Charming Hadronic Decays of b Hadrons

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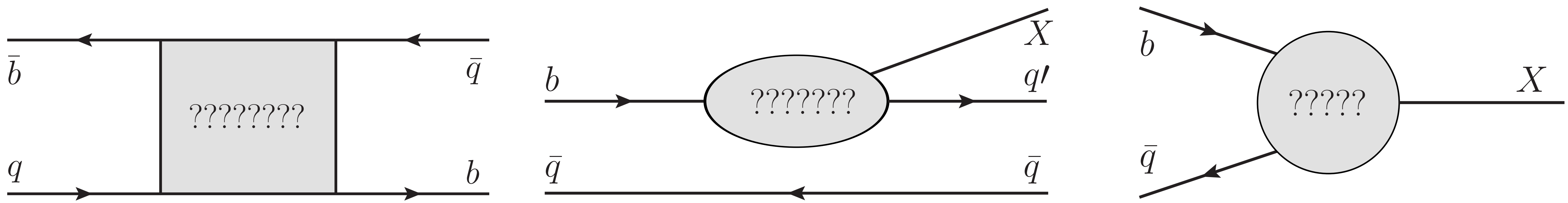
*on behalf of the LHCb collaboration

LHCb Overview

LHCb is performing precise tests of the SM, and searching for physics beyond the SM, by studying rare and CP-violating decays of b and c hadrons.

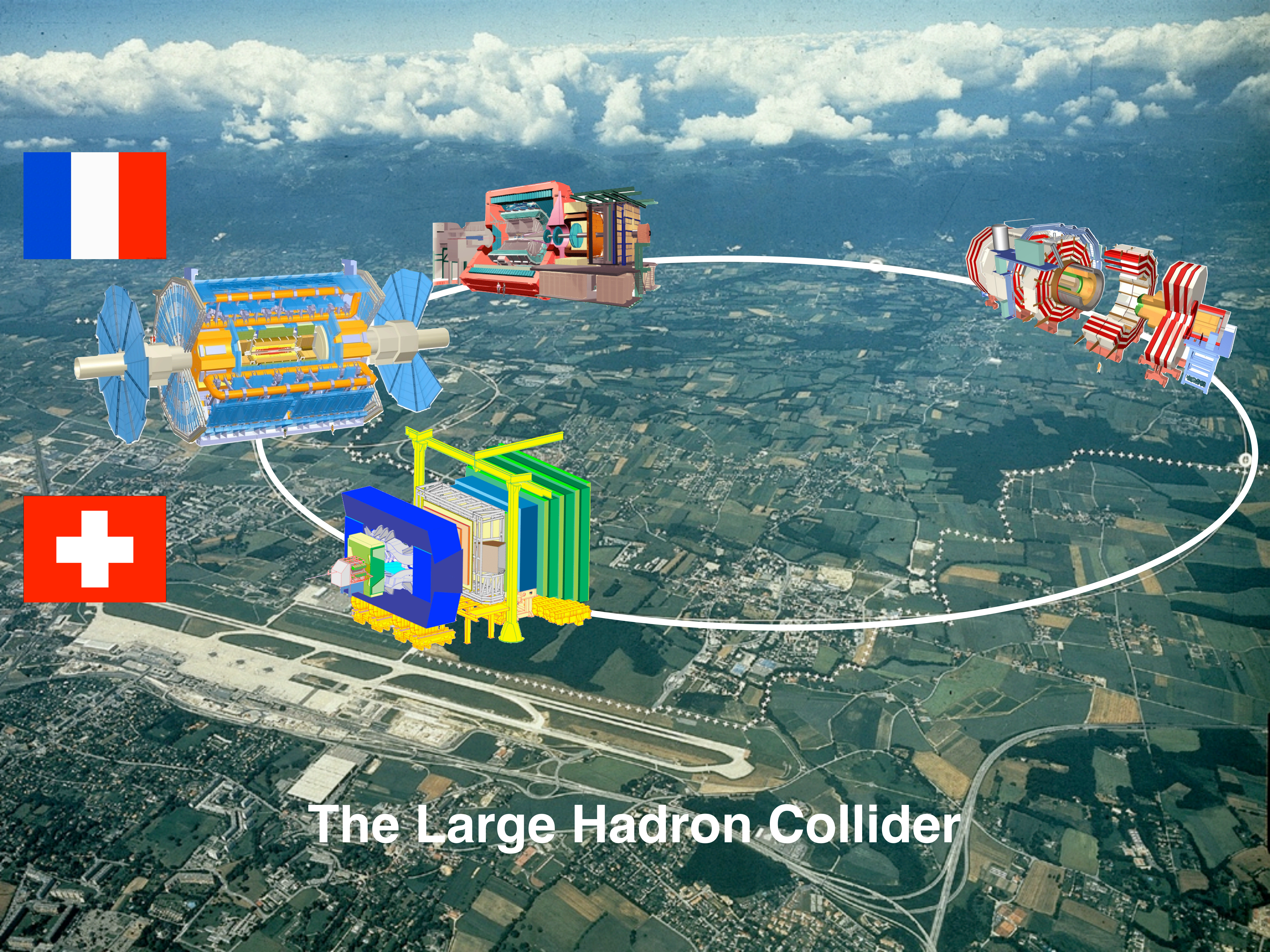
There are no tree-level FCNCs in the SM; FCNCs require loops.



TeV-scale particles can make significant contributions here:

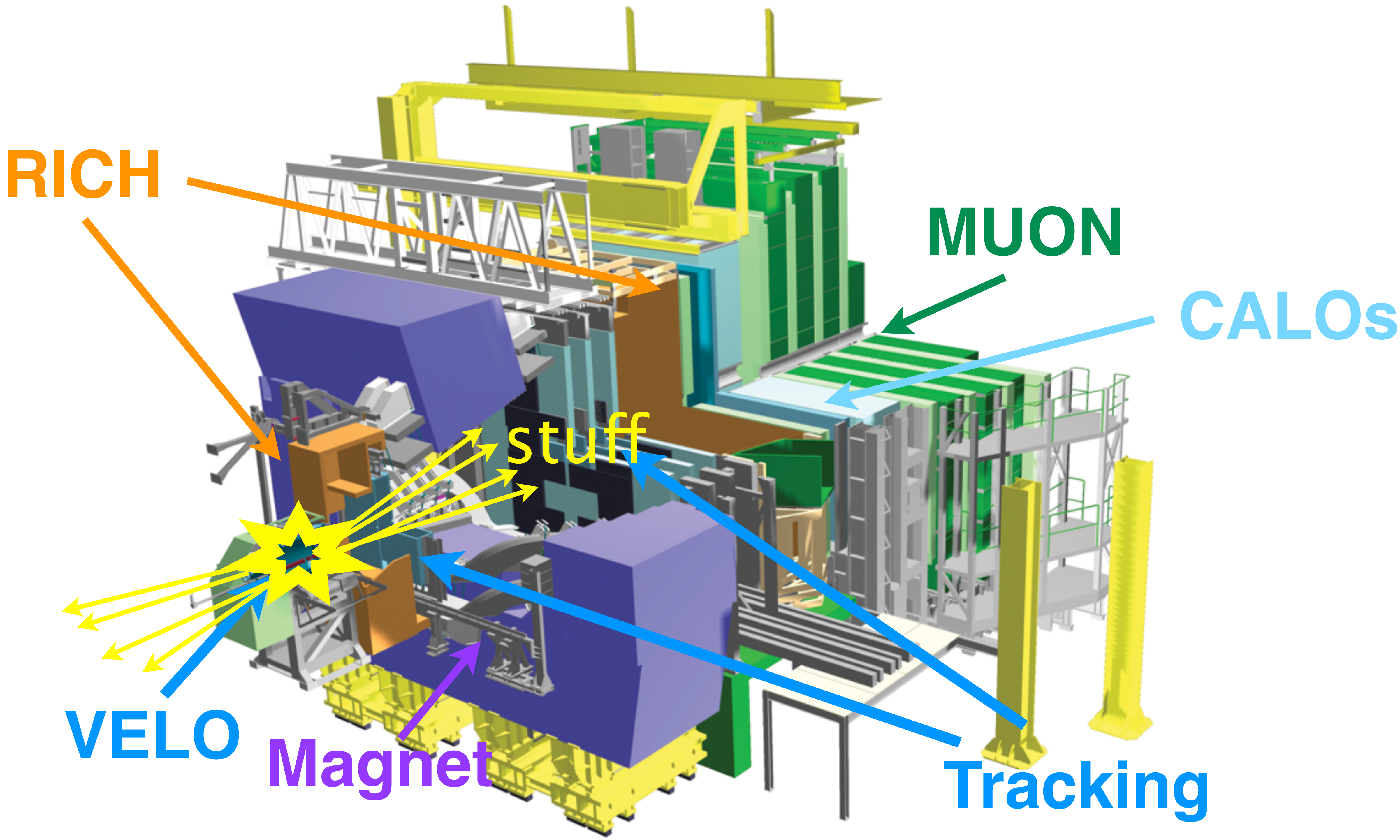
- $\Delta|\mathcal{A}|$: compare *Br* vs SM;
- $\Delta\phi$: compare ϕ vs SM or from trees vs loops;
- Lorentz structure: compare angular distributions vs SM.

LHCb is also doing W,Z,t,..., physics, studying exotic spectroscopy, etc. This talk is restricted to the $b \to X_c$ corner of LHCb phase space.

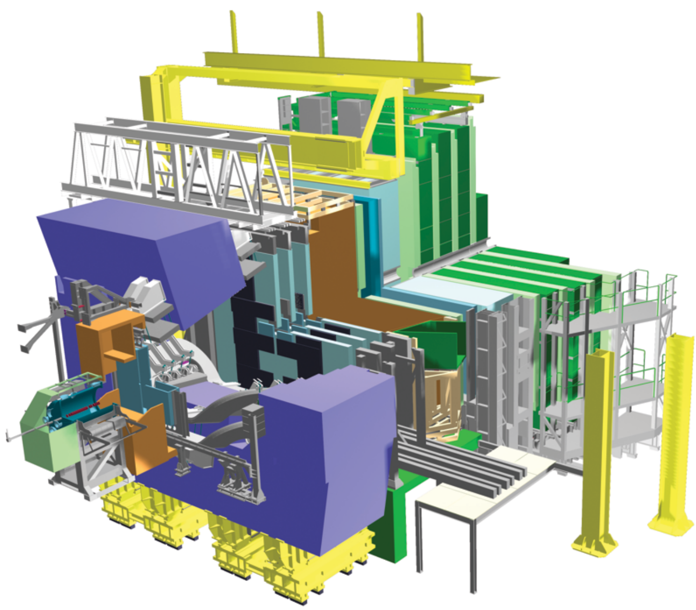

The Large Hadron Collider

LHCb Detector

LHCb is a FWD Spectrometer ($2 < \eta < 5$)



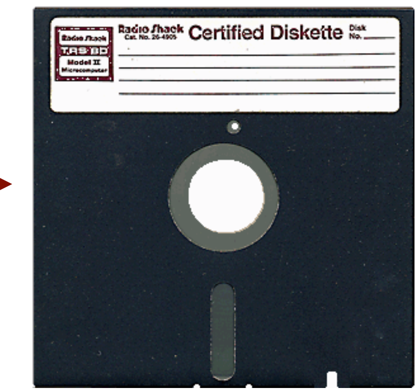
LHCb Trigger



20 MHz →

1 MHz →

5 kHz →



We can "only" read out the detector at 1 MHz; thus, a hardware trigger is required. The basic trigger strategy is

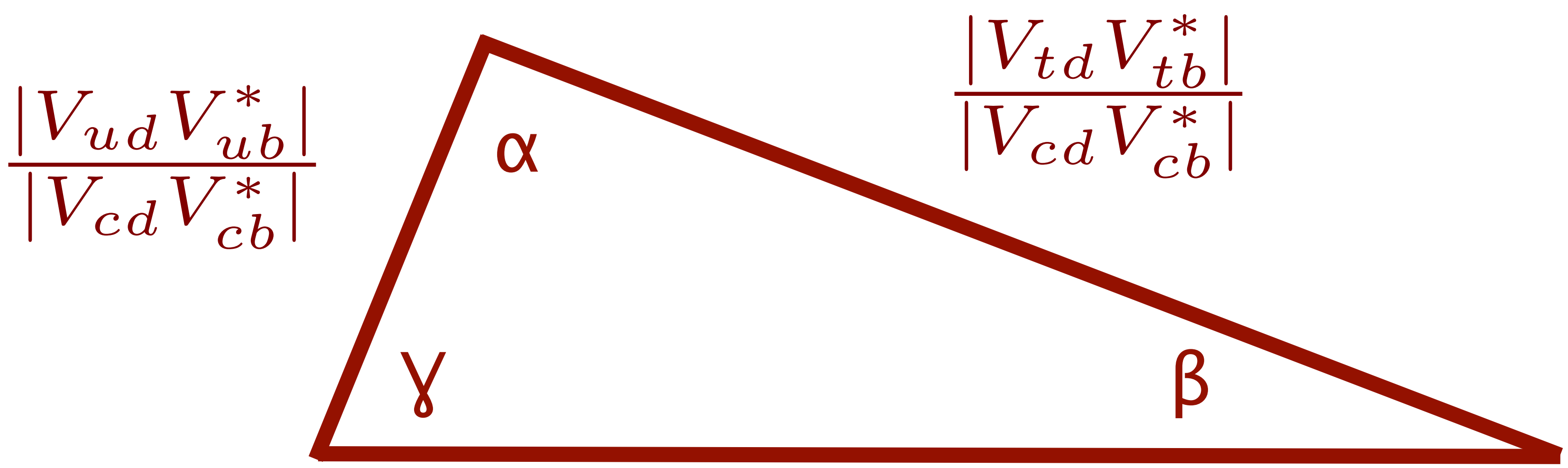
- hardware requires "large" ET in CALOs or "large" PT in the muon stations, along with low multiplicity;
- software runs ~30k PROCs (giving it 30 ms/event) to reduce the rate by ~200. It uses a combo of simple and inclusive BDT-based selections to produce a nearly 100% pure bb sample.

See talks by C.Fitzpatrick, F.Alessio & poster by M.Sokoloff

LHCb-DP-2012-004 [arXiv:1211.3055]
V.Gligorov & MW, JINST 8, P02013 (2013). [arXiv:1210.6861]

CKM

The CKM matrix describes the mixing between mass and weak quark eigenstates. In the SM, it is unitary providing 9 constraint equations that relate its elements to one another.

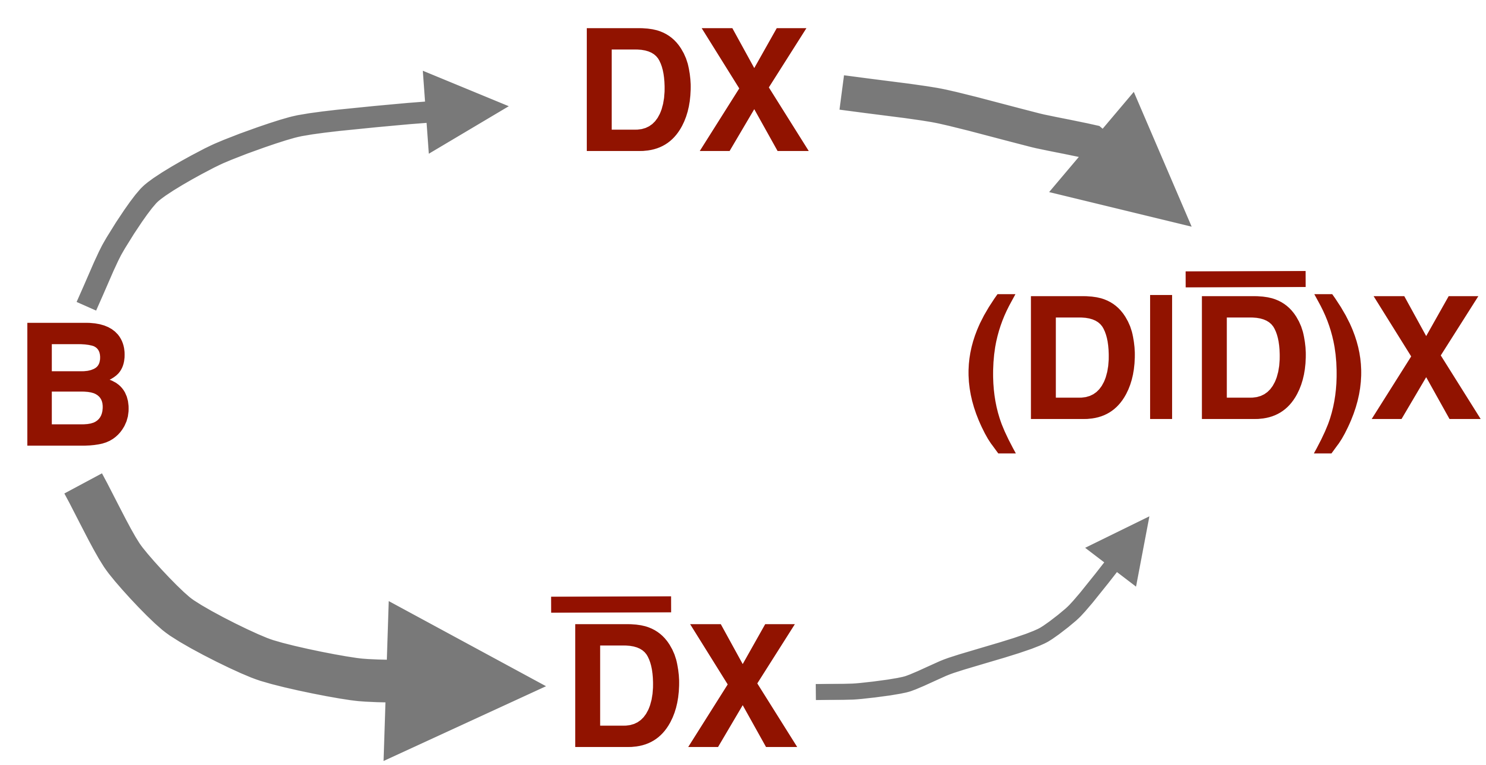


The most "popular" UT

Six of these constraint equations form "unitary triangles" (each of equal area, but different shapes). By measuring all "sides" and "angles", the unitary hypothesis and, thus, the SM can be tested.

CKM γ

Use interference b/t $\mathcal{A}_{b\to u}^{\bar{b}\to\bar{u}} = \mathcal{A}_{bu}e^{\pm i\gamma}$ and $\mathcal{A}_{b\to c}^{\bar{b}\to\bar{c}} = \mathcal{A}_{bc}$ to extract γ.

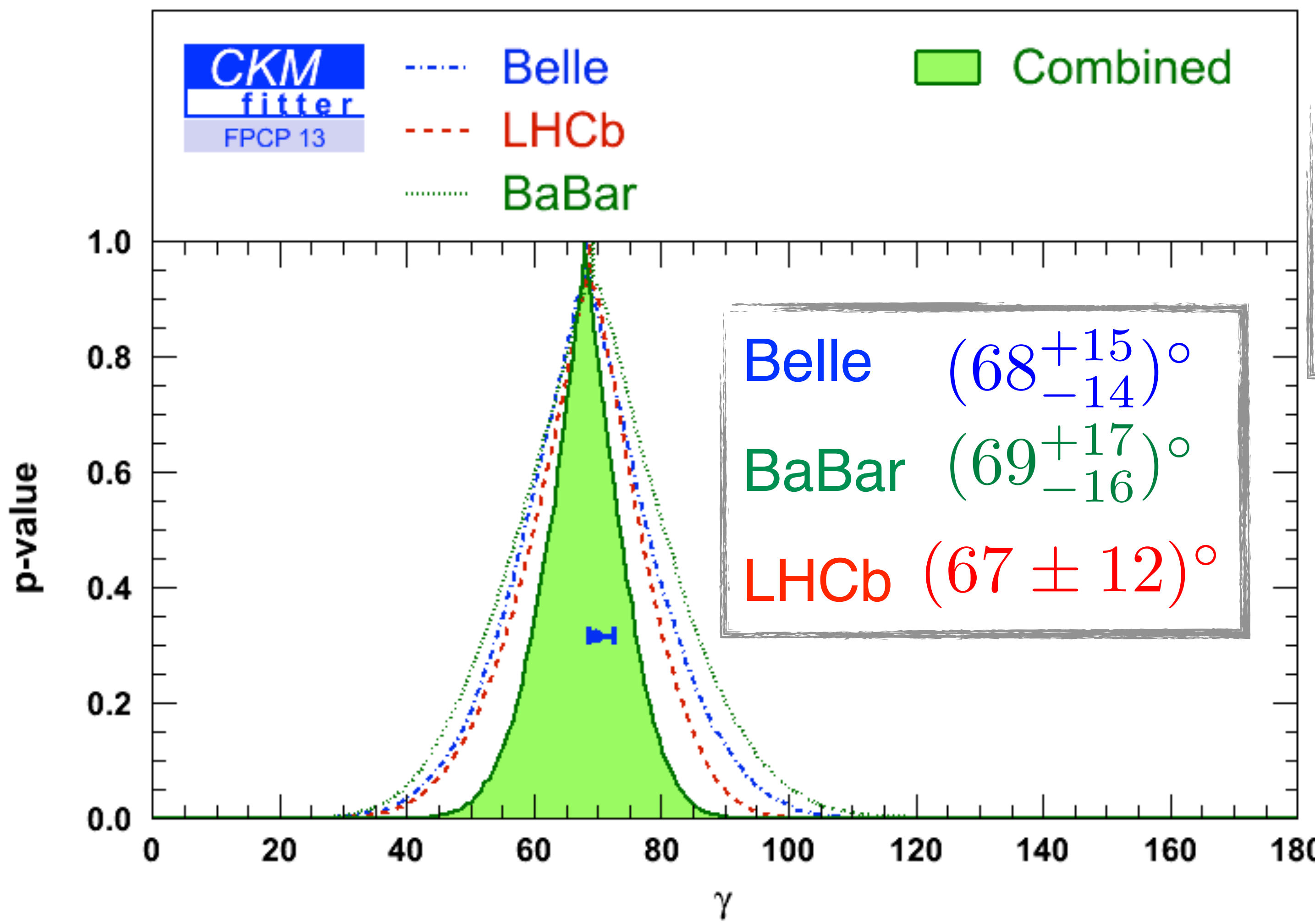


$$\mathcal{N}_{\pm} = |\mathcal{A}_{B\to DX} + \mathcal{A}_{B\to\bar{D}X}|^2$$
$$= |\mathcal{A}_D|^2 + |\mathcal{A}_{\bar{D}}|^2 + 2|\mathcal{A}_D||\mathcal{A}_{\bar{D}}|\cos\left(\Delta\theta_{\rm strong} \pm \gamma\right)$$

These are tree-level decays; no pollution from penguins, etc. This is SM ɣ. Can look for BSM by comparing to ɣ from loops.

CKM γ

Comparable results from Belle, BaBar and LHCb from $B \to D^{(*)} K^{(*)}$ using ADS/ GLW & GGSZ methods and a variety of D decay modes.



Refs

arXiv:1301.2033

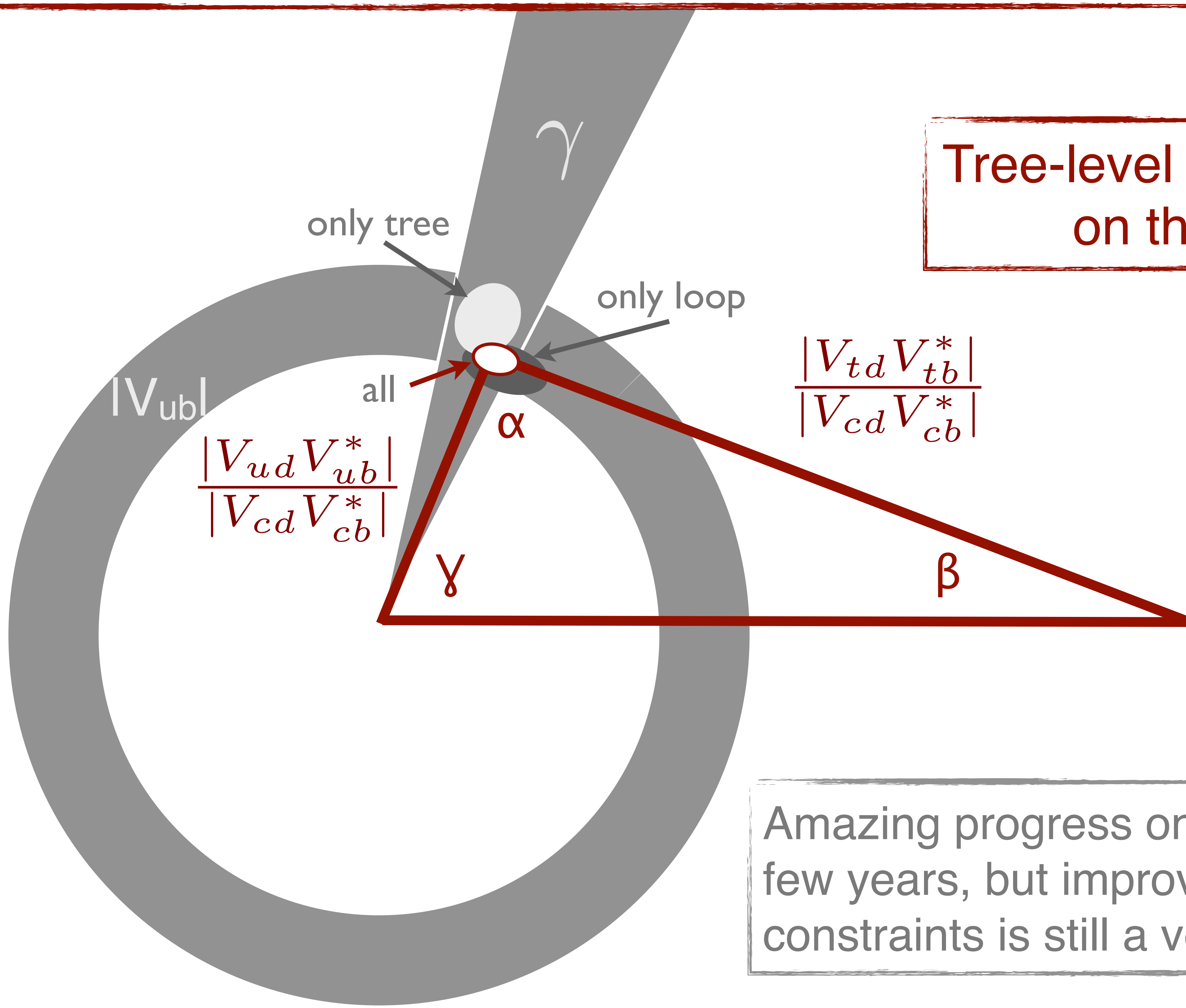
PRD 87, 052015 (2013)

LHCb-CONF-2013-006

LHCb now has best single-experiment ɣ measurement!

See talk by D. Craik for details on measuring ɣ using B→DK decays and for some LHCb results updated to include the full 3/fb (2011+2012) data!

CKM γ



Tree-level constraints on the UT.

Amazing progress on γ in the past few years, but improving tree-level constraints is still a very high priority.

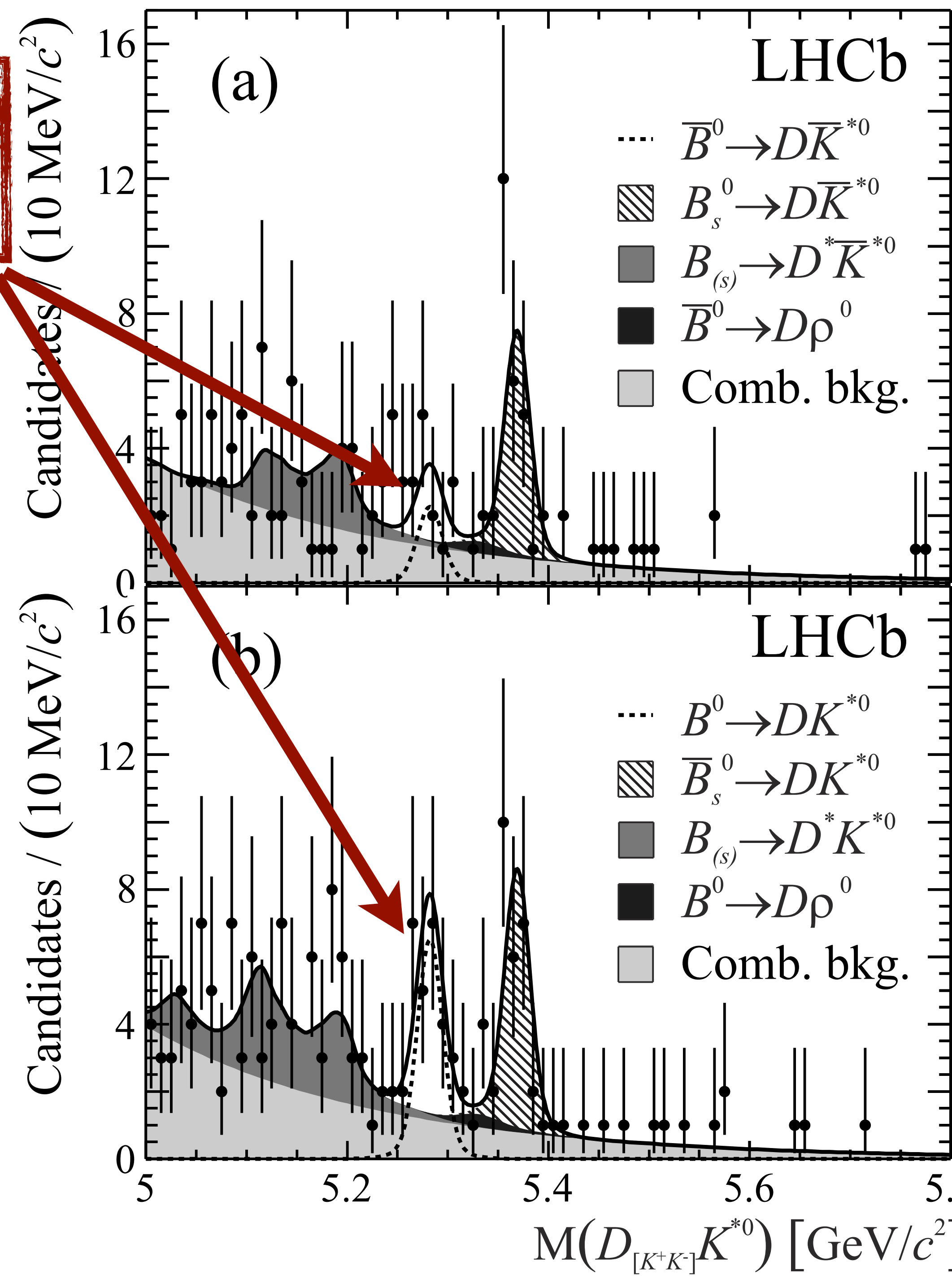
CKM γ : TNG

Measurements using B→D$^{(*)}$K$^{(*)}$ modes will continue to improve with more data, but new decay modes will also begin to contribute soon.

- B→DK* (ADS/GLW);
  LHCb-PAPER-2012-042 [arXiv:1212.5205]
- B→DKπ (Dalitz analysis);
  LHCb-PAPER-2013-022 [arXiv:1304.6317]
- B_s→Dϕ (ADS/GLW);
  LHCb-PAPER-2013-035
- B_s→DKK (Dalitz analysis);
  LHCb-PAPER-2012-018 [arXiv:1207.5991]
- B→DKππ (ADS/GLW);
  LHCb-PAPER-2011-040 [arXiv:1201.4402]
- etc.

2σ CPV in B→DK*

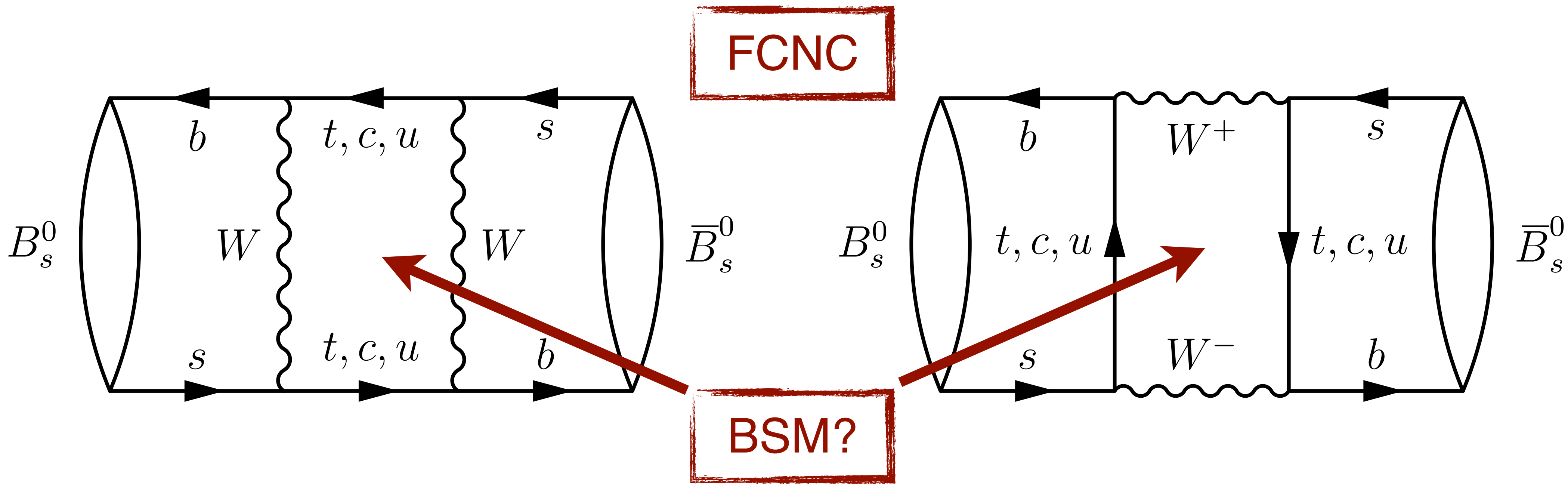
See talks by D.Craik & S.Blusk for details



Many new constraints on ɣ expected in the next few years.

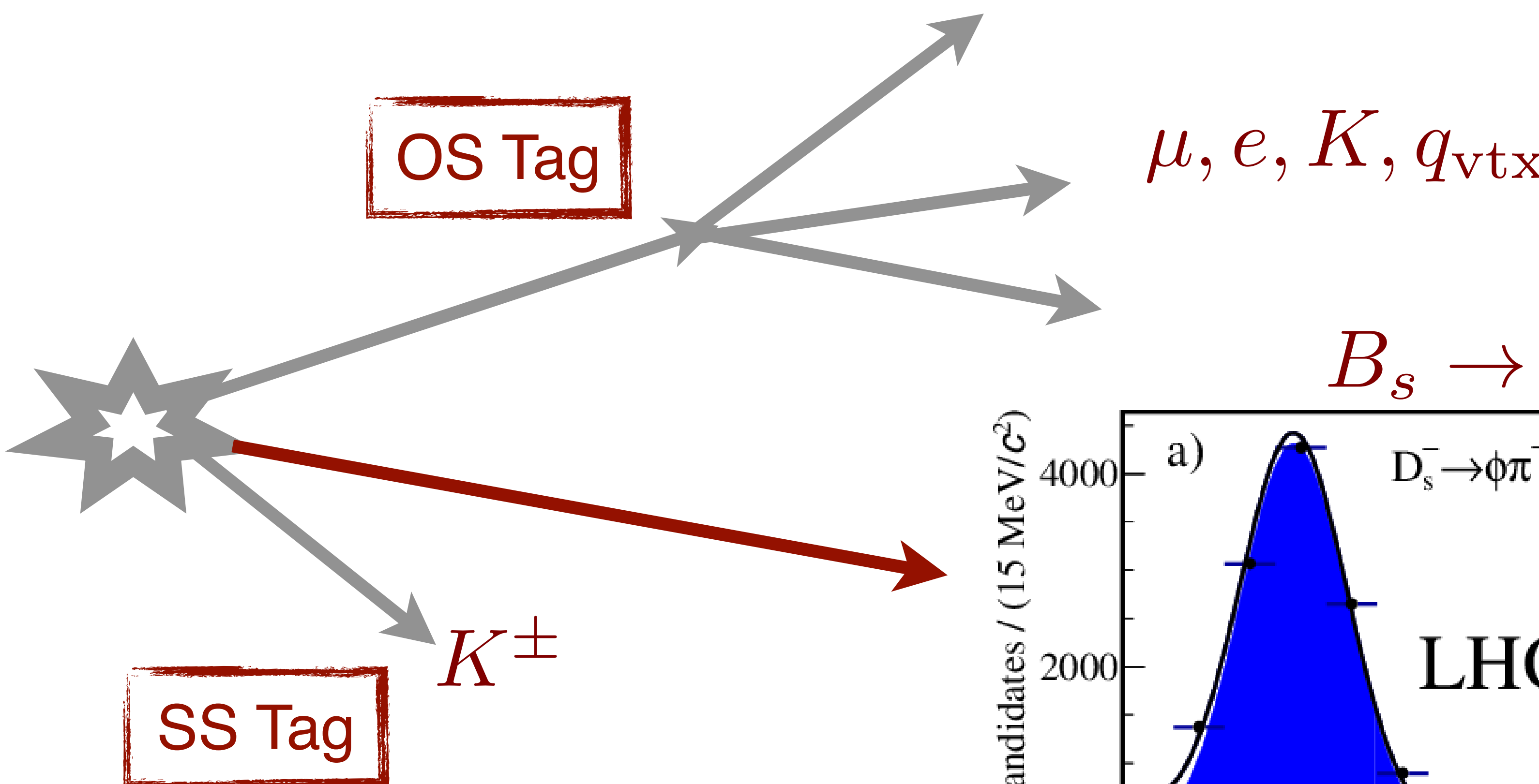
$\Delta m_{d,s}$

Neutral meson oscillations have now been observed in the K, B_d, B_s and D systems. The B_s has the highest oscillation frequency and changes flavor on average 9 times between production and decay.



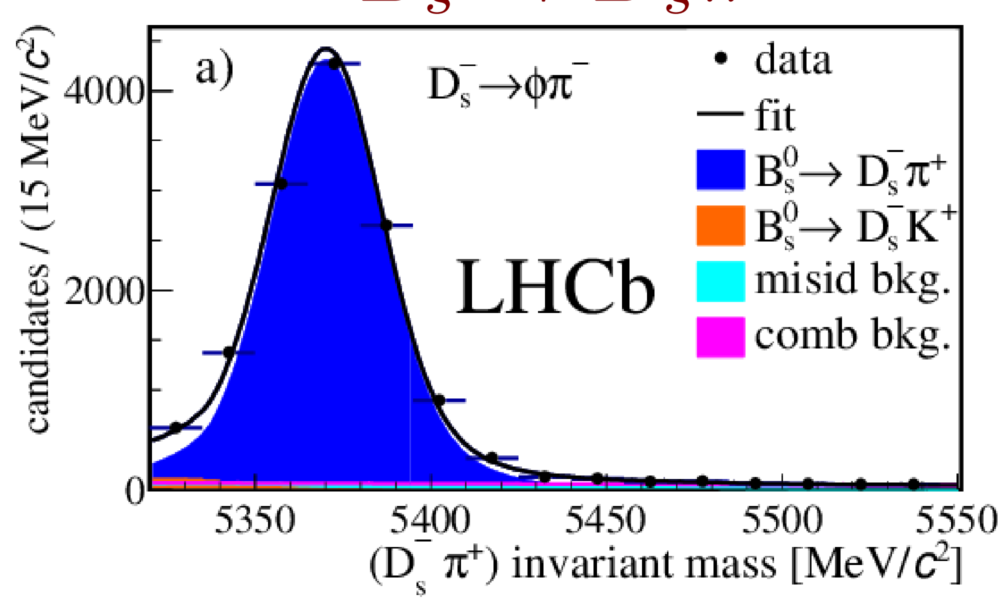
Measuring the B_d and B_s oscillations frequencies provides direct constraints on the UT and also vital input to many BSM searches, e.g., $B_s \to \mu\mu$ and $B_s \to J/\psi\phi$.

Basic strategy to measure B_s oscillations: Reconstruct the B_s in a flavor-specific decay and also tag its flavor at production.



LHCb-PAPER-2013-006
[arXiv:1304.4741]

$B_s \to D_s\pi$

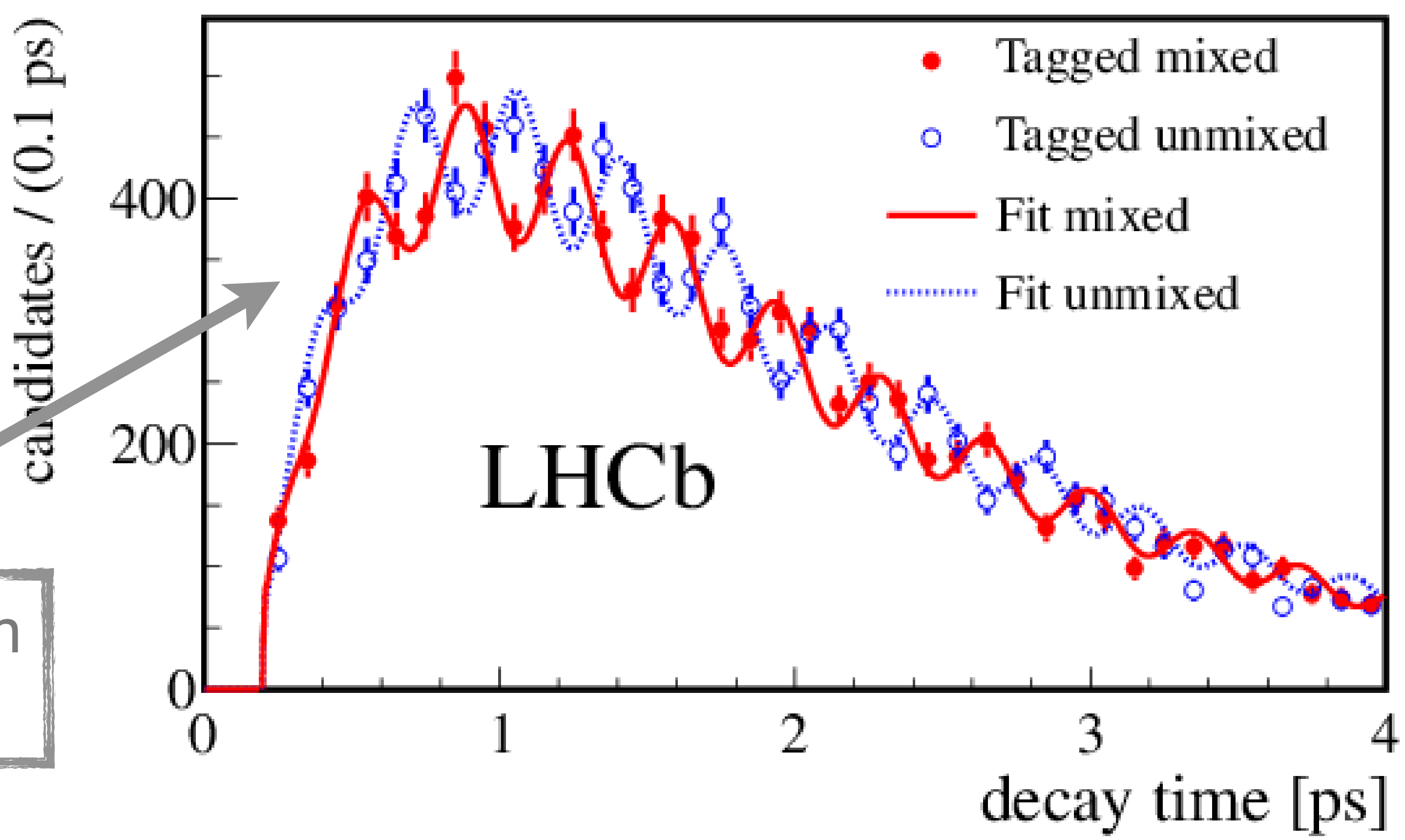


LHCb sees ~34k signal events in 1/fb of data (2011) with an effective tagging power of (2.6±0.4)% from OST and (1.2±0.3)% from SST.

Δm_s

LHCb achieves a mean decay-time resolution in this mode of 44 fs!

$$\Delta m_s = 17.768 \pm 0.023(\text{stat}) \pm 0.006(\text{syst})\text{ps}^{-1}$$



Detector/selection efficiency effect

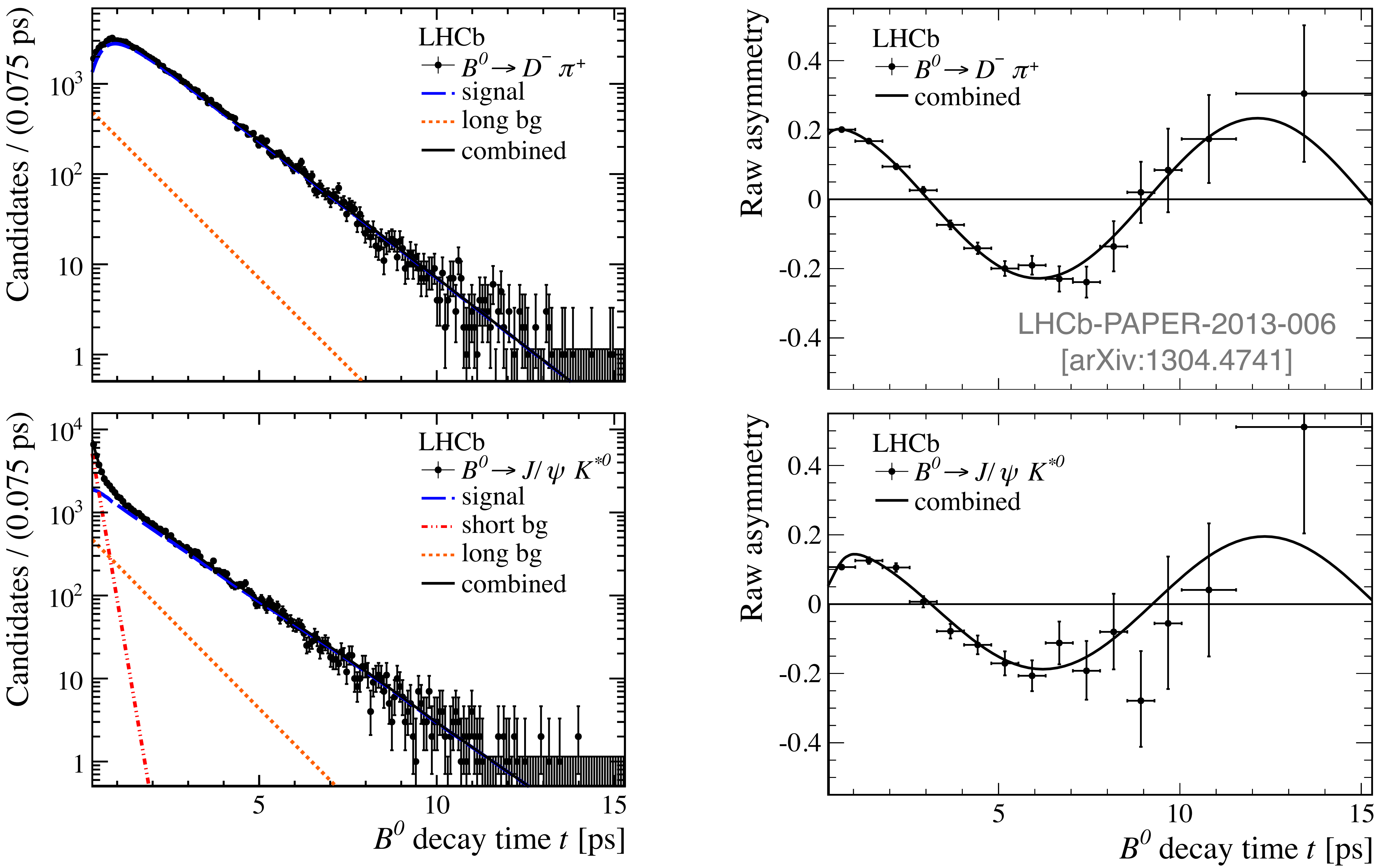
LHCb-PAPER-2013-006
[arXiv:1304.4741]

This is the most precise measurement of the B_s oscillation frequency.

Δm_d

Similarly, we measure Bd oscillations using 1/fb of (2011) data.

$$\Delta m_d = 0.5156 \pm 0.0051(\text{stat}) \pm 0.0033(\text{syst})\ \text{ps}^{-1}$$

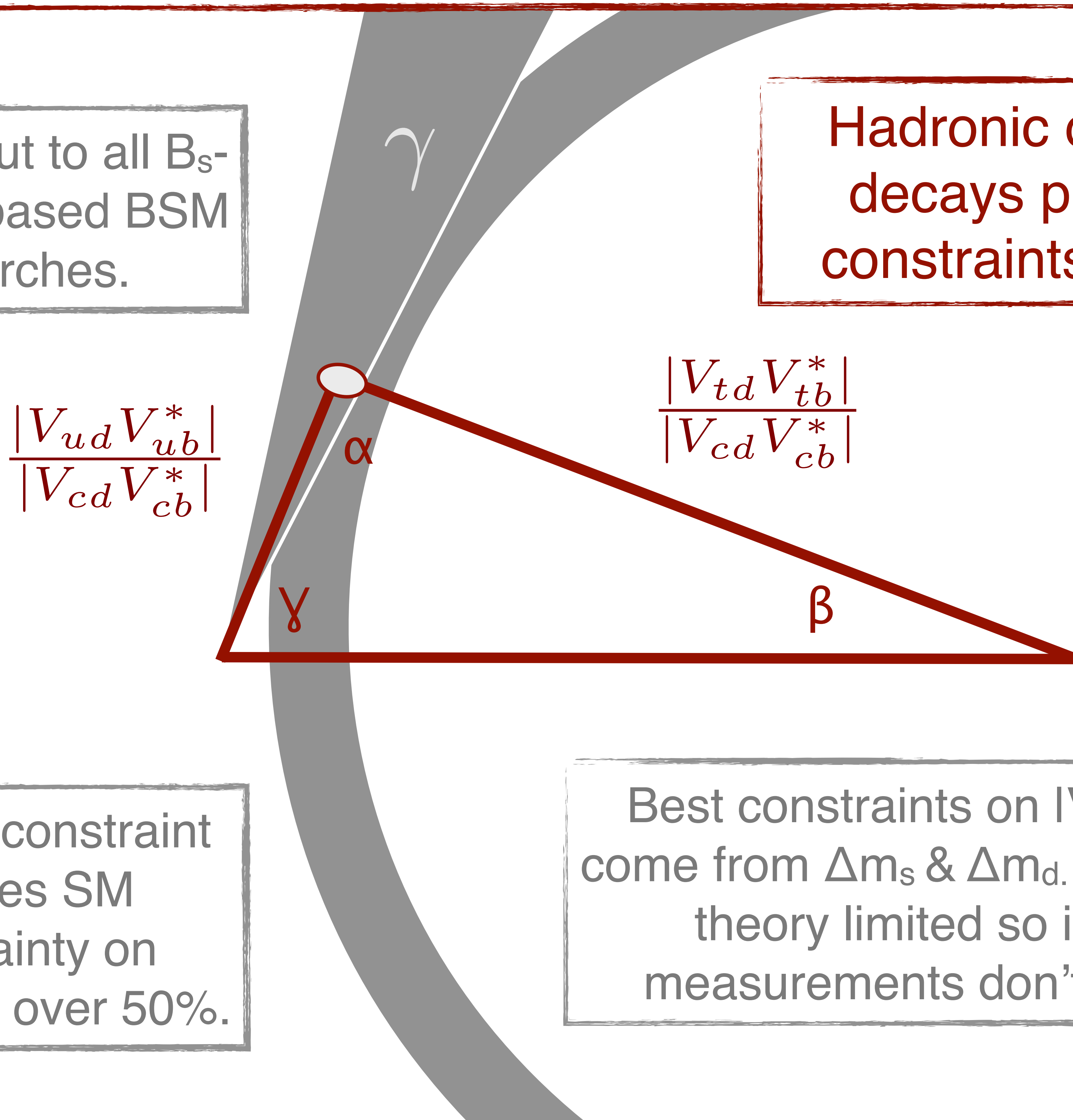


most precise!

$\Delta m_{d,s}$

Vital input to all B_s-mixing-based BSM searches.

Hadronic open charm decays provide vital constraints on the UT!

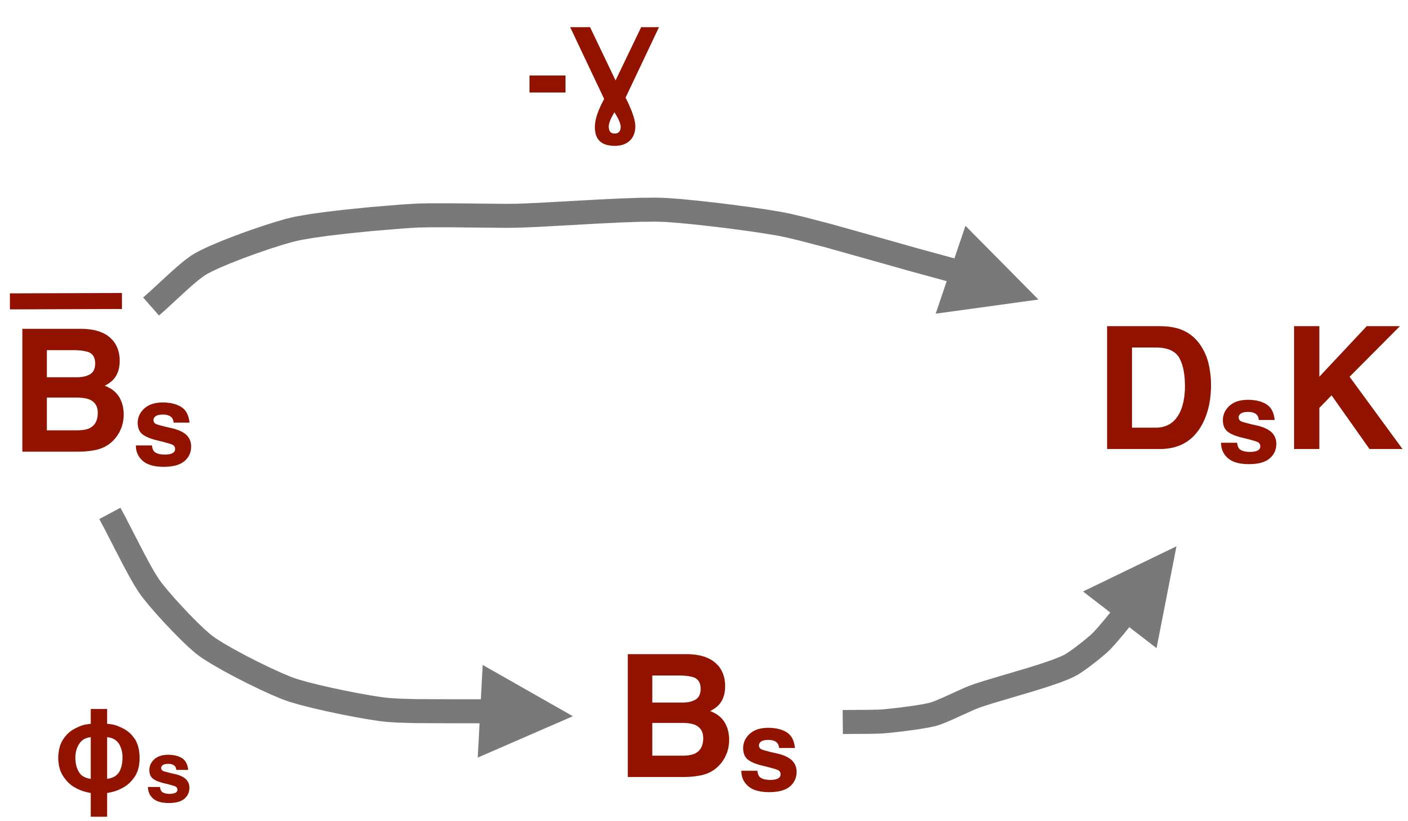


The Δm_s constraint reduces SM uncertainty on $B_s \to \mu\mu$ by over 50%.

Best constraints on $|V_{td}|$ and $|V_{ts}|$ come from Δm_s & Δm_d. Unfortunately, theory limited so improved measurements don't help ATM.

TD CKM γ

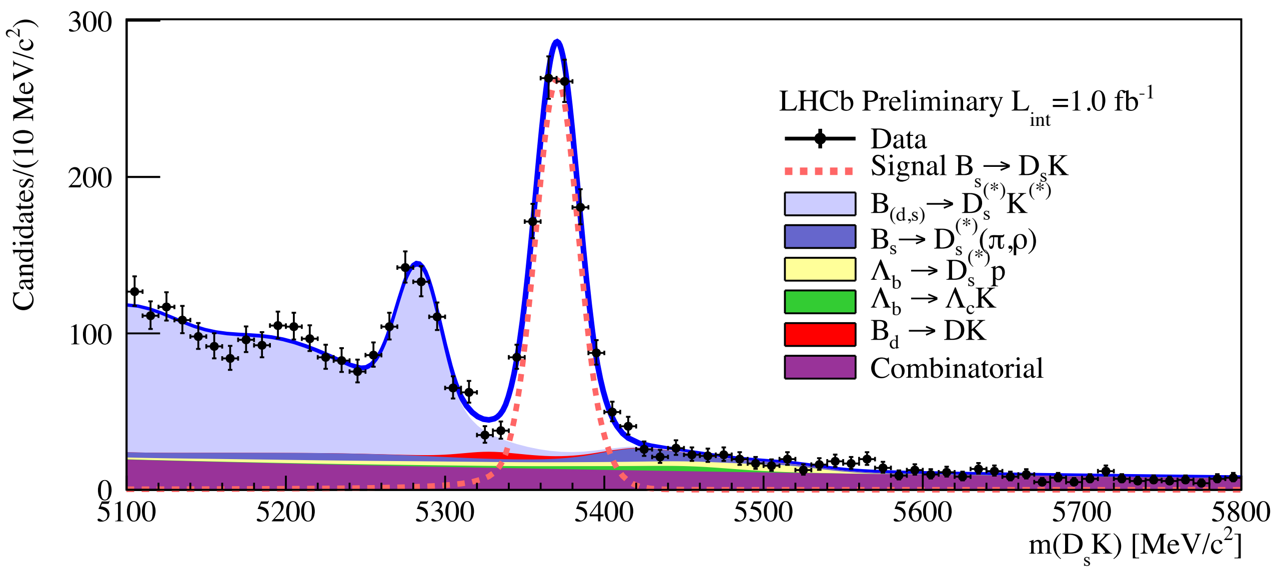
Can also use mixing to measure γ! Interference between mixing and decay amplitudes gives rise to a CPV phase $\gamma+\phi_s$.

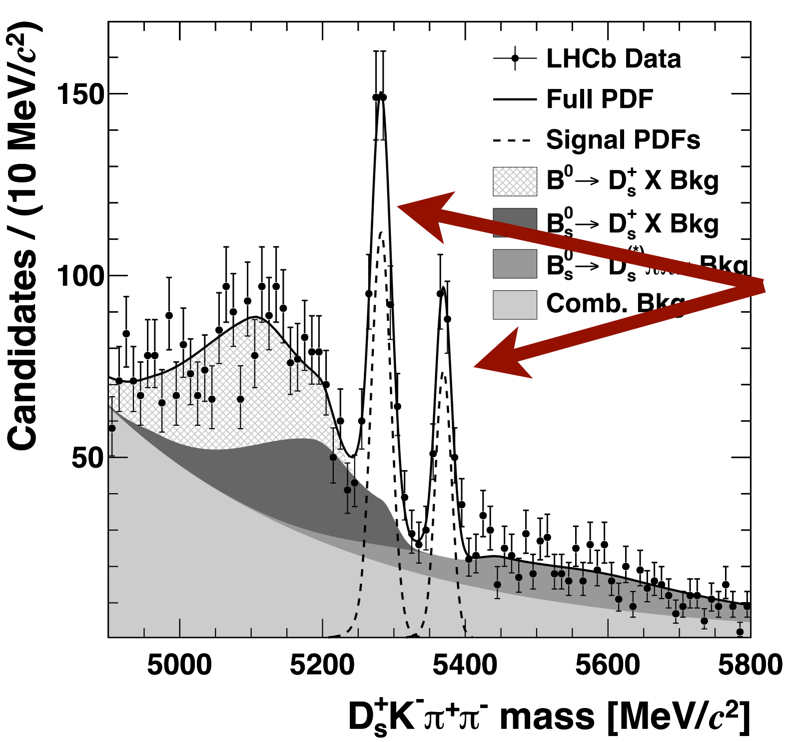


This phase is accessible experimentally via a time-dependent analysis (much more difficult than simple counting).

TD CKM γ

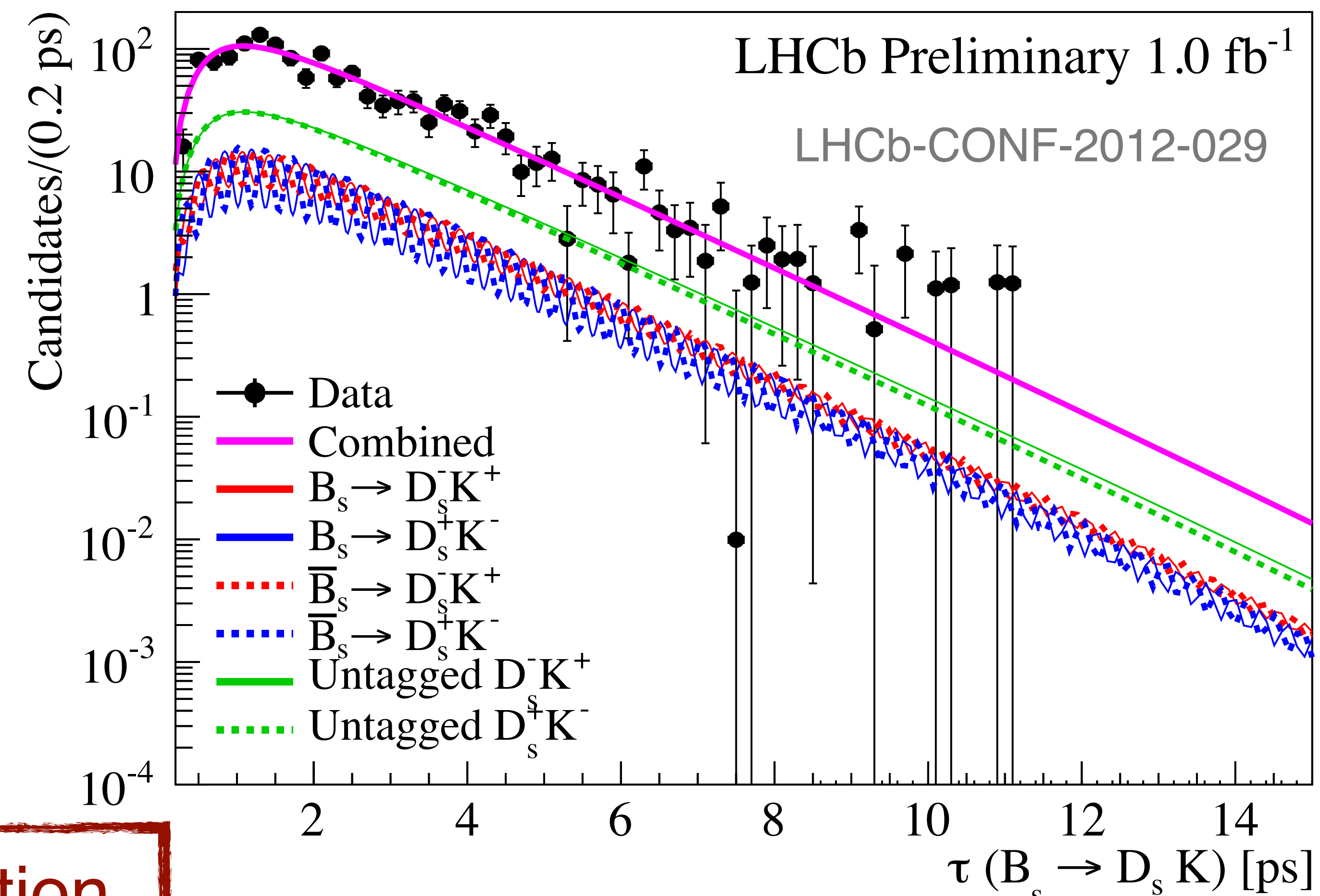
LHCb has made a first (preliminary) measurement of TD CPV observables in $B_s \to D_s K$ using 1/fb of data.





1st observation $B_{(s)} \to D_{(s)} K\pi\pi$

LHCb-PAPER-2012-033 [arXiv:1211.1541]

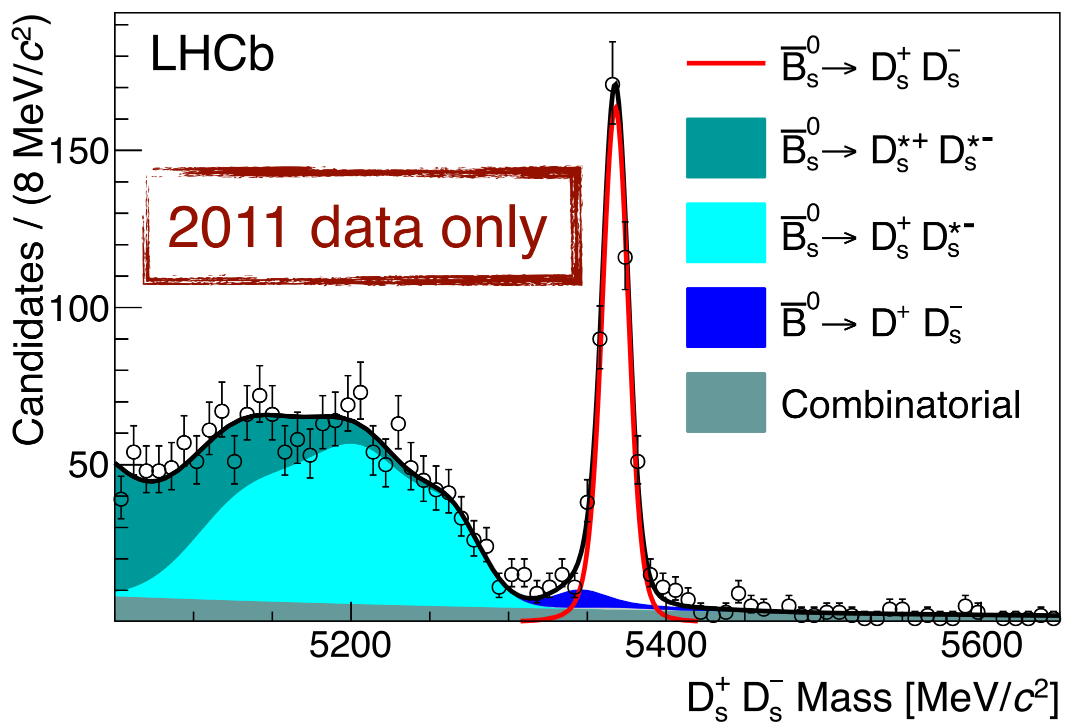


Constraints on γ require a better understanding of systematics.

Double Open Charm

Further CKM constraints possible in the very near future using double-open-charm modes. The $B_{d(s)}$ mixing phase can be obtained using $B_{d(s)} \to D_{(s)} D_{(s)}$.

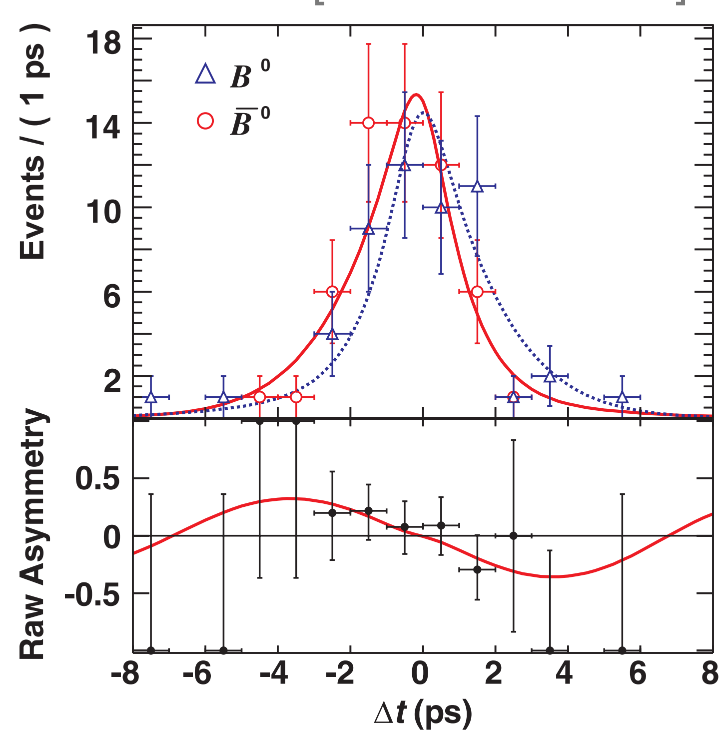
LHCb-PAPER-2012-050
[arXiv:1302.5854]



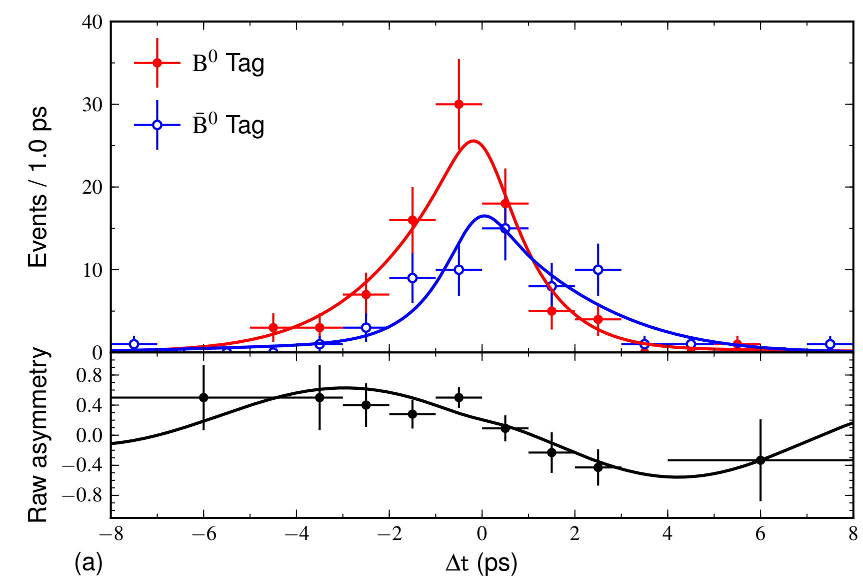
CPV Results from BaBar & Belle!

e.g.) $B \to DD$

BaBar [arXiv:0808.1866]



Belle [arXiv:1203.6647]



See talk by S. Blusk for discussion on double-open-charm modes.

Double Open Charm

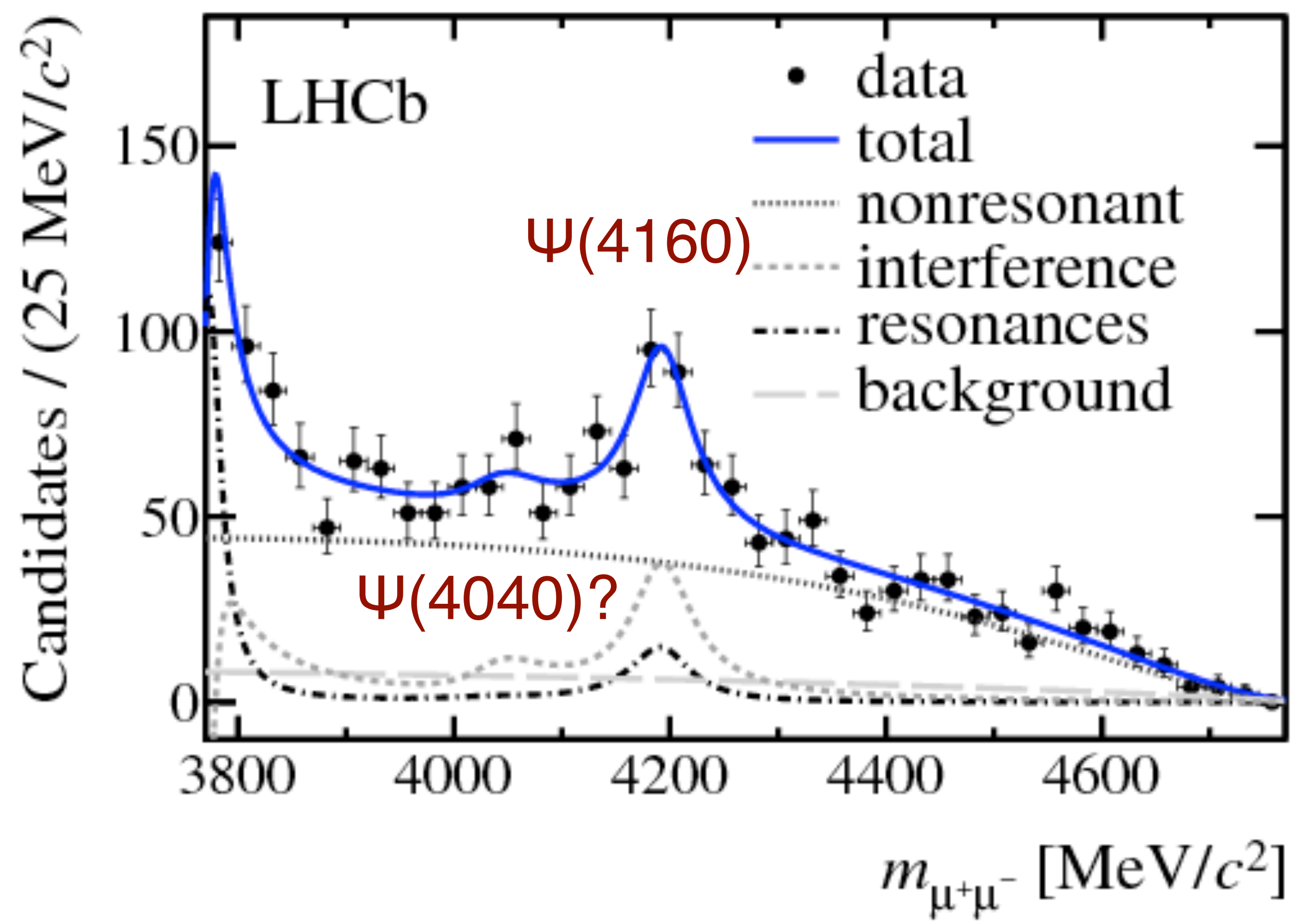
LHCb recently observed an unexpected resonant contribution in B→Kμμ. Even the golden modes cannot escape QCD!

LHCb-PAPER-2013-039
[arXiv:1307.7595]

See talk by E.Bowen for details on Kμμ

$B \to \psi(4160)K$ → $\mu\mu K$

$B \to \psi(4160)K$ → $DD'K$

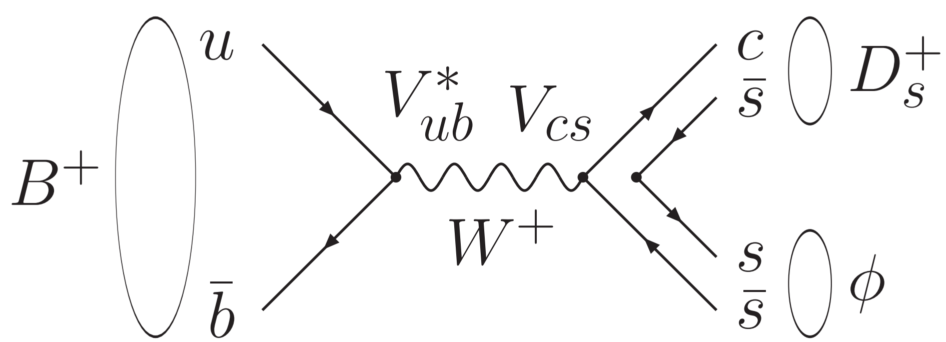


The B→DD'K(*) decay modes could be used to constrain the charmonium amplitudes for B→K(*)μμ. Furthermore, these modes can be used as an exotic QCD laboratory (e.g., to search for hybrid charmonium).

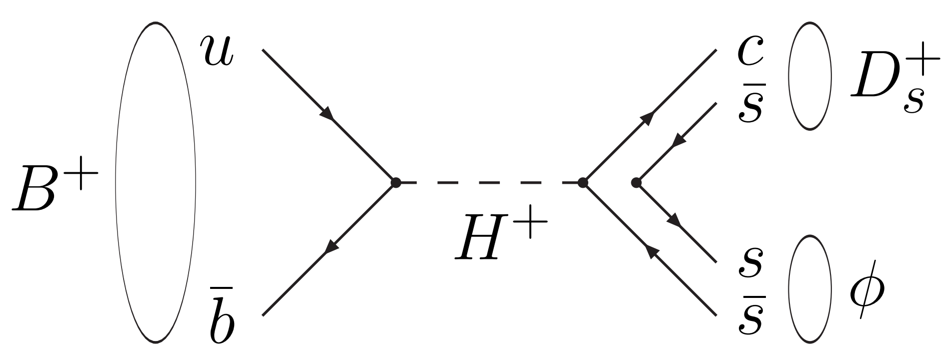
First evidence for a hadronic annihilation-type decay observed at LHCb using 1/fb (2011) of data.

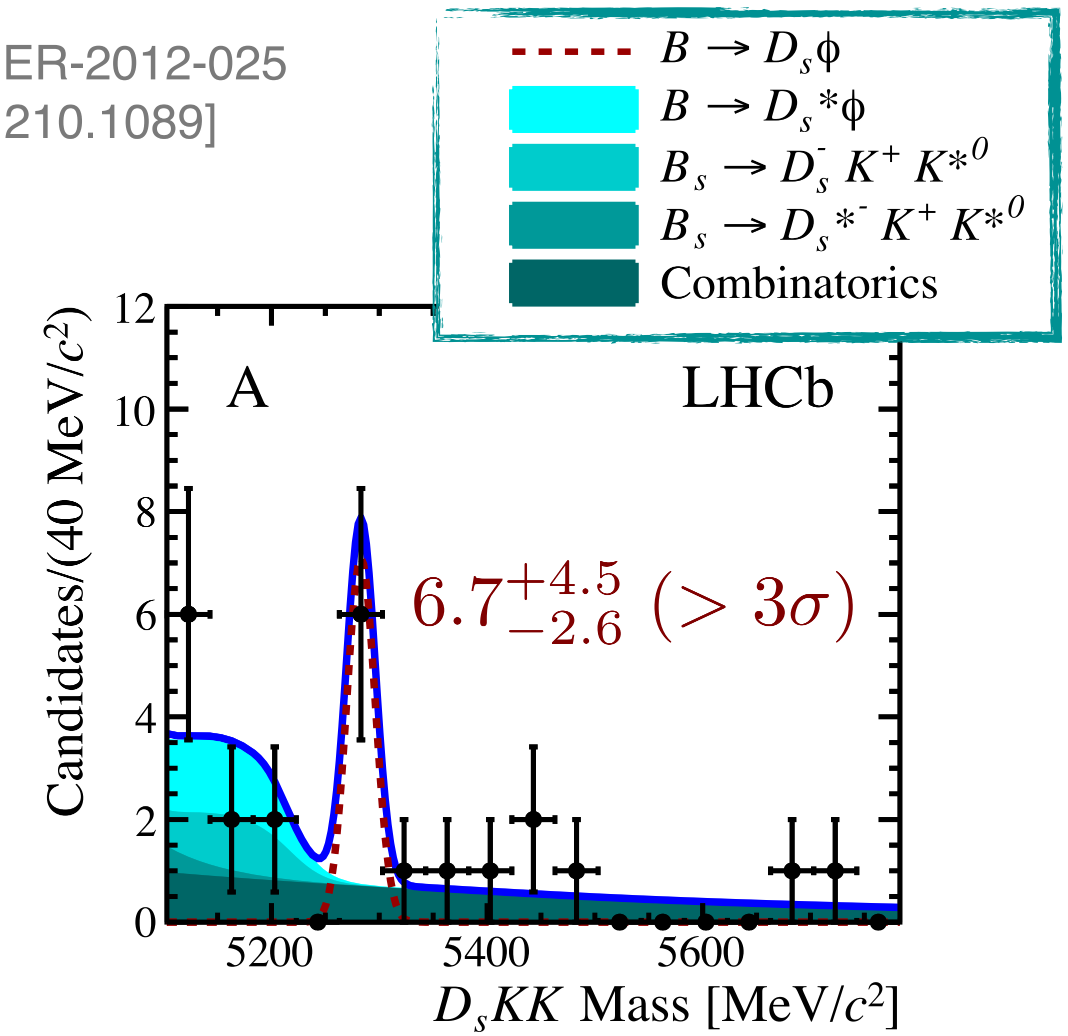
LHCb-PAPER-2012-025 [arXiv:1210.1089]

SM



BSM





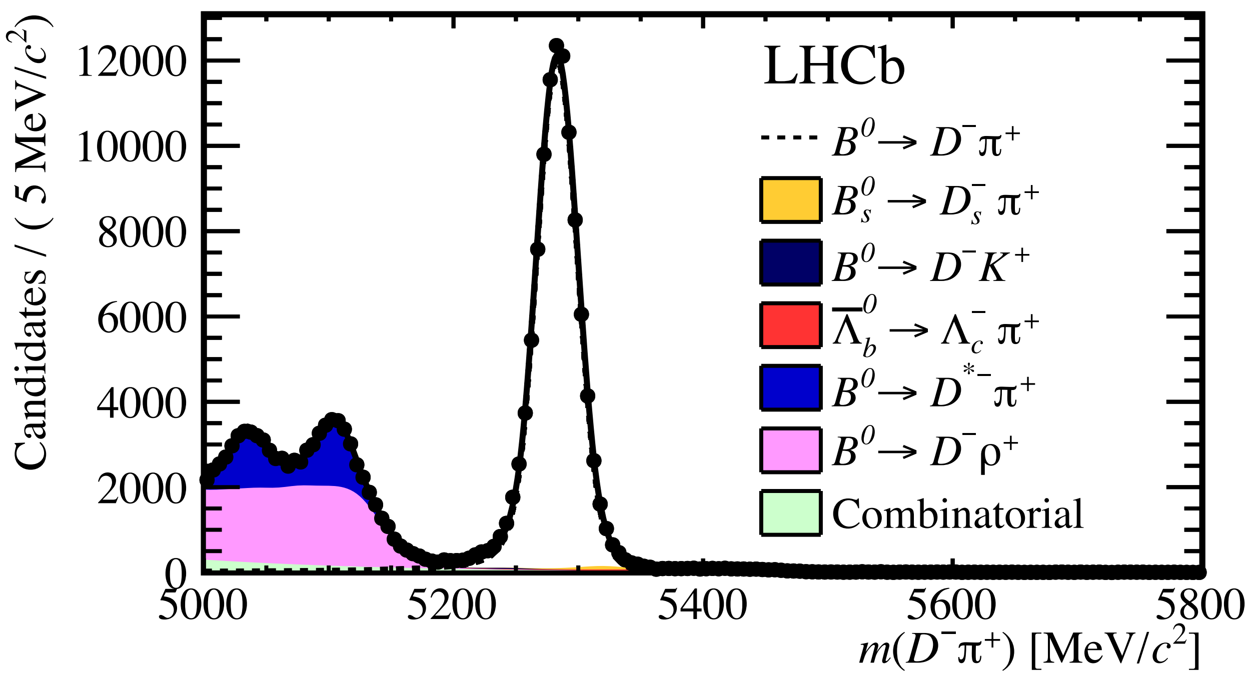
$$\mathcal{B}(B^\pm \to D_s^\pm \phi) = \left(1.87\,^{+1.25}_{-0.73}\,(\text{stat}) \pm 0.19\,(\text{syst}) \pm 0.32\,(\text{norm})\right) \times 10^{-6}$$

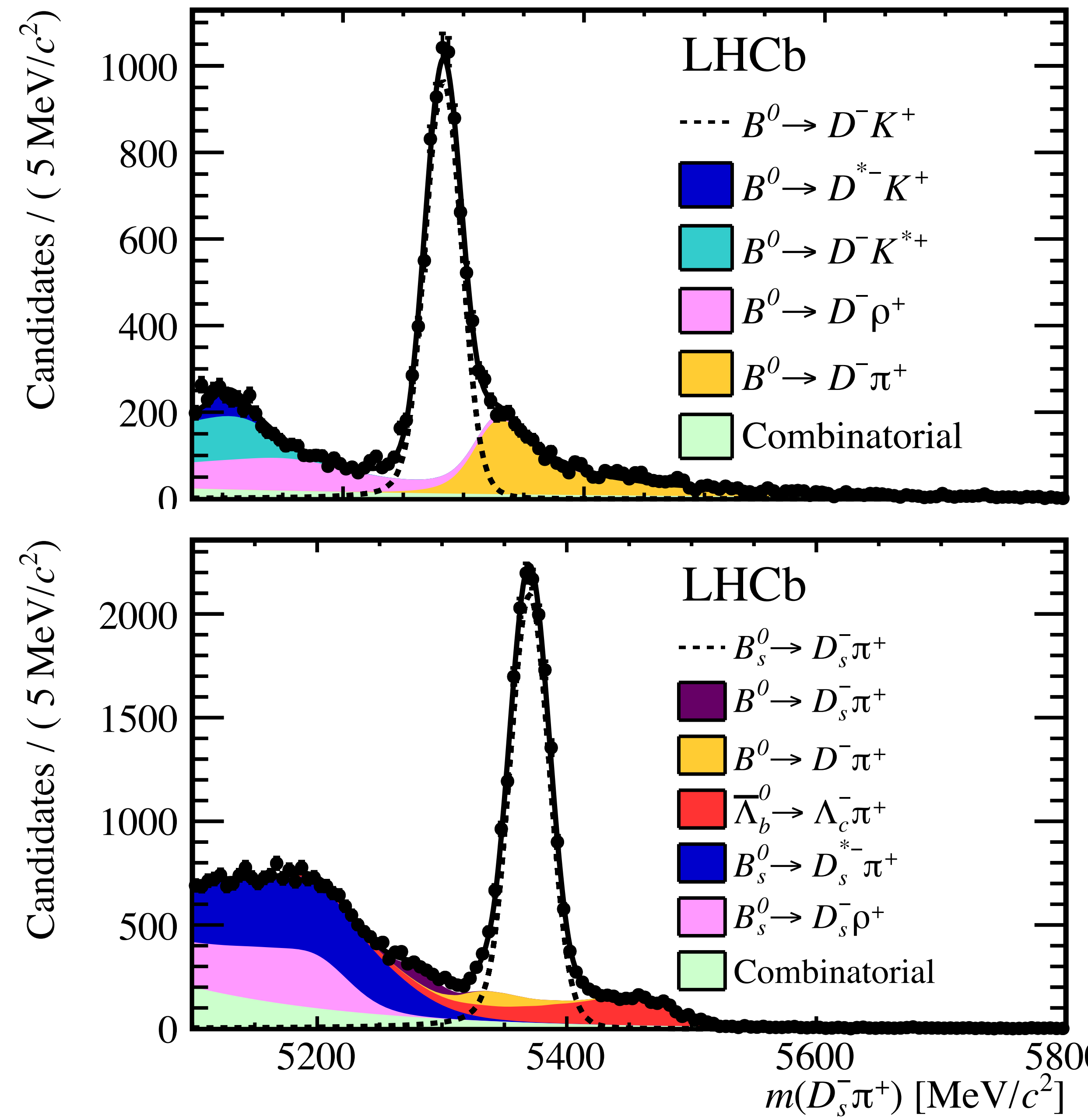
$$\mathcal{A}_{CP}(B^\pm \to D_s^\pm \phi) = -0.01 \pm 0.41\,(\text{stat}) \pm 0.03\,(\text{syst})$$

f_s/f_d

Hadronic open-charm decays are also used to make “utility” measurements, e.g., f_s/f_d (required for $B_s \rightarrow \mu\mu$, etc).

LHCb-PAPER-2012-037
[arXiv:1301.5286]





$$f_s/f_d = 0.259 \pm 0.015$$

LHCb-CONF-2013-011

Summary

- Hadronic-open-charm decays provide a tree-level way to measure the CKM angle γ. Great progress has been made over the past few years using $B \rightarrow D^{(*)}K^{(*)}$ decays; the uncertainty on γ is now only 8^{o}. Soon, many new decay modes will also begin to contribute to constraining γ.

- Δm_s and Δm_d, which are measured using hadronic-open-charm modes, place strong constraints on the UT (although, these constraints are currently theory limited) and are vital inputs to many BSM searches.

- Double-open-charm modes will soon provide additional constraints to CKM parameters. They can also help constrain "nuisance" charmonium amplitudes for "golden" modes.

- We have entered the era of rare hadronic-open-charm decays!