Hadronic decays of charm mesons and baryons at BESIII

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On behalf of BESIII Collaboration

Outline

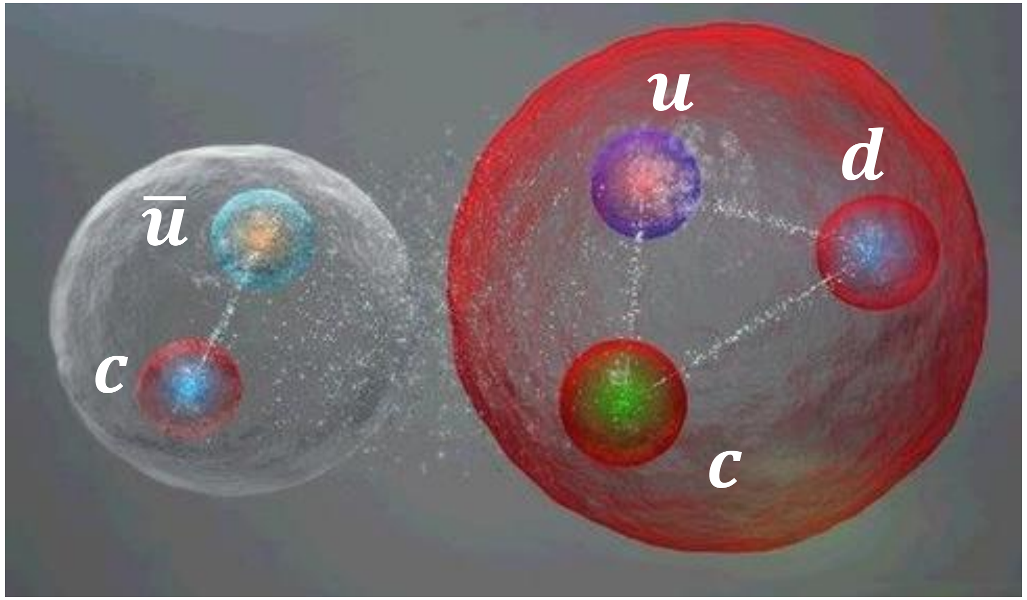
CKM

Precise BF

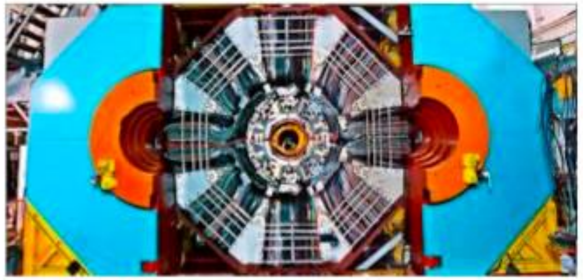
Rare decay

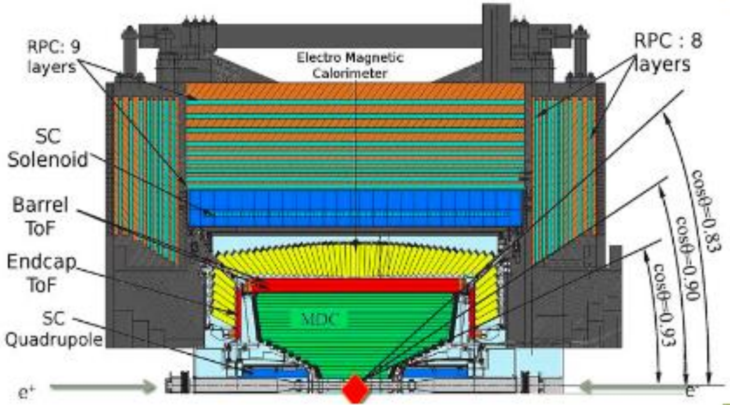
New resonances

- Charm mesons at BESIII
- Charm baryons at BESIII

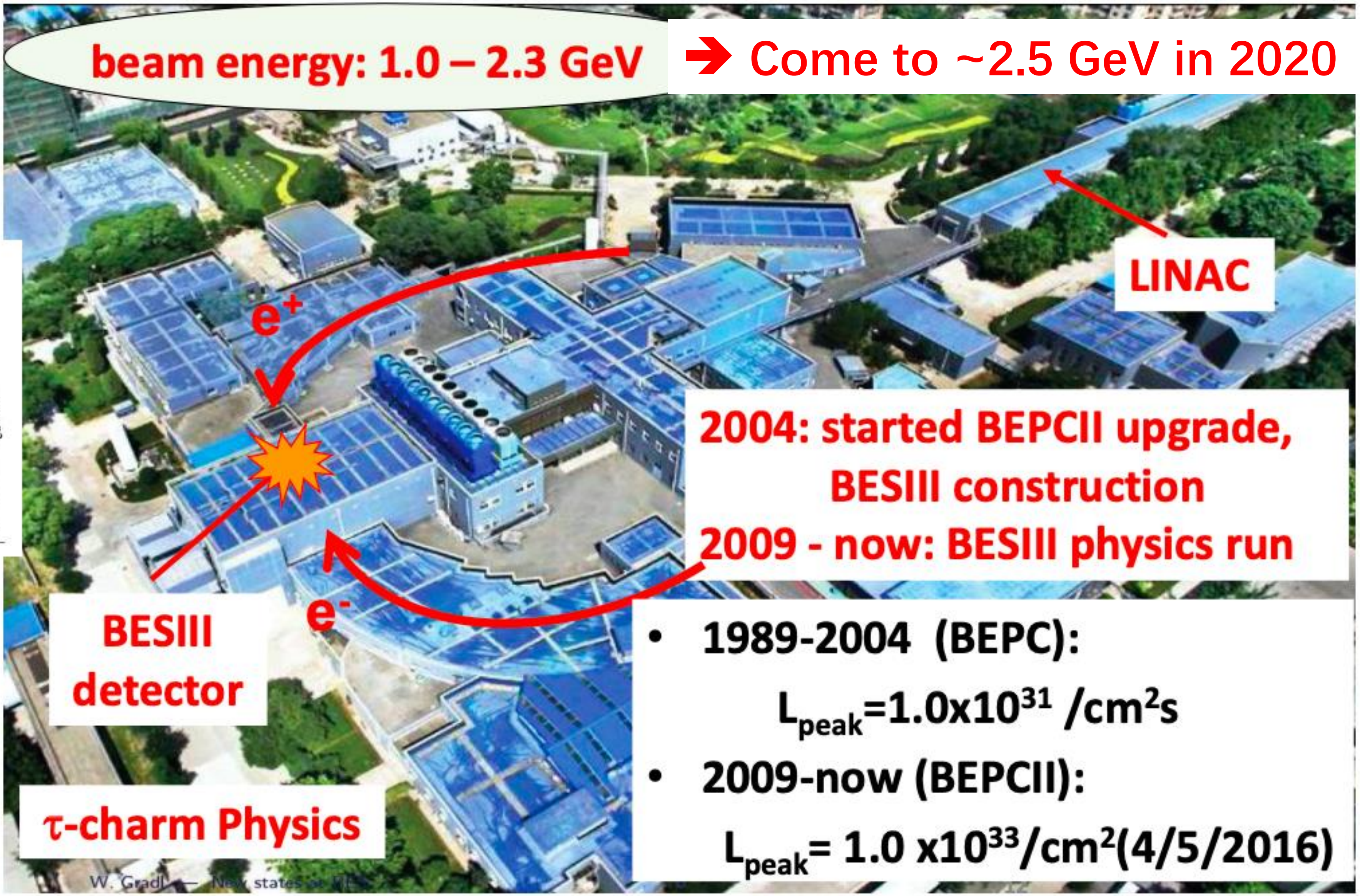


BEPCII and BESIII



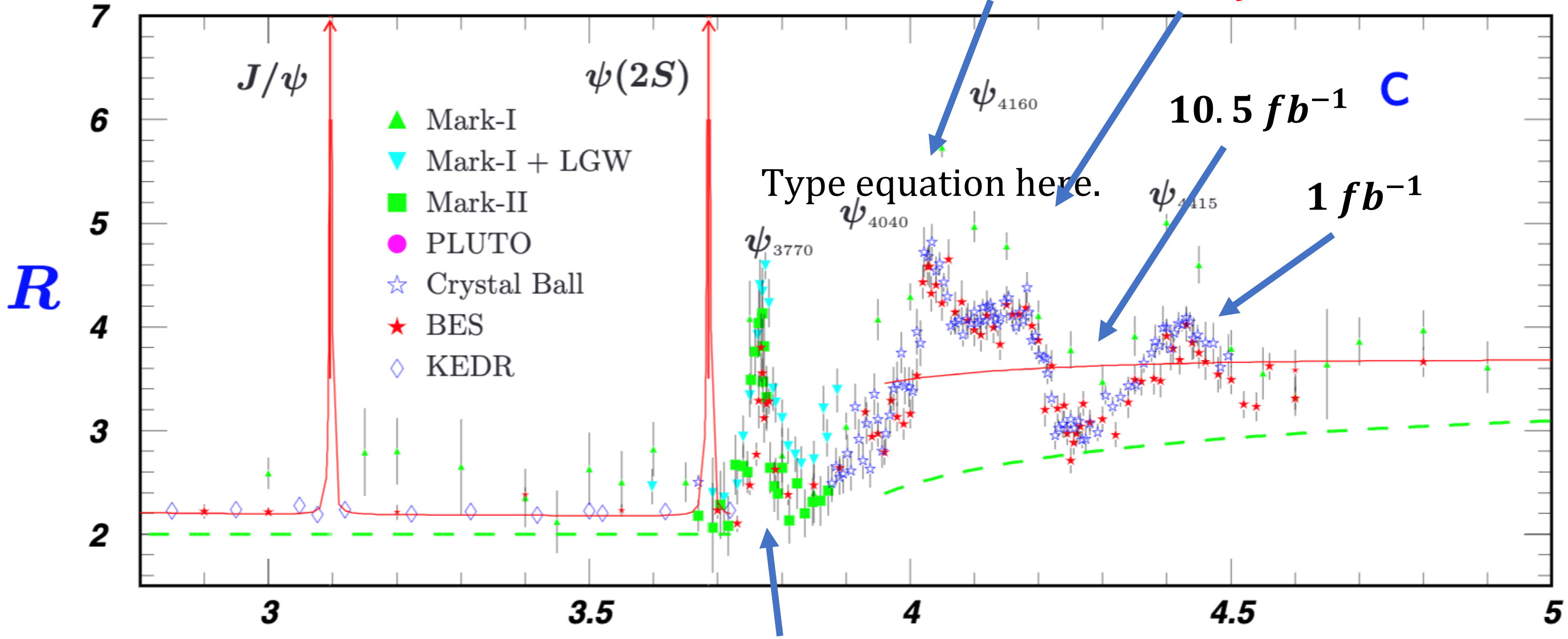


MDC: spatial reso. 115μm
dE/dx reso: 5%
EMC: energy reso.: 2.4%
BTOF: time reso.: 70 ps
ETOF: time reso.: 60 ps



Data sets for D and Λ_c productions

1×10^{10} events 3×10^{9} events $0.5\ fb^{-1}$ $3.2\ fb^{-1}$

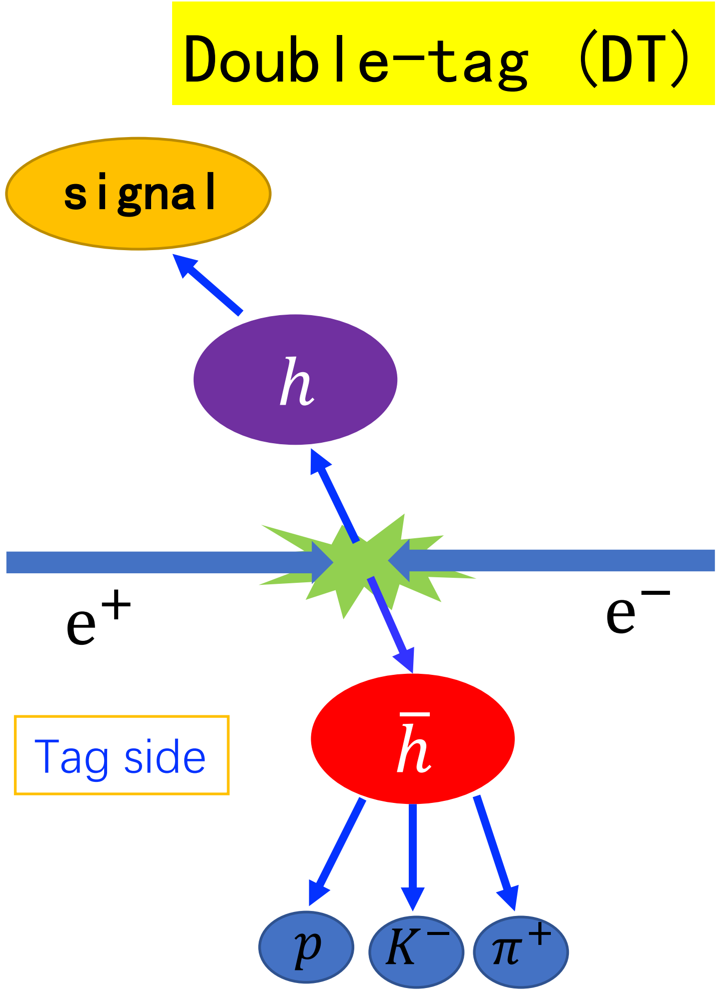


130 points, 2.0$< \sqrt{s} < 4.6$ GeV
1×10^{5} had. events each

$2.9\ fb^{-1}$

$5.6\ fb^{-1}$ at 10 points
$4.6 < \sqrt{s} < 5.0$ GeV

Advantage at BESIII



- Threshold characteristic:

  Symmetric pair production: $\Delta E = E_{rec} - E_{beam}$

  Beam-constrained mass: $m_{BC} = \sqrt{E_{beam}^2 - \vec{p}_{rec}^{\,2}}$

- Advantage of DT:

  Probe correlation of the pair

  Absolute Br measurement:

$$\mathcal{B} = \frac{N_{\text{obs}}}{\Sigma_i N_i^{\text{single-tag}} \cdot (\epsilon_i^{\text{double-tag}} / \epsilon_i^{\text{single-tag}})}$$

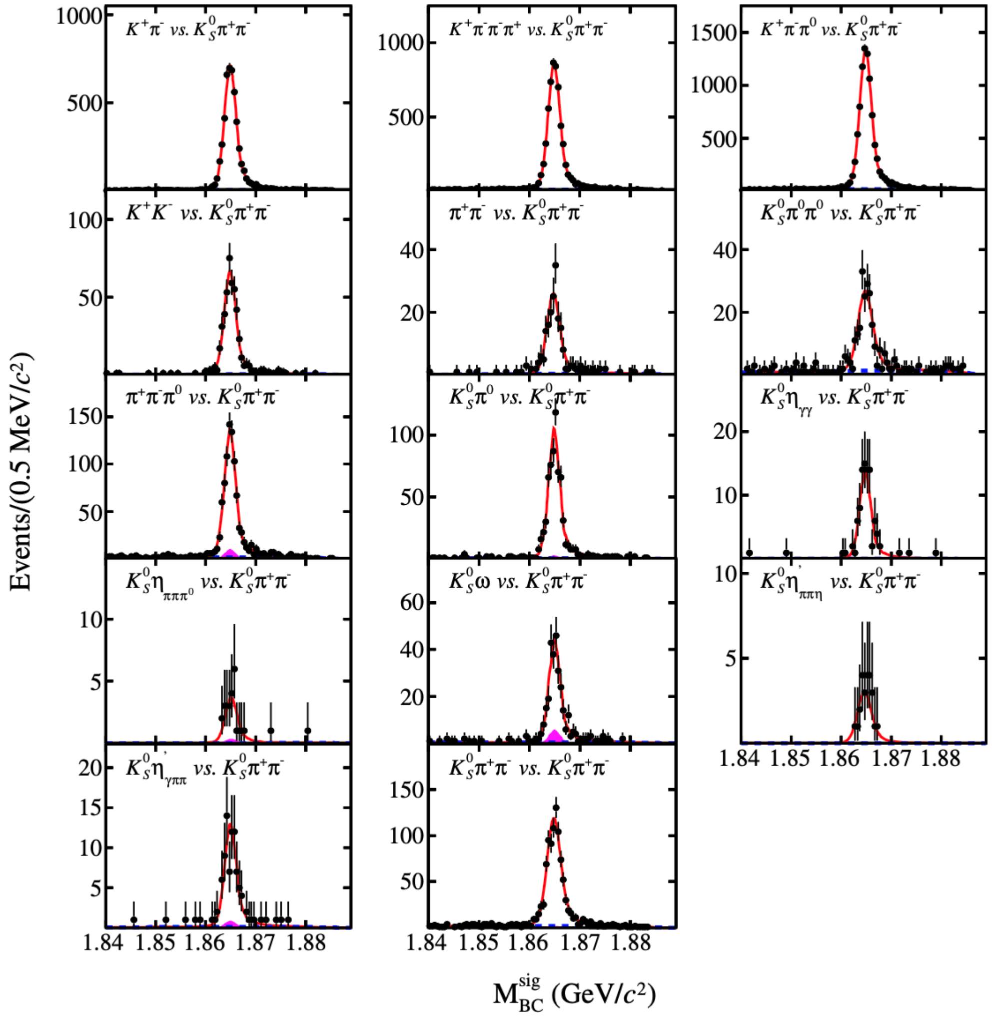
  Missing particle reconstruction: υ, n

$$M_{miss}^2 = E_{miss}^2 - p_{miss}^2, \; U_{miss} = E_{miss} - |\vec{p}_{miss}|$$

Charm Meson

$D^0 \to K_{S,L}\pi^+\pi^-$

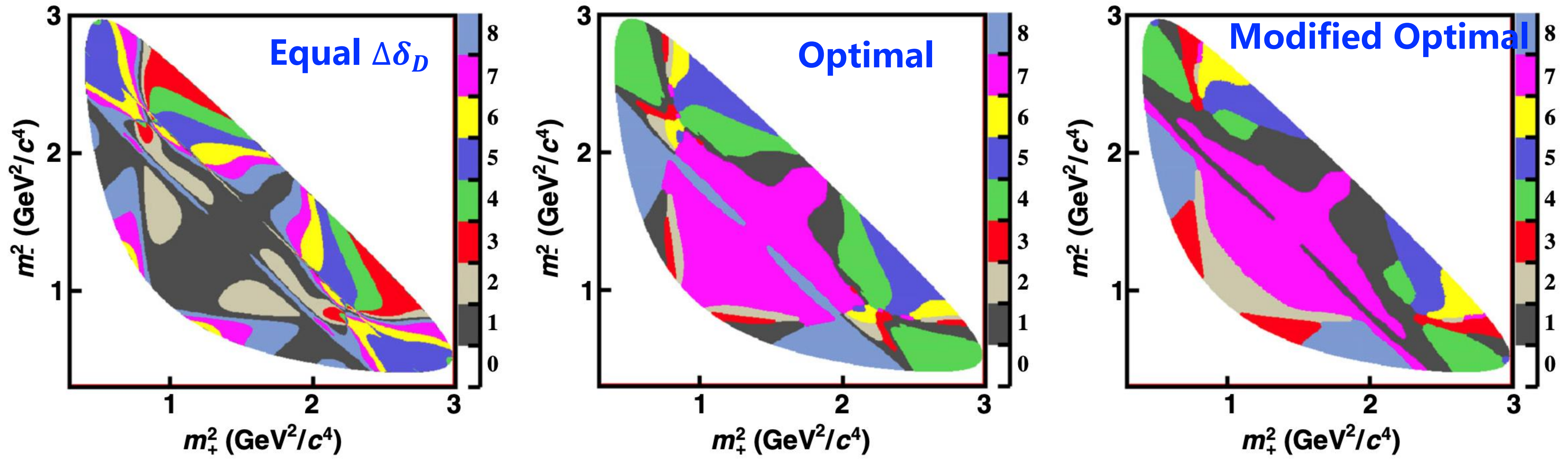
- **2.93 fb^{-1} of data @ $\sqrt{s} = 3.773$ GeV**
- **Measurement of $D^0/\bar{D}^0 \to K_{S,L}\pi^+\pi^-$ strong phase parameters $c_i[s_i] \equiv$ amplitude-weighted $cos[sin]\Delta\delta_D$ in phase-space bin i**
- **17 tag modes employed, yields determined with 2-D fit to $M_{BC} \equiv \sqrt{E_{beam}^2 - p_D^2}$**



$D^0 \to K_{S,L}\pi^+\pi^-$

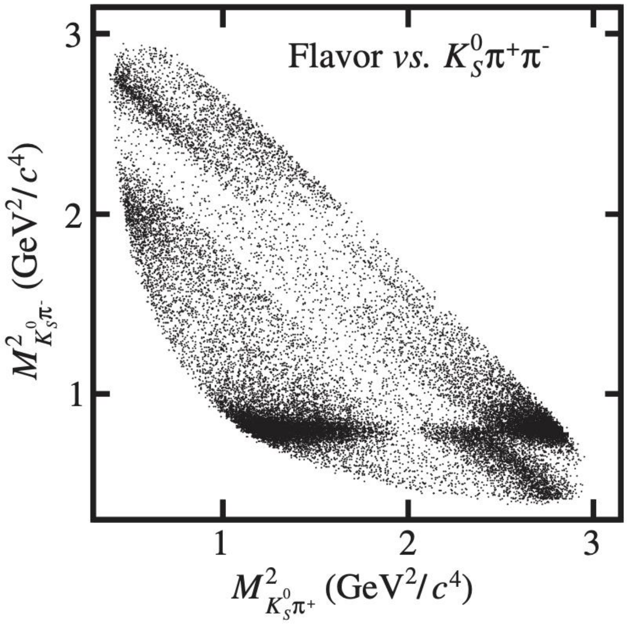
Phase space described by $m_\pm = m(K^0\pi^\pm)$

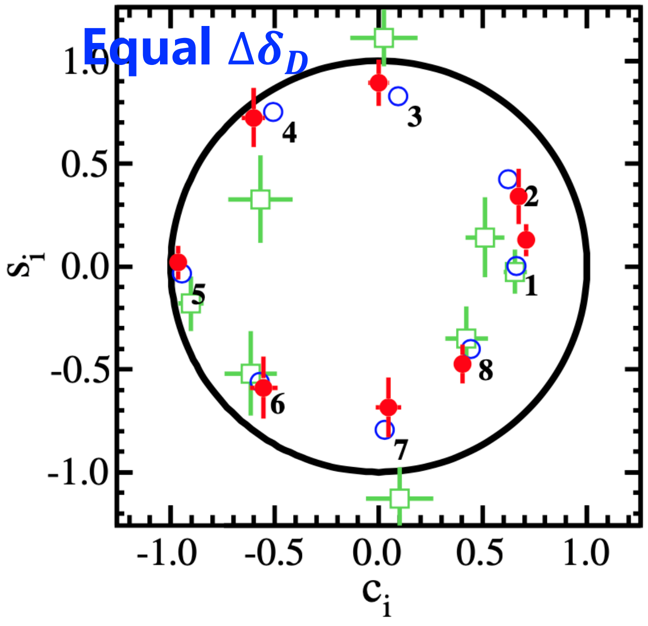
Binning schema from CLEO PRD 82,112006 (2010)



$D^0 \to K_{S,L}\pi^+\pi^-$

PRL 124 241802 (2020)
PRD 101 112002 (2020)





Red circles are BESIII measurements.
Blue Circles are predictions from Belle and Babar
Green square are CLEO results.

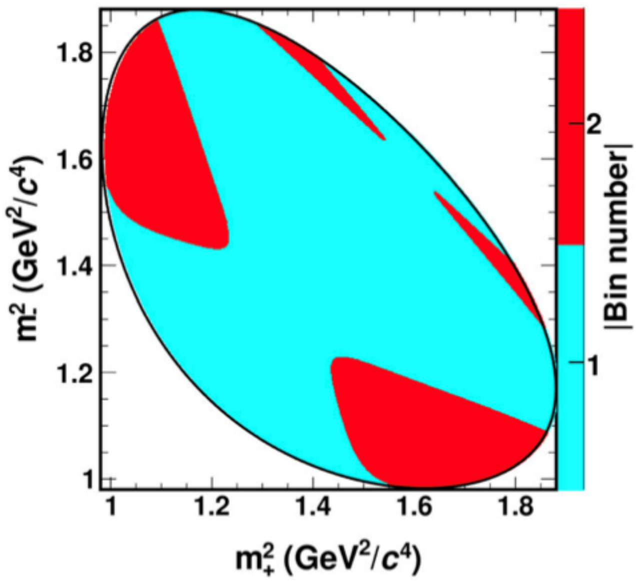
Impact on the γ is improved by a factor of 3 comparing to CLEO results.

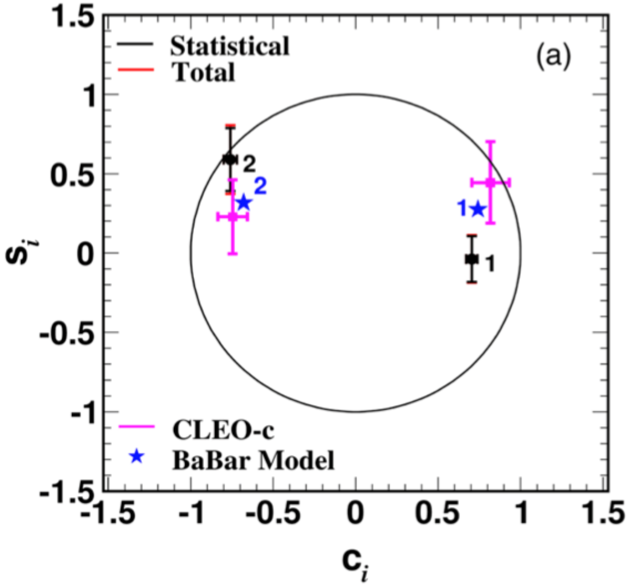
The uncertainty in γ due to the strong-phase is reduced to $\sim 1^o$

$D^0 \to K_{S,L}K^+K^-$

PRD 102 052008 (2020)

- 2.93 fb^{-1} of data @ $\sqrt{s} = 3.773$ GeV
- Measurement of $D^0/\bar{D}^0 \to K_{S,L}K^+K^-$ strong phase parameters $c_i[s_i]$; fewer bins

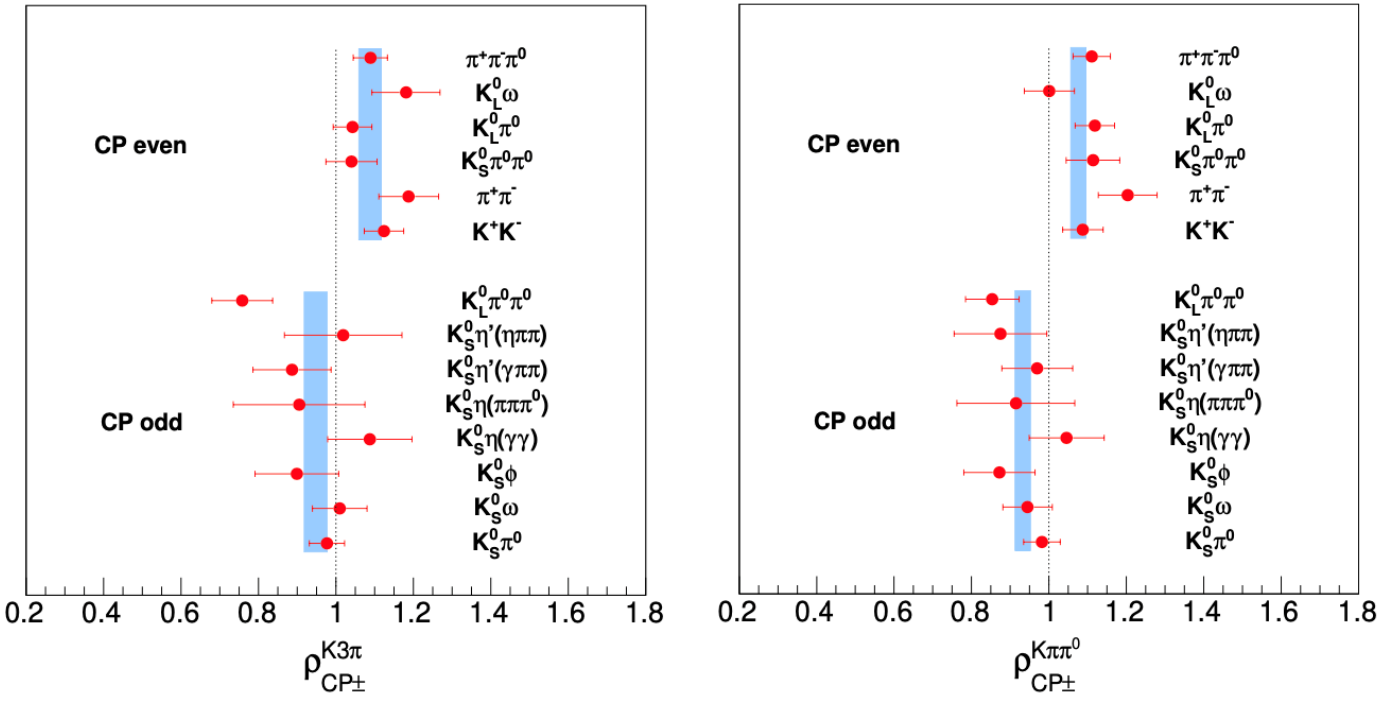




$D^0 \to K^-\pi^+\pi^+\pi^-, K^-\pi^+\pi^0$

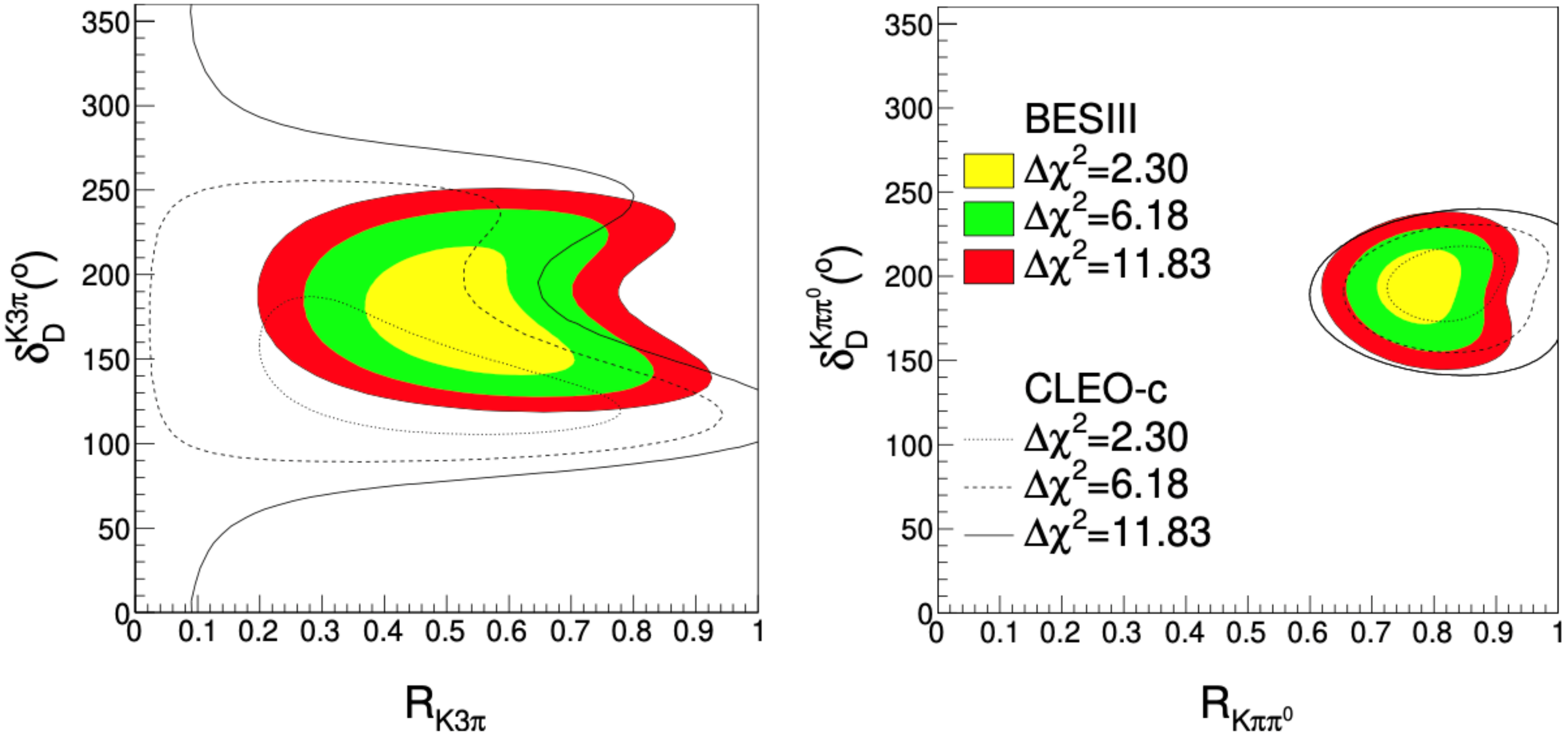
JHEP 05 (2021) 164

- 2.93 fb^{-1} of data @ $\sqrt{s} = 3.773$ GeV
- Measurement of phase-space-averaged δ_D, coherence factors R, and amplitude ratios r_D^X



$$\rho_{CP}^X \sim \frac{\mathcal{B}(D_{CP} \to X)}{\mathcal{B}(D^0 \to X)}$$

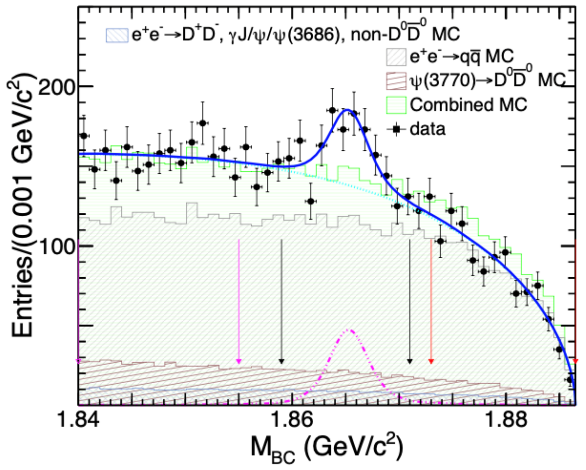
$D^0 \rightarrow K^-\pi^+\pi^+\pi^-, K^-\pi^+\pi^0$

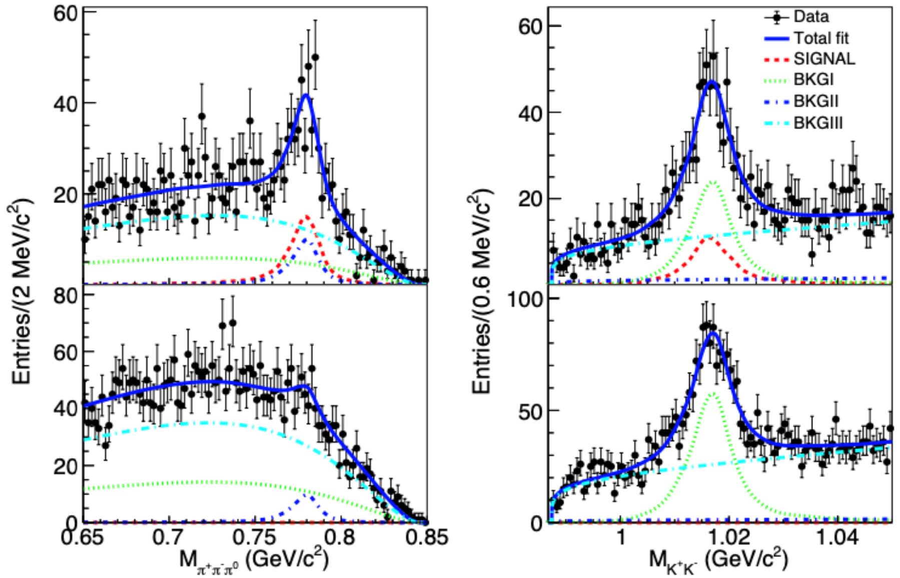


Significantly more constrained !
Impact on the γ : an uncertainty of $\sim 7^o$

$D^0 \to \omega\phi$

- **2.93 fb^{-1} of data @ $\sqrt{s} = 3.773$ GeV**
- **Polarization puzzle: Many heavy meson to vector-vector decays have large transverse polarization fraction**
- **ω reconstructed through $\pi^+\pi^-\pi^0$, ϕ through K^+K^-**
- **Signal yields determined with fit to $M_{\pi^+\pi^-\pi^0}$ vs $M_{K^+K^-}$**





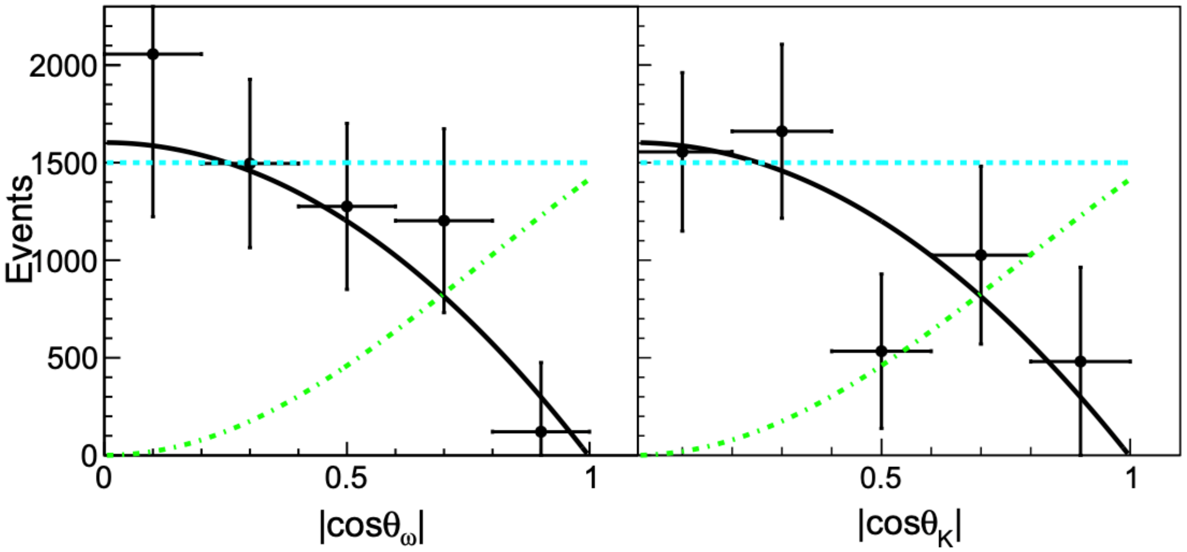
$D^0 \to \omega\phi$

arXiv:2108.02405

$$\mathcal{B}\left(D^0 \to \omega\phi\right) = (6.48 \pm 0.96 \pm 0.38) \times 10^{-4}$$

First observation

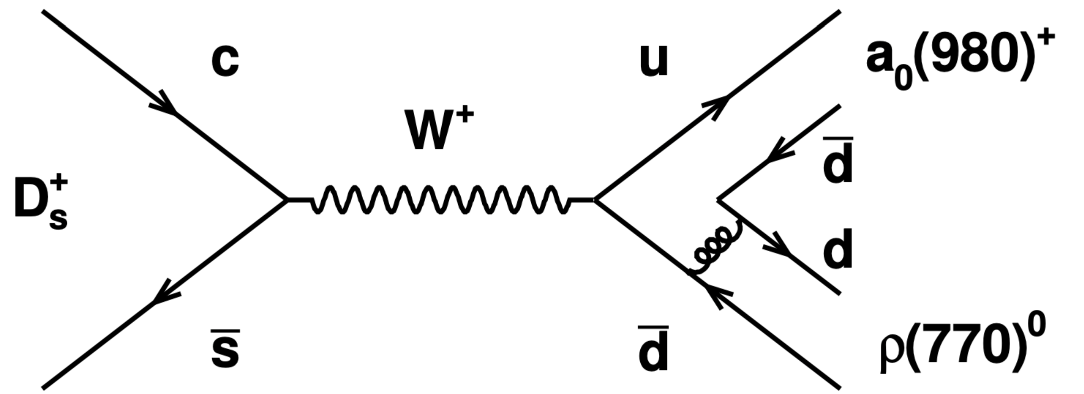
Large transverse polarization of $D^0 \to \omega\phi$



Black: Fit   Green: Longitudinal   Cyan: Phase space

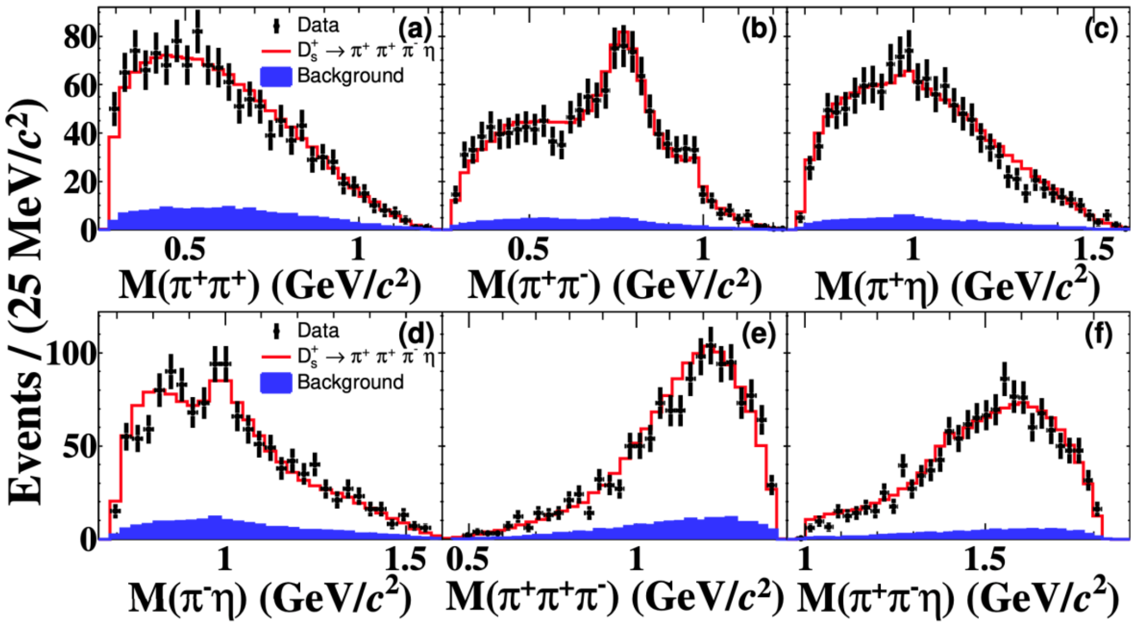
$D_s^+ \to \pi^+\pi^+\pi^-\eta$

- **6.32 fb^{-1} of data @ $\sqrt{s} = 4.178 - 4.230$ GeV**
- **$D_s^+ \to \pi^+\pi^+\pi^- X$ decays are important background in $B \to D^{(*)}\tau\nu$**
- **W-annihilation (WA) decay $D_s^+ \to a_0(980)\pi$ significantly enhanced over other WA decays**
- **$D_s^+ \to a_0(980)^+\rho^0$ is pure WA**



$D_s^+ \to \pi^+\pi^+\pi^-\eta$

PRD 104 L071101 (2021)



Amplitude	Phase	FF(%)
$a_1(1260)^+(\rho(770)^0\pi^+)\eta$	0.0(fixed)	$55.4 \pm 3.9 \pm 2.0$
$a_1(1260)^+(f_0(500)\pi^+)\eta$	$5.0 \pm 0.1 \pm 0.1$	$8.1 \pm 1.9 \pm 2.1$
$a_0(980)^+\rho(770)^0$	$2.5 \pm 0.1 \pm 0.1$	$6.7 \pm 2.5 \pm 1.5$
$\eta(1405)(a_0(980)^-\pi^+)\pi^+$	$0.2 \pm 0.2 \pm 0.1$	$0.7 \pm 0.2 \pm 0.1$
$\eta(1405)(a_0(980)^+\pi^-)\pi^+$	$0.2 \pm 0.2 \pm 0.1$	$0.7 \pm 0.2 \pm 0.1$
$f_1(1420)(a_0(980)^-\pi^+)\pi^+$	$4.3 \pm 0.2 \pm 0.4$	$1.9 \pm 0.5 \pm 0.3$
$f_1(1420)(a_0(980)^+\pi^-)\pi^+$	$4.3 \pm 0.2 \pm 0.4$	$1.7 \pm 0.5 \pm 0.3$
$[a_0(980)^-\pi^+]_S\pi^+$	$0.1 \pm 0.2 \pm 0.2$	$5.1 \pm 1.2 \pm 0.9$
$[a_0(980)^+\pi^-]_S\pi^+$	$0.1 \pm 0.2 \pm 0.2$	$3.4 \pm 0.8 \pm 0.6$
$[f_0(980)\eta]_S\pi^+$	$1.4 \pm 0.2 \pm 0.3$	$6.2 \pm 1.7 \pm 0.9$
$[f_0(500)\eta]_S\pi^+$	$2.5 \pm 0.2 \pm 0.3$	$12.7 \pm 2.6 \pm 2.0$

$$\mathcal{B}(D_s^+ \to \pi^+\pi^+\pi^-\eta) = (3.12 \pm 0.13 \pm 0.09)\%$$

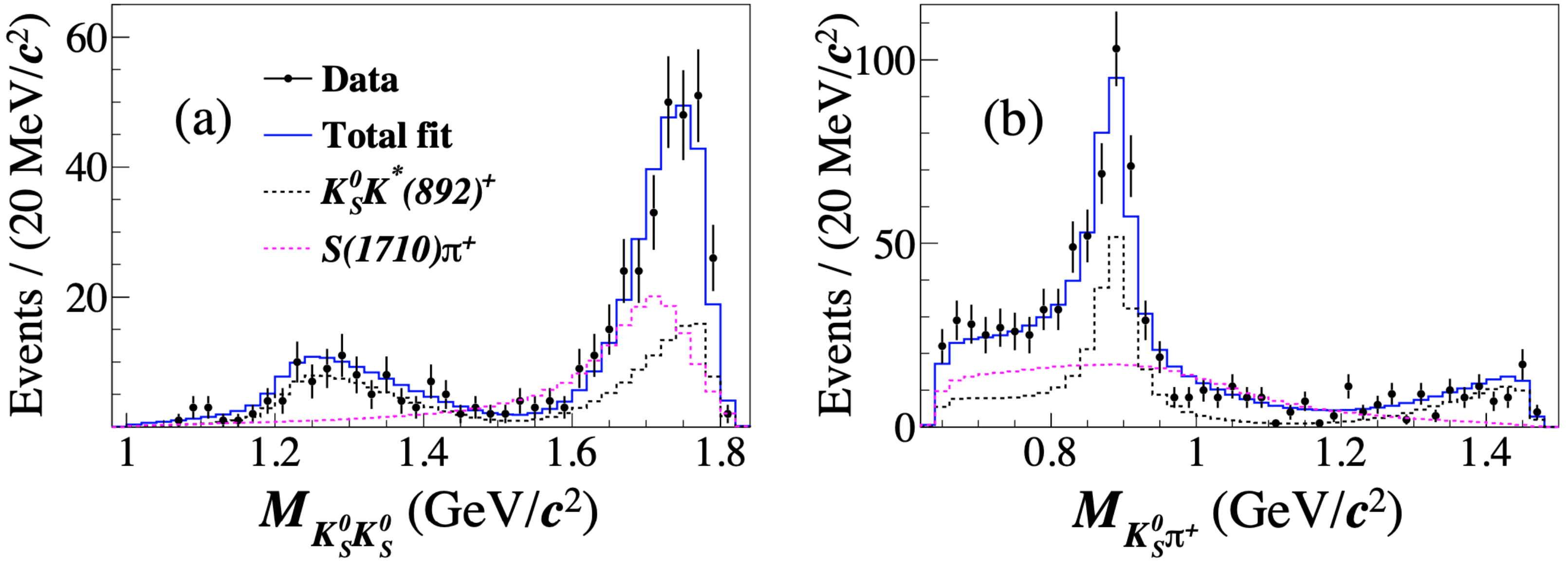
$$\mathcal{B}\left(D_s^+ \to a_0(980)^+\rho^0, a_0(980)^+ \to \pi^+\eta\right) = (0.21 \pm 0.08 \pm 0.05)\%$$

Significantly larger WA effects than seen in other D_s^+ decays

$D_s^+ \to K_S^0 K_S^0 \pi^-$

arXiv:2110.07650

- **6.32 fb^{-1} of data @ $\sqrt{s} = 4.178 - 4.230$ GeV**
- **Isovector partner observed for $f_0(1710)$**

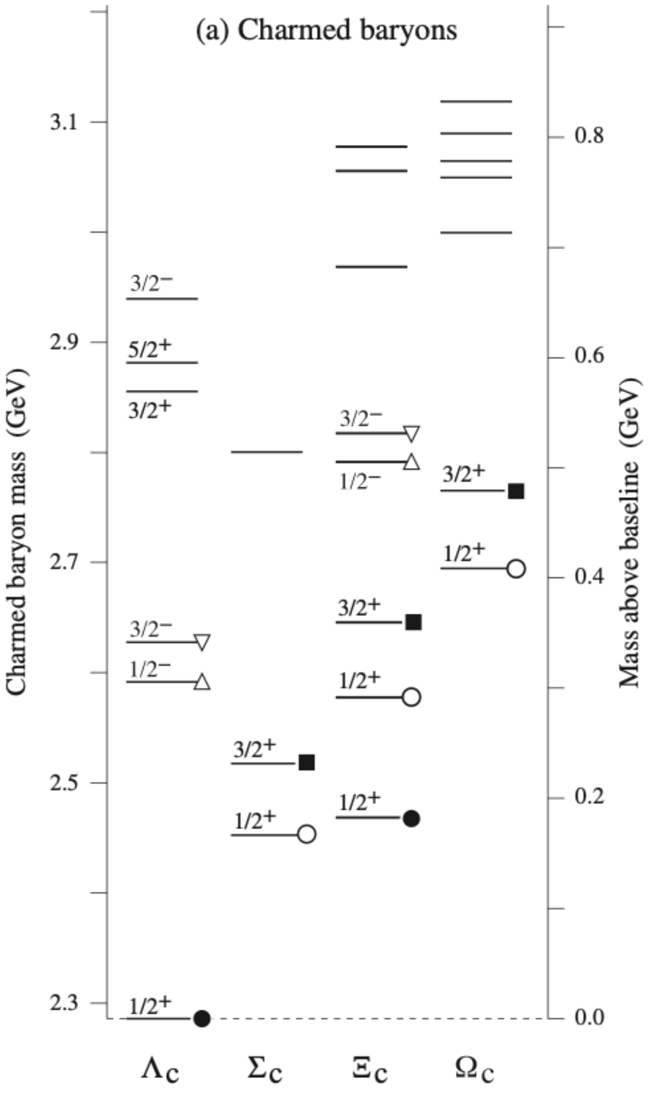


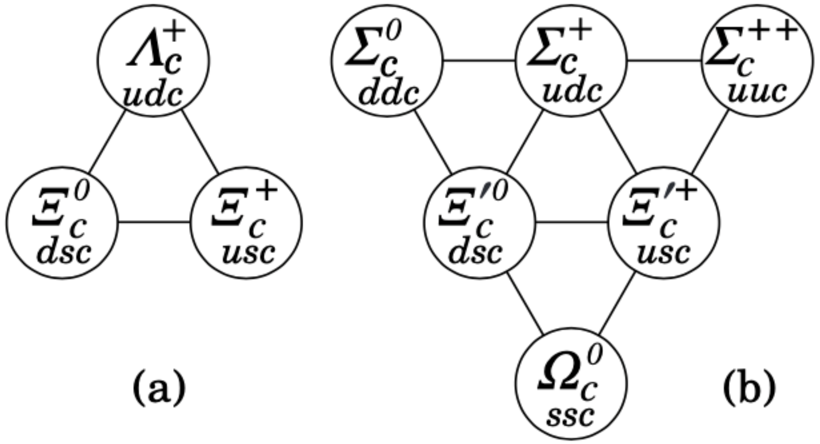
Amplitude	BF (10^{-3})
$D_s^+ \to K_S^0 K^*(892)^+ \to K_S^0 K_S^0 \pi^+$	$3.0 \pm 0.3 \pm 0.1$
$D_s^+ \to S(1710)\pi^+ \to K_S^0 K_S^0 \pi^+$	$3.1 \pm 0.3 \pm 0.1$

Not seen in earlier $D_s^+ \to K^+K^-\pi^-$ work

Charm Baryon

Singly Charm-Baryon Family





Ground state $J^p = \frac{1}{2}^+$

PDG in 2015

Λ_c^+ DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Hadronic modes with a p: $S = -1$ final states			
Γ_1	$p\overline{K}^0$		(3.21 ± 0.30) %	
Γ_2	$pK^-\pi^+$		($6.84^{+0.32}_{-0.40}$) %	
Γ_3	$p\overline{K}^*(892)^0$	[a]	(2.13 ± 0.30) %	
Γ_4	$\Delta(1232)^{++}K^-$		(1.18 ± 0.27) %	
Γ_5	$\Lambda(1520)\pi^+$	[a]	(2.4 ± 0.6) %	
Γ_6	$pK^-\pi^+$ nonresonant		(3.8 ± 0.4) %	
Γ_7	$p\overline{K}^0\pi^0$		(4.5 ± 0.6) %	
Γ_8	$p\overline{K}^0\eta$		(1.7 ± 0.4) %	
Γ_9	$p\overline{K}^0\pi^+\pi^-$		(3.5 ± 0.4) %	
Γ_{10}	$pK^-\pi^+\pi^0$		(4.6 ± 0.8) %	
Γ_{11}	$pK^*(892)^-\pi^+$	[a]	(1.5 ± 0.5) %	
Γ_{12}	$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(5.0 ± 0.9) %	
Γ_{13}	$\Delta(1232)\overline{K}^*(892)$		seen	
Γ_{14}	$pK^-\pi^+\pi^+\pi^-$		(1.5 ± 1.0) $\times 10^{-3}$	
Γ_{15}	$pK^-\pi^+\pi^0\pi^0$		(1.1 ± 0.5) %	
Γ_{16}	$pK^-\pi^+3\pi^0$			
	Hadronic modes with a p: $S = 0$ final states			
Γ_{17}	$p\pi^+\pi^-$		(4.7 ± 2.5) $\times 10^{-3}$	
Γ_{18}	$pf_0(980)$	[a]	(3.8 ± 2.5) $\times 10^{-3}$	
Γ_{19}	$p\pi^+\pi^+\pi^-\pi^-$		(2.5 ± 1.6) $\times 10^{-3}$	
Γ_{20}	pK^+K^-		(1.1 ± 0.4) $\times 10^{-3}$	
Γ_{21}	$p\phi$	[a]	(1.12 ± 0.23) $\times 10^{-3}$	
Γ_{22}	pK^+K^- non-ϕ		(4.8 ± 1.9) $\times 10^{-4}$	

PDG in 2020

	Mode		Fraction		
	Hadronic modes with a p or n: $S = -1$ final states				
Γ_1	pK^0_S		(1.59 ± 0.08) %	↓ 44%	S=1.1
Γ_2	$pK^-\pi^+$		(6.28 ± 0.32) %		S=1.4
Γ_3	$p\overline{K}^*(892)^0$	[a]	(1.96 ± 0.27) %		
Γ_4	$\Delta(1232)^{++}K^-$		(1.08 ± 0.25) %		
Γ_5	$\Lambda(1520)\pi^+$	[a]	(2.2 ± 0.5) %		
Γ_6	$pK^-\pi^+$ nonresonant		(3.5 ± 0.4) %		
Γ_7	$pK^0_S\pi^0$		(1.97 ± 0.13) %	↓ 50%	S=1.1
Γ_8	$nK^0_S\pi^+$		(1.82 ± 0.25) %	First	
Γ_9	$p\overline{K}^0\eta$		(1.6 ± 0.4) %		
Γ_{10}	$pK^0_S\pi^+\pi^-$		(1.60 ± 0.12) %	↓ 28%	S=1.1
Γ_{11}	$pK^-\pi^+\pi^0$		(4.46 ± 0.30) %	↓ 61%	S=1.5
Γ_{12}	$pK^*(892)^-\pi^+$	[a]	(1.4 ± 0.5) %		
Γ_{13}	$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(4.6 ± 0.8) %		
Γ_{14}	$\Delta(1232)\overline{K}^*(892)$		seen		
Γ_{15}	$pK^-2\pi^+\pi^-$		(1.4 ± 0.9) $\times 10^{-3}$		
Γ_{16}	$pK^-\pi^+2\pi^0$		(1.0 ± 0.5) %		
	Hadronic modes with a p: $S = 0$ final states				
Γ_{17}	$p\pi^0$		< 2.7 $\times 10^{-4}$		CL=90%
Γ_{18}	$p\eta$		(1.24 ± 0.30) $\times 10^{-3}$	First	
Γ_{19}	$p\omega(782)^0$		(9 ± 4) $\times 10^{-4}$		
Γ_{20}	$p\pi^+\pi^-$		(4.61 ± 0.28) $\times 10^{-3}$	First	
Γ_{21}	$pf_0(980)$	[a]	(3.5 ± 2.3) $\times 10^{-3}$		
Γ_{22}	$p2\pi^+2\pi^-$		(2.3 ± 1.4) $\times 10^{-3}$		
Γ_{23}	pK^+K^-		(1.06 ± 0.06) $\times 10^{-3}$		
Γ_{24}	$p\phi$	[a]	(1.06 ± 0.14) $\times 10^{-3}$	↓ 36%	
Γ_{25}	pK^+K^- non-ϕ		(5.3 ± 1.2) $\times 10^{-4}$		
Γ_{26}	$p\phi\pi^0$		(10 ± 4) $\times 10^{-5}$		
Γ_{27}	$pK^+K^-\pi^0$ nonresonant		< 6.3 $\times 10^{-5}$		CL=90%

PDG in 2015

Hadronic modes with a hyperon: $S = -1$ final states

Γ_{23}	$\Lambda\pi^+$		(1.46 ± 0.13) %	
Γ_{24}	$\Lambda\pi^+\pi^0$		(5.0 ± 1.3) %	
Γ_{25}	$\Lambda\rho^+$		< 6 %	CL=95%
Γ_{26}	$\Lambda\pi^+\pi^+\pi^-$		(3.59 ± 0.28) %	
Γ_{27}	$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+} \to \Lambda\pi^+$		(1.0 ± 0.5) %	
Γ_{28}	$\Sigma(1385)^-\pi^+\pi^+$, $\Sigma^{*-} \to \Lambda\pi^-$		$(7.5 \pm 1.4) \times 10^{-3}$	
Γ_{29}	$\Lambda\pi^+\rho^0$		(1.4 ± 0.6) %	
Γ_{30}	$\Sigma(1385)^+\rho^0$, $\Sigma^{*+} \to \Lambda\pi^+$		$(5 \pm 4) \times 10^{-3}$	
Γ_{31}	$\Lambda\pi^+\pi^+\pi^-$ nonresonant		< 1.1 %	CL=90%
Γ_{32}	$\Lambda\pi^+\pi^+\pi^-\pi^0$ total		(2.5 ± 0.9) %	
Γ_{33}	$\Lambda\pi^+\eta$	[a]	(2.4 ± 0.5) %	
Γ_{34}	$\Sigma(1385)^+\eta$	[a]	(1.16 ± 0.35) %	
Γ_{35}	$\Lambda\pi^+\omega$	[a]	(1.6 ± 0.6) %	
Γ_{36}	$\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω		$< 9 \times 10^{-3}$	CL=90%
Γ_{37}	$\Lambda K^+\overline{K}^0$		$(6.4 \pm 1.3) \times 10^{-3}$	S=1.6
Γ_{38}	$\Xi(1690)^0K^+$, $\Xi^{*0} \to \Lambda\overline{K}^0$		$(1.8 \pm 0.6) \times 10^{-3}$	
Γ_{39}	$\Sigma^0\pi^+$		(1.43 ± 0.14) %	
Γ_{40}	$\Sigma^+\pi^0$		(1.37 ± 0.30) %	
Γ_{41}	$\Sigma^+\eta$		$(7.5 \pm 2.5) \times 10^{-3}$	
Γ_{42}	$\Sigma^+\pi^+\pi^-$		(4.9 ± 0.5) %	
Γ_{43}	$\Sigma^+\rho^0$		< 1.8 %	CL=95%
Γ_{44}	$\Sigma^-\pi^+\pi^+$		(2.3 ± 0.4) %	
Γ_{45}	$\Sigma^0\pi^+\pi^0$		(2.5 ± 0.9) %	

Semileptonic modes

Γ_{64}	$\Lambda\ell^+\nu_\ell$	[b]	(2.8 ± 0.4) %
Γ_{65}	$\Lambda e^+\nu_e$		(2.9 ± 0.5) %
Γ_{66}	$\Lambda\mu^+\nu_\mu$		(2.7 ± 0.6) %

PDG in 2020

Improvement: Not only the central value, but also the uncertainty

Hadronic modes with a hyperon: $S = -1$ final states

Γ_{28}	$\Lambda\pi^+$	(1.30 ± 0.07) %		S=1.1
Γ_{29}	$\Lambda\pi^+\pi^0$	(7.1 ± 0.4) %	↓ 78%	S=1.1
Γ_{30}	$\Lambda\rho^+$	< 6 %		CL=95%
Γ_{31}	$\Lambda\pi^-2\pi^+$	(3.64 ± 0.29) %		S=1.4
Γ_{44}	$\Sigma^0\pi^+$	(1.29 ± 0.07) %	↓ 45%	S=1.1
Γ_{45}	$\Sigma^+\pi^0$	(1.25 ± 0.10) %	↓ 33%	
Γ_{46}	$\Sigma^+\eta$	$(4.4 \pm 2.0) \times 10^{-3}$		
Γ_{47}	$\Sigma^+\eta'$	(1.5 ± 0.6) %		
Γ_{48}	$\Sigma^+\pi^+\pi^-$	(4.50 ± 0.25) %	↓ 46%	S=1.3
Γ_{49}	$\Sigma^+\rho^0$	< 1.7 %		CL=95%
Γ_{50}	$\Sigma^-2\pi^+$	(1.87 ± 0.18) %		
Γ_{51}	$\Sigma^0\pi^+\pi^0$	(3.5 ± 0.4) %		
Γ_{52}	$\Sigma^+\pi^0\pi^0$	(1.55 ± 0.15) %		
Γ_{53}	$\Sigma^0\pi^-2\pi^+$	(1.11 ± 0.30) %		

Semileptonic modes

Γ_{72}	$\Lambda e^+\nu_e$	(3.6 ± 0.4) %	↓ 35%
Γ_{73}	$\Lambda\mu^+\nu_\mu$	(3.5 ± 0.5) %	

Publications at BESIII

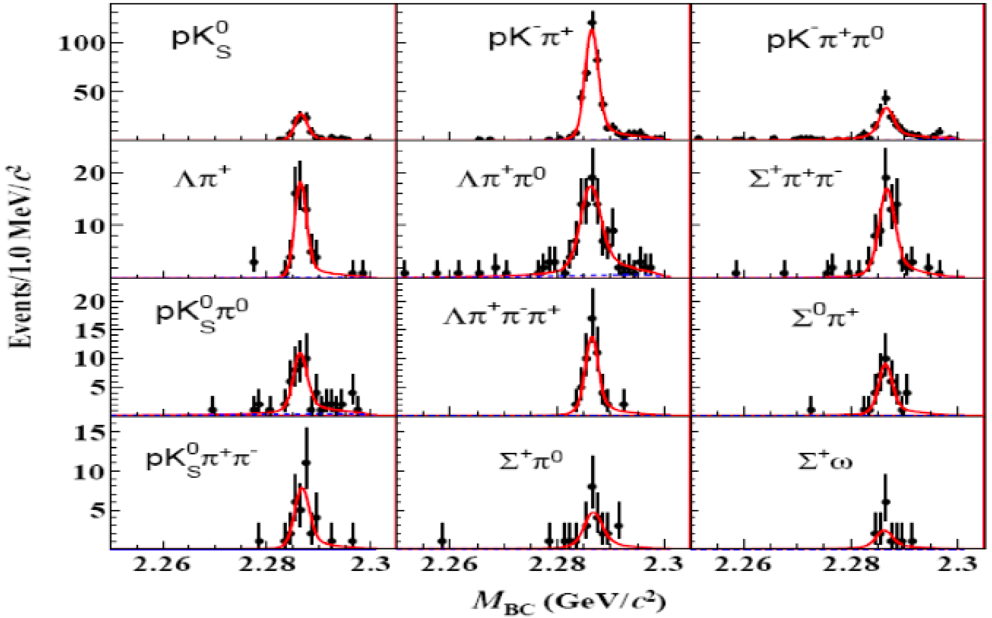
Hadronic decays	
$\Lambda_c \to pK\pi$ + 11 CF modes	PRL 116, 052001 (2016)
$\Lambda_c \to pK^+K^-, p\pi^+\pi^-$	PRL 117, 232002 (2016)
$\Lambda_c \to nK_s\pi$	PRL 118, 112001 (2017)
$\Lambda_c \to p\eta, p\pi^0$	PRD 95, 111102(R) (2017)
$\Lambda_c \to \Sigma\pi^+\pi^-\pi^0$	PLB 772, 338 (2017)
$\Lambda_c \to \Xi^{0(*)}K$	PLB 783, 200 (2018)
$\Lambda_c \to \Lambda\eta\pi$	PRD 99, 032010 (2019)
$\Lambda_c \to pK_s\eta$	PLB 817 (2021) 136327

Semi-leptonic decays	
$\Lambda_c \to \Lambda e^+\nu$	PRL 115, 221805 (2015)
$\Lambda_c \to \Lambda\mu^+\nu$	PLB 767m 42 (2017)
Inclusive decays	
$\Lambda_c \to \Lambda + X$	PRL 121, 062003 (2018)
$\Lambda_c \to e^+ + X$	PRL 121, 251801 (2018)
$\Lambda_c \to K_s + X$	EPJC 80, 935 (2020)
Production	
$\Lambda_c^+\bar{\Lambda}_c^-$	PRL 120, 132001 (2018)

One of the highlights at BESIII !

Cabbibo-favor hadronic decays

- BESIII: 567pb^{-1}at 4.599GeV, 12 MeV above $\Lambda_c^+\bar{\Lambda}_c^-$ threshold in $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$
- Double tag method to measure absolute Brs.

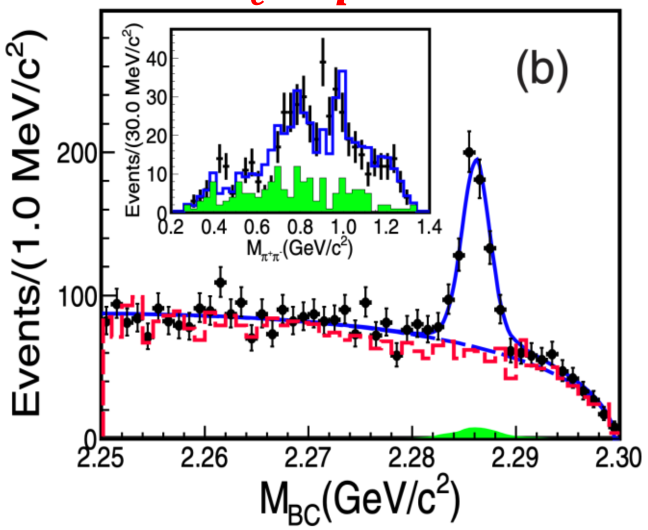


Mode	This work (%)	PDG (%)	BELLE $\mathcal{B}$
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53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

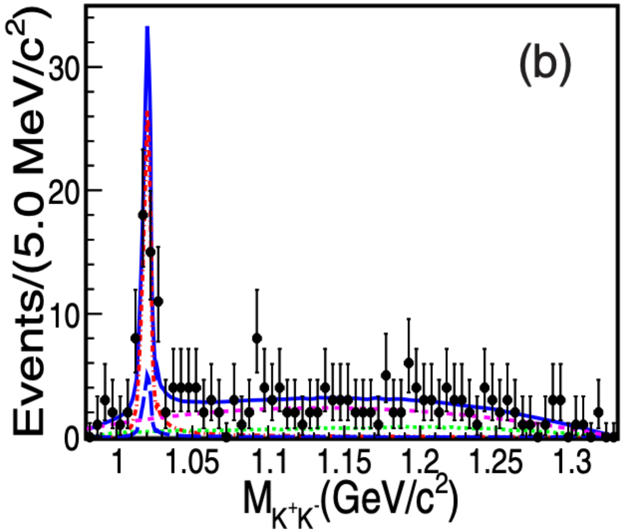
- $B(\Lambda_c^+ \to pK^-\pi^+)$: BESIII precision comparable with Belle's
- BESIII $B(\Lambda_c^+ \to pK^-\pi^+)$ is compatible with BELLE's within 2σ
- Improved precisions in other modes significantly

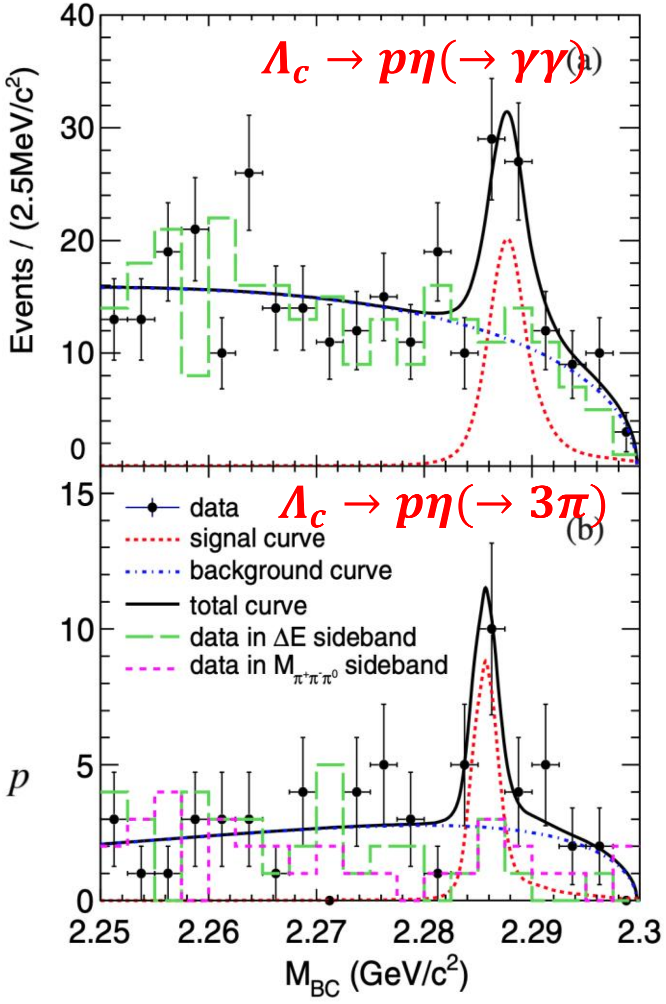
Cabbibo-Suppressed hadronic decay

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

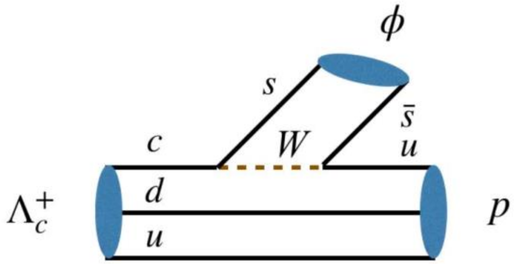


$\Lambda_c \to pK^+K^-$



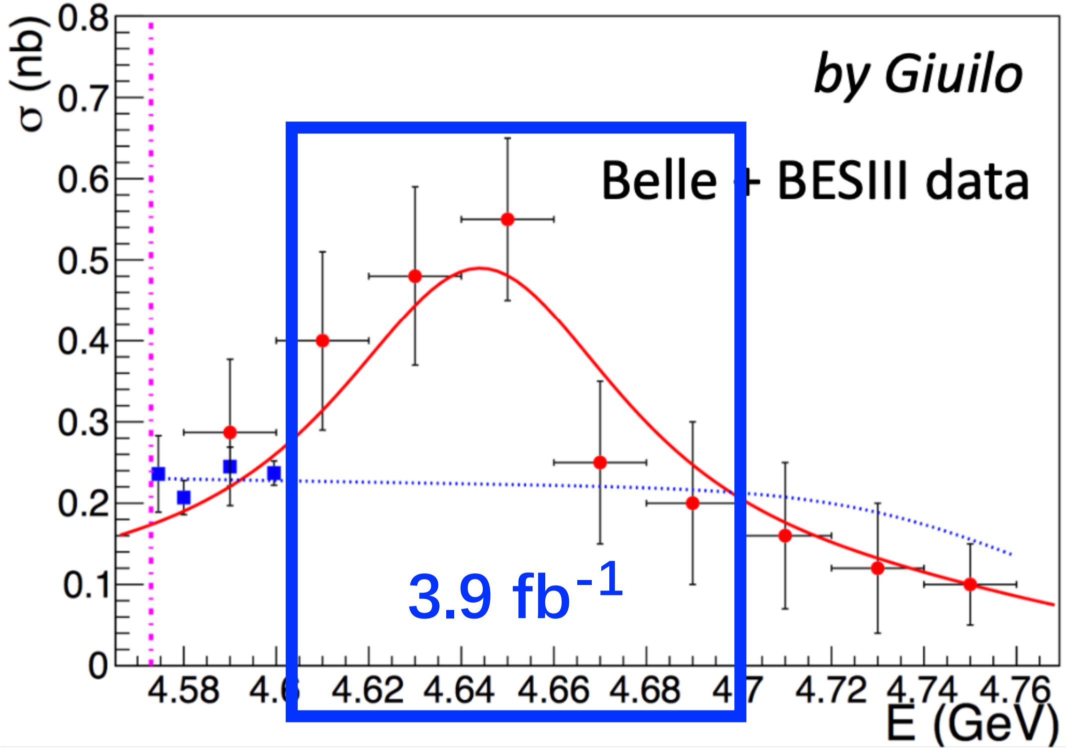


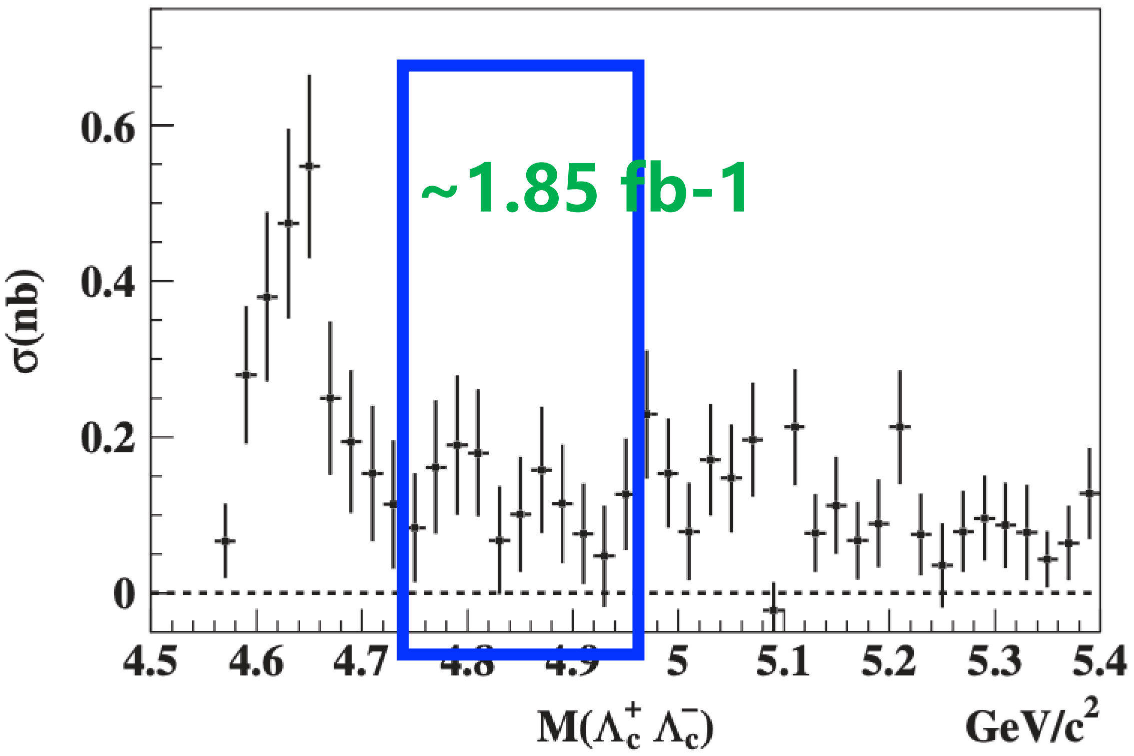
- First observation of $\Lambda_c \to p\pi^+\pi^-$ and improved measurement of $\Lambda_c \to p\phi$
- Evidence of $\Lambda_c \to p\eta$ (4.2σ); No hint for $\Lambda_c \to p\pi^0$
- Br ~ 10^{-3}



$\Lambda_c \to p\phi$ only receives the internal W-emission

New Opportunity at BESIII





- 4.612 - 4.700 GeV, 3.9 fb^{-1} collected in 2019-2020
- 4.7 – 4.95 GeV, ~1.85 fb-1 collected in 2020-2021

Singly-CS hadronic process

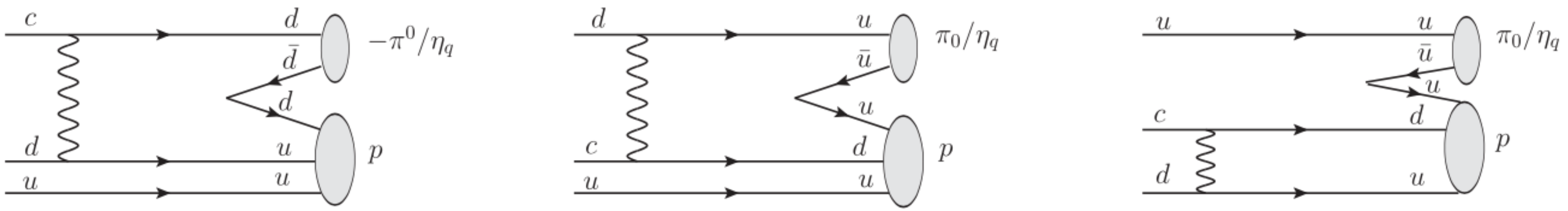
H.-Y. Cheng, et al, PRD 97, 074028 (2018)

TABLE III. Comparison of various theoretical predictions for the branching fractions (in units of 10^{-3}) of singly Cabibbo-suppressed decays of Λ_c^+.

	Sharma *et al.* [24]	Uppal *et al.* [42]	Chen *et al.* [43]	Lu *et al.* [25]	Geng *et al.* [28]	This work	Experiment [7,19]
$\Lambda_c^+ \to p\pi^0$	0.2	0.1–0.2	0.11–0.36	0.48	0.57 ± 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	1.13 ± 0.29	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	

[a] The P-wave amplitude of $\Lambda_c^+ \to \Xi^0 K^+$ is assumed to be positive.
[b] The P-wave amplitude of $\Lambda_c^+ \to \Xi^0 K^+$ is assumed to be negative.

Important information for understanding the non-factorizable component!



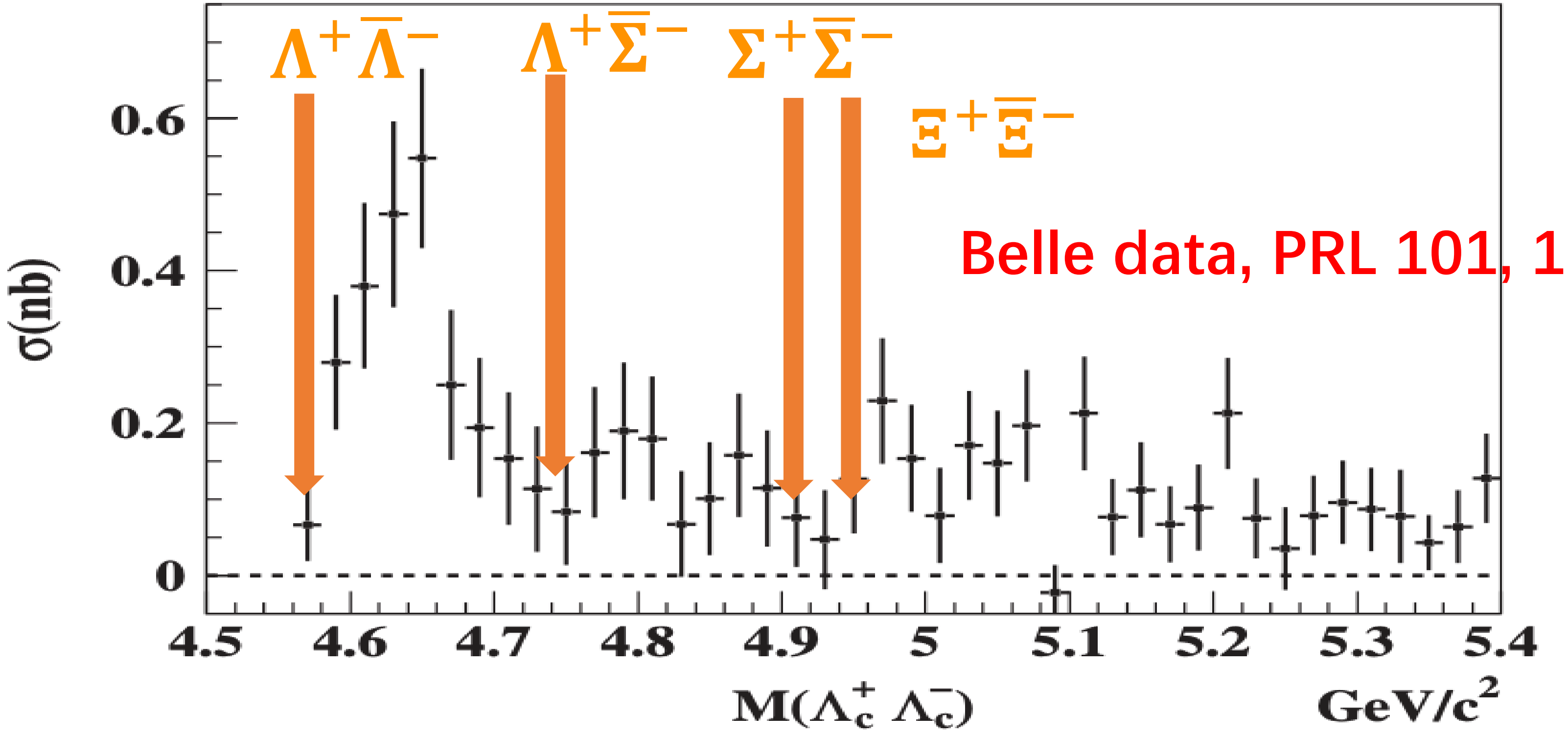
Other interests

- SCS $\Lambda_c \to p\eta'$, $\Sigma^+ K_s$, $\Sigma^0 K^+$, ΛK^+, and three-body decay as well.
- Weak radiative decay $\Lambda_c \to \gamma\Sigma^+$
- PWA to extract hadronic decays: $\Lambda_c \to \Lambda\pi^+\pi^0$, $\Lambda_c \to p\pi^+\pi^-$, ...
- Inclusive decay: $\Lambda_c \to hadron$ + X

...

Stay tuned!

Charm Baryon threshold



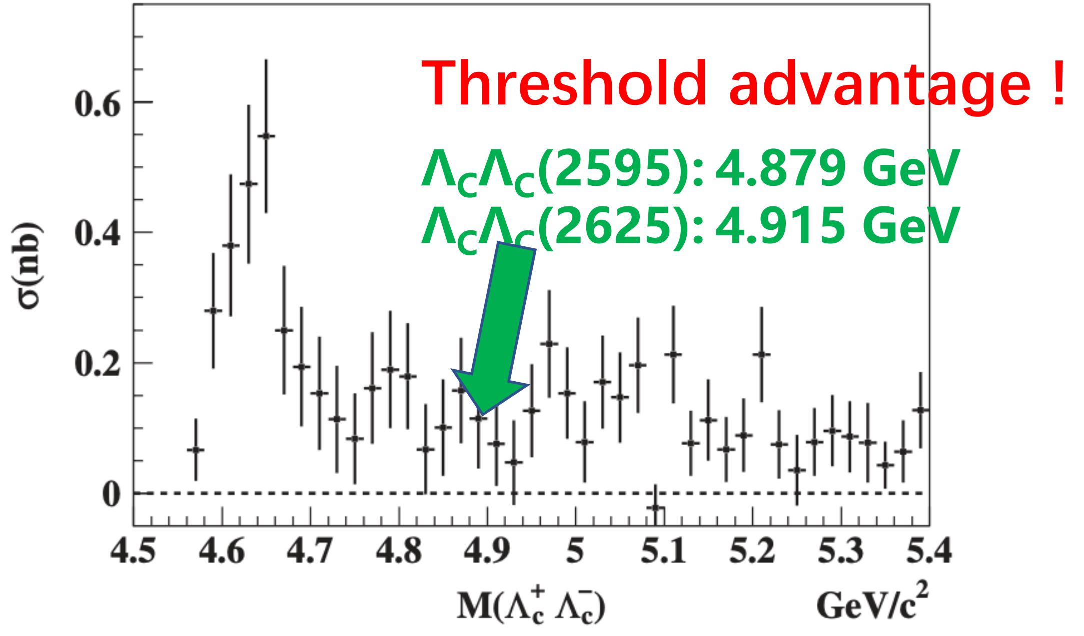
Belle data, PRL 101, 172001 (2008)

Energy thresholds

- ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ 4.74 GeV
- ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c\ \pi$ 4.88 GeV
- ✓ $e^+e^- \to \Sigma_c\ \bar{\Sigma}_c$ 4.91 GeV (10MeV above current limit)
- ✓ $e^+e^- \to \Xi_c\ \bar{\Xi}_c$ 4.95 GeV (50 MeV above current limit)

$\Lambda_C{}^*$ production

Except the Σ_c and Ξ_c, the $\Lambda_C{}^*$ will be produced associated with Λ_C.



$\Lambda_c(2595)^+$ $\quad I(J^P) = 0(\frac{1}{2}^-)$

The spin-parity follows from the fact that $\Sigma_c(2455)\pi$ decays, with little available phase space, are dominant. This assumes that $J^P = 1/2^+$ for the $\Sigma_c(2455)$.

Mass $m = 2592.25 \pm 0.28$ MeV
$m - m_{\Lambda_c^+} = 305.79 \pm 0.24$ MeV
Full width $\Gamma = 2.6 \pm 0.6$ MeV

$\Lambda_c^+\pi\pi$ and its submode $\Sigma_c(2455)\pi$ — the latter just barely — are the only strong decays allowed to an excited Λ_c^+ having this mass; and the submode seems to dominate.

$\Lambda_c(2595)^+$ DECAY MODES		Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+\pi^+\pi^-$	[s]	—	117
$\Sigma_c(2455)^{++}\pi^-$		24 ± 7 %	†
$\Sigma_c(2455)^0\pi^+$		24 ± 7 %	†
$\Lambda_c^+\pi^+\pi^-$ 3-body		18 ± 10 %	117

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Lambda_c(2625)^+$ $\quad I(J^P) = 0(\frac{3}{2}^-)$

J^P has not been measured; $\frac{3}{2}^-$ is the quark-model prediction.

Mass $m = 2628.11 \pm 0.19$ MeV $\quad (S = 1.1)$
$m - m_{\Lambda_c^+} = 341.65 \pm 0.13$ MeV $\quad (S = 1.1)$
Full width $\Gamma < 0.97$ MeV, CL = 90%

$\Lambda_c^+\pi\pi$ and its submode $\Sigma(2455)\pi$ are the only strong decays allowed to an excited Λ_c^+ having this mass.

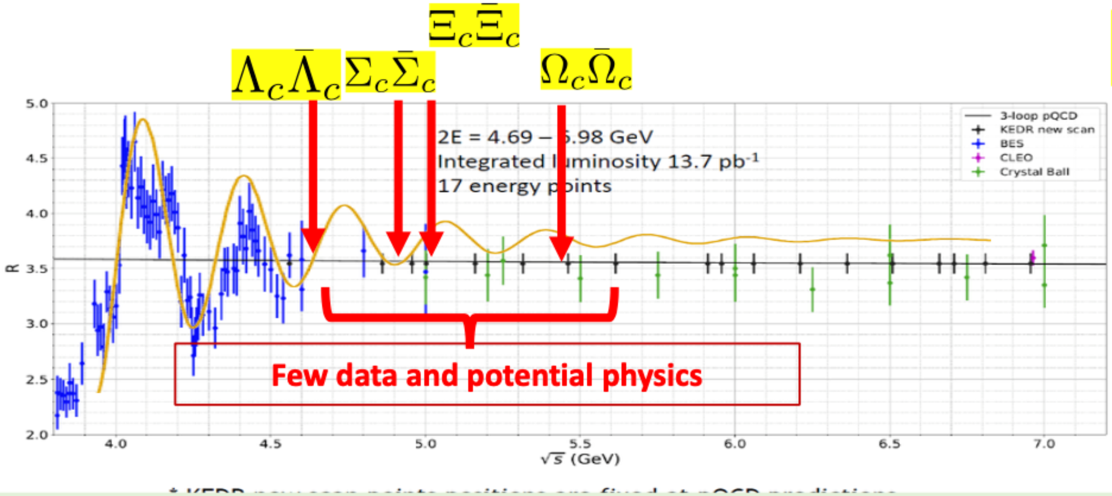
$\Lambda_c(2625)^+$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda_c^+\pi^+\pi^-$	≈ 67%		184
$\Sigma_c(2455)^{++}\pi^-$	<5	90%	102
$\Sigma_c(2455)^0\pi^+$	<5	90%	102
$\Lambda_c^+\pi^+\pi^-$ 3-body	large		184

See Particle Listings for 2 decay modes that have been seen / not seen.

"New era"

From Haibo Li

Many charmed baryon thresholds



BEPCII upgrade:

Scan data: 65 fb^{-1}

4.01 GeV: 20 fb^{-1} DsDs

4.60 GeV: 20 fb^{-1} Λ_c Λ_c

Others

- ✓ Ξ_c $\bar{\Xi}_c$ 6 fb^{-1} 4.95 -4.97GeV
- ✓ $\Omega_c^0\bar{\Omega}_c^0$ 6 fb^{-1} 5.4 -5.5 GeV

Total: **117fb^{-1}**

Unique data samples near thresholds, and using quantum-entanglement:

- **Hadron physics: spectroscopy, (transition-)form-factors, decay constants, fragmentation /Collins function, charmed hadron decays…**
- **Precise test of SM: charm hadron weak decays, CKM, CP violation in hyperon decays, and rare/forbidden charm and hyperon decays…**

Charm still unique to test QCD in low energy, and charm still a probe for precise test of SM!

谢谢！