Prospects on time-integrated CPV measurements at Belle II

Seema Bahinipati
Indian Institute of Technology Bhubaneswar

CKM2016
9th International Workshop
on the CKM Unitarity Triangle
TIFR, Mumbai
Nov. 28 – Dec. 2, 2016

Image: https://en.wikipedia.org/wiki/Bandra-Worli_Sea_Link

Outline

- Motivation
- Charm time-integrated CPV
- Belle II projections for time-integrated CPV studies (error analysis)
- Belle II sensitivity study for K_sK_s
- Belle II sensitivity study for Vγ
- New flavour tagging techniques at Belle II
- Summary

Motivation

- Belle, Belle II : although primarily B-factories, have large cross-section for charm production

$e^+e^- \to \Upsilon(4S) \to B\overline{B}$ 1.1 nb

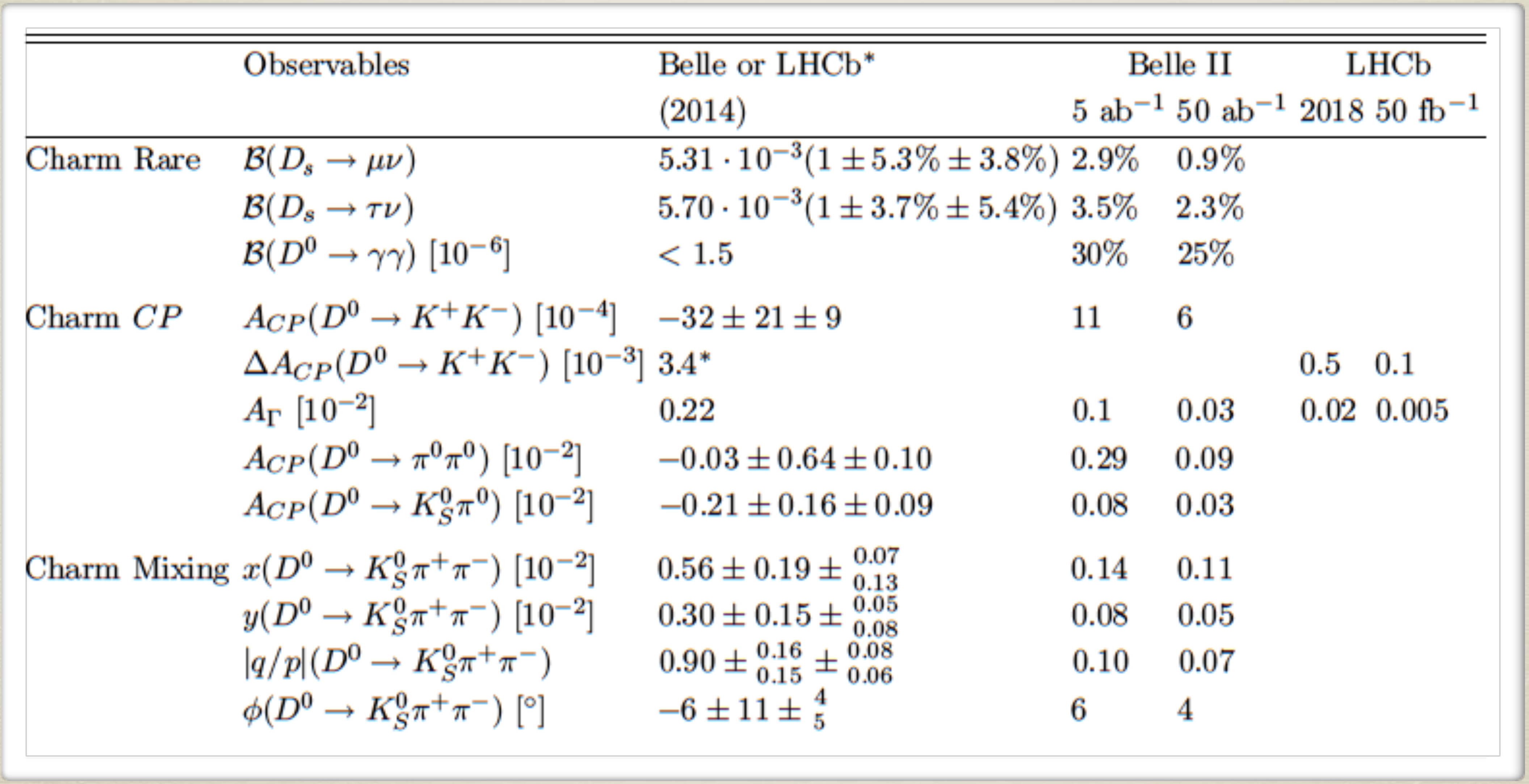
$e^+e^- \to c\overline{c}$ 1.3 nb

- e^+- e^- machines can access NP modes such as FCNC decays
- Clean environment
- High trigger efficiency
- Excellent neutral particle (γ, π^0) reconstruction
- Possible to detect decay modes with missing energy
- Complementary to LHCb results

CPV in neutral D: experimental technique

- D^{*+} to $D^0\pi^+_{slow}$: Flavor tagging used is usually π^+_{slow}
- Data used is usually Upsilon (4S) data: p_{D^*} in CMS frame > 2.5 GeV to suppress D^{*+} coming from B decays
- Kinematic variables looked at: D^0 invariant mass ($M_D{}^0$), Mass difference $M_{D^*} - M_D{}^0$

Belle II and LHCb projections



	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	 50 ab^{-1}	LHCb 2018	 50 fb^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	$\mathcal{B}(D^0 \to \gamma\gamma)$ $[10^{-6}]$	< 1.5	30%	25%		
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	$-32 \pm 21 \pm 9$	11	6		
	$\Delta A_{CP}(D^0 \to K^+K^-)$ $[10^{-3}]$	3.4*			0.5	0.1
	A_Γ $[10^{-2}]$	0.22	0.1	0.03	0.02	0.005
	$A_{CP}(D^0 \to \pi^0\pi^0)$ $[10^{-2}]$	$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ $[^\circ]$	$-6 \pm 11 \pm {}^{4}_{5}$	6	4		

{Belle II Internal Note}

Time-integrated CPV in charm sector

- Direct CPV using time-integrated approach

$$A_{CP} = \frac{\Gamma(D \to f) - \Gamma(\overline{D} \to \overline{f})}{\Gamma(D \to f) + \Gamma(\overline{D} \to \overline{f})}$$

- Excepted A_{CP} is small
- Observation of large direct A_{CP} would indicate New Physics

Complementary experiments:

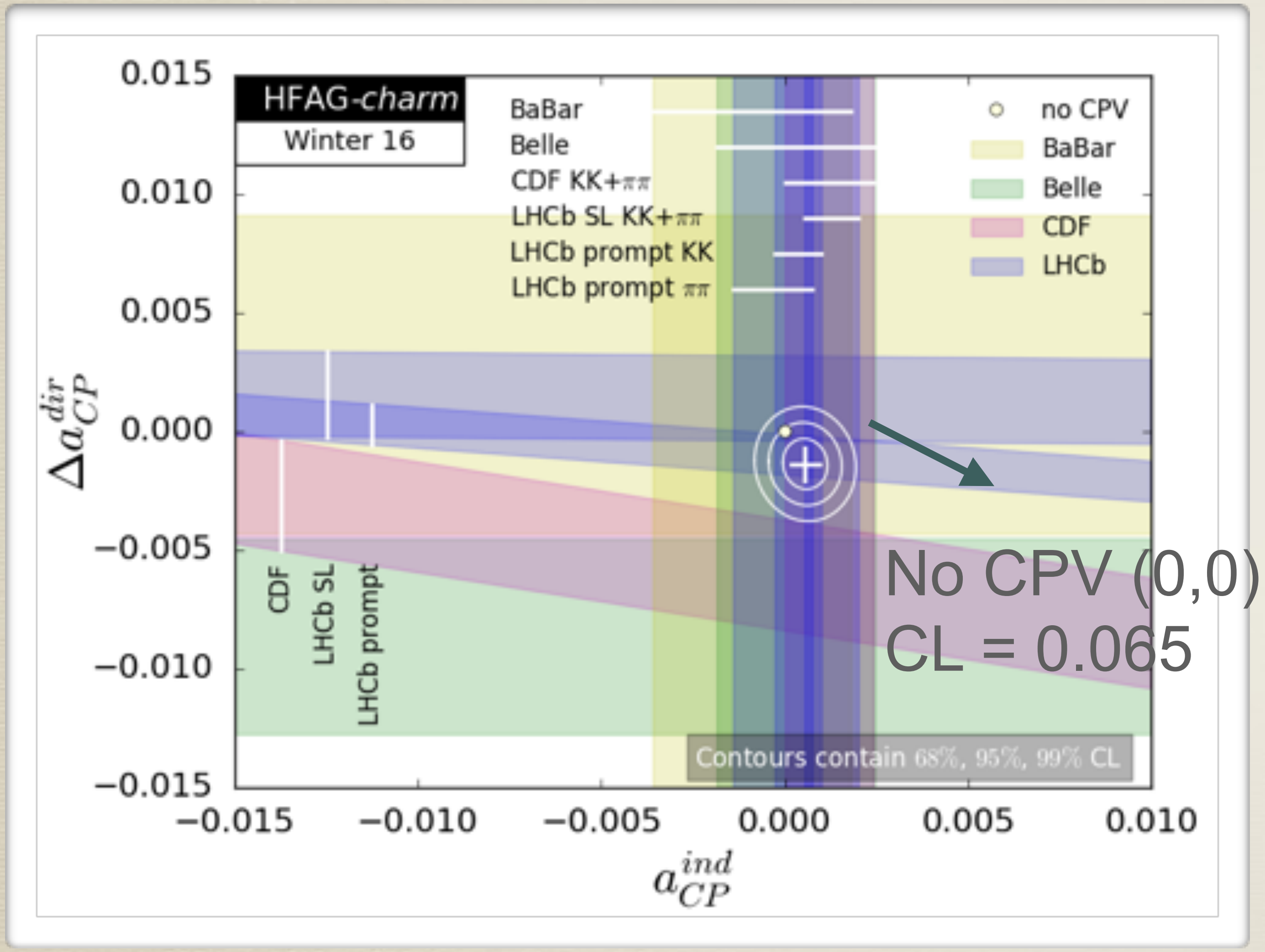
Belle II: Reconstruction asymmetries between K^+,K^- and π^+, π^-, Forward-backward asymmetry from interference between γ and Z production modes

LHCb: Underlying pp initial state not CP symmetric: prone to systematic uncertainties

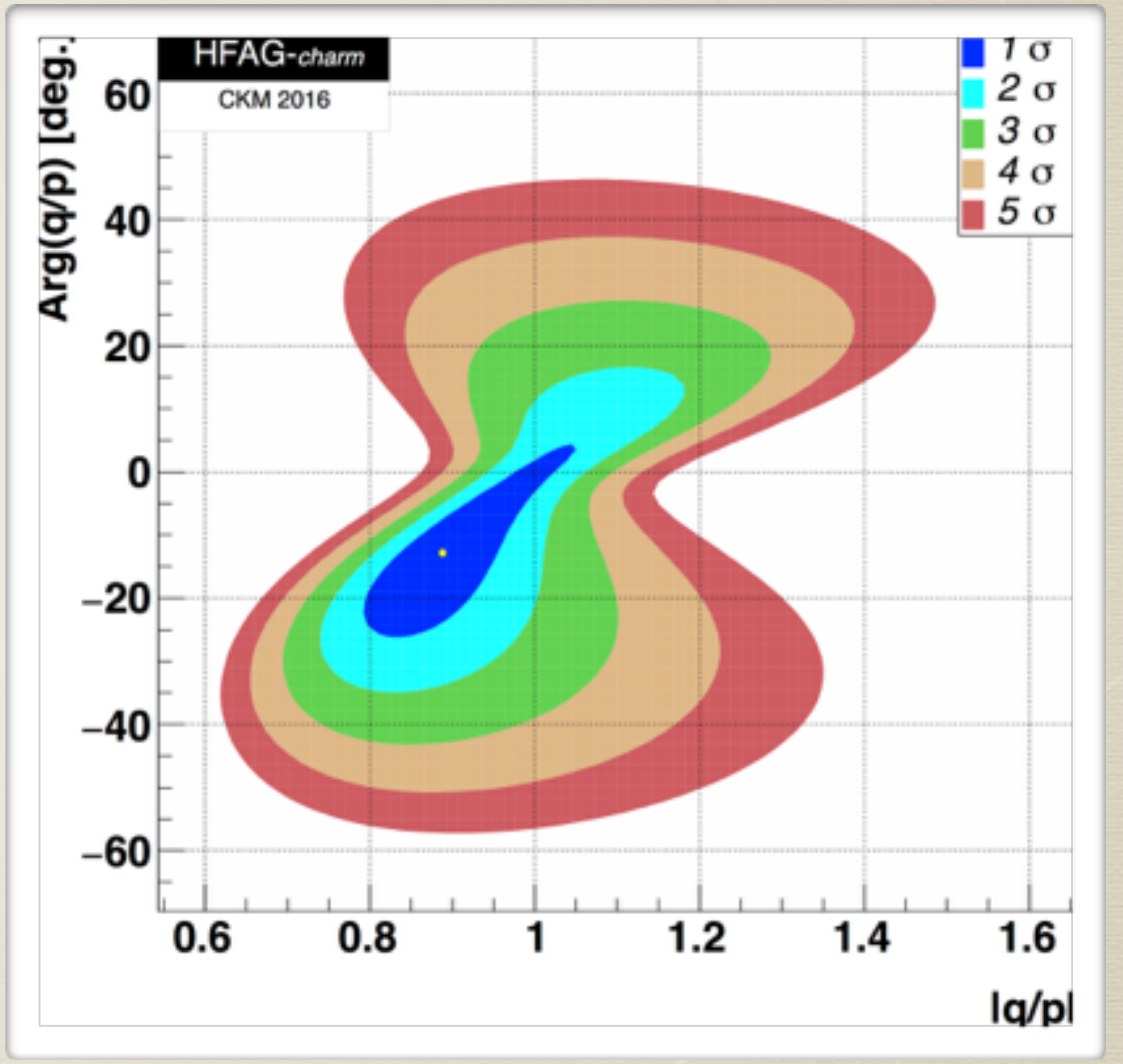
- Belle II has an advantage in modes with neutral particles in the final state

Charm CPV results

CPV in D^0 to h^+h^- decays

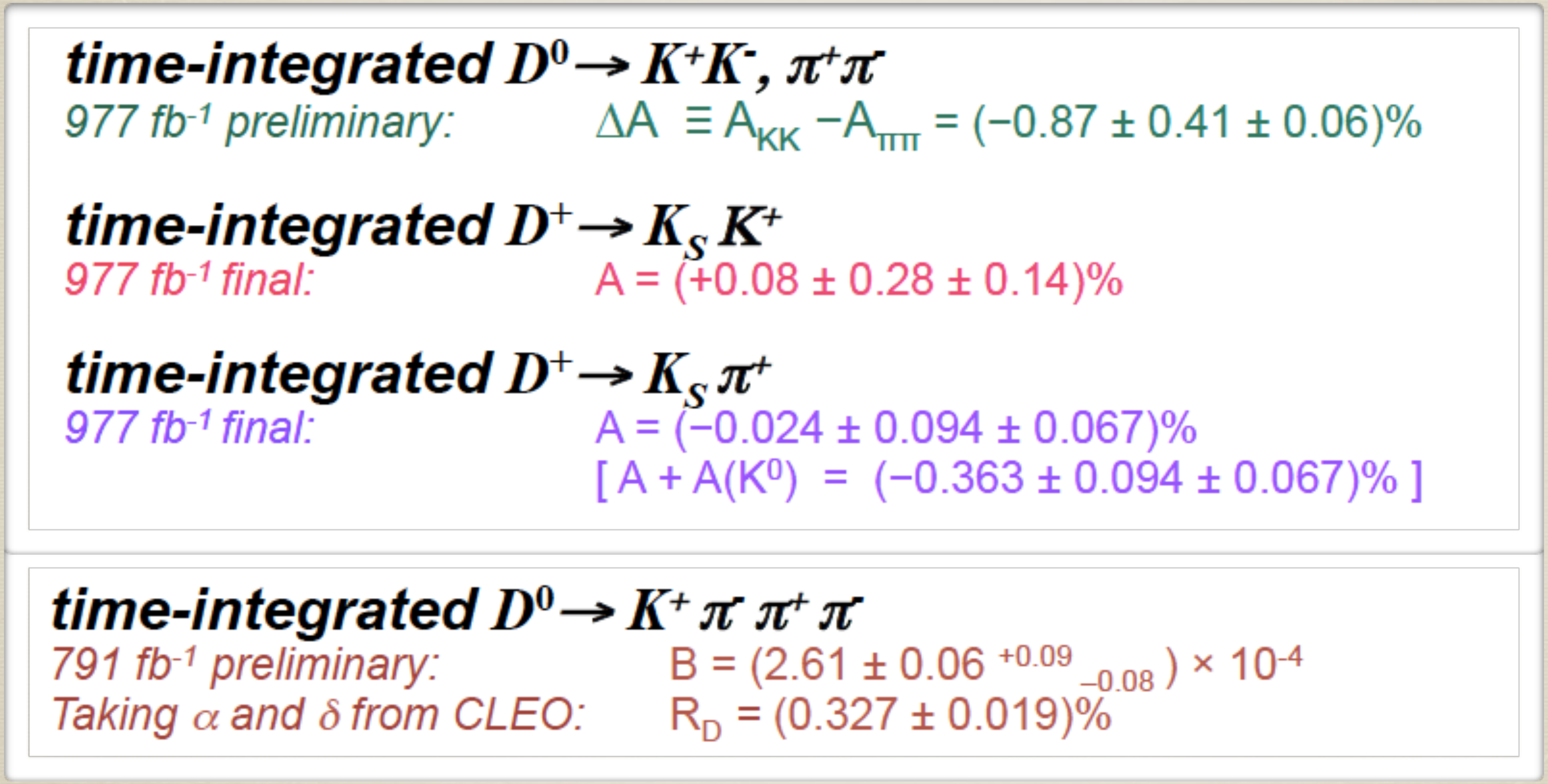


No CPV (0,0)
CL = 0.065



- No clear evidence of direct CPV
- No hints of indirect CPV

Time-integrated CPV Belle results



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

977 fb^{-1} preliminary: $\Delta A \equiv A_{KK} - A_{\pi\pi} = (-0.87 \pm 0.41 \pm 0.06)\%$

time-integrated $D^+ \to K_S K^+$

977 fb^{-1} final: $A = (+0.08 \pm 0.28 \pm 0.14)\%$

time-integrated $D^+ \to K_S \pi^+$

977 fb^{-1} final: $A = (-0.024 \pm 0.094 \pm 0.067)\%$

$[\, A + A(K^0) = (-0.363 \pm 0.094 \pm 0.067)\% \,]$

time-integrated $D^0 \to K^+ \pi^- \pi^+ \pi^-$

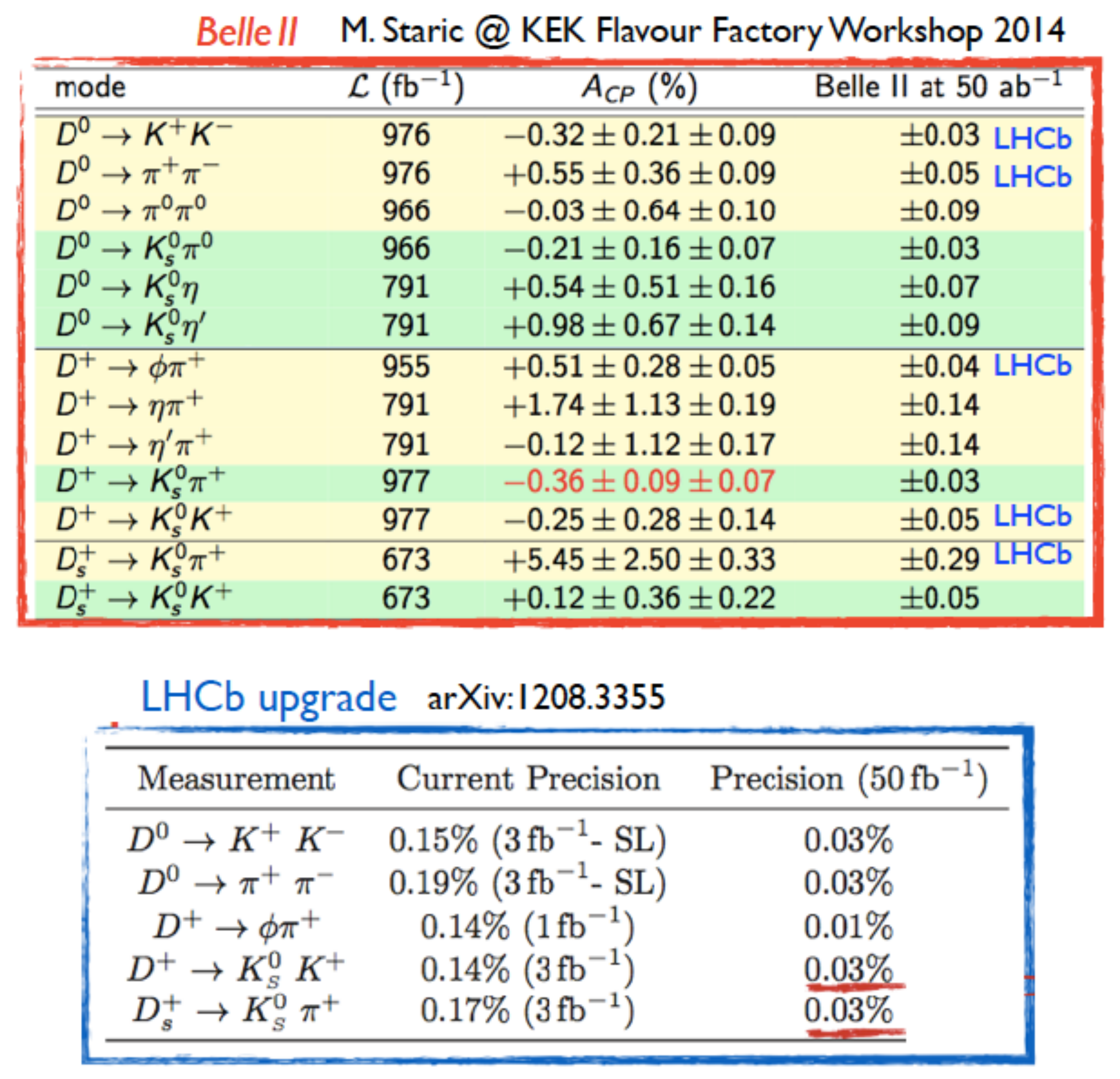
791 fb^{-1} preliminary: $B = (2.61 \pm 0.06\, ^{+0.09}_{-0.08}) \times 10^{-4}$

Taking α and δ from CLEO: $R_D = (0.327 \pm 0.019)\%$

Time-integrated D^0 to $\pi^0\pi^0$, 977 fb^{-1}

A_{CP} = (-0.03 +/- 0.64 +/- 0.10) x 10^{-2}

Belle II projections



Belle II M. Staric @ KEK Flavour Factory Workshop 2014

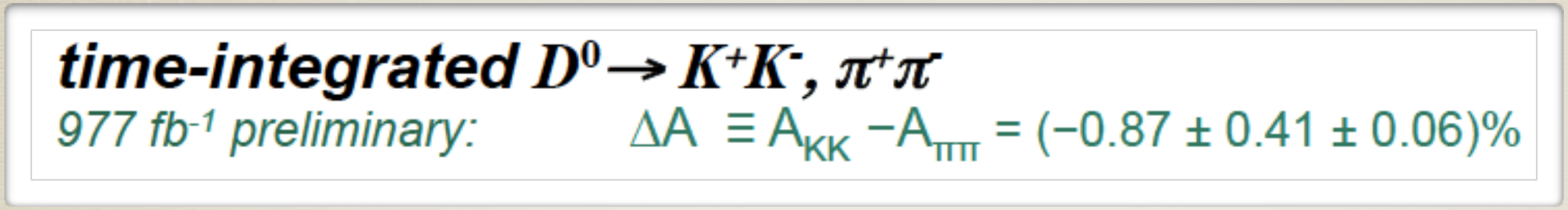
mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II at 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03 LHCb
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05 LHCb
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	± 0.09
$D^0 \to K_s^0\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.03
$D^0 \to K_s^0\eta$	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
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04 LHCb
$D^+ \to \eta\pi^+$	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	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K_s^0K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05 LHCb
$D_s^+ \to K_s^0\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29 LHCb
$D_s^+ \to K_s^0K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

LHCb upgrade arXiv:1208.3355

Measurement	Current Precision	Precision (50 fb^{-1})
$D^0 \to K^+ K^-$	0.15% (3 fb^{-1}- SL)	0.03%
$D^0 \to \pi^+ \pi^-$	0.19% (3 fb^{-1}- SL)	0.03%
$D^+ \to \phi\pi^+$	0.14% (1 fb^{-1})	0.01%
$D^+ \to K_S^0 K^+$	0.14% (3 fb^{-1})	0.03%
$D_s^+ \to K_S^0 \pi^+$	0.17% (3 fb^{-1})	0.03%

- Only D* tagging method considered
- A_{CP} precision will reach O(10^{-4}) better than the current theoretical predictions
- Interesting channels such as D^0 to K_SK_S, D^+ to $\pi^+\pi^0$, 3-body final states (DP analysis) not included
- Belle II will provide best precision for neutral particle final states, but will be competitive with LHCb for charged particle final states as well

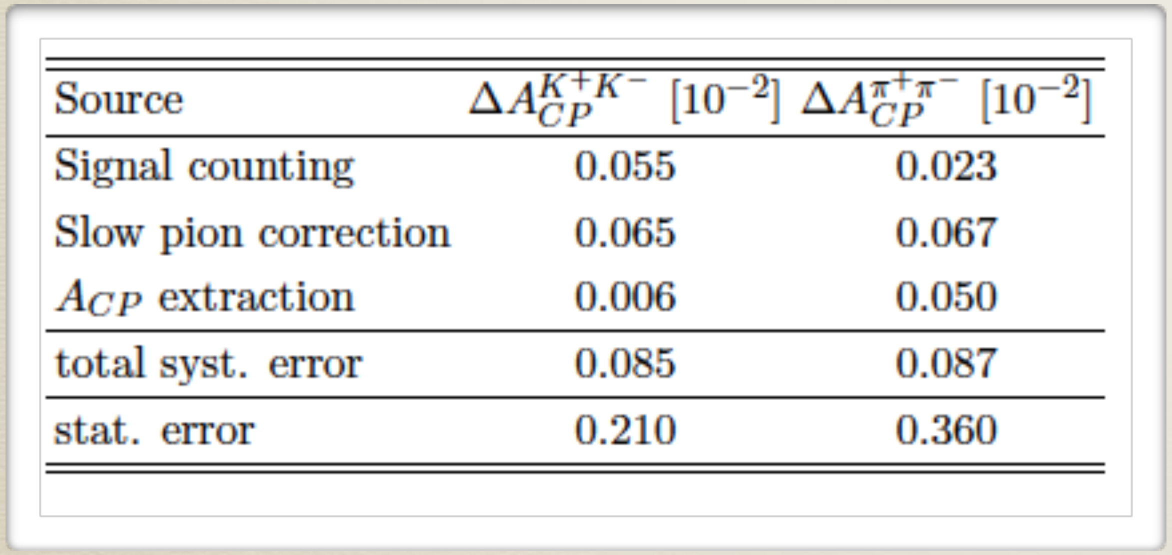
D^0 to hh



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

977 fb^{-1} preliminary: $\Delta A \equiv A_{KK} - A_{\pi\pi} = (-0.87 \pm 0.41 \pm 0.06)\%$

Uncertainties on A_{CP} measurements of K^+K^-, $\pi^+\pi^-$



Source	$\Delta A_{CP}^{K^+K^-}$ $[10^{-2}]$	$\Delta A_{CP}^{\pi^+\pi^-}$ $[10^{-2}]$
Signal counting	0.055	0.023
Slow pion correction	0.065	0.067
A_{CP} extraction	0.006	0.050
total syst. error	0.085	0.087
stat. error	0.210	0.360

D^0 to hh

Reducible errors:

- Slow π correction uncertainty:
  Difference in the reconstruction efficiencies of π^+ and π^- from tagging D*
- scales with integrated luminosity
- ACP extraction:
  Calculation of final CP asymmetry in the bins of different kinematic variable

\- higher statistics, uncertainty becomes negligible

Irreducible errors:

Signal counting:

Possible difference between the background shape in signal and sideband intervals of

$$q = (m(h^+h^-\pi_s) - m(h^+h^-) - m_\pi)c^2$$

KK final state: +/- 0.055 x 10^{-2}
ππ final state: +/- 0.18 x 10^{-2}

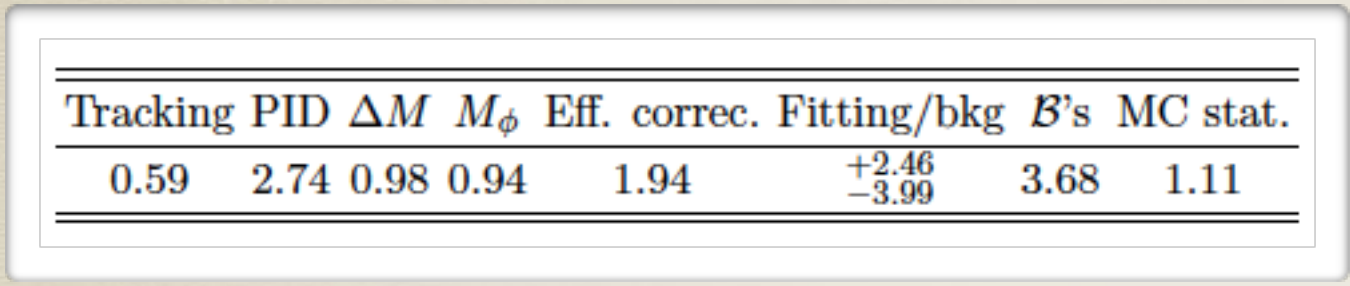
Expected precision for future measurements

$$\sigma_{\text{total}}^{A_{CP}^{K^+K^-}} = \sqrt{(0.220 + 0.066^2) \times 0.976\ \text{ab}^{-1}/\mathcal{L}_{\text{int}} + 0.055^2}\ [\times 10^{-2}]$$
$$\sigma_{\text{total}}^{A_{CP}^{\pi^+\pi^-}} = \sqrt{(0.370 + 0.085^2) \times 0.976\ \text{ab}^{-1}/\mathcal{L}_{\text{int}} + 0.018^2}\ [\times 10^{-2}]$$

[Belle II Internal Note]

Radiative decays

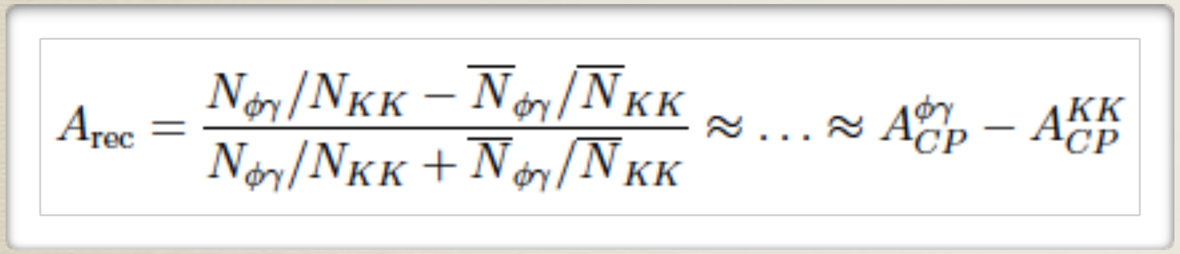
Fractional systematic errors (%) on B(D^0 to φγ)



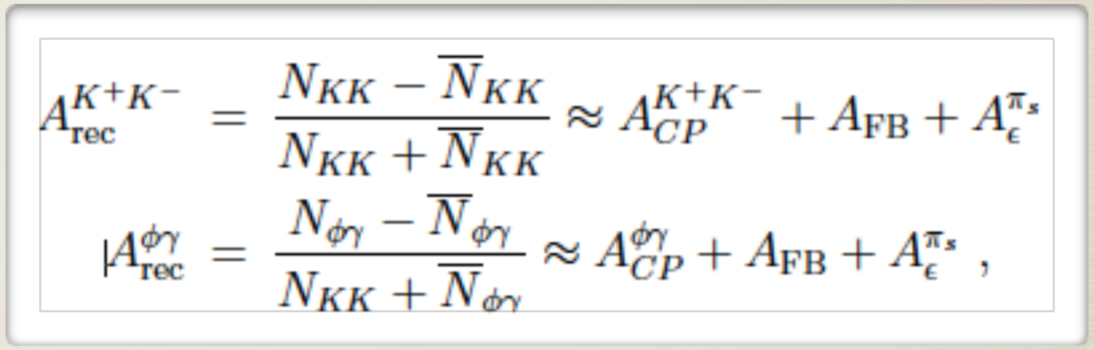
Tracking	PID	ΔM	M_ϕ	Eff. correc.	Fitting/bkg	$\mathcal{B}$'s	MC stat.
0.59	2.74	0.98	0.94	1.94	$^{+2.46}_{-3.99}$	3.68	1.11

Normalization mode: D^0 to K$^+$K$^-$

A$_{CP}$ in D^0 to φγ is a future measurement using the same normalization mode



$$A_{\rm rec} = \frac{N_{\phi\gamma}/N_{KK} - \overline{N}_{\phi\gamma}/\overline{N}_{KK}}{N_{\phi\gamma}/N_{KK} + \overline{N}_{\phi\gamma}/\overline{N}_{KK}} \approx \ldots \approx A^{\phi\gamma}_{CP} - A^{KK}_{CP}$$



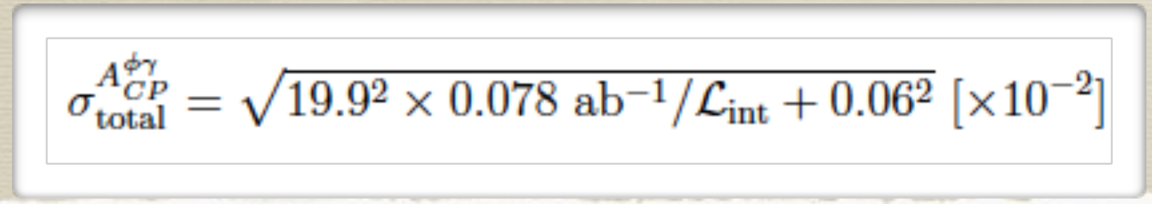
$$\begin{aligned} A^{K^+K^-}_{\rm rec} &= \frac{N_{KK} - \overline{N}_{KK}}{N_{KK} + \overline{N}_{KK}} \approx A^{K^+K^-}_{CP} + A_{\rm FB} + A^{\pi_s}_{\epsilon} \\ A^{\phi\gamma}_{\rm rec} &= \frac{N_{\phi\gamma} - \overline{N}_{\phi\gamma}}{N_{KK} + \overline{N}_{\phi\gamma}} \approx A^{\phi\gamma}_{CP} + A_{\rm FB} + A^{\pi_s}_{\epsilon} \ , \end{aligned}$$

Detector induced symmetry

Forward-backward asymmetry

Physical CP asymmetry

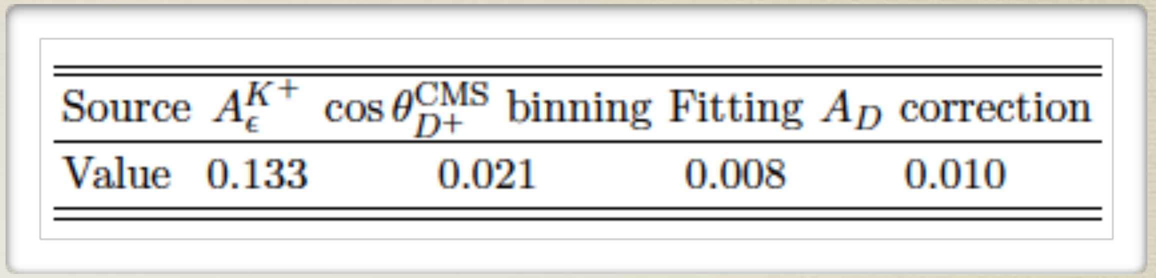
Expected precision for future measurements



$$\sigma^{A^{\phi\gamma}_{CP}}_{\rm total} = \sqrt{19.9^2 \times 0.078\ {\rm ab}^{-1}/\mathcal{L}_{\rm int} + 0.06^2}\ [\times 10^{-2}]$$

[Belle II Internal Note]

D^+ to $K_S K^+$



Source	$A_\epsilon^{K^+}$	$\cos\theta_{D^+}^{\text{CMS}}$ binning	Fitting	A_D correction
Value	0.133	0.021	0.008	0.010

Reducible

- Detector induced asymmetries due to differences in reconstruction efficiencies of K^+ and K^-

- will scale with increased statistics

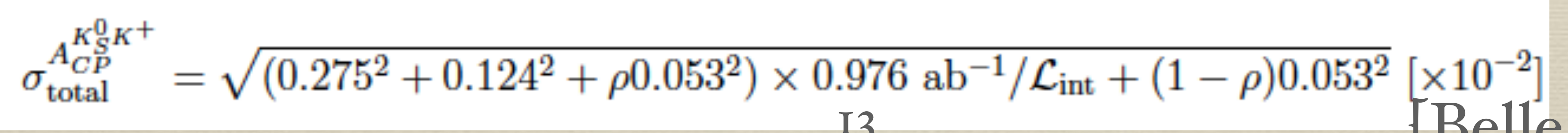
- Effect of binning in few kinematic variables

- can be reduced with increased statistics

Irreducible

- To A_ε^{K+} uncertainty, additional contributions due to sys. err. of $A_{CP}(D_s$ to $\varphi\pi)$ and t-integrated A_{CP} in D^0 to $K^-\pi^+$
- Fitting: binning in kinematic variables
- Difference in interactions of K and anti-K in detector

Expected precision for future measurements



$$\sigma_{\text{total}}^{A_{CP}^{K_S^0 K^+}} = \sqrt{(0.275^2 + 0.124^2 + \rho 0.053^2) \times 0.976\ \text{ab}^{-1}/\mathcal{L}_{\text{int}} + (1-\rho)0.053^2}\ [\times 10^{-2}]$$

[Belle II Internal Note]

D^0 to $\pi^0\pi^0$, D^0 to $K_S\pi^0$

Belle measurement (D^0 to $\pi^0\pi^0$, 996 fb^{-1}):

A_{CP} =(-0.03 +/- 0.64 +/- 0.10) x 10^{-2}

- Expect similar systematic error in Belle II
- Large fraction of systematics will be reduced with higher statistics (using dedicated sample of tagged and untagged D^0 to $K\pi$

Expected precision for future measurements

$$\sigma_{\text{total}}^{A_{CP}^{\pi^0\pi^0}} = \sqrt{(0.64^2 + 0.10^2) \times 0.996\ \text{ab}^{-1}/\mathcal{L}_{\text{int}} + 0.01^2}\ [\times 10^{-2}]$$

Similar uncertainties for D^0 to $K_S\pi^0$

Only difference: additional irreducible sys. err. due to the neutral K interactions in the material (+/-0.01 x 10^{-2})

Expected precision for future measurements

$$\sigma_{\text{total}}^{A_{CP}^{K_S^0\pi^0}} = \sqrt{(0.16^2 + 0.09^2) \times 0.996\ \text{ab}^{-1}/\mathcal{L}_{\text{int}} + 0.01^2}\ [\times 10^{-2}]$$

[Belle II Internal Note]

D^0 to K_SK_S

SM limit 1.1% for direct CPV in $D^0 \to K_S^0K_S^0$

U. Nierste and A. Schacht, PRD 92 (2015) 054036

SCS decays (such as $D^0 \to K_S^0K_S^0$) are special interest: possible interference with NP amplitude could lead to larger nonzero CPV

The previous measured A_{CP} ($D^0 \to K_S^0K_S^0$) :

CLEO	$(-23 \pm 19)\%$	$13.7\ \mathrm{fb}^{-1}$	PRD 63 (2001) 071101
LHCb	$(-2.9 \pm 5.2 \pm 2.2)\%$	$3\ \mathrm{fb}^{-1}$	JHEP 10 (2015) 055

Method: $A_{CP}(D^0 \to K_S^0K_S^0) = (A_{rec}(K_S^0K_S^0) - A_{rec}(K_S^0\pi^0)) + A_{CP}(D^0 \to K_S^0\pi^0) + A_{K0/K^-0}$

A_{K0/K^-0} : Asymmetry originating from the different strong interaction of K0 and $\overline{K0}$ mesons with nucleons of the detector material = $(-0.11 \pm 0.01)\%$

[B. R. Ko et al., PRD 84 (2011) 111501]

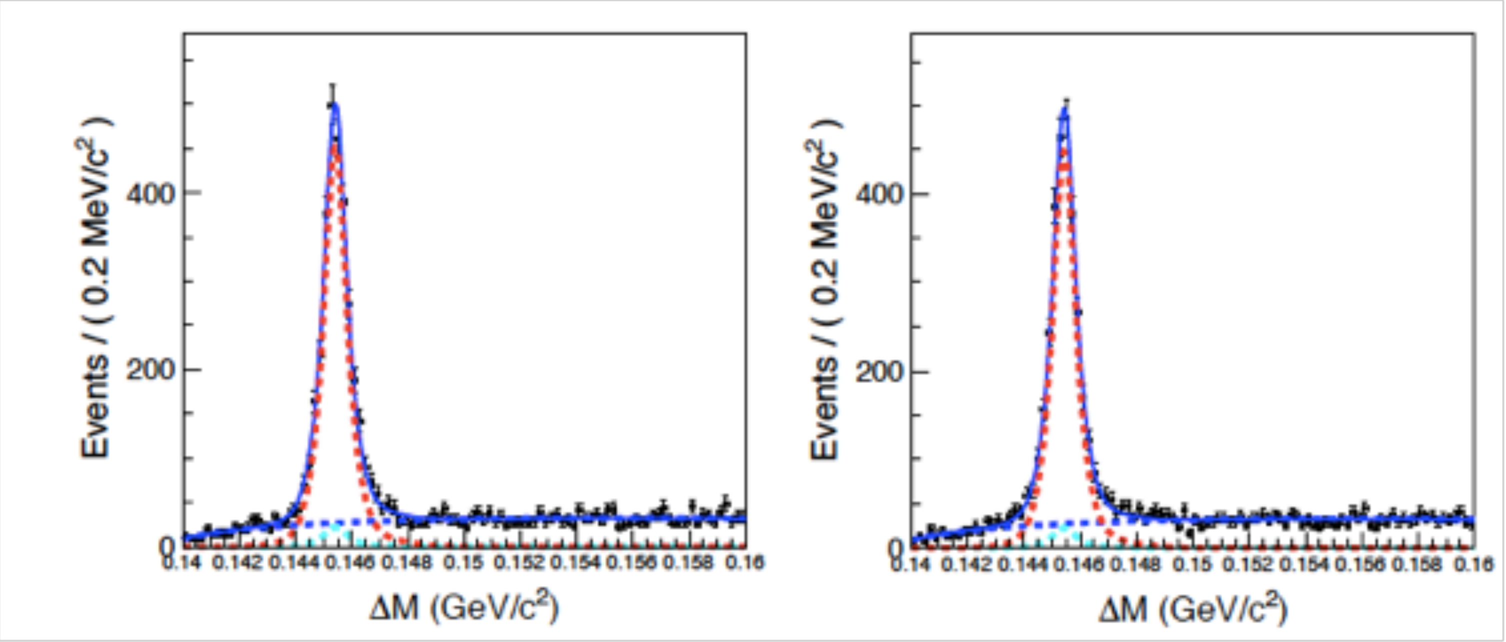
$A_{CP}(D^0 \to K_S^0\pi^0) = (-0.20 \pm 0.17)\%$ [PDG]

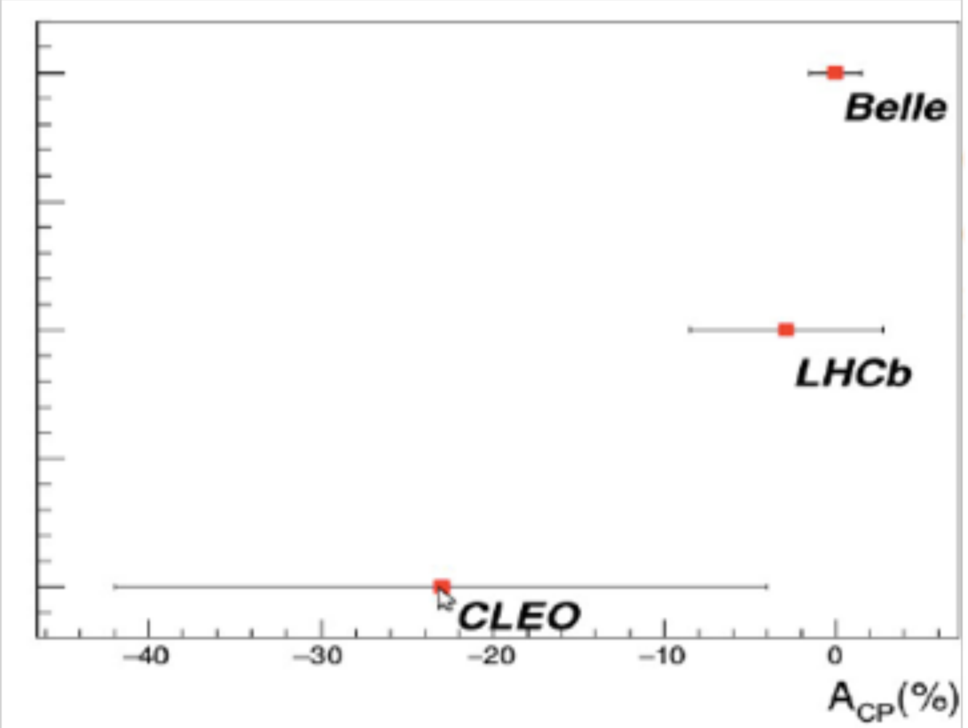
N. Dash, ICHEP 2016

D^0 to K_SK_S

$A_{CP}(D^0 \to K_S^0K_S^0) = (-0.02 \pm 1.53 \pm 0.17)\%$ **[Preliminary result]**

[arXiv: 1609.06393]

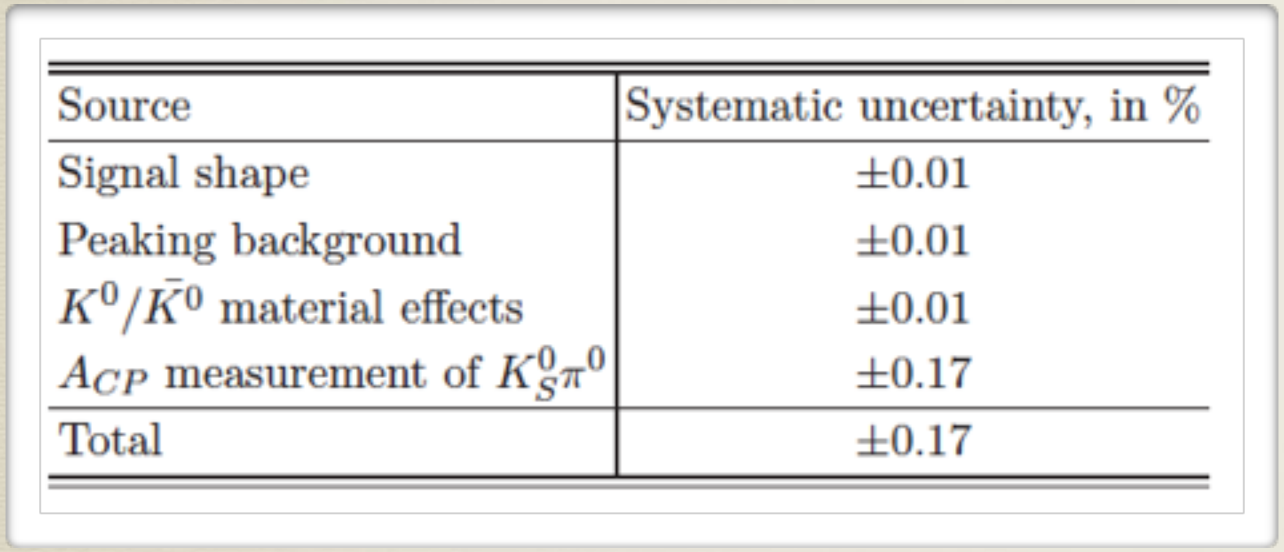




Consistent with no CPV, improve precision of previous best measurement by more than a factor 3 !!

Future prospects of D^0 to K_sK_s at Belle II

Dominant error in measurement is statistical: Belle II can greatly improve precision: expect a precision of 0.2% with similar systematic errors as at Belle



Source	Systematic uncertainty, in %
Signal shape	±0.01
Peaking background	±0.01
$K^0/\bar{K}^0$ material effects	±0.01
A_{CP} measurement of $K_S^0\pi^0$	±0.17
Total	±0.17

Systematic errors at Belle

- Irreducible errors:

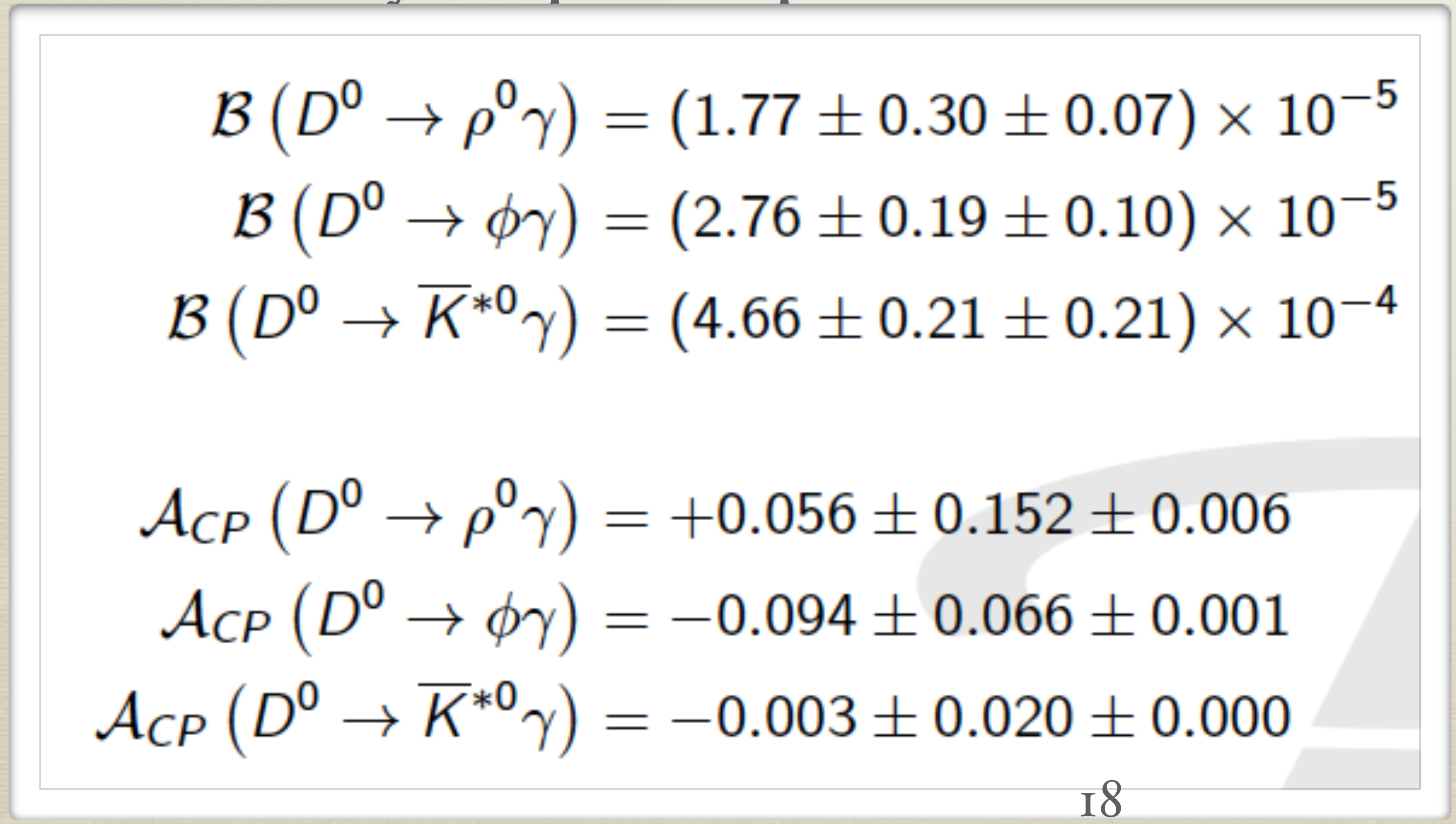
  Fitting: binning in kinematic variables

  Difference in interactions of K and anti-K in detector
- Dominant error arises from A_{CP} measurements of $K_s\pi^0$

  Errors on $K_s\pi^0$ will reduce with increased statistics at Belle II

D^0 to Vγ

- Study of Do to Vγ completed at Belle, branching fractions and ACP measurements done
- Dominant errors on A_{CP} are statistical: Belle II can drastically improve precision



$$\mathcal{B}\left(D^0 \to \rho^0\gamma\right) = (1.77 \pm 0.30 \pm 0.07) \times 10^{-5}$$

$$\mathcal{B}\left(D^0 \to \phi\gamma\right) = (2.76 \pm 0.19 \pm 0.10) \times 10^{-5}$$

$$\mathcal{B}\left(D^0 \to \overline{K}^{*0}\gamma\right) = (4.66 \pm 0.21 \pm 0.21) \times 10^{-4}$$

$$\mathcal{A}_{CP}\left(D^0 \to \rho^0\gamma\right) = +0.056 \pm 0.152 \pm 0.006$$

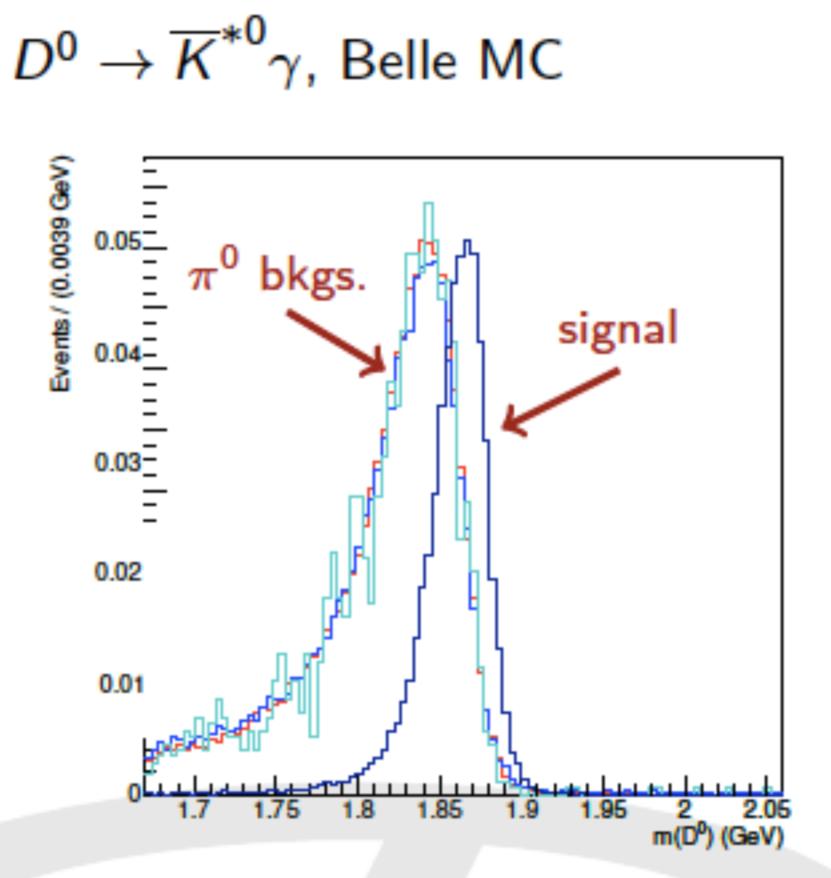
$$\mathcal{A}_{CP}\left(D^0 \to \phi\gamma\right) = -0.094 \pm 0.066 \pm 0.001$$

$$\mathcal{A}_{CP}\left(D^0 \to \overline{K}^{*0}\gamma\right) = -0.003 \pm 0.020 \pm 0.000$$

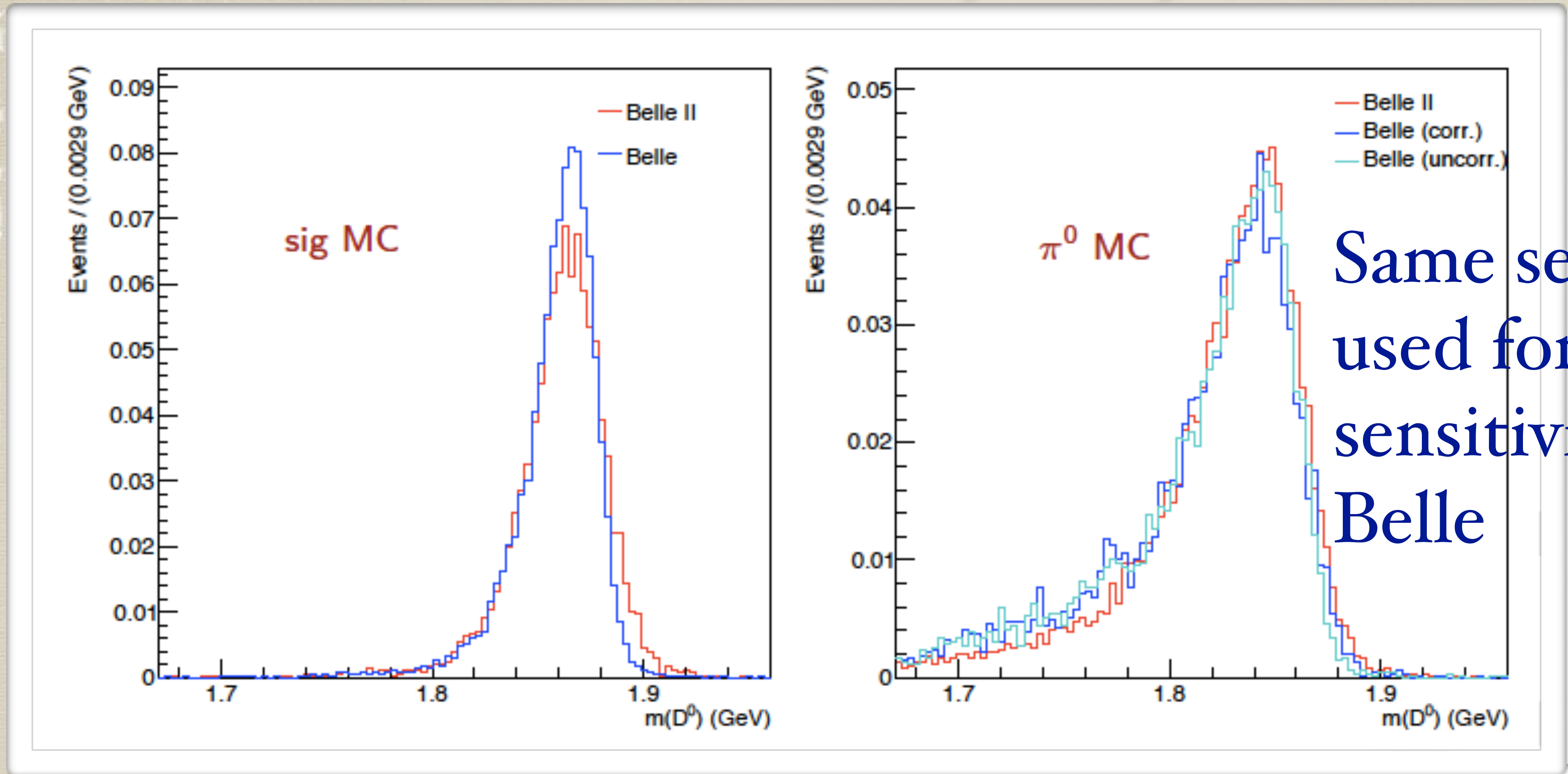
arXiv:1603.03257

Belle II sensitivity study for D^0 to $V\gamma$

- Decay mode: D^{*+} to D^0 π_s^+, D^0 to $\Phi\gamma$
- Same preselection cuts as in Belle
- Look at fit variables distributions in Belle: $m(D^0)$, cos(theta_h)
- Dominant background: π^0 то $\gamma\gamma$
- Determining signal resolution, π^0 background and overlap of the peaks
- π^0 veto checked in Belle II



$m(D^0)$

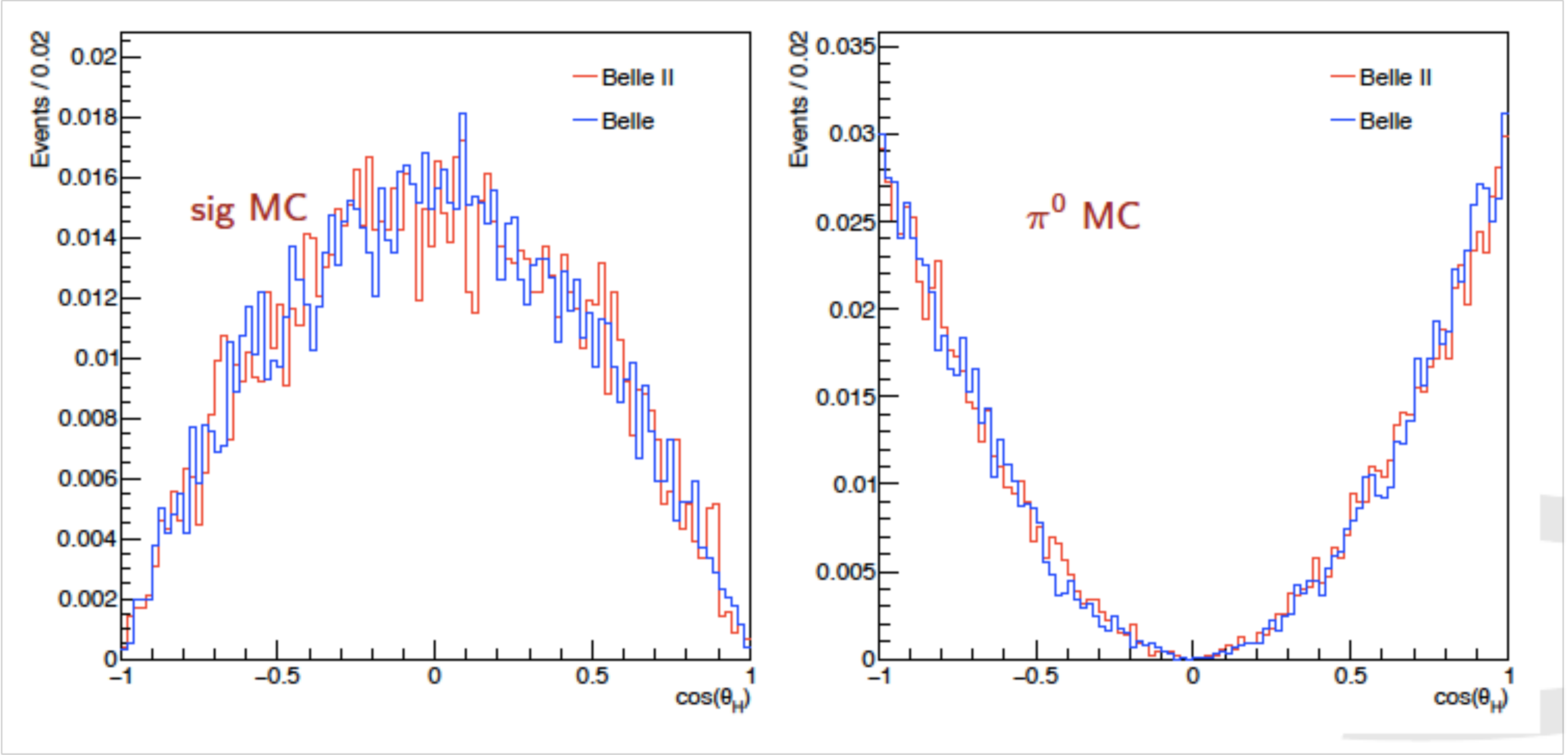


Same selection criteria used for Belle II sensitivity study as in Belle

	Belle:	Belle II:
Signal efficiency:	9.8%	7.2%
Signal mean:	1.8645±0.0003	1.8642±0.0003
Signal width:	0.0122±0.0001	0.0164±0.0002
π^0 bkg. mean:	1.8428±0.0007	1.8421±0.0005
π^0 bkg. width:	0.0162±0.0004 (0.0187±0.0003)	0.0194±0.0003

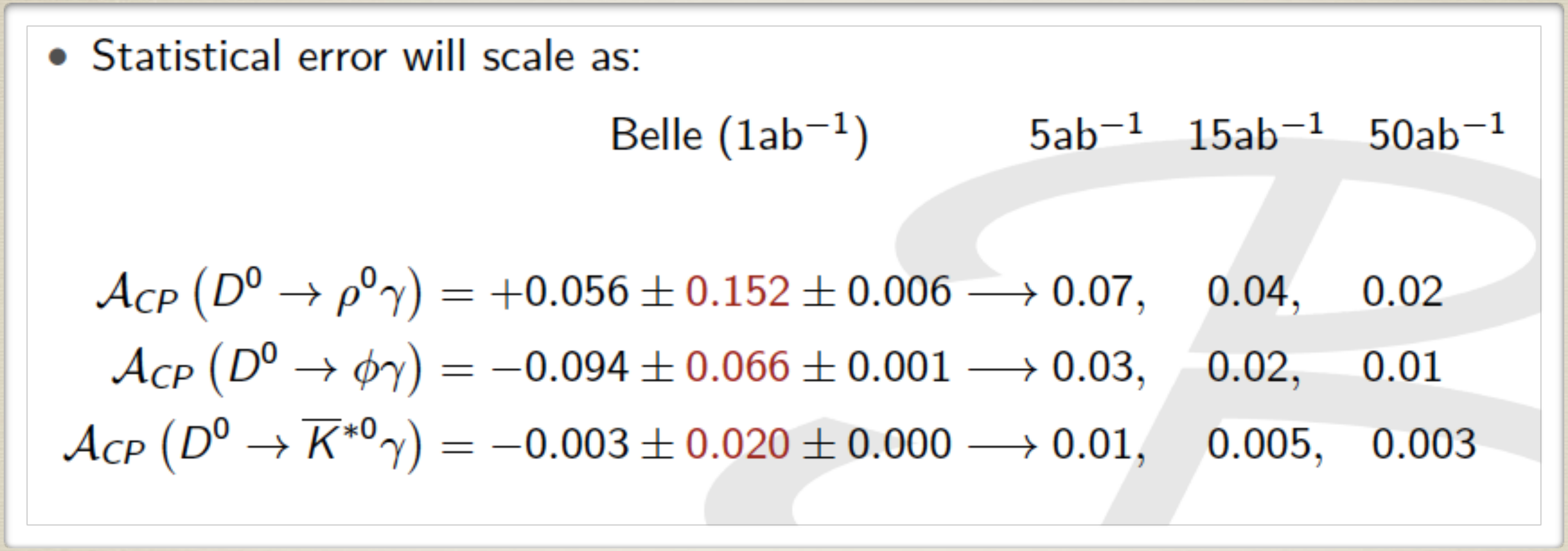
Resolution in $m(D^0)$ is slightly worse than in Belle

cos(theta_H)



Resolution in $\cos(\theta_H)$ is the same as in Belle

D^0 to Vγ



- Statistical error will scale as:

	Belle (1ab^{-1})	5ab^{-1}	15ab^{-1}	50ab^{-1}
$\mathcal{A}_{CP}\left(D^0 \to \rho^0\gamma\right)$	$= +0.056 \pm 0.152 \pm 0.006 \longrightarrow$	0.07,	0.04,	0.02
$\mathcal{A}_{CP}\left(D^0 \to \phi\gamma\right)$	$= -0.094 \pm 0.066 \pm 0.001 \longrightarrow$	0.03,	0.02,	0.01
$\mathcal{A}_{CP}\left(D^0 \to \overline{K}^{*0}\gamma\right)$	$= -0.003 \pm 0.020 \pm 0.000 \longrightarrow$	0.01,	0.005,	0.003

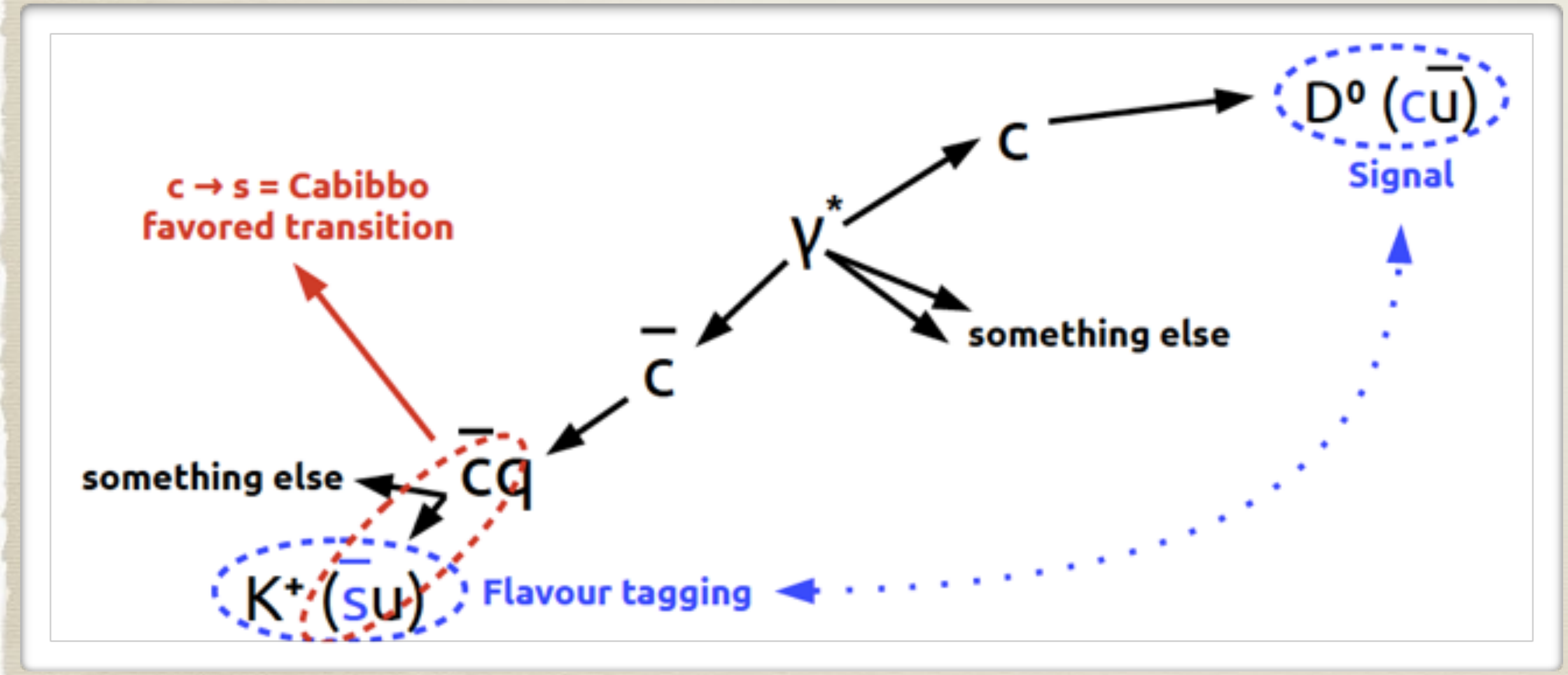
New flavour tagging method

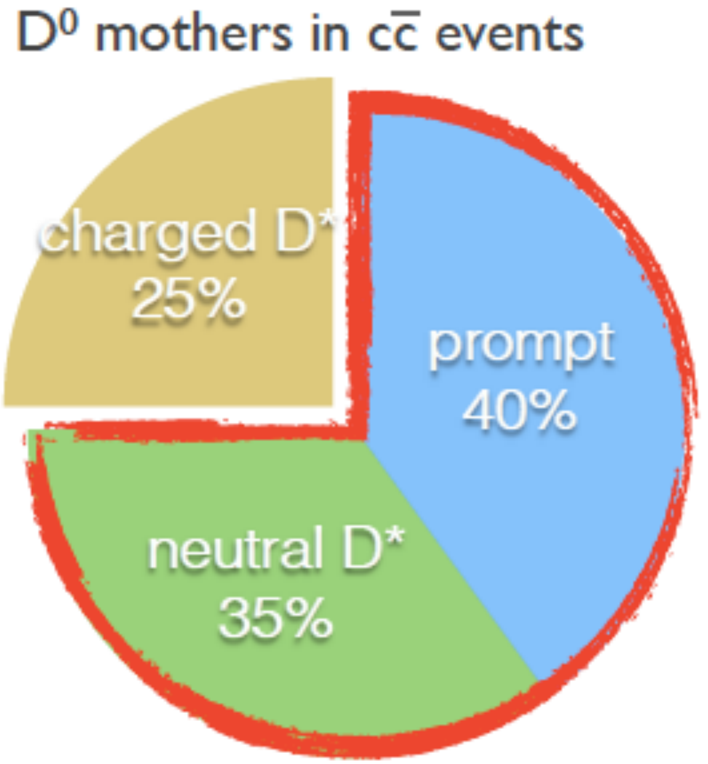
Usual flavour tagging

D^{*+} to $D^0\pi^+_{slow}$:

- Flavor tagging used is usually π^+_{slow}
- Lose 75% of D^0 in cc-bar events at B-factories

Rest of the event (ROE) / Prompt D^0 flavour tagging [improve statistics]




D⁰ mothers in $c\bar{c}$ events

Typical Correctly Tagging Events

$cc \to D^0 D^- X$, $D^0 \to$ signal ch

$D^- \to K^{*0} e^- \nu$; $K^{*0} \to K^+ \pi^-$

$cc \to D^0 \Lambda_c^- X$, $D^0 \to$ signal ch

$\Lambda_c^- \to \Delta^{--} K^{*+}$; $K^{*+} \to K^+ \pi^0$

Select events with only one $K^{+/-}$ in the ROE and charge of K determines the flavour of D^0 at production

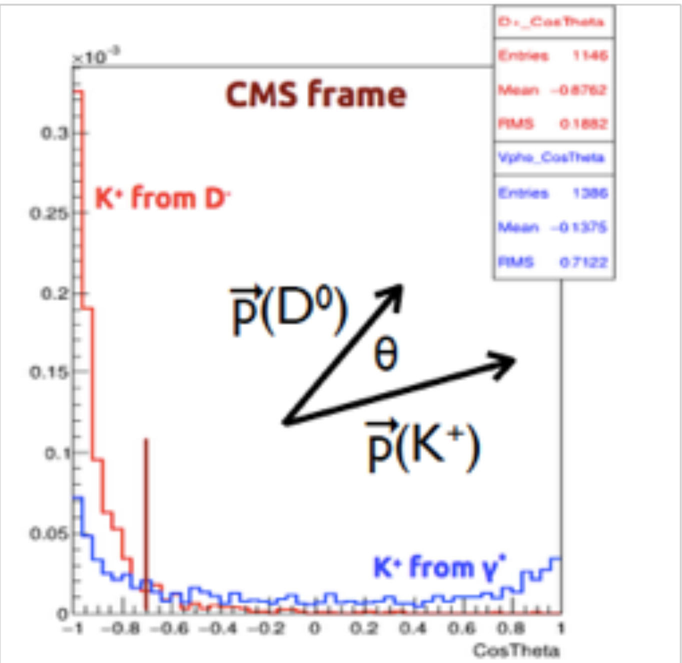
New flavour tagging method

- Selection of tagging charged kaon is most important: two-step selection based on a BDT with a first loose cut to reject most of the background and count the number of charged kaons, and a second tighter cut to reject fake kaons

- Tagging kaons are mostly back-to-back

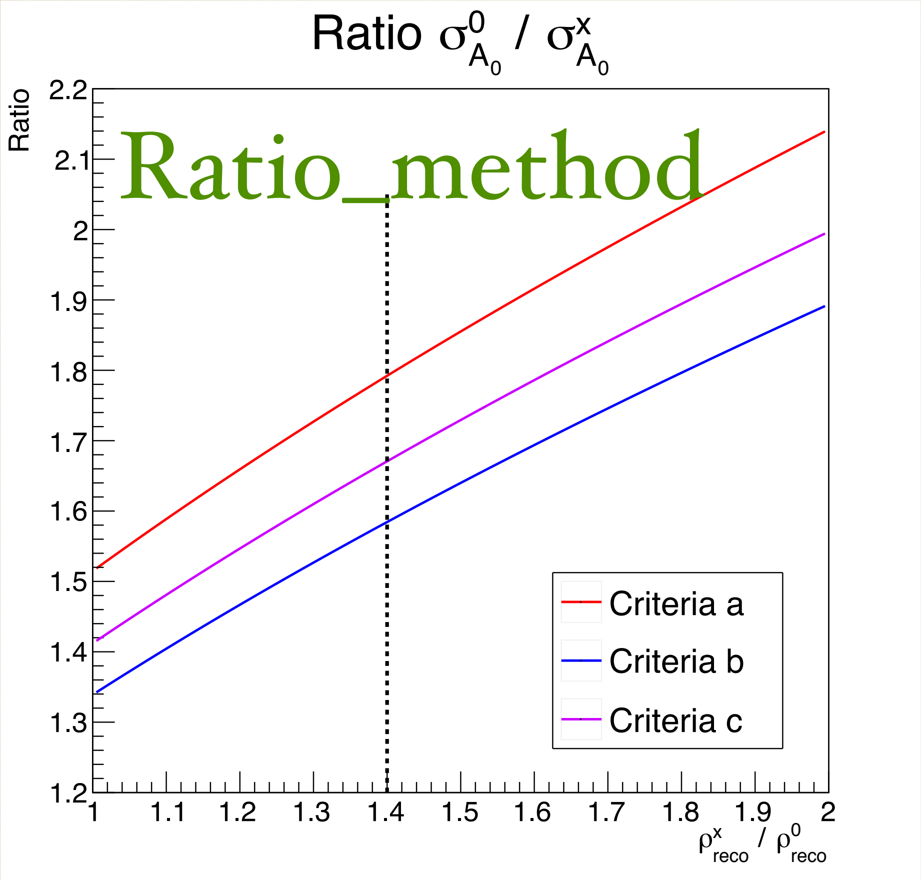
- Tagging efficiency (ε) = 15 %, mis-tagging level (w) < 5%, after vetoing presence of neutral kaons K_L and K_S in the ROE [from MC truth]

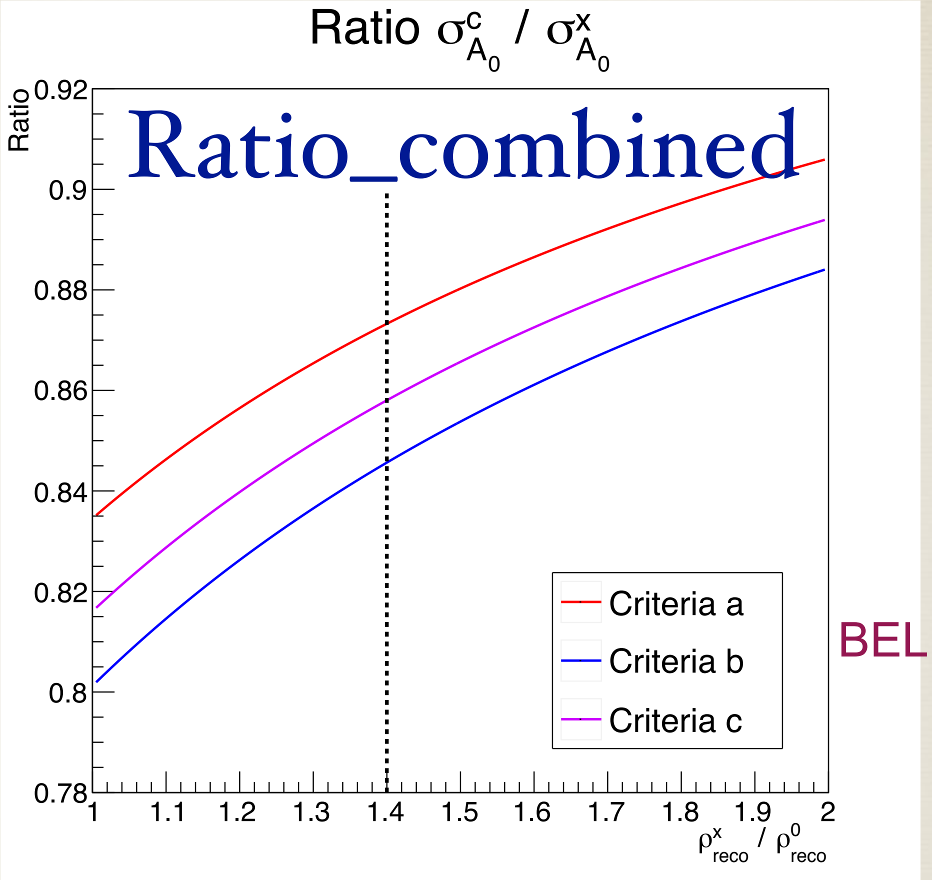
A novel tagging method which will: increase statistics with an additional D^0 sample and will be very useful to evaluate systematics independently



a cut at cosθ<0.7 rejects 66% of the mis-tagging K and 10% of the signal

New flavour tagging method





case I: only BDT selection
case II: BDT + veto K_s + cos(θ)
case III: BDT + veto MC K^0 + cos(θ)

BELLE2-MTHESIS-2016-007;
To be published

- Left plot: Ratio between the statistical error on a A_{CP} measurement using the two different flavour tagging methods (D* and ROE, given by σ^X and σ^0) as a function of the purity of D^0 samples.
- Right plot: Ratio between the combined statistical error (σ^C) and the statistical error from the D* method.
- Reference point for the ratio of the purity of D^0 samples: 1.4 [PhysRevD.87.012004]
- In the best case, assuming the value 1.4 for Belle II, we can expect a reduction of ~15% of the statistical error on a A_{CP} measurement.

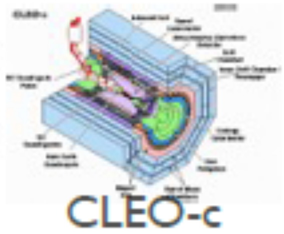
Summary

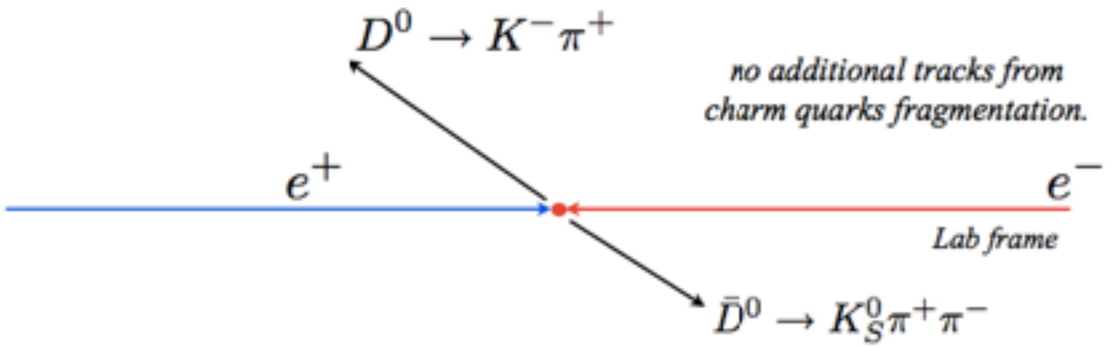
- B-factories have successfully been charm factories
- For K_sK_s channel, Belle II expects a precision of ~0.2%
- For K^+K^-, $\pi^+\pi^-$ at Belle II, errors will be +/- 0.05, +/-0.07 respectively for 50 ab^{-1} and for K_sK^+, $K_s\pi^+$, errors will be +/-0.1, +/-0.3 respectively
- Belle II will implement novel tagging method (ROE) to increase statistics
- Belle II sensitivity studies performed for D^0 to Vγ: statistical errors will be +/- 0.01 for Φγ, +/-0.02 for ργ for 50 ab^{-1}
- Belle II errors will be smaller than LHCb for the neutral particle final state modes and will be of the same order as LHCb for the charged particle final state modes

Exciting road ahead for charm physics @ Belle II !!

BACK-UP

threshold production

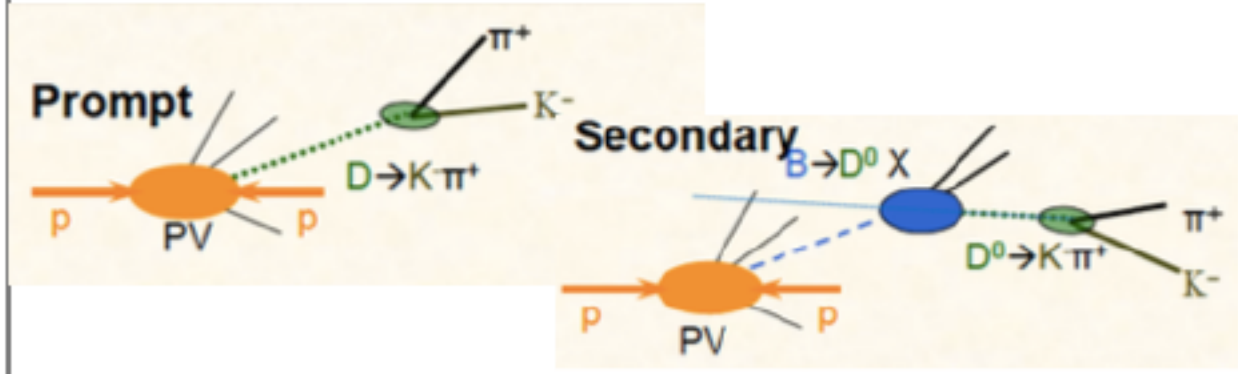




no additional tracks from charm quarks fragmentation.

- ✓ extremely clean environment
- ✓ pure D-beam, almost no bkg
- ✓ quantum coherence
- ◉ no CM boost, no T-dep analyses

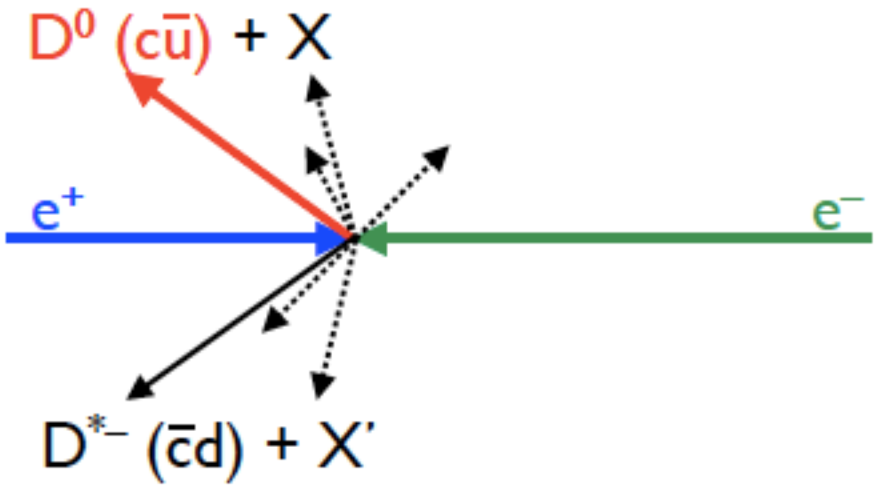
hadron colliders



- ✓ large production cross-section
- ✓ large boost: excellent time res
- ◉ dedicated trigger required
- ◉ hard to do neutrals and neutrinos

B-Factories

high-luminosity B-Factory

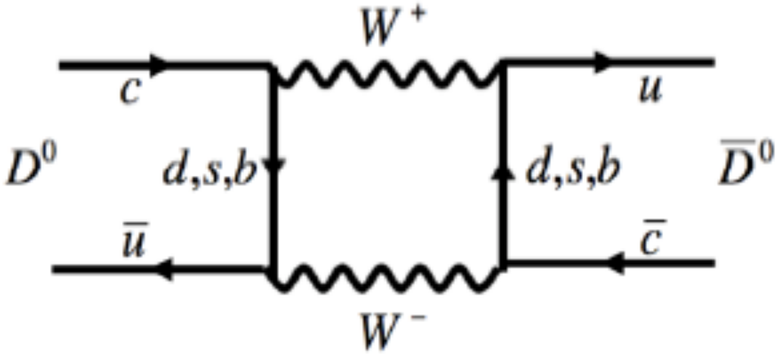


- ✓ clean event environment
- ✓ high trigger efficiency
- ✓ high-efficiency detection of neutrals
- ✓ many high-statistics control samples
- ✓ time-dependent analysis
- ◉ smaller cross-section than hadron colliders

Charm mixing

Evolution of neutral D^0 flavour eigenstates follows the Schrodinger ’s equation:

$$i\partial_t \begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix} = \left(M + \frac{i}{2}\Gamma\right) \begin{pmatrix} D^0(t) \\ \bar{D}^0(t) \end{pmatrix}$$



Mixing parameters: $|M_{12}|$, $|\Gamma_{12}|$, $|\varphi_{12} = \arg(\Gamma_{12}/M_{12})|$

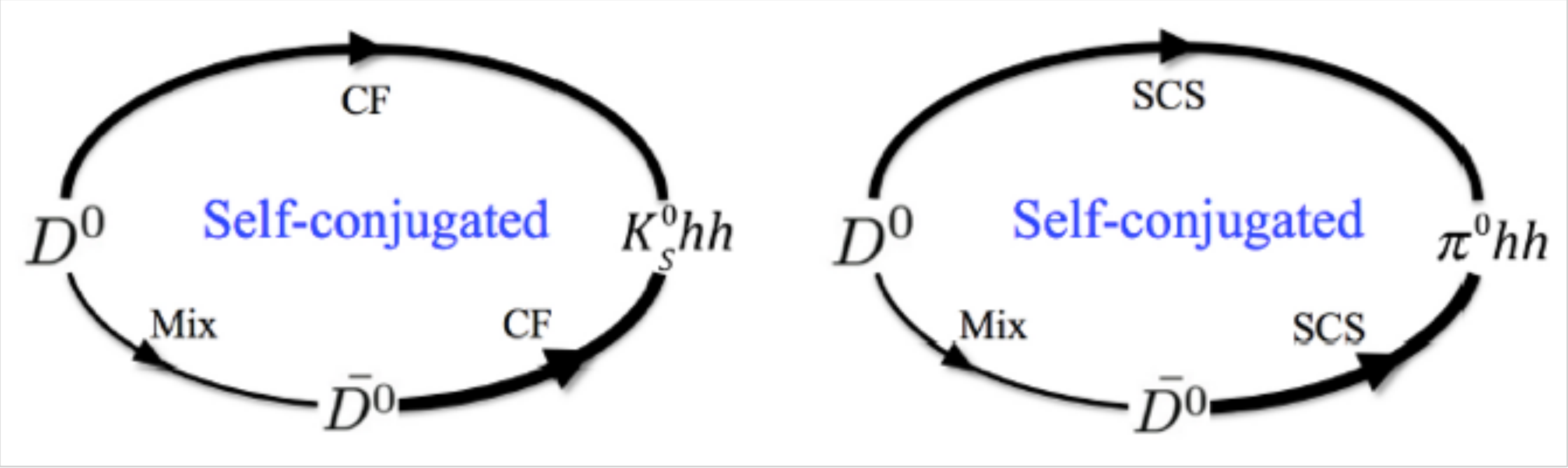
Dispersive part of the amplitude M_{12}

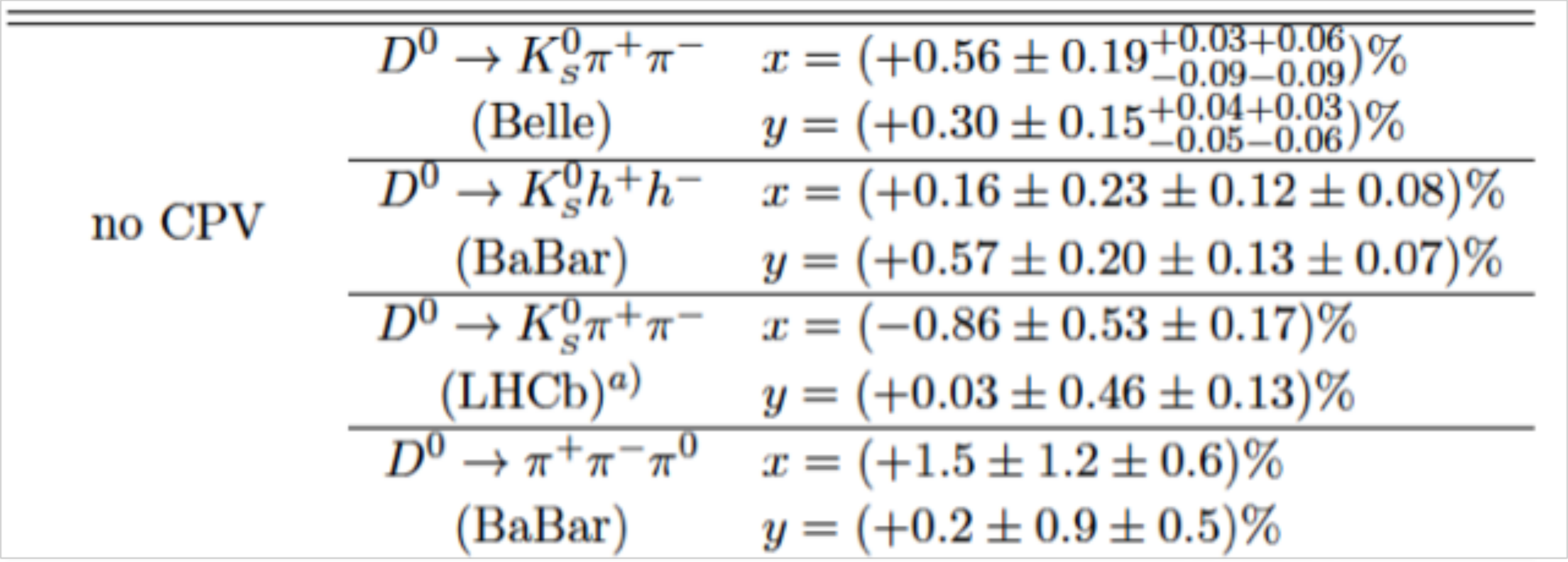
- SM: Long-distance dominated. Not calculated reliably
- NP: Short-distance dominated

Absorptive part of the amplitude Γ_{12}

- SM: Long-distance dominated. Not calculated reliably
- NP: Negligible

Mixing results





no CPV	$D^0 \to K^0_S\pi^+\pi^-$	$x = (+0.56 \pm 0.19^{+0.03+0.06}_{-0.09-0.09})\%$
	(Belle)	$y = (+0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.06})\%$
	$D^0 \to K^0_S h^+h^-$	$x = (+0.16 \pm 0.23 \pm 0.12 \pm 0.08)\%$
	(BaBar)	$y = (+0.57 \pm 0.20 \pm 0.13 \pm 0.07)\%$
	$D^0 \to K^0_S\pi^+\pi^-$	$x = (-0.86 \pm 0.53 \pm 0.17)\%$
	(LHCb)$^{a)}$	$y = (+0.03 \pm 0.46 \pm 0.13)\%$
	$D^0 \to \pi^+\pi^-\pi^0$	$x = (+1.5 \pm 1.2 \pm 0.6)\%$
	(BaBar)	$y = (+0.2 \pm 0.9 \pm 0.5)\%$

[B2TiP Report, to be published]

Charm mixing

Mass eigenstates D_1 and D_2 are linear combinations of flavour eigenstates D_0 and D_0 bar:

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle \quad , \quad \frac{q}{p} = \sqrt{\frac{M_{12}{}^* - \frac{i}{2}\Gamma_{12}{}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}} \quad , \quad \phi = \mathrm{Arg}(q/p)$$

- Mixing in neutral D mesons is an example of FCNC. Within SM, FCNC are absent at the tree level but can occur through box diagrams

- Strong suppression of FCNC is due to GIM mechanism

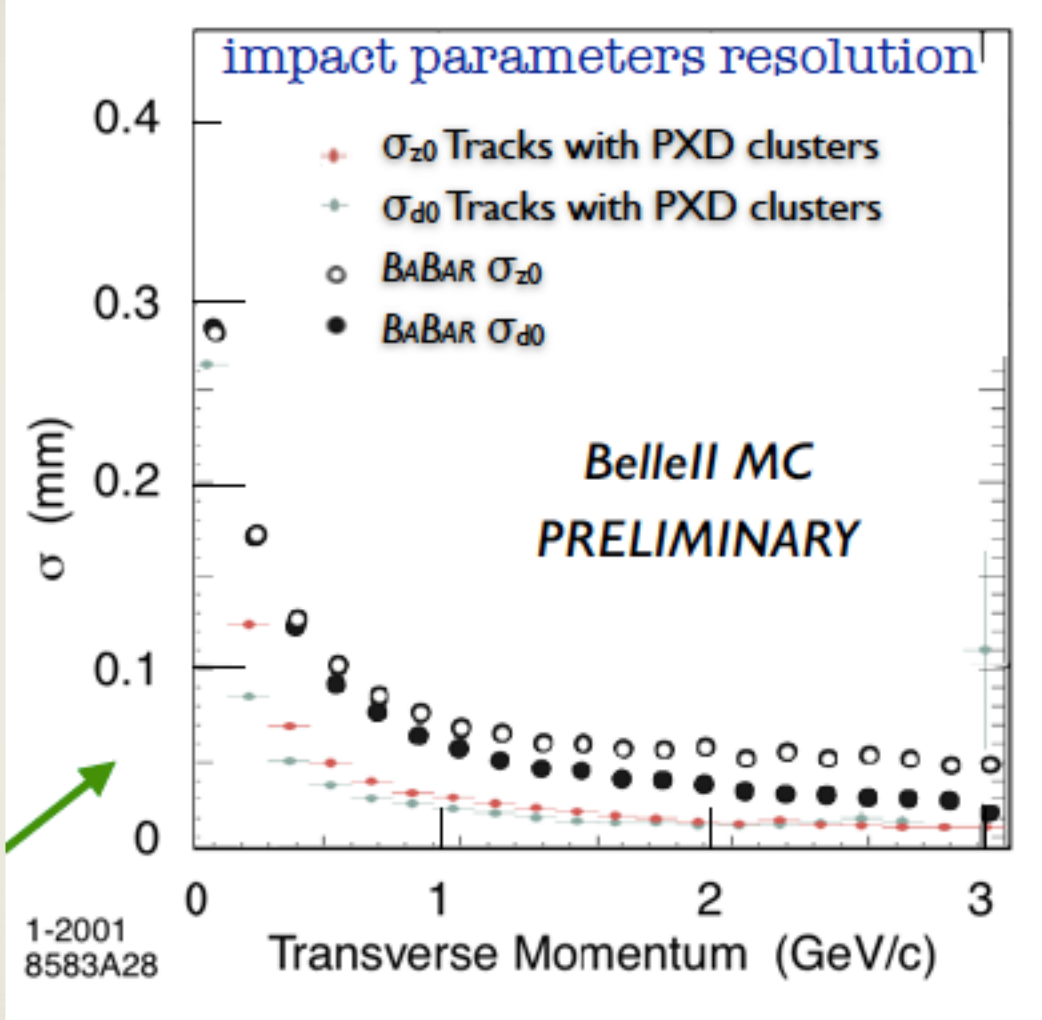
- Mixing rate in D mesons is small; discovered in 1976 at SLAC, in 2007 at KEK, SLAC with mixing parameters x ~ 0.01 and y ~ 0.01

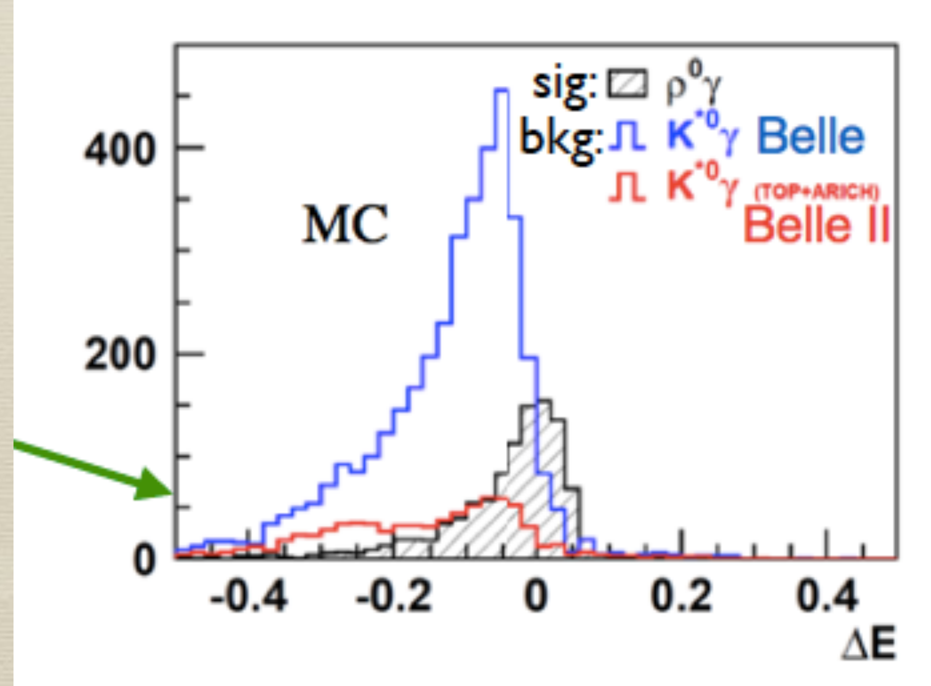
$$\boxed{x = \frac{m_1 - m_2}{\Gamma} \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma}} \qquad \text{with} \quad \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

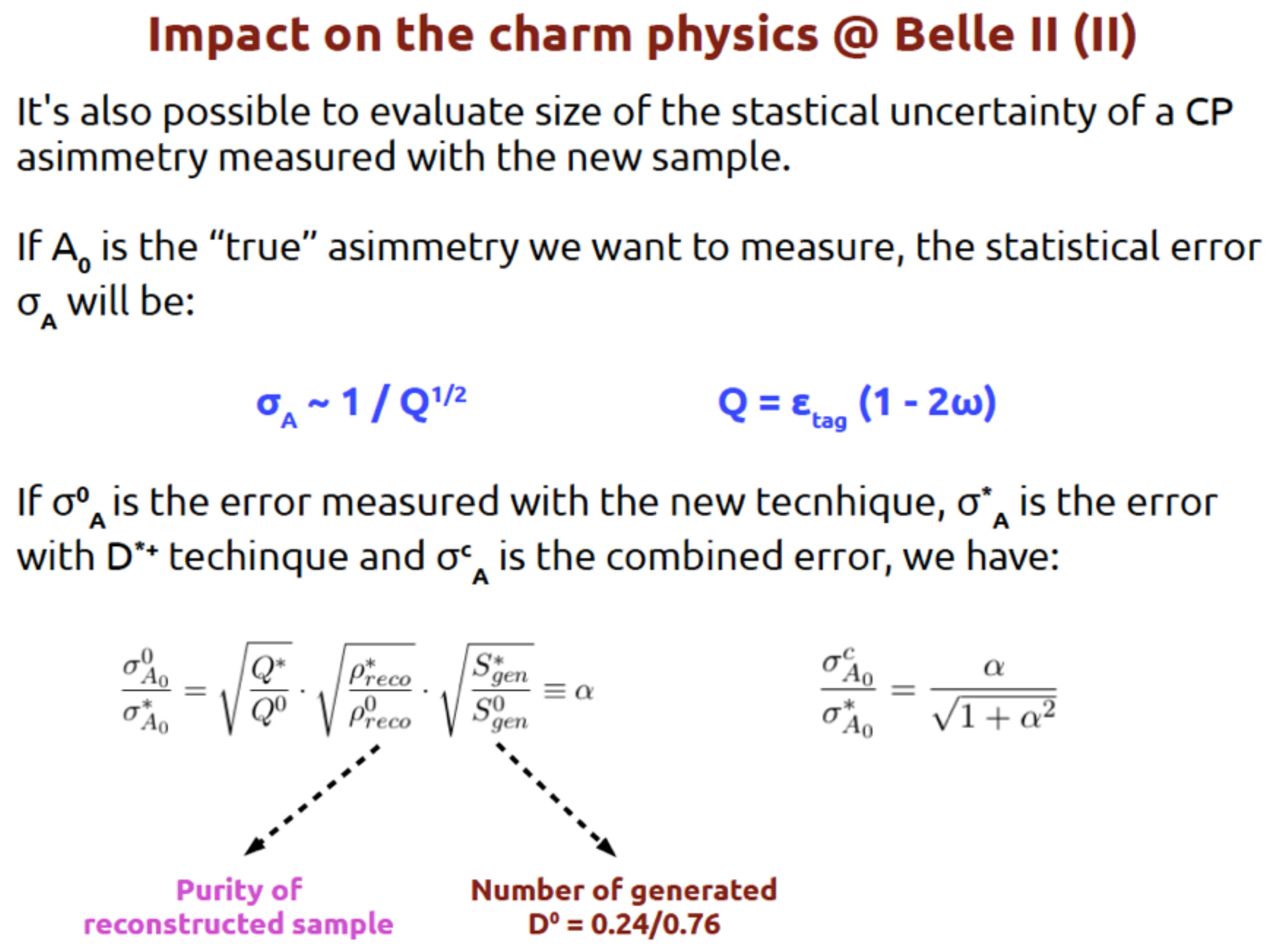
Belle II performance

IMPROVEMENTS wrt Belle

- IP and secondary vertex resolution
- K_S and π^0 reconstruction
- K/π separation
- PID and μ ID in the end caps







Impact on the charm physics @ Belle II (II)

It's also possible to evaluate size of the stastical uncertainty of a CP asimmetry measured with the new sample.

If A_0 is the “true” asimmetry we want to measure, the statistical error σ_A will be:

$$\sigma_A \sim 1 / Q^{1/2} \qquad Q = \varepsilon_{tag} (1 - 2\omega)$$

If σ^0_A is the error measured with the new tecnhique, σ^*_A is the error with D^{*+} techinque and σ^c_A is the combined error, we have:

$$\frac{\sigma^0_{A_0}}{\sigma^*_{A_0}} = \sqrt{\frac{Q^*}{Q^0}} \cdot \sqrt{\frac{\rho^*_{reco}}{\rho^0_{reco}}} \cdot \sqrt{\frac{S^*_{gen}}{S^0_{gen}}} \equiv \alpha \qquad \frac{\sigma^c_{A_0}}{\sigma^*_{A_0}} = \frac{\alpha}{\sqrt{1+\alpha^2}}$$

Purity of reconstructed sample

Number of generated D^0 = 0.24/0.76

[Slide from Giacomo De Pietro]