γ (ϕ_3) from $B \to DK$ and friends – where we are and what's next?

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2nd B2TIP meeting; Krakow

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Importance of γ from B→DK

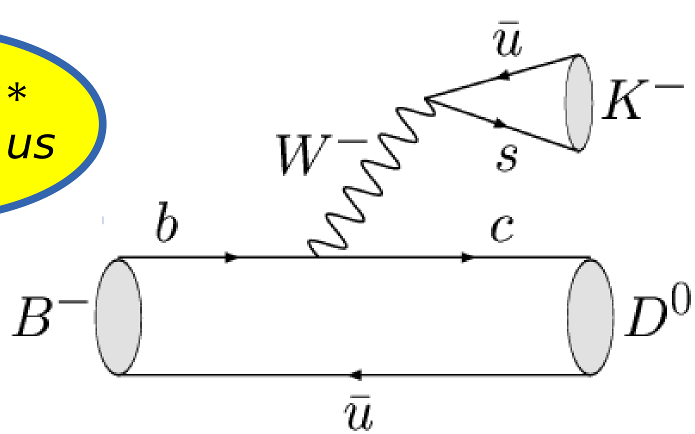
- γ plays a unique role in flavour physics

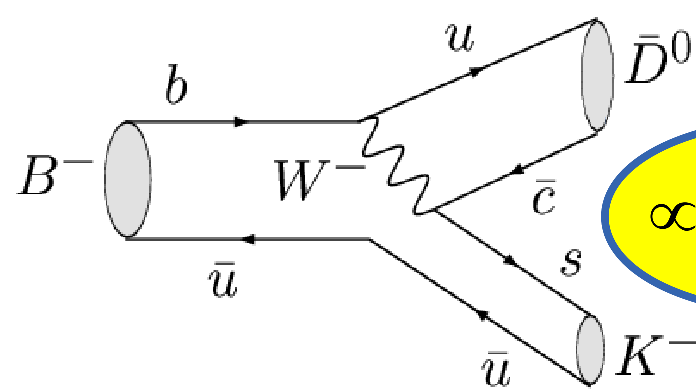
the only CP violating parameter that can be measured through tree decays (*)

(*) more-or-less

- A benchmark Standard Model reference point
  - doubly important after New Physics is observed

$\propto V_{cb} V_{us}^*$

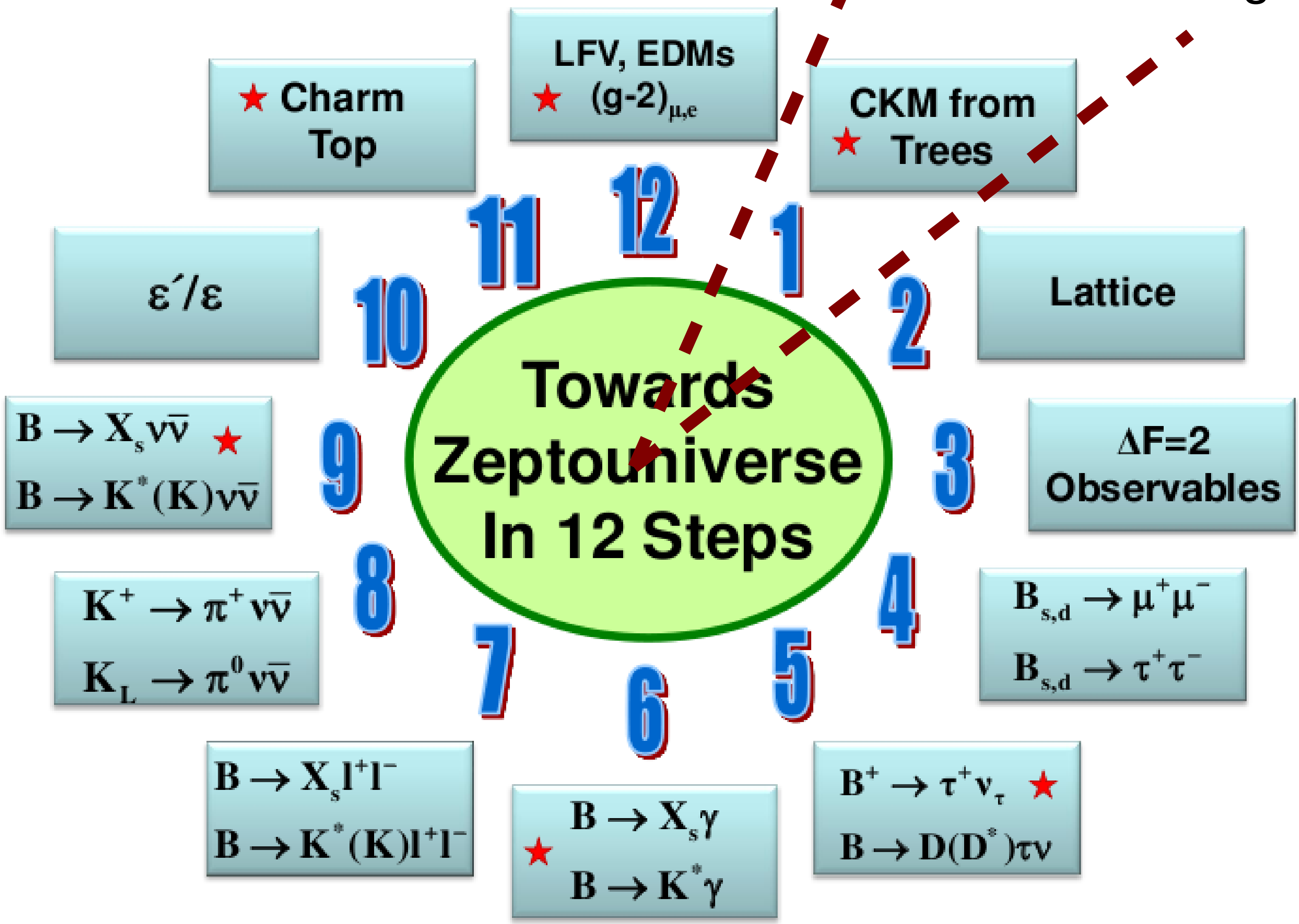




$\propto V_{ub} V_{cs}^*$

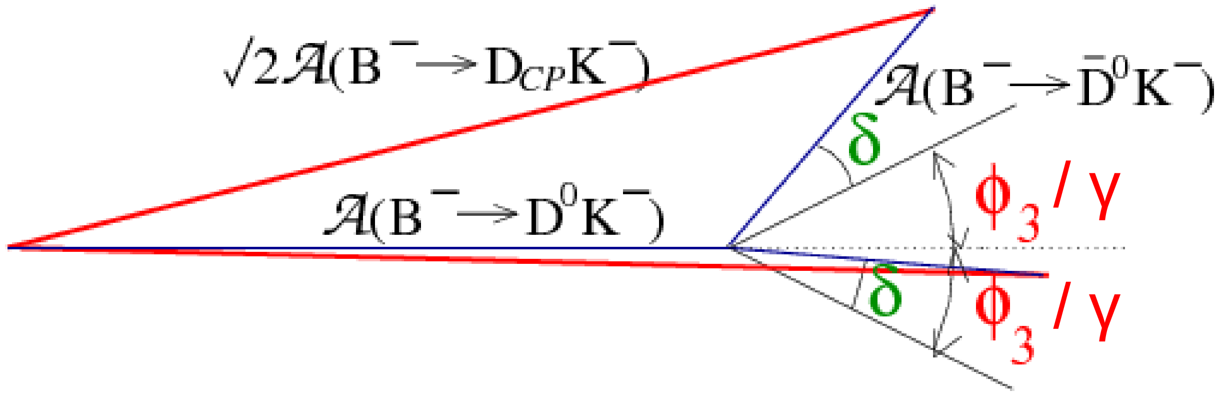
Variants use different B or D decays
require a final state common to both D^0 and $\bar{D}^0$

Essential to know the SM
before we can go beyond the SM



The GLW method

- Phys. Lett. B 253 (1991) 483, Phys. Lett. B 265 (1991) 172

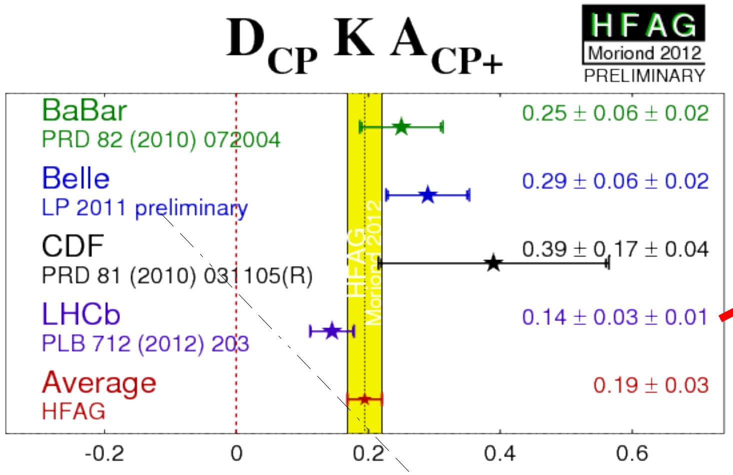


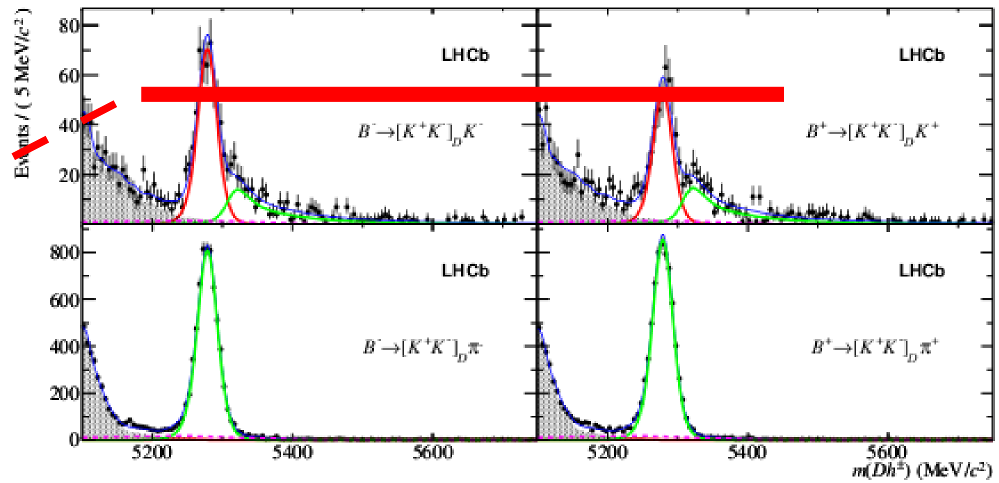
Common final state for D^0 and $\bar{D}^0$ – CP eigenstates

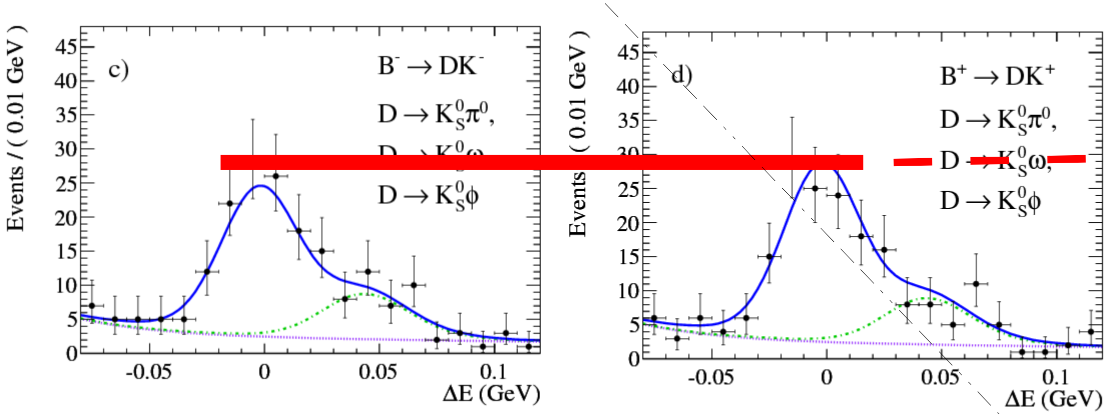
- CP even: K^+K^-, $\pi^+\pi^-$
- CP odd: $K_S\pi^0$, $K_s\eta$, $K_s\varphi$ (see later), $K_s\omega$

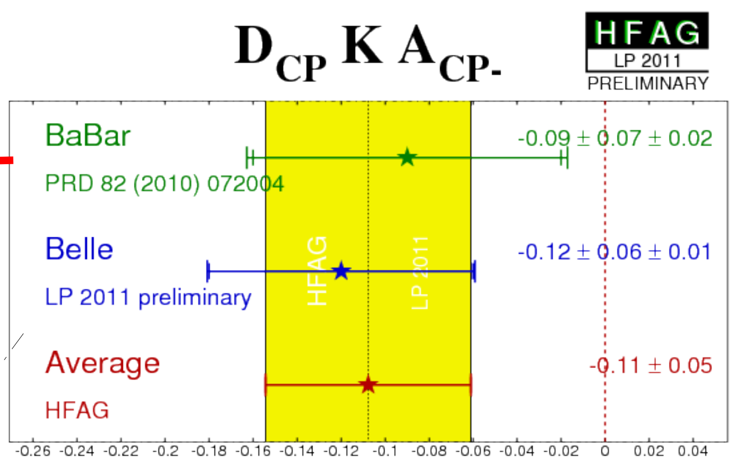
these are challenging for LHCb

GLW results





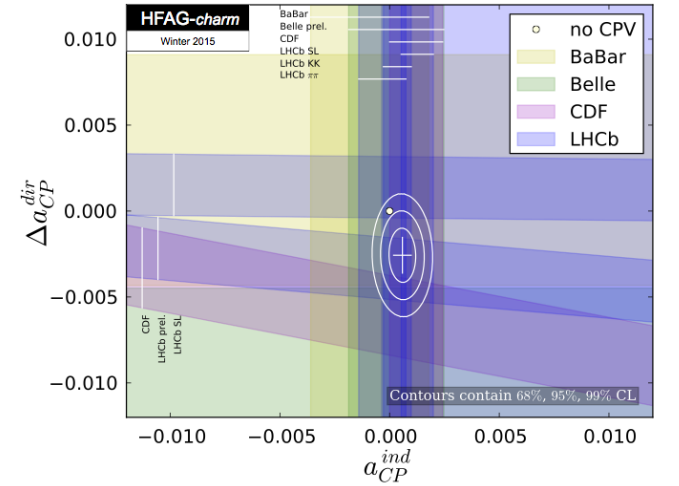




p.s. please publish these results!

Subtleties of GLW

- Over the last few years, considerable effort expended to understand how to deal with % level (or smaller) effects
  - Possible CPV in SCS D decays
    - → report results for K^+K^- and $\pi^+\pi^-$ separately
  - Charm mixing effects
    - → understand D decay-time acceptance effects
  - CPV/regeneration effects in K^0 system
    - → still negligible



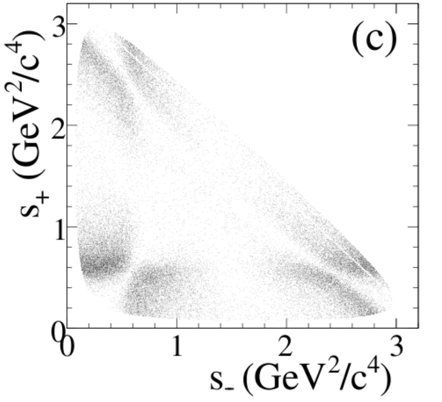
- The drive to control these effects has come from the desire to include results with B→Dπ (smaller r_B → larger subleading effects)
  - Even if B→ Dπ does not contribute much statistically to the γ combination, it is worth including to ensure control of systematic uncertainties

Can we use more D decays?

- GLW analyses to date have used
  - CP even
    - K^+K^-, $\pi^+\pi^-$
  - CP odd
    - $K_S\pi^0$, $K_s\eta$, $K_s\varphi$ (see later), $K_s\omega$
- No other experimentally accessible pure CP eigenstates ...
  - are there "quasi CP eigenstates"?
  - can we handle them with a "quasi GLW analysis"?

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

- Seminal Dalitz plot analysis from BaBar (PRL 99 (2007) 251801)
  - Gives the parameter $x_0 = 0.850$ (without uncertainty)
  - Relation to fractional CP-even content: $x_0 = 2F_+ - 1$



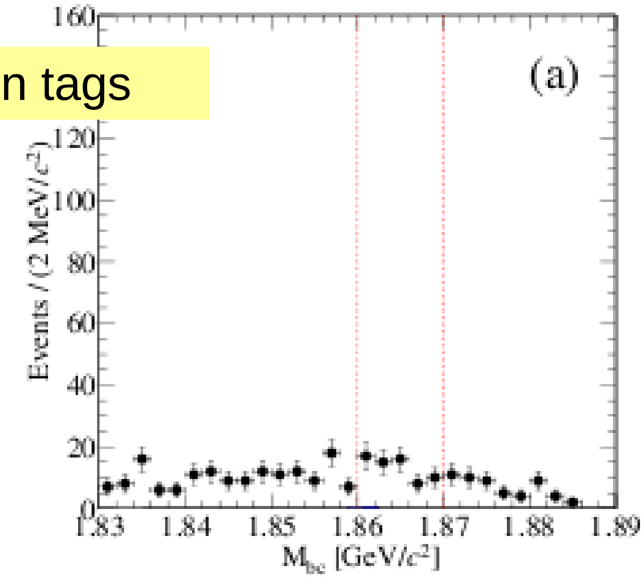
- Effect of CP-even dominance included in modified GGSZ-type analysis
  - Message that simpler quasi-GLW analysis gives good sensitivity was not clear
- Noted that decay is almost pure isospin 0 (PR D78 (2008) 014015)

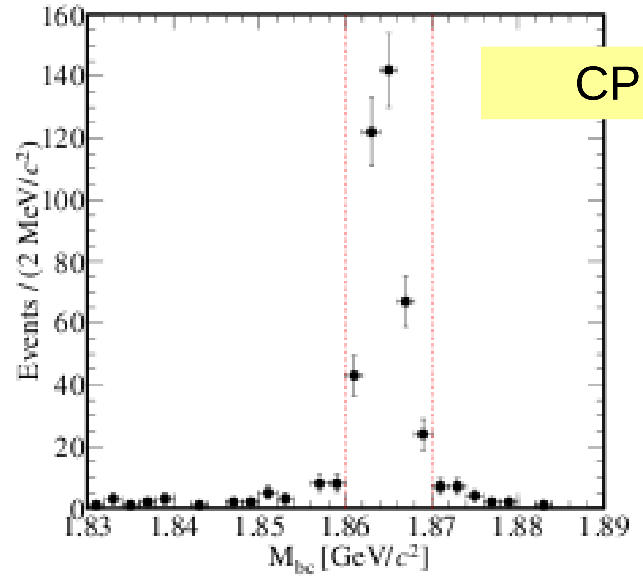
$D \to \pi^+\pi^-\pi^0$ with CLEO-c data

- Exploit $\Psi(3770) \to D\overline{D}$ decays for direct measurement of CP content
- PLB 740 (2015) 1, arXiv:1504.05878

$$F_+ = 0.973 \pm 0.017$$

CP-even tags





CP-odd tags

Aside on $D \to \pi^+\pi^-\pi^0$

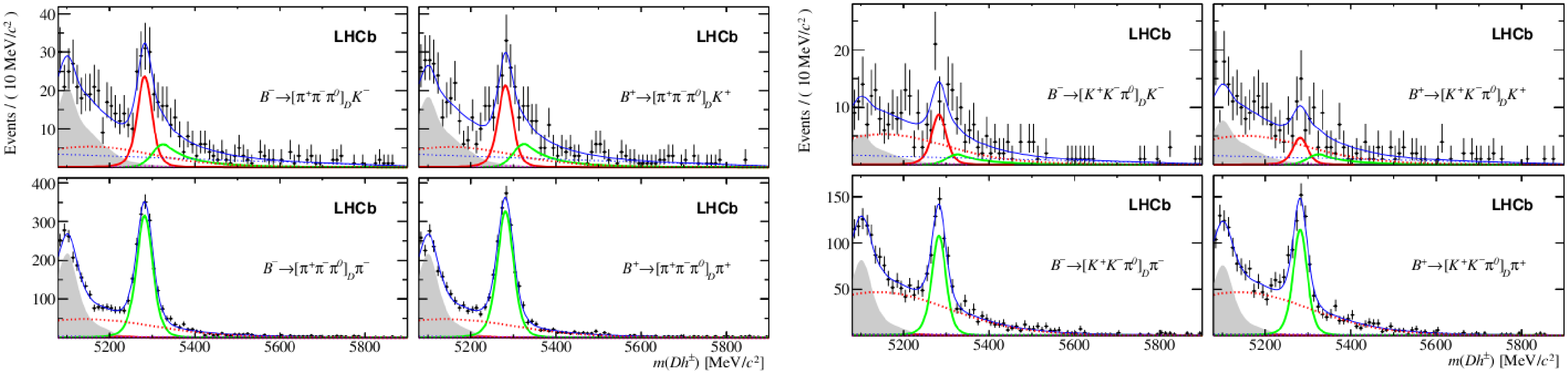
- It seems remarkable that $D \to \pi^+\pi^-\pi^0$ is so close to pure CP-even
  - no known a priori reason for this to be so
  - n.b. $K \to \pi^+\pi^-\pi^0$ is ~pure CP-odd (but this is understood)
- How about $B \to \pi^+\pi^-\pi^0$?
  - if this is almost pure CP-eigenstate, what happens to the Snyder-Quinn method to measure α?

Can we use more D decays?

- GLW analyses to date have used
  - CP even
    - K^+K^-, $\pi^+\pi^-$
    - $\pi^+\pi^-\pi^0$ ($F_+ = 0.973 \pm 0.017$), $K^+K^-\pi^0$ ($F_+ = 0.732 \pm 0.055$), $\pi^+\pi^-\pi^+\pi^-$ ($F_+ = 0.737 \pm 0.028$)
  - CP odd
    - $K_S\pi^0$, $K_s\eta$, $K_s\varphi$ (see below), $K_s\omega$
- Other 3 body modes have more complicated CP-content
  - $K_SK^+K^-$, $K_S\pi^+\pi^-$ both have $F_+ \sim 0 \rightarrow$ GGSZ analysis
  - n.b. $K_SK^+K^-$, has ~50% CP-odd ($K_s\varphi$) + ~50% CP-even (the rest)

First quasi-GLW analysis with $D \to \pi^+\pi^-\pi^0$ & $K^+K^-\pi^0$

- LHCb-PAPER-2015-014 (arXiv:1504.05442)
  - (see Sneha's talk for details)



Expect these modes to be useful for Belle II

Beyond $B \to DK$

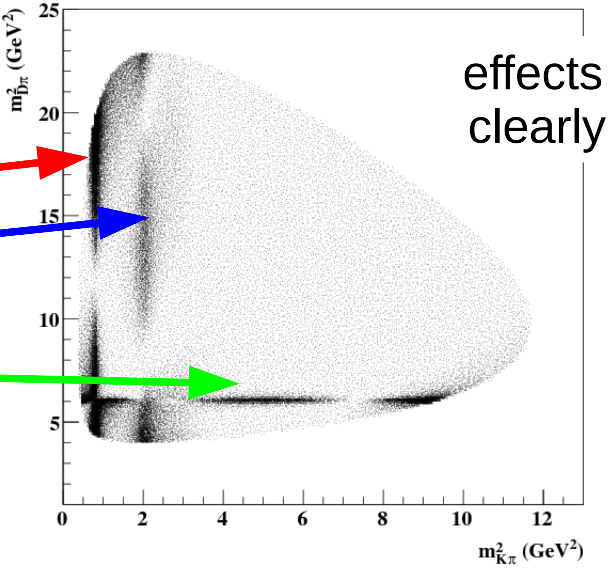
- Attractive feature of $B \to D^*K$
  - Effective CP-flip between $D^* \to D\pi^0$ and $D^* \to D\gamma$
    - PRD70 (2004) 091503
  - Additional sensitivity, but also necessitates good separation between the two D* decays
- Attractive feature of $B \to DK^{*0}$
  - Interference between D_2^* and K^{*0} resonances resolves ambiguities
    - PRD 79 (2009) 051301(R), PRD 80 (2009) 092002

Extension to B→DπK decays

TG PRD 79 (2009) 051301(R)
TG & M. Williams PRD 80 (2009) 092002

- Powerful extension of the method exploits additional sources of interference that occur in multibody decays
  - $B^0 \to D(\pi^- K^+)$ decays can have CP violation
  - $B^0 \to (D\pi^-)K^+$ decays have no CP violation
    - Provides ideal reference amplitude from which to determine relative phases via interference between different resonances on the Dalitz plot

Toy example containing
$K^*(892)^0$
$K_2^*(1430)^0$
$D_2^*(2460)^-$



effects of spin clearly visible

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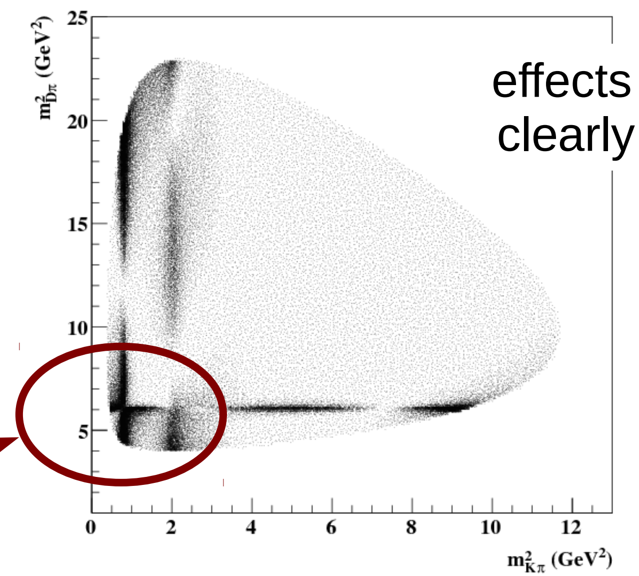

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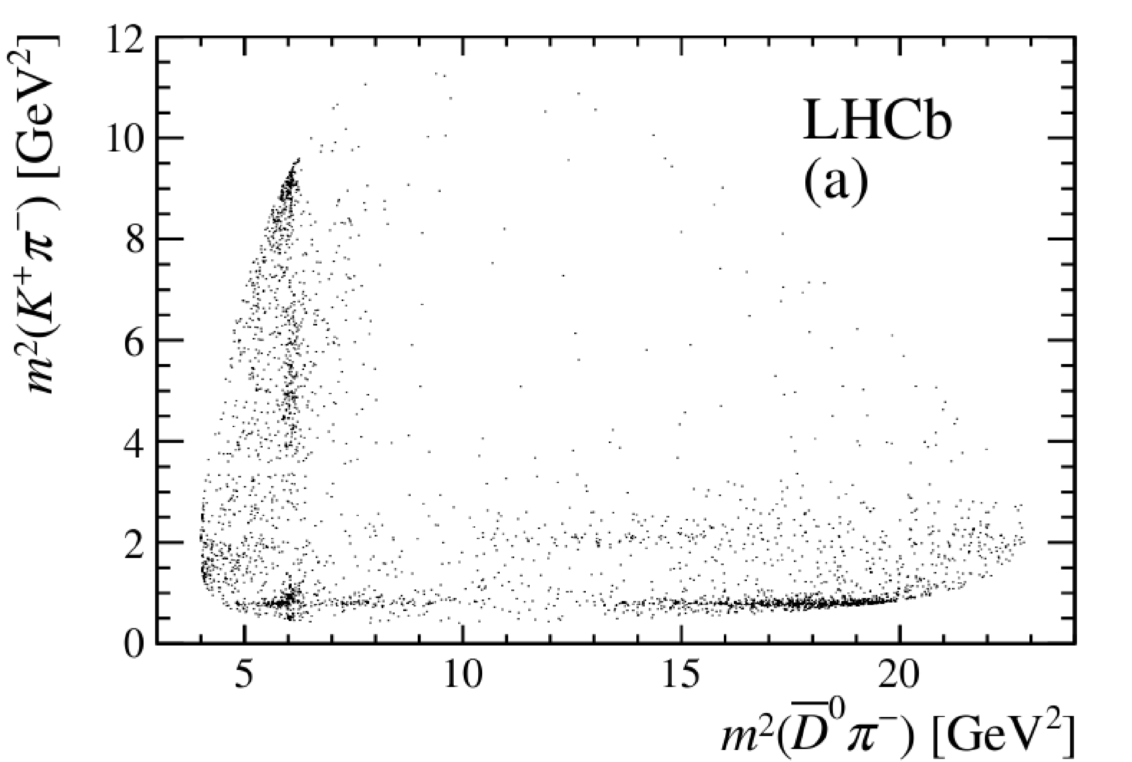
Interference region

B→DπK Dalitz plot

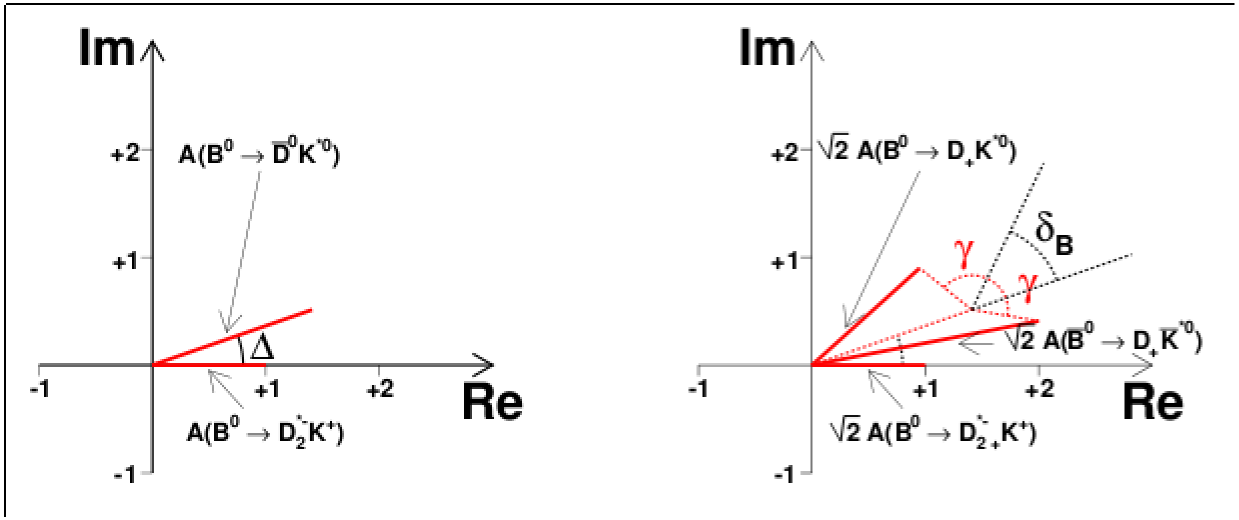
- LHCb-PAPER-2015-017 (arXiv next week)
  - use D→Kπ decays to determine Dalitz plot model for favoured b→c amplitude



n.b. axes flipped c.f. previous slides

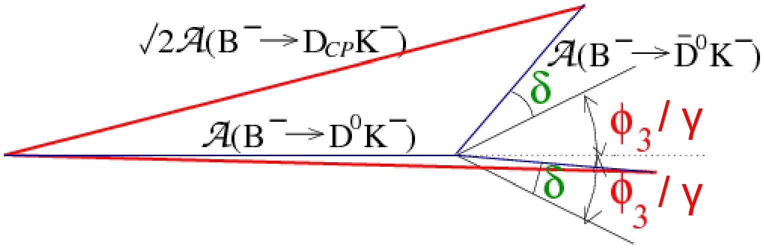
The B→DπK Dalitz plot method

D^0 flavour eigenstate



D^0 CP eigenstate

- Basic idea is that pion from D_2* decay tags flavour of that resonance
- Amplitude for $B^0 \rightarrow D_2$*K is same, independent of D decay used
- Allows direct reconstruction of GLW triangle
- How is the sensitivity?
  - PRD 80 (2009) 092002 claims similar to B→DK
  - will need to wait and see …
  - (n.b. r_B(DK*0) = $0.240^{+0.055}_{-0.048}$ – LHCb PRD 90 (2014) 112002)



Summary

- Despite many people thinking about γ for many years, there are still good new ideas emerging
- The best sensitivity comes from combining results from all of $B \rightarrow DK$ and friends
- Many channels make useful contributions
  - including several that I did not discuss today
  - still a lot of work (potential improvement) to arrive at ultimate precision on γ for both LHCb & Belle II
- Measurements from BESIII on $\Psi(3770) \rightarrow D\overline{D}$ are needed