The Laura++ Dalitz-plot Fitter

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History

- Package originally developed within BaBar by members of the Warwick group
- The LAURA (Fortran) package was written in 2002 by Paul Harrison
- Converted into C++ by John Back in 2003
- Developed subsequently by John Back and TL, adding many extra features
- TL now main developer (with several contributors)

History (cont.)

- Used in many Dalitz-plot (and other) analyses published by BaBar collaboration
  - Mainly charmless 3-body B decays
- Already being used by several analyses in LHCb ($B \longrightarrow K_S hh$, $B \longrightarrow Dhh$, etc.)
- First public version released on HepForge on Monday!

http://laura.hepforge.org

Main features

- Can form isobar models for the decay of spin-0 parent into 3 spin-0 children
- Many resonance line-shape options available
- Different forms for isobar coefficients implemented
- Extended maximum likelihood fitter
- Toy MC generation from PDFs
- Can include additional discriminating variables
- Many different PDF shapes for non-DP variables, including forms that allow for correlation with the DP position

Main features (cont.)

- Can fit for direct CP violation
- Also possible to model time-dependent CP violation (code currently being updated from being rather B-factory specific to more general – not yet available in public release)
- Can add as many different background categories as needed
- Possible to model variation of reconstruction efficiency over the DP, as well as migration of mis-reconstructed events
- Automated calculation and storage of per-event likelihoods and sPlot weights from fit results

Technical introduction

- A set of C++ classes that are built into a (shared) library
- Package depends only on ROOT
- Several example programs that can be built into executables to generate and fit toy data
- Built with handmade Makefiles at present, will use autotools/cmake soon (should give greater portability)
- Code comes with doxygen documentation

Amplitude models

- As we've seen already this week, we want to describe each contributing amplitude in the decay and the interference between them
- Most common technique known as isobar model
- Total amplitude is sum of contributing amplitudes, each with a complex coefficient:

$$\mathcal{A}(x,y) = \sum_{j=1}^{N} c_j F_j(x,y)$$

Complex coefficient

Decay dynamics
(function of DP position)

Amplitude models

- You set the F_j forms by choosing the resonance lineshapes as well as their mass, width and spin

```
106         // Create the isobar model
107         LauIsobarDynamics* sigModel = new LauIsobarDynamics(daughters, effModel);
108         sigModel->addResonance("rho0(770)",  1, "RelBW"); // resPairAmpInt = 1 => resonance mass is m23.
109         sigModel->addResonance("rho0(1450)", 1, "RelBW");
110         sigModel->addResonance("f_0(980)",   1, "Flatte");
111         sigModel->addResonance("f_2(1270)",  1, "RelBW");
112         sigModel->addResonance("NonReson",   0);
```

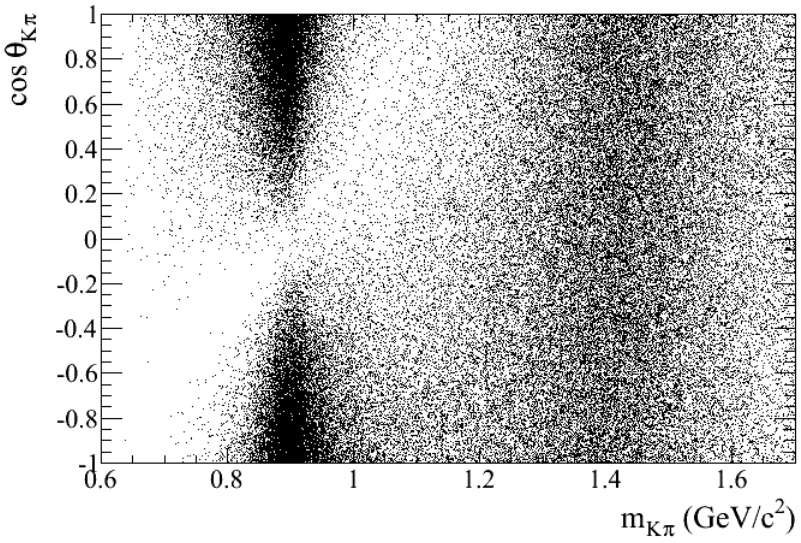
Amplitude models

- The c_j can be set in the generation of toy MC and in the fits are the free parameters that you wish to determine
- Need to be cast into a pair real numbers to become fit parameters, e.g.:
  - $c_j = x_j + i\, y_j$
  - $c_j = a_j\, e^{i\theta_j}$

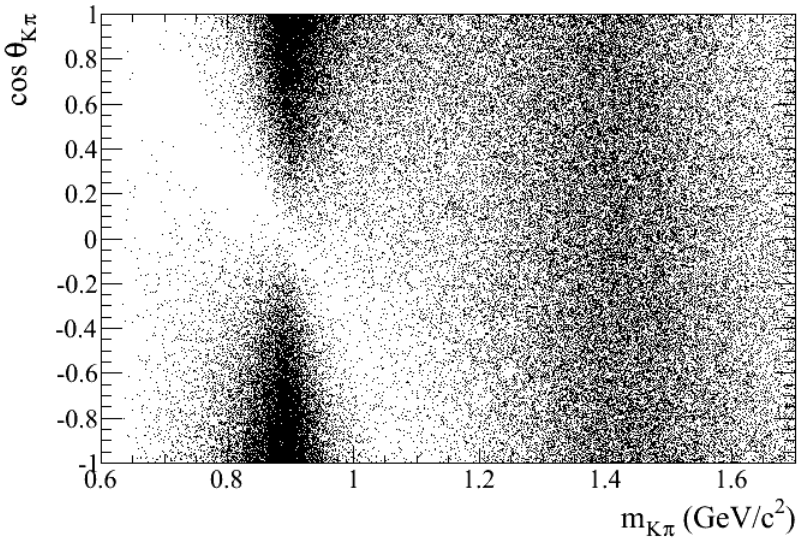
```
121         // Create the fit model
122         LauSimpleFitModel* fitModel = new LauSimpleFitModel(sigModel);
123
124         // Create the complex coefficients for the isobar model
125         std::vector<LauAbsCoeffSet*> coeffset;
126         coeffset.push_back( new LauMagPhaseCoeffSet("rho0(770)",  1.00,  0.00,  kTRUE,  kTRUE) );
127         coeffset.push_back( new LauMagPhaseCoeffSet("rho0(1450)", 0.37,  1.99, kFALSE, kFALSE) );
128         coeffset.push_back( new LauMagPhaseCoeffSet("f_0(980)",   0.27, -1.59, kFALSE, kFALSE) );
129         coeffset.push_back( new LauMagPhaseCoeffSet("f_2(1270)",  0.53,  1.39, kFALSE, kFALSE) );
130         coeffset.push_back( new LauMagPhaseCoeffSet("NonReson",   0.54, -0.84, kFALSE, kFALSE) );
131         for (std::vector<LauAbsCoeffSet*>::iterator iter=coeffset.begin(); iter!=coeffset.end(); ++iter) {
132                 fitModel->setAmpCoeffSet(*iter);
133         }
```

Examples

K*(892)



K_0*(1430)



- Both resonances modelled as relativistic BW in this toy example
- Different relative phases lead to different interference patterns

Integration Trick

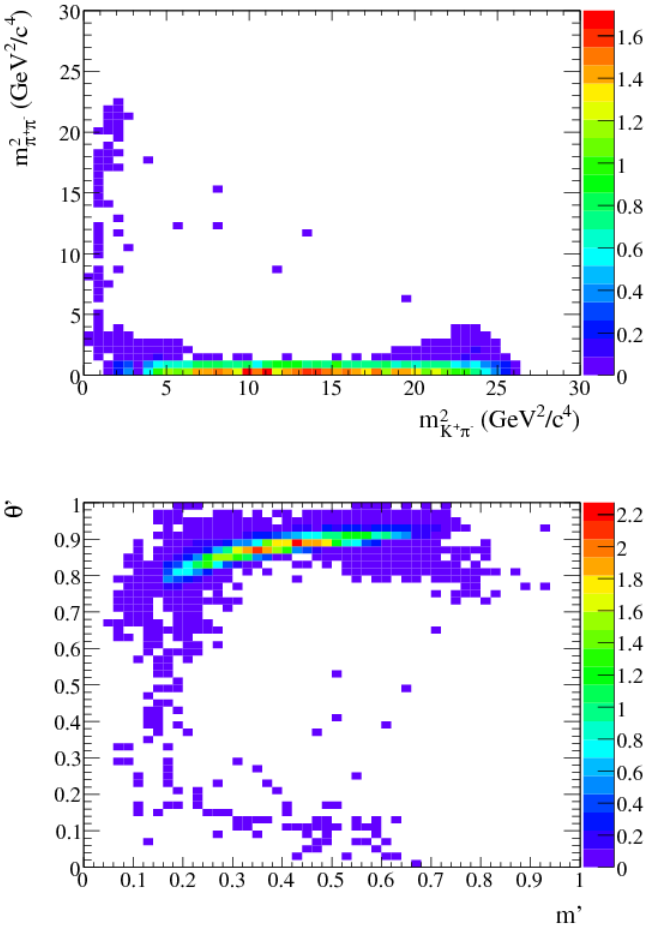
- When calculating the normalisation of the amplitude, find that the c_j's factorise:

$$\int |A(x,y)|^2 \, dx\, dy = |c_1|^2 \int |F_1(x,y)|^2 \, dx\, dy + c_1 c_2^* \int F_1(x,y) F_2^*(x,y) \, dx\, dy + \ldots$$

- Can calculate all the integrals once and cache
  - Assumes resonance parameters are fixed
- Gives massive speed benefits!

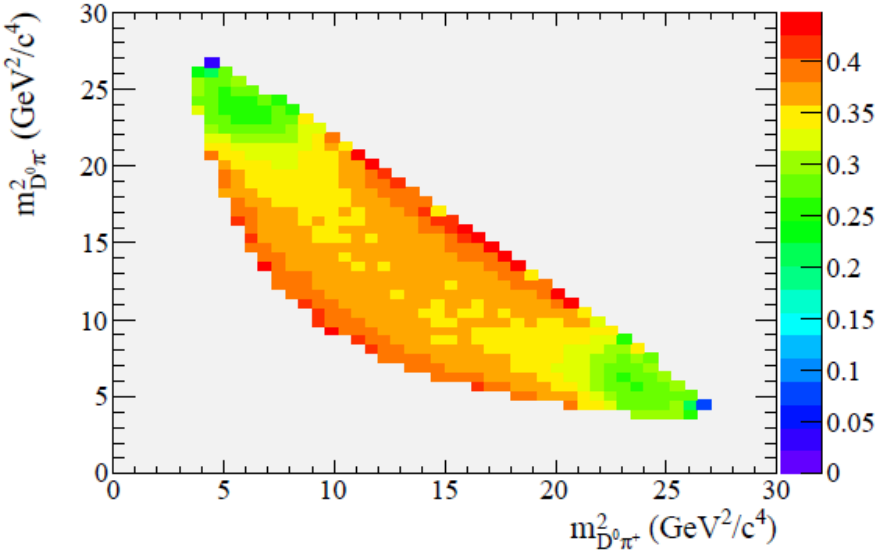
Backgrounds

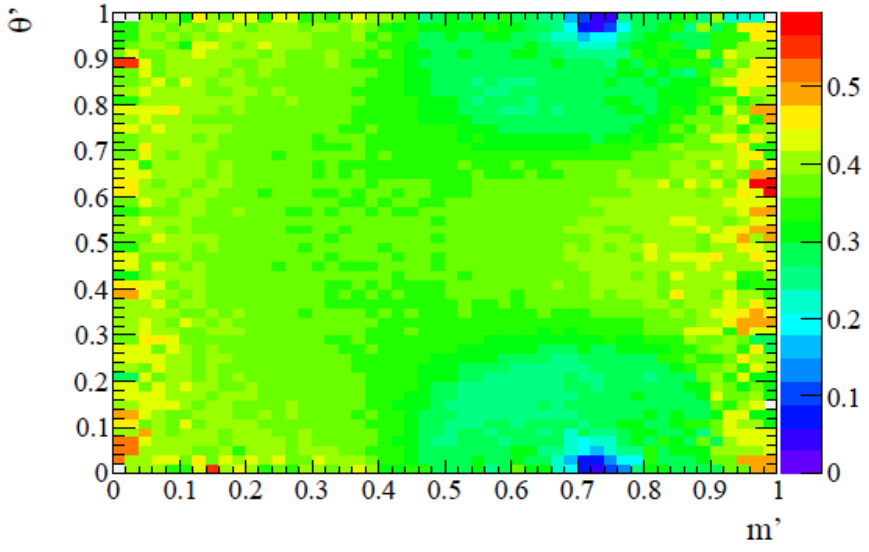
- Background model included as 2D histogram
- Either in conventional DP co-ordinates or in the “square DP”
- Can optionally use linear interpolation to smooth shape



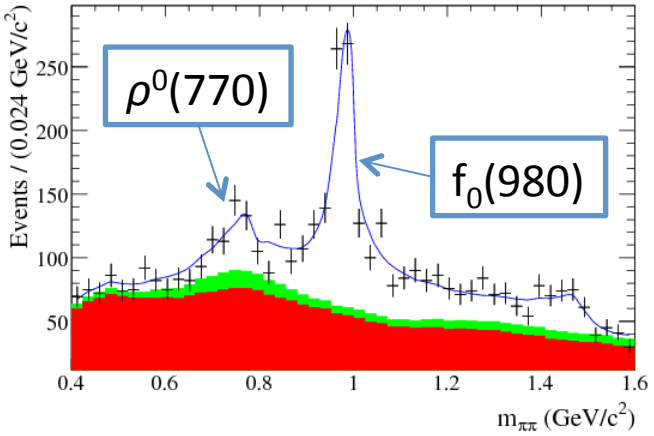
Efficiency variation

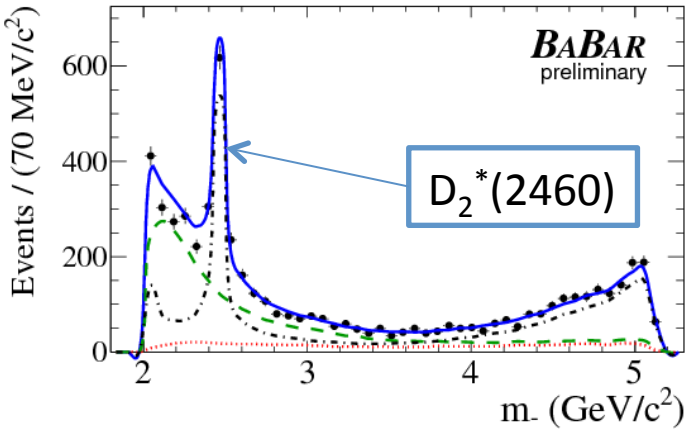
- Implemented in similar way to backgrounds
- 2D histogram with optional linear interpolation
- Will soon be able to use 2D splines for smoothing





Some example fits

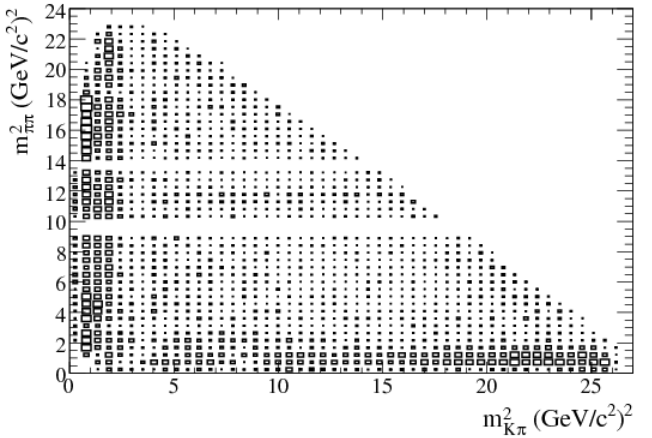


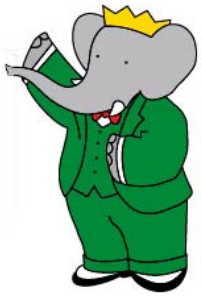


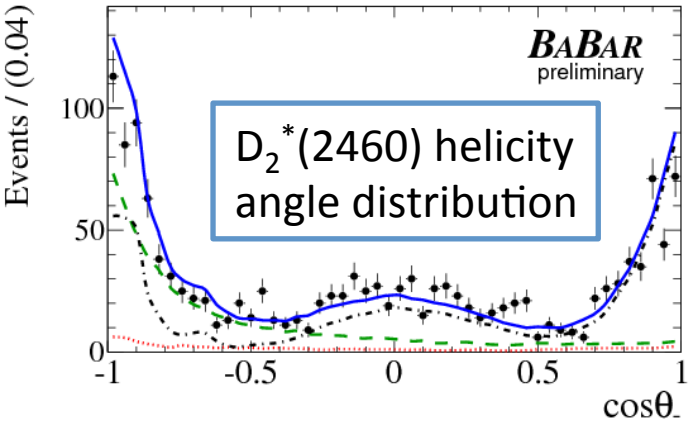
Total Fit Result

Continuum background

BB background







B+ -> K+ pi+ pi-

B0 -> D0 pi+ pi-

Summary

- Laura++ is a mature package, used for many published analyses
  - Well tested, lots of features, e.g. K-matrix, sPlot, etc.
- Specialised fitter for DP analysis – very fast!!
- Under active development – new features being added
- Current major items on the TODO list:
  - Model for time-dependent Dalitz-plot analysis for time-dependent CP asymmetry measurements
  - Allow floating of resonance parameters, e.g. masses and widths
  - Extend to deal with initial-state and final-state particles with non-zero spin, e.g. Λ_b decays

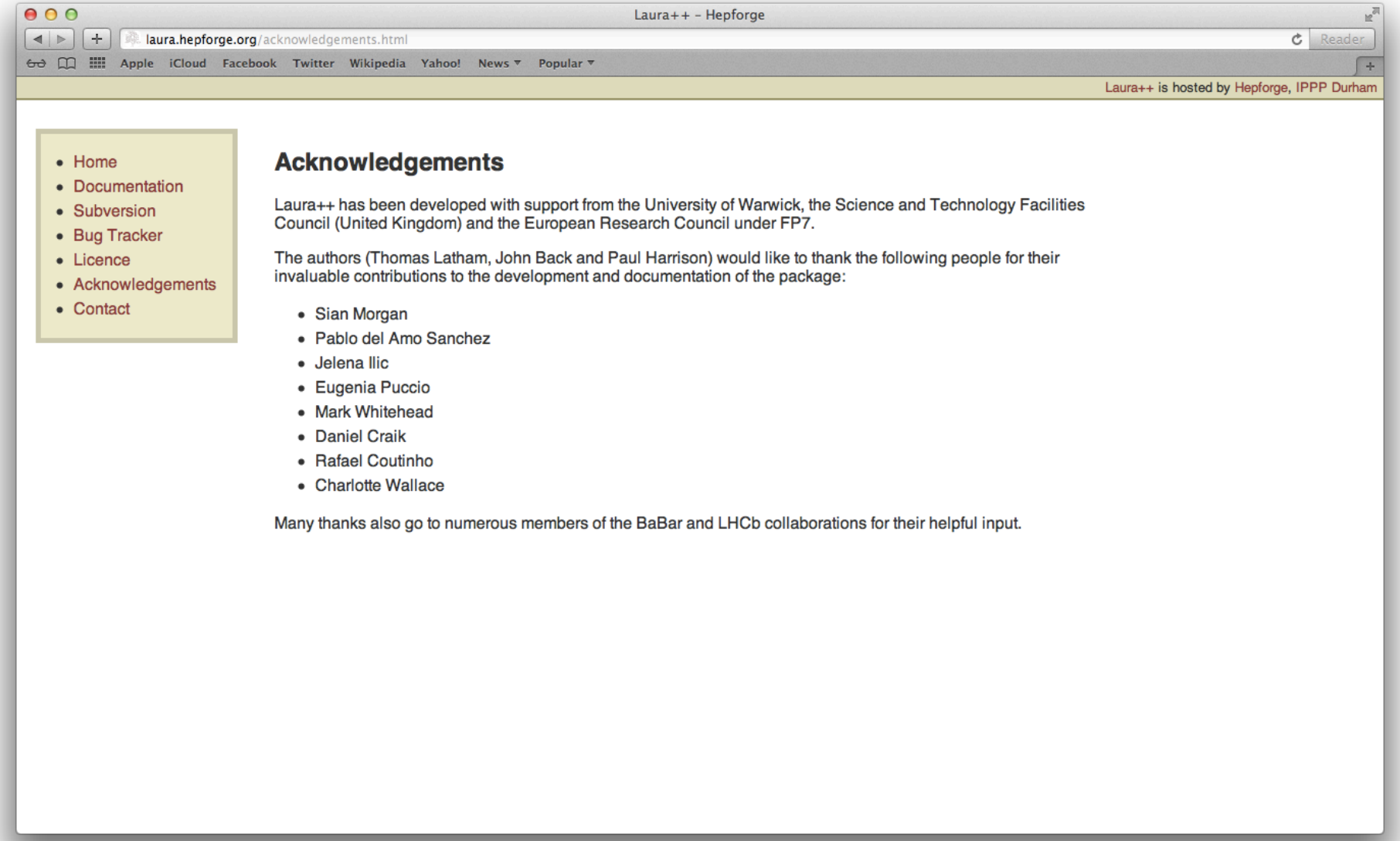
Conclusion

- Please take a look:

  http://laura.hepforge.org

- There is documentation on the website to help you get started, plus several examples
- A quick-start tutorial is also on the indico agenda (along with the slides for this talk)
- A full user guide is in preparation
- A paper is also in preparation, which will document the conventions and formulae used

Thanks!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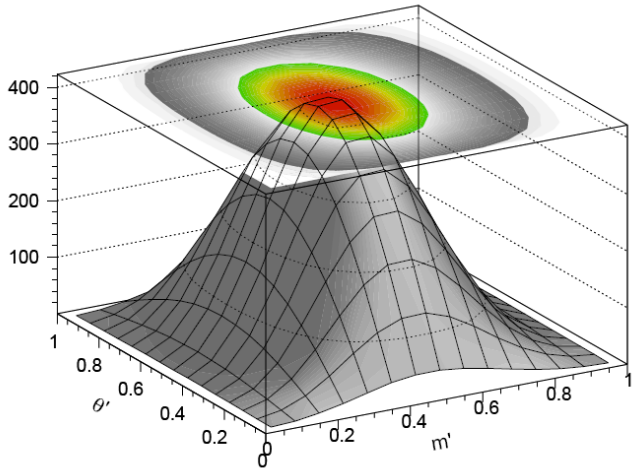
BACKUP

The square Dalitz plot

$$m' \equiv \frac{1}{\pi}\arccos\left(2\frac{m_{K^+\pi^+} - m^{\min}_{K^+\pi^+}}{m^{\max}_{K^+\pi^+} - m^{\min}_{K^+\pi^+}} - 1\right),$$

$$\theta' \equiv \frac{1}{\pi}\theta_{K^+\pi^+},$$



- Transformation of coordinates
- "Zooms" into the areas around the boundary of the conventional Dalitz plot
- Increases resolution in those areas of interest
- Also avoids effect from kinematic boundary not being aligned with bin edges

List of DP papers

- B. Aubert et al. (BABAR Collaboration), Dalitz-plot analysis of the decays B+ -> K+ pi+ pi-,
  - Phys. Rev. D 72, 072003 (2005) [Erratum-ibid. D 74, 099903 (2006)], arXiv:hep-ex/0507004
- B. Aubert et al. (BABAR Collaboration), An amplitude analysis of the decay B+ -> pi+ pi+ pi-,
  - Phys. Rev. D 72, 052002 (2005), arXiv:hep-ex/0507025
- B. Aubert et al. (BABAR Collaboration), Evidence for Direct CP Violation from Dalitz-plot analysis of B+ -> K+ pi+ pi-,
  - Phys. Rev. D 78, 012004 (2008), arXiv:0803.4451 [hep-ex]
- T. Latham and T. Gershon, A Method to Measure cos(2beta) Using Time-Dependent Dalitz Plot Analysis of B0 -> D_CP pi+ pi-,
  - J. Phys. G 36, 025006 (2009), arXiv:0809.0872 [hep-ph]
- B. Aubert et al. (BABAR Collaboration), Dalitz plot analysis of B+ -> pi+ pi+ pi- decays,
  - Phys. Rev. D 79, 072006 (2009), arXiv:0902.2051 [hep-ex]
- B. Aubert et al. (BABAR Collaboration), Time-dependent amplitude analysis of B0 -> KS pi+ pi-,
  - Phys. Rev. D 80, 112001 (2009), arXiv:0905.3615 [hep-ex]
  - (Used as a cross-check, not for the main results.)
- P. del Amo Sanchez et al. (BABAR Collaboration), Dalitz-plot Analysis of B0 -> D0 pi+ pi-,
  - Presented at ICHEP 2010, arXiv:1007.4464 [hep-ex]

List of other papers

- B. Aubert et al. (BABAR Collaboration), Observation of the Decay B+ -> K+ K- pi+,
  - Phys. Rev. Lett. 99, 221801 (2007), arXiv:0708.0376 [hep-ex]
- B. Aubert et al. (BABAR Collaboration), Search for the highly suppressed decays B- -> K+ pi- pi- and B- -> K- K- pi+,
  - Phys. Rev. D 78, 091102(R) (2008), arXiv:0808.0900 [hepex]
- B. Aubert et al. (BABAR Collaboration), Search for the decay B+ -> KS KS pi+,
  - Phys. Rev. D 79, 051101(R) (2009), arXiv:0811.1979 [hep-ex]
- P. del Amo Sanchez et al. (BABAR Collaboration), Observation of the Rare Decay B0 -> KS K+ pi-,
  - Phys. Rev. D 82, 031101(R) (2010), arXiv:1003.0640 [hep-ex]
- J. P. Lees et al. (BABAR Collaboration), Observation of the rare decay B+ -> K+ pi0 pi0 and measurement of the quasi-two body contributions B+ -> K*(892)+ pi0, B+ -> f0(980) K+ and B+ -> chi_c0 K+,
  - Phys. Rev. D 84, 092007 (2011), arXiv:1109.0143 [hep-ex]