Λ_c decays at BESIII

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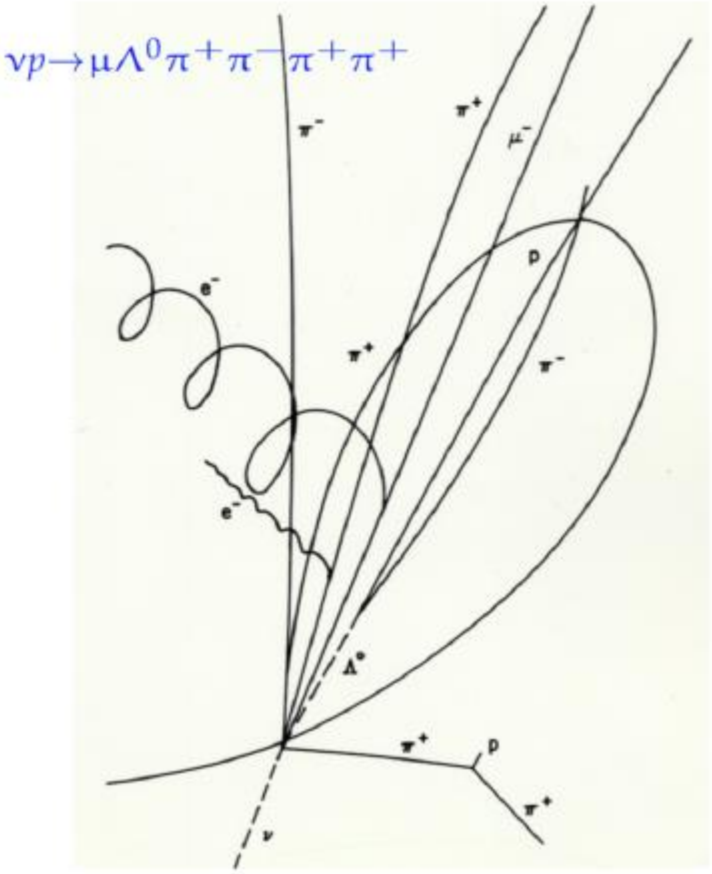
HFCPV-2018 @ ZhengZhou

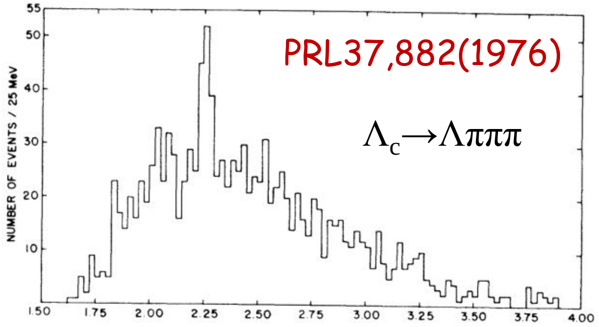
Overview

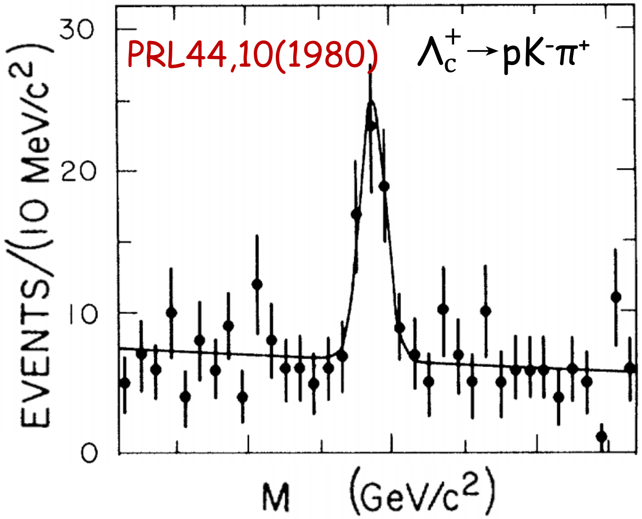
- Introduction of Λ_c
- BESIII Data Taken Near $\Lambda_c^+\bar{\Lambda}_c^-$ Threshold
- Analysis Method
- Λ_c Decays at BESIII
  - Λ_c hadronic decays
  - Λ_c semi-leptonic decays
  - Λ_c inclusive decays
- Cross Section Measurement of $e^+e^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-$ at Threshold
- Summary

Discovery of Λ_c

- First hint of charmed baryon $\Sigma_c^{++} \rightarrow \Lambda_c^{+} \pi^{+}$ at BNL in 1975. PRL 34, 1125 (1975)
- The Λ_c^{+} is firstly evidenced at Fermi Lab in 1976. PRL37,882(1976)
- MarkII firstly established Λ_c^{+} in 1980. PRL 44, 10 (1980)







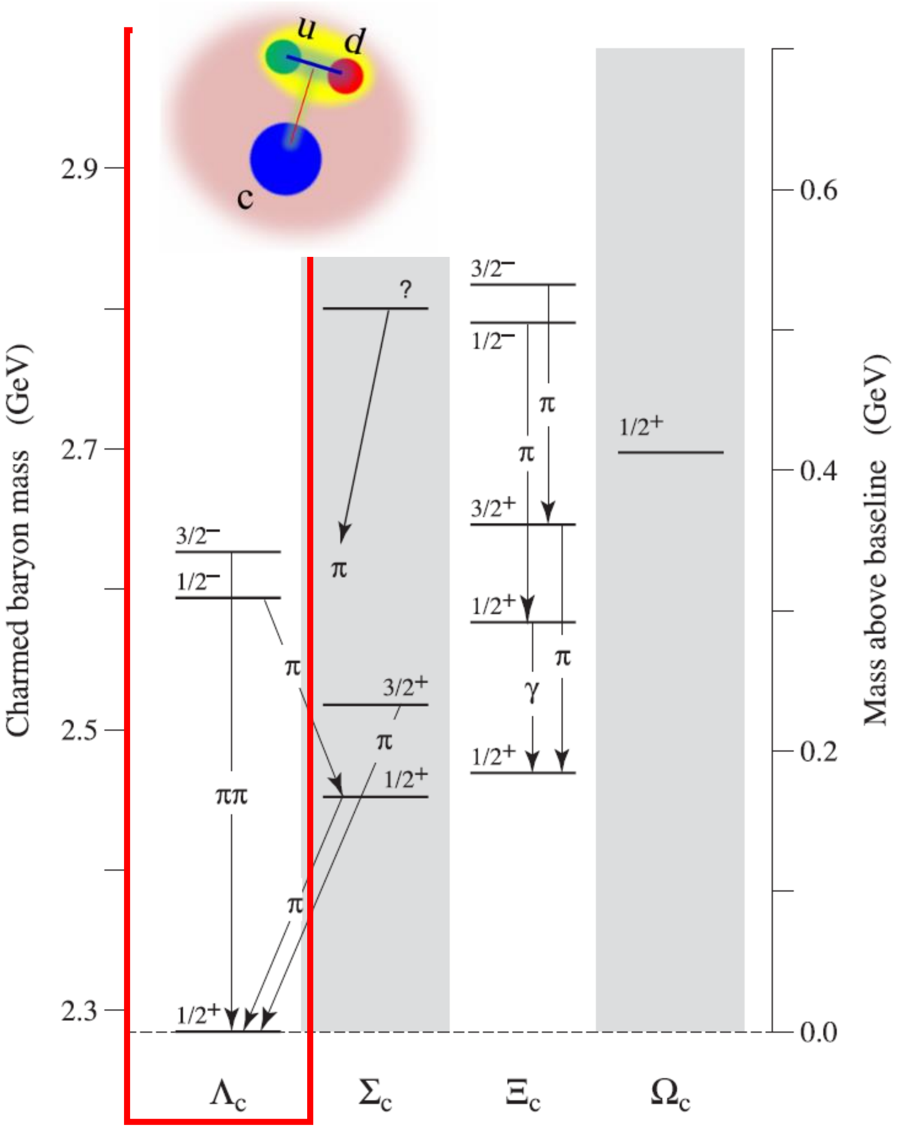
Introduction of Λ_c

- The lightest and most common charmed baryon,

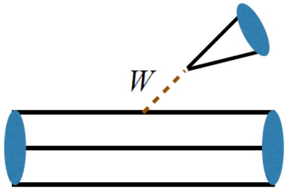
  → most of the charmed baryons will eventually decay into Λ_c.

  ☺ Important to know the decay properties of Λ_c.
- The golden mode, $\Lambda_c^+ \to pK^-\pi^+$, often used to normalize BFs.

  ☺ Very important to determine the absolute BF.
- Total known measured BF is ~ 60%.

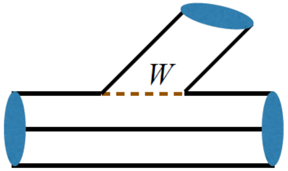


Introduction of Λ_c



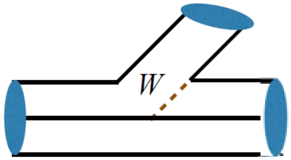
(T)
color-favored tree

factorizable



(C)
color-suppressed tree

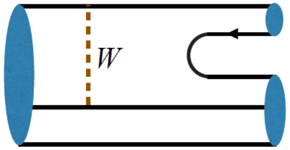
fac + nonfac



(C′)
color-commensurate

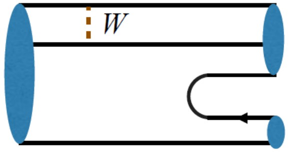
non-factorizable

Decay only Weakly!



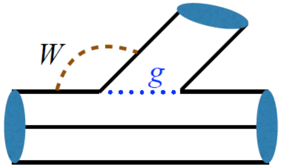
(E)
W-exchange

non-factorizable



(B)
Bow tie

non-factorizable

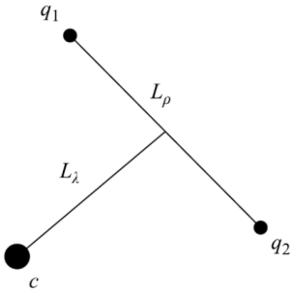


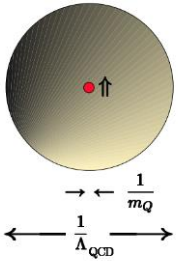
(P)
penguin

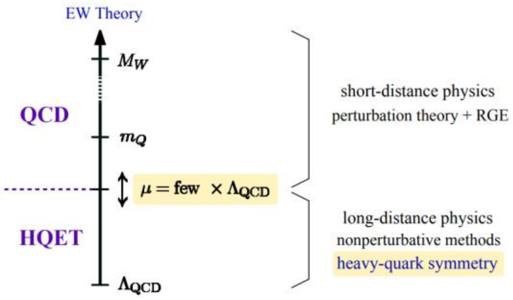
neglected

- **Heavy Quark Effective Theory**

- **Quark-diquark**
  3-body → 2-body





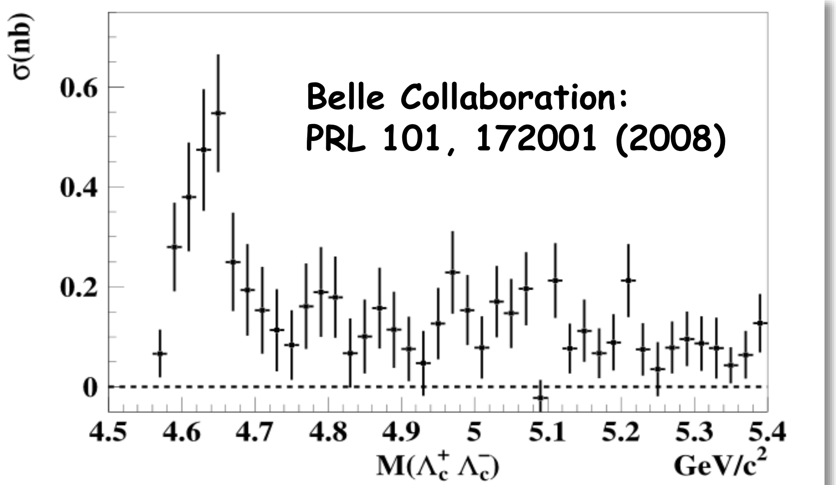


BESIII Data Taken about Λ_c

- In 2014, BESIII collected Λ_c data with excellent performance near the pair-production threshold.

Energy (GeV)	Luminosity (pb^{-1})
4.5745	47.67
4.5800	8.545
4.5900	8.162
4.5995	566.9

Presented results use this sample



Belle Collaboration:
PRL 101, 172001 (2008)

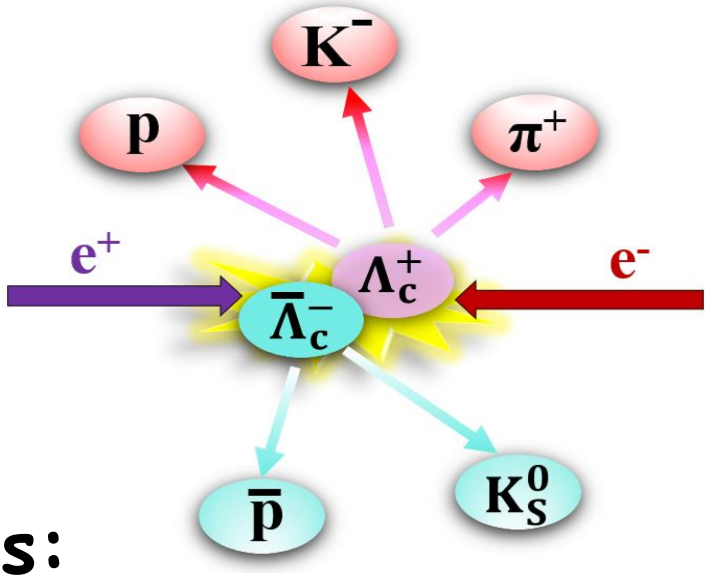
FIG. 4: The cross section for the exclusive process $e^+e^- \to \Lambda_c^+\Lambda_c^-$.

- ✓ Direct measurement on Λ_c^+ BFs at threshold
- ✓ ~106× 10^3 $\Lambda_c^+\bar{\Lambda}_c^-$ pairs make sensitivity to 10^{-3}
- ✓ More Λ_c^+ data will be collected

Charm Production @ Mass Threshold

- **Around E_{cms} ~ 4.6 GeV,**
  - $(E_{cms} - 2M_{\Lambda c})$ ~ 26 MeV
  - Pair production:

    $e^+e^- \rightarrow \gamma^* \rightarrow \Lambda_c^+\bar{\Lambda}_c^-$
  - no additional accompany hadrons.



- **Two ways to study Λ_c decays:**
  - ✓ Single Tag (ST): Reconstruct only one of the Λ_c-pair.
    - Larger backgrounds
    - Higher efficiencies
  - ✓ Double Tag (DT): Find both of them.
    - Smaller backgrounds
    - Lower efficiencies
    - Systematics in tag side can be mostly cancelled
    - Missing technique

Analysis Method

- **In ST studies frequently used variables:**
  - ✓ Energy Difference (ΔE)

$$\boxed{\Delta E = E - E_{\text{beam}}}$$

  - ✓ Beam-Constrained Mass (M_{BC})

$$\boxed{M_{\text{BC}} = \sqrt{E^2_{\text{beam}}/c^4 - p^2/c^2}}$$

- **In DT Studies:**

$$\boxed{U_{\text{miss}} = E_{\text{miss}} - c|\vec{p}_{\text{miss}}|}$$

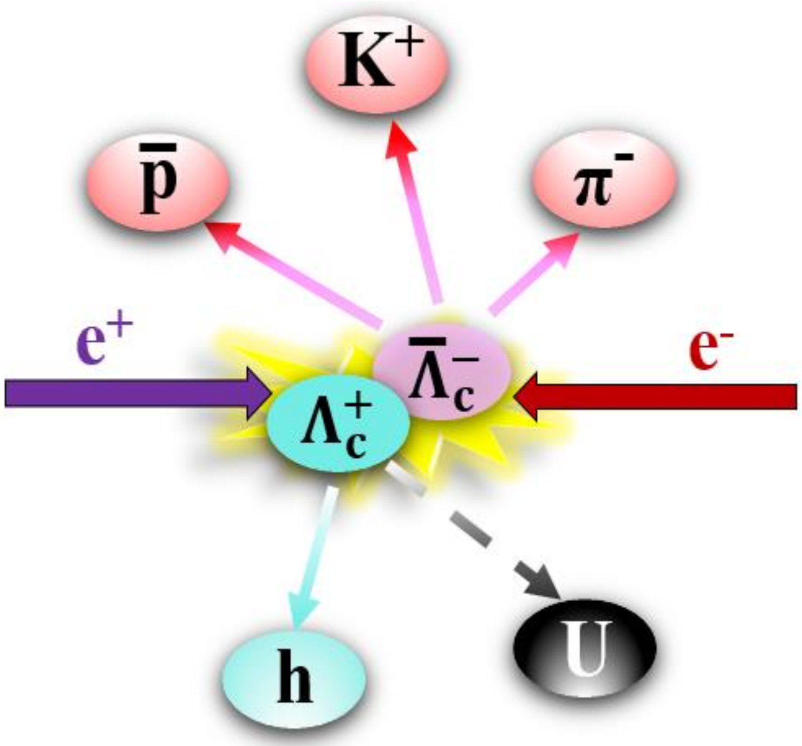
$$\boxed{M_{\text{miss}} = \sqrt{E^2_{\text{miss}} - c^2|\vec{p}_{\text{miss}}|^2}}$$

$$E_{\text{miss}} = E_{\text{beam}} - E_{\text{h}}$$

$$\vec{p}_{\text{miss}} = \vec{p}_{\Lambda_c^+} - \vec{p}_{\text{h}}$$

$$\vec{p}_{\Lambda_c^+} = -\boxed{\vec{p}_{\text{tag}}} \cdot \sqrt{E^2_{\text{beam}} - m^2_{\Lambda_c^+}}$$

direction of singly tagged Λ_c^+



Measurements that I report today

Hadronic Decays

- BF of 12 CF hadronic decays	PRL 116, 052001 (2016)
- BF($\Lambda_c^+ \to nK_S\pi^+$)	PRL 118, 112001 (2017)
- BF($\Lambda_c^+ \to p\pi^+\pi^-, pK^+K^-$)	PRL 117, 232002 (2016)
- BF($\Lambda_c^+ \to p\eta, p\pi^0$)	PRD 95, 111102(R) (2017)
- BF($\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$)	PLB 772, 388 (2017)
- BF($\Lambda_c^+ \to \Xi^{0(*)}K^+$)	PLB 121, 062003 (2018)

Semi-leptonic Decays

- BF($\Lambda_c^+ \to \Lambda e^+ v_e$)	PRL 115, 221805 (2015)
- BF($\Lambda_c^+ \to \Lambda\mu^+ v_\mu$)	PLB 747, 42 (2017)

Inclusive Decays

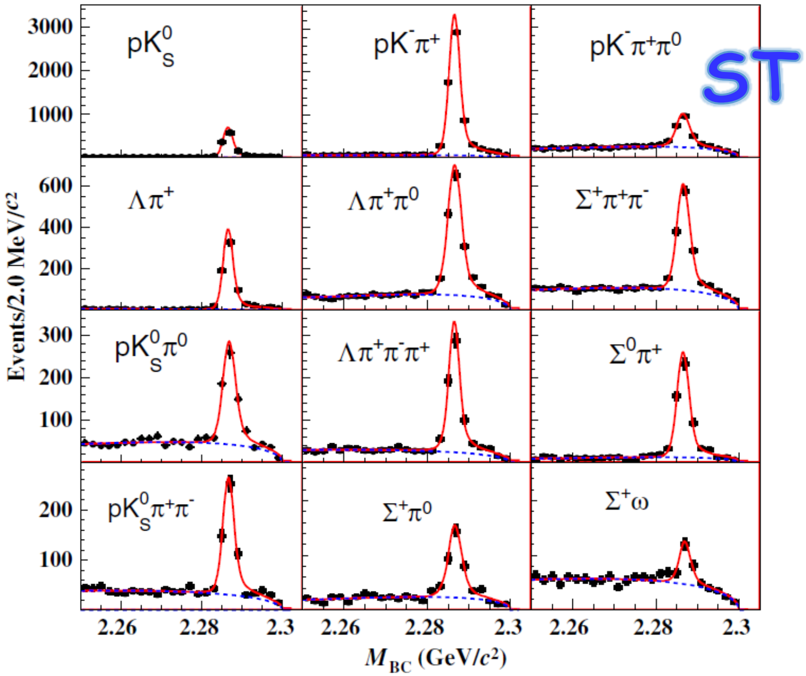
- BF($\Lambda_c^+ \to \Lambda + X$)	PRL 121, 062003 (2018)
- BF($\Lambda_c^+ \to e + X$)	arXiv: 1805.09060

Cross Section Measurement of e+e- → $\Lambda_c^+\Lambda_c^-$ at Threshold

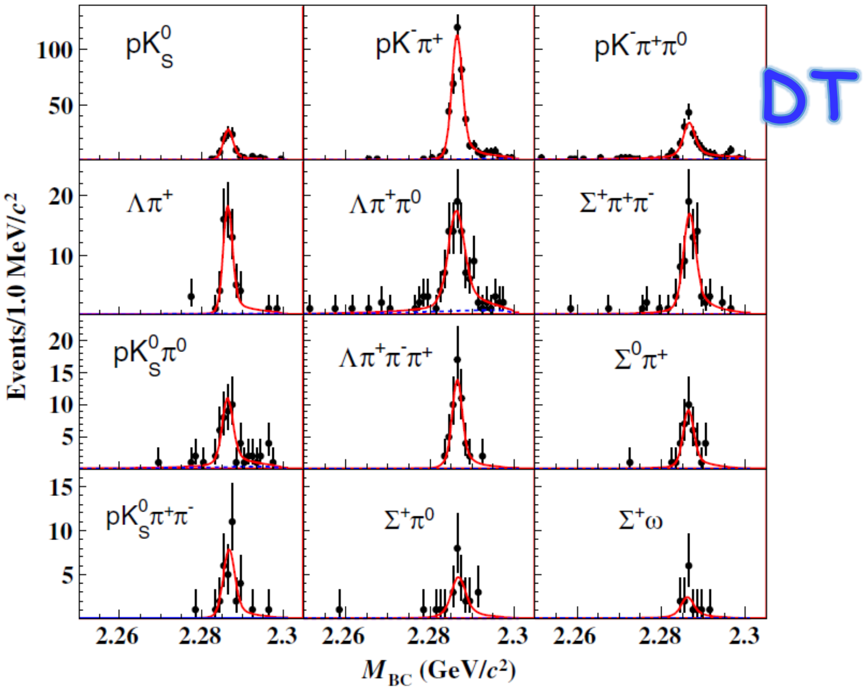
PRL 120, 132001 (2018)

Λ_c^+ hadronic decays

Absolute BFs for 12 Λ_c Hadronic Decays



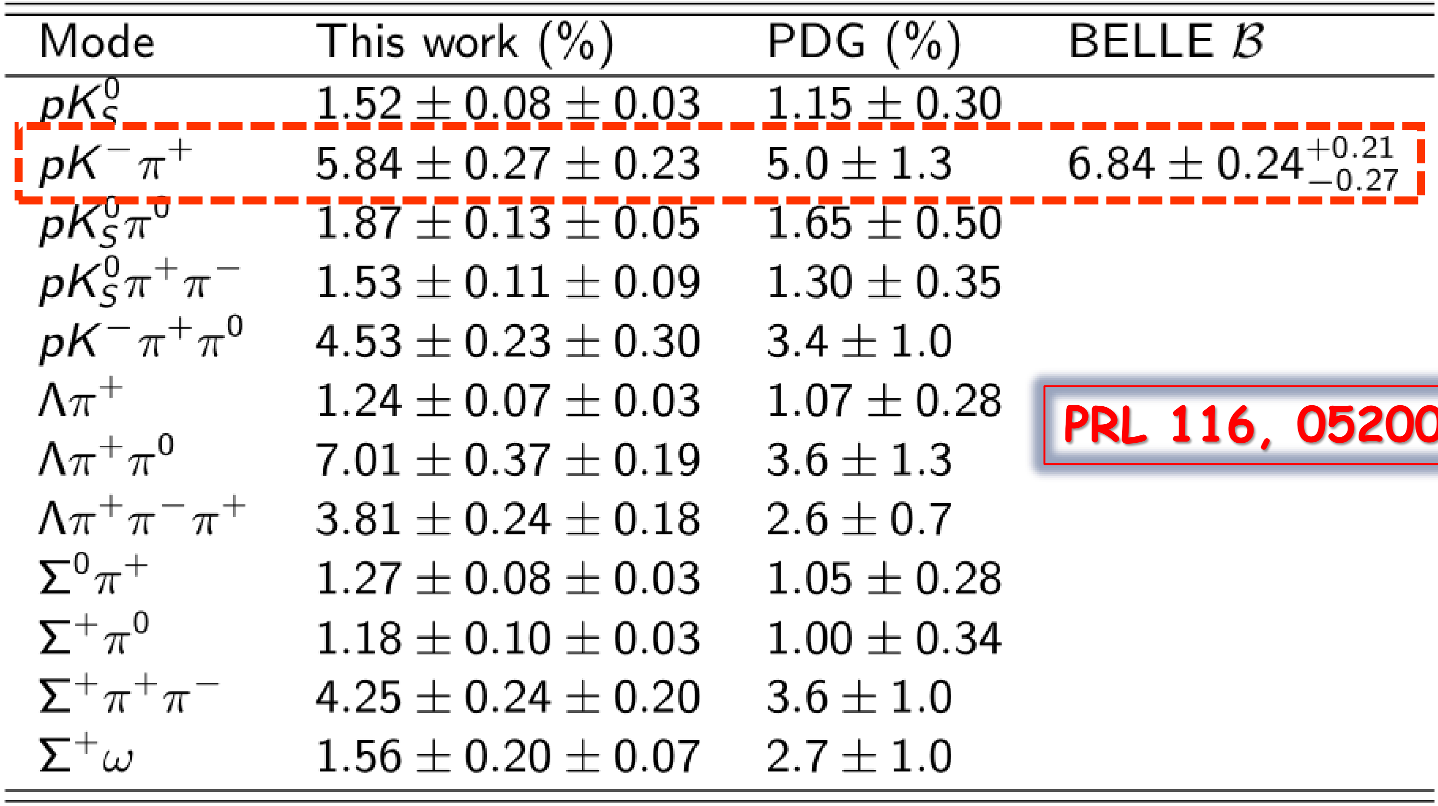
$$N_j^{\mathrm{ST}} = N_{\Lambda_c^+\bar{\Lambda}_c^-}\mathcal{B}_j\varepsilon_j$$



$$N_{ij}^{\mathrm{DT}} = N_{\Lambda_c^+\bar{\Lambda}_c^-}\mathcal{B}_i\mathcal{B}_j\varepsilon_{ij}$$

- First **absolute BF measurement** of the Λ_c
- ***A least square global fit:***
  To improve to precision, simultaneous fit to all the tag modes, while constraining the total $\Lambda_c^+\bar{\Lambda}_c^-$ pair number, taking into account the correlations.
- Also obtained $N_{\Lambda_c^+\Lambda_c^-}$ = (105.9±4.8±0.5) x 10^3

First direct measurement of Λ_c BF



Mode	This work (%)	PDG (%)	BELLE $\mathcal{B}$
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	

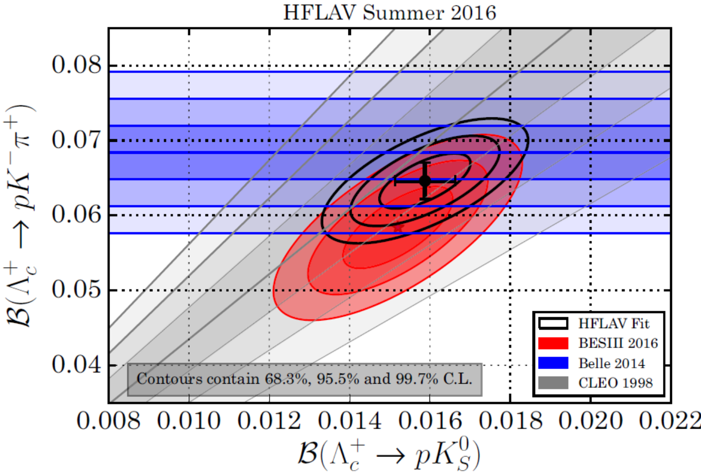
PRL 116, 052001 (2016)

- The precision of absolute BFs of 12 modes are improved significantly
- The precision of BF($pK^-\pi^+$) is comparable with BELLE's

HFLAV Fit to World Data

Mode	HFLAV Fit (%)	BESIII (%)	PDG 2014 (%)	BELLE (%)
pK^0_S	1.59 ± 0.07	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	6.46 ± 0.24	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK^0_S\pi^0$	2.03 ± 0.12	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK^0_S\pi^+\pi^-$	1.69 ± 0.11	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	5.05 ± 0.29	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	1.28 ± 0.06	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	7.09 ± 0.36	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	3.73 ± 0.21	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	1.31 ± 0.07	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	1.25 ± 0.09	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	4.64 ± 0.24	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	1.77 ± 0.21	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	
$\Lambda e^+\nu_e$	3.18 ± 0.32	$3.63 \pm 0.38 \pm 0.20$	2.1 ± 0.6	

EPJC 77,895 (2017)

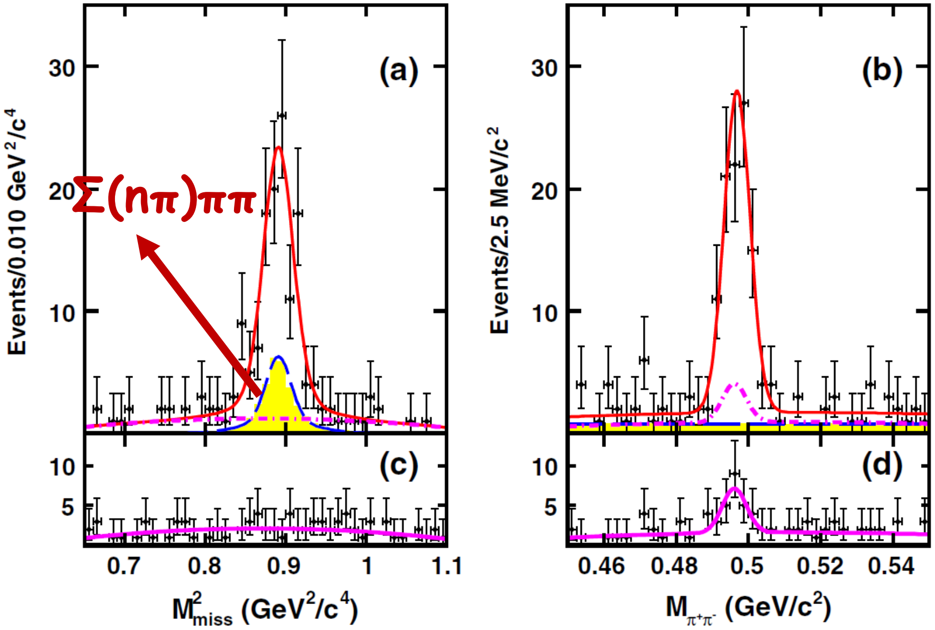


- A fitter to constrain the 12 hadronic BFs and 1 SL BF, based on world's all the existing experimental data
- Correlated systematics are fully considered.

Observation of $\Lambda_c^+ \to nK_s\pi^+$

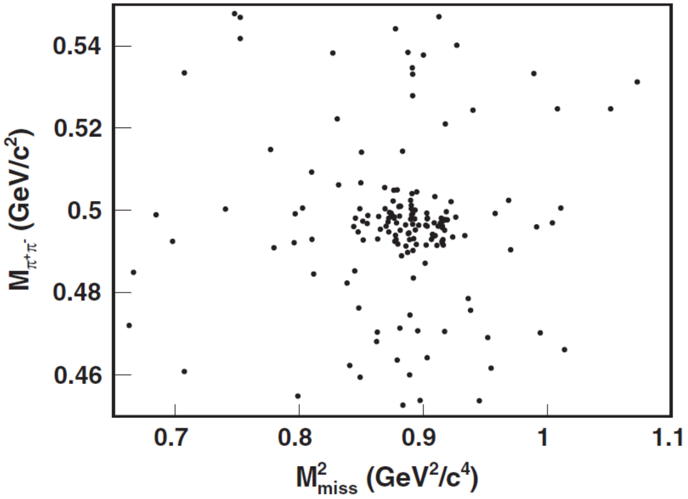
- First direct measurement in a final state involving a neutron
- Test if Isospin symmetry holds in charmed baryon decay (after it fails in charmed meson)

Simultaneous 2D fit



$$\mathcal{B}(\Lambda_c^+ \to nK_S^0\pi^+) = (1.82 \pm 0.23 \pm 0.11)\%$$

$$\mathcal{B}(\Lambda_c^+ \to n\bar{K}^0\pi^+)/\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = 0.62 \pm 0.09$$
$$\mathcal{B}(\Lambda_c^+ \to n\bar{K}^0\pi^+)/\mathcal{B}(\Lambda_c^+ \to p\bar{K}^0\pi^0)) = 0.97 \pm 0.16$$

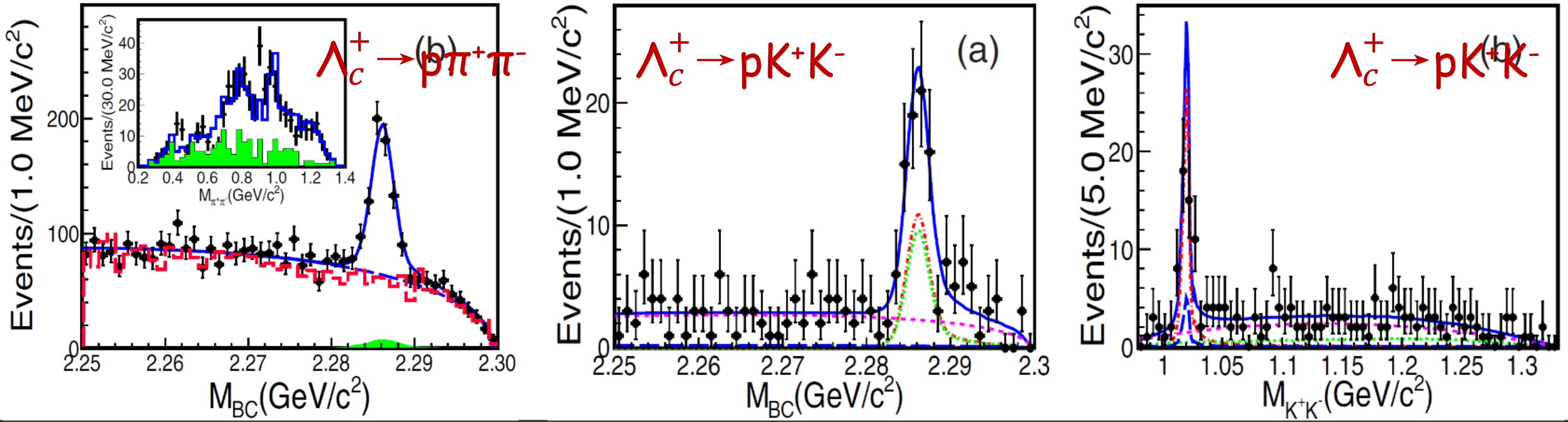


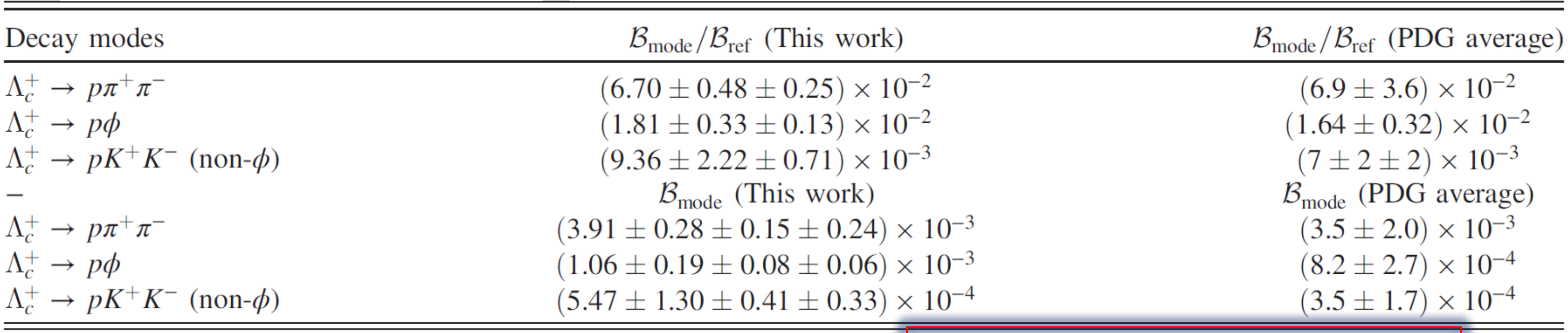
First Observation!

PRL 118, 112001 (2017)

$\Lambda_c^+ \to p\pi^+\pi^-$ and pK^+K^-

- ST method relative BF w.r.t. the pKπ mode
- First observation of Singly Cabibbo Suppressed (SCS) decay $\Lambda_c^+ \to p\pi^+\pi^-$
- Improved measurements on the SCS decays, $\Lambda_c^+ \to p\Phi$ and $\Lambda_c^+ \to pK^+K^-_{\text{non-}\Phi}$
- $\Lambda_c^+ \to p\Phi$ proceeds via internal W-emission only, which is essential to test the application of large-Nc factorization in charmed baryon.





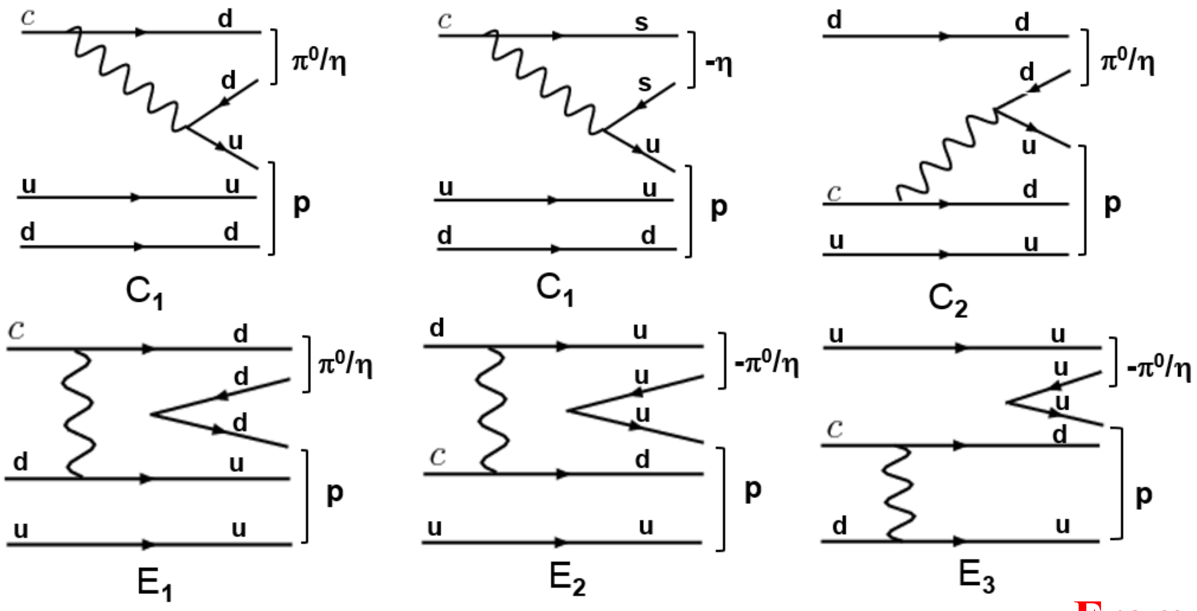
Decay modes	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref}}$ (This work)	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref}}$ (PDG average)
$\Lambda_c^+ \to p\pi^+\pi^-$	$(6.70 \pm 0.48 \pm 0.25) \times 10^{-2}$	$(6.9 \pm 3.6) \times 10^{-2}$
$\Lambda_c^+ \to p\phi$	$(1.81 \pm 0.33 \pm 0.13) \times 10^{-2}$	$(1.64 \pm 0.32) \times 10^{-2}$
$\Lambda_c^+ \to pK^+K^-$ (non-ϕ)	$(9.36 \pm 2.22 \pm 0.71) \times 10^{-3}$	$(7 \pm 2 \pm 2) \times 10^{-3}$
–	$\mathcal{B}_{\text{mode}}$ (This work)	$\mathcal{B}_{\text{mode}}$ (PDG average)
$\Lambda_c^+ \to p\pi^+\pi^-$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \to p\phi$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$
$\Lambda_c^+ \to pK^+K^-$ (non-ϕ)	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$

PRL 117, 232002 (2016)

$\Lambda_c^+ \to p\eta$ and $p\pi^0$

- First evidence of the SCS decay, $\Lambda_c^+ \to p\eta$ (4.2σ stat. significance)
- No signals seen in $\Lambda_c^+ \to p\pi^0$
- Predicted BFs vary under different theoretical models (SU(3) symmetry and FSI)

Singly Cabibbo-suppressed modes: $\Lambda_c^+ \to p\pi^0, p\eta$



$\pi^0 = (d\bar{d} - u\bar{u})/\sqrt{2}$, $\eta = (d\bar{d} + u\bar{u} - s\bar{s})/\sqrt{3}$ for $\eta - \eta'$ mixing angle $= 19.5^0$

From Prof HY Cheng's report

$A(\Lambda_c^+ \to p\pi^0) = (C_1 + C_2 + E_1 - E_2 - E_3)/\sqrt{2}$

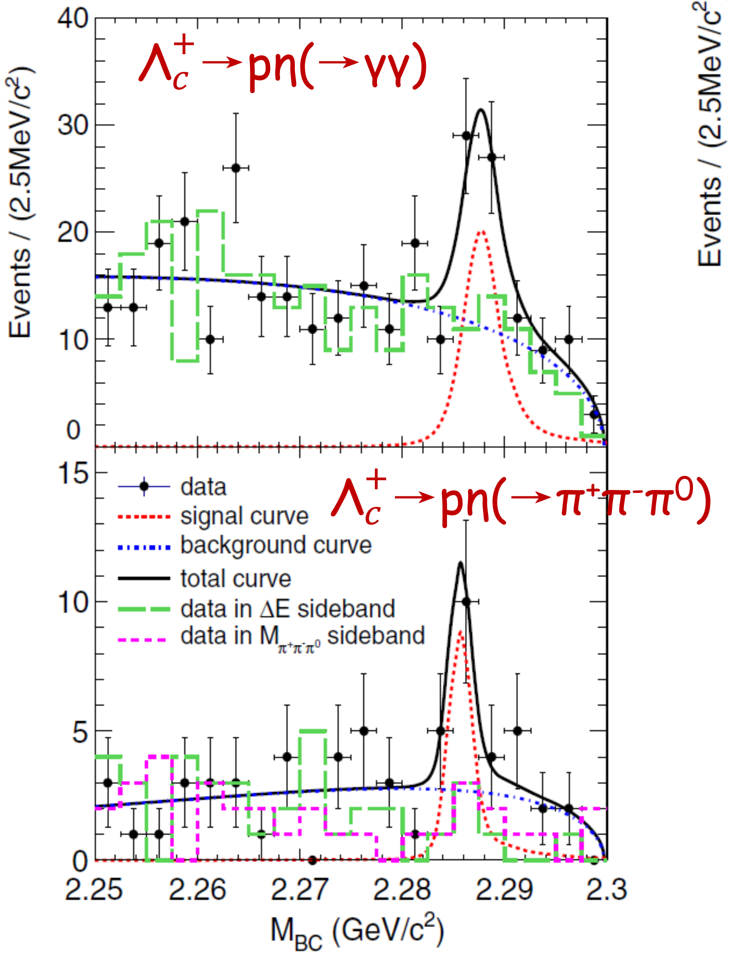
$A(\Lambda_c^+ \to p\eta) = (2C_1 + C_2 + E_1 + E_2 + E_3)/\sqrt{3}$

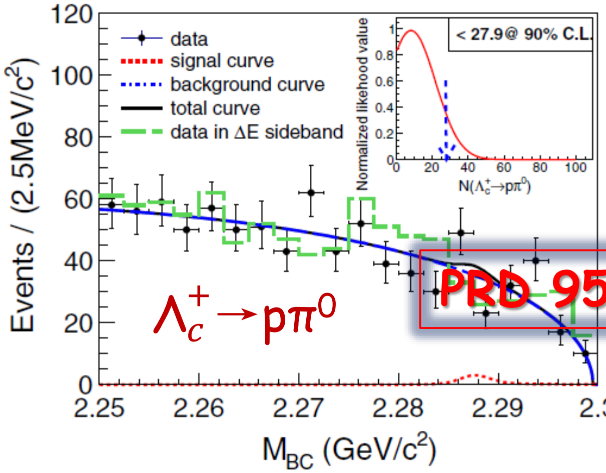
It is most likely that

$\Gamma(\Lambda_c^+ \to p\eta) >> \Gamma(\Lambda_c^+ \to p\pi^0)$

$\Lambda_c^+ \to p\eta$ and $p\pi^0$

- First evidence of the SCS decay, $\Lambda_c^+ \to p\eta$ (4.2σ stat. significance)
- No signals seen in $\Lambda_c^+ \to p\pi^0$
- Predicted BFs vary under different theoretical models (SU(3) symmetry and FSI)





PRD 95, 111102(R) (2017)

	$\Lambda_c^+ \to p\eta$	$\Lambda_c^+ \to p\pi^0$	$\frac{\mathcal{B}_{\Lambda_c^+\to p\pi^0}}{\mathcal{B}_{\Lambda_c^+\to p\eta}}$
BESIII	1.24 ± 0.29	<0.27	<0.24
Sharma *et al.* [3]	$0.2^a(1.7^b)$	0.2	$1.0^a(0.1^b)$
Uppal *et al.* [4]	0.3	0.1–0.2	0.3–0.7
S. L. Chen *et al.* [12]	...	$0.11–0.36^c$	...
Cai-Dian Lü *et al.* [13]	...	0.45	...

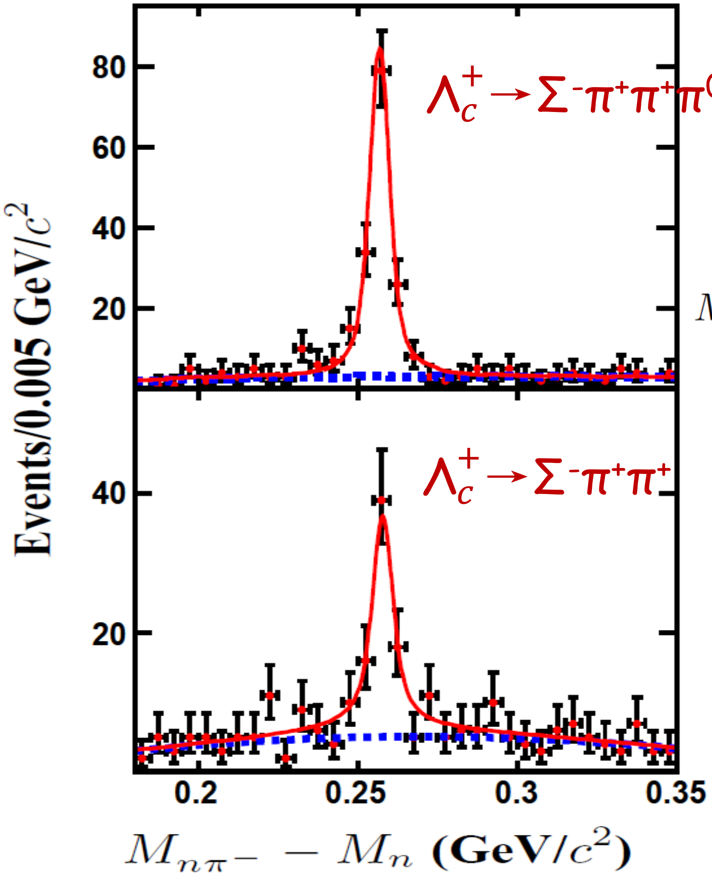
[a] Assumed to have a positive sign for the p-wave amplitude of $\Lambda_c^+ \to \Xi^0 K^+$.

[b] Assumed to have a negative sign for the p-wave amplitude of $\Lambda_c^+ \to \Xi^0 K^+$.

[c] Calculated relying on different values of parameters b and α.

$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$

- First observation of a large-rate forgotten CF decay, $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$
- Improved BF on $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$
- $\Sigma^- \to n\pi^-$ is reconstructed.



Fit to $M_{n\pi^-} - M_n$ to extract the signal yield

$$M_{n\pi^-} = \sqrt{(E_{\rm beam} - E_{\pi^+\pi^+(\pi^0)})^2 - |\vec{p}_{\Lambda_c^+} - \vec{p}_{\pi^+\pi^+(\pi^0)}|^2}$$

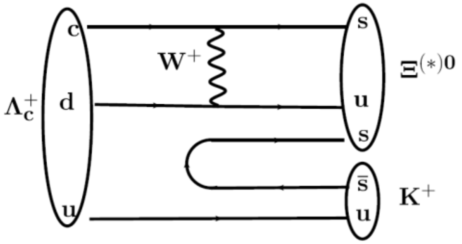
$$M_n = \sqrt{(E_{\rm beam} - E_{\pi^+\pi^+\pi^-(\pi^0)})^2 - |\vec{p}_{\Lambda_c^+} - \vec{p}_{\pi^+\pi^+\pi^-(\pi^0)}|^2}$$

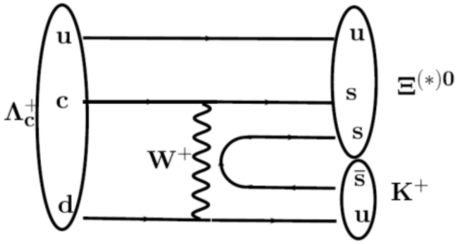
$$\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0) = (2.11\pm0.33\pm0.14)\%$$

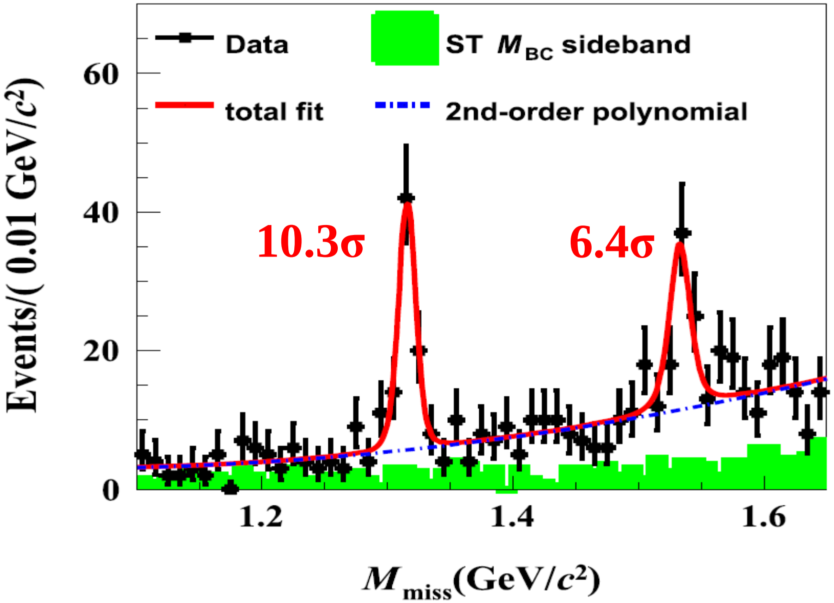
$$\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+) = (1.81 \pm 0.17 \pm 0.09)\%$$

PLB 772, 388 (2017)

$\Lambda_c^+ \rightarrow \Xi^{0(*)}K^+$







- W-exchange only process
- Important to identify non-factorizable contribution in different theoretical calculations
- First absolute measurement
- $\Lambda_c^+ \rightarrow \Xi(1530)^0K^+$ firmly established

Decay	Measured $\frac{\mathcal{B}(\Lambda_c^+\to\Xi^{(*)0}K^+)}{\mathcal{B}(\Lambda_c^+\to pK^-\pi^+)}$	Predicted $\mathcal{B}(\Lambda_c^+ \to \Xi^{(*)0}K^+)$
Ξ^0K^+	$(7.8 \pm 1.8)\%$ [18]	2.6×10^{-3} [4] 3.6×10^{-3} [6] 3.1×10^{-3} [10] 1.0×10^{-3} [14] 1.3×10^{-3} [15]
$\Xi^{*0}K^+$	$(5.3 \pm 1.9)\%$ [18] $(9.3 \pm 3.2)\%$ [19, 20]	5.0×10^{-3} [4] 0.8×10^{-3} [16] 0.6×10^{-3} [17]

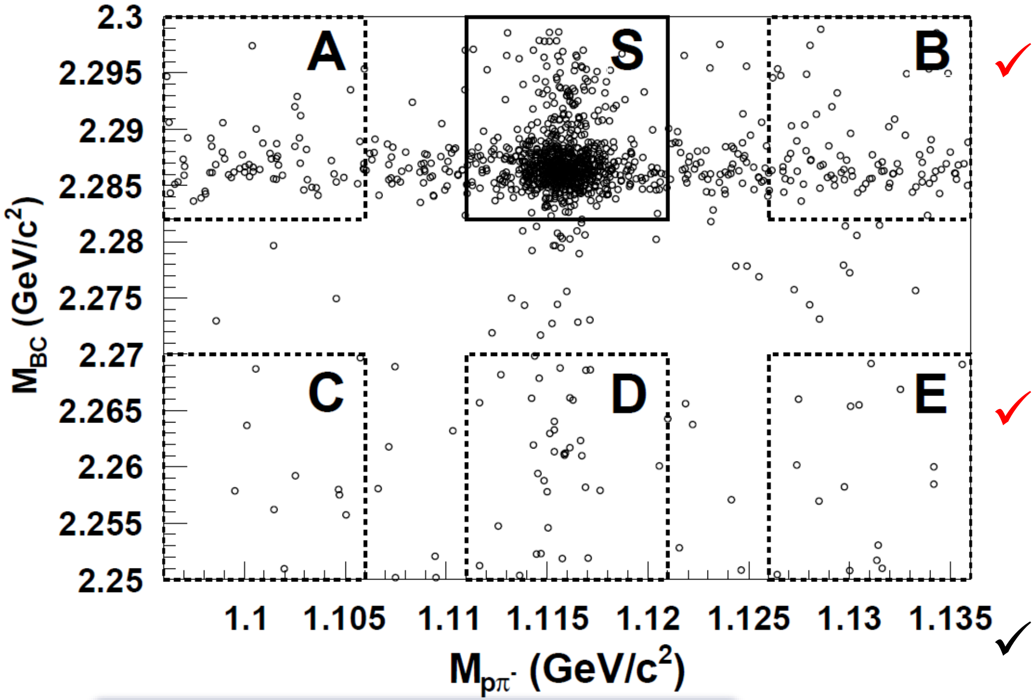
$$\mathcal{B}(\Lambda_c^+ \to \Xi^0K^+) = (5.90 \pm 0.86 \pm 0.39) \times 10^{-3}$$

$$\mathcal{B}(\Lambda_c^+ \to \Xi(1530)^0K^+) = (5.02 \pm 0.99 \pm 0.31) \times 10^{-3}$$

PLB 121, 062003 (2018)

$\Lambda_c^+ \to \Lambda + X$

- Currently PDG: BF($\Lambda_c^+ \to \Lambda$+X) = (35±11)%
  - Large rate, but also with large uncertainty…
- DT method: ST with pKπ and pK_S
- Extract yields from 2D distributions in bins of $p_{p\pi}$ and |cosθ| where θ is the polar angle w.r.t. the beam pipe.



PRL 121, 062003 (2018)

✓ B($\Lambda_c^+ \to \Lambda$+X) = $(38.2^{+2.8}_{-2.2} \pm 0.9)\%$

In PDG, only (24.5±2.1)%, indicating more unobserved decays including Λ

✓ A_{CP} = $(2.1^{+7.0}_{-6.6} \pm 1.6)\%$

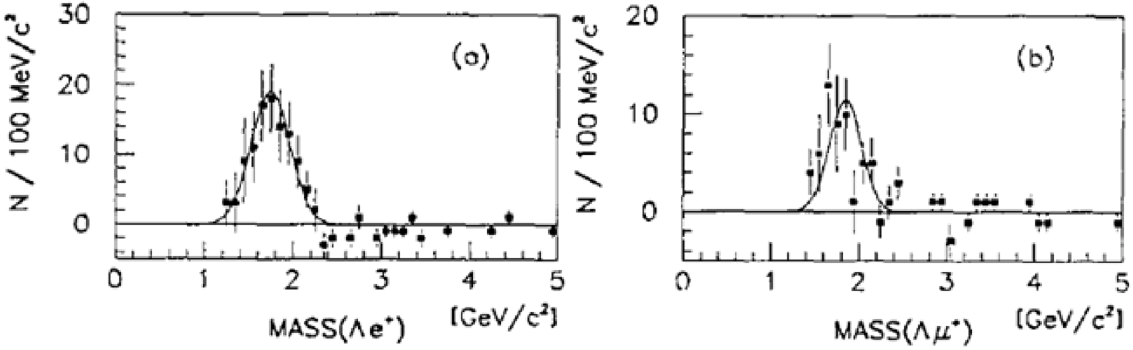
No evidence for CPV

✓ Comparison with K+X will shed light on the internal dynamics

Λ_c^+ semi-leptonic decays

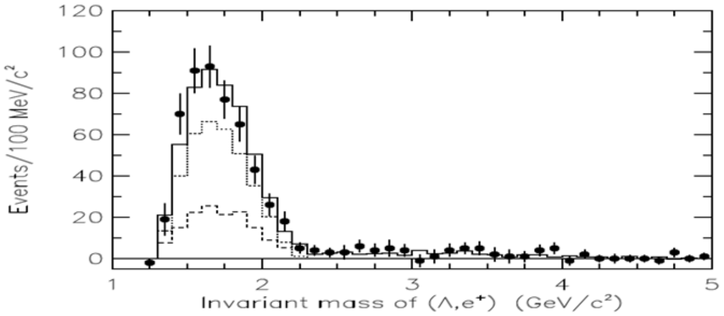
$\Lambda_c^+ \to \Lambda l^+ \nu_l$ Decays

- In 1991, ARGUS reported the first measurement of $\Lambda_c^+ \to \Lambda l^+ \nu_l$ decays with 477 pb^{-1} Υ(1S), Υ(2S) and Υ(4S) data



PLB 296, 234 (1991)

- In 1994, CLEO performed same measurement with 1.6 fb^{-1} Υ(4S) data



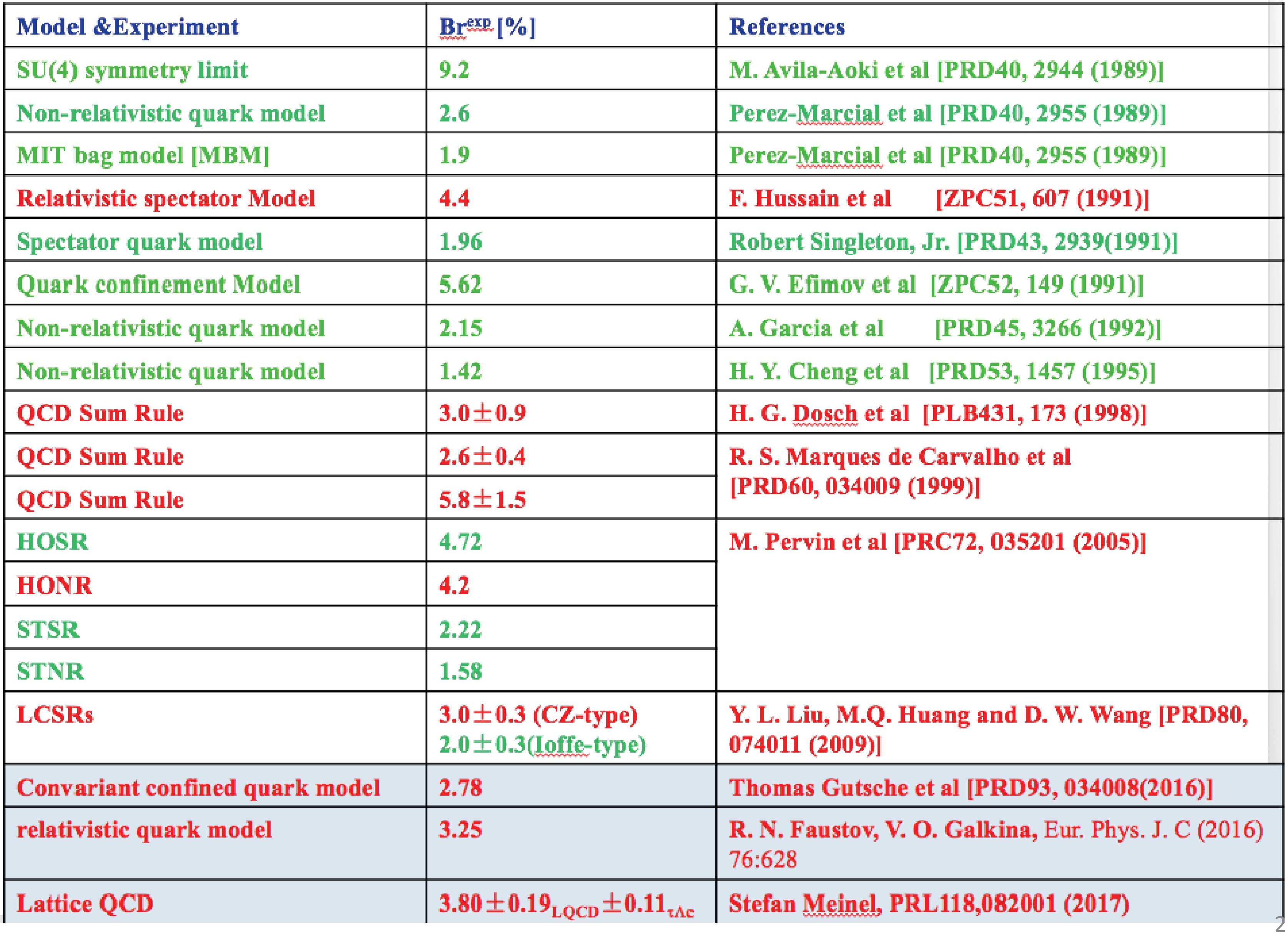
PLB 323, 219 (1994)

- Based on above two measurements, PDG extracts BF for $\Lambda_c^+ \to \Lambda l^+ \nu_l$ with $\tau(\Lambda_c^+)$ and the assumption for form factors

$\Lambda \ell^+ \nu_\ell$	[r]	(2.8 ± 0.4) %
$\Lambda e^+ \nu_e$		(2.9 ± 0.5) %
$\Lambda \mu^+ \nu_\mu$		(2.7 ± 0.6) %

Not a direct measurement!

Theoretical calculations on $\Lambda_c^+ \to \Lambda l^+ \nu_l$

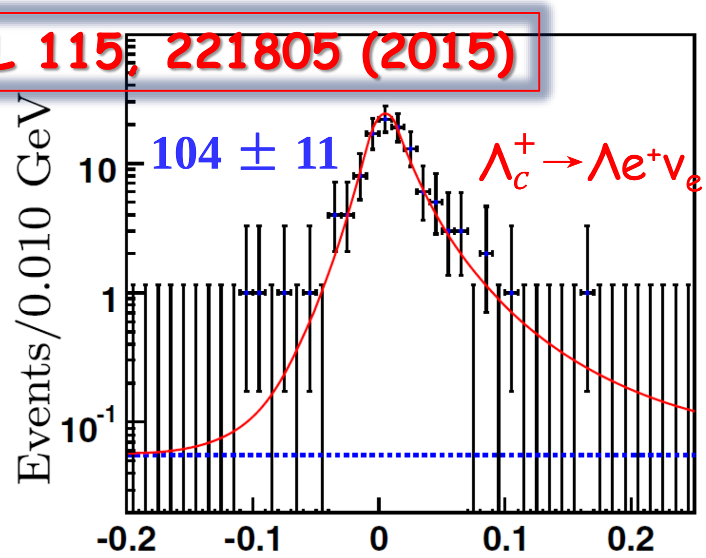


Model &Experiment	Br^{exp} [%]	References
SU(4) symmetry limit	9.2	M. Avila-Aoki et al [PRD40, 2944 (1989)]
Non-relativistic quark model	2.6	Perez-Marcial et al [PRD40, 2955 (1989)]
MIT bag model [MBM]	1.9	Perez-Marcial et al [PRD40, 2955 (1989)]
Relativistic spectator Model	4.4	F. Hussain et al [ZPC51, 607 (1991)]
Spectator quark model	1.96	Robert Singleton, Jr. [PRD43, 2939(1991)]
Quark confinement Model	5.62	G. V. Efimov et al [ZPC52, 149 (1991)]
Non-relativistic quark model	2.15	A. Garcia et al [PRD45, 3266 (1992)]
Non-relativistic quark model	1.42	H. Y. Cheng et al [PRD53, 1457 (1995)]
QCD Sum Rule	3.0 ± 0.9	H. G. Dosch et al [PLB431, 173 (1998)]
QCD Sum Rule	2.6 ± 0.4	R. S. Marques de Carvalho et al [PRD60, 034009 (1999)]
QCD Sum Rule	5.8 ± 1.5	
HOSR	4.72	M. Pervin et al [PRC72, 035201 (2005)]
HONR	4.2	
STSR	2.22	
STNR	1.58	
LCSRs	3.0 ± 0.3 (CZ-type) 2.0 ± 0.3(Ioffe-type)	Y. L. Liu, M.Q. Huang and D. W. Wang [PRD80, 074011 (2009)]
Convariant confined quark model	2.78	Thomas Gutsche et al [PRD93, 034008(2016)]
relativistic quark model	3.25	R. N. Faustov, V. O. Galkina, Eur. Phys. J. C (2016) 76:628
Lattice QCD	$3.80 \pm 0.19_{\mathrm{LQCD}} \pm 0.11_{\tau\Lambda c}$	Stefan Meinel, PRL118,082001 (2017)

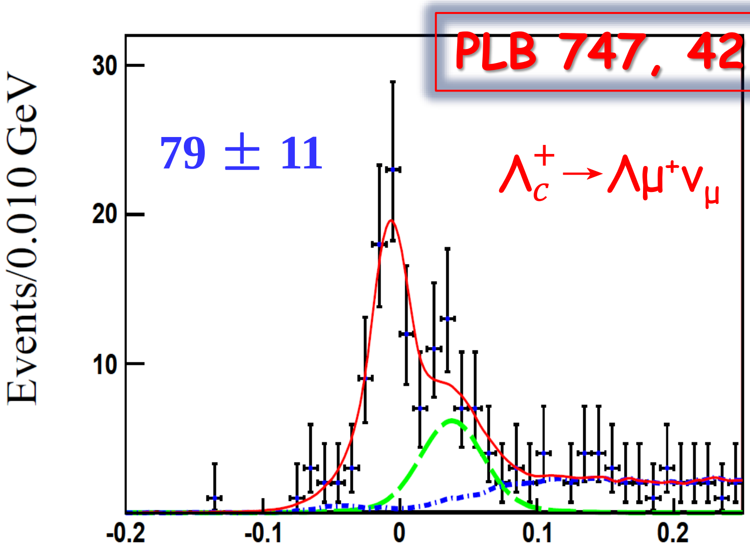
$\Lambda_c^+ \to \Lambda l^+ \nu_l$

- $\Lambda_c^+ \to \Lambda l^+ \nu_l$ is a $c \to s l^+ \nu_l$ dominated process
- First absolute BF of semi-leptonic mode
- First measurement of its muonic mode!
- Important for testing and calibrating the Lattice-QCD calculations

PRL 115, 221805 (2015)



PLB 747, 42 (2017)



$$U_{\mathrm{miss}} = E_{\mathrm{miss}} - c|\vec{p}_{\mathrm{miss}}|$$

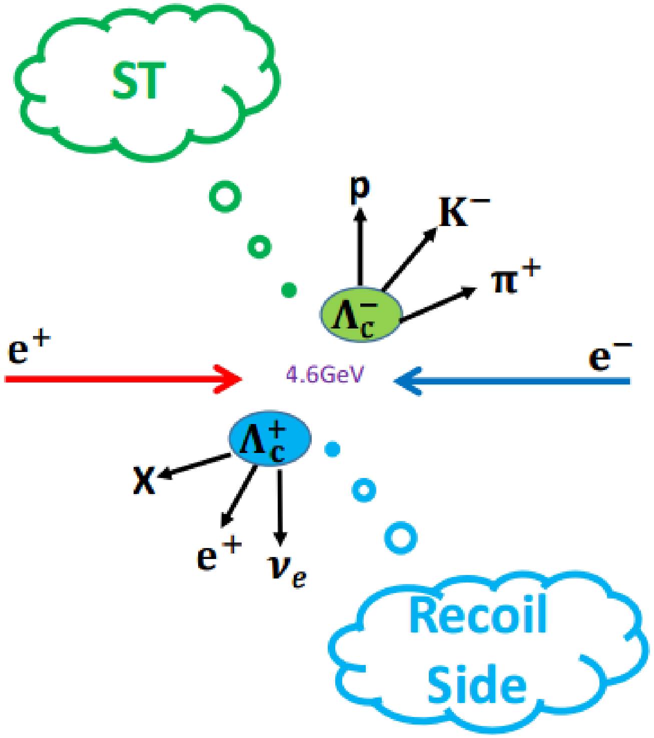
$$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$$

$$\mathcal{B}(\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu) = (3.49 \pm 0.46(\mathrm{stat}) \pm 0.27(\mathrm{syst}))\%$$

$$\mathcal{B}(\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu)/\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$$

$$= 0.96 \pm 0.16(\mathrm{stat}) \pm 0.04(\mathrm{syst})$$

$\Lambda_c^+ \to e^+ + X$



$$Br(\Lambda_c^+ \to Xe^+\nu_e) = \frac{N_{gen}}{N_{ST}}$$

N_{gen}: number of generated semileptonic decays in the ST samples

N_{ST}: ST yields

Result	$\Lambda_c^+ \to Xe^+\nu_e$	$\frac{\Gamma(\Lambda_c^+ \to Xe^+\nu_e)}{\bar{\Gamma}(D \to Xe^+\nu_e)}$
BESIII	3.95 ± 0.35	1.26 ± 0.12
MARK II [7]	4.5 ± 1.7	1.44 ± 0.54
Effective-quark Method [9, 10]		1.67
Heavy-quark Expansion [11]		1.2

$$\boxed{\frac{\mathcal{B}(\Lambda_c^+ \to \Lambda e^+\nu_e)}{\mathcal{B}(\Lambda_c^+ \to Xe^+\nu_e)} = (91.9 \pm 12.5 \pm 5.4)\%}$$

Real positron yields

$$\begin{pmatrix} N_e^{\text{obs}} \\ N_\pi^{\text{obs}} \\ N_K^{\text{obs}} \\ N_p^{\text{obs}} \end{pmatrix} = \begin{pmatrix} P_{e\to e} & P_{\pi\to e} & P_{K\to e} & P_{p\to e} \\ P_{e\to\pi} & P_{\pi\to\pi} & P_{K\to\pi} & P_{p\to\pi} \\ P_{e\to K} & P_{\pi\to K} & P_{K\to K} & P_{p\to K} \\ P_{e\to p} & P_{\pi\to p} & P_{K\to p} & P_{p\to p} \end{pmatrix} \begin{pmatrix} \boxed{N_e^{\text{true}}} \\ N_\pi^{\text{true}} \\ N_K^{\text{true}} \\ N_p^{\text{true}} \end{pmatrix}$$

PID efficiency matrix

arXiv: 1805.09060

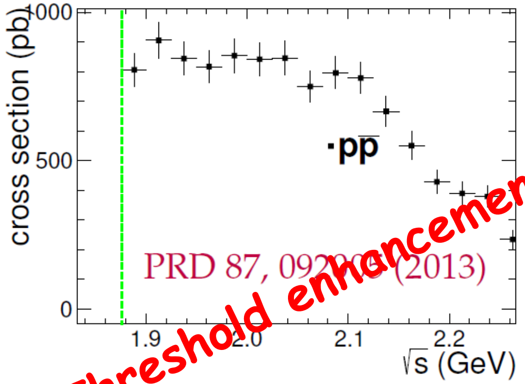
Cross Section of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ near threshold

- The Born Cross Section of $e^+e^- \to \gamma^* \to B\bar{B}$ can be parameterized in terms of electromagnetic form factors:

$$\sigma_{B\bar{B}}(s) = \frac{4\pi\alpha^2 C\beta}{3s}|G_M(s)|^2\left(1+\frac{2m_B^2c^4}{s}\left|\frac{G_E(s)}{G_M(s)}\right|^2\right)$$

- Baryon velocity: $\beta = \sqrt{1-4m_B^2c^4/s}$

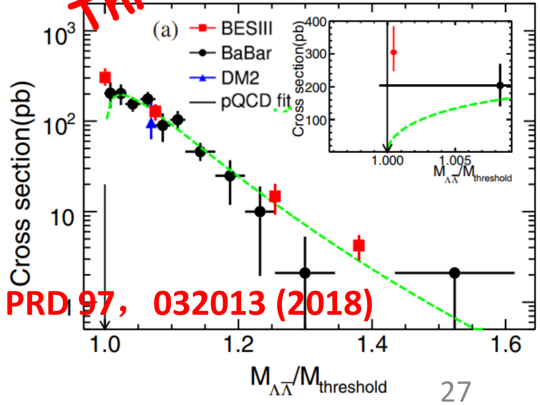
- For charged Baryon, the Coulomb factor C will results in a non-zero cross section at threshold.



- $e^+e^- \to p\bar{p}$: an enhancement and wide-range plateau in the line-shape
- $e^+e^- \to \Lambda\bar{\Lambda}$: non-zero cross section near threshold
- It can be anticipate that Λ_c^+ has a similar behaviour with proton

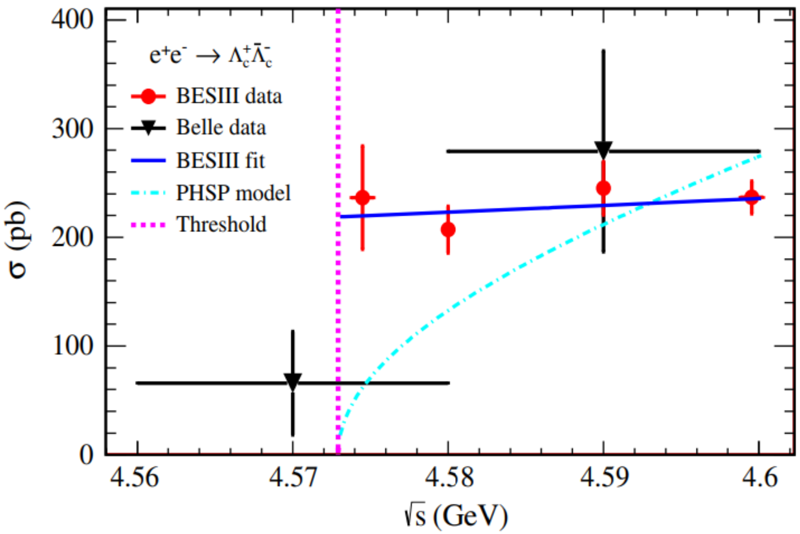
Coulomb enhanced factor in $e^+e^- \to \gamma^* \to \Lambda_c^+\Lambda_c^-$?

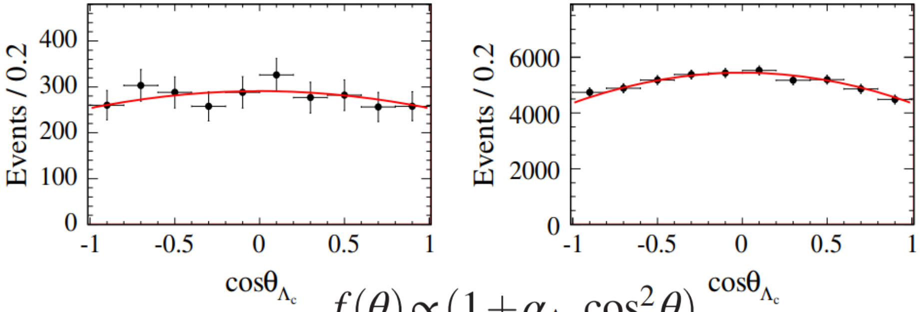
Threshold enhancement!



PRD 97, 032013 (2018)

Cross Section of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ near threshold





$$f(\theta) \propto (1+\alpha_{\Lambda_c}\cos^2\theta)$$

FIG. 3. Angular distribution after efficiency correction and results of the fit to data at $\sqrt{s} = 4574.5$ MeV (left) and 4599.5 MeV (right).

$$\boxed{|G_E/G_M|^2(1-\beta^2) = (1-\alpha_{\Lambda_c})/(1+\alpha_{\Lambda_c})}$$

$\sqrt{s}$ (MeV)	α_{Λ_c}	$\lvert G_E/G_M \rvert$
4574.5	$-0.13 \pm 0.12 \pm 0.08$	$1.14 \pm 0.14 \pm 0.07$
4599.5	$-0.20 \pm 0.04 \pm 0.02$	$1.23 \pm 0.05 \pm 0.03$

- Unprecedented precision
- **Enhanced cross section** of $e^+e^- \to \Lambda_c^+\Lambda_c^-$ near threshold is discerned for the first time
- Column enhanced factor?

PRL 120, 132001 (2018)

Provide important insights into the **production mechanism and structure** of Λ_c baryons.

Summary

- **Threshold data at BESIII opens a new door to direct measurements of Λ_c decays → precise study of Λ_c decays**
  - clean environment
  - DT method, absolute BF measurement
- **Many Ongoing Λ_c analyses**

More potentials

- **A larger data set**
  - BESIII will keep collecting data in the next ~ decade
  - The current plan is to accumulate 1M Λ_c in total
- BESIII and B factories will be complementary in Λ_c decays and provide the precise measurements in the future

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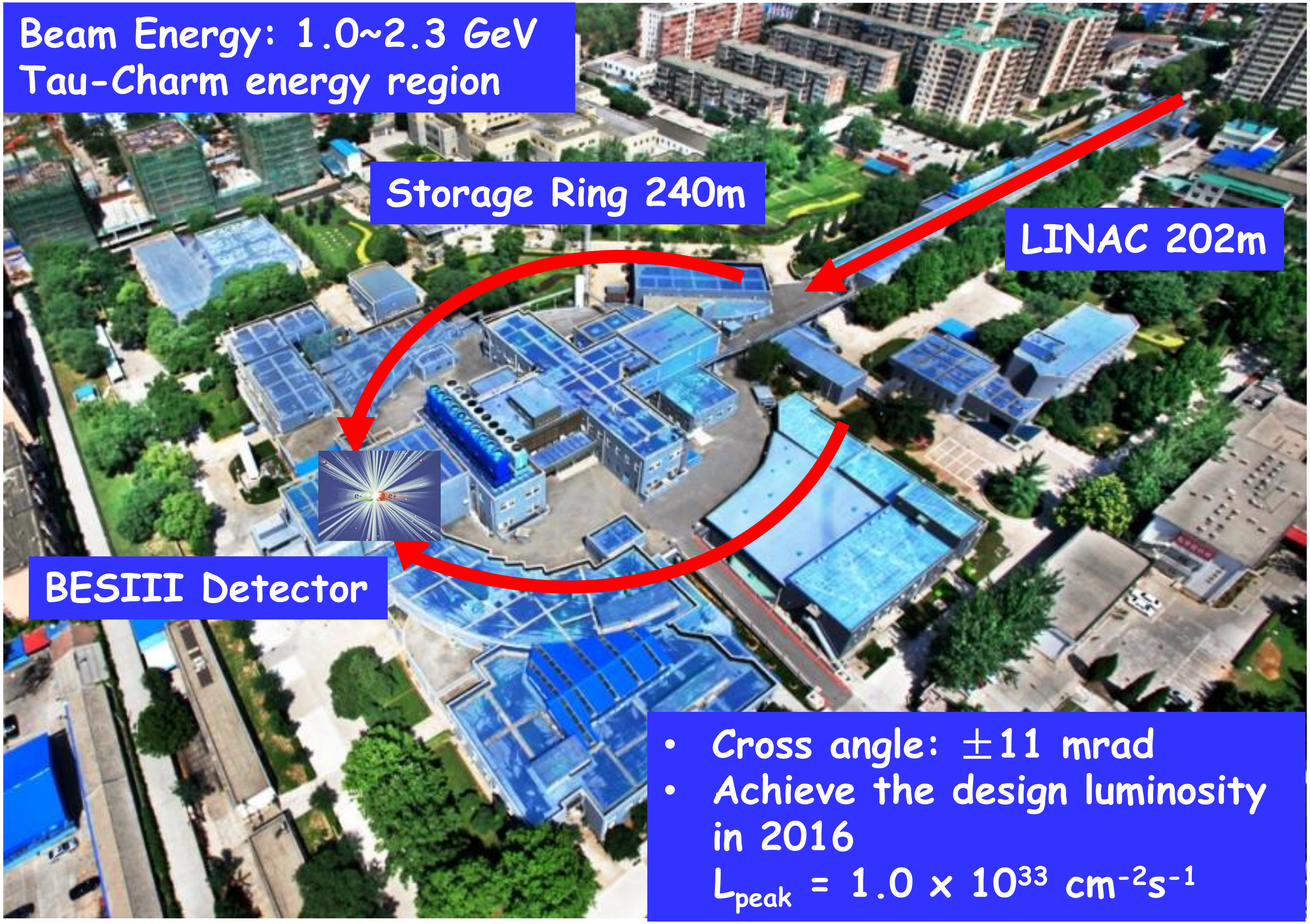
Thank you!

BackUp

Beijing Electron and Positron Collider(BEPCII)



Beam Energy: 1.0~2.3 GeV
Tau-Charm energy region

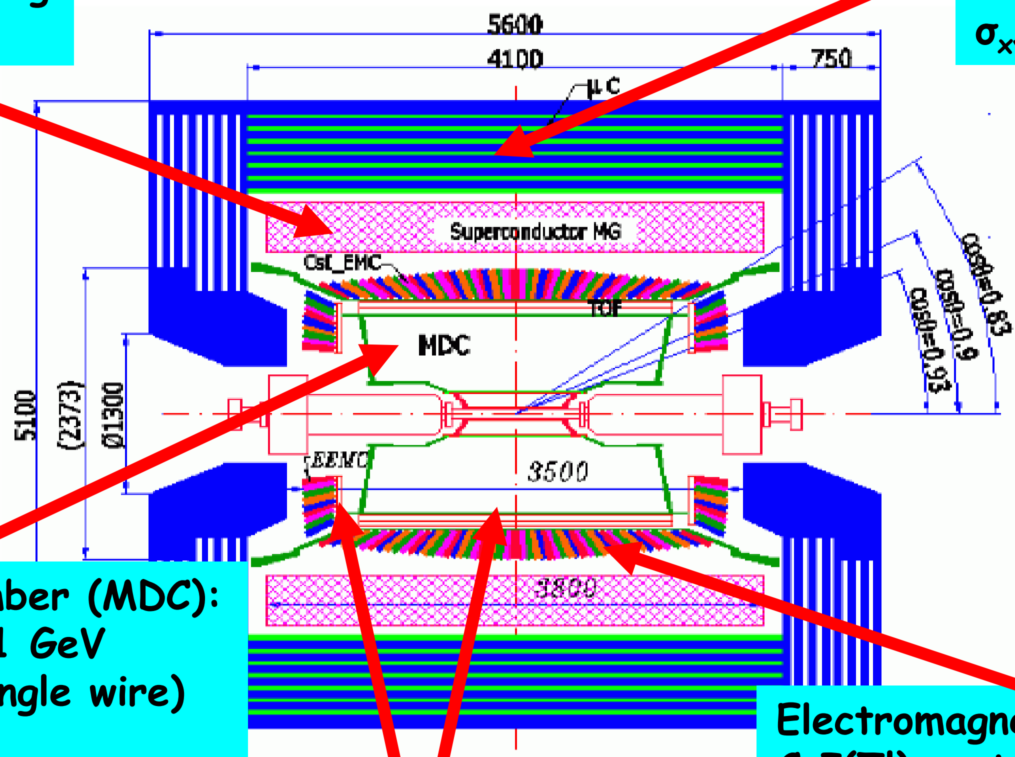
Storage Ring 240m

LINAC 202m

BESIII Detector

- Cross angle: ±11 mrad
- Achieve the design luminosity in 2016
  $L_{peak} = 1.0 \times 10^{33}\ cm^{-2}s^{-1}$

BESIII detector



Superconducting Solenoid: 1T

Muon Counter (MUC):
Resistive Plate Chamber
σ_{xy} < 2 cm

Main Drift Chamber (MDC):
σ_p/p = 0.5% @ 1 GeV
σ_{xy} = 130 μm (single wire)
$\sigma_{dE/dx}$ = 6%

Time of Flight (TOF):
σ_t = 80 ps (barrel)
σ_t = 110 (65) ps (endcap)

Electromagnetic Calorimeter (EMC):
CsI(Tl) cystal
σ_E/E < 2.5% @ 1 GeV (barrel)
σ_E/E < 5.0% @ 1 GeV (endcap)
σ_{xy} = (6 mm)/$\sqrt{E}$ @ 1 GeV

$\Lambda_c \to \Lambda l^+ \nu_l$ Form Factors and Decay Rates from Lattice QCD with Physical Quark Masses

Stefan Meinel
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(Received 1 December 2016; published 21 February 2017)

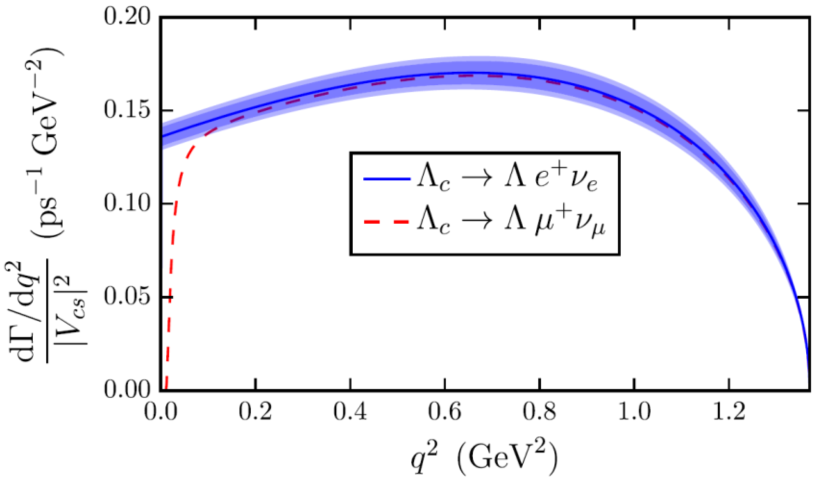
PLB 747, 42 (2017)

- Input the measured BFs from BESIII

$$\mathcal{B}(\Lambda_c \to \Lambda \ell^+ \nu_\ell) = \begin{cases} 0.0380(19)_{\mathrm{LQCD}}(11)_{\tau_{\Lambda_c}}, & \ell = e, \\ 0.0369(19)_{\mathrm{LQCD}}(11)_{\tau_{\Lambda_c}}, & \ell = \mu, \end{cases}$$

- The first LQCD calculations on BFs and forms factors

$$\mathcal{B}(\Lambda_c \to \Lambda \ell^+ \nu_\ell) = \begin{cases} 0.0363(38)(20), & \ell = e, \\ 0.0349(46)(27), & \ell = \mu. \end{cases}$$



- The first determination of $|V_{cs}|$ based on BFs of $\Lambda_c^+ \to \Lambda l^+ \nu_l$ measured by BESIII

$$|V_{cs}| = \begin{cases} 0.951(24)_{\mathrm{LQCD}}(14)_{\tau_{\Lambda_c}}(56)_{\mathcal{B}}, & \ell = e, \\ 0.947(24)_{\mathrm{LQCD}}(14)_{\tau_{\Lambda_c}}(72)_{\mathcal{B}}, & \ell = \mu, \\ 0.949(24)_{\mathrm{LQCD}}(14)_{\tau_{\Lambda_c}}(49)_{\mathcal{B}}, & \ell = e, \mu, \end{cases}$$

$\Lambda_c^+ \to \Lambda l^+ \nu_l$ BF is the largest error source