58th Rencontres de Moriond - EW Interactions & Unified Theories

Charm Physics at BELLE & *Belle II*

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on behalf of the

Belle II Collaboration

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Experiments

➡ **BELLE** & ***Belle II*** collect(ed) data at asymmetric e^+e^- colliders at or near the Υ(4S) resonance

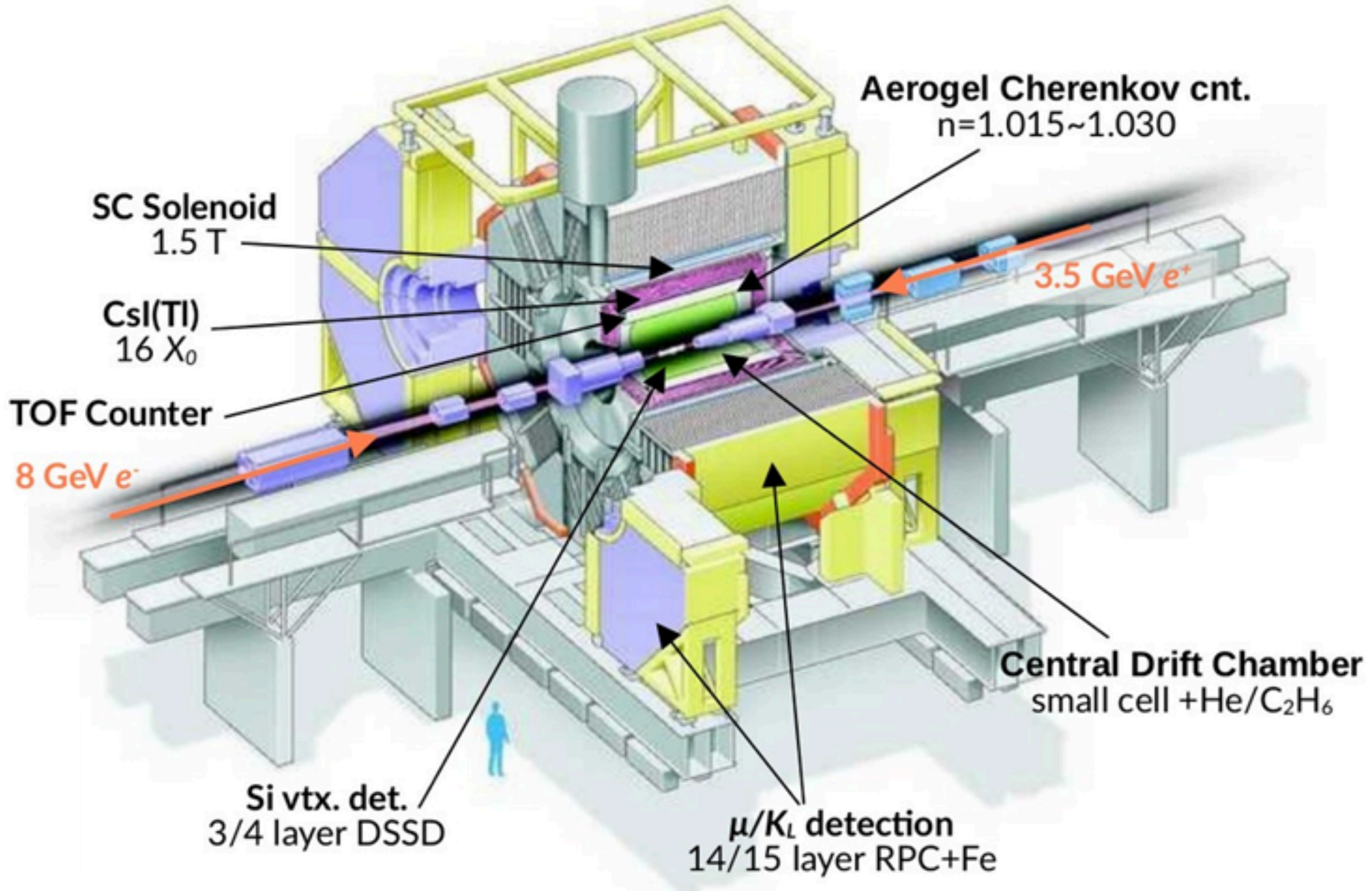
- KEKB (2009-2010), peak lumi = $2\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$, L_{int} = 1/ab
- SuperKEKB, peak lumi = $4.7\text{x}10^{34}\text{cm}^{-2}\text{s}^{-1}$, L_{int} = 0.42/ab
  - Run1 (2019-2022), Run2 (just started)

➡ BELLE & *Belle II* are now **synergic** experiments

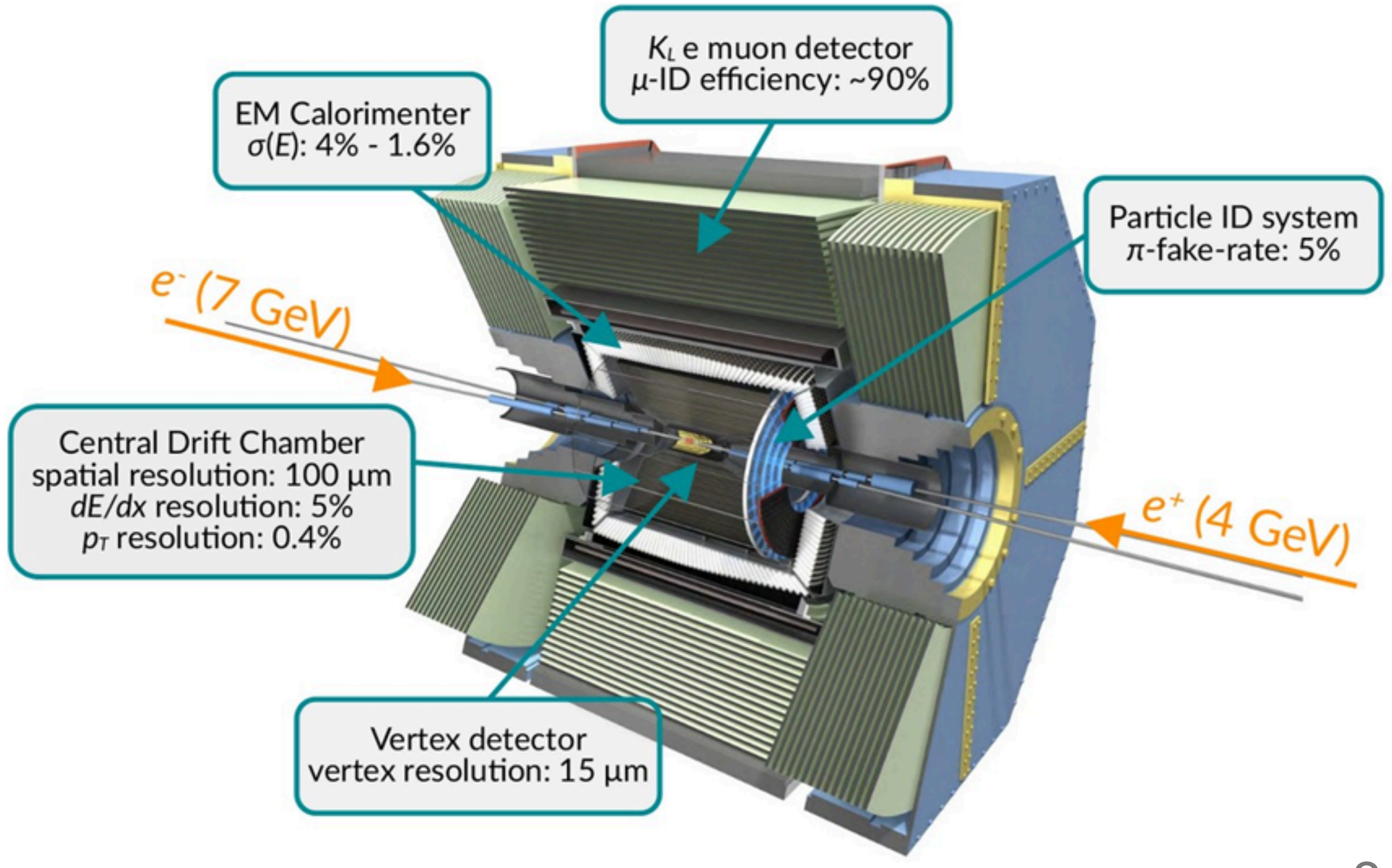
- BELLE data can be analysed with the *Belle II* software framework
- common review procedures since last summer
- especially important for charm analyses, where large statistics is crucial to improve the precision

streamlines combined analyses

BELLE @ KEKB



Belle II @ SuperKEKB



Charm at a B-Factory

$$e^+e^- \to c\bar{c} \to D_{\mathrm{tag}} X_{\mathrm{frag}} D_{\mathrm{sig}}$$

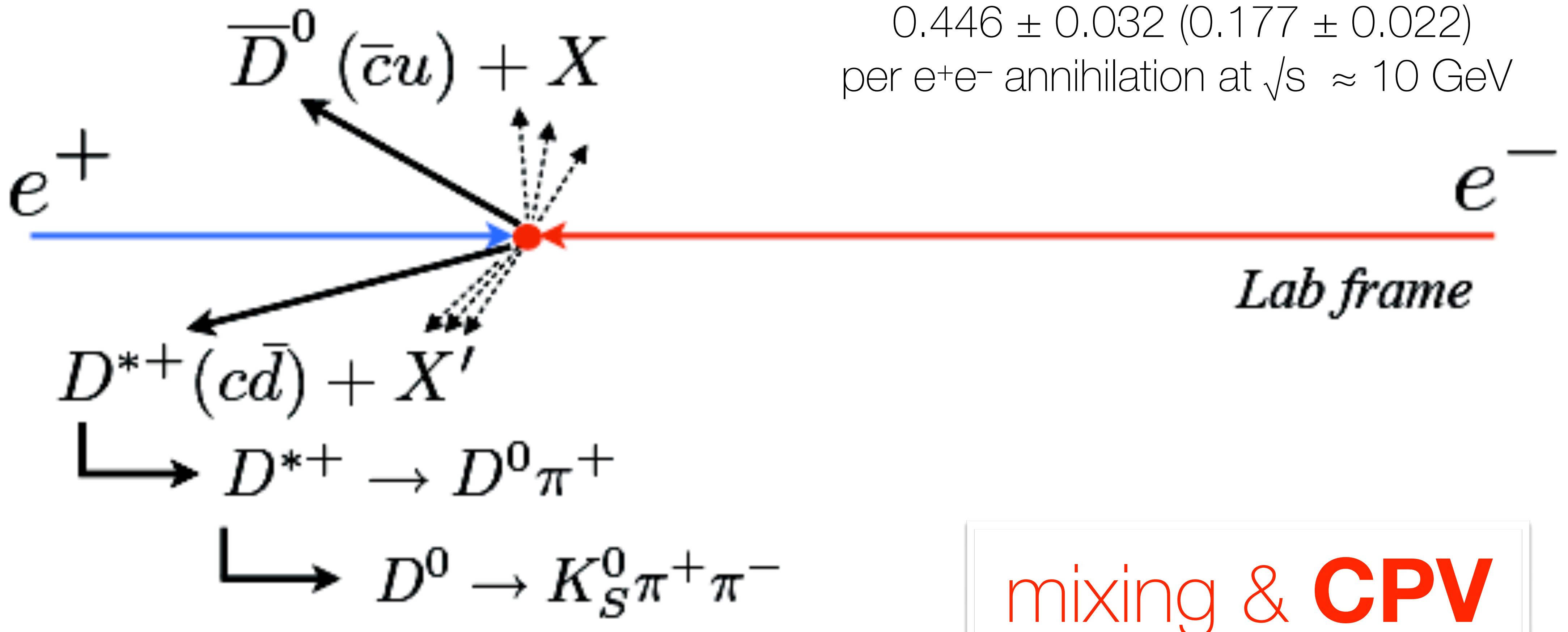
➡ **e^+e^- → two charm hadrons + *fragmentation***

- no entanglement between the two charm hadrons, inaccessible strong phases
- production of charm baryons **Baryons**

➡ usually reconstruct only the signal channel…

- average 11 tracks & 5 π^0 in an event
- D^0 flavour tagging: $D^{*+} \to D^0\pi^+$ decays, or exploiting the rest-of-the-event information

average D^0 (D^*) multiplicity is 0.446 ± 0.032 (0.177 ± 0.022) per e^+e^- annihilation at $\sqrt{s} \approx 10$ GeV



mixing & **CPV**

Charm Flavour Tagger new@Belle II

PRD **107, 112010** (2023)

high-precision SM (e.g. lifetimes), **BR**

search for rare or forbidden decays

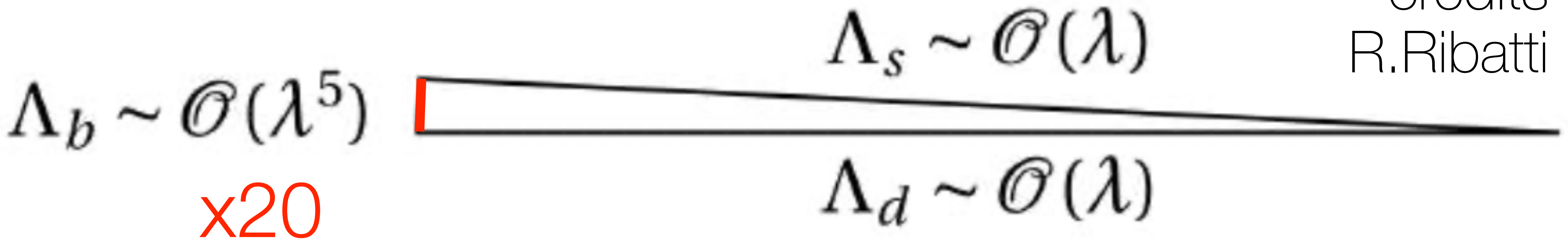
➡ … for some analyses, we can perform the $(D_{tag}X_{\mathrm{frag}})$-system reconstruction

- inclusive charm mesons & baryons with fixed kinematics

channels with missing energy (semi-leptonic, invisible), form factors & CKM elements

CP Violation in Charm

Charm Unitary Triangle:



credits R.Ribatti

- ➡ in the Standard Model, CP Violation originates from the complex phase of the CKM matrix and can be visualised as the area of the Unitary Triangles built from unitary relations of the CKM matrix
  - CPV in charm is also difficult to predict, experimental measurements play a major role
- ➡ first and only evidence of CPV in 2019 by LHCb
  - $\Delta A_{CP}(D^0 \to KK, \pi\pi) = (-15.4 \pm 2.9) \times 10^{-4}$ [5.3σ] —with→ $A^f_{\mathrm{CP}} = \frac{|A_f|^2 - |\bar{A}_{\bar{f}}|^2}{|A_f|^2 + |\bar{A}_{\bar{f}}|^2} \propto \sin(\phi)\sin(\delta)$ (weak phase: $\sin(\phi)$; strong phase: $\sin(\delta)$)
- ➡ it is fundamental to continue searching for CPV in charm hadrons to understand its origin and further constrain the SM
  - increase the number of channels/observables we look at
  - increase the precision, i.e. statistics with systematics under control
  - BELLE & *Belle II* mainly contribute with channels (mesons & baryons) with neutral particles in the final state

assuming CPT, T-odd observables are also sensitive to CP Violation:

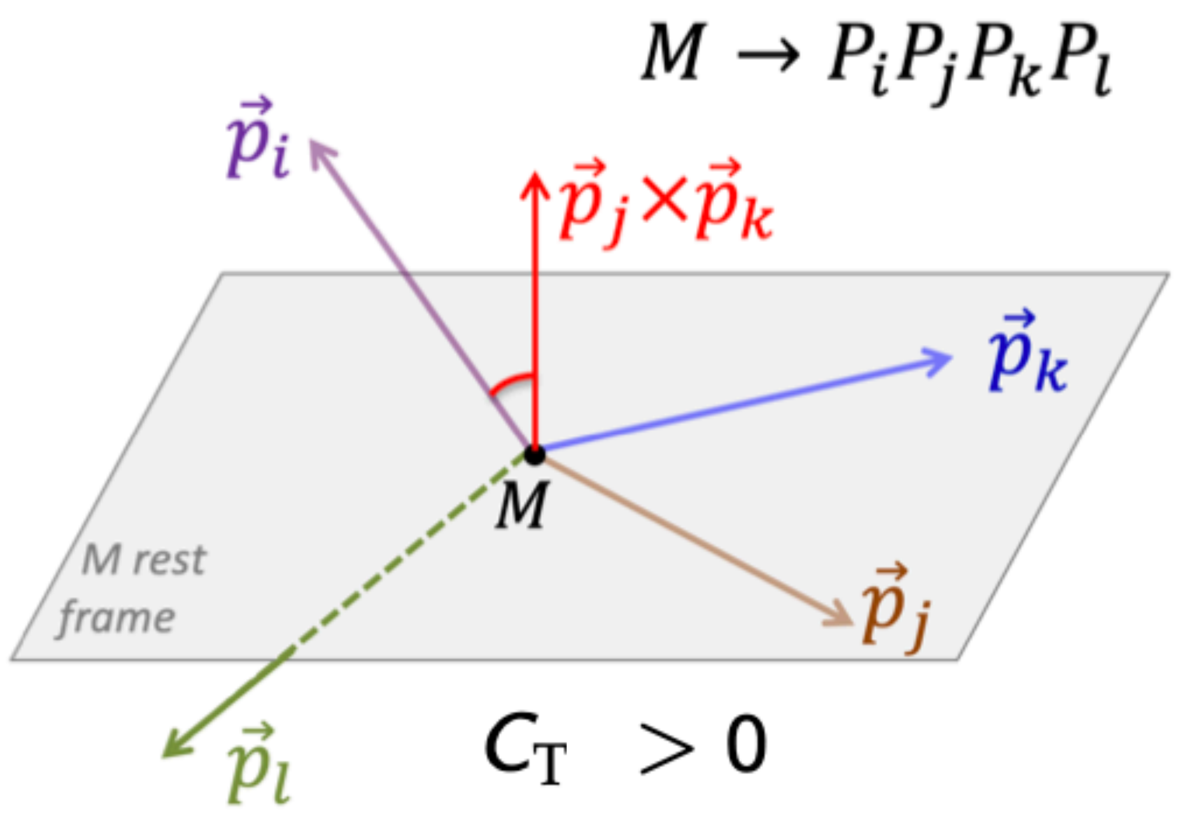
$a_{CP}^{T-\mathrm{odd}} \propto \sin(\phi)\cos(\delta)$ (weak phase: $\sin(\phi)$; strong phase: $\cos(\delta)$)

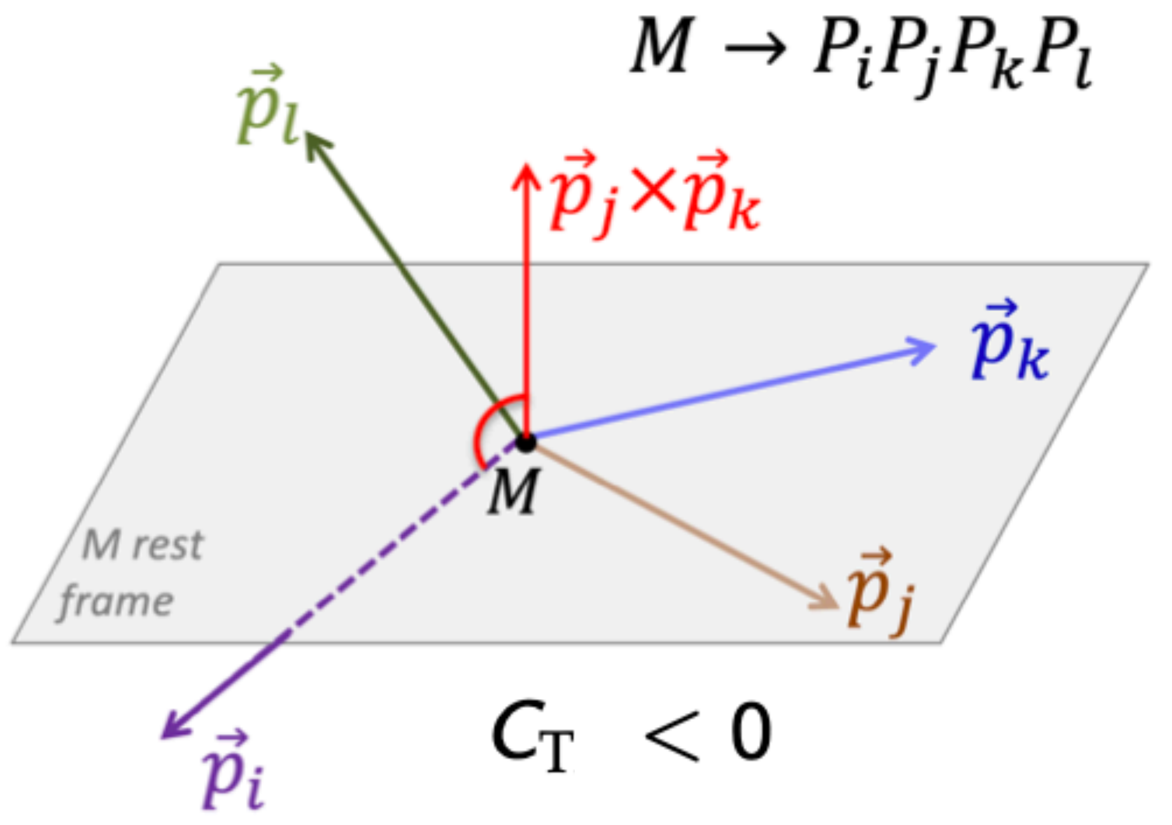
complementary to A^f_{CP}

CPV with T-odd Observables

➡ the most known T-odd observable is $C_T = \bar{p}_i \cdot (\bar{p}_j \times \bar{p}_k)$

- need at least 4 particles in the final state





- build asymmetries for particles and antiparticles

$$A_T = \frac{\Gamma_+(C_T > 0) - \Gamma_+(C_T < 0)}{\Gamma_+(C_T > 0) + \Gamma_+(C_T < 0)}$$

$$\bar{A}_T = \frac{\Gamma_-(-\bar{C}_T > 0) - \Gamma_-(-\bar{C}_T < 0)}{\Gamma_-(-\bar{C}_T > 0) + \Gamma_-(-\bar{C}_T < 0)}$$

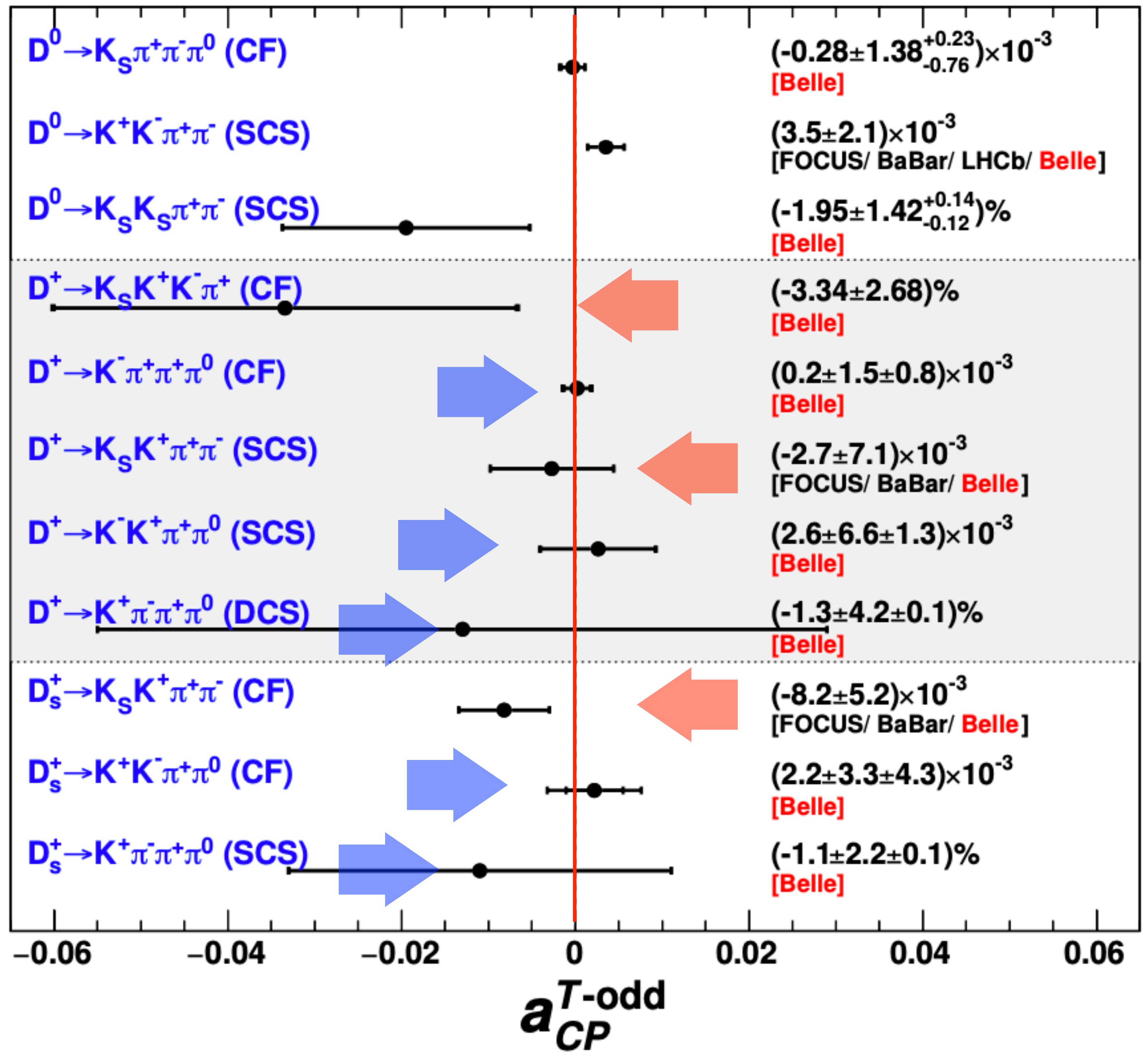
- combine them to remove final-state interaction effects:

$$a_{CP}^{\text{T-odd}} = \frac{1}{2}(A_T - \bar{A}_T)$$

slide 6

slides 7, 18

recent measurements



➡ several more observables can be built, e.g. quadruple products and "two-fold forward backward asymmetry"

Phys.Rev.D107, L011301 (2023)

SCS = Singly Cabibbo Suppressed
CF = Cabibbo Favoured
DCS = Doubly Cabibbo Suppressed

$D^+ \to K_S K^+ \pi^+ \pi^-$ (SCS)
$D_s^+ \to K_S K^+ \pi^+ \pi^-$ (CF)
$D^+ \to K_S K^+ \pi^+ K^-$ (CF)

$a_{CP}^{\text{T-odd}}$ for $D_{(s)}^+ \to K_S K^+ h^+ h^-$

- procedure to extract the asymmetry
  - suppress backgrounds using D decay length significance, vertex fit quality and scaled momentum
  - divide candidates in 4 categories and parameterise signal yields as a function of $N(D^\pm)$, A_T, $a_{CP}^{\text{T-odd}}$:

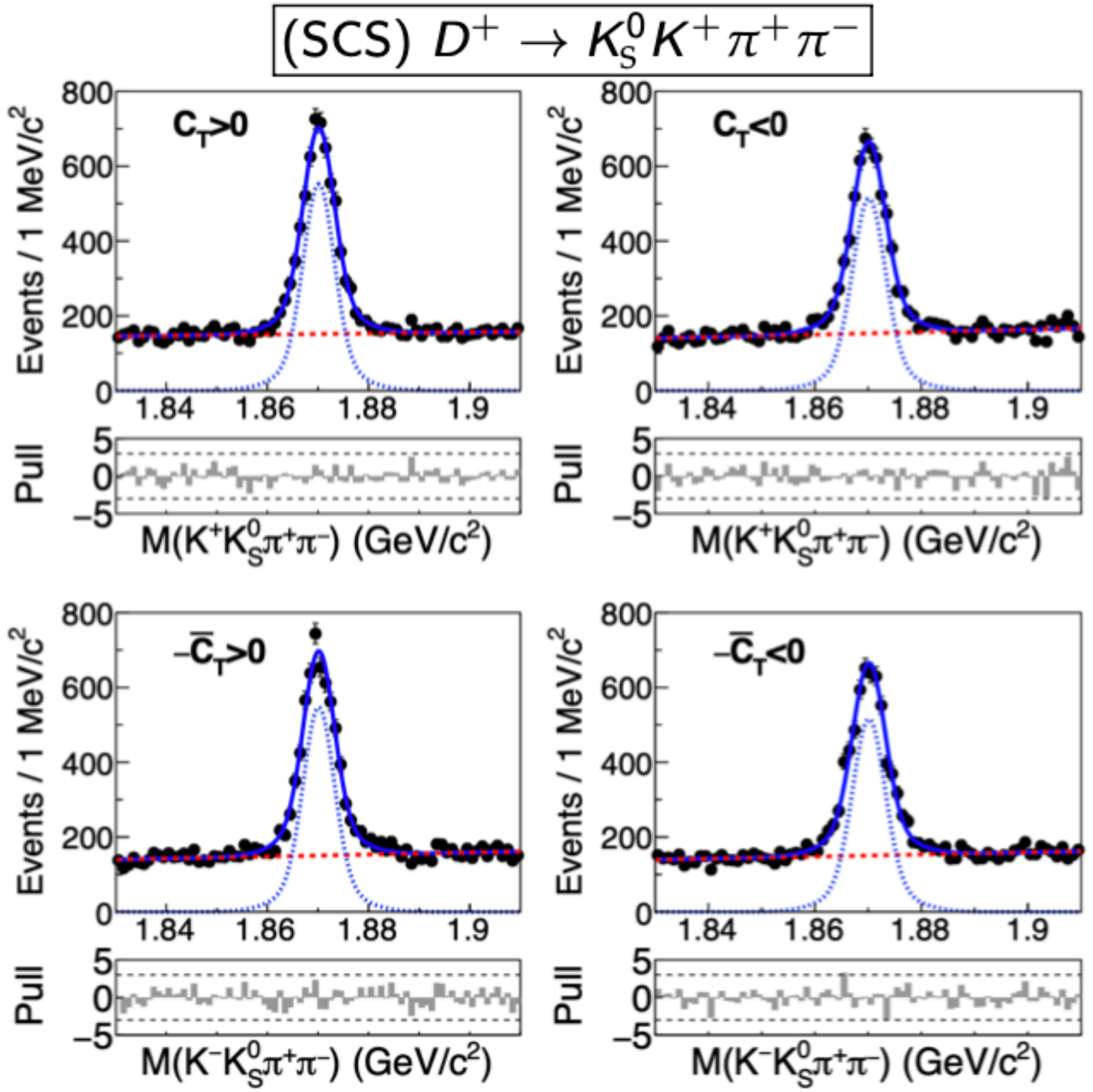
$$N_1 = N(D_{(s)}^+)\frac{1+A_T}{2}, \quad N_3 = N(D_{(s)}^-)\frac{1+A_T-2\cdot a_{CP}^{T\text{-odd}}}{2},$$
$$N_2 = N(D_{(s)}^+)\frac{1-A_T}{2}, \quad N_4 = N(D_{(s)}^-)\frac{1-A_T+2\cdot a_{CP}^{T\text{-odd}}}{2}.$$

  - extract observables with a simultaneous fit:

$$a_{CP}^{T\text{-odd}} = (+0.34 \pm 0.87 \pm 0.32)\%$$

most precise measurement

  - no evidence of CPV, precision reaches fractions of %, dominated by stat. uncertainty



- BONUS: first measurement of (SCS) $D_s^+ \to K_S K^+ \pi^+ K^-$ [9.2σ]
  - BR = $(1.29 \pm 0.14 \pm 0.04 \pm 0.11) \times 10^{-4}$ with $D_s^+ \to K_S K^+ \pi^- \pi^+$ as reference mode

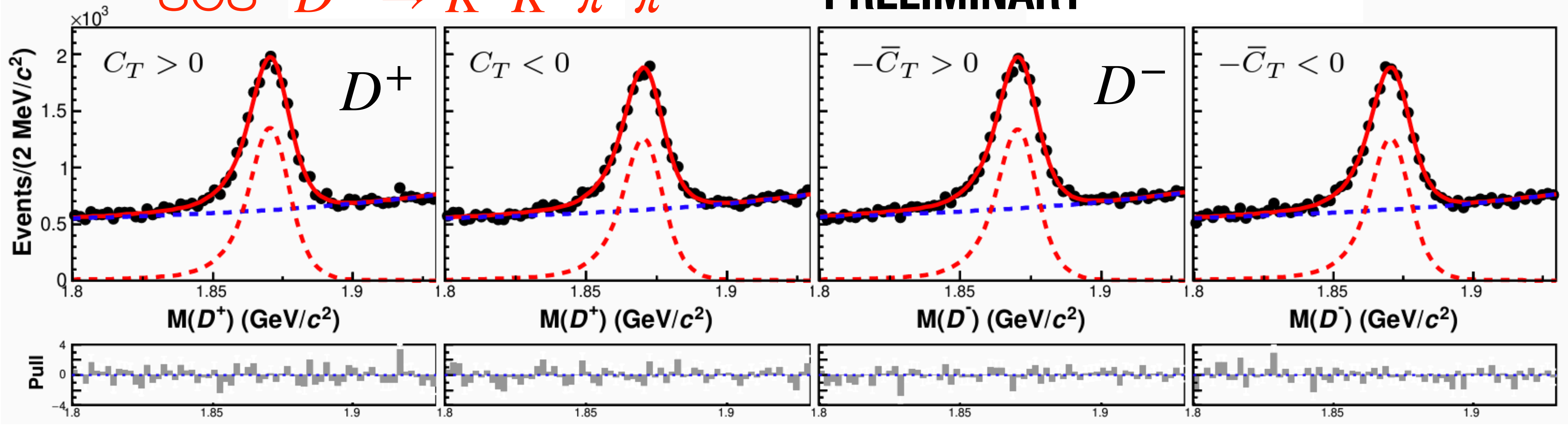
$a_{CP}^{T-\mathrm{odd}}$ for $D_{(s)}^+ \to Kh\pi^+\pi^0$

weak phase ↑ strong phase ↑

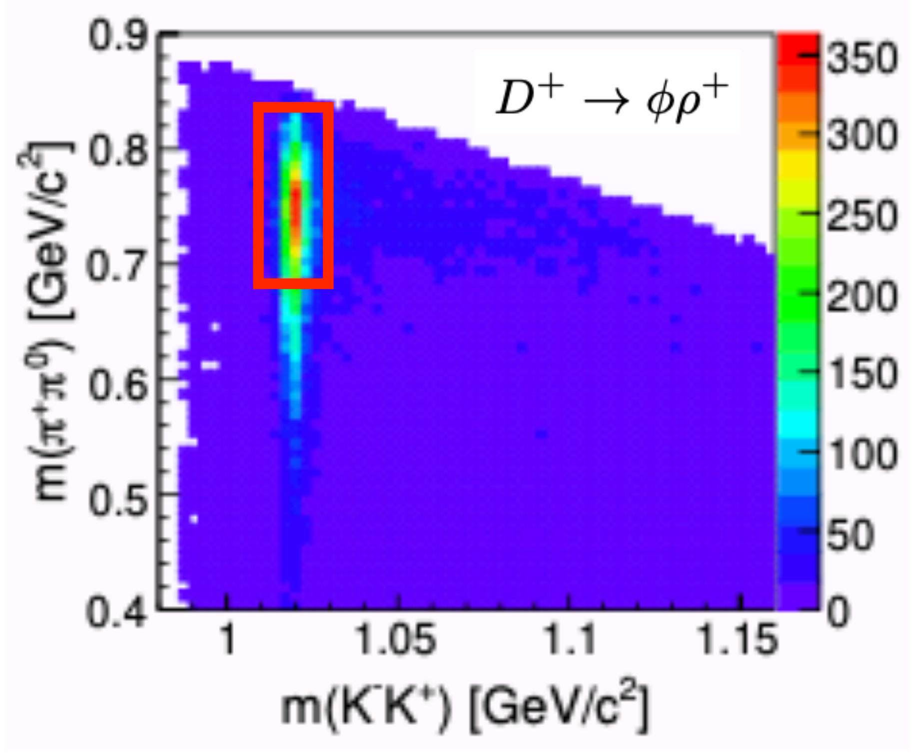
$a_{CP}^{T-\mathrm{odd}} \propto \sin(\phi)\cos(\delta)$

SCS	$a_{CP}^{T\text{-odd}}(D^+ \to K^-K^+\pi^+\pi^0)$	$=$	$(+2.6 \pm 6.6 \pm 1.3) \times 10^{-3}$
DCS	$a_{CP}^{T\text{-odd}}(D^+ \to K^+\pi^-\pi^+\pi^0)$	$=$	$(-1.3 \pm 4.2 \pm 0.1) \times 10^{-2}$
CF	$a_{CP}^{T\text{-odd}}(D^+ \to K^-\pi^+\pi^+\pi^0)$	$=$	$(+0.2 \pm 1.5 \pm 0.8) \times 10^{-3}$
SCS	$a_{CP}^{T\text{-odd}}(D_s^+ \to K^+\pi^-\pi^+\pi^0)$	$=$	$(-1.1 \pm 2.2 \pm 0.1) \times 10^{-2}$
CF	$a_{CP}^{T\text{-odd}}(D_s^+ \to K^-K^+\pi^+\pi^0)$	$=$	$(+2.2 \pm 3.3 \pm 4.3) \times 10^{-3}$

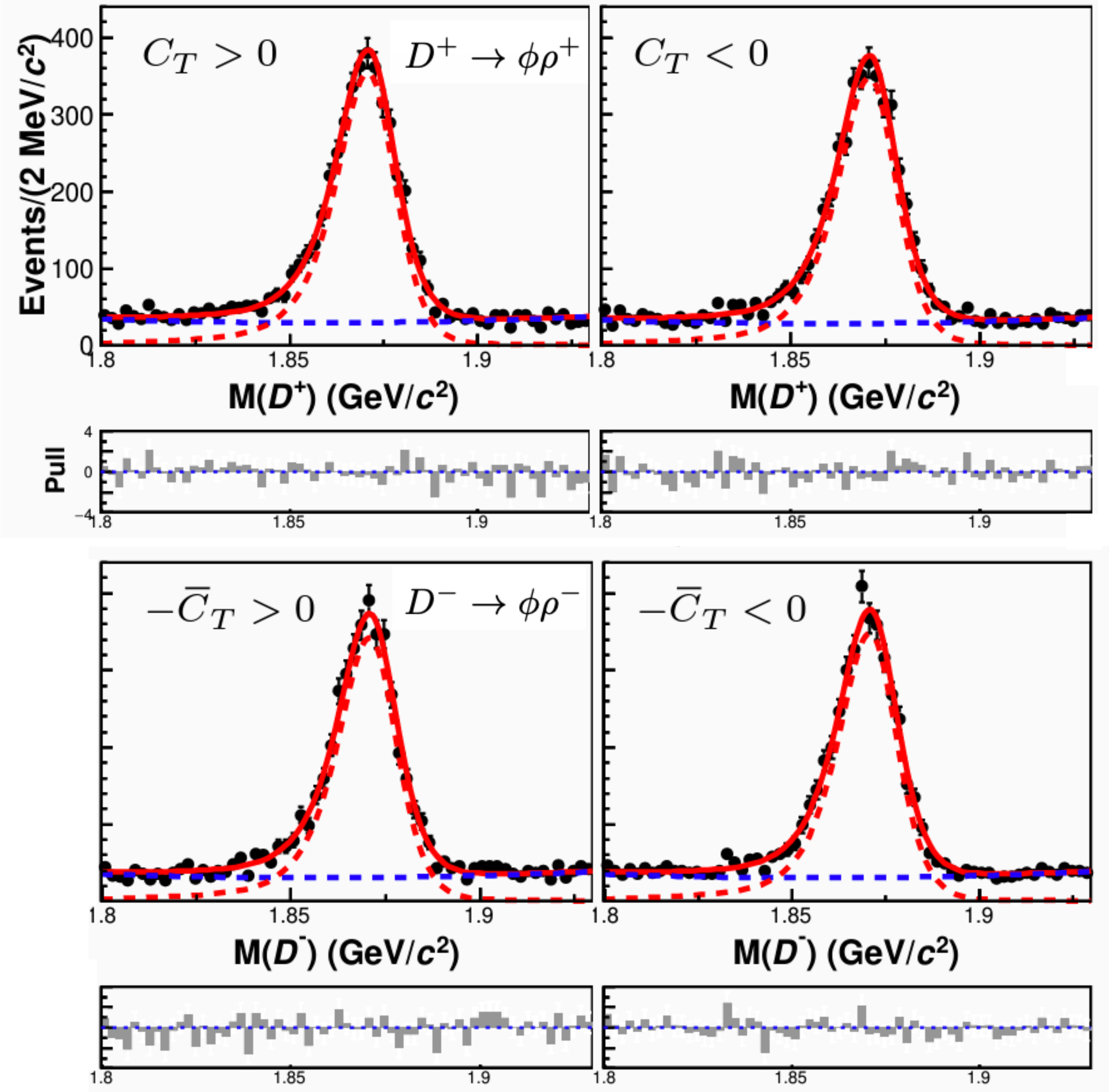
SCS $D^+ \to K^-K^+\pi^+\pi^0$ PRELIMINARY



- ➡ no evidence of (global) CPV
  - statistical uncertainty < 1% for most of them & systematic at o(1‰)
- ➡ check $a_{CP}^{T-\mathrm{odd}}$ in regions corresponding to the dominant resonances (with *different* strong phases)
  - e.g. $D^+ \to \phi\rho^+$ shown on the right plots
  - vector resonances: $\phi, \rho^{+,0}, \bar{K}^{*0}, K^{*+}$
  - no evidence of local CPV on the Dalitz



PRELIMINARY



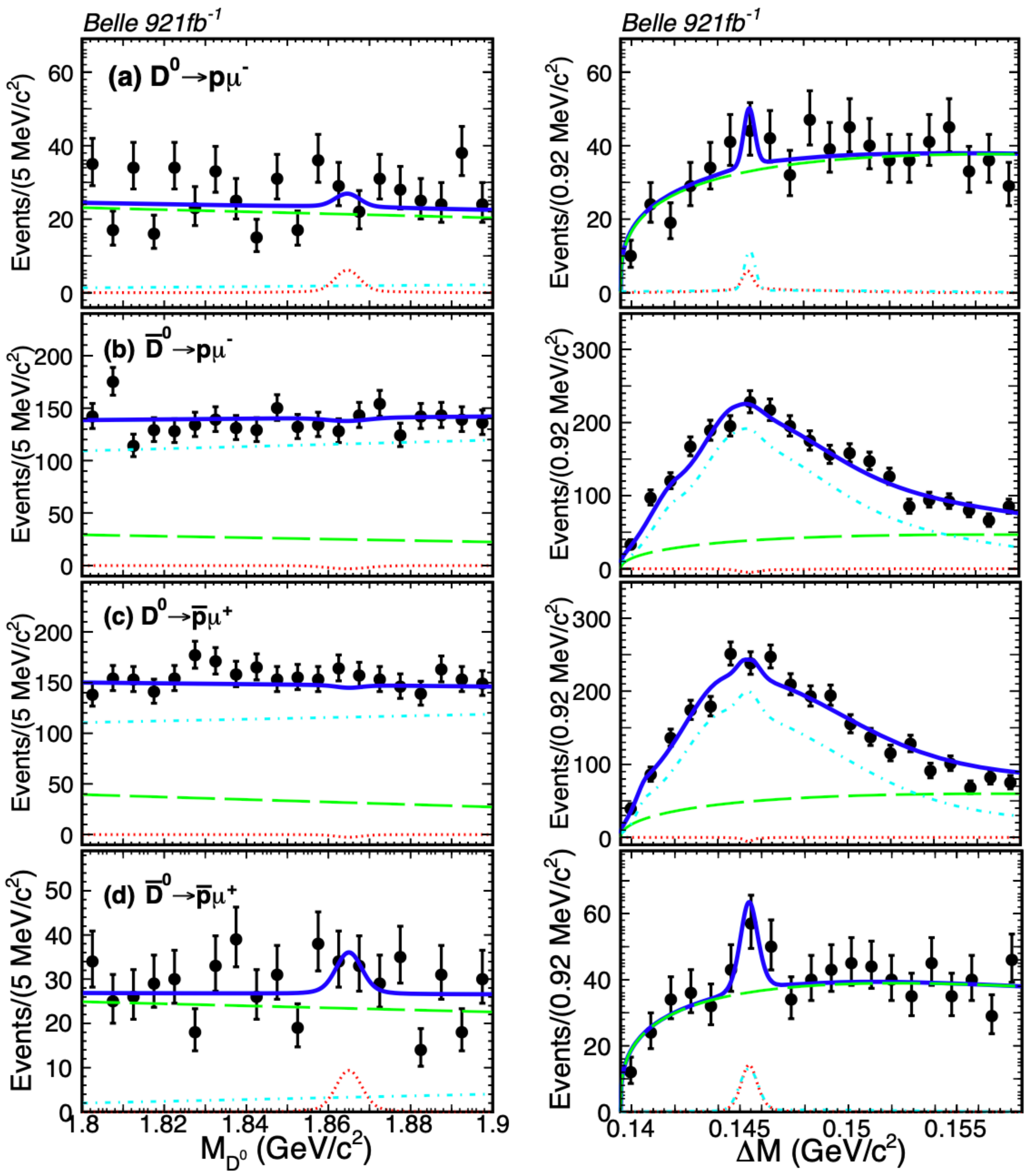
(*) e.g.: PRD8,240 (1973); PRL32,438(1974); PRD20,776(1979); PLB91,222(1980); PLB314,336(1993)

Search for neutral $D \to p\ell$

- Baryon Number Violation (BNV) is a required condition to explain the observed matter-antimatter asymmetry
  - nucleon BNV allowed in several BSM theories (*), with Δ(B – L) = 0, where B (L) is the baryon (lepton) number
  - interest in search for BNV processes also in meson decays [allowed e.g. in GUT, leptoquarks]

- in $D \to p\ell$, B and L separately violated with Δ(B – L) = 0
  - searched separately for D^0 and $\overline{D}^0$ with $\ell = e, \mu$
  - use $D^0 \to K\pi$ as reference channel

- no signal observed, set upper limits (5-8)x10^{-7} @ 90%CL
  - most stringent limit to date for the electron channels
  - first measurement for the muon channels



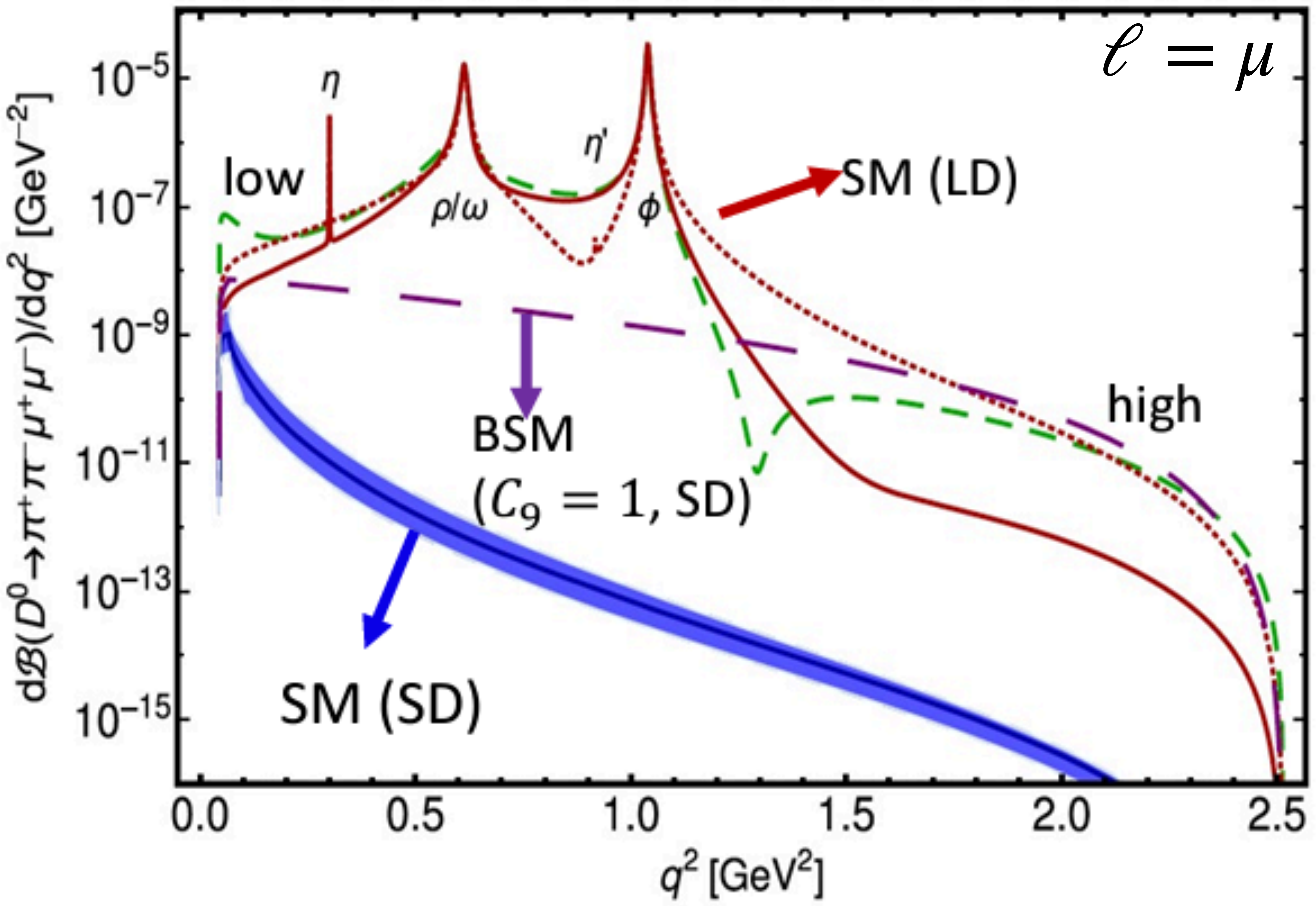
NEW for Moriond – BELLE (942/fb)

BESIII PRD97(2019):072015
BaBar PRL122(2019):081802
LHCb PRL119(2017):181805
PLB517(2016):558
MSSM PRD66(2002):014009

Search for $D^0 \to hh'e^+e^-$

- FCNC c → u$\ell\ell$ are suppressed processes in the SM, interesting place to look for NP
  - SM long-distance contributions dominate, especially near resonances
  - BSM contributions maybe visible far from resonances, e.g. BF($D^0 \to \pi\pi\ell\ell$) ~ 10^{-6} in MSSM

S. de Boer, G. Hiller Phys. Rev., D98(2018):035041



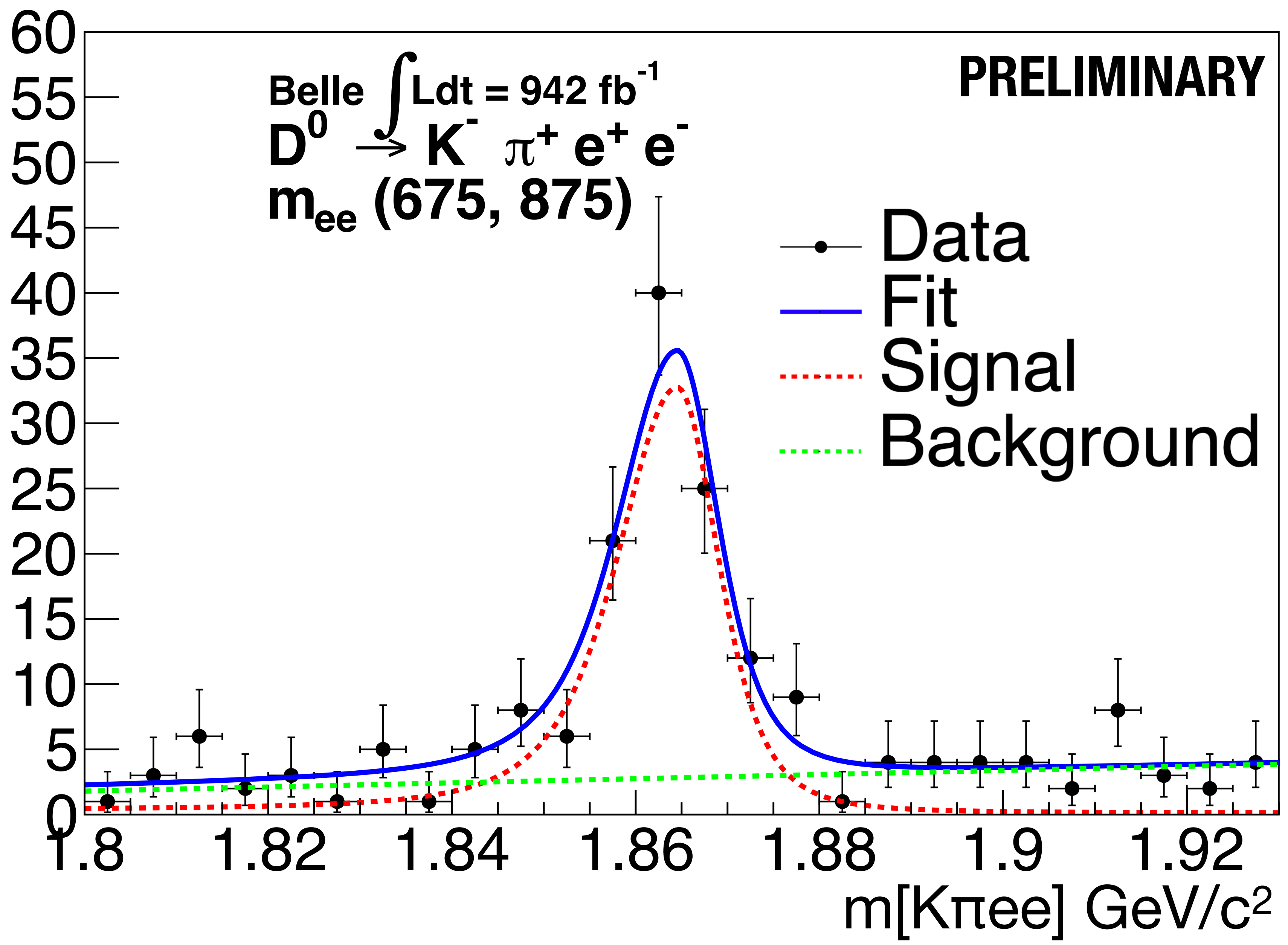
measured BRs or ULs at 90%CL [x10^{-7}]

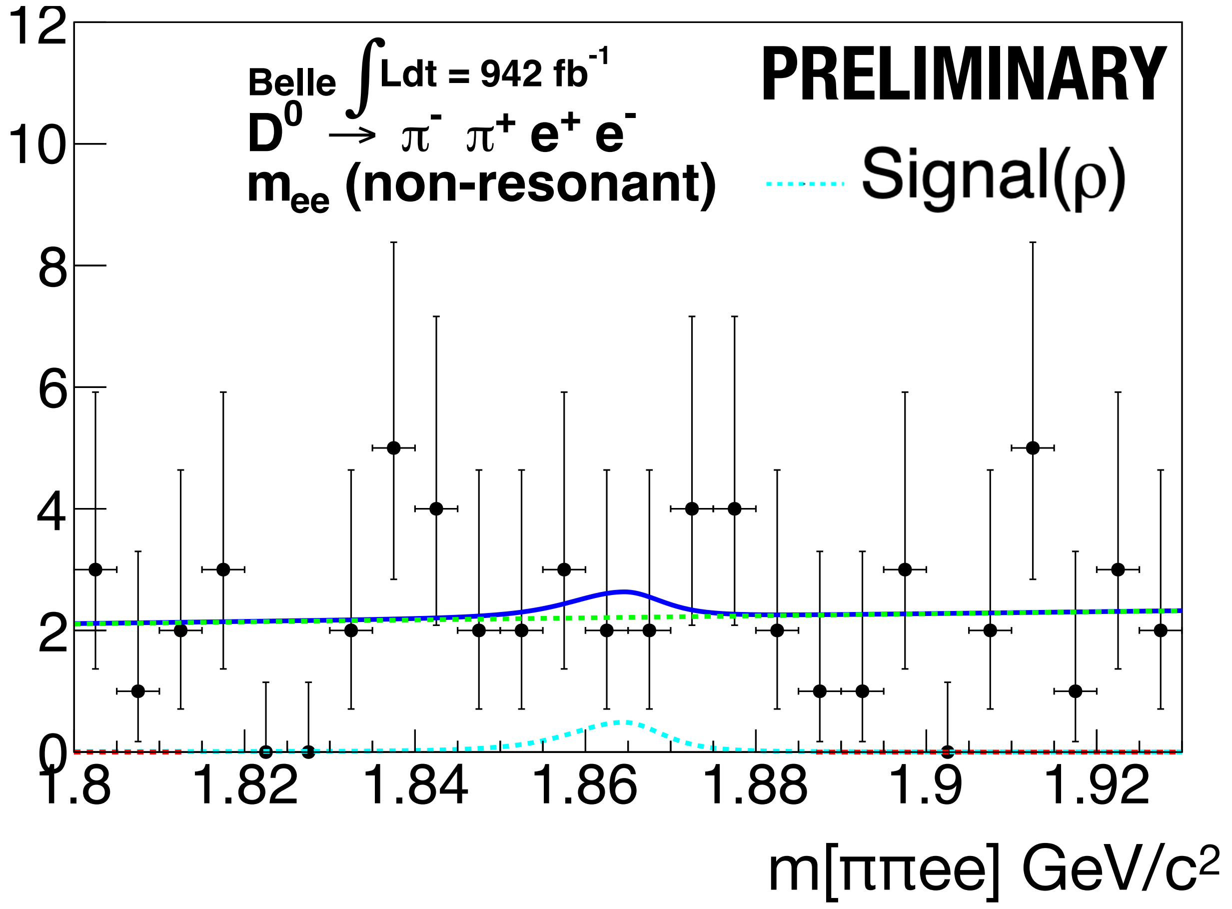
	KKee	ππee	Kπee
BaBar	–	–	40.0±5.0±2.3 (ρ/ω) < 31 (non-resonant)
BESIII	< 110	< 70	< 410
	KKμμ	ππμμ	Kπμμ
LHCb	1.54±0.27±0.19	9.64±0.48±1.10	4.17±0.12±0.40 (ρ/ω)

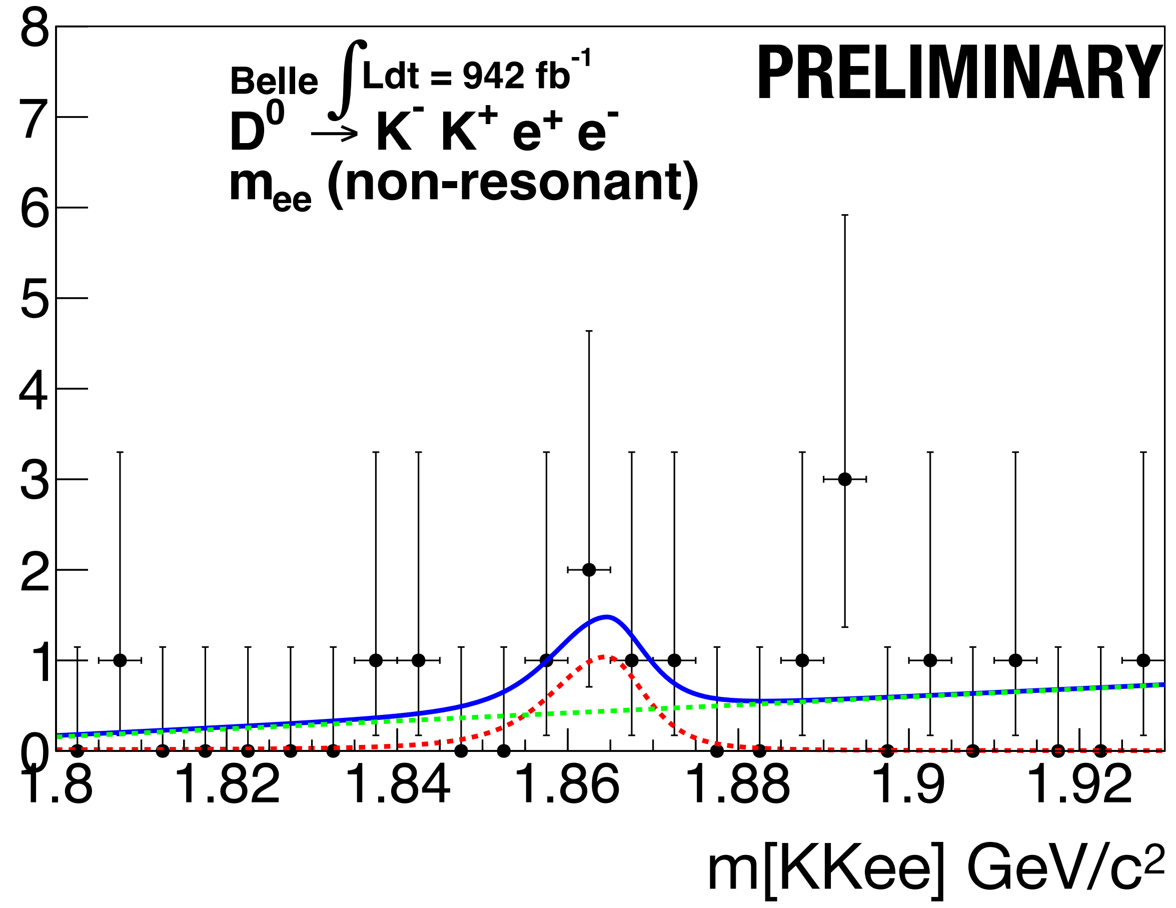
- search for signal candidates in $q^2 = m^2(e^+e^-)$ regions *near resonances* (→ BR measurement) and *far* from resonances (→ sensitive to NP)
  with $D^0 \to K\pi\pi\pi$ as reference

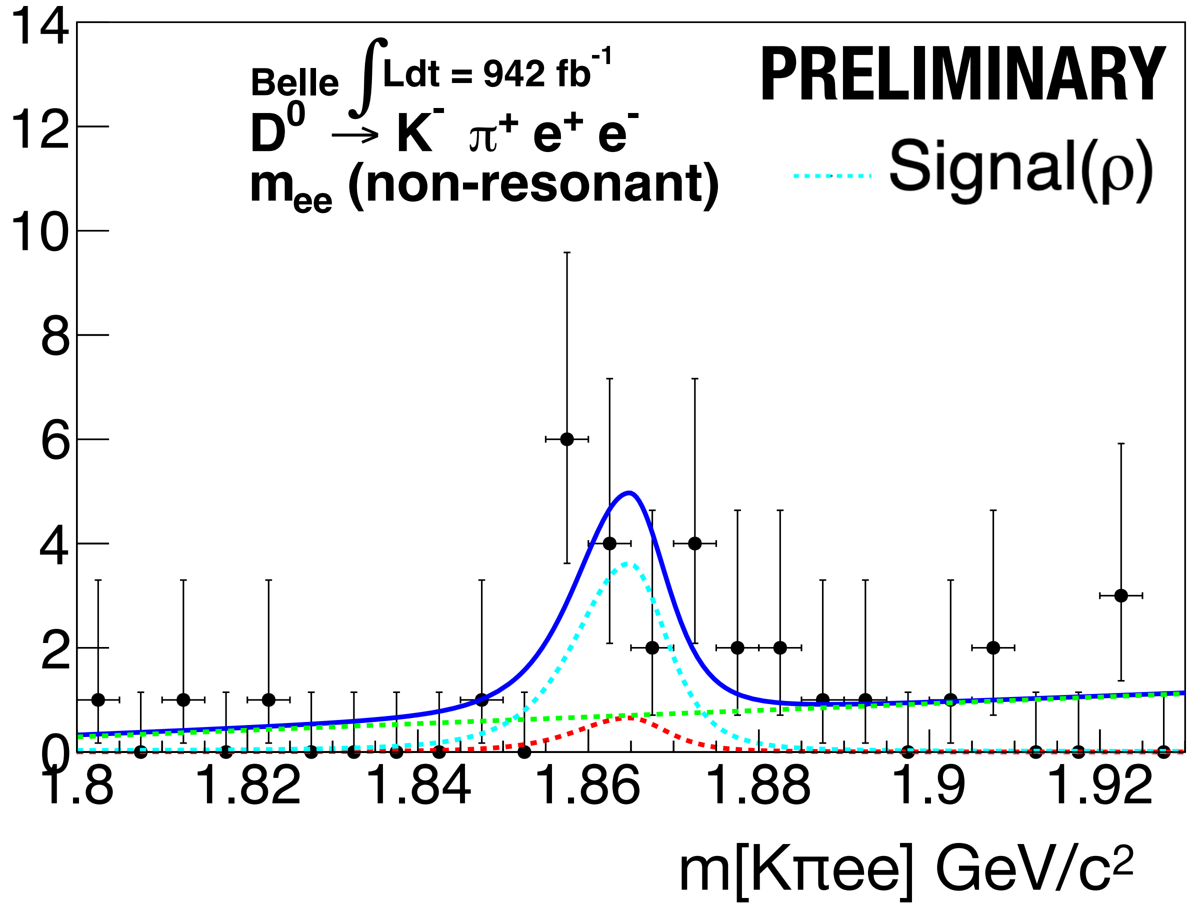
$D^0 \to hh'e^+e^-$ Results

- signal observed in $D^0 \to K\pi e^+e^-$, in the ρ/ω region
  - measured BR = (39.6 ± 4.5 ± 2.9)x10^{-7} [11.8σ]
  - compatible with BABAR and with SM expectations
- no signal observed in the other regions & channels
  - upper limits set at 90% CL [2-8] 10^{-7} (best to date)
  - significantly improved limits wrt BESIII and BABAR (but different q^2 regions were investigated) more in slide 20









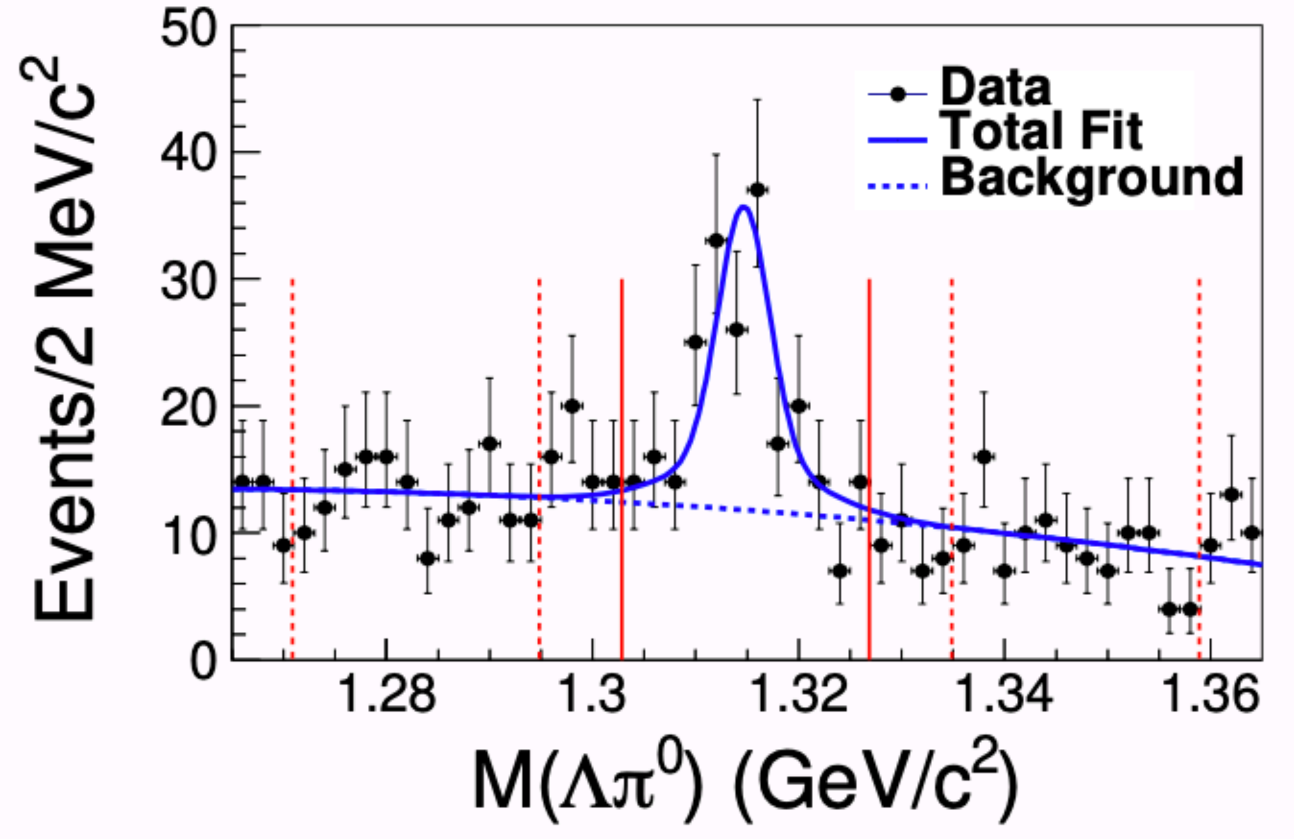
First Search for $\Xi_c \to \Xi^0 \ell^+ \ell^-$

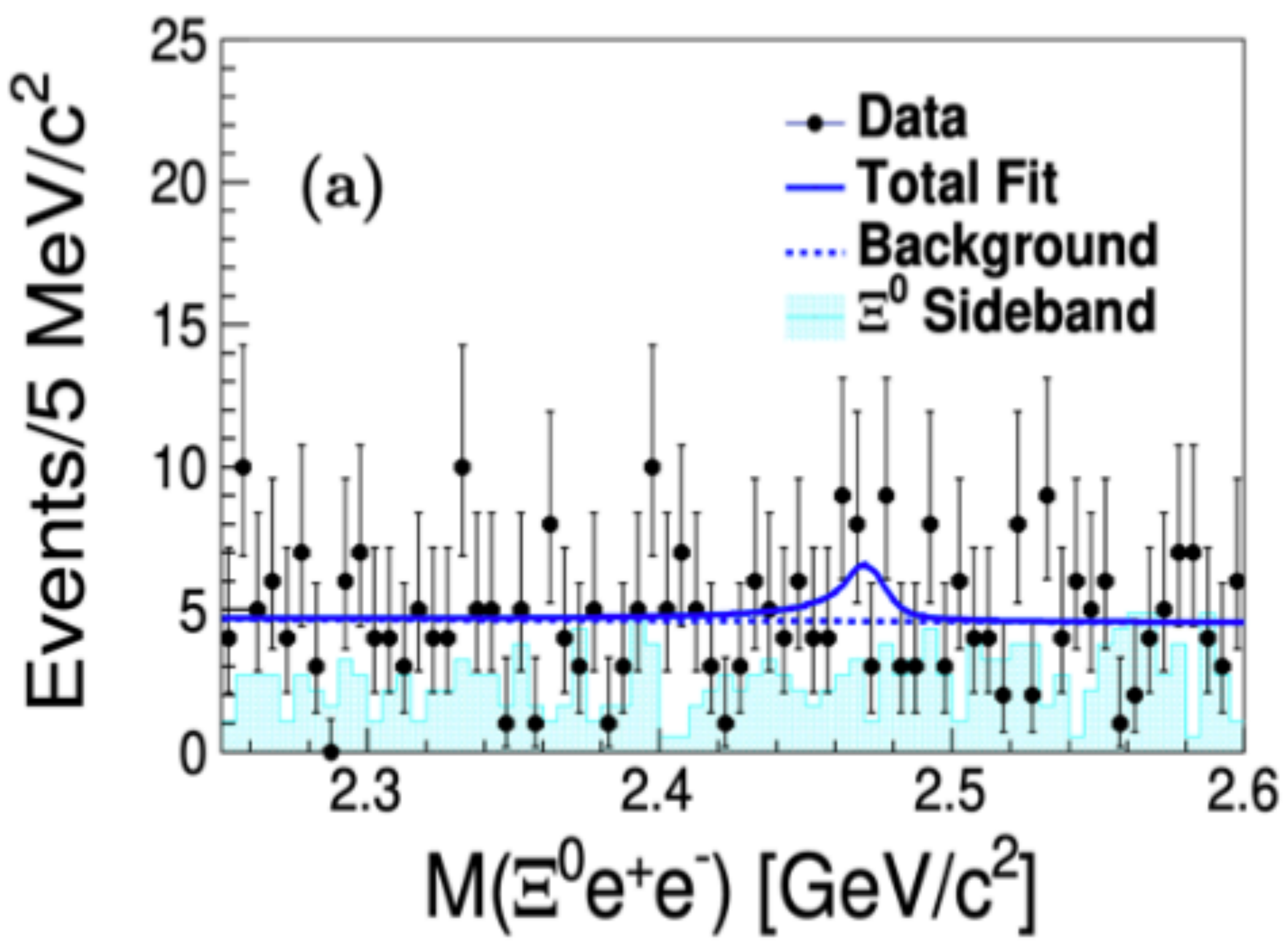
- no FCNC neutrino-less semileptonic decays of charm baryons observed yet
  - theoretically more complicated than the equivalent meson decays as they are sensitive to the hamiltonian helicity structure though W-exchange diagrams
  - if observed, the signal channels would allow to test LFU with $\ell = e,\ \mu$
- reconstruct $\Xi^0 \to \Lambda\pi^0$ and then combine with $\ell^+\ell^-$
  use $\Xi_c \to \Xi^- \pi^+$ as reference mode (BR = 1.43±0.32 %)
  20% relative uncertainty
  - no signal observed
  - upper limits set at 90% CL:
    9.9x10^{-5} (e channel)
    6.5x10^{-5} (μ channel)
  - compatible with SM expectations

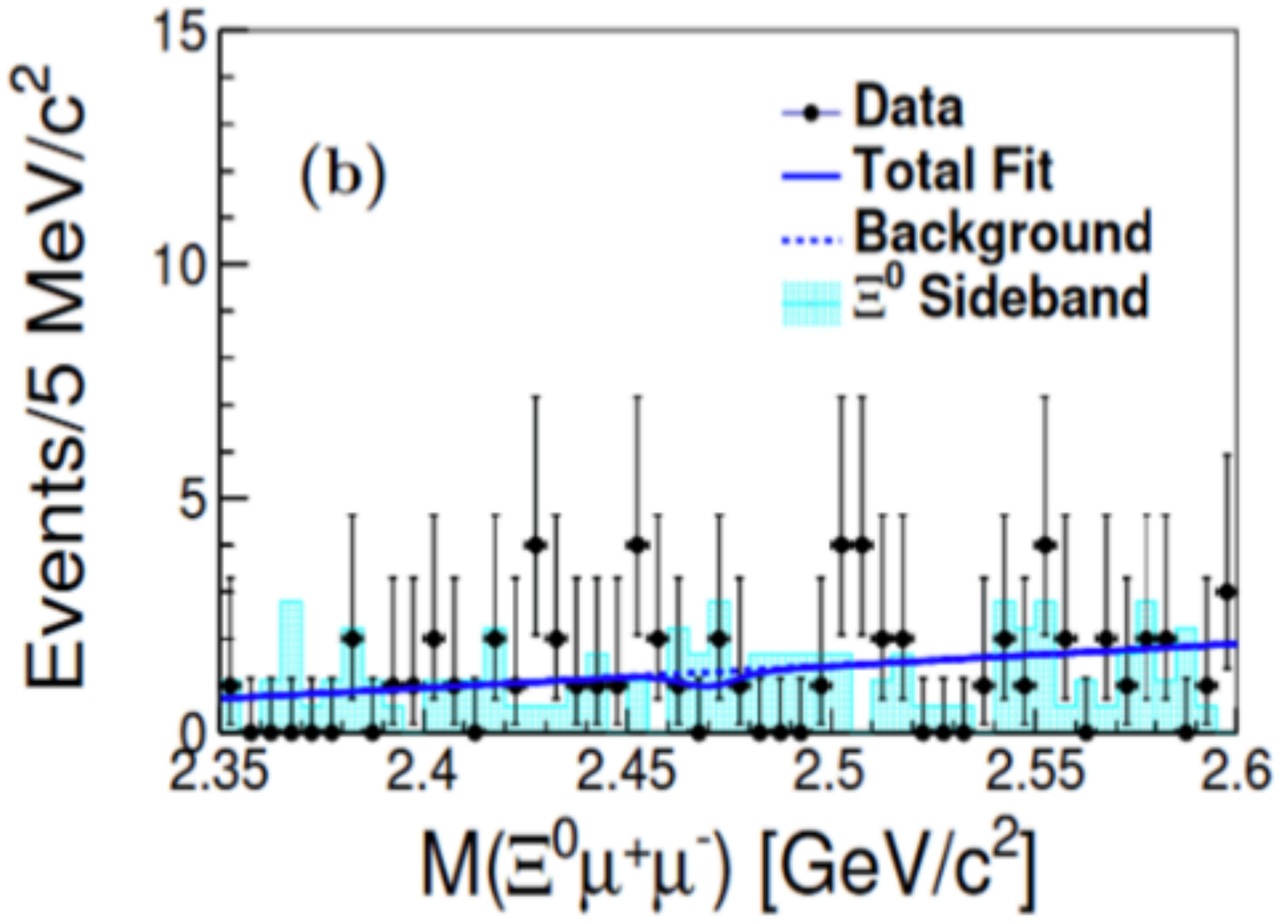
$$\mathscr{B}_{SM}(\Xi_c \to \Xi^0 e^+ e^-) < 2.35 \times 10^{-6}$$
$$\mathscr{B}_{SM}(\Xi_c \to \Xi^0 \mu^+ \mu^-) < 2.25 \times 10^{-6}$$

PRD103(2021):013007

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







(*) in backup slides 22, 23

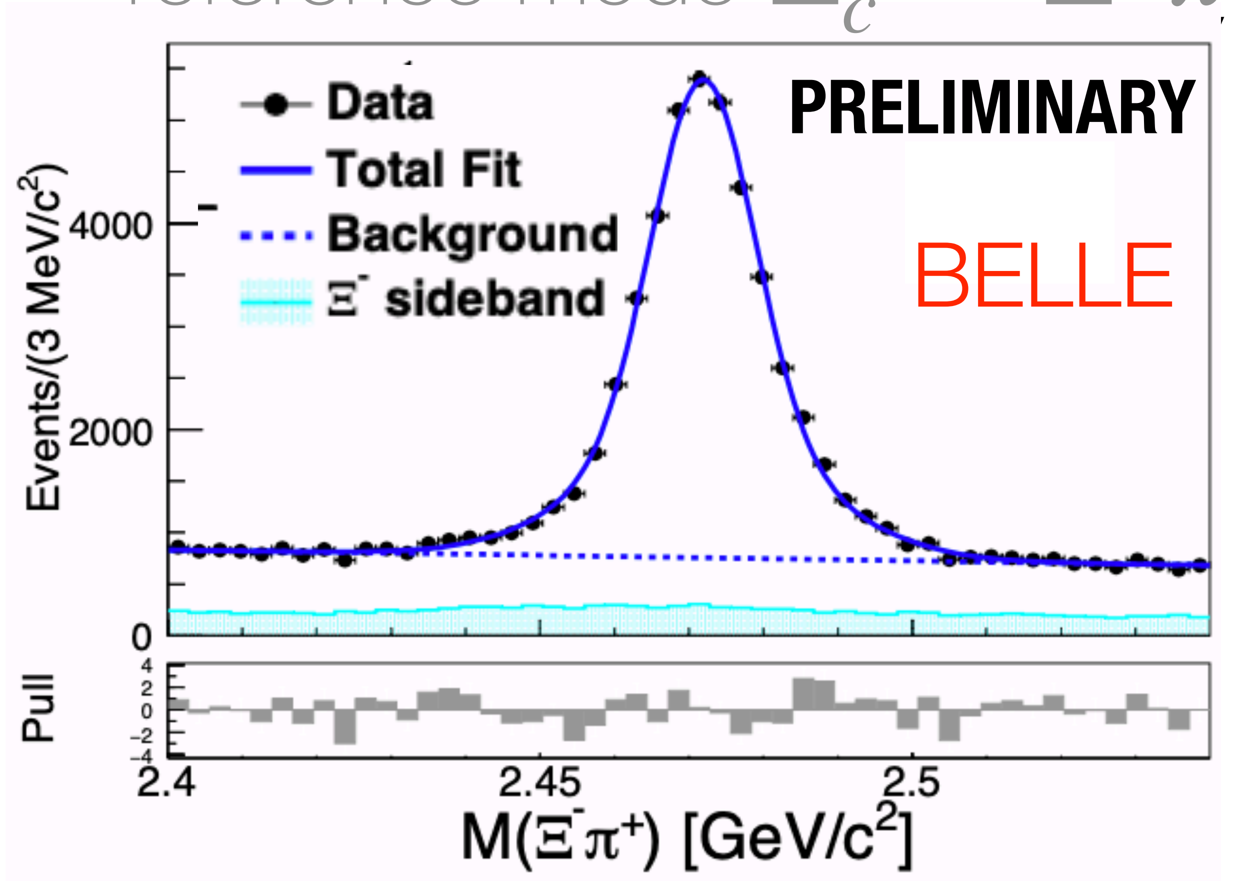
Study of $\Xi_c \to \Xi^0 h^0$, $h^0 = \pi^0, \eta, \eta'$ decays

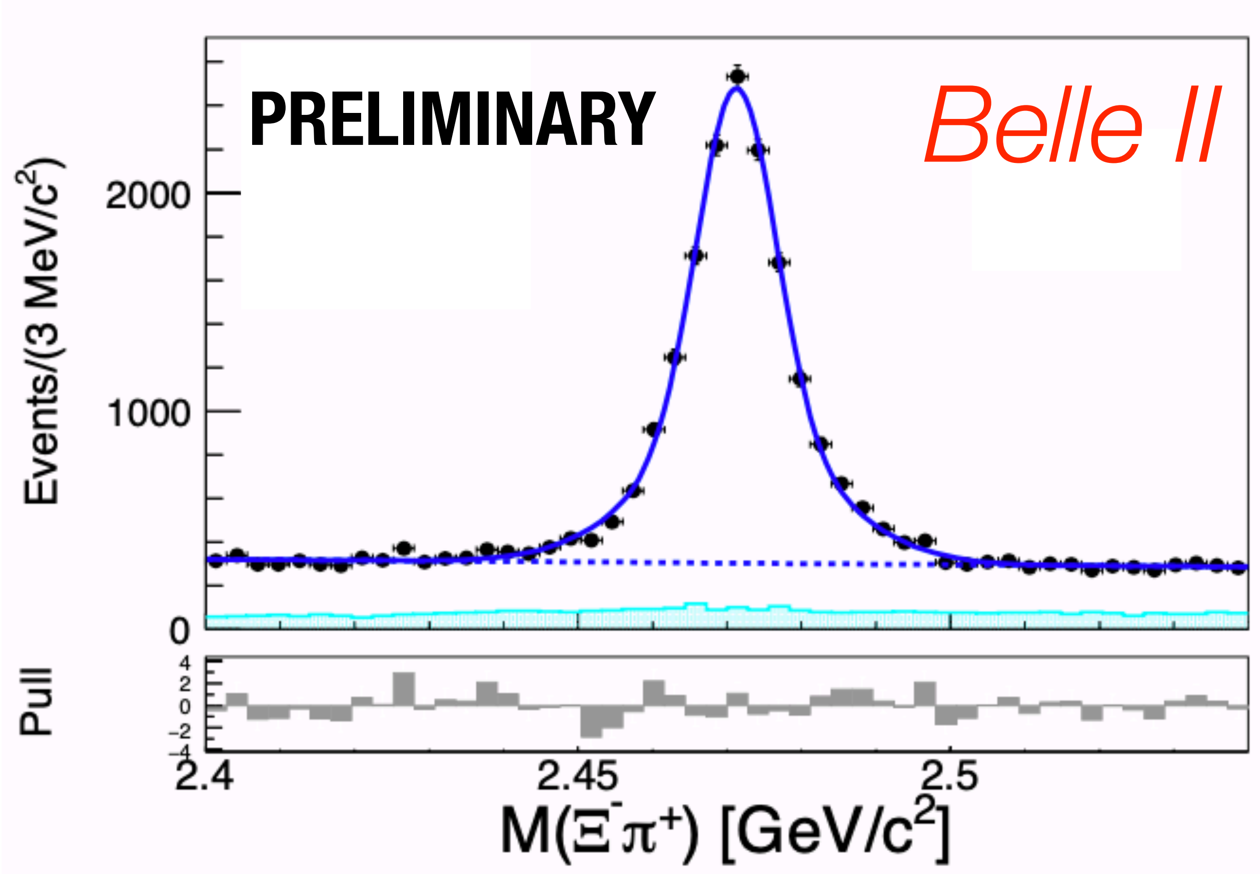
- Several theoretical approaches have been proposed(*) to deal with non-factorizable amplitudes from W-exchange and internal W-emission diagrams, yielding different predictions for these branching ratios
  - need a measurement of the BRs to clarify the theoretical picture
- First BELLE + *Belle II* combined charm measurement
  - after the selection of signal candidates with ε≃o(1%), yields are extracted with a fit to the invariant mass with a simultaneous fit to BELLE and *Belle II* datasets
- The asymmetry parameter α, related to P-violation, is also measured through the differential decay rate:

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

  - using $\alpha(\Xi^0 \to \Lambda\pi^0) = -0.349 \pm 0.009$

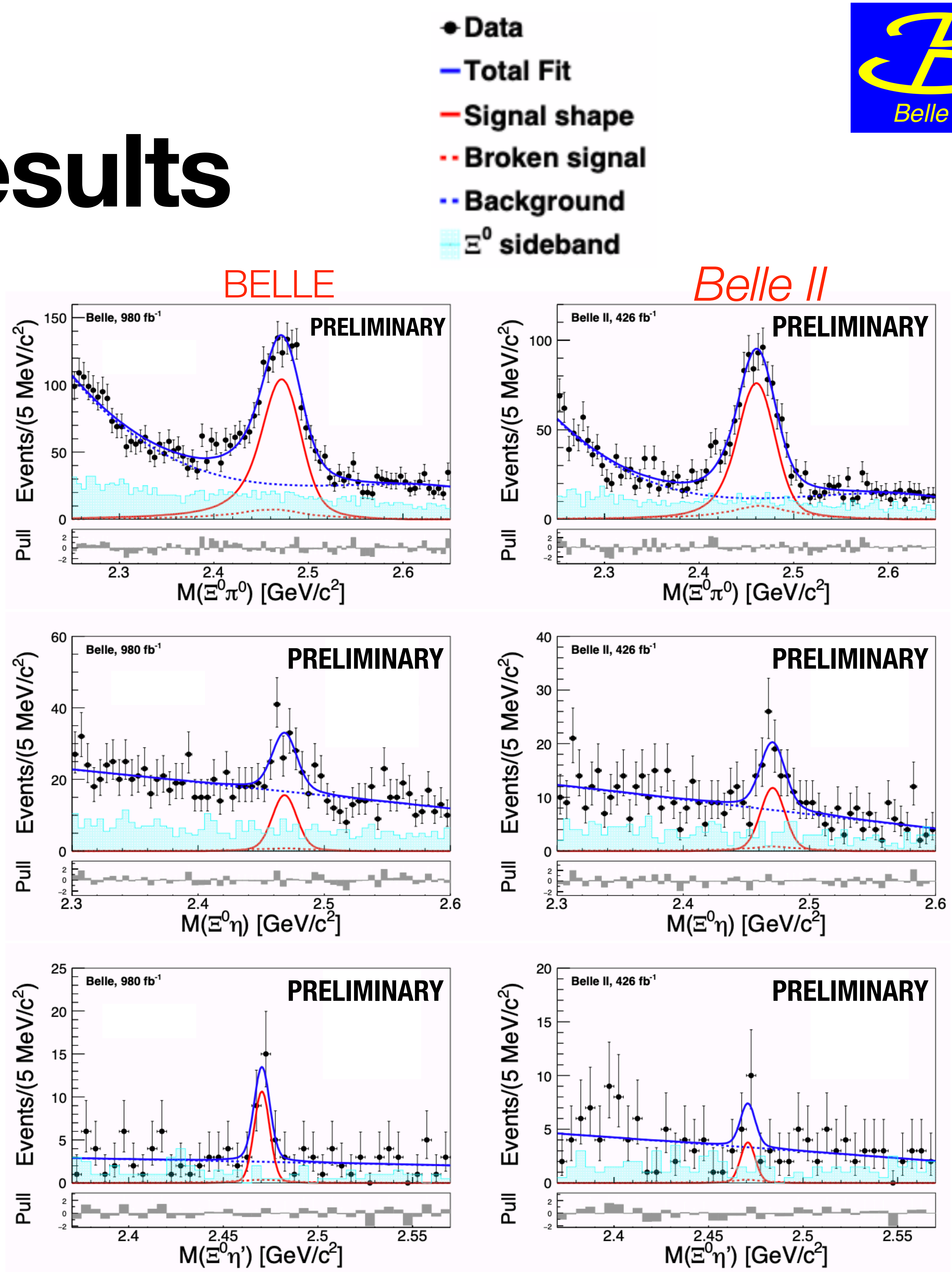
reference mode $\Xi_c \to \Xi^- \pi^+$





results in the next slide

$\Xi_c \rightarrow \Xi^0 h^0,\, h^0 = \pi^0, \eta, \eta'$ Results



- first measurement of the following three BRs …

$$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^0\pi^0) = (6.9 \pm 0.3(\text{stat.}) \pm 0.5(\text{syst.}) \pm 1.5(\text{norm.})) \times 10^{-3}$$

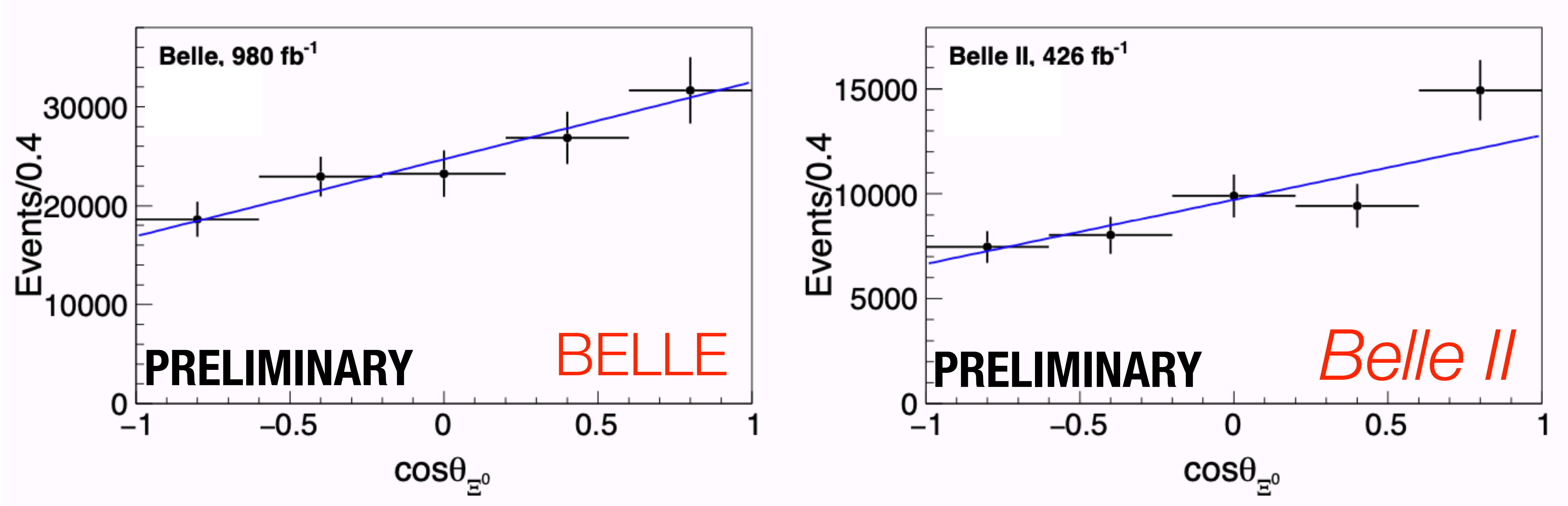
$$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^0\eta) = (1.6 \pm 0.2(\text{stat.}) \pm 0.2(\text{syst.}) \pm 0.4(\text{norm.})) \times 10^{-3}$$

$$\mathcal{B}(\Xi_c^0 \rightarrow \Xi^0\eta') = (1.2 \pm 0.3(\text{stat.}) \pm 0.1(\text{syst.}) \pm 0.3(\text{norm.})) \times 10^{-3}$$

  - rules out several theoretical models, favouriting those based on $SU(3)_F$-breaking

- … and of the $\Xi_c \rightarrow \Xi^0\pi^0$ asymmetry parameter:

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



Conclusions

➡ BELLE & *Belle II* provide a unique environment & unique sensitivity for SM measurements as well as for the search for physics beyond the SM in the charm sector both in meson and baryon decays

- significant room to improve the basic knowledge of baryon decays (BR, Dalitz structure…)

➡ BELLE is still producing important measurements after more than 10 years after the end of data taking

- search for CPV using T-odd observables in several channels, BR measurements
- search for $D \to p\ell$ and $\Xi_c \to \Xi^0 \ell^+ \ell^-$ with $\ell = e, \mu$
- study of rare FCNC decay $D^0 \to hh'e^+e^-$ NEW for Moriond

➡ First BELLE + *Belle II* combined analysis of the $\Xi_c \to \Xi^0 h^0$ decays rules out several theoretical approaches proposed to deal with non-factorizable amplitudes NEW for Moriond

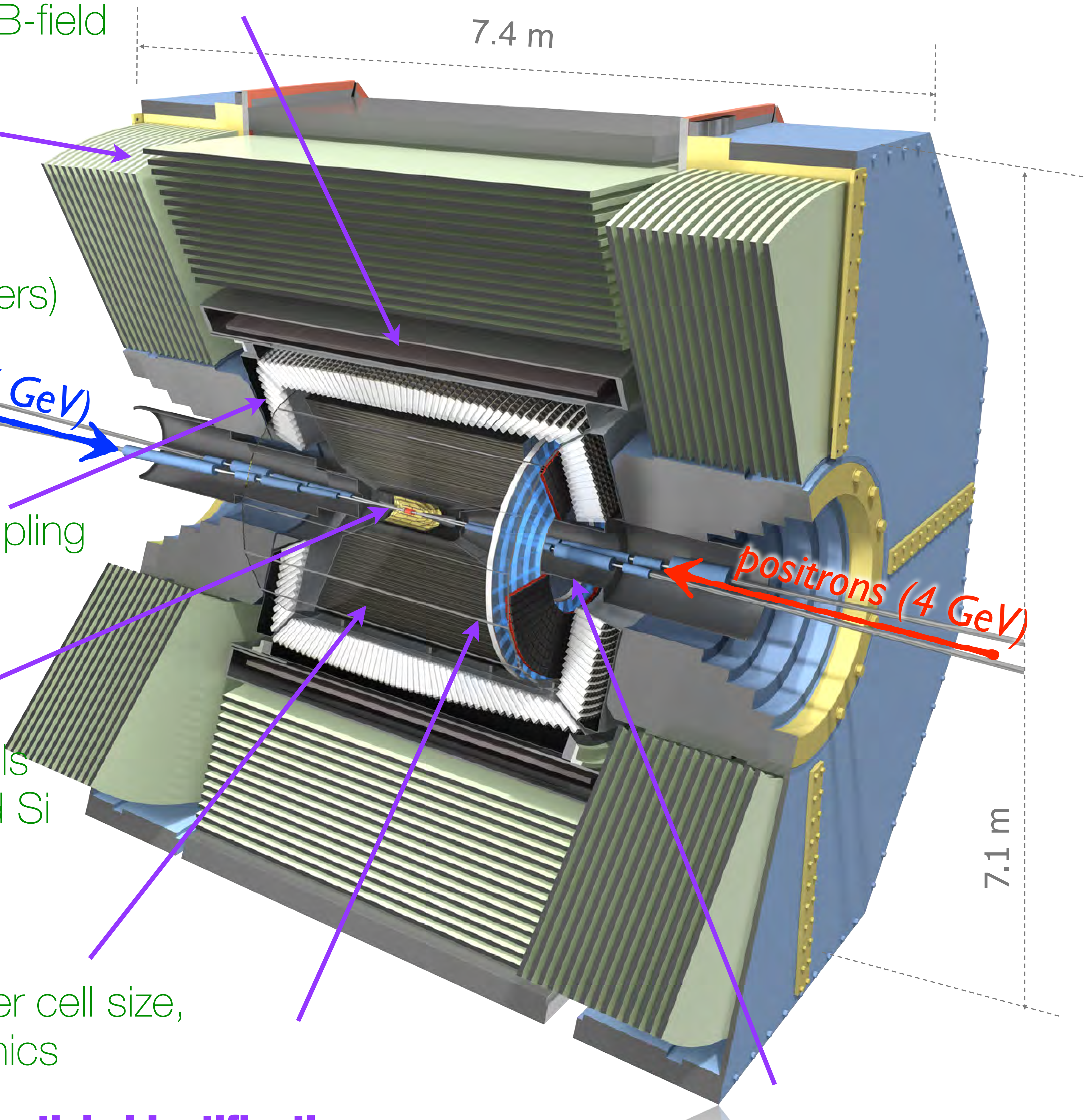
Thank you for your attention.

backup slides

Belle II

experiment @ SuperKEKB
High-Luminosity B-Factory

- *multi-purpose detector* well suited for inclusive analyses & missing energy measurements
  - 90% solid angle coverage & known initial state
- excellent vertexing & high-efficiency detection of neutrals (γ, π^0, η, η', …)
- high trigger efficiency, including for low-multiplicity events
- reconstruction performance *at least as good as* BELLE & *BABAR*

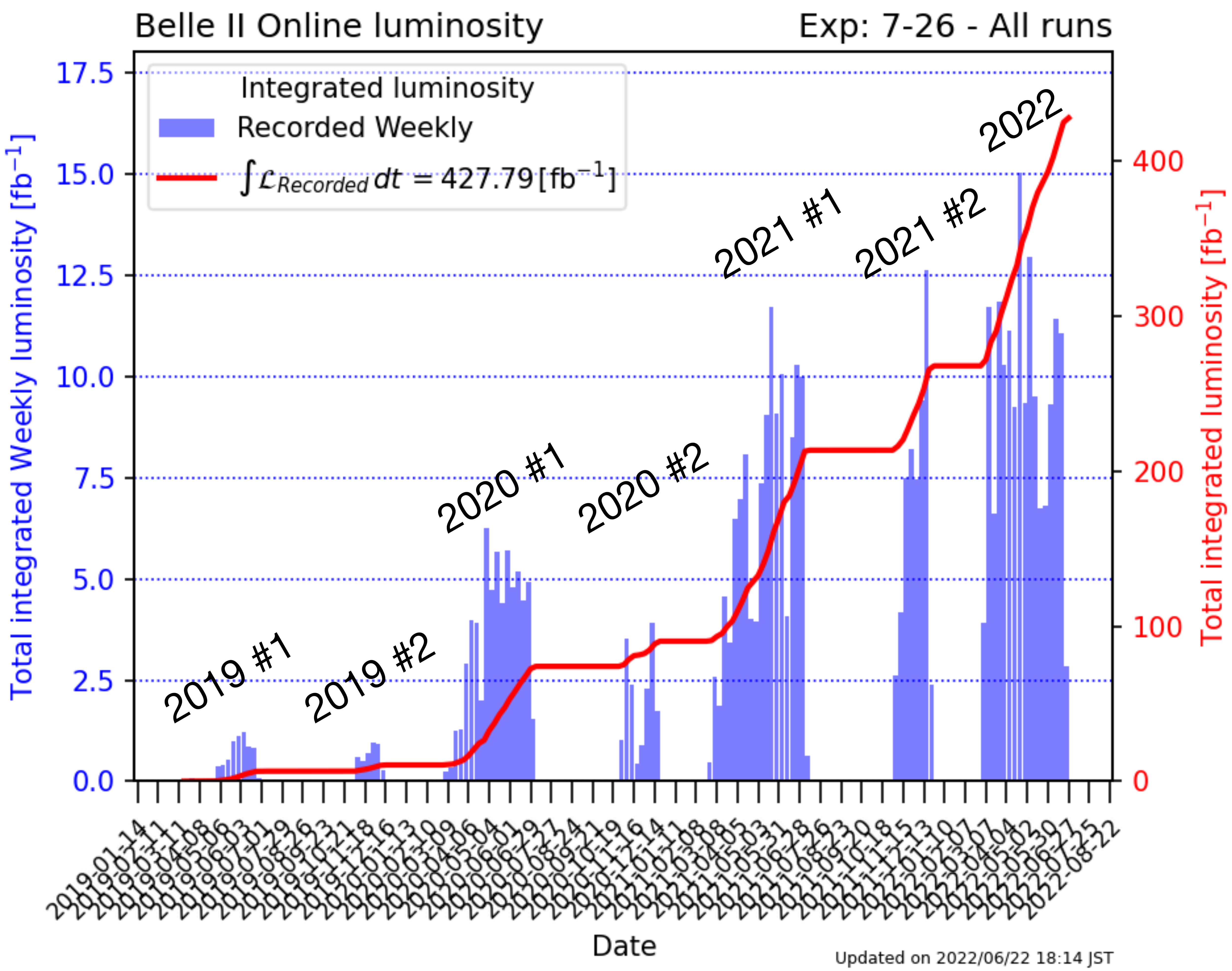


Belle II TDR

Belle II Run1 Dataset

- first data recorded in 2019
  - two data-taking periods per year
- collected data, 424/fb
  - 362/fb at Υ(4S)*
  - 42/fb off-resonance, 60 MeV below Υ(4S)
  - 19/fb energy scan between 10.6 to 10.8 GeV for exotic hadron studies

L (fb^{-1})	Belle	BABAR	total
Υ(5S)	121	-	121
Υ(4S)	711	433	1144
Υ(3S)	3	30	33
Υ(2S)	25	14	39
Υ(1S)	6	-	6
off-res	100	54	154



*corresponds to ~0.54 (0.88) of the BELLE (BABAR) Υ(4S) datasets

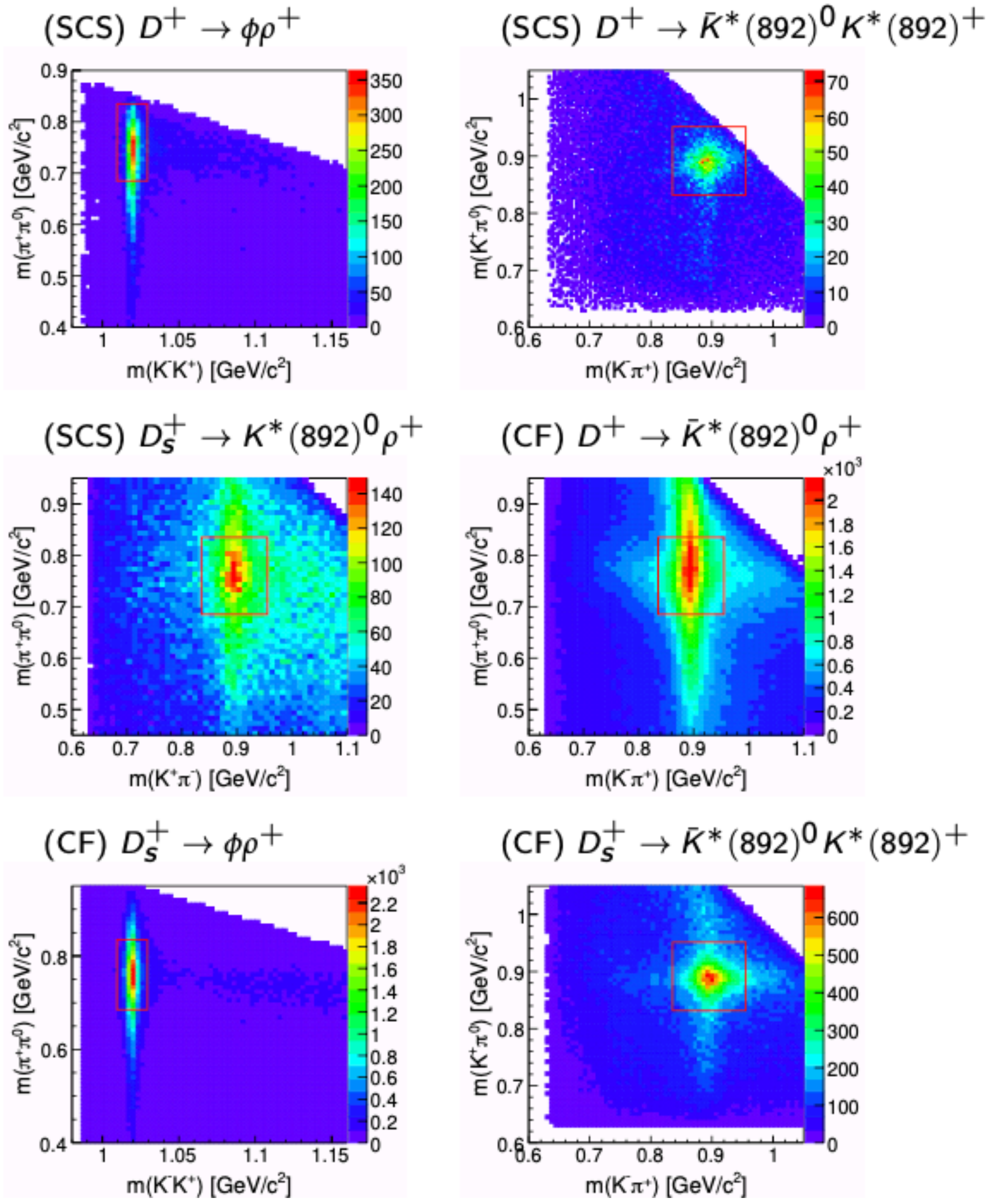
$a_{CP}^{\mathrm{T-odd}}$ for $D^+_{(s)} \to K^{\pm}h^{\pm}\pi^+\pi^0$ in Dalitz regions

➡ no evidence of local CPV in the Dalitz:

PRELIMINARY

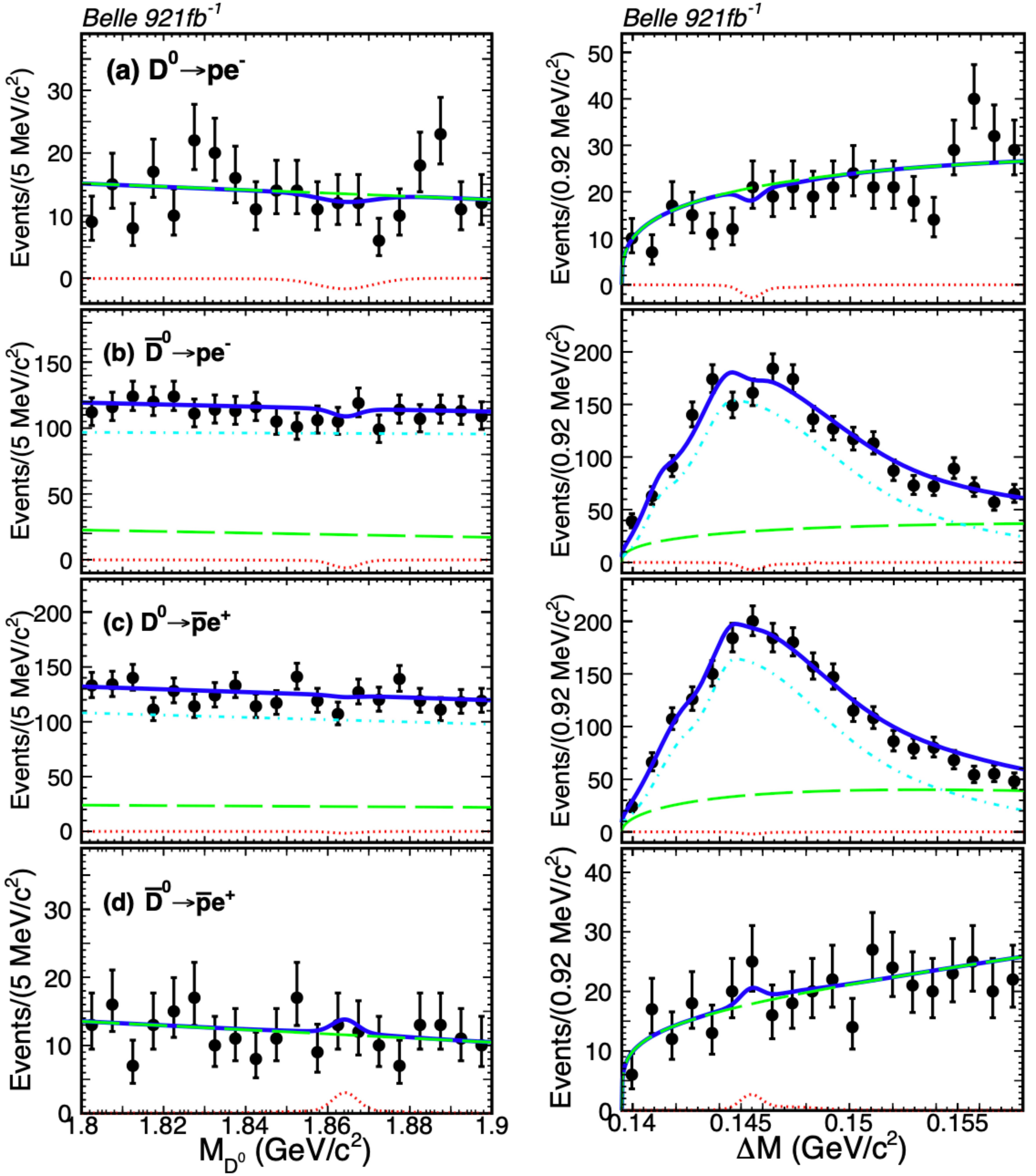
Subregion	$D^+_{(s)} \to VV$	Signal region (SR)	$a_{CP}^{T\text{-odd}}$ $(\times 10^{-2})$
(1) SCS	$D^+ \to \phi\rho^+$	ϕ-SR, ρ^+-SR	$0.85 \pm 0.95 \pm 0.25$
(2) SCS	$D^+ \to \bar{K}^{*0}K^{*+}$	$K^{*(0,+)}$-SR, veto ϕ-SR	$0.17 \pm 1.26 \pm 0.13$
(3) CF	$D^+ \to \bar{K}^{*0}\rho^+$	K^{*0}-SR, ρ^+-SR	$0.25 \pm 0.25 \pm 0.13$
(4) SCS	$D_s^+ \to K^{*0}\rho^+$	K^{*0}-SR, ρ^+-SR	$6.2 \pm 3.0 \pm 0.4$
(5) SCS	$D_s^+ \to K^{*+}\rho^0$	K^{*+}-SR, ρ^0-SR	$1.7 \pm 6.1 \pm 1.5$
(6) CF	$D_s^+ \to \phi\rho^+$	ϕ-SR, ρ^+-SR	$0.31 \pm 0.40 \pm 0.43$
(7) CF	$D_s^+ \to \bar{K}^{*0}K^{*+}$	$K^{*(0,+)}$-SR, veto ϕ-SR	$0.26 \pm 0.76 \pm 0.37$

SR: $|M_{KK} - m_\phi| < 10\ \mathrm{MeV}/c^2$, $-90 < (M_{\pi\pi} - m_\rho) < 60\ \mathrm{MeV}/c^2$, and $|M_{K\pi} - m_{K^*}| < 60\ \mathrm{MeV}/c^2$.



Search for $D \to p\ell$

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
$\overline{D}^0 \to pe^-$	10.2	-18.4 ± 23.0	—	22.0	< 6.9
$D^0 \to \overline{p}e^+$	9.7	-4.7 ± 23.0	—	22.0	< 7.2
$\overline{D}^0 \to \overline{p}e^+$	9.6	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
$\overline{D}^0 \to p\mu^-$	10.7	-10.8 ± 27.0	—	21.8	< 6.5
$D^0 \to \overline{p}\mu^+$	10.5	-4.5 ± 14.0	—	21.1	< 6.3
$\overline{D}^0 \to \overline{p}\mu^+$	10.4	16.7 ± 8.8	1.6	21.4	< 6.5



NEW for Moriond – BELLE (980/fb)

BESIII PRD97(2019):072015
BABAR PRL122(2019):081802

$D^0 \to hh'e^+e^-$ Upper Limits [x10^{-7}]

m_{ee} region	[MeV/c^2]	Yield	Significance	$\mathcal{B}$	BELLE UL @ 90% CL	Efficiency (%)	BESIII (UL @ 90% CL)	BABAR (UL @ 90% CL)
$K^-K^+e^+e^-$							< 110	–
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		
$\pi^-\pi^+e^+e^-$							< 70	–
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		
$K^-\pi^+e^+e^-$							< 410	< 31*
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.

*non resonant regions only, excluding:
$100 < m(e^+e^-) < 200$ MeV/c^2
$675 < m(e^+e^-) < 875$ MeV/c^2; $491 < m(e^+e^-) < 560$ MeV/c^2
$902 < m(e^+e^-) < 964$ MeV/c^2; $1.005 < m(e^+e^-) < 1.035$ GeV/c^2

$D^0 \to hh'\mu^+\mu^-$ at LHCb

The decay $D^0 \to K^-\pi^+\mu^+\mu^-$ is studied using proton–proton collision data corresponding to an integrated luminosity of 2.0 fb^{-1} collected in 2012 by the LHCb detector at a centre-of-mass energy of 8 TeV. The branching fraction of the decay $D^0 \to K^-\pi^+\mu^+\mu^-$ in the dimuon mass range 675–875 MeV/c^2 is measured to be

$$\mathcal{B}(D^0 \to K^-\pi^+\mu^+\mu^-) = (4.17 \pm 0.12\,(\text{stat}) \pm 0.40\,(\text{syst})) \times 10^{-6}.$$

$m(\mu^+\mu^-)$ region	[MeV/c^2]	$\mathcal{B}$ [10^{-8}]
	$D^0 \to \pi^+\pi^-\mu^+\mu^-$	
Low mass	<525	$7.8 \pm 1.9 \pm 0.5 \pm 0.8$
η	525–565	<2.4(2.8)
ρ^0/ω	565–950	$40.6 \pm 3.3 \pm 2.1 \pm 4.1$
ϕ	950–1100	$45.4 \pm 2.9 \pm 2.5 \pm 4.5$
High mass	>1100	<2.8(3.3)
	$D^0 \to K^+K^-\mu^+\mu^-$	
Low mass	<525	$2.6 \pm 1.2 \pm 0.2 \pm 0.3$
η	525–565	<0.7(0.8)
ρ^0/ω	>565	$12.0 \pm 2.3 \pm 0.7 \pm 1.2$

$$\mathcal{B}(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7},$$

$$\mathcal{B}(D^0 \to K^+K^-\mu^+\mu^-) = (1.54 \pm 0.27 \pm 0.09 \pm 0.16) \times 10^{-7}.$$

NEW for Moriond – BELLE + *Belle II (1.4/ab)*

$\Xi_c \to \Xi^0 h^0$ Theoretical Predictions

BF 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
Xu, Kamal [7]	pole	7.7	-	-	0.92
Cheng, Tseng [8]	pole	3.8	-	-	-0.78
Cheng, Tseng [8]	CA	17.1	-	-	0.54
Żenczykowski [9]	pole	6.9	1.0	9.0	0.21
Ivanov *et al.* [6]	quark	0.5	3.7	4.1	0.94
Sharma, Verma [11]	CA	-	-	-	-0.8
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	-
Zou *et al.* [10]	pole	18.2	26.7	-	-0.77
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

references in the next slide

$\Xi_c \to \Xi^0 h^0$ Theoretical Predictions Refs

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$\Xi_c \to \Xi^0 h^0$ Systematic Uncertainties

Source	$\frac{\mathcal{B}(\Xi_c^0\to\Xi^0\pi^0)}{\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)}$		$\frac{\mathcal{B}(\Xi_c^0\to\Xi^0\eta)}{\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)}$		$\frac{\mathcal{B}(\Xi_c^0\to\Xi^0\eta')}{\mathcal{B}(\Xi_c^0\to\Xi^-\pi^+)}$	
	Belle	Belle II	Belle	Belle II	Belle	Belle II
Tracking	0.7	0.8	0.7	0.7	1.0	1.5
$\pi^\pm$ PID	0.4	0.2	0.4	0.2	1.4	0.2
π^0 reconstruction	4.4	8.8	2.3	4.3	2.3	4.2
Photon reconstruction	-	-	4.0	2.0	4.0	1.9
MC statistics	0.8	0.7	0.9	0.9	1.2	1.0
α uncertainty	1.1	1.2	3.0	3.4	1.0	3.5
Ξ^0 signal mass window	0.5	2.0	0.5	2.0	0.5	2.0
Normalization mode statistics	1.0	1.3	1.0	1.3	1.0	1.3
Broken-signal ratio ($n_{\text{broken}}/n_{\text{sig}}$)	2.1	1.5	3.5	3.6	3.6	5.7
Mass Resolution	-	-	7.2	7.0	2.4	1.4
Intermediate states $\mathcal{B}$	-	-	0.5	0.5	1.3	1.3
Background shape	4.9	4.9	9.2	9.2	6.8	6.8
Total	7.2	10.6	13.5	13.7	9.7	11.2

Charm Baryons

- ➡ Baryon physics is rich and bring complementary information to that of meson physics
- ➡ A lot of room to **improve the basic knowledge** of charm baryons
  - e.g.: branching ratios, Dalitz structure of multi-body decays, hadronic form factors, …
  - critical to experimentally access measurements of CPV, search for NP, search for rare or forbidden processes
- ➡ BELLE & *Belle II* have a sample of charm baryons that can be exploited to improve our knowledge of baryon decays and search for NP in these decays
  - *e.g*. search for CPV in the D→hh baryon-equivalent system, for which U-spin sum rule indicates:

EPJC79,429 (2019)

$$A_{CP}^{dir}(\Lambda_c^+ \to pK^+K^-) + A_{CP}^{dir}(\Xi_c^+ \to \Sigma^+\pi^+\pi^-) = 0$$
$$A_{CP}^{dir}(\Lambda_c^+ \to p\pi^+\pi^-) + A_{cp}^{dir}(\Xi_c^+ \to \Sigma^+K^+K^-) = 0$$

ΔA_{cp} LHCb, JHEP03(2018)182