Towards a measurement of the unitarity triangle angle gamma:

Observation of CP violation in $B^{\pm} \rightarrow DK^{\pm}$ decays

Malcolm John, for the LHCb collaboration

13 March 2012

UNIVERSITY OF OXFORD

THE ROYAL SOCIETY

2 Methods for measuring γ at tree-level

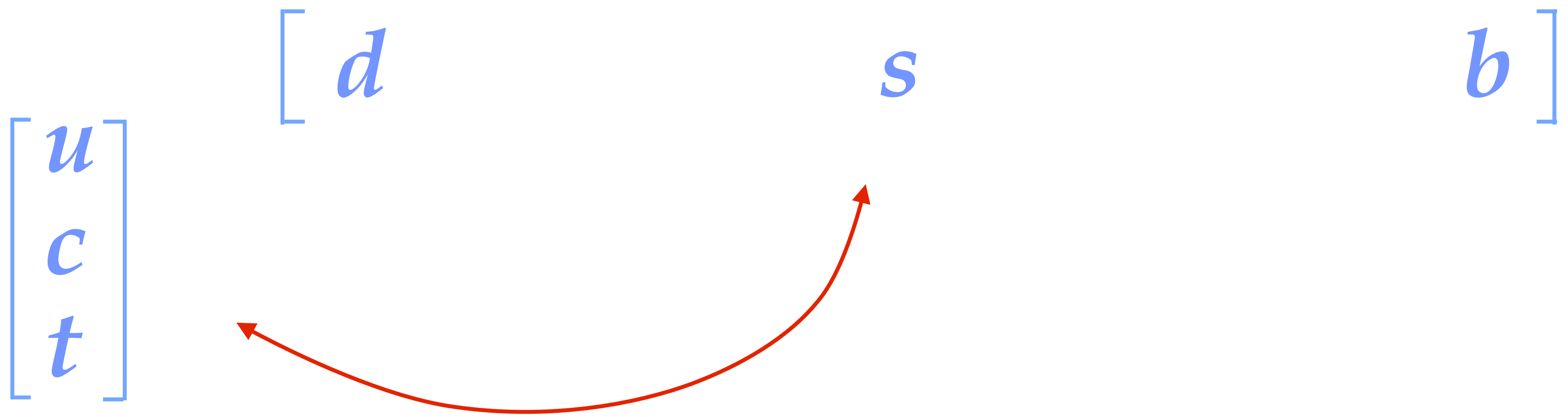
The techniques for measuring γ at LHCb fall into two categories: measurements of direct CP-violation in the decays $B^- \to DK^-$ and $\bar{B}^0 \to D\bar{K}^{*0}$,[2] where D indicates a D^0 or $\bar{D}^0$ decaying into a common final state; and time-dependent measurements of CP-violation in $B^0 \to D^{(*)\mp}\pi^\pm$ and $B_s^0 \to D_s^\mp K^\pm$ decays.

The most likely first measurement, amongst those presented here, is the two-body ADS analysis, where there is limited evidence for the suppressed modes [40, 41]; the observation of these decays would be a significant first step toward the programme outlined in this document.

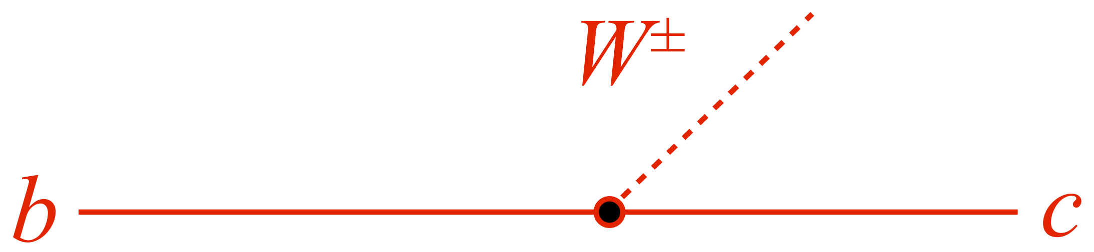
LHCb “Roadmap”—16 February 2010

(1) The importance of measuring γ with trees

CP violation known only to occur in the weak interaction of quarks



by emission or absorption of a
$W^{\pm}$ boson, quarks change flavour



CKM model: 3 quark generations ⇒ 3 mixing angles, 1 phase

$$V_{CKM} = \begin{matrix} \\ u \\ c \\ t \end{matrix} \begin{matrix} d & s & b \\ \left(\begin{matrix} 1-\frac{1}{2}\lambda^2 \\ -\lambda \\ A\lambda^3(1-\rho-i\eta) \end{matrix}\right. & \begin{matrix} \lambda \\ 1-\frac{1}{2}\lambda^2 - i\eta A^2\lambda^4 \\ -A\lambda^2 \end{matrix} & \left.\begin{matrix} A\lambda^3(\rho - i\eta + \frac{i}{2}\eta\lambda^2) \\ A\lambda^2(1+i\eta\lambda^2) \\ 1 \end{matrix}\right) \end{matrix} + \mathcal{O}(\lambda^6)$$

Wolfenstein expansion in powers of the Cabibbo angle, λ, up to λ^5

This single phase give rise to *all* *CP* violation phenomena

$$V_{CKM} = \begin{matrix} u \\ c \\ t \end{matrix} \overset{\begin{matrix} d & s & b \end{matrix}}{\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta + \frac{i}{2}\eta\lambda^2) \\ -\lambda & 1-\frac{1}{2}\lambda^2 - i\eta A^2\lambda^4 & A\lambda^2(1+i\eta\lambda^2) \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}} + \mathcal{O}(\lambda^6)$$

Wolfenstein expansion in powers of the Cabibbo angle, λ, up to λ^5

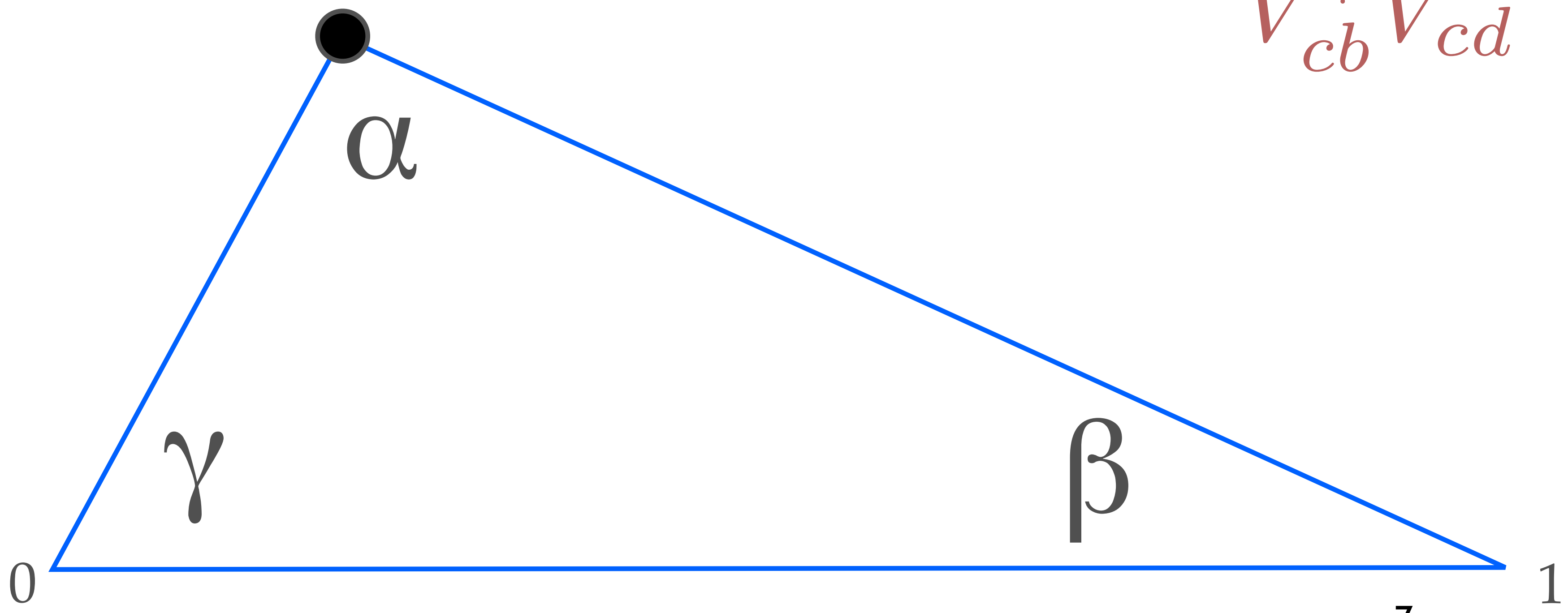
$$0 = 1 + \frac{V_{tb}^* V_{td}}{V_{cb}^* V_{cd}} + \frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}$$

Testing the unitarity of this matrix is a huge part of flavour physics

$$V_{CKM} = \begin{matrix} \\ u \\ c \\ t \end{matrix} \begin{matrix} d & s & b \\ \left(\begin{matrix} 1-\frac{1}{2}\lambda^2 \\ -\lambda \\ A\lambda^3(1-\rho-i\eta) \end{matrix} \right. & \begin{matrix} \lambda \\ 1-\frac{1}{2}\lambda^2 - i\eta A^2\lambda^4 \\ -A\lambda^2 \end{matrix} & \left. \begin{matrix} A\lambda^3(\rho - i\eta + \frac{i}{2}\eta\lambda^2) \\ A\lambda^2(1+i\eta\lambda^2) \\ 1 \end{matrix} \right) \end{matrix} + \mathcal{O}(\lambda^6)$$

Wolfenstein expansion in powers of the Cabibbo angle, λ, up to λ^5

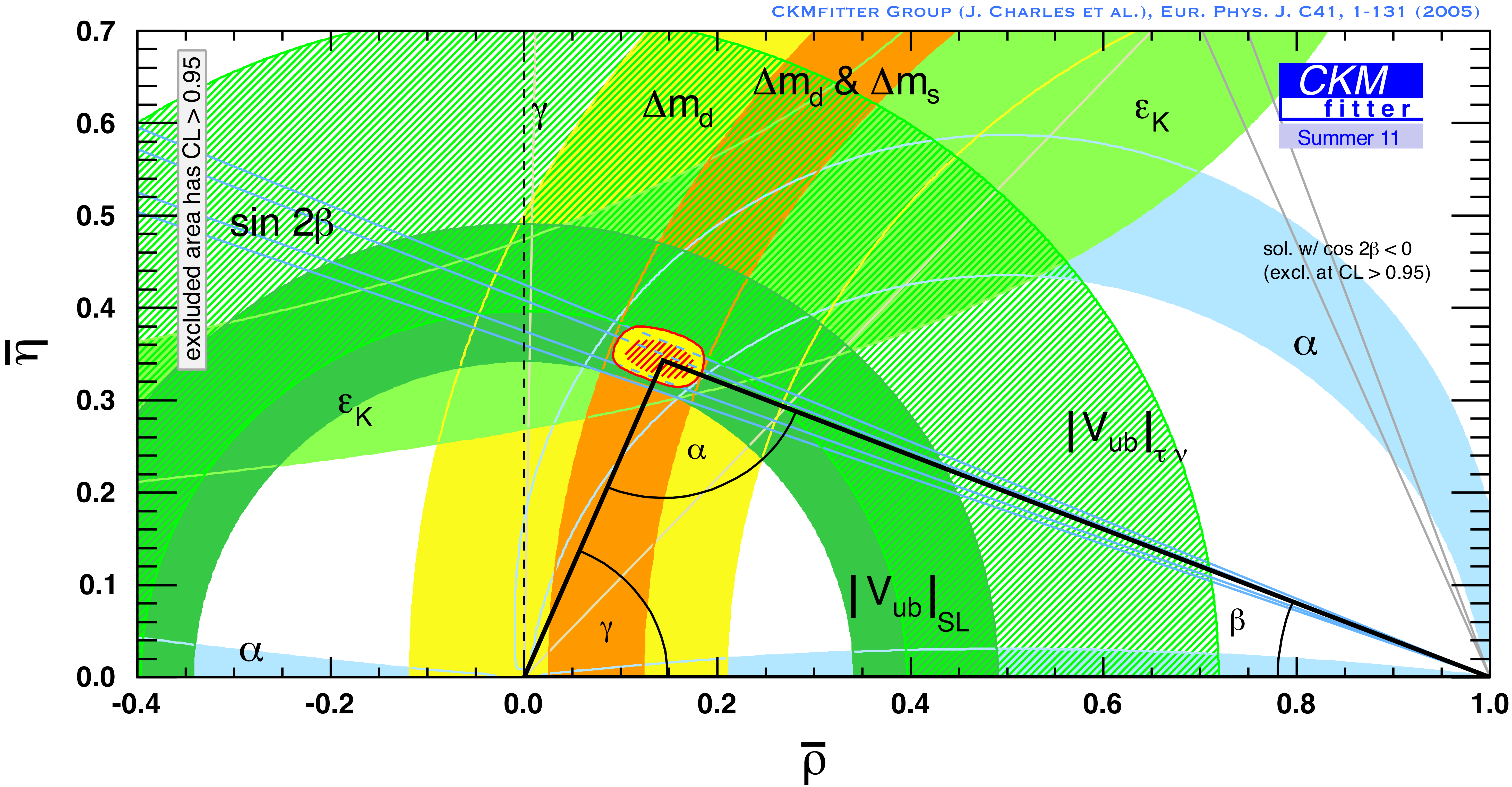
$$0 = 1 + \frac{V_{tb}^* V_{td}}{V_{cb}^* V_{cd}} + \frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}$$



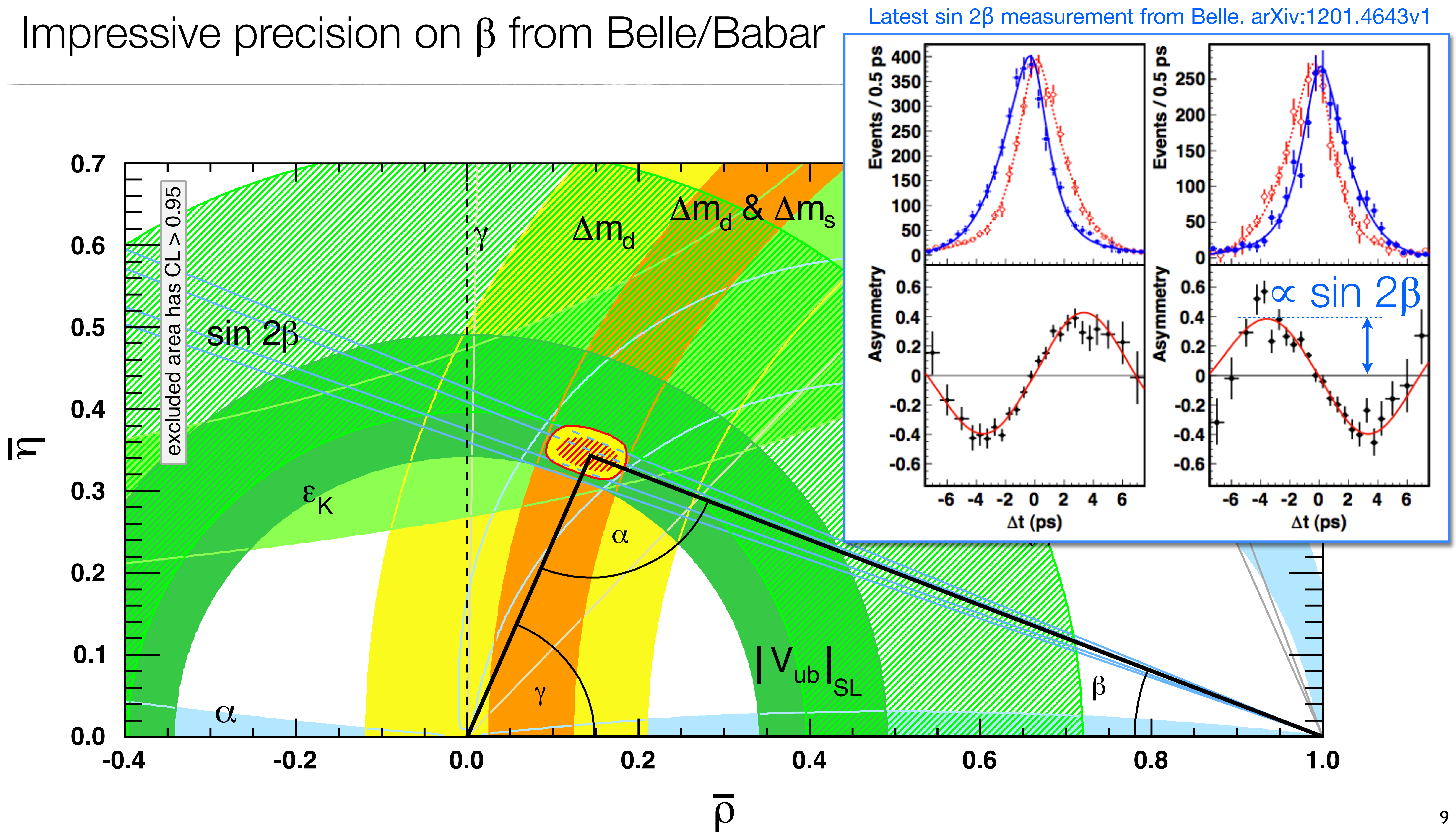
no phase information in V_{ud}/V_{cd} so:

$$\gamma = \arg\left(-\frac{V_{ub}^*}{V_{cb}^*}\right)$$

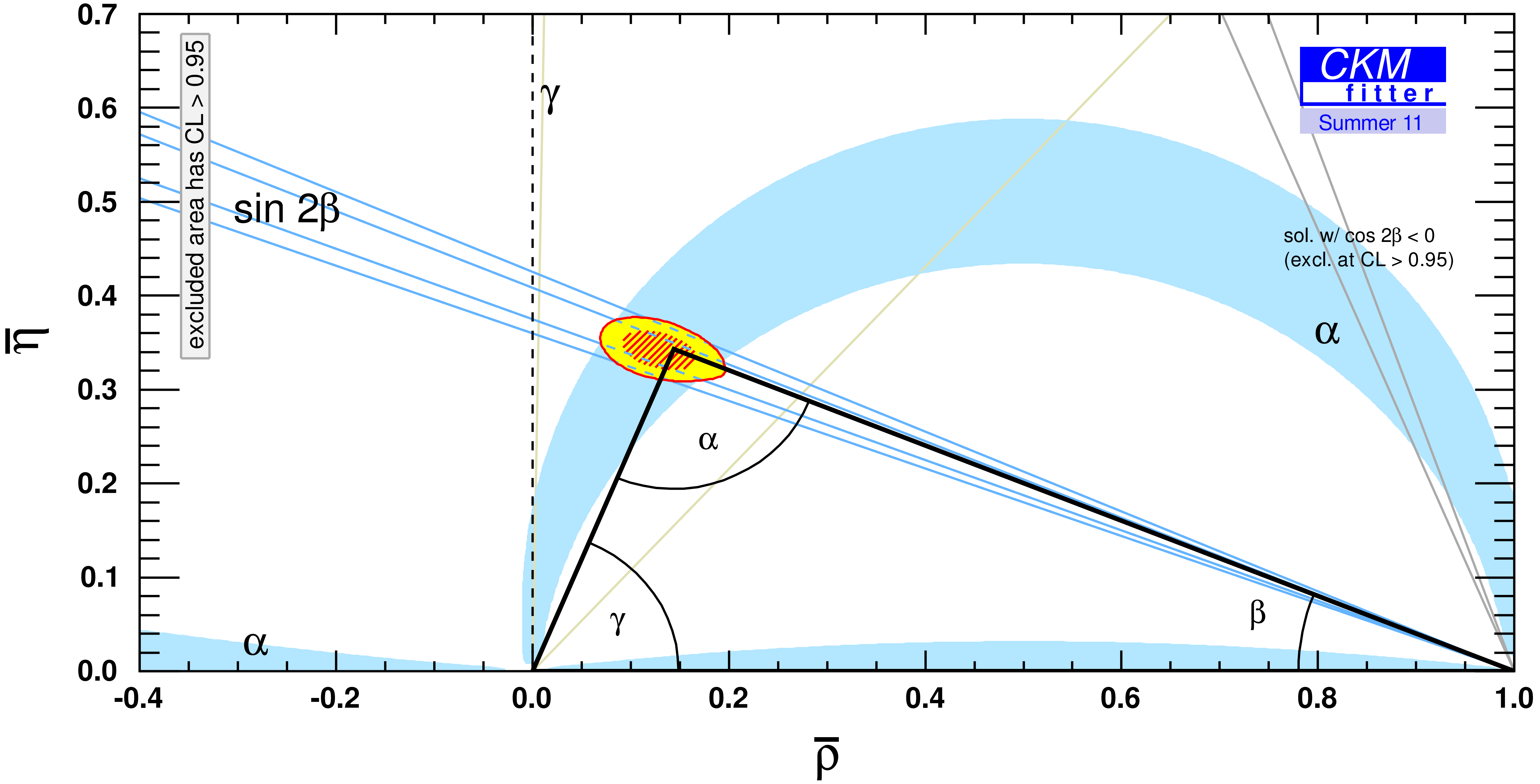
We know the Standard Model describes Nature well.



Impressive precision on β from Belle/Babar

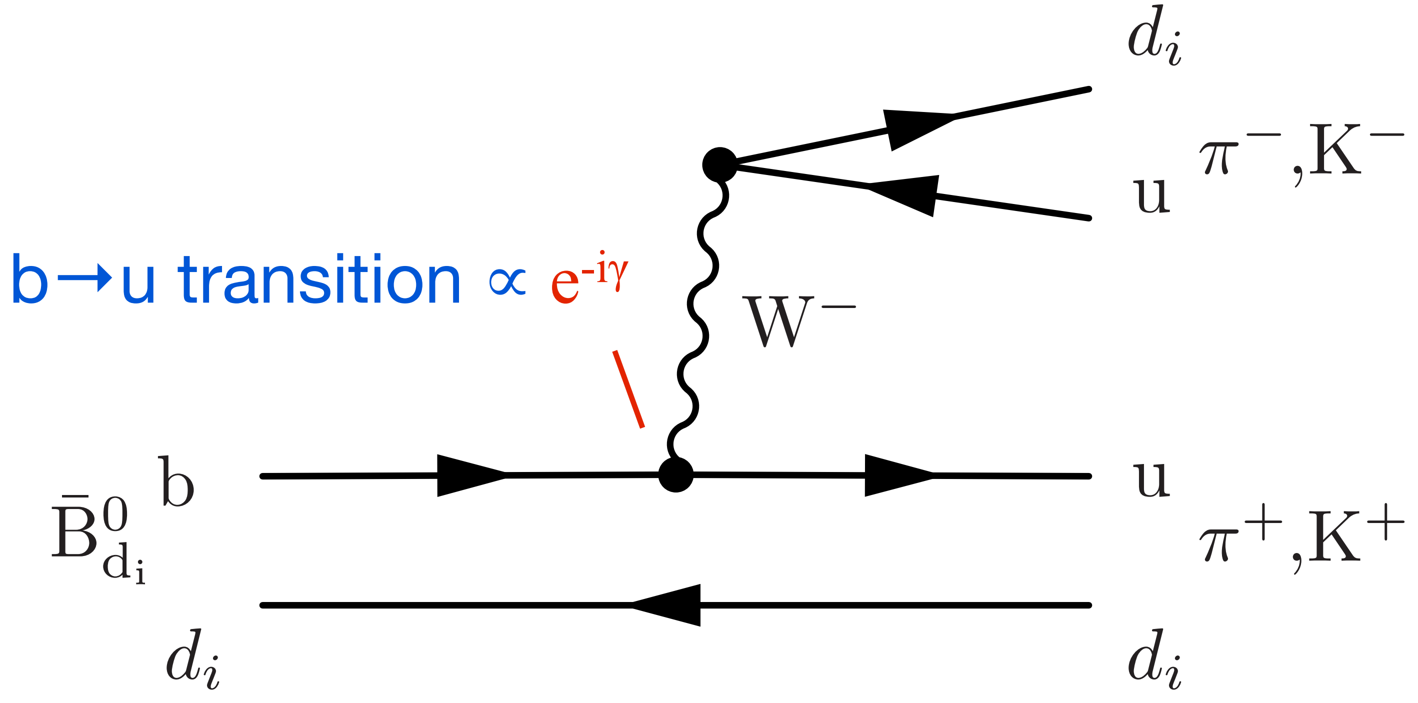


But γ is poorly determined by direct methods

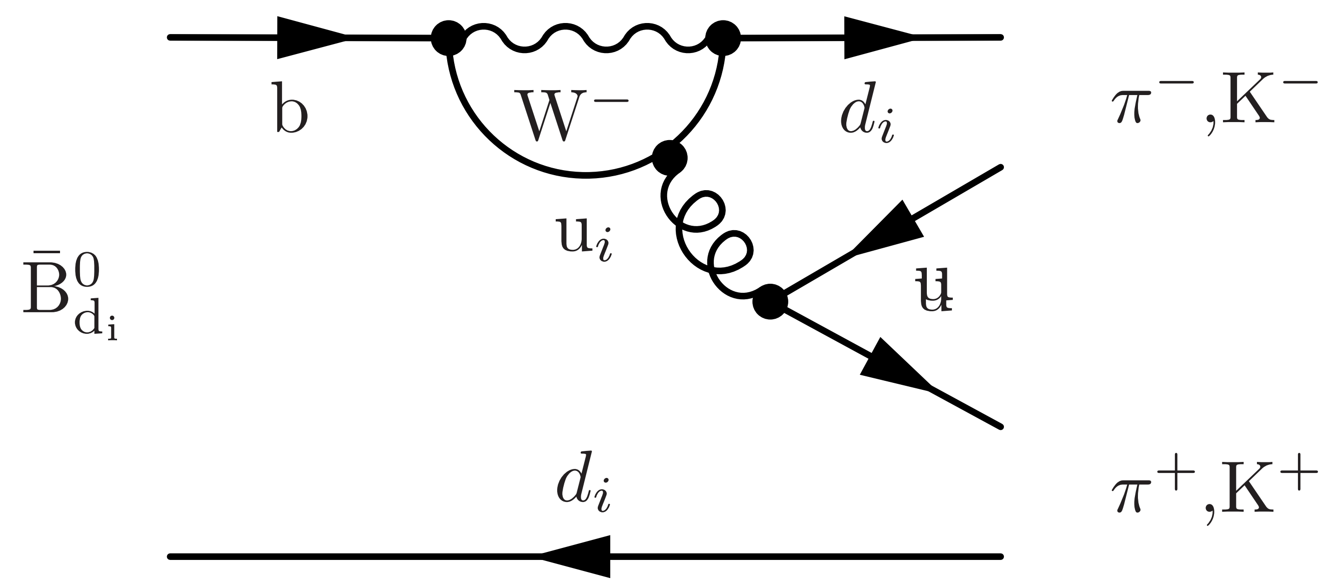


Uses of γ from trees: comparison with loop-mediated processes

- Charmless decays of B_d and B_s mesons can exhibit CP violation from tree-penguin interference



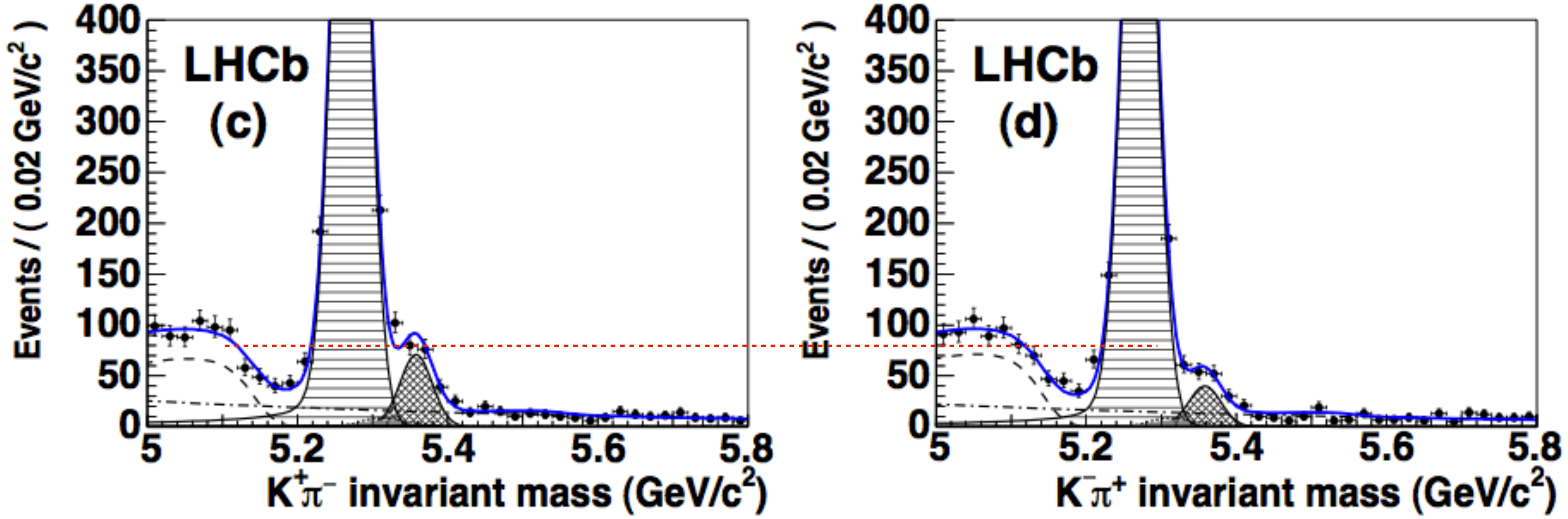
Penguin diagram could contribute a φ_{NP}



- Important ongoing analysis at LHCb

First evidence of direct *CP* violation in charmless two-body decays of B^0_s mesons

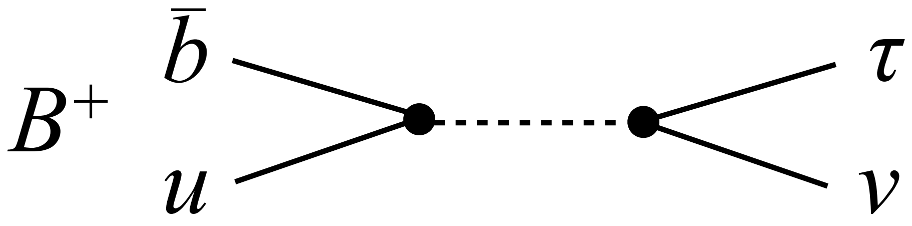
LHCb. arXiv:1202.6251

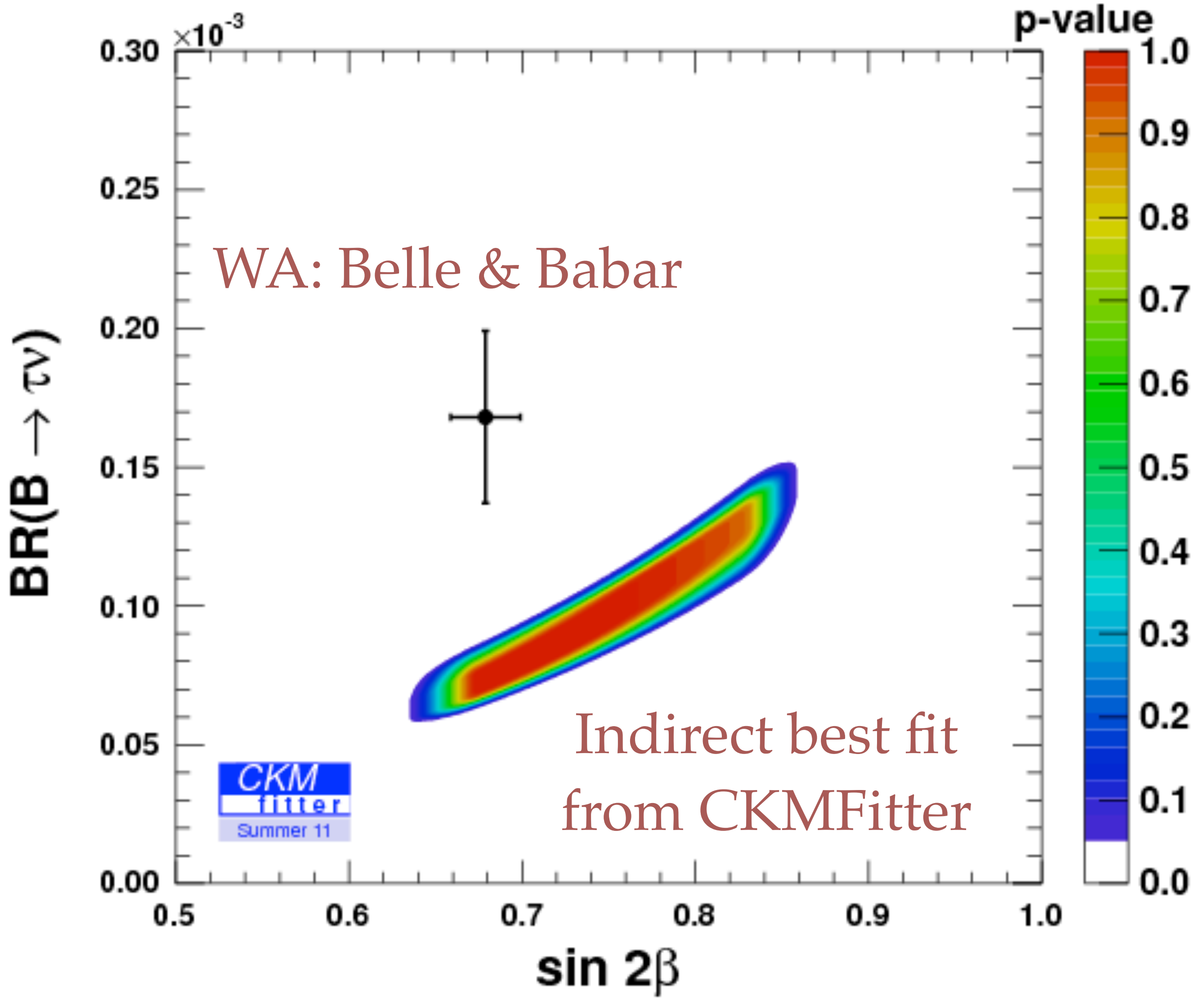


Uses of γ from trees: CKM triangle metrology

- $\sin 2\beta$ is the most precisely determined component of the unitarity triangle
  - the penguin contribution is usually neglected, but, this could be naive

- An example of tension in the unitarity triangle is with $|V_{ub}|$ from $B^+ \to \tau^+ \nu$ and $\sin 2\beta$
  - This is a simple tree decay (exchange diagram)
  - Small theoretical uncertainties.



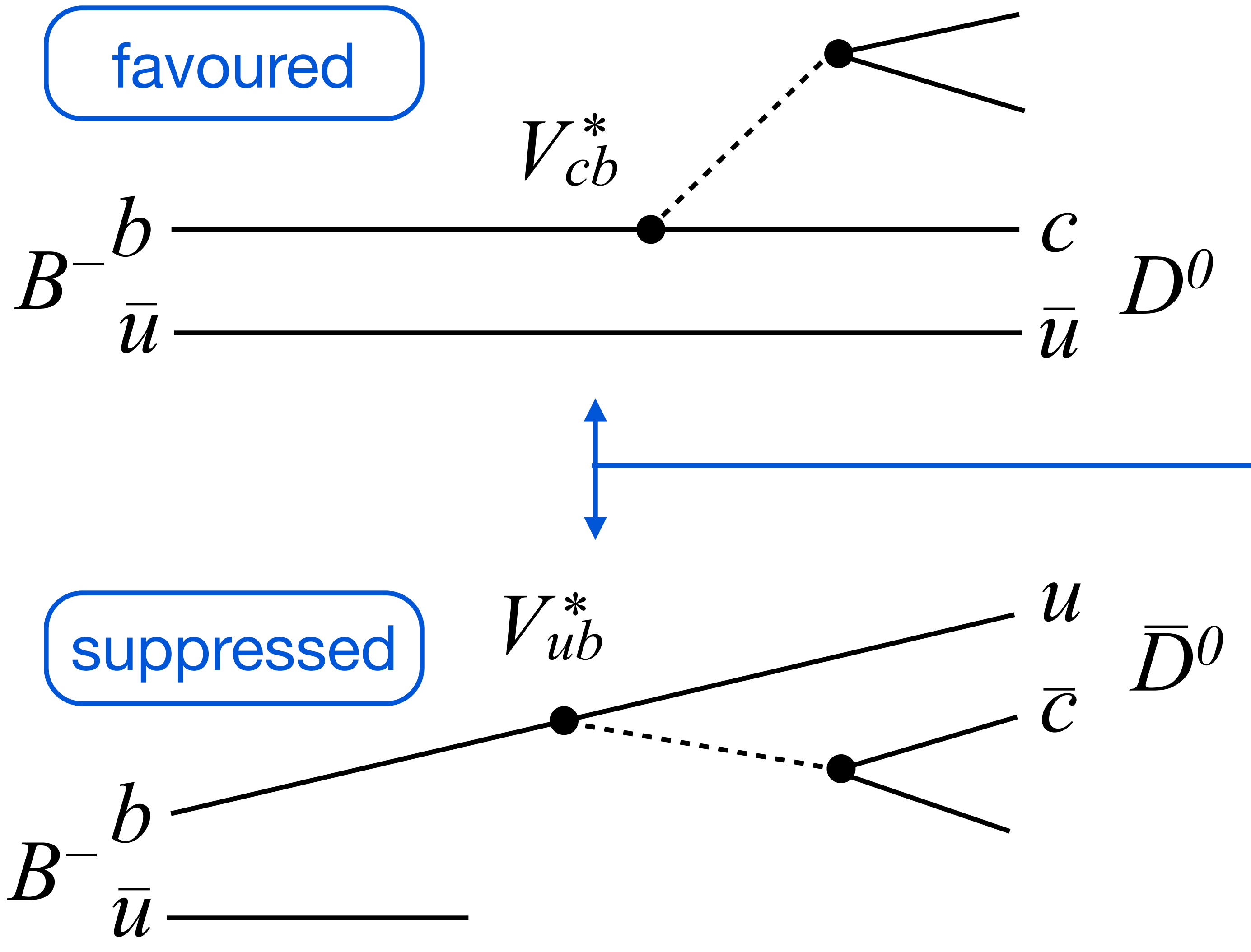


- As we seek to test the unitarity of the CKM paradigm, it become increasingly important to distinguish “tree” measurements from those with sensitivity to loop processes.

(2) How to measure γ with trees

How could we measure γ ?

- Need a $b \to c$ and $b \to u$ transition



weak phase difference:

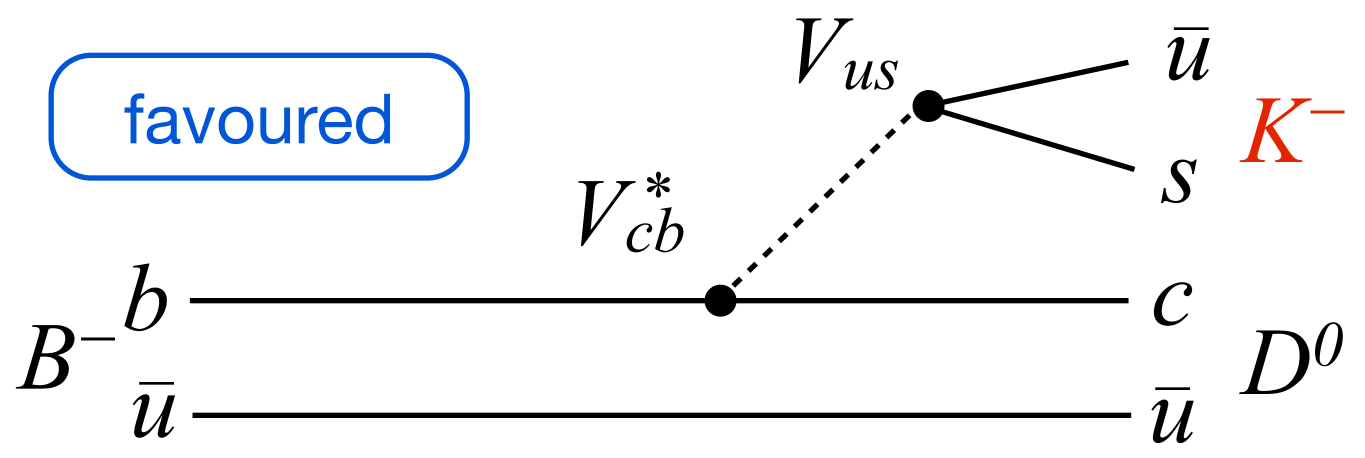
$$= \arg\left(-\frac{V_{ub}^*}{V_{cb}^*}\right)$$

$$= \gamma$$

How could we measure γ ?

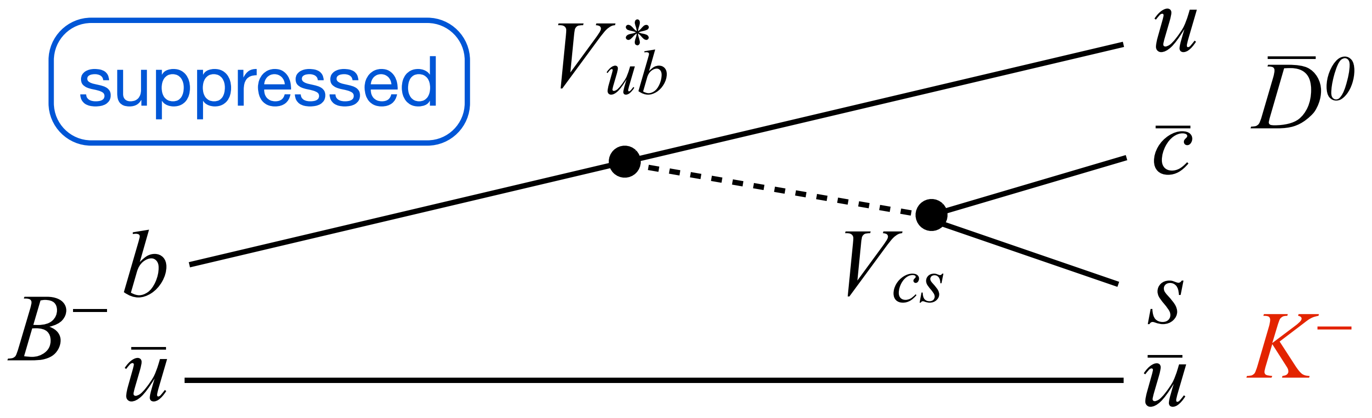
- Need a $b \to c$ and $b \to u$ transition of similar probability

favoured



$r_B \approx 0.1$

suppressed



relative amplitude:

$$\left|\frac{V_{cs}\,V_{ub}^*}{V_{us}\,V_{cb}^*}\right| f_{col}$$

$$= r_B$$

relative strong phase:

$$= \delta_B$$

weak phase difference:

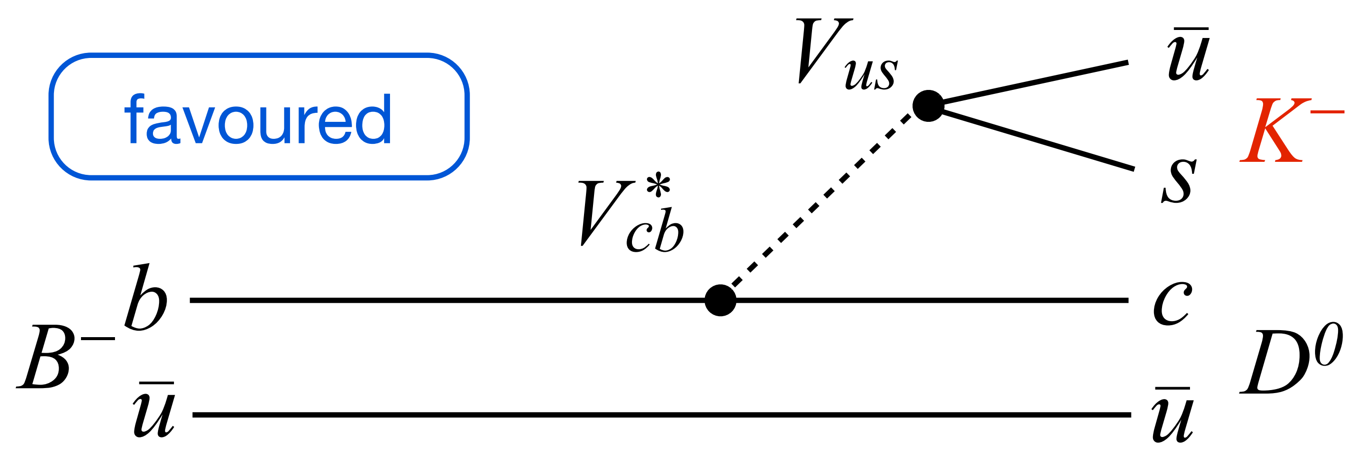
$$\arg\left(\frac{V_{cs}\;V_{ub}^*}{V_{us}\;V_{cb}^*}\right)$$

$$= \arg\left(-\frac{V_{ub}^*}{V_{cb}^*}\right)$$

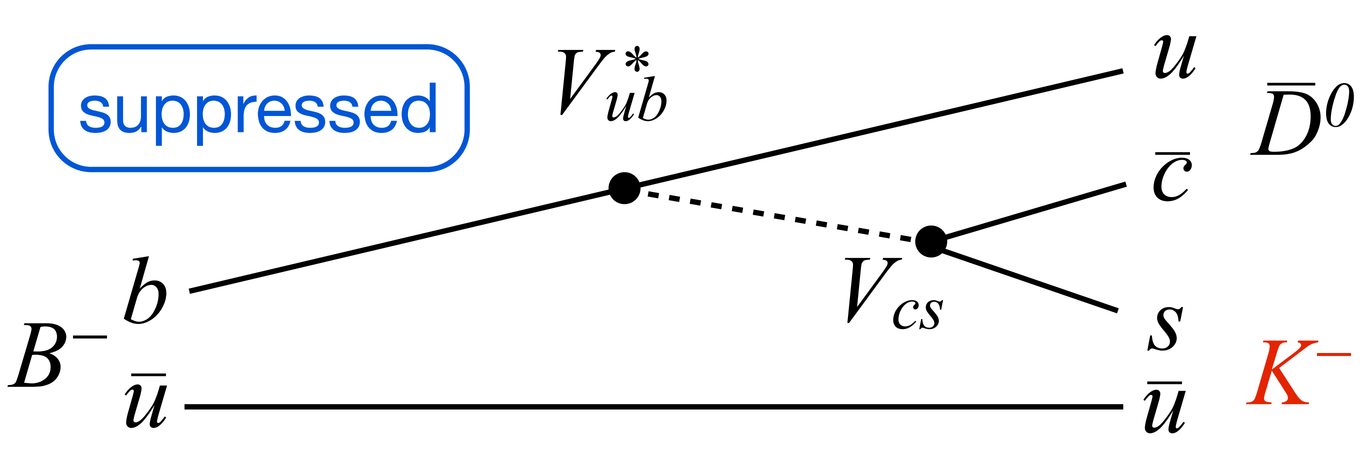
$$= \gamma$$

How could we measure γ ?

- Need a $b \to c$ and $b \to u$ transition of similar probability and a <u>common final state</u>



$r_B \approx 0.1$



$$D^0/\bar{D}^0 \begin{array}{l} \to K^+K^- \\ \to \pi^+\pi^- \end{array}$$

relative amplitude:

$$\left| \frac{V_{cs} V_{ub}^*}{V_{us} V_{cb}^*} \right| f_{col} = r_B$$

weak phase difference:

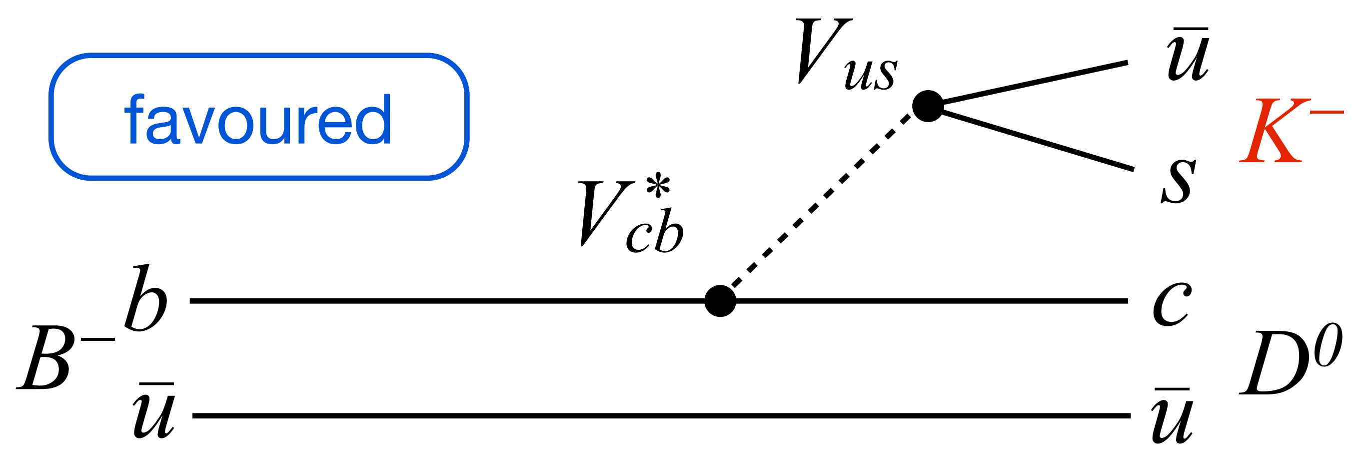
$$\arg\left(\frac{V_{cs} \; V_{ub}^*}{V_{us} \; V_{cb}^*} \right) = \arg\left(-\frac{V_{ub}^*}{V_{cb}^*} \right) = \gamma$$

relative strong phase:

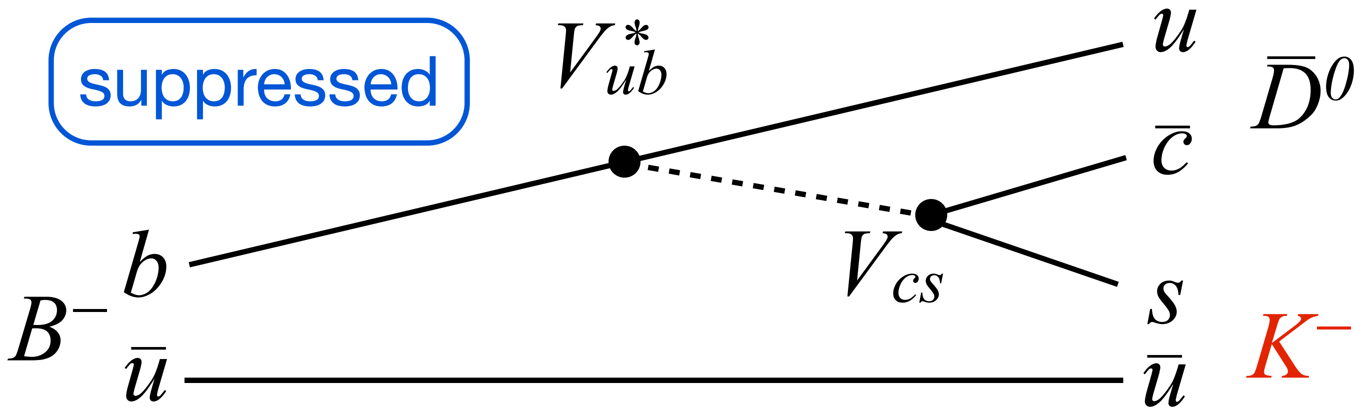
$$= \delta_B$$

How could we measure γ ?

- Need a $b \to c$ and $b \to u$ transition of similar probability and a <u>common final state</u>



$r_B \approx 0.1$



$D^0/\bar{D}^0 \to K^+K^-$, $\to \pi^+\pi^-$ — *CP* eigenstates

Nota bene:

$D \to K^+K^-$, $\pi^+\pi^-$ are *CP*+ eigenstates

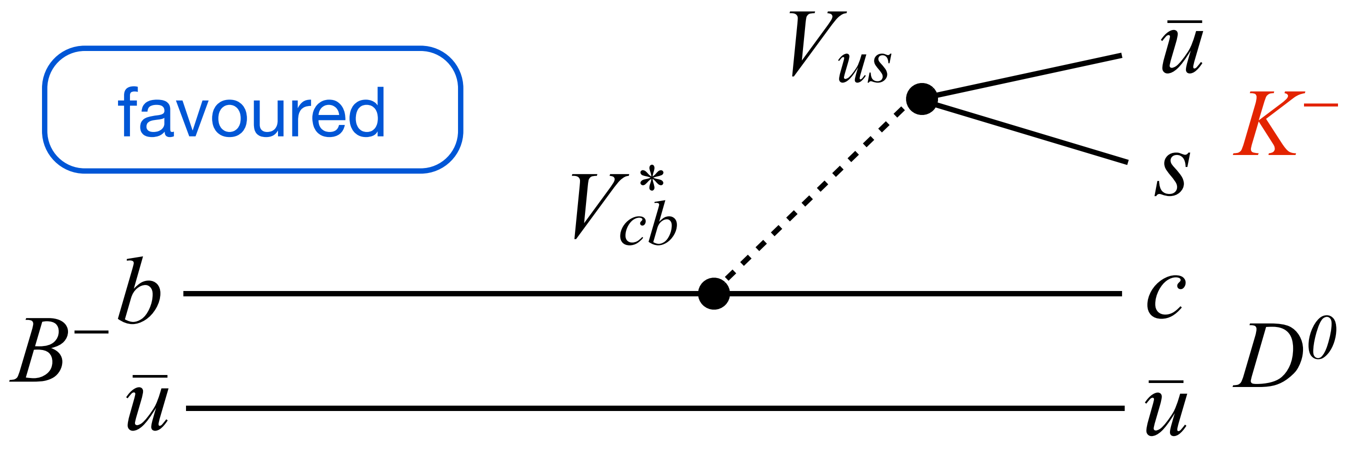
$D \to K^0\pi^0$, $K^0\omega$... are *CP*– eigenstates

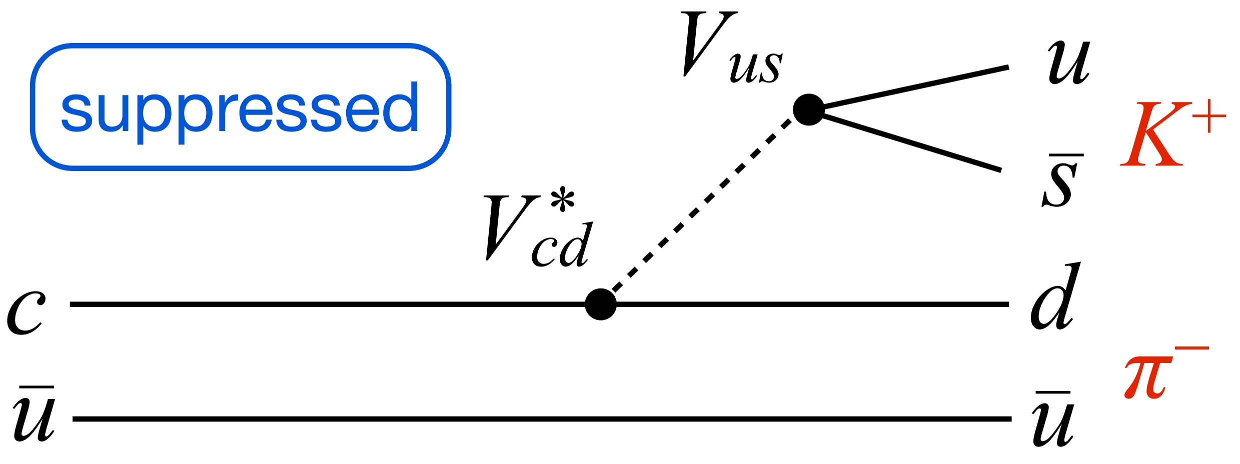
However:

modes with $K^0 + \pi^0$ are difficult to trigger and reconstruct at LHCb so are not considered [yet].

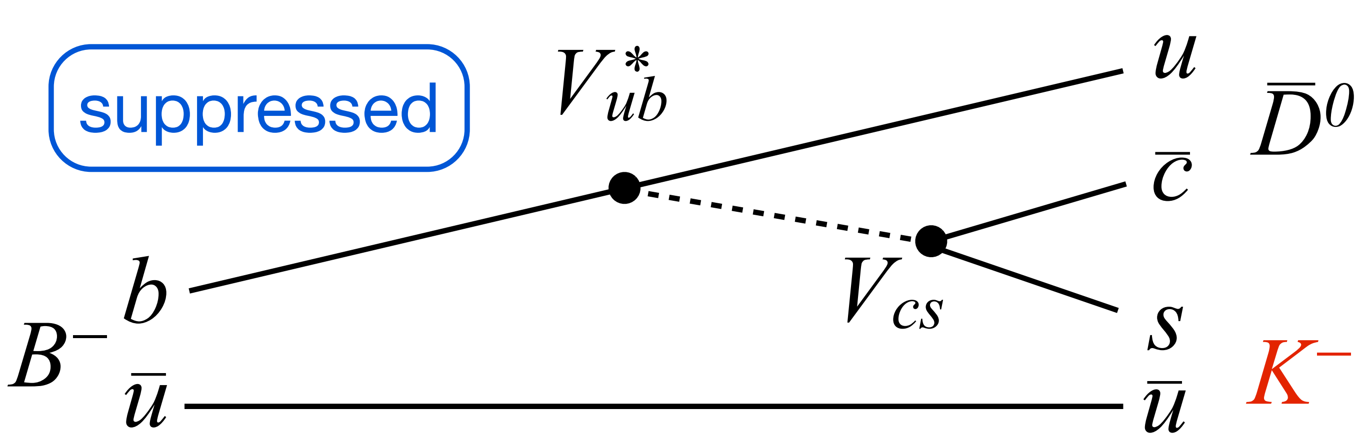
But the larger the interference, the greater the sensitivity to γ

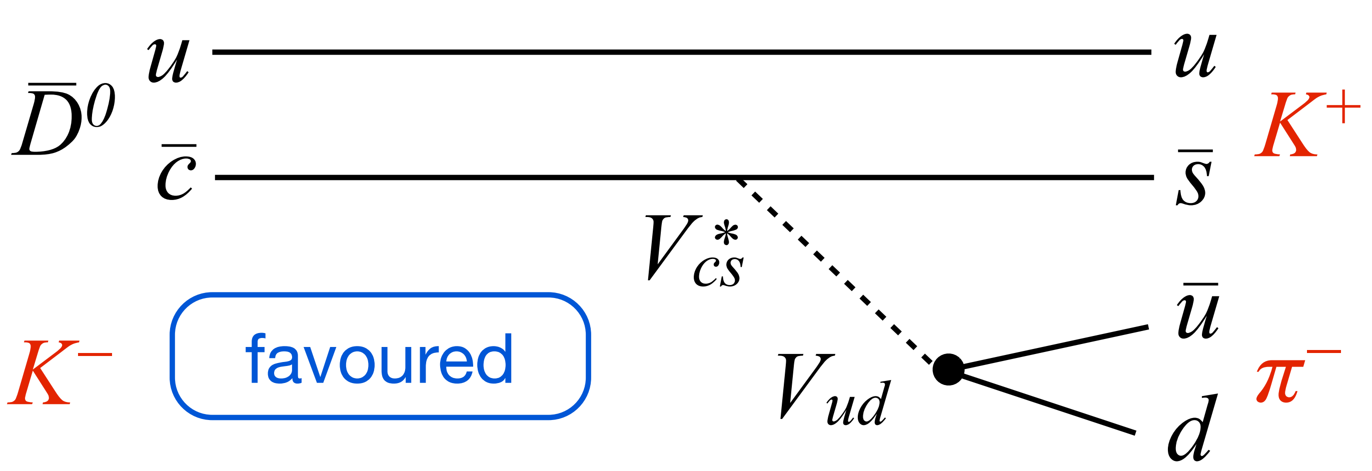
- Need a $b \to c$ and $b \to u$ transition of similar probability and a <u>common final state</u>





$r_B \approx 0.1$ $\quad$ $r_D \approx 0.06$ $\quad$ $r_D / r_B \approx 0.6 \sim 1$





$B^- \rightarrow DK^-$ $D, \rightarrow K^+K^-, \pi^+\pi^-$

favoured $\oplus$ suppressed $\otimes$ *CP* eigenstates

"*CP*" or "GLW" modes

M. Gronau and D. London, *How to determine all the angles of the unitarity triangle from $B_d^0 \to DK_S^0$ and $B_s^0 \to D\phi$*, Phys. Lett. **B253** (1991) 483; M. Gronau and D. Wyler, *On determining a weak phase from CP asymmetries in charged B decays*, Phys. Lett. **B265** (1991)

$B^- \rightarrow DK^-$ $D \rightarrow \pi^- K^+$

favoured $\oplus$ suppressed $\otimes$ suppressed $\oplus$ favoured

"ADS" mode

D. Atwood, I. Dunietz, and A. Soni, *Enhanced CP violation with $B \to KD^0(\bar{D}^0)$ modes and extraction of the CKM angle γ*, Phys.Rev.Lett. **78** (1997) 3257, arXiv:hep-ph/9612433;

$B^- \rightarrow DK^-$ $D \rightarrow K^-\pi^+$

favoured $\oplus$ suppressed $\otimes$ favoured $\oplus$ suppressed

"Favoured" mode

- Logic is equally applicable to $B^- \rightarrow D\pi^-$ though r_B, and hence the interference is smaller

$r_{B(\pi)} \sim 0.01$ compared to $r_{B(K)} \sim 0.1$

- The "physics" observables are ratios of branching fractions and CP asymmetries
- All mode has dependence on γ though this is essentially negligible in the favoured mode

The “physics” observables

CP modes

$$\frac{<\Gamma(B^{\pm}\rightarrow[\pi\pi]_D K^{\pm}), \Gamma(B^{\pm}\rightarrow[KK]_D K^{\pm})>}{\Gamma(B^{\pm}\rightarrow[K\pi]_D K^{\pm})}$$

favoured mode

average of *KK* and *ππ modes*

$$\frac{\Gamma(B^{-}\rightarrow D_{CP}K^{-}) - \Gamma(B^{+}\rightarrow D_{CP}K^{+})}{\Gamma(B^{-}\rightarrow D_{CP}K^{-}) + \Gamma(B^{+}\rightarrow D_{CP}K^{+})}$$

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

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

ADS mode

$$\frac{\Gamma(B^{\pm}\rightarrow[\pi K]_D K^{\pm})}{\Gamma(B^{\pm}\rightarrow[K\pi]_D K^{\pm})}$$

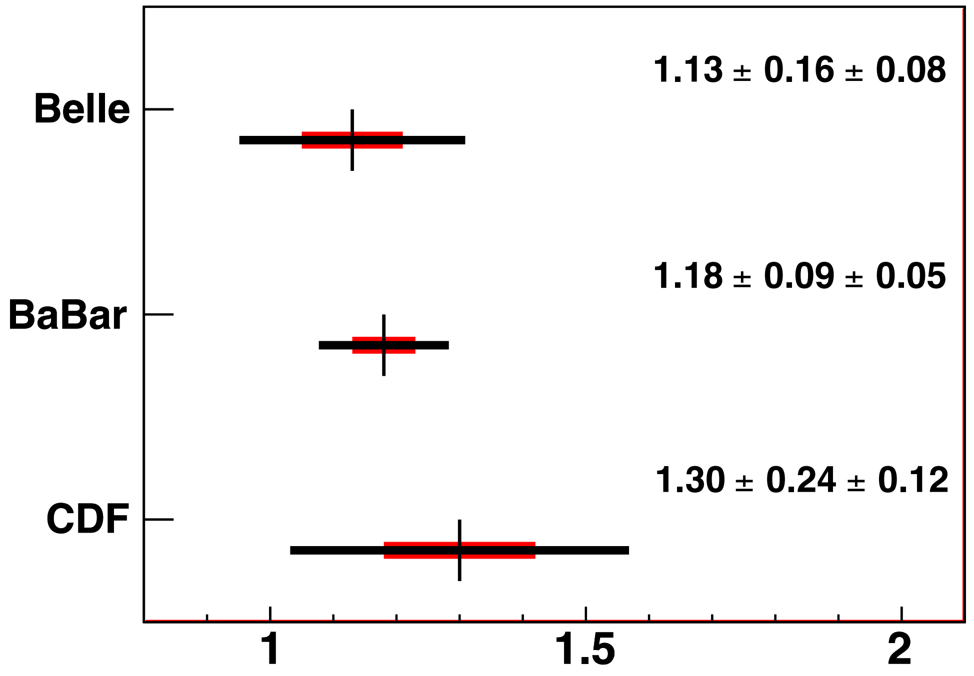
favoured mode

$$\frac{\Gamma(B^{-}\rightarrow D_{ADS}K^{-}) - \Gamma(B^{+}\rightarrow D_{ADS}K^{+})}{\Gamma(B^{-}\rightarrow D_{ADS}K^{-}) + \Gamma(B^{+}\rightarrow D_{ADS}K^{+})}$$

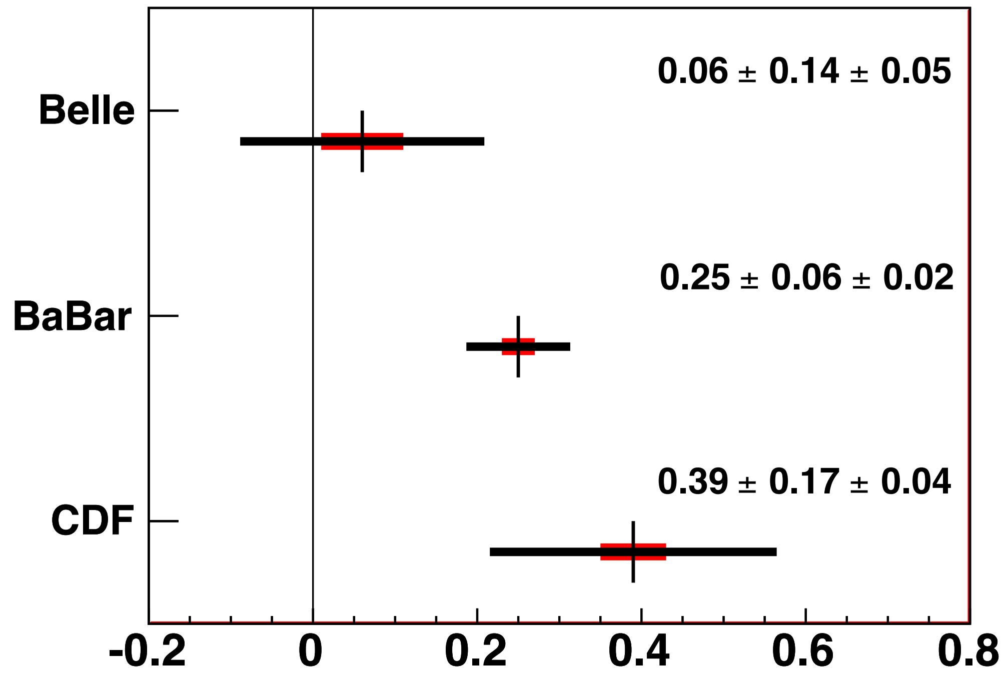
$$R^{ADS} = \frac{{r_B}^2 + {r_D}^2 + 2r_B r_D\cos(\delta_B + \delta_D)\cos\gamma}{1 + (r_B r_D)^2 + 2r_B r_D\cos(\delta_B - \delta_D)\cos\gamma}$$

$$A^{ADS} = \frac{2r_B r_D\sin(\delta_B + \delta_D)\sin\gamma}{{r_B}^2 + {r_D}^2 + 2r_B r_D\cos(\delta_B + \delta_D)\cos\gamma}$$

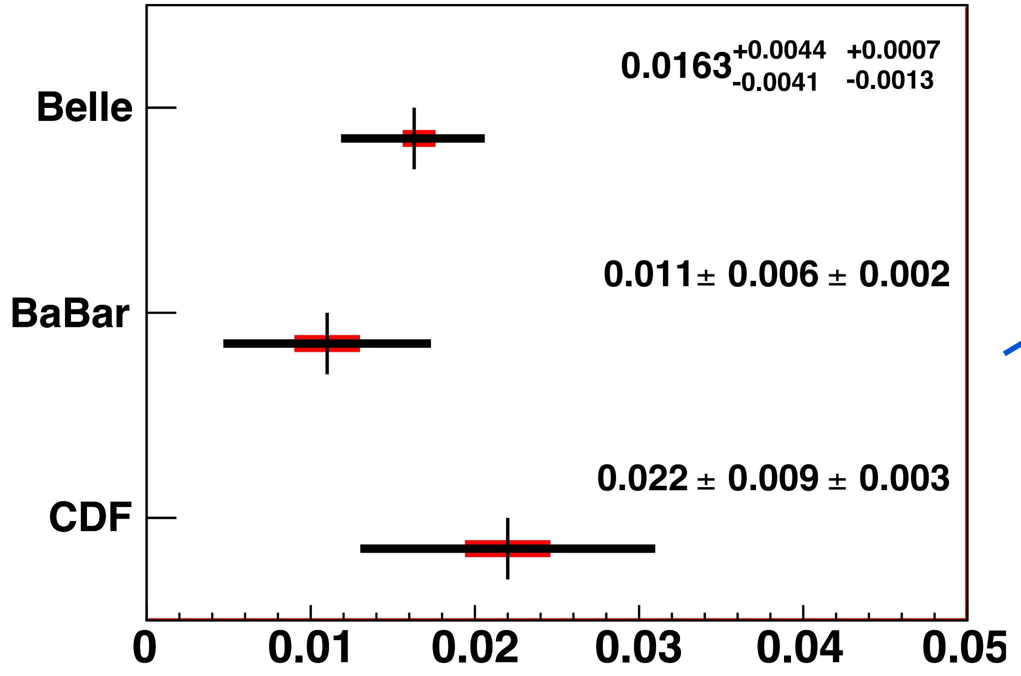
Status of published results



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

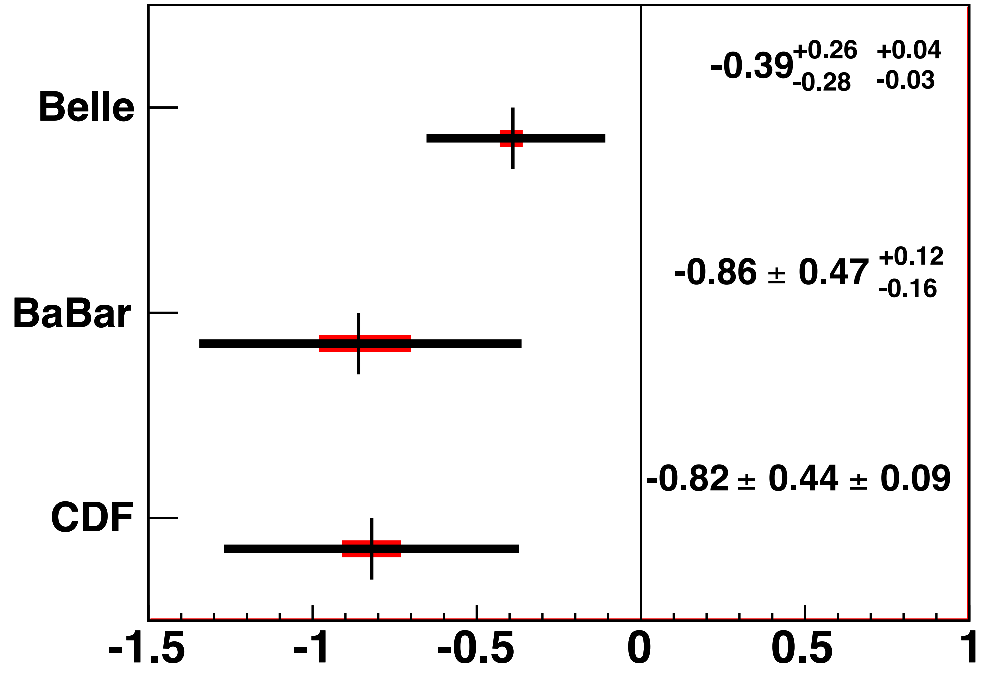


$$A_{CP+} = \frac{2 r_B \sin\delta_B \sin\gamma}{1 + {r_B}^2 + 2 r_B \cos\delta_B \cos\gamma}$$



ADS mode

effective BF~10^{-7}



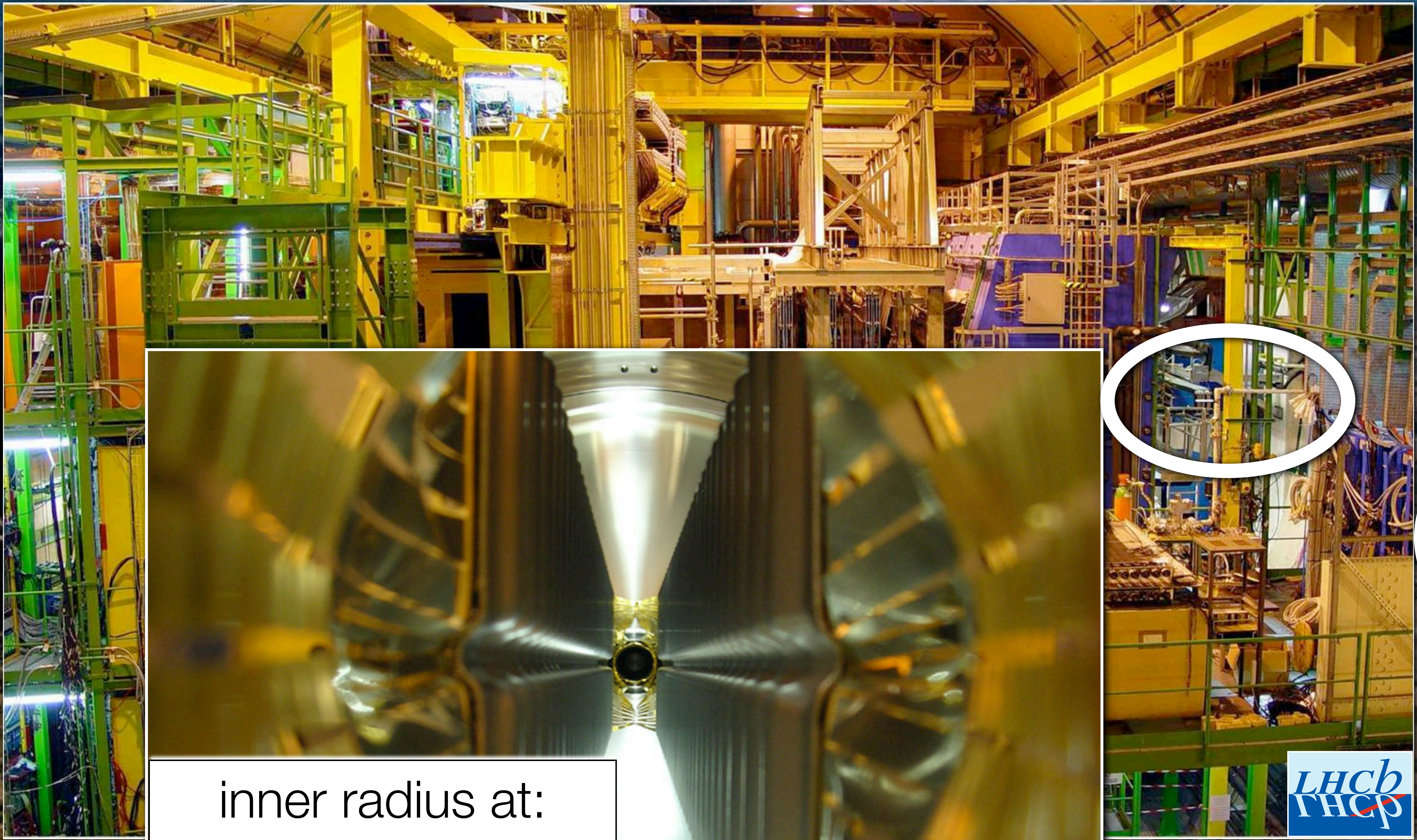
$$R^{ADS} = \frac{{r_B}^2 + {r_D}^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma}{1 + (r_B r_D)^2 + 2 r_B r_D \cos(\delta_B - \delta_D) \cos\gamma}$$

$$A^{ADS} = \frac{2 r_B r_D \sin(\delta_B + \delta_D) \sin\gamma}{{r_B}^2 + {r_D}^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma}$$

(3) So, where might we find billions of $B^{\pm}$?

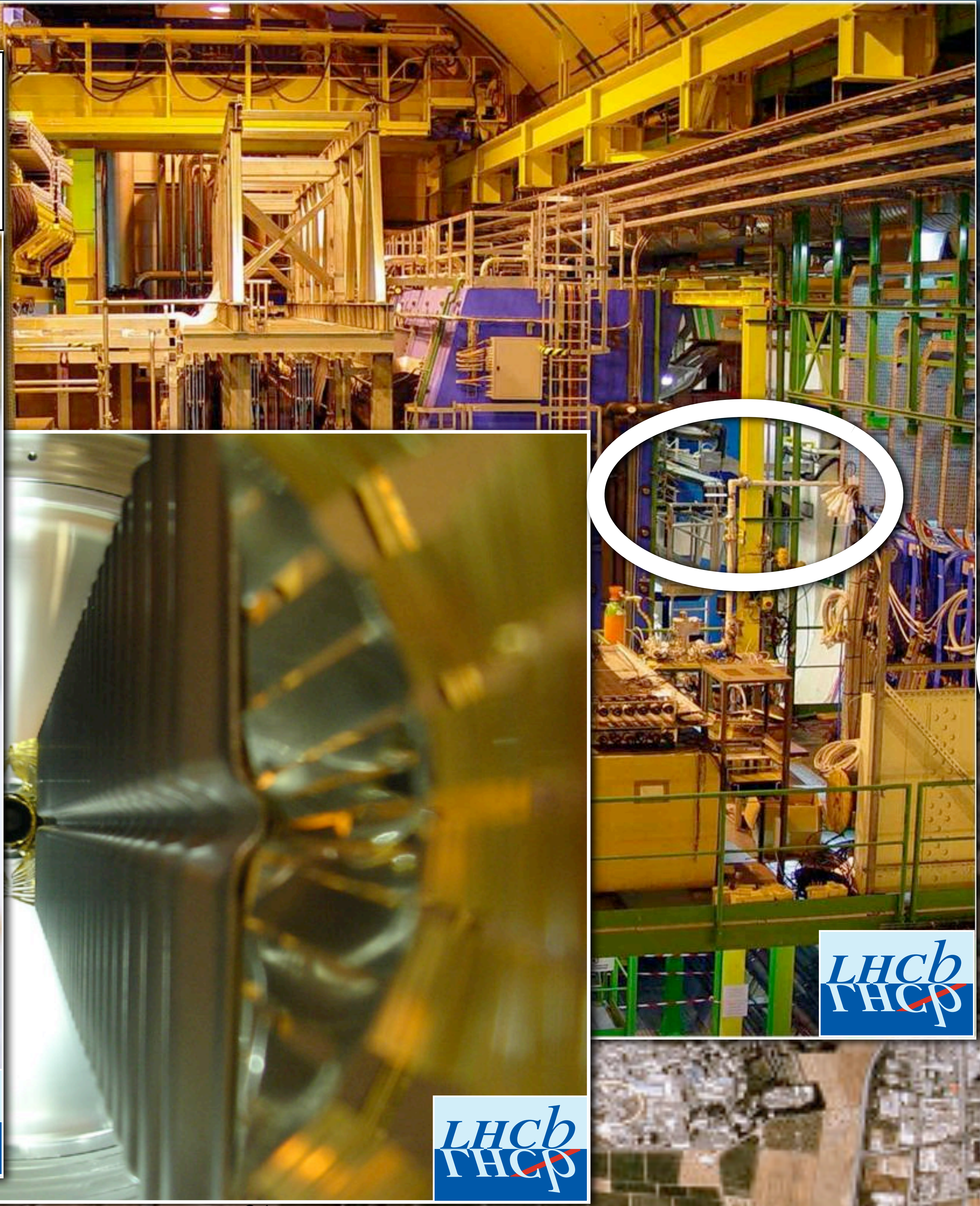
You will recognise this...

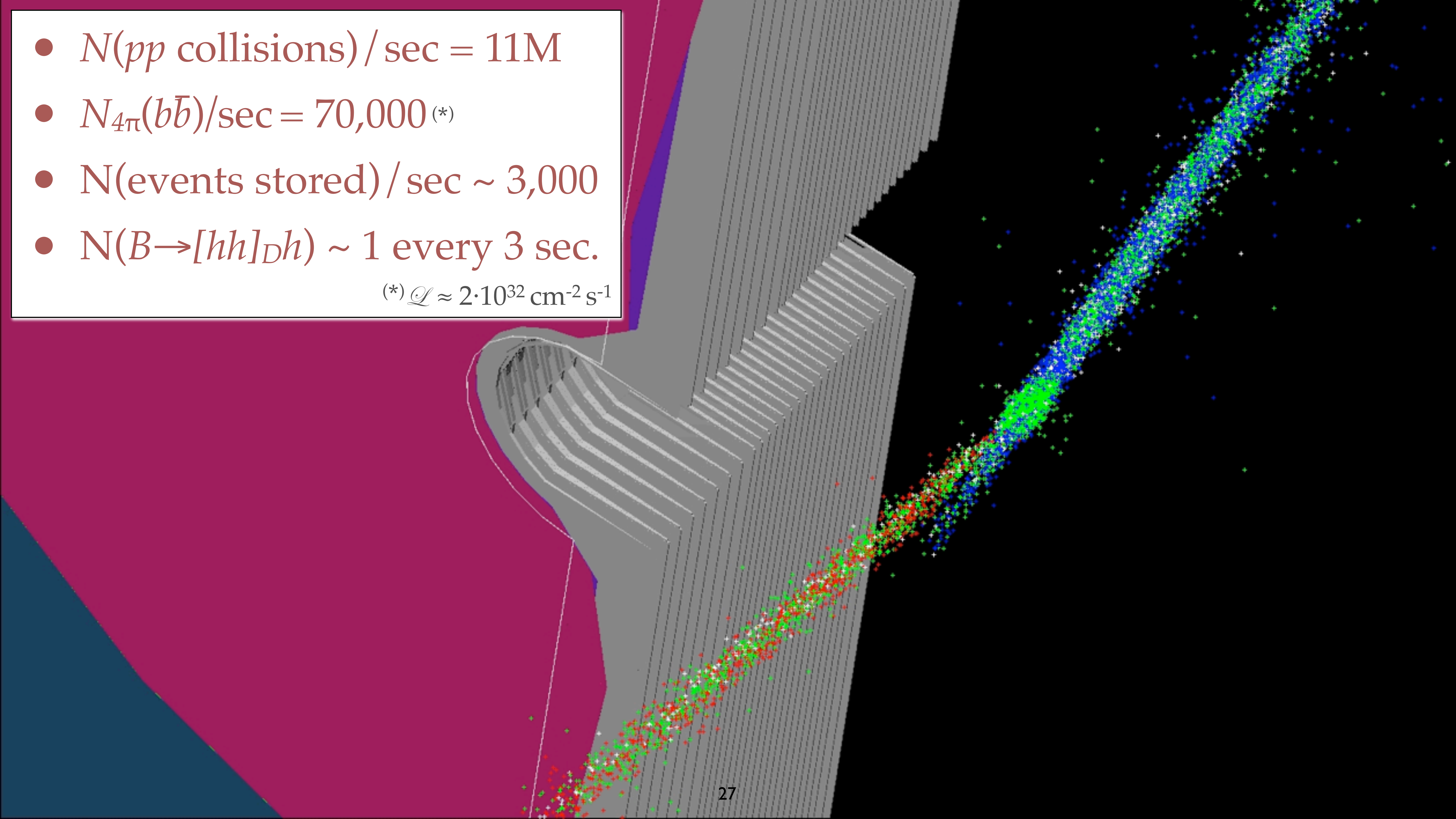
And at point 8, LHCb



inner radius at:
29mm (injection)
5mm (stable beams)

Silicon strip vertex detector.
>40μm pitch at 8.2mm radius



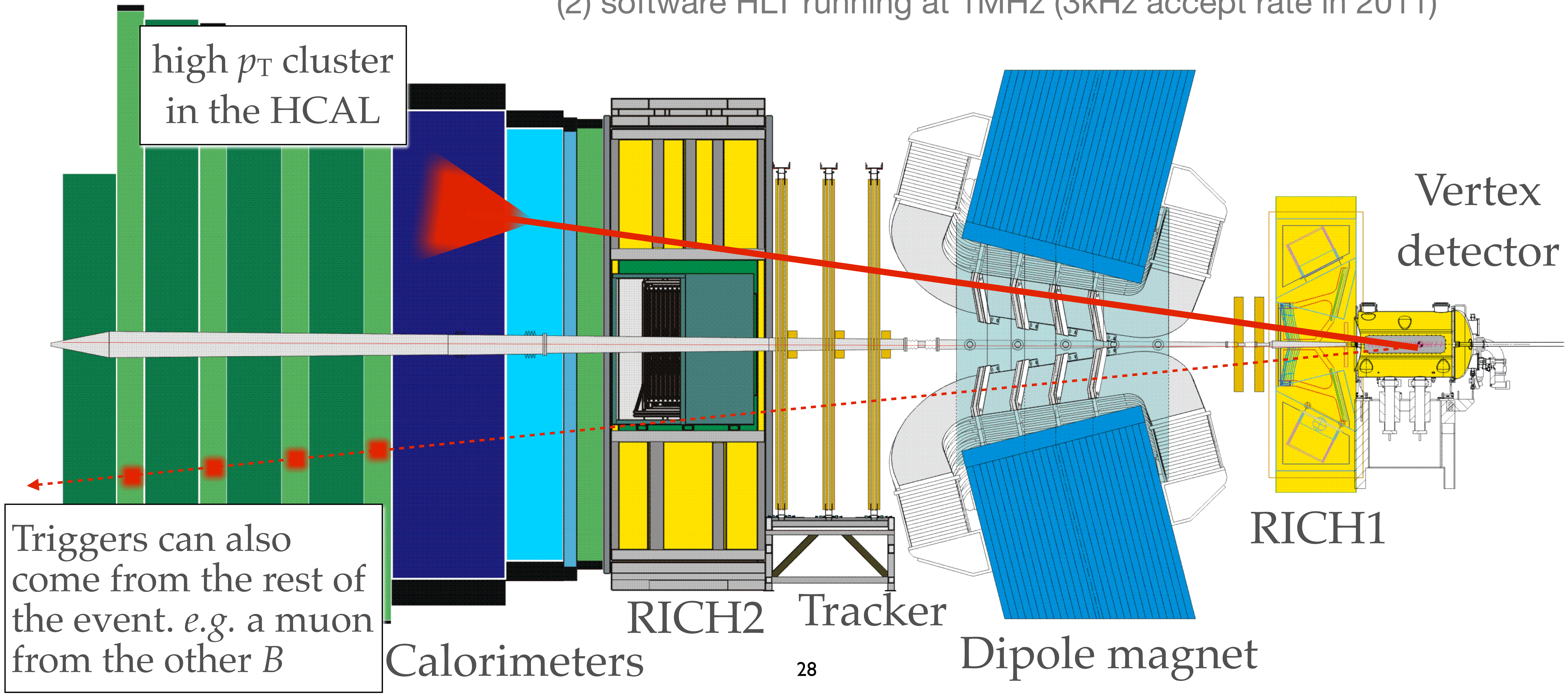


- $N(pp$ collisions$)\,/\,$sec $= 11$M
- $N_{4\pi}(b\bar{b})$/sec $= 70{,}000$ (*)
- N(events stored) / sec ~ 3,000
- N($B \to [hh]_D h$) ~ 1 every 3 sec.

(*) $\mathscr{L} \approx 2 \cdot 10^{32}\ \mathrm{cm^{-2}\,s^{-1}}$

Triggering of the exclusive hadronic final state: $B^{\pm} \rightarrow [h^{+}h^{-}]_{D}\, h^{\pm}$

- LHCb has a two-stage trigger. (1) hardware “L0” trigger running at 40MHz
  (2) software HLT running at 1MHz (3kHz accept rate in 2011)

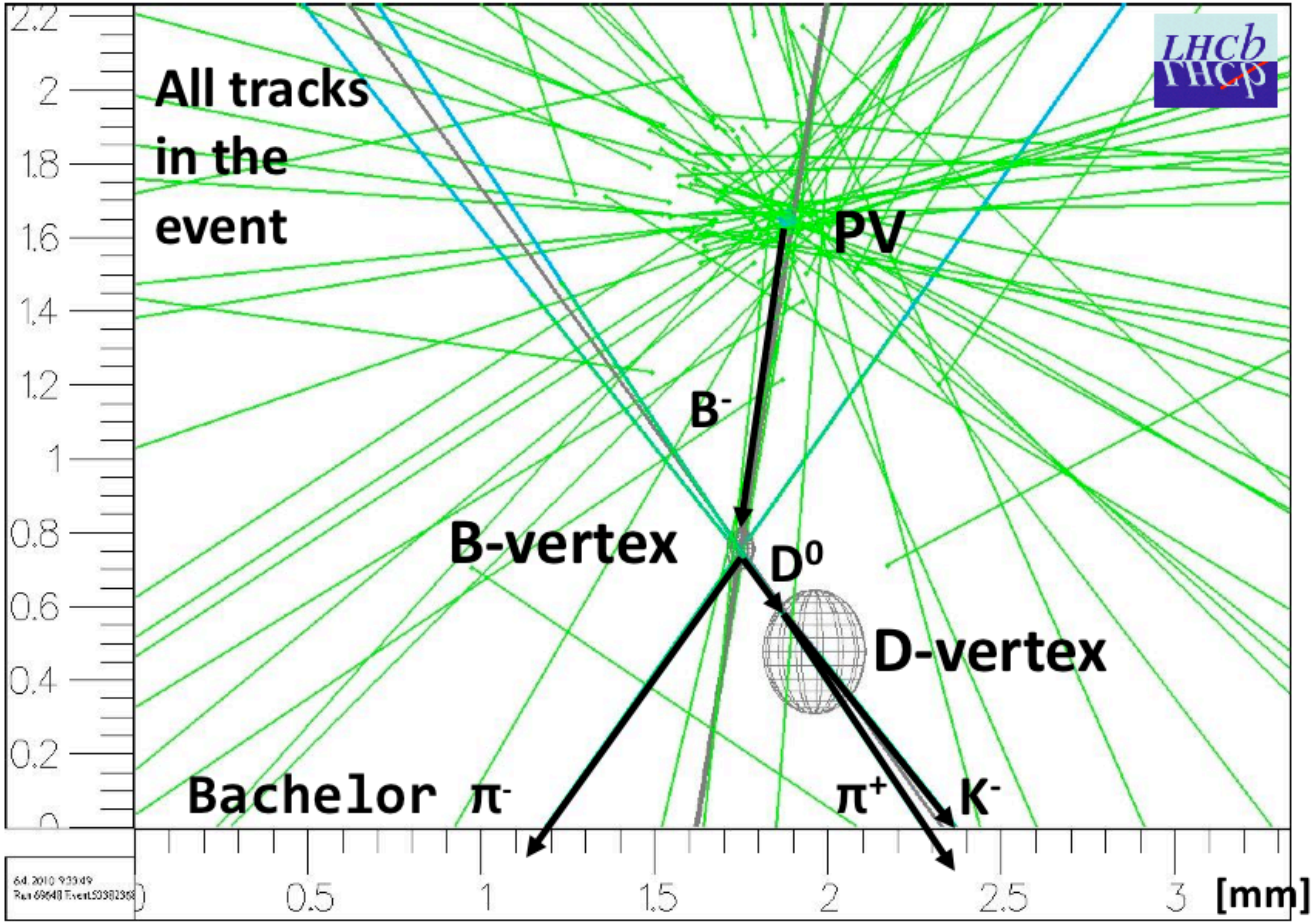


The high level trigger for $B^{\pm} \to [h^{+}h^{-}]_{D}\, h^{\pm}$

- The HLT for these hadronic modes runs in two steps:

- Find a high quality, high p_T, high impact parameter track (this is often the 'bachelor' π or K from the B decay)

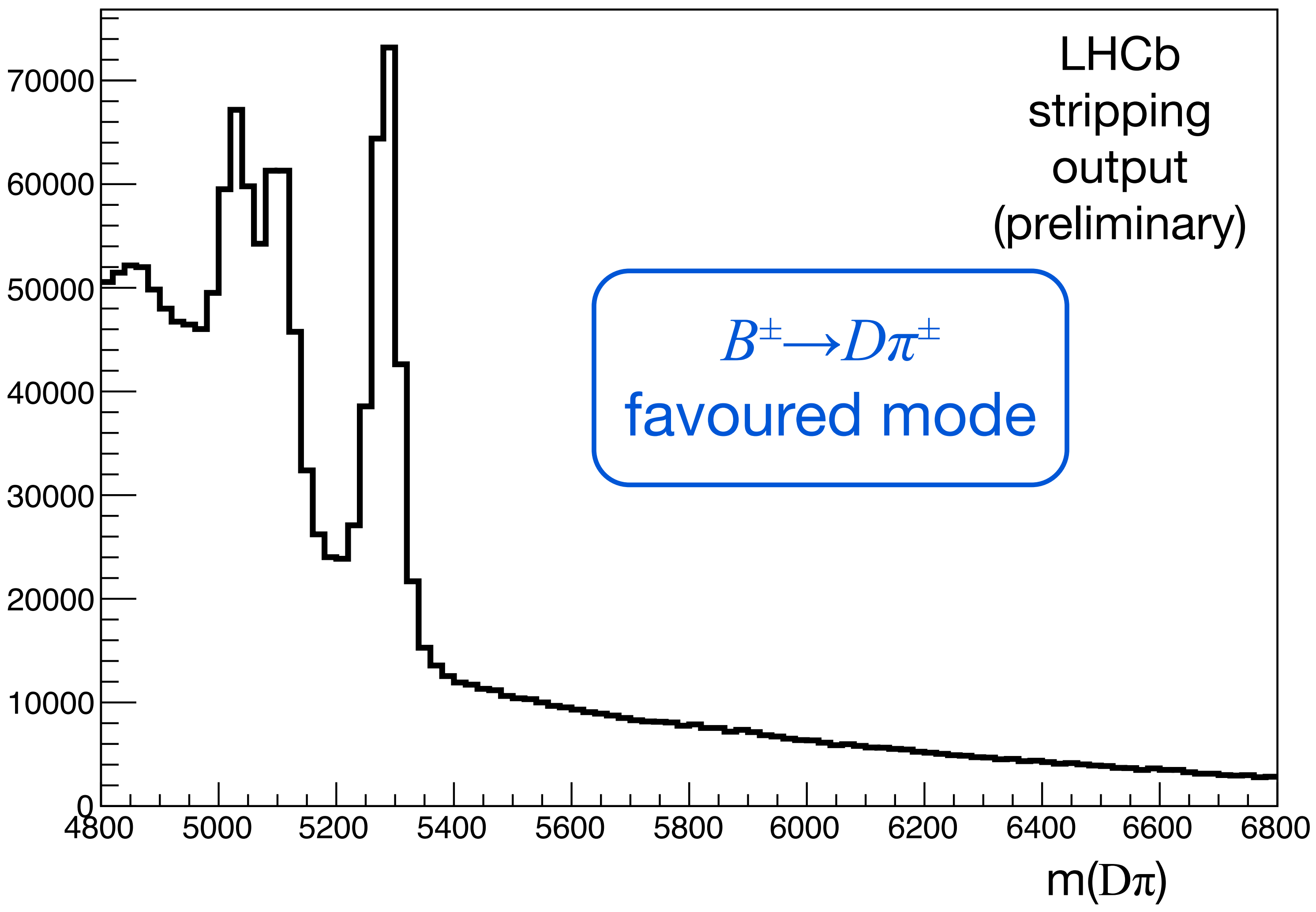
- If this successful, then require it to be part of a good quality displaced vertex, consistent with the B mass.
  - In 2011, a decision tree algorithm has been successfully used.

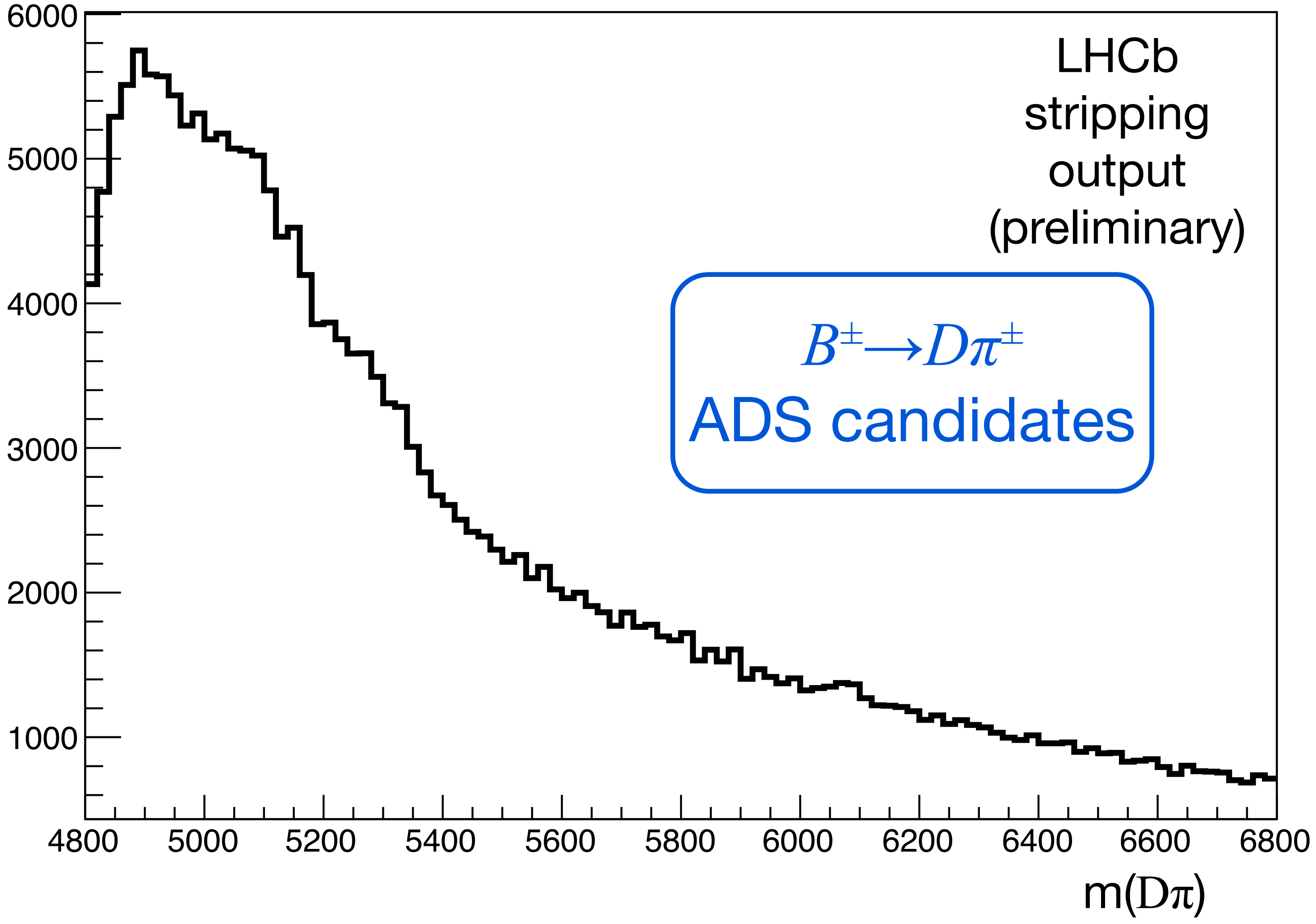


(4) An exclusive hadronic *B* decay with BF~10^{-7}

Analysis of $B^{\pm} \rightarrow [h^+h^-]_D\, h^{\pm}$

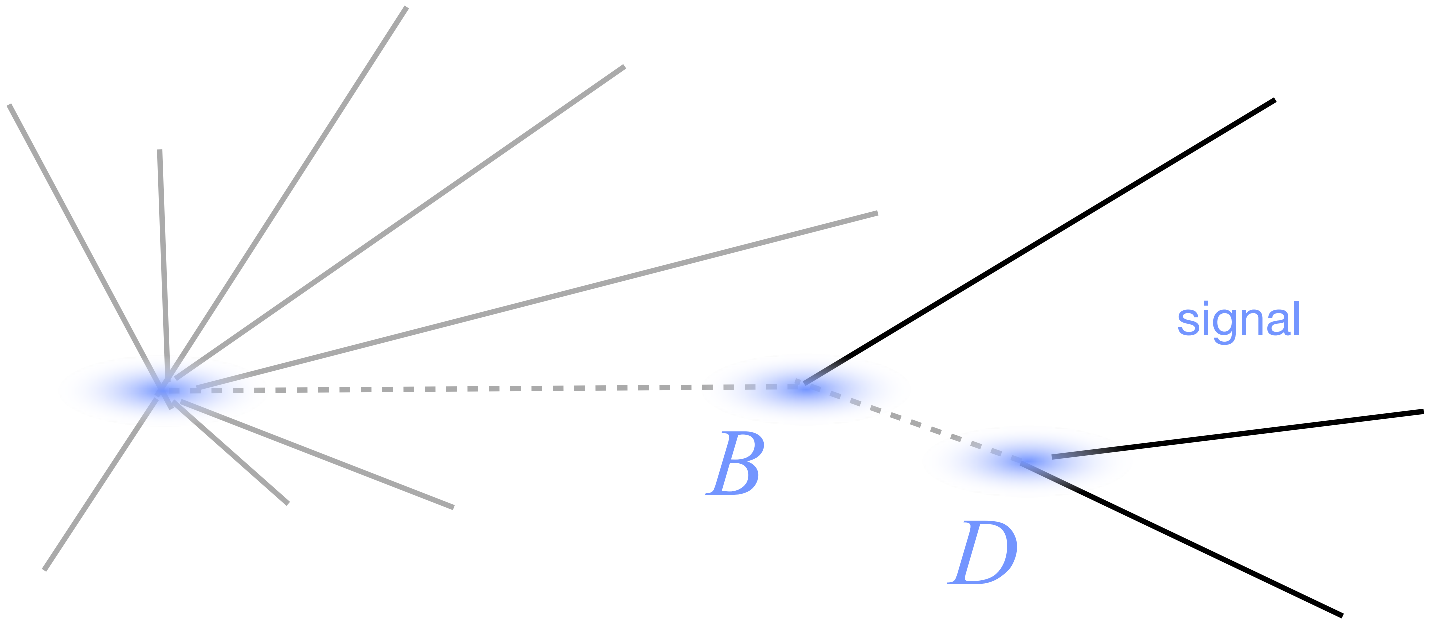
- The full 2011 dataset is used in this analysis, approximately **1 fb^{-1}**
- *B* candidates are refitted, constraining vertices to points and the *D*-candidate mass to m(D^0)$_{PDG}$
- The data are "stripped" down to a manageable size with a loose selection.
  - At this point *B* peaks are clearly visible in the most abundant modes

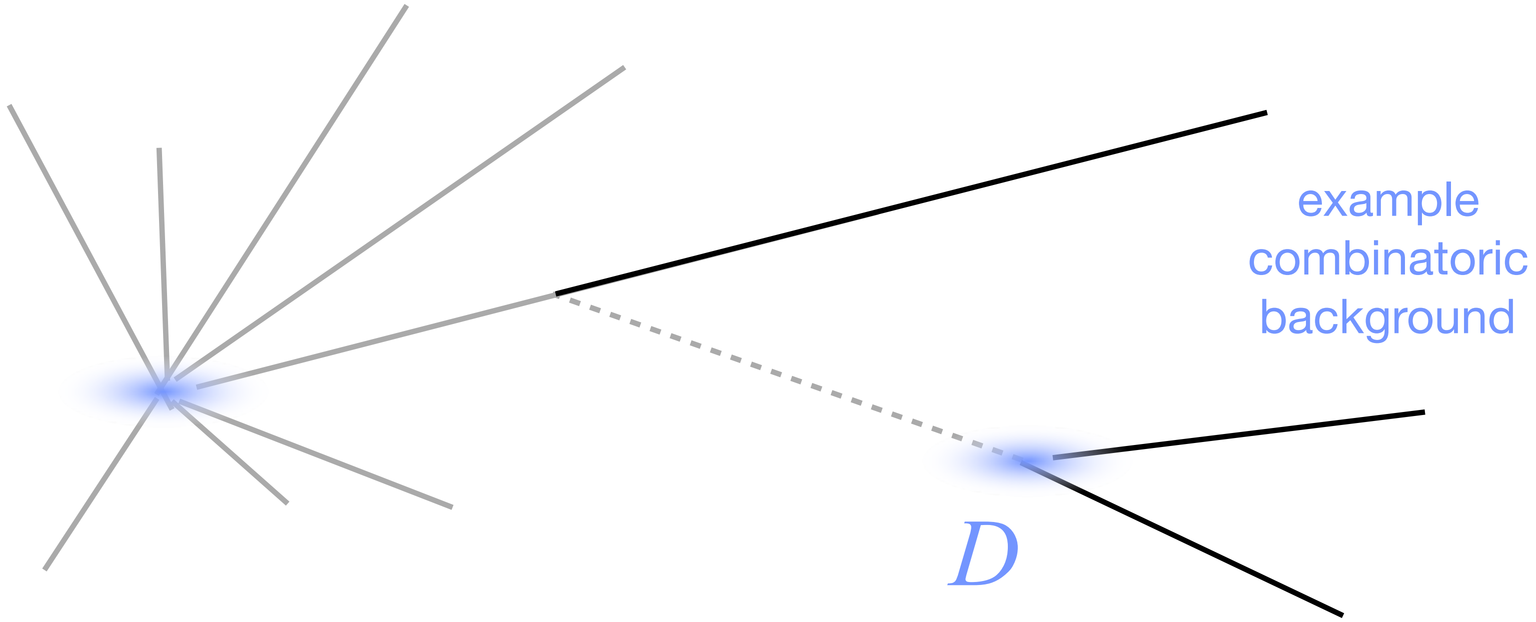




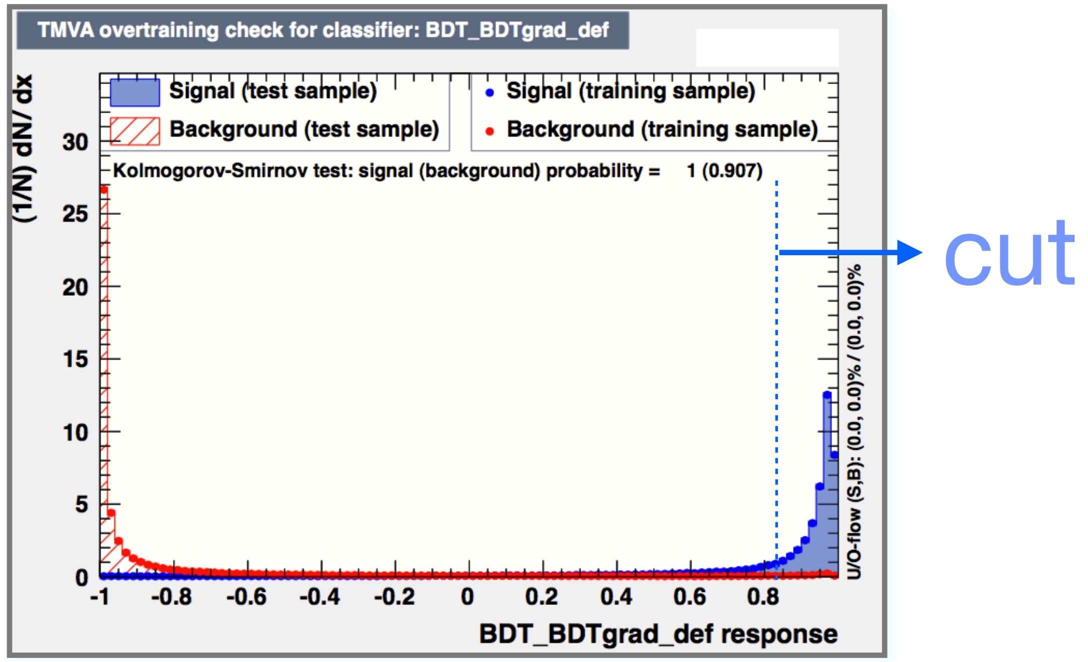
Minimising combinatoric background

- Use the TMVA Boosted Decision Tree with 20 variables.
- Train on a simulated $B^{\pm} \to [K\pi]_D K^{\pm}$ sample vs. the data sidebands from the **2010 dataset** (35 pb^{-1})



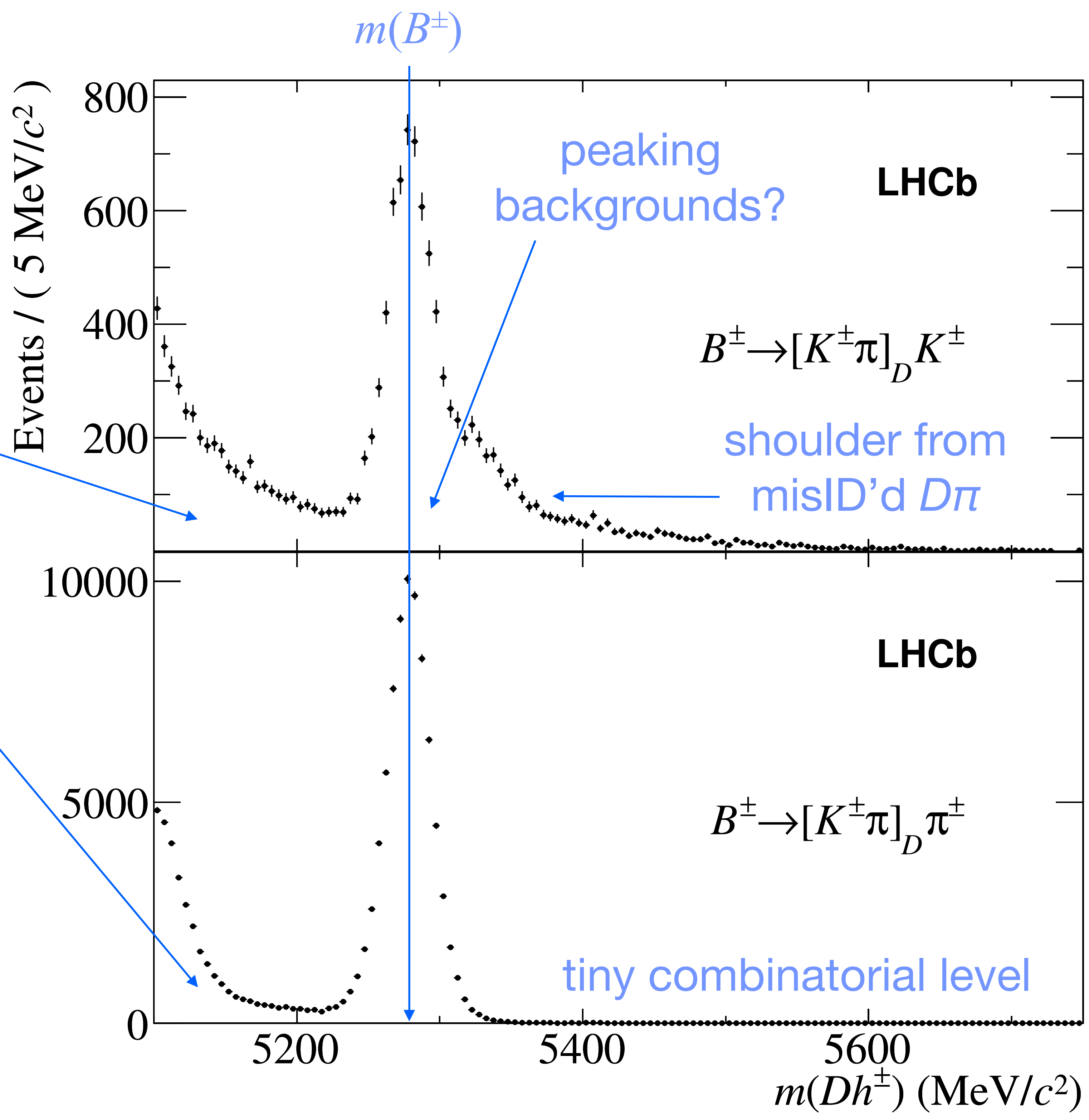


- Useful quantities to distinguish the signal:
  - Transverse momenta
  - Impact parameters
  - Flight distances
  - Quality of vertices
  - Distances of closest approach
  - Comparison of momentum and spatial vectors
  - And some pT information from the rest of the event



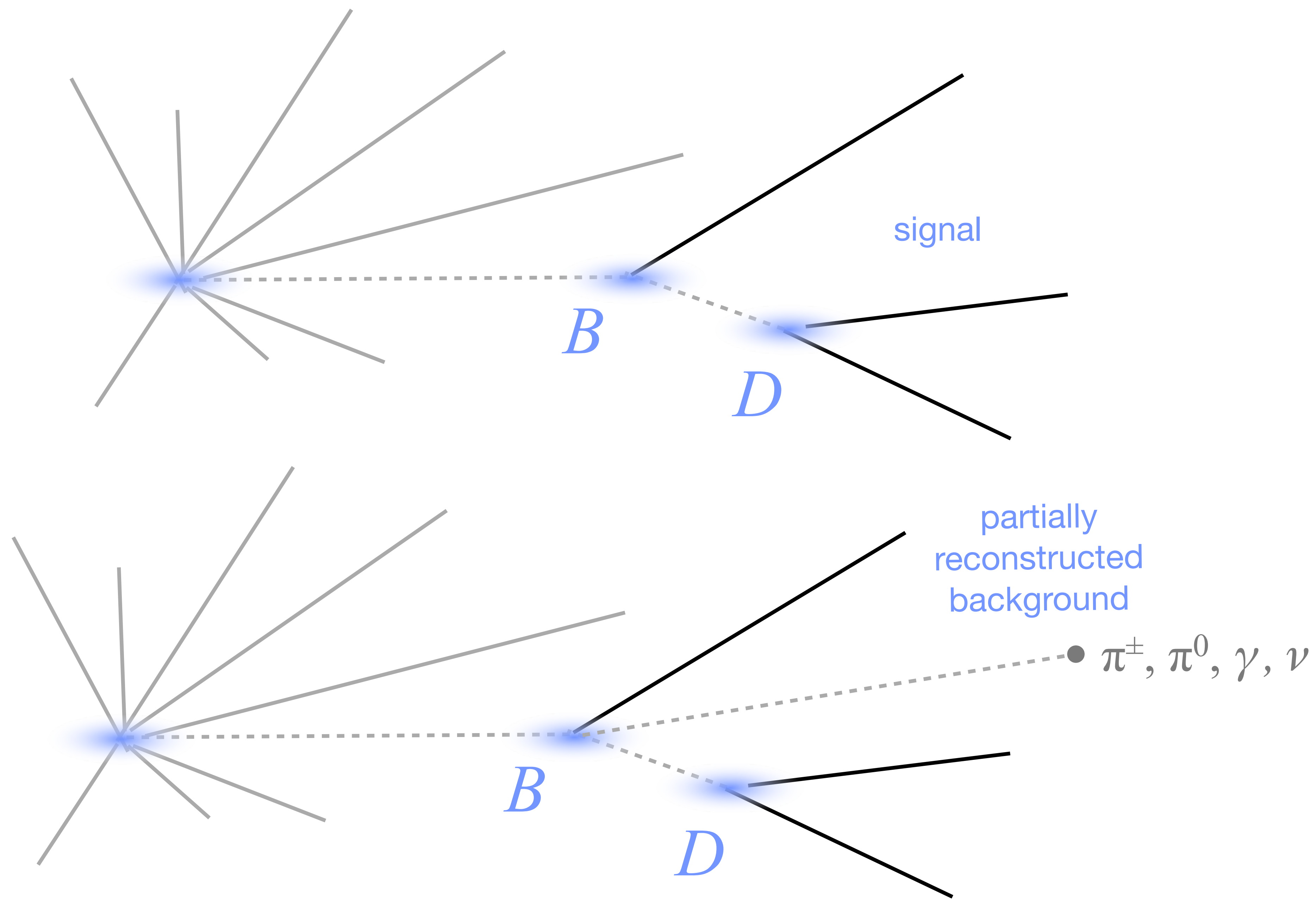
Hey presto...!

partially-reconstructed backgrounds have different shapes in *DK* and *Dπ*

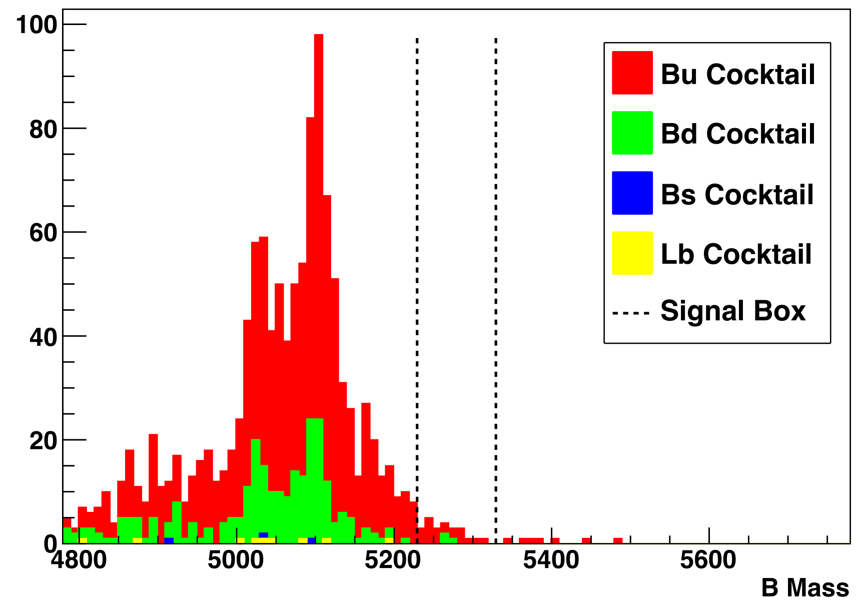


Modelling partially reconstructed backgrounds from simulation

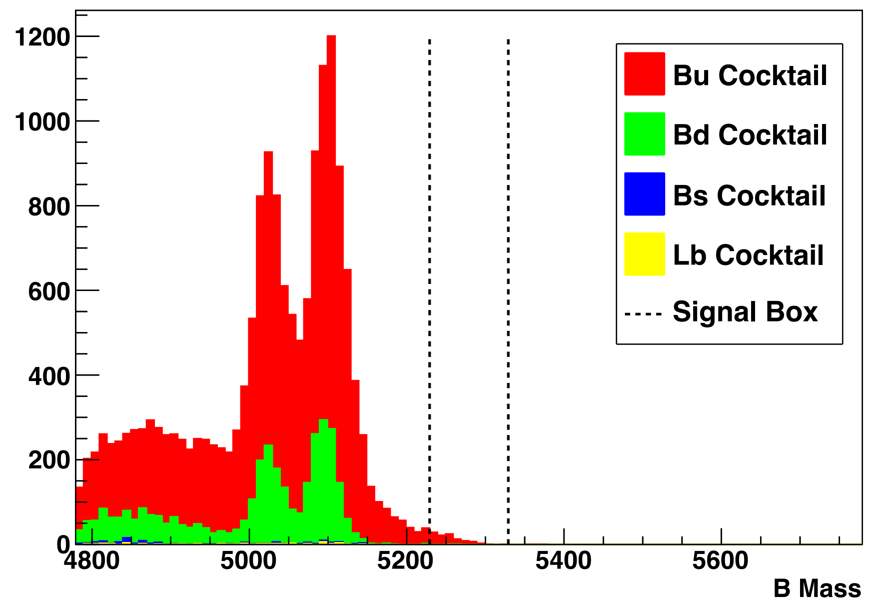
- A single PDF is used to model the part. reco. background in $B \to [K\pi]_D h$
- A sample of inclusive $B \to DX$ simulation is used to define this shape



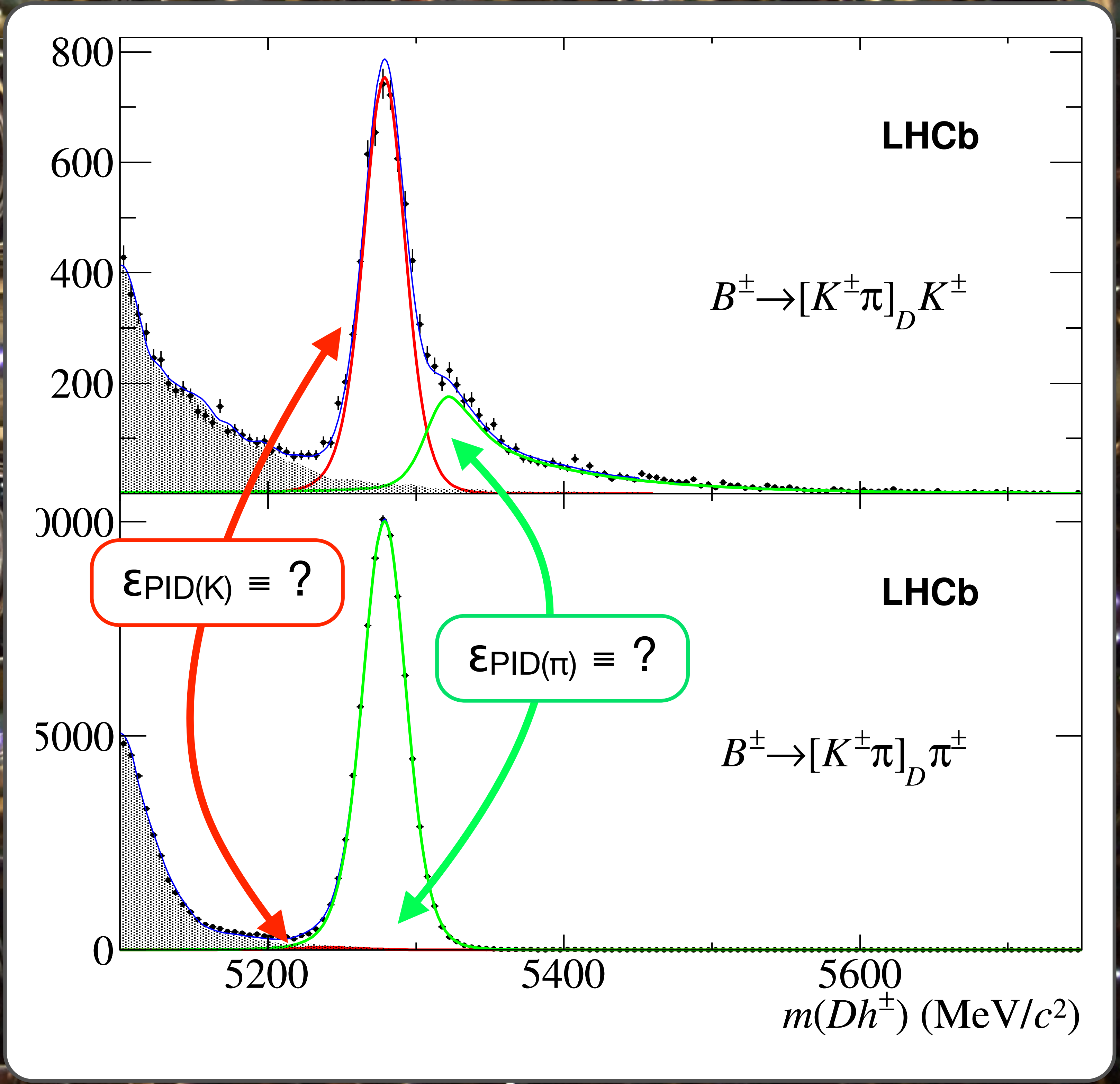
LHCb simulation $B^{\pm} \to [K\pi]_D K^{\pm}$



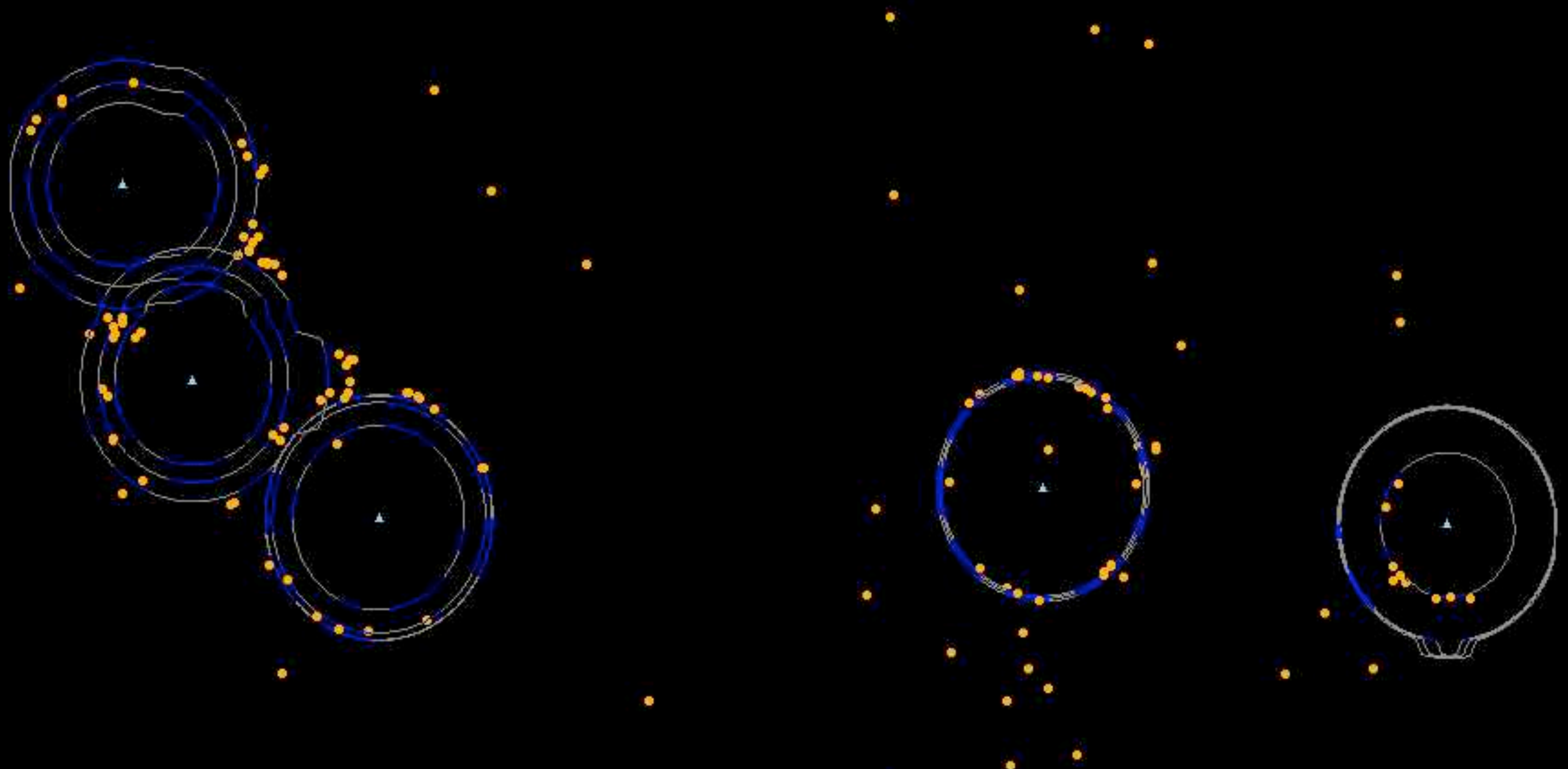
LHCb simulation $B^{\pm} \to [K\pi]_D \pi^{\pm}$



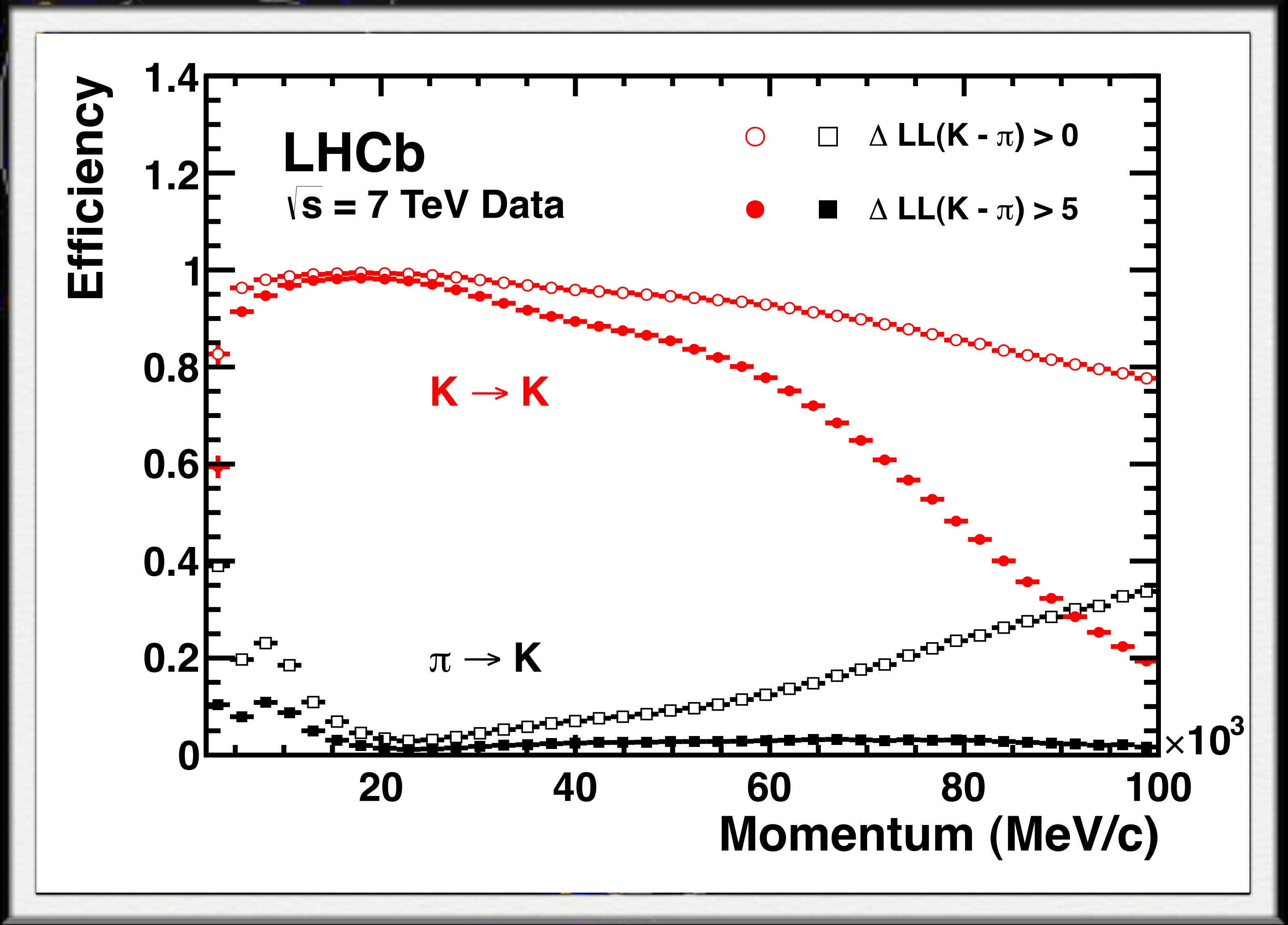
Dedicated particle identification

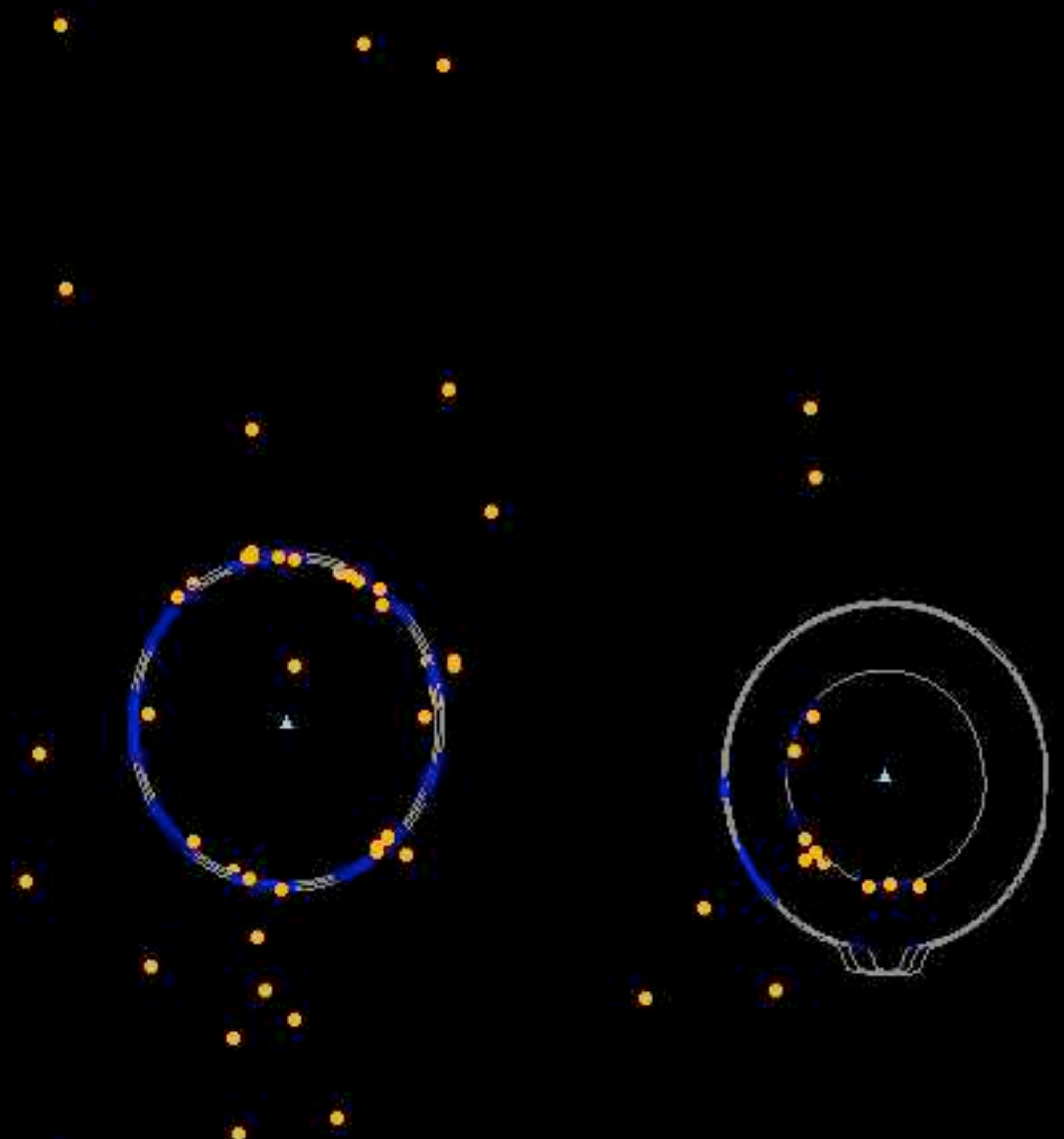


Dedicated particle identification

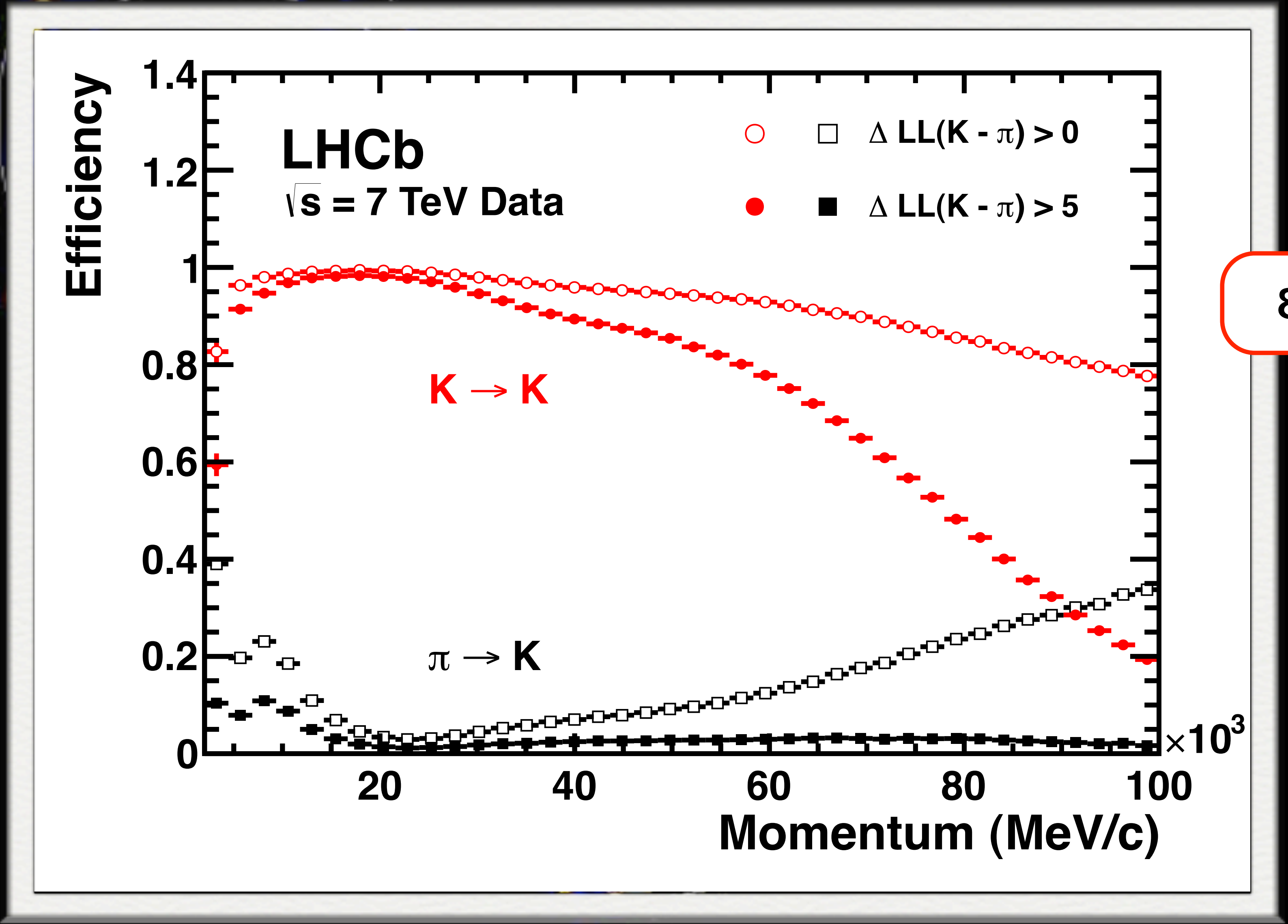


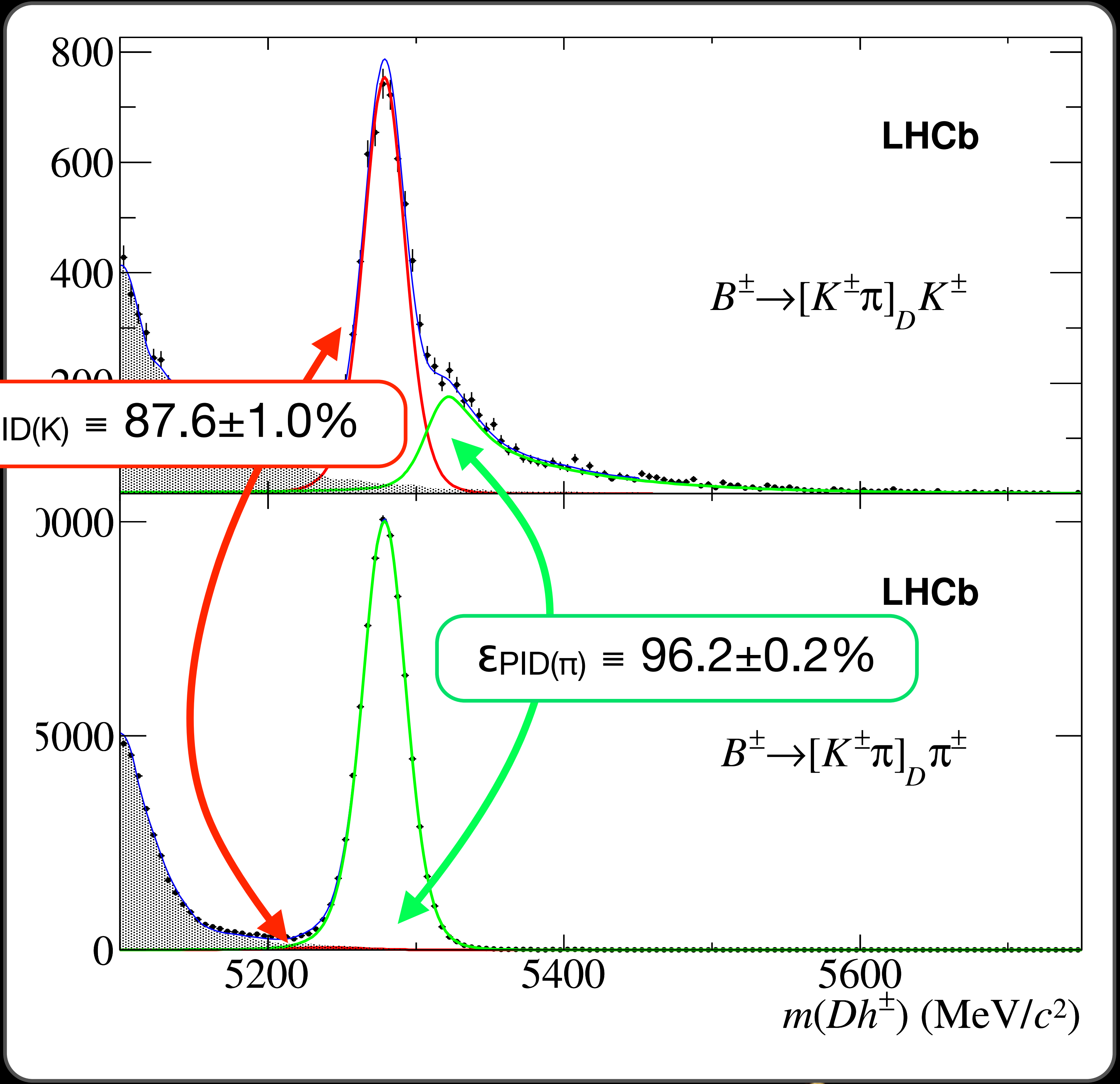
Achieves pion-kaon separation from ~5 to 100 GeV/*c*





- The result is applicable to all modes considered

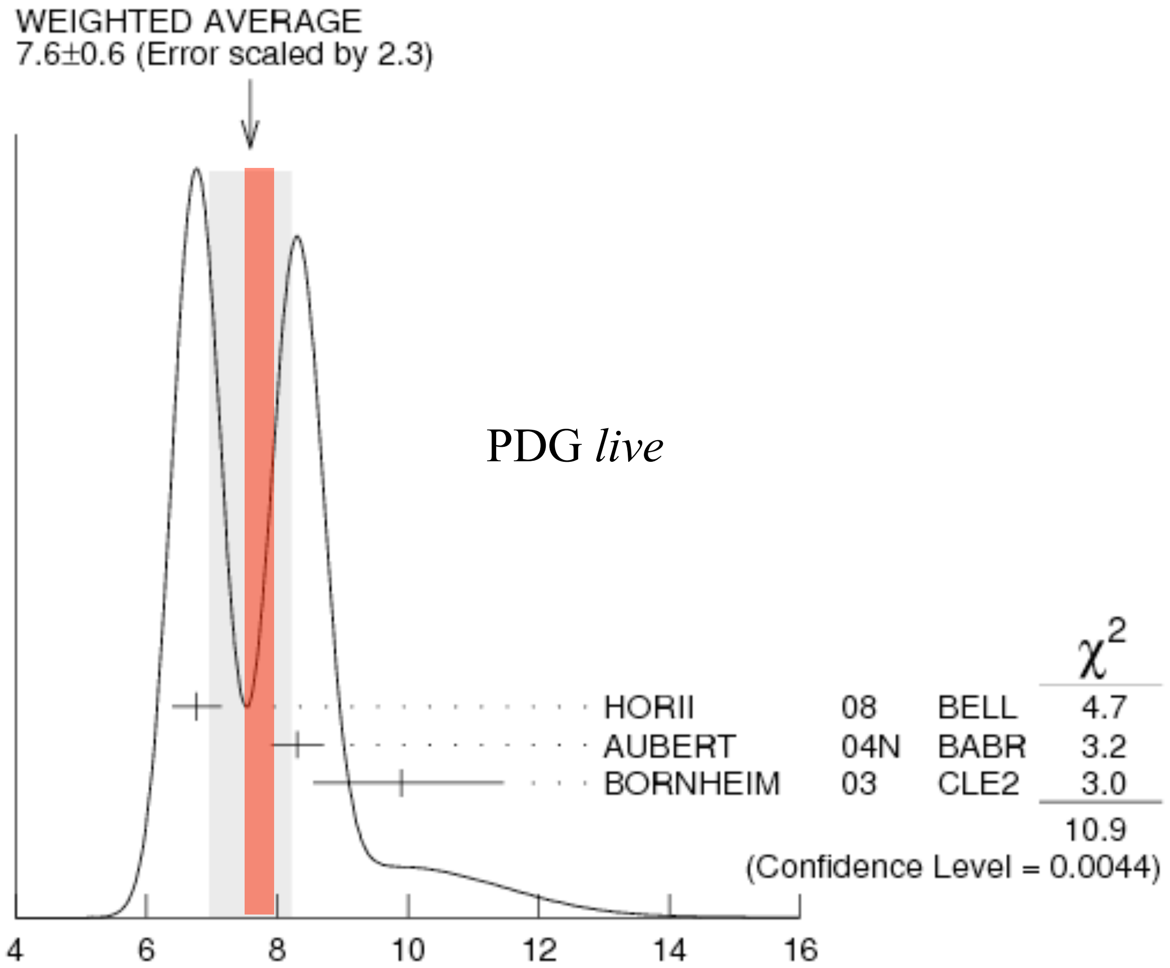


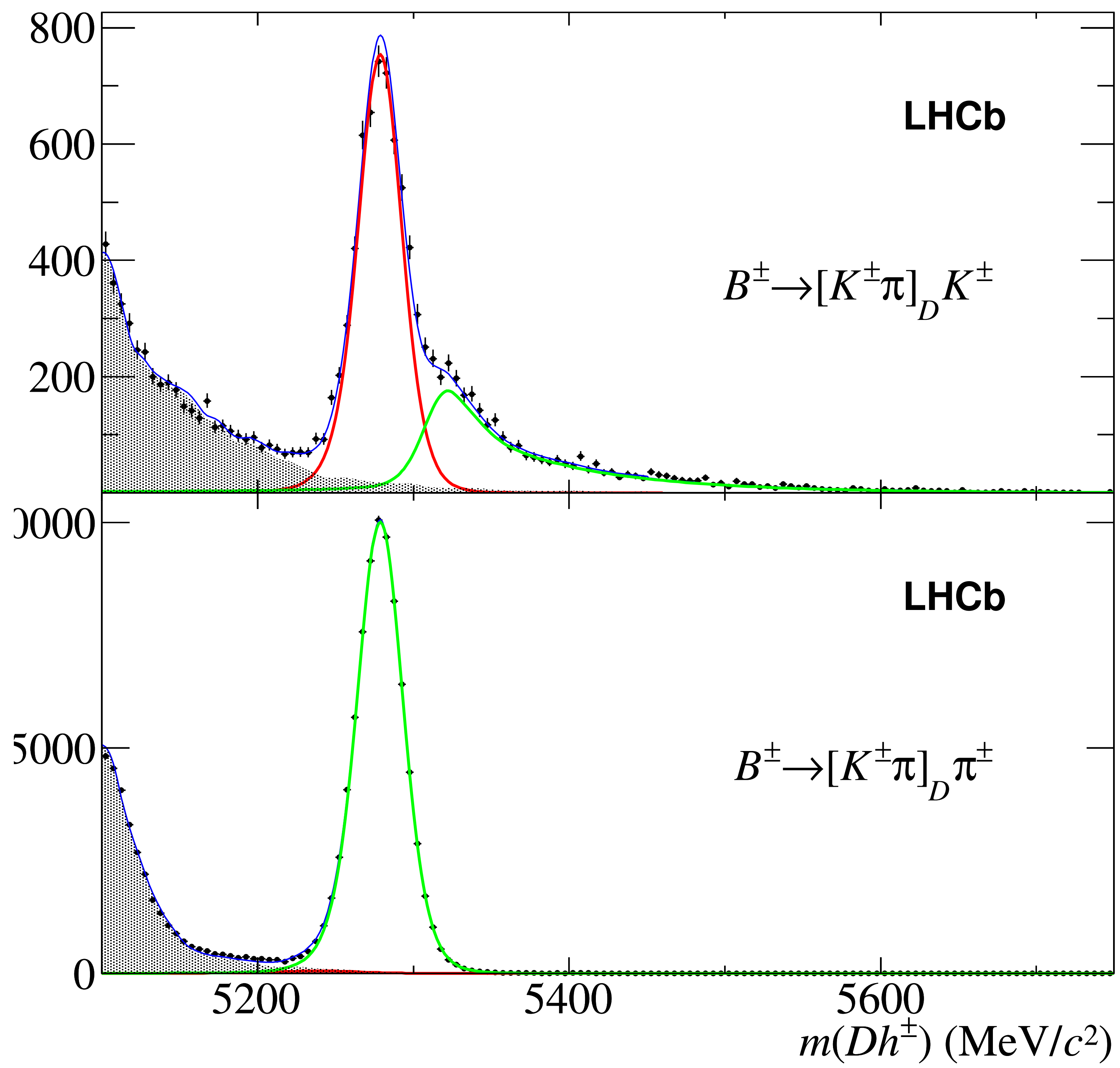


First result: the ratio of $B^- \to D^0 h^-$ branching fractions

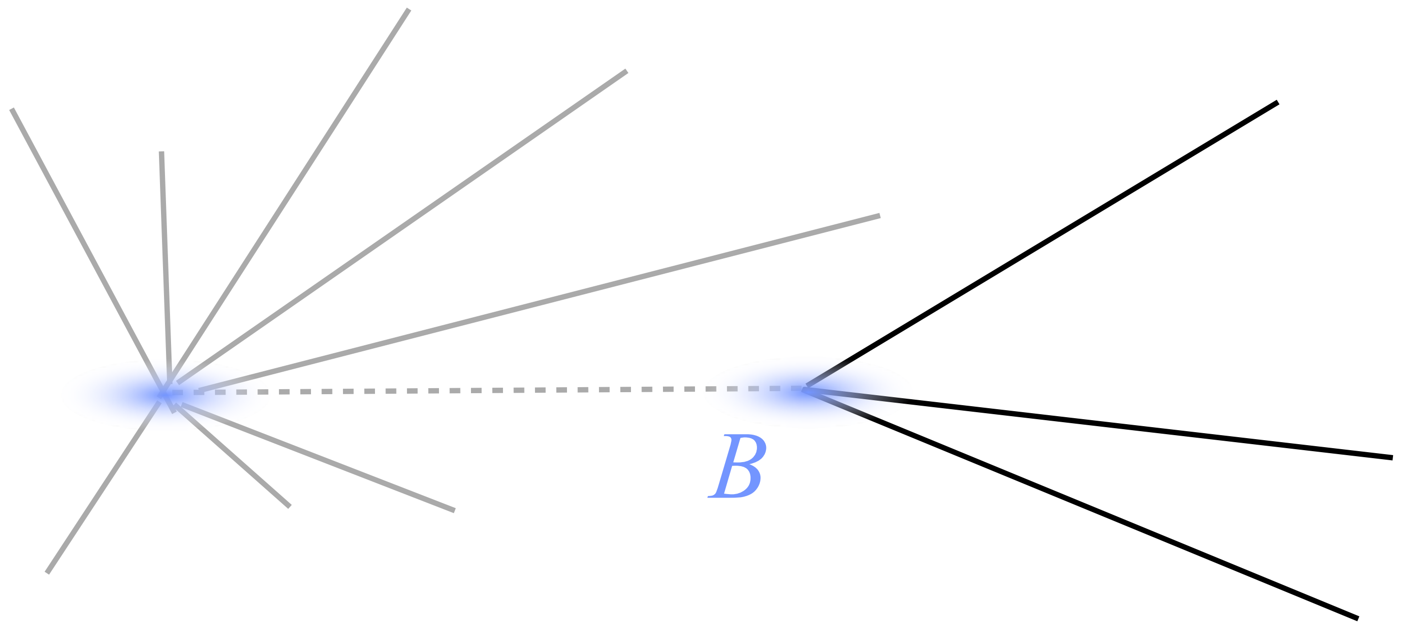
$$\frac{\Gamma(B^- \to D^0 K^-)}{\Gamma(B^- \to D^0 \pi^-)} = (7.74 \pm 0.12 \pm 0.19)\%$$

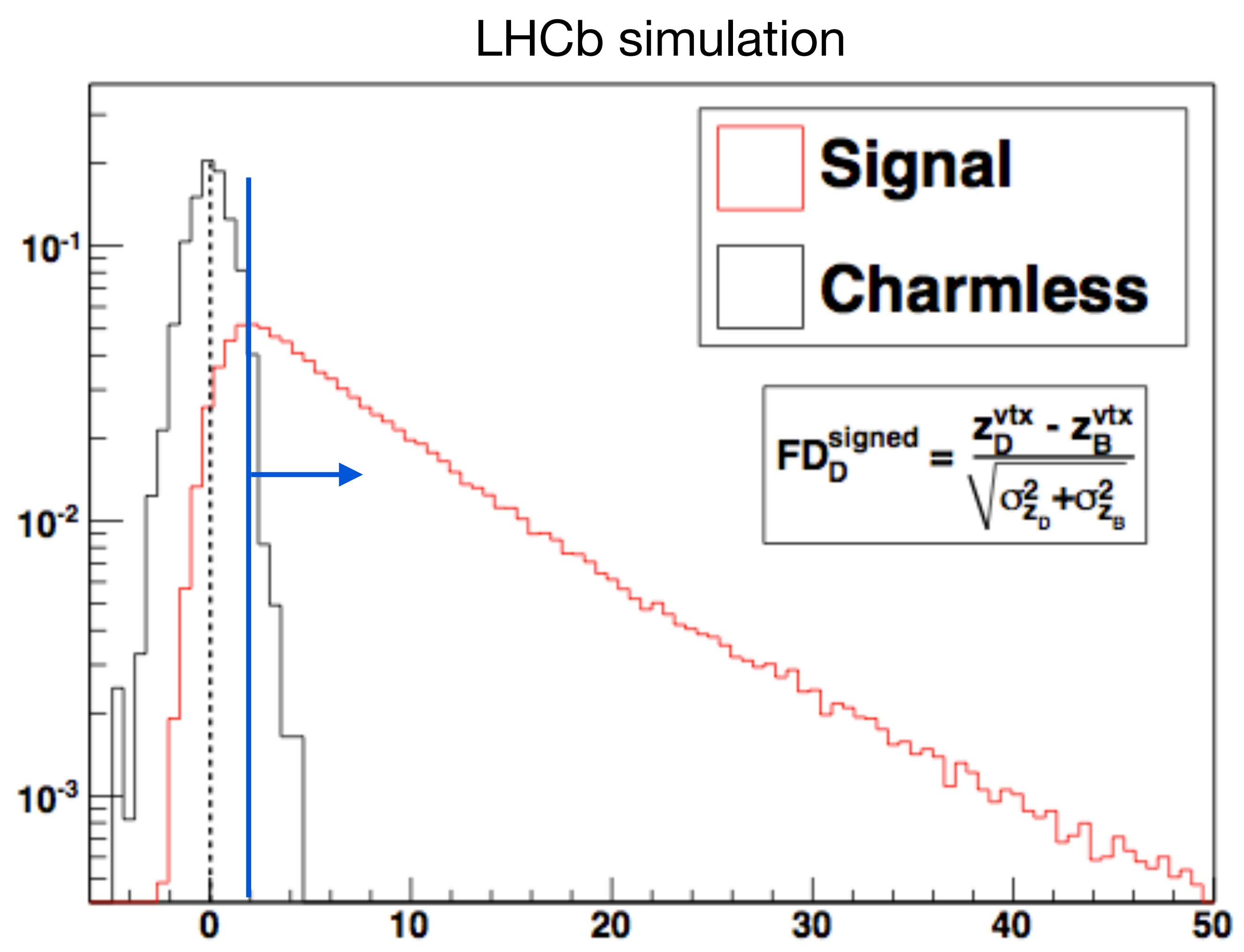
A factor 2 more precise than current world average





Non-true-*D* peaking backgrounds in the *CP* and ADS modes



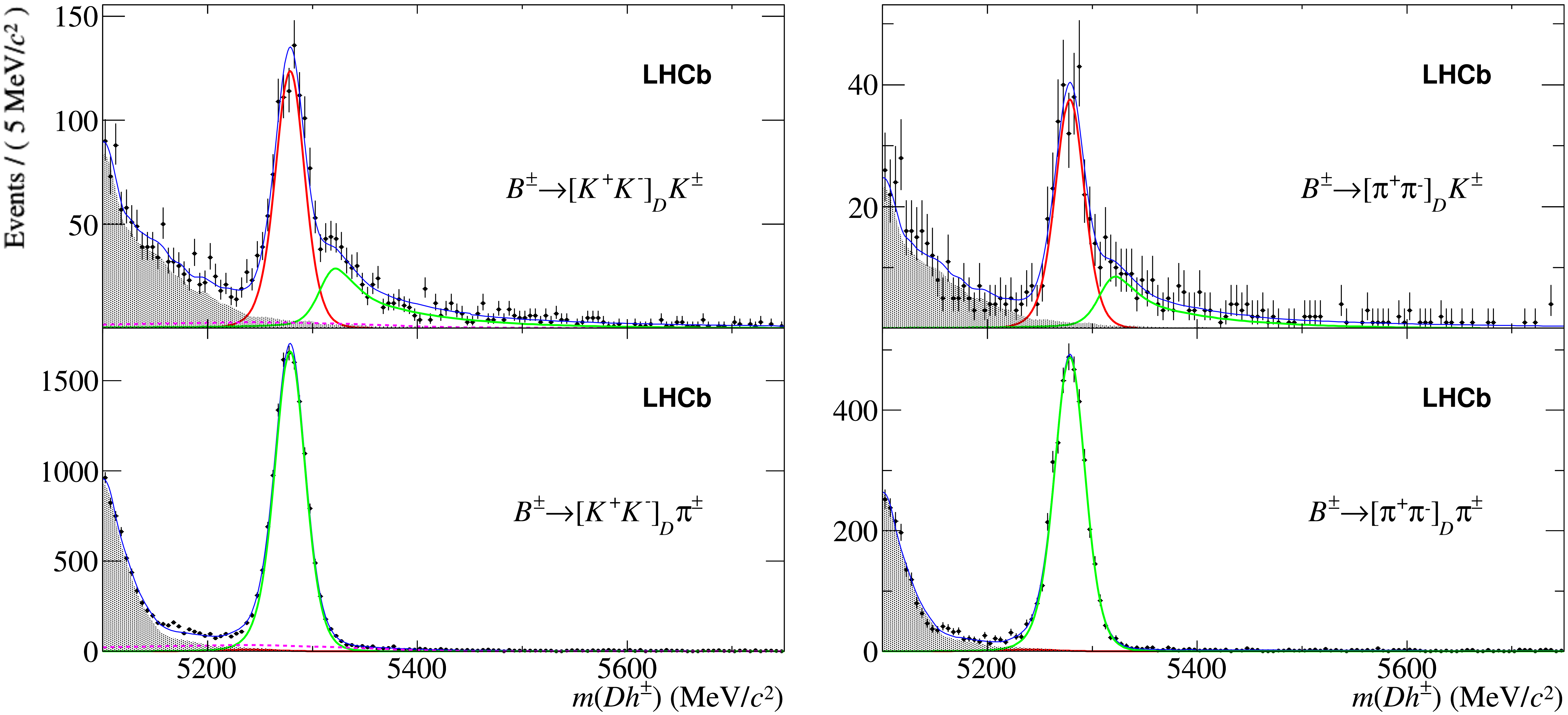


e.g. $B^{\pm}\to[\pi\pi]K^{\pm}$ suffers from:

$B^{\pm}\to K\pi\pi^{\pm}$	Charmless
$B^{\pm}\to[K\pi]\pi^{\pm}$	Cross feed
$B^{\pm}\to[\pi\pi\pi^0]\pi^{\pm}$	Part. reco. cross feed

- Thanks to the large boost at LHCb non-true-*D* backgrounds can be easily removed.
- The above cut is ~85% efficient and removes 97% of zero-lifetime backgrounds

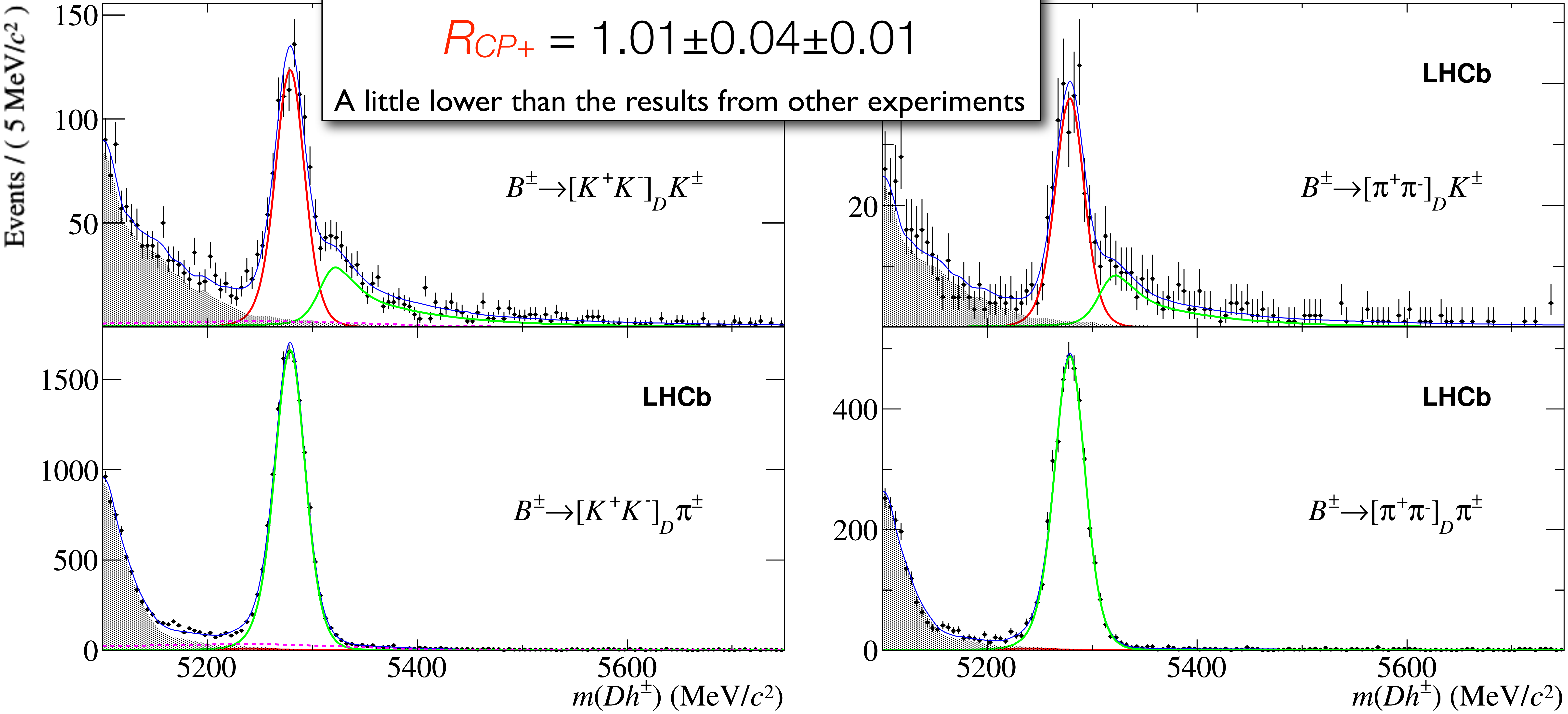
The *CP* eigenstate modes



The *CP* eigenstate modes

R_{CP+} = 1.01±0.04±0.01

A little lower than the results from other experiments



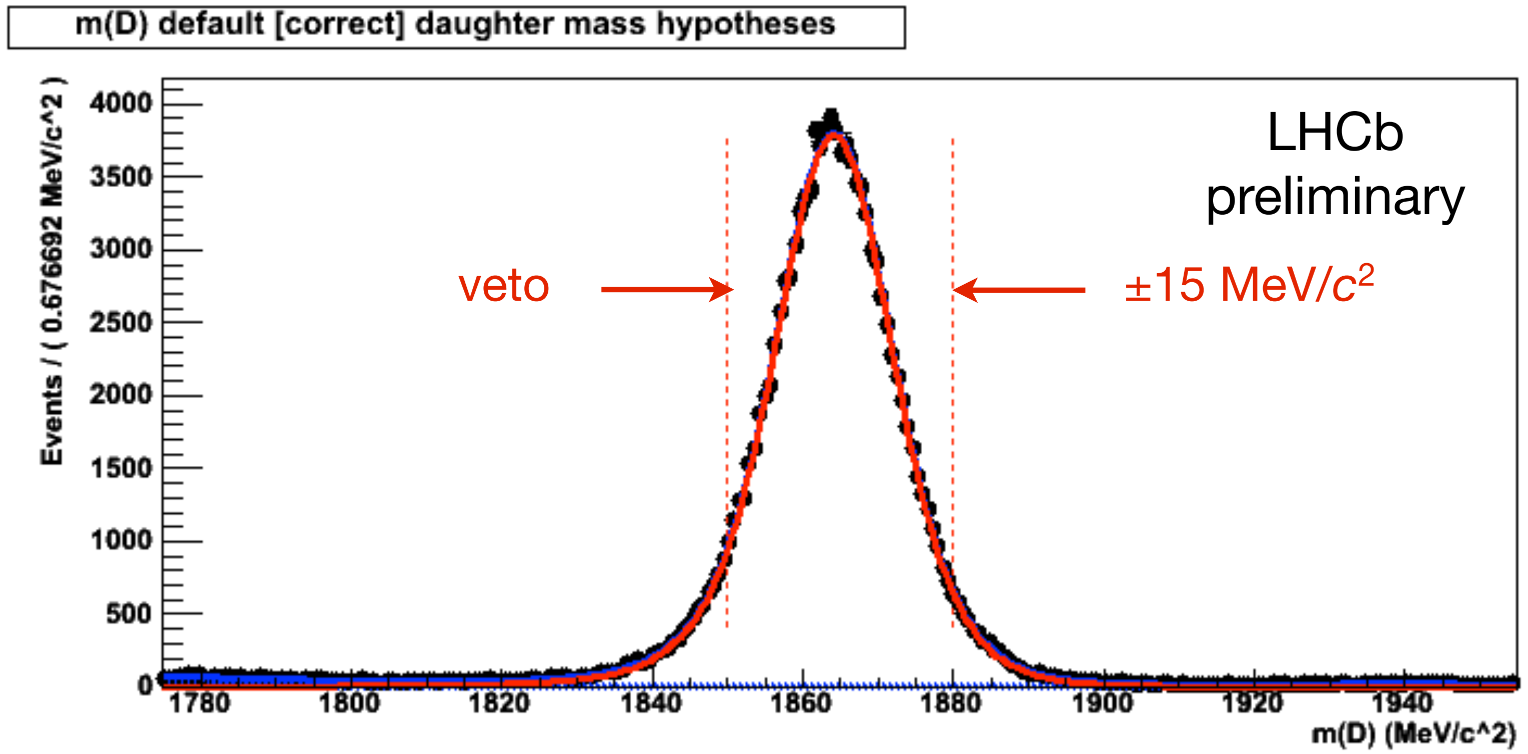
Favoured mode→ADS mode cross feed

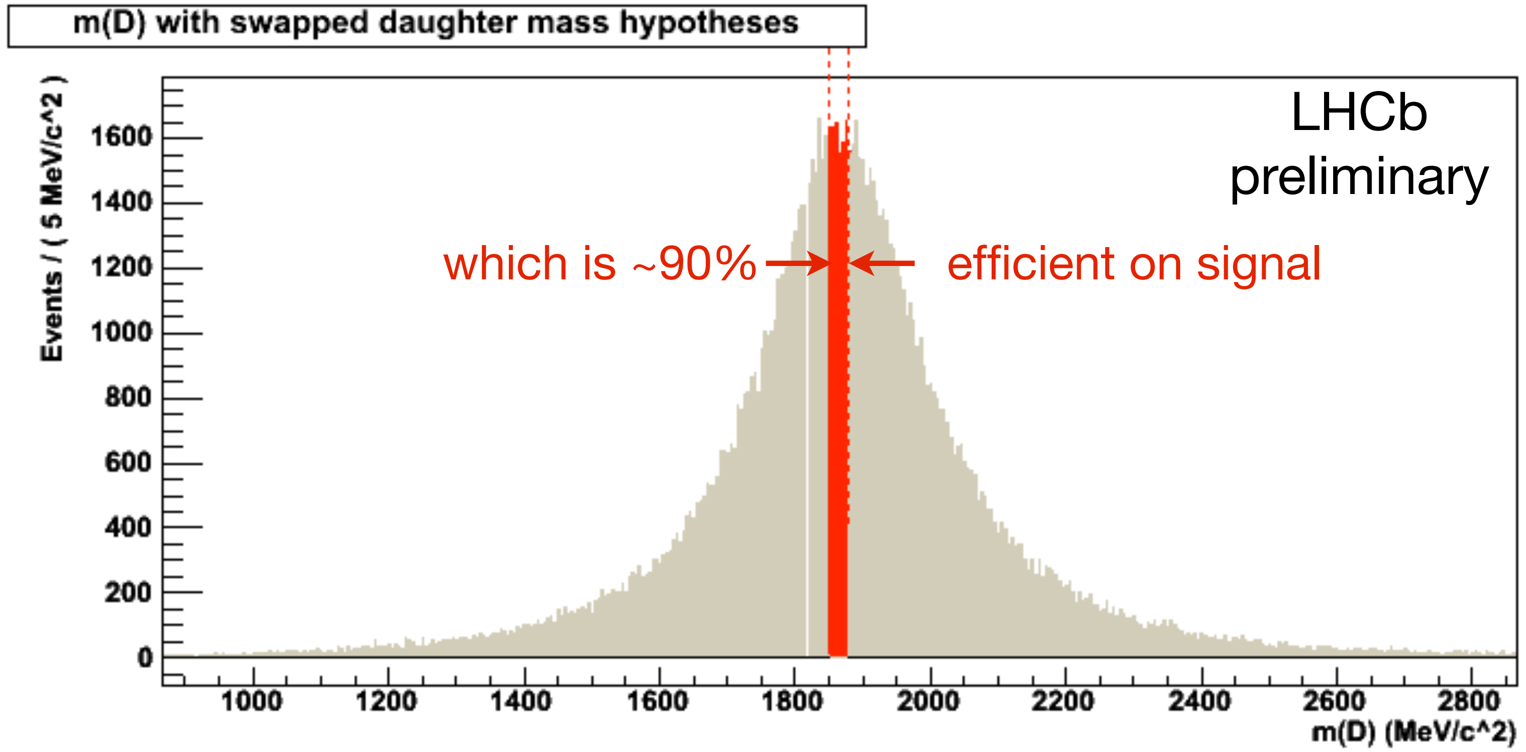
$B^{\pm}\to[K\pi]h^{\pm}$

double | misID

$B^{\pm}\to[\pi K]h^{\pm}$

check for by swapping mass hypothesis back





- Combat with PID cuts on the *D* daughter tracks.
- But this is not sufficient. A veto is needed.

- After PID cuts and the veto, the expected cross feed rate is 6×10^{-5}.
- This is just 2% of $R_{ADS(\pi)}$.

Additional partially reconstructed background for the ADS mode

- The shape derived from simulation of $B\to[K\pi]_D h$ decays works well for the ADS mode
- However, one particular B_s decay needs special consideration:

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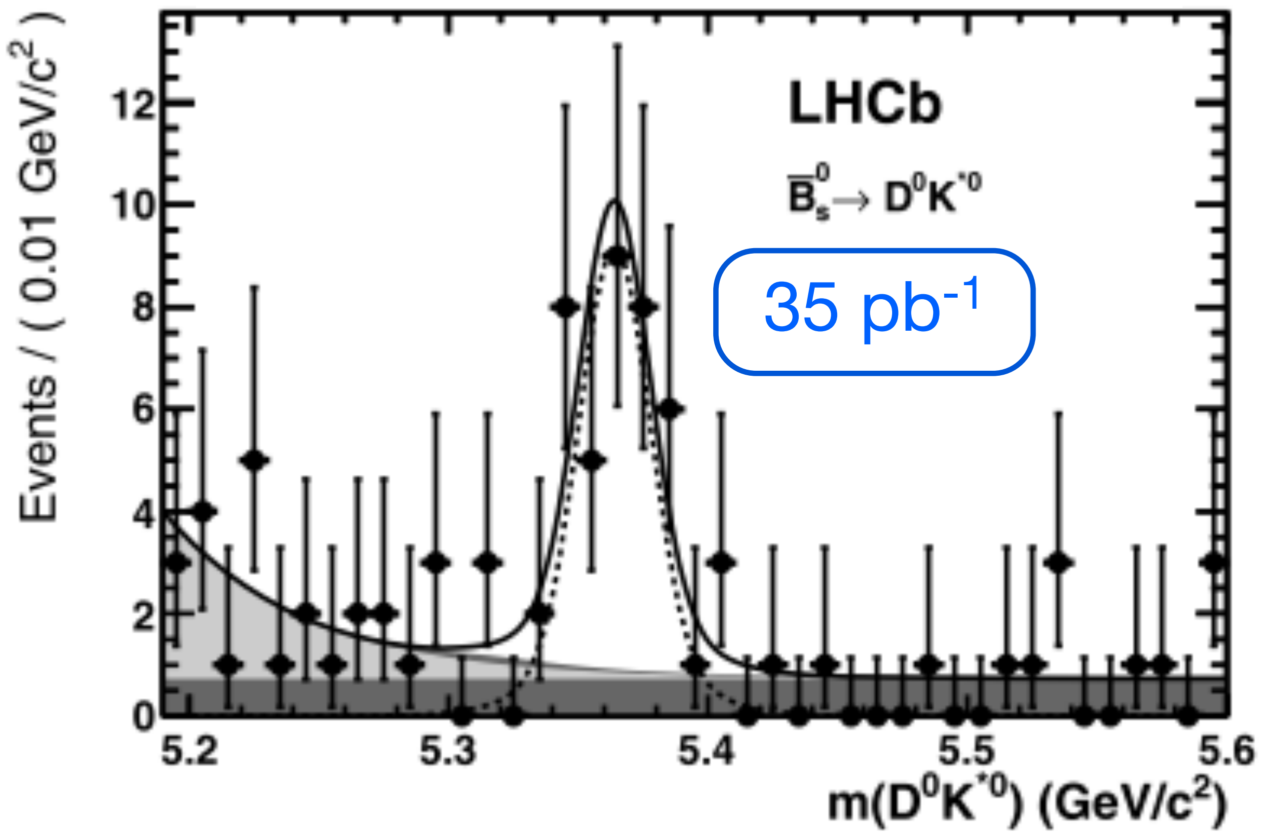
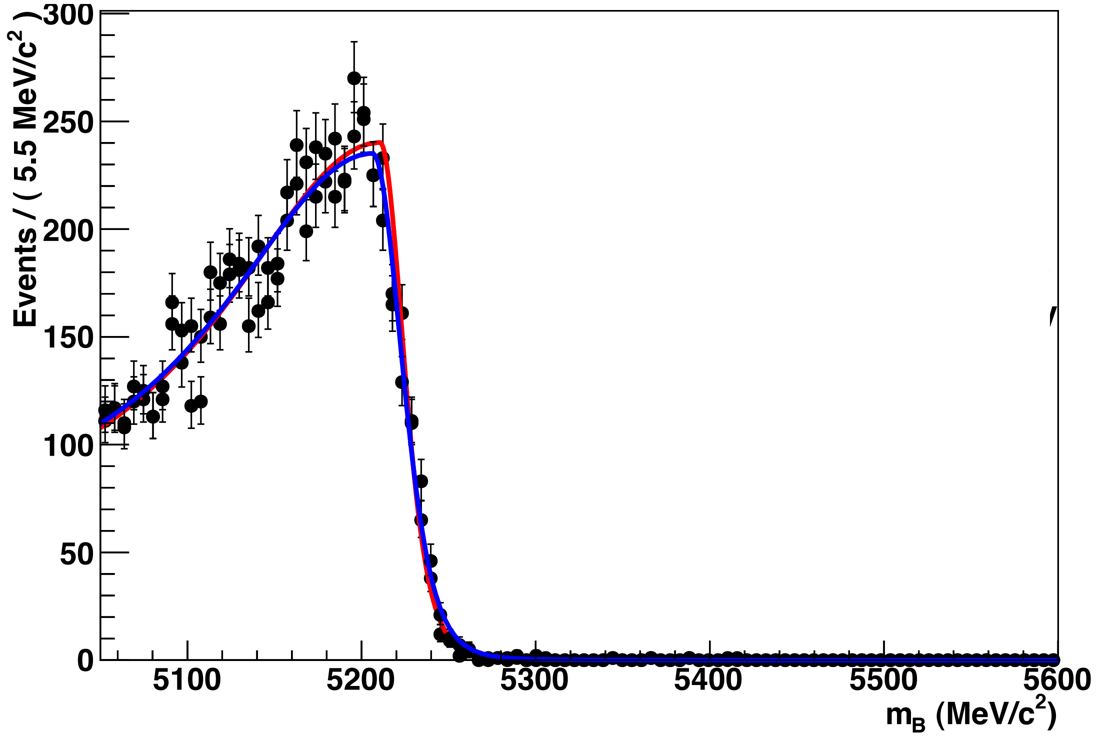
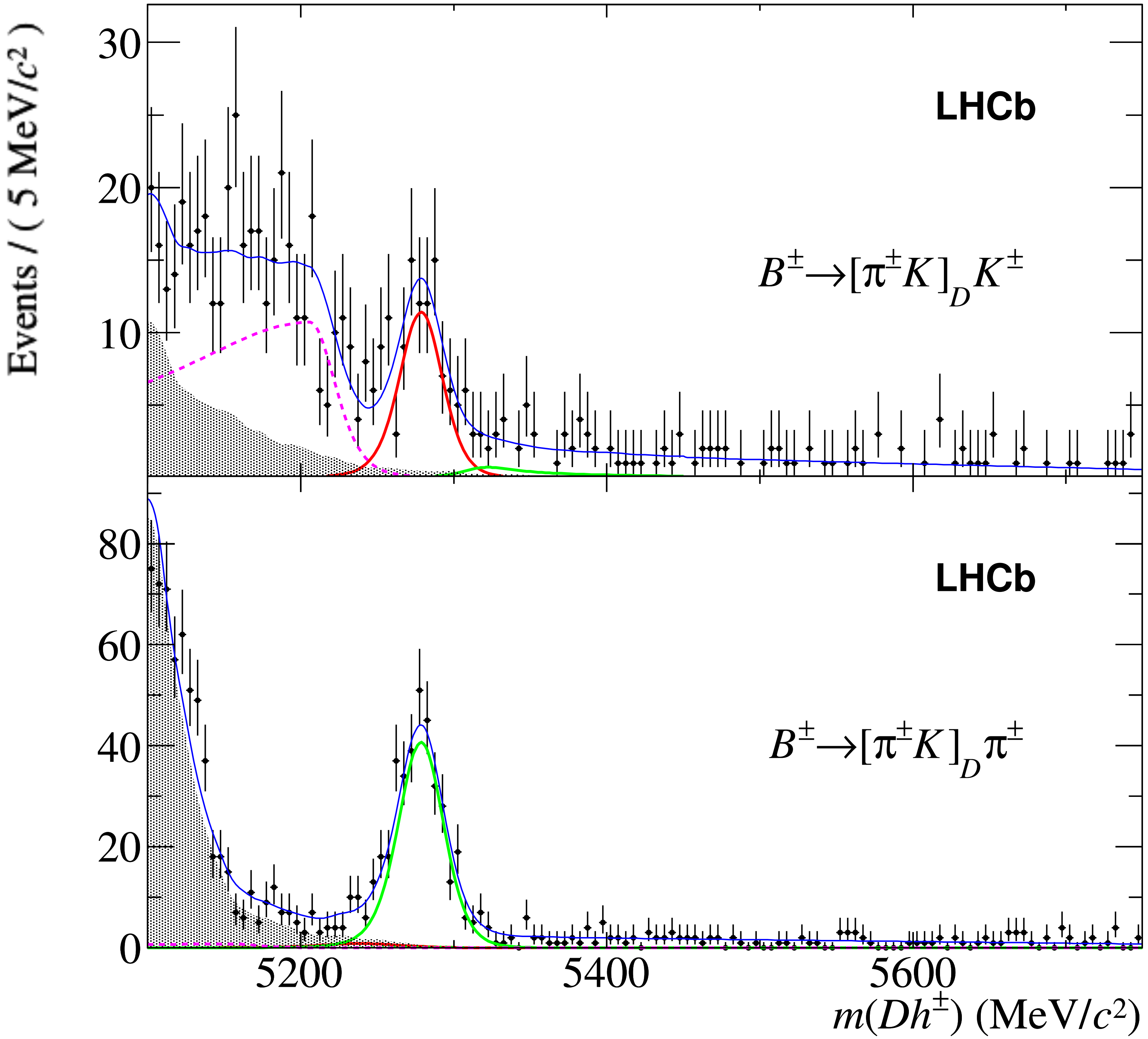


$B_s\to D^0\overline{K}^*$
$\to K^-\pi^+K^+\pi^-$
$(4.7\pm1.4)\times10^{-4}$

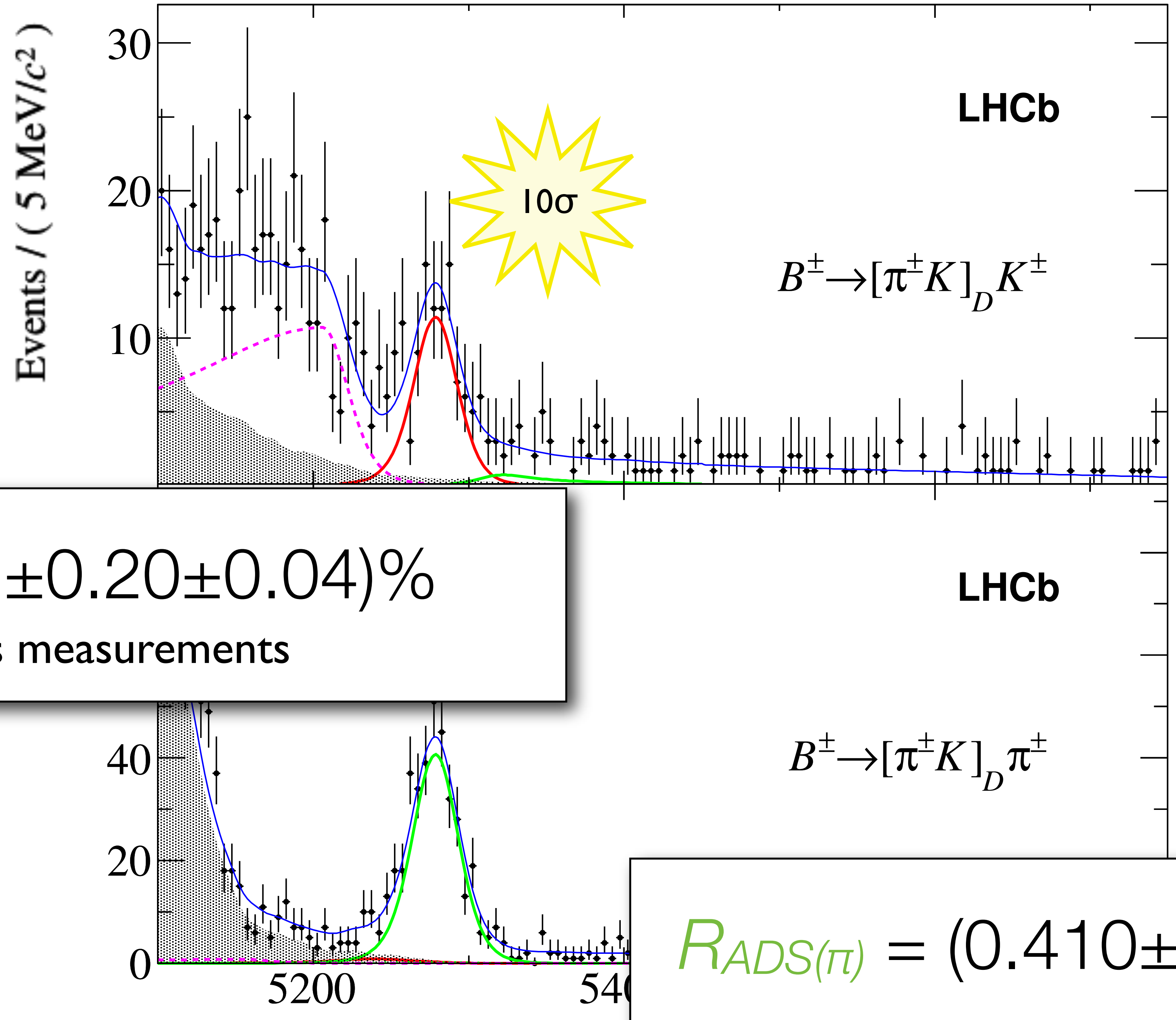
LHCb simulation of the ADS mode:
$B^+\to[\pi^+K^-]_D K^+$



First observation of the $DK^{\pm}$, ADS mode



First observation of the $DK^{\pm}$, ADS mode



$\mathscr{B}(B^{\pm}\to[\pi^{\pm}K^{+}]_D K^{\pm}) \approx (2.2 \pm 0.3)\times10^{-7}$

$R_{ADS} = (1.52\pm0.20\pm0.04)\%$

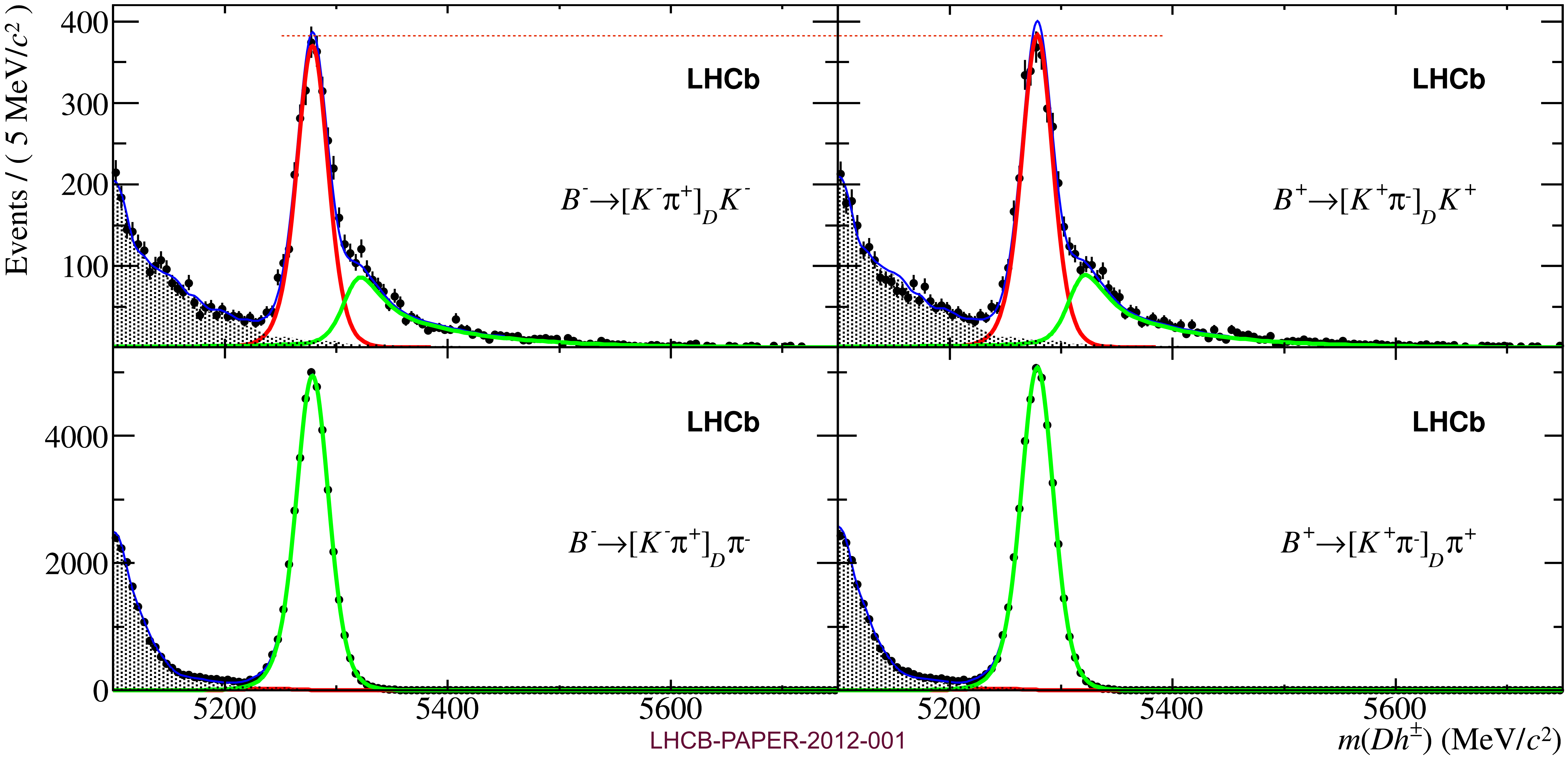
Compatible with previous measurements

$R_{ADS(\pi)} = (0.410\pm0.025\pm0.005)\%$

~2σ higher than previous measurements

(5) Wasn’t this talk about *CP* violation?

The favoured mode, split by the charge of the B



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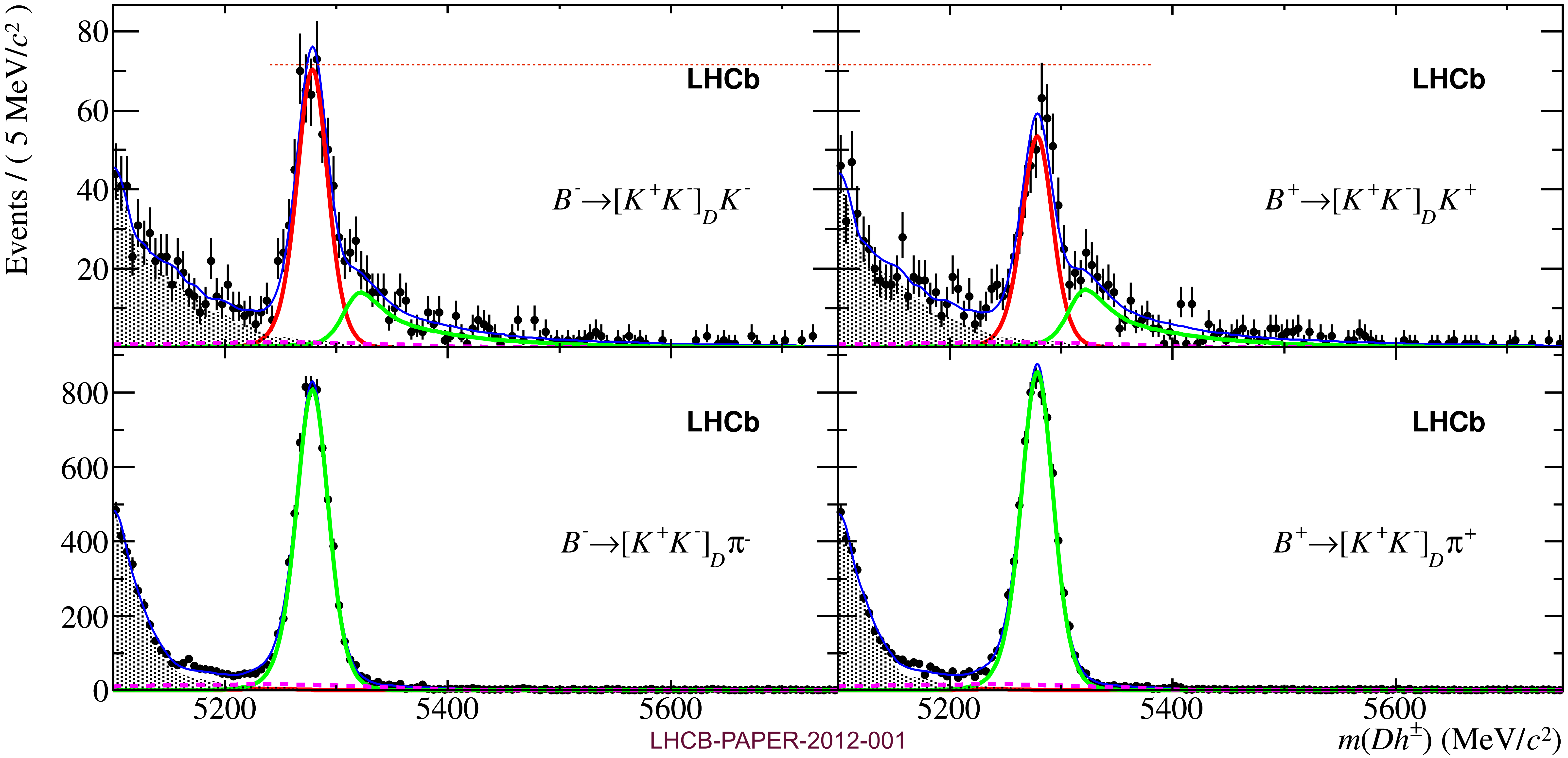
KK mode, split by the charge of the *B*



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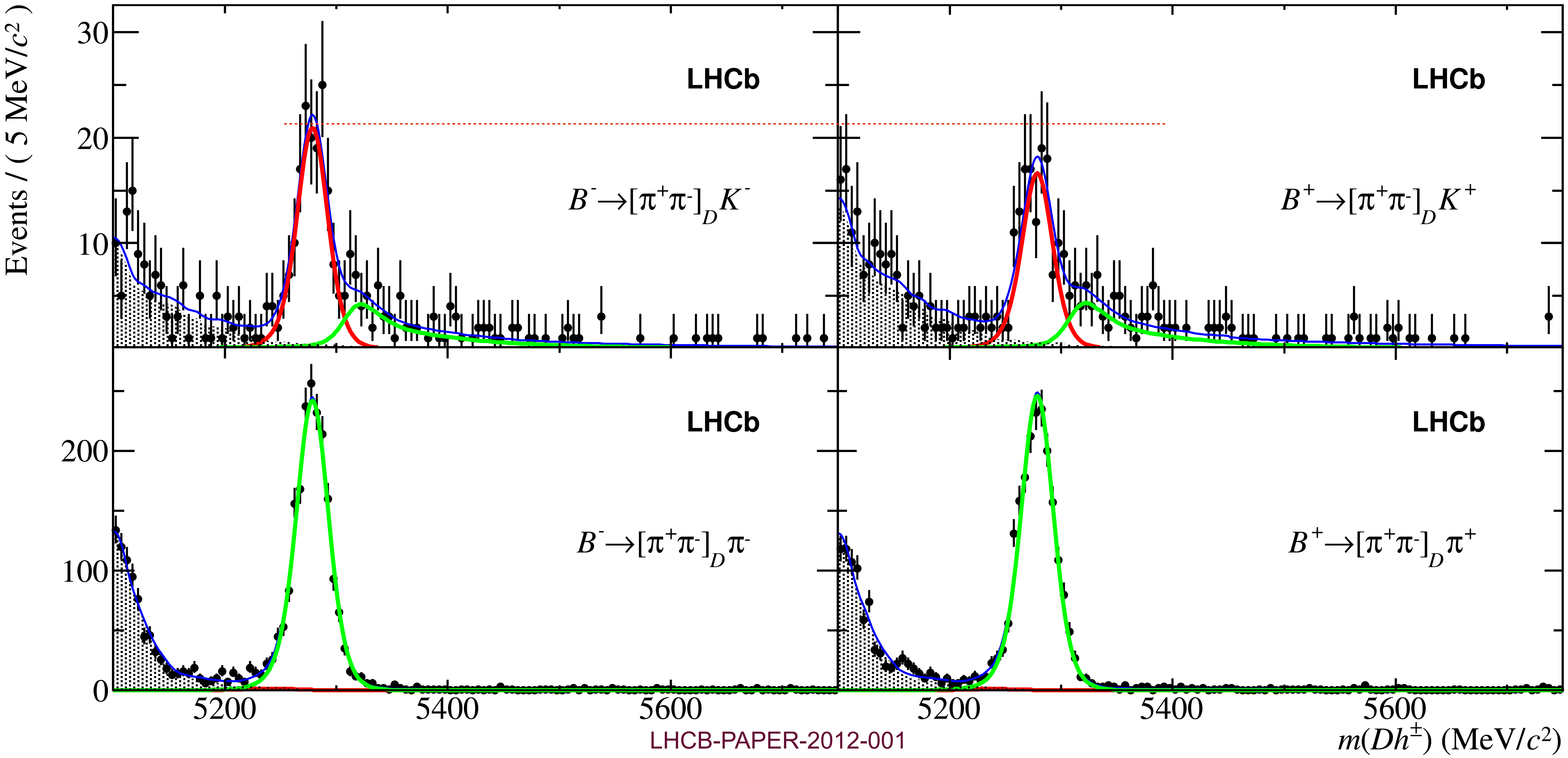
$\pi\pi$ mode, split by the charge of the B



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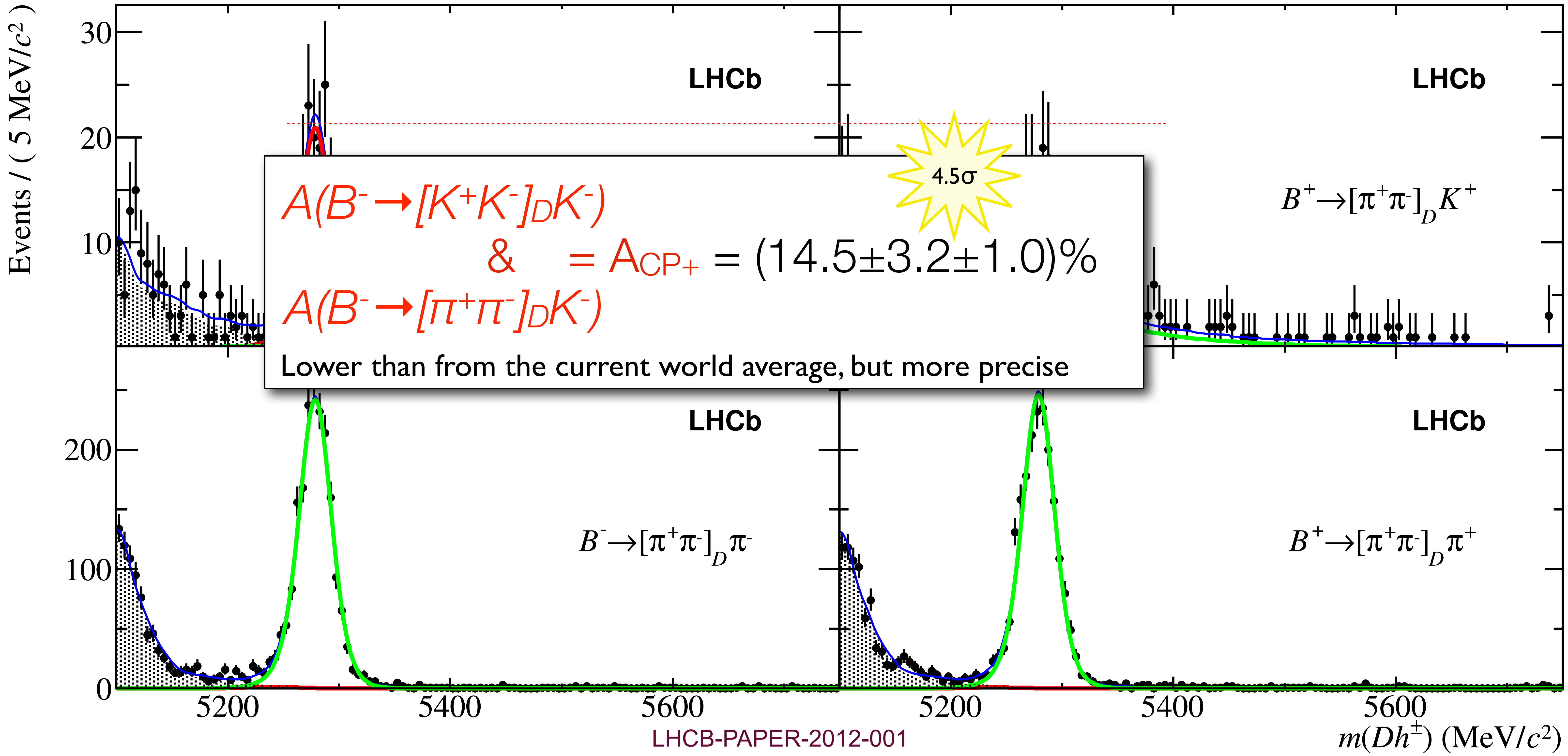
$\pi\pi$ mode, split by the charge of the B



$A(B^- \to [K^+K^-]_D K^-)$ & $A(B^- \to [\pi^+\pi^-]_D K^-)$ $= A_{CP+} = (14.5 \pm 3.2 \pm 1.0)\%$

Lower than from the current world average, but more precise

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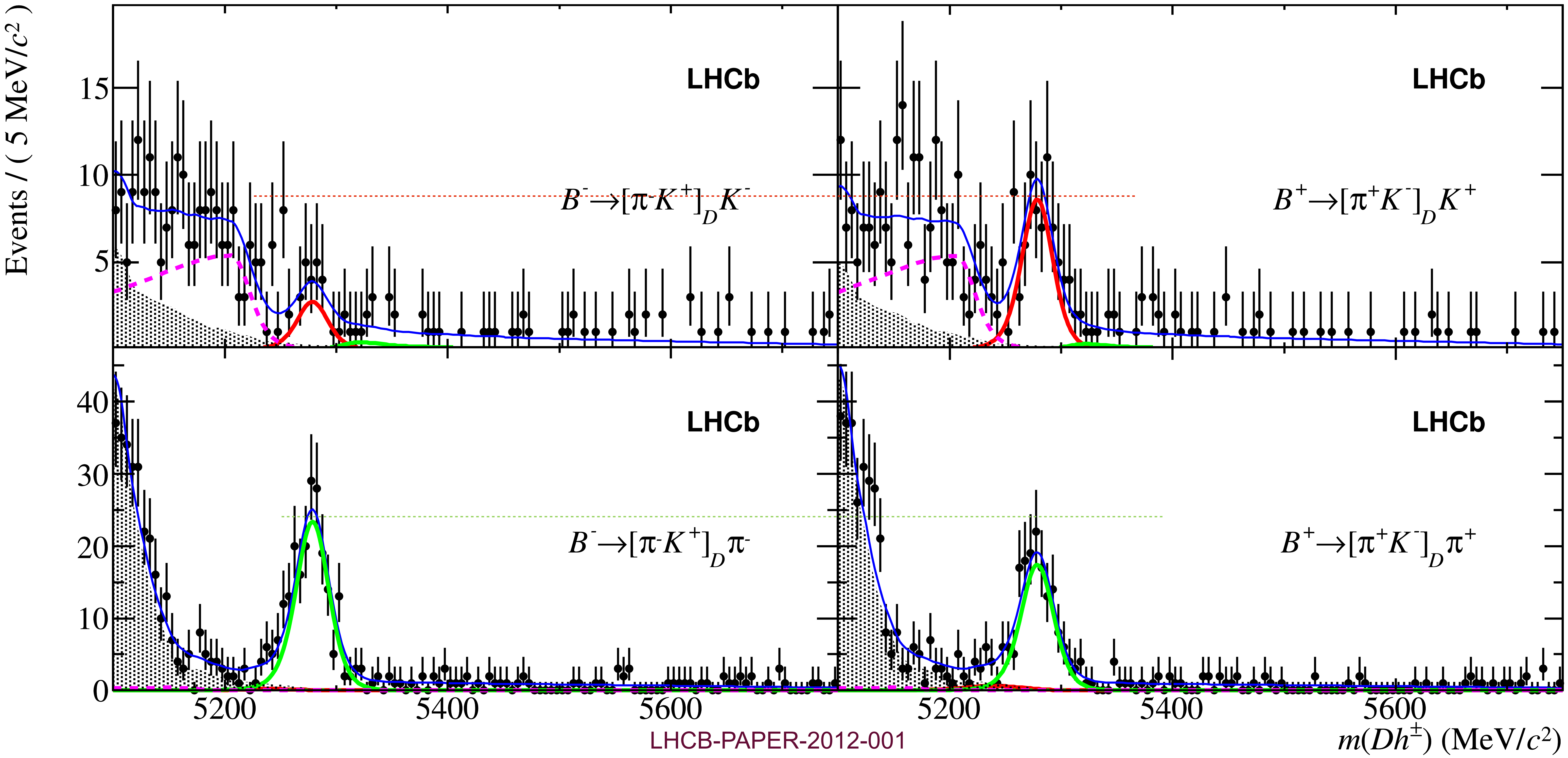
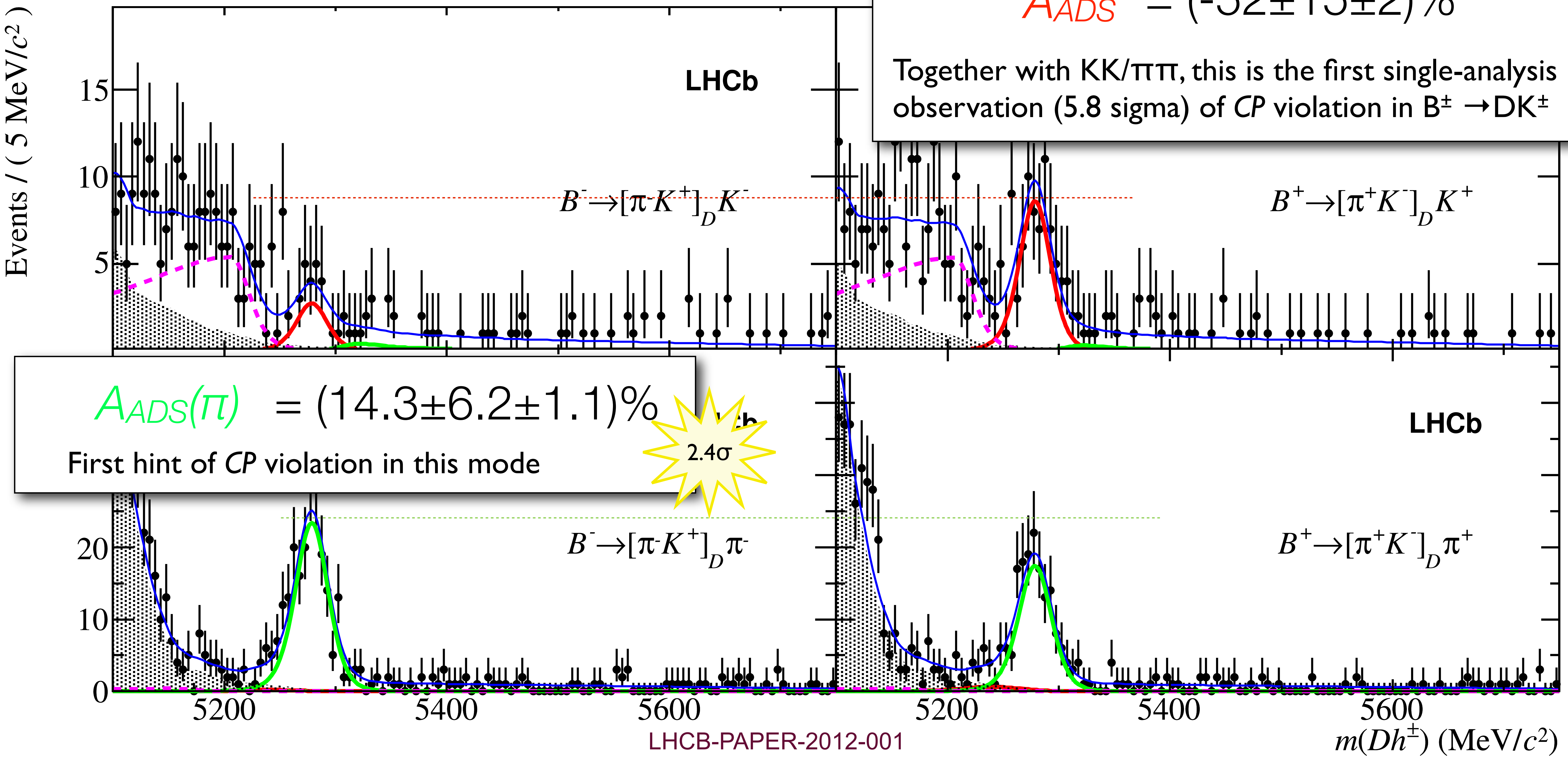
ADS mode, split by the charge of the B



LHCB-PAPER-2012-001

ADS mode, split by the charge of the B



A_{ADS} = (-52±15±2)%

Together with KK/ππ, this is the first single-analysis observation (5.8 sigma) of *CP* violation in $B^{\pm} \to DK^{\pm}$

$A_{ADS}(\pi)$ = (14.3±6.2±1.1)%

First hint of *CP* violation in this mode

LHCB-PAPER-2012-001

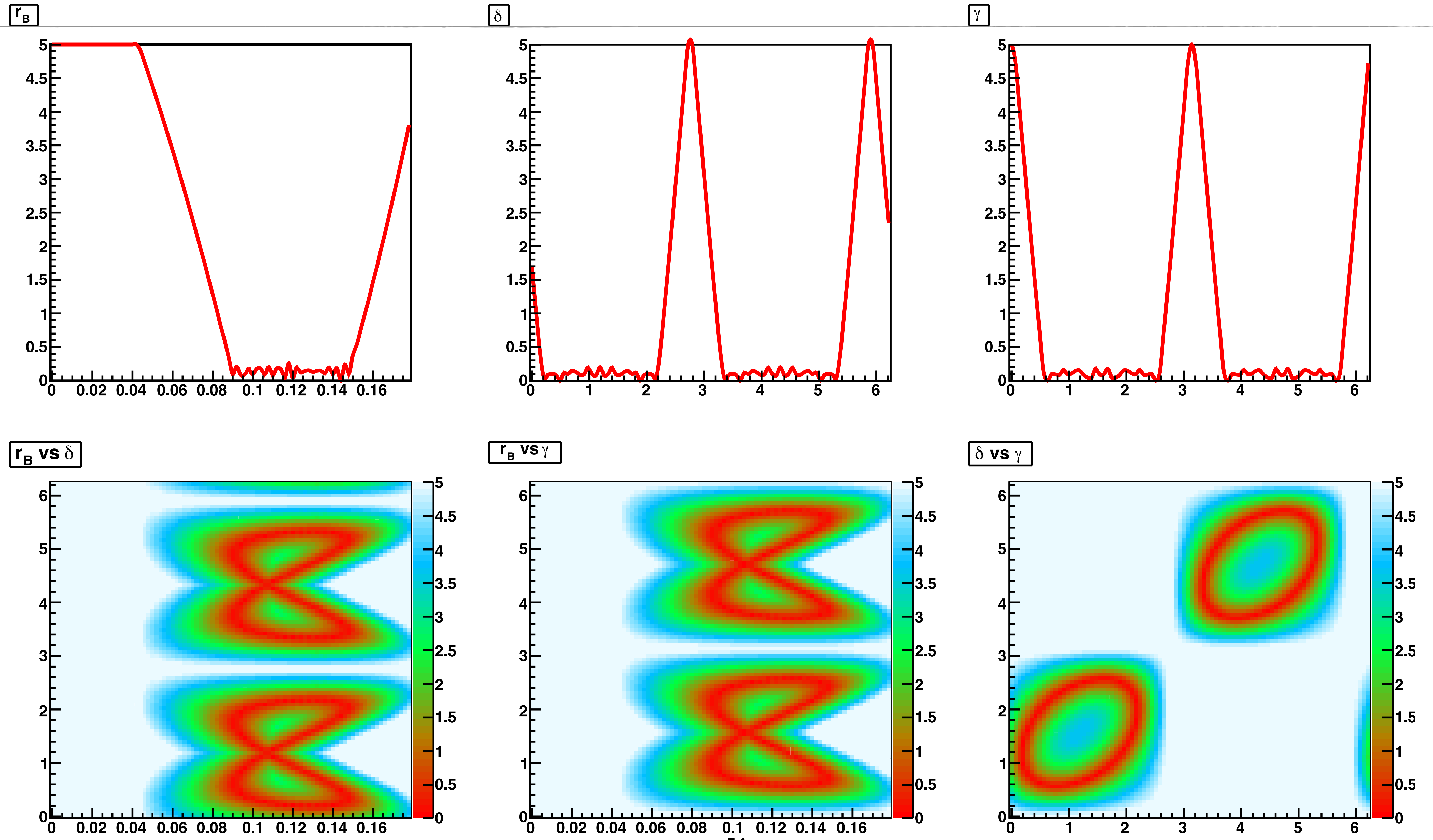
(6) Interpretation of the present result, and thinking about the future

But how does this tie-in with γ?

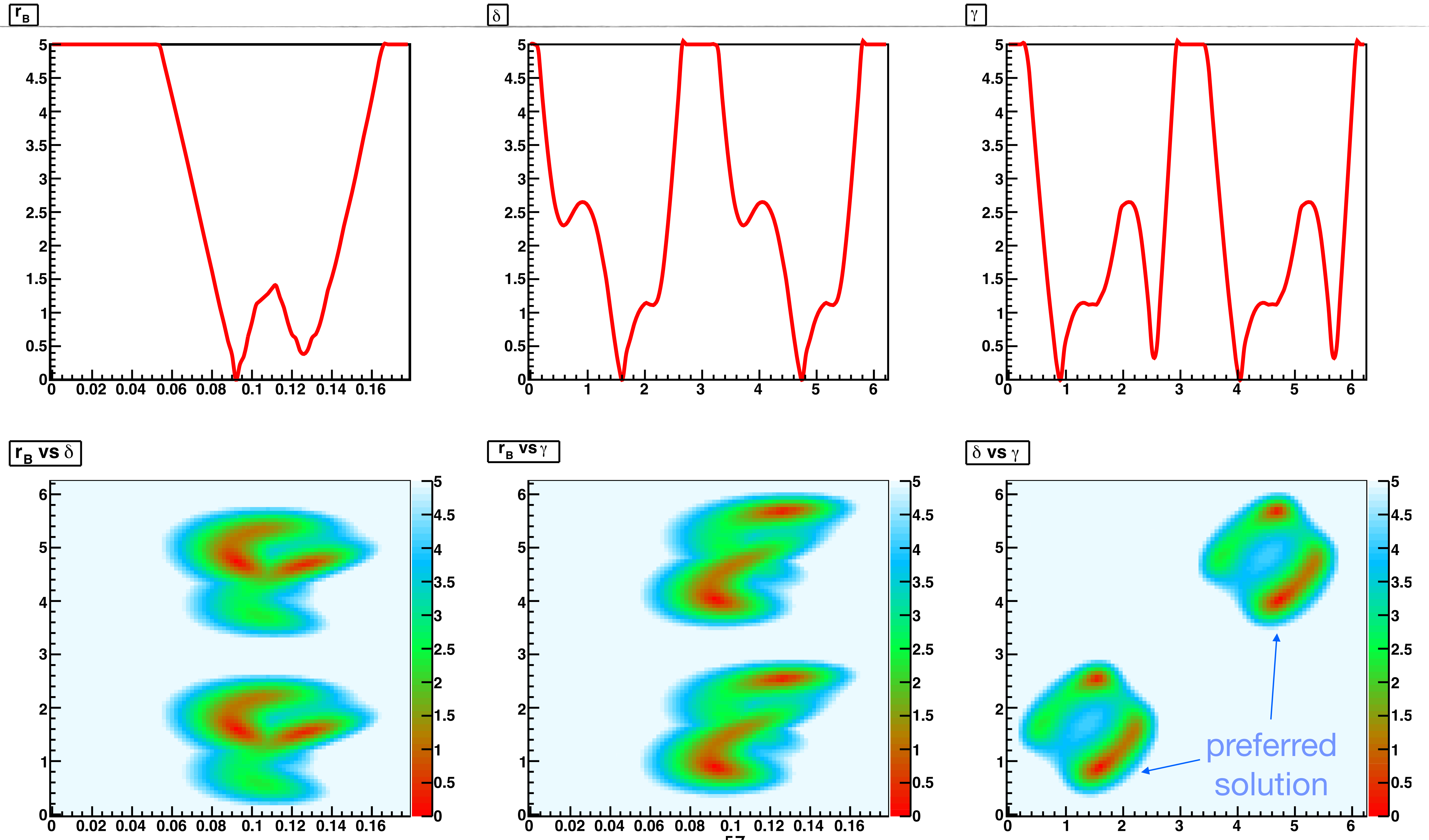
- All of the physics observables may be written in terms of the “fundamental” parameters: r_B, γ, δ_B
- A full multi-mode treatment, leading to an LHCb measurement of r_B, γ, δ_B is in preparation.
- However, in the short-term, we can get an idea by:
  - using the published results;
  - taking the standard equations (below);
  - assuming normally distributed errors on the observables and no correlations between them.
  - take the strong phase δ_D is well known. (neglecting a ±12° uncertainty)

$$
\begin{aligned}
R_{CP+} &= 1 + {r_B}^2 + 2 r_B \cos\delta_B \cos\gamma \\
A_{CP+} &= \frac{2 r_B \sin\delta_B \sin\gamma}{1 + {r_B}^2 + 2 r_B \cos\delta_B \cos\gamma} \\
R^{ADS} &= \frac{{r_B}^2 + {r_D}^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma}{1 + (r_B r_D)^2 + 2 r_B r_D \cos(\delta_B - \delta_D) \cos\gamma} \\
A^{ADS} &= \frac{2 r_B r_D \sin(\delta_B + \delta_D) \sin\gamma}{{r_B}^2 + {r_D}^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma}
\end{aligned}
$$

Using: $R_{ADS(K)}$ and $A_{ADS(K)}$



Using: $R_{ADS(K)}$ and $A_{ADS(K)}$ and R_{CP+} and A_{CP+}

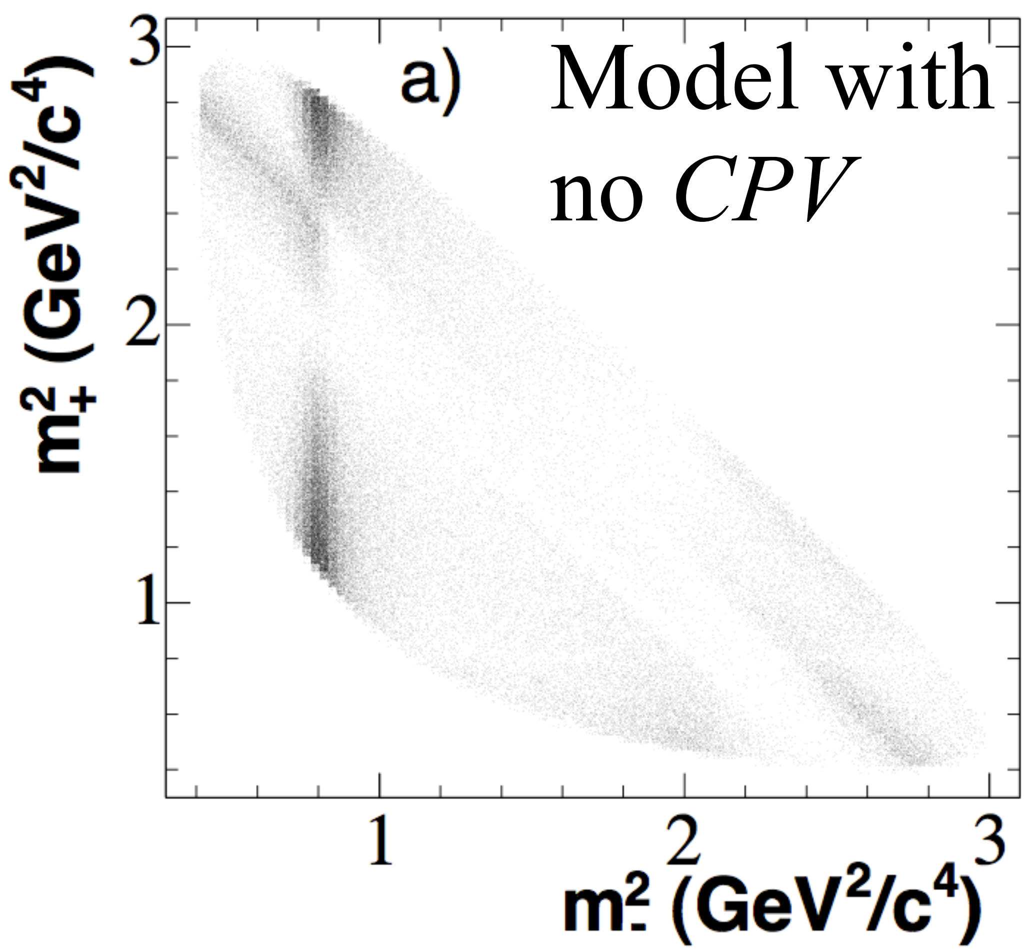


Aside: important information on γ comes from the "GGSZ" method

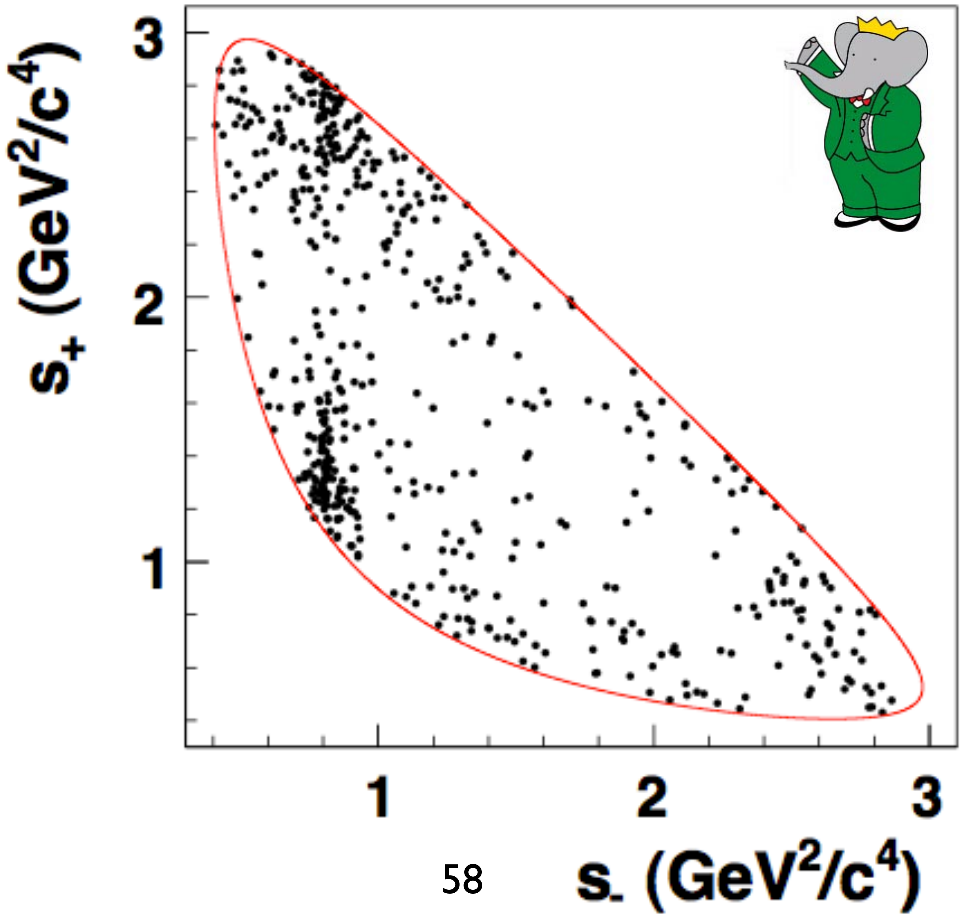
- Exactly the same idea: interference between b→u and b→c transitions but this time, use a three-body common final state

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

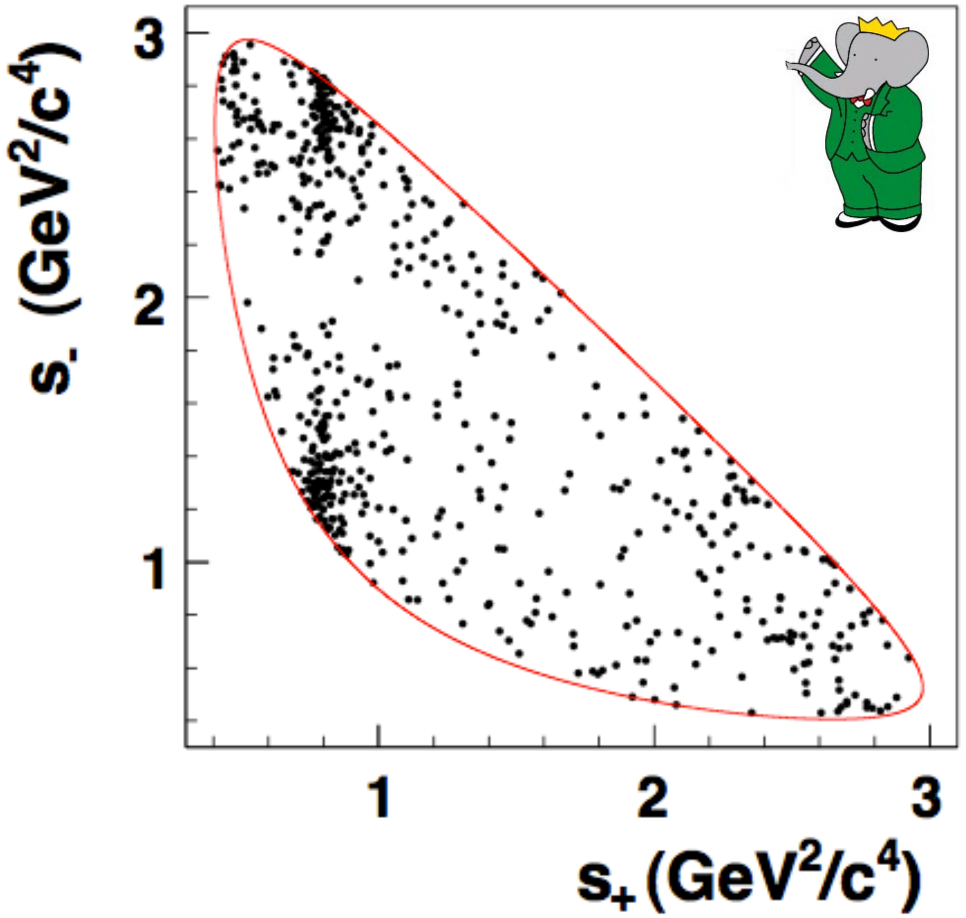
- This method is particularly useful for combatting the trigonometric ambiguities present in the determination of γ from the ADS & *CP* methods

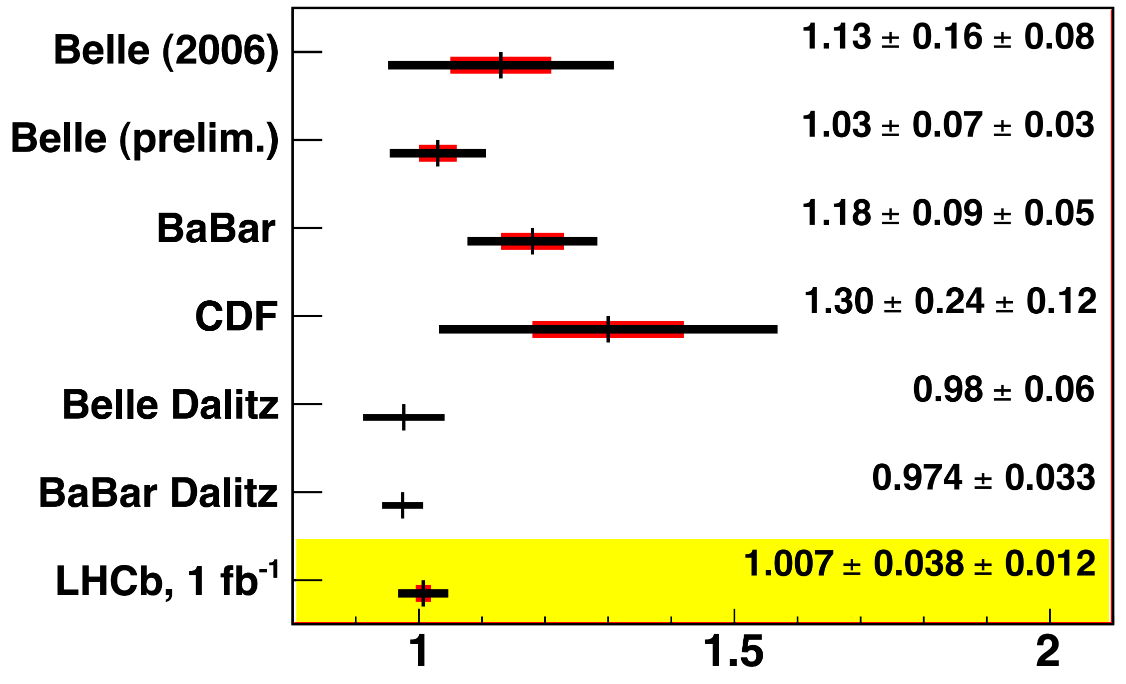


$B^- \to D\, K^-$

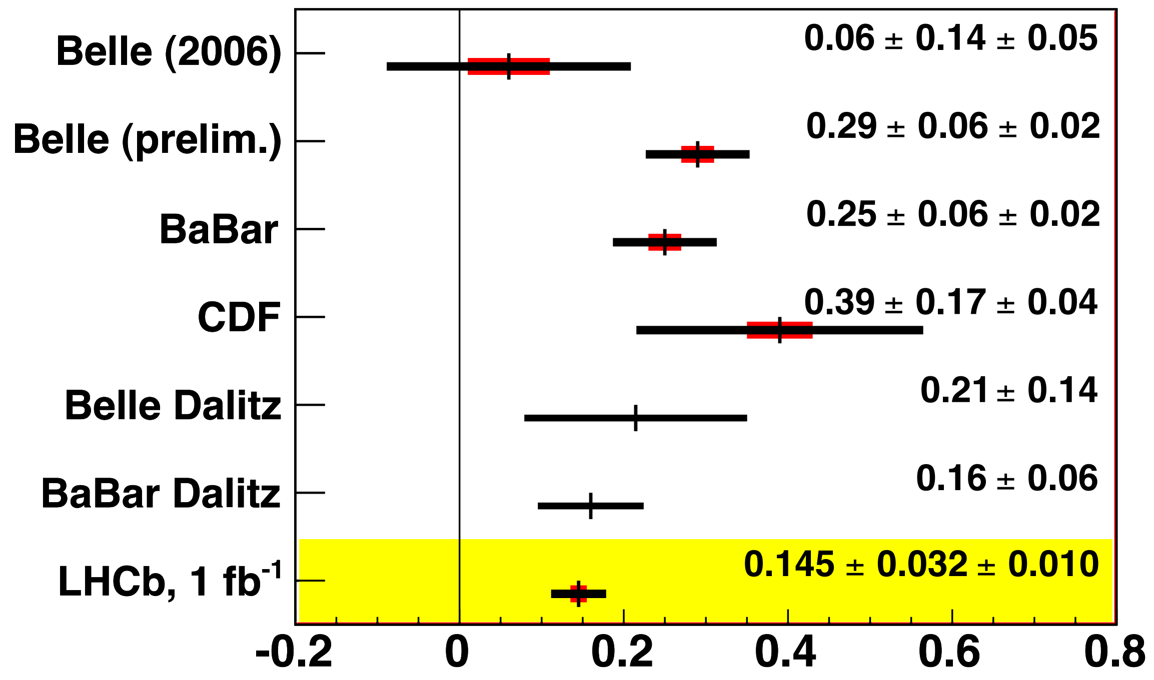


$B^+ \to D\, K^+$



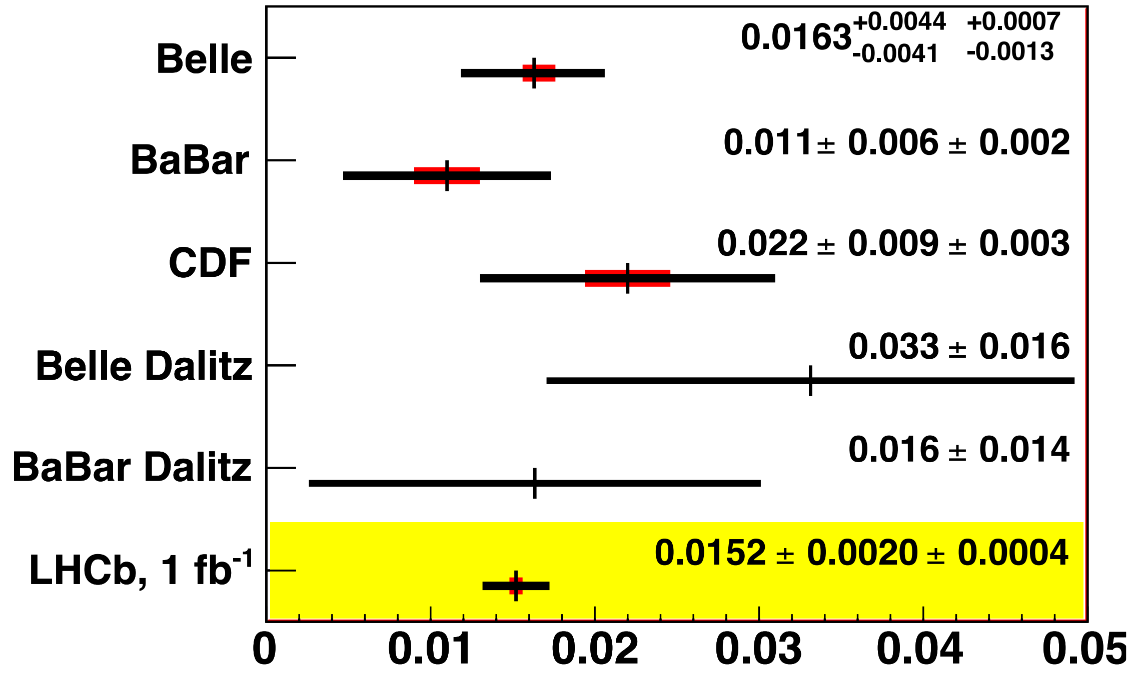


$$R_{CP+} = 1 + {r_B}^2 + 2 r_B \cos\delta_B \cos\gamma$$

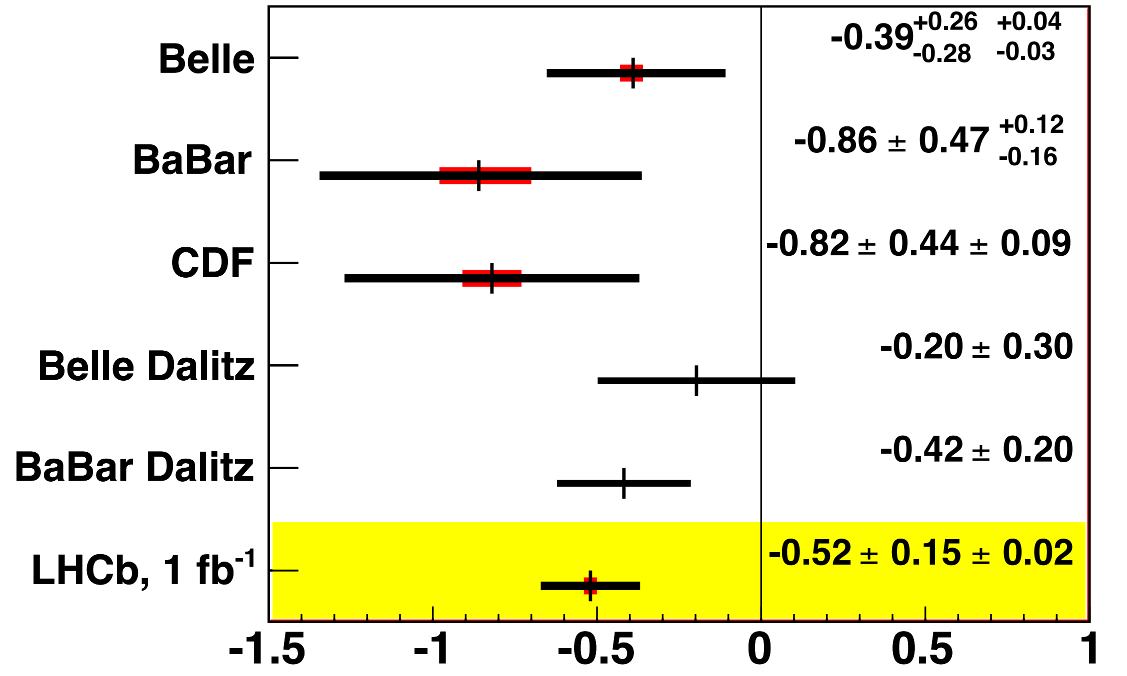


$$A_{CP+} = \frac{2 r_B \sin\delta_B \sin\gamma}{1 + {r_B}^2 + 2 r_B \cos\delta_B \cos\gamma}$$

GGSZ methods measure the underlying parameters, r_B,γ,δ. From these, we can calculate the four observables for comparison.

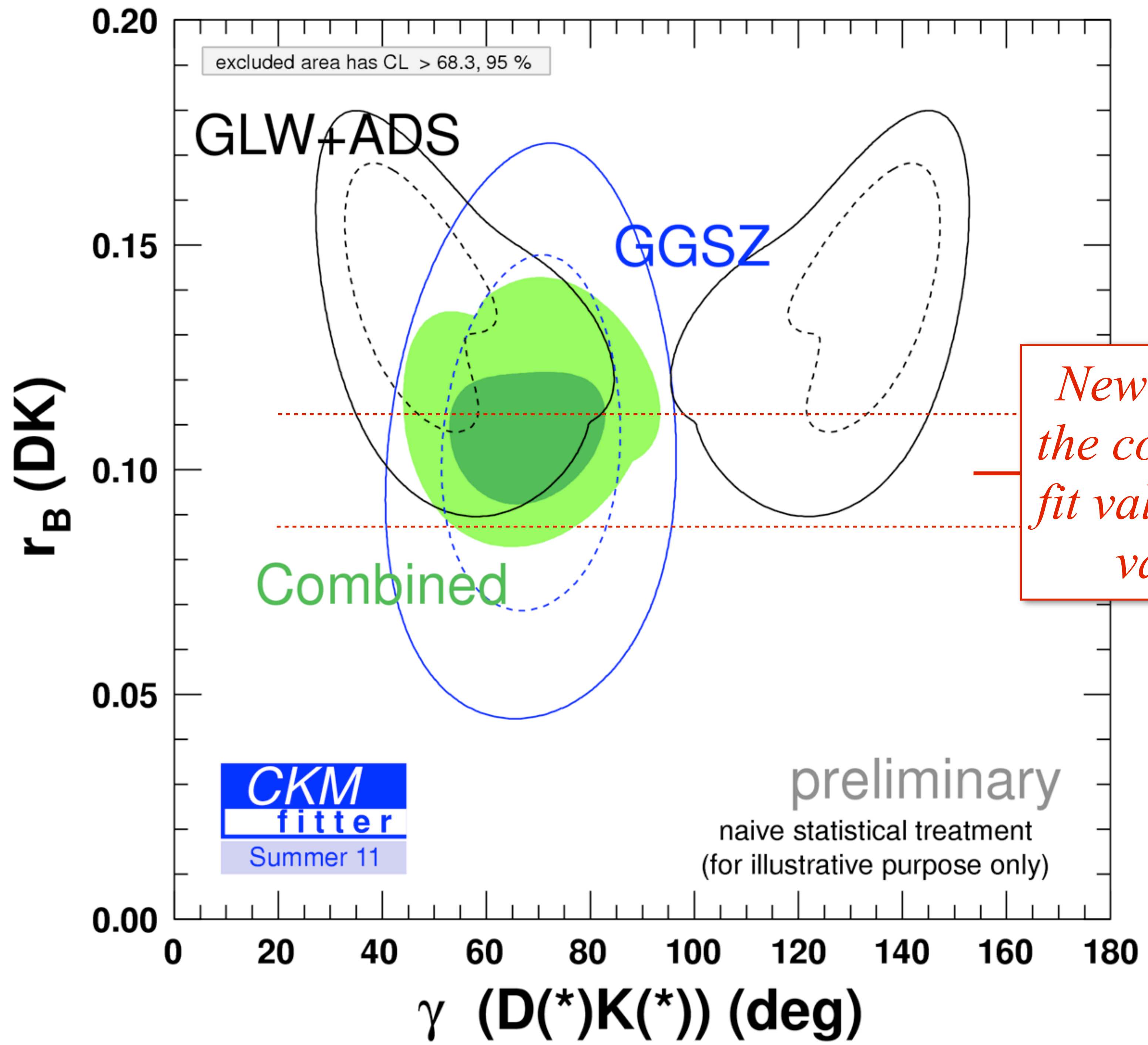


$$R^{ADS} = \frac{{r_B}^2 + {r_D}^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma}{1 + (r_B r_D)^2 + 2 r_B r_D \cos(\delta_B - \delta_D) \cos\gamma}$$

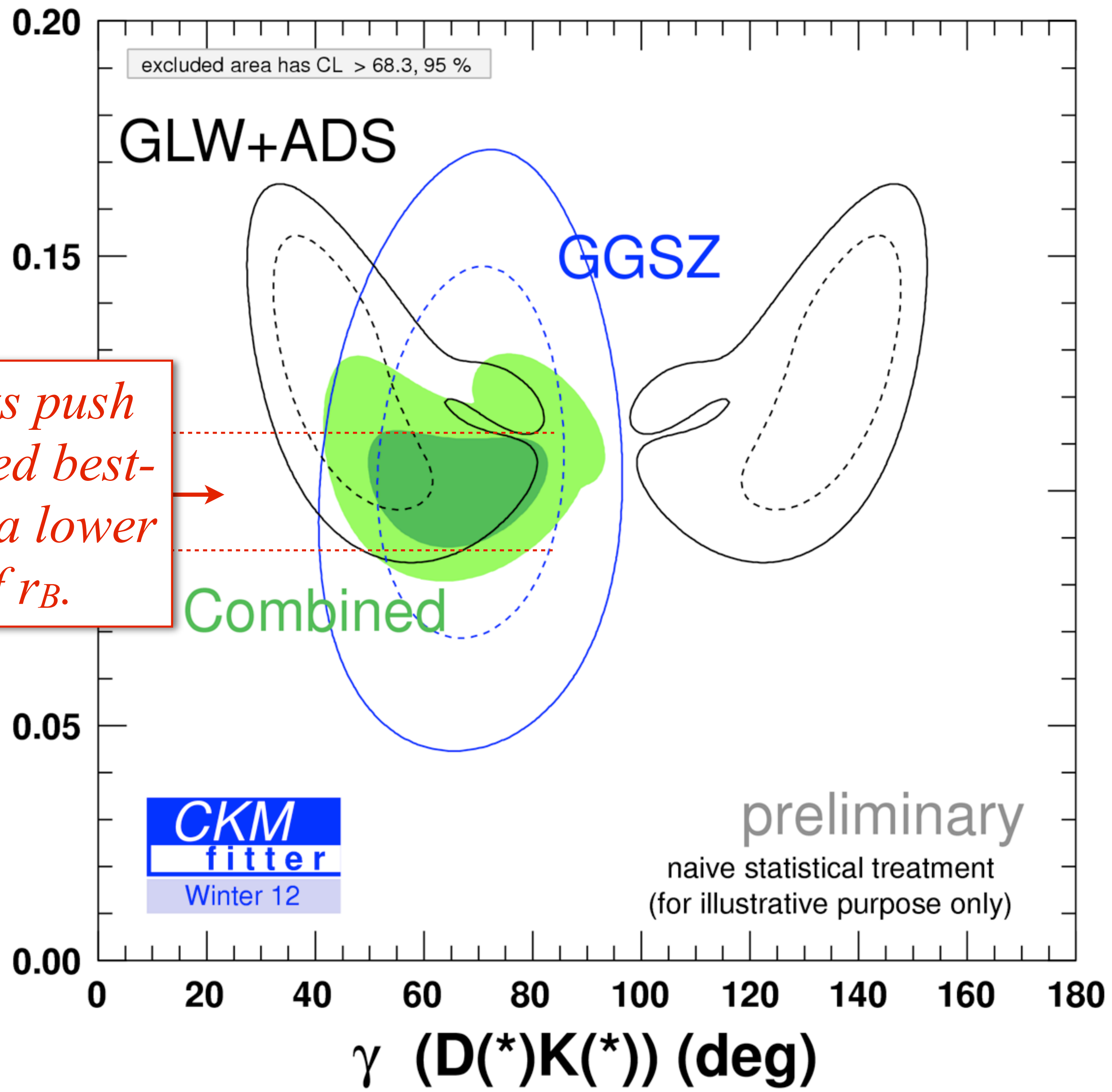


$$A^{ADS} = \frac{2 r_B r_D \sin(\delta_B + \delta_D) \sin\gamma}{{r_B}^2 + {r_D}^2 + 2 r_B r_D \cos(\delta_B + \delta_D) \cos\gamma}$$

Many thanks to the CKMFitter collaboration for absorbing these results



New results push the combined best-fit value to a lower value of r_B.



This is just the first step for LHCb!

> The most likely first measurement, amongst those presented here, is the two-body ADS analysis, where there is limited evidence for the suppressed modes [40, 41]; the observation of these decays would be a significant first step toward the programme outlined in this document.

LHCb "Roadmap"

Many direct CPV analyses coming to maturity:

$B^- \to D\, K^-$

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

presented today. *CP* violation observed

$D \to K_S{}^0\pi^+\pi^-$
$D \to K_S{}^0K^+K^-$
$D \to K^+\pi^-\pi^+\pi^-$
$D \to K^+\pi^-\pi^0$

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

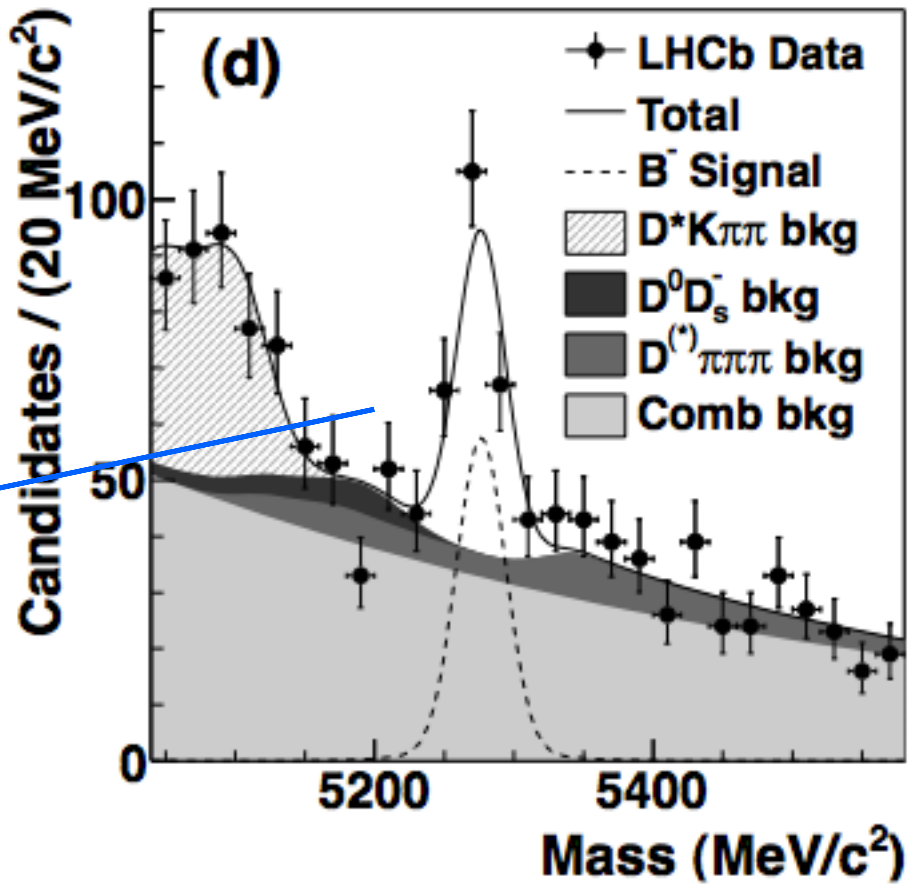
$D \to K^+\pi^-$
$D \to K^-K^+$
$D \to \pi^-\pi^+$

$B^- \to D\, K^-\pi^+\pi^-$

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

Favoured mode first observed in 2010

arXiv:1201.4402



And unique to LHCb: γ from B_s tree decays

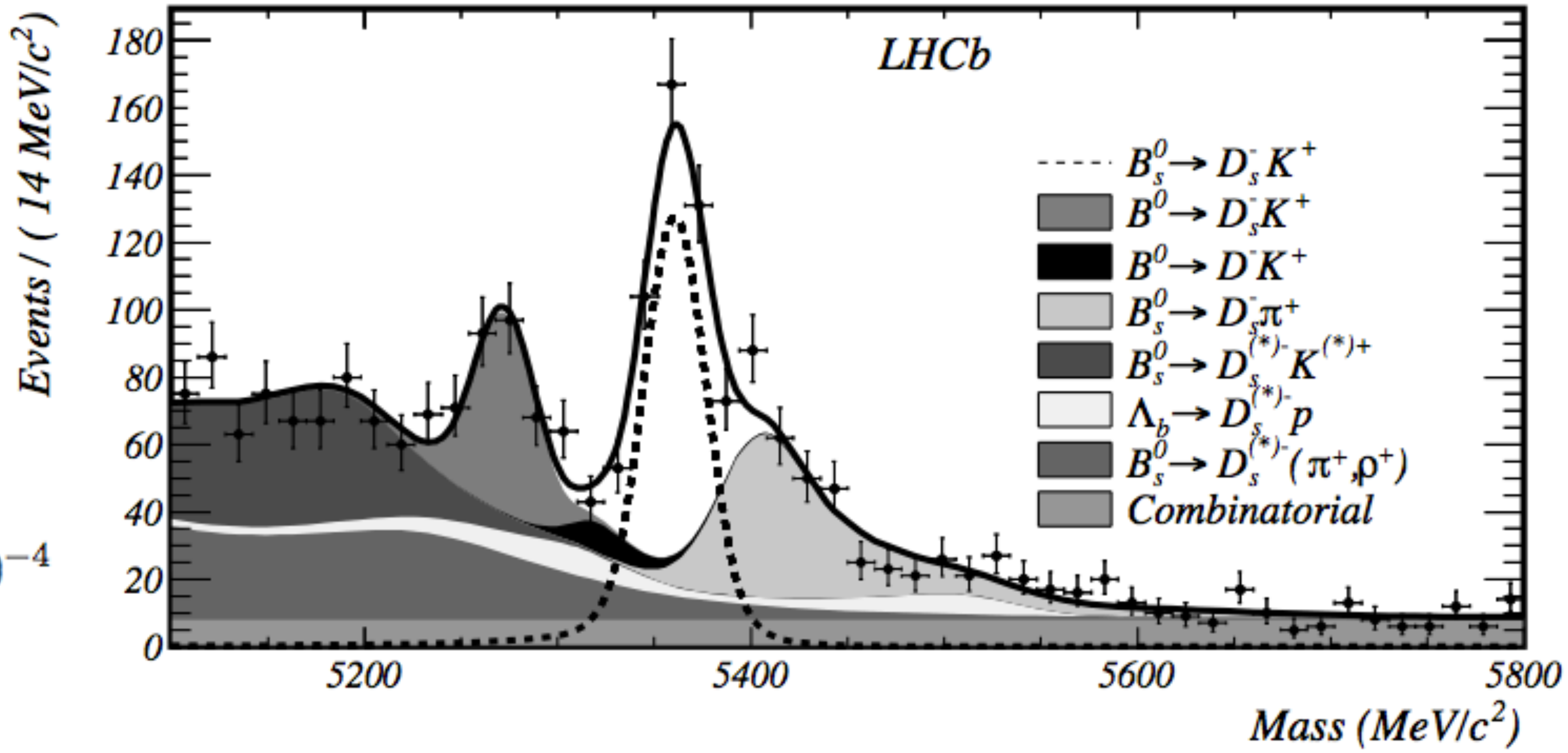
Precise measurement of

$$B_s^0 \rightarrow D_s^- K^+$$

branching now made. Time-dependent measurement of γ on-going.

$$\mathcal{B}(B_s^0 \to D_s^- K^+) = (1.90 \pm 0.12 \pm 0.13)^{+0.12}_{-0.14} \times 10^{-4}$$

LHCB-PAPER-2011-022

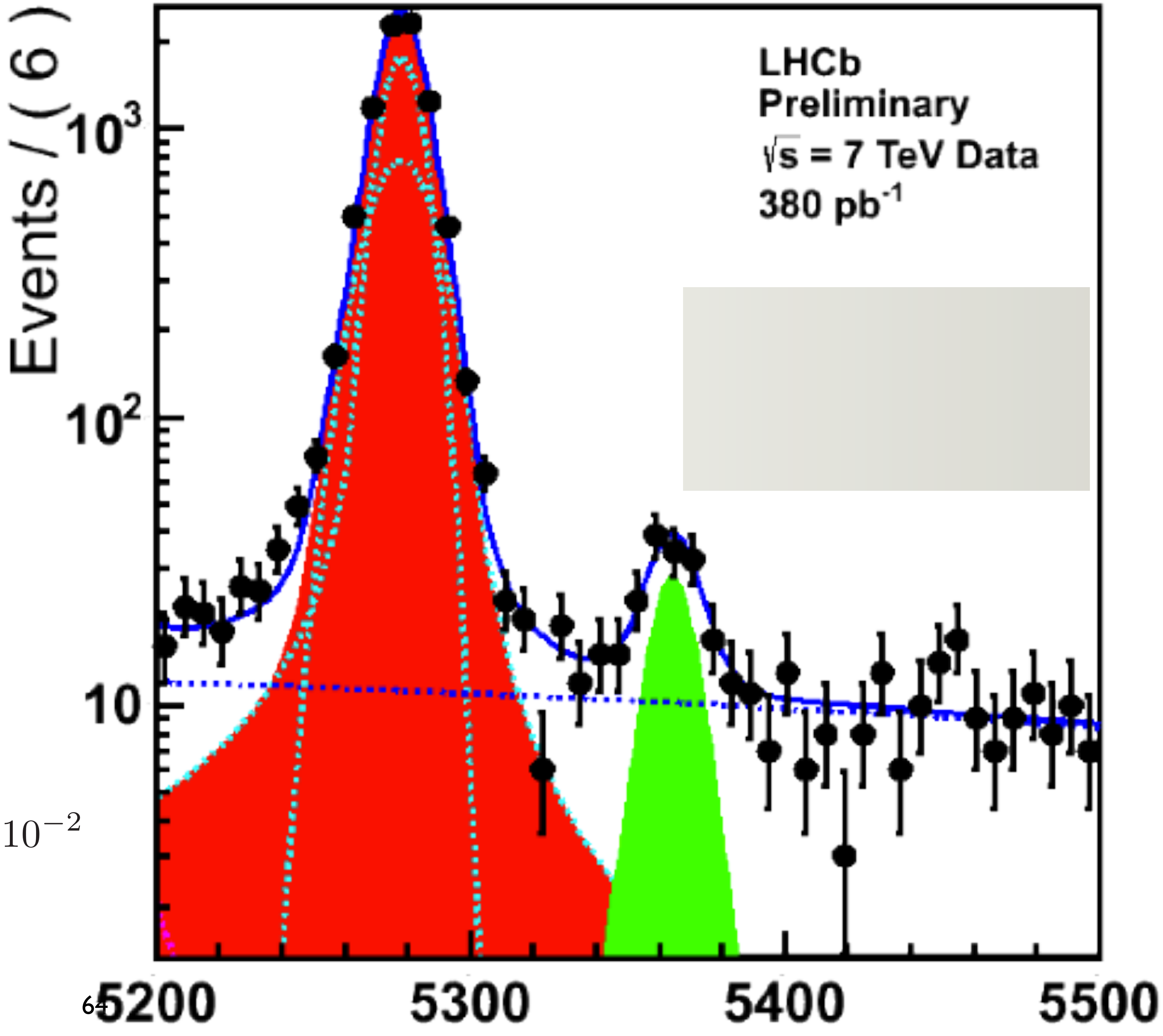


LHCb is on-track to make a combined measurement of γ using $B^\pm, B^0, B_s$ tree decays, to an accuracy of 5~8° with the 2011+2012 dataset.

Fin

Penguins in sin(2β): $B_s \to J/\psi K_S$

- The unitarity triangle shows some tension between $|V_{ub}|$ and sin(2β).
- How much of "sin(2β)" is sin(2β)? How large are the hadronic penguin contributions?
- Could be eventually deduced by comparing $B_d \to J/\psi K_S^0$ and its U-spin partner: $B_s \to J/\psi K_S^0$
- First step: confirmation in LHCb dataset.



$$\frac{\mathcal{B}(B_s \to J/\psi K_S^0)}{\mathcal{B}(B_d \to J\psi K_S^0)} = (3.78 \pm 0.58 \pm 0.20 \pm 0.30) \times 10^{-2}$$

Dealing with production/detection asymmetries

$B^{\pm}\to[K\pi]_D h^{\pm}$	$A_{CP}((K\pi)_D\pi) = A_{raw}((K\pi)_D\pi) - A_{Prod} - A_K$
	$A_{CP}((K\pi)_D K) = A_{raw}((K\pi)_D K) - A_{Prod} - 2\times A_K$
$B^{\pm}\to[\pi K]_D h^{\pm}$	$A_{CP}((\pi K)_D\pi) = A_{raw}((\pi K)_D\pi) - A_{Prod} + A_K$
	$A_{CP}((\pi K)_D K) = A_{raw}((\pi K)_D K) - A_{Prod}$
$B^{\pm}\to[KK]_D h^{\pm}$	$A_{CP}((KK)_D\pi) = A_{raw}((KK)_D\pi) - A_{Prod}$
	$A_{CP}((KK)_D K) = A_{raw}((KK)_D K) - A_{Prod} - A_K$
$B^{\pm}\to[\pi\pi]_D h^{\pm}$	$A_{CP}((\pi\pi)_D\pi) = A_{raw}((\pi\pi)_D\pi) - A_{Prod}$
	$A_{CP}((\pi\pi)_D K) = A_{raw}((\pi\pi)_D K) - A_{Prod} - A_K$

$A^{J/\psi K^{\pm}}_{Raw} = -0.012\pm0.004$

$+A_{PDG}$, -0.001 ± 0.007

→

FIXED (%)

$A_{Prod} = -0.8\pm0.7$

$A_K = -0.5\pm0.7$

$A_\pi = 0.0\pm0.7$

Track momentum of final sample