Prospects and interest in Λ_c running + measurements

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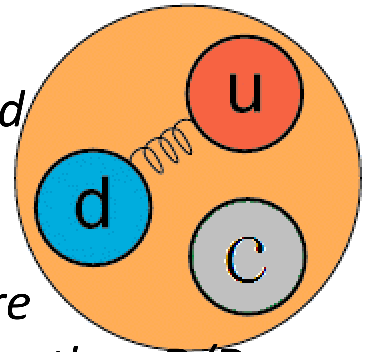
Outline

- Introduction
- Λ_c^+ Measurements at BESIII
- Prospects at BESIII
- Summary

Λ_c^+ cornerstone of charmed baryon spectroscopy

Quark model picture:



a heavy quark (c) with a unexcited spin-zero diquark (u-d)
Heavy Quark Effective Theory predicts that Λ_c may provide more powerful test on internal dynamics than D/D_s

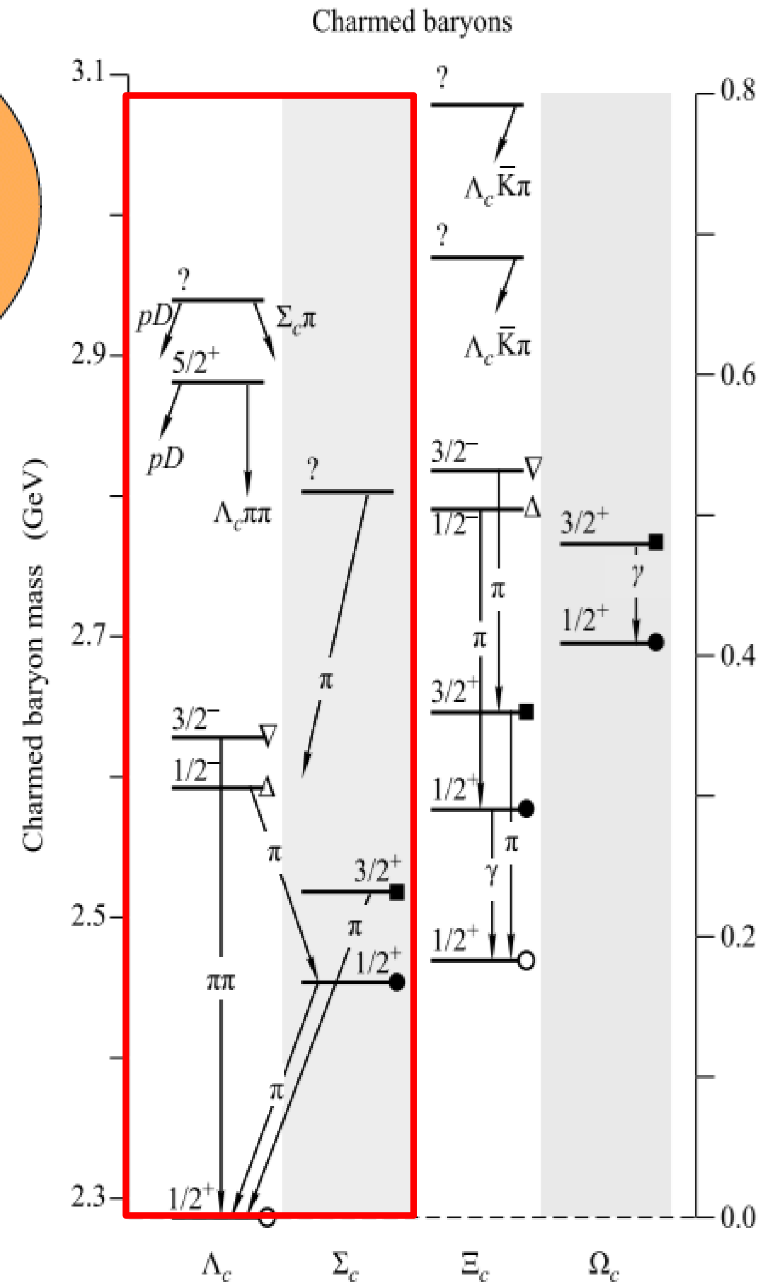
Cornerstone of charmed baryons:

Λ_c^+ is the lightest charmed baryon, most of th charmed baryons will eventually decay to Λ_c

Essential input for study the decays of b-flavored hadrons involving Λ_c in final state

Status of Λ_c^+ measurement [PDG2015]:

- *poorly understood compared to charm mesons total BF~60%, large uncertainties(>20%)*
- *Relative measurement*
- *No neutron mode has been observed yet.*



Λ_c^+ Measurements [PDG2015]

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	ΔB/B
Hadronic modes with a p: $S=-1$ final states				
$p\overline{K}^0$		$(3.21\pm0.30)\,\%$		9.3%
$pK^-\pi^+$		$(6.84^{+0.32}_{-0.40})\,\%$		5.8%
$p\overline{K}^*(892)^0$	[q]	$(2.13\pm0.30)\,\%$		14.1%
$\Delta(1232)^{++}K^-$		$(1.18\pm0.27)\,\%$		22.9%
$\Lambda(1520)\pi^+$	[q]	$(2.4\pm0.6)\,\%$		25.0%
$pK^-\pi^+$ nonresonant		$(3.8\pm0.4)\,\%$		10.5%
$p\overline{K}^0\pi^0$		$(4.5\pm0.6)\,\%$		13.3%
$p\overline{K}^0\eta$		$(1.7\pm0.4)\,\%$		23.5%
$p\overline{K}^0\pi^+\pi^-$		$(3.5\pm0.4)\,\%$		11.4%
$pK^-\pi^+\pi^0$		$(4.6\pm0.8)\,\%$		13.0%
$pK^*(892)^-\pi^+$	[q]	$(1.5\pm0.5)\,\%$		33.3%
$p(K^-\pi^+)_{\rm nonresonant}\,\pi^0$		$(5.0\pm0.9)\,\%$		18.0%
$\Delta(1232)\overline{K}^*(892)$		seen		
$pK^-\pi^+\pi^+\pi^-$		$(1.5\pm1.0)\times10^{-3}$		66.7%
$pK^-\pi^+\pi^0\pi^0$		$(1.1\pm0.5)\,\%$		45.4%
Hadronic modes with a p: $S=0$ final states				
$p\pi^+\pi^-$		$(4.7\pm2.5)\times10^{-3}$		45.4%
$pf_0(980)$	[q]	$(3.8\pm2.5)\times10^{-3}$		53.2%
$p\pi^+\pi^+\pi^-\pi^-$		$(2.5\pm1.6)\times10^{-3}$		64.0%
pK^+K^-		$(1.1\pm0.4)\times10^{-3}$		36.4%
$p\phi$	[q]	$(1.12\pm0.23)\times10^{-3}$		
pK^+K^- non-ϕ		$(4.8\pm1.9)\times10^{-4}$		
Hadronic modes with a hyperon: $S=-1$ final states				
$\Lambda\pi^+$		$(1.46\pm0.13)\,\%$		8.9%
$\Lambda\pi^+\pi^0$		$(5.0\pm1.3)\,\%$		26.0%
$\Lambda\rho^+$		$<6\,\%$	CL=95%	
$\Lambda\pi^+\pi^+\pi^-$		$(3.59\pm0.28)\,\%$		7.8%
$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+}\to\Lambda\pi^+$		$(1.0\pm0.5)\,\%$		20.0%
$\Sigma(1385)^-\pi^+\pi^+$, $\Sigma^{*-}\to\Lambda\pi^-$		$(7.5\pm1.4)\times10^{-3}$		18.7%

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				ΔB/B
$\Lambda\pi^+\rho^0$		$(1.4\pm0.6)\,\%$		42.8%
$\Sigma(1385)^+\rho^0$, $\Sigma^{*+}\to\Lambda\pi^+$		$(5\pm4)\times10^{-3}$		80.0%
$\Lambda\pi^+\pi^+\pi^-$ nonresonant		$<1.1\,\%$	CL=90%	
$\Lambda\pi^+\pi^+\pi^-\pi^0$ total		$(2.5\pm0.9)\,\%$		36.0%
$\Lambda\pi^+\eta$	[q]	$(2.4\pm0.5)\,\%$		20.8%
$\Sigma(1385)^+\eta$	[q]	$(1.16\pm0.35)\,\%$		30.2%
$\Lambda\pi^+\omega$	[q]	$(1.6\pm0.6)\,\%$		37.5%
$\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω		$<9\times10^{-3}$	CL=90%	
$\Lambda K^+\overline{K}^0$		$(6.4\pm1.3)\times10^{-3}$	S=1.6	20.3%
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Lambda\overline{K}^0$		$(1.8\pm0.6)\times10^{-3}$		33.3%
$\Sigma^0\pi^+$		$(1.43\pm0.14)\,\%$		10.0%
$\Sigma^+\pi^0$		$(1.37\pm0.30)\,\%$		21.9%
$\Sigma^+\eta$		$(7.5\pm2.5)\times10^{-3}$		33.3%
$\Sigma^+\pi^+\pi^-$		$(4.9\pm0.5)\,\%$		10.2%
$\Sigma^+\rho^0$		$<1.8\,\%$	CL=95%	
$\Sigma^-\pi^+\pi^+$		$(2.3\pm0.4)\,\%$		17.4%
$\Sigma^0\pi^+\pi^0$		$(2.5\pm0.9)\,\%$		36.0%
$\Sigma^0\pi^+\pi^+\pi^-$		$(1.13\pm0.31)\,\%$		27.4%
$\Sigma^+\pi^+\pi^-\pi^0$		—		
$\Sigma^+\omega$	[q]	$(3.7\pm1.0)\,\%$		27.1%
$\Sigma^+K^+K^-$		$(3.8\pm0.6)\times10^{-3}$		15.8%
$\Sigma^+\phi$	[q]	$(4.3\pm0.7)\times10^{-3}$		16.3%
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Sigma^+K^-$		$(1.11\pm0.29)\times10^{-3}$		26.2%
$\Sigma^+K^+K^-$ nonresonant		$<9\times10^{-4}$	CL=90%	
Ξ^0K^+		$(5.3\pm1.3)\times10^{-3}$		24.5%
$\Xi^-K^+\pi^+$		$(7.0\pm0.8)\times10^{-3}$	S=1.1	11.4%
$\Xi(1530)^0K^+$	[q]	$(3.5\pm1.0)\times10^{-3}$		28.6%
Hadronic modes with a hyperon: $S=0$ final states				
ΛK^+		$(6.9\pm1.4)\times10^{-4}$		20.3%
$\Lambda K^+\pi^+\pi^-$		$<6\times10^{-4}$	CL=90%	
Σ^0K^+		$(5.7\pm1.0)\times10^{-4}$		17.5%
$\Sigma^0K^+\pi^+\pi^-$		$<2.9\times10^{-4}$	CL=90%	
$\Sigma^+K^+\pi^-$		$(2.3\pm0.7)\times10^{-3}$		30.4%
$\Sigma^+K^*(892)^0$	[q]	$(3.8\pm1.2)\times10^{-3}$		31.6%
$\Sigma^-K^+\pi^+$		$<1.3\times10^{-3}$	CL=90%	
Doubly Cabibbo-suppressed modes				
$pK^+\pi^-$		$<3.1\times10^{-4}$	CL=90%	
Semileptonic modes				
$\Lambda\ell^+\nu_\ell$	[r]	$(2.8\pm0.4)\,\%$		
$\Lambda e^+\nu_e$		$(2.9\pm0.5)\,\%$		17.2%
$\Lambda\mu^+\nu_\mu$		$(2.7\pm0.6)\,\%$		22.2%

- ✓ *Total branching fraction ~60%.*
- ✓ *Lots of unknown decay channels*
- ✓ *Quite large uncertainties(>20%)*
- ✓ *Most BFs are measured relative to $\Lambda_c^+\to pK^-\pi^+$*

Λ_c Data samples at BESIII

In 2014, BESIII collected data above Λ_c pair threshold and run machine at 4.599 GeV with excellent performance.

Energy (GeV)	Luminosity (pb^{-1})
4.575	~48
4.580	~8.5
4.590	~8.1
4.599	~567

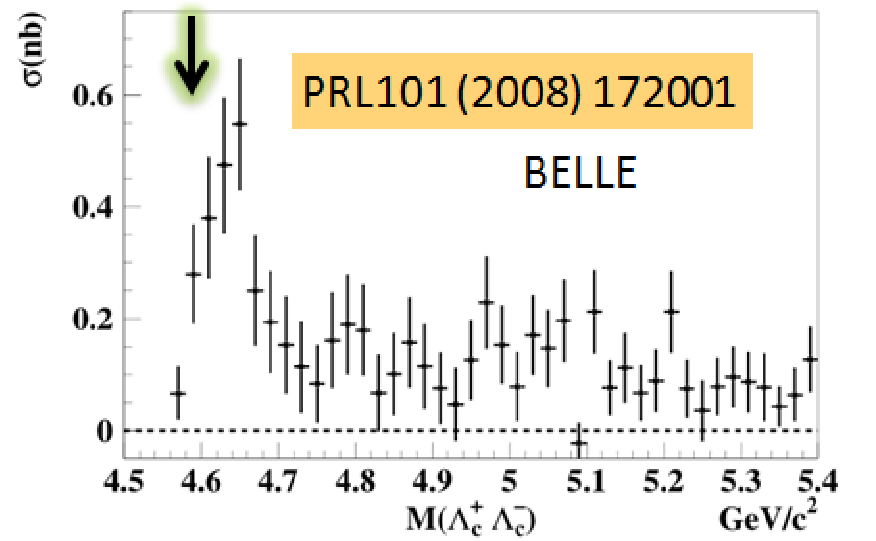
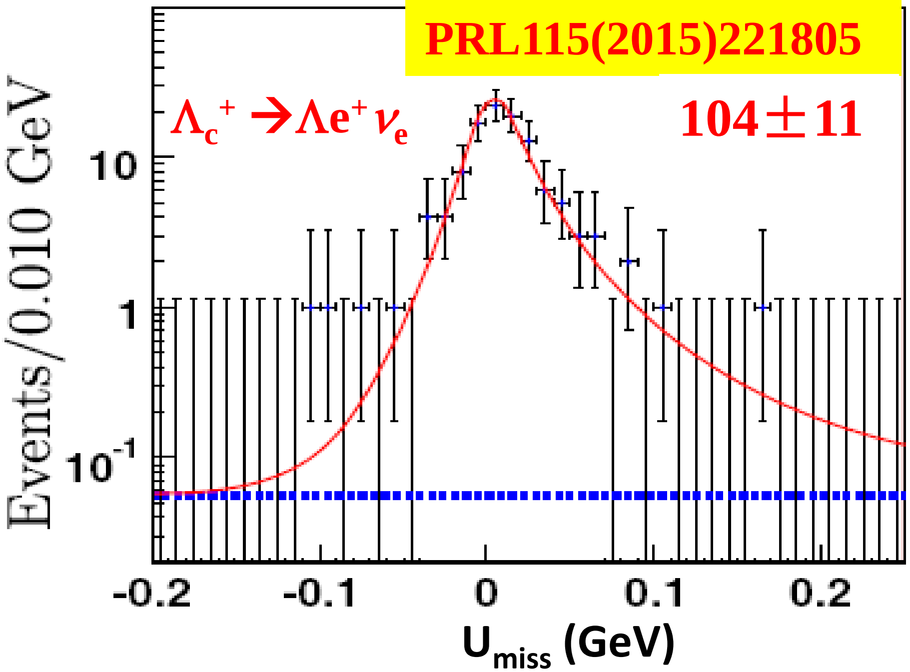


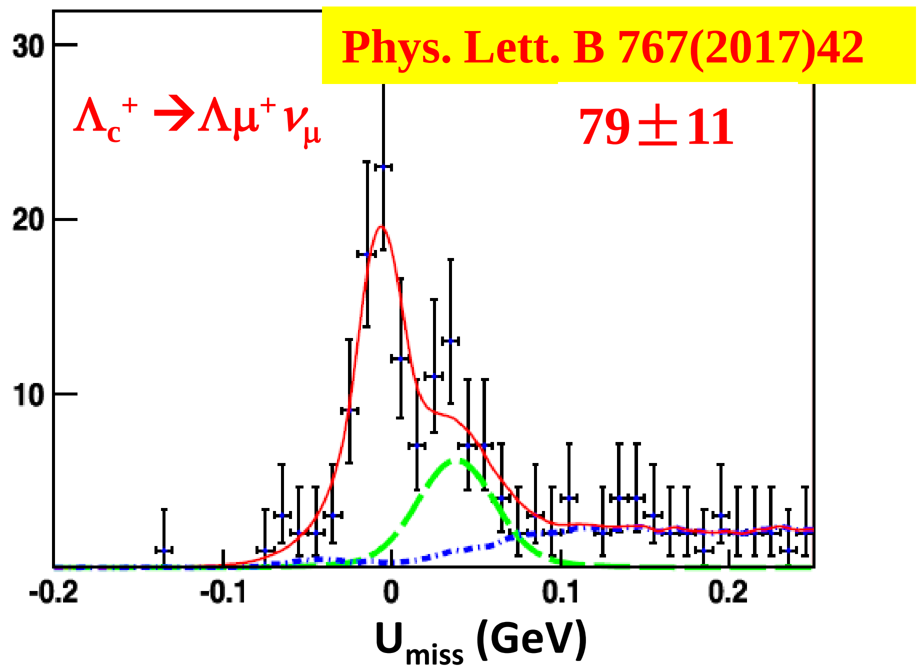
FIG. 4: The cross section for the exclusive process $e^+e^- \to \Lambda_c^+\Lambda_c^-$.

With 567/pb data collected at E_{cm}=4.599 GeV, lots of the works are performed to study the decay property of Λ_c at BESIII.

$\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l$ decays

- Theoretical calculations on the BF ranges from 1.4% to 9.2%
- BESIII performed the first absolute BF measurements.
- The BFs provide complementary information on determining $|V_{cs}|$.





$B[\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e] = (3.63 \pm 0.38 \pm 0.20)\%$

$B[\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$

$\Gamma[\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu]/\Gamma[\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$

Provides important input for calibrating the LQCD calculations.

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

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(Received 1 December 2016; published 21 February 2017)

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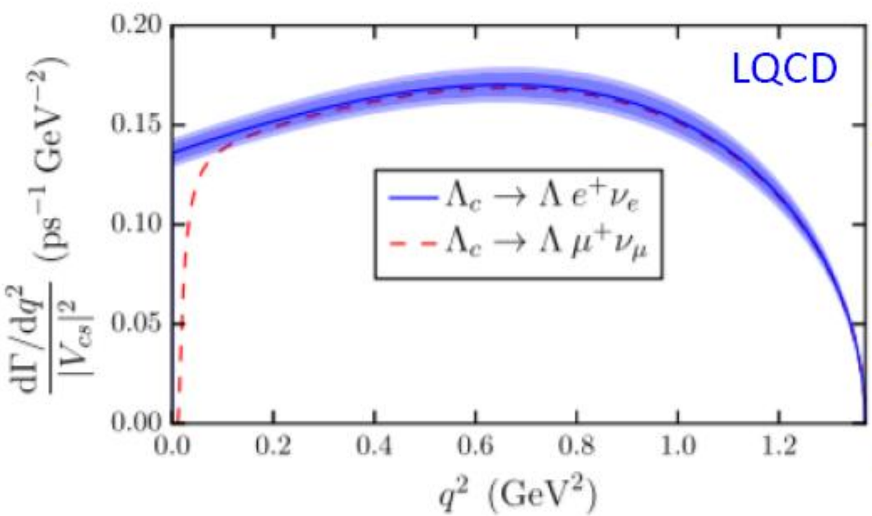
- Input the measured BFs from BESIII

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

- The first LQCD calculations on BFs and form factors

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



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

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

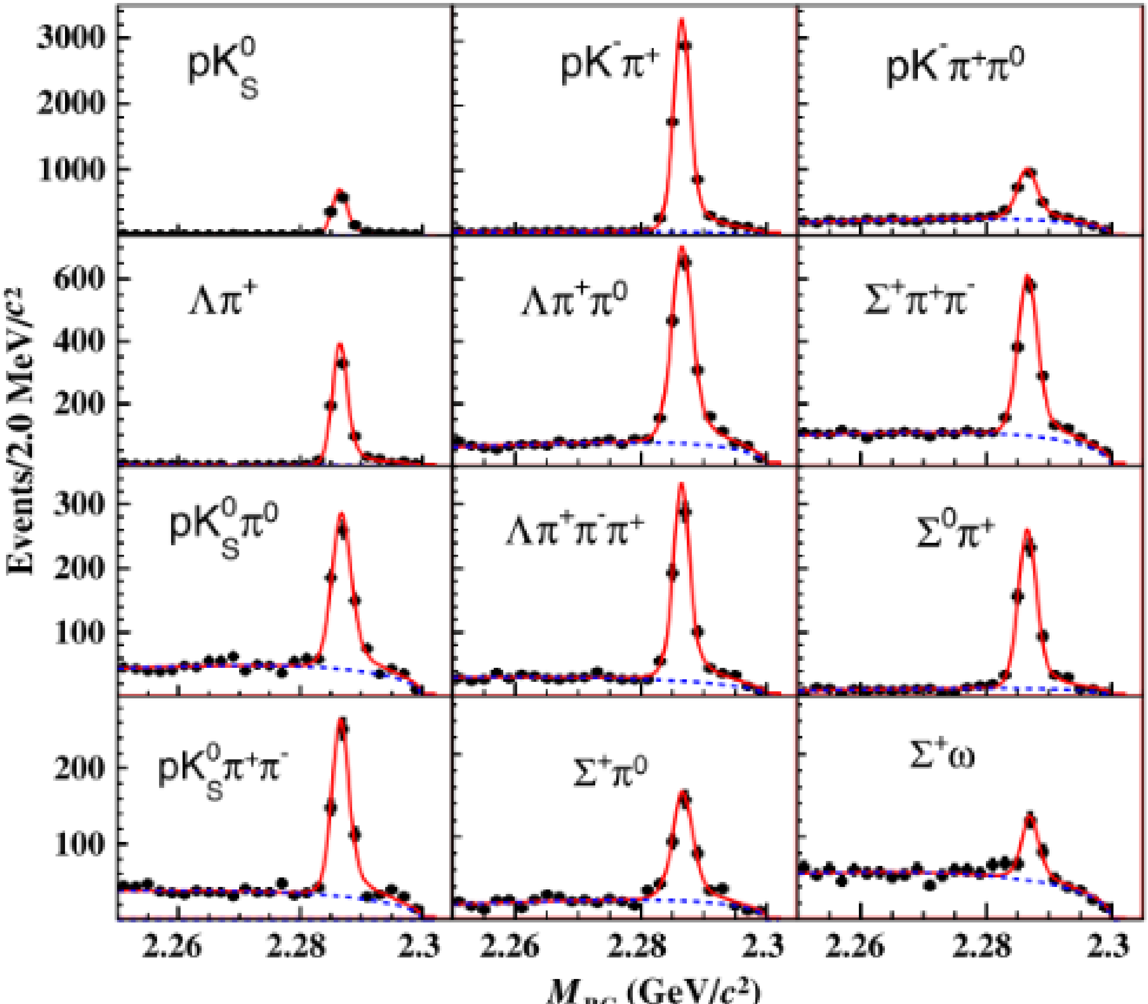
✓ More data on Λ_c^+ will be collected at BESIII

Absolute BFs for Λ_c^+ hadron decays

Measurement using the threshold pair-productions via e^+e^- annihilation is unique: the most simple and straightforward

PRL116(2016)052001

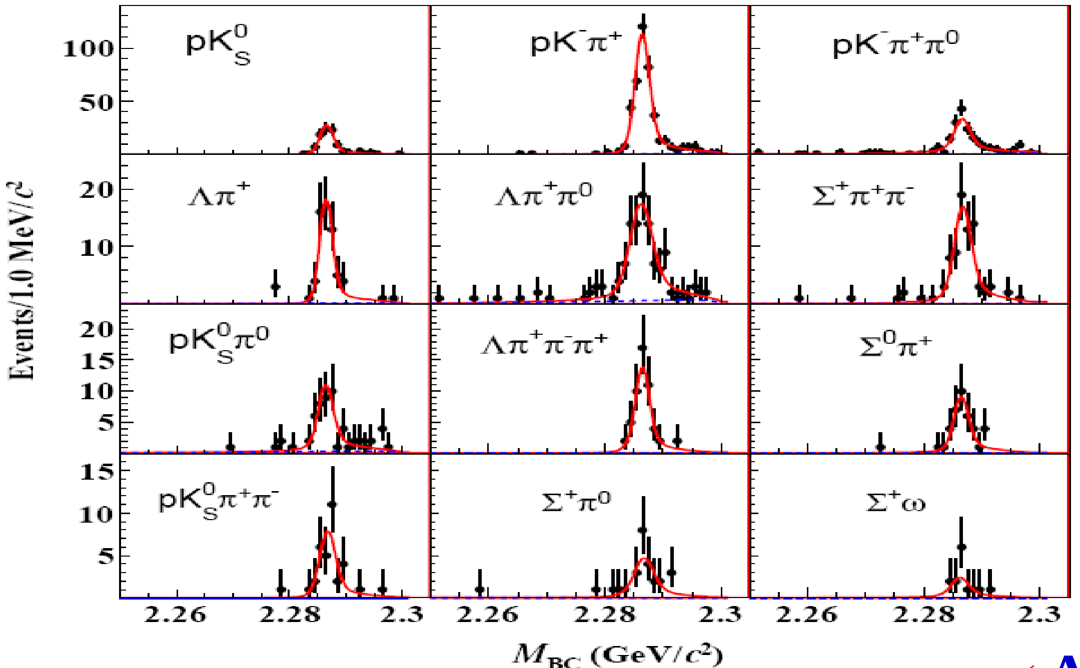
The M_{BC} distributions for ST



The yields for ST

Mode	ΔE (MeV)	N_j^{ST}
pK^0_S	$(-20, 20)$	1243 ± 37
$pK^-\pi^+$	$(-20, 20)$	6308 ± 88
$pK^0_S\pi^0$	$(-30, 20)$	558 ± 33
$pK^0_S\pi^+\pi^-$	$(-20, 20)$	485 ± 29
$pK^-\pi^+\pi^0$	$(-30, 20)$	1849 ± 71
$\Lambda\pi^+$	$(-20, 20)$	706 ± 27
$\Lambda\pi^+\pi^0$	$(-30, 20)$	1497 ± 52
$\Lambda\pi^+\pi^-\pi^+$	$(-20, 20)$	609 ± 31
$\Sigma^0\pi^+$	$(-20, 20)$	522 ± 27
$\Sigma^+\pi^0$	$(-50, 30)$	309 ± 24
$\Sigma^+\pi^+\pi^-$	$(-30, 20)$	1156 ± 49
$\Sigma^+\omega$	$(-30, 20)$	157 ± 22

Absolute BFs for Λ_c^+ hadron decays



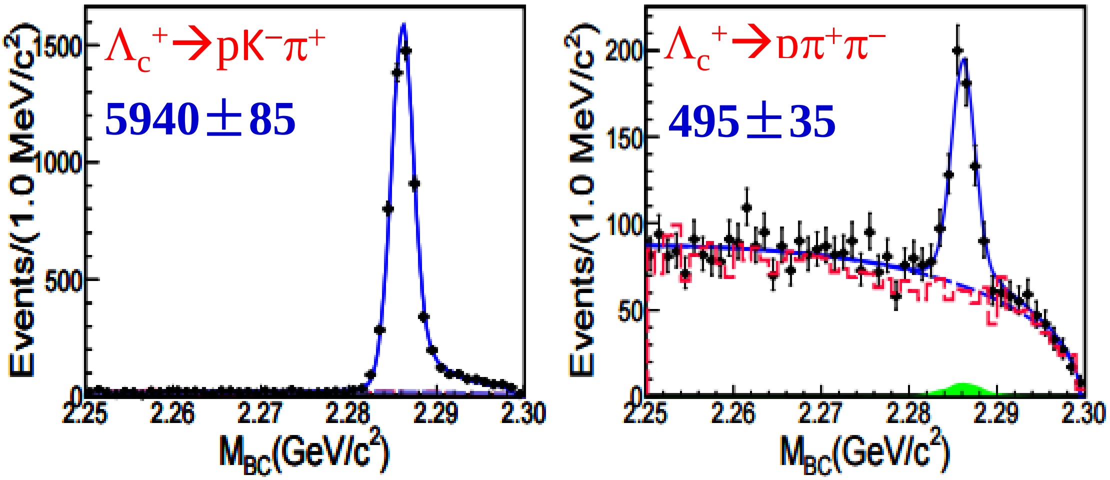
A global least-square fitter is utilized to improve the measured precision for 12 Λ_c^+ hadronic decay channels.

$$N^{DT}_{-j} = \sum_{i^+\neq j} N^{DT}_{i^+j^-} + \sum_{i^-\neq j} N^{DT}_{i^-j^+} + N^{DT}_{jj}$$

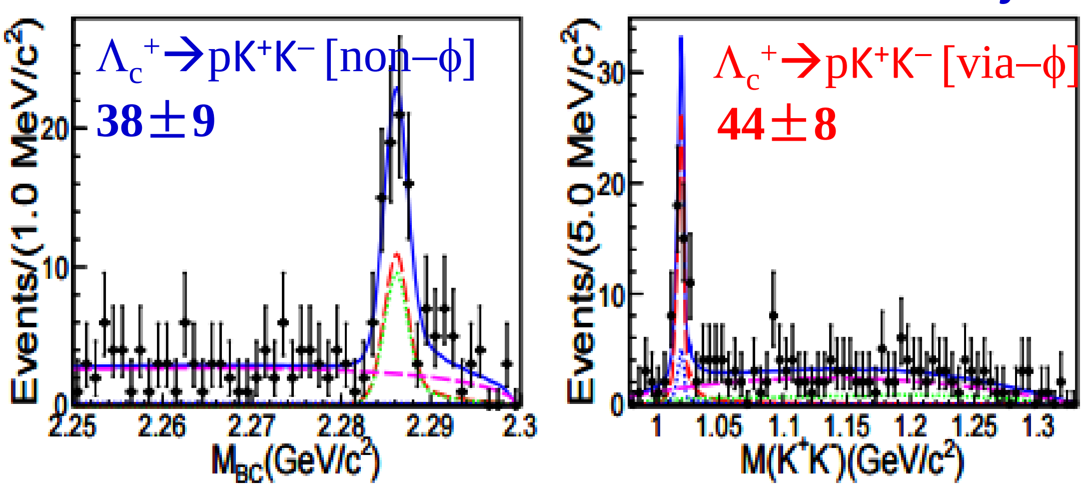
Mode	This work (%)	PDG (%)	BELLE $\mathcal{B}$
pK^0_S	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK^0_S\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK^0_S\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	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	

- ✓ **Absolute BFs are improved significantly.**
- ✓ **BESIII BF for $\Lambda_c^+ \rightarrow pK^-\pi^+$ is smaller.**
- ✓ **Improved absolute BF of $pK^-\pi^+$ together with BELLE's result are key to calibrate other decays.**

Study of SCS Decays $\Lambda_c^+ \to p\pi^+\pi^-$ and $\Lambda_c^+ \to pK^+K^-$



Two-dimensional unbinned maximum likelihood fit



PRL117(2016)232002

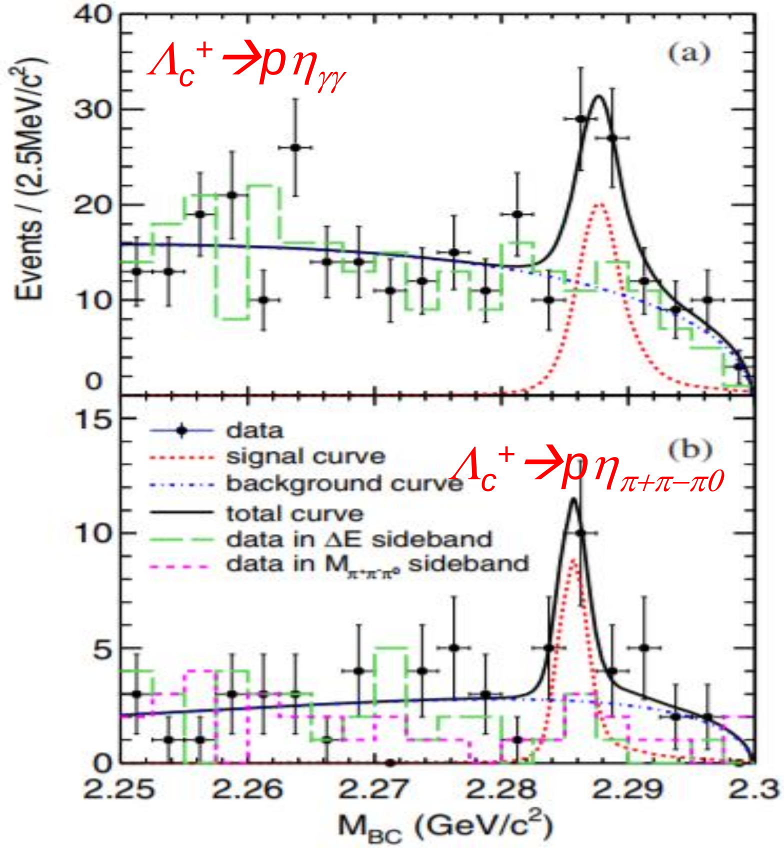
- ✓ Study of SCS decays can shed light on dynamics of Λ_c^+ decays
- ✓ $B[\Lambda_c^+ \to p\phi]$ is of particular interest since it proceeds W-exchange only, which is essential to validate the theoretical models and test the application of large-N_c factorization in charmed baryon.
- ✓ ST study, relative BFs to $\Lambda_c^+ \to pK^-\pi^+$ is measured.
- ✓ Input BESIII measurement: $B[\Lambda_c^+ \to pK^-\pi^+] = (5.84 \pm 0.27 \pm 0.23)\%$

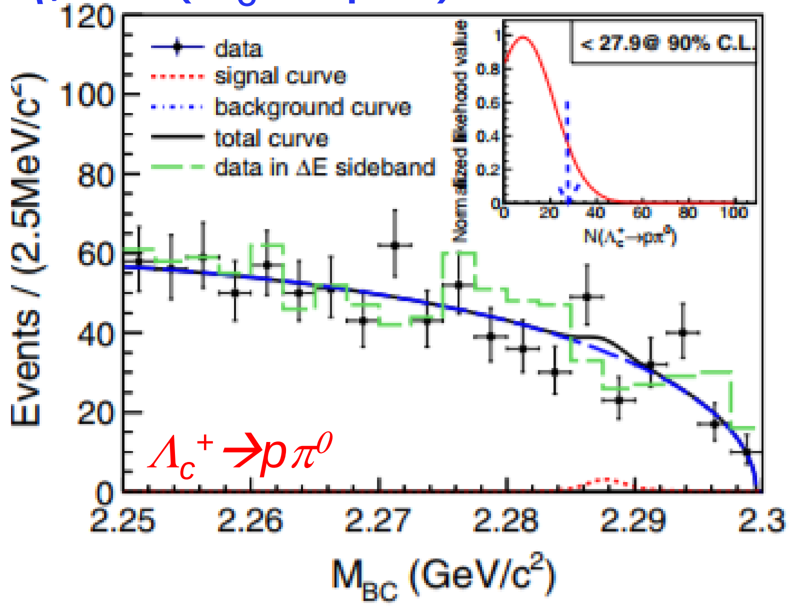
—	$\mathcal{B}_{\text{mode}}$	$\mathcal{B}(\text{PDG})$
$\Lambda_c^+ \to p\pi^+\pi^-$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \to p\phi$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$
$\Lambda_c^+ \to pK^+K^-$ (non-ϕ)	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$

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

- Their relative size essential to understand the interference of different non-factorizable diagrams
- It is expected that $\Gamma(\Lambda_c^+ \to p\eta) >> \Gamma(\Lambda_c^+ \to p\pi^0)$

PRD95(2017)111102(R)





$$B = \frac{N^{obs}}{2 \cdot N_{\Lambda_c^+\overline{\Lambda}_c^-} \cdot \varepsilon \cdot B_{int}}$$

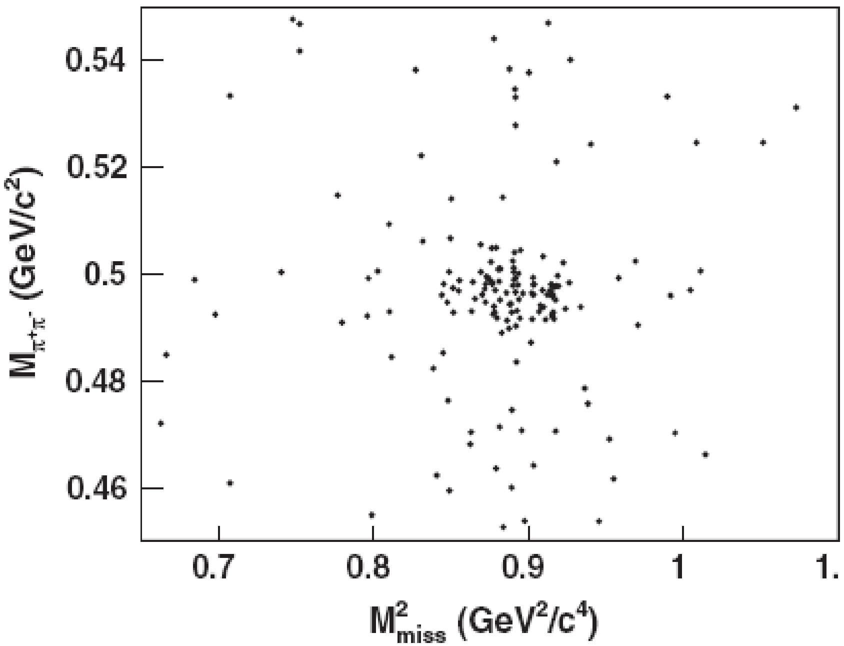
BESIII Measurements:

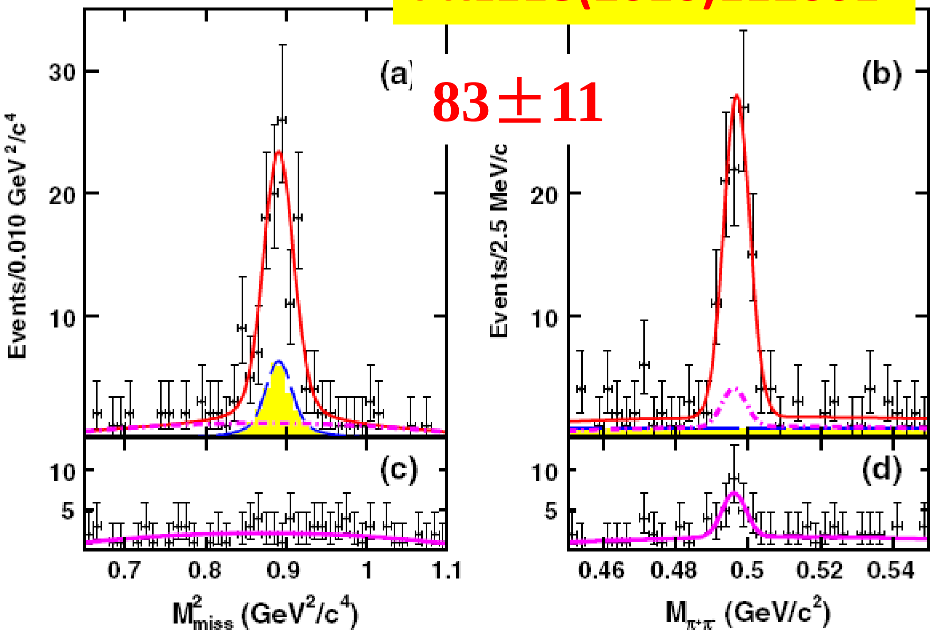
- ✓ First evidence of $\Lambda_c^+ \to p\eta$ *with 4.2σ;*
- ✓ $B[\Lambda_c^+ \to p\eta] = (1.24 \pm 0.28 \pm 0.010) \times 10^{-3}$;
- ✓ $B[\Lambda_c^+ \to p\pi^0] < 2.7 \times 10^{-4}$;
- ✓ $B[\Lambda_c^+ \to p\pi^0]/B[\Lambda_c^+ \to p\eta] < 0.24$;

Observation of $\Lambda_c^+ \rightarrow nK_S^0\pi^+$

- The relative BF of neutron-involved mode to proton-involved mode is essential to test the isospin symmetry and extract the strong phases of different final states. [PRD93 (2016) 056008]
- First observation of Λ_c^+ decays to final states involving the neutron.

PRL118(2016)112001





$B[\Lambda_c^+ \rightarrow nK_S^0\pi^+] = (1.82 \pm 0.23 \pm 0.11)\%$

$B[\Lambda_c^+ \rightarrow nK^0\pi^+]/B[\Lambda_c^+ \rightarrow pK^-\pi^+] = 0.62 \pm 0.09$

$B[\Lambda_c^+ \rightarrow nK^0\pi^+]/B[\Lambda_c^+ \rightarrow pK^0\pi^0] = 0.97 \pm 0.16$

The phase difference between $I^{(0)}$ and $I^{(1)}$:

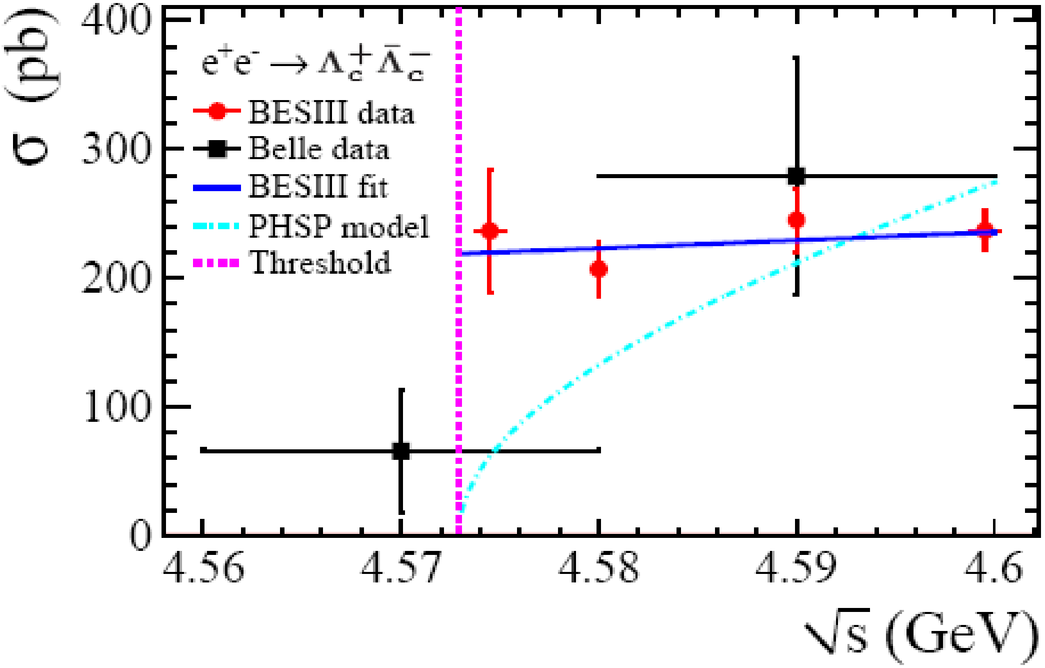
$\cos\delta = -0.24 \pm 0.08$

and relative strength: $|I^{(1)}|/|I^{(0)}| = 1.14 \pm 0.11$

The first errors are statistical and the second systematic.

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

✓ *Precision measurement of the born cross section of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$.* arXiv:1710.00150



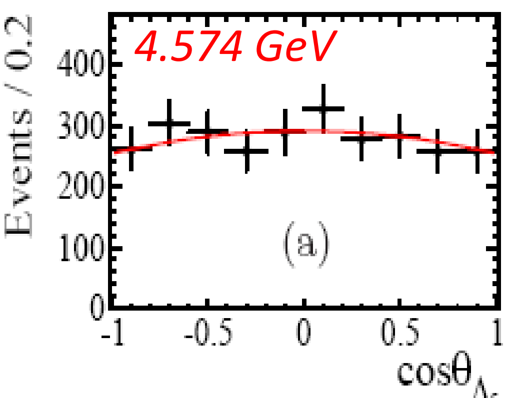
✓ *Born cross section near threshold*

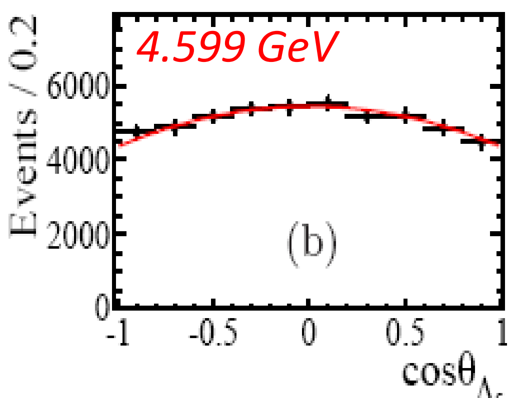
$\sqrt{s}$ (MeV)	$\mathcal{L}_{int}$ (pb^{-1})	f_{ISR}	σ (pb)
4574.5	47.67	0.45	$236 \pm 11 \pm 46$
4580.0	8.545	0.66	$207 \pm 17 \pm 13$
4590.0	8.162	0.71	$245 \pm 19 \pm 16$
4599.5	566.9	0.74	$237 \pm 3 \pm 15$

✓ *the cross section has a jump at threshold*

✓ *the cross section appears flat, in part at odd with Belle*

☐ *Fits to the angular distributions*





✓ *Fitted by $f(\theta) \propto (1+\alpha_{\Lambda c}\cos^2\theta)$*

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

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

$\sqrt{s}$ (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	$-0.20 \pm 0.04 \pm 0.02$	$1.23 \pm 0.05 \pm 0.03$

The first time to Measure Λ_c form factor ratio $|G_E/G_M|$ near threshold.

Λ_c^+ Measurements at BESIII

Published papers (7 papers):

Measurement of the absolute BF for $\Lambda_c^+ \to \Lambda e^+ \nu_e$ [PRL115,221805 (2015)]

Measurement of the absolute hadronic BFs for Λ_c Baryon [PRL116, 052001 (2016)]

Measurement of SCS decays $\Lambda_c \to p\pi^+\pi^-$ and $\Lambda_c \to pK^+K^-$ [PRL117, 232002 (2016)]

Observation of $\Lambda_c \to nK_S^0\pi^+$ [PRL118, 112001 (2017)]

Evidence of the SCS decay $\Lambda_c \to p\eta$ and search for $\Lambda_c \to p\pi^0$ [PRL117, 232002 (2016)]

Measurement of the absolute BF for $\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu$ [PLB767,42 (2017)]

Observation of the decay $\Lambda_c^+ \to \Sigma^- \pi^+\pi^+\pi^0$ [PLB772, 388(2017)]

ongoing topics (7 and more):

BAM-00247 *Measurement of absolute BF of the inclusive decay $\Lambda_c^+ \to \Lambda + X$*

BAM-00251 *Measurement of Λ_c+ weak decay asymmetry*

BAM-00254 *Measurement of BFs for Λ_c+ decays to $\Sigma^+\eta$ and $\Sigma^+\eta'$*

BAM-00265 *Inclusive semileptonic decay of $\Lambda_c + \to e^+X$*

BAM-00276 *Measurement of BFs for $\Lambda_c + \to \Xi^0 K^+$ and $\Xi(1530)^0 K^+$*

BAM-00305 *Study of $\Lambda_c + \to \Lambda\pi^+\eta$*

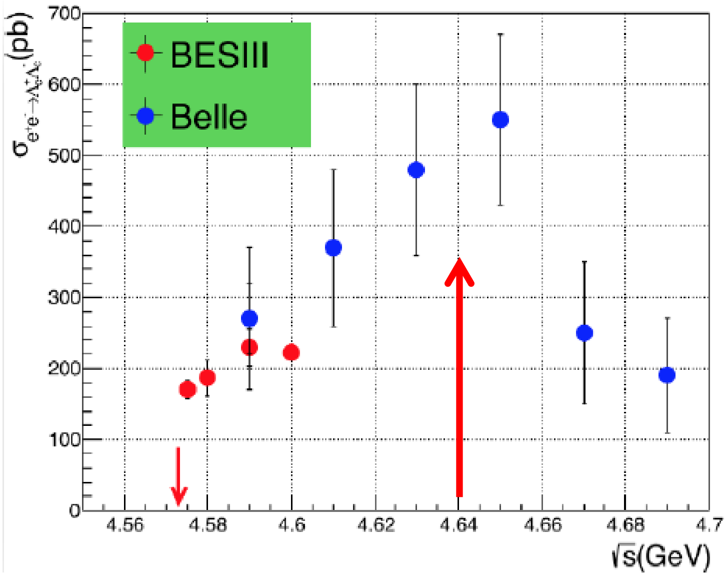
BAM-00328 *Measurement of $\Lambda_c^+ \to K_S^0 X$*

With 567/pb data collected at BESIII during a month, 7 (4 PRL) papers are published! Lots of the Λ_c related topics are undergoing at BESIII.

Prospects of Λ_c^+ running at BESIII

■ The energy upgrade project had approved. The machine can increase the collision energy to 4.7 GeV in 2018 and to 4.9 GeV by 2020.

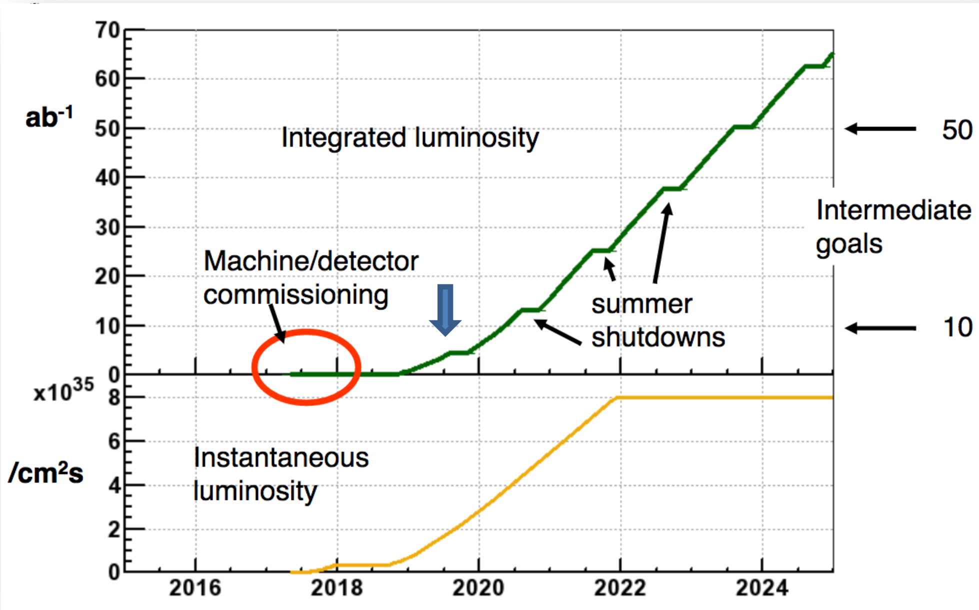
■ In next few years (may be 2019), BESIII will be able to collect 5/fb Data at E_{cm}=4.64 GeV, which is expected to be the peak of $\Lambda_c^+\Lambda_c^-$ production threshold. The new data is about 16 times larger than current Λ_c data sample.



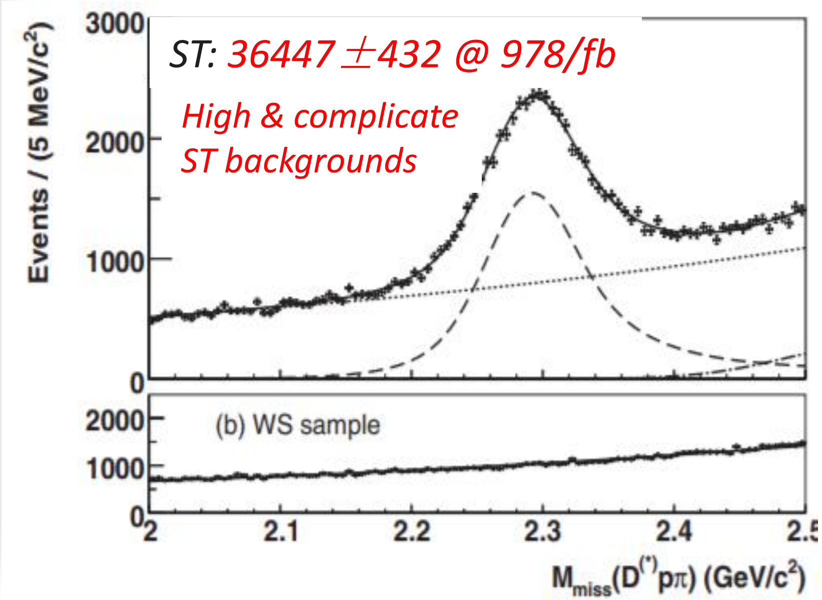
■ **Unique data taken near $\Lambda_c^+\Lambda_c^-$ threshold :**

- ✓ Precise measurement of BFs
- ✓ Clean and low backgrounds
- ✓ Easily control of the systematic uncertainties – very important
- ✓ Channels containing K_L^0 and neutron—DT method
- ✓ Can almost systematically study all Λ_c^+ decay channels.

Competitions from Belle/Belle-II



PRL113,042002(2014)

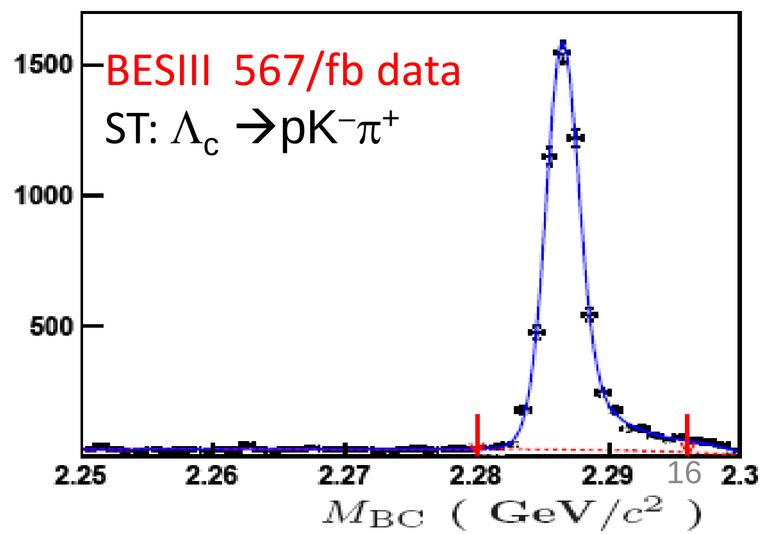


✓ Belle tags 36K Λ_c events with ~1/ab data, while BESIII tags 15K Λ_c events with 0.5/fb data @ E_{cm}=4.6 GeV.

✓ By middle of 2019, Belle-II will have 5/ab data, about 180K Λ_c events.

✓ With 5/fb data @ E_{cm}=4.64 GeV at BESIII (16 times current Λ_c data sample), about 240K Λ_c events will be collected.

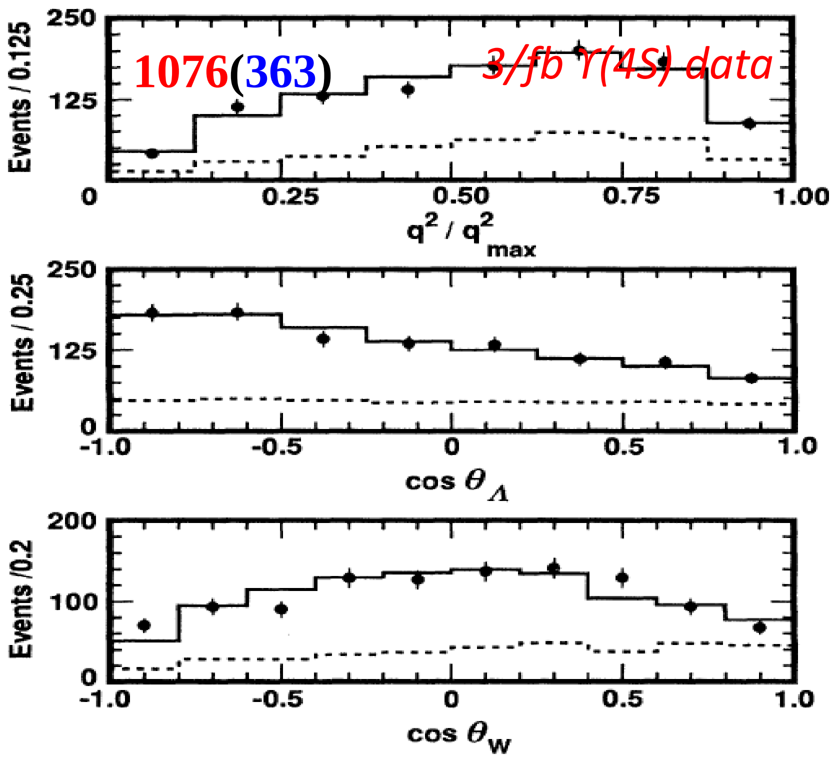
✓ BESIII had advantages on backgrounds and systematic uncertainties.

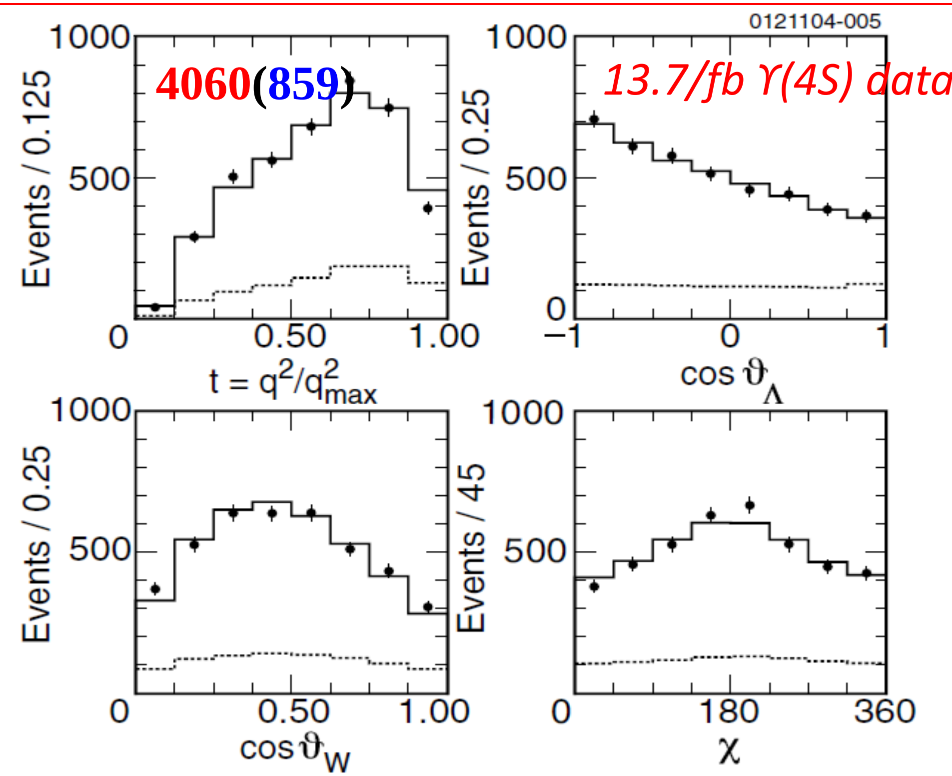


Interest topics—FFs in $\Lambda_c^+ \to \Lambda l^+ \nu_l$

- *Previous Measurements from CLEO.*

$$\Gamma_S = \frac{d\Gamma}{dq^2 d\cos\Theta_W d\cos\Theta_\Lambda} = B(\Lambda \to p\pi)\frac{1}{2}\frac{G_F^2}{(2\pi)^4}|V_{cs}|^2\frac{q^2 P}{24M^2_{\Lambda_c}}$$
$$\times \{\tfrac{3}{8}(1-\cos\Theta_W)^2|H_{(1/2)1}|^2(1+\alpha_\Lambda\cos\Theta_\Lambda) + \tfrac{3}{8}(1+\cos\Theta_W)^2|H_{(-1/2)-1}|^2(1-\alpha_\Lambda\cos\Theta_\Lambda)$$
$$+ \tfrac{3}{4}\sin^2\Theta_W[|H_{(1/2)0}|^2(1+\alpha_\Lambda\cos\Theta_\Lambda) + |H_{(-1/2)0}|^2(1-\alpha_\Lambda\cos\Theta_\Lambda)]\},$$





f_2/f_1=-0.25±0.14 ±0.08 (64%)

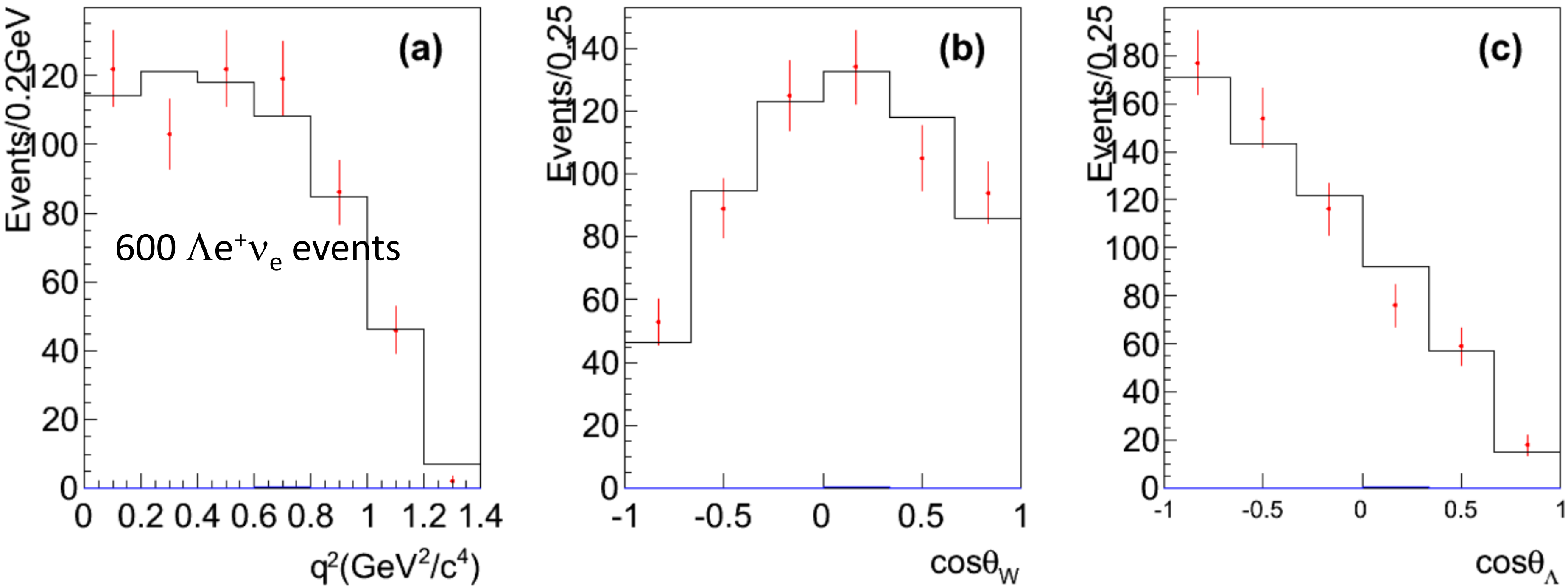
CLEO Collaboration, PRL75, 624(1995);

f_2/f_1=-0.31±0.05±0.04 (21%)

CLEO Collaboration, PRL94, 191801(2005);

Interest topics—FFs in $\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l$

- *MC simulation (~6 times of current data sample)-[3-D fit].*



✓ Based on MC simulation, we obtain f_2/f_1=-0.31±0.08(25%), input: -0.31;

✓ with 16 times data, the precision for f_2/f_1 will be ~15%;

✓ If we combine the data from electron and muon channels, the precision for measuring f_2/f_1 will expected to reach ~12%.

Interest topics—$\Lambda_c^+ \to n l^+ \nu_l$

- ✓ Provides important information for Lattice calculation of $\Lambda_b \to p l^+ \nu_l$
- ✓ Helps to test theoretical predictions.

Predictions	**Predictions for $\Lambda_c^+ \to n l^+ \nu_l$**
K. Azizi et al, PRD80, 096007 (2009) **Light cone QCD sum rule**	**(0.25±0.09)%**
T. Gutsche et al., PRD90, 114033 (2014) **Covariant confined quark model**	**0.2%**
Cai-Dian Lü, Wei Wang and Fu-Sheng Yu, Phys. Rev. D 93, 056008 (2016); **SU(3) symmetry**	**(0.293 ± 0.034)%**
R. N. Faustov, V. O. Galkina, Eur. Phys. J. C. 76, 628 (2016); **relativistic quark model**	**0.268%**
Cheng-Fei Li, Yong-Lu Liu, Ke Liu, Chun-Yu Cui, Ming-Qiu Huang, arXiv: 1610.05418 **light-cone QCD sum rules**	**(0.26±0.01)%**
Stefan Meinel, arXiv:1712.05783 [accepted by PRD], **Lattice QCD**	$e^+\nu_e$: $0.410 \pm 0.026_{LQCD} \pm 0.012_{\tau\Lambda c} \pm 0.002_{\lvert Vcd \rvert}$ $\mu^+\nu_\mu$: $0.400 \pm 0.026_{LQCD} \pm 0.012_{\tau\Lambda c} \pm 0.002_{\lvert Vcd \rvert}$

Challenge: 1) two missing particles; 2) Suffers huge backgrounds from $\Lambda_c^+ \to \Lambda l^+ \nu_l$.

Search for $\Lambda_c^+ \rightarrow \Lambda^* l^+ \nu_l$

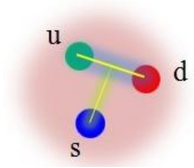
- **If Λ_c^+ is J=1/2, it favors the decay $\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l$.**

Λ_c^+ $\quad I(J^P) = 0(\frac{1}{2}^+)$

J is not well measured; $\frac{1}{2}$ is the quark-model prediction.

Mass $m = 2286.46 \pm 0.14$ MeV
Mean life $\tau = (200 \pm 6) \times 10^{-15}$ s $\quad$ (S = 1.6)
$c\tau = 59.9\ \mu$m

$B[\Lambda_c^+ \rightarrow \Lambda^* l^+ \nu_l] << B[\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l]$?



suggestive of di-quark model

- **Searching for $\Lambda_c^+ \rightarrow \Lambda^* l^+ \nu_l$ is very important.**

Dominant channel

$\Lambda^* \rightarrow pK^-/\Sigma\pi$

$\Lambda(1405)$ 1/2$^-$ $\quad I(J^P) = 0(\frac{1}{2}^-)$

Mass $m = 1405.1^{+1.3}_{-1.0}$ MeV
Full width $\Gamma = 50.5 \pm 2.0$ MeV
Below $\overline{K}N$ threshold

$\Lambda(1405)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Sigma\pi$	100 %	155

$\Lambda(1520)$ 3/2$^-$ $\quad I(J^P) = 0(\frac{3}{2}^-)$

Mass $m = 1519.5 \pm 1.0$ MeV [a]
Full width $\Gamma = 15.6 \pm 1.0$ MeV [a]

$\Lambda(1520)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	(45 $\pm$1) %	243
$\Sigma\pi$	(42 $\pm$1) %	268
$\Lambda\pi\pi$	(10 $\pm$1) %	259
$\Sigma\pi\pi$	(0.9 $\pm$0.1) %	169
$\Lambda\gamma$	(0.85$\pm$0.15) %	350

$\Lambda(1600)$ 1/2$^+$ $\quad I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 1560$ to 1700 (≈ 1600) MeV
Full width $\Gamma = 50$ to 250 (≈ 150) MeV
$p_{beam} = 0.58$ GeV/c $\quad 4\pi\lambda^2 = 41.6$ mb

$\Lambda(1600)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	15–30 %	343
$\Sigma\pi$	10–60 %	338

$\Lambda(1670)$ 1/2$^-$ $\quad I(J^P) = 0(\frac{1}{2}^-)$

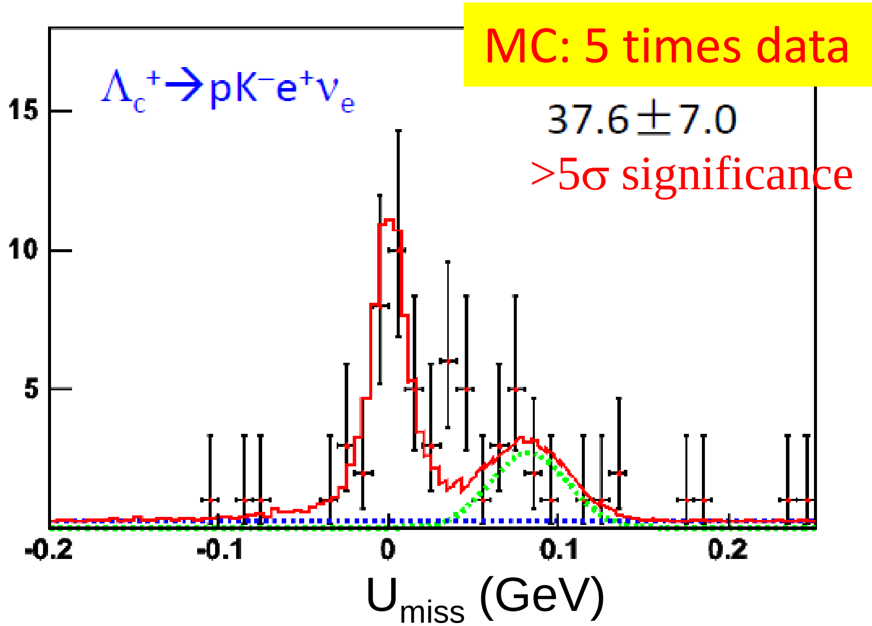
Mass $m = 1660$ to 1680 (≈ 1670) MeV
Full width $\Gamma = 25$ to 50 (≈ 35) MeV
$p_{beam} = 0.74$ GeV/c $\quad 4\pi\lambda^2 = 28.5$ mb

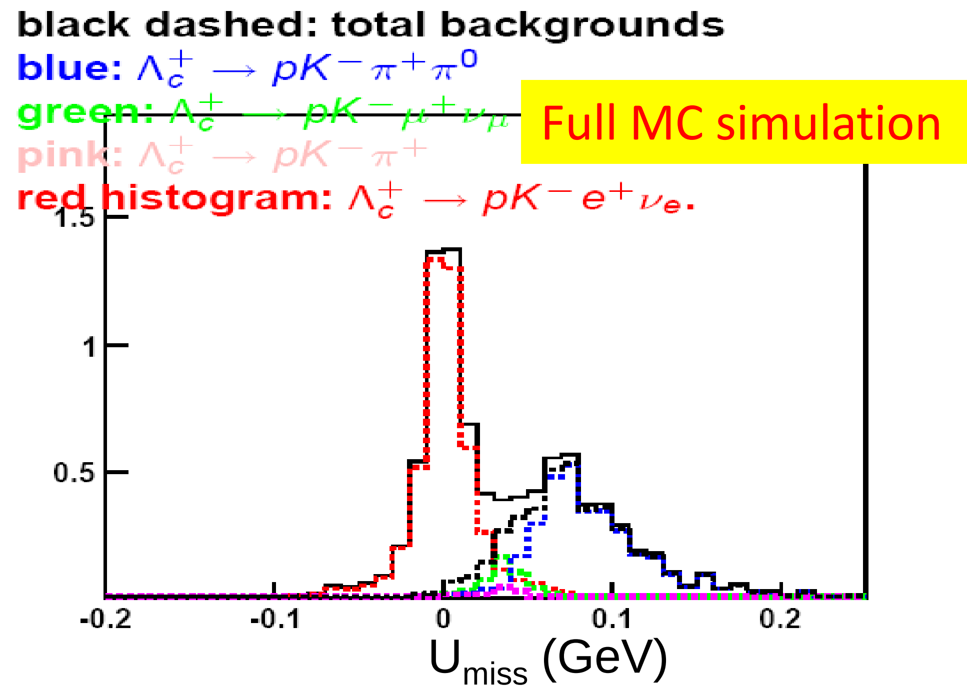
$\Lambda(1670)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	20–30 %	414
$\Sigma\pi$	25–55 %	394
$\Lambda\eta$	10–25 %	69
$N\overline{K}^*(892)$, S=3/2, D-wave	(5$\pm$4) %	†

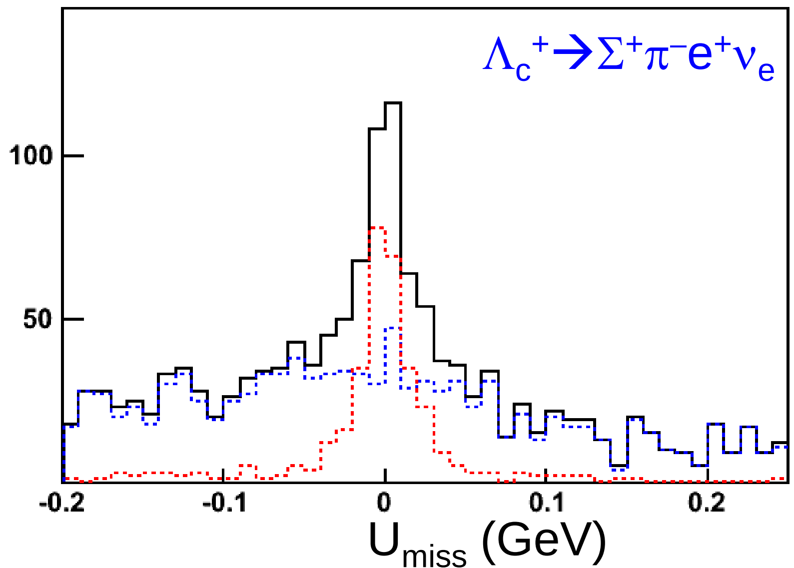
channel	N. Ikeno et al. [PRD93, 014021]	M. Pervin et al [PRC72, 035201]
$\Lambda_c^+ \rightarrow \Lambda(1405) e^+\nu_e$	2×10^{-5}	0. 6%
$\Lambda_c^+ \rightarrow \Lambda(1520) e^+\nu_e$	--	0. 1%

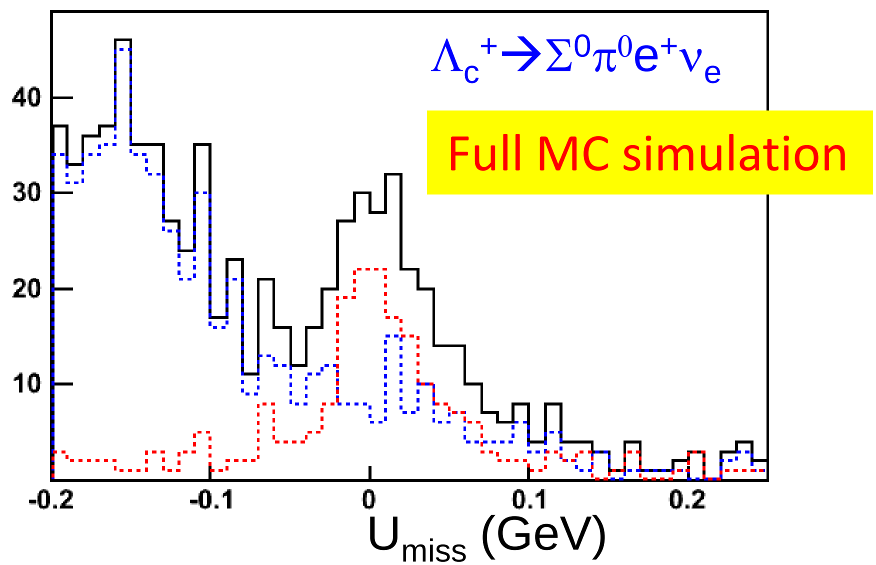
Some theories suggested that the weak decay processes are important to clarify the existence and the nature of *$\Lambda(1405)$*. *Thus, study of $\Lambda_c^+ \rightarrow \Lambda(1405) l^+ \nu_l$* is very important.

$\Lambda_c^+ \rightarrow pK^-/\Sigma\pi e^+\nu_e$









Λ_c^+ Hadronic decay

- Systematically study channels via W-exchanges.

Comparisons of the lift time of Λ_c, D^0 and D^+ [PDG2017]:

$\tau_{\Lambda C}$ =(200±6)×10^{-15} s τ_{D0} =(410.1±1.5)×10^{-15} s τ_{D+} =(1040±7)×10^{-15} s

Theoretically, two explanations for D^0 and D^+ lifetime difference[ZPC33,297]:
[1] light quark interference(D^+: c->sud-bar and d-bar);
[2] W-exchange (D^0: cu-bar -> sd-bar, W-exchange but suppressed by helicity conservation)

✓It is expected that the W-exchange (no helicity suppression) mechanism plays an important role in Λ_c^+ decays.

✓ The channels proceeds only through W-exchange in Λ_c^+ decays!!

	BFs in PDG 2017	
$\Lambda_c^+ \to \Xi^0 K^+$	$(5.0 \pm 1.2) \times 10^{-3}$	BESIII can systematically study and precisely measure the branching fractions for these channels.
$\Lambda_c^+ \to \Delta^{++} K^-$	$(1.09 \pm 0.25) \times 10^{-2}$	
$\Lambda_c^+ \to \Sigma^+ K^+ K^-$	$(3.6 \pm 0.4) \times 10^{-3}$	
$\Lambda_c^+ \to \Sigma^+ \phi$	$(4.0 \pm 0.6) \times 10^{-3}$	

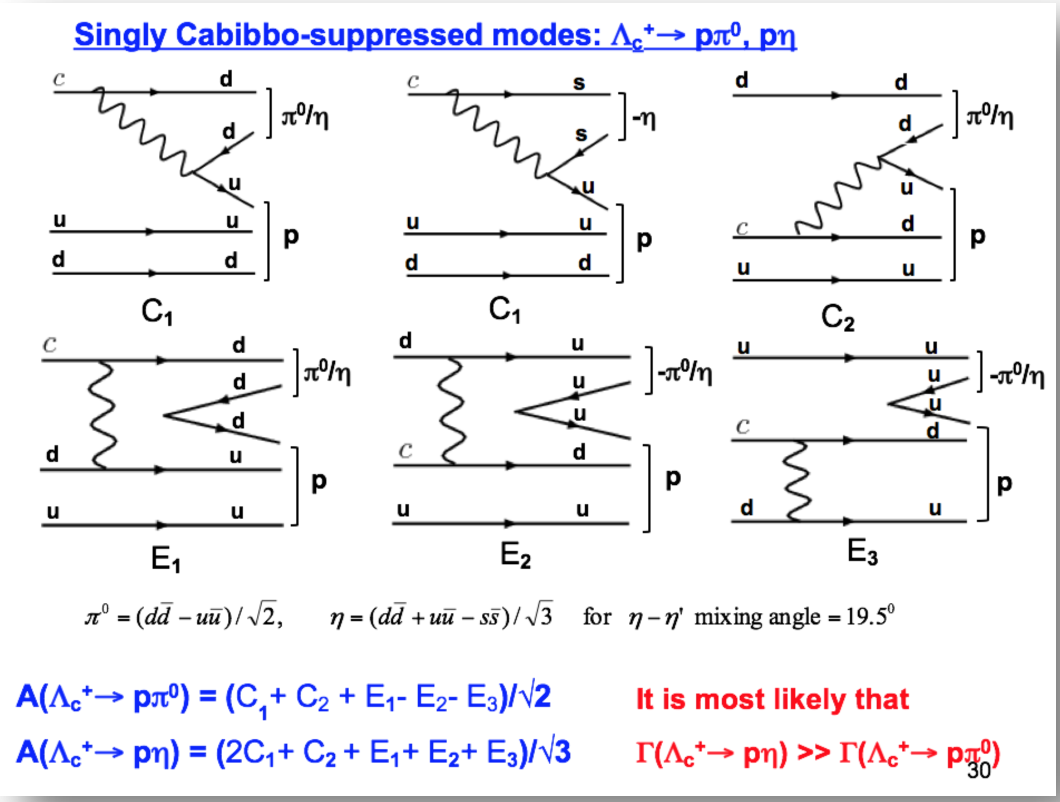
Important to study W-exchanges mechanism, clean and straightforward

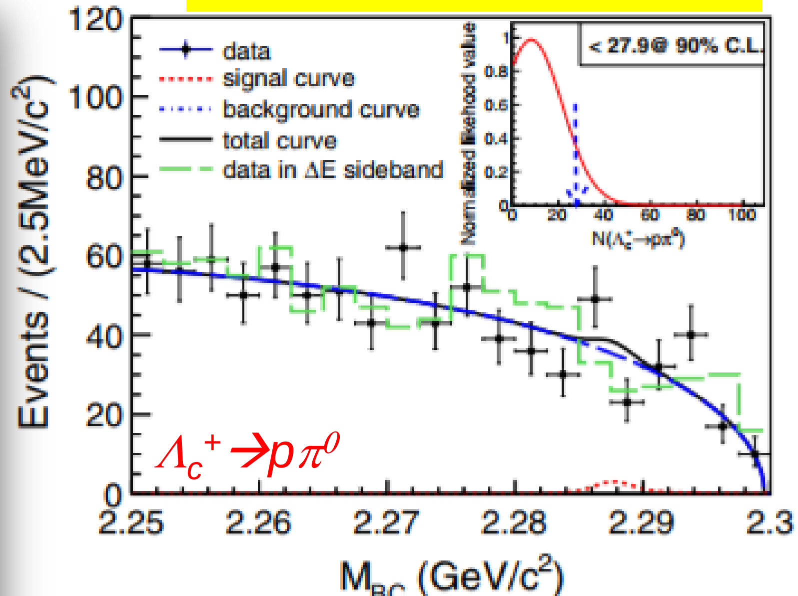
Λ_c^+ Hadronic decay

■ Study of SCS channels: $\Lambda_c^+ \rightarrow \Lambda K^+, p\pi^0, p\eta, n\pi^+, \Sigma^0 K^+, \Sigma^+ K^0$ etc.

From Prof. Hai-Yang Cheng's report.

PRD95(2017)111102(R)





BESIII: $B[\Lambda_c^+ \rightarrow p\pi^0] < 2.7\times10^{-4}$

$$M(\Lambda_c^+ \to n\pi^+) = \sqrt{2}M(\Lambda_c^+ \to p\pi^0),$$

- More precise comparison of the two BFs are desired to explore the interference of different non-factorizable diagrams and BESIII result support the theoretic prediction. It is predicted that $Br[\Lambda_c^+ \rightarrow n\pi^+] \sim 3.5\times Br[\Lambda_c^+ \rightarrow p\pi^0]$ [Hai-Yang Cheng, arXiv: 1801.08625]
- With more data, BESIII may report the first observation of these channels.

Predictions and Measurements

Hai-Yang Cheng etc, arXiv: 1801.08625

	Sharma *et al.* [24]	Uppal *et al.* [41]	Chen *et al.* [42]	Lu *et al.* [25]	Geng *et al.* [26]	This work [in units of 10^{-3}]	Expt [7, 19]
$\Lambda_c^+ \to p\pi^0$	0.2	0.1-0.2	0.11-0.36	0.48	0.56 ± 0.15	0.08	< 0.27 **?**
$\Lambda_c^+ \to p\eta$	$0.2^a(1.7)^b$	0.3			1.24 ± 0.41	1.28	1.24 ± 0.29
$\Lambda_c^+ \to p\eta'$	0.4-0.6	0.04-0.2			$1.22^{+1.43}_{-0.87}$		**?**
$\Lambda_c^+ \to n\pi^+$	0.4	0.8-0.9	0.10-0.21	0.97		0.27	**?**
$\Lambda_c^+ \to \Lambda K^+$	1.4	1.2	0.18-0.39		0.46 ± 0.09	1.06	0.61 ± 0.12
$\Lambda_c^+ \to \Sigma^0 K^+$	0.4-0.6	0.2-0.8			0.40 ± 0.08	0.72	0.52 ± 0.08
$\Lambda_c^+ \to \Sigma^+ K^0$	0.9-1.2	0.4-0.8			0.80 ± 0.16	1.44	**?**

- Measuring the decay BFs of these decay channels can provide important data for understanding the W-exchange and non-factorizable mechanism.

Other relevant topics

- Λ_c^+ hadronic weak decays
  - ✓ *Decay asymmetry parameters in Λ_c^+ two-body decays, $\Lambda_c^+ \rightarrow BP/BV$*

    which can be used to study the relative phase between S-wave and P-wave decays
- Exclusive decays containing neutron or K_L^0
  - ✓ *First observation of $\Lambda_c^+ \rightarrow n\pi^+$, nK^+, $n\pi^+\pi^0$, $nK^+\pi^0$, etc*

    It can provides a good test on isospin/SU(3) symmetry by combing the measurements of the Λ_c^+ decays proton channels.
  - ✓ $\Lambda_c^+ \rightarrow pK_S^0/K_L^0$, $pK_S^0\pi^0/K_L^0\pi^0$, *etc*

$$R \equiv \frac{\Gamma(\Lambda_c^+ \to pK_S^0) - \Gamma(\Lambda_c^+ \to pK_L^0)}{\Gamma(\Lambda_c^+ \to pK_S^0) + \Gamma(\Lambda_c^+ \to pK_L^0)}$$

[Fu-Sheng Yu, arXiv: 1709.09873]

Helps to explore K_S^0-K_L^0 asymmetry in Λ_c^+ decays.

- Weak radiative decays

  First evidence or observation of $\Lambda_c^+ \rightarrow \gamma\Sigma^+$

  The BF for $\Lambda_c^+ \rightarrow \gamma\Sigma^+$ is predicted to be 2.8×10^{-4} [PRD47,2858(1993)]

Expected precision

✓ *Expectations of the typical Λ_c^+ decay BFs* *from Prof. Li Hai-Bo and Lyu Xiao-Rui*

	typical hadronic decays	typical two-body decay	SL decay
D^0	$B(K^-\pi^+)=(3.89\pm0.04)\%$ Precision: 1.0%	$B(K_S^0\pi^0)=(1.19\pm0.04)\%$ 3.4%	$B(K^-e^+\nu_e)=(3.53\pm0.03)\%$ 0.8%
D^+	$B(K^-\pi^+\pi^+)=(8.98\pm0.28)\%$ Precision: 3.1%	$B(K_S^0\pi^+)=(1.47\pm0.08)\%$ 5.4%	$B(K_S^0e^+\nu_e)=(4.41\pm0.07)\%$ 1.5%
D^+_s	$B(K^-K^+\pi^+)=(5.45\pm0.17)\%$ Precision: 3.8%	$B(K_S^0K^+)=(1.40\pm0.05)\%$ 3.6%	$B(\phi e^+\nu_e)=(2.39\pm0.23)\%$ 9.6%
Λ^+_c	$B(pK^-\pi^+)=(6.35\pm0.33)\%$ Precision: 5.2%, BESIII&Belle	$B(pK_S^0)=(1.52\pm0.08)\%$ 5.6%, BESIII	$B(\Lambda e^+\nu_e)=(3.63\pm0.43)\%$ 12%, BESIII
	5/fb @4.64GeV ➔ Expected precision: <2% (systematic error dominant)	5/fb @4.64GeV ➔ Expected precision: <2% (systematic error dominant)	5/fb @4.64GeV ➔ Expected precision: ~3% (statistical error dominant)

With 5/fb data at 4.64 GeV, BESIII can precisely and systematically study the decay property of Λ_c baryon, which is also important for excited baron studies.

- *With 5/fb data at E_{cm}=4.64 GeV, we could expect for the typical Λ_c^+ decay:*

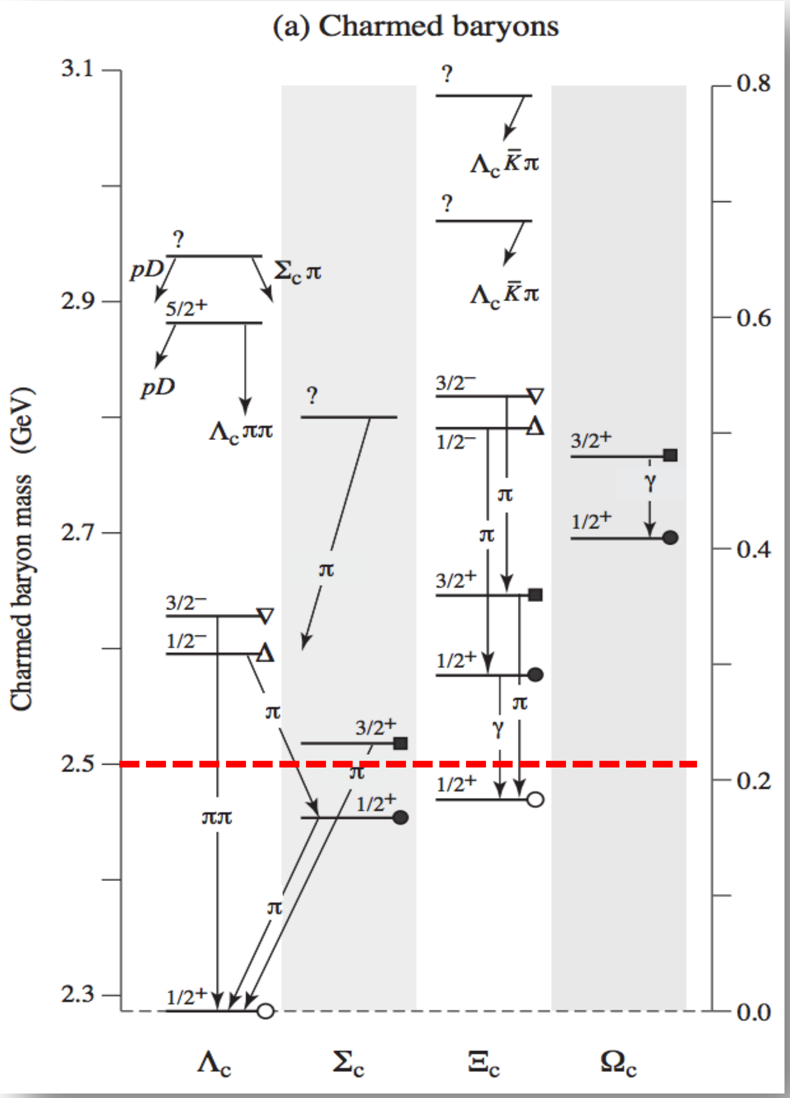
$\Lambda_c^+ \rightarrow$	BF(stat.) [%]	ΔB(stat.)/B	Expected ΔB(stat.)/B
pK_s^0	1.52 $\pm$ 0.08	5.3%	1.3%
$pK^-\pi^+$	5.84 $\pm$ 0.27	4.6%	1.2%
$pK_s^0\pi^0$	1.87 $\pm$ 0.13	7.0%	1.8%
$pK_s^0\pi^+\pi^-$	1.53 $\pm$ 0.11	7.2%	1.8%
$pK^-\pi^+\pi^0$	4.53 $\pm$ 0.23	5.1%	1.3%
$\Lambda\pi^+$	1.24 $\pm$ 0.07	5.6%	1.4%
$\Lambda\pi^+\pi^0$	7.01 $\pm$ 0.37	5.3%	1.3%
$\Lambda\pi^+\pi^-\pi^+$	3.81 $\pm$ 0.24	6.3%	1.6%
$\Sigma^0\pi^+$	1.27 $\pm$ 0.08	6.3%	1.6%
$\Sigma^+\pi^+\pi^-$	4.25 $\pm$ 0.24	5.6%	1.4%
$\Sigma^+\pi^0$	1.18 $\pm$ 0.10	8.5%	2.1%
$\Sigma^+\omega$	1.56 $\pm$ 0.20	12.8%	3.2%
$\Lambda l^+\nu_l$	3.6 $\pm$ 0.4	11.1%	2.8%
$\Lambda^* l^+\nu_l$	0.6 [predicted]	- -	10%
$n l^+\nu_l$	0.2 [predicted]	- -	17%

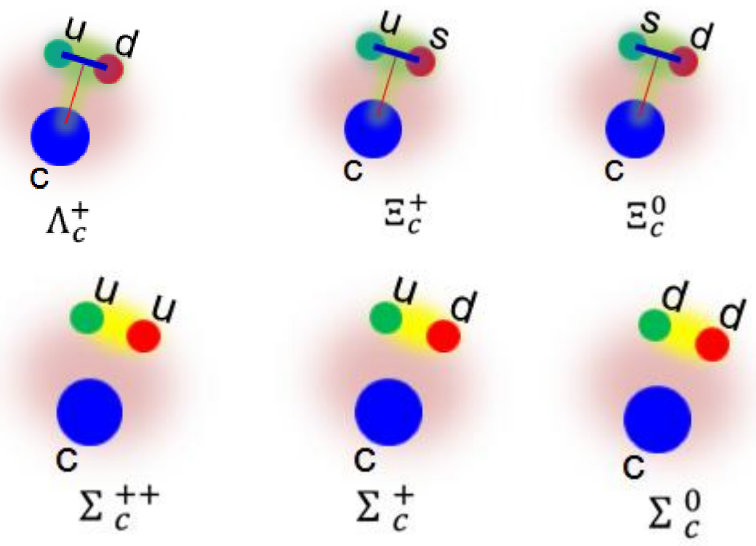
~2%

For typical CF decays, the precision of BFs will be dominated by systematic errors.

Σ_c and Ξ_c

If BEPCII can access energy up to 5 GeV, we can study the decay properties of Σ_c and Ξ_c baryons.





- *No BFs have been measured for Ξ_c^+ (relative to $\Xi^-\pi^+\pi^+$) and Ξ_c^0 (relative to $\Xi^-\pi^+$).*
- *Ξ_c weak decays;*
- *Ξ_c semileptonic decays;*
- *Decay asymmetry in Ξ_c CF weak decays;*
  [more details can be seen in backup slides]

Summary

- **BESIII provides unique data to systematically study Λ_c^+ decays**
  - **Semi-leptonic decays**

    Measuring Form factors, Searching for more SL decay channels
  - **Hadronic decays**

    Precise measurement of typical hadronic decays

    PWA for studying sub-structures

    SCS and W-exchange decays

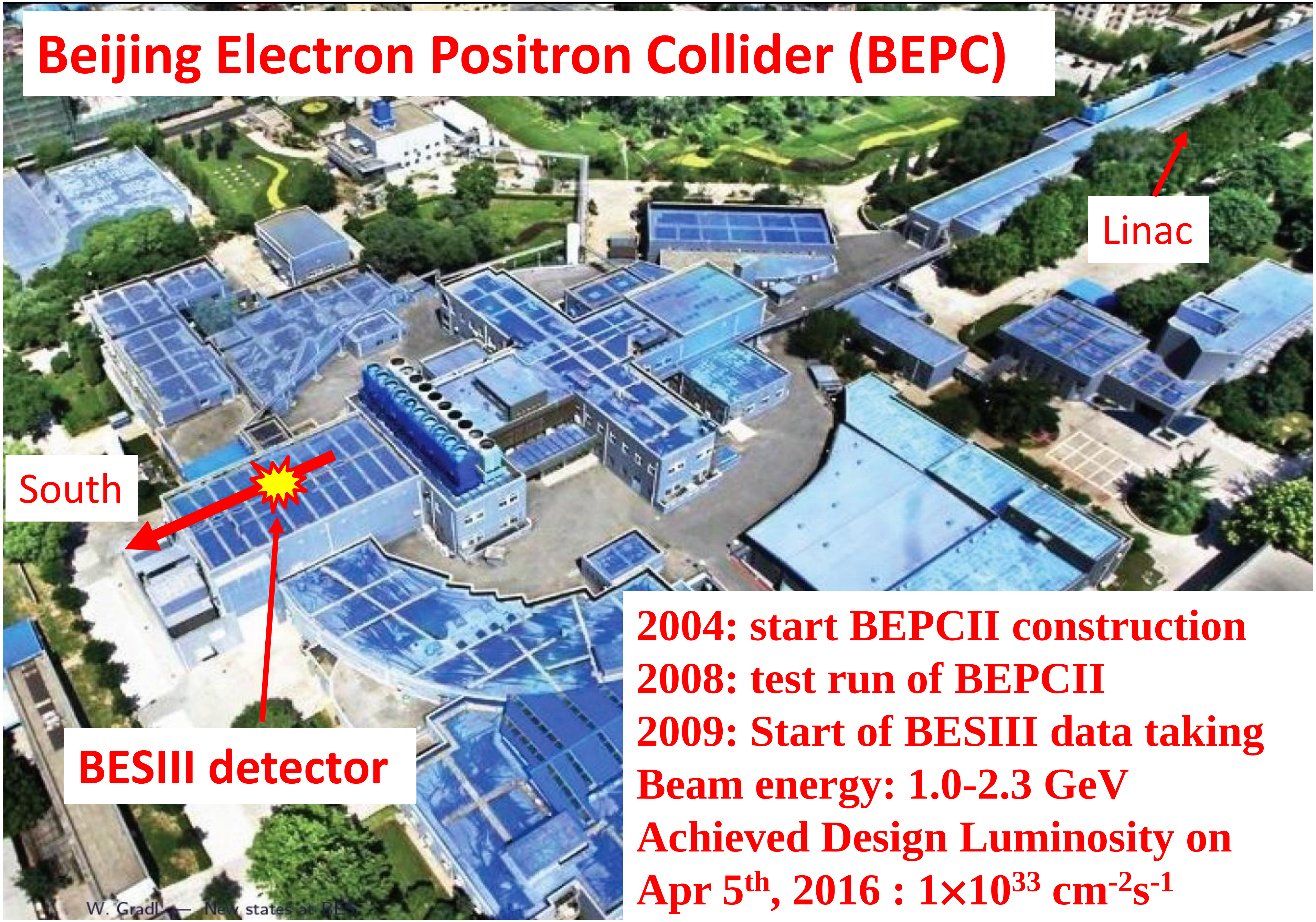
    Exclusive decays containing K_L^0 and neutron

    Decay asymmetry measurements
  - **Weak radiative decays**

    First evidence or observation of $\Lambda_c^+ \rightarrow \gamma\Sigma^+$

Thanks!

Beijing Electron Positron Collider (BEPC)



2004: start BEPCII construction
2008: test run of BEPCII
2009: Start of BESIII data taking
Beam energy: 1.0-2.3 GeV
Achieved Design Luminosity on Apr 5th, 2016 : 1×10^{33} cm^{-2}s^{-1}

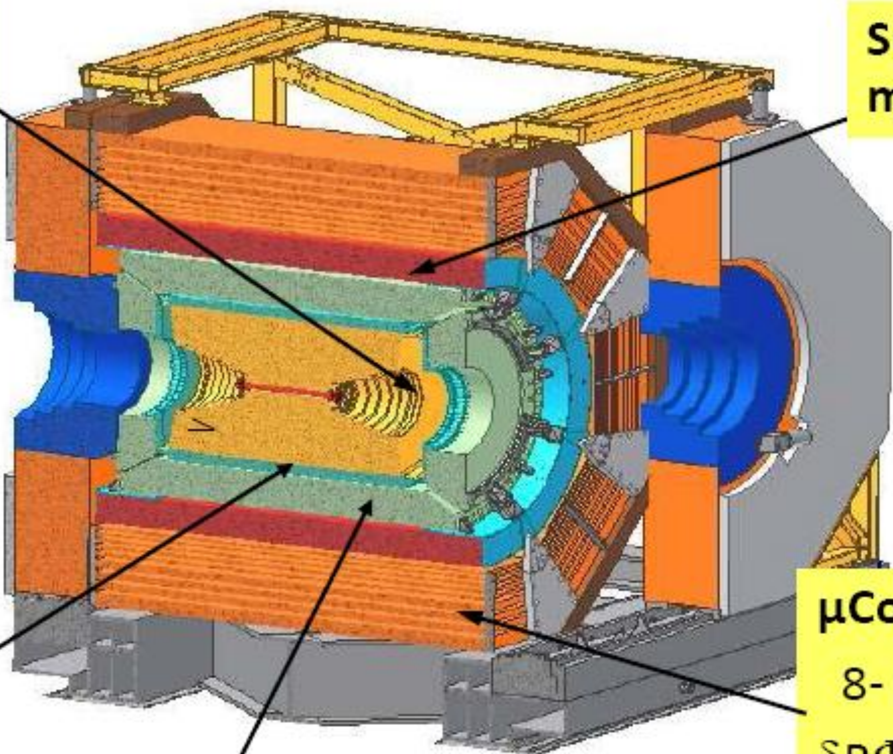
BESIII Detector

Drift Chamber (MDC)

$\sigma P/P$ ($^0/_0$) = 0.5%(1GeV)

$\sigma_{dE/dx}$ ($^0/_0$) = 6%

Super-conducting magnet (1.0 tesla)



Time Of Flight (TOF)

σ_T: 90 ps Barrel

110 ps endcap

μCounter

8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)

(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

BESIII Collaboration

USA (5)

Carnegie Mellon Univ.,

Indiana Univ.,

Univ. of Hawaii,

Univ. of Minnesota,

Univ. of Rochester,

Europe (14)

Germany: Bochum Ruhr Univ., GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg Univ. of Mainz, Justus-Liebig-Univ. Giessen, Univ. of Münster; Russia: Budker Institute of Nuclear Physics, Joint Institute for Nuclear Research

Italy: Ferrara Univ., INFN Laboratori Nazionali di Frascati, Univ. of Turin;

The Netherlands : KVI-CART Univ. of Groningen; Sweden: Uppsala Univ.,

Turkey: *Turkish Accelerator Center Particle Factory Group*

China (34)

IHEP, Beihang Univ., Beijing Institute of Petro-chemical Technology, Central China Normal Univ., CCAST, Guangxi Normal Univ., Guangxi Univ., Hangzhou Normal Univ., Henan Normal Univ., Henan Univ. of Science and Technology, Huangshan College, Hunan Univ., Jinan Univ., Lanzhou Univ., Liaoning Univ., Nanjing Normal Univ., Nanjing Univ., Nankai Univ., Peking Univ., Shandong Univ., Shanghai Jiao Tong Univ., Shanxi Univ., Sichuan Univ., Soochow Univ., Sun Yat-Sen Univ., Tsinghua Univ., Univ. of Chinese Academy of Sciences , Univ. of Sciences and Technology Liaoning, Univ. of Science and Technology of China, Univ. of South China, Wuhan Univ., Zhejiang Univ., Zhengzhou Univ.

Others In ASIA(6)

COMSATS Institute of Information Technology, Pakistan,

Indian Institute of Technology, Madras, India

Institute of Physics and Technology Mongolia,

Seoul National Univ., Korea,

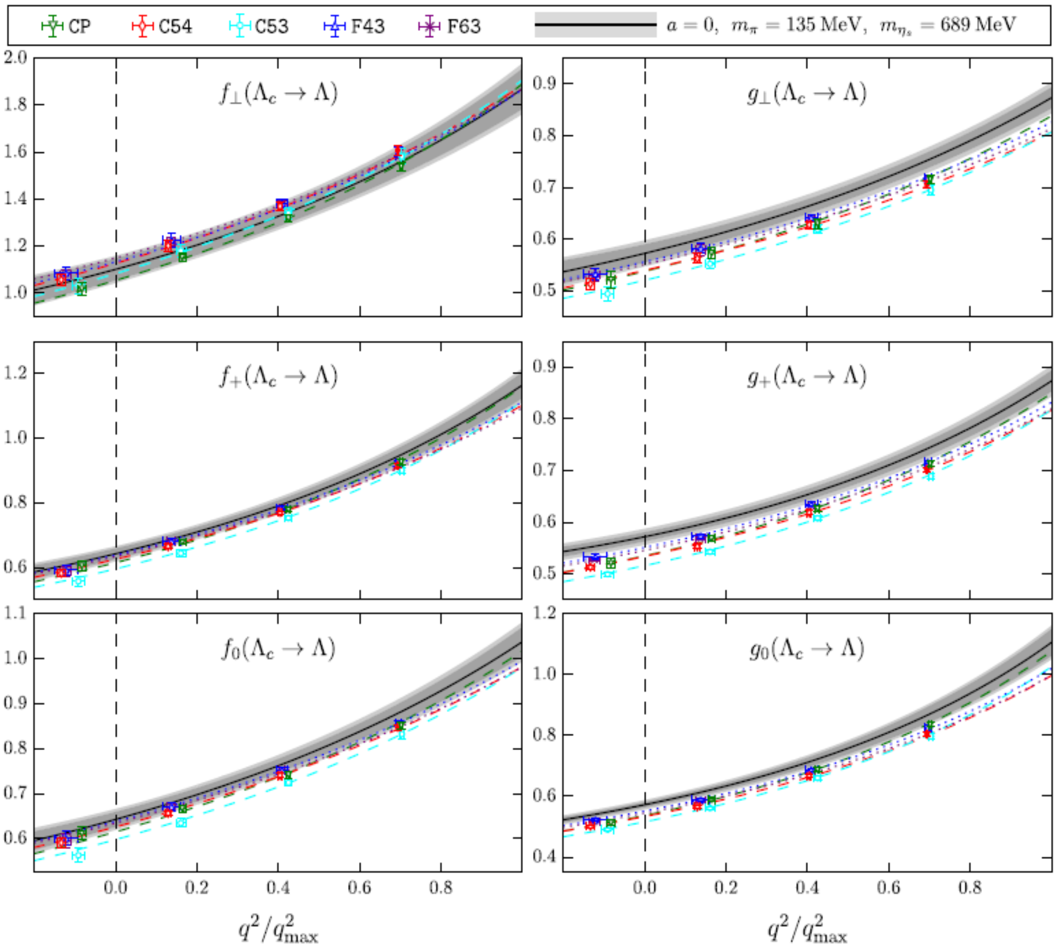
Tokyo University, Japan

Univ. of Punjab, Pakistan

~350 members
59 institutes from
12 countries

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	$3.80 \pm 0.19_{LQCD} \pm 0.11_{\tau\Lambda c}$	Stefan Meinel, PRL118,082001 (2017)
BESIII [First absolute measurement]	3.63±0.43	PRL 115, 221805 (2015)]

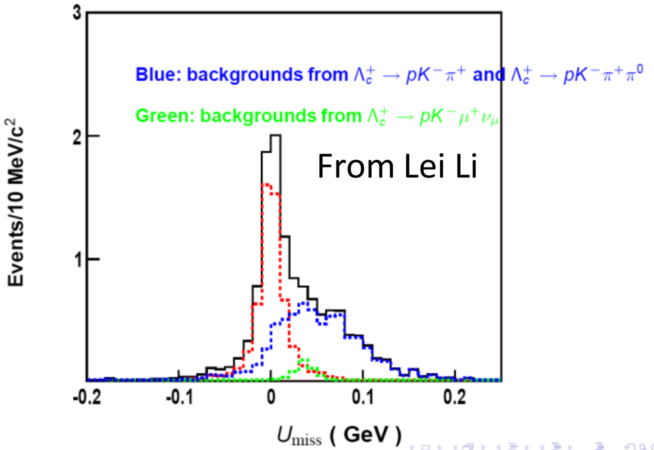
PRL **118,** 082001 (2017)

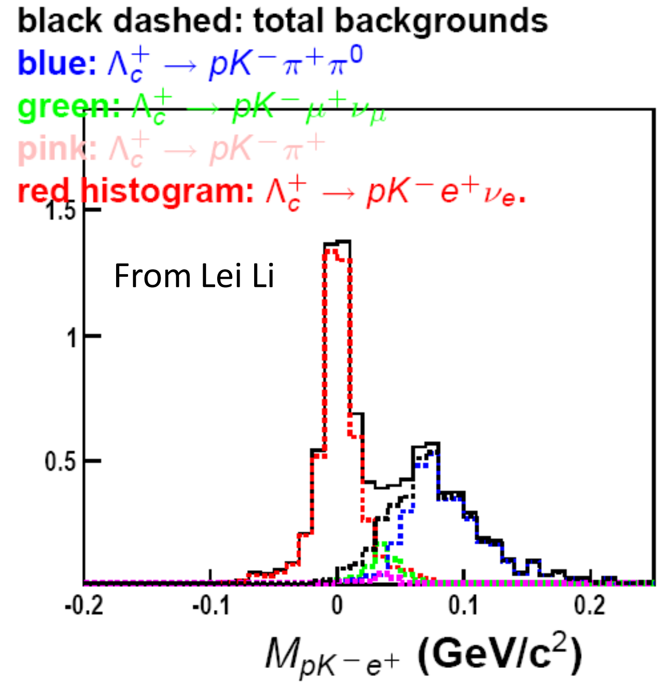


$$f(q^2) = \frac{1}{1 - q^2/(m_{\rm pole}^f)^2} \sum_{n=0}^{n_{\rm max}} a_n^f [z(q^2)]^n,$$

	Nominal fit	Higher-order fit
$a_0^{f_\perp}$	1.30 ± 0.06	1.28 ± 0.07
$a_1^{f_\perp}$	-3.27 ± 1.18	-2.85 ± 1.34
$a_2^{f_\perp}$	7.16 ± 11.6	7.14 ± 12.2
$a_3^{f_\perp}$		-1.08 ± 30.0
$a_0^{f_+}$	0.81 ± 0.03	0.79 ± 0.04
$a_1^{f_+}$	-2.89 ± 0.52	-2.38 ± 0.61
$a_2^{f_+}$	7.82 ± 4.53	6.64 ± 6.07
$a_3^{f_+}$		-1.08 ± 29.8
$a_0^{f_0}$	0.77 ± 0.02	0.76 ± 0.03
$a_1^{f_0}$	-2.24 ± 0.51	-1.77 ± 0.58
$a_2^{f_0}$	5.38 ± 4.80	4.93 ± 6.28
$a_3^{f_0}$		-0.26 ± 29.8
$a_0^{g_\perp, g_+}$	0.68 ± 0.02	0.67 ± 0.02
$a_1^{g_\perp}$	-1.91 ± 0.35	-1.73 ± 0.54
$a_2^{g_\perp}$	6.24 ± 4.89	5.97 ± 6.64
$a_3^{g_\perp}$		-1.68 ± 29.8
$a_1^{g_+}$	-2.44 ± 0.25	-2.22 ± 0.35
$a_2^{g_+}$	13.7 ± 2.15	12.1 ± 4.43
$a_3^{g_+}$		12.9 ± 29.2
$a_0^{g_0}$	0.71 ± 0.03	0.72 ± 0.04
$a_1^{g_0}$	-2.86 ± 0.44	-2.80 ± 0.53
$a_2^{g_0}$	11.8 ± 2.47	11.7 ± 4.74
$a_3^{g_0}$		1.35 ± 29.4

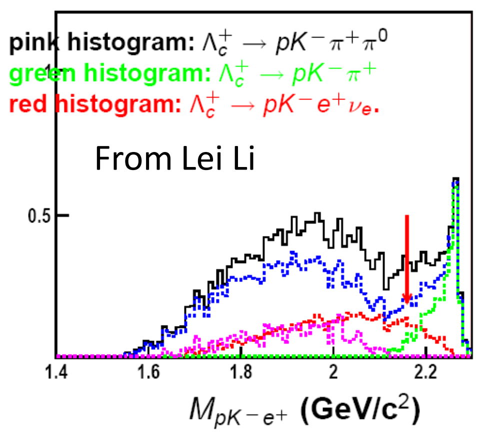
$\Lambda_c^+ \to pK^-e^+\nu_e$

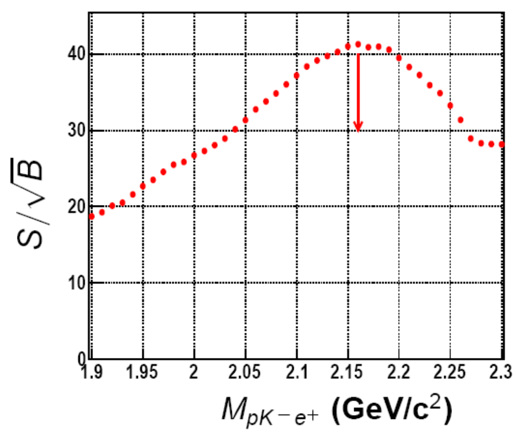




$\Lambda_c^+ \to pK^-e^+\nu_e$

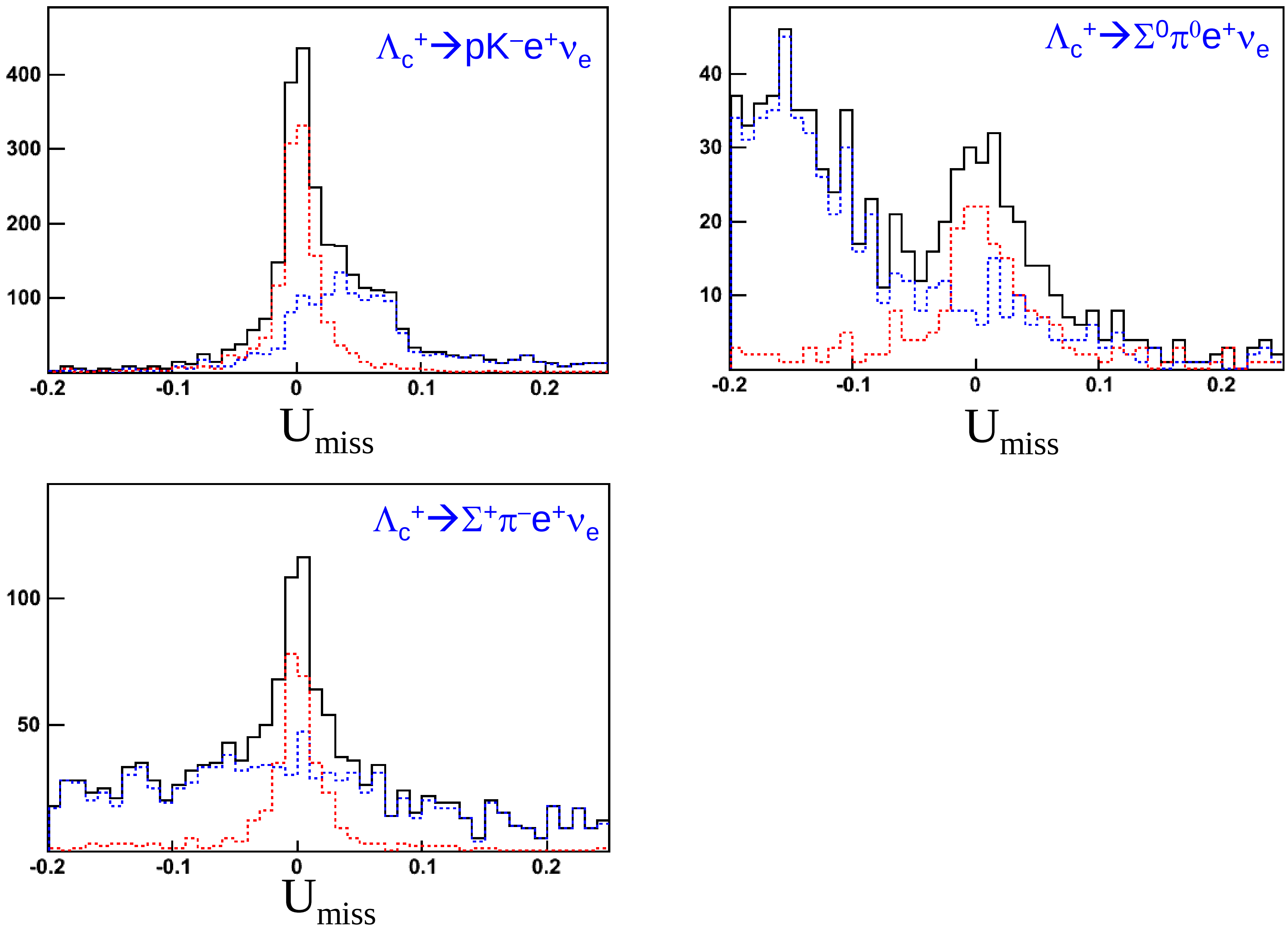
Figure: Optimization for $M_{pK^-e^+}$ Selection.





From above optimization, the $M_{pK^-e^+} < 2.16$ GeV/c^2 is required.

MC simulations



From Lyu Xiao-Rui

No absolute branching fractions have been measured/calculated

Ξ_c^+: relative to the decay of $\Xi^- 2\pi^+$

	Mode	Fraction (Γ_i / Γ)
	No absolute branching fractions have been measured.The following are branching to $\Xi^-\ \pi^+$ .Cabibbo-favored ($S = -2$) decays — relative to $\Xi^-\ \pi^+$	
Γ_1	$p 2 K_S^0$	0.087 ± 0.021
Γ_2	$\Lambda \overline{K}^0 \pi^+$	
Γ_3	$\Sigma(1385)^+ \overline{K}^0$	1.0 ± 0.5
Γ_4	$\Lambda K^- 2\pi^+$	0.323 ± 0.033
Γ_5	$\Lambda \overline{K}^*(892)^0 \pi^+$	< 0.16
Γ_6	$\Sigma(138$	
Γ_7	$\Sigma^+ K^- \pi^+$	
Γ_8	$\Sigma^+ \overline{K}^*$	
Γ_9	$\Sigma^0 K^- 2\pi$	
Γ_{10}	$\Xi^0 \pi^+$	0.55 ± 0.16
Γ_{11}	$\Xi^- 2\pi^+$	**DEFINEDAS1**
Γ_{12}	$\Xi(1530)^0 \pi^+$	< 0.10
Γ_{13}	$\Xi^0 \pi^+ \pi^0$	2.3 ± 0.7
Γ_{14}	$\Xi^0 \pi^- 2\pi^+$	1.7 ± 0.5
Γ_{15}	$\Xi^0 e^+ \nu_e$	$2.3^{+0.7}_{-0.8}$
Γ_{16}	$\Omega^- K^+ \pi^+$	0.07 ± 0.04
	Cabibbo-suppressed decays — relative to $\Xi^-\ \pi^+$	
Γ_{17}	$p K^- \pi^+$	0.21 ± 0.04
Γ_{18}	$p \overline{K}^*(892)^0$	0.116 ± 0.030
Γ_{19}	$\Sigma^+ \pi^+ \pi^-$	0.48 ± 0.20
Γ_{20}	$\Sigma^- 2\pi^+$	0.18 ± 0.09
Γ_{21}	$\Sigma^+ K^+ K^-$	0.15 ± 0.06

Ξ_c^0: relative to the decay of $\Xi^- \pi^+$

	Mode	Fraction (Γ_i / Γ)
	No absolute branching fractions have been measured.The following are bran $= -2$) decays — relative to $\Xi^-\ \pi^+$	
Γ_1	$p K^- K^- \pi^+$	0.34 ± 0.04
Γ_2	$p K^- \overline{K}^*(892)^0$	0.21 ± 0.05
Γ_3	$p K^- K^- \pi^+$ (no $\overline{K}^{*0}$)	0.21 ± 0.04
		28
Γ_8	$\Xi^- \pi^+$	**DEFINEDAS1**
Γ_9	$\Xi^- \pi^+ \pi^+ \pi^-$	3.3 ± 1.4
Γ_{10}	$\Omega^- K^+$	0.297 ± 0.024
Γ_{11}	$\Xi^- e^+ \nu_e$	3.1 ± 1.1
Γ_{12}	$\Xi^- \ell^+$ anything	1.0 ± 0.5
	Cabibbo-suppressed decays — relative to $\Xi^-\ \pi^+$	
Γ_{13}	$\Xi^- K^+$	0.028 ± 0.006
Γ_{14}	$\Lambda K^+ K^-$ (no ϕ)	0.029 ± 0.007
Γ_{15}	$\Lambda \phi$	0.034 ± 0.007

Very limited knowledge on their decays

We have opportunity to firstly fill up the decay tables

Most of the Ξ_c weak decays to BP are missing in experiment.

From Lyu Xiao-Rui

BFs of Cabibbo-allowed decays

RQM Pole Pole RQM Pole Pole (in units of %)

Decay	Körner, Krämer ('92)	Xu, Kamal ('92)	Cheng, Tseng ('93)	Ivanov et al. ('98)	Żenczykowski ('94)	Sharma, Verma ('99)	Expt.
$\Xi_c^+ \to \Sigma^+ \bar{K}^0$	6.45	0.44	0.84	3.08	1.56	0.04	
$\Xi_c^+ \to \Xi^0 \pi^+$	3.54	3.36	3.93	4.40	1.59	0.53	0.55 ± 0.16[a]
$\Xi_c^0 \to \Lambda \bar{K}^0$	0.12	0.37	0.27	0.42	0.35	0.54	seen
$\Xi_c^0 \to \Sigma^0 \bar{K}^0$	1.18	0.11	0.13	0.20	0.11	0.07	
$\Xi_c^0 \to \Sigma^+ K^-$	0.12	0.12		0.27	0.36	0.12	
$\Xi_c^0 \to \Xi^0 \pi^0$	0.03	0.56	0.28	0.04	0.69	0.87	
$\Xi_c^0 \to \Xi^0 \eta$	0.24			0.28	0.01	0.22	
$\Xi_c^0 \to \Xi^0 \eta'$	0.85			0.31	0.09	0.06	
$\Xi_c^0 \to \Xi^- \pi^+$	1.04	1.74	1.25	1.22	0.61	2.46	seen
$\Omega_c^0 \to \Xi^0 \bar{K}^0$	1.21		0.09	0.02			

Most of the Ξ_c weak decay asymmetries are missing in experiment.

From Lyu Xiao-Rui

Decay asymmetry α for Cabibbo-allowed decays

Longitudinal pol. of daughter baryon from unpol. parent baryon

⇒ information on the relative sign between s- and p-waves

Decay	Körner, Krämer ('92)	Xu, Kamal ('92)	Cheng, Tseng ('93)	Ivanov et al. ('98)	Żenczykowski ('94)	Sharma, Verma ('99)	Expt.
$\Xi_c^+ \to \Sigma^+ \bar{K}^0$	-1.0	0.24	-0.09	-0.99	1.00	0.54	
$\Xi_c^+ \to \Xi^0 \pi^+$	-0.78	-0.81	-0.77	-1.0	1.00	-0.27	
$\Xi_c^0 \to \Lambda \bar{K}^0$	-0.76	1.0	-0.73	-0.75	-0.29	-0.79	
$\Xi_c^0 \to \Sigma^0 \bar{K}^0$	-0.96	-0.99	-0.59	-0.55	-0.50	0.48	
$\Xi_c^0 \to \Sigma^+ K^-$	0	0		0	0	0	
$\Xi_c^0 \to \Xi^0 \pi^0$	0.92	0.92	-0.54	0.94	0.21	-0.80	
$\Xi_c^0 \to \Xi^0 \eta$	-0.92			-1.0	-0.04	0.21	
$\Xi_c^0 \to \Xi^0 \eta'$	-0.38			-0.32	-1.00	0.80	
$\Xi_c^0 \to \Xi^- \pi^+$	-0.38	-0.38	-0.99	-0.84	-0.79	-0.97	-0.6 ± 0.4
$\Omega_c^0 \to \Xi^0 \bar{K}^0$	0.51		-0.93	-0.81			

Charm-flavor-conserving weak decays

■ Light quarks undergo weak transitions, while c quark behaves as a "spectator" e.g. $\Xi_c \to \Lambda_c \pi$. Can be studied using HHChPT.

From Lyu Xiao-Rui

$$\left.\begin{array}{l} Br(\Xi_c^0 \to \Lambda_c^+ \pi^-) = 2.9\times10^{-4} \\ Br(\Xi_c^+ \to \Lambda_c^+ \pi^0) = 6.7\times10^{-4} \end{array}\right\}$$

$s \to W^- u$

can be firstly explored at BESIII

Cheng, Cheung, Lin, Lin, Yan, Yu ('92)

Semileptonic decays

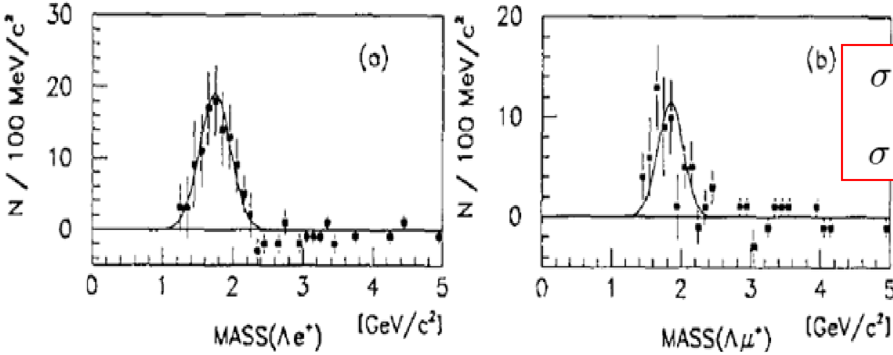
|→ NRQM ←| RQM LFQM QSR QSR

Process	Pérez-Marcial et al. [85]	Singleton [86]	Cheng, Tseng [81]	Ivanov et al. [87]	Luo [88]	Marques de Carvalho et al. [89]	Huang, Wang [90]	Expt. [3]
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	18.1 (12.5)	8.5	7.4	8.16	9.7			seen
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	18.4 (12.7)	8.5	7.4	8.16	9.7			seen

in units of $10^{10}\ s^{-1}$

$\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l$ decays

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

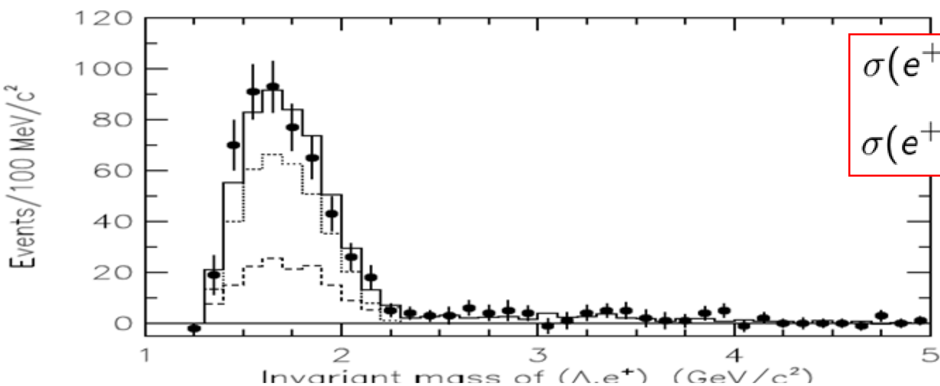


$$\sigma(e^+e^- \to \Lambda_c^+ X) \cdot \mathrm{BR}(\Lambda_c^+ \to \Lambda e^+ X) = 4.20 \pm 1.28 \pm 0.71\ \mathrm{pb}$$

$$\sigma(e^+e^- \to \Lambda_c^+ X) \cdot \mathrm{BR}(\Lambda_c^+ \to \Lambda \mu^+ X) = 3.91 \pm 2.02 \pm 0.90\ \mathrm{pb}$$

Phys. Lett. B 269, 234 (1991).

- **In 1994, CLEO improved the measurement with 1.6 fb^{-1} Υ(4S) data**



$$\sigma(e^+e^- \to \Lambda_c^+ X) \cdot \mathrm{BR}(\Lambda_c^+ \to \Lambda e^+ X) = 4.87 \pm 0.28 \pm 0.69\ \mathrm{pb}$$

$$\sigma(e^+e^- \to \Lambda_c^+ X) \cdot \mathrm{BR}(\Lambda_c^+ \to \Lambda \mu^+ X) = 4.43 \pm 0.51 \pm 0.64\ \mathrm{pb}$$

Phys. Lett. B 323, 219 (1994).

- **Based on above two measurements , PDG extracts BF for $\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l$ with $\tau(\Lambda_c^+)$ and the assumption of 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 direct measurement!