Electromagnetic Production of Strangeness at Jefferson Lab

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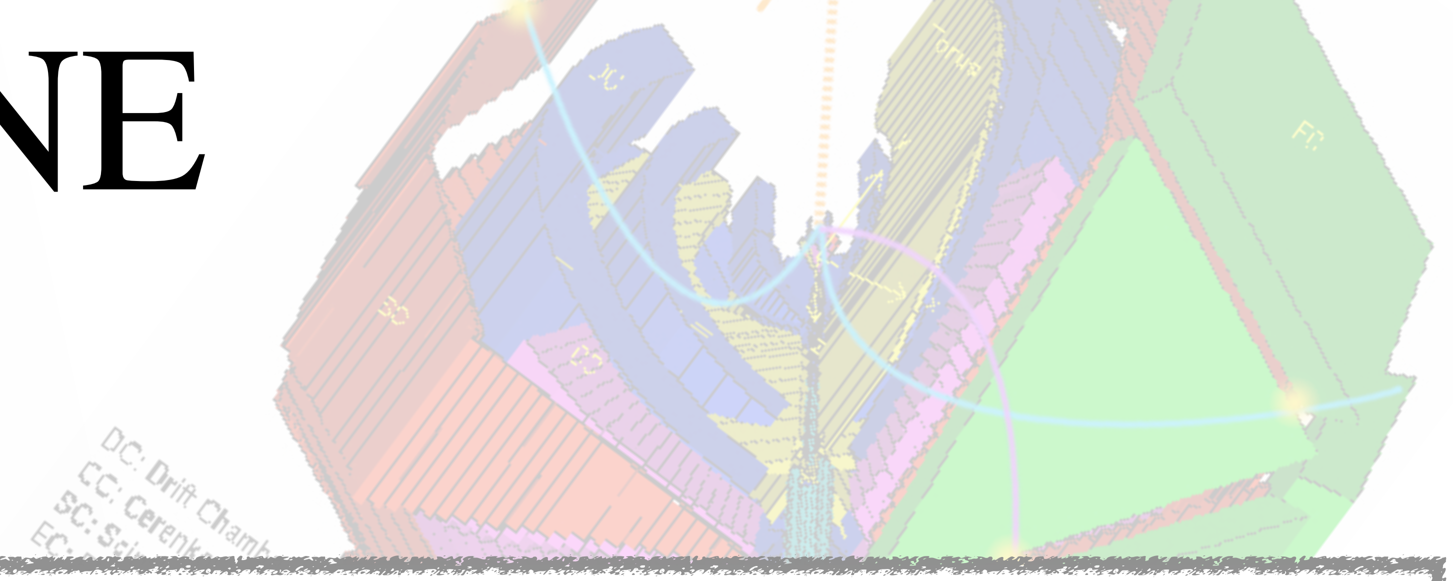
HYP2015: 12th International Conference on Hypernuclear and Strange Particle Physics

Jefferson Lab
Thomas Jefferson National Accelerator Facility

September 8, 2015



OUTLINE

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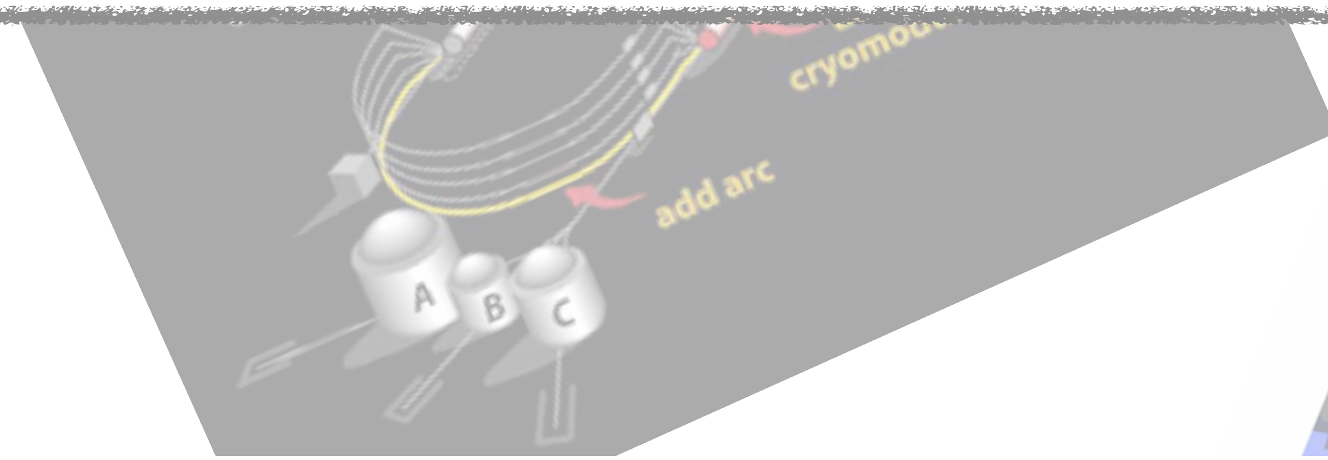
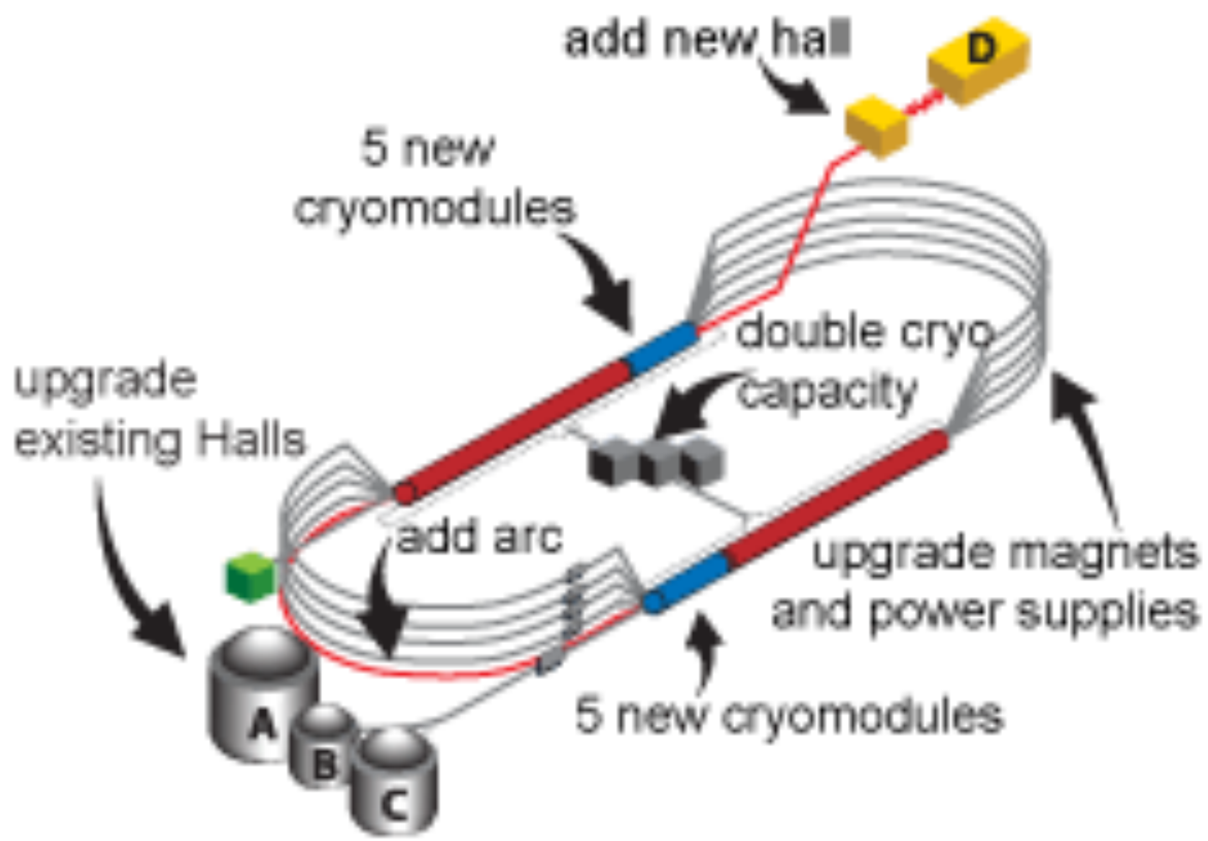


I. Jefferson Lab

Jefferson Lab

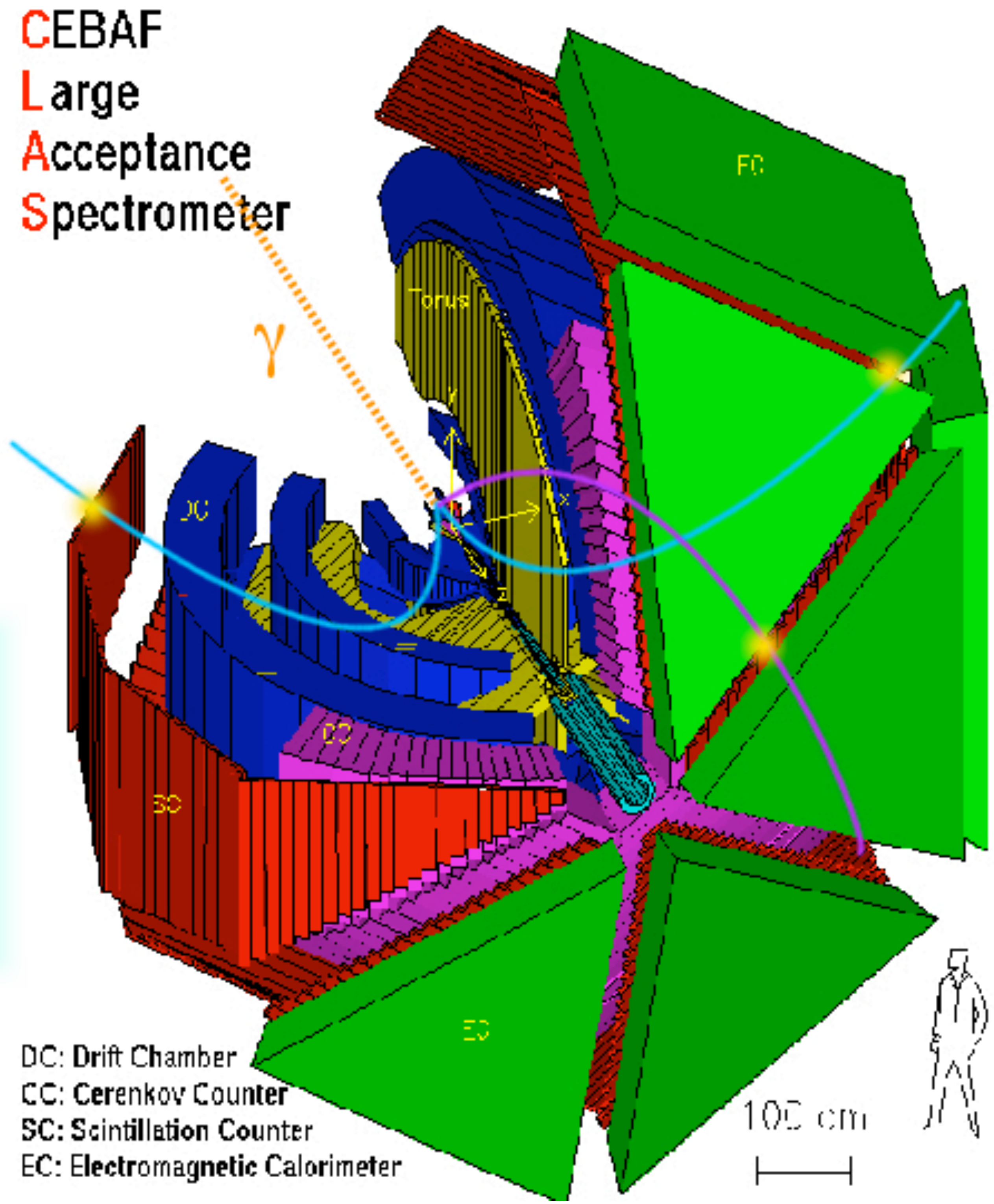
- Located in Newport News, VA
- Ran for >10 years at 6 GeV with Halls A, B, C
- Upgraded to 12 GeV, new Hall D
- CEBAF accelerator provides e^- beam every 2 ns



CLAS

- CLAS was in Hall B of Jefferson Lab, took data for > 10 years
- Experiments on hadron spectroscopy, nuclear structure functions, nuclear processes

  - 3-layer drift chamber with $\delta p/p \sim 0.5\%$
  - Start Counter around target
  - Scintillator TOF paddles for PID



Talks by Ken Hicks (Session 2a), Natalie Walford (Session 2b)

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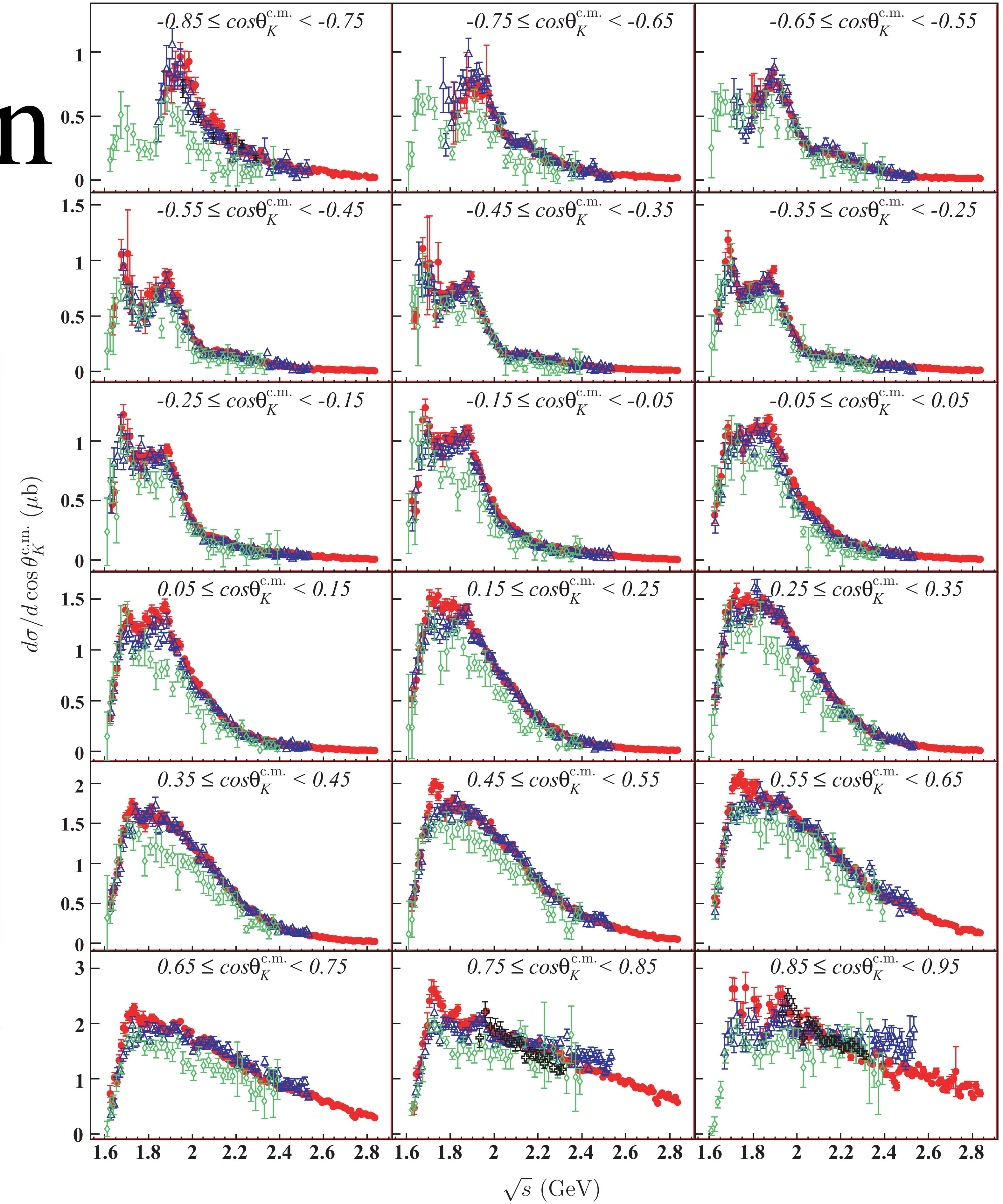
Strangeness Production with CLAS

- K⁺ Λ photoproduction: differential cross sections, recoil polarizations
- Results also available for K⁺ Σ^0, φp
- Has contributed to our knowledge of production mechanisms, coupling to N* states



○CLAS(2010) △CLAS(2006) ◇SAPHIR ✚LEPS

M McCracken (CLAS) PRC81, 025201 (2010)

N^* States

- Recent results have lead to updates in PDG

N^*	J^P $(L_{2I,2J})$	2010	2012	Δ	J^P $(L_{2I,2J})$	2010	2012
p	$1/2^+$ (P_{11})	****	****	$\Delta(1232)$	$3/2^+$ (P_{33})	****	****
n	$1/2^+$ (P_{11})	****	****	$\Delta(1600)$	$3/2^+$ (P_{33})	***	***
$N(1440)$	$1/2^+$ (P_{11})	****	****	$\Delta(1620)$	$1/2^-$ (S_{31})	****	****
$N(1520)$	$3/2^-$ (D_{13})	****	****	$\Delta(1700)$	$3/2^-$ (D_{33})	****	****
$N(1535)$	$1/2^-$ (S_{11})	****	****	$\Delta(1750)$	$1/2^+$ (P_{31})	*	*
$N(1650)$	$1/2^-$ (S_{11})	****	****	$\Delta(1900)$	$1/2^-$ (S_{31})	**	**
$N(1675)$	$5/2^-$ (D_{15})	****	****	$\Delta(1905)$	$5/2^+$ (F_{35})	****	****
$N(1680)$	$5/2^+$ (F_{15})	****	****	$\Delta(1910)$	$1/2^+$ (P_{31})	****	****
$N(1685)$			*				
$N(1700)$	$3/2^-$ (D_{13})	***	***	$\Delta(1920)$	$3/2^+$ (P_{33})	***	***
$N(1710)$	$1/2^+$ (P_{11})	***	***	$\Delta(1930)$	$5/2^-$ (D_{35})	***	***
$N(1720)$	$3/2^+$ (P_{13})	****	****	$\Delta(1940)$	$3/2^-$ (D_{33})	*	**
$N(1860)$	$5/2^+$		**				
$N(1875)$	$3/2^-$		***				
$N(1880)$	$1/2^+$		**				
$N(1895)$	$1/2^-$		**				
$N(1900)$	$3/2^+$ (P_{13})	**	***	$\Delta(1950)$	$7/2^+$ (F_{37})	****	****
$N(1990)$	$7/2^+$ (F_{17})	**	**	$\Delta(2000)$	$5/2^+$ (F_{35})	**	**
$N(2000)$	$5/2^+$ (F_{15})	**	**	$\Delta(2150)$	$1/2^-$ (S_{31})	*	*
~~$N(2080)$~~	D_{13}	**		$\Delta(2200)$	$7/2^-$ (G_{37})	*	*
~~$N(2090)$~~	S_{11}	*		$\Delta(2300)$	$9/2^+$ (H_{39})	**	**
$N(2040)$	$3/2^+$		*				
$N(2060)$	$5/2^-$		**				
$N(2100)$	$1/2^+$ (P_{11})	*	*	$\Delta(2350)$	$5/2^-$ (D_{35})	*	*
$N(2120)$	$3/2^-$		**				
$N(2190)$	$7/2^-$ (G_{17})	****	****	$\Delta(2390)$	$7/2^+$ (F_{37})	*	*
~~$N(2200)$~~	D_{15}	**		$\Delta(2400)$	$9/2^-$ (G_{39})	**	**
$N(2220)$	$9/2^+$ (H_{19})	****	****	$\Delta(2420)$	$11/2^+$ $(H_{3,11})$	****	****
$N(2250)$	$9/2^-$ (G_{19})	****	****	$\Delta(2750)$	$13/2^-$ $(I_{3,13})$	**	**
$N(2600)$	$11/2^-$ $(I_{1,11})$	***	***	$\Delta(2950)$	$15/2^+$ $(K_{3,15})$	**	**
$N(2700)$	$13/2^+$ $(K_{1,13})$	**	**				

V Crede, W Roberts, Rep. Prog. Phys. 76, 076301 (2013)

Complete Experiments

- Unpolarized beam, target → cross section and recoil polarization only
- Polarized beam and/or target → access to many more observables

- Allows a "complete" determination of the production amplitudes
- More observables leads to more constraints on production mechanism

see talk by Natalie Walford, Session 2b

	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z	CLAS run Period
$p\pi^0$	✔ (red)	✓	✓ (blue)	✓	✓	✓ (blue)	✓	✓ (blue)									g1, g8, g9
$n\pi^+$	✔ (red)	✓	✓ (blue)	✓	✓	✓ (blue)	✓	✓ (blue)									g1, g8, g9
$p\eta$	✔ (red)	✓	✓ (blue)	✓	✓	✓ (blue)	✓	✓ (blue)									g1, g11, g8, g9
$p\eta'$	✔ (red)	✓	✓ (blue)	✓	✓	✓ (blue)	✓	✓ (blue)									g1, g11, g8, g9
$p\omega$	✔ (red)	✓	✓ (blue)	✓	✓	✓ (blue)	✓	✓ (blue)									g11, g8, g9
$K^+\Lambda$	✔ (red)	✓	✓ (blue)	✔ (red)	✓	✓ (blue)	✓	✓ (blue)	✓ (blue)	✓ (blue)	✓	✓	✓	✓	✔ (red)	✔ (red)	g1, g8, g11
$K^+\Sigma^0$	✔ (red)	✓	✓ (blue)	✔ (red)	✓	✓ (blue)	✓	✓ (blue)	✓ (blue)	✓ (blue)	✓	✓	✓	✓	✔ (red)	✔ (red)	g1, g8, g11
$K^{0*}\Sigma^+$	✔ (red)										✓	✓			✓	✓	g1, g8, g11

published, acquired, FroST

source: Volker Burkert

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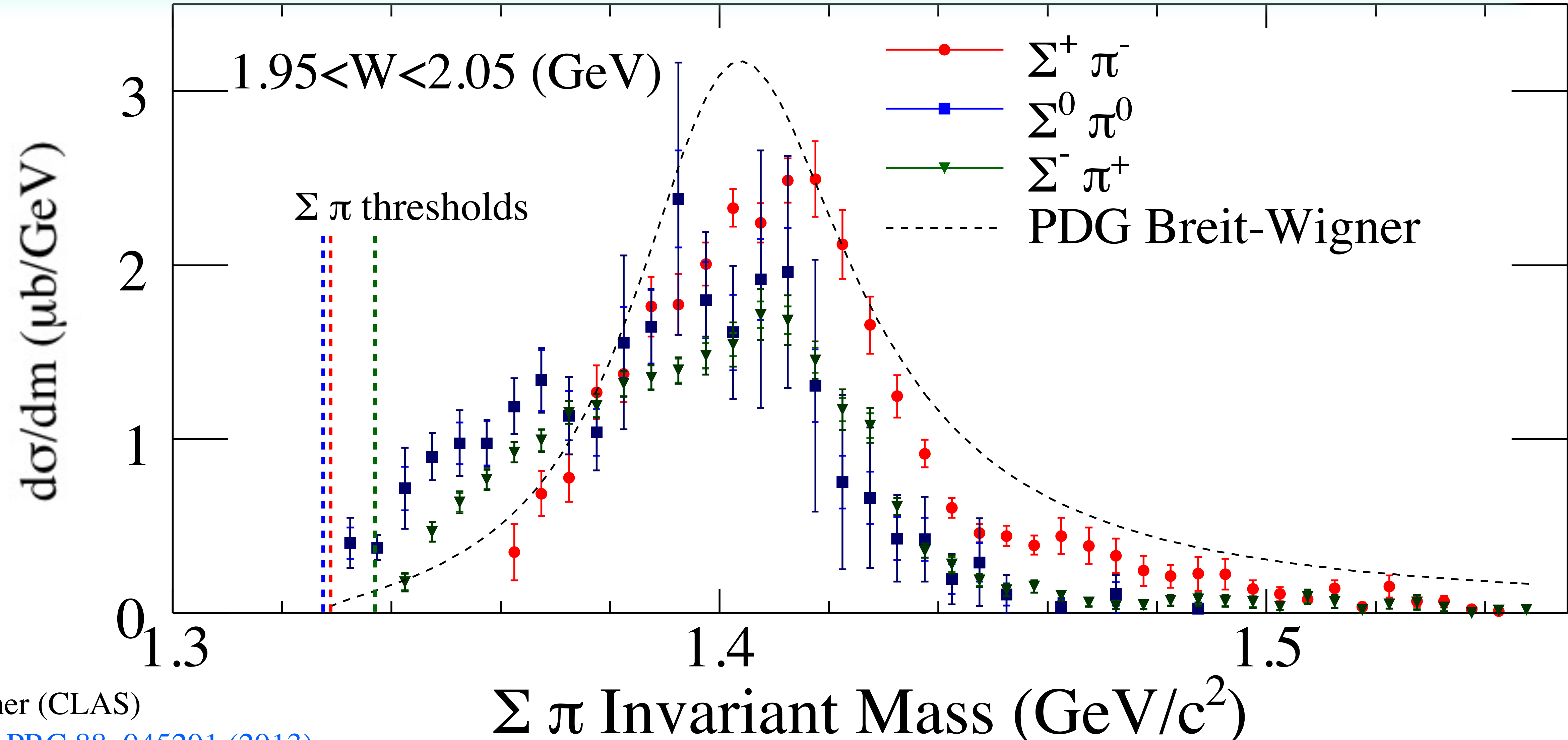
Excited Hyperons

- Differential cross sections of Σ(1385), Λ(1405), Λ(1520)
  - Claims of N(2120) ($3/2^-$) based on Λ(1520) cross section[1]
- Line shapes of Λ(1405) were shown to be different for each Σπ channel
  - Discussions by Oset, Jido[2]

1. Jun He, NPA 927, 24 (2014), En Wang, Ju-Jun Xie, Juan Nieves PRC 89, 015203 (2014), PRC 90, 065203 (2014)
2. L. Roca, E. Oset, PRC 88, 055206 (2013), PRC 87, 055201 (2013)
S. X. Nakamura, D. Jido Prog. Theor. Exp. Phys. 2014, 023D01



K. Moriya, R. Schumacher (CLAS)
PRC 87, 035206 (2013), PRC 88, 045201 (2013)

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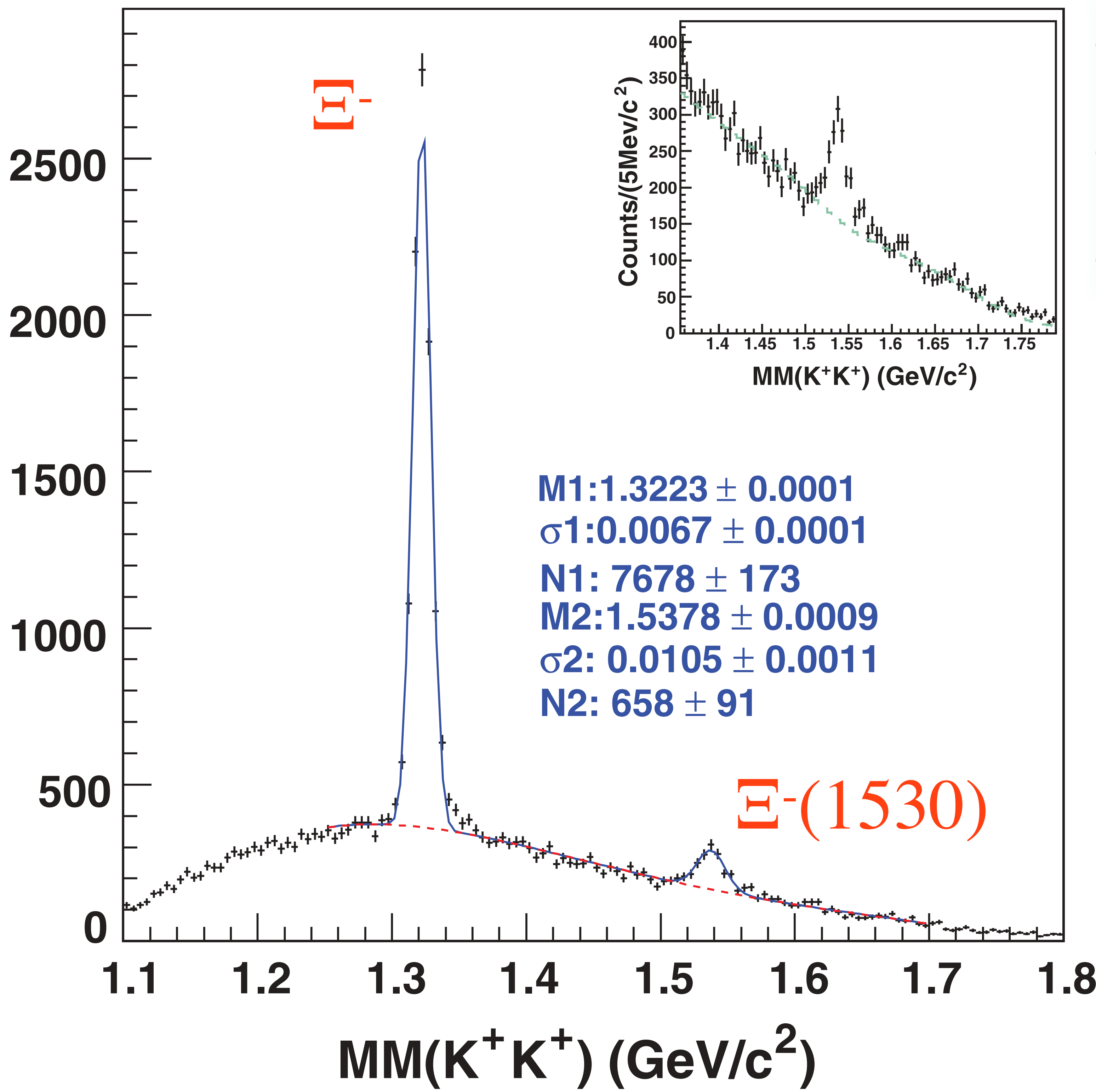
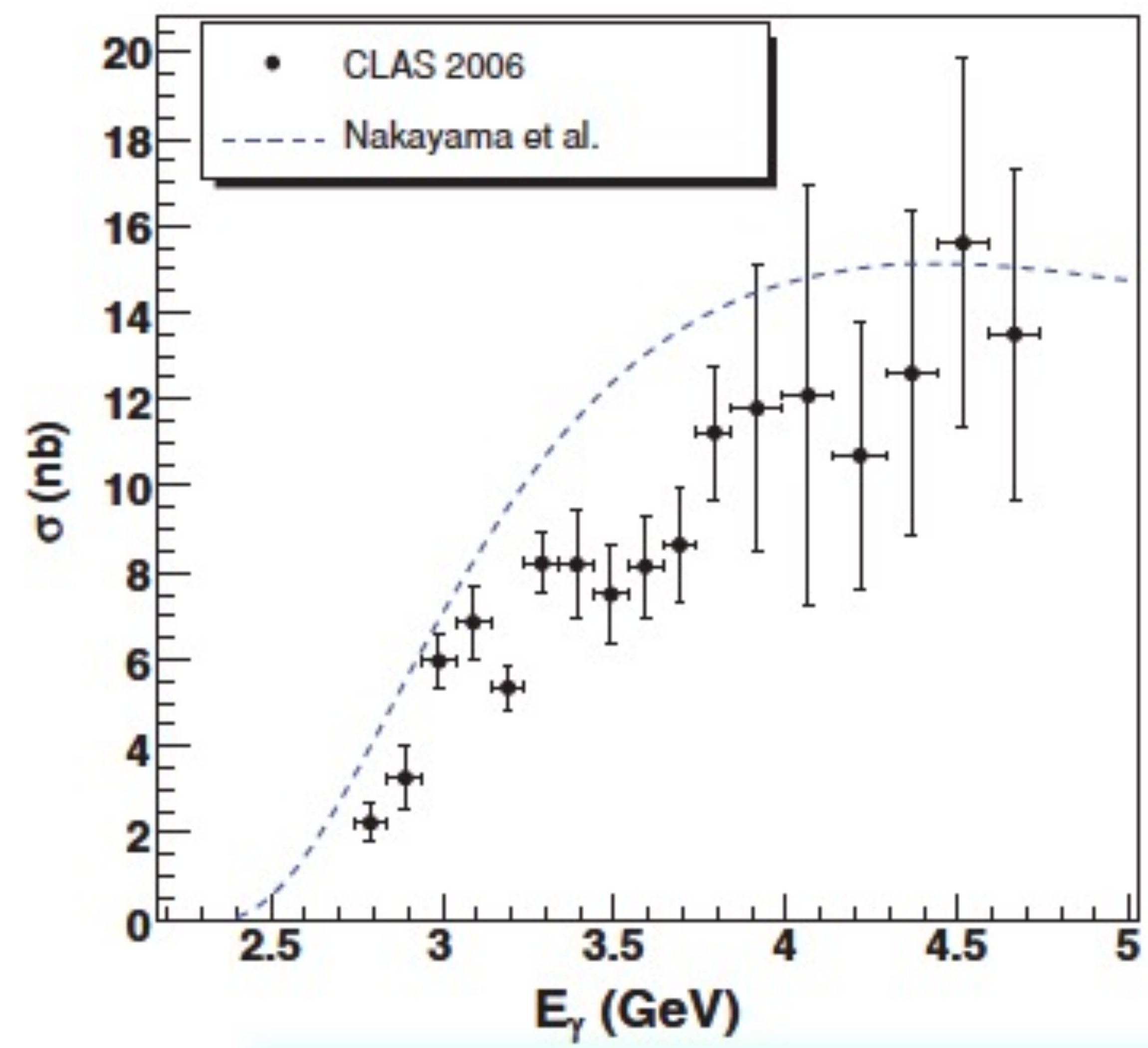
Ξ Production

L. Guo (CLAS), PRC 76, 025208 (2007)

- Ξ photoproduction: $\gamma + p \rightarrow K^+ K^+ X^-$
- Max E_γ = 4 GeV
- Observation of Ξ ($1/2^+$) and Ξ(1530) ($3/2^+$)





- Ξ σ_{tot} ~10 nb at E_γ = 4 GeV

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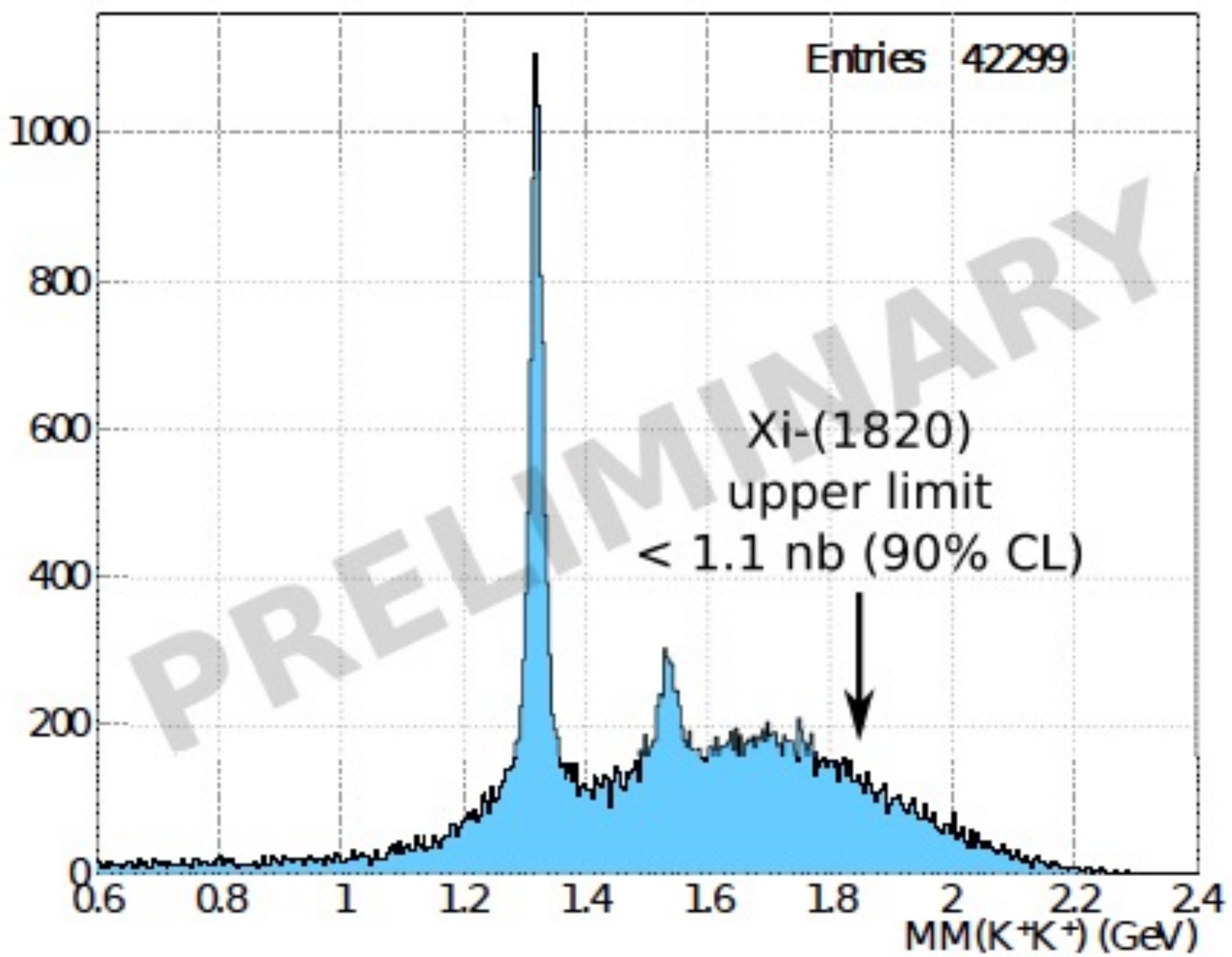
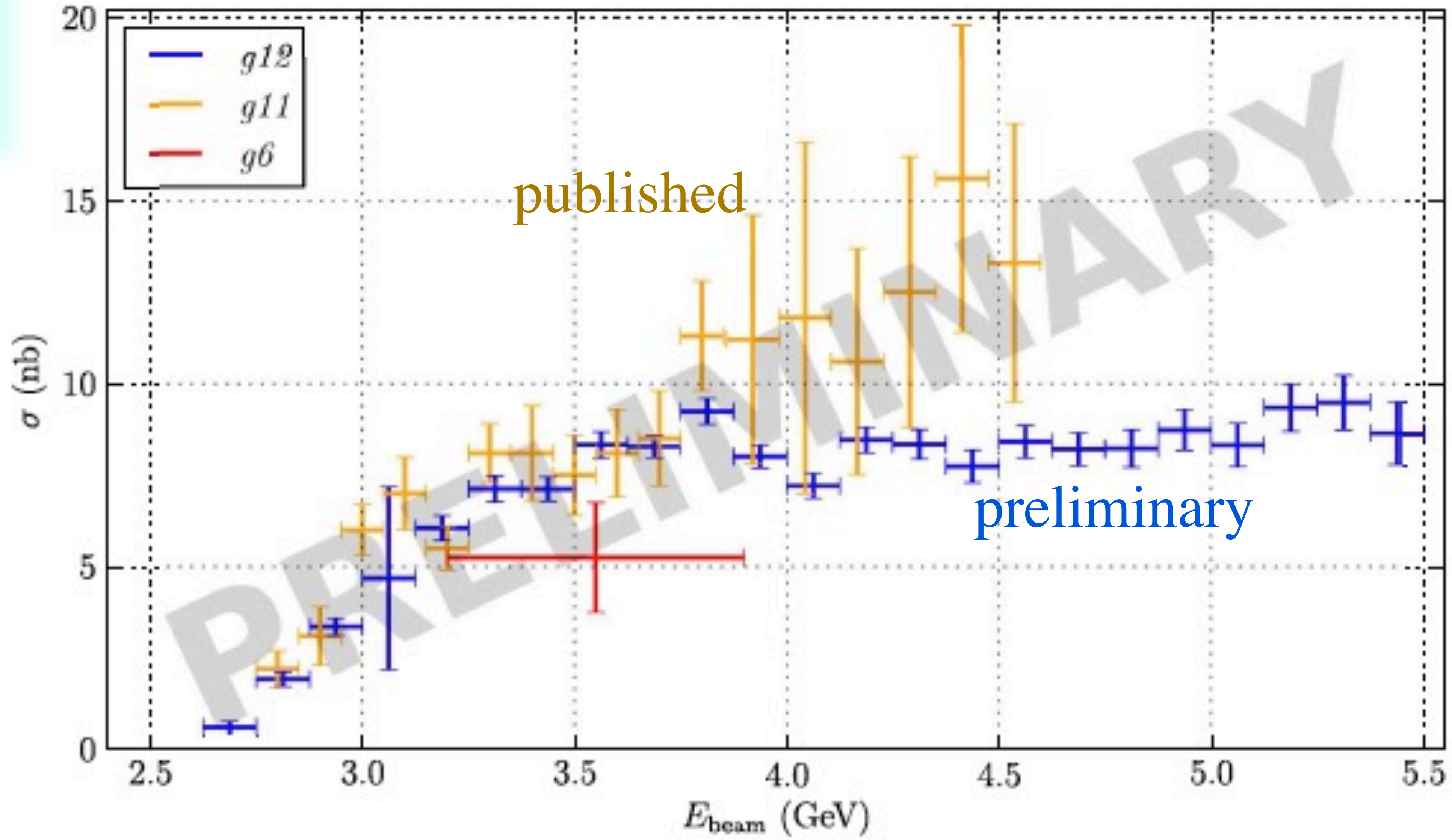
Ξ Production

- Dataset with max E_γ = 5.4 GeV
- Results are still preliminary



J. Goetz (CLAS), presented at HADRON2013
http://pos.sissa.it/archive/conferences/205/097/Hadron%202013_097.pdf



- Upper limit of 1.1 nb for Ξ(1820)

II. The GlueX Experiment

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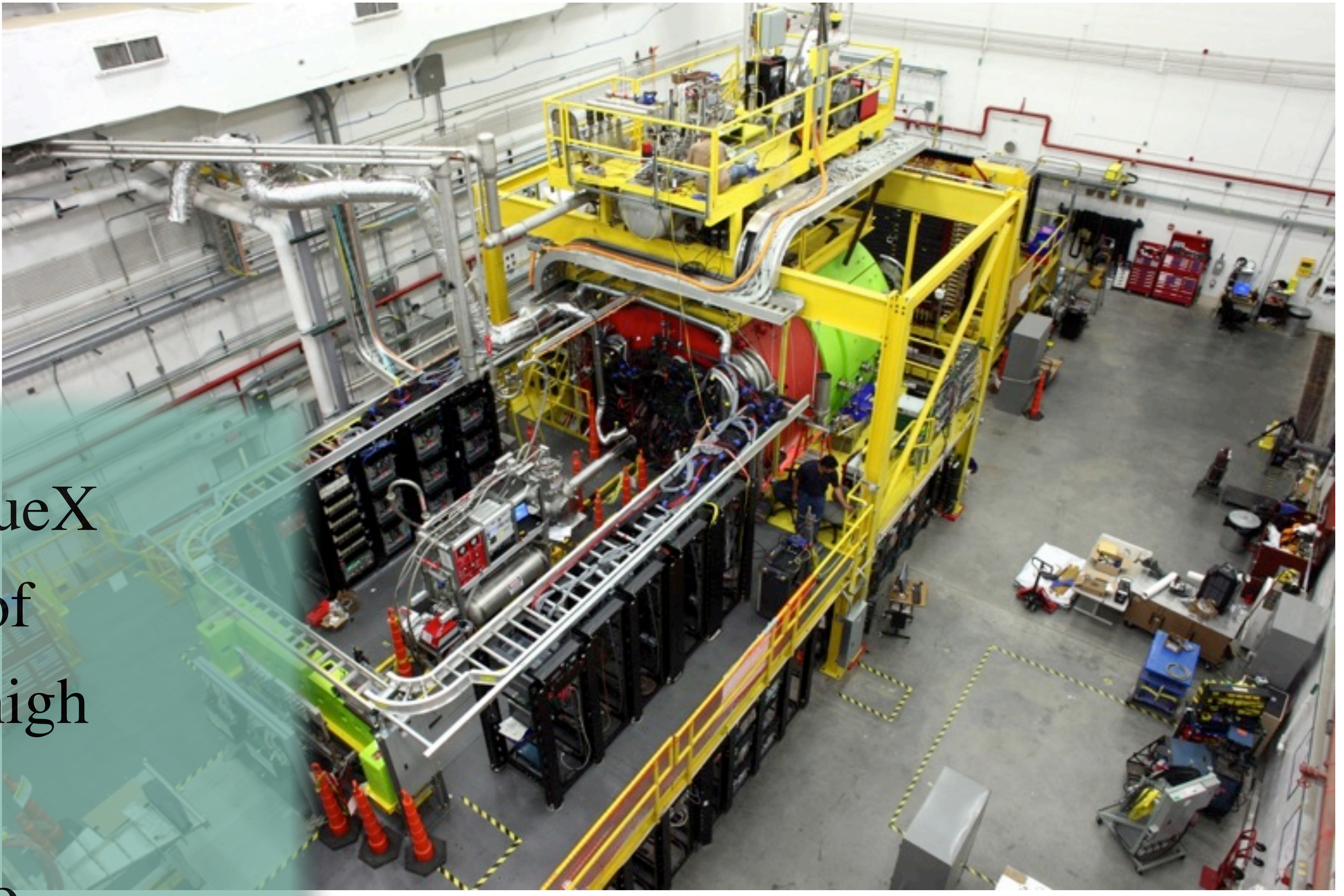
New Hall D

- New Hall, will mainly run GlueX
- Approved for 120 PAC days of commissioning, 220 days of high statistics running
- Has already taken data for two commissioning periods



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Goals for GlueX

- Can we make a connection between the spectrum that we observe with QCD?

- Many holes in our knowledge of spectra for both mesons, baryons

First step is to systematically map out spectra of states

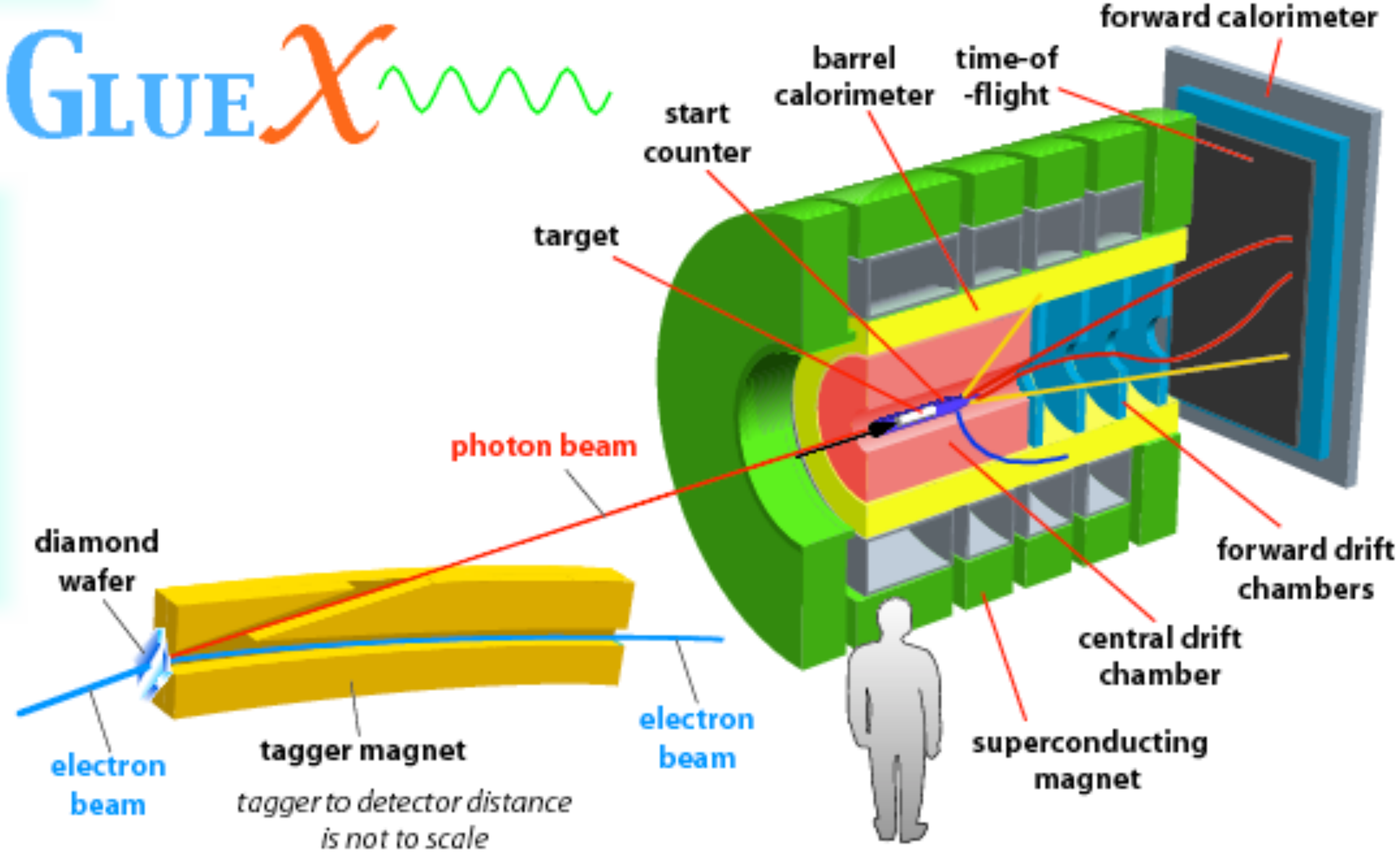
Comparison with models, lattice calculations, identification of groups

- Can we observe/identify specific states that tell us more about how QCD works?

Identify states excluded from $q\bar{q}$ scheme, i.e., *exotic* quantum number states

Overview of GlueX

- Real photon beam centered at 9 GeV
- Liquid hydrogen target



- Reconstruct charged and neutral particles over large angular range
- Hermetic detector with solenoid magnetic field

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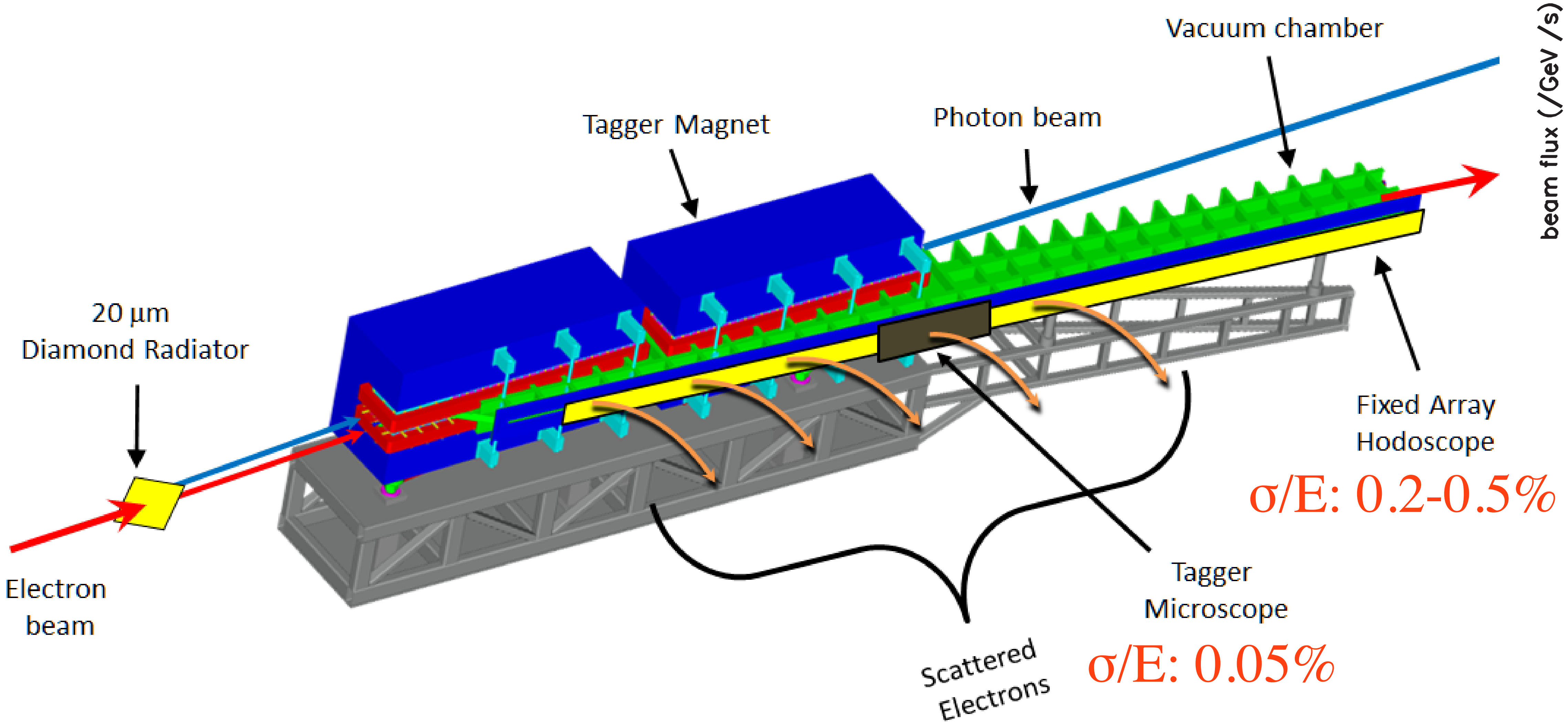
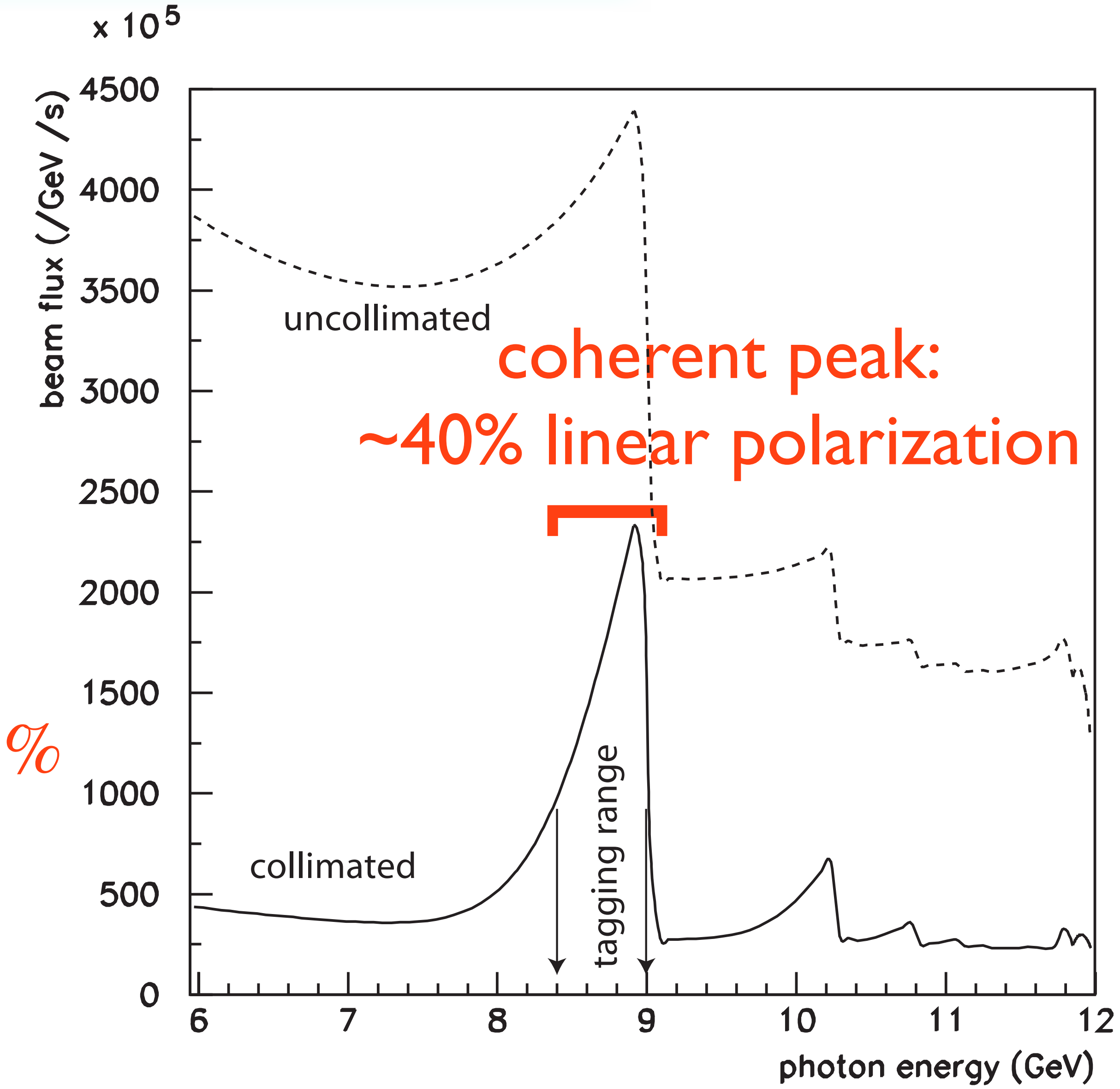
Photon Beam

- Coherent bremsstrahlung from diamond radiator → linearly polarized photons
- Recoil electrons detected with tagger using dipole magnet





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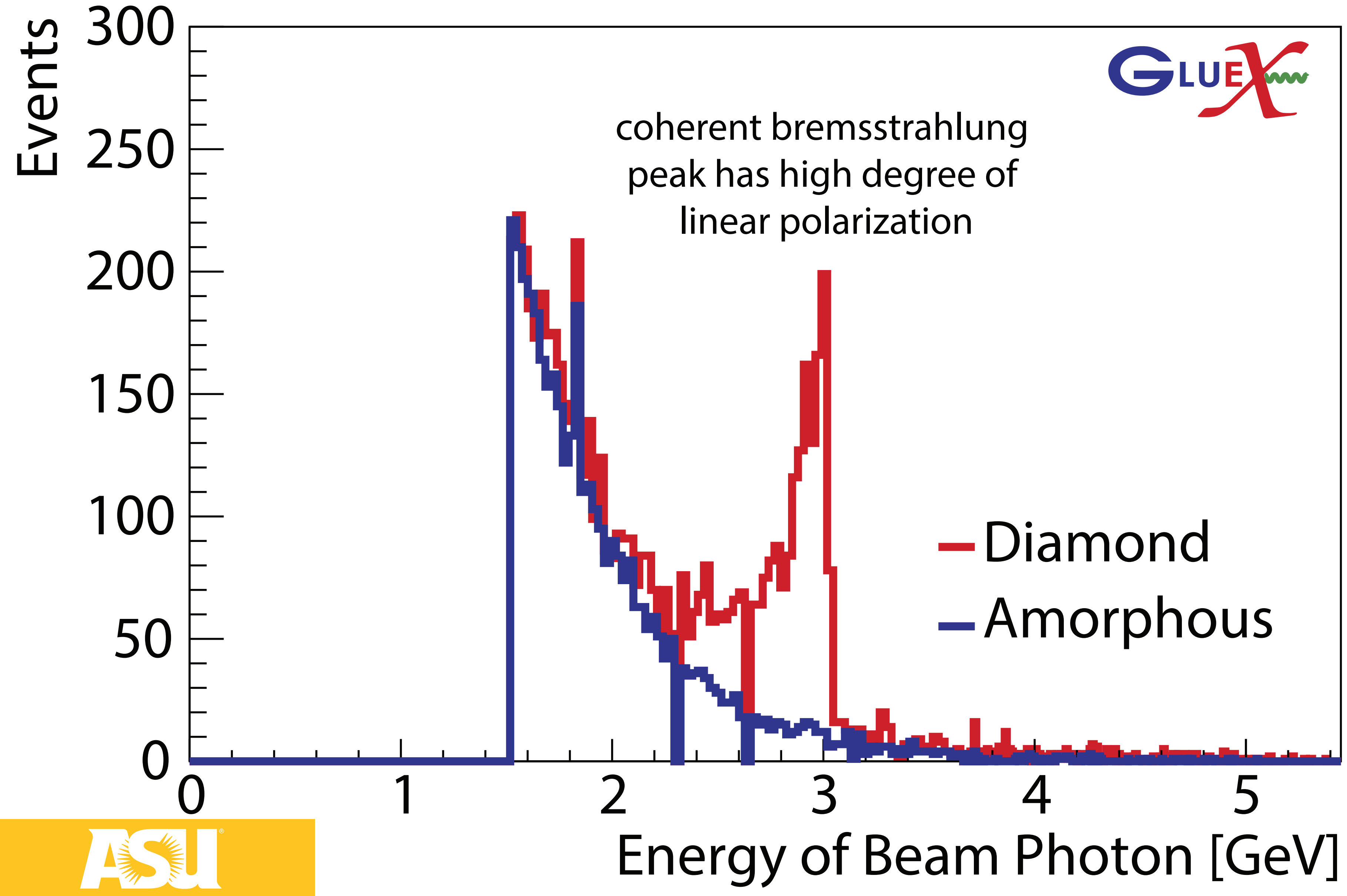
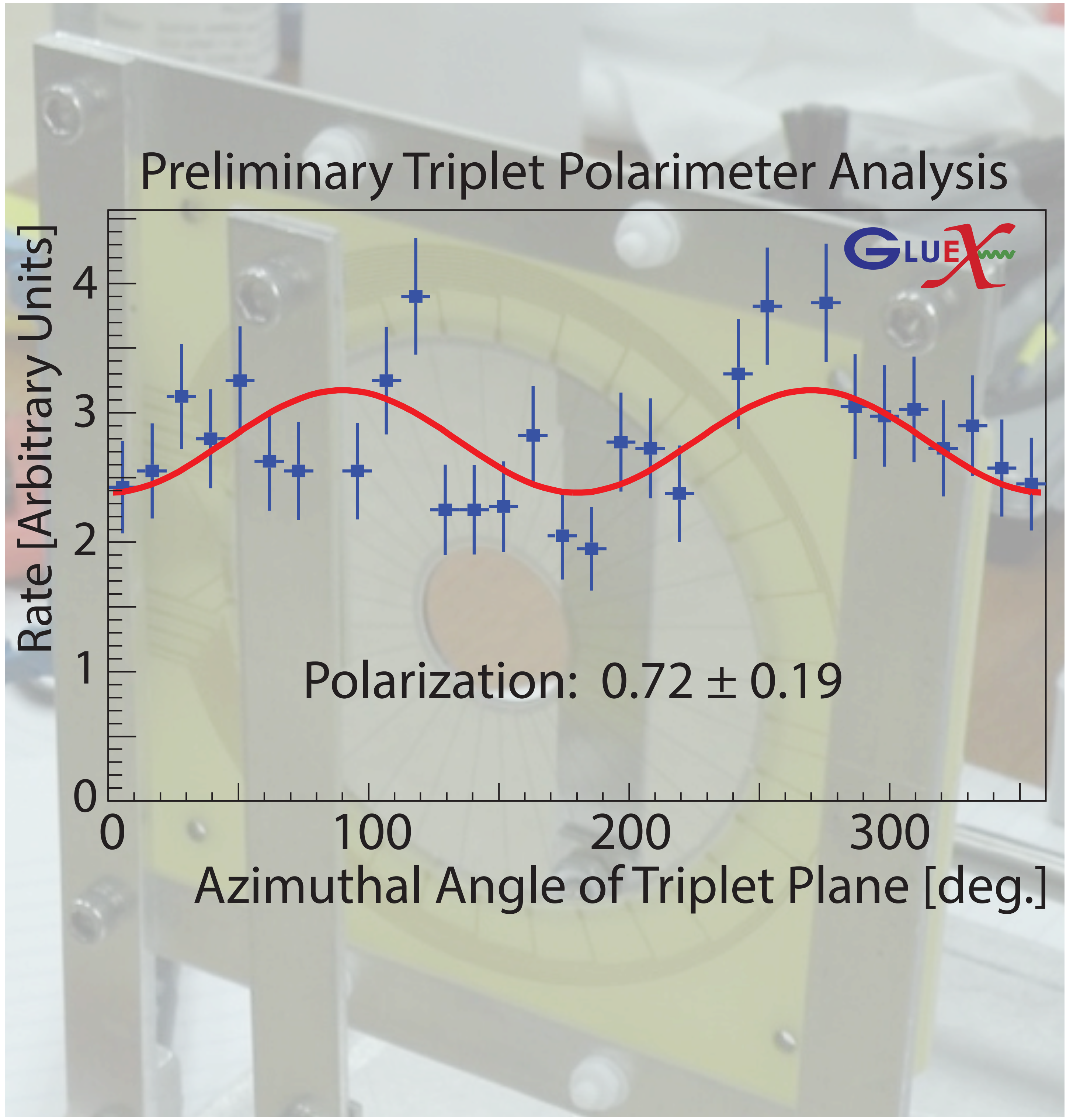
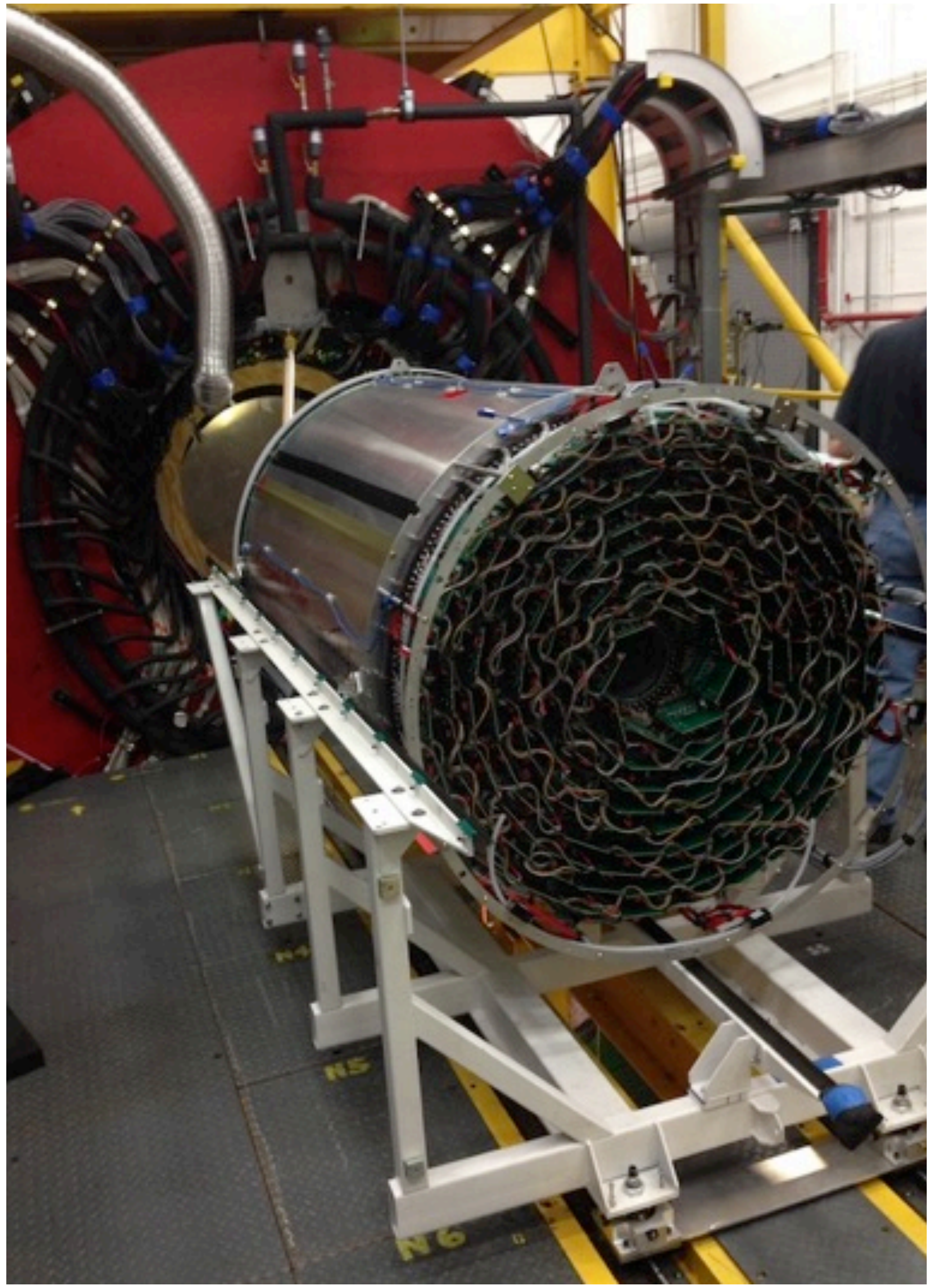
Photon Beam Commissioning

- Ran with 5.5 GeV e^- beam in Spring 2015
- Photon energy spectrum shows strong coherent edge
- Estimated peak polarization of ~65%





Drift Chambers



- Central Drift Chamber (CDC) covers 6˚ - 165˚ around target
- $\sigma_{r\phi}$ ~ 150 μm, σ_z ~ 1.5 mm
- Provide charged track hits, *dE*/*dx*
- Forward Drift Chamber (FDC) covers forward region
- σ_{xy} ~ 200 μm, $\sigma(\delta p/p)$ ~ 1-5%

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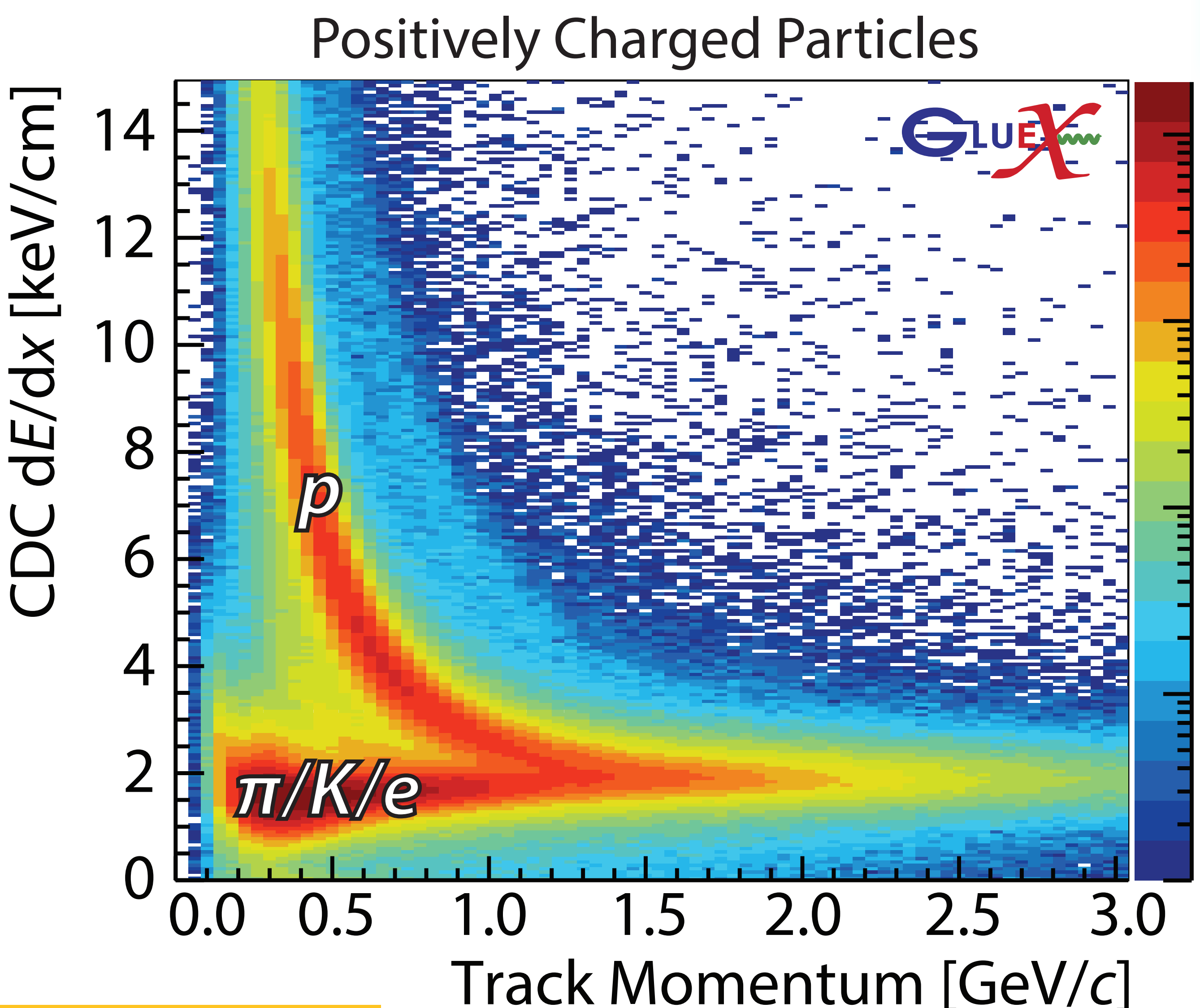
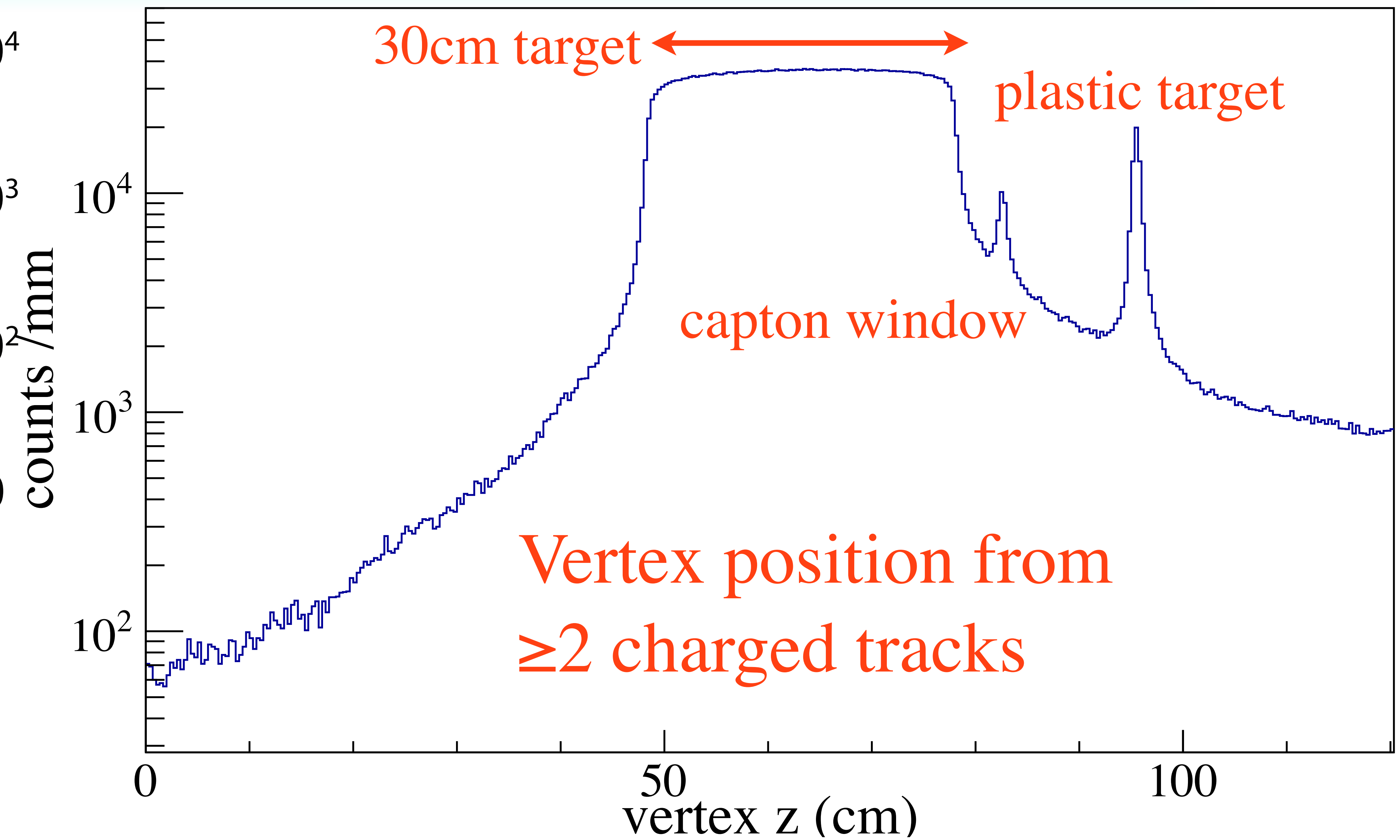
Drift Chambers

- Commissioning results
- Separation of protons from π/K shown in *dE/dx*
- Nearing design goal for resolution (200-250 μm)





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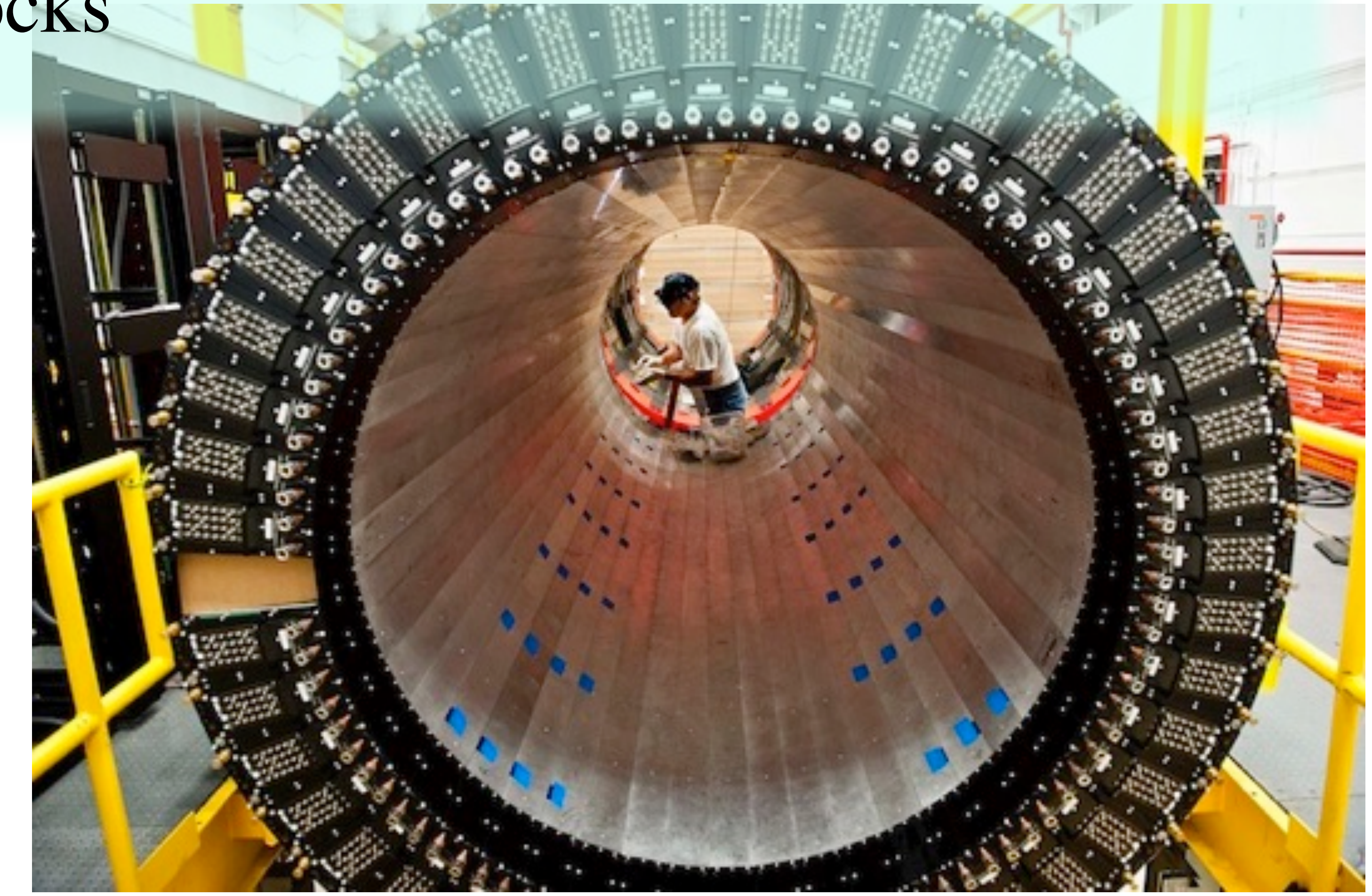
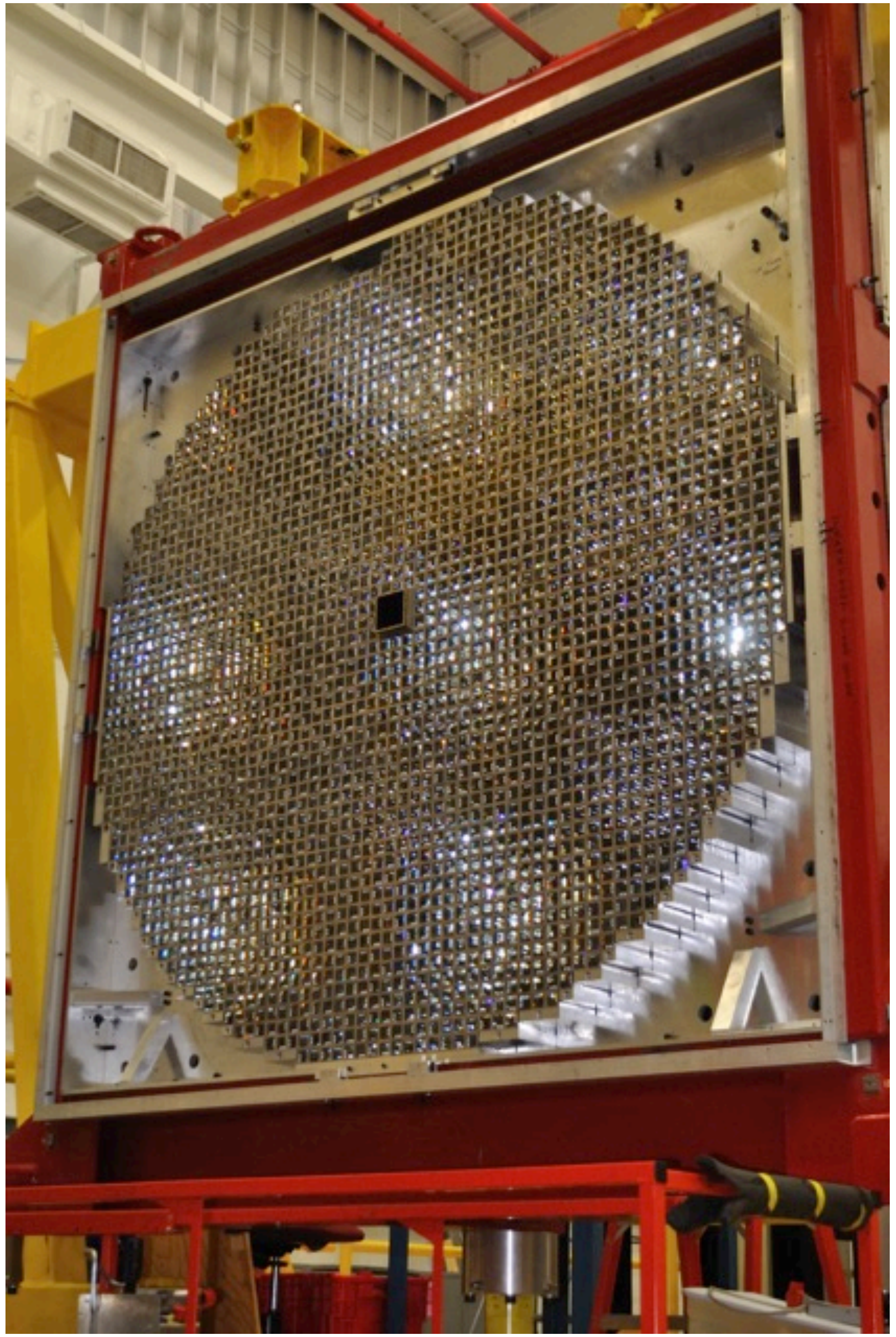
Calorimeters

- Barrel Calorimeter provides timing for charged particles and photon detection (11° - 126°)
- Pb and scintillating fibers, SiPM readout
- Forward Calorimeter provides photon detection downstream
- 2800 lead glass blocks





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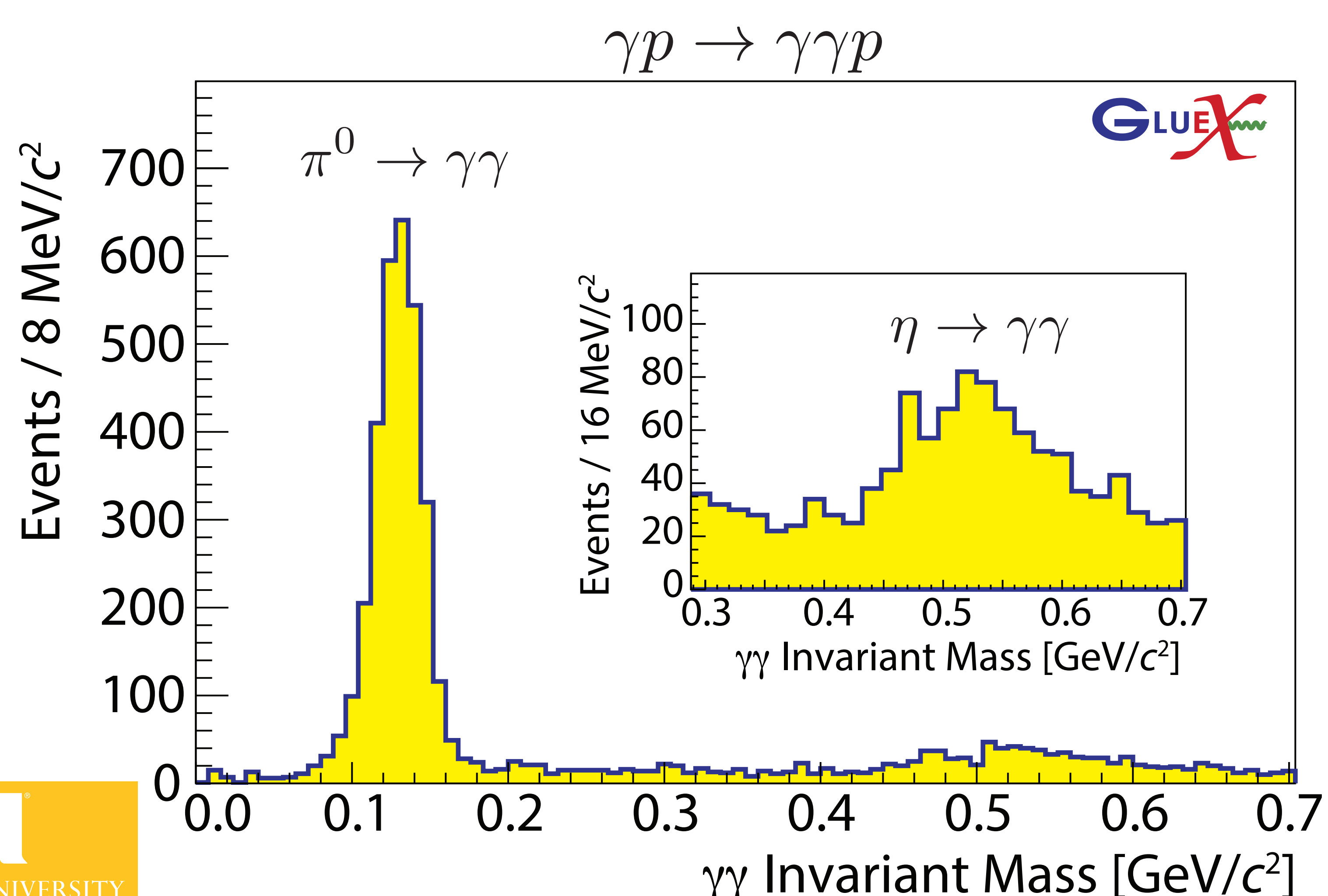
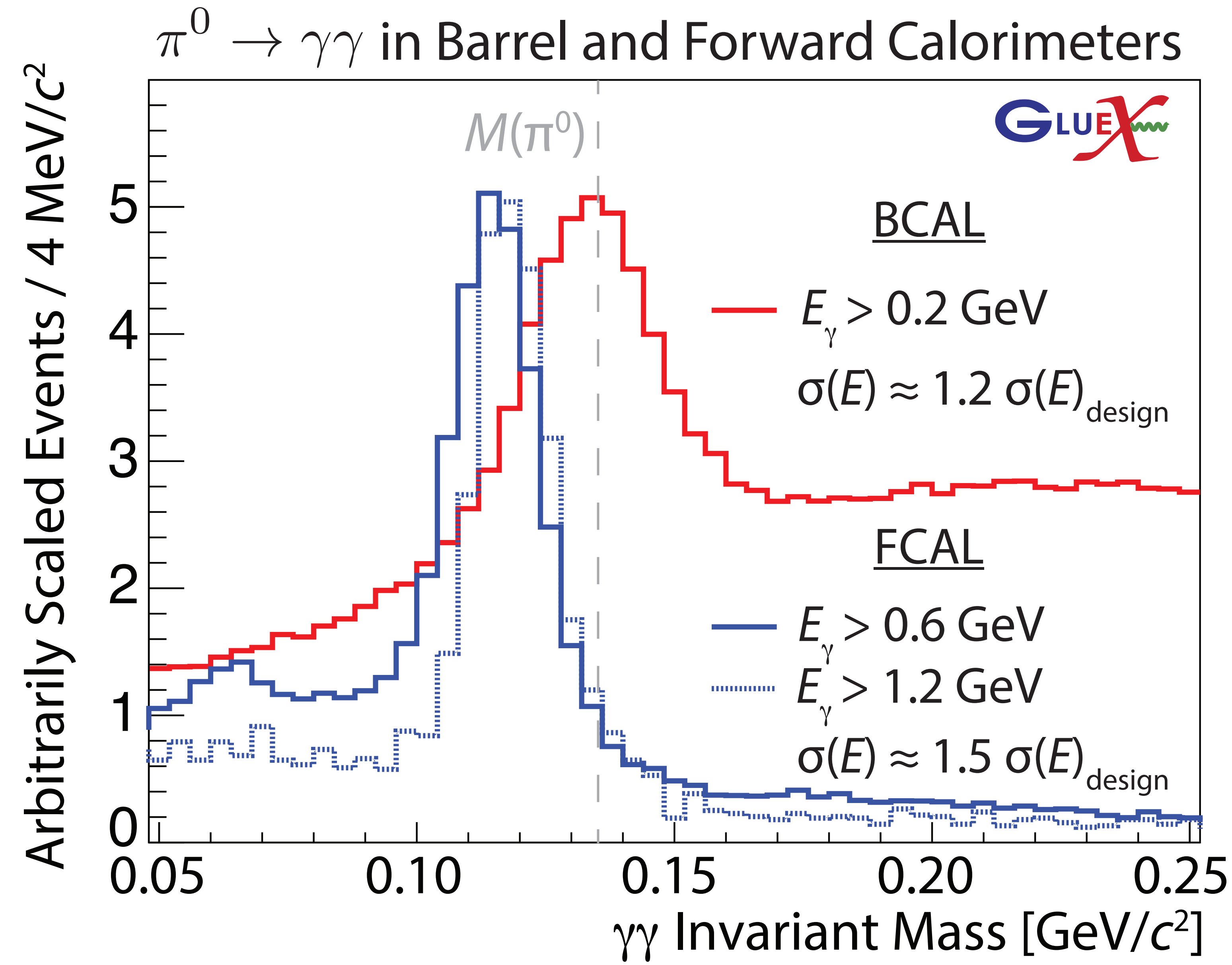
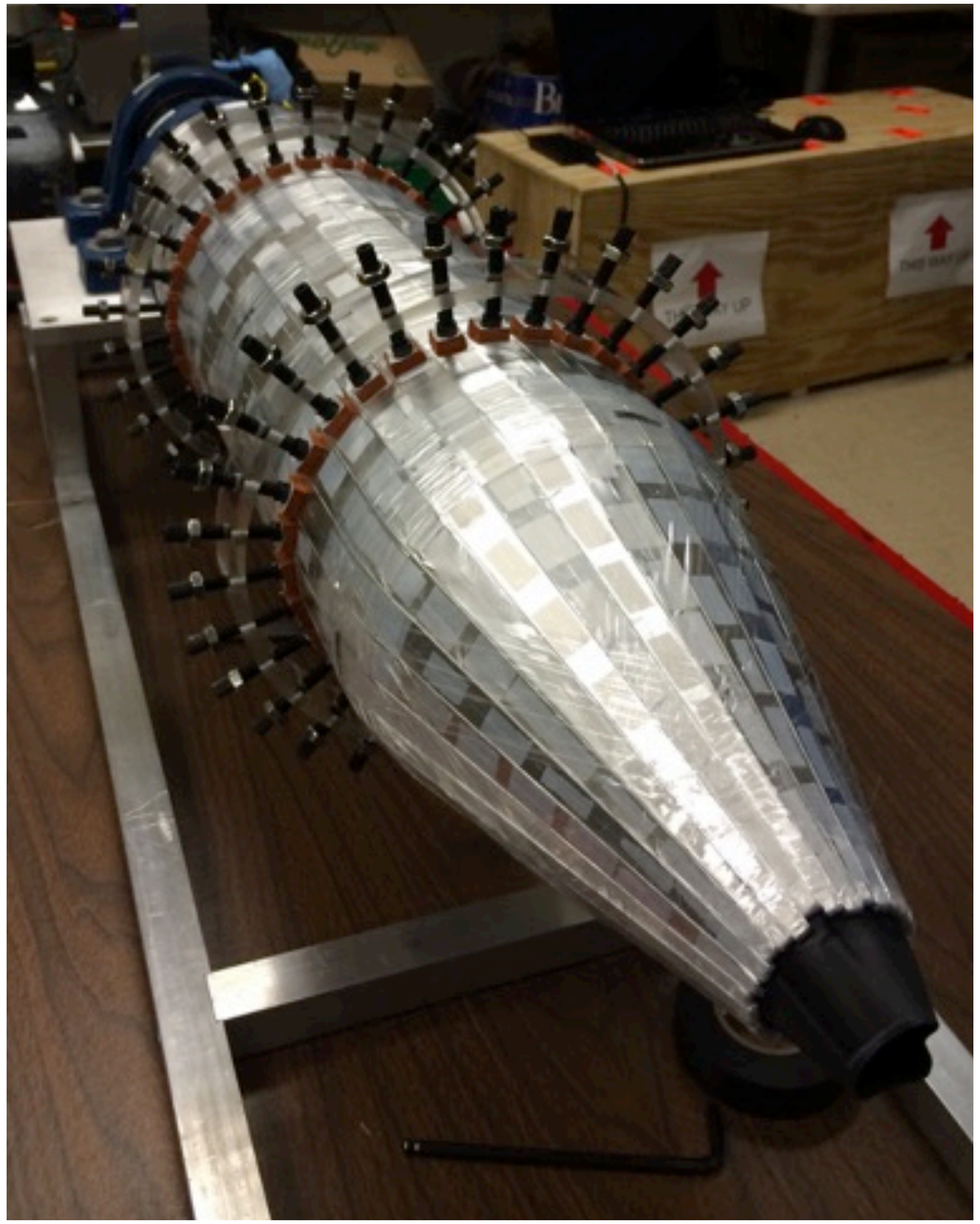
Calorimeters

- π^0, η seen in 2γ decays
- Resolution near design goals, more data needed







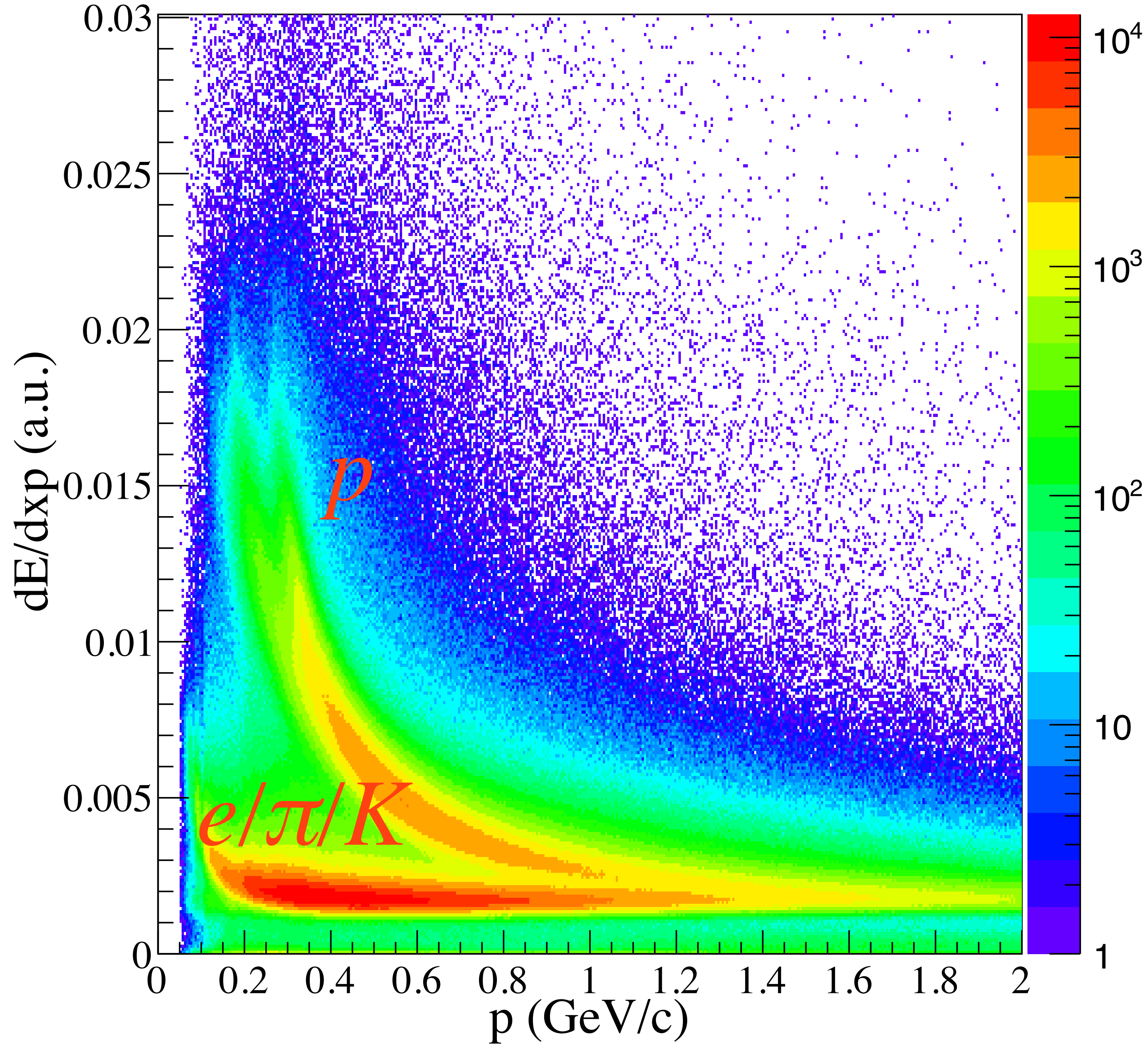
PID

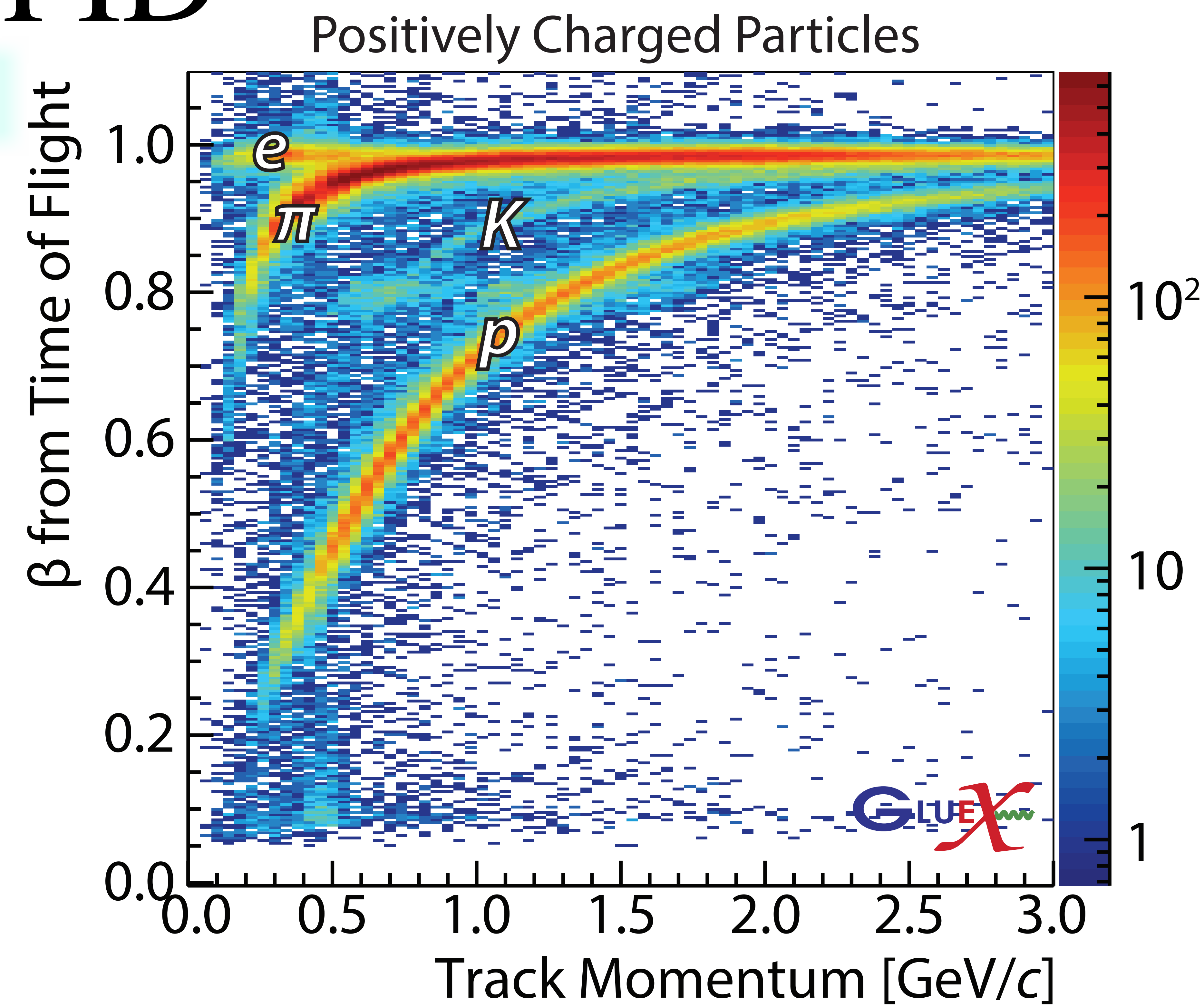
- TOF: 2 layers of scintillator paddles
- Combined resolution of 70 ps, 3σ K/π separation up to 2.5 GeV/*c*

- Start Counter surrounds target, 30 segments
- Helps in beam bunch selection, time resolution of 300 ps

PID

- *dE/dx* measurements from Start Counter





- Already reached design goal of 90 ps

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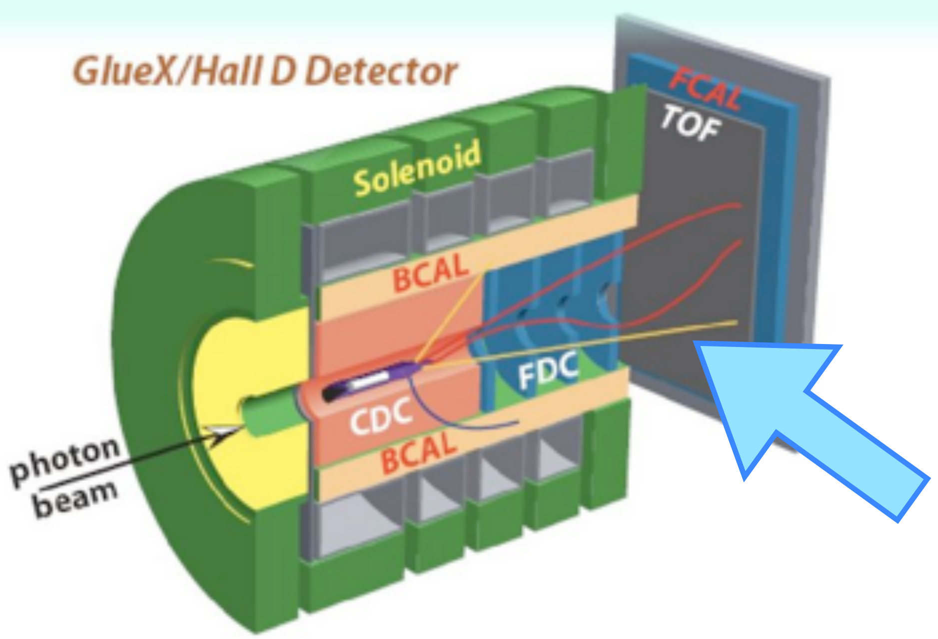
Forward DIRC

- DIRC bars originally for BaBar2
- Bars made of synthetic fused silica
- Read out with PMT plane
- Provide good π/K separation up to 4 GeV/c
- Approved for future high-statistics running
- Developing design, readout, etc.



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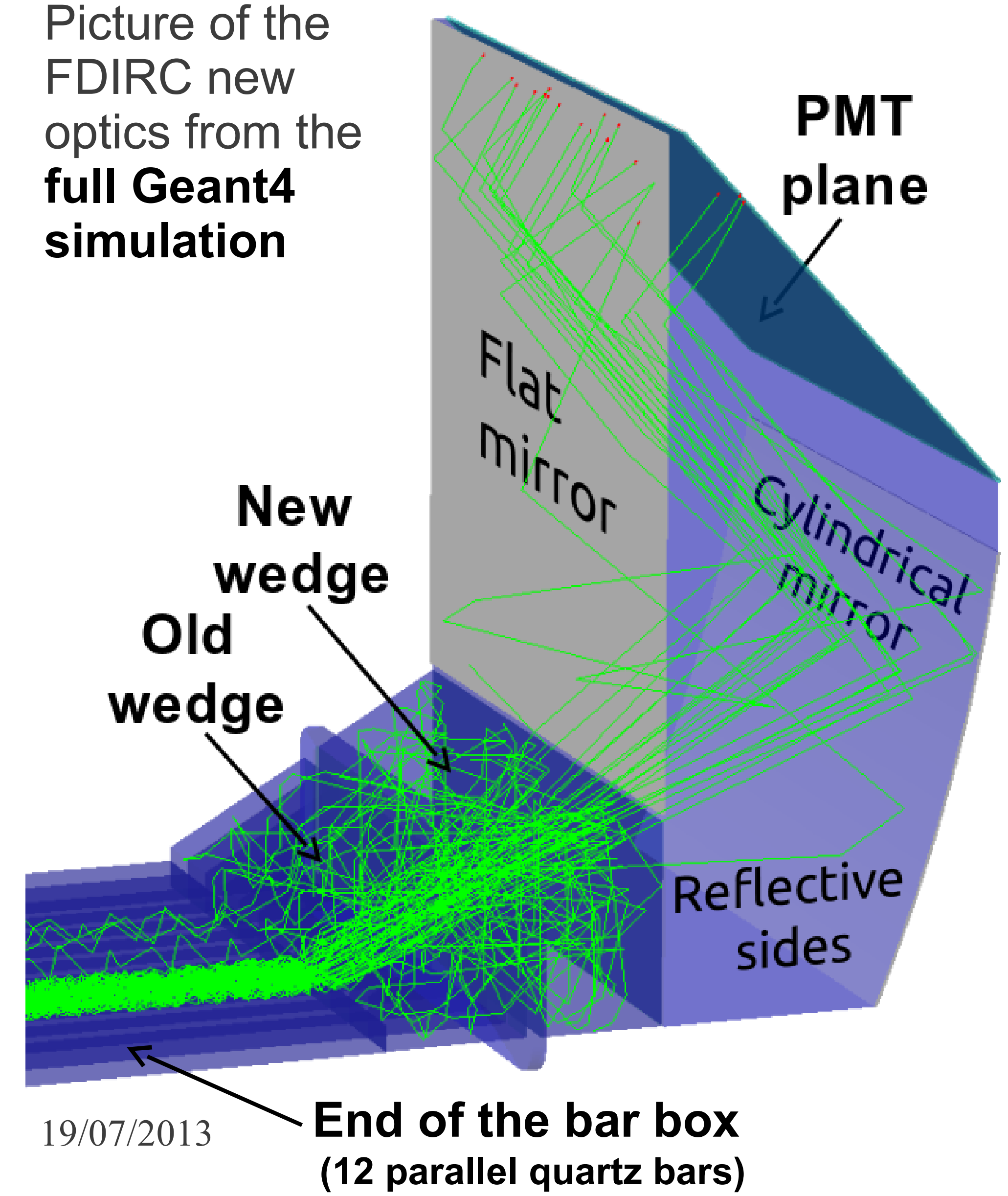
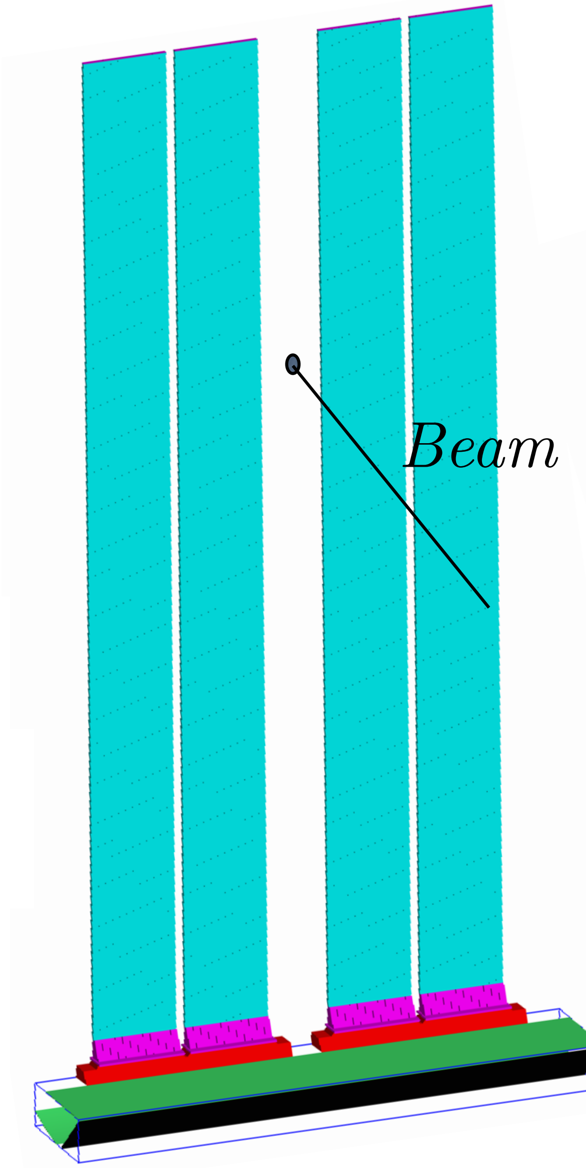
Picture of the FDIRC new optics from the **full Geant4 simulation**

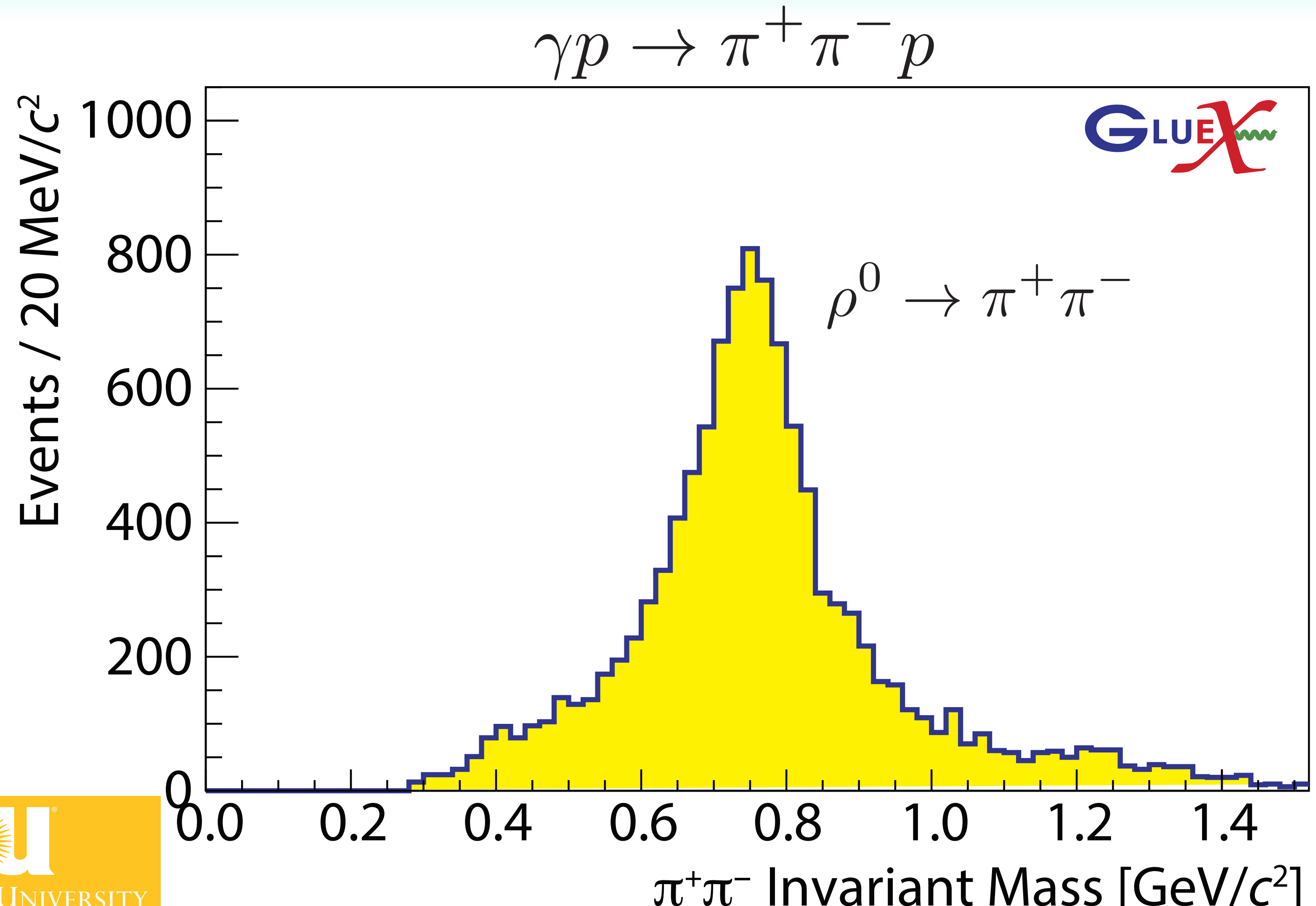


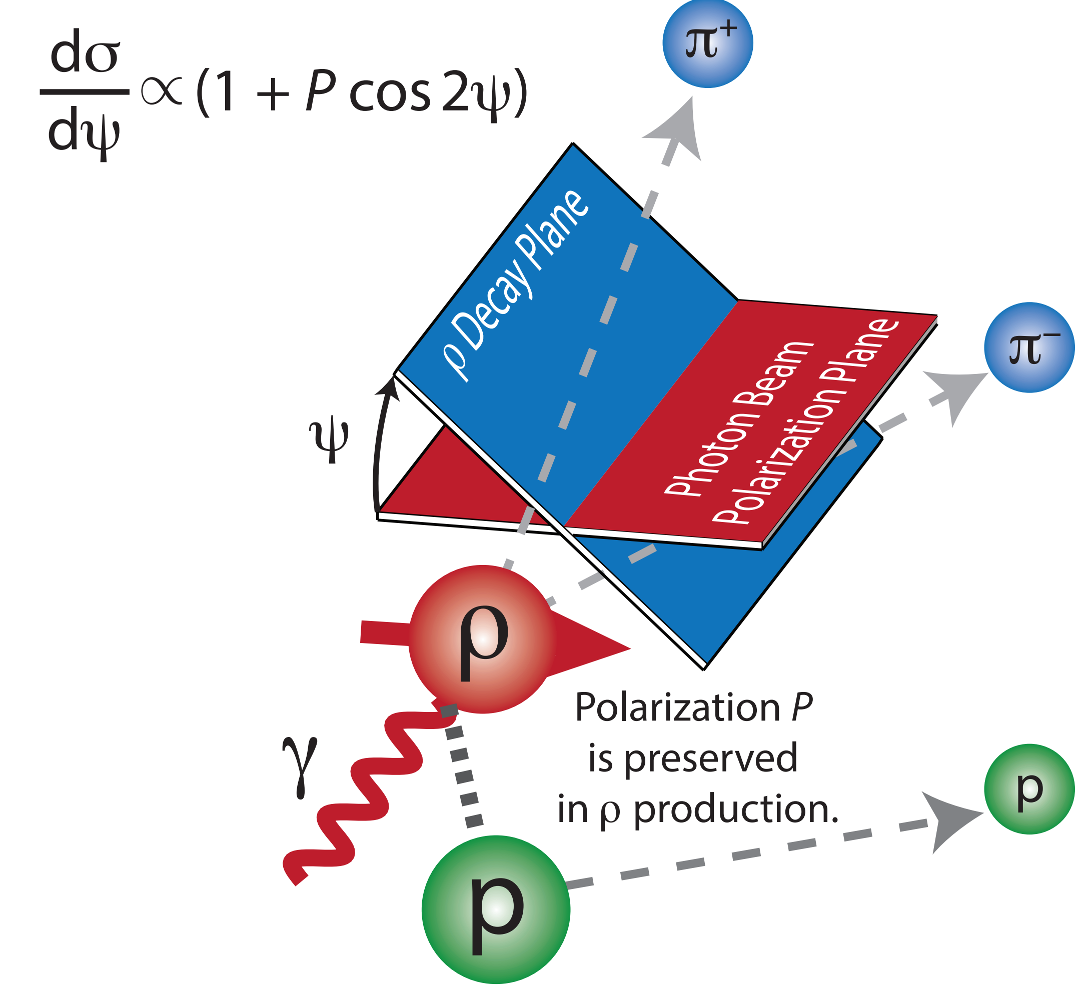
19/07/2013

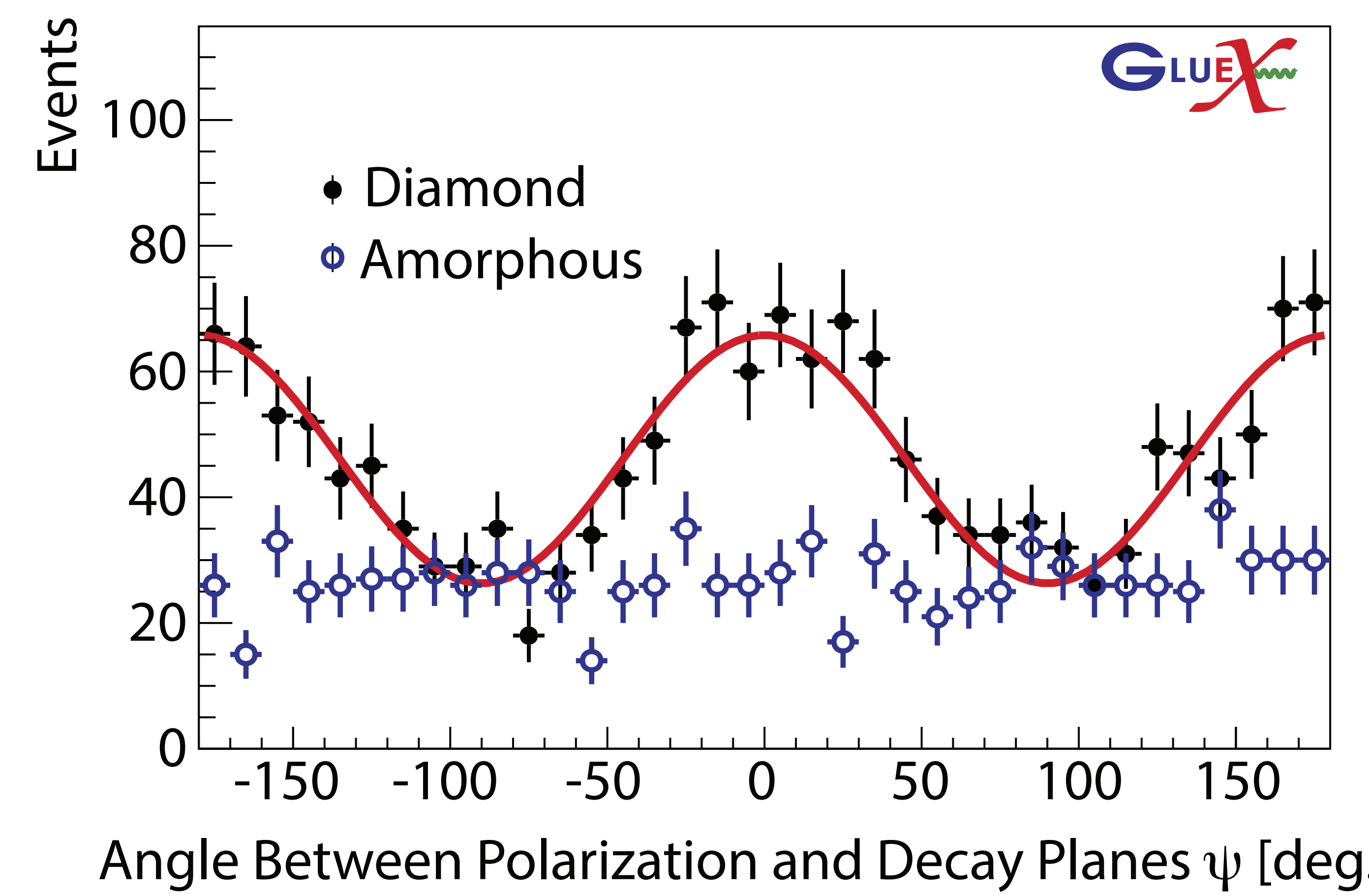


ρ Production

- $\gamma + p \rightarrow p\, \rho^0$ is ~10% of total cross section
- Reconstruct p, π^+, π^-
- Clear asymmetry observed in angle of decay plane from photon polarization







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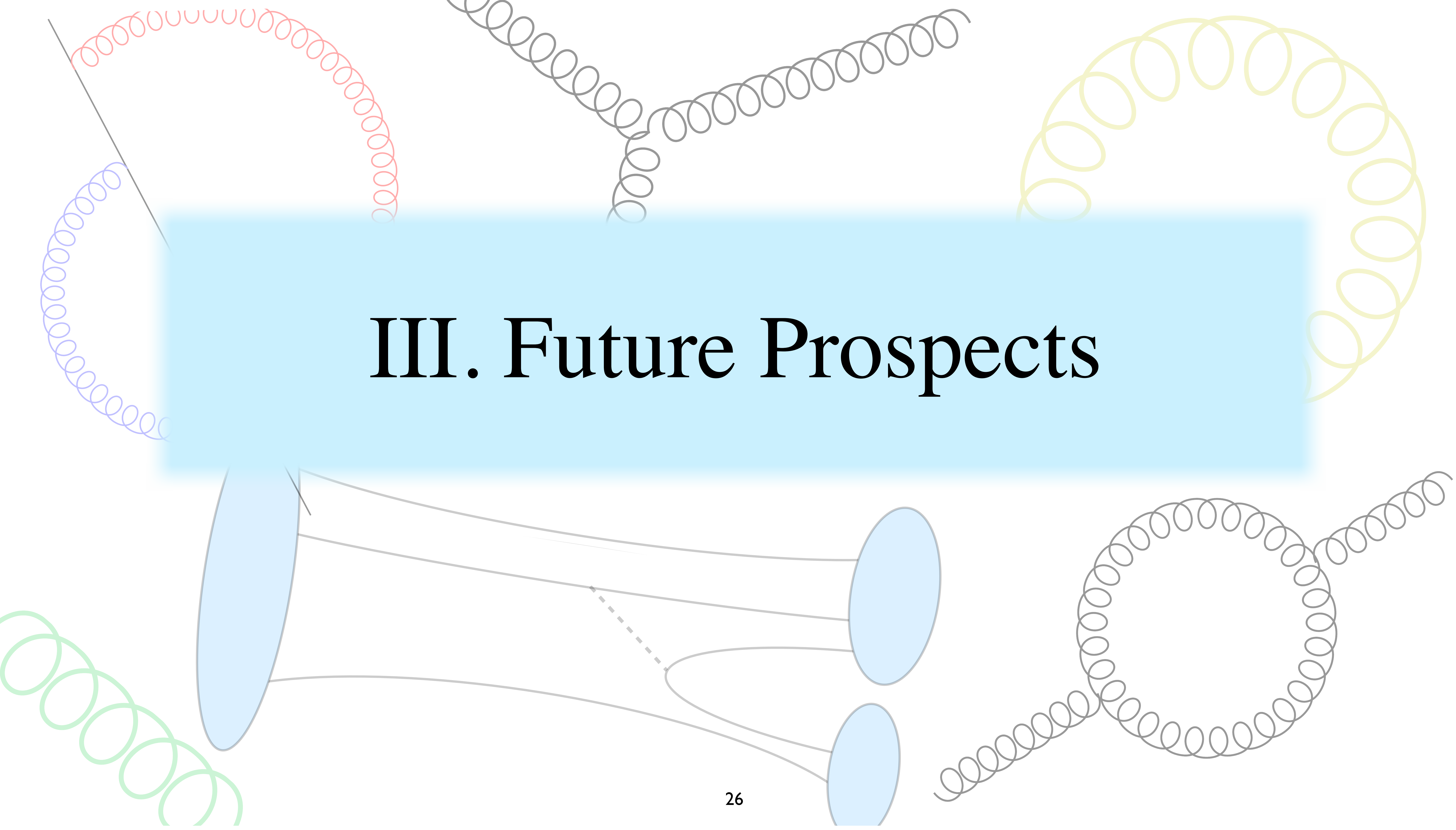
III. Future Prospects



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Meson Spectroscopy

- For reactions with large cross sections, very high statistics
- Likely targets for exotic mesons are $\pi_1(1600)$, $\pi_1(1900)$

Expected reconstructed yields

Final State	Cross Section (μb)	Proposed Phase IV ($\times 10^6$ events)
$\pi^+\pi^-\pi^+$	10	3000
$\pi^+\pi^-\pi^0$	2	600
$KK\pi\pi$	0.5	40
$KK\pi$	0.1	10
$\omega_{3\pi}\pi\pi$	0.2	40
$\omega_{\gamma\pi}\pi\pi$	0.2	6
$\eta_{\gamma\gamma}\pi\pi$	0.2	30
$\eta_{\gamma\gamma}\pi\pi\pi$	0.2	20
$\eta'_{\gamma\gamma}\pi$	0.1	1
$\eta'_{\eta\pi\pi}\pi$	0.1	3

Theory Predictions of Exotic Meson Decays

	Approximate Mass (MeV)	J^{PC}	Total Width (MeV) PSS	IKP	Relevant Decays	Final States
π_1	1900	1^{-+}	$80-170$	120	$b_1\pi^\dagger$, $\rho\pi^\dagger$, $f_1\pi^\dagger$, $a_1\eta$, $\eta'\pi^\dagger$	$\omega\pi\pi^\dagger$, $3\pi^\dagger$, 5π, $\eta 3\pi^\dagger$, $\eta'\pi^\dagger$
η_1	2100	1^{-+}	$60-160$	110	$a_1\pi$, $f_1\eta^\dagger$, $\pi(1300)\pi$	4π, $\eta 4\pi$, $\eta\eta\pi\pi^\dagger$
η'_1	2300	1^{-+}	$100-220$	170	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$, $KK\omega^\dagger$
b_0	2400	0^{+-}	$250-430$	670	$\pi(1300)\pi$, $h_1\pi$	4π
h_0	2400	0^{+-}	$60-260$	90	$b_1\pi^\dagger$, $h_1\eta$, $K(1460)K$	$\omega\pi\pi^\dagger$, $\eta 3\pi$, $KK\pi\pi$
h'_0	2500	0^{+-}	$260-490$	430	$K(1460)K$, $K_1(1270)K^\dagger$, $h_1\eta$	$KK\pi\pi^\dagger$, $\eta 3\pi$
b_2	2500	2^{+-}	10	250	$a_2\pi^\dagger$, $a_1\pi$, $h_1\pi$	4π, $\eta\pi\pi^\dagger$
h_2	2500	2^{+-}	10	170	$b_1\pi^\dagger$, $\rho\pi^\dagger$	$\omega\pi\pi^\dagger$, $3\pi^\dagger$
h'_2	2600	2^{+-}	$10-20$	80	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K_2^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$

$\sigma_{tot} = 126\ \mu b$

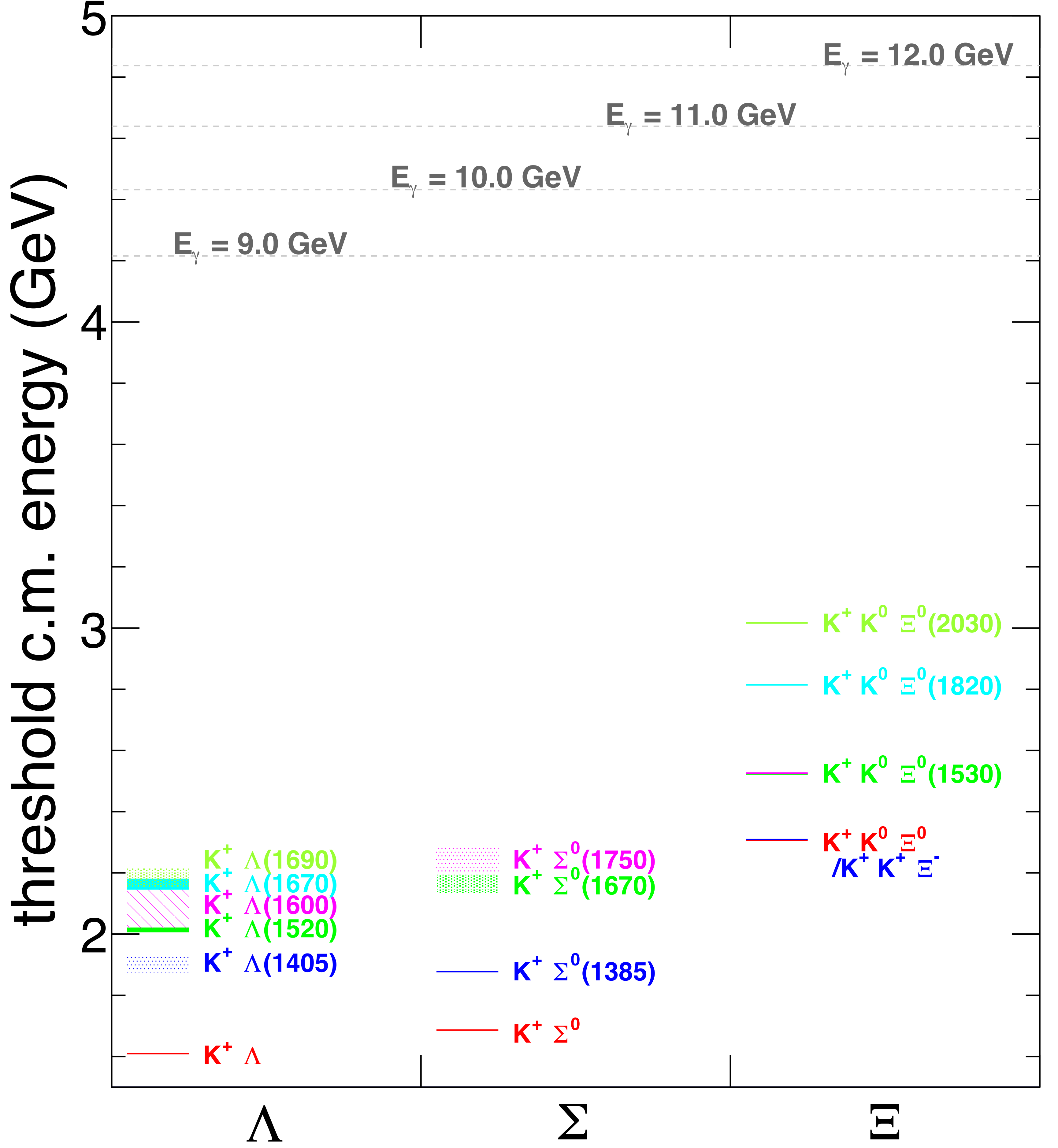
PAC proposals:

http://arxiv.org/abs/1305.1523

http://arxiv.org/abs/1408.0215

Y* Spectroscopy

- Augment and extend previous CLAS results
- Knowledge of Y* states very limited



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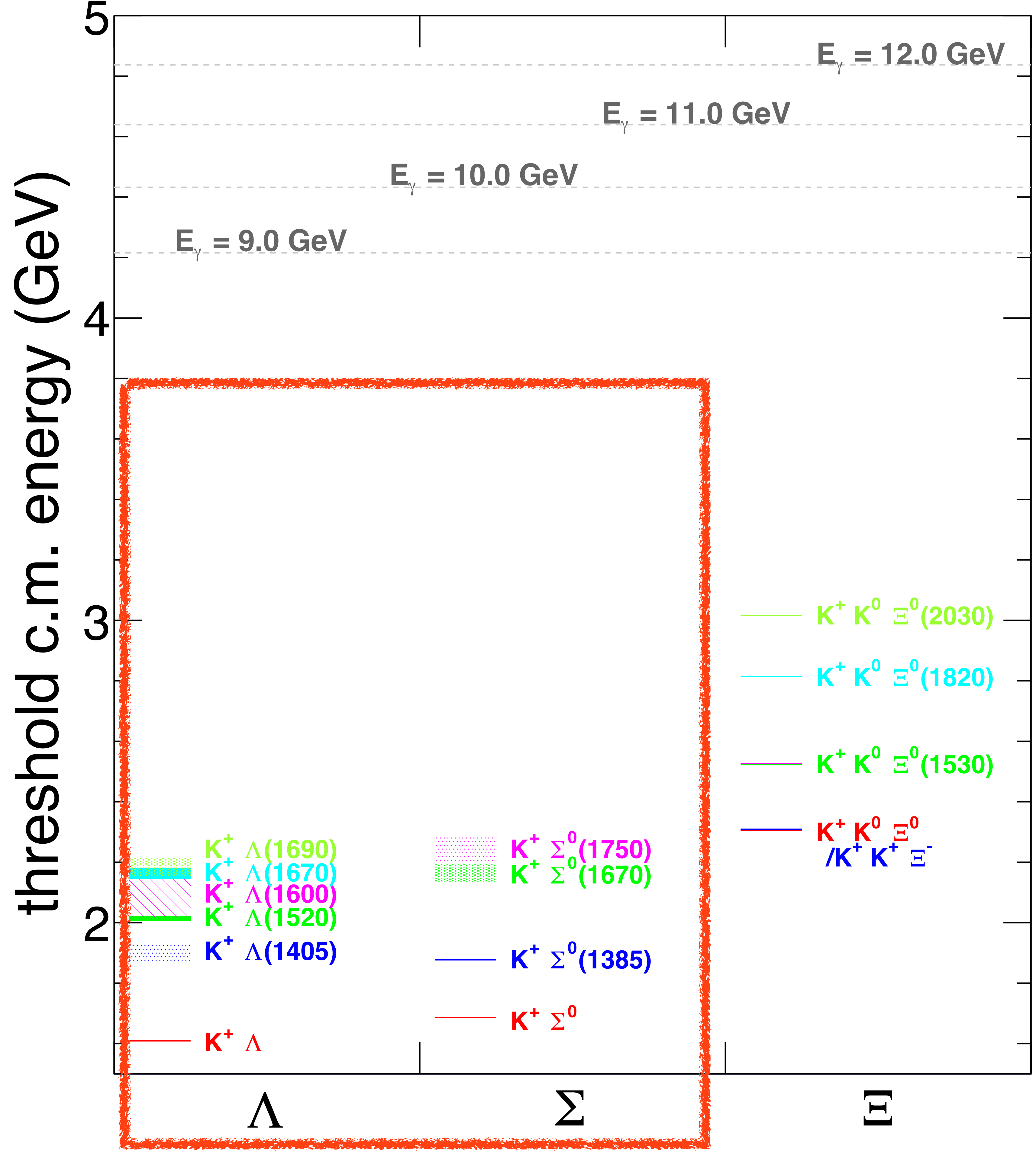
Y* Spectroscopy

- Augment and extend previous CLAS results
- Knowledge of Y* states very limited



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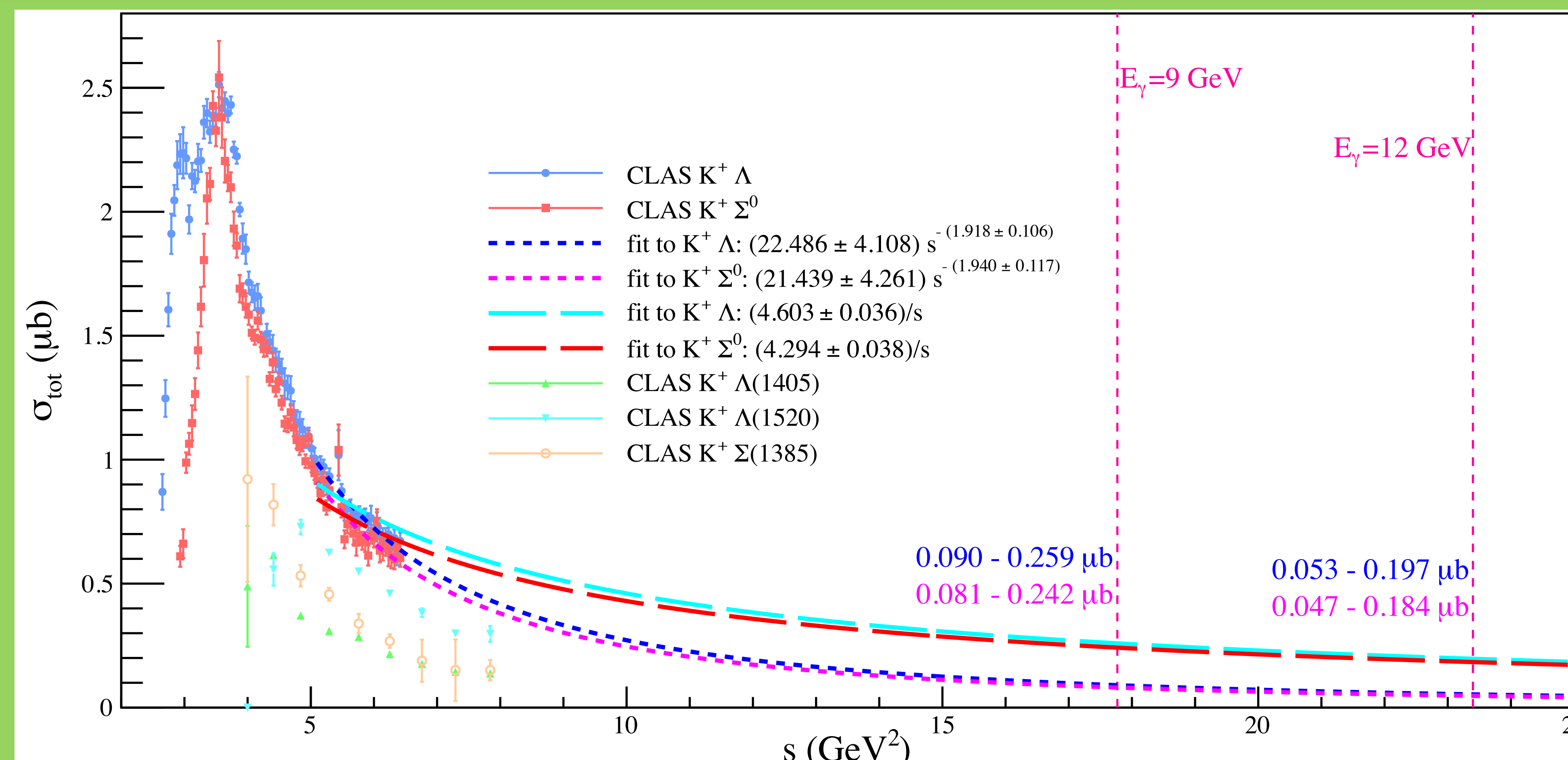
Y* Spectroscopy

- Augment
  CLAS re
- Knowled
  limited

- Extrapolation of CLAS results shows cross sections of ~0.1 μb
- For *S = -1* baryons, kinematic reach is M_{Y*} ~3.5 GeV/c^2
- Decay modes are Λπ, Σπ, N$\bar{K}$, Λη, ···



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Y* Spectroscopy

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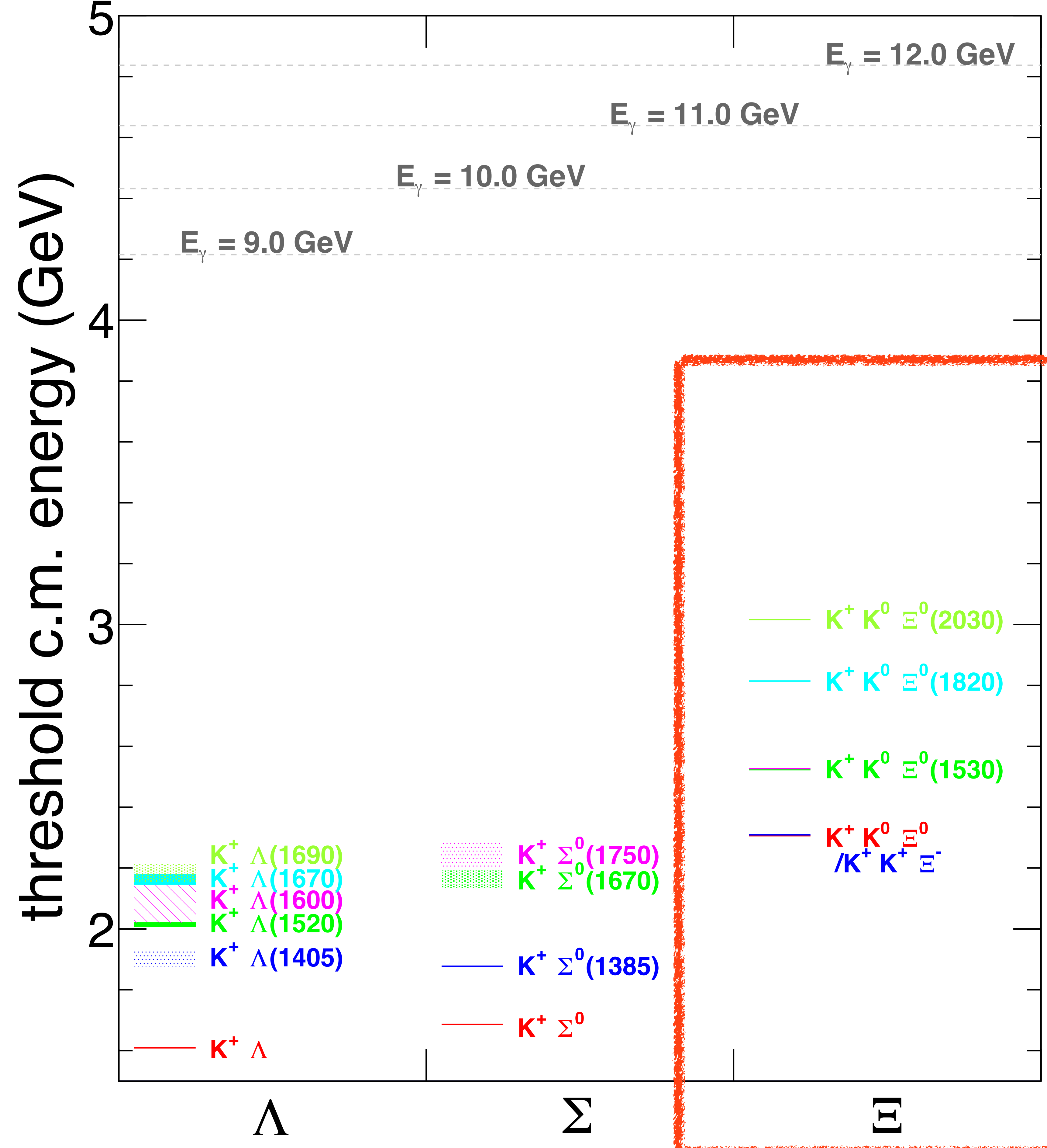

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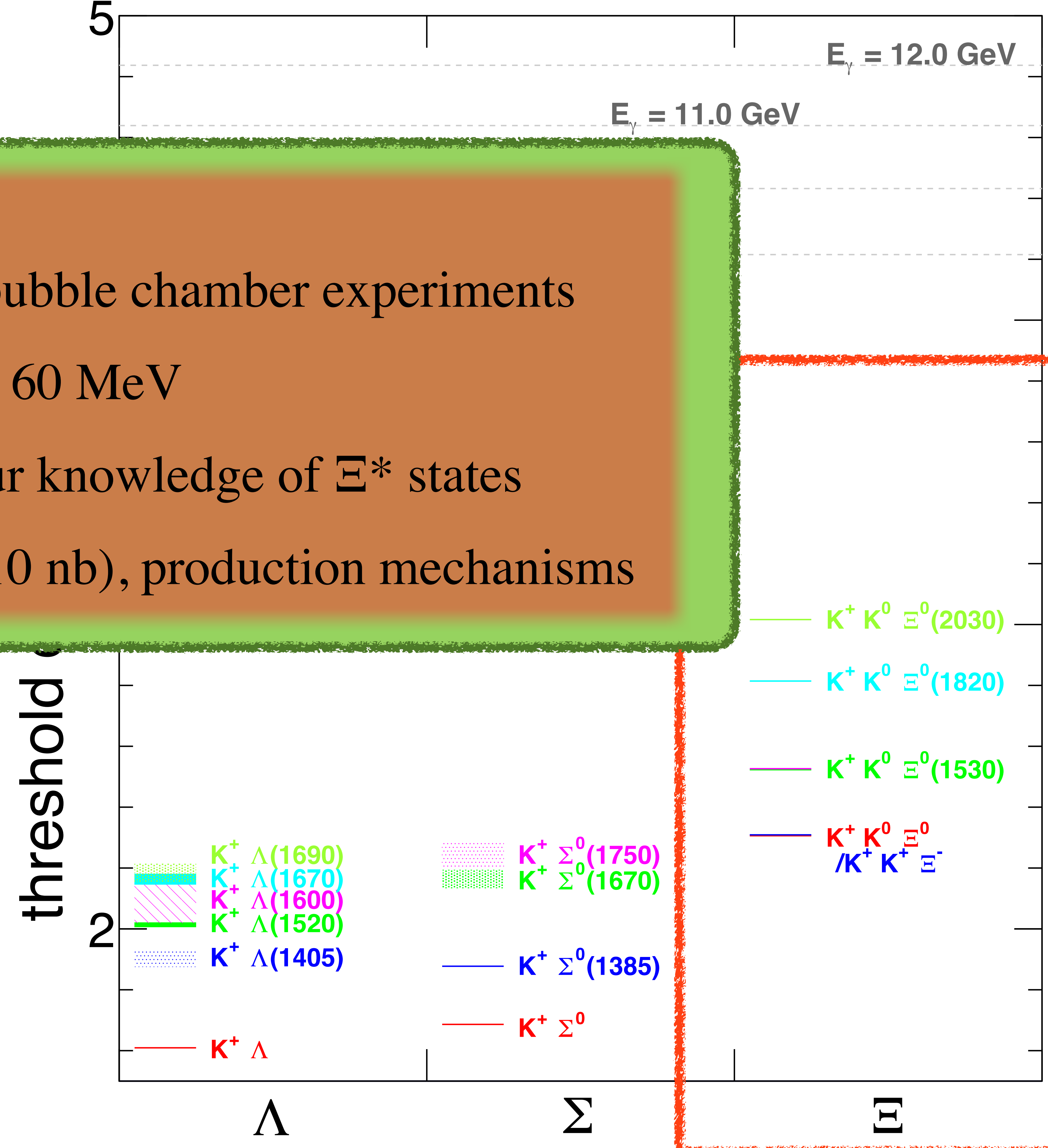
Y* Spectroscopy

- Only 11 Ξ (*) states listed in PDG
- Spectrum of Ξ* largely unexplored since bubble chamber experiments
- Known states have narrow widths Γ < 20 - 60 MeV
- GlueX will make a large contribution to our knowledge of Ξ* states
- Largest uncertainties are cross sections (≲10 nb), production mechanisms



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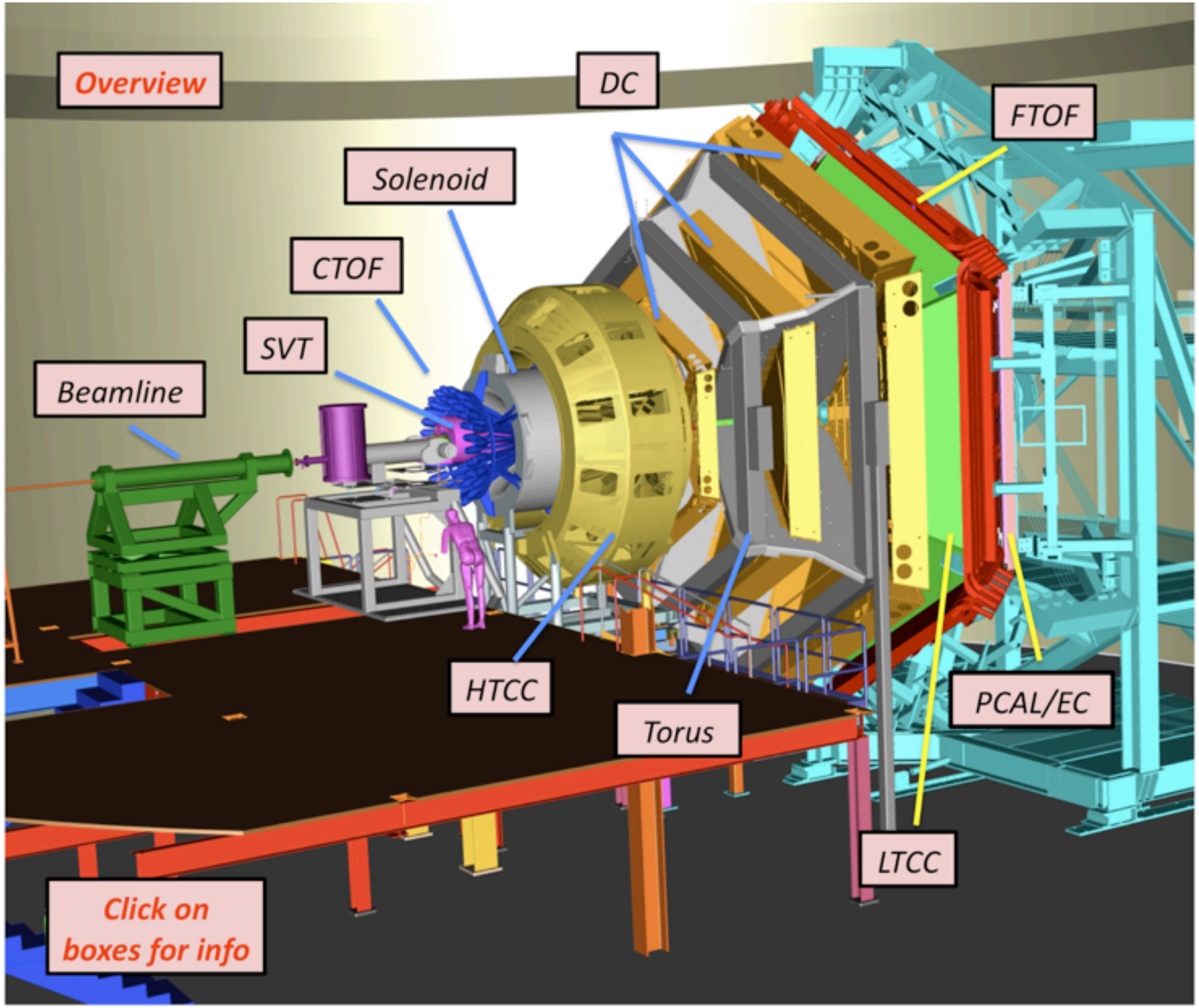
CLAS12

- New detectors for a wide range of experiments
- Under construction, commissioning in 2016
- Hadronic experiments to look for exotic mesons and strange baryons approved



PAC proposals:

http://www.jlab.org/exp_prog/proposals/11/PR12-11-005.pdf

http://www.jlab.org/exp_prog/proposals/12/PR12-12-008.pdf

IV. Conclusion

- The Jefferson Lab 12 GeV upgrade is almost complete
- GlueX is a dedicated hadron spectroscopy experiment
  - Commissioning has started, data taking to continue for several years
  - Mapping out the spectrum of mesons will be the primary goal
  - The spectrum of strange baryons will also be very interesting
- Please consider joining the Jefferson Lab 12 GeV program

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Backup

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GlueX References

- Jefferson Lab https://www.jlab.org/
- Hall D https://www.jlab.org/Hall-D/
- GlueX portal http://gluex.org/GlueX/Home.html
- Current Physics Proposal: http://arxiv.org/abs/1305.1523
- PID Upgrade Proposal: http://arxiv.org/abs/1408.0215

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GlueX Institutions

- Arizona State University
- University of Athens
- Carnegie Mellon University
- Catholic University
- University of Connecticut
- Florida International University
- Florida State University
- George Washington University
- University of Glasgow
- Indiana University
- ITEP Moscow
- Jefferson Lab
- University of Massachusetts, Amherst
- Massachusetts Institute of Technology
- MePhi
- Norfolk State University
- North Carolina A&T State
- University of North Carolina, Wilmington
- Northwestern University
- Santa Maria University
- University of Regina
- Yerevan Physics Institute

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http://gluex.org/GlueX/Collaboration.html

Other Hall D Experiments

- Charged pion polarizability

  - approved for 25 days

  - measure polarizability of π from $\gamma + \gamma \rightarrow \pi^+ + \pi^-$

  - determine α_π - β_π to ~10%

- η decay width via Primakoff effect
  - approved for 79 days
  - determine $\Gamma_{\gamma\gamma}$ to 3%

- Rare η proposal
  - conditionally approved
  - search for rare η decays
  - mass distribution of $M(\gamma,\gamma)$ in $\eta \rightarrow \gamma\gamma\pi^0$

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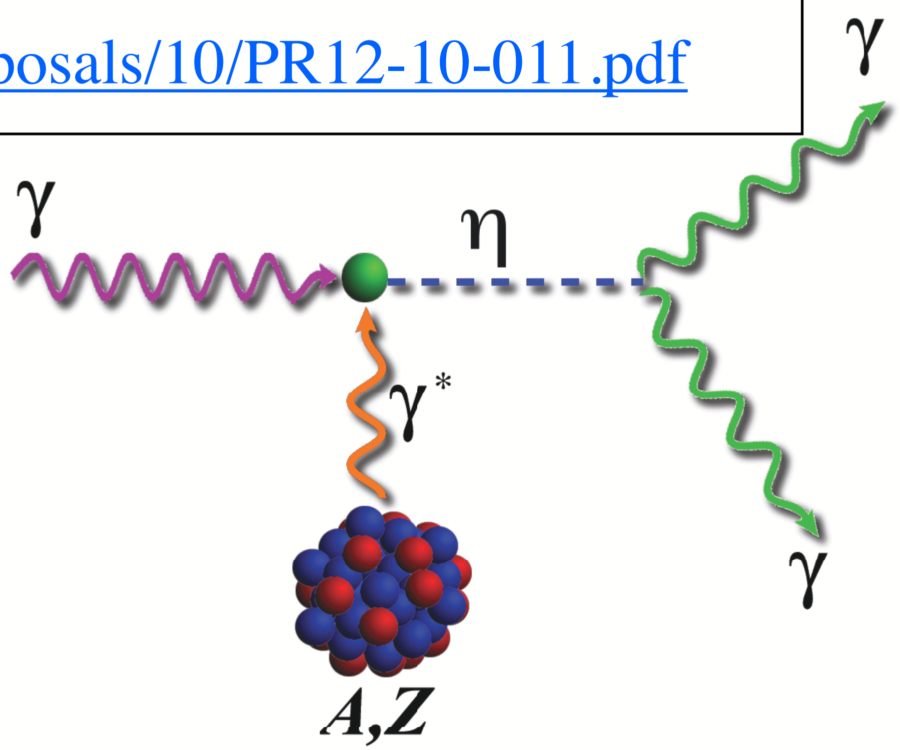
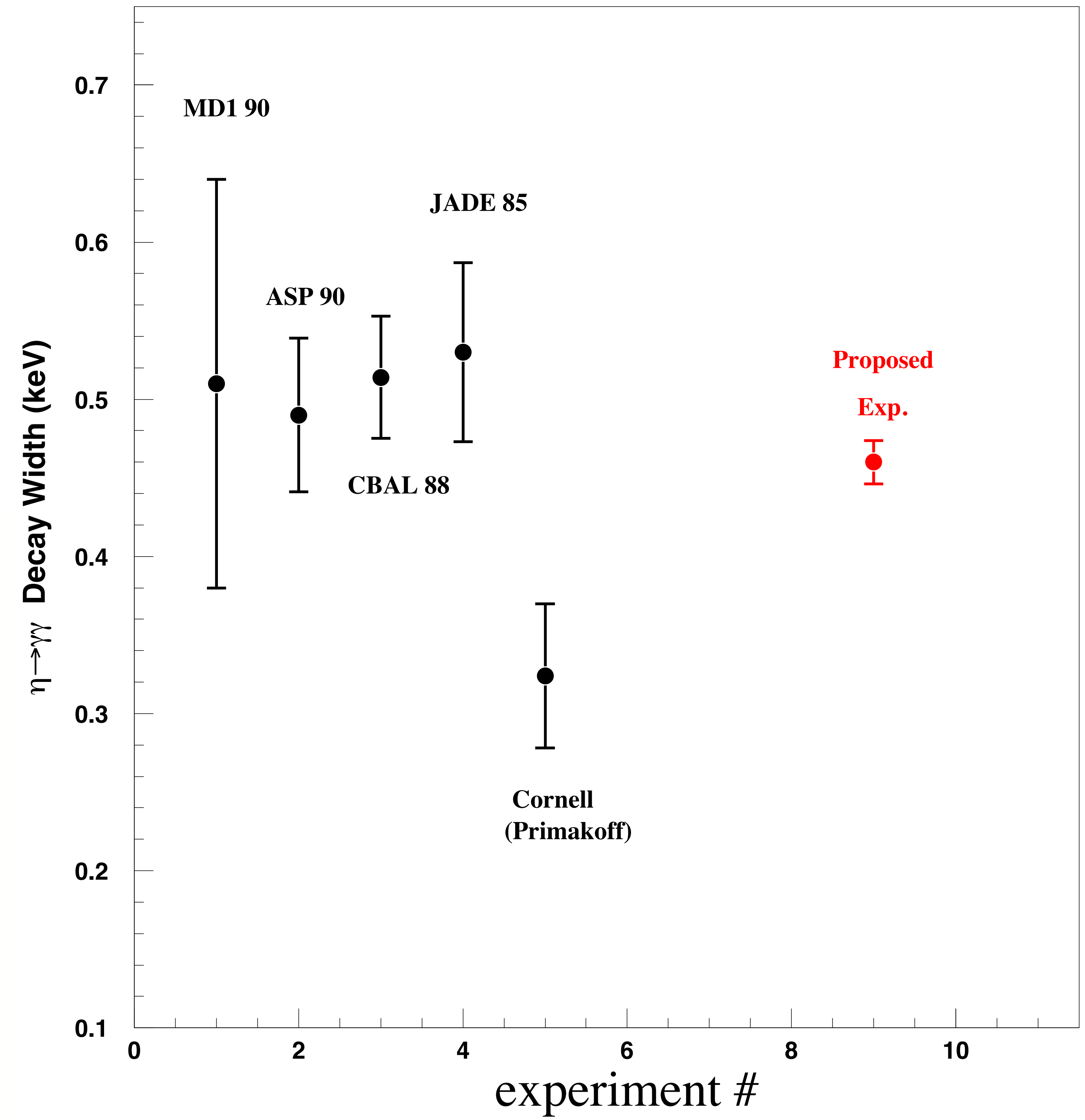
A Precision Measurement of the η Radiative Decay Width via the Primakoff Effect

- Approved for 79 PAC days at PAC37 (Jan 2011)
- Goal: determination of η width $\Gamma_{\gamma\gamma}$ to 3%
- Test of chiral perturbation theory
- PAC proposal:

  http://www.jlab.org/exp_prog/proposals/10/PR12-10-011.pdf





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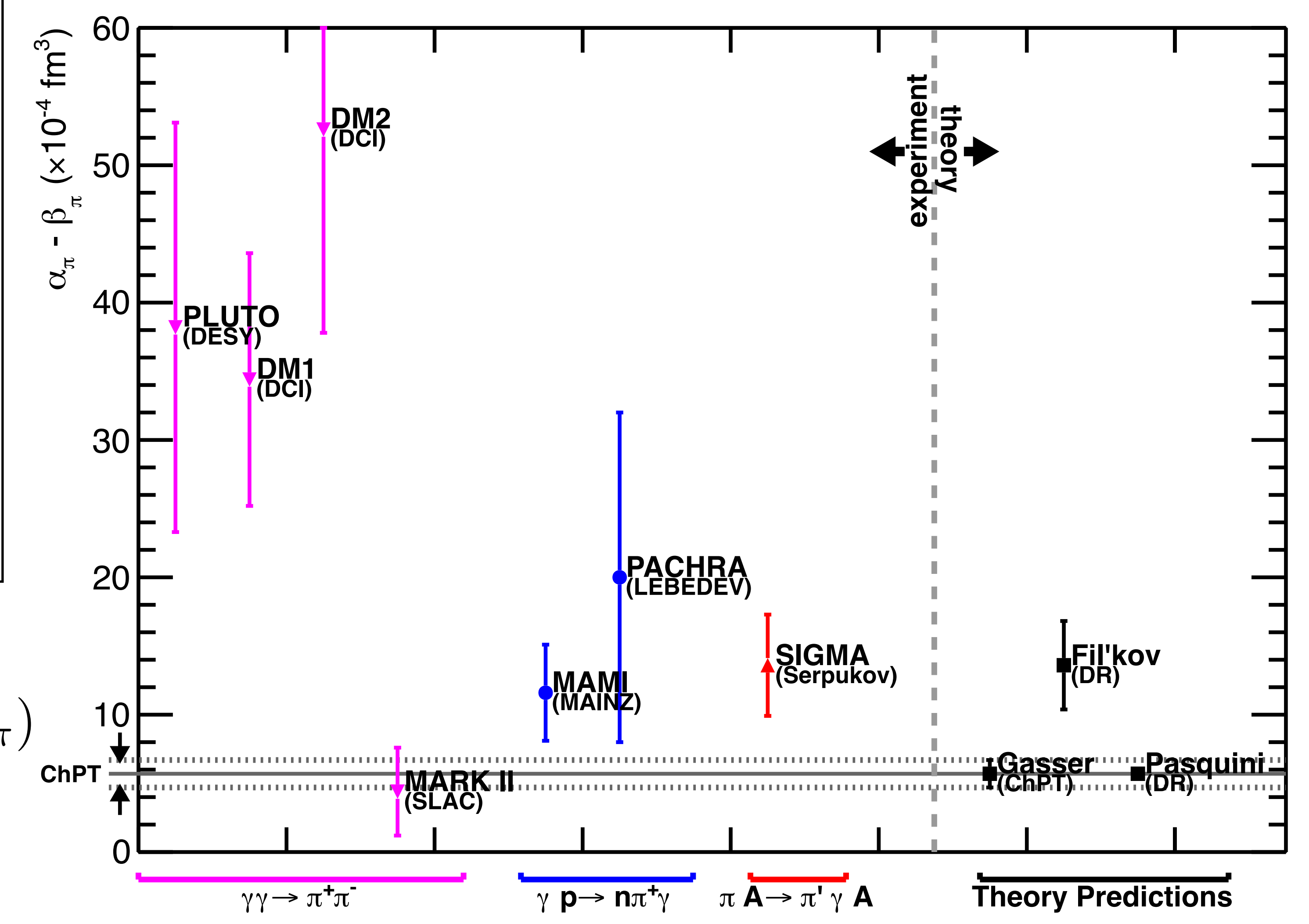
Measuring the Charged Pion Polarizability in the $\gamma\gamma \rightarrow \pi^+\pi^-$ Reaction

- Approved for 25 PAC days at PAC40 (Jun 2013)
- Goal: measure α_π - β_π (electric and magnetic polarizabilities) to 10%
- Test of chiral perturbation theory
- PAC proposal: http://www.jlab.org/exp_prog/proposals/13/PR12-13-008.pdf



$$\frac{d^2\sigma}{d\Omega_{\pi\pi}dW_{\pi\pi}} = \frac{2\alpha Z^2}{\pi^2}\frac{E_\gamma^4\beta^2}{W_{\pi\pi}}\frac{\sin^2\theta_{\pi\pi}}{Q^4}|F(Q^2)|^2\sigma(\gamma\gamma\rightarrow\pi\pi)(1+P_\gamma\cos 2\phi_{\pi\pi})$$

Primakoff cross section

related to α_π - β_π, calculate from χPT and other theories

Linear Polarization

- Linear polarization: coherent superposition of circular polarizations

→ Decay distributions with azimuthal dependence around γ polarization plane

→ Access to more physics observables

→ Helps constrain production mechanisms

example : cross section for pseudoscalar meson production

$$\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{pol}} = \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{unpol}} [1 + \Sigma P_\gamma \cos 2\phi]$$

P_γ: photon polarization Σ: beam asymmetry

can be measured in $K^+ \Lambda$, $K^+ \Sigma^0$, ...

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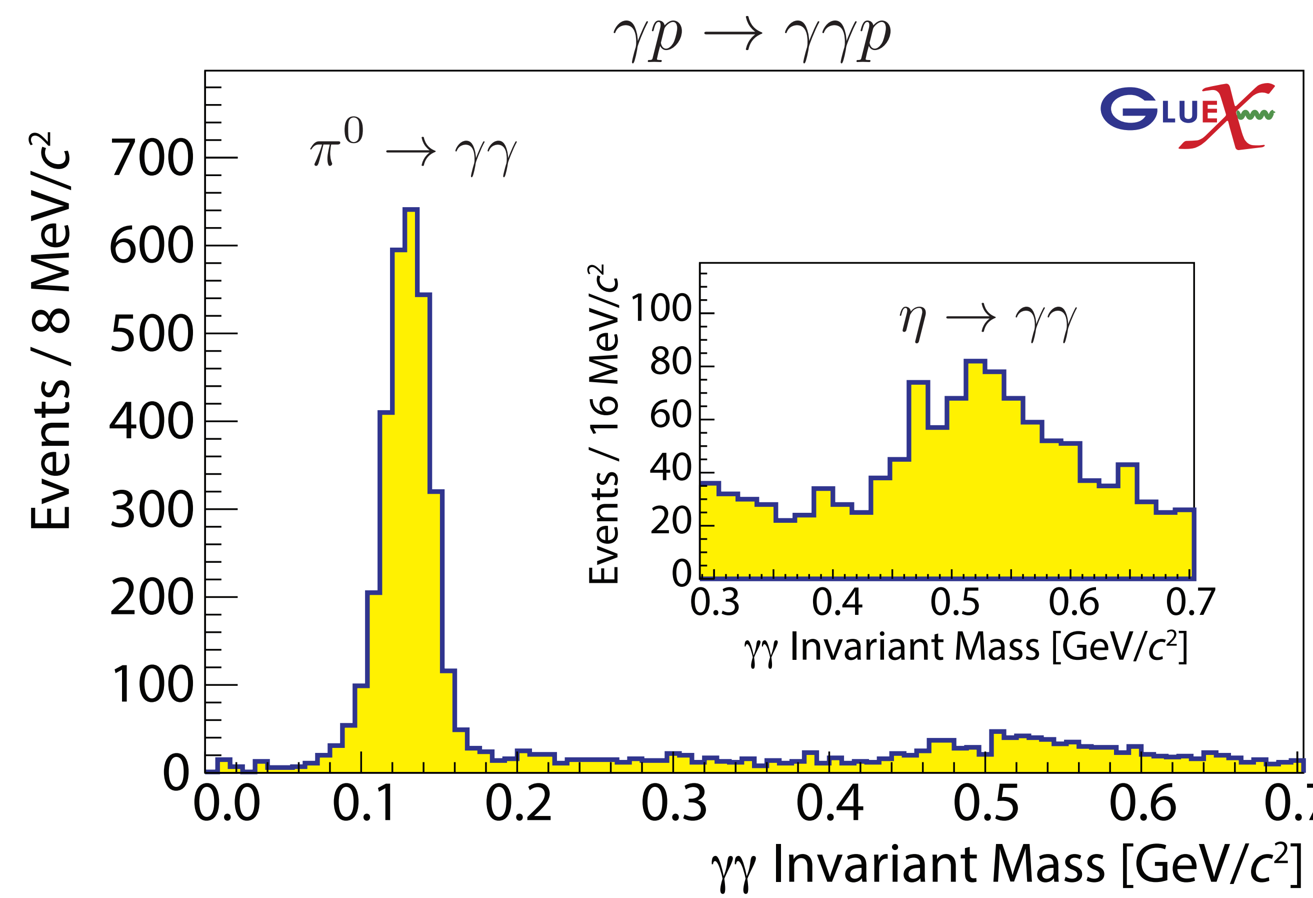
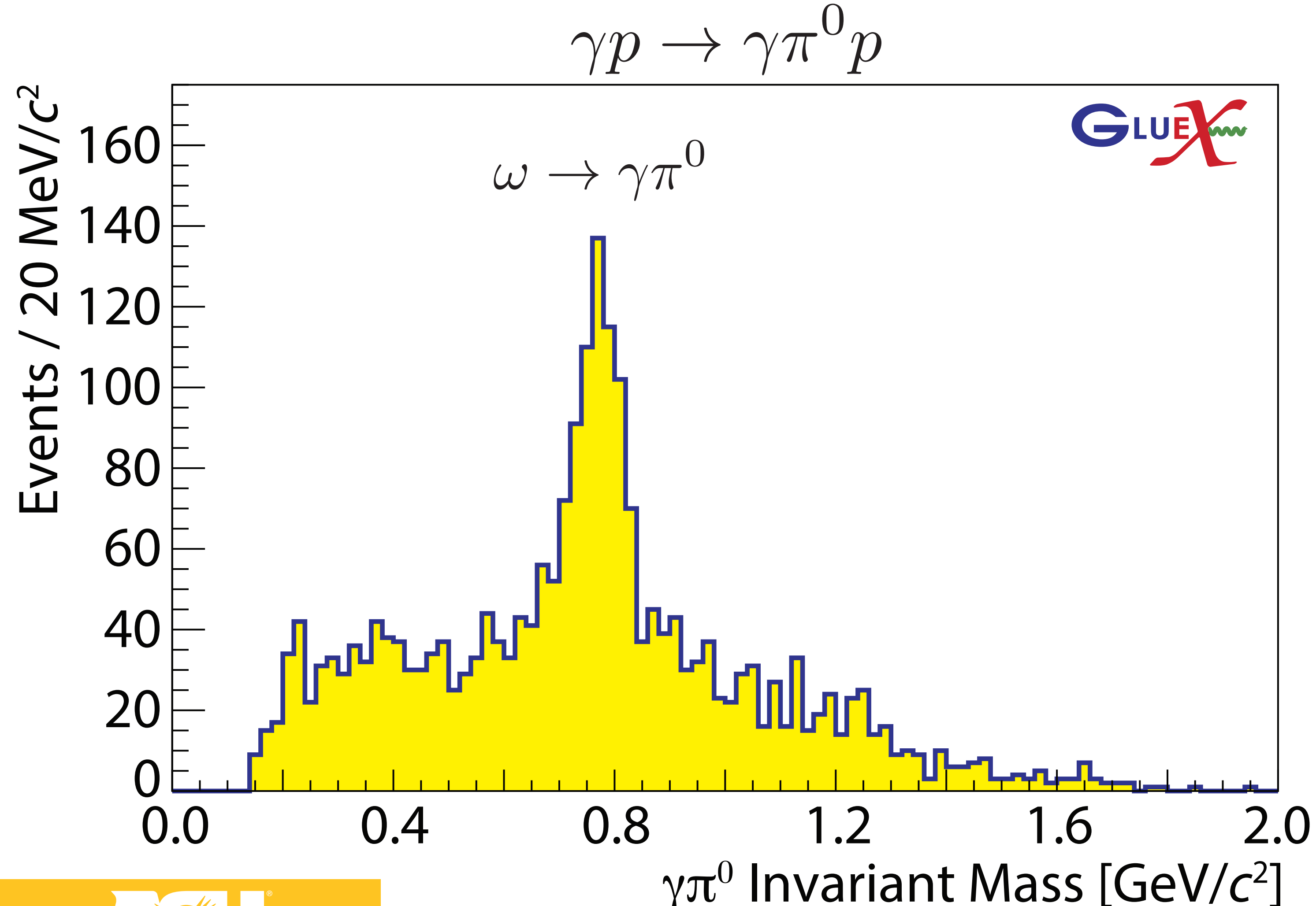
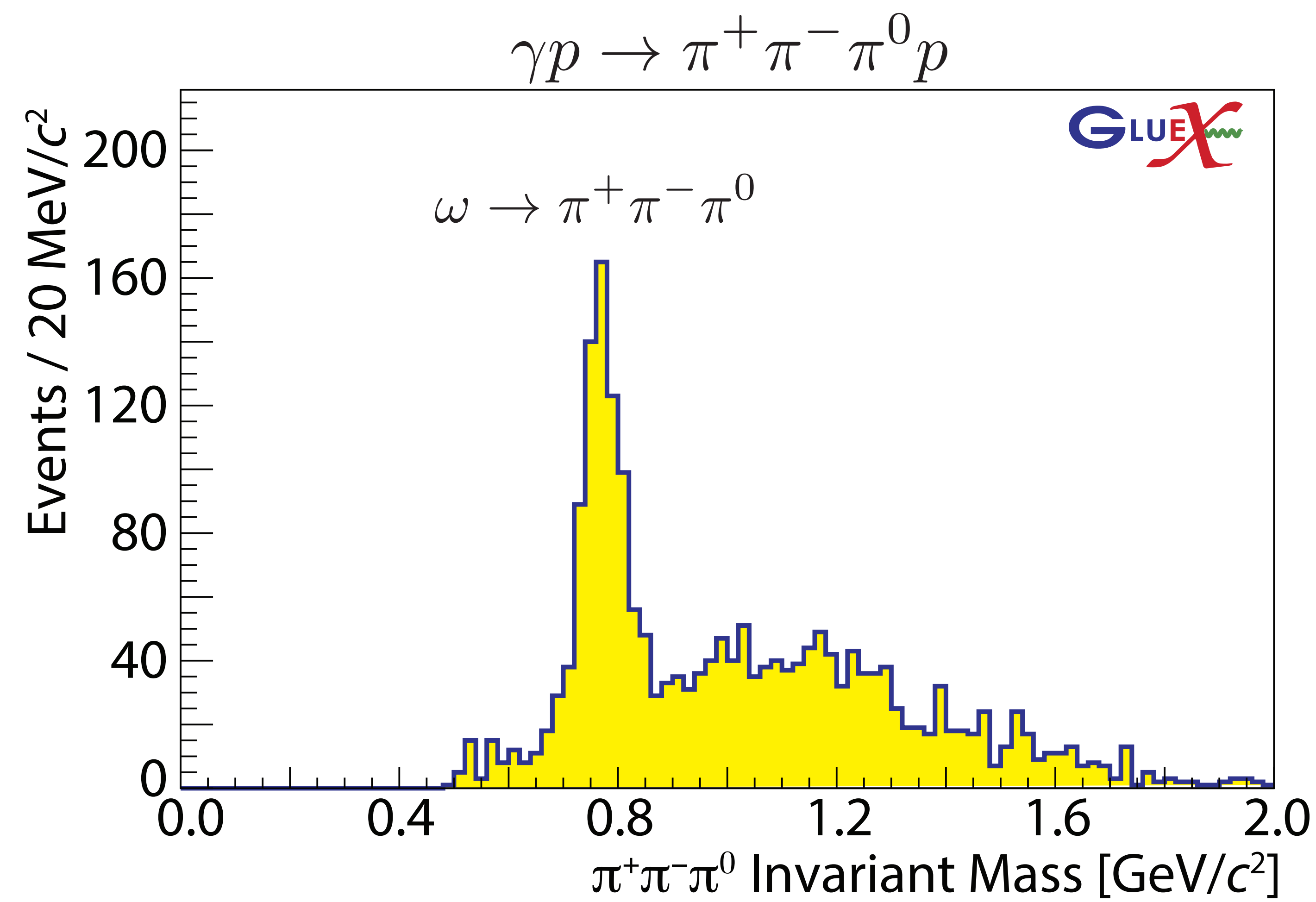
Further Results From Commissioning



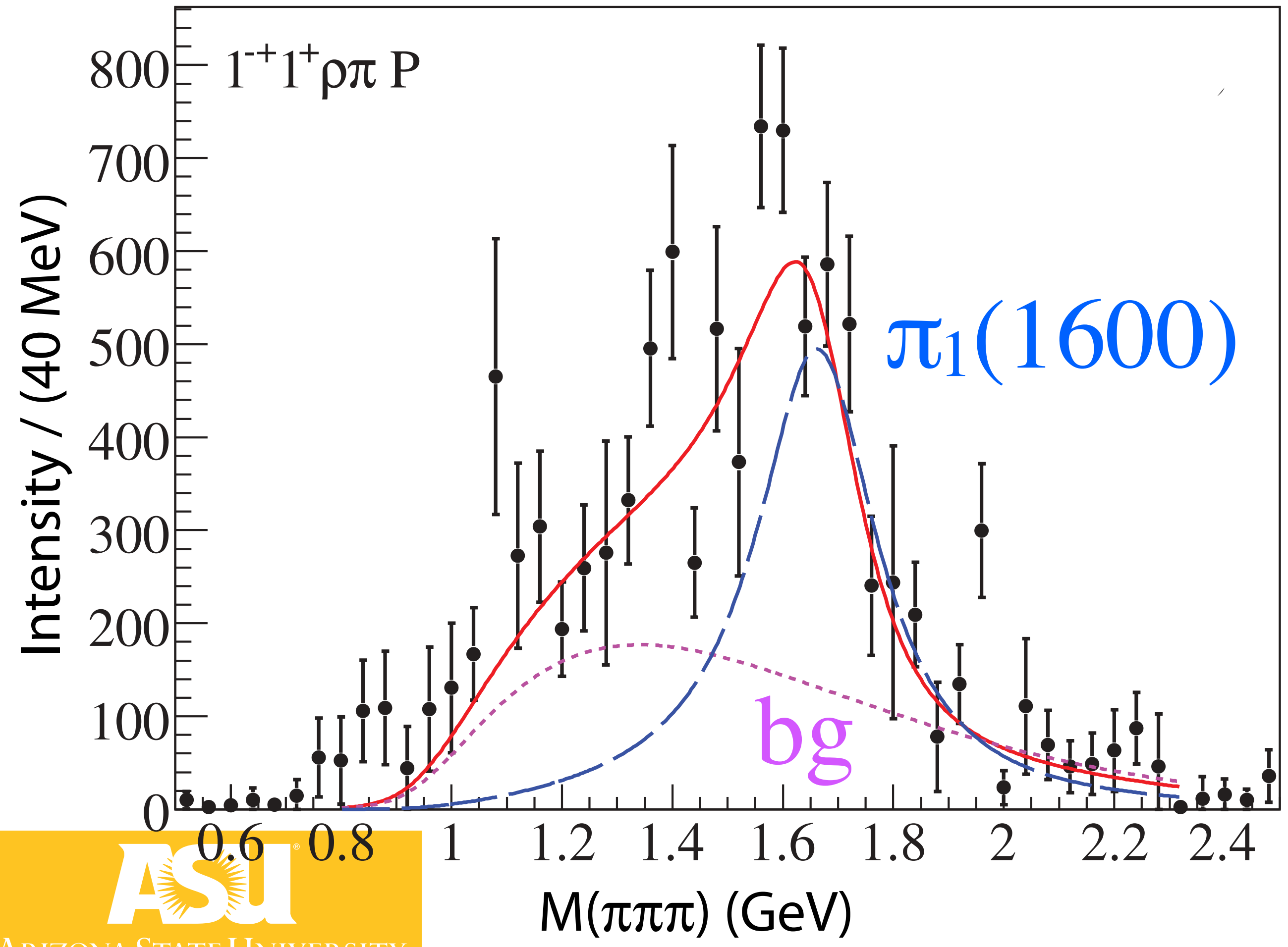


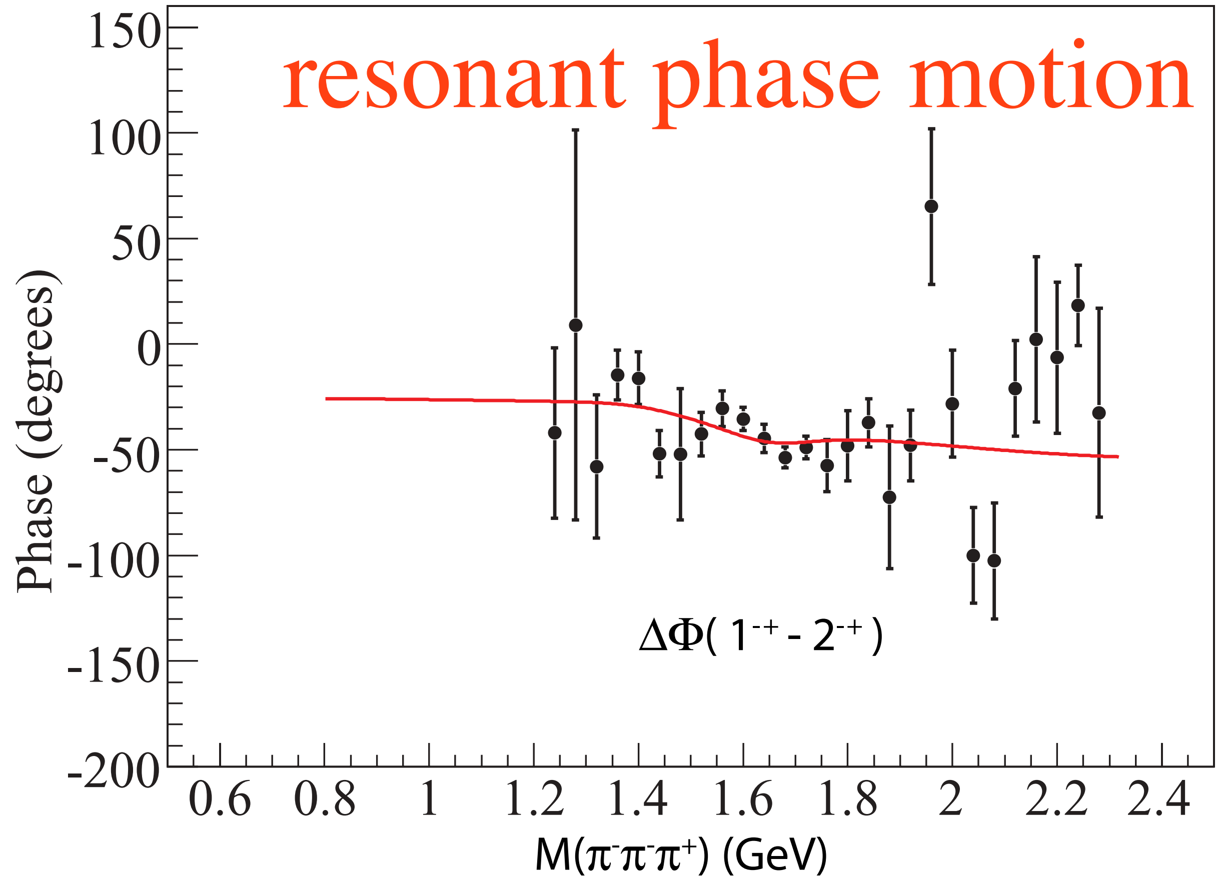


Experimental Results for Exotics

- Some reports on states with $J^{PC} = 1^{-+}$
- $\pi_1(1600)$ thought to be most established state
- Most recently COMPASS reported $\pi_1(1600)$ in $\pi^- + Pb \rightarrow \pi^+\pi^-\pi^- + Pb$

See C. Meyer, Y. Van Haarlem, PRC 82, 025208 (2010) for review of exotic mesons



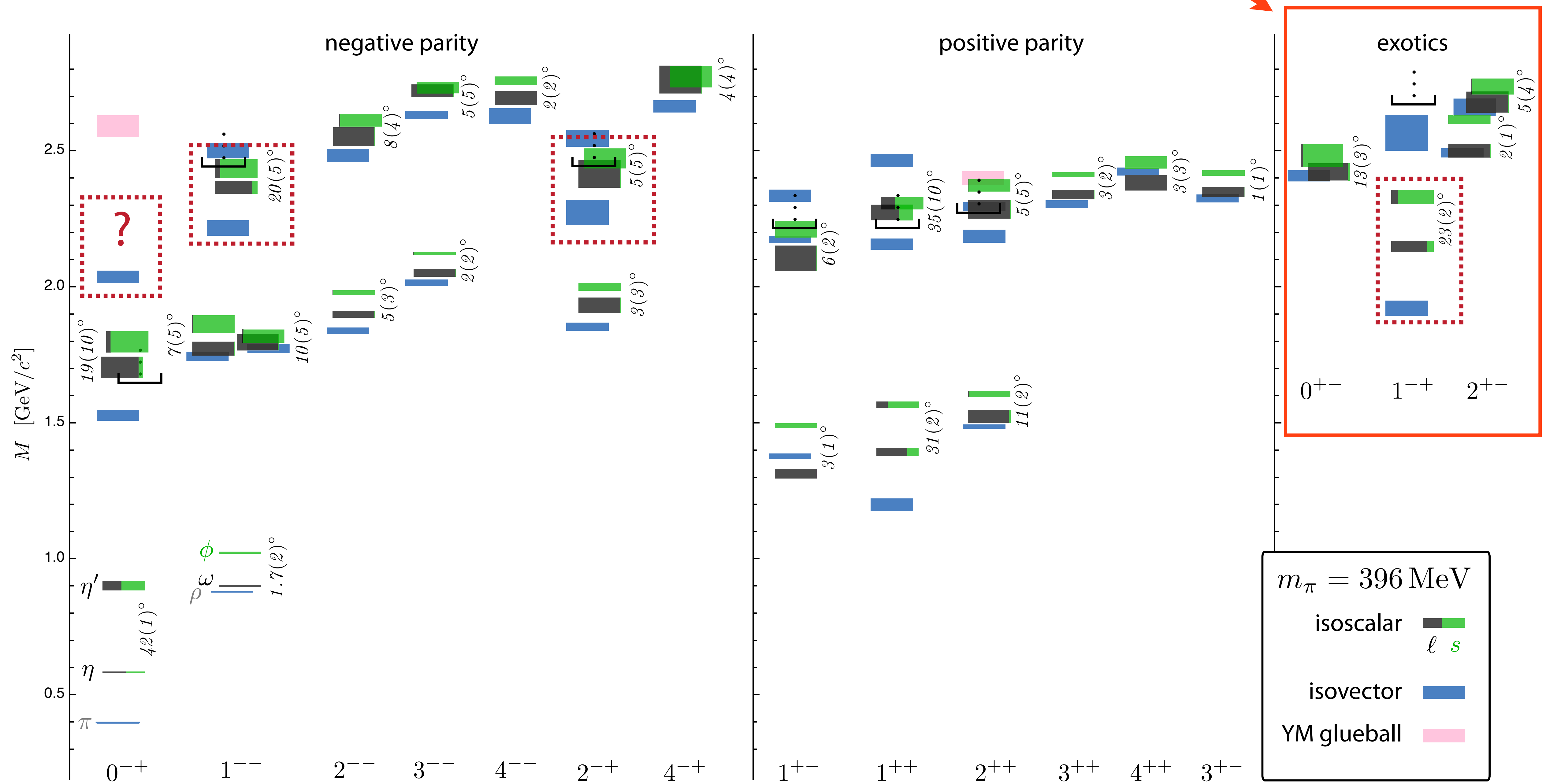


M. G. Alekseev et al.(COMPASS), PRL 104, 241803 (2010)

Lattice QCD Predictions

- Lattice QCD can give predictions on spectrum of mesons
- States that have strong overlap with exotic quantum numbers are predicted

Jozef Dudek, PRD 84, 074023 (2011)



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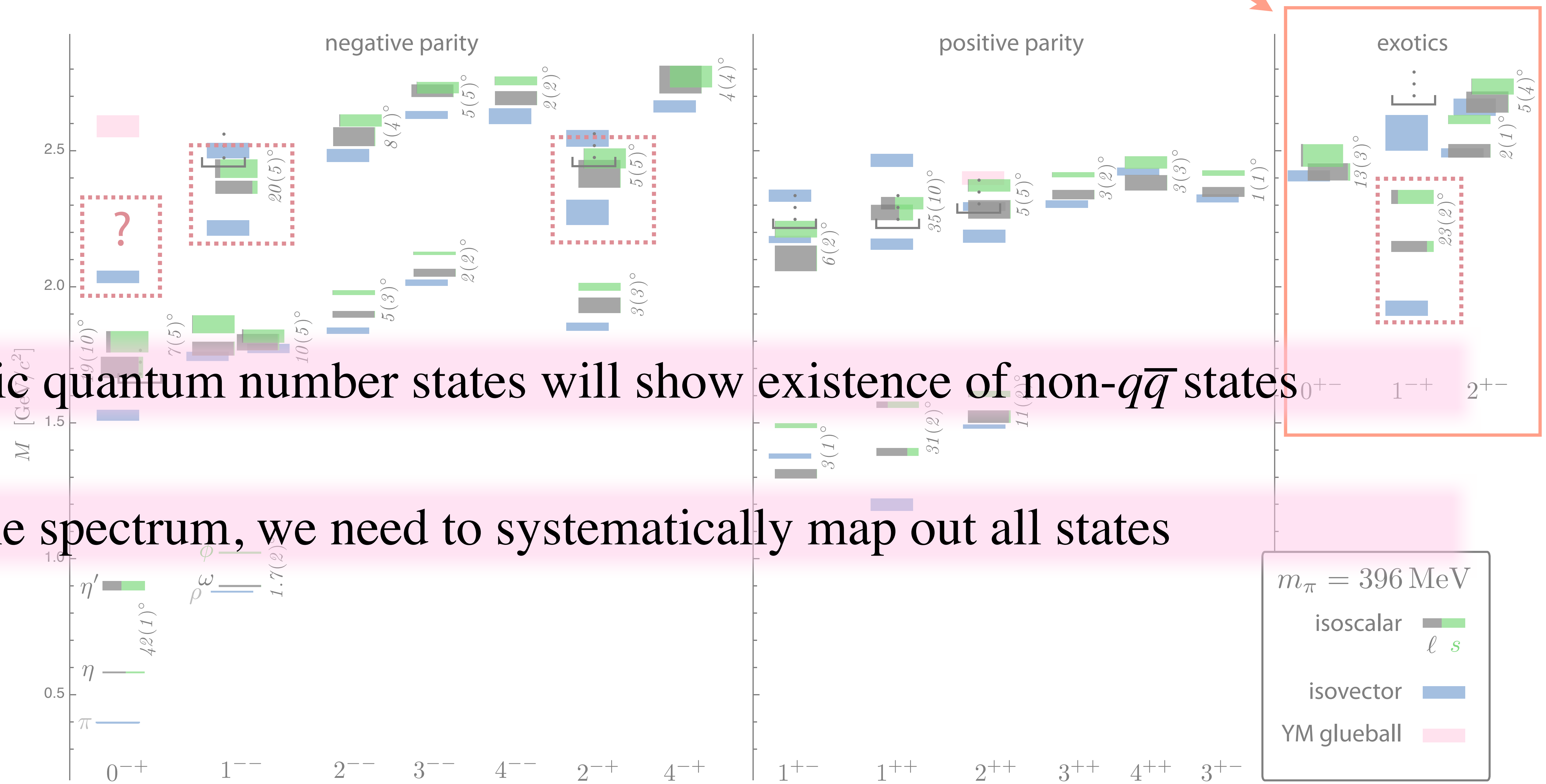

- Identifying exotic quantum number states will show existence of non-$q\overline{q}$ states
- To understand the spectrum, we need to systematically map out all states

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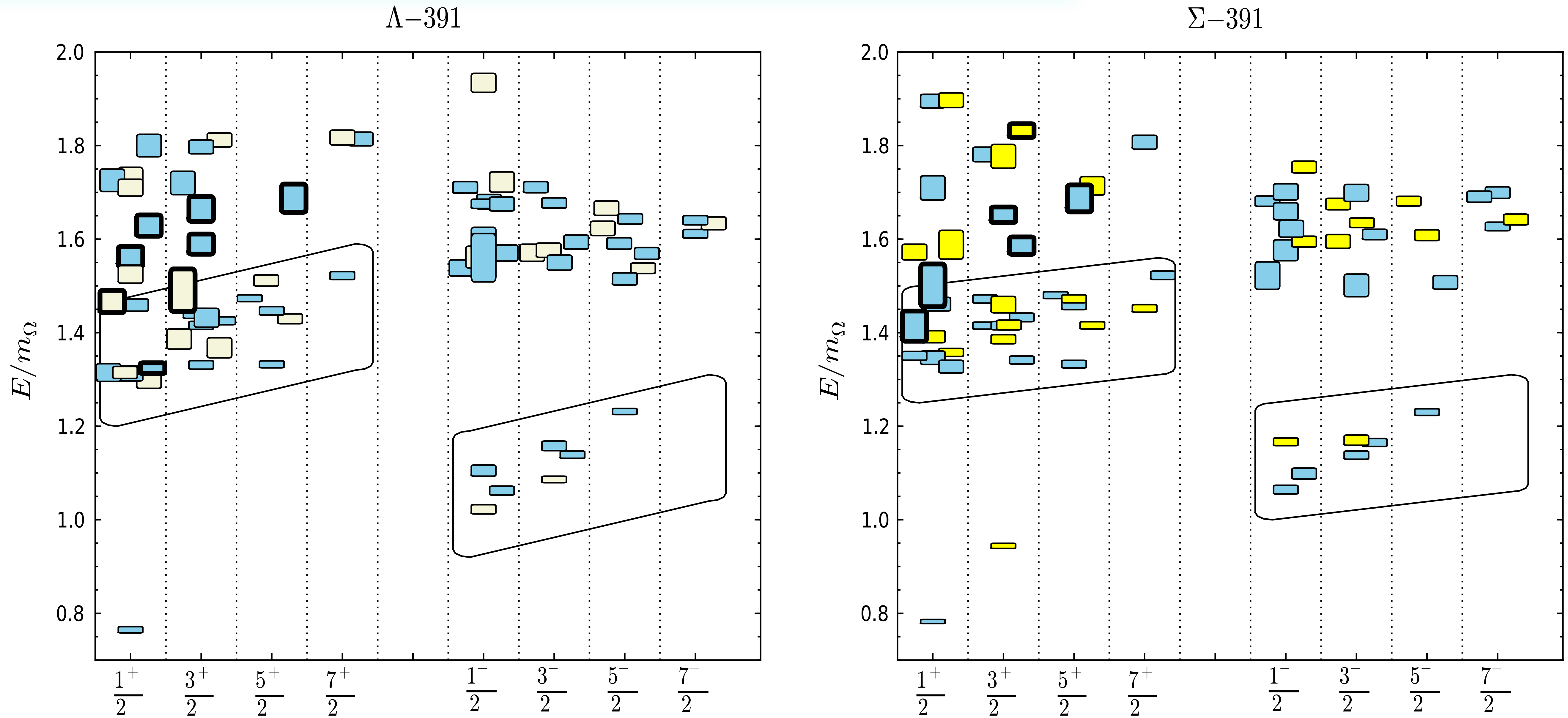
Lattice QCD Predictions

- Lattice QCD can predict spectrum of baryons
- Most states not identified by experiment yet



flavor singlet

flavor octet

flavor decouplet

R. Edwards *et al*.,
PRD 87, 054506 (2013)

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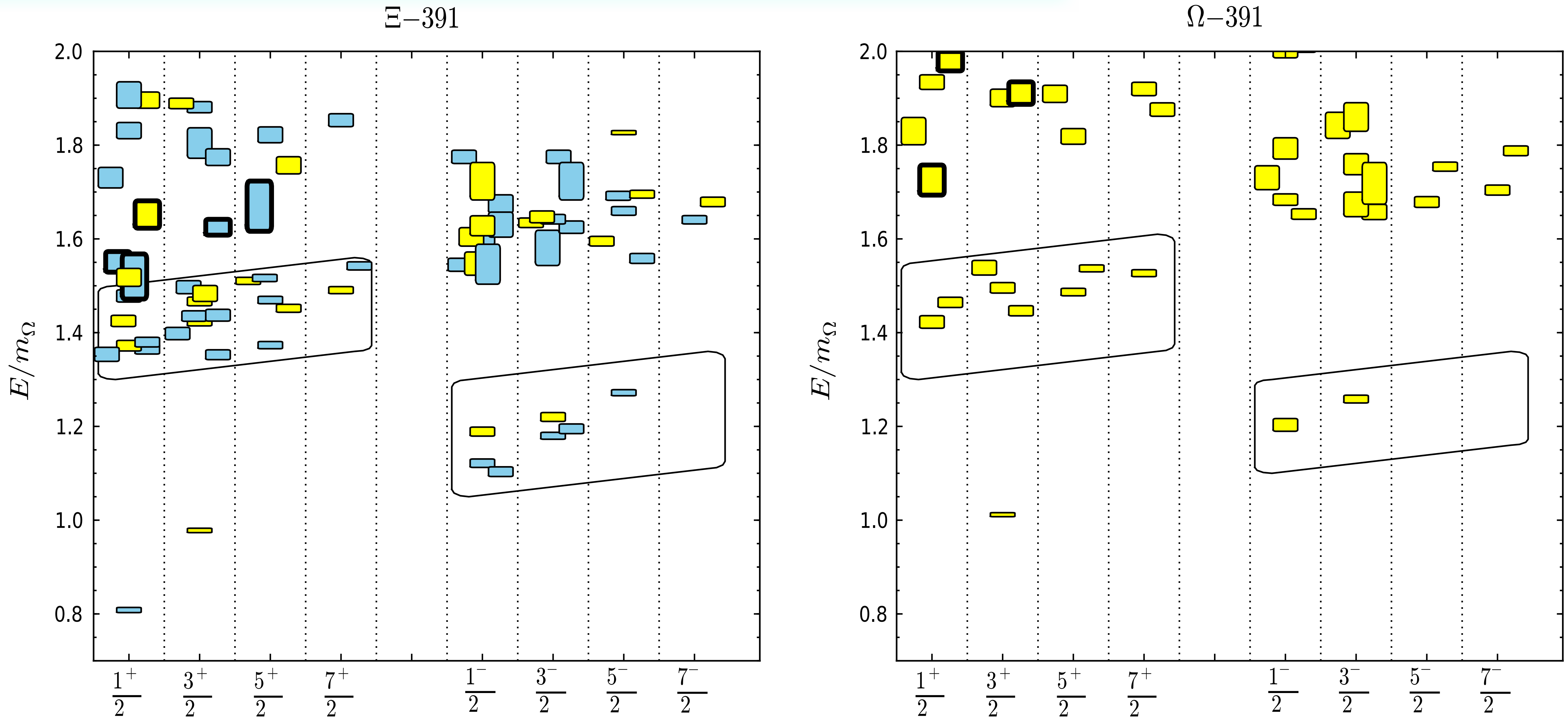

R. Edwards *et al.*,
PRD 87, 054506 (2013)

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Baryons with S = -3

- Only 4 known $\Omega^{(*)}$ states
- Never detected in photoproduction - need $\gamma + p \rightarrow K^+ K^+ K^0 \Omega^-$
- First excited state in PDG is $\Omega(2250)$ - excitation of >550 MeV/c^2
- Rates, acceptance expected to be extremely small at GlueX
- If we can tag vertices of $\Xi^- \rightarrow \Lambda\pi^-$ and $\Lambda \rightarrow p\,\pi^-$, we can discriminate most backgrounds

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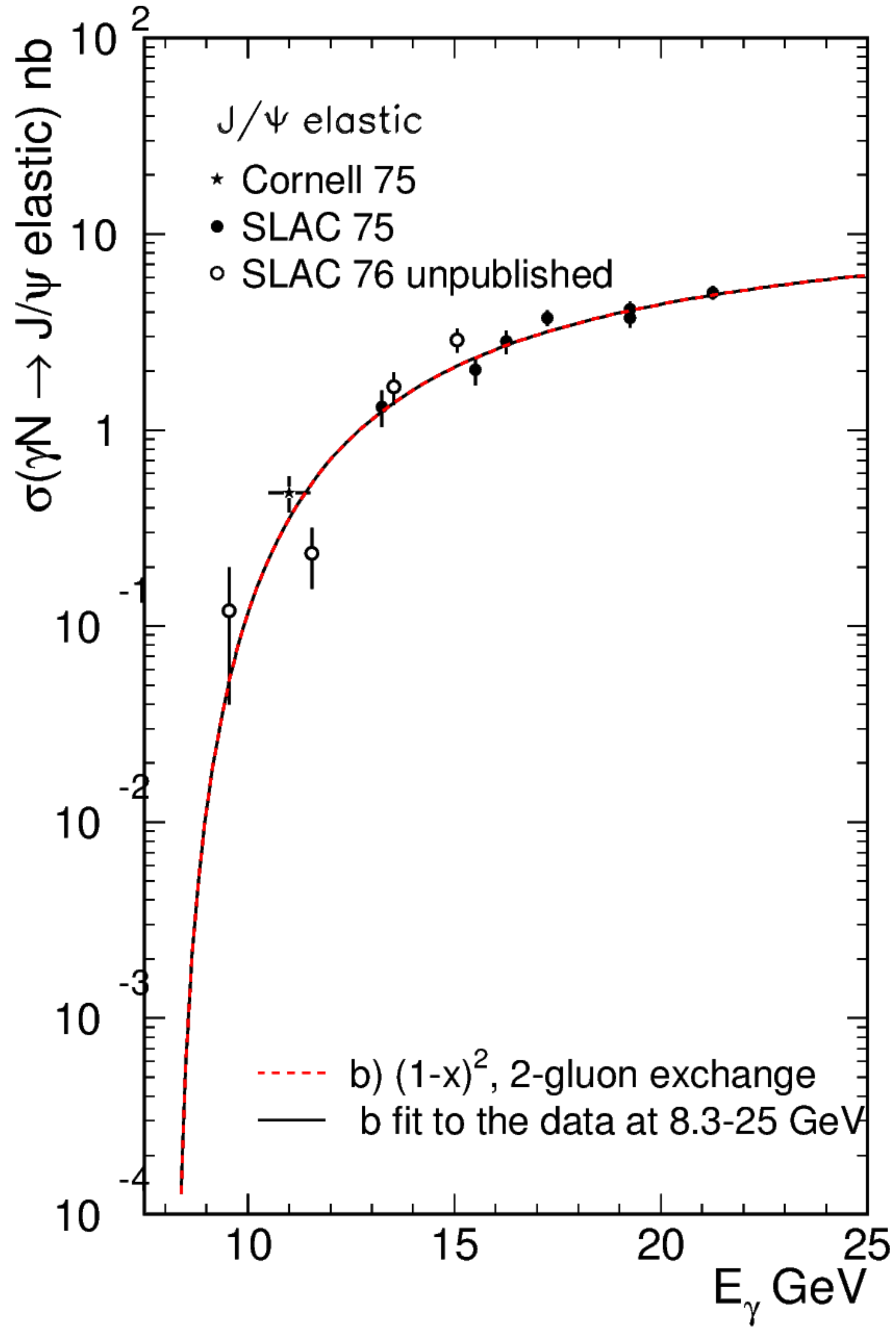
Charm Production

- Charm production requires much more energy
- Threshold for $\gamma + p \rightarrow J/\psi + p$ is $E_\gamma = 8.2$ GeV
- Open charm: $\gamma + p \rightarrow D^0 \Lambda_c^+$ at $E_\gamma = 8.7$ GeV
- Rates will be very small
- Current estimates are ~400 J/ψ events in 2 months of running (study by Kamal Seth, Northwestern University)



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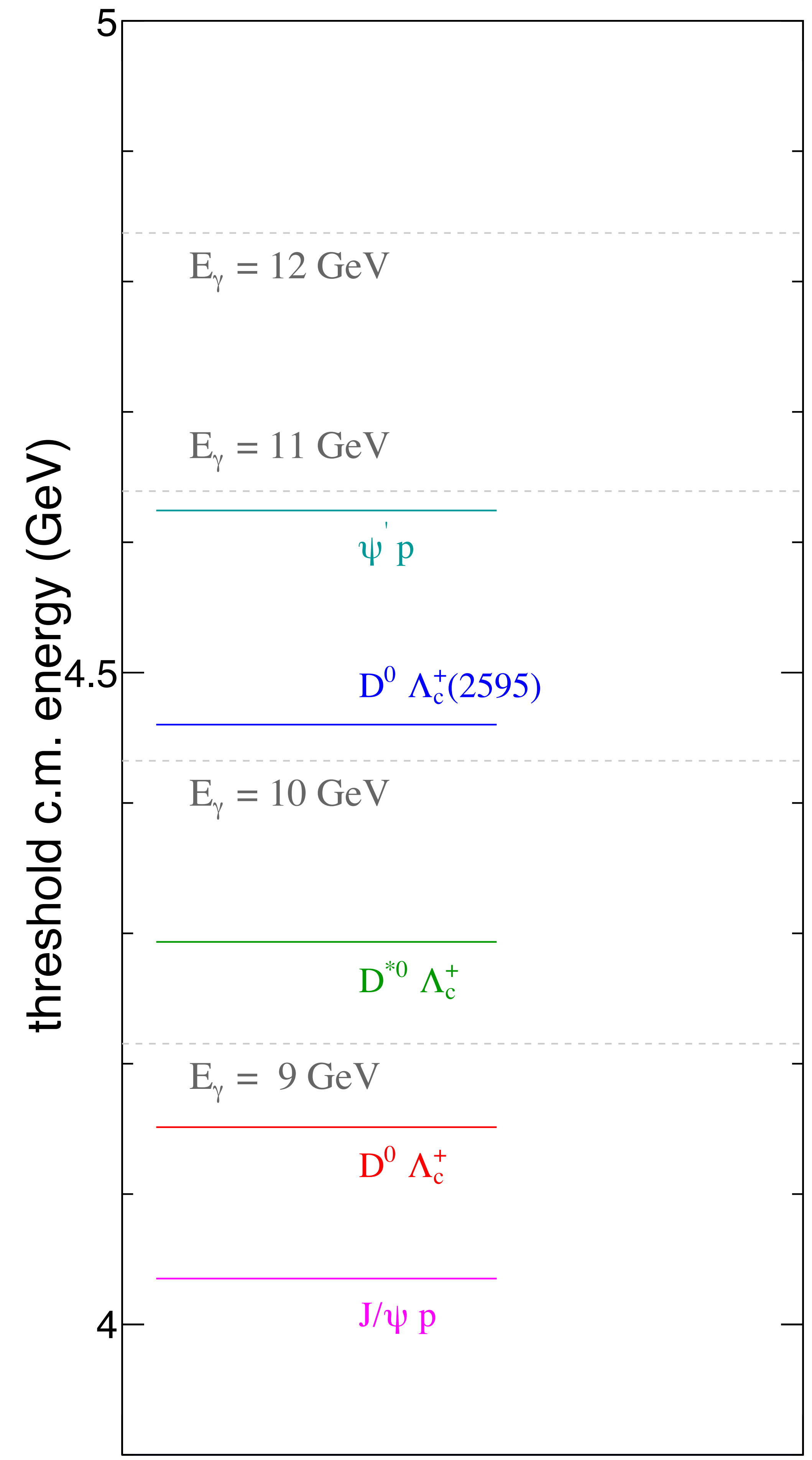
P_c^+ States

- Discovered by LCHb in $\Lambda_b \to K^- + J/\psi + p$[1]
- Final state of $J/\psi + p$, masses are above open charm threshold
- Photoproduction cross section, branching fraction to $J/\psi + p$ unknown
- Photon flux, polarization will be small at these energies for GlueX



1. R. Aaij *et al*. (LHCb), arXiv hep-ex:1507.03414

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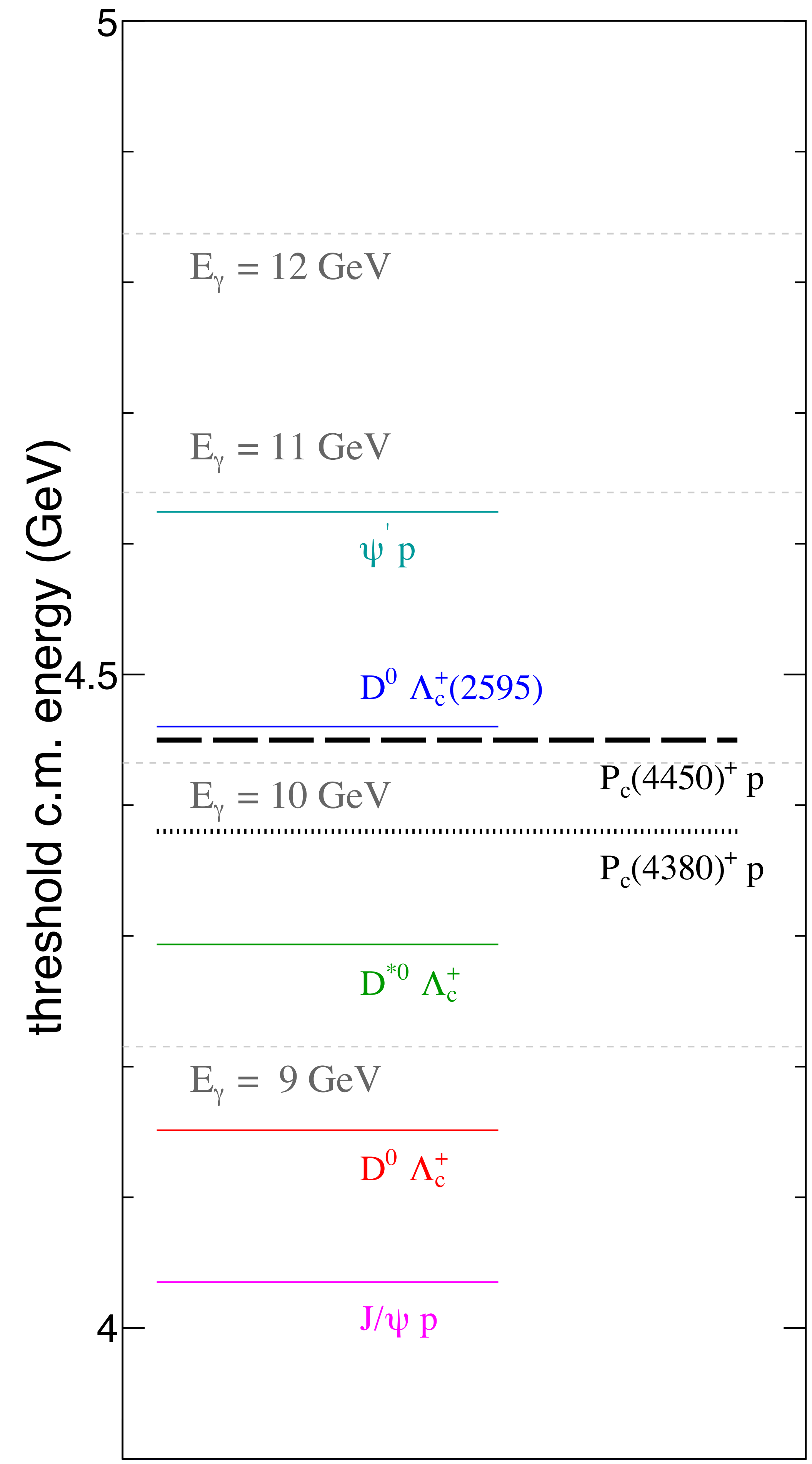

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1. R. Aaij *et al*. (LHCb), arXiv hep-ex:1507.03414