Measurements of gamma angle using B→DK at LHCb

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Rencontres de Moriond QCD and High Energy Interactions

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Outline

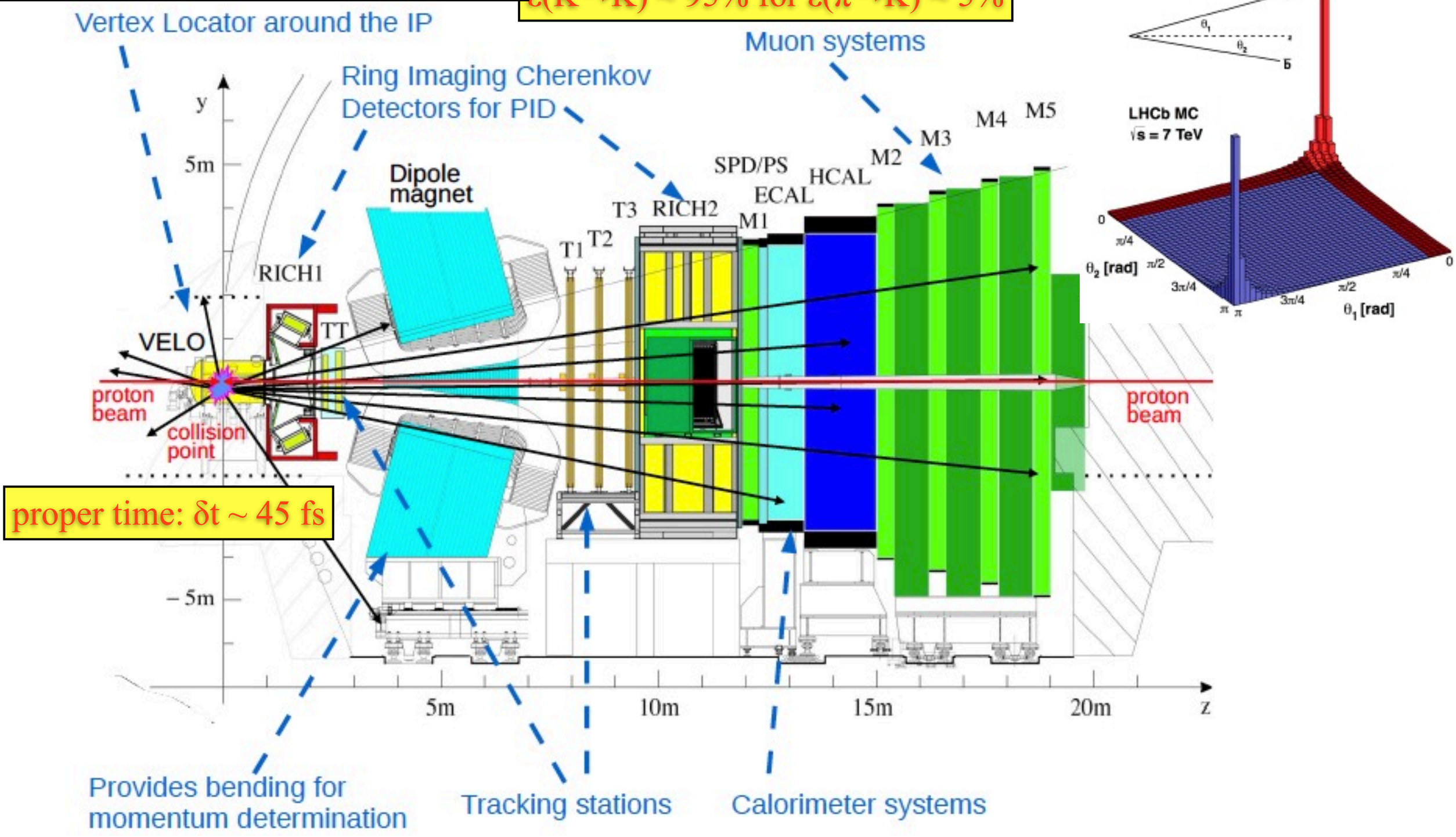
- ➢ **Brief view of the LHCb experiment**
- ➢ **Brief introduction of gamma Measurements at tree level**
- ➢ **Measurements with D→2Body**
- ➢ **Measurements with D→3Body**
- ➢ **Gamma Combination**
- ➢ **Conclusion**

LHCb Apparatus

Designed for heavy quark physics
Forward detector

~20μm IP resolution for high-p_T tracks

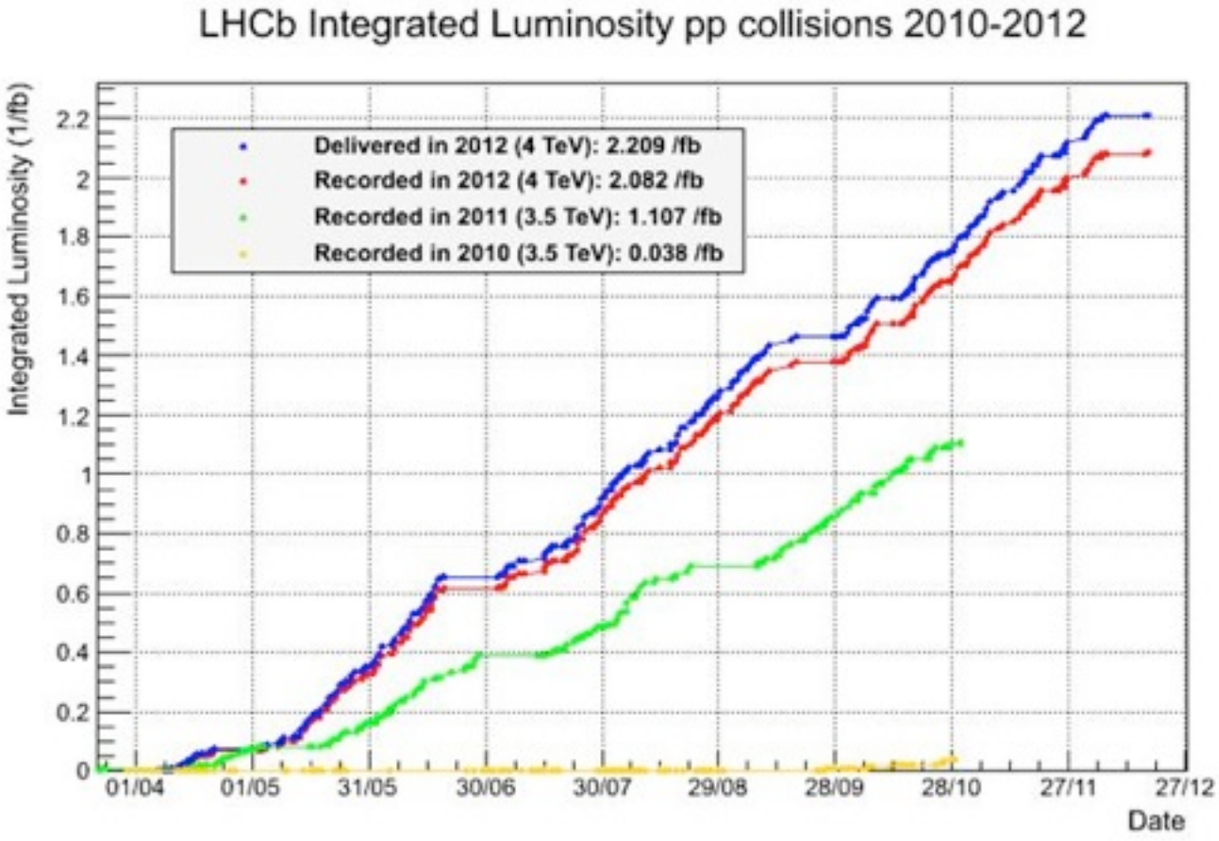
$\varepsilon(K\to K) \sim 95\%$ for $\varepsilon(\pi\to K) \sim 5\%$

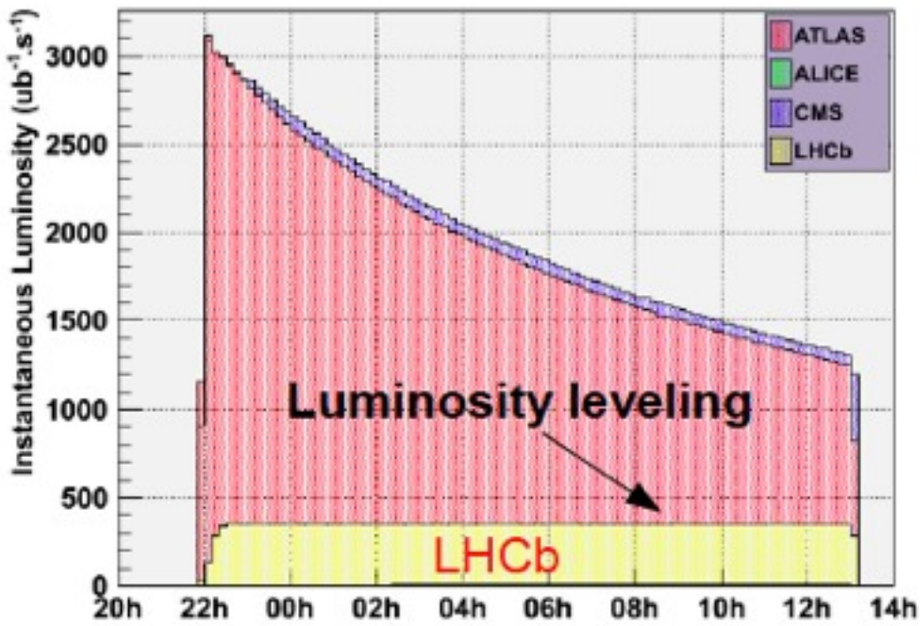


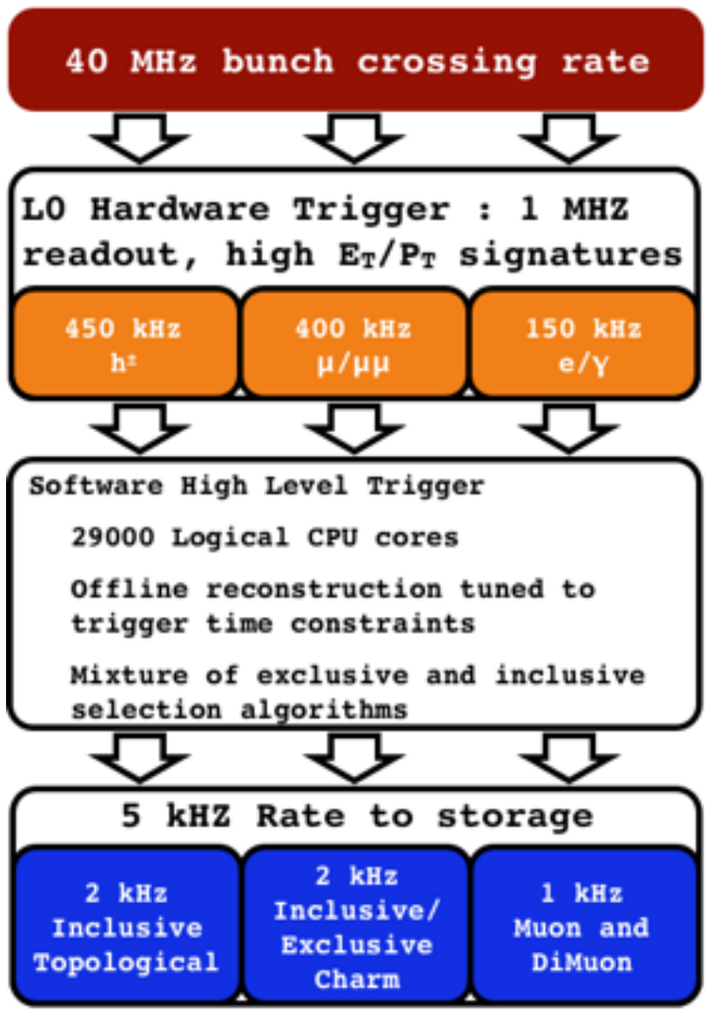
proper time: $\delta t \sim 45$ fs

Charged Tracks $\Delta p/p \sim 0.4\%$ at 5 GeV/c to 0.6% at 100 GeV/c, $\sigma(m) \sim 10$-25 MeV

LHCb Operation & Trigger



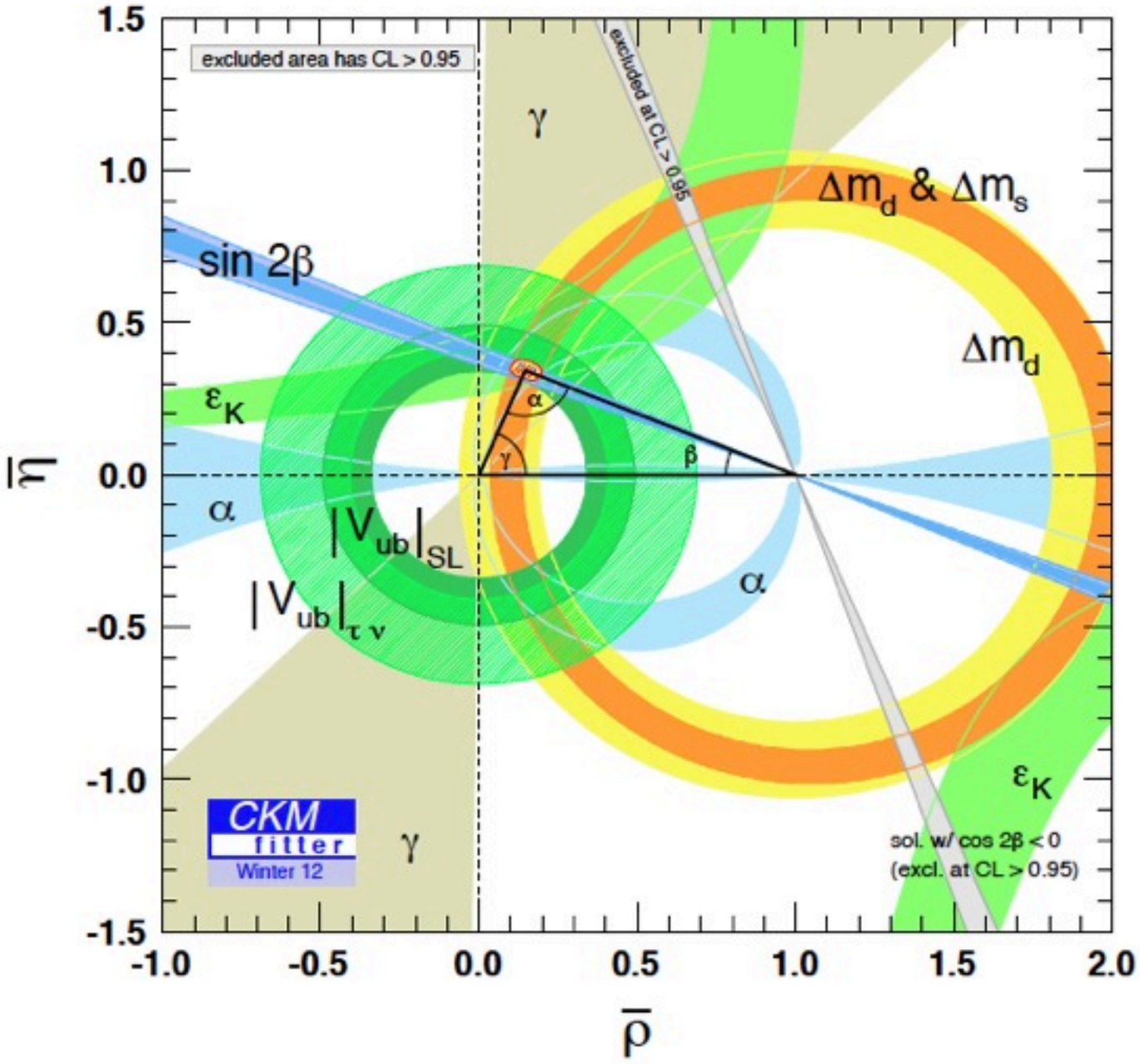




- **1.0 fb^{-1} data @ 7 TeV in 2011**
  (Results in this talk)
- **~2 fb^{-1} data @ 8 TeV in 2012**
- **Luminosity leveling**
- **Three level triggers:**
  B decays with hadrons
  ε (L0 x HLT) ~ 20-50 %

CKM Angle gamma

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$



$$\gamma = \arg\left[-V_{ud}V_{ub}^{*}/(V_{cd}V_{cb}^{*})\right]$$

➢ **The least well known variable**

Babar: $\gamma = (69^{+17}_{-16})°$ Babar Collaboration arXiv:1301.1029

Belle: $\gamma = (68^{+15}_{-14})°$ Belle Collaboration arXiv:1301.2033

CKMFitter: $\gamma = (66 \pm 12)°$

UTFit: $\gamma = (76 \pm 10)°$

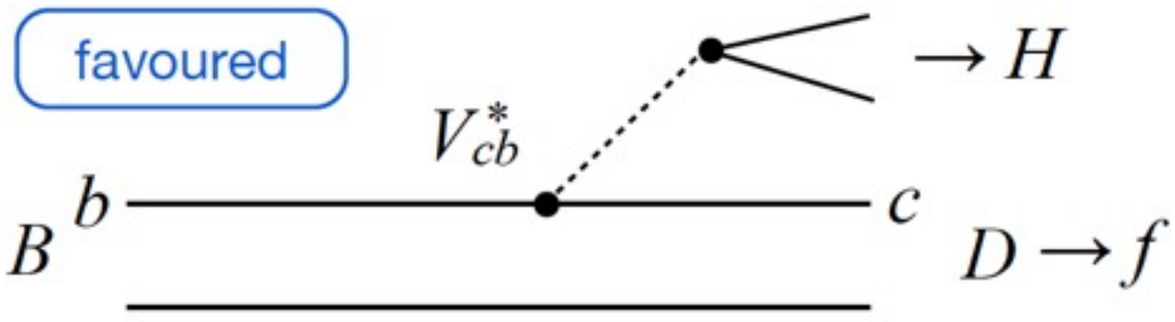
γ from other constraints: ~ 4.3° CKM Fitter

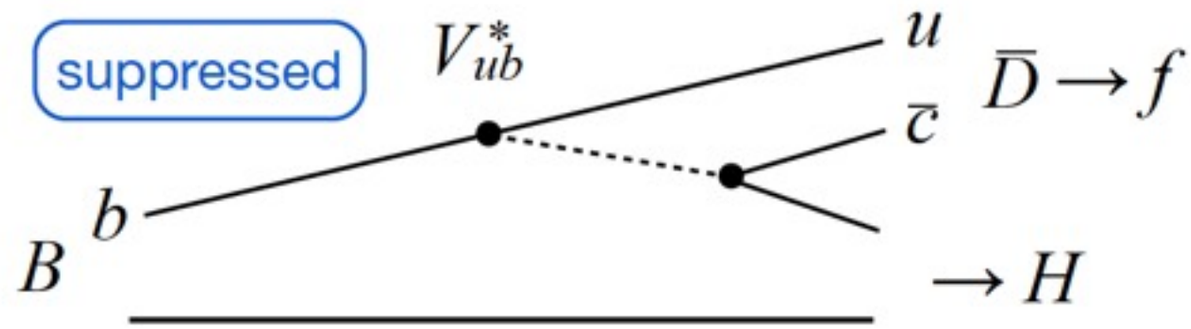
Theory: $\delta\gamma/\gamma \sim 0.000001$ Jure Zupan, arXiv:1101.0134

➢ **Can be accessed through tree-level transitions (i.e. B→DK) ➡ Test of standard model (This Talk)**

➢ **Can be accessed through loop-level transitions (i.e. $B_{(s)}$→ππ(KK)) ➡ Probe of new physics**

γ in B decays to Open Charm





H = K (π, KK, Kππ etc)

f = CP eigenstates, e.g. KK, ππ (GLW)

M. Gronau and D. Wyler, Phys. Lett. B 253 (1991) 483
M.Gronau and D. London, Phys. Lett. B 265 (1991) 172

f = quasi-flavour-specific states
e.g. Kπ (ADS)

D. Atwood, I. Dunietz and A. Soni,
Phys. Rev. Lett. 78 (1997) 3257

f = self-conjugate multi(3)-body states
e.g. $K_s\pi\pi$ (GGSZ)

A. Giri, Y. Grossman, A. Soffer and J. Zupan, Phys. Rev. D68 (2003) 054018

$$\Gamma(B \to D[\to f]H) = A_c^2(r_D^2 + r_B^2 + 2r_B r_D Re(e^{i(\delta_B + \delta_D \pm \gamma)}))$$

δ_B, δ_D: hadronic phase difference for B and D decays

r_D: ratio of D decay amplitudes, r_D=1 for GLW

Neglecting mixing in D:

T. Grossman, A. Soffer, J. Zupan, arXiv: hep-ph/0505270

Neglecting CPV in D:

B. Bhattacharya, D. London, M. Gronau, J. L. Rosner, arXiv: 1301.5631

Sensitivity of γ depends largely on $r_B = A_u/A_c$:

B→DK: $r_B^K \sim 0.1$ **(more sensitive)** **B→Dπ:** $r_B^\pi \sim 0.01$

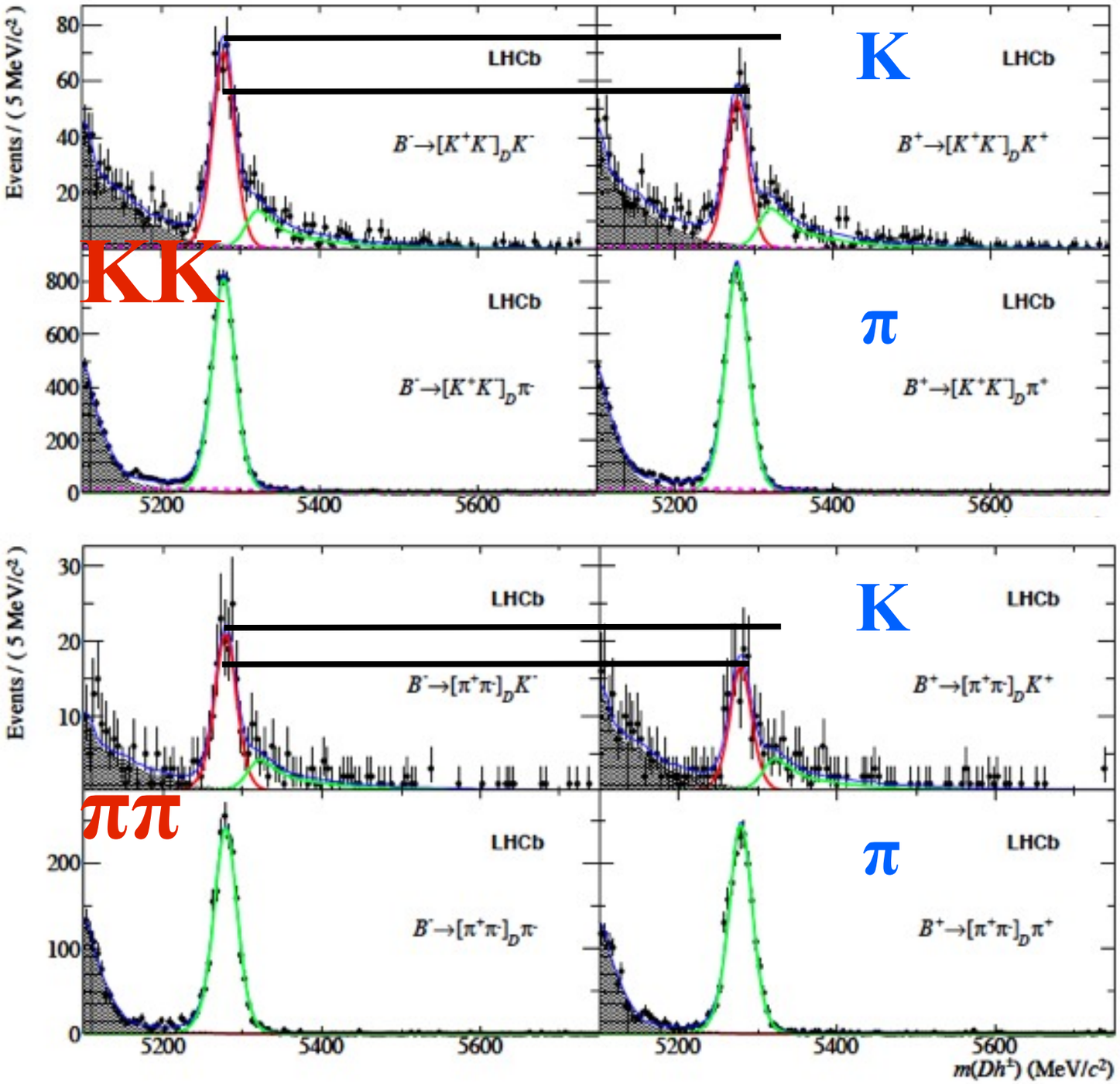
γ Studies with $B^+ \to D^0 K^+$ (GLW)

Phys. Lett. B 712 (2012) 203,
arXiv: 1203.3662

$$R_{CP+} = 2\frac{\Gamma(B^- \to D_{CP+}K^-) + \Gamma(B^+ \to D_{CP+}K^+)}{\Gamma(B^- \to D^0K^-) + \Gamma(B^+ \to \bar{D}^0K^+)} = 1 + r_B^2 + 2r_B \cos\delta_B \cos\gamma$$

$$A_{CP+} = \frac{\Gamma(B^- \to D_{CP+}K^-) - \Gamma(B^+ \to D_{CP+}K^+)}{\Gamma(B^- \to D^0K^-) + \Gamma(B^+ \to \bar{D}^0K^+)} = \frac{2r_B \sin\delta_B \sin\gamma}{R_{CP+}}$$

$D^0 \to KK$
$D^0 \to \pi\pi$



➢ **3 parameters, 2 observables**

➢ **Two GLW channels used and averaged over R_{CP} and A_{CP}: $D^0 \to KK$, $D^0 \to \pi\pi$**

➢ **No CP violation assumed in H=π channels and favored D decay mode**

$$R_{CP+} = 1.007 \pm 0.038 \pm 0.012\,,$$
$$A_{CP+} = 0.145 \pm 0.032 \pm 0.010\,,$$

4.5σ!!

γ Studies with $B^+ \to D^0 K^+$ (ADS)

Phys. Lett. B 712 (2012) 203,
arXiv: 1203.3662

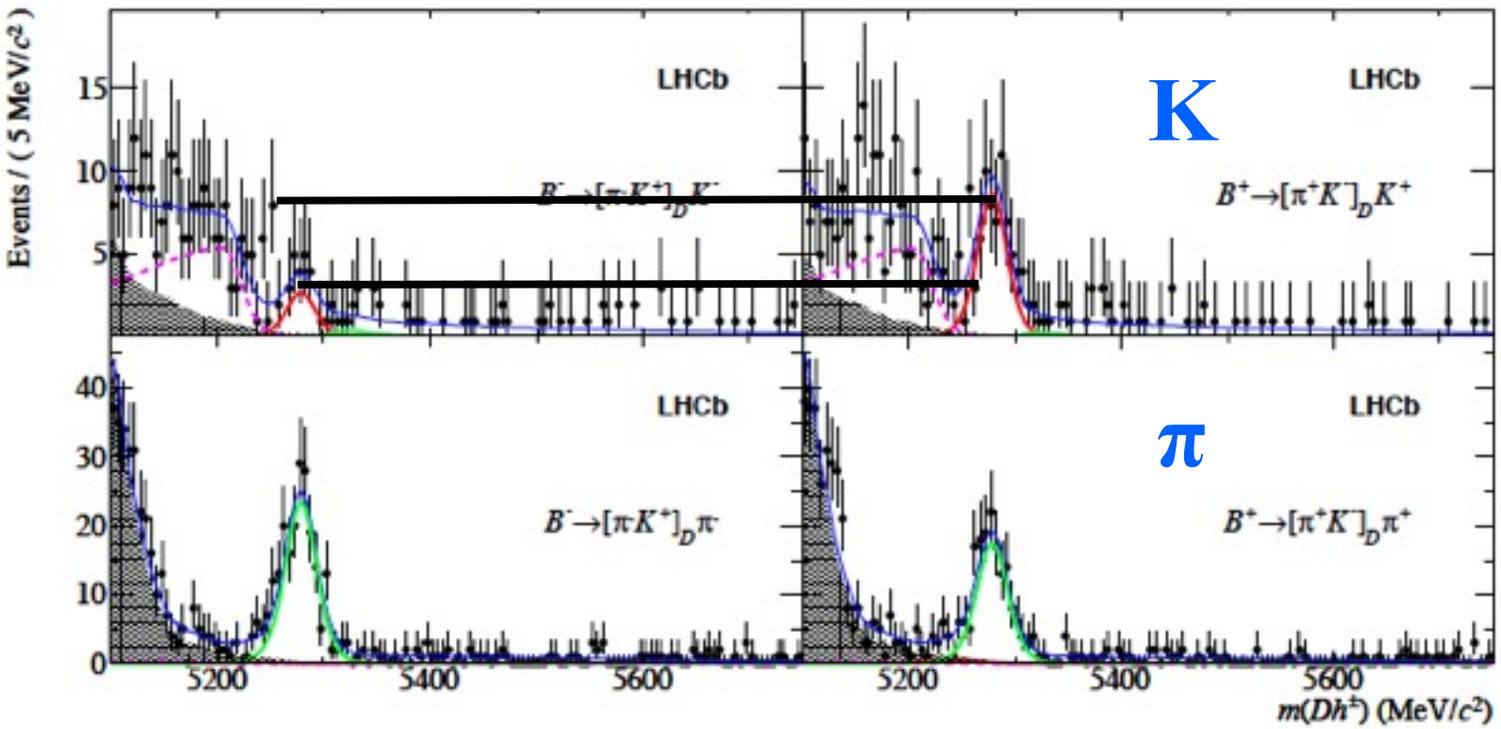
$$R_{ADS} = \frac{\Gamma(B^- \to D[\to \pi^- K^+]K^-) + \Gamma(B^+ \to D[\to \pi^+ K^-]K^+)}{\Gamma(B^- \to D[K^- \pi^+]K^-) + \Gamma(B^+ \to D[\to K^+ \pi^-]K^+)} = r_B^2 + r_D^2 + 2 r_B r_D \cos\gamma \cos(\delta_B + \delta_D)$$

$$A_{ADS} = \frac{\Gamma(B^- \to D[\to \pi^- K^+]K^-) - \Gamma(B^+ \to D[\to \pi^+ K^-]K^+)}{\Gamma(B^- \to D[K^- \pi^+]K^-) + \Gamma(B^+ \to D[\to K^+ \pi^-]K^+)} = \frac{2 r_B r_D \sin\gamma \sin(\delta_B + \delta_D)}{R_{ADS}}$$

➢ **5 parameters, 4 observables + 2 inputs from D decays**

CLEO Collaboration, Phys. Rev.D 82(2010) 112006

First observation of $B^+ \to D^0 K^+$ ADS mode: 5.1σ



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

$B \to D\pi$ channel:

$$R_{\mathrm{ADS}(\pi)} = 0.00410 \pm 0.00025 \pm 0.00005$$
$$A_{\mathrm{ADS}(\pi)} = 0.143 \pm 0.062 \pm 0.011$$

$B \to DK$ channel:

$$R_{\mathrm{ADS}(K)} = 0.0152 \pm 0.0020 \pm 0.0004$$
$$A_{\mathrm{ADS}(K)} = -0.52 \pm 0.15 \pm 0.02$$

4.0σ

➢ **Combining GLW and ADS modes, we have 5.8σ! significance of direct CP violation (first observation)**

γ Studies with $B^+ \to D^0 K^+$ (GGSZ)

Phys. Lett. B 718 (2012) 43,
arXiv: 1209.5869

➢ **Model independent method (using CLEO-c information) with binning on $D^0 \to K_s\pi\pi$ and $D^0 \to K_sKK$ Dalitz region:**

Re-phase of parameters:

$$x_\pm = \mathrm{Re}[r_B e^{i(\delta_B \pm \gamma)}] \qquad y_\pm = \mathrm{Im}[r_B e^{i(\delta_B \pm \gamma)}]$$

Number of events in bins of the Dalitz plot:

$$N^+_{\pm i} = h_{B+}\left[K_{\mp i} + (x_+^2 + y_+^2)K_{\pm i} + 2\sqrt{K_i K_{-i}}(x_+ c_{\pm i} \mp y_+ s_{\pm i})\right]$$

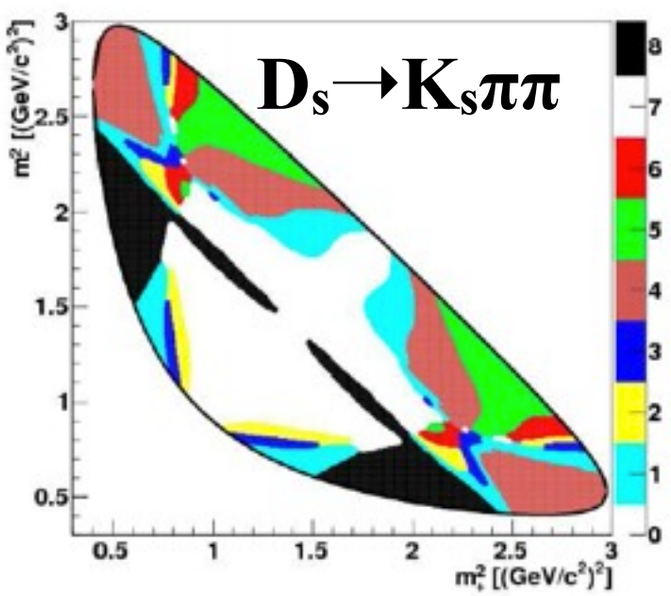
$$N^-_{\pm i} = h_{B-}\left[K_{\pm i} + (x_-^2 + y_-^2)K_{\mp i} + 2\sqrt{K_i K_{-i}}(x_- c_{\pm i} \pm y_- s_{\pm i})\right]$$

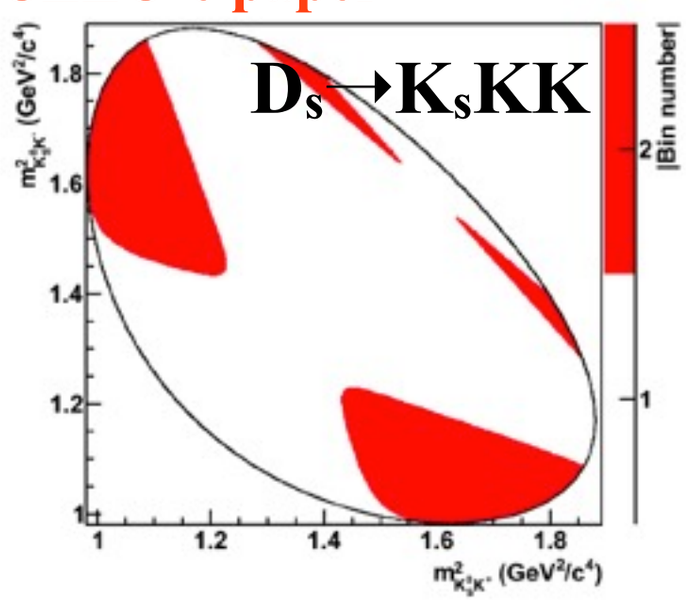
CLEO-c information

CLEO Collaboration, Phys. Rev.D 82(2010) 112006

K_i represent Dalitz distribution in flavor-tagged D decays

Colors for bin number as in CLEO-c paper



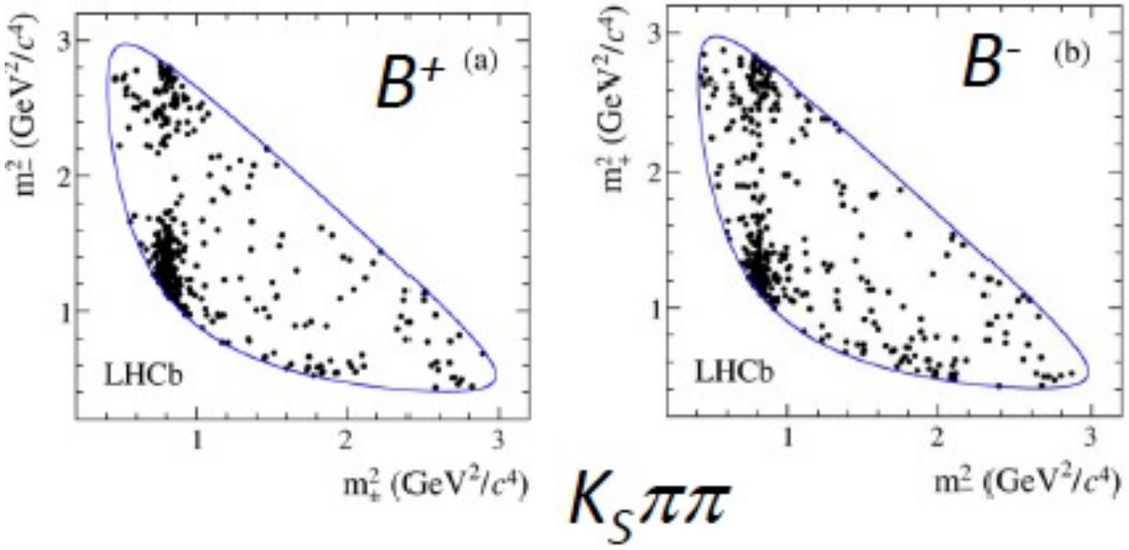


Binning optimized according to Dalitz analysis;
Deviation only reduces sensitivity but does not introduces bias

γ Studies with $B^+ \to D^0 K^+$ (GGSZ): Results

Phys. Lett. B 718 (2012) 43, arXiv: 1209.5869

➢ **Around 660 $K_s\pi\pi$ and 100 K_sKK signal events**

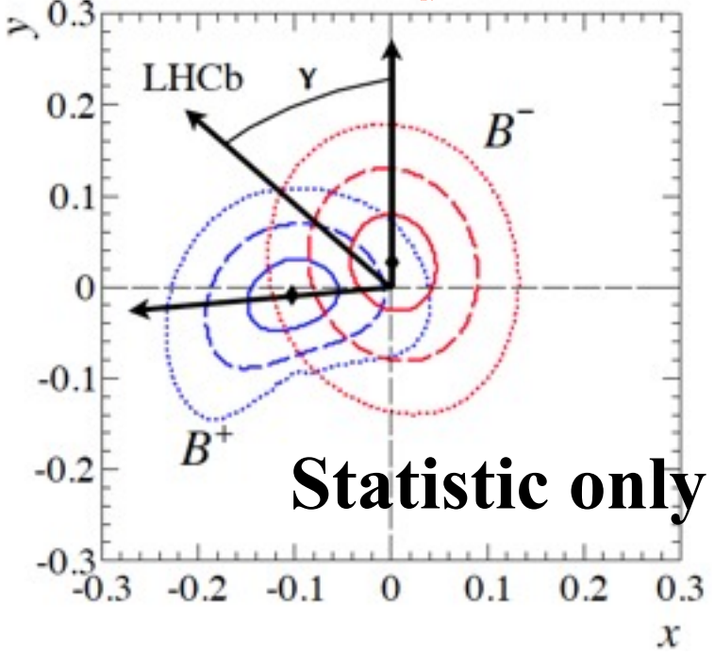


$K_S\pi\pi$

$$x_- = (0.0 \pm 4.3 \pm 1.5 \pm 0.6) \times 10^{-2},$$
$$y_- = (2.7 \pm 5.2 \pm 0.8 \pm 2.3) \times 10^{-2},$$
$$x_+ = (-10.3 \pm 4.5 \pm 1.8 \pm 1.4) \times 10^{-2},$$
$$y_+ = (-0.9 \pm 3.7 \pm 0.8 \pm 3.0) \times 10^{-2},$$

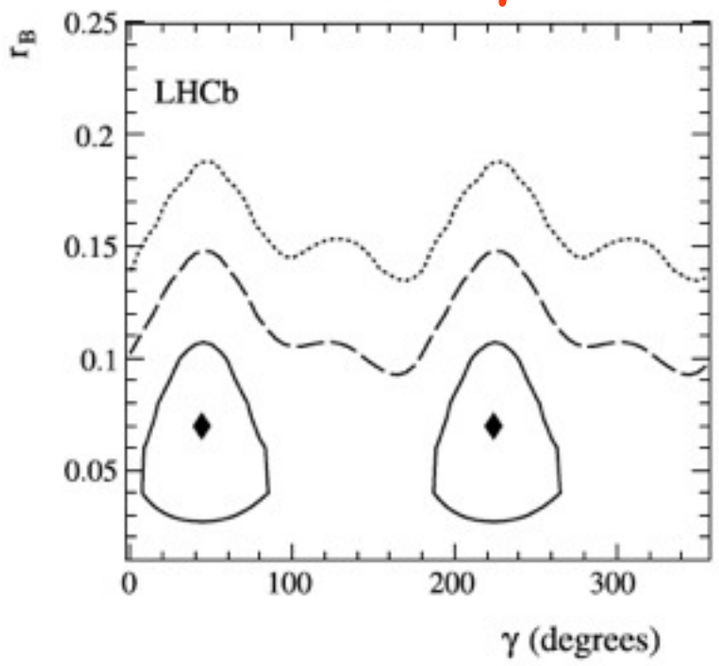
Stat. Sys. CLEO-c input

Measured x-y contour

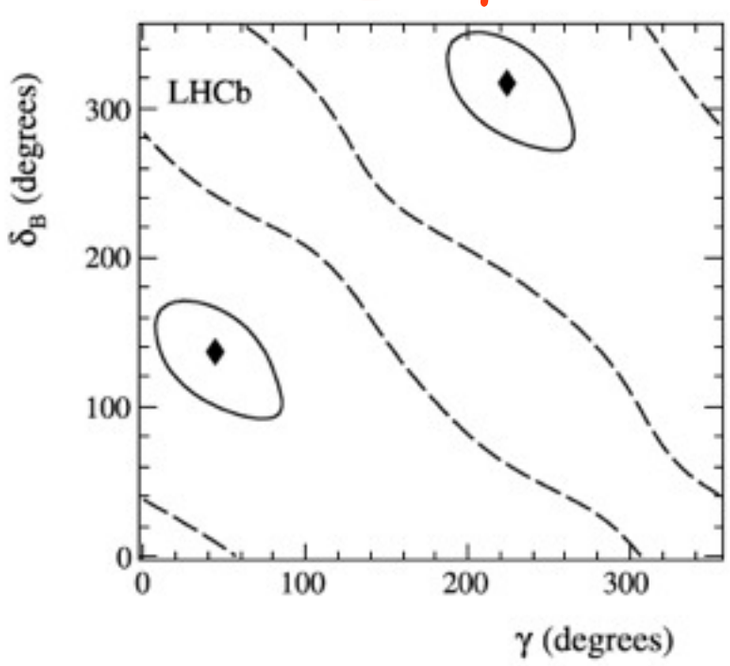


Statistic only

Fitted r_B vs γ



Fitted δ_B vs γ



$r_B = 0.07 \pm 0.04$

$\gamma = (44^{+43}_{-38})^\circ$

$\delta_B = (137^{+35}_{-46})^\circ$

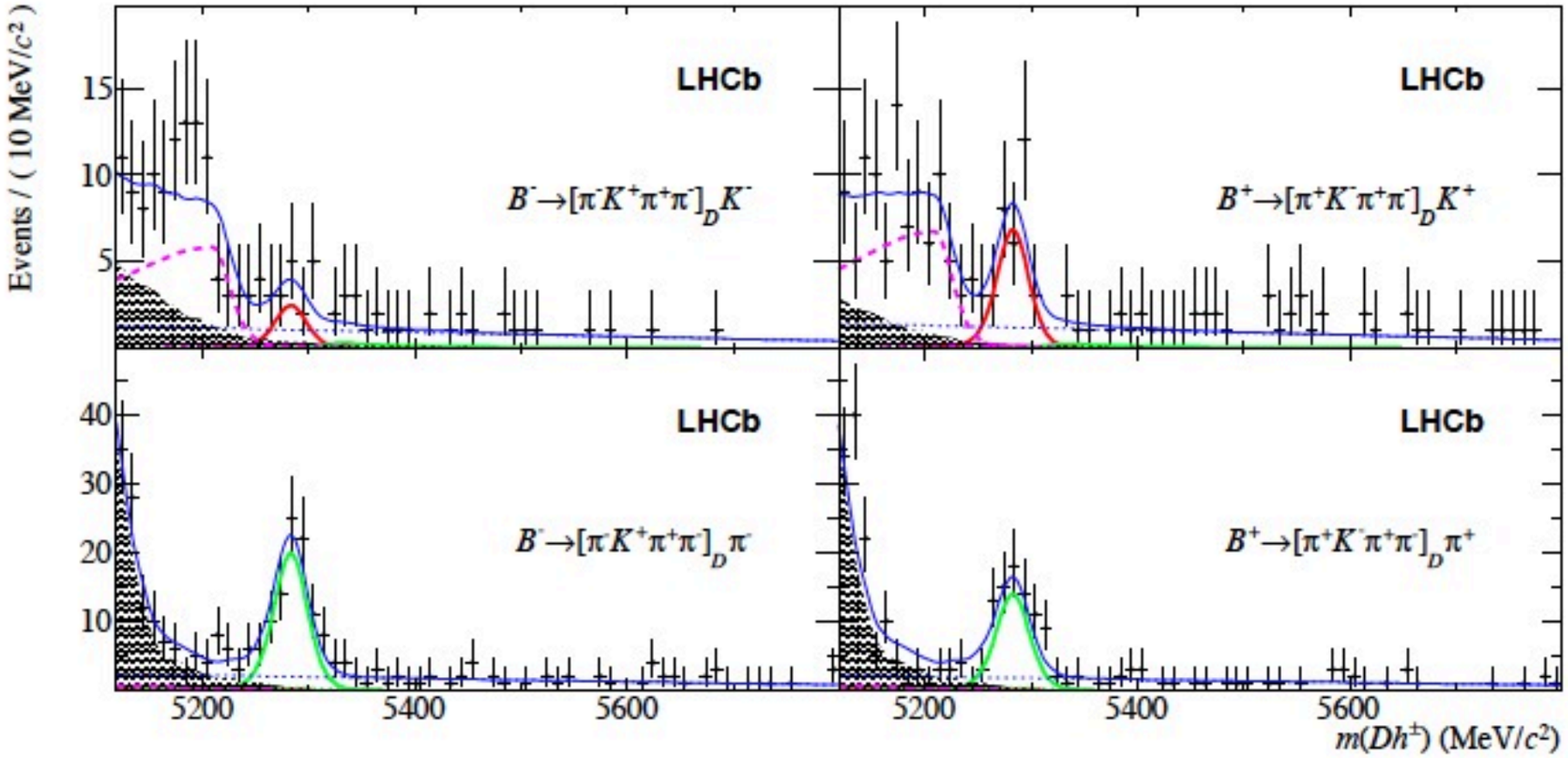
➢ **r_B lower than world average (but consistent) → smaller sensitivity to γ**

γ Studies with $B^+ \to D^0 K^+$ (4-Body ADS)

LHCb-PAPER-2012-055

➢ **D^0 decay to $K\pi\pi\pi$ (similar analysis as 2-Body)**

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



Yields for suppressed mode:

~ 40 B→DK

First observation: 5.7σ

~ 160 B→Dπ > 10σ

Inputs from CLEO-c:

CLEO Collaboration, Phys. Rev. D80 (2009) 031105, arXiv:0903.4853

$$R^{K3\pi}_{\mathrm{ADS}(K)} = 0.0124 \pm 0.0027 \qquad A^{K3\pi}_{\mathrm{ADS}(K)} = -0.42 \pm 0.22$$

$$R^{K3\pi}_{\mathrm{ADS}(\pi)} = 0.00369 \pm 0.00036 \qquad A^{K3\pi}_{\mathrm{ADS}(\pi)} = +0.13 \pm 0.10$$

➢ **Constraint on r_B:** $r_B^K = 0.097 \pm 0.011$

γ Combination with LHCb data: Inputs

Analysis	$N_{\rm obs}$	Parameters
$B^+ \to Dh^+$, $D \to hh$, GLW/ADS	14	γ, r_B, δ_B, r_B^π, δ_B^π, $R_{K/\pi}$, $r_{K\pi}$, $\delta_{K\pi}$, $\Delta a_{CP}^{\rm dir}$
$B^+ \to DK^+$, $D \to K_S^0 h^+ h^-$, GGSZ	4	γ, r_B, δ_B
$B^+ \to Dh^+$, $D \to K\pi\pi\pi$, ADS	7	γ, r_B, δ_B, r_B^π, δ_B^π, $R_{K/\pi}$, $r_{K3\pi}$, $\delta_{K3\pi}$, $\kappa_{K3\pi}$
Cleo $D^0 \to K\pi$, $D^0 \to K\pi\pi\pi$	9	x_D, y_D, $\delta_{K\pi}$, $\delta_{K3\pi}$, $\kappa_{K3\pi}$, $r_{K\pi}$, $r_{K3\pi}$, $\mathcal{B}(K\pi)$, $\mathcal{B}(K\pi\pi\pi)$
CP violation in the charm system	2	$A_{CP}^{D\to KK}$, $A_{CP}^{D\to\pi\pi}$
$B^0 \to DK^{0*}$, $D \to hh$, $K^* \to K\pi$, GLW	2	γ, $r_B^{K^{0*}}$, $\delta_B^{K^{0*}}$, $\kappa_B^{K^{0*}}$
$B^+ \to DK^+\pi^+\pi^-$, $D \to K\pi$, ADS	2	γ, $r_B^{DK\pi\pi}$, $\delta_B^{DK\pi\pi}$, $\kappa_B^{DK\pi\pi}$, $r_{K\pi}$, $\delta_{K\pi}$
$B^0 \to D^+\pi^-$ time dependent	5	γ, $\lambda_{D^+\pi^-}$, $\delta_{D^+\pi^-}$, Δm_d, $\sin 2\beta$
$B_s^0 \to D_s^+ K^-$ time dependent	5	γ, λ_{D_sK}, δ_{D_sK}, Δm_s, Γ_s, $\Delta\Gamma_s$, ϕ_s

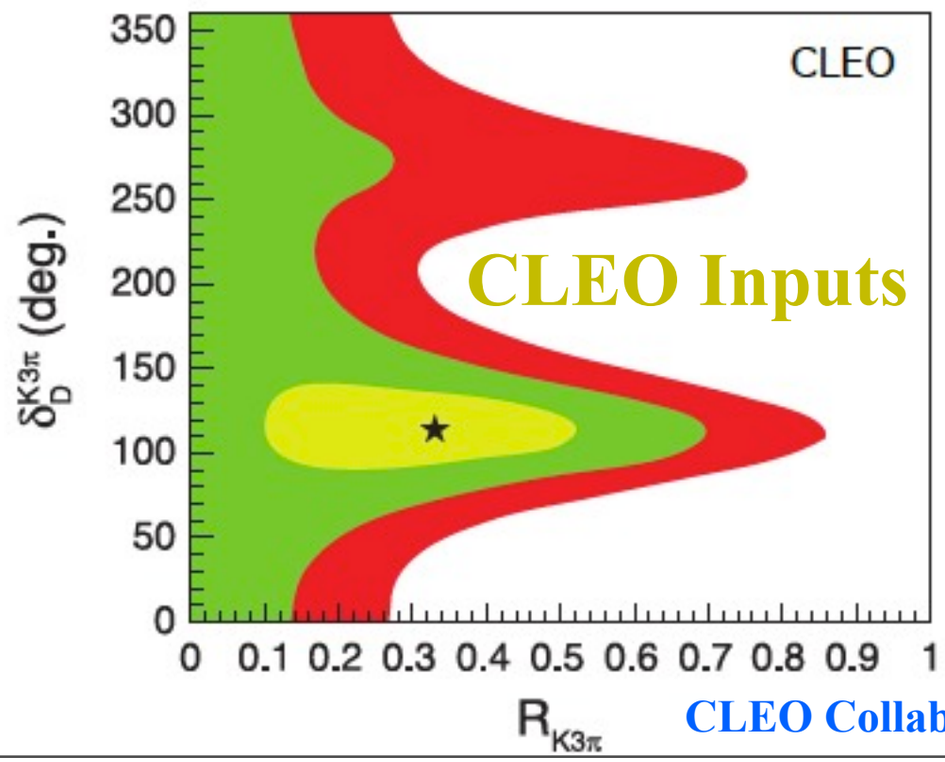
Parameters common: gamma combination improve better than simple average

Included in Combination

Not Included in Combination

Observed variables

γ, r_B etc + nuisance parameters



➢ **D mixing ignored at this precision**

➢ **CP violation in charm system included**

$$\Delta a_{CP}^{\rm dir} = (-0.656 \pm 0.154) \times 10^{-2}$$

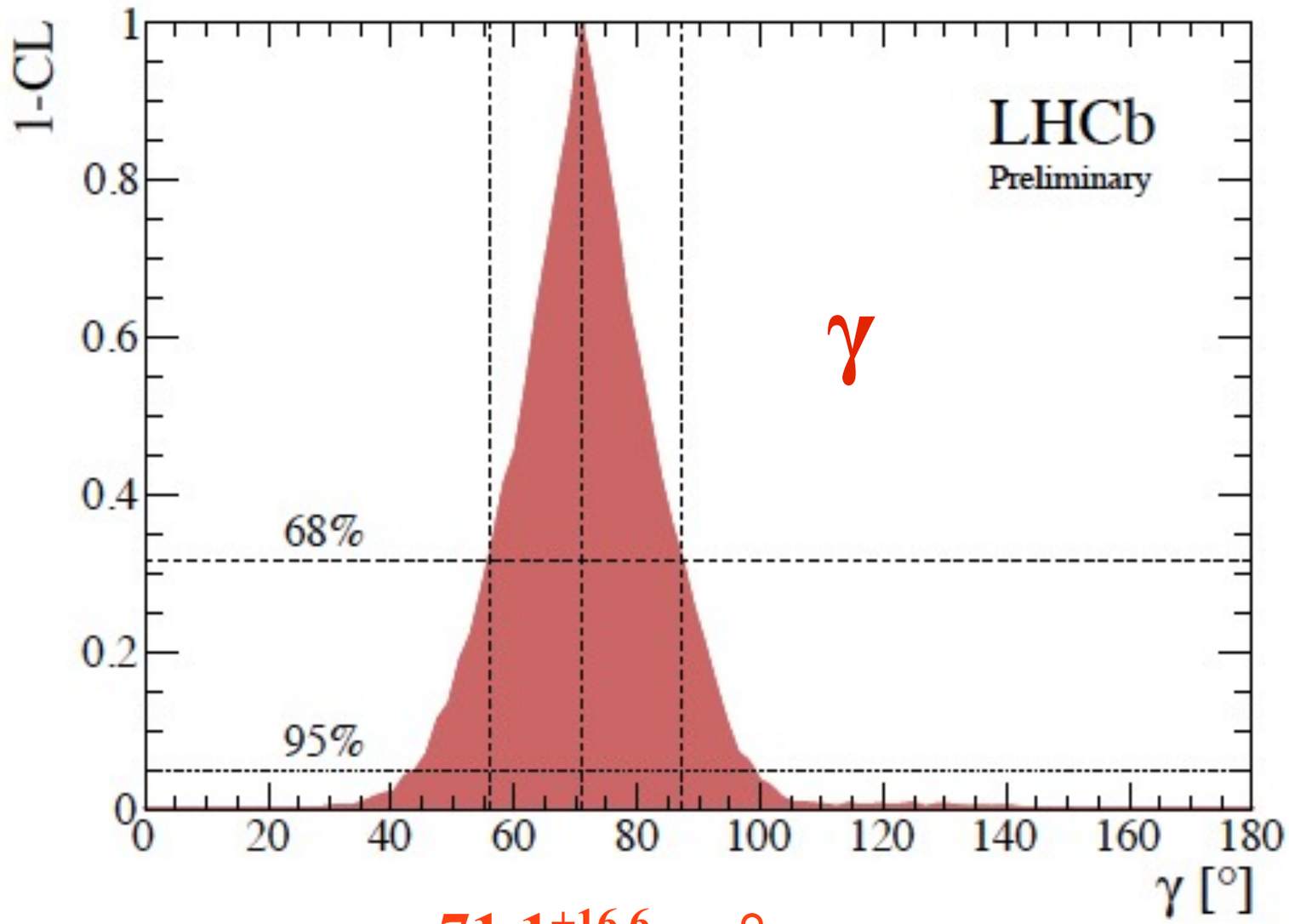
HFAG, arXiv: 1207.1158

➢ **The combination uses frequentist technique**

CLEO Collaboration, Phys. Rev. D80 (2009) 031105, arXiv:0903.4853

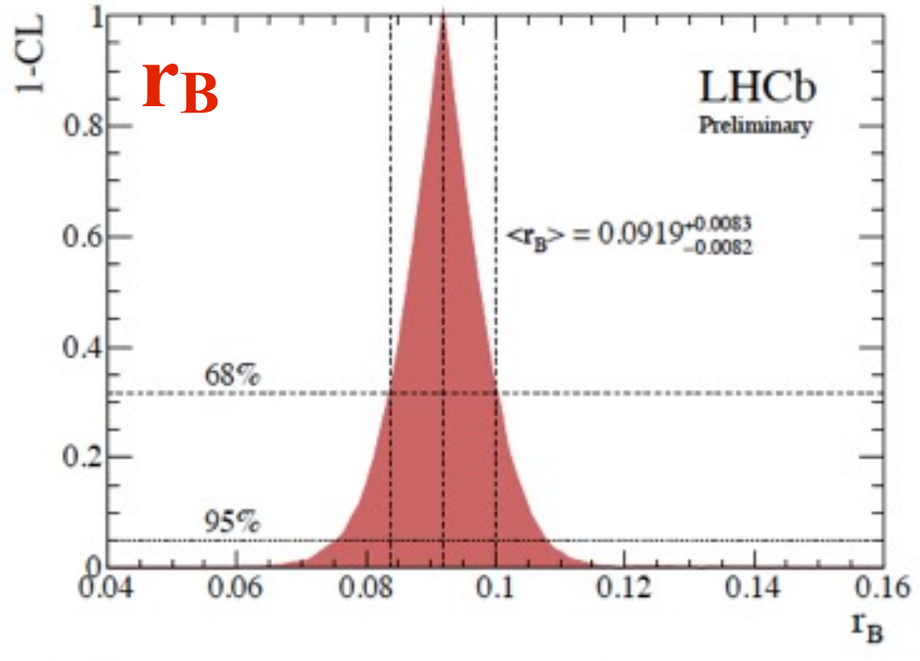
γ Combination with LHCb data: Results

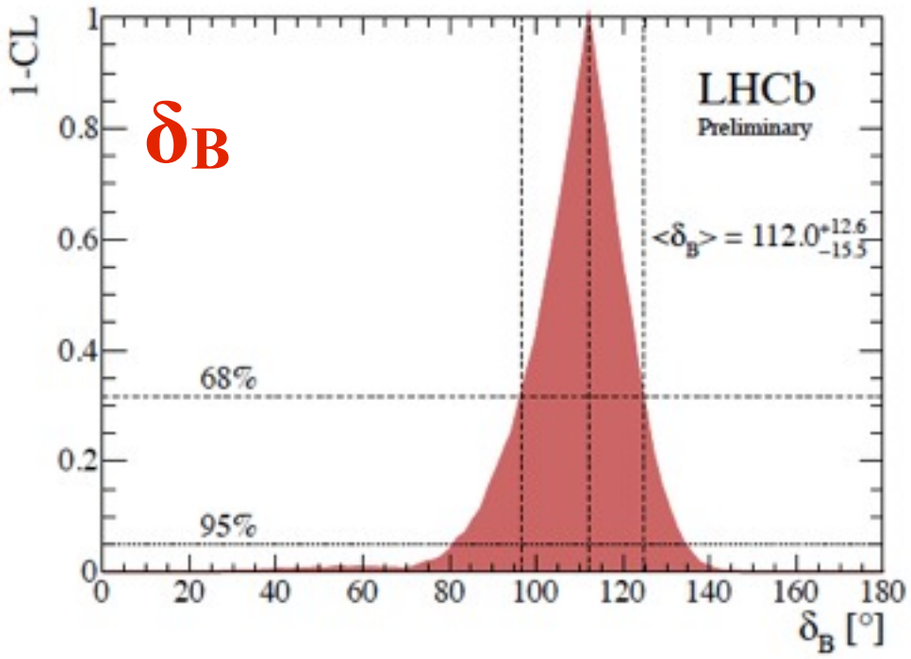
LHCb-CONF-2012-032



$71.1^{+16.6}_{-15.7}°$

$$\gamma \in [55.4,\ 87.7]° \ @68\%\ \mathrm{CL}\ ,$$
$$\gamma \in [41.4, 101.3]° \ @95\%\ \mathrm{CL}\ ,$$





Other Measurements for γ

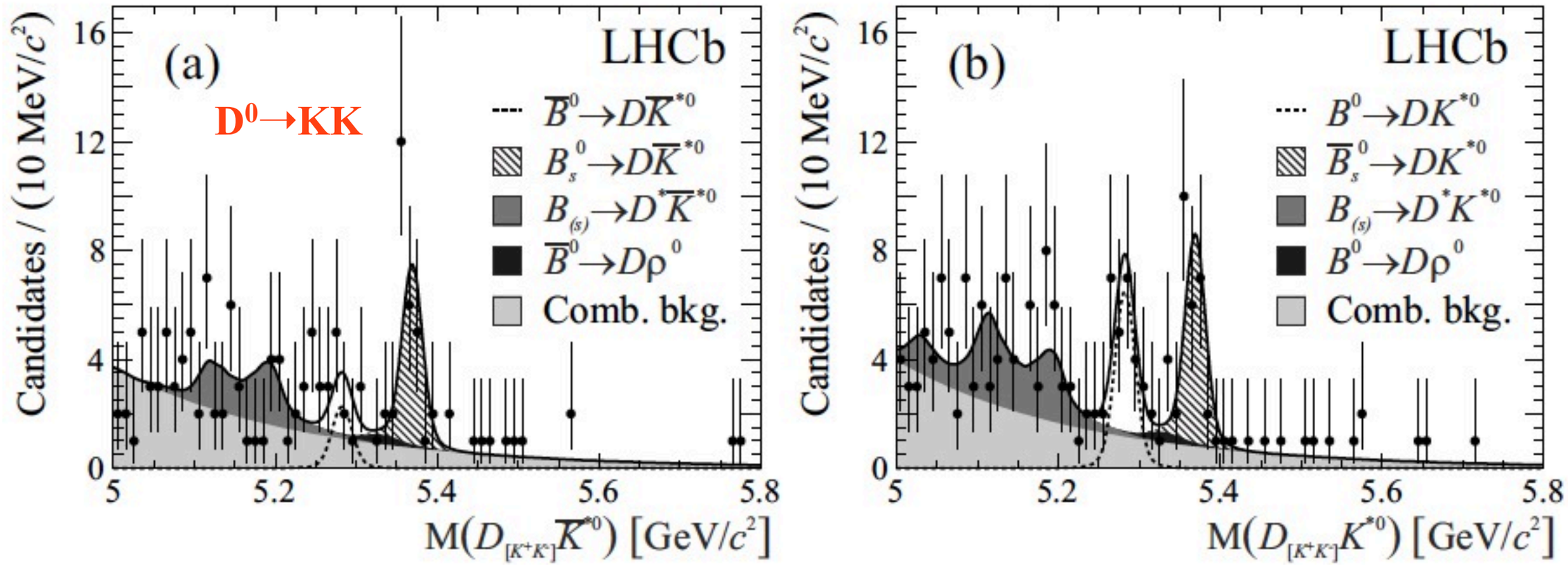
arXiv:1212.5205

LHCb-CONF-2012-021

➢ **Self-tagging decay: $B^0 \to D^0 K^*$ (GLW mode); Direct extension of $B \to D^0 K$; Dalitz analysis possible**

$D^0 \to K^- K^+$

~30 events



➢ **Decays like $B^+ \to Dh^+\pi^+\pi^-$ also explored:**

➢ **For GLW mode: ~120 per fb^{-1} signals for KK and ~60 per fb^{-1} for ππ**

➢ **For GGSZ mode: ~200 per fb^{-1} signals for K_sKK and $K_s\pi\pi$**

➢ **Other decays like $B^0 \to D^0K\pi$, $B_s^0 \to D^0KK$, $B^0 \to D^0\pi\pi$, $B_s^0 \to D_sK$ etc.**

Conclusion

➢ **LHCb has performed very well during the past three years of data taking**

➢ **With 1.0 fb^{-1} data taken in 2011, it already improves our knowledge on γ**

➢ **None of the channels dominates the sensitivity**

➢ **Combination of $B \to DK$ measurements gives $\gamma = 71.1°$ with uncertainty ~16°**

➢ **Other channels like $B_s \to D_s K$, $B \to D^0 K^*$ etc. also explored**

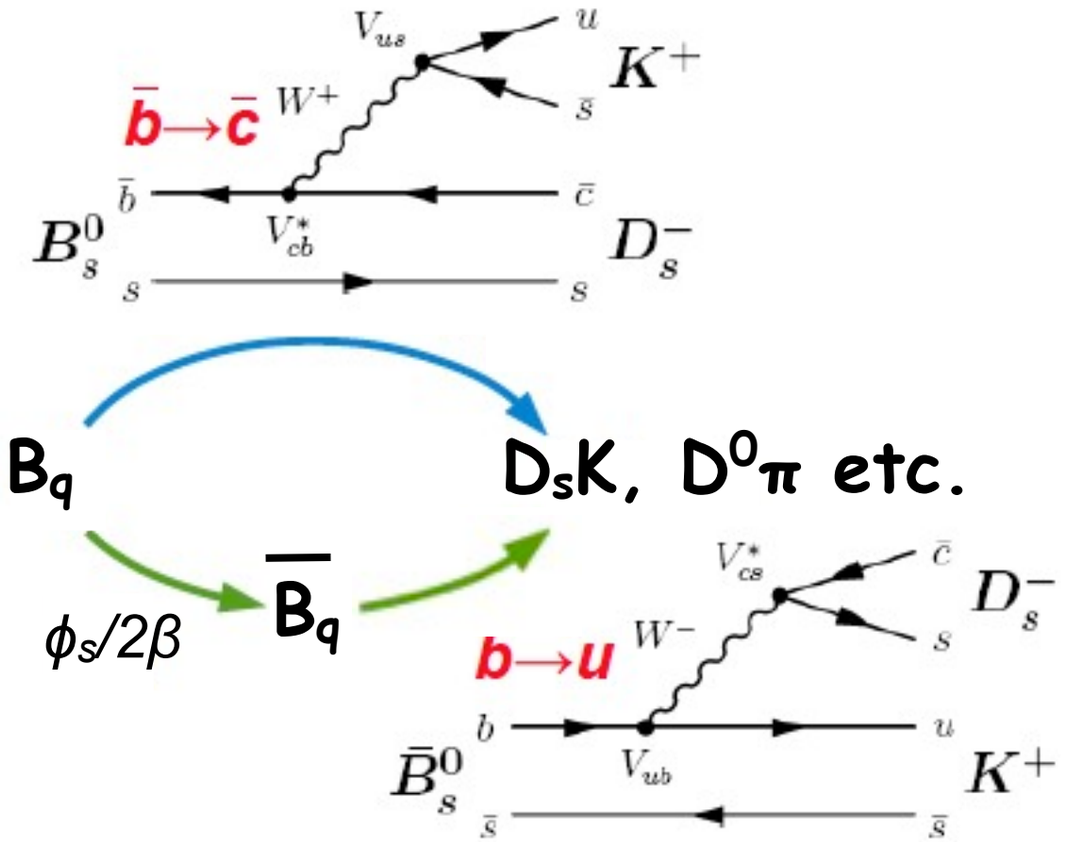
➢ **Stay tuned for more results with 3 fb^{-1} data**

Thank You for your attention

γ Studies with other $B_s \to D_s K$ (1)

➢ **Interference between b→u and b→c can appear through mixing**

➢ **$\gamma+\phi_s$ (2β) can be accessed with $B_s \to D_s K$ ($r_B \sim 0.3$), $B^0 \to D^0\pi$ ($r_B \sim 0.02$) etc.**



$$\frac{d\Gamma_{B_s\to f}(t)}{e^{-\Gamma_s t}} \propto [\cosh(\frac{\Delta\Gamma_s t}{2}) - D_f \sinh(\frac{\Delta\Gamma_s}{2}) + C\cos(\Delta m_s t) - S_f \sin(\Delta m_s t)]$$

$$\frac{d\Gamma_{\overline{B}_s\to f}(t)}{e^{-\Gamma_s t}} \propto [\cosh(\frac{\Delta\Gamma_s t}{2}) - D_f \sinh(\frac{\Delta\Gamma_s}{2}) - C\cos(\Delta m_s t) + S_f \sin(\Delta m_s t)]$$

Similar for $\overline{f}$

Change sign for $\overline{f}$

$$D_f = \frac{2r_{D_sK}\cos(\Delta - (\gamma - 2\beta_s))}{1+r_{D_sK}^2}$$

$$C = \frac{1-r_{D_sK}^2}{1+r_{D_sK}^2}$$

$$S_f = \frac{2r_{D_sK}\sin(\Delta - (\gamma - 2\beta_s))}{1+r_{D_sK}^2}$$

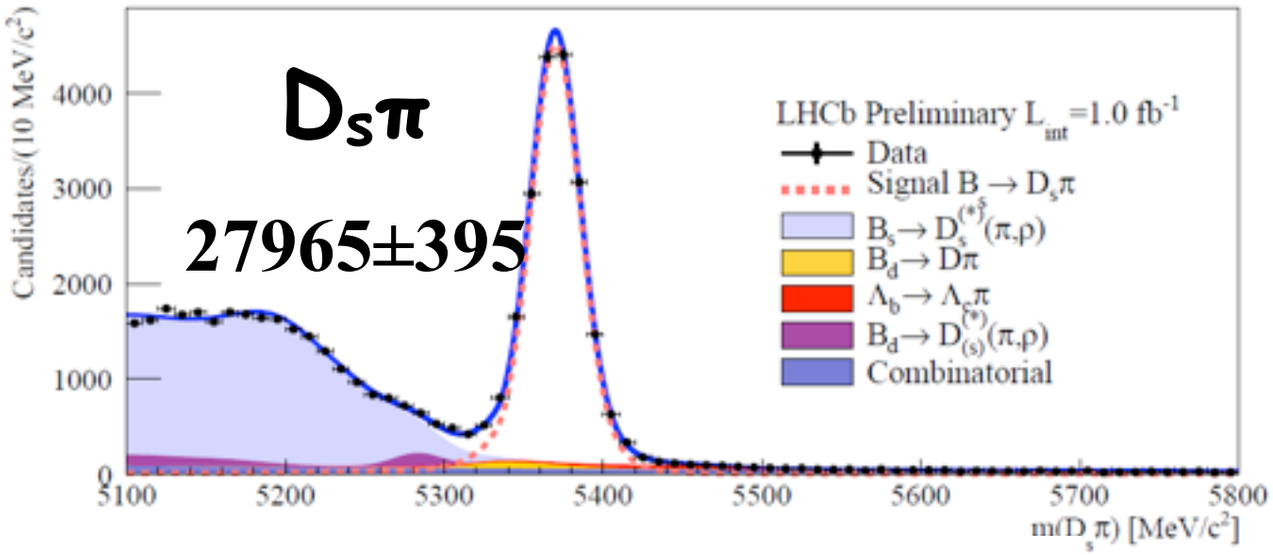
D_f can be measured due to non zero Γ_s Independent of tagging

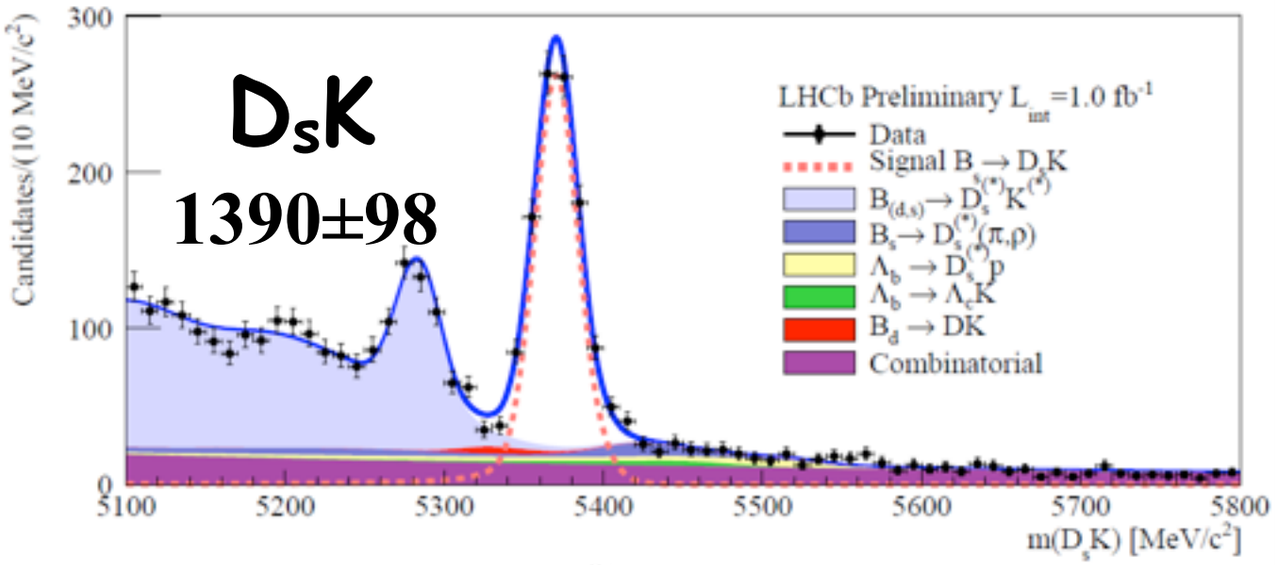
Tagging info. required

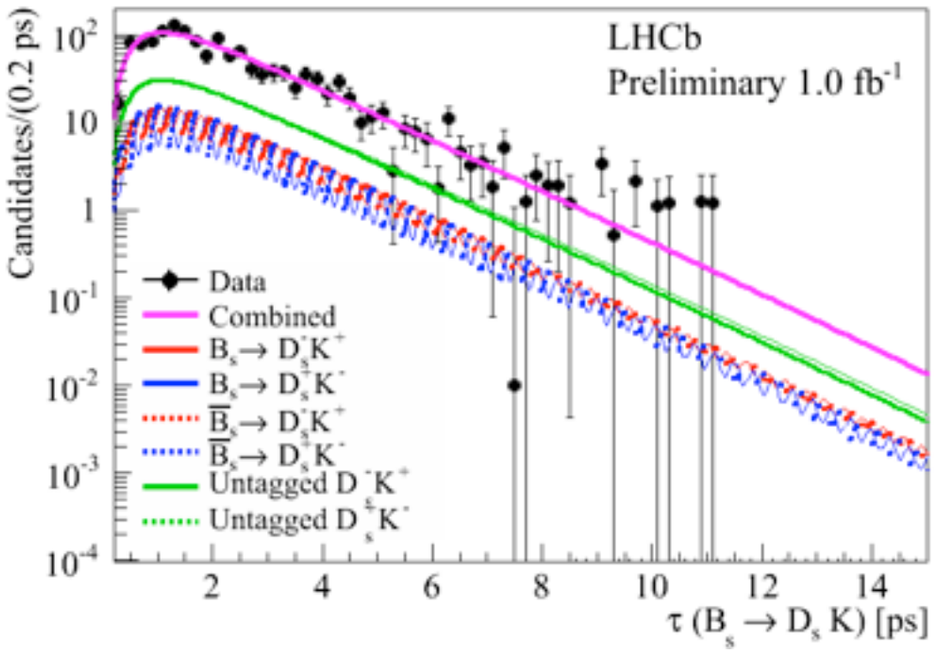
γ Studies with other $B_s \to D_s K$ (2)

LHCb-CONF-2012-029

➢ **Event Yields (with D_s decays to KKπ, Kππ and πππ)**







	Stat.	Sys.
$C =$	1.01 ± 0.50	± 0.23,
$S_f =$	-1.25 ± 0.56	± 0.24,
$S_{\bar{f}} =$	0.08 ± 0.68	± 0.28,
$D_f =$	-1.33 ± 0.60	± 0.26,
$D_{\bar{f}} =$	-0.81 ± 0.56	± 0.26,

➢ **Systematic uncertainties dominated by fixed parameters (Δm_s, Γ_s, $\Delta\Gamma_s$), flavor tagging calibration, background description**

➢ **γ extraction ongoing**