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Rare and baryonic decays of charm hadrons at Belle and Belle II

YoungJun Kim (Korea University)
On behalf of Belle & Belle II Collaborations

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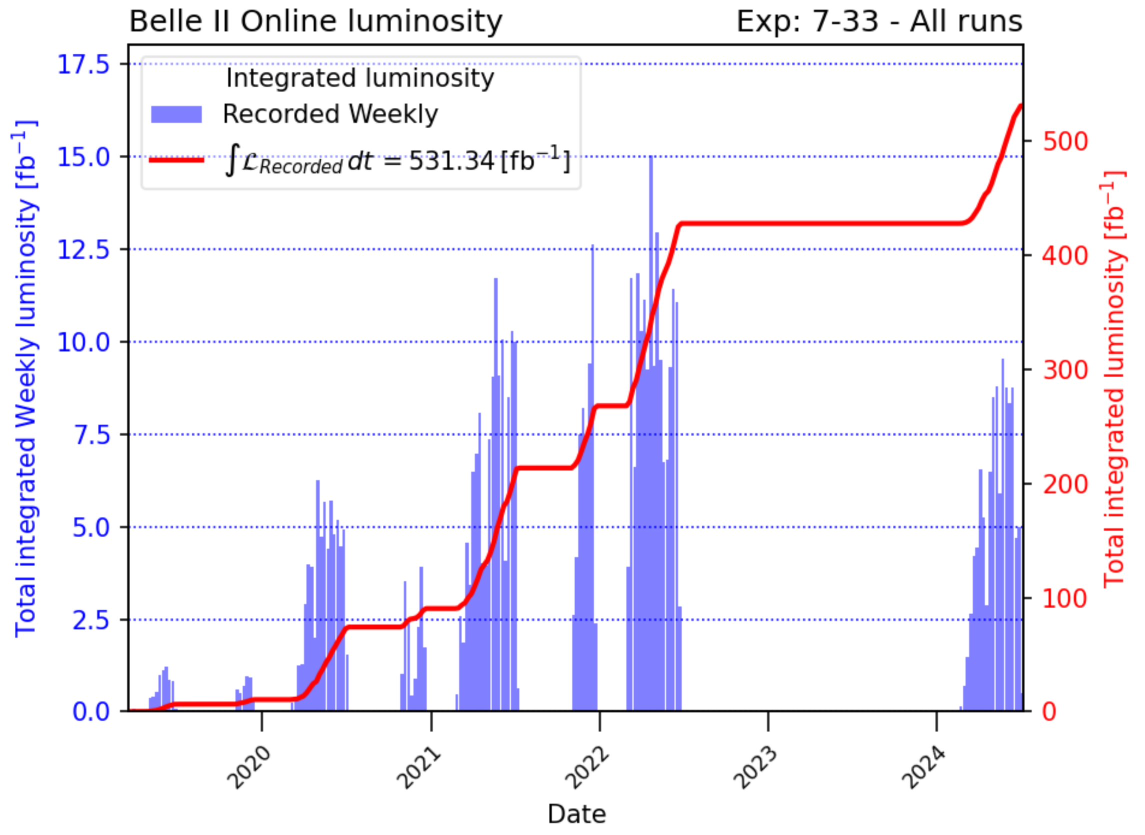
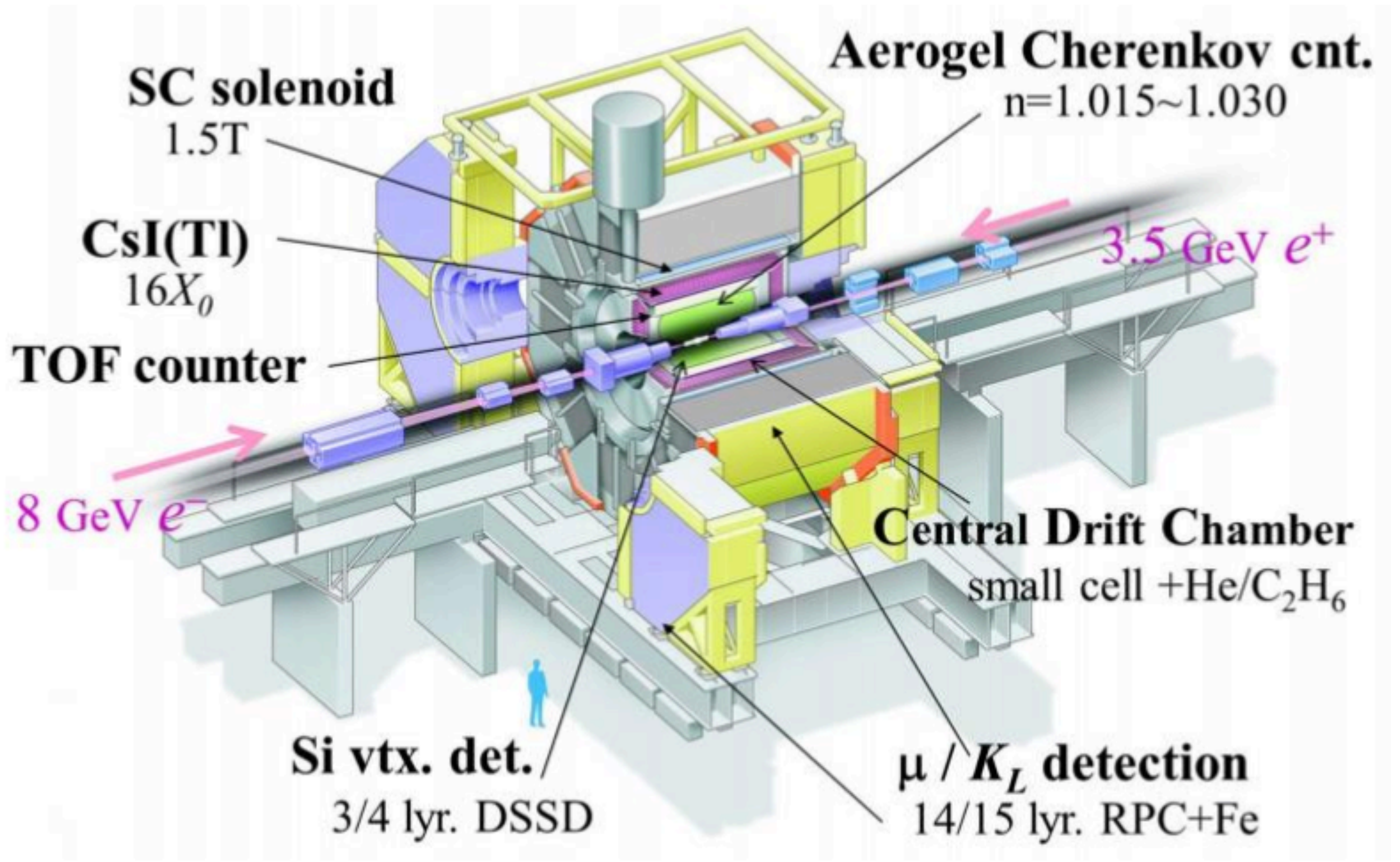
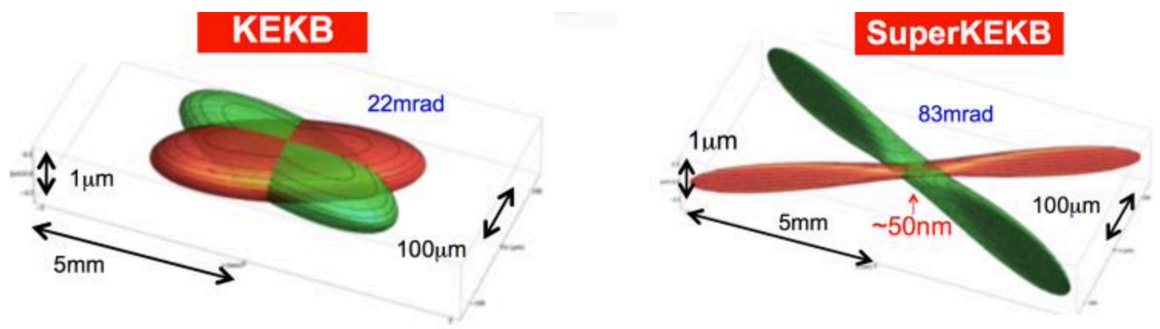
Belle and Belle II Experiments

- Asymmetric e^+e^- collider
  - ➡ Collision CM energies at or near $\Upsilon(4S)$ → B-factories
- Belle and Belle II detectors
  - ➡ Large acceptance
  - ➡ Excellent vertexing and tracking
  - ➡ high-efficiency detection of neutral particles (γ, π^0, η ...)
- Belle + Belle II data sample: $\mathscr{L}_{int} = 1.5\ ab^{-1}$

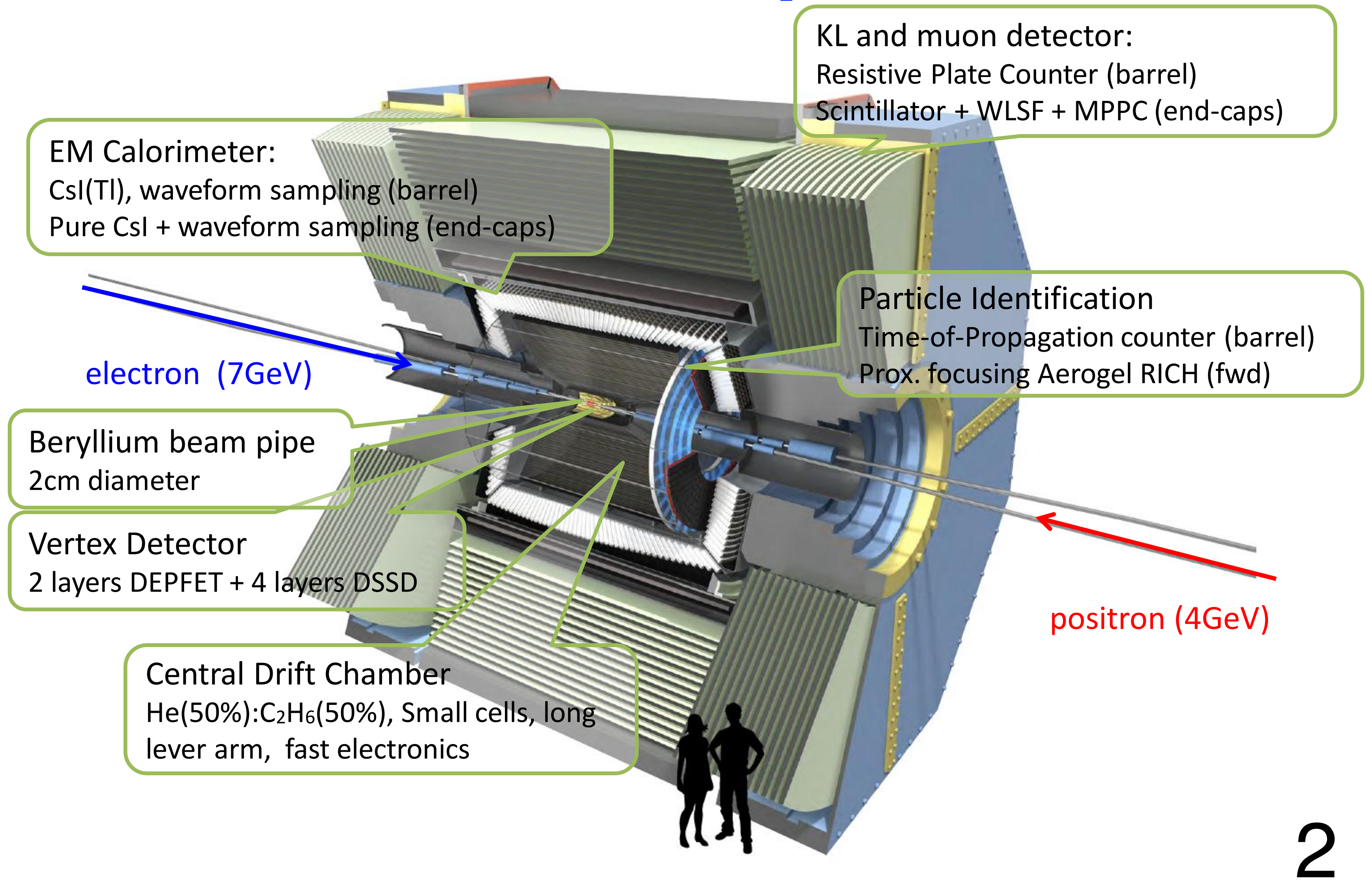


BELLE @ KEKB





Belle II @ SuperKEKB



- **Large Cross section of** $e^+e^- \to c\bar{c} \to$ **two charm hadrons +** X_{frag}
  - ➡ Lifetime
  - ➡ $D^0 - \bar{D}^0$ mixing
  - ➡ Amplitude analysis
  - ➡ CP Violation
  - ➡ Search for rare decays
  - ➡ Branching fraction

→ **Large charm hadron sample!**

$e^+e^- \to$	Cross section [nb]
$\Upsilon(4S)$	1.05 ± 0.10
$c\bar{c}$	1.30
$s\bar{s}$	0.38
$u\bar{u}$	1.61
$d\bar{d}$	0.40
$\tau^+\tau^-(\gamma)$	0.919
$\mu^+\mu^-(\gamma)$	1.148
$e^+e^-(\gamma)$	300 ± 3

Selected Topics

- Rare FCNC $c \to ul^+l^-$ decays
  - $D^0 \to h^-h^{(\prime)+}e^+e^-(h = K, \pi)$
  - $\Xi_c^0 \to \Xi^0 l^+ l^-$
- Baryon number violation
  - $D^0 \to pl$
- Branching fraction of Ξ_c^0 and Λ_c^+ decays
  - $\Xi_c^0 \to \Xi^0 h^0 (h^0 = \pi^0, \eta, \eta')$
  - $\Lambda_c^+ \to p K_S^0 \pi^0$
  - $\Lambda_c^+ \to p K_S^0 \eta$, $\Lambda_c^+ \to p K_S^0 K_S^0$
  - $\Lambda_c^+ \to \Sigma^+ \eta^{(\prime)}$
  - $\Lambda_c^+ \to \Lambda K^+$, $\Lambda_c^+ \to \Sigma^0 K^+$

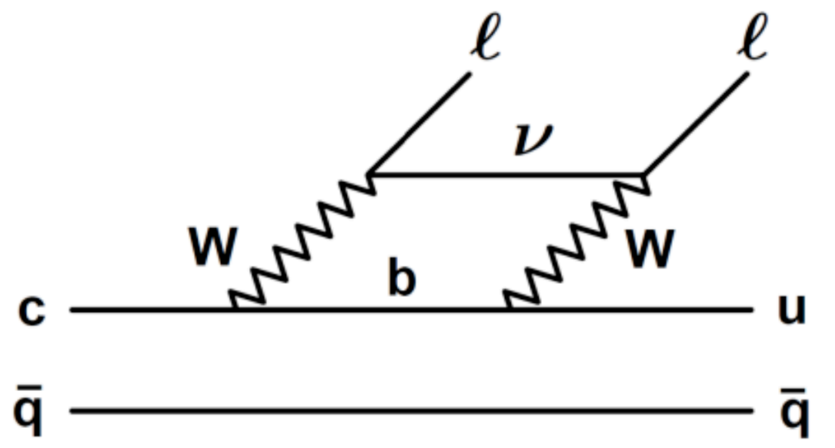
Search for $D^0 \to hh'e^+e^-, (h = K, \pi)$

- **FCNC processes with $c \to ull$** are suppressed in SM, good probe for NP
- **SM long-distance** contributions dominate, especially near resonances.

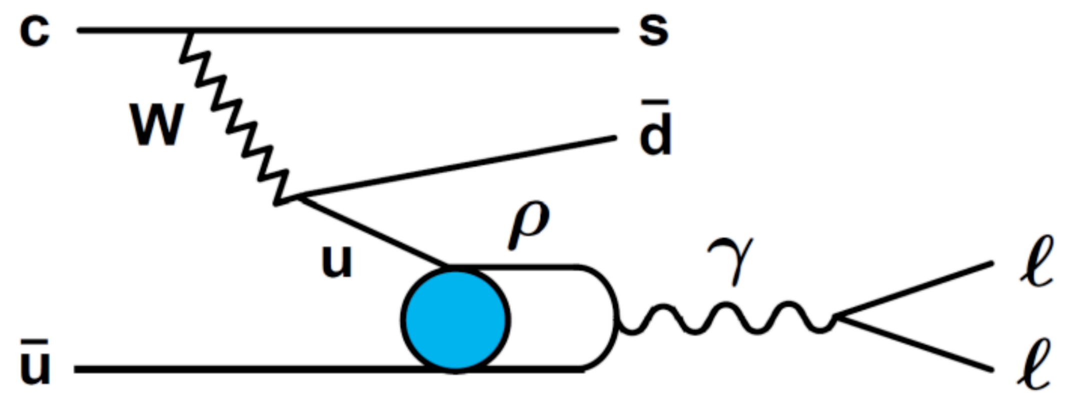
➡ BSM contributions may be visible far from resonances.

BABAR: PRL **122**, 081802 (2019)
BESIII: PRD **97**, 072015 (2019)
LHCb: PRL **119**, 181805 (2017)
PLB **517**, 558(2016)

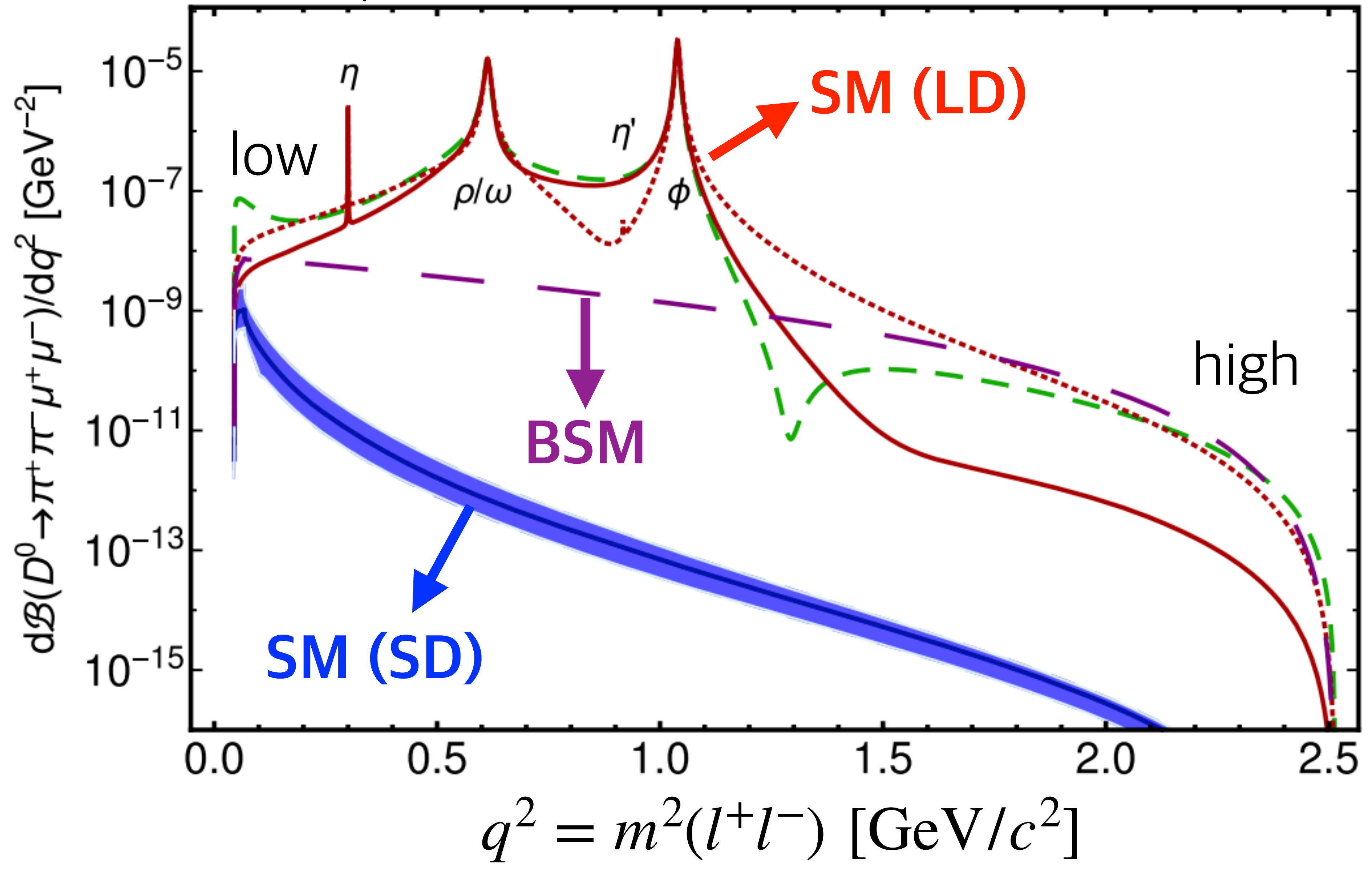
Short distance



Long distance



PRD **98**, 035041 (2018)



Measured BFs or ULs at 90% CL [$\times 10^{-7}$]

	$KKee$	$\pi\pi ee$	$K\pi ee$
BABAR	–	–	$40.0 \pm 5.0 \pm 2.3$ (ρ/ω) < 31 (non-resonant)
BESIII	< 110	< 70	< 410
	$KK\mu\mu$	$\pi\pi\mu\mu$	$K\pi\mu\mu$
LHCb	$1.54 \pm 0.27 \pm 0.19$	$9.64 \pm 0.48 \pm 1.10$	$4.17 \pm 0.12 \pm 0.40$ (ρ/ω)

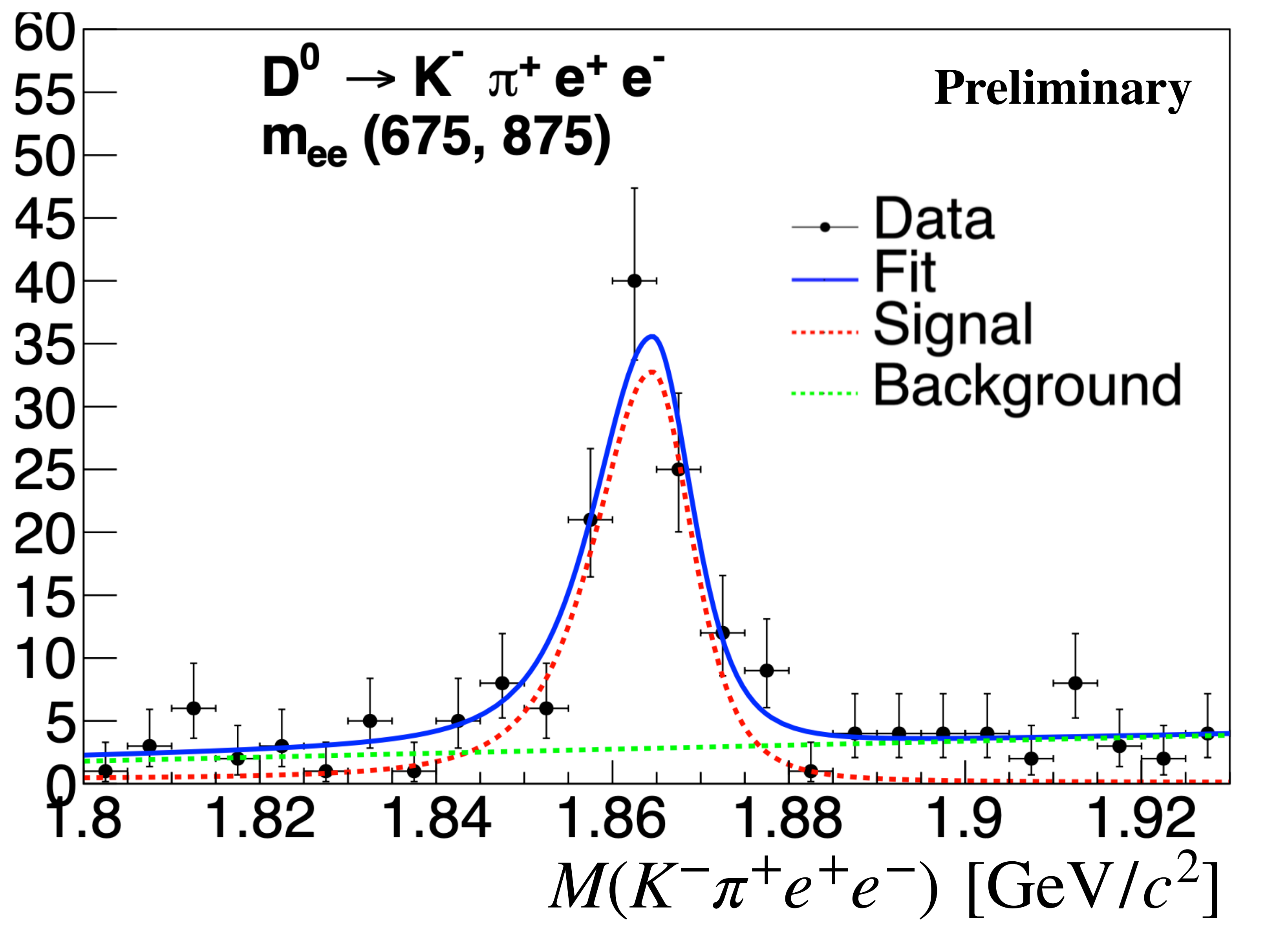
- Search for signal candidates in $q^2 = m^2(e^+e^-)$ regions

➡ Near resonances → BR measurement

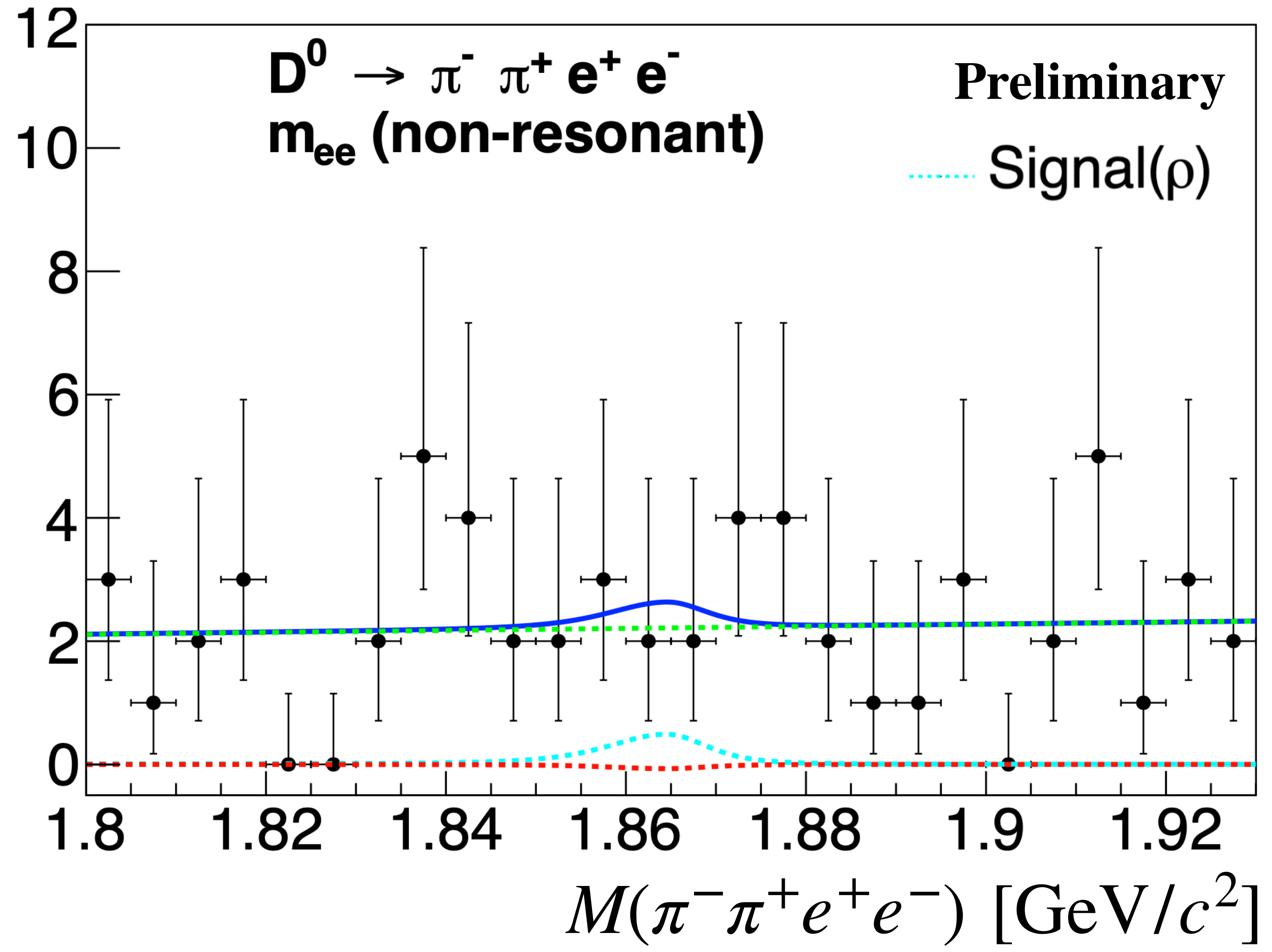
➡ Far from resonances (non-resonant) → Sensitive to NP

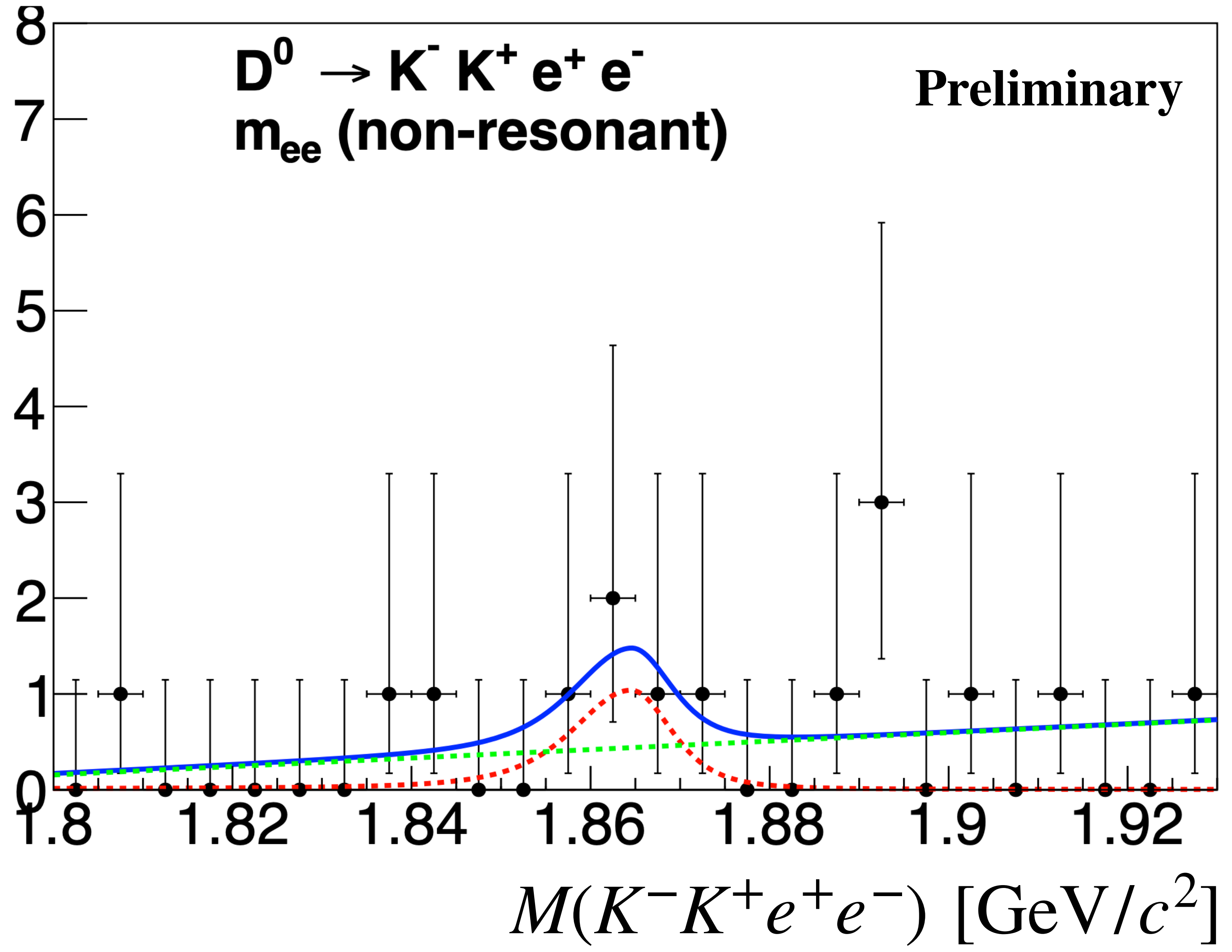
$D^0 \to hh'e^+e^-, (h = K, \pi)$ Results

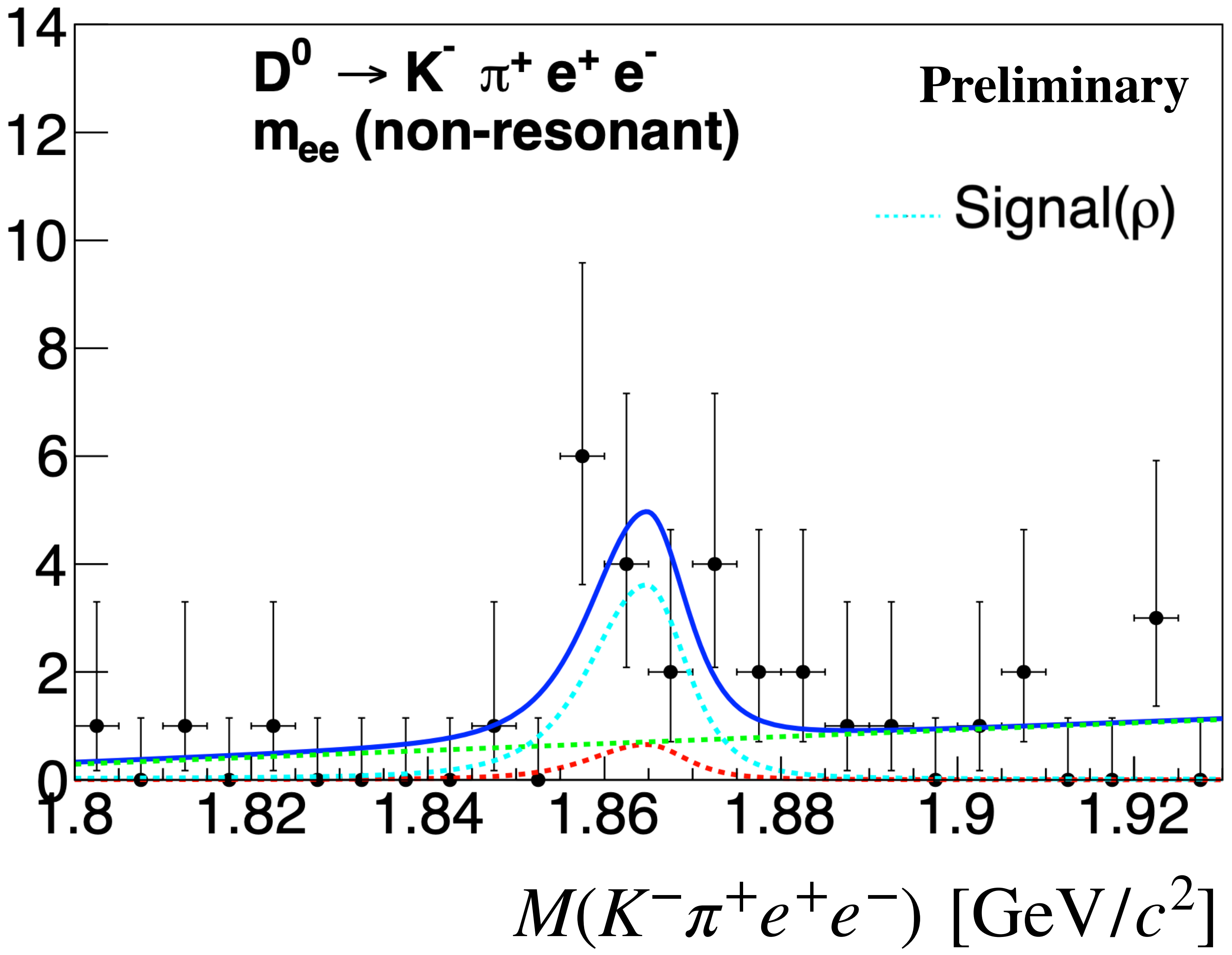
Preliminary Belle 942/fb



- New Belle Results
  - Signal in ρ/ω region: $\mathscr{B}(K\pi e^+e^-) = (39.6 \pm 4.5 \pm 2.9) \times 10^{-7}$ (11.8σ), matches BABAR with higher precision and SM expectations
  - 90% CL upper limits set at $(2-8) \times 10^{-7}$ for other regions (best to date)
    - Significant improvements than BESIII and BABAR but different m_{ee} regions







First Search for $\Xi_c^0 \to \Xi^0 l^+ l^-$

Belle 980/fb, PRD **109**, 052003 (2024)

- No FCNC neutrino-less decays in charm baryons
  - ➡ Only upper limits of $\Lambda_c^+ \to p l^+ l^-$ [1,2] decays were set for charmed baryons
    - ➡ Both W-exchange and FCNC processes contribute.
  - ➡ Theoretically more complicated than $c \to ull$ in meson decays.
    Sensitive to Hamiltonian helicity structure through W-exchange diagrams.
  - ➡ If observed, the signal channels would allow to test LFU with $l = e, \mu$

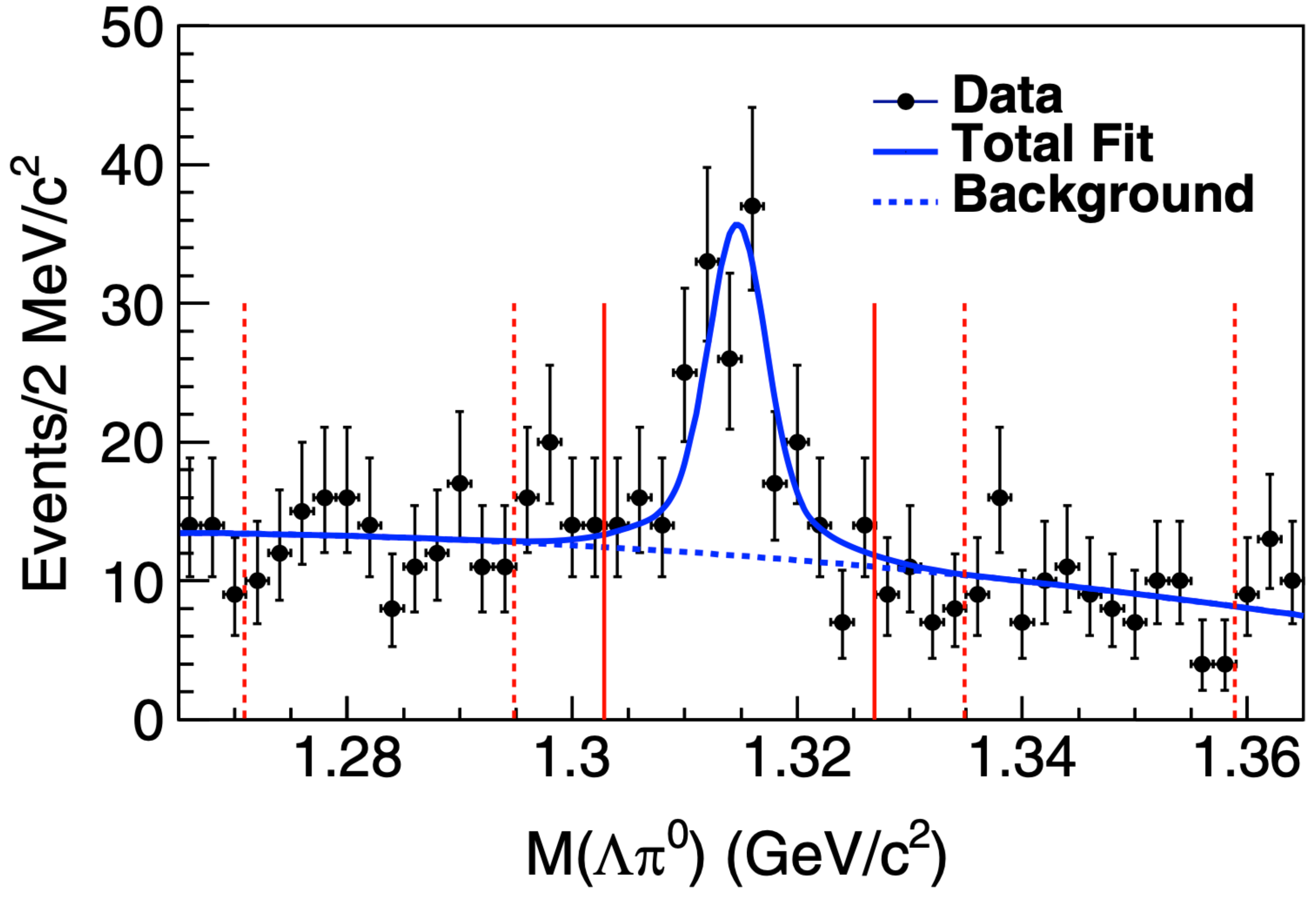
[1] PRD **84**, 072006 (2011)
[2] PRD **97**, 091101 (2018)

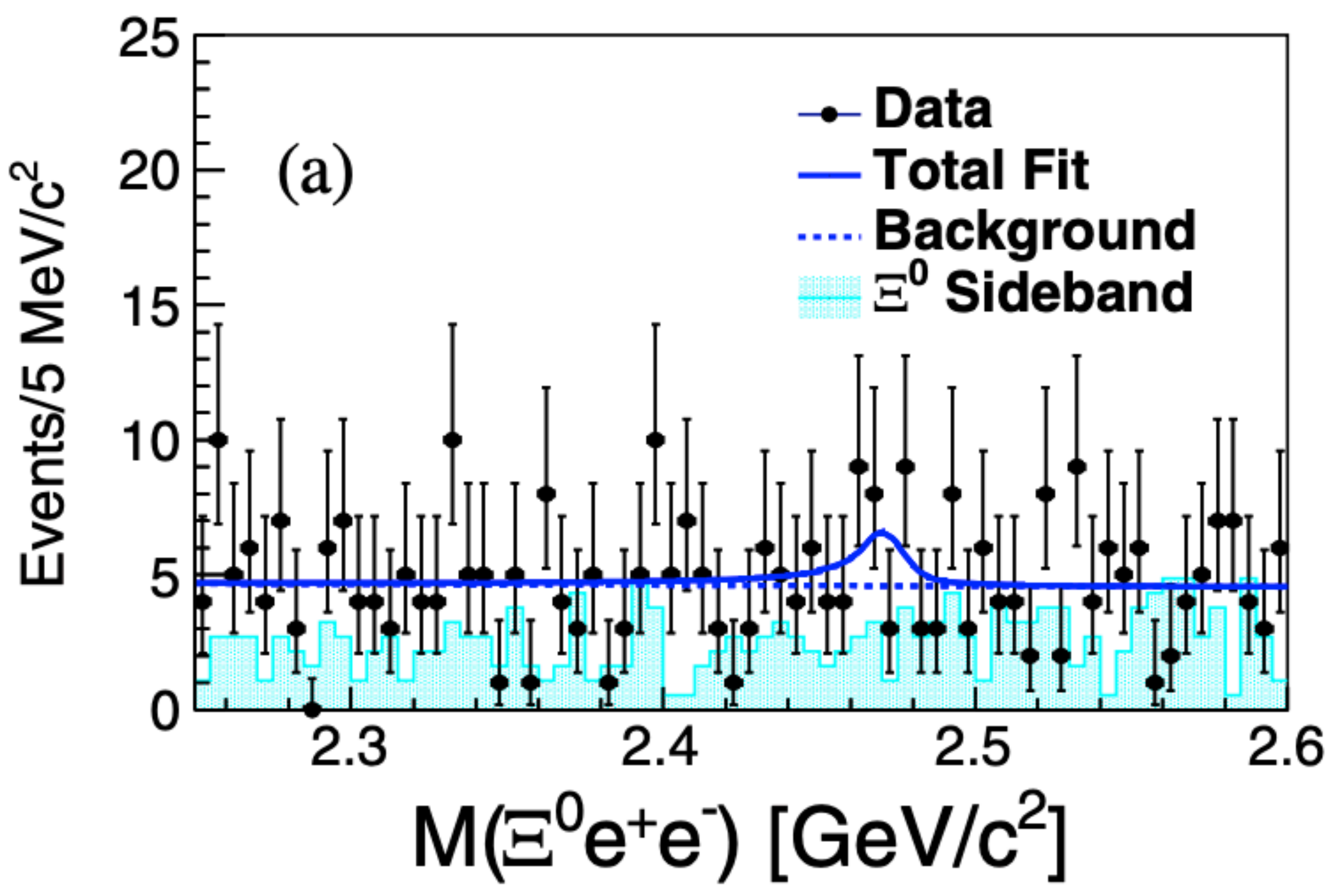
- **Belle Result**: No significant signal was observed but consistent with SM
  - ➡ First set upper limits set at 90% CL:

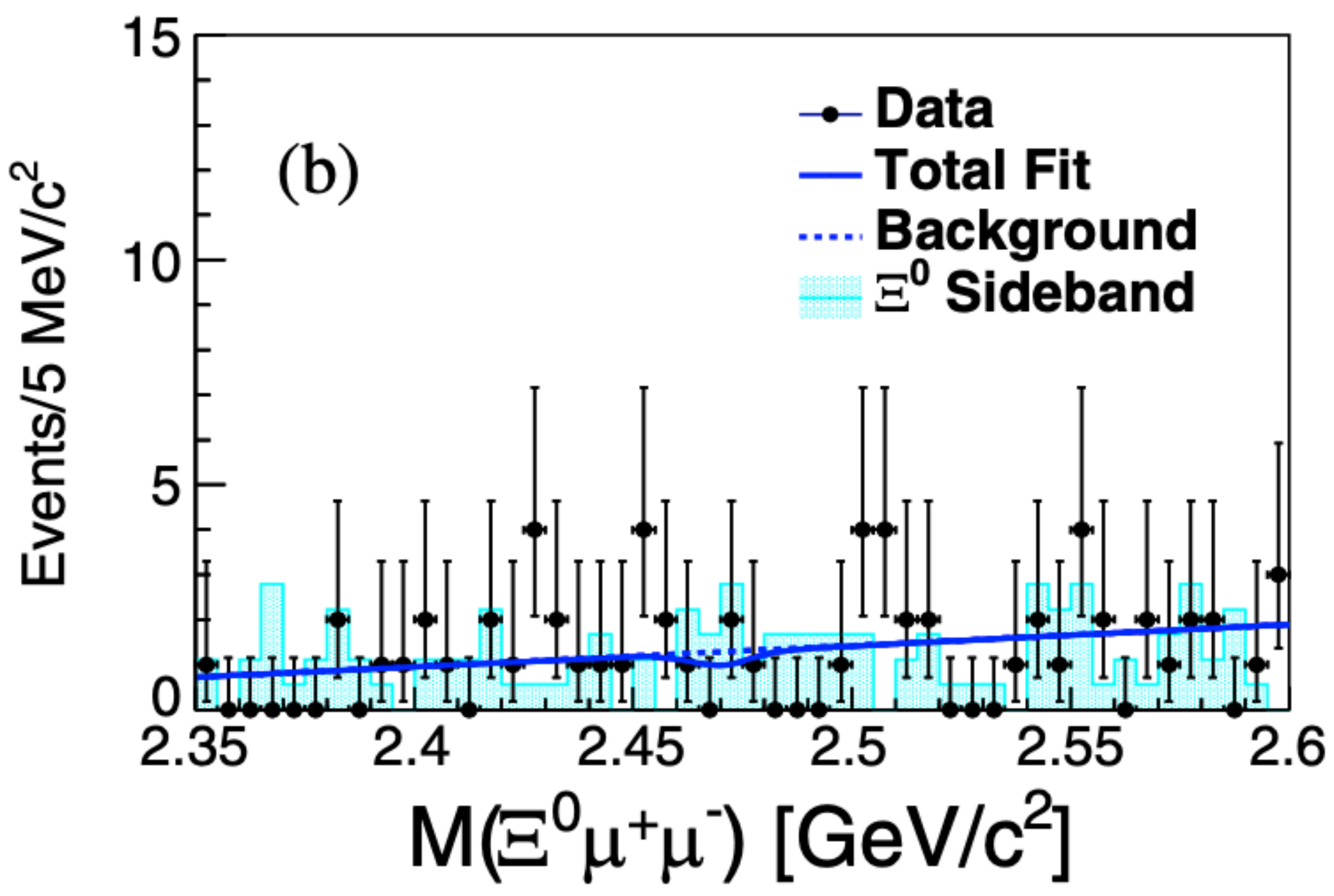
	Measured	SM prediction
$\mathscr{B}(\Xi_c^0 \to \Xi^0 e^+ e^-)$	< 9.9 x 10^{-5}	< 2.35 x 10^{-6}
$\mathscr{B}(\Xi_c^0 \to \Xi^0 \mu^+ \mu^-)$	< 6.5 x 10^{-5}	< 2.25 x 10^{-6}

SM prediction: PRD **103**, 013007 (2021)

$\Xi^0 \to \Lambda\pi^0$ **candidates**

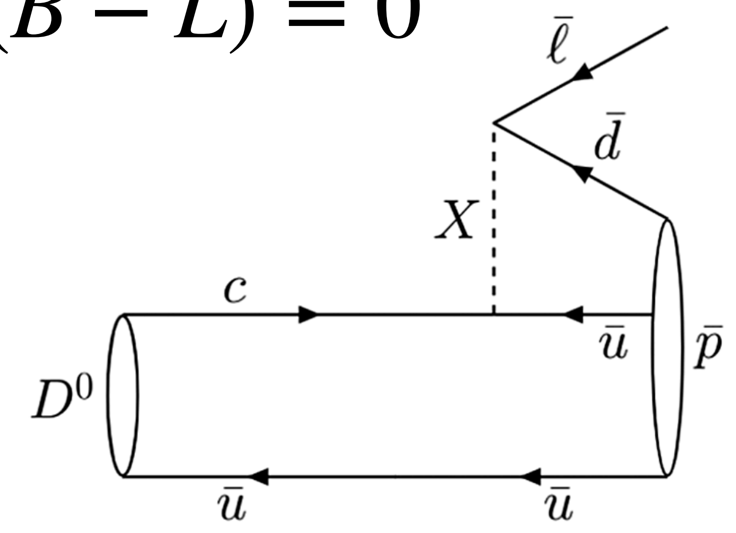






$D^0 \to pl$

- **Baryon Number Violation (BNV)** is a required condition to explain the observed matter-antimatter asymmetry in the universe
  - ➡ Several BSM models[1-5] allow nucleon BNV with $\Delta(B-L)=0$
    - ➡ B: baryon number, L: lepton number



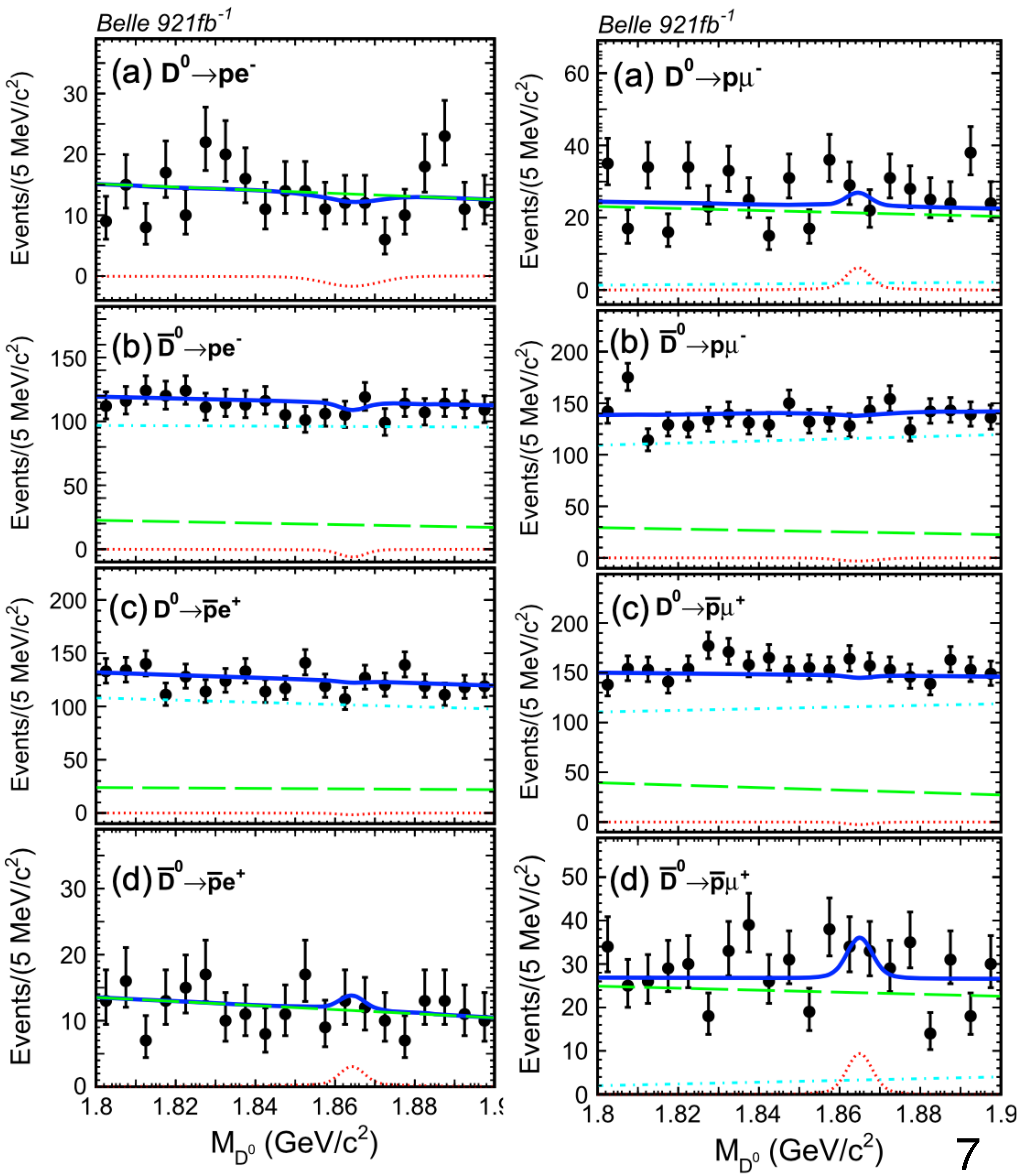
X : non-SM gauge bosons

- **Belle Result**:

2 × 2 × 2

- Search for **8 channels**: $D^0/\overline{D}^0 \to pl^-, \bar{p}l^+$ with $l = e, \mu$
  - ➡ D^* tag for $D^0/\overline{D}^0$ determination
  - ➡ $D^0 \to K\pi$ as a reference mode
- No significant signal was observed
- Set upper limits at $(5-8)\times 10^{-7}$ (90% CL)
  - ➡ Most stringent upper limit for the electron channels to date
  - ➡ First measurement for the muon channels

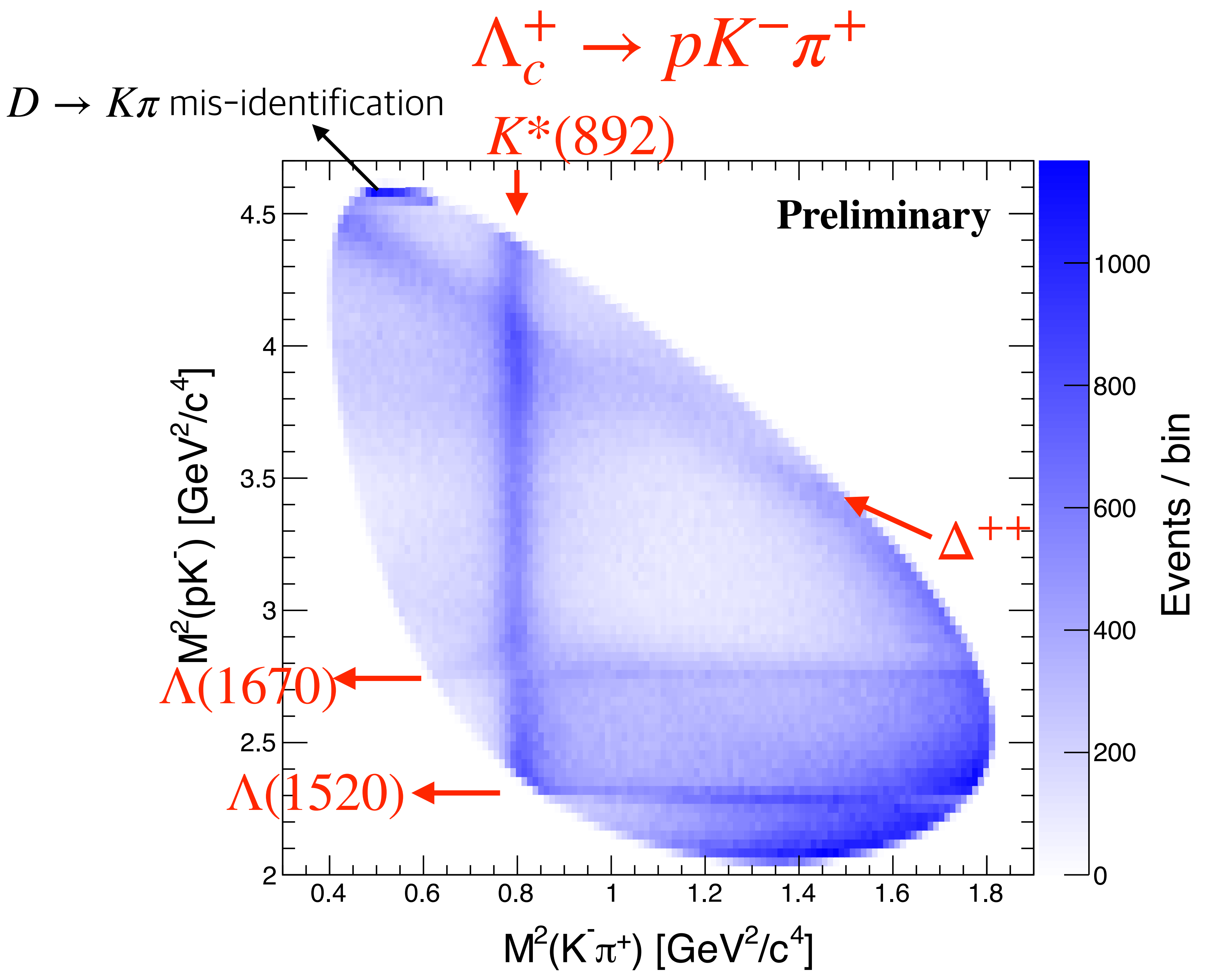
Belle 921/fb, PRD **109**, L031101 (2024)

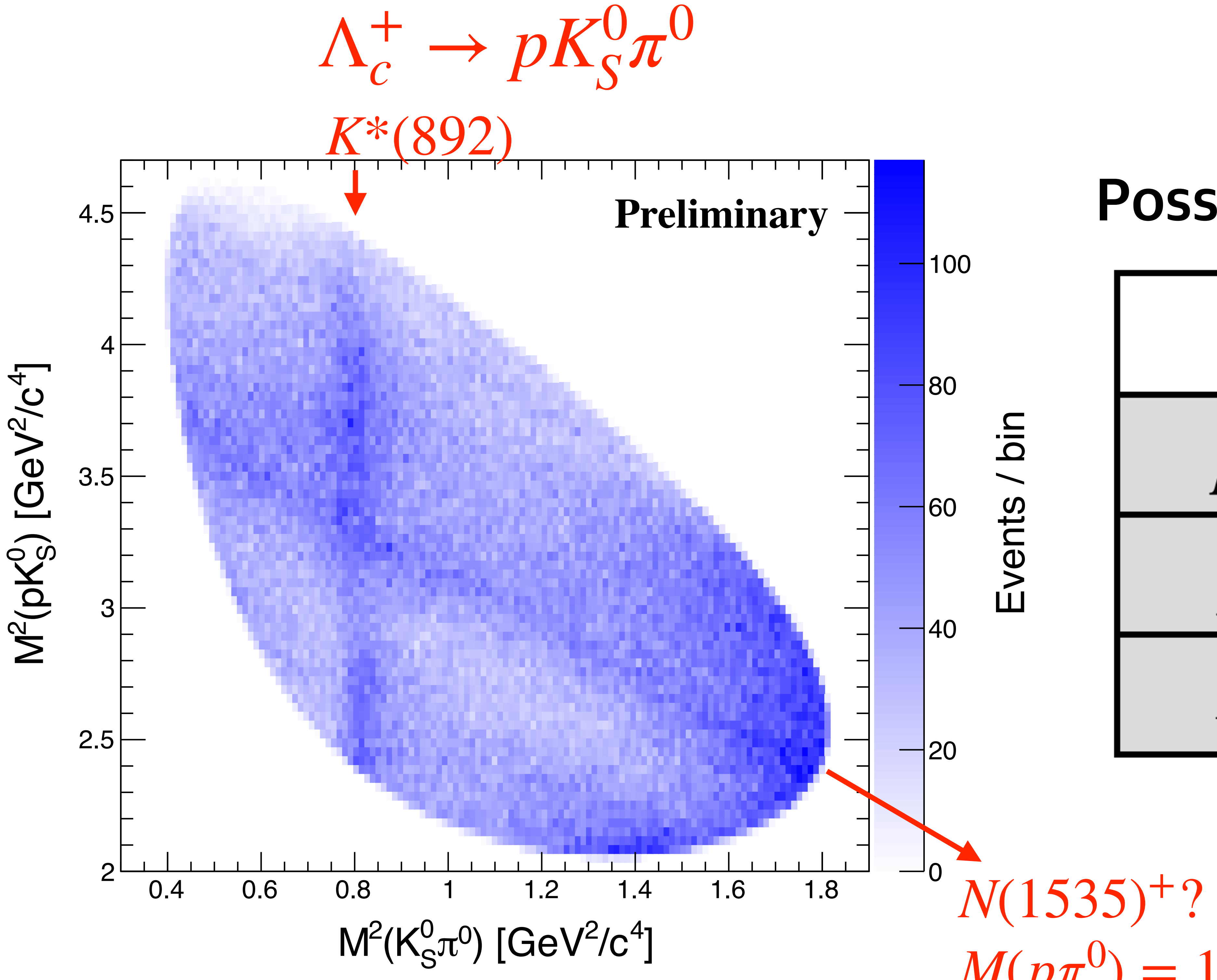


[1] PRD, **8**, 1240 (1973) [2] PRL. **32**, 438 (1974) [3] PRD **20**, 776 (1979)
[4] PLB. **91B**, 222 (1980) [5] PLB **314**, 336 (1993).

Intermediate states in $\Lambda_c^+ \to pK_S^0\pi^0$ Preliminary Belle 980/fb

- With a large statistics, first investigation of Dalitz plots/Intermediate states





Possible resonance contributions

	$pK^-\pi^+$	$pK_S^0\pi^0$
pK	Λ, Σ^0	Σ^+
$p\pi$	Δ^{++}	Δ^+, N^+
$K\pi$	$\bar{K}^{*0}$	

➡ No distinct peaking structure of Σ^{*+} in $M(pK_S^0)$

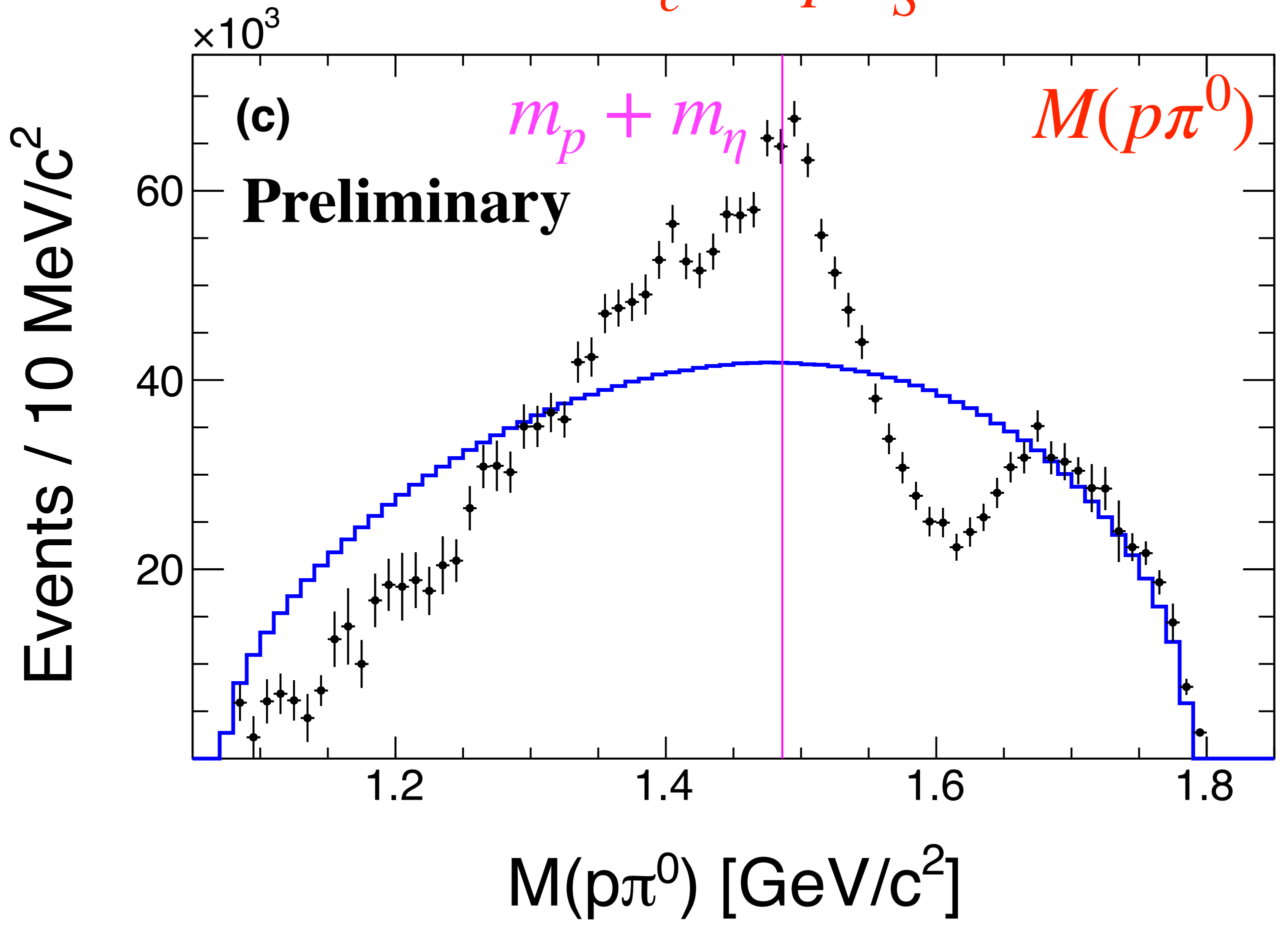
➡ At $1.5\ \mathrm{GeV}/c^2$, a clear structure is seen in $M(p\pi^0)$ (continued in next page)

Possible $N(1535)^+$ enhanced by $p\eta$ threshold

$N(1535)^+$

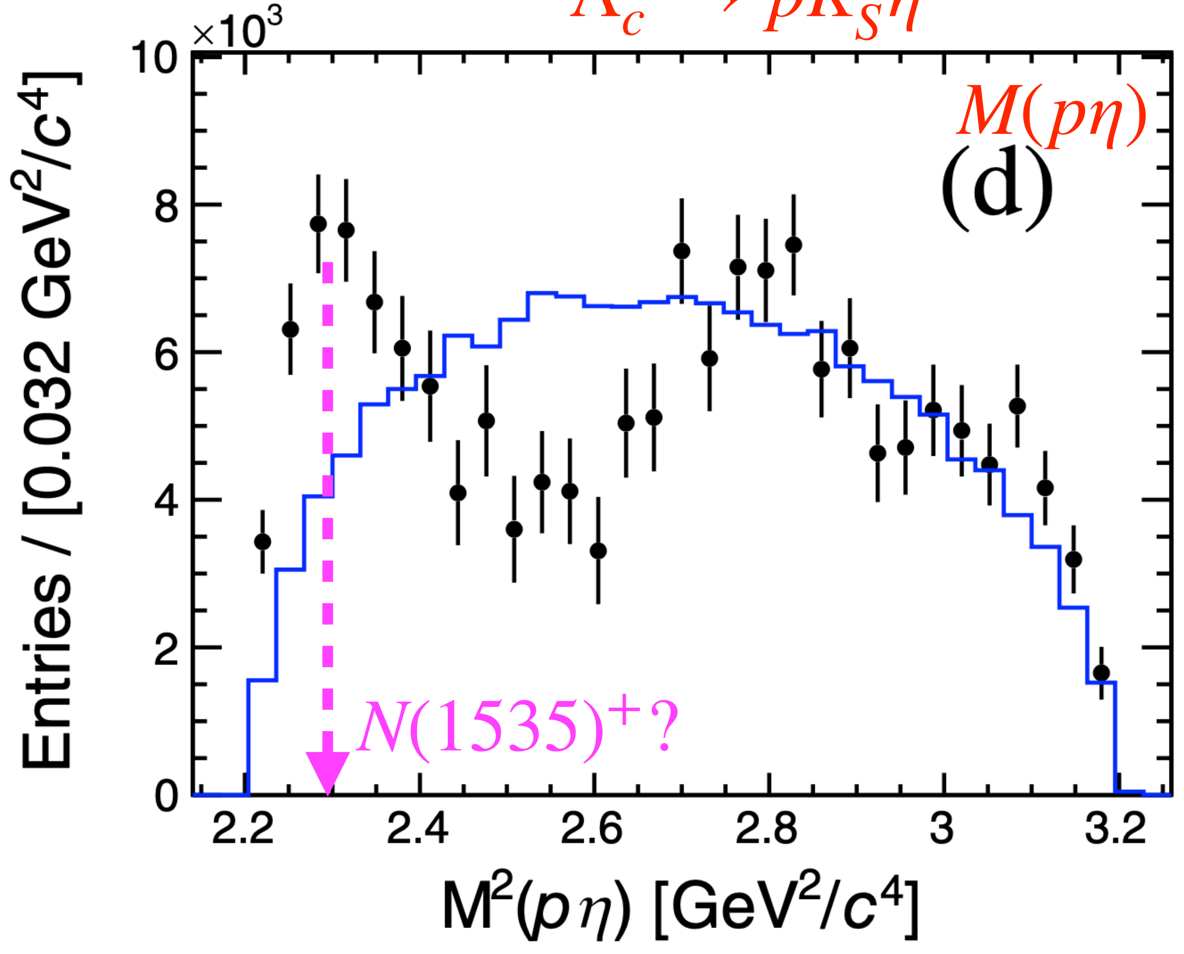
Preliminary Belle 980/fb

$\Lambda_c^+ \to pK_S^0\pi^0$



Belle 980/fb,
PRD **103**, 032004 (2023)

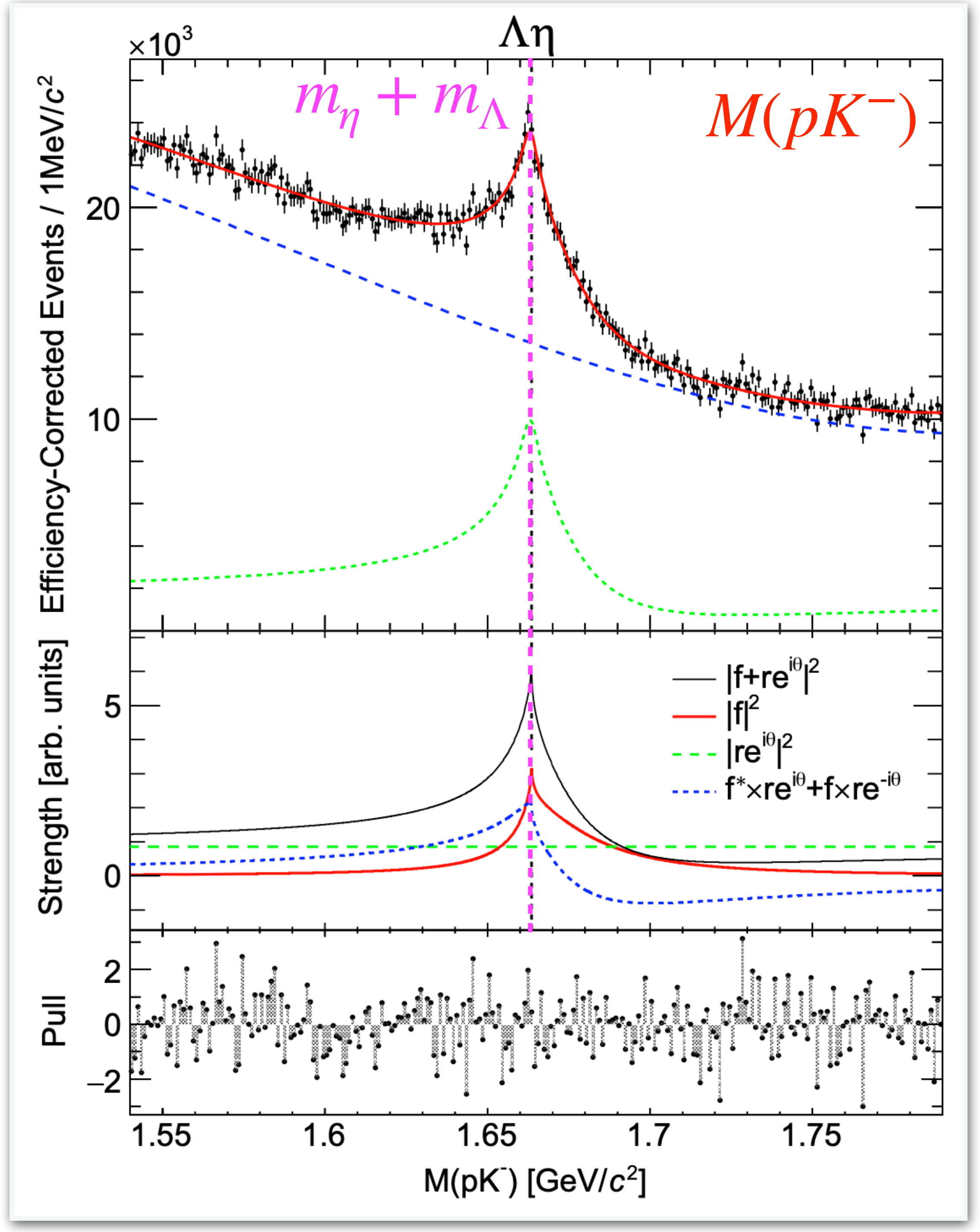
$\Lambda_c^+ \to pK_S^0\eta$



$\Lambda(1670)$

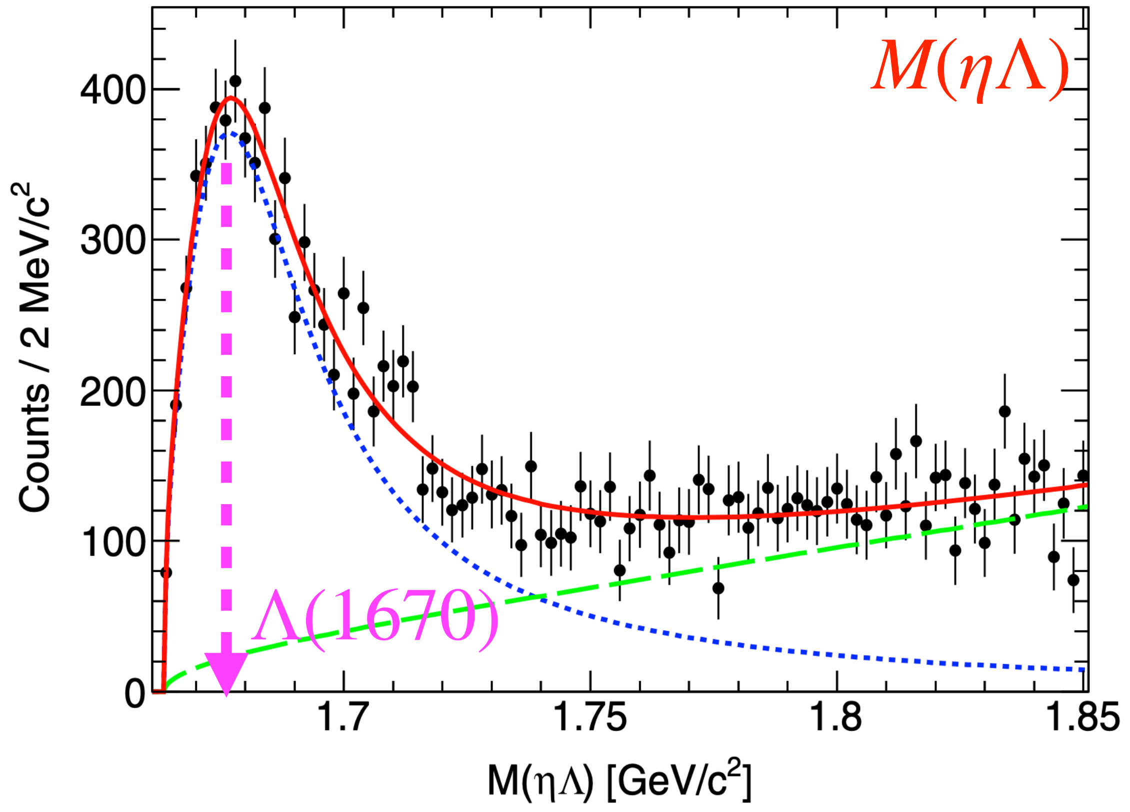
Belle 980/fb,
PRD **108**, L031104 (2023)

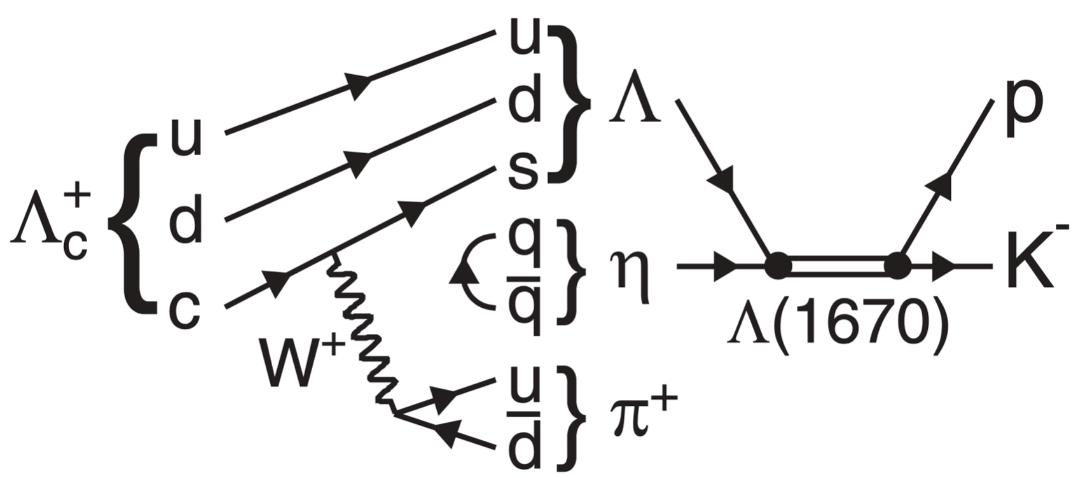
$\Lambda_c^+ \to pK^-\pi^+$



Belle 980/fb,
PRD **103**, 052005 (2021)

$\Lambda_c^+ \to \eta\Lambda\pi^+$





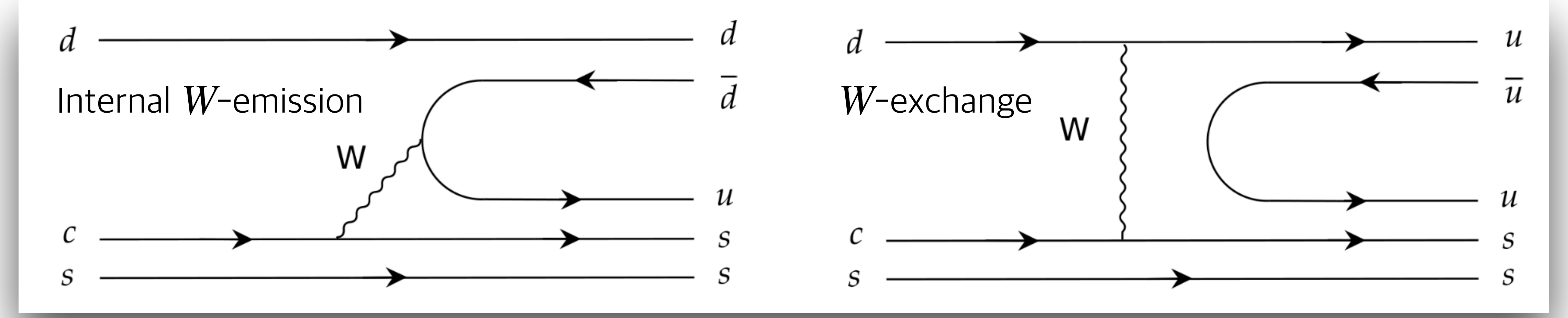
- Enhancement near $p\eta$ mass threshold in $M(p\pi^0)$
  - ➡ Narrower than known width of $N(1535)^+$ (~$100\ \mathrm{MeV}/c^2$)
  - ➡ Possibility of $p\eta$ threshold cusp enhanced by $N(1535)^+$
- Scenario analogous to $\eta\Lambda$ threshold cusp enhanced by $\Lambda(1670)$
  - ➡ $\Lambda(1670) \to \eta\Lambda$ observed in $M(\eta\Lambda)$
  - ➡ $\eta\Lambda$ threshold cusp in $M(pK^-)$ is well explained by Flatté model

$\Xi_c^0 \to \Xi^0 h^0, (h^0 = \pi^0, \eta, \eta')$

Preliminary Belle + Belle II 1.4/ab

arXiv:2406.04642

- Several theoretical approaches(*) predicting BFs and asymmetry parameter α to deal with **non-factorizable processes** (*) backup slide p16
  - ➡ Only non-factorizable amplitudes contribute to $\Xi_c^0 \to \Xi^0 h^0$

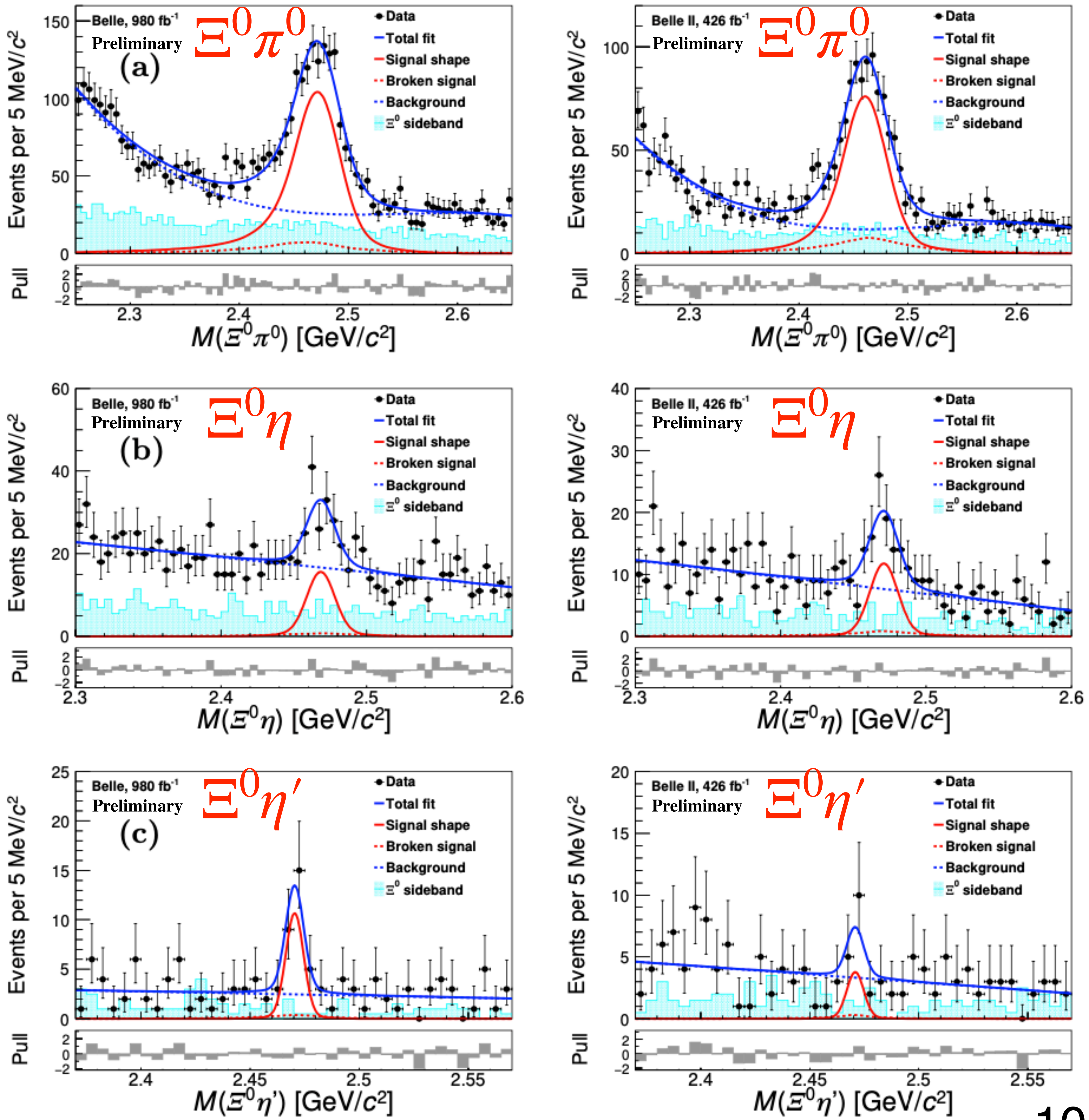


- First Belle + Belle II combined charm measurement
- First measurements of branching fractions
  - ➡ $B(\Xi_c^0 \to \Xi^0\pi^0) = (6.9 \pm 0.3(\text{stat.}) \pm 0.5(\text{syst.}) \pm 1.3(\text{norm.})) \times 10^{-3}$
  - ➡ $B(\Xi_c^0 \to \Xi^0\eta) = (1.6 \pm 0.2(\text{stat.}) \pm 0.2(\text{syst.}) \pm 0.3(\text{norm.})) \times 10^{-3}$
  - ➡ $B(\Xi_c^0 \to \Xi^0\eta') = (1.2 \pm 0.3(\text{stat.}) \pm 0.1(\text{syst.}) \pm 0.2(\text{norm.})) \times 10^{-3}$
- Rules out several theoretical models
  - ➡ The results prefer a $SU(3)_F$ - breaking model(*)

Model	$\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0)$	$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta)$	$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta')$
SU(3)$_F$-breaking	$7.74^{+2.52}_{-2.32}$	$2.43^{+2.79}_{-2.90}$	$1.63^{+5.09}_{-5.14}$

(*) backup slide p16

Belle **Belle II**



Branching fraction of Λ_c^+ decays

- First or most precise BF measurements with uncertainties in $(\pm\text{stat.} \pm \text{syst.} \pm \text{norm.})$

➡ CF decays

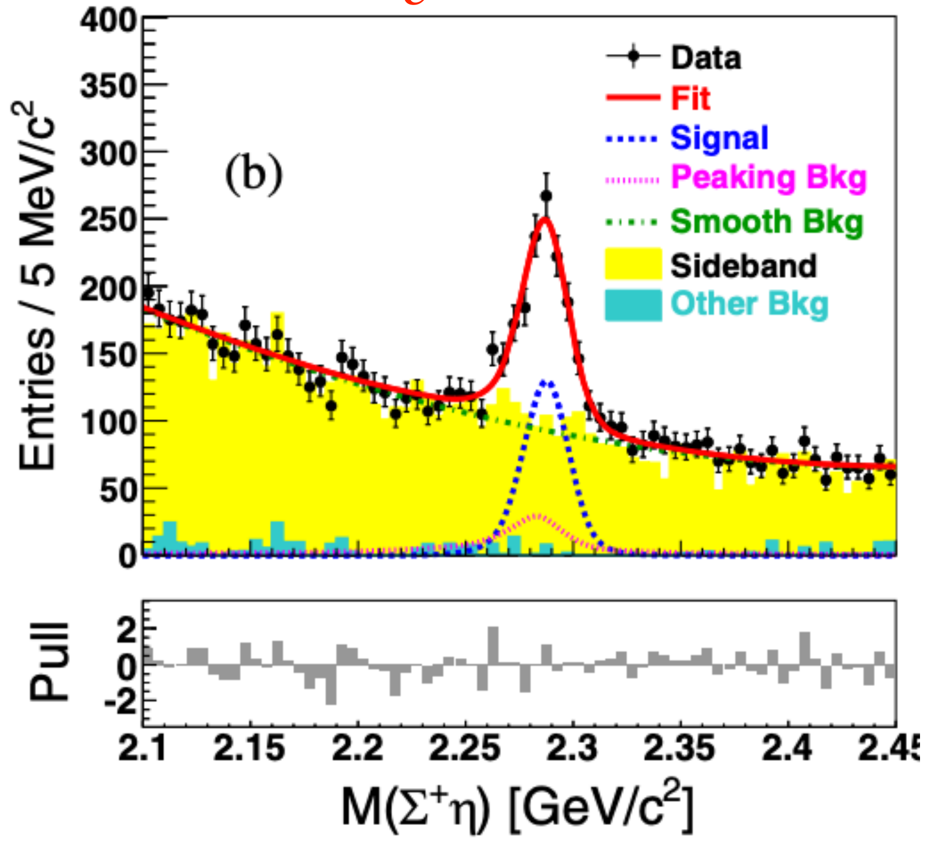
- $B(\Lambda_c^+ \to \Sigma^+\eta) = (3.14 \pm 0.35 \pm 0.17 \pm 0.25) \times 10^{-3}$
- $B(\Lambda_c^+ \to \Sigma^+\eta') = (4.16 \pm 0.75 \pm 0.17 \pm 0.25) \times 10^{-3}$
- $B(\Lambda_c^+ \to pK_S^0\eta) = (4.35 \pm 0.10 \pm 0.20 \pm 0.22) \times 10^{-3}$
- $B(\Lambda_c^+ \to pK_S^0\pi^0) = (2.11 \pm 0.01 \pm 0.05 \pm 0.10) \times 10^{-2}$ **(new)**

➡ SCS decays

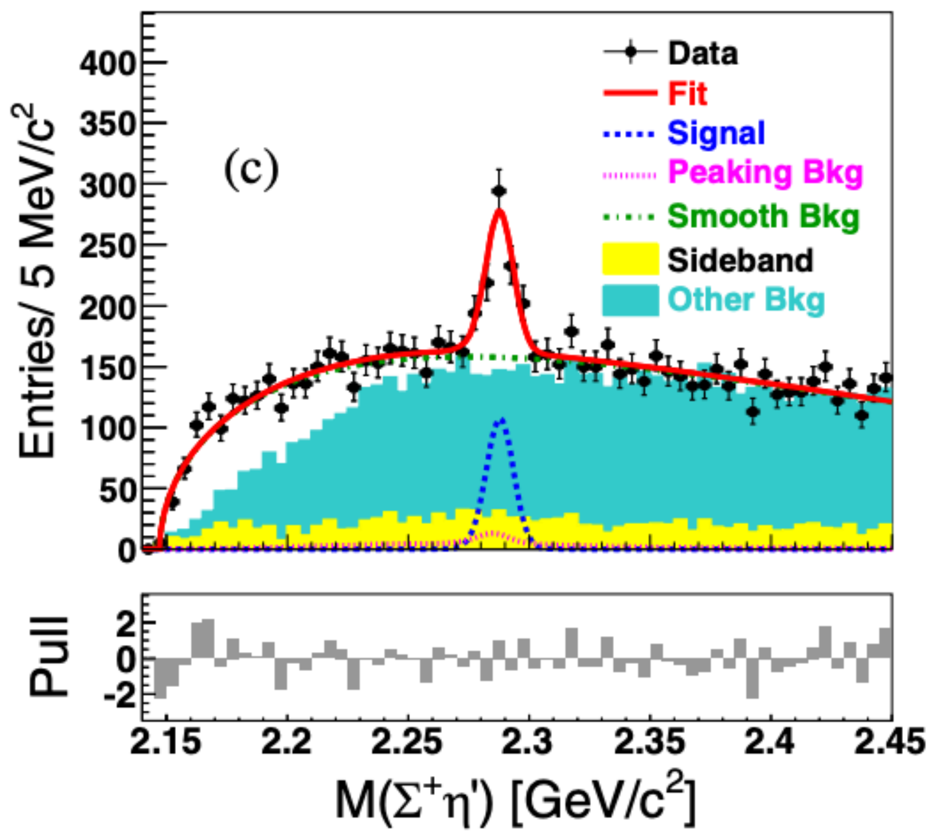
- $B(\Lambda_c^+ \to pK_S^0K_S^0) = (2.35 \pm 0.12 \pm 0.07 \pm 0.04) \times 10^{-4}$
- $B(\Lambda_c^+ \to \Lambda K^+) = (6.57 \pm 0.17 \pm 0.11 \pm 0.35) \times 10^{-4}$
- $B(\Lambda_c^+ \to \Sigma^0 K^+) = (3.58 \pm 0.19 \pm 0.06 \pm 0.19) \times 10^{-4}$

Belle 980/fb, PRD **107**, 032003 (2023)

$\Lambda_c^+ \to \Sigma^+\eta$

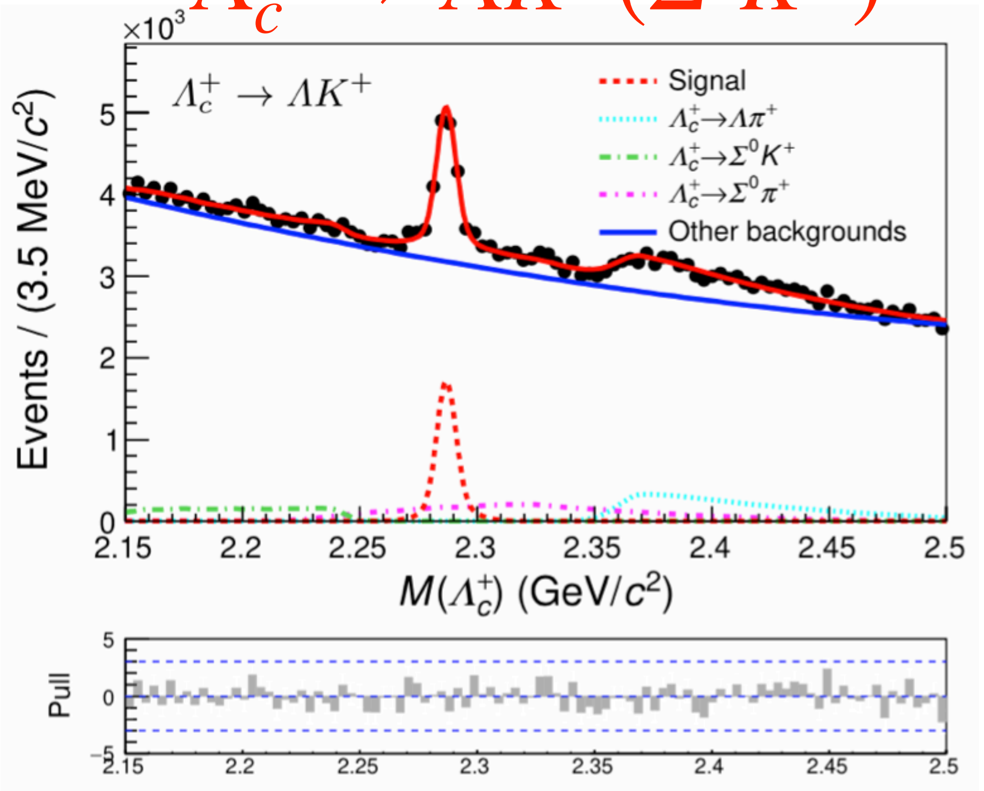


$\Lambda_c^+ \to \Sigma^+\eta'$



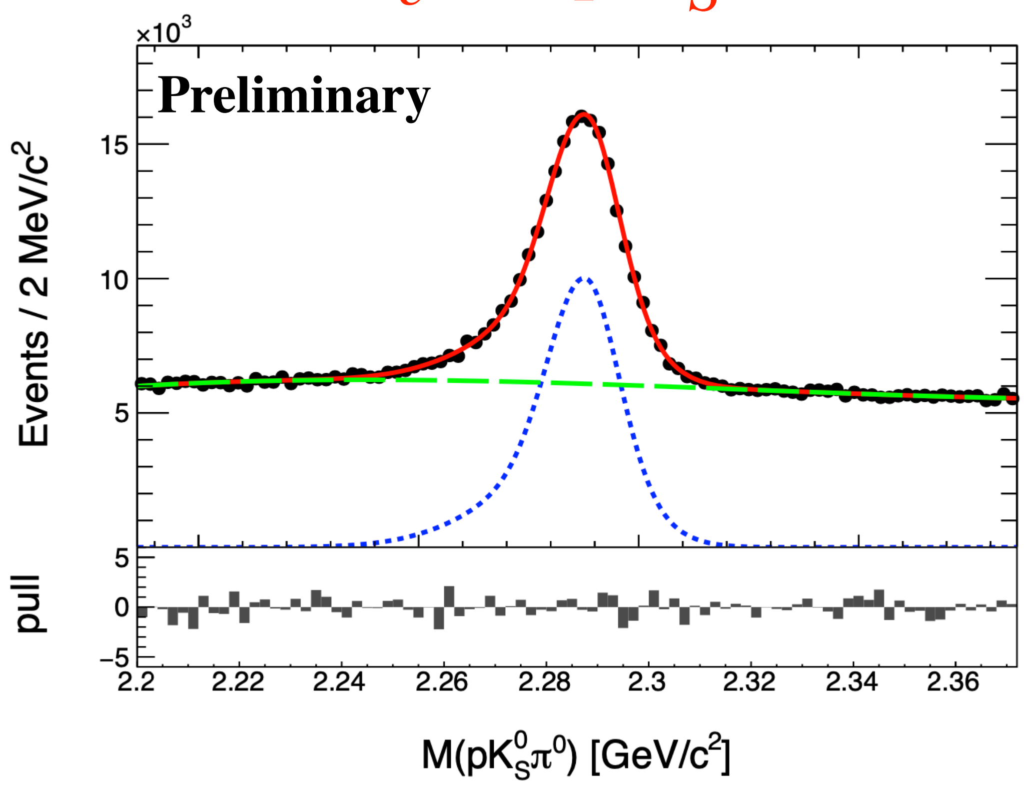
Belle 980/fb, Science Bulletin **68**, 583 (2023)

$\Lambda_c^+ \to \Lambda K^+(\Sigma^0 K^+)$



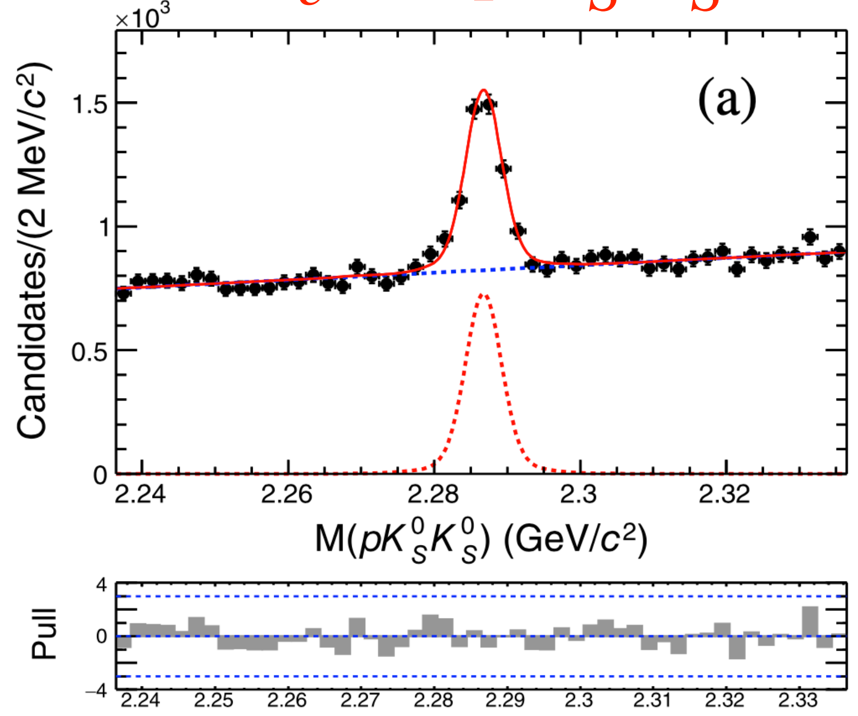
Preliminary Belle 980/fb

$\Lambda_c^+ \to pK_S^0\pi^0$

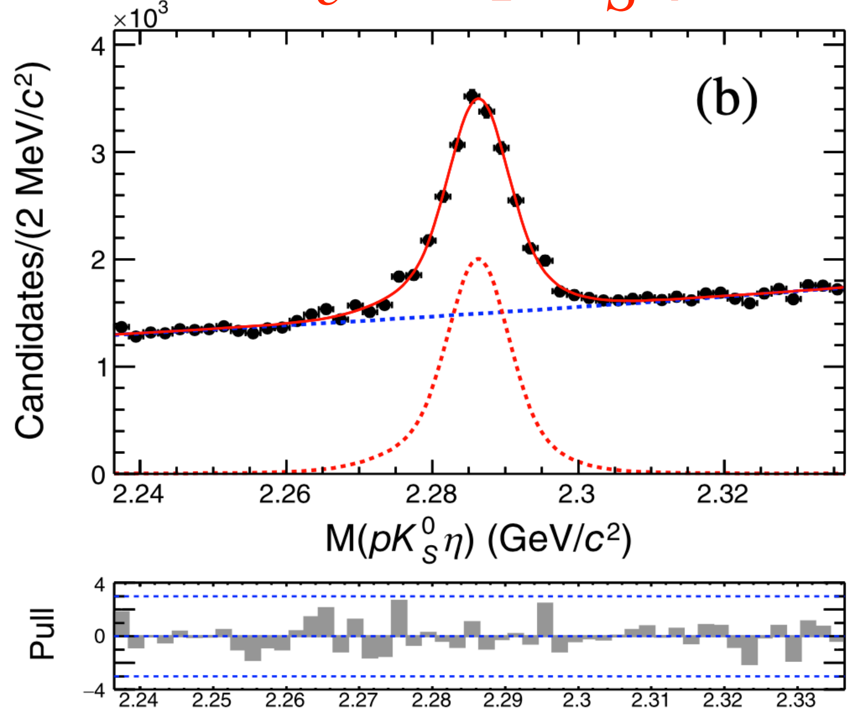


Belle 980/fb, PRD **103**, 032004 (2023)

$\Lambda_c^+ \to pK_S^0K_S^0$



$\Lambda_c^+ \to pK_S^0\eta$



Summary

- **Belle is still producing important measurements although its data-taking finished nearly 15 years ago**
  - A large amount of data samples allows significant improvement in our understanding of SM and baryon decays.
    - Rare FCNC $c \to ul^+l^-$
      - $D^0 \to h^-h^{(\prime)+}e^+e^-(h = K, \pi)$
      - $\Xi_c^0 \to \Xi^0 l^+l^-$
    - Baryon number violating $D^0 \to pl$
    - Branching fraction measurements
      - $\Lambda_c^+ \to pK_S^0\pi^0$ (and Intermediate structures)
      - $\Lambda_c^+ \to pK_S^0\eta$, $\Lambda_c^+ \to pK_S^0K_S^0$
      - $\Lambda_c^+ \to \Sigma^+\eta^{(\prime)}$
      - $\Lambda_c^+ \to \Lambda K^+, \Lambda_c^+ \to \Sigma^0K^+$
- First Belle + Belle II combined data analysis in charm physics
  - $\Xi_c^0 \to \Xi^0 h^0(h^0 = \pi^0, \eta, \eta')$: Branching fraction
    - Rules out several theoretical approaches. Preferring one of theoretical models based on $SU(3)_F$-breaking

Backup

Results for $m(e^+e^-)$ regions ($D^0 \to hh^{(\prime)}l^+l^-$)

TABLE I. $D^0 \to h^- h^{(\prime)+} e^+ e^-$ modes yields, significance, branching fractions, branching fraction upper limits, and the efficiencies of each m_{ee} region [$\times 10^{-7}$]. A fitted yield and a branching fraction are not reported for $K^-K^+e^+e^-$ mode with m_{ee} in the m_η region since only one event is observed, and the significance is determined from the CL_s distribution.

m_{ee} region	[MeV/c^2]	Yield	Significance	$\mathcal{B}$	UL @ 90% CL	Efficiency
$K^-K^+e^+e^-$						
η	520-560	-	$< 0.1\sigma$	-	< 2.3	3.53 ± 0.04
ρ^0/ω	> 675	2.6 ± 1.8	2.0σ	$1.2 \pm 0.9 \pm 0.1$	< 3.0	6.00 ± 0.06
non-resonant	> 200 [a]	3.5 ± 3.3	1.5σ	$3.1 \pm 3.0 \pm 0.4$	< 7.7	3.19 ± 0.04
$\pi^-\pi^+e^+e^-$						
η	520-560	0.6 ± 2.3	0.3σ	$0.4 \pm 1.4 \pm 0.2$	< 3.2	5.31 ± 0.05
ρ^0/ω	675-875	3.7 ± 4.1	0.9σ	$2.0 \pm 2.2 \pm 0.8$	< 6.1	5.69 ± 0.05
ϕ	995-1035	3.6 ± 3.2	1.1σ	$1.1 \pm 1.1 \pm 0.2$	< 3.1	9.41 ± 0.06
non-resonant	> 200	-0.2 ± 4.1	$< 0.1\sigma$	$-0.2 \pm 3.4 \pm 0.9$	< 7.2	3.69 ± 0.04
$K^-\pi^+e^+e^-$						
η	520-560	4.0 ± 2.7	1.6σ	$2.2 \pm 1.5 \pm 0.5$	< 5.6	5.09 ± 0.04
ρ^0/ω	675-875	110 ± 13	11.8σ	$39.6 \pm 4.5 \pm 2.9$	-	8.01 ± 0.06
ϕ	990-1034	4.6 ± 2.4	2.5σ	$1.4 \pm 0.8 \pm 0.3$	< 2.9	9.19 ± 0.06
non-resonant	> 560	2.2 ± 4.2	0.4σ	$1.3 \pm 2.4 \pm 0.6$	< 6.5	4.89 ± 0.09

[a] Excluding resonance regions, which is same for all three modes.

(90% CL)

Mode	BABAR	BESIII
$K^-K^+e^+e^-$		< 110
$\pi^-\pi^+e^+e^-$		< 70
$K^-\pi^+e^+e^-$	< 31* (non-resonant)	< 70

*non-resonant region excluding [100,200], [491,560], [675, 875], [902,964], [1005,1035] MeV/c²

Results of $D^0 \to pl$

TABLE I. Reconstruction efficiency (ϵ), signal yield (N_S), signal significance ($\mathcal{S}$), upper limit on the signal yield ($N_{p\ell}^{UL}$), and branching fraction ($\mathcal{B}$) at 90% confidence level for each decay mode.

Decay mode	ϵ (%)	N_S	$\mathcal{S}$ (σ)	N_{pl}^{UL}	$\mathcal{B} \times 10^{-7}$
$D^0 \to pe^-$	10.2	-6.4 ± 8.5		17.5	< 5.5
$\bar{D}^0 \to pe^-$	10.2	-18.4 ± 23.0		22.0	< 6.9
$D^0 \to \bar{p}e^+$	09.7	-4.7 ± 23.0		22.0	< 7.2
$\bar{D}^0 \to \bar{p}e^+$	09.6	7.1 ± 9.0	0.6	23.0	< 7.6
$D^0 \to p\mu^-$	10.7	11.0 ± 23.0	0.9	17.1	< 5.1
$\bar{D}^0 \to p\mu^-$	10.7	-10.8 ± 27.0		21.8	< 6.5
$D^0 \to \bar{p}\mu^+$	10.5	-4.5 ± 14.0		21.1	< 6.3
$\bar{D}^0 \to \bar{p}\mu^+$	10.4	16.7 ± 8.8	1.6	21.4	< 6.5

$\Xi_c^0 \to \Xi^0 h^0$ theoretical predictions

Table 1. Theoretical predictions for the branching fractions and decay asymmetry parameters for $\Xi_c^0 \to \Xi^0 h^0$ decays. Branching fractions are given in units of 10^{-3}.

Reference	Model	$\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0)$	$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta)$	$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta')$	$\alpha(\Xi_c^0 \to \Xi^0\pi^0)$
Körner, Krämer [5]	Quark	0.5	3.2	11.6	0.92
Ivanov *et al.* [6]	Quark	0.5	3.7	4.1	0.94
Xu, Kamal [7]	Pole	7.7	-	-	0.92
Cheng, Tseng [8]	Pole	3.8	-	-	-0.78
Żenczykowski [9]	Pole	6.9	1.0	9.0	0.21
Zou *et al.* [10]	Pole	18.2	26.7	-	-0.77
Sharma, Verma [11]	CA	-	-	-	-0.8
Cheng, Tseng [8]	CA	17.1	-	-	0.54
Geng *et al.* [12]	$SU(3)_F$	4.3 ± 0.9	$1.7^{+1.0}_{-1.7}$	$8.6^{+11.0}_{-6.3}$	-
Geng *et al.* [13]	$SU(3)_F$	7.6 ± 1.0	10.3 ± 2.0	9.1 ± 4.1	$-1.00^{+0.07}_{-0.00}$
Zhao *et al.* [14]	$SU(3)_F$	4.7 ± 0.9	8.3 ± 2.3	7.2 ± 1.9	-
Huang *et al.* [15]	$SU(3)_F$	2.56 ± 0.93	-	-	-0.23 ± 0.60
Hsiao *et al.* [16]	$SU(3)_F$	6.0 ± 1.2	$4.2^{+1.6}_{-1.3}$	-	-
Hsiao *et al.* [16]	$SU(3)_F$-breaking	3.6 ± 1.2	7.3 ± 3.2	-	-
Zhong *et al.* [17]	$SU(3)_F$	$1.13^{+0.59}_{-0.49}$	1.56 ± 1.92	$0.683^{+3.272}_{-3.268}$	$0.50^{+0.37}_{-0.35}$
Best fit → Zhong *et al.* [17]	$SU(3)_F$-breaking	$7.74^{+2.52}_{-2.32}$	$2.43^{+2.79}_{-2.90}$	$1.63^{+5.09}_{-5.14}$	$-0.29^{+0.20}_{-0.17}$
Xing *et al.* [18]	$SU(3)_F$	1.30 ± 0.51	-	-	-0.28 ± 0.18
Geng *et al.* [19]	$SU(3)_F$	7.10 ± 0.41	2.94 ± 0.97	5.66 ± 0.93	-0.49 ± 0.09
Zhong *et al.* [20]	Diagrammatic-$SU(3)_F$	7.45 ± 0.64	2.87 ± 0.66	5.31 ± 1.33	-0.51 ± 0.08
Zhong *et al.* [20]	Irreducible-$SU(3)_F$	7.72 ± 0.65	2.28 ± 0.53	5.66 ± 1.62	-0.51 ± 0.09

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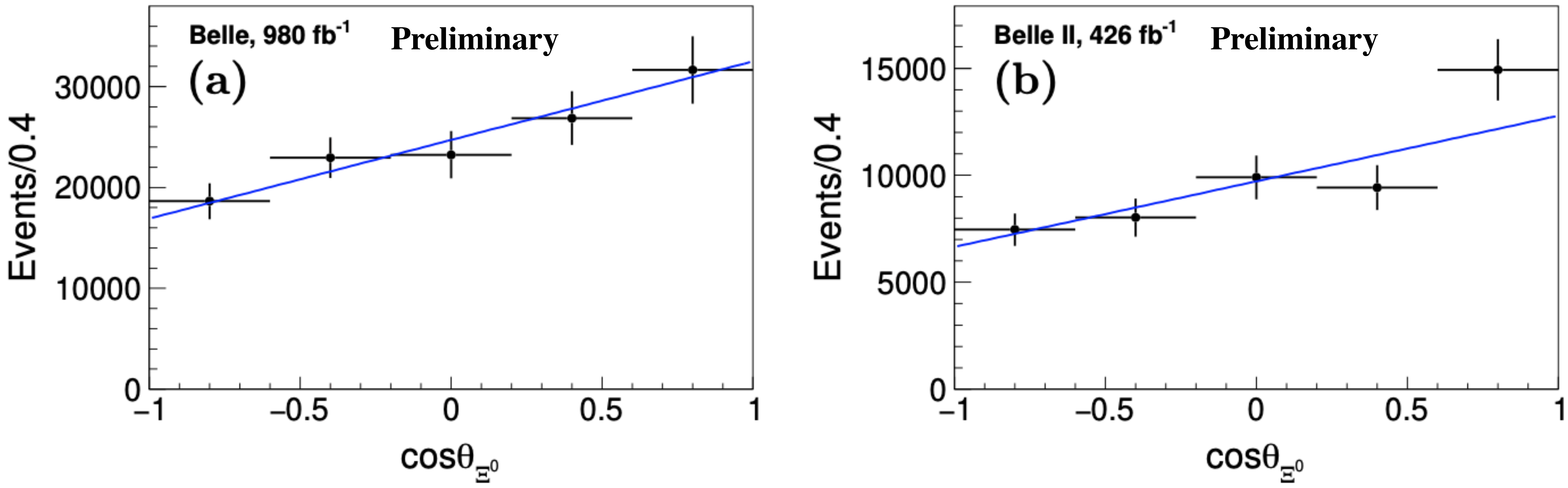
$\Xi_c^+ \to \Xi^0\pi^0$ asymmetry parameter



- $\Xi_c^+ \to \Xi^0\pi^0$ asymmetry parameter:

➡ $\alpha(\Xi_c^+ \to \Xi^0\pi^0) = -0.90 \pm 0.15(\text{stat.}) \pm 0.23(\text{syst.})$

➡ $\frac{dN}{d\cos\theta_{\Xi^0}} \propto 1+\alpha(\Xi_c^0 \to \Xi^0\pi^0)\alpha(\Xi^0 \to \Lambda\pi^0)\cos\theta_{\Xi^0}$

$\Lambda_c^+ \to \Lambda K^+$ and $\Lambda_c^+ \to \Sigma K^+$

Belle 980/fb, Science Bulletin **68** (2023) 583

- Direct CPV via raw asymmetry measurements in SCS decays:

$$A_{raw}(\Lambda_c^+ \to \Lambda K^+) = \frac{N(\Lambda_c^+ \to \Lambda K^+) - N(\bar{\Lambda}_c^- \to \bar{\Lambda} K^-)}{N(\Lambda_c^+ \to \Lambda K^+) + N(\bar{\Lambda}_c^- \to \bar{\Lambda} K^-)}$$

➡ The raw asymmetry of $\Lambda_c^+ \to \Lambda K^+$ includes several asymmetry sources:

$$A_{raw}(\Lambda_c^+ \to \Lambda K^+) = A_{CP}^{dir}(\Lambda_c^+ \to \Lambda K^+) + A_{CP}^{dir}(\Lambda \to p\pi^-) + A_\epsilon^\Lambda + A_\epsilon^{K^+} + A_{FB}^{\Lambda_c^+}$$

Detection efficiency correction between K^+, K^-

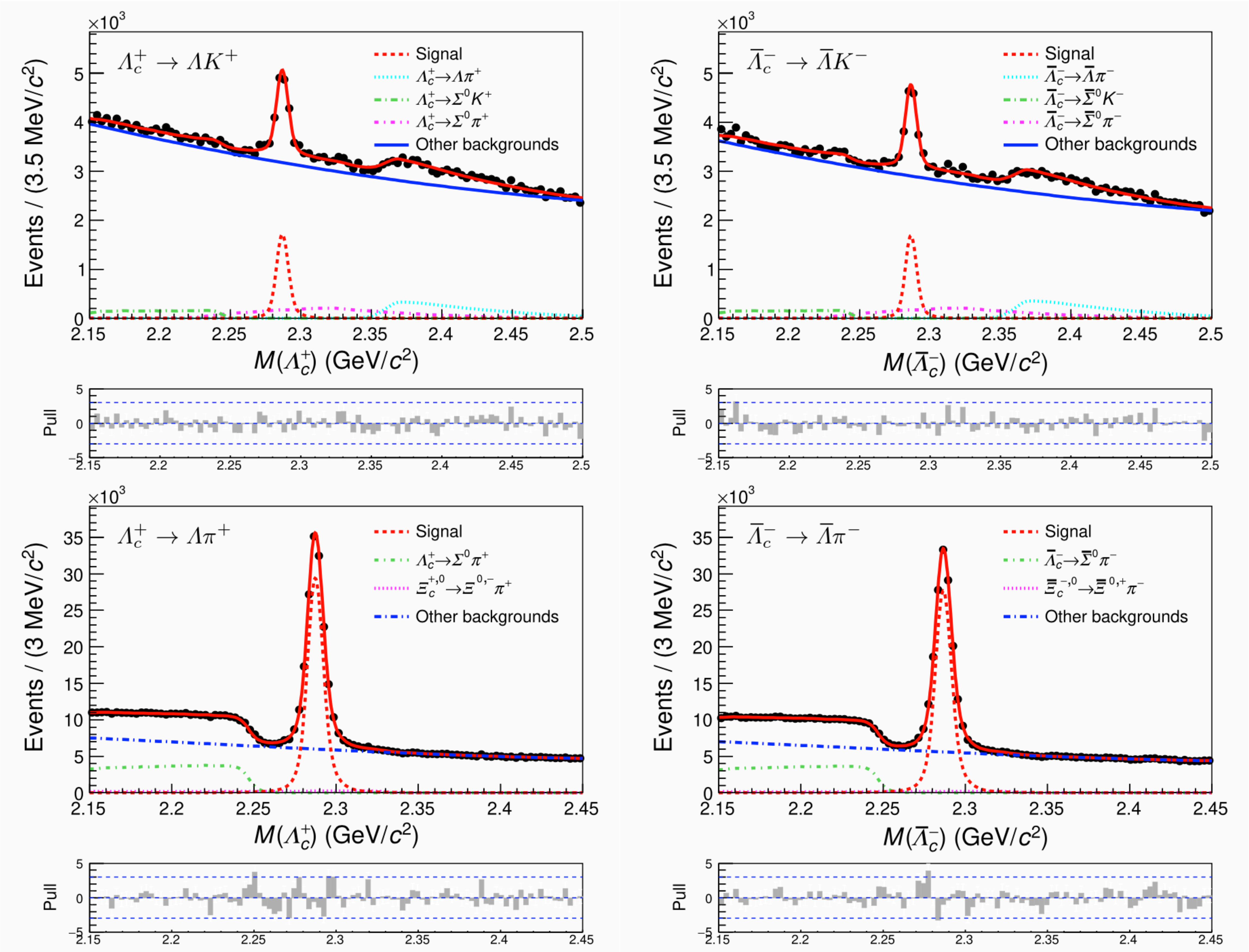
➡ Using CF mode $\Lambda_c^+ \to \Lambda\pi^+$ as a reference mode, common asymmetry sources are canceled out.

A_{raw}^{corr}

➡ $\Delta A_{raw} = A_{raw}^{corr}(\Lambda_c^+ \to \Lambda K^+) - A_{raw}^{corr}(\Lambda_c^+ \to \Lambda\pi^+)$

$= A_{raw}^{dir}(\Lambda_c^+ \to \Lambda K^+) - A_{raw}^{dir}(\Lambda_c^+ \to \Lambda\pi^+) = A_{raw}^{dir}(\Lambda_c^+ \to \Lambda K^+)$

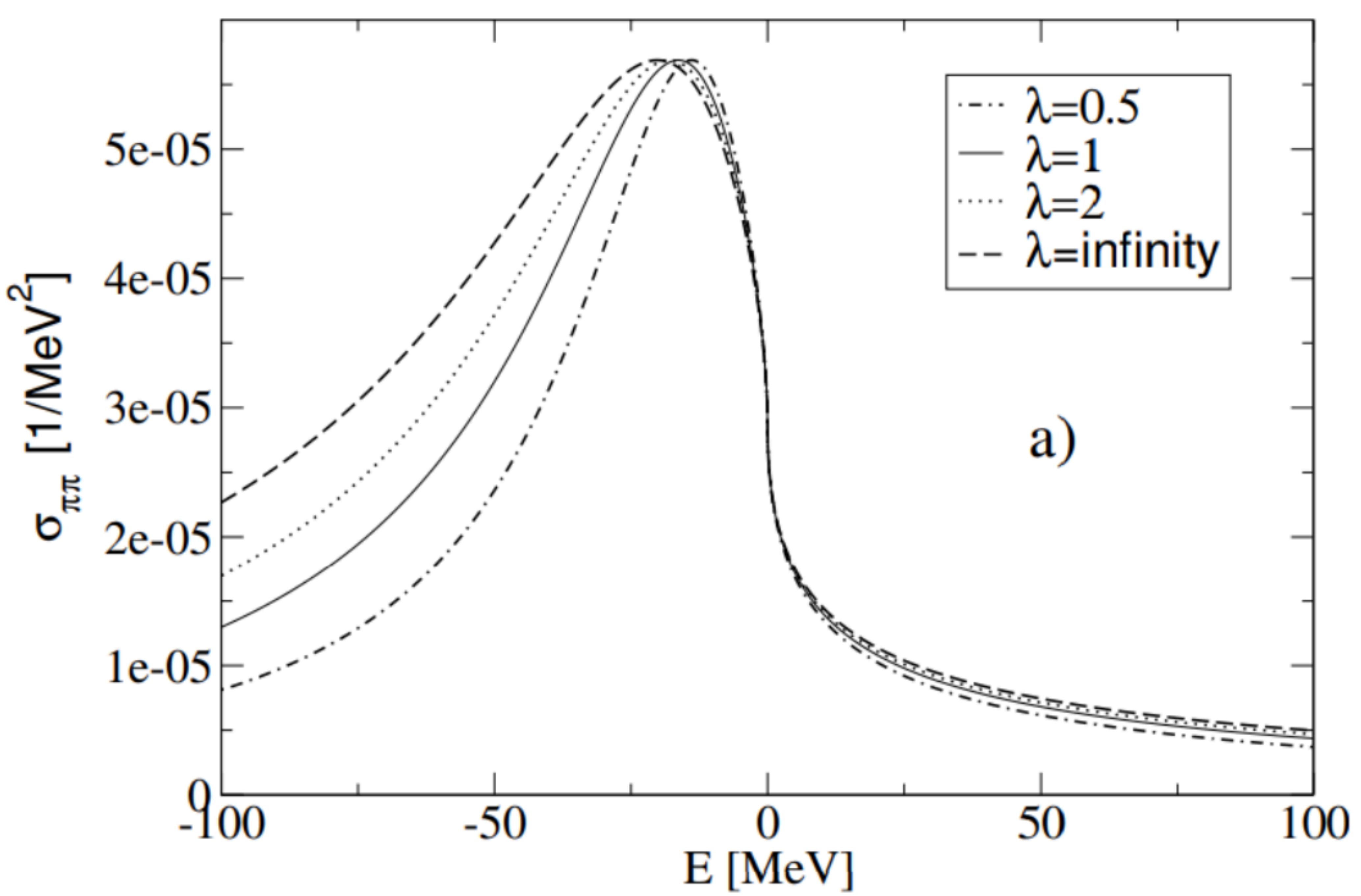
➡ Similarly, $\Lambda_c^+ \to \Sigma^0\pi^+$ mode was used as a reference mode for $\Lambda_c^+ \to \Sigma^0 K^+$.

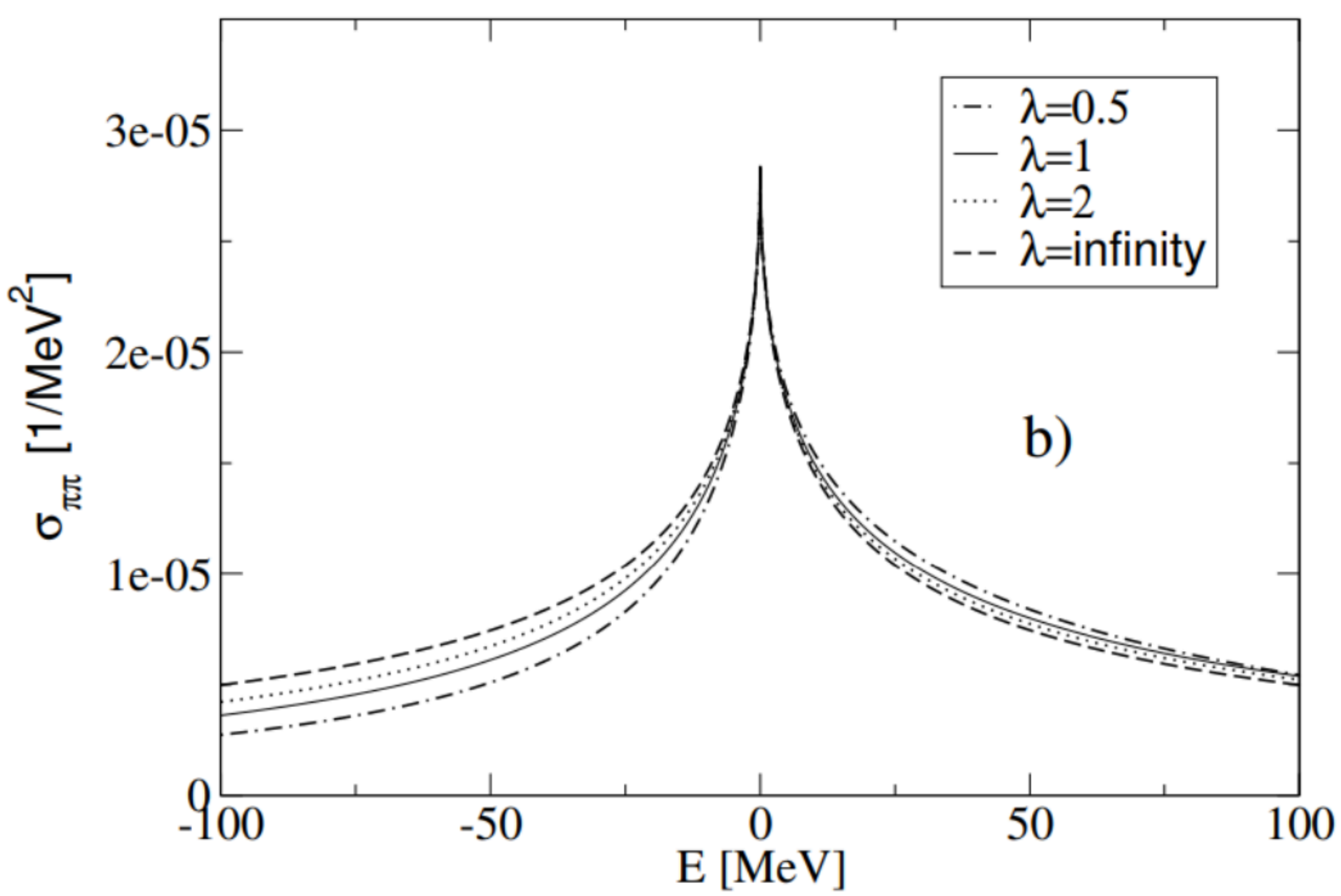


- First A_{CP}^{dir} for SCS two-body decays of charmed baryons.
  - $A_{CP}^{dir}(\Lambda_c^+ \to \Lambda K^+) = (2.1 \pm 2.6 \pm 0.1) \times 10^{-2}$
  - $A_{CP}^{dir}(\Lambda_c^+ \to \Sigma^0 K^+) = (2.5 \pm 5.4 \pm 0.4) \times 10^{-2}$
- No significant direct CP violation was observed.

- Branching fractions were measured as well
- $B(\Lambda_c^+ \to \Lambda K^+) = (6.57 \pm 0.17 \pm 0.11 \pm 0.35) \times 10^{-4}$
- $B(\Lambda_c^+ \to \Sigma^0 K^+) = (3.58 \pm 0.19 \pm 0.06 \pm 0.19) \times 10^{-4}$

Flatté model





$$f_{\rm el} = -\frac{1}{2q}\frac{\Gamma_P}{E - E_{\rm BW} + i\frac{\Gamma_P}{2} + i\bar{g}_K\frac{k}{2}}$$

where, $k = \sqrt{m_K(\sqrt{s} - 2m_k)}$ *k is imaginary when $m < 2m_K$