PyPWA

A Software Framework for Partial Wave Analysis

g12-CLAS6 PWA

(Jefferson Lab)

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Norfolk State University
and
The Thomas Jefferson National Accelerator Facility

Future Directions in Spectroscopy Analysis-JLab-Nov 2014

Jefferson Lab

Outline

- **Why PyPWA?**
- **Example: Baryon contamination**
- **JLab-PWA group (HallB-HallD-JPAC)**
- **g12: $n\pi\pi\pi$ and pKK**
- **Others: eg6 and g12-$\Delta\eta\pi$**
- **Summary**

Future of Spectroscopy Analysis will be in the study resonances that are hidden?

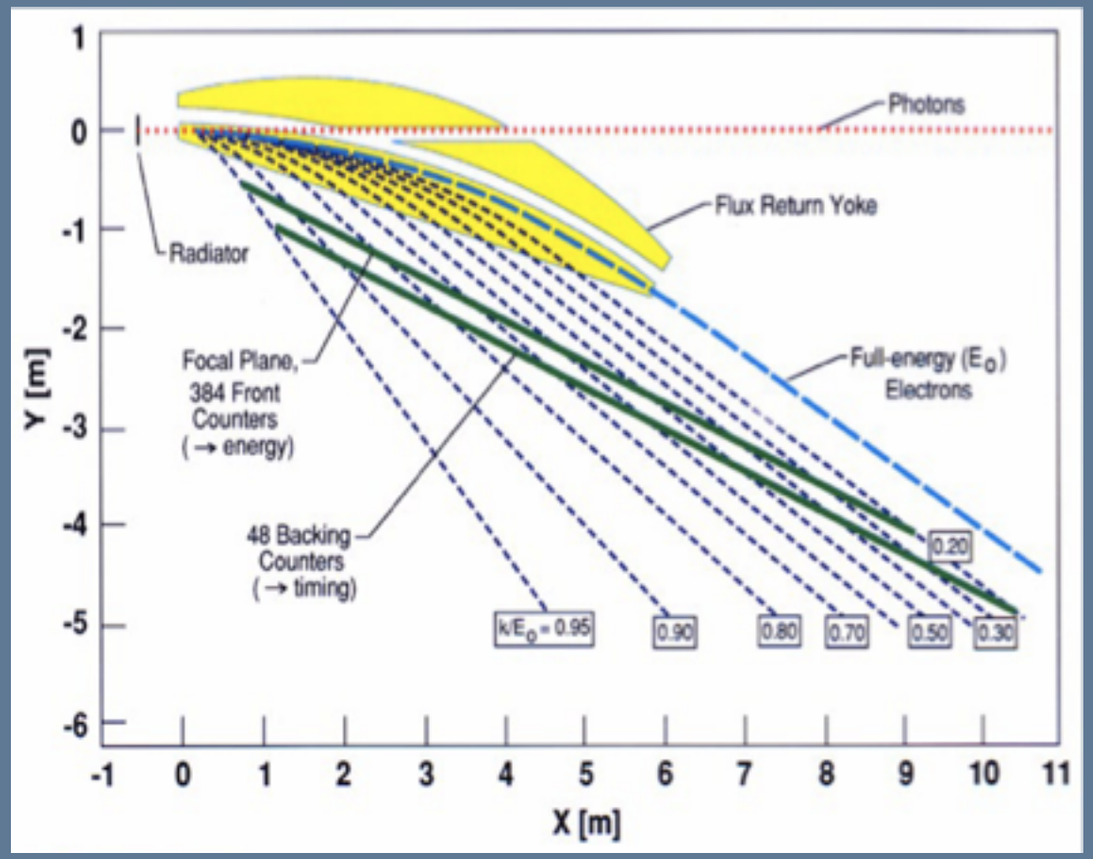
★ overlapping
★ interfering
★ wide
★ small cross-sections
★ non-resonant backgrounds
★ ...

Furthermore

- Wave ambiguities
- Leakages
- Baryon contamination (JLab)

- More final state particles in the channel implies fewer ambiguities.
- Better known or larger acceptance implies less leakage.
- Better resolution implies less leakage.

CLAS6
photoproduction



Tagger System

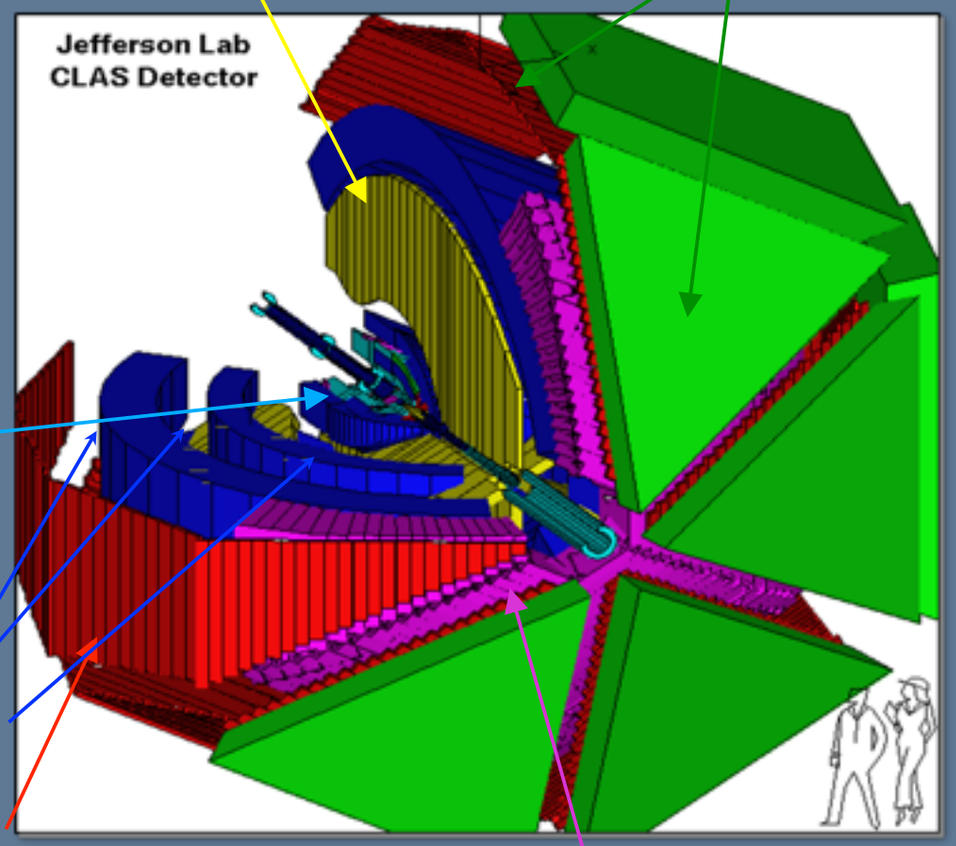
Target +
start counter

γ

Torus Magnet

6 Superconductive Coils

Electromagnetic Calorimeter
lead/plastic scintillator, 1296 PMTs



Drift Chamber

35,000 cells

Time of Flight
Plastic Scintillator,
684 PMTs

Cherenkov Counter
e/π separation, 256 PMTs

g12 CLAS run

Search for new forms of hadronic matter in photoproduction

- Data taking completed in 2008
- Photon Energy up to 5.5 GeV
- More than 26 billion triggers (2-prong + 3-prong)
- Total Luminosity: 68 pb^{-1}
- Data processing completed and physics analysis in progress

Several exclusive channels are being analyzed

$\gamma p \rightarrow \pi^+\pi^+\pi^-(n)$
$\gamma p \rightarrow (\pi^0)\pi^+\pi^- p$
$\gamma p \rightarrow K^+K^+ (\Xi^{*-})(1530)$
$\gamma p \rightarrow pK^+K^- (\eta\Phi)$
$\gamma p \rightarrow (p\pi^+\Delta)\ \pi^-(\eta)$
$\gamma p \rightarrow \pi^+K^+K^-(n)$
$\gamma p \rightarrow e^+e^- p$
...

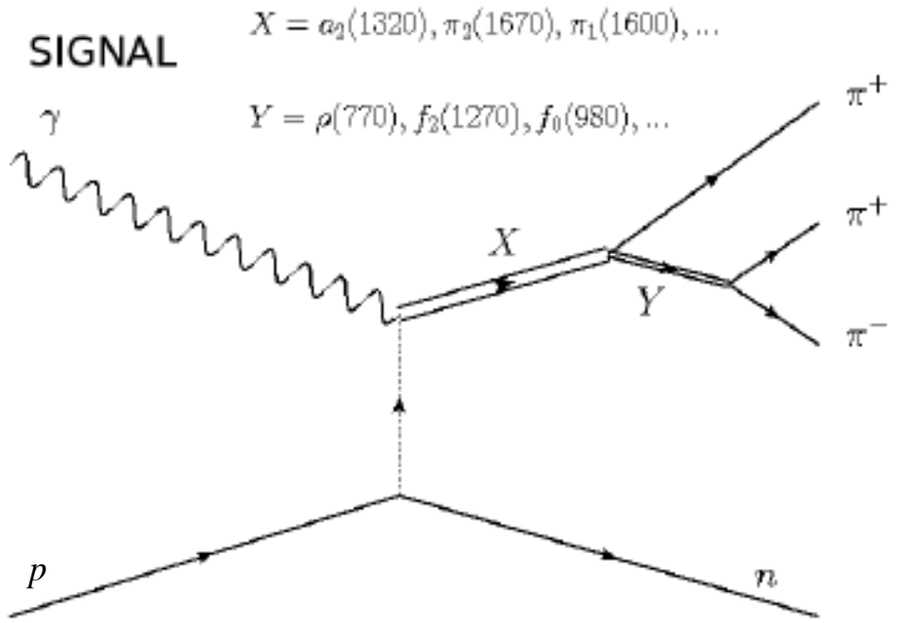
Meson Spectroscopy
- Search for exotic mesons
- Study of Strangeonia
- …

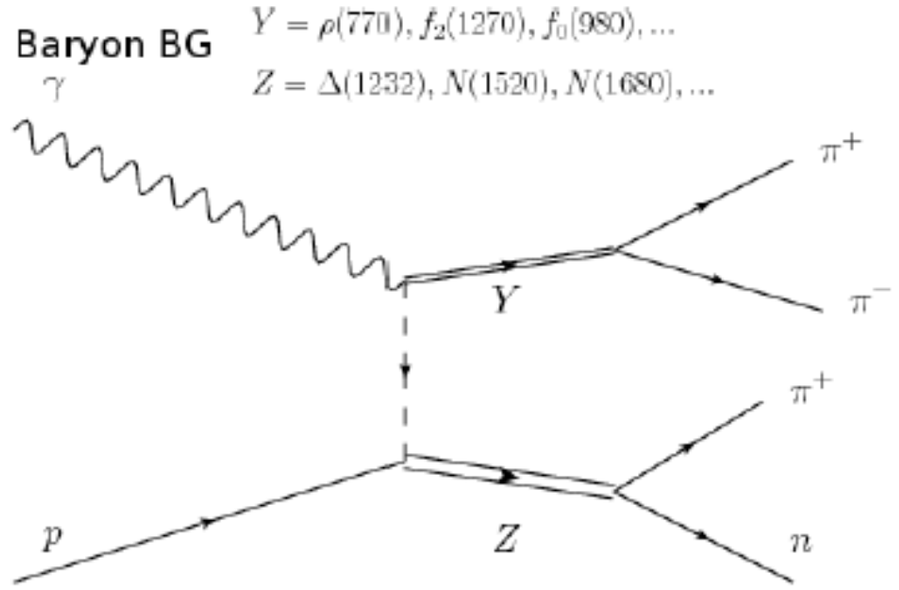
Baryon Spectroscopy
- Cascades

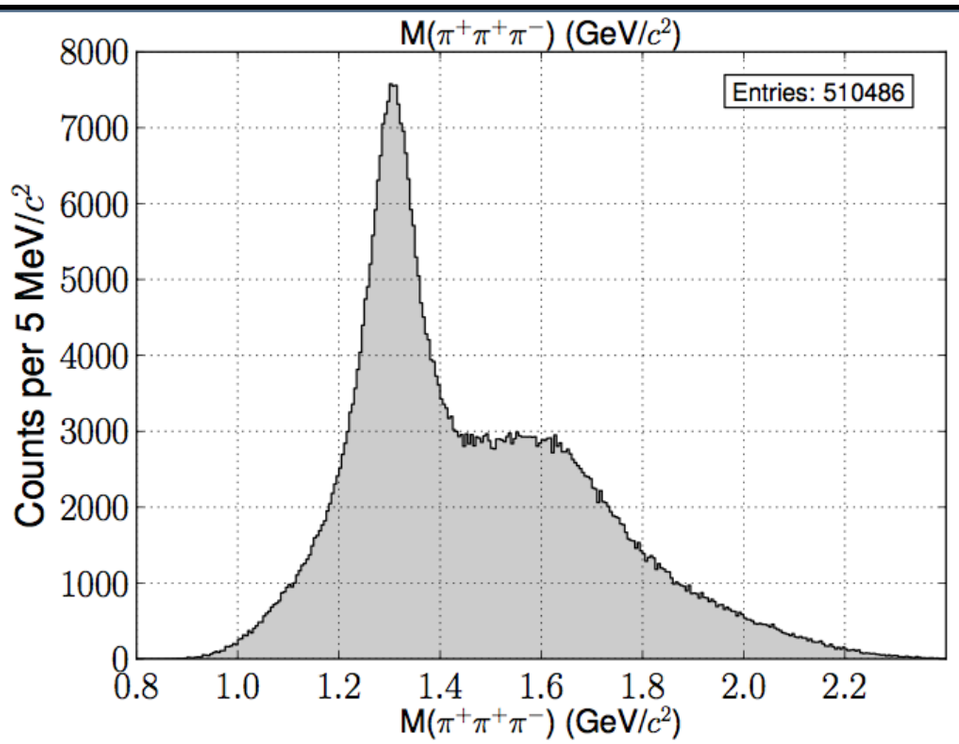
Jefferson Lab

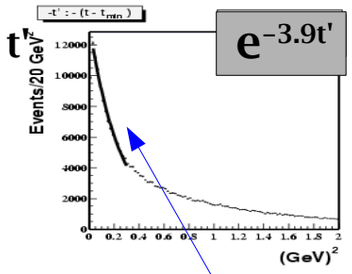
Search for π_1 (1600)

C. Bookwalter thesis - FSU g12





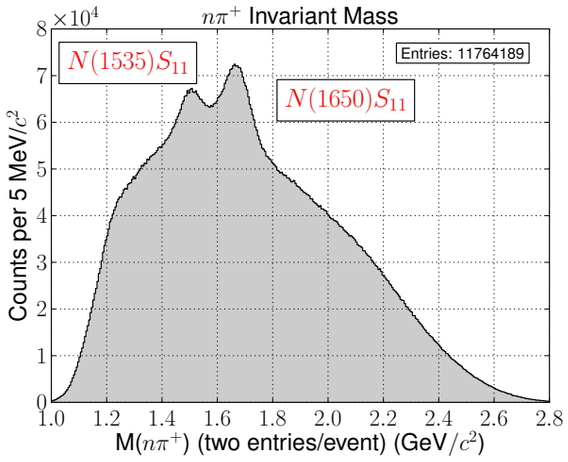


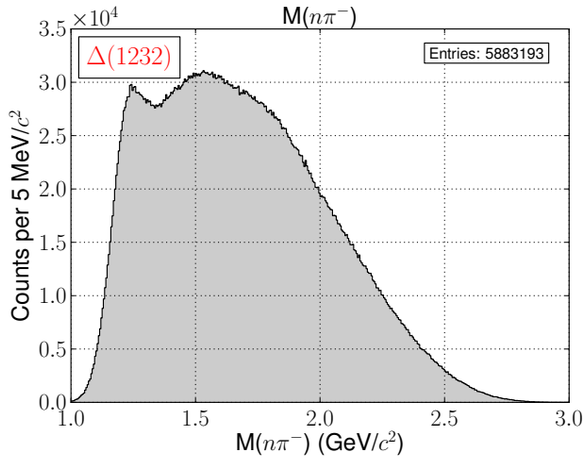


Sharp **t** dependence consistent with π-exchange production

Baryon background cuts: $|t'| < 0.1$ & $\theta_{lab}(\pi^+) < 25^o$

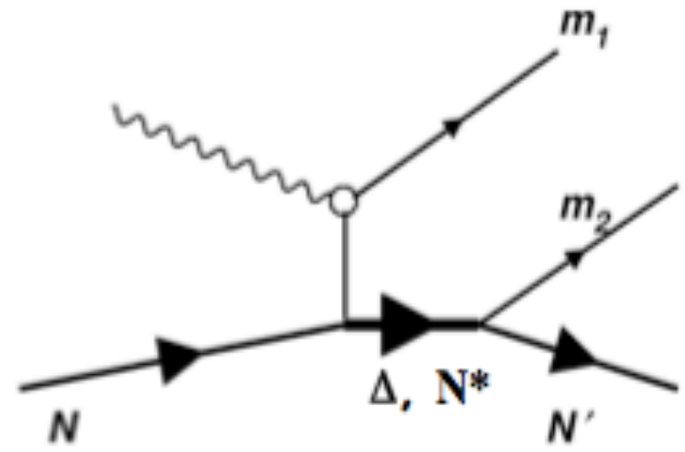
$\gamma p \to \pi^+\pi^+\pi^- n$ in g12 data

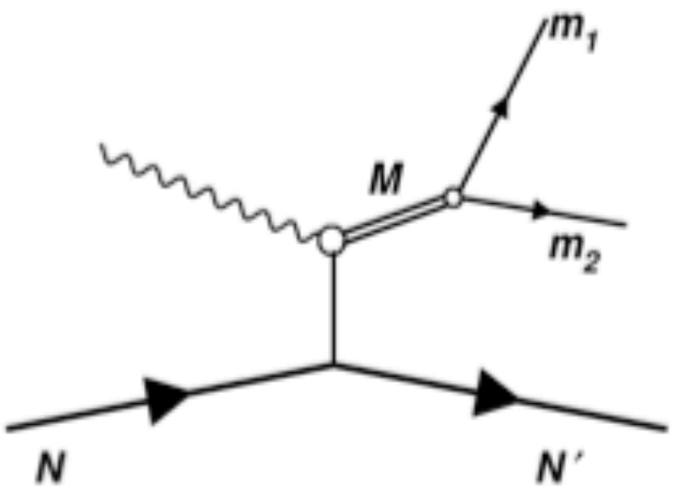


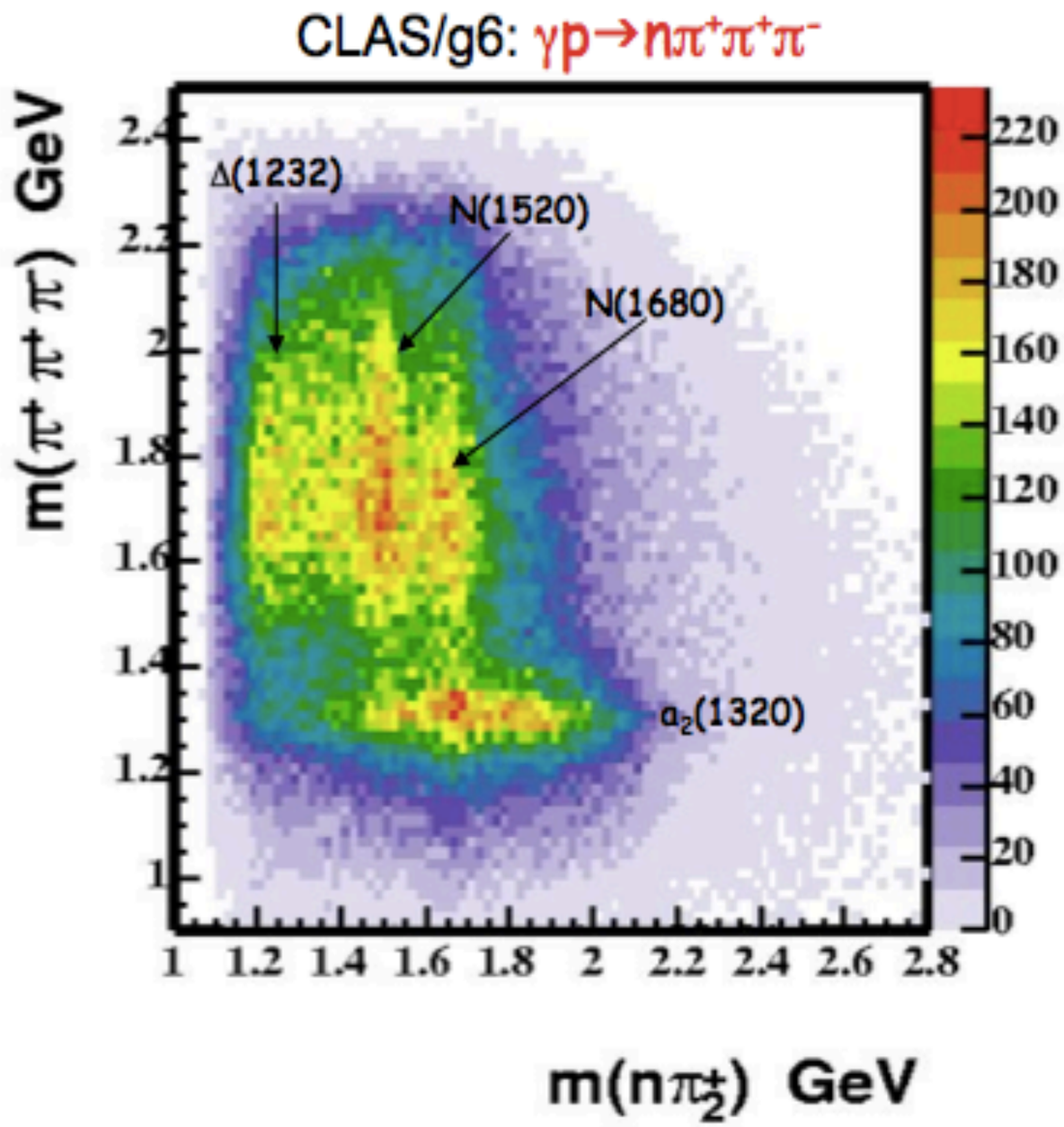


Copious baryon backgrounds present!

Physics background from associated baryon resonance production







Strong kinematical cuts and a complex PWA are required

Going to higher energies increase phase space: 5.75 to 9 GeV?

M.Nozar - g6c

An experimental approach to deal with this problem is to introduce kinematical cuts with some discrimination between baryon and meson production. Since mesons are in general produced more in the lab forward direction than baryons, we can think of angular cuts to reduce baryon backgrounds.

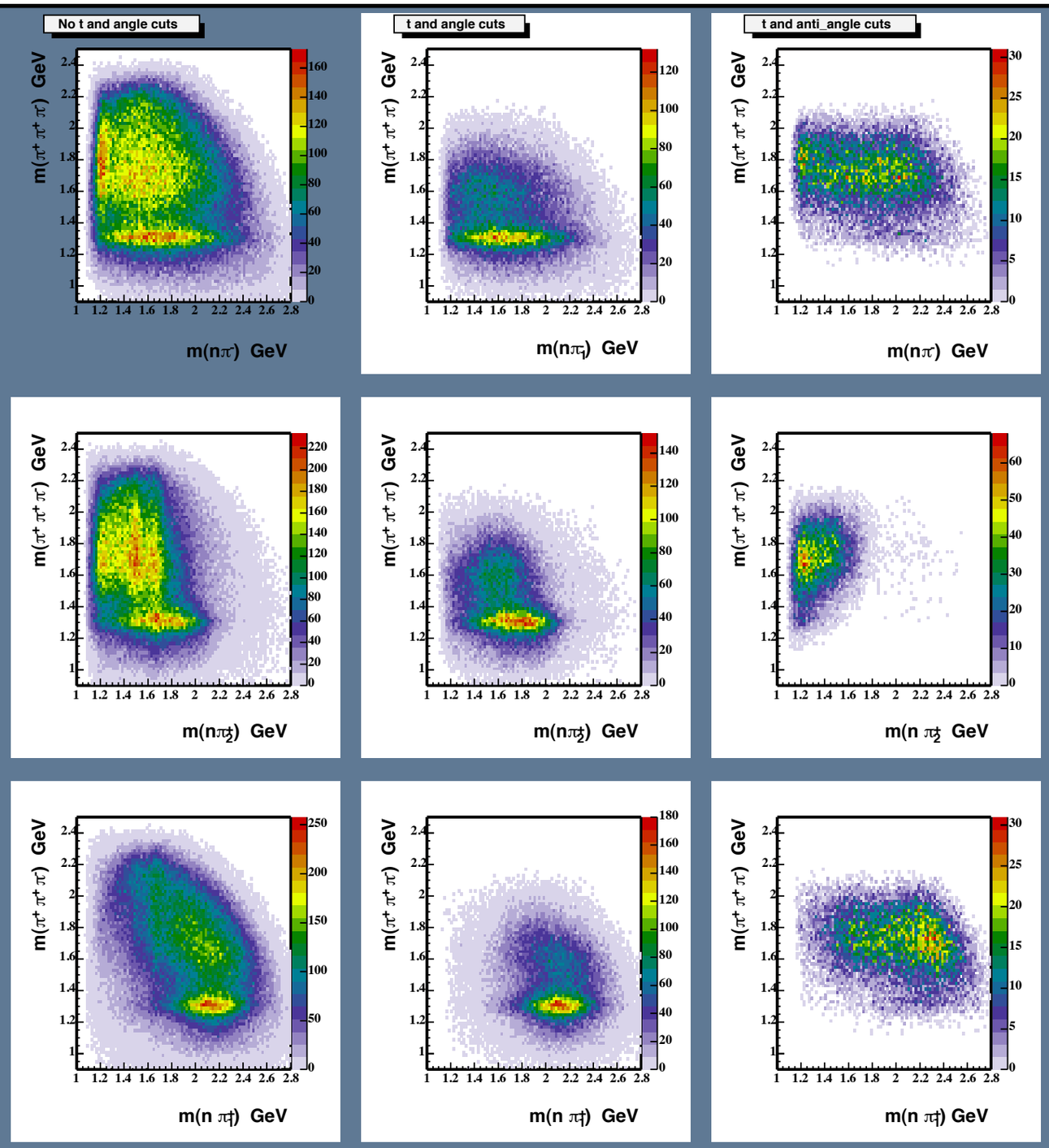
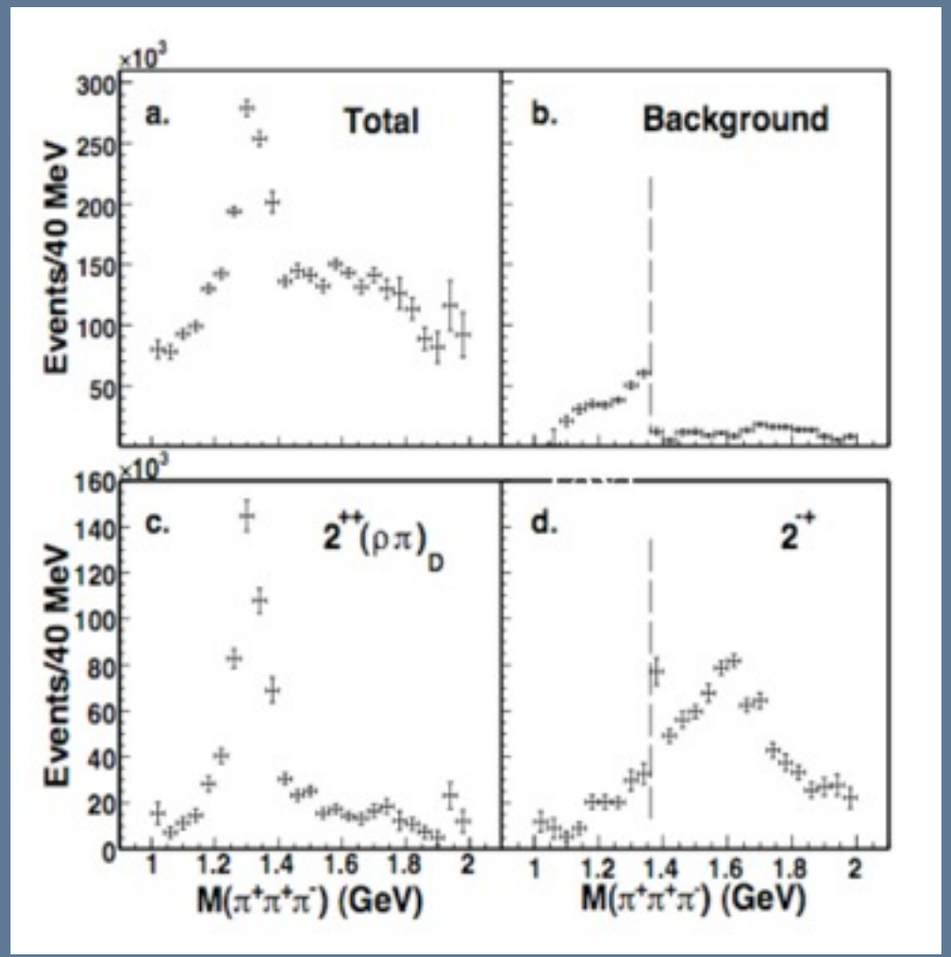
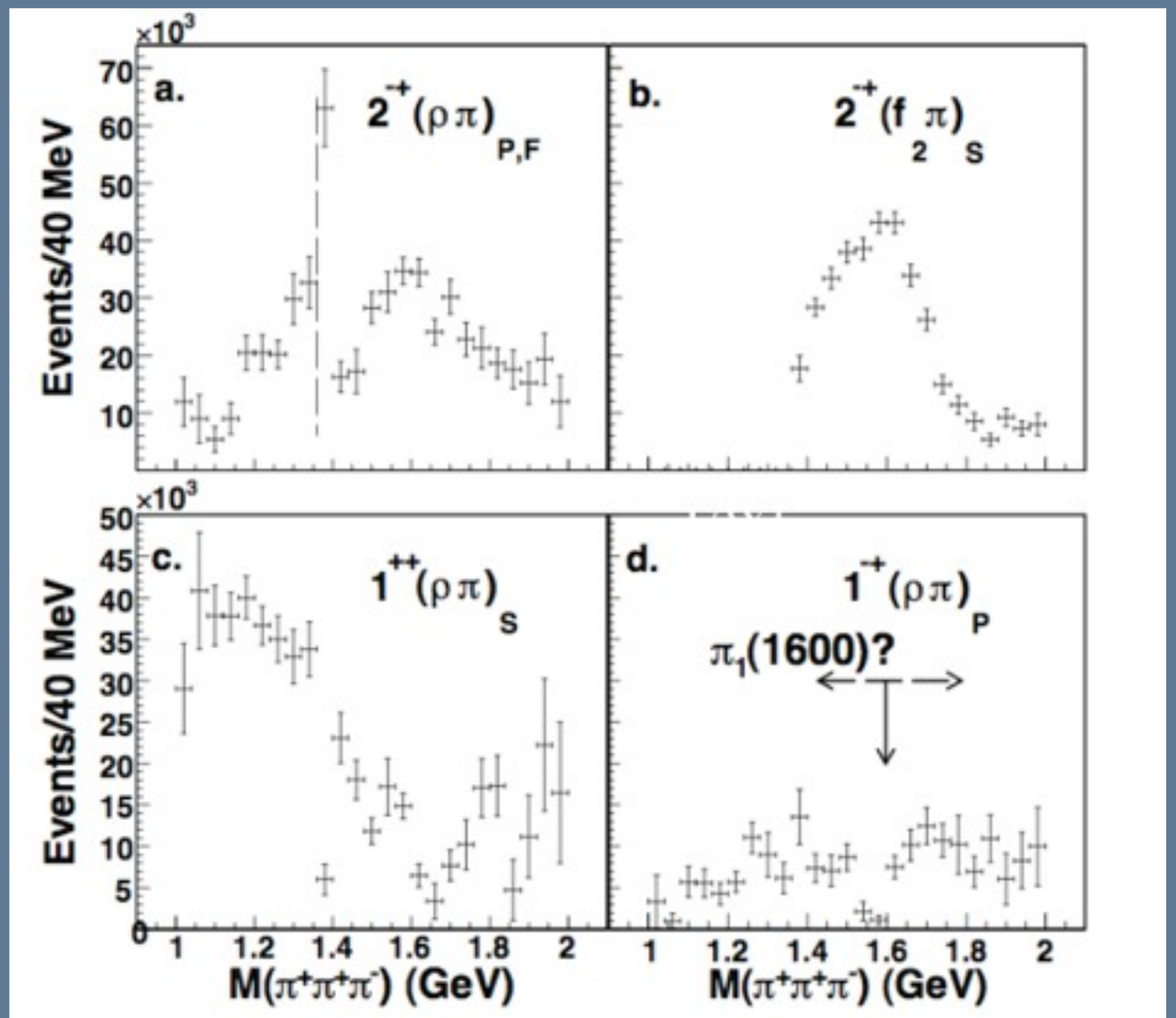


Figure 22: 3π-$n\pi$ scatter plots. Top row: $m(3\pi)$ vs $m(n\pi^-)$; Middle row: $m(3\pi)$ vs $m(n\pi_2^+)$; Bottom row: $m(3\pi)$ vs $m(n\pi_1^+)$.
Left column: before any low $-t$ and $\pi^+_{1(2)}$ small lab angle cuts; Middle column: after low $-t$ and $\pi^+_{1(2)}$ small lab angle cuts; Right column: after low $-t$ cut, but with $\pi^+_{1(2)}$ lab angles $>= 30°$.

Unpolarised 4.8-5.2 GeV photon beam

$\gamma p \rightarrow \pi^+\pi^+\pi^-(n)$





- Clear evidence of non-exotic 2^{++} state $a_2(1320)$
- No-evidence of exotic 1^{-+} state $\pi_1(1600)$ at the expected yield

$\sigma_{\pi 1} < 13.5$ n*b*

(<2% of a_2)

Nozar, et al
Phys.Rev.Lett.
102:102002,2009.
e-Print: arXiv:
0805.4438 [hep-ex]

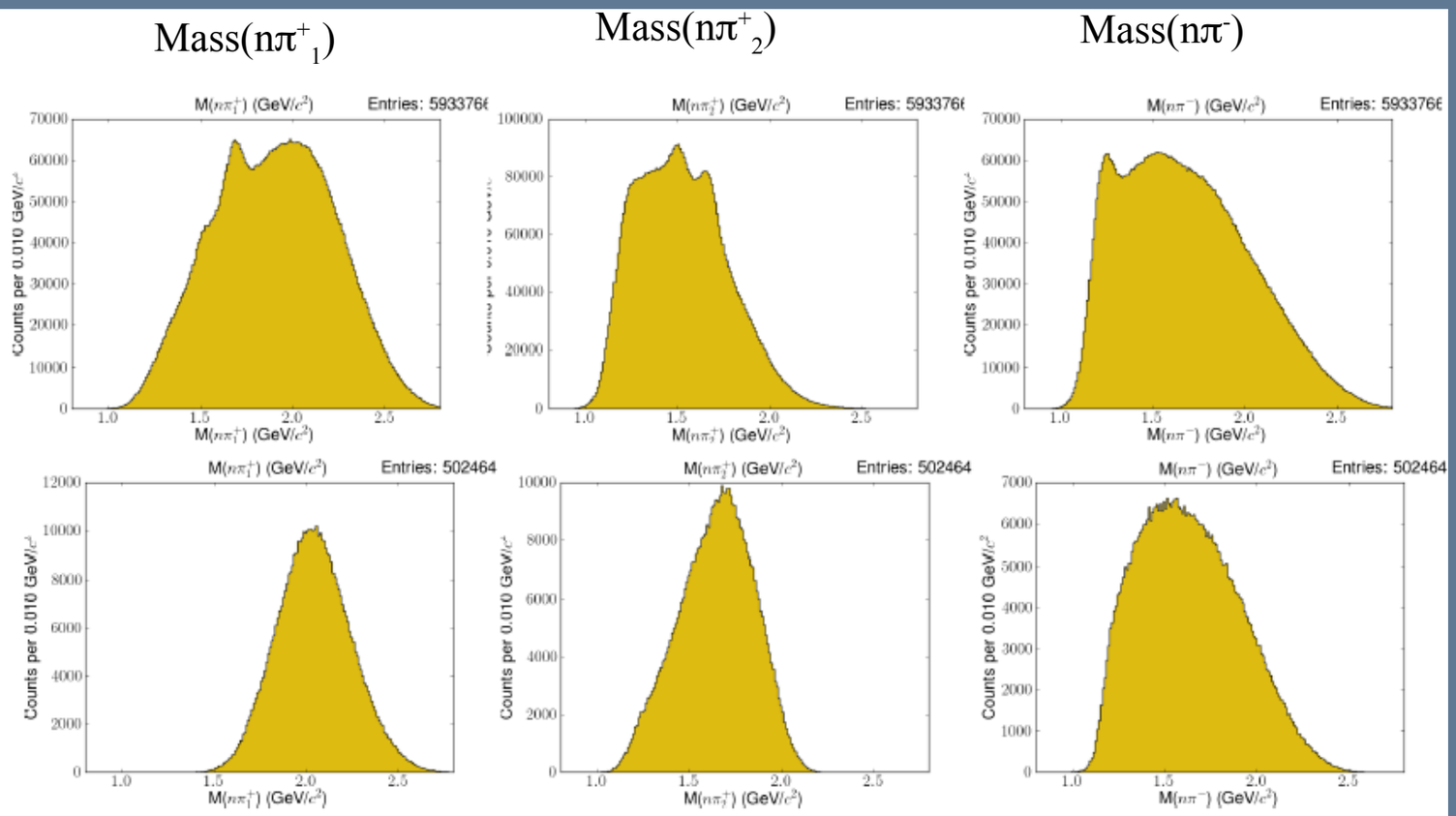
Baryon background removal

- Large contribution from $\gamma p \to \rho\Delta$, $\gamma p \to \rho N$ processes
- We limit our sample to events with low t'
  - Also events with low-angle slow π^+
  - 510K events remain from 6M $\gamma p \to \pi^+\pi^+\pi^- n$ events with $E_\gamma > 4.4$ GeV (494K from $M_{3\pi}$ between 1 and 2 GeV)

g12

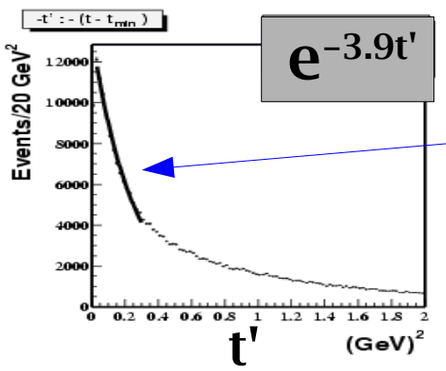
Before Selection

After Selection



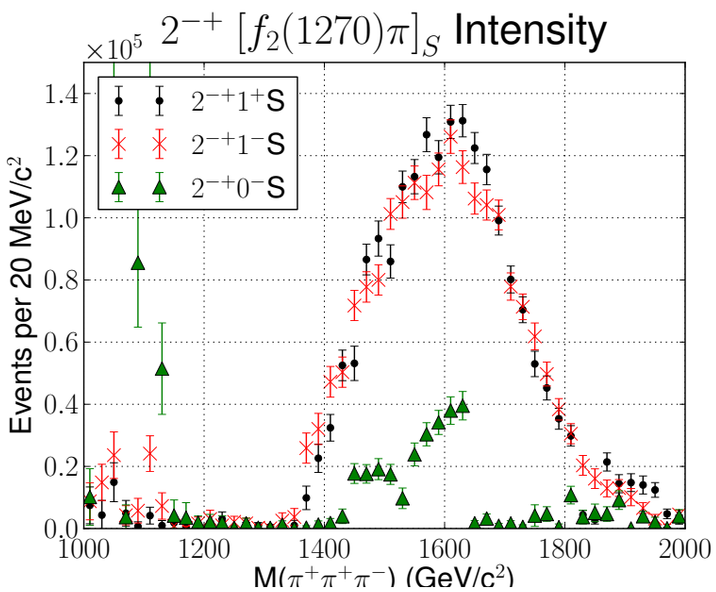
$|t'| < 0.105$

$\theta_{lab}(\pi^+) < 25°$ (both)

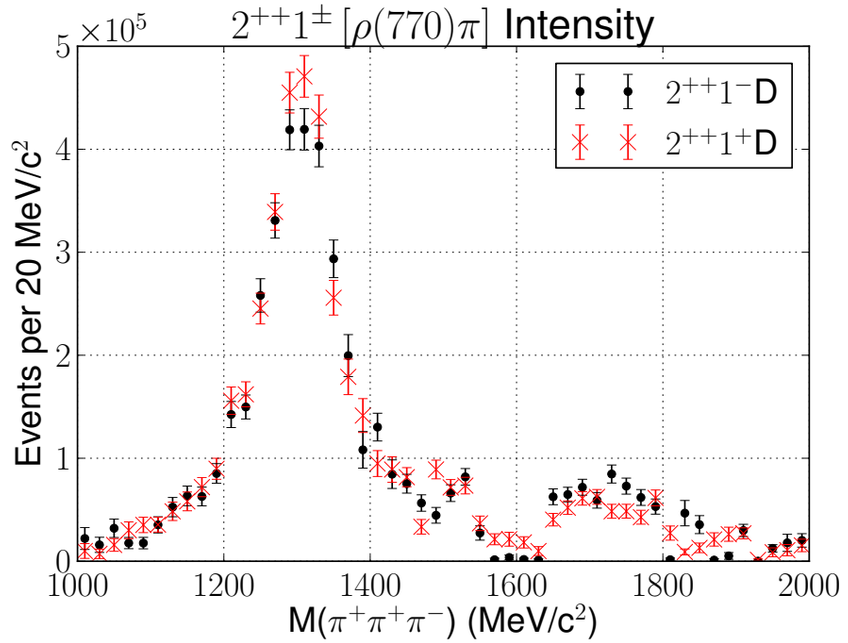


Sharp **t** dependence consistent with π-exchange production

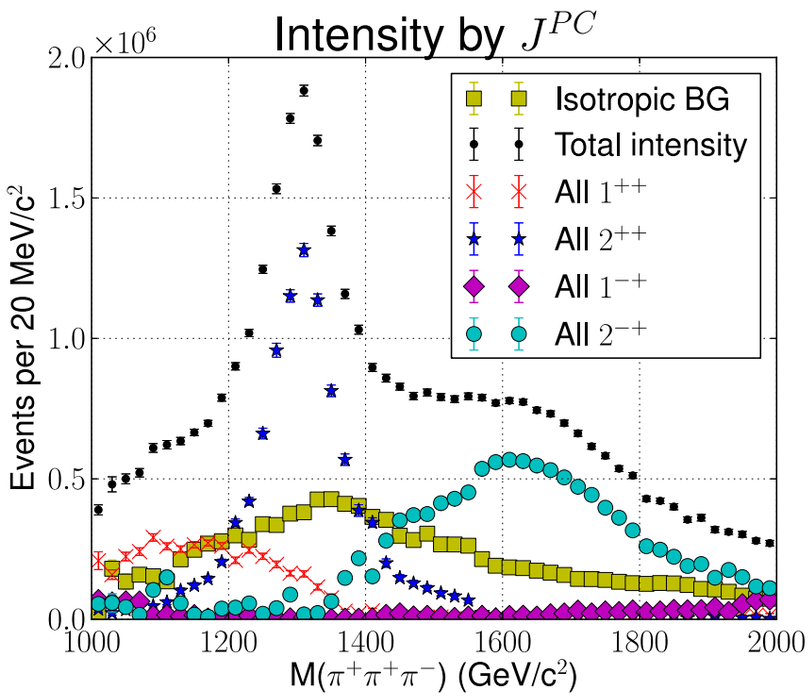
PWA: 2^{-+} $[f_2(1270)\pi]_S$ Intensity



PWA: 2^{++} Intensity



PWA: Intensity by J^{PC}



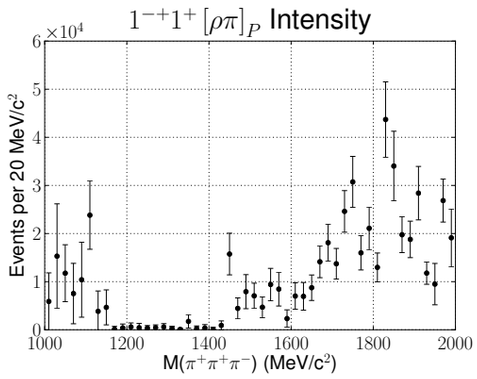
g12 3π: PWA setup

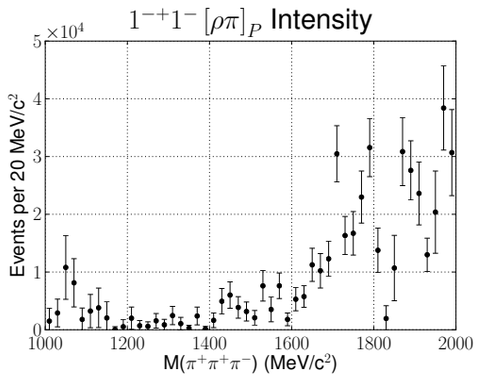
Major waves

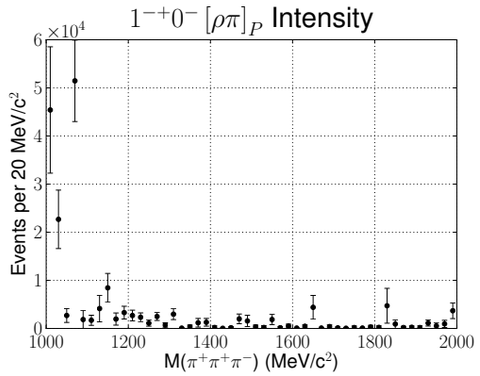
J^{PC}	M^{ϵ}	L	Y	# waves
1^{++}	$1^{\pm}$	S	$\rho(770)$	2
1^{++}	$1^{\pm}$, 0^+	D	$\rho(770)$	3
1^{-+}	0^-, $1^{\pm}$	P	$\rho(770)$	3
2^{++}	$1^{\pm}$	D	$\rho(770)$	2
2^{-+}	0^-, $1^{\pm}$	S, P, D	$f_2(1270)$, $\rho(770)$	9

+ isotropic background wave

PWA: 1^{-+} Intensity

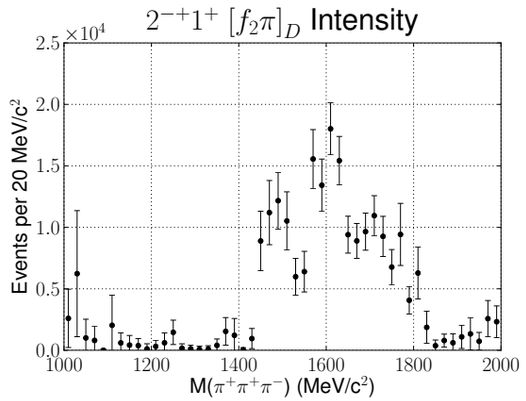


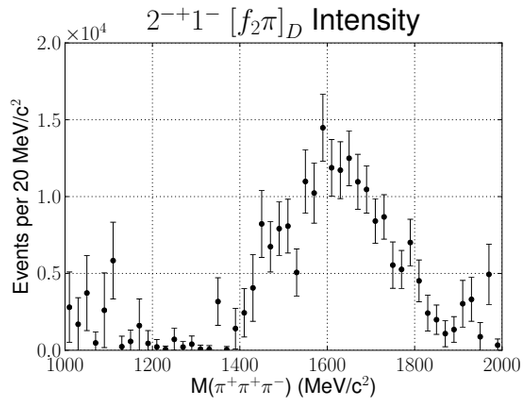


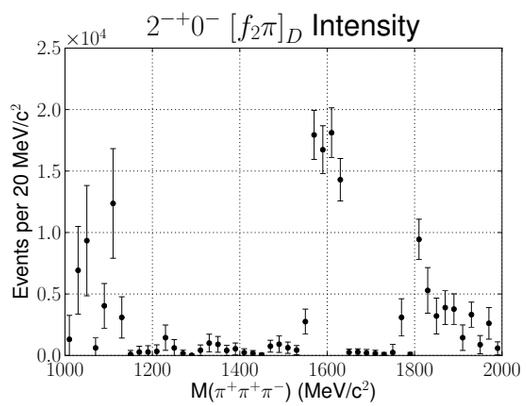


Accounts for up to 3% of total intensity

PWA: $2^{-+}\,[f_2(1270)\pi]_D$ Intensity

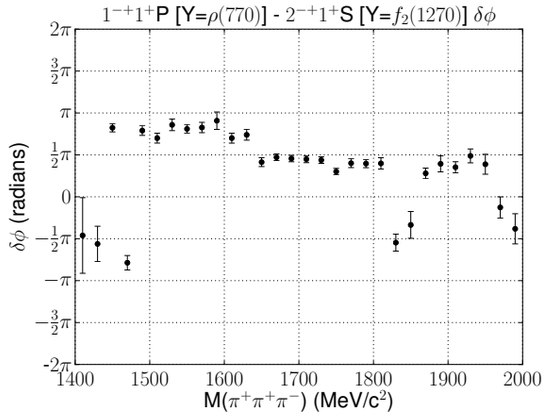


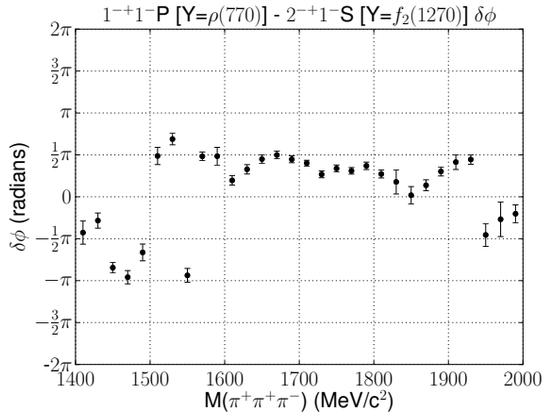


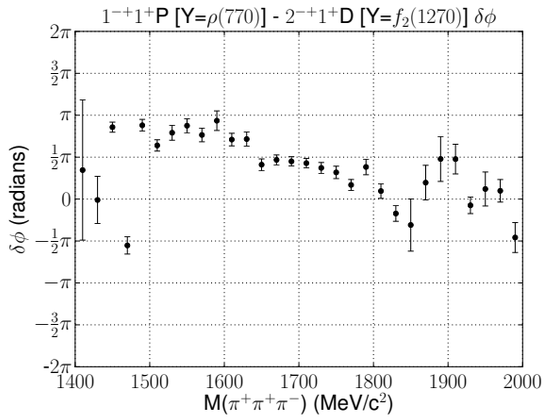


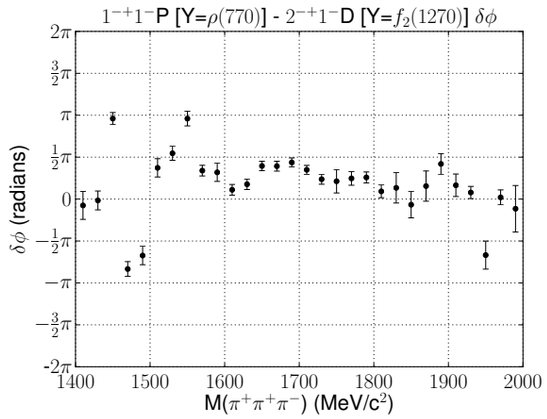
- More $M = 0$ issues
- Small signals (2%) cleanly extracted in $f_2\pi$ $M = 1$

PWA: 1^{-+} - 2^{-+} phase motion





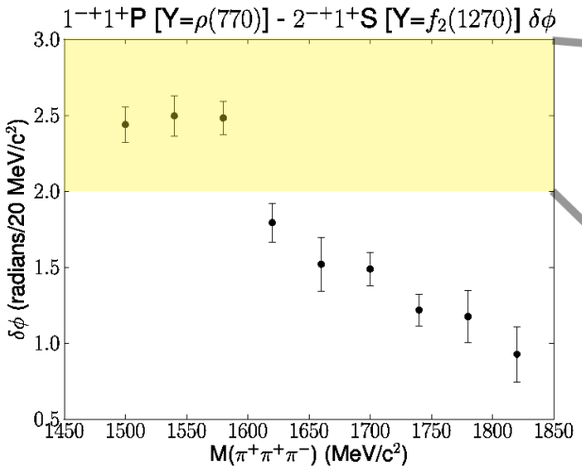




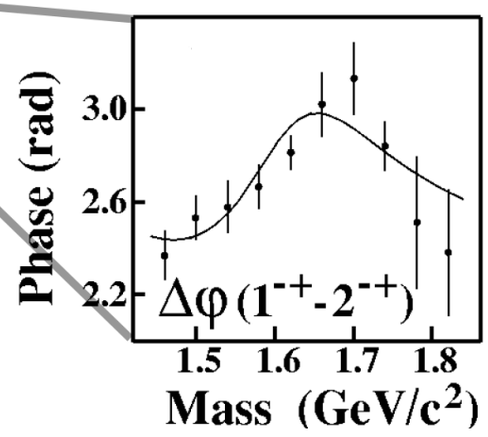
- No resonant 1^{-+} phase motion observed!

PWA: 1^{-+} - 2^{-+} phase motion

CLAS g12



BNL-E852



JLab-PWA group

HallD-HallB-JPAC

JPAC: M. Pennington, A. Szczepaniak, Igor Danilkin, Cesar Fernandez-Ramirez, Meng Shi, Peng Guo

Hall-B: Diane Schott,Veronique Ziegler, Will Phelps, Rafael Badui, Lei Guo, Dennis Weygand, Viktor Mokeev

Hall-D: Elton Smith, Mark Ito, Simon Taylor ,Yi Qiang, Mark Dalton, Carlos Salgado

- every other Friday @ 10:00 am Eastern (B101)
- e-mail list: jlab-pwa@jlab.org

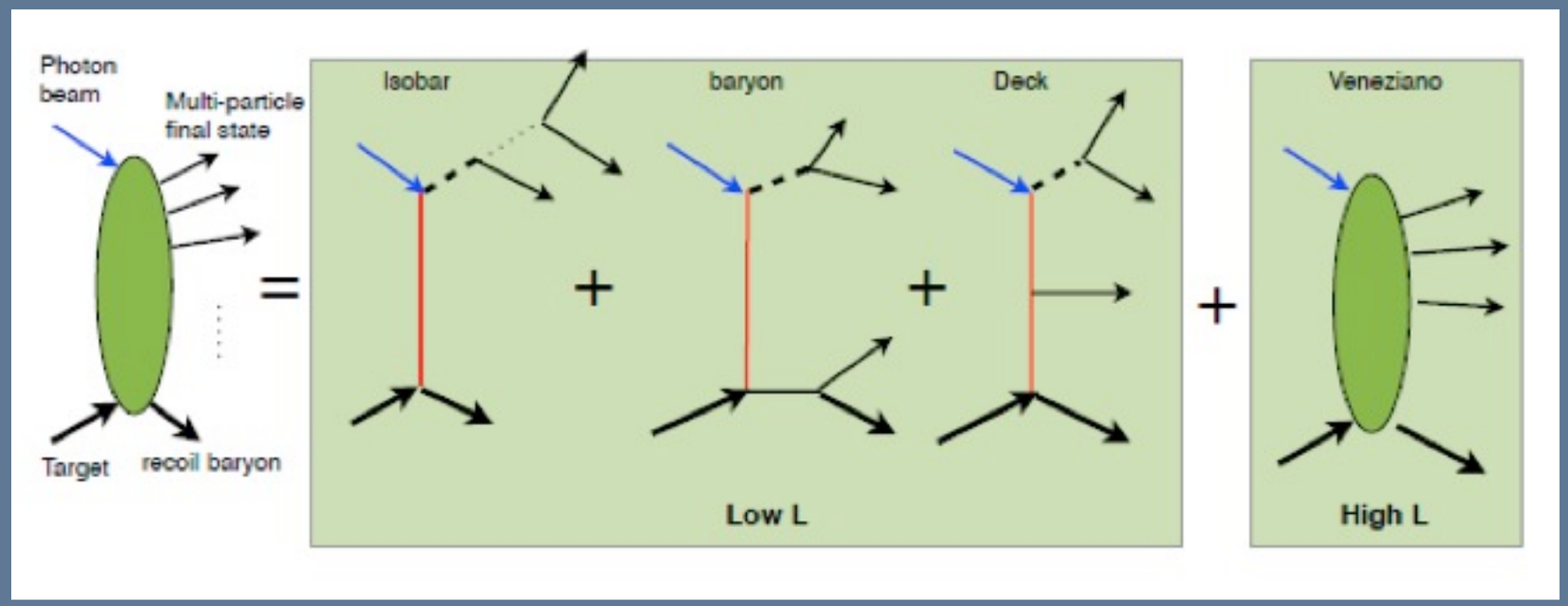
since July 2012

https://wiki.jlab.org/pwawiki/index.php/Main_Page

A physics model that extends the isobar model; i.e. to consider baryon vertices, Deck-effect vertices. Furthermore other theoretical amplitude we would like to include (we had coded the Veneziano single- and double-Regge-B5 Veneziano amplitudes).

- Analyticity, Unitarity, crossing
- Regge theory
- Dispersion relations
- ...

Cesar Fernandez-Ramirez Meng-Shi
Vincent Mathieu B5 Model

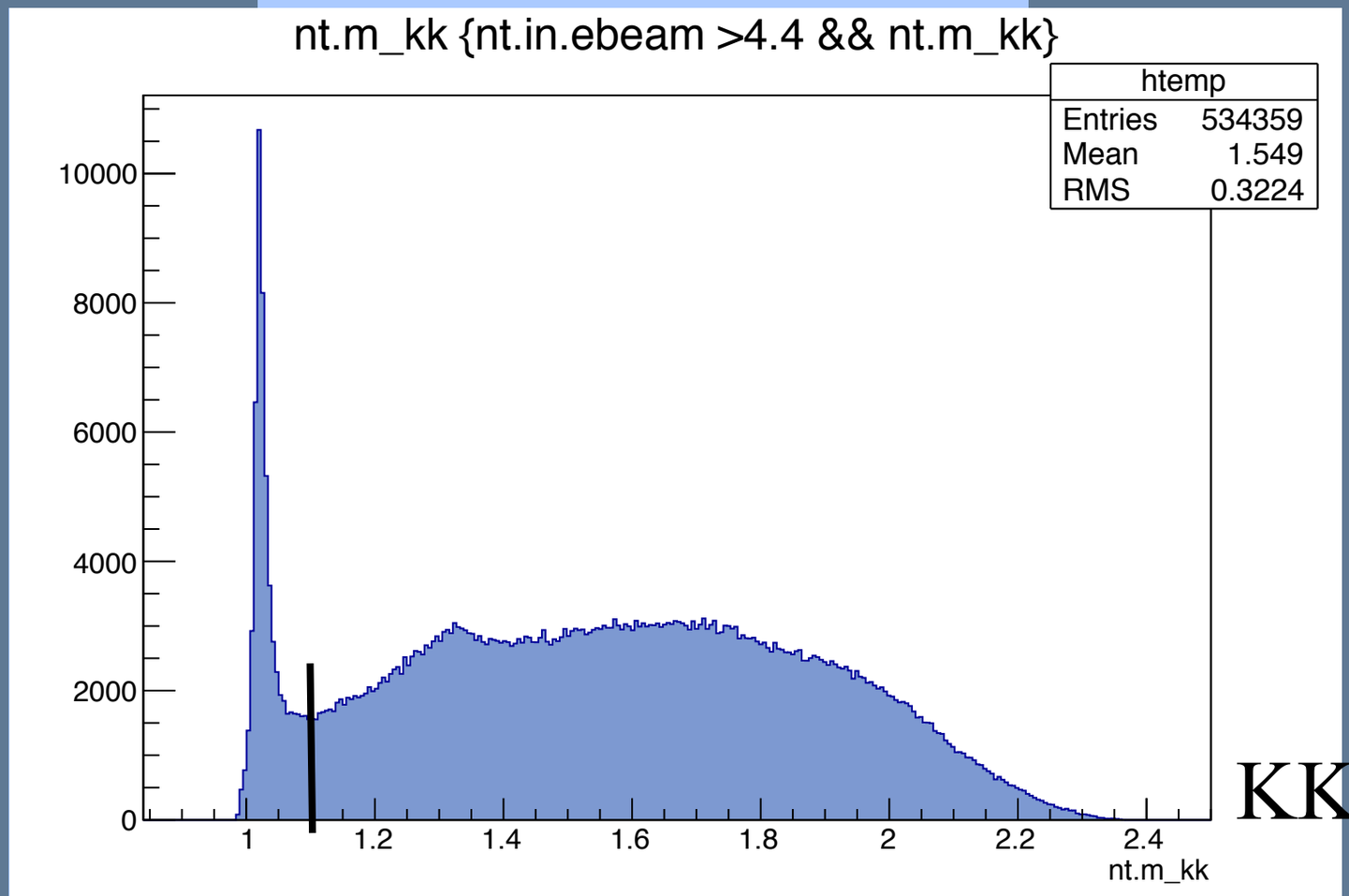


Decided to start from

$\gamma p \rightarrow pK^+(K^-)$

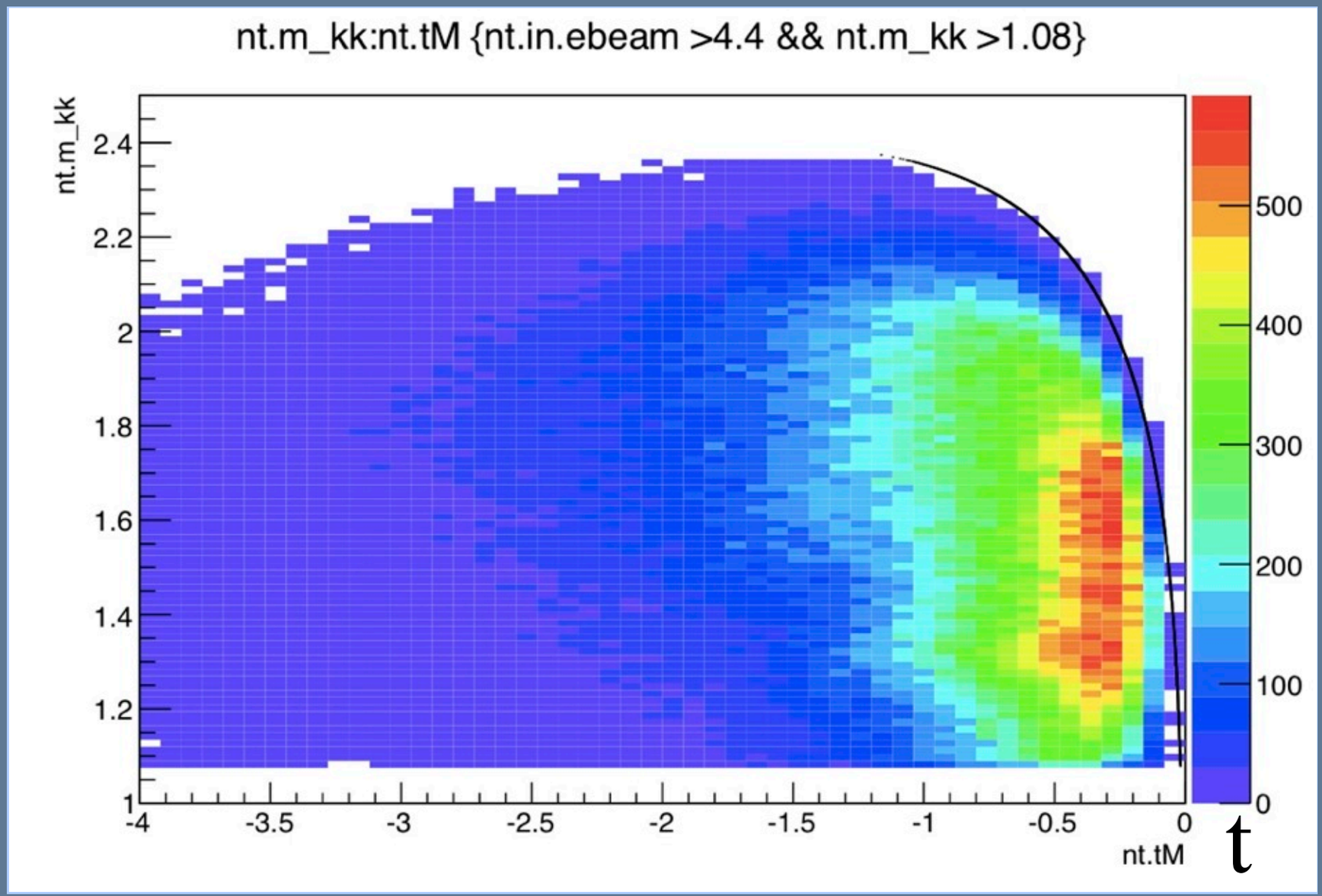
g12 CLAS run -

6.7M events after ID/KF

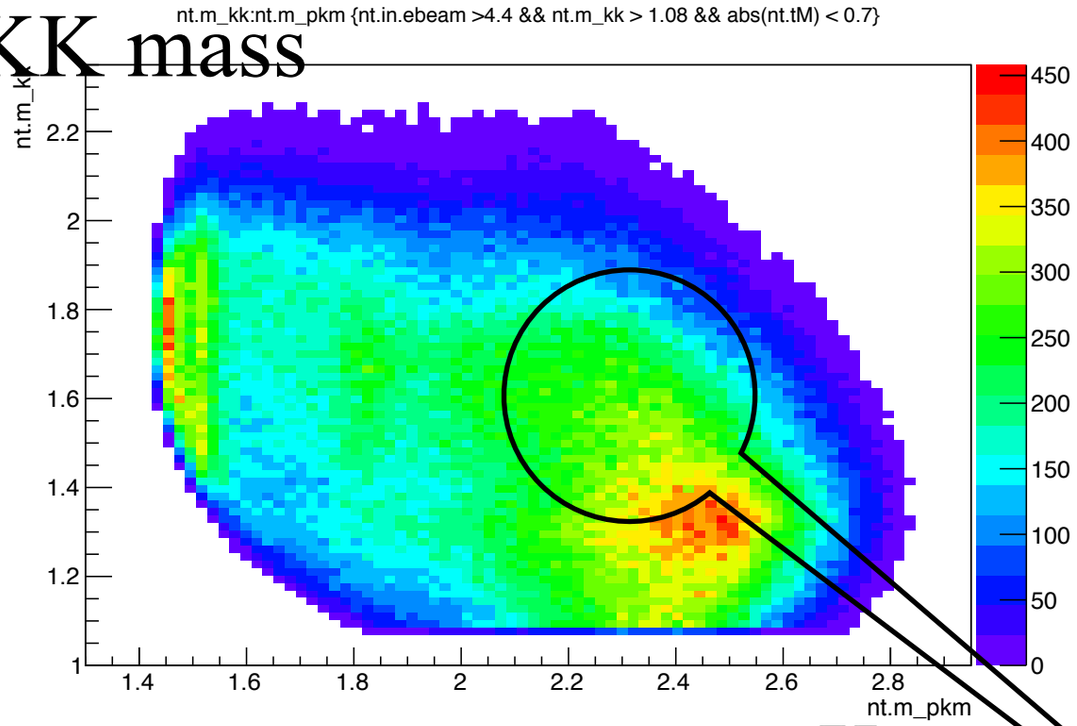


KK mass

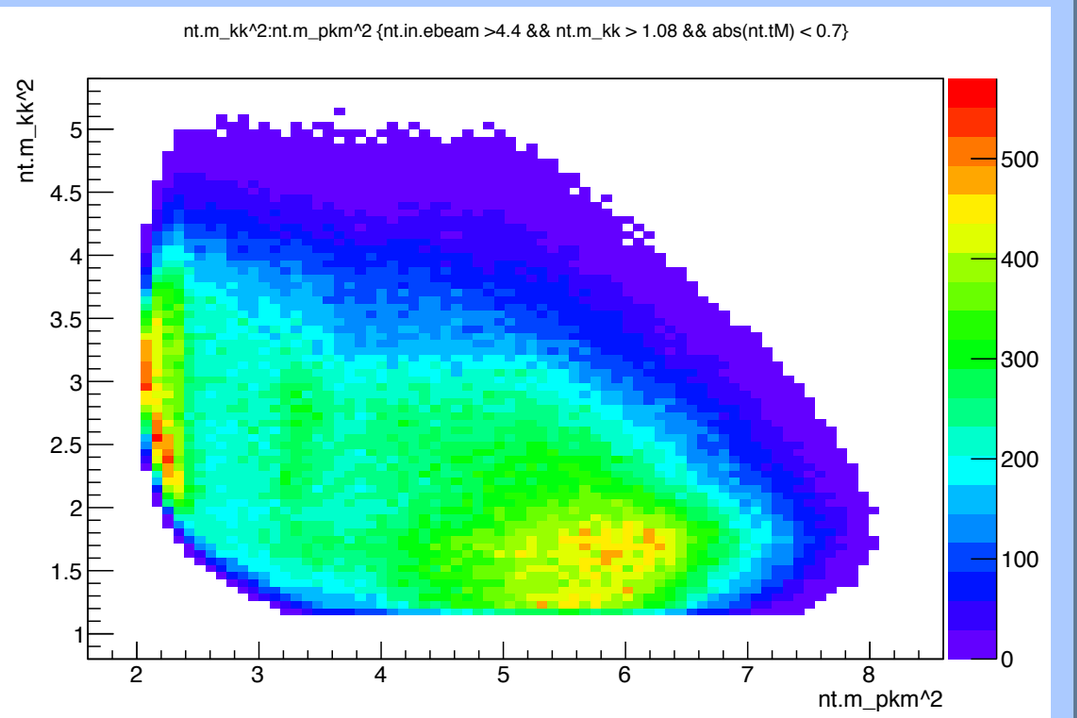
KK mass


nt.m_kk:nt.tM {nt.in.ebeam >4.4 && nt.m_kk >1.08}
nt.m_kk
2.4
2.2
2
1.8
1.6
1.4
1.2
1
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
nt.tM
500
400
300
200
100
0
t

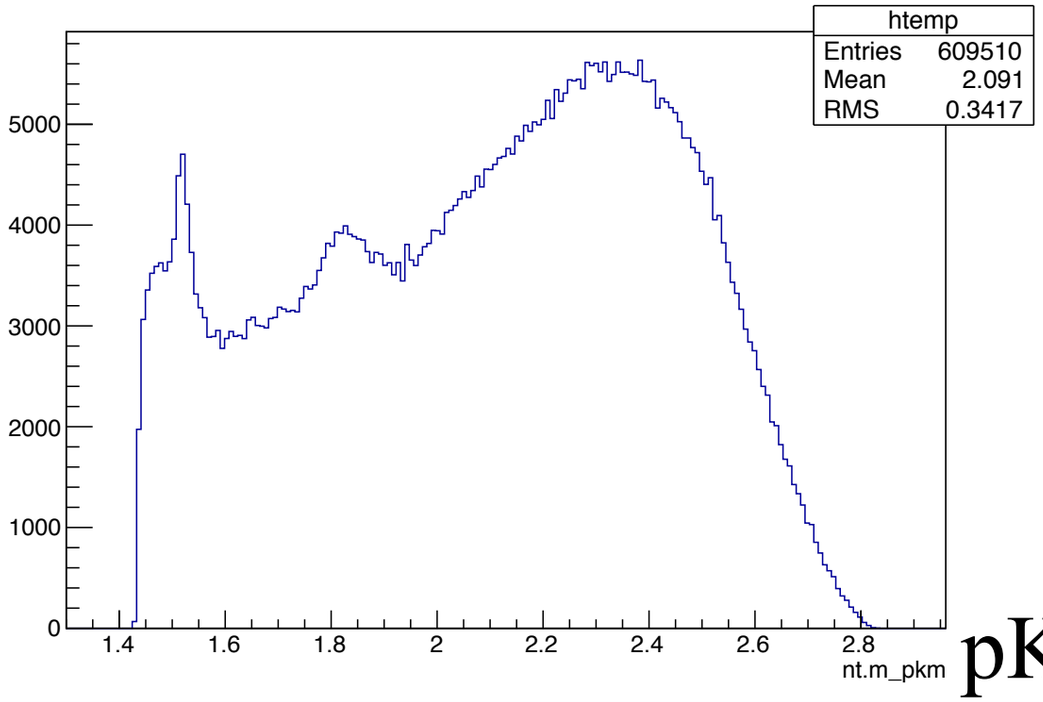
KK mass



pK mass



pK mass^2



pK mass

Interesting region for strangeonia

Problems of destroying "factorization"

Data events

MC events

$$\mathscr{F}(\vec{p}) = -ln\mathscr{L} = -\sum_{i=1}^{N} ln\left[\sum_{ext.\ spins}(\mathscr{M}\mathscr{M}^*)\right] + \eta_x \frac{1}{N_a}\sum_{i}^{N_a}\sum_{ext.\ spins}(\mathscr{M}\mathscr{M}^*). \quad (9)$$

$$I(\tau) = \sum_{k\epsilon}\sum_{b,b'} {}^{\epsilon}A_b(\tau)^{\epsilon}\ {}^{\epsilon}V_b^k\ \widehat{\rho_\gamma}^{\epsilon}V_{b'}^{k*\epsilon}A_{b'}^*(\tau)$$

$$-ln\mathscr{L} \propto \sum_{i=1}^{N} ln\left[\sum_{k\epsilon}\widehat{\rho_\gamma}\sum_{b,b'}{}^{\epsilon}V_b^{k\epsilon}V_{b'}^{k*}\ {}^{\epsilon}A_b(\tau_i)\ {}^{\epsilon}A_{b'}^*(\tau_i)\right] - \eta_x\sum_{k\epsilon}\sum_{b,b'}{}^{\epsilon}V_b^k\ {}^{\epsilon}V_{b'}^{k*}\ {}^{\epsilon}\Psi_{b,b'}^x$$

Normalization Integrals

PyPWA
A Partial-Wave-Analysis Software Framework

R. Badui[3], S. Bramlett[1], L. Guo[3], B. DeMello[1], C. W. Salgado[1,2], W. Phelps[3], J. Pond[1] and D. P. Weygand[1]

Norfolk State University[1]
The Thomas Jefferson National Accelerator Facility[2]
Florida International University[3]

Abstract

We describe a software framework used to perform Partial Wave Analysis (PWA) with the goal of extracting resonance information from multiparticle final states. The software is directed to photoproduction experiments using linear polarized beams. This software can also be used to extract model parameters from data by performing extended likelihood fits. Although general amplitudes can be use, the framework includes a very specific realization of the Isobar model, with extensions to include Deck-type and baryon vertices corrections. We describe the step-by-step precesses leading to a full PWA of data. A tutorial and examples are also included. Most of the code is in Python, but hybrid code (in Cyhon or Fortran) has been used when appropriate. Scripting for use of the JLab Linux computer farm, parallel coprocessors (Xeon-Phi or GPUs) are also included. The goal of this software framework is to create an user friendly environment of fast executing code to perform PWA.

Jefferson Lab

PyPWA PWA at JLab using JLab resources

Our goal is to write a very flexible PWA package that interface with different languages, codes and formats.

- GUI driven use of JLab resources (i.e,Farms).

- Hybrid programming, where languages are used as they are adequate for the specific task and then interfaced. For example, Python being a high-level programming language makes a better scripting language to “glue” several programming modules, and Fortran and C are more basic languages with much faster number-crunching looping.

- Vectorization works by exploiting the combined add-multiply unit of the Intel Xeon Phi

- Include full documentation (tutorials examples...)

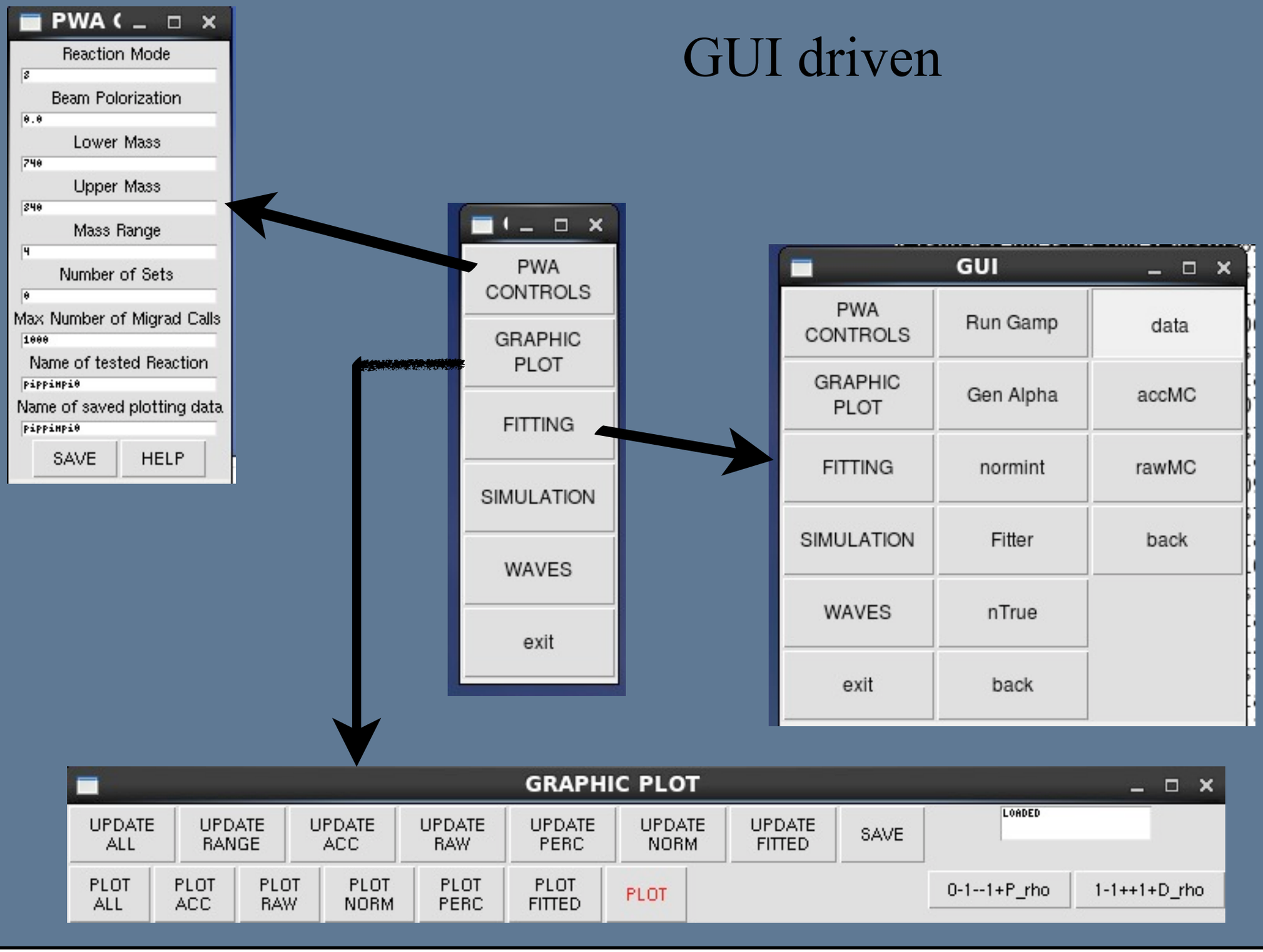
- Many options for optimization (i.e. minimization algorithms) and plotting tools

Jefferson Lab

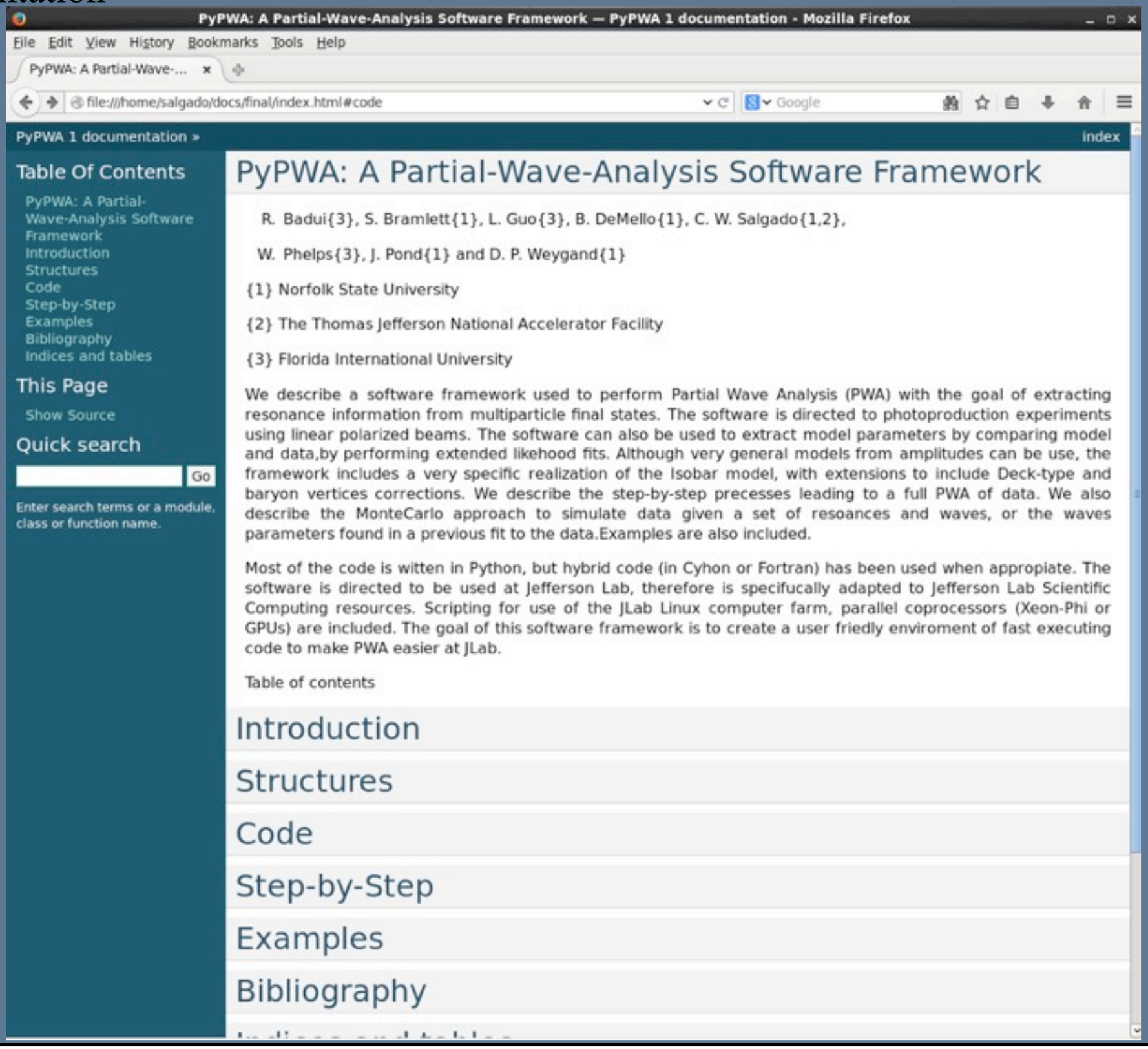
Intel-Xeon-Phi cards using for example **OpenMP** . Xeon Phi's contain about 61 of x86 cores that are functionally identical to those of standard laptops and desktops. There are just many more of them running at a lower clock speed to fit into a reasonable thermal design envelope (currently a PCI Express card). The maximum output is at 1TFlop and they have comparable performance with GPGPUs. Writing code for the Xeon Phi is, initially, less complicated than writing code for GPUs since it will behave as any normal CPU

PyPWA software environment is flexible, completely open, and ready-made for integration with external tools (modules). It provides a collection of modules with lots of functions and classes that can be contained in a single file simplifying bookkeeping. Interfacing with Fortran, C and C++ code is made easy; there very efficient toolkits for data computing (Numpy and Scipy) and graphics (Matplotlib) that are easy to interface and offer fast array handling, many options for optimization (i.e. minimization algorithms) and plotting tools

GUI driven


PWA
Reaction Mode
3
Beam Polorization
0.0
Lower Mass
740
Upper Mass
840
Mass Range
4
Number of Sets
0
Max Number of Migrad Calls
1000
Name of tested Reaction
pippimpi0
Name of saved plotting data
pippimpi0
SAVE
HELP
PWA CONTROLS
GRAPHIC PLOT
FITTING
SIMULATION
WAVES
exit
GUI
PWA CONTROLS
Run Gamp
data
GRAPHIC PLOT
Gen Alpha
accMC
FITTING
normint
rawMC
SIMULATION
Fitter
back
WAVES
nTrue
exit
back
GRAPHIC PLOT
UPDATE ALL
UPDATE RANGE
UPDATE ACC
UPDATE RAW
UPDATE PERC
UPDATE NORM
UPDATE FITTED
SAVE
LOADED
PLOT ALL
PLOT ACC
PLOT RAW
PLOT NORM
PLOT PERC
PLOT FITTED
PLOT
0-1--1+P_rho
1-1++1+D_rho

Documentation



Welcome to PyPWA! — pythonPWA 1.0.5 documentation - Mozilla Firefox

File Edit View History Bookmarks Tools Help

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file:///home/salgado/bdemello/pythonPWA/pythonPWA/docs/finalDocumentation/index.html

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Enter search terms or a module, class or function name.

dataTypes

This module contains the various data types used within the PWA project.

gampEvent

class pythonPWA.dataTypes.gampEvent.**gampEvent**(*particles=, []accepted=None, raw=None*)

This class represents a single gamp event. That is to say that this class contains a set of particles and a flag to specify if this event is accepted into the filtered data set.

gampParticle

class pythonPWA.dataTypes.gampParticle.**gampParticle**(*particleID=None, particleCharge=None, particleXMomentum=None, particleYMomentum=None, particleZMomentum=None, particleE=None*)

This class represents a particle described in a single line of a .gamp file.

toString()

Returns a string of the particle data members delimited by newlines.

resonance

class pythonPWA.dataTypes.resonance.**resonance**(*cR=1.0, wR=, []w0=1.0, r0=0.5, phase=0.0*)

This class represents a resonance.

toString()

Returns a string of the resonance data memebers delimited by newlines.

wave

class pythonPWA.dataTypes.wave.**wave**(*epsilon=0, complexamplitudes=, []w0=1000.0, r0=100.0, beta=0, k=0*)

This class represents a PWA wave.

toString()

returns a string of all the wave properties delimited by newlines.

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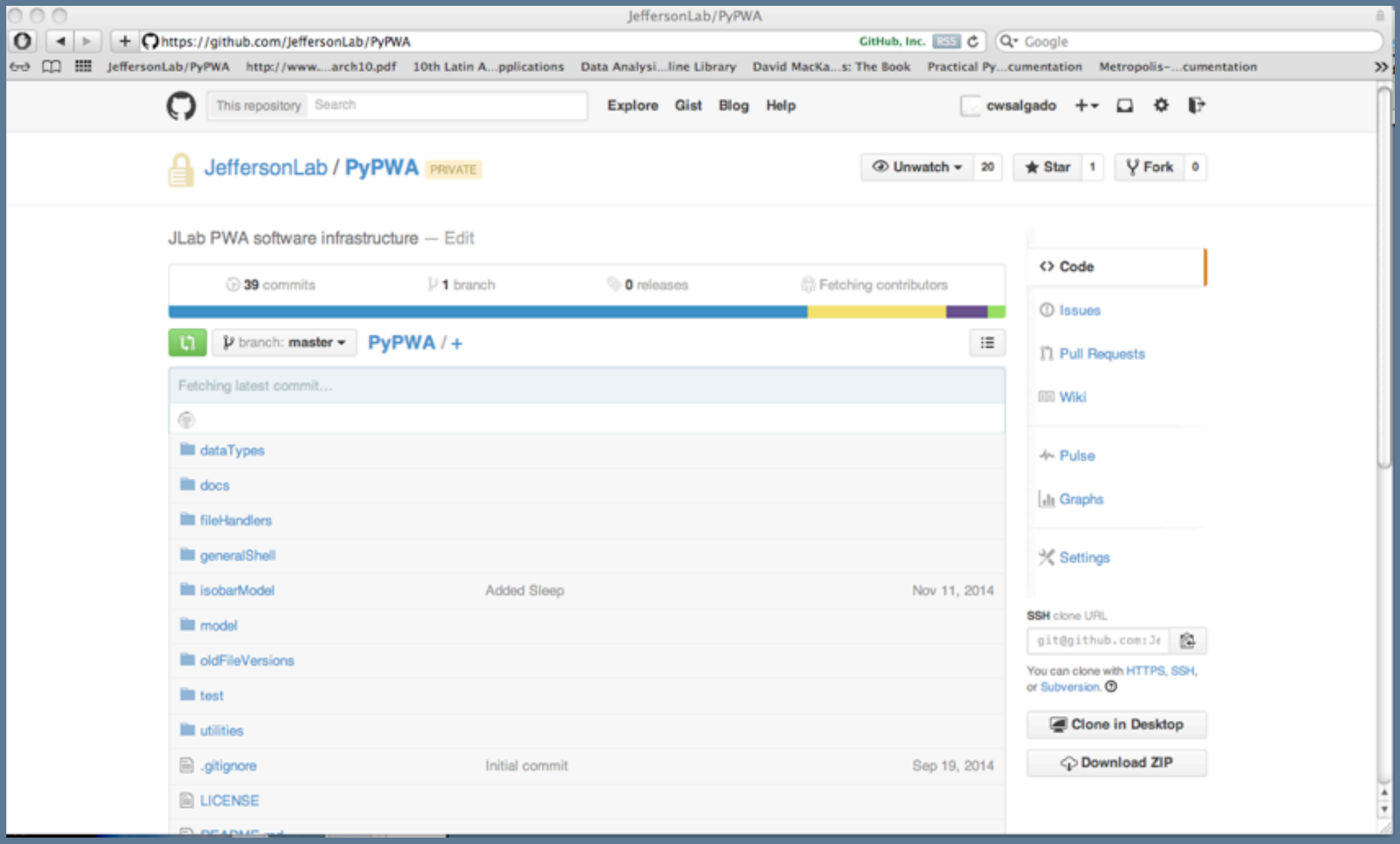
Jlab web-page - Tutorials and links
wiki - github JeffersonLab/PyPWA
Sphinx generated : docs



SciComp

Experimental Physics Computing

The batch farm contains 116 nodes with 8, 16 or 32 cores:

2013: 24 nodes, 16 core 2.6 GHz Xeon (Ivy Bridge), 32 GB memory, dual 1 TB disks, DDR IB

2012: 32 nodes, 16 core 2.0 GHz Xeon (Sandy Bridge), 32 GB memory, dual 500 GB disks, DDR IB

2011: 2 nodes, 32 core 2.0 GHZ AMD, 64 GB memory, 1 TB disk, SDR IB

2011: 18 nodes, 8 core 2.53 GHz Xeon (Westmere), 24 GB memory, dual 500 GB disk, SDR IB

2010: 24 nodes, 8 core 2.4 GHz Xeon (Nehalem), 24 GB memory, 500 GB disk, SDR IB

2009: 16 nodes, 8 core 2.4 GHz Xeon (Nehalem), 24 GB memory, 500 GB disk, SDR IB

The batch farm runs mostly serial jobs which spend part of their time in wait states for file I/O, and so the number of cores is slightly oversubscribed by the batch system, with 1,800 job slots available for the 1,400 available cores. Hyperthreading is enabled for the Xeons, giving the appearance of 2,800 cores. Memory per core is typically 2GB, depending on the node generation. Jobs with larger memory requirements than 2 GB can still run by declaring their memory requirements. The batch system will leave slots on the same node unused so as to effectively allocate that memory to the larger job.

Farm Networking

All farm nodes are connected to both the Ethernet fabric and the Infiniband fabric, where the IB fabric is used for high speed access to the file servers. About half of the nodes have SDR cards (single data rate IB, 10 Gb/s), recycled from the decommissioned 2006 LQCD 6n cluster. The latest nodes have DDR cards (double data rate IB, 20 Gb/s), recycled from the decommissioned 2007 LQCD 7n cluster. Up to 22 nodes are connected to an SDR or DDR switch. These "leaf" switches have uplinks to a farm "core" DDR switch, which in turn has a pair of uplinks to an adjacent QDR LQCD switch, and from there they can reach the file systems.

By using Infiniband, the total file system bandwidth into the farm can now be >3 GBytes/s, sufficient for 40 nodes to be streaming data to or from their local disks concurrently. For additional information on the file system, see the next chapter on Disk Servers.

‹ GPU Specifications up Disk Servers (online storage) ›

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SciComp

HPC / LQCD Computing Systems

The HPC / LQCD batch system includes 3 Infiniband clusters (3 generations of Intel CPUs), 3 GPU clusters with 5 types of GPU cards, and one small cluster with Xeon Phi accelerators.

Infiniband Clusters

12s (2012 Sandy Bridge) -- 275 nodes, 16 cores, 32 GB memory, QDR Infiniband (40 Gb/s).

10q (2010 QDR) -- 224 nodes, 8 cores, 24 GB memory, QDR IB.

9q (2009 QDR) -- 328 nodes, 8 cores, 24 GB memory, QDR IB.

MIC / Xeon Phi Cluster

12m (2012 MIC) -- 16 nodes,16 cores, 64 GB memory, FDR (56 Gb/s) IB.

GPU Clusters are organized as four clusters according to the generation of the host servers:

12k (2012 Kepler) -- 42 nodes, 16 cores, 128 GB memory, quad K20m, FDR IB.

11g (2011 gpu) -- 8 nodes, 8 cores, 48 GB memory, quad C2050, QDR IB.

10g (2010 gpu) -- 53 nodes, 8 cores, 48 GB memory, quad GPU (mix), QDR/SDR IB.

9g (2009 gpu) -- 62 nodes), 8 cores, 48 GB memory, quad GPU (mix), SDR IB.

All clusters (partitions) have 2 IB uplinks into the main disk server Infiniband fabric, and access all of the filesystems except some of the /group areas over Infiniband.

IB Cluster Specifications
MIC Specifications
GPU Specifications

‹ Scientific Computing Resources up IB Cluster Specifications ›

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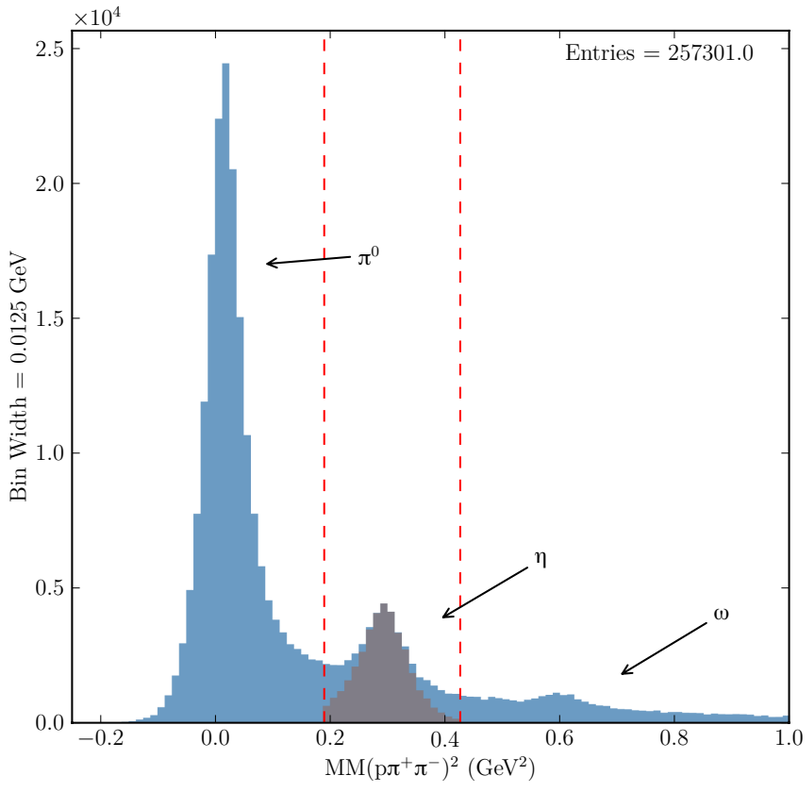
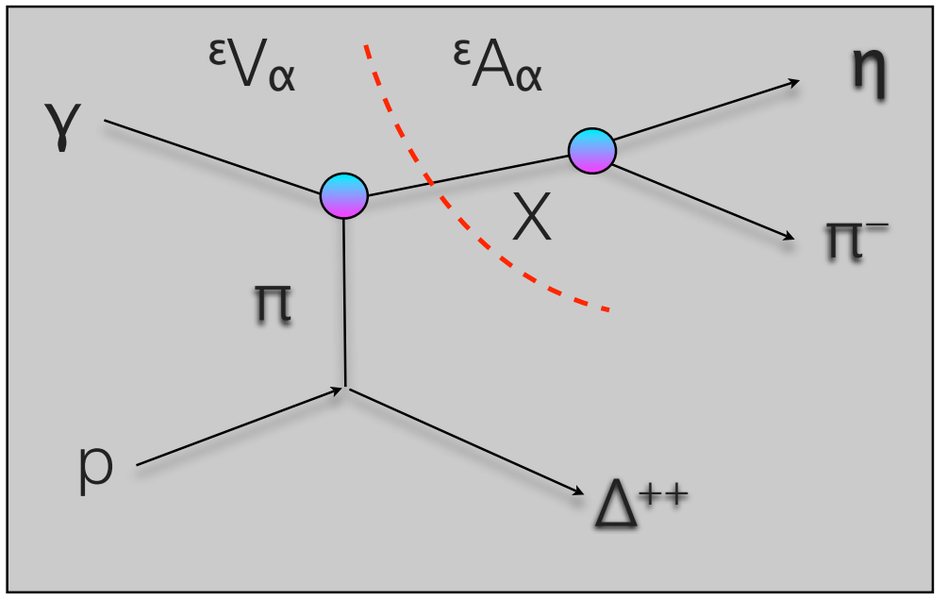
Event Selection

- To reconstruct η, the missing mass off of the p π^+ π^- was used in combination with the γ γ.
- Selected the η and fit the kinematic variables using conservation of E and p to improve tracks.
- The fitter is given the assumption the neutral particle is η. The kinematic fitter refits the kinematic variables under the this assumption and returns a probability of the assumption being correct.



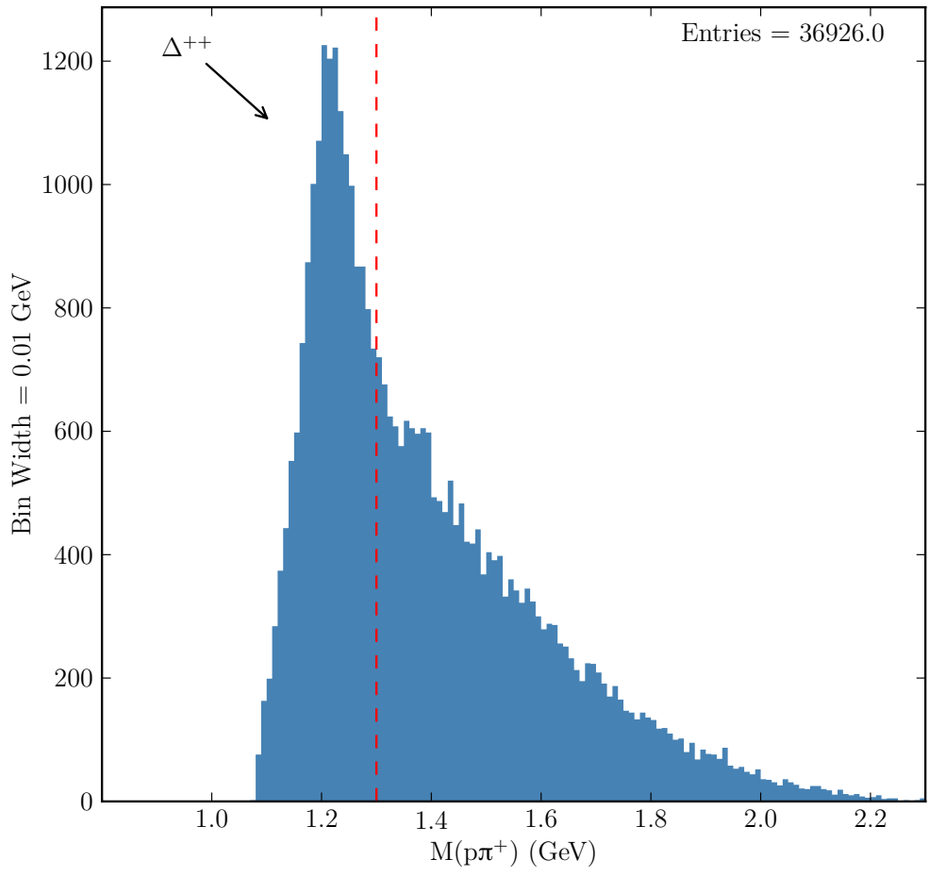


CLAS g12

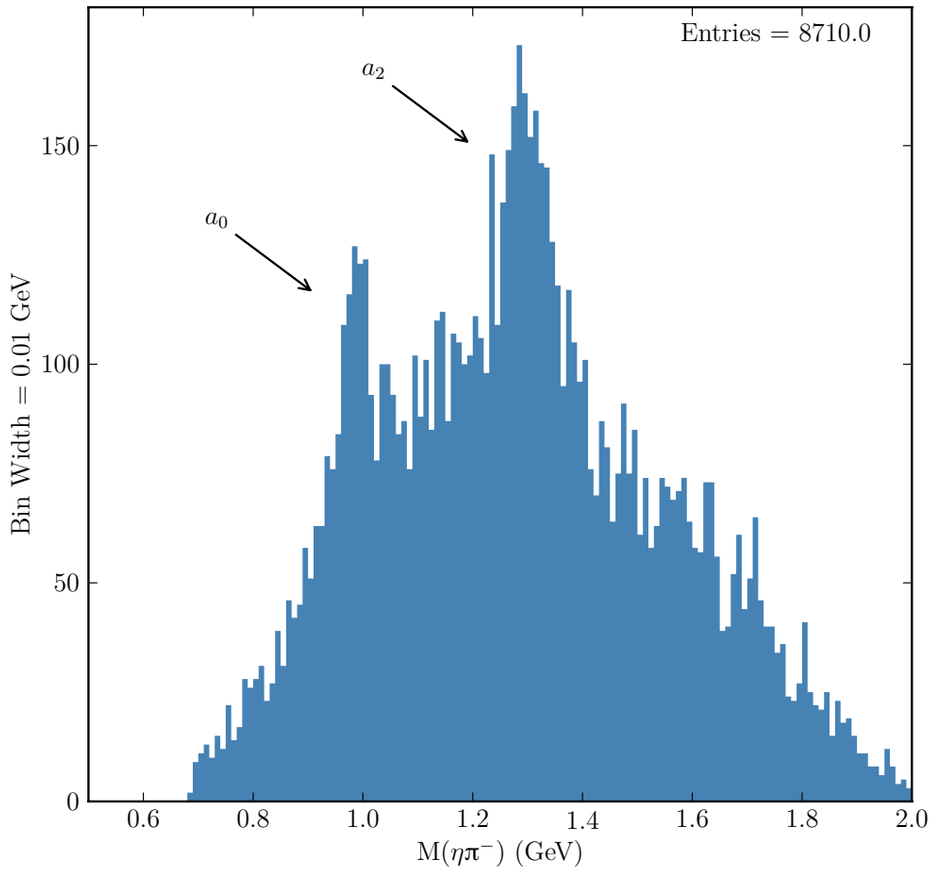
Diane Schott - FIU Thesis

Baryon Selection: γ p → Δ^{++} X, Δ^{++} → pπ^+

M(pπ^+) < 1.3 GeV

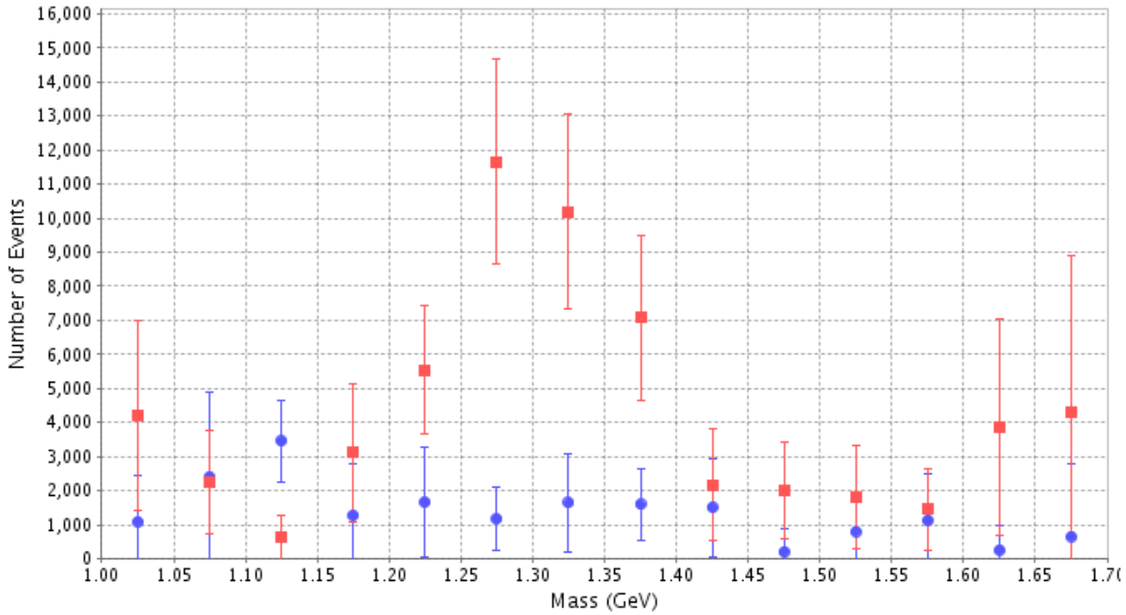


M($\eta\pi^-$)



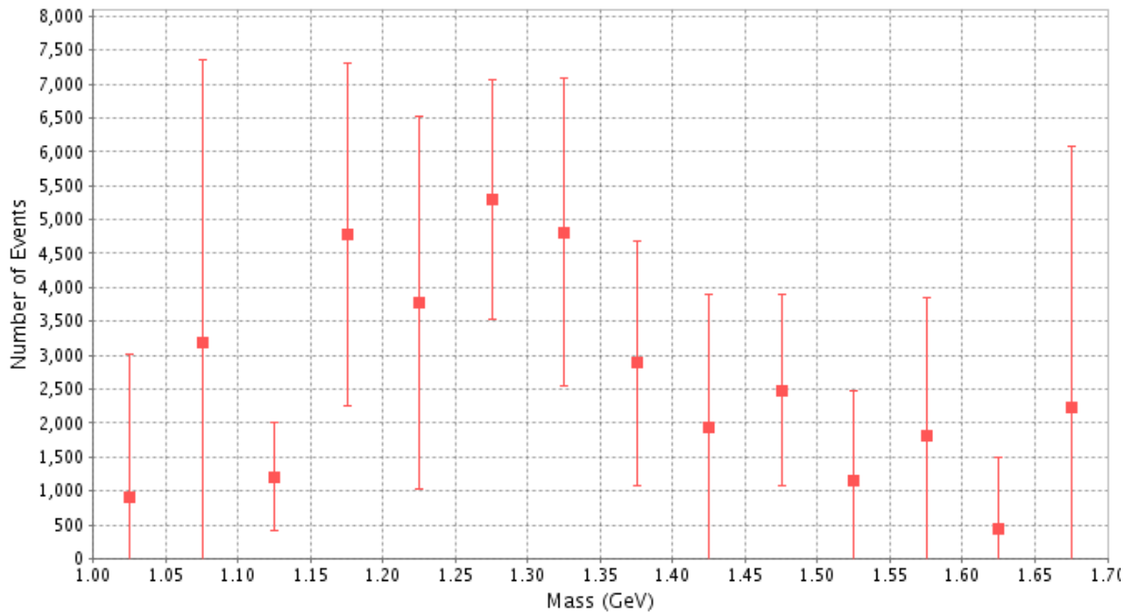
PWA: Mass Independent Fit

$J^{PC}m = 1^{-+}1, 2^{++}1$



- The strongest contribution is from the D wave.

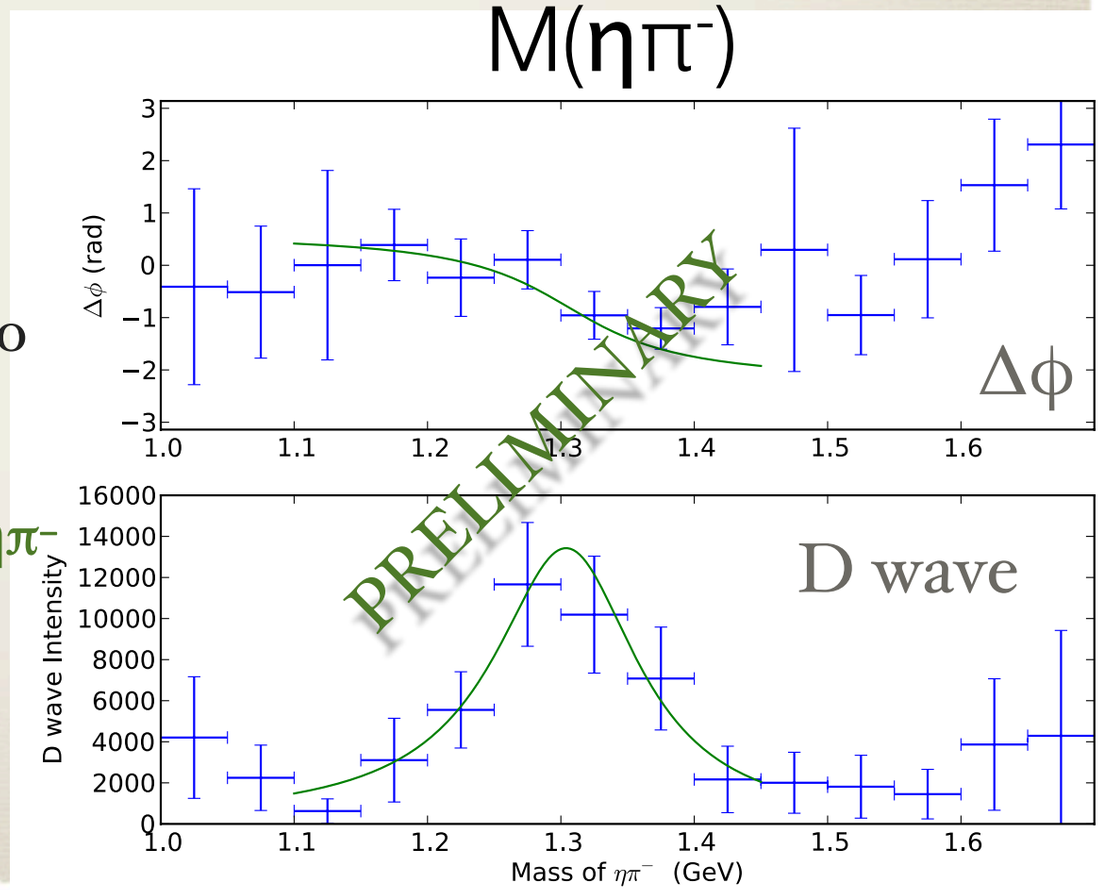
$J^{PC}m = 0^{++}0$



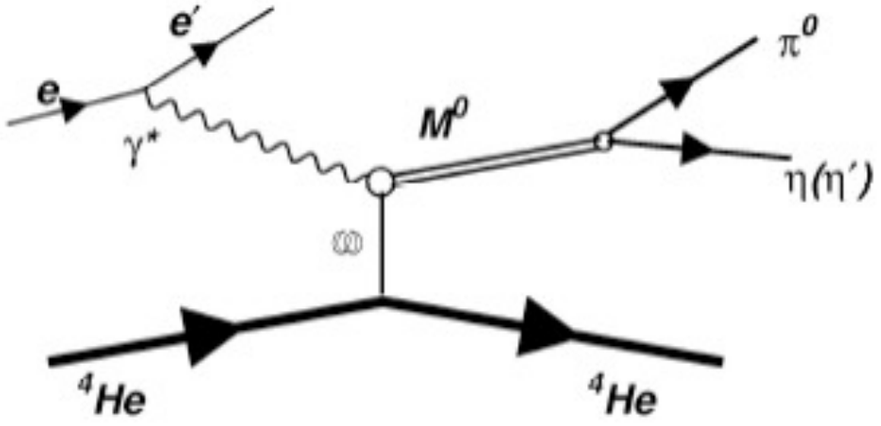
- The S wave shows a broad background with 1/2 the intensity of the D wave.

$\gamma p \to \Delta^{++} \eta \pi^-$

- fit with a_2 and constant background
- mass: 1.32 ± 0.01 GeV
- width: 0.14 ± 0.01 GeV
- No exotic was concluded to be seen in the final fit.
- This is the first look into ηπ- using photoproduction!



eg6: Meson spectroscopy in coherent production off ^{4}He



Scattering off a spin and isospin zero target works as a spin and parity filter

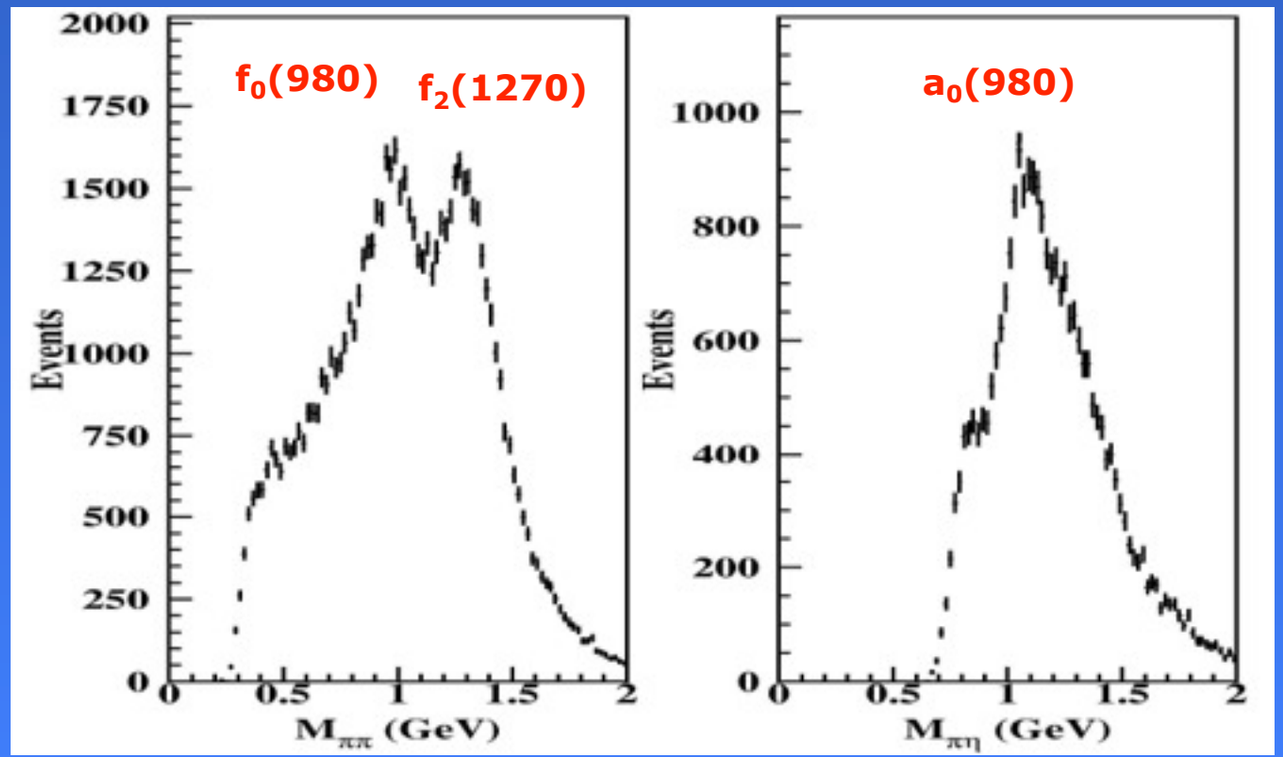
- search for exotics in $\pi\eta$, $\pi\eta'$ final states - π_1 (1400)

$ep \rightarrow (e')p\pi^0\eta$

- 6 GeV electron beam on target on high pressure gas target
- All neutrals triggers (no scattered electron measured)
- recoiling nucleus detected in Radial TPC
- hadronic final state detected in CLAS
- PWA greatly simplify: C=-1 and NPE only allowed (ω exchange)
- No baryon background

STATUS

- data taking completed in fall 2009
- Reconstruction of data in progress



Summary

Meson Spectroscopy together with LQCD calculations promise to provide a window to detailed studies of **strong interactions** at intermediate energies

PyPWA - High-statistics Photoproduction with Linear Polarization :
Two Hadron Spectroscopy program at Jefferson Lab

- CLAS12 using a beam of "quasi-real" photons
- GlueX using a linearly polarized photo beam

Partial Wave Analysis progress :

- Theory: improve models - include more amplitudes in PWA
- Computing: increase computer efficiency - Parallel computing - vectorization of existing code (GPU, Xeon Phi). Faster / user friendly.
- Algorithms: Minimization/Optimization (Genetic Algorithms,...)

For a good understanding of the meson spectrum we will need to analyze data from different beams (production mechanisms), different channels (coupled channel analysis) and consider an
improvement in our models and analysis (software & hardware) tools
accordingly with the expected high statics experiments.