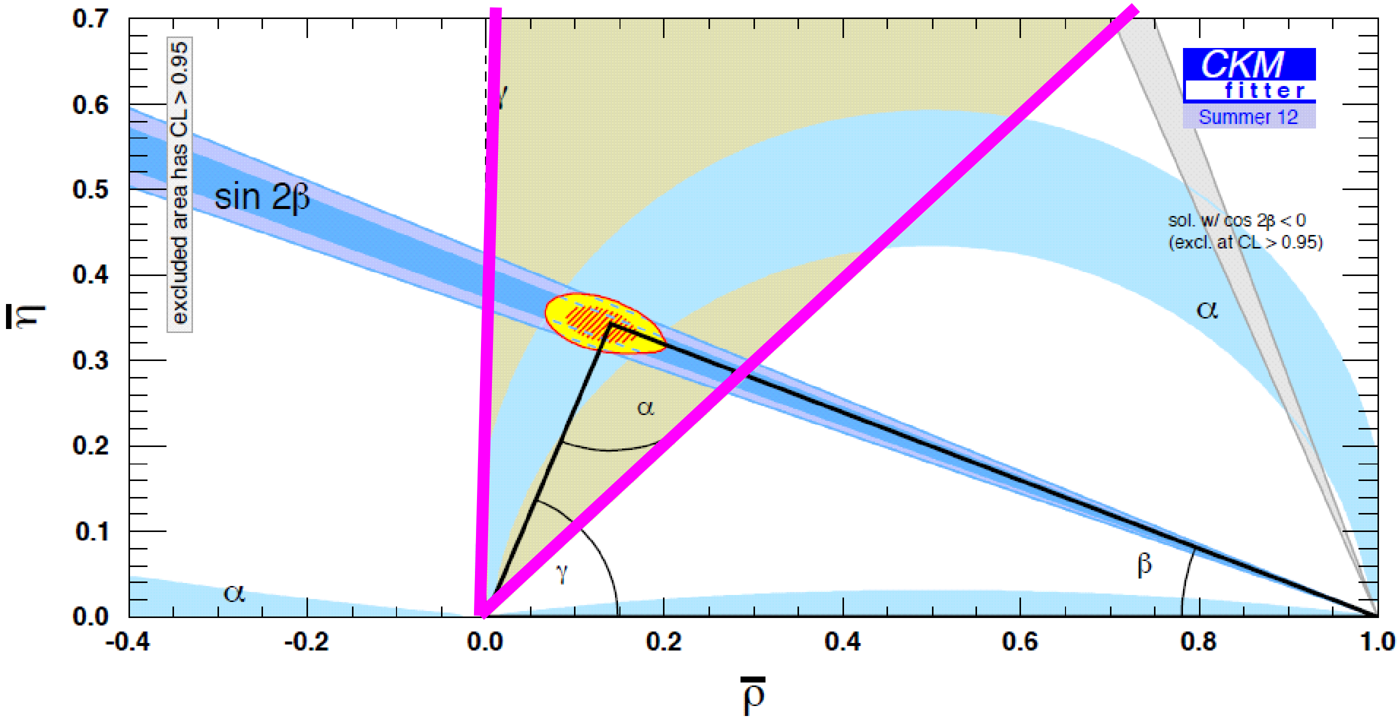
Measurement of CP Observables in $B^0 \rightarrow DK^{*0}$ decays at LHCb

Edmund Smith

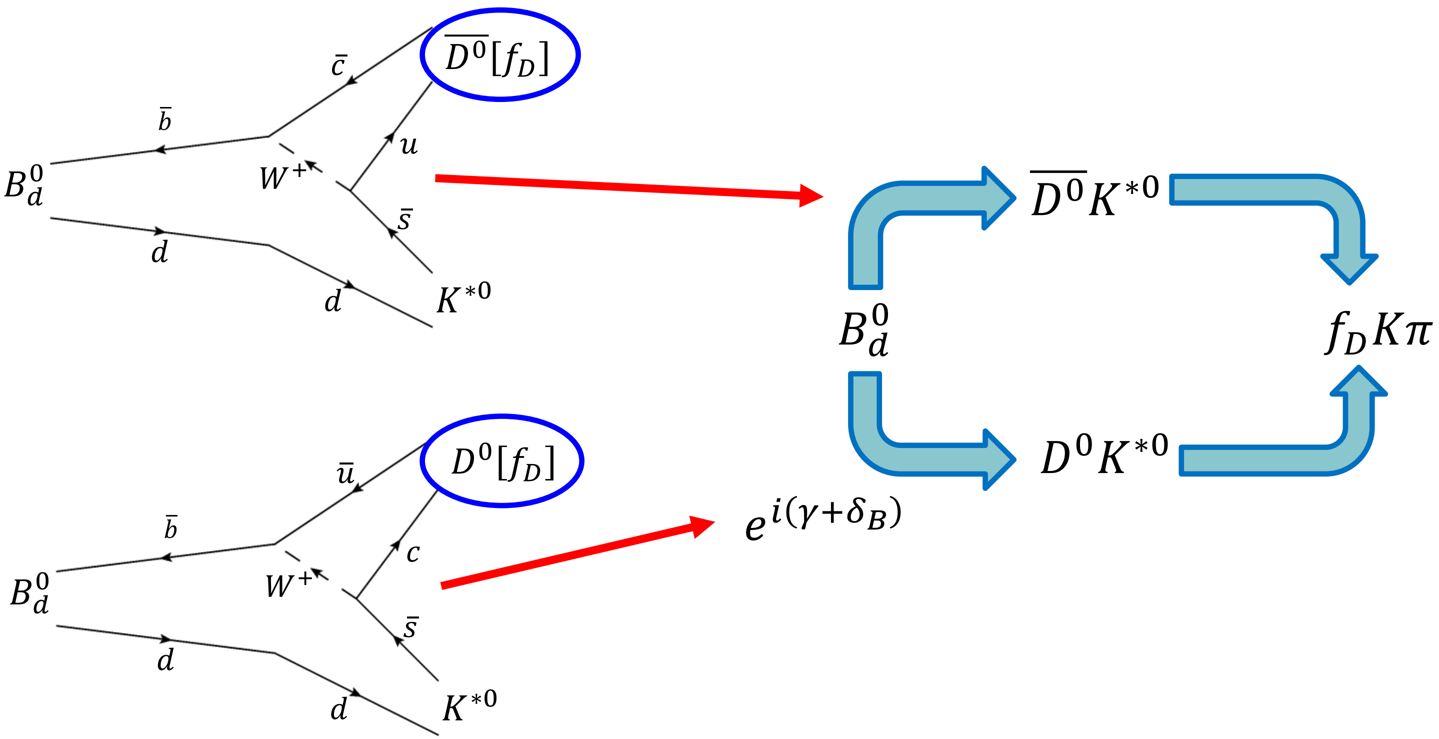
IOP HEPP and APP Group Meeting 2013, 8 – 10 May 2013, University of Liverpool.

CKM triangle

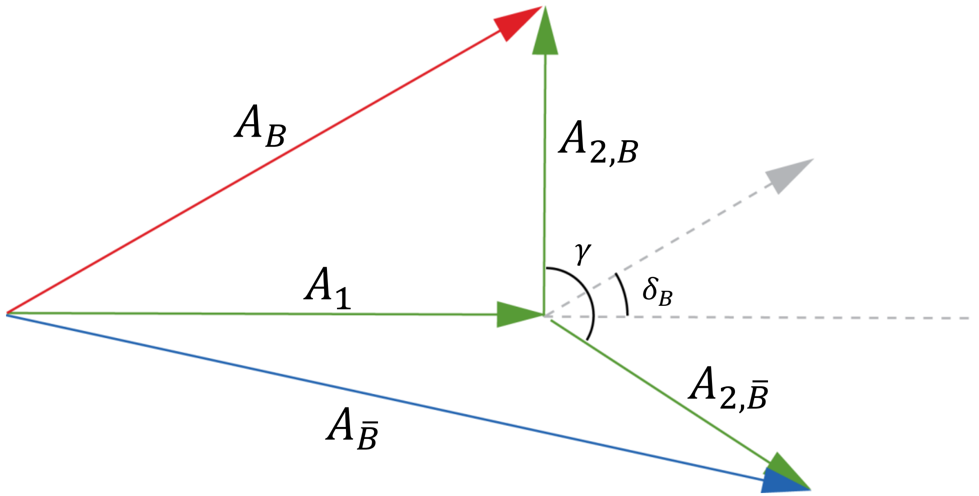


- γ is the least well known of the angles in the UT, $66 \pm 12°$.
- Accessed with $b \rightarrow u$ transitions, which are rare.
- $B^0 \rightarrow D^0 K^{*0}$ gives a tree-level/SM determination of γ.

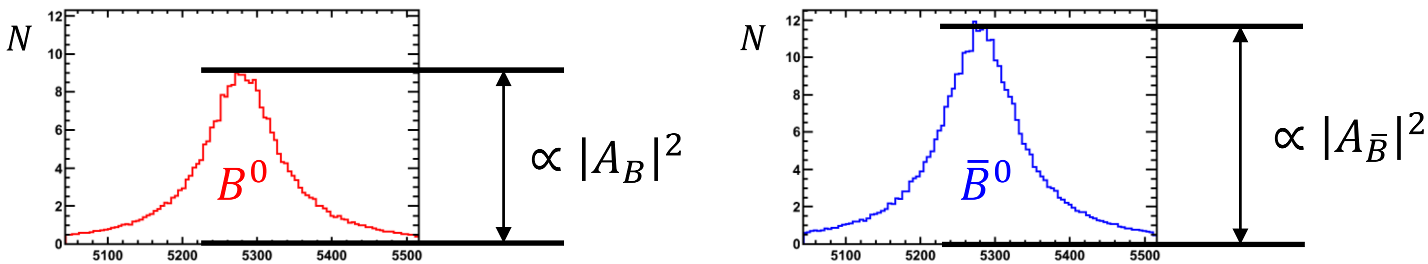
CP violation in interference



- Common final state f_D of $\overline{D^0}K^{*0}$ and $D^0K^{*0} \longrightarrow$ interference.
- Weak phase difference $= \gamma$.
- CP invariant strong phase difference $= \delta_B$.



$|A_B| \neq |A_{\bar{B}}| \Rightarrow$ CP violation



- Charge conjugate process has different amplitude.
- Measure γ from the different decay rates.

CP Observables

We Measure

$$R_{CP+} = \frac{\Gamma(\bar{B}^0 \to D(KK)\bar{K}^{*0}) + \Gamma(B^0 \to D(KK)K^{*0})}{\Gamma(\bar{B}^0 \to D(K^-\pi^+)\bar{K}^{*0}) + \Gamma(B^0 \to D(K^+\pi^-)K^{*0})}$$

$$A_{CP+} = \frac{\Gamma(\bar{B}^0 \to D(KK)\bar{K}^{*0}) - \Gamma(B^0 \to D(KK)K^{*0})}{\Gamma(\bar{B}^0 \to D(KK)\bar{K}^{*0}) + \Gamma(B^0 \to D(KK)K^{*0})}$$

Relation to physics parameters:

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

$$A_{CP+} = \frac{2r_B\kappa sin\delta_B sin\gamma}{R_{CP+}}$$

δ_B = strong phase difference.
r_B = amplitude ratio.
κ = coherence factor.
γ = CKM angle.

- Not sensitive to γ independently yet.
- Can provide input when combined with other LHCb analyses.

Analysis Summary:

- Rectangular cut based selection, optimised for the $B^0 \to D(KK)K^{*0}$ signal.
- Simultaneous fit to the B^0 invariant mass.

Backgrounds:

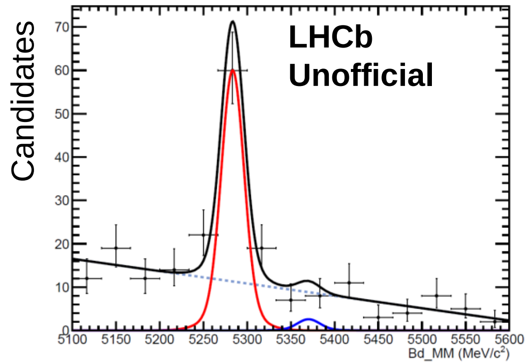
- $B \to D_{(s)}h$
- $\Lambda_b \to D^0 ph$

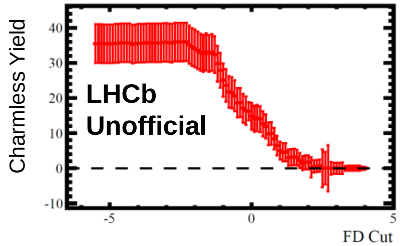
Excluded with cuts

- $B^0 \to KKK^{*0}$

Charmless Background

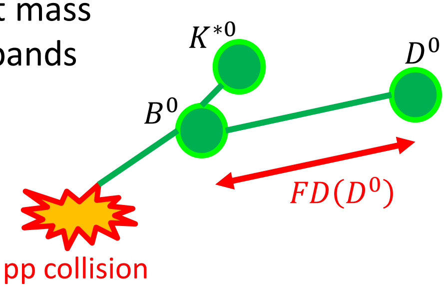
- $B_d^0 \to D\rho^0$
- $B_{(s)}^0 \to D^* K^{*0}$



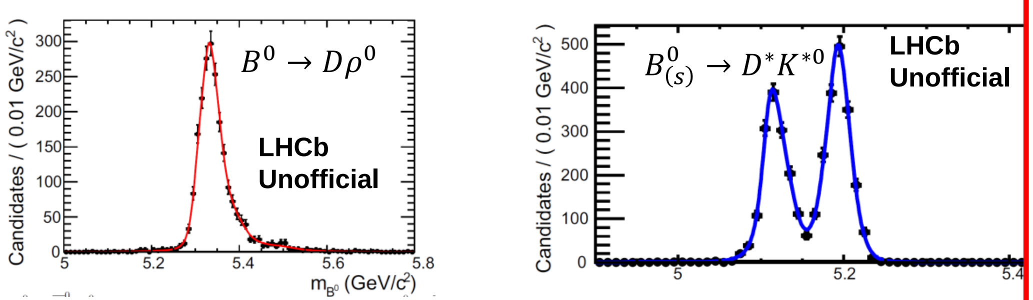


Reduced this yield to 0 with cut on D^0 flight distance.

B^0 invariant mass in D^0 sidebands

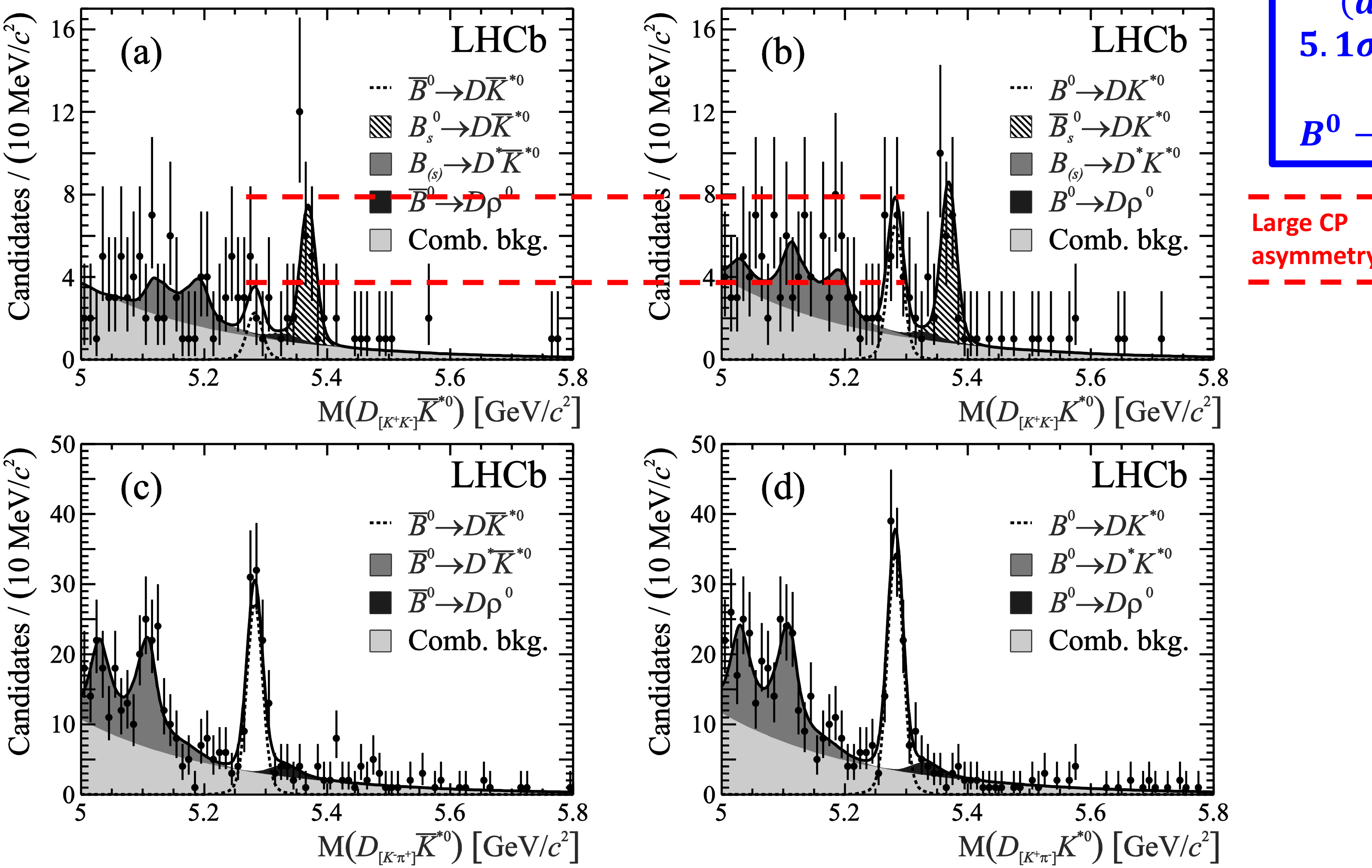


Modelled



2011 Dataset = $1 fb^{-1}$

$(a) + (b) =$ **5.1σ observation of $B^0 \to D(KK)K^{*0}$**



[JHEP **1303** (2013) 067]

Systematics and Results

Sources of systematic uncertainty:

- Production asymmetry.
- Trigger efficiency.
- Particle ID efficiency.
- Selection efficiency.
- Fit-related effects.
- Branching ratios.

External Input

Data-driven Calibration

Monte Carlo

Toy Experiments

Sources of systematic uncertainty:

- Production asymmetry.
- Trigger efficiency.
- Particle ID efficiency.
- Selection efficiency.
- Fit-related effects.
- Branching ratios.

External Input

Data-driven Calibration

Monte Carlo

Toy Experiments

$$A_{CP+} = -0.45 \pm 0.23\ (stat) \pm 0.02\ (syst)$$

$$R_{CP+} = 1.36^{+0.37}_{-0.32}\ (stat) \pm 0.07\ (syst)$$

[JHEP **1303** (2013) 067]

Future plans

What's missing? → **ADS observables** from $\boldsymbol{B^0 \to D^0(K^+\pi^-)K^{*0}}$

$$R_{ADS} = r_B^2 + r_f^2 + 2r_B r_f \cos(\delta_B + \delta_f) cos\gamma$$

$$A_{ADS} = \frac{2r_B r_f \kappa\, sin(\delta_B + \delta_f) sin\gamma}{R_{ADS}}$$

- Measured with non-CP eigenstate D^0 final states.
- r_f and δ_f depend on the final state.
- Potentially larger interference effects.
- Requires suppressed $D^0 \to K^+\pi^-$.

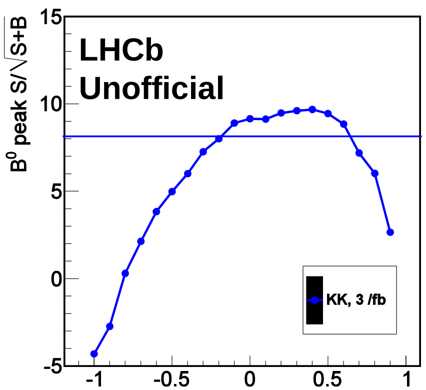
Future plans:

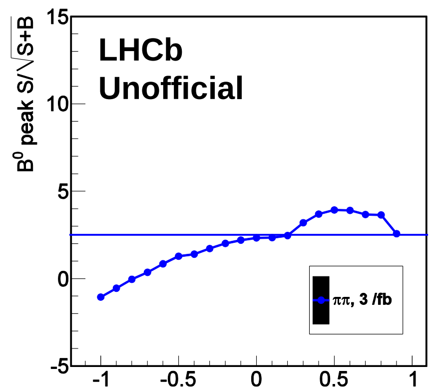
- ADS observables give sensitivity to γ → search for the suppressed mode.
- Move to a multi-variate selection.
- Additional constraints on A_{CP+} and R_{CP+} from $B^0 \to D(\pi\pi)K^{*0}$.

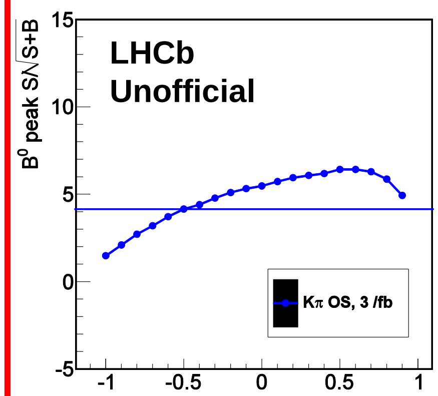
Sneak preview

BDT Performance

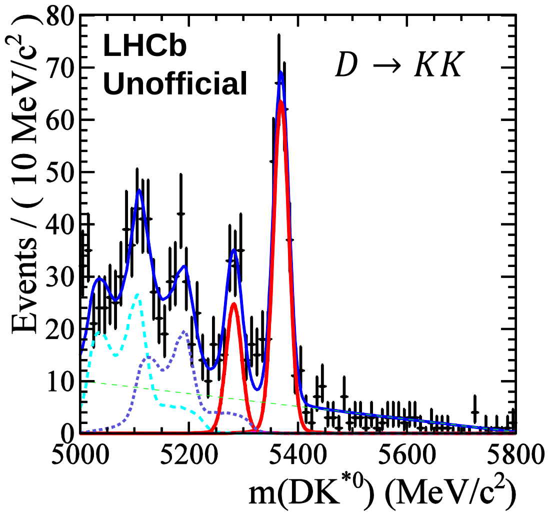
(relative to rectangular cuts)

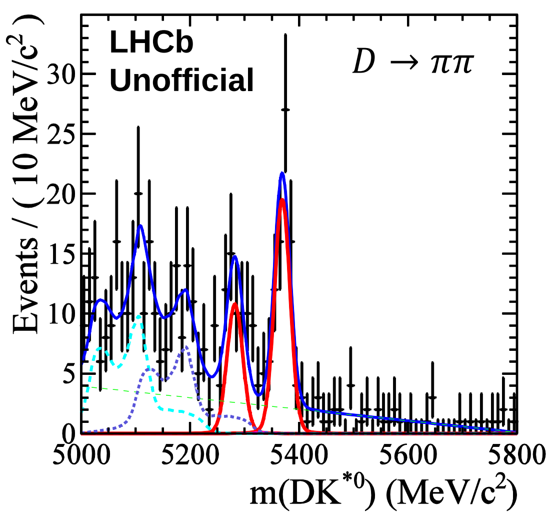






Suppressed ADS mode



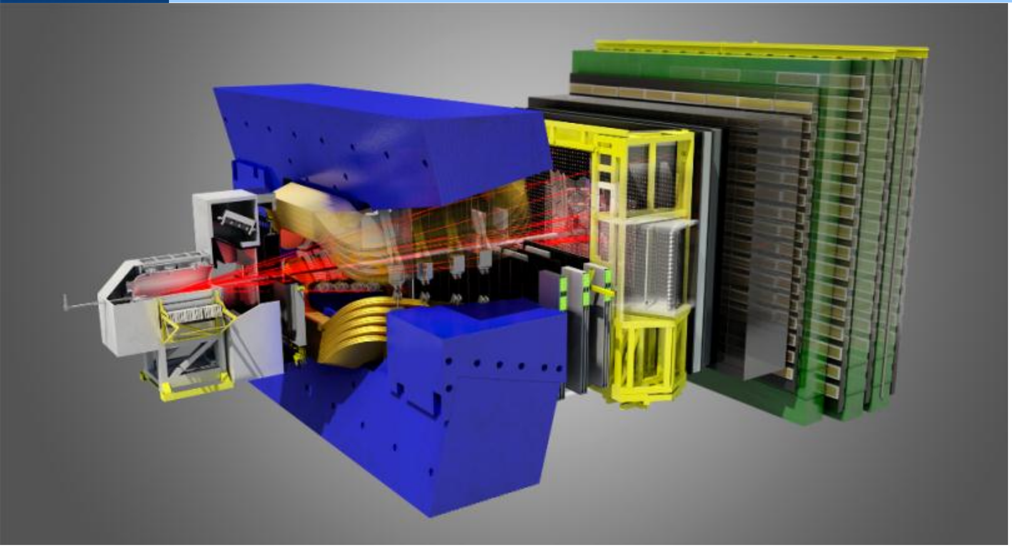


$$\frac{(B \to D(KK)K^{*0})}{N_{2011+2012} = 3.1 \times N_{2011}}$$

$$2fb^{-1}\ 8TeV + 0.9fb^{-1}\ 7TeV$$

BACKUP

LHCb Detector



Datasets:

- 2011: $1fb^{-1}$ collected (published analysis).
- 2012: $2fb^{-1}$ collected (analysis in progress).

Detector:

- Trigger is 30% efficient for multibody hadronic final states.
- Makes use of unique detector elements e.g. RICH and VELO.

Acceptance

- pseudorapidity: $2 < \eta < 5$

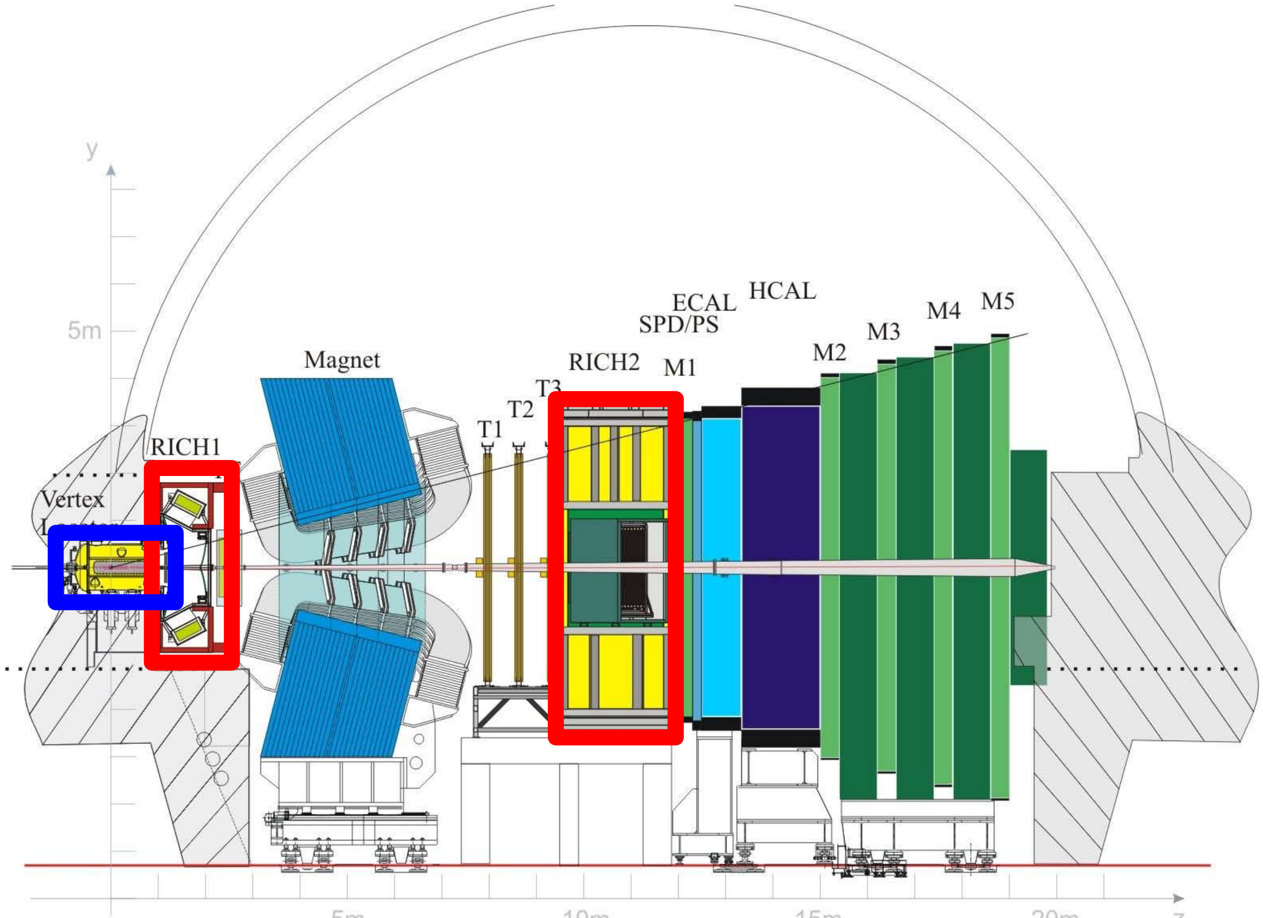
Resolutions

- momentum resolution: $\Delta p / p$ = 0.4 % at 5 GeV/c to 0.6 % at 100 GeV/c
- ECAL resolution (nominal): 1 % + 10 % / $\sqrt{E[\mathrm{GeV}]}$
- impact parameter resolution: 20 μm for high-pT tracks
- invariant mass resolution: ~8 MeV/c^2 for $B \rightarrow J/\psi\, X$ decays with constraint on J/ψ mass ~22 MeV/c^2 for two-body B decays ~100 MeV/c^2 for $B_s \rightarrow \phi\, \gamma$, dominated by photon contribution
- decay time resolution: 45 fs for $B_s \rightarrow J/\psi\, \phi$ and for $B_s \rightarrow D_s\, \pi$

Efficiencies

- percentage of working detector channels: ~ 99 % for all sub-detectors
- data taking efficiency: > 90 %
- data good for analyses: > 99 %
- trigger efficiencies: ~ 90 % for dimuon channels ~ 30 % for multi-body hadronic final states
- track reconstruction efficiency: > 96 % for long tracks
- electron ID efficiency: ~ 90 % for ~ 5 % $e \rightarrow h$ mis-id probability
- kaon ID efficiency: ~ 95 % for ~ 5 % $\pi \rightarrow K$ mis-id probability
- muon ID efficiency: ~ 97 % for 1-3 % $\pi \rightarrow \mu$ mis-id probability

- Huge $b\bar{b}$ cross section at the LHC.
- **VELO** – displaced vertex reconstruction.
- **RICH** – final state hadron identification.



Selection

Kinematic selection:

- $p_T(h_D) > 400MeV$
- $p_T(h_{K^{*0}}) > 300MeV$
- $Vertex\chi^2(B^0) < 4$
- $Vertex\ \chi^2(D^0) < 5$
- Flight distance significance > 2.5
- $Min\ IP\ \chi^2\ (K^{*0}) > 25$
- $Min\ IP\ \chi^2\ (D^0) > 4$
- $Min\ IP\ \chi^2\ (B^0) < 9$
- $\cos(\theta_{dira})(B^0) > 0.99995$
- $\Sigma_{tracks}\sqrt{IP\chi^2} > 32$
- $\left|M(D^0) - M_{pdg}(D^0)\right| < 20MeV$
- $\left|M(K^{*0}) - M_{pdg}(K^{*0})\right| < 50MeV$
- $|\cos(\theta^*)| > 0.4$
- $\left|M(K\pi\pi) - M_{pdg}(D^+)\right| > 15MeV$
- $\left|M(KK\pi) - M_{pdg}(D_s^+)\right| > 15MeV$

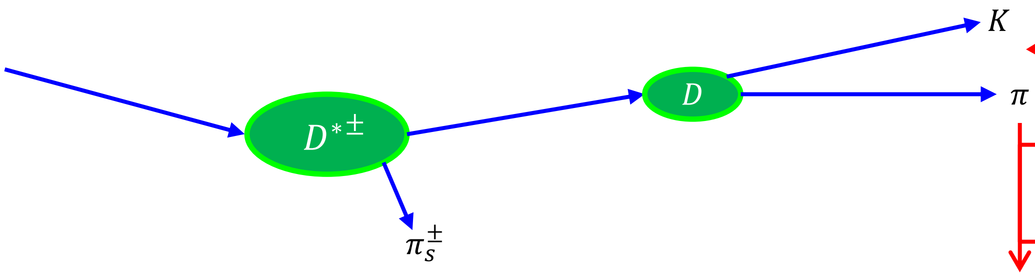
Particle ID:

- D→Kπ
- $DLL_{K\pi}(K_D) > 0$
- $DLL_{K\pi}(\pi_D) < 4$
- D→KK
- $DLL_{K\pi}(K_D) > 0$
- ALL
- $DLL_{K\pi}(\pi_{K^{*0}}) < 3$
- $DLL_{K\pi}(K_{K^{*0}}) > 3$
- $DLL_{pK}(K_{K^{*0}}) < 10$

Multiple Candidate Removal: Keeping candidate with largest FDCHI2 of the B.

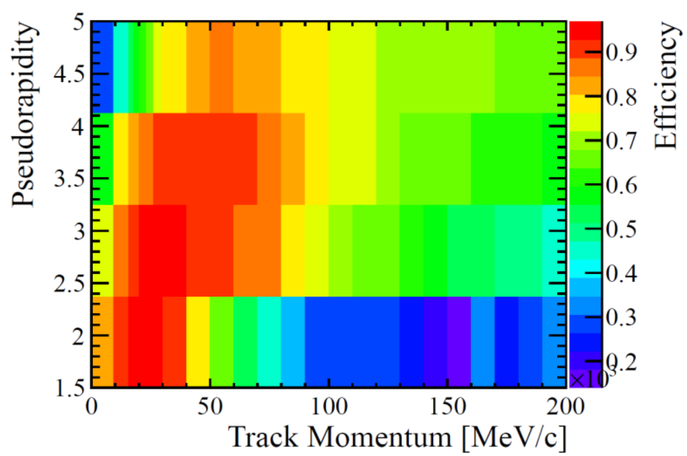
Particle ID calibration

Calibration sample:

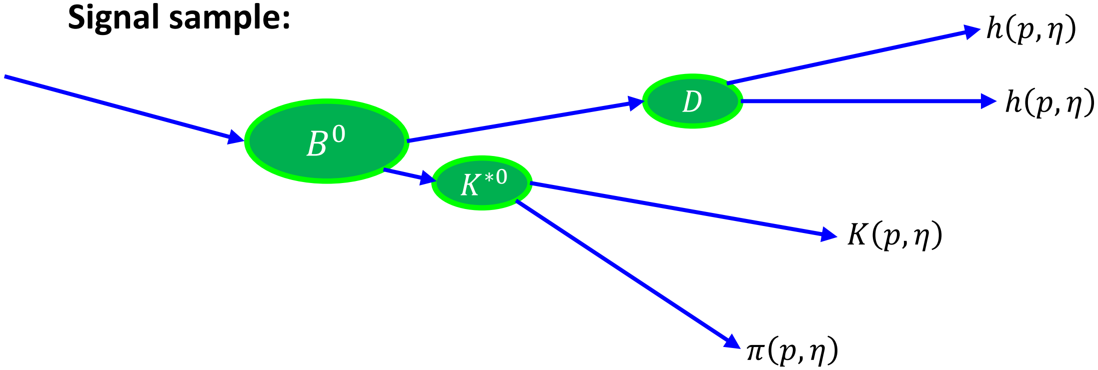


- Can identify these from their charges.
- No PID required.
- Pure samples of real Ks and πs.

- Apply PID cut.
- Bin efficiency in kinematic variables.



Signal sample:



- Calibration histogram for each track.
- Efficiency taken from the histograms according to decay kinematics.
- Takes into account correlations between tracks in multi-body final states.

Production asymmetry

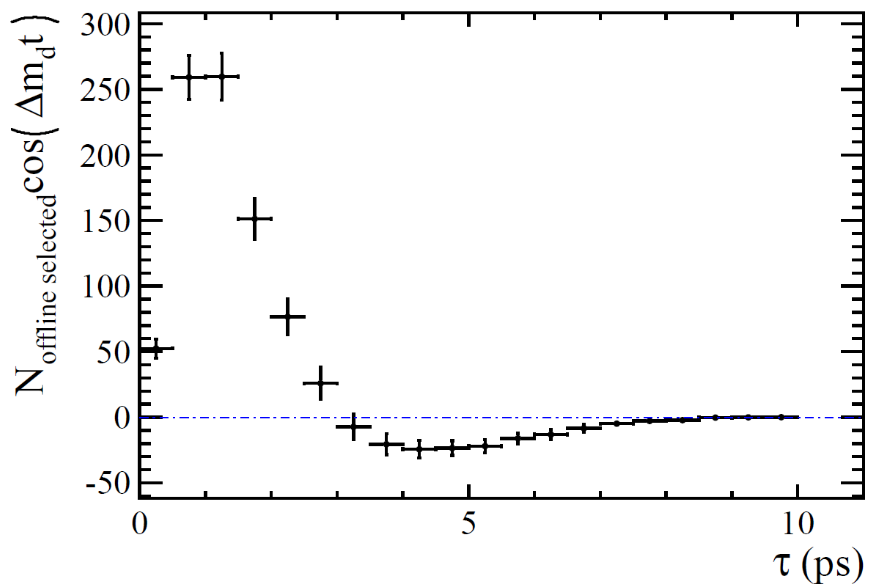
Correction factor

$$a^{d}_{prod} = \frac{1-\kappa A_{prod}}{1+\kappa A_{prod}}$$

Dilution due to mixing

$$\kappa(B^0 \to \bar{D}^0 K^{*0}) = \frac{\int_0^{+\infty} e^{-\Gamma_d t}\cos(\Delta m_d t)\epsilon_{B^0\to\bar{D}^0K^{*0}}(t)dt}{\int_0^{+\infty} e^{-\Gamma_d t}\cosh\left(\frac{\Delta\Gamma_d t}{2}\right)\epsilon_{B^0\to\bar{D}^0K^{*0}}(t)dt}$$

$$\kappa(B^0 \to \bar{D}^0 K^{*0}) = \frac{1}{N_{offline\ total}}\int_0^{+\infty} \boxed{\cos(\Delta m_d t)N_{offline\ selected}(t)dt}$$



$$\boxed{A_{prod} = 0.010 \pm 0.013}$$

External Input

$$\boxed{\kappa = 0.456 \pm 0.011}$$

- Monte Carlo for kinematic acceptance.
- Data-driven calibration for PID acceptance.