Search for exotic states in Photo-production at GlueX

Abdennacer Hamdi

On behalf of GlueX collaboration

FAIRness 6th Edition Workshop

Genova, Italy, 20 - 24 May 2019

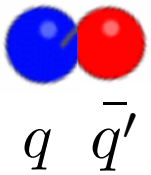
- Mesons are made of quark anti-quark bound system

J^{PC} = 0^{++}, 0^{-+}, 1^{--}, 1^{++}, 1^{+-},...

$$J = L + S$$

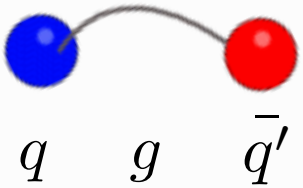
$$C = (-1)^{L+S}$$

$$P = (-1)^{L}$$



- QCD predicts the existence of exotic states

J^{PC} = 0^{--}, 0^{++}, 0^{-+}, 0^{+-}, 1^{--}, 1^{++}, 1^{-+}, 1^{+-},...



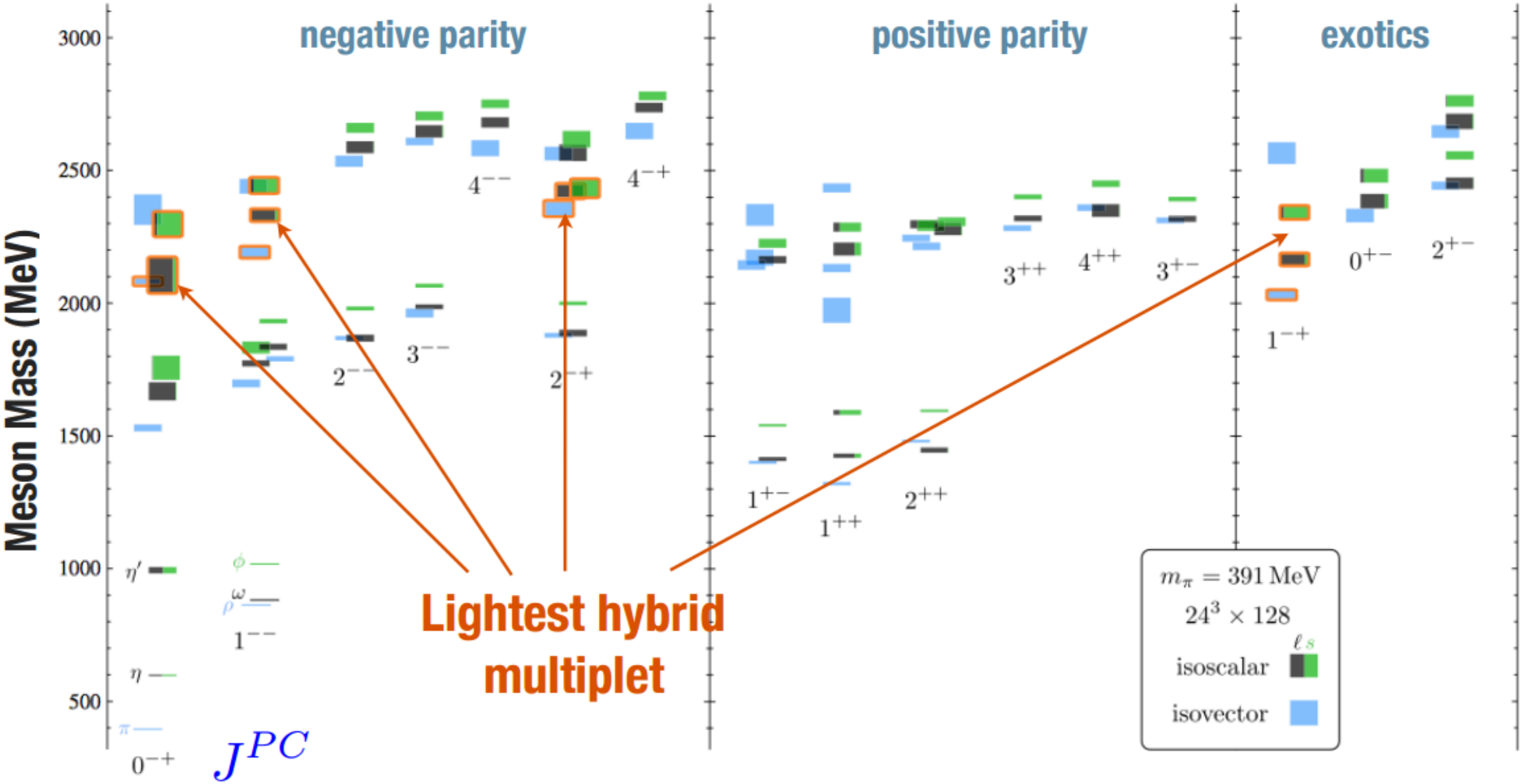
➡ Manifestation of Hybrid and spin exotic Hybrid Mesons

- Gluonic Excitation Models (Flux Tube, Bag Model, Constituent Gluon,…)

and Lattice QCD Calculations predict exotic J^{PC} states

Lattice QCD predictions

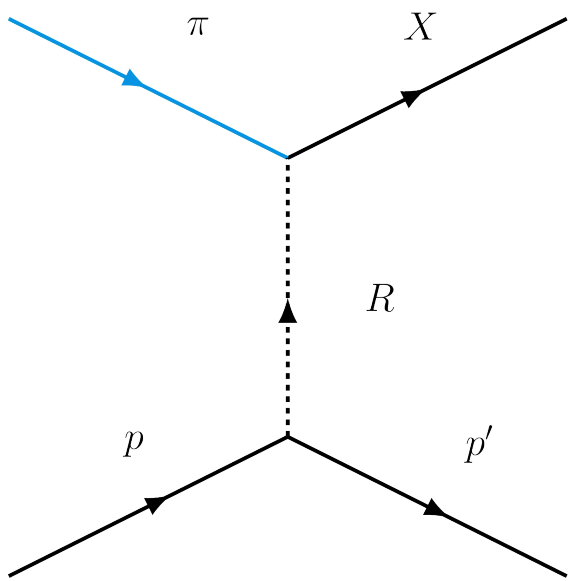
Dudek et al. PRD 88 (2013) 094505

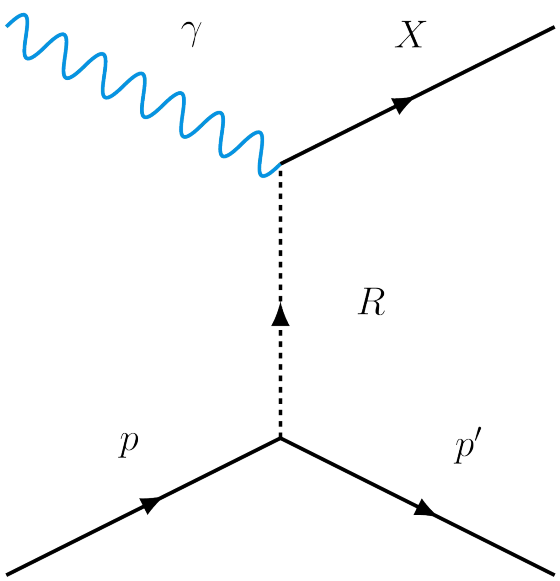


1^{--}, 0^{-+}, 1^{-+}, 2^{-+}

- The primary physics goal of GlueX is to discover and study hybrid mesons

Hybrid Meson Mass Estimates

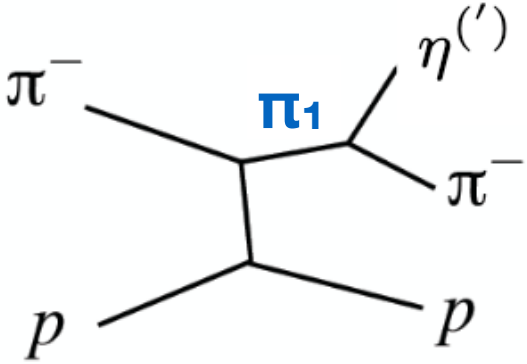


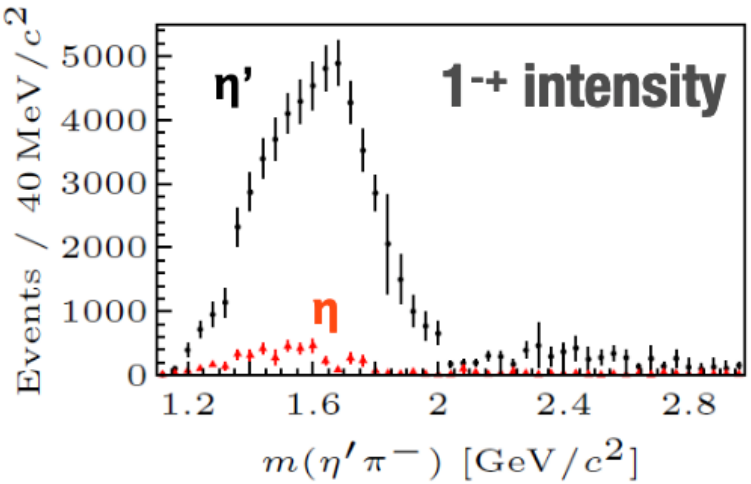


- π beam (S = 0)
- 1^{++}, 1^{--}
- Exotic hybrids require spin flip
- E852, Gams, KEK, VES, COMPASS

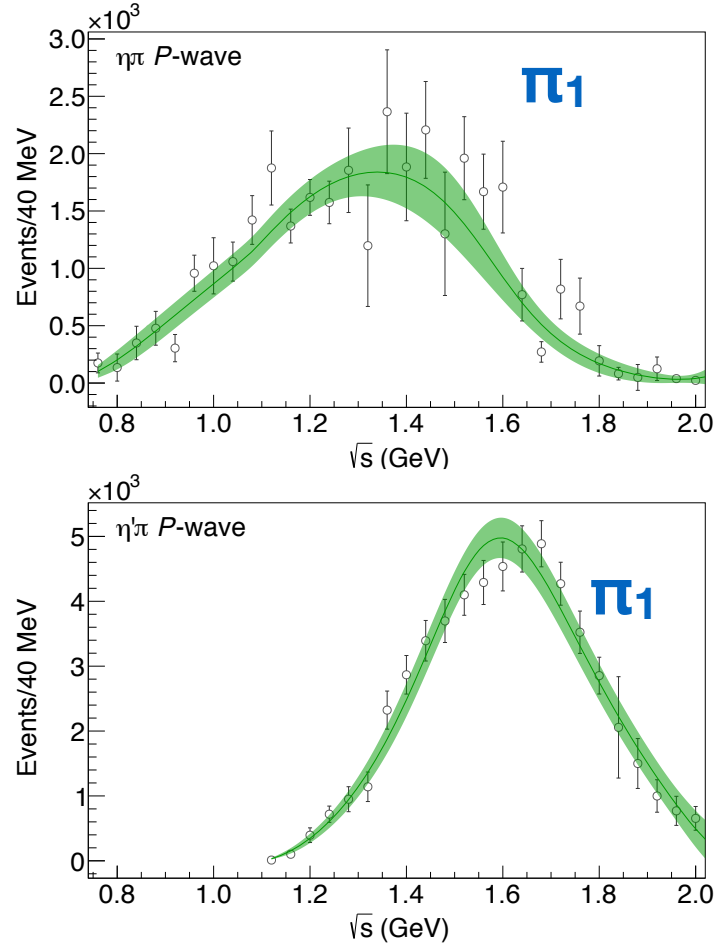
- γ beam (S = 1)
- 0^{-+}, 0^{+-}, 1^{-+}, 1^{+-}, 2^{-+}, 2^{+-}
- No spin flip Required
- CLAS, Omega-Photon Coll., GlueX

Evidence for light-quark exotic meson





COMPASS: PLB 740, 303 (2015)



A. Rodas et al. (JPAC) [arXiv:1810.04171]

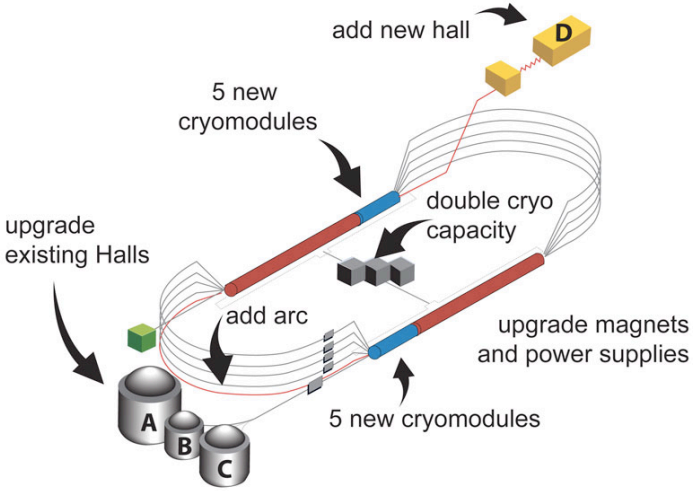
Evidence for π_1 in η′π and ρπ P-waves (116k ηπ and 39k η'π)

Extract resonance parameters with unitary reaction model

Expect 280k ηπ and 52k η'π from current dataset for a single decay mode

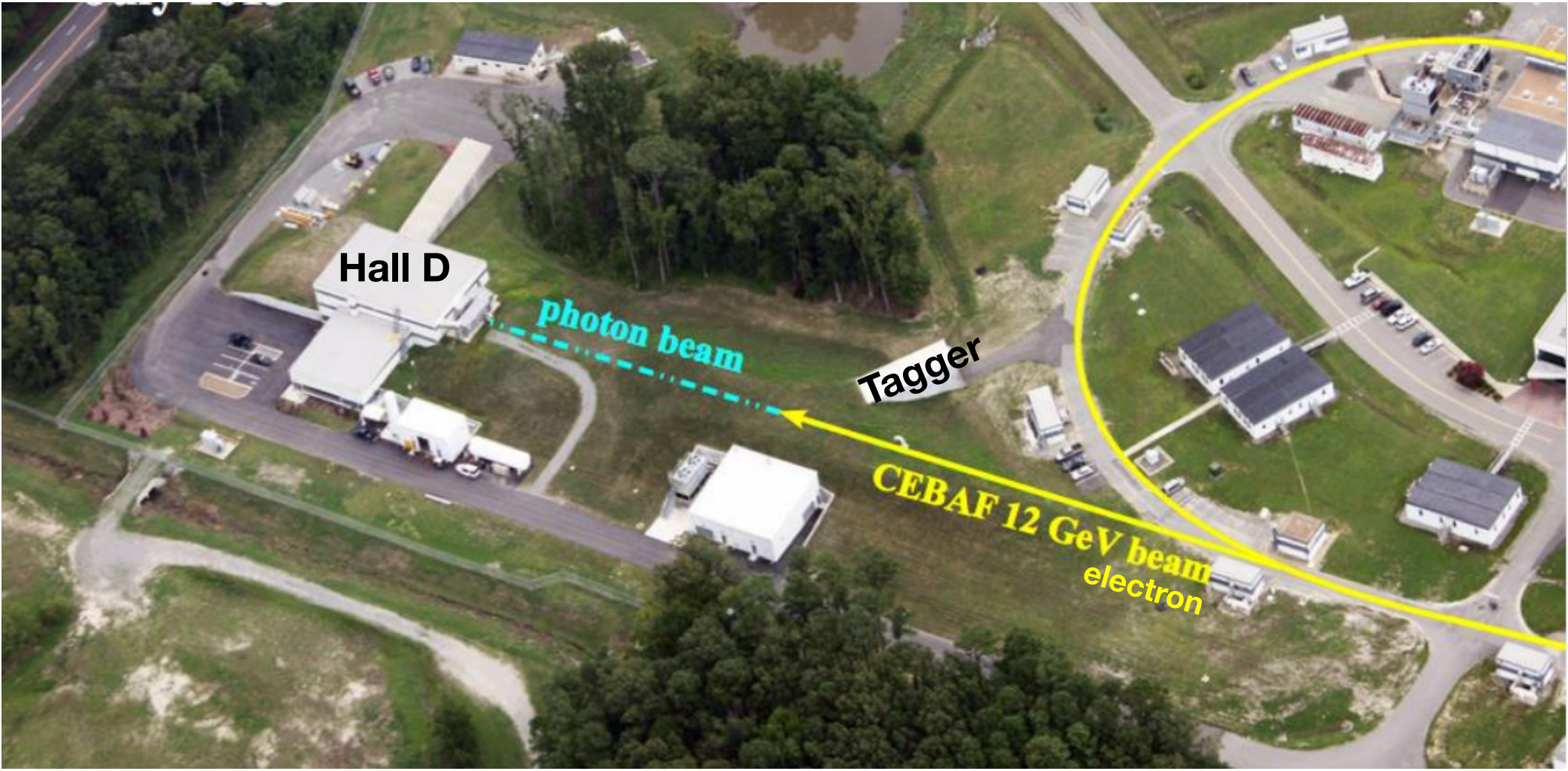
GlueX Hall D

- Thomas Jefferson Lab and the Continuous Electron Beam Accelerator Facility (CEBAF)



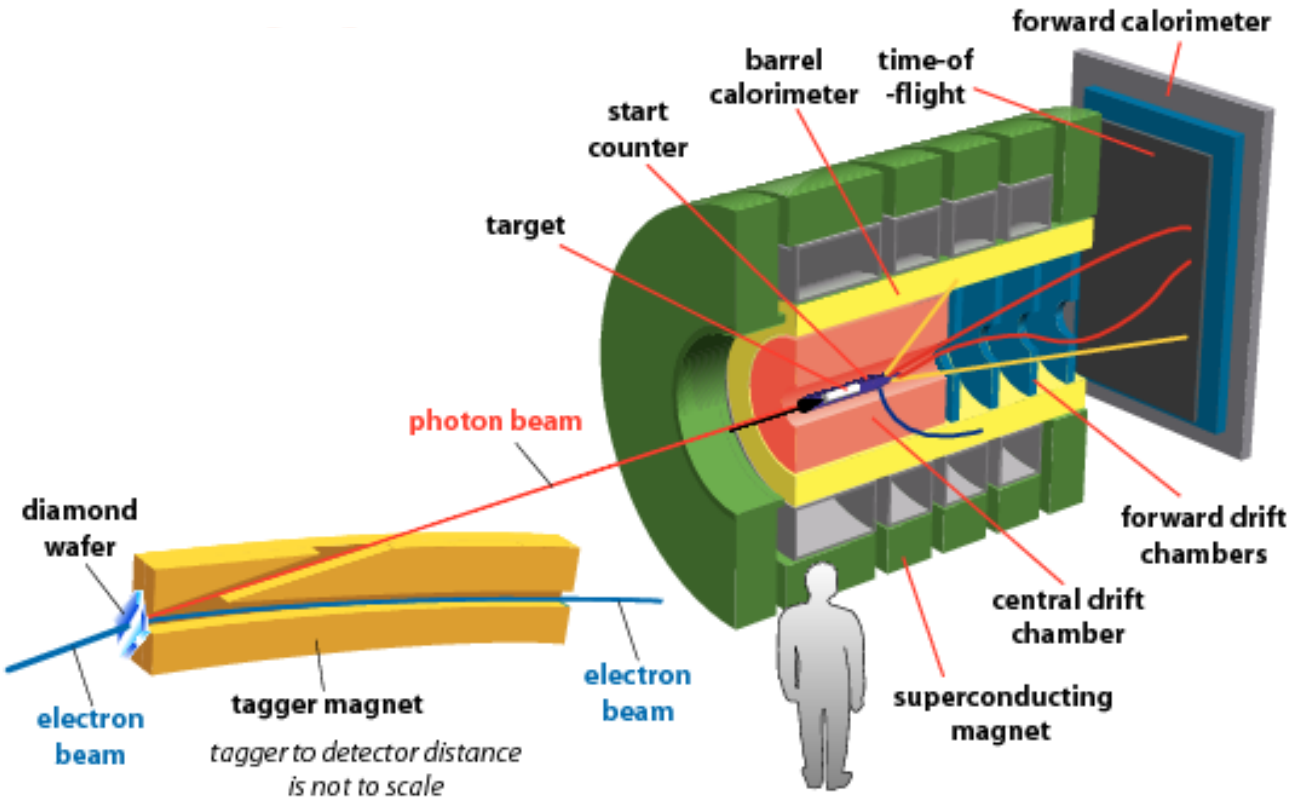
- Over 120 collaborators from 34 institutions

Photon Beam production

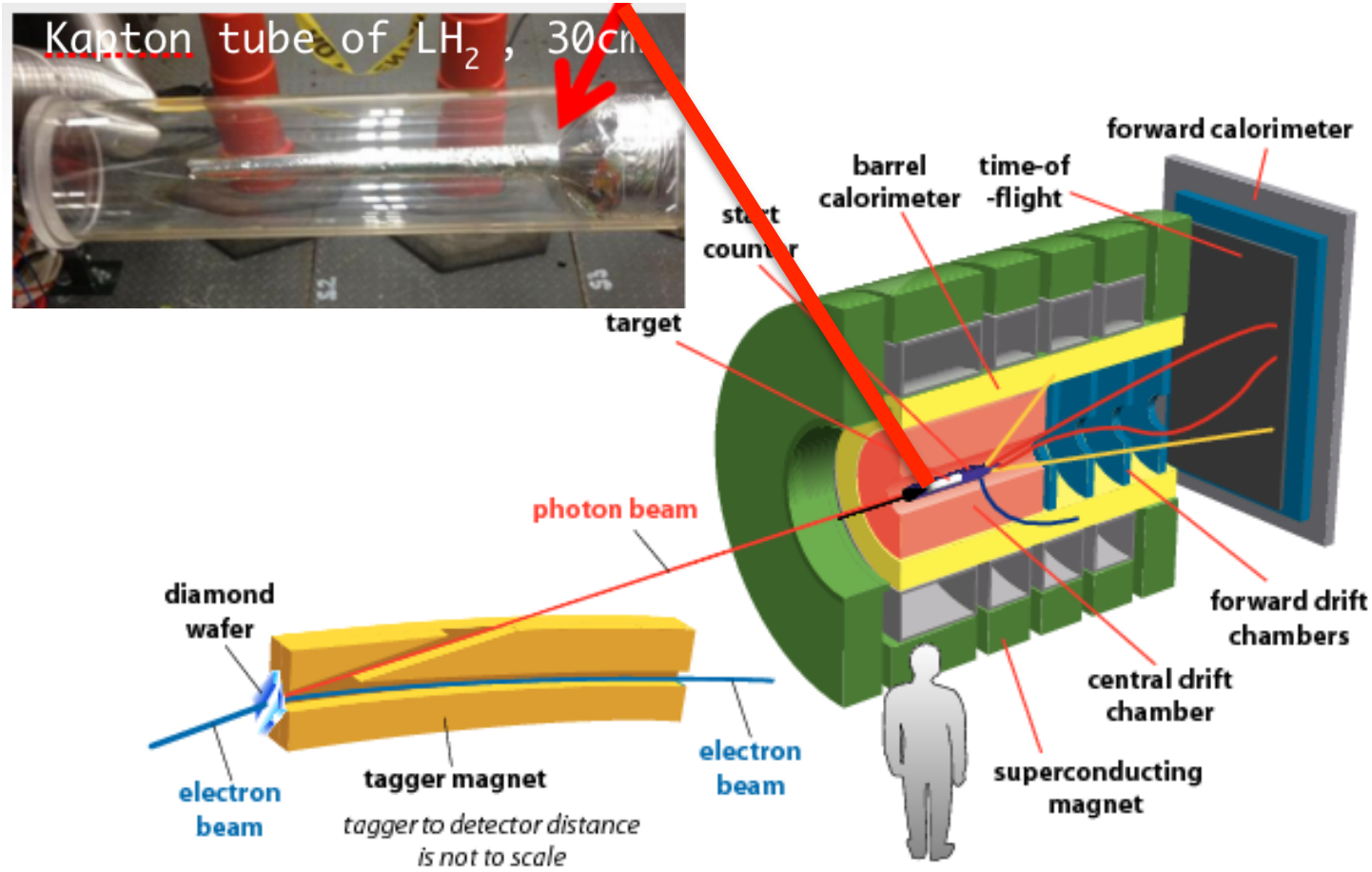


The GlueX Detector

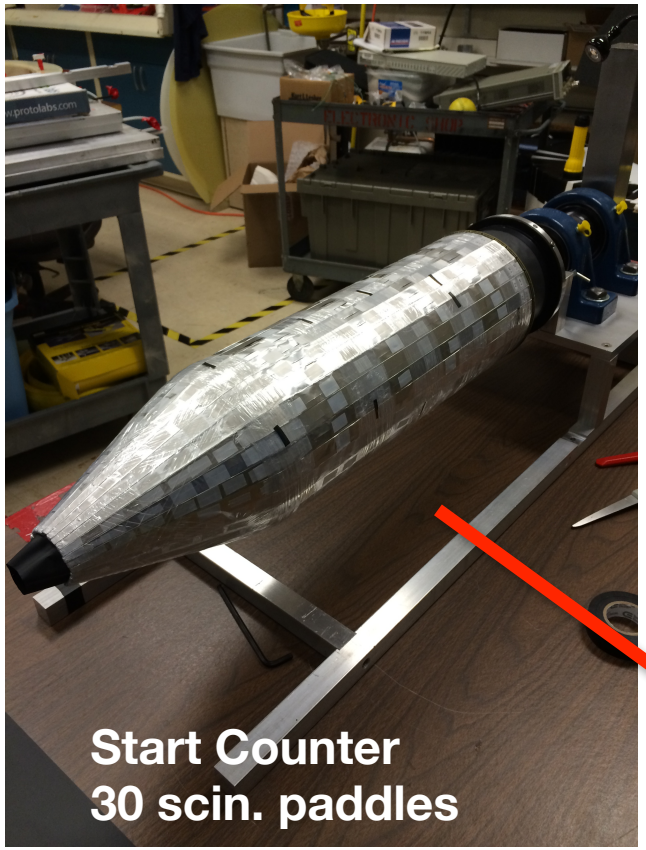
- Acceptance: 1 - 120°
- Charged particles: $\sigma_p/p \sim 1 - 3\%$
- Photons: $\sigma_E/E = 6\%/\sqrt{E} \oplus 2\%$

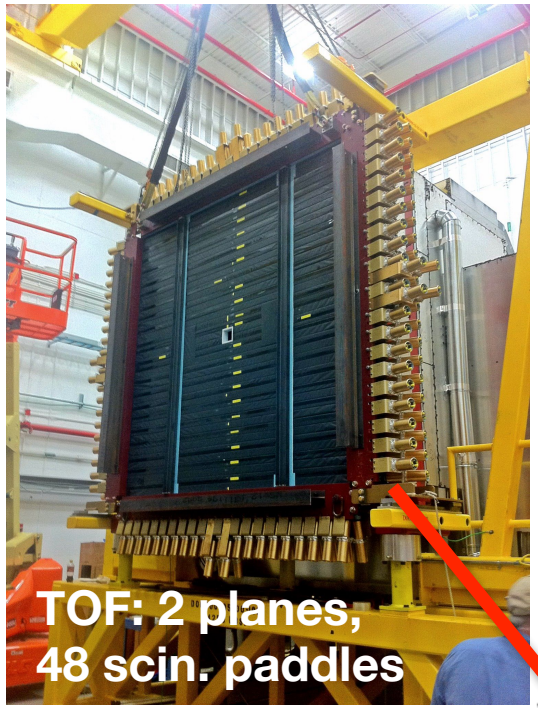


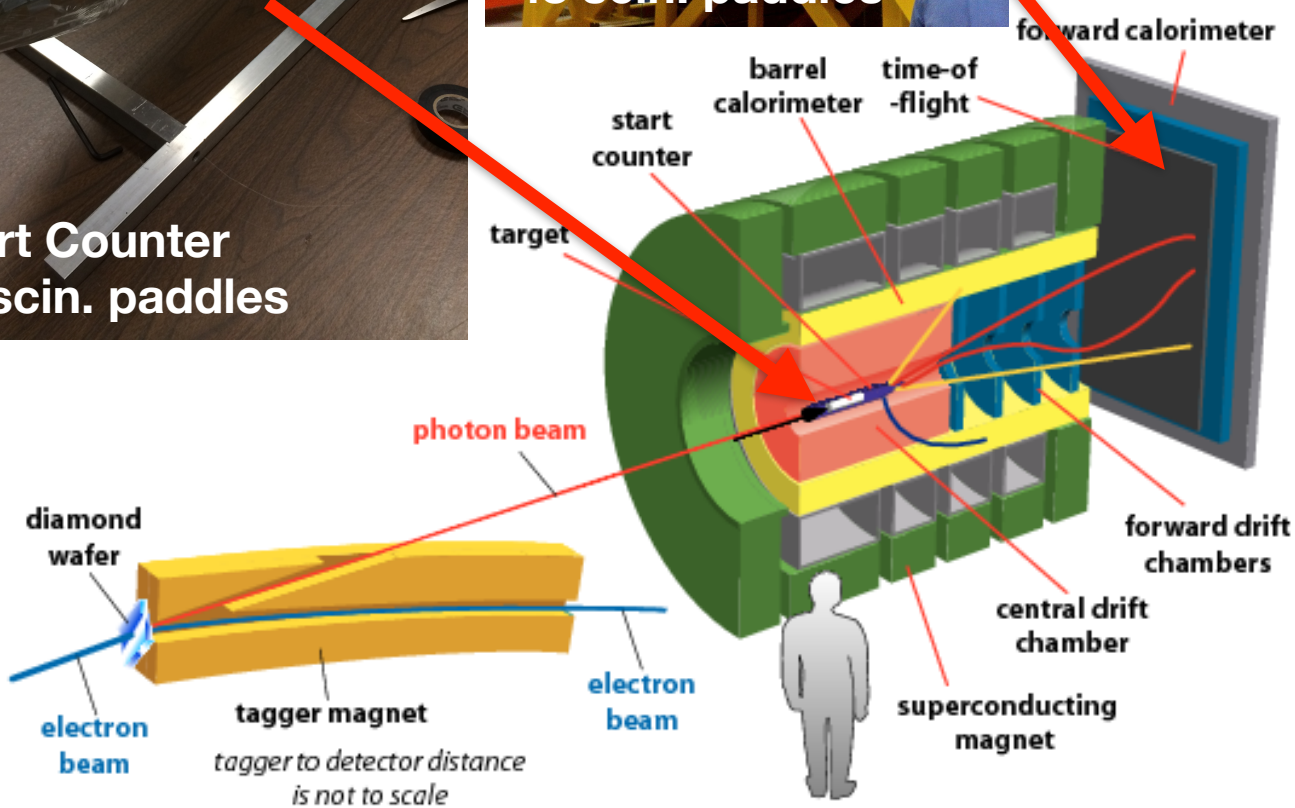
The GlueX Detector



The GlueX Detector







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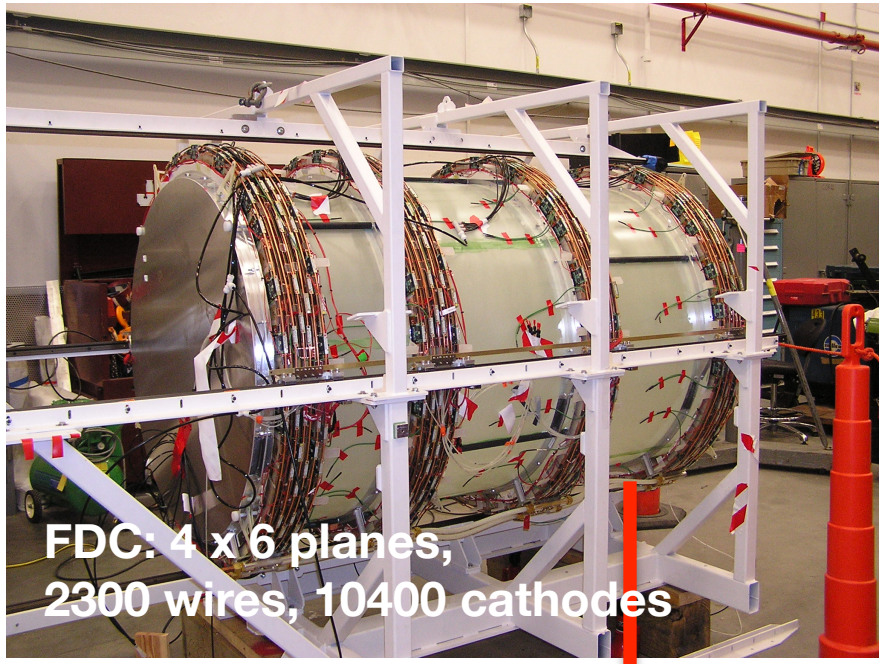

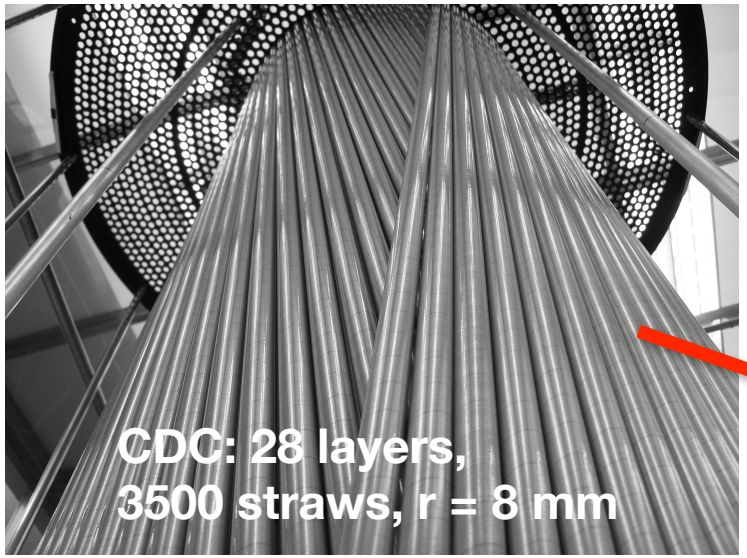

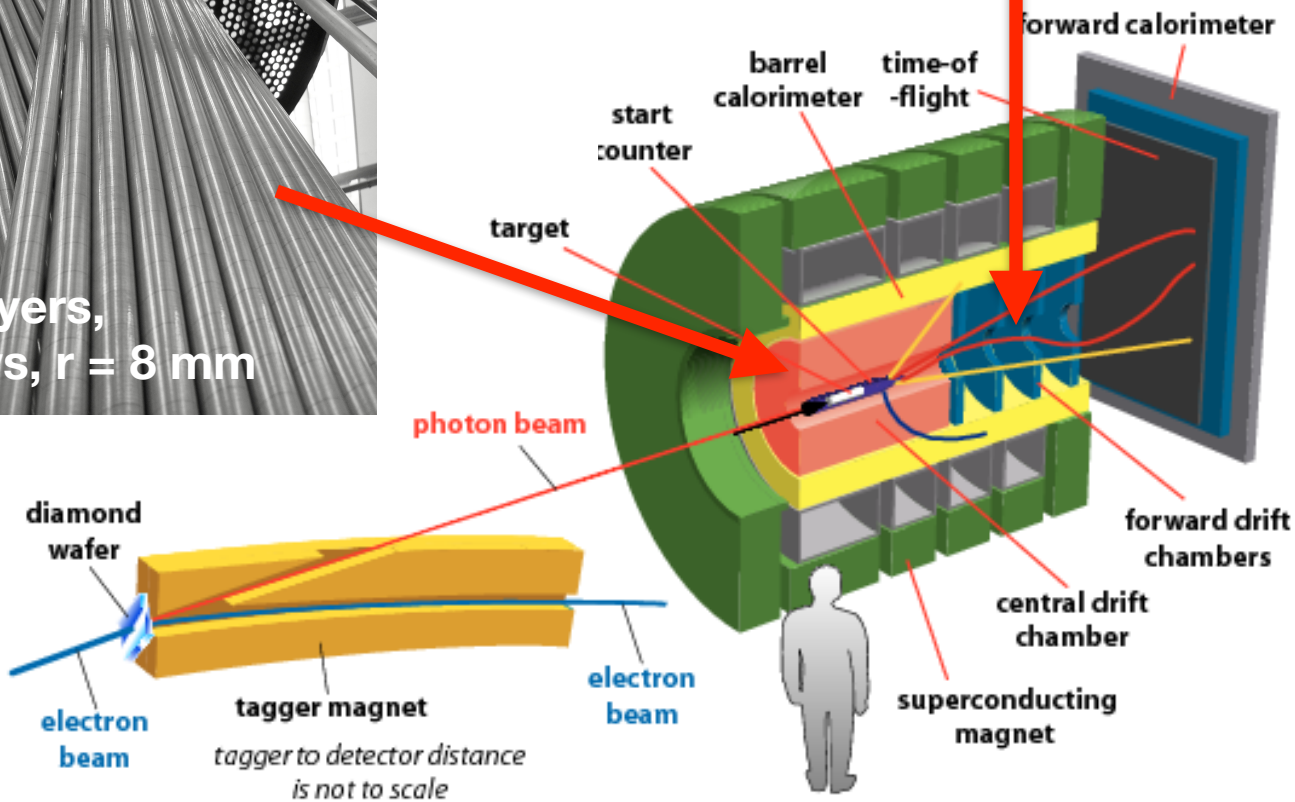

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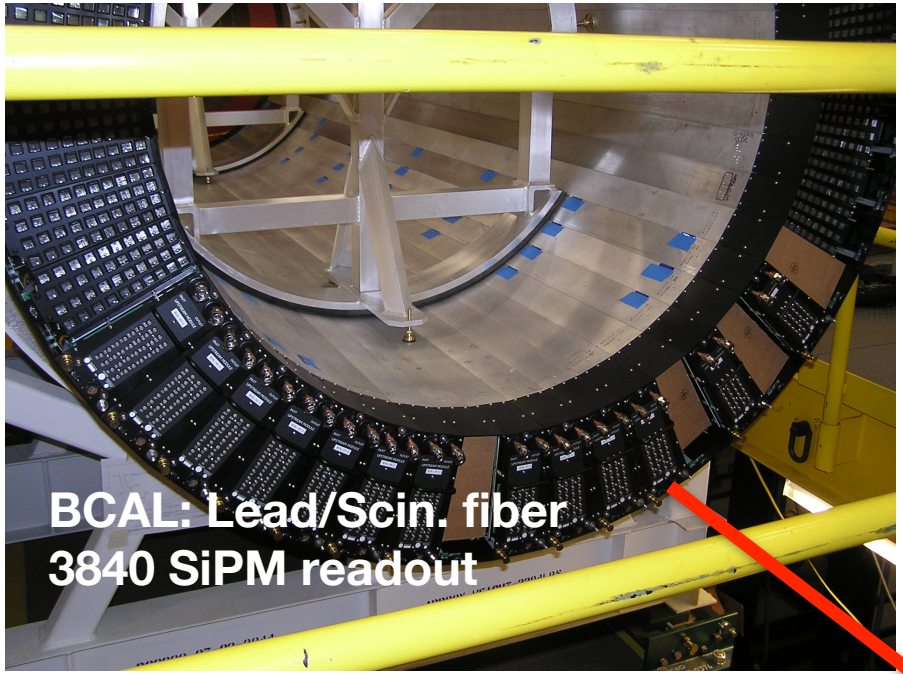

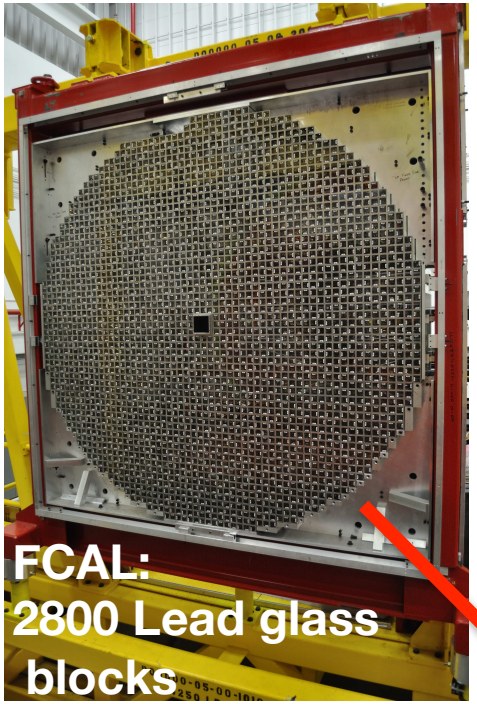

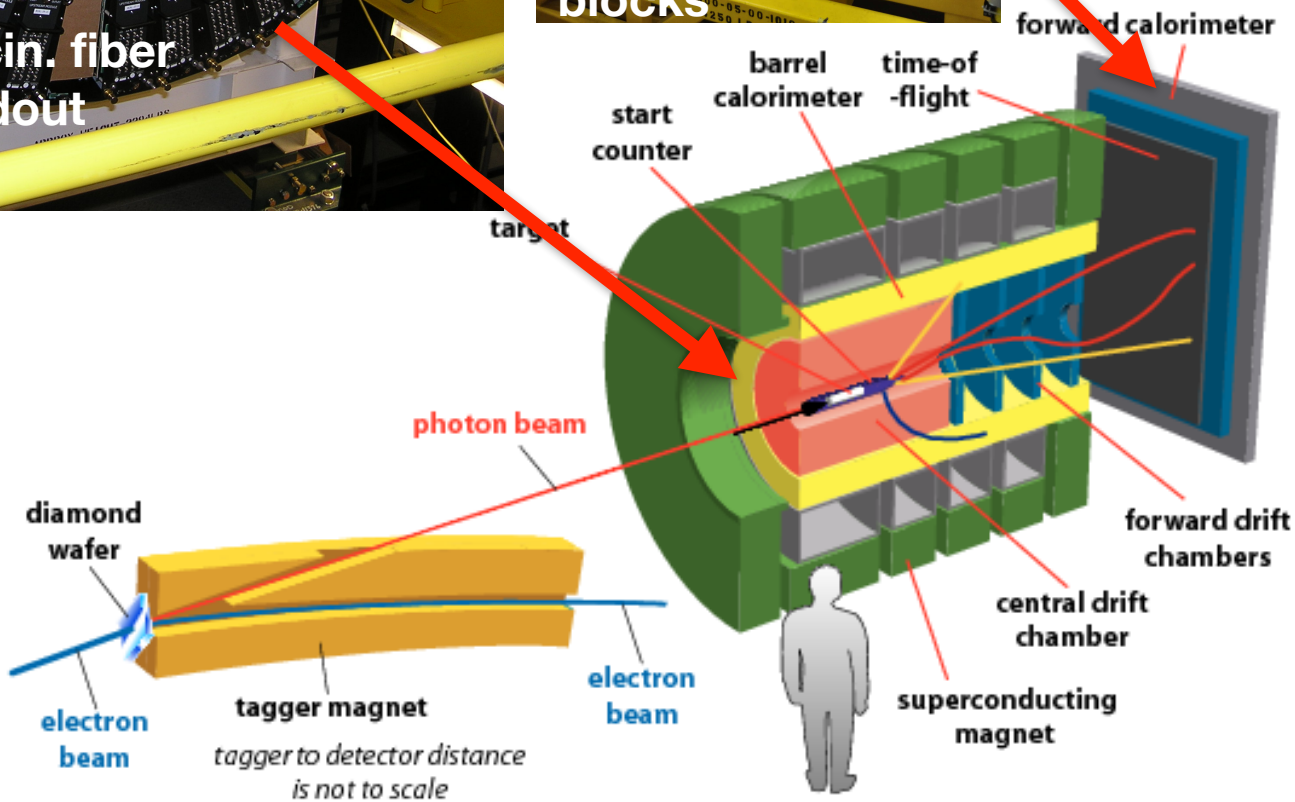

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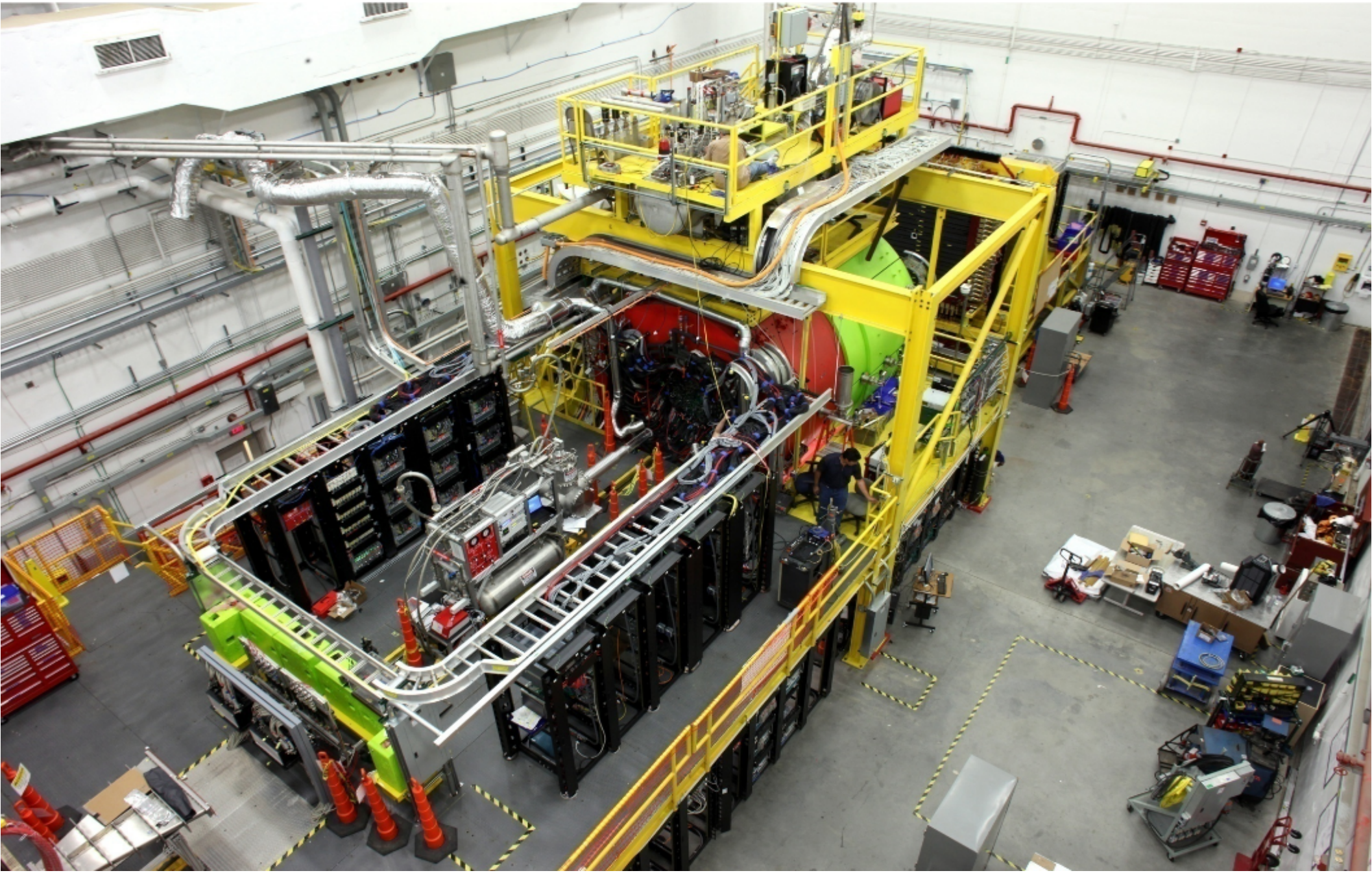
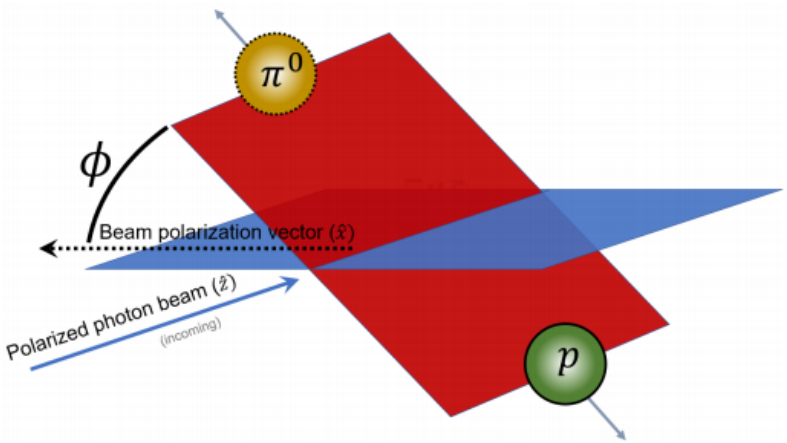


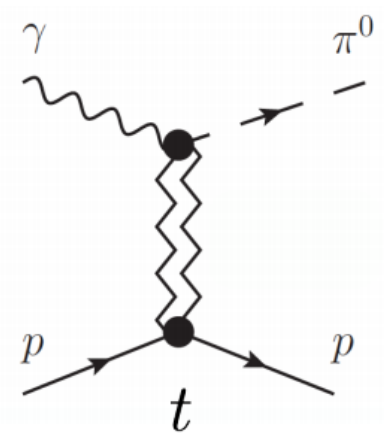
Azimuthal Beam Asymmetries

- Understanding production mechanism critical to disentangling J^{PC} of observed states in exotic hybrid search

$$Y_{\perp/\parallel} \propto N_{\perp/\parallel}(1 \pm P_{\perp/\parallel}\Sigma cos2\phi)$$

$$\Sigma \propto \frac{Y_\perp - F_R Y_\parallel}{Y_\perp + F_R Y_\parallel}$$

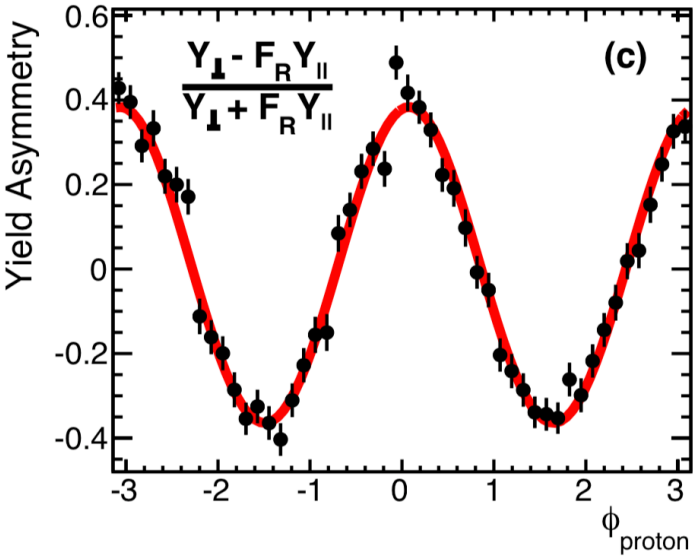




Exchange J^{PC}

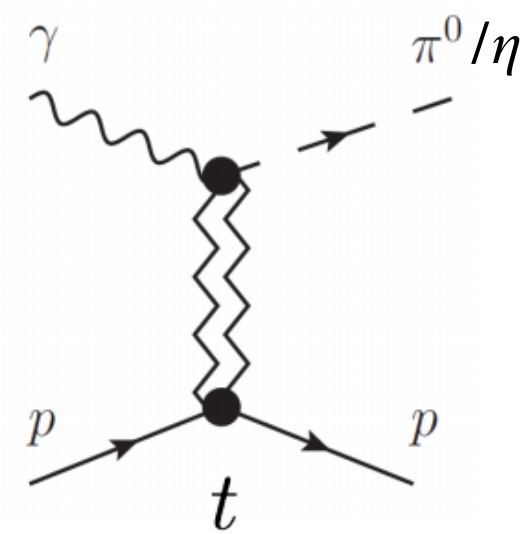
$1^{--} : \omega, \rho$

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



- Beam asymmetry sensitive to nature of exchange particles

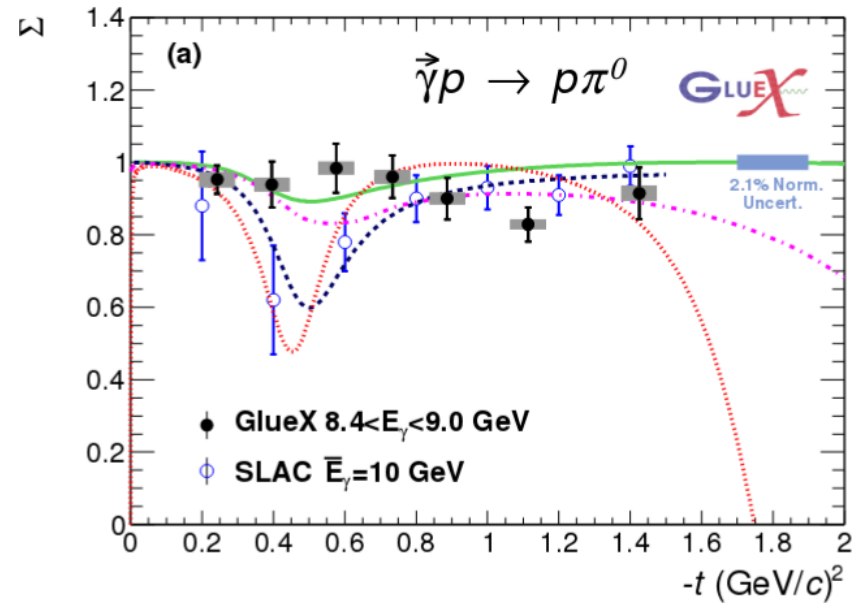
Azimuthal Beam Asymmetries in π^0 and η production

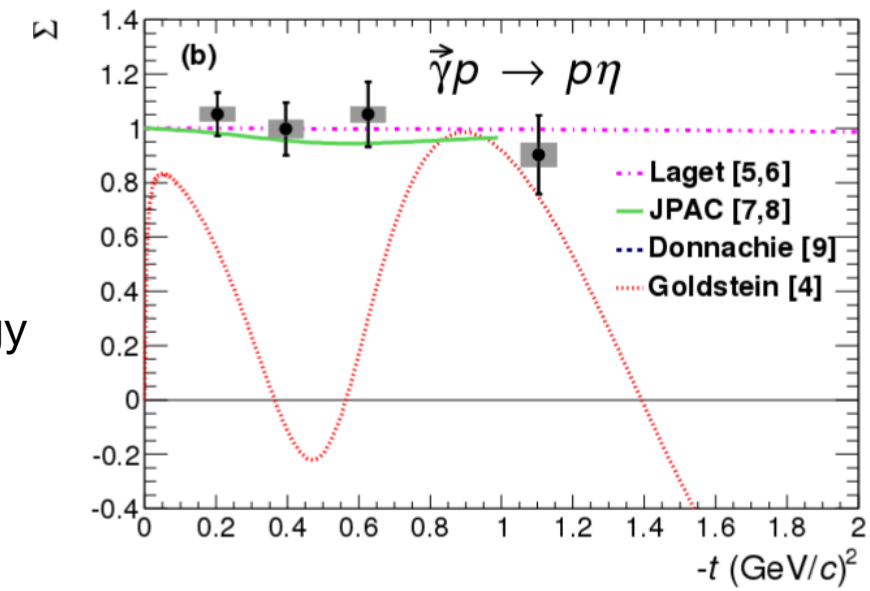


Exchange J^{PC}

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

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



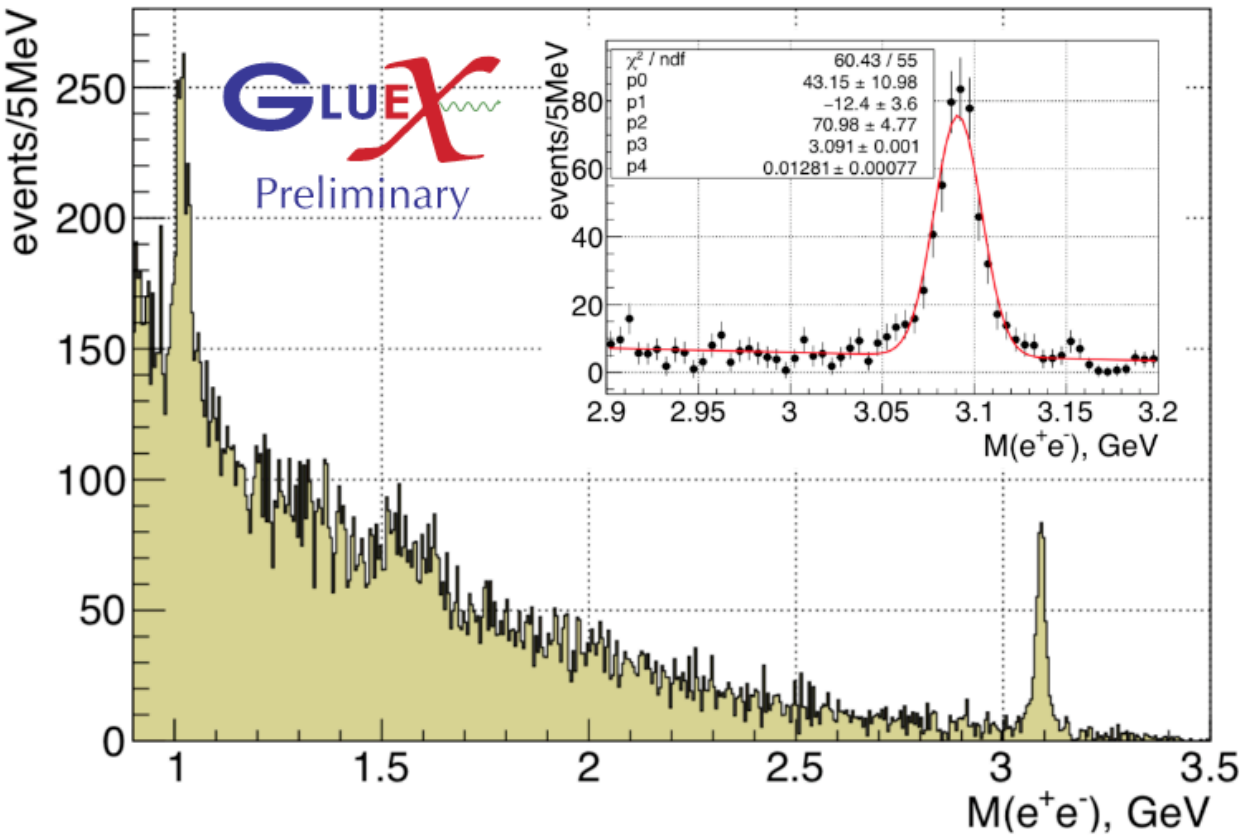


- Both π^0 and η asymmetries close to +1
- No dip observed at t = -0.5 (GeV/c)^2
- First measurement on η asymmetries at this energy
- $\Sigma \approx +1 \Longrightarrow$ vector meson exchange dominates

J/ψ Photo-production

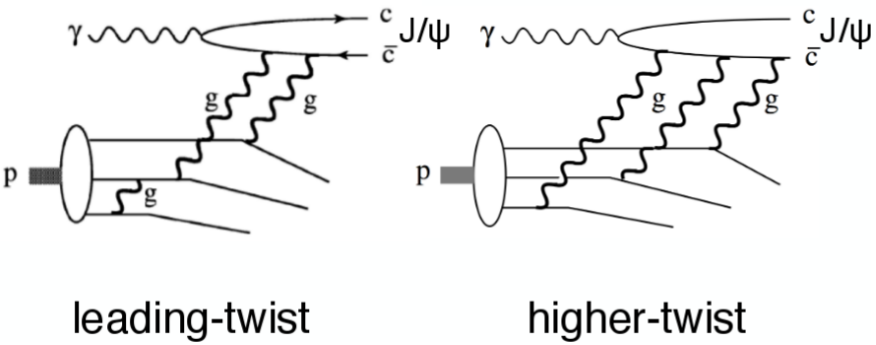
- 70% of 2016+2017 data used
- First observation of charmonium at CEBAF
- Photo-production of J/ψ near threshold is experimentally clean

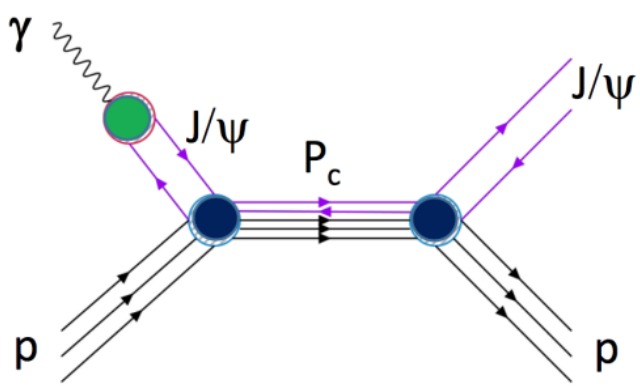
$$\gamma p \rightarrow p e^+ e^-$$

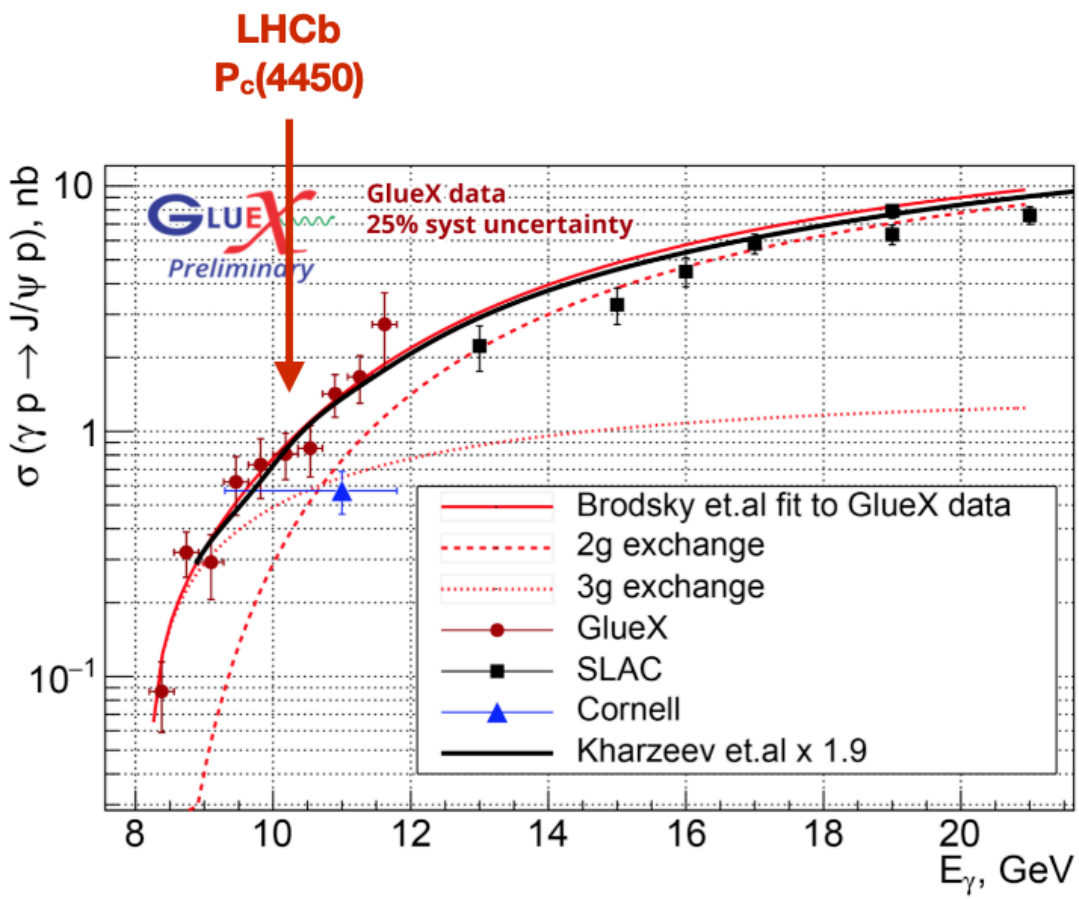


J/ψ Photo-production

- Ideal for studying gluon distribution in the nucleon (sensitive to production through 2 or 3 gluon exchange)
- Comparing with predictions for pentaquark production in the s-channel, and Setting limits on the branching fractions of the Pentaquarks decaying in J/ψ+p

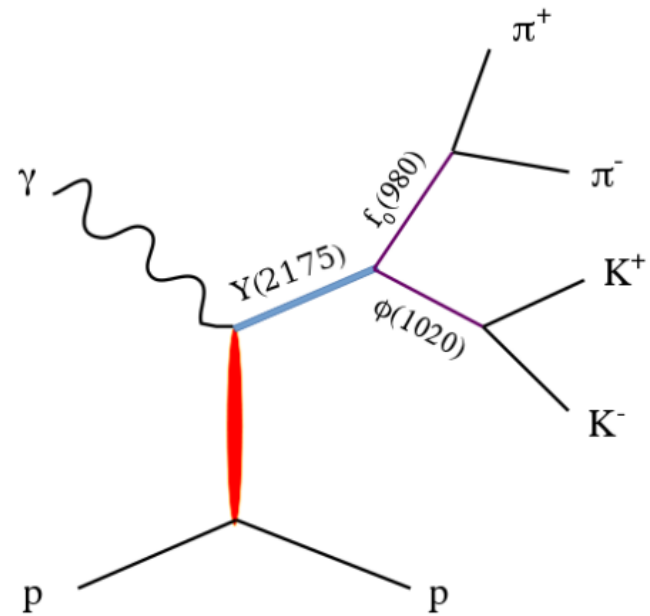




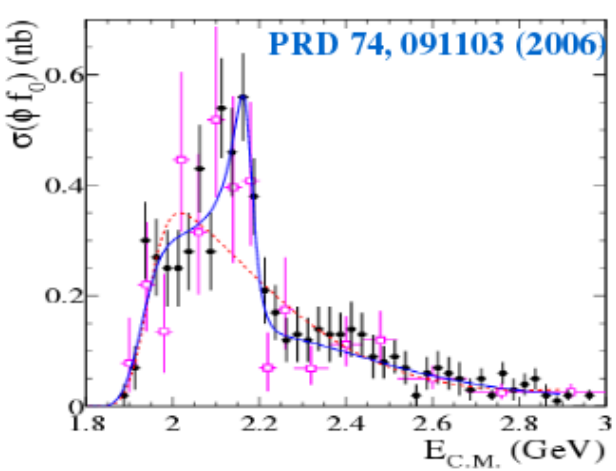


Y(2175) Photo-production

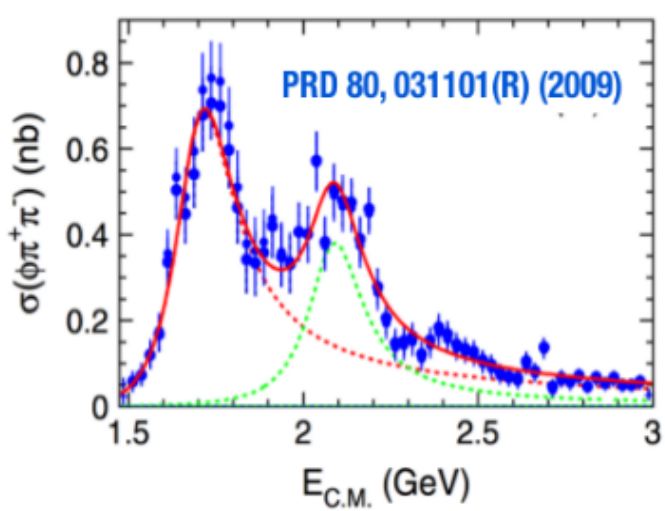
- Hybrid meson candidate: Y(2175) [PDG: $\phi(2170)$]
- $J^{PC} = 1^{--}$ state observed in 3 experiments
- Goal:
  - ➡ Search for: $\gamma p \to Y(2175)p$
  - ➡ Study the nature of this resonance



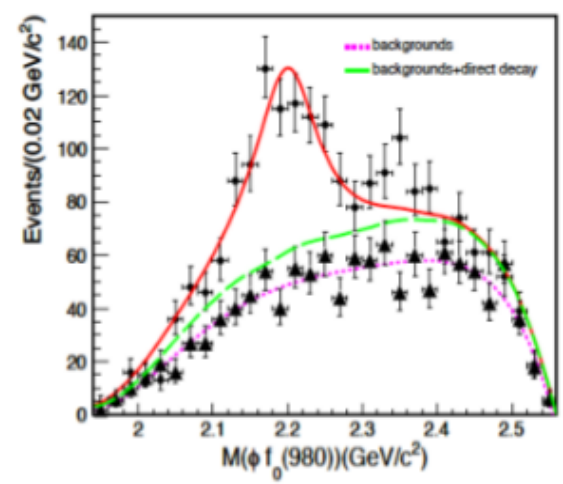
BABAR: $e^+e^- \to \phi f_0(980)$



Belle: $e^+e^- \to \phi\pi^+\pi^-(\gamma)$



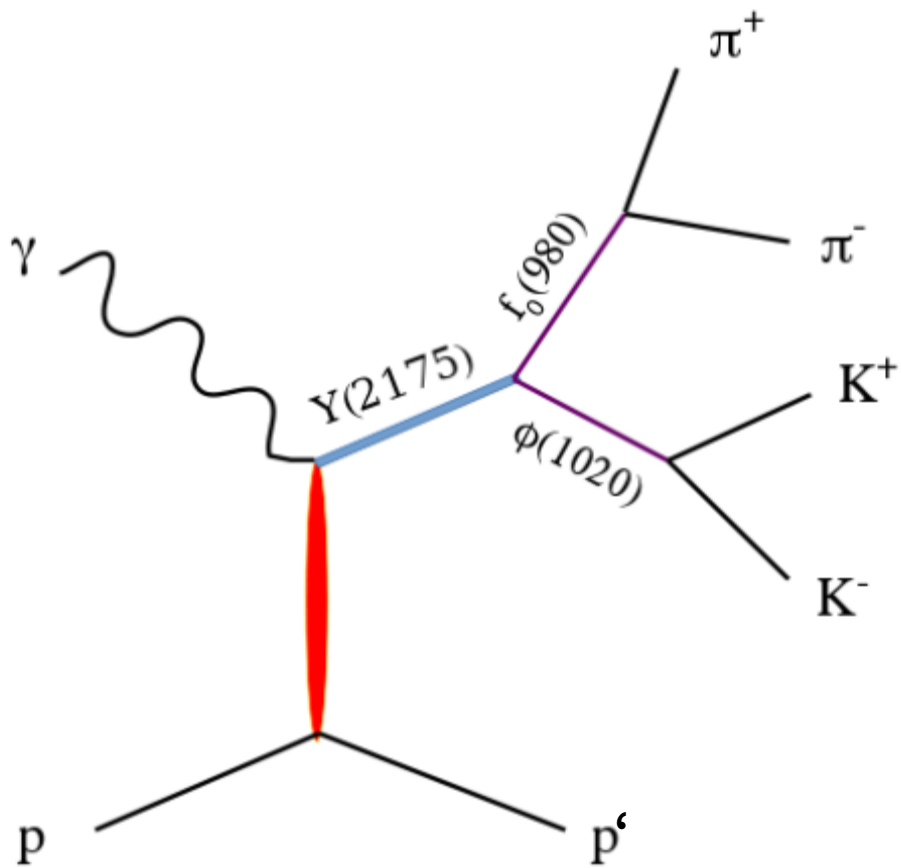
BES III: $J/\psi \to \eta\phi\pi^+\pi^-$



PRD 91, 052017 (2015)

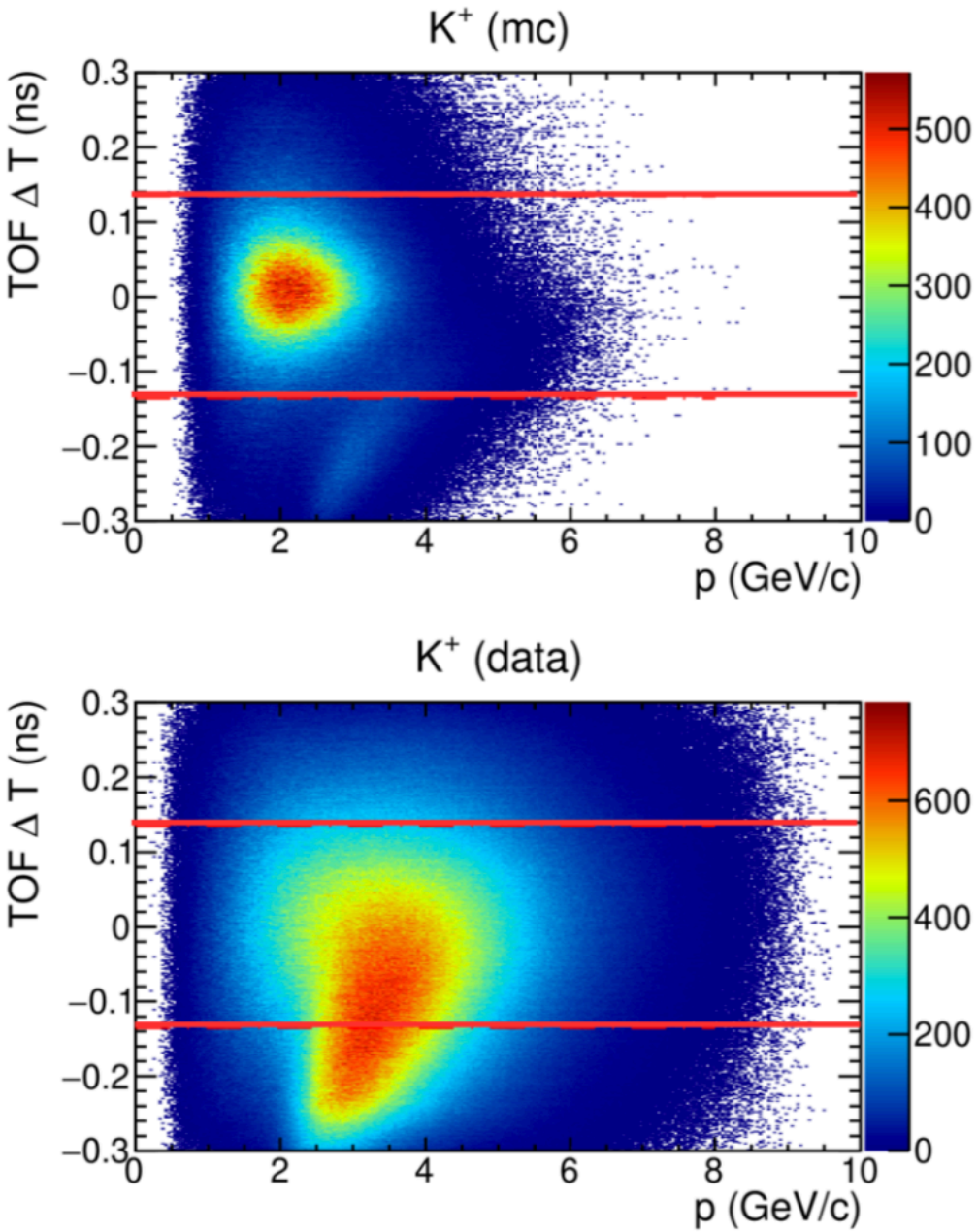
Input

- Data : 45 pb^{-1} currently available data
- Simulation : 10 M signal events generated



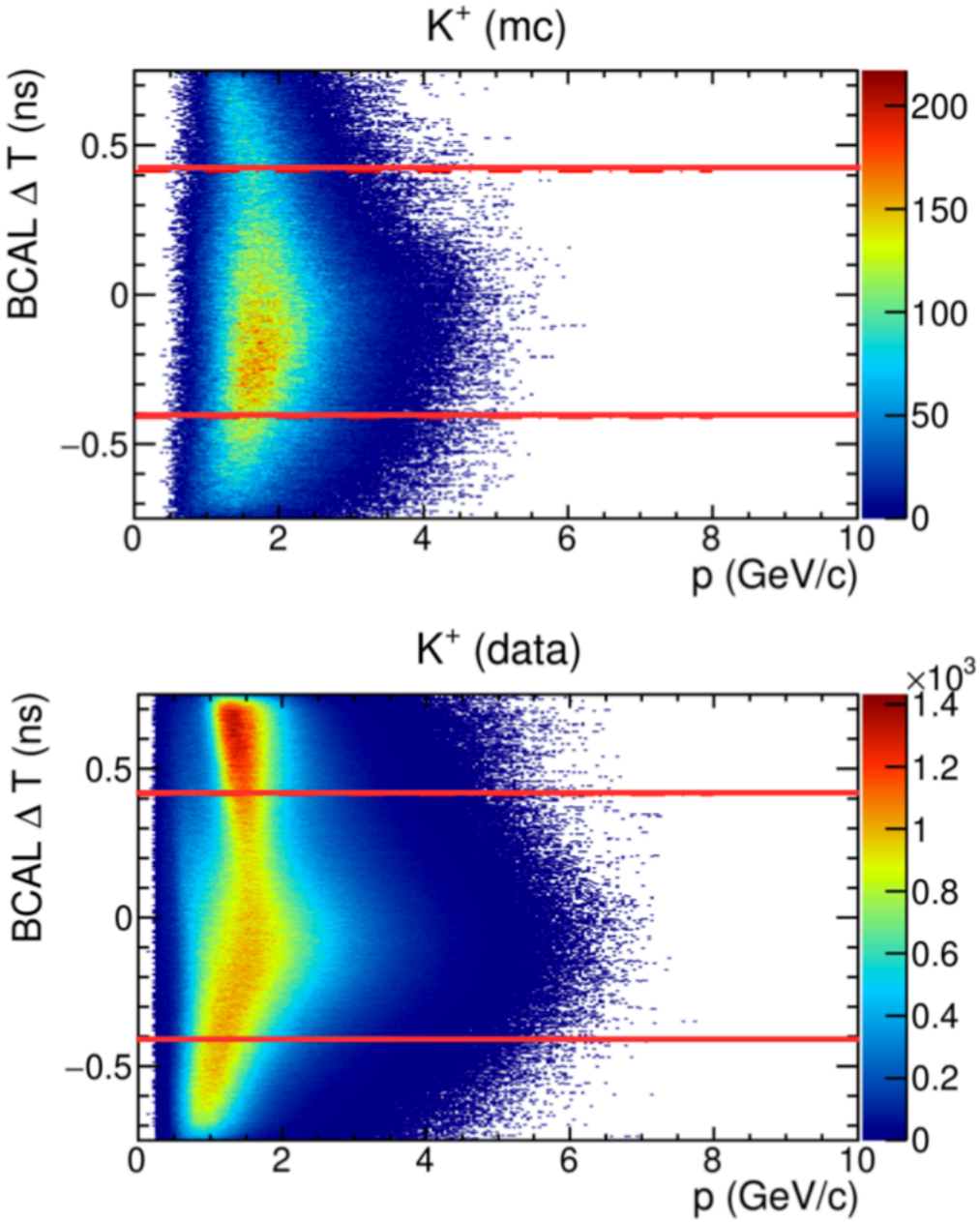
Event selection

- TOF/RF ΔT: ±0.135 ns ($K^{\pm}$)



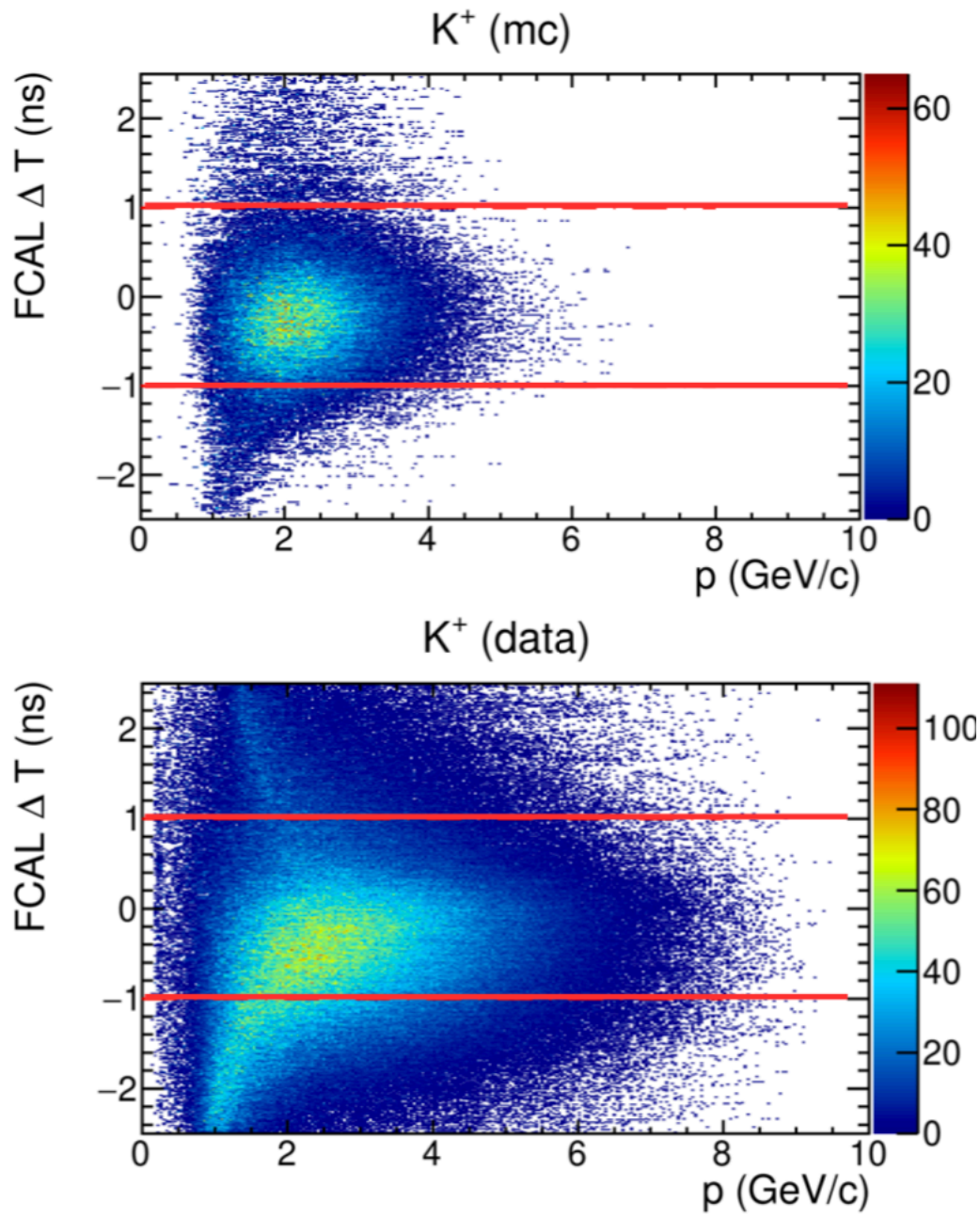
Event selection

- TOF/RF ΔT: ±0.135 ns ($K^{\pm}$)
- BCAL/RF Δt: ±0.4125 ns (K±)



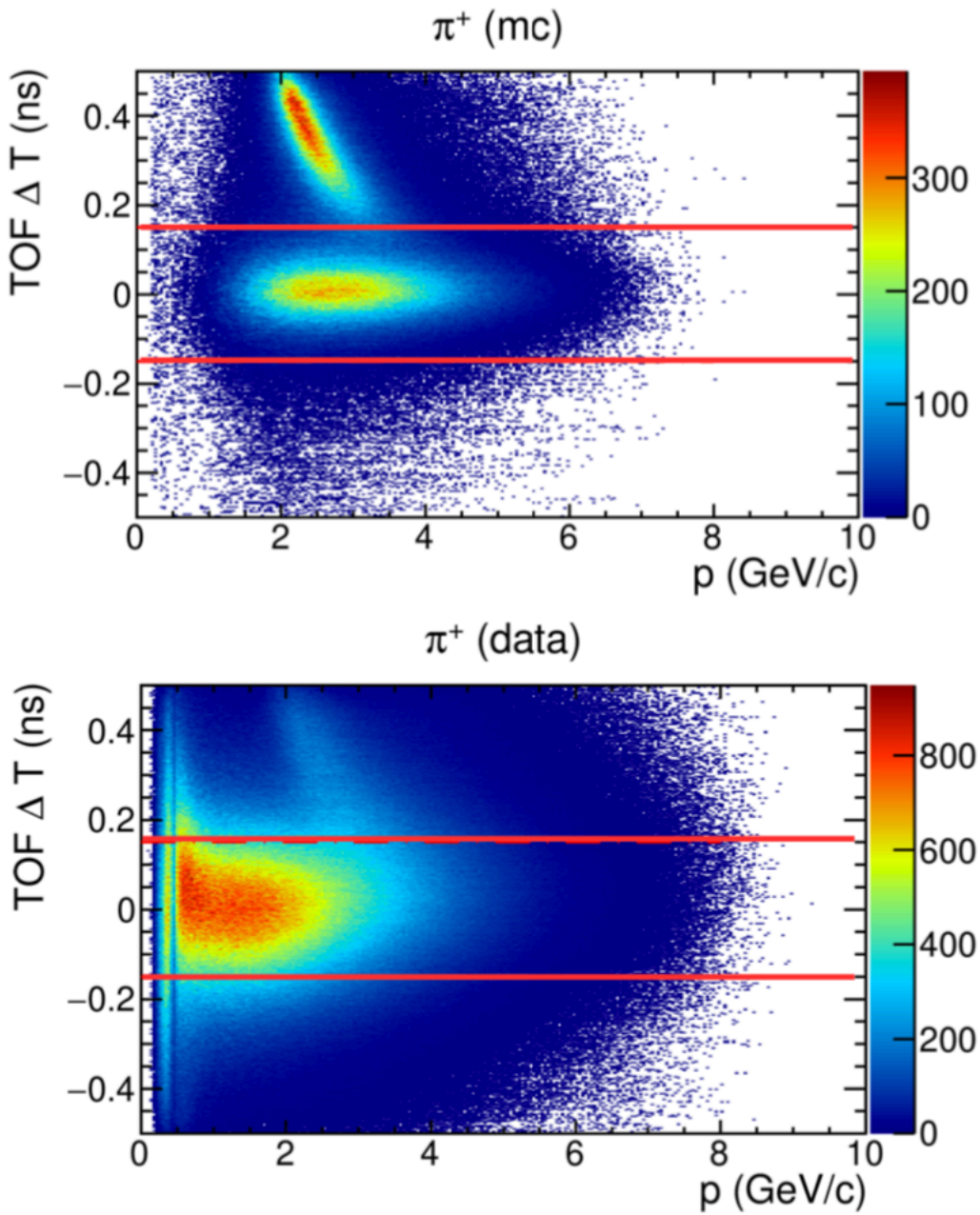
Event selection

- TOF/RF ΔT: ±0.135 ns ($K^{\pm}$)
- BCAL/RF Δt: ±0.4125 ns ($K^{\pm}$)
- FCAL/RF Δt: ±1 ns ($K^{\pm}$)



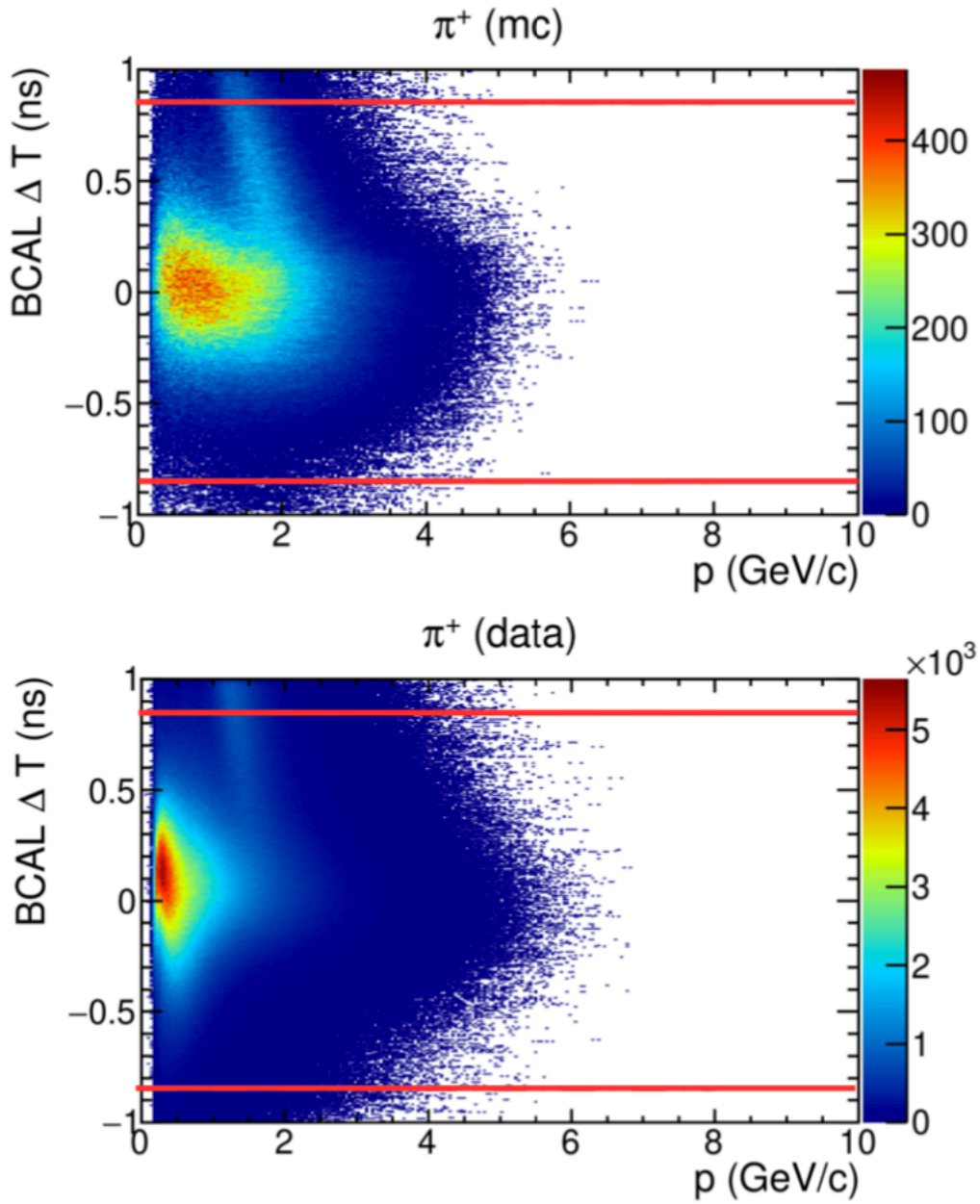
Event selection

- TOF/RF ΔT: ±0.135 ns ($K^{\pm}$)
- BCAL/RF Δt: ±0.4125 ns ($K^{\pm}$)
- FCAL/RF Δt: ±1 ns ($K^{\pm}$)
- TOF/RF Δt: ±0.15 ns ($\pi^{\pm}$)



Event selection

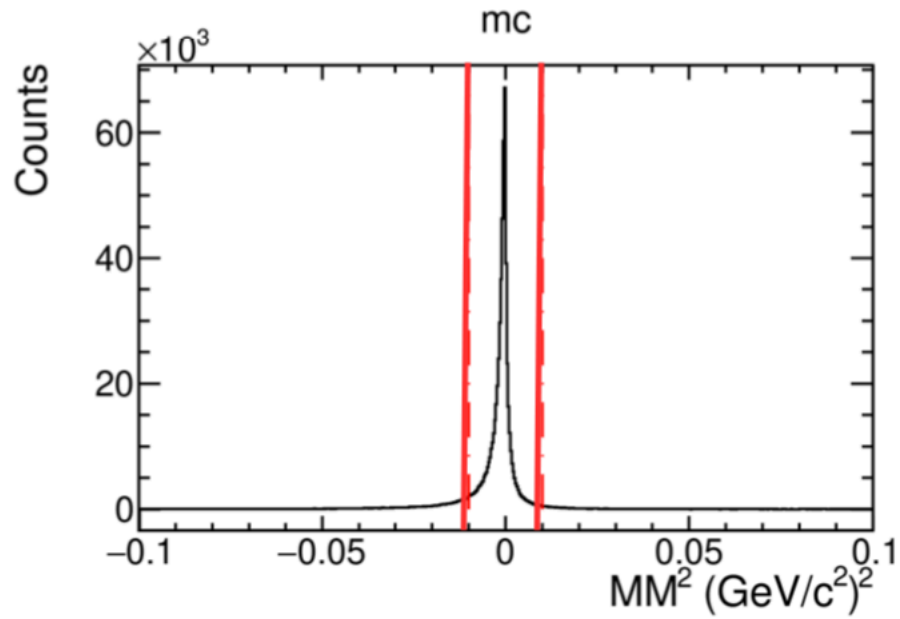
- TOF/RF ΔT: ±0.135 ns ($K^{\pm}$)
- BCAL/RF Δt: ±0.4125 ns ($K^{\pm}$)
- FCAL/RF Δt: ±1 ns ($K^{\pm}$)
- TOF/RF Δt: ±0.15 ns ($\pi^{\pm}$)
- BCAL/RF Δt: ±0.85 ns ($\pi^{\pm}$)

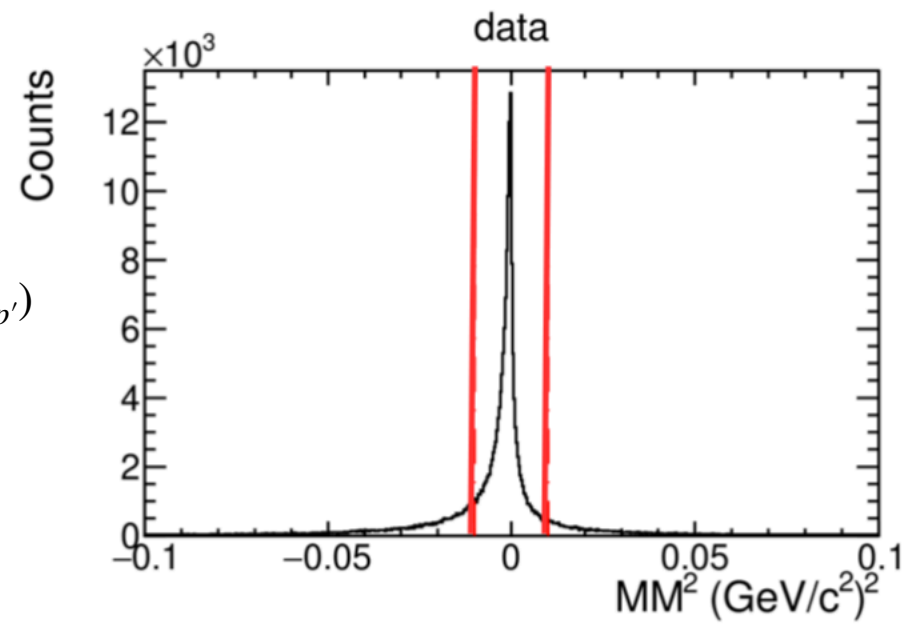


Event selection

- TOF/RF ΔT: ±0.135 ns ($K^{\pm}$)
- BCAL/RF Δt: ±0.4125 ns ($K^{\pm}$)
- FCAL/RF Δt: ±1 ns ($K^{\pm}$)
- TOF/RF Δt: ±0.15 ns ($\pi^{\pm}$)
- BCAL/RF Δt: ±0.85 ns ($\pi^{\pm}$)
- TOF/RF Δt: ±0.27 ns (proton)
- |Missing Mass|2 < 0.01GeV

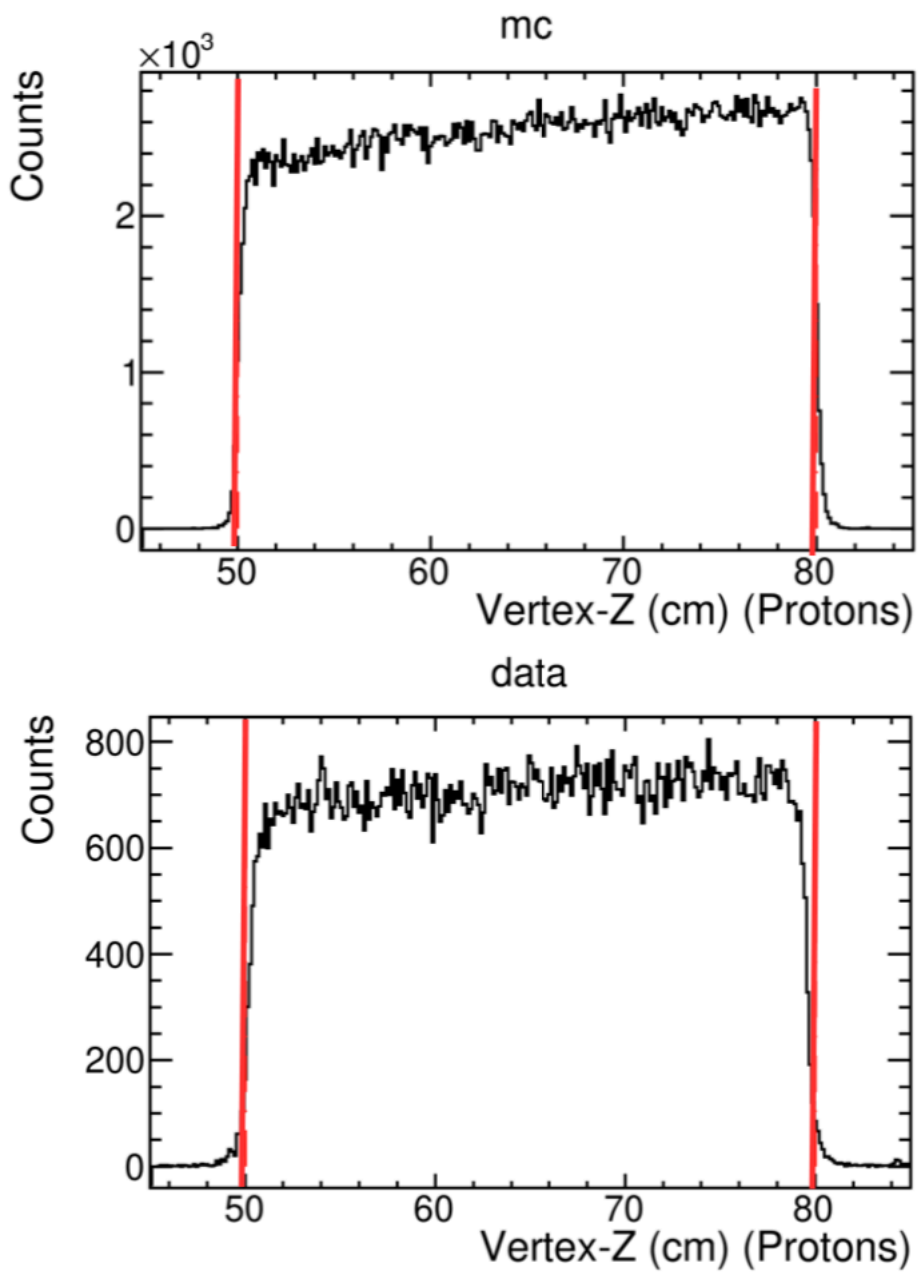
$$MM = (m_{\gamma} + m_{p}) - (m_{K^+} + m_{K^+} + m_{\pi^+} + m_{\pi^-} + m_{p'})$$





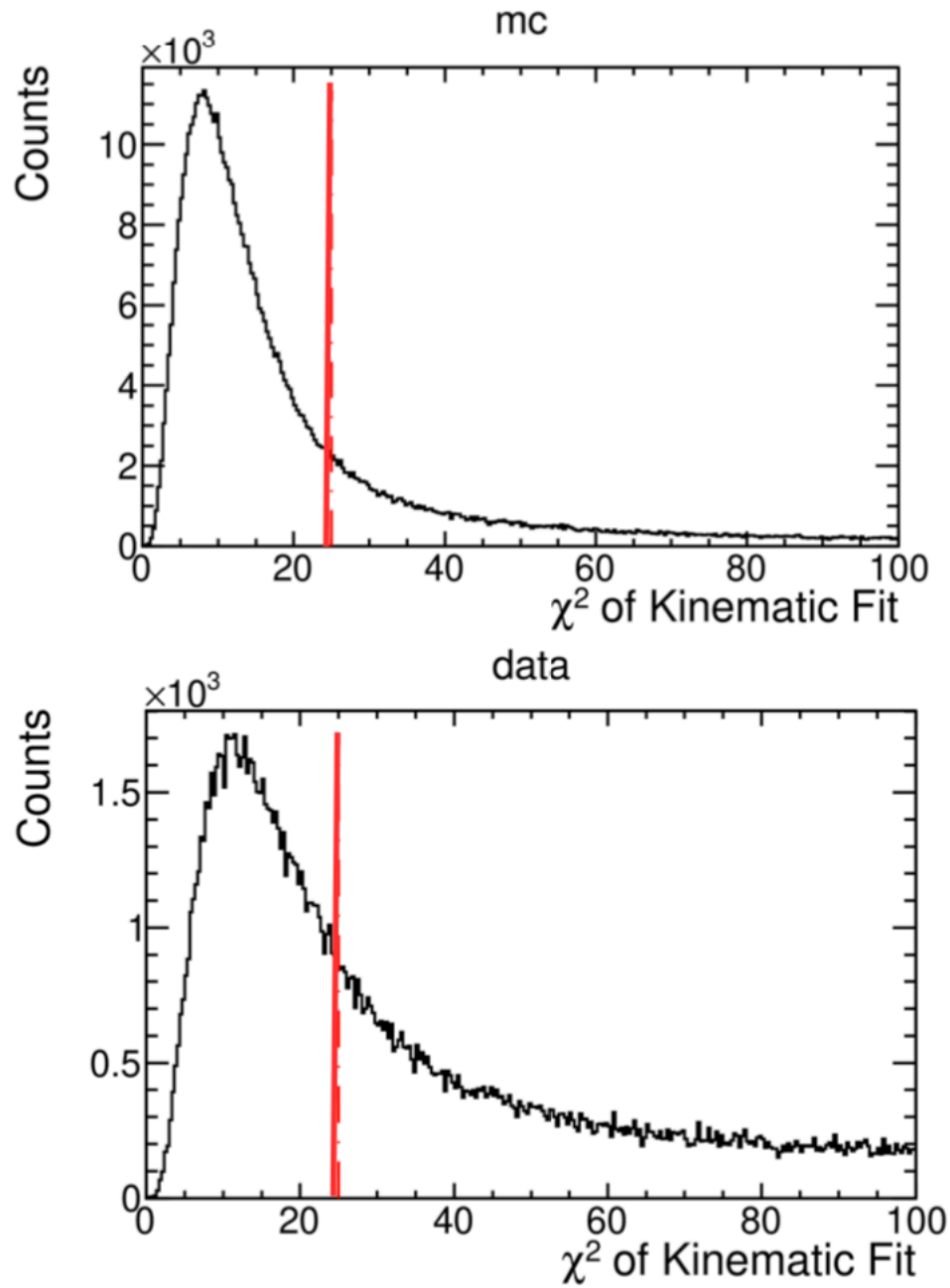
Event selection

- TOF/RF ΔT: ±0.135 ns ($K^{\pm}$)
- BCAL/RF Δt: ±0.4125 ns ($K^{\pm}$)
- FCAL/RF Δt: ±1 ns ($K^{\pm}$)
- TOF/RF Δt: ±0.15 ns ($\pi^{\pm}$)
- BCAL/RF Δt: ±0.85 ns ($\pi^{\pm}$)
- TOF/RF Δt: ±0.27 ns (proton)
- |Missing Mass|2 < 0.01GeV
- Vertex Z : [50, 80 cm]



Event selection

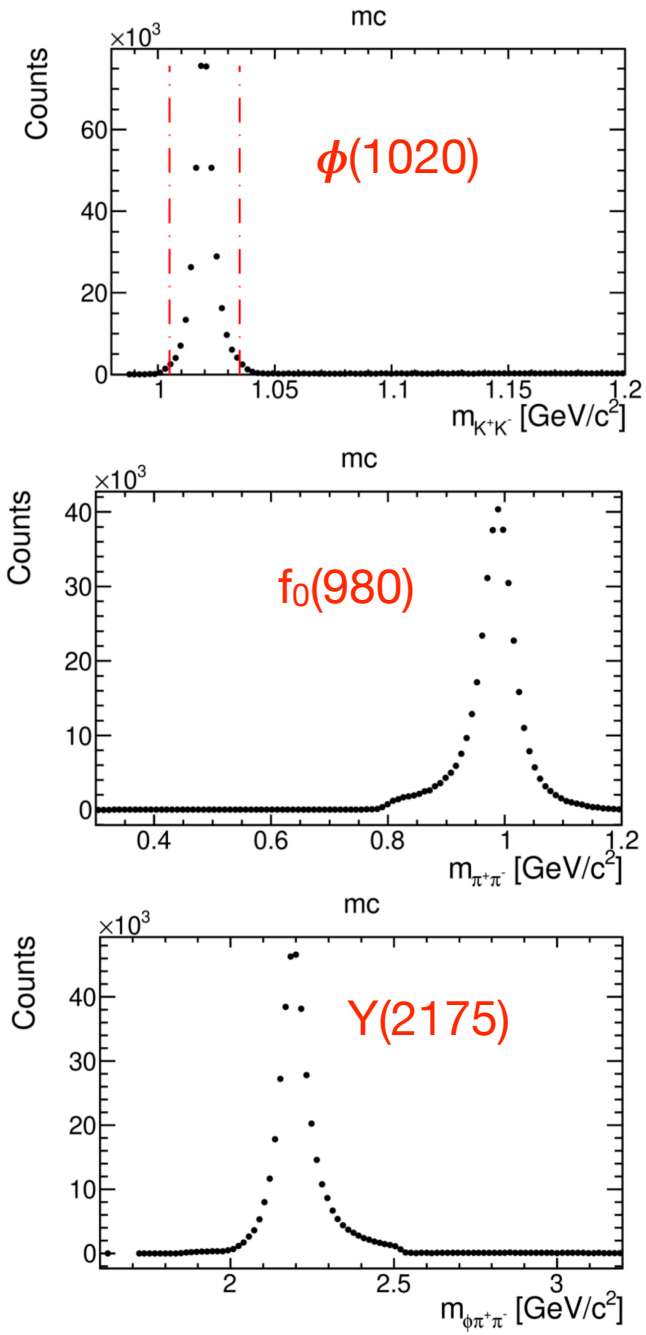
- TOF/RF ΔT: ±0.135 ns ($K^{\pm}$)
- BCAL/RF Δt: ±0.4125 ns ($K^{\pm}$)
- FCAL/RF Δt: ±1 ns ($K^{\pm}$)
- TOF/RF Δt: ±0.15 ns ($\pi^{\pm}$)
- BCAL/RF Δt: ±0.85 ns ($\pi^{\pm}$)
- TOF/RF Δt: ±0.27 ns (proton)
- |Missing Mass|2 < 0.01GeV
- Vertex Z : [50, 80 cm]
- Kinematic fit: χ2 < 25

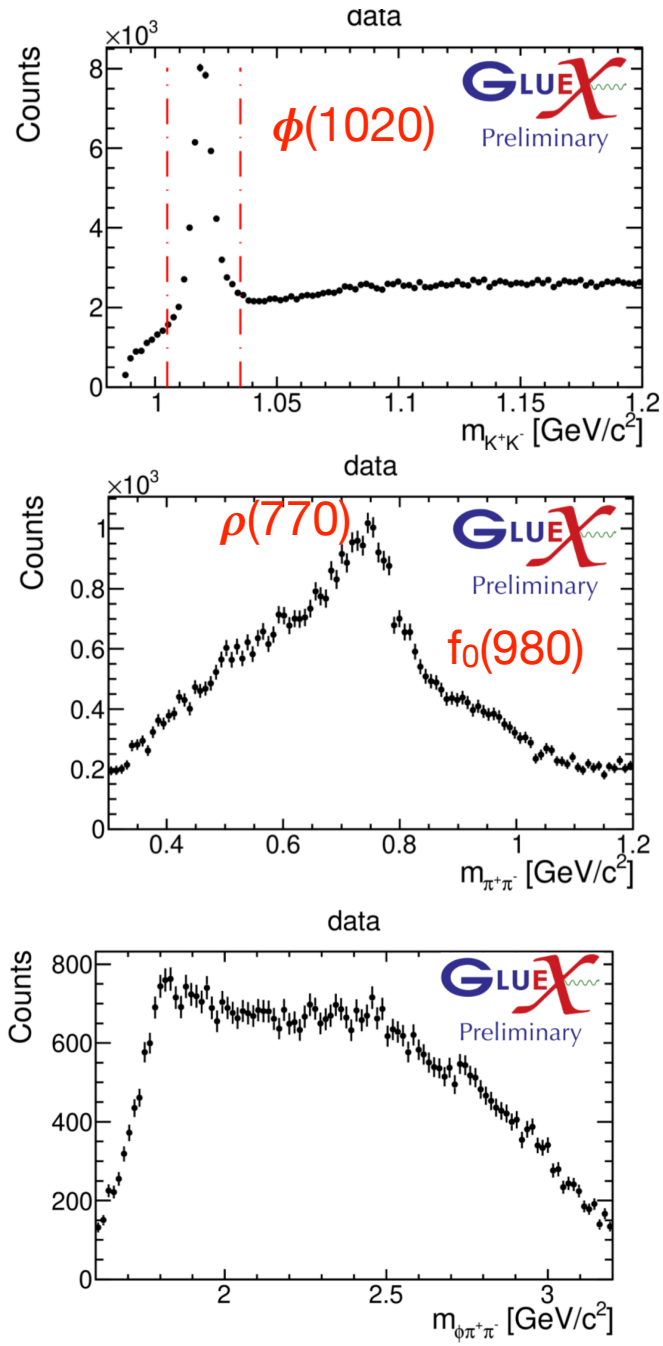


Invariant Mass

Signal MC

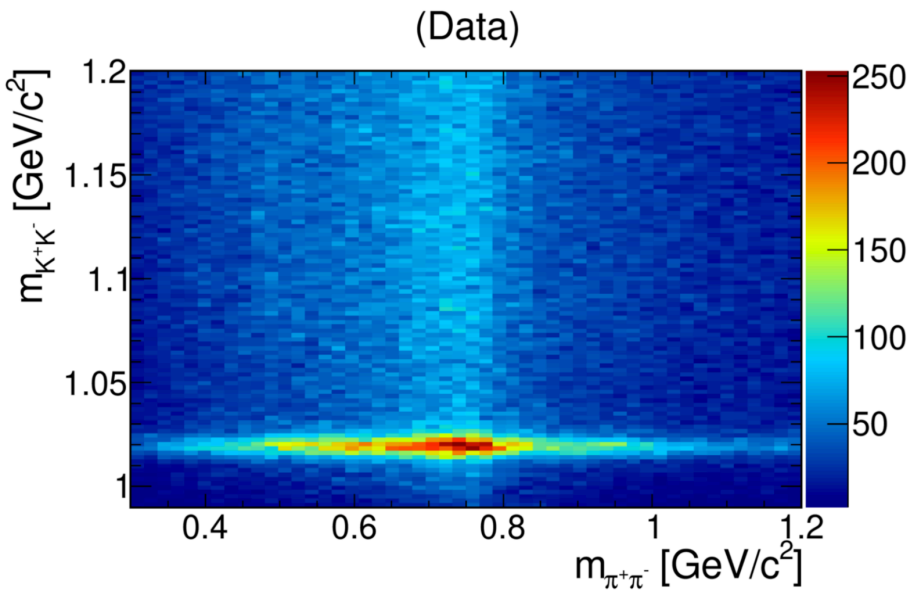
Data





(ϕ,$\pi^+\pi$-) invariant mass correlation

- ϕ(1020) yields in $\pi^+\pi^-$ invariant mass bins



(ϕ,$\pi^+\pi$-) invariant mass correlation

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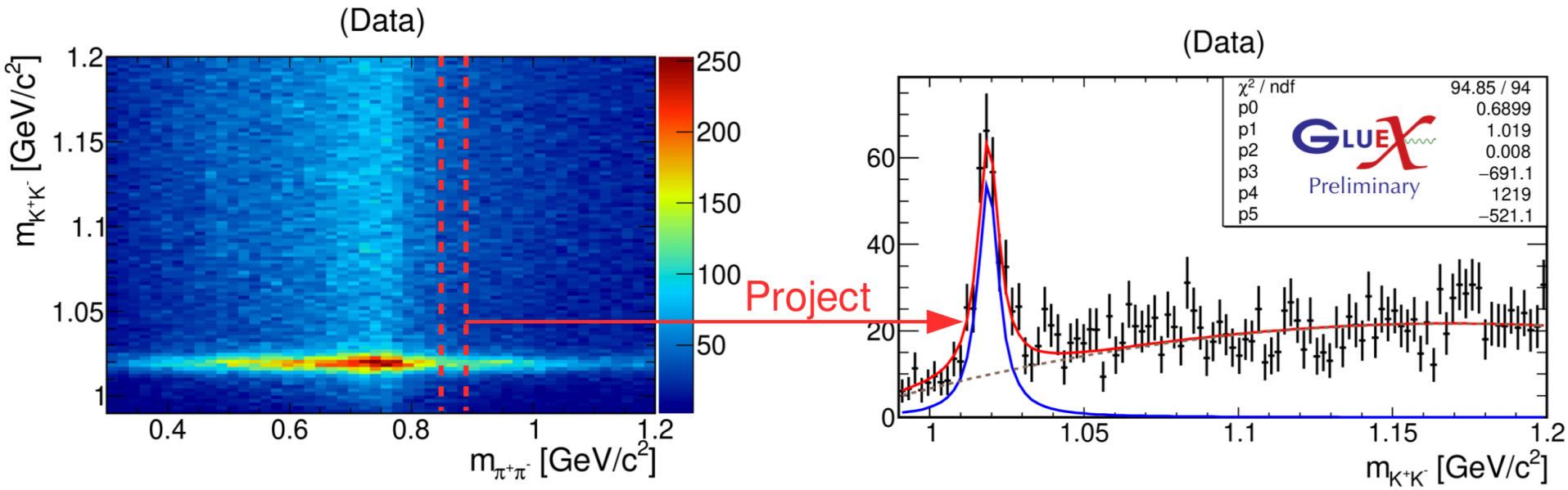
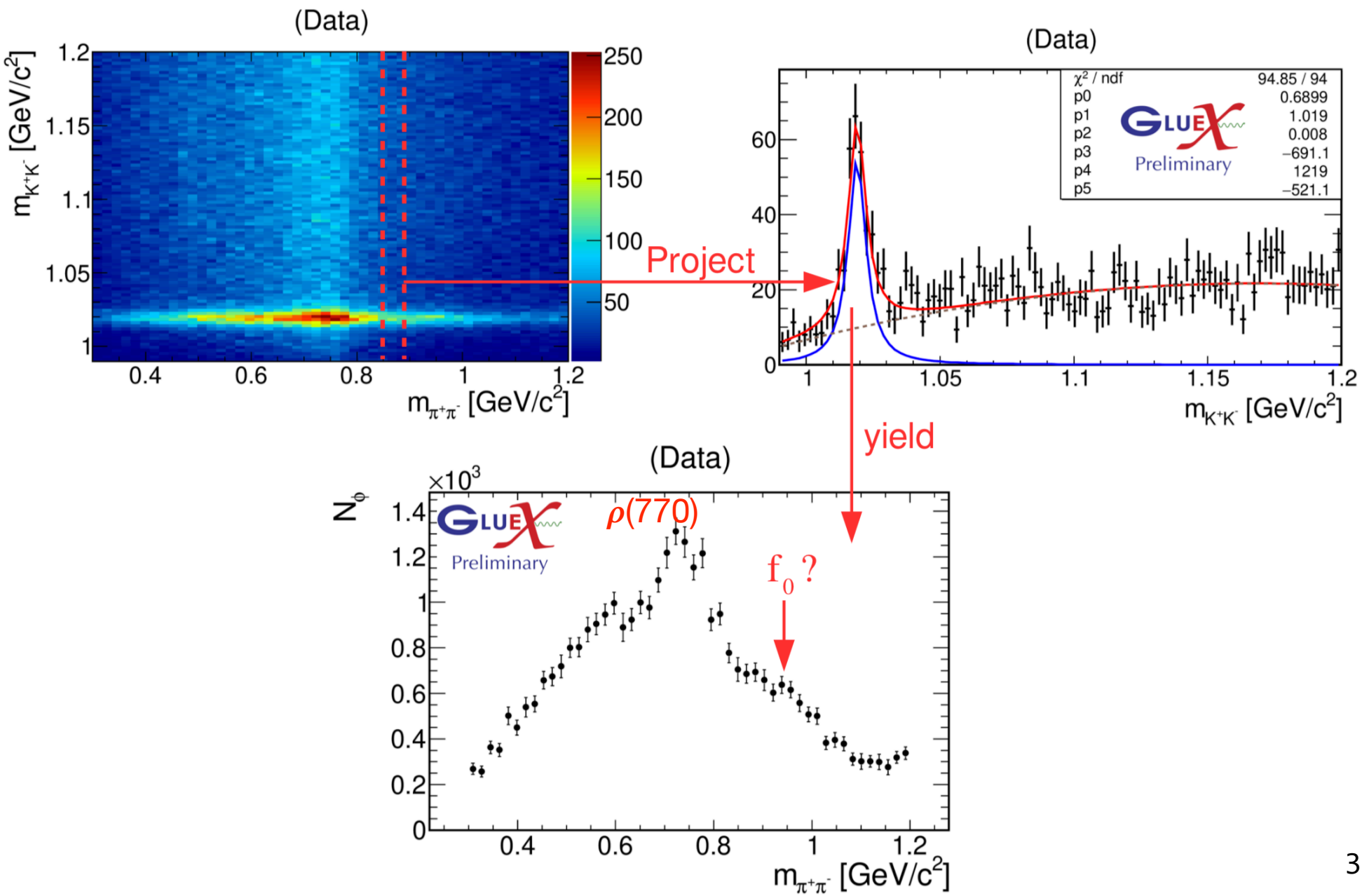


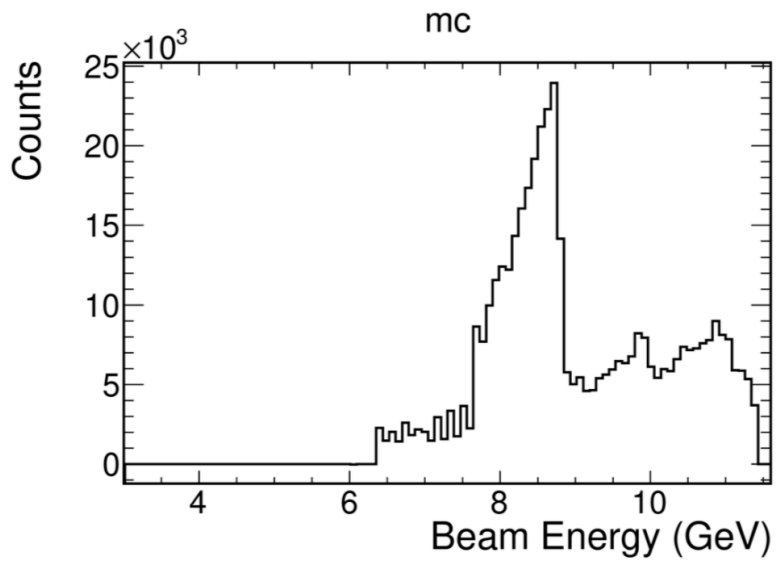
(ϕ,$\pi^+\pi$-) invariant mass correlation

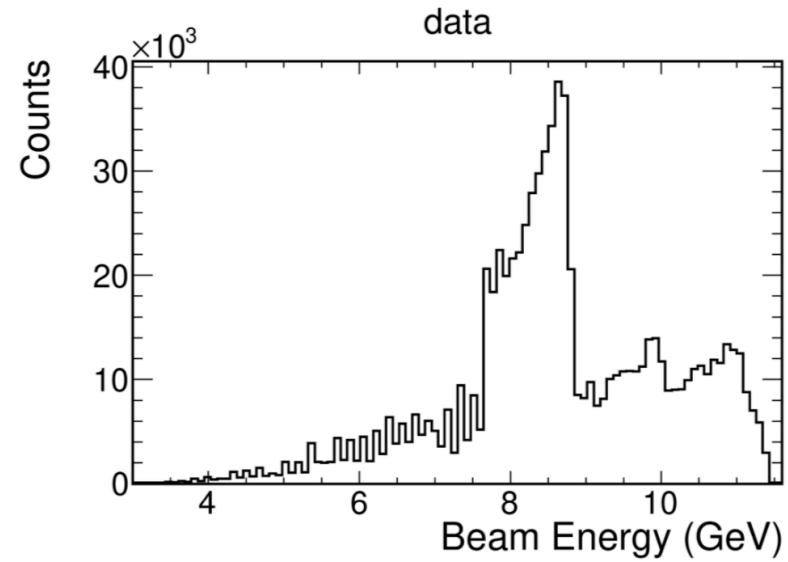
- ϕ(1020) yields in $\pi^+\pi^-$ invariant mass bins

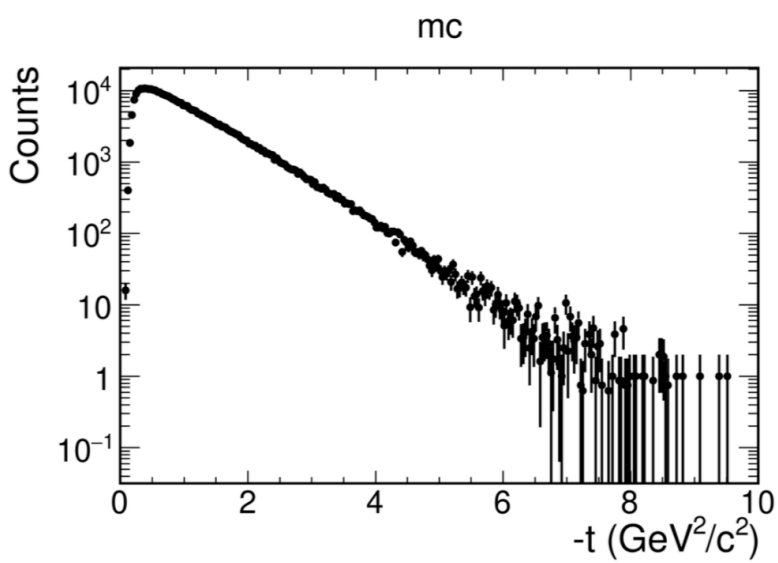


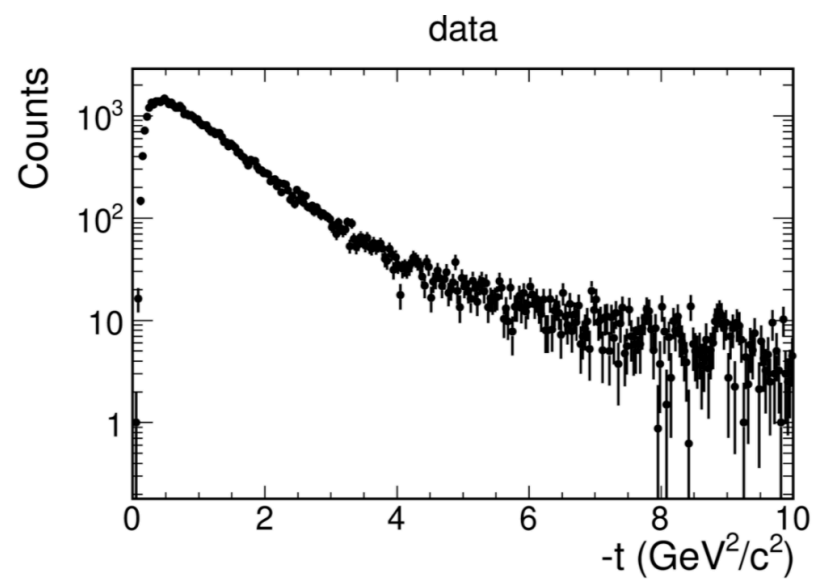
Beam energy & proton transfer momentum

- Efficiency and cross section will depend on the beam energy & transfer momentum







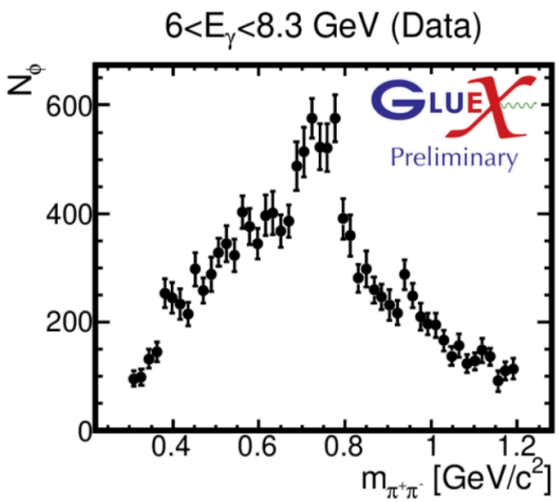


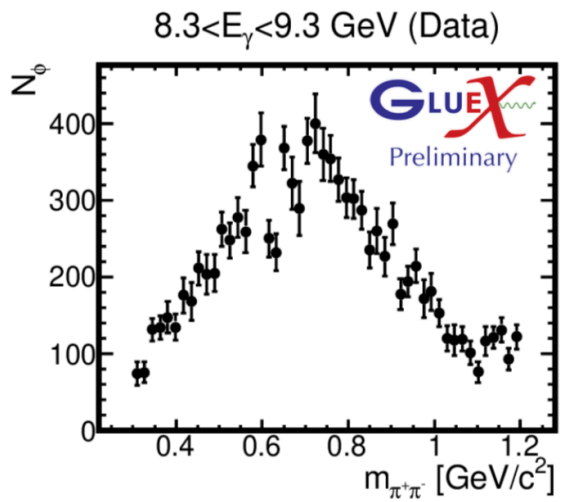
$$\frac{\partial \sigma}{\partial t} \propto e^{-bt}$$

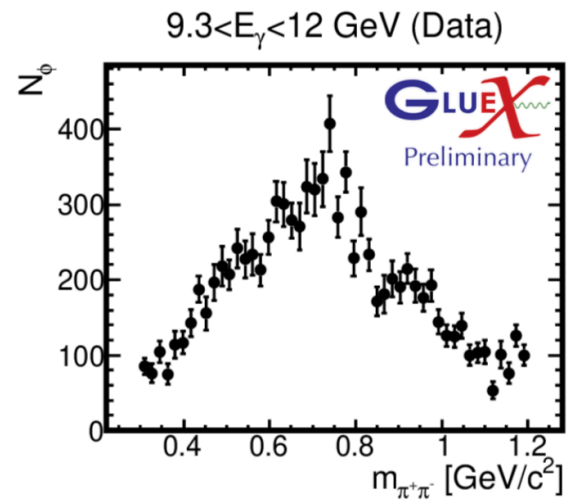
(ϕ, $\pi^+\pi$-) mass correlation

- ϕ(1020) yields vs. $\pi^+\pi^-$ invariant mass in beam energy and Proton momentum transfer bins

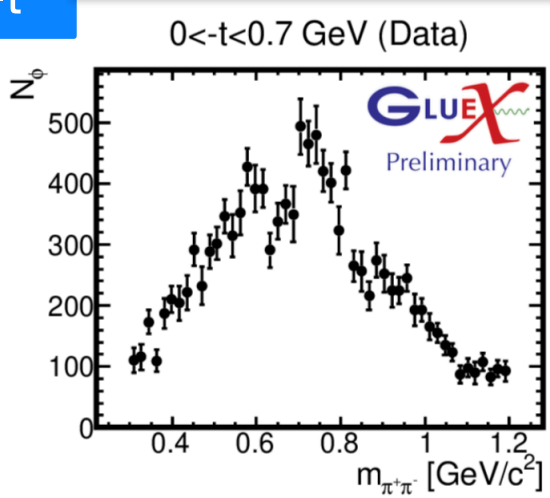
E_γ

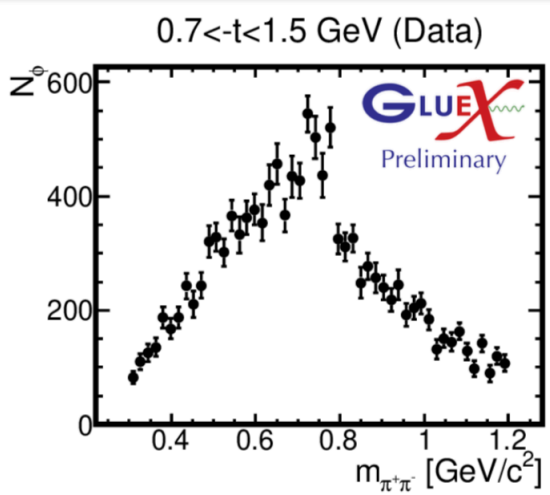


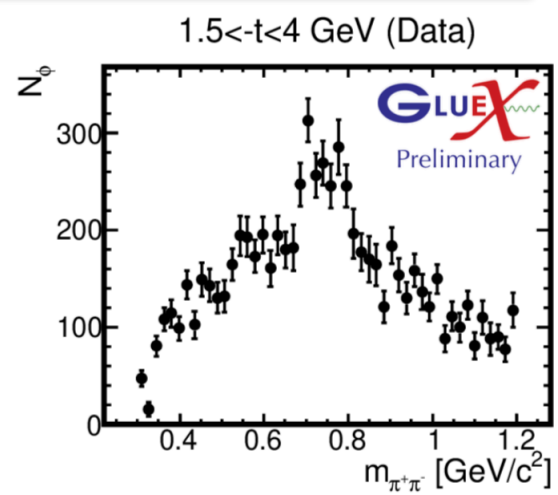




-t



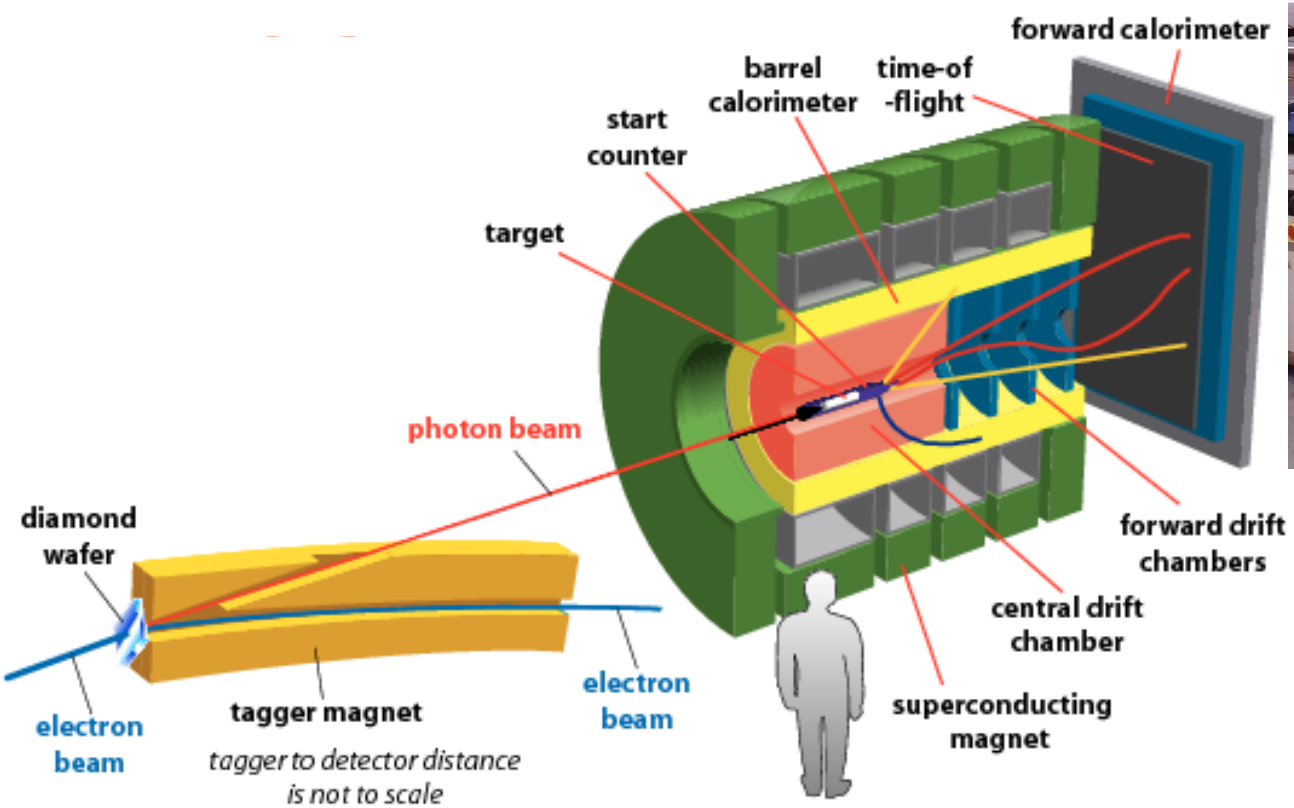




Moving forward: GlueX phase II

PID Upgrade: DIRC (**D**etection of **I**nternally **R**eflected **C**herenkov light)

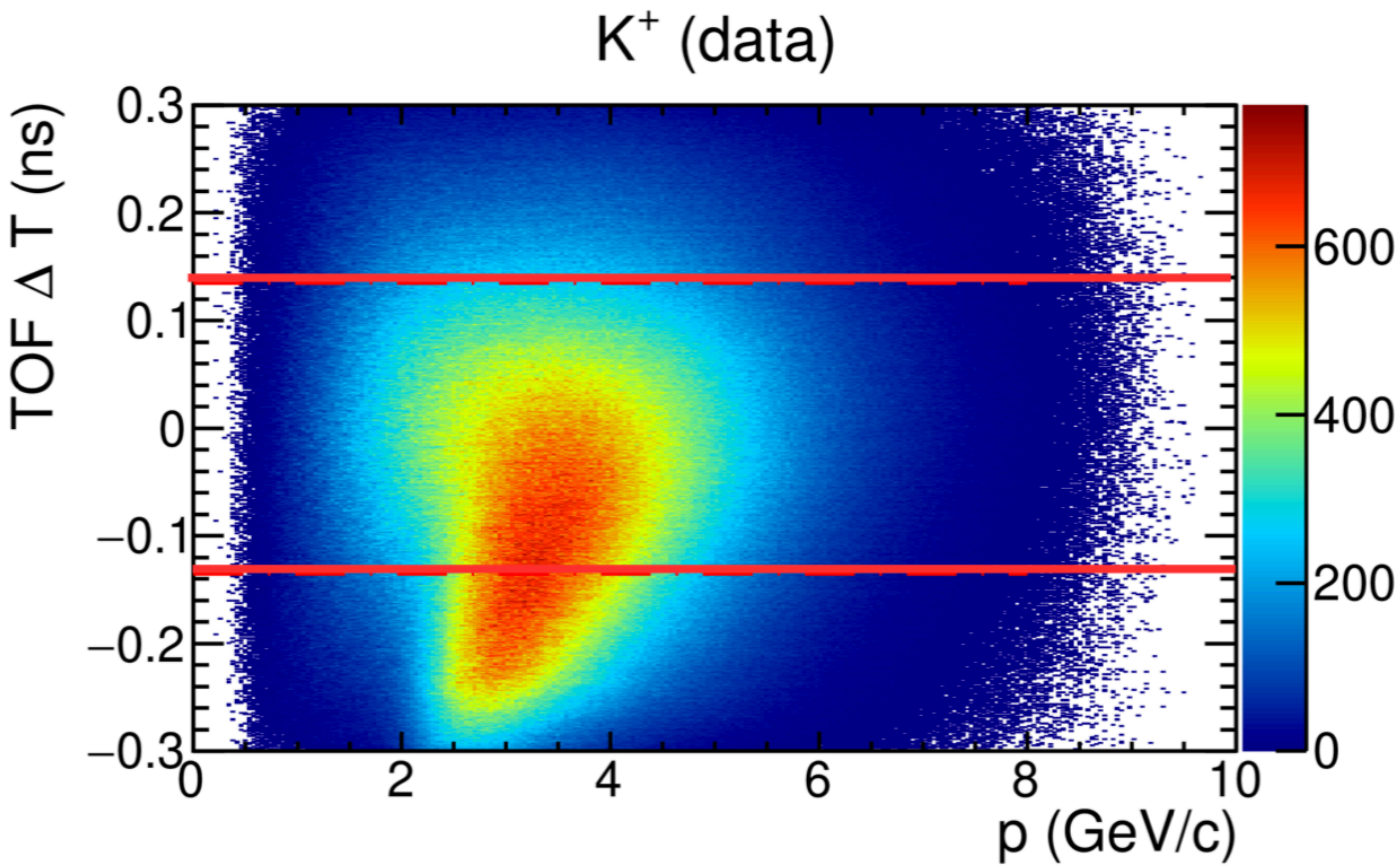
- Installation and Commissioning is currently ongoing



Moving forward: GlueX phase II

PID Upgrade: DIRC (**D**etection of **I**nternally **R**eflected **C**herenkov light)

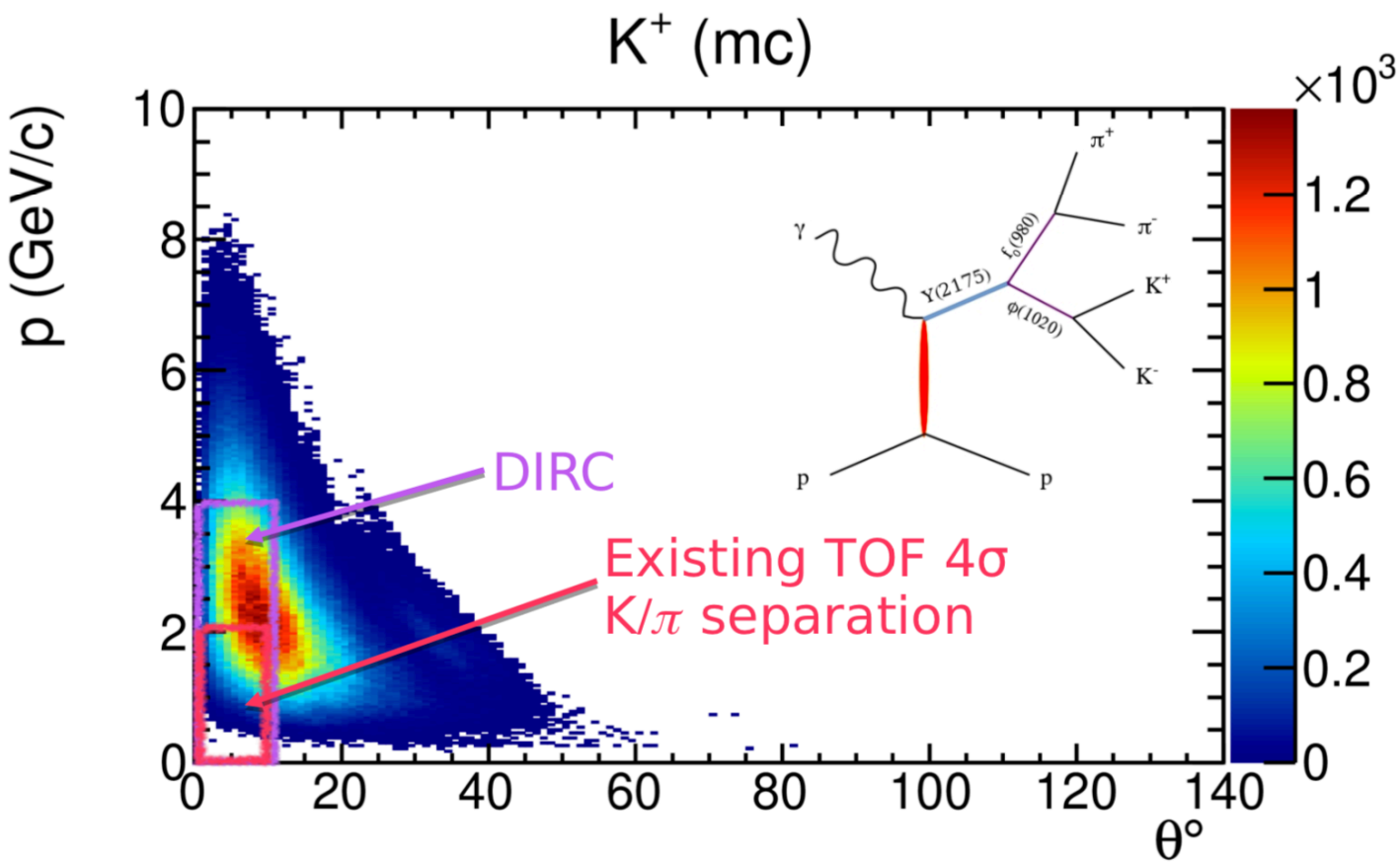
- Limited separation between K and π up to p = 2 GeV/c



Moving forward: GlueX phase II

PID Upgrade: DIRC (**D**etection of **I**nternally **R**eflected **C**herenkov light)

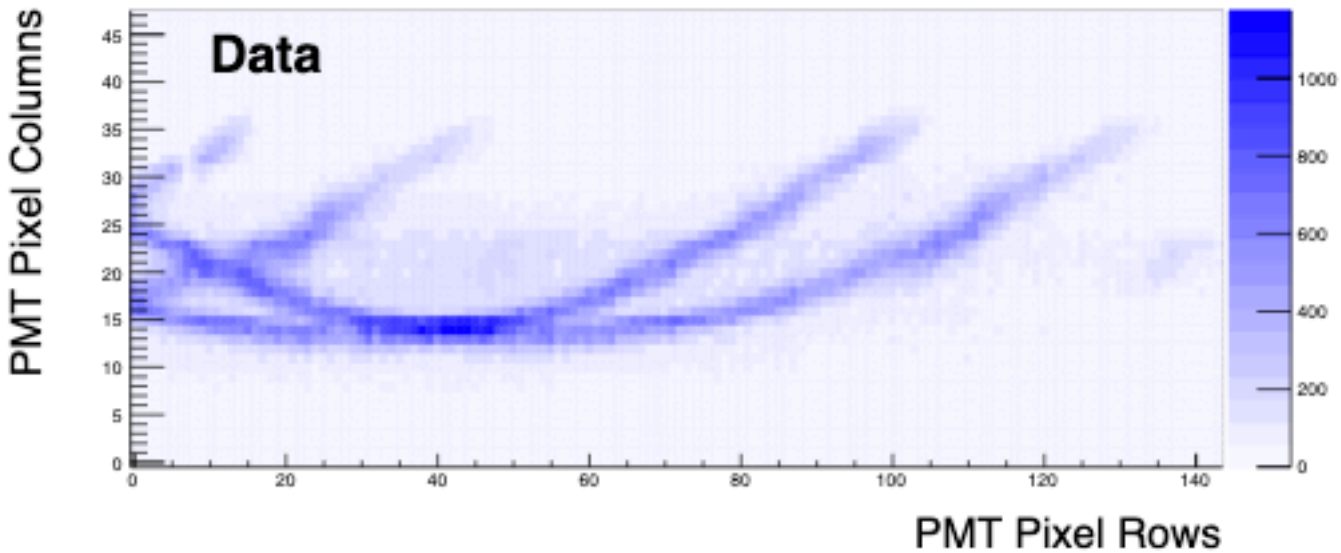
- Separation between K and π up to p = 4 GeV/c
- Collect 10x more data
- Extends reach for exotic hadrons containing strange quark

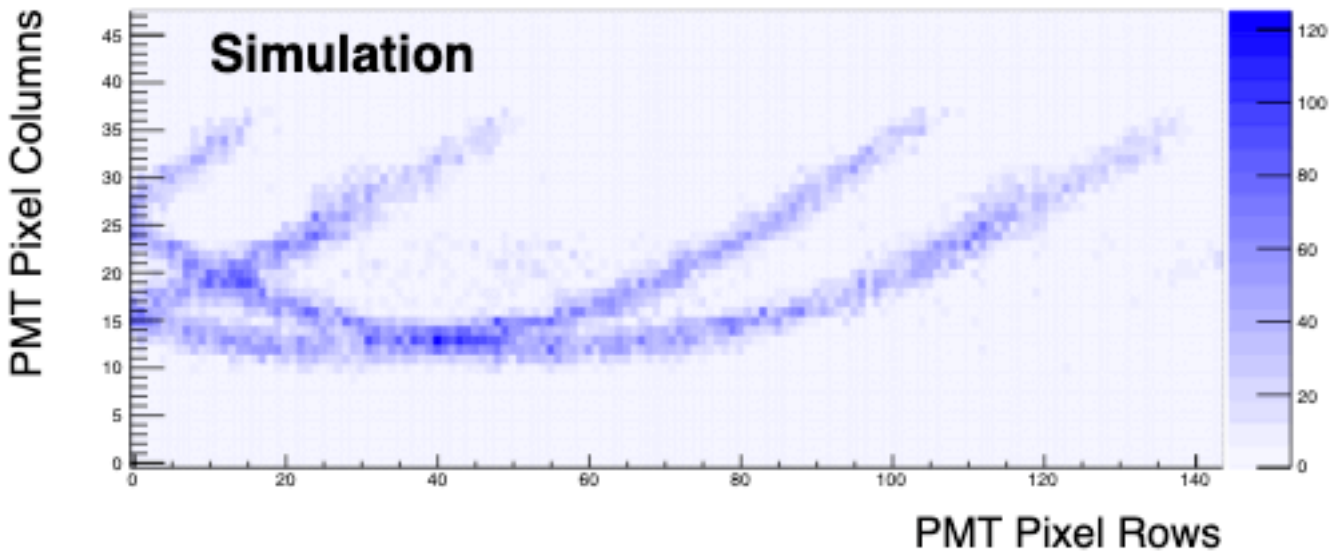


Moving forward: GlueX phase II

PID Upgrade: DIRC (**D**etection of **I**nternally **R**eflected **C**herenkov light)

- Installation and Commissioning is currently ongoing



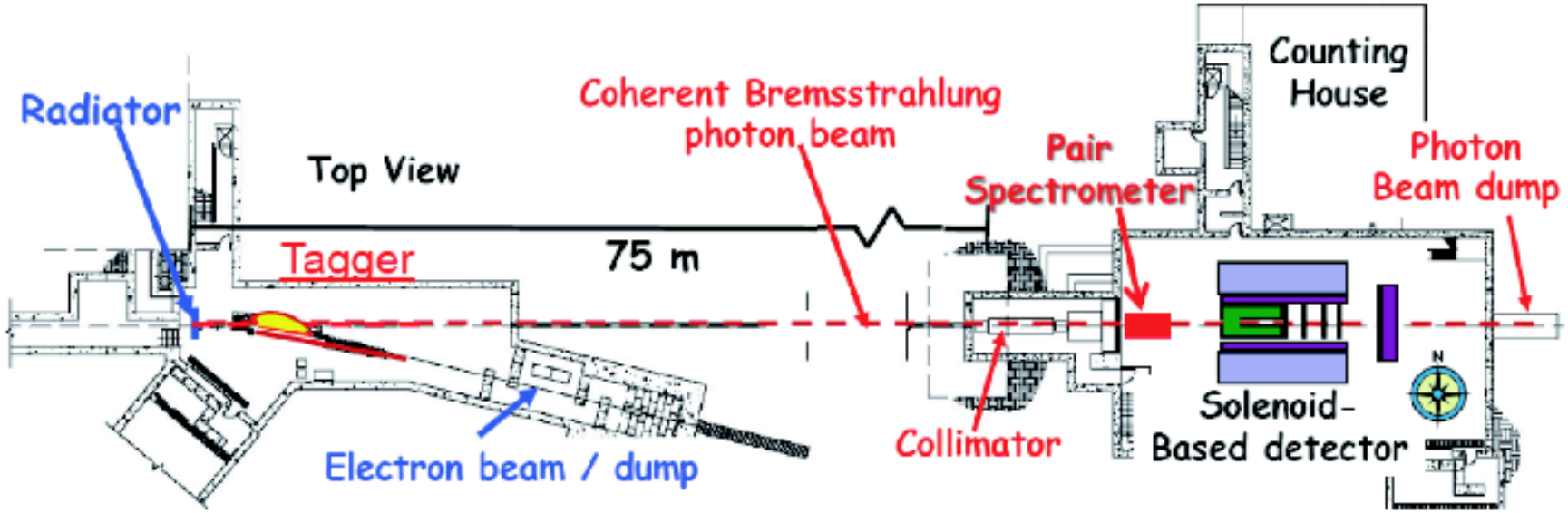


Summary

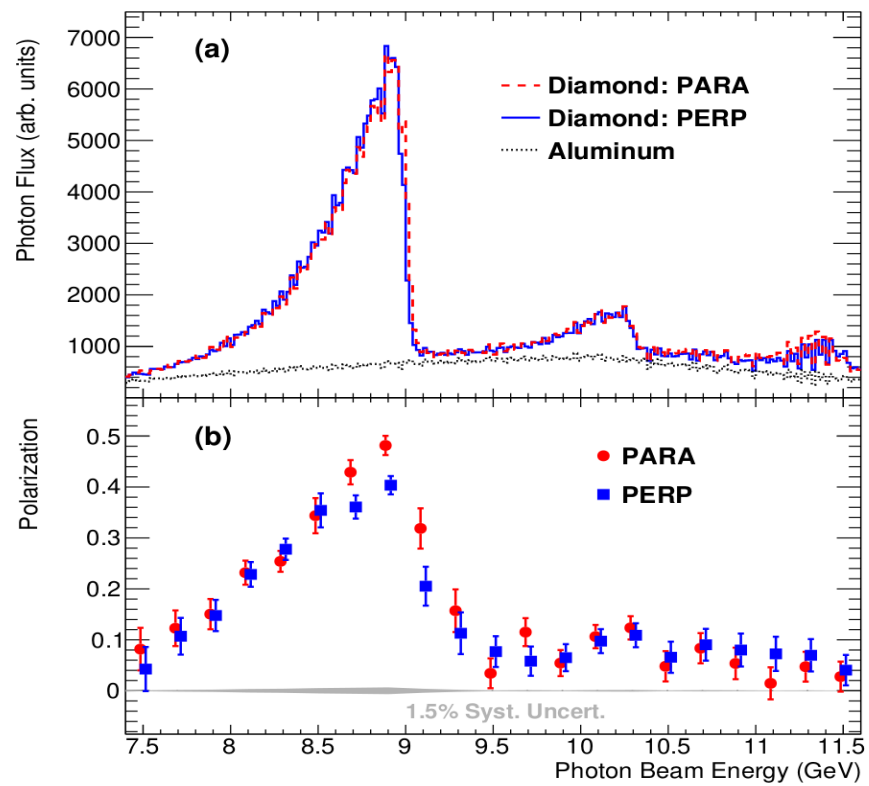
- The GlueX experiment has started mapping the conventional meson spectrum, as a first step towards the search for hybrid mesons.
- GlueX Physics Analysis :
- Production mechanism studies (beam asymmetries: π^0,η, $\pi^{\pm}$, ρ, ω,...)
- Measurement of the J/ψ cross section (paper coming soon)
- Y(2175) Photo-production: ϕ(1020) observation, improve selection (Van Hove ,...)
- ...
- Data production:
- 2016: 10 pb^{-1} → 80 hours of physics-quality commissioning data
- 2017: 45 pb^{-1} → used in the Y(2175) study
- 2018: 100 pb^{-1} → end of GlueX Phase-I

Thank you for your attention!

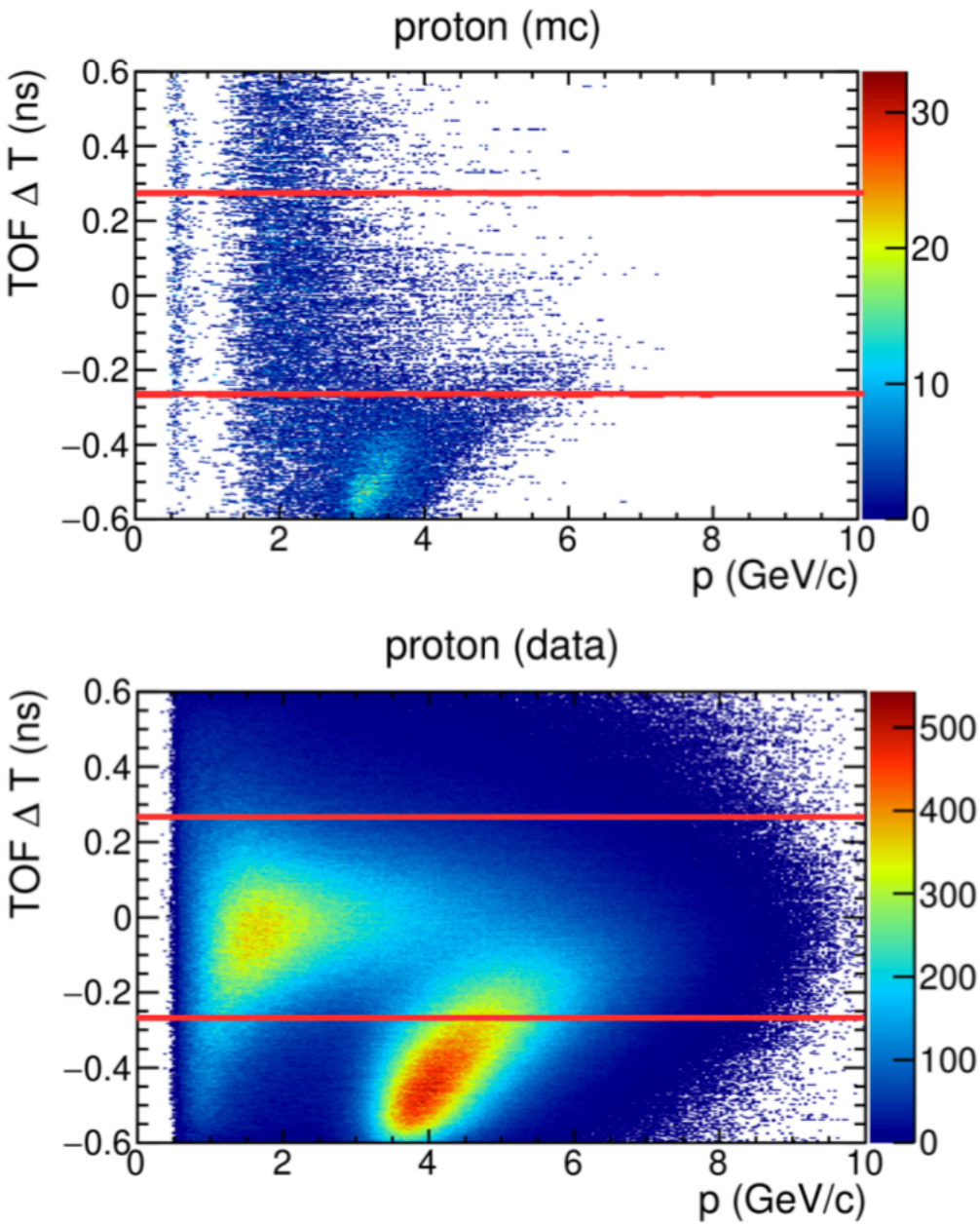
Hall-D Beam Line



- 12 GeV e^- beam
- Linearly polarized photons from coherent bremsstrahlung on a thin diamond radiator.
- Polarization parallel & perpendicular to the floor
- Goal intensity is 10^8 γ/s in coherent peak (8.4 – 9 GeV)



Phys. Rev. C95, 042201 (2017)

Event selection

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- BCAL/RF Δt: ±0.4125 ns ($K^{\pm}$)
- FCAL/RF Δt: ±1 ns ($K^{\pm}$)
- TOF/RF Δt: ±0.15 ns ($\pi^{\pm}$)
- BCAL/RF Δt: ±0.85 ns ($\pi^{\pm}$)
- TOF/RF Δt: ±0.27 ns (proton)