GlueX/Hall-D: Analysis and Physics

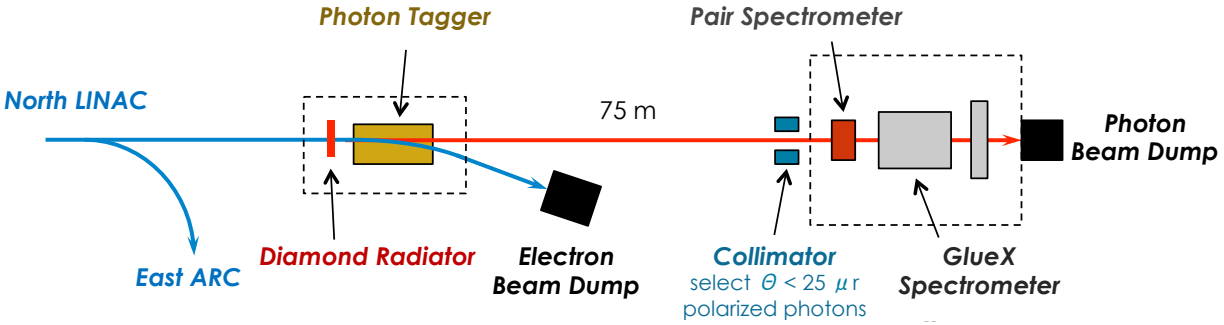
The Photoproduction of Exotic Mesons

The GlueX Collaboration

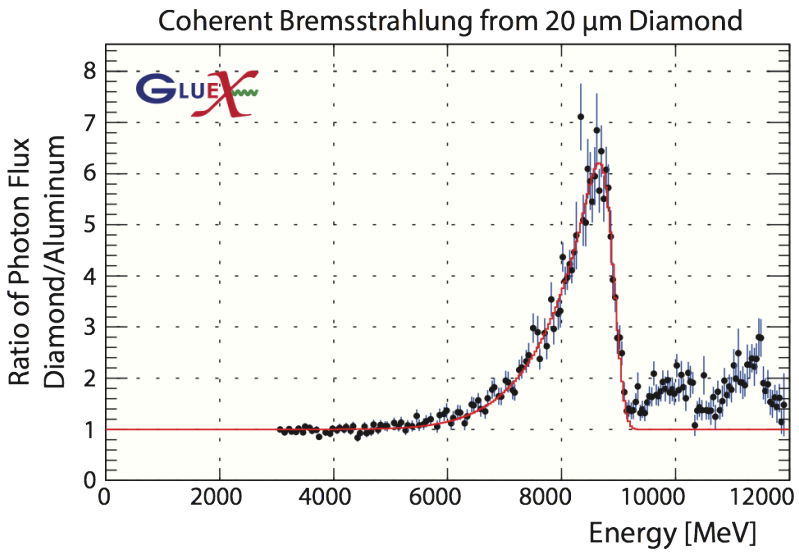
Arizona State, Athens, Carnegie Mellon, Catholic University, Univ. of Connecticut, Florida International, Florida State, George Washington, Glasgow, GSI, IHEP (Chinese Academy of Sciences) Indiana University, ITEP, Jefferson Lab, U. Mass Amherst, MIT, MePhi, Norfolk State, North Carolina A&T, Univ. North Carolina Wilmington, Northwestern, Old Dominion, Santa Maria, University of Regina, Tomsk, William & Mary, Wuhan and Yerevan Physics Institute. (>125 members)

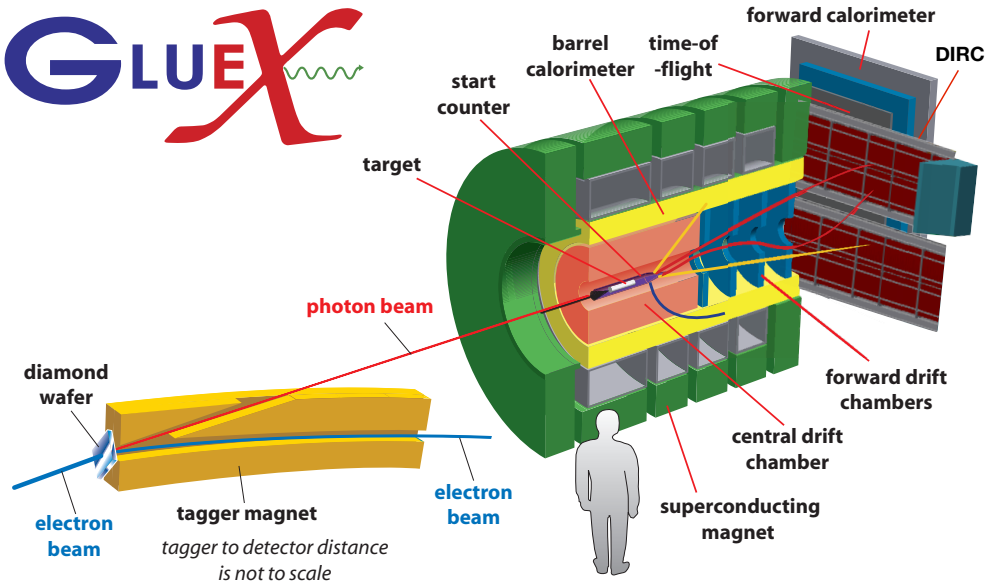
- Commissioning started in Fall 2014.
- Physics started in Spring 2017, GlueX-I is completing data taking
- GlueX-II starts in Fall 2019 and at least 5 years of running.

The GlueX Experiment



Electron Energy: 11.6GeV
Coherent Edge: 8.6GeV
Avg. Lin. Pol: 36%



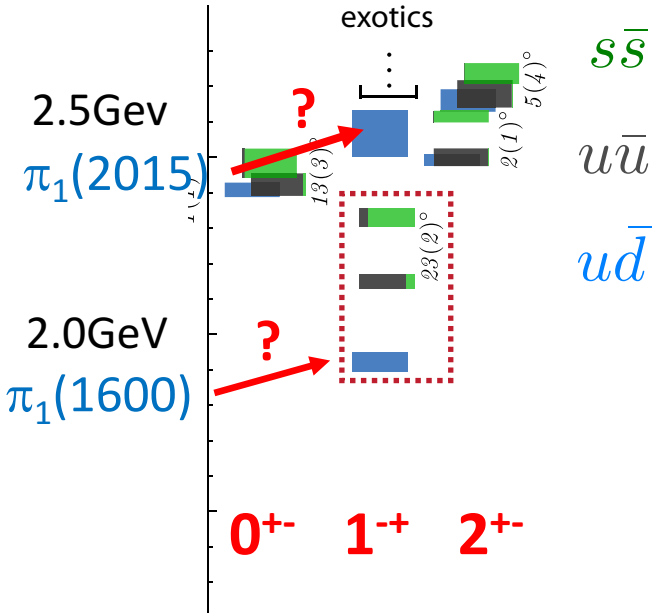


Hermetic detector for charged particles & photons.
Multiple PID systems.
Reconstruct exclusive photoproduction final states.

The GlueX Physics Program

LQCD Predictions

Exotic QN Hybrids



Not observed:

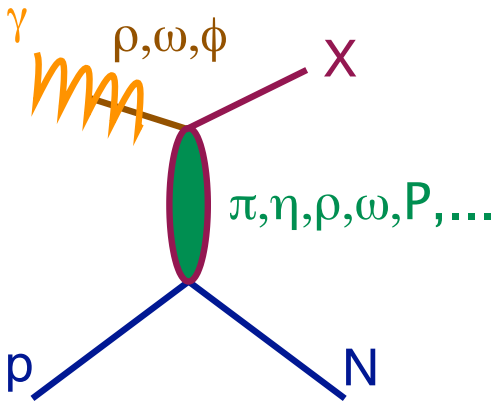
η_1 , η_1'

b_0 , h_0 , h_0'

b_2 , h_2 , h_2'

Photoproduction of Exotic Hybrids

Can couple to all exotic hybrid mesons through photoproduction



Linear polarization ← → Production Mechanism

Early Reach

$\pi_1 \rightarrow \pi\rho$

$\eta_1 \rightarrow \eta f_2, a_2\pi$

$\eta_1' \rightarrow K^*K$

$b_2 \rightarrow \omega\pi, a_2\pi, \rho\eta$

$h_2 \rightarrow \rho\pi,$

Opportunistic physics

Beam asymmetry measurements

Spin-density matrix elements

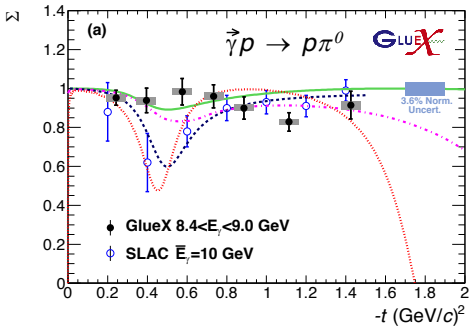
Identify known states

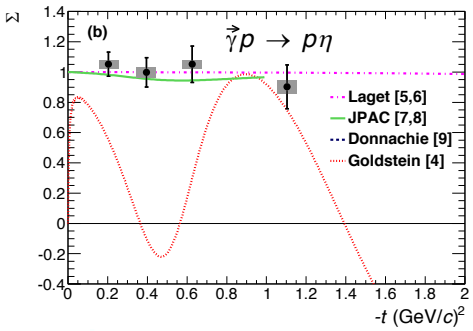
Search for exotic hybrids

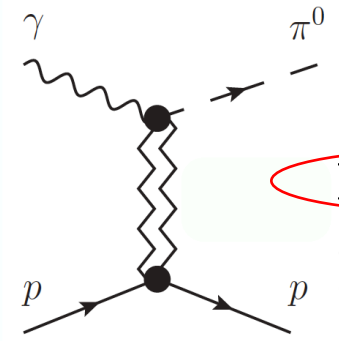
Physics from GlueX/Hall-D

Beam Asymmetry for π^0 & η

Phys. Rev. C**95**, 042201 (2017)





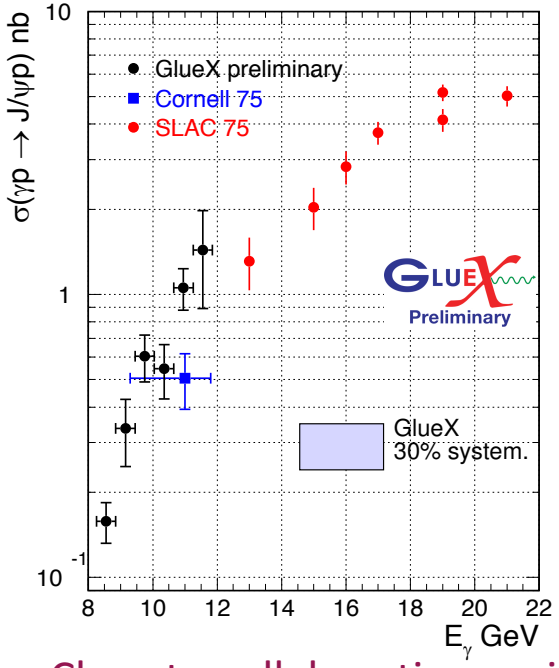


Exchange J^{PC}

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

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

J/ψ Threshold photoproduction In collaboration Review



- SLAC:
  U.Camerini et al, PRL 35 (1975)
  Calculated from the measured $\frac{d\sigma}{dt}|_{t=tmin}$ assuming $\frac{d\sigma}{dt} \propto e^{a \cdot t}$, $a = 2.9 \pm 0.3\ \text{GeV}^{-2}$ measured at 19 GeV
- Cornell:
  B.Gittelman et al, PRL 35 (1975)
  t-slope $a = 1.25 \pm 0.2\ \text{GeV}^{-2}$
  horizontal error bar represents the acceptance

Close to collaboration review:

- Beam asymmetry for η & η'
- Beam asymmetry for π^+
- SDME for ρ, ω and ϕ

Many other physics analyses ongoing

- Starting to see first look in channels for exotic hybrids.

User Experience for Analysis

Established an elected Physics Coordinator

Physics analysis discussed weekly in several physics meetings:

- Physics WG
- Amplitude analysis WG
- Di-lepton WG
- Eta/eta-prime WG

Analysis Workshops held regularly

- June 2018
- June 2016
- June 2013

Videos of presentations available online
Tutorials available online

- Users start their analysis with root-tree skims of a desired reaction channel.
- Standard analysis tools for getting at data (DSelector)
- Do physics, not data production

User Experience for Analysis

Production of data and MC is centrally managed by the collaboration.
Event skims for analysis are centrally managed by the collaboration.

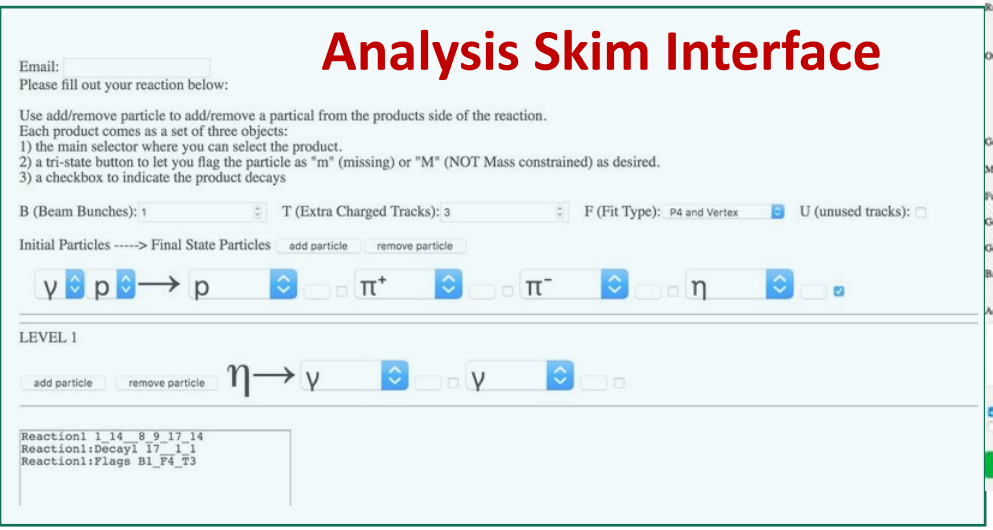
Many analysis cuts centrally managed.

Monte Carlo production including background events managed centrally.

Users Request data and MC through Web

Monte Carlo Interface

Analysis Skim Interface



Moving to Amplitude Analysis

- Requires a full understanding of the detector and beam: acceptance, efficiency, polarization, flux, …
- We are getting close to this understanding.
- Tools are available and in use: AMPtools (GPU Enabled).

On going analyses:

- Extract SDMEs of the ρ meson using AMPtools.
- Use moment analysis in $\gamma p \rightarrow \pi^- \Delta^{++}$.
- Look at $\gamma p \rightarrow p\eta$ & $p\eta'$ (reported hybrid channel)

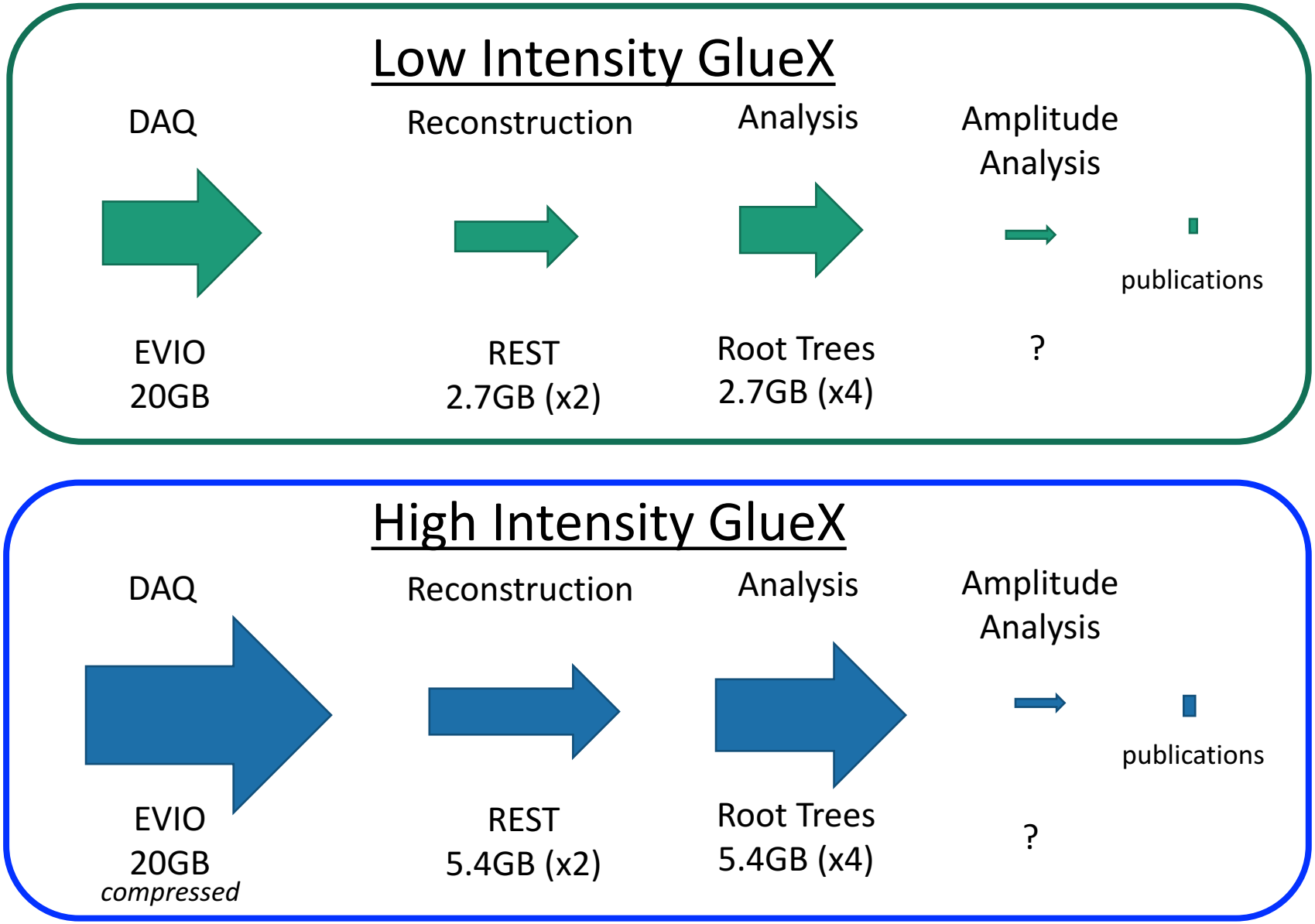
Next round of analyses:

- Search for η_1 and b_2 in $\gamma p \rightarrow p\eta\pi\pi$
- Search for π_1 and h_2 in $\gamma p \rightarrow p\pi\pi\pi$
- Search for η_1' in $\gamma p \rightarrow pK^*K$

Full Strangeness Physics Program with DIRC

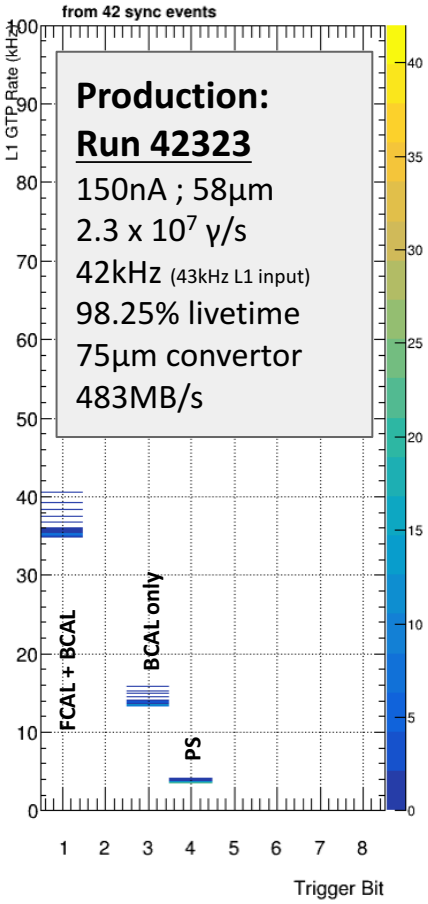
Part B

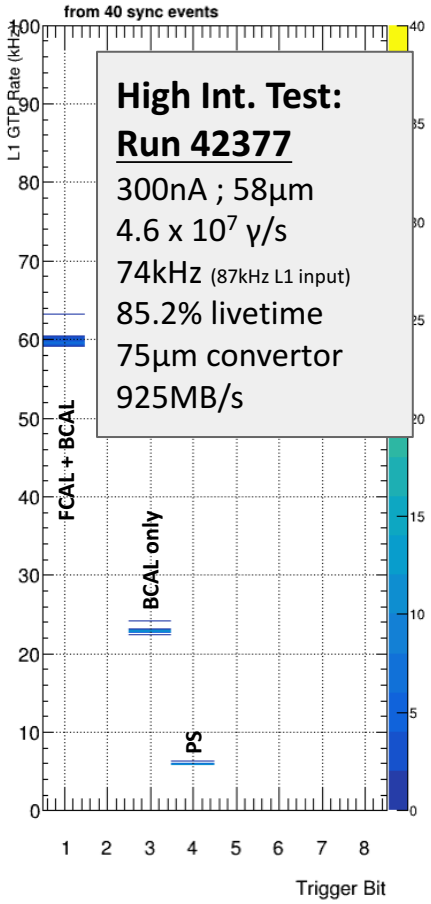
Data volumes and high-level data flow



High-intensity Testing Spring 2018

Production vs. High Intensity Spring 2018





- Two types of **production running in 2018** with different Pair Spectrometer triggers
  - 438MB/s
  - 760MB/s
- **High Intensity test**
  - Beam intensity ~92% of planned High Intensity running
  - Data rate ~80% of planned
  - Livetime limited by disk write speed

GlueX Computing Needs

	2017 (low intensity GlueX)	2018 (low intensity GlueX)	2019 (PrimEx)	2019 (high intensity GlueX)
Real Data	1.2PB	6.3PB	1.3PB	3.1PB
MC Data	0.1PB	0.38PB	0.16PB	0.3PB
Total Data	**1.3PB**	**6.6PB**	**1.4PB**	**3.4PB**
Real Data CPU	21.3Mhr	67.2Mhr	6.4Mhr	39.6Mhr
MC CPU	3.0Mhr	11.3MHr	1.2Mhr	8.0Mhr
Total CPU	**24.3PB**	**78.4Mhr**	**7.6Mhr**	**47.5Mhr**

Anticipate 2018 data will be processed by end of summer 2019

Projection for out-years of GlueX High Intensity running at 32 weeks/year

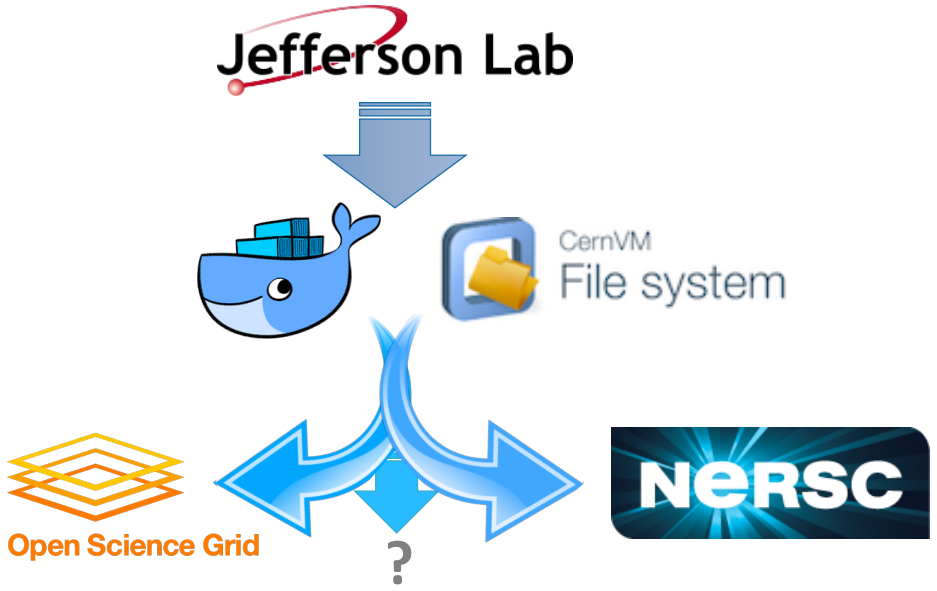
	Out - years (high intensity GlueX)
Real Data	16.2PB
MC Data	1.4PB
Total Data	**17.6PB**
Real Data CPU	125.6Mhr
MC CPU	36.5Mhr
Total CPU	**162.1Mhr**

Offsite Computing Resources

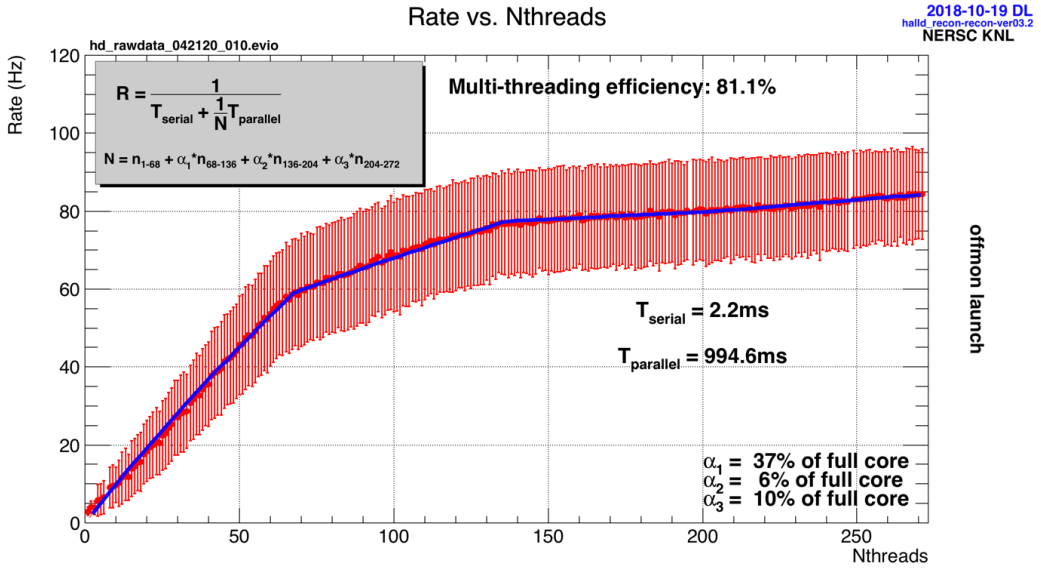
Both OSG and NERSC jobs use the same:

- Docker container*
- CVMFS share
  - GlueX Software builds
  - 3rd party software
  - Calibration Constants (CCDB SQLite file)
  - Resource file (field and material maps)

**converted to Singularity and Shifter*



Containerized software runs at NERSC on both **Cori I** *(Haswell)* and **Cori II** *(KNL)*



Computing Resources

NERSC - raw data

- Last year received **23Mhr** allocation
- AY2019 Request submitted for **112M** units (~16-45 Mhr)
- Reconstruction of single 20GB raw data file in 3.6 hours by 32 core computer = 1.54MB/s
- With 10Gbps bandwidth offsite, we can process up to 1300 files continuously (assuming factor of 2 compression)
- Each file processed on single 32 core computer means we can keep at most 42kcores busy
- We can utilize up to **30.2Mhr of offsite resources per month with a 10Gbps link**

Practical Maximum per year: 120Mhr

(processing 4 months/year)

OSG - simulated data

- UConn - 10M core hours
- FSU - 5M core hours (so far, more on the horizon)
- Northwestern - 2M core hours
- Regina - 2M core hours (so far, maybe more can be found)
- Indiana - 4M core hours
- Florida International - 2M core hours
- opportunistic cycles - 10M core hours (rough estimate, from experience so far)
- George Washington – XY core hours

Total anticipated per year: 35-50Mhr

JLab – Calibrations & Monitoring

- Incoming data monitoring: first 5 files of each run as it is copied to tape
- Misc. calibration jobs and skims

Total anticipated per year: 35Mhr

Recommendations from Nov. 2016 Review

Experimental Halls – General

… We recommend to add the concept of a stable run list either to the Analysis Train (and so make them "named trains"), or as a separate tool…

The run-conditions database (RCDB) implements tags. We use this feature to for tags such as "@is_2018production" and "@status_approved" which, when combined with a run number range, produce a reproducible run list

https://halldweb.jlab.org/rcdb

Hall-D

… We recommend to explore the possibility of trading CPU power used for data reduction for data compression …

This is still under development by the CODA/DAQ group. There are still plans to integrate it into the event recorder. Testing will be done over the next few months.

Summary

- Physics program well defined
  - 1 physics publication (π^o beam asymmetry)
  - 2 more close
- User training and support
  - Workshops and Video tutorials
  - Web interfaces for submitting MC and Analysis skims
- Amplitude Analysis
  - AMPTools (GPU enabled)
- Roughly 3.8 PB of data collected to date
- Model for estimating computing and storage requirements
  - Projected requirements well matched to anticipated resources
- Production use of Offsite Computing
  - MC routinely done on OSG
  - Raw data processing being done at NERSC

Backups

Data volumes and high-level data flow

	Low Intensity	High Intensity
Beam	2.4 x 10^7 γ/s	5 x 10^7 γ/s
Trigger	42 kHz	90 kHz
Front End	0.5 GB/s	1.2 GB/s
Disk	0.5 GB/s	ξ 600 MB/s
Tape	4.2 PB/yr	ξ 5.8 PB/yr

In coherent peak: Eγ =8.5-9GeV

DAQ needs to be capable of 1.5GB/s sustained

raw data only (compressed)

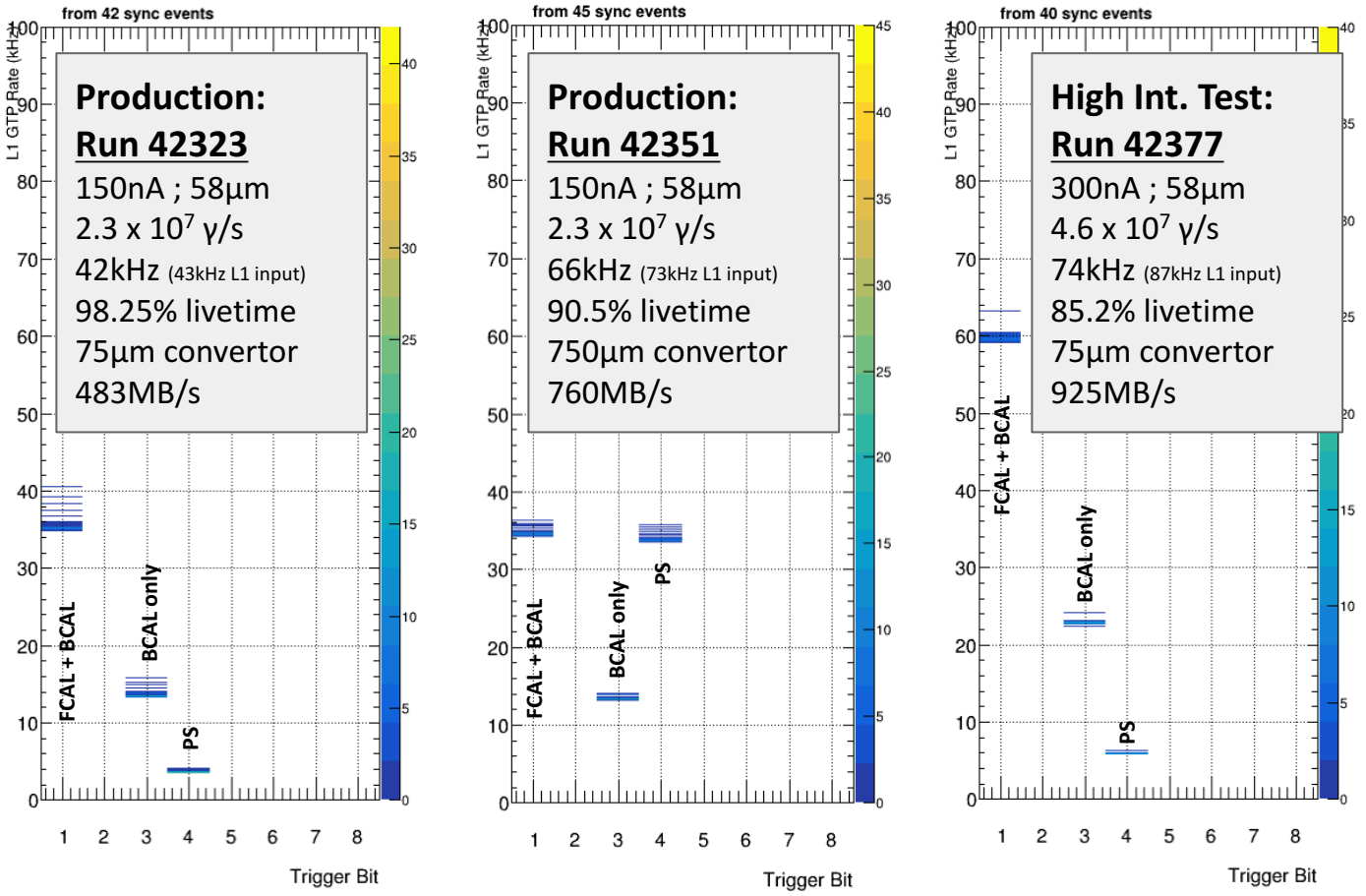
ξ *Assumes factor 2 compression*

GlueX + DIRC : E12-12-002 220 PAC Days

GlueX II : PR12-13-003 200 PAC Days

High-intensity Testing Spring 2018

Production vs. High Intensity Spring 2018



Two types of routine production running in 2018:

- 75µm and 750µm TPOL convertor (**T**riplet **POL**arimeter)
- Full detector read out in both cases, but one with higher trigger rate
- Livetime limited by disk write speed

GlueX Computing Resource Model

A model was developed based on experience processing 2017 GlueX data to estimate compute resources required based on several inputs

https://github.com/JeffersonLab/hd_utilities/tree/master/comp_mod

```
<compMod>
<parameter name="triggerRate" value="45.0e3" units="Hz"/>
<parameter name="runningTimeOnFloor" value="60.0" units="days"/>
<parameter name="runningEfficiency" value="0.44"/>
<parameter name="eventsize" value="11.5" units="kB"/>
<parameter name="eventsPerRun" value="200" units="Mevent"/>
<parameter name="compressionFactor" value="1.0"/>
<parameter name="RESTfraction" value="0.15"/>

<parameter name="reconstructionRate" value="5.5" units="Hz"/>
<parameter name="reconPasses" value="2.0"/>
<parameter name="goodRunFraction" value="0.85"/>
<parameter name="analysisRate" value="75.0" units="Hz"/>
<parameter name="analysisPasses" value="2.82"/>
<parameter name="cores" value="10000"/>
<parameter name="incomingData" value="5" units="files"/>
<parameter name="calibRate" value="0.250" units="Mhr/week"/>
<parameter name="offlineMonitoring" value="0.00800" units="Mhr/run"/>
<parameter name="miscUserStudies" value="810"/>

<parameter name="simulationRate" value="25" units="Hz"/>
<parameter name="simulationpasses" value="2"/>
<parameter name="simulatedPerRawEvent" value="0.4"/>
</compMod>
```

```
                GlueX Computing Model
                RunPeriod-2018-08.xml
==========================================
                  PAC Time: 4.3 weeks
              Running Time: 8.6 weeks
       Running Efficiency: 44%
  ------------------------------------
              Trigger Rate: 45.0 kHz
     Raw Data Num. Events: 87.2 billion (good production runs only)
     Raw Data compression: 1.00
      Raw Data Event Size: 11.5 kB
  Front End Raw Data Rate: 0.53 GB/s
       Disk Raw Data Rate: 0.53 GB/s
          Raw Data Volume: 1.209 PB
     Bandwidth to offsite: 460 MB/s (all raw data in 1 month)
       REST/Raw size frac.: 15.00%
          REST Data Volume: 0.511 PB (for 2.82 passes)
   Total Real Data Volume: 1.7 PB
  ------------------------------------
        Recon. time/event: 182 ms (5.5 Hz/core)
           Available CPUs: 10000 cores (full)
         Time to process: 5.2 weeks (all passes)
        Good run fraction: 0.85
  Number of recon passes: 2.0
Number of analysis passes: 2.82
        Reconstruction CPU: 8.8 Mhr
              Analysis CPU: 0.911 Mhr
           Calibration CPU: 2.1 Mhr
    Offline Monitoring CPU: 3.5 Mhr
             Misc User CPU: 8.2 Mhr
         Incoming Data CPU: 0.192 Mhr
      Total Real Data CPU: 23.7 Mhr
  ------------------------------------
       MC generation Rate: 25.0 Hz/core
      MC Number of passes: 2.0
      MC events/raw event: 0.40
           MC data volume: 0.145 PB  (REST only)
         MC Generation CPU: 0.8 Mhr
    MC Reconstruction CPU: 3.5 Mhr
             Total MC CPU: 4.3 Mhr
  ------------------------------------
                   TOTALS:
                      CPU: 28.0 Mhr
                     TAPE: 1.9 PB
```

Raw Data File 2.3x10^{7}γ/s vs. 4.6x10^{7}γ/s