Belle II

Fighting ~~Systematics~~ *all-out* in Charm CPV at Belle II

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Beauty2019, Sep.30-Oct.4, Ljubljana, Slovenia

Outline

- Introduction & Belle II Improvements
  - vertexing, hadron ID, D-tagging
- for CPV, time-integrated
  - $A_{\mathrm{CP}}(D^0 \to V\gamma)$
  - $A_{\mathrm{CP}}(D \to PP')$
- for CPV, time-dependent
  - Mixing & CPV parameters for $D^0 \to K^0_S \pi^+ \pi^-$
- Summary

KEK Preprint 2018-27
BELLE2-PAPER-2018-001
FERMILAB-PUB-18-398-T
JLAB-THY-18-2780
INT-PUB-18-047
UWThPh 2018-26

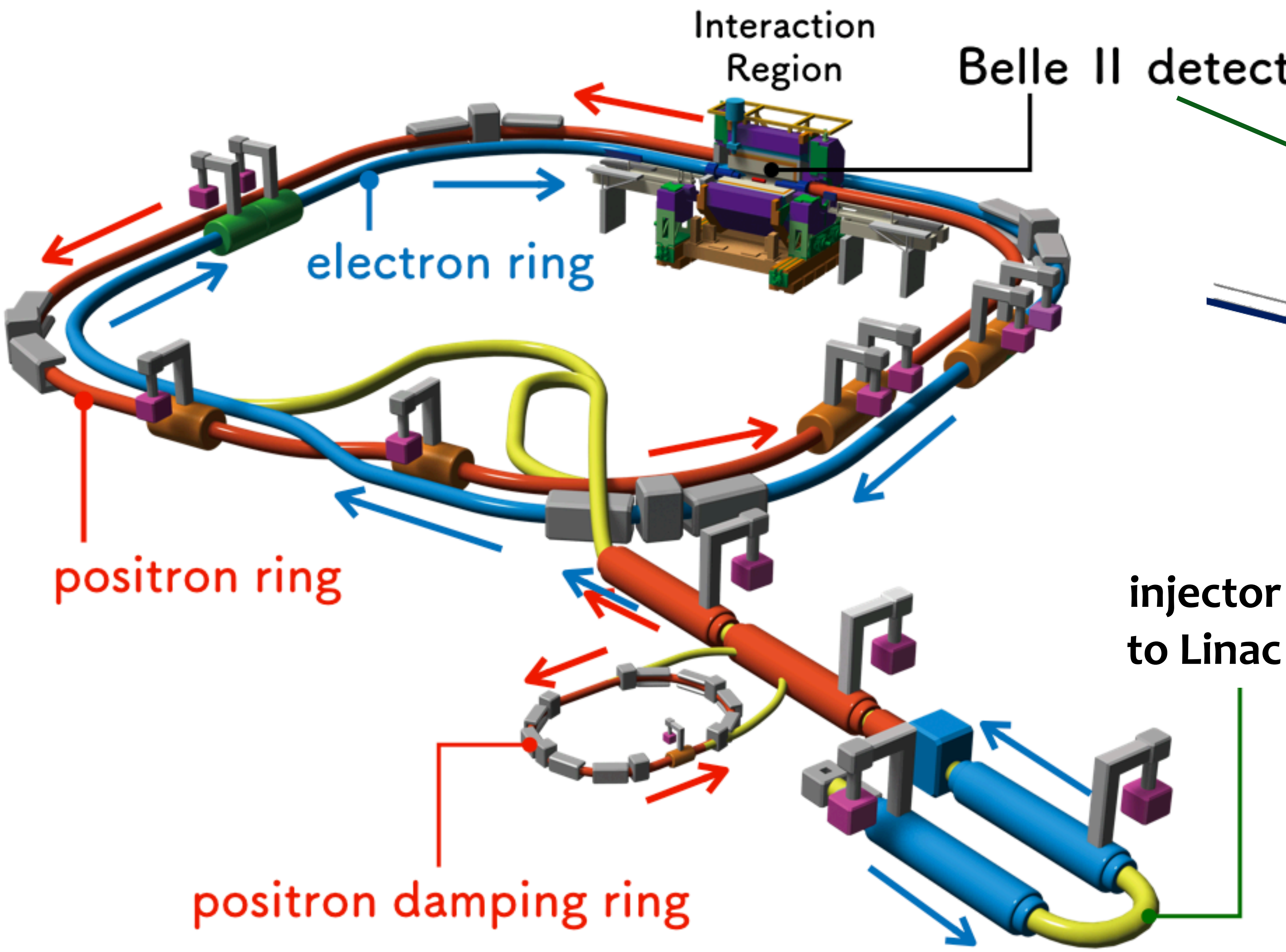
The Belle II Physics Book

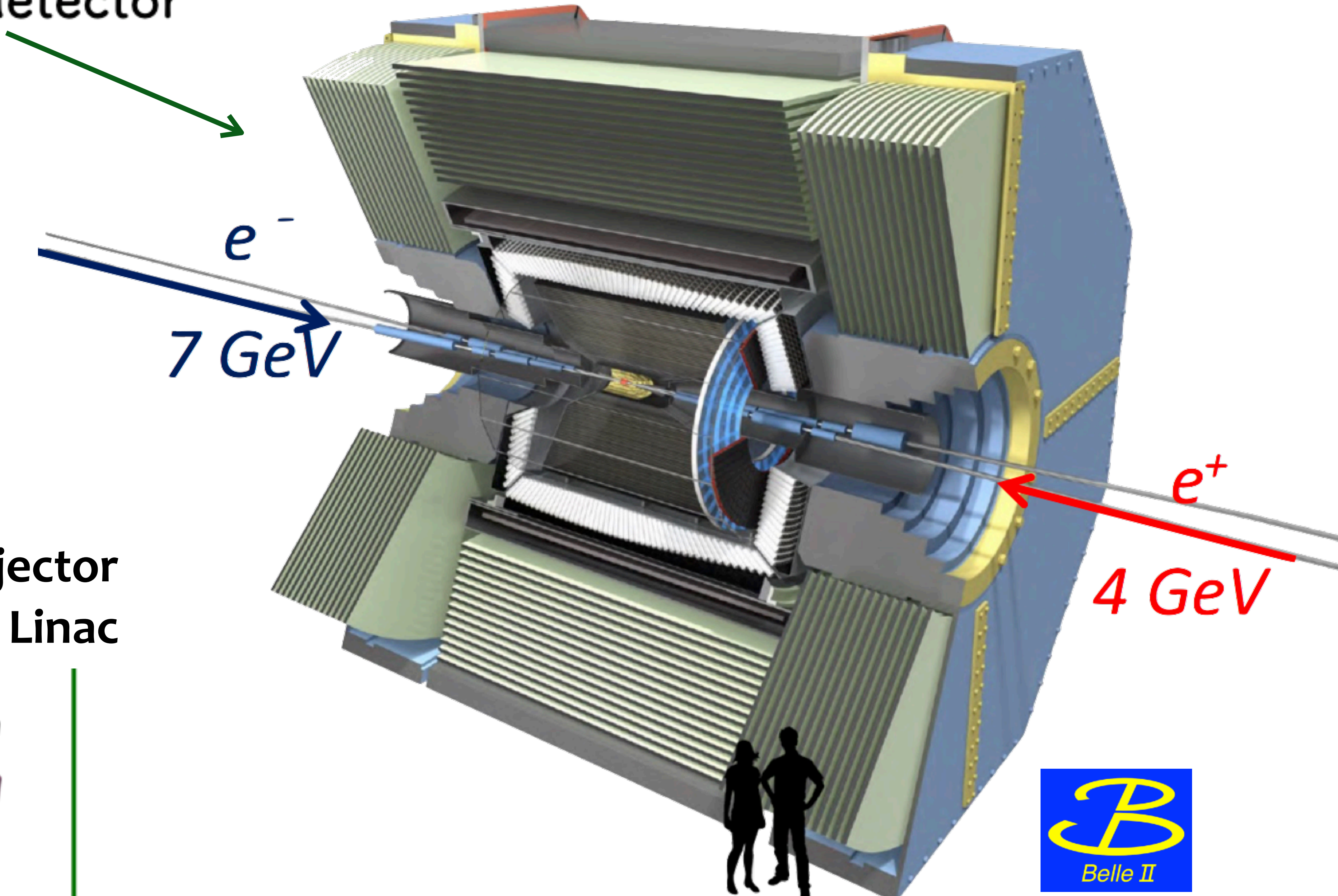
E. Kou[74,¶,†], P. Urquijo[143,§,†], W. Altmannshofer[133,¶], F. Beaujean[78,¶], G. Bell[120,¶], M. Beneke[112,¶], I. I. Bigi[146,¶], F. Bishara[148,16,¶], M. Blanke[49,50,¶], C. Bobeth[111,112,¶], M. Bona[150,¶], N. Brambilla[112,¶], V. M. Braun[43,¶], J. Brod[110,133,¶], A. J. Buras[113,¶], H. Y. Cheng[44,¶], C. W. Chiang[91,¶], M. Ciuchini[58,¶], G. Colangelo[126,¶], H. Czyz[154,29,¶], A. Datta[144,¶], F. De Fazio[52,¶], T. Deppisch[50,¶], M. J. Dolan[143,¶], J. Evans[133,¶], S. Fajfer[107,139,¶], T. Feldmann[120,¶], S. Godfrey[7,¶], M. Gronau[61,¶], Y. Grossman[15,¶], F. K. Guo[41,132,¶], U. Haisch[148,11,¶], C. Hanhart[21,¶], S. Hashimoto[30,26,¶], S. Hirose[88,¶], J. Hisano[88,89,¶], L. Hofer[125,¶], M. Hoferichter[166,¶]

Many figures and tables are taken from “**The Belle II Physics Book**” (arXiv:1808.10567) which is *accepted for publication* in PTEP. It is indicated, in this talk, with a symbol **B2TiP**

SuperKEKB

Belle II





$$e^- \xrightarrow{\text{7 GeV}} (\star) \xleftarrow{\text{4 GeV}} e^+$$

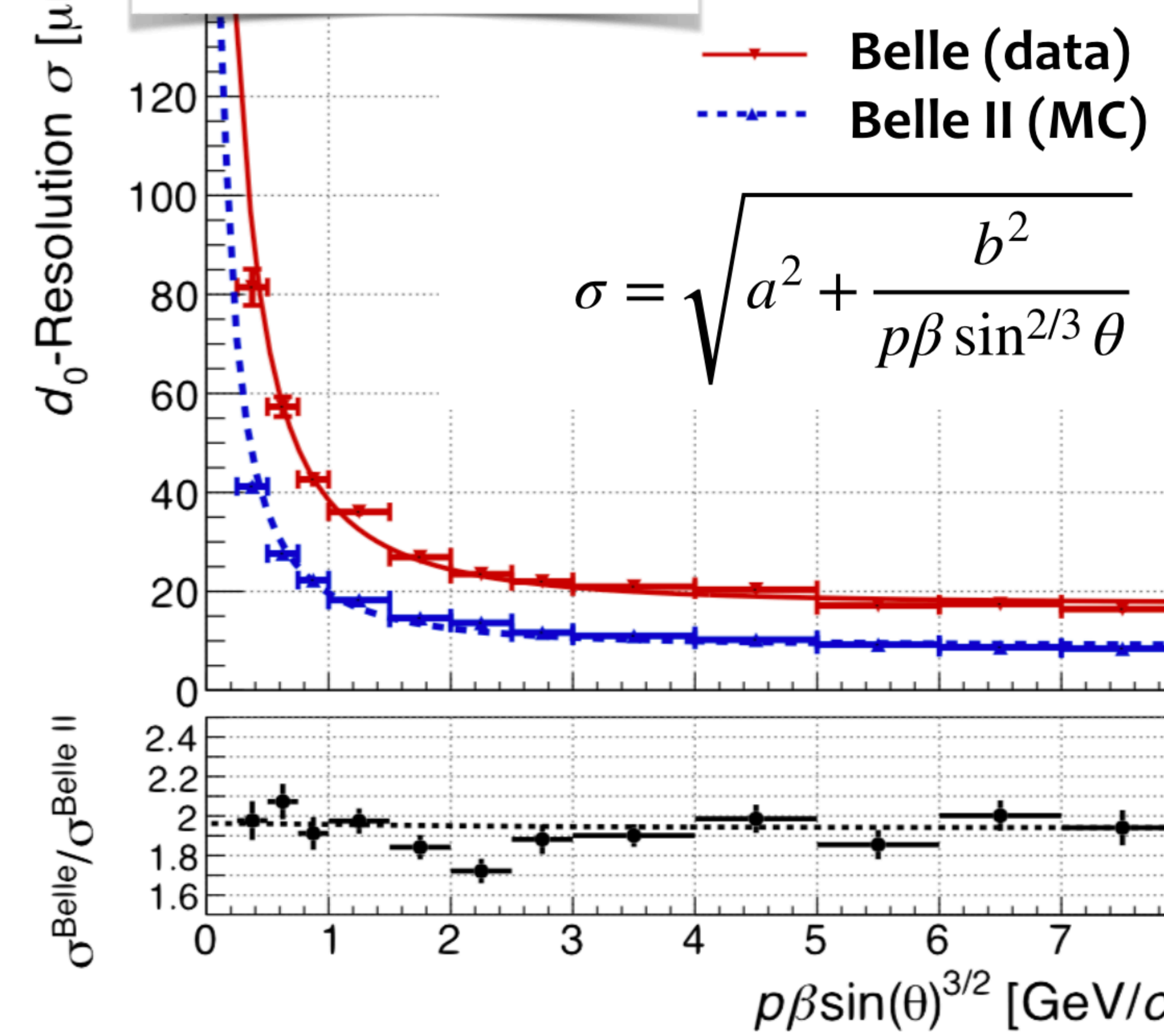
$$\mathcal{L}_{\text{peak}} = 8 \times 10^{35} \text{cm}^{-2}\text{s}^{-1}$$

$$\int^{\text{goal}} \mathcal{L}\, dt = 50 \text{ ab}^{-1}$$

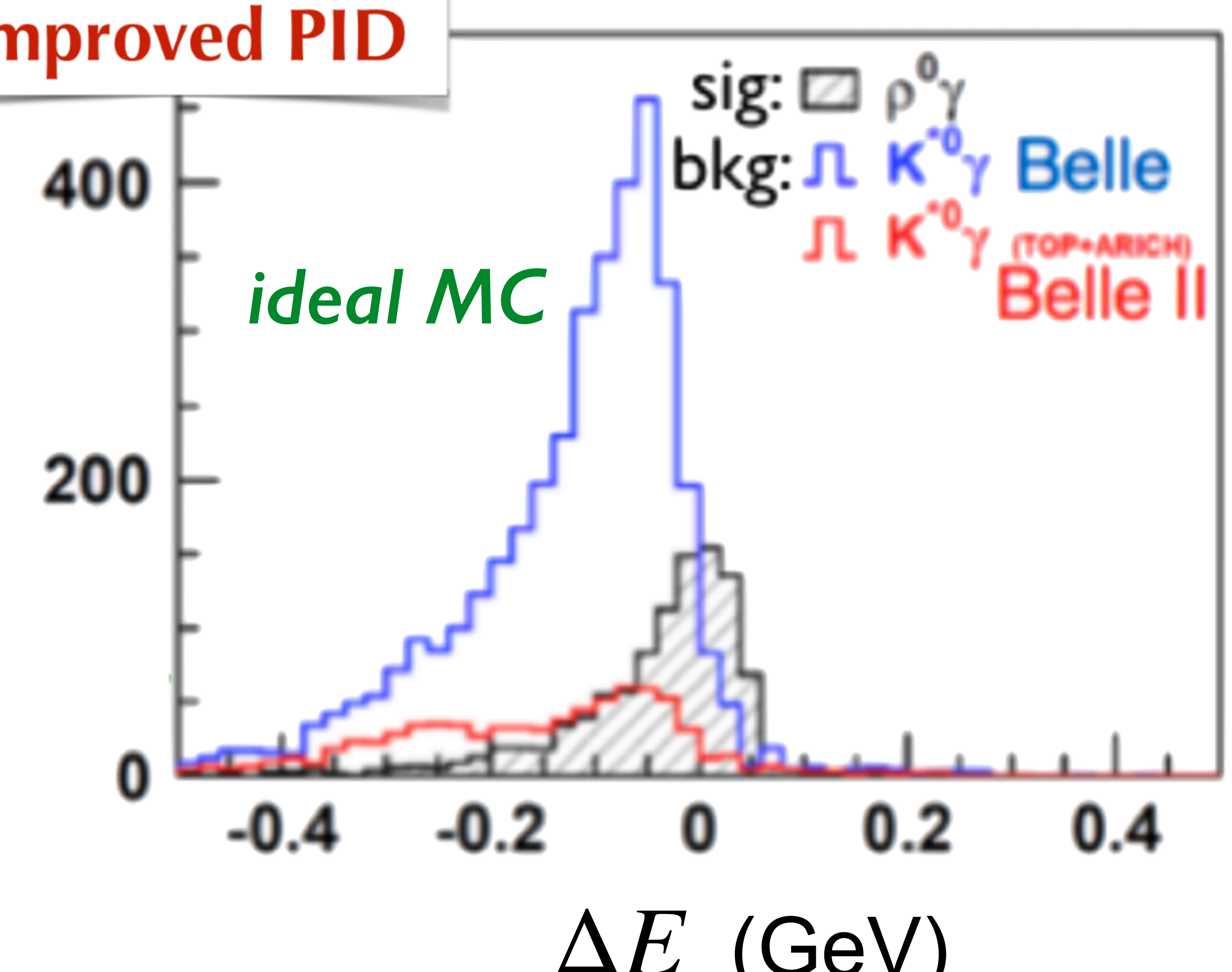
Belle II improvements

- vertex resolution
- K_S^0 and π^0reconstruction efficiency
- K/π separation
- hadron & muon ID in the endcaps
- flavor tagging
  - (Belle) D* tagging only
  - (Belle II) D* & ROE tagging

Improved Vertex

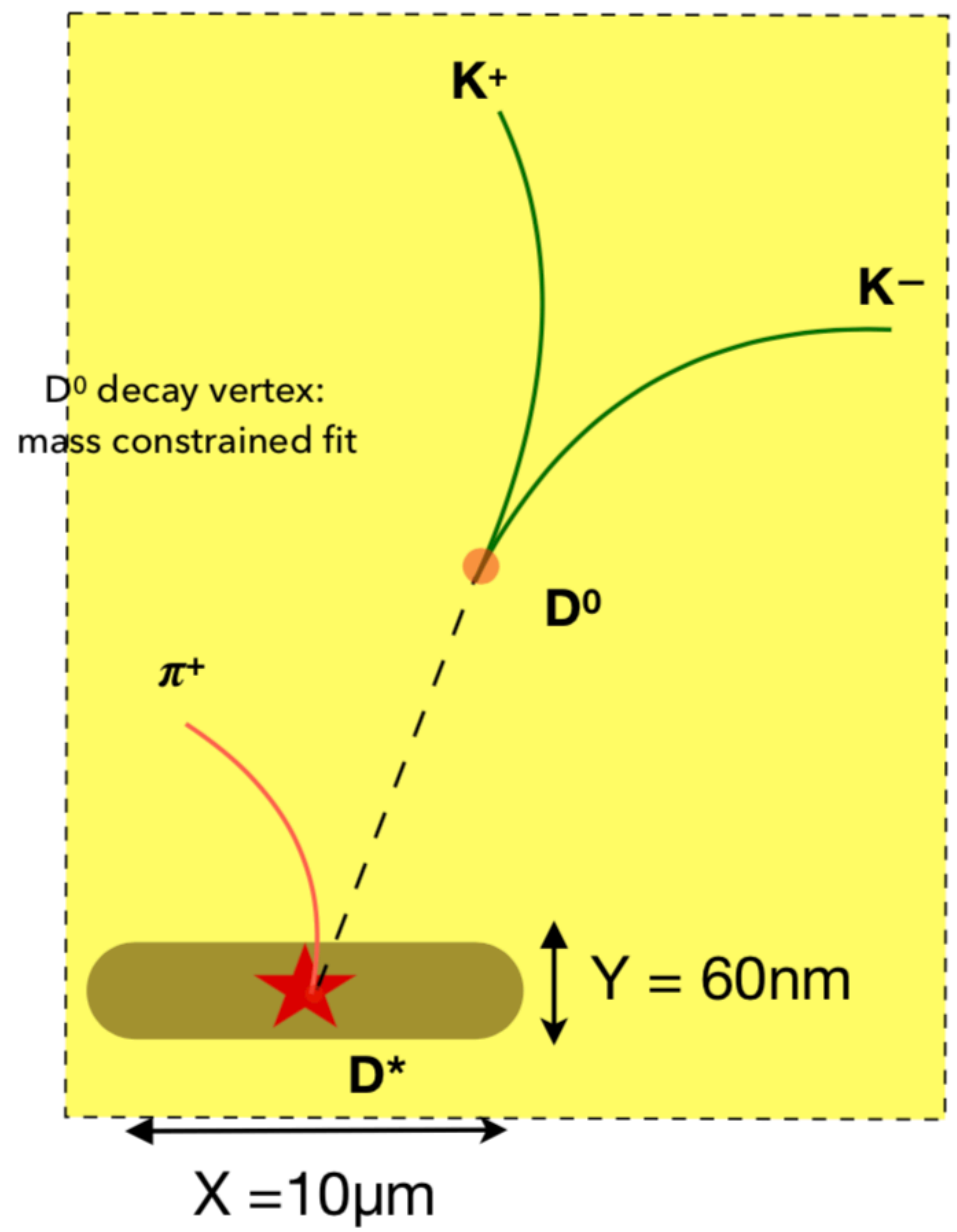


Improved PID

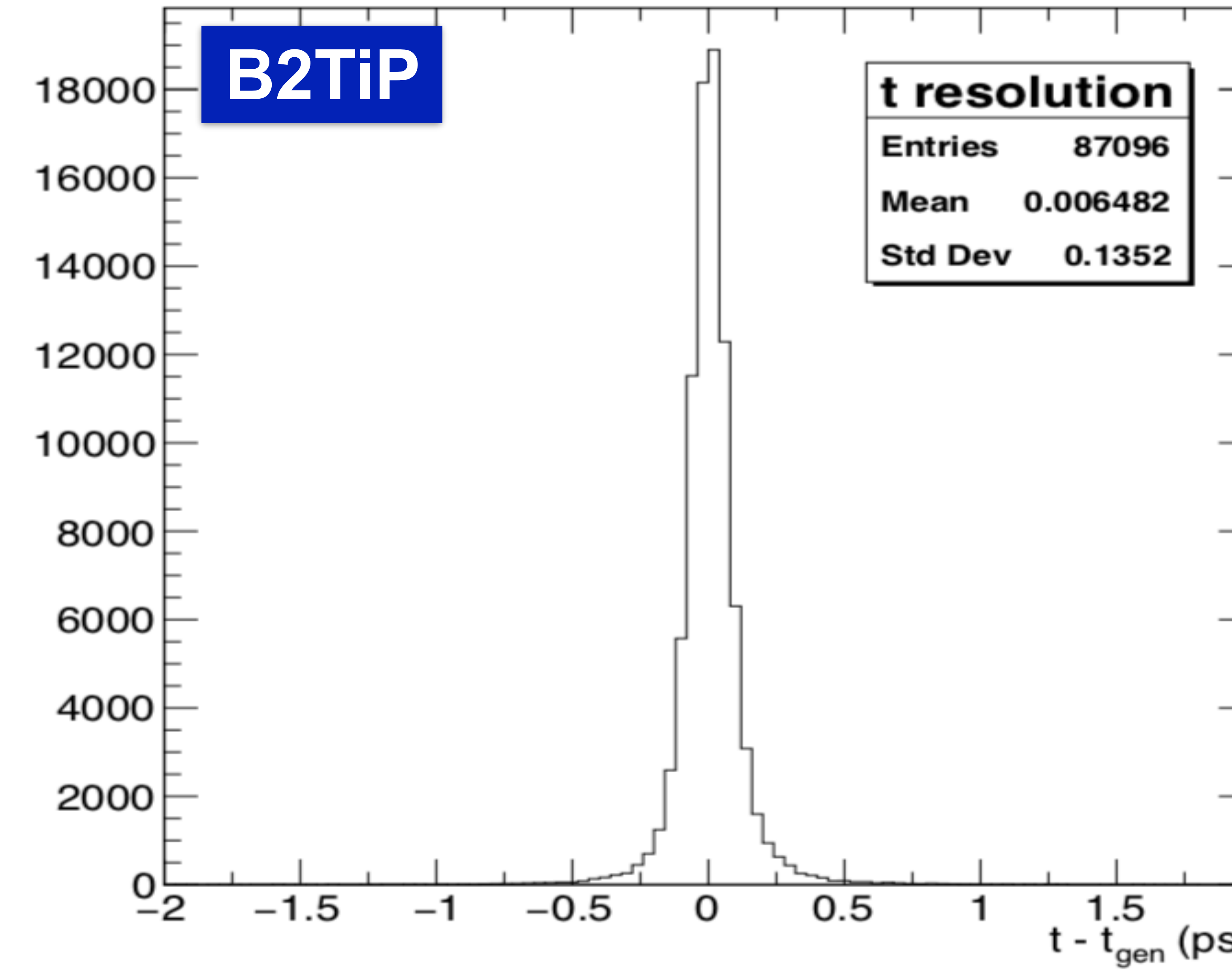


Time & Vertex resolution in Belle II

- factor ~2 better than Belle and BaBar
  - $\delta r_{xy} \sim 40\ \mu\mathrm{m}$
  - $\delta t \sim 0.15$ ps



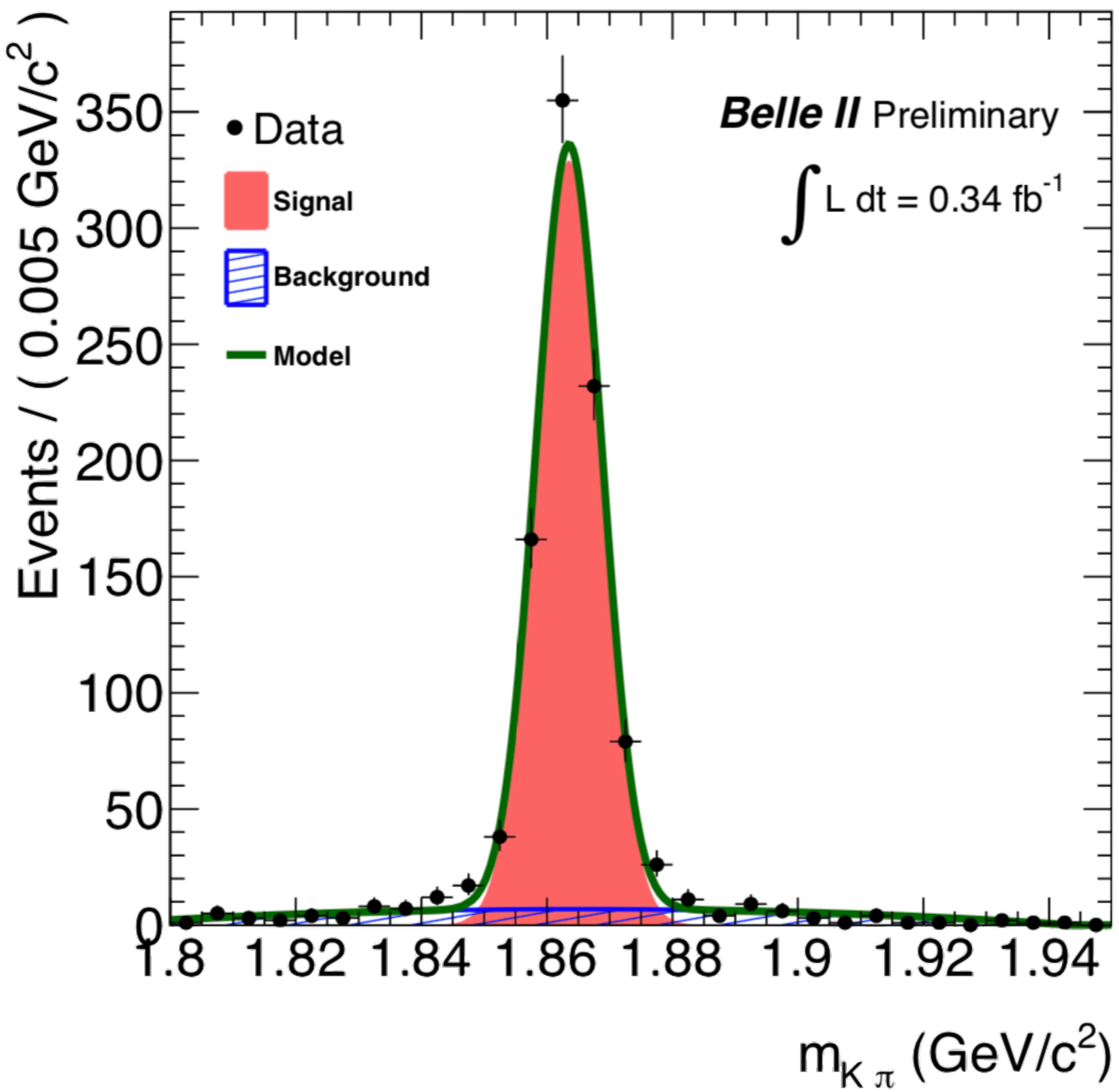
$D^0 \to K^+K^-$ (Belle II MC)

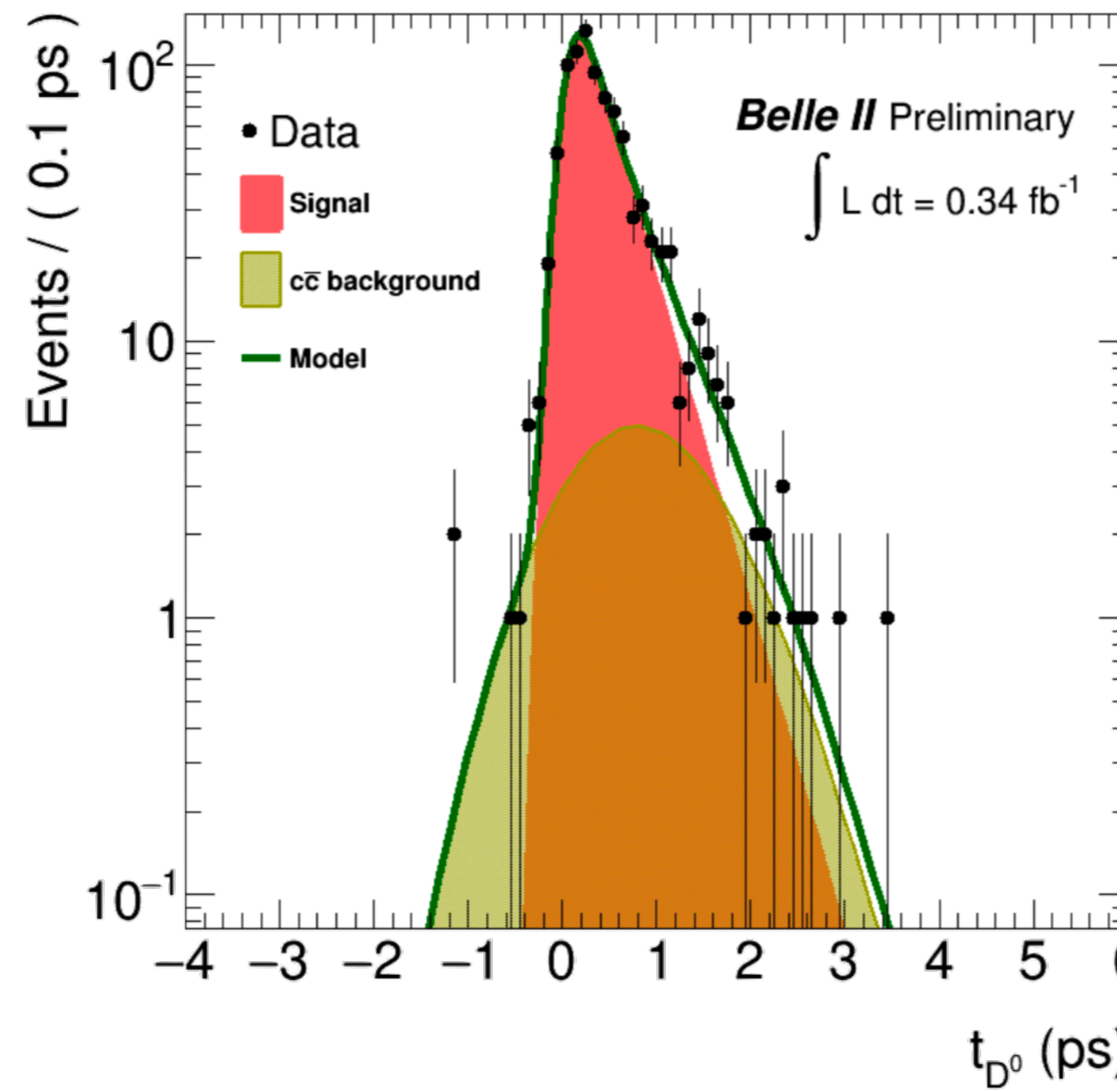


Experiment	t resolution	
	Mean	RMS
Belle II	6.5 fs	135 fs
BaBar	-0.48 fs	271 fs

D^0 lifetime in Belle II (Phase 3)

D^{*+}-tagged $D^0 \to K\pi$ decays (using 1/15 sample of Phase 3)



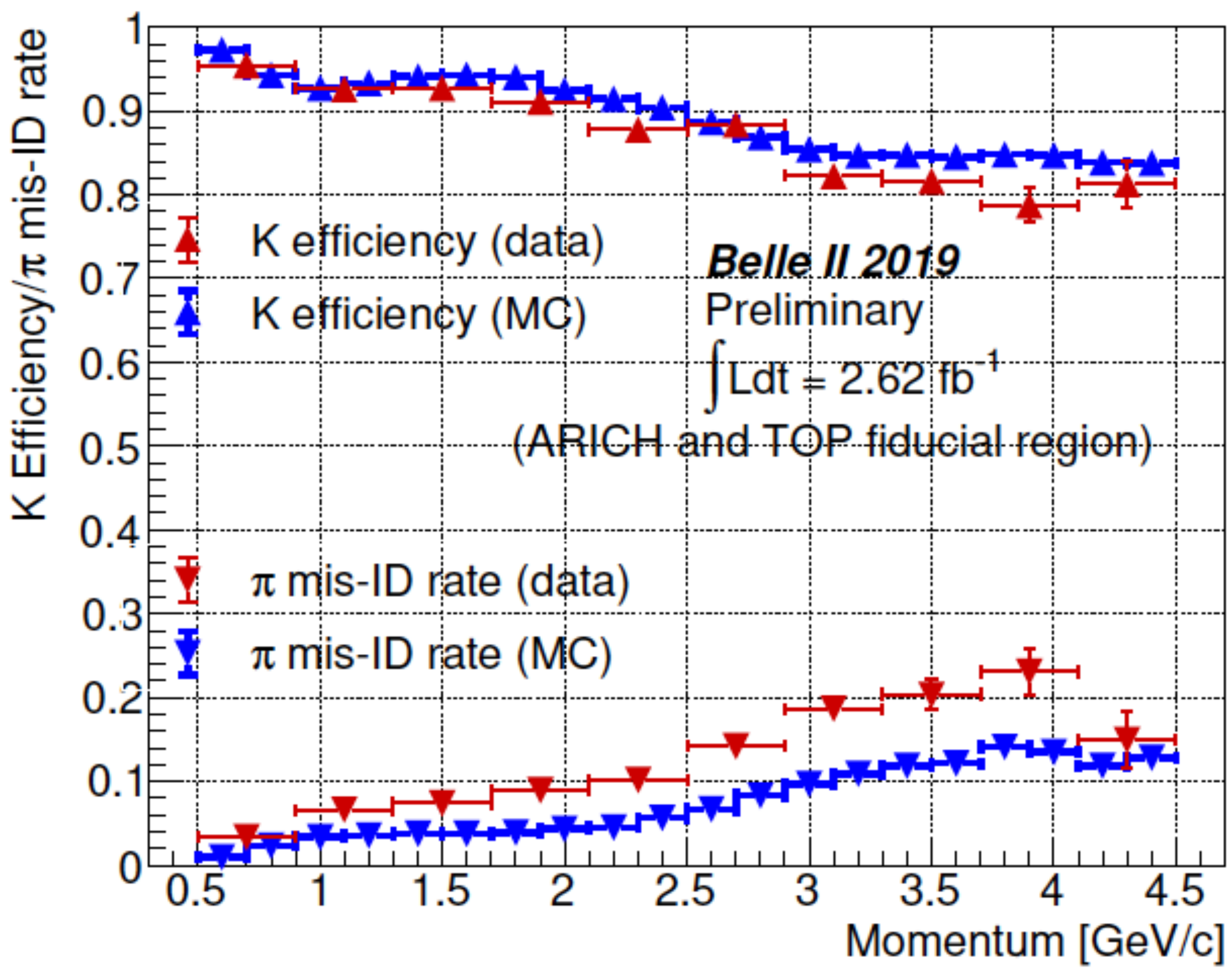


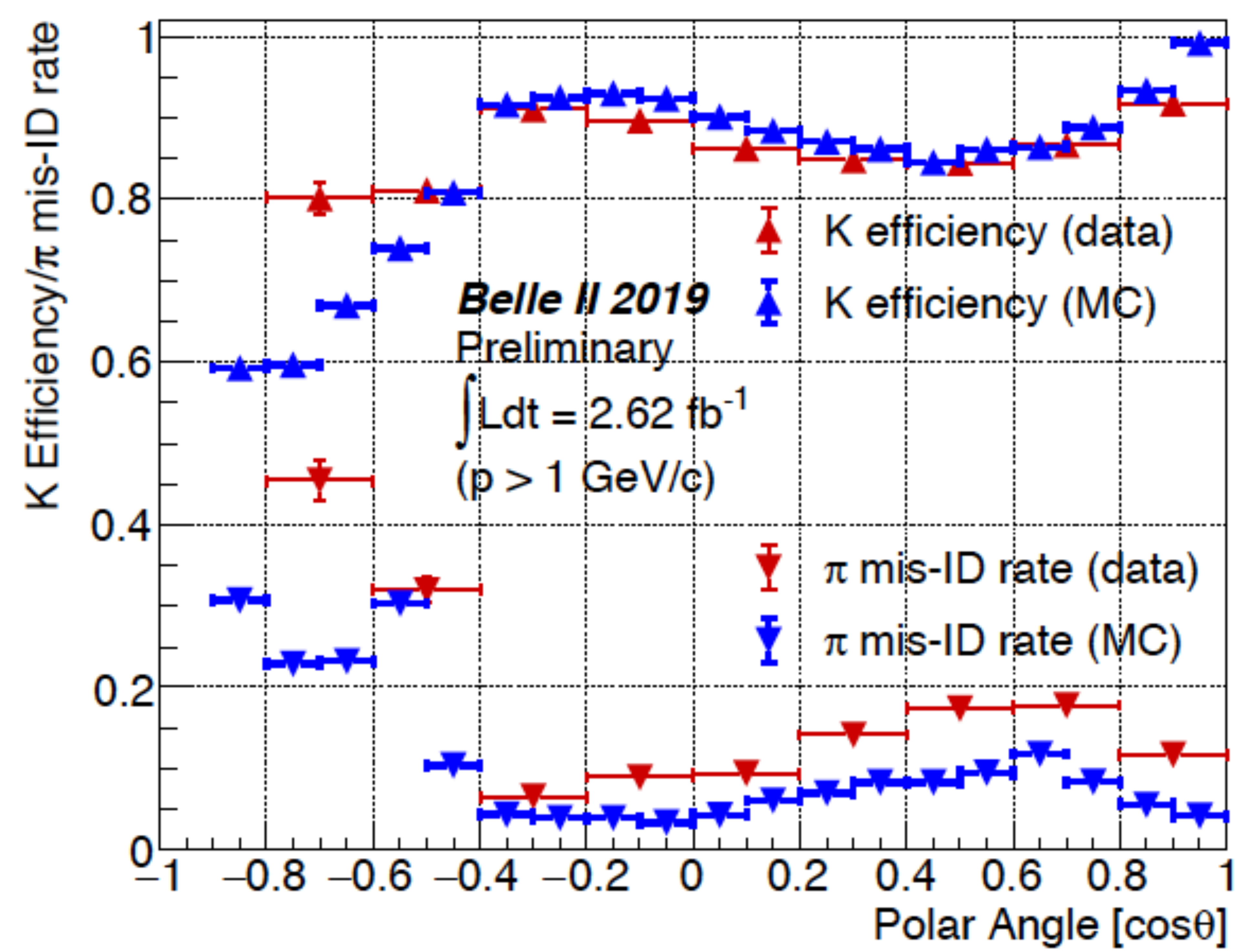
$$\tau_{D^0} = 370 \pm 40 \text{ fs}$$

$$\tau_{D^0}^{\text{PDG}} = 410 \text{ fs}$$

Belle II K/π separation (Phase 3)

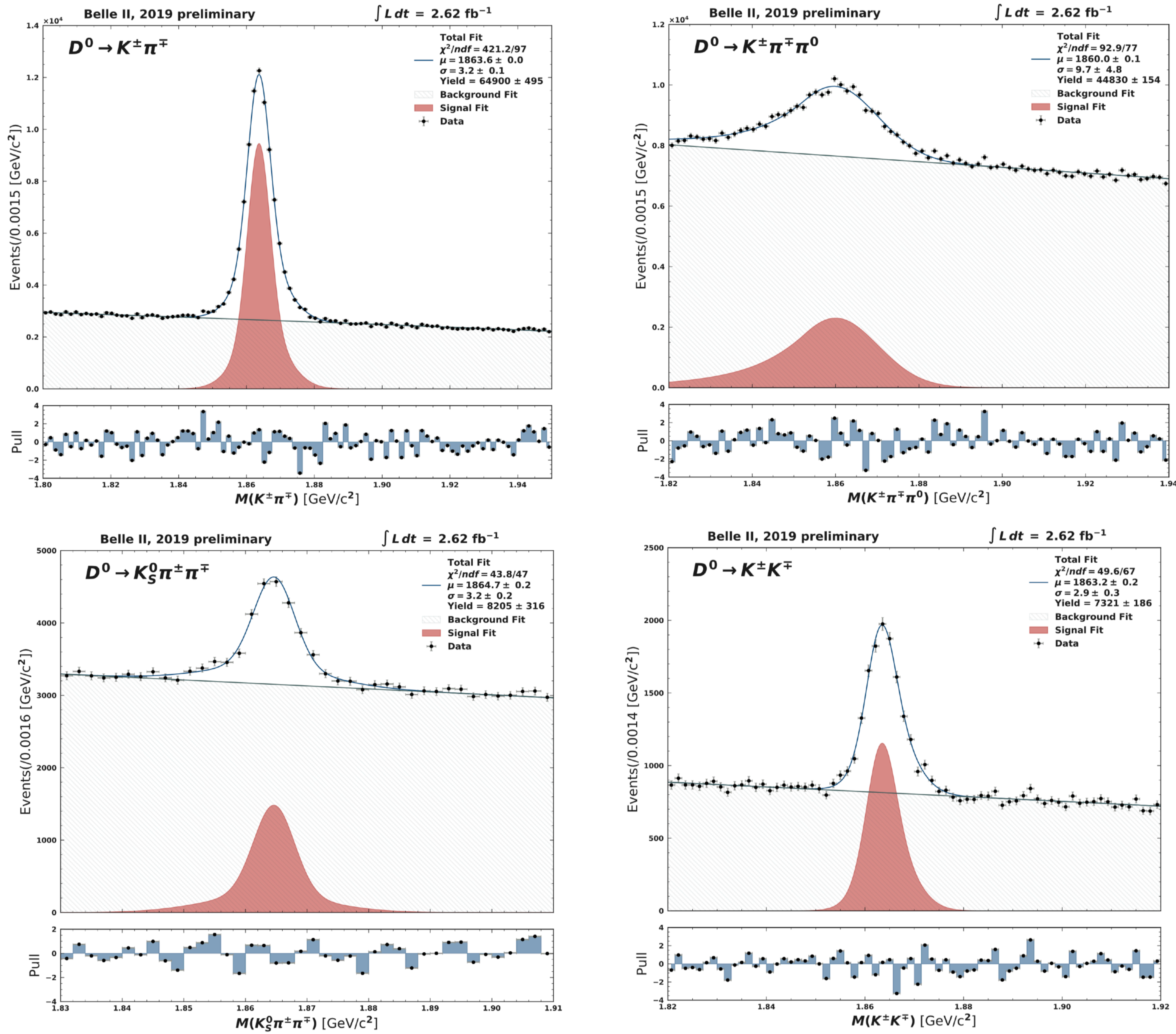
$K,\ \pi$ from D^{*+}-tagged $D^0 \to K\pi$ decays





▲▼ *ideal MC, not including background, etc.*

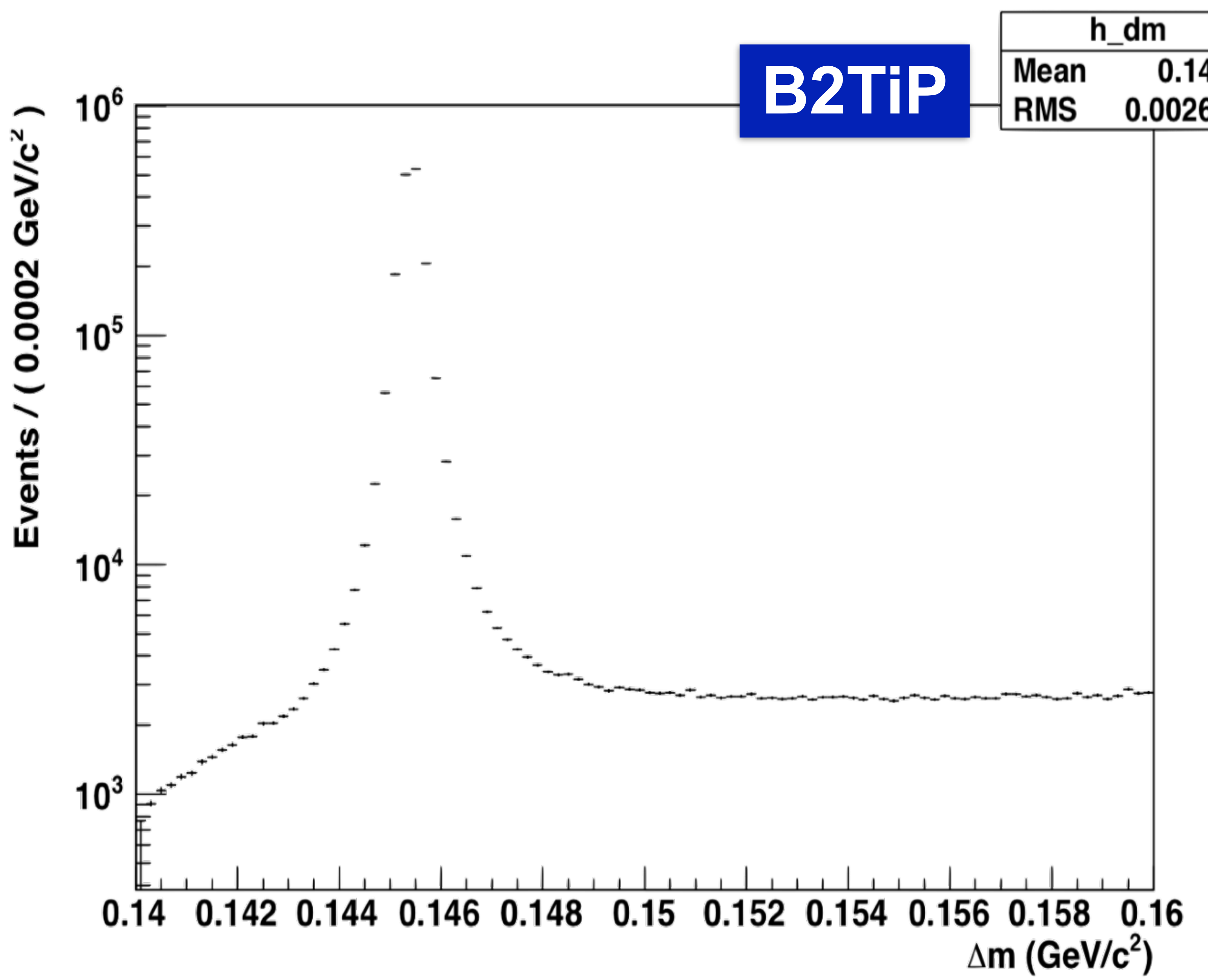
$M(D^0)$ plots (Belle II)



Flavor tagging for charm at Belle II

- To tag the flavor of the CP eigenstate modes and/or clean up the signal candidates

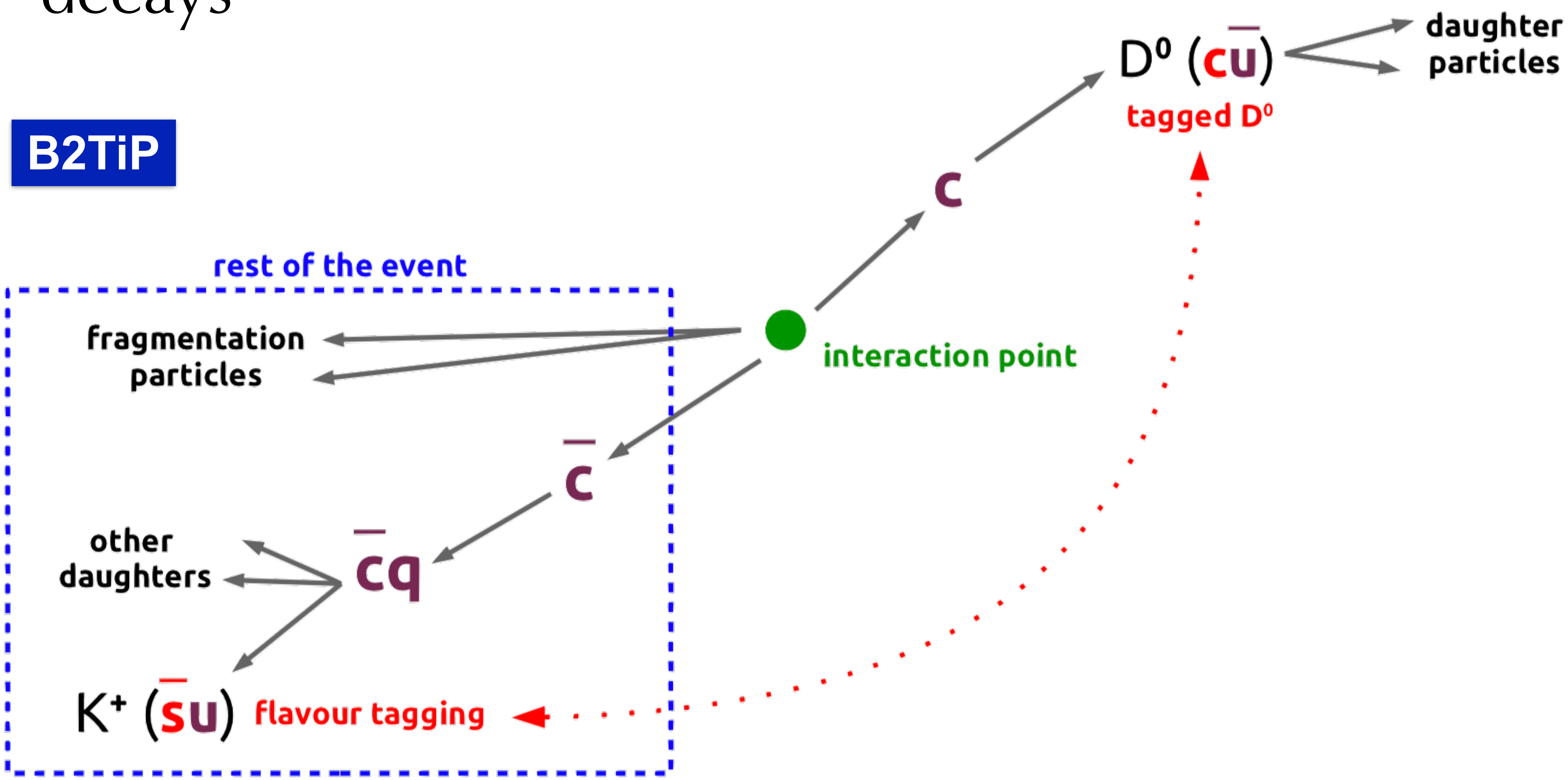
- D^* tagging ("golden method")
  - $D^{*+} \to D^0 \pi_s^+$
  - observables: $M(D^0)$, $\Delta M \equiv M(D^*) - M(D)$
  - ΔM resolution at Belle II ~ $180\ \mathrm{keV}/c^2$; factor ~2 better than Belle



- Rest-of-event (ROE) tagging

Flavor tagging — ROE

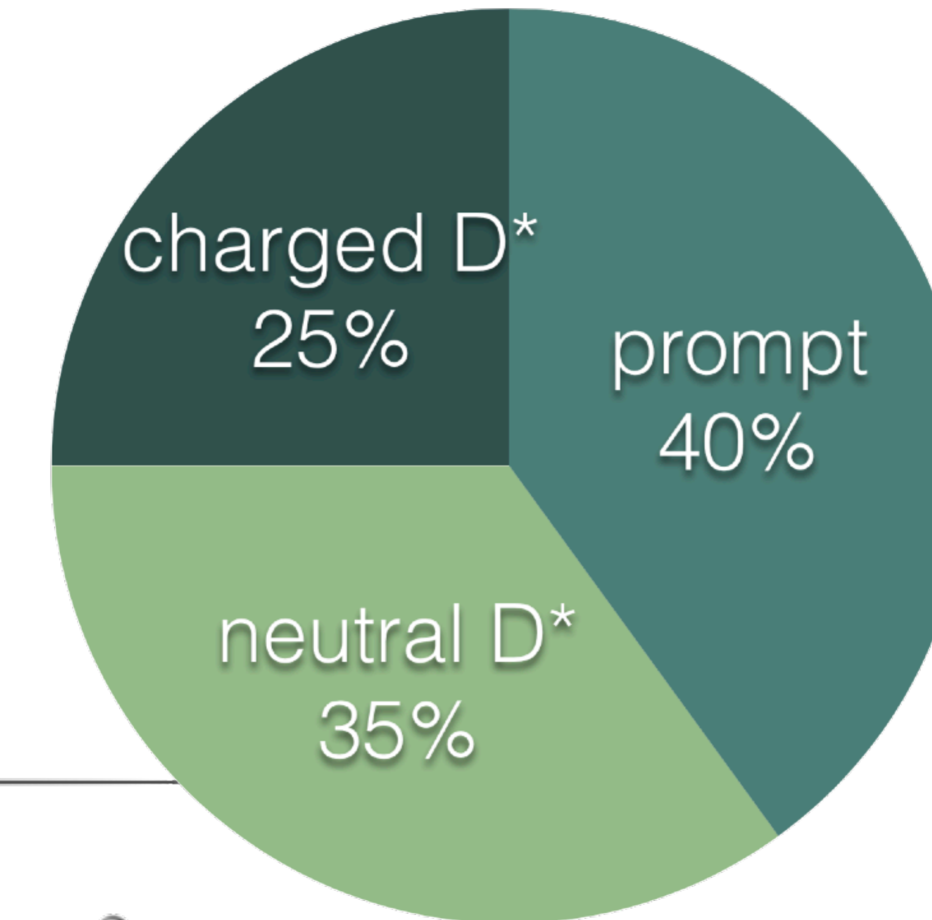
- to increase tagged sample size by adding D^0 mesons not reconstructed in D^* decays



- **reconstruct** a D^0 and look at the rest-of-event (ROE); **select** events with only one $K^\pm$ in the ROE; **tag** the flavor of D^0 with the charge of $K^\pm$

Flavor tagging — ROE

D^0 mother in $c\bar{c}$ events



- lower tagging efficiency (~1/4) is compensated by ~x3 higher production of non-D^* source

B2TiP

comparison of tagging methods

Flavour-tagging Method	Produced D^0 N_{D^0}	Mistagging ω	ϵ	Efficiency $Q = \epsilon\,(1-2\omega)^2$
D^*	1	0.2%	80%	79.7%
ROE - criteria A	3	13.3%	26.7%	20.1%
ROE - criteria B	3	9.8%	16.8%	13.7%
ROE - criteria C	3	4.9%	15.9%	15.7%

- nearly double the sample; but with higher mistagging and lower purity

A_{CP} improvement with ROE

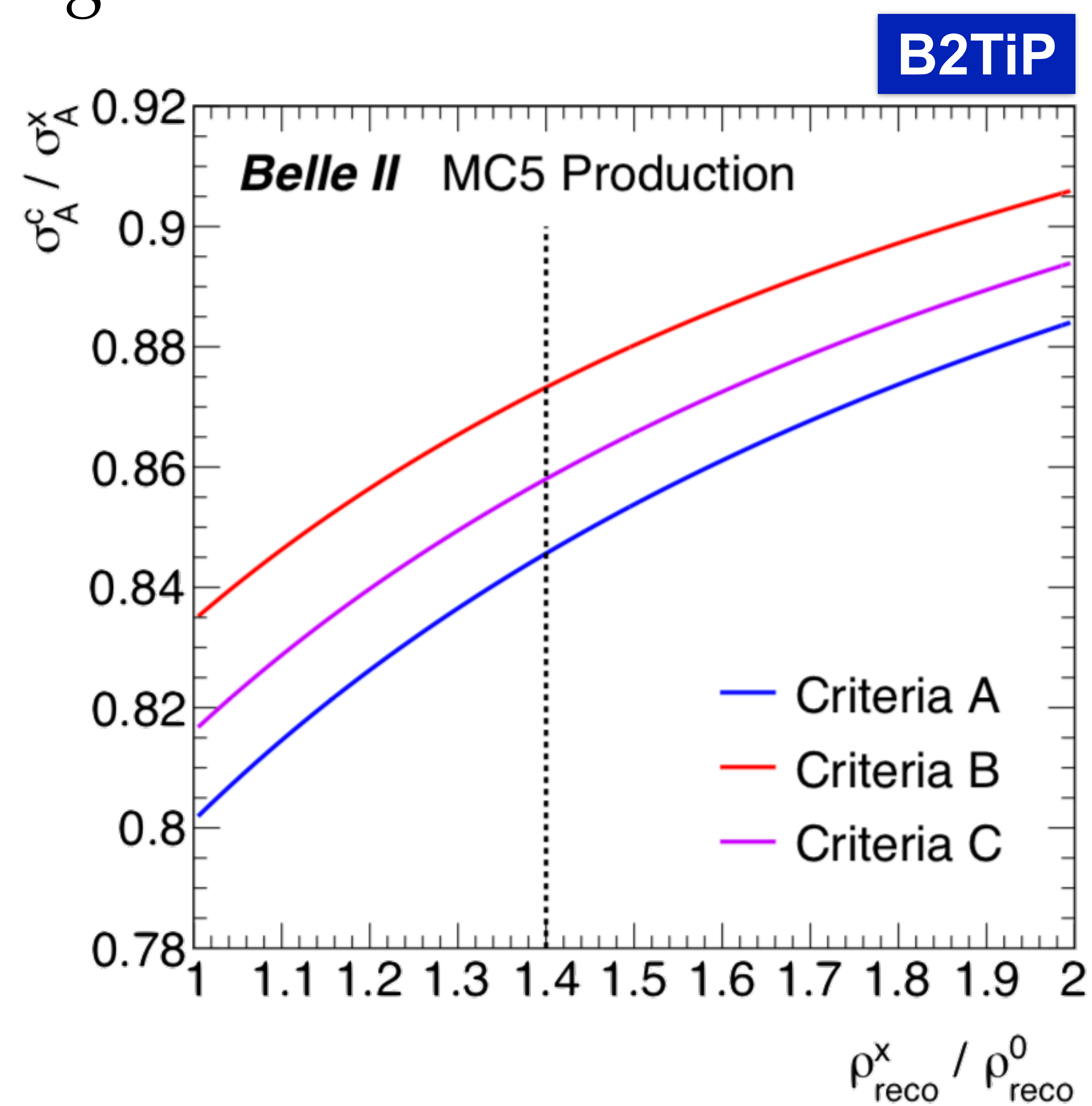
- Let α be the ratio of $\sigma_{A_{CP}}$ (stat.) with ROE-tagging to D^*-tagging

$$\alpha = \frac{\sigma_{A_{CP}}^{\mathrm{ROE}}}{\sigma_{A_{CP}}^{D^*}} = \sqrt{\frac{1}{3}\,\frac{Q^{D^*}}{Q^{\mathrm{ROE}}}\,\frac{\rho^{D^*}}{\rho^{\mathrm{ROE}}}}$$

where 1/3 = production ratio, Q = effective efficiency, ρ = tagged sample purity.
(ρ ratio ≈ 1.4, BaBar, PRD 87, 012004 (2013))

- Combining both methods:

$$\sigma_{A_{CP}}^{c} = (\alpha/\sqrt{1+\alpha^2})\ \sigma_{A_{CP}}^{D^*}$$



~15% improvement in $\sigma_{A_{CP}}$

'Prospects' for A_{CP} in Belle II

- Extrapolating Belle results to $50\ \mathrm{ab}^{-1}$
- Systematic uncertainties
  - reducible sys. err. σ_{red} — scale with luminosity
  - irreducible sys. err. σ_{irred} — asym. $K^0/\bar{K}^0$ interactions in matter ($\approx 0.02\,\%$), K^0 CPV, etc.

$$\sigma_{\mathrm{Belle\ II}} = \sqrt{\left(\sigma^2_{\mathrm{stat}} + \sigma^2_{\mathrm{red}}\right)^2 \frac{\mathscr{L}_{\mathrm{Belle}}}{50\ \mathrm{ab}^{-1}} + \sigma^2_{\mathrm{irred}}}$$

- In this talk, improvements in detector performance as well as ROE tagging are not included in the extrapolation.

Time-integrated CPV

- $A_{\mathrm{CP}}(D^0 \to V\gamma)$
- $A_{\mathrm{CP}}(D \to PP')$

Time-integrated A_{CP} (in Belle II)

- **A_{CP} vs. A_{raw}**

$$A_{\mathrm{raw}} = \frac{N(D^0 \to f) - N(\bar{D}^0 \to \bar{f})}{N(D^0 \to f) + N(\bar{D}^0 \to \bar{f})}$$

$$= A_{\mathrm{D}} + A_{\epsilon} + A_{\mathrm{CP}}$$

$$\mathcal{A}_{\mathrm{CP}} = \frac{\mathcal{B}(D^0 \to f) - \mathcal{B}(\overline{D}^0 \to \overline{f})}{\mathcal{B}(D^0 \to f) + \mathcal{B}(\overline{D}^0 \to \overline{f})}$$

$$\mathcal{A}_{CP}^{\mathrm{sig}} = A_{\mathrm{raw}}^{\mathrm{sig}} - A_{\mathrm{raw}}^{\mathrm{norm}} + \mathcal{A}_{CP}^{\mathrm{norm}}$$

- **tagged (D*, ROE) or self-tagged**

- A_{D} = production asymmetry

  = $A_{\mathrm{FB}}(\cos\theta^*)$

  an odd function in $\cos\theta^*$

  can be easily disentangled by

$$A_{\mathrm{CP}} = \frac{1}{2}\left[A_{\mathrm{raw}}^{\mathrm{cor}}(\cos\theta^*) + A_{\mathrm{raw}}^{\mathrm{cor}}(-\cos\theta^*)\right]$$

$$A_{\mathrm{FB}} = \frac{1}{2}\left[A_{\mathrm{raw}}^{\mathrm{cor}}(\cos\theta^*) - A_{\mathrm{raw}}^{\mathrm{cor}}(-\cos\theta^*)\right]$$

- A_{ϵ} = efficiency asymmetry

  measured with enough precision using CF decays

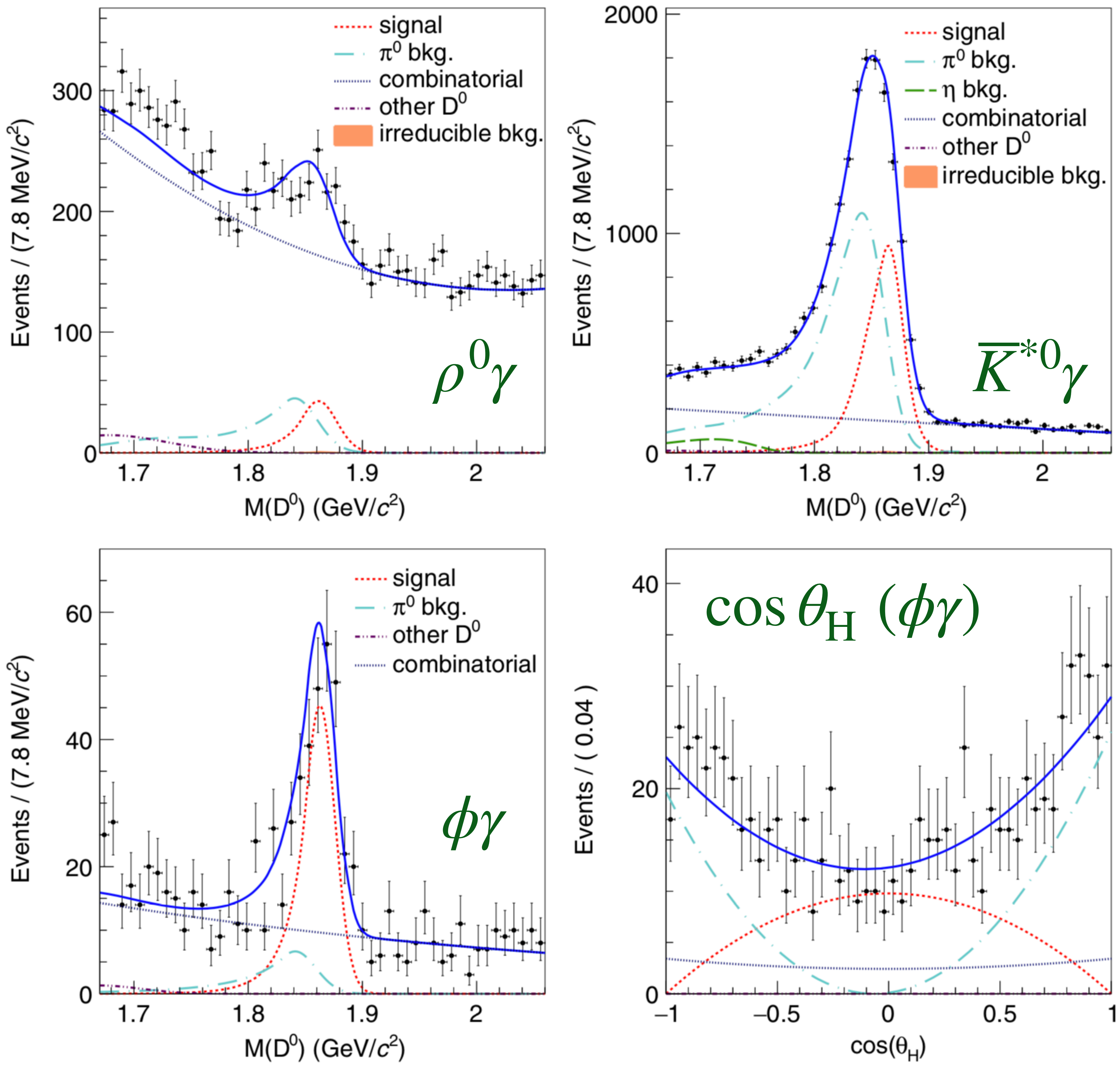
$D^0 \to V\gamma$

[1] Isidori & Kamenik, PRL(2012); de Boer & Hiller, JHEP 1708:91 (2017)

[2] Burdman et al., PRD(1995); Khodjamirian et al., PLB(1995); Fajfer et al., EPJC (1999)

[3] de Bore & Hiller, EPJC 78, 188 (2018)

PRL **118**, 051801 (2017)



- $A_{CP}^{SM}(D^0 \to V\gamma) \sim O(10^{-3})$

  NP can enhance it to $O(10^{-2})$[1]

- SM: dominated by long-range effect → test of QCD[2]

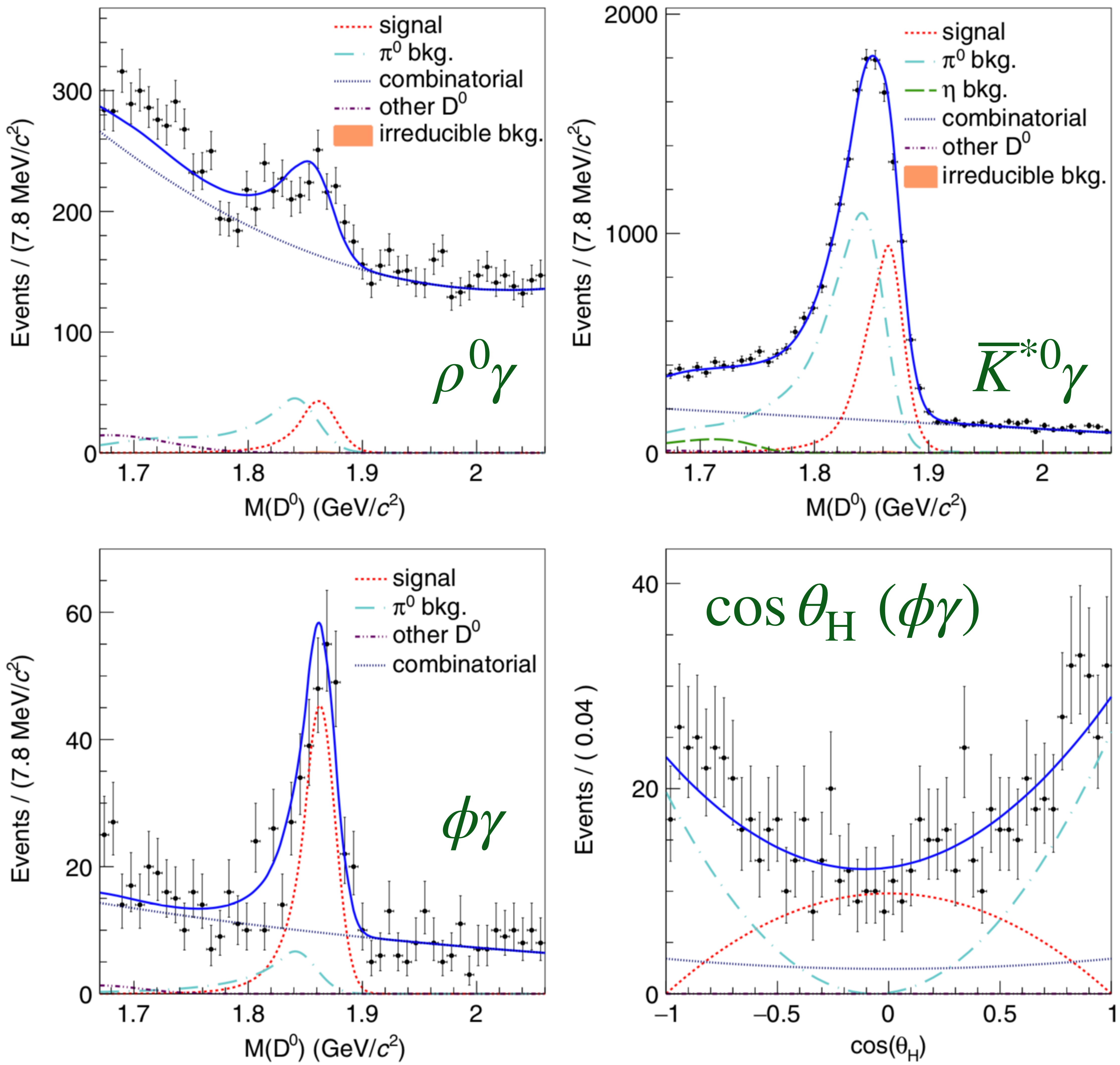
- measure γ pol. with time-dep. analysis to test SM[3]

- use normalization modes to reduce systematic errors

$$\mathcal{A}_{CP}^{\rm sig} = A_{\rm raw}^{\rm sig} - A_{\rm raw}^{\rm norm} + \mathcal{A}_{CP}^{\rm norm}$$

$D^0 \to V\gamma$

PRL **118**, 051801 (2017)



- $A_{CP}^{SM}(D^0 \to V\gamma) \sim O(10^{-3})$

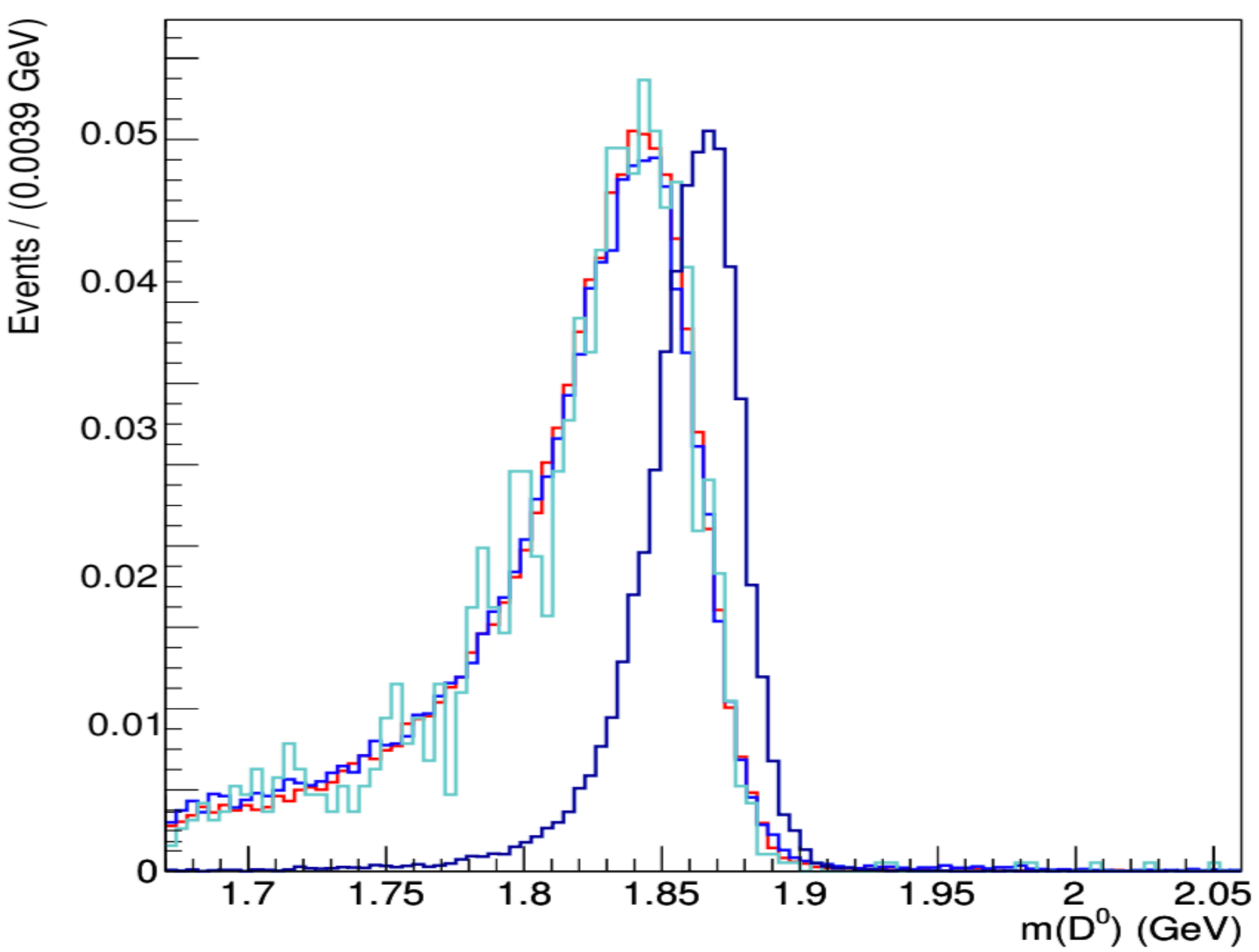
  NP can enhance it to $O(10^{-2})$
- SM: dominated by long-range effect → test of QCD
- A_{CP} measured by Belle w/ ~1 ab^{-1}

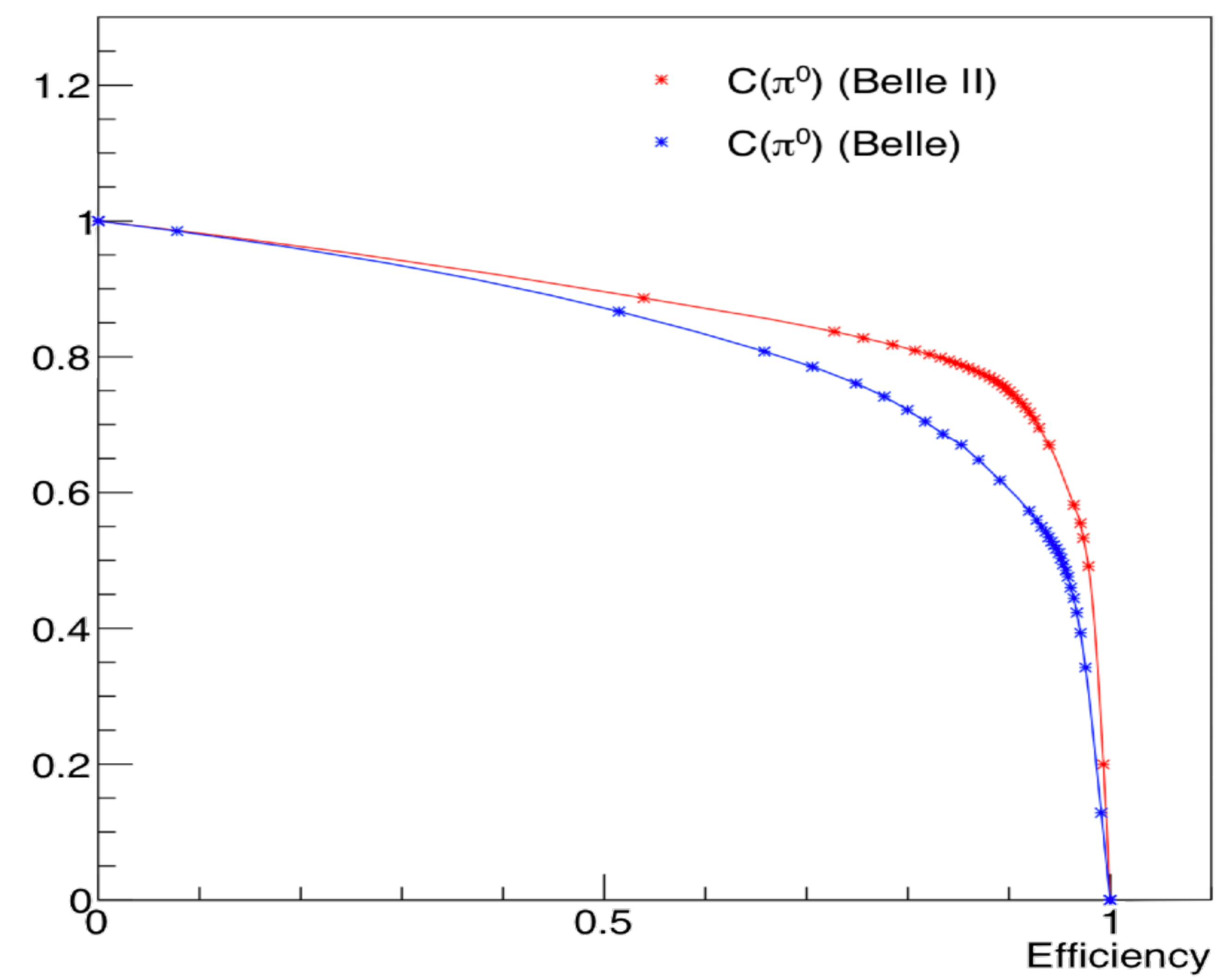
  → dominated by stat. error[1]

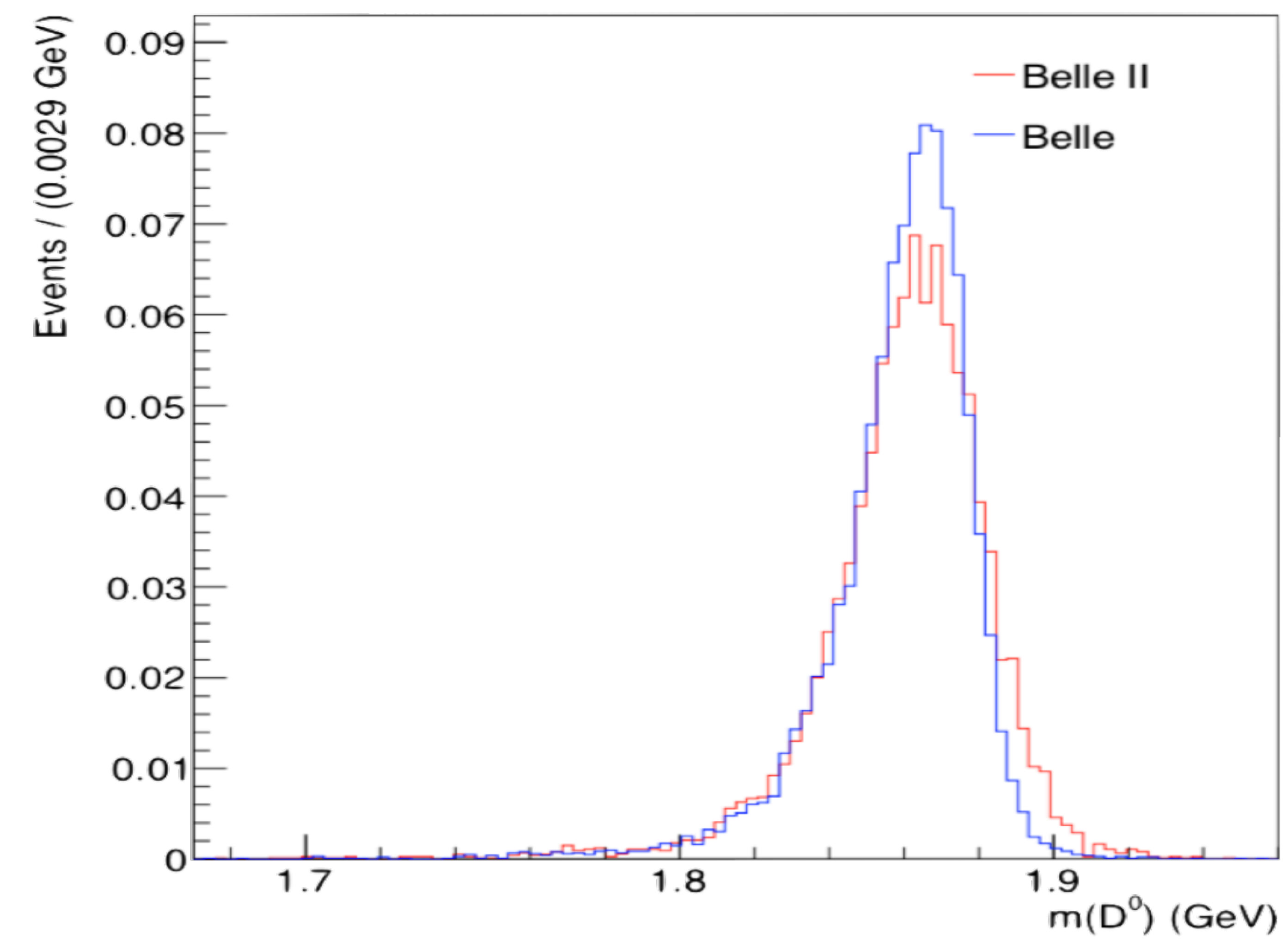
$$\mathcal{A}_{CP}(D^0 \to \rho^0\gamma) = +0.056 \pm 0.152 \pm 0.006$$
$$\mathcal{A}_{CP}(D^0 \to \phi\gamma) = -0.094 \pm 0.066 \pm 0.001,$$
$$\mathcal{A}_{CP}(D^0 \to \bar{K}^{*0}\gamma) = -0.003 \pm 0.020 \pm 0.000,$$

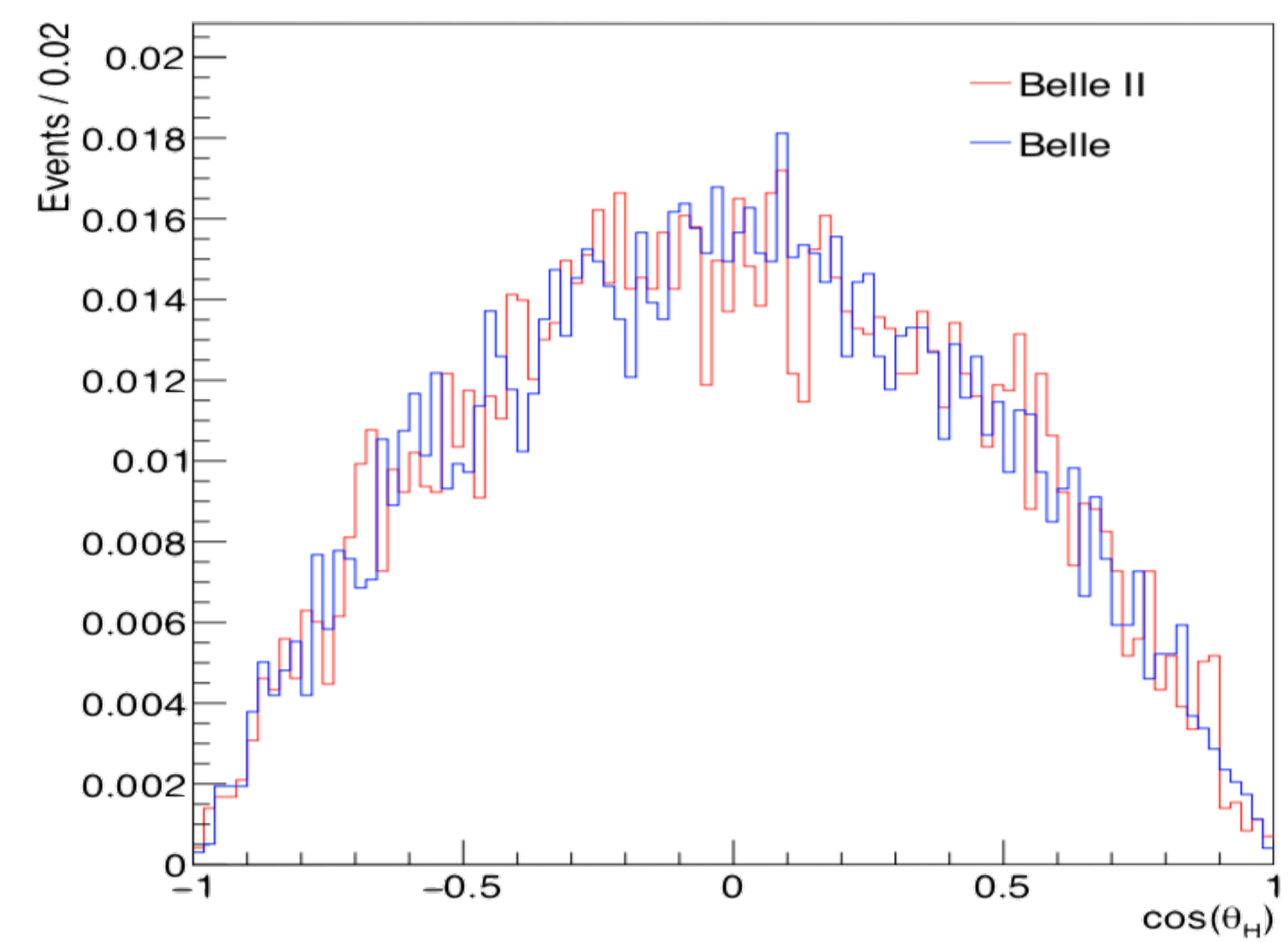
[1] For BF, stat error is slightly larger than or similar to syst error

$D^0 \to V\gamma$ systematics









- $D^0 \to X\pi^0$ is a dominant background
  - ✓ D^0 mass is shifted (∵ a missing γ)
  - ✓ π^0 veto (*slightly better for Belle II*)
- $M(D^0)$ resolution is crucial
- Belle II MC study
  resolutions for both $M(D^0)$ and $\cos\theta_H$ comparable to Belle
  → we can extrapolate based on luminosity

$D^0 \to V\gamma$ prospects

B2TiP

δA_{CP} on	Belle	Belle II (stat. err.)		
	1 ab^{-1}	5 ab^{-1}	15 ab^{-1}	50 ab^{-1}
$D^0 \to \rho\gamma$	±0.152±0.006	±0.07	±0.04	±0.02
$D^0 \to \phi\gamma$	±0.006±0.001	±0.03	±0.02	±0.01
$D^0 \to \overline{K}^{*0}\gamma$	±0.020±0.000	±0.01	±0.005	±0.003

- $O(\%)$ precision is expected for $A_{CP}(D^0 \to V\gamma)$ at Belle II
- Statistical error will still dominate

$A_{\rm CP}(D \to PP')$

- $A_{\rm CP}^{\rm SM}(D \to PP') \sim O(10^{-3})$

  ✓ not an automatic NP probe, ∵ uncertainties in hadronic matrix elements

  ✓ symmetry (e.g. SU(3)$_F$) can predict patterns among different modes

- existing most precise measurements → **Sum Rule test!**

Mode	A_{CP} [%]	
$D^0 \to K^+K^-$	$0.04 \pm 0.12 \pm 0.10$	**LHCb, 2017**
$D^0 \to \pi^+\pi^-$	$0.07 \pm 0.14 \pm 0.11$	**LHCb, 2017**
$D^0 \to K_S^0 K_S^0$	$-0.02 \pm 1.53 \pm 0.17$	**Belle, 2017**
$D^0 \to \pi^0\pi^0$	$-0.03 \pm 0.64 \pm 0.10$	**Belle, 2014**
$D^+ \to K_S^0 K^+$	$0.03 \pm 0.17 \pm 0.14$	**LHCb, 2014**
$D^+ \to K_S^0 \pi^+$	$-0.36 \pm 0.09 \pm 0.07$	**Belle, 2012**

$A_{\rm CP}(D \to PP')$

- $A_{\rm CP}^{\rm SM}(D \to PP') \sim O(10^{-3})$
  - ✓ not an automatic NP probe, ∵ uncertainties in hadronic matrix elements
  - ✓ symmetry (e.g. $SU(3)_F$) can predict patterns among different modes

→ **Sum Rule test!**

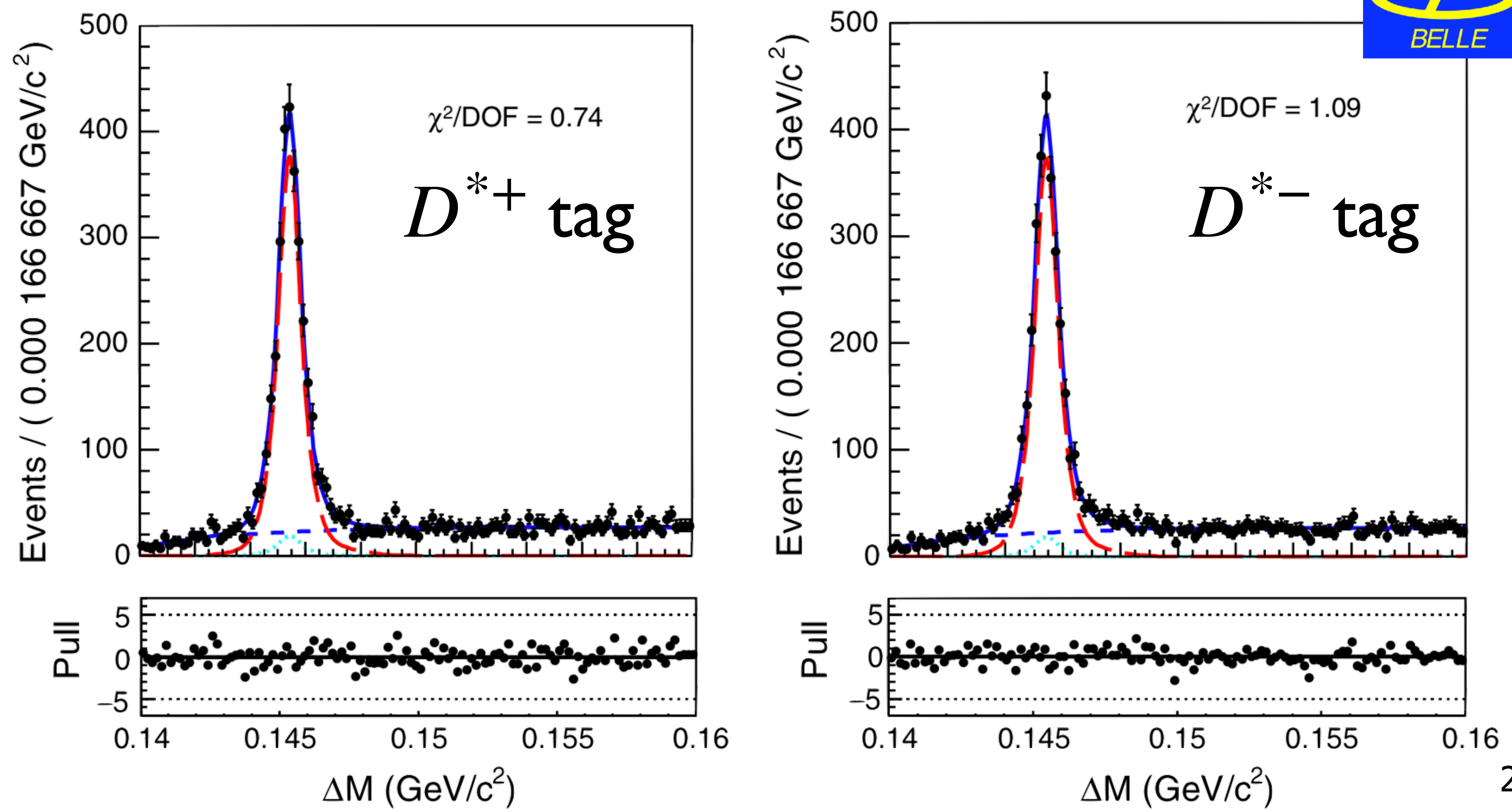
- **key expectations**
  - ✓ $A_{\rm CP}(D^+ \to \pi^+\pi^0) = 0$ in the isospin limit
  - ✓ $A_{\rm CP}(D^0 \to K_S^0 K_S^0)$ — enhanced to O(%) level due to large exchange diagram contribution (*hence a nice place for early discovery*)

    $|A_{\rm CP}| \le 1.1\,\%$ (95% CL) Nierste & Schacht (PRD, 2015)
  - ✓ Belle II can do well with neutral particles (π^0, η, η', ρ^+) in the final state

$A_{CP}(D^0 \to K_S^0 K_S^0)$

- $A_{CP}^{SM}(D^0 \to K_S^0 K_S^0) \sim O(1\%)$
  - ✓ promising for discovery
- Belle with 921 fb^{-1}
  - ✓ $A_{CP} = (-0.02 \pm 1.53 \pm 0.17)\,\%$
  - ✓ normalize to $K_S^0 \pi^0$
  - ✓ CPV in K^0 is subtracted
  - ✓ $\sigma_{irred} \approx 0.02\,\%$
- Belle II expectation
  - ✓ $\sigma_{A_{CP}} = 0.23\,\%$ at 50 ab^{-1}

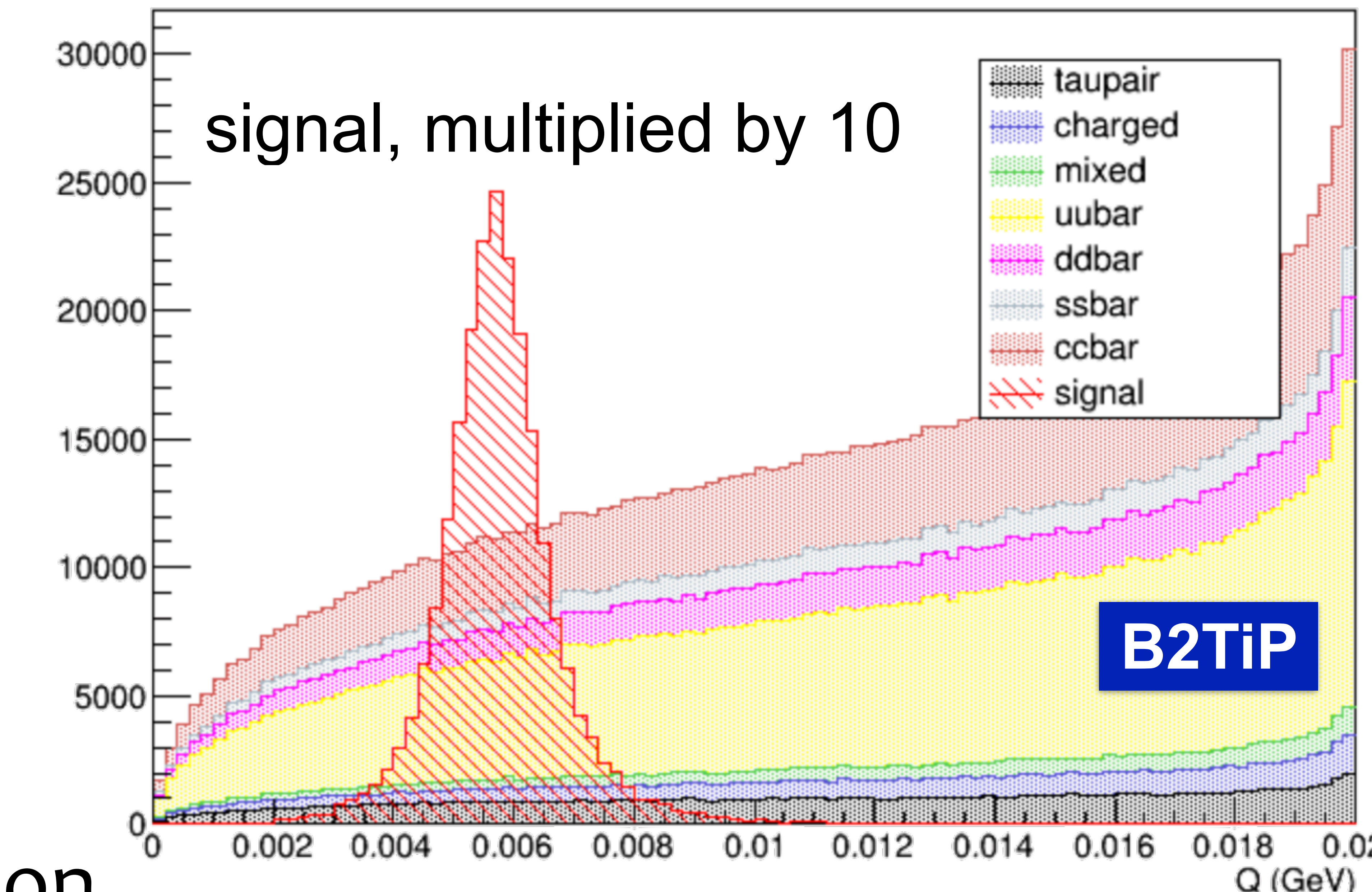
PRL **119**, 171801 (2017)



$A_{\rm CP}(D^+ \to \pi^+\pi^0)$

- $A_{\rm CP}^{\rm SM}(D^+ \to \pi^+\pi^0) = 0$
  - ✓ a smoking gun for NP
- Belle with 921 fb^{-1}
  - ✓ $A_{\rm CP} = (2.31 \pm 1.24 \pm 0.23)\ \%$
  - ✓ normalize to $D^+ \to K^0_S\pi^+$

$Q \equiv M(D^+\pi^0) - M(D^+) - M(\pi^0)$



- Belle II MC study (50 ab^{-1})
  - ✓ using D^{*+} tag for background suppression
  - ✓ efficiency, background rejection, similar to Belle, using earlier recon S/W
  - ✓ can expect further improvement with updated S/W
  - ✓ $\sigma_{A_{\rm CP}} \approx 0.17\ \%$

Time-dependent CPV

$$\left|\frac{\bar{A}}{A}\right| \neq 1$$

Direct CPV
(decay)

time-integrated

$$\left|\frac{q}{p}\right| \neq 1$$

Indirect CPV
(mixing)

$$Im(\lambda_f) \neq 0$$

$$\lambda_f = -\eta_{\text{CP}} \left|\frac{q}{p}\right| \left|\frac{\bar{A}_f}{A_f}\right| e^{i\phi} \neq 0$$

Interference of
mixing and decay

need time-dependent measurement

CPV and Mixing — *a quick reminder*

$$|M_{1,2}\rangle = p\,|M^0\rangle \pm q\,|\overline{M}^0\rangle$$

$$|M^0_{\rm phys}(t)\rangle = (g_+(t) + z\,g_-(t))\,|M^0\rangle - \sqrt{1-z^2}\,\frac{q}{p}\,g_-(t)|\overline{M}^0\rangle$$

$$|\overline{M}^0_{\rm phys}(t)\rangle = (g_+(t) - z\,g_-(t))\,|\overline{M}^0\rangle - \sqrt{1-z^2}\,\frac{p}{q}\,g_-(t)|M^0\rangle$$

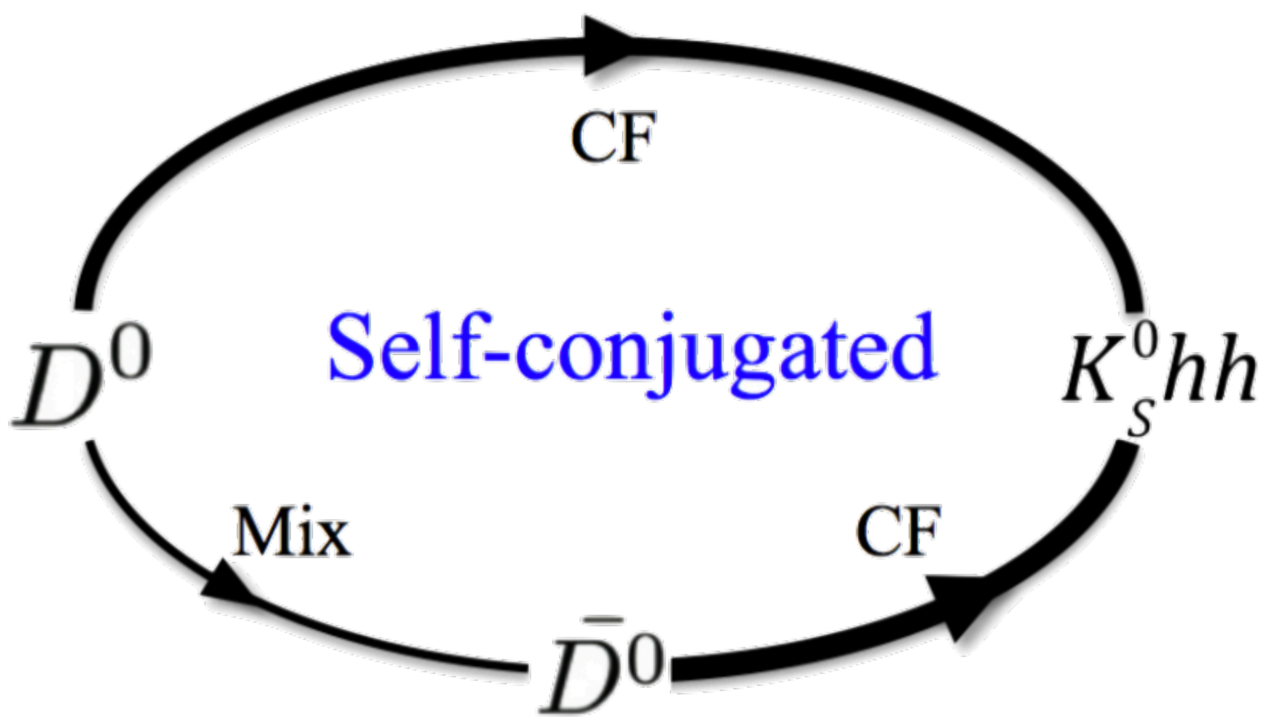
$z = 0$ if CP or CPT is conserved

$$g_\pm(t) \equiv \frac{1}{2}\left(e^{-im_H t - \frac{1}{2}\Gamma_H t} \pm e^{-im_L t - \frac{1}{2}\Gamma_L t}\right)$$

$$\frac{d\Gamma\left[M^0_{\rm phys}(t) \to f\right]/dt}{e^{-\Gamma t}\mathcal{N}_f} = \left(|A_f|^2 + |(q/p)\overline{A}_f|^2\right)\cosh(y\Gamma t) + \left(|A_f|^2 - |(q/p)\overline{A}_f|^2\right)\cos(x\Gamma t)$$
$$+\,2\,\mathcal{R}e((q/p)A_f^*\overline{A}_f)\sinh(y\Gamma t) - 2\,\mathcal{I}m((q/p)A_f^*\overline{A}_f)\sin(x\Gamma t)\ ,$$

mixing parameters $x = \frac{\Delta m}{\Gamma}$ $\quad y = \frac{\Delta\Gamma}{2\Gamma}$

Mixing & CPV in $D^0 \to K_S^0 \pi^+ \pi^-$ (Dalitz)



- Systematic error will be dominated by D^0 decay modeling (*irreducible*)
  - ✓ currently using info. from CLEO-c, **PRD 82, 112006 (2010)**
  - ✓ should improve with strong phase difference to be measured at BESIII BEAUTY 2019 **(talk by Lei Li)**

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

(Belle 921 fb^{-1})

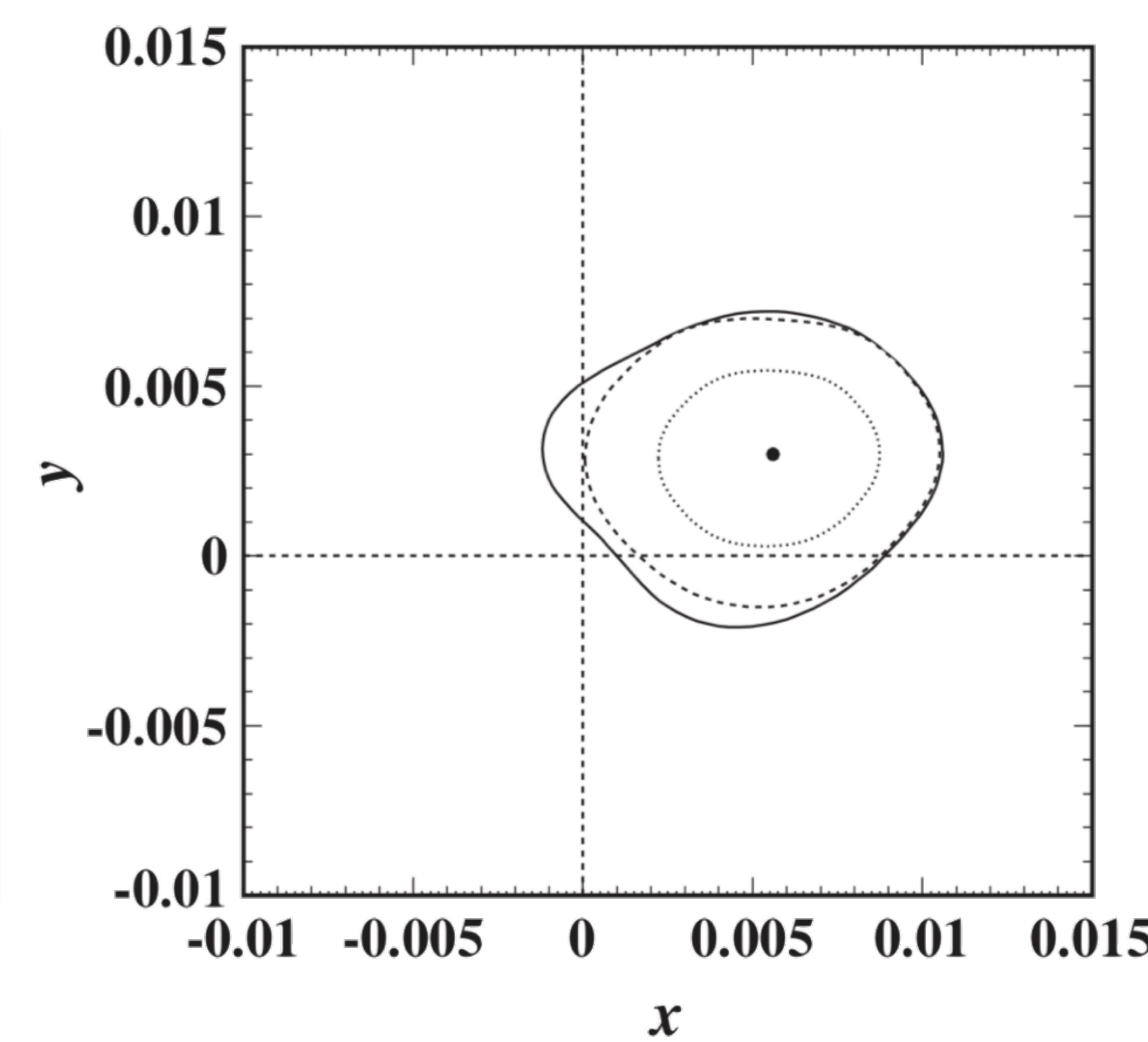
Phys. Rev. D **89**, 091103(R) (2014)

$$x = \left(+0.56 \pm 0.19\,^{+0.04}_{-0.08}\,^{+0.06}_{-0.08}\right)\%$$

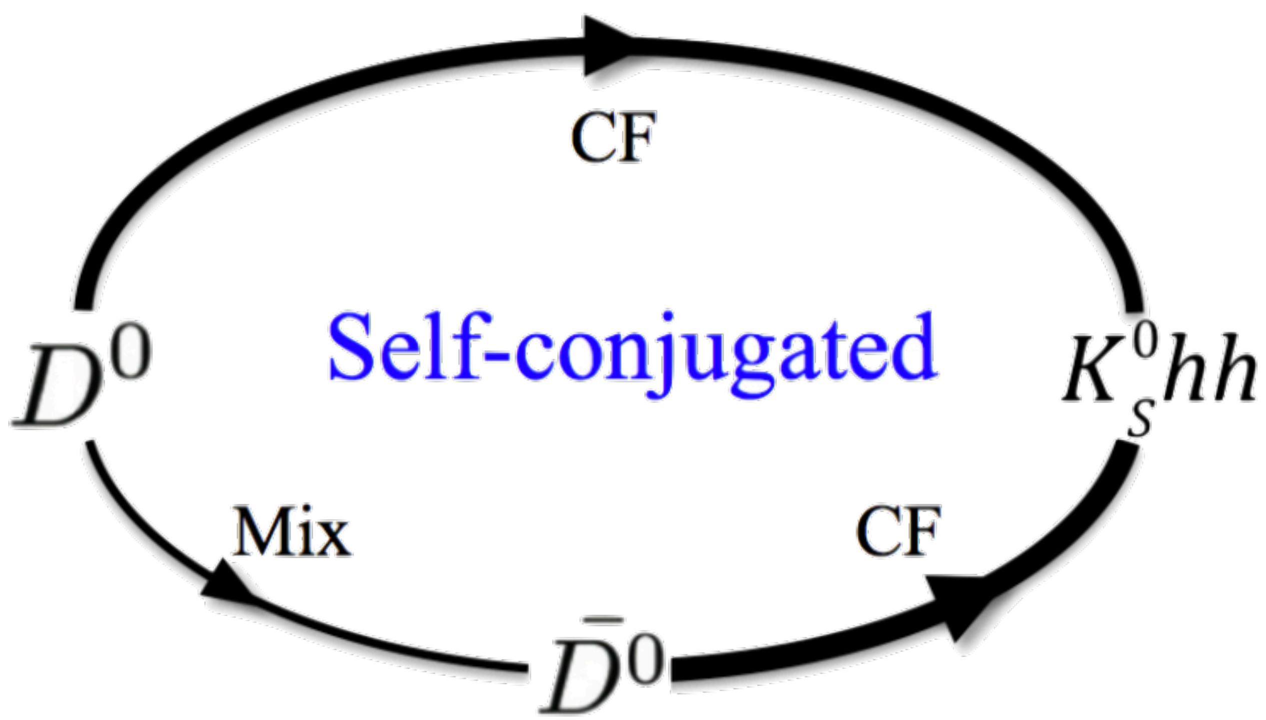
$$y = \left(+0.30 \pm 0.15\,^{+0.04}_{-0.05}\,^{+0.03}_{-0.07}\right)\%$$

$$|q/p| = 0.90\,^{+0.16}_{-0.15}\,^{+0.05}_{-0.04}\,^{+0.06}_{-0.05}$$

$$\arg(q/p) = \left(-6 \pm 11 \pm 3\,^{+3}_{-4}\right)^\circ$$



Mixing & CPV in $D^0 \to K_S^0\pi^+\pi^-$ (Dalitz)



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B2TiP

Data	stat.	syst. red.	syst. irred.	Total	stat.	syst. red.	syst. irred.	Total
	σ_x (10^{-2})				σ_y (10^{-2})			
976 fb^{-1}	0.19	0.06	0.11	0.20	0.15	0.06	0.04	0.16
5 ab^{-1}	0.08	0.03	0.11	0.14	0.06	0.03	0.04	0.08
50 ab^{-1}	0.03	0.01	0.11	0.11	0.02	0.01	0.04	0.05
	$\lvert q/p\rvert$ (10^{-2})				ϕ $(^\circ)$			
976 fb^{-1}	15.5	5.2-5.6	7.0-6.7	17.8	10.7	4.4-4.5	3.8-3.7	12.2
5 ab^{-1}	6.9	2.3-2.5	7.0-6.7	9.9-10.1	4.7	1.9-2.0	3.8-3.7	6.3-6.4
50 ab^{-1}	2.2	0.7-0.8	7.0-6.7	7.0-7.4	1.5	0.6	3.8-3.7	4.0-4.2

Summary

- CP violation in the charm sector is a great place to probe new physics beyond the SM.
- Belle II is making all-out efforts to fight for systematic uncertainties as well as effectively increase the sample size (improved tagging, etc.).
- With the design luminosity of $50\ \mathrm{ab}^{-1}$, interesting results will come one by one.

Thank you!

Extra slides

Charm machines, old & new

Experiment	Year	$\sqrt{s}$	$\sigma_{acc}(D^0)$	L	$n(D^0)$
CLEO-c	2003-2008	3.77 GeV	8 nb	0.5 fb^{-1}	4.0×10^6
BESIII	2010-2011	3.77 GeV	8 nb	3 fb^{-1}	2.4×10^7
BaBar	1999-2008	10.6 GeV	1.45 nb	500 fb^{-1}	7.3×10^8
Belle	1999-2010	10.6 – 10.9 GeV	1.45 nb	1000 fb^{-1}	1.5×10^9
CDF	2001-2011	2 TeV	13 μb	10 fb^{-1}	1.3×10^{11}
LHCb	2011	7 TeV	1.4 mb	1 fb^{-1}	1.4×10^{12}
LHCb	2012	8 TeV	1.6 mb*	2 fb^{-1}	3.2×10^{12}
Belle II	**2019-202***			**50 ab^{-1}**	

$A_{CP}(D \to PP')$ Belle II prospects

Mode	$\mathcal{L}$ (fb^{-1})	A_{CP}(%) (Belle)	Belle II 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	± 0.09
$D^0 \to K_S^0\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.02
$D^0 \to K_S^0 K_S^0$	921	$-0.02 \pm 1.53 \pm 0.02 \pm 0.17$	± 0.23
$D^0 \to K_S^0\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K_S^0\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	± 0.33
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04
$D^+ \to \pi^+\pi^0$	921	$+2.31 \pm 1.24 \pm 0.23$	± 0.17
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.14
$D^+ \to K_S^0\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.02
$D^+ \to K_S^0 K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.04
$D_s^+ \to K_S^0\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D_s^+ \to K_S^0 K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

$A_{CP}^{SM} \sim 1\,\%$ ($D^0 \to K_S^0 K_S^0$)

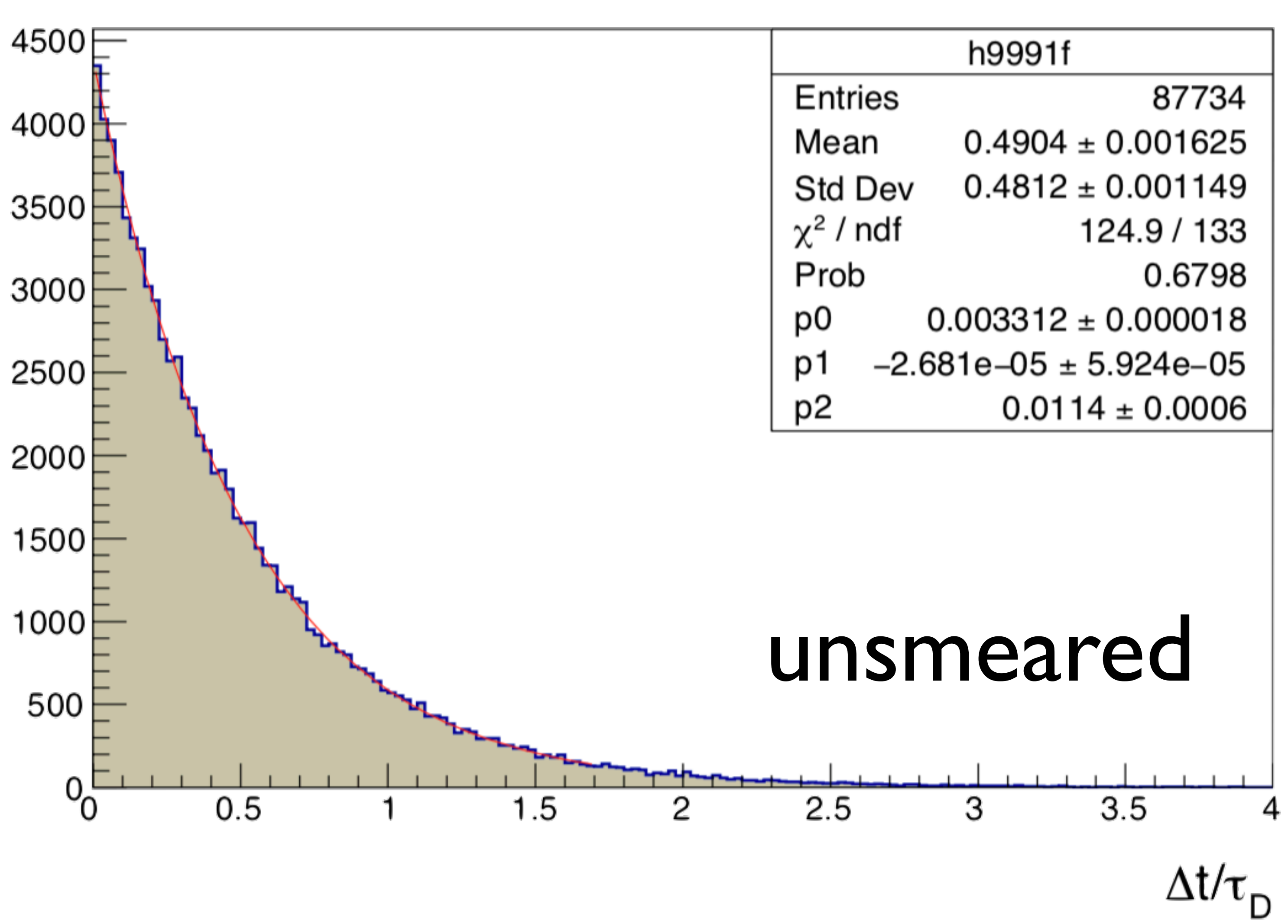
$A_{CP}^{SM} = 0$ ($D^+ \to \pi^+\pi^0$)

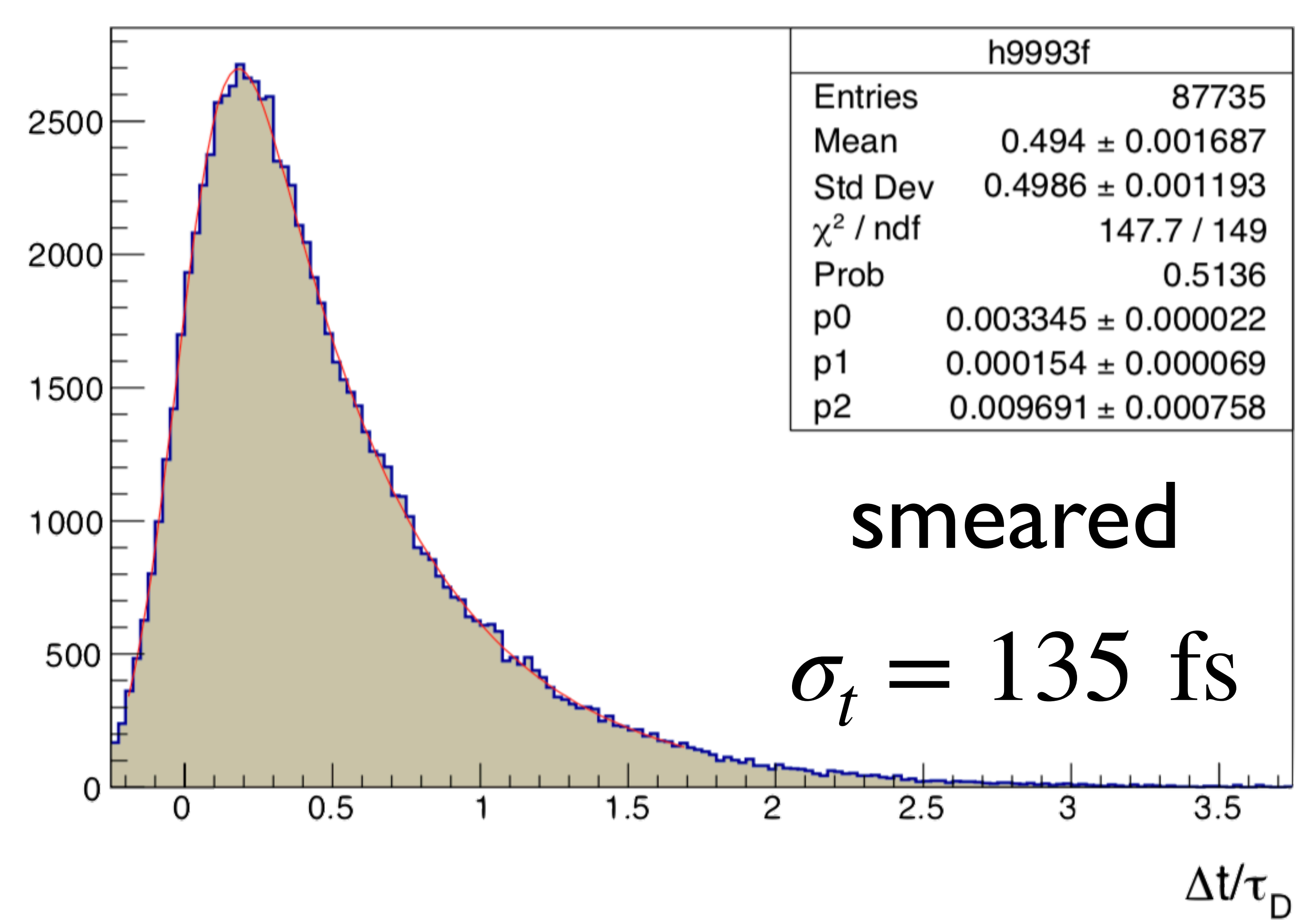
Mixing & CPV in $D^0 \to K^+\pi^-$ (WS)

$$\frac{N(D^0 \to f)}{dt} \propto e^{-\overline{\Gamma} t} \left\{ R_D + \left|\frac{q}{p}\right| \sqrt{R_D}(y' \cos\phi - x' \sin\phi)(\overline{\Gamma} t) + \left|\frac{q}{p}\right|^2 \frac{(x'^2 + y'^2)}{4} (\overline{\Gamma}\, t)^2 \right\}$$

$$\frac{N(\overline{D}^0 \to \bar{f})}{dt} \propto e^{-\overline{\Gamma} t} \left\{ \overline{R}_D + \left|\frac{p}{q}\right| \sqrt{\overline{R}_D}(y' \cos\phi + x' \sin\phi)(\overline{\Gamma} t) + \left|\frac{p}{q}\right|^2 \frac{(x'^2 + y'^2)}{4} (\overline{\Gamma}\, t)^2 \right\}$$

$$x' = x\cos\delta + y\sin\delta \qquad y' = y\cos\delta - x\sin\delta$$





Belle II MC (20 ab^{-1})

fit w/o CPV

for R_D, x'^2, y'

Mixing & CPV in $D^0 \to K^+\pi^-$ (WS)

B2TiP Belle II MC fit

Parameter	5 ab^{-1}	20 ab^{-1}	50 ab^{-1}
$\delta x'^2$ (10^{-5})	6.2	3.2	2.0
$\delta y'$ (%)	0.093	0.047	0.029
$\delta x'$ (%)	0.32	0.22	0.13
$\delta y'$ (%)	0.23	0.15	0.097
$\delta\|q/p\|$	0.174	0.073	0.043
$\delta\phi$ ($^\circ$)	13.2	8.4	5.4

no CPV

CPV allowed

$D^0 \to V\gamma$ systematics (Belle, 2017)

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	$\sigma(\mathcal{B})/\mathcal{B}$ (%)			A_{CP} ($\times 10^{-3}$)		
	ϕ	$\bar{K}^{*0}$	ρ^0	ϕ	$\bar{K}^{*0}$	ρ^0
Efficiency	2.8	3.3	2.8	···	···	···
Fit parametrization	1.0	2.8	2.3	0.1	0.4	5.3
Background normalization	···	0.3	0.6	···	0.2	0.5
Normalization mode	0.0	0.0	0.1	0.5	0.0	0.3
External $\mathcal{B}$ and $\mathcal{A}_{CP}$	2.0	1.0	1.8	1.2	0.0	1.5
Total	3.6	4.5	4.1	1.3	0.4	5.5