Prospect of D^0 mixing and CPV at LHCb

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Outline

1. LHCb detector
2. CPV and mixing in D^0-$\overline{D}^0$
3. Time-integrated CPV searches
4. Summary

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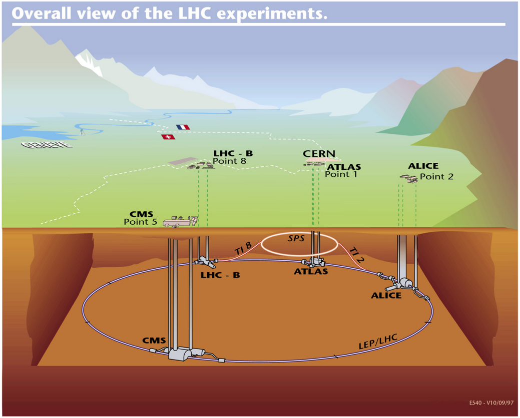
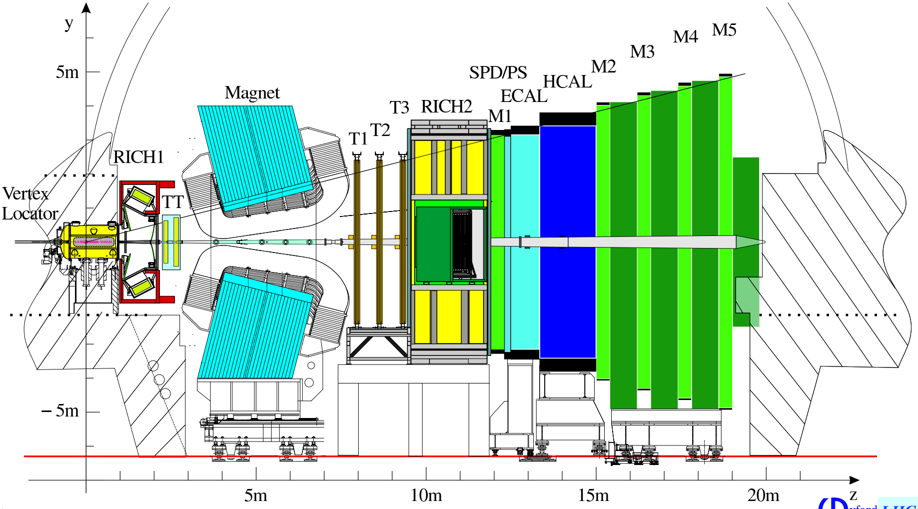
Large Hadron Collider



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,
- Good tracking and momentum resolution,
- Excellent K-π discrimination.

LHCb trigger

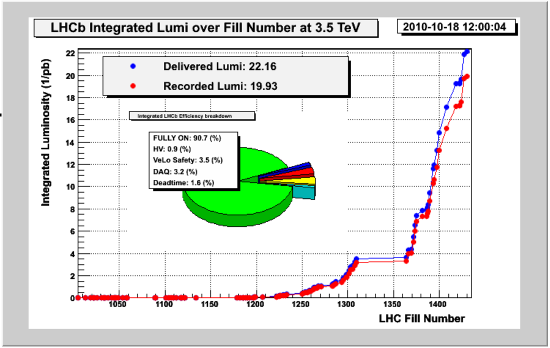
Two stage trigger:

- $\sim$ **25** 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.

LHCb in 2010

Data taking in 2010 is rapidly evolving,

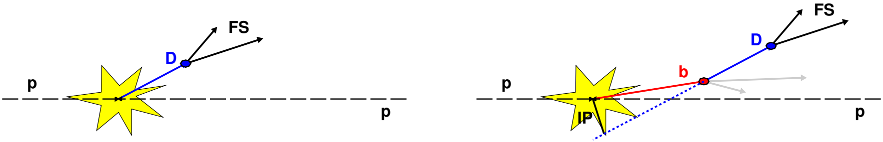
- Recorded almost 20 pb^{-1}…
  …and still collecting!
- Prolific charm production,
- Early data taking with relaxed trigger
  $\Rightarrow$ Excellent for prompt charm collection.



Beam conditions have evolved rapidly,

- Luminosity per bunch crossing now significantly exceeds design values.
  Design: mean visible *p*-*p* interactions / crossing $\mu = 0.4$.
  Current: peak $\mu \approx 2.5$.
- Trigger has rapidly evolved to keep up.

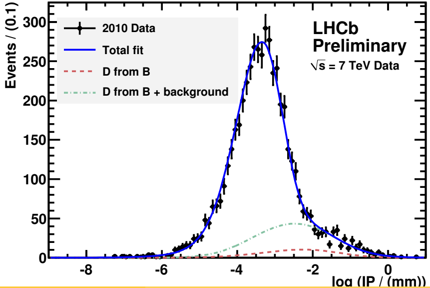
Charm in hadronic collisions



Prompt production

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

- Secondary is an important background.
- IP used for discrimination in c and b cross-sections.
- Aside: Secondary charm may be used for some CPV and mixing measurements.



Outline

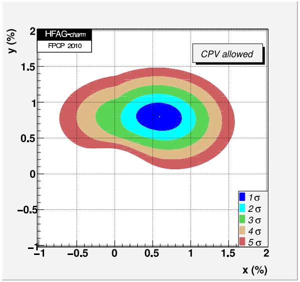
D^0 CPV and mixing

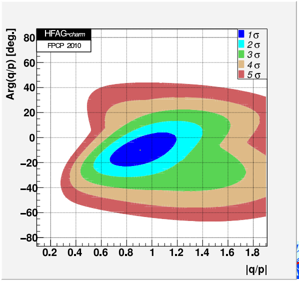
D^0 is unique: the only 'up'-type meson that mixes,

- Unique sector of NP probes.
- First evidence for D^0-$\overline{D^0}$ mixing in 2007,
- Averages show compelling evidence for mixing,
- Still no single $5\,\sigma$ measurement.

CPV is very small in the SM

- Can be enhanced by NP, but generally highly suppressed,
- *B*-factory data sets have probed down to $\mathcal{O}(10^{-2})$





Complementary measurements

Several complementary measurements illuminate different aspects of mixing.

- CP eigenstates: y_{CP} through ratio of lifetimes,
- Wrong sign decays: x'^2 and y' through lifetime distribution,
- Time-dependent Dalitz analyses: direct access to x and y,
- Semileptonic decays: total mixing rate.

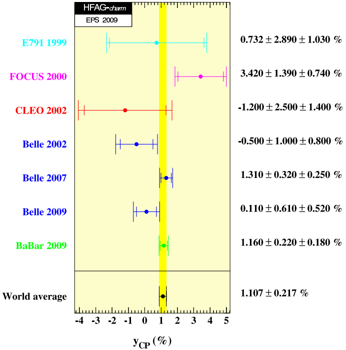
LHCb will have sensitivity with several hadronic final states.

Two-body mixing and CPV with CP eigenstates

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

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

Both untagged and D^{*+}-tagged measurements in preparation



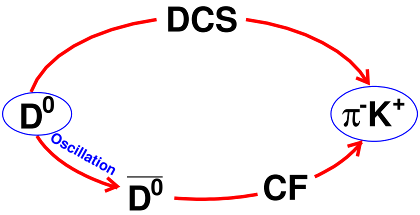
Tagged measurement easily extended to a CP asymmetry measurement

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

Two-body mixing and CPV with WS $K\pi$

Two paths from D^0 to the 'wrong sign' (WS) $\pi^- K^+$

- Direct Doubly Cabibbo Suppressed (DCS) decay,
- Mixing to $\overline{D}^0$ followed by a Cabibbo Favored (CF) decay,



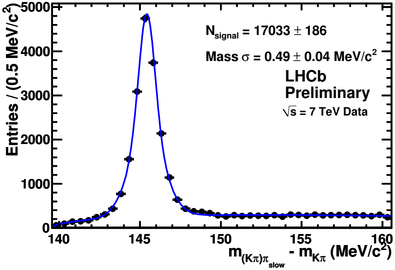
Expanding resulting proper time distribution in small parameters x' and y' to second order:

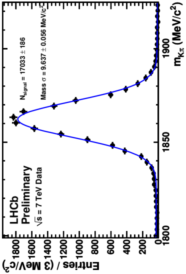
$$\boxed{\Gamma(t; D^0 \to \pi^- K^+) \propto e^{-\Gamma t}\left[R_D + \sqrt{R_D}y'\Gamma t + \tfrac{1}{4}(y'^2 + x'^2)(\Gamma t)^2\right]}$$

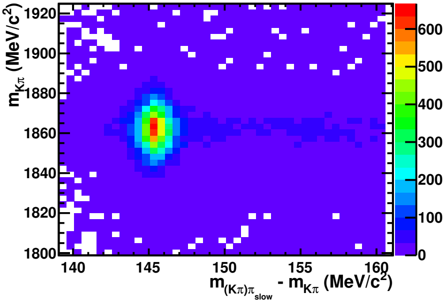
- R_D: ratio of DCS to CF decay rates
- (x', y') related to (x, y) by a strong phase

Beautiful signal samples: $D^0 \to K^-\pi^+$, $124\,\mathrm{nb}^{-1}$

D^{*+}-tagging necessary for CP-violation measurements.







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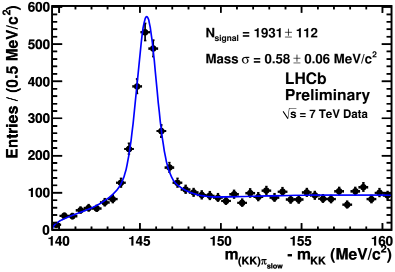
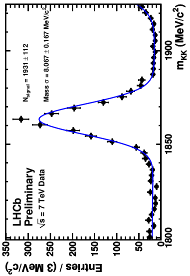
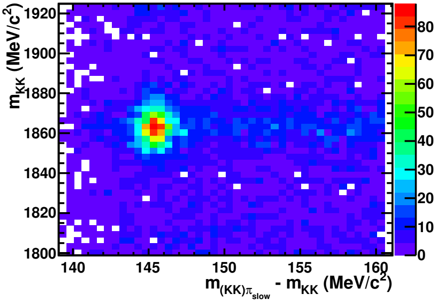
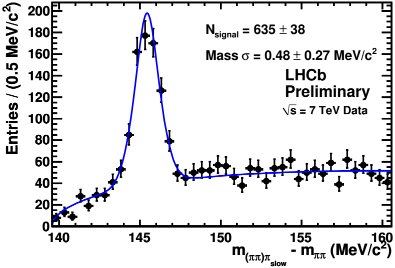


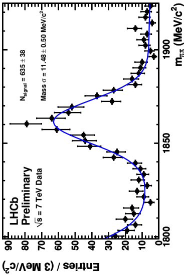


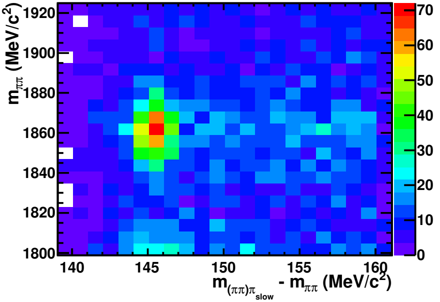


Beautiful signal samples: $D^0 \rightarrow \pi^-\pi^+$, 124 nb^{-1}

D^{*+}-tagging necessary for CP-violation measurements.



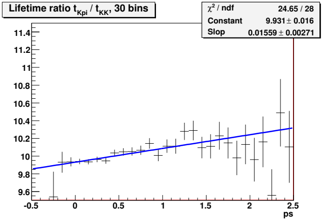




Two-body time-dependent analysis methods

Binned method

LHCb toy Monte Carlo.



- Partition data in bins of proper time,
- Measure ratios of yields in each bin,
- Mixing parameters estimated from polynomial fits.

Potentially easier to control systematics,

- Most acceptance effects cancel.

Unbinned fits to proper time distribution,

- Carefully model proper time acceptance,
- Also requires careful modelling variation of secondary discrimination variable (IP) with proper time.

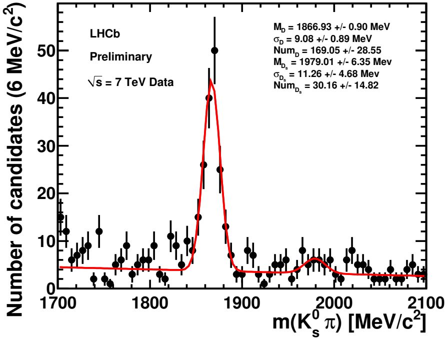
Potentially higher statistical sensitivity.

Outline

Time-integrated CPV searches: two-body

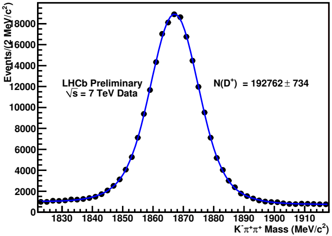
Time-integrated CPV with two-body decays,

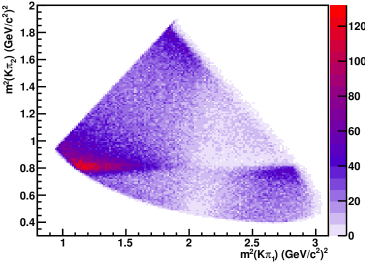
- Currently investigating two-body D^0 decays and $D^+_{(s)} \to K^0_S h$,
- Requires careful control of production and detection asymmetries,
- Careful use of control channels, e.g., CDF's recent $D^0 \to \pi^-\pi^+$ measurement,
- Measurements of relative asymmetries.



$D^+ \to K^0_S \pi^+$ in $2\,\mathrm{nb}^{-1}$

Time-integrated CPV searches: 3-body





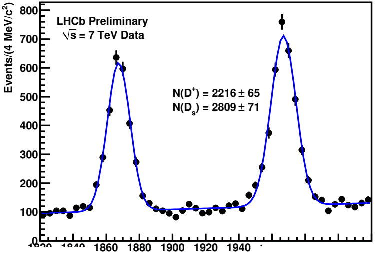
$D^+ \to K^-\pi^+\pi^-$ in 580 nb^{-1}

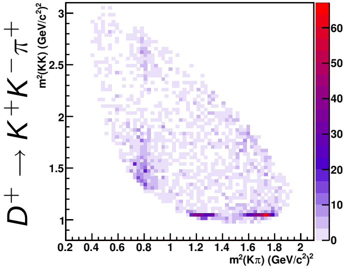
Final-state distributions in multibody decays,

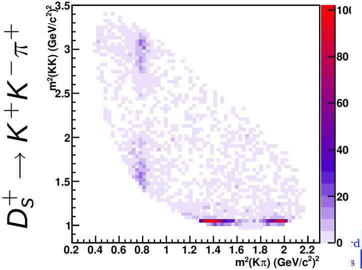
- Amplitude analysis,
- Model-independent method,
  - See Bediaga et. al, Phys.Rev.D80(2009),096006.
  - Partition the Dalitz plot into bins,
  - Model-independent mapping of local CP asymmetries,
  - Can be made largely insensitive to production asymmetries,
  - Focusing on SCS $K^+K^-\pi^+$ and $\pi^+\pi^-\pi^+$ final states.

Beautiful signal samples: $D^+ \to K^-K^+\pi^-$, $580\,\mathrm{nb}^{-1}$

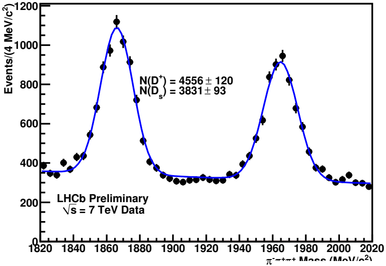
10% of selected events in $580\,\mathrm{nb}^{-1}$

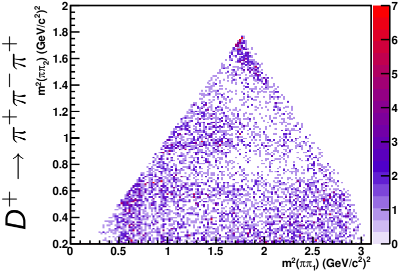


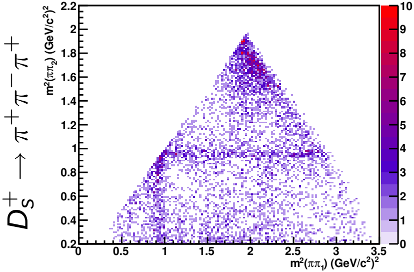




Beautiful signal samples: $D^+ \to \pi^-\pi^+\pi^-$, 580 nb^{-1}





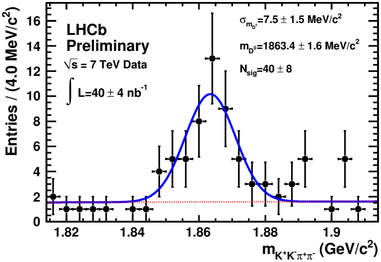


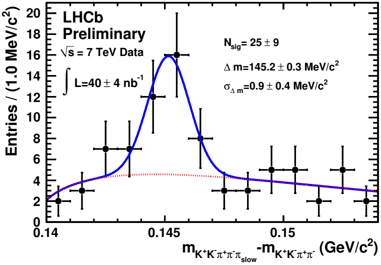
Time-integrated CPV searches: four-body

Time-integrated CPV with four-body decays,

- Focusing on $D^0 \to K^+K^-\pi^+\pi^-$ and the rare decay $D^0 \to K^+K^-\mu^+\mu^-$,
- T-odd moments,
  - Construct observable that is odd under time reversal, e.g. a scalar triple product of vectors or the KK-$\pi\pi$ decay plane angle,
  - Construct a T-violating asymmetry from this observable on the conjugate decays,
- Eventually, full amplitude analysis.

$D^0 \to K^+K^-\pi^+\pi^-$ in 40 nb^{-1}





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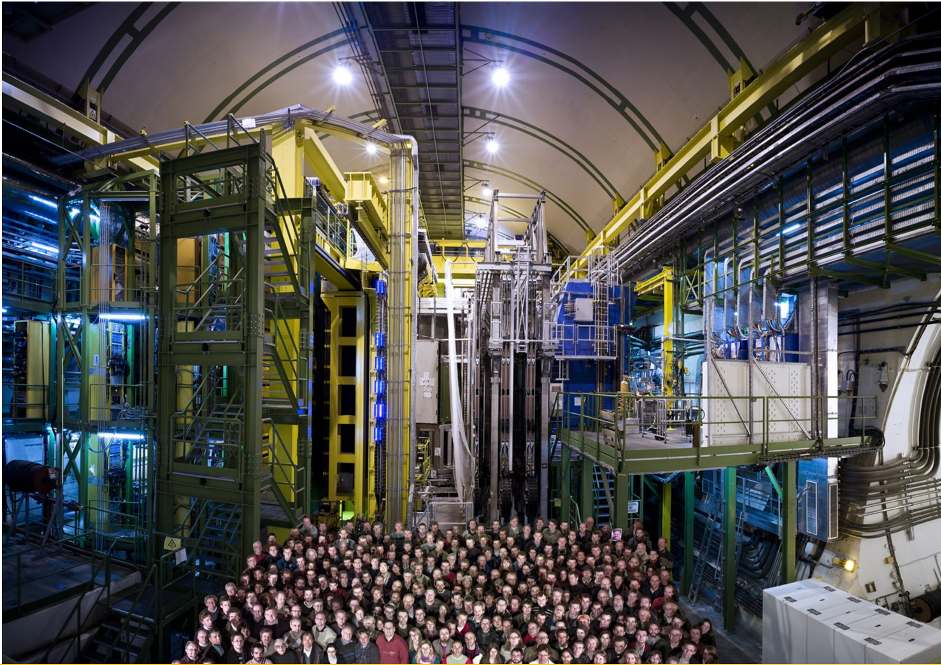
LHCb charm data sets

- Current sample sizes in D^0 to right sign $K^-\pi^+$, K^-K^+, $\pi^-\pi^+$ and D^+ to 3 charged final state particles are in the ball park of those of existing measurements,
- Collected with rapidly evolving beam and trigger conditions,
  - Sample sizes for analysis in 2010 will depend on the trigger analysis,
- 2011 data taking conditions will be more stable,
  - Strong effort to optimize trigger for larger and more consistent data set in 2011.

Summary

- LHCb is producing beautiful charm samples!
- First charm cross-section measurements public
  See talk by Zhenwei Yang.
- Raw sample sizes in several modes already approaching those of existing measurements,
- 2011 expected to produce samples capable of significant improvements in sensitivity over existing measurements,
- A broad program of charm CPV and mixing measurements are in preparation,
- We look forward to making significant contributions to charm physics!



BACKUP

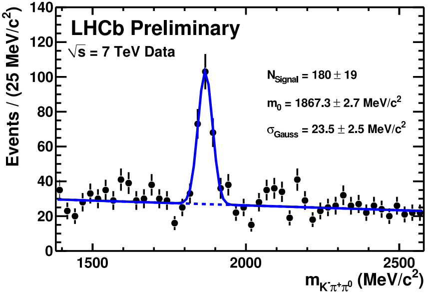
Other charm topics

Investigating CPV and mixing in additional modes

- WS $D^0 \to K^+\pi^-\pi^0$,
- WS $D^0 \to K^+\pi^-\pi^-\pi+$,

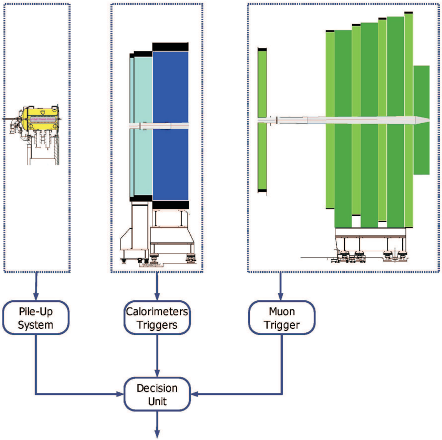
Rare decay measurements,

- $D^0 \to \mu\mu$,
- $D^+ \to \pi^+\mu^-\mu^+$.
- Lepton flavor violation searches, e.g., $D^0 \to e^-\mu^+$.



Untagged $D^0/\overline{D^0} \to K^-\pi^+\pi^0$ in 3.4 nb^{-1}

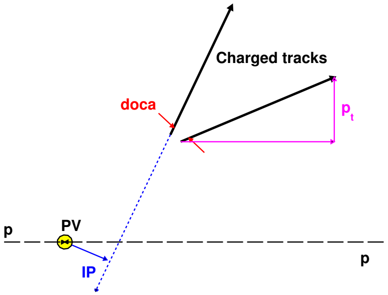
L0 trigger



- 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.
- $40\,\mathrm{MHz}$ input $\longrightarrow$ $1\,\mathrm{MHz}$ output

High Level Trigger stage 1 (HLT1)

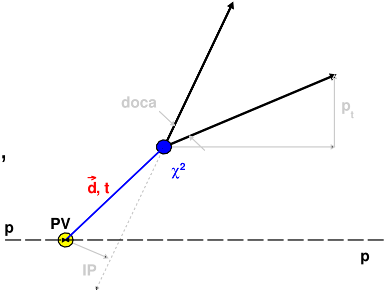
- First stage of software trigger,
- Identify 1 and 2 final state particle signatures,
- Parallel trigger paths for various final state particles,
- Fast identification of simple *B* event features,



  - 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., $D^{*+} \to \pi_s^+ D^0(h^- h^+)$



- Channels can also be layered with increasing precision of parameter estimates.
- 2 kHz total output rate