Laura++ : Extension to time-dependence

Daniel O'Hanlon, on behalf of the Laura++ developers

Workshop on multi-body charmless b-hadron decays, 07/06/2018

Follows from the first part of the

Laura++ double act

Why care about time dependence?

- Access to CP violation observables and mixing phases in neutral B meson modes
- The most robust way to make measurements of CKM angles with charmless decays

α from $B^0 \to \pi^+\pi^-\pi^0$

Phys. Rev. D 44, 1454 (1991), (Lipkin, Nir, Quinn, Snyder)

Phys. Rev. D 48, 2139 (1993), (Quinn, Snyder)

arXiv:hep-ph/9705356 (Grossman, Quinn)

γ from three-body $B \to K^+\pi^-\pi^0$, $B \to K^0_S\pi^+\pi^-$ and $B^0_s \to K^0_S K^+\pi^-$

arXiv:hep-ph/0602207, arXiv:hep-ph/0601233, (Ciuchini, Pierini, Silvestrini)

arXiv:hep-ph/0608243, (Gronau, Pirjol, Soni, Zupan)

J. Nucl. Part. Phys. Proc. 273–275 (2016) 1417–1422 (Coutinho, Latham, Gershon)

- Probe hadronic amplitudes (given measured CKM parameters):

  arXiv:1705.02981, (Charles, Deschamps, Descotes-Genon, Niess)

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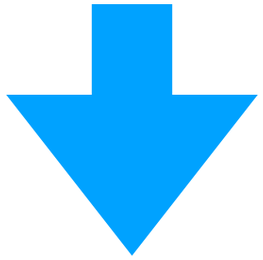

- Procedure used by BaBar and Belle to measure $B^0 \to \rho\pi$ amplitudes
- Measurements ultimately limited by background (and low statistics)
- Inconsistent with other determinations of α ?

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γ from three-body $B \to K^+\pi^-\pi^0$, $B \to K^0_S\pi^+\pi^-$ and $B^0_s \to K^0_S K^+\pi^-$

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- Use $B^0 \to K^*(K^+\pi)\pi$ to cancel penguin contributions (like in $B^0 \to \rho\pi$)
- Use $B^0 \to K^{*+}(K^0_S\pi^+)\pi^-$ to determine relative phase between $B^0, \bar{B}^0$
- Also possible for B^0_s (leverage untagged, time integrated $B^0_s \to K^0_S K^+\pi^-$ to determine the relative phase between $B^0, \bar{B}^0$)

Time-dependent evolution

$$\frac{d\Gamma(B \to f)}{dt} \propto e^{-\Gamma t}\{(|A_f|^2 + |\bar{A}_f|^2)\cosh\left(\frac{\Delta\Gamma}{2}t\right) + (|A_f|^2 - |\bar{A}_f|^2)\cos(\Delta m t) + 2Re\left(\frac{q}{p}A_f^*\bar{A}_f\right)\sinh\left(\frac{\Delta\Gamma}{2}t\right) + 2Im\left(\frac{q}{p}A_f^*\bar{A}_f\right)\sin(\Delta m t)\}$$

Conventional Laura++ amplitude model (covered in the previous talk)

Convolved with experimental decay time resolution (* acceptance)

$$f(m_{13}^2, m_{23}^2, t, \Omega_{\text{tag}}) = \Omega_{\text{tag}}(\omega_{\text{tag}}, \epsilon_{\text{tag}}, q_{\text{tag}})\frac{d\Gamma(B \to f)}{dt} + \overline{\Omega}_{\text{tag}}(\omega_{\text{tag}}, \epsilon_{\text{tag}}, q_{\text{tag}})\frac{d\Gamma(\overline{B} \to f)}{dt}$$

Overall model

Function of mis-tag probability ω, tagging efficiency ϵ, and tag decision, q

Decay time resolution

Implementation: **Analytical convolutions** of the decay time PDFs with (multiple) Gaussian resolution functions

For B^0, $\Delta\Gamma \sim 0$:

$$e^{-\Gamma t}\cos,\sin(\Delta m\ t) \rightarrow \{[e^{-\Gamma t'}\cos,\sin(\Delta m\ t')] \otimes G(0,\sigma_{t'})\} \cdot \epsilon(t')$$

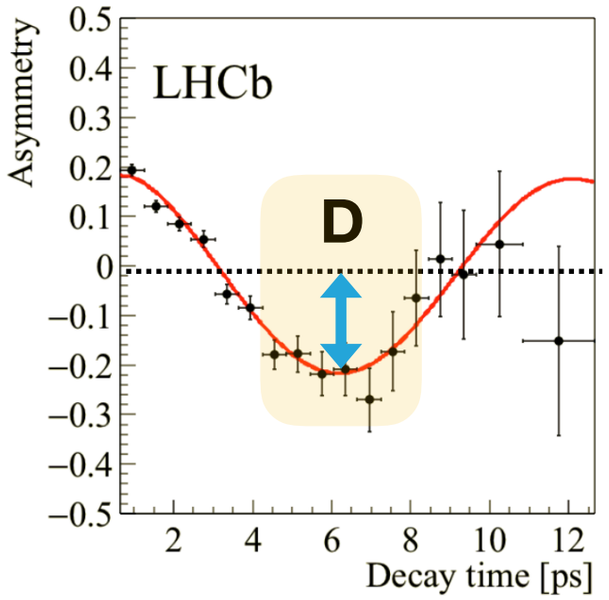
For B_s^0, $\Delta\Gamma > 0$ and the situation is more complicated :

$$e^{-\Gamma t}\cosh,\sinh\left(\frac{\Delta\Gamma}{2}t\right) \rightarrow \left\{\left[e^{-\Gamma t'}\cosh,\sinh\left(\frac{\Delta\Gamma}{2}t\right)\right] \otimes G(0,\sigma_{t'})\right\} \cdot \epsilon(t')$$

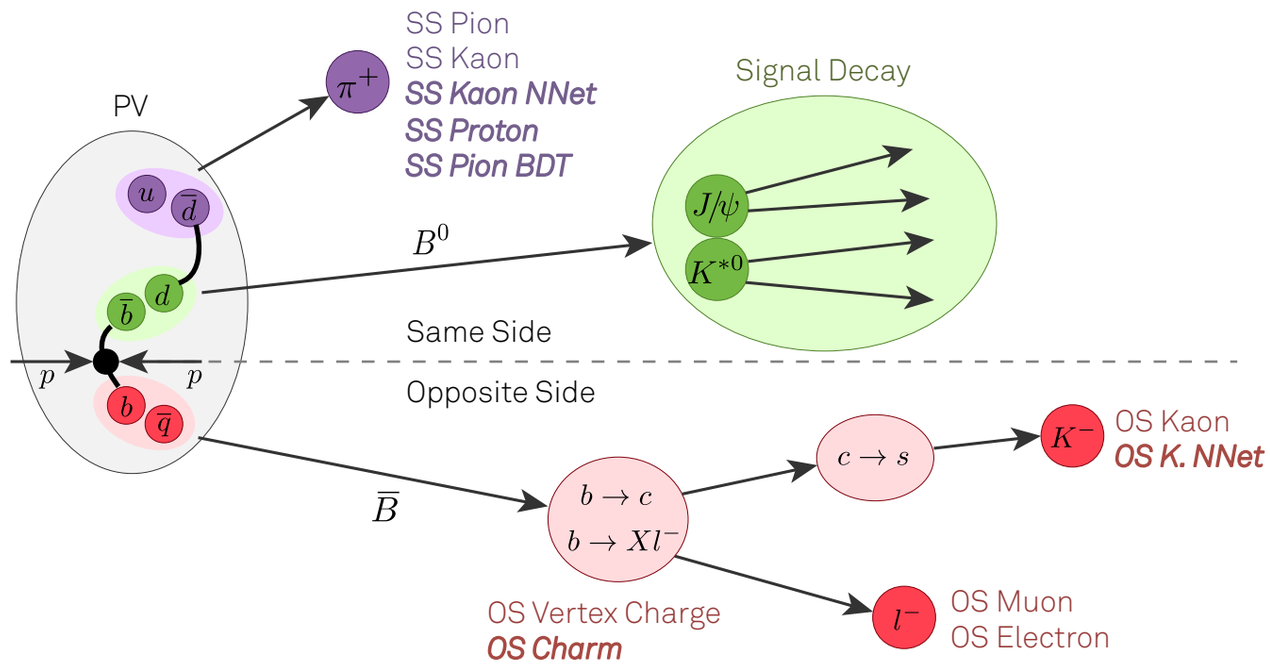
$$\rightarrow \text{ nightmare fuel}$$

Flavour tagging at LHCb

- Mistag probability calculated *event-by-event*
- $B\bar{B}$ pair not quantum-correlated, maybe not even a pair, and identification is hard
- Dilution, $D = 1 - 2\omega$



Combination of same-side and opposite-side taggers



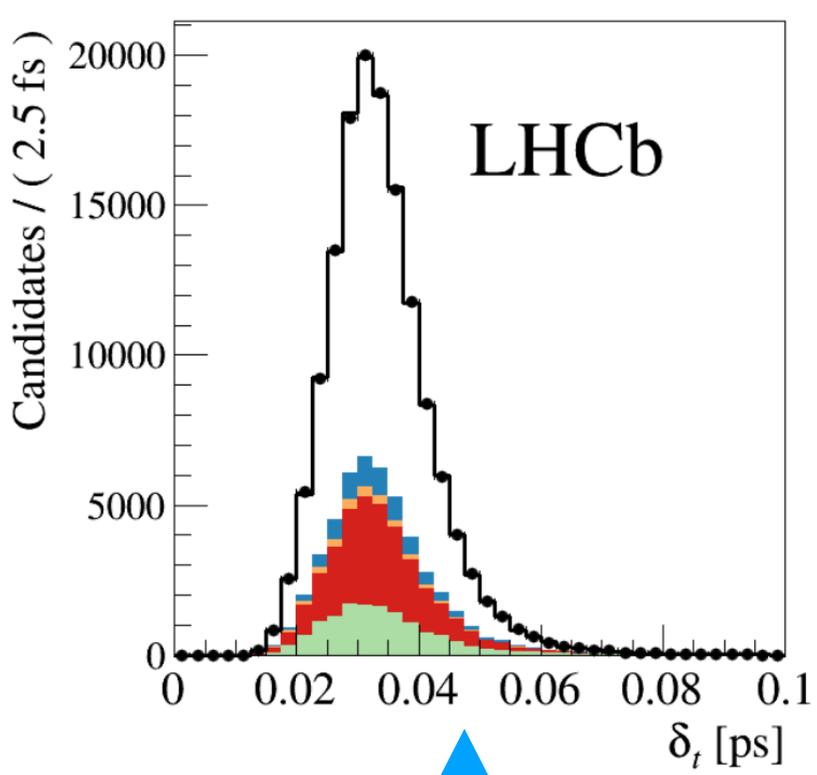
Calibration: $\omega = p_0 + p_1(\eta - \langle\eta\rangle)$

$$\omega(B) - \omega(\overline{B}) = \Delta p_0 + \Delta p_1(\eta - \langle\eta\rangle)$$

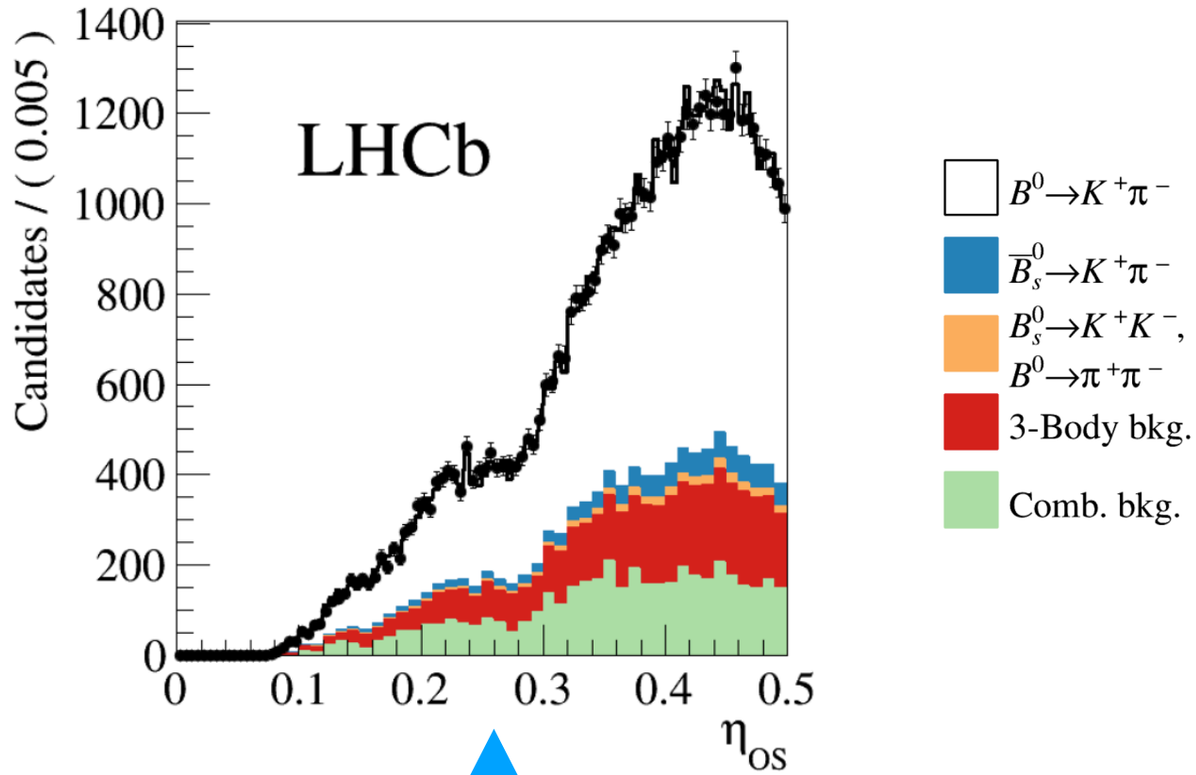
Effective tagging power, ϵD^2 varies from around 2% to around 5%

Input distributions

An example from $B \to hh$ (LHCb-PAPER-2018-006)



Decay time distribution



Mistag rate (OS)

Workflow

(Very preliminary interface)

Initialise flavour tagging class:

From calibration fit

```
// Flavour tagging calibration parameters
LauParameter * p0 = new LauParameter("calib_p0", 0.4512);
LauParameter * p1 = new LauParameter("calib_p1", 1.0);

// Calibration parameter vector
std::vector<LauParameter *> params;
params.push_back(p0);
params.push_back(p1);

// Instantiate LauFlavTag
LauFlavTag* flavTag = new LauFlavTag(params, kTRUE);
```

Use untagged events (category == 0)

Tag category ID (arbitrary at LHCb)

Add a tag category:

Float category fraction?

```
// Set up a tag category
flavTag->addValidTagCat(cat);
flavTag->setSignalTagCatPars(cat, catFrac, D, deltaD, fixFrac, userPerEventMistag);
```

Category fraction

Dilution

Delta dilution

Use per-event mis-tag?

Workflow

Initialise fit model:

```
LauTimeDepFitModel * fitModel = new LauTimeDepFitModel(sigModelB0bar, sigModelB0, flavTag);
```

LauIsobarDynamics

Specify conventions:

Eigenvalue (if not specified event-wise in input file)

```
fitModel->setCPEigenvalue( LauTimeDepFitModel::CPOdd );
fitModel->setPhiMix( 2.0*LauConstants::beta, fixPhiMix, useSinCos );
```

Mixing phase

Fix mixing phase?

Separate into sin and cos?

Workflow

Create decay time PDF:

Decay time variable name

Decay time error variable name

Decay time model parameter vector

Min and max values of decay time and error

```
LauDecayTimePdf * dtPdf = new LauDecayTimePdf( "decayTime", "decayTimeErr", tPars, minT, maxT, minTErr, maxTErr,
                                               LauDecayTimePdf::ExpTrig, nGauss, scale, LauDecayTimePdf::DecayTime );
```

Number of Gaussians in decay time resolution model

Scale resolution by per-event error

Model decay time (LHCb style) or difference in decay time (B-factory style)

```
enum FuncType {
    Hist,       /*< Hist PDF for fixed background*/
    Delta,      /*< Delta function - for prompt background */
    Exp,        /*< Exponential function - for non-prompt background or charged B's */
    DeltaExp,   /*< Delta + Exponential function - for background with prompt and non-prompt parts */
    ExpTrig,    /*< Exponential function with Delta m driven mixing- for neutral B_d's */
    ExpHypTrig  /*< Exponential function with both Delta m and Delta Gamma driven mixing- for neutral B_s's */
};
```

Current status

First version of:

- Time-dependent decay amplitude for B0
- Decay time signal distributions
- Event-by-event flavour tags

In progress:

- Time-dependent decay amplitude for Bs
- Background flavour tagging
- Simultaneous calibration of flavour tags
- Decay time acceptance

Summary

Time-dependent Dalitz-plot analyses are important
for many proposed charmless measurements
(particularly for Bs decays which only LHCb has access to)

Update of Laura++ for ‘LHCb style’ time-dependent
analyses well underway

If you have any comments/ideas/suggestions, please let us know!

(We also have a hackathon tomorrow if you are interested in getting involved)

Backup