Belle II input for γ
+
[considerations on global γ combinations]

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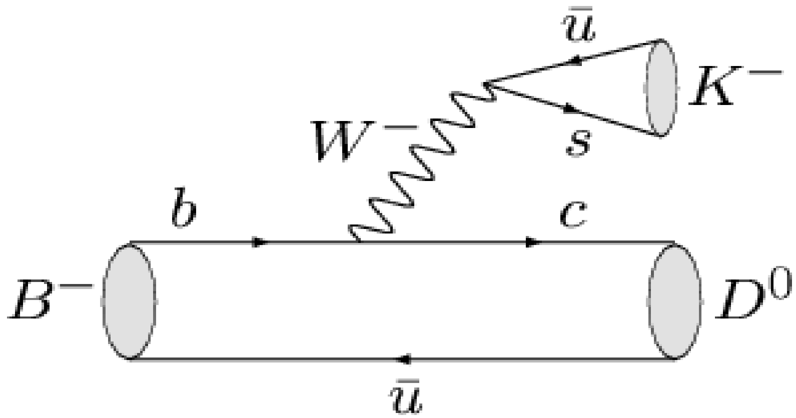
Outline

- Quick estimation of Belle II sensitivity for γ with $B \to DK$, $D \to K_S \pi^+ \pi^-$ as golden mode
- Potential improvements

Towards the Ultimate Precision in Flavour Physics

γ measurements from $B^{\pm} \rightarrow DK^{\pm}$

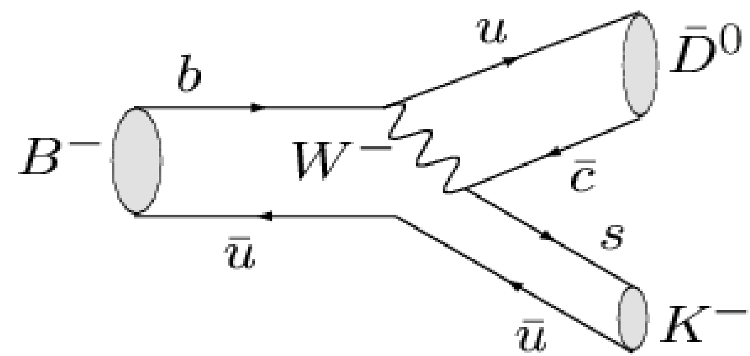
- Theoretically pristine $B \rightarrow DK$ approach
- Access γ via interference between $B^{-} \rightarrow D^{0} K^{-}$ and $B^{-} \rightarrow \overline{D}^{0} K^{-}$



color allowed

$B^{-} \rightarrow D^{0} K^{-} \sim V_{cb} V_{us}^{*}$

$\sim A\lambda^{3}$



color suppressed

$B^{-} \rightarrow \overline{D}^{0} K^{-} \sim V_{ub} V_{cs}^{*}$

$\sim A\lambda^{3}(\rho + i\eta)$

relative magnitude of suppressed amplitude is r_B

$$r_B = \frac{|A_{suppressed}|}{|A_{favoured}|} \sim \frac{|V_{ub} V_{cs}^{*}|}{|V_{cb} V_{us}^{*}|} \times [\text{color supp}] = 0.1 - 0.2$$

relative weak phase is γ, relative strong phase is δ_B

γ measurements from $B^{\pm} \to DK^{\pm}$

- Reconstruct D in final states accessible to both D^0 and $\overline{D}^0$
  - $D = D_{CP}$, CP eigenstates as K^+K^-, $\pi^+\pi^-$, $K_S\pi^0$

    GLW method (Gronau-London-Wyler)
  - $D = D_{sup}$, Doubly-Cabbibo suppressed decays as $K\pi$

    ADS method (Atwood-Dunietz-Soni)
  - Three-body decays as $D \to K_S\pi^+\pi^-$, $K_S K^+ K^-$

    GGSZ (Dalitz) method (Giri-Grossman-Soffer-Zupan)

- Largest effects due to
  - charm mixing
  - charm CP violation

  } negligible

  Y.Grossman, A.Soffer, J.Zupan [PRD 72, 031501 (2005)]

- Different B decays (DK, D^*K, DK^*)
  - different hadronic factors (r_B, δ_B) for each

γ measurements from $B^{\pm} \to DK^{\pm}$

$B^{\pm} \to D K^{\pm}$

$B^{\pm} \to D^{*} K^{\pm}$, $D^{*} \to D \pi^{0}$

$B^{\pm} \to D^{*} K^{\pm}$, $D^{*} \to D \gamma$

$B^{\pm} \to D K^{*\pm}$

$B^{0} \to D K^{*0}$

$B^{\pm} \to D K \pi \pi$

$B \to \ldots$

$D \to K^{+} K^{-}$, $\pi^{+} \pi^{-} \ldots$

$D \to K_{S} \pi^{0}$, $K_{S} \eta \ldots$

$D \to K K \pi^{0}$, $\pi \pi \pi^{0} \ldots$

$D \to K_{S} \pi \pi$, $K_{S} K K$

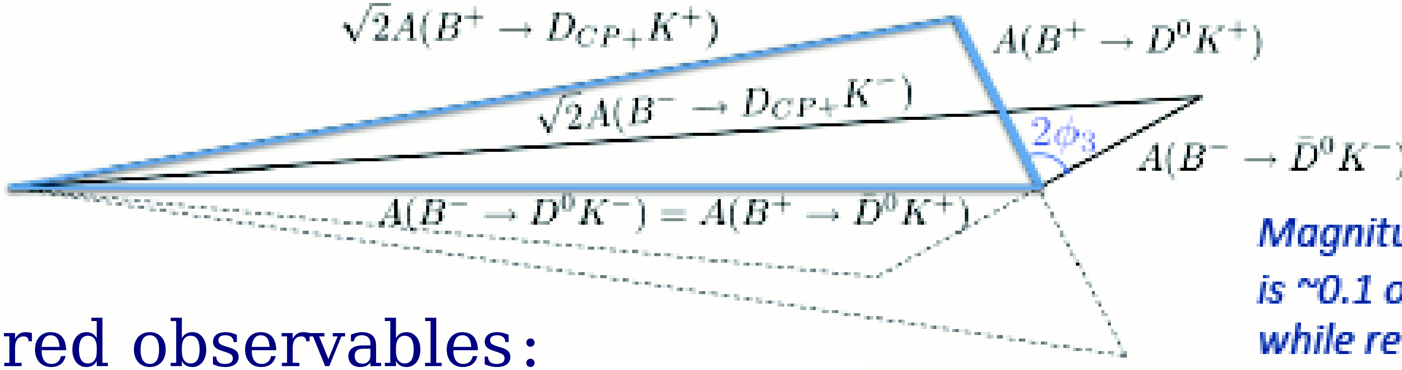
$D \to K_{S} \pi \pi \pi^{0}$

$D \to \ldots$

GLW with $D^{(*)}_{CP}K$

D decays to CP eigenstates

- Amplitude triangle:



Magnitude of one side is ~0.1 of the others while relative magnitude of the others help ϕ_3 constraint.

measured observables:

$$R_{CP\pm} \equiv \frac{Br(B^- \to D_{CP\pm}K^-) + Br(B^+ \to D_{CP\pm}K^+)}{Br(B^- \to D^0 K^-) + Br(B^+ \to \bar{D}^0K^+)}$$

$$A_{CP\pm} \equiv \frac{Br(B^- \to D_{CP\pm}K^-) - Br(B^+ \to D_{CP\pm}K^+)}{Br(B^- \to D_{CP\pm}K^-) + Br(B^+ \to D_{CP\pm}K^+)}$$

Relation between $(R_{CP+}, R_{CP-}, A_{CP+}, A_{CP-})$ and (γ, r_B, δ_B)

$$R_{CP+} = 1 + r_B{}^2 + 2r_B \cos\delta_B \cos\gamma \qquad R_{CP-} = 1 + r_B{}^2 - 2r_B \cos\delta_B \cos\gamma$$

$$A_{CP+} = \frac{+2r_B \sin\delta_B \sin\gamma}{1 + r_B{}^2 + 2r_B \cos\delta_B \cos\gamma} \qquad A_{CP-} = \frac{-2r_B \sin\delta_B \sin\gamma}{1 + r_B{}^2 - 2r_B \cos\delta_B \cos\gamma}$$

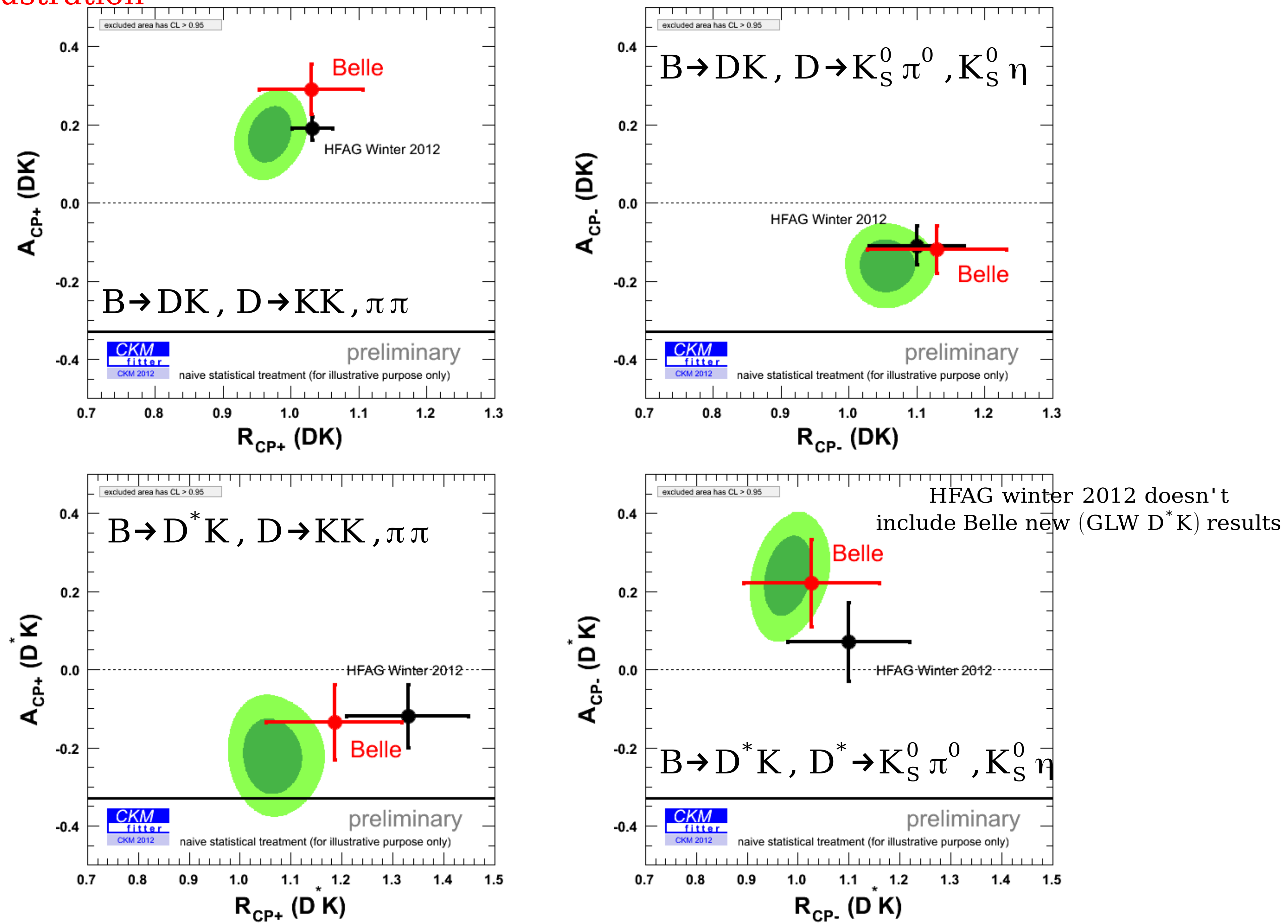
$\Rightarrow$ look for $R_{CP\pm} \neq 1$ and $A_{CP\pm} \neq 0$

$\Rightarrow$ $\neq$ CP, $\neq$ sign of asymmetry

Comparison of the results obtained for GLW $D^{(*)}K$ with expectations

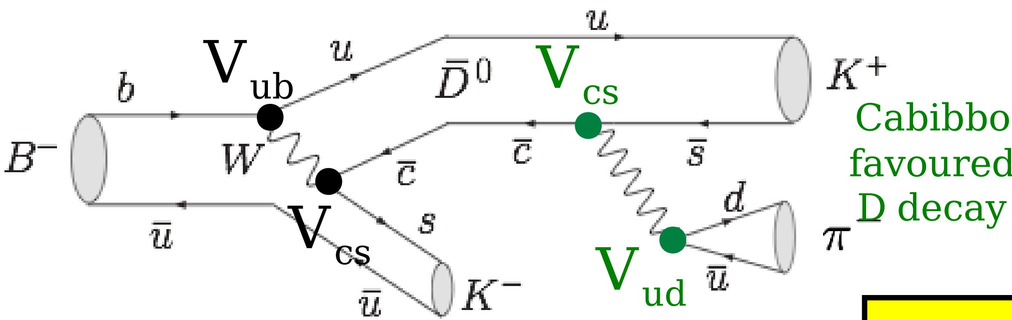
where ''expectations'' are derived from the GGSZ observables (W.A.), δ_D and γ_{UT}

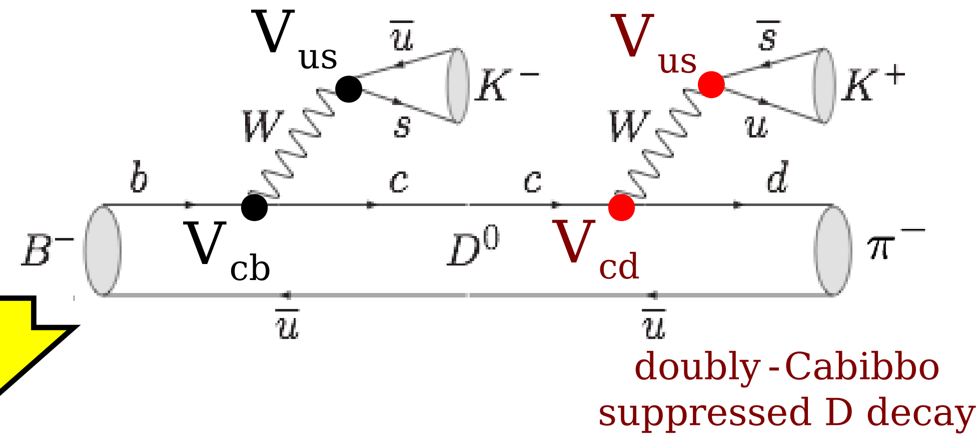
for illustration



ADS method: γ via the interference in rare $B^- \to [K^+\pi^-]_D K^-$ decays

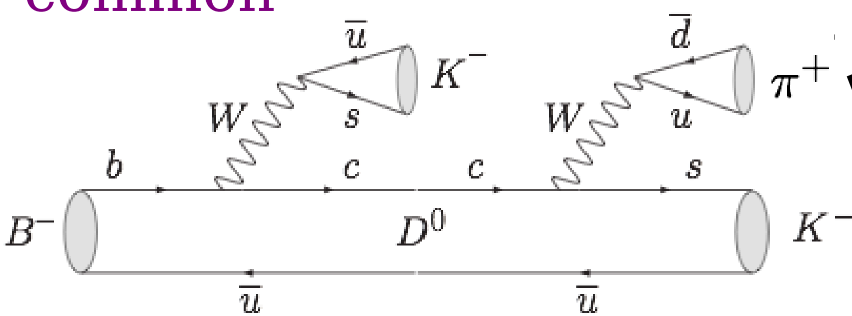
rate and asymmetry (relative to the common decay):





$$\mathcal{R}_{DK} = \frac{\Gamma([K^+\pi^-]K^-) + \Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-) + \Gamma([K^+\pi^-]K^+)}$$

common



$$= r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma$$

$$\mathcal{A}_{DK} = \frac{\Gamma([K^+\pi^-]K^-) - \Gamma([K^-\pi^+]K^+)}{\Gamma([K^-\pi^+]K^-) + \Gamma([K^+\pi^-]K^+)}$$

$$= 2 r_B r_D \sin(\delta_B + \delta_D) \sin\gamma \ / \mathcal{R}_{DK}$$

where $r_D = \left| \frac{\mathcal{A}(D^0 \to K^+\pi^-)}{\mathcal{A}(\bar{D}^0 \to K^+\pi^-)} \right| = 0.0613 \pm 0.0010$

How to get δ_D and related (charm) hadronic parameters ?

- dedicated experiments (CLEO-c, BES III) using quantum correlations, running at $\psi(3770)$
  - CLEO-c: R_D, $\cos\delta_D$, $\sin\delta_D$ (but also BES III result...)
  - CLEO-c: $R_{K\pi\pi^0}$, $\delta_{K\pi\pi^0}$, $R_{K3\pi}$, $\delta_{K3\pi}$

R_f: coherence factor, can take any value from 0 to 1
indicates lack coherence between the intermediate states involved in the decay

- mixing/CPV results from BaBar, Belle, CDF, LHCb...
  - $D\to KK,\ \pi\pi$: y_{CP}, A_Γ (BaBar, Belle, LHCb)
  - $D\to K^0_S\pi\pi$: x, y, $|q/p|$, ϕ (BaBar, Belle)
  - $D\to K l \nu$: R_M (BaBar, Belle...)
  - $D\to K\pi\pi^0$: x'', y'' (BaBar)
  - $D\to K\pi$: x', y' (BaBar, Belle, CDF, LHCb)
  - ...

- **CLEO-c/BES III, use external inputs to access the relevant physics parameters**
- **strong phases information in B-factories/LHCb**
- **x, y are also needed for D-mixing corrections in ADS observables**

$$R^{\mp} = r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B \mp \gamma + \delta_D)$$

$$\rightarrow R^{\mp} = r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B \mp \gamma + \delta_D) - y\, r_D \cos\delta_D - y\, r_B \cos(\delta_B \mp \gamma) + x\, r_D \sin\delta_D - x\, r_B \sin(\delta_B \mp \gamma)$$

⇒ combine charm observables to obtain γ and mixing/CPV charm parameters

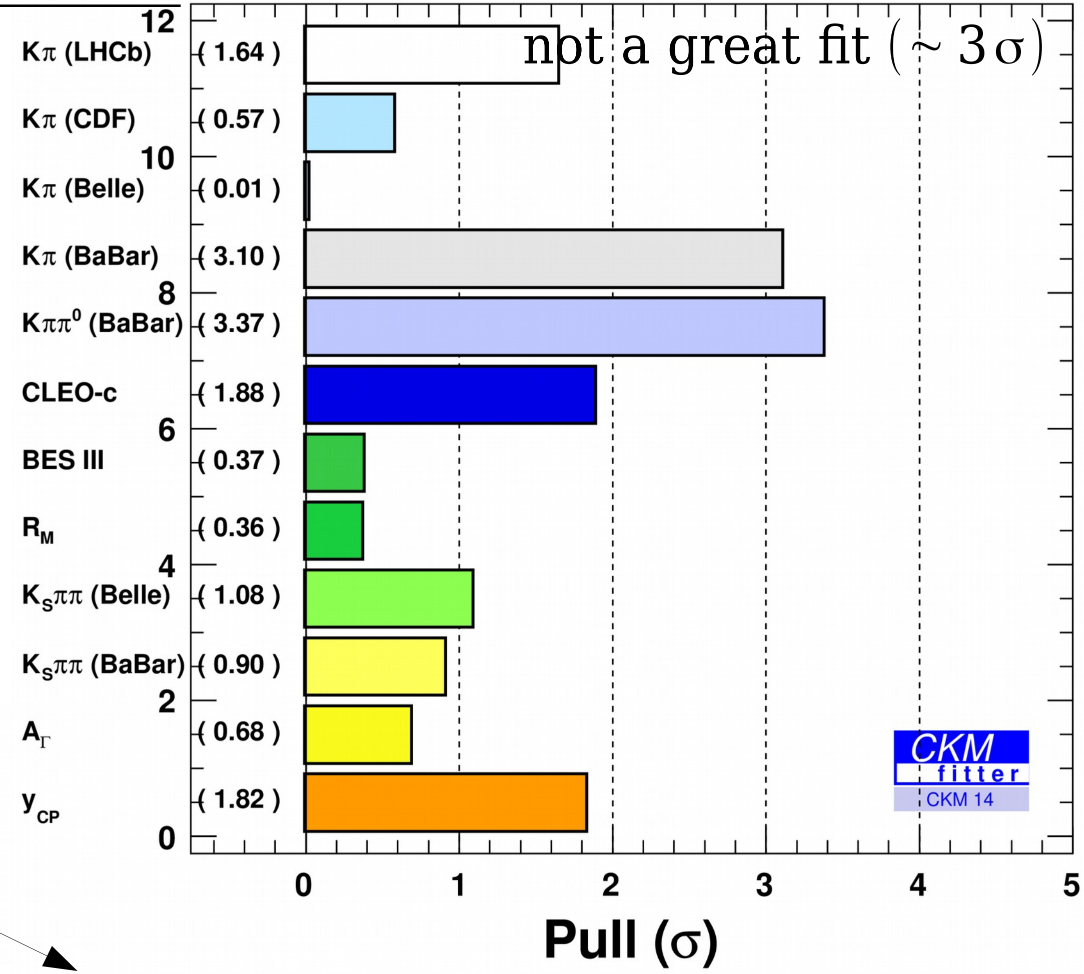
δ_D grand combination à la HFAG

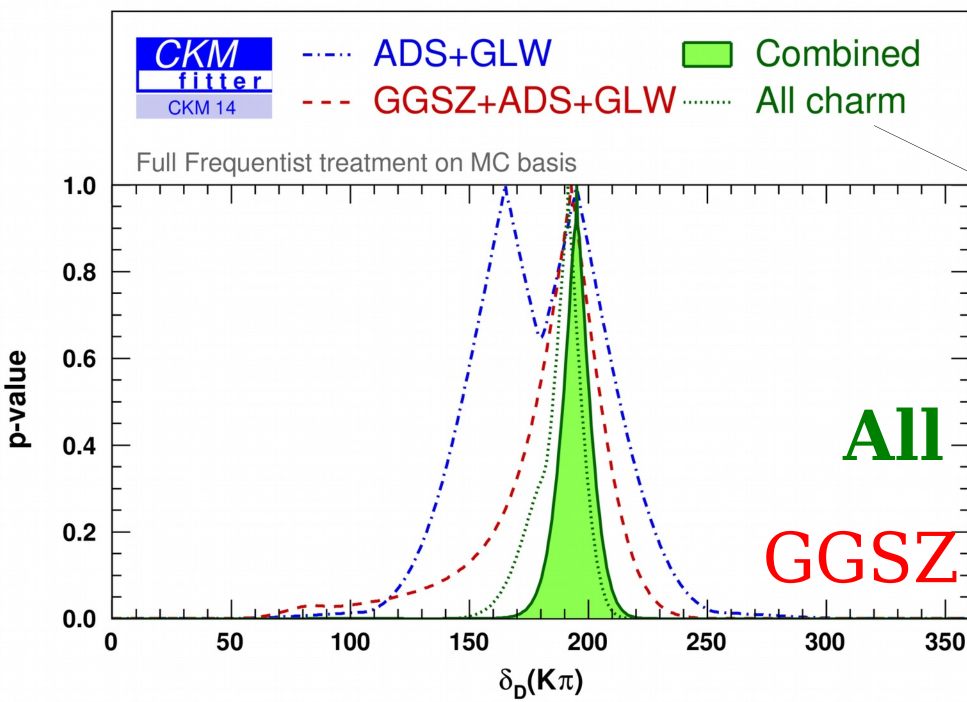
~ 35 observables

not a great fit (~ 3σ)

8 parameters:

$x,\ y,\ \delta_D^{K\pi},\ r_D,\ A_D,\ |q|/|p|,\ \phi,\ \delta_D(K\rho)$





(include $K3\pi$, $K\pi\pi^0$ info, see next slides)

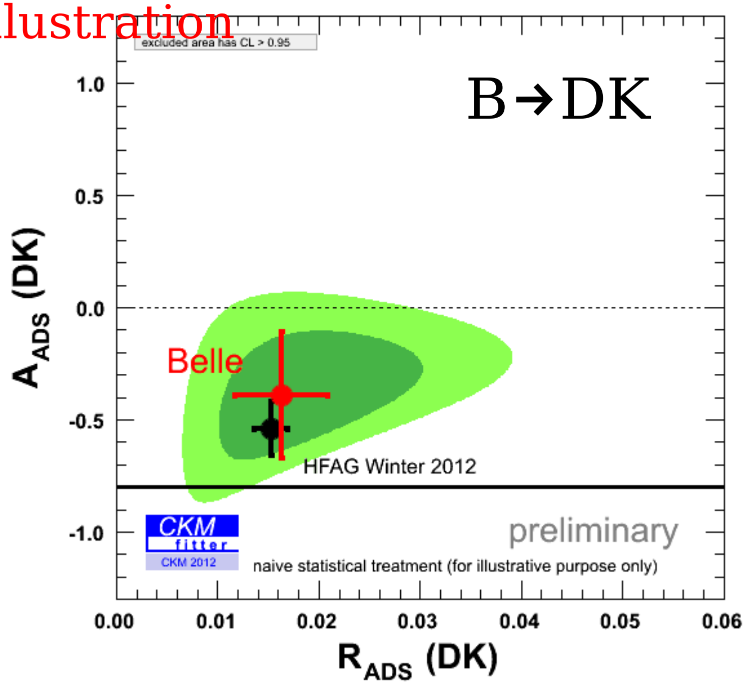
All charm: $\delta_D^{K\pi} = (191.4^{+8.2}_{-11.4})^\circ \ \ (^{+16}_{-30})$

GGSZ+GLW+ADS: $\delta_D^{K\pi} = (193^{+18}_{-23})^\circ \ \ (^{+34}_{-77})$

Comparison of the results obtained for $D^{(*)}K$ with expectations

where ''expectations'' are derived from the GGSZ observables, δ_D and γ_{UT}

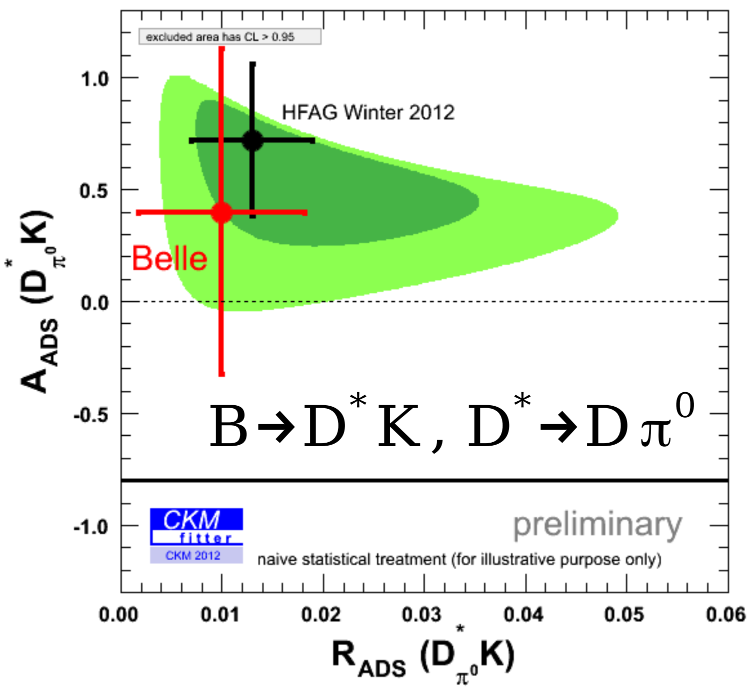
for illustration

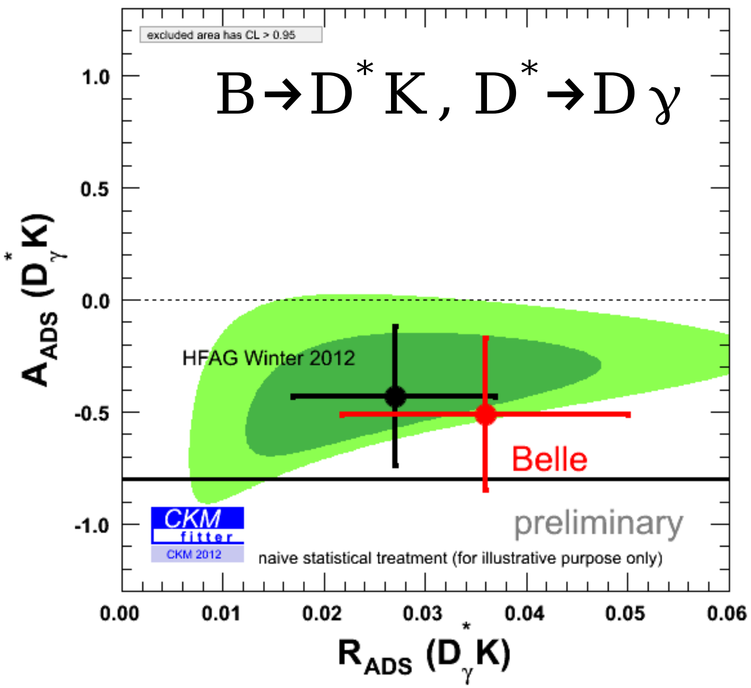


$$R_{ADS}(DK) = r_B^{\,2} + r_D^2 + 2\, r_B r_D \cos(\delta_B + \delta_D) \cos\gamma$$
$$A_{ADS}(DK) = 2\, r_B r_D \sin(\delta_B + \delta_D) \sin\gamma / R_{ADS}(DK)$$

$$R_{ADS}(D^*_{\pi^0}K) = r_B^{*\,2} + r_D^2 + 2\, r^*_B r_D \cos(\delta^*_B + \delta_D) \cos\gamma$$
$$A_{ADS}(D^*_{\pi^0}K) = 2\, r^*_B r_D \sin(\delta^*_B + \delta_D) \sin\gamma / R_{ADS}(D^*_{\pi^0}K)$$

$$R_{ADS}(D^*_{\gamma}K) = r_B^{*\,2} + r_D^2 - 2\, r^*_B r_D \cos(\delta^*_B + \delta_D) \cos\gamma$$
$$A_{ADS}(D^*_{\gamma}K) = -2\, r^*_B r_D \sin(\delta^*_B + \delta_D) \sin\gamma / R_{ADS}(D^*_{\gamma}K)$$

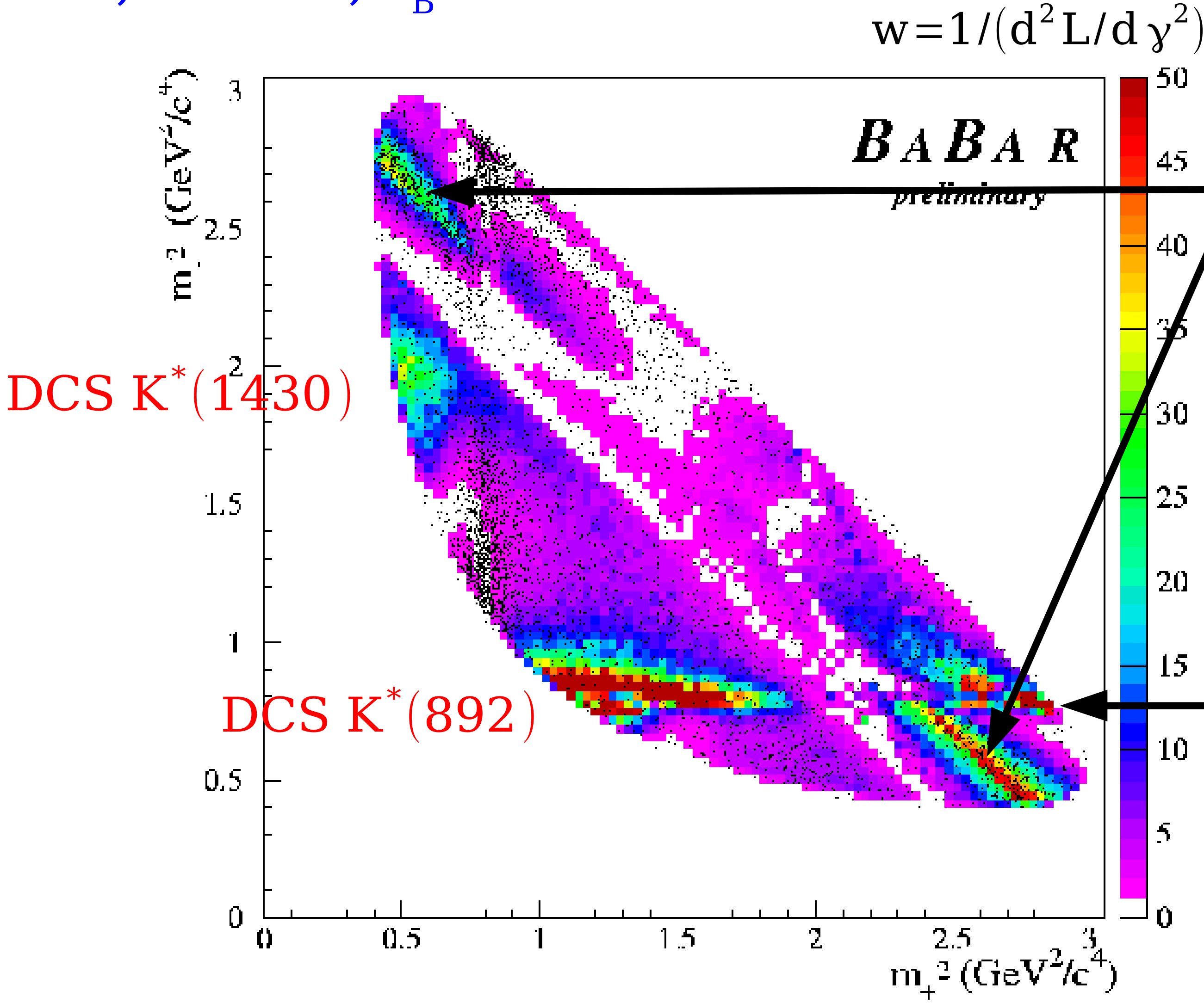




Sensitivity to γ in $B \to D(K_S\pi\pi)K$ mode

sensitivity to γ/ϕ_3 varies across the Dalitz plot

$\gamma=75^\circ$, $\delta=180^\circ$, $r_B=0.125$



GLW like

Interference of

$B^- \to D^0 K^-$, $D^0 \to K_S^0 \rho^0$

with

$B^- \to \overline{D}^0 K^-$, $\overline{D}^0 \to K_S^0 \rho^0$

ADS like

Interference of

$B^- \to D^0 K^-$, $D^0 \to K^{*+} \pi^-$

with

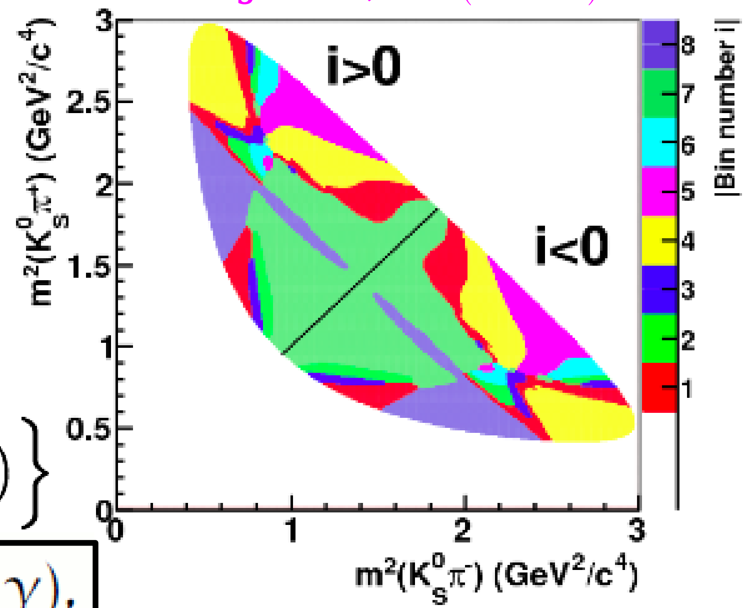
$B^- \to \overline{D}^0 K^-$, $\overline{D}^0 \to K^{*+} \pi^-$

- golden mode !! even more for Belle II than for LHCb
- focusing our efforts/resources on this mode

Binned Dalitz method: avoid the modeling error by ''optimal'' binning of the Dalitz plot

[choice of bins guided by model, but extraction of γ is not biased by this choice]

Bondar and Poluektov EPJ C 55, 51 (2008)



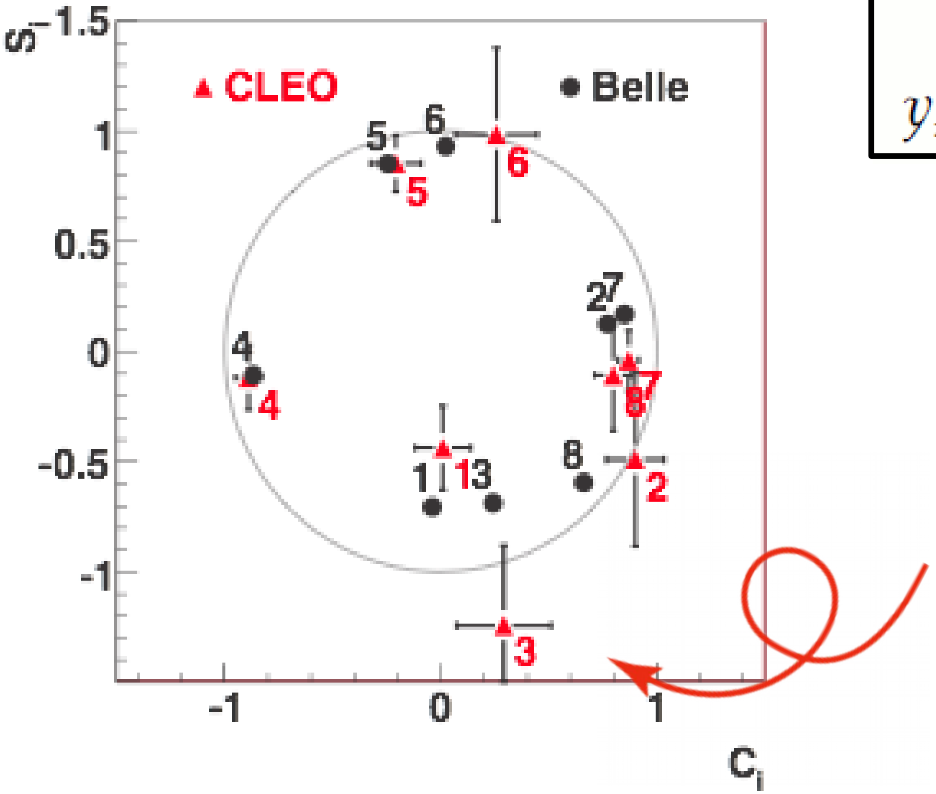
minimize χ^2 in fit to all bins for each mode

Expected number of $B^\pm \to DK^\pm$ events in bin *i* is:

$$N_i^\pm = h\left\{K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_\pm c_i + y_\pm s_i)\right\}$$

$$x_\pm \equiv r_B \cos(\delta_B \pm \gamma),$$

$$y_\pm \equiv r_B \sin(\delta_B \pm \gamma).$$

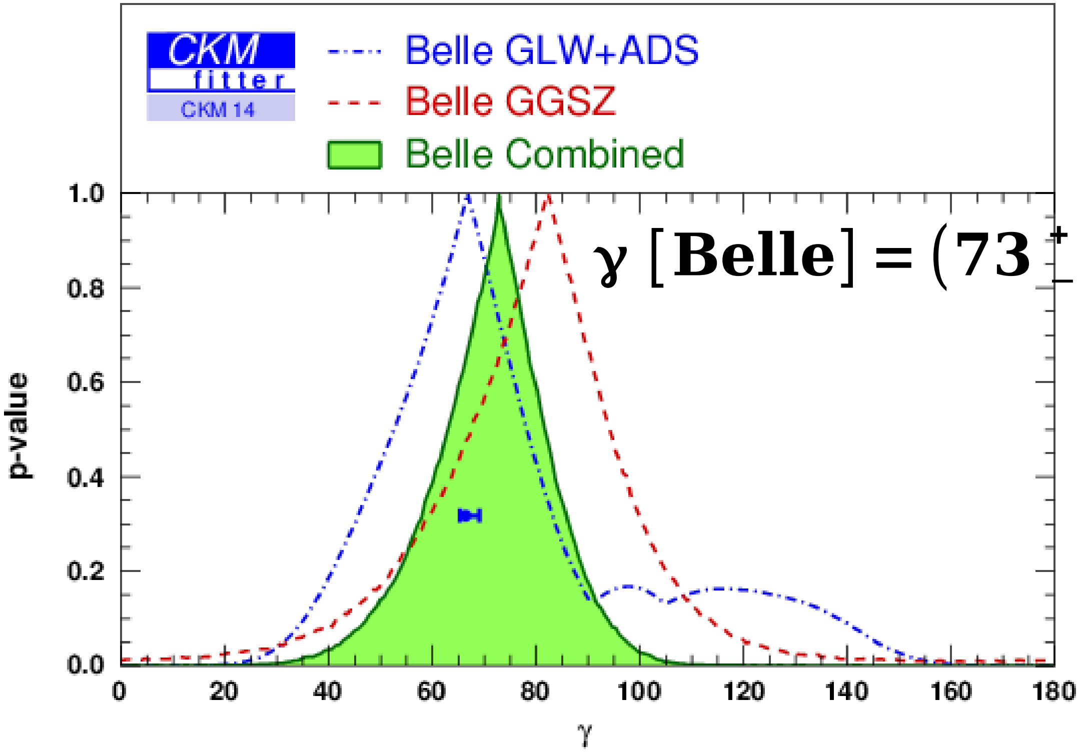


K_i is the # of events in bin *i* from a flavour-tagged sample ($D^{*\pm} \to D\pi^\pm$)

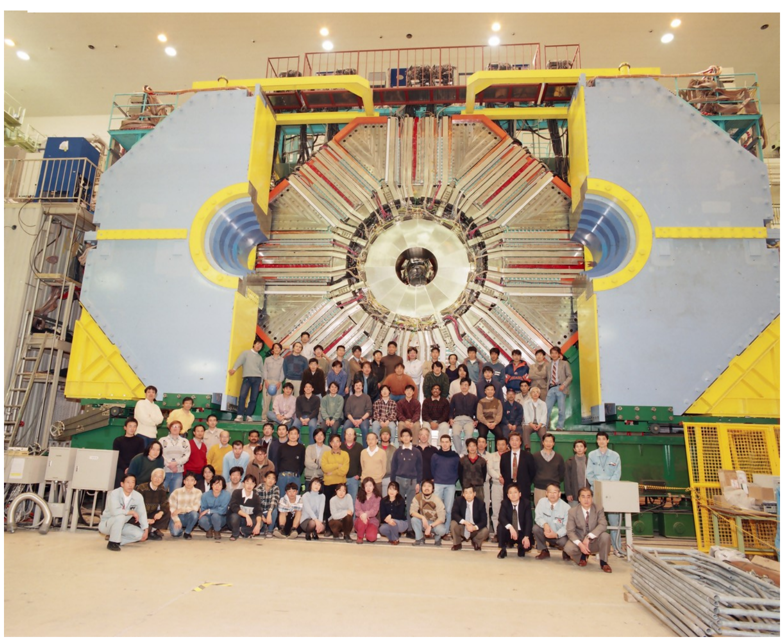
c_i and s_i contain information about the strong-phase difference in bin *i*

(use CLEO data for $\psi(3770) \to D^0\,\overline{D}^0$ here; measured by BES-III too)

Combining measurements for γ from all methods



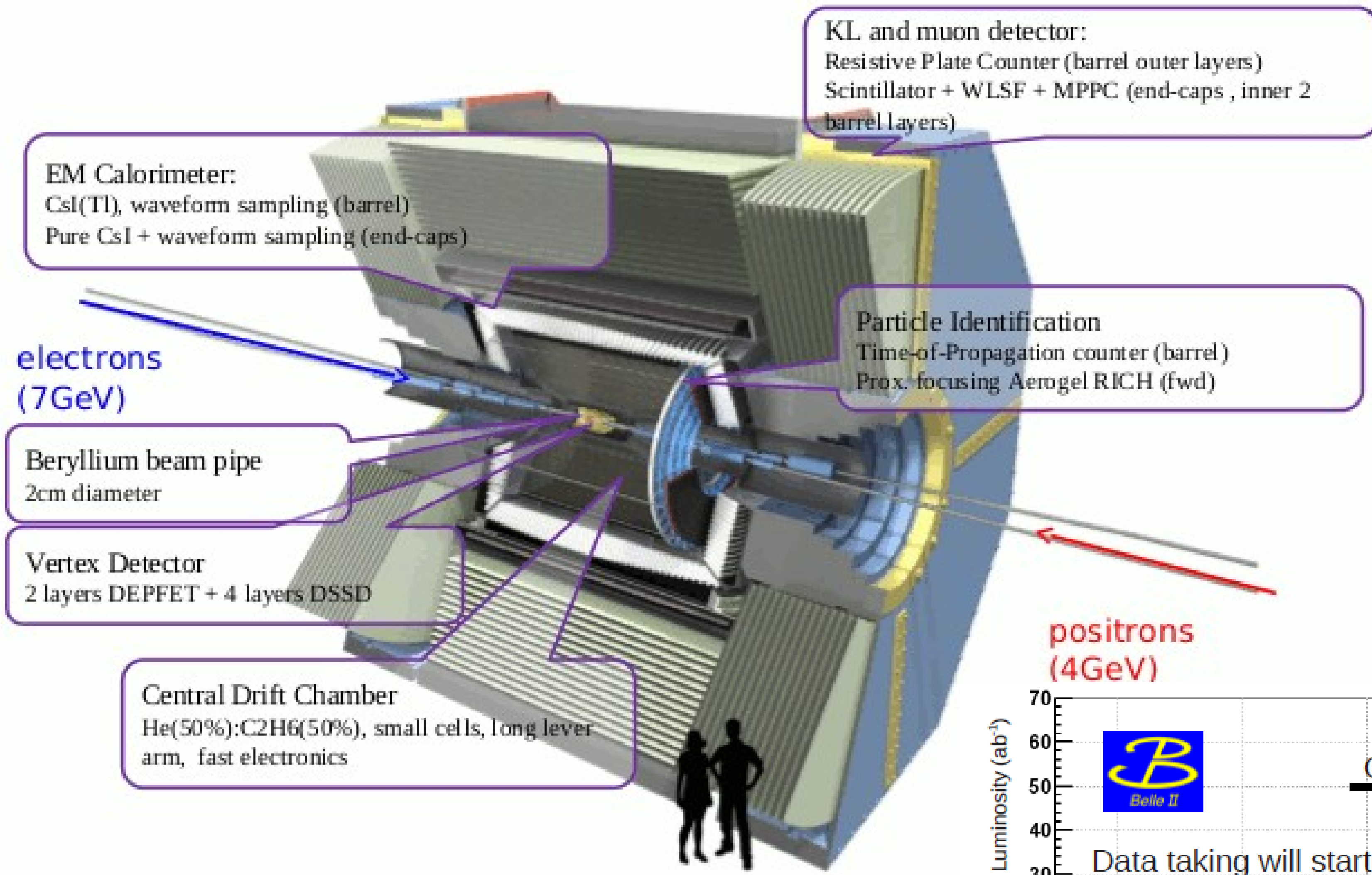
$$\gamma\,[\mathrm{Belle}] = \left(73\,^{+13}_{-15}\right)^{\circ}$$

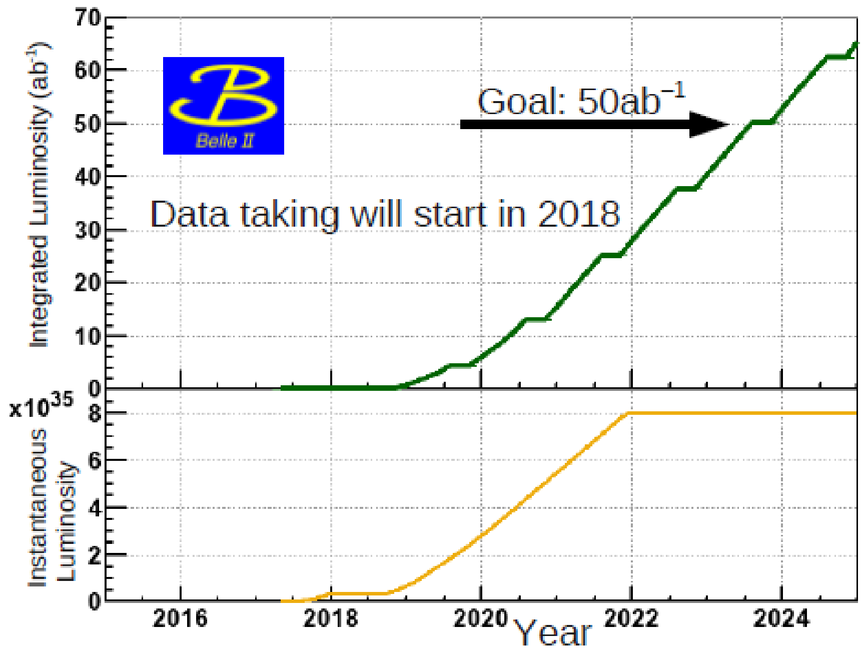


From Belle to Belle II

BELLE → Belle II

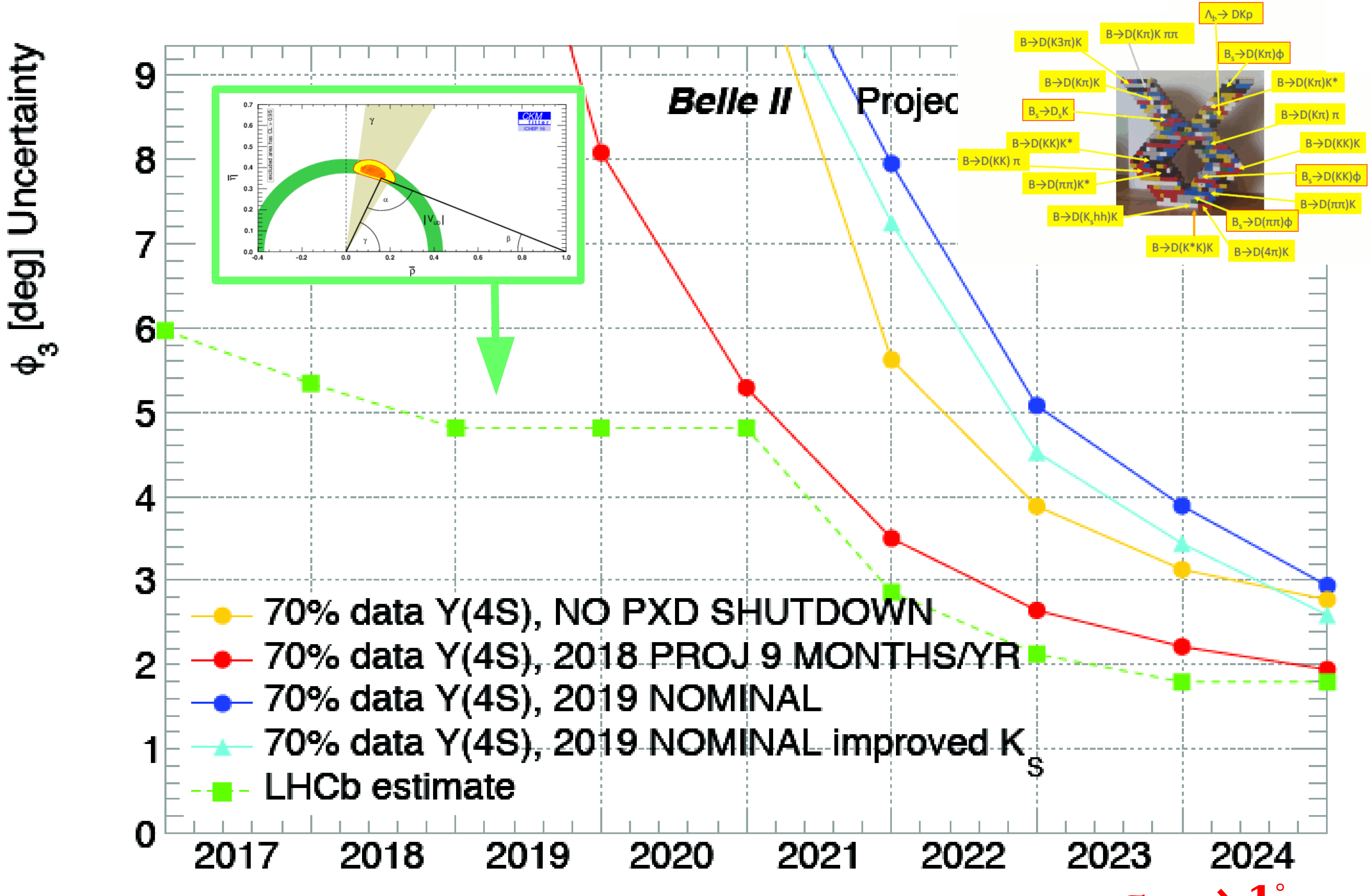
Belle II: an improved detector to record 100 × larger sample





Ultimate γ-from-tree decays

precision will be reached through many individual measurements



$\sigma_{exp} \rightarrow 1^{\circ}$

$(\sigma_{theory}$ **negligible**$)$

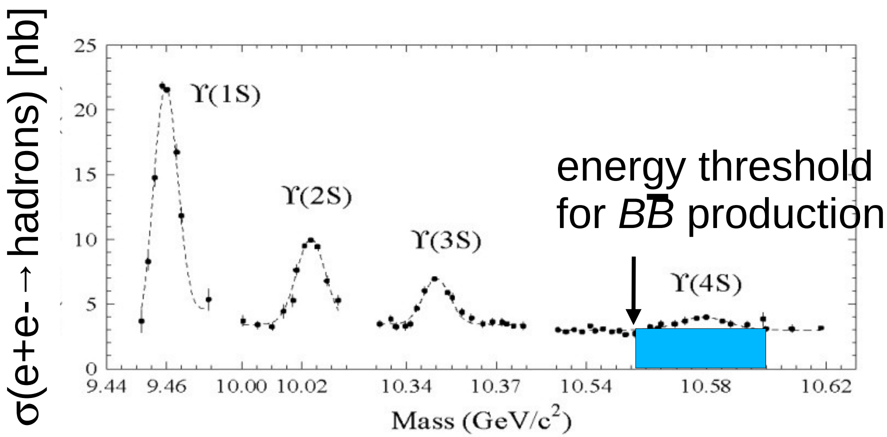
Potential improvements Belle II vs Belle

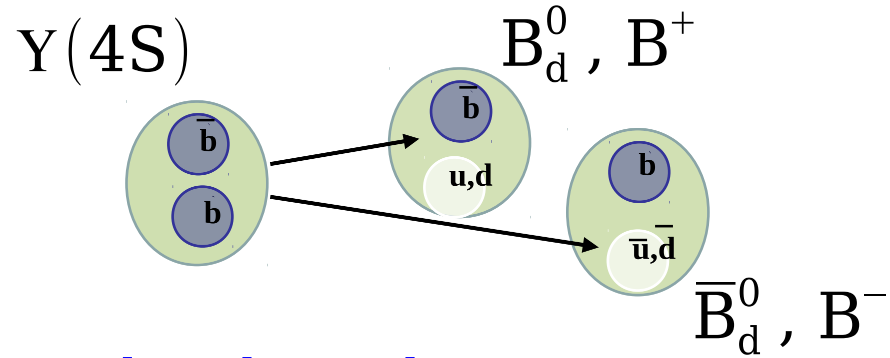
(beyond only statistics)

- continuum suppression
- PID performances
- new possible avenues...

$\Upsilon(4S)$ B-factory

but also continuum factory ....





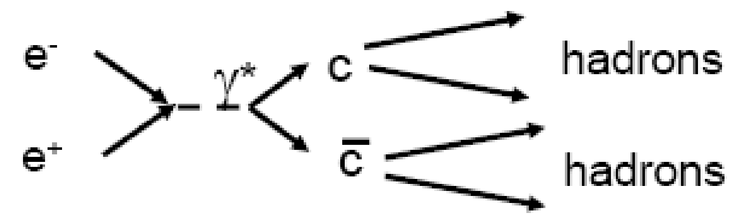
- 2 B's and nothing else !
- 2 B mesons are created simultaneously in a L=1 coherent state

$\Rightarrow$ before first decay, the final states contains a B and a $\overline{\text{B}}$

- **''on resonance'' production**

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B_d^0\overline{B}_d^0,\ B^+B^-$$

$$\sigma(e^+e^- \rightarrow B\overline{B}) \simeq 1.1\ \text{nb}\ (\sim 10^9\ B\overline{B}\ \text{pairs})$$

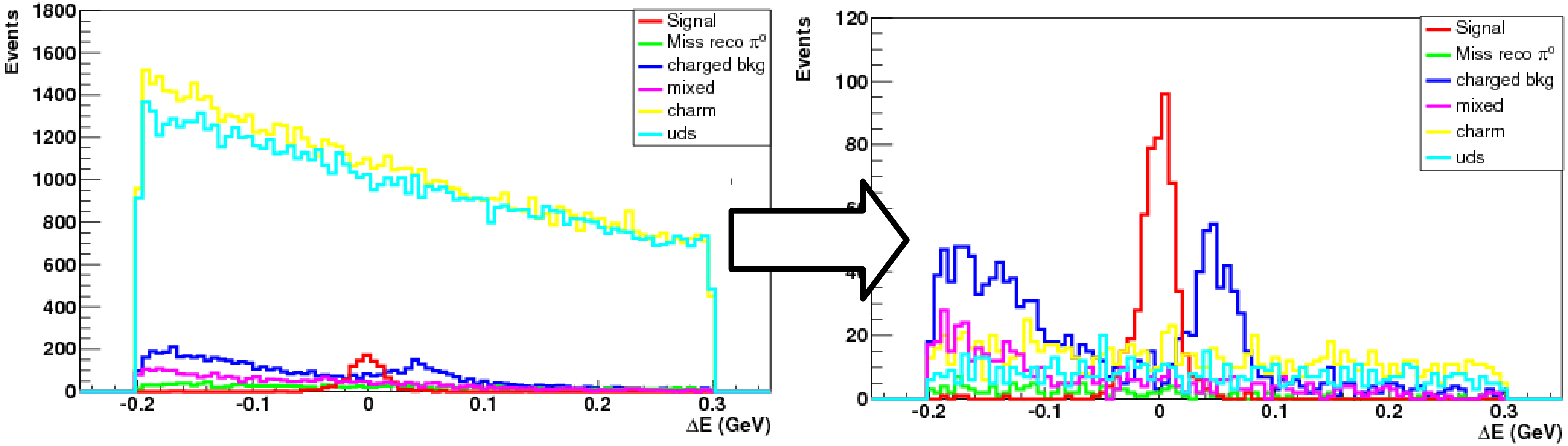


- **''continuum'' production $(q\overline{q} = u\overline{u},\ d\overline{d},\ s\overline{s},\ c\overline{c})$**

$$\sigma(e^+e^- \rightarrow c\overline{c}) = 1.3\ \text{nb}$$
$$\sigma(e^+e^- \rightarrow s\overline{s}) = 0.4\ \text{nb}$$
$$\sigma(e^+e^- \rightarrow u\overline{u}) = 1.6\ \text{nb}$$
$$\sigma(e^+e^- \rightarrow d\overline{d}) = 0.4\ \text{nb}$$

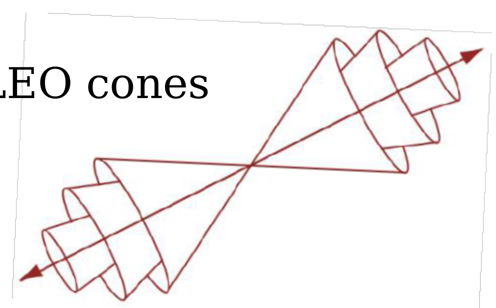
$B \to [K_S \pi^+ \pi^-]_D K^\pm$ Dalitz Analysis with Belle II

illustration MC for Belle $B \to D(K_S \pi \pi \pi^0)K$ analysis

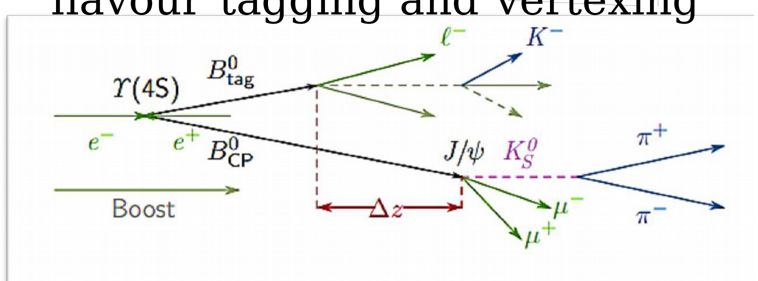


efficiency loss = 33 %
background rejection = 97 %

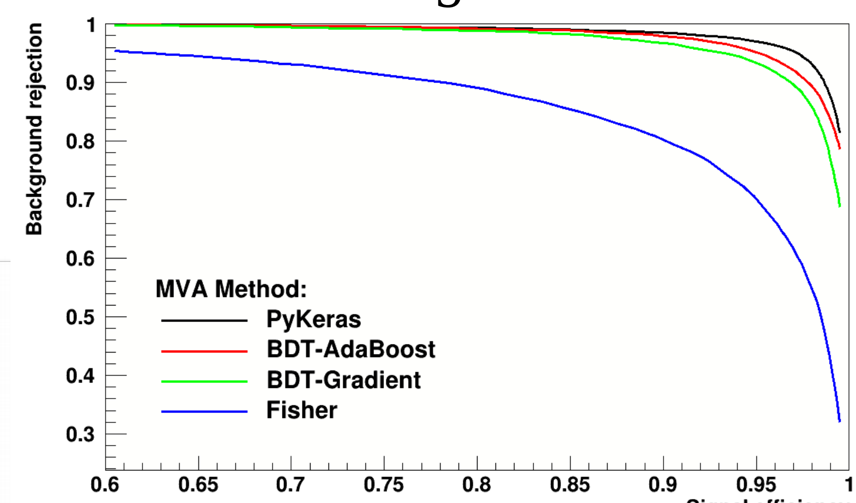
using NB



flavour tagging and vertexing

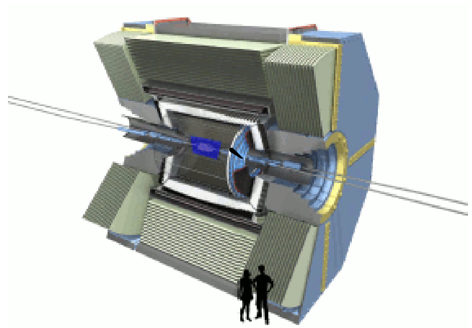


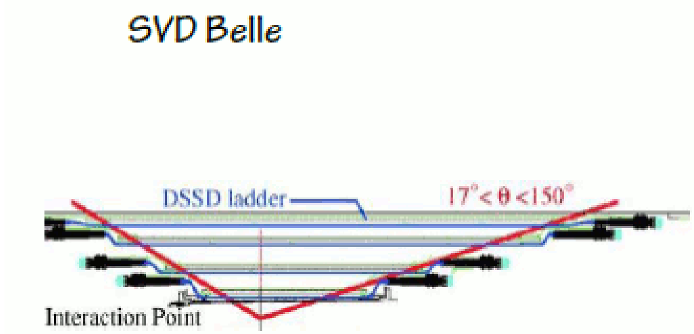
combined using DNN ...

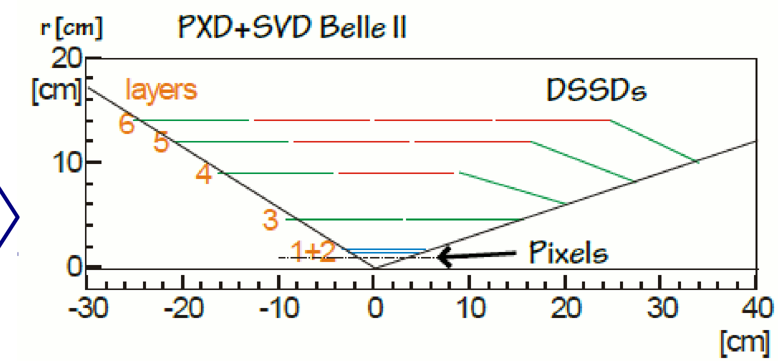


Belle II in few words

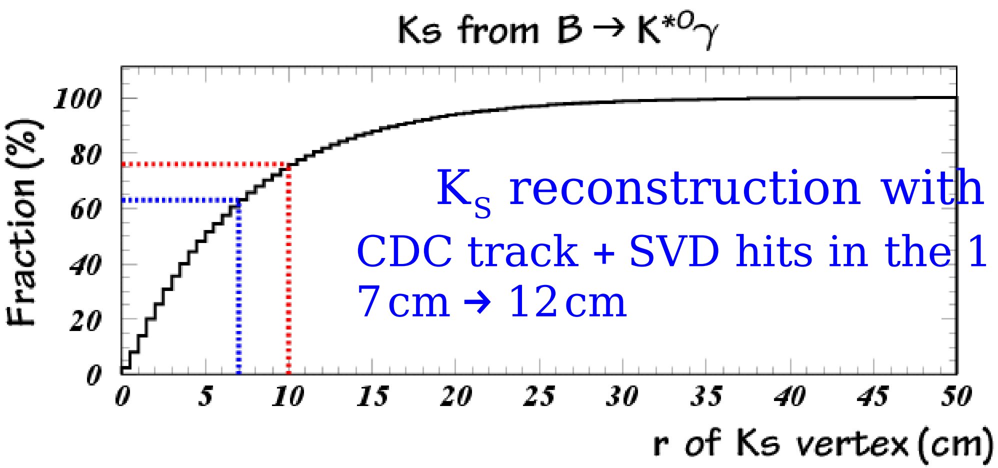
- collecting $50\,ab^{-1}$ from 2019 to 2027





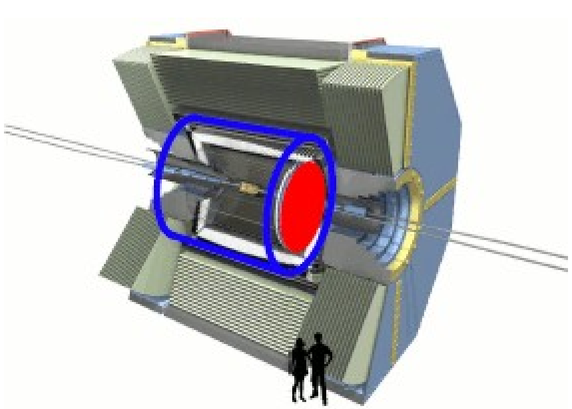


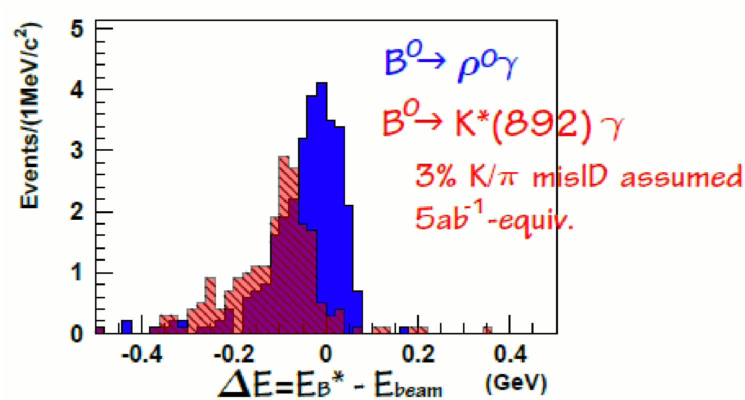
4 DSSD layers → 2 pixel layers + 4 DSSD layers
larger radius outermost layer (8.8 cm → 14 cm)

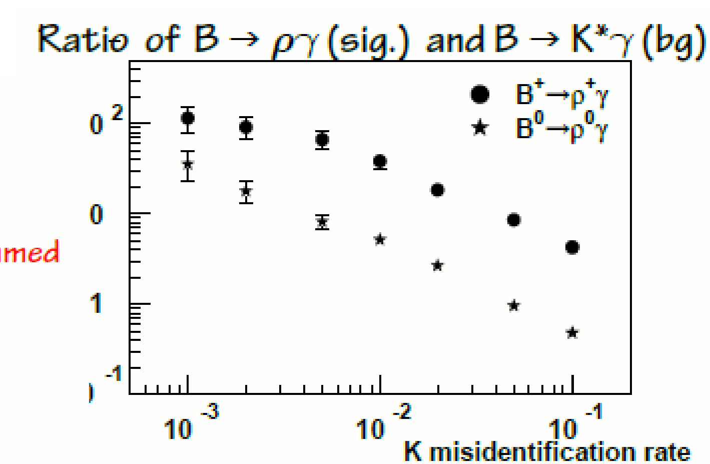


K_S reconstruction with PXD/SVD: $K^{*0}\gamma$ TCPV

CDC track + SVD hits in the 1st and 2nd outermost layers
7 cm → 12 cm







⇒ new detectors (CDC, TOP, ARICH) in place (see P. Urquijo's talk)

B→DK$^{\pm}$ at Belle II

illustration with Belle B→D(Kπ)K analysis

KID<0.6 (pion-like)

$$N^{DK}_{\eta,\,KID>0.6} = \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\, R_{K/\pi}\, \epsilon$$

$$N^{DK}_{\eta,\,KID<0.6} = \frac{1}{2}\left(1-\eta A^{DK}\right) N^{D\pi}_{tot}\, R_{K/\pi}\, (1-\epsilon)$$

$$N^{D\pi}_{\eta,KID>0.6} = \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\, \kappa$$

$$N^{D\pi}_{\eta,KID<0.6} = \frac{1}{2}\left(1-\eta A^{D\pi}\right) N^{D\pi}_{tot}\, (1-\kappa)$$

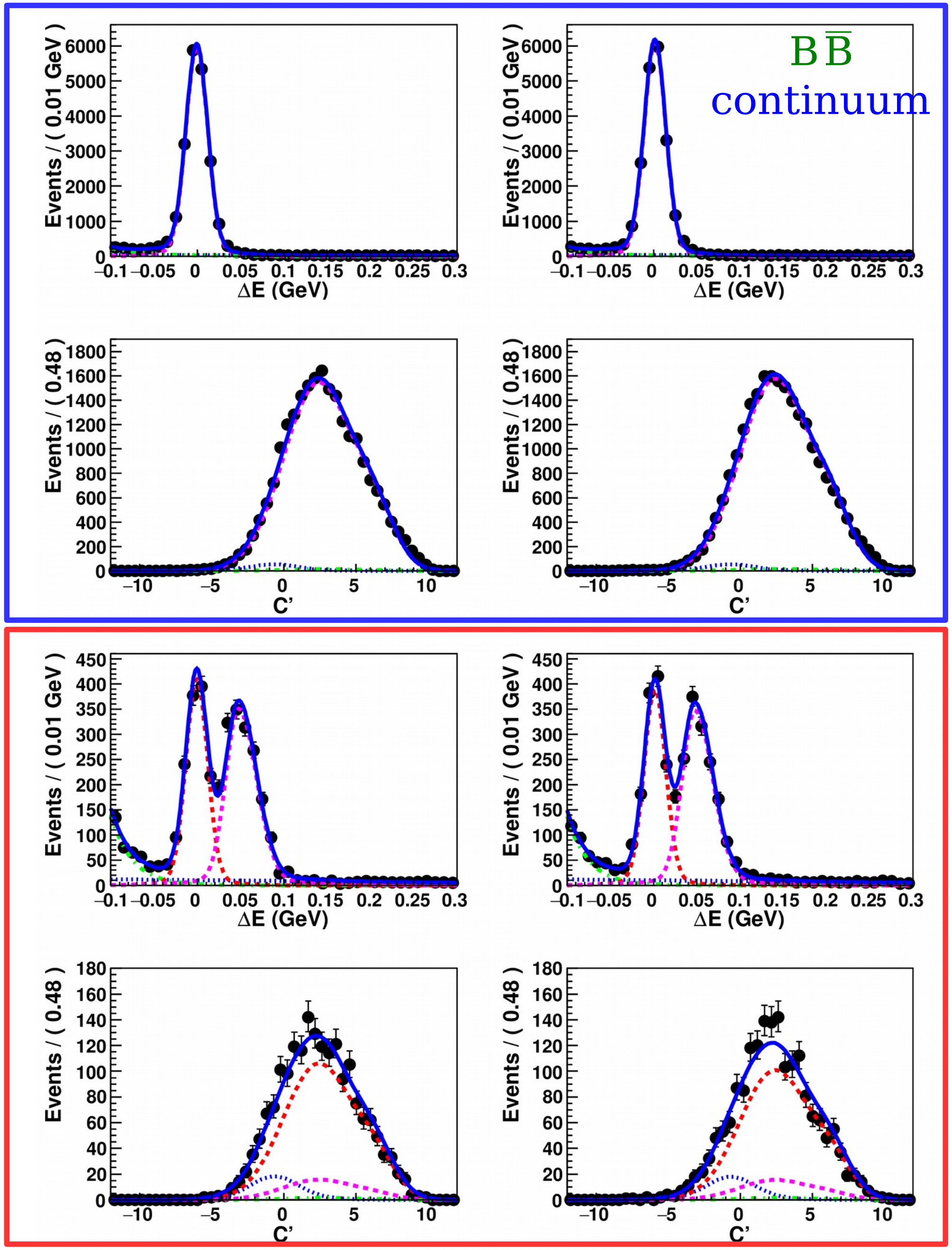
KID>0.6 (kaon-like)

	kaon fake $(1-\epsilon)$	kaon eff ϵ	pion eff $(1-\kappa)$	pion fake κ
MC	14.70 ± 0.06	85.41 ± 0.06	95.42 ± 0.03	4.47 ± 0.03
data	15.86 ± 0.40	84.32 ± 0.39	92.13 ± 0.46	7.94 ± 0.31

⇐

for Belle

B → Dπ
B → DK



for Belle II: performances expected
to be as good (better ?) as for Belle MC...
one of the important outputs of current data taking (jury is still out)

Lot of interesting modes...

not used until now

D mode	$2F_+-1$	branching ratio ($\times 10^{-3}$)
K^+K^-	+1	3.96 ± 0.08
$\pi^+\pi^-$	+1	1.40 ± 0.03
$\pi^0\pi^0$	+1	0.82 ± 0.04
$K^0_L\pi^0$	+1	10.0 ± 0.7
$K^0_S\pi^0\pi^0$	+1	9.1 ± 1.1
$K^0_S\eta\pi^0$	+1	5.5 ± 1.1
$K^0_SK^0_SK^0_S$	+1	0.91 ± 0.13
$\pi\pi\pi^0$		14.3 ± 0.6
$KK\pi^0$		3.3 ± 0.1
$\pi\pi\pi\pi$		7.4 ± 0.2

D mode	$2F_+-1$	branching ratio ($\times 10^{-3}$)
$K^0_S\pi^0$	−1	11.9 ± 0.4
$K^0_S\eta$	−1	4.8 ± 0.3
$K^0_S\eta'$	−1	9.4 ± 0.5
$K^0_SK^0_SK^0_L$	−1	1.0
$\eta\pi^0\pi^0$	−1	unknown
$\eta'\pi^0\pi^0$	−1	unknown
$K^0_SK^0_S\pi^0$	−1	< 0.6
$K^0_SK^0_S\eta$	−1	unknown

D mode	branching ratio ($\times 10^{-3}$)
$K^0_S\pi^+\pi^-$	28.3 ± 2.0
$K^0_SK^+K^-$	4.6 ± 0.2
$K^0_L\pi^+\pi^-$	
$K^0_LK^+K^-$	
$K^0_S\pi^+\pi^-\pi^0$	52 ± 6
$\pi^+\pi^-\pi^0\pi^0$	10.0 ± 0.9

current study with Belle promising promising →

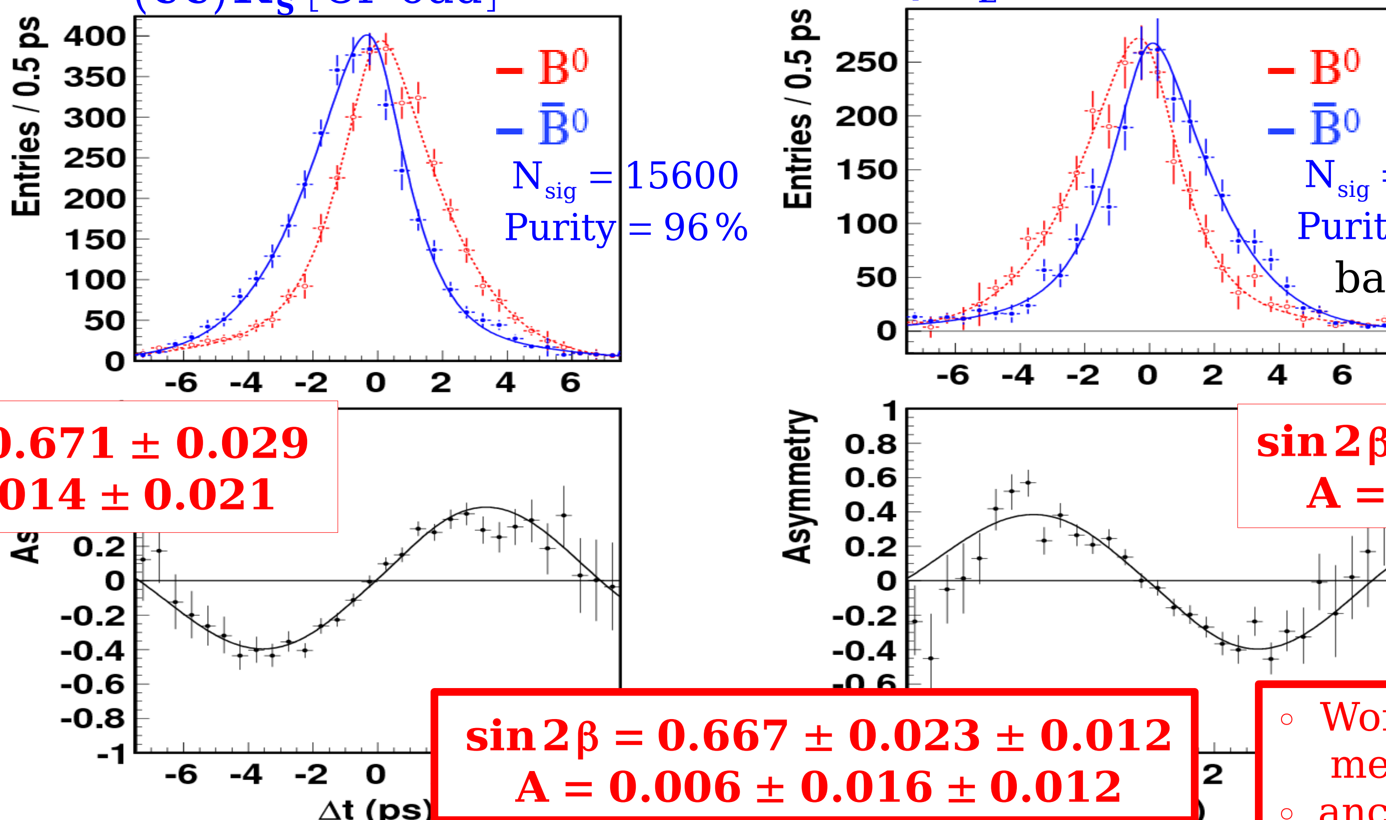
challenging modes with K_L, two π^0's...

$B \to D(K_L \pi\pi)K$

- $D \to K_L \pi\pi$ has never been explored in B-factories
- However, $J/\psi K_L$ has been used for $\sin 2\beta$ extraction
- with a reasonable efficiency/purity (and a significant impact)
- potential is even more promising in Belle II (upgraded KLM with scintillators)

''Precise Measurement of the CP Violation Parameter $\sin 2\beta$ in $B^0 \to (c\bar{c})K^0$ Decays''
[PRL 108 (2012) 171802]
772×10^6 $B\bar{B}$ pairs

$(c\bar{c})K_S$ [CP odd] $\qquad$ $J/\psi K_L$ [CP even]



$\sin 2\beta = 0.671 \pm 0.029$
$A = -0.014 \pm 0.021$

$\sin 2\beta = 0.642 \pm 0.047$
$A = 0.019 \pm 0.026$

$\sin 2\beta = 0.667 \pm 0.023 \pm 0.012$
$A = 0.006 \pm 0.016 \pm 0.012$

- World's most precise measurements
- anchor point of the SM
- still statistically limited !

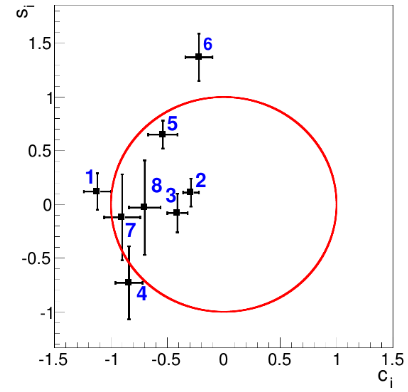
Estimates of γ sensitivity with $B^{\pm} \to D(K_S \pi\pi\pi\pi^0) K^{\pm}$

- The decay $D^0 \to K_S^0 \pi^+ \pi^- \pi^0$ has a relatively large branching fraction of 5.2%, almost twice that of $K_S^0 \pi^+ \pi^-$
- Interesting resonance substructure
  - $K_S^0 \omega$ – CP eigenstate GLW like
  - $K^{*+} \pi^- \pi^0$ – Cabibbo-favored state (CF) – ADS like
  - CLEO-c obtained $F_+ = 0.240 \pm 0.021$ (significantly CP-odd)

Bin number	Specification
1	$m(\pi^+\pi^-\pi^0) \approx m(\omega)$
2	$m(K_S^0\pi^-) \approx m(K^{*-})$ & $m(\pi^+\pi^0) \approx m(\rho^+)$
3	$m(K_S^0\pi^+) \approx m(K^{*+})$ & $m(\pi^-\pi^0) \approx m(\rho^-)$
4	$m(K_S^0\pi^-) \approx m(K^{*-})$
5	$m(K_S^0\pi^+) \approx m(K^{*+})$
6	$m(K_S^0\pi^0) \approx m(K^{*0})$
7	$m(\pi^+\pi^0) \approx m(\rho^+)$
8	Remainder

- $c_i < 0 \Rightarrow$ CP oddness of $K_S^0 \pi^+ \pi^- \pi^0$

Bin	c_i	s_i
1	-1.12 ± 0.12	0.12 ± 0.17
2	-0.29 ± 0.07	0.11 ± 0.13
3	-0.41 ± 0.09	-0.08 ± 0.18
4	-0.84 ± 0.12	-0.73 ± 0.34
5	-0.54 ± 0.13	0.65 ± 0.13
6	-0.22 ± 0.12	1.37 ± 0.22
7	-0.90 ± 0.16	-0.12 ± 0.40
8	-0.70 ± 0.14	-0.03 ± 0.44



- Project to a 50 ab^{-1} sample $\sigma_\gamma \sim 3.5^\circ$
- compare to $B^{\pm} \to D(K_S^0 \pi^+ \pi^-) K^{\pm}$ $\sigma_\gamma \sim 2^\circ$
- on-going Belle analysis should give us a more precise estimation soon

c_i and s_i at charm factory

at $\psi(3770)$, $J^{PC} = 1^{--}$, decays to a $D\overline{D}$ pair (decay are quantum related)
D mesons decay to final states f_a and f_b with CP eigenvalues η_a and η_b
CP conservation requires that $\eta_a \eta_b (-1)^L = 1$, hence $\eta_a / \eta_b = -1$
$\Rightarrow$ if one D meson is reconstructed in a CP even (odd) eigenstate, other D meson must be CP odd (even) eigenstate

measurements of c_i and s_i require that one of the D mesons decays to $K^0_S \pi^+ \pi^-$ final state and the other decays to final state X_D

if X_D is CP even (odd) eigenstate, D meson decaying to $K^0_S \pi^+ \pi^-$ must be CP-odd (even)
amplitude and partial width of $D_\pm$ at Dalitz plot coordinate (m^2_-, m^2_+):

$$A(D_\pm \to K^0_S h^+ h^-) = \frac{1}{\sqrt{2}} \left(A_D \pm \overline{A}_D \right),$$

$$\frac{d\Gamma(D_\pm \to K^0_S h^+ h^-)}{dm^2_- \, dm^2_+} = \frac{1}{2} \left(A^2_D + \overline{A}^2_D \right) \pm A_D \overline{A}_D \cos\delta_D.$$

decay rate to bin i of the $D_\pm$ Dalitz plot:

$$\Gamma_i(D_\pm \to K^0_S h^+ h^-) \propto \frac{1}{2}(T_i + T_{-i}) \pm \sqrt{T_i T_{-i}}\, c_i.$$

if X_D is $K^0_S \pi^+ \pi^-$:

$$\Gamma_{ij} \propto T_i T_{-j} + T_{-i} T_j - 2\sqrt{T_i T_{-i} T_j T_{-j}}(c_i c_j + s_i s_j).$$

arXiv:1010.2817, arXiv:0903.1681

c_i, s_i for $D \to K_S^0 \pi^+ \pi^-$

$$M_i^{\pm} = h_{CP\pm}(K_i \pm 2c_i\sqrt{K_i K_{-i}} + K_{-i}),$$

$$M_{ij} = h_{\rm corr}(K_i K_{-j} + K_{-i} K_j - 2\sqrt{K_i K_{-j} K_{-i} K_j}(c_i c_j + s_i s_j)).$$

c'_i, s'_i for $D \to K_L^0 \pi^+ \pi^-$

$$M_i'^{\pm} = h_{CP\pm}(K_i' \mp 2c_i'\sqrt{K_i' K_{-i}'} + K_{-i}'),$$

$$M_{ij}' = h_{corr}(K_i K_{-j}' + K_{-i} K_j' + 2\sqrt{K_i K_{-j}' K_{-i} K_j'}(c_i c_j' + s_i s_j'))$$

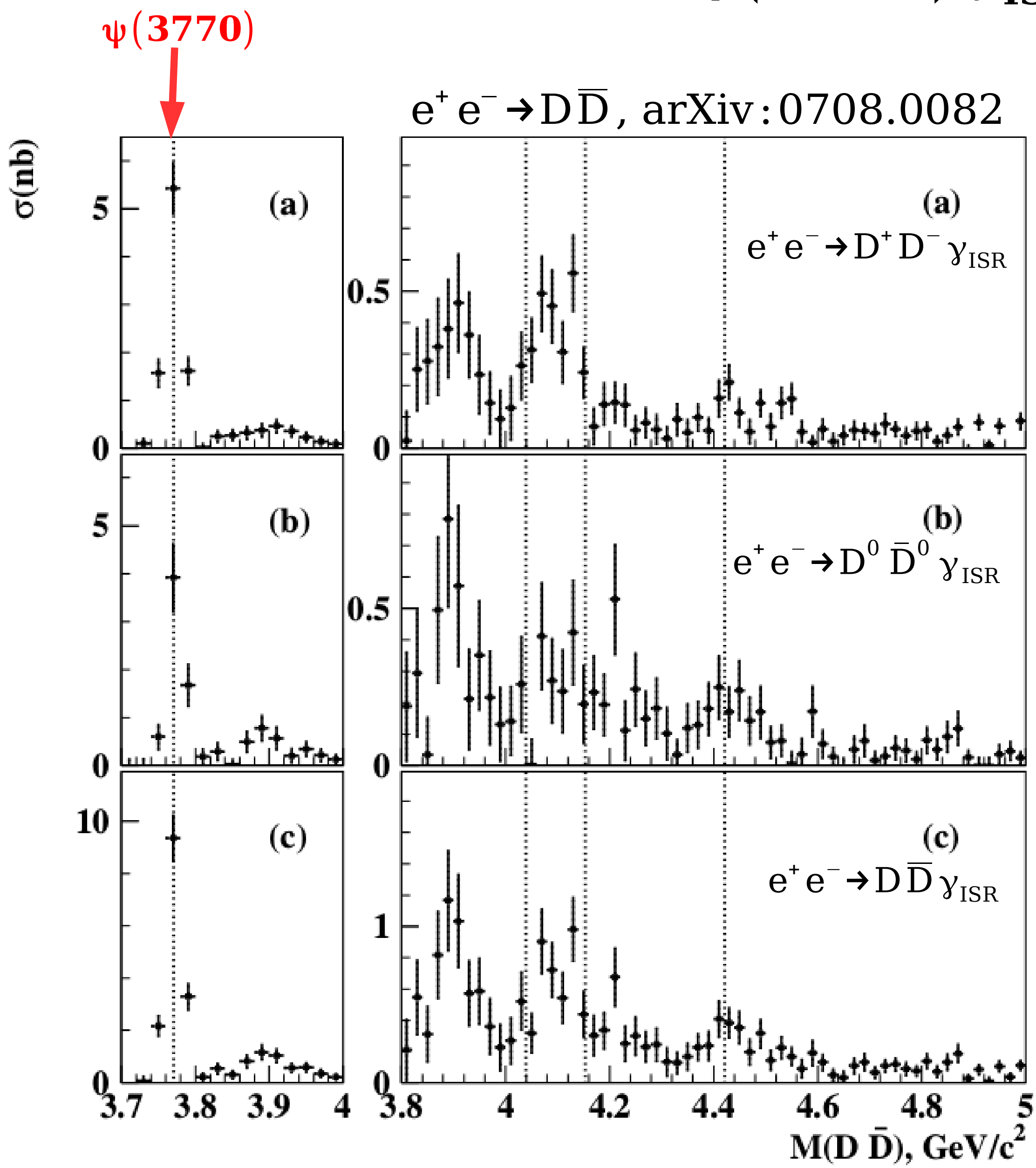
Δc_i, Δs_i are model-dependent

with assumption made to deduce Δc_i, as
DCS decays contribute with opposite sign,
CP-eigenstate amplitudes related by factor
$(1-2re^{i\delta})$, $r = \tan^2\theta_C$, δ any value
use BaBar model

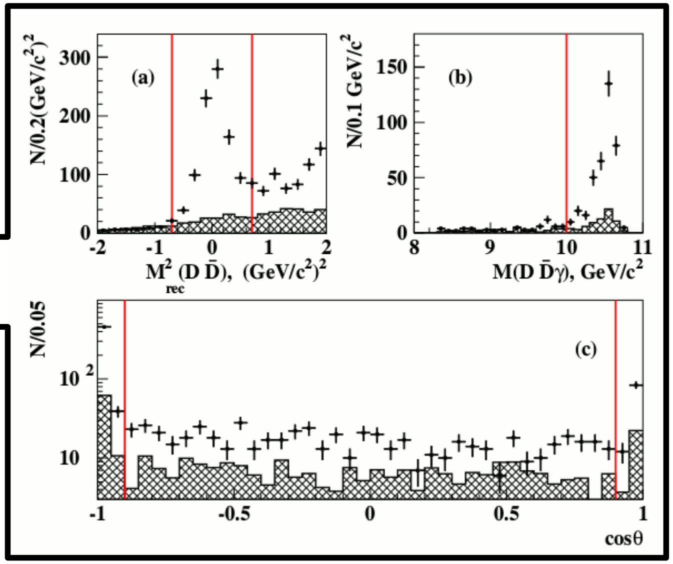
i	Δc_i	Δs_i
1	0.39 ± 0.17	0.07 ± 0.06
2	0.18 ± 0.05	0.01 ± 0.10
3	0.61 ± 0.15	0.30 ± 0.12
4	0.09 ± 0.08	0.00 ± 0.08
5	0.16 ± 0.17	0.06 ± 0.06
6	0.57 ± 0.21	-0.15 ± 0.24
7	0.03 ± 0.01	-0.04 ± 0.06
8	-0.10 ± 0.15	-0.15 ± 0.21

By the way, c_i and s_i come from charm factories (CLEO-c, BESIII)
but could we use $e^+e^- \to \psi(3770)\gamma_{ISR}$ sample ?

Could we use $e^+e^- \to \psi(3770)\gamma_{ISR}$ sample ?



both D candidates reconstructed
in $K\pi$, $K\pi\pi^0$, $K3\pi$, $K_S\pi\pi$, KK channels
signal yield ~ 150 evts for 673 fb^{-1}
⇒ 11,000 evts for 50 ab^{-1}



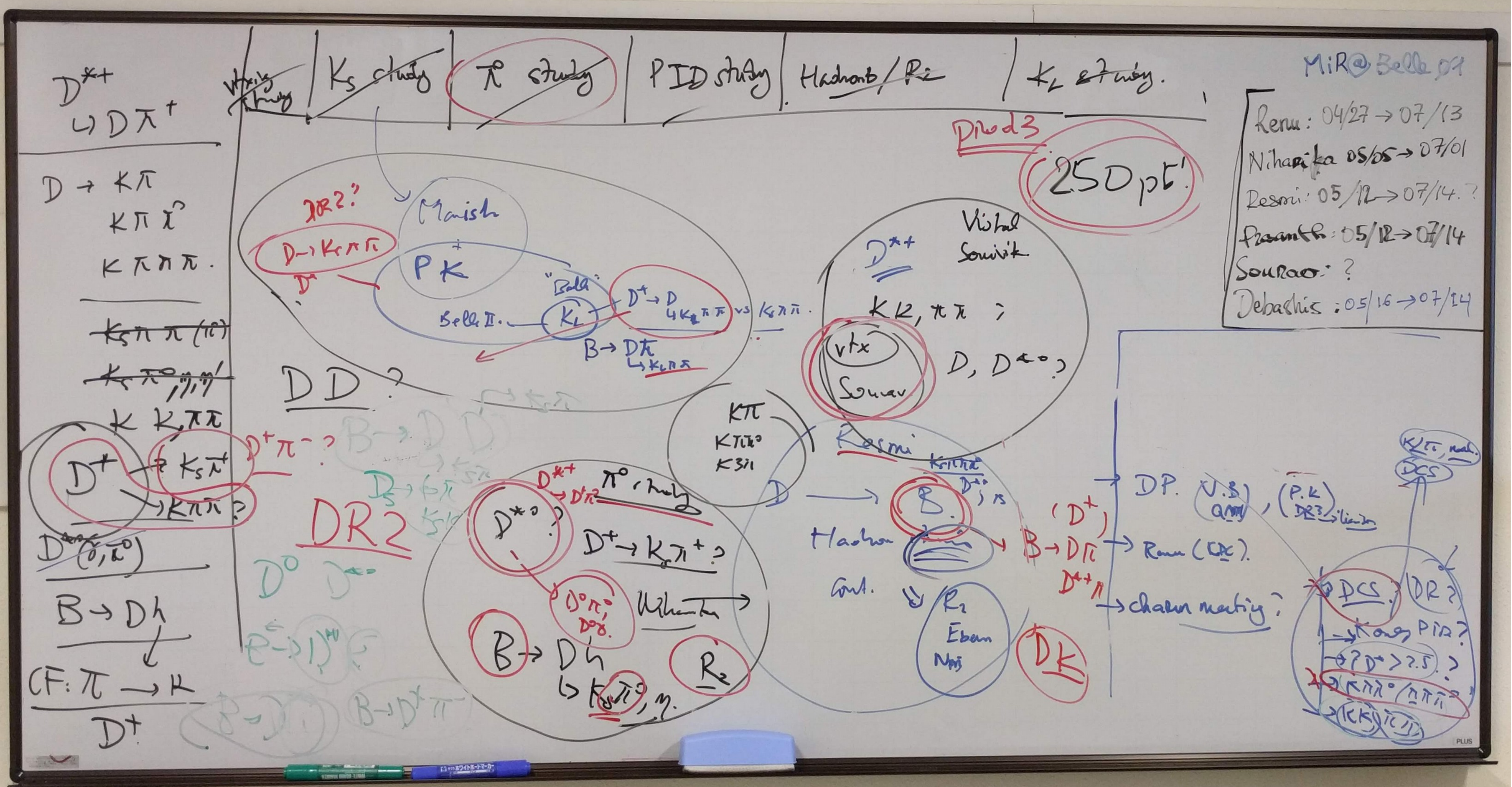
to be compared to CLEO-c, DT yield ($K_S\pi\pi$, $K\pi+K\pi\pi^0+K3\pi+K_S\pi\pi+KK$) = 7,000 evts @ 0.8 fb^{-1}
only for $K_S\pi\pi$ mode, only for 0.8 fb^{-1} so doesn't seem to be competitive

Time - dependent measurements

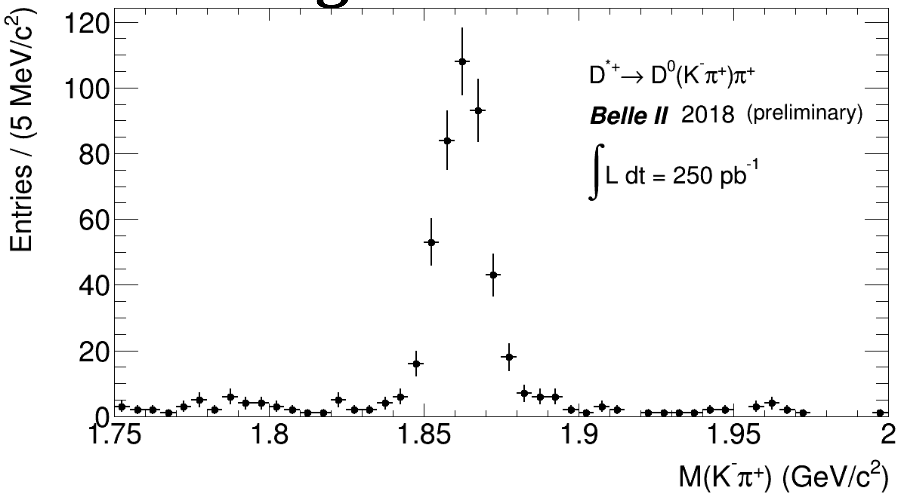
- All of the measurements presented so far were time-independent
- Time-dependent measurements (mixing induced CPV) also possible:
  - $B^0 \to D^{(*)}\pi$, $B^0 \to D^{(*)}\rho$
- In order to extract γ from $B \to SS/SV$ decays, must supply $r = |A_{DCS}/A_{CF}|$ externally (expected to be ~ 1-2%), usually assuming SU(3) symmetry
  $\Rightarrow$ not good idea to include those measurements in γ average

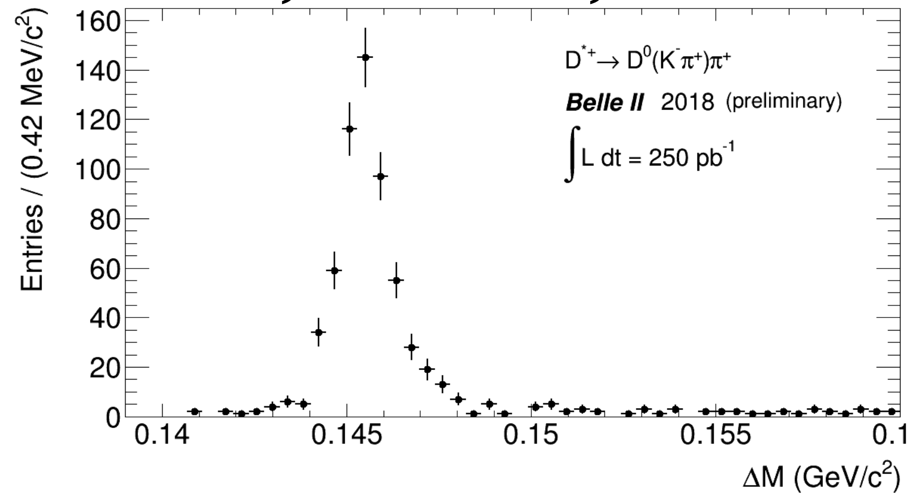
- In $B \to VV$ decays, one can extract all physics parameters from data
- Belle study: ~ 100 k evts per ab^{-1},
  3 helicity configurations: $A = \sum_\lambda A_\lambda$
  we use Cartesian coordinates $\{r_\lambda, \delta_\lambda, \phi_w\} \to \{x_\lambda, y_\lambda, \bar{x}_\lambda, \bar{y}_\lambda\}$
  $\sigma(2\beta+\gamma) \simeq 11^\circ$ for Belle II with 50 ab^{-1}
- on-going Belle analysis should give us a more precise estimation soon

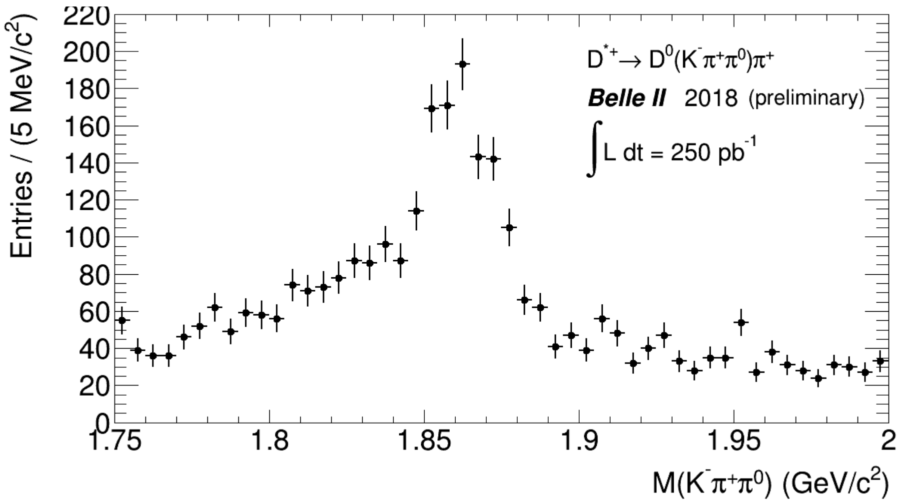
A look at first data… (phase 2)

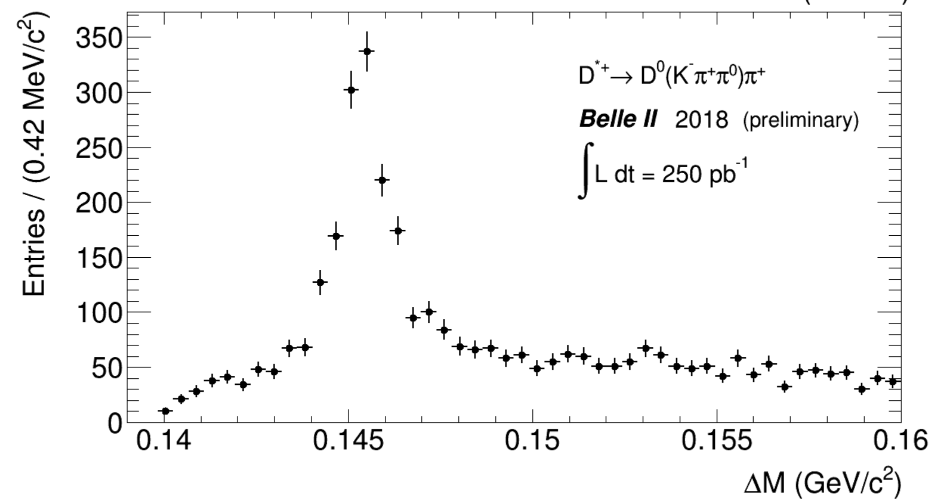


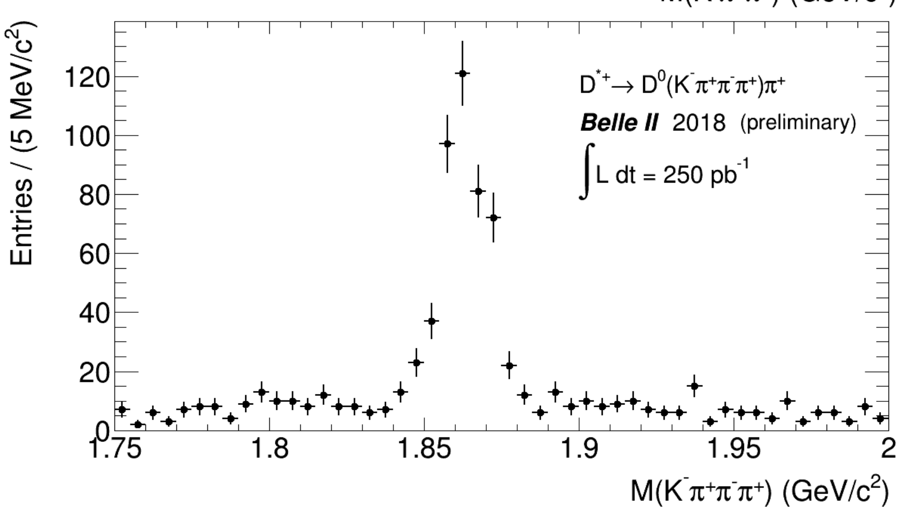
Rediscovering charm: $D^{*+} \to D\pi^+$, $D \to K^- \pi^+$, $K^- \pi^+ \pi^0$, $K^- \pi^+ \pi^- \pi^+$

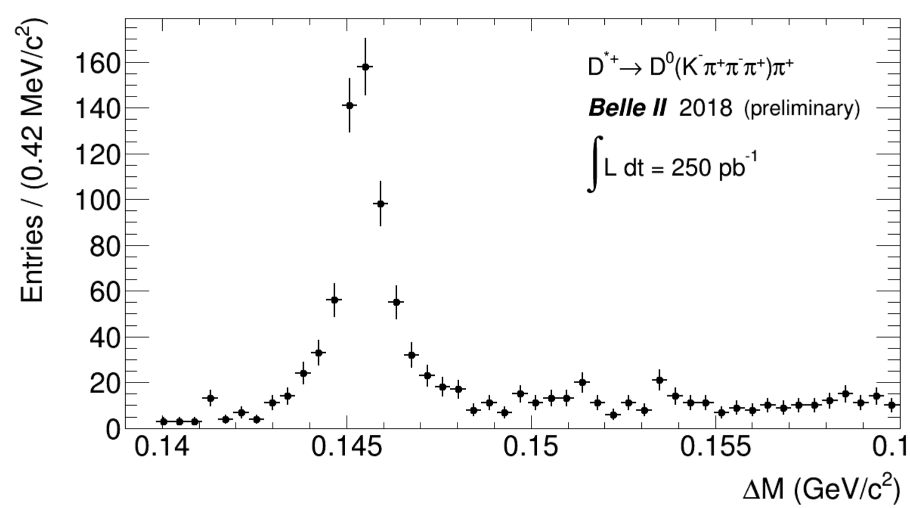




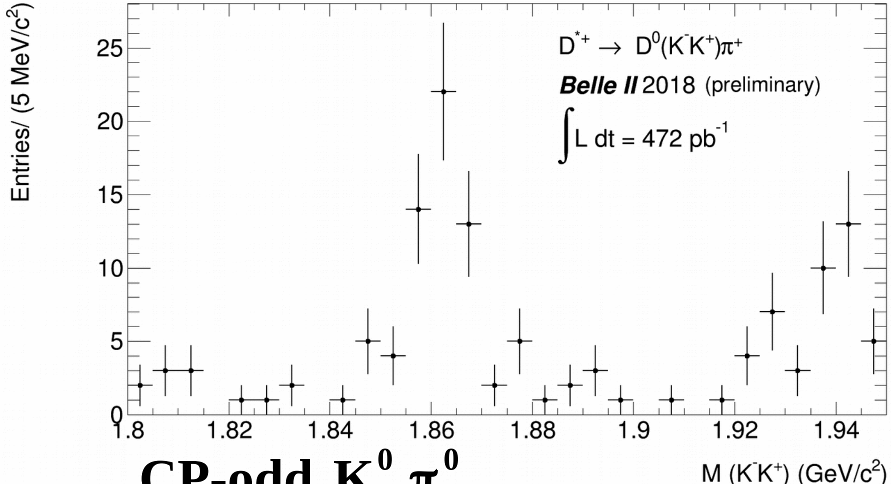


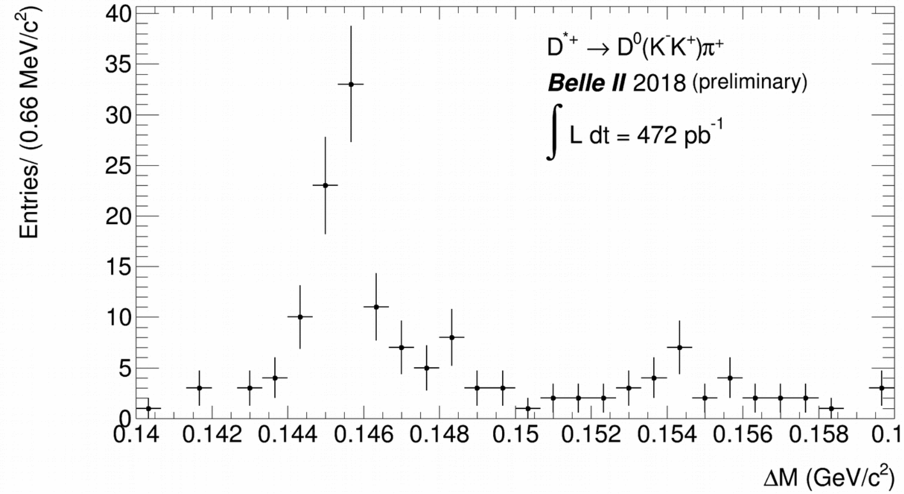




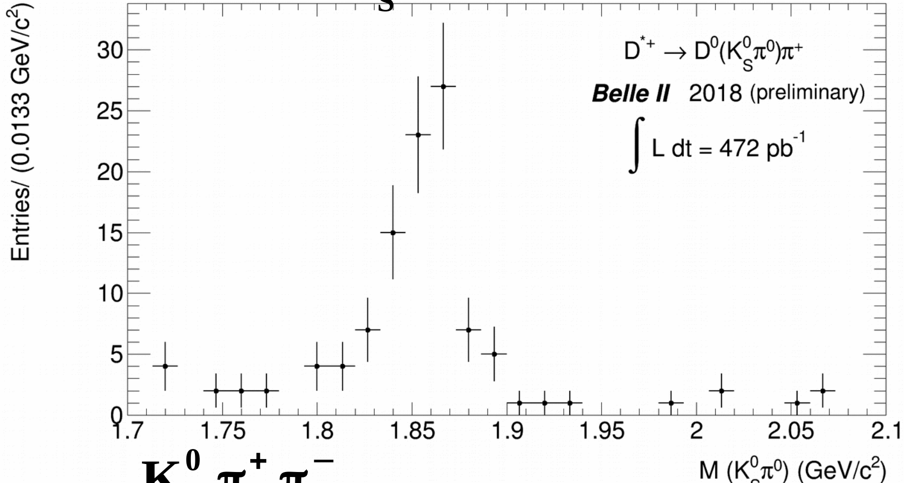


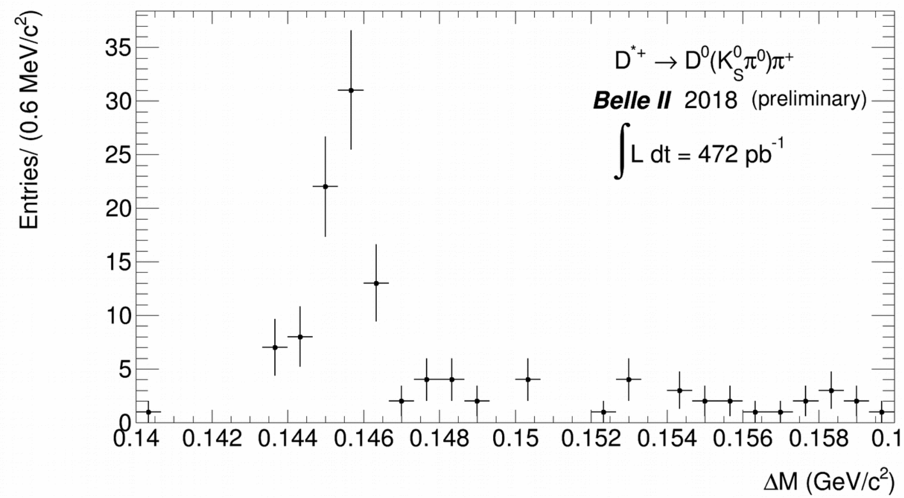
CP-even K^+K^-



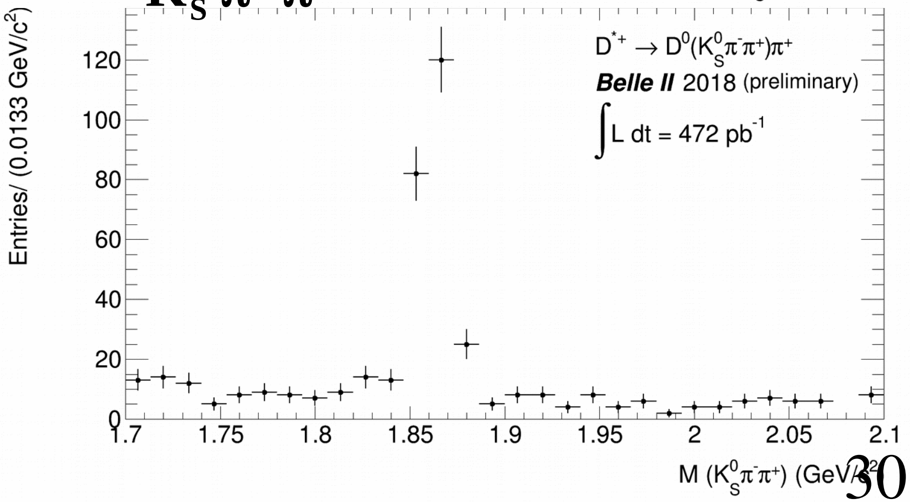


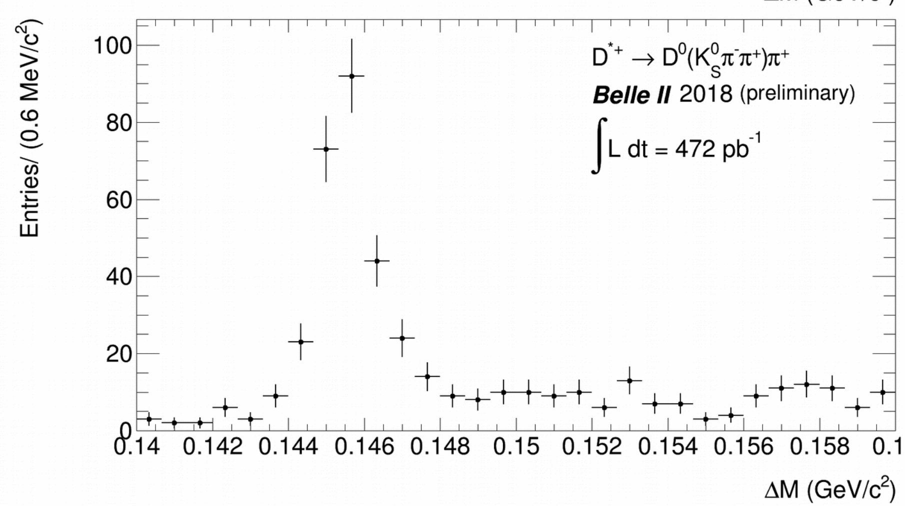
CP-odd $K_S^0\pi^0$





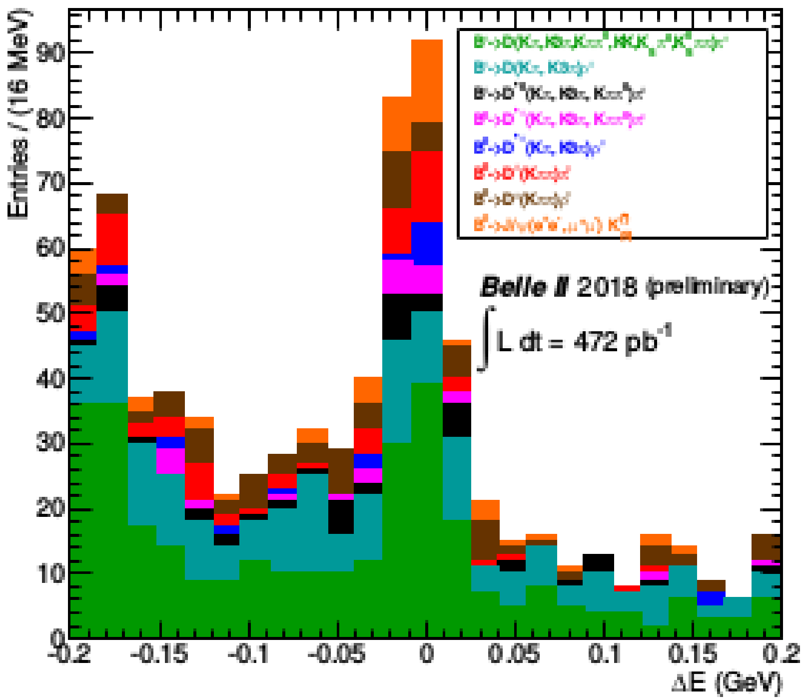
$K_S^0\pi^+\pi^-$

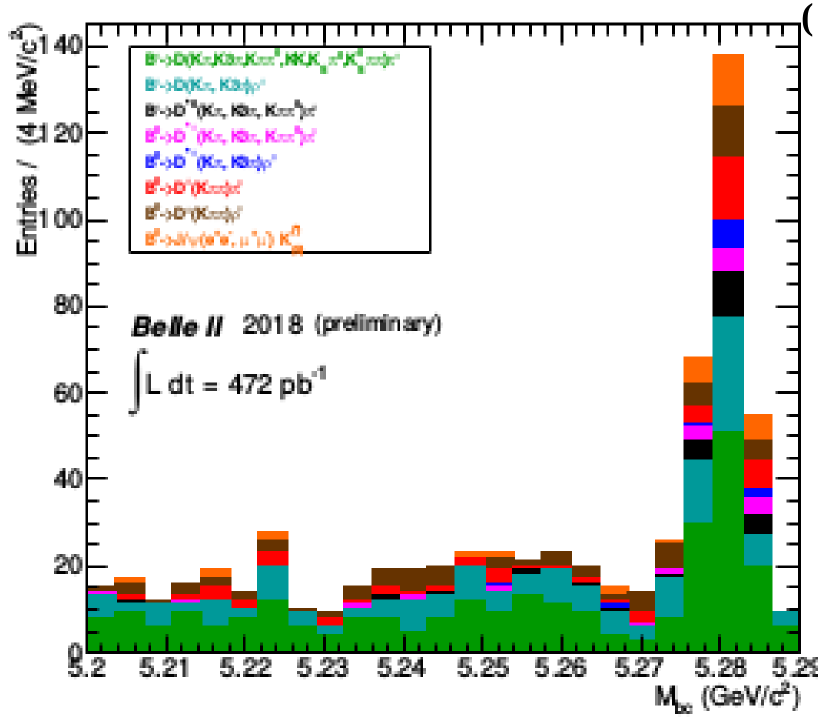




Rediscovering beauty : $B \to D^{(*)}h$ + $B \to J/\psi K^{(*)}$

Results for 0.5 fb^{-1}





Candidates in signal box

($M_{bc} > 5.27$ GeV/c^2 , $|\Delta E| < 0.050$ GeV)

Mode	yield
$B^{\pm} \to D\pi^{\pm}$	116
$B^{\pm} \to D\rho^{\pm}$	61
$B^{\pm} \to D^{*}\pi^{\pm}$	22
$B^{0} \to D^{*\pm}\pi^{\mp}$	13
$B^{0} \to D^{*\pm}\rho^{\mp}$	10
$B^{0} \to D^{\pm}\pi^{\mp}$	25
$B^{0} \to D^{\pm}\rho^{\mp}$	33
$B \to J/\psi K^{(*)}_{(S)}$	29

Show capacity for charm physics in $e^+e^- \to c\bar{c}$

- D^0, D^+, D^*
- Cabibbo favoured and suppressed modes

...for B-physics

- hadronic modes from $b \to c$
- semileptonic decay modes from $b \to c$

Conclusion

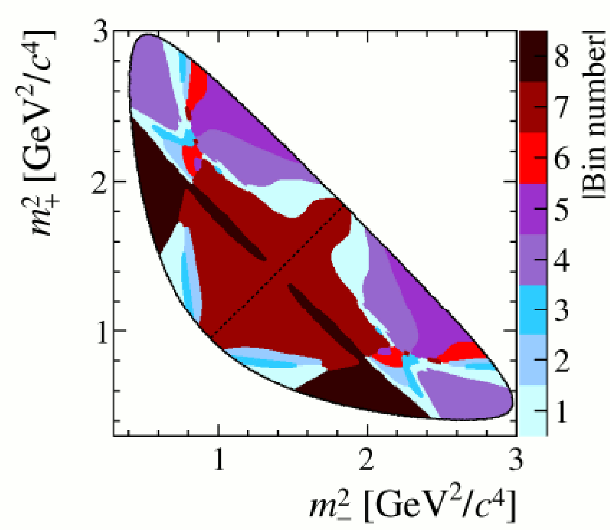
"Data ! data ! data !" he cried impatiently
"I can't make bricks without clay." (Arthur Conan Doyle)

- Promising perspectives at Belle II for γ measurement
- To stay competitive, we need to stay on schedule...
- With first data, more realistic estimation on going
- But also plenty of room for improvements
  - improved methods
  - new modes (some pioneered on Belle data sample)

equations for the rate of events in bins i and −i of the Dalitz plots for B^- and B^+ decays:

$$x_\pm \equiv r_B \cos(\delta_B \pm \gamma),$$

$$y_\pm \equiv r_B \sin(\delta_B \pm \gamma).$$



$$\Gamma_{+i}(B^- \to D(\to K_S^0 h^+ h^-)K^-) \propto \left[T_{+i} + (x_-^2 + y_-^2)T_{-i} + 2\sqrt{T_{+i}T_{-i}}(x_- c_{+i} + y_- s_{+i})\right],$$

$$\Gamma_{-i}(B^- \to D(\to K_S^0 h^+ h^-)K^-) \propto \left[T_{-i} + (x_-^2 + y_-^2)T_{+i} + 2\sqrt{T_{+i}T_{-i}}(x_- c_{-i} + y_- s_{-i})\right],$$

$$\Gamma_{+i}(B^+ \to D(\to K_S^0 h^+ h^-)K^+) \propto \left[T_{-i} + (x_+^2 + y_+^2)T_{+i} + 2\sqrt{T_{+i}T_{-i}}(x_+ c_{+i} - y_+ s_{+i})\right],$$

$$\Gamma_{-i}(B^+ \to D(\to K_S^0 h^+ h^-)K^+) \propto \left[T_{+i} + (x_+^2 + y_+^2)T_{-i} + 2\sqrt{T_{+i}T_{-i}}(x_+ c_{-i} - y_+ s_{-i})\right].$$

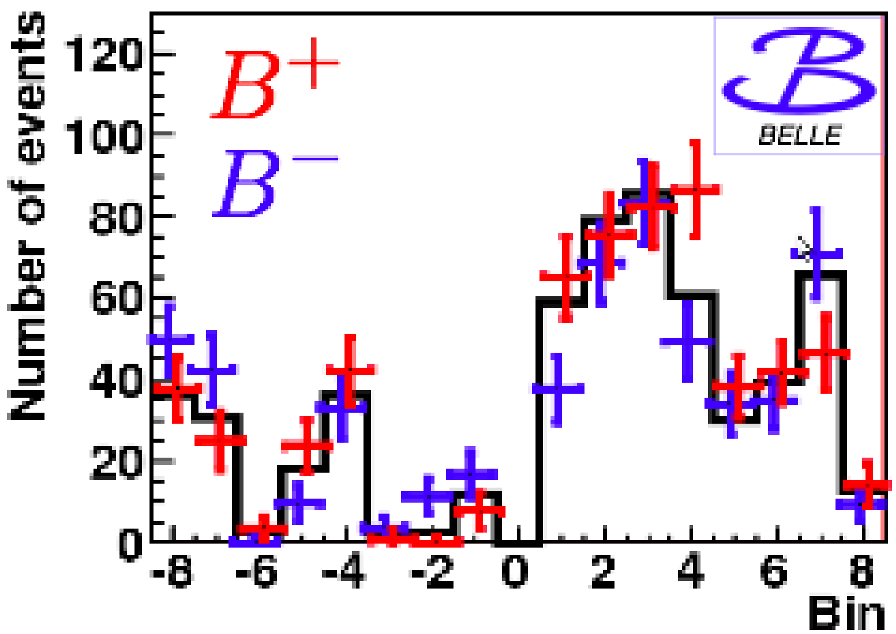
parameters $\mathbf{T_{\pm i}}$ can be determined by measuring decay rates of flavour-tagged $D^0 \to K_S^0 \pi^+ \pi^-$ decays, i.e. where D meson can be identified as D^0 or $\overline{D}^0$

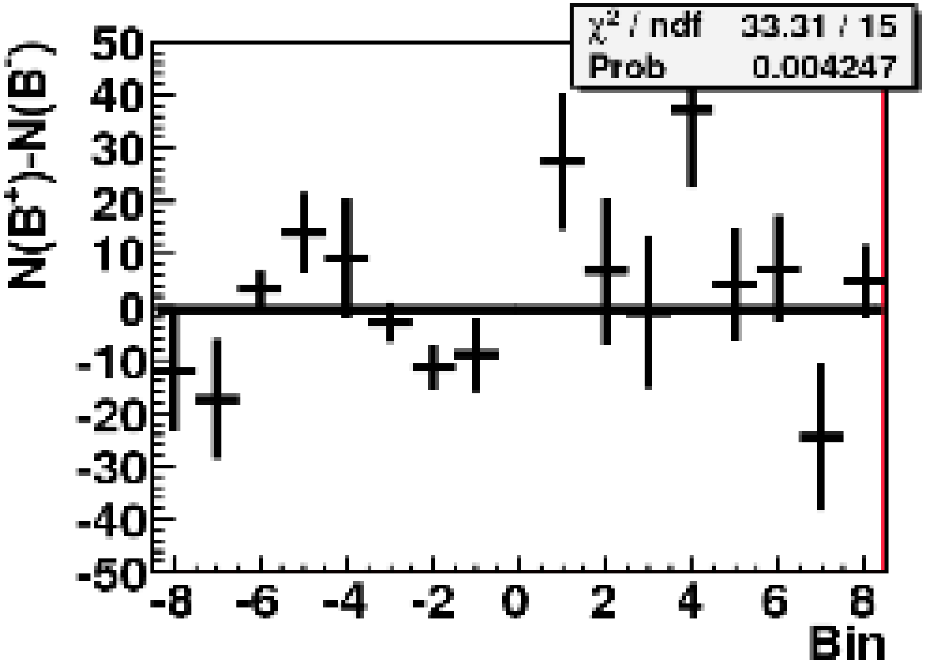
measuring $B \to DK$ decay rates in each bin, 2k+3 unknowns = $\mathbf{c_i}$, $\mathbf{s_i}$, $\mathbf{r_B}$, $\mathbf{\delta_B}$ and $\boldsymbol{\gamma}$
$k \geq 2$: greater number of equations than unknowns and γ can be determined

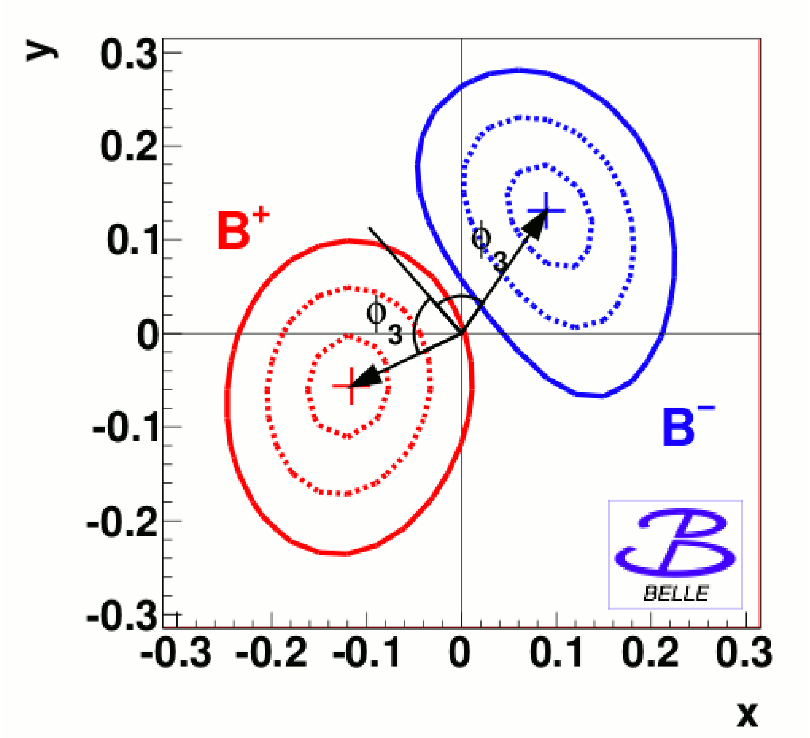
preferable to perform dedicated measurements of $\mathbf{c_i}$ and $\mathbf{s_i}$, use them as inputs

Binned Dalitz method result in B → DK

772M $B\bar{B}$
PRD 85, 112014 (2012)
[arXiv:1204.6561]







$$\gamma = (77.3\,^{+15.1}_{-14.9} \pm 4.1 \pm 4.3)^\circ$$

$$r_B = 0.145 \pm 0.030 \pm 0.010 \pm 0.011$$

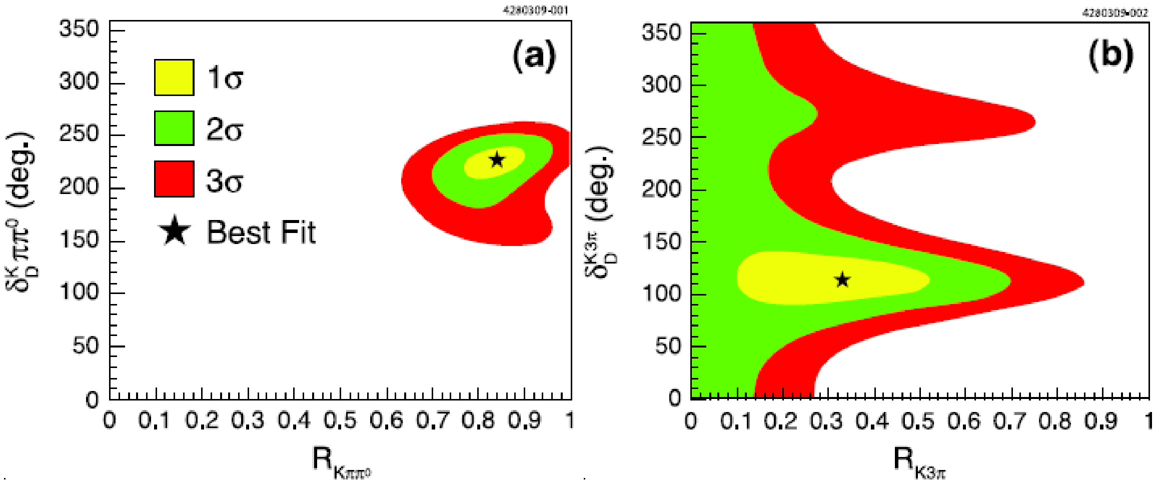
$$\delta_B = (129.9 \pm 15.0 \pm 3.8 \pm 4.7)^\circ$$

uncertainty in c_i, s_i
from CLEO data size
(can be reduced using
future BES-III data)

quasi-GLW, quasi-ADS...

certain multi-body decays are almost pure CP-eigenstates:
⇒ quasi-GLW, for example for $D \rightarrow 4\pi$, $2F_{+} - 1 = 0.737 \pm 0.028$

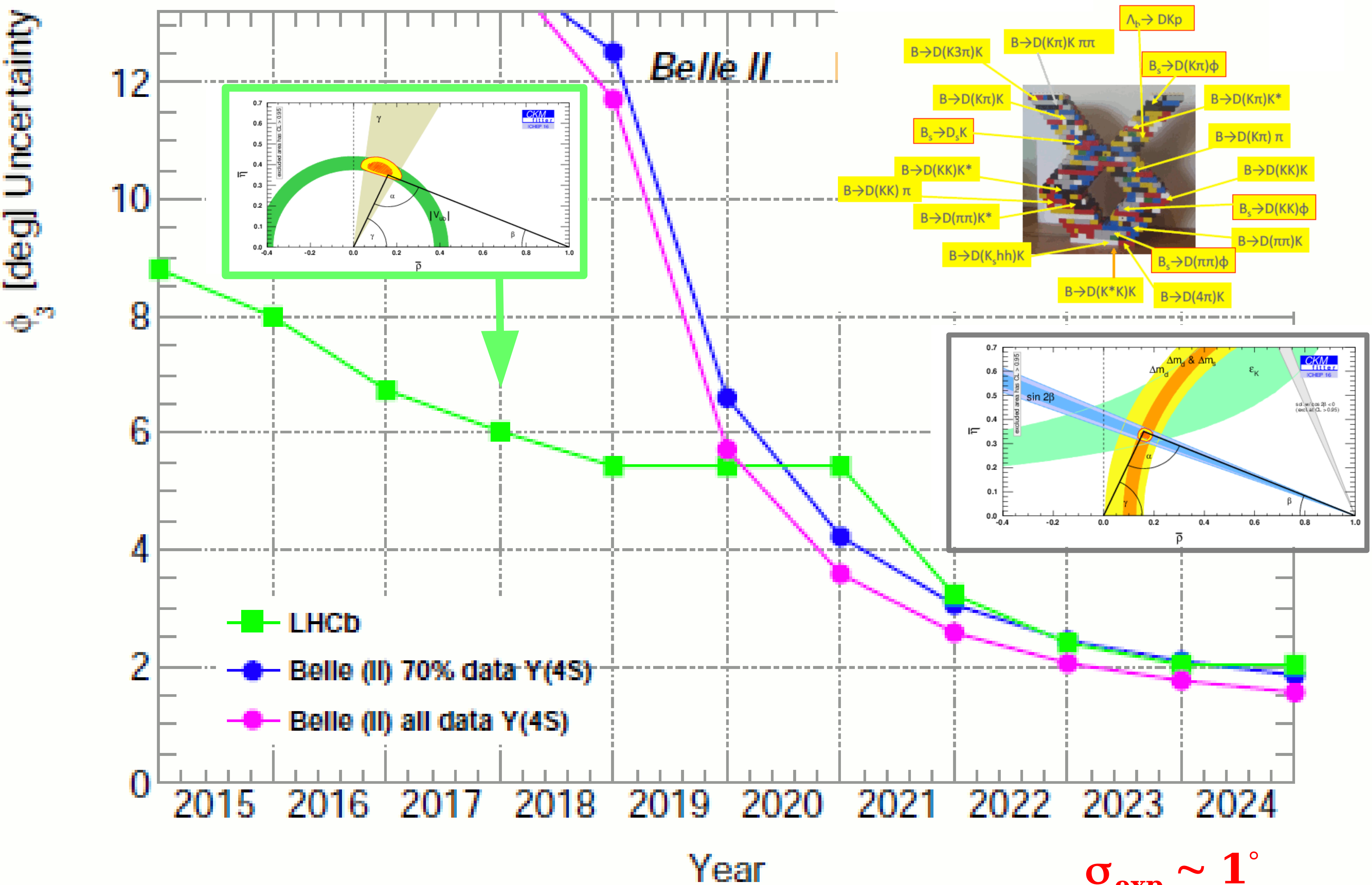
other like ADS modes: for example $D \rightarrow K\pi\pi^0$, coherence factor ~ 1



yields of double-tagged events where one meson decays into $K^-\pi^+\pi^0$ (or $K3\pi$), and the other meson decays into CP-odd, CP-even and $K\pi$

Ultimate γ-from-tree decays

precision will be reached through many individual measurements

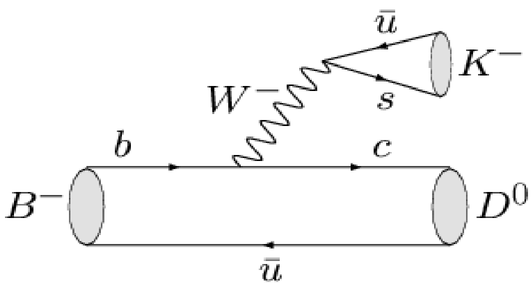


$\sigma_{exp} \sim 1^\circ$

(σ_{theory} negligible)

γ measurements from $B^{\pm} \rightarrow DK^{\pm}$

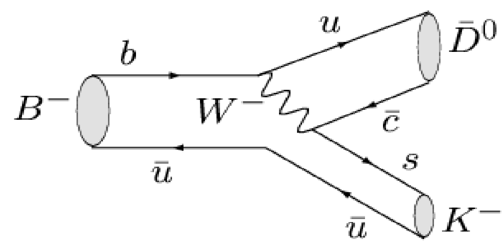
- Theoretically pristine $B \rightarrow DK$ approach
- Access γ via interference between $B^- \rightarrow D^0 K^-$ and $B^- \rightarrow \overline{D}^0 K^-$



color allowed

$B^- \rightarrow D^0 K^- \sim V_{cb} V_{us}^*$

$\sim \mathbf{A\lambda^3}$



color suppressed

$B^- \rightarrow \overline{D}^0 K^- \sim V_{ub} V_{cs}^*$

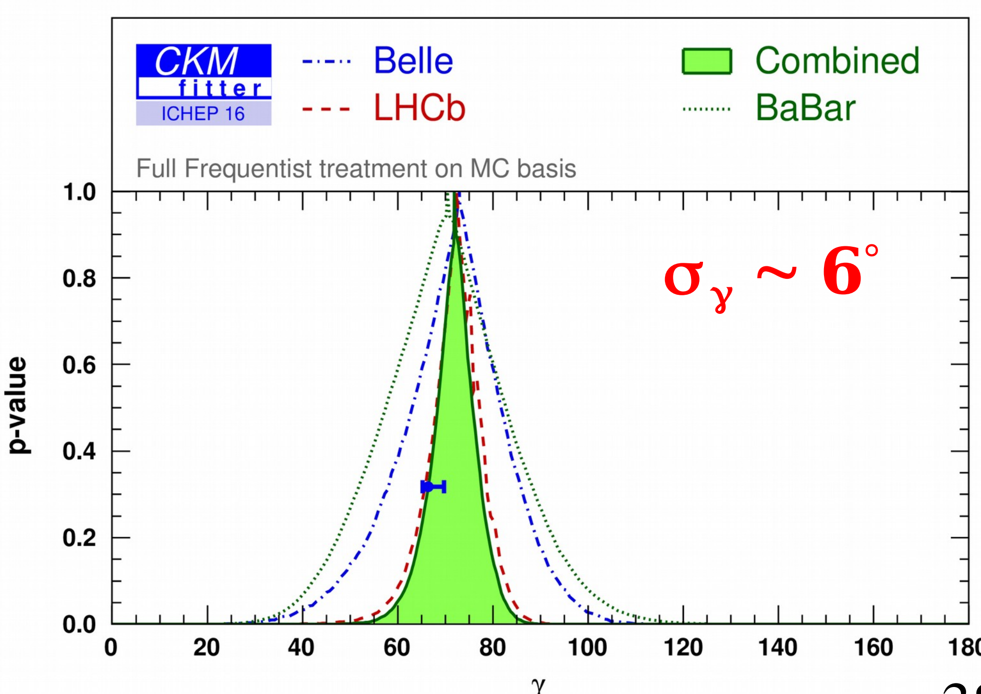
$\sim \mathbf{A\lambda^3(\rho + i\eta)}$

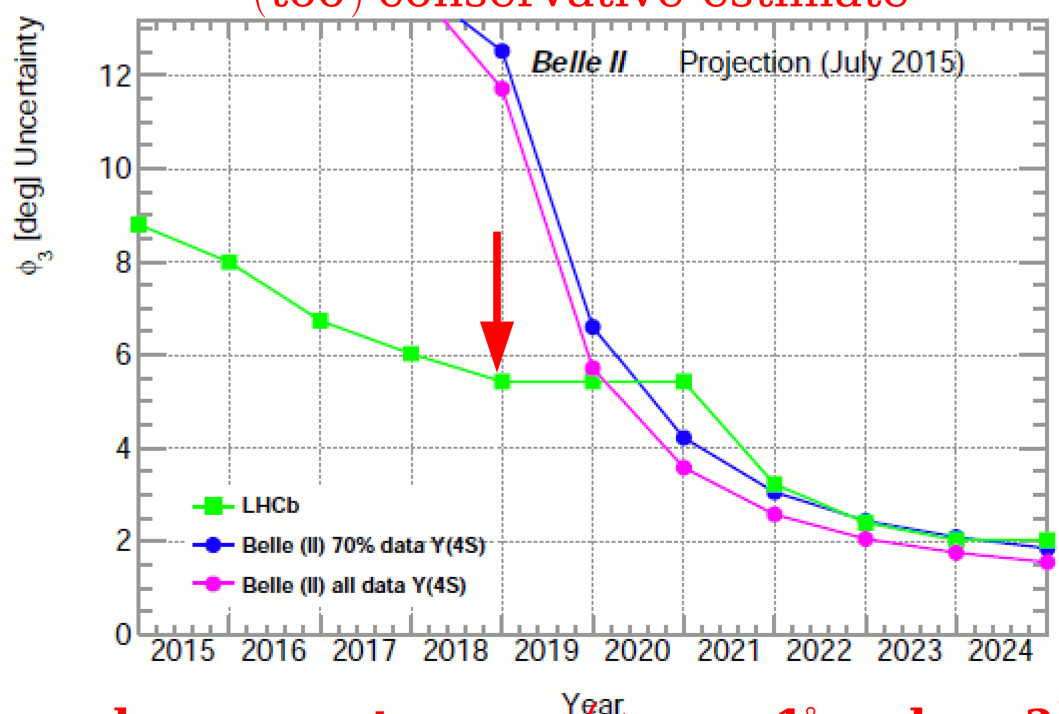
relative weak phase is γ

relative strong phase is δ_B

$r_B \simeq 0.1$

(too) conservative estimate

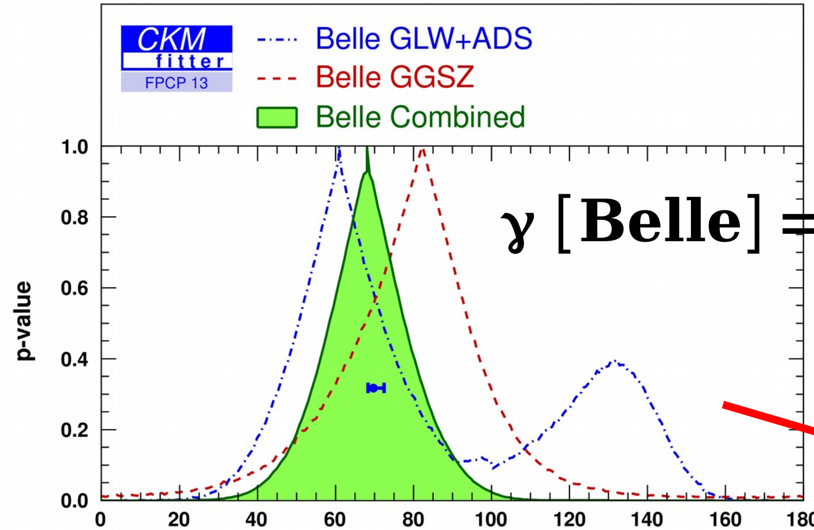




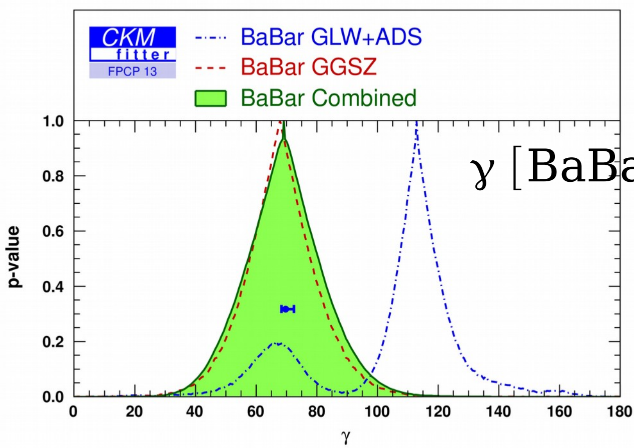
long way to go ... ($\rightarrow \sigma_\gamma = 1^\circ$ or less ?)

Combined measurements for γ from all methods

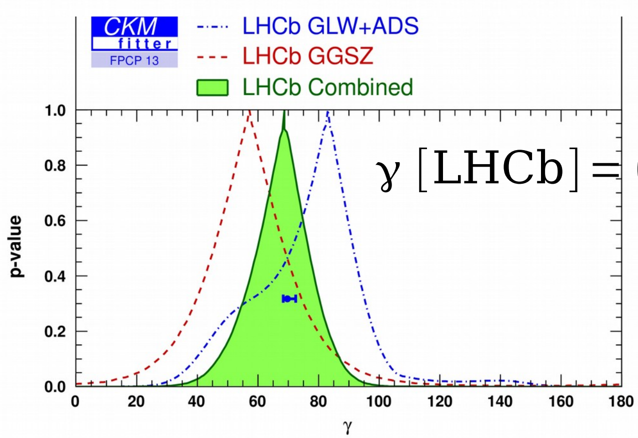
http://ckmfitter.in2p3.fr



$$\gamma\,[\text{Belle}] = (68 \pm 14)^\circ$$

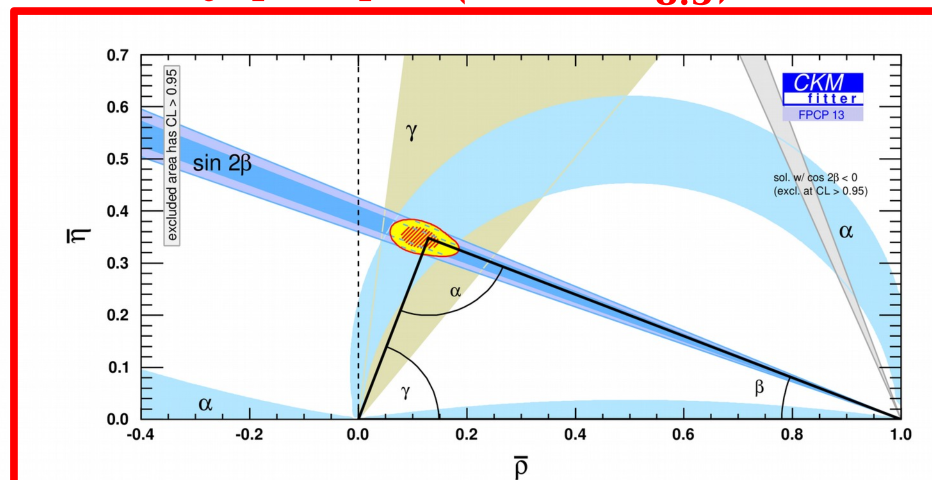


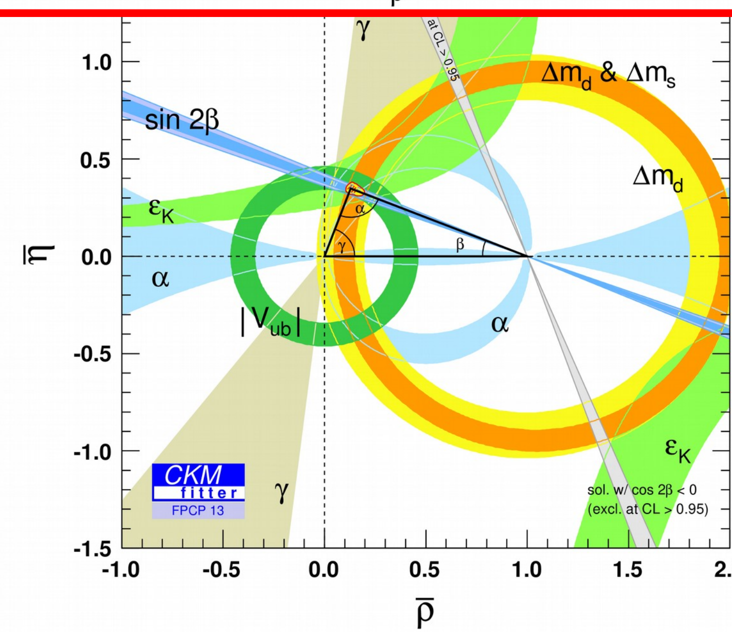
$$\gamma\,[\text{BaBar}] = (69 \pm 17)^\circ$$



$$\gamma\,[\text{LHCb}] = (69\,^{+11}_{-13})^\circ$$

$$\gamma\,[\text{all}] = (68.0\,^{+8.0}_{-8.5})^\circ$$





Charm mixing in $D^0 \to K^+\pi^-$

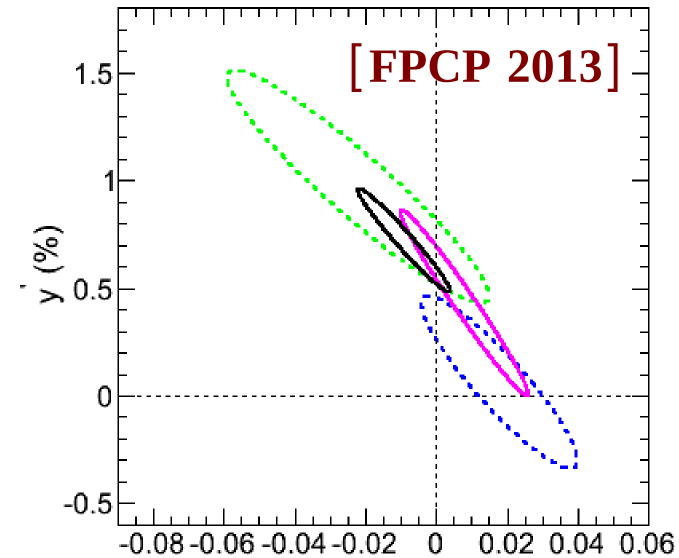
The ratio $R(t)$ of WS $D^{*+} \to D^0\pi^+_s \to K^+\pi^-\pi^+_s$ to RS $D^{*+} \to D^0\pi^+_s \to K^-\pi^+\pi^+_s$ decay rates can be approximated (assuming $|x|, |y| << 1$ and no CPV) by:

DCS to CF ratio — mixing rate

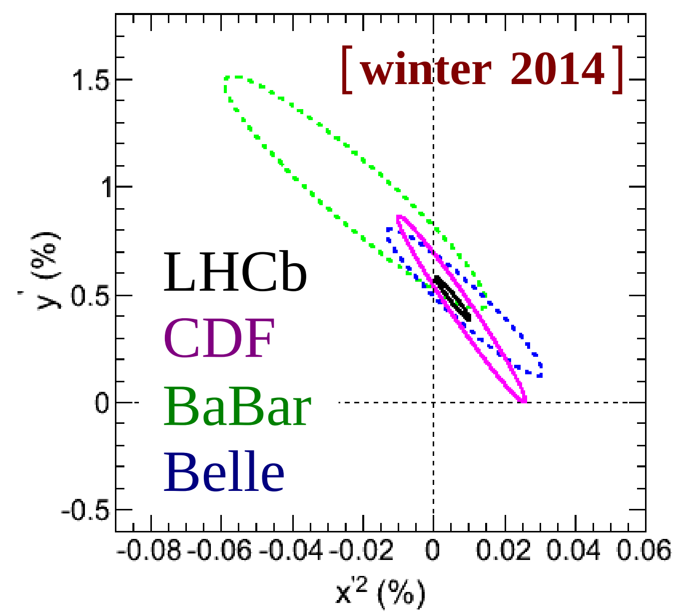
$$R(t) = R_D + \sqrt{R_D}\, y' t + \frac{x'^2 + y'^2}{4} t^2$$

$$x' = x\cos\delta_{K\pi} + y\sin\delta_{K\pi}$$
$$y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi}$$

$\delta_{K\pi}$: strong phase difference btw DCS and CF amplitudes



Exp	R_D (10^{-3})	y' (10^{-3})	x'^2 (10^{-3})	Σ
Belle PRL 112 (2014) 111801	3.53 ± 0.13	4.6 ± 3.4	+0.09 ± 0.22	5.1
BaBar PRL 98 (2007) 211802	3.03 ± 0.19	9.7 ± 5.4	−0.22 ± 0.37	3.9
LHCb PRL 111 (2013) 251801	3.57 ± 0.07	4.8 ± 1.0	+0.055 ± 0.049	?
CDF preliminary (2013)	3.51 ± 0.35	4.3 ± 4.3	+0.08 ± 0.18	6.1



ADS observables

- (R_+ , R_-) **instead of** (R_{ADS} , A_{ADS}) **whenever available**

Effect of D-$\bar{D}$ mixing on γ

- M. Rama, arXiv:1307.4384
- $R^{\mp} = r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B \mp \gamma + \delta_D)$

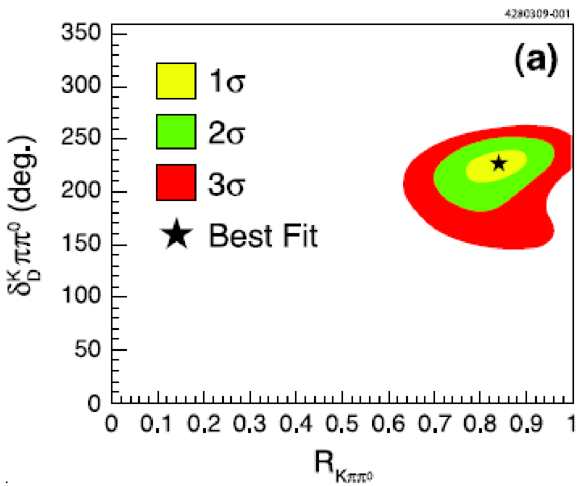
  → $R^{\mp} = r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B \mp \gamma + \delta_D) - y r_D \cos\delta_D - y r_B \cos(\delta_B \mp \gamma) +$
  $x r_D \sin\delta_D - x r_B \sin(\delta_B \mp \gamma)$
- tried on the current LHCb average (DK): ~ 1 degree difference

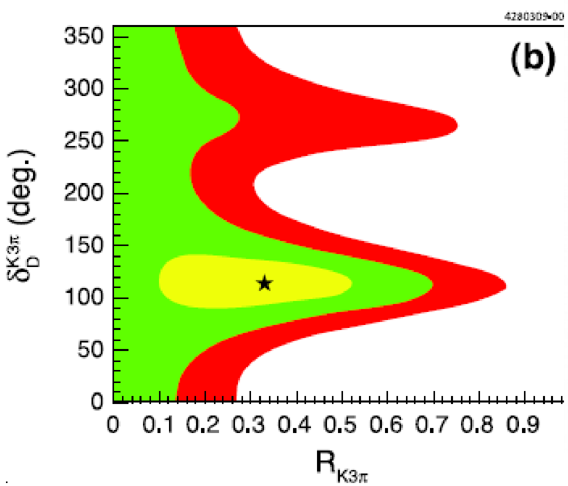
$K\pi\pi^0$, $K3\pi$ from CLEO-c

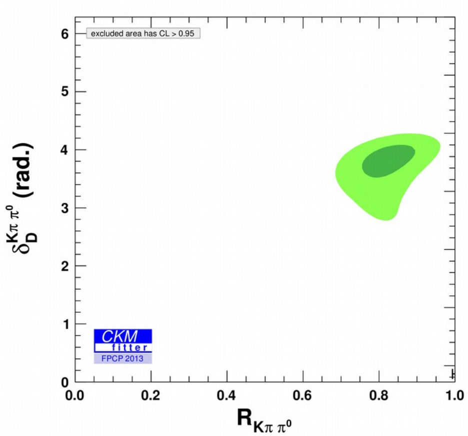
yields of double-tagged events where one meson decays into $K^-\pi^+\pi^0$ (or $K3\pi$), and the other meson decays into CP-odd, CP-even and $K\pi$

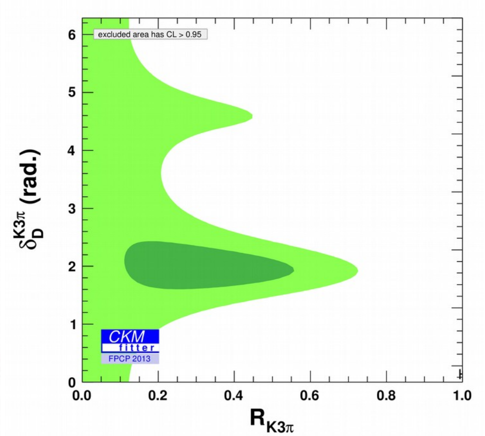
[arXiv:0903.4853, N.Lowrey et al]
(combined with external inputs: x, y, δ_D...)

that we could reproduce earlier extending the charm fitter (+ Br's)

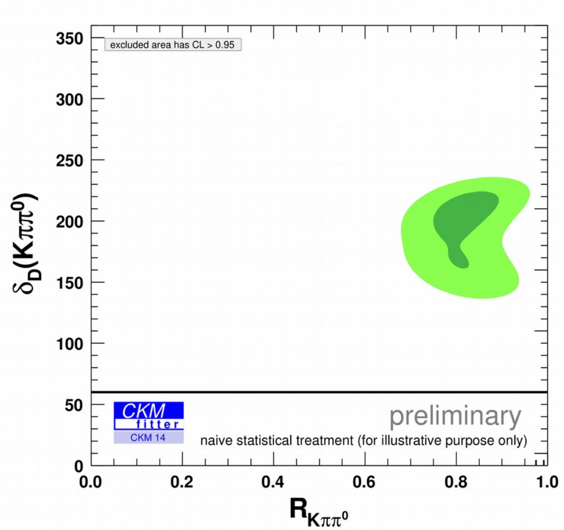


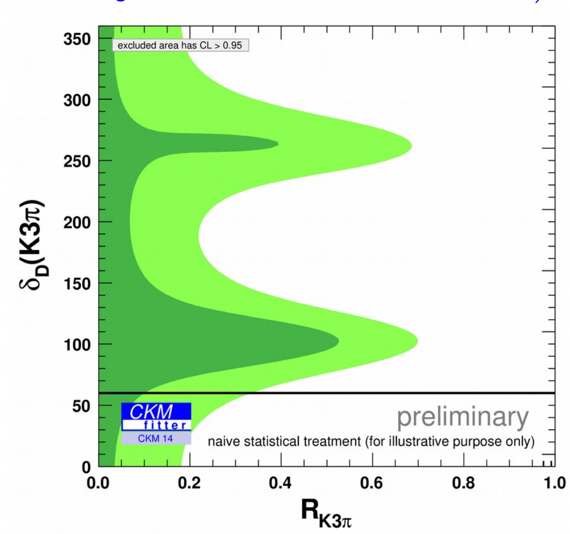






2014 version (currently used in our γ combination):





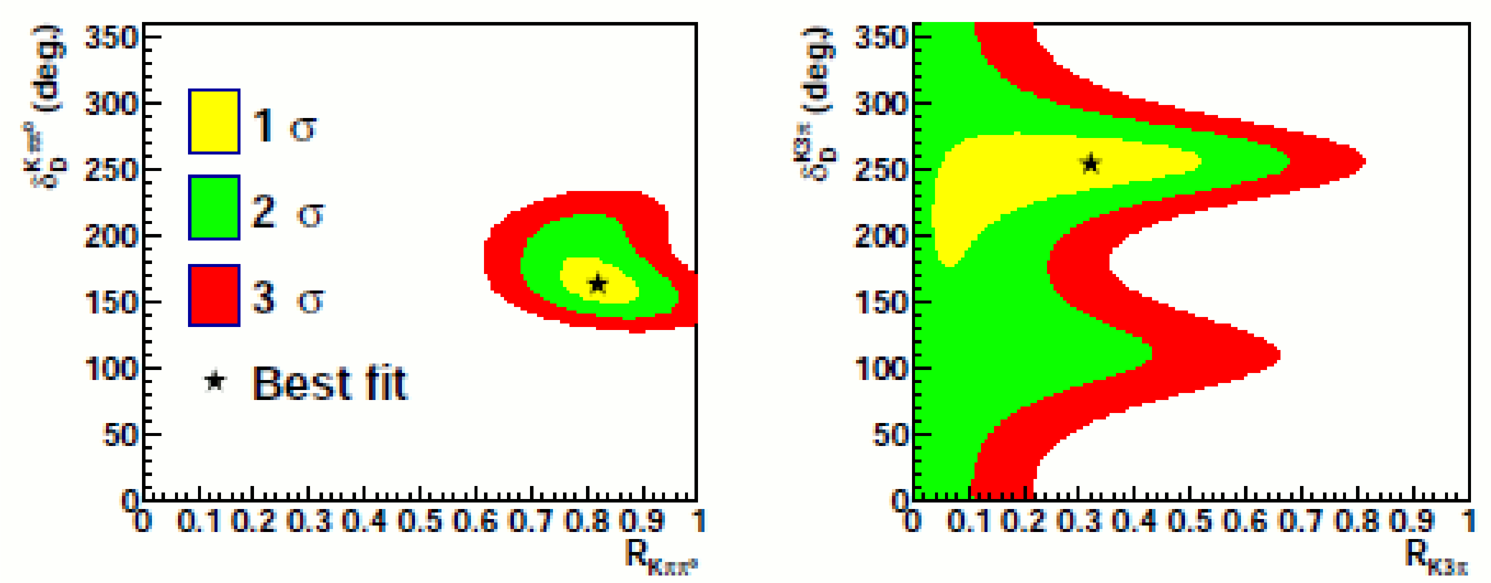
$K\pi\pi^0$, $K3\pi$ from CLEO-c [J. Libby et al, arXiv:1401.1904]

yields of double-tagged events where one meson decays into $K^-\pi^+\pi^0$ (or $K3\pi$), and the other meson decays into $K^0_S\pi^+\pi^-$

$$Y_i = H_{K\pi\pi^0}\Big(K_i + (r_D^{K\pi\pi^0})^2 K_{-i} - 2r_D^{K\pi\pi^0}\sqrt{K_i K_{-i}}R_{K\pi\pi^0}[c_i\cos\delta_D^{K\pi\pi^0} + s_i \sin\delta_D^{K\pi\pi^0}]\Big),$$

measure by CLEO-c

K_i : fractional yield of D^0 decays that fall into bin i



⇒ will soon include this information

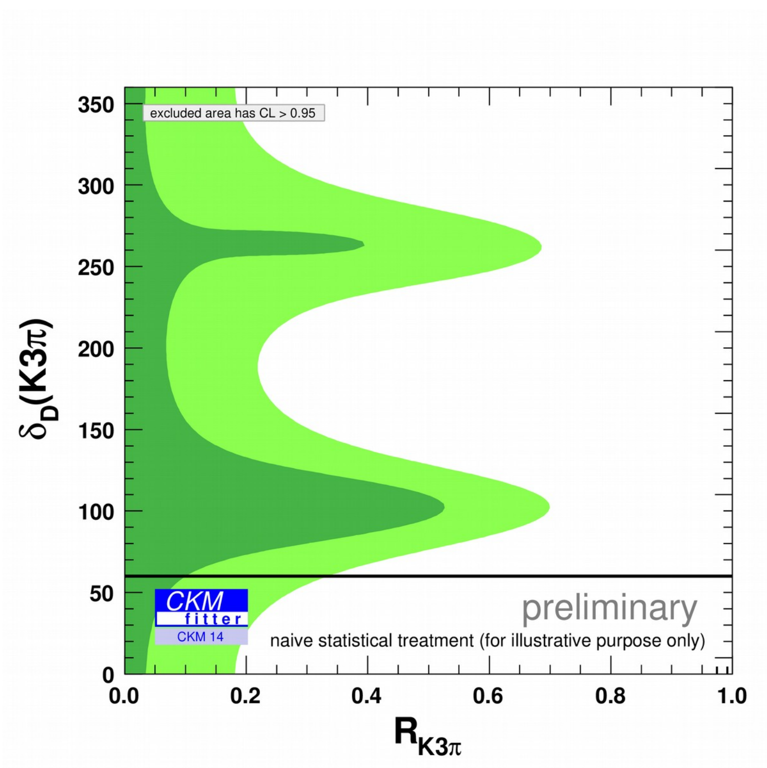
$K3\pi$ charm information is limited:

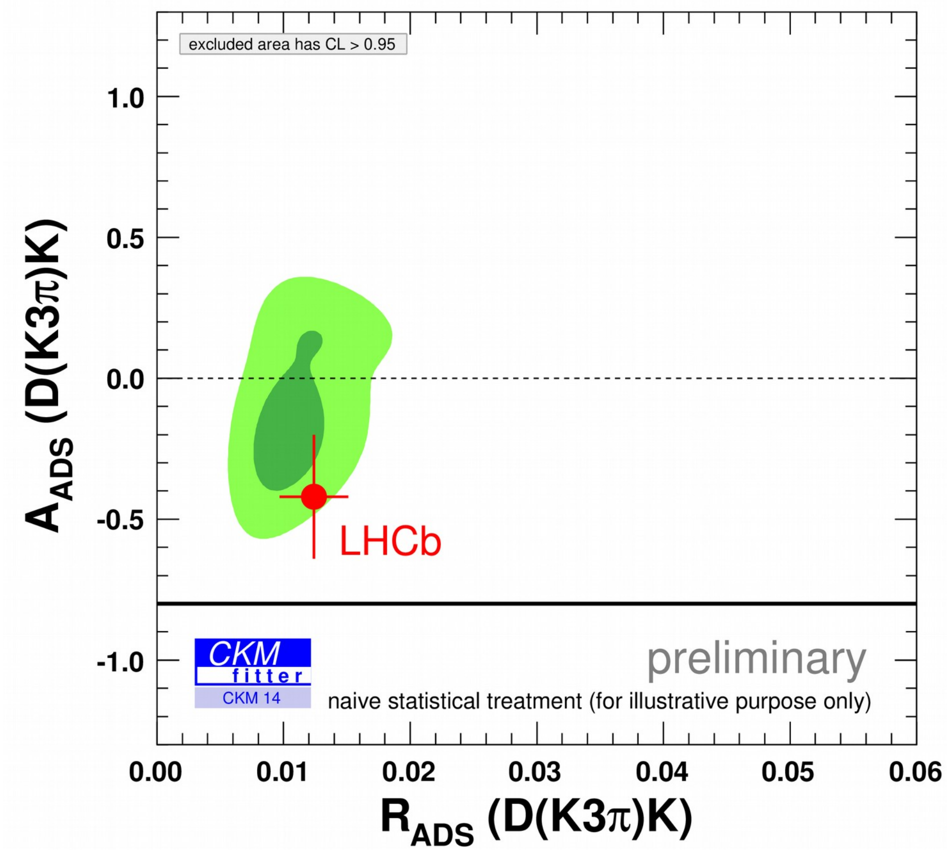
- possible additional inputs from BES III
- B factories/LHCb [S. Harnew and J. Rademacker, arXiv:1309.0134]

ADS $B \to D(K3\pi)K$

where "expectations" derived from the GGSZ observables, δ_D, r_D and R (for $K3\pi$)

$D(K3\pi)K$ [PLB 723 (2013) 44]

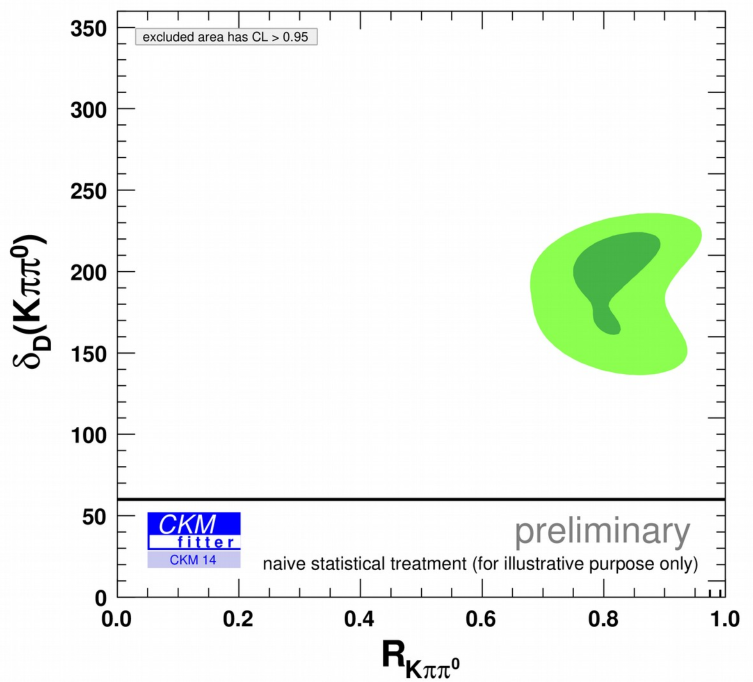


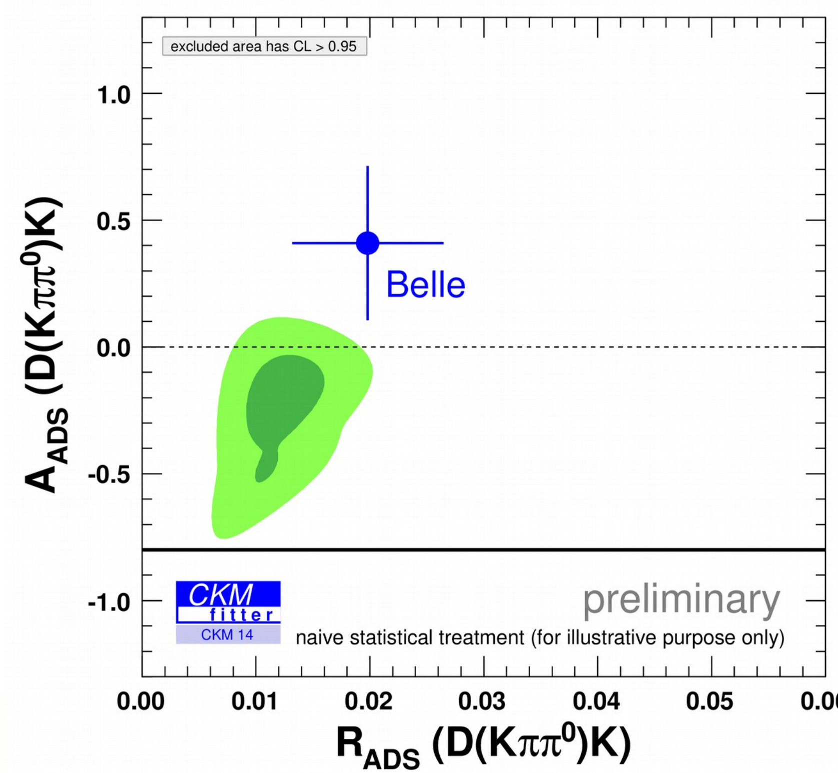


$\Rightarrow$ $D(K3\pi)K$ LHCb result included in the γ combination

ADS $B \to D(K\pi\pi^0)K$

where "expectations" derived from the GGSZ observables, δ_D, r_D and R (for $K\pi\pi^0$)





Evidence for the suppressed decay $B^- \to DK^-, D \to K^+\pi^-\pi^0$

M. Nayak,[16] J. Libby,[16] K. Trabelsi,[12] I. Adachi,[12] H. Aihara,[55] D. M. Asner,[42] T. Aushev,[20] A. M. Bakich,[49] A. Bala,[43] P. Behera,[16] K. Belous,[18] V. Bhardwaj,[34] G. Bonvicini,[60] A. Bozek,[38] M. Bračko,[27,21] T. E. Browder,[11] D. Červenkov,[5] M.-C. Chang,[8] P. Chang,[37] V. Chekelian,[28] A. Chen,[35] B. G. Cheon,[10] R. Chistov,[20] I.-S. Cho,[62] K. Cho,[24] V. Chobanova,[28] Y. Choi,[48] D. Cinabro,[60] J. Dalseno,[28,51] M. Danilov,[20,30] Z. Doležal,[5] Z. Drásal,[5] ...
G. Varner,[11] K. E. Varvell,[49] M. N. Wagner,[9] C. H. Wang,[36] M.-Z. Wang,[37] Y. Watanabe,[22] K. M. Williams,[59] E. Won,[25] Y. Yamashita,[39] S. Yashchenko,[7] Y. Yusa,[40] V. Zhilich,[4] V. Zhulanov,[4] and A. Zupanc[23]
(The Belle Collaboration)

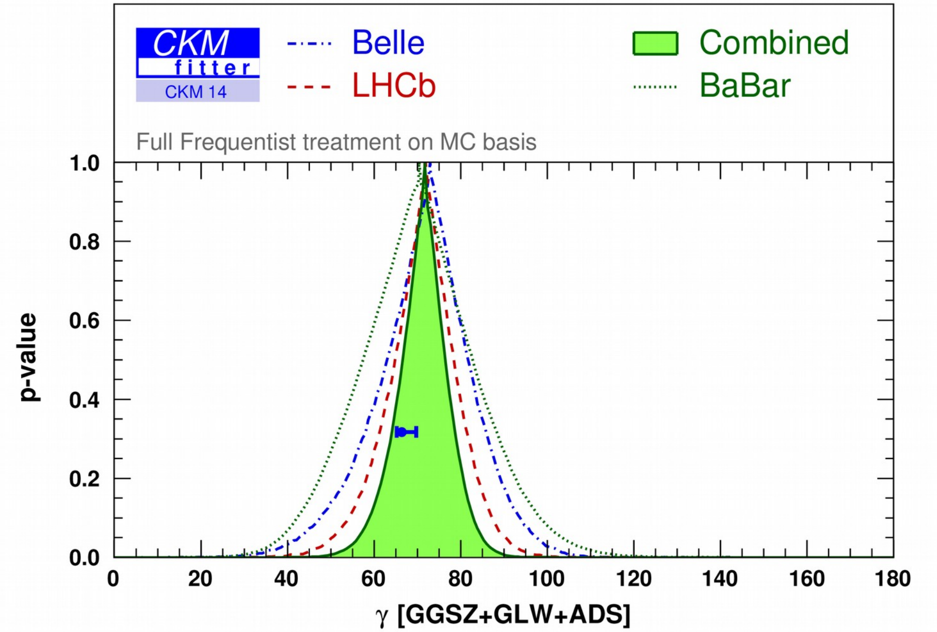
We report a study of the suppressed decay $B^- \to DK^-$, $D \to K^+\pi^-\pi^0$, where D denotes either a D^0 or a $\overline{D}^0$ meson. The decay is sensitive to the CP-violating parameter ϕ_3. Using a data sample of 772×10^6 $B\overline{B}$ pairs collected at the $\Upsilon(4S)$ resonance with the Belle detector, we measure the ratio of branching fractions of the above suppressed decay to the favored decay $B^- \to DK^-$, $D \to K^-\pi^+\pi^0$. Our result is $R_{DK} = [1.98 \pm 0.62(\text{stat.}) \pm 0.24(\text{syst.})] \times 10^{-2}$, which indicates the first evidence of the signal for this suppressed decay with a significance of 3.2 standard deviations. We measure the direct CP asymmetry between the suppressed B^- and B^+ decays to be $A_{DK} = 0.41 \pm 0.30(\text{stat.}) \pm 0.05(\text{syst.})$. We also report measurements for the analogous quantities $R_{D\pi}$ and $A_{D\pi}$ for the decay $B^- \to D\pi^-$, $D \to K^+\pi^-\pi^0$.

DK [PRD 88, 091104(R) (2013)]

⇒ Belle (and BaBar) $D(K\pi\pi^0)K$ results included in the γ combination

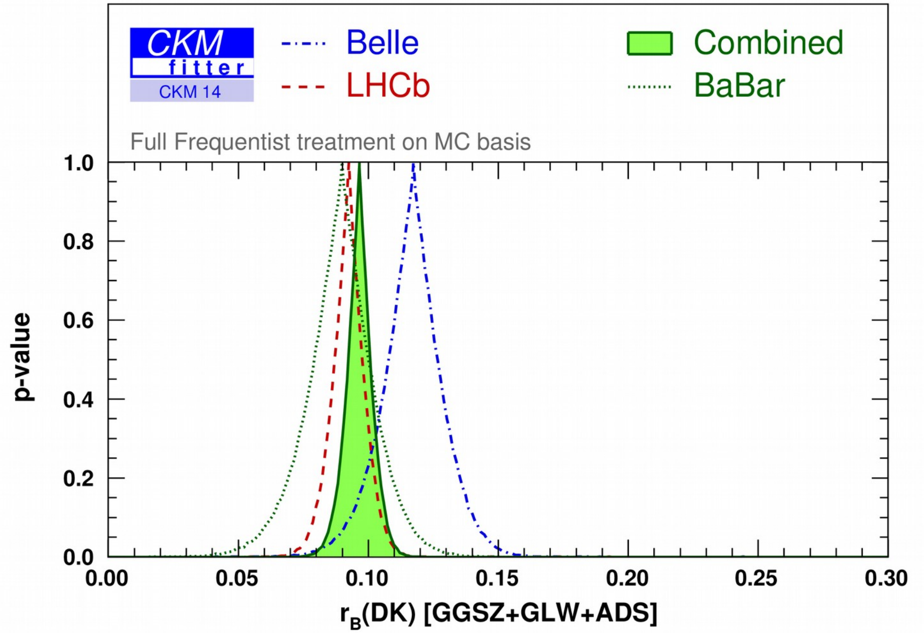
GGSZ+GLW+ADS

+20 obs.

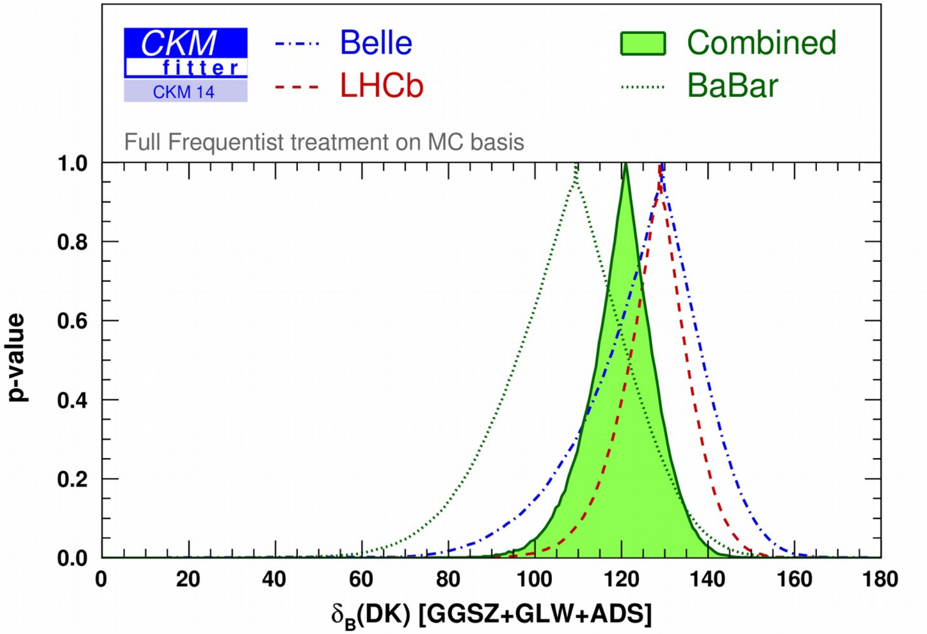


$$\gamma^{\mathbf{GGSZ+GLW+ADS}} = \left(71.7\,^{+7.1}_{-7.4}\right)^\circ$$

(results for DK)



$$r_B^{\mathbf{GGSZ+GLW+ADS}} = \left(0.0965\,^{+0.0062}_{-0.0063}\right)$$

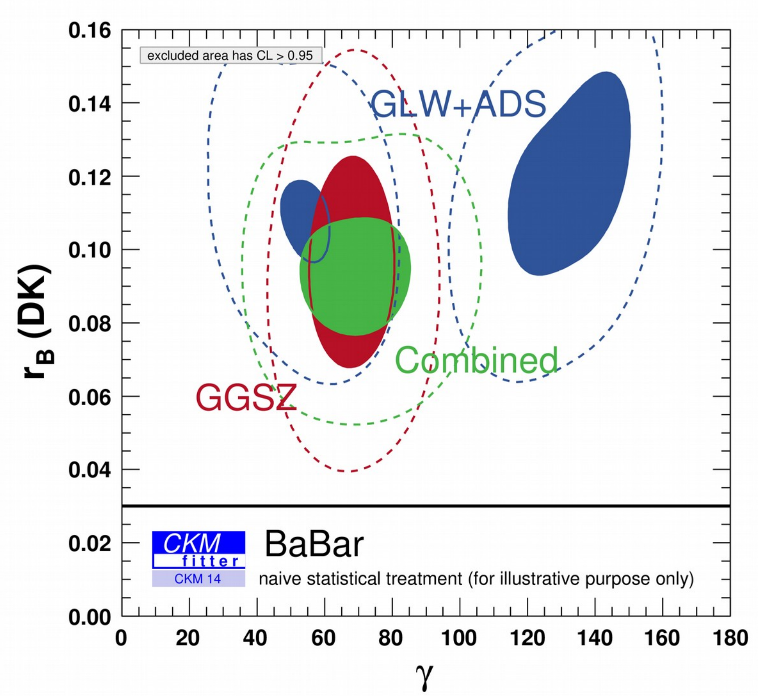


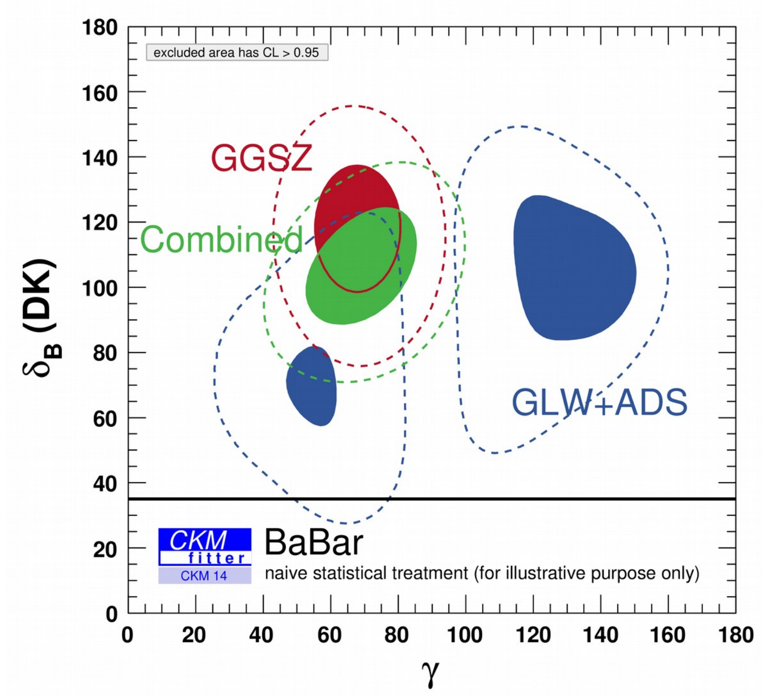
$$\delta_B^{\mathbf{GGSZ+GLW+ADS}} = \left(124.6\,^{+7.2}_{-7.9}\right)^\circ$$

GGSZ versus GLW+ADS

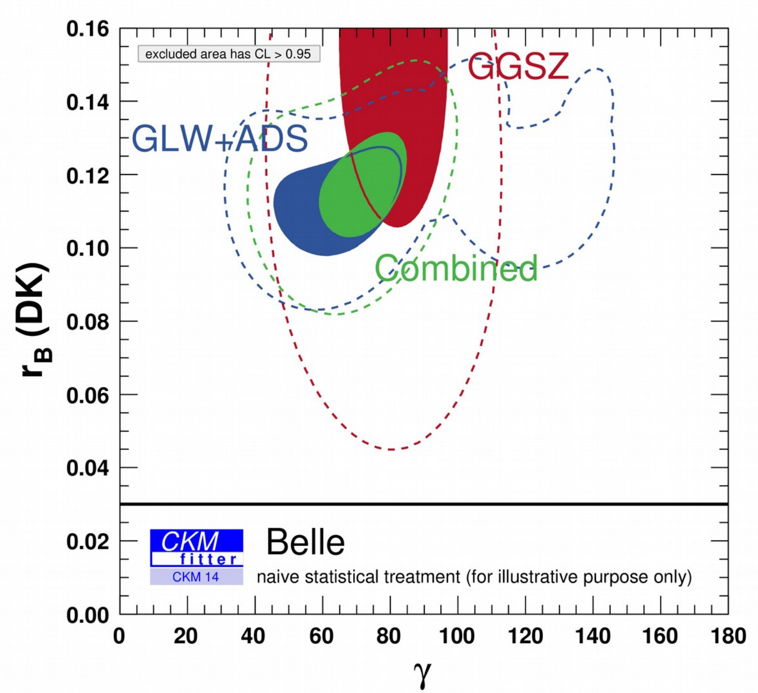
($r_B(DK)$ vs γ, $\delta_B(DK)$ vs γ)

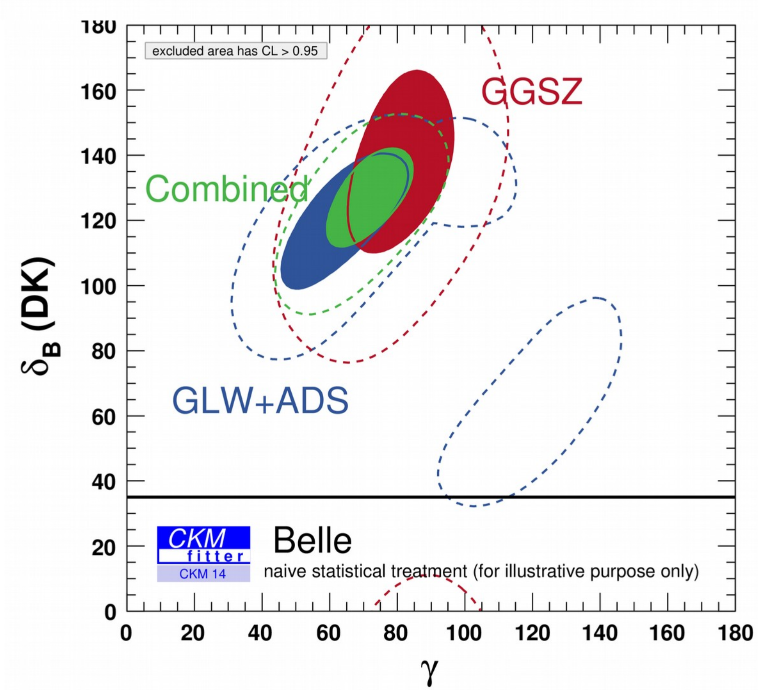
BaBar





Belle

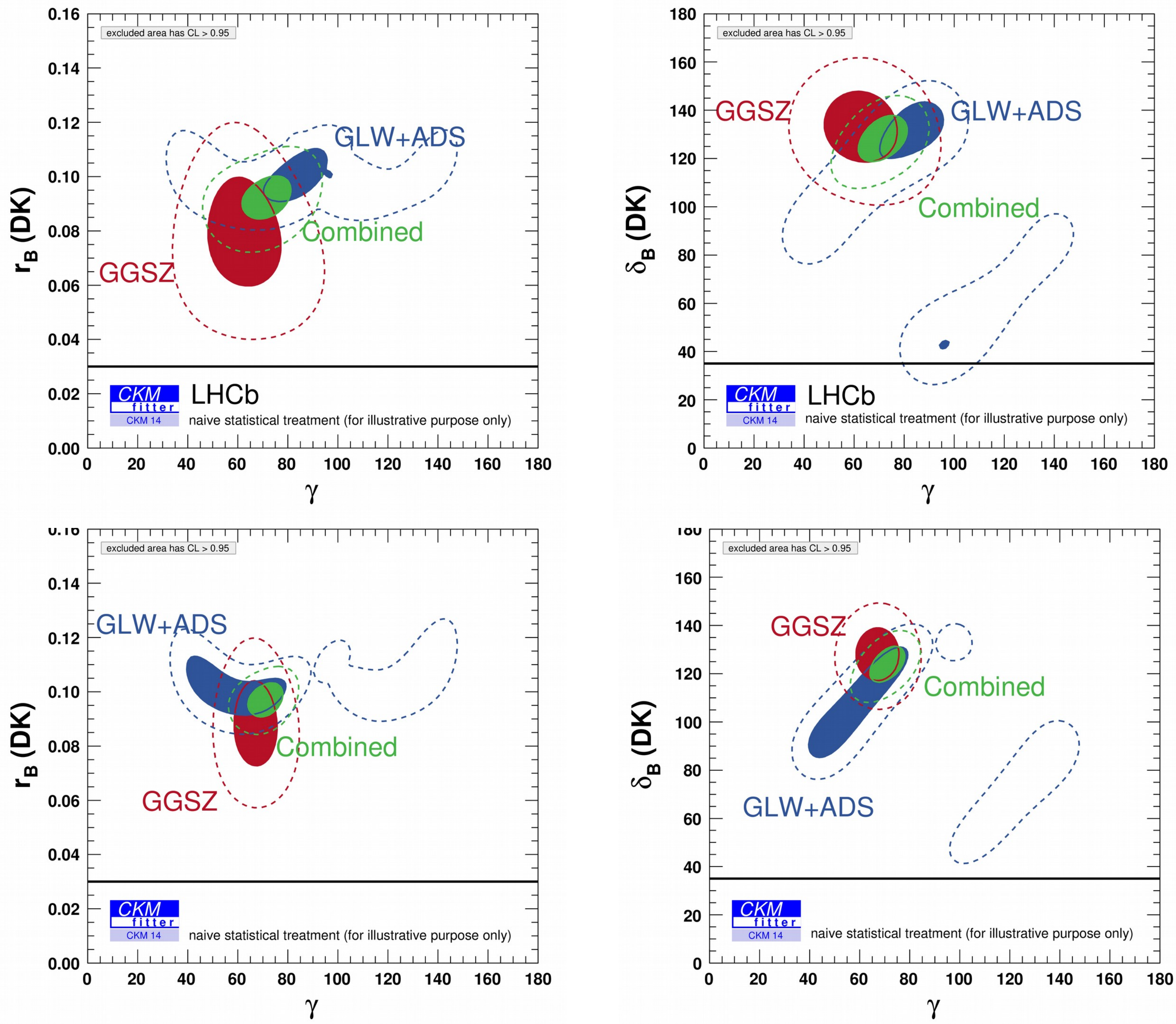




GGSZ versus GLW+ADS (r_B(DK) vs γ, δ_B(DK) vs γ)

LHCb

All



The small r_B issue

clearly in the $r_B \to 0$ limit the interference disappears and there is no sensitivity to the phase γ

when the true value of r_B is small, then the distribution of $\hat{r}_B$ best fit values for randomly generated data is biased towards larger values, until the experimental errors are sufficiently small to exclude the $r_B \sim 0$ region

on the other hand the error on γ is roughly proportional to $1/r_B$, hence for small r_B it is biased towards smaller values

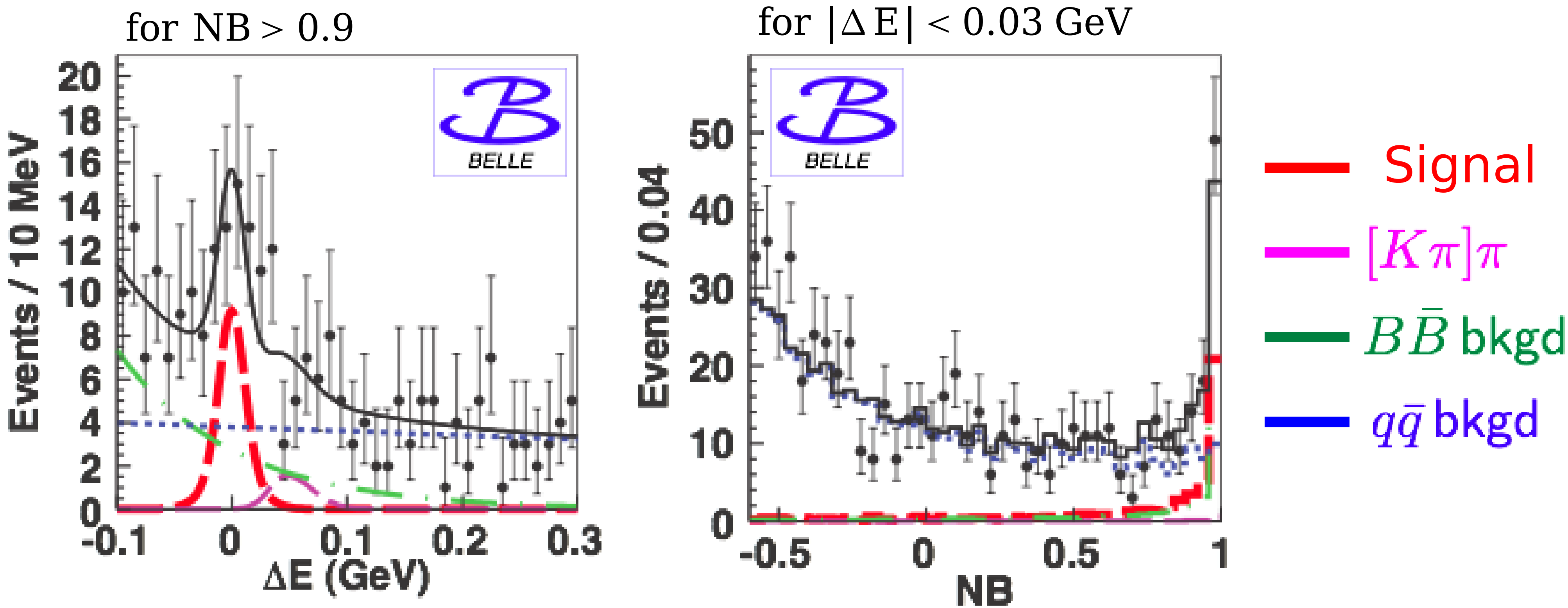
in the language of frequentist statistics it means that the usual $\Delta \ln \mathcal{L} = 1/2$ rule does not work here, the 68%CL interval extracted from it does not cover the true value of γ at 68% frequency (undercoverage)

to correct for this effect one has to compute the actual distribution of the profile log-likelihood, and from that distribution deduce a p-value or a CL interval

problem: as soon as the log-likelihood is not distributed as a χ^2, its distribution *a priori* depends on the *nuisance parameters*, namely r_B, δ_B etc.

Yields for the ADS mode $B^- \to [K^+\pi^-]_D K^-$ from 772 million $B\bar{B}$ events

PRL 106, 231803 (2011)



$56.0^{+15.1}_{-14.2}$ events

First evidence obtained with a significance of 4.1σ (including syst.)

$$R_{DK} = (1.63\,^{+0.44}_{-0.41}\,^{+0.07}_{-0.13}) \times 10^{-2}$$

$$A_{DK} = -0.39\,^{+0.26}_{-0.28}\,^{+0.04}_{-0.03}$$