Charmed baryon decays at Belle

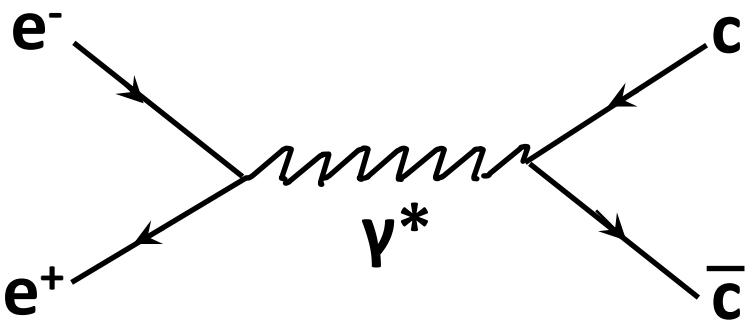
Yuji Kato (KMI, Nagoya University)

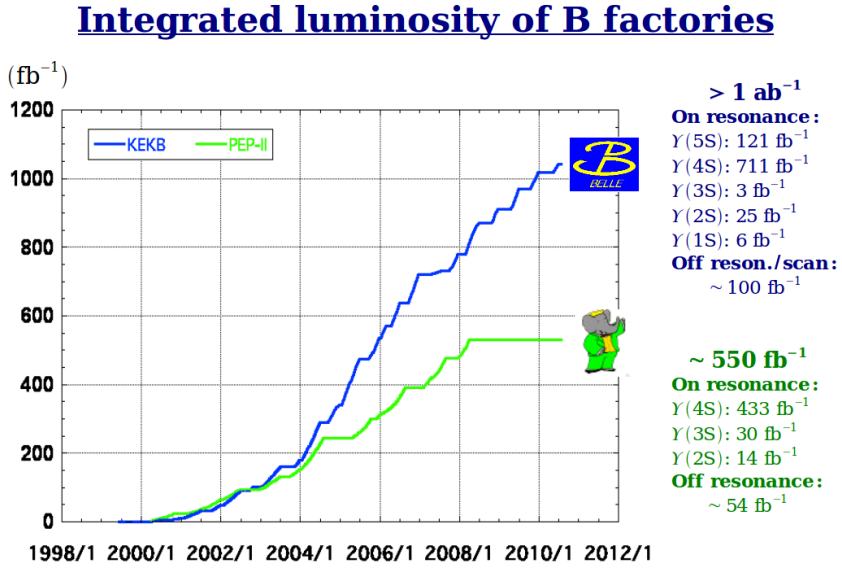
- $\Xi_c^* \rightarrow \Lambda D$
- Doubly Cabibbo Suppressed decay $\Lambda_c^+ \rightarrow pK^+\pi^-$
- Hidden Strange pentaquark via $\Lambda_c^+ \rightarrow \pi^0 \phi p$ decay

Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe

BELLE

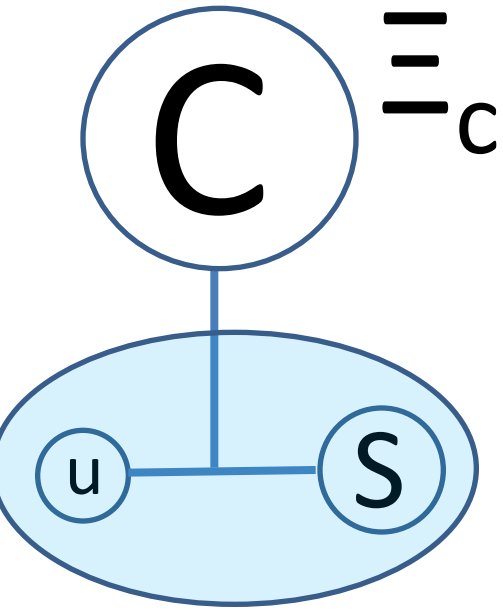
Charmed baryon production at Belle





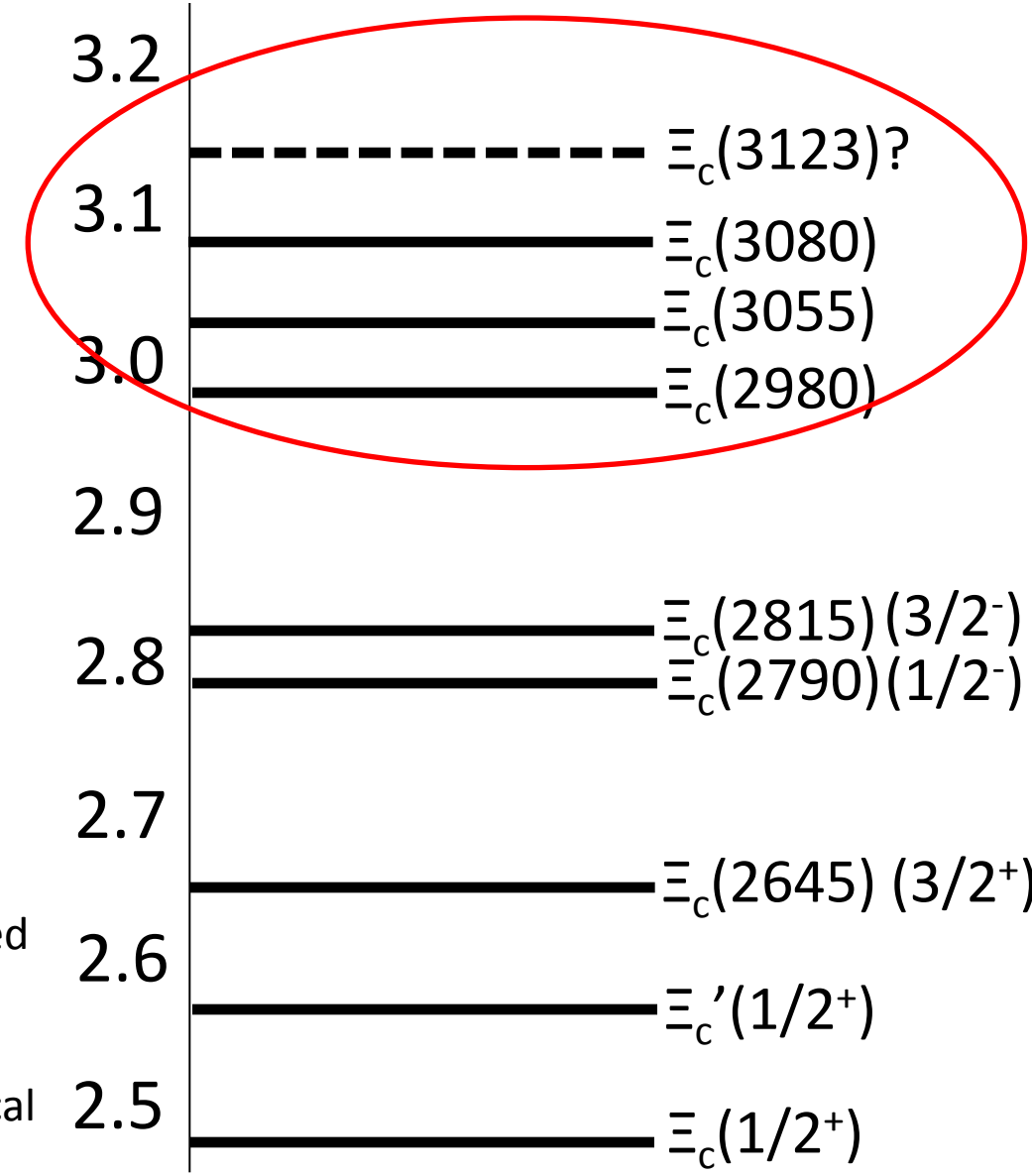
- Charmed baryons are produced mainly via $e^+e^- \rightarrow \gamma^* \rightarrow c\bar{c}$
- Total integrated luminosity ~=1.0 ab^{-1}. → ~1.0×10^9 $e^+e^- \rightarrow c\bar{c}$.
- Many charmed baryons are discovered by Belle and BaBar so far.
  ($\Lambda_c(2940)$, $\Sigma_c(2800)$, $\Xi_c(2980)$, $\Xi_c(3055)$, $\Xi_c(3080)$, $\Omega_c(2770)$)

Charmed strange baryons (Ξ_c)



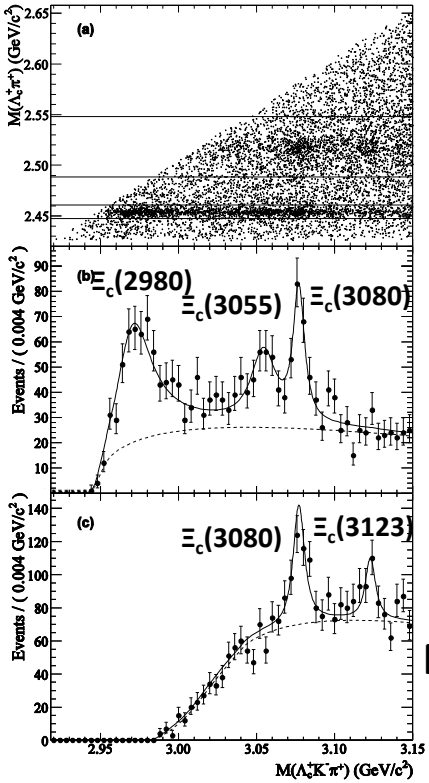
u/d-s diquark system!

- u-s di-quark, which can not be achieved in the Λ state.
- The states below $\Xi_c(2815)$ are well descrived by the quark model.
- Higher excited states contains rich dynamical information!



Higher excited Ξ_c states in $\Sigma_c^{++}K^-$ (past studies)

Phys. Rev. D 77, 012002



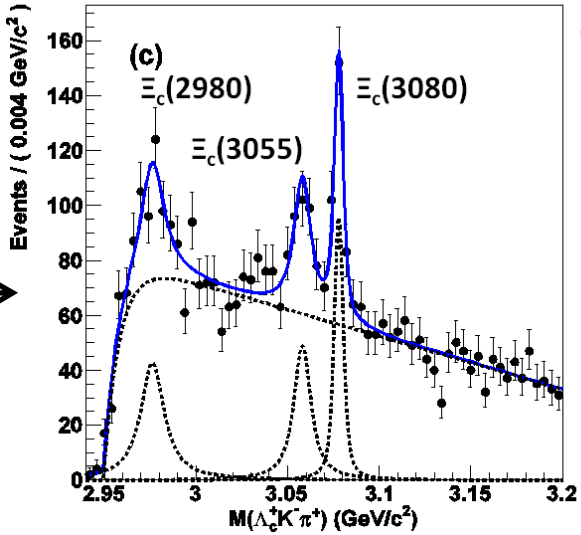
$M(\Sigma_c^{++}K^-)$

$M(\Sigma_c^{*++}K^-)$

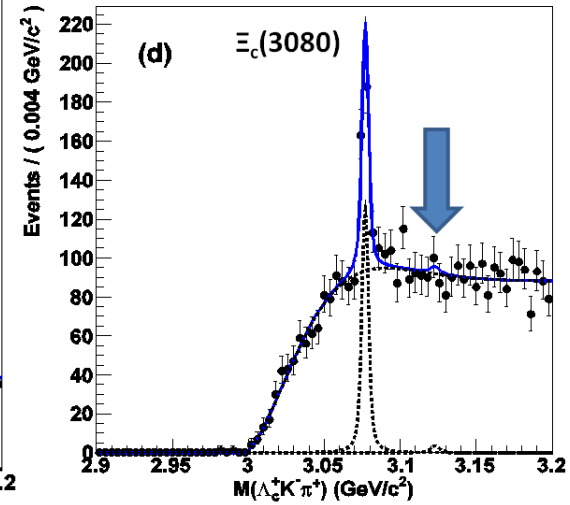
Phys. Rev. D 89, 052003

BELLE

$M(\Sigma_c^{++}K^-)$



$M(\Sigma_c^{*++}K^-)$



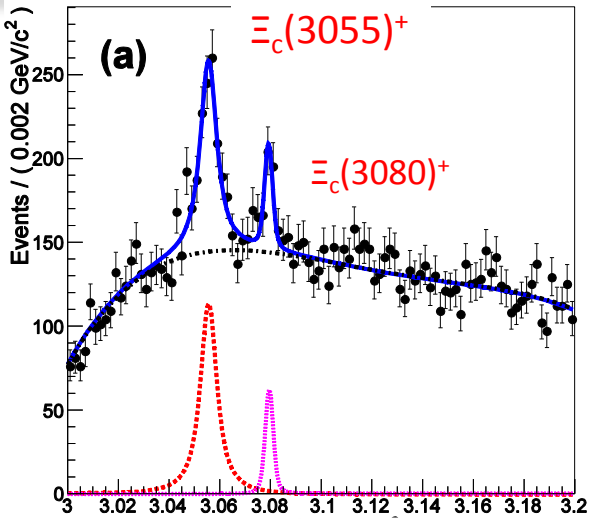
- Both Belle and BaBar observed
  $\Xi_c(2980)^+$, $\Xi_c(3055)^+$, and $\Xi_c(3080)^+$ in $\Sigma_c^{++}K^-$ final state.
  $\Xi_c(3080)^+$ in $\Sigma_c^{*++}K^-$ final state (only BaBar observed $\Xi_c(3123)^+$)

- Decays where charm quark in contained in meson will give more insight → Λ D!

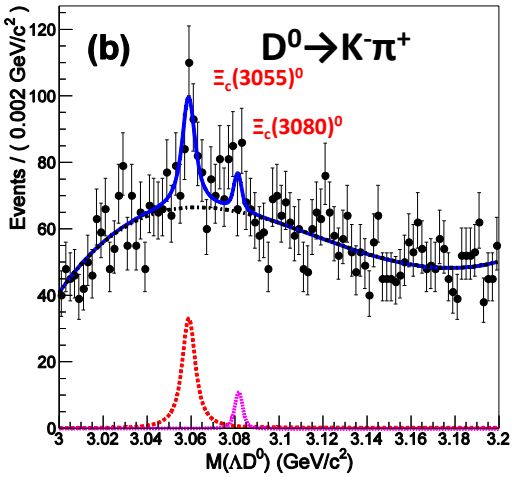
M(ΛD)

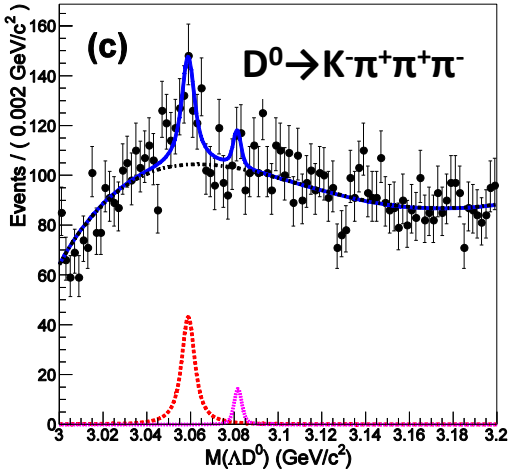
Phys. Rev. D 94, 032002

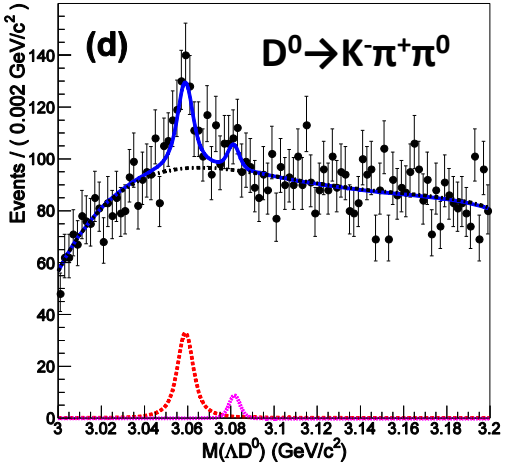
M(ΛD$^+$)



M(ΛD^0)







- First observation of the "decay" of $\Xi_c(3055/3080)$ into ΛD^+.
- $N(\Xi_c(3055)^+) > N(\Xi_c(3080)^+)$: Opposite to $\Sigma_c^{++}K^-$.
- First observation of $\Xi_c(3055)^0$ (8.6σ)

Relative branching fractions

$\Xi_c(3055)^+$ Prefer ΛD **Phys. Rev. D 94, 032002**

$Br(\Lambda D^+)/Br(\Sigma_c^{++}K^-) = 5.09 \pm 1.01 \pm 0.76$

$\Xi_c(3080)^+$ Similar in 3 decays

$Br(\Lambda D^+)/Br(\Sigma_c^{++}K^-) = 1.29 \pm 0.30 \pm 0.15$

$Br(\Sigma_c^{*++}K^-)/Br(\Sigma_c^{++}K^-) = 1.07 \pm 0.27 \pm 0.01$

First ever measurement of relative branching fraction of (heavy-baryon + light-meson) and (light-baryon + heavy-meson).

Partial width of $\Xi_c(3055)$ by chiral quark model (MeV)

	$\Sigma_c\bar{K}$	$\Xi_c^*(2645)\pi$	$\Xi_c'\pi$	$\Sigma_c^*\bar{K}$	$D\Lambda$	total
$\|\Xi_c{}^2D_{\lambda\lambda}(3/2^+)\rangle$	2.3	0.5	1.0	0.1	0.1	4.0
$\|\Xi_c{}^2D_{\rho\rho}(3/2^+)\rangle$	5.6	0.8	3.3	0.3	-	10.0

Inconsistent with our measurement!

Phys. Rev. D 86, 034024

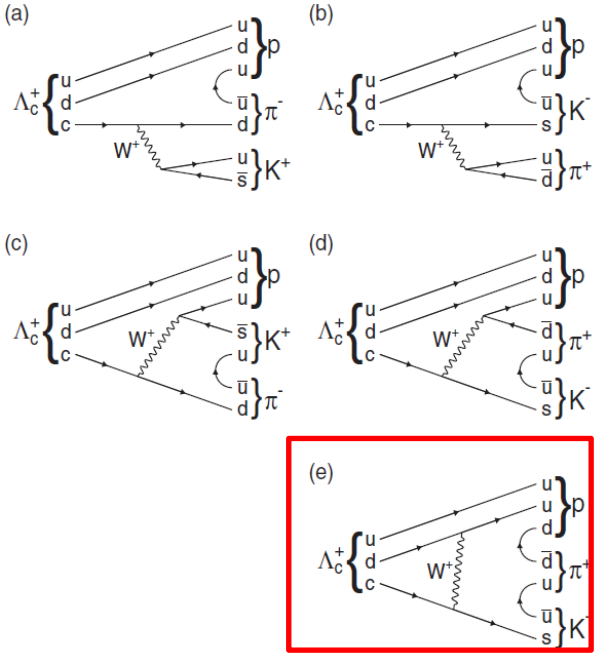
Doubly Cabibbo Suppressed decay: $\Lambda_c^+ \to pK^+\pi^-$

- In the baryon sector, Doubly Cabbibo Suppressed (DCS) decay had never been observed. $\Lambda_c^+ \to pK^+\pi^-$ is expected to be sensitive.

- Naively, ratio to CF decay, $pK^-\pi^+$ is expected to be $\frac{B(\Lambda_c^+ \to pK^+\pi^-)}{B(\Lambda_c^+ \to pK^-\pi^+)} \cong \tan^4\theta_c$

- W-exchange diagram can contribute only in CF decay.

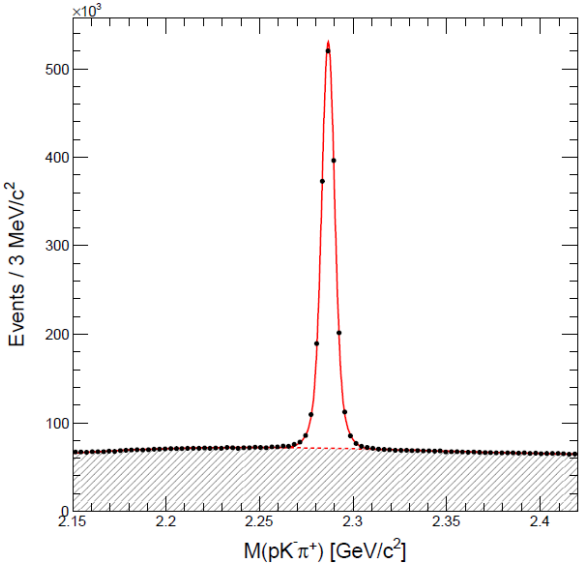
DCS decays



CF decays

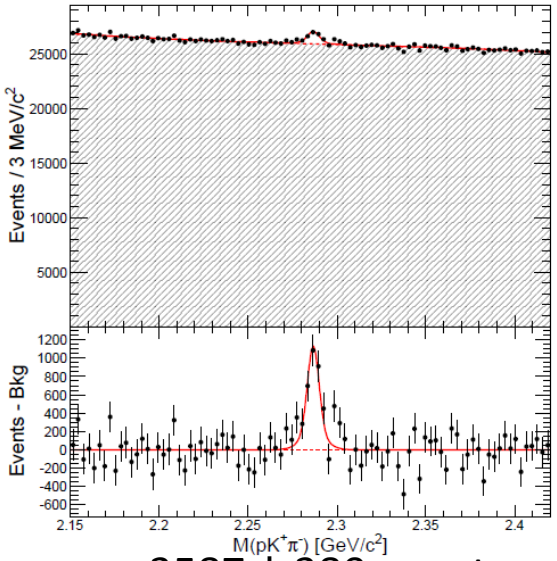
Results

CF mode: $pK^-\pi^+$



$(1.452 \pm 0.015) \times 10^6$ events

DCS mode: $pK^+\pi^-$



- 3587 ± 380 events
- Significance: 9σ

- Branching fraction ratio = ($2.35 \pm 0.27(\text{Stat}) \pm 0.21(\text{Sys})$) $\times 10^{-3}$
  $= (0.82 \pm 0.12) \times \tan^4\Theta_c$

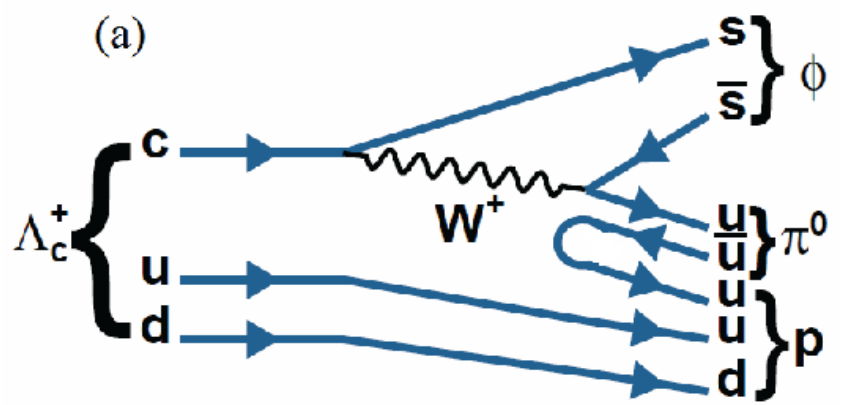
- After subtracting contribution of Λ(1520) or Δ intermediate, which contribute only on the CF decay, the ratio is
  $(1.10 \pm 0.17) \times \tan^4\Theta$

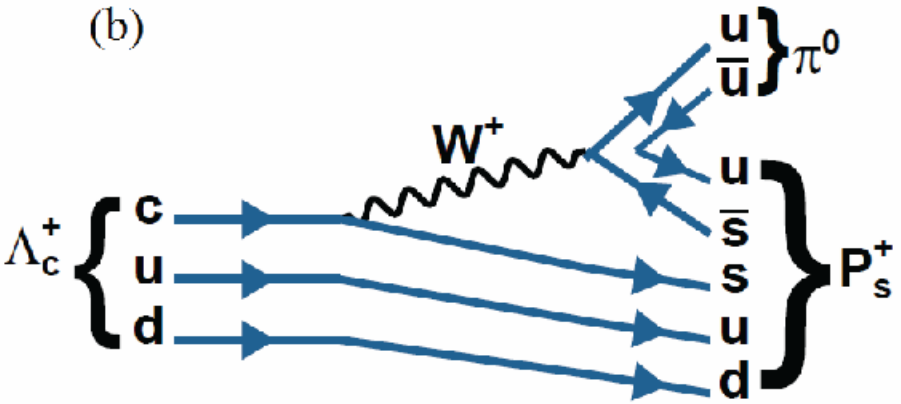
Phys. Rev. Lett. 117, 011801

- Contribution from W exchange diagram is not large.

Search for pentaquark via $\Lambda_c^+ \to \pi^0 \phi p$

- LHCb observed hidden charm pentaquark state in the $\Lambda_b^0 \to K^- P_c^+ \to K^- (J/\psi\ p)$
- Natural extension is analogue search for hidden-strange pentaquark by switching b->c ($\Lambda_b^0 \to \Lambda_c^+$), c->s ($J/\psi$ -> ϕ) :$\Lambda_c^+ \to \pi^0 P_s^+ \to \pi^0 (\phi\ p)$
- $\Lambda_c^+ \to \pi^0 \phi p$ decay itself is not observed so far.

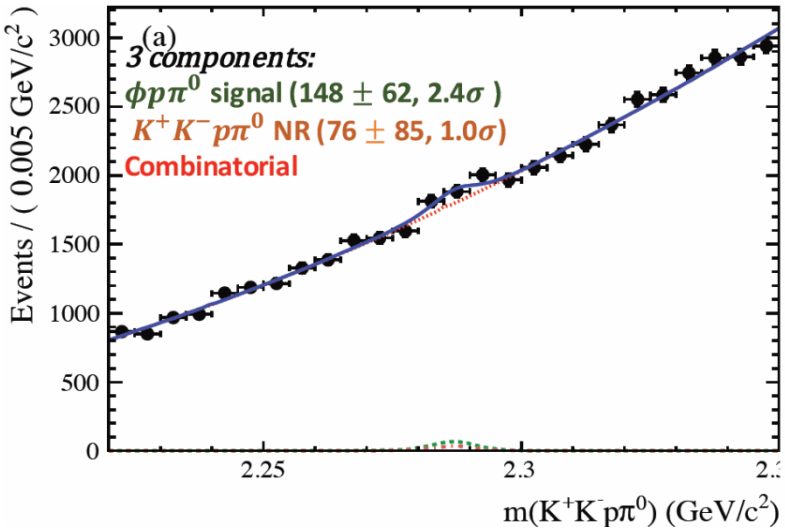




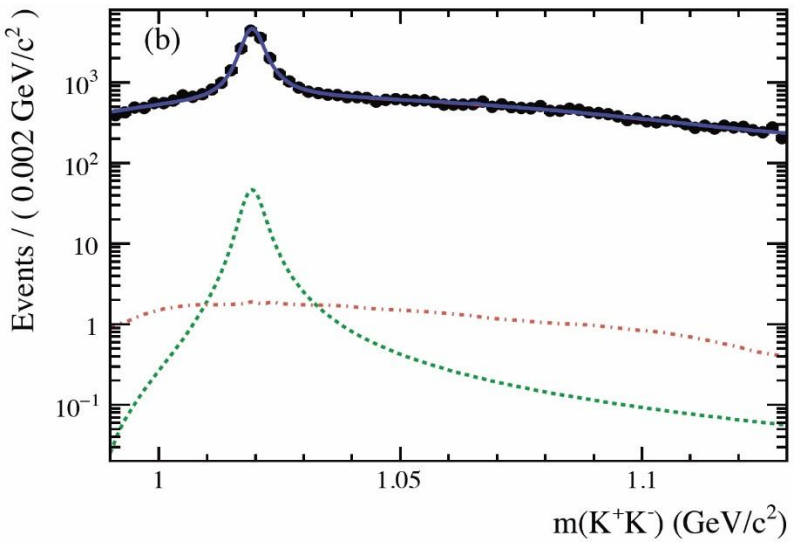
Results

Phys. Rev. D 96, 051102(R)

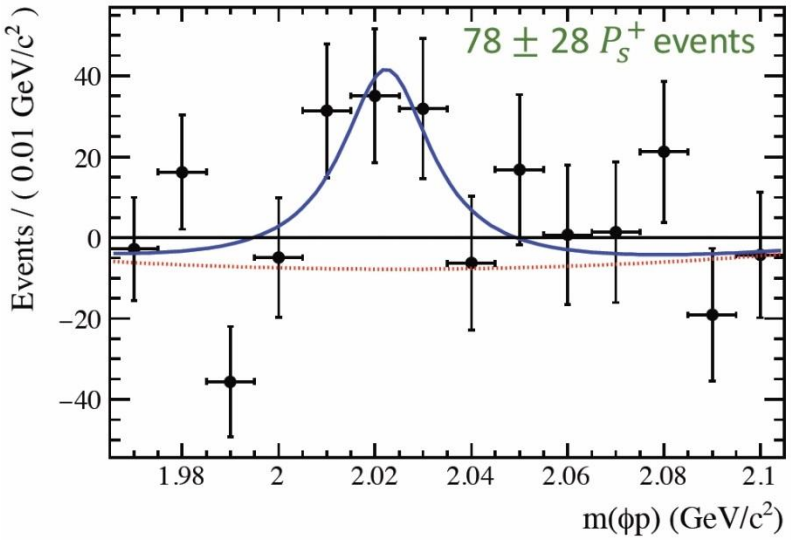
M($K^+K^-p\pi^0$)



M(K^+K^-)



M(ϕp)



- Perform 2D fit on M($K^+K^-p\pi^0$) and M(K^+K^-) plane.
  No significant Λ_c^+ signals is observed.
  New upper limits:
  - Br ($\Lambda_c^+ \to \phi\, p\, \pi^0$) < 15.3×10^{-5}
  - Br ($\Lambda_c^+ \to K^+K^-p\pi^0$)$_{NR}$ < 6.3×10^{-5}

- Also perform 2D fit in each M(ϕp) bin.
  No significant P_s^+ signal observed.
  - Br($\Lambda_c^+ \to P_s^+\pi^0$)xBr($P_s^+ \to \phi p$) < 8.3×10^{-5}

Summary

- First observation of the decay $\Xi_c(3055)$ and $\Xi_c(3080) \rightarrow \Lambda D$
  - $Br(\Lambda D)/Br(\Sigma_c^{++}K^-)$ are different for two states.
  - First observation of $\Xi_c(3055)^0$

- First observation of Doubly Cabibbo Suppressed decay: $\Lambda_c^+ \rightarrow pK^+\pi^-$
  - The ratio to CF decay can be explained by CKM suppression. Contribution from W-exchange diagram is small.

- Search for hidden strange pentaquark P_s^+ in $\Lambda_c^+ \rightarrow \pi^0 (\phi\, p)$
  - No signal for P_s^+ as well as the decay $\Lambda_c^+ \rightarrow \pi^0 (\phi\, p)$

- Stay tune for more results on charmed baryon from Belle!

Backup

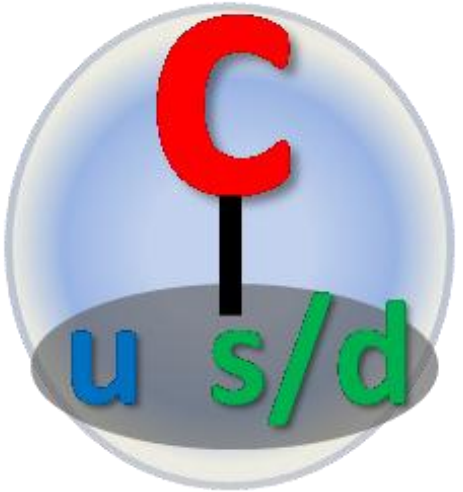
Physics of single charmed baryons

- Charm quark is heavy: (1500 MeV/c^2) > u,d,s quarks (300-500 MeV/c^2)
- spin-spin interaction $\propto 1/m_1 m_2$
- Di-quark correlation in light quarks (more simple!).

Nucleon

Every pair can not be distinguished.

Charmed baryon

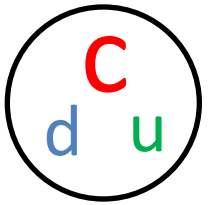


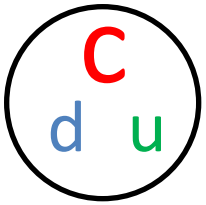
Light di-quark and charm quark.

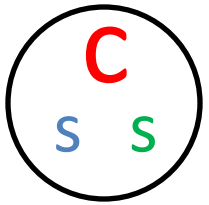
Observed charmed baryons

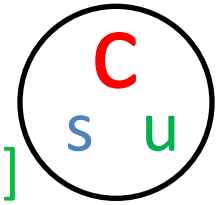
Λ_c^+	$(1/2^+)$	$\Sigma_c(2455)$	$(1/2^+)$	Ξ_c	$(1/2^+)$
$\Lambda_c(2595)^+$	$1/2^-$	$\Sigma_c(2520)$	$(3/2^+)$	Ξ'_c	$(1/2^+)$
$\Lambda_c(2625)^+$	$(3/2^-)$	$\Sigma_c(2800)$	$?^?$	$\Xi_c(2645)$	$(3/2^+)$
$[\Lambda_c(2765)^+$	$?^?]$			$\Xi_c(2790)$	$(1/2^-)$
$\Lambda_c(2880)^+$	$5/2^+$			$\Xi_c(2815)$	$(3/2^-)$
$\Lambda_c(2940)^+$	$?^?$			$[\Xi_c(2930)$	$?^?]$
				$\Xi_c(2980)$	$?^?$
				$\Xi_c(3055)$	$?^?$
				$\Xi_c(3080)$	$?^?$
				$[\Xi_c(3123)$	$?^?]$

Ω_c	$(1/2^+)$		
$\Omega_c(2770)$	$(3/2^+)$		









CLEO 8(7) (1995～2001)
BELLE 3 (2006～)
BABAR 5(2) (2007～)

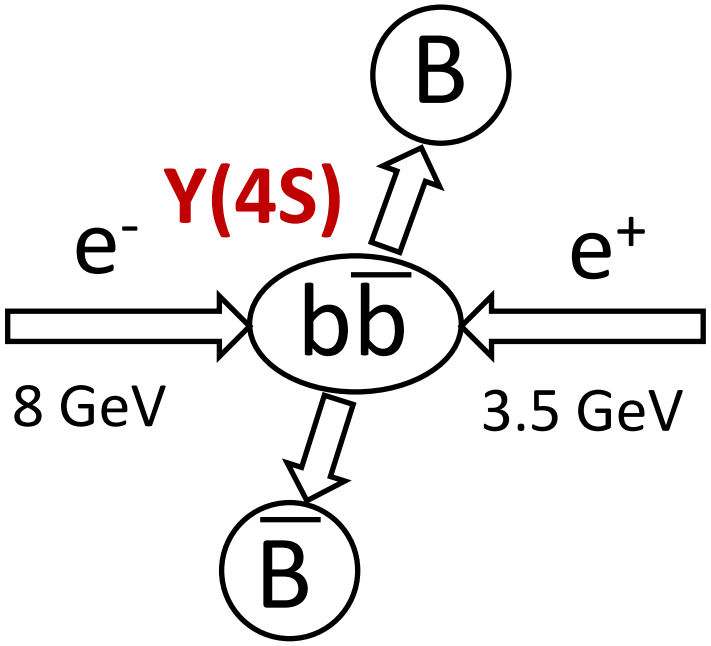
- 16/21 (12/17) charmed baryons are observed in e^+e^- collider experiment.
- All the ground states predicted by quark model are discovered.

Still many things to do!

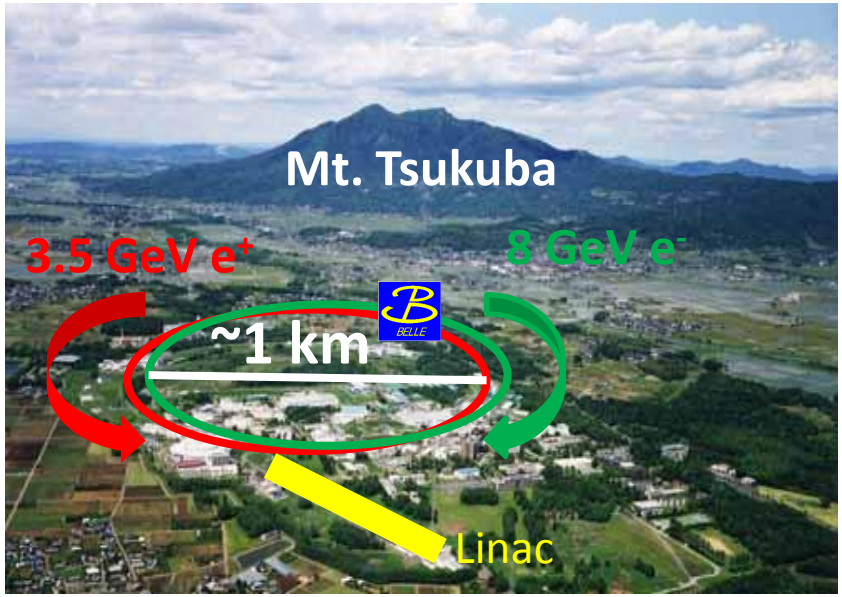
- Spin-parity almost from quark model prediction ().
- Some states has only poor evidence (states in []).
- Many states are observed in only 1 decay mode.
- Accuracy of mass/width is not good enough.
- No λ and ρ mode excitation states identified.

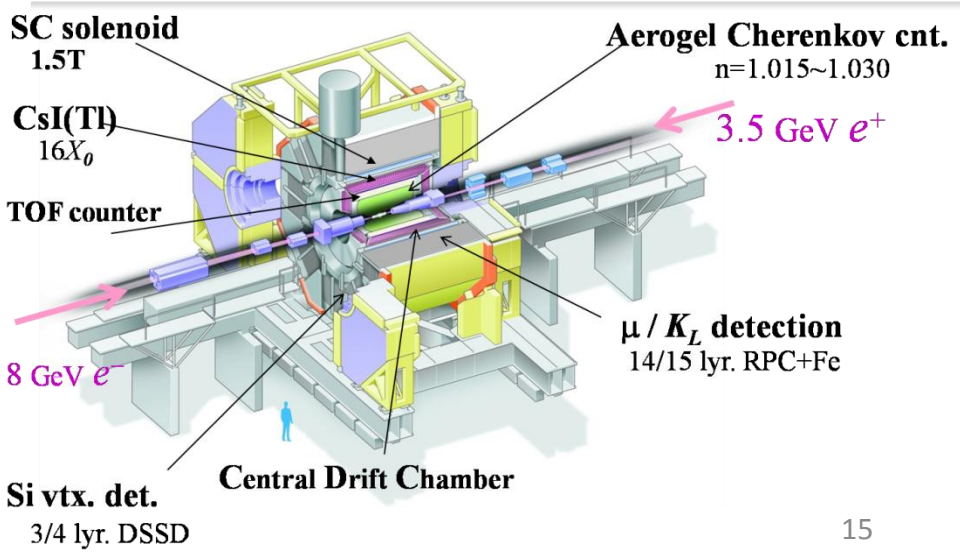
} Today's topic

Belle experiment



- Asymmetric energy e^+e^- collider.
- $\sqrt{s}$=10.58 GeV = Y(4S) mass (and other energies)
- Peak luminosity = 2.1×10^{34} $cm^{-2}s^{-1}$
  = **World highest luminosity!**
- General purpose feature of the Belle detector make it possible to study hadron spectroscopy.





Comparison with quark model prediction

- In the quark model, they should be N=2 shell and these states are identified as:
  $\Xi_c(3055) = {}^2D_{\lambda\lambda}(3/2^+)$ or ${}^2D_{\rho\rho}(3/2^+)$.
  (Phys. Rev. D 86, 034024)

	$\Sigma_c\bar{K}$	$\Xi_c^*(2645)\pi$	$\Xi_c'\pi$	$\Sigma_c^*\bar{K}$	$D\Lambda$	total
$\lvert\Xi_c\, {}^2D_{\lambda\lambda}(3/2^+)\rangle$	2.3	0.5	1.0	0.1	0.1	4.0
$\lvert\Xi_c\, {}^2D_{\rho\rho}(3/2^+)\rangle$	5.6	0.8	3.3	0.3	-	10.0

- They predicted
  - ΛD decay is suppressed for both $\Xi_c(3055)^+$
- Inconsistent with this measurement.
- Challenge for theorists!

Comparison of Λ_c^+ and Ξ_c or Σ_c and Ξ_c'

J^p	Λ_c^+	Ξ_c	$\Delta M(Mev/c^2)$	Note
$1/2^+$	$\Lambda_c(2286)^+$	$\Xi_c(2470)$	181	ground state
$1/2^-$	$\Lambda_c(2595)^+$	$\Xi_c(2790)$	194	$\Lambda(1405)$ like
$3/2^-$	$\Lambda_c(2625)^+$	$\Xi_c(2815)$	188	$\Lambda(1520)$ like
??	$\Lambda_c(2765)^{+?}$	$\Xi_c(2980)$?	205	Isospin not determined
$5/2^+$	$\Lambda_c(2880)^+$	$\Xi_c(3080)$?	200	

spin0 di-quark

J^p	Σ_c	Ξ_c'	$\Delta M(Mev/c^2)$	Note
$1/2^+$	$\Sigma_c(2455)$	$\Xi_c(2575)$	120	ground state
$3/2^+$	$\Sigma_c(2520)$	$\Xi_c(2645)$	125	$\Sigma(1385)$ like
??	$\Sigma_c(2800)$	??		

spin1 di-quark

- The mass difference of Λ_c and Ξ_c is ~200 MeV/c^2, Σ_c and Ξ_c' is ~120 MeV

$\Xi_c(3055)$ has no corresponding state in Λ_c/Σ_c

DCS decay of the Λ_c^+

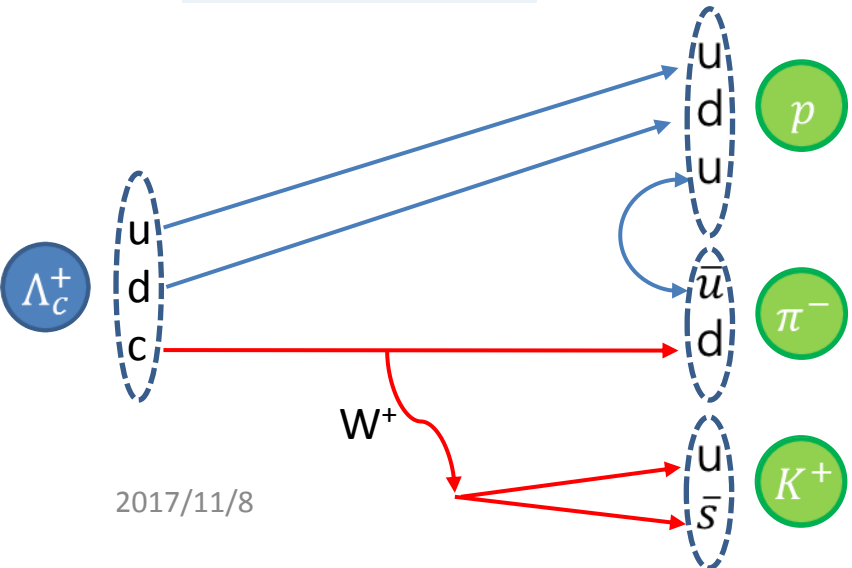
- In the baryon sector, Doubly Cabbibo Suppressed (DCS) decay has NEVER been observed. $\Lambda_c^+ \to pK^+\pi^-$ is expected to be sensitive.

- Naively, ratio to CF decay, $pK^-\pi^+$ is expected to be

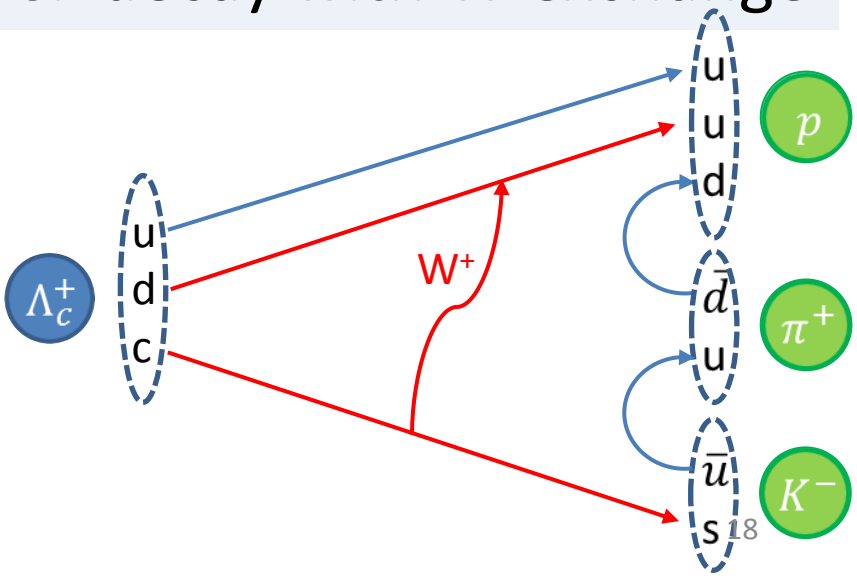
$$\frac{B(\Lambda_c^+ \to pK^+\pi^-)}{B(\Lambda_c^+ \to pK^-\pi^+)} \cong \tan^4\theta_c$$

- In the CF decay, the W exchange diagram may contribute.

DCS decay

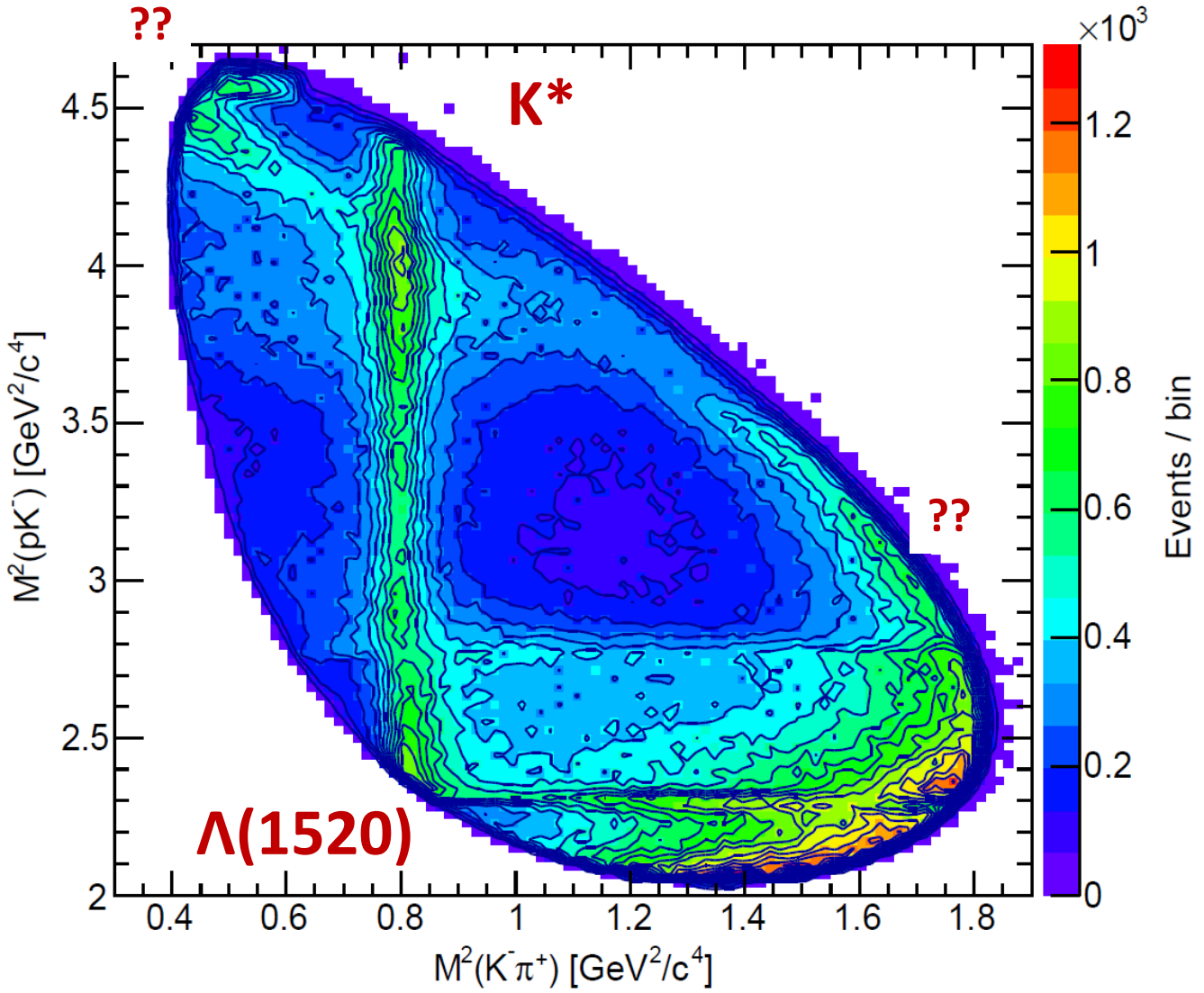


CF decay with W exchange



Dalitz plot for $\Lambda_c^+ \to pK^-\pi^+$

Phys. Rev. Lett. 117, 011801



Weak decay of charmed baryon is unique light baryon laboratory