SHORT DISTANCE STRUCTURE OF NUCLEI: MINING THE WEALTH OF EXISTING JLAB DATA

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And a cast of thousands

Collaboration:

Spokespeople:
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Data Mining Scientist: G. Gavalian

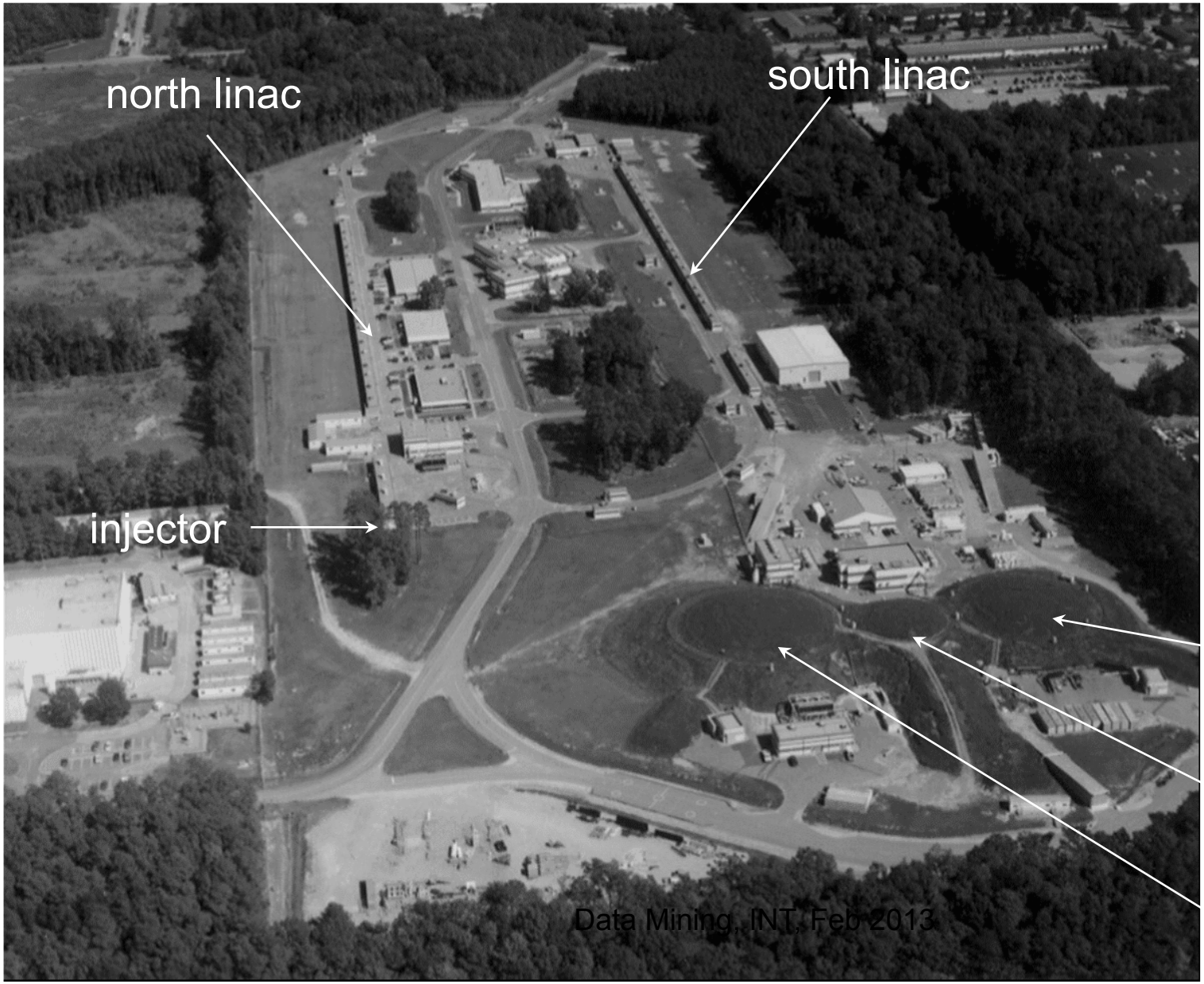
Institutions:
ODU, Penn State, Florida International, Tel Aviv, Glasgow, William and Mary, Edinburgh, Ohio State, New Hampshire, MIT, Richmond, George Washington, Your Name Here

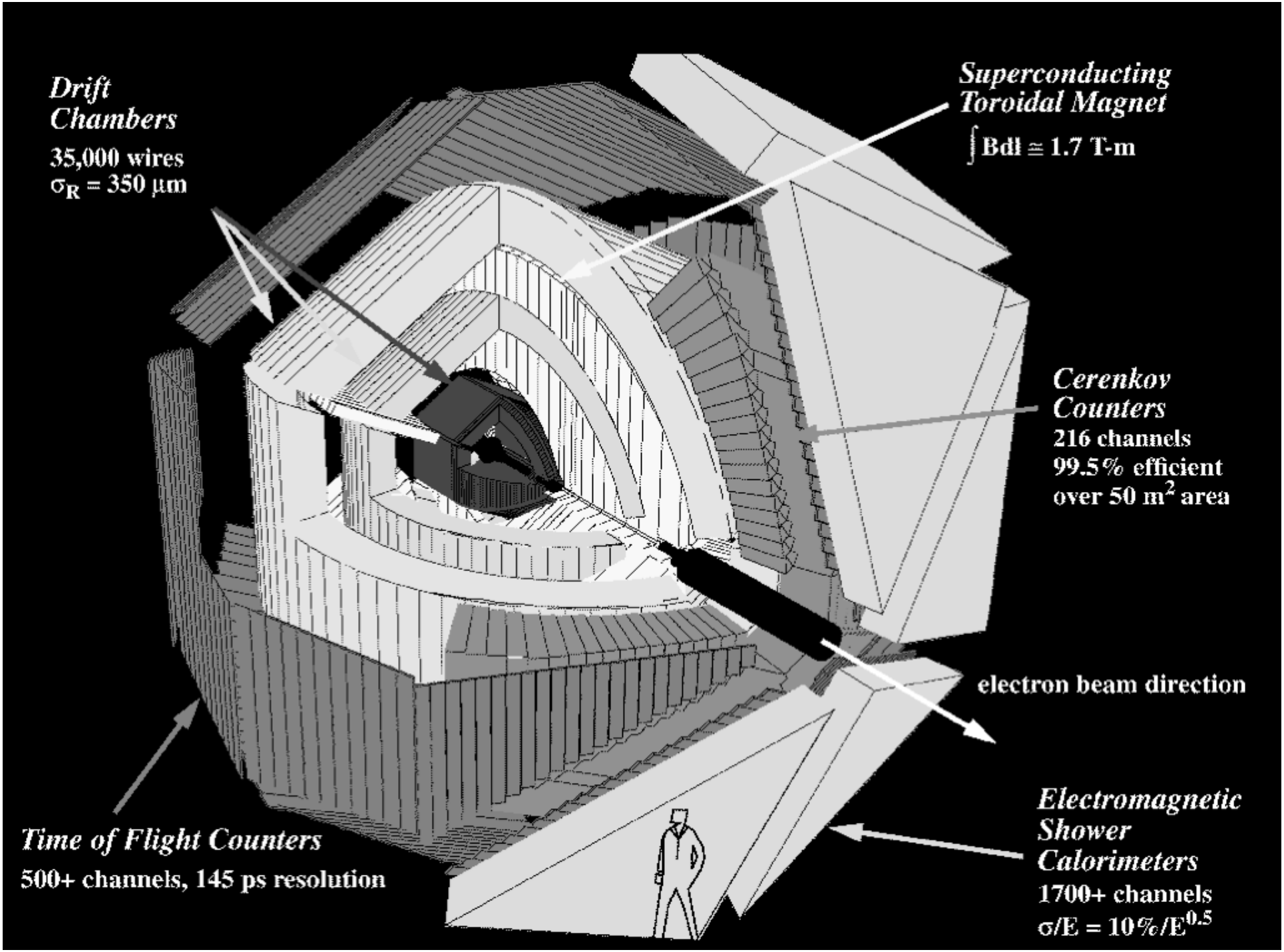
Support:
DOE Grant for the Data Mining Scientist plus travel
2011-2014
ODU computer support

Why Data Mining?

- Build on the progress made at JLab on SRC and dynamics of interactions with nuclei at medium Q^2
- Take advantage of the huge CLAS data set
  - Mostly taken with A(e,e') inclusive trigger
- Take advantage of the otherwise "wasted" time while we upgrade JLab to 12 GeV

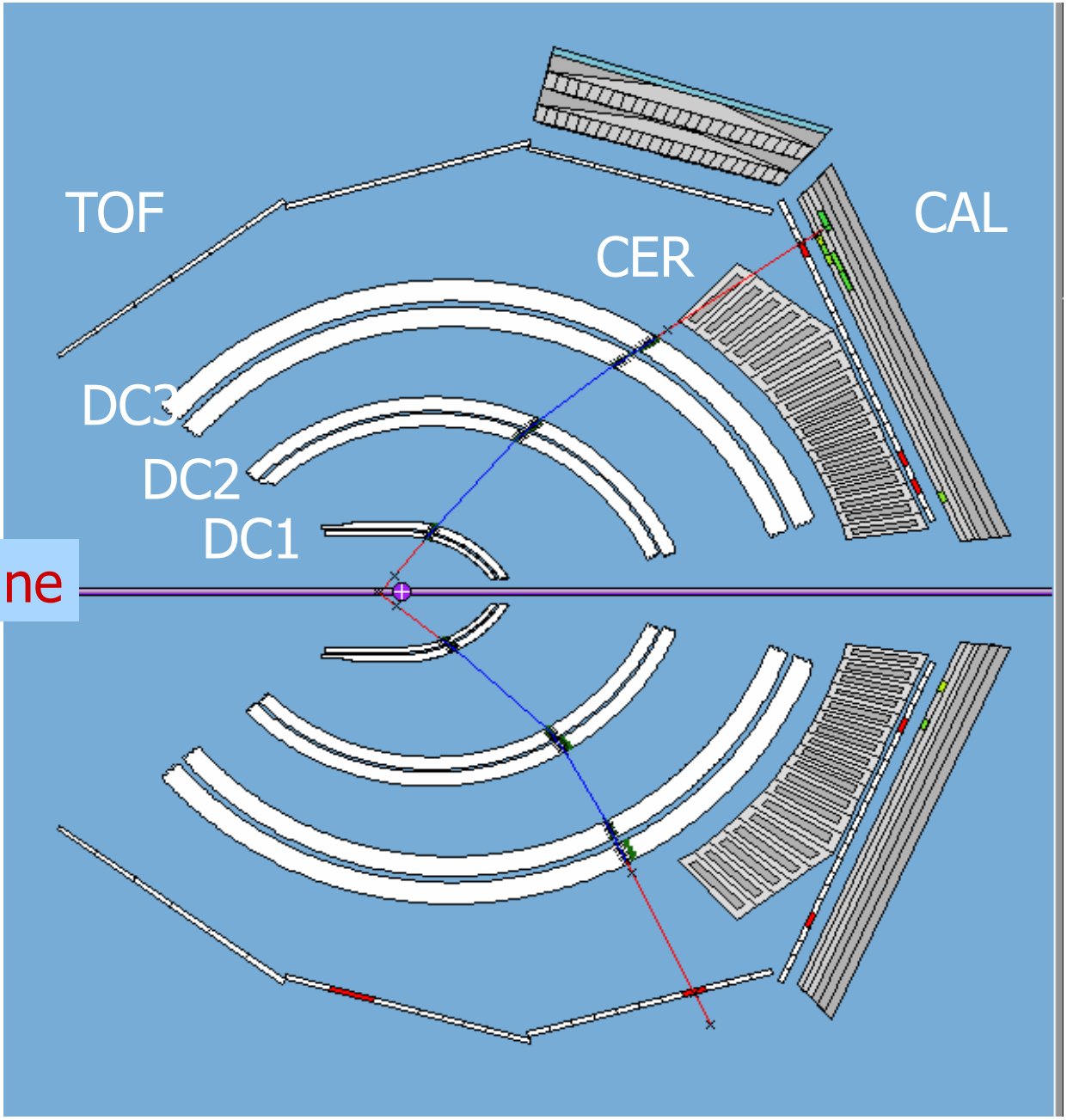
Jefferson Lab Site



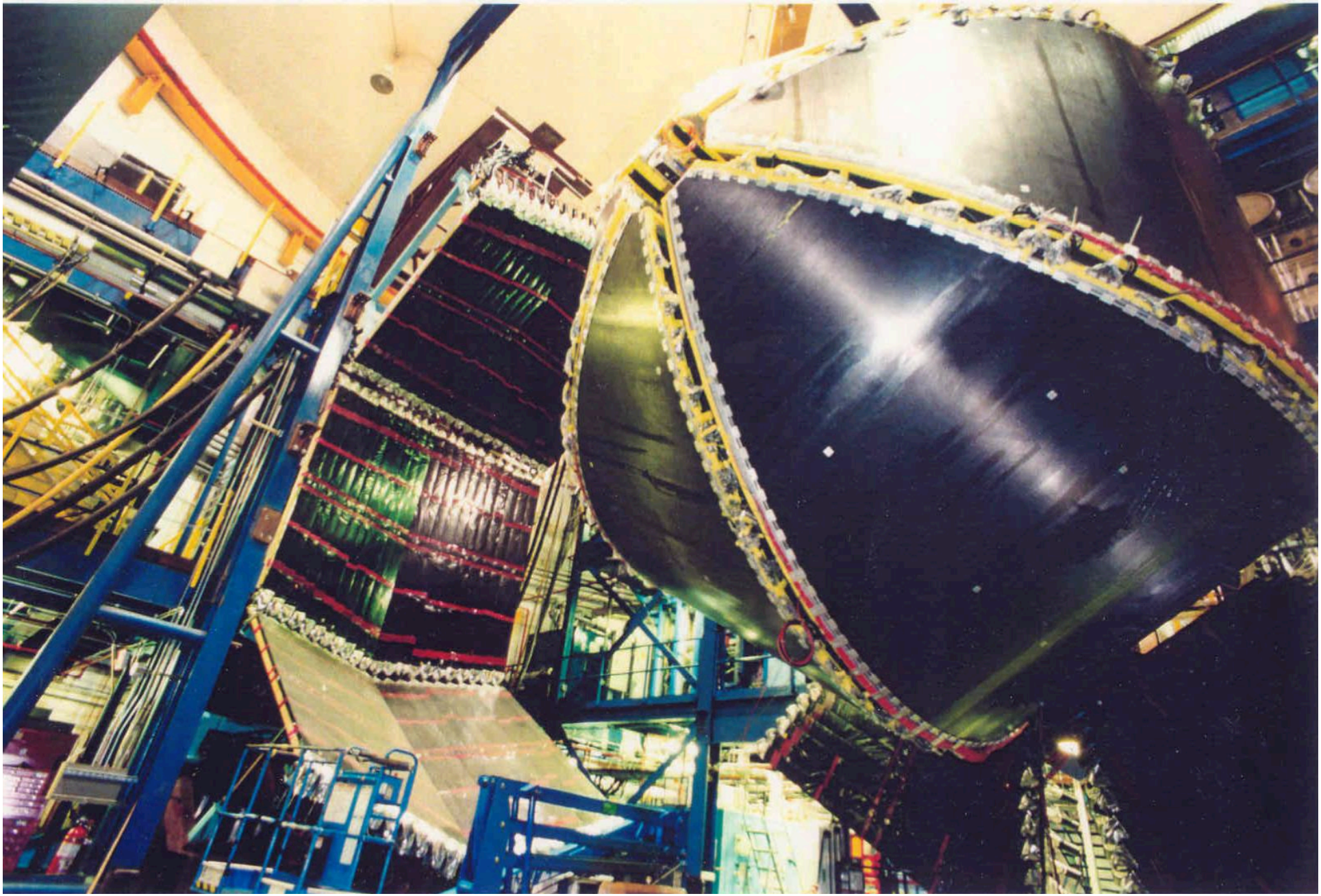

Drift Chambers
35,000 wires
σ_R = 350 μm
Superconducting Toroidal Magnet
$\int$Bdl ≅ 1.7 T-m
Cerenkov Counters
216 channels
99.5% efficient
over 50 m^2 area
electron beam direction
Time of Flight Counters
500+ channels, 145 ps resolution
Electromagnetic Shower Calorimeters
1700+ channels
$\sigma/E = 10\%/E^{0.5}$

CLAS Event Display

Sectors 1 and 4



CLAS in Maintenance Position



Data Sets with inclusive triggers

Run Period	Beam	Energy (GeV)	Targets
E2a	e	2.2, 4.4	^{3}He, ^{4}He, C, Fe
E2b	e	1.1, 4.5, 4.7	^{3}He, Fe
EG2	e	4.0, 4.7, 5.0	^{2}H and (C, Al, Fe, ^{120}Sn, or Pb)
G8	gamma	<3.1, <4.0	^{2}H, C, Ti, Fe, Pb
E6	e	5.77	^{2}H
EG1a,b	e	1.6 to 5.7	Polarized NH_3, ND_3, C
E5	e	2.56, 4.23	^{1}H and ^{2}H
E1e	e	2.04	^{2}H
EG3	gamma	<5.76	^{2}H
E8 (BoNuS)	e	1.1, 2.2, 4.3, 5.4	^{1}H, ^{2}H, ^{4}He

Topics to investigate

- NN Short Range Correlations with A(e,e'pN)
  - A and Q^2 dependence
  - np vs pp
  - Compare NN forward/forward (x>1) and forward/backward (x<1) events
  - Compare real and virtual photons
    - eg: $\gamma n \rightarrow p\pi^-$ plus a backward proton
- Deuteron d(e,e'p)n
  - unpolarized
  - Beam spin asymmetry (A'_{LT}) $d(\vec{e},e'p)n$
  - Beam and target spin asymmetry $\vec{d}(\vec{e},e'p)n$
- Deuteron d(e,e'p)X
  - DIS and EMC

More Topics

- Delta production
  - Backward emitted Deltas
    - Backward hyperons?
  - Forward Delta++ at x > 1
  - Delta production on Quasifree neutron in ^{3}He
- Color Transparency
  - Deuteron transverse kinematics
    - Compare pn and pDelta^0 final states
  - $\pi^+\pi^-$ vs ρ production in nuclei
  - S_{11} production in nuclei
- Your idea here!

Project Outline

- Collect **all** CLAS nuclear target data in one place with **one** interface
- Provide **easy** access to this data set to participating universities.
- Provide **universal** analysis tools for all data sets (data selection, momentum corrections, fiducial cuts).
- Provide easy framework for combining data from different data sets.
- Provide SOA based multi-process analysis.

Analysis Framework

- Same analysis framework for all data sets with Corrections, Fiducial Cuts and Event Constructor modules loaded automatically based on the run info loaded from the file.
- Parallel processing
- The output can be any of these:
  - Event Stream
  - Ntuples
  - Histograms
- Other analysis tools can be deployed to the server, requires a little advanced programming.

Software Progress

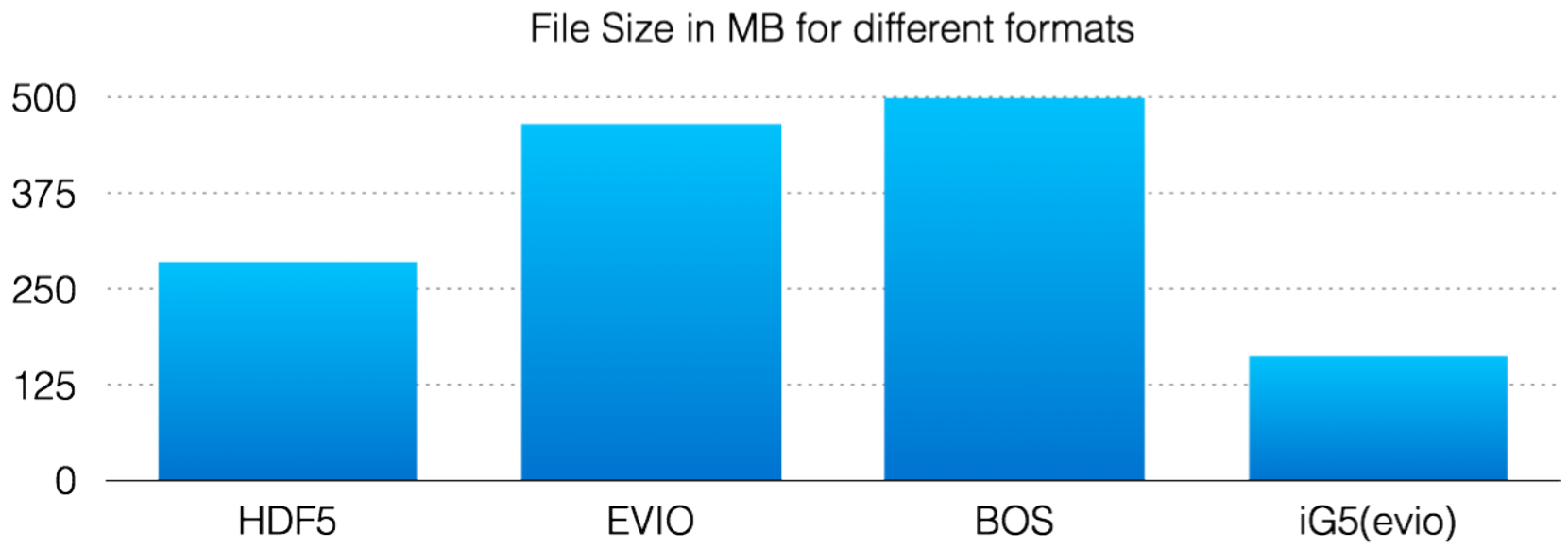
G.Gavalian (ODU)

Software progress

- **Current Status:**
  - CLARA was developed to meet the needs of data mining project.
  - Parallel data processing is now available on ODU farms for data skimming.
  - The software project was translated to JAVA and requires no compilation to run skimming and do analysis (using Jython).
  - ROOT interface
    - convert skimmed files to ROOT tree for further analysis,
    - example analysis routines included in the package.
- **Recent development:**
  - Implemented IG5 data format in JAVA, with built in compression (GZ) to reduce data size.
  - Implementing a Graphical User Interface for accessing the data.
  - Cataloging existing data sets.
  - Implementing GUI for data viewing and analysis in JAVA.
  - Tools were developed for Jython scripting for quick analysis and plotting with JAIDA.

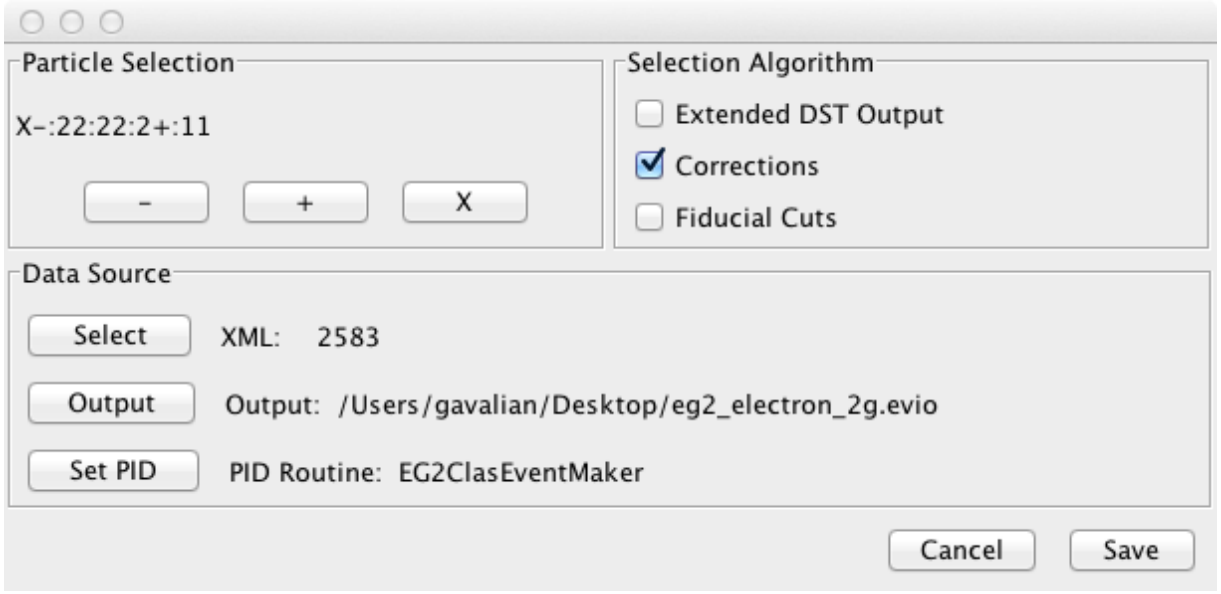
Data Formats

- The experimental data is stored in BOS format at 500 MB per file.
- The EVIO container used to store the data
  - native JAVA interface,
  - allows analysis and skimming of the data using JAVA CLARA Services.
- Native EVIO interface unacceptable due to data file size
- EVIO/IG5 data format uses compression to reduce data file size 145 MB.



Data Access Interface

- Data access interface is extended to allow more flexibility in analysis.
- Users can select a Run-Specific data analyzer
- Can select experiment-specific corrections (vertex, momentum) and cuts (fiducial cuts, vertex cuts)
- Advanced options for final state selection.
  - Particle selection
  - Run list
  - Analysis Services:
    - BasicAnalysis
    - EG2Analysis
    - E2Analysis



Data Output Interface

- Output data options:
  - simple - includes particle momentum and vertex with CLAS default particle ID and experiment specific PID.
  - extended - includes data from all detectors, for each particle.

```
pid - particle LUND id (experiment specific)
sebpid - particle LUND id assigned by SEB in case it differs from run specific particle ids
charge - particle charge (determined by DC)
status - number of detectors the particle hit
px - x-component of particle momenta
py - y-component of particle momenta
pz - z-component of particle momenta
vx - x-component of particle vertex
vy - y-component of particle vertex
vz - z-component of particle vertex
sctime - time from SC counters (corrected by event start time)
scpath - path length of the particle from vertex to  SC counters
scpaddle - the paddle in the SC that was hit
ccnphe - the number of photoelectrons produced in the Cherenkov Detector
ectime - time for EC (corrected by start time)
ecpath - particle path length from vertex to EC
ecin - energy deposited in the Inner EC
ecout - energy deposited in Outer EC
ectot - total EC energy for the particle
ecu - U coordinate for EC hit
ecv - V coordinate for EC hit
ecw - W coordinate for EC hit
```

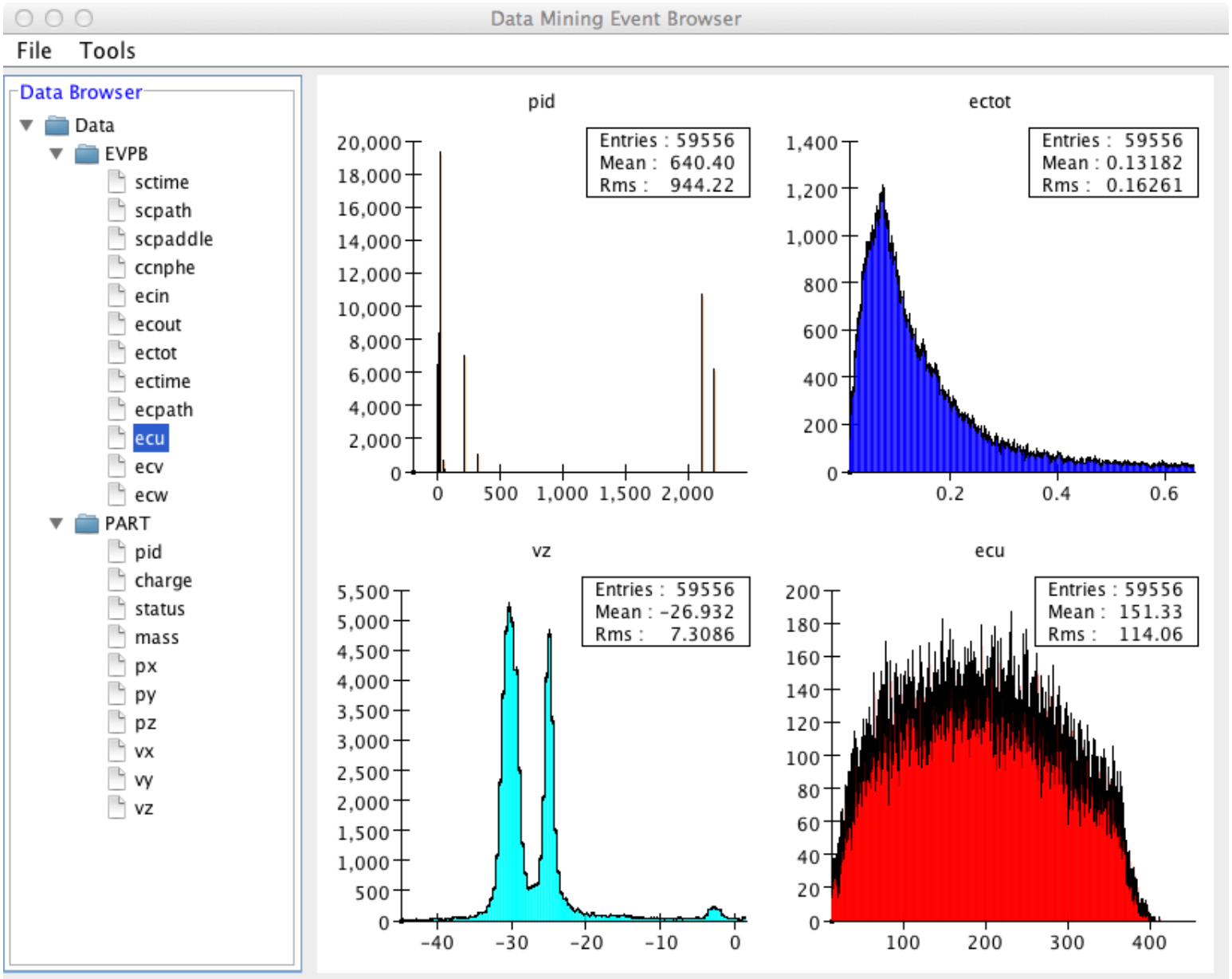
Particle Selection

- CLAS default (SEB) or experiment specific particle ID.
- New particle selection filter addresses all possible inclusive and exclusive selections.

```
X+ : any number of positive particles (includes 0)
X- : any number of negative particles (includes 0)
Xn : any number of neutral particles (including 0)
```

- Inclusive flags can be combined with particle IDs to make semi-inclusive selections:
- To specify a definite number of particles with particular charge a number instead of "X" can be used ("2-", "1+" or "3n")
  - `(11:2212:2n:1-)` one electron and one proton, two neutral particles and one additional negative particle.
  - `(11:211:2n:X+)` one electron and one pion, two neutral particles and any number of additional positive particles.
  - `(11:X+:2n:1-)` one electron, at least two neutral particles, one additional negative particle and any number of positive particles.

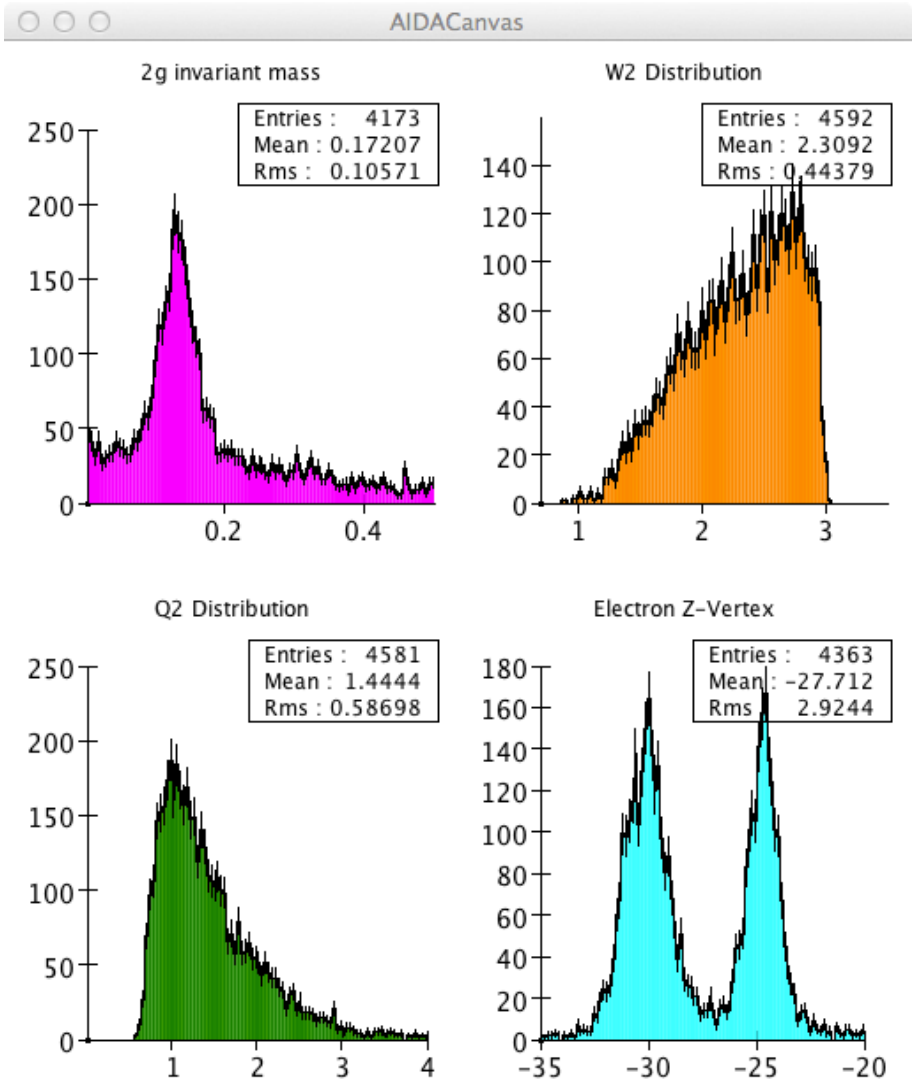
Data Browser (simple viewing)



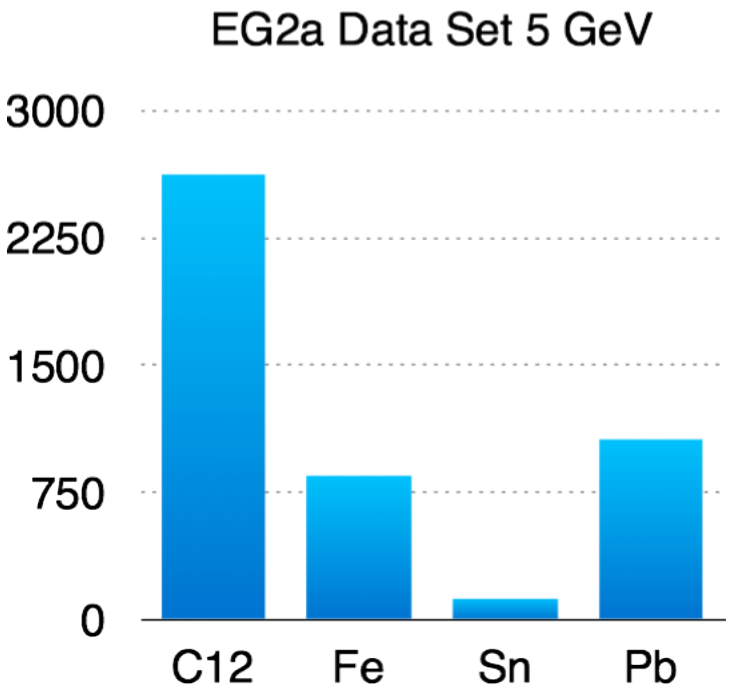
Data Analysis with Jython

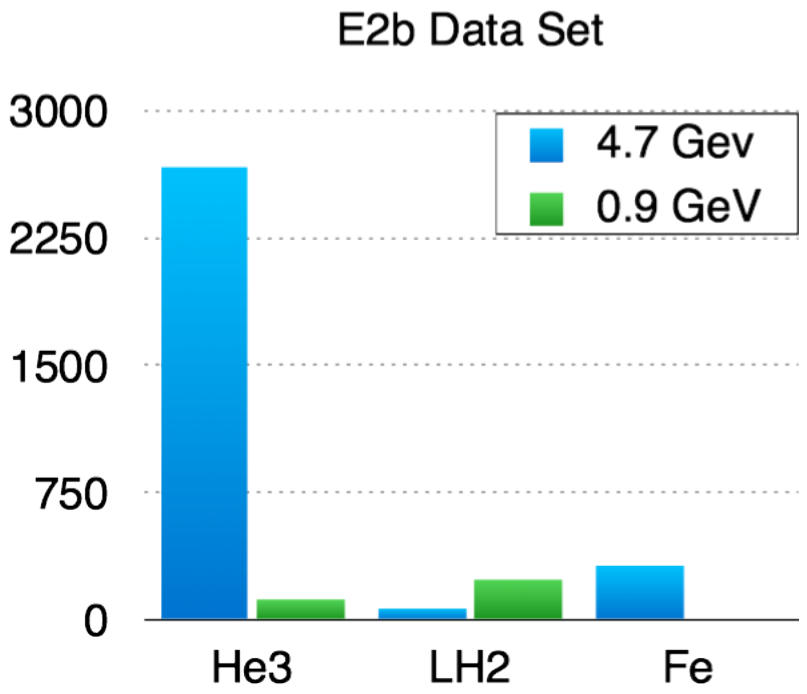
```
cana =
ClasAnalysis()cana.addFile(eviofilename)cana.init()

while(cana.next()):    iCounter = iCounter+1
cana.getEvent(event)    pi0 =
oper.getParticle(event,'[22,0]+[22,1]')    pQ2 =
oper.getParticle(event,'[b]-[11,0]')    pW2 =
oper.getParticle(event,'[b]+[t]-[11,0]')    pEp =
oper.getParticle(event,'[11,0]')
histPi0.fill(pi0.vector().mass())    histQ2.fill(-
pQ2.vector().mass2())
histW2.fill(pW2.vector().mass())
histV.fill(pEp.vertex().z())
```

```
# Simple Plotting
canvas =
AIDACanvas(500,500)canvas.setVisible(True)c
anvas.divide(2,2)canvas.draw(histPi0,0)canva
s.draw(histQ2,1)canvas.draw(histW2,2)canvas
.draw(histV,3)
```



Available Data & Analysis





- **Data Processing:**
  - Simple event selection (particle ID based on SEB).
  - EG2 Run specific Particle ID, vertex and momentum corrections and fiducial cuts.
  - E2B Run specific particle ID, cuts and corrections (work in progress).

Software Status

- Current version of Data Mining Software (3.0) is up and running on ODU servers.
- The data is being converted into EVIO/iG5 format and cataloged.
- GUI interface is implemented for easy analysis mode selection.
- New particle final state filters are implemented for flexible selection.
- Data processing for different run groups are implemented.
- Tools for simulation and Jython analysis are being developed.

To Do:

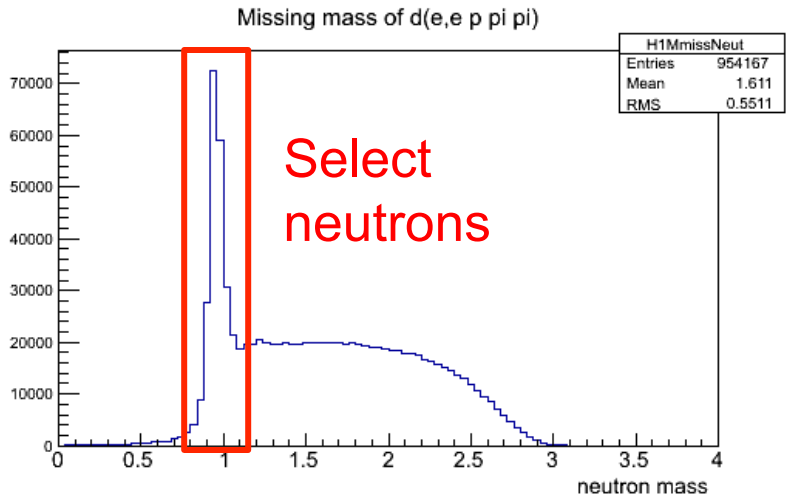
- Complete E2b Run specific analysis implementation.
- Transition to CLARA 2.0 version, which allows multi-computer process distribution (analysis will significantly speed up).
- Complete converting E6 data set for Data Mining.
- Convert E2a data into EVIO format and implement cuts and corrections.

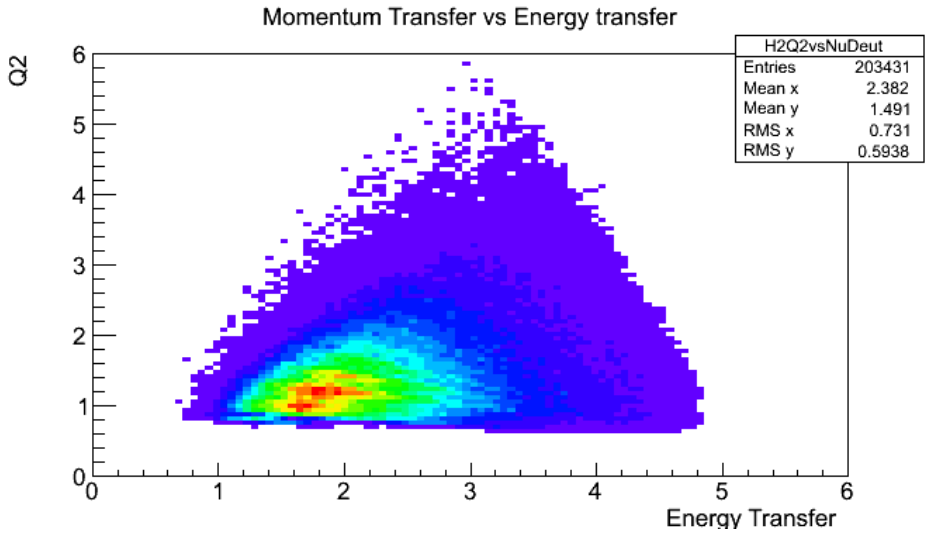
Data Mining Analyses, Feb 2013

- SRC Proton Transparency: Or Hen (Tel Aviv), submitted to journal
- Mean Field Proton Transparency: Or Hen (Tel Aviv), under analysis review
- *pp* SRC pair cm-momentum distribution, Or Hen, under analysis review
  - See talks today and tomorrow
- Double Spin asymmetry in $d(e,e'p)n$, Mike Mayer (ODU), analysis note about to be submitted
- Many proton knockout from nuclei to explore the potential to reach *r*-process path below 208Pb, Dan Watts (Edinburgh)
- backward Deltas in deuterium, Chris Wooten (ODU senior thesis)
- 3He(*e,e'pn*)*p*, Uttar Pudaisini (ODU)
- *p*- and *n*- single nucleon momentum distributions in asymmetric nuclei, Tel Aviv
- EMC and SRC: Barak Schmookler and Longwu Ou (MIT)

Deuterium Delta-Delta hunting

Eg2 data set: select p, pi+, pi- events. Cut on *d* target



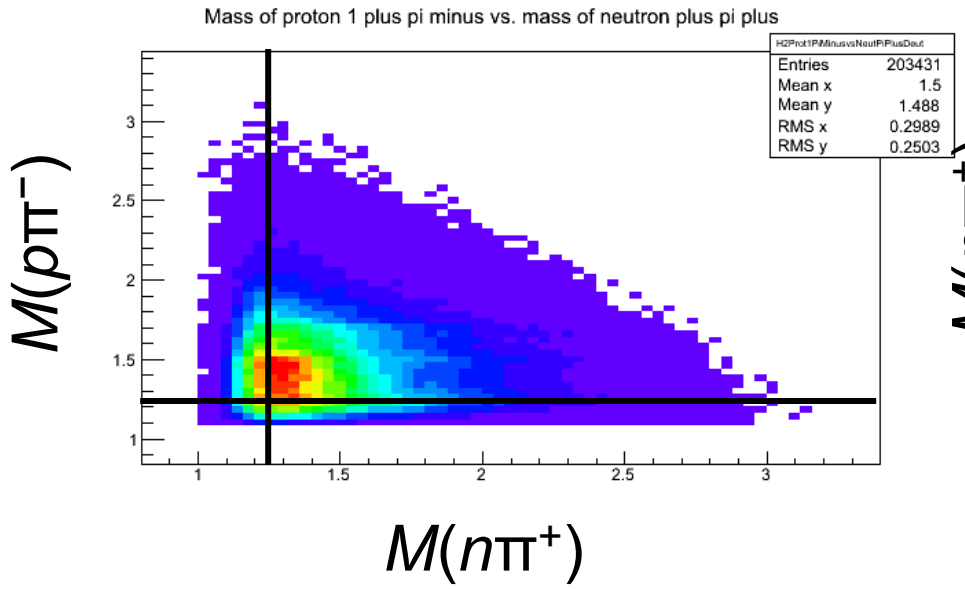


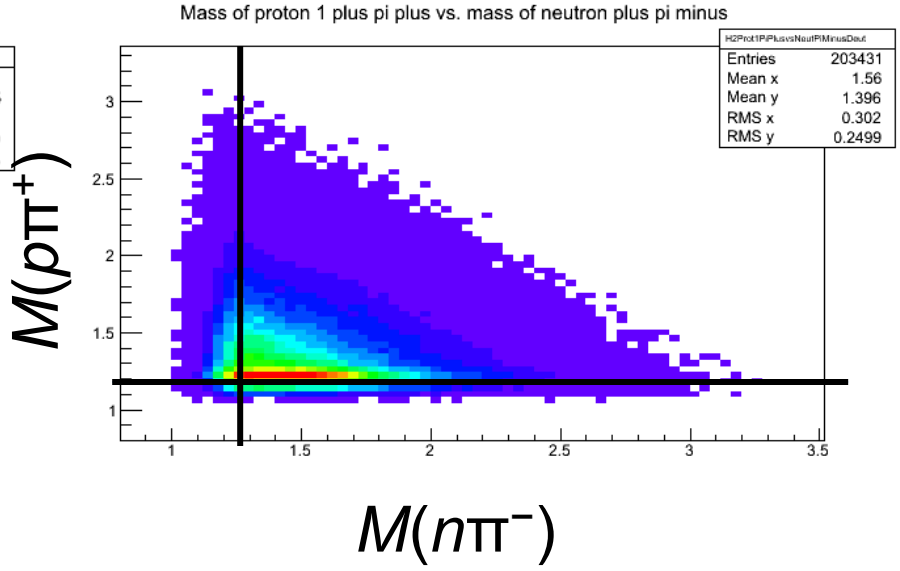
$d(e,e'p\pi^-\pi^+)n$
200,000 events
No fiducial cuts, CLAS default PID

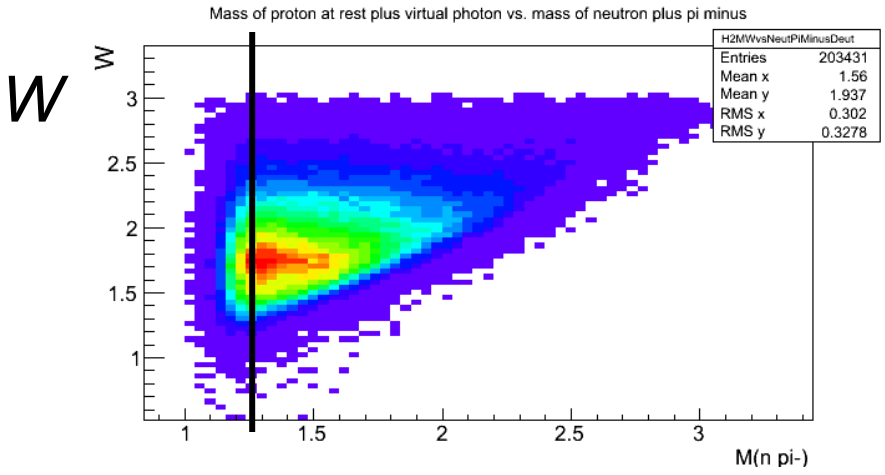
Wide range of energy and momentum transfer

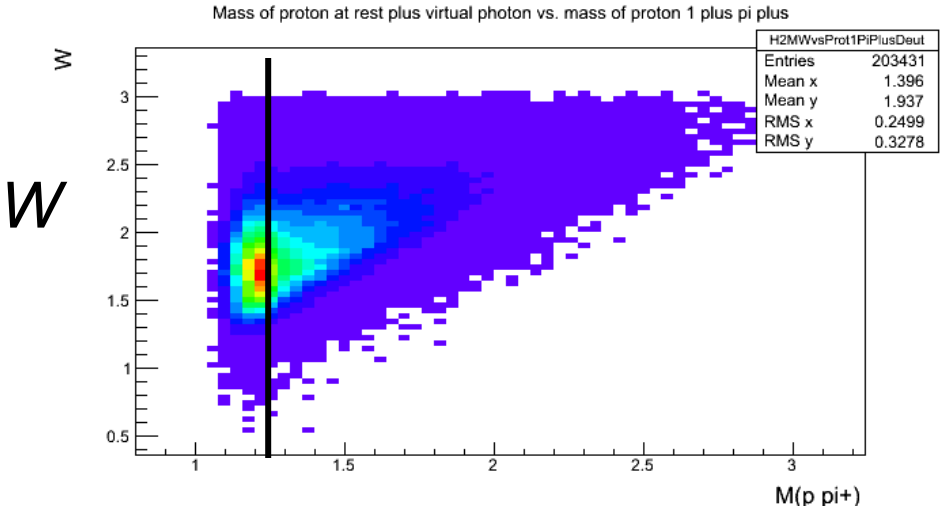
Note: *p* threshold 300 MeV/c precludes spectator deltas in the $d(e,e'pp\pi^-)\pi^0$ channel

Now look for Deltas:





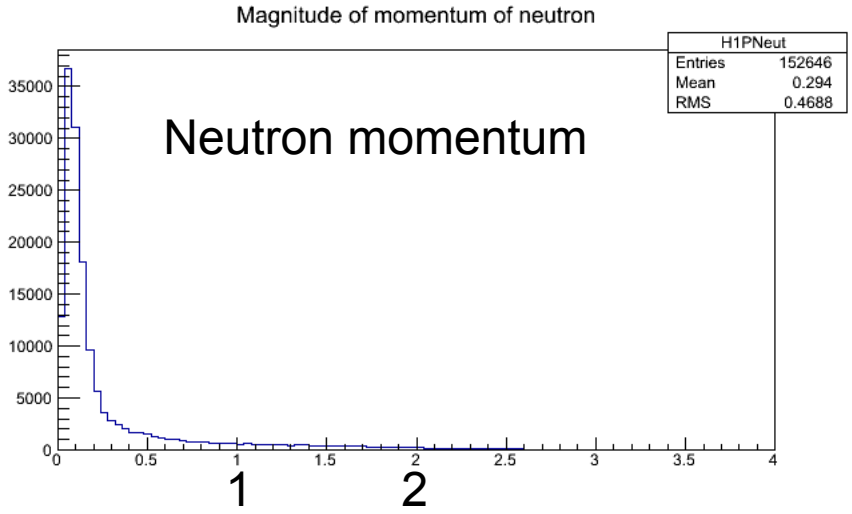




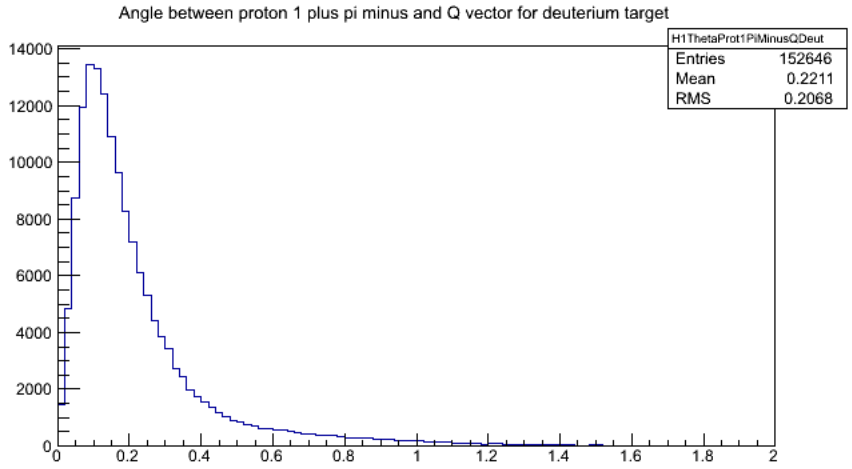
I think we found one …

Cut on W>1.7 GeV

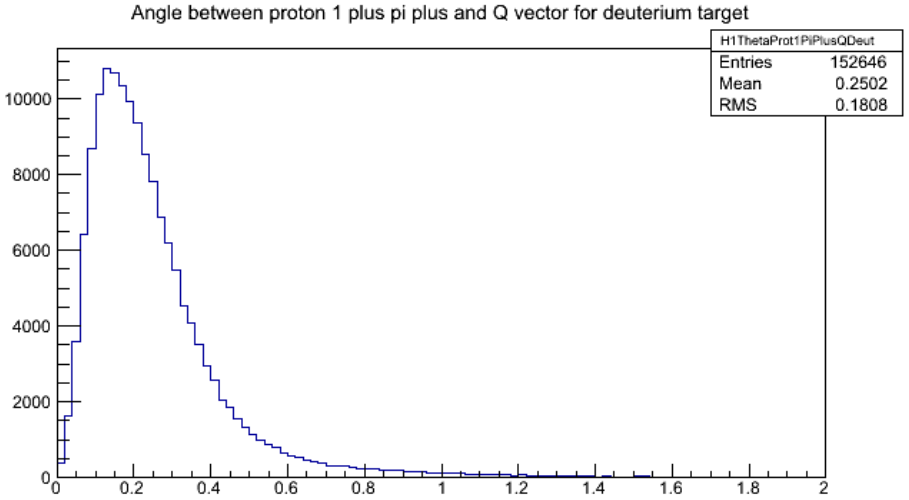
If W too low, then all *N*π combinations will have a mass near the Delta (i.e. near threshold)



$p\pi^-$ more likely to be the struck Delta than $p\pi^+$??



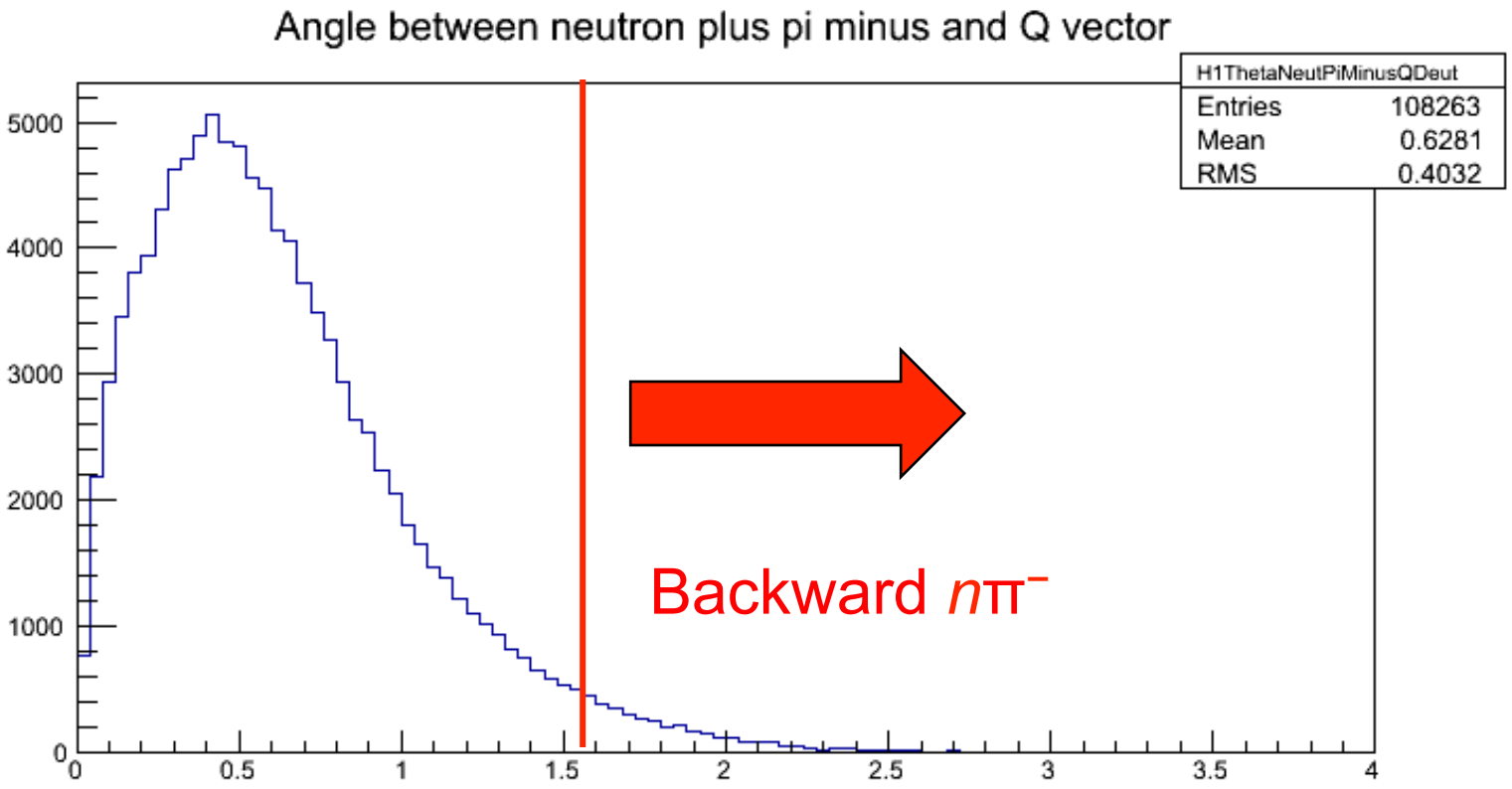
Theta(q_$p\pi^-$)



Theta(q_$p\pi^+$)

Cut on pn < 0.25 GeV/c

More likely to come from spectator delta decay



But are they deltas??

Delta Delta summary

Still inconclusive

No strong evidence in either the

$d(e,e'pp\pi^-)\pi^0$ channel (shown in August)

or the $d(e,e'p\pi^-\pi^+)n$ channel

It still makes a good BS thesis

Data mining summary

- Software is almost final
- Data being added
  - Two data sets almost complete
  - Two more data sets in process
  - Cuts and corrections being implemented
- Looking for Delta-Delta events is hard
- Lots more fascinating physics to analyze
- Join us!