First measurement of near-threshold J/ψ photoproduction and search for the LHCb P_c^+ states at GlueX

Sean Dobbs

Florida State U.

[For the GlueX Collaboration]

HADRON 2019

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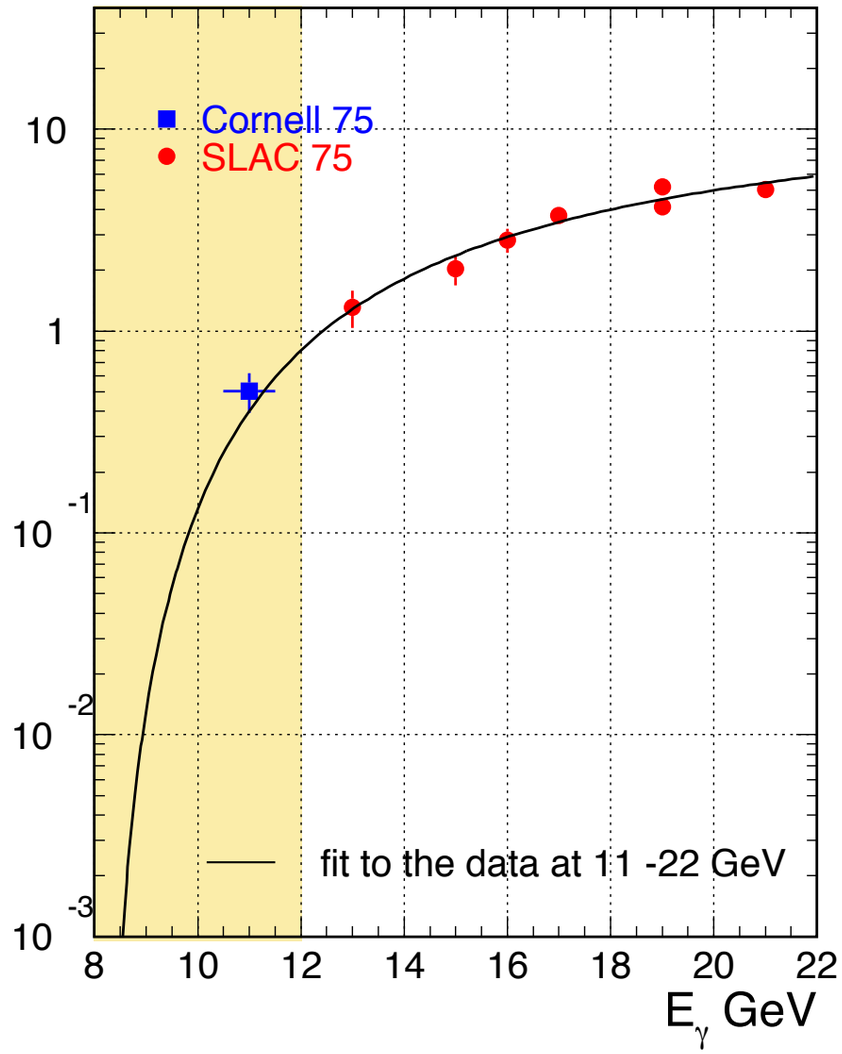
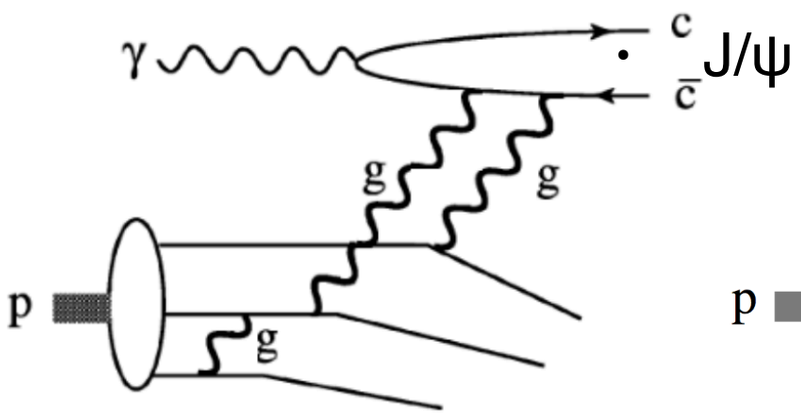
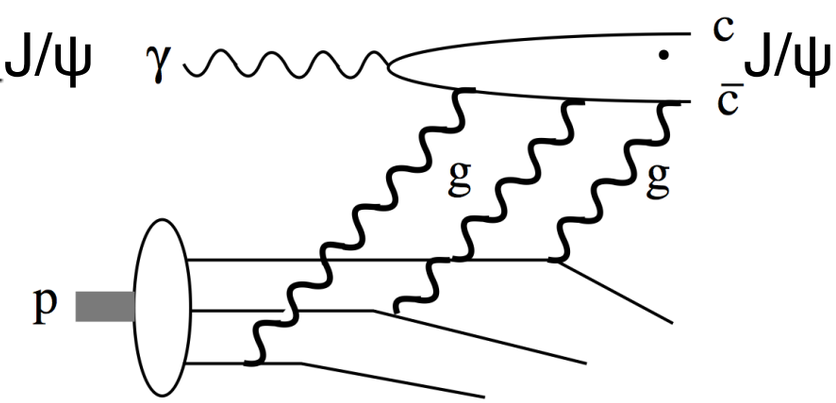
J/ψ Photoproduction Near Threshold

- Threshold production is experimentally clean, ideal for studying J/ψ+N interaction
  - Probes distributions of high-x gluons in proton, trace anomaly, …
    Kharzeev et al., NPA 661, 568 (1999)
    Brodsky et al., PLB 498, 23 (2001)
- Experimentally little-explored
  - 1970's dual-arm spectrometer measurements at SLAC and Cornell





leading-twist



higher-twist

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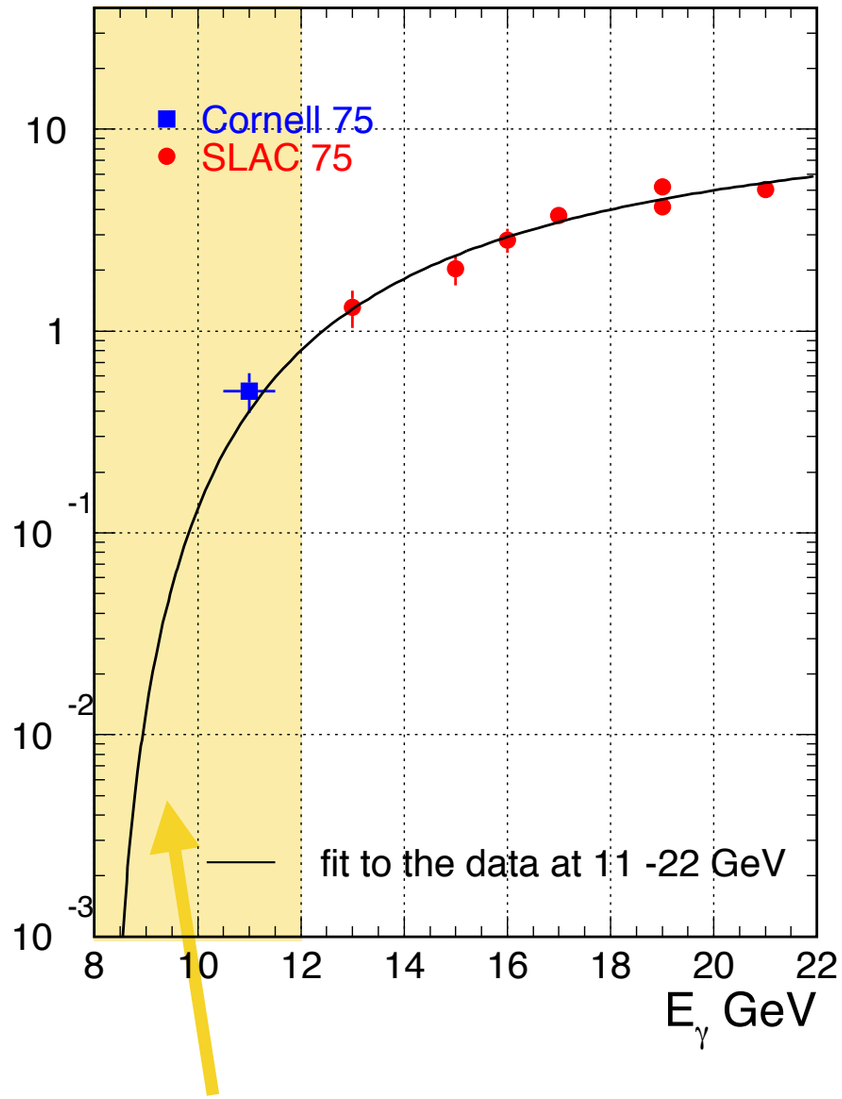

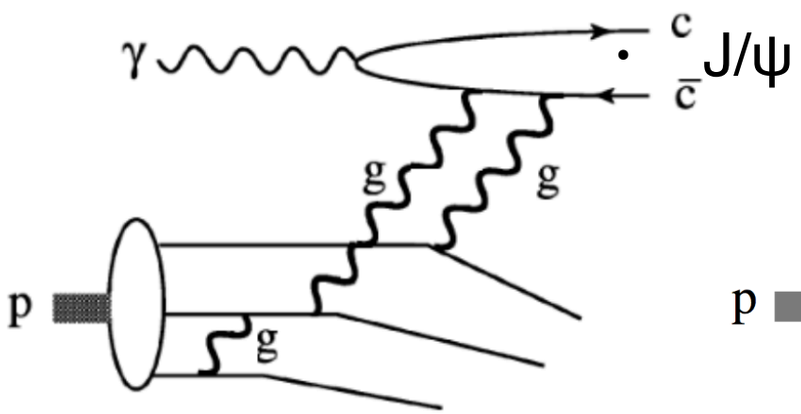

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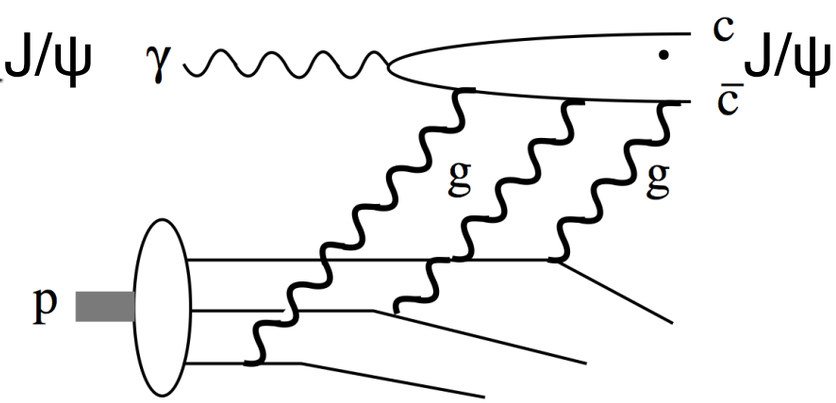


higher-twist

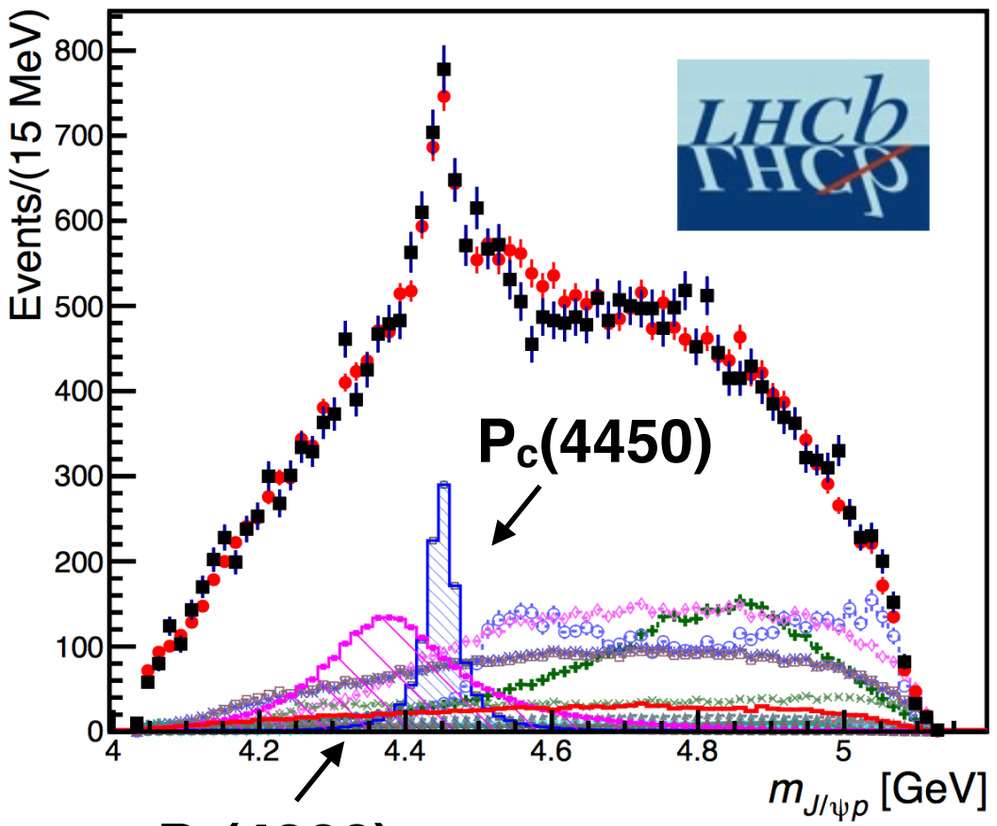
LHCb P_c States

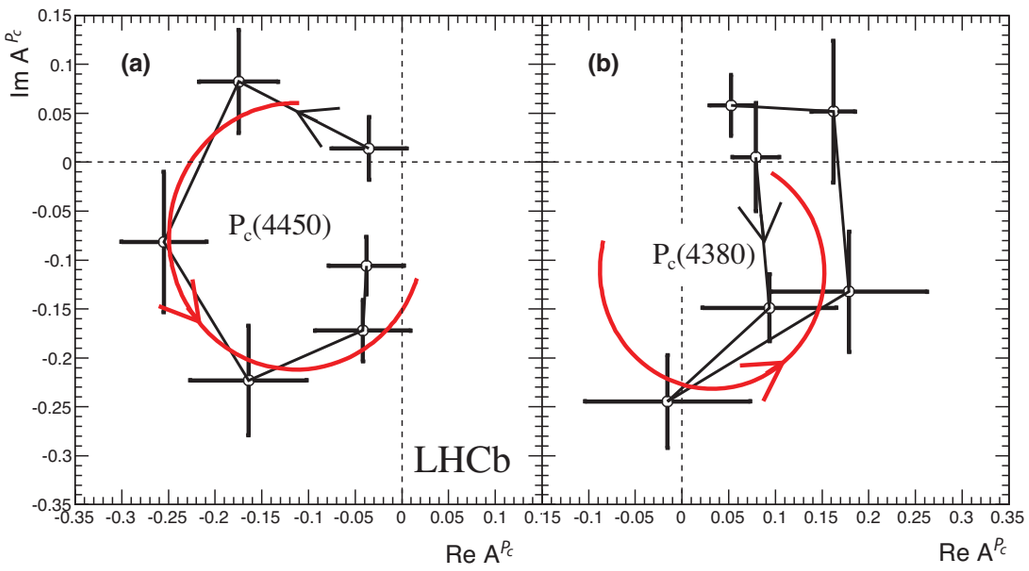
- Many “exotic” hadrons with cc-bar content have been observed in recent years
  - Most interesting: charged exotics
    Strongly implies multiquark content, but what type?

- In 2015, LHCb identified two (J/ψ p) states in an amplitude analysis of the decay $\Lambda_b \to K^- J/\psi\, p$
  - One narrow, one wide
  - Preferred J = 3/2 and 5/2 with opposite parity

LHCb, PRL 115 072001 (2015)

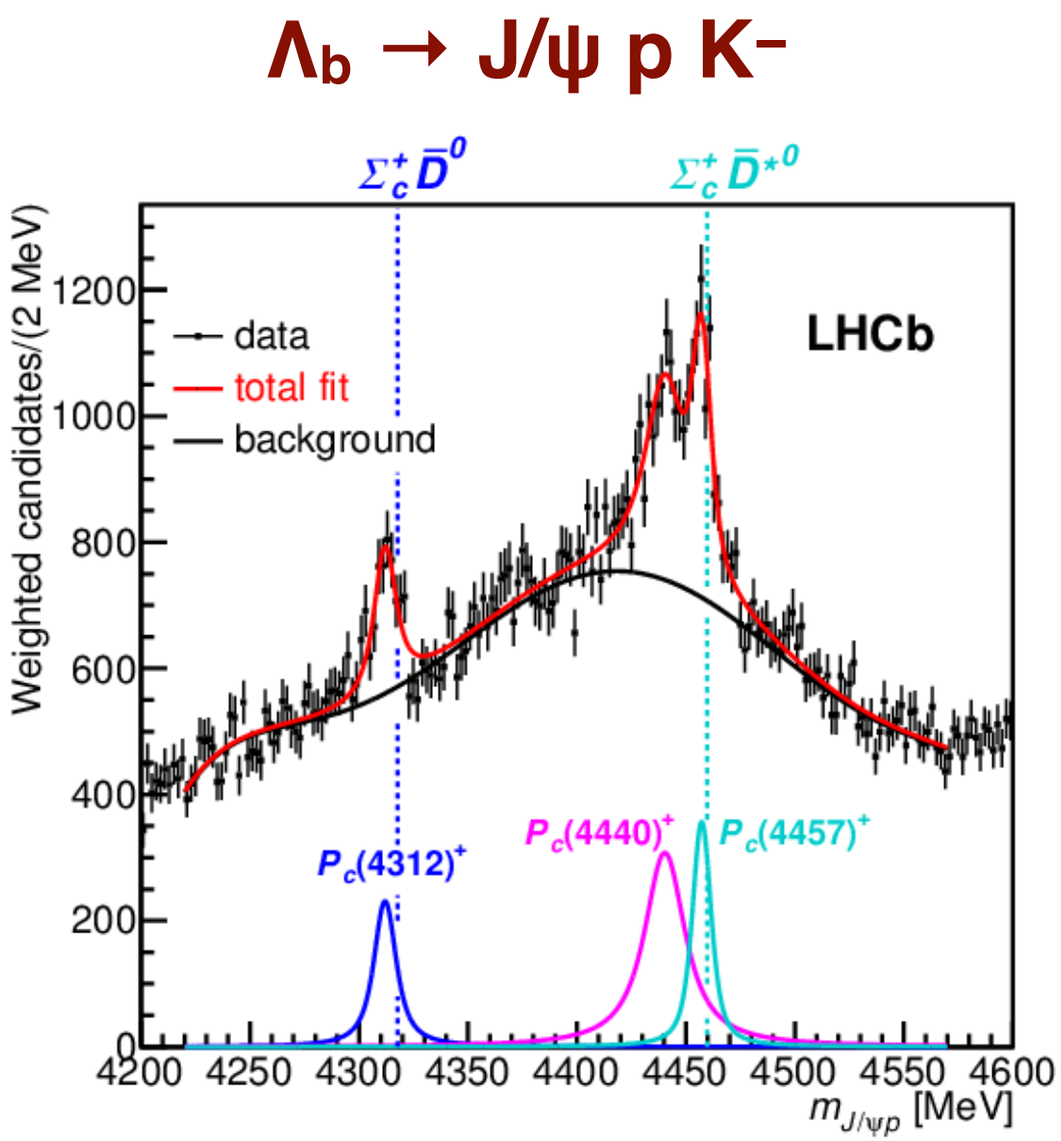
$\Lambda_b \to J/\psi\, p\, K^-$





LHCb P_c States

- In 2019, LHCb identified three narrow (J/ψ p) states in a fit of the mass spectrum with a 9x larger sample
  - Near mass thresholds
  - No spin-parity identification
- Many possible descriptions, including:
  - Tightly-bound or “molecular” multiquark states
  - Hadrocharmonia
  - Cusps, triangle singularities, or other kinematic effects

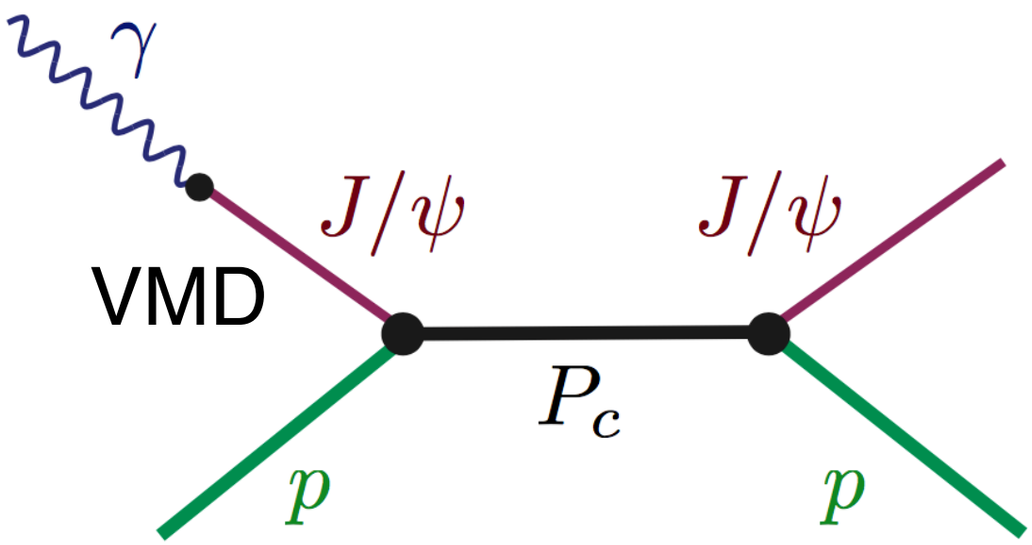


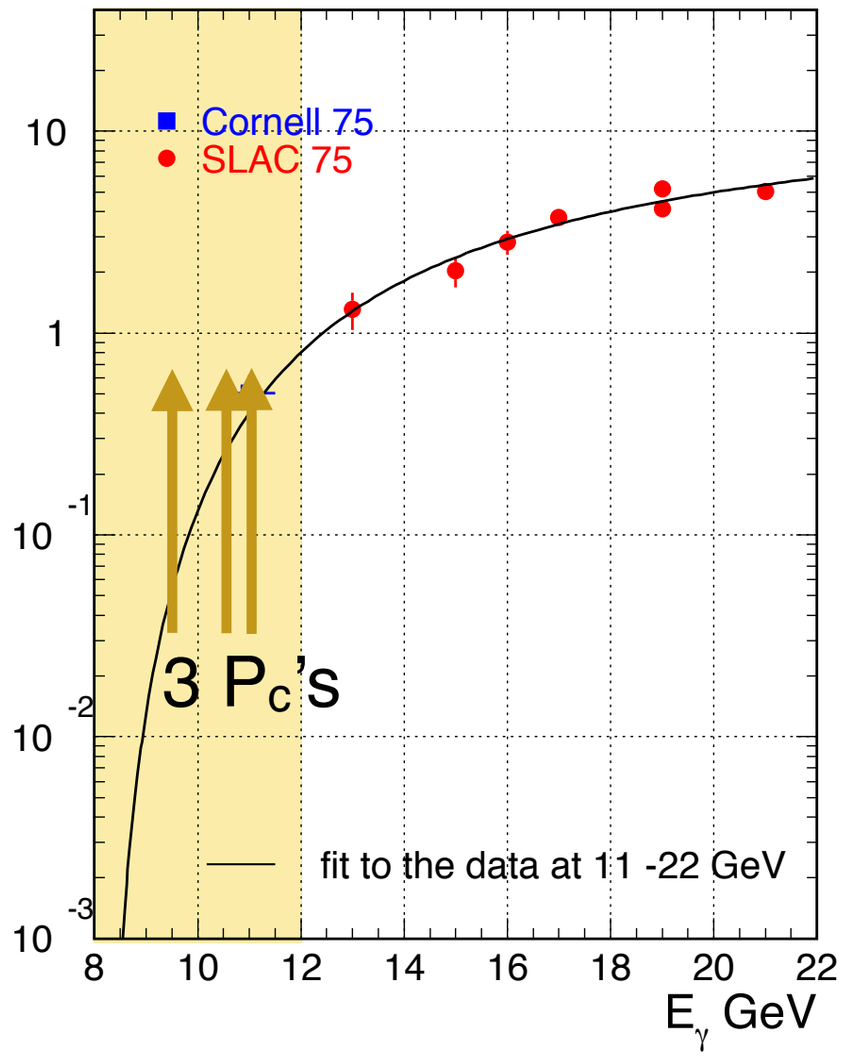
State	M [MeV]	Γ [MeV]	(95% CL)
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)

LHCb, PRL 122, 222001 (2019)

LHCb P_c States & J/ψ Photoproduction

- Look in different production mechanism: coupling of J/ψ+p resonances to photon
  - Kinematic effects from decay will not be reproduced
  - P_c's produced at **E(γ) ≈ 9.5—10.3 GeV**
  - Assuming VMD, primary uncertainty is **B(P_c → J/ψ p)**



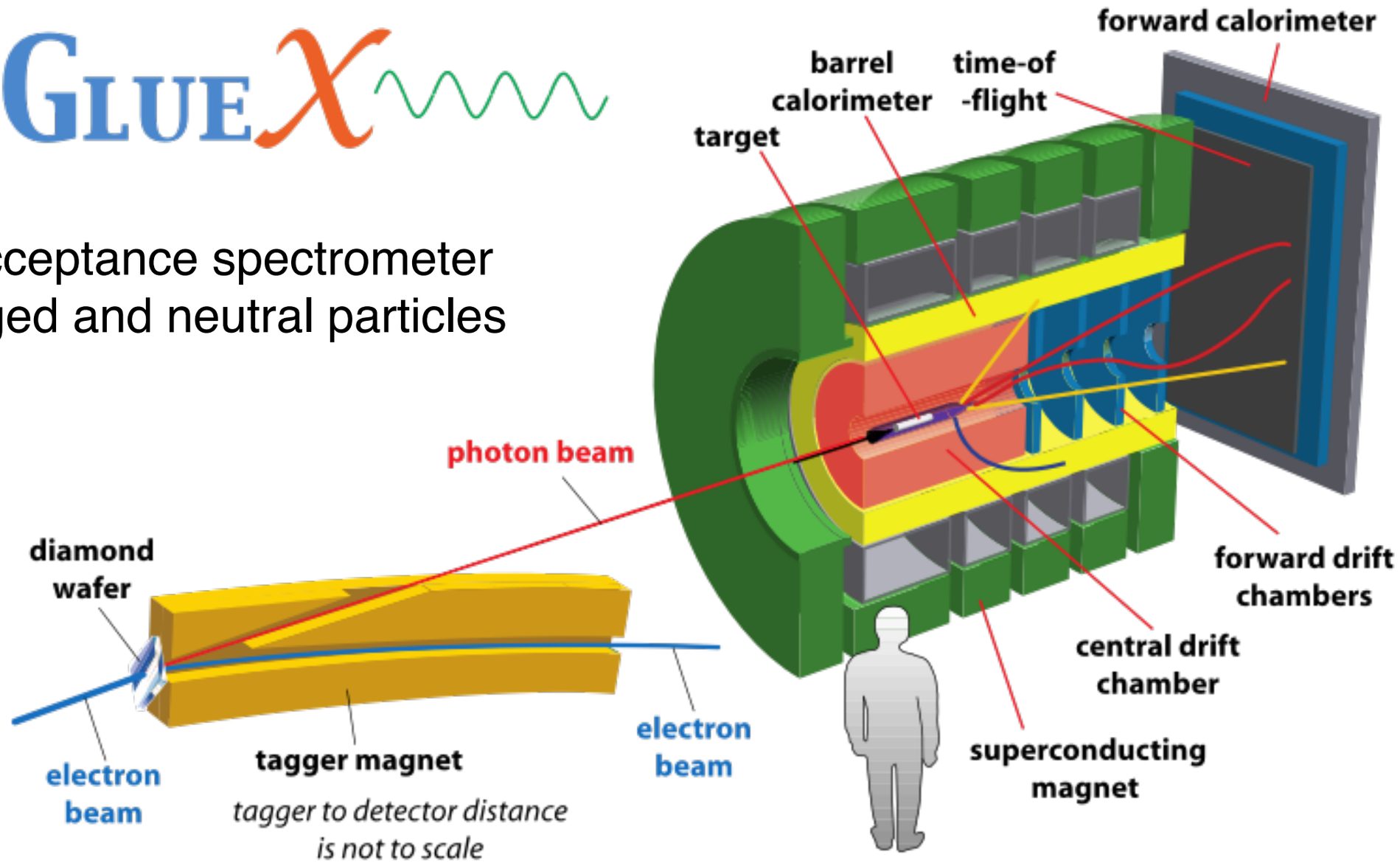


Theory papers:

Wang, Liu, and Zhao, PRD 92, 034022 (2015).
Kubarovsky and Voloshin, PRD 92, 031502 (2015).
Karliner and Rosner, PLB 752, 329 (2016).
Hiller Blin et al. (**JPAC**), PRD 94, 034002 (2016).
and many more…

The GlueX Experiment

Large acceptance spectrometer
for charged and neutral particles



Luminosity for $E_\gamma > 8$ GeV

- **2016: 10 pb^{-1}**
- **2017: 45 pb^{-1}**

Data currently analyzed

- **2018: ≈150 pb^{-1}** in spring & fall, GlueX Phase-I is now finished!

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GLUEX

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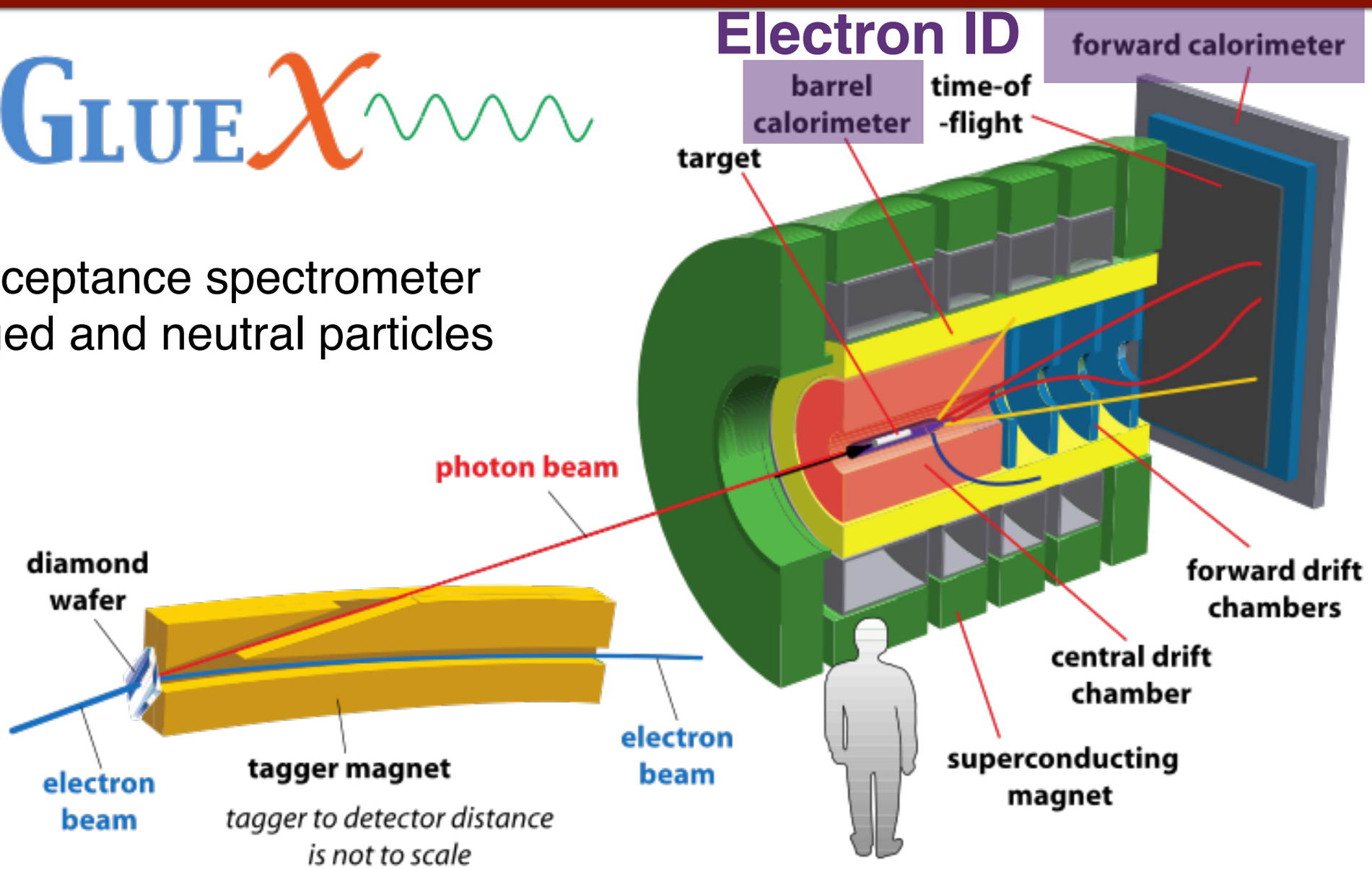

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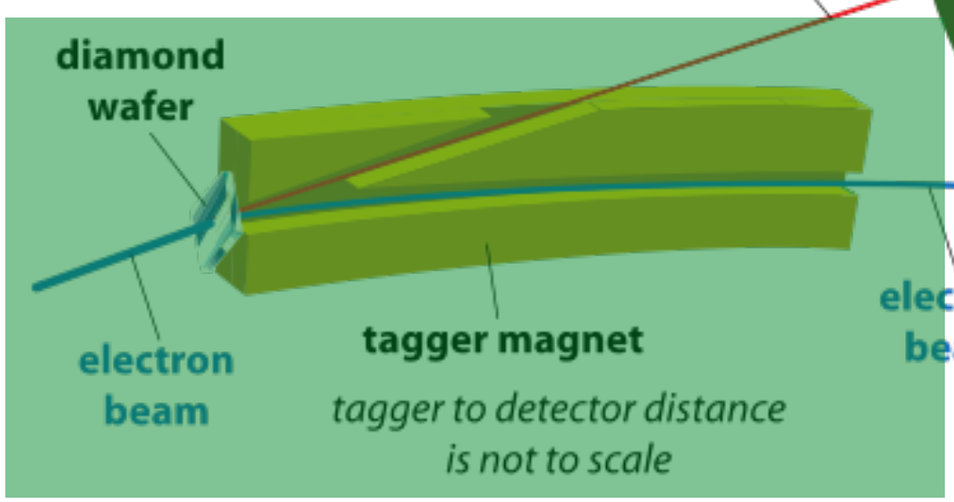
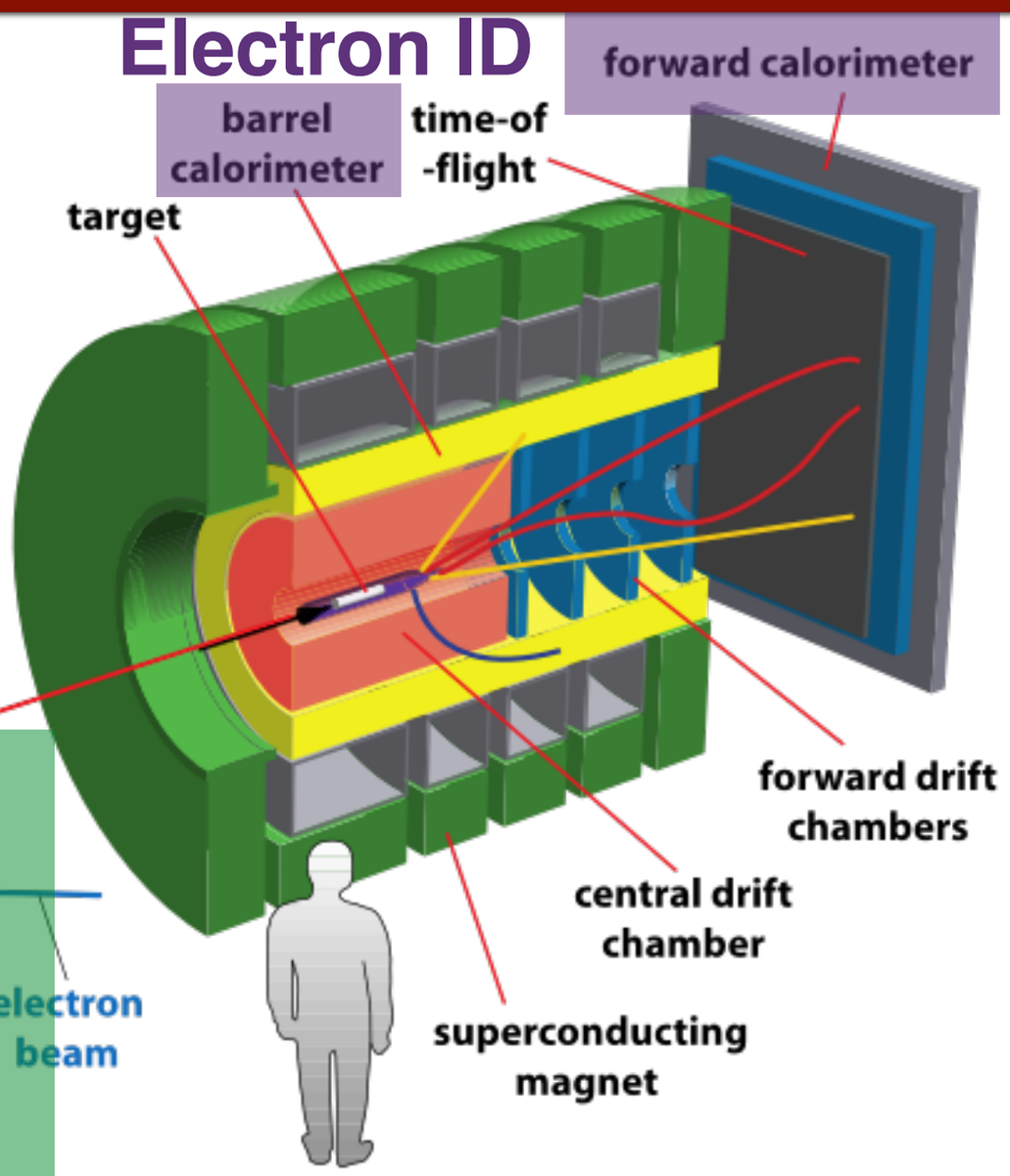
Tagged Photon

$\sigma(E)/E \sim 0.1\%$





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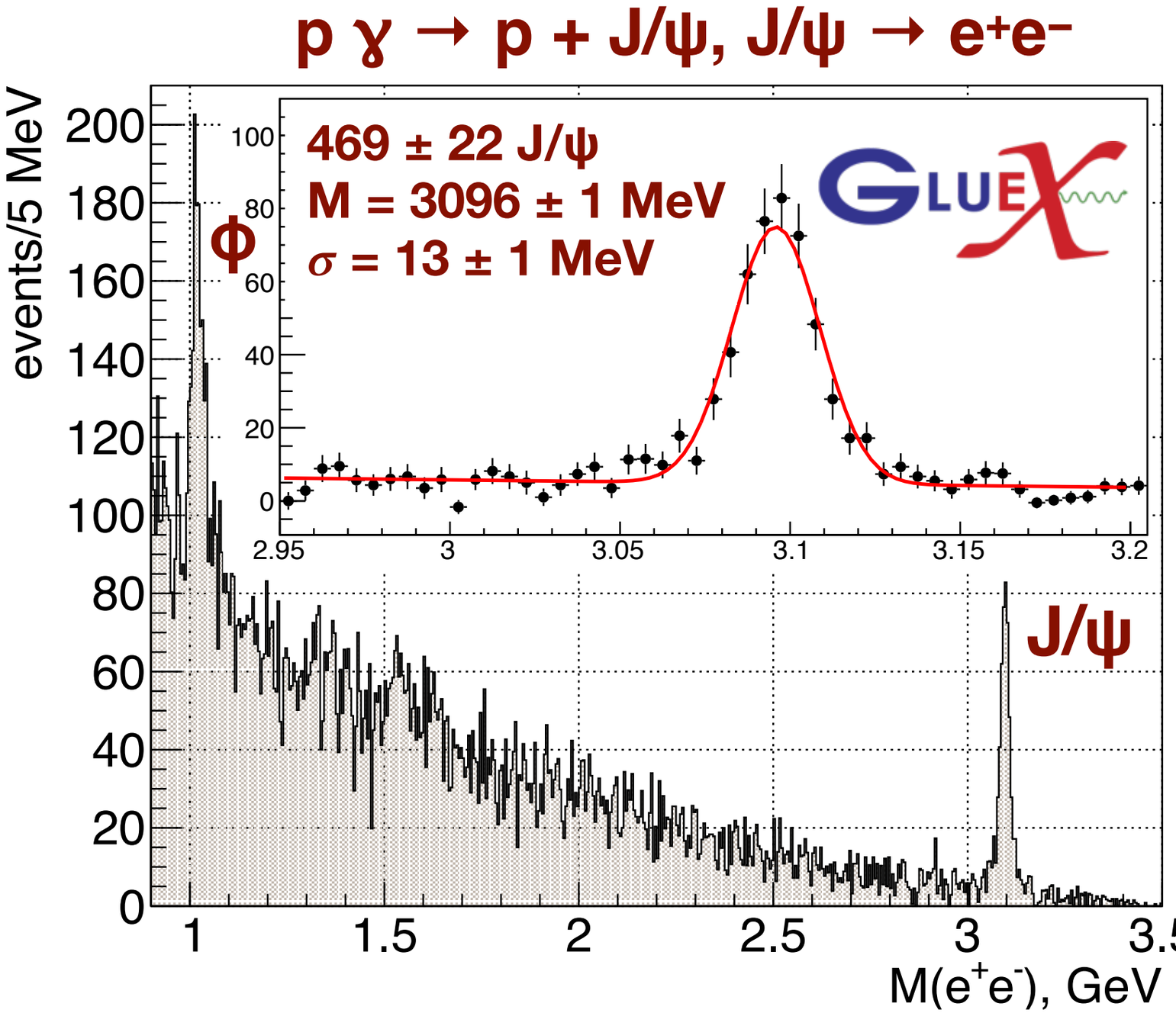
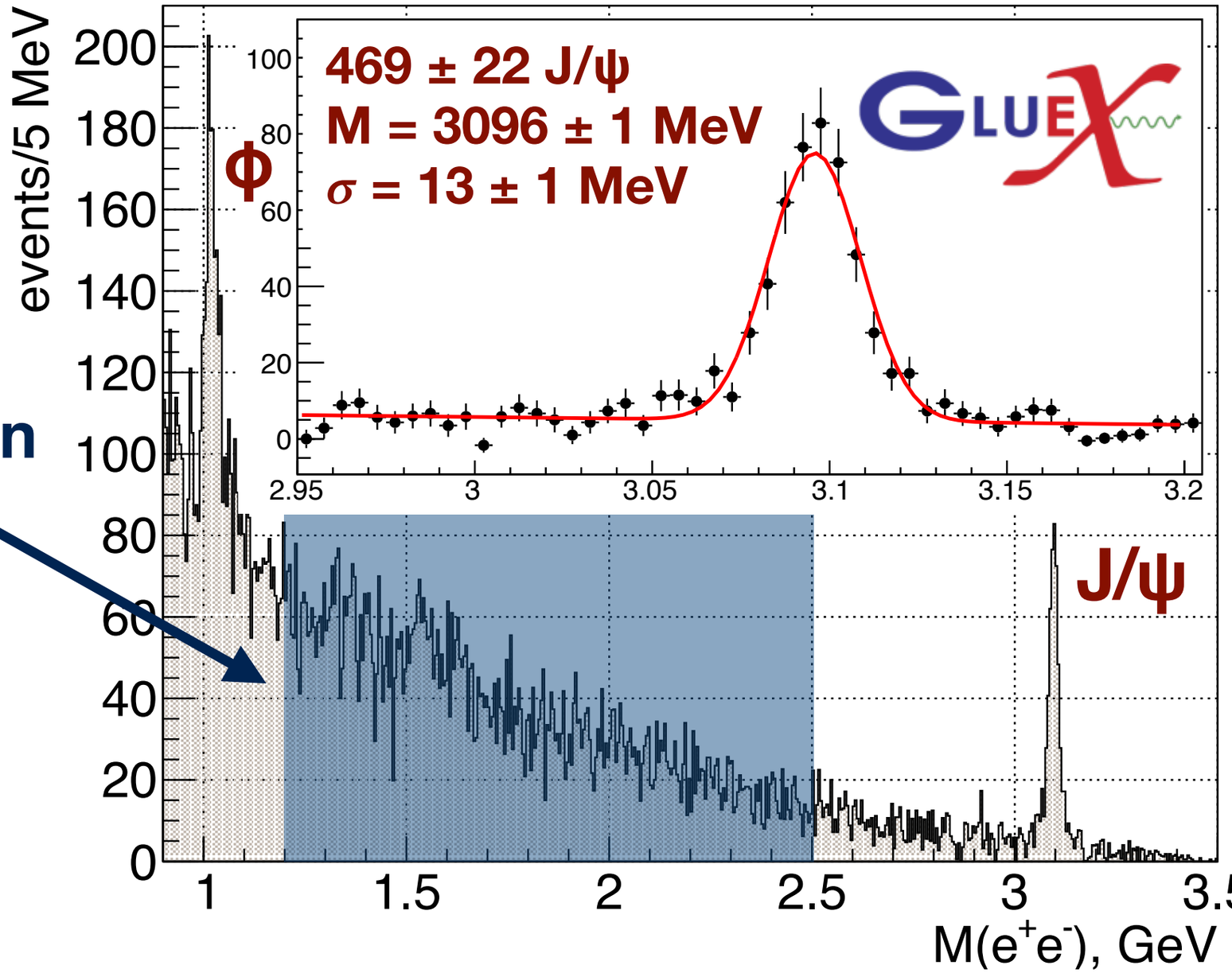
J/ψ Photoproduction at GlueX: Mass Spectrum



- Reconstruct and kinematically fit exclusive reaction
- Calculate J/ψ cross sections normalized by non-resonant e^+e^-

J/ψ Photoproduction at GlueX: Mass Spectrum

$p\,\gamma \rightarrow p + J/\psi,\ J/\psi \rightarrow e^+e^-$

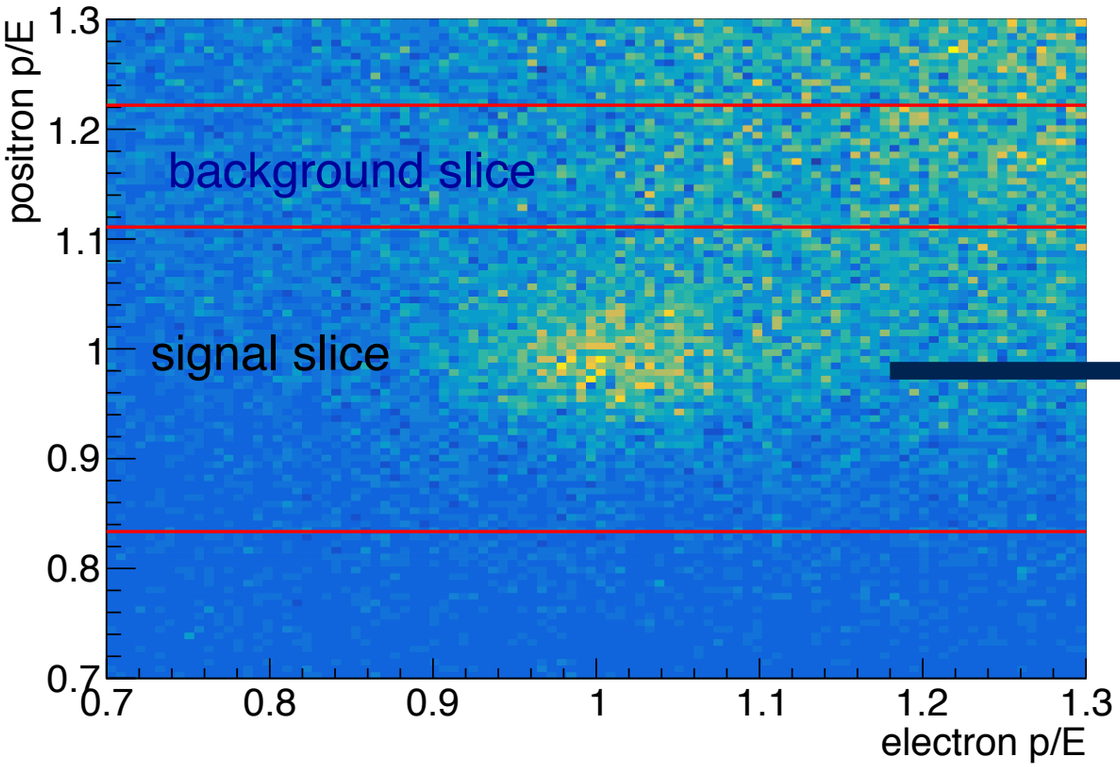


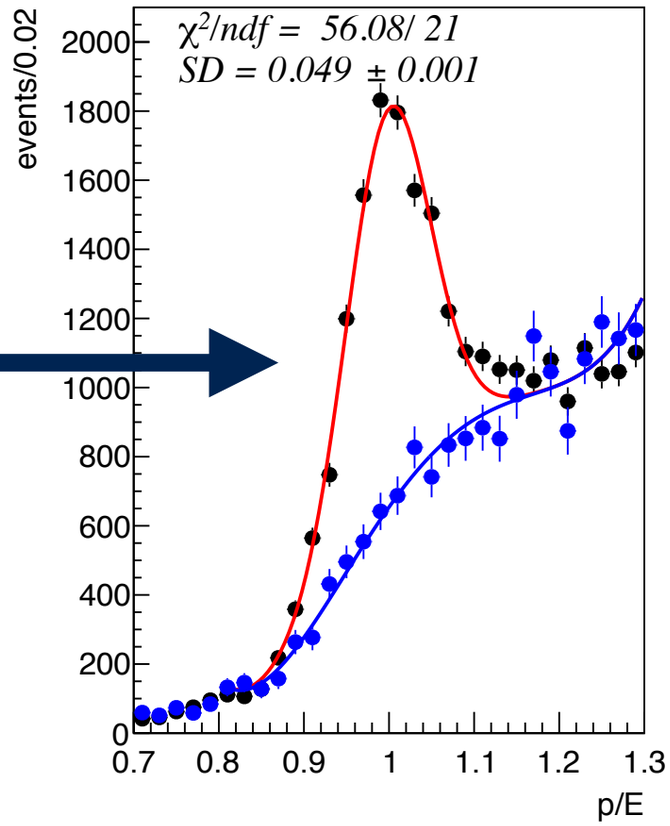
Normalization range

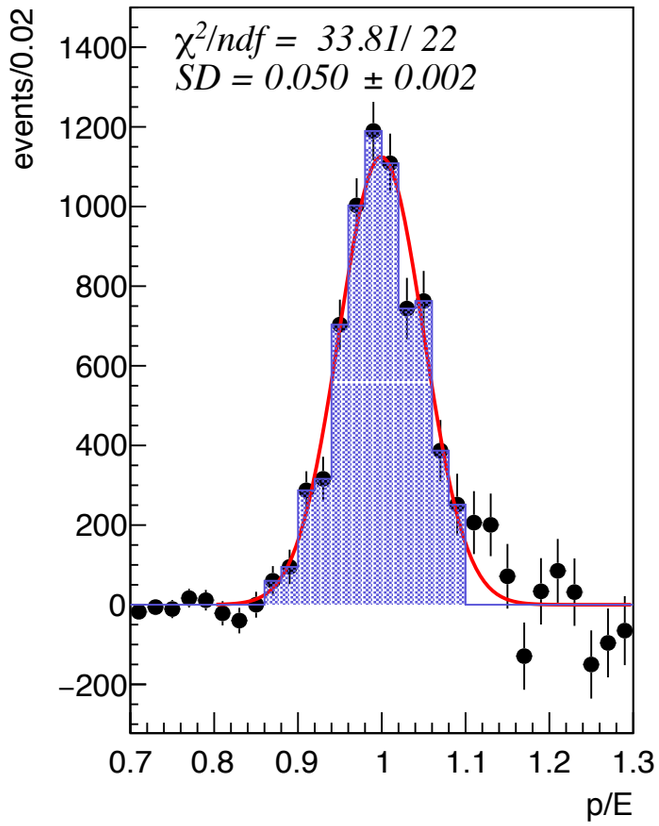
- Reconstruct and kinematically fit exclusive reaction
- Calculate J/ψ cross sections normalized by non-resonant e^+e^-

J/ψ Photoproduction at GlueX: Normalization

- Calculate J/ψ cross sections normalized by non-resonant e^+e^-
  - Events in normalization region about 50% pions
  - Extract e^+e^- non-resonant yield from p(track)/E(cal) distribution







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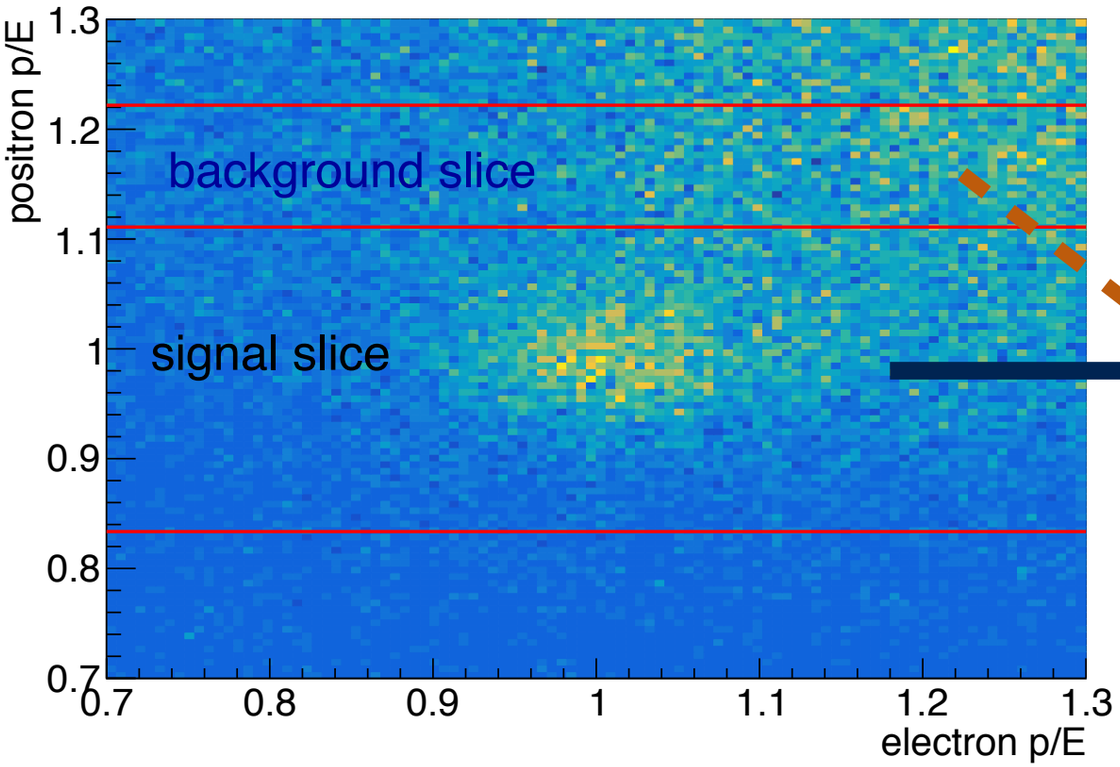
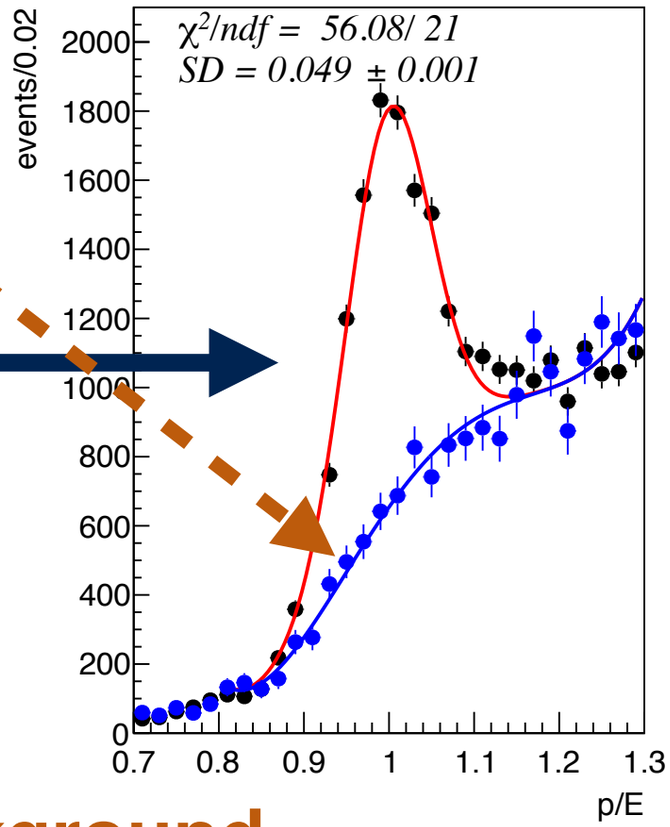
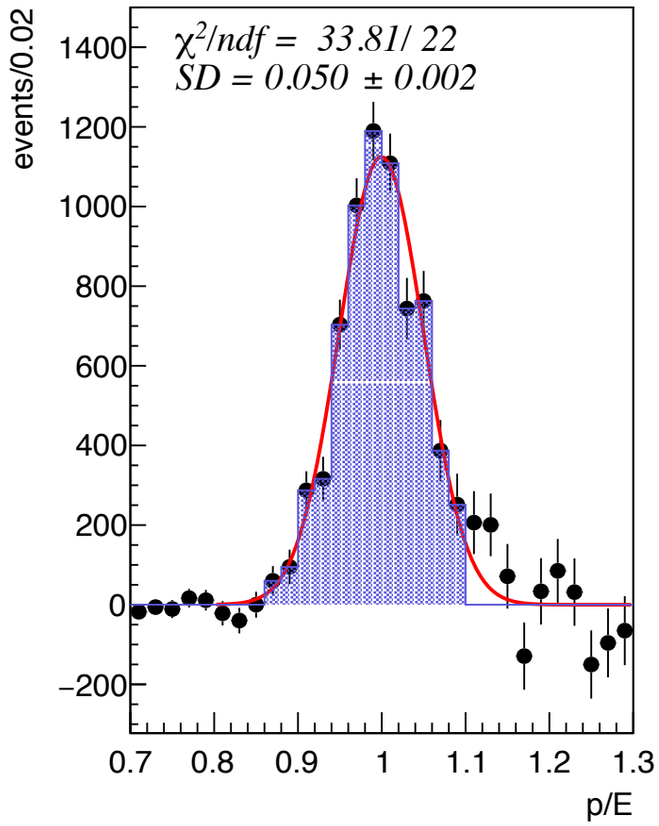




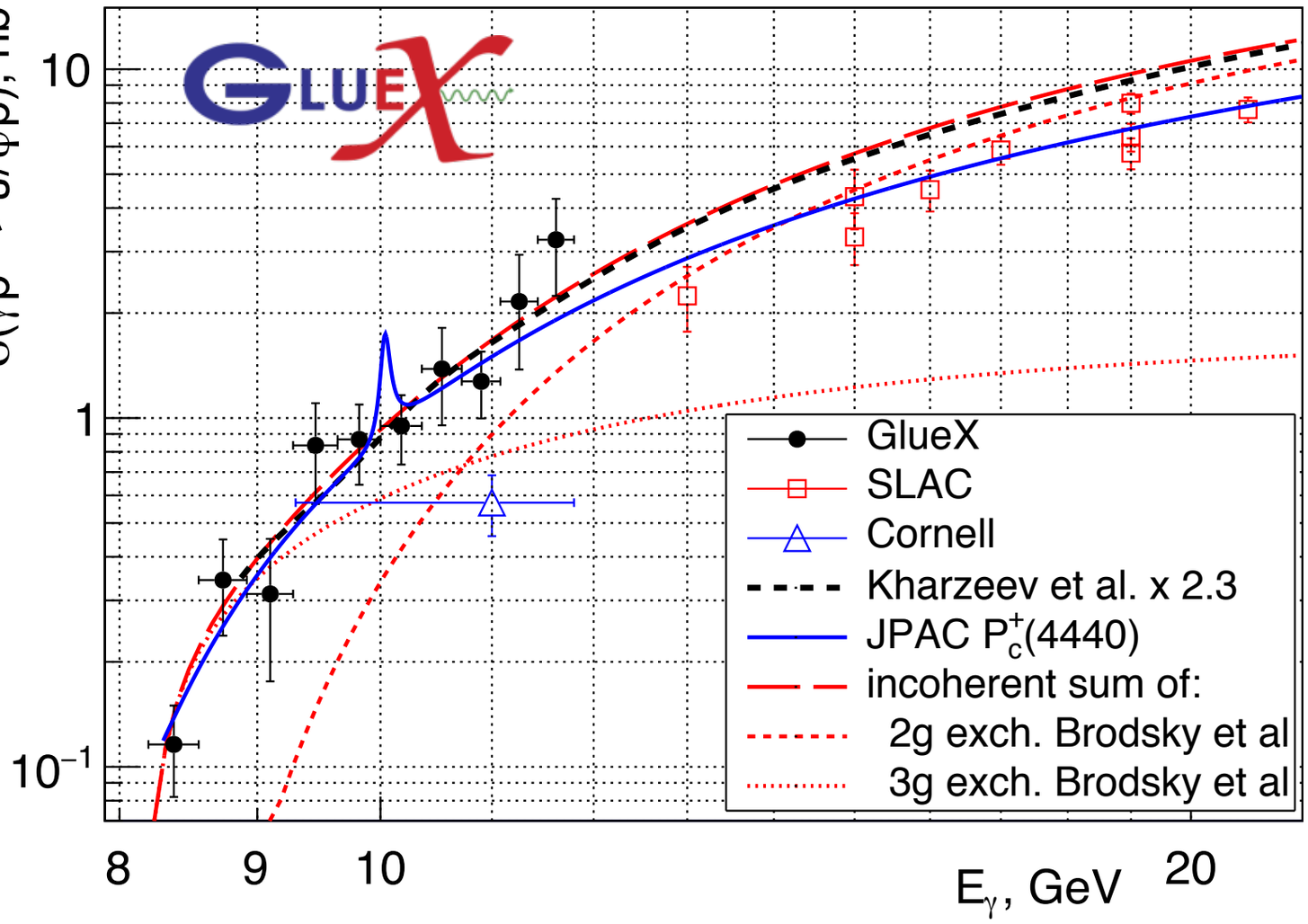
Background fixed by sideband



Background subtracted

J/ψ @ GlueX: Cross sections vs. theory

PRL 123, 072001 (2019): Editor's Suggestion!



- First J/ψ cross section measurement at threshold
  - 27% normalization uncertainty
- Higher-order contributions needed to describe near-threshold behavior (Brodsky et al.)
- Gluonic contribution to the nucleon mass is large (Kharzeev et al., Y. Hatta et al., Phys. Rev. D 100, 014032 (2019))

- SLAC points calculated from measured $d\sigma/dt$ and dipole t-dependence
- Cornell horizontal error bars illustrate acceptance

J/ψ @ GlueX: Search for P_c states

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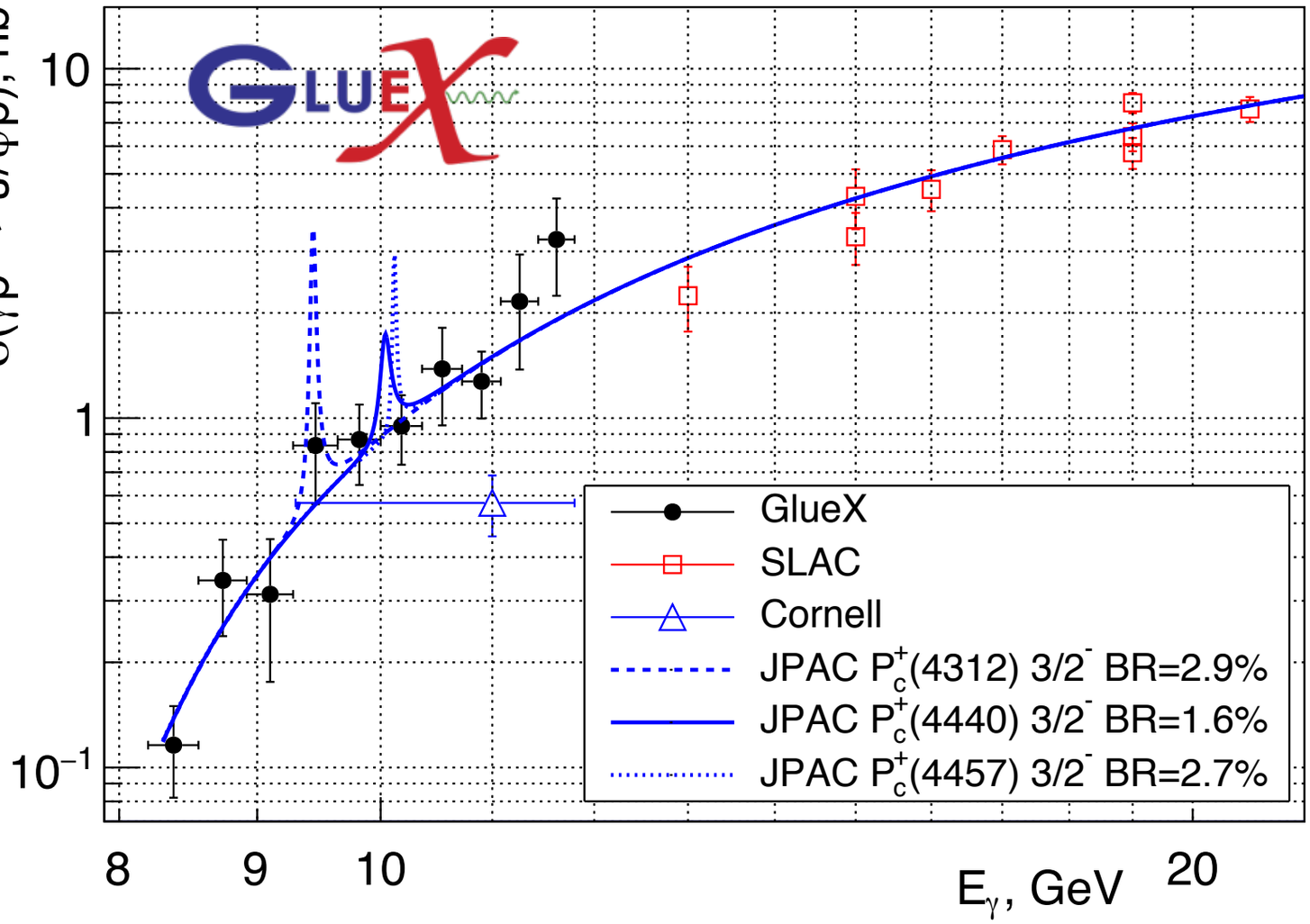
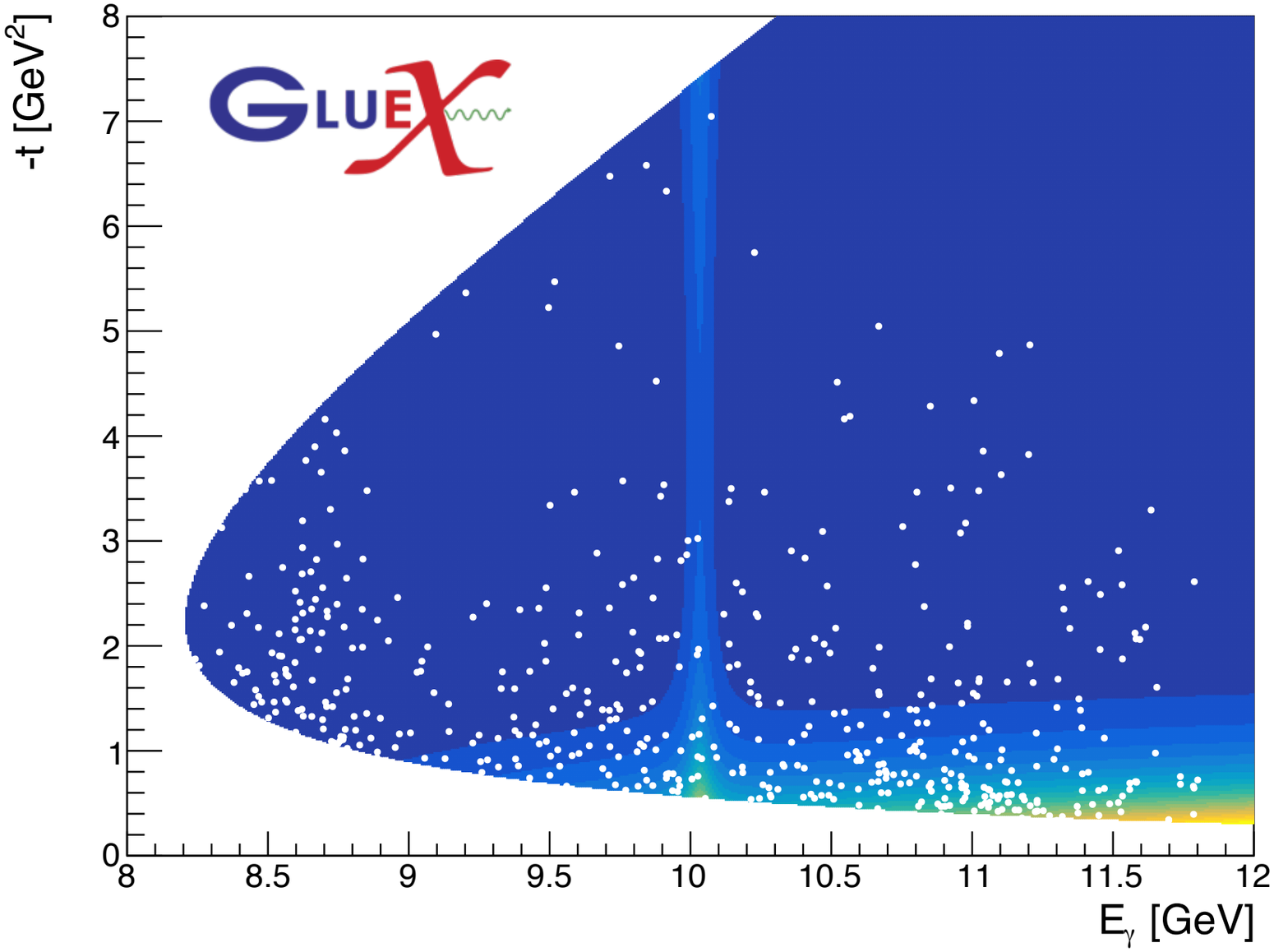


- No evidence of Pc states!
- Model-dependent upper limits at 90% CL (assuming $J^P=3/2^-$):
  - Br($P_c(4312)$ → J/ψ p) **< 4.6%**
  - Br($P_c(4440)$ → J/ψ p) **< 2.3%**
  - Br($P_c(4457)$ → J/ψ p) **< 3.8%**

  [ULs scale as (2J+1)]
- Disfavors hadrocharmonium and some molecular models. Pc's could preferentially couple to other channels?
  - Need consistent picture with Λ_b decays.

JPAC A.N. Hiller Blin, et al., PRD 94, 034002 (2016).

J/ψ @ GlueX: Unbinned E(ɣ) vs. t



- Points: GlueX data in J/ψ mass region
- JPAC model: 5% $P_c(4440)$, $J^P = 3/2^-$

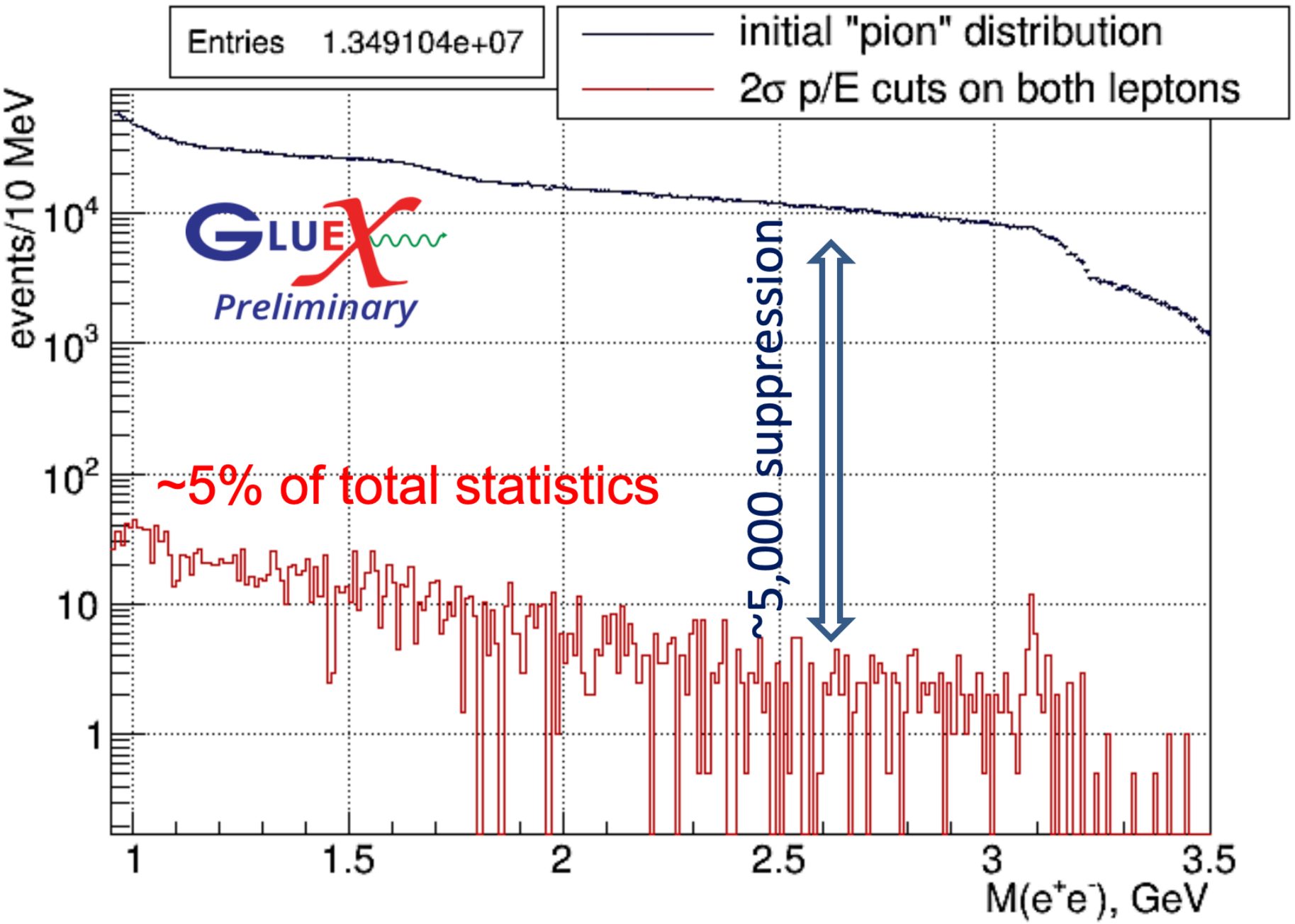
- More sensitive search will come from fitting E(ɣ) vs. t dependence
- Distribution not corrected for beam spectrum or acceptance
- No clear evidence for s-channel production
- Fit requires detailed study of backgrounds and beam energy calibration

Summary

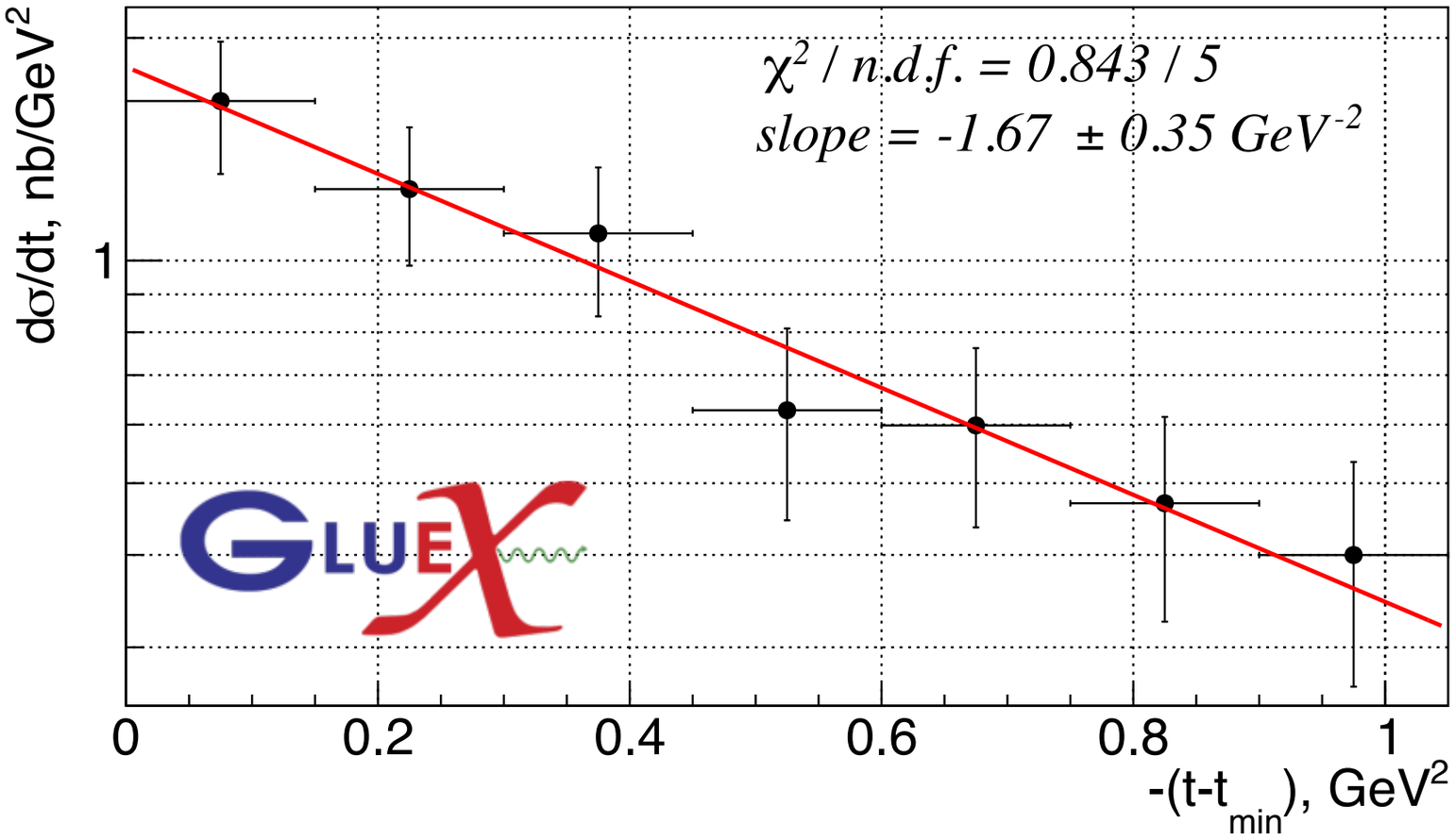
- GlueX has measured J/ψ photoproduction near threshold
  - First determination of σ_{total} shape for **$E_\gamma < 12$ GeV**
  - No evidence for P_c states, determined model-dependent upper limits on **$B(P_c^+ \rightarrow J/\psi\, p)$** of less than **a few percent**
- Further analyses are ongoing with additional data
  - **> 1500 J/ψ** on tape, will be able to measure $d\sigma$ / dE dt
  - Unbinned fits will allow more sensitive searches for P_c states
  - GlueX has large acceptance and large data volume, will be able to search for more charm-quark hadrons
    - High-intensity run starts this Fall!

Backup Slides

J/ψ @ GlueX: Background Rejection



J/ψ @ GlueX: t-slope



Measurements near threshold

- Cornell at ~11 GeV
  1.25 ± 0.20 GeV^{-2}
- **GlueX at 10–11.8 GeV**
  1.67 ± 0.35 GeV^{-2}
- SLAC at 19 GeV
  2.9 ± 0.3 GeV^{-2}