Time-integrated measurements of the CKM angle γ

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On behalf of the LHCb collaboration

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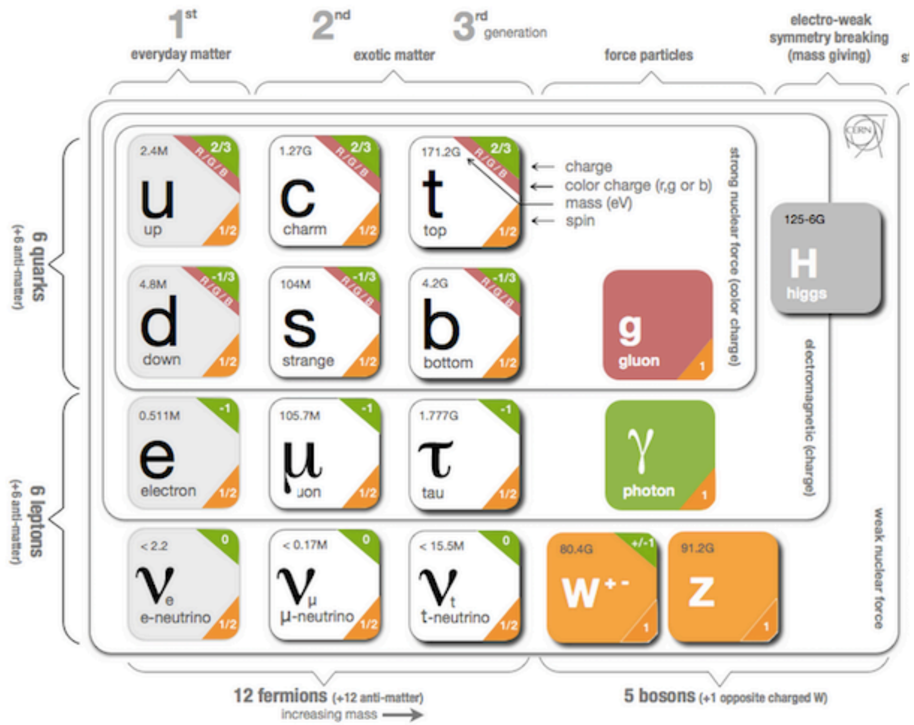
The Standard Model – not full story



Empirical

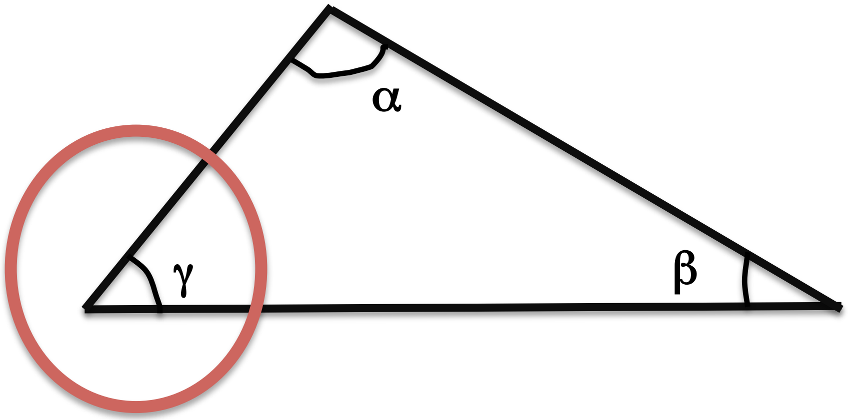
- **Dark Matter**
- **Matter rather than antimatter**
- **Gravity**
- **… more**

Aesthetic

- **Why 3 generations?**
- **Unification**
- **Fine tuning / hierarchy**

A promising area - CP violation

- Probing CPV further may uncover the effects of NP
- CKM matrix describes the coupling of the weak and mass eigenstates of quarks.
- Single free phase in the CKM matrix gives rise to Standard Model CPV



$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Using the properties of unitary matrices

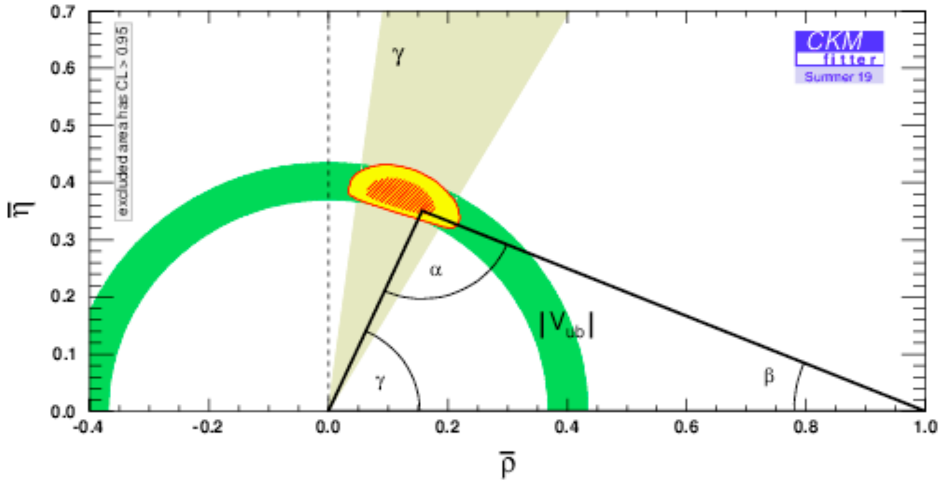
$$0 = 1 + \frac{V_{tb}^{*} V_{td}}{V_{cb}^{*} V_{cd}} + \frac{V_{ub}^{*} V_{ud}}{V_{cb}^{*} V_{cd}}$$

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

CKM angle γ

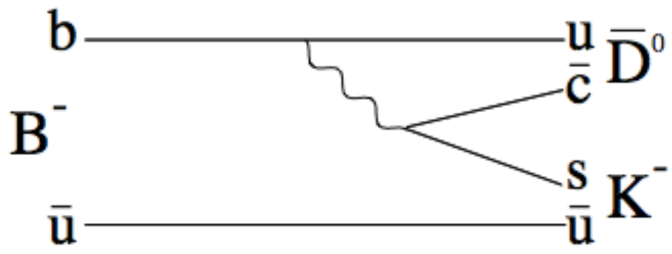
Direct measurement

- γ only angle easily accessible at tree level.
- Tree level measurements are "SM" benchmark values - no interference from New Physics
- Effectively no theory uncertainties.



Standard model benchmark

Tree level



CKM angle γ

Direct measurement vs Indirect determination

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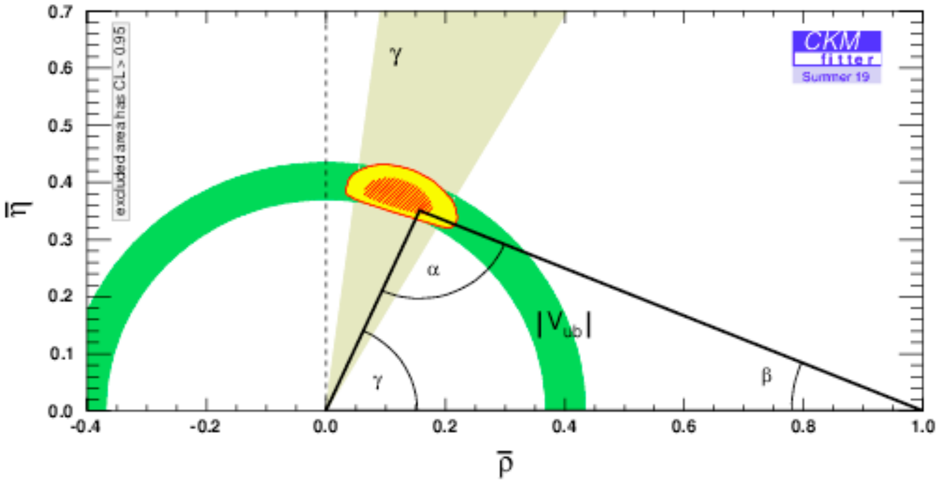
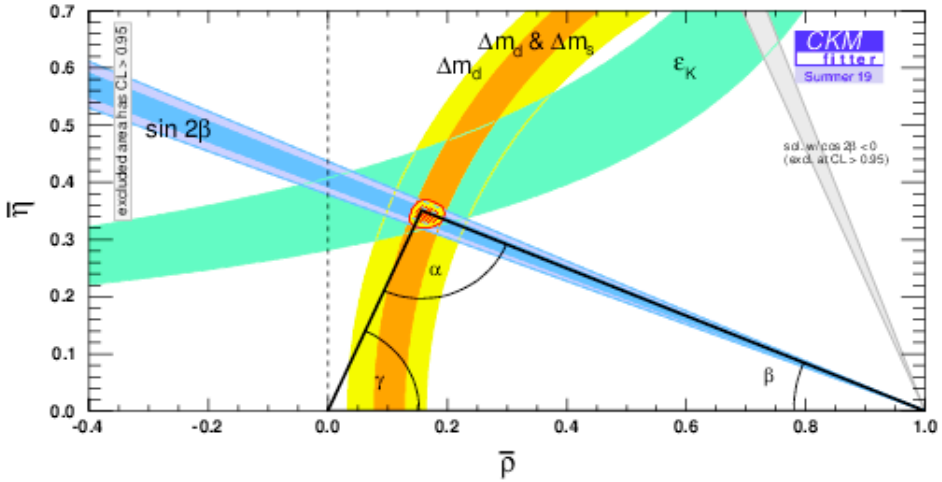
- Effectively no theory uncertainties.

- Assume the triangle is closed. Measurements of the other sides and angles are used to infer the value of γ.
- New Physics can contribute – potential for different central value.





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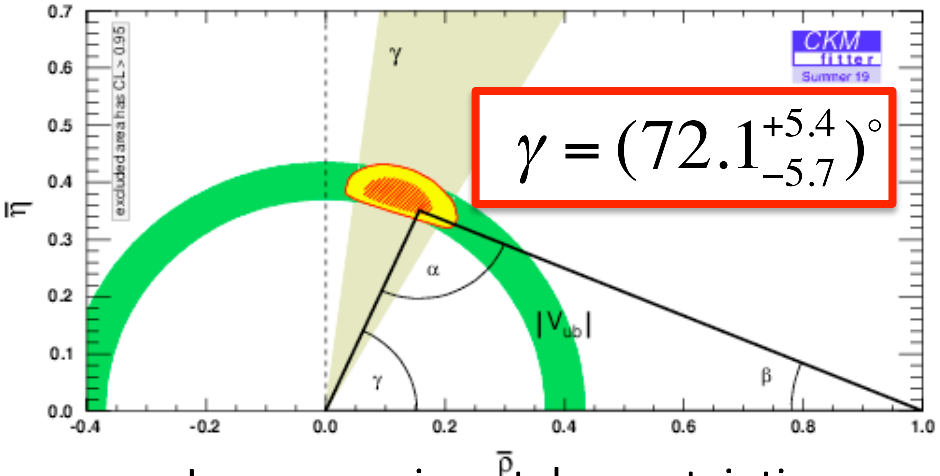
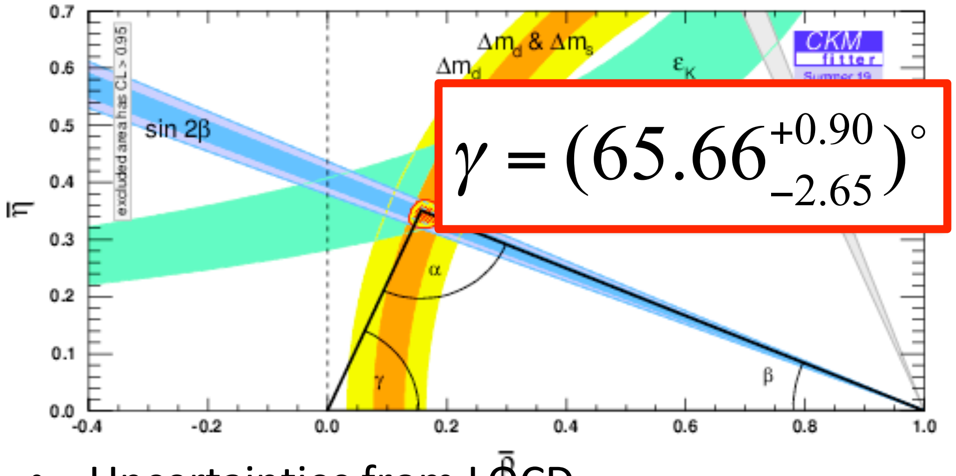
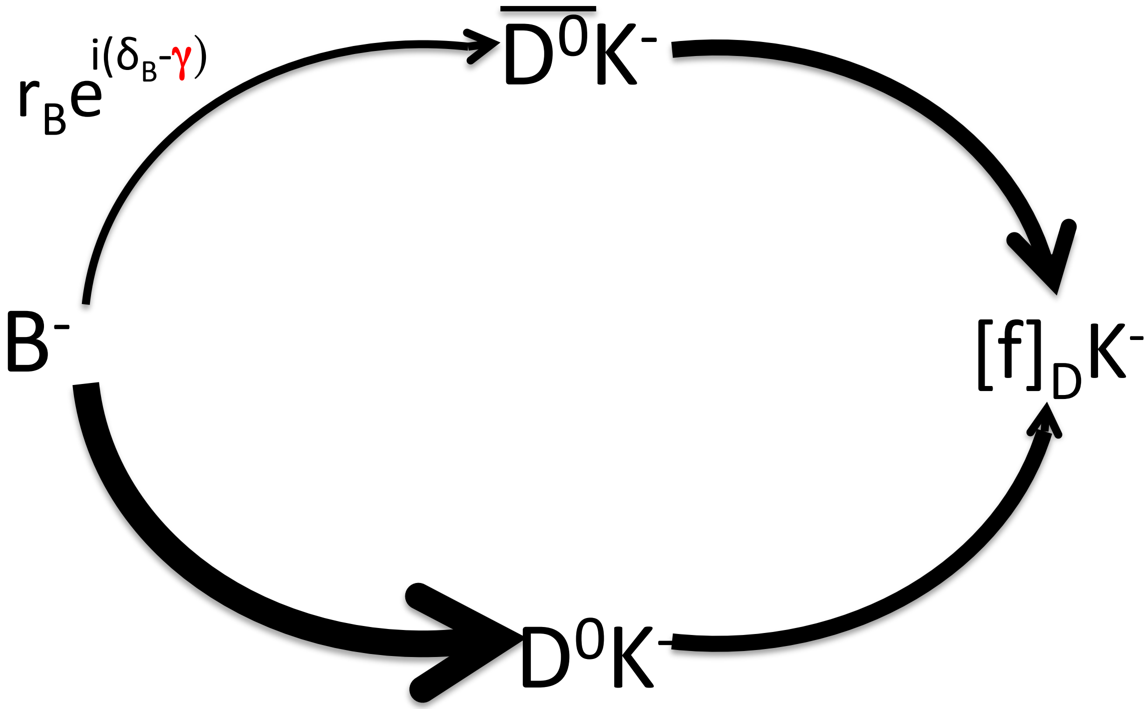




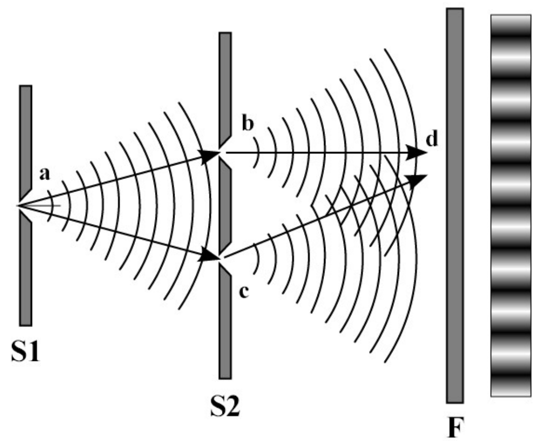
- Large experimental uncertainties.
- **Significant progress possible in next few years**

- Uncertainties from LQCD
- Can expect reduction in time

Using a common D decay final state

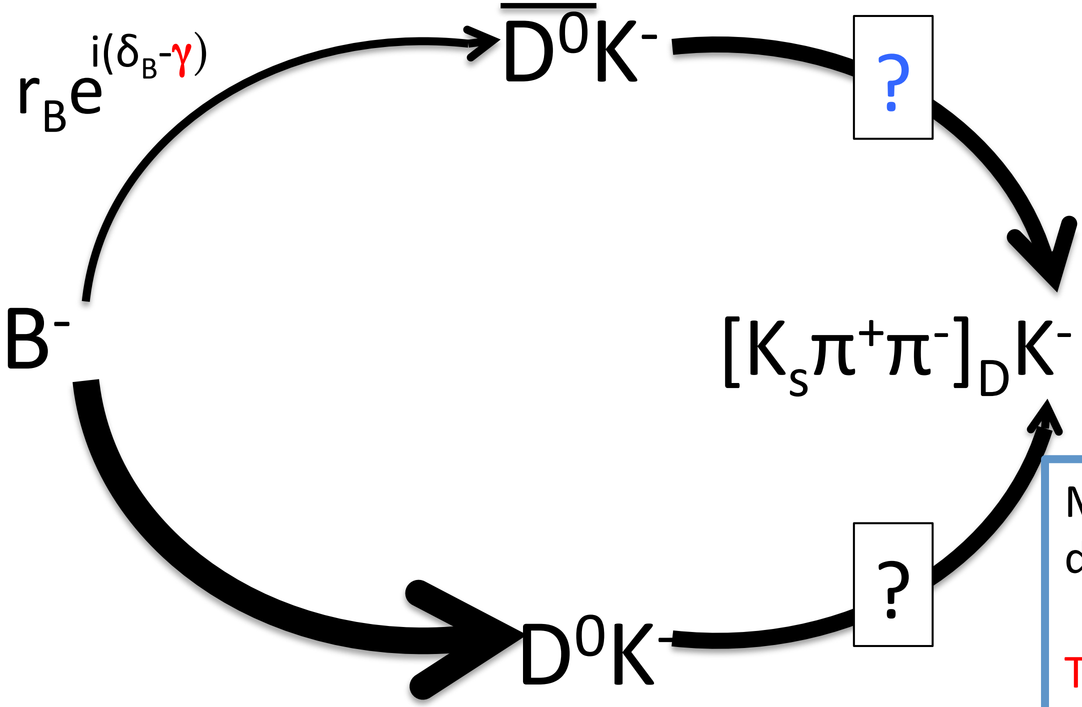


- Common final state allows interference between the two paths
- Interference gives access to the phase



The level of interference, and its exact manifestation is dependent on the physics of the B decay AND D decay

Self-conjugate D decays using Dalitz plot “BPGGSZ”



3-body D meson decay.

The level of interference, and its exact manifestation is dependent on the physics of the B decay AND D decay

Many combinations of B and D decays give sensitivity to γ

This talk:

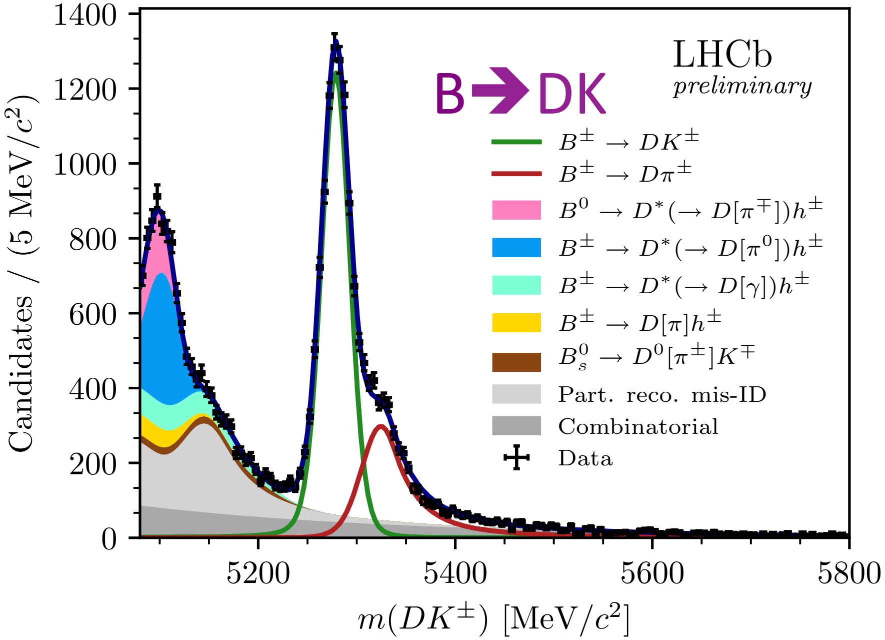
- Focus on $B^+ \rightarrow D(Kshh)h'$ NEW
- Briefly $B^+ \rightarrow D(KsK\pi)h$

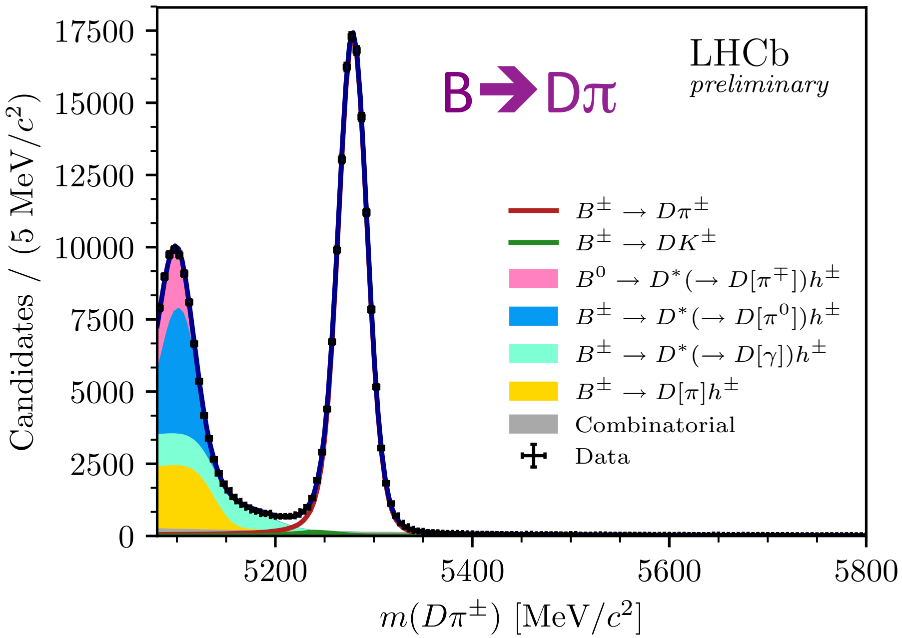
Time dependent results shown in Eva Gersabeck’s talk – Next talk!

LHCb data selection

Excellent detector performance:

- Trigger efficiency, IP resolution, momentum resolution and hadron PID lead to large yields with high purity

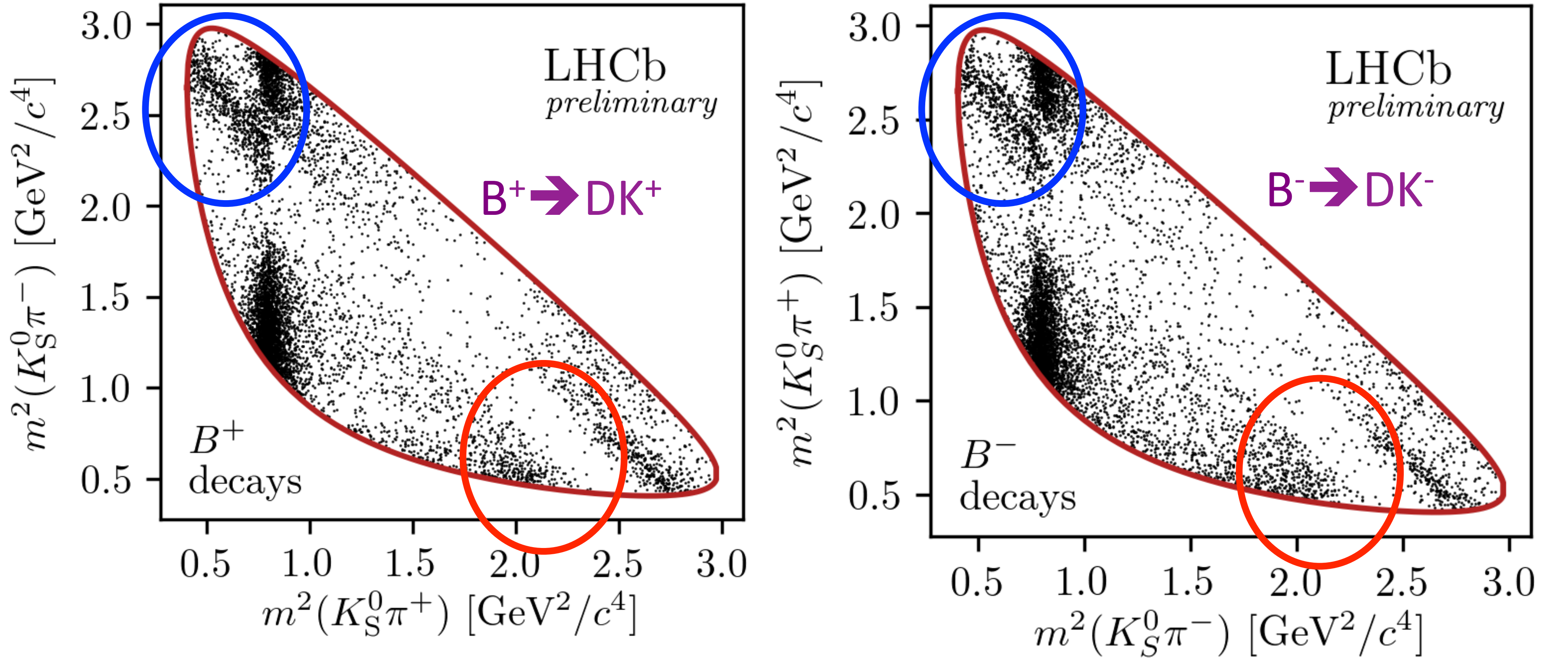




In total ~ 15K B→DK
210K B→Dπ

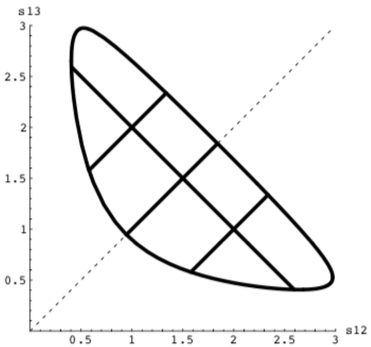
Full dataset from 2011 - 2018

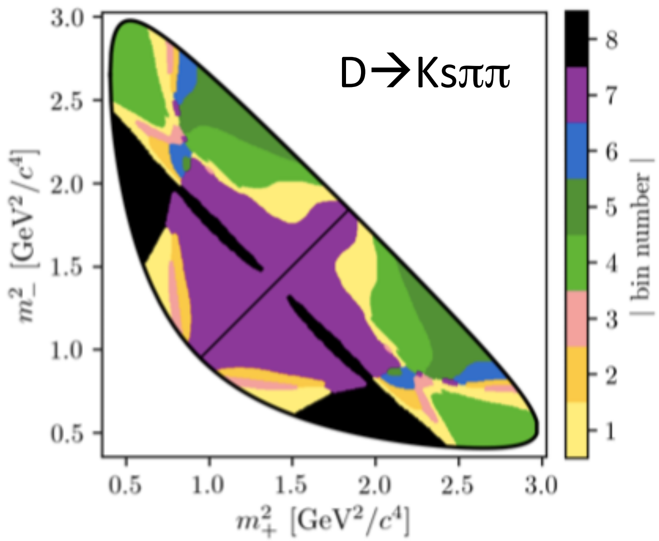
CP violation on the D-Dalitz plot distribution

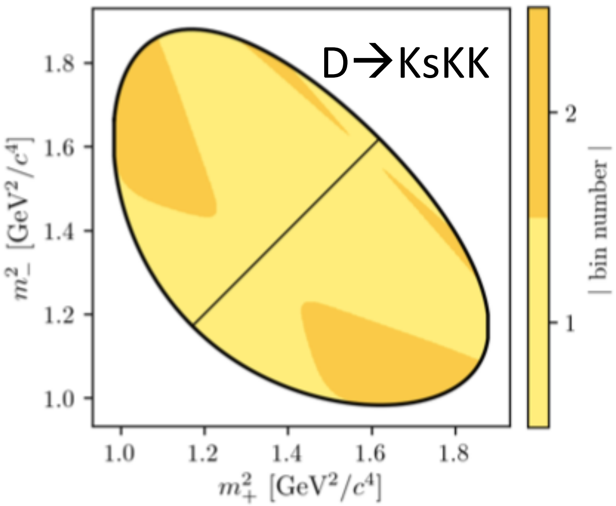


The magnitude and position of the differences is driven by the values of r_B, δ_B, γ, and the physics of the D decay

Compare Bin yields







- Idea – compare yields in bins between B+ and B-
- Non uniform binning scheme chosen to maximise statistical sensitivity
- D→KsKK can also be included

- Results are **independent** of any amplitude model

Yield equations

- Observed yields in each bin can be related to physics parameters of interest and D^0 decay information

$$N^{+}_{+i} = h_{B^+}\left[F_{-i} + \left(\left(x_{+}^{DK}\right)^2 + \left(y_{+}^{DK}\right)^2\right)F_{+i} + 2\sqrt{F_i F_{-i}}\left(x_{+}^{DK}c_{+i} - y_{+}^{DK}s_{+i}\right)\right]$$

$$N^{-}_{+i} = h_{B^-}\left[F_{+i} + \left(\left(x_{-}^{DK}\right)^2 + \left(y_{-}^{DK}\right)^2\right)F_{-i} + 2\sqrt{F_i F_{-i}}\left(x_{-}^{DK}c_{+i} + y_{-}^{DK}s_{+i}\right)\right]$$

Yield equations

- Observed yields in each bin can be related to physics parameters of interest and D^0 decay information

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  - Physics parameters of interest $x_{\pm} = r_B\cos(\delta_B \pm \gamma)$; $y_{\pm} = r_B\sin(\delta_B \pm \gamma)$

Yield equations

- Observed yields in each bin can be related to physics parameters of interest and D^0 decay information

$$N_{+i}^{+} = h_{B^+}\left[F_{-i} + \left(\left(x_{+}^{DK}\right)^2 + \left(y_{+}^{DK}\right)^2\right)F_{+i} + 2\sqrt{F_i F_{-i}}\left(x_{+}^{DK} c_{+i} - y_{+}^{DK} s_{+i}\right)\right]$$

$$N_{+i}^{-} = h_{B^-}\left[F_{+i} + \left(\left(x_{-}^{DK}\right)^2 + \left(y_{-}^{DK}\right)^2\right)F_{-i} + 2\sqrt{F_i F_{-i}}\left(x_{-}^{DK} c_{+i} + y_{-}^{DK} s_{+i}\right)\right]$$

  - Physics parameters of interest $x_\pm = r_B\cos(\delta_B \pm \gamma)$; $y_\pm = r_B\sin(\delta_B \pm \gamma)$

  - Strong phase parameters of the D decay from BESIII+CLEO*
  - Access to quantum-correlated D decay allows them access to the phase information.

  PRD 101 112002, PRD 82 112006

* Preliminary result doesn't use the recent D→KsKK result arXiv:2007.07959

Yield equations

- Observed yields in each bin can be related to physics parameters of interest and D^0 decay information

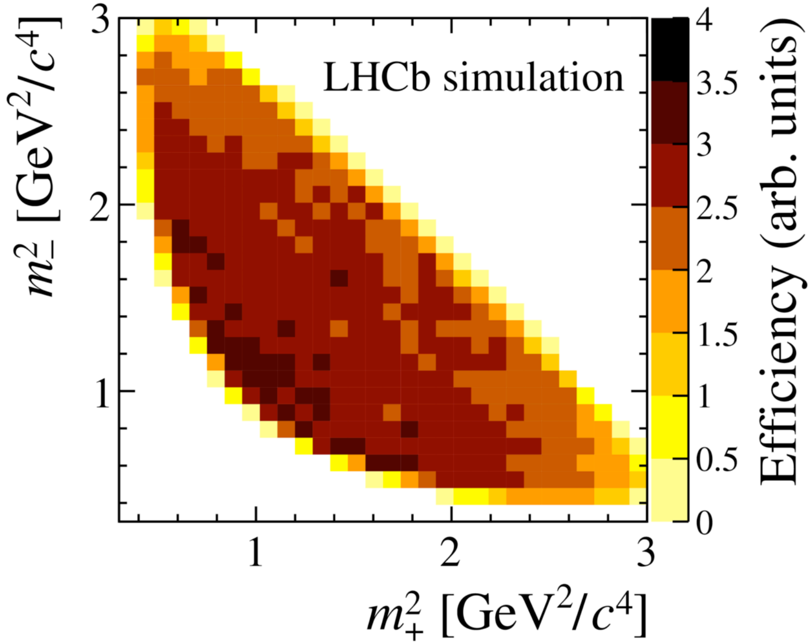
$$N^+_{+i} = h_{B^+}\left[F_{-i} + \left(\left(x_+^{DK}\right)^2 + \left(y_+^{DK}\right)^2\right)F_{+i} + 2\sqrt{F_i F_{-i}}\left(x_+^{DK}c_{+i} - y_+^{DK}s_{+i}\right)\right]$$

$$N^-_{+i} = h_{B^-}\left[F_{+i} + \left(\left(x_-^{DK}\right)^2 + \left(y_-^{DK}\right)^2\right)F_{-i} + 2\sqrt{F_i F_{-i}}\left(x_-^{DK}c_{+i} + y_-^{DK}s_{+i}\right)\right]$$

  - Physics parameters of interest $x_\pm = r_B\cos(\delta_B \pm \gamma)$; $y_\pm = r_B\sin(\delta_B \pm \gamma)$
  - Strong phase parameters of the D decay from BESIII+CLEO
  - Fraction of pure D^0 decay to bin *i* taking into account the reconstruction and selection efficiency

Efficiency and B→Dπ

Efficiency profile is not uniform

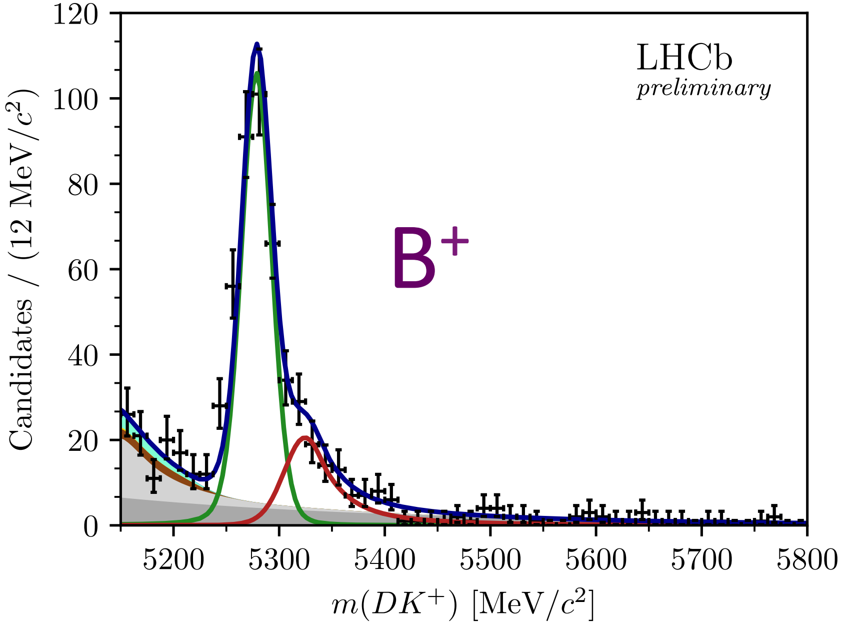


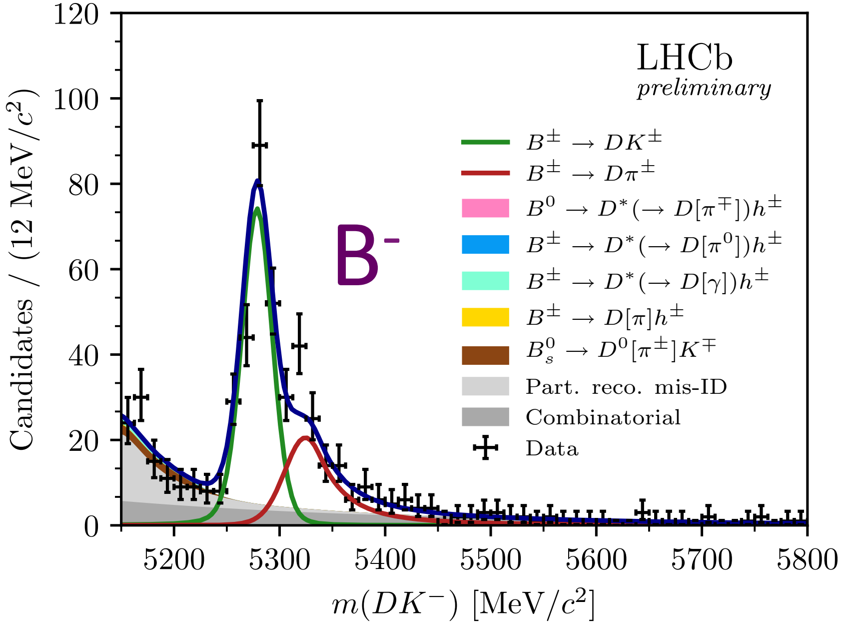
Reduce systematic uncertainties, reduce reliance on simulation

- Previously used B→D*μν and simulation to determine the F_i – but the trigger and selection can't be the same.
- Efficiency profile in B→Dπ would be the same – topology same
- Branching fraction ~ x12 larger - obvious control mode BUT CPV and other physics effects in this channel must be understood/taken into account.
- For the first time, use this as the control mode to determine the F_i (and simultaneously determine the CPV parameters in B→Dπ)

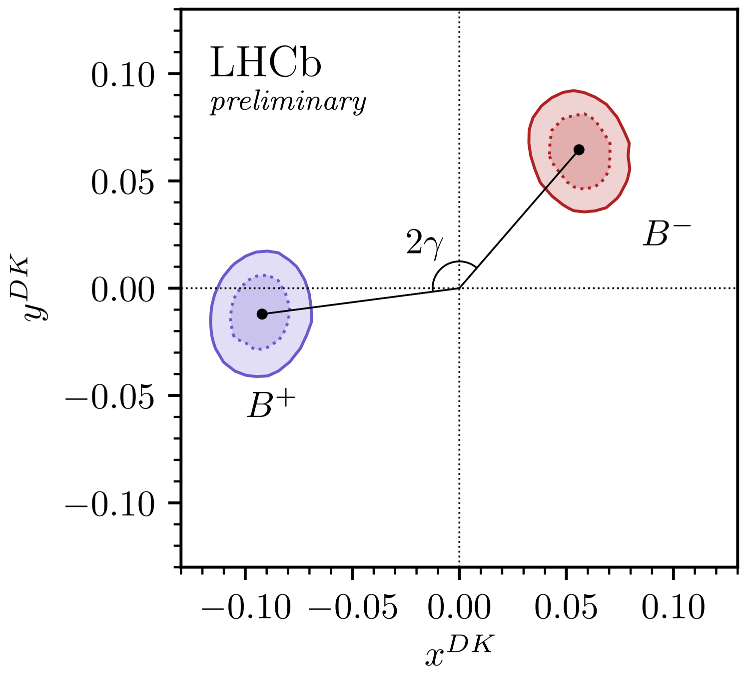
Fit

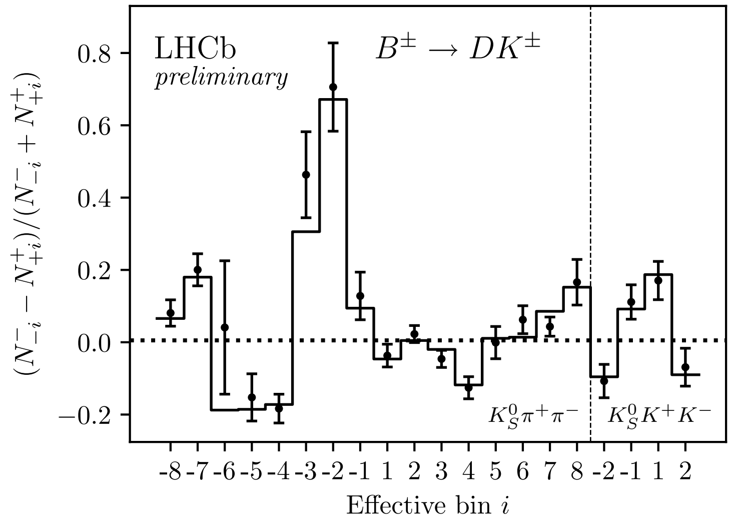
- Mass fit performed in each Dalitz plot bin to determine x, y CP observables
- Example bin 4 shown below and demonstrates a region of large asymmetry

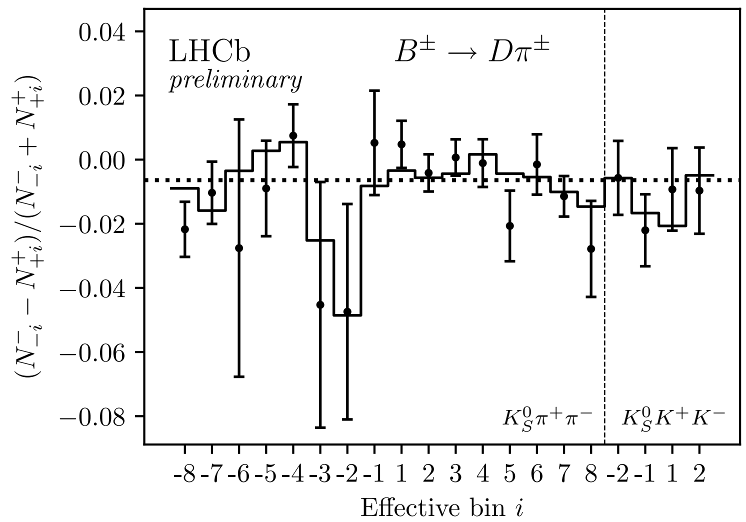




Results







- CP violation is clearly observed in B→DK.
- Data insufficient to see CPV in B→Dπ

Interpretation + Comparison

2011 -2018: Preliminary

$$\gamma = (69 \pm 5)^{\circ}$$

σ(stat) ~ 5° σ(BESIII+CLEO) ~ 1°, σ(syst) ~1°

Interpretation + Comparison

2011 -2018: Preliminary

$$\gamma = (69 \pm 5)^{\circ}$$

σ(stat) ~ 5° σ(BESIII+CLEO) ~ 1°, σ(syst) ~1°

2011 -2016:

$$\gamma = (80^{+10}_{-9})^{\circ}$$

σ(stat) ~ 9° σ(CLEO) ~ 4°, σ(syst) ~3°

New inputs from BESIII on strong phases in D→Ksππ make a large difference

Use of the B→Dπ decay mode to incorporate the efficiency effects reduces the experimental systematic uncertainties.

Interpretation + Comparison

2011 -2018: Preliminary

$$\gamma = (69 \pm 5)^\circ$$

2011 -2016:

$$\gamma = (80^{+10}_{-9})^\circ$$

$$r_B^{DK} = 0.089^{+0.008}_{-0.007},$$
$$\delta_B^{DK} = (118 \pm 6)^\circ,$$
$$r_B^{D\pi} = 0.0048^{+0.0017}_{-0.0016},$$
$$\delta_B^{D\pi} = (287^{+26}_{-27})^\circ.$$

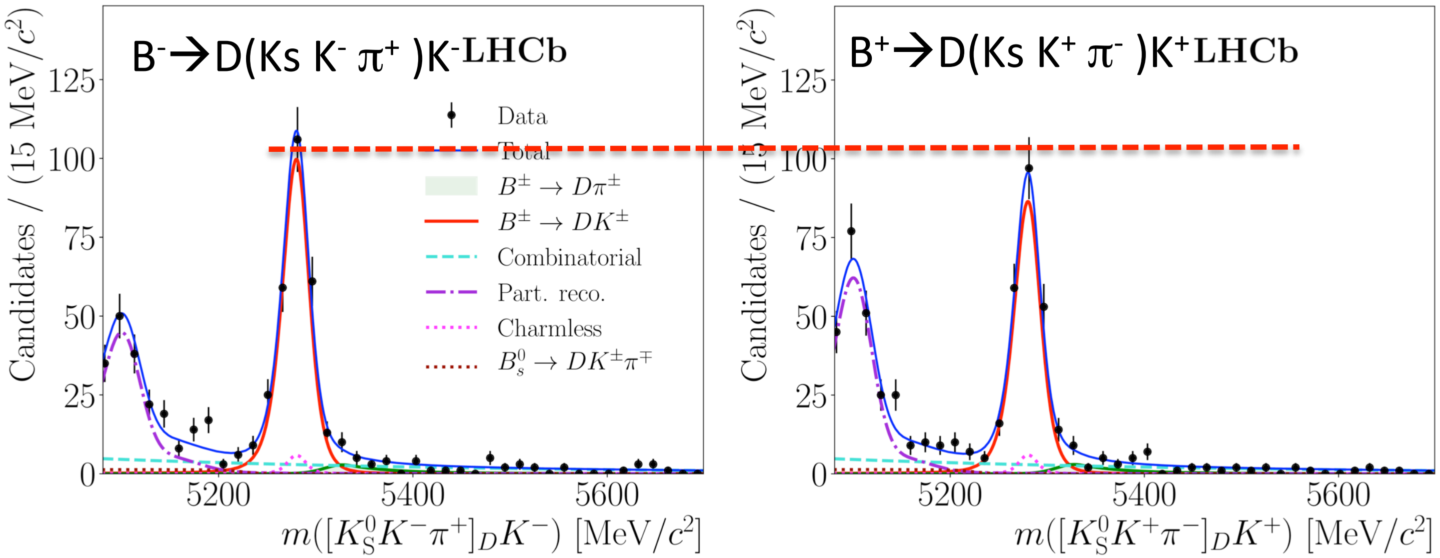
- B→Dπ parameters measured for the first time.
- Impact in the γ combination of many results, as CPV is seen in other B→Dπ decay modes.
- This result is the most precise to date.

- Reaches similar precision as all other measurements of γ combined

Other measurements

A large number of different B and D decays are pursued at LHCb to measure γ
Large amount of current activity to update these to the full data sample

- Asymmetries in $B \to D[K_S K\pi]K$ have sensitivity to γ.



Another full Run1 + Run2 analysis –

Standalone measurement not possible.

Will contribute to the next γ combination

Summary and Outlook

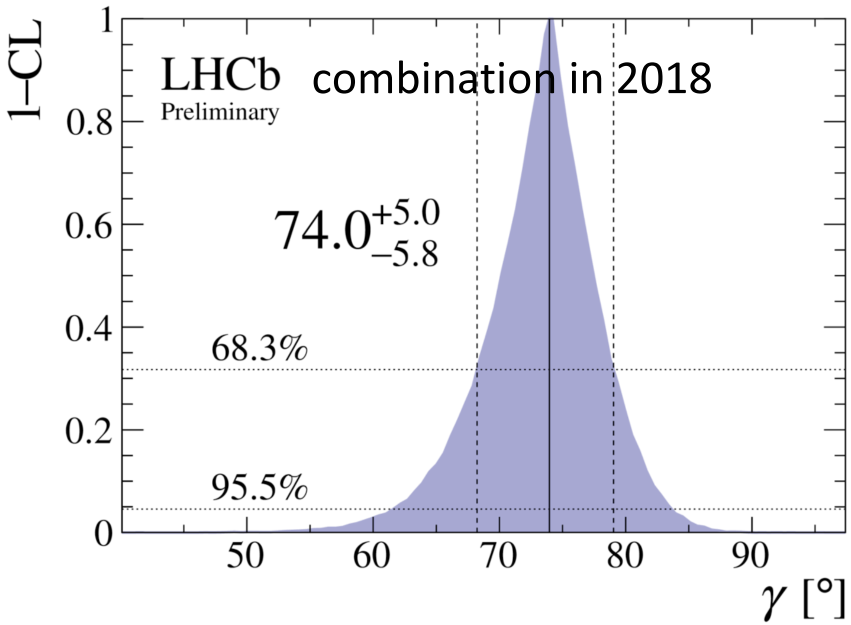
LHCb started to release full Run1 and Run2 measurements of γ

New result using $B \rightarrow D(K_S hh)h'$

$$\gamma = (69 \pm 5)^{\circ}$$

Most precise measurement from single measurement.

Benefit from new control and new external inputs of strong phases



LHCb is on track to surpass the 4° Run1+2 target