Charm physics at LHCb: triggering and selection

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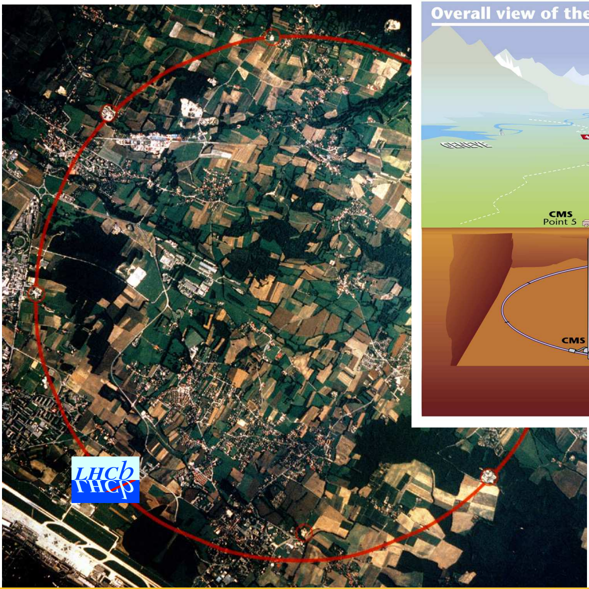
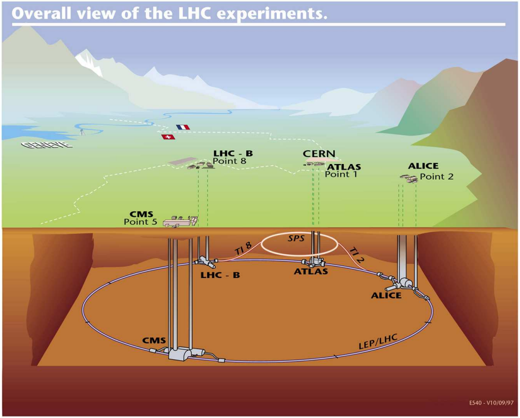
Outline

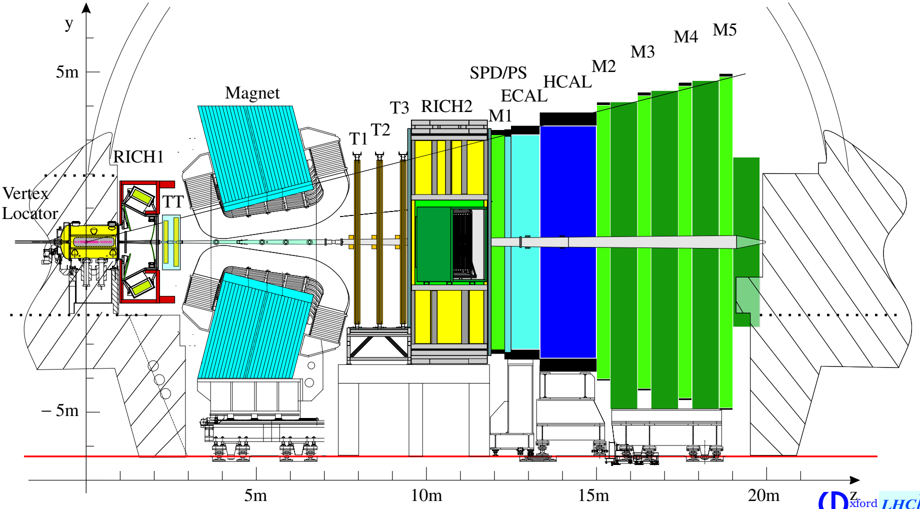
1. LHCb detector
   - LHC
   - LHCb
2. Charm physics
   - Sources of charm
3. The LHCb trigger
   - Trigger structure
   - Charm trigger uses
4. Charm selection
   - D^0 tagging
   - Creation vertex
   - Selection yields

Large Hadron Collider





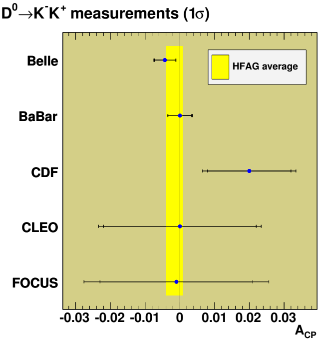
LHCb detector



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: $\sim 7\,\mathrm{MeV}$ D^0 mass
- Excellent K-π discrimination

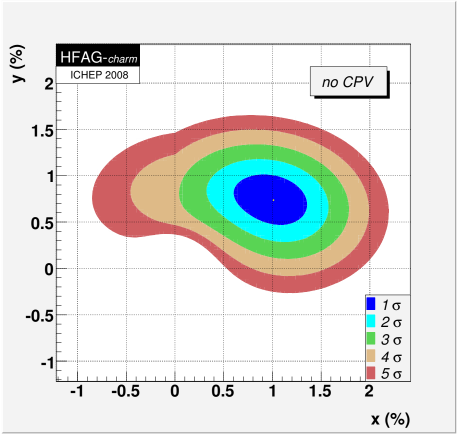
Charm physics w/hadronic final states: CPV



CP violation in D decays

- Currently unobserved
- SM predictions very small,
  - $\mathcal{O}(10^{-3})$ for singly Cabibbo suppressed (SCS) (e.g. $D^0 \to K^-K^+$),
  - Negligibly small for Cabibbo favored (CF) and doubly suppressed (DCS).
- Measurements in many decay modes,
  - Relative decay rates,
  - Final state distributions (e.g. Dalitz space) in multibody decays,
  - CP violation in mixing.
- Individual experimental upper limits $\sim 0.5\%$.

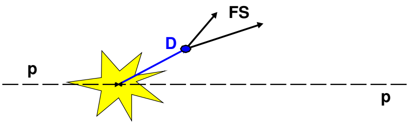
Charm physics w/hadronic final states: mixing

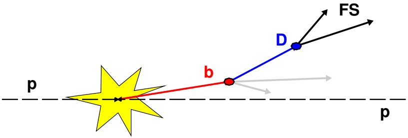


D^0–$\overline{D^0}$ mixing

- Recent strong evidence of mixing,
  - Three independent 3σ measurements.
- Observed level consistent with standard model,
  - SM mixing very small: $\mathcal{O}(10^{-3})$,
  - Useful constraints on new physics models.
- CP violation in mixing.

Two sources of charm





Prompt production

- \+ Prolific production
- \+ Strong potential on early data
- 0 Less efficient in trigger
- \- Potentially larger backgrounds
- \- Unavoidable significant proper time acceptance effects
- \+ CDF proved that measurements are possible in hadronic environment

B decays ($B \to D^{(*)} X$)

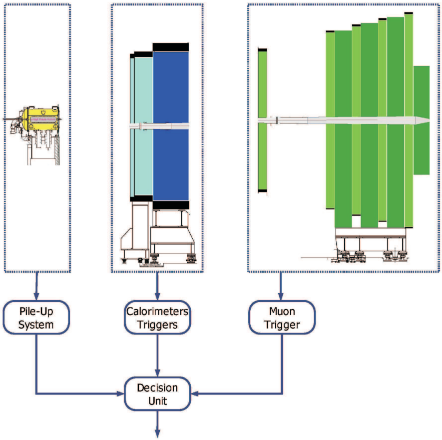
- \+ Strongly favored by LHCb triggers
- \+ Potentially less background
- \- New techniques need to be developed—no published measurements

LHCb trigger

Two stage trigger:

- **40** MHz crossing rate at nominal design luminosity.
- L0 hardware trigger — high p_t particles,
  - Subset of detector information,
  - Fast decision,
  - **1** MHz output rate.
- High Level Trigger (HLT) in software — physics signatures
  - Software trigger running in event farm,
  - All detector information available,
  - Multiple layers with increasing levels of decision complexity.
- $\sim$ **2** kHz output rate.

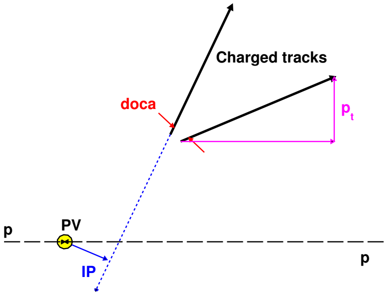
L0 trigger



- Identify single particle *b*-hadron decay products,
  - Final state particles (π, K, e, γ, μ) with significant p_t,
  - Threshold p_t values of a few GeV,
  - Sets of thresholds optimized for physics goals.
- 40 MHz input → 1 MHz output

High Level Trigger stage 1 (HLT1)

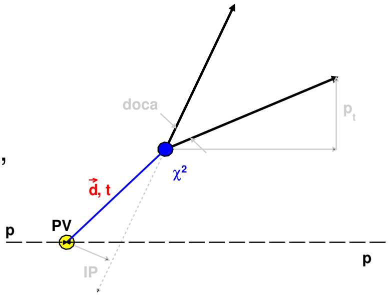
- First stage of software trigger,
- Identify 1 and 2 final state particle signatures,
- Parallel trigger paths for various final state particles,
- Fast identification of simple *B* event features,



  - High p_t particles (hadrons, muons, electrons, and photons),
  - Charged tracks with sizable impact parameter with respect to primary interaction vertex (PV),
- Products of prompt *D* have smaller mean p_t than those of secondary *D*.

High Level Trigger stage 2 (HLT2)

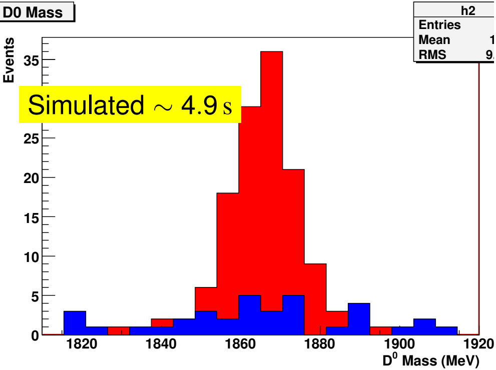
- Require events pass HLT1,
- Reduced input rate allows compute-intensive reconstruction,
- Complete final state reconstruction,
- Channels for specific topologies,
  - Inclusive selections of related groups of decays,
  - Exclusive decay chain, e.g., $D^{*+} \rightarrow \pi_s^+ D^0(h^- h^+)$

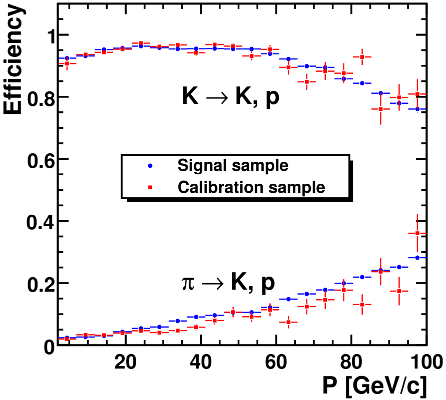


- Channels can also be layered with increasing precision of parameter estimates.
- $2\,\mathrm{kHz}$ total output rate

Uses of LHCb D^{*+} trigger

Charm physics

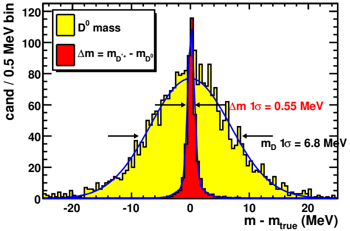


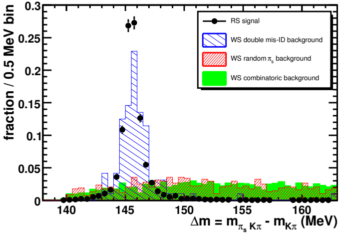


RICH calibration

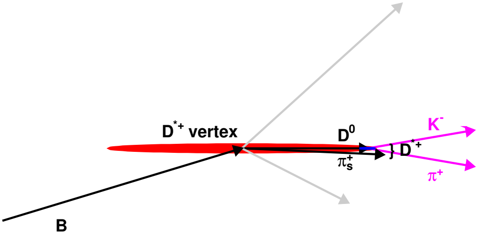
D^{*+} tagging

- CP violation and mixing studies with D^0 requires 'tagging' as D^0 or $\overline{D^0}$,
- Same-side tag for D^0 flavor,
- Reconstruct $D^*(2010)^+ \to D^0\pi_s^+ \; + \;$ c.c.,
  - Strong decay, instantaneous,
  - 'Slow' pion, $\pi_s^\pm$, charge identifies D^0 or $\overline{D^0}$.
- Tightly constrained phase space,
  - $m_{D^{*+}} - m_{D^0} \equiv \Delta m = 145.421 \pm 0.010\,\mathrm{MeV}$,
- Very narrow peak in Δm,
  - Clear signal/background discriminant.

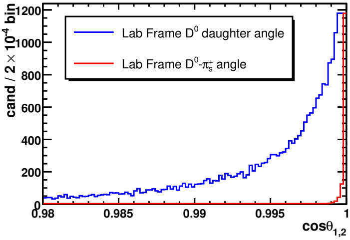




Vertex resolution for mixing



Signal MC lab frame angles



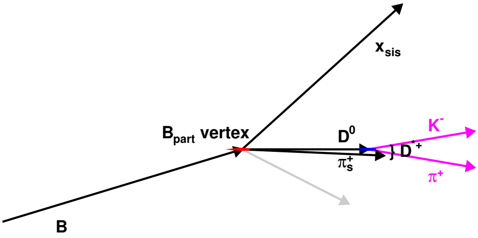
Decay vertex resolutions

	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^{*+} vertex poorly estimated,
- 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

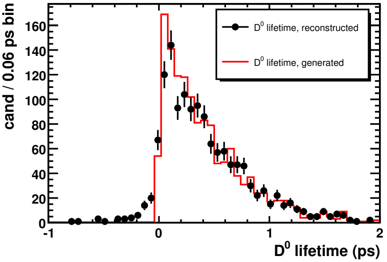
Birth vertex improvement for secondary charm



- Use additional tracks at production vertex,
- For prompt charm: use PV,
- For D^0 from B: use 1 additional track from 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 $= 0.045\,\text{ps}$

Selection yields

Estimated selection yields for two body hadronic channels

- $D^{*+} \to \pi_s D^0$, $D^0 \to hh'$
  - $h, h' \in \{K^\pm, \pi^\pm\}$
- Tagged selections,
  - CP violation measurements,
  - Time-dependent mixing measurements.
- Yield estimates include trigger.

Estimated selection yields in $2\,\mathrm{fb}^{-1}$

	$D^0 \to K^-\pi^+$	$\to K^-K^+$	$\to \pi^-\pi^+$
Prompt signal yield ($\times 10^6$)	109 ± 12	10 ± 3	2 ± 1
S/B	8	6	> 2
Secondary signal yield ($\times 10^6$)†	12.38 ± 0.59	1.32 ± 0.19	0.50 ± 0.12
S/B	5	5	3

See Philip Xing's talk for physics estimates with this selections

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,
- See talk by Philip Xing in this session for estimates of physics performance.