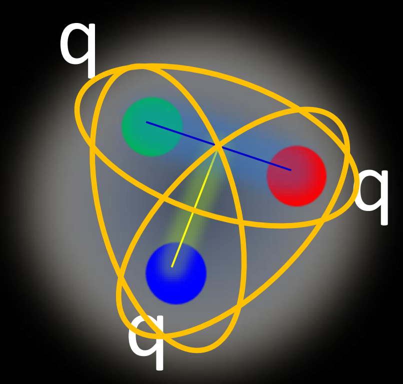
P50
Charmed Baryon Spectroscopy via the (π, D^{*-}) reactions

The 18th PAC for P50, May, 2014

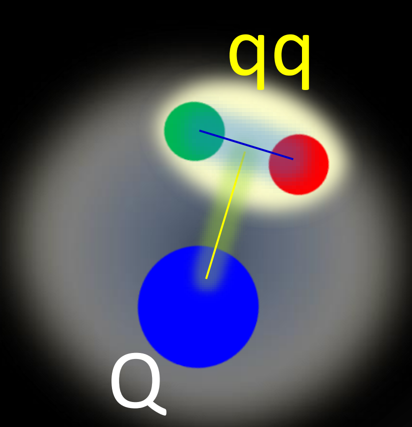
1. Physics Motivation
2. Strategy
3. Summary

Quark-quark correlation in baryons



- How hadrons are formed?
- Quark dynamics in hadrons

to understand the low-E QCD



→ The heavy Q helps to isolate "qq" motion in baryons.

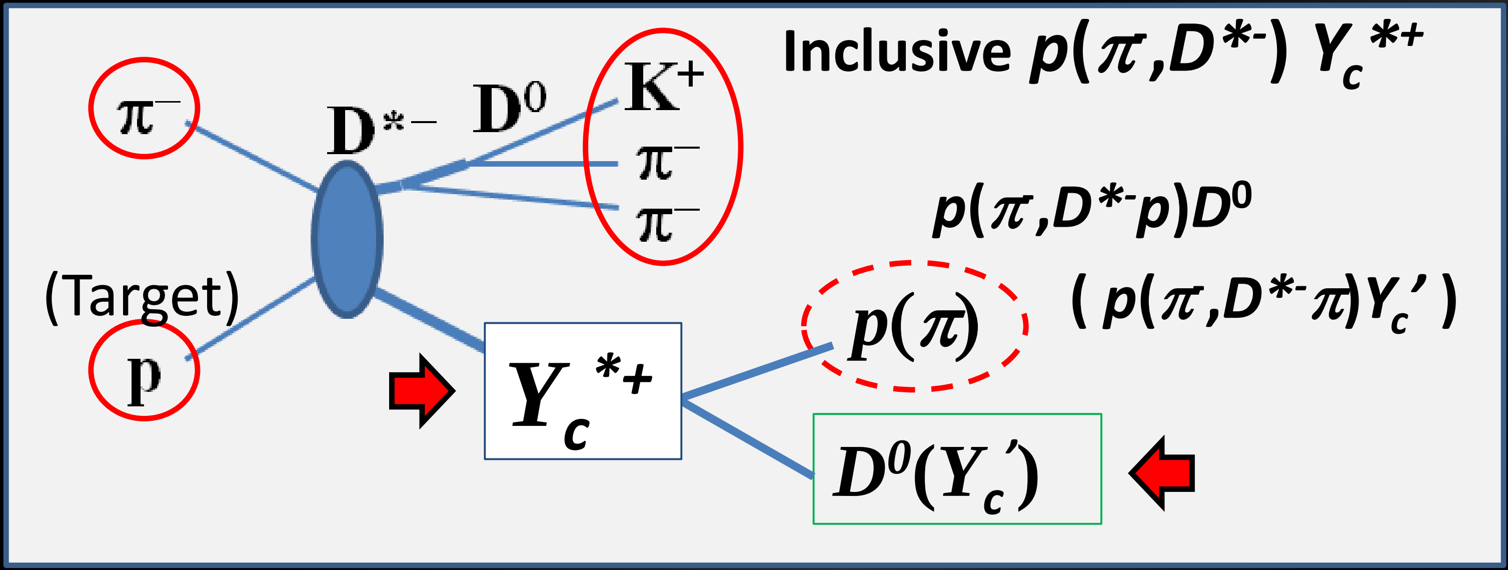
- HQ spin couples weakly to the rest.

→ HQ spin doublets ($\vec{s}_{HQ} \pm \vec{J}_{rest}$)

Level Structure, Production, and Decay

Charmed Baryon Spectroscopy

Using Missing Mass Techniques

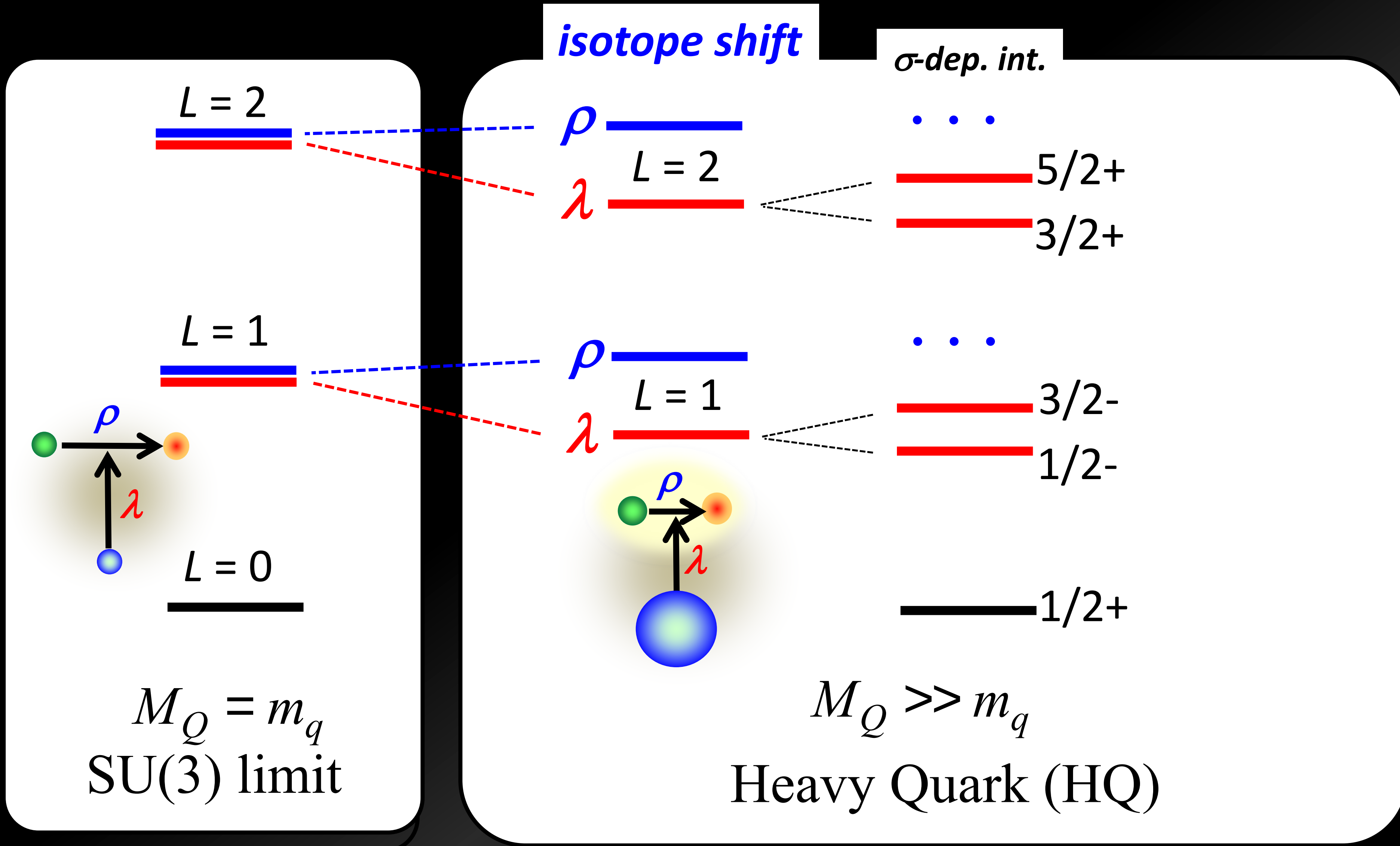


What we will measure

- Spectrum identified by productions:
  - ✓ Basic modes of diquark motions (λ/ρ modes)
  - ✓ Heavy Quark Spin doublets ($\vec{s}_{HQ} \pm \vec{J}_{rest}$)
- Production Rate: reflect quark configuration
  Heavy quark + light diquark
- Decay properties:
  $M(Qq^{bar}) + N(qqq)$ / $m(qq^{bar}) + Y_c(Qqq)$

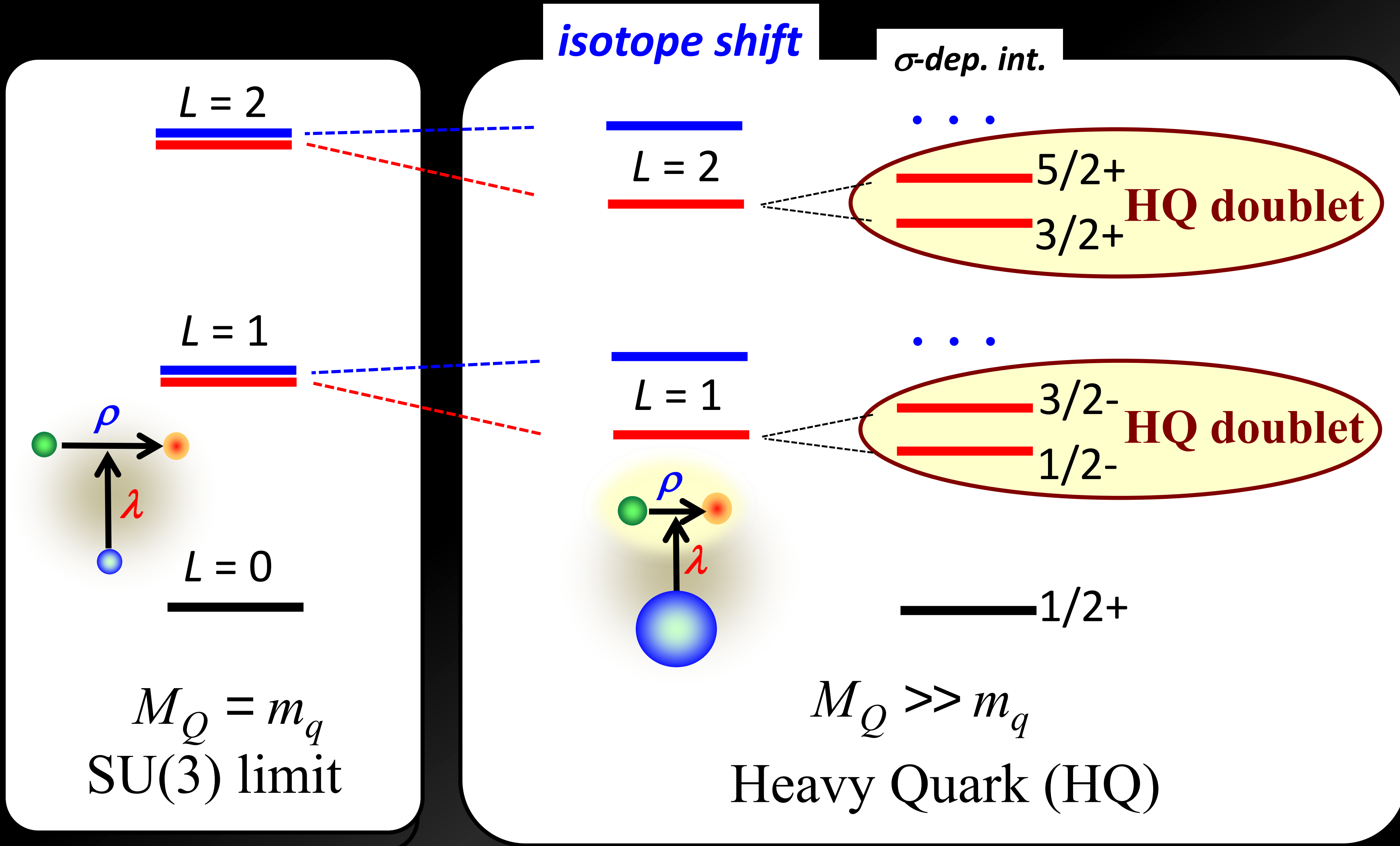
A heavy quark differentiates ***diquark*** motions = modes

λ and ρ modes are distinct ~ ***isotope shift***



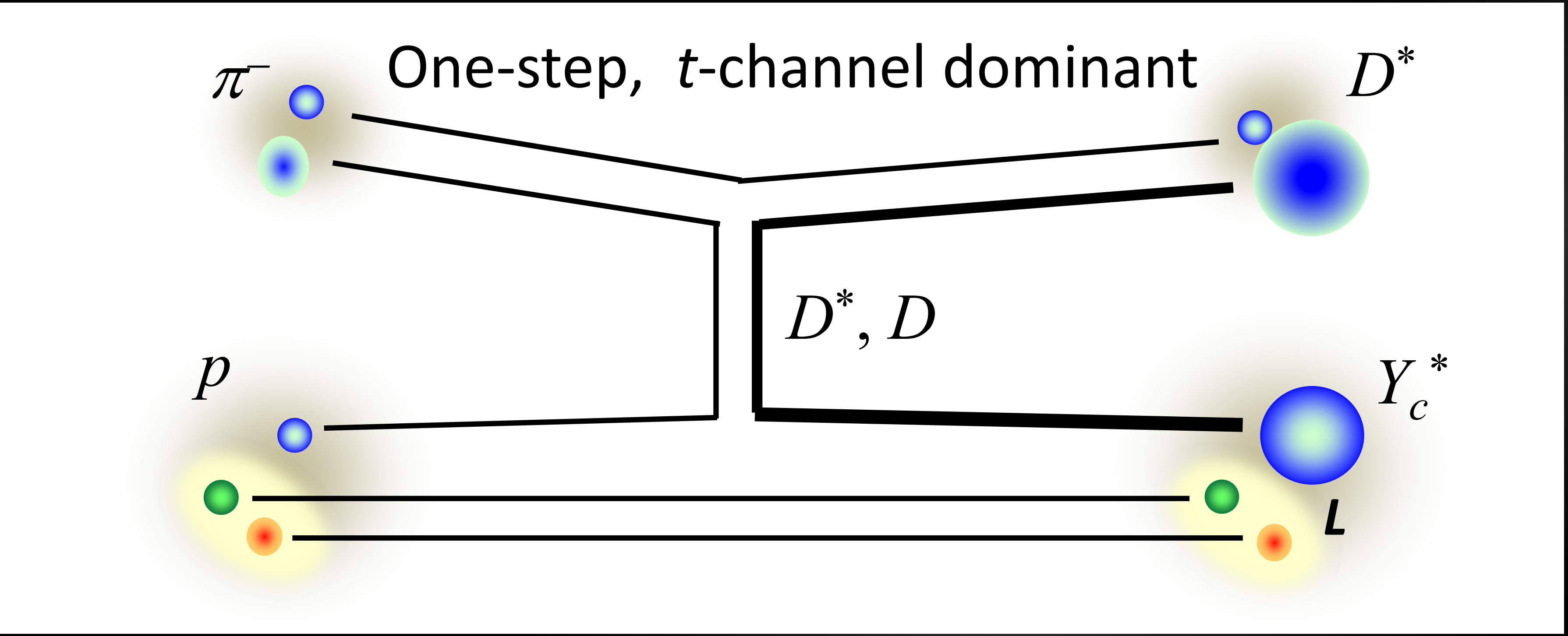
A heavy quark differentiates *diquark* motions = modes

λ and ρ modes are distinct ~ *isotope shift*

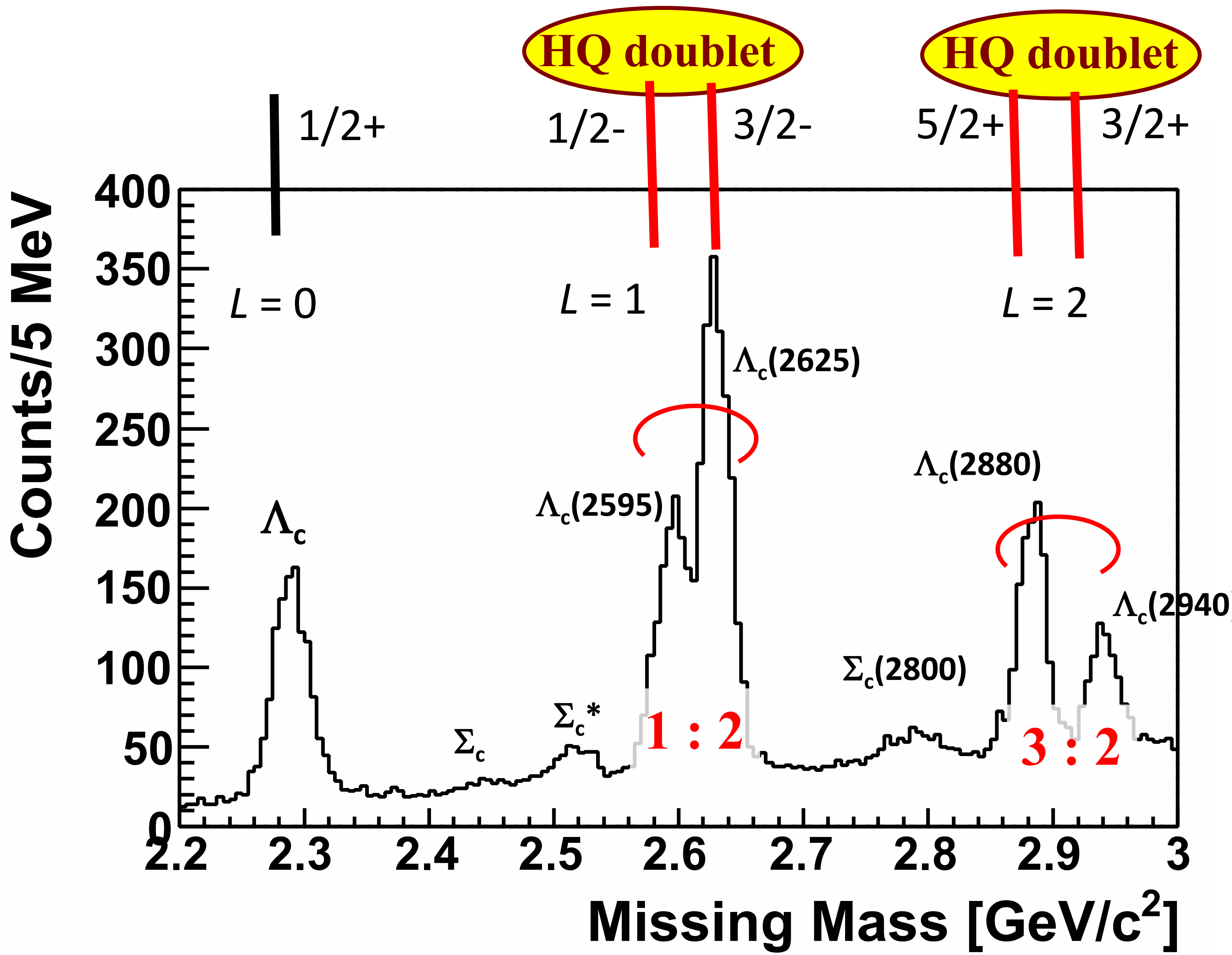


Production

S.H. Kim, A. Hosaka, H.C. Kim, HN, K. Shirotori, arXiv:1405.3445, 14 May, 2014.

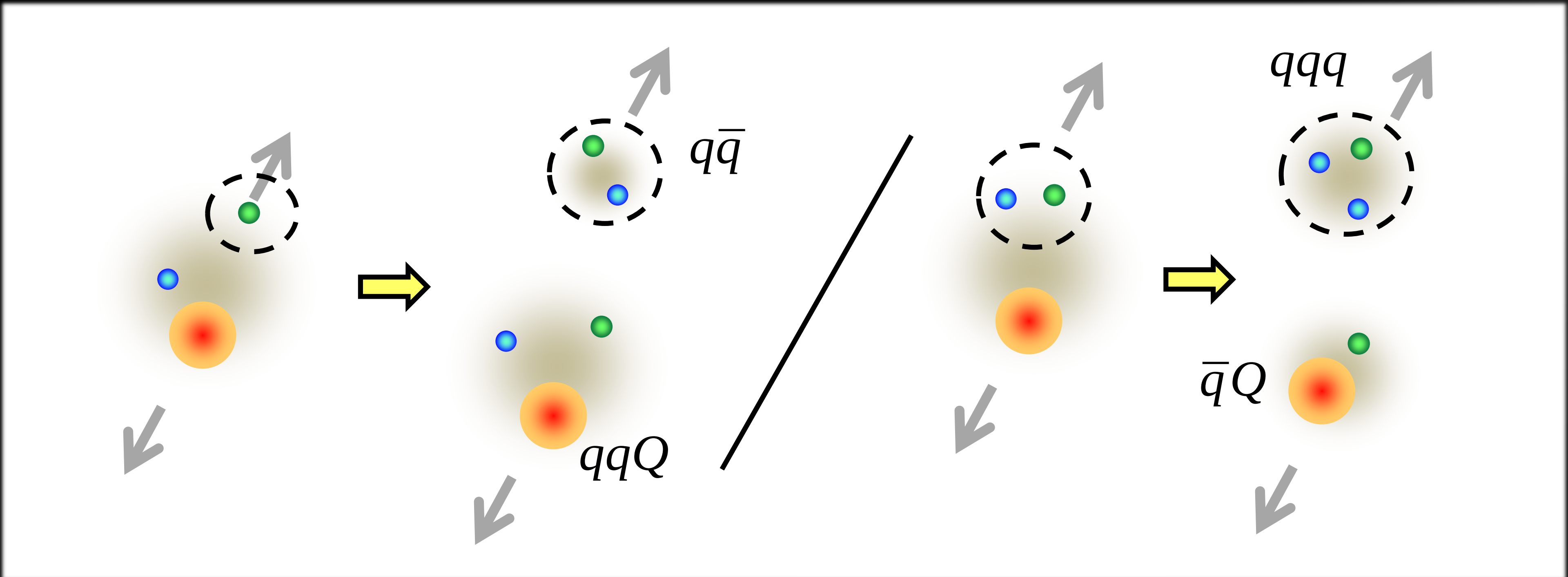


- ✓ C.S. DOES NOT go down at higher L due to large q_{eff}
- ✓ λ modes are excited by a simple mechanism
  - *HQ spin doublet*
  - *Spin/Parity from Production Ratio*



HQ doublet
HQ doublet
1/2+
1/2-
3/2-
5/2+
3/2+
L = 0
L = 1
L = 2
Λc(2625)
Λc(2595)
Λc(2880)
Λc(2940)
Λc
Σc
Σc*
Σc(2800)
1 : 2
3 : 2
Counts/5 MeV
0
50
100
150
200
250
300
350
400
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
Missing Mass [GeV/c2]

Decay Properties



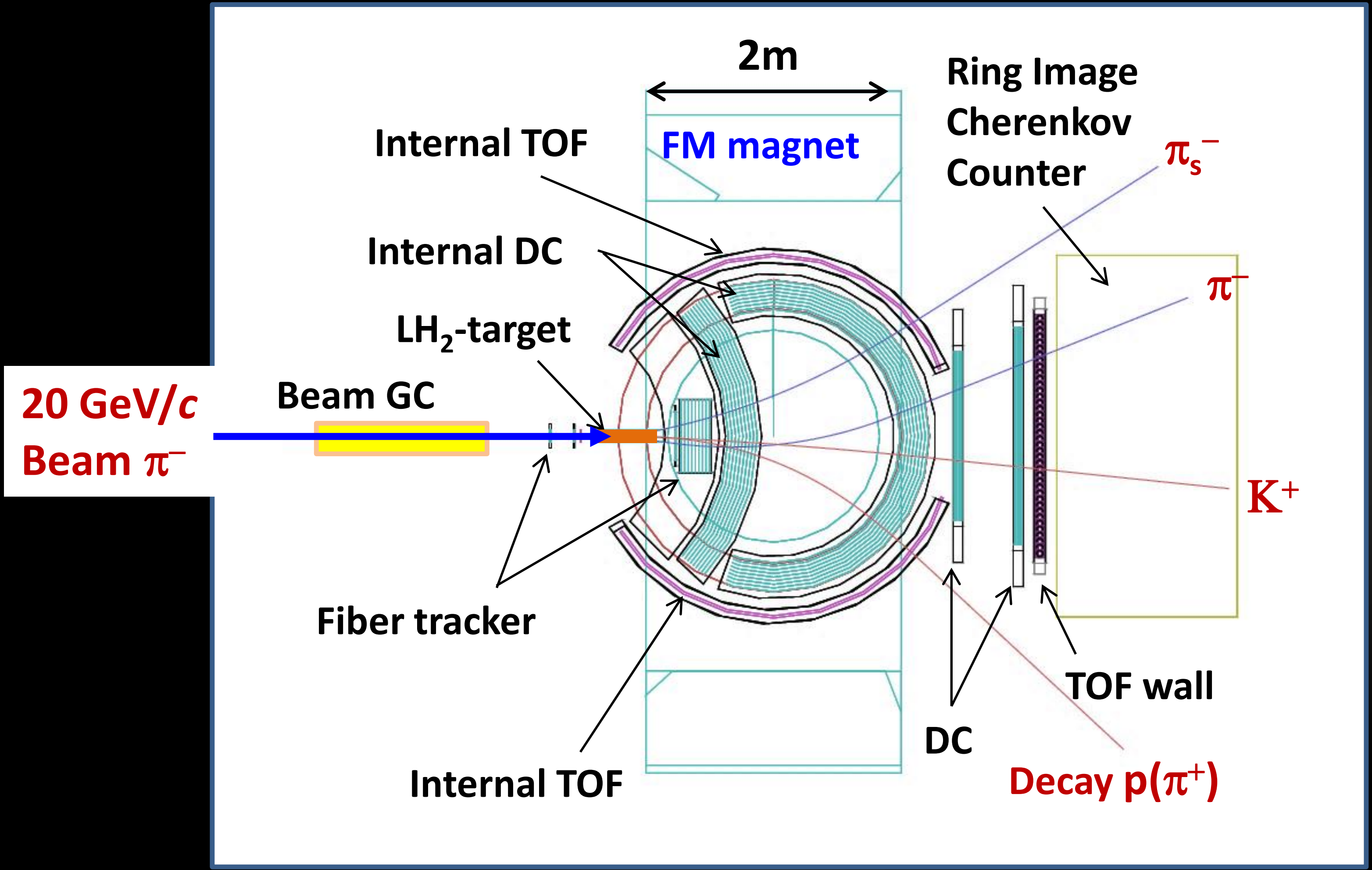
ρ mode (qq)

$\Gamma(\Sigma_c\pi) > \Gamma(pD)$

λ mode [qq]

$\Gamma(\Sigma_c\pi) < \Gamma(pD)$

Charmed Baryon Spectrometer



Large acceptance ~ 60% (for *D), ~85% (for decay π^+)**

Good resolution: $\Delta p/p$~0.2% at ~5 GeV/*c*

Strategy

1. Charmed baryon spectroscopy.

   Key issue is the p(π^-,D^{*-})Λ_c cross section...

   "C.S. ~ 1 nb" can be confirmed in ~10 days or so.

   – Go to the *2nd* step when the C.S. << 1 nb.

2. Hyperon spectroscopy via (π^-,K^{*0})...

   – Diquark motions (λ/ρ mode ID) for *known states*

     ✓ Production Rate: favor λ-mode

     $\leftrightarrow$ ρ-mode through λ/ρ mixing

     ✓ Decay Branching Ratio: $\Gamma(NK)/\Gamma(\pi Y)$ in terms of λ/ρ modes

   – x1000~10000 higher statistics

Populated states via $p(\pi^-, K^{*0})X$

L		state	*Rate (Rel.)*
0		$\Lambda^{1/2+}(1116)$	1000
		$\Sigma^{1/2+}(1192)$	49
		$\Sigma^{3/2+}(1385)$	244
1	λ	$\Lambda^{1/2-}(1405)$	72
		$\Lambda^{3/2-}(1520)$	127
	ρ	$\Lambda^{1/2-}(1670)$	7
		$\Sigma^{3/2-}(1690)$	4
		$\Lambda^{3/2-}(1690)$	13
	λ	$\Sigma^{1/2-}(1750)$	4
		$\Sigma^{5/2-}(1775)$	18
2		$\Lambda^{3/2+}(1890)$	25
		$\Lambda^{5/2+}(1820)$	52

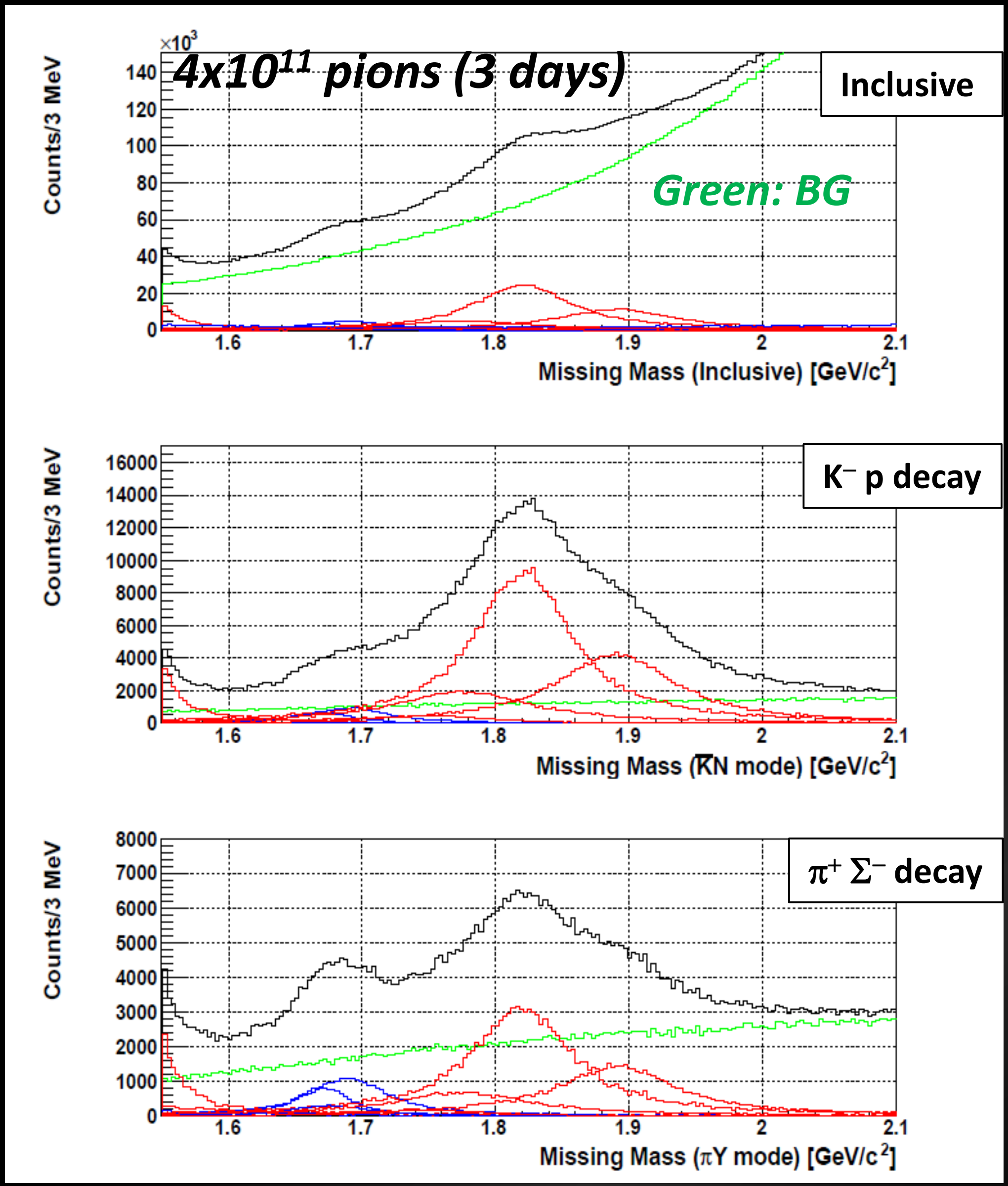
Cal. w/ t-channel K ex. reaction*
at $p_\pi = 5$ GeV/c

- λ mode states
  well populated
- ρ mode states
  excited through λ / ρ mixing (P_{mix})
  P_{mix}(*strange*) is given,
  P_{mix}(*charm*) could be deduced.

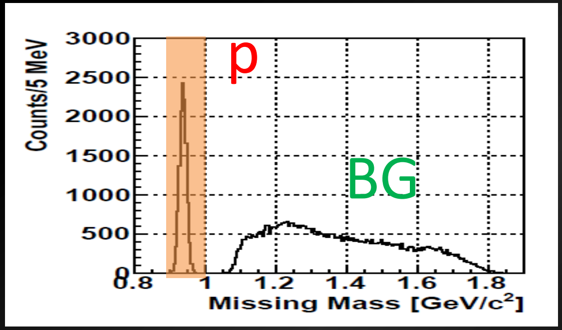
✓ P_{mix}(*strange*) > P_{mix}(*charm*)

S.H. Kim, A. Hosaka, H.C. Kim, HN, K. Shirotori, arXiv:submit/0978210, 14 May, 2014.

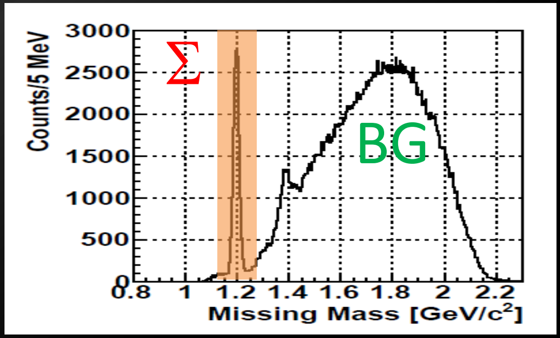
Hyperon production via $p(\pi^-,K^{*0})X$



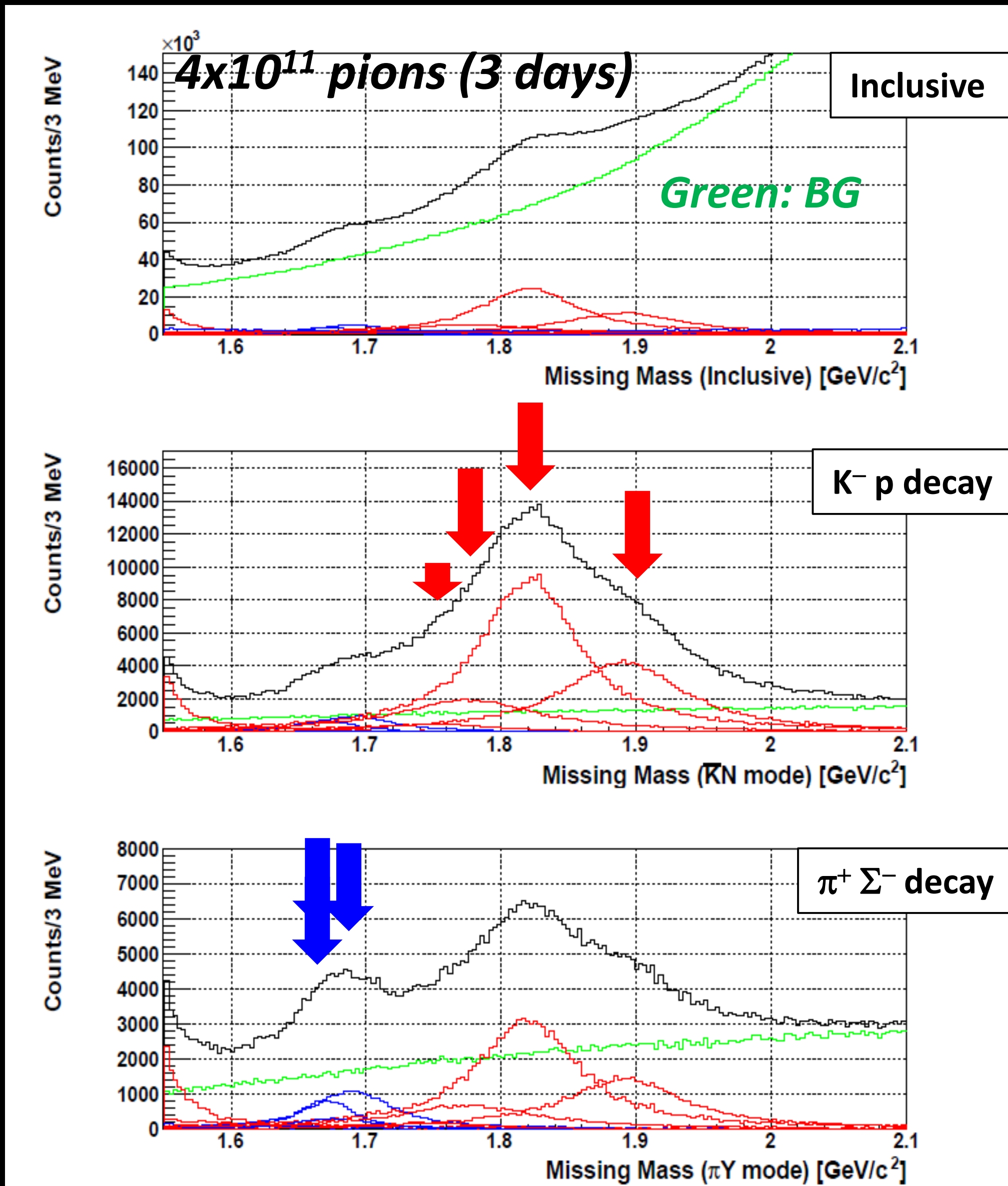
- K^- p decay
  - K^- tagged, Missing "p" gated



- $\pi^+\Sigma^-$ decay
  - π^+ tagged, Missing "Σ" gated



Hyperon production via $p(\pi^-,K^{*0})X$



- K^- p decay
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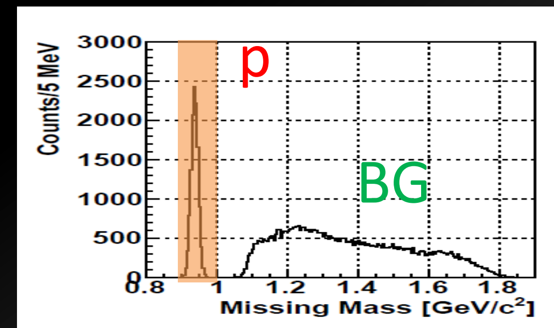

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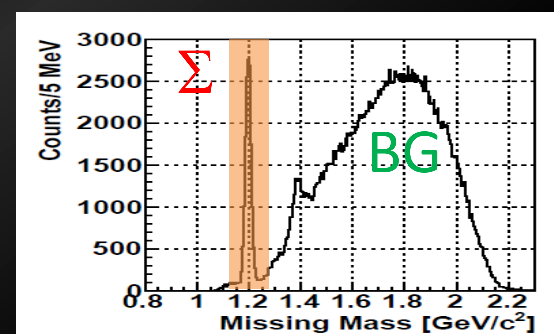
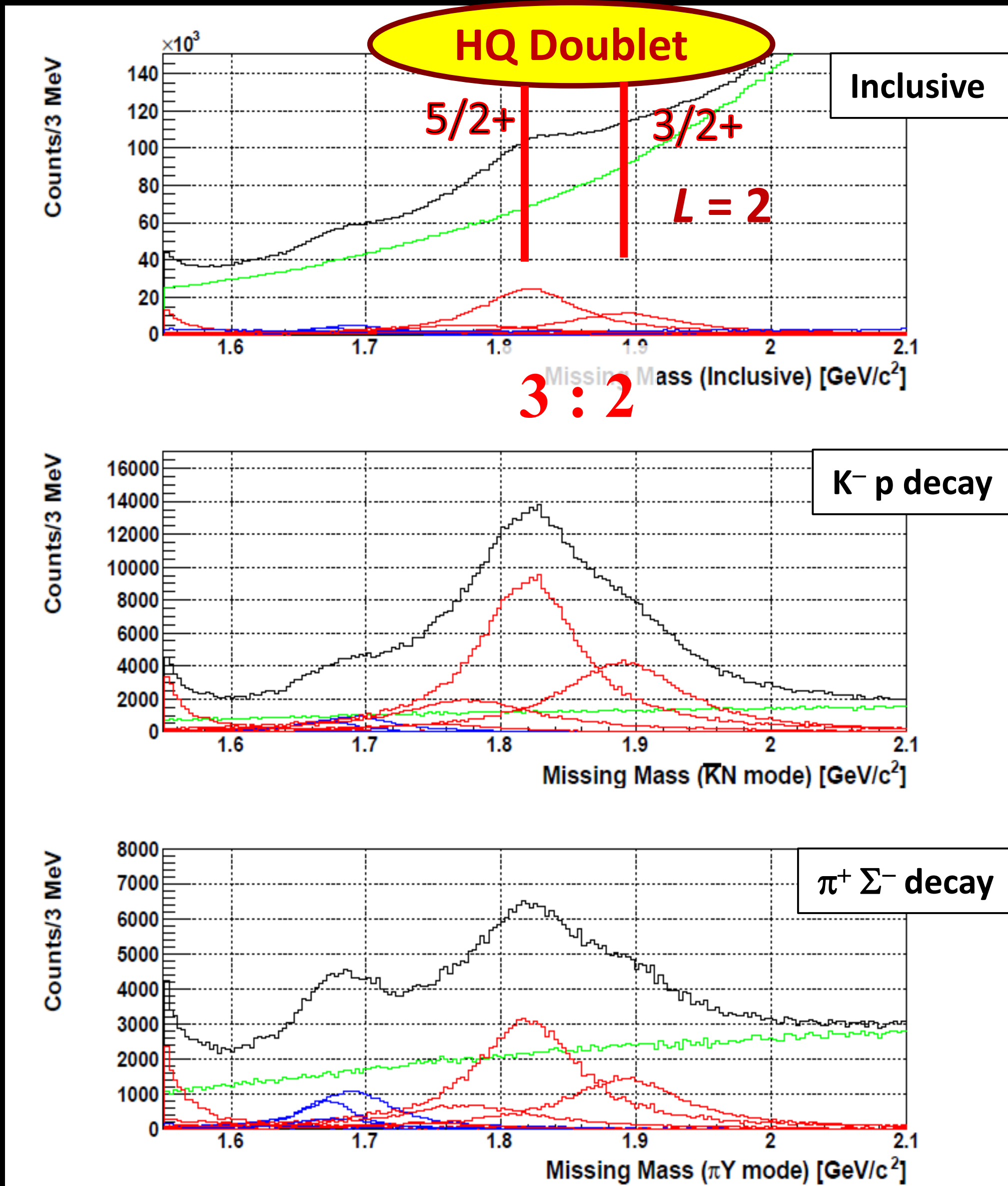


Hyperon production via $p(\pi^-,K^{*0})X$



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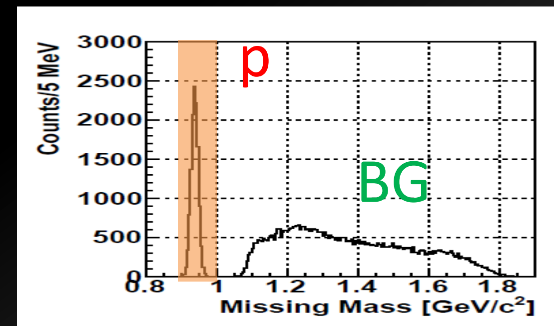
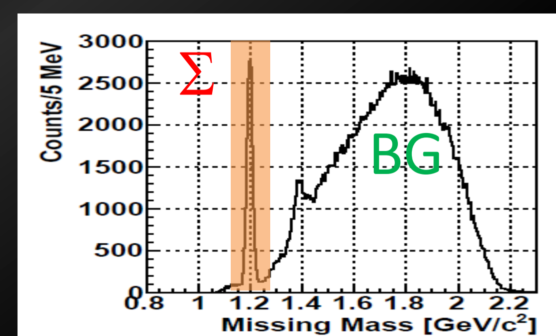
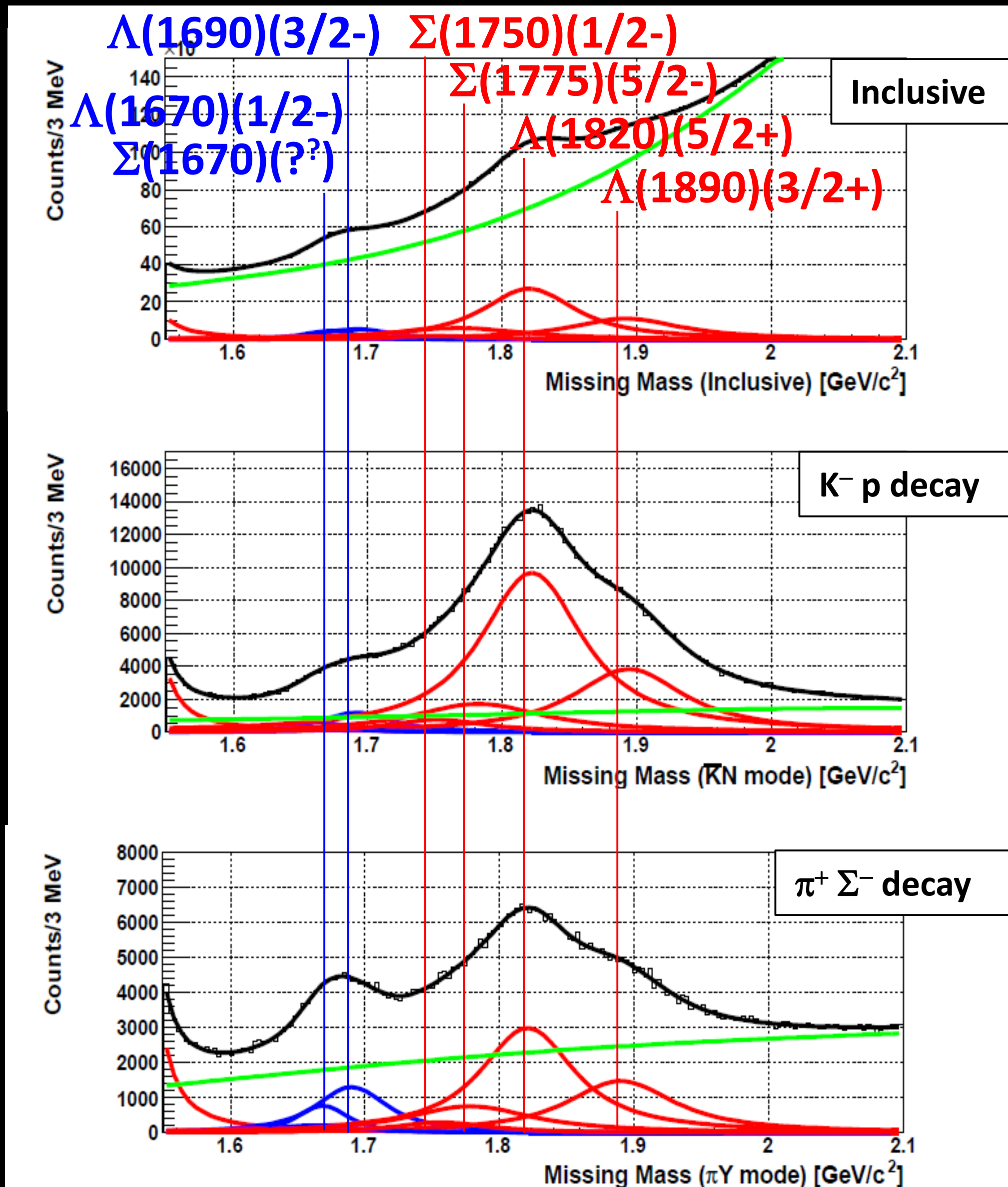


- $\pi^+\Sigma^-$ decay
  - π^+ tagged, Missing "Σ" gated



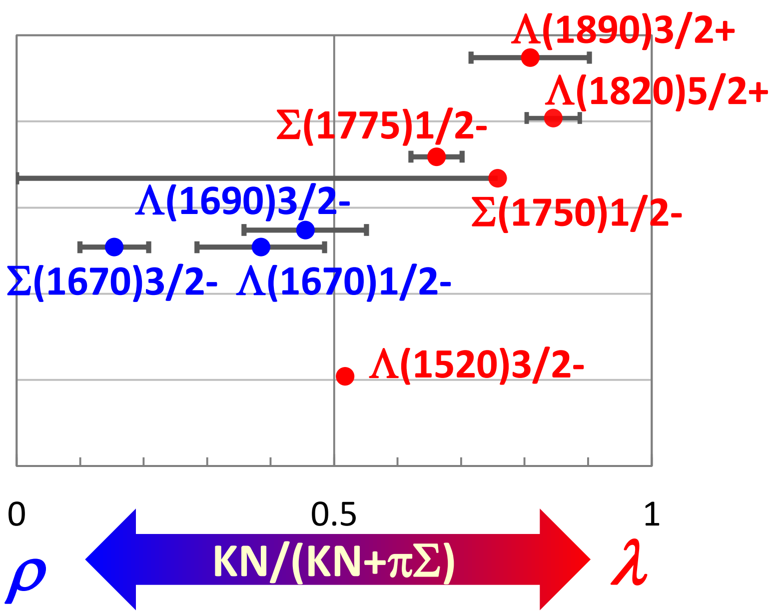
Hyperon Production (Fitting Results)



- Extract 7 states.
  - Constraint from known M & Γ
  - BG: 5^{th} O. Polynomial F.
- Cross Section
  - λ / ρ mode ID
  - λ / ρ mixing: $P_{mix}(strange)$ (ρ-mode C.S.)
  - *HQ spin multiplets*
- $\Gamma(KN)/\Gamma(\pi Y)$
  - λ / ρ mode ID

Decay mode: $\Gamma(NK)/\Gamma(\pi\Sigma)$

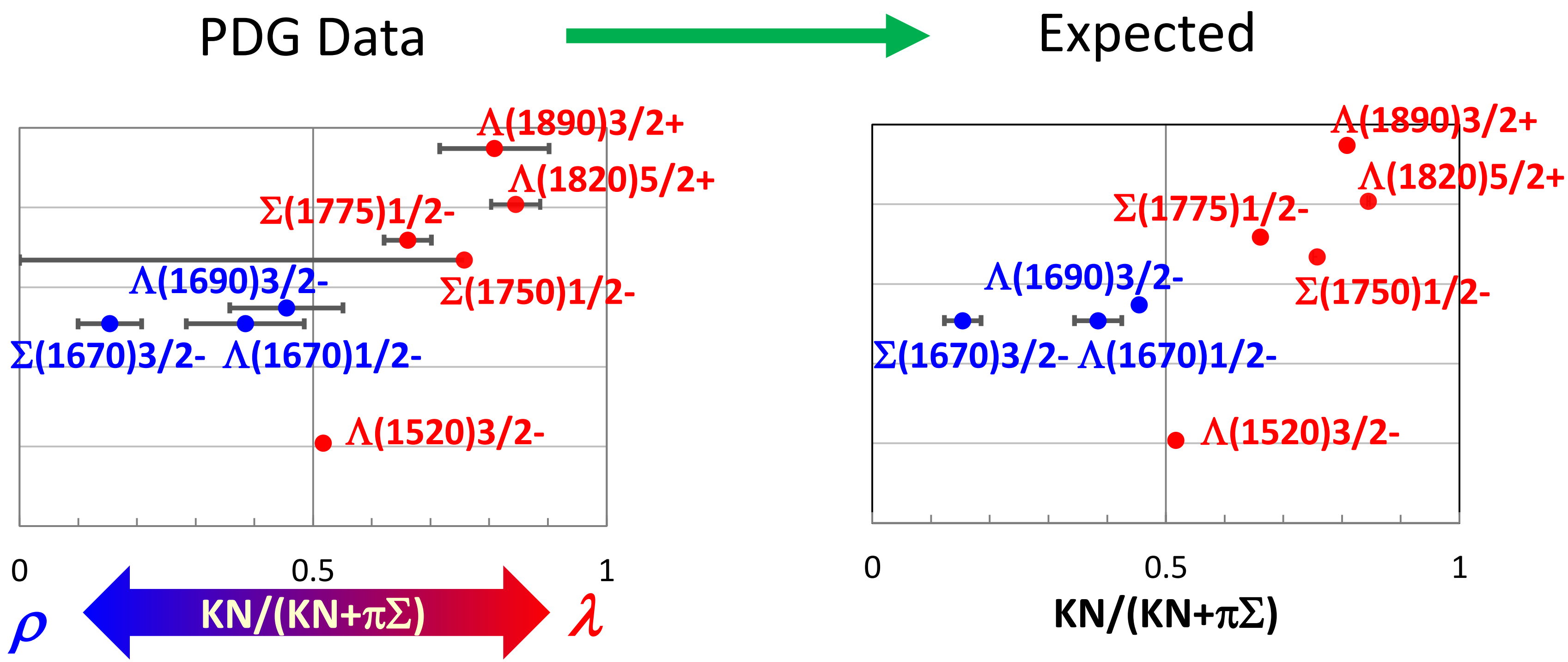
PDG Data



- λ/ρ mode ID by productions correlate w/ Decay Ratios
  → to be established
- The ratios <-> $P_{mix}(strange)$

- Hyperon data indicate mode dependence
  → Errors should be improved.
- No data in charmed baryons

Decay mode: $\Gamma(NK)/\Gamma(\pi\Sigma)$



- Hyperon data indicate mode dependence
  → Errors should be improved.
- No data in charmed baryons

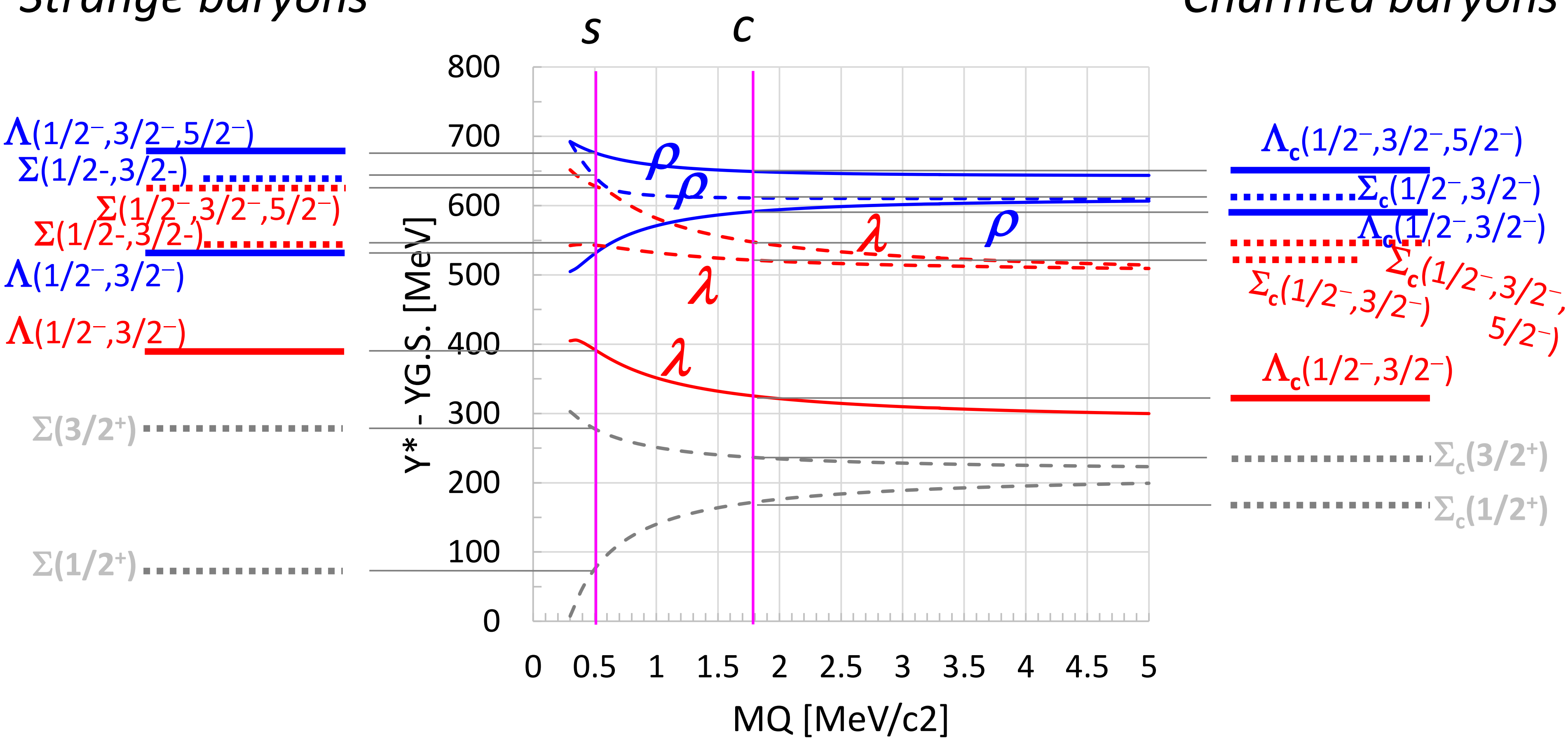
Summary

- Charmed baryons are good to see diquark motions in baryons clearly.
  - λ/ρ modes are separated clearly.
  - Level, Production rate, and decay branching ratios
- We demonstrated that strange baryon spectroscopy can also be carried out.
  - High performance of the spectrometer
  - λ/ρ modes ID for known states will be established

Bakup slide

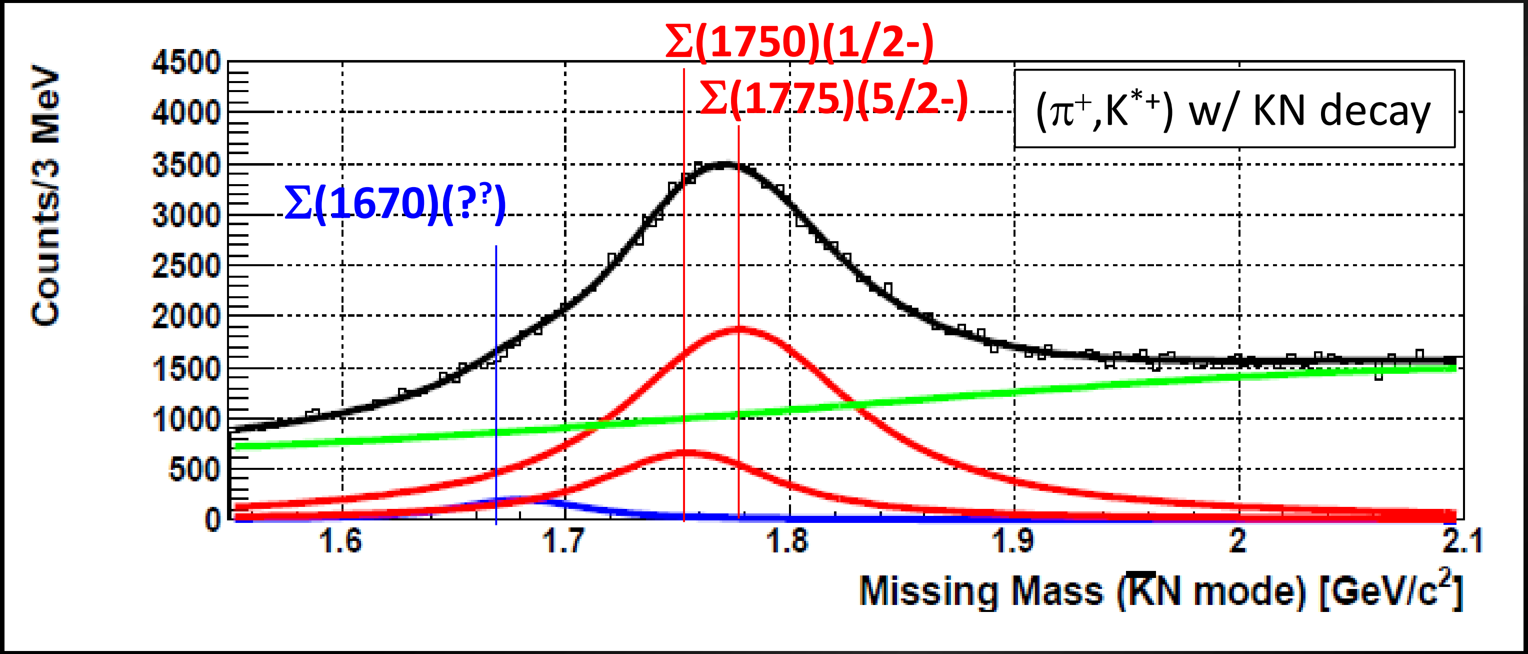
Baryon spectroscopy in different flavors

Strange baryons *Charmed baryons*



non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$
ρ–λ mixing (cal. By T. Yoshida)

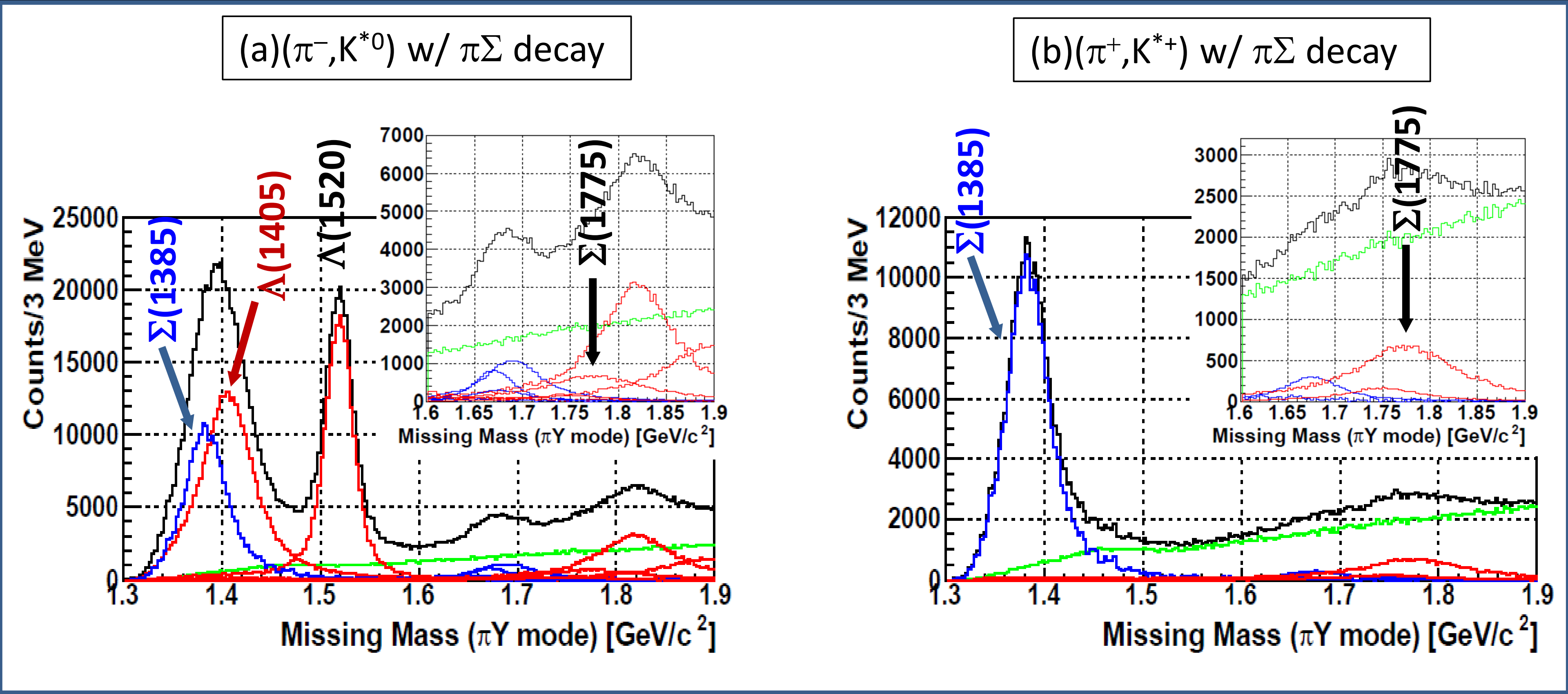
Peak fitting for $p(\pi^+, K^{*+})\Sigma^{*+}$



M and Γ of 3 Σ^{*+}'s are fixed first.

Λ(1405)

I = 0, 1 *I* = 1 only



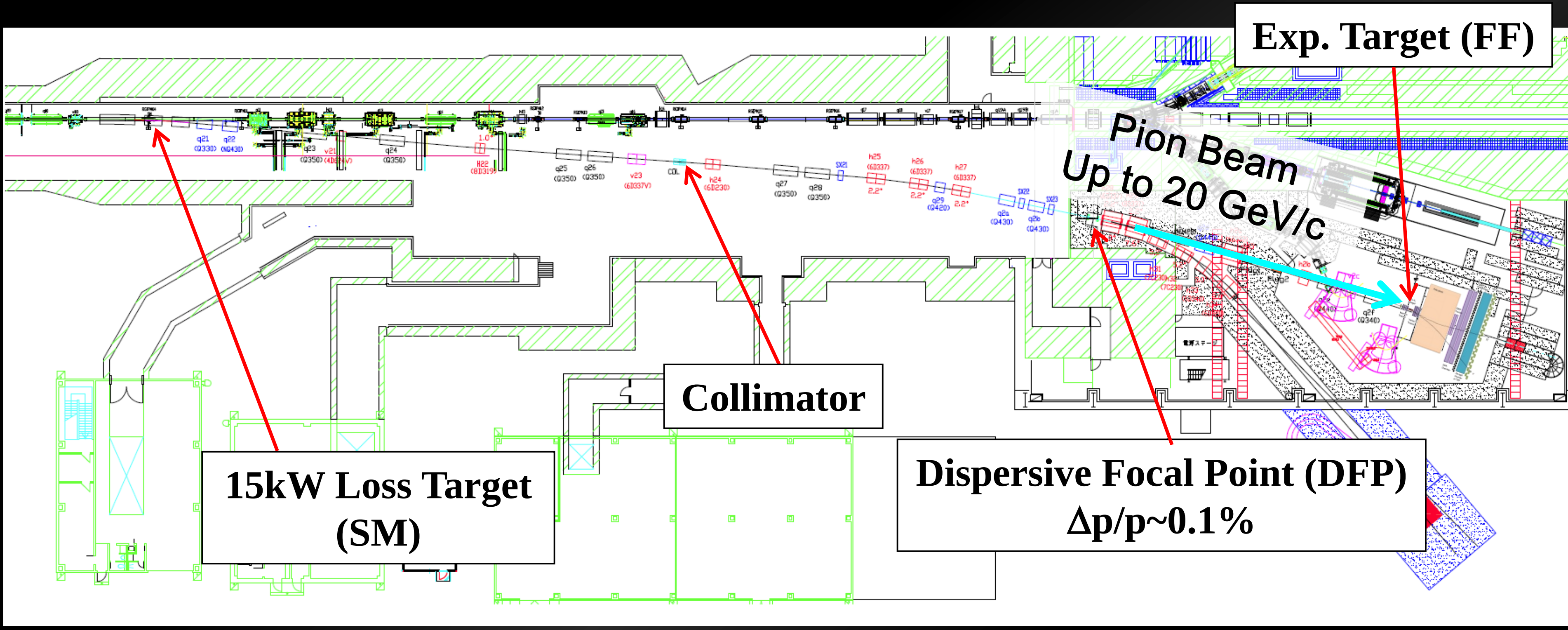
✓ Contribution of *Σ*(1385) can be subtracted
to extract the Λ(1405) amplitude.

Expected Yield

- Conditions
  - σ(p(π^-,K^{*0})Λ)= 53 μb, others: cal. by t-ch. K* ex. model
  - t-channel dominance: ~exp{2.5(t-t_0)}
  - 10 MeV mass resolution, $\Delta\Omega$(K^{*0}) ~ 70%
  - BG source: JAM at p_π=5 GeV/*c*
- Yield for 10^{13} pions (100 days w/ 7 Mpps)
  - 4 g/cm^2 H_2 TGT
  - Large production yield: ~6 M/1μb (w/ ε_{ana}~0.5)
  - Large decay events: $\Delta\Omega$($\pi\Sigma$/KN) ~ 70%
    - 210 k for Λ^* -> K-p, 140 k for Λ^* -> $\pi^-\Sigma^+$ if br(10%)

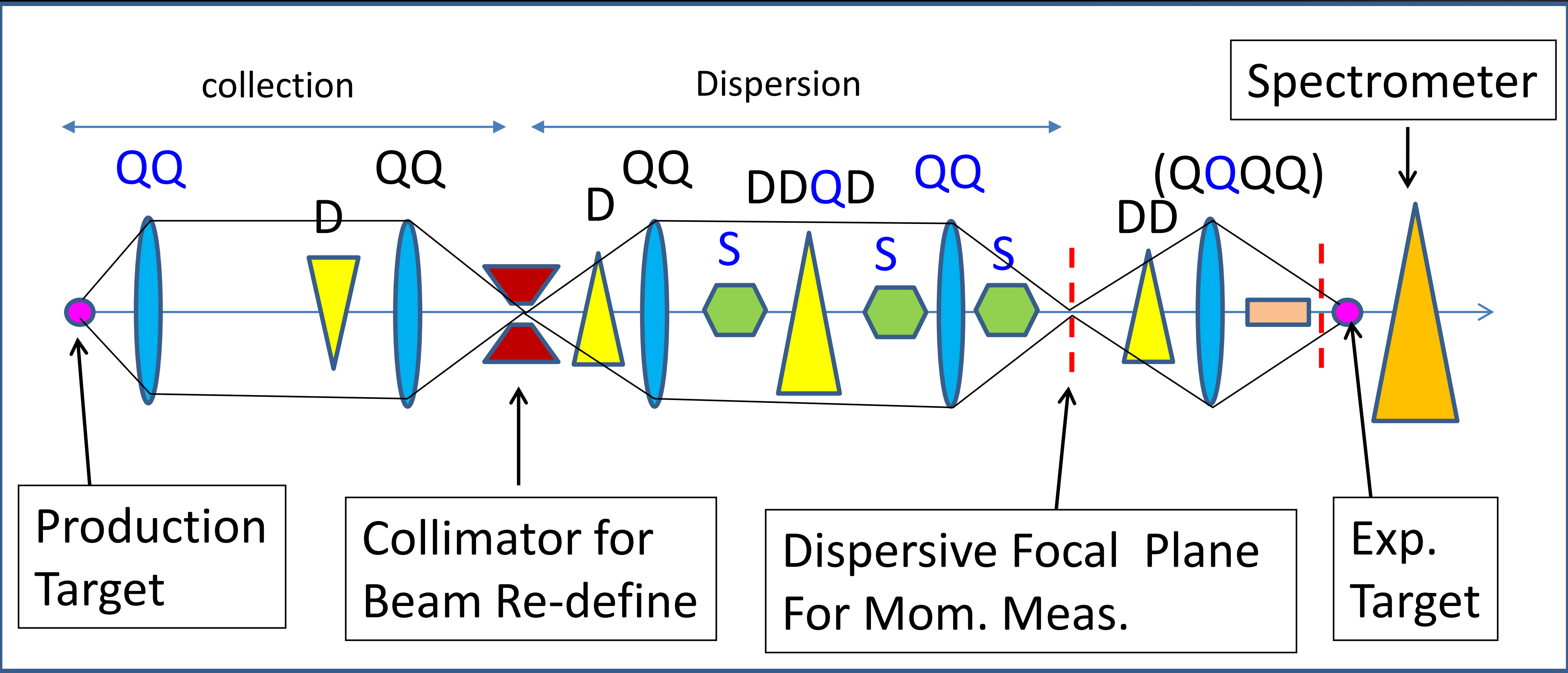
High-res., High-momentum Beam Line

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



High-res., High-momentum Beam Line

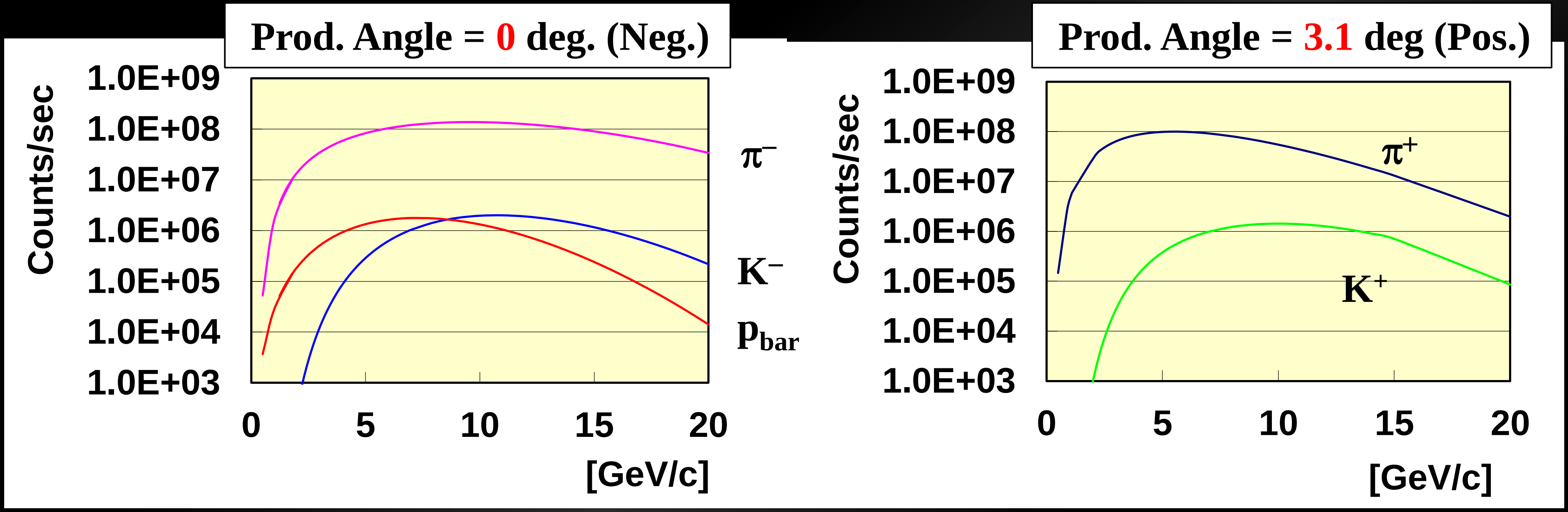
- High-intensity secondary Pion beam
- High-resolution beam: $\Delta p/p \sim 0.1\%$



High-res., High-momentum Beam Line

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

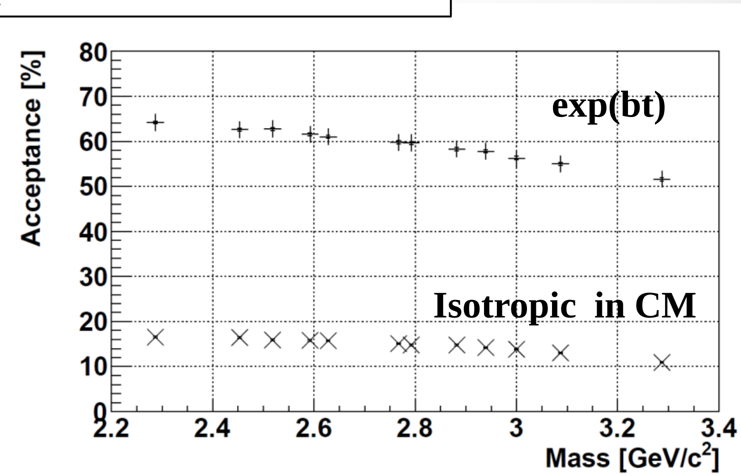
Sanford-Wang
15 kW Loss on Pt
Acceptance :1.5 msr%, 133.2 m



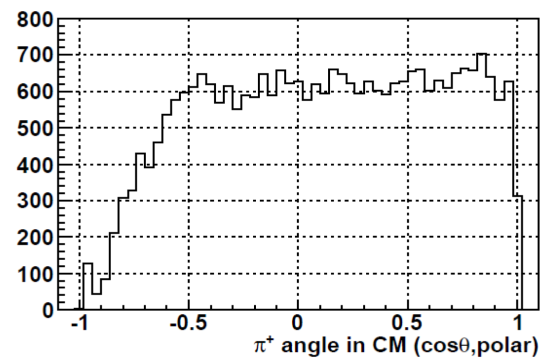
Basic performances

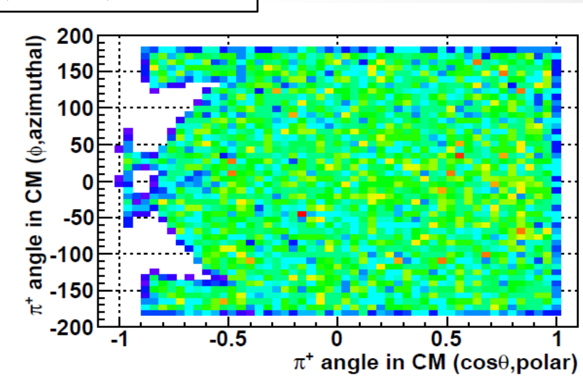
- **Resolution**
  - **Missing mass resolution**
    - Λ_c^+: 16.0 MeV
    - $\Lambda_c(2880)^+$: 9.0 MeV
- **Acceptance**
  - **for D^{*-} $(K^+p^-p^-)$: 50–60%**
  - **for decay particles: ~85%**
    - ∗ complete coverage cosθ > –0.5

Acceptance: D*⁻ detection



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





Forward direction (Beam direction) →

Backup slides for estimation of the production Cross Section

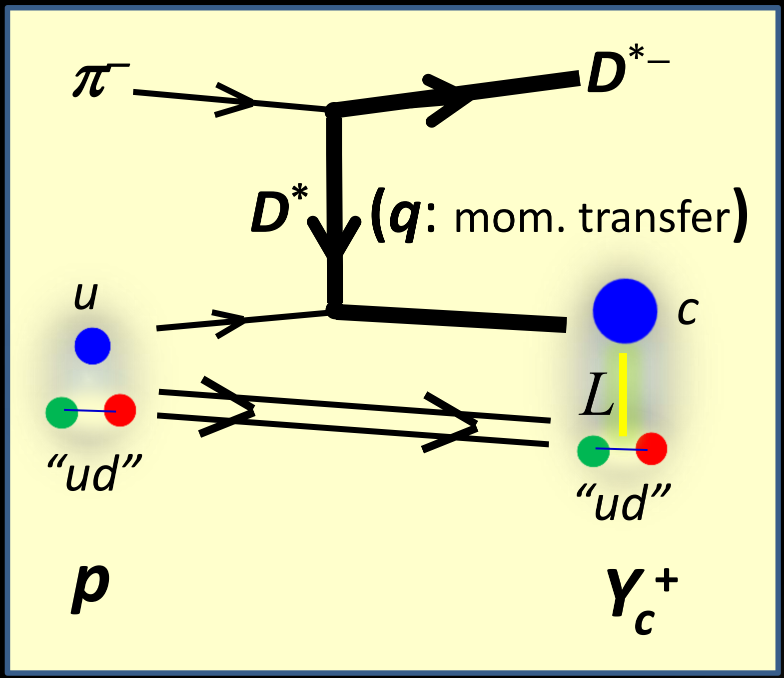
Calculated production rates (revised)

	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	0.17
L=1	$\Lambda_c^{1/2-}$	2595	1/2	1/3	1.37	0.93
	$\Lambda_c^{3/2-}$	2625	1/2	2/3	1.38	1.75
	$\Sigma_c^{1/2-}$	2750	1/6	1/27	1.49	0.02
	$\Sigma_c^{3/2-}$	2820	1/6	2/27	1.50	0.04
	$\Sigma_c^{1/2-\prime}$	2750	1/6	2/27	1.49	0.05
	$\Sigma_c^{3/2-\prime}$	2820	1/6	56/135	1.50	0.21
	$\Sigma_c^{5/2-\prime}$	2820	1/6	2/5	1.50	0.21
L=2	$\Lambda_c^{3/2+}$	2940	1/2	2/5	1.42	0.49
	$\Lambda_c^{5/2+}$	2880	1/2	3/5	1.41	0.86

Populated states: (π^-, K^{*0})

		p_π=4.5 GeV/c	Mass (GeV/c)	*isospin factor*	*Spin factor*	q_{eff} (GeV/c)	*Rate (Relative)*	$\sigma(\mu b)$
L=0		$\Lambda^{1/2+}$	1116	1/2	1	0.29	1	53(+-2)*
L=0		$\Sigma^{1/2+}$	1192	1/6	1/9	0.32	0.049	2.6
L=0		$\Sigma^{3/2+}$	1385	1/6	8/9	0.38	0.244	12.9
L=1	λ	$\Lambda^{1/2-}$	1405	1/2	1/3	0.36	0.072	3.8
L=1	λ	$\Lambda^{3/2-}$	1520	1/2	2/3	0.40	0.127	6.7
L=1	ρ	$\Lambda^{1/2-}$	1670	excited through λ/ρ mixing			0.007	0.4
L=1	ρ	$\Sigma^{3/2-}$	1690				0.004	0.2
L=1	ρ	$\Lambda^{3/2-\prime}$	1690				0.013	0.7
L=1	λ	$\Sigma^{1/2-\prime}$	1750	1/6	2/27	0.53	0.004	0.2
L=1	λ	$\Sigma^{5/2-\prime}$	1775	1/6	2/5	0.55	0.018	1.0
L=2	λ	$\Lambda^{3/2+}$	1890	1/2	2/5	0.56	0.025	1.3
L=2	λ	$\Lambda^{5/2+}$	1820	1/2	3/5	0.52	0.052	2.8

Production Rate



- *t*-channel *D** *Reggeon* at a forward angle

A. Hosaka et al., paper in preparation.

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})

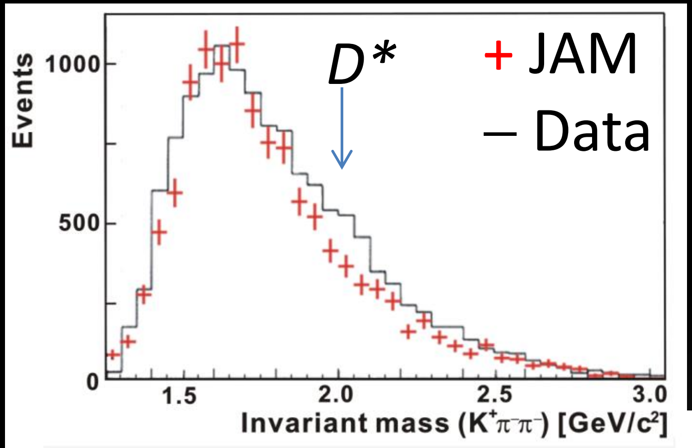
$$I_L \sim (q_{eff}/A)^L \exp(-q_{eff}^2/2A^2)$$

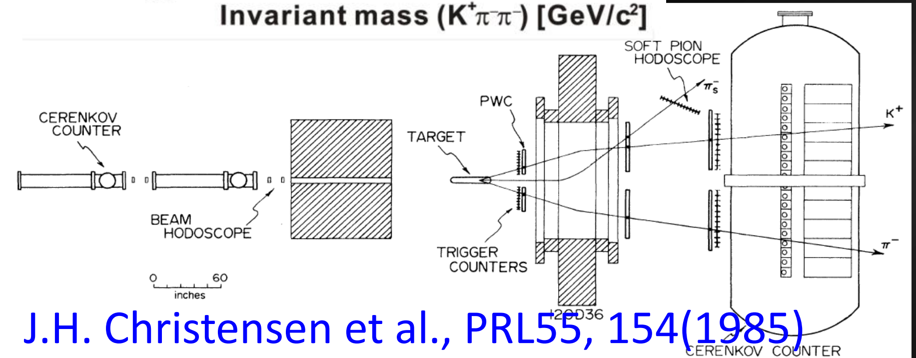
A~0.42 GeV ([Baryon size]$^{-1}$)
q_{eff}~1.4 GeV/c

Production Cross Section

A. Hosaka et al., paper in preparation.

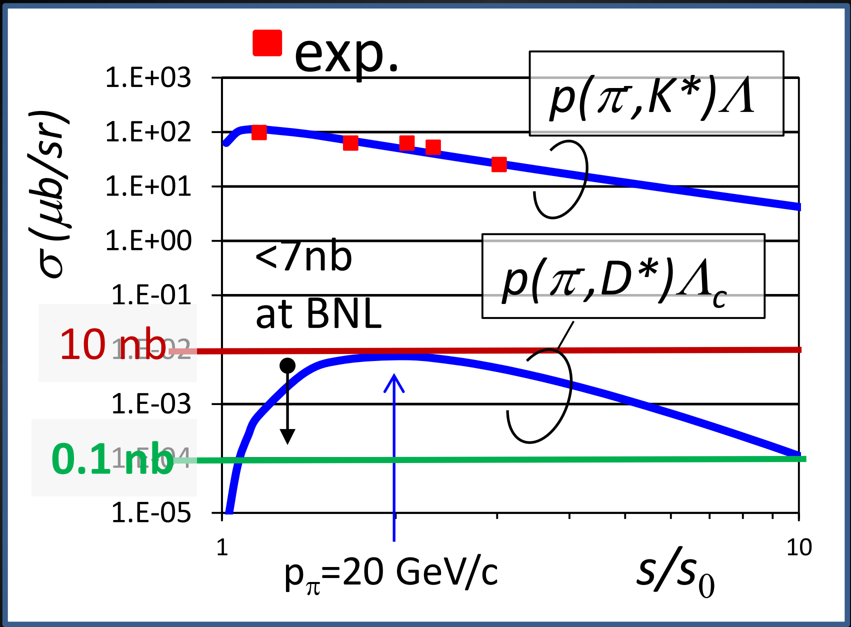
- Experimental data:
  - $\sigma(p(\pi^-,D^{*-})\Lambda_c) <$ 7 nb (68%CL) (BNL exp., 1985)
  - BG spectrum is well reproduced by a MC simulation w/ JAM
- Regge Theory suggests 10^{-4} of the hyperon production
  - $\sigma(p(\pi^-,D^{*-})\Lambda_c) \sim$ a few nb





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

Regge Theory



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*

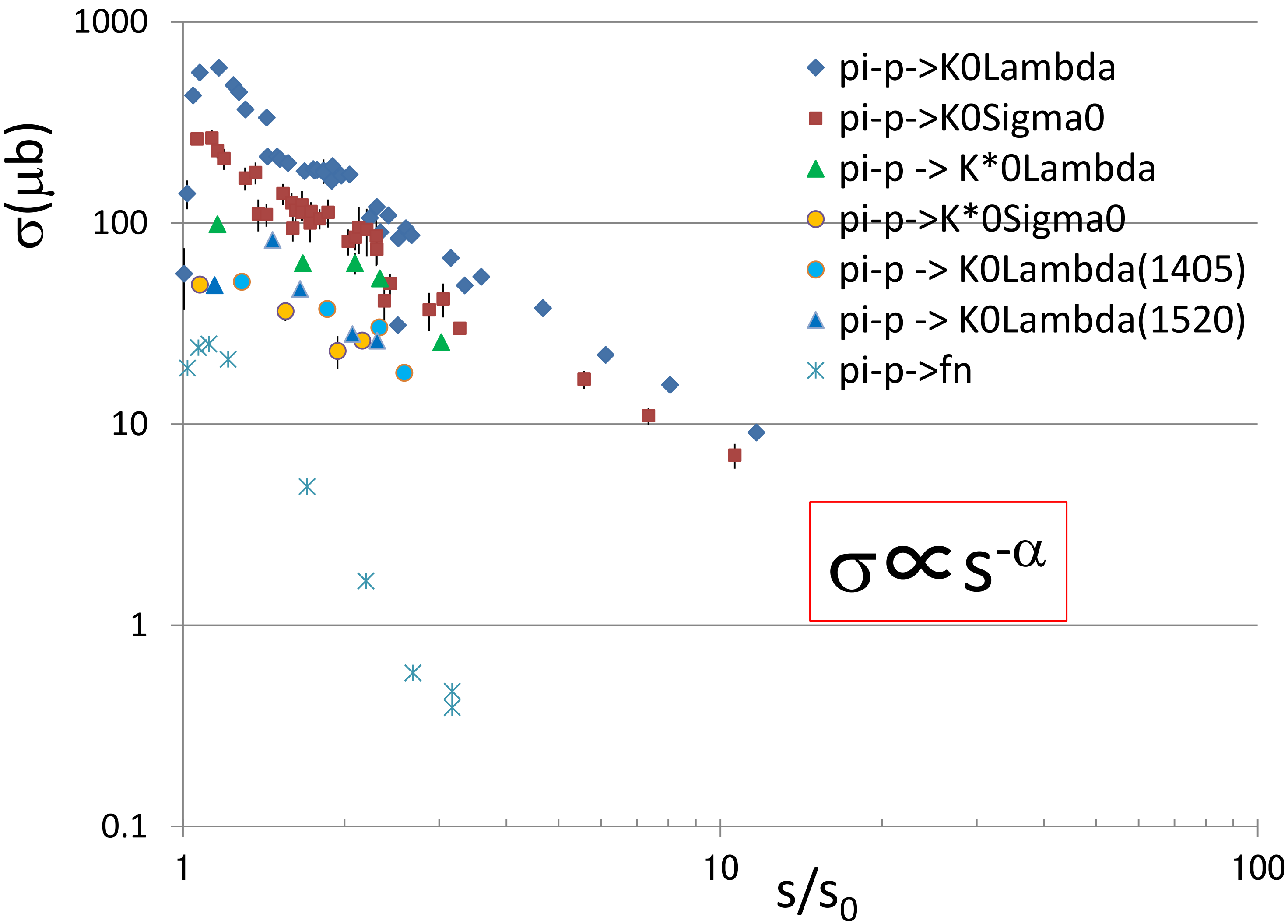
*note:g[Bracco]/2=g[Khodjamirian]

$g_{K^*K\pi}$	$g_{D^*D\pi}$	$g_{D^*D\pi}/g_{K^*K\pi}$
~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 $\sigma(p(\pi,D^*)\Lambda_c)$ ~a few nb.

Comparison in strange sector



$\sigma \propto s^{-\alpha}$

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

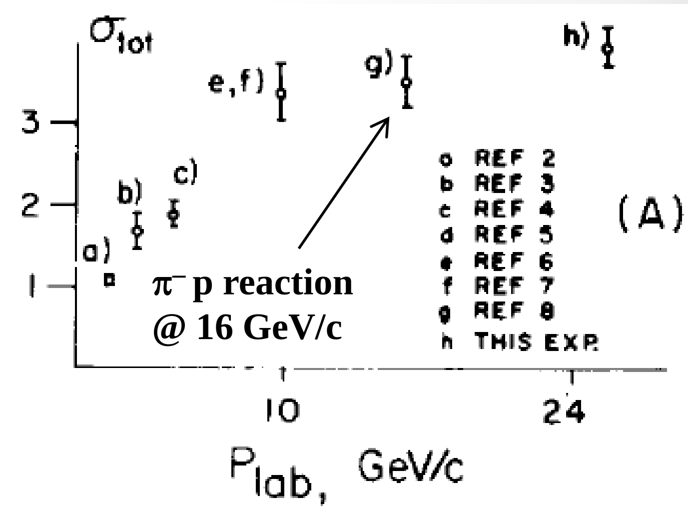
All events including K^+, π^-, π^-

- ∗ 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**
  - $K^{*0}(\to K^+, \pi^-) + \pi^-$
  - 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**
  - $\rho/(\pi+\rho)$ = 0.5, K*/(K+K*)=0.6, D*/(D+D*)=0.75

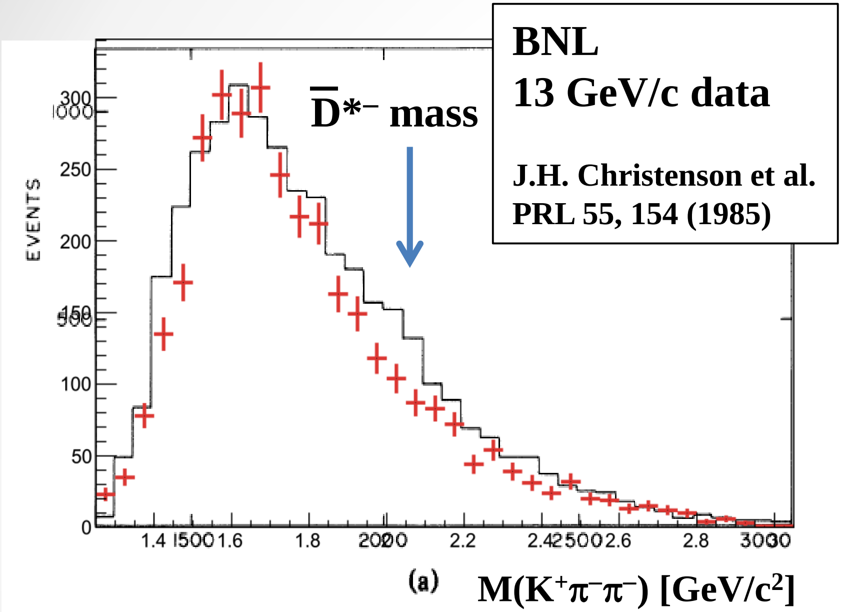
∗ Almost same as of PYTHIA

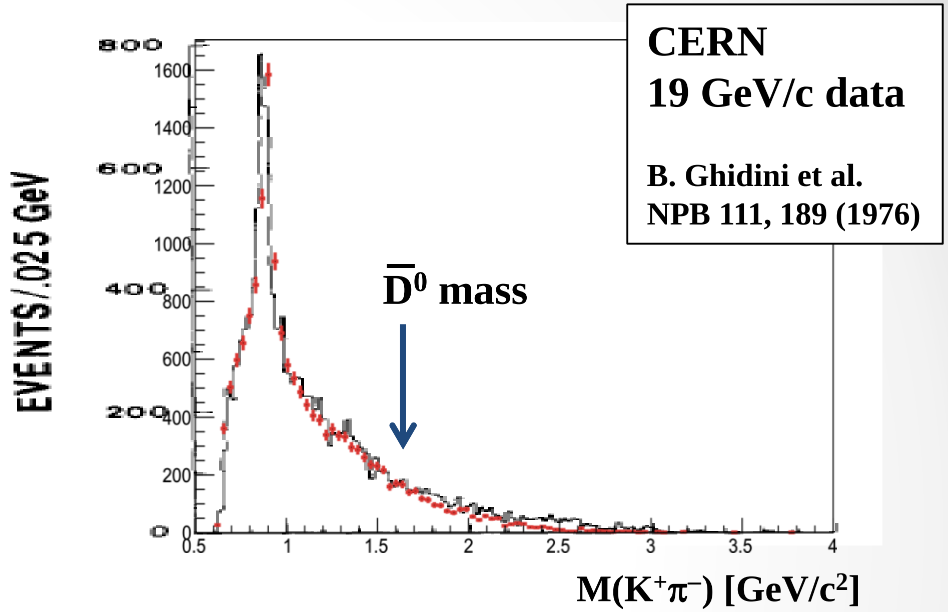
Difference from PYTHIA

- 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.)**

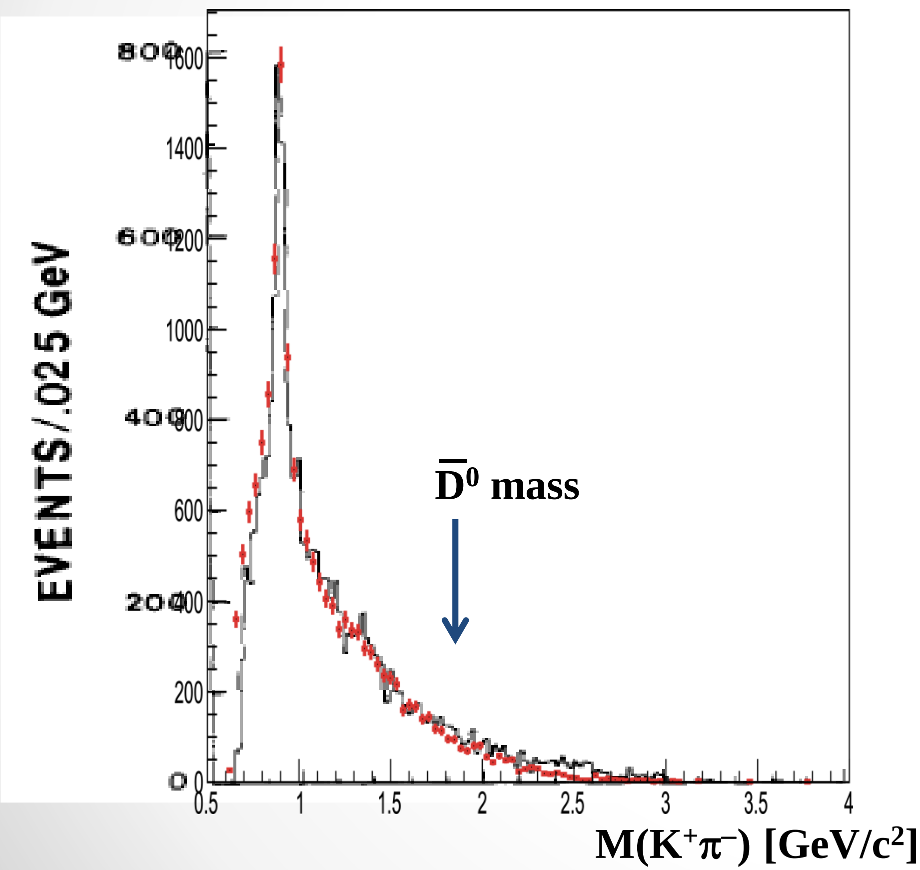
⇒ Old data background reproduced with small ambiguity (20-30%)

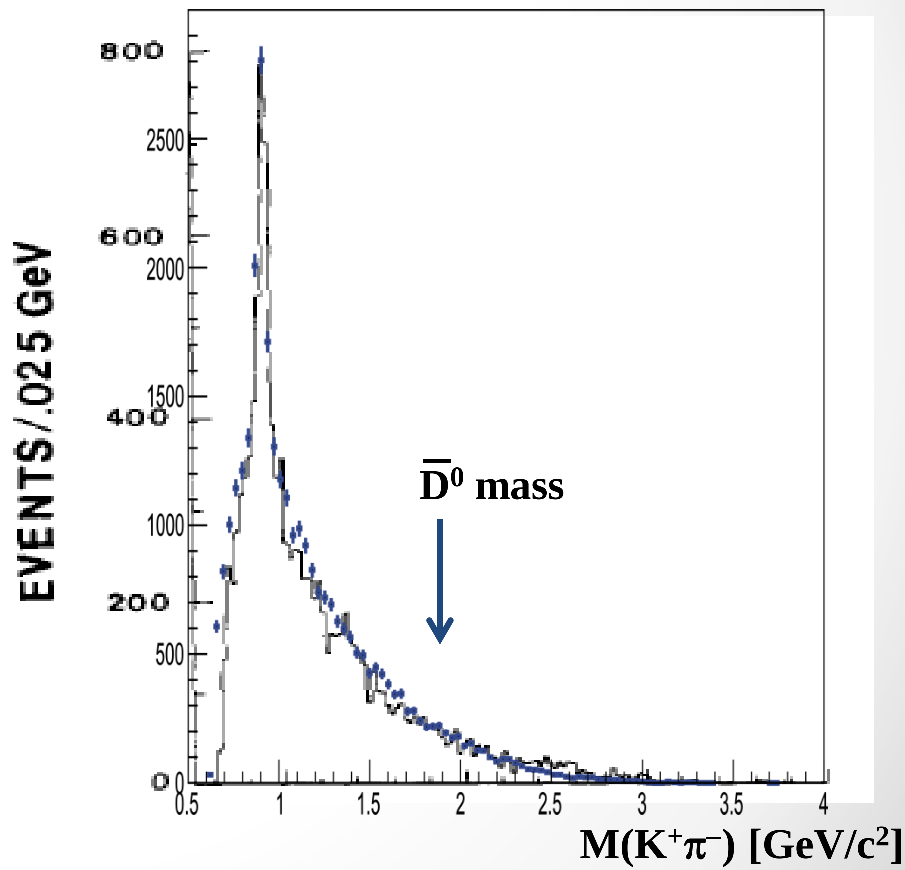
JAM simulation check: $M(K^+ \pi^-)$

Black line	Data
Red line	JAM simulation
Blue line	PYTHIA simulation

CERN
19 GeV/c data

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





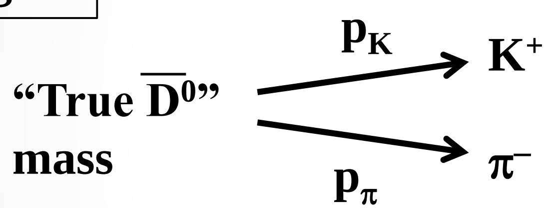
Peak position normalized

Backup slides for the BG reduction

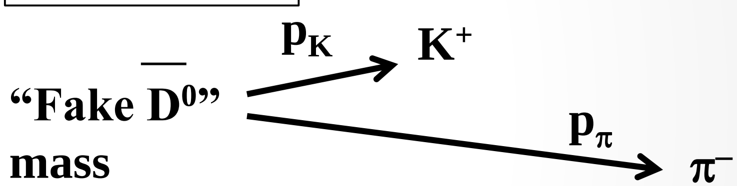
Background reduction

- S/N improvement (reduction factor):
  - Mass resolution: 2×10^6
  - Decay angle cut: 2
  - Production angle cut 4 (depends on $d\sigma/dt$)

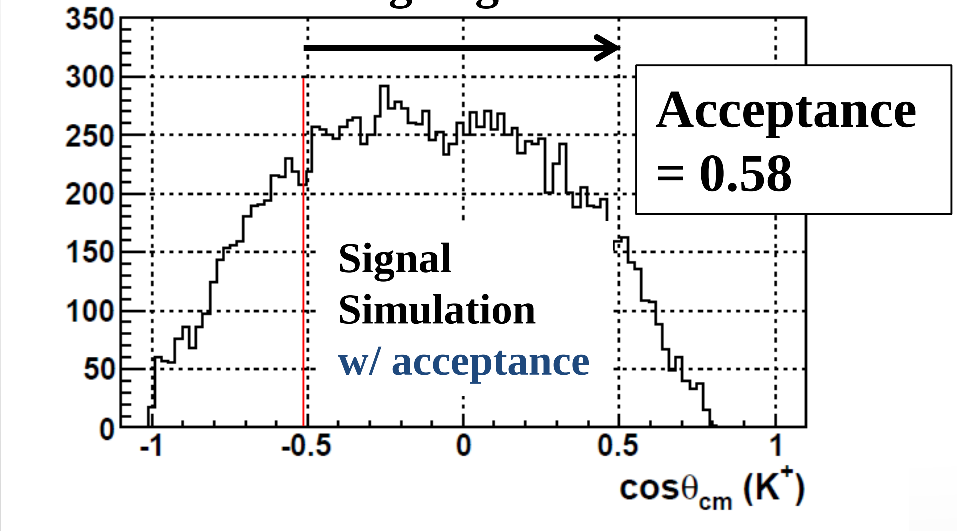
Signal



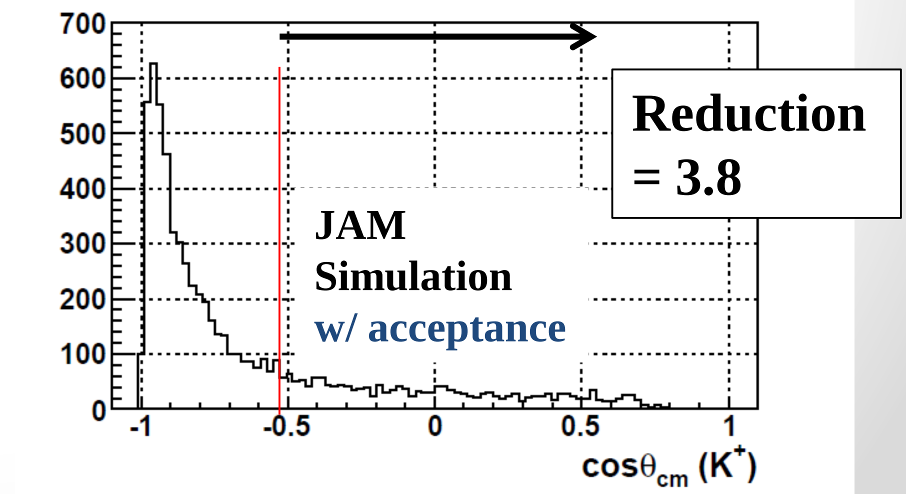
Background



K^+ scattering angle in CM



K^+ scattering angle in CM



Background reduction

Total cross section @ 20 GeV/c: 25.1 mb

- **(K^+, π^-, π^-) final state: 2.43 mb**
- **D^0 mass region (1.852–1.878 GeV/c^2): 21.7 μb (1/112)**
- **D^{*-} tagging (Q = 4.3–7.5 MeV): 50.2 nb (1/434)**
  - **Old experiment: 1/100 by 4 time worse resolution**
- **Acceptance: 1.2 nb (1/43)**
  - **Detector: 50% for D* tagged background events**
  - **Momentum cut (p_{K+} & $p_{\pi-}$ > 2.0 GeV/c, Soft π^- = 0.5–1.7 GeV/c)**

- **Total reduction: $112 \times 434 \times 43 \sim 2 \times 10^6$**

S/N ratio

Background reduction

- **Total reduction: 112 × 434 × 43 ~ 2 × 10^6**
- **Event selection: 16**

- **Signal: 12 nb (1 nb × 12 states)**
  - **B.R. × 0.026 ⇒ 0.312 nb**
  - **Event selection × 1/2 ⇒ 0.156 nb**
- **BG: 2.43 mb ((K^+, π^-, π^-) final state)**
  - **0.081 nb**

⇒ S/N = 2.1 for D^0 and D* mass region

S/N estimation

- **Signal: 12 × 1000 = 12000 counts**
- **BG: 12000/2.1 = 5700 counts**

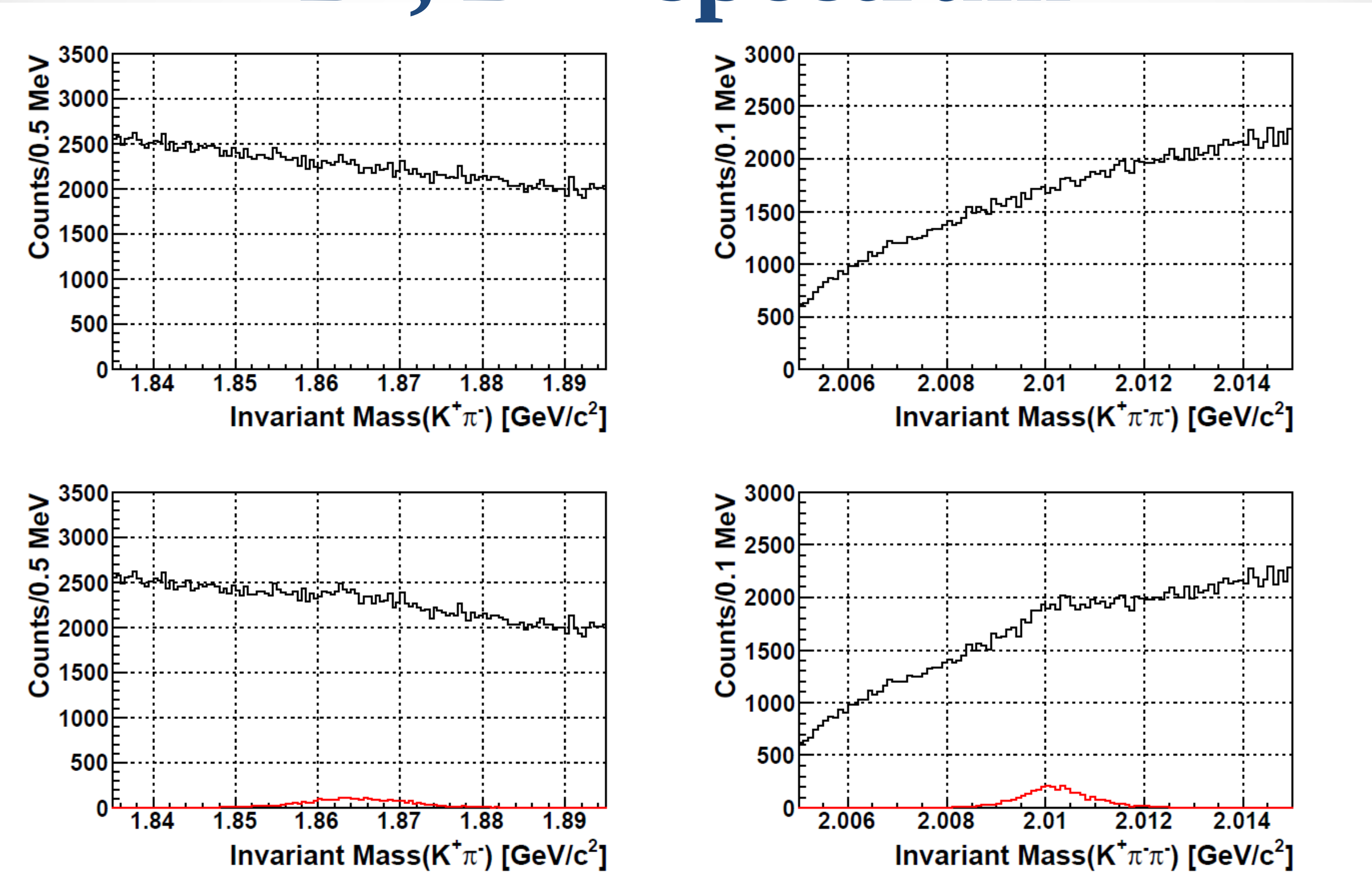
⇒ Mass region: 2.2-3.4 GeV ⇒ ~5 counts/MeV

⇒ S/N = 1000/150 ~ 7

  - **30 MeV region: 150 counts**

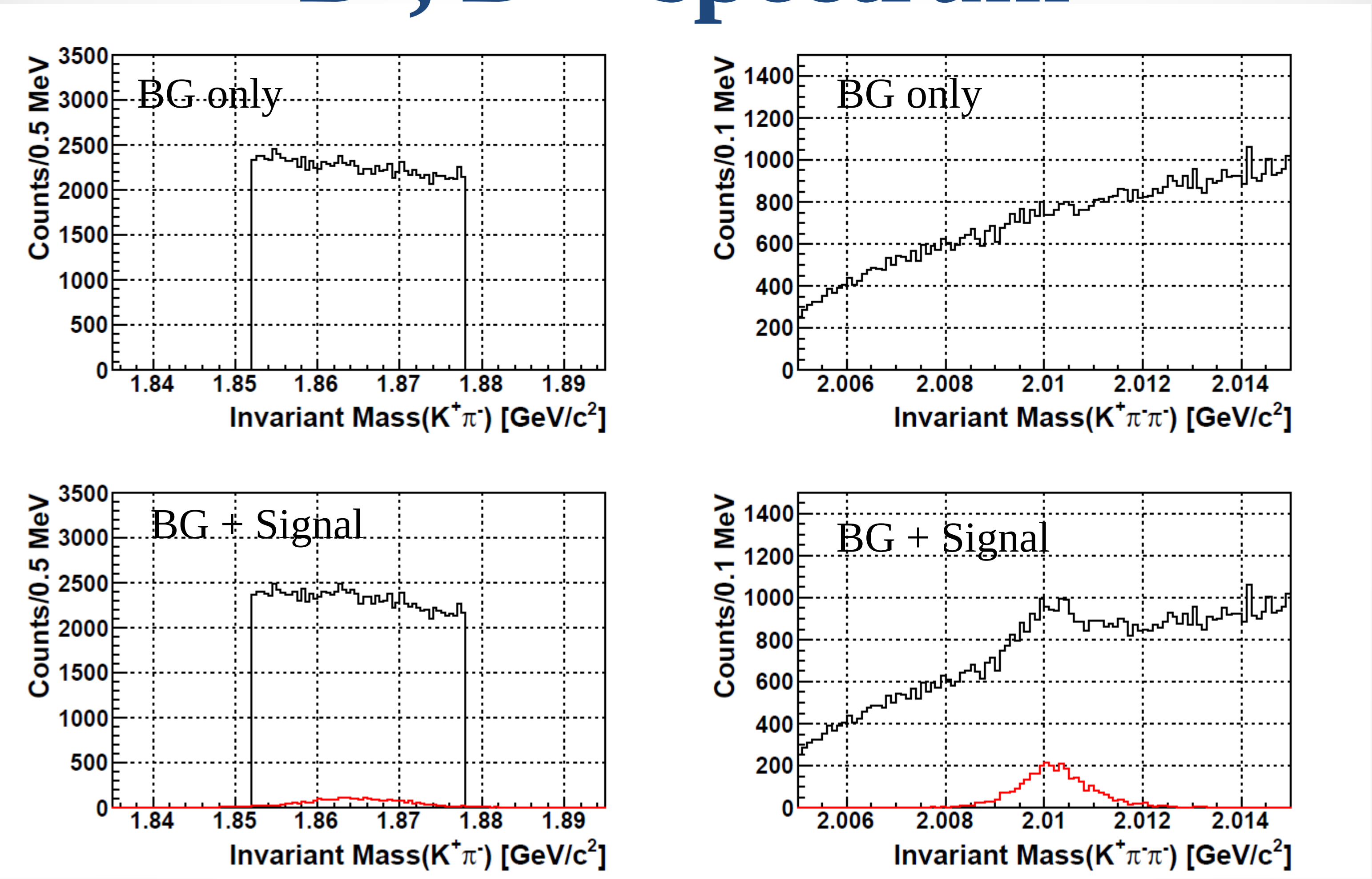
- **$S/\sqrt{N} = 100/\sqrt{1000} \sim 3$**
  - **Signal: σ= 0.1 nb, Γ = 100 MeV: ⇒ 100 counts**
  - **BG: 200 MeV region ⇒ 1000 counts**

D^0, D^{*-} spectrum



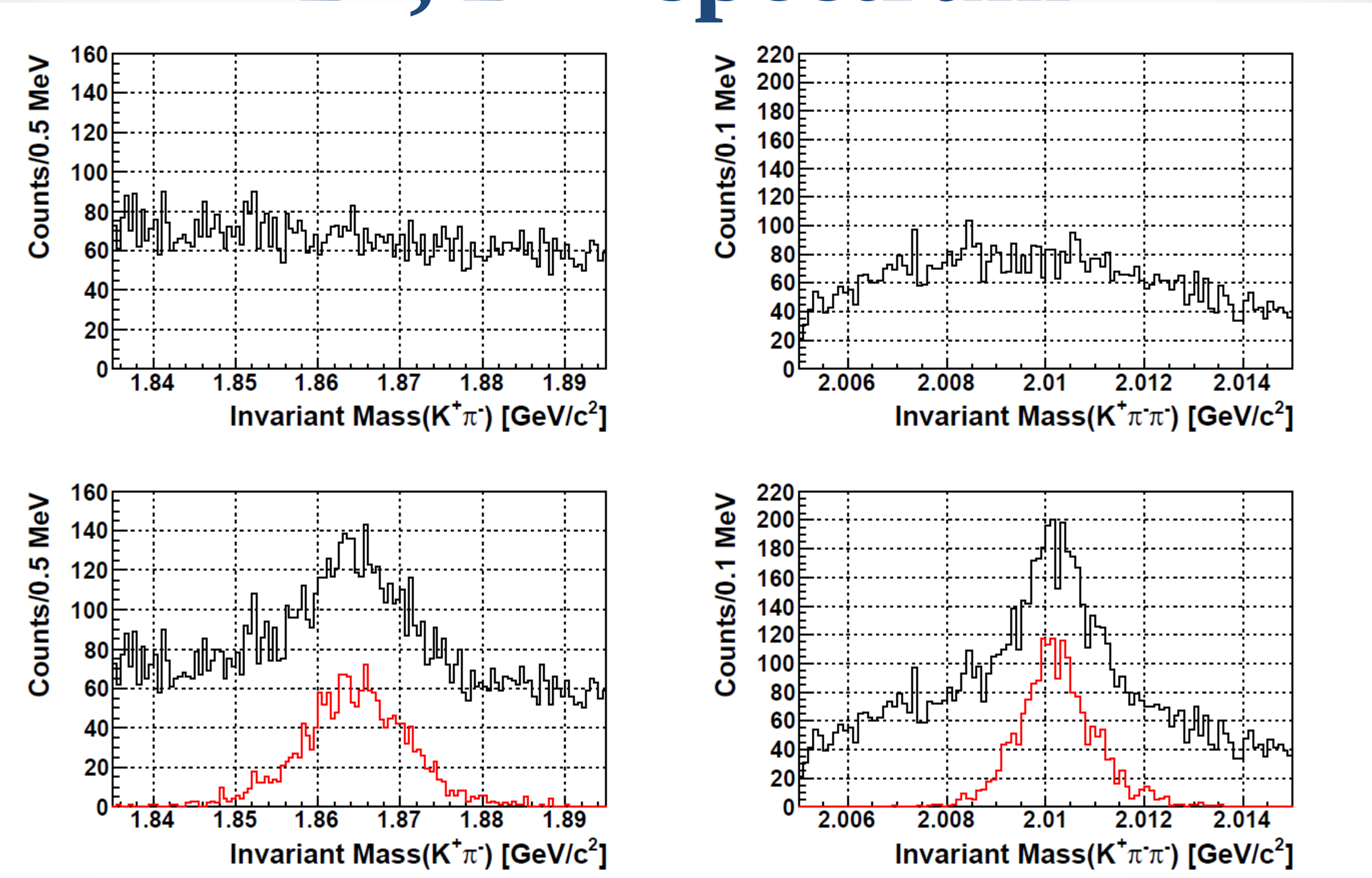
- **Full conditionの1/7 event, 12 nb in total: ~ 3200 events**
- **Invariant massを組むだけだとpeakは見えない**
  - **BGが連続的な分布なのでfittingすれば有意なpeakと認識される**

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**

D^0, D^{*-} spectrum



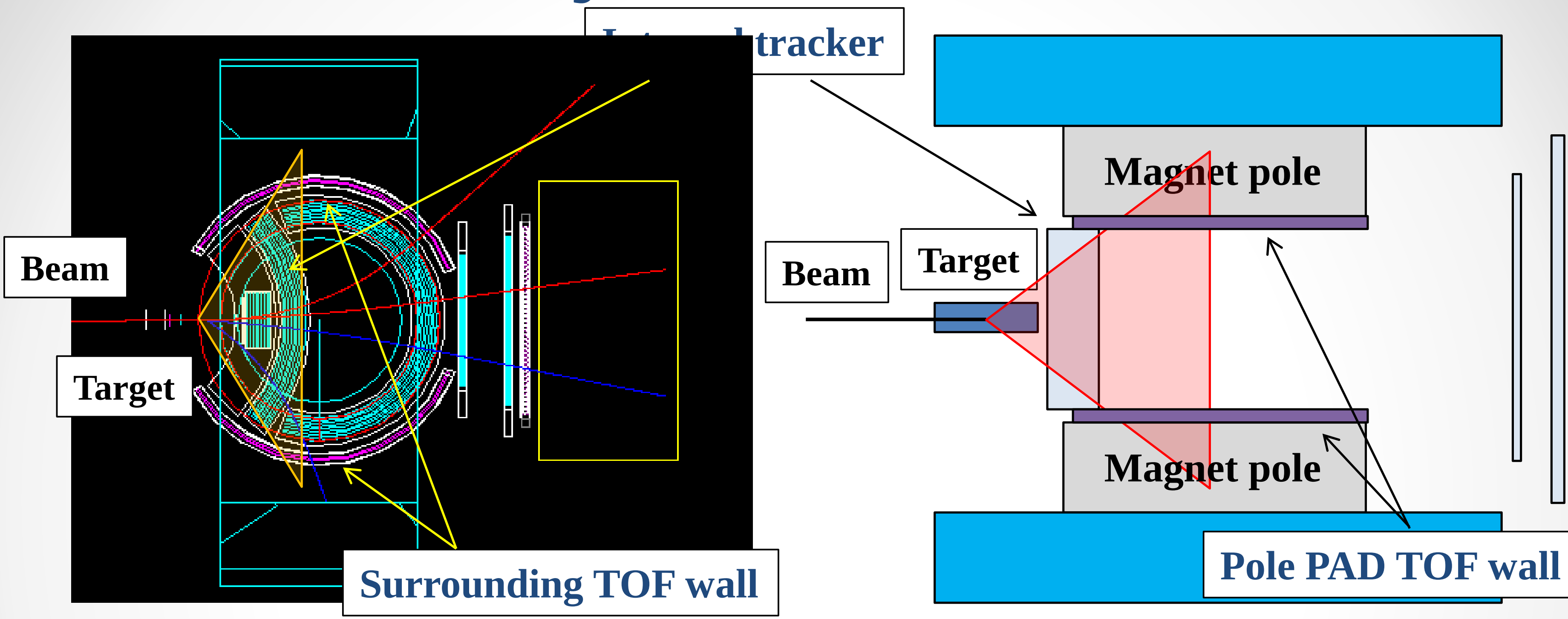
- Full conditionの1/7 event, 12 nb in total: ~ 2000 events
- t-channel dominanceを利用したevent selection
  - Clearなpeakが見える

Decay measurement

Setup modification

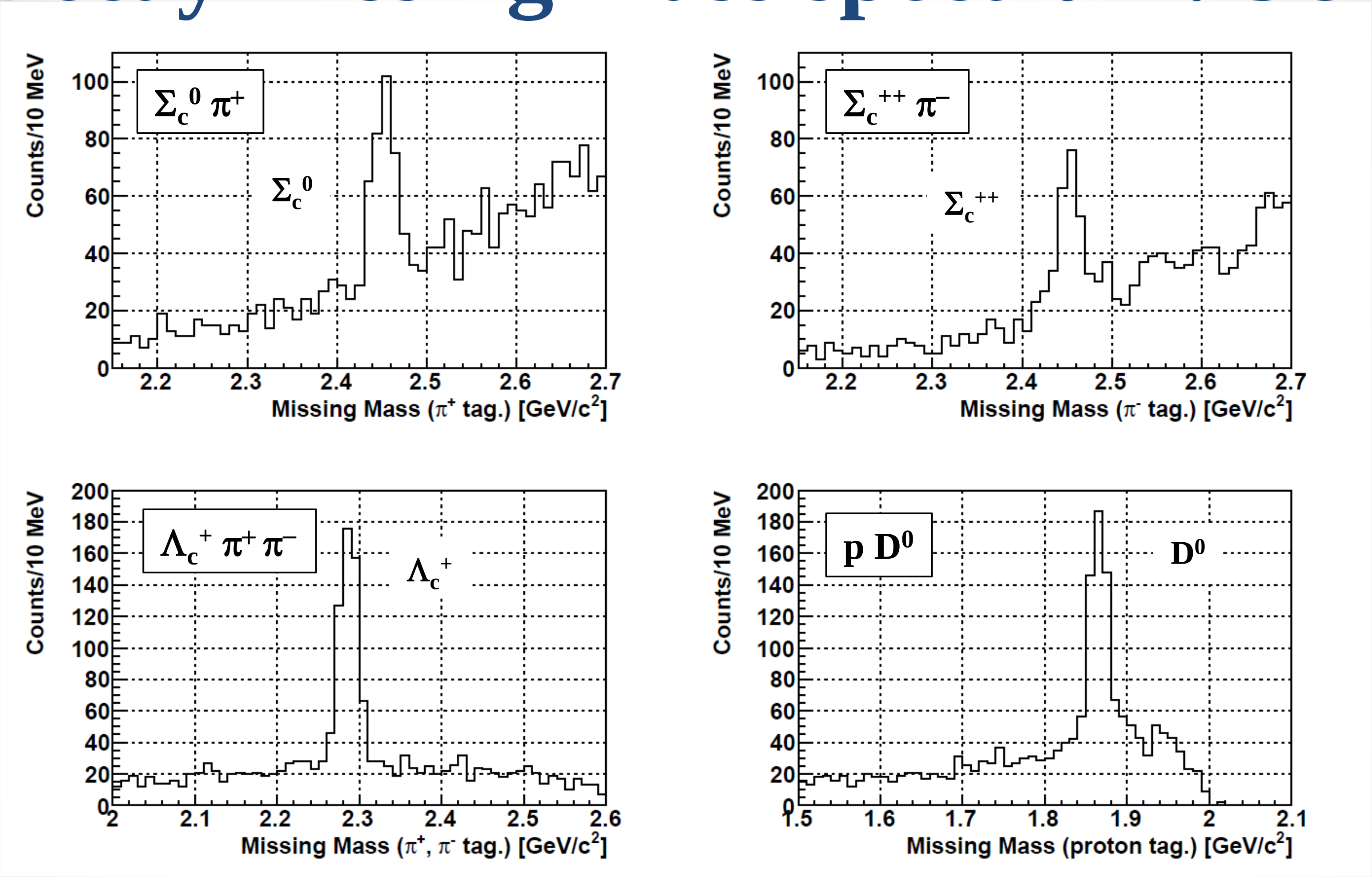
Performances

Decay measurement



- **Method: Mainly Forward scattering due Lorentz boost ($\theta < 40^\circ$)**
  - **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**

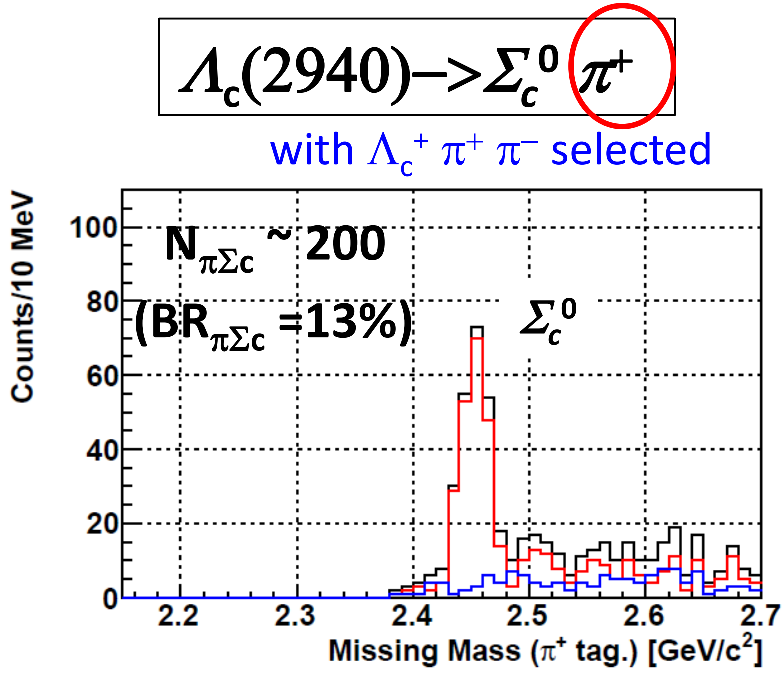
Decay missing mass spectrum: SUM

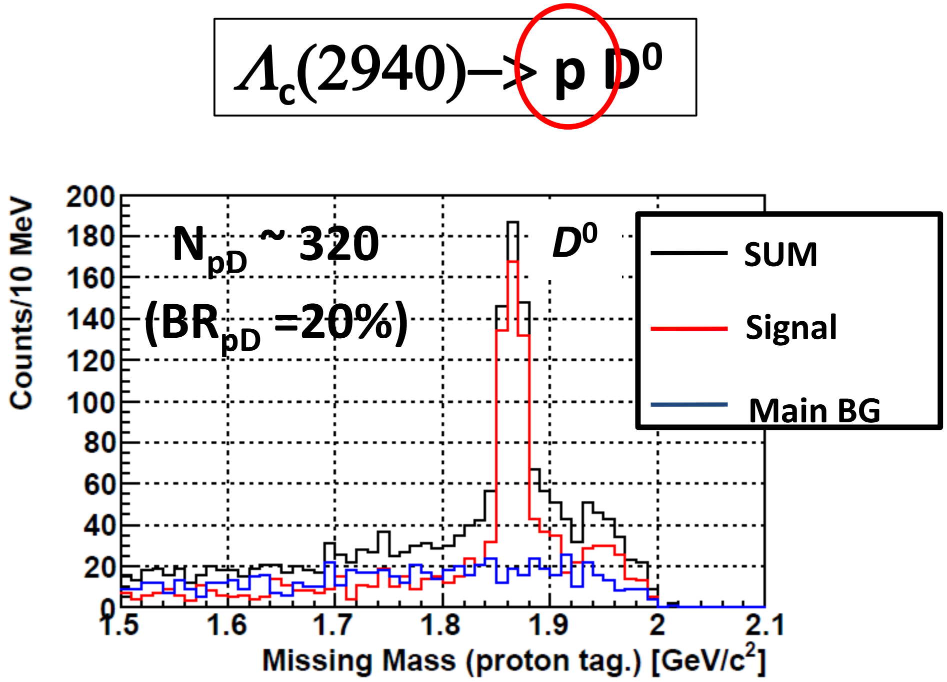


∗ **Full event w/ background/ No "$\Lambda_c^+ \pi^+ \pi^-$ gated"**

- **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.**

Decays





* Decay properties can be measured by the missing mass technique.

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

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 $\Rightarrow 1900 \times 0.2 \times 0.8 =$ ~300**
  - **$\Sigma_c^{++,0} \pi^{-,+}$: 0.4/3 $\Rightarrow 1900 \times 0.4/3 \times 0.8 =$ ~200**
    - **Forward scattering of protons**
    - **Wider scattering angle of pions**
    - **Combined with 4-body D^0 decay mode: 3 times larger yield**
      - **$D^0 \rightarrow K^+ \pi^-$ (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.**

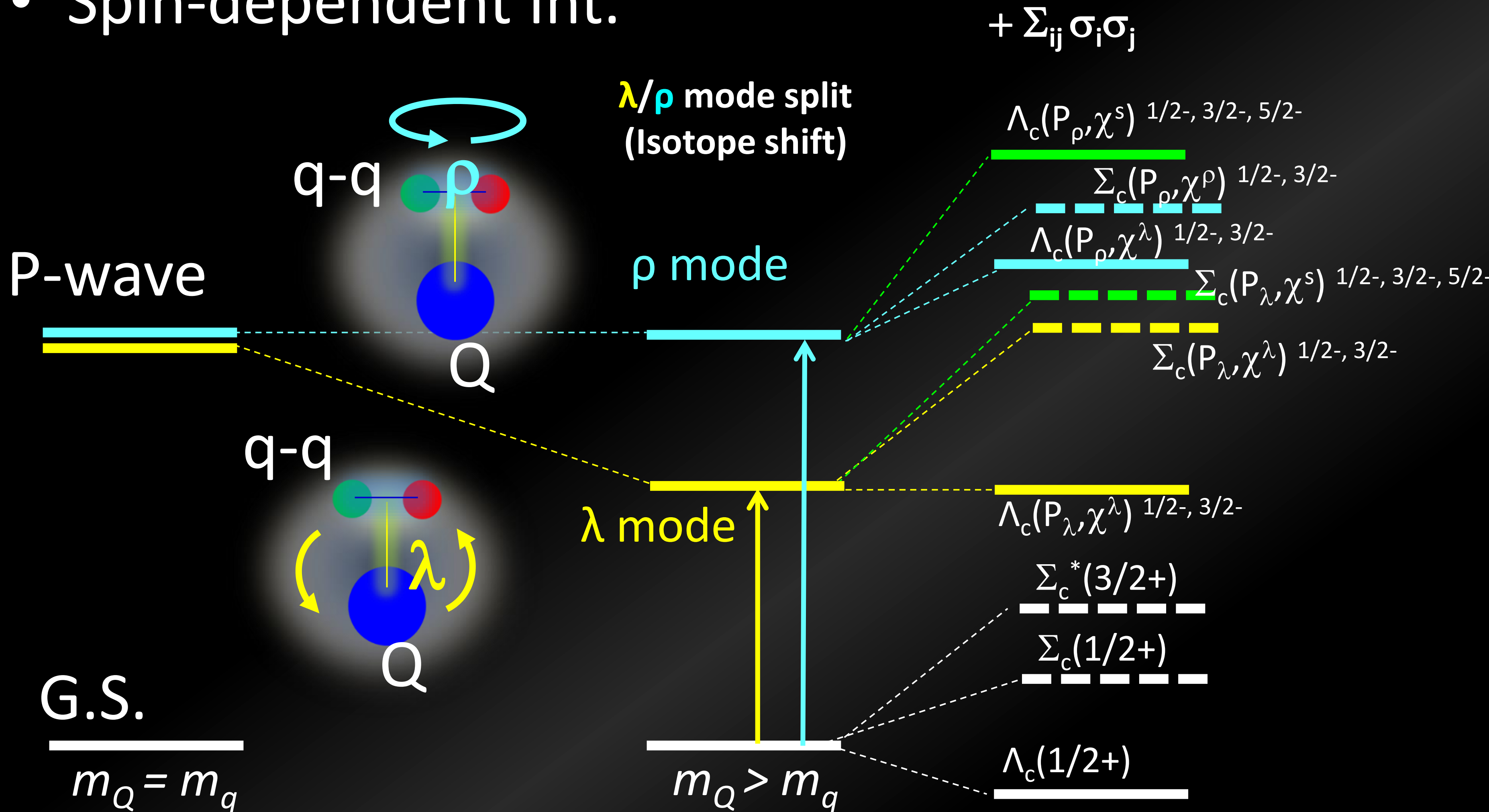
- **Signal counts**
  - **Combine 2-body and 4-body D^0 decay channels**
    - **$\Sigma_c\ \pi$ mode: > 500 counts**
    - **p D mode: > 800 counts**
  - **Braining ratio obtained with ~5% statistical error**
    - **Assumed branching ratio @ 1 nb case & 100 days beam time**
  - **Angular distribution**
    - **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**

Backup slides for Baryon Spectroscopy

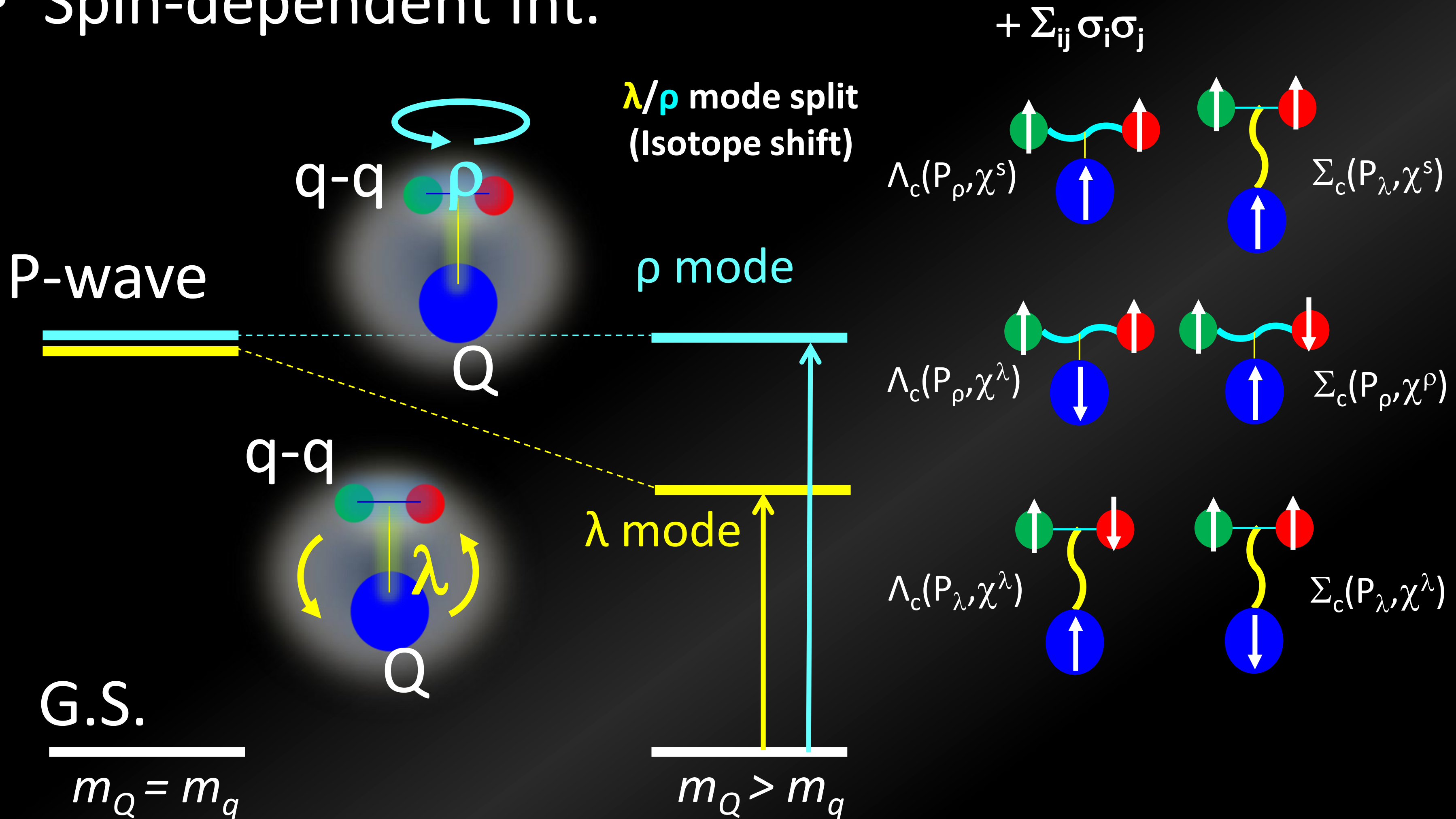
“Schematic” Level Structure of Heavy Baryons

- λ and ρ motions split (Isotope Shift)
- Spin-dependent Int.

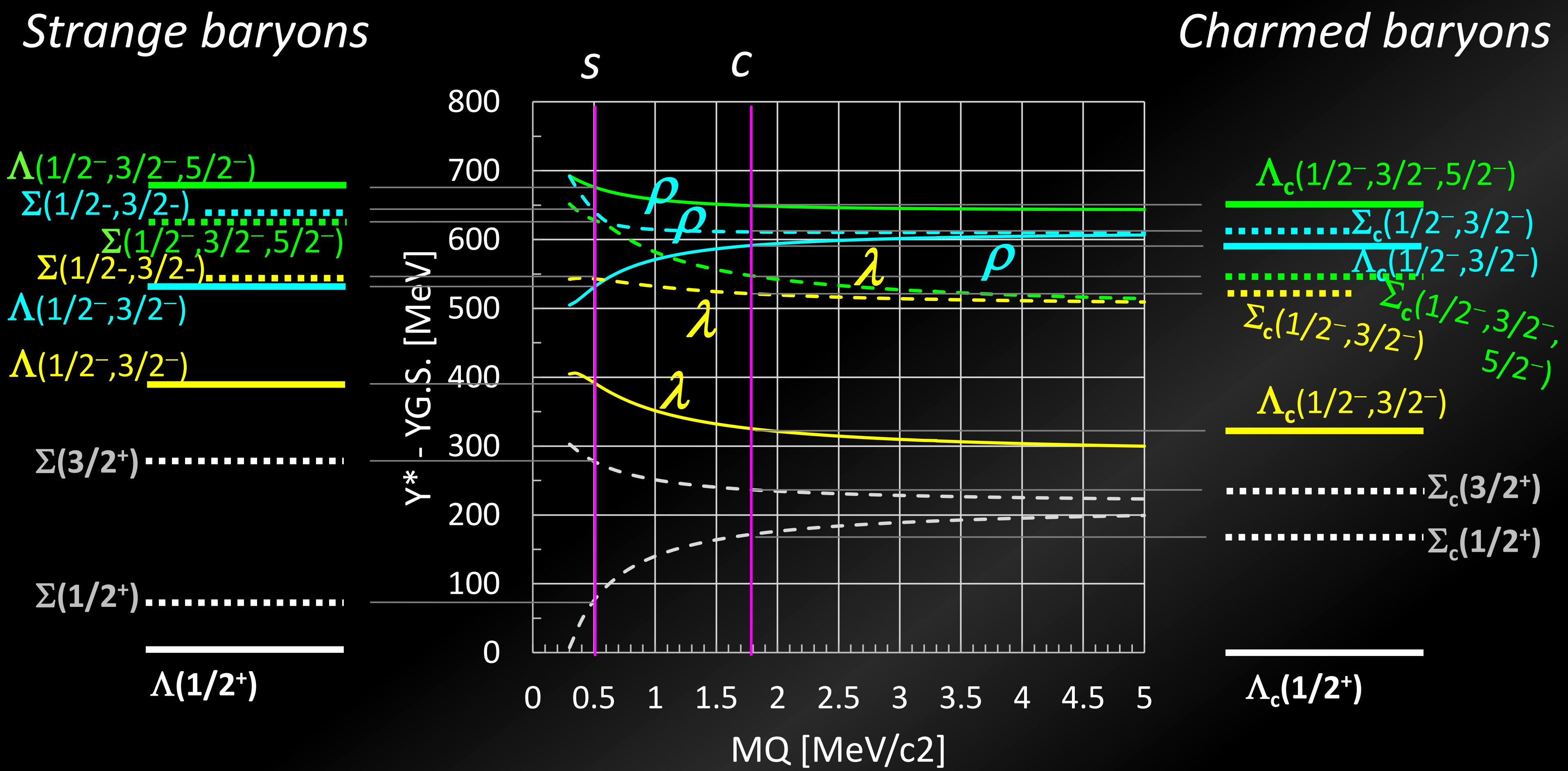


"Schematic" Level Structure of Heavy Baryons

- λ and ρ motions split (Isotope Shift)
- Spin-dependent Int.



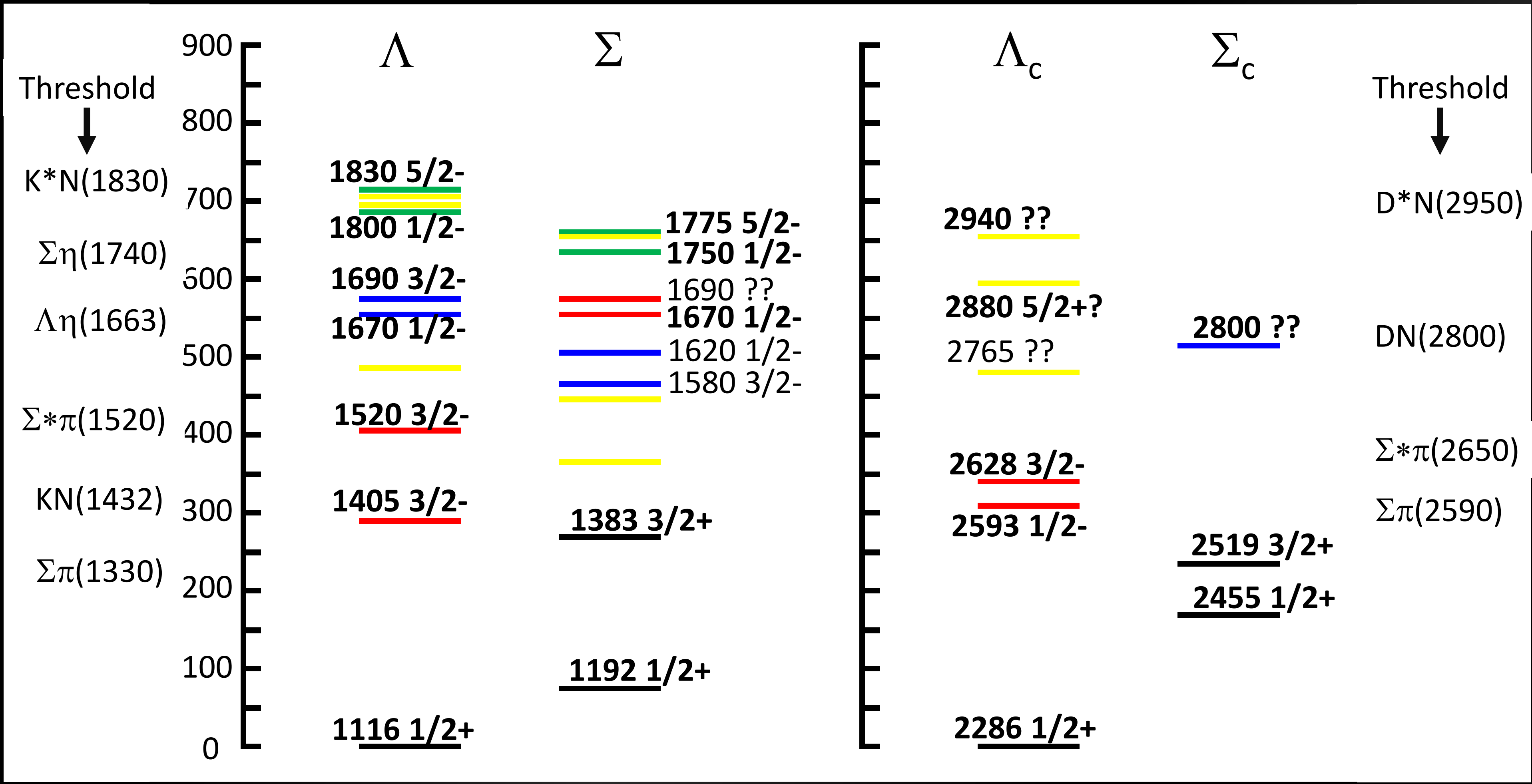
Baryon spectroscopy in different flavors



non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

ρ–λ mixing (cal. By T. Yoshida)

Level structure (Exp.)



Threshold			JP	rating	Width [MeV]	→NK [%]	→Λπ [%]	→Σπ [%]	
		Σ(1940)	3/2-	4*	220	<20	seen	Seen	
		Σ(1915)	5/2+	3*	120	5-15	seen	Seen	
	Λ(1890)		3/2+	4*	95	20~35		3~10	
		Σ(1880)	1/2+	2*	220?				
		Σ(1840)	3/2+	1*	120?				
K*N(1830)	**Λ(1830)**		5/2-	4*	95	3~10		35~75	
	Λ(1820)		5/2+	4*	80	55~65		8~14	
Ση(1790)	Λ(1810)		1/2+	3*	150	20~50		10~40	
	Λ(1800)		1/2-	3*	300	25~40		Seen	
Λη(1710)		**Σ(1775)**	5/2-	4*	120	37~43	14-20	2-5	
		Σ(1750)	1/2-	3*	90	10~40	seen	<8	(Ση)15~55
		Σ(1690)	??	2*					
	Λ(1690)		3/2-	4*	60	20~30		20~40	
		Σ(1670)	3/2-	4*	60	7~13	5~15	30-60	
KN(1432)	**Λ(1670)**		1/2-	4*	35	20~30		25~55	
Σπ(1330)		Σ(1620)	1/2-	1*					
		Σ(1580)	3/2-	1*					
Σ*π(1520)	Λ(1520)			4*	19	45+-1		42+-1	

Y* production and decay channels

- **Production**
  - $\pi^- + p \rightarrow \Lambda^*, \Sigma^{*0} + K^{*0}\ (K_s^0)$
    - From $K^{*0} \rightarrow K^+ \pi^-$ reconstruction
  - $\pi^- + p \rightarrow \Sigma^{*-} + K^{*+}\ (K^+)$
    - From $K^{*+} \rightarrow K_s^0 + \pi^+ \rightarrow \pi^+ \pi^- \pi^+$ reconstruction

  ✱ Both channels are needed to study each Y^* resonance

- **Decay**
  - $K_{bar}N$ mode
    - $\Lambda^* \rightarrow K^- p, K^0_{bar} n, (\Sigma^{*0} \rightarrow K^- p, K^0_{bar} n)$
    - $\Sigma^{*-} \rightarrow K^- n$
  - πY mode
    - $\Lambda^* \rightarrow \Sigma^- \pi^+, \Sigma^0 \pi^0, \Sigma^+ \pi^-$ $(\Sigma^{*0} \rightarrow \Lambda \pi^0, \Sigma^- \pi^+, \Sigma^0 \pi^0, \Sigma^+ \pi^-)$
    - $\Sigma^{*-} \rightarrow \Lambda \pi^-, \Sigma^- \pi^0, \Sigma^0 \pi^-$

  ✱ Detection of charged π or K

Simulation conditions

- **JAM simulation: $\pi^- + p$ reaction @ p_π = 5 GeV/c ($\sqrt{s}$ = 3.21 GeV)**
  - **w/ Charmed baryon spectrometer system**

⇒ To check background

  - **$K^{*0} \to K^+ \pi^-$ reconstruction (B.R. = 0.67)**
  - **$K^{*+} \to K_s^0 + \pi^+ \to \pi^+ \pi^- \pi^+$ reconstruction (B.R. = 0.67 × 0.5 × 0.69 = 0.23)**
  - **Production angle: Isotropic in CM**

- **Yield**

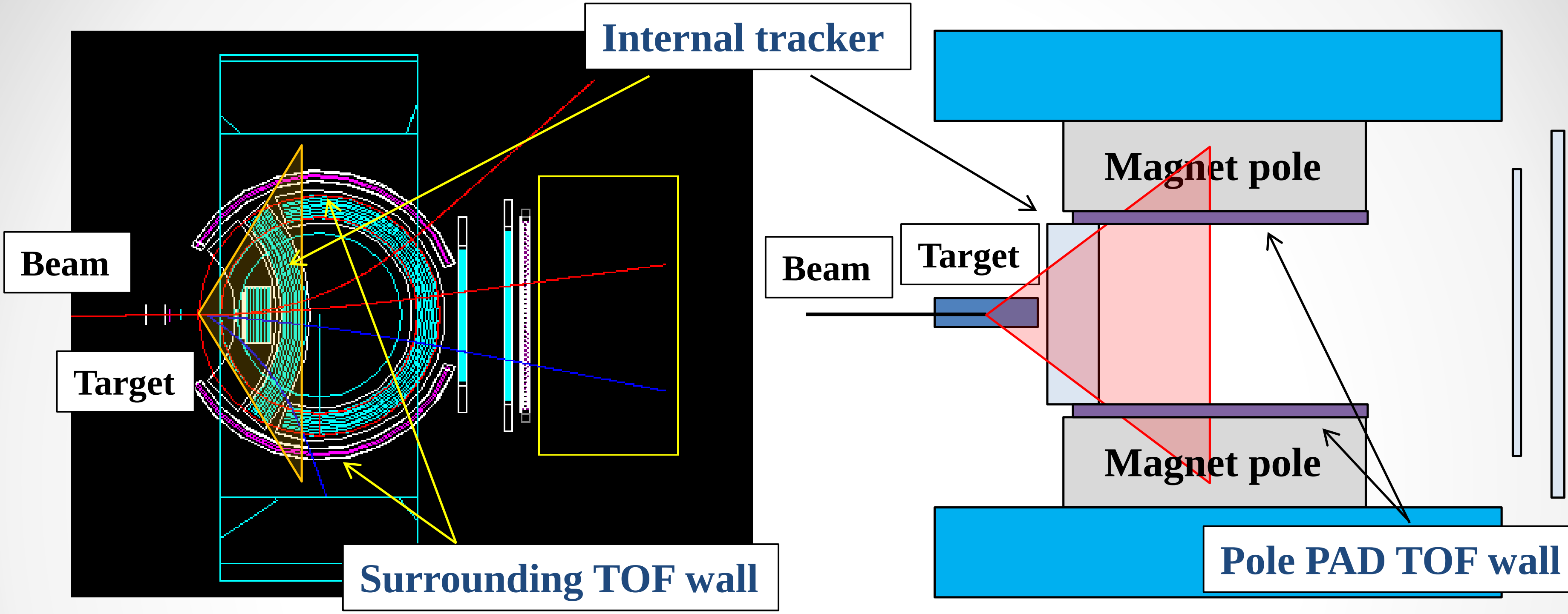
✱ $N_\pi = 1.0 \times 10^{12}$

  - **7 M/spill × 10 days**
  - **10 M/spill × 7 days**

⇒ N_{Y*} = 1.0 [μb] × 10^{-6} × 10^{-24} × 4.0 [g/cm^2] × 6.02 × 10^{23} × 1.0 × 10^{12} × 0.5 (acceptance) × 0.5 (efficiency)

= ~6.0 × 10^5 events (no branching ratio)

Acceptance



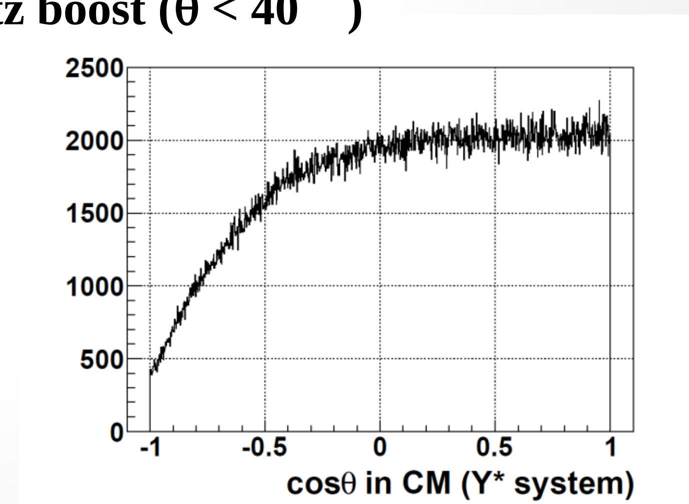
- Method: Mainly Forward scattering due Lorentz boost (θ < 40°)
  - Horizontal direction
    - Internal tracker and Surrounding TOF wall
  - Vertical direction
    - Internal tracker and Pole PAD TOF detector

  ⇒ ~70% acceptance for K* detection

- Decay measurement: Angle in CM

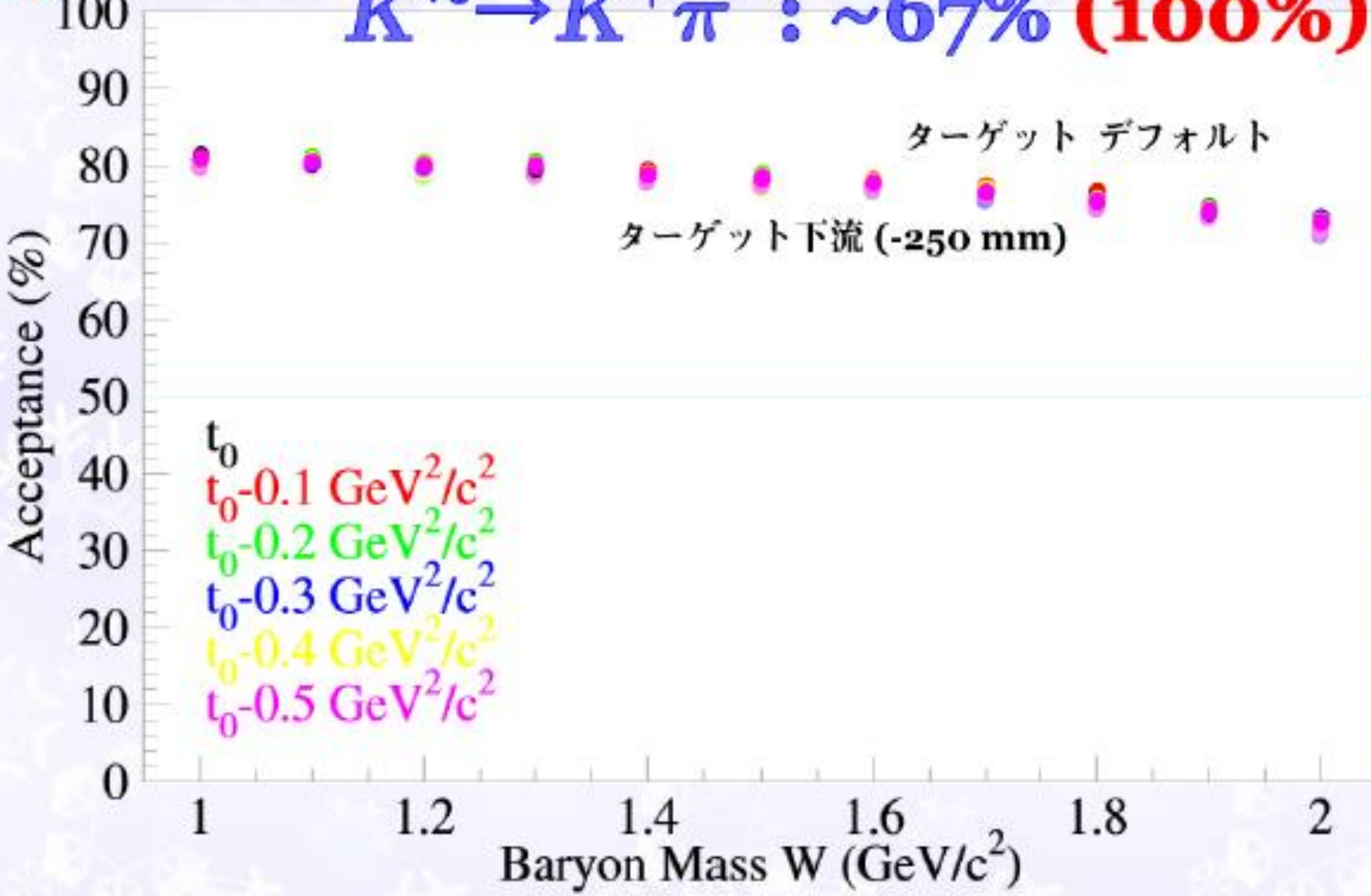
⇒ Both pole and azimuthal angles: cosθ > –0.5

- ✱Minor change of detector system needed



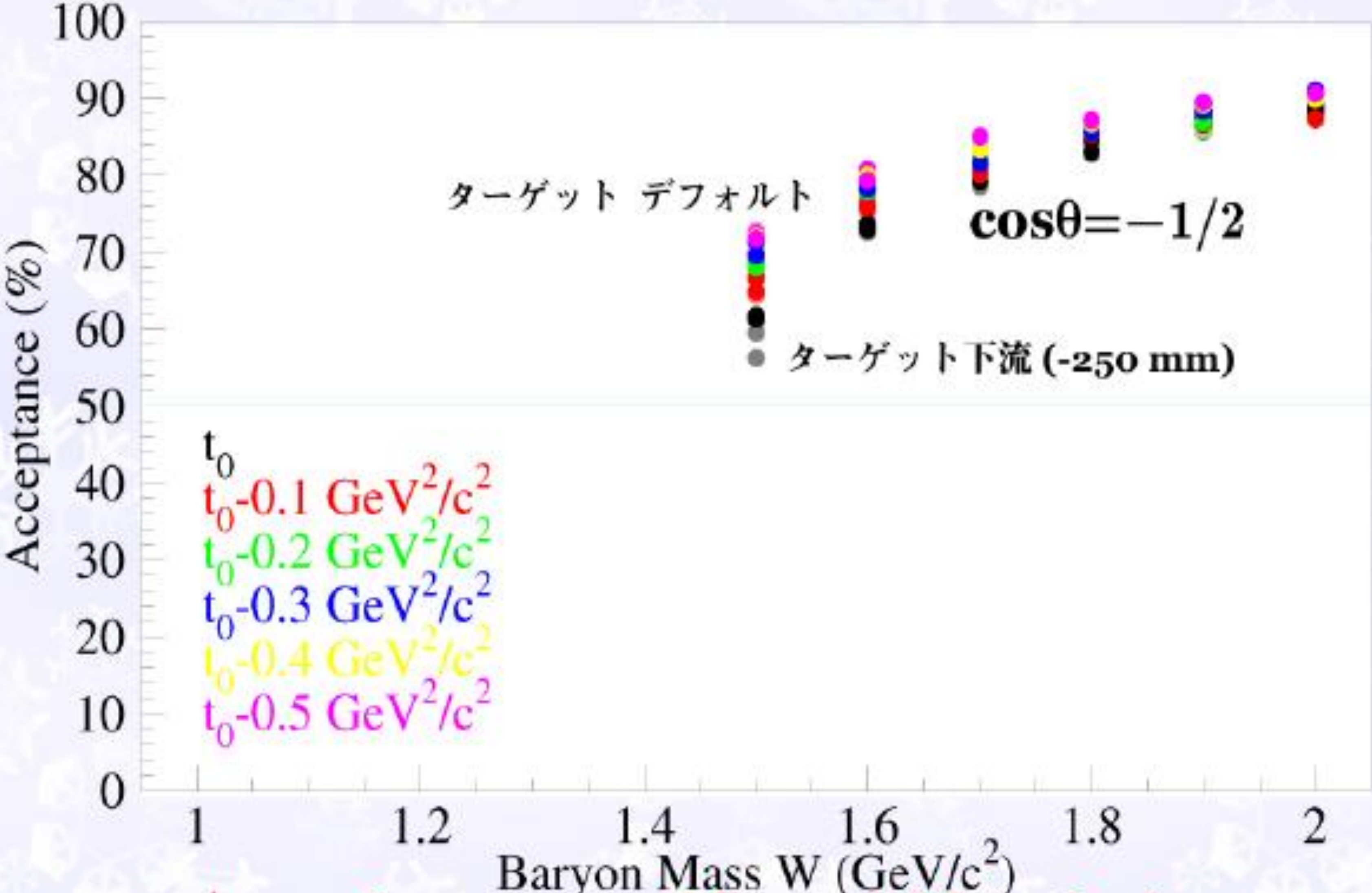
(π, K^{*0}) Efficiency @ 5 GeV/c

$K^{*0} \to K^+\pi^-$: ~67% (100%)



T. Ishikawa, 10 Mar 2014

$Y^* \to \pi^+\Sigma^-$ / K^-p @ 5 GeV/c

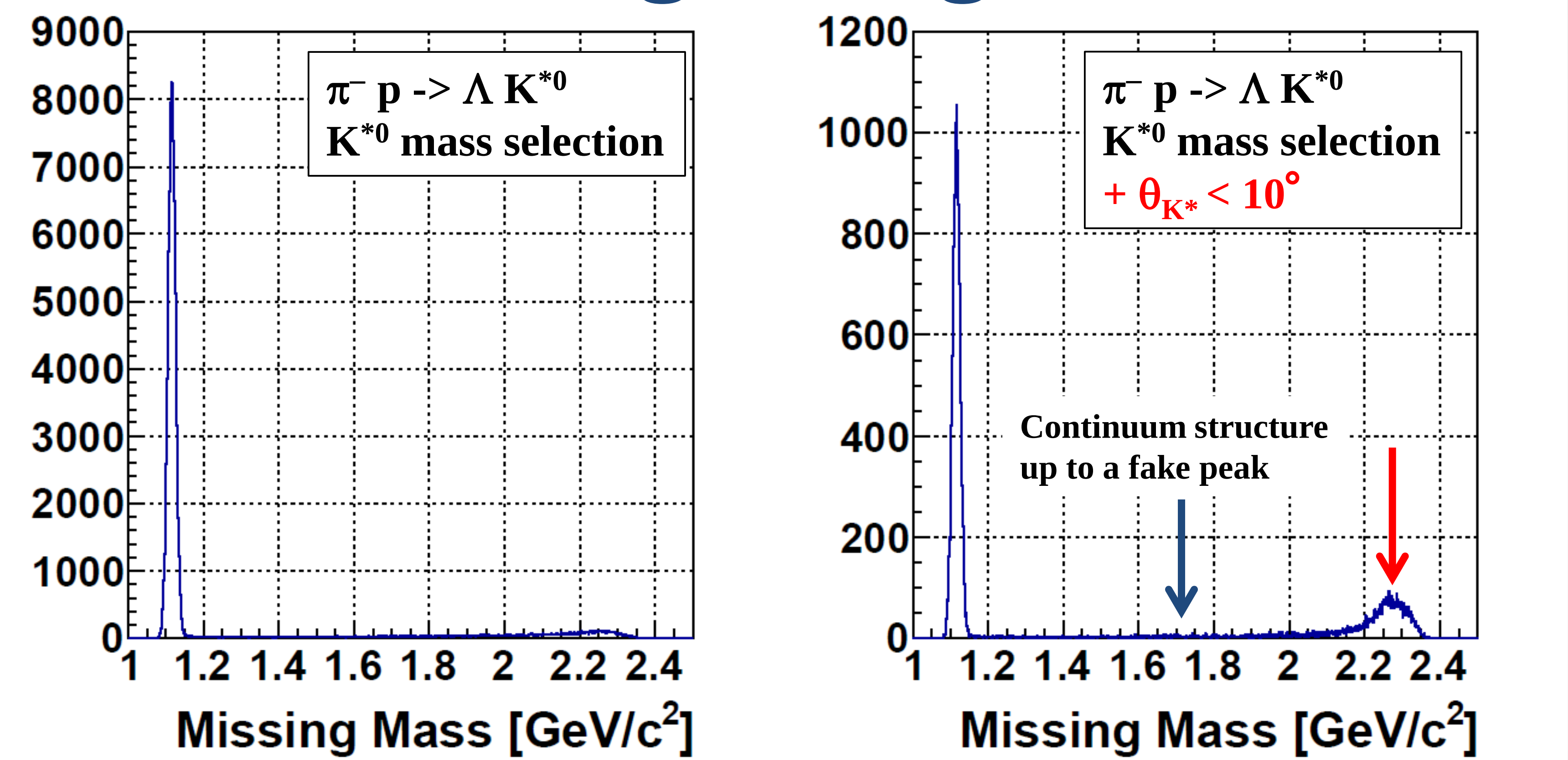


$\pi^+\Sigma^-$とK^-pの違いは見られない

Signal responses

$p(\pi^-,K^{*0})\Lambda,\Sigma^0$ and $p(\pi^-,K^{*+})\Sigma^-$

Peaking background

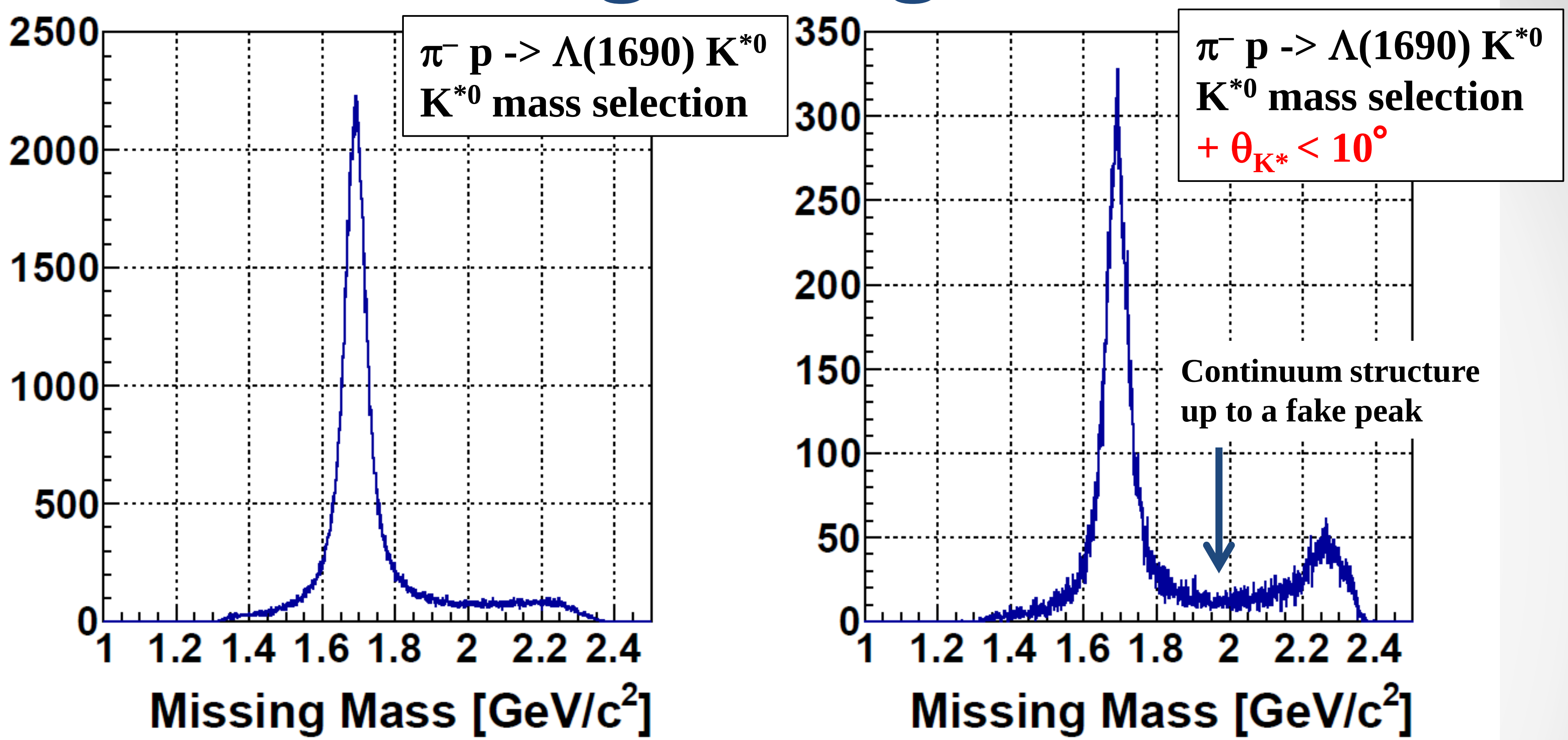


- Wrong combination of the K*^{0} background makes a fake peak.
  - K*^{0} inv. mass background: K$^+$ + slow π^- from $\Lambda \to$p π^- event
- θ_{K*} selection enhanced peak structure

⇒ Only around 2.2 GeV/c region: All states have same structure.

  - Peak with depends on width of the state.
  - Continuum structure
- Contribution from higher K* resonance: Being checked

Peaking background



- Wrong combination of the K^{*0} background makes a fake peak.
  - K^{*0} inv. mass background: K^+ + slow π^- from $\Lambda \rightarrow p\ \pi^-$ event
- θ_{K*} selection enhanced peak structure

⇒ Only around 2.2 GeV/c region: All states have same structure.
  - Peak with depends on width of the state.
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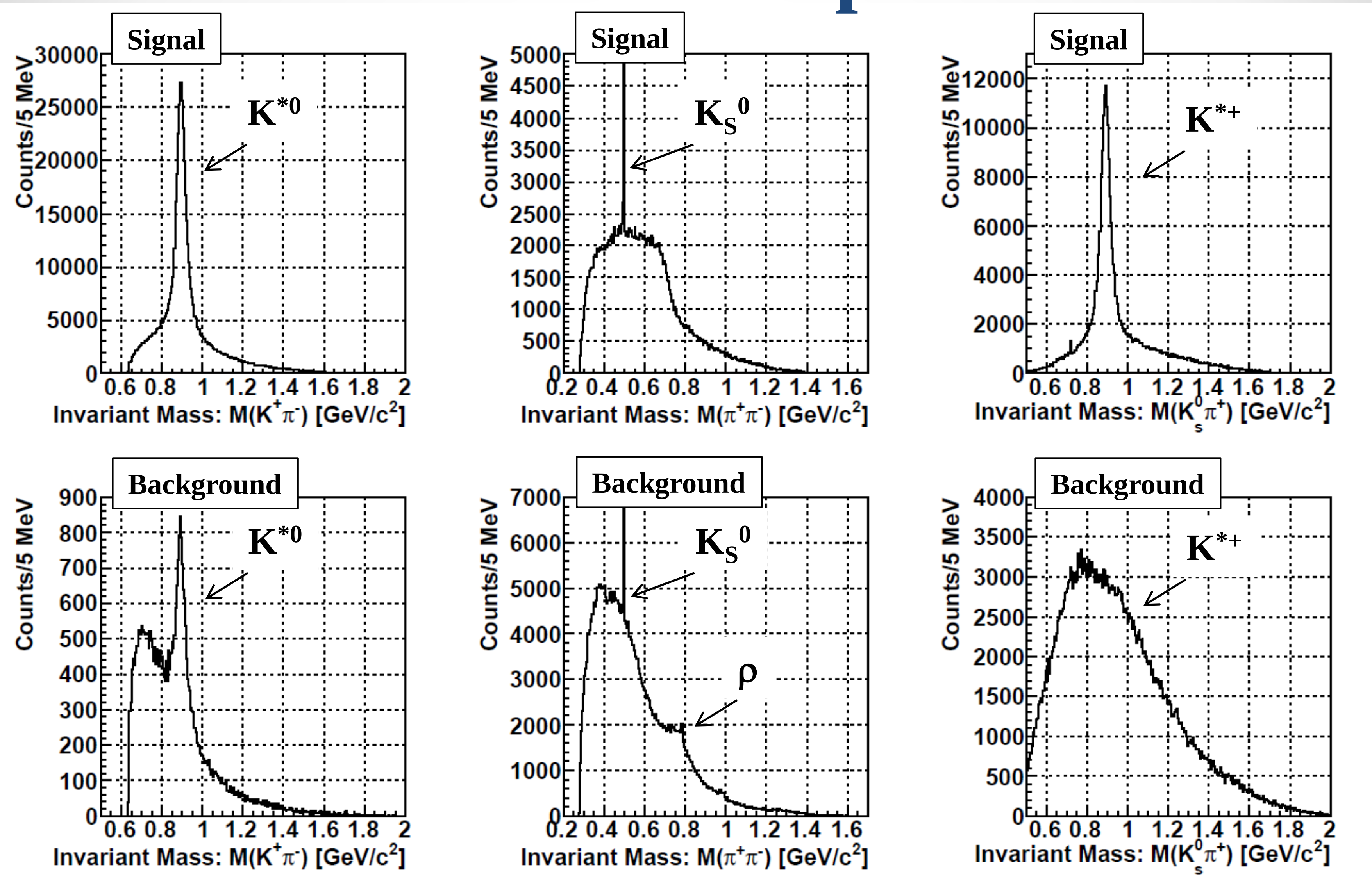
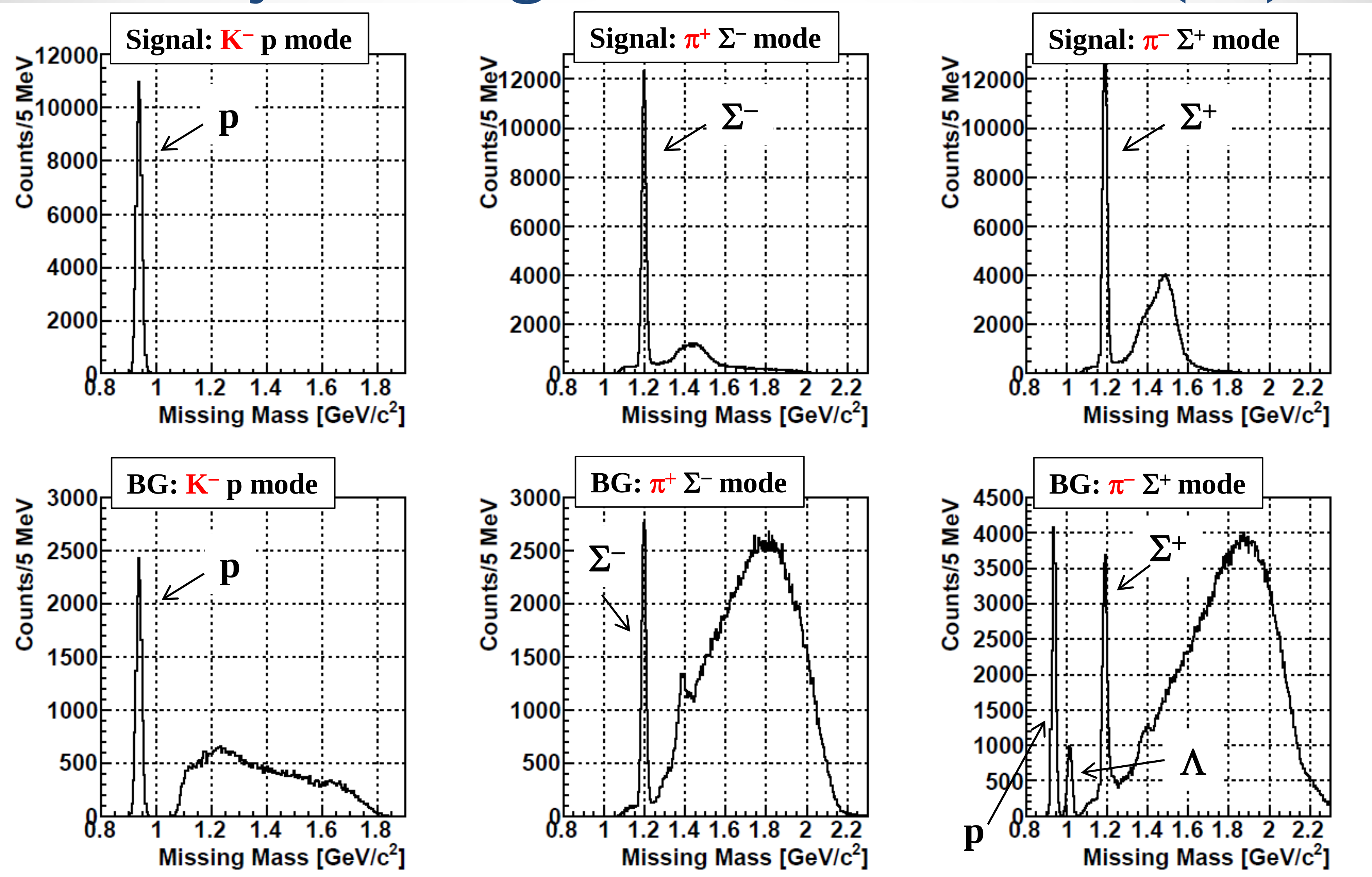
Invariant mass spectrum



- **Signal: Only signals generated**
- **Background: JAM simulation output result**

Decay missing mass: K^{*0} channel (Λ^*)



- **Signal: Only signals generated**
- **Background: JAM simulation output result**

Summary

- **Large Acceptance**
- **Peaking background**
  - **K^+ (K^0) + slow π: wrong combination makes a fake peak at ~2.2 GeV/c^2**
    - **No affect < 2 GeV**
  - **Continuum BG above the Resonance mass**
    - **No affect peak shapes**
- **Missing mass spectrum**
  - **Major structure can be observed in the inclusive spectrum.**
  - **λ/ρ mode separation**
    - **Improve S/N in coincidence with a decay mode**
  - **Possible selection: Prod./Decay modes/Angular Dist.**
    - **Decay Branching Ratios**
    - **Production rate, density matrix**
- **Background Estimation**
  - **Major structure can be observed at the signal level of 1 μb.**
  - **BG shape seems a smooth function.**
    - **BG subtraction should be demonstrated.**

Backup slides for Spectroscopy of QQq system

Little is known for Ξ

Threshold

ΩK(2166)

ΣK*(1983)

ΛK*(1908)

Σ*K(1878)

ΣK(1685)

Ξ*π(1665)

ΛK(1610)

Ξπ(1450)

	JP	rating	Width [MeV]	→Ξπ [%]	→ΛK [%]	→ΣK [%]	
Ξ(2500)	??	1*	150?				
Ξ(2370)	??	2*	80?				ΩK~9±4
Ξ(2250)	??	2*	47+-27?				
Ξ(2120)	??	1*	25?				
Ξ(2030)	>=5/2?	3*	20^{+15}_{-5}	small	~20	~80	
Ξ(1950)	??	3*	60+-20	seen	seen		
Ξ(1820)	3/2-	3*	24^{+15}_{-10}	small	Large	Small	
Ξ(1690)	??	3*	<30	seen	seen	seen	
Ξ(1620)	??	1*	20~40?				
Ξ(1530)	3/2+	4*	19	100			

- Narrow width: ~ a few 10 MeV
- Large production cross section: ~ 1 μb

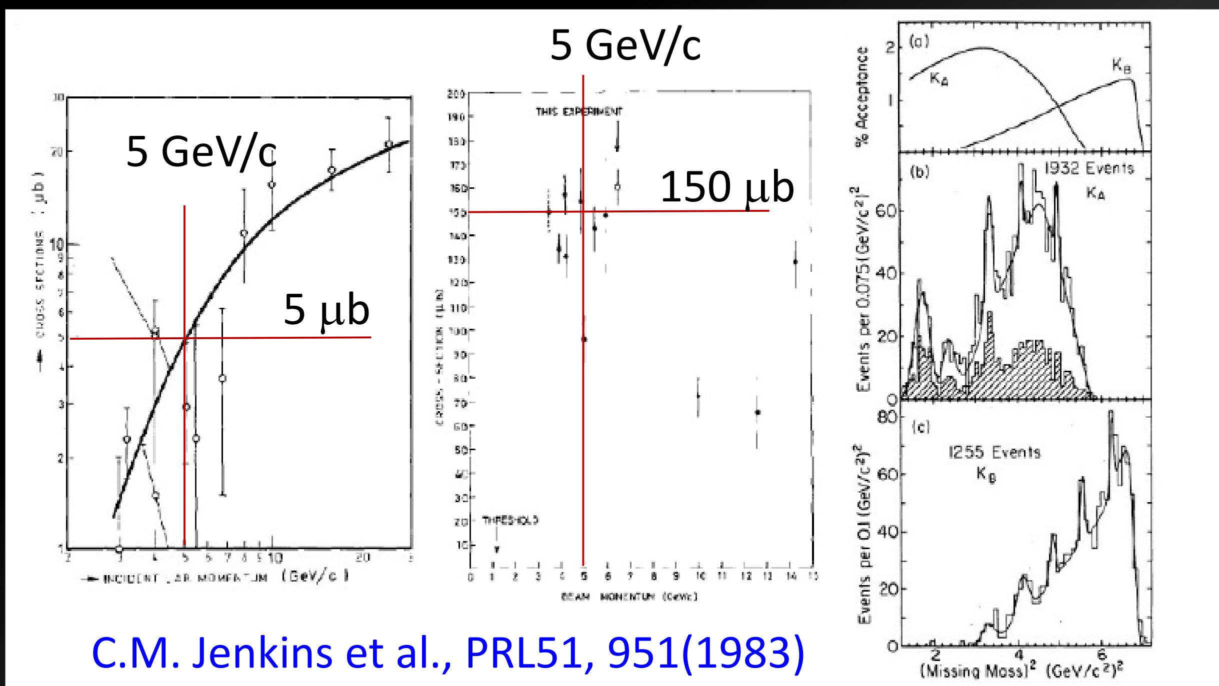
Ξ Baryon Spectroscopy w/ the High-p Secondary Beam

LoI submitted by M. Naruki and K. Shirotori

- Sizable yields are expected for a month.

Reaction	σ [μb]	Beam [/spill]	B.R.	Acceptance [%]	Y_{Total}	$Y_{Decay/bin}$
$K^- p \to \Xi^{*-} K^+$	1.0	10^6	1.0	50	3.1×10^5	2500
$K^- p \to \Xi^{*-} K^{*+}$	1.0	10^6	0.23	50	0.7×10^5	580
$K^- p \to \Xi^{*0} K^{*0}$	1.0	10^6	0.67	50	2.1×10^5	1700
$\pi^- p \to \Xi^{*-} K^{*0} K^+$	0.1	10^7	0.67	50	3.1×10^5	2500

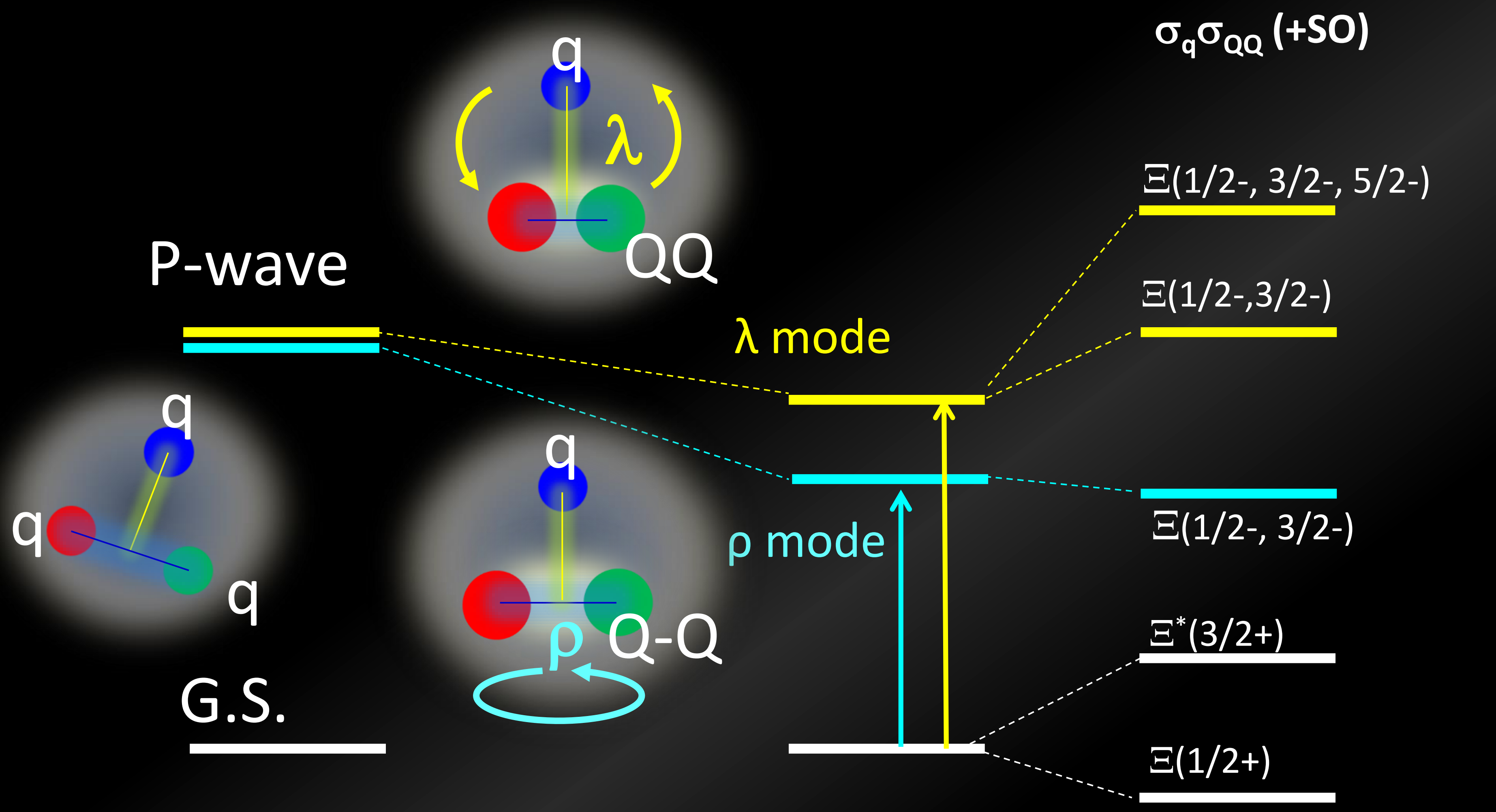
- Past exp.



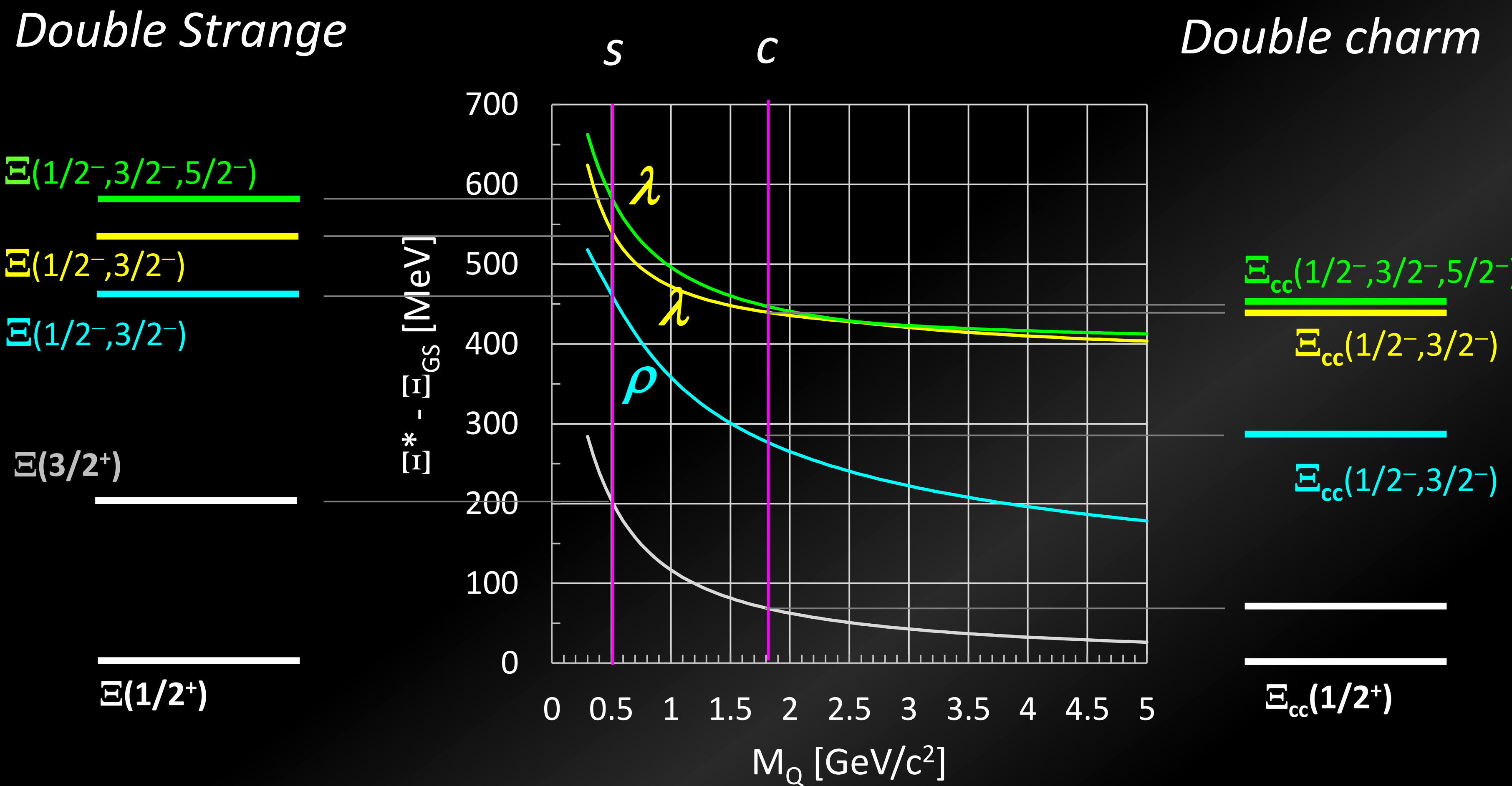
C.M. Jenkins et al., PRL51, 951(1983)

Level Structure of double-strange baryons

- λ and ρ mode excitations interchange



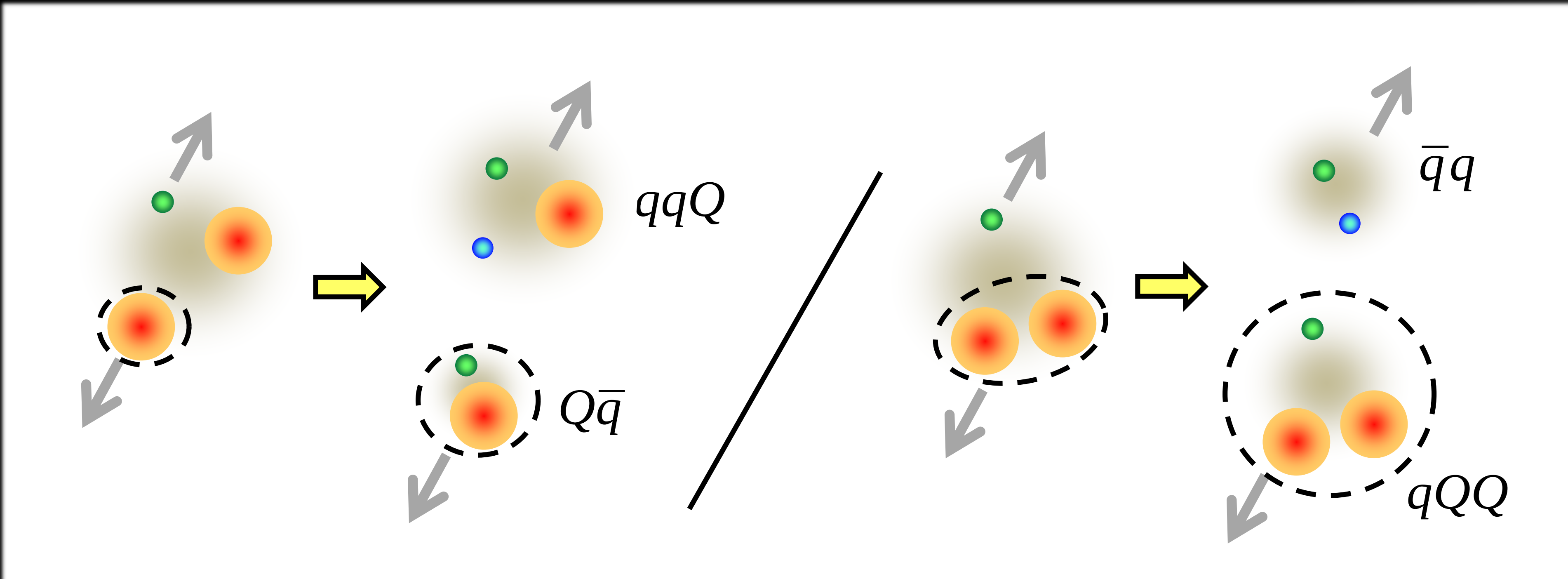
qQQ Baryon spectroscopy



non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

ρ–λ mixing (cal. By T. Yoshida)

Structure and Decay Partial Width



ρ mode (QQ)

λ mode [QQ]