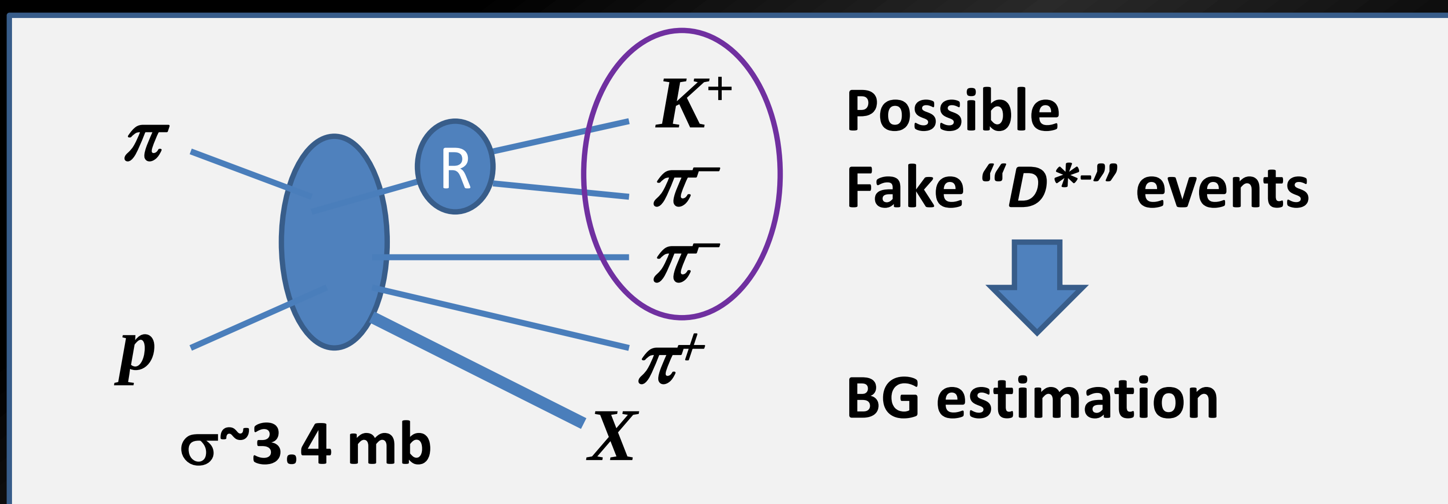
Calculated by A. Hosaka

Charmed Baryon Spectroscopy Using Missing Mass Techniques

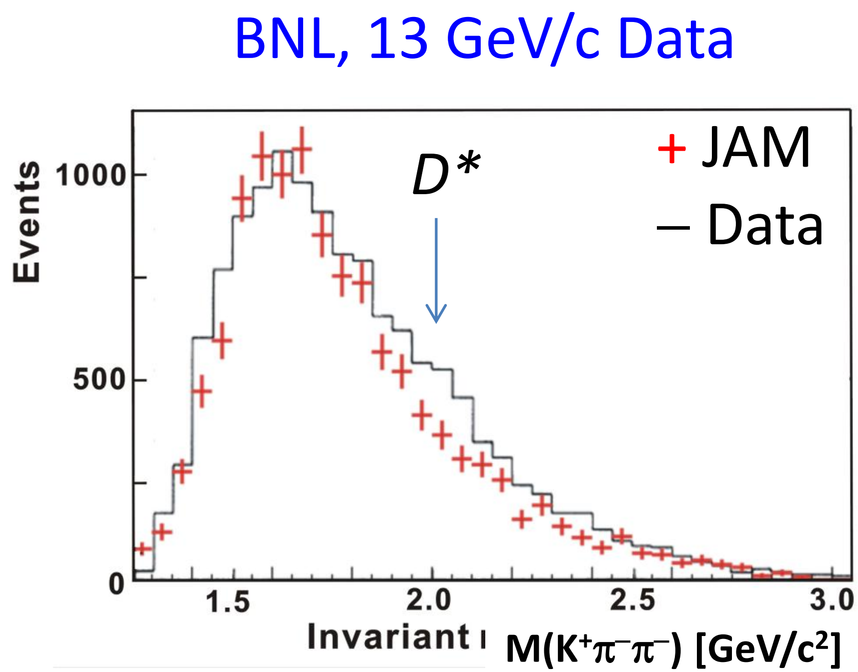
Signal

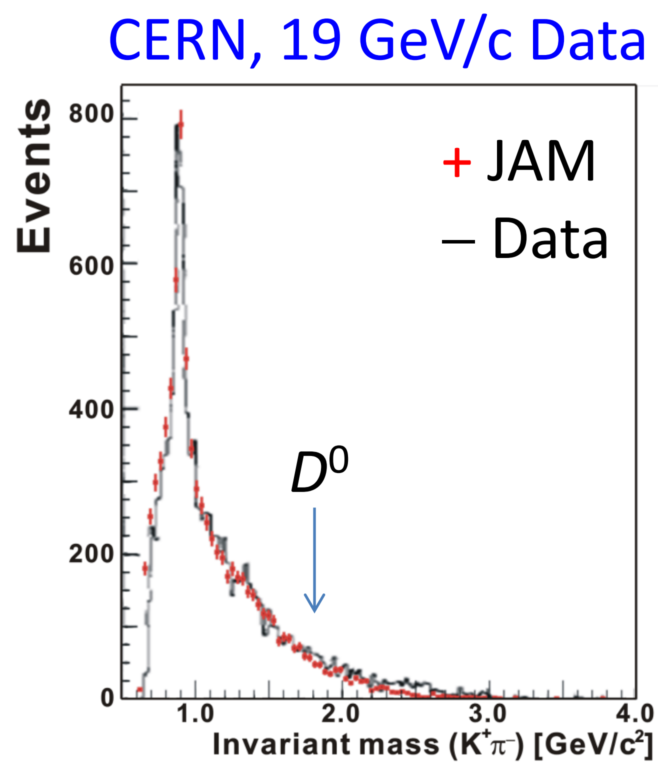


BG



BG simulation by JAM





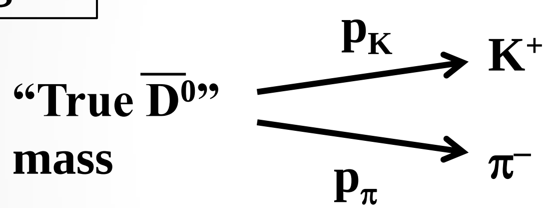
BGs of the past exp's were well reproduced.

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

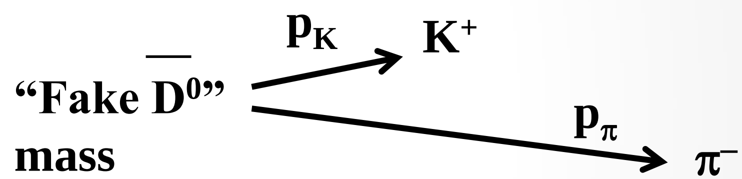
Background reduction

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

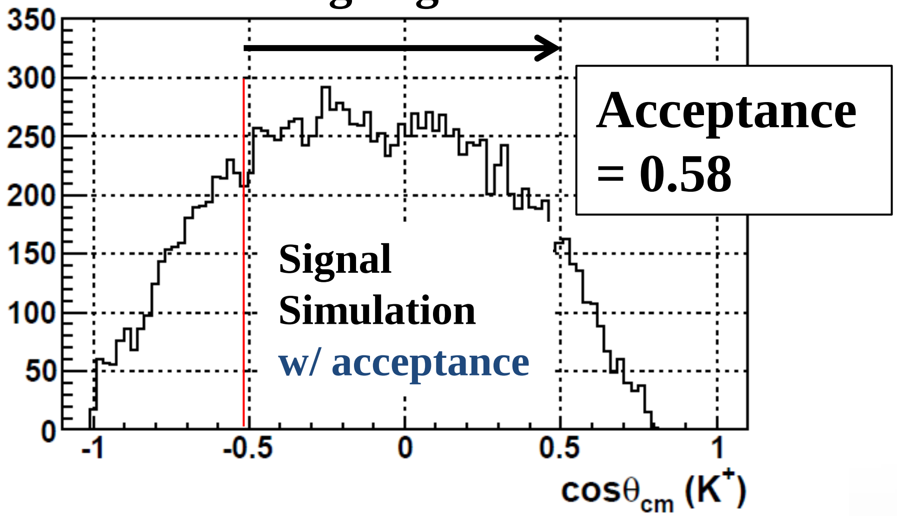
Signal



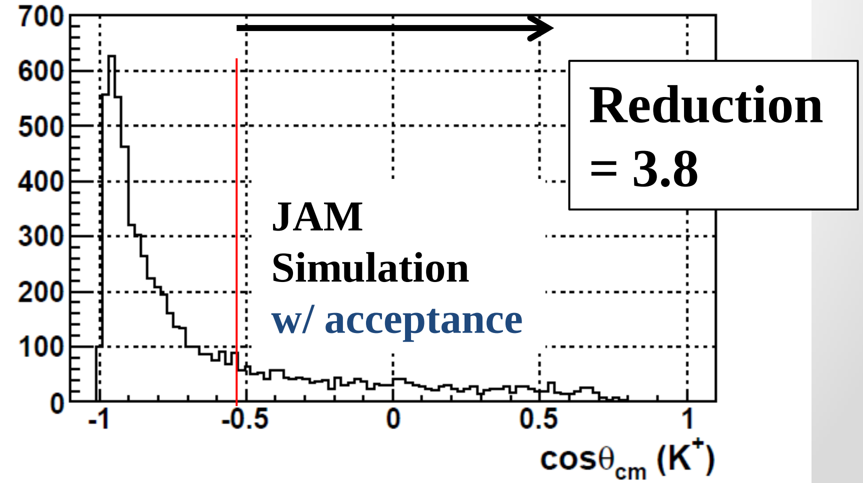
Background



K^+ scattering angle in CM



K^+ scattering angle in CM



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

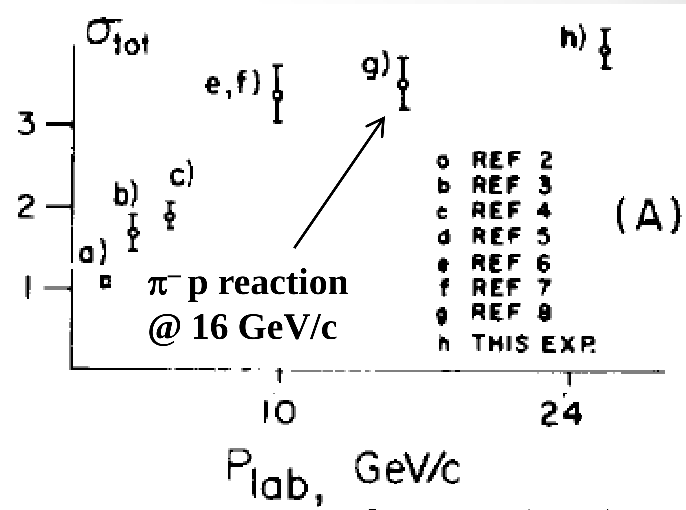
– σ_{Total} of $\pi^- p$ @ 16 GeV/c : 25.7 mb

⇔ 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

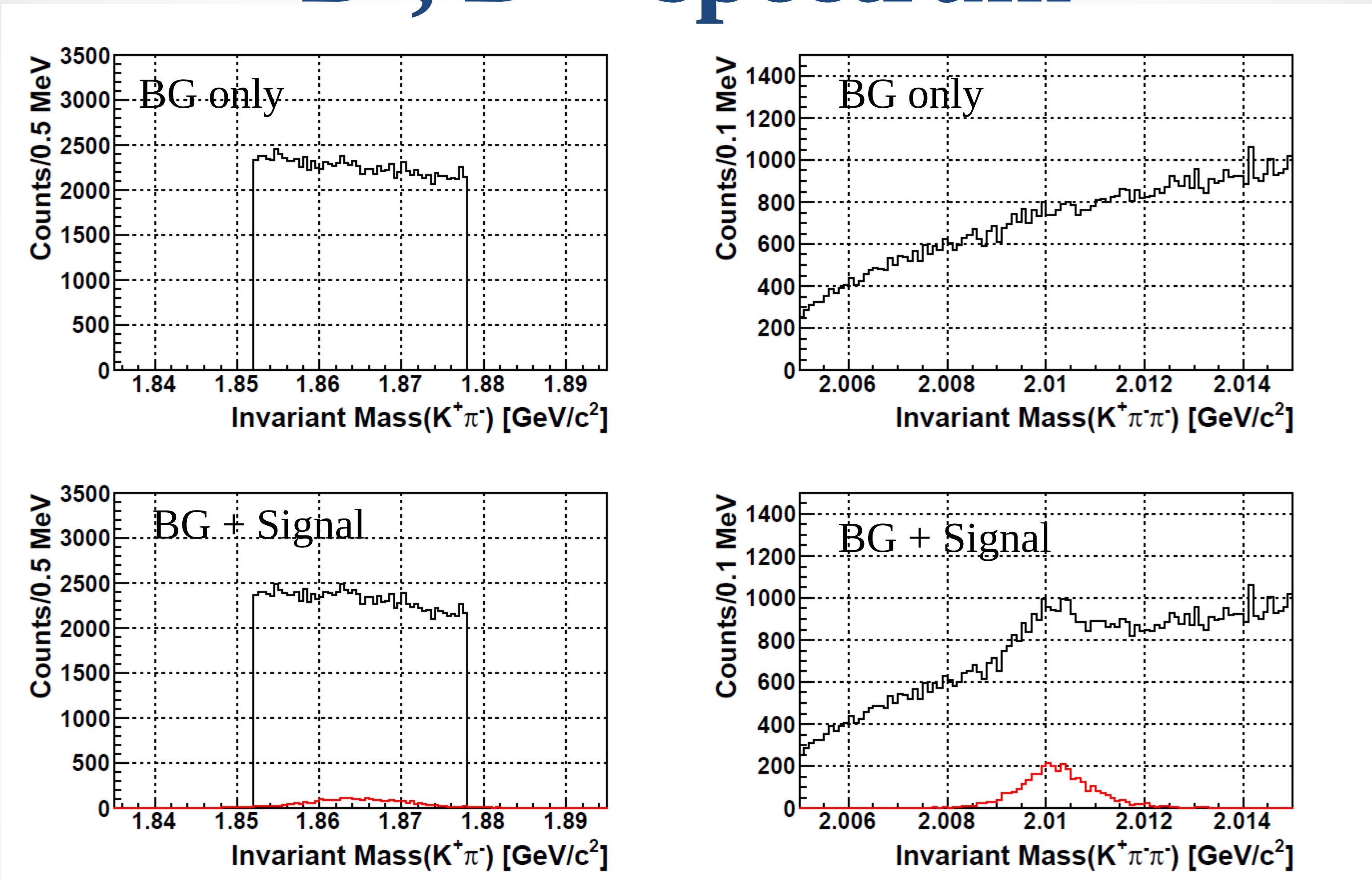
∗ Almost same as of PYTHIA

Difference from PYTHIA

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

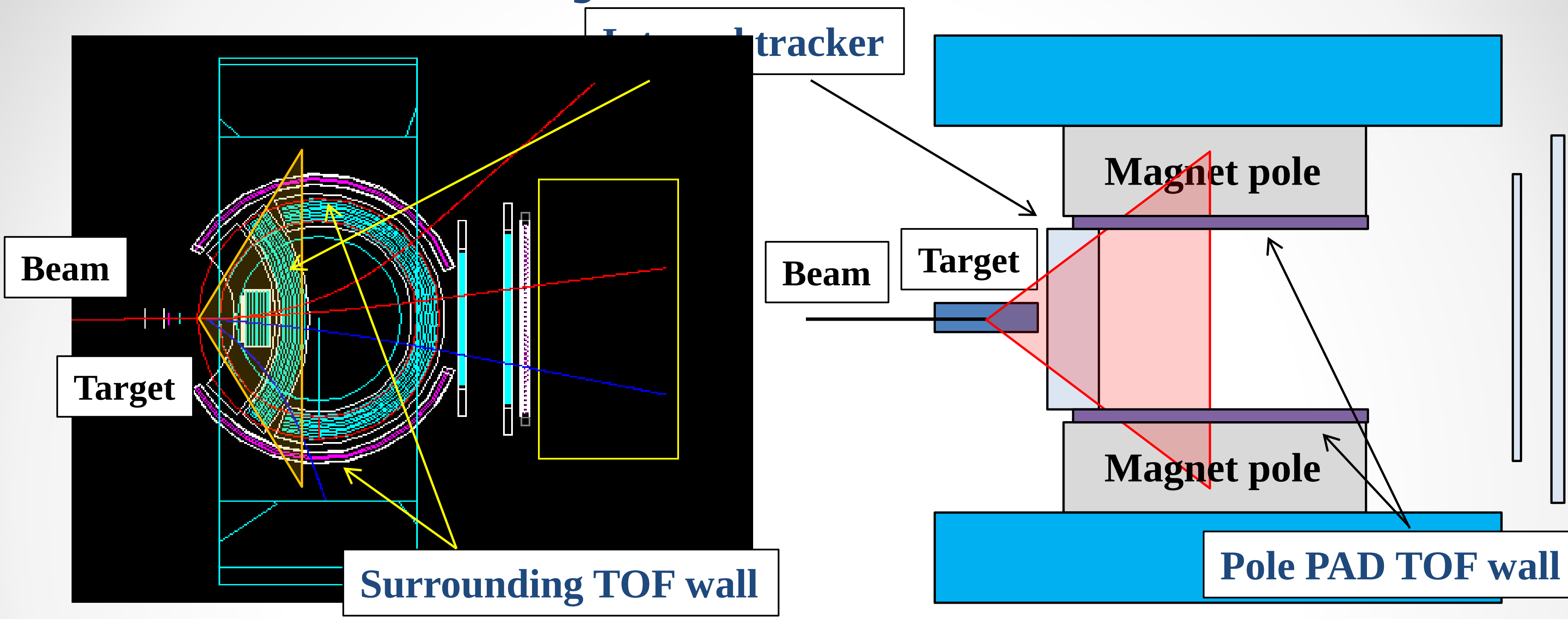
⇒To be checked by experimental data

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**

Decay measurement

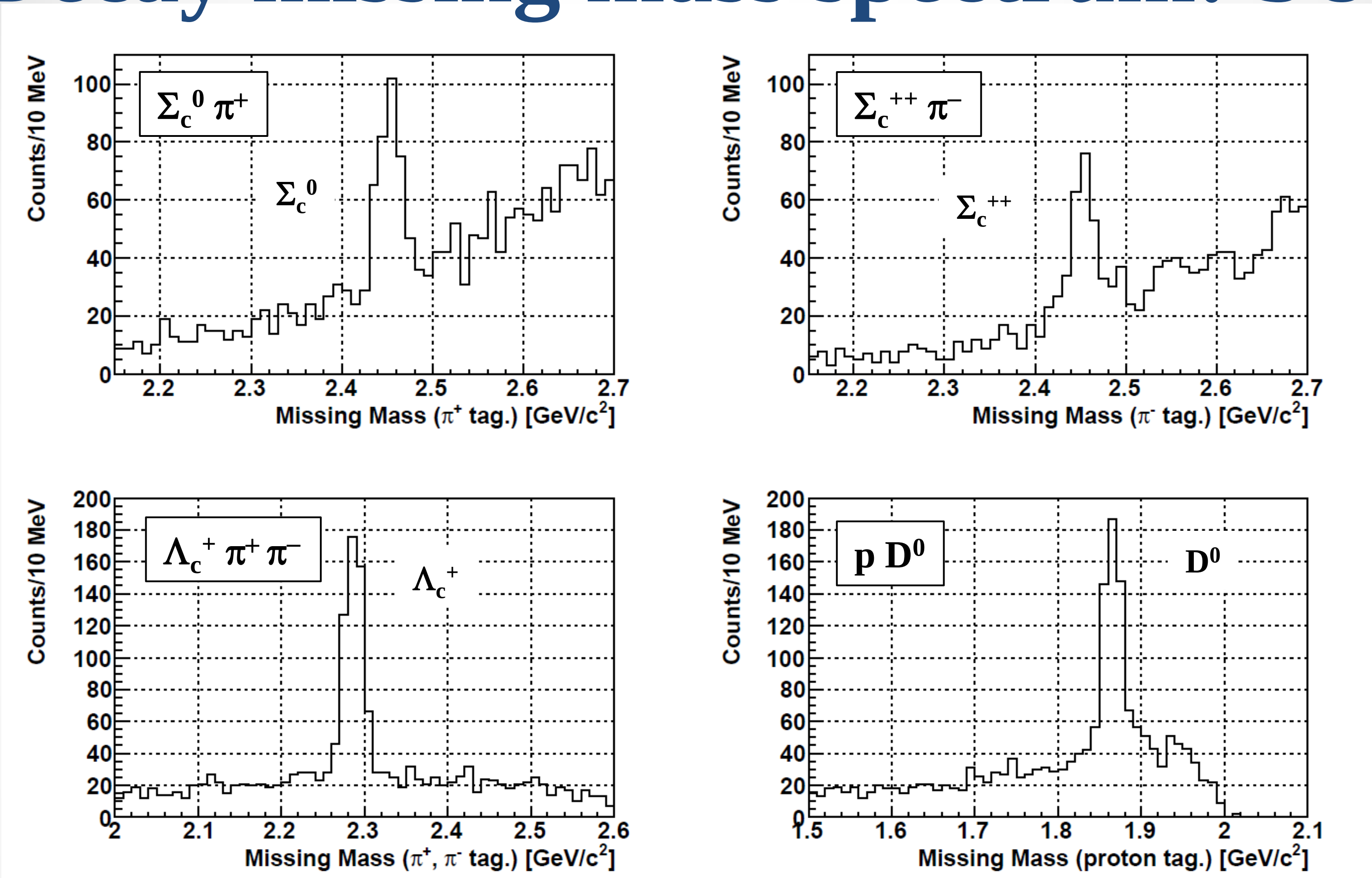


- **Method: Mainly Forward scattering due Lorentz boost ($\theta < 40°$)**
  - **Horizontal direction: Internal tracker and Surrounding TOF wall**
  - **Vertical direction: Internal tracker and Pole PAD TOF detector**

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

- **PID requirement: TOF time difference (π & K) $\Rightarrow \Delta T > 500$ ps**
  - **Decay particle has slow momentum: < 1.0 GeV/c**

Decay missing mass spectrum: SUM



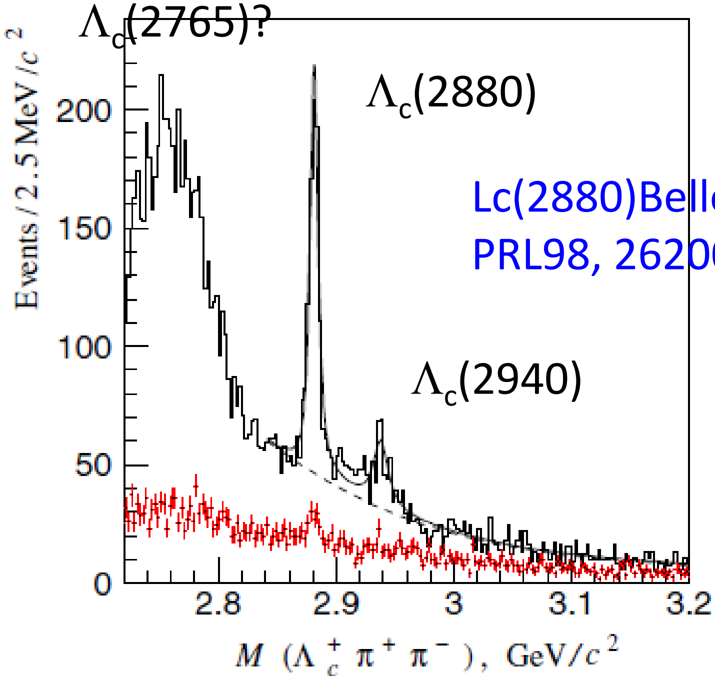
∗ **Full event w/ background/ No “$\Lambda_c^+ \pi^+ \pi^-$ gated”**

- **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.**

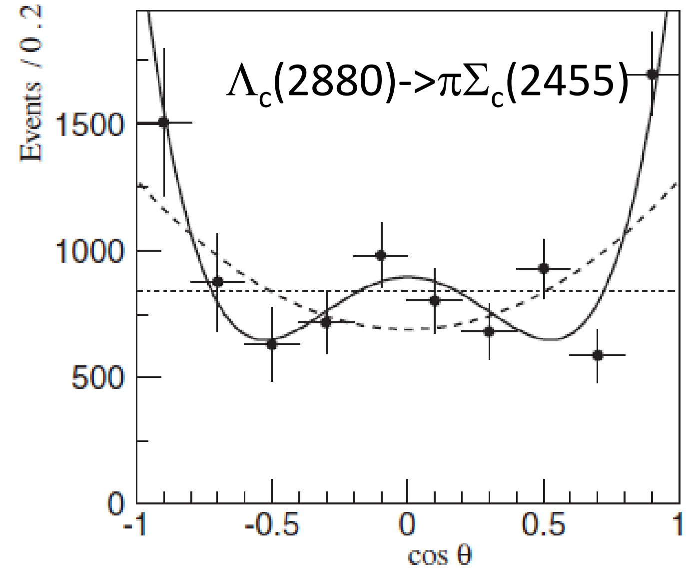
Study condition

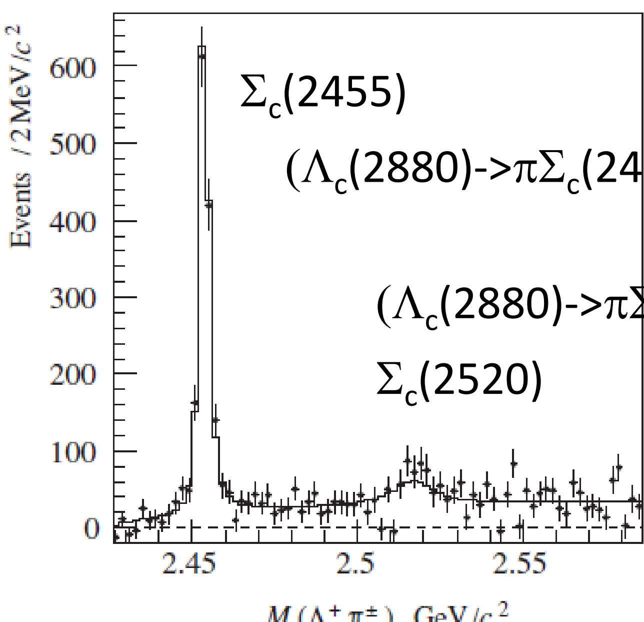
- **Assumed decay mode for Λ_c^{*+}(J^P = 3/2$^+$, M = 2.94 GeV/c^2)**
  - **N + D: Γ = 0.4 $\Rightarrow$ p D^0: 0.2, n D^+ :0.2**
  - **Σ_c + π: Γ = 0.4 $\Rightarrow$ Σ_c^{++} π^-: 0.4/3, Σ_c^+ π^0: 0.4/3, Σ_c^0 π^+: 0.4/3**
    - **Decay to Σ_c(2455) assumed**
  - **Λ_c + π + π: Γ = 0.2 $\Rightarrow$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

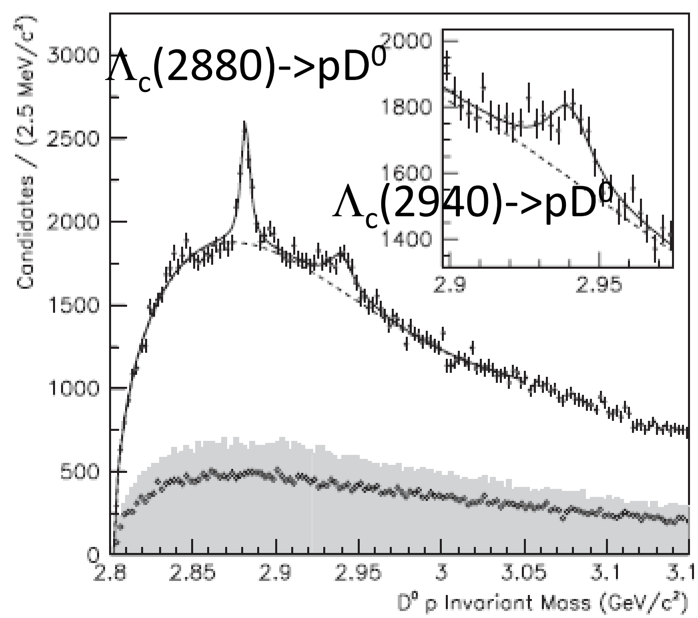
- **Yield estimation @ 1 nb case (~1900 counts)**
  - **p D^0: 0.2 $\Rightarrow$ 1900 × 0.2 × 0.8 = ~300**
  - **$\Sigma_c^{++,0}$ $\pi^{-,+}$: 0.4/3 $\Rightarrow$ 1900 × 0.4/3 × 0.8 = ~200**
    - **Forward scattering of protons**
    - **Wider scattering angle of pions**
    - **Combined with 4-body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



Lc(2880)Belle,
PRL98, 262001('07)

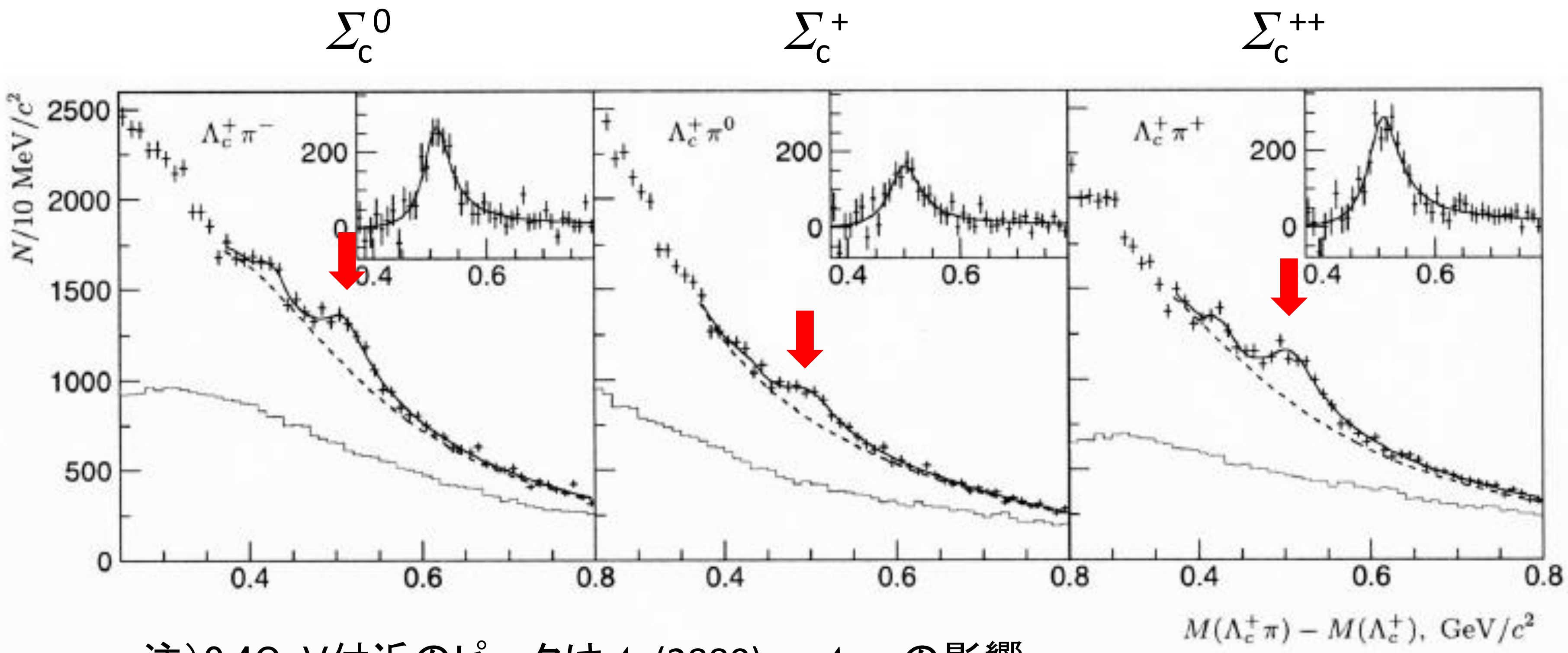






Babar, PRL98, 012001('07)

Σ_c (2800) -> $\Lambda_c + \pi$



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

Belle, PRL94, 122002('05)