Charm Physics at LHCb

Javier Magnin

on behalf of the LHCb Collaboration

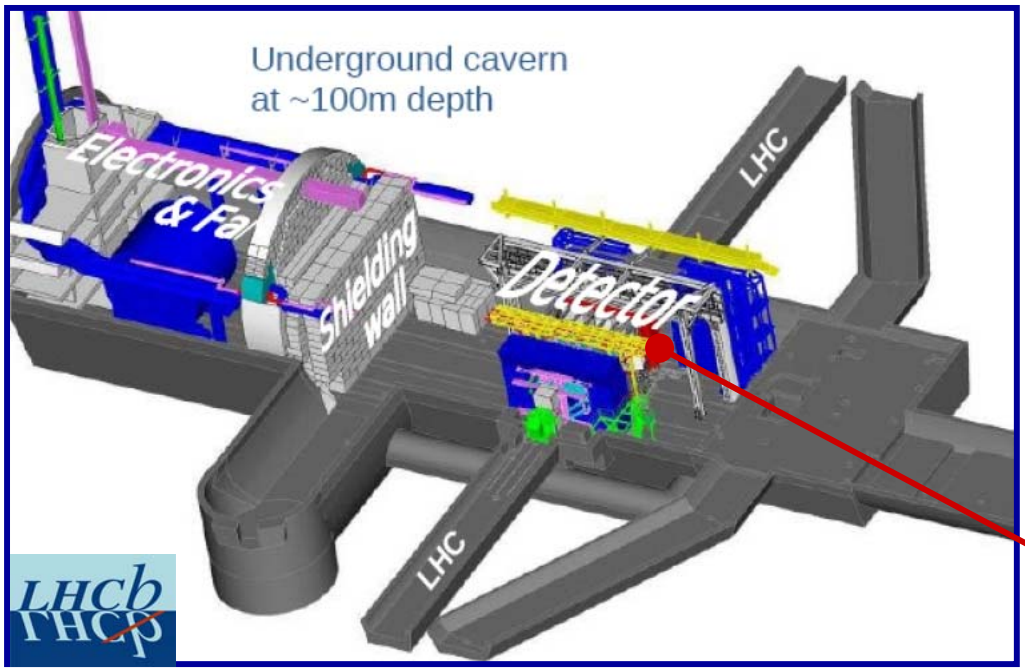
CBPF - Brazilian Center for Research in Physics



BEAUTY 2009

12TH INTERNATIONAL CONFERENCE ON B-PHYSICS AT HADRON MACHINES

SEPTEMBER 7TH - 11TH 2009, HEIDELBERG UNIVERSITY, GERMANY



E_{cm} = 14 TeV

LHCb luminosity:

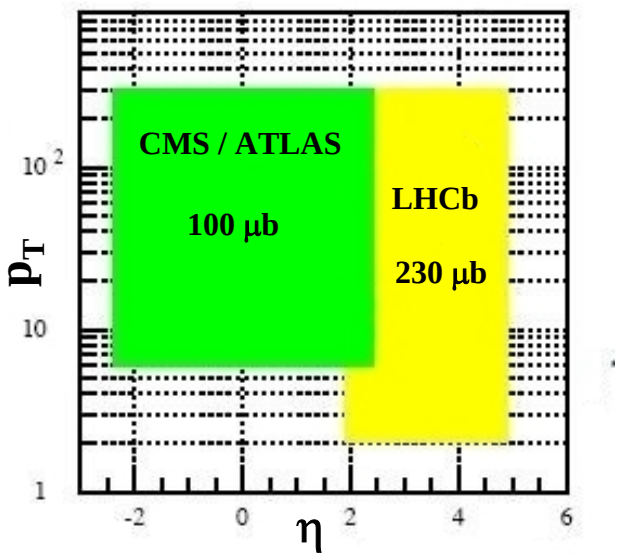
$2\text{-}5 \times 10^{32}\ cm^{-2}\ s^{-1}$

1 LHCb year:

$10^{7}\ s - \int Ldt \sim 2 fb^{-1}$

$\sigma_{c\bar{c}}$ = 8.31 mb @ 14 TeV
(Pythia)

single arm forward spectrometer
angular coverage: 10 – 250 mrad (V)
10 – 300 mrad (H)



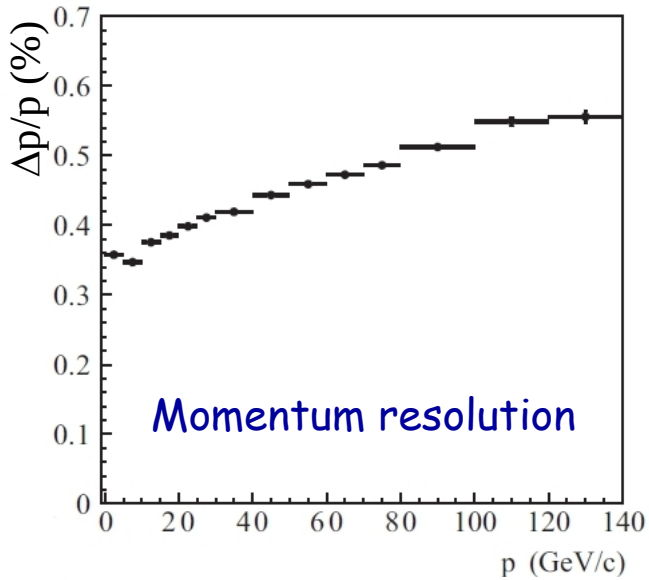
Expected operation conditions for the first year:

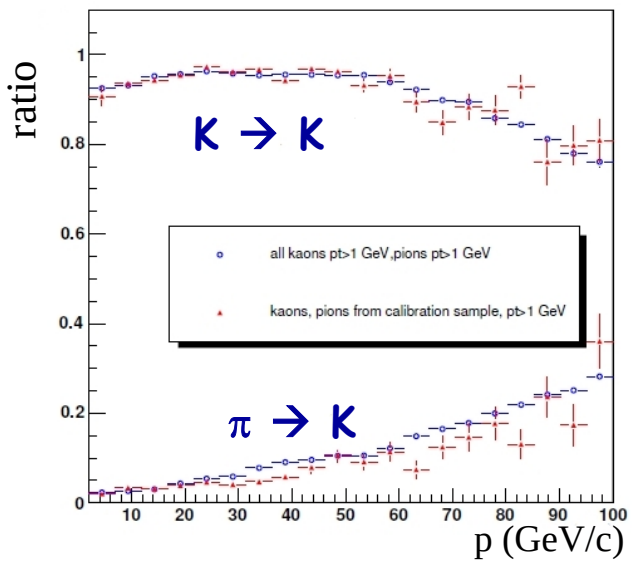
- ✓ E_{cm} = 7 – 10 TeV
- ✓ $\int Ldt \sim 100\ pb^{-1}$

LHCb optimized for B-physics → and also a good charm physics experiment

ADVANTAGES

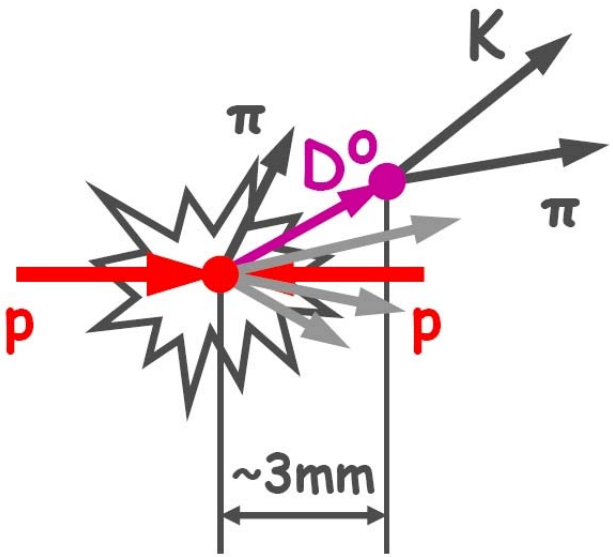
- ✓ High production cross section
- ✓ Dedicated heavy flavor trigger
- ✓ Excellent vertexing
- ✓ Proper time resolution ~ 45 fs for secondary D^0
- ✓ Good tracking and momentum resolution (~ 6 MeV for D^0 mass)
- ✓ Excellent PID
- ✓ Large rapidity range





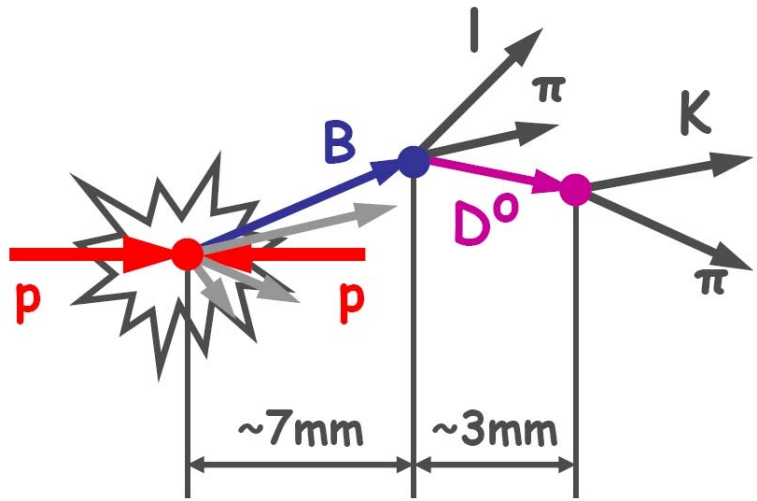
Charm physics at LHCb

prompt charm



- ✓ *generator suggest x7 wrt secondary charm at E_{cm} = 14 TeV*
- ✓ *trigger has to be simultaneously optimized for b-physics and prompt charm*
- ✓ *potentially large backgrounds*

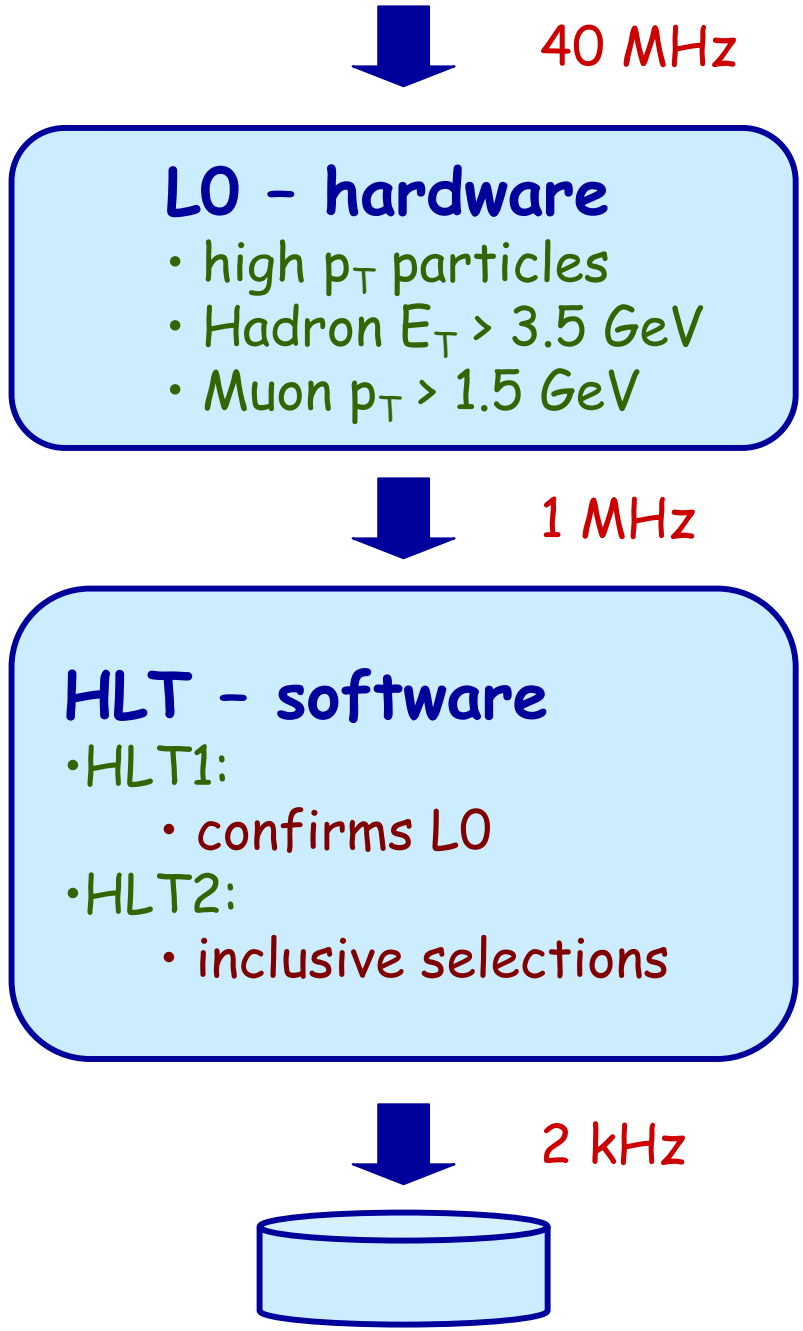
secondary charm



- ✓ *BR(B→D*±X) ~ 0.23*
- ✓ *BR(B→D⁰X) ~ 0.63*
- ✓ *BR(B→D±X) ~ 0.24*
- ✓ *potentially less background*

Ongoing studies for both prompt and secondary charm

Trigger


40 MHz
L0 – hardware
• high p_T particles
• Hadron E_T > 3.5 GeV
• Muon p_T > 1.5 GeV
1 MHz
HLT – software
•HLT1:
• confirms L0
•HLT2:
• inclusive selections
2 kHz

Trigger

Low luminosity run in 2010:

- ✓ lower p_T thresholds
- ✓ better performance for charm:
  - $\varepsilon_{L0xHLT1}(D^0 \to hh) \sim 70\%$
  - $\varepsilon_{L0xHLT1}(D^0 \to \mu\mu) \sim 92\%$
  - ...

40 MHz

L0 – hardware

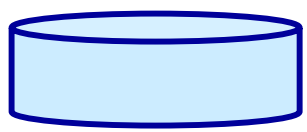
- high p_T particles
- Hadron $E_T > 3.5$ GeV
- Muon $p_T > 1.5$ GeV

1 MHz

HLT – software

- HLT1:
  - confirms L0
- HLT2:
  - inclusive selections

2 kHz



Trigger

See Leandro De Paula's talk on Friday for details

40 MHz

LO – hardware

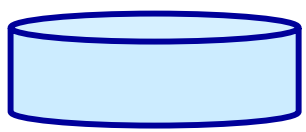
- high p_T particles
- Hadron E_T > 3.5 GeV
- Muon p_T > 1.5 GeV

1 MHz

HLT – software

- HLT1:
  - confirms L0
- HLT2:
  - inclusive selections

2 kHz



Possible 2010 bandwidth division for HLT2

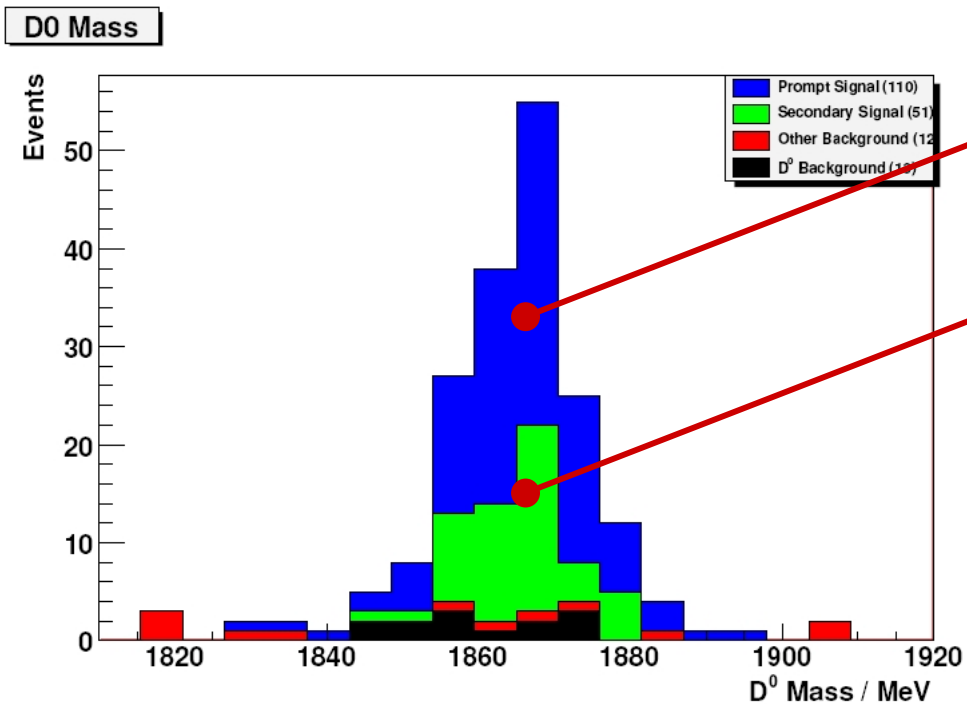
Leptons	→	30 %
Topological-B	→	20 %
Inclusive φ	→	5 %
Topo-charm	→	40 %
Min. bias	→	5 %

Fractions of band width

Estimated efficiencies
(wrt L0 x HLT1)

$D^* \rightarrow D^0(hh)$	86%
$D^* \rightarrow D^0(K_s\pi\pi)$	13%
$D^+ \rightarrow KK\pi$	65%

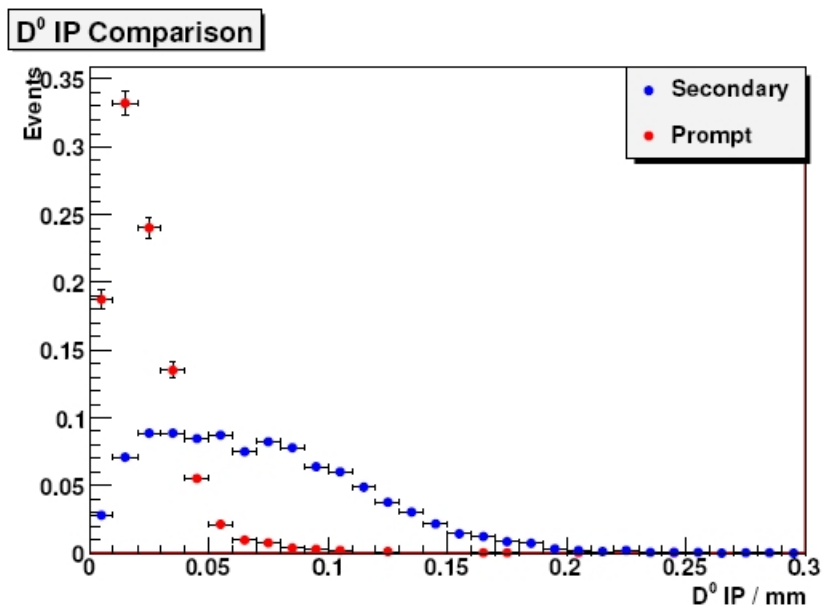
Expected charm samples: *prompt charm*



$D^0 \rightarrow K^-\pi^+$ prompt

$D^0 \rightarrow K^-\pi^+$ secondary

Fit to the IP of the D^0 to separate prompt from secondary charm



estimated yields for the 2010 trigger scenario (100 pb^{-1})

- ✓ $D^0 \rightarrow K^-\pi^+$ 24 x 10^6
- ✓ $D^0 \rightarrow K^+K^-$ 2.4 x 10^6

Expected charm samples: *secondary charm*

D* trigger for nominal luminosity
~ 10^8 tagged $D^0/2fb^{-1}$

$D^* \rightarrow D^0(hh)\ \pi_s$ for RICH calibration

$BR(B \rightarrow D^{*\pm}X) \sim 0.23$

Estimated $D^* \rightarrow D^0(hh)\ \pi_s$ ($2fb^{-1}$)	
$D^0 \rightarrow K^-\ \pi^+$	$50\ 10^6$
$D^0 \rightarrow K^+\ \pi^-$	$0.2\ 10^6$
$D^0 \rightarrow K^-\ K^+$	$5\ 10^6$
$D^0 \rightarrow \pi^-\ \pi^+$	$2\ 10^6$

Potential in other modes

- ✓ Three and four body decays
  - $D^0 \rightarrow K_s\pi\pi$
  - $D^0 \rightarrow KK\pi\pi$
  - $D^0 \rightarrow K^-\pi^+\pi^0$
  - $D^+ \rightarrow K^+K^-\pi^+$
- ✓ Semileptonic modes
  - $D^0 \rightarrow K^-l^+\nu$
- ✓ Rare decays
  - $D^0 \rightarrow \mu\mu$

Charm physics

CPV with $D^0 \to K^+K^-;\ K^-\pi^+$

S. Bergmann et al. Phys. Lett. **B486** (2000) 418

$$y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1 = y\cos\phi - \frac{1}{2}A_M x \sin\phi$$

CPV phase

CPV in mixing

Mixing

$$x = \frac{m_1 - m_2}{\Gamma} = \frac{\Delta m}{\Gamma}$$

$$y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma} = \frac{\Delta\Gamma}{2\Gamma}$$

$$R_M = |q/p|, \quad R_M^{\pm 2} = 1 \pm A_M$$

Fit to lifetime distribution

Belle: Phys. Rev. Lett. 98 (2007) 211803

$Y_{cp} = 1.31 \pm 0.32 \pm 0.25$ %

LHCb @ 100 pb^{-1} (2010)

$\sigma_{stat}(y_{cp}) \sim 1.1 \times 10^{-3}$

$$A_M = \phi = 0 \quad \Rightarrow \quad y_{CP} = y$$

CP conserved

CPV with $D^0 \rightarrow K^+K^-;\ K^-\pi^+$

Measuring y_{cp} with a binned fit

- ✓ Bin candidates in proper time
- ✓ Estimate RS $K\pi$ and $KK/\pi\pi$ in each bin
- ✓ Plot the ratio

$$R_i(t) = N_{K\pi}(t)/N_{KK}(t)$$

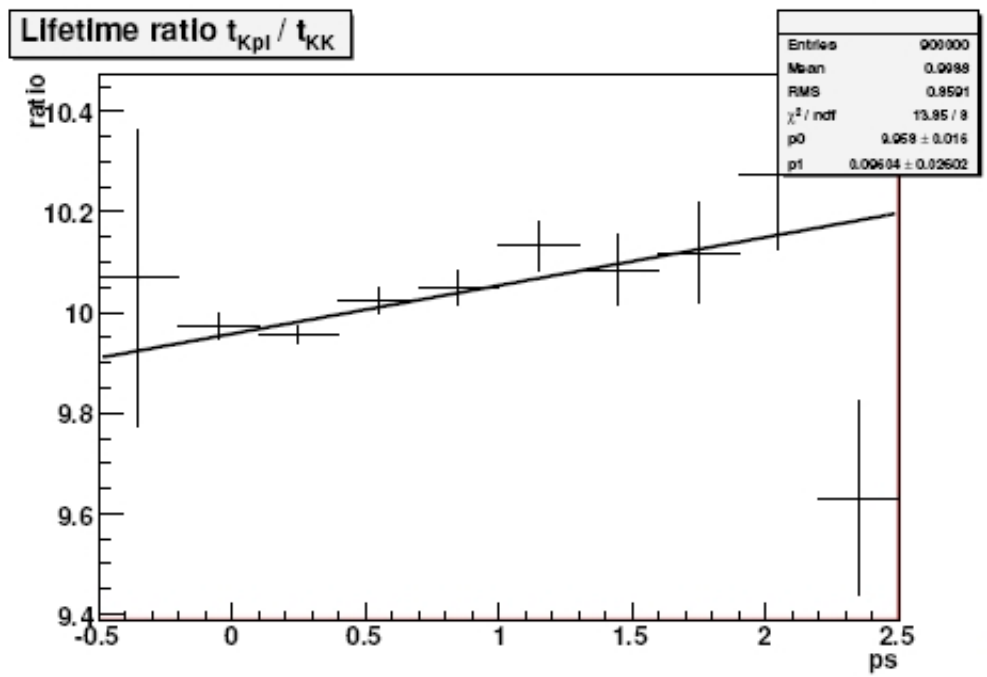
as a function of proper time

- ✓ Estimate y_{cp} from slope

*** 2010 – prompt charm ***
LHCb @ 100 pb^{-1}
$\sigma_{stat}(y_{cp}) \sim 1.1 \times 10^{-3}$

$$N_{\substack{KK \\ K\pi}}(t) = N_{\substack{KK \\ K\pi}} \int_{t'}^{t'+\Delta t} e^{-t/\tau_{\substack{KK \\ K\pi}}} \, dt$$

$$R(t) \approx \frac{N_{K\pi}}{N_{KK}} \frac{\tau_{KK}}{\tau_{K\pi}} \left(1 - \frac{y_{CP}}{\tau_{K\pi}} t\right)$$



D^0 – $\bar{D}^0$ mixing with the WS $D^0 \to K\pi$

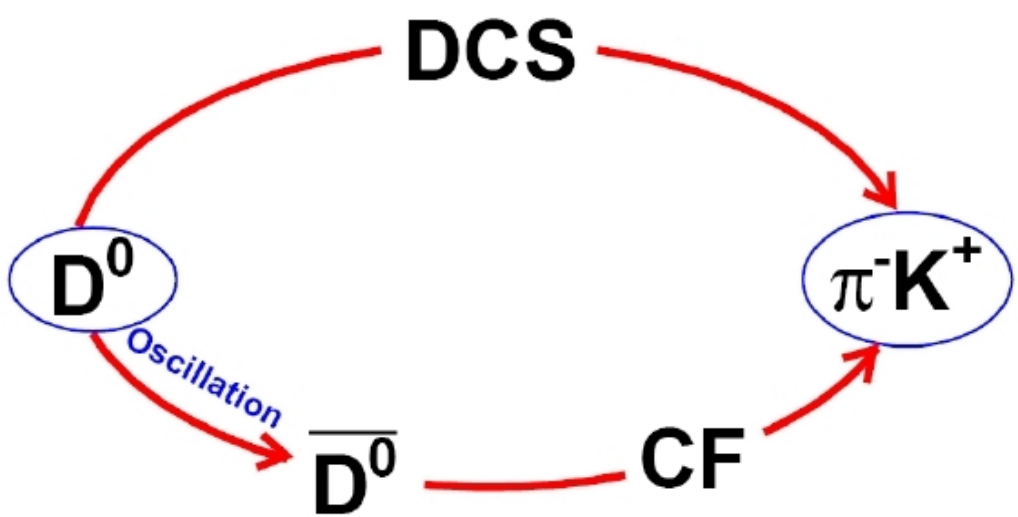
Time-dependent WS decay rate:

$$r_{\rm WS}(t) \propto e^{-\Gamma t}\left(R_D + \sqrt{R_D}y'(\Gamma t) + \frac{1}{2}R_M(\Gamma t)^2\right)$$

R_D → ratio of the DCS to CF decay rates

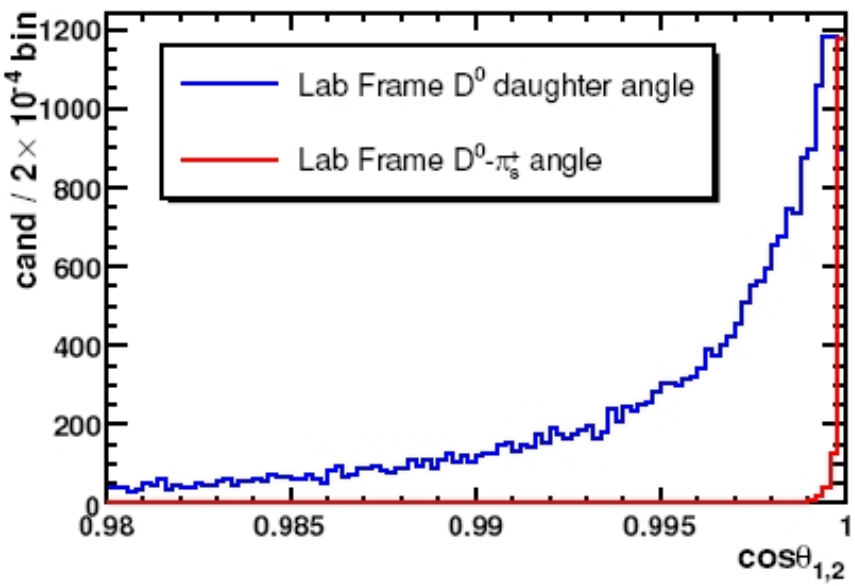
$R_M = (x^2 + y^2)/2 = (x'^2 + y'^2)/2$ mixing rate

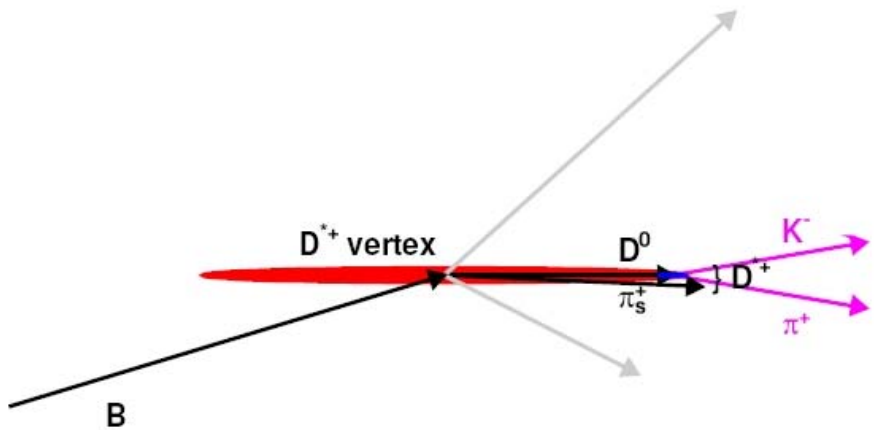
$$\begin{aligned} x' &\equiv x\cos\delta + y\sin\delta \\ y' &\equiv y\cos\delta - x\sin\delta \end{aligned}$$



$D^0 - \bar{D}^0$ mixing with the WS $D^0 \rightarrow K\pi$

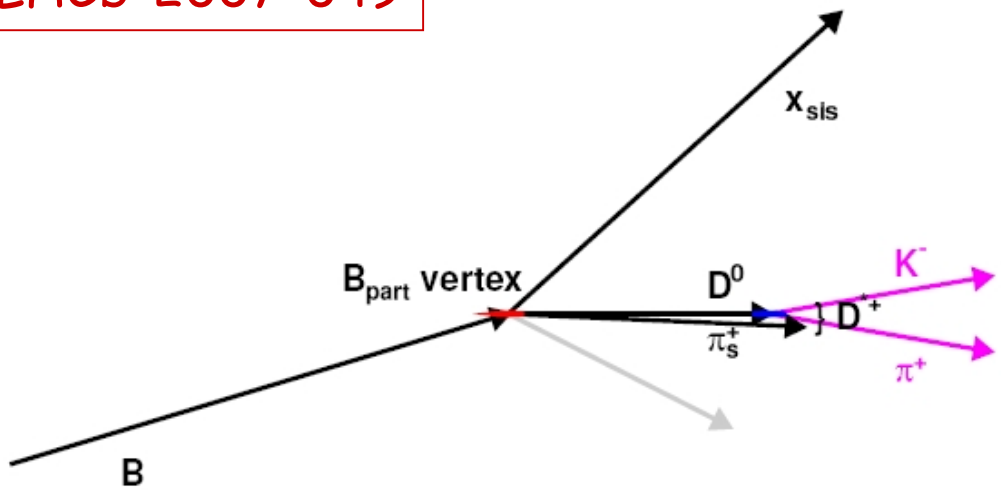
- ✓ $D^0/\bar{D}^0$ candidates tagged at the birth vertex
- ✓ Analysis requires a precise measurement of the decay time
  - the birth vertex of D^0 poorly determined (π_s and D^0 are almost collinear)
  - needs new techniques to improve resolution of the birth vertex





$D^0 - \bar{D}^0$ mixing with the WS $D^0 \to K\pi$

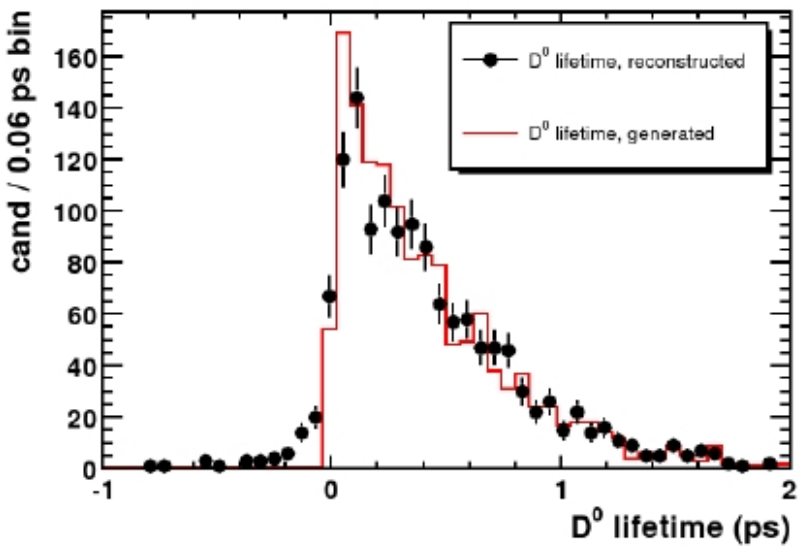
LHCb-2007-049



Improvement of the D^0 birth vertex

- partial reconstruction of the mother B-meson
- use the decay vertex of B-meson as the birth vertex of the D^0

	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



proper time resolution
0.465 ps → 0.045 ps

(secondary charm only)

$D^0 - \bar{D}^0$ mixing with the WS $D^0 \to K\pi$

LHCb-2007-049

LHCb sensitivity

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

(secondary charm only)

Current status:

- BaBar, Belle and CDF reported evidence of mixing

  (BaBar, Phys. Rev. Lett **98** (2007) 211802; Belle, Phys. Rev. Lett. **98** (2007) 211803; CDF, Phys. Rev. Lett. **100** (2008) 121802)
- No evidence of CP-Violation in mixing

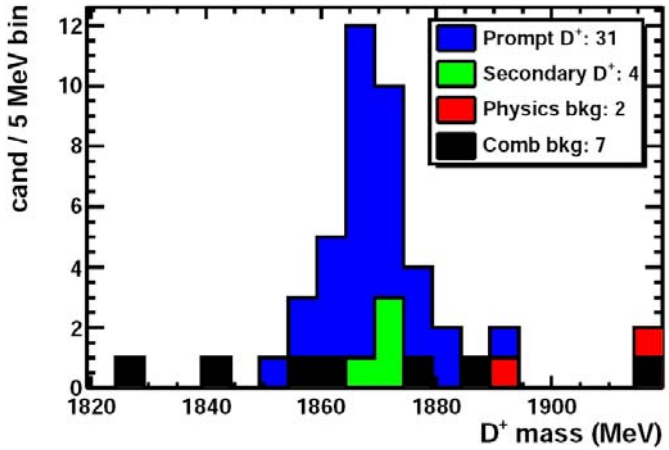
CPV in $D^+ \to K^+K^-\pi^+$

Single Cabibbo suppressed decay

- ✓ CPV in SM $O(10^{-3})$
- ✓ Possible enhancement due to NP

Amplitude analysis

- ✓ better sensitivity than rate analysis
- ✓ eliminate effects of production asymmetries
- ✓ amplitude analysis with model independent search for CPV in Dalitz Plot (Miranda Procedure - arXiv:0905.4233)

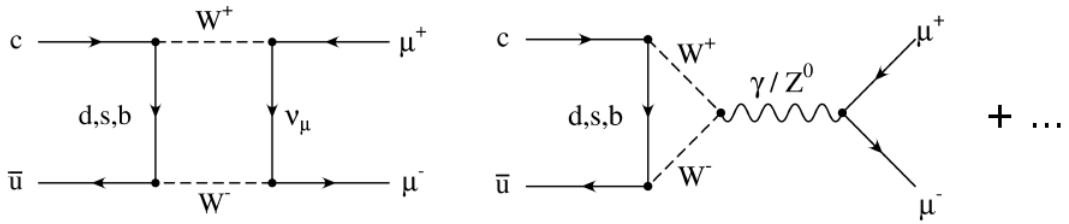


LHCb @ 100 pb^{-1} prompt charm

~ 1 x 10^6 events

Rare decays

$D^0 \rightarrow \mu\mu$



- ✓ BR < 10^{-12} in SM
- ✓ BR up to $O(10^{-6})$ in R-parity violating SUSY
  (G. Burdmann, Phys. Rev. D66 (2002))

Best limit:

- ✓ CDF – BR < 4.7×10^{-7} @ 90% CL with 360 pb^{-1}

LHCb:

- ✓ Search for $D^0 \rightarrow \mu\mu$ with high priority in first physics run
- ✓ Significant improvement expected
- ✓ Multivariate analysis using tagged D^0

Summary

- ✓ LHCb has the potential to have a large charm data set for analysis.
  - ✓ Secondary charm
  - ✓ Prompt charm
- ✓ Efforts are underway to exploit both prompt and secondary charm
- ✓ Ongoing analysis also in
  - ✓ Doubly charm baryons
  - ✓ X,Y,Z spectroscopy: mass, width, new states, etc.
  - ✓ J/Ψ, $D_{s1,2,J}$, etc. production
- ✓ Exciting possibilities with the first data in 2010 (~100 pb^{-1})

Backup Slides

Miranda's procedure

- ✓ Difference of Dalitz plots for c.c. decays
- ✓ Significance of the difference calculated bin by bin

$$\mathcal{S}_{CP}(i) = \frac{N^+(i) - N^-(i)}{\sqrt{N^+(i) + N^-(i)}}$$

- ✓ Clear signature for CP (Gaussian distribution with $\mu = 0$ and $\sigma = 1$
- ✓ No fixed scale – will change with overall statistics

CPV with $D^0 \to K^+K^-$; $K^-\pi^+$

$$A_\Gamma = \frac{\tau\left(\overline{D}^{\,0} \to K^-K^+\right) - \tau\left(D^{\,0} \to K^+K^-\right)}{\tau\left(\overline{D}^{\,0} \to K^-K^+\right) + \tau\left(D^{\,0} \to K^+K^-\right)} = \frac{1}{2}A_M\, y\cos\phi - x\sin\phi$$

- ✓ $A_\Gamma \leq 10^{-3}$ in SM
- ✓ Up to 1% with NP

HFAG 09: $A_\Gamma = (-1.6 \pm 2.3) \times 10^{-3}$

LHCb @ 2 fb^{-1}: $A_\Gamma \to \sigma_{stat} \sim 1.1 \times 10^{-3}$

prompt c → x3 better ?

CPV via T-odd observable: $D^0 \to K^+K^-\pi^+\pi^-$

$$\frac{d\Gamma}{d\phi} = \Gamma_1\cos^2\phi + \Gamma_2\sin^2\phi + \Gamma_3\cos\phi\sin\phi$$

$$A = \frac{\int_0^{\pi/2} d\phi\frac{d\Gamma}{d\phi} - \int_{\pi/2}^{\pi} d\phi\frac{d\Gamma}{d\phi}}{\int_0^{\pi} d\phi\frac{d\Gamma}{d\phi}} = \frac{2\Gamma_3}{\pi(\Gamma_1+\Gamma_2)}$$

ϕ = angle between the KK and $\pi\pi$ planes

$$A_{TViol} = \frac{A_{D^0} - A_{\overline{D}^0}}{2}$$

Focus: $A_{TViol} = 0.01 \pm 0.057 \pm 0.037$ (828 events)

(Phys. Lett. **B622** (2005) 239)

LHCb @ 2fb^{-1} ~ 10^5 events + prompt