Simulations For JEF/GlueX

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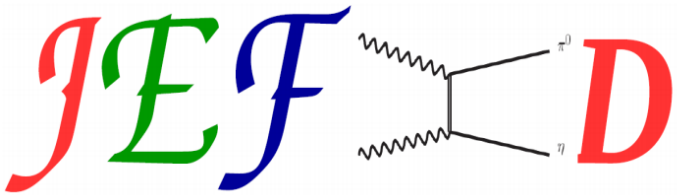
3/8/21

First Workshop on New Light Physics and Photon-beam Experiments

NSERC CRSNG

Introduction

- About me:
  - GlueX member since 2013, JEF subgroup since 2019
  - A little exposure to BESIII & Belle I
- I don’t claim to be a software guru
  - But familiar with all the steps
  - Happy to connect people with JEF & GlueX experts



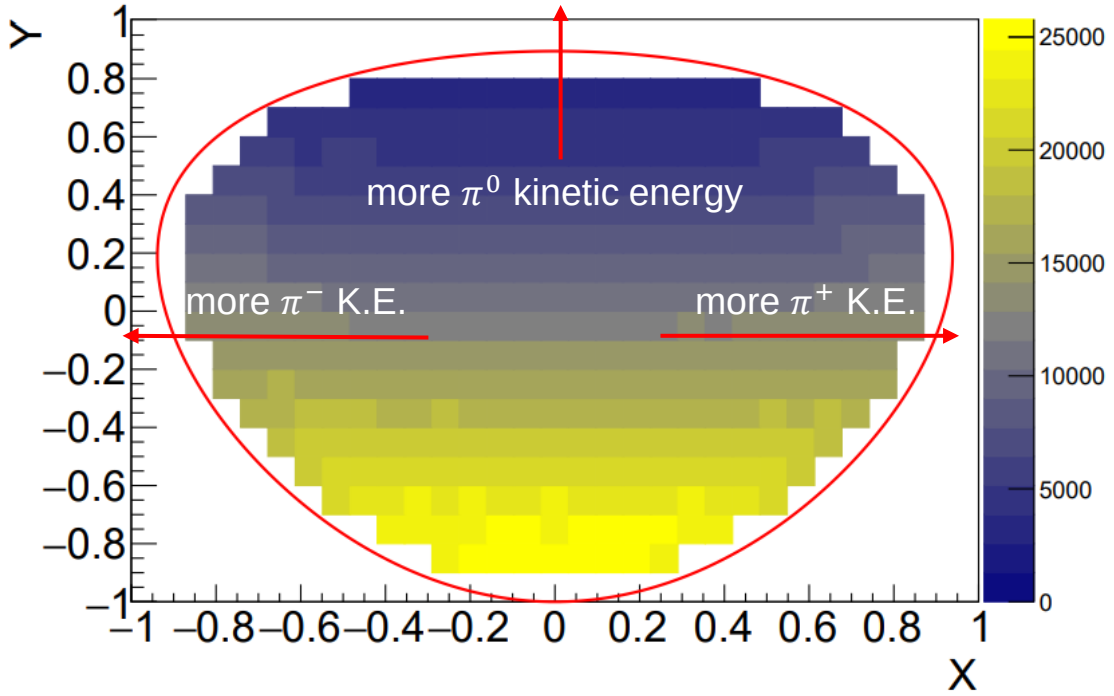
- Talk serves as an overview and reference for simulating photoproduction
  - And experiences of GlueX collaboration

Example decay mode

$\gamma p \to \eta\, p, \eta \to \pi^+\pi^-\pi^0$

- Sensitive to C-violating, P-conserving physics
- Daniel Lersch analyzing for GlueX
- Likely revisited with $\mathcal{JEF}$ upgrade to GlueX spectrometer
- Stepping stone to analysis of
  - $\eta \to 3\pi^0$
  - $\eta \to \pi^0\gamma\gamma$

KLOE
JHEP **05** 019 (2016)
$\eta \to \pi^+\pi^-\pi^0$



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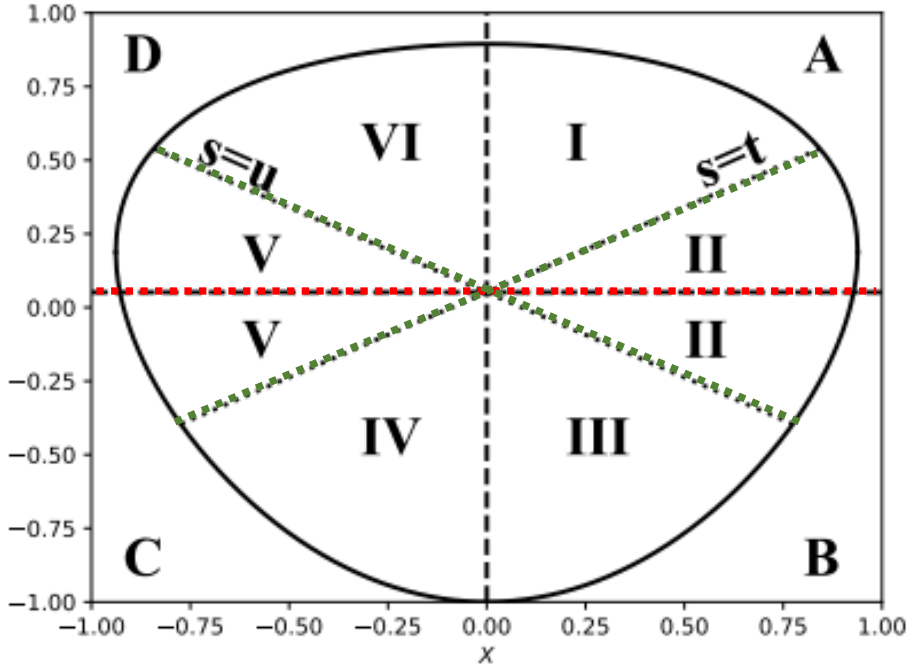

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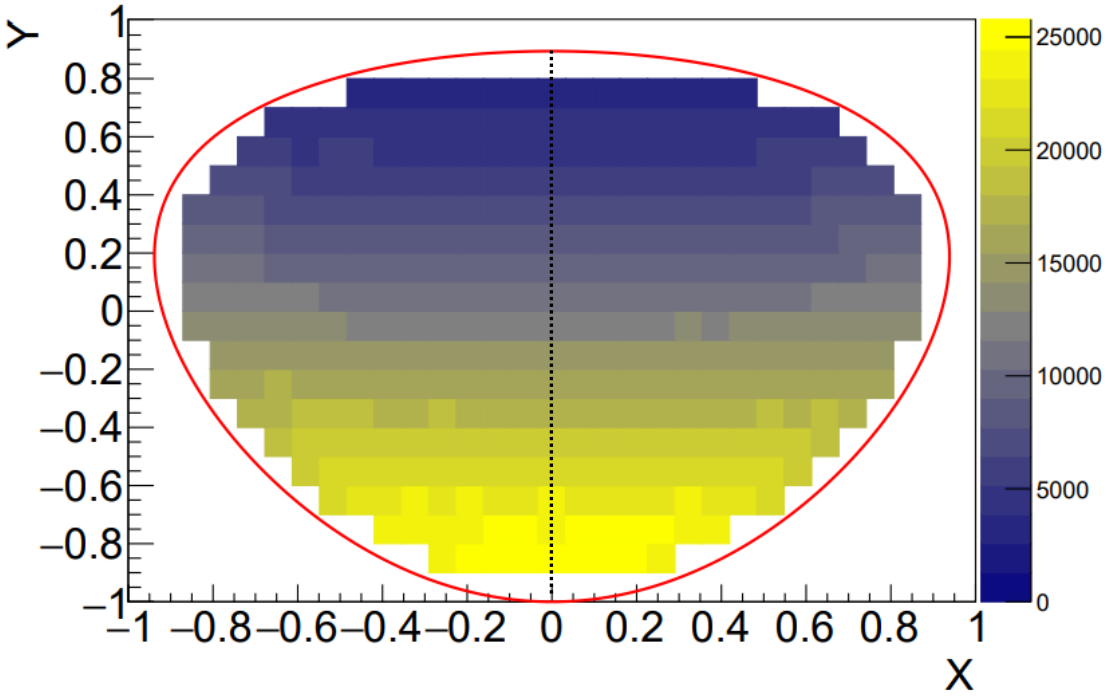

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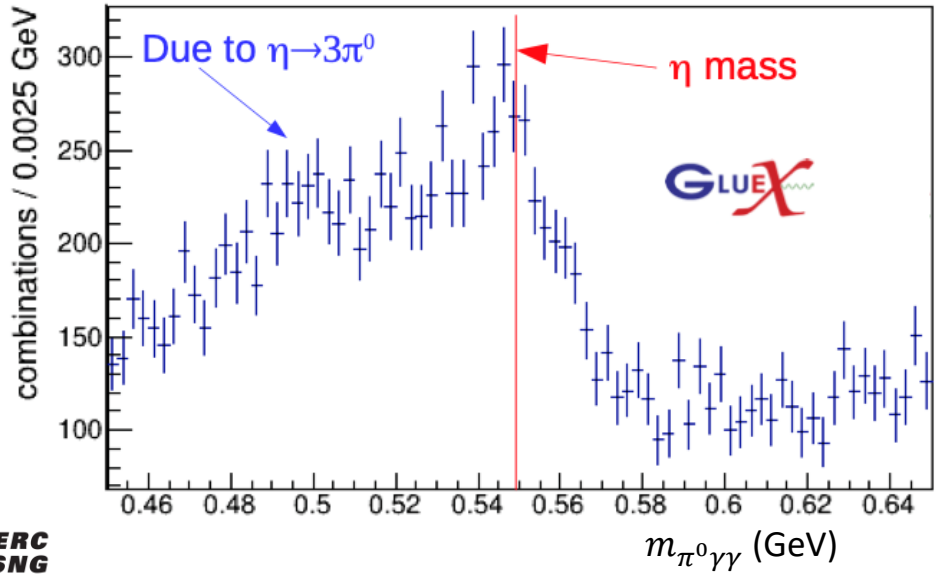
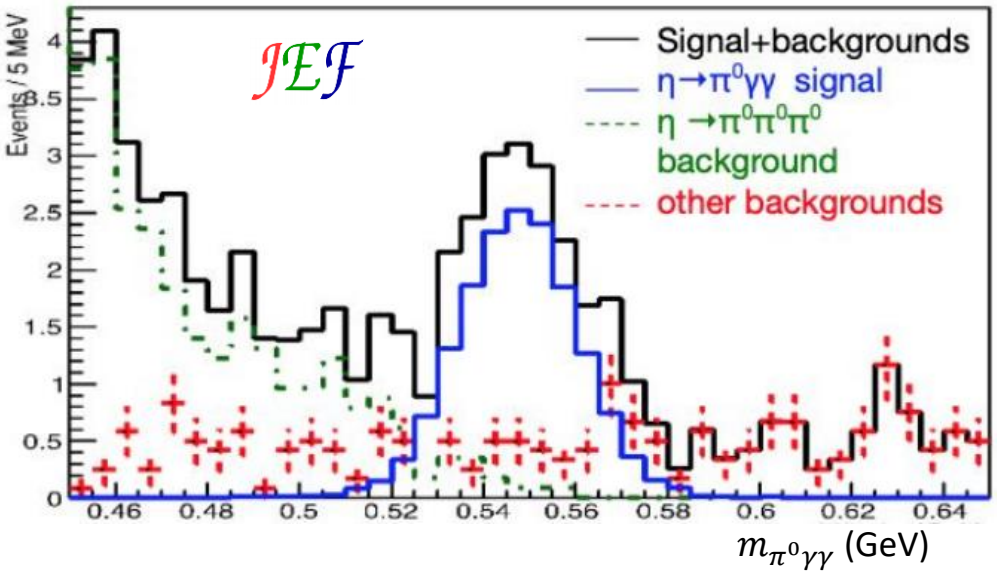
Motivating JEF Upgrade

- Rare decay mode $\eta \rightarrow \pi^0\gamma\gamma$ (2.6×10^{-4} B.F.)

Current detector

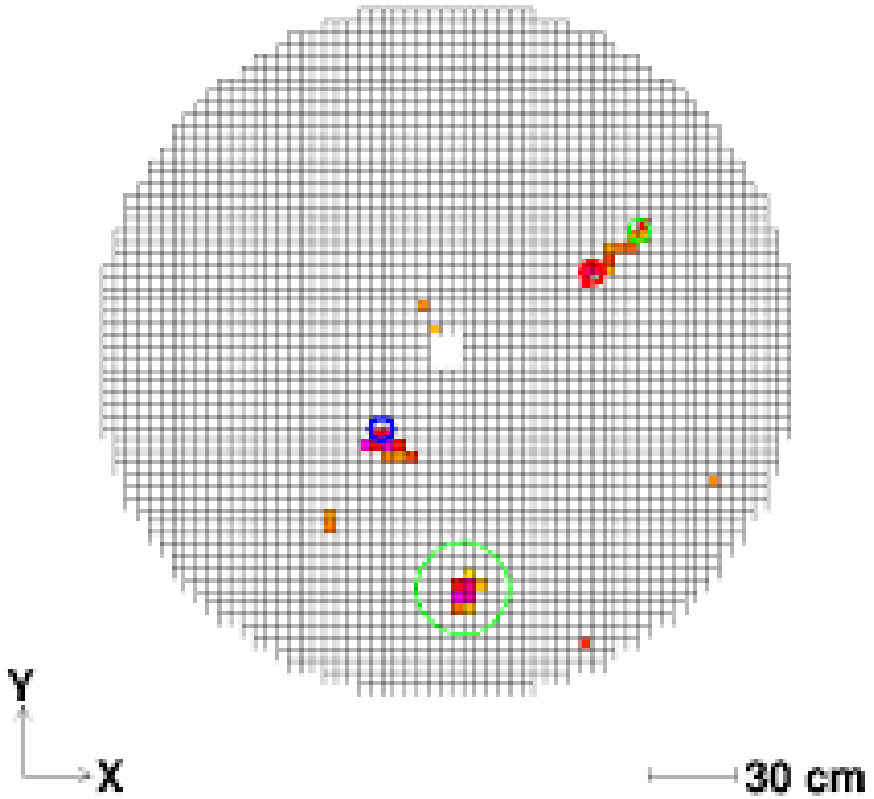


With upgraded calorimeter [simulated]

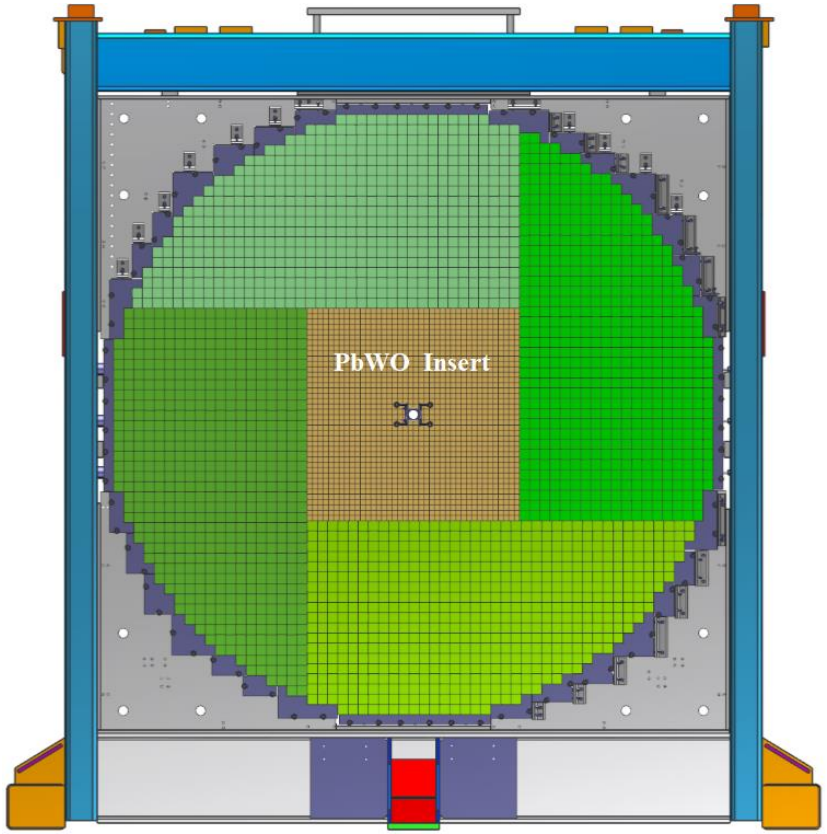


JEF Upgraded Geometry

Current Geometry



JEF upgrade

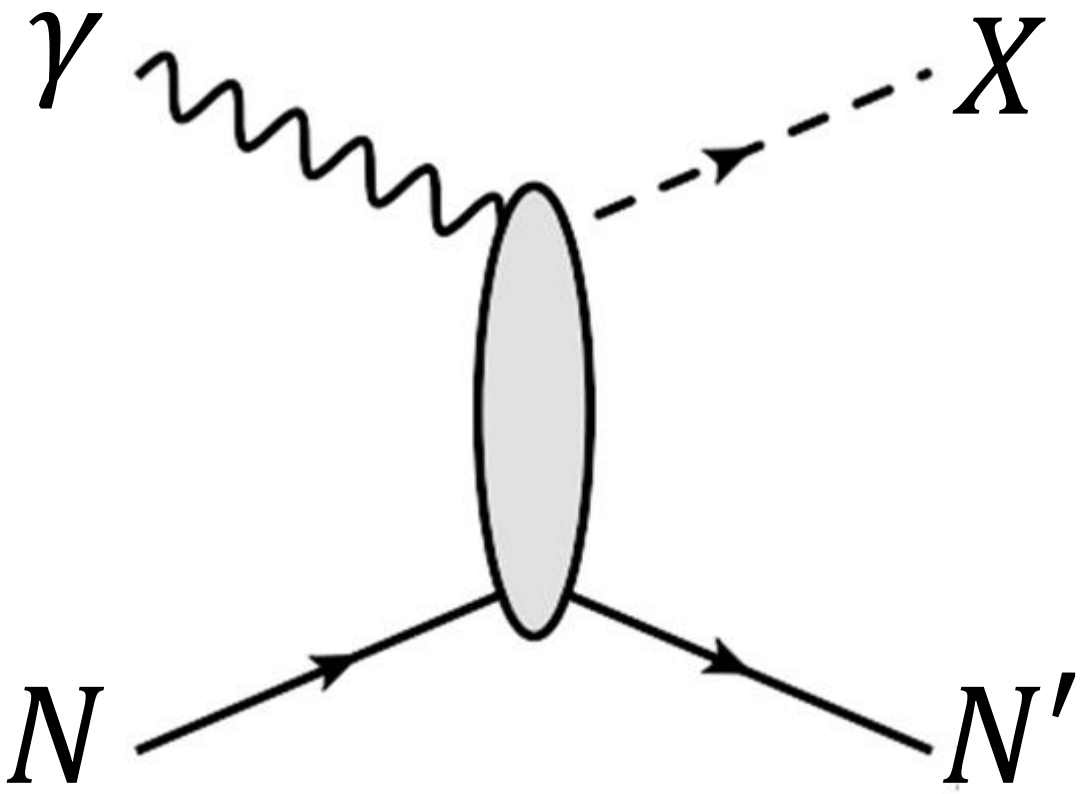


Defining Photoproduction (scope)

My definition:

- The interaction of a high energy photon and nuclei
  - And associated atomic electrons

- Photons may be:
  - real
  - virtual
  - Polarized
- Nuclei may be:
  - fixed target
  - beam
  - polarized

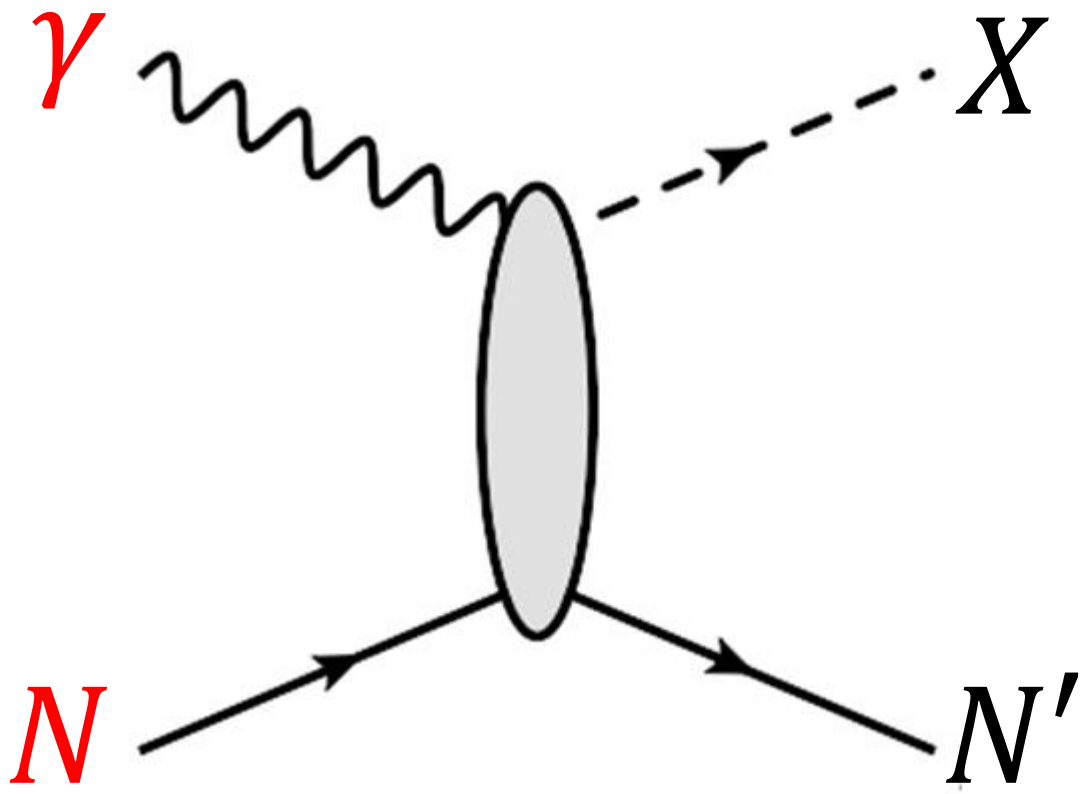


Defining Photoproduction (more details)

My definition:

- The interaction of a high energy photon and nuclei
  - And associated atomic electrons

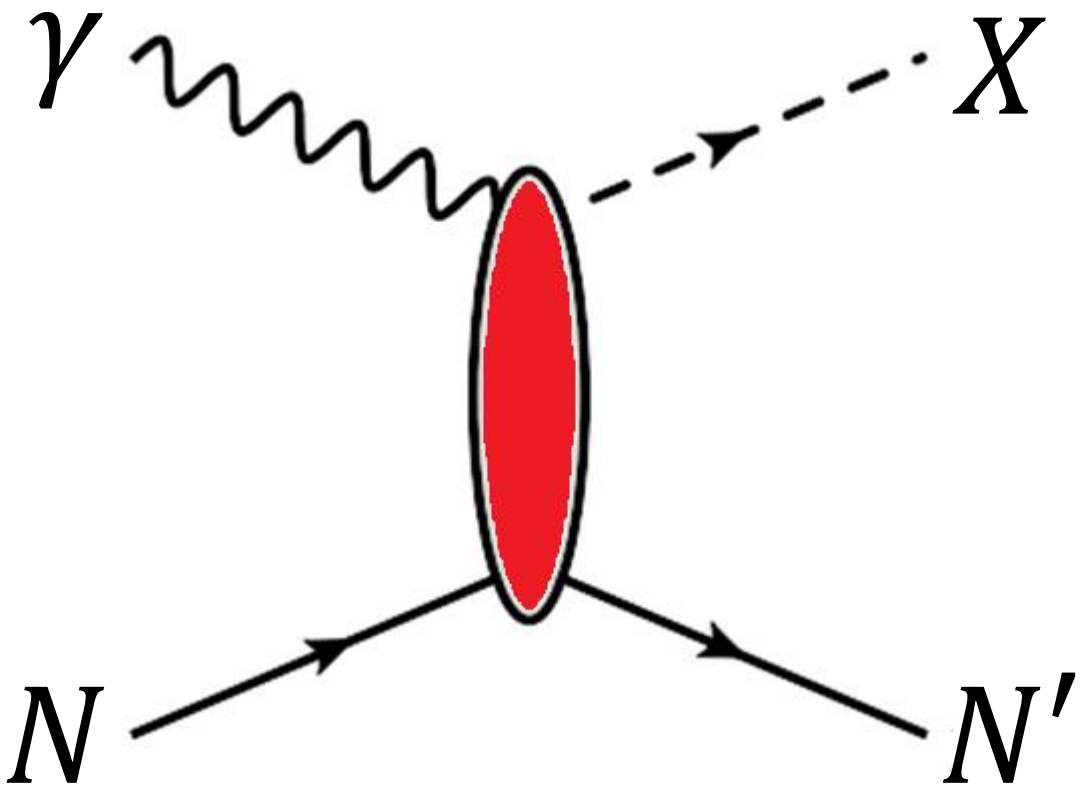
- Photons may be:
  - Real (bremsstrahlung, Compton backscattering)
  - virtual (lepton beam)
  - polarized (linear or elliptical)
- Nuclei may be:
  - fixed target (GlueX, CLAS, LEPS, A2, MESA, …)
  - Beam (HERA, EIC)
  - Polarized (longitudinal or transverse)



***Pythia definition**: Interactions involving one or two photons, either in photon-photon or photon-hadron collision or photons emitted from lepton beams*

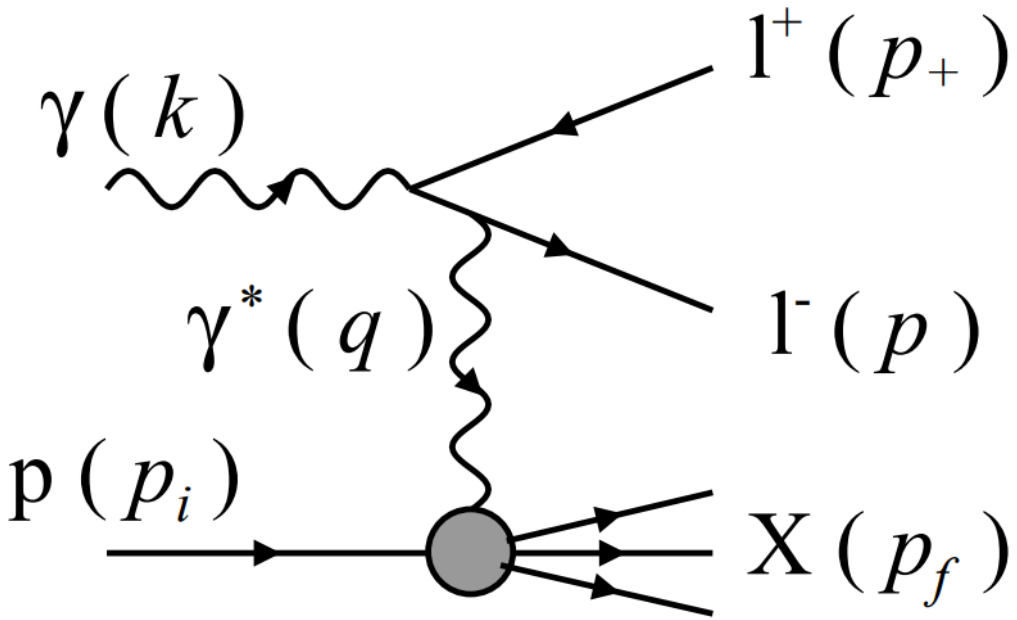
Interaction Forces

- Strong force
  - GlueX + JEF focus
- Electromagnetic
- …BSM?

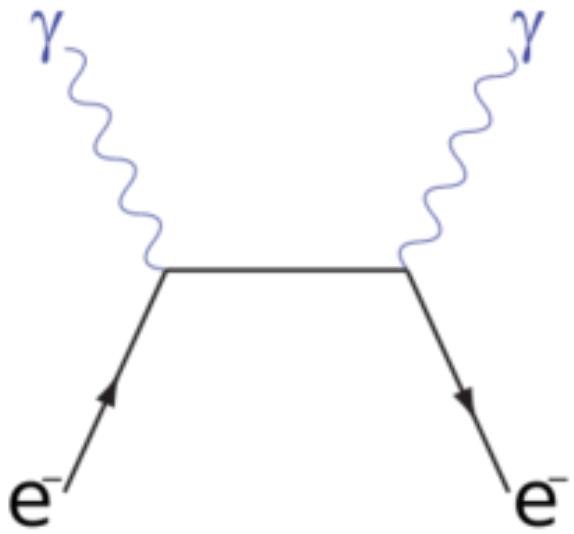


Electromagnetic Interactions

Bethe-Heitler



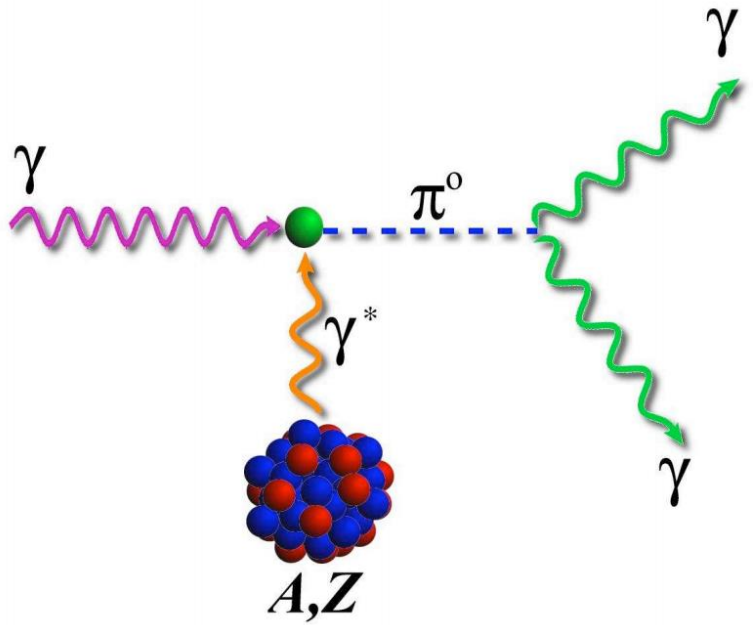
Compton Scattering



Special Mention: Primakoff Reaction

- Production of pseudoscalar via $\gamma\gamma^*$ coupling (pictured: π^0)
- Strongly peaked at small θ

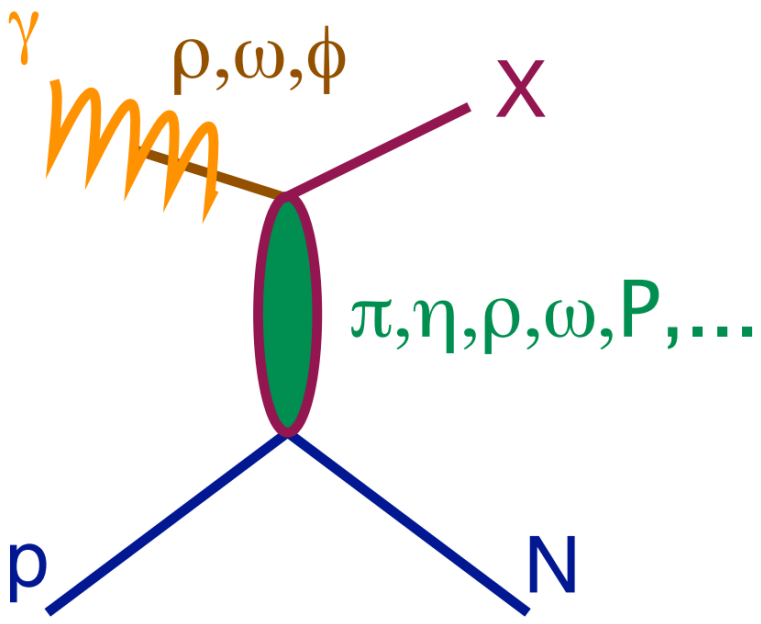
$$\frac{d\sigma_{\mathrm{Pr}}}{d\Omega} = \Gamma_{\gamma\gamma} \frac{8\alpha Z^2}{m_\pi^3} \frac{\beta^3 E^4}{Q^4} \left|F_{e.m.}(Q)\right|^2 \sin^2\theta_\pi$$



Hadronic Production

Hand-wavy picture

- Photon as off-shell vector meson
- Interacts with target as vector meson state

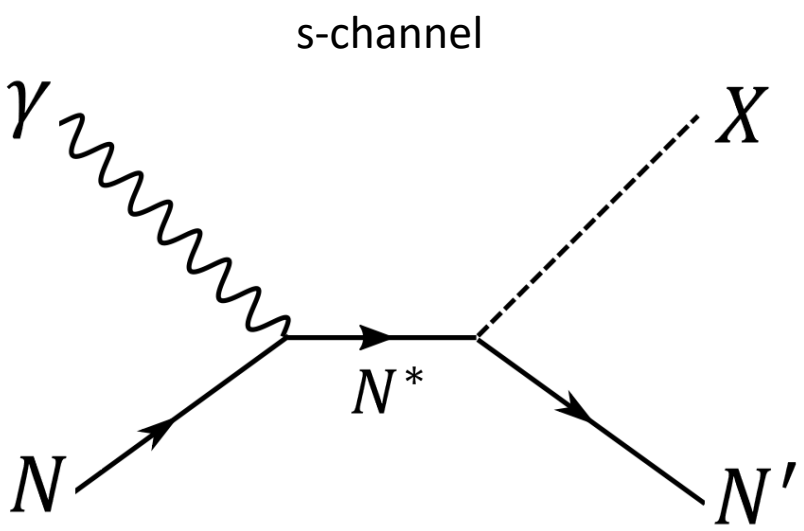


Simulating $\gamma p \rightarrow \eta\, p, \quad \eta \rightarrow \pi^+\pi^-\pi^0$

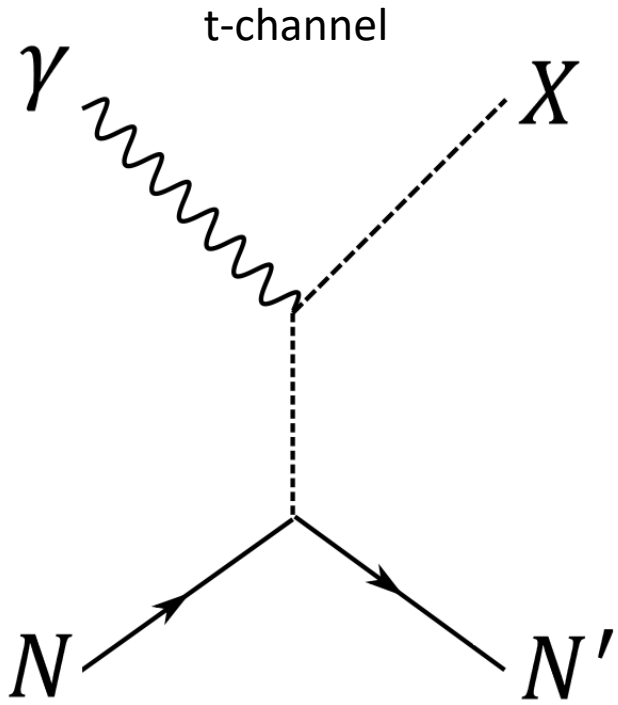
What might we need to simulate?

1. Model for signal production
   And decay kinematics (if any)
2. Potential backgrounds
3. Simulation of final state particles through matter (Geant4)
4. Realistic detector response
5. Computing power!

Modeling Hadronic Production



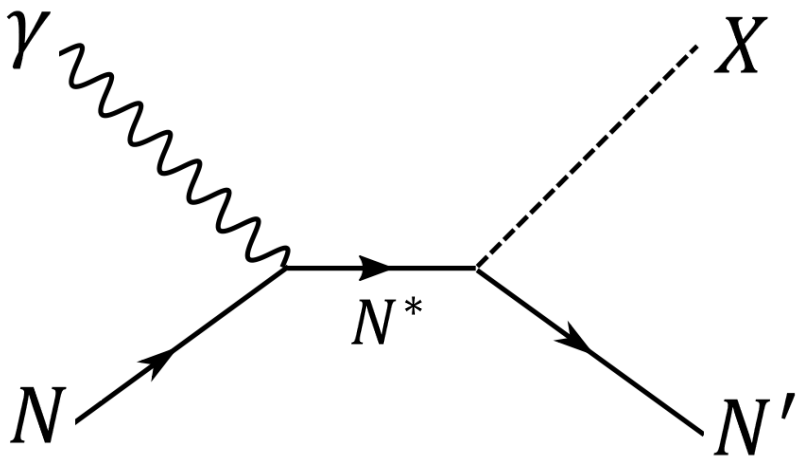
Via baryonic excitation



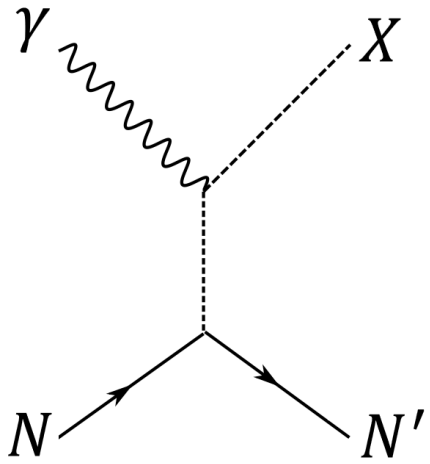
Via “Reggeon” exchange

Nothing is Ever Simple…

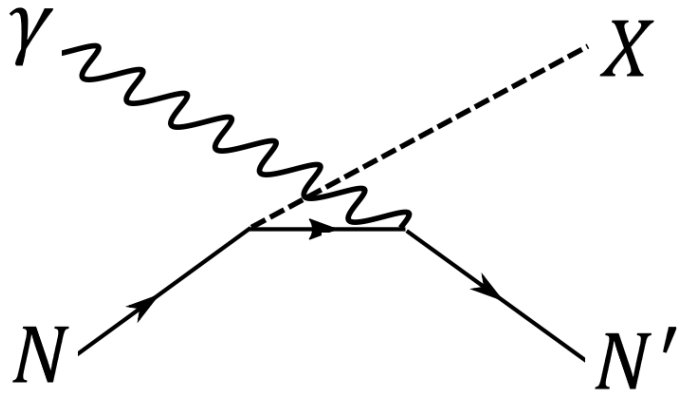
s-channel



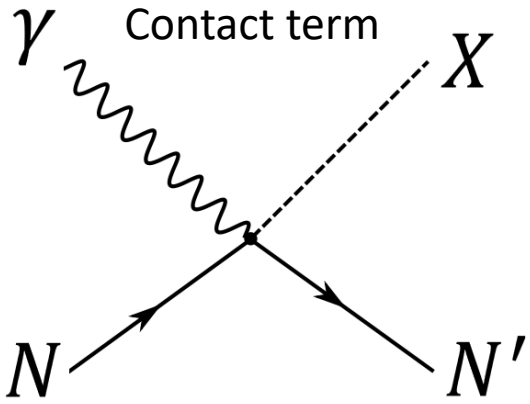
t-channel



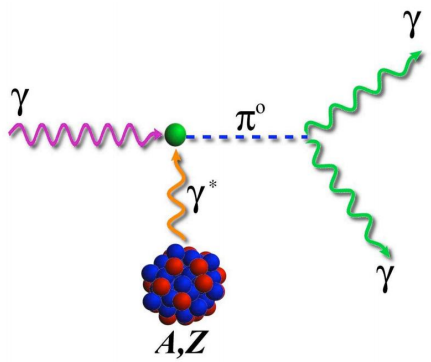
u-channel



Contact term



Primakoff



Pick a Model (Any Model?)

You'll want:

- Dependence of cross section:
  - E_{beam}
  - Mandelstam t (equivalently $\cos\theta_{CM}$)
- Experimental beam E spectrum

Options for η @ GlueX-JEF

- Isobar
- t-channel Regge exchange
  - Laget
  - JPAC (J. Nys)
- Effective Field Theories
- Dispersion relations
- Mix-and-match (etaMAID)
- …

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genEtaRegge Event Generator

Finally something practical!

Setup:

- Set up your environment (workshop instructions)

➢ `git clone https://github.com/JeffersonLab/gluex_workshops/`

➢ `cd NewLightPhys_2021`

➢ `source JEF_MC_env.(c)sh`

➢ `genEtaRegge -N1000 -Ieta_3piq_evtgen.in -R30330`

Some Notes on genEtaRegge

- Model of Laget (Primakoff + Regge exchange)
- Inputs:
  - eta548.in (model parameters, selects η decay mode)
  - cobrems.conf (beam parameters)
- Outputs:
  - Hddm file
  - Root file

Decay Kinematics: EvtGen

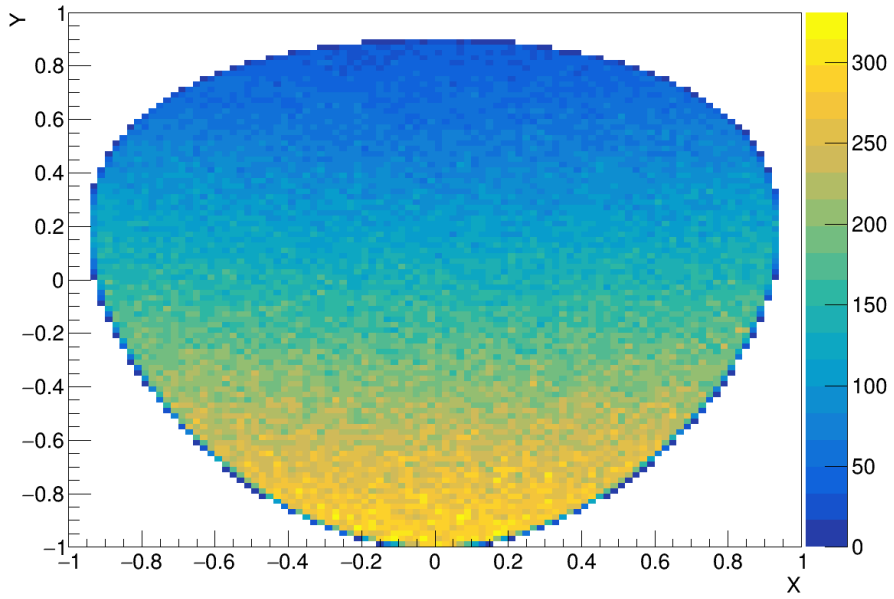
- Spin-0 η
- 3+ body decays still carry energy dependence

In GlueX software framework

➢`decay_evtgen eta_gen.hddm -udecay_eta_3piq.dec`

Simulated Distribution

"ETA_DALITZ_GLUEX" sim



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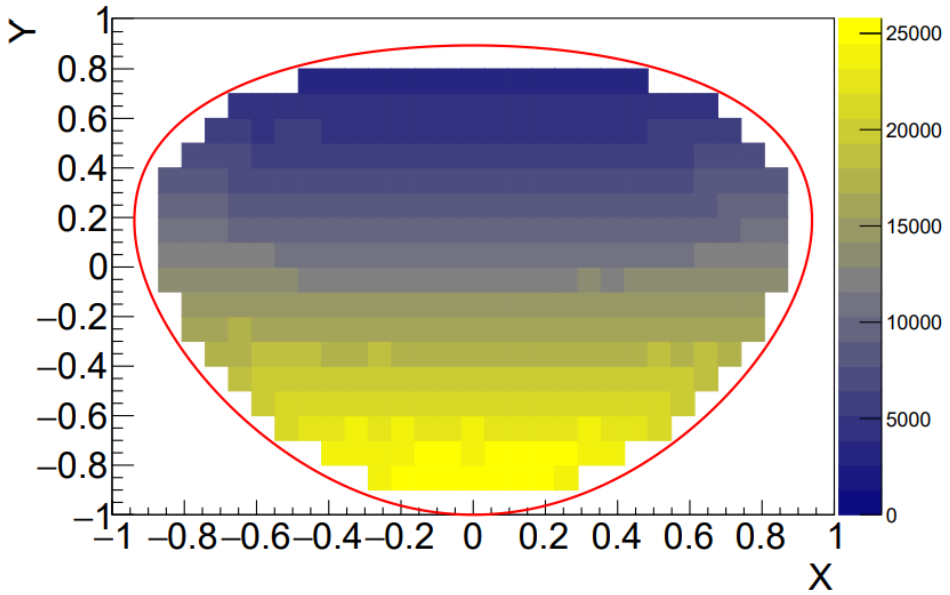
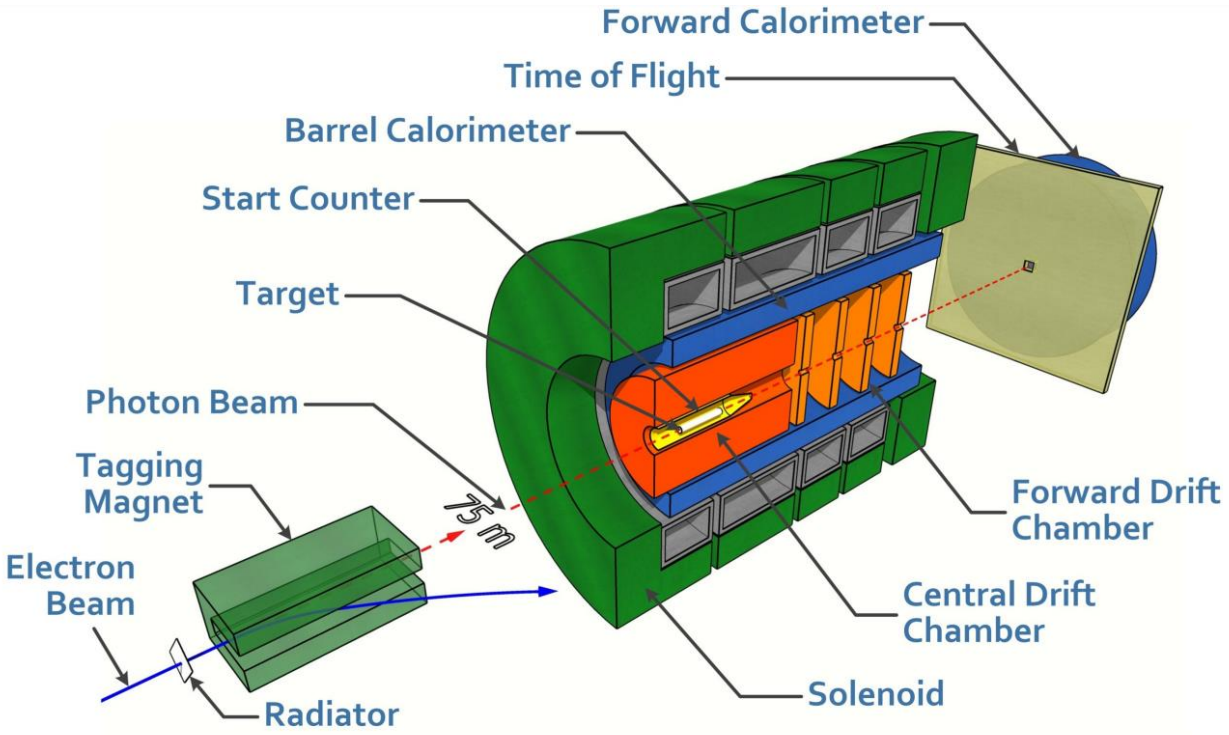


Notes on EvtGen

- Primarily developed for B, D, quarkonia meson decays
- Use across many experiments
- Generalized or custom models
- Incorporates
  - Sets of interfering amplitudes
  - Final state radiation (via PHOTOS)
  - Angular + time dependent processes (CP-violating simulation)
- https://evtgen.hepforge.org/

Simulating Passage Through Detector

- Geant4 remains industry standard
- Implemented as hdgeant4
  - “hd” for JLab Hall D facility
  - Material maps for GlueX
  - Bugfixes, workarounds, etc.
- Data-driven detector noise
  - “Random triggers” during data collection
  - 50 Hz



Running hdgeant4

control.in file (included) contains all config options for geant4

(e.g. we'll use TRIG card to simulate only 100 events)

To run:

- `hdgeant4`

Geant4: The GlueX Experience

- Simulation of photons, charged tracking quite reliable
- Simulation of hadrons in thick material is tricky!
  - Splitoffs, timing tails, etc. may not be precisely
- FLUKA also proved useful in narrow use cases

Hit-Level Response

- Handled by “mcsmear” program
  - Resolution/granularity of detectors
  - Fold in data-driven backgrounds obtained from real data taking

- To run:

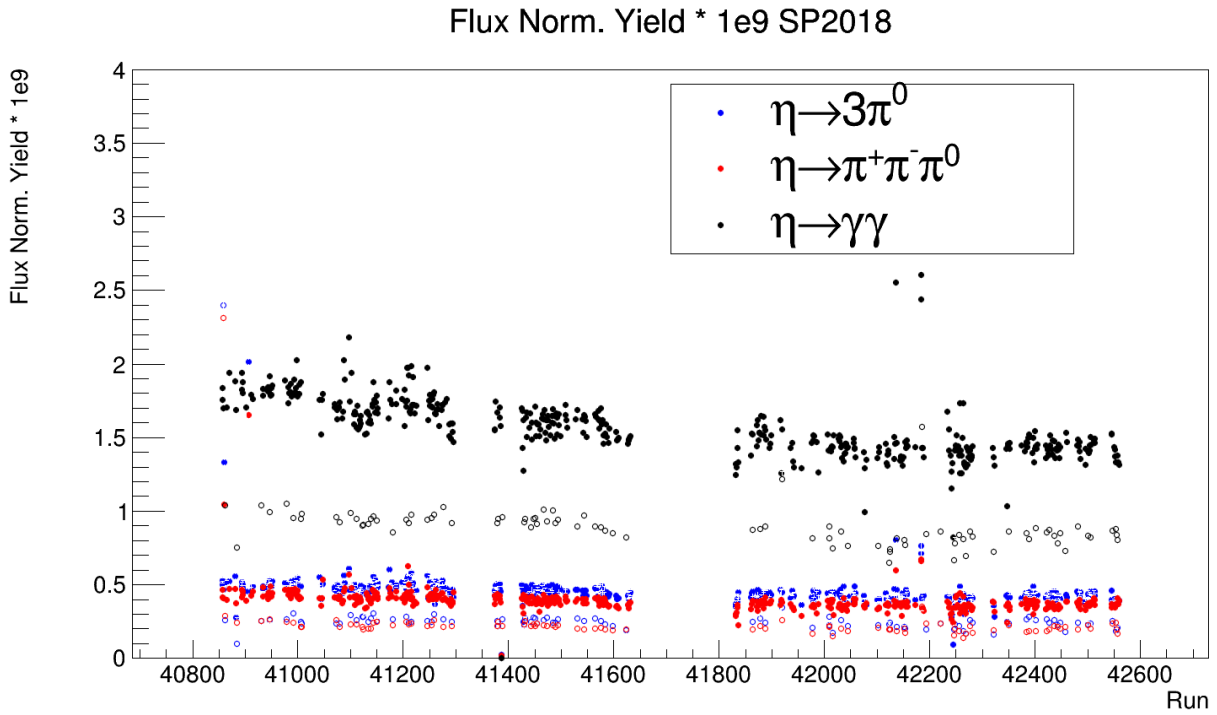
➢ `mcsmear eta_3piq_geant4.hddm \`
`/group/halld/www/halldweb/html/gluex_simulations/rand_trig/ run030330_random.hddm:1`

(If you can’t see run030330_random, then first do:)

➢ `wget https://halldweb.jlab.org/gluex_simulations/rand_trig/run030330_random.hddm`

Comments on “mcsmear”

- Calibrations are contained in external databases (sqlite or mysql)
  - One for subdetector calibration numbers (ccdb)
  - Another for global run conditions (rcdb)
  - Runtime option allows one to use previous versions of database by calendar time
- Our experience: time-dependence matters!



Reconstruction & Analysis

- hd_root program with selected plugins:
  - Performs reconstruction, combo-ing, kinematic fitting, …
  - Plugins to run, reactions, other configurations in `hd_root_Eta3piq.config`
  - Events matching specified topology saved to ROOT trees
- To run:

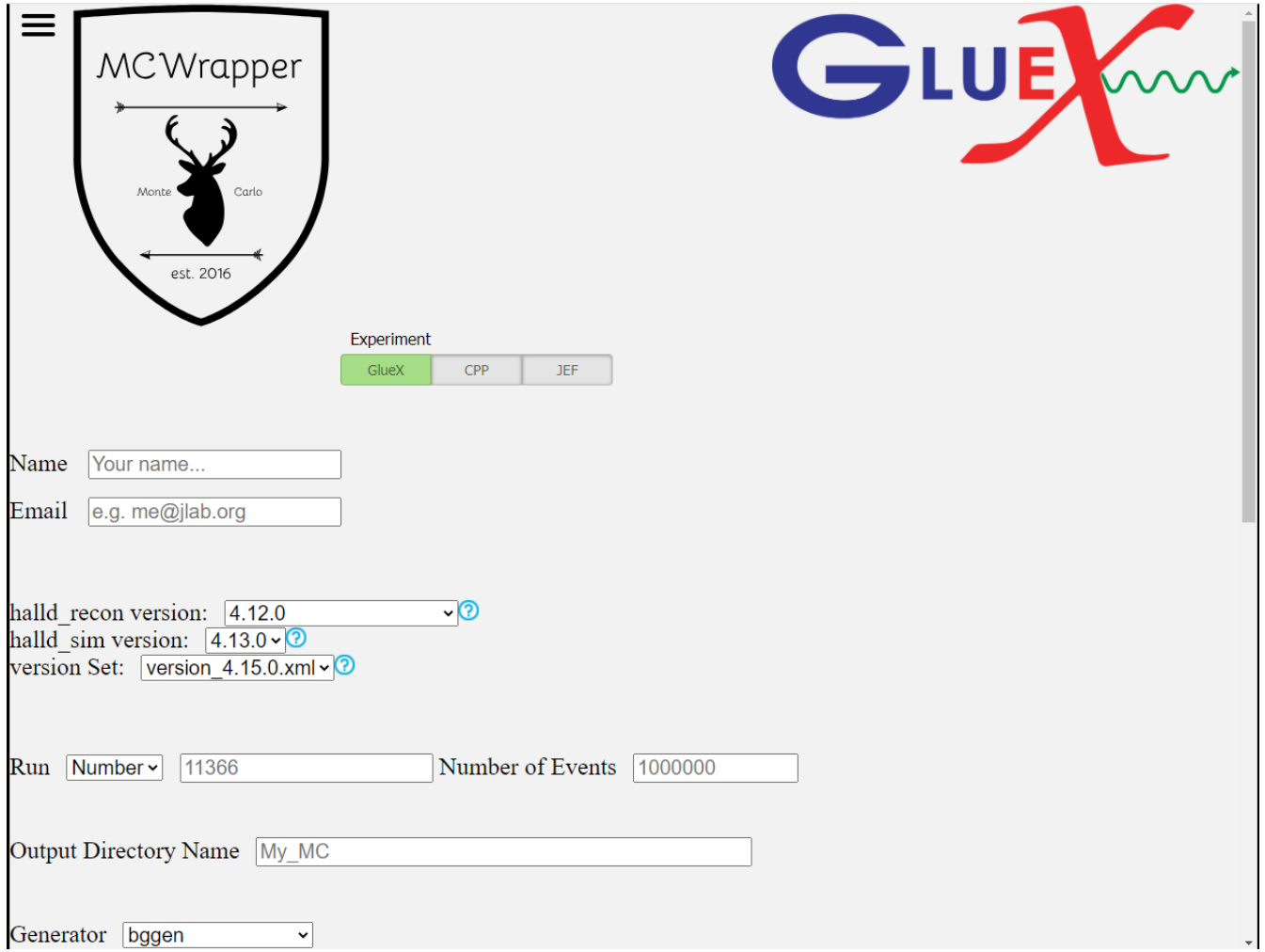
➢ `hd_root --config=hd_root_Eta3piq.config eta_3piq_geant4_smeared.hddm`

MCWrapper

- Set of scripts to bundle up simulation steps
- To run:
- `cd MCWrapper`
- `$MCWRAPPER_CENTRAL/gluex_MC.py MC_eta_3piq.config 30330 10`

- `MC_eta_3piq.config` contains details of config
  - Check out $MCWRAPPER_CENTRAL/examples/ for more configuration options

MCWrapper Web Submission



Submit to Open Science Grid via software containers

https://halldweb.jlab.org/gluex_sim/SubmitSim.html (JLab credentials required)

Inclusive Background Simulation

- `bggen`: Pythia tuned for photoproduction at GlueX
- Let's try using MCWrapper this time:

➢ `cd bggen_MCWrapper`

➢ `$MCWRAPPER_CENTRAL/gluex_MC.py MC_bggen.config 30330 100`

What's next?

- Tighter event selection, more combinatorics, actual analysis
- DSelectors (expanded from TSelectors) generally used
  - Session 3a https://halldweb1.jlab.org/wiki/index.php/GlueX_Physics_Workshop_2016
  - Github repo: https://github.com/JeffersonLab/gluex_root_analysis

So Summarizing…

Starting fresh with a new idea?

- Think of production mechanism for generator
  - EM: analytical
  - Primakoff: very forward, mostly analytical
  - Hadronic: beam energy dependent
    (exponentially decreasing in t often works…)
- Consider decay, or at least general spin-structure
  - Recalling: some targets, beams are polarizable

So Summarizing…

Putting idea into practice

- Properly tuned simulations (resolutions and efficiencies in particular)
- Bundle up simulation steps
  - Share with others!
- Scale up simulations:
  - Computing resources
  - Software deployment
  - Ease of access to calibration database
- Thanks for tuning in!

All Commands

Setup:

- Set up your environment (workshop instructions)
  - `git clone https://github.com/JeffersonLab/gluex_workshops/`
  - `cd NewLightPhys_2021`
  - `source JEF_MC_env.(c)sh`

`Individual simulation steps`

- `genEtaRegge -N1000 -Ieta_3piq_evtgen.in -R30330`
- `decay_evtgen eta_gen.hddm -udecay_eta_3piq.dec`
- `hdgeant4`
- `mcsmear eta_3piq_geant4.hddm /group/halld/www/halldweb/html/gluex_simulations/rand_trig/run030330_random.hddm:1`
  - (If you can't see run030330_random, then first do:)
  - `(wget https://halldweb.jlab.org/gluex_simulations/rand_trig/run030330_random.hddm)`
- `hd_root --config=hd_root_Eta3piq.config eta_3piq_geant4_smeared.hddm`

Or with MCWrapper

- `cd MCWrapper`
- `$MCWRAPPER_CENTRAL/gluex_MC.py MC_eta_3piq.config 30330 10`

bggen background:

- `cd bggen_MCWrapper`
- `$MCWRAPPER_CENTRAL/gluex_MC.py MC_bggen.config 30330 10`

More Resources

- 2013 workshop https://halldweb1.jlab.org/wiki/index.php/GlueX_Analysis_Workshop_2013
- 2016 workshop https://halldweb1.jlab.org/wiki/index.php/GlueX_Physics_Workshop_2016

Most core functionality unchanged

- GlueX/JEF simulation repository
  - https://github.com/JeffersonLab/halld_sim
  - More complicated hadronic generators rely on AmpTools (https://github.com/mashephe/AmpTools)

- MCWrapper:
  - Documentation: https://www.overleaf.com/project/5bb7b3423bb4c259308b56c5
  - Github: https://github.com/JeffersonLab/gluex_MCwrapper/