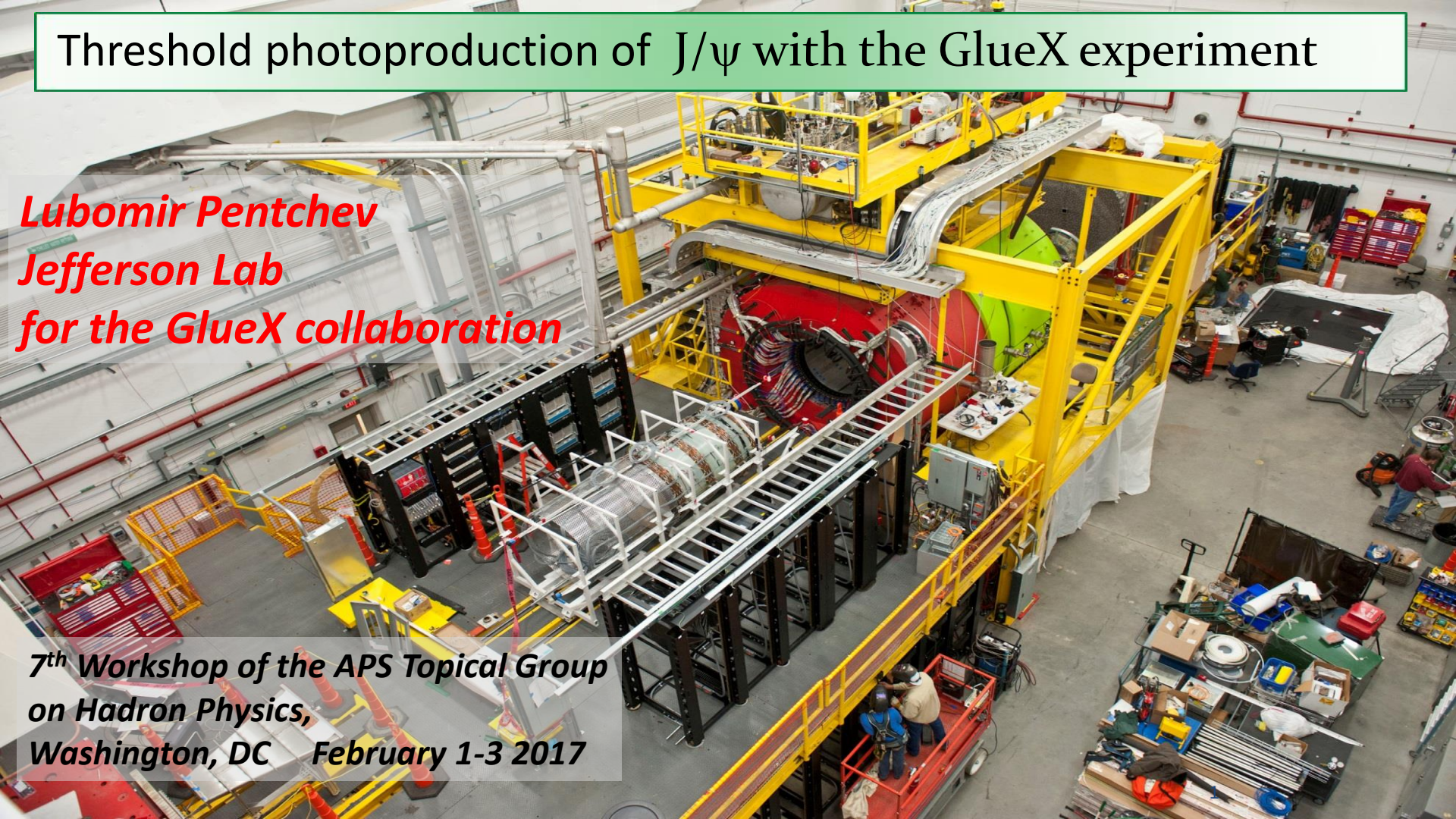
Threshold photoproduction of J/ψ with the GlueX experiment



Lubomir Pentchev
Jefferson Lab
for the GlueX collaboration

7th Workshop of the APS Topical Group on Hadron Physics,
Washington, DC February 1-3 2017

What's in the talk

- *Motivation*
- *The GlueX Detectors*
- *Electron identification*
  - *Using calorimeters*
- *Early results from engineering run (~7 pb^{-1})*
  - *Di-electron invariant mass spectrum:* $\gamma p \rightarrow p\, e^+ e^-$
  - *J/ψ photoproduction – energy and t-dependence:*

    $\gamma p \rightarrow p\, J/\psi, \quad J/\psi \rightarrow e^+ e^-$
- *Future plans – more statistics*
  - *(Improved PID with Transition Radiation Detector)*

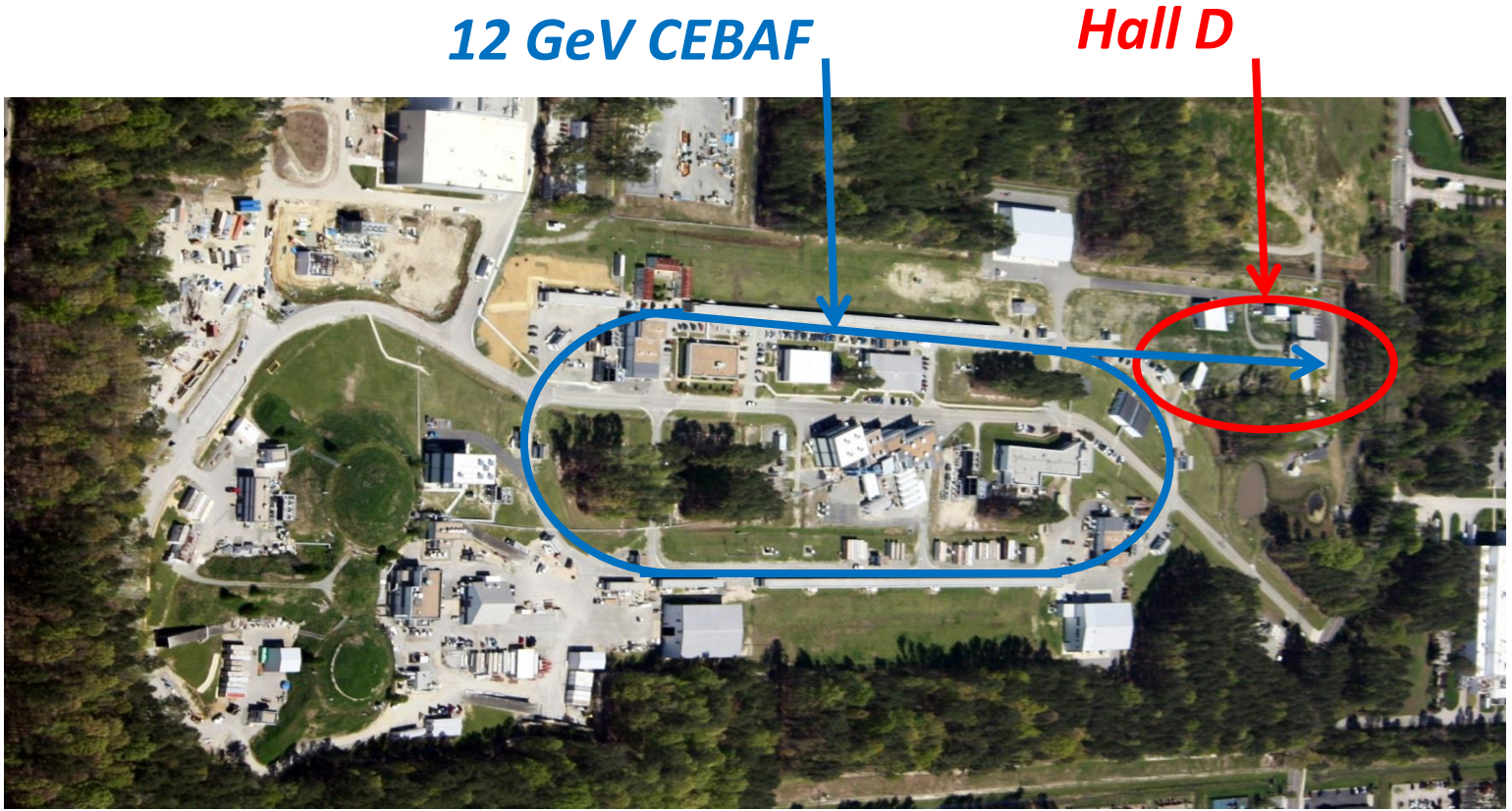
No absolute results will be shown!

This work done in collaboration with Northwestern University group: Prof. K. Seth (leader and initiator of the project), S. Dobbs, and L. Robison (Ph.D. student)

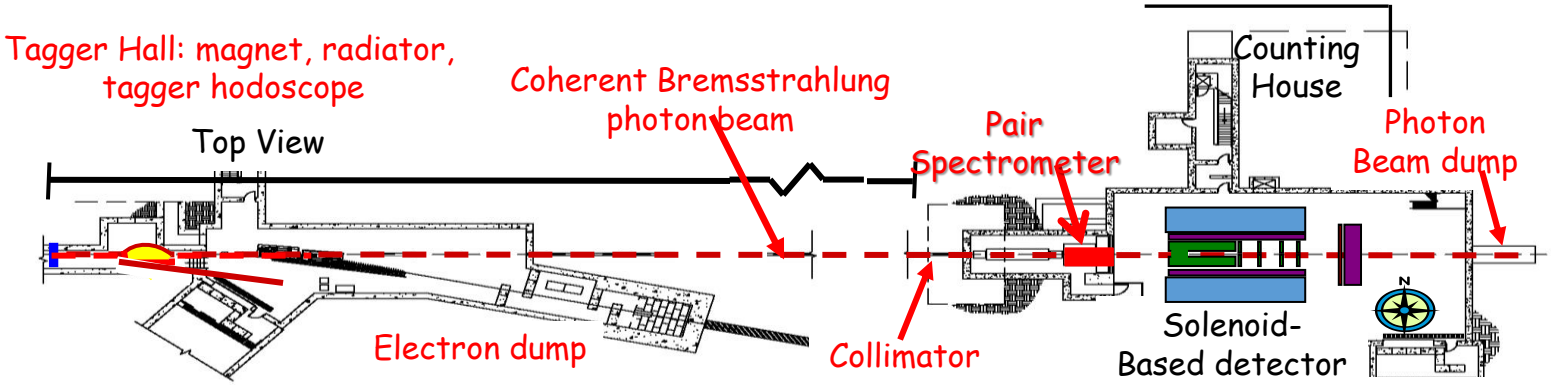
Motivation

- *For J/ψ photoproduction - limited data exists in the low energy region: from SLAC [Camerini et al. PRL 35, 389 (1975) and Cornell [Gittelman et al. PRL 35, 1616(1975)]*
- *Production mechanism not well understood (more than 40 years after its discovery in 1974) especially near the threshold.*
- *Kharzaev et al. [NPA 661, 568 (1999)] – connection to gluon configuration of the nucleon*
- *Brodsky et al. [PLB 498, 23 (2001)] – near threshold J/ψ photoproduction sensitive to multi-quark correlation in nucleon; made predictions using two- and three-gluon-exchange model*
- *LHCb observed exotic states (pentaquark) P_c (4380,4450) in the p J/ψ channel. If produced in s-channel $\gamma p \rightarrow P_c \rightarrow p\, J/\psi$, will show up at E_γ = 10 GeV, within the GlueX energy range.*

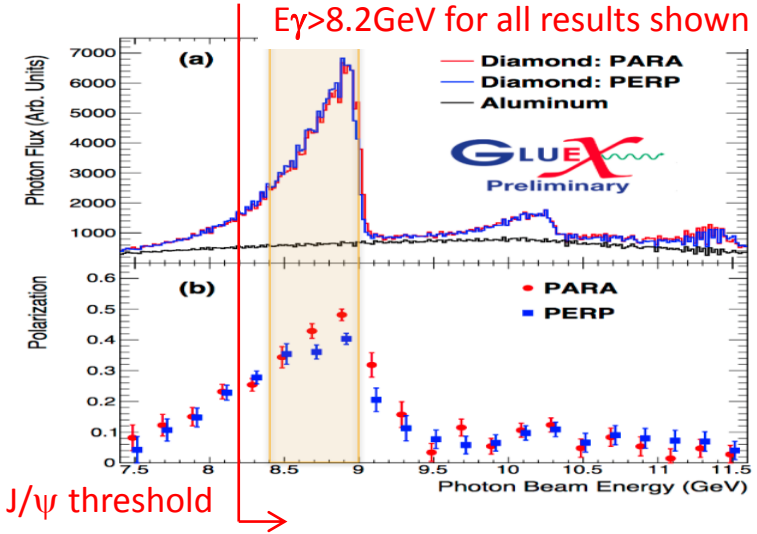
GlueX experiment - Introduction



GlueX experiment – polarized photon beam

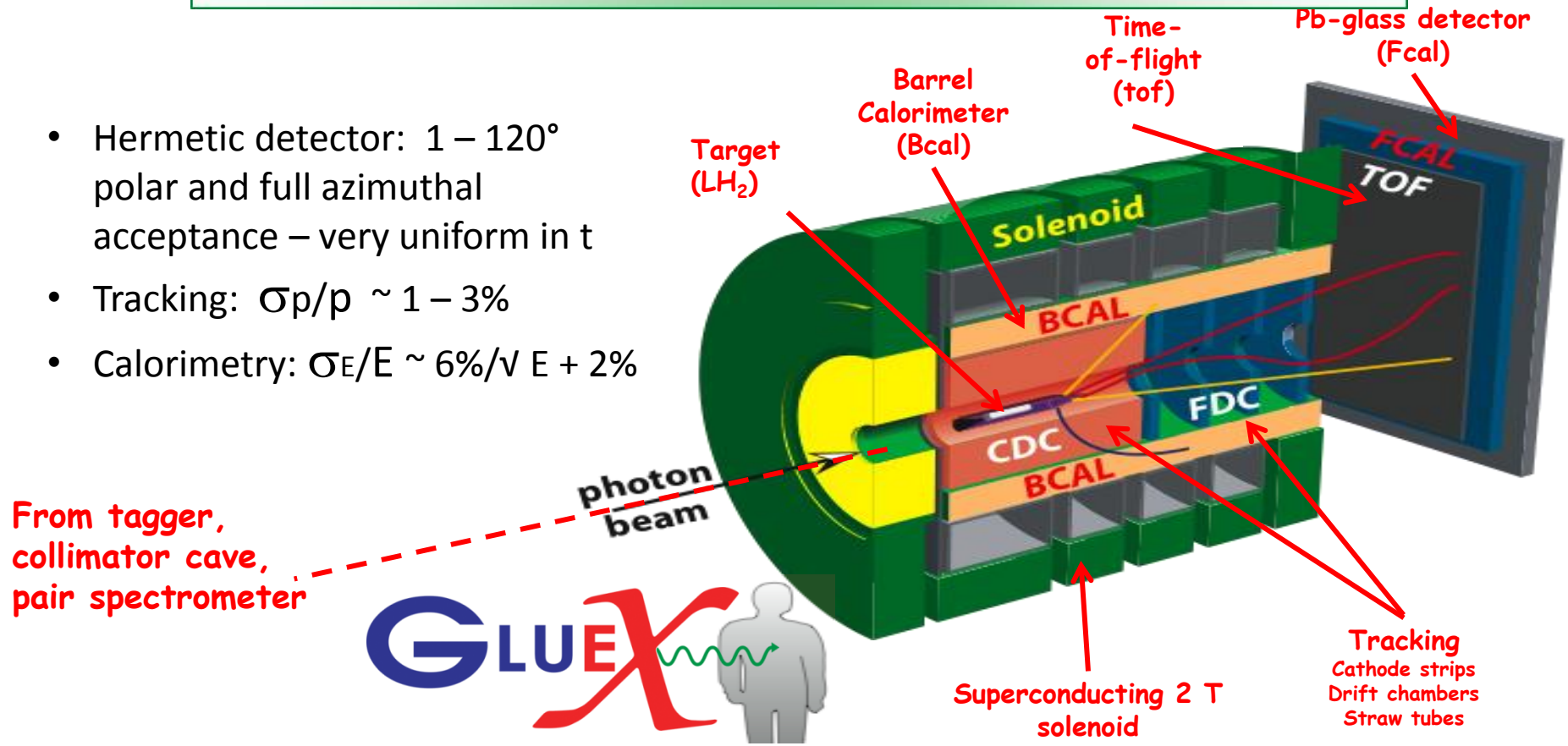


- Electron beam incident on thin diamond radiator produces coherent bremstrahlung
- Photon energy tagged by scattered electron ~ 0.1-0.3% resolution
- Photon beam collimated at 75m, <25 μrad
- Coherent bremstrahlung polarization after collimation up to 40%
- Intensity: now ~ 10^7 γ/sec, later 5 10^7 γ/sec (in the coherent peak)

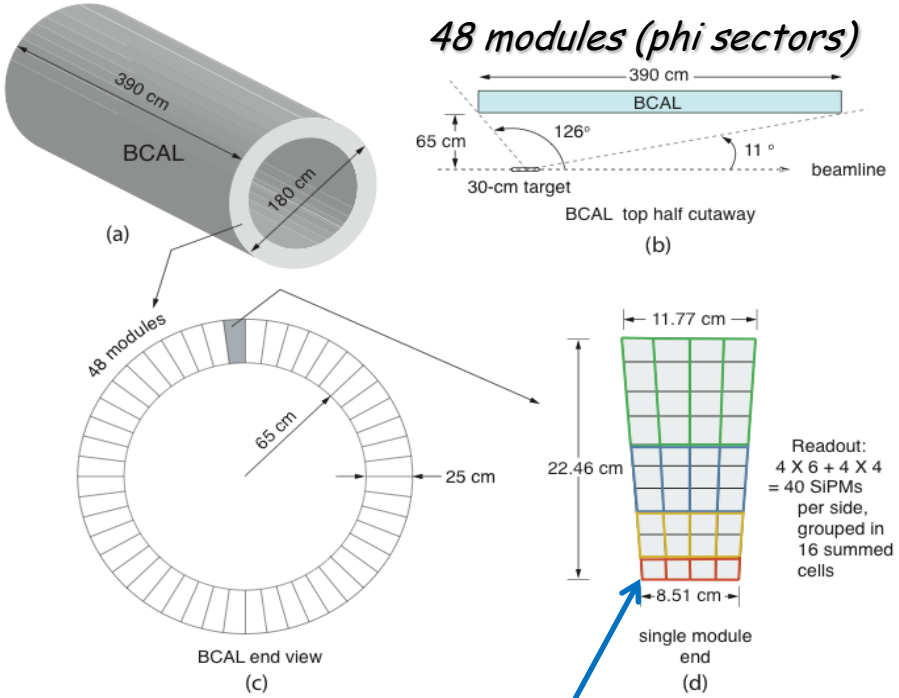


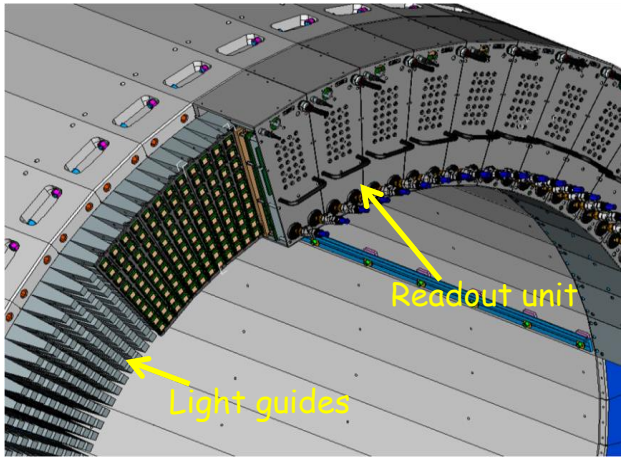
The GlueX detector

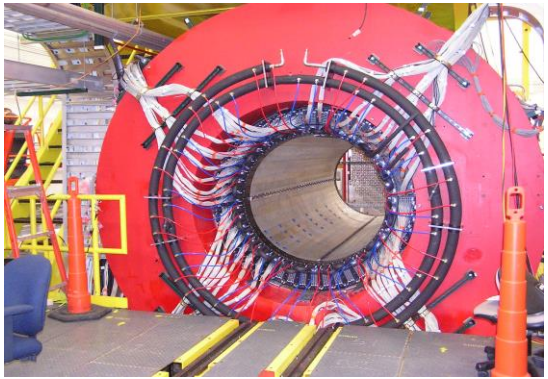
- Hermetic detector: 1 – 120° polar and full azimuthal acceptance – very uniform in t
- Tracking: $\sigma p/p$ ~ 1 – 3%
- Calorimetry: σ_E/E ~ 6%/√ E + 2%



Electron identification – BCAL (barrel calorimeter)

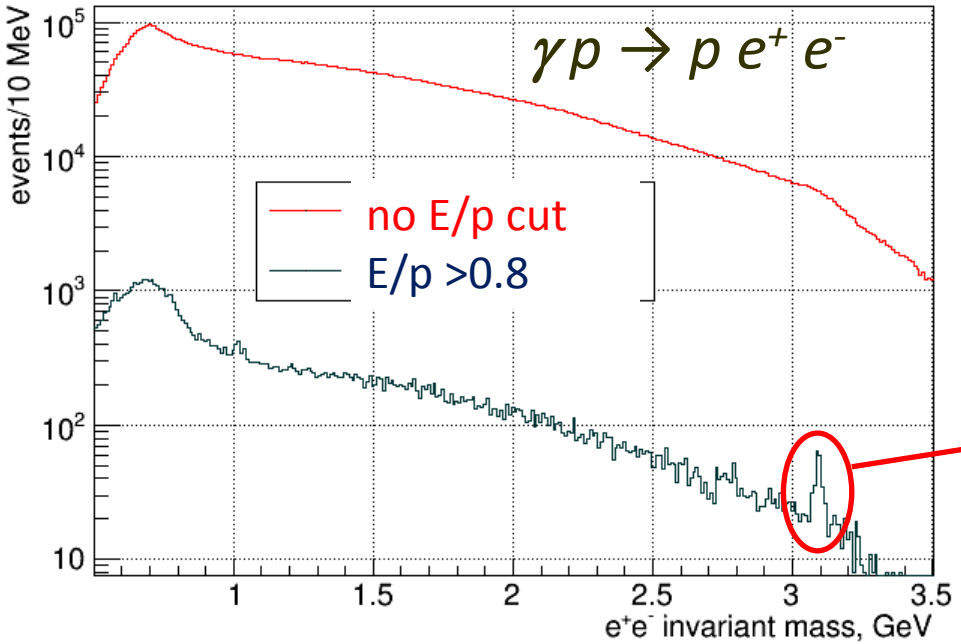




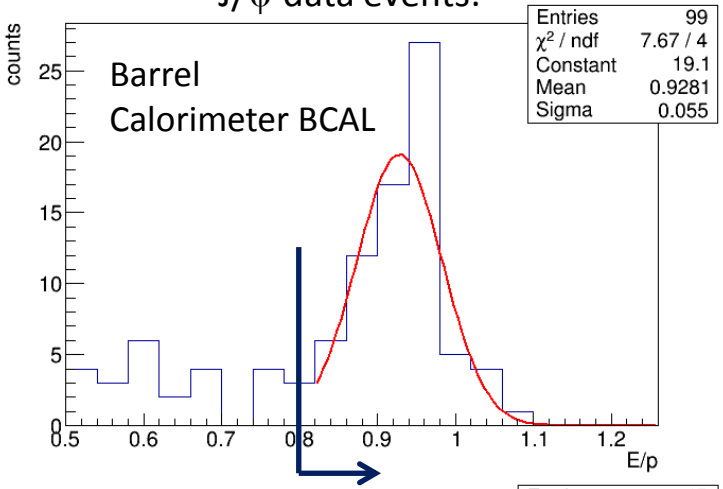


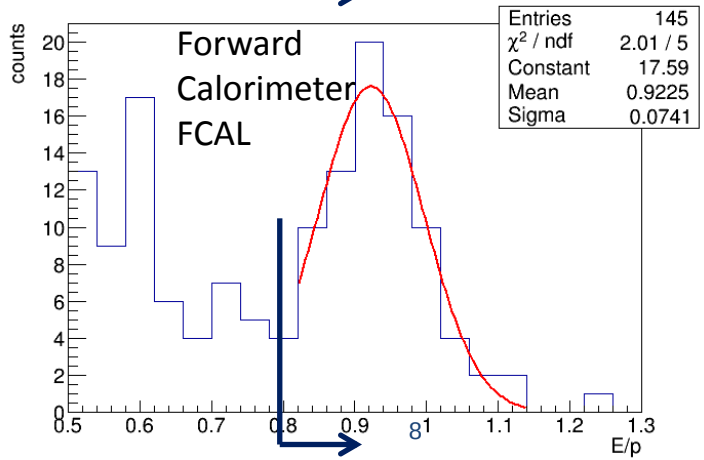
- Radial segmentation can be used for information on longitudinal shower development
- In this studies we use the first layer (out of 10) as pre-shower

Electron identification – using E/p



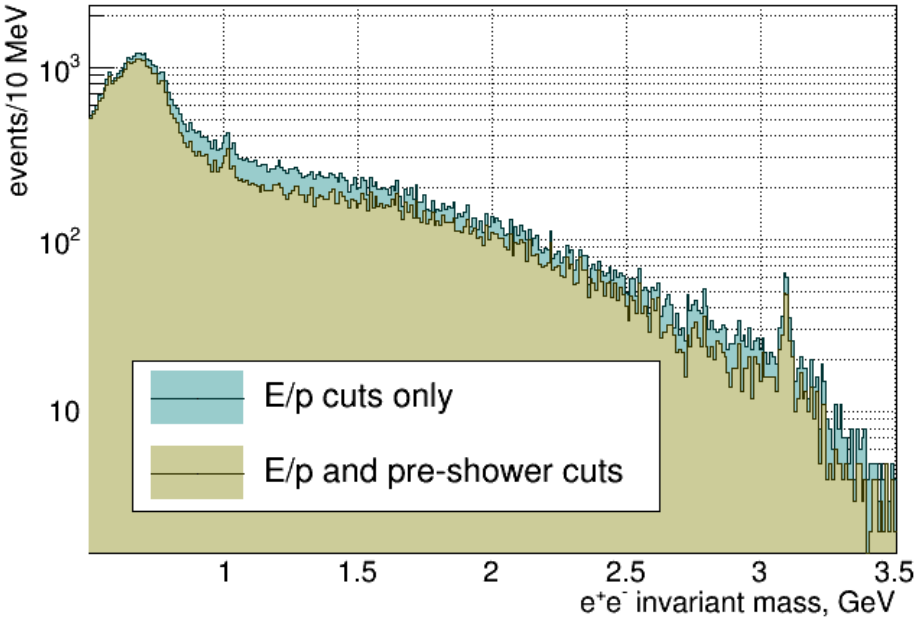
J/ψ data events:

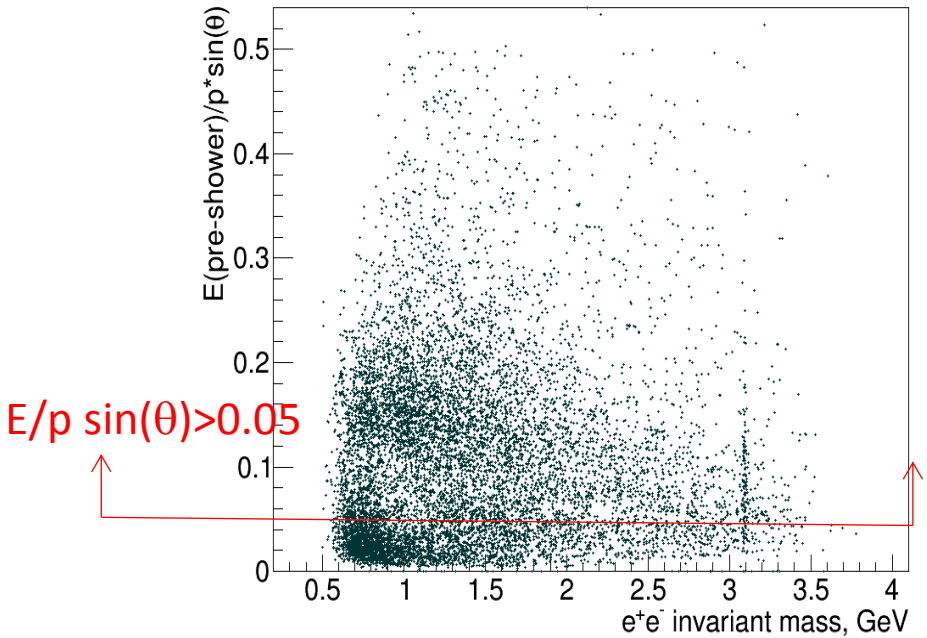




Electrons identified by energy deposition in calorimeters E, relative to momentum from tracking p: E/p

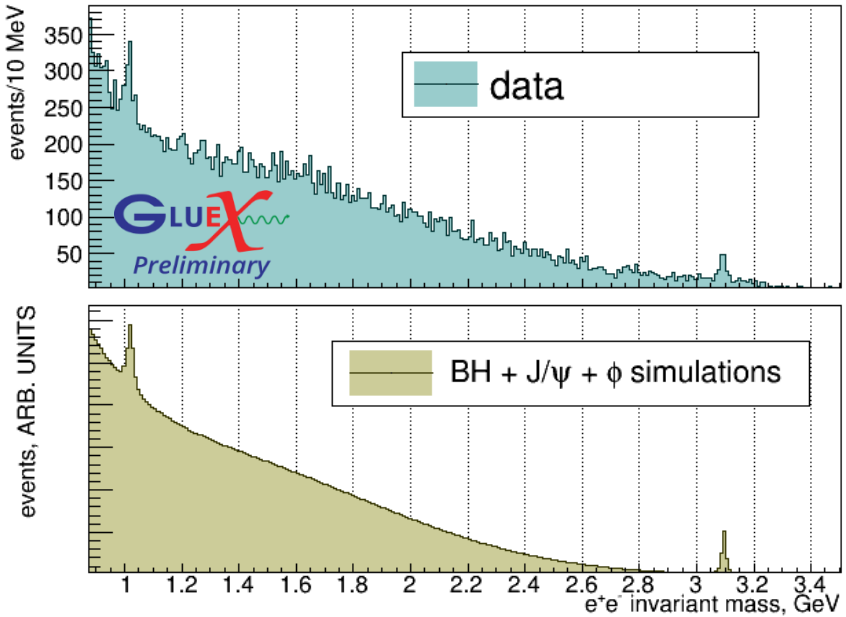
Electron identification – barrel calorimeter as pre-shower

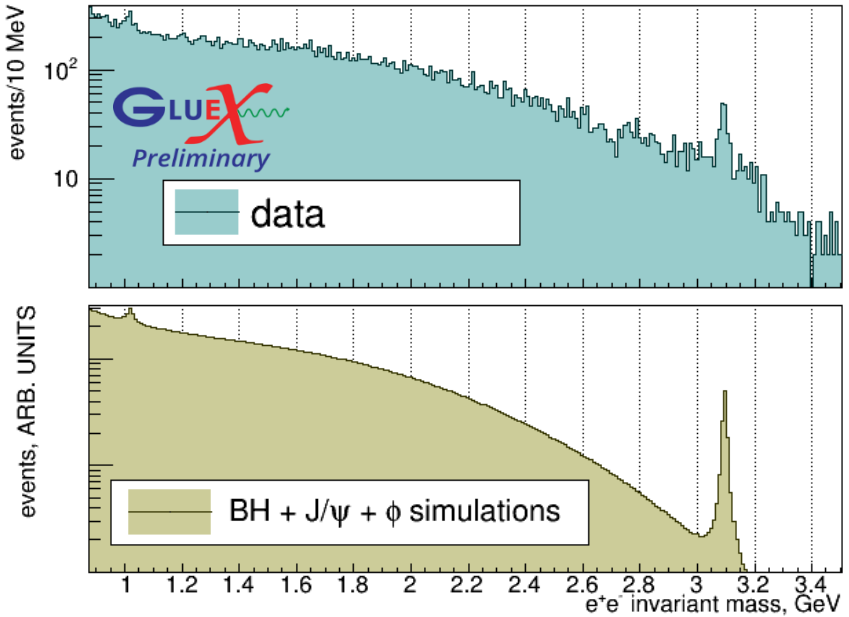




- For high invariant masses at least one of the electrons is in the barrel calorimeter and the pre-shower helps to separate pions
- For invariant masses < 1.5 GeV, electrons in forward direction, higher pion background, requiring better electron identification – Transition Radiation Detector under study

Di-electron Spectrum – comparison to MC



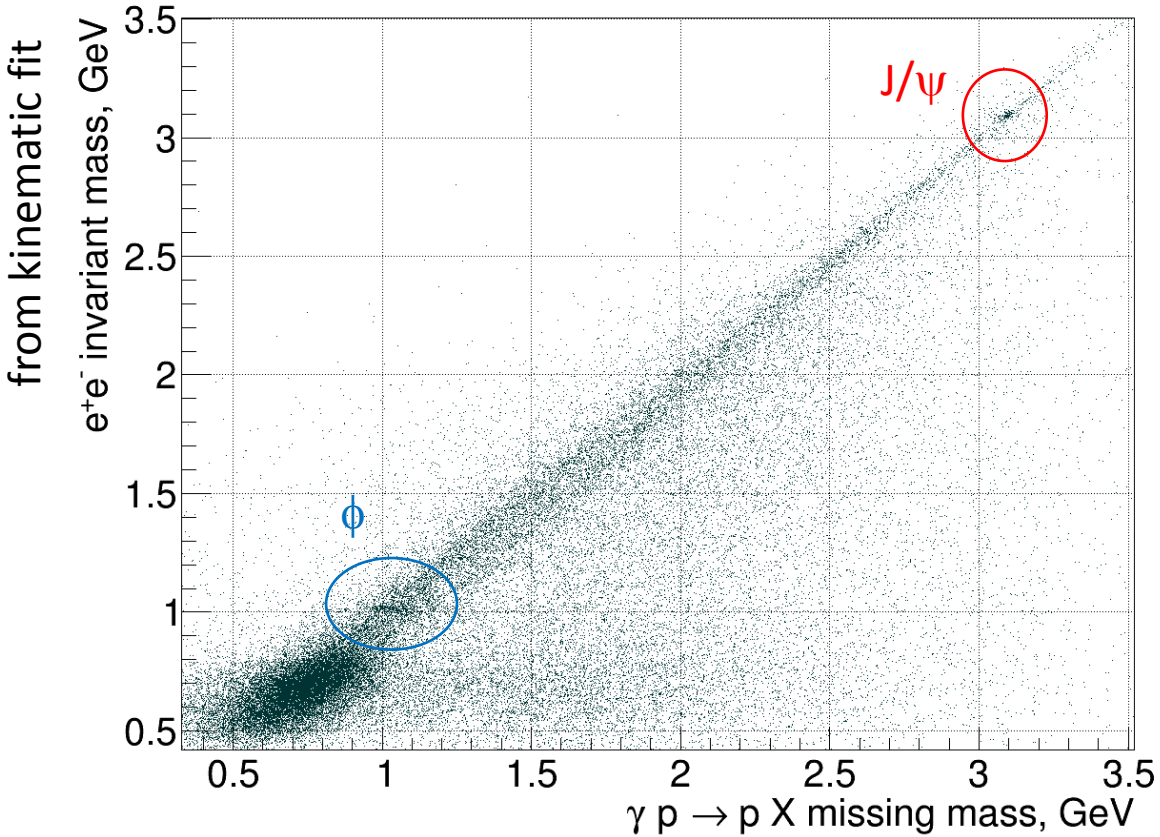


- Bethe-Heitler simulation using code GenTCS (JLab Hall B), based on:

E.Berger, M.Diehl and B.Pire "Time - like Compton scattering: Exclusive photoproduction of lepton pairs"
http://inspirehep.net/record/563798

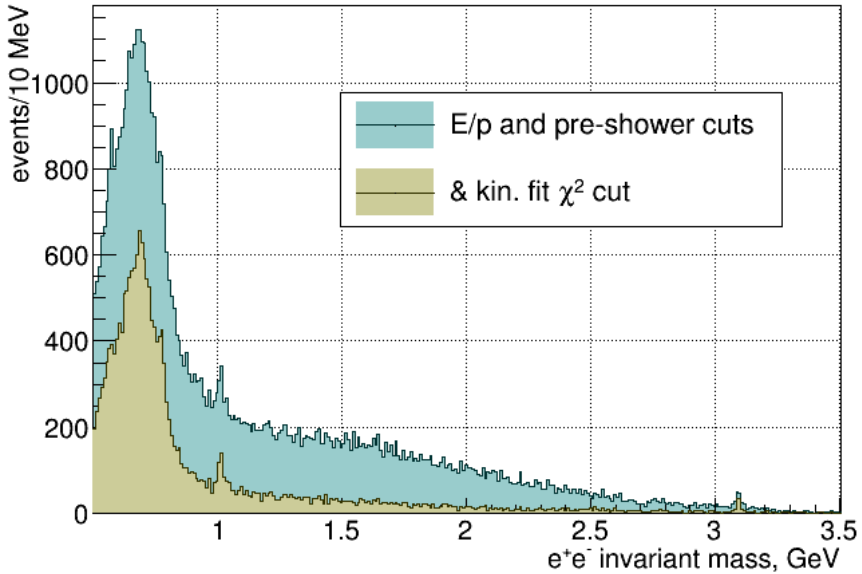
- Generated also J/ψ and ϕ events assuming t-slopes of 1 and 4 GeV^{-2} respectively

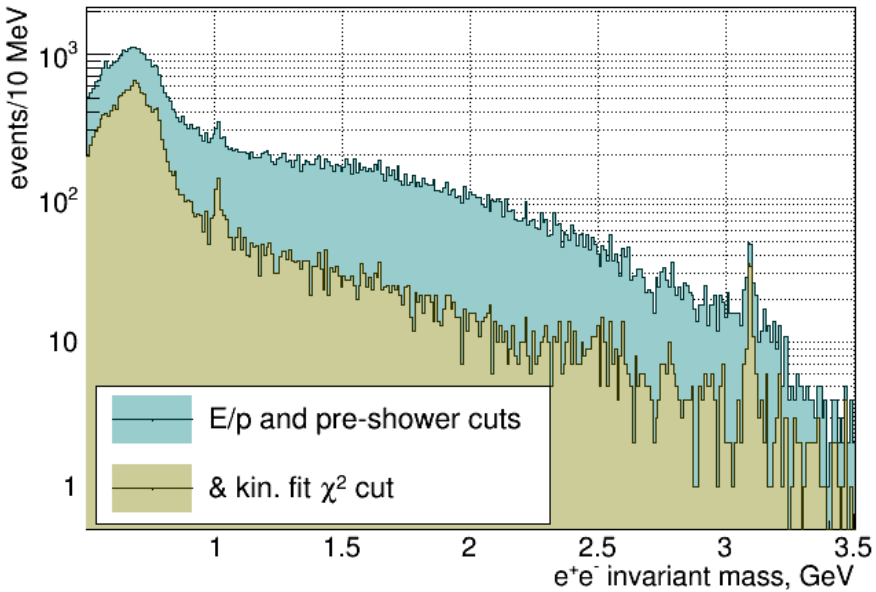
Di-electron Spectrum – kinematic fit vs missing mass



- Another method for invariant mass reconstruction – missing mass of inclusive reaction γ p → p X
- Missing mass has good enough resolution in J/ψ region
- Kinematic fit (without any cuts) needed for lower invariant masses (including ϕ)

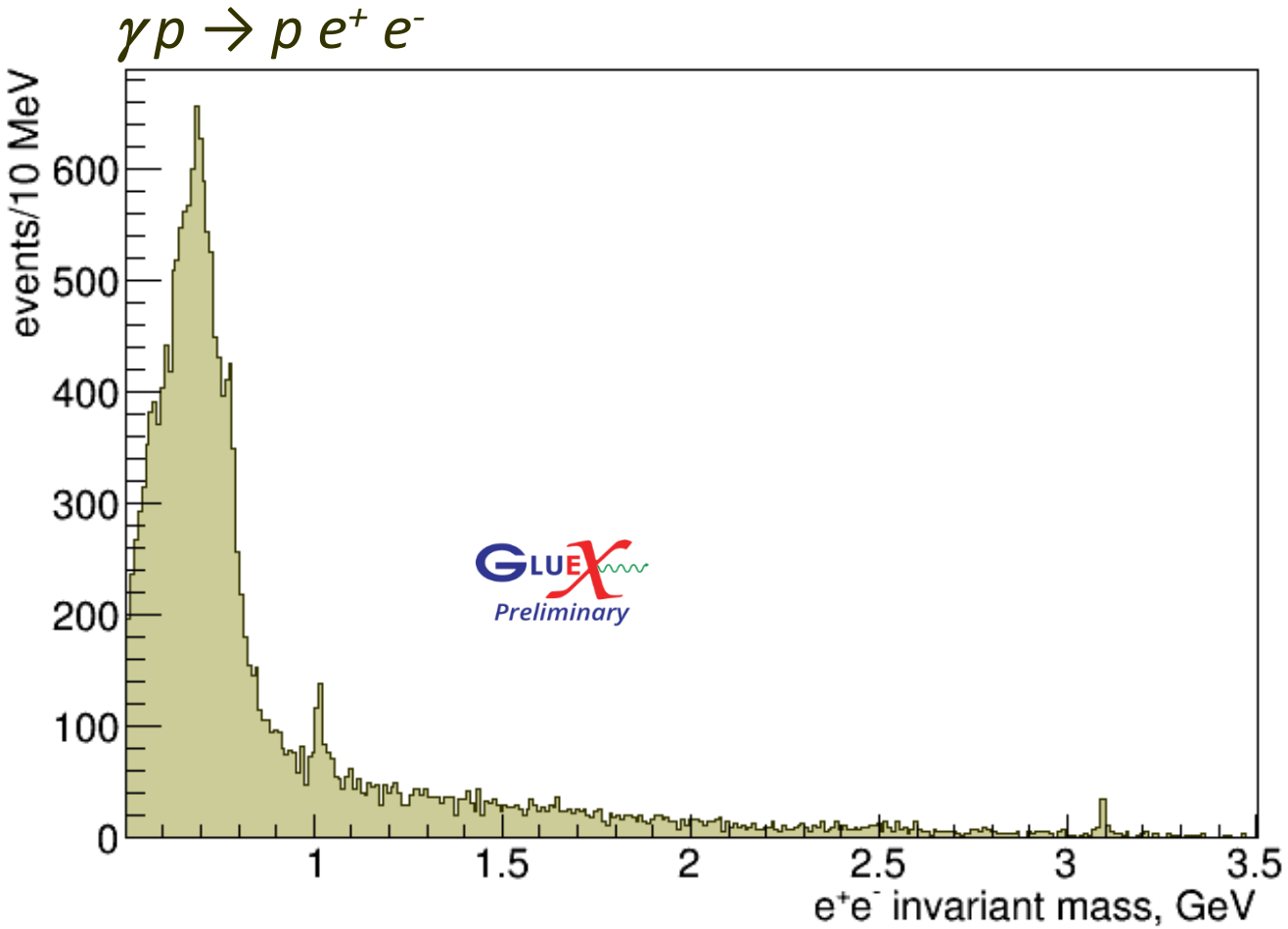
γ p -> J/ψ p background – kinematic fit cut



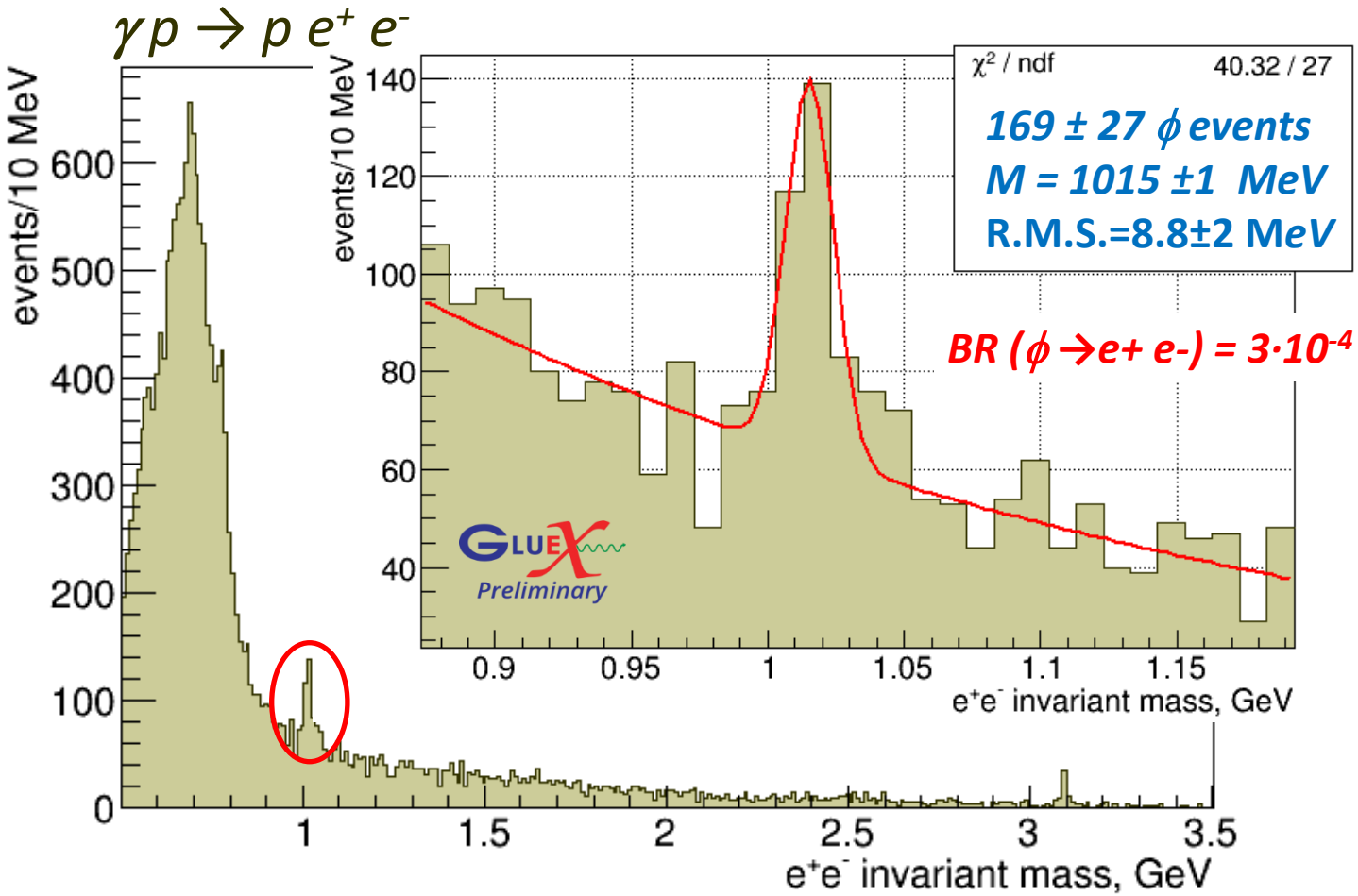


- Applying cut on kinematic fit χ2 that significantly reduces the background, while the signals in J/ψ and ϕ drop only by ~25%

Di-electron Spectrum

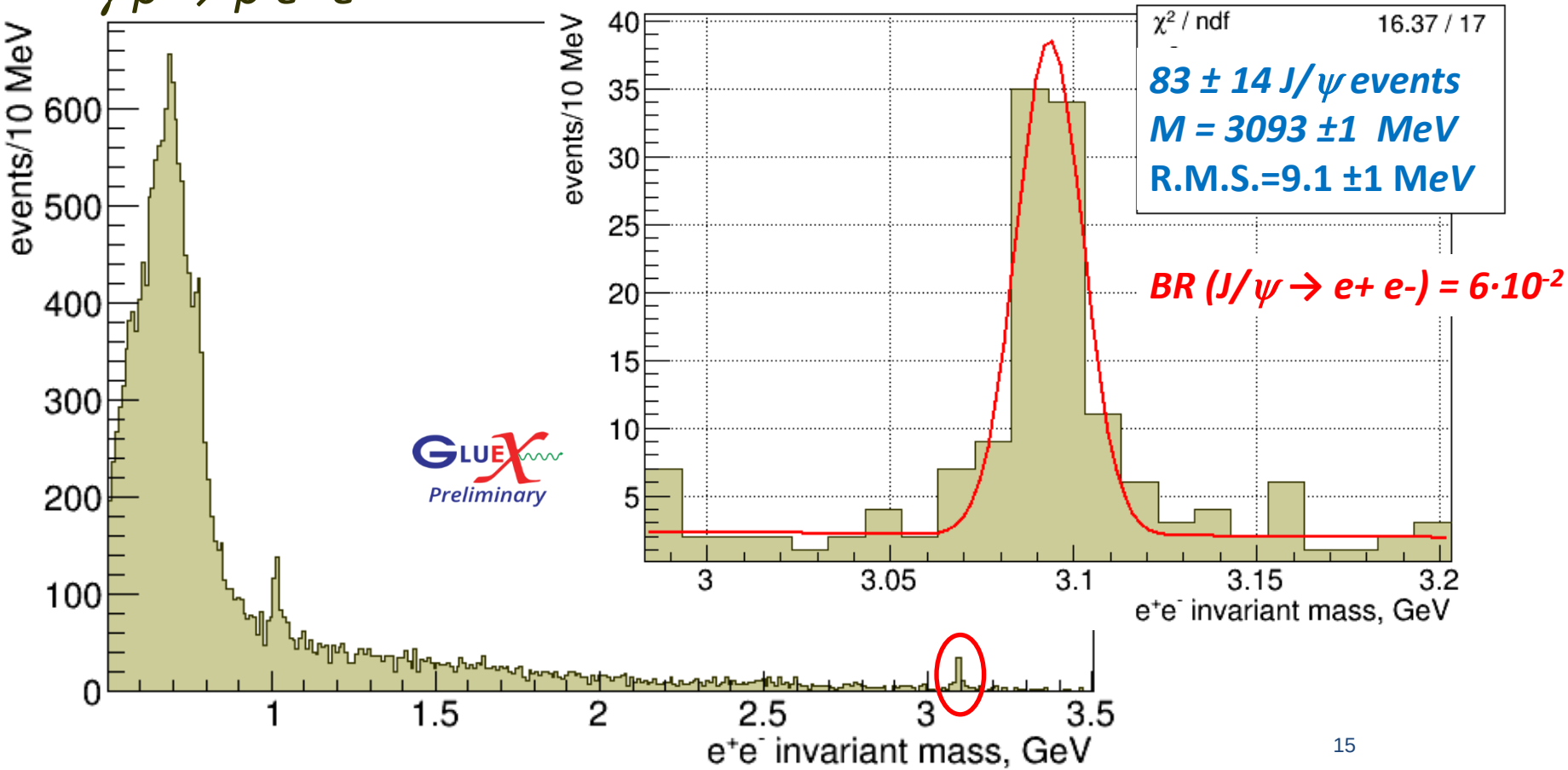


Di-electron Spectrum - ϕ

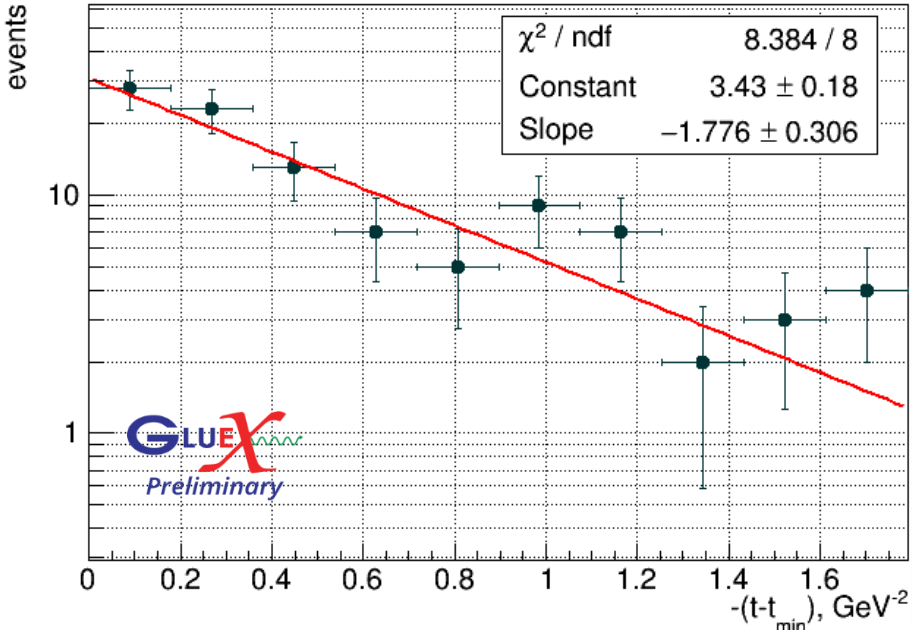


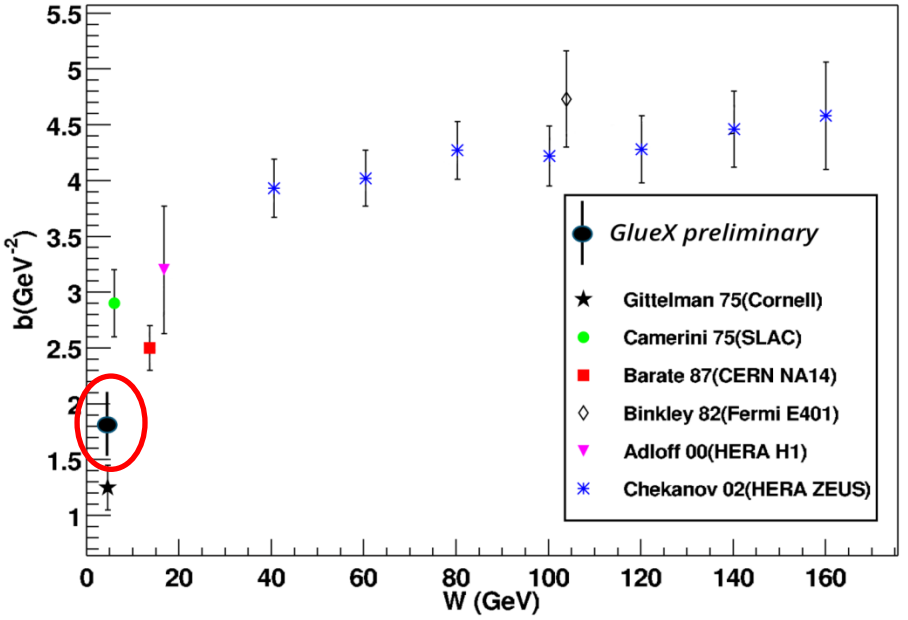
Di-electron Spectrum – J/ψ

$\gamma p \rightarrow p\, e^+ e^-$



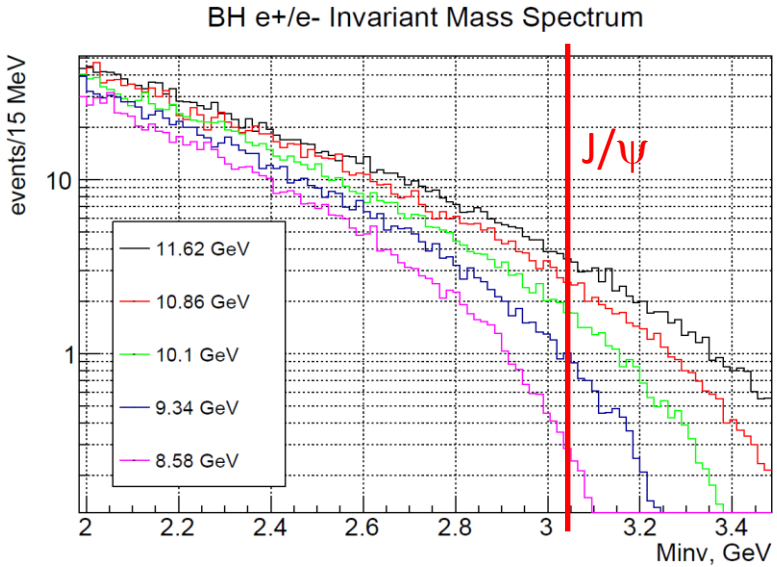
γ p -> J/ψ p t-dependence

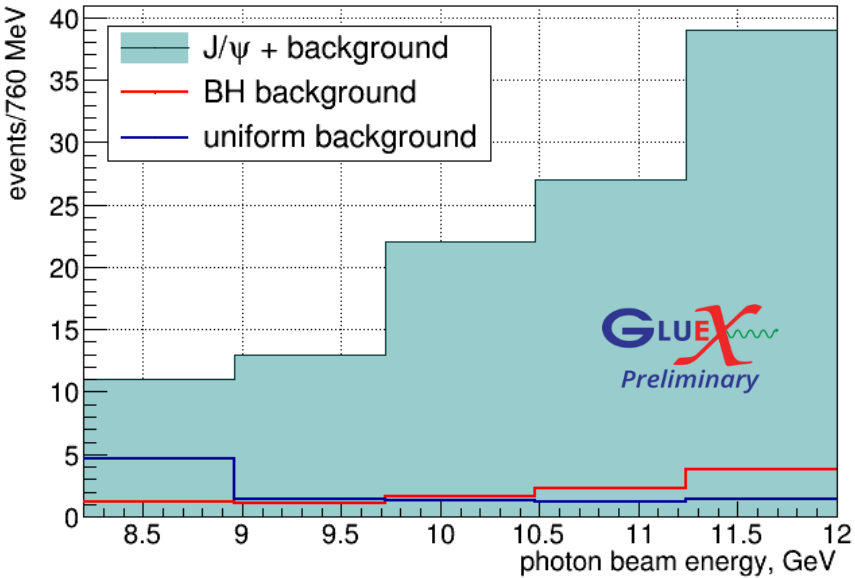




- GlueX has uniform acceptance down to t_{min} (< 10% variations); t_{min} ranges 0.25-1.5 GeV^2
- Average (*4.14-4.9 GeV W-range*) t-slope of -1.8 +/-0.3 GeV^{-2} in agreement with other (mostly high-energy) measurements

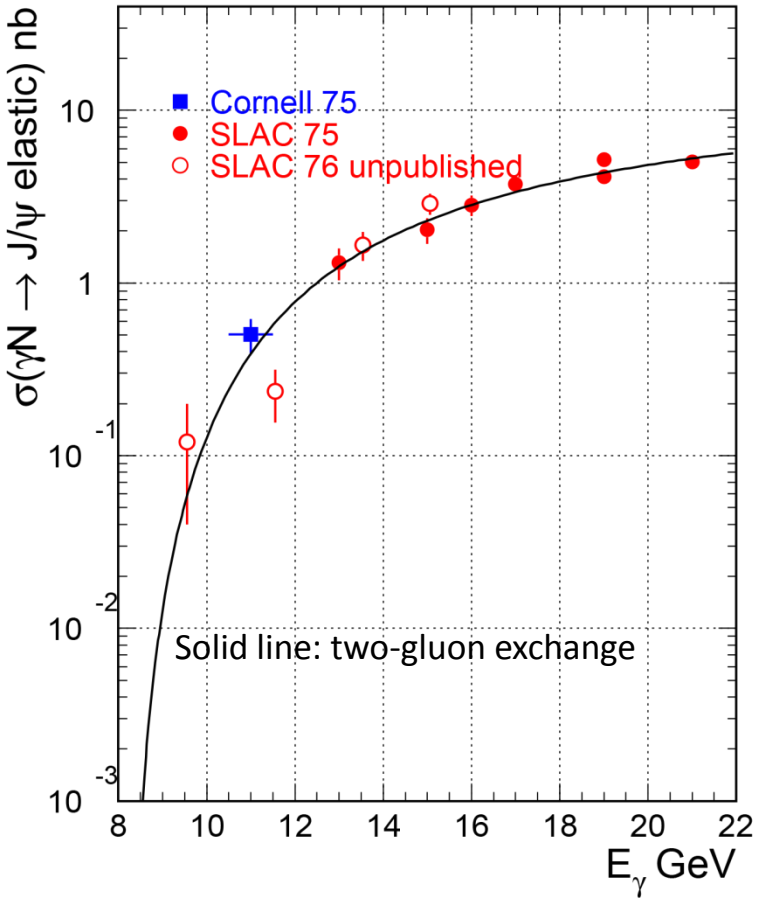
γ p -> J/ψ p - beam energy dependence





Total background under the peak (12 events out of ~100) distributed over the energy bins assuming BH energy dependence (left plot), or uniformly – doesn't make significant difference for the J/ψ energy dependence

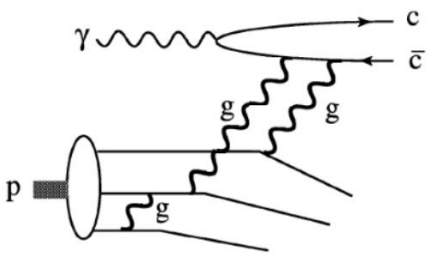
γ p -> J/ψ p cross-section vs beam energy – existing data



Total elastic cross-section extracted from dσ/dt measurements on nuclear targets and re-normalized to total cross-section on proton:

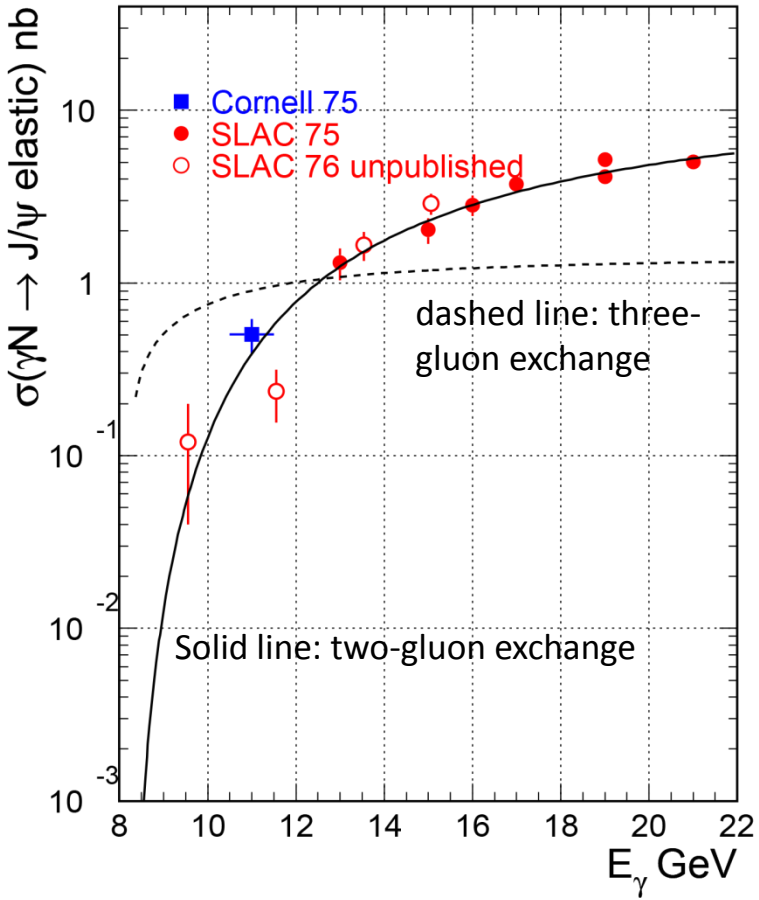
- SLAC data (on data on deuterium target) assuming t-slope of 2.9 GeV^{-2}
- Cornell data (on Be target) with t-slope of 1.25 GeV^{-2}

two-gluon exchange



Brodsky et al. [PLB 498, 23 (2001)]

γ p -> J/ψ p cross-section vs beam energy – existing data



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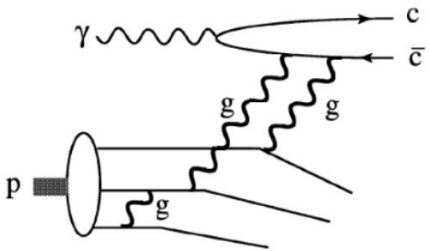
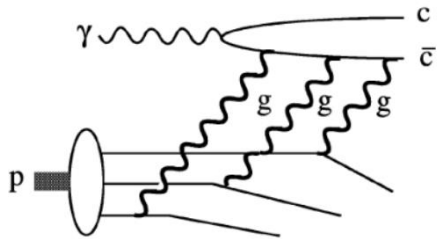


three-gluon exchange

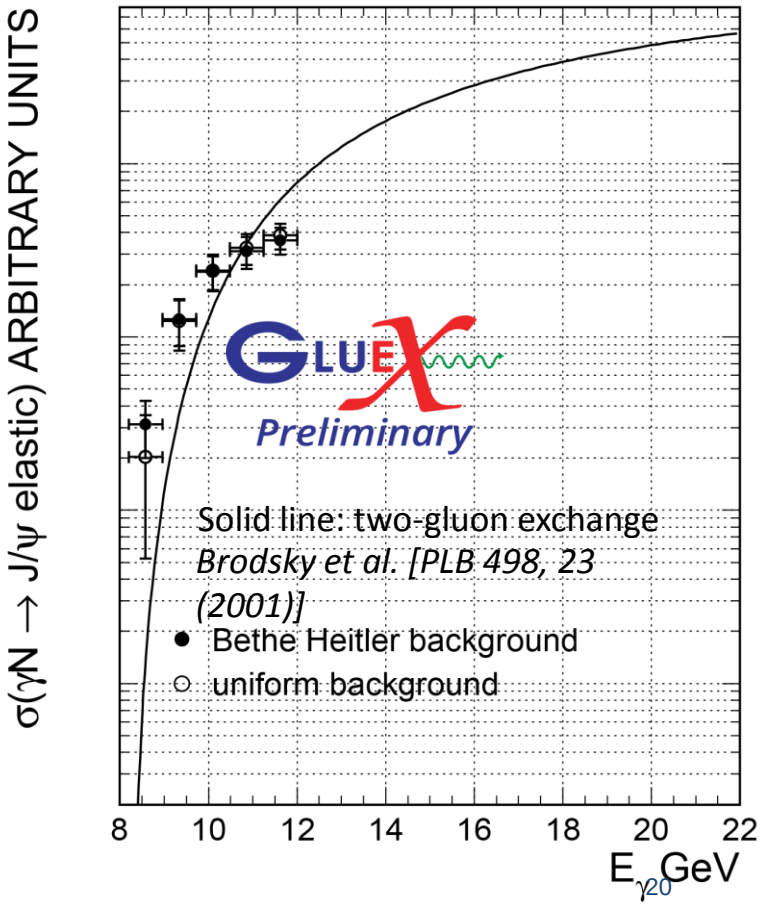


Brodsky et al. [PLB 498, 23 (2001)]

$\gamma p \rightarrow J/\psi p$ cross-section vs beam energy - GlueX

Total elastic cross-section on proton extracted from GlueX data shown without absolute normalization.

The energy slope of the GlueX data, that extends down to the threshold, can be compared to the two calculations (curves normalized to data for comparison)



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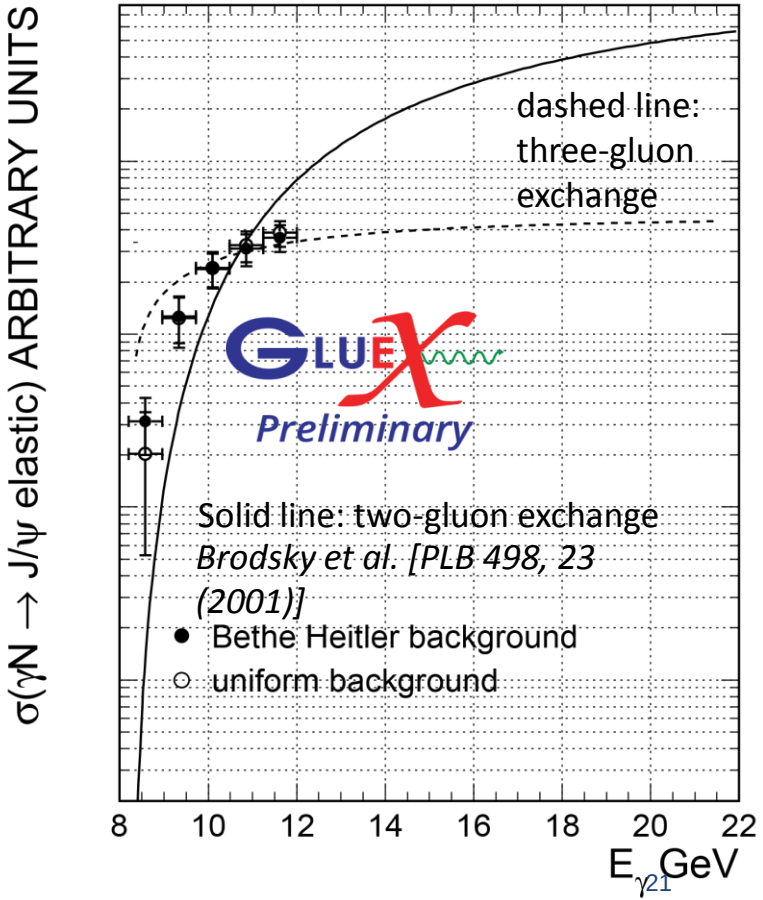
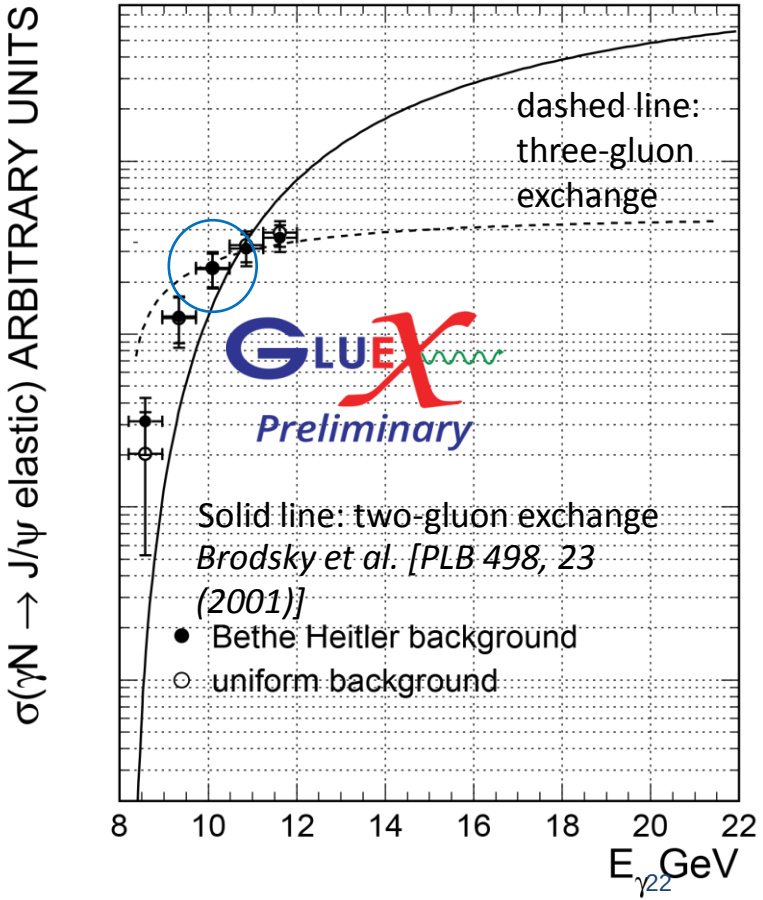


$\gamma p \rightarrow J/\psi p$ cross-section vs beam energy - GlueX

Total elastic cross-section on proton extracted from GlueX data shown without absolute normalization.

The energy slope of the GlueX data, that extends down to the threshold, can be compared to the two calculations (curves normalized to data for comparison)

No structure visible at $E_\gamma = 10.02$ GeV, expected position of LHCb pentaquark



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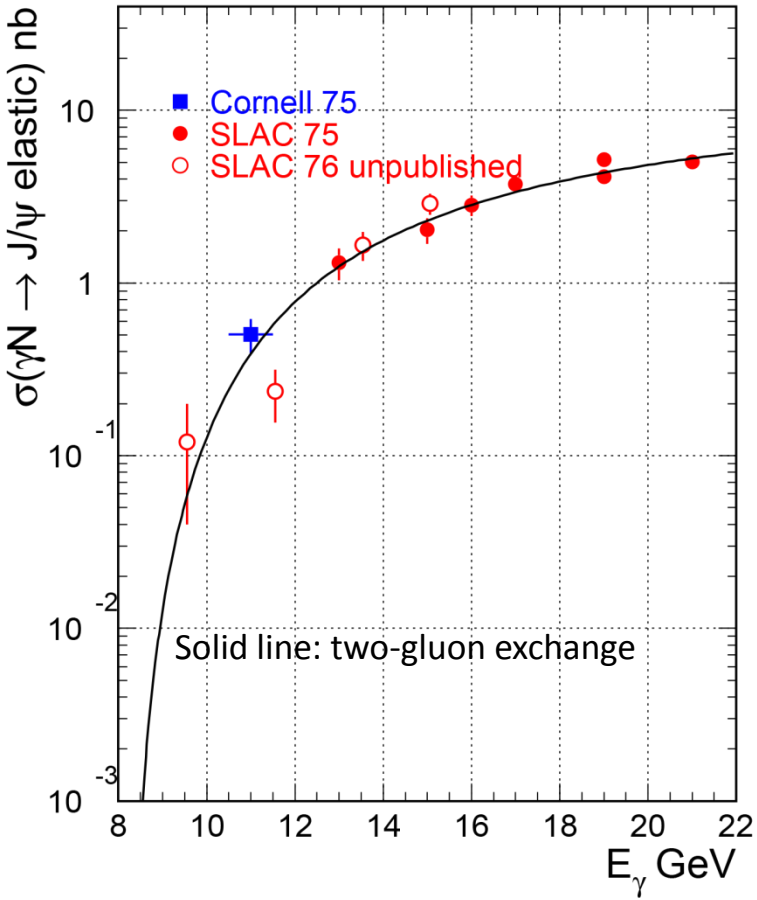
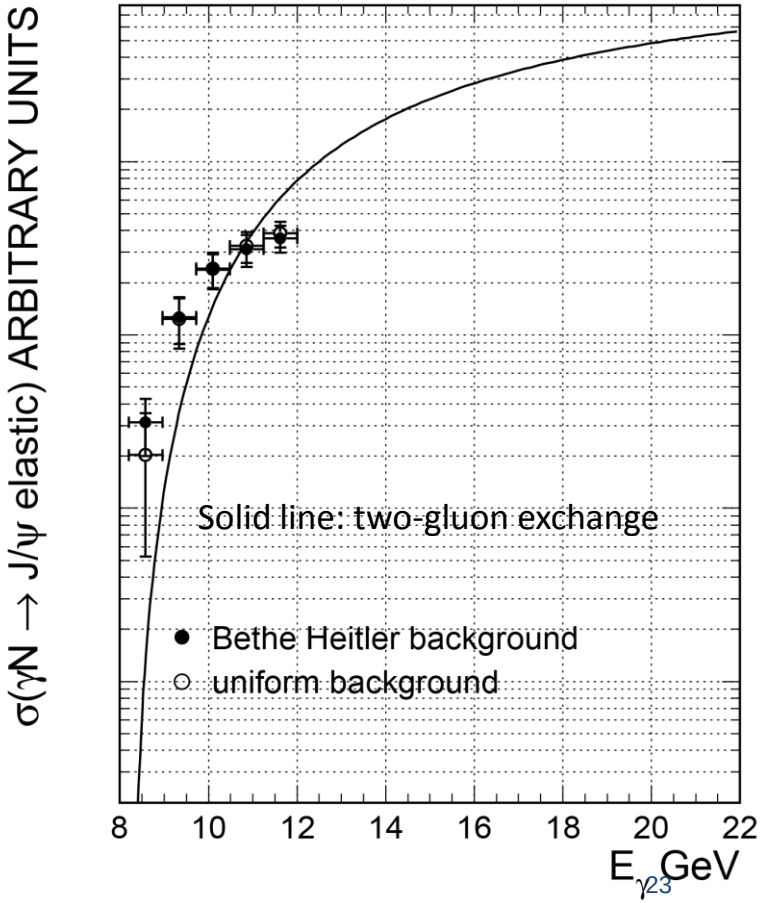
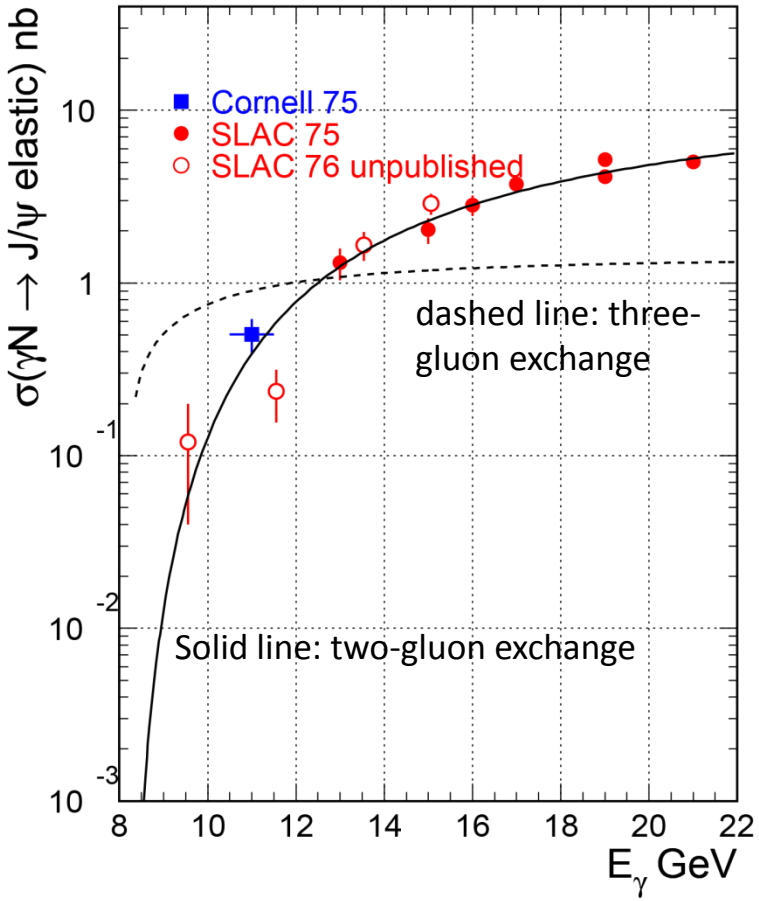
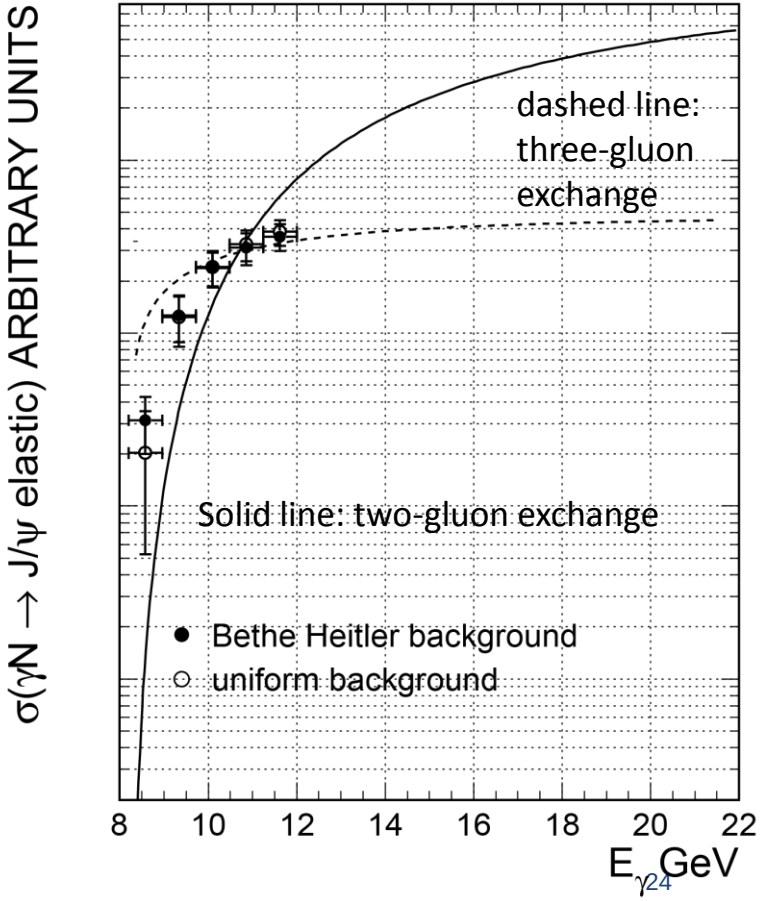




γ p -> J/ψ p cross-section vs beam energy





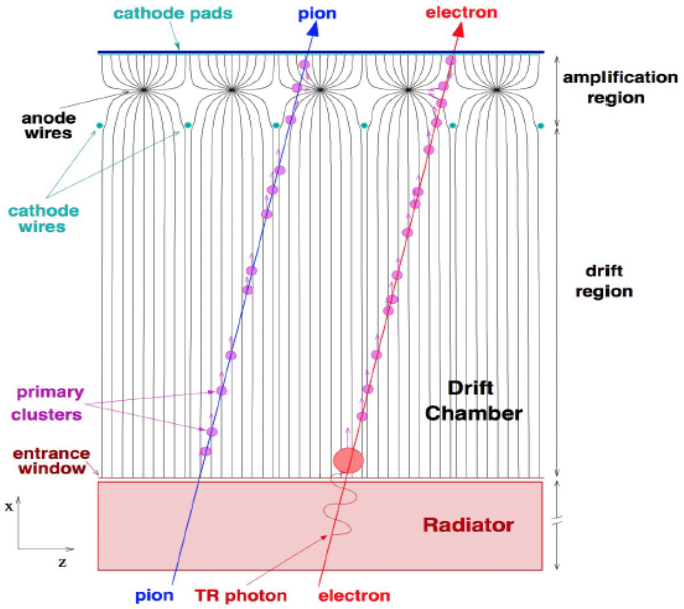
Outlook

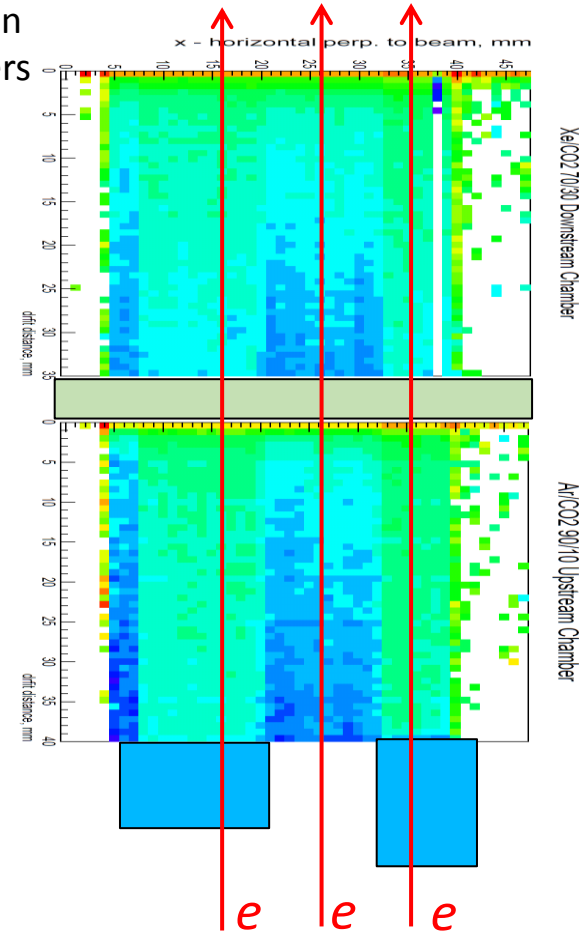
- *Preliminary results form engineering running (~ two weeks 10^7 γ/s) demonstrate the possibility for di-electron spectrum studies – J/ψ, ϕ, Bethe-Heitler, …*
- *High resolution (10 MeV) for J/ψ invariant mass - result of precise beam energy knowledge, detection of recoil proton, and electron identification*
- *Measurements of elastic J/ψ photoproduction extended for the first time down to the threshold*
- *In the first physics run (that starts now) expect to increase the J/ψ statistics by a factor 2 to 4, thus being able to better distinguish between different near threshold production mechanism*
- *In the future GlueX runs expect to have enough statistics to use the photon polarization and study polarization observables for the di-electron spectrum*

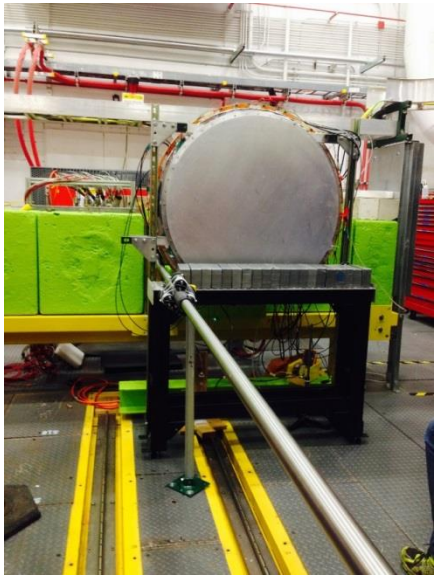
Back-ups

Transition Radiation Detector – R&D studies for forward e/π separation

- e/π separation: for p>1.5 GeV, p suppression factor 100-1000 depending on # of chambers
- Prototype tests done with Ar and Xe gas mixtures, using electrons with/without radiator
- Chamber design similar to ALICE TRD:



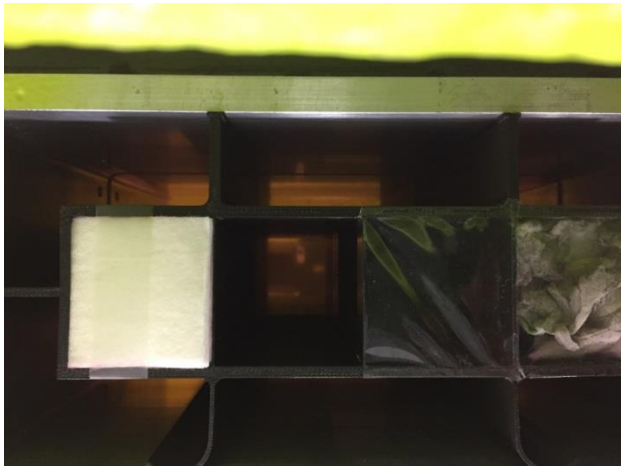


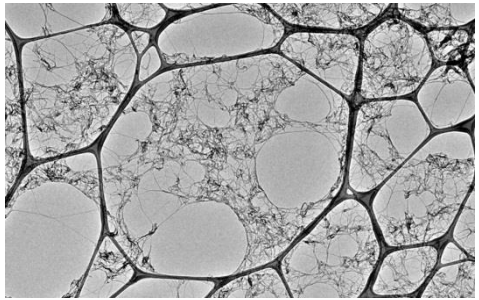


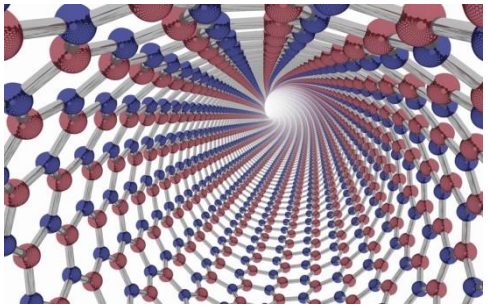
Color represents the deposited charge per track

Transition Radiation Detector – R&D studies for forward e/π separation

- Small-scale prototype under tests during the current run
- Using different radiators: conventional one (left) and also Boron Nitride Nanotubes, produced by BNNT company (right):

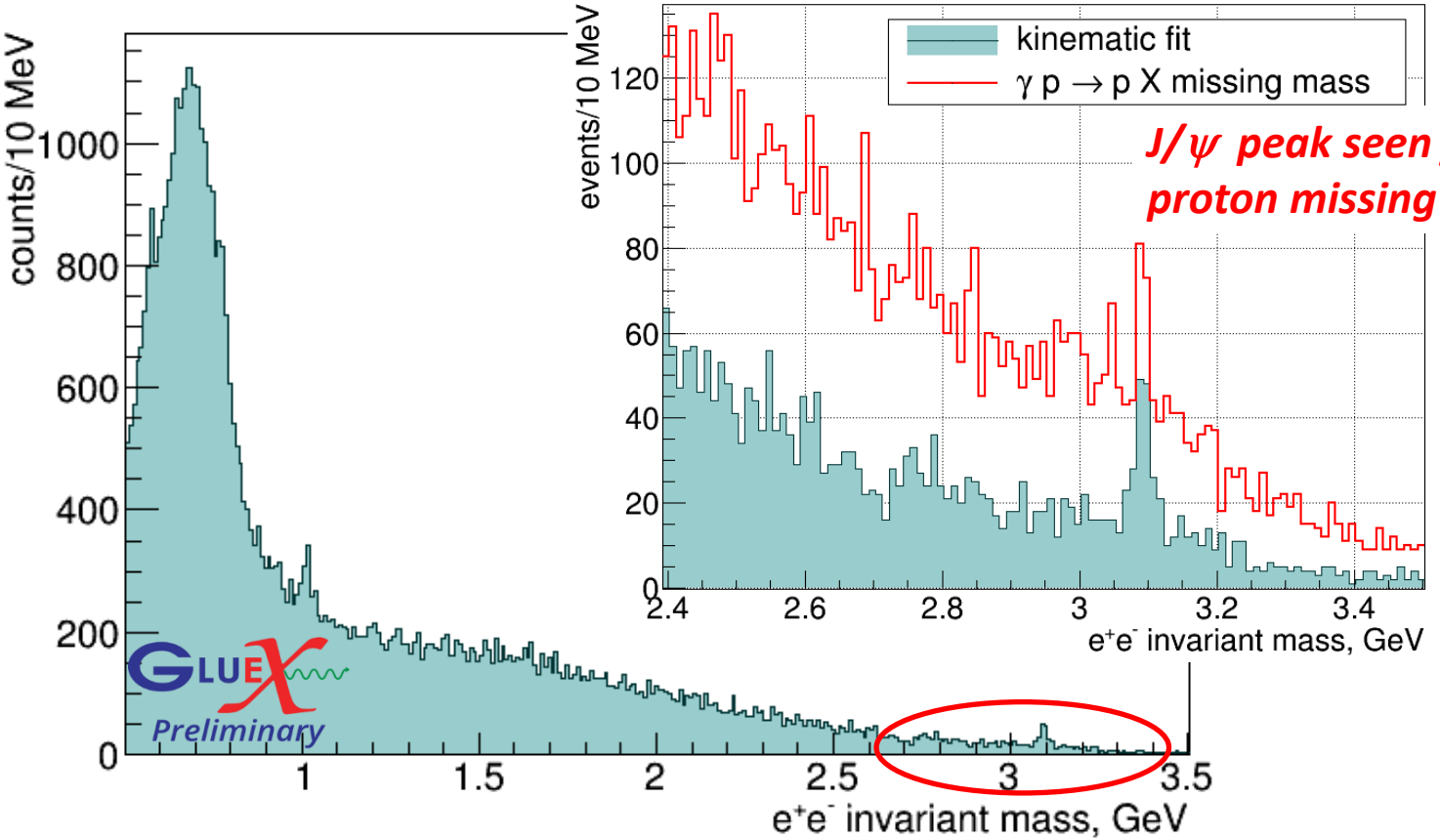






Boron Nitride Nanotubes

Di-electron Spectrum – J/ψ



J/ψ peak seen from recoil proton missing mass

Di-electron Spectrum