Hadronic Charm Decays and Lifetimes

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Outline

- Amplitude analysis of charmed meson decays
  - $D^0 \to K^- \pi^+ \pi^0 \pi^0$; $D^+ \to K^0_S \pi^+ \pi^+ \pi^-$; $D^+_s \to \pi^+ \pi^0 \eta$ BESIII
  - $D^+ \to K^- K^+ K^+$ LHCb

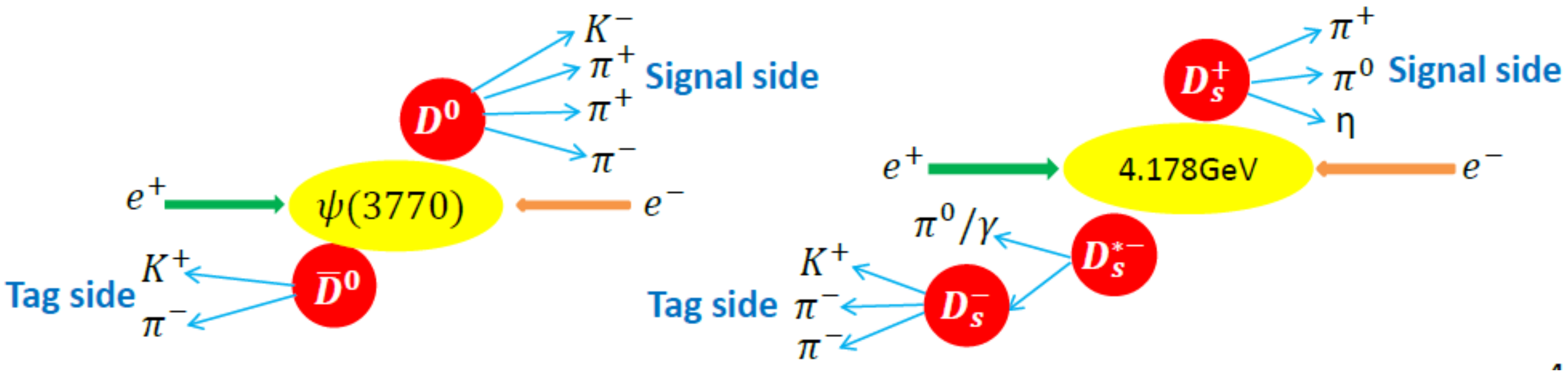
- Two body decays of charmed mesons
  - $D^+_s \to p\, n$; $D^+_s \to \omega \pi^+$ and ωK^+ ; $D^+_s \to K^0_S K^+$ and $K^0_L K^+$ BESIII

- Charmed baryon decays
  - $\Lambda_c^+ \to \Sigma^+ \eta$ and $\Lambda_c^+ \to \Sigma^+ \eta'$; $\Lambda_c^+ \to \Lambda \eta \pi^+$ and $\Lambda_c^+ \to \Sigma^+(1385)\eta$ BESIII
  - $\Xi_{cc}^{++} \to D^+ p K^- \pi^+$; $\Xi_c^+ \to p\phi$ LHCb
  - Charmed baryons lifetimes LHCb

- Not covered in this talk:
  - Mixing and CPV in charm (see Fabio Ferrari's talk)
  - Leptonic and semileptonic decays of charmed hadrons (See Sifan Zhang's talk)

Charm Production at Threshold

- Single tag: fully reconstruct the signal $D_{(S)}$, Λ_c
- Double tag:
  - Fully reconstruct the tag $D_{(S)}$, Λ_c taking advantage of kinematic constrains
  - Search for the signal mode in the recoil system
  - Possible to measure absolute Branching Fraction

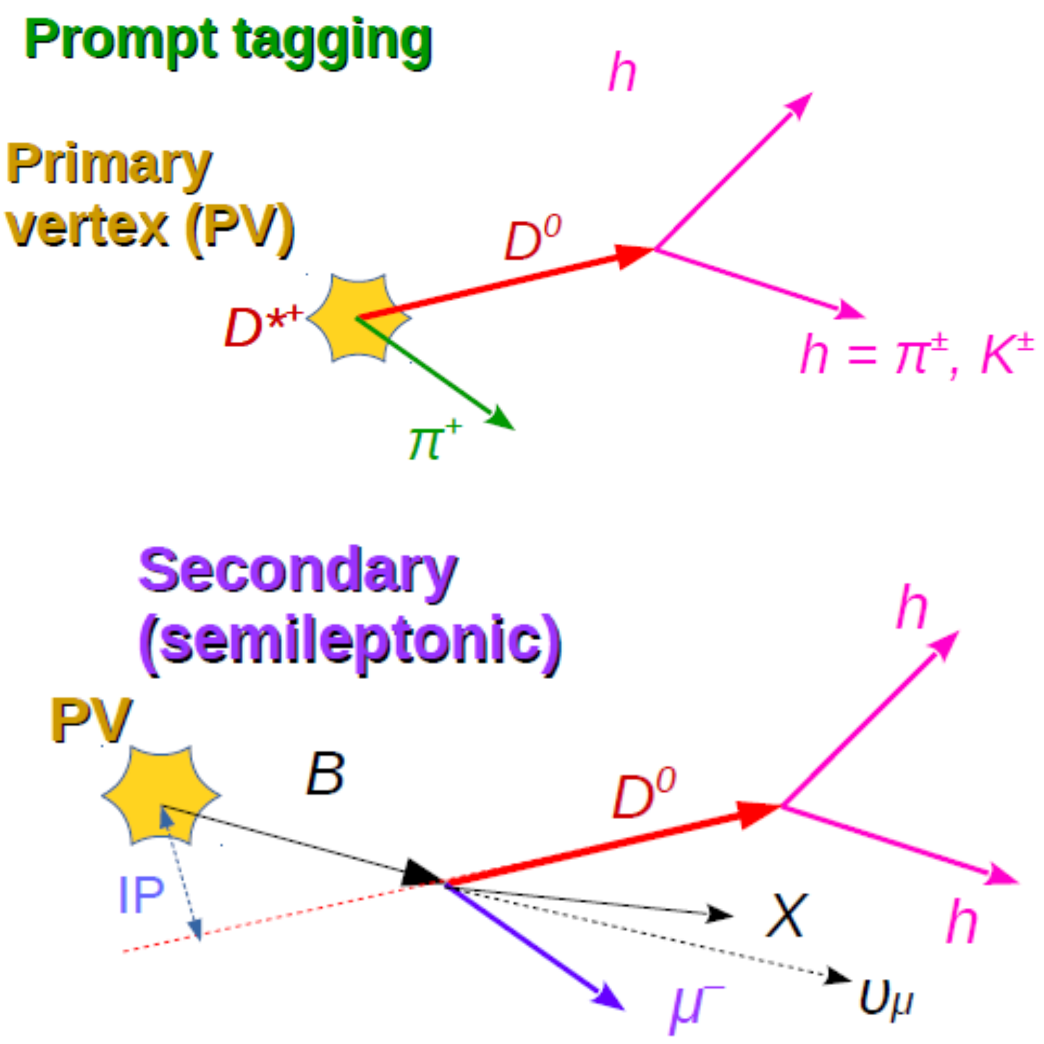


$$\Delta E = E_D - E_{\text{Beam}}$$

$$M_{\text{BC}} = \sqrt{E_{\text{Beam}}^2 - p_D^2}$$

Charm Production in the Forward Region

- Gluon fusion is main production mechanism for heavy (c & b) quark-antiquark pairs
- Produced charmed hadrons go together in forward direction (LHCb acceptance $2<\eta<5$)
- Lorentz boost provides signature for **c-& b**- hadrons selection
- Tagging for prompt-c production gives the highest tagging rate
- Tagging for c from b decays gives the most efficient triggering



Amplitude Analysis of Charmed Meson Decays

Amplitude Analysis of $D^0 \to K^-\pi^+\pi^0\pi^0$

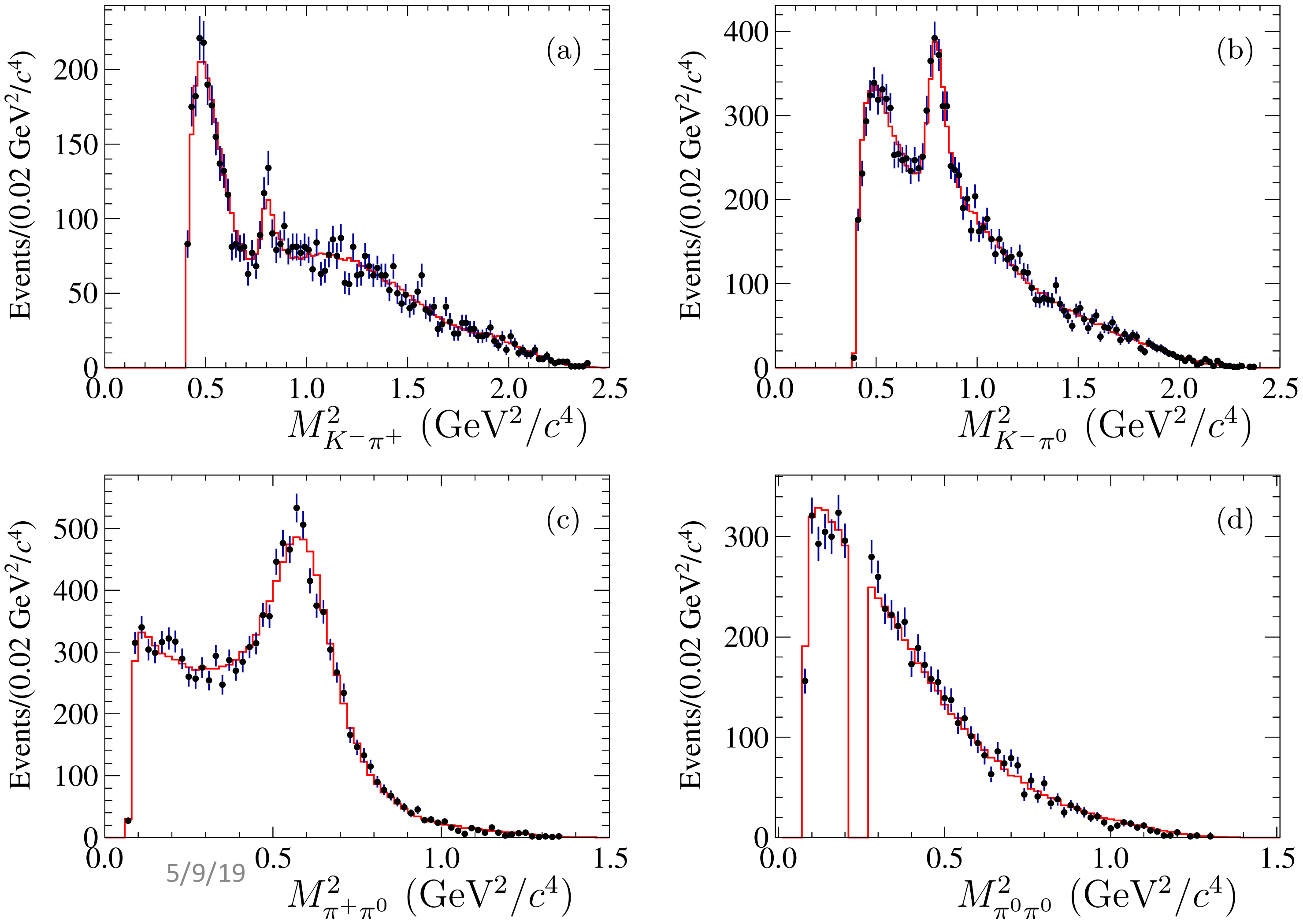
arXiv: 1903.06316

$2.93 fb^{-1} @ \sqrt{s} = 3.773 GeV$

Double tag analysis: tag mode: $\bar{D}^0 \to K^+\pi^-$ signal mode: $D^0 \to K^-\pi^+\pi^0\pi^0$

6100 events with 99% purity used for amplitude analysis

$$B(D^0 \to K^-\pi^+\pi^0\pi^0) = (8.86 \pm 0.13(stat) \pm 0.19(syst))\%$$



Amplitude mode	**FF** (%)	**Phase** (ϕ)	**Significance** (σ)
$D \to SS$			
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_S$	$6.92 \pm 1.44 \pm 2.86$	$-0.75 \pm 0.15 \pm 0.47$	> 10
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_S$	$4.18 \pm 1.02 \pm 1.77$	$-2.90 \pm 0.19 \pm 0.47$	6.0
$D \to AP, A \to VP$			
$D \to K^-a_1(1260)^+, \rho^+\pi^0[S]$	$28.36 \pm 2.50 \pm 3.53$	0 (fixed)	> 10
$D \to K^-a_1(1260)^+, \rho^+\pi^0[D]$	$0.68 \pm 0.29 \pm 0.30$	$-2.05 \pm 0.17 \pm 0.25$	6.1
$D \to K_1(1270)^-\pi^+, K^{*-}\pi^0[S]$	$0.15 \pm 0.09 \pm 0.15$	$1.84 \pm 0.34 \pm 0.43$	4.9
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[S]$	$0.39 \pm 0.18 \pm 0.30$	$-1.55 \pm 0.20 \pm 0.26$	4.8
$D \to K_1(1270)^0\pi^0, K^{*0}\pi^0[D]$	$0.11 \pm 0.11 \pm 0.11$	$-1.35 \pm 0.43 \pm 0.48$	4.0
$D \to K_1(1270)^0\pi^0, K^-\rho^+[S]$	$2.71 \pm 0.38 \pm 0.29$	$-2.07 \pm 0.09 \pm 0.20$	> 10
$D \to (K^{*-}\pi^0)_A\pi^+, K^{*-}\pi^0[S]$	$1.85 \pm 0.62 \pm 1.11$	$1.93 \pm 0.10 \pm 0.15$	7.8
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[S]$	$3.13 \pm 0.45 \pm 0.58$	$0.44 \pm 0.12 \pm 0.21$	> 10
$D \to (K^{*0}\pi^0)_A\pi^0, K^{*0}\pi^0[D]$	$0.46 \pm 0.17 \pm 0.29$	$-1.84 \pm 0.26 \pm 0.42$	5.9
$D \to (\rho^+K^-)_A\pi^0, K^-\rho^+[D]$	$0.75 \pm 0.40 \pm 0.60$	$0.64 \pm 0.36 \pm 0.53$	5.1
$D \to AP, A \to SP$			
$D \to ((K^-\pi^+)_{S\text{-wave}}\pi^0)_A\pi^0$	$1.99 \pm 1.08 \pm 1.55$	$-0.02 \pm 0.25 \pm 0.53$	7.0
$D \to VS$			
$D \to (K^-\pi^0)_{S\text{-wave}}\rho^+$	$14.63 \pm 1.70 \pm 2.41$	$-2.39 \pm 0.11 \pm 0.35$	> 10
$D \to K^{*-}(\pi^+\pi^0)_S$	$0.80 \pm 0.38 \pm 0.26$	$1.59 \pm 0.19 \pm 0.24$	4.1
$D \to K^{*0}(\pi^0\pi^0)_S$	$0.12 \pm 0.12 \pm 0.12$	$1.45 \pm 0.48 \pm 0.51$	4.1
$D \to VP, V \to VP$			
$D \to (K^{*-}\pi^+)_V\pi^0$	$2.25 \pm 0.43 \pm 0.45$	$0.52 \pm 0.12 \pm 0.17$	> 10
$D \to VV$			
$D \to K^{*-}\rho^+[S]$	$5.15 \pm 0.75 \pm 1.28$	$1.24 \pm 0.11 \pm 0.23$	> 10
$D \to K^{*-}\rho^+[P]$	$3.25 \pm 0.55 \pm 0.41$	$-2.89 \pm 0.10 \pm 0.18$	> 10
$D \to K^{*-}\rho^+[D]$	$10.90 \pm 1.53 \pm 2.36$	$2.41 \pm 0.08 \pm 0.16$	> 10
$D \to (K^-\pi^0)_V\rho^+[P]$	$0.36 \pm 0.19 \pm 0.27$	$-0.94 \pm 0.19 \pm 0.28$	5.7
$D \to (K^-\pi^0)_V\rho^+[D]$	$2.13 \pm 0.56 \pm 0.92$	$-1.93 \pm 0.22 \pm 0.25$	> 10
$D \to K^{*-}(\pi^+\pi^0)_V[D]$	$1.66 \pm 0.52 \pm 0.61$	$-1.17 \pm 0.20 \pm 0.39$	7.6
$D \to (K^-\pi^0)_V(\pi^+\pi^0)_V[S]$	$5.17 \pm 1.91 \pm 1.82$	$-1.74 \pm 0.20 \pm 0.31$	7.6
$D \to TS$			
$D \to (K^-\pi^+)_{S\text{-wave}}(\pi^0\pi^0)_T$	$0.30 \pm 0.21 \pm 0.30$	$-2.93 \pm 0.31 \pm 0.82$	5.8
$D \to (K^-\pi^0)_{S\text{-wave}}(\pi^+\pi^0)_T$	$0.14 \pm 0.12 \pm 0.10$	$2.23 \pm 0.38 \pm 0.65$	4.0

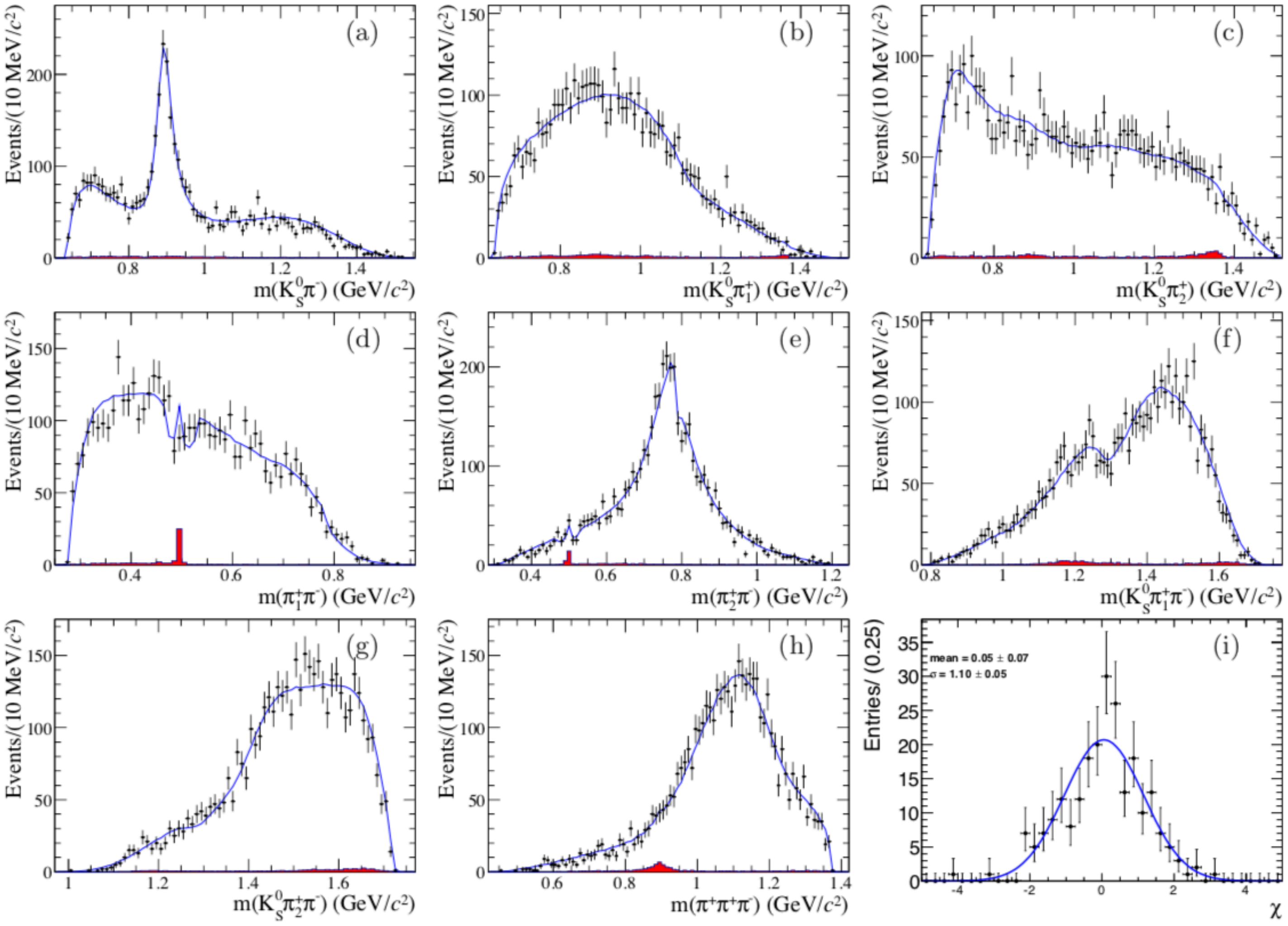
Amplitude Analysis of $D^+ \to K^0_S\pi^+\pi^+\pi^-$

arXiv: 1902.05936

$2.93 fb^{-1} @ \sqrt{s} = 3.773 GeV$

Double tag analysis: tag mode $D^- \to K^+\pi^-\pi^-$

4559 events with 97.5% purity used for amplitude analysis



Component	Branching fraction (%)
$D^+ \to K^0_S a_1(1260)^+(\rho^0\pi^+)$	$1.197 \pm 0.062 \pm 0.086 \pm 0.044$
$D^+ \to K^0_S a_1(1260)^+(f_0(500)\pi^+)$	$0.163 \pm 0.021 \pm 0.005 \pm 0.006$
$D^+ \to \bar{K}_1(1400)^0(K^{*-}\pi^+)\pi^+$	$0.642 \pm 0.036 \pm 0.033 \pm 0.024$
$D^+ \to \bar{K}_1(1270)^0(K^0_S\rho^0)\pi^+$	$0.071 \pm 0.009 \pm 0.021 \pm 0.003$
$D^+ \to \bar{K}(1460)^0(K^{*-}\pi^+)\pi^+$	$0.202 \pm 0.018 \pm 0.006 \pm 0.007$
$D^+ \to \bar{K}(1460)^0(K^0_S\rho^0)\pi^+$	$0.024 \pm 0.006 \pm 0.015 \pm 0.009$
$D^+ \to \bar{K}_1(1650)^0(K^{*-}\pi^+)\pi^+$	$0.048 \pm 0.012 \pm 0.027 \pm 0.002$
$D^+ \to K^0_S\pi^+\rho^0$	$0.190 \pm 0.021 \pm 0.089 \pm 0.007$
$D^+ \to K^0_S\pi^+\pi^+\pi^-$	$0.241 \pm 0.018 \pm 0.018 \pm 0.009$

- Improved precision for sub decay modes
- Agreement with previous measurement
- Comparison with neutral mode $D^0 \to K^-\pi^+\pi^+\pi^-$
  - $D^+ \to \bar{K}_1(1400)^0\pi^+$ larger

Amplitude Analysis of $D^+_s \to \pi^+\pi^0\eta$

BESIII

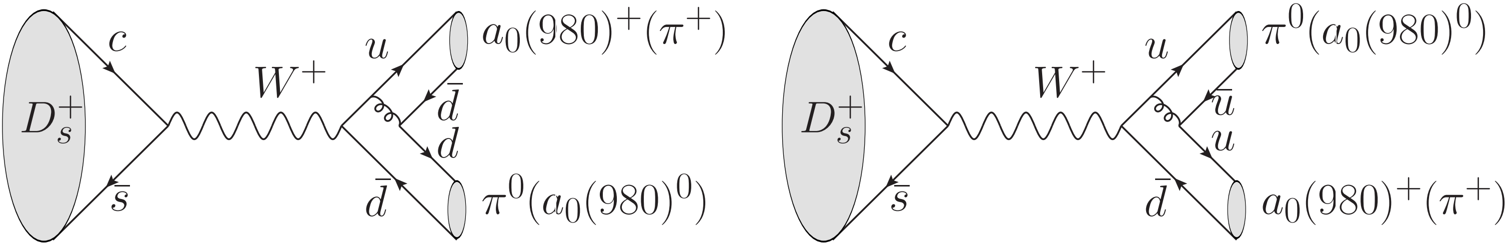
arXiv: 1903.04118

$3.19 fb^{-1} @ \sqrt{(s)} = 4.178 GeV$

Double tag analysis:

tag modes $D_s^- \to K_S^0 K^-, D_s^- \to K^+K^-\pi^-, D_s^- \to K_S^0 K^- \pi^0, D_s^- \to K^+K^-\pi^-\pi^0,$
$D_s^- \to K_S^0 K^+\pi^-\pi^-, D_s^- \to \pi^-\eta$

1239 events with 97.7% purity used for amplitude analysis

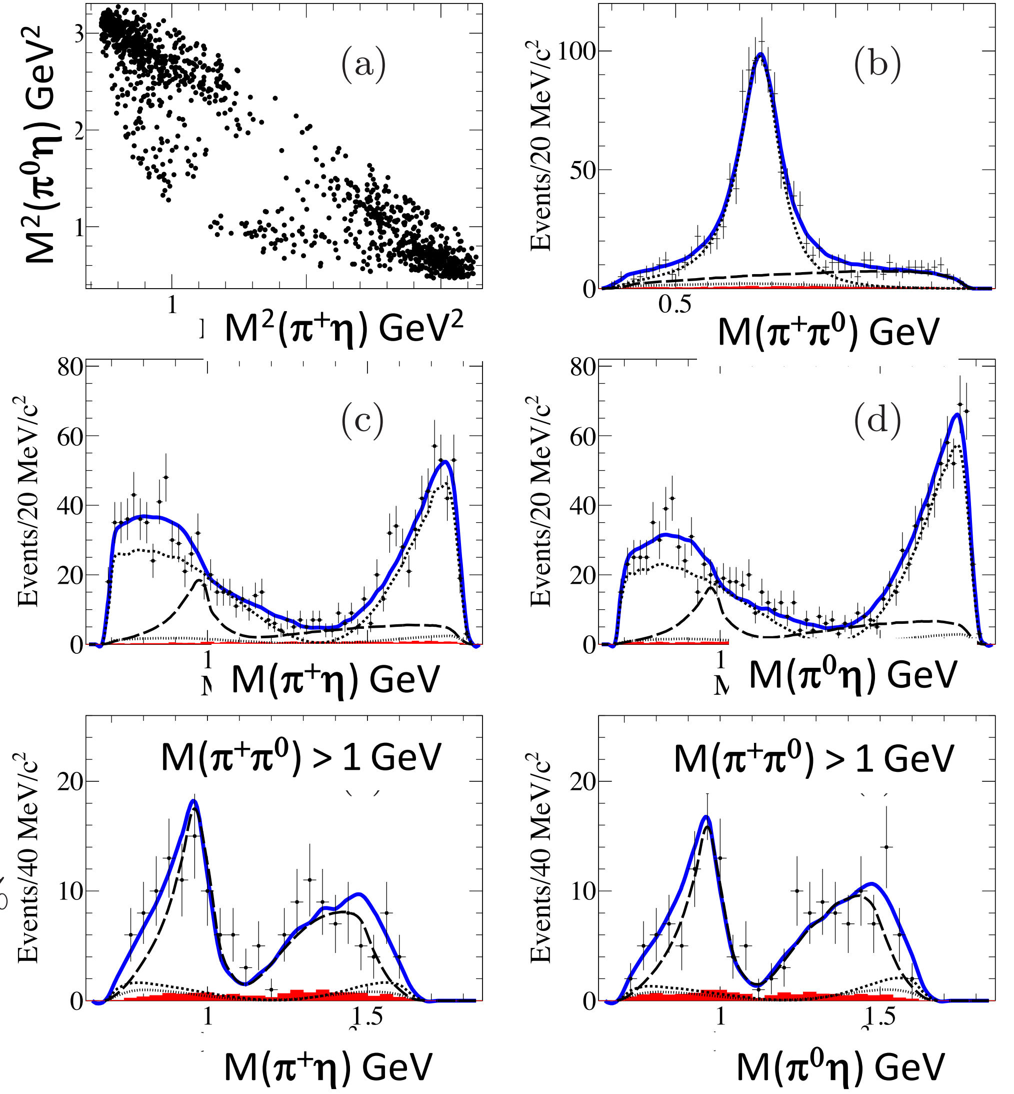


$$B(D_s^+ \to \pi^+\pi^-\eta) = (9.50 \pm 0.28(stat) \pm 0.41(sys))\%$$

Amplitude	ϕ_n (rad)	FF_n
$D_s^+ \to \rho^+\eta$	0.0 (fixed)	$0.783 \pm 0.050 \pm 0.021$
$D_s^+ \to (\pi^+\pi^0)_V\eta$	$0.612 \pm 0.172 \pm 0.342$	$0.054 \pm 0.021 \pm 0.025$
$D_s^+ \to a_0(980)\pi$	$2.794 \pm 0.087 \pm 0.044$	$0.232 \pm 0.023 \pm 0.033$

$$\mathcal{B}(D_s^+ \to a_0(980)^{+(0)}\pi^{0(+)}, a_0(980)^{+(0)} \to \pi^{+(0)}\eta) = (1.46 \pm 0.15_{\text{stat.}} \pm 0.23_{\text{sys.}})\%$$

First observation of $D^+_s \to a^0 \pi^+$, 16.2σ significance



Dalitz Plot Analysis of $D^+ \to K^-K^+K^+$ (1)

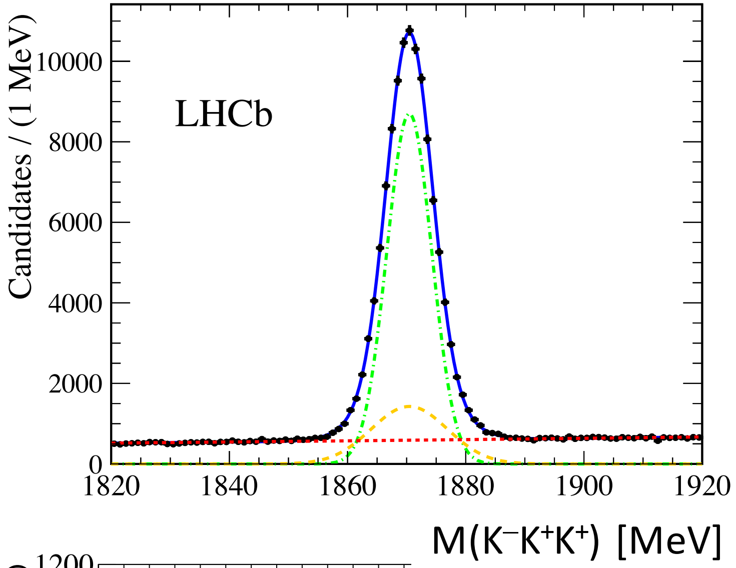
JHEP 04,063 (2019)

$2fb^{-1}@\sqrt{(s)} = 8TeV$

Dalitz plot analysis performed with the isobar model and a phenomenological model based on an effective chiral lagrangian (Triple M amplitude).

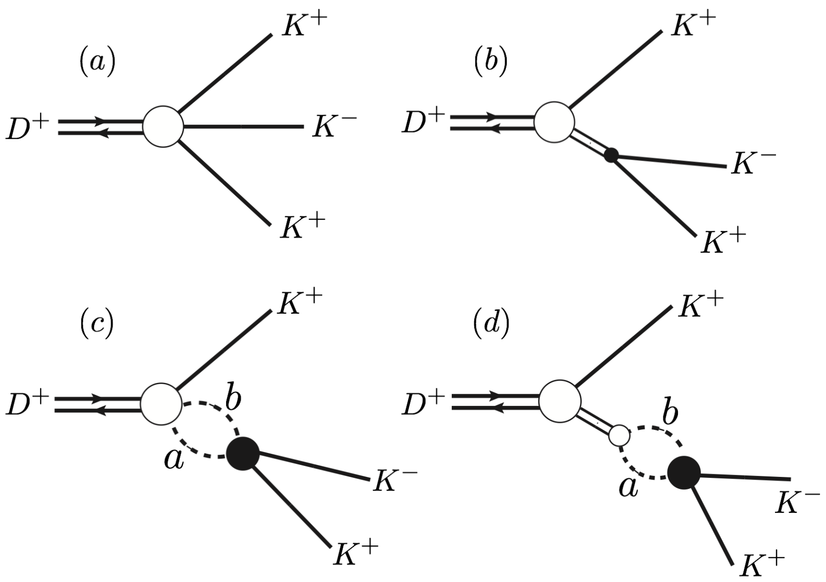
Possible contributions in the Isobar Model:

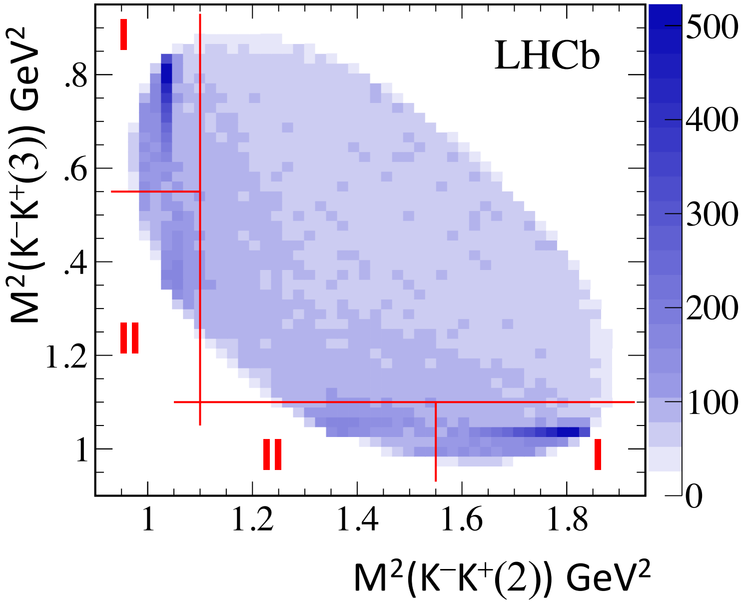
- Isoscalars: $f_0(980)$, $f_0(1370)$, $f_0(1500)$
- Isovector $a_0(980)$, $a_0(1450)$
- Vector $\phi(1020)$
- Tensor f2(1270)

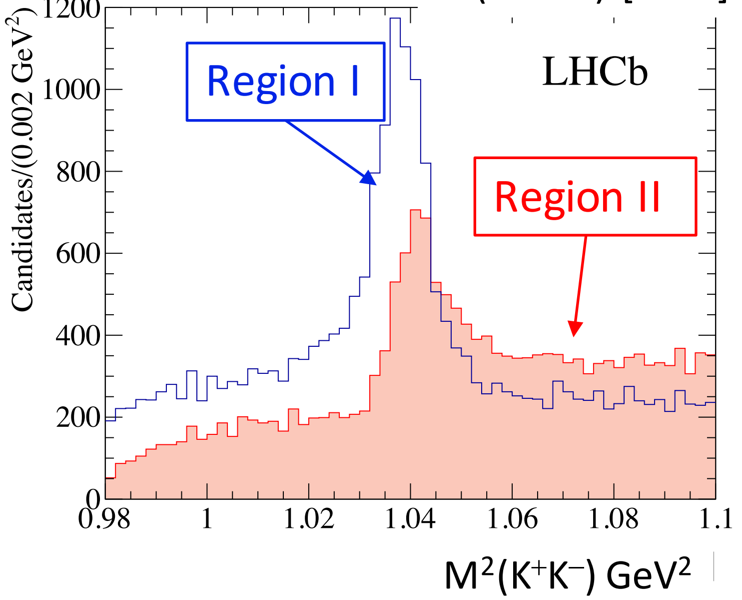


Different Diagrams contibute to Triple M Amplitude:

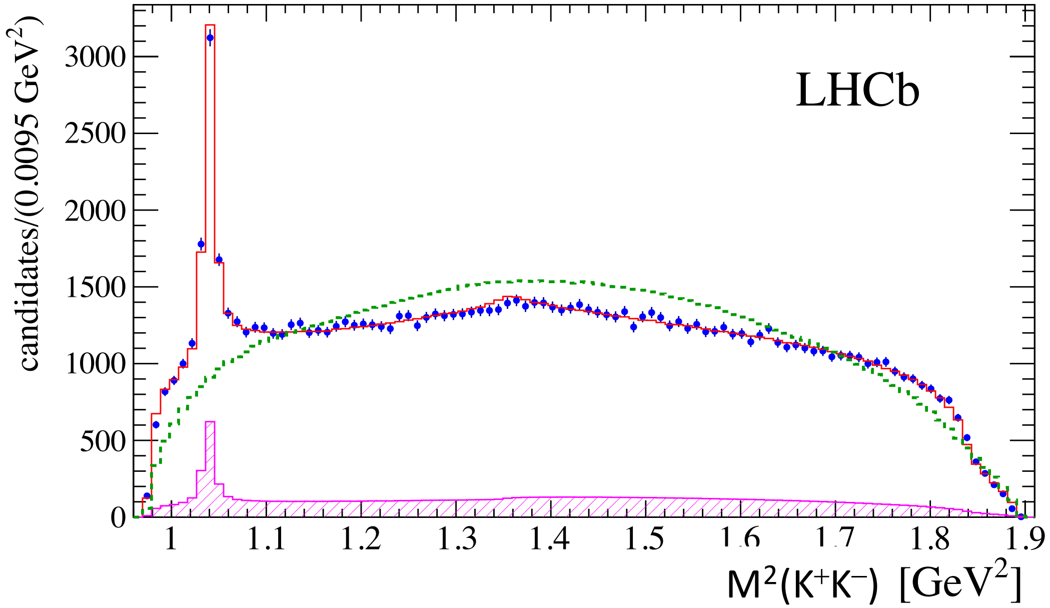
PRD 98,056021(2018)

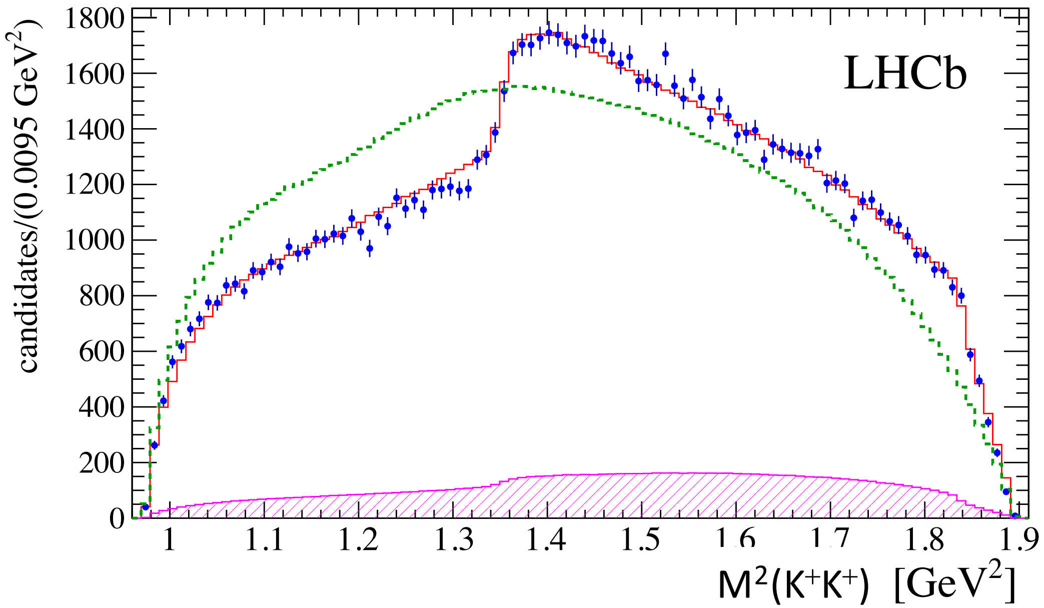






Dalitz Plot Analysis of $D^+ \to K^-K^+K^+$ (2)





Isobar model: several variation of the decay amplitude give similar fit results
Baseline result includes $\phi(1020)\,K^+$, $f_0(980)\,K^+$, $f_0(1370)\,K^+$

Triple M amplitude has a non resonant component plus the minimal SU(3) content corresponding to $\phi(1020)$, $a(980)$, $f_0(980)$, $f_0(1370)\,K^+$

Both approaches give a good description of data

Resonance structure is largely dominated by S-wave component with a 7% contribution from $\phi(1020)\,K^+$

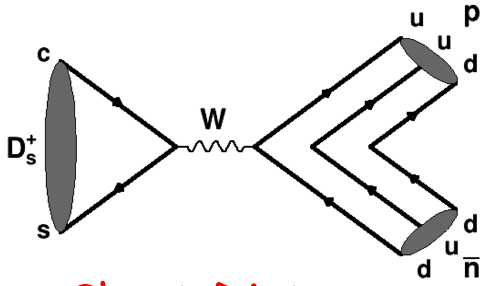
Two Body Decays of Charmed Mesons

$D^+_s \to p\bar{n}$

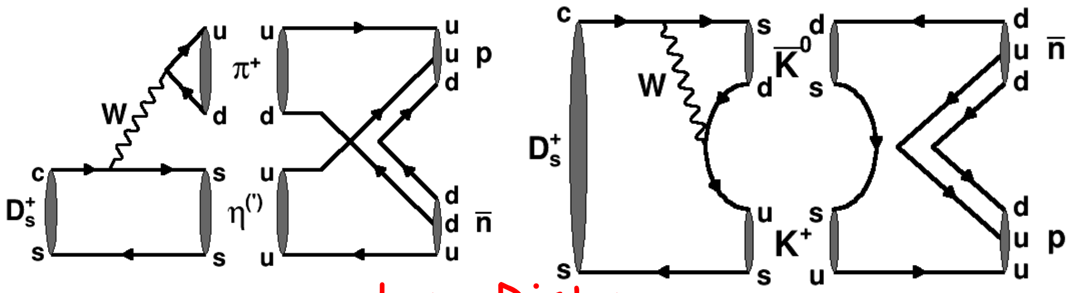
Phys.Rev.D99, 031101 (2019)

$3.19 fb^{-1} @ \sqrt{(s)} = 4.178 GeV$

At short distance BR expected to be $O(10^{-6})$, due to the chiral suppression factor $(m_\pi/m_{D_s})^4$
Long distance effect can enhance BR up to $O(10^{-3})$



Short Distance



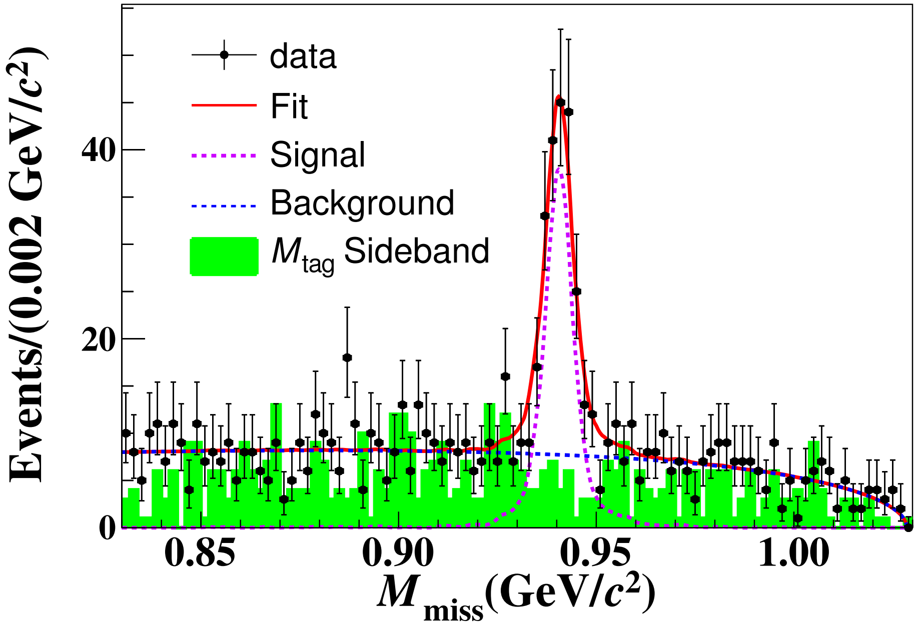
Long Distance

First evidence by CLEO-c: $(1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$ PRL 100, 181802(2008)

BESIII $B(D^+_s \to p\bar{n}) = (1.21 \pm 0.10(stat) \pm 0.05(sys)) \times 10^{-3}$

- Double tag analysis: $D^+_s \to p\bar{n}$ is reconstructed in the recoil of a fully reconstructed D_s
- Signal yield from unbinned likelihood fit to the missing mass

- The short distance weak annihilation process is not the driving mechanism
- The hadronization process driven by non-perturbative dynamics determines the underlying physics



$D^+_s \to \omega\pi^+$ and ωK^+

arXiv: 1811.00392

$3.19 fb^{-1} @ \sqrt{(s)} = 4.178 GeV$

Pure W annihilation processes, sensitive to direct CP violation

From CLEO: evidence of $D^+_s \to \omega\pi^+$ and UL on $D^+_s \to \omega K^+$

Using $B(D^+_s \to \omega\pi^+)$ as input, Q. Quin et al. [PRD 89, 054006] predict:

$\mathcal{B}(D_s^+ \to \omega K^+) = 0.6 \times 10^{-3}, \mathrm{A_{CP}}(D_s^+ \to \omega K^+) = -0.6 \times 10^{-3}$ **(without $\rho - \omega$ mixing)**

$\mathcal{B}(D_s^+ \to \omega K^+) = 0.07 \times 10^{-3}, \mathrm{A_{CP}}(D_s^+ \to \omega K^+) = -2.3 \times 10^{-3}$ **(with $\rho - \omega$ mixing)**

Double tag technique.

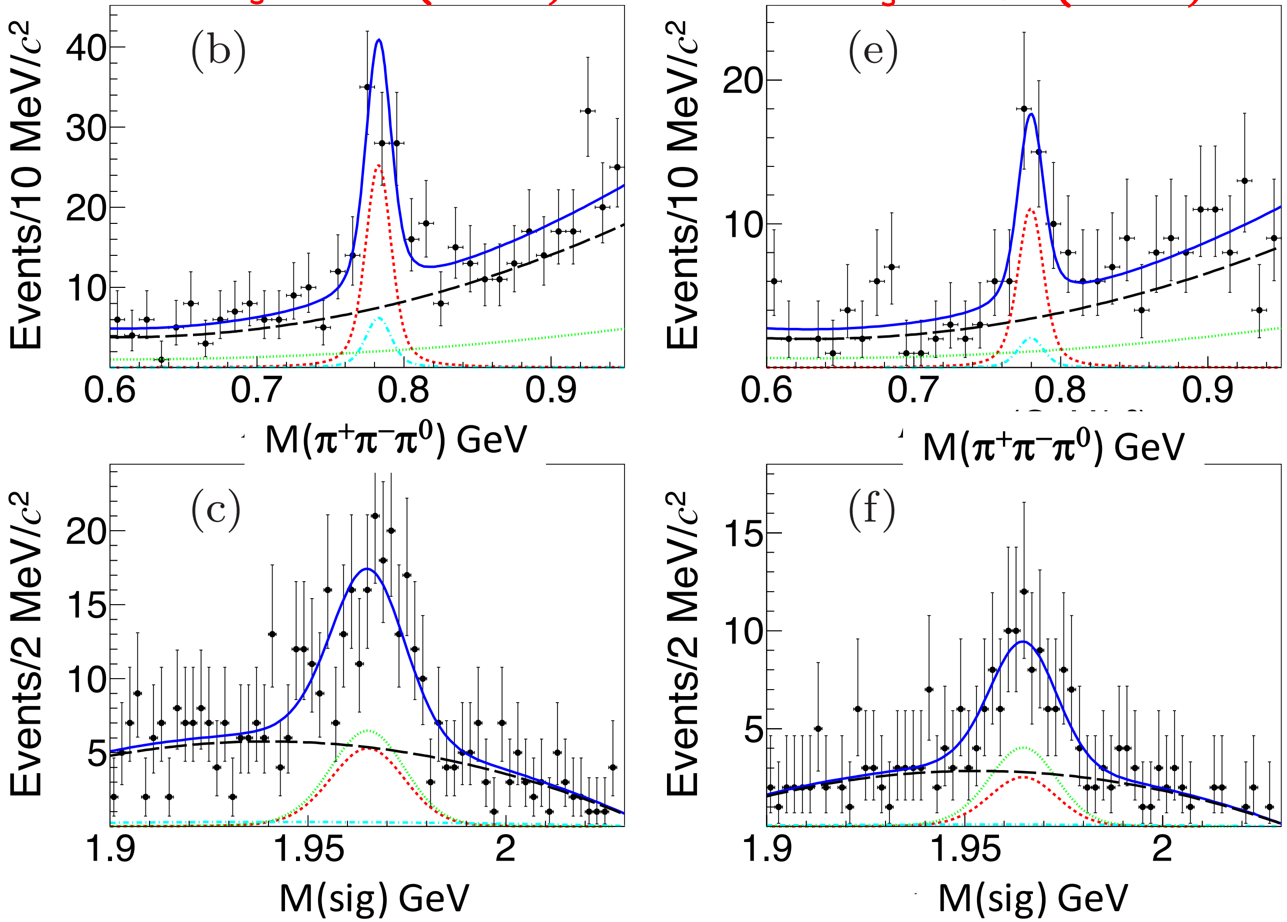
Signal yield from fit to M_ω and M_{sig}

$$B(D_s^+ \to \omega\pi^+) = (1.77 \pm 0.32(stat) \pm 0.12(sys)) \times 10^{-3}$$

$$B(D_s^+ \to \omega K^+) = (0.87 \pm 0.24(stat) \pm 0.07(sys)) \times 10^{-3}$$

First evidence

$D^+_s \to \omega\pi^+$ (6.7 σ) $D^+_s \to \omega K^+$ (4.4 σ)



According to Q. Quin et al. this results imply that $\rho - \omega$ mixing is negligible and that direct A_{CP} is of the order of -0.6×10^{-3}

$D^+_s \to K^0_S K^+$ and $K^0_L K^+$

arXiv: 1903.04164

$3.19 fb^{-1} @ \sqrt{(s)} = 4.178 GeV$

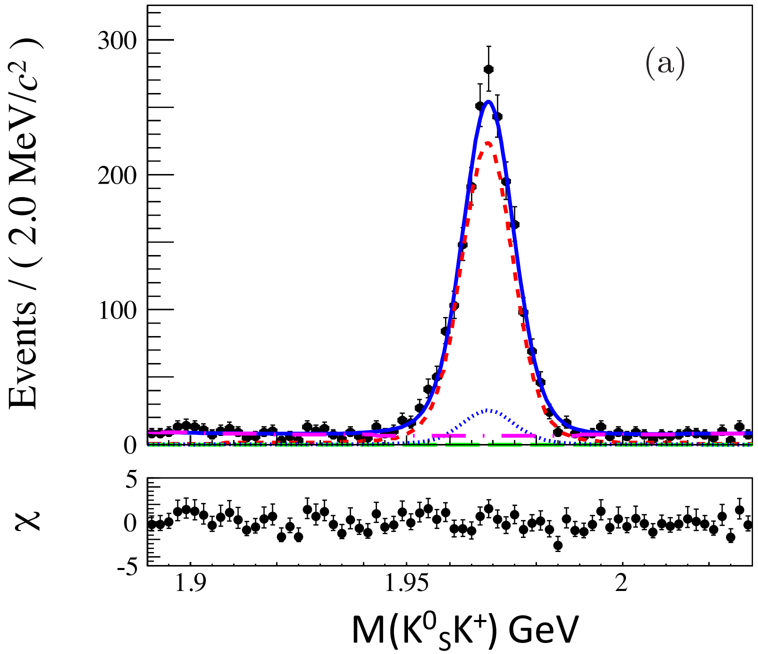
D_s candidates from the process

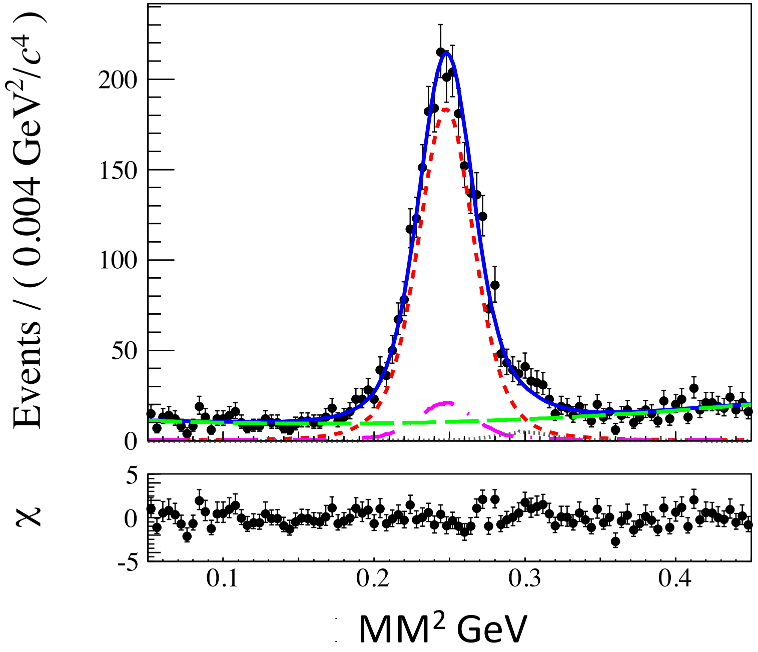
$$e^+e^- \to D_s^{*\pm} D_s^{\mp} \to \gamma D_s^+ D_s^-$$

Double tag analysis

Signal yields from UML fit to $M(K^0_S K^+)$

$$MM^2 = (P_{e^+e^-} - P_{D_s^-} - P_\gamma - P_{K^+})^2$$





$$\mathcal{B}(D^+_s \to K^0_S K^+) = (1.425 \pm 0.038_{\rm stat.} \pm 0.031_{\rm syst.})\%$$

Compatible with WA

$$\mathcal{B}(D^+_s \to K^0_L K^+) = (1.485 \pm 0.039_{\rm stat.} \pm 0.046_{\rm syst.})\%$$

New

$$\frac{\mathcal{B}(D^+_s \to K^0_S K^+) - \mathcal{B}(D^+_s \to K^0_L K^+)}{\mathcal{B}(D^+_s \to K^0_S K^+) + \mathcal{B}(D^+_s \to K^0_L K^+)} = (-2.1 \pm 1.9_{\rm stat.} \pm 1.6_{\rm syst.})\%$$

Charmed Baryons

Charmed Baryons

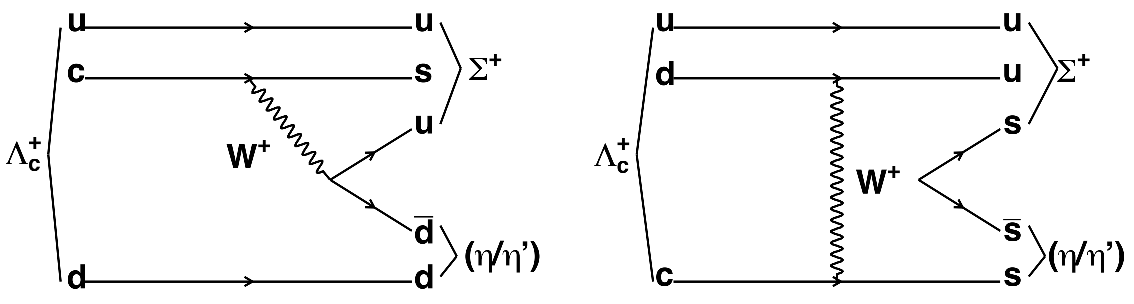
- Studies of charmed baryon decays provides insights on internal dynamic complementary to the ones coming from charmed meson decays.
- Until 2014, the charmed baryons measurements had large experimental uncertainties and the development in theory was limited
- Afterwards, more extensive measurements from BESIII, BELLE and LHCb:
  - The absolute BF measurements (BESIII/BELLE)
  - The observation of DCS mode $\Lambda_c^+ \to pK^+\pi^-$ (BELLE)
  - The observation of Ξ_{cc}^{++} (LHCb)
  - The lifetime measurement of Ξ_{cc}^{++} and Ω_c^+
- These experimental progresses stimulated renewed theoretical efforts

BESIII

arXiv: 1811.08028

Λ_c^+ -> $\Sigma^+\eta$ and Λ_c^+ -> $\Sigma^+\eta'$ (1)

$567pb^{-1}@\sqrt{(S)} = 4.6GeV$



CF decays that proceed through non-factorizable internal W emission and exchange

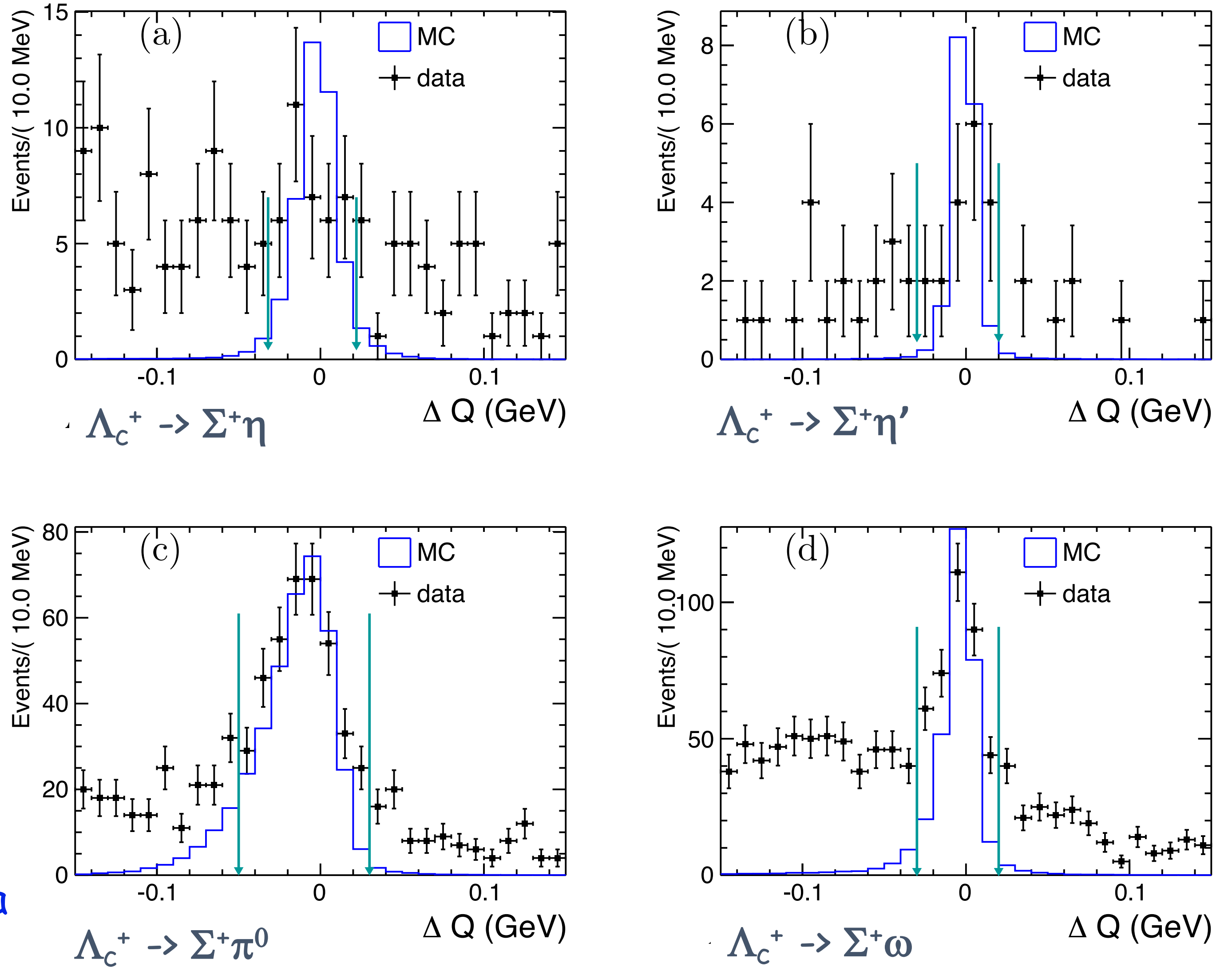
Single tag analysis, Λ_c fully reconstructed in $\Sigma^+\eta$, $\Sigma^+\eta'$, $\Sigma^+\pi^0$, $\Sigma^+\omega$ channels

Applied a mode dependent selection on ΔQ

$$\Delta Q = \Delta E - k(M_{p\pi^0} - M_{\Sigma^+})$$

$$\Delta E = E_{beam} - E_{\Lambda_c^+}$$

K is determined from data with a fit to the two-dimensional distributions of ΔE versus $M_{p\pi^0}$ with a linear function



$\Lambda_c^+ \to \Sigma^+\eta$ and $\Lambda_c^+ \to \Sigma^+\eta'$ (2)

Signal yields from UML fit to M_{BC} distributions

$N_{\Sigma\eta} = 14.6 \pm 6.6$ $\quad N_{\Sigma\eta'} = 13.0 \pm 4.8$

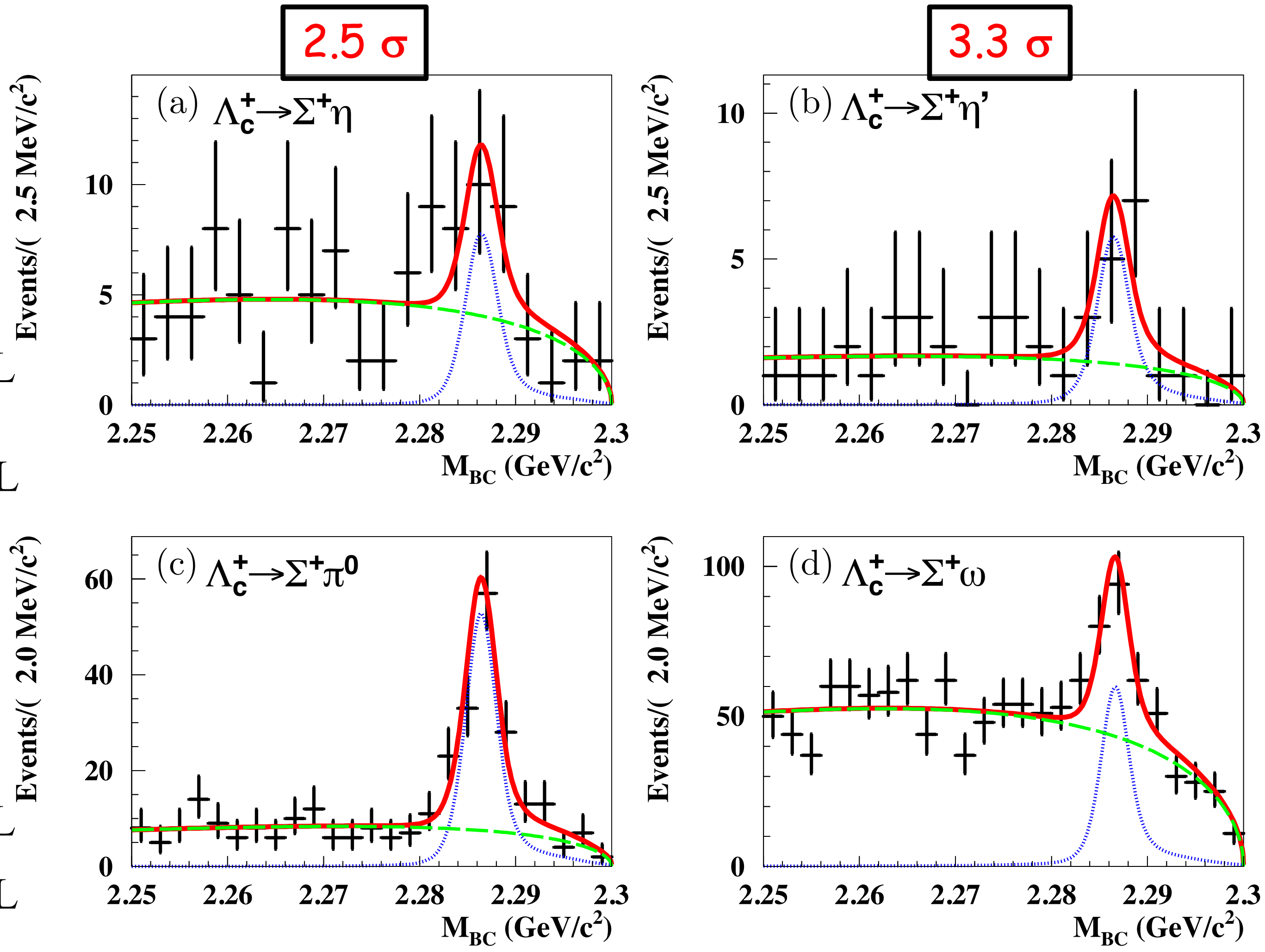
$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta)}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^0)} = 0.35 \pm 0.16 \pm 0.03 \quad < 0.58 \text{ @ } 90\% \text{ CL}$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta')}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\omega)} = 0.86 \pm 0.34 \pm 0.07 \quad < 1.2 \text{ @ } 90\% \text{ CL}$$

Using previous BESIII measurement of $\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^0)$ and $\mathcal{B}(\Lambda_c^+ \to \Sigma^+\omega)$ from PRL 116, 052001 (2016):

$$B(\Lambda_c \to \Sigma\eta) = (0.41 \pm 0.19 \pm 0.05)\% < 0.68\% \text{ @ } 90\% \text{ CL}$$

$$B(\Lambda_c \to \Sigma\eta') = (1.34 \pm 0.53 \pm 0.21)\% < 1.9\% \text{ @ } 90\% \text{ CL}$$



$$M_{BC} = \sqrt{E_{beam}^2 - |\vec{p}_{\Lambda_c^+}|^2}$$

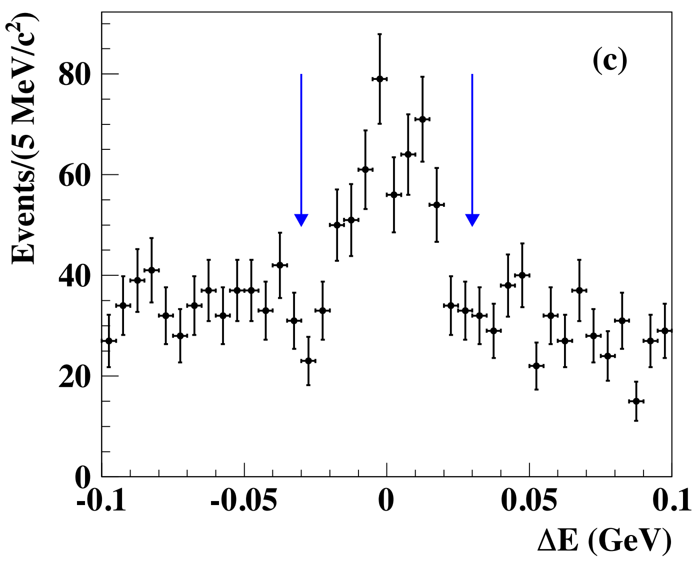
BESIII

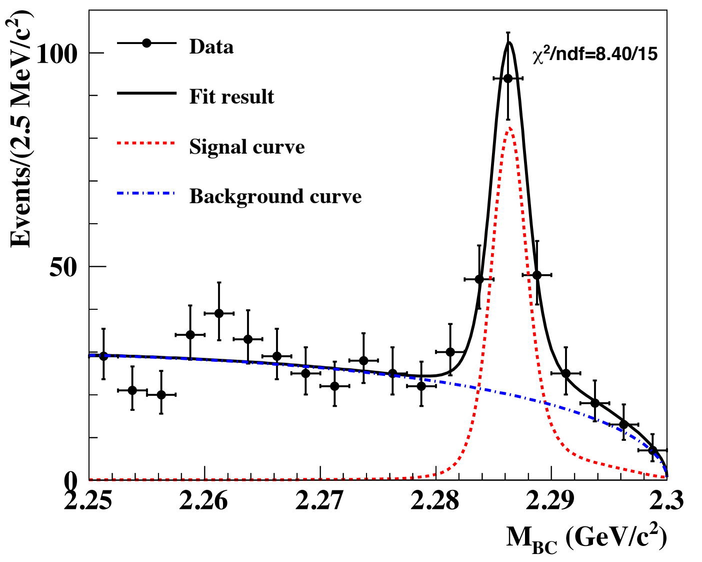
$\Lambda_c^+ \to \Lambda\eta\pi^+$ and $\Lambda_c^+ \to \Sigma^+(1385)\eta$

PRD 99, 032010(2019)

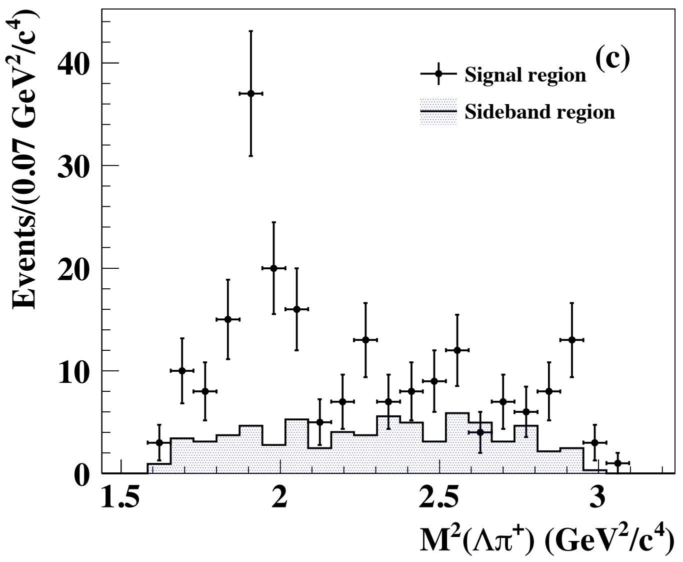
$567pb^{-1}@\sqrt{(S)} = 4.6GeV$

- Single tag analysis.
- Cuts on $M(p\pi^-)$, $M(\gamma\gamma)$ and ΔE.
- Event yield for $\Lambda\eta\pi^+$ from UML fit to M_{BC}
- Event yield for $\Sigma^+(1385)\eta$ from UML fit to $M(\Lambda\pi^+)$ on events within the M_{BC} signal region





	$\Lambda\eta\pi^+$	$\Sigma^{*+}\eta$
$N_{\rm sig}$	154 ± 17	54 ± 11
$\varepsilon(\%)$	15.73 ± 0.01	12.84 ± 0.01
$\mathcal{B}(\%)$	$1.84 \pm 0.21 \pm 0.15$	$0.91 \pm 0.18 \pm 0.09$



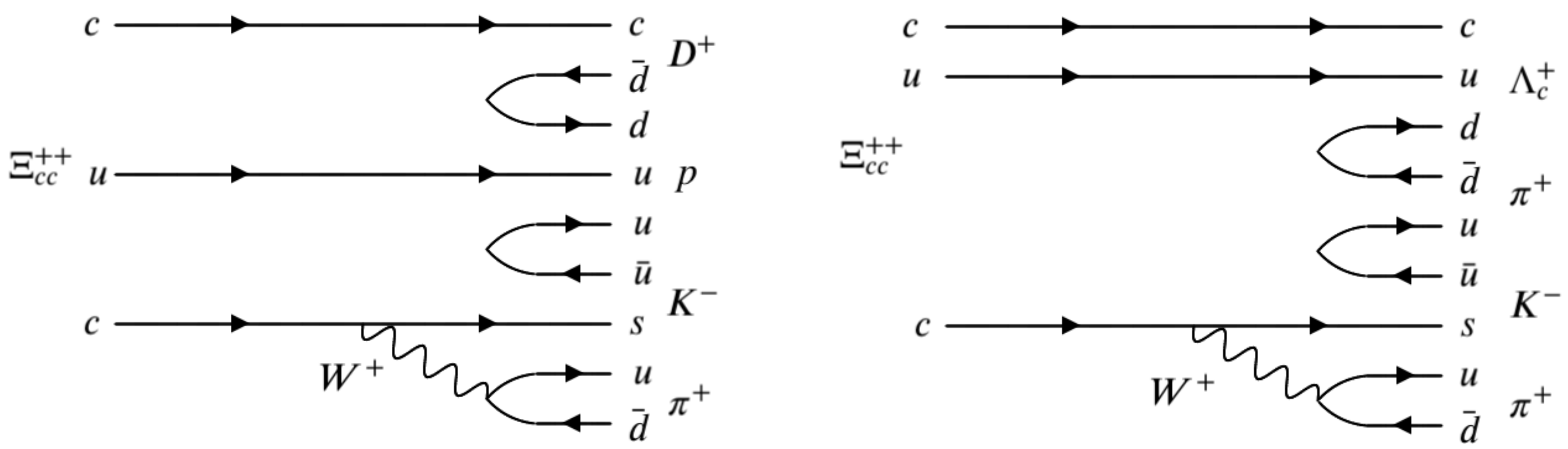
Search for $\Xi_{cc}^{++} \to D^+ p K^- \pi^+$ (1)

arXiv: 1905.02421

$1.7 fb^{-1} @ \sqrt{s} = 13 TeV$

Searched for $\Xi_{cc}^{++} \to D^+ p K^- \pi^+$ (CF) $D^+ \to K^- \pi^+ \pi^+$ (CF) in 2016 data

Naïve expectation: $\mathcal{B}(\Xi_{cc}^{++} \to D^+ p K^- \pi^+) \simeq \mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)$



In addition:
LHCb has an excellent $D^+ \to K^- \pi^+ \pi^+$ trigger
Longer D+ lifetime implies that D+ flies further away from Ξ_{cc}^{++} decay vertex

Search for $\Xi_{cc}^{++} \to D^+ p K^- \pi^+$ (2)

After selection:

- 80% purity D^+ sample
- No $\Xi_{cc}^{++} \to D^+ p K^- \pi^+$ signal in 2016 data
- RS and WS candidate mass distributions look similar

Set Upper Limits on:

$$\mathcal{R} = \frac{\mathcal{B}(\Xi_{cc}^{++} \to D^+ p K^- \pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)} =$$

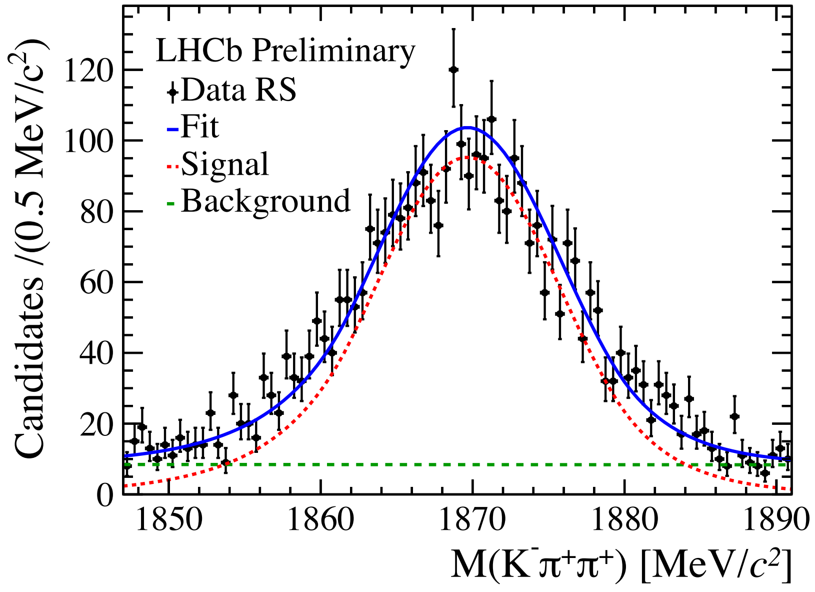
$$= \frac{N(D^+ p K^- \pi^+)}{N(\Lambda_c^+ K^- \pi^+ \pi^+)} \times \frac{\varepsilon(\Lambda_c^+ K^- \pi^+ \pi^+)}{\varepsilon(D^+ p K^- \pi^+)} \times \frac{\mathcal{B}(\Lambda_c^+ \to p K^- \pi^+)}{\mathcal{B}(D^+ \to K^- \pi^+ \pi^+)}$$

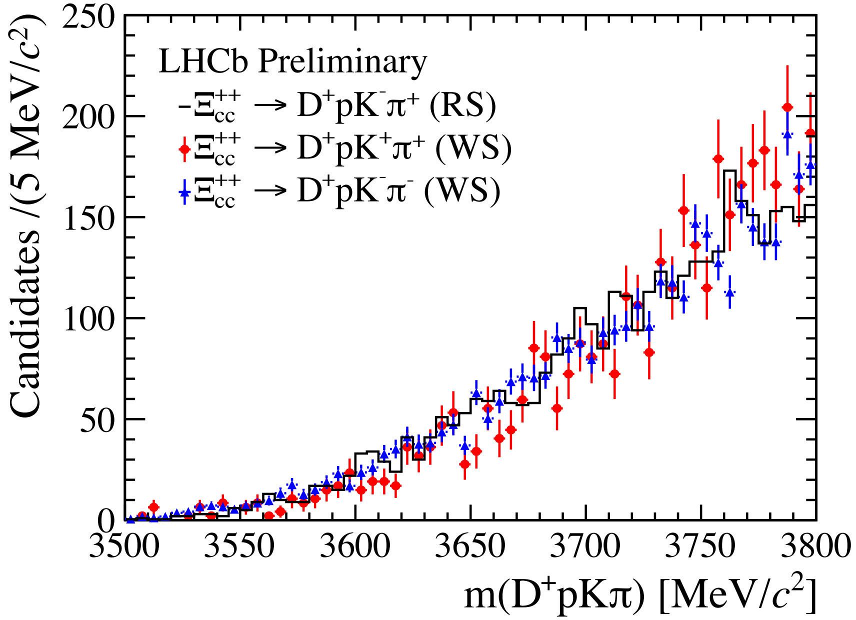
$= 184 \pm 29$ (from data)

$= 0.46 \pm 0.01$ (from simulation)

$\mathcal{R} < 1.7\ (2.1) \times 10^{-2}$ at 90% (95%) CL

Better understanding of resonant and non resonant contribution is needed to explain large difference in Branching Ratios



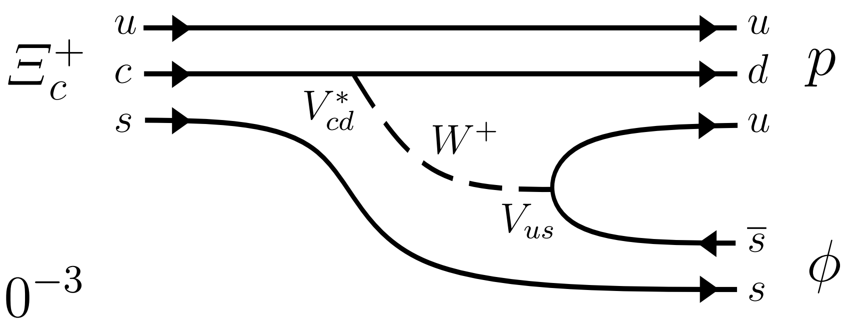


Observation of DCS Decay $\Xi_c^+ \to p\phi$

JHEP 04, 084 (2019)

$2fb^{-1}@\sqrt{(s)} = 8TeV$

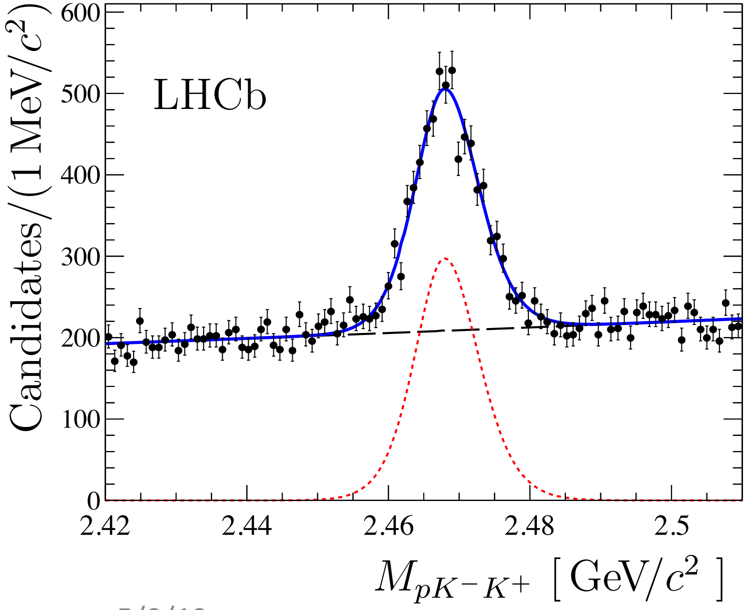
Measured the ratio: $$R_{p\phi} \equiv \frac{\mathcal{B}(\Xi_c^+ \to p\phi)}{\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)}$$

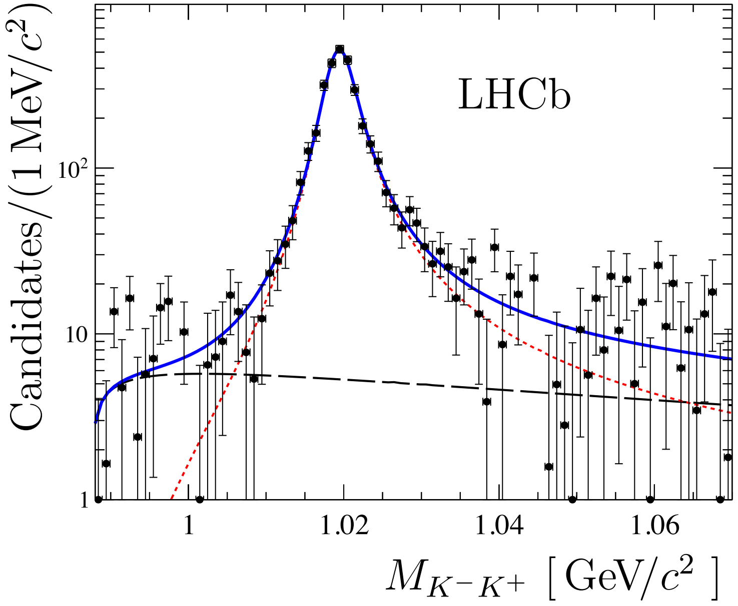


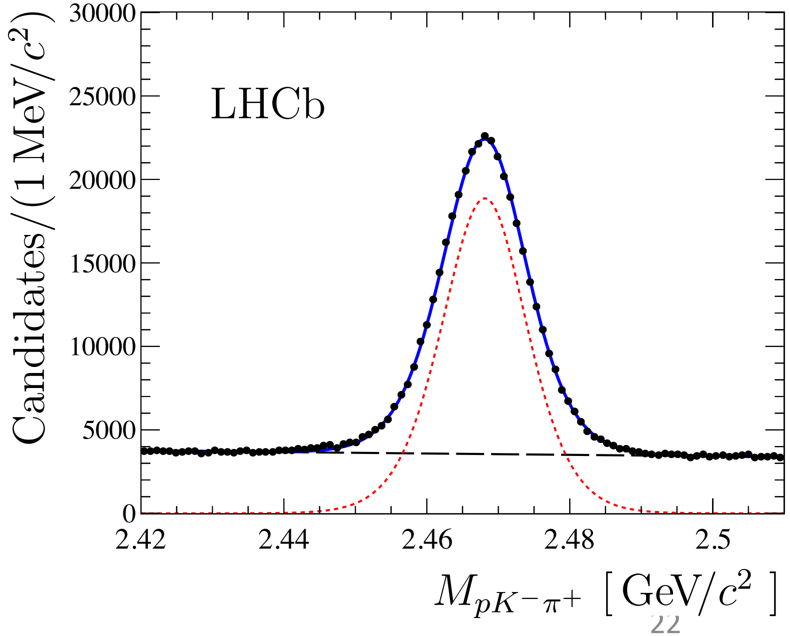
Fraction of ϕ in KK mass spectrum

$$R_{p\phi} = \frac{N_{pKK} f_\phi}{\mathcal{B}(\phi \to K^+K^-)} \times \frac{1}{N_{pK\pi}} \times \frac{\epsilon_{\rm total}^{pK\pi}}{\epsilon_{\rm total}^{p\phi}} = (19.8 \pm 0.7 \pm 0.9 \pm 0.2) \times 10^{-3}$$

From knowledge of ϕ -> KK branching fraction

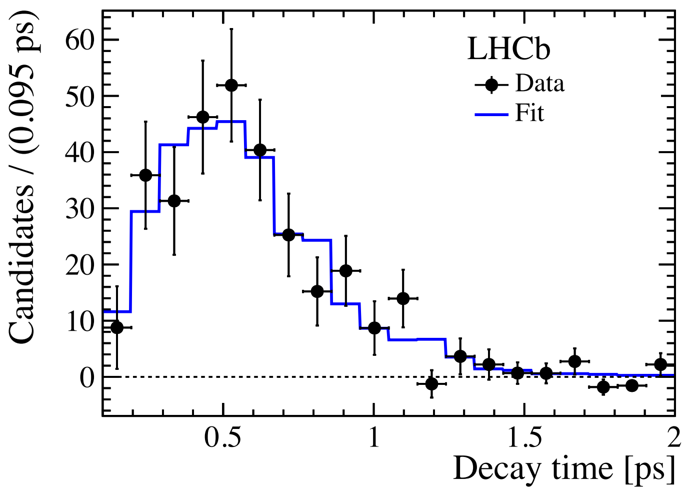






Charmed Baryons Lifetimes

Ξ_{cc}^{++} background subtracted data



Ξ_{cc}^{++} lifetime PRL 121, 052002 (2018)

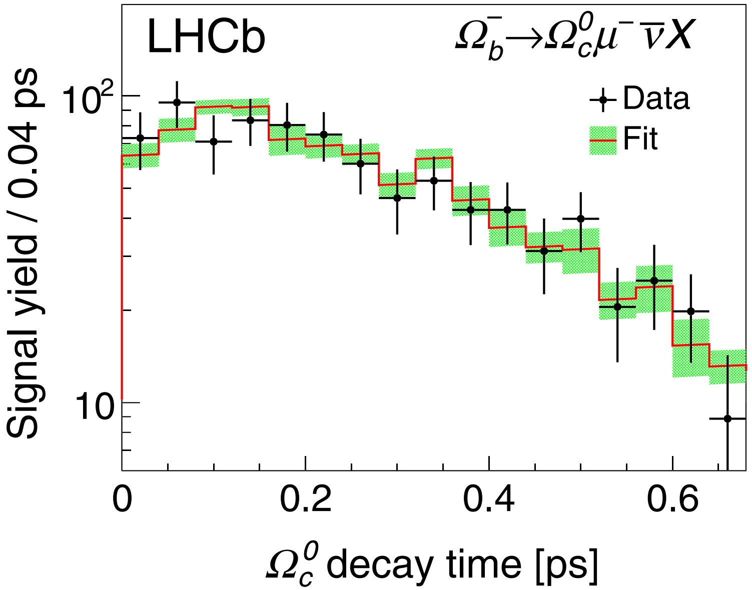
Measured in $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^+$ decays
relative to $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^- \pi^+ \pi^-$ decays

From a fit t to data: $\tau(\Xi_{cc}^{++}) = 0.256^{+0.024}_{-0.022}$ (stat) $\pm$ 0.014 (syst) ps

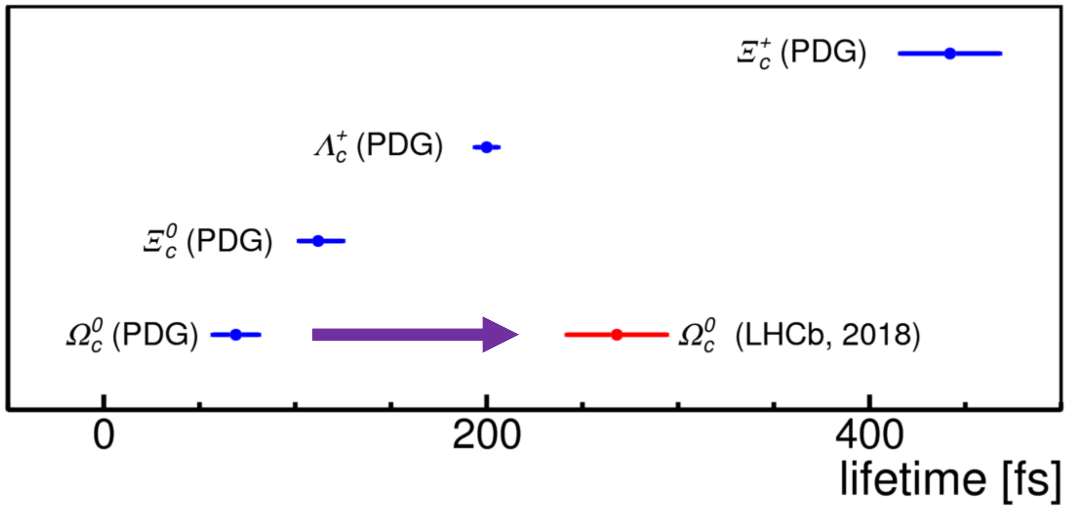
Ω_c lifetime PRL 121, 092003 (2018)

Measured in $\Omega_c^0 \rightarrow pK^-K^-\pi^+$
from $\Omega_b^- \rightarrow \Omega_c^0 \mu^- \overline{\nu} X$
relative to $D^+ \rightarrow K^-\pi^+\pi^+$
from $B \rightarrow D^+\mu^-\overline{\nu}_\mu X$

$$\frac{\tau_{\Omega_c^0}}{\tau_{D^+}} = 0.258 \pm 0.023 \pm 0.010,$$
$$\tau_{\Omega_c^0} = 268 \pm 24 \pm 10 \pm 2 \text{ fs},$$



Expectation: $\tau_{\Xi_c^+} > \tau_{\Lambda_c^+} > \tau_{\Xi_c^0} > \tau_{\Omega_c^0}$



Summary and Outlook

- The present:
  - Many new interesting results from BESIII and LHCb
  - More can be extracted from the already existing dataset of BESIII, LHCb, BaBar and Belle

- The future looks bright for charm:
  - More data from BESIII are being collected and Belle II has started data taking with the complete detector
  - And then there is the LHCb upgrade to higher luminosities
  - And may be a super tau-charm factory in China or in Russia

Backup Slides

Amplitude Analysis of D -> Kπππ

- Seven D -> Kπππ modes:

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

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

- Knowledge of different modes can be used in many measurements:
  - Branching fraction measurements
  - Strong phase measurements
  - CKM measurements

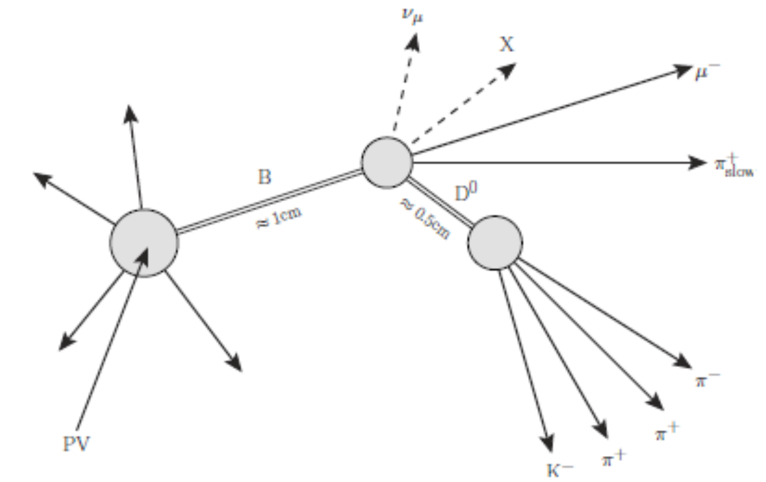
- Previous measurements of $D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-, K_S^0 \pi^+ \pi^- \pi^0$ and $D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0, K_S^0 \pi^+ \pi^+ \pi^-$ performed by Mark III and E691 are affected by low statistics

- Now all modes are measured by BESIII and/or LHCb

- Presented in this talk: $D^0 \rightarrow K^- \pi^+ \pi^0 \pi^0$; $D^+ \rightarrow K^0_S \pi^+ \pi^+ \pi^-$

D -> $K^-\pi^+\pi^+\pi^-$ (RS) and D -> $K^+\pi^-\pi^-\pi^+$ (WS) (1)

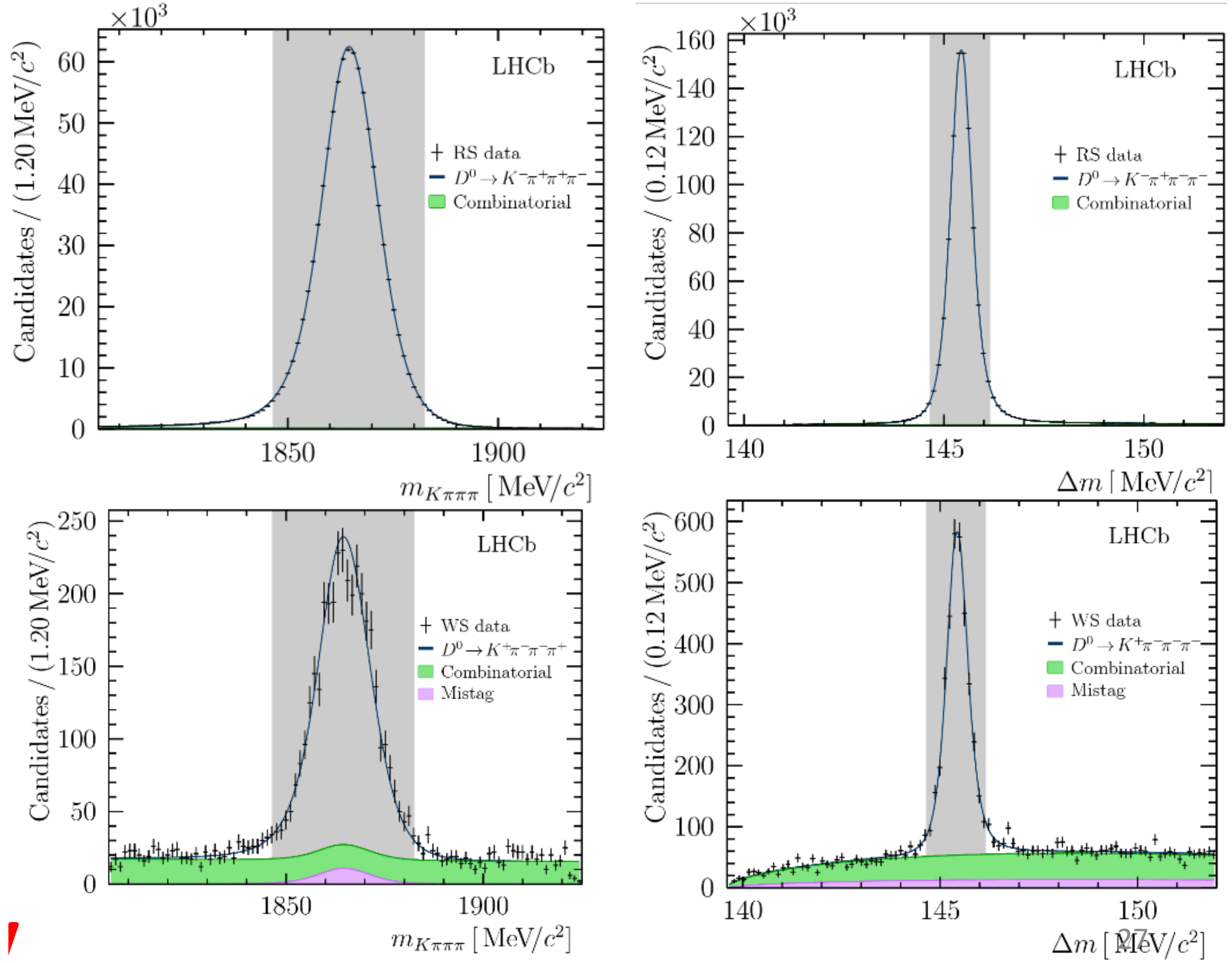
EPJC 78, 443 (2018)



	Yield		
	Signal	Combinatorial Background	Mistag Background
$D^0 \to K^-\pi^+\pi^+\pi^-$			
2011	$266\,368 \pm 490$	977 ± 10	—
2012	$624\,332 \pm 765$	2475 ± 19	—
Total	$890\,701 \pm 927$	3452 ± 24	—
$D^0 \to K^+\pi^-\pi^-\pi^+$			
2011	875 ± 32	151 ± 3	47 ± 6
2012	2154 ± 51	340 ± 5	108 ± 9
Total	3028 ± 61	491 ± 7	155 ± 11

RS: 890,000 sig. evts, >99% purity
WS: 3,000 sig. evts, 80% purity

3 fb^{-1} @ 7 and 8 TeV
Reconstruct B -> D*(2010) [$D^0\pi$] μ X as a clean source of D^0



D -> $K^-\pi^+\pi^+\pi^-$ (RS) and D -> $K^+\pi^-\pi^-\pi^+$ (WS) (2)

- D^0 four-body decays are described in terms of a sequence of two-body states.
- Isobar model is used.

D -> $K^-\pi^+\pi^+\pi^-$ (RS)

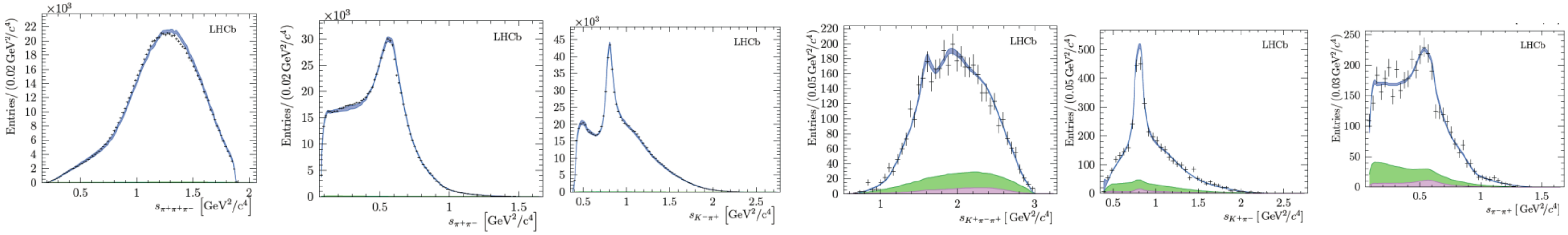
Largest contributions from:

- $D^0 \to a_1(1260)^+K^- \sim 40\%$
- $D^0 \to \overline{K}^*(892)^0\rho(770)^0 \sim 20\%$
- $D^0 \to [K^-\pi^+]^{L=0}[\pi^+\pi^-]^{L=0} \sim 20\%$

D -> $K^+\pi^-\pi^-\pi^+$ (WS)

Largest contributions from:

- $D^0 \to K_1(1270/1400)^+\pi^- \sim 40\%$
- $D^0 \to K^*(892)^0\rho(770)^0 \sim 20\%$
- $D^0 \to [K^+\pi^-]^{L=0}[\pi^+\pi^-]^{L=0} \sim 20\%$



Doubly Cabibbo Suppressed WS Decay studied for the first time

Λ_c measurements @ BESIII

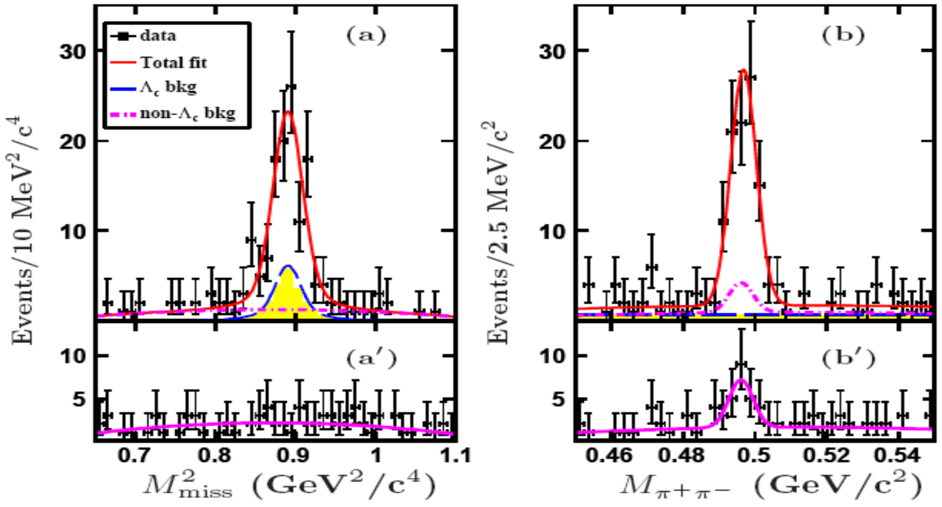
PRL 118,112001(2017)

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

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

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

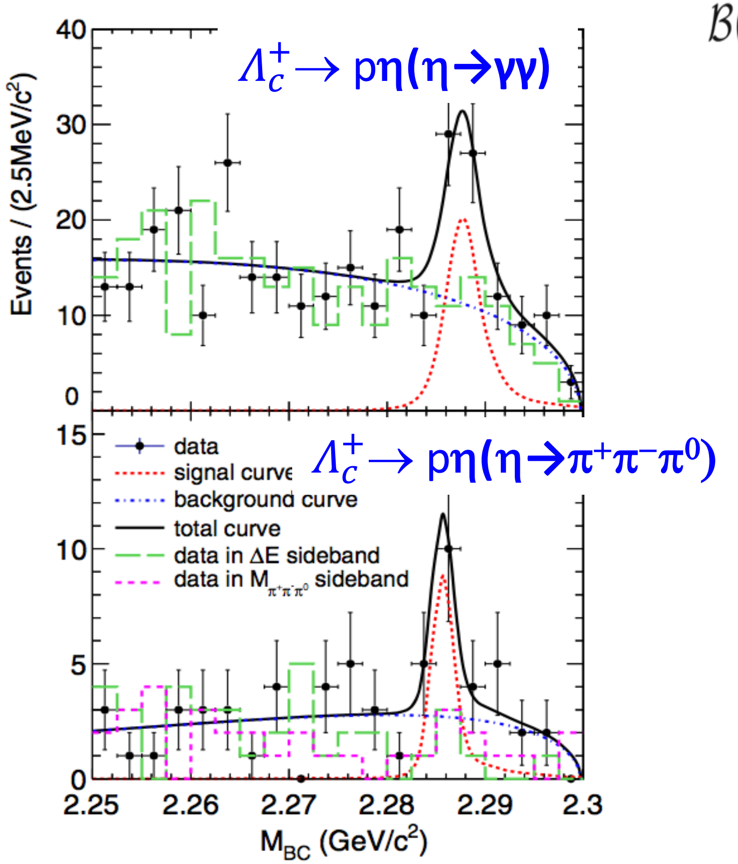
$$M_{\rm miss}^2 = (p_{\Lambda_c^+} - p_{K_S^0} - p_{\pi^+})^2 = E_{\rm miss}^2 - c^2|\vec{p}_{\rm miss}|^2$$



PRD 95, 111102(R) (2017)

$$B(\Lambda_c^+ \to p\eta) = (1.24 \pm 0.28 \pm 0.10) \times 10^{-3}$$

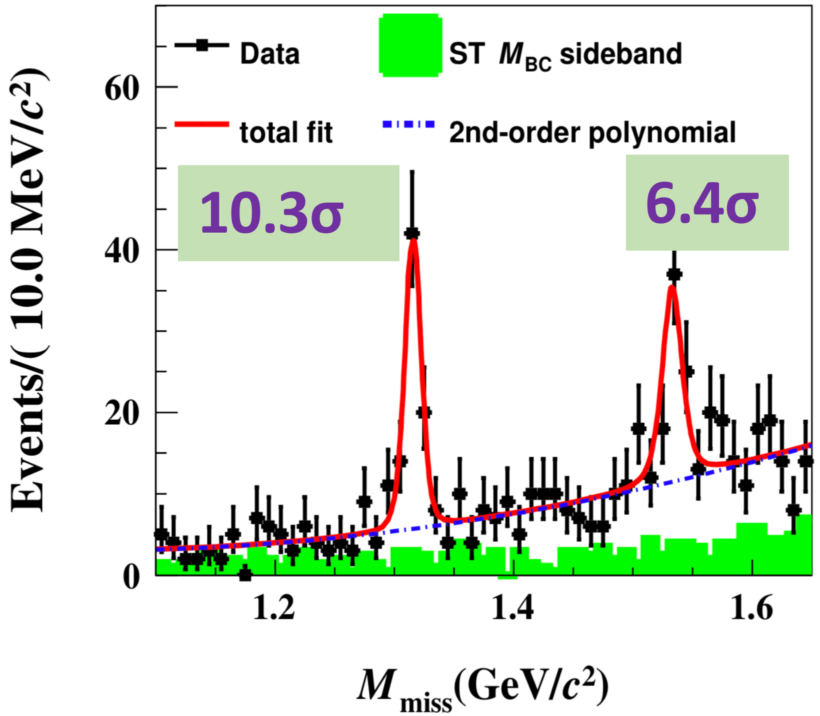
$$B(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}$$



PLB 783, 200(2018)

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

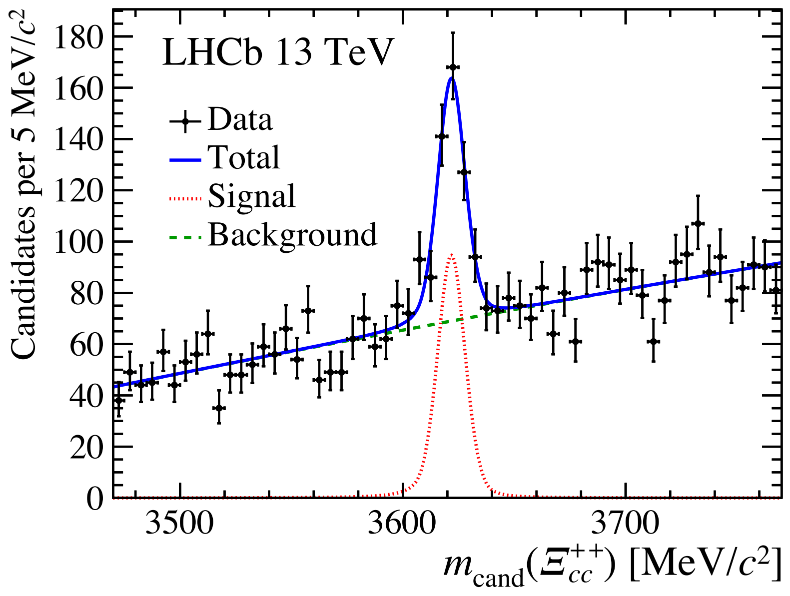
$$\mathcal{B}(\Lambda_c^+ \to \Xi(1530)^0 K^+) = (5.02 \pm 0.99 \pm 0.31) \times 10^{-3}$$



Ξ_{cc} measurements @ LHCb

PRL 119, 112001 (2017)

Discovery of Ξ_{cc} in: $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ (CF), $\Lambda_c^+ \to pK^-\pi^+$ (CF)



PRL 121, 162002 (2018)

$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$ (CF), $\Xi_c^+ \to pK^-\pi^+$ (SCS)

Expectation from theory:

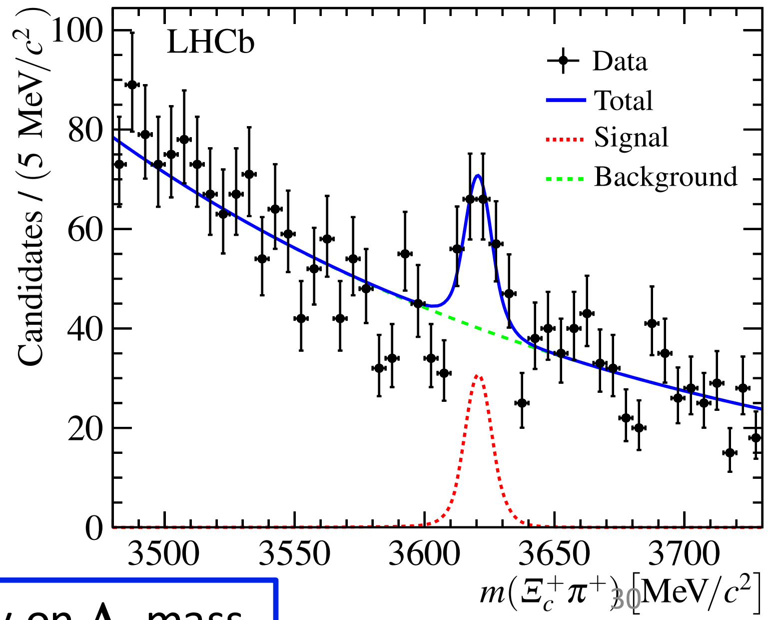
Yu et al., Chin. Phys. C42 (2018)

$\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) \simeq 10\%\ \mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+)$

$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^+ \pi^+) \times \mathcal{B}(\Xi_c^+ \to pK^-\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+) \times \mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = 0.035 \pm 0.009\ (\text{stat}) \pm 0.003\ (\text{syst})$$

$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = 6.35\%$

$\mathcal{B}(\Xi_c^+ \to pK^-\pi^+) = 2.20\%$



Average: m $(\Xi_{cc}^{++}) = 3621.40 \pm 0.72\ (\text{stat}) \pm 0.27\ (\text{syst}) \pm 0.14\ (\Lambda_c^+)$ MeV/c^2

From uncertainty on Λ_c mass