D^0-$\overline{D}^0$ mixing and CP violation at LHC

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on behalf of the LHCb collaboration

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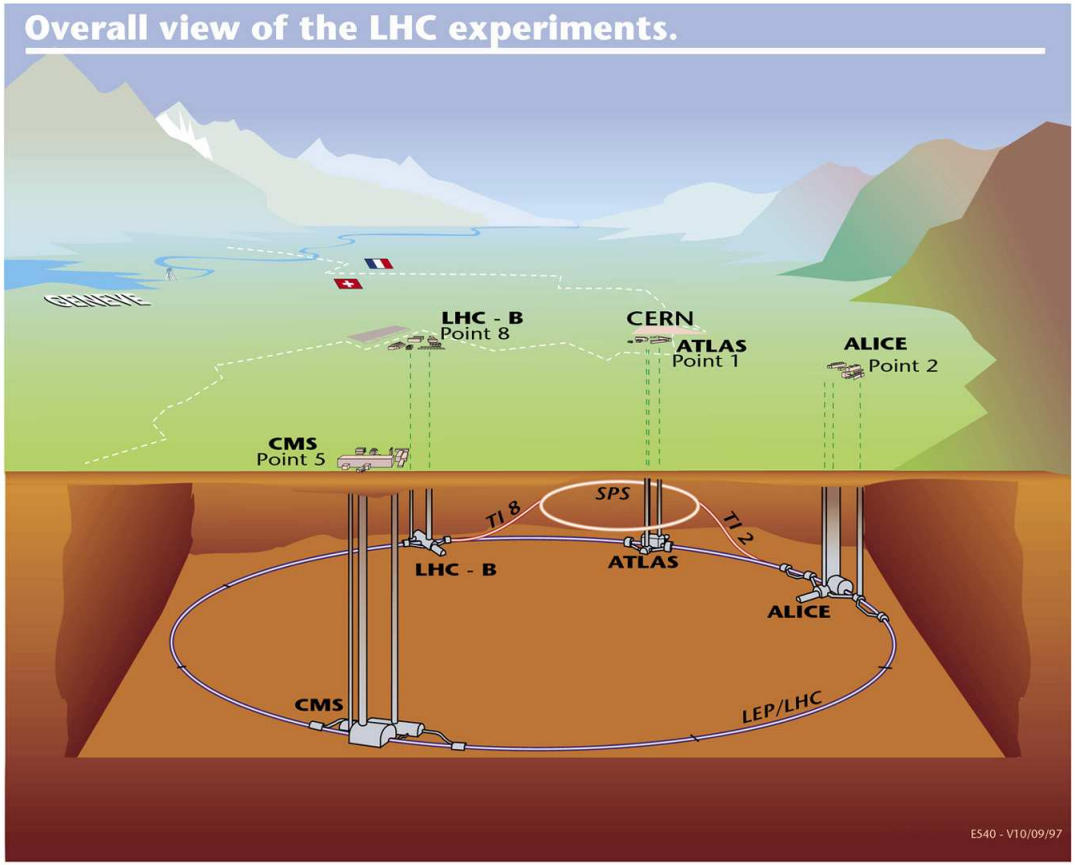
Outline

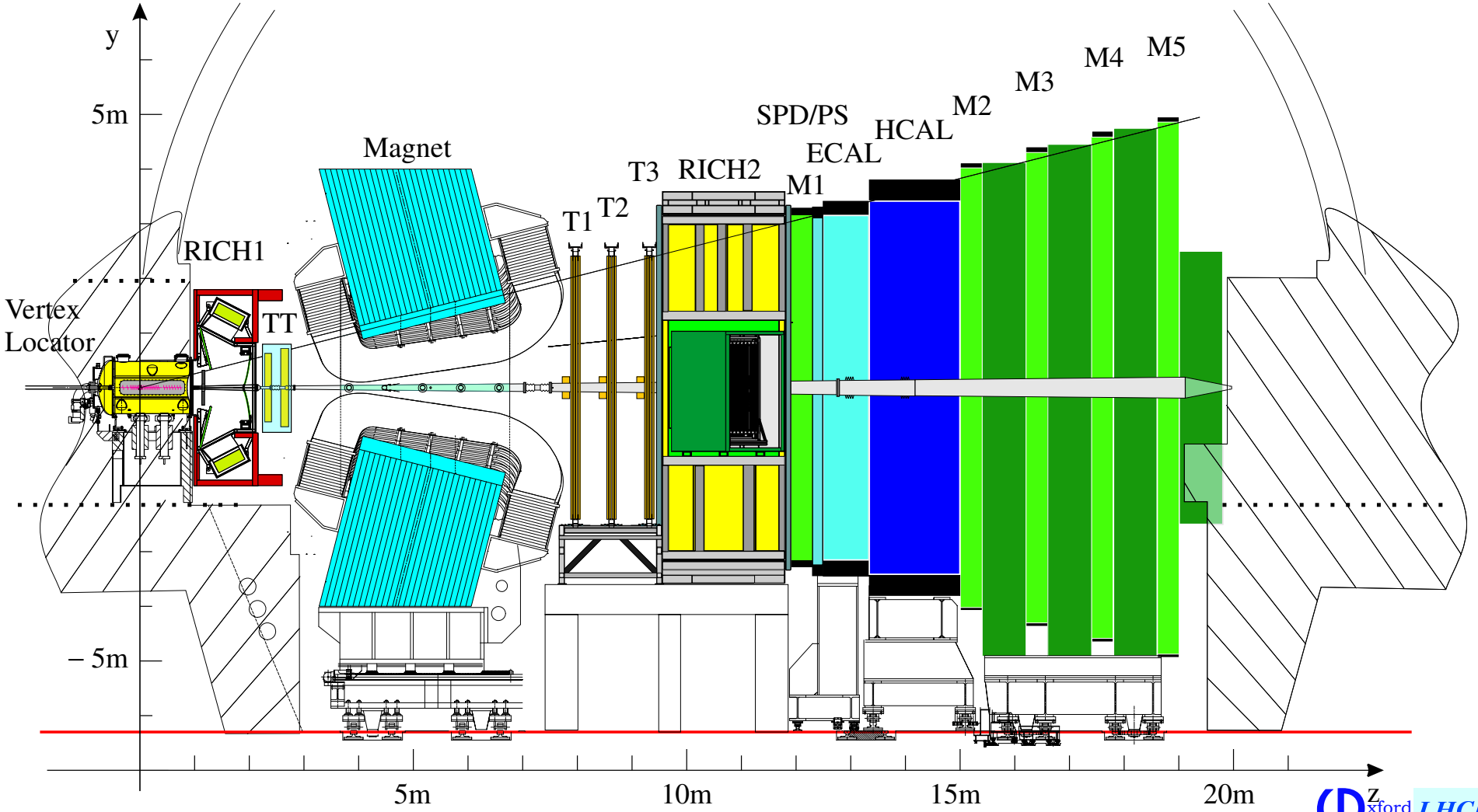
1. LHCb detector
   - LHC
   - LHCb
2. The LHCb trigger
   - Trigger structure
   - Sources of charm
3. CP violation searches
   - Introduction
   - Prompt charm
4. D^0-$\overline{D}^0$ mixing
   - Overview
   - Creation vertex
   - Mixing sensitivity studies

Outline

Large Hadron Collider



LHCb detector



LHCb features

- The features that make LHCb excellent for B physics also make it a good charm physics experiment
- High event rate
- Excellent vertexing and proper time resolution: $\sim 45\,\mathrm{fs}$ for secondary D^0
- Good tracking and momentum resolution: $\sim 6\,\mathrm{MeV}$ D^0 mass
- Excellent K-π discrimination

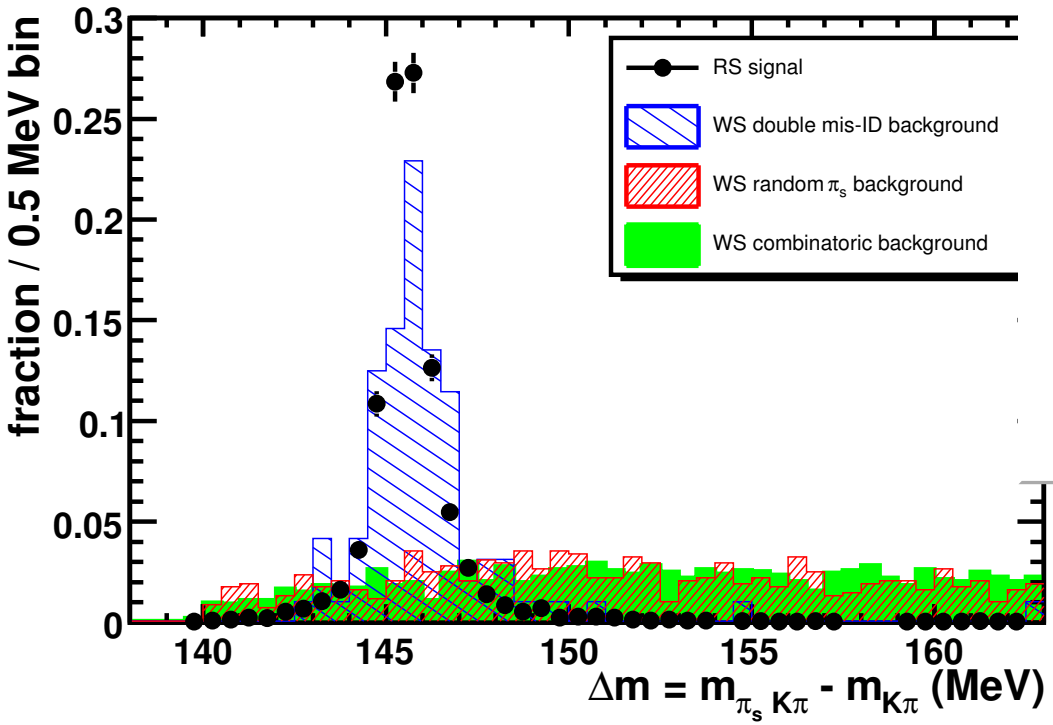
Outline

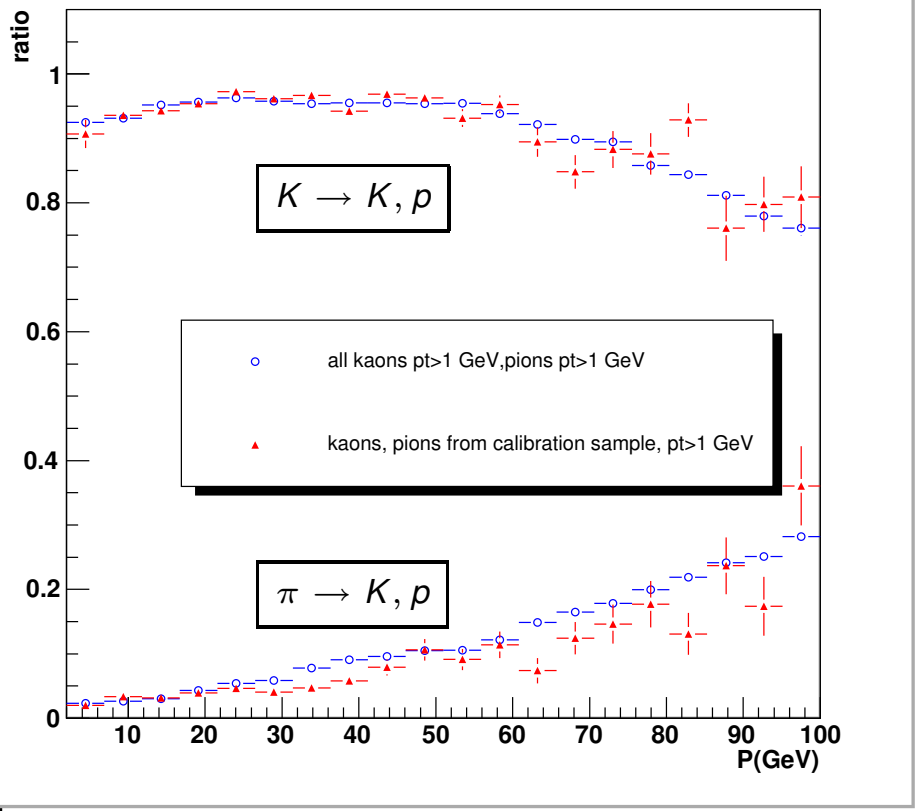
LHCb trigger

- L0 hardware trigger — high p_t particles
  - Including Calorimeter hadrons $E_t >\sim 3.5\,\mathrm{GeV}$; Muon $p_t >\sim 1.5\,\mathrm{GeV}$
  - Input $40\,\mathrm{MHz} \rightarrow 1\,\mathrm{MHz}$ output
  - Efficiently favors $b\bar{b}$ events over prompt charm
- HLT1 first stage software trigger
  - Parallel trigger paths: 'alleys'
  - Partial reconstruction of limited detector information
  - Fast identification of general B event features
    - High p_t particles (hadrons, muons, electrons, and photons)
    - Charged tracks with sizable impact parameter
- HLT2 second stage software trigger
  - Channels for specific interesting decays
  - Fast final state candidate reconstruction
  - Composite decay chain reconstruction, e.g., $D^{*+} \rightarrow \pi_s^+ D^0 (h^- h^+)$
- 2 kHz total output rate
  - Potentially up to 300 Hz for D^*/charm

Uses of LHCb D^{*+} trigger

Charm physics





RICH calibration

Two sources of charm

- B decays ($B \to D^{(*)} X$)
  - \+ Strongly favored by LHCb triggers
  - \+ Potentially less background
  - \- New techniques need to be developed—no published measurements
- Prompt production in primary interaction
  - 0 Triggered less efficiently—compensated by prolific production
  - \- Potentially larger backgrounds
  - \+ CDF has proven that measurements are possible in hadronic environment

Outline

CP violation searches

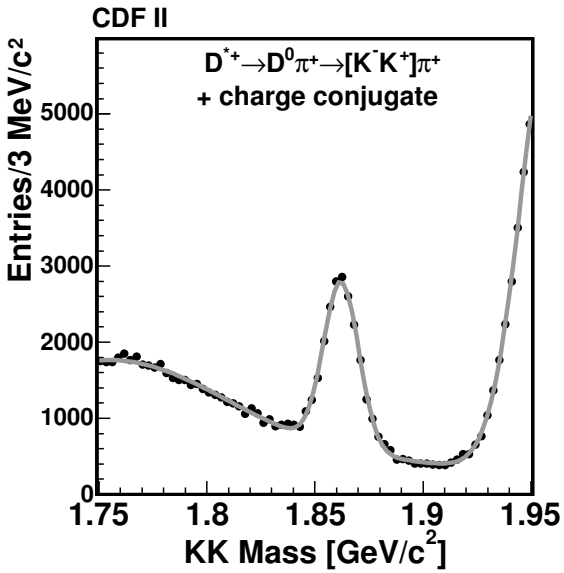
Looking for unambiguous signs of New Physics in as many channels as possible

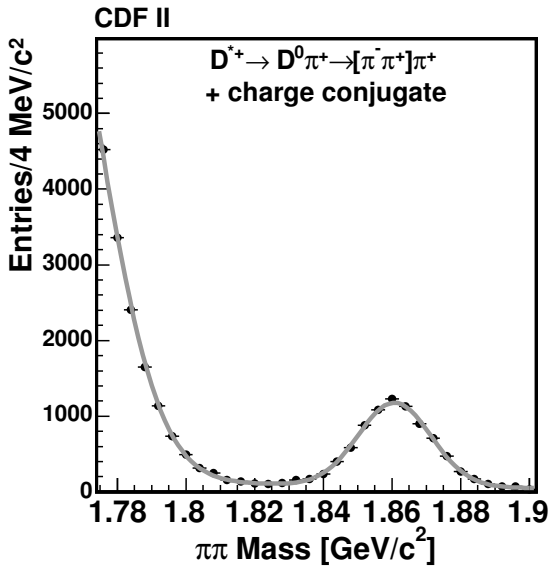
(A vital part of any charm physics program)

- Both time integrated and time dependent CPV searches
- Two body $K\pi$, K^-K^+, and $\pi^-\pi^+$ modes
- Three body charged and neutral decays
  - Amplitude analyses
  - $D^0 \to K_S\pi^+\pi^-, K_SK^+K^-, K_SK\pi$; $D^+ \to K^+K^-\pi^+, K\pi\pi$
- Four body decays
  - Quantities odd under T
  - Amplitude analyses (analysis code already exists in LHCb)
  - $D^0 \to K^+K^-\pi^+\pi^-, K\pi\pi\pi$

CPV in $D^0 \to K^-K^+$ (and $\pi^-\pi^+$)

	Data set	$N(K^-K^+)$	$A_{CP}(K^-K^+)(\%)$
Belle	$540\,\text{fb}^{-1}$	120×10^3	$-0.43 \pm 0.30 \pm 0.11$
BaBar	$386\,\text{fb}^{-1}$	130×10^3	$0.00 \pm 0.34 \pm 0.13$
CDF	$123\,\text{pb}^{-1}$	16×10^3	$2.0 \pm 1.2 \pm 0.6$
HFAG Avg			-0.16 ± 0.23
LHCb	$10\,\text{fb}^{-1}$	8×10^6	$A_{CP} \pm 0.04\,(\text{stat})^*$





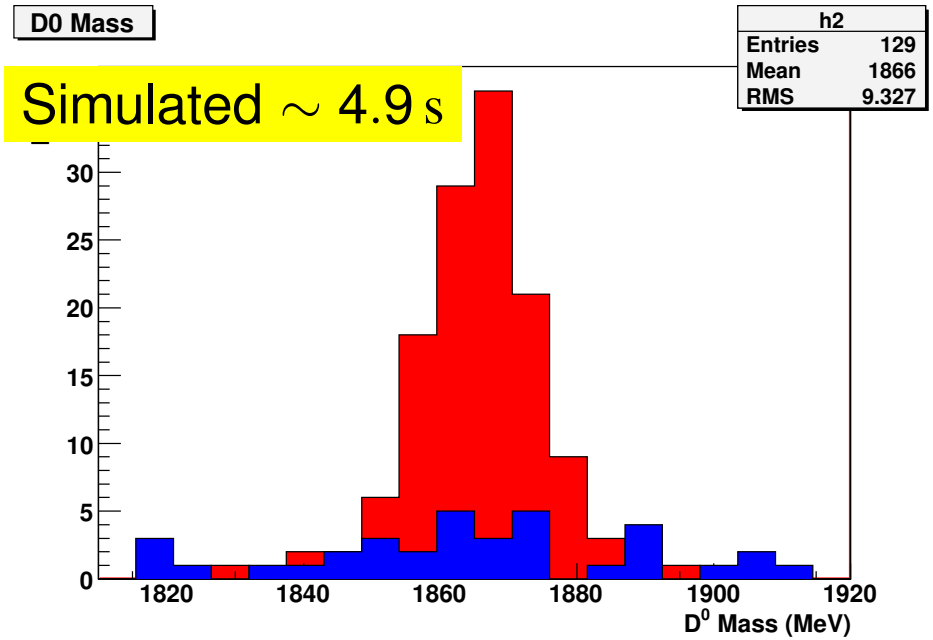
* from secondary D^{*+}

Similar analysis with
$D^0 \to \pi^-\pi^+$

CDF direct CPV search

Developments with prompt charm

Preliminary selection with promptly produced D^0 show promise.



Prompt RS signal (red) and background (blue) in simulated minimum bias events after L0 trigger.

- Preliminary selection for prompt $D^0 \to hh'$
- Selection rates after L0 trigger:
  - $D^0 \to K^-\pi^+$ (RS): $\sim 23\,\mathrm{Hz}$
  - $D^0 \to K^-K^+$: $\sim 2\,\mathrm{Hz}$
- Reasonable backgrounds
  - Preliminary $S/B \approx 5$
  - Random π_s background under control
    - $S/B(\mathrm{Rnd}\ \pi_s) \approx 9$
  - Promising tagging purity for CPV measurements

Prompt charm sample

Estimated selection yields in $10\,\mathrm{fb}^{-1}$

$10\,\mathrm{fb}^{-1}$ Yield:	Secondary selection	Prompt selection
$K^-\pi^+$ RS	62×10^6 †	1200×10^6 ‡
K^-K^+	8×10^6 †	100×10^6 ‡

† Secondary yield estimates include L0 and HLT. Selection optimized for WS π^-K^+, and may not be optimal for K^-K^+.

‡ Prompt yield estimates include L0, but do not include HLT.

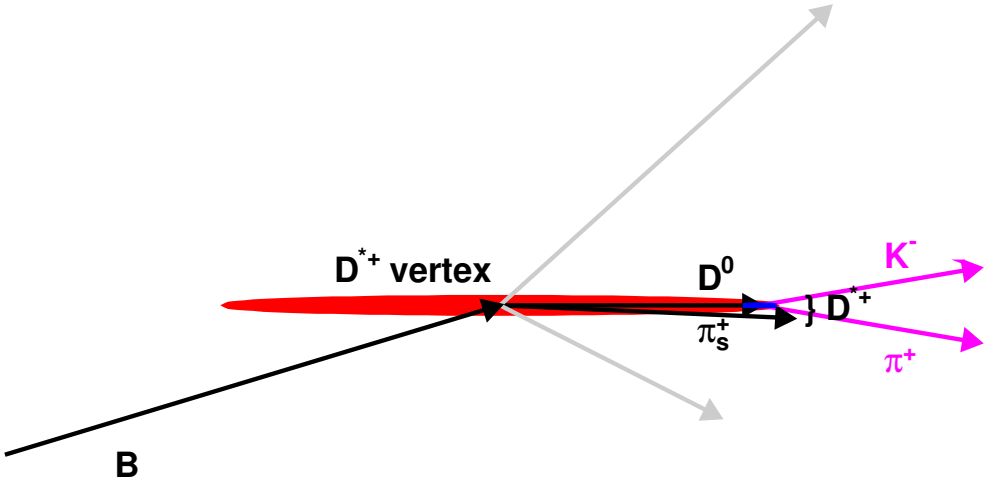
- Selection of prompt $D^0 \to K^-K^+$ for
  - Tagged CPV measurement
  - Tagged and Untagged y_{CP} measurements
- Lifetime measurements
  - Use precisely estimated primary vertex
  - Acceptance effects can be derived in data
- Efficient implementation in HLT under study.

Outline

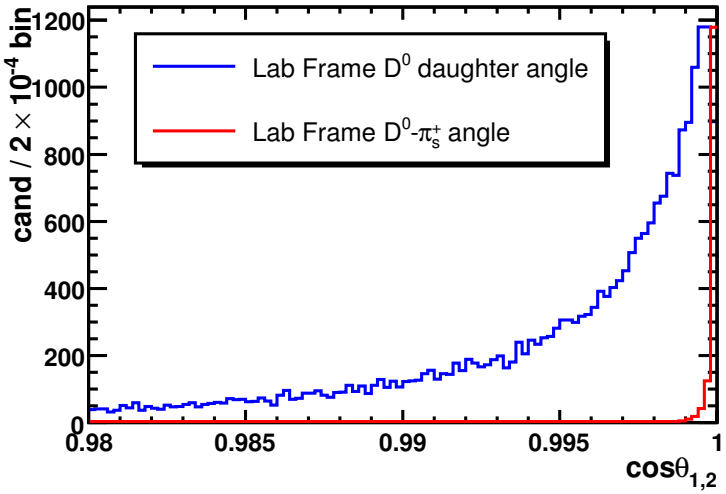
Mixing measurements at LHCb

- Precise mixing measurements
  - Measure CP violation in mixing
  - Determine relative values of x and y—dominant mixing processes
- WS $D^0 \to \pi^- K^+$ mixing analysis
  - Sensitive to x'^2 and y'
  - BaBar 3.9σ evidence, CDF 3.8σ evidence
  - Requires measurement of strong phase δ by CLEO / BES-III
- Two body lifetime ratio measurement of y_{CP}
  - SCS $D^0 \to K^- K^+$ and $\pi^- \pi^+$
  - Belle $3.2\,\sigma$ evidence, BaBar $3\,\sigma$ evidence
- Amplitude analysis of $D^0 \to K_S \pi^+ \pi^-$
  - Sensitive to x and y. Powerful technique used by CLEO and Belle
- Mixing measurements in $D^0 \to 4h$
  - Preliminary: up to 25×10^6 RS $D^0(4h)$ events per $2\,\mathrm{fb}^{-1}$ to tape
  - 4-body amplitude analysis already in development at LHCb

D^* vertex resolution



Signal MC lab frame angles



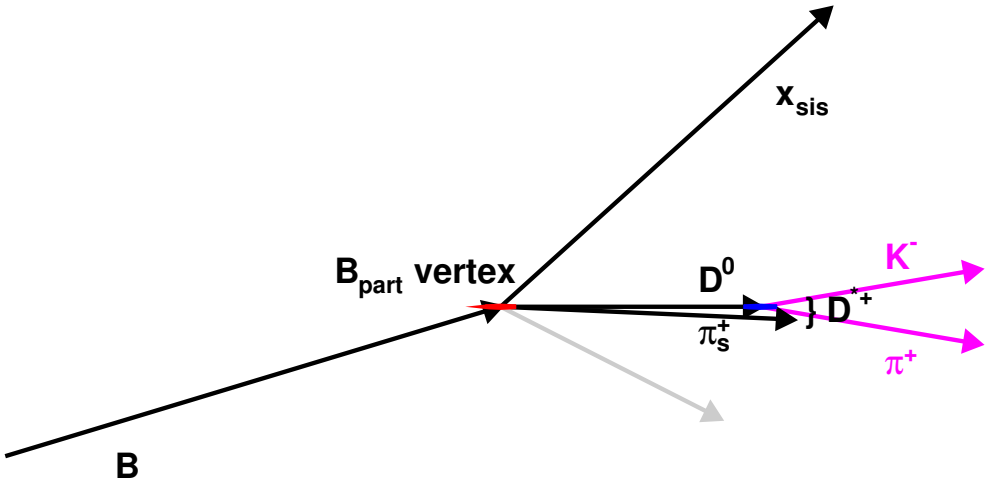
Decay vertex resolutions

	D^0	D^{*+}
x	21.6 μm	187. μm
y	16.9 μm	144. μm
z	257. μm	4232. μm
τ	0.465 ps	

- D^0 and π_s^+ almost collinear
- Add tracks at birth vertex

D^0 flight distance at 60 GeV:
$\beta\gamma c\tau \approx 4$ mm

Birth vertex improvement for secondary charm

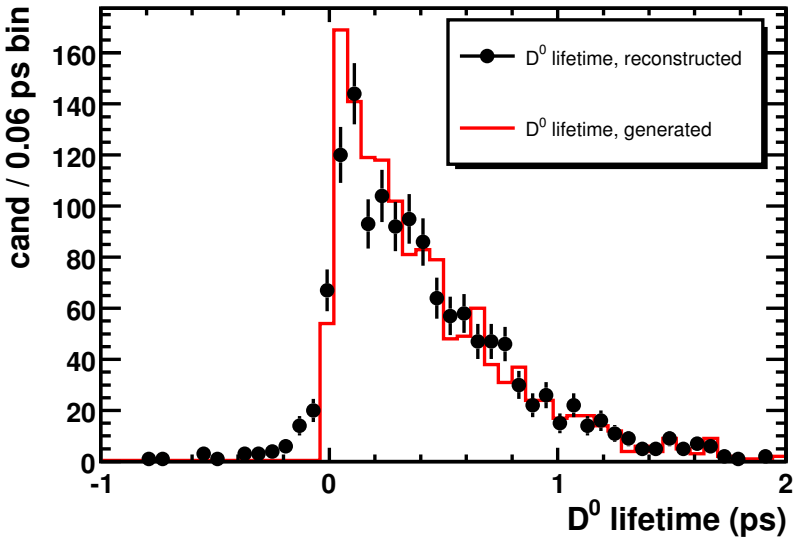


- Use additional tracks at production vertex
- 76% of D^{*+} from B's have at least one charged sister
- Use 1 additional track to partially reconstruct parent B

Decay vertex resolutions

	D^0	D^{*+}	B_{part}
x	21.6 μm	187. μm	18.1 μm
y	16.9 μm	144. μm	18.4 μm
z	257. μm	4232. μm	237. μm

Improved proper time resolution $= 0.045$ ps

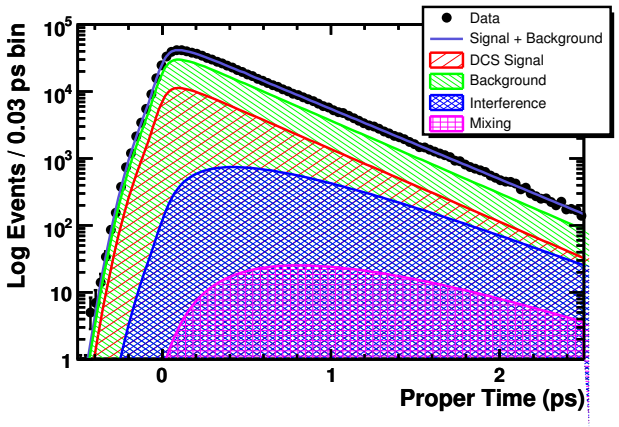


Sensitivity study of WS mixing

Investigate sensitivity to x'^2 and y' 1-D fit to proper time

$$\Gamma(t; D^0 \to \pi^- K^+) \propto e^{-\Gamma t}\left[R_D + \sqrt{R_D} y' \Gamma t + \tfrac{1}{4}(y'^2 + x'^2)(\Gamma t)^2\right]$$

- Based on secondary charm selection
- 10 fb^{-1} of simulated signal ev/toy
- Exponential background exp $(-t/\tau_{D^0})$
- Acceptance and resolution effects
- Fit to x'^2 and y'



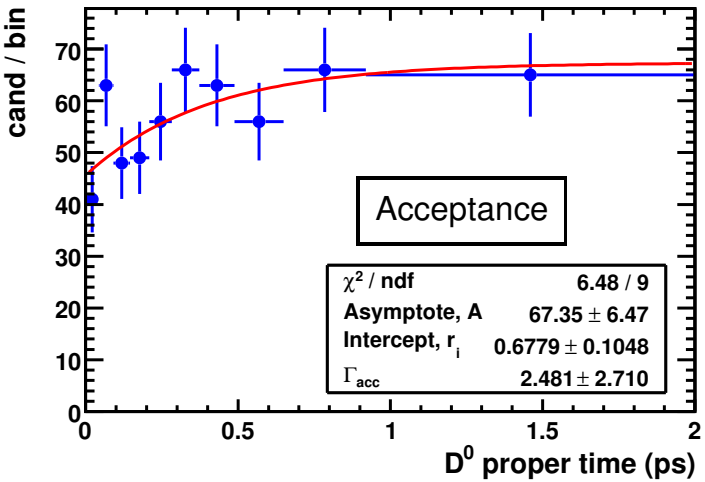
	Data set	N_{WS}	$x'^2(\times 10^{-3})$	$y'(\times 10^{-3})$
BaBar	384 fb^{-1}	4030	$-0.22 \pm 0.30 \pm 0.21$	$9.7 \pm 4.4 \pm 3.1$
Belle	400 fb^{-1}	4024	$0.18^{+0.21}_{-0.23}$	$0.6^{+4.0}_{-3.9}$
CDF	1.5 fb^{-1}	12700	-0.12 ± 0.35	8.5 ± 7.6
LHCb	**10 fb^{-1}**	**232500**	$\boldsymbol{x'^2 \pm 0.064\ (\mathrm{stat})}$	$\boldsymbol{y' \pm 0.87\ (\mathrm{stat})}$

Sensitivity study of lifetime ratio

Compare lifetimes of the non-eigenstate RS decay $D^0 \to K^-\pi^+$ and CP even decays $D^0 \to K^-K^+(\pi^-\pi^+)$

$$y_{CP} \equiv \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to (K^+K^-, \pi^+\pi^-)} - 1 = y\cos\phi - x\sin\phi \left[\frac{R_m^2 - 1}{2}\right]$$

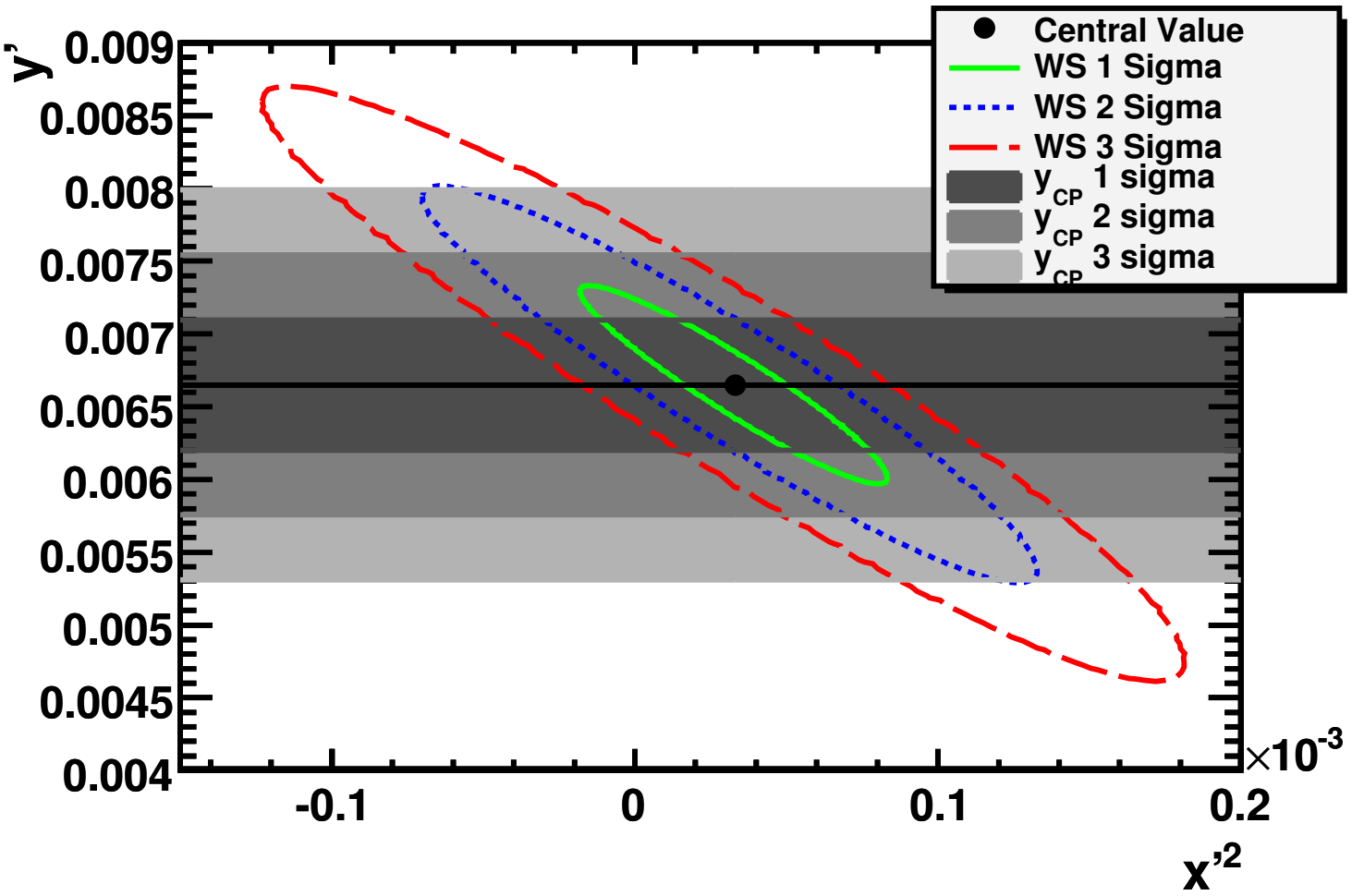
- Based on secondary charm selection
- $2\,\mathrm{fb}^{-1}$ of simulated signal ev/toy
- Exponential background $\exp(-t/\tau_{D^0})$
- Acceptance and resolution effects included



	Data set	$N(K^-K^+\pi_s^\pm)$	$y_{CP}(\%)$
Belle	$540\,\mathrm{fb}^{-1}$	111000	$1.31 \pm 0.32 \pm 0.25$
BaBar	$384\,\mathrm{fb}^{-1}$	70000	$1.03 \pm 0.33 \pm 0.19$
LHCb	$\mathbf{10\,fb^{-1}}$	$\mathbf{8 \times 10^6}$	$\mathbf{y_{CP} \pm 0.05\,(stat)}$

Summary of LHCb at 10 fb^{-1}

Toy statistical 1, 2, and 3 σ contours for secondary WS mixing (ellipses) and K^-K^+ y_{CP} studies (bars) in 10 fb^{-1} of LHCb data.



Summary

- First collisions at LHC are imminent
- LHCb will record unprecedented numbers of charm events
- Efforts are underway to exploit both prompt and secondary sources for charm physics analyses
- We look forward to making significant contributions to charm physics!