Dalitz Analysis Tools in BaBar

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Charge of the DTF includes to provide a catalog of existing Dalitz tools
- List of main features of each tool
- Help new analysers to identify if an already existing piece of code accommodates to what he/she wants

Particularly important now since traditional Dalitz techniques of light meson spectroscopy are taking new roles in measurements of CKM angles:
- Time independent in 3-body D and B decays
- Time dependent in 3-body B decays

Catalog of tools and features based on AWG feed-back
- Focus on currently used, public, and maintained tools
- Each tool had a checklist to fill-out (next slide)
- If any existing tool is missing in the list or you see any mistake, please let me know

It is not the purpose of this report to give details on Dalitz analysis techniques but only identify, classify and list main features
Dalitz fit tools checklist

- Software basis (Fortran, ROOT, RooFit, EvtGenBase, etc.)
- B and/or D decays?
- Fit techniques: unbinned/binned maximum likelihood (UML/BML), chi2
- Goodness-of-fit (GOF): likelihood, chi2, adaptative binning
- Dalitz model(s):
  - Dynamics: isobar (BW), K-matrix/P-vector, partial waves
  - Spin formalism: helicity, Zemach tensors (covariant, non-covariant), partial waves
- Normalization of amplitudes: toy MC, numerical, analytical
- Efficiency and mass resolution (for narrow resonances) treatment
- Background Dalitz shapes and characterization ($m_{ES}$, $\Delta E$, Fisher, $m_D$, tag info)
- Fit support for masses and widths?
- How are fit fractions calculated?
- Visualization of results ALL
- Input: flat and/or ROOT file ALL
- Any other specific feature (CVS availability, documentation,...) ?
Overview of Dalitz tools

- **Charm AWG**
  - Bari (A. Palano)
  - Cincinnati (B. Meadows)

- **Breco AWG**
  - $D^0(Dalitz)K$
    - RooDKDalitz
    - RooBenDalitz
  - $D^*-a_1^+\ DOOM$
  - $D^{(*)+}\pi\pi$ (D_j states): BToDjFittingTools

- **Charmless AWG**
  - $3\pi,K\pi\pi,3K$: Laura++
  - KKKs: custom
  - $h^+h^+h^- (h=\pi/K)$: custom
  - $K\pi\pi^0,\rho\pi$: RhoPiTools
Charm fitters

- Custom, Fortran based
- D decays
- UML
- Likelihood, chi2 and adaptive binning GOF
- Isobar model (BW, Flatté, LASS), partial wave analysis
- Helicity and Zemach tensors (no covariant)
- Normalization: phase space MC weighted by the polynomial efficiency
- Efficiency correction: fitted 3rd order polynomial. No mass resolution
- Background: Gaussian to describe D
- Fractions computed as:
  - Errors on fit fractions from MC simulation
  - The fitted amplitudes and phases are randomly modified according to full covariance matrix

\[ f_i = \frac{|c_i|^2 \int |A_i|^2 dm_x^2 dm_y^2}{\sum_{j,k} c_j c_k^* \int A_j A_k^* dm_x^2 dm_y^2} \]
RooDKDalitz
(D^0K^-, D^0→3-body)

- General framework, RooFit and EvtGenBase based
  - EvtGenBase classes for 2- and 3-body kinematics, Dalitz plot boundaries, penetration factors, BWs, Flatté, d-functions, etc.
  - Optimized a general purpose fitter for γ from DK Dalitz
    - Model dependent and model independent methods
    - Flexibility for combining different B and D decays for γ

- D decays, can easily be adapted for B decays
- UML and BML
- Likelihood and binned chi2 GOF
  - Use independent (Fortran based) code for adaptative binning chi2 GOF
- Isobar model and K-matrix/P-vector
- Helicity and Zemach tensors (no covariant)
- Normalization: numerical and phase space MC
- Efficiency correction: fitted 3rd order polynomial. No mass resolution
- Background: 3rd order polynomial, on-reso SB+BB MC, m_{ES}, ΔE, Fisher
- Mass and width fitting
- Fit fractions: account for interference
- Available in CVS: cvs co RooDKDalitz
RooBenDalitz

\((D^0K^-, D^0 \rightarrow K_S^{\pi^+ \pi^-})\)

- Custom, RooFit based
- Essentially, a custom version of RooDKDalitz optimized for \(D^0 \rightarrow K_S^{\pi^+ \pi^-}\) (3-body) studies and tuning
  - Simple
  - Fast
  - Addition of channels requires hard coding
  - Complementary to RooDKDalitz
- Available in CVS: `cvs co RooBenDalitz`
**DOOM** Dalitz Object Oriented Modeling

\( \text{(D}^*\text{-a}_1^+) \)

- General framework, ROOT and StatTools based
- Potentially for B and D decays
  - Now applied to study of 3 pion system in the \( B \rightarrow D^*3\pi \) decay
- UML
- Isobar model with covariant Zemach tensors
- Likelihood GOF
- Normalization: Phase space MC
- Efficiency correction: not yet available
- Background: SB \( m_{ES} \)
- Mass and width fitting: could be implemented if required
- Fit fractions: account for interference
- Visualization based on toy MC random extraction
- Available in CVS: `cvs co BToDstar3pi`
- Optimized for batch running rather than interactive analysis
BToDjFittingTools
\((D^{(*)}^+\pi^-\pi^-, D_j \text{ states})\)

- General framework, RooFit and EvtGenBase based
  - EvtGenBase classes for amplitude calculation (Pto3P classes)
- Potentially for B and D decays (P\(\rightarrow\)PPP and P\(\rightarrow\)VPP)
  - Only B decay tested
- UML
- Isobar model
- Likelihood goodness-of-fit
- Normalization: Phase space MC and several numerical methods
  - Normalization calculated for each fit iteration, allowing mass and width fitting
- Efficiency correction: yes
- Fit fractions: account for interference
- Available in CVS: cvs co BToDjFittingTools
RhoPiTools

\((K\pi\pi^0, \rho\pi)\)

- General framework, RooFit based
- UML
- Likelihood and binned chi2 GOF
- Isobar model
- Normalization: phase space MC
- Efficiency correction: 2D histograms
- Mass resolution: reweighting of phase space MC
- Background: 2D histograms, on-reso SB+BB MC
- No mass and width fitting
- Fit fractions: ignore interference
- Square Dalitz plot, time and tag dependence
- Available in CVS: `cvs co RooPiTools`
- Poorly documented: link from Charmless AWG page (simple recipe, but old)
Laura++
(3π,Kππ,3K)

- General framework, ROOT based
- 3-body B and D decays to π/K/π0/K0s
- UML
- Likelihood and chi2 GOF
- Isobar model (BW, Flatté, LASS) with Zemach tensors
- Normalization: MC and numerical Gauss-Legendre integration
- Efficiency correction: 2D histograms
- Mass resolution with MC reweighting technique (3K only)
- Background: 2D histograms, on-reso SB+ BB MC
- No mass and width fitting. Genetic
- Fit fractions: ignore interference
- Available in CVS: cvs co NonCharmBDecayTools/ThreeBody/Laura++
- Well documented: web page (link from Charmless Home page) and BAD# 806
$h^+ h^+ h^-$ ($h=\pi/K$) fitter

- Custom, ROOT based
- BML
- Binned chi2 GOF
- Isobar model
- Normalization: numerical
- Efficiency correction: 2D histograms
- Mass resolution: interbin migration (convolution)
- Background: substracted
- Mass and width fitting
- Fit fractions: ignore interference
- Poorly documented: pages 4-11 of BAD#643
KKK\(_S\) fitter

- Custom, RooFit and EvtGenBase based
- UML
- Likelihood and chi2 GOF
- Isobar model
- Normalization: numerical
- Efficiency correction: 2D histograms
- No mass resolution (for now)
- Background: 2D histograms, on-reso SB+ BB MC
- Mass and width fitting
- Fit fractions: ignore interference
- Square Dalitz plot, time and tag dependence
Summary and comments

- Many DP packages (10 counted here)
  - optimal flexibility for each particular analysis (configuration, visualization, etc.)
  - ...but kernel of all these do the same thing:
    - 2- and 3-body kinematics, Dalitz plot boundaries, penetration factors, BWs, d-functions,...

- Having a minimal “standarization” (library of classes) would help
  - Too late?
  - Some already “standarized” using EvtGenBase classes (RooDKDalitz, BToDjFittingTools, KKK_S fitter)

- Starting to have available K-matrix/P-vector and time/tag dependence in some codes
  - Should this be standarized?