CP Violation in the beauty system at LHCb

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On behalf of LHCb collaboration

24th Rencontres de Blois
Particles Physics and Cosmology

Outline

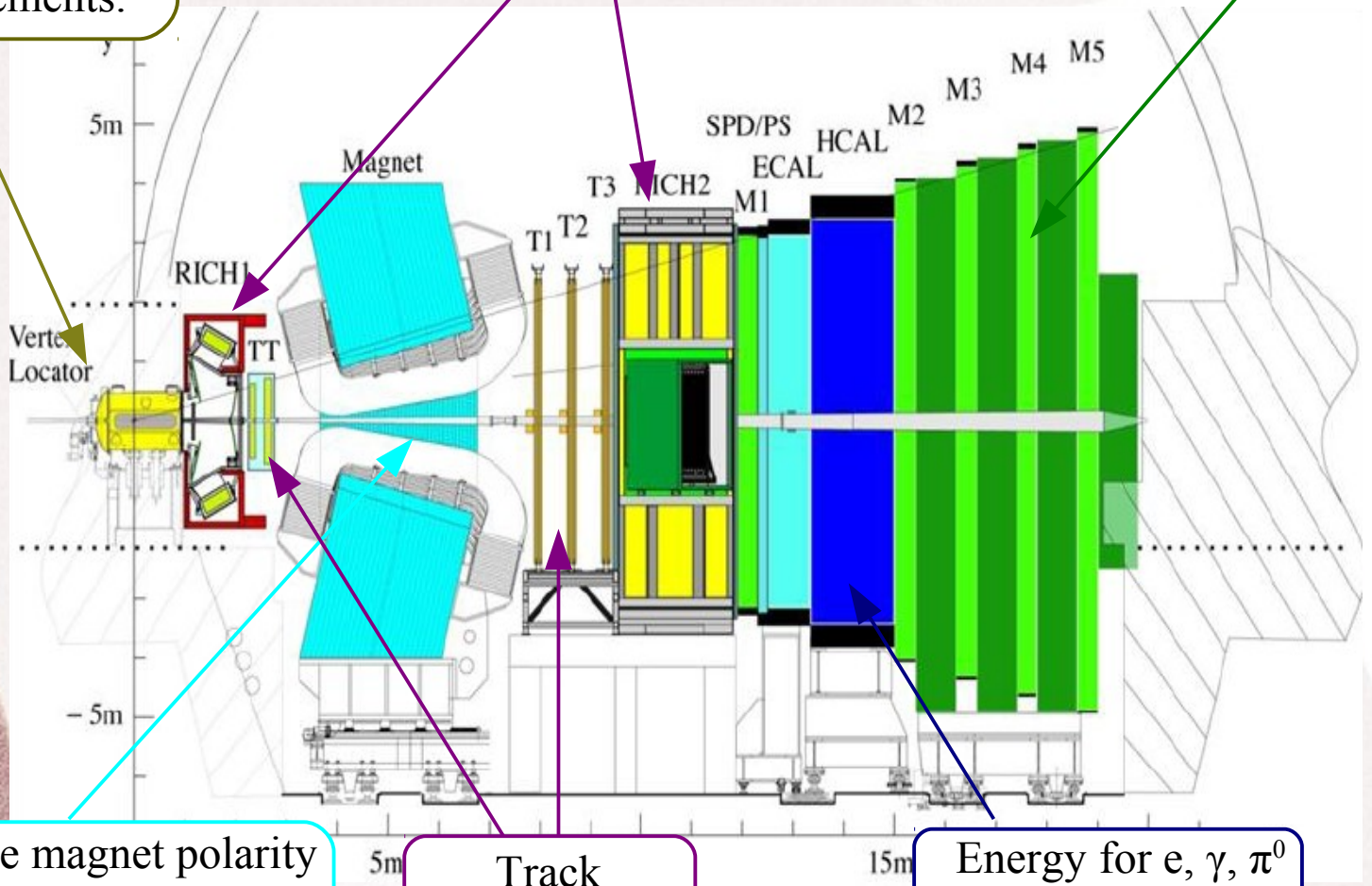
- LHCb experiment.
- CKM angle γ.
- Charmless two body decays.
    - o Direct CP violation results. (0.35 fb^{-1})
    - o Time-dependent CP violation results. (0.69 fb^{-1})
- CP asymmetry of $B_u \rightarrow J/\psi\pi$ and $B_u \rightarrow \psi(2s)\pi$. (0.37 fb^{-1})
- CP asymmetry of $B_u \rightarrow DK$ decays. (1.0 fb^{-1})

The LHCb experiment

Vertices Reconstruction and Impact parameters measurements.

Kaons and Pions separation.

Muons reconstruction.



Change magnet polarity and momentum measurements.

Track reconstruction.

Energy for e, γ, π^0 and hadrons.

CKM angle γ

• CKM matrix on Wolfenstein parametrization:

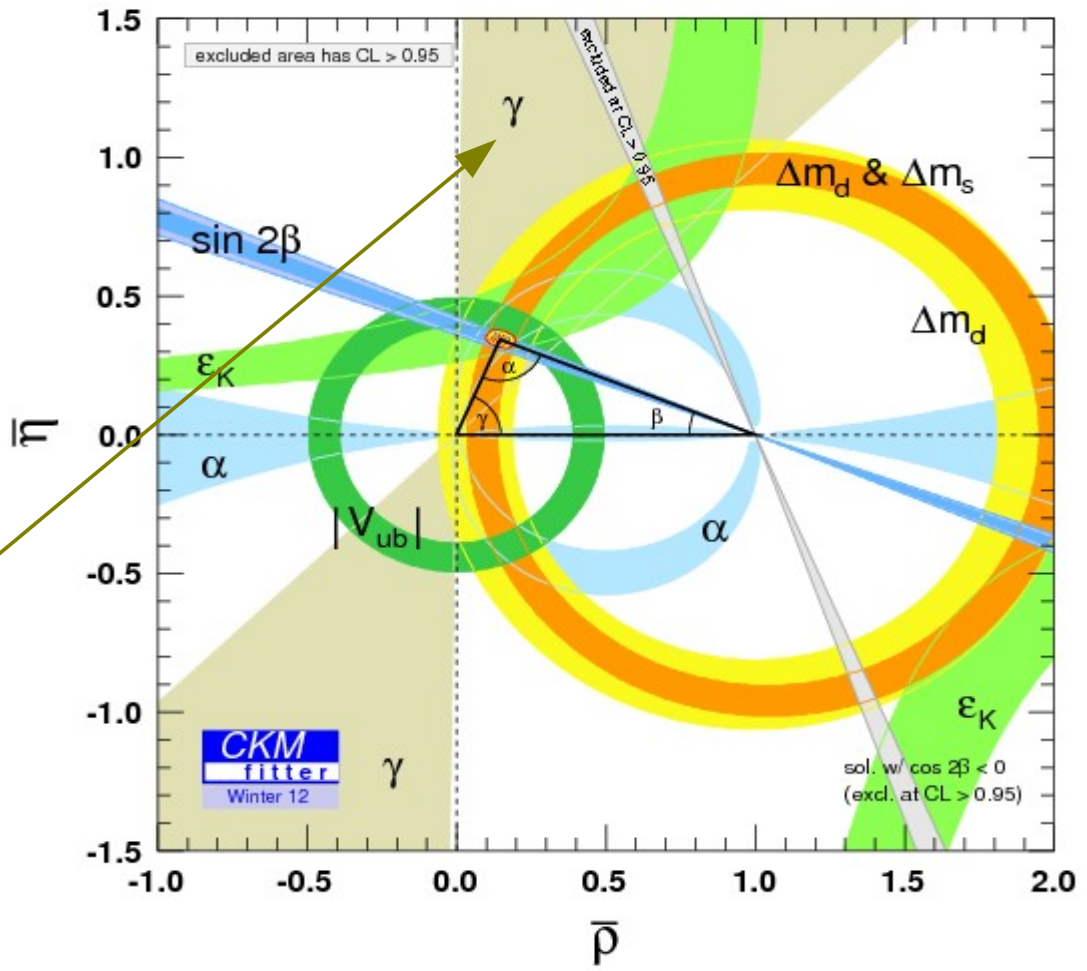
$$\begin{bmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}$$

• Unitary triangle:

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

Despite the effort at B factories and CDF, γ error is still dominated by experimental uncertainties.

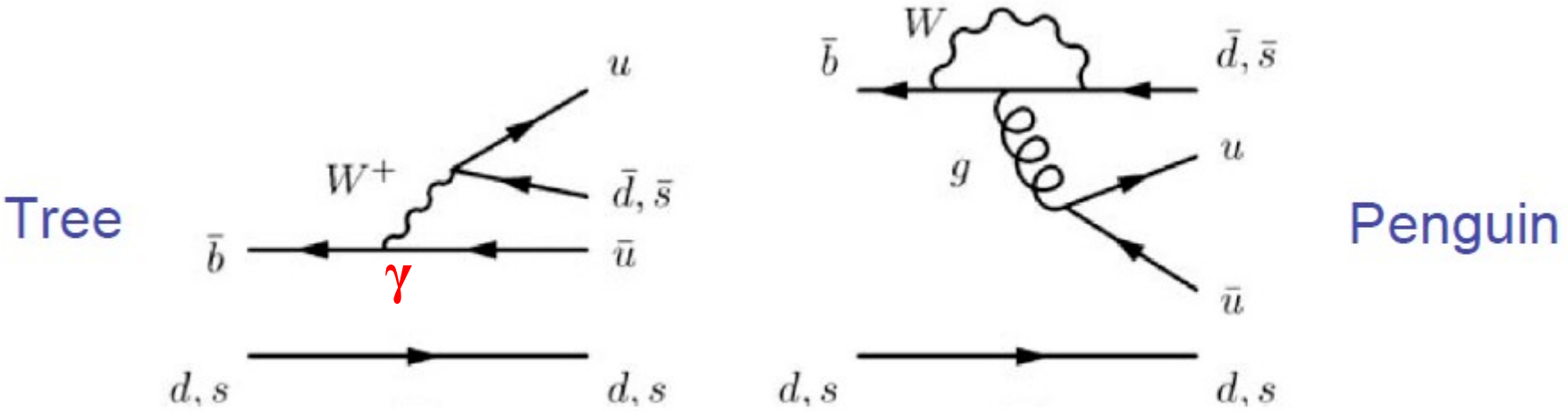
γ (dir.) = (66 ± 12)°
γ (indir.) = (67.1 ± 4.3)°



Most recent γ measurement: $\gamma = (77.3^{+15.1}_{-14.9} \pm 4.1 \pm 4.3)^\circ$

Belle:arXiv:1204.6561

Charmless 2 body B decays



- Decay amplitudes have contribution from tree and penguin diagrams;
- Sensitive to V_{ub} → CKM angle γ; **arxiv:hep-ph/9903456; arxiv:0705.1121; arxiv:1011.1096**
- May be sensible to new physics contribution at penguin level;
- Tree and penguin interference allows to look for direct CP violation using the following observable:

$$A_{CP} = \frac{(N_{\bar{B}\to\bar{f}} - N_{B\to f})}{(N_{\bar{B}\to\bar{f}} + N_{B\to f})} \qquad B \to f = \begin{cases} B^0 \to K^+\pi^- \\ B_s \to \pi^+ K^- \end{cases}$$

Direct CPV in 2 body decays

LHCB-PAPER-2011-029
PRL 108.201601

Extracted from the fit!

$$A_{raw} = A_{cp} + A_{det} + \kappa^* A_{prod} = A_{cp} + A_{\Delta}$$

Instrumental Asymmetry

A_{det} measured using charm control samples: $D^{*+} \rightarrow D0(K\pi)\pi^+$, $D^{*+} \rightarrow D^0(KK)\pi^+$ and $D^0 \rightarrow K\pi$.

Production Asymmetry

- κ: dilution of A_{prod} due to mixing, lifetime and acceptance.
- A_{prod} measured using $B^0 \rightarrow J/\psi\, K^{*0}(K\pi)$.

Final total correction A_{Δ} small.

Direct CPV in 2 body decays

LHCB-PAPER-2011-029
PRL 108.201601

- **0.35 fb^{-1}: 13250 ± 150 B_d candidates.**

$A_{cp}(B_d \to K\pi) = -0.088 \pm 0.011 \pm 0.008$

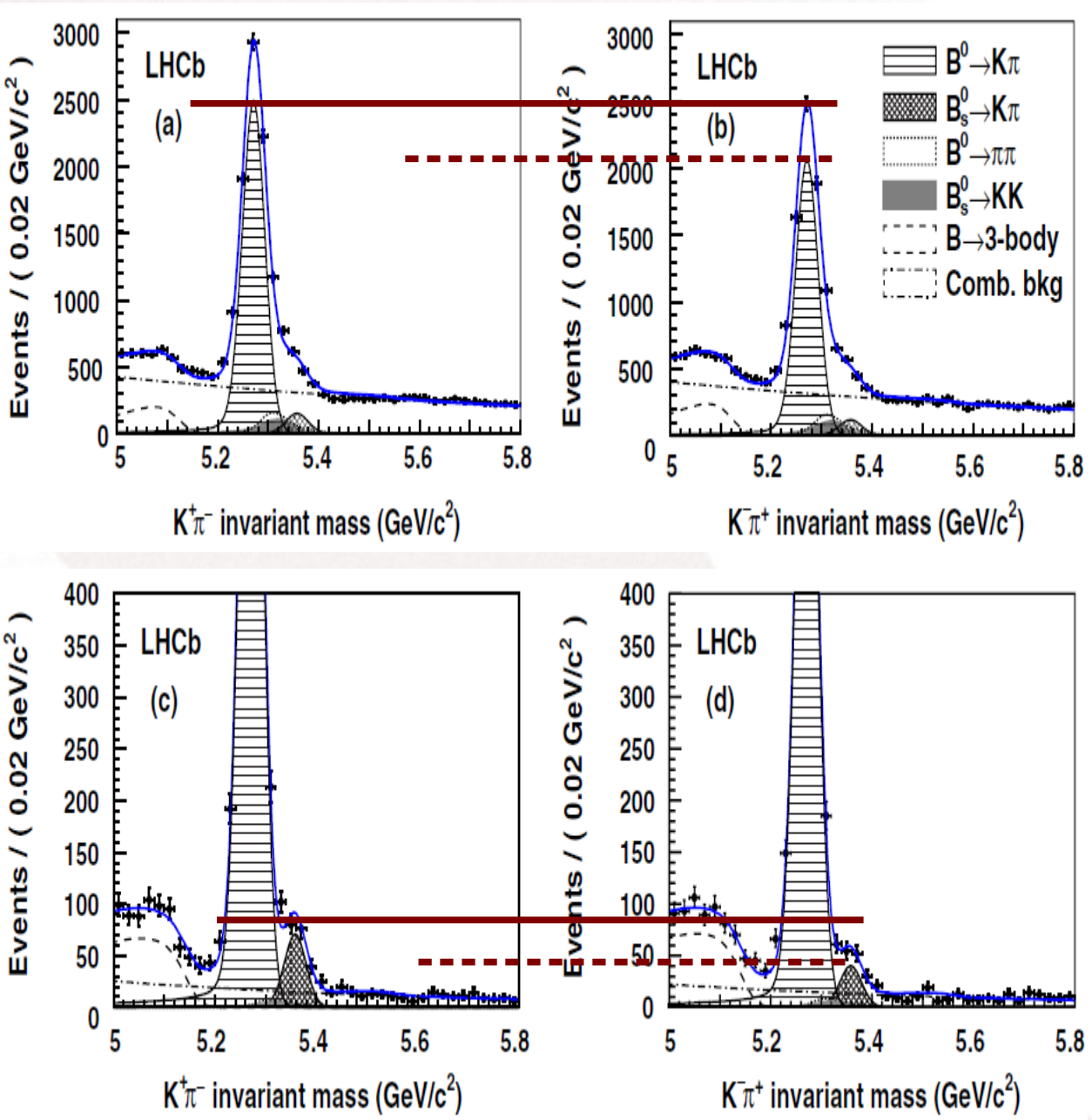
- Agrees with world average:
  -0.098 ± 0.013 [PDG]
- **World's most precise measurement**

First 5σ observation of CP violation at hadron colliders.

- **0.35 fb^{-1}: 314 ± 27 B_s candidates.**

$A_{cp}(B_s \to \pi K) = 0.27 \pm 0.08 \pm 0.02$

First 3σ evidence of direct CP violation in B_s decays.



Time-dependent CPV in 2 body decays

LHCb-CONF-2012-007

The time-dependent asymmetry can be written as:

$$A_{CP}(t) = \frac{A_f^{\rm dir}\cos(\Delta m t) + A_f^{\rm mix}\sin(\Delta m t)}{\cosh\left(\frac{\Delta\Gamma}{2}t\right) - A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma}{2}t\right)},$$

where:

$$A_f^{\rm dir} = \frac{|\lambda_f|^2 - 1}{|\lambda_f|^2 + 1},$$

$$A_f^{\rm mix} = \frac{2{\rm Im}\lambda_f}{|\lambda_f|^2 + 1},$$

and:

$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}.$$

The current measurements for $B_d \to \pi\pi$ are:

Experiment	$A_{\pi\pi}^{\rm dir}$	$A_{\pi\pi}^{\rm mix}$	$\rho(A_{\pi\pi}^{\rm dir}, A_{\pi\pi}^{\rm mix})$
BABAR	$0.25 \pm 0.08 \pm 0.02$	$-0.68 \pm 0.10 \pm 0.03$	0.06
Belle	$0.55 \pm 0.08 \pm 0.05$	$-0.61 \pm 0.10 \pm 0.04$	0.15
HFAG average	0.38 ± 0.06	-0.65 ± 0.07	0.08

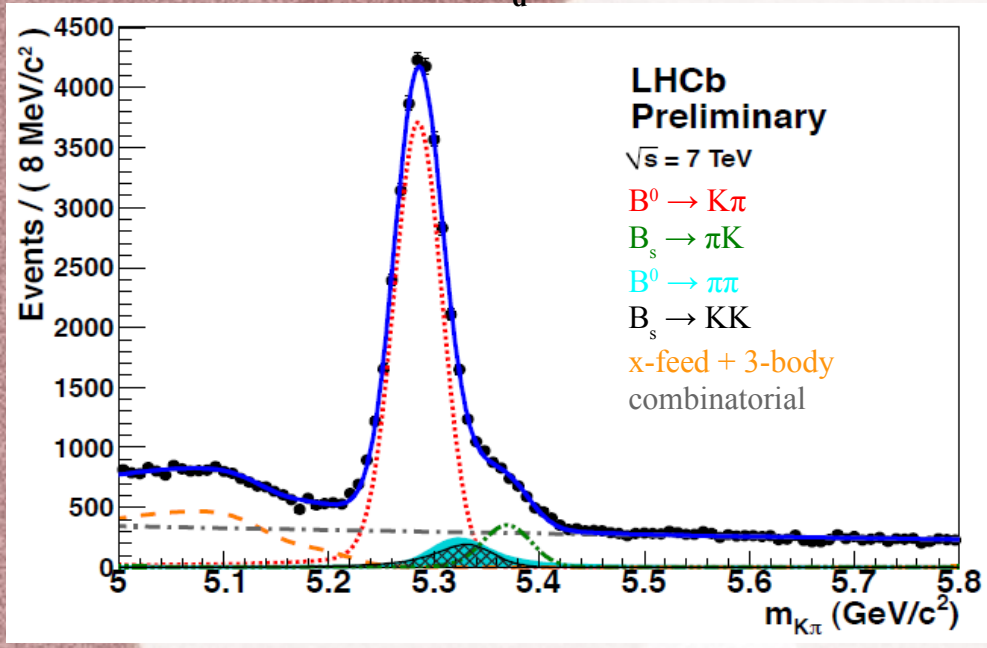
BaBar
arXiv:0807.4226
Belle
PRL 98 (2007) 211801
HFAG
arxiv:1010.1589

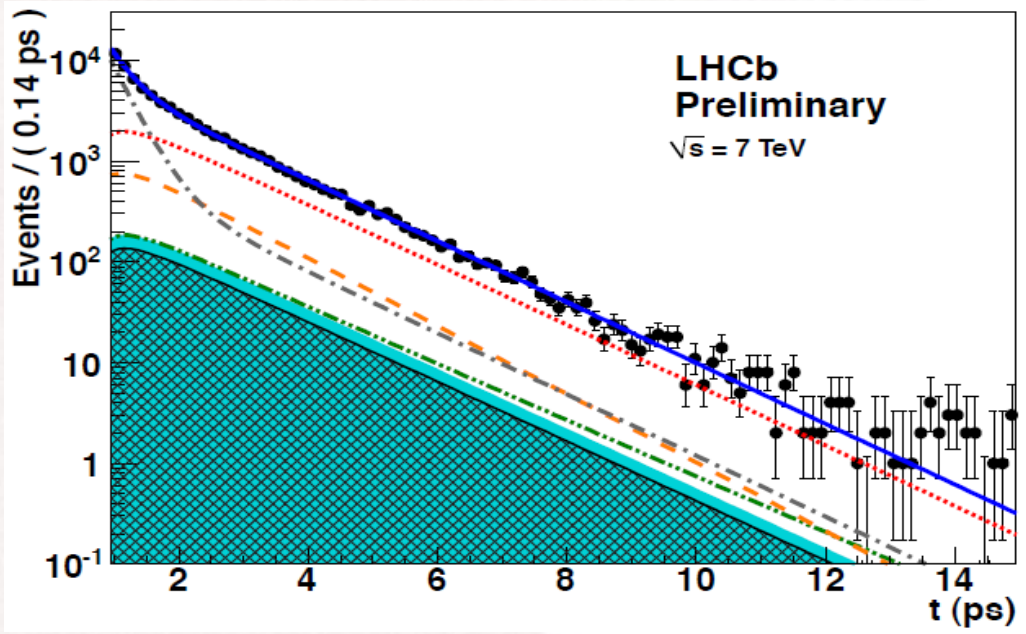
- Decay time acceptance determined from Monte Carlo.
- Decay time resolution from data: σ_t = 50fs.
- Opposite side flavor tagging, efficiency and mistag rate calibrated by $B_d \to K\pi$.

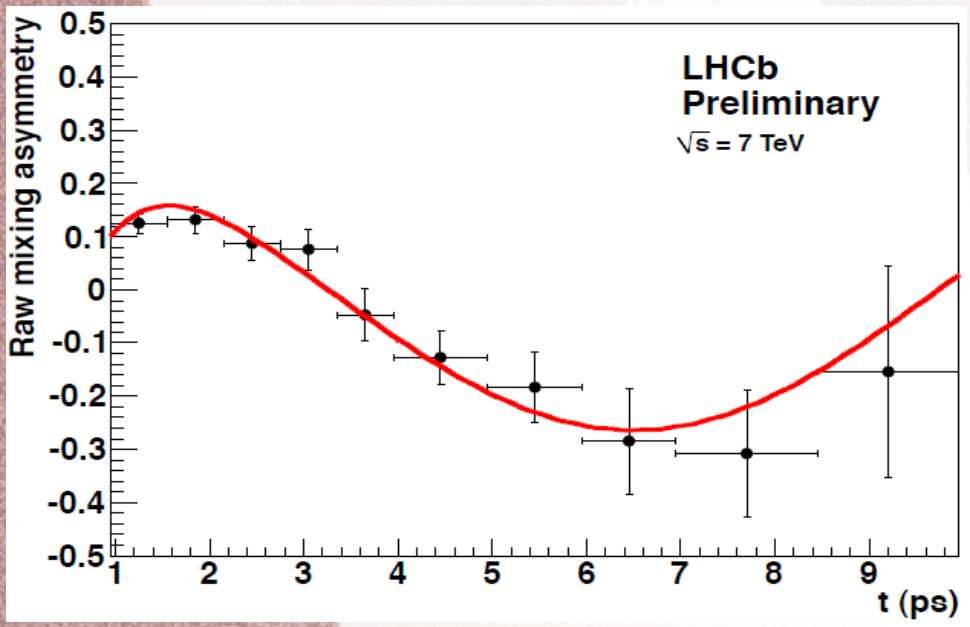
$B_d \to K\pi$ fit results

LHCb-CONF-2012-007

- **0.69 fb^{-1}: 27967 ± 204 B_d candidates.**







Extract B_d parameters from fit, input for $B_d \to \pi\pi$ and $B_s \to KK$:

- Tagging power (opposite-side taggers):
  $(2.3 \pm 0.1)\%$
- Production asymmetry:
  $A_{prod}(B_d) = (-1.5 \pm 1.3)\%$
  $A_{prod}(B_s) = (-3 \pm 6)\%$

$\Delta m_d = (0.484 \pm 0.019)\ ps^{-1}$

$\tau(B_d) = (1.509 \pm 0.011)$ ps (Agree with WA [PDG]) [9]

$B_d \to \pi\pi$ fit results

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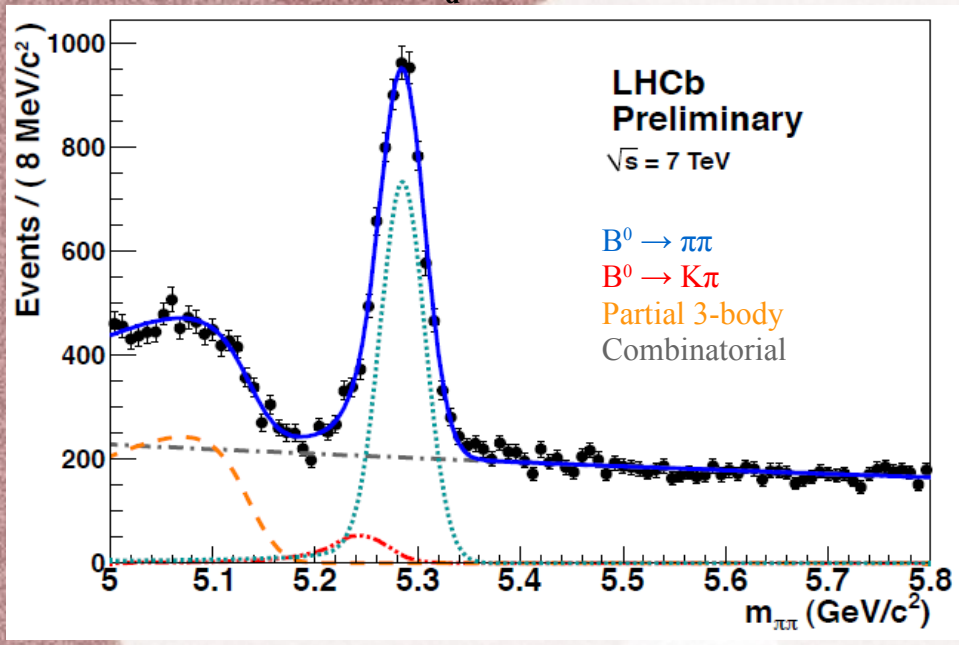
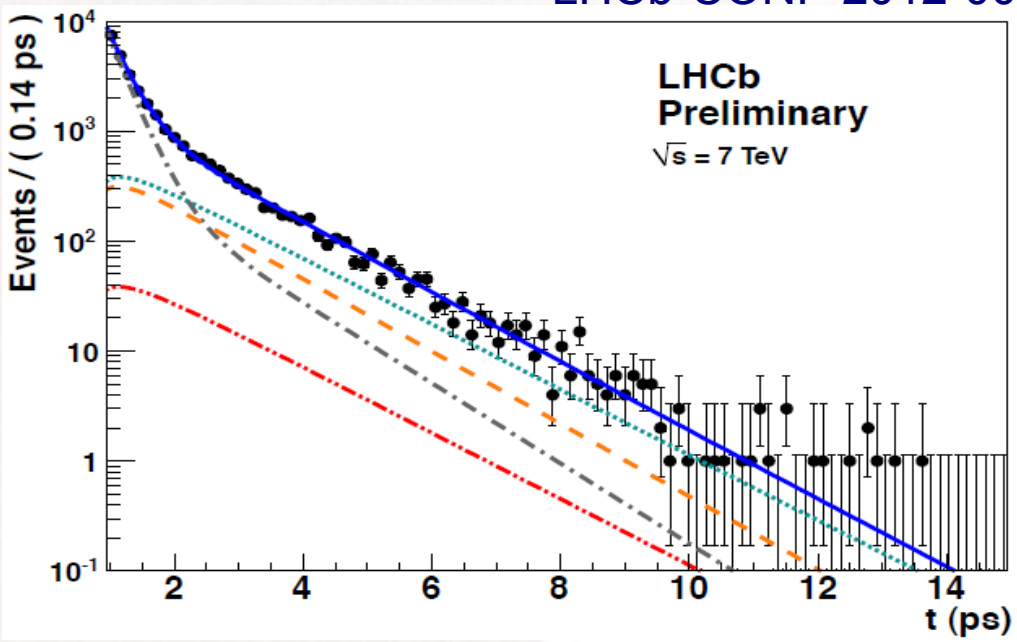
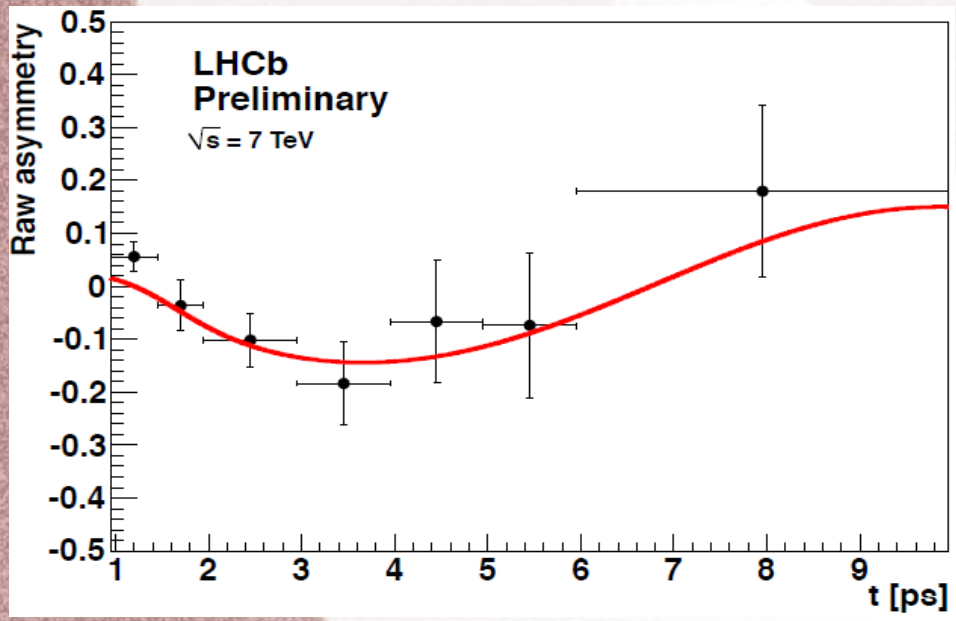
- **0.69 fb^{-1}: 5359 ± 96 B_d candidates.**







Extract CPV terms from fit:

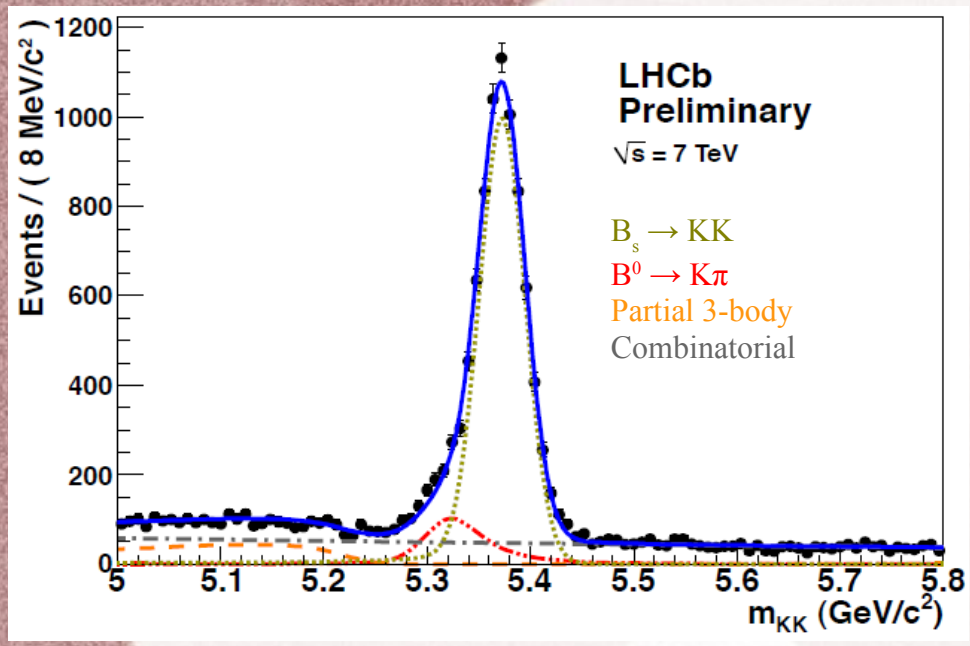
$$A_{\pi\pi}^{\mathrm{dir}} = 0.11 \pm 0.21,$$
$$A_{\pi\pi}^{\mathrm{mix}} = -0.56 \pm 0.17,$$
$$\rho(A_{\pi\pi}^{\mathrm{dir}}, A_{\pi\pi}^{\mathrm{mix}}) = -0.34.$$

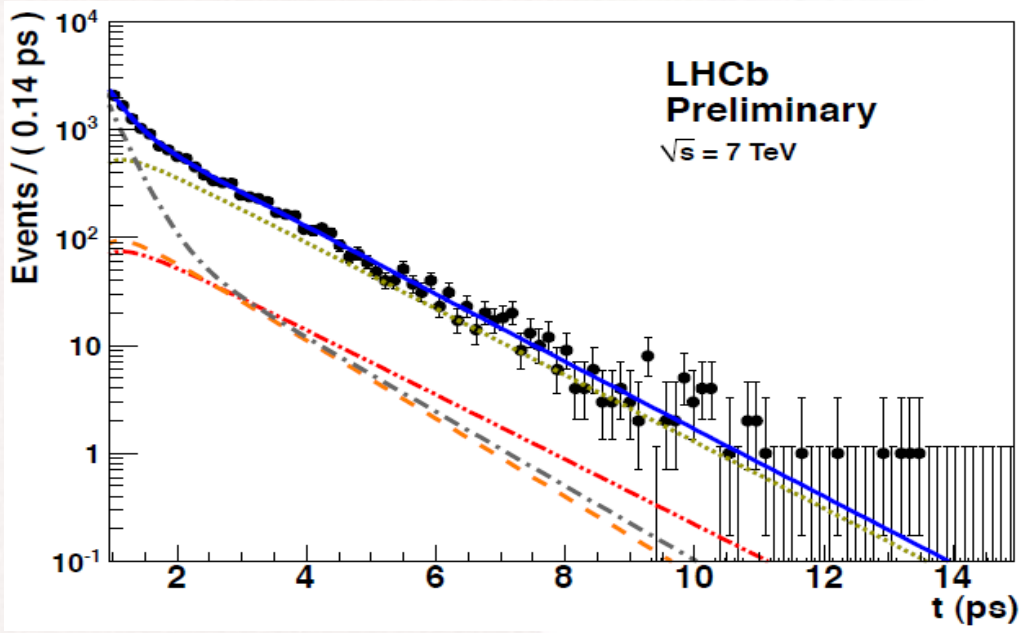
Only statistical uncertainties.

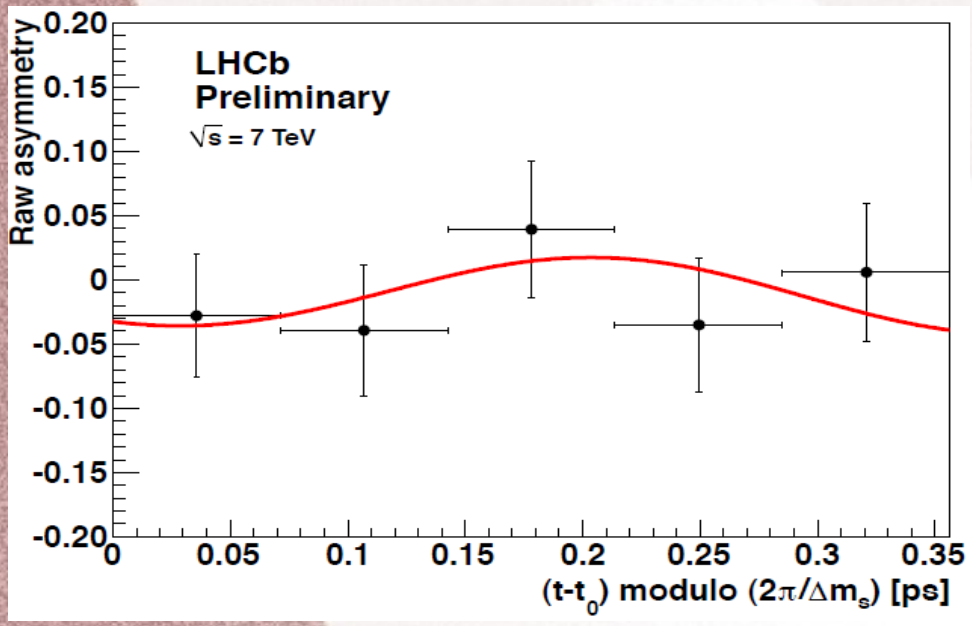
$B_s \to KK$ fit results

LHCb-CONF-2012-007

- **0.69 fb^{-1}: 7155 ± 97 B_s candidates.**







Extract CPV terms from fit:

$$A_{KK}^{\mathrm{dir}} = 0.02 \pm 0.18,$$
$$A_{KK}^{\mathrm{mix}} = 0.17 \pm 0.18,$$
$$\rho(A_{KK}^{\mathrm{dir}}, A_{KK}^{\mathrm{mix}}) = -0.10.$$

Only statistical uncertainties.

$B_d \to \pi\pi$ and $B_s \to KK$ results

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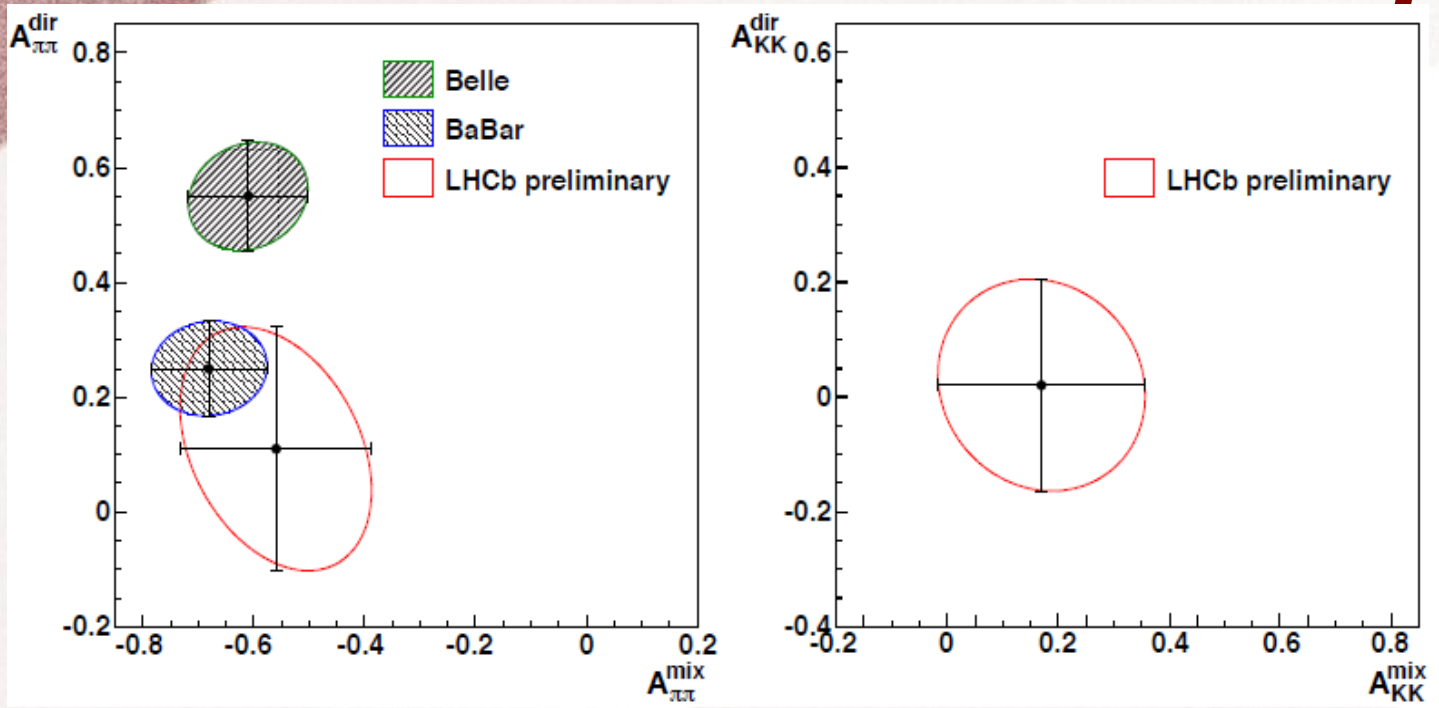


- $B_d \to \pi\pi$ and $B_s \to KK$ results:

$$A^{dir}_{\pi\pi} = 0.11 \pm 0.21 \pm 0.03,$$
$$A^{mix}_{\pi\pi} = -0.56 \pm 0.17 \pm 0.03,$$
$$A^{dir}_{KK} = 0.02 \pm 0.18 \pm 0.04,$$
$$A^{mix}_{KK} = 0.17 \pm 0.18 \pm 0.05,$$

- For $B_d \to \pi\pi$, A^{mix} in agreement with world average from the B factories.

First 3.2σ evidence of time-dependent CPV at hadronic colliders.

Direct CP in $B_u \to \psi\pi$

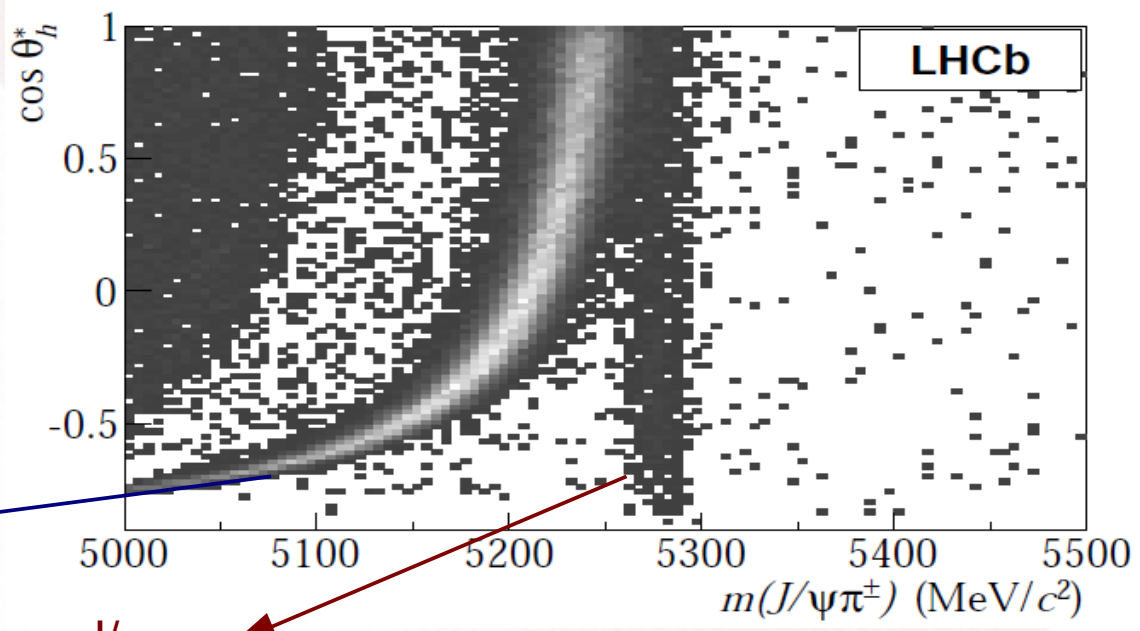
arXiv:1203.3592
LHCB-PAPER-2011-024

ψ holds for J/ψ or ψ(2s)

- SM predicts the same tree-penguin week phase for b → ccs (ψK decays);
- SM predicts different tree-penguin weak phase for b → ccd (ψπ decays): CPV ~ ?(?10^{-3});
- Analysis selects $\mu^+\mu^-h^+$ decays (charge conjugation implied);
- K/π identification done by helicity angle ($\cos(\theta^*_h)$) and by RICH particle ID;
- Two important observables:

$$A^{\psi\pi} = \frac{\mathcal{B}(B^- \to \psi\pi^-) - \mathcal{B}(B^+ \to \psi\pi^+)}{\mathcal{B}(B^- \to \psi\pi^-) + \mathcal{B}(B^+ \to \psi\pi^+)}$$

$$R^{\psi} = \frac{\mathcal{B}(B^\pm \to \psi\pi^\pm)}{\mathcal{B}(B^\pm \to \psi K^\pm)}$$



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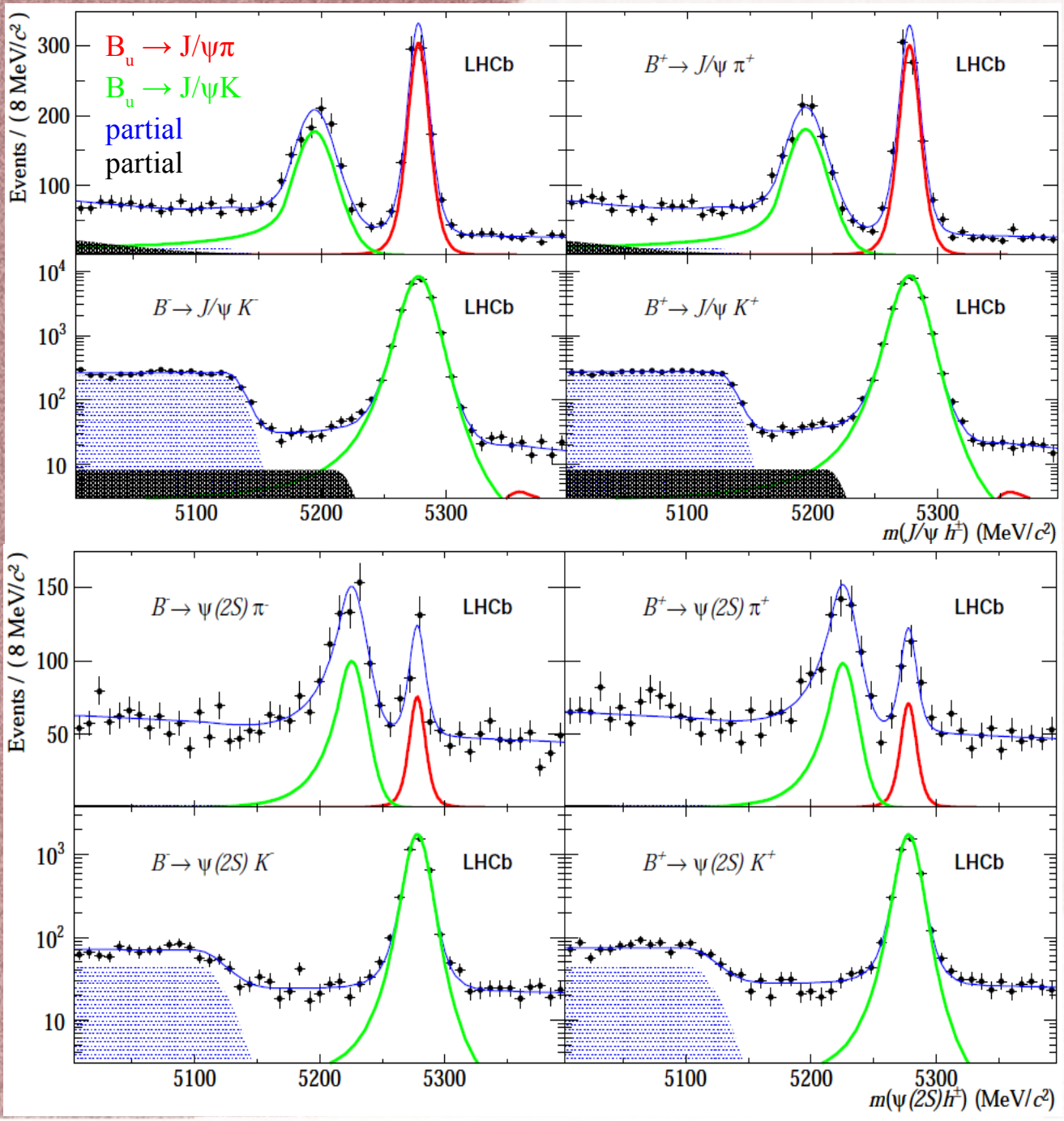


$R^{J/\psi} = (3.83 \pm 0.11 \pm 0.07)\%$

$R^{\psi(2s)} = (3.95 \pm 0.40 \pm 0.12)\%$

$A_{cp}(J/\psi\pi) = 0.005 \pm 0.027 \pm 0.011$

$A_{cp}(\psi(2s)\pi) = 0.048 \pm 0.090 \pm 0.011$

$A_{cp}(\psi(2s)K) = 0.024 \pm 0.014 \pm 0.08$

No evidence of CP Violation.

Direct CPV in $B_u \to DK$ decays

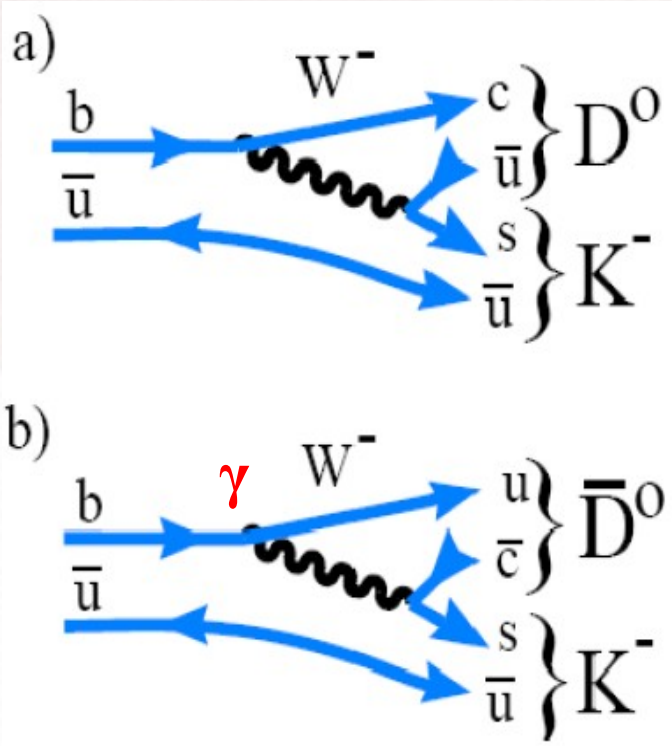
• CP violation in tree level decays → CKM angle γ measurement;

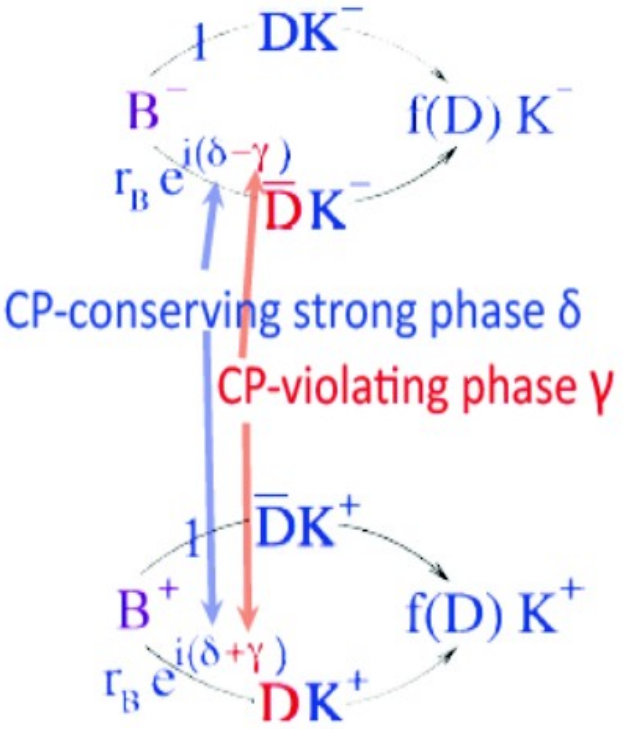
• Many decay modes allow γ measurements through interferences between b → c and b → u transitions:

Time-dependent CPV:
$B_s \to D^*_s K$
$B^0 \to D^*\pi$

Direct CPV:
$B_u \to D^0(KK, \pi\pi)K$ (**GLW**)
$B_u \to D^0(K\pi)K$ (**ADS**)

Dalitz Plot Analysis:
$B_u \to D^0(K_s hh)K$; (**GGSZ**)
o Best constrains to γ.
$B_u \to DK\pi$;





Gronau, London, Wyler: Phys.Lett.B253:483,1991;Phys.Lett.B265:172,1991
Atwood, Dunietz, Soni: Phys.Rev.Lett.78:3257,1997
Giri, Grossman, Solfer, Zupan: Phys.Rev.D 68,0504018 (2003)

Direct CPV in $B_u \to DK$ decays

LHCB-PAPER-2012-001
PLB 712 (2012) 203

• Analysis deals with 13 observables;

• Three ratios of partial widths:

$$R^f_{K/\pi} = \frac{\Gamma(B^- \to [f]_D K^-) + \Gamma(B^+ \to [f]_D K^+)}{\Gamma(B^- \to [f]_D \pi^-) + \Gamma(B^+ \to [f]_D \pi^+)},$$

where f represents ππ, KK and the favored Kπ mode.

• Six CP asymmetries:

$$A^f_h = \frac{\Gamma(B^- \to [f]_D h^-) - \Gamma(B^+ \to [f]_D h^+)}{\Gamma(B^- \to [f]_D h^-) + \Gamma(B^+ \to [f]_D h^+)},$$

• Four charged-separated partial widths of the ADS suppressed modes relative to the ADS favored mode:

$$R^\pm_h = \frac{\Gamma(B^\pm \to [\pi^\pm K^\mp]_D h^\pm)}{\Gamma(B^\pm \to [K^\pm \pi^\mp]_D h^\pm)}.$$

Direct CPV in $B_u \to DK$ decays

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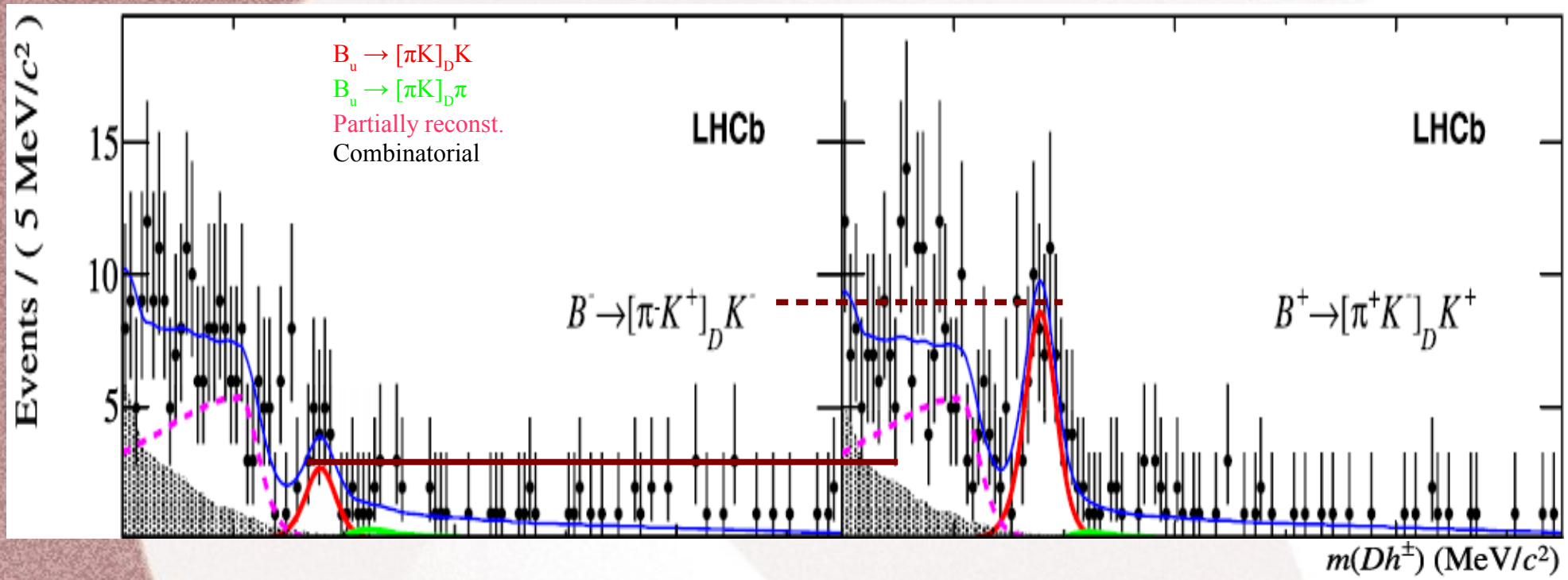
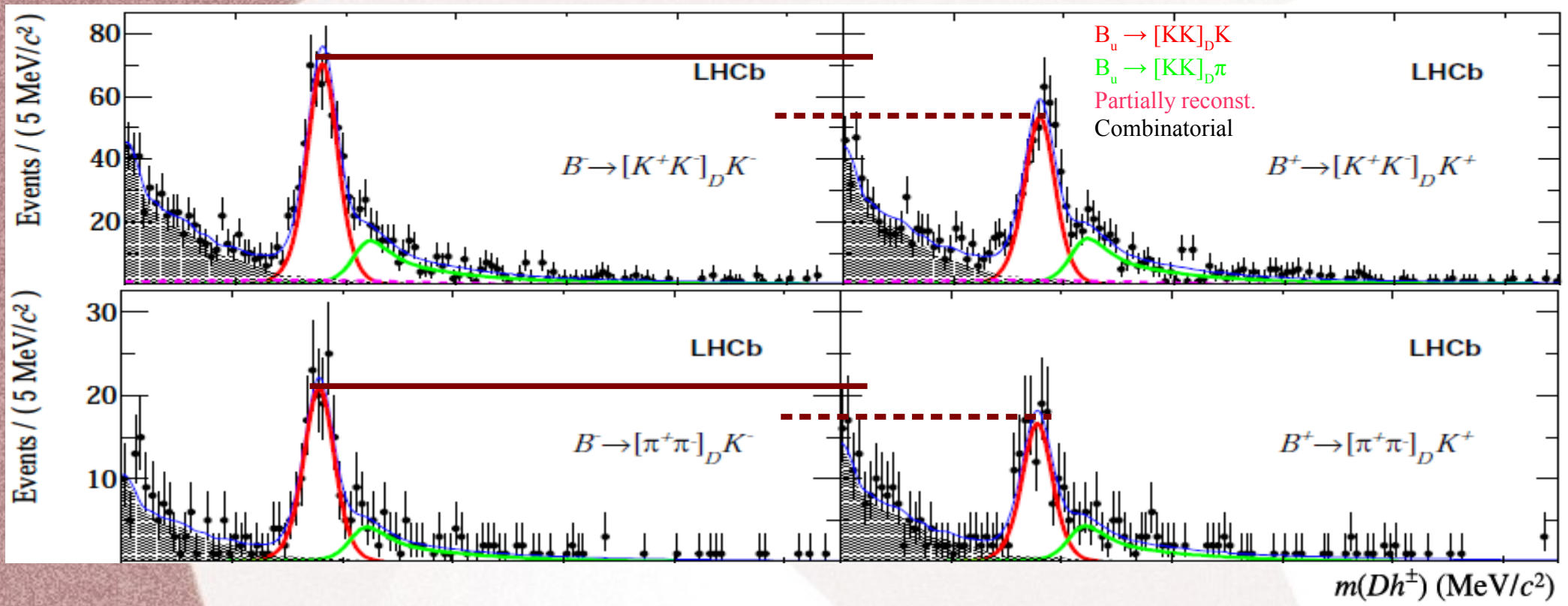


First 10σ observation of ADS suppressed mode
$B_u \to [\pi K]_D K$

$A_{ADS}(K) = -0.52 \pm 0.15 \pm 0.02$; ~3.5σ

Direct CPV in $B_u \to DK$ decays

LHCB-PAPER-2012-001
PLB 712 (2012) 203



Evidence of CPV

$A_{CP}([KK]_D K) = 0.148 \pm 0.037 \pm 0.010$

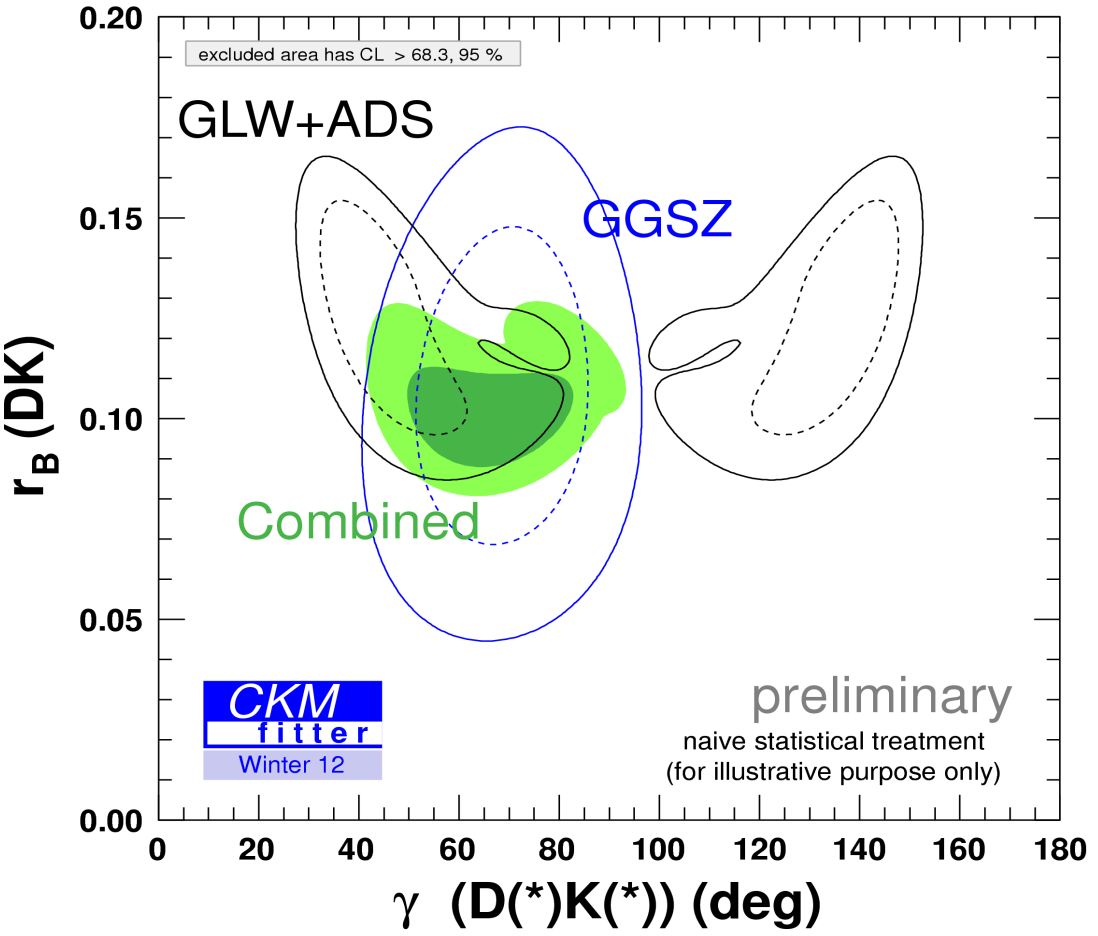
$A_{CP}([\pi\pi]_D K) = 0.135 \pm 0.066 \pm 0.010$

γ from $B_u \rightarrow DK$ decays

- Precise measurements of A_{cp} not necessarily leads to good gamma measurements (but it helps!).

- Many different analysis output will contribute to an accurate measurement.

LHCb expects to measure γ with an error of 5^o until 2018.



Conclusions

- **Many new results and improvements related to CPV in B → hh decays:**
  - o World's most precise measurement of direct CPV in $B_d \to K\pi$.
  - o First evidence of direct CPV in $B_s \to KK$.
  - o First evidence of time-dependent CPV in $B_d \to \pi\pi$.

- **Direct CPV measurement in $B_u \to \psi\pi$:**
  - o Comparable or better precision than previous results but no evidence of CPV.

- **New results related to $B_u \to DK$ decays:**
  - o First observation of the ADS suppressed mode $B_u \to [\pi K]_D K$.
  - o First evidence of direct CPV in the ADS suppressed mode $B_u \to [\pi K]_D K$.
  - o Evidences of direct CPV in $B_u \to [\pi\pi]_D K$ and $B_u \to [KK]_D K$.

- Important results from B_s system at LHCb: see **Gaia Lanfranchi's talk.**

LHCb will collect another 1.5 fb^{-1} during 2012 run at 8 TeV center-of-mass energy.
Stay tunned!