Measurements of indirect *CP* asymmetries in $\mathrm{D}^0 \to \mathrm{K}^+\mathrm{K}^-$ and $\mathrm{D}^0 \to \pi^+\pi^-$ decays

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Beauty, Edinburgh University, 17^{th} July 2014

Theory

[J. Phys. G39 (2012) 045005]

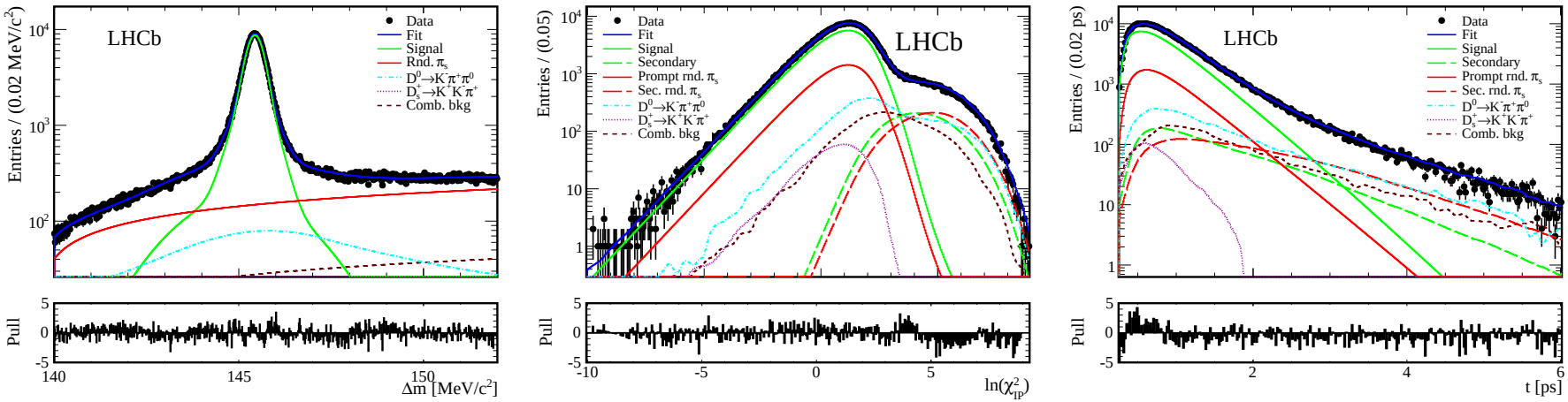
- Mass eigenstates of D^0 system defined as $|\mathrm{D}_{1,2}\rangle = p|\mathrm{D}^0\rangle \pm q|\bar{\mathrm{D}}^0\rangle$, with p and q complex. Masses and decay widths denoted by $m_{1,2}$ and $\Gamma_{1,2}$, resp.
- CP asymmetry of effective lifetime of D^0 decaying to CP eigenstate final state, f, is sensitive to indirect CPV

$$A_\Gamma \equiv \frac{\hat{\Gamma}(\mathrm{D}^0 \to f) - \hat{\Gamma}(\bar{\mathrm{D}}^0 \to f)}{\hat{\Gamma}(\mathrm{D}^0 \to f) + \hat{\Gamma}(\bar{\mathrm{D}}^0 \to f)} \approx \eta_{CP}\left[\frac{1}{2}(A_m + A_d)y\cos\phi - x\sin\phi\right].$$

- $\hat{\Gamma}$ is inverse of effective lifetime, η_{CP} the CP eigenvalue of f, $x \equiv 2(m_2 - m_1)/(\Gamma_1 + \Gamma_2)$, $y \equiv (\Gamma_2 - \Gamma_1)/(\Gamma_1 + \Gamma_2)$, $A_m \equiv (|q/p|^2 - |p/q|^2)/(|q/p|^2 + |p/q|^2)$, $A_d \equiv (|A_f|^2 - |\bar{A}_f|^2)/(|A_f|^2 + |\bar{A}_f|^2)$, with $\overset{(-)}{A}_f$ the decay amplitude, and $\phi \equiv arg(q\bar{A}_f/pA_f)$.
- Indirect CPV for D^0 predicted to be very small in Standard Model - observation of significantly larger CPV would indicate new physics.

Methodology

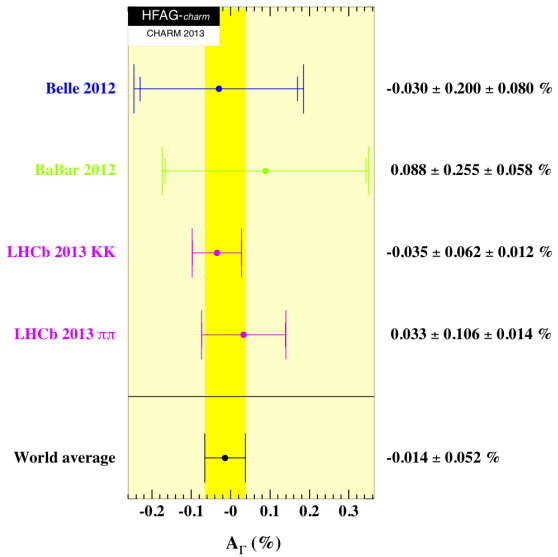
[LHCb-PAPER-2013-054]

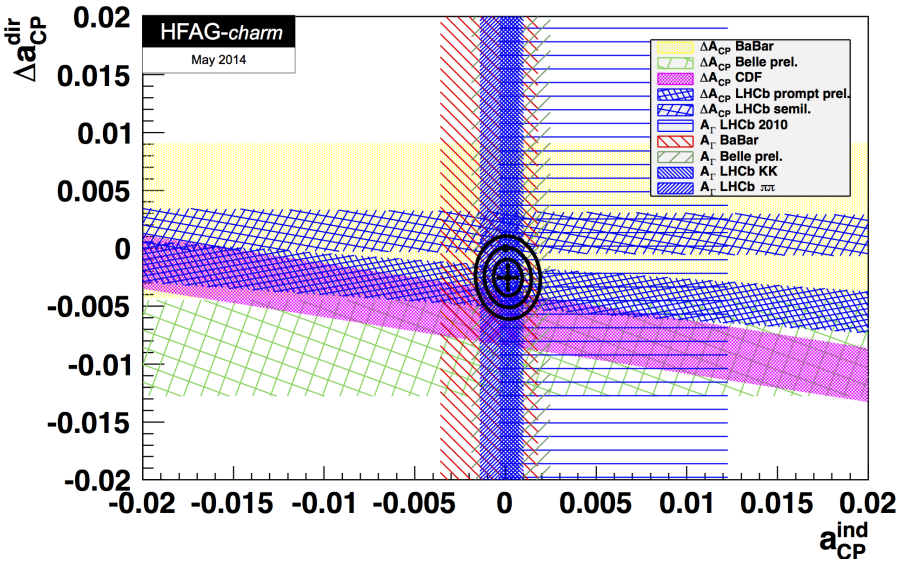


- $\mathrm{D}^{*+} \to \mathrm{D}^0\pi_s^+$ gives D^0 flavour. $\mathrm{K}^+\mathrm{K}^-$ and $\pi^+\pi^-$ final states used.
- Combinatorial and partially reconstructed backgrounds discriminated by fit to D^0 mass and $\Delta m \equiv m(\mathrm{D}^{*+}) - m(\mathrm{D}^0)$.
- Background from $\mathrm{B} \to \mathrm{D}^0\mathrm{X}$ decays is discriminated by fit to decay-time and χ^2 of hypothesis that D^0 originates directly from pp collision - χ^2_{IP}.
- Selection efficiency vs decay-time obtained from data using per-candidate acceptance functions.

Results & Systematics

[LHCb-PAPER-2013-054]
[HFAG]





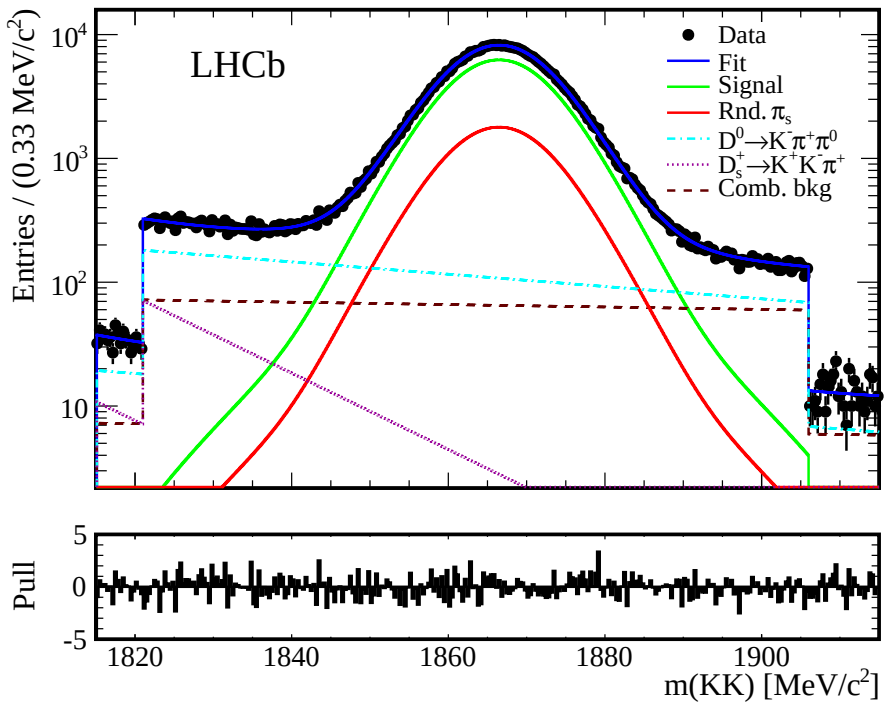
- Using 1 fb^{-1} of data collected in 2011 yields:

$$A_\Gamma(\pi\pi) = \quad (0.33 \pm 1.06 \pm 0.14) \times 10^{-3},$$
$$A_\Gamma(\mathrm{KK}) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3}.$$

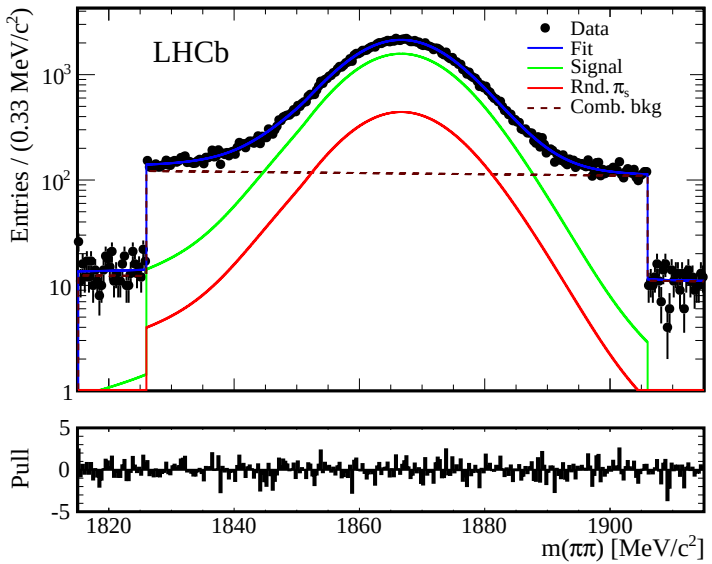
- Dominant systematics from modelling of the acceptance vs decay-time and $\mathrm{B} \to \mathrm{D}^0\mathrm{X}$ decays.
- Most precise measurements of their kind to date.
- No indication of *CP* violation.

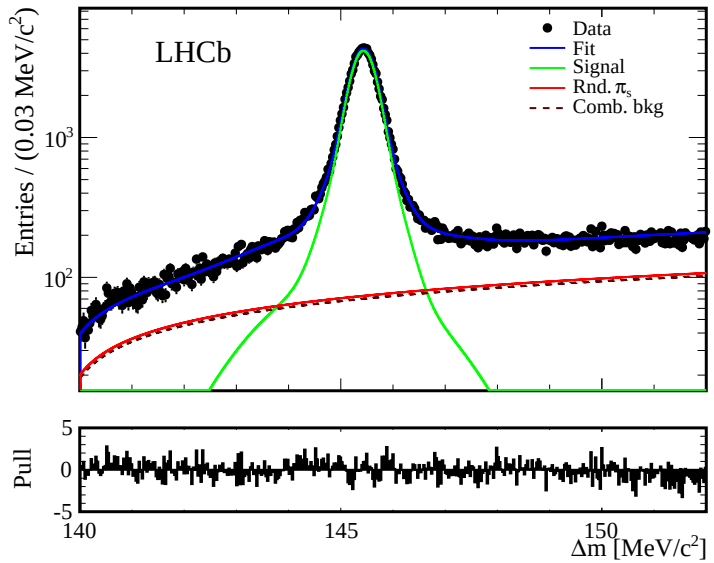
Backup

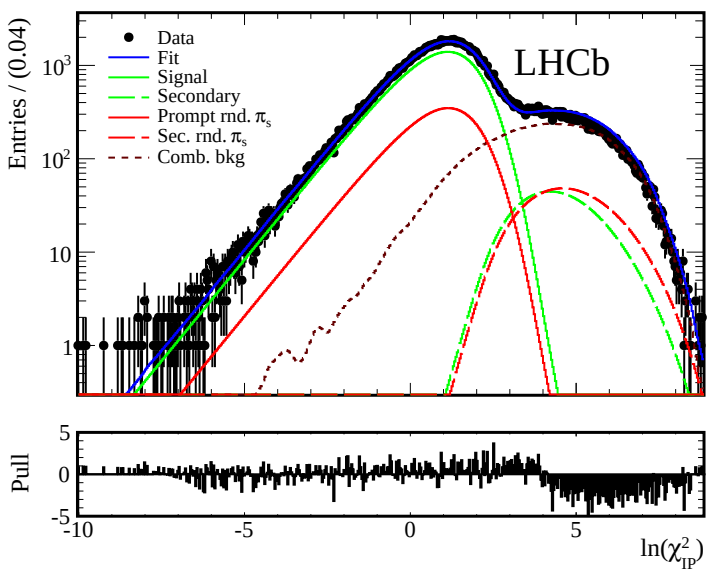
K^+K^- Mass fit

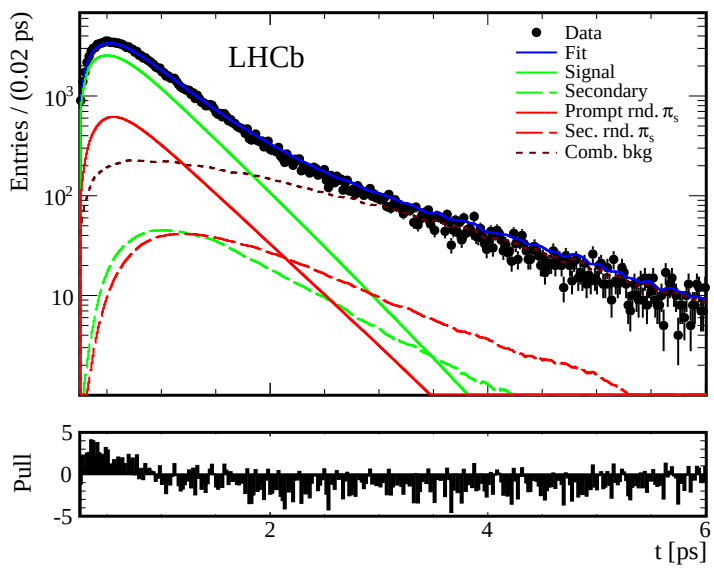

LHCb
Data
Fit
Signal
Rnd. π_s
$D^0 \to K^-\pi^+\pi^0$
$D_s^+ \to K^+K^-\pi^+$
Comb. bkg
Entries / (0.33 MeV/c^2)
10^4
10^3
10^2
10
Pull
5
0
-5
1820
1840
1860
1880
1900
m(KK) [MeV/c^2]

$\pi^+\pi^-$ Fits

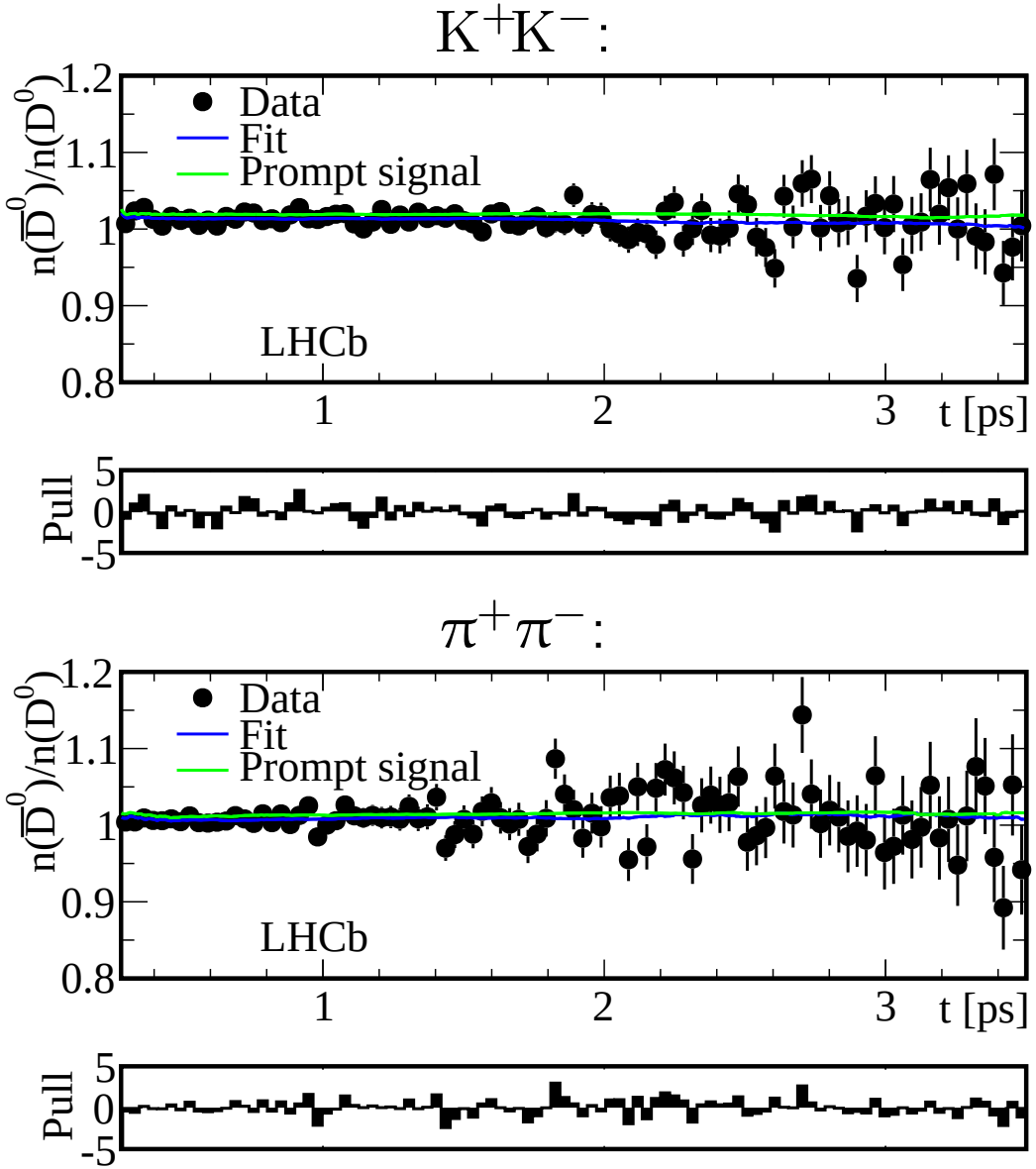

LHCb
Data
Fit
Signal
Rnd. π_s
Comb. bkg
Entries / (0.33 MeV/c^2)
Pull
m($\pi\pi$) [MeV/c^2]


LHCb
Data
Fit
Signal
Rnd. π_s
Comb. bkg
Entries / (0.03 MeV/c^2)
Pull
Δm [MeV/c^2]

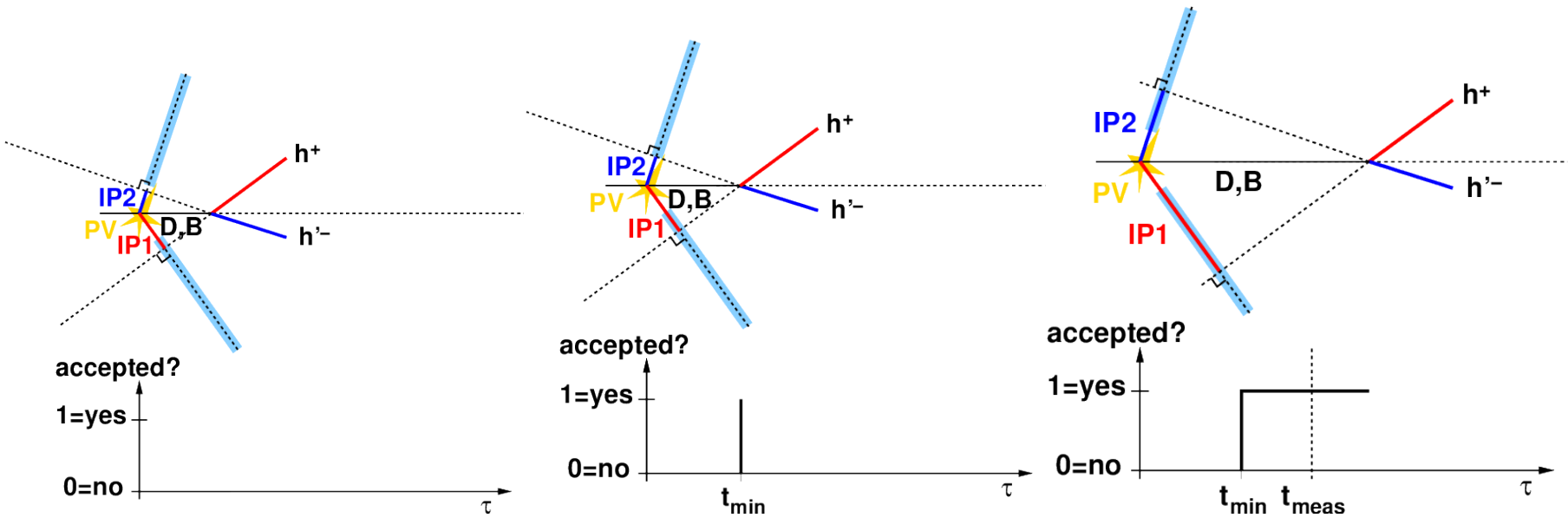

LHCb
Data
Fit
Signal
Secondary
Prompt rnd. π_s
Sec. rnd. π_s
Comb. bkg
Entries / (0.04)
Pull
ln(χ^2_{IP})


LHCb
Data
Fit
Signal
Secondary
Prompt rnd. π_s
Sec. rnd. π_s
Comb. bkg
Entries / (0.02 ps)
Pull
t [ps]

Decay-Time Ratios



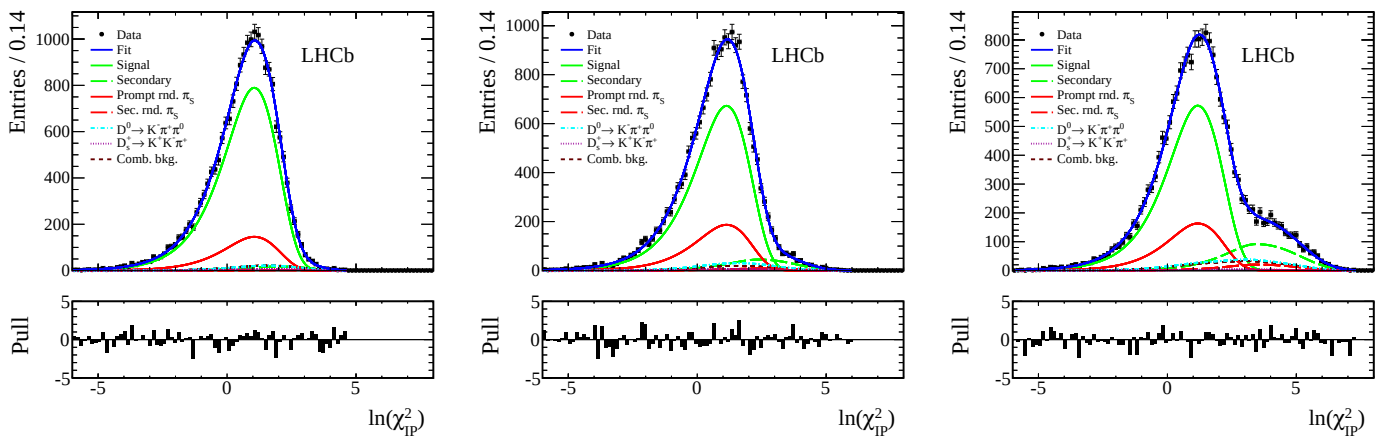
Swimming



- Move PV to change decay-time of candidate.
- Re-evaluate selection decision at each decay-time to build the acceptance function for that candidate.
- Average acceptance calculated as sum of per-candidate acceptance functions.

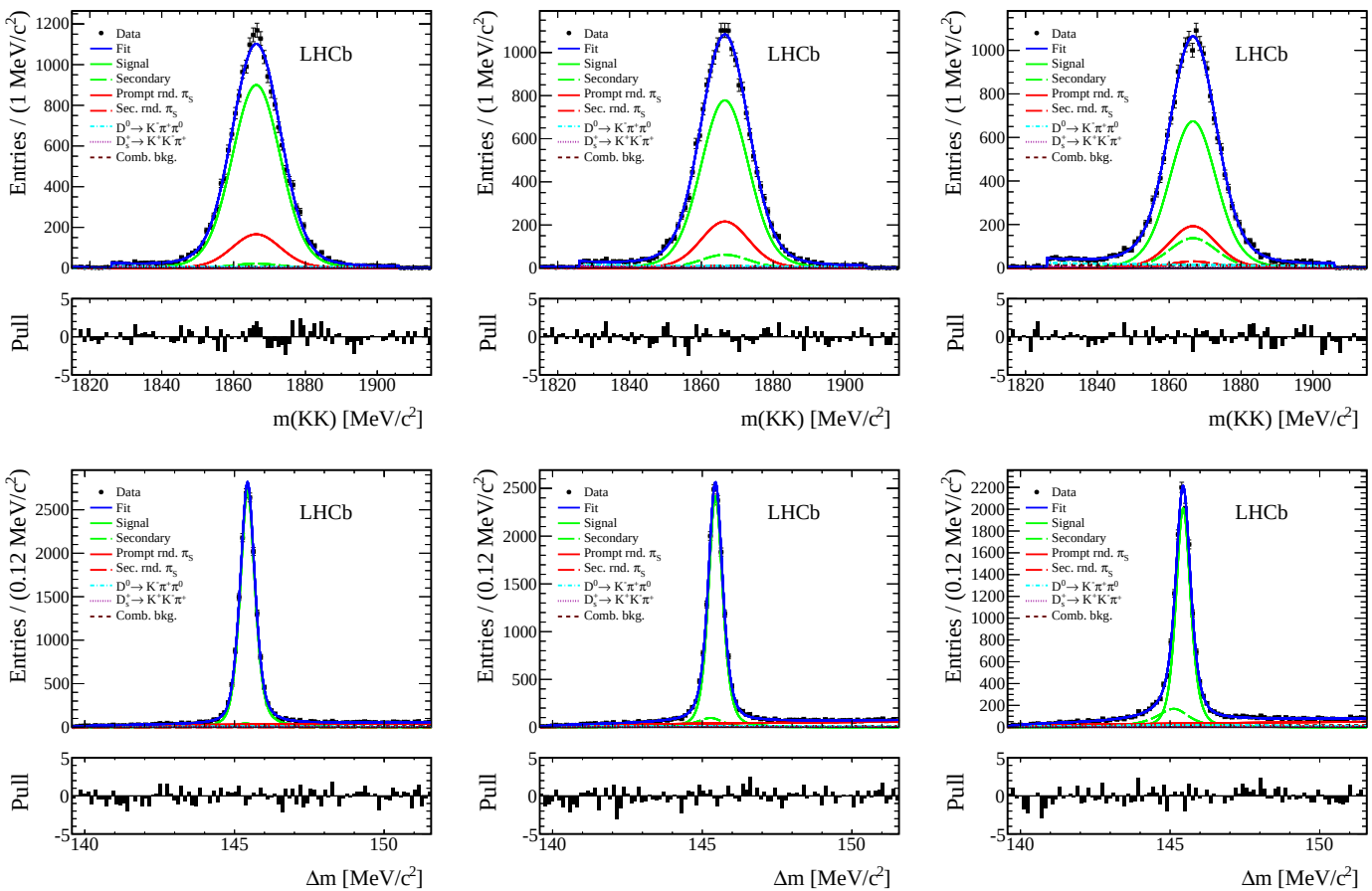
Binned Fit

- Complementary technique of fitting for yields in bins of decay time also used.
- Acceptance effects cancel in ratio - no need to know acceptance.
- Fits to $\mathrm{K^+K^-}$ data for decay-times $0.25 - 0.37$ ps, $0.74 - 0.78$ ps, and $1.55 - 1.80$ ps (left to right):



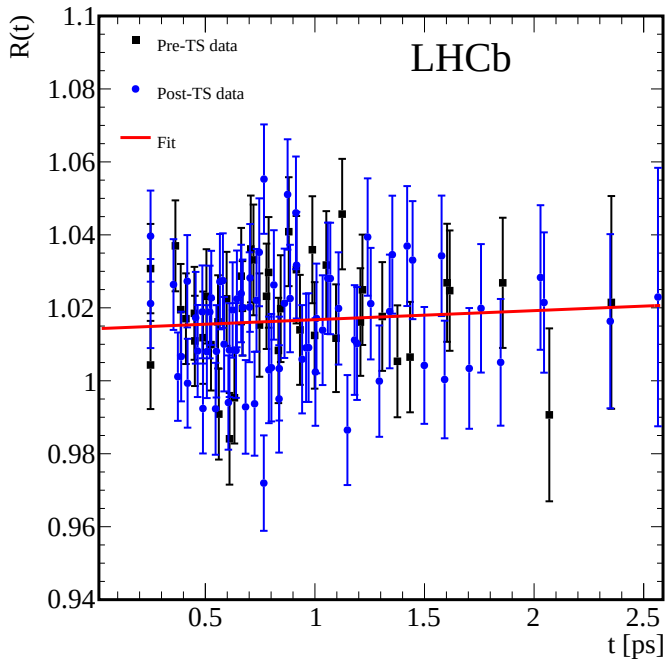
Binned Fit, Mass and Δm Fits

- Fits to $\mathrm{K^+K^-}$ data for decay-times $0.25 - 0.37$ ps, $0.74 - 0.78$ ps, and $1.55 - 1.80$ ps (left to right):

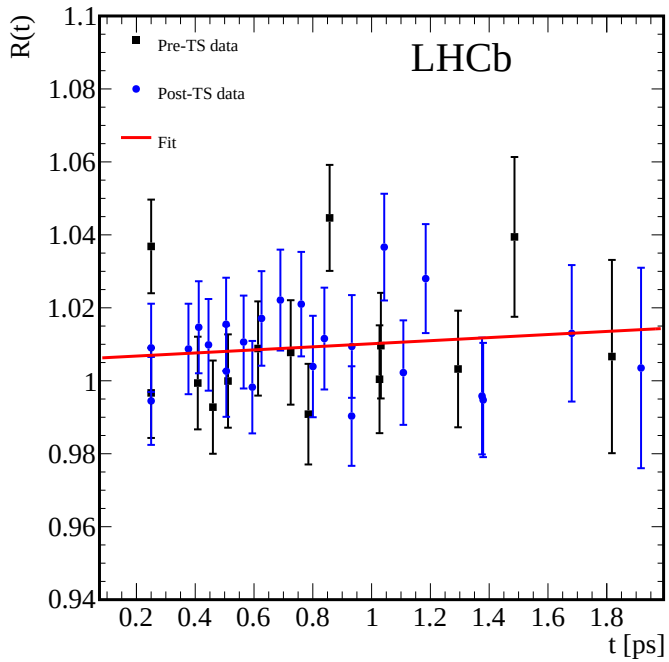


Binned Fit Results

K^+K^-:



$\pi^+\pi^-$:



$$A_\Gamma(\pi\pi) = (0.85 \pm 1.22 \pm 1.13) \times 10^{-3},$$
$$A_\Gamma(\mathrm{KK}) = (0.50 \pm 0.65 \pm 0.89) \times 10^{-3}.$$