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LHCb

# Time Dependent CP Violation Measurements in Two Body Hadronic $D^0$ Decays at LHCb:

# Prospects and First Results for Measurement of $y_{CP}$ and $A_\Gamma$ via Direct Lifetime Measurements

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On behalf of the LHCb Collaboration

# Overview

- Motivation
- Method
- Results so far
- Outlook

# Motivation

$$y_{CP} = \frac{\tau(D^0 \to K^+K^-)}{\tau(D^0 \to K^-\pi^+)} - 1 = y\cos\phi - x\sin\phi\left(\frac{A_m}{2} + A_{prod}\right)$$

- Any deviation from mixing parameter $y$ indicates CP violation.
- Current best single measurement from BABAR[1]:

$$y_{CP} = (11.2 \pm 2.6 \pm 2.2) \times 10^{-3}$$

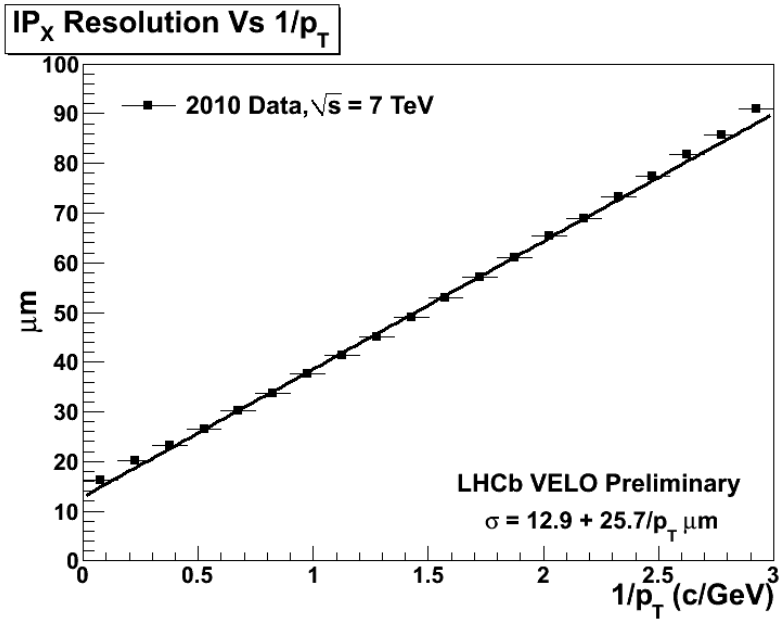
$$A_\Gamma = \frac{\tau(\bar{D}^0 \to K^+K^-) - \tau(D^0 \to K^+K^-)}{\tau(\bar{D}^0 \to K^+K^-) + \tau(D^0 \to K^+K^-)} = \left(\frac{A_m}{2}y\cos\phi - x\sin\phi\right)\frac{1}{1+y_{CP}}$$

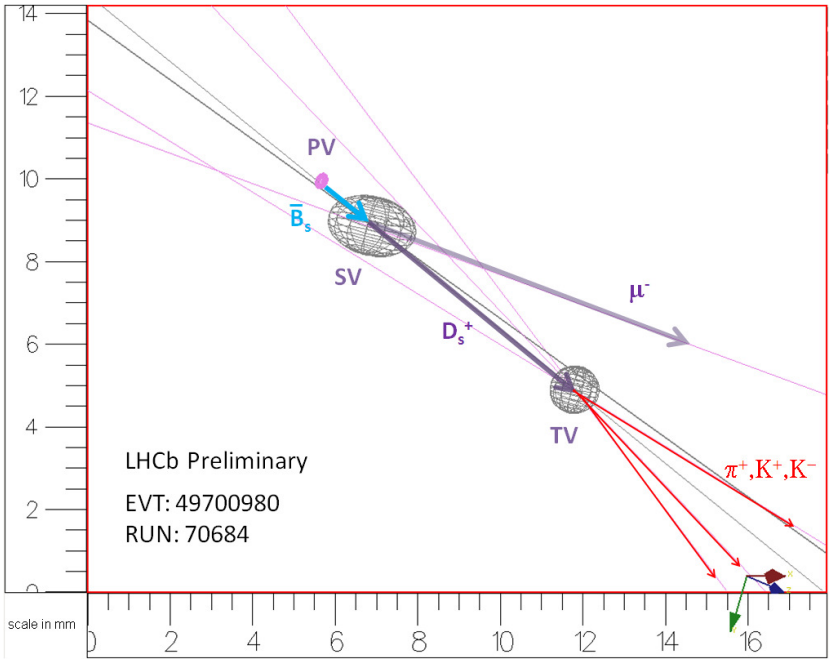
- Deviation from 0 quantifies CP violation.
- Requires $D^0$ flavour tag.
- Current best single measurement from BELLE[2]:

$$A_\Gamma = (\ 0.1 \pm 3.0 \pm 1.5\ ) \times 10^{-3}$$

# LHCb Detector

- Silicon strip VErtex LOcator (VELO) achieves proper time resolution ~50 fs (~12% $\tau(D^0)$).
- Excellent impact parameter (IP) resolution allows precise reconstruction of displaced decay vertices.




- Two Ring Imaging CHerenkov (RICH) detectors give clean separation of $\pi$ and K over a wide momentum range.

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# Method

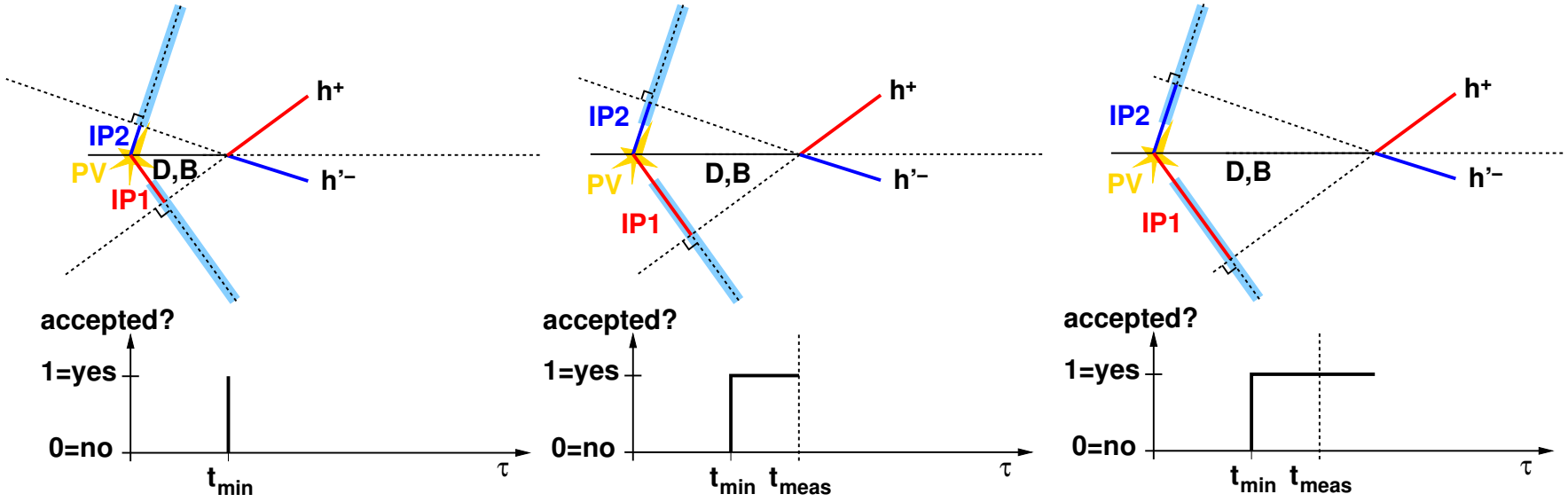
# Method

- $y_{CP}$: Use untagged $D^0 \rightarrow K^-\pi^+$ and $D^0 \rightarrow K^+K^-$.
- $A_\Gamma$: Flavour tag $D^0 \rightarrow K^+K^-$ using $D^{*+} \rightarrow D^0 \pi^+$.
- Unbinned fit to mass distribution for yields.
- Unbinned fit to proper time distribution to measure $\tau(D^0)$ directly in each channel.
- Common methodology with $B_s \rightarrow KK$ analysis.

- Challenges:
  - Selection favours long lived candidates: biases proper time distribution.
  - ~10% of $D^0$ at LHCb produced in decays $B \rightarrow D^0 X$: B time of flight augments measured $\tau(D^0)$.
  - Must achieve per mille measurement accuracy to be competitive.

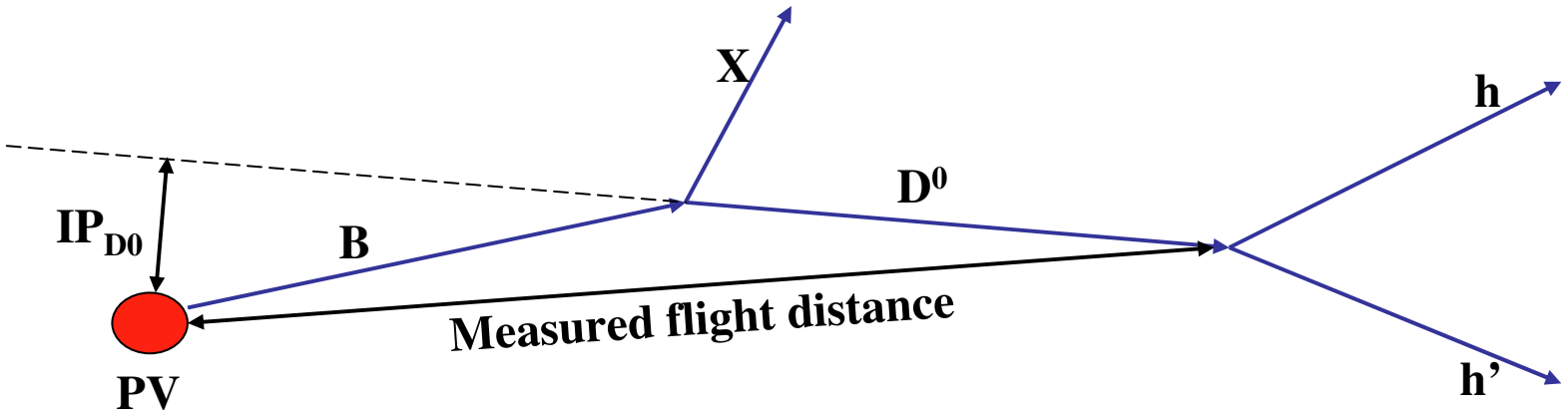
# Correcting Selection Bias: 'Swimming'

- Data driven per candidate acceptance vs proper time calculation, pioneered at CDF.
- Artificially change $D^0$ time of flight by moving the primary vertex.
- Re-evaluate selection decision at each time.



# Prompt-Secondary Separation

- $\chi^2$ of impact parameter (IP) of prompt $D^0$ independent of proper time.
- Displacement by B flight distance causes time dependent $\chi^2(IP_{D0})$ for secondaries.
- Simultaneous fit to $D^0$ proper time & $\ln(\chi^2(IP_{D0}))$ allows statistical prompt-secondary discrimination.



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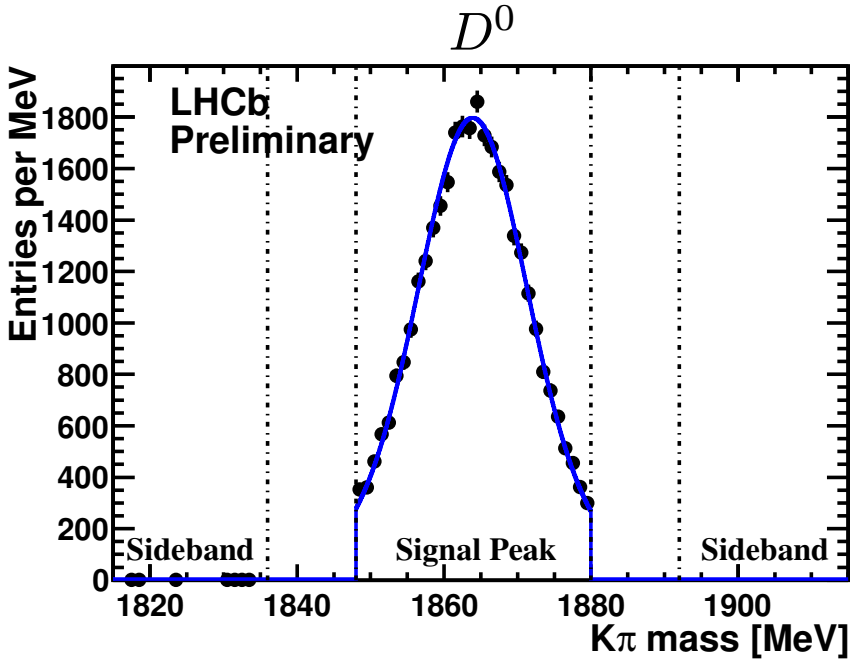
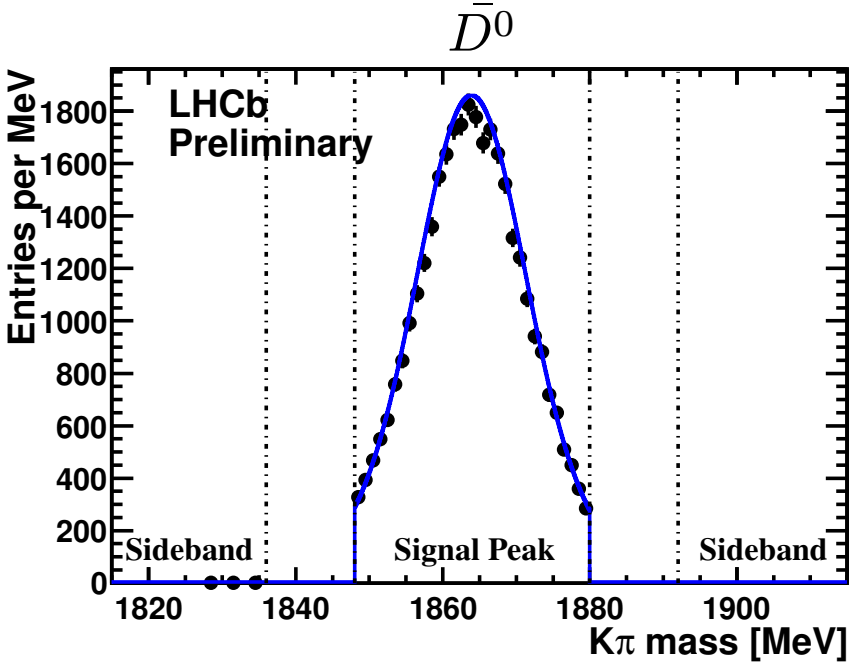
# Results So Far: Control Measurement

$$A_{\Gamma}^{K\pi,eff} = \frac{\tau^{eff}(\bar{D}^0 \to K^+\pi^-) - \tau^{eff}(D^0 \to K^-\pi^+)}{\tau^{eff}(\bar{D}^0 \to K^+\pi^-) + \tau^{eff}(D^0 \to K^-\pi^+)}$$

Expected consistent with 0.

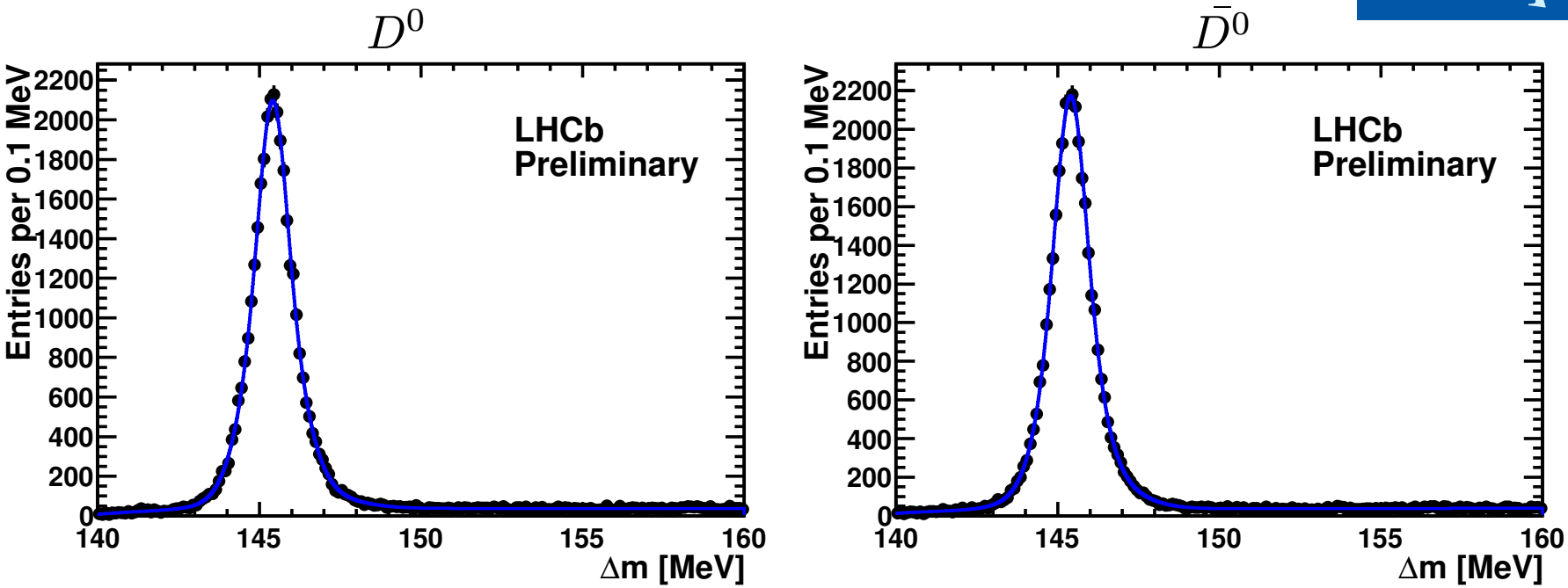
# Mass Fit for Yields



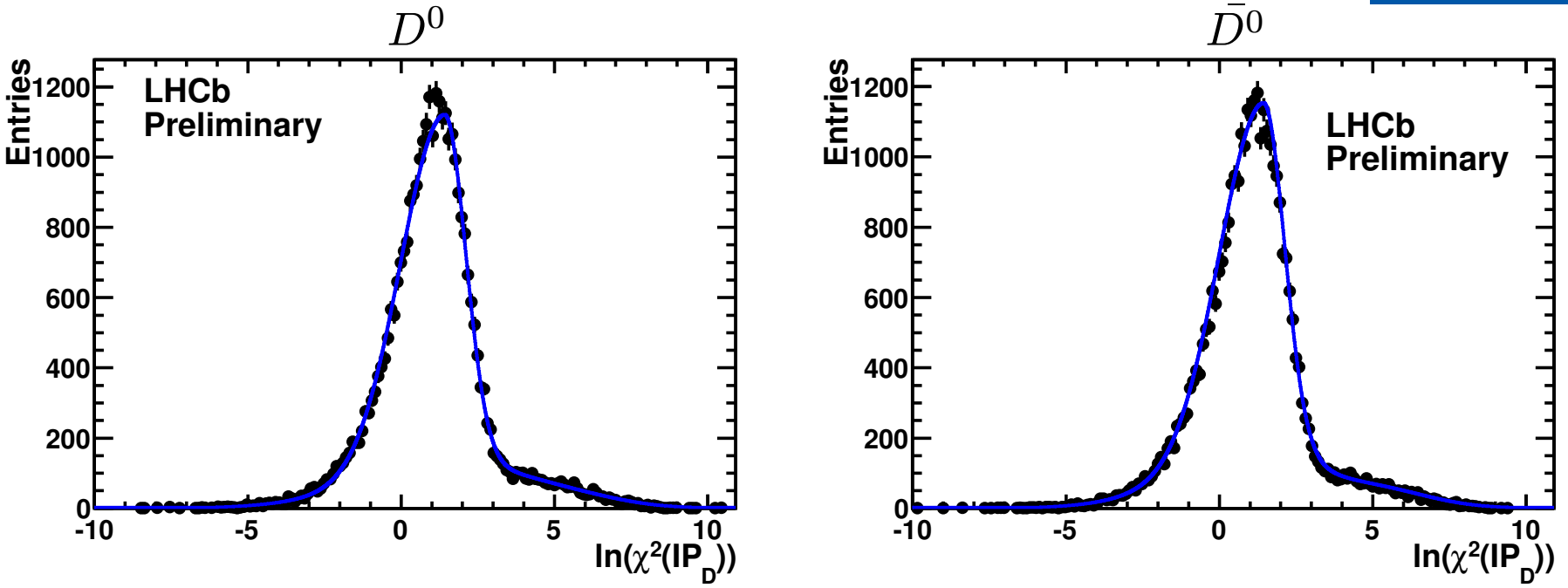

- ~40K candidates of each flavour (~40% of candidates from ~17 $pb^{-1}$, ~20% of total available, applies to all following plots).
- Signal region 1864 ± 16 MeV.
- Double Gaussian fit gives width 0.64 x 6.9 MeV + 0.36 x 11.7 MeV
- Only 1% of sideband candidates kept by trigger.
- Backgrounds < 2%, currently neglected.

# Δm Fit for Mis-Tag



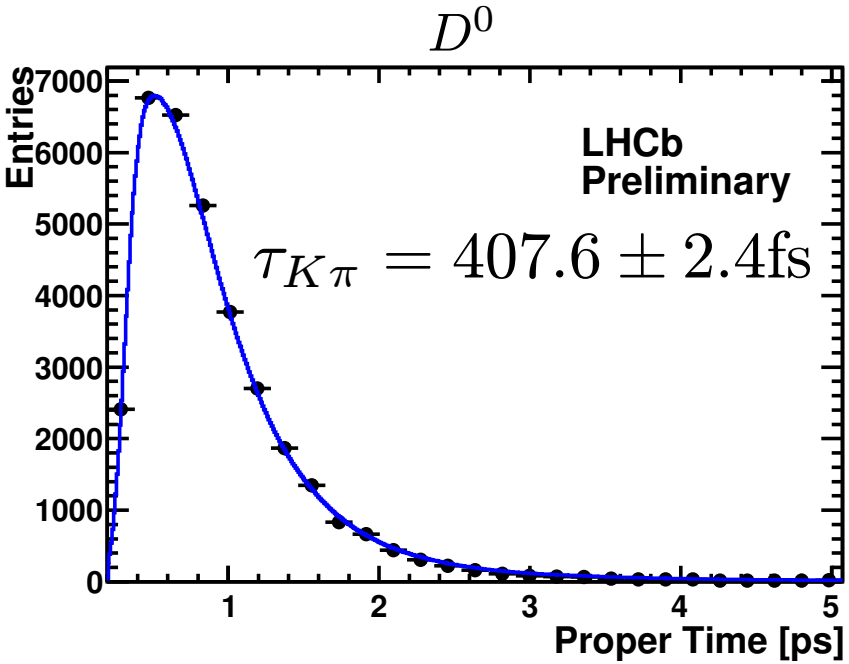

- $\Delta m = m(D^*) - m(D^0)$.
- Background from combination of $D^0$ with random $\pi$.
- Very low mis-tag rate, currently neglected.

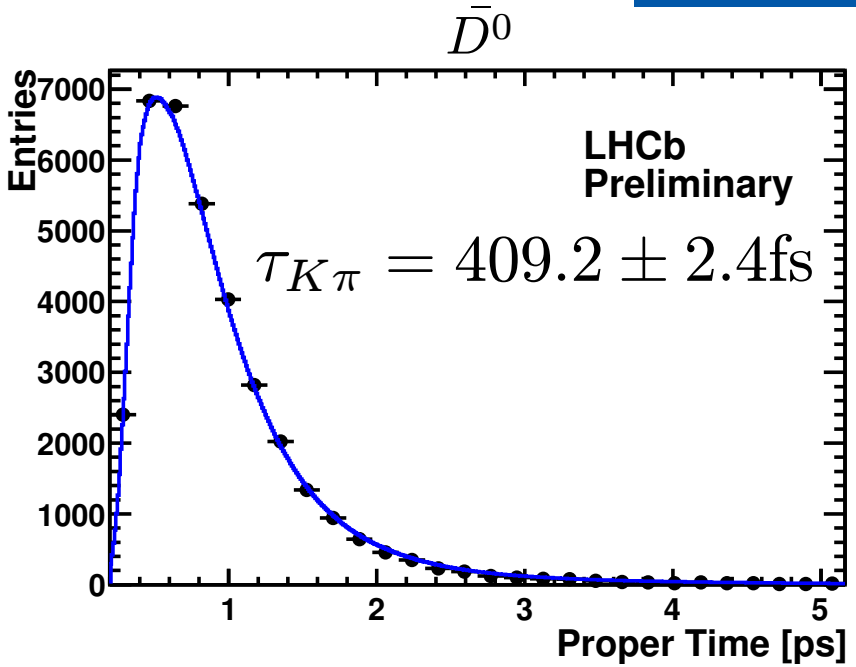
# Projection of $\ln(\chi^2(IP_{D0}))$ Fit




- Tail on right from secondary $D^0$.
- Reasonable level of discrimination achieved.
- Fit model still being refined.

# Proper Time Fit




- Acceptance well modelled by Swimming.
- Lifetimes agree with world average
  $\tau = 410.1 \pm 1.5$ fs [3]

$$A_{\Gamma}^{K\pi,eff} = (-2 \pm 4) \times 10^{-3}$$

- Consistent with 0 (preliminary, statistical errors only).

# Outlook

- Sub-percent accuracy achieved with control measurement.

$$A_{\Gamma}^{K\pi,eff} = (-2 \pm 4) \times 10^{-3}$$

- Now working to get to $\leq 3$ per mille.
- Trigger issues to be overcome to account for combinatorial background.
- Improvements to be made to fit model for sufficiently accurate discrimination of secondaries.

- Untagged sample ~10 x larger than tagged.
- Sufficient data is available, should soon have competitive measurements of $y_{CP}$ and $A_{\Gamma}$!

# References


- [1] B. Aubert *et al.* (BABAR Collaboration), "Measurement of $D^0$ - $\bar{D}^0$ Mixing using the Ratio of Lifetimes for the Decays $D^0 \to K^-\pi^+$, and $K^-K^+$", Phys. Rev. D80 (2009) 071103.
- [2] M. Staric et al. (Belle Collab.), "Evidence for $D^0$ - $\bar{D}^0$ Mixing", Phys. Rev. Lett. 98 (2007) 211803
- [3] K. Nakamura *et al.* (Particle Data Group), "Review of Particle Physics", J. Phys. G 37 (2010) 075021