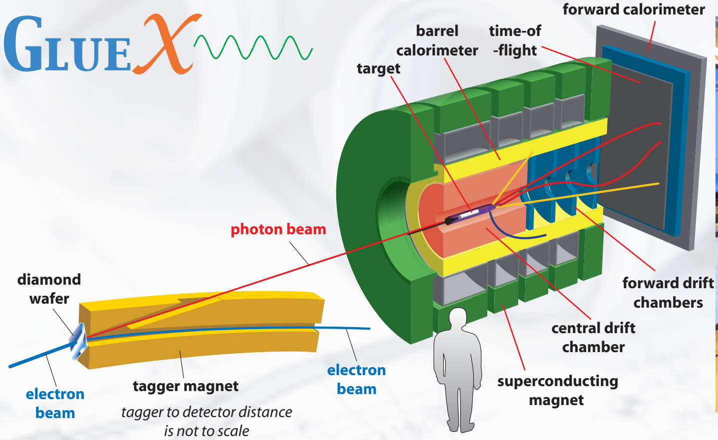
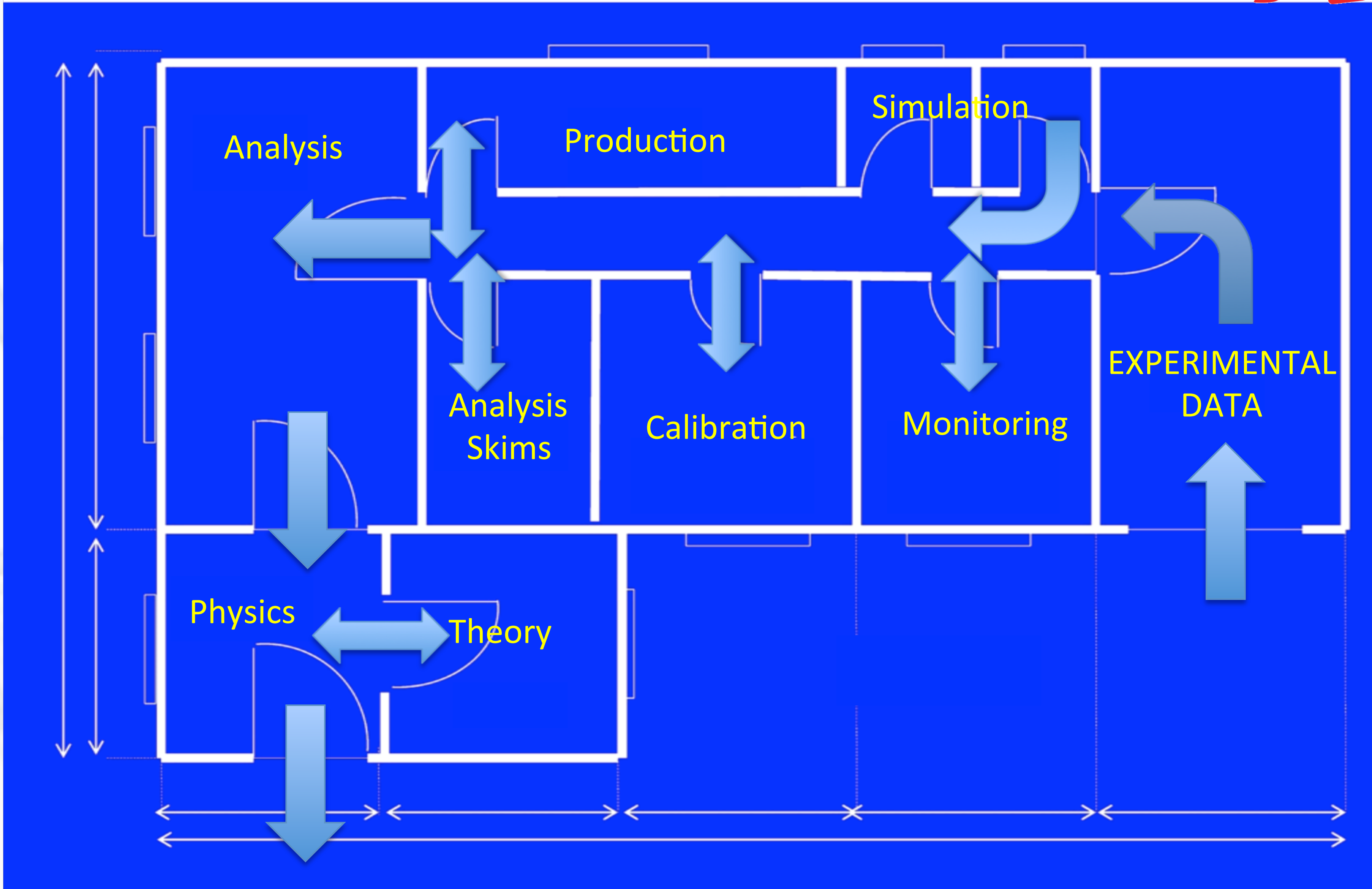
GlueX/Hall-D: A Blueprint for Physics

Curtis A. Meyer: The GlueX Collaboration



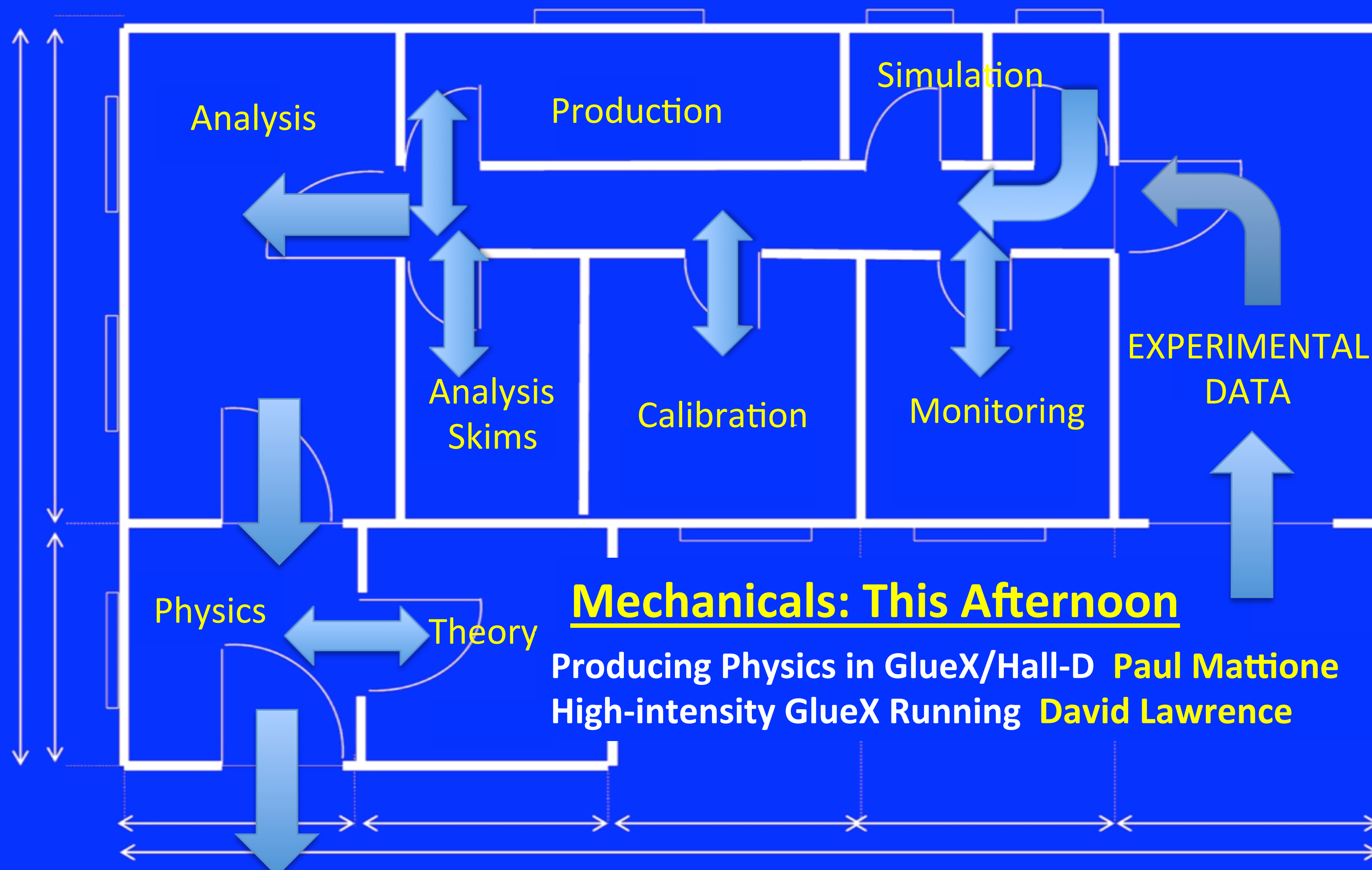
Athens University, Arizona State University, Carnegie Mellon University, Catholic University, University of Connecticut, Florida International University, Florida State University, George Washington University, University of Glasgow, G.S.I., Indiana University, Jefferson Lab, University of Massachusetts Amherst, Massachusetts Institute of Technology, MEPHI, ITEP Moscow, University of North Carolina A&T, University of North Carolina Wilmington, Northwestern, Tecnica Federico Santa Maria, University of Regina, Tomsk, William and Mary, and Yerevan.

The Plan



Analysis
Production
Simulation
Analysis Skims
Calibration
Monitoring
EXPERIMENTAL DATA
Physics
Theory

The Plan



Mechanicals: This Afternoon

Producing Physics in GlueX/Hall-D Paul Mattione

High-intensity GlueX Running David Lawrence

GlueX Running

Commissioning:

Fall 2014

Spring 2015

Engineering/Commissioning:

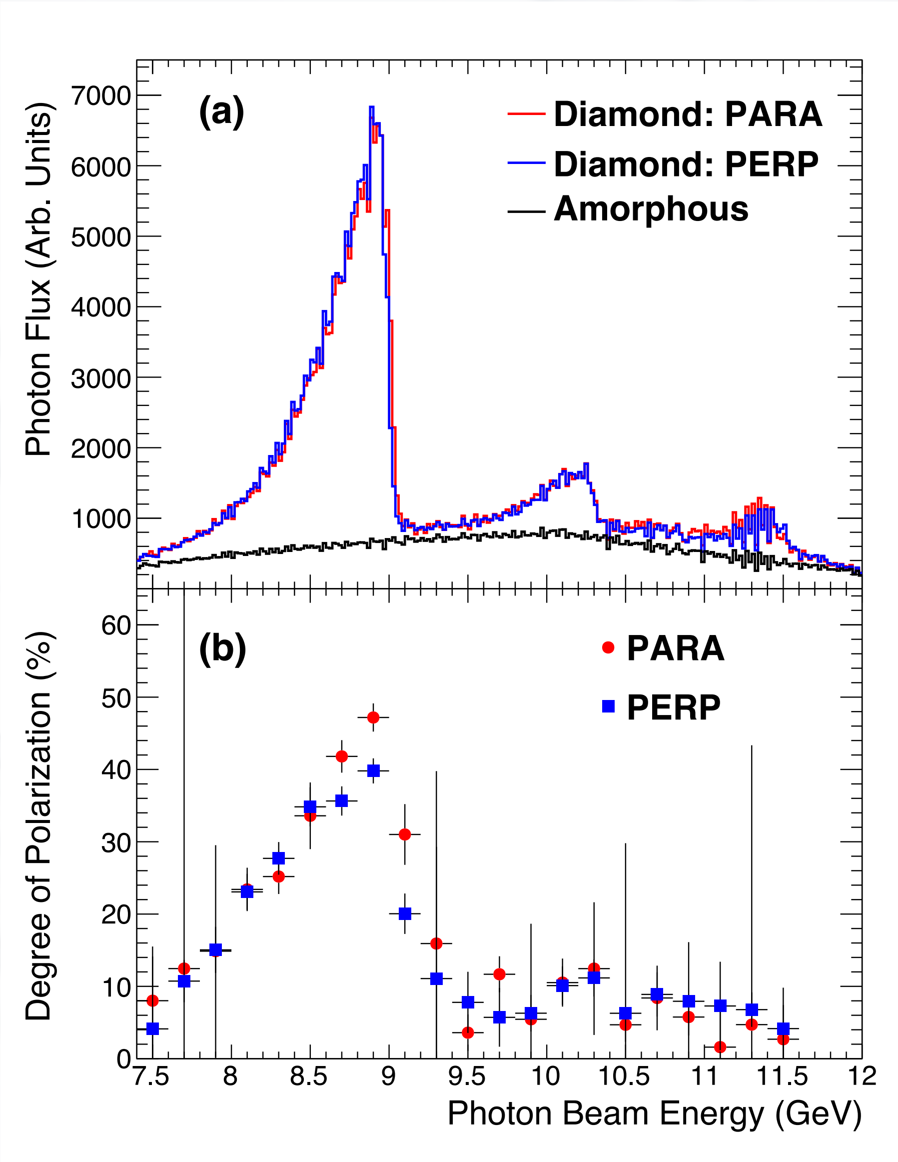
Spring 2016

Physics Running:

Fall 2016 and beyond

Run Period	Trigger Rate		Live Time	Data Rates		Data Volume	
	Average	Peak	Time	Average	Peak	Raw	REST
Fall '14	1.5kHz	3.2kHz	60%	150MB/s		150TB	
Spring'15	14kHz	30kHz	80%	300MB/s		80TB	
Spiring'16 (estimated)	28kHz	40kHz	90%	600MB/s	800MB/s	554TB	37TB
Fall'16	30kHz	80kHz	90%	800MB/s	2000MB/s	500TB	50TB

Linearly Polarized Photons



Coherent bremsstrahlung on diamond radiator. We tuned on a 9GeV photon energy for a 12GeV electron beam.

Polarization expected to be about 40% in the coherent peak.

Measured using the triplet polarimeter.

Can reliably produce linearly polarized photons for physics.

Monitoring: Quality Assurance

Monitor Software:
nightly builds, regular archived jobs, performance checks & valgrind.

Monitor Data from DAQ:
Automated jobs run over data in counting house. Shift crew monitors plots.

Monitor Prior to Production:
Periodic monitoring launches to check software performance and tune production launches.

Monitor Data in CC:
Automated jobs look at the first 5 files of each run. Outputs available from web interface. Discuss at daily run meeting.

Archive all monitoring output to allow back checking

Calibrations

Databases:
Run Conditions DB
Calibration & Conditions DB
Geometry: HDDS

Geometrical Alignments:
Internal Chamber Alignment
Inter-detector Alignments

Automated Calibrations:
Evolved procedures that run on data as it is collected and output to CCDB. Most procedures will eventually be here.

Data-intensive Calibrations
Calorimeter π^0 calibration
Alignment monitoring
…

Our goal is to be able to start production 2-3 weeks after a run starts. Expect to exercise this with a fraction of the data in Fall '16.

Simulations

Event Generator

Many available, work with theory/JPAC

HDGEANT Simulation
Geant3 and Geant4

Multithreaded GEANT4 is complete, in beta-release.

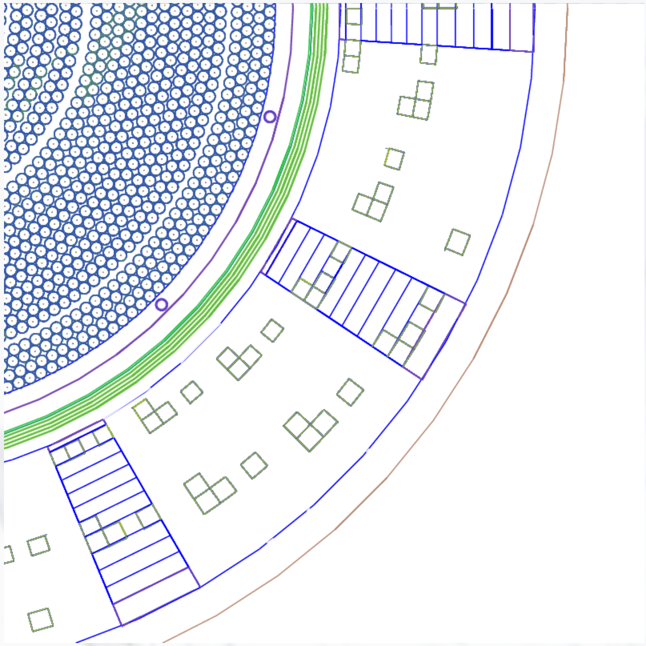
MCSmear
Implement resolution and efficiencies

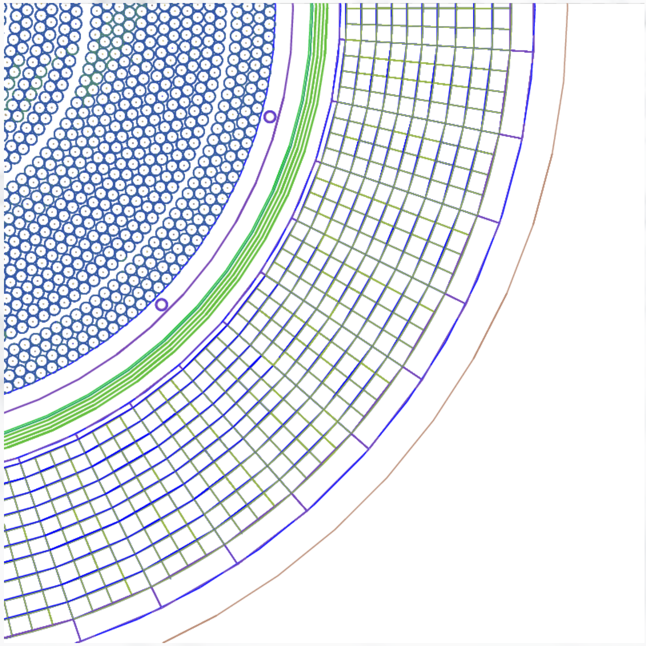
Produce "signals". Tune simulation to match the detector. Efficiencies, dead channels, etc. …

Produce REST Files
Process data and only retain REST files

Same code as for data. Do not retain large intermediate files.

HDGEANT4



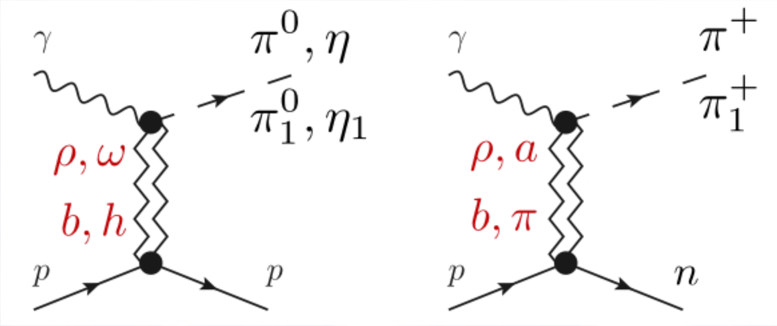


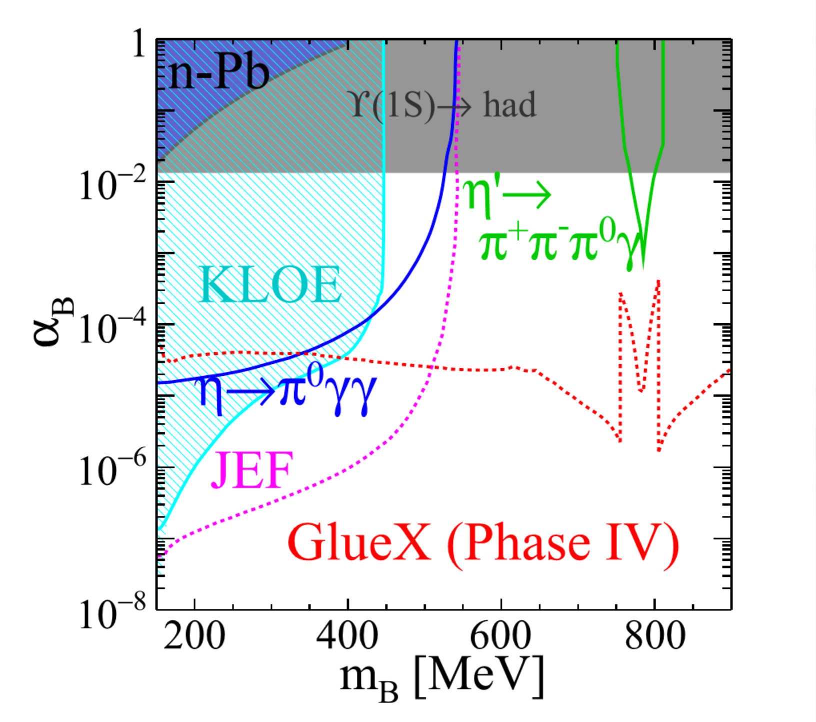
- GEANT3 is our only code that does not run multithreaded, GEANT4 needs to.
- Requires version 4.10 which has bugs. Need to work with developers (slow).
- Have a patched release that has full detector geometry and some hit packages. Others being developed.
- Matches GEANT3 output and scales with threads.

- Detector matching (mcsmear) is common for all versions of GEANT.

Promoting Physics Analysis in GlueX

- **Analysis Workshop:** update learning tools to allow new people to rapidly come up to speed with analysis
- **Produce the Data ASAP:** promote excitement for doing physics.
- **Encourage Collaboration:** Analysis WG to push for physics.
- **Set Milestones for Early Results:** Fall DNP meeting, publication(s).





Analysis Organization

Collaboration Management

Physics Working Group

Analysis Working Group

Calibration Working Group

Offline Working Group

Organize, monitor and vet physics analyses and results.

Coordinate activities to understand the data and run production and analysis trains.

Coordinate calibration activities from detector groups and vet readiness of databases for analysis.

Coordinate software improvements and organize releases....

Fall 2016 DNP Meeting

GlueX was able to arrange an mini-symposium: an invited overview talk and as many contributed talks as you want. Our session spanned three time slots over two days.

Run ends on 4/25, DNP starts 10/13

1. Overview GlueX talk
2. Photoproduction of ρ
3. Beam Asymmetries π^0, η
4. Photoproduction of $\pi\pi$
5. η' Decays
6. Multi-photon final states
7. Photoproduction of ω
8. Transition form factor for η'
9. Lepto-phobic Boson Search
10. Photoproduction of J/ψ
11. K_L Facility
12. GlueX Photon Source

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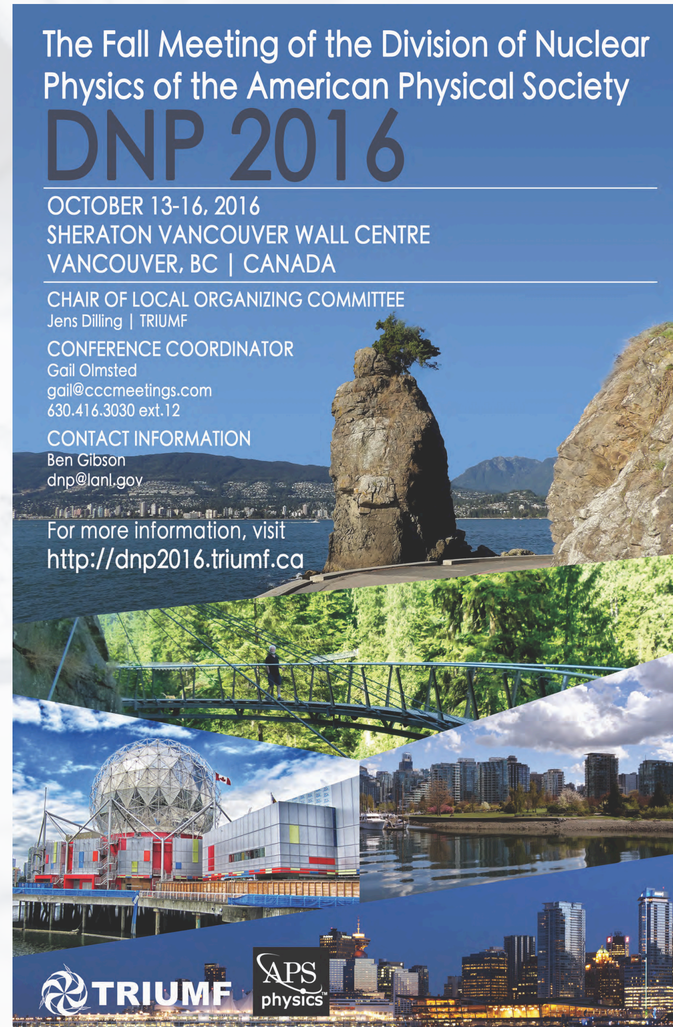


Physics being Pursued in GlueX

An incomplete list of reactions selected from the Analysis Skims performed by the collaboration.

$\gamma p \rightarrow p\pi^0$

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

$\gamma p \rightarrow p\eta$

$\gamma p \rightarrow p\rho^0$

$\gamma p \rightarrow p\omega$

$\gamma p \rightarrow p\phi$

$\gamma p \rightarrow \Lambda K^+$

$\gamma p \rightarrow \Sigma^0 K^+$

$\gamma p \rightarrow \Sigma^+ k^0$

$\gamma p \rightarrow p\pi^0\pi^0$

$\gamma p \rightarrow p\eta\eta$

$\gamma p \rightarrow p\eta'\eta$

$\gamma p \rightarrow p\pi^0\omega$

$\gamma p \rightarrow p\eta\phi$

$\gamma p \rightarrow pK^0K^0$

$\gamma p \rightarrow pK\bar{K}$

$\gamma p \rightarrow pp\bar{p}$

$\gamma p \rightarrow pJ/\psi$

$\gamma p \rightarrow \Lambda K^0\pi^+$

$\gamma p \rightarrow \Lambda K^+\pi^0$

$\gamma p \rightarrow \Sigma^0 K^0\pi^+$

$\gamma p \rightarrow \Sigma^0 K^+\pi^0$

$\gamma p \rightarrow \Sigma^+ K^0\pi^0$

$\gamma p \rightarrow \Sigma^+ K^\pm\pi^\mp$

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

$\gamma p \rightarrow pK\bar{K}\pi^0$

$\gamma p \rightarrow pK^0K^-\pi^+$

$\gamma p \rightarrow \Xi KK\pi^0$

$\gamma p \rightarrow \Lambda(KKK)^+$

$\gamma p \rightarrow \Lambda K^0\pi\pi$

$\gamma p \rightarrow \Lambda K\pi\pi$

$\gamma p \rightarrow \Sigma^0 K\pi\pi$

$\gamma p \rightarrow \Xi K^+K^0\pi$

$\gamma p \rightarrow p\pi^+\pi^-\pi^0\pi^0$

$\gamma p \rightarrow p\pi^+\pi^-\pi^+\pi^-$

$\gamma p \rightarrow p\gamma\gamma\gamma\gamma$

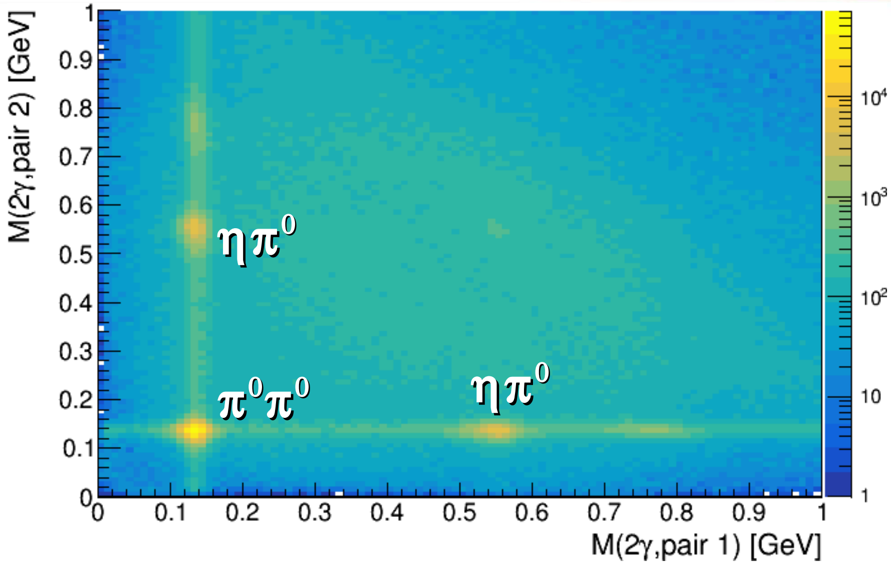
$\gamma p \rightarrow pK^+K^-\pi^+\pi^-$

Multi-photon Final States in GlueX

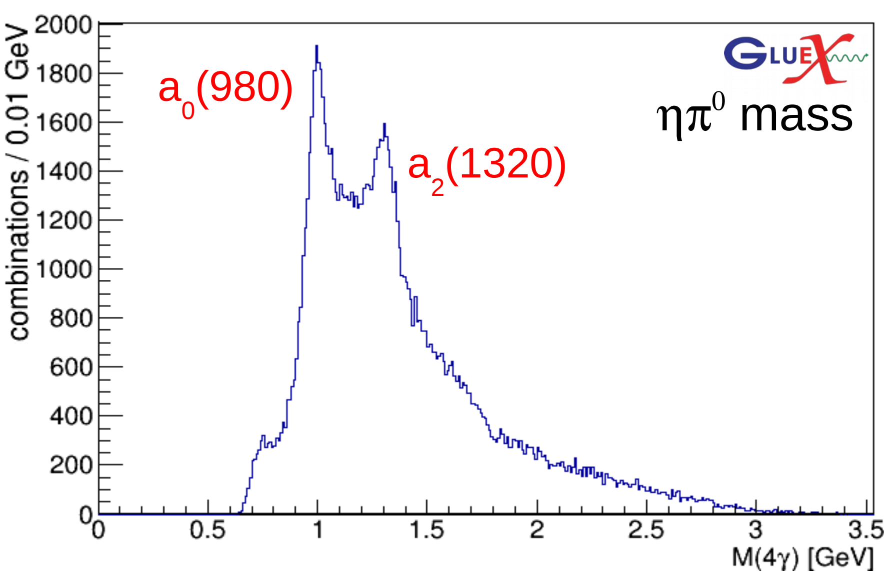
$$\gamma p \to p\gamma\gamma\gamma\gamma$$

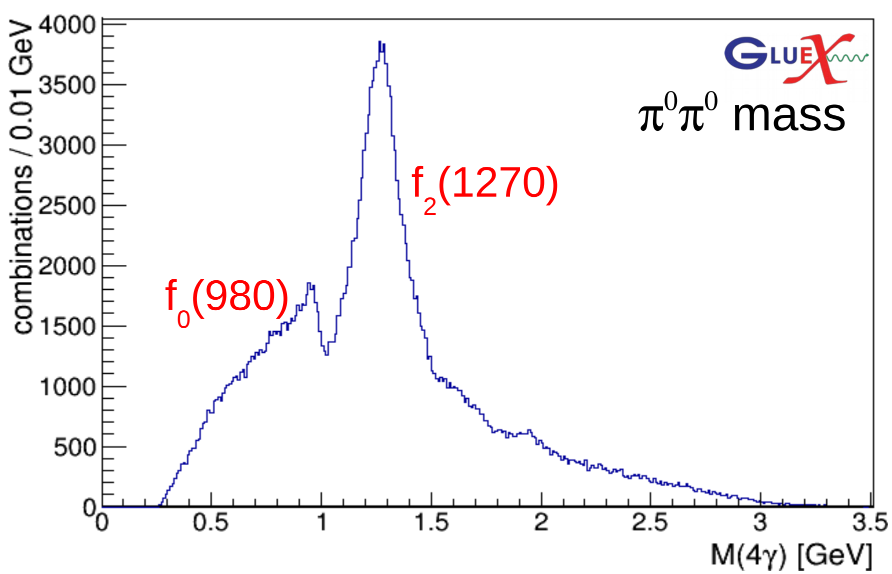
$$\gamma p \to p\pi^0\pi^0$$

$$\gamma p \to p\pi^0\eta$$



Rich resonant structure is visible in GlueX data.





Photoproduction of the ω meson

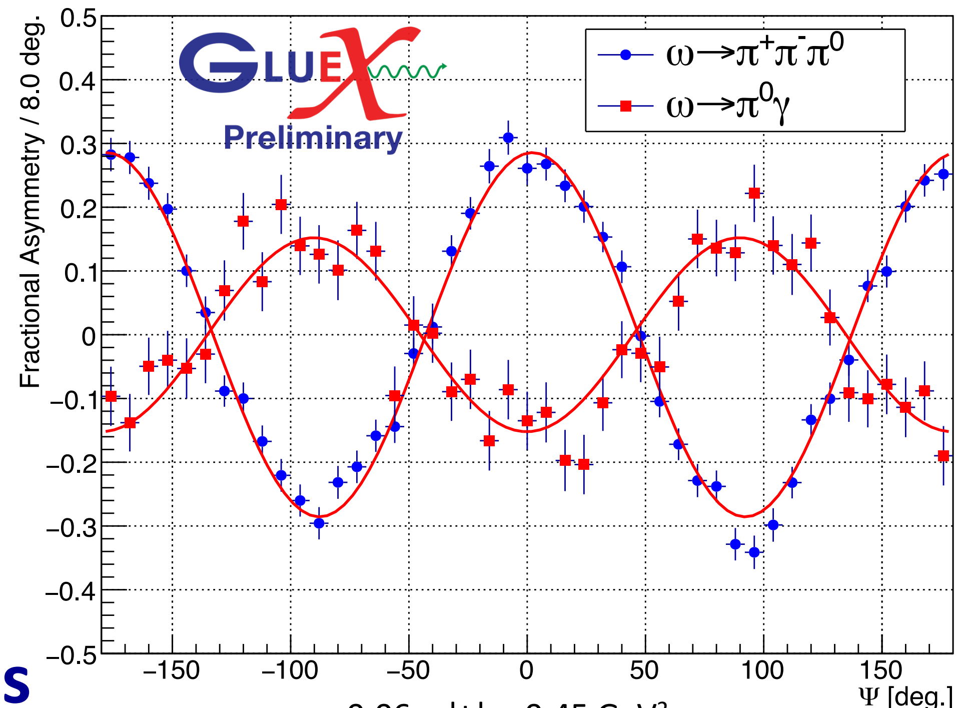
Fractional Asymmetry – Both decays

<u>Prediction</u>

$$\Sigma_d^h / \Sigma_d^r = -2$$

<u>Measurement</u>

$$\Sigma_d^h / \Sigma_d^r = -1.88 \pm 0.13$$



$0.06 < |t| < 0.45$ GeV^2

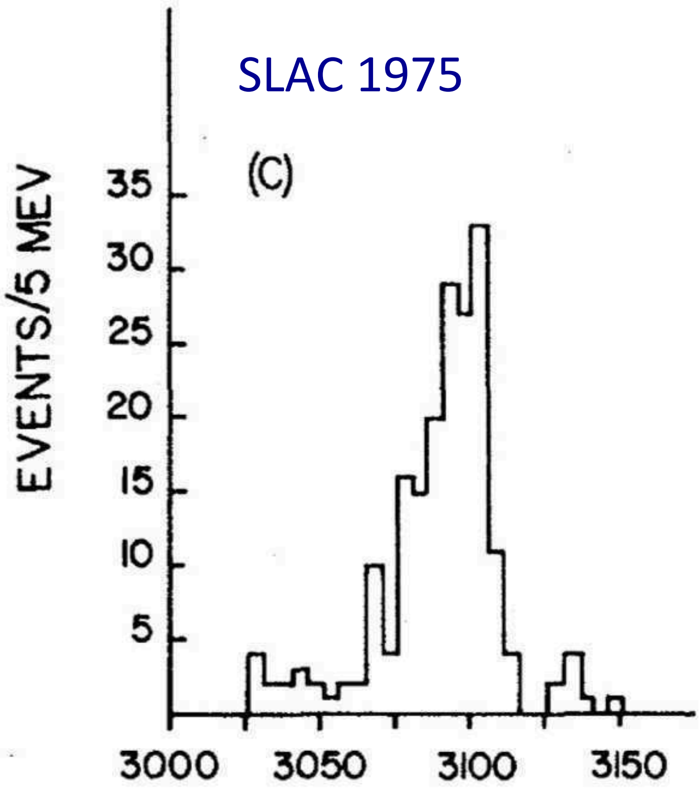
Statistical errors only

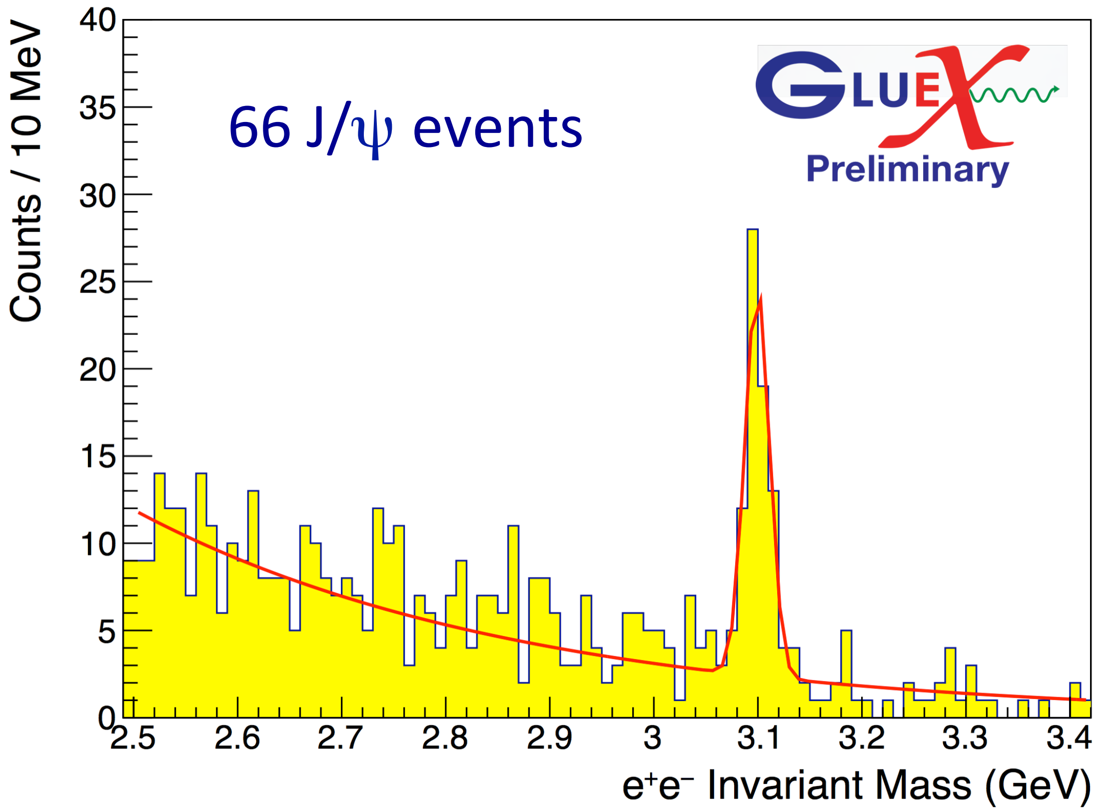
Goal is spin observables

Carnegie Mellon University 10

Photoproduction of J/ψ

Exclusive reaction: $\gamma p \to pJ/\psi \to pe^+e^-$





Identify both electrons using E/p in calorimeters

First GlueX Publication

GLUEX

Collaboration has a vision that early physics results are important and benefit everyone.

Identify a large cross section scientifically-important results.

Results should be not require full understanding of detector acceptance or beam normalization.

Develop analysis procedures before start of running. And track the results by sampling data during running.

Measurement of the beam asymmetry Σ for π^0 and η photoproduction on the proton at $E_\gamma = 9$ GeV

(GLUEX Collaboration)

(Dated: October 28, 2016)

We report measurements of the photon beam asymmetry Σ for the reactions $\vec{\gamma}p \to \pi^0 p$ and $\vec{\gamma}p \to \eta p$ from the GLUEX experiment using the 9 GeV linearly-polarized, tagged photon beam incident on a liquid hydrogen target in Jefferson Lab's Hall D. The asymmetries, measured as a function of the proton momentum transfer, posses greater precision than previous π^0 measurements, and are the first η measurements in this energy regime. The results are compared with theoretical predictions based on t-channel, quasi-particle exchange and constrain the axial-vector component of the neutral meson production mechanism in these models.

PACS numbers: 13.60.Le, 13.88.+e, 14.40.Be, 12.40.Nn

In high-energy photoproduction the dominant meson production mechanism at small momentum transfer is expected to be the exchange of massive quasi-particles known as Reggeons (see Ref. [1] for a review). Interest in this theoretical description of high energy photoproduction has increased recently as it provides constraints on the quantum mechanical amplitudes utilized in low energy meson photoproduction to extract the spectrum of excited baryons [2], which depends strongly on the internal dynamics of the underlying constituents [3]. In addition, understanding the meson photoproduction mechanism at high energy is a vital component of a broader program to search for gluonic excitations in the meson spectrum through photoproduction reactions, which is the primary goal of the GLUEX experiment at Jefferson Lab.

The first model developed for high-energy $\vec{\gamma}p \to \pi^0 p$ by Goldstein and Owens [4] was based on the exchange of Reggeons with the allowed t-channel quantum numbers $J^{PC} = 1^{--}$ and 1^{+-}, corresponding to the leading trajectories of the ρ^0/ω and b_1^0/h_1 Reggeons, respectively. Similar approaches addressing both π^0 and η photoproduction have been developed and extended recently by several groups including Laget [5, 6], Mathieu, Fox, and Szczepaniak [7], Donnachie and Kalashnikova [8]. Predictions for the linearly-polarized beam asymmetry are sensitive to the relative contribution from 1^{--} and 1^{+-} exchange and new data can provide important constraints to better understand this production mechanism.

In this Letter we report on the linearly-polarized photon beam asymmetry Σ in high-energy π^0 and η photoproduction from the GLUEX experiment. The data were collected in the spring of 2016 utilizing the newly upgraded Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab and represent the first measurement with a 12 GeV electron beam at Jefferson Lab and the first measurement from the GLUEX experiment. CEBAF operated at a repetition rate of 250 MHz (4 ns RF bunch spacing), providing GLUEX with a beam current of about 150 nA during most of this period.

The GLUEX experiment makes use of a new high-energy photon beam facility, where the electrons provided by CEBAF are incident on a thin aluminum (30 μm) or diamond (50 μm) radiator producing a bremsstrahlung photon beam. The aluminum radiator produces a conventional incoherent bremsstrahlung spectrum with the characteristic intensity proportional to $1/E_\gamma$. The lattice structure of the diamond radiator was aligned with the beam to produce coherent bremsstrahlung, with the coherent photon intensity peaking in specific energy ranges where the photons are linearly polarized relative to the crystal axes in the diamond. Two different diamond orientations were used for this dataset (alternating every few hours), with the electric field vector parallel or perpendicular to the lab floor (x-axis), denoted as PARA and PERP, respectively.

After passing through the thin diamond radiator, the scattered beam-electrons propagate through a warm dipole magnet and are detected in a scintillator-hodoscope array, thus tagging the energy of the radiated beam-photon. In the photon beam energy range from 3.0 to 11.8 GeV there are two independent detectors, with the fine-grained tagger microscope instrumenting the region $8.2 < E_\gamma < 9.2$ GeV in increments of about 10 MeV, and the remaining energy range covered by the tagger hodoscope with individual counter widths covering between 10 and 25 MeV.

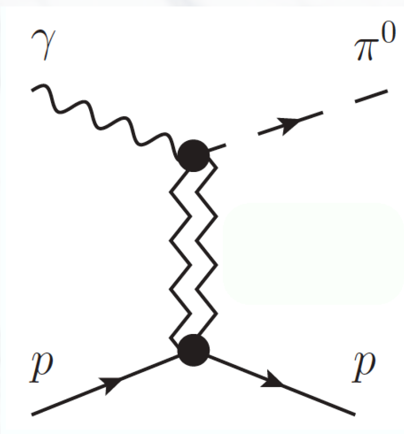
The coherent bremsstrahlung photons are predominantly produced along the direction of the incident electron beam, while the incoherent bremsstrahlung photons are produced with a broader angular distribution. Therefore, after the photons travel through a 75 m long vacuum beamline, they pass through a 3.4 mm diameter collimator where the off-axis photons are removed, increasing the fraction of coherently produced photons. The energy of the photon beam is monitored using e^+e^- pair conversion from a thin (75 μm) beryllium foil downstream of the collimator, where the e^+ and e^- energies are measured in a pair spectrometer system consisting of a 1.5 T dipole magnet and a pair of scintillator counter arrays [9]. The photon-beam energy spectrum, as measured by the pair spectrometer and not corrected for instrumental acceptance, is shown in Figure 1(a) where the characteristic peak of coherent photons is clearly visible in the diamond distributions at $E_\gamma = 9$ GeV relative to the incoherent photons from the aluminum radiator (amorphous).

The polarization of the coherent photons is measured by a triplet polarimeter, where photons convert on atomic electrons in the same beryllium foil as used by the pair spectrometer, via the process $\vec{\gamma}e^- \to e^-e^+e^-$. The high energy e^-e^+ pair is detected in the pair spectrometer, while the low energy recoil e^- is detected in a 1 mm thick silicon detector which has 32 segments in azimuthal angle, ϕ_{e^-}, around the beamline. The distribution of the recoil e^- in azimuth is given by $d\sigma/d\phi_{e^-} \propto 1 + P_\gamma \lambda \cos 2(\phi_{e^-} - \phi_\gamma^{lin})$, where P_γ is the pho-

First GlueX Publication

Beam Asymmetry, Σ:

$$\frac{d\sigma}{d\phi} = \sigma_0 \left[1 - p_\gamma \Sigma \cos 2\left(\phi_p - \phi_\gamma^{lin}\right)\right]$$

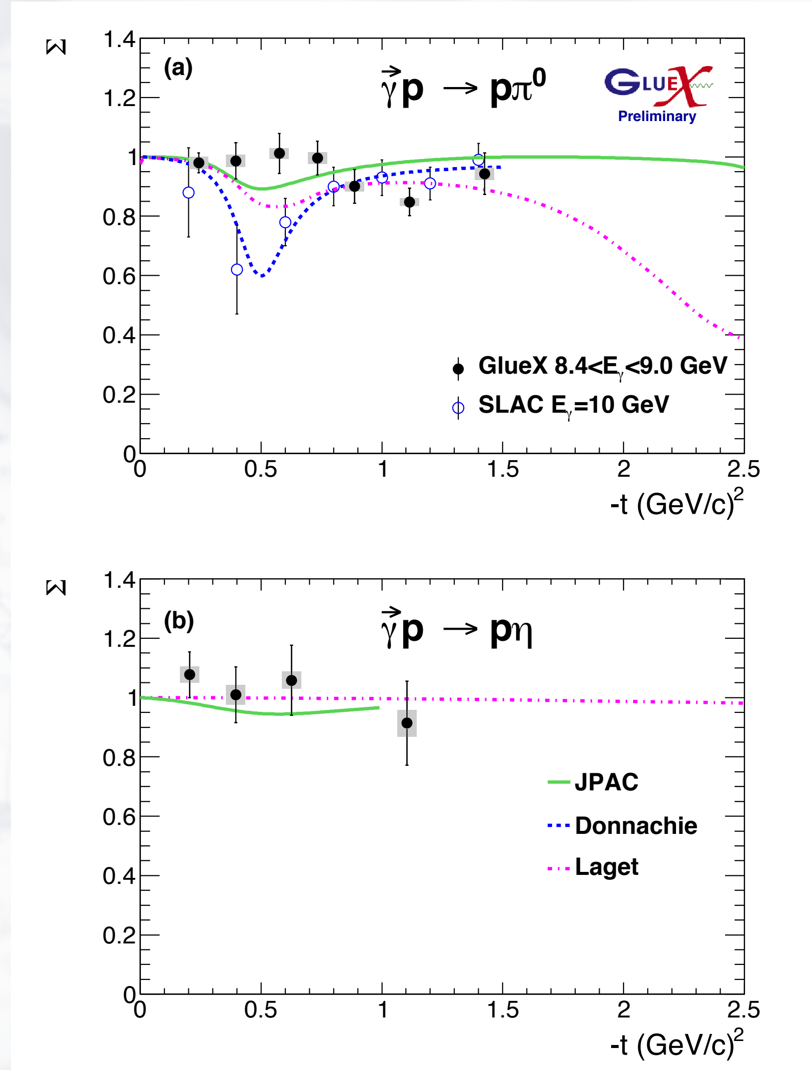


Exchange J^PC

$$1^{--} : \omega, \rho$$

$$1^{+-} : b, h$$

$$\Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2}$$



Target as PRL Publication

Software Performance

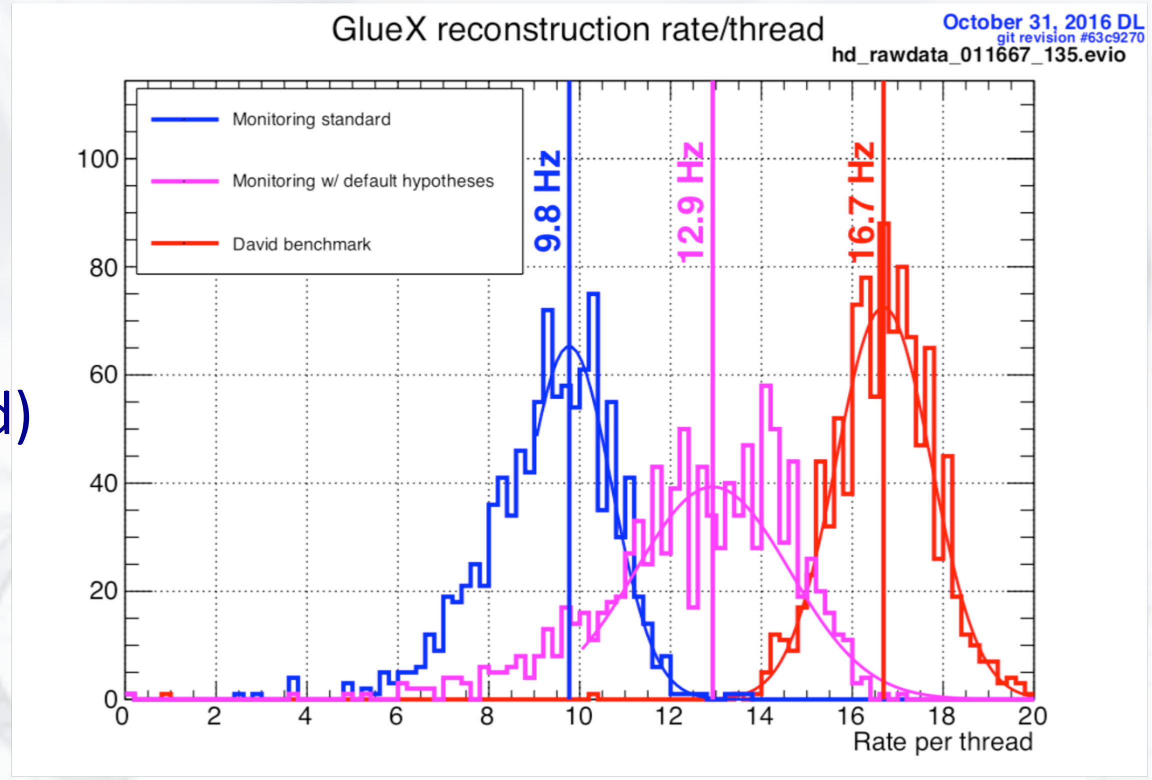
Reconstruction Rate:
9.8 Hz/core #

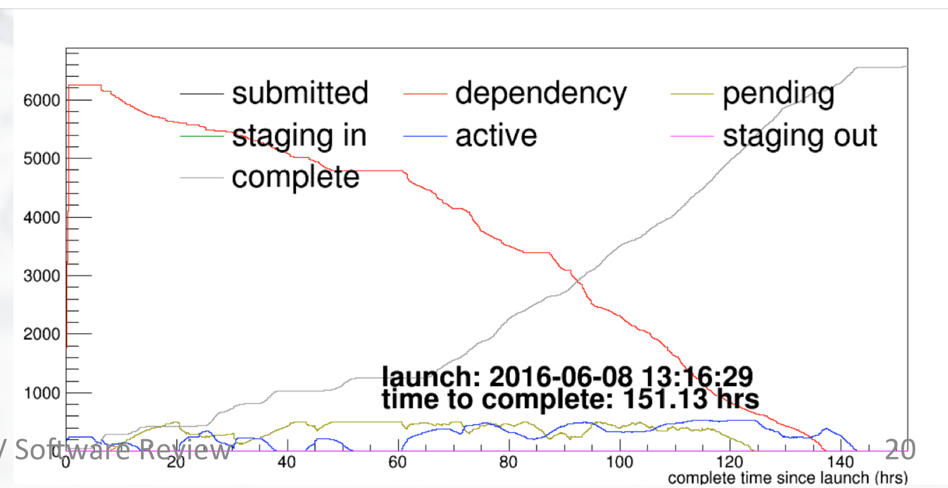
GEANT3 Simulation:
17.9 Hz # (not multithreaded)

GEANT4 Simulation:
9.2 Hz/core (estimate)

Peak at about 650 simultaneous jobs on farm

 # Intel Xeon E5-2697 @ 2.30GHz (Broadwell)





Response to Recommendations

- Move to GEANT4: Have a scalable threaded version of GEANT4 working in beta-release.
- Data Management/Cataloging: Have integrated EventStore into our software. Have not fully exploited yet as data sets are still small.
- Tracking Performance/Profiling: regular use of valgrind and careful monitoring of scalability.
- Analysis Trains: In very regular use since March 2014. Worked with CC in deploying SWIF. Coordinated launches at all levels.

Lessons Learned

- **LARGE** data challenges are very important.
  - 12/12 ~6 G-Evts., 4/14 ~15 G-Evts, 11/14 Commissioning, 3/16 ~25 G-Evts. Data.
- Work closely with the computer center.
  - Their goals are the same as yours.
- You cannot monitor your software enough—**archive everything**.
  - When you break it, you need to know quickly.
- You must have **automatic** online data monitoring & simple output.
  - Make it very easy for shift workers to spot issues.
- Identify physics that can be analyzed quickly.
  - You exercise your analysis procedures & get physics out.
- Communicate

Summary and Moving Forward

- GlueX/Hall-D software production level with calibrations steadily being automated.
- GlueX/Hall-D works closely with CC to coordinate and optimize large-scale activities on appropriate time scales.
- GlueX/Hall-D has identified early physics topics and has a very active and program that is publishing.