CP Violation in the B System

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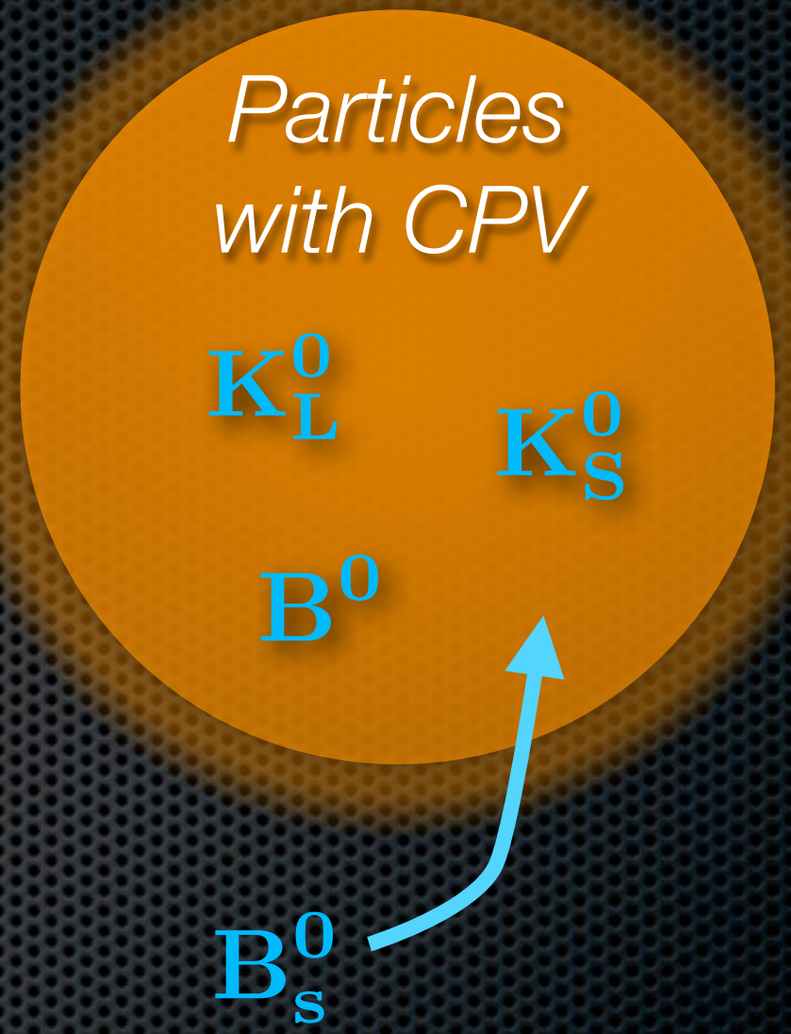
Outline

1. Introduction & LHCb
2. CPV in $B_s \to K\pi$ *New!*
3. CPV in $B_s \to J/\psi KK$: ϕ_s
4. CPV in $B^{\pm} \to DK$: γ
5. Conclusions

CP Violation

- CP Violation arises in the Standard Model as both direct and indirect
- Indirect CPV discovered in 1964 in neutral Kaons here at **Brookhaven**
- Direct CPV discovered also in neutral Kaons in the 90's at CERN and Fermilab
- Shortly thereafter CPV also discovered in B_d and B_u system by BaBar and Belle
- Currently CPV in B mesons is being studied
- CPV could explain the matter/anti-matter imbalance that we observe today



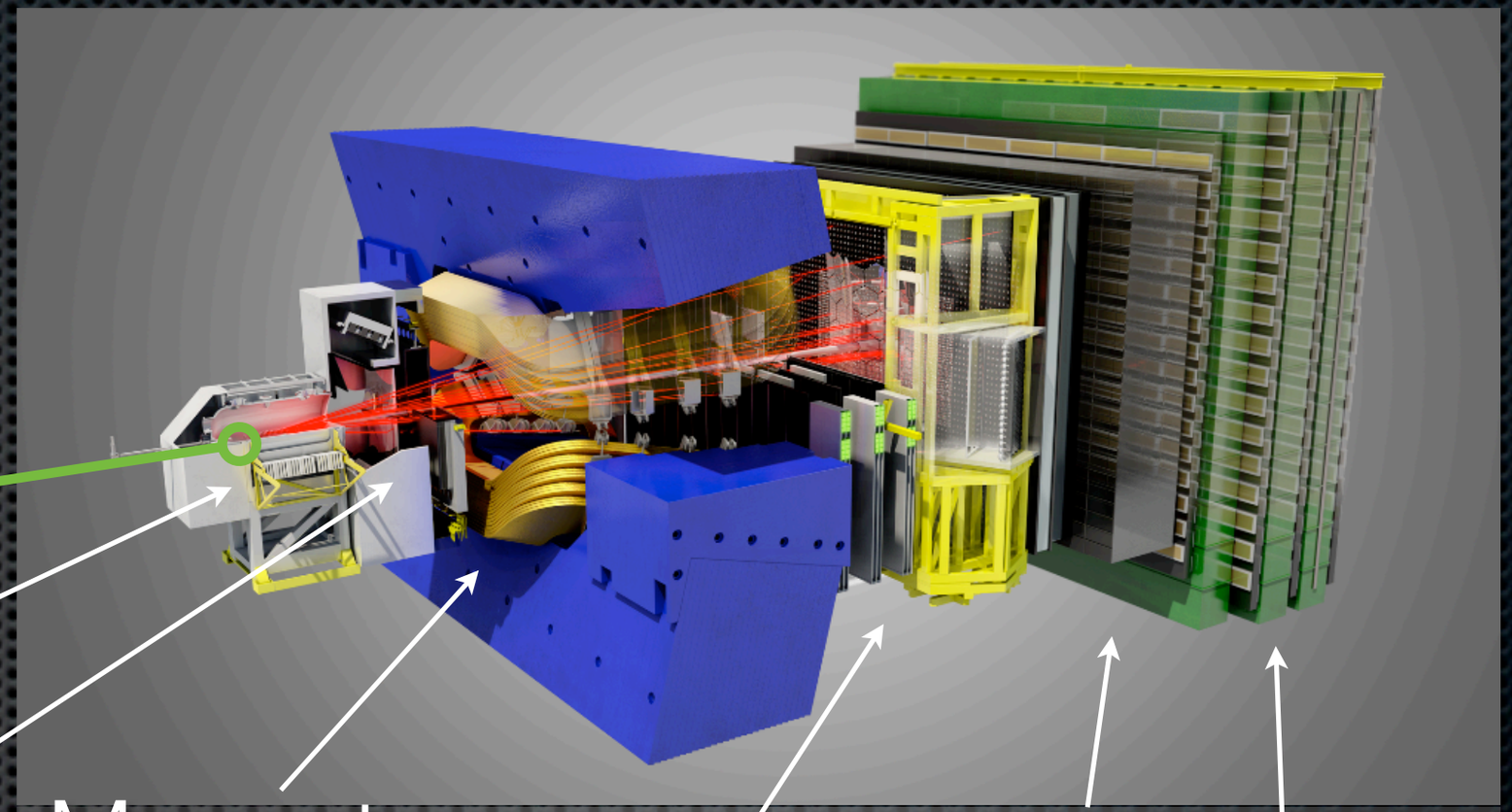
The LHCb Detector

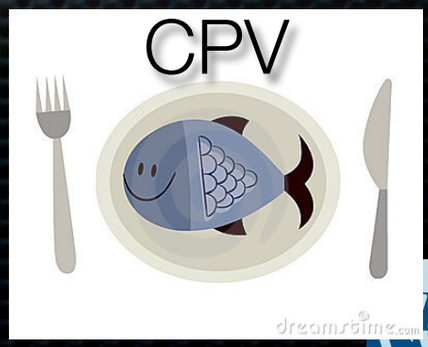
Now With 8 TeV

LHCb is a single arm spectrometer in the forward direction with PID

2011 dataset: 1 fb^{-1}, E_{cm} = 7 TeV, pp collisions at LHC

2012 dataset: 2 fb^{-1}, E_{cm} = 8 TeV, pp collisions at LHC



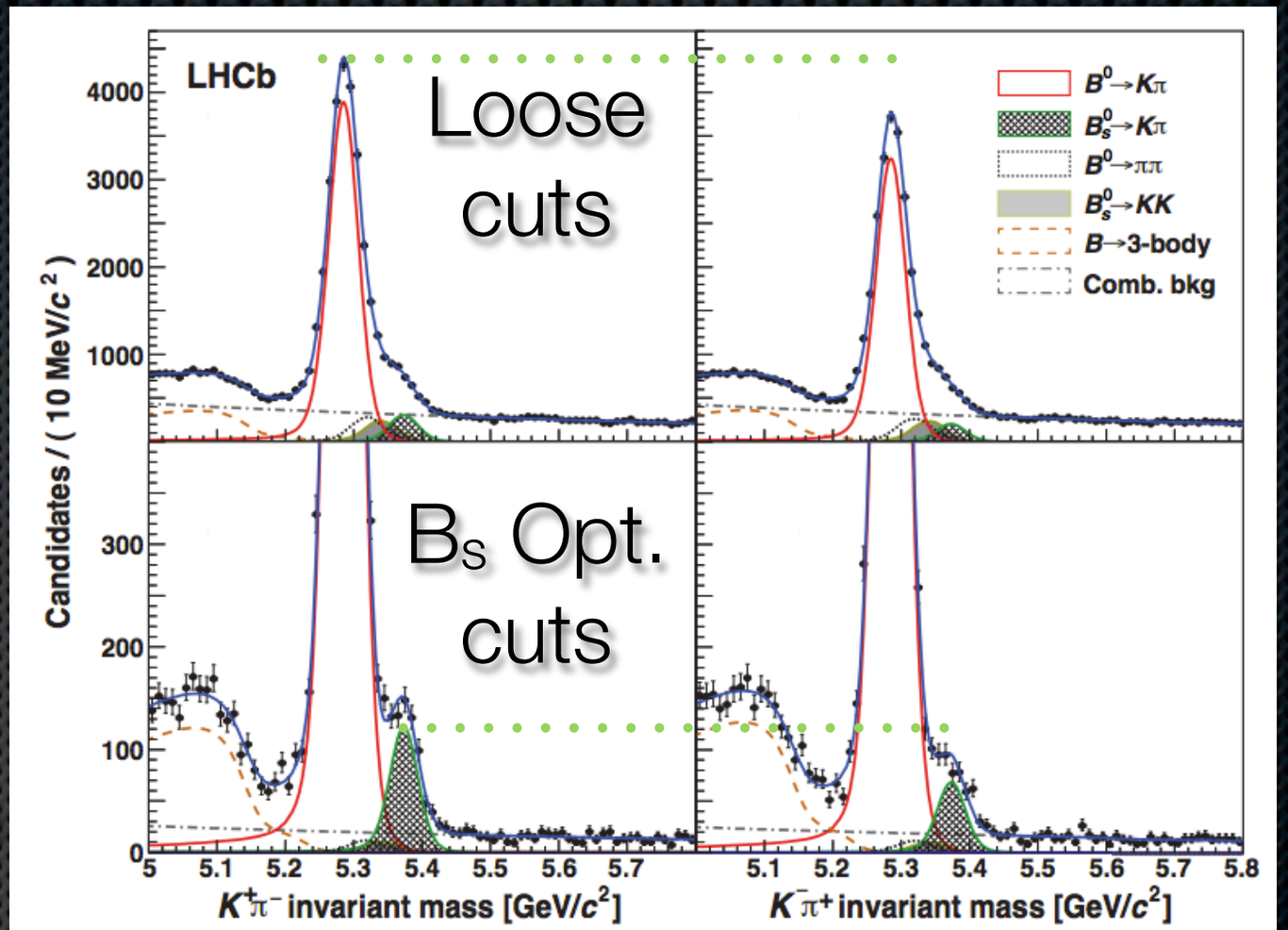


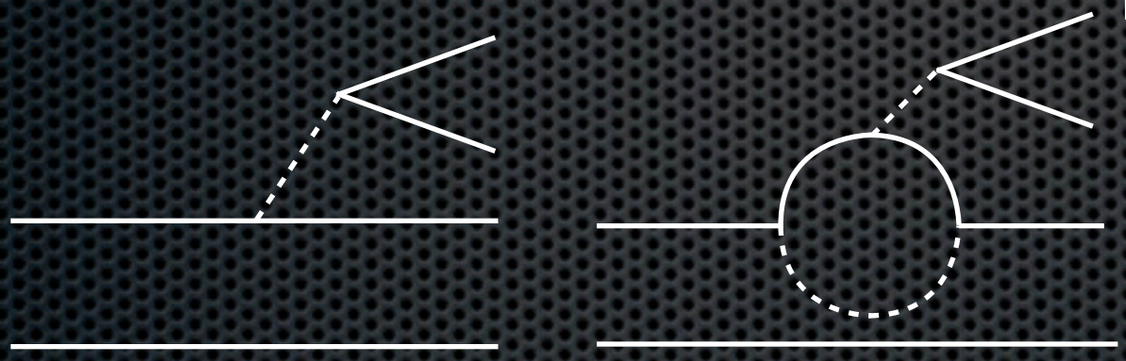
See Paras' or Tim's talk for more details

NEW

CPV in $B_s \to K\pi$

- ***First Observation*** of direct CPV in B_s mesons! (6.5σ)
- Also improved measurement of CPV for $B^0 \to K\pi$ (10.5σ)
- Expected CPV in B^0 and B_s is found, to experimental precision





Penguin and Tree diagrams contribute to this interference

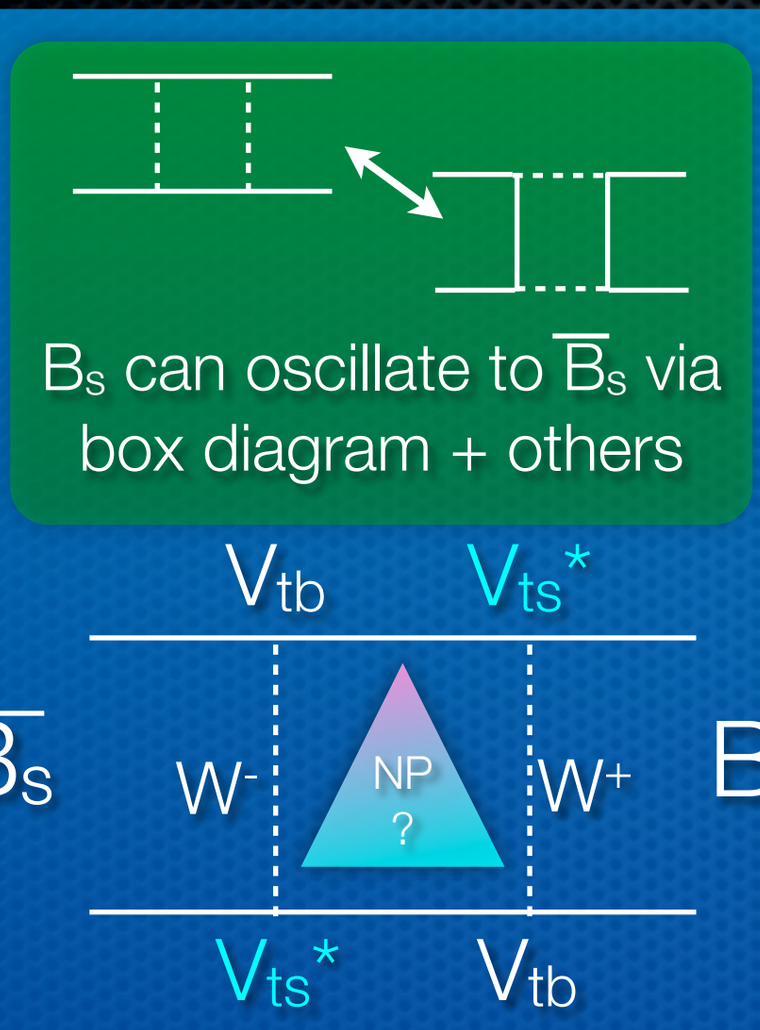
First Observation

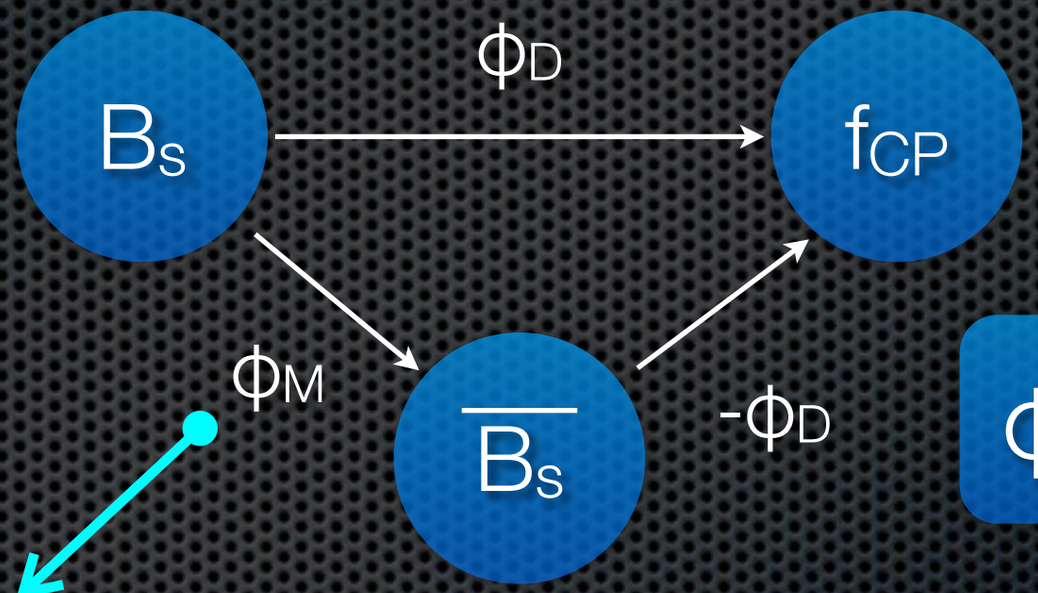
$$A_{CP}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.04(\text{stat}) \pm 0.01(\text{syst})$$

arxiv:1304.6173

ϕ_s from $B_s \to J/\psi(\mu\mu)\,\phi(KK)$

- The Standard Model makes a precise prediction of ϕ_s
- Mixing angle, ϕ_s, can be measured with the above decay





$\phi_s = \phi_M + 2\phi_D$

$$\phi_s^{SM} = -0.0364 \pm 0.0016\ \mathrm{rad}$$

Because the SM is so precise here, we are sensitive to the possibility of New Physics appearing

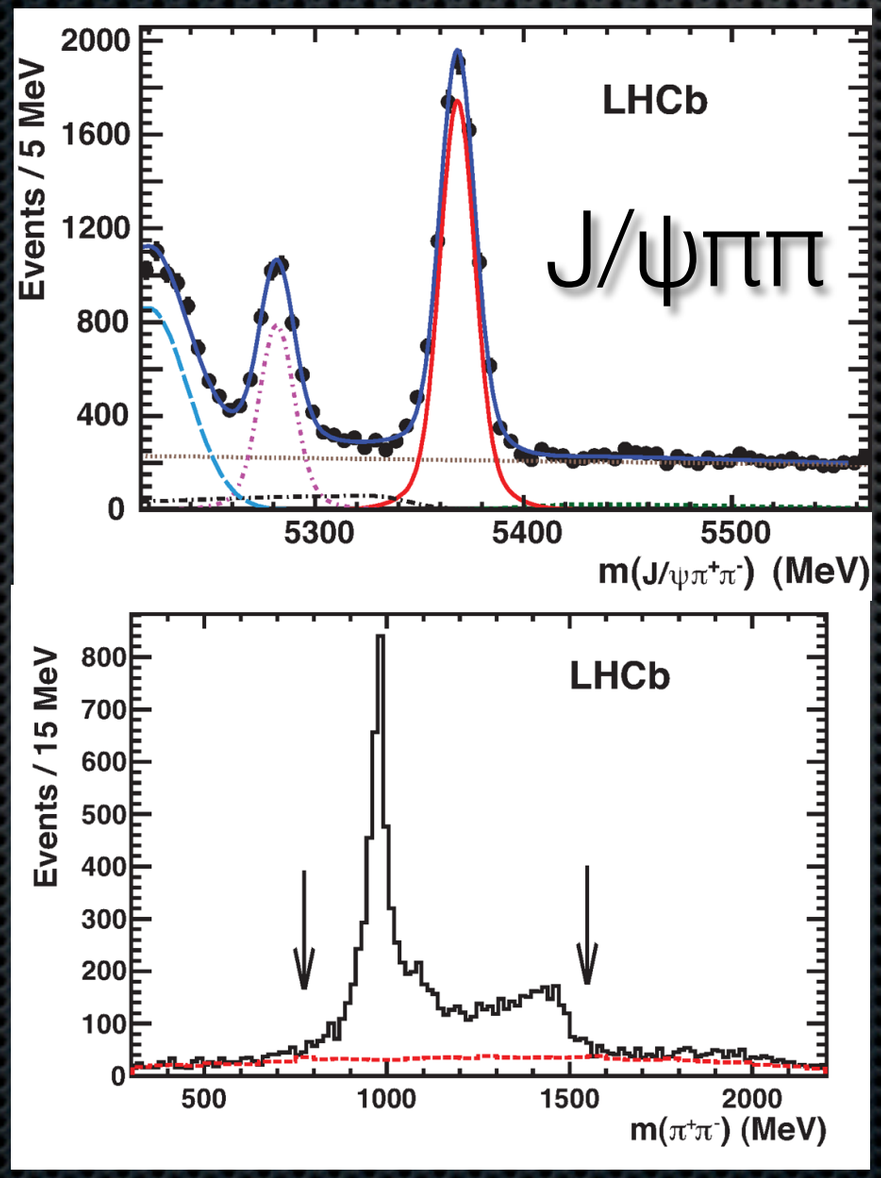
$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$

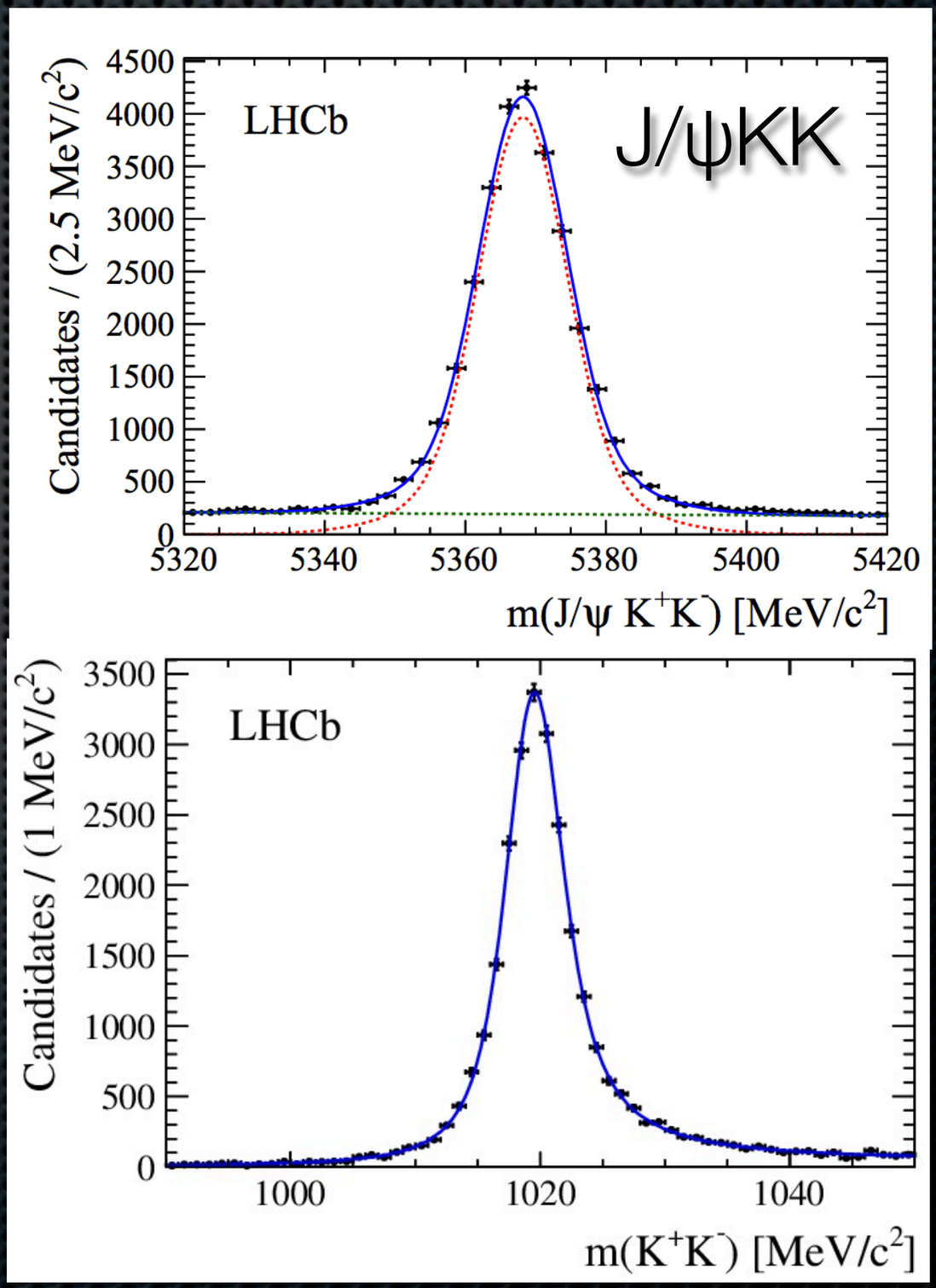
arXiv:1304.2600

ϕ_s from $B_s \to J/\psi$ hh

h=K or π

- Very clean measurement
- sPlot and multidimensional fit



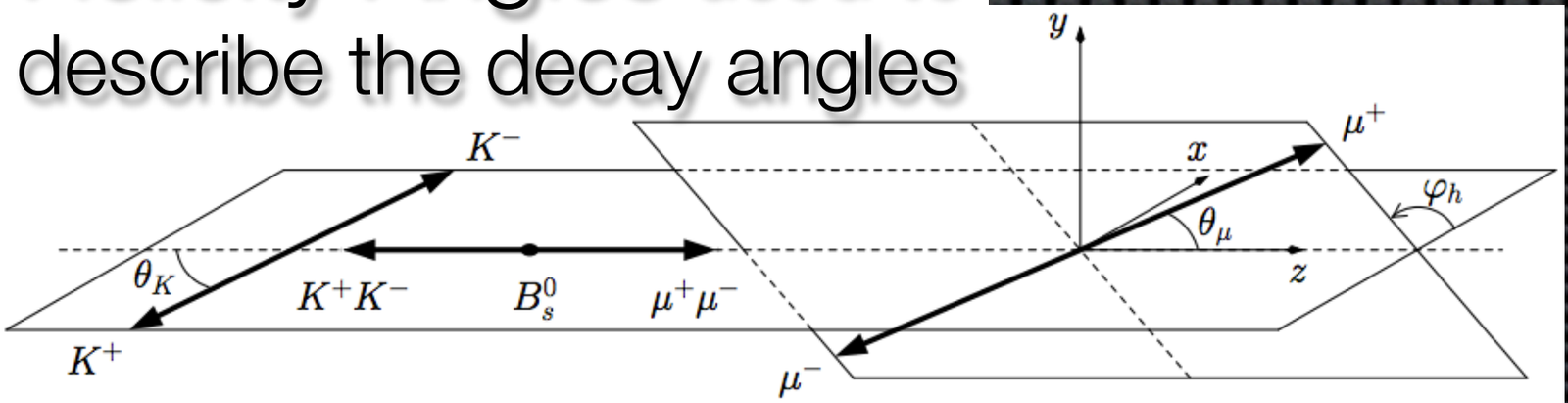


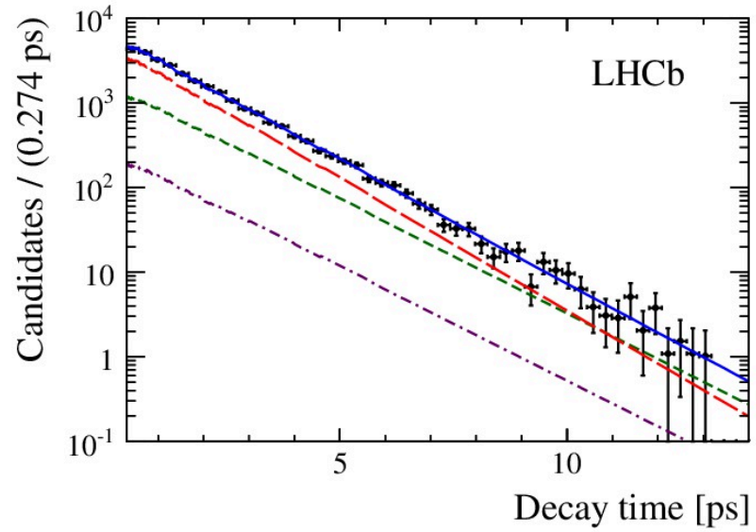
arXiv:1204.5675, arXiv:1304.2600

ϕ_s from $B_s \to J/\psi\, hh$

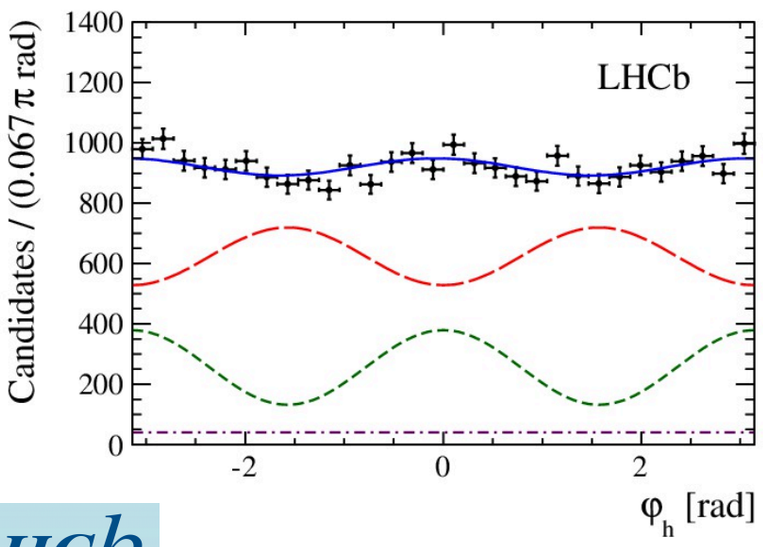
- Signal PDF is a function of decay time and helicity angles
- VV final state

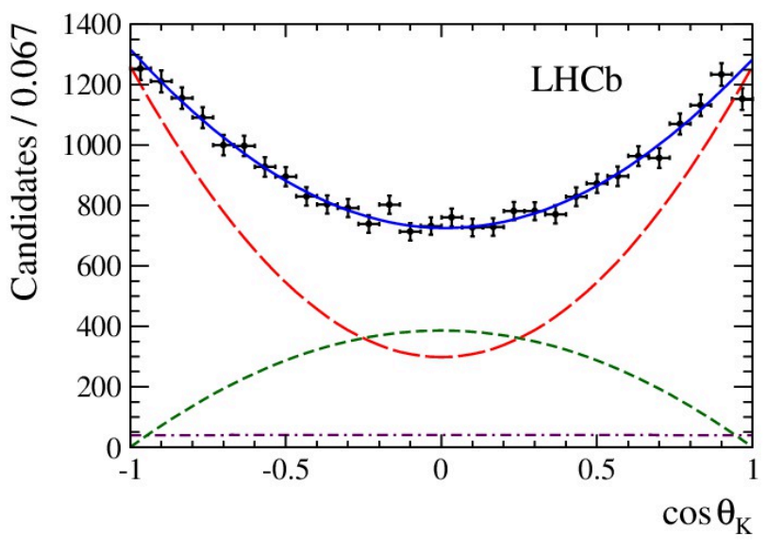
Helicity Angles used to describe the decay angles

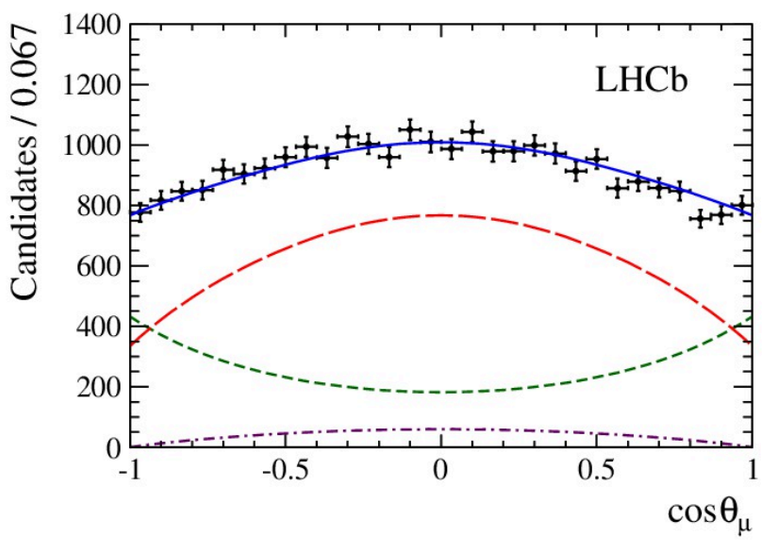




CP-odd CP-even S-wave





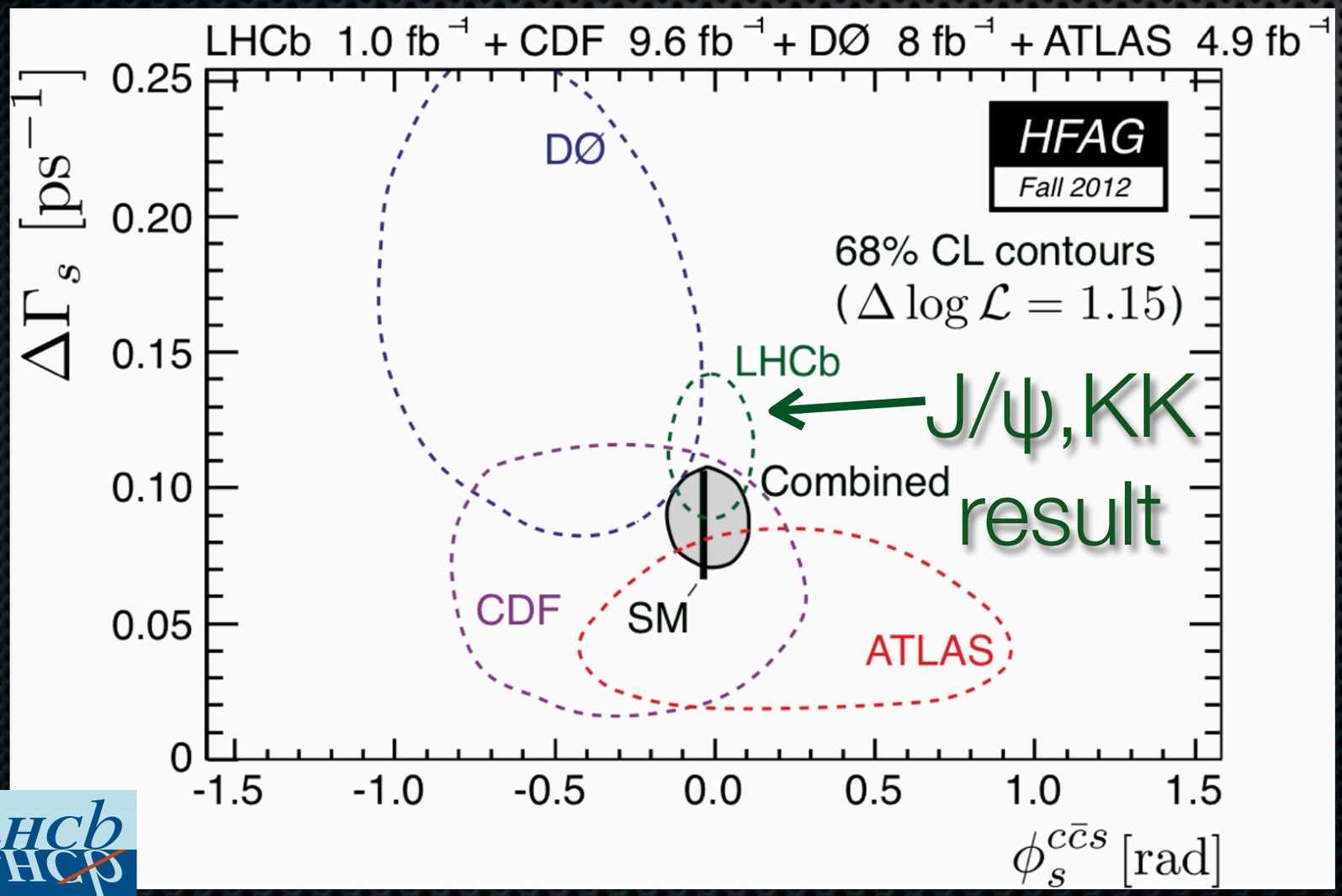


arXiv:1304.2600

$B_s \to J/\psi\, hh$ Results

Combined KK & ππ results

$$\begin{aligned}
\phi_s &= 0.01 \pm 0.07\ (\text{stat}) \pm 0.01\ (\text{syst})\ \text{rad},\\
\Gamma_s &= 0.661 \pm 0.004\ (\text{stat}) \pm 0.006\ (\text{syst})\ \text{ps}^{-1},\\
\Delta\Gamma_s &= 0.106 \pm 0.011\ (\text{stat}) \pm 0.007\ (\text{syst})\ \text{ps}^{-1}.\\
|\lambda| &= 0.93 \pm 0.03\,(\text{stat}) \pm 0.02\,(\text{syst})
\end{aligned}$$

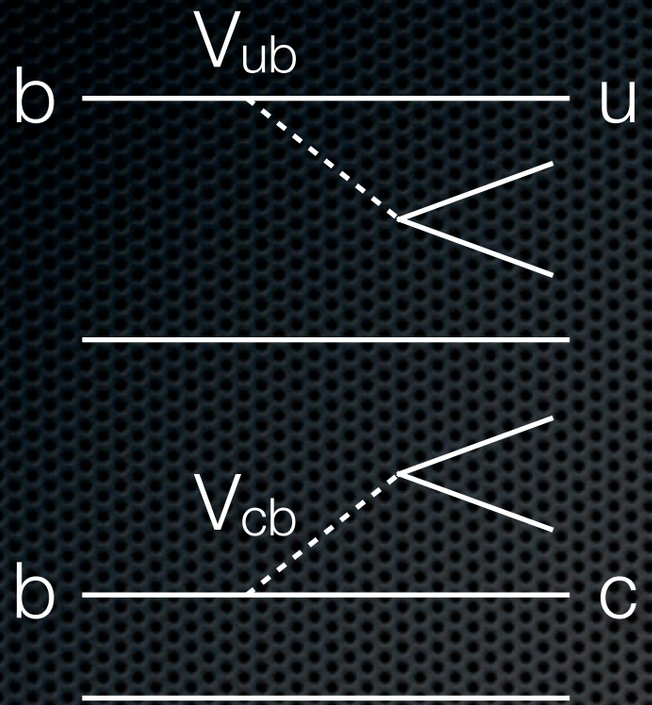


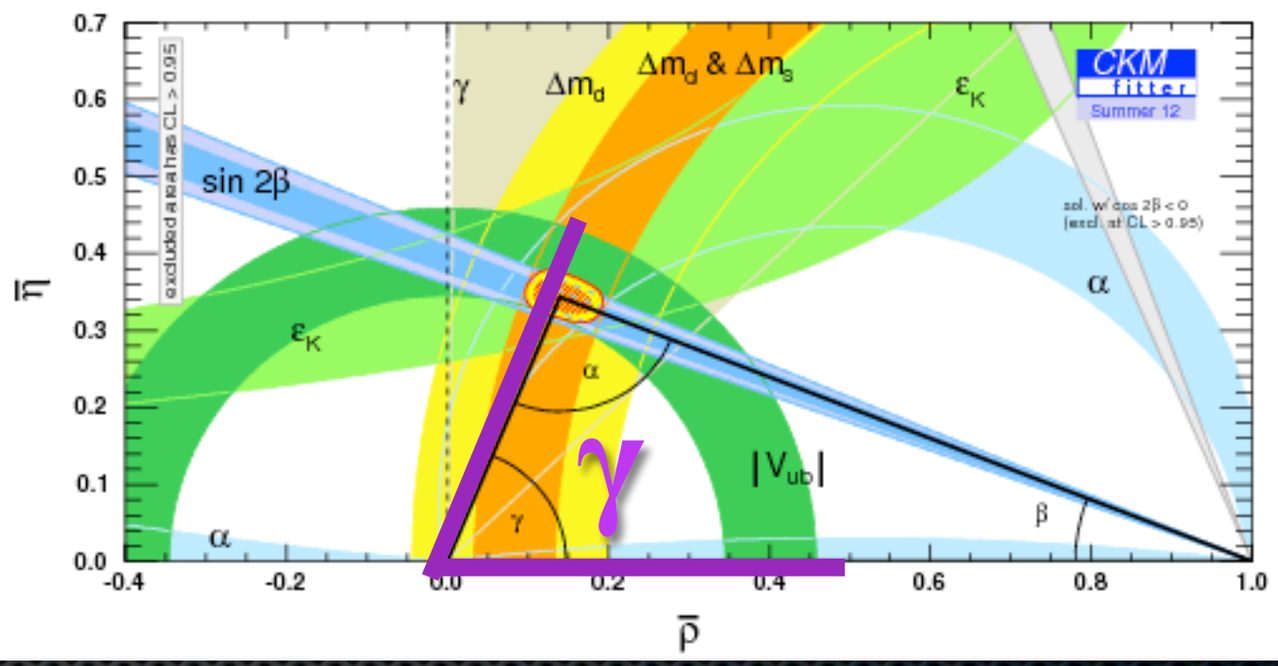
Systematics:
ϕ_s: angular acceptance
$\Delta\Gamma$: bkg, t acceptance

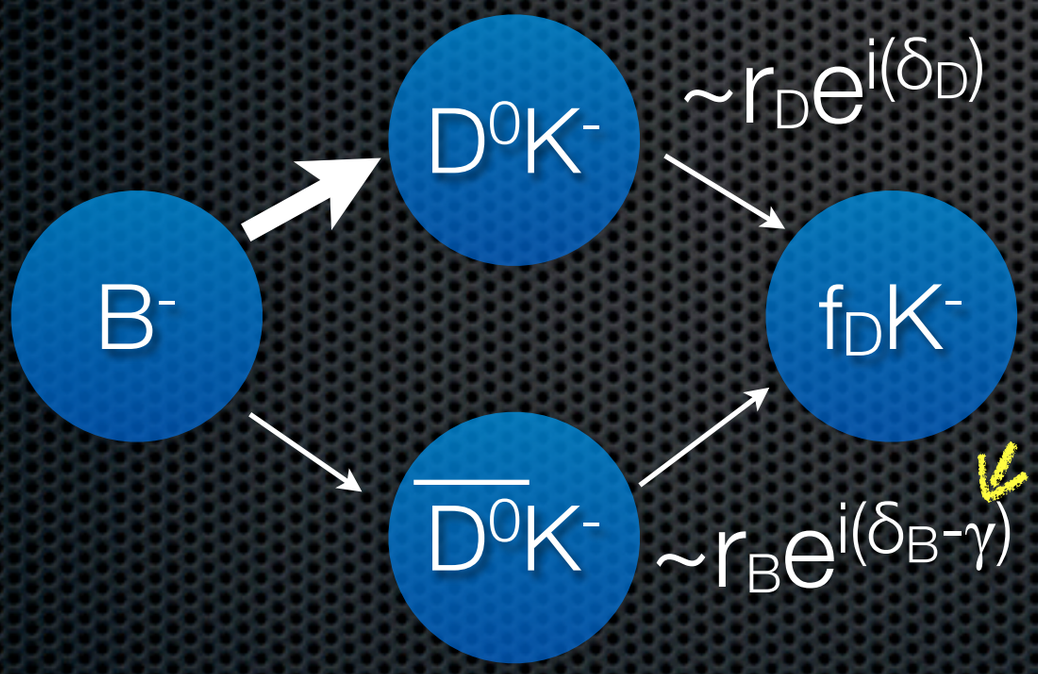
Compatible with no CP Violation in decay

arXiv:1304.2600

Measuring γ in $B^- \to D^0 h$ decays







$$f_D = D^0 \to K^+\pi^-, K^-\pi^+, KK, \pi\pi,$$
$$K_s\pi\pi, K_sKK, K\pi\pi\pi$$

Gronau, London, Wyler (GLW)
f_D = KK, ππ (CP eigenstate) [1]

Atwood, Dunietz, Soni (ADS)
f_D = Kπ, πK, Kππ [2]

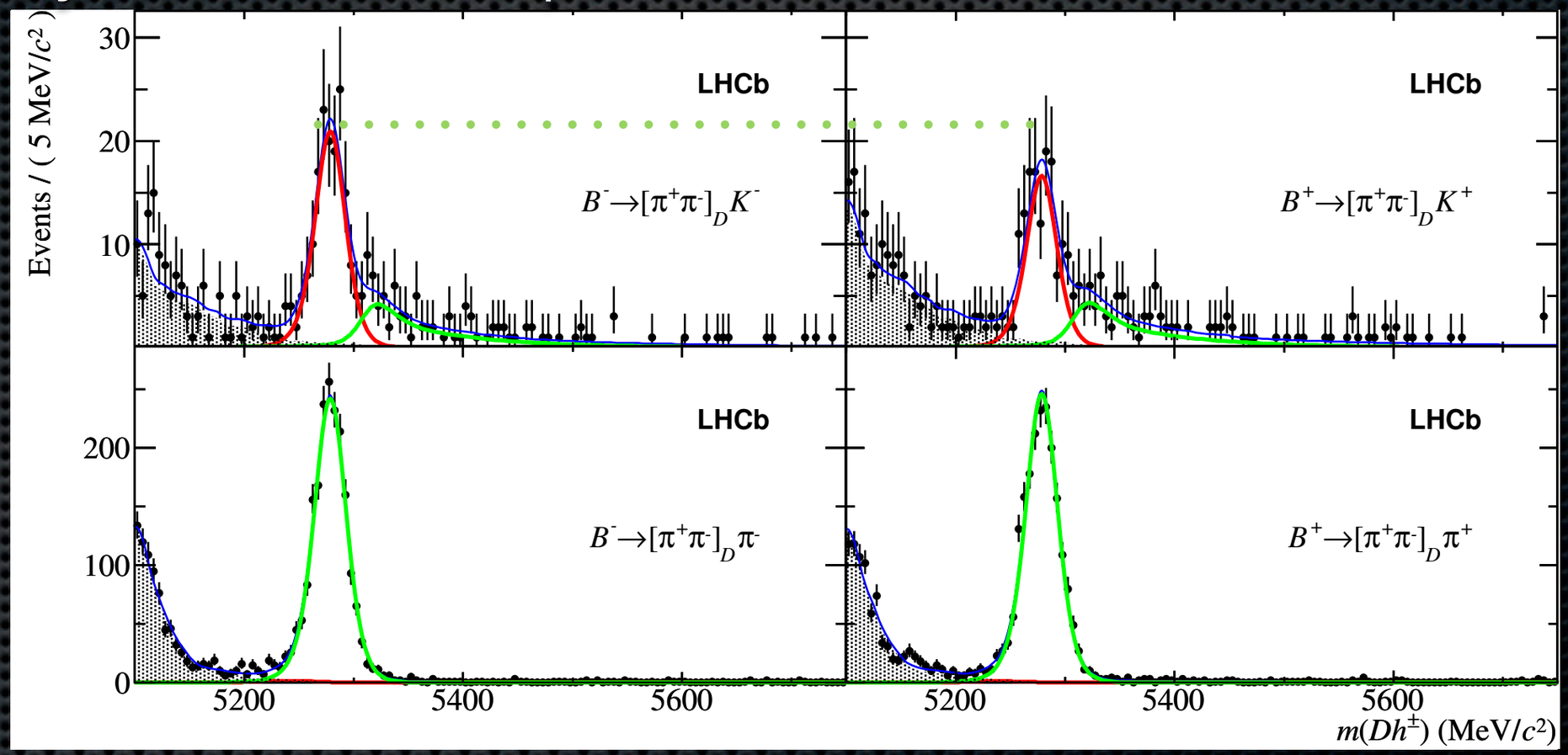
Giri, Grossman, Soffer, Zupan [3]
(GGSZ), Self conjugated Dalitz modes, $K_s$hh

[1] Phys Lett B265 (1991) 172
[2] Phys Rev Lett 78 (1997) 3257
[3] Phys Rev D68 (2003) 054018

GLW&ADS: $B \to D^0(hh)h$

- Simultaneously fit to 16 B mass plots to extract the ratios ($B^- \to D^0K^-/B^- \to D^0\pi^-$), and charge asymmetries (B^+/B^-)
- 7 ratios + 6 asymmetries: 13 parameters

GLW
f_D=KK,ππ



$$A_{CP+} = 0.145 \pm 0.032 \pm 0.010$$

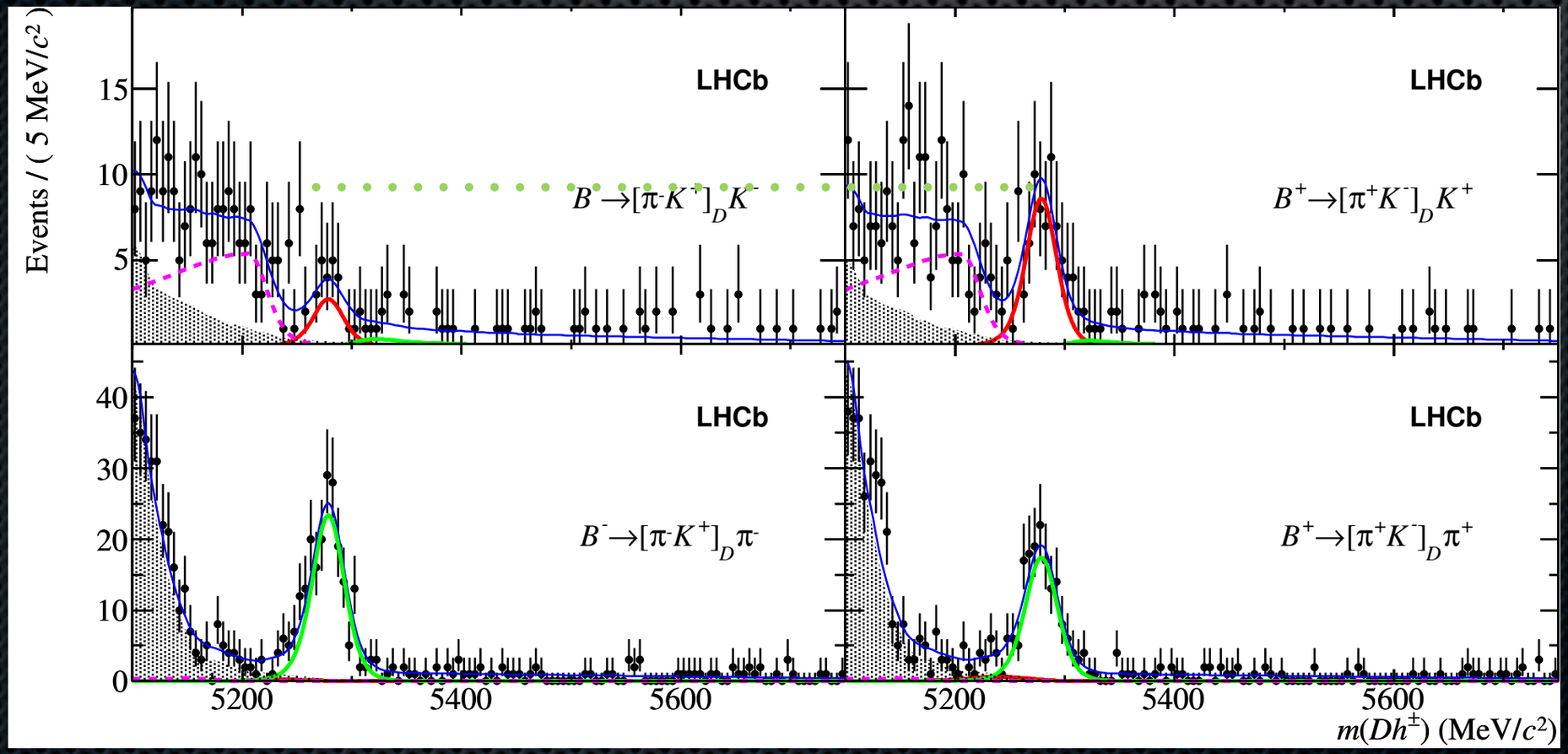
Direct CPV (5.8σ)

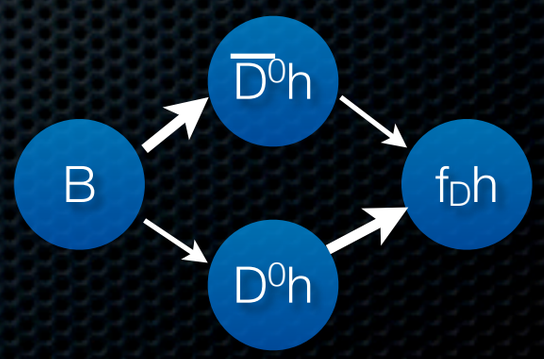
LHCb-PAPER-2012-001

ADS: $B^- \to D^0(K\pi)h^-$

- $D^0 \to K^-\pi^+$ is doubly Cabibbo suppressed
- ~100 candidates in 1 fb^{-1} of data (~10σ)

$$A_{ADS(K)} = -0.52 \pm 0.15 \pm 0.02$$





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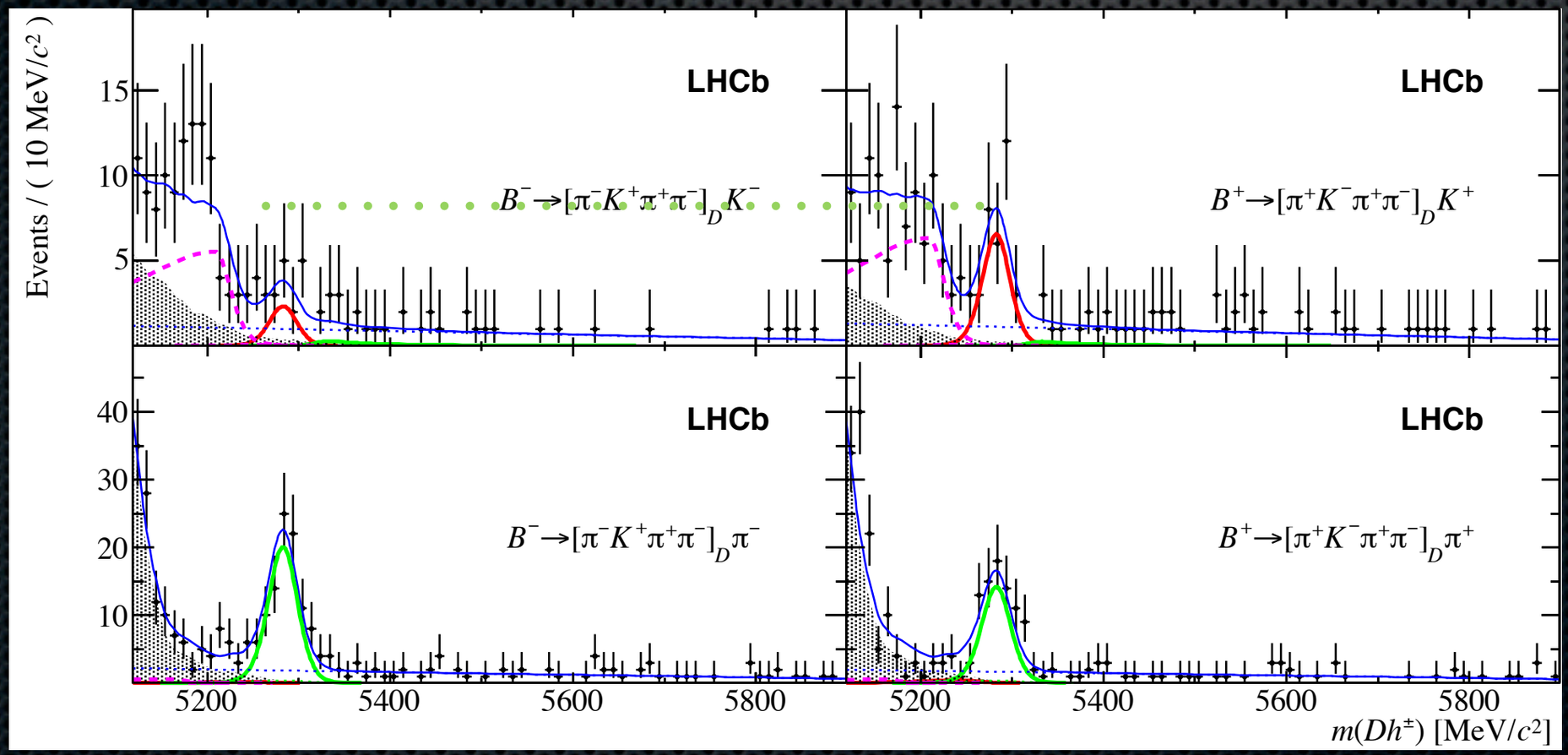
ADS: $B^- \to D^0(K\pi\pi\pi)h^-$

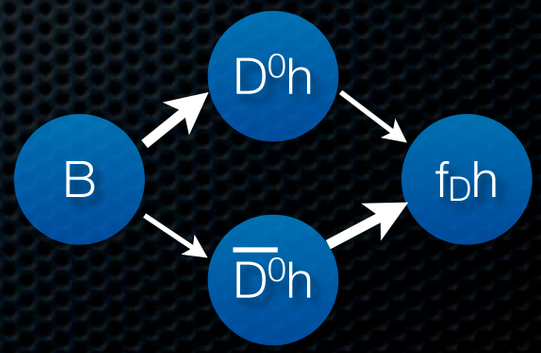
- ***First Observation*** of these decays (5.1σ)
- Measure CP asymmetries and ratios

$$r_B^K = 0.097 \pm 0.011$$



~40 candidates

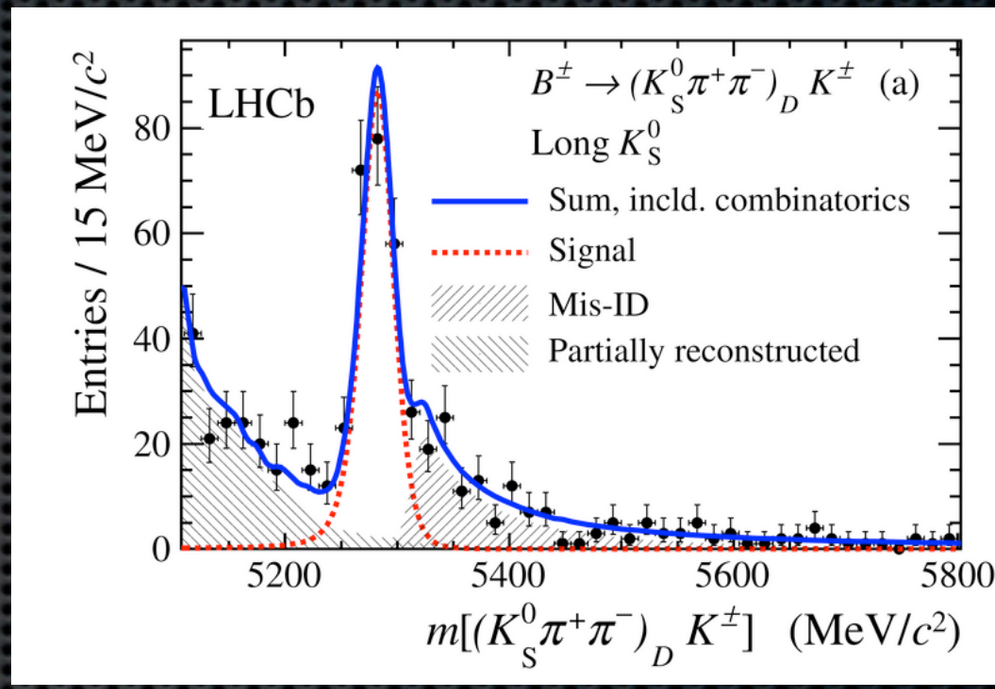
ADS
f_D=Kπππ,πKππ

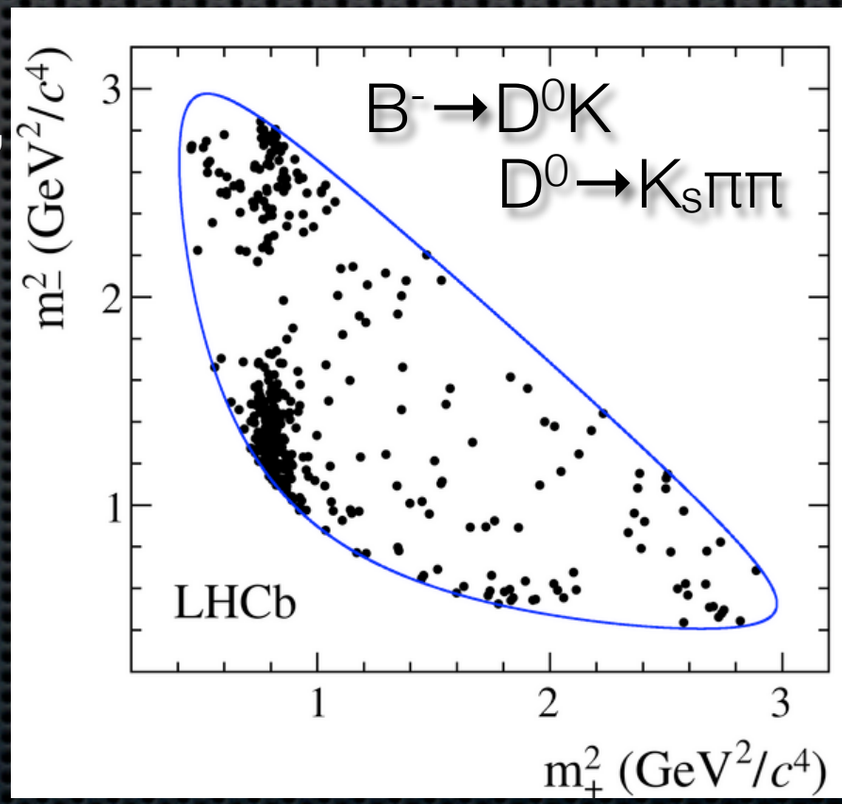


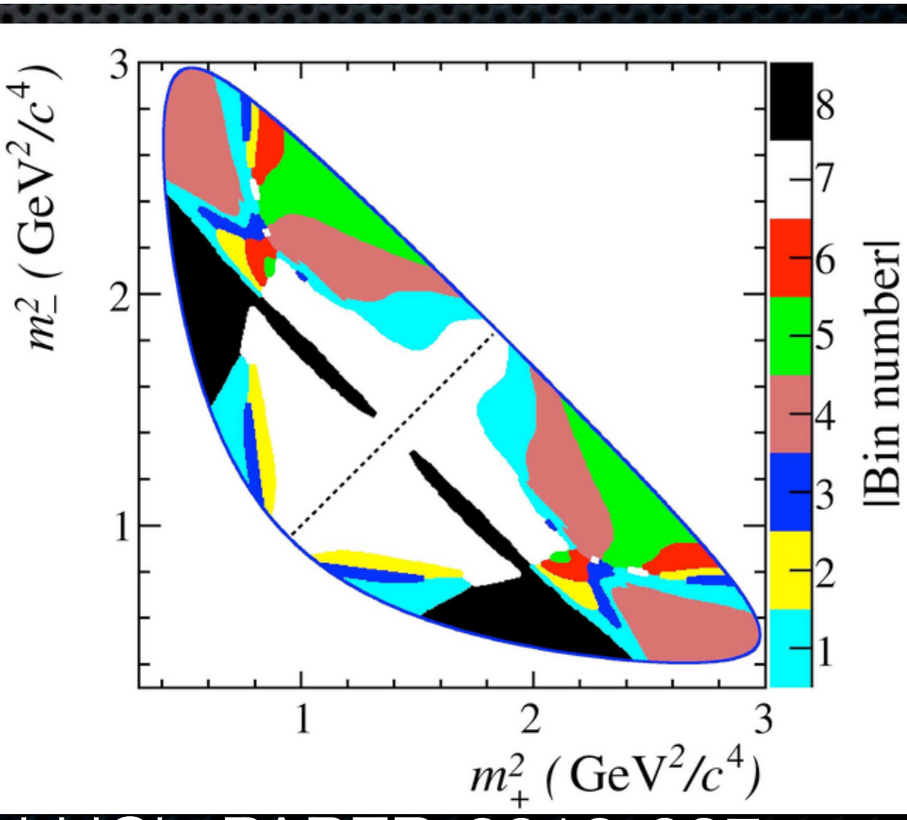
arxiv.org:1303.4646

GGSZ: $B \to D^0(K_s hh)h$

- Model independent, making no assumptions about strong phase in D decay, uses CLEO-c measurement of this as an input
- Binned Dalitz analysis
- $K_s\pi\pi$ Dalitz plane divided into 8x2 bins, K_sKK into 2x2 bins
- Fit for ratios and asymmetry parameters







LHCb-PAPER-2012-027

Combined $B \to D^0 h$ results

- Frequentist statistical approach used to combine the measured observables from $B \to DK$ analyses
- Assume Gaussian uncertainties of input observables

$B \to D^0 K$

GLW/ADS

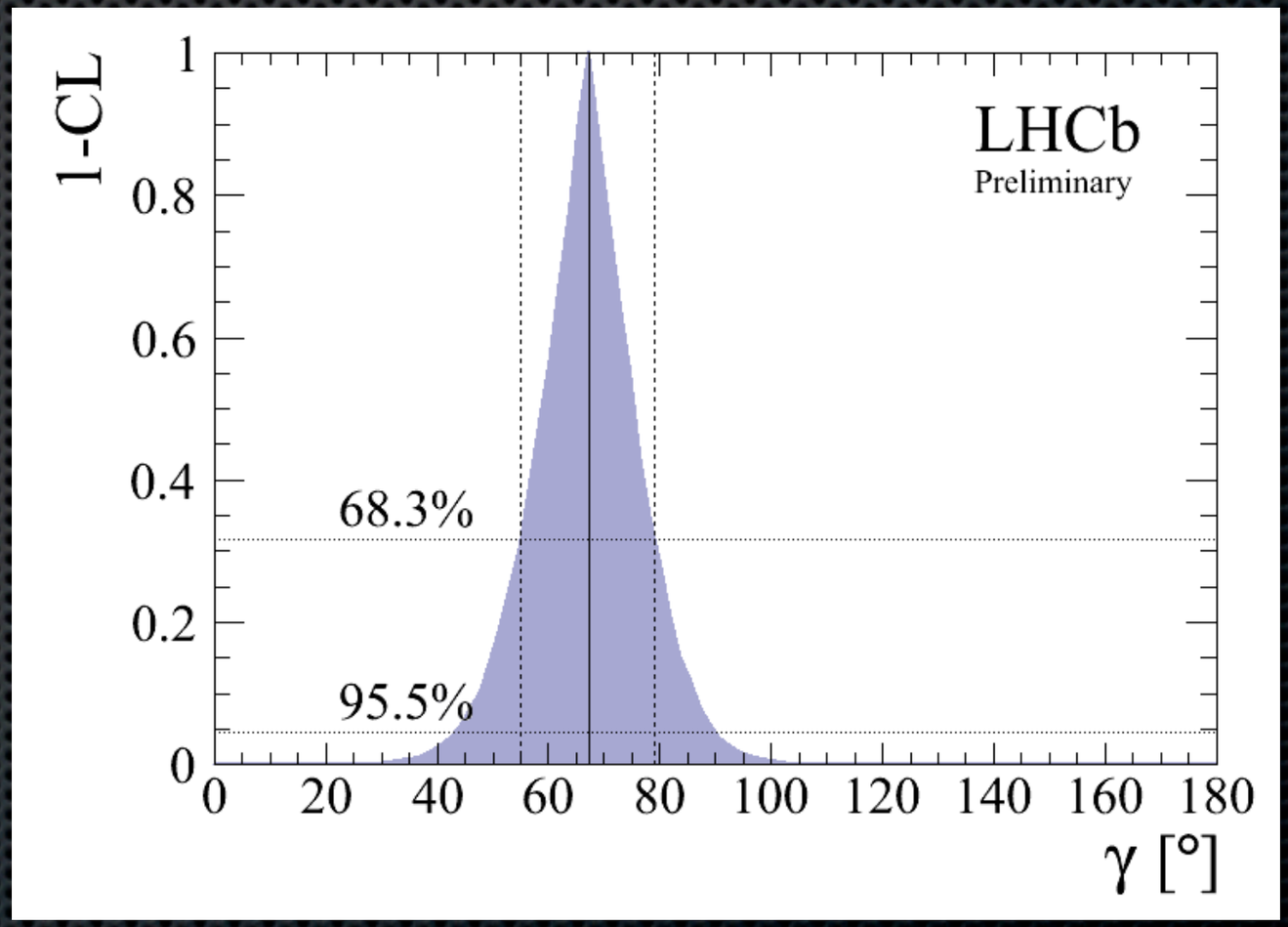
$D^0 \to KK, \pi\pi, K\pi$

ADS

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

GGSZ

$D^0 \to K_S\pi\pi$



$$\langle \gamma \rangle = 67^\circ \pm 12^\circ$$

LHCb-CONF-2013-006

Conclusions, Looking Forward

- ϕ_s measured as 0.01±0.07±0.01 rad.
- γ measured as 67°±12°
- *NEW* First Observation of Direct CPV in B_s^0 decays
- 2011 data set is analyzed, 1 fb^{-1}
- 2012 data set is being analyzed now, an additional 2 fb^{-1}
- What's next? More Data, More Modes, *Exciting Results!*
- *See also talks by Tim, Paras, and Cédric*

Thank you!