Using AmpTools to Extract the $a_2(1320)$ Yield from GlueX 2017 Data

GlueX Software Tutorial
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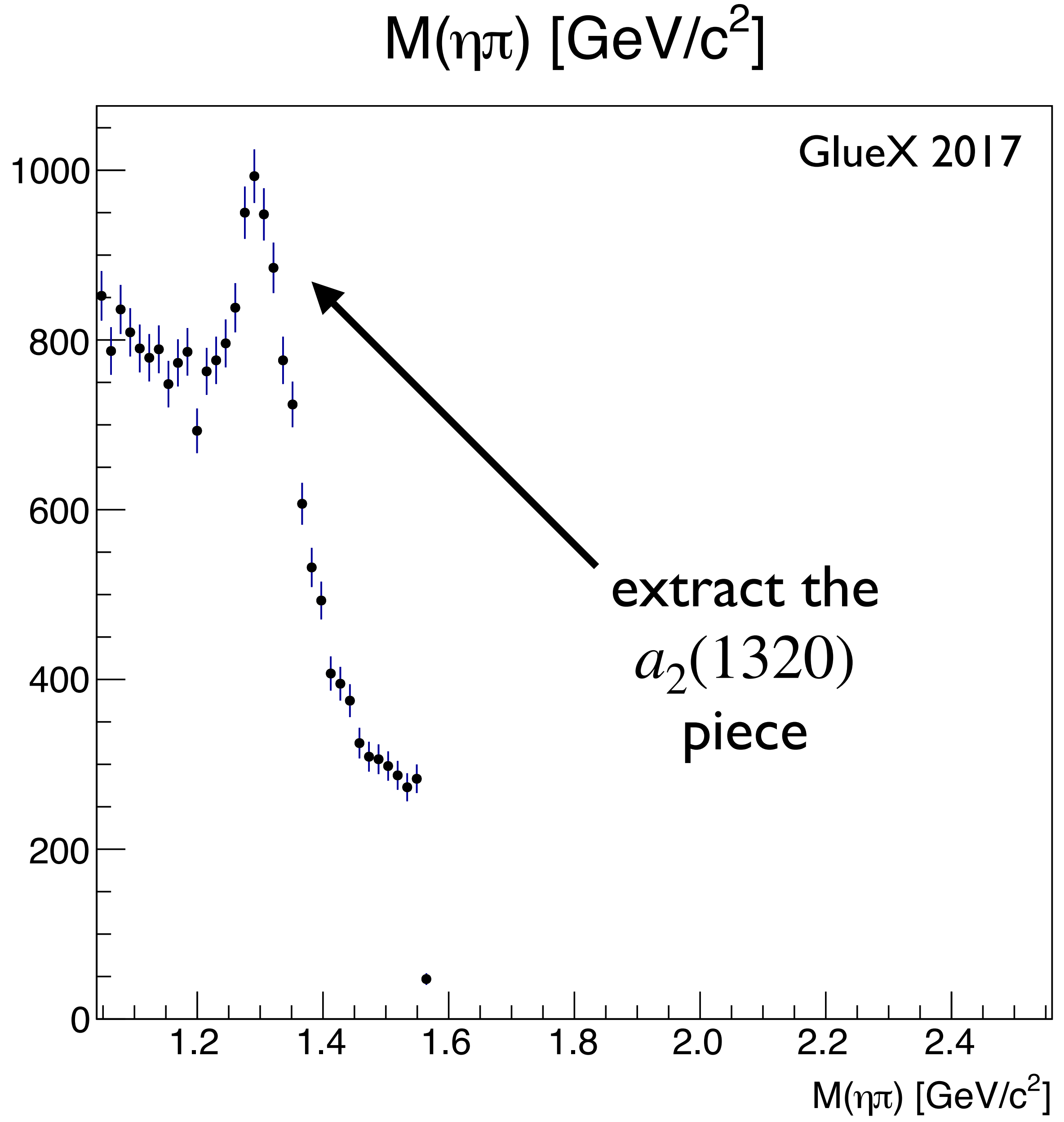
Example Fit Goal: Extract a_2 from $\eta\pi^0$

- Use data sample from previous exercise
- The kinematics of $\eta\pi^0$ system (angular distributions) are given by the Z_ℓ^m functions discussed in the morning session
- Dynamical assumptions about how the amplitude depends on $M(\eta\pi^0)$
  - D-waves: a complex-valued Breit-Wigner with parameters consistent with the $a_2(1320)$
    - certain m-projections/reflectivities excluded based on tensor meson dominance (TMD) model
  - S-waves: fixed complex number in four coarse bins of $M(\eta\pi^0)$ (a piecewise complex function)
- Goal: extract the total efficiency corrected yield of $a_2(1320)$ (the coherent sum of all D-waves)



Required Code: AmpTools

- AmpTools: library that is distributed independently of GlueX code base
  - available through GitHub: github.com/mashephe/AmpTools
  - installed as external package in GlueX environment: setup as part of gxenv using xml version files (see Alex's talk)
  - if you want to rebuild yourself, rebuild AmpTools first then halld_sim -- in your local version.xml use similar lines to point to your own install:

```
<package name="amptools" home="/home/shepherd/src/AmpTools"/>
<package name="halld_sim" home="/home/shepherd/src/halld_sim"/>
```

- The AmpTools library (not an executable) provides a general interface for doing fits
  - fully functional example of how to use AmpTools is also provided in Tutorials/Dalitz
    - copyDalitz.py is provided to generate your own project based on the Dalitz tutorial (not needed for a typical GlueX user)
  - GlueX has a set of libraries and executables that rely on the core AmpTools package
    - halld_sim/src/libraries/AMPTOOLS_...
    - halld_sim/src/programs/AmplitudeAnalysis
  - Documentation concerning the theory of operation of AmpTools is available on GitHub
  - AmpTools "knows" nothing about GlueX data format, physics, etc.
- Issue tracking system on GitHub is used -- report AmpTools problems there if they pertain to the core package and not the GlueX implementation

Required Code: Amplitudes

- Provide AmpTools with a method (code via a library) to convert the four-vectors of an event to a complex number
  - inherits from the Amplitude class in AmpTools which defines the interface for the object -- a template is provided to handle some necessary functions
    - see Tutorials/Dalitz/DalitzLib/DalitzAmp/BreitWigner.h
  - accepts arguments as an arbitrarily long list of strings (which will be specified in the config file)
- A collection of GlueX related amplitudes is here:
  - halld_sim/src/libraries/AMPTOOLS_AMPS
- Several optional features:
  - embed floating fit parameters (e.g., BreitWigner mass) into the calculation of the amplitude
  - perform a data reduction step to reduce four-vectors to "user variables," e.g., angles or Lorentz invariants, that are used to compute the amplitude
  - GPU acceleration of amplitude calculation -- requires additional code
  - *use of features increases complexity but can optimize performance -- not a one-size-fits-all solution: ask for advice if you considering additional development to make fits run faster*
- The executable you write knows about the existence of the amplitudes through the static registration methods of the AmpToolsInterface
  - AmpToolsInterface::registerAmplitude(BreitWigner());
  - register before creating an instance of AmpToolsInterface to do your fit, generate MC, ...

Required Code: DataReader

- Provide AmpTools with a class that is able to turn a file on disk into a set of four-vectors
  - similar to Amplitude class: inherits from DataReader, uses a template for some key functions, and accepts arguments as a list of strings
  - see example in Tutorials/Dalitz
- Not usually analysis specific, but more specific to the file format
  - GlueX collection of data readers is here: halld_sim/src/libraries/AMPTOOLS_DATAIO
- Common GlueX formats for AmpTools input:
  - standard ROOT tree from tree_to_amptools : ROOTDataReader
  - FSRoot format tree: FSRootDataReader
- Complex functionality can be added:
  - perform filtering or cuts during read into AmpTools
  - bootstrap: random sample with oversampling to evaluate uncertainties
- Not all components of a fit need to use the same data reader
- Like amplitudes, readers need to be registered prior to use:
  - AmpToolsInterface::registerDataReader(DalitzDataReader());

Configuration File: General Remarks

- See sample: Tutorials/Dalitz/run/dalitz3.cfg
- all lines begin with a keyword that informs the parser how to process the rest of the line
  - no continuation character: put it all on one line
  - ordering of the lines is not important
- useful keywords for organizing files:
  - `include <file>`
  - `define <word> (defn1) (defn2) (defn3)` ...
    - `<word>` must be isolated (spaces on each side) to be replaced with one or more words
  - `loop  <word>  <value1> (value2) (value3)` ...
    - any line containing `<word>` will be repeated replacing `<word>` with `<value1>`, `(value2)`, ...
    - multiple loops can be in a single line but they must be of the same length N -- then the line is repeated N times stepping through all loops in sync simultaneously
- some special syntax:
  - # as the first character denotes a comment
  - `::` is treated like a space
  - `[parname]` -- use square brackets when the name of a parameter (instead of a numerical value) should be passed as an argument to an amplitude

Reactions, sums, and amplitudes

- Within a reaction, the intensity must be defined as a sum of coherent sums of amplitudes, where each amplitude can be a product of factors

$$\mathcal{I}(\mathbf{x}) = \sum_{\sigma} \left| \sum_{\alpha} s_{\sigma,\alpha} V_{\sigma,\alpha} A_{\sigma,\alpha}(\mathbf{x}) \right|^2$$

$$A_{\sigma,\alpha}(\mathbf{x}) = \prod_{\gamma=1}^{n_{\sigma,\alpha}} a_{\sigma,\alpha,\gamma}(\mathbf{x}).$$

- Amplitudes can be scaled by a real number $s_{\sigma,\alpha}$ (default 1) and have a complex production coefficient $V_{\sigma,\alpha}$
- This matches the general form for $\eta\pi$ production:

$$I(\Omega,\Phi) = 2\kappa \sum_k \left\{ (1-P_\gamma) \left| \sum_{\ell,m} [\ell]^{(-)}_{m;k} \mathrm{Re}[Z^m_\ell(\Omega,\Phi)] \right|^2 + (1-P_\gamma) \left| \sum_{\ell,m} [\ell]^{(+)}_{m;k} \mathrm{Im}[Z^m_\ell(\Omega,\Phi)] \right|^2 + \right.$$
$$\left. (1+P_\gamma) \left| \sum_{\ell,m} [\ell]^{(+)}_{m;k} \mathrm{Re}[Z^m_\ell(\Omega,\Phi)] \right|^2 + (1+P_\gamma) \left| \sum_{\ell,m} [\ell]^{(-)}_{m;k} \mathrm{Im}[Z^m_\ell(\Omega,\Phi)] \right|^2 \right\}.$$

- We absorb $\sqrt{1 \pm P_\gamma}$ into the definition of Z^m_l and write $[\ell]^{(\pm)}_m$ as either a BreitWigner (for $\ell = 2$) or piecewise-defined function (for $\ell = 0$): `BreitWigner.cc`, `Zlm.cc`, and `Piecewise.cc`
- Note that one $[\ell]^{(\pm)}_m$ appears in two sums: the production coefficients for each must be constrained to be the same and both terms must be included when computing anything physical from the result
- Multiple reactions are like doing multiple fits simultaneously: contributions to ln(L) add, parameters can be constrained across reactions

Example: Configuring Inputs

```
#####################################
# GLOBAL VARIABLES
#####################################

fit etapi0_SD_TMD_onePol

define polVal_00 0.3519
define polAngle_00 0.0


define atwo 1.312 0.113




include starting_params.cfg


#####################################
# SETUP INPUT, REACTIONS, SUMS
#####################################

reaction EtaPi0_00 Beam Proton Eta Pi0

data EtaPi0_00 FSRootDataReader fsroot/tree_pi0eta__B4_M17_M7_DATA_sp17_pol0_SIGNAL_SKIM_A2.root ntFSGlueX_101_1 3

bkgnd EtaPi0_00 FSRootDataReader fsroot/tree_pi0eta__B4_M17_M7_DATA_sp17_pol0_SIDEBANDS_SKIM_A2.root ntFSGlueX_101_1 3
fsroot/tree_pi0eta__B4_M17_M7_DATA_sp17_pol0_SIDEBANDS_SKIM_A2.root.weight ntFSGlueX_101_1_weight weight

accmc EtaPi0_00 FSRootDataReader fsroot/tree_pi0eta__B4_M17_M7_MC_sp17_pol0_SIGNAL_SKIM_A2.root ntFSGlueX_101_1 3
fsroot/tree_pi0eta__B4_M17_M7_MC_sp17_pol0_SIGNAL_SKIM_A2.root.weight ntFSGlueX_101_1_weight weight

genmc EtaPi0_00 FSRootDataReader fsroot/tree_pi0eta__B4_M17_M7_MCGEN_sp17_pol0_GENERAL_SKIM_A2.root ntFSGlueX_101_1 3 MC
```

`data`: signal region events usually with unity weight, may contain backgrounds

`bkgnd`: (often) weighted sample that is statistically consistent with the background contribution to the signal region (GlueX: weighted RF sidebands + others)

`accmc`: accepted signal MC, consistent with the signal portion of the data sample (GlueX: remove beam accidentals)

`genmc`: generated MC, used for denominator in efficiency calculations be mindful of M,t regions, branching fractions, etc.; (GlueX: this should include the tagger efficiency)

`reaction`: number of particles matches number of four-vectors provided by reader; AmpTools doesn't care about particle names unless they are the same, then the amplitude is symmetrized
n.b.: other GlueX software, e.g., gen_amp, may use these names

Example: Setting Up Amplitudes

```
sum EtaPi0_00 ReZ_1-P
sum EtaPi0_00 ImZ_1+P
sum EtaPi0_00 ReZ_1+P
sum EtaPi0_00 ImZ_1-P
```

$$I(\Omega,\Phi) = 2\kappa \sum_k \Big\{ (1-P_\gamma)\Big|\sum_{\ell,m}[\ell]^{(-)}_{m;k}\mathrm{Re}[Z^m_\ell(\Omega,\Phi)]\Big|^2 + (1-P_\gamma)\Big|\sum_{\ell,m}[\ell]^{(+)}_{m;k}\mathrm{Im}[Z^m_\ell(\Omega,\Phi)]\Big|^2 + (1+P_\gamma)\Big|\sum_{\ell,m}[\ell]^{(+)}_{m;k}\mathrm{Re}[Z^m_\ell(\Omega,\Phi)]\Big|^2 + (1+P_\gamma)\Big|\sum_{\ell,m}[\ell]^{(-)}_{m;k}\mathrm{Im}[Z^m_\ell(\Omega,\Phi)]\Big|^2 \Big\}.$$

```
#####################################
# DEFINE AMPLITUDES
#####################################

# S-wave amplitudes
amplitude EtaPi0_00::ReZ_1-P::S0- Zlm 0 0 +1 -1 polAngle_00 polVal_00
amplitude EtaPi0_00::ImZ_1+P::S0- Zlm 0 0 -1 +1 polAngle_00 polVal_00
amplitude EtaPi0_00::ReZ_1-P::S0- Piecewise 1.04 1.56 4 23 Neg ReIm [pcwsBin_0ReNeg] [pcwsBin_0ImNeg]
[pcwsBin_1ReNeg] [pcwsBin_1ImNeg] [pcwsBin_2ReNeg] [pcwsBin_2ImNeg] [pcwsBin_3ReNeg] [pcwsBin_3ImNeg]
amplitude EtaPi0_00::ImZ_1+P::S0- Piecewise 1.04 1.56 4 23 Neg ReIm [pcwsBin_0ReNeg] [pcwsBin_0ImNeg]
[pcwsBin_1ReNeg] [pcwsBin_1ImNeg] [pcwsBin_2ReNeg] [pcwsBin_2ImNeg] [pcwsBin_3ReNeg] [pcwsBin_3ImNeg]

amplitude EtaPi0_00::ImZ_1-P::S0+ Zlm 0 0 -1 -1 polAngle_00 polVal_00
amplitude EtaPi0_00::ReZ_1+P::S0+ Zlm 0 0 +1 +1 polAngle_00 polVal_00
amplitude EtaPi0_00::ImZ_1-P::S0+ Piecewise 1.04 1.56 4 23 Pos ReIm [pcwsBin_0RePos] [pcwsBin_0ImPos]
[pcwsBin_1RePos] [pcwsBin_1ImPos] [pcwsBin_2RePos] [pcwsBin_2ImPos] [pcwsBin_3RePos] [pcwsBin_3ImPos]
amplitude EtaPi0_00::ReZ_1+P::S0+ Piecewise 1.04 1.56 4 23 Pos ReIm [pcwsBin_0RePos] [pcwsBin_0ImPos]
[pcwsBin_1RePos] [pcwsBin_1ImPos] [pcwsBin_2RePos] [pcwsBin_2ImPos] [pcwsBin_3RePos] [pcwsBin_3ImPos]

# D-wave amplitudes
amplitude EtaPi0_00::ImZ_1-P::a2_D0+ Zlm 2 0 -1 -1 polAngle_00 polVal_00
amplitude EtaPi0_00::ReZ_1+P::a2_D0+ Zlm 2 0 +1 +1 polAngle_00 polVal_00
amplitude EtaPi0_00::ImZ_1-P::a2_D0+ BreitWigner atwo 2 2 3
amplitude EtaPi0_00::ReZ_1+P::a2_D0+ BreitWigner atwo 2 2 3
```

amplitude factors with the same `reaction::sum::amplitude` are multiplied together

Example: Constraints and Initialization

- We need to constrain the production coefficients ($V_{\sigma,\alpha}$) in front of the specific $[\ell]^{(\pm)}_{m}$ amplitude that appears in two coherent sums:

```
constrain EtaPi0_00::ImZ_1-P::S0+ EtaPi0_00::ReZ_1+P::S0+
constrain EtaPi0_00::ReZ_1-P::S0- EtaPi0_00::ImZ_1+P::S0-
constrain EtaPi0_00::ImZ_1-P::a2_D0+ EtaPi0_00::ReZ_1+P::a2_D0+
constrain EtaPi0_00::ReZ_1-P::a2_D0- EtaPi0_00::ImZ_1+P::a2_D0-
```

- Initialize (optional) production coefficients with initialized commands -- only need to initialize one of the constrained amplitudes

```
initialize EtaPi0_00::ReZ_1-P::S0- cartesian 1 0 fixed
initialize EtaPi0_00::ReZ_1+P::S0+ cartesian 1 0 fixed
initialize EtaPi0_00::ReZ_1-P::a2_D0- cartesian 27.2 26.9
initialize EtaPi0_00::ReZ_1+P::a2_D0+ cartesian -12.2 19.9
```

  - in our example the freedom in the S-wave is in the parameters that make up the piecewise function -- we keep the lead coefficient fixed to one

- Generally required: one of the production coefficients in each coherent sum should be initialized with the flag "real" to avoid overall phase ambiguities

- Parameters are declared and initialized in one line:

```
parameter pcwsBin_0ImNeg -307.092917227354
parameter pcwsBin_0ImPos 423.787950826515
parameter pcwsBin_0ReNeg -29.1570576067053
parameter pcwsBin_0RePos 343.007639956881
parameter pcwsBin_1ReNeg -25.8844360633494
parameter pcwsBin_1RePos 340.647573417975

parameter pcwsBin_1ImPos 0.0 fixed
parameter pcwsBin_1ImNeg 0.0 fixed
```

technical note: these two things together coupled with the fact we are using a Breit-Wigner function in the D wave remove the phase ambiguity

Extending to Multiple Polarization States

- We treat each polarization state as an independent "reaction"
  - data are statistically independent; similar to a coupled-channel or multi-experiment fit, which are ideas supported in AmpTools
  - minimize a global sum of -2 ln(L)
  - constrain amplitudes across reactions up to a floating scale parameter of $\mathcal{O}(1)$ that absorbs differences in integrated luminosity for each data set
  - accepted and generated MC can (likely) be reused for each reaction
- Extend our fit configuration using the AmpTools looping structure:

```
loop LOOPREAC EtaPi0_00 EtaPi0_45 EtaPi0_90 EtaPi0_135
loop LOOPPOLANG polAngle_00 polAngle_45 polAngle_90 polAngle_135
loop LOOPPOLVAL polVal_00 polVal_45 polVal_90 polVal_135
```

  which effectively creates four copies of many lines of the config file:

```
reaction LOOPREAC Beam Proton Eta Pi0
amplitude LOOPREAC::ReZ_1-P::S0- Zlm 0 0 +1 -1 LOOPPOLANG LOOPPOLVAL
```

- See full example in: etapi0_SD_TMD_allPol.cfg

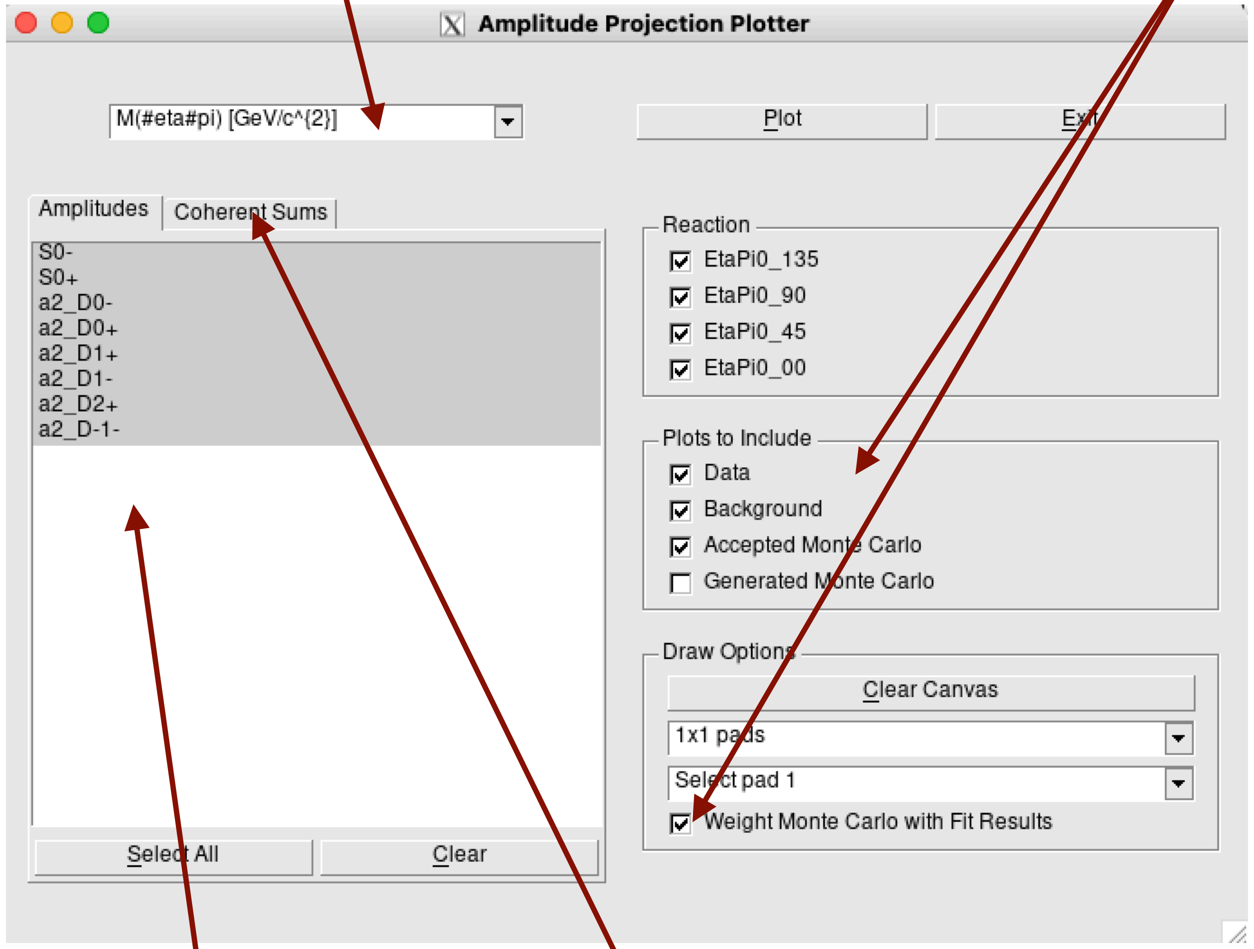
Running the Fit and Visualizing the Result

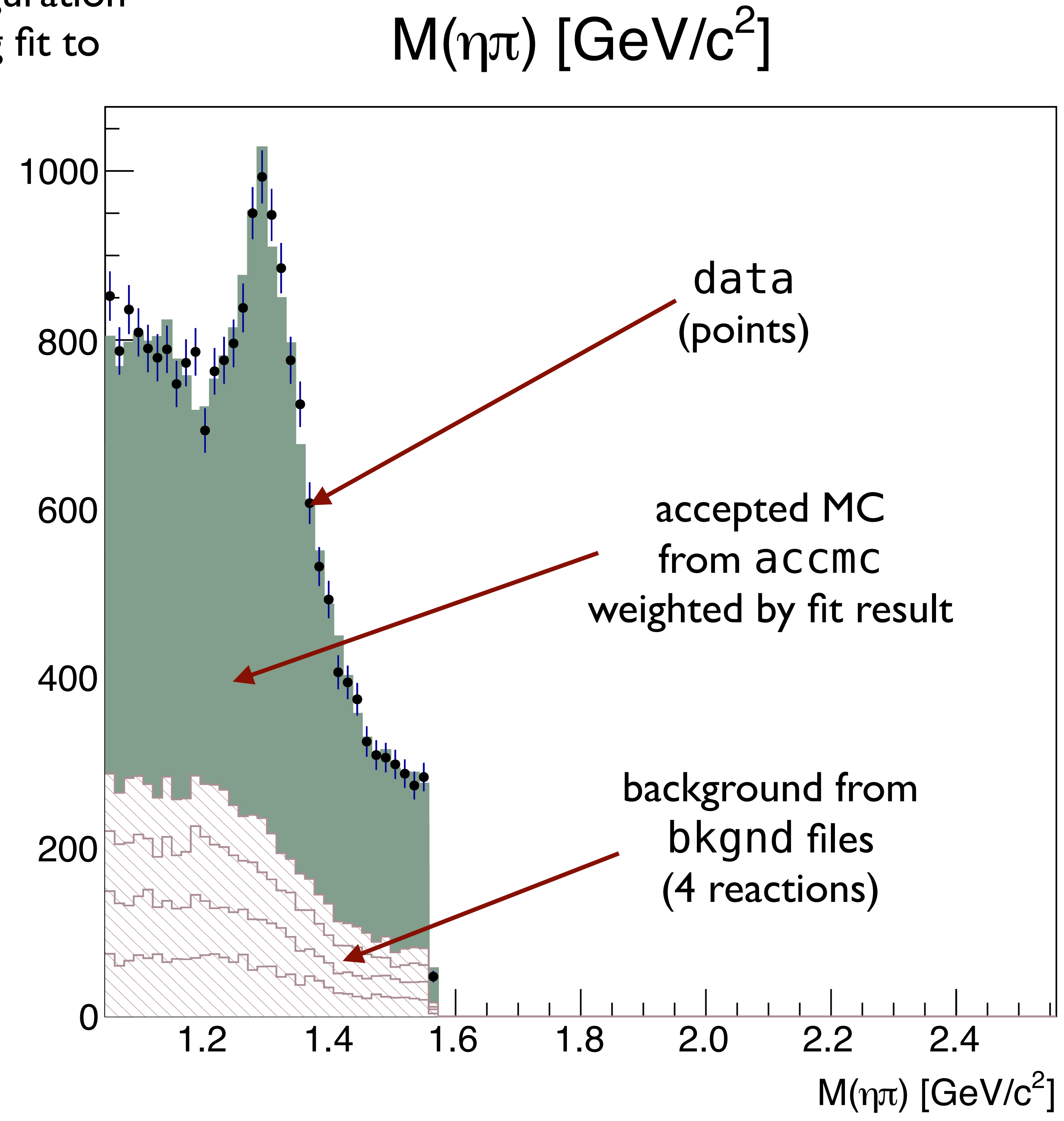
- To run a single core fit interactively invoke fit (source code)
    - run `fit -h` to see options
    - typical: `fit -c etapi0_SD_TMD_allPol.cfg` (wait for it.... wait for it... ...still waiting...)
        - output: `etapi0_SD_TMD_allPol.fit`
- Visualization requires the creation of PlotGenerator class to fill histograms
    - see example DalitzPlotGenerator in the AmpTools Dalitz Tutorial
    - collection of GlueX plot generators: halld_sim/libraries/AMPTOOLS_DATAIO
        - for this tutorial see: etaPiPlotGenerator
- And you need an executable that uses this class to generate the plots you want
    - see AmpTools Dalitz Tutorial example: plotResults
        - good for batch processing of many plots -- non-interactive
    - plots of GlueX data that follow were made with: plot_etapi0 (in halld_sim)
        - uses AmpPlotter library distributed with AmpTools to provide a GUI front-end to the underlying PlotGenerator
        - good for interactively exploring the amplitudes in a single fit
        - starts ROOT-based X11 session: best to run locally.... which, for now, requires a local build of halld_sim 🙁

Viewing the Output

pick a plot to generate

common configuration for comparing fit to the data





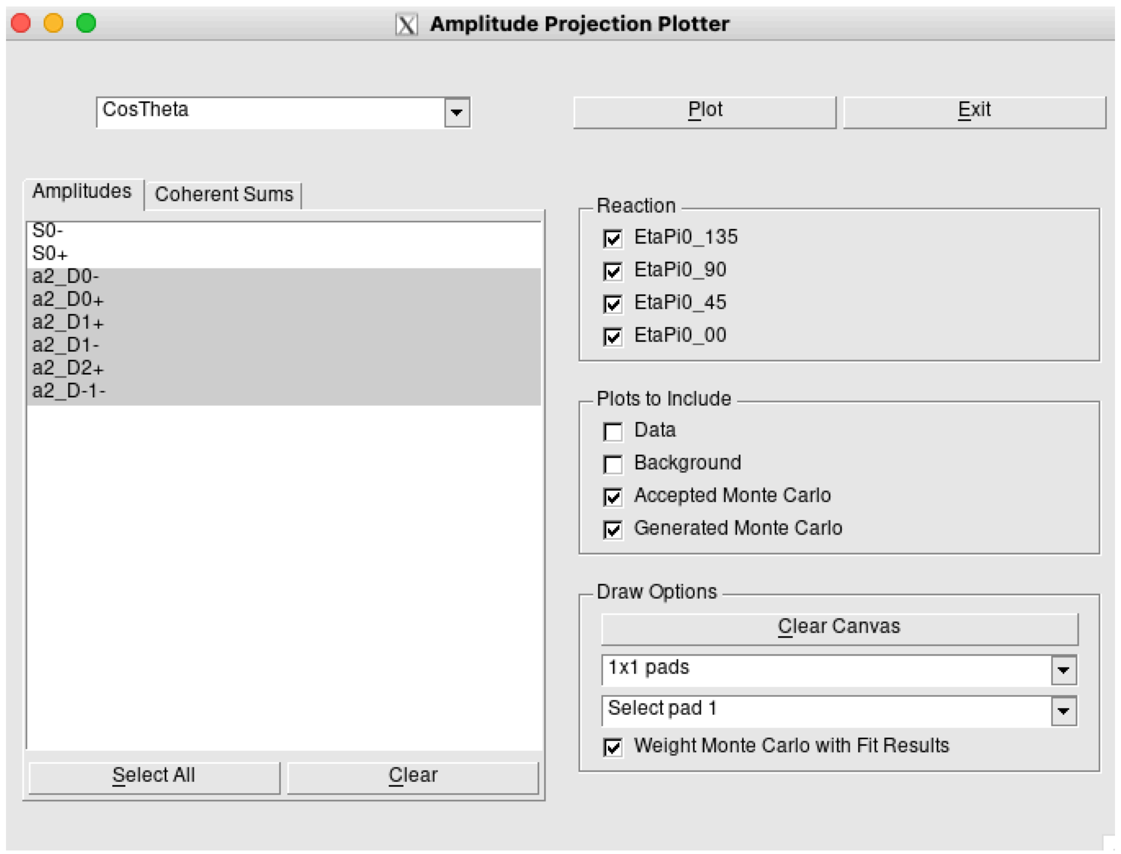
data (points)

accepted MC from `accmc` weighted by fit result

background from `bkgnd` files (4 reactions)

select amplitudes

typical: leave all coherent sums on


Amplitude Projection Plotter

CosTheta | Plot | Exit

Amplitudes | Coherent Sums

S0-
S0+
a2_D0-
a2_D0+
a2_D1+
a2_D1-
a2_D2+
a2_D-1-

Select All | Clear

Reaction
- [✓] EtaPi0_135
- [✓] EtaPi0_90
- [✓] EtaPi0_45
- [✓] EtaPi0_00

Plots to Include
- [ ] Data
- [ ] Background
- [✓] Accepted Monte Carlo
- [✓] Generated Monte Carlo

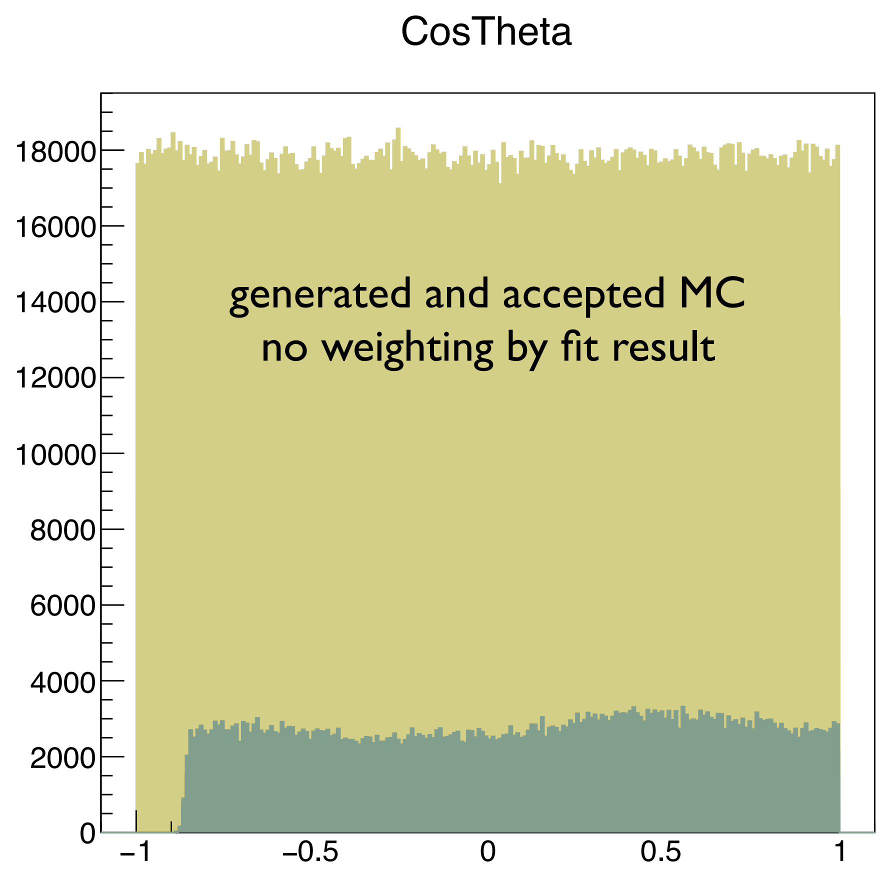
Draw Options

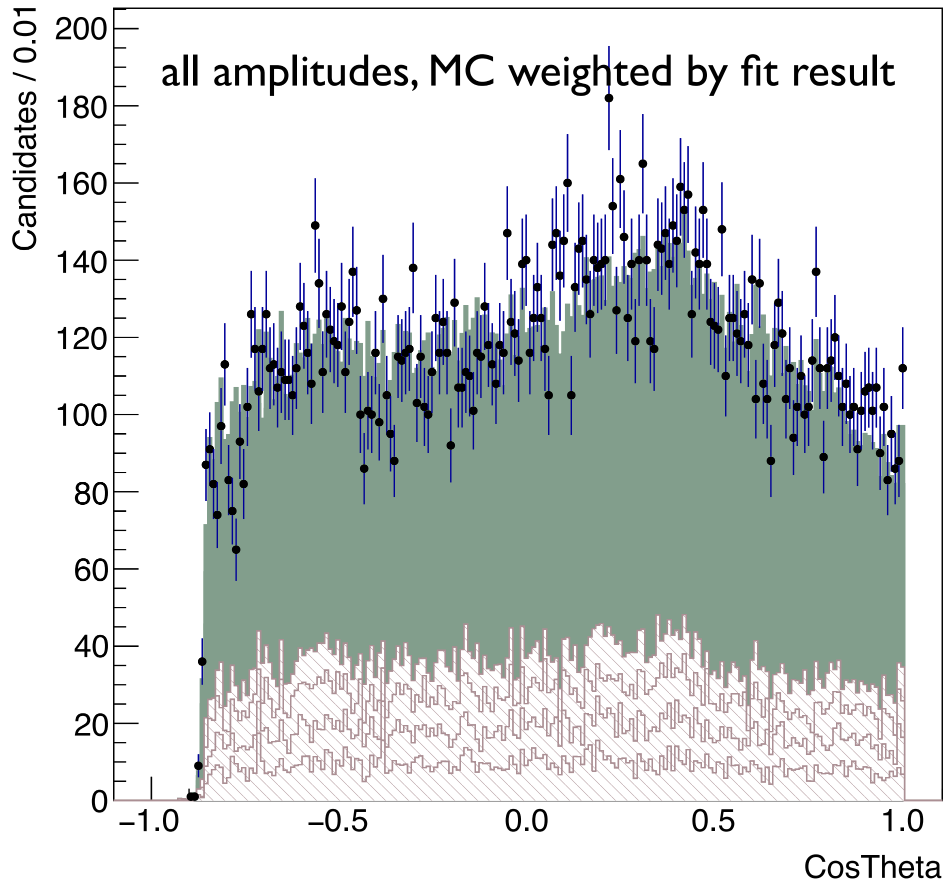
Clear Canvas

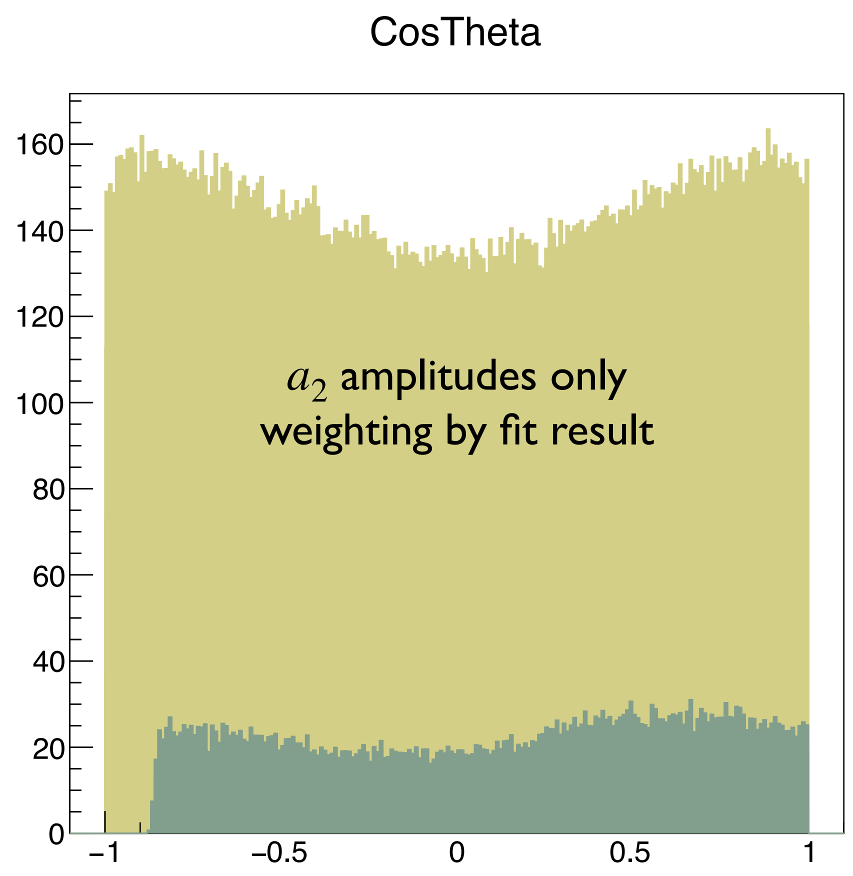
1x1 pads

Select pad 1

- [✓] Weight Monte Carlo with Fit Results







Useful Quantities from FitResults

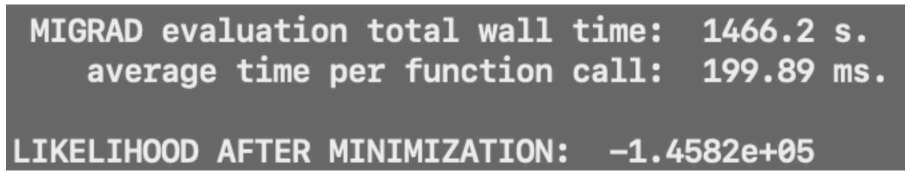
- The `*.fit` output can be used to create an object of type <u>FitResults</u> which is intended to provide a C++ interface to the results of a fit
- In the `session2e` directory see <u>`displayResults.cc`</u> for an example of how to create this object and print some useful information to the screen
    - copy <u>`displayResults.cc`</u> and the `Makefile` to your own directory and play with it

```
====== REACTIONS ======
 Number of reactions:  4
   (reaction name):  (observed signal events from fit)  [contribution to -2 ln L]
   EtaPi0_00:  3866.11 +/- 55.0971  [-37262.7]
   EtaPi0_45:  3652.82 +/- 100.789  [-34984.4]
   EtaPi0_90:  4105.35 +/- 109.639  [-38119.9]
   EtaPi0_135:  3748.66 +/- 102.619  [-35453.1]
     TOTAL:  15372.9 +/- 276.389 [-145820]

====== AMPLITUDES ======
   (amplitude name):  (acceptance corrected yield) (fit fraction) [detection efficiency]
   a2_D0-   :  2350.81 +/- 829.937  (0.0224004) [0.117551]
   a2_D0+   :  3781.52 +/- 800.061  (0.0360334) [0.117551]
   a2_D1-   :  5327.23 +/- 2208.54  (0.0507621) [0.150105]
   a2_D1+   :  1198.49 +/- 561.491  (0.0114202) [0.150106]
   a2_D-1-  :  6256.73 +/- 2144.09  (0.0596192) [0.150105]
   a2_D2+   :  10255.8 +/- 1525.7  (0.0977258) [0.153705]
   S0+  :  63909.5 +/- 1078.84  (0.608981) [0.144667]
   S0-  :  11910.2 +/- 200.964  (0.11349) [0.145053]
-----
     ALL a2(1320)   :   29178 +/- 1415.98  (0.278031) [0.147189]

====== MINUIT DIAGNOSTICS ======
  Error Matrix Status ( 3 = full/accurate ):  3
  Last Command Status ( 0 = normal ):  0
  Estimated Distance to Minimum:  5.49816e-06
```

Efficiency-corrected number of $a_2(1320)$ events in the data sample (assuming $\mathcal{B}(a_2 \to \eta\pi^0) = 100\,\%$ and $\mathcal{B}(\eta \to \gamma\gamma) = 100\,\%$)

MPI Acceleration

- Invoking `fit -c etapi0_SD_TMD_allPol.cfg` on an ifarm node will give you time to eat lunch before convergence:

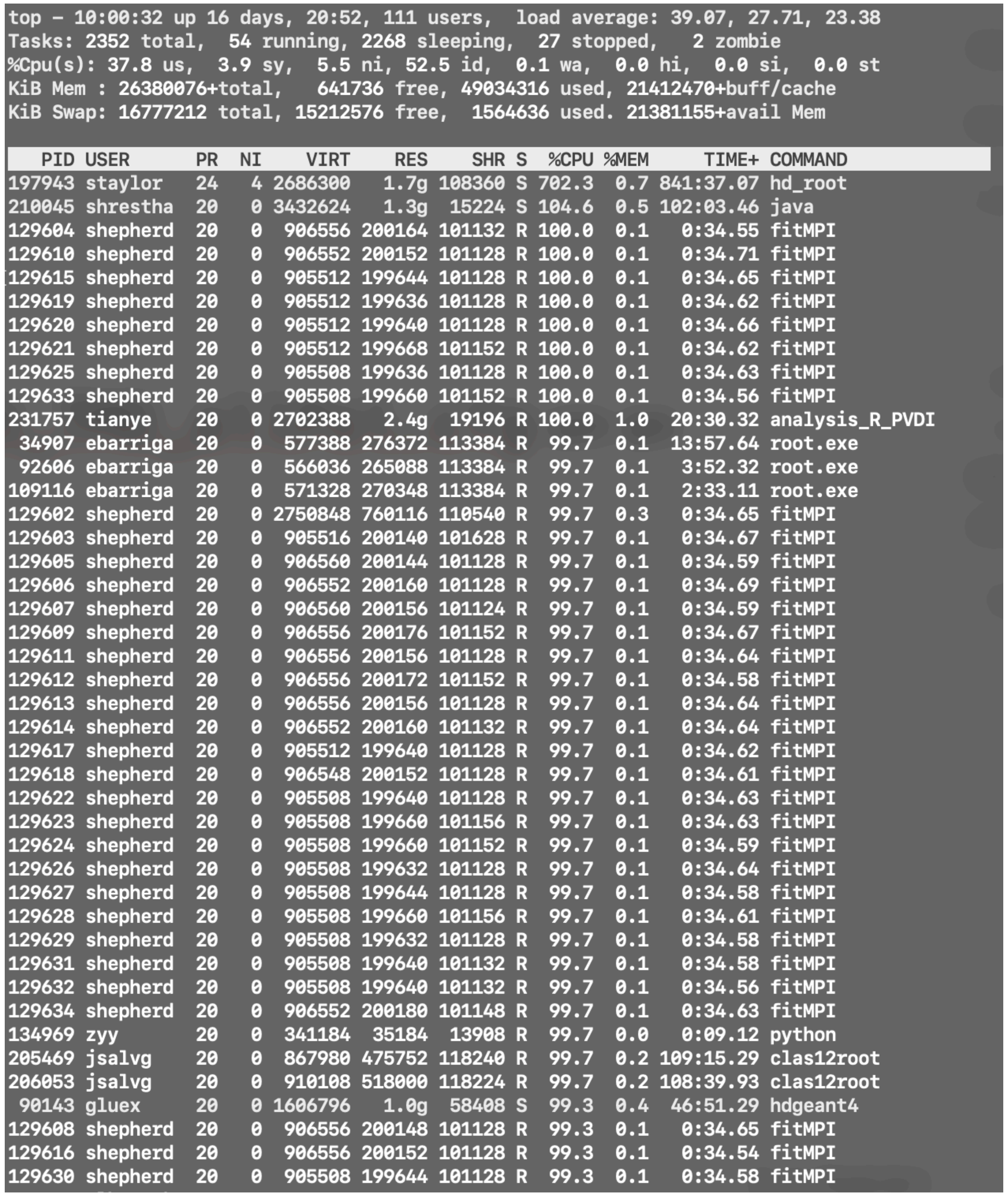


```
 MIGRAD evaluation total wall time:  1466.2 s.
    average time per function call:  199.89 ms.

LIKELIHOOD AFTER MINIMIZATION:  -1.4582e+05
```

- AmpTools supports MPI (Message Passing Interface) acceleration: multiple single-threaded processes (potentially across nodes of a cluster) working on a common fit while communicating through the MPI layer
  - allows aggregating RAM across cluster nodes for large data sets
  - enhances speed because each process runs in parallel
  - can be used to accelerate fits on multi-core CPU much like multi-threading a single job
- Requires registration of Amplitudes and parallelized DataReaders (via an AmpTools template) in an executable that can setup and manage the MPI layer:
  - for GlueX use: <u>fitMPI</u> (in halld_sim)
  - if `fitMPI` is compiled with your release of halld_sim, it is likely you don't need to do anything but load the MPI module in your shell

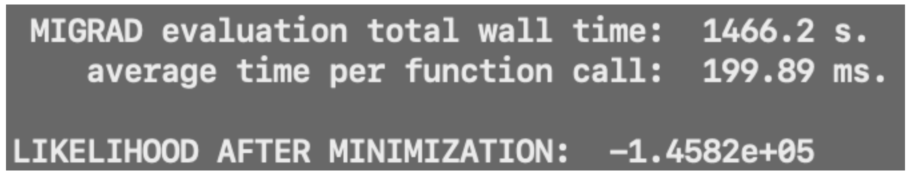
    ```
    module use /apps/modulefiles
    module load mpi/openmpi3-x86_64
    ```
  - full documentation on ifarm/GlueX MPI usage for fitting is here: <u>https://halldweb.jlab.org/wiki/index.php/HOWTO_use_AmpTools_on_the_JLab_farm_with_MPI</u>

use `mpirun` to spawn multiple `fitMPI` processes that work together: `mpirun -np 33 fitMPI -c etapi0_SD_TMD_allPol.cfg`

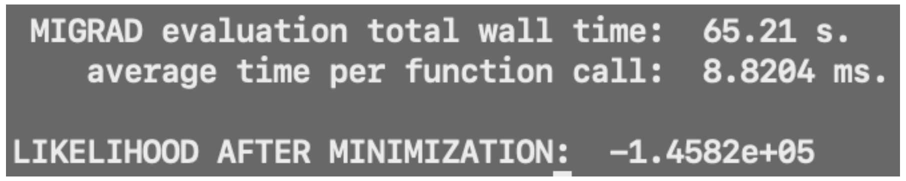


```
top - 10:00:32 up 16 days, 20:52, 111 users,  load average: 39.07, 27.71, 23.38
Tasks: 2352 total,  54 running, 2268 sleeping,  27 stopped,   2 zombie
%Cpu(s): 37.8 us,  3.9 sy,  5.5 ni, 52.5 id,  0.1 wa,  0.0 hi,  0.0 si,  0.0 st
KiB Mem : 26380076+total,   641736 free, 49034316 used, 21412470+buff/cache
KiB Swap: 16777212 total, 15212576 free,  1564636 used. 21381155+avail Mem

   PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
197943 staylor   24   4 2686300   1.7g 108360 S 702.3  0.7 841:37.07 hd_root
210045 shrestha  20   0 3432624   1.3g  15224 S 104.6  0.5 102:03.46 java
129604 shepherd  20   0  906556 200164 101132 R 100.0  0.1   0:34.55 fitMPI
129610 shepherd  20   0  906552 200152 101128 R 100.0  0.1   0:34.71 fitMPI
129615 shepherd  20   0  905512 199644 101128 R 100.0  0.1   0:34.65 fitMPI
129619 shepherd  20   0  905512 199636 101128 R 100.0  0.1   0:34.62 fitMPI
129620 shepherd  20   0  905512 199640 101128 R 100.0  0.1   0:34.66 fitMPI
129621 shepherd  20   0  905512 199668 101152 R 100.0  0.1   0:34.62 fitMPI
129625 shepherd  20   0  905508 199636 101128 R 100.0  0.1   0:34.63 fitMPI
129633 shepherd  20   0  905508 199660 101152 R 100.0  0.1   0:34.56 fitMPI
231757 tianye    20   0 2702388   2.4g  19196 R 100.0  1.0  20:30.32 analysis_R_PVDI
 34907 ebarriga  20   0  577388 276372 113384 R  99.7  0.1  13:57.64 root.exe
 92606 ebarriga  20   0  566036 265088 113384 R  99.7  0.1   3:52.32 root.exe
109116 ebarriga  20   0  571328 270348 113384 R  99.7  0.1   2:33.11 root.exe
129602 shepherd  20   0 2750848 760116 110540 R  99.7  0.3   0:34.65 fitMPI
129603 shepherd  20   0  905516 200140 101628 R  99.7  0.1   0:34.67 fitMPI
129605 shepherd  20   0  906560 200144 101128 R  99.7  0.1   0:34.59 fitMPI
129606 shepherd  20   0  906552 200160 101128 R  99.7  0.1   0:34.69 fitMPI
129607 shepherd  20   0  906560 200156 101124 R  99.7  0.1   0:34.59 fitMPI
129609 shepherd  20   0  906552 200176 101152 R  99.7  0.1   0:34.67 fitMPI
129611 shepherd  20   0  906556 200156 101128 R  99.7  0.1   0:34.64 fitMPI
129612 shepherd  20   0  906556 200172 101152 R  99.7  0.1   0:34.58 fitMPI
129613 shepherd  20   0  906556 200156 101128 R  99.7  0.1   0:34.64 fitMPI
129614 shepherd  20   0  906552 200160 101132 R  99.7  0.1   0:34.64 fitMPI
129617 shepherd  20   0  905512 199640 101128 R  99.7  0.1   0:34.62 fitMPI
129618 shepherd  20   0  906548 200152 101128 R  99.7  0.1   0:34.61 fitMPI
129622 shepherd  20   0  905508 199640 101128 R  99.7  0.1   0:34.63 fitMPI
129623 shepherd  20   0  905508 199660 101156 R  99.7  0.1   0:34.63 fitMPI
129624 shepherd  20   0  905508 199660 101152 R  99.7  0.1   0:34.59 fitMPI
129626 shepherd  20   0  905508 199632 101128 R  99.7  0.1   0:34.64 fitMPI
129627 shepherd  20   0  905508 199644 101128 R  99.7  0.1   0:34.58 fitMPI
129628 shepherd  20   0  905508 199660 101156 R  99.7  0.1   0:34.61 fitMPI
129629 shepherd  20   0  905508 199632 101128 R  99.7  0.1   0:34.58 fitMPI
129631 shepherd  20   0  905508 199640 101132 R  99.7  0.1   0:34.58 fitMPI
129632 shepherd  20   0  905508 199640 101132 R  99.7  0.1   0:34.56 fitMPI
129634 shepherd  20   0  906552 200180 101148 R  99.7  0.1   0:34.63 fitMPI
134969 zyy       20   0  341184  35184  13908 R  99.7  0.0   0:09.12 python
205469 jsalvg    20   0  867980 475752 118240 R  99.7  0.2 109:15.29 clas12root
206053 jsalvg    20   0  910108 518000 118224 R  99.7  0.2 108:39.93 clas12root
 90143 gluex     20   0 1606796   1.0g  58408 S  99.3  0.4  46:51.29 hdgeant4
129608 shepherd  20   0  906556 200148 101128 R  99.3  0.1   0:34.65 fitMPI
129616 shepherd  20   0  906556 200152 101128 R  99.3  0.1   0:34.54 fitMPI
129630 shepherd  20   0  905508 199644 101128 R  99.3  0.1   0:34.58 fitMPI
```

(single process ifarm CPU)



```
MIGRAD evaluation total wall time:  1466.2 s.
   average time per function call:  199.89 ms.

LIKELIHOOD AFTER MINIMIZATION:  -1.4582e+05
```



```
MIGRAD evaluation total wall time:  65.21 s.
   average time per function call:  8.8204 ms.

LIKELIHOOD AFTER MINIMIZATION:  -1.4582e+05
```

(33 processes via MPI on ifarm)

Do **NOT** do this on the ifarm interactive node as a matter of regular practice!!!

(...but isn't it beautiful to see 33 jobs each at >99% CPU working together on one fit?)

DEPARTMENT OF PHYSICS
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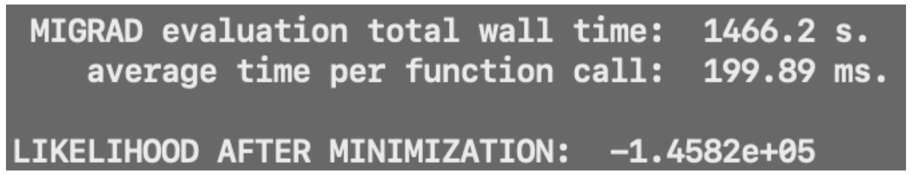
M. R. Shepherd
GlueX Software Tutorial
May 23, 2022

GPU Acceleration

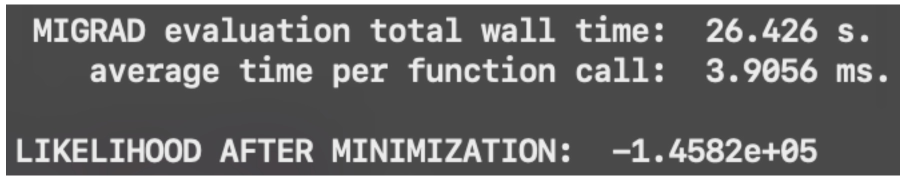
- AmpTools supports acceleration using GPUs (Graphical Processing Units) for numerical computation
  - GPU nodes are available on the ifarm -- these are suitable for fast interactive fitting
- Requires the user to write the amplitude calculation as a GPU "kernel" in a language similar to C called CUDA
  - technically more involved: potential for code-divergence as CPU and GPU code must both be maintained
  - Example in Dalitz Tutorial: BreitWigner_kernel.cu
- Many GlueX amplitudes are already implemented in CUDA for GPU fitting
- GPU acceleration is also useful for interactive plotting
- Speed gains are highly dependent on particular fit strategy, GPU hardware, etc. -- ask for advice on optimization
- Multiple GPUs can be used (even across nodes) by using the MPI layer where each process uses a GPU

(single process ifarm CPU)



```
 MIGRAD evaluation total wall time:  1466.2 s.
    average time per function call:  199.89 ms.

LIKELIHOOD AFTER MINIMIZATION:  -1.4582e+05
```



```
 MIGRAD evaluation total wall time:  26.426 s.
    average time per function call:  3.9056 ms.

LIKELIHOOD AFTER MINIMIZATION:  -1.4582e+05
```

(single process with GPU acceleration)

GlueX Documentation: https://halldweb.jlab.org/wiki/index.php/HOWTO_use_AmpTools_on_the_JLab_farm_GPUs

Summary

- There is a suite of libraries and executables built off of the AmpTools framework for doing amplitude analysis on GlueX data
  - AmpTools is largely independent of physics process or experiment
  - common GlueX-specific problems to be solved in the context of AmpTools
- A variety of resources are available for issues, questions, help:
  - AmpTools Fits Best Practices
  - AmpTools Documentation
  - AmpTools Issues on GitHub
  - GlueX Software Google group
  - meetings of the Amplitude Analysis Working Group
  - use old technology and phone a friend: *mashephe@indiana.edu*