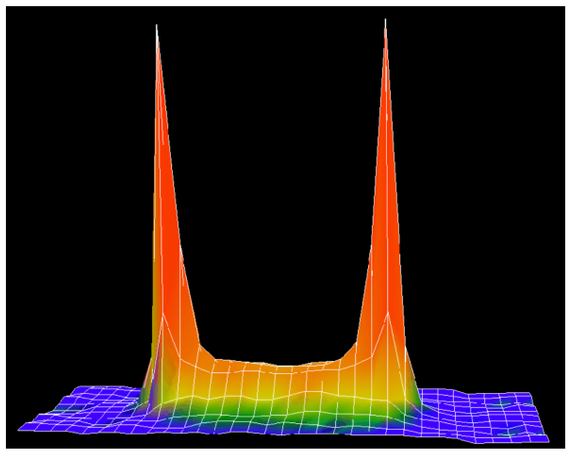
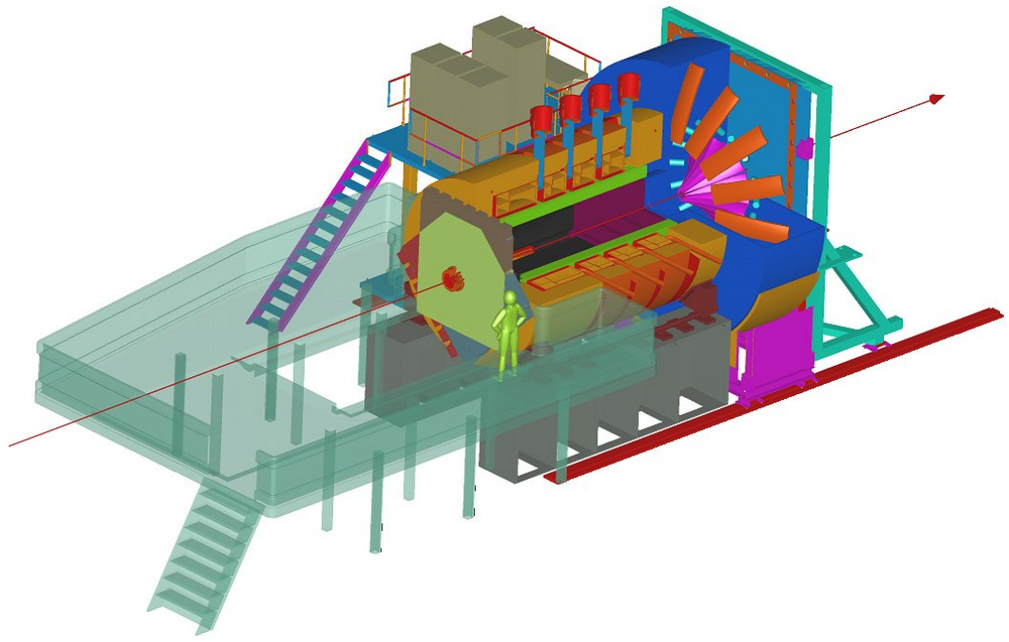
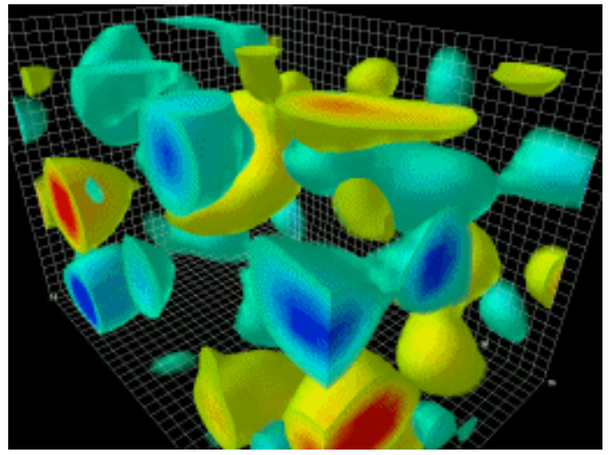






First Physics Results from the GlueX Experiment

Dr. Zisis Papandreou

University of Regina

CAP Congress
Kingston, ON
May 30, 2017

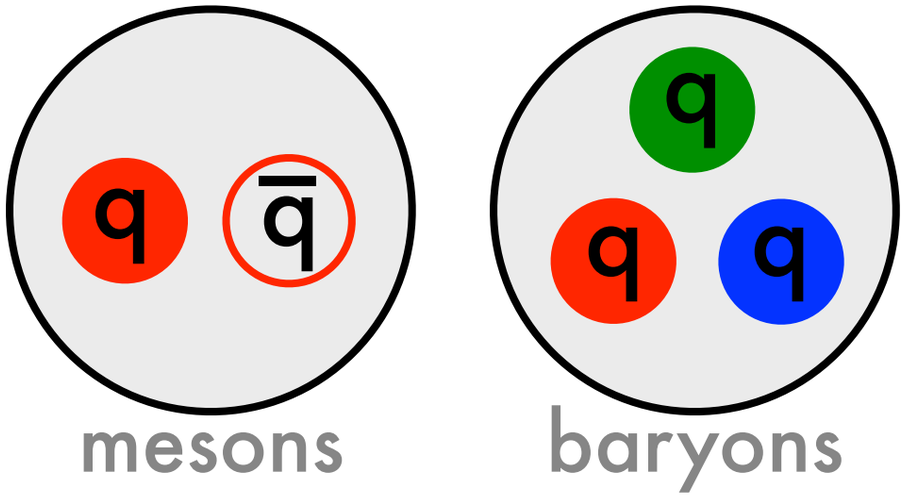
GLUEX Excitations Experiment

Jefferson Lab
EXPLORING THE NATURE OF MATTER

Experimental Hall D

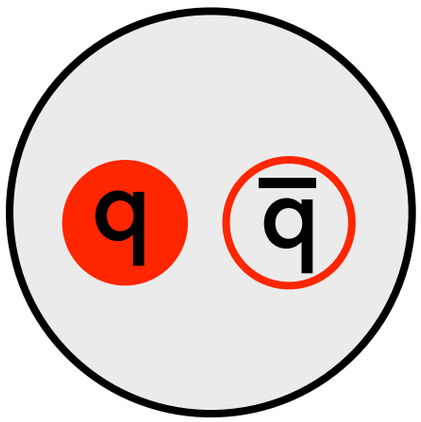
Confined States of Quarks and Gluons

Confined States of Quarks and Gluons

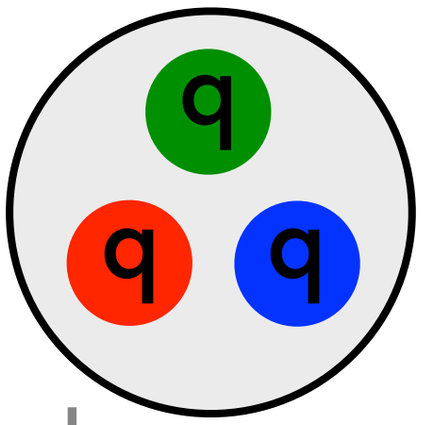


QCD predicts more types of states than just mesons & baryons

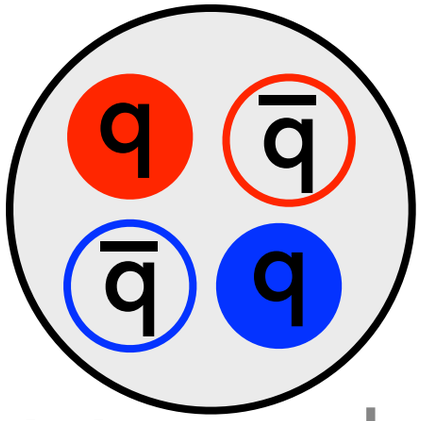
Confined States of Quarks and Gluons



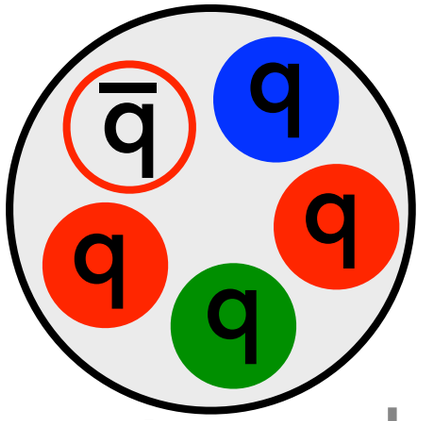
mesons



baryons



tetraquark



pentaquark

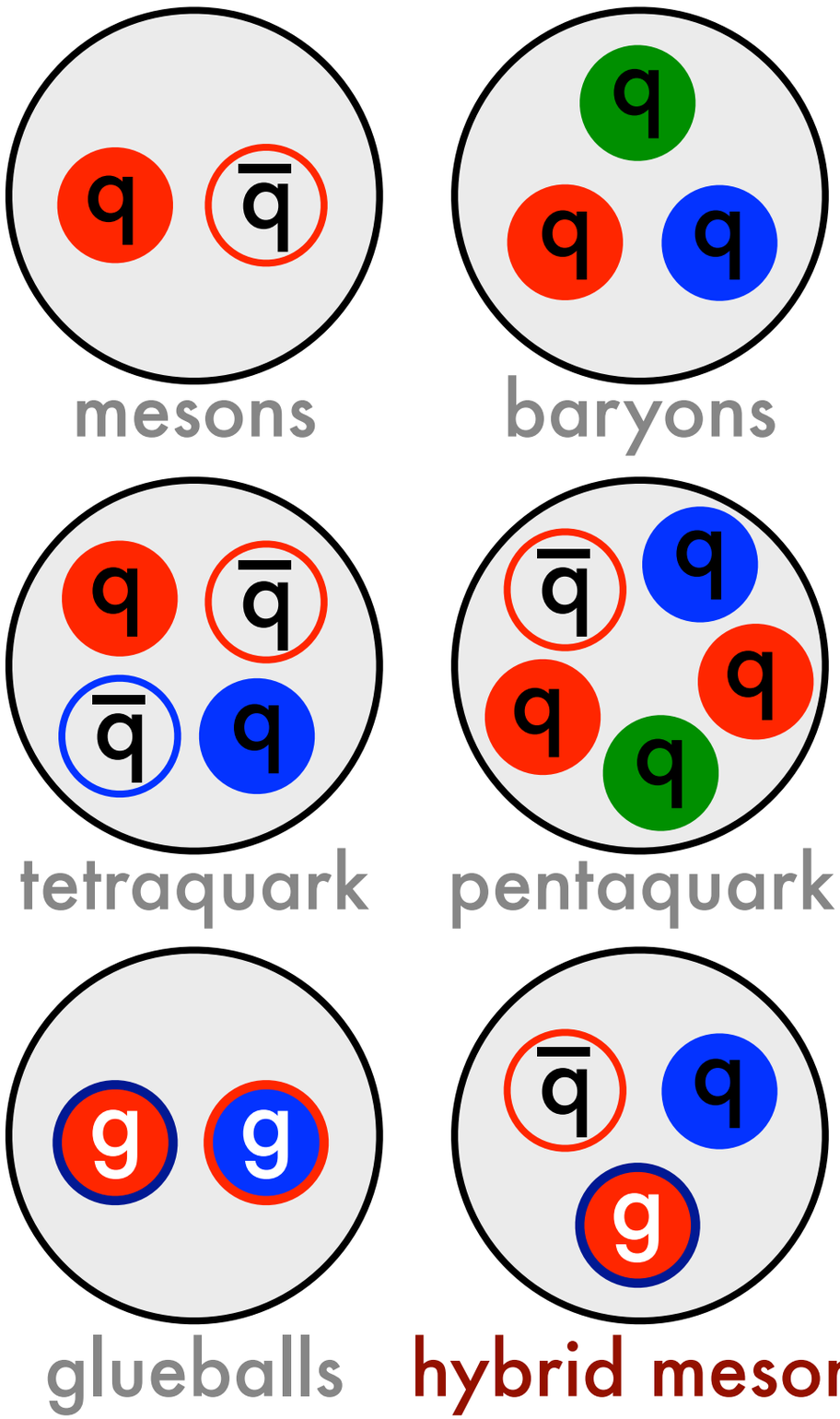
QCD predicts more types of states than just mesons & baryons

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

... Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. ... **Phys.Let.8 (1964) 214**

Confined States of Quarks and Gluons



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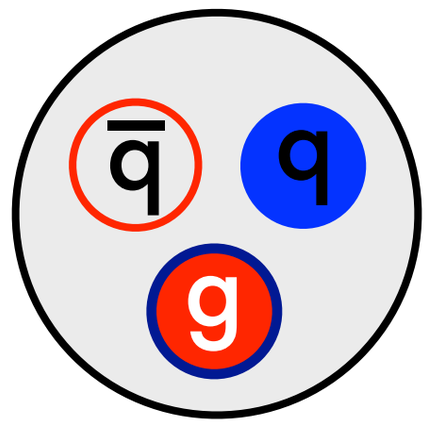
Can we observe explicit gluonic degrees of freedom in nature's bound states?

Hadron Spectrum

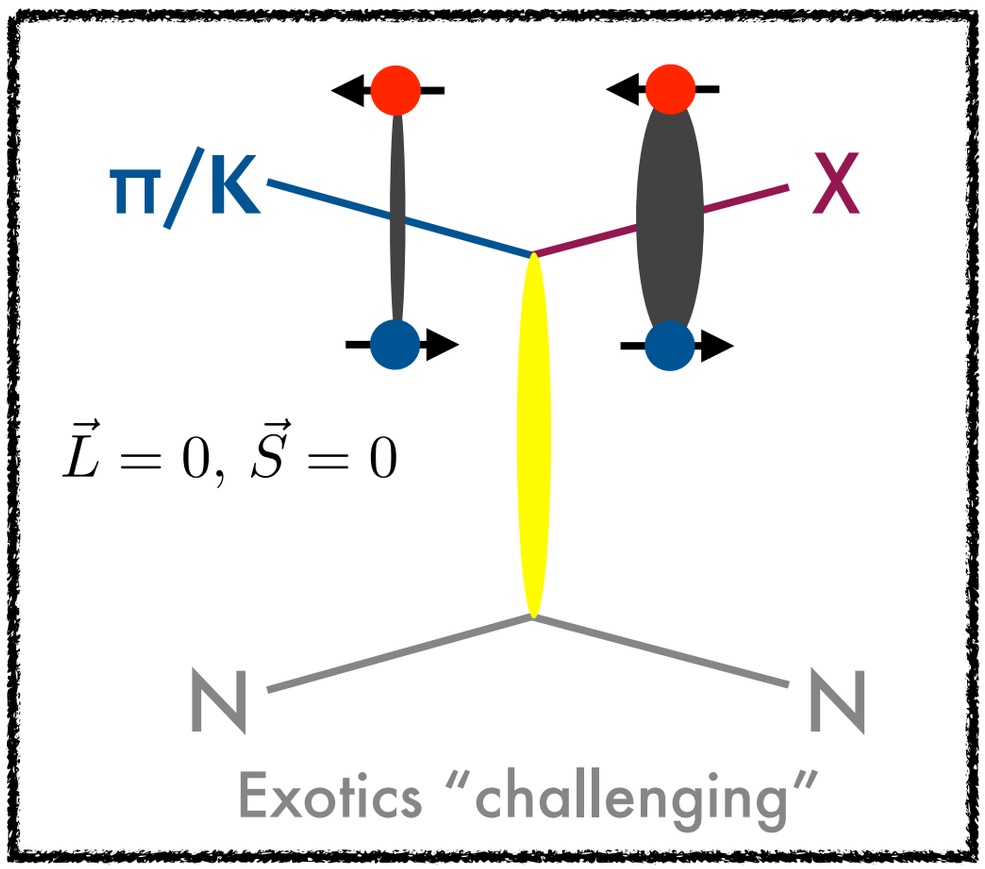
- QCD Lagrangian has quark and gluon d.o.f. → spectrum of hadrons?
- Gluon-gluon interactions give rise to states with **gluonic excitations**.
- **Lattice QCD** predicts a rich spectrum of hybrid mesons.



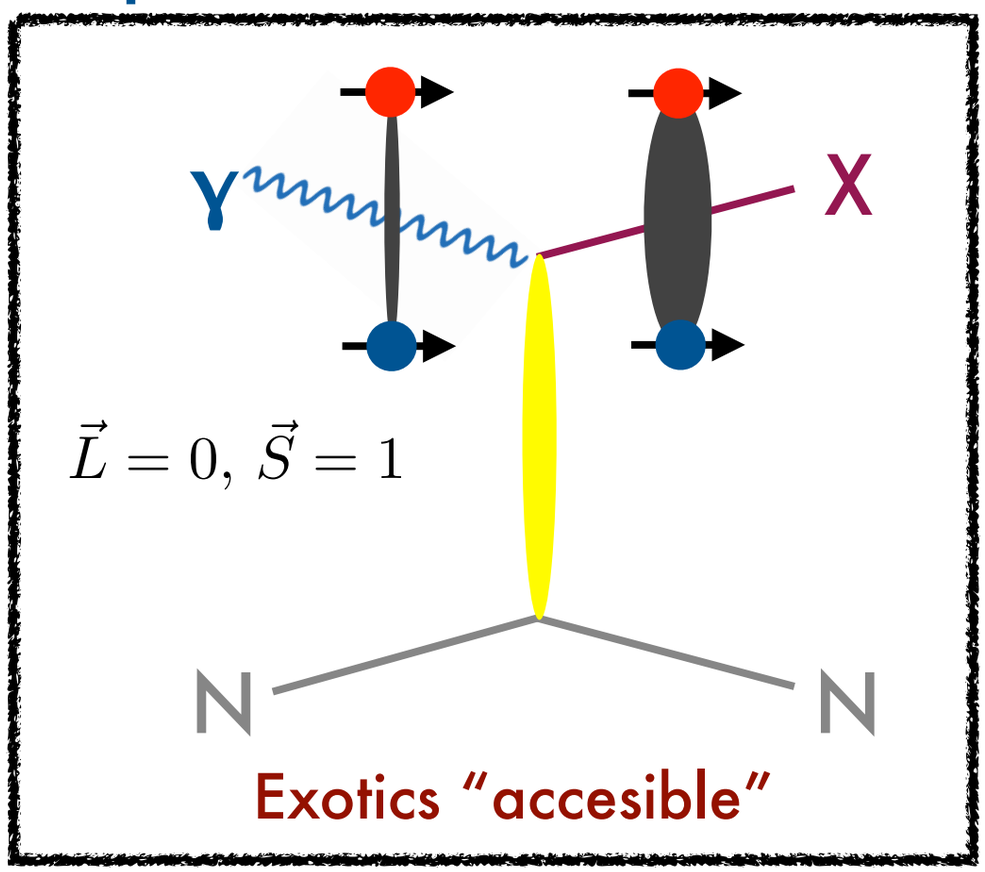
- A subset of these has an distinct signature: **"exotic" J^{PC}**, not possible from the simple, non-relativistic quark model.

Production of Hybrid Mesons

Combine the QN $J^{PC} = 1^{+-}, 1^{-+}$ of the excited gluonic field with those of the quarks:



Exotics "challenging"



Exotics "accesible"

Conventional $J^{PC} = 0^{-+}, 1^{+-}, 1^{++}, 1^{--}, 2^{-+}, \ldots$

Exotic $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

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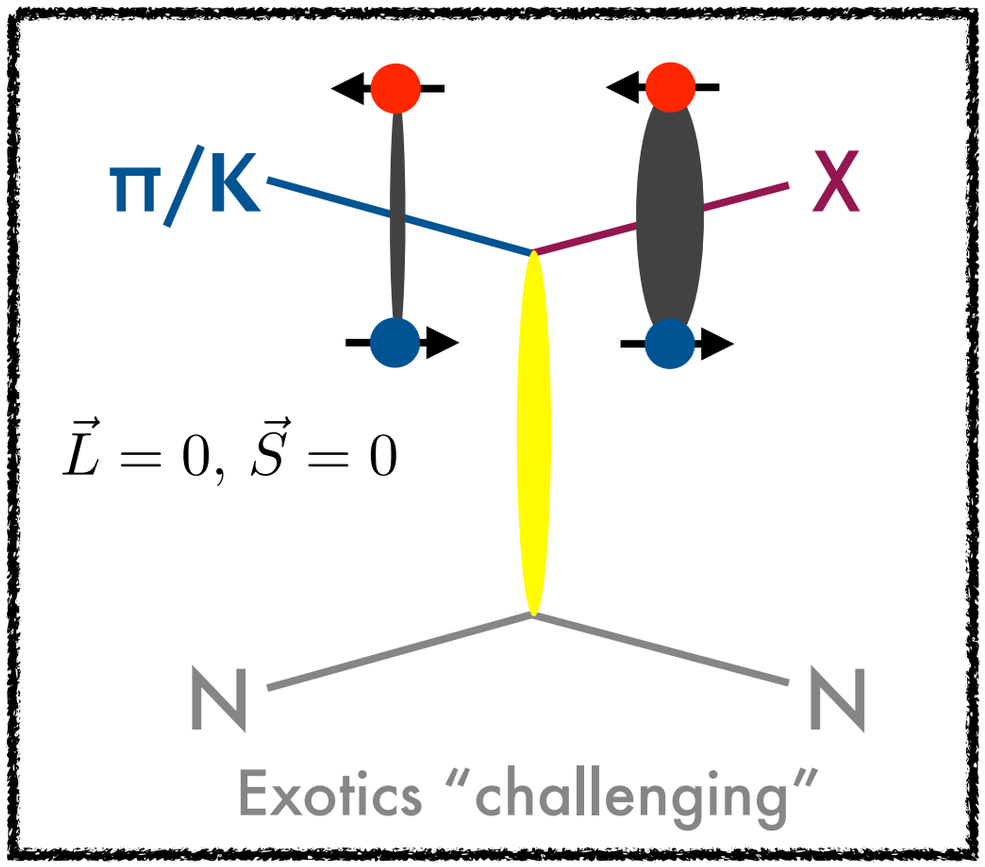
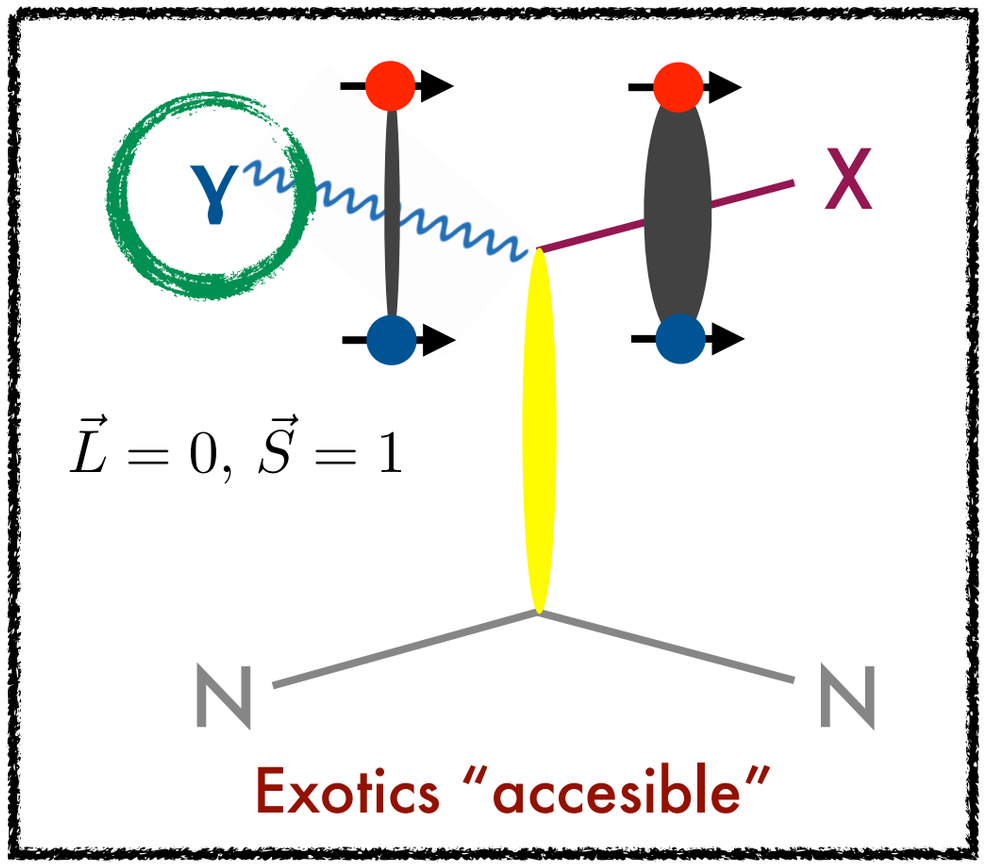
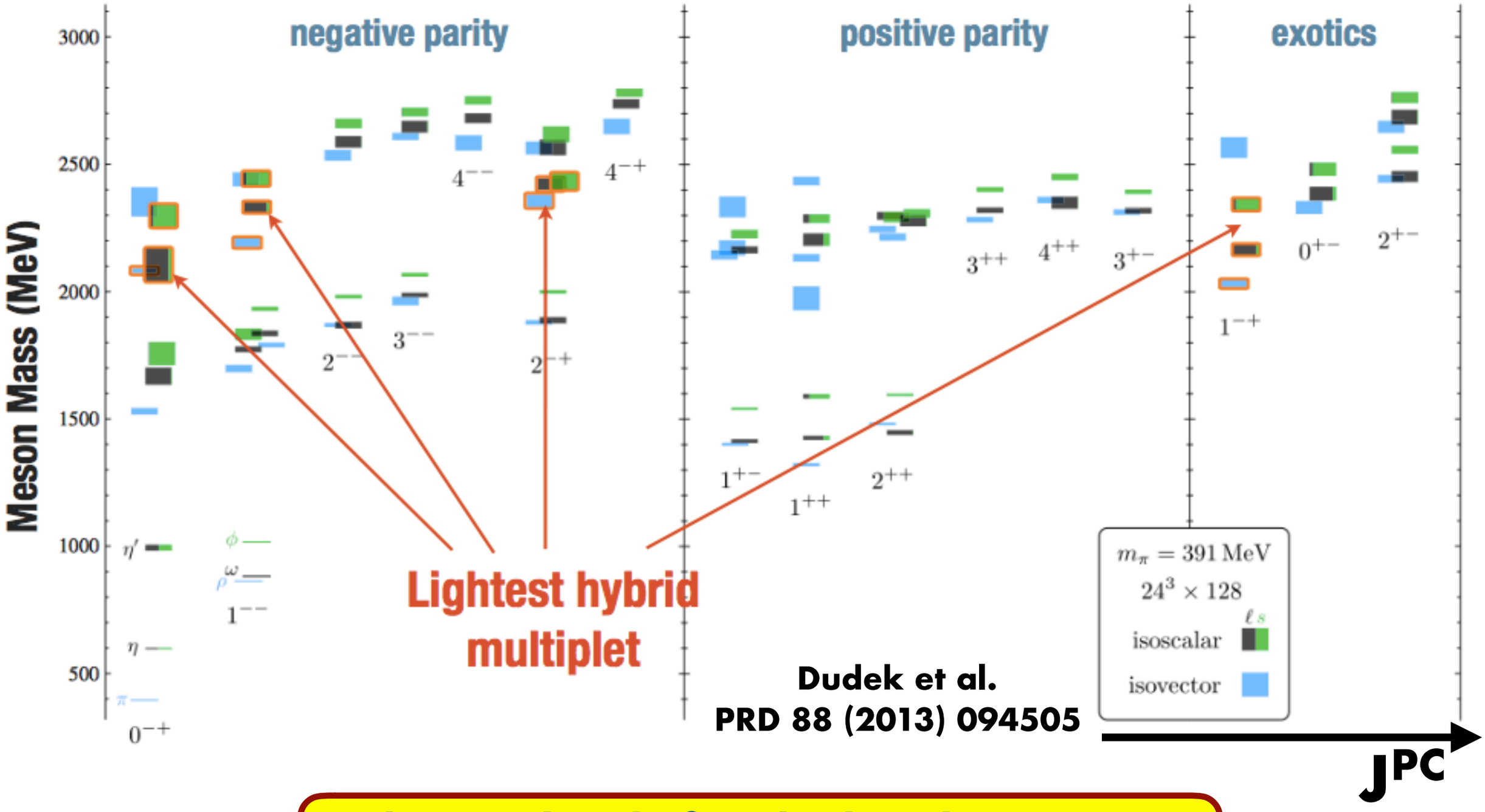




Conventional $J^{PC} = 0^{-+}, 1^{+-}, 1^{++}, 1^{--}, 2^{-+}, \ldots$

Exotic $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

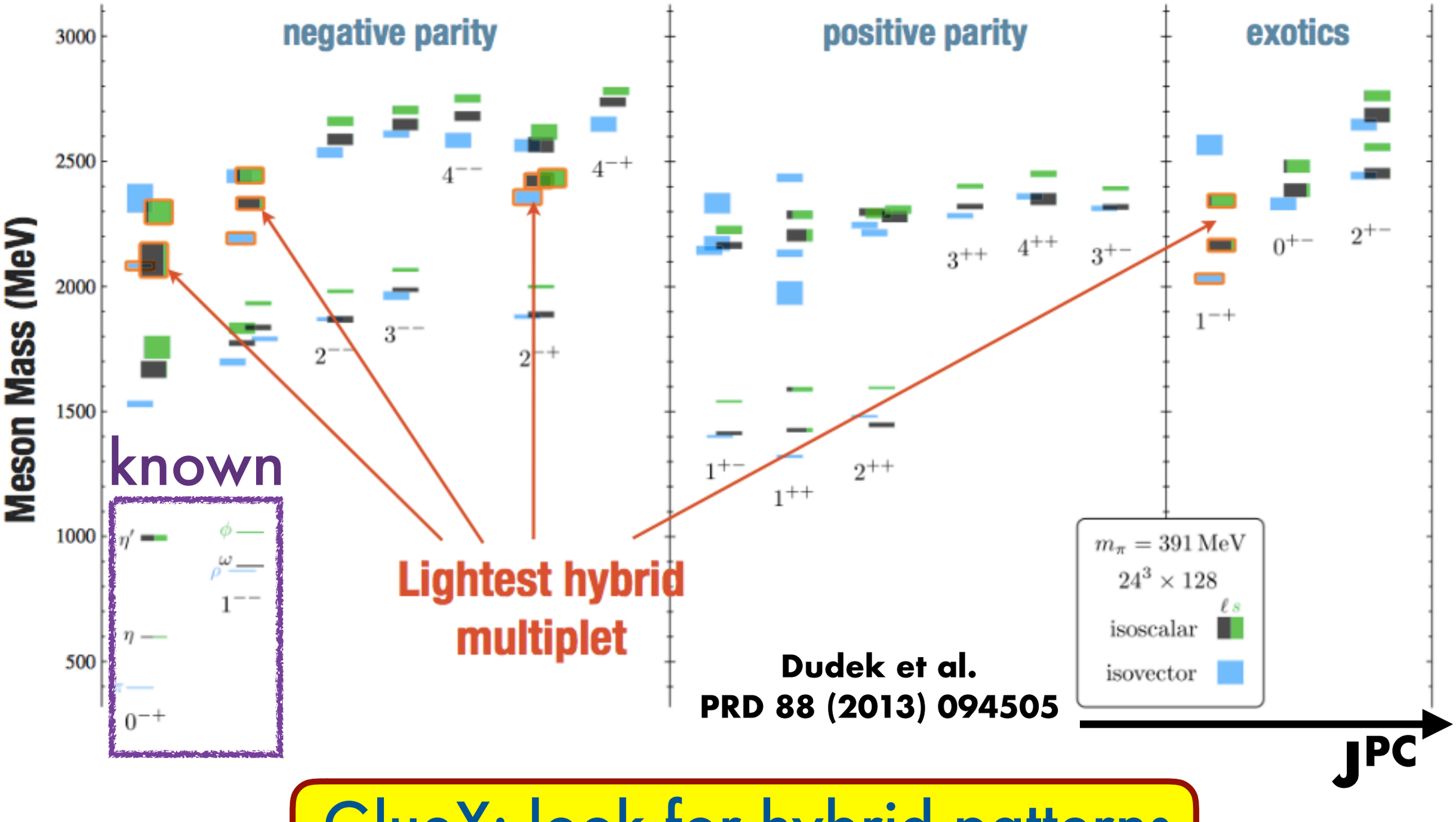
LQCD Full Spectrum



Dudek et al.
PRD 88 (2013) 094505

GlueX: look for hybrid patterns

LQCD Full Spectrum



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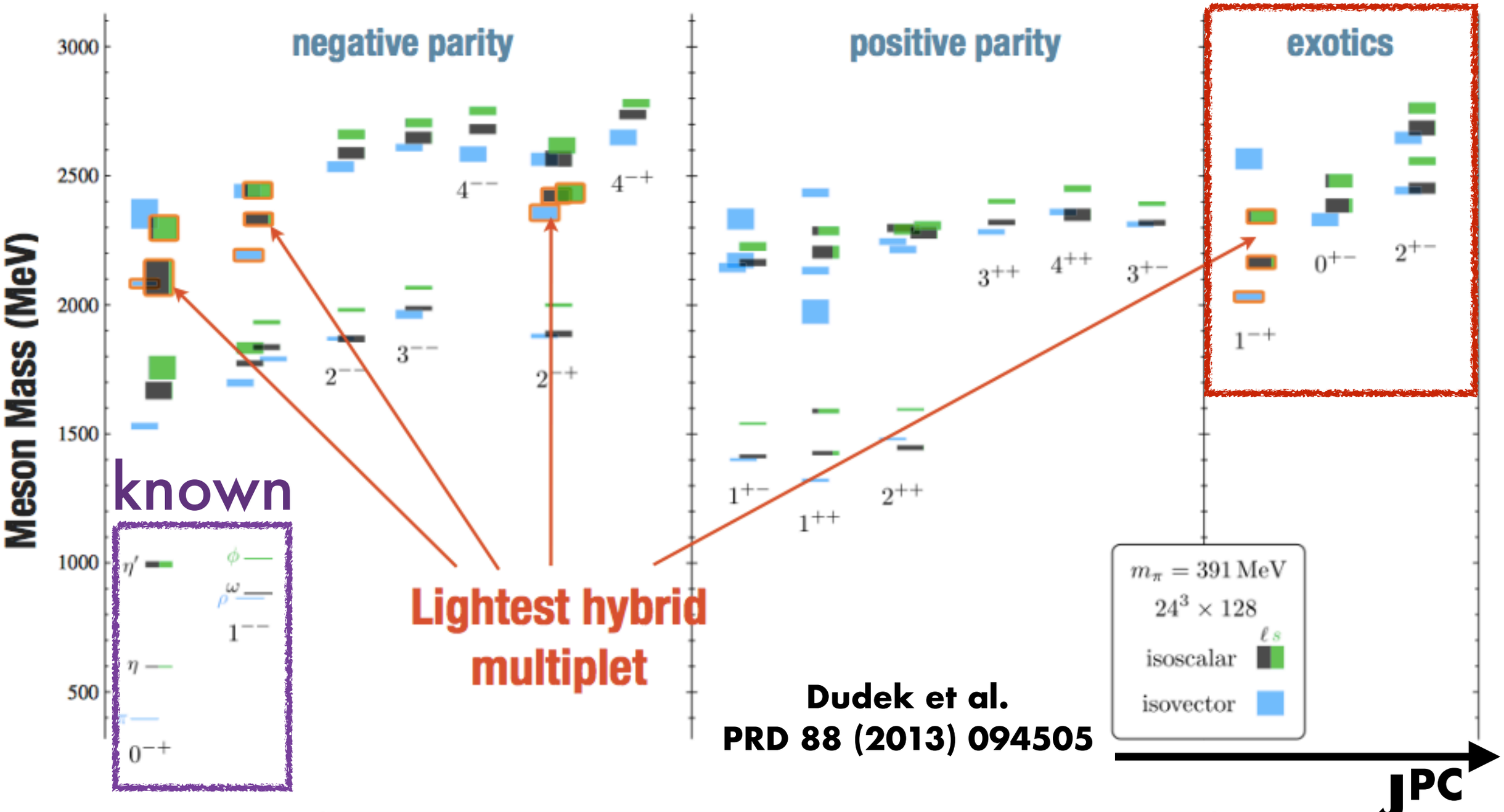

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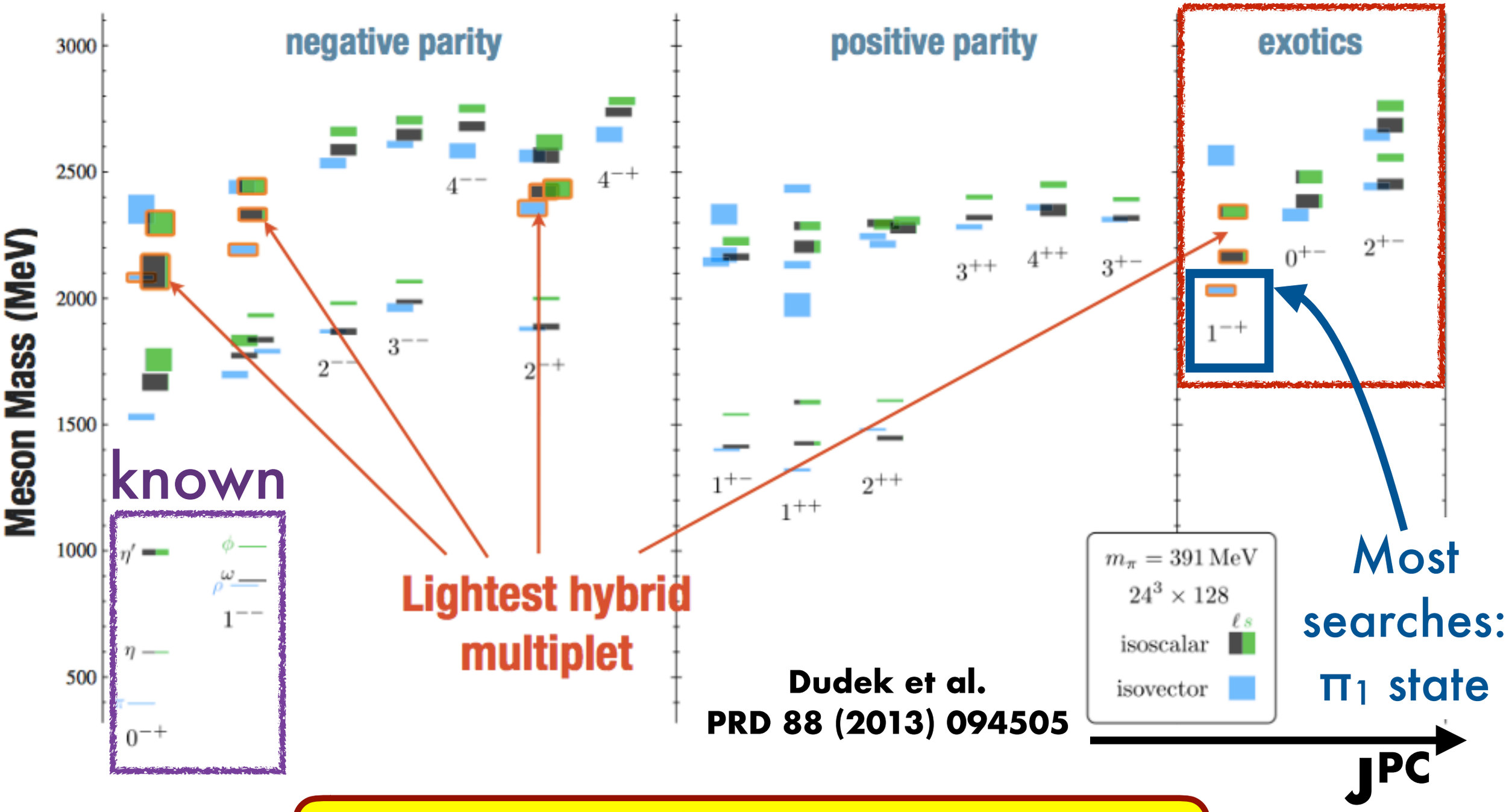
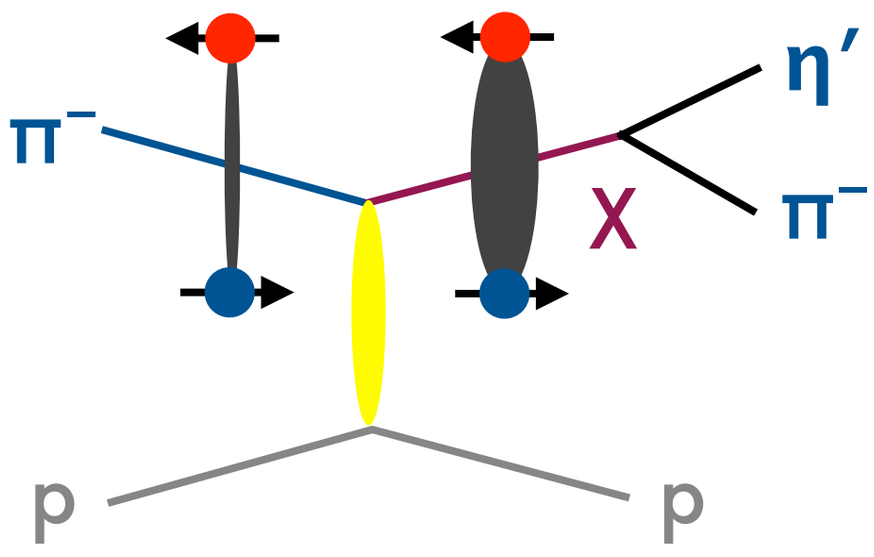
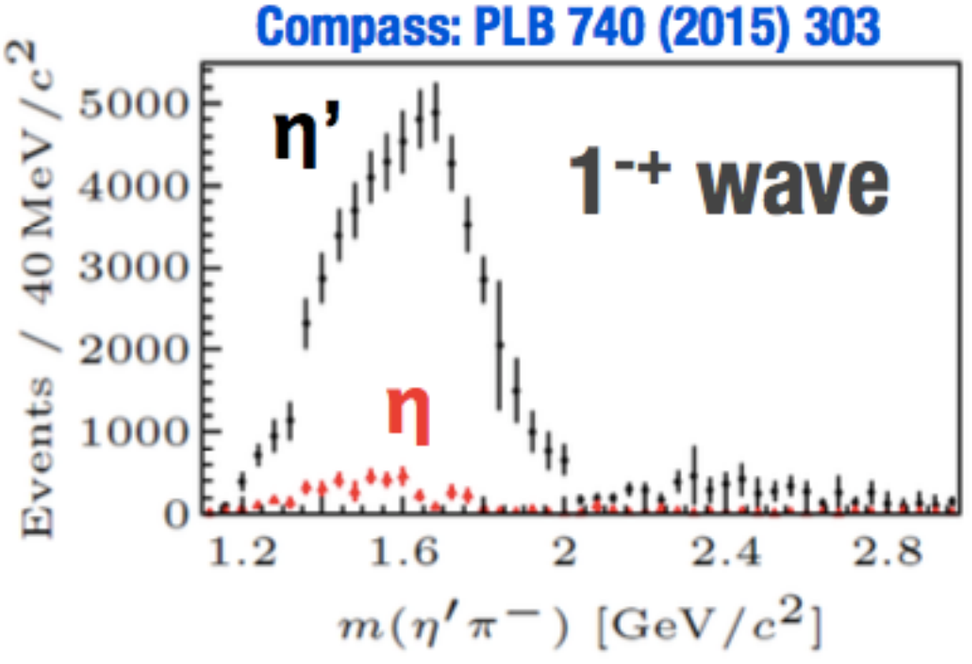


GlueX: look for hybrid patterns

Hybrid Searches

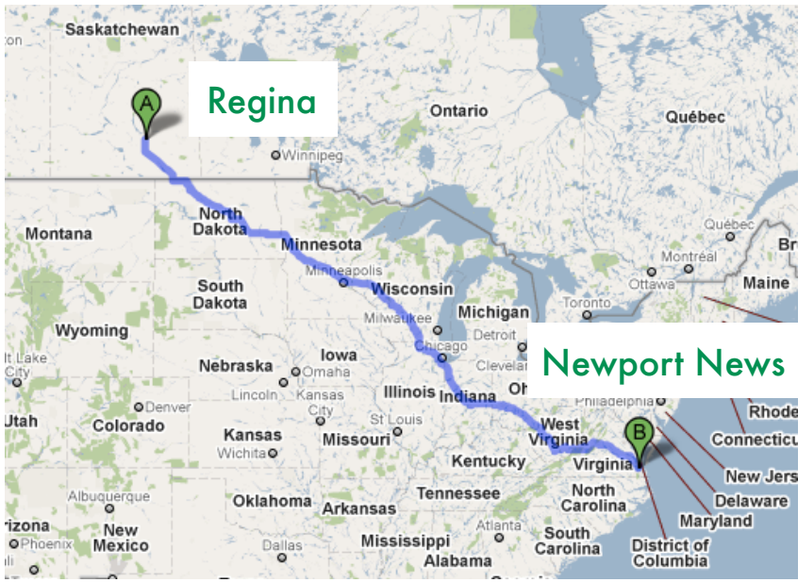
	Approximate Mass (MeV)	J^{PC}	Total Width (MeV) PSS	IKP	Relevant Decays	Final States
π_1	1900	1^{-+}	$80-170$	120	$b_1\pi^\dagger$, $\rho\pi^\dagger$, $f_1\pi^\dagger$, $a_1\eta$, $\eta'\pi^\dagger$	$\omega\pi\pi^\dagger$, $3\pi^\dagger$, 5π, $\eta 3\pi^\dagger$, $\eta'\pi^\dagger$
η_1	2100	1^{-+}	$60-160$	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	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K_2^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$



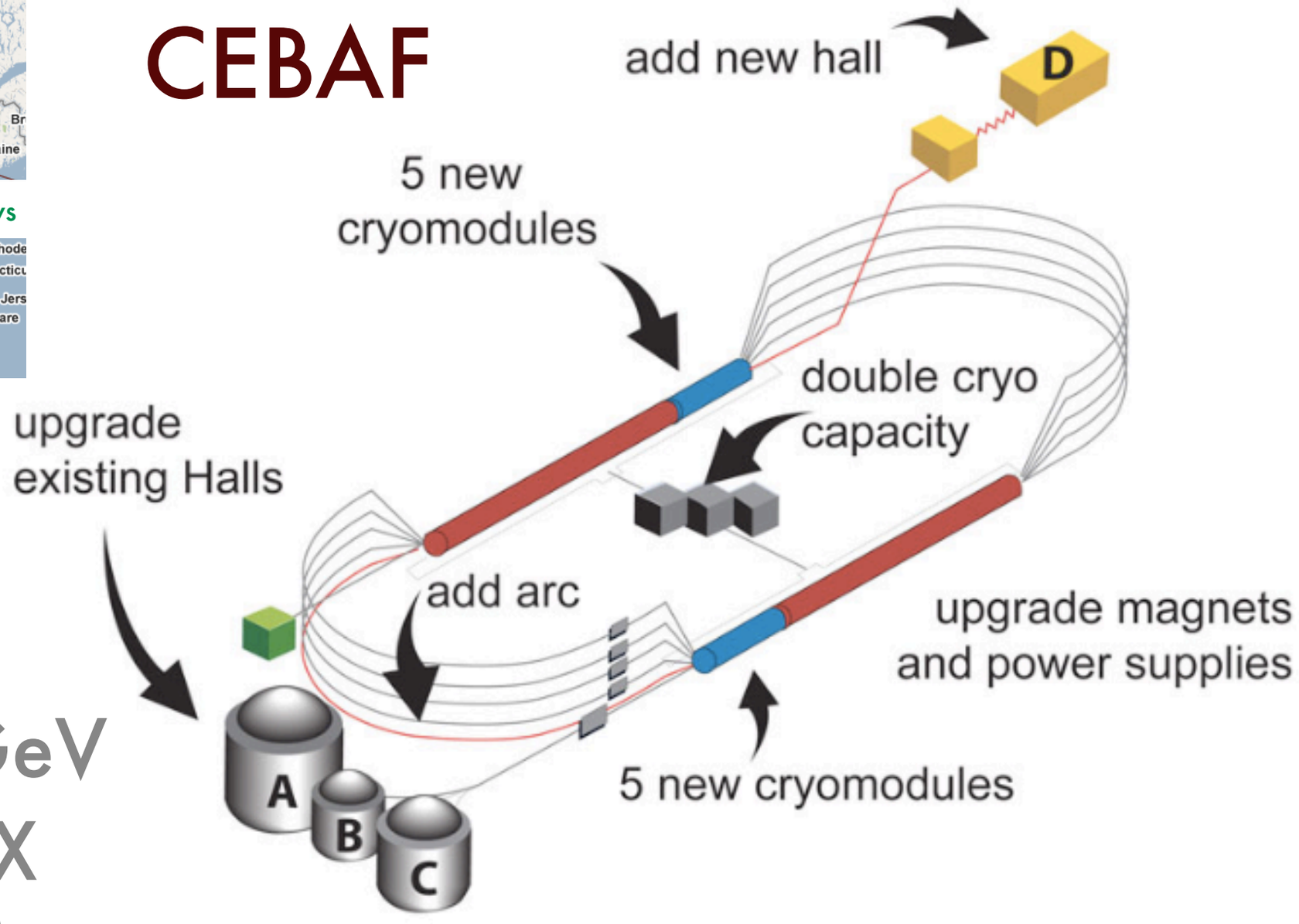



GLUE
Collaboration
• Board, Spokesman, Deputy, Executive
• Working Groups, Technical Committees
• Membership
116 members from 26 institutions

Jefferson Lab



CEBAF



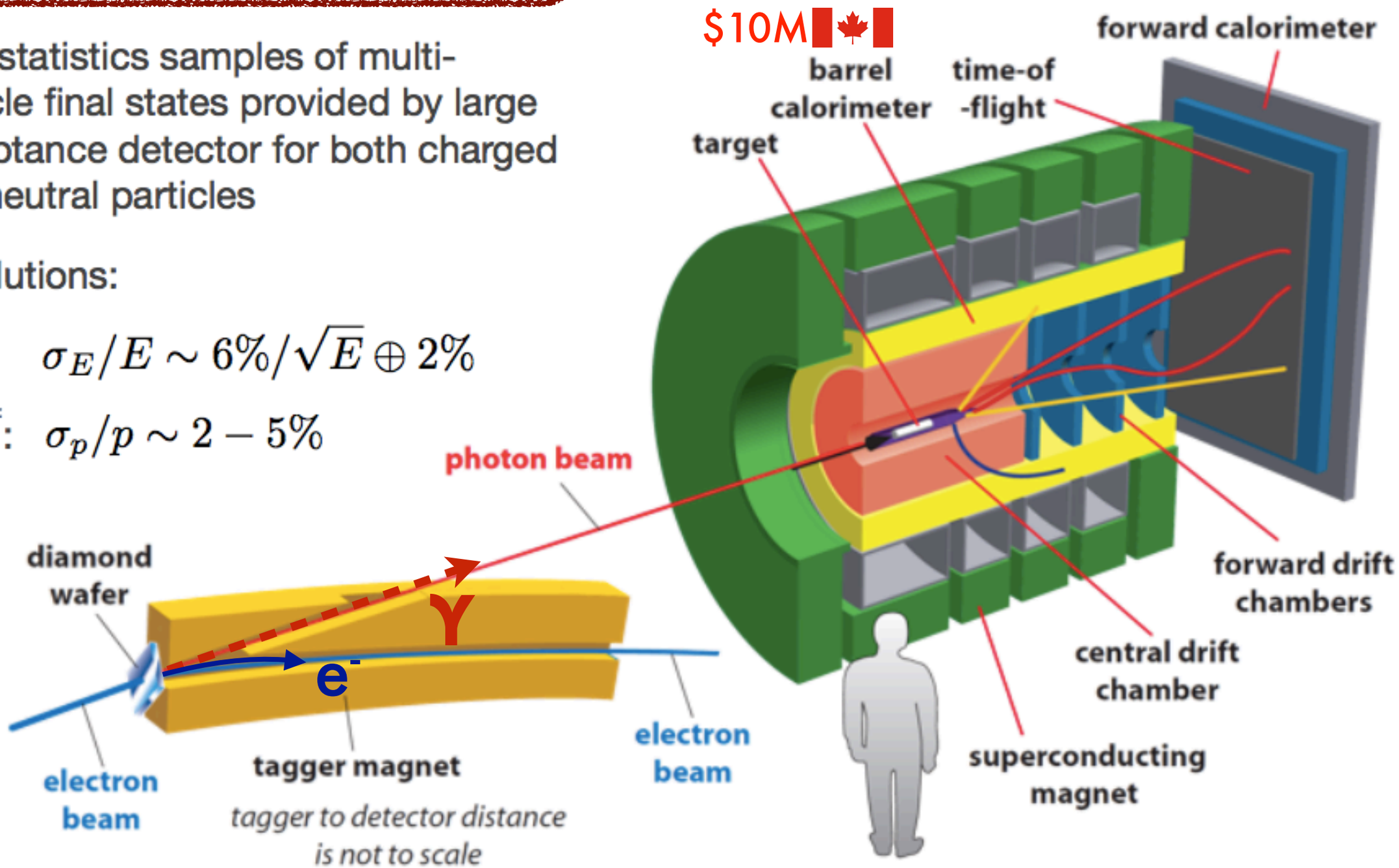
Upgraded: 12 GeV

4th Hall: GlueX

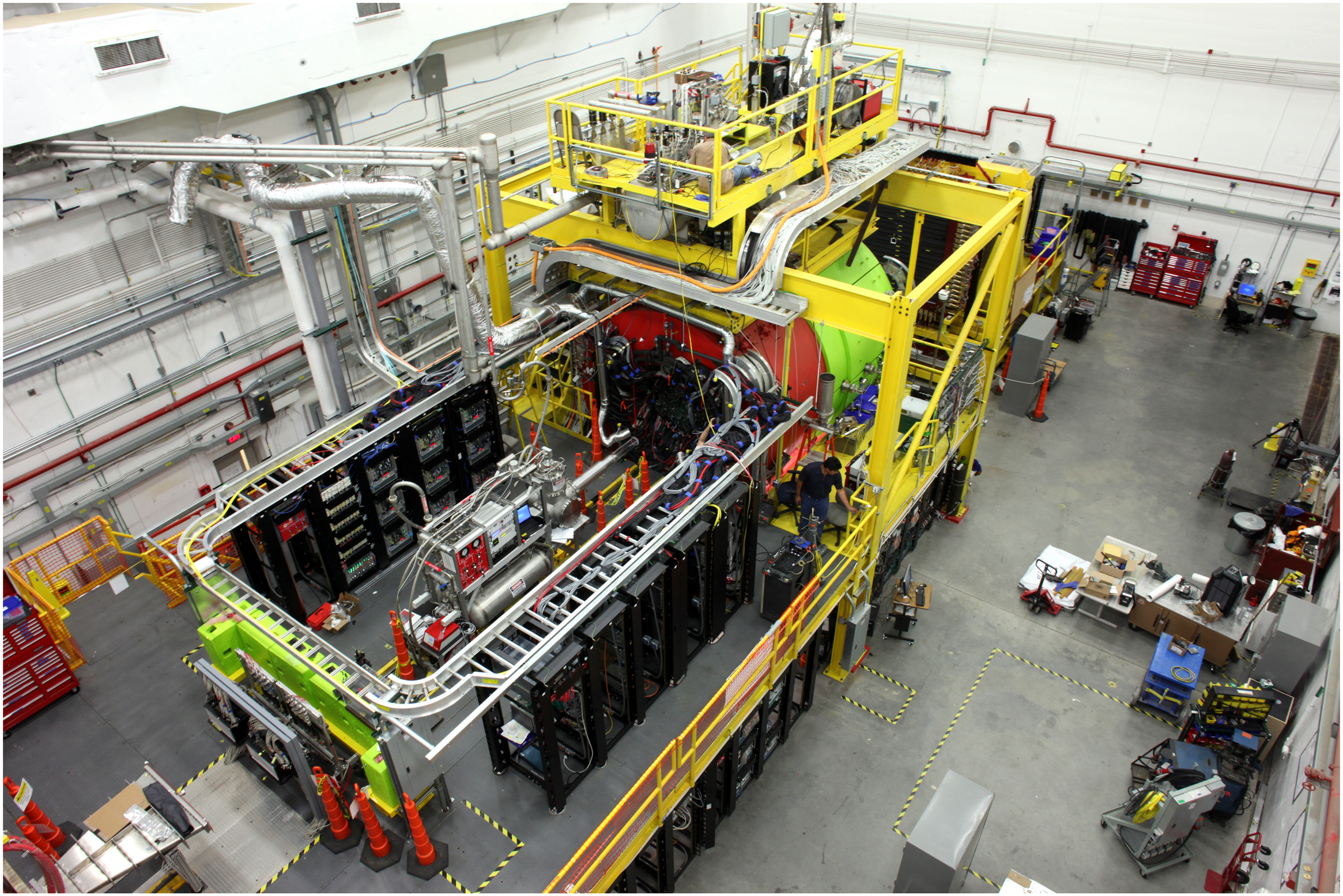
Cost > $310M

The Setup

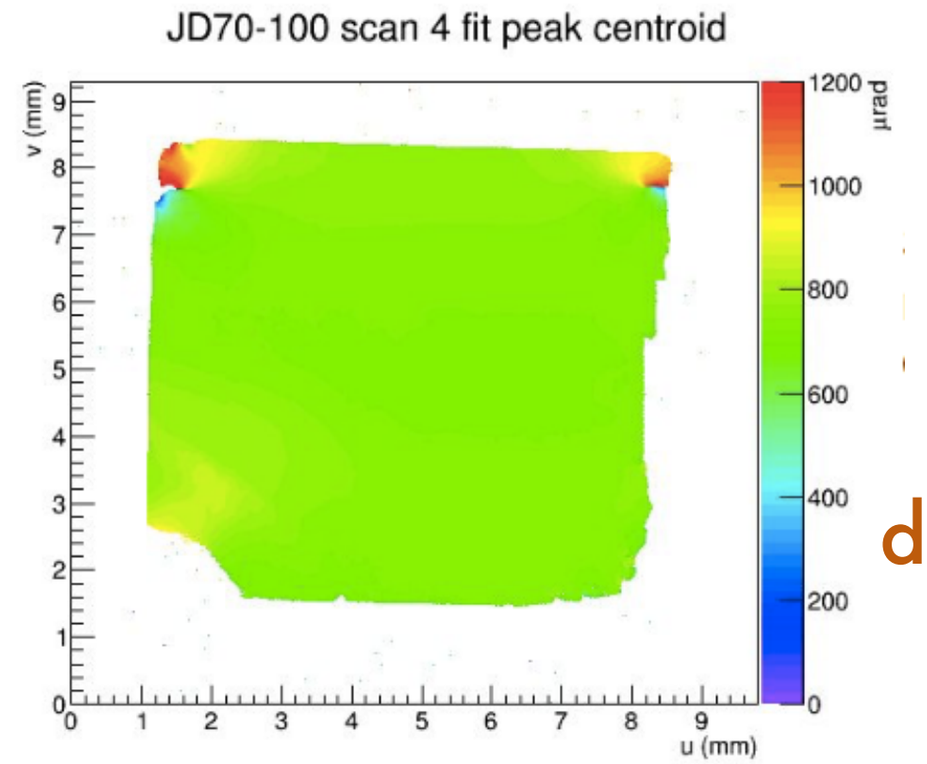
- Linearly polarized bremsstrahlung photon beam from CEBAF 12 GeV e$^-$
- High statistics samples of multi-particle final states provided by large acceptance detector for both charged and neutral particles
- Resolutions:
  - γ: $\sigma_E/E \sim 6\%/\sqrt{E} \oplus 2\%$
  - q$^\pm$: $\sigma_p/p \sim 2-5\%$



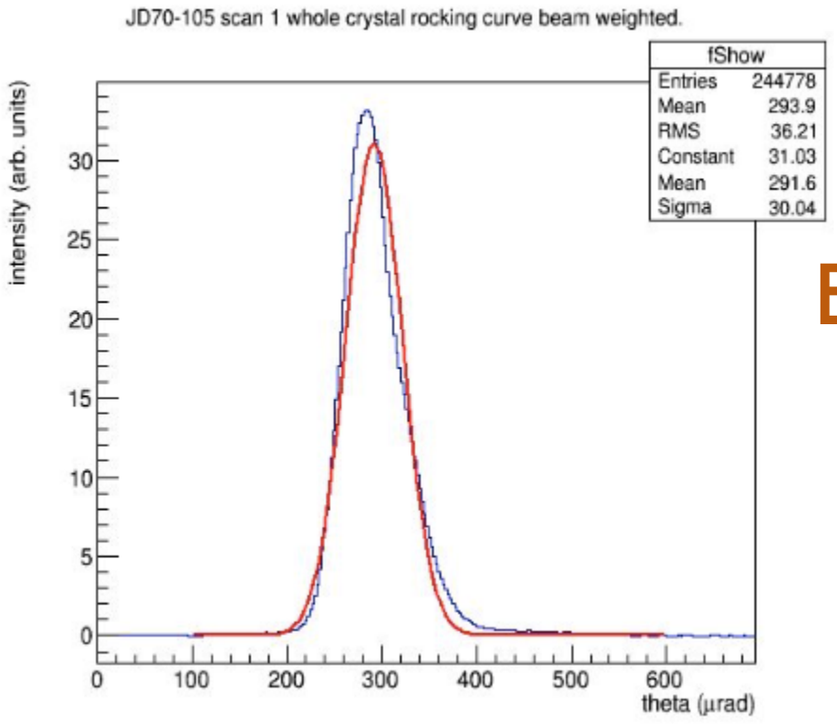
The Detector



Diamonds "sparkle"

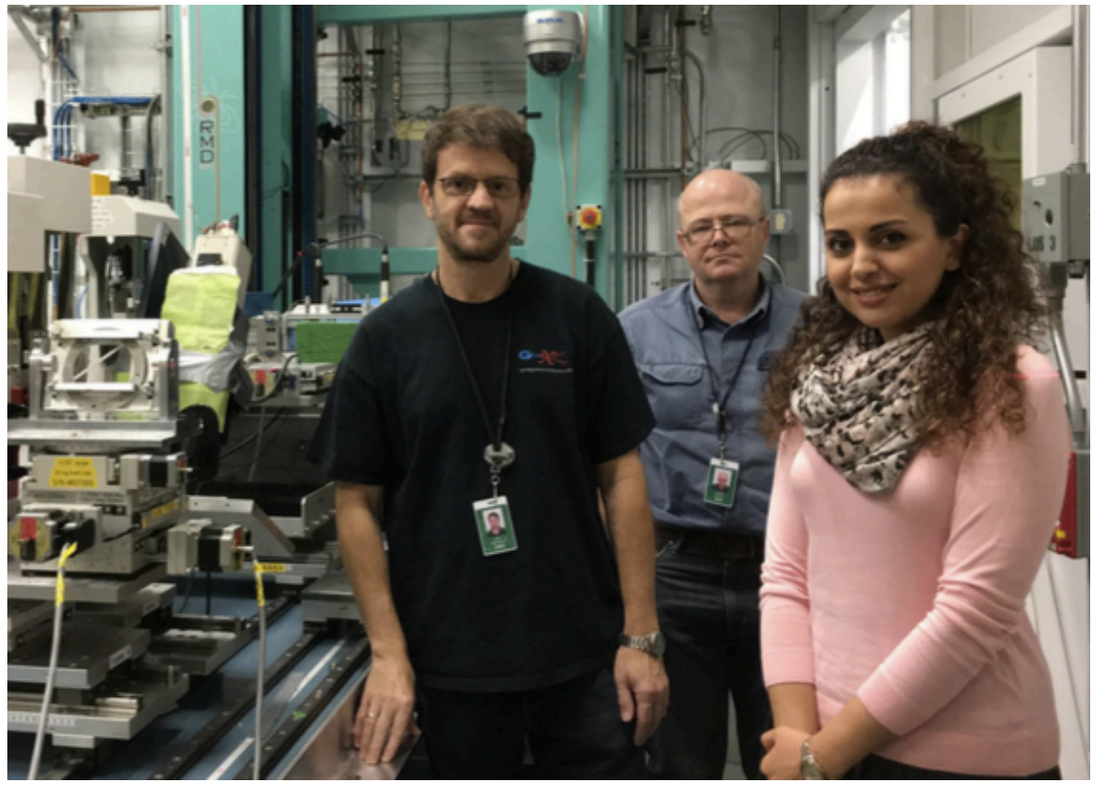


diamond scan



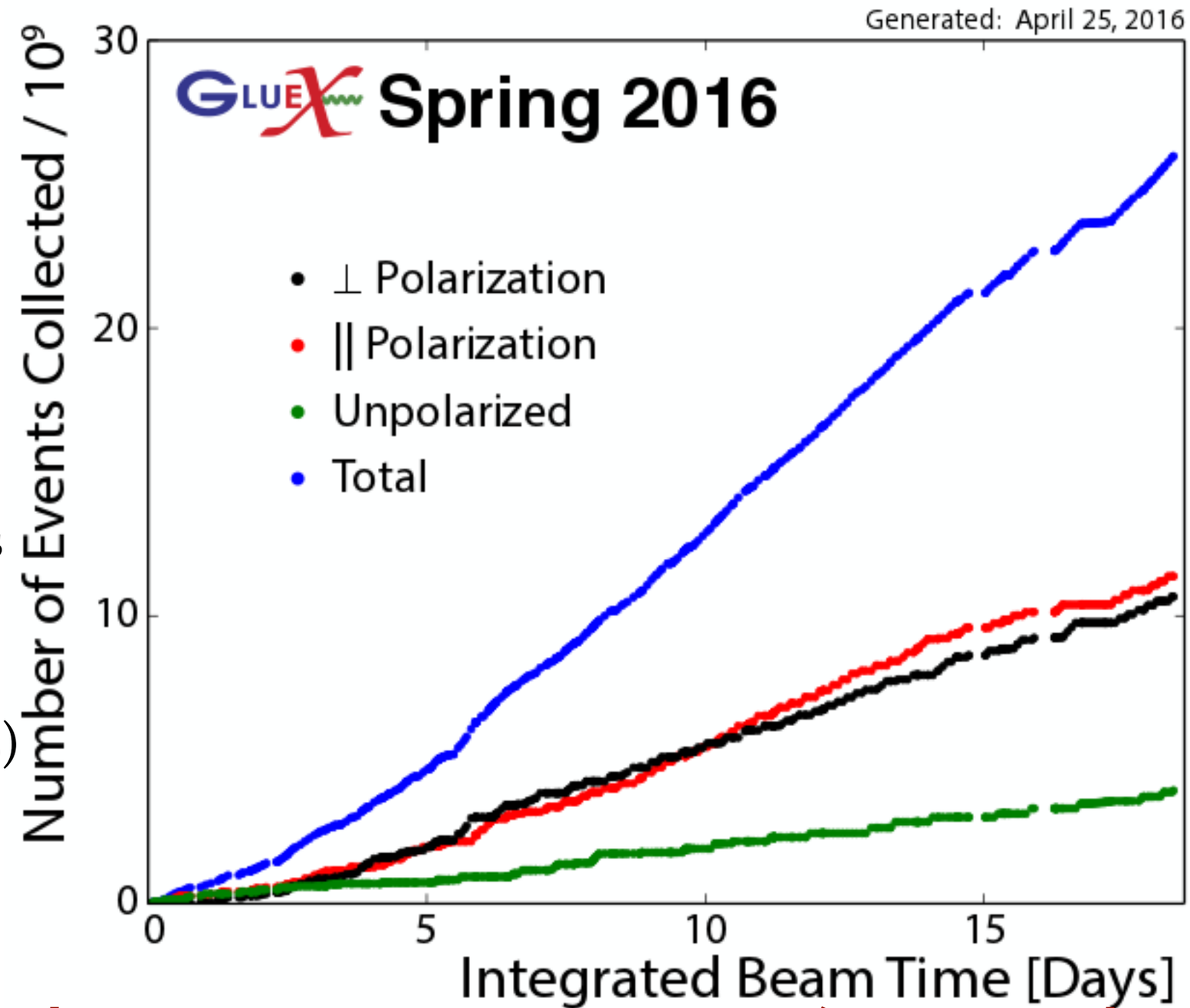
Excellent rocking curve widths

50 µm diamond radiators scanned at **CLS**



Data Taking

- **2014-2015**: Beam and detector commissioning
- **Spring 2016**: Detector commissioning and first physics results
  - 10^7 γ/s in coherent peak $8.4 < E\gamma < 9$ GeV
  - Golden period: ~80 hours of beam time
- **2017-> physics program**:
  - 100 days @ ~10^7 (10x stats)
- **High intensity running**:
  - 200 days @ ~5x10^7 (100x stats)



Event rate 55kHz, data rate 900 MBytes/sec; 2 Pb

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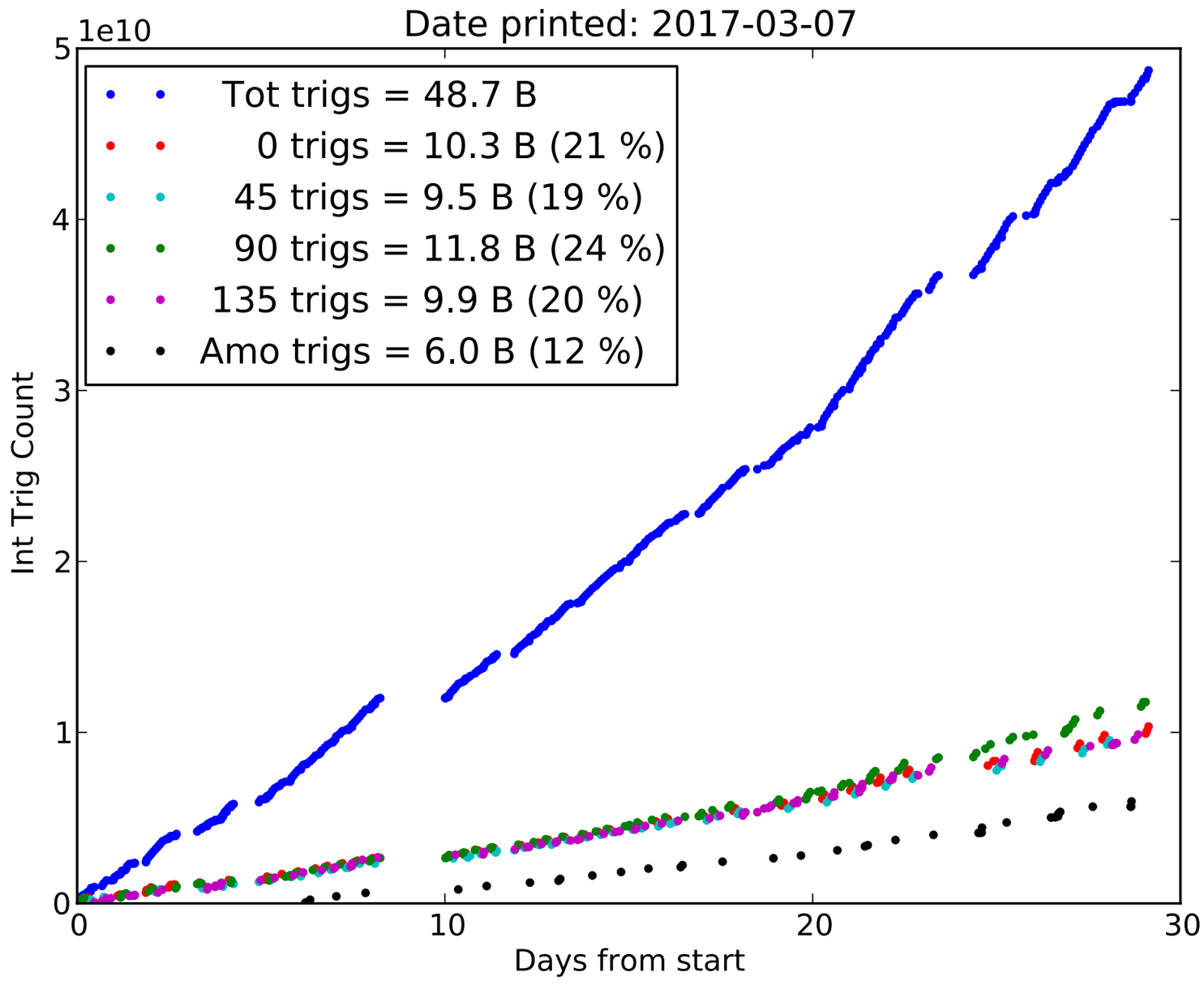


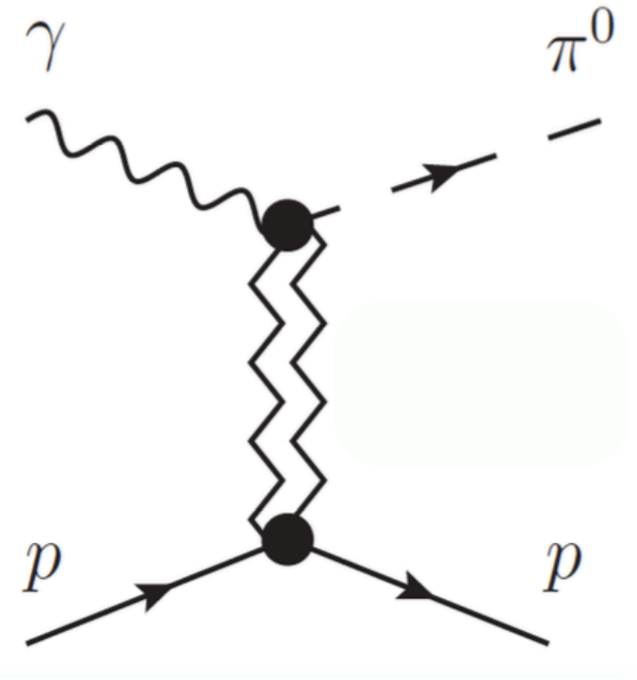
Event rate 55kHz, data rate 900 MBytes/sec; 2 Pb

Beam Asymmetry Σ: $\gamma p \to p\pi^0$

- Low hanging fruit: **asymmetries** (acceptances cancel)

$$\Sigma = \frac{|\omega+\rho|^2 - |h+b|^2}{|\omega+\rho|^2 + |h+b|^2}$$

- Asymmetry: information on the **production mechanism**



- The production mechanism is an **effective J^{PC} filter** (non-exotic here)
- SLAC π^0 results from 1971
- No η results exist!

Exchange J^{PC}	Σ
$1^{--}: \omega, \rho$	+1
$1^{+-}: b, h$	−1

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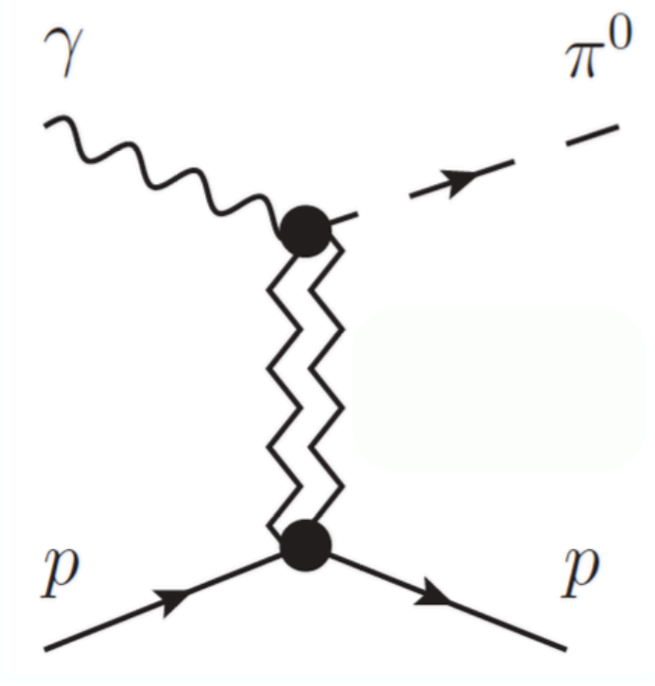

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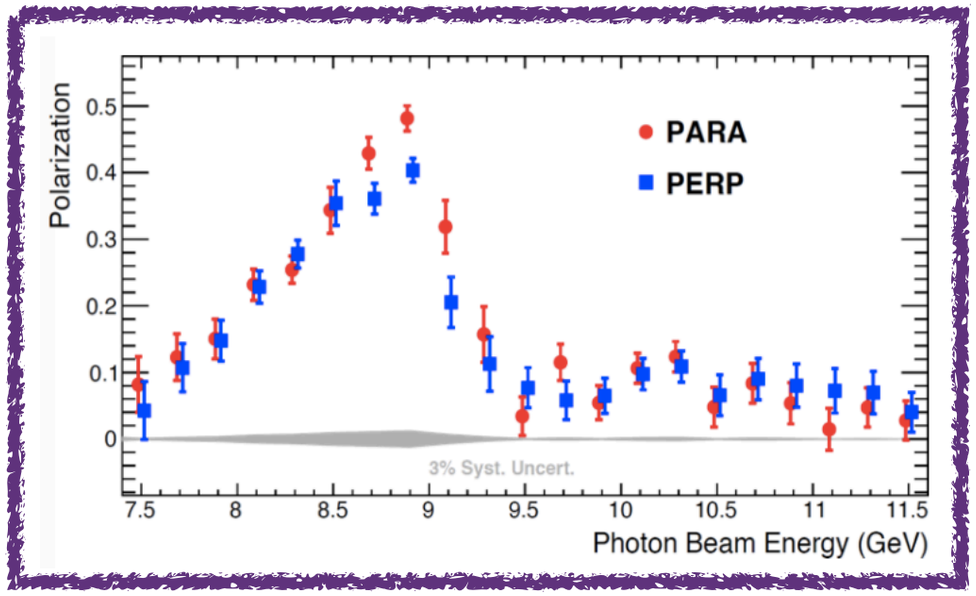
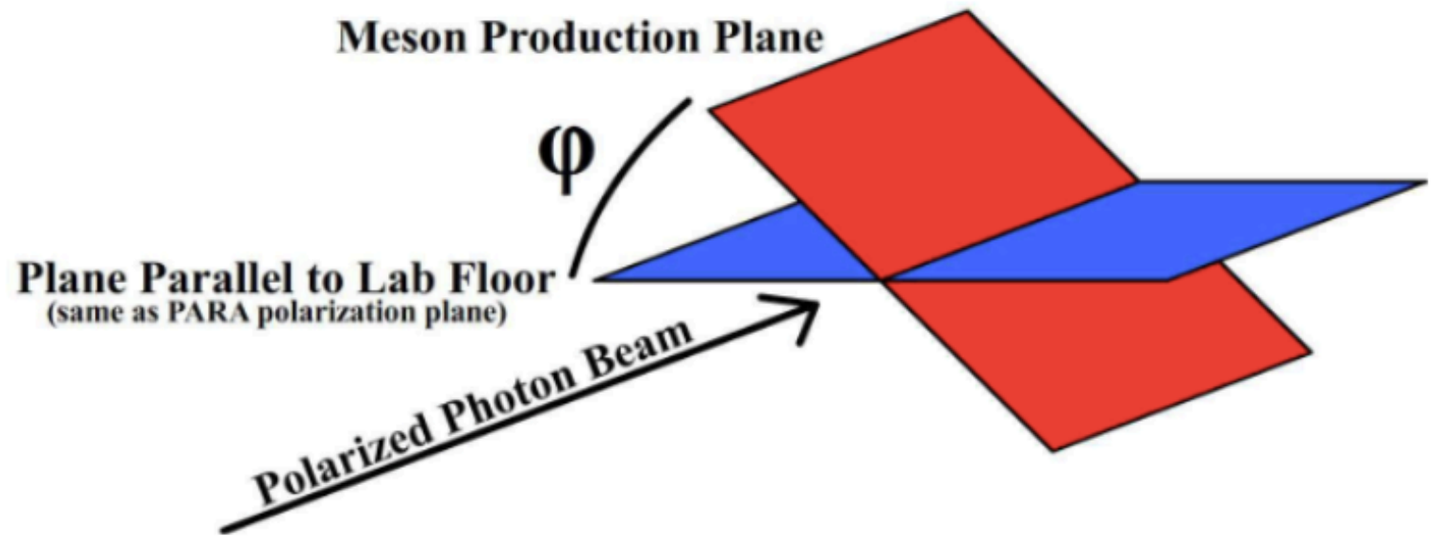
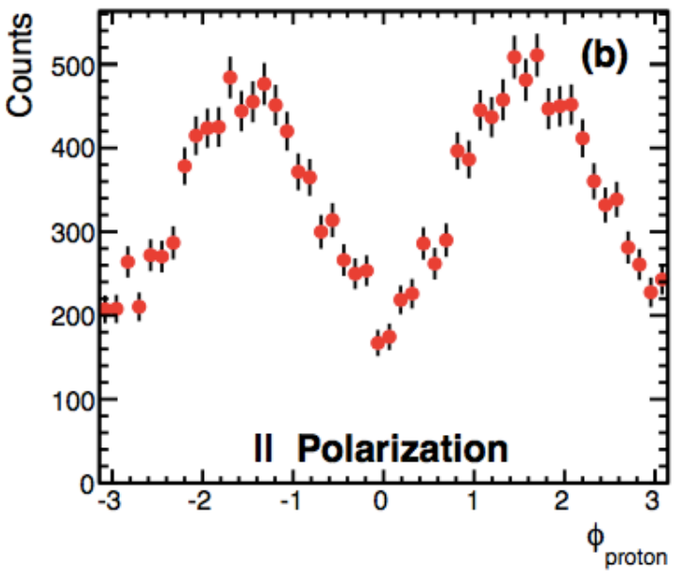
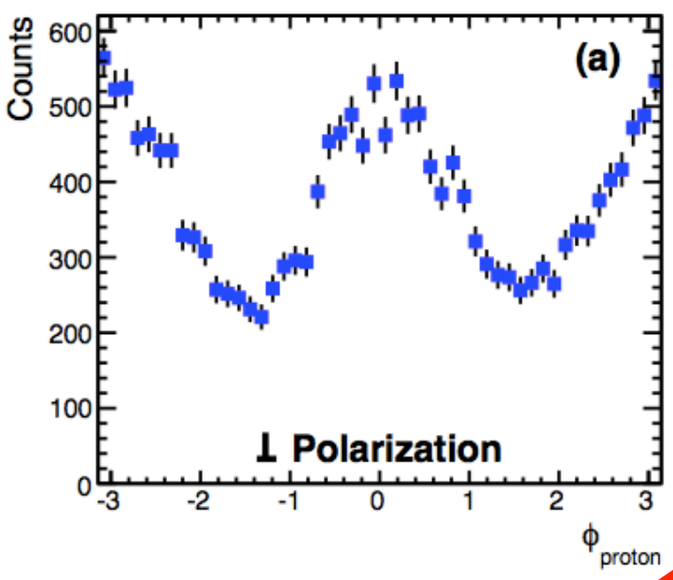
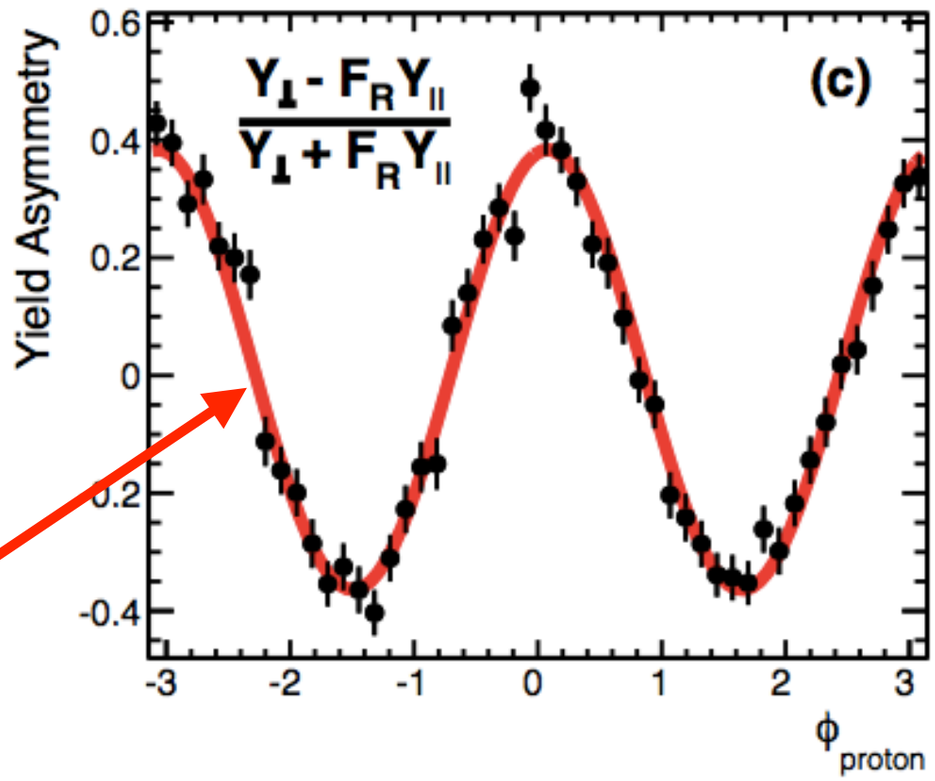
Beam Asymmetry Extraction





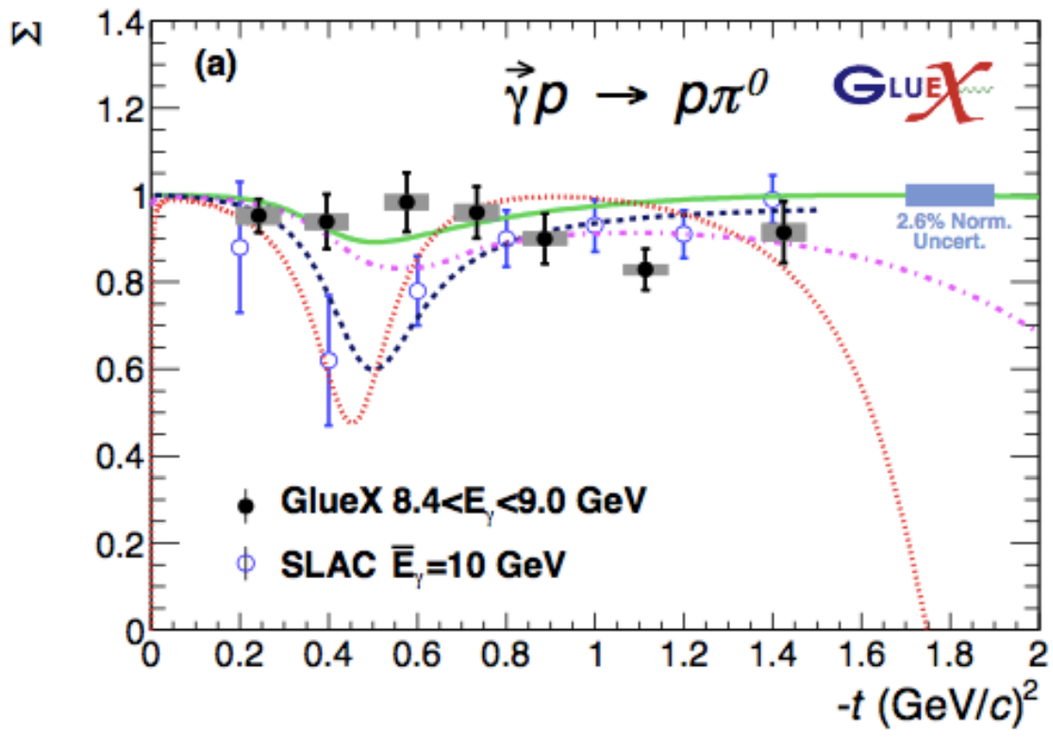


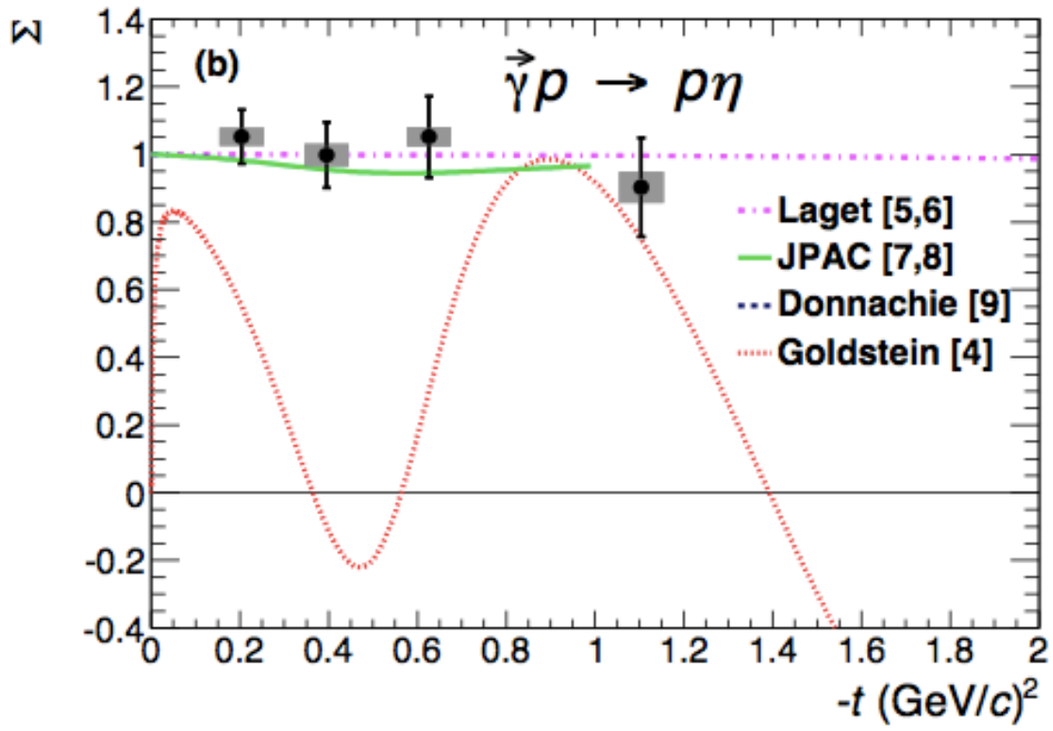




$$Y_{\parallel} \propto A(\phi)(1 - P_{\gamma}\Sigma cos(2(\phi - \phi_{\gamma}^{lin}))$$

π^0 and η Beam Asymmetries





$$\pi^0, \eta \rightarrow \gamma\gamma$$

- Data compared to Regge theory calculations
- No dip at -t = 0.5 (GeV/c)^2
- Vector exchange dominance at this energy

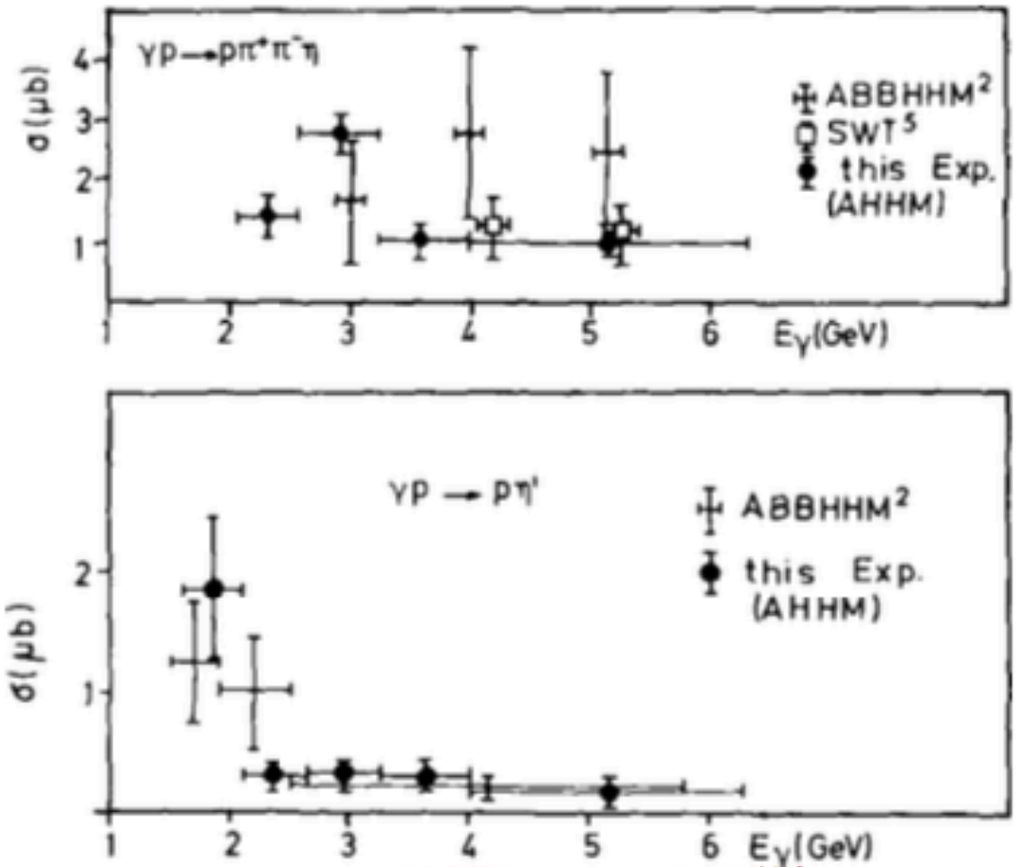
Exchange J^{PC}	Σ
1^{--} : ω, ρ	+1
1^{+-} : b, h	−1

First GlueX publication

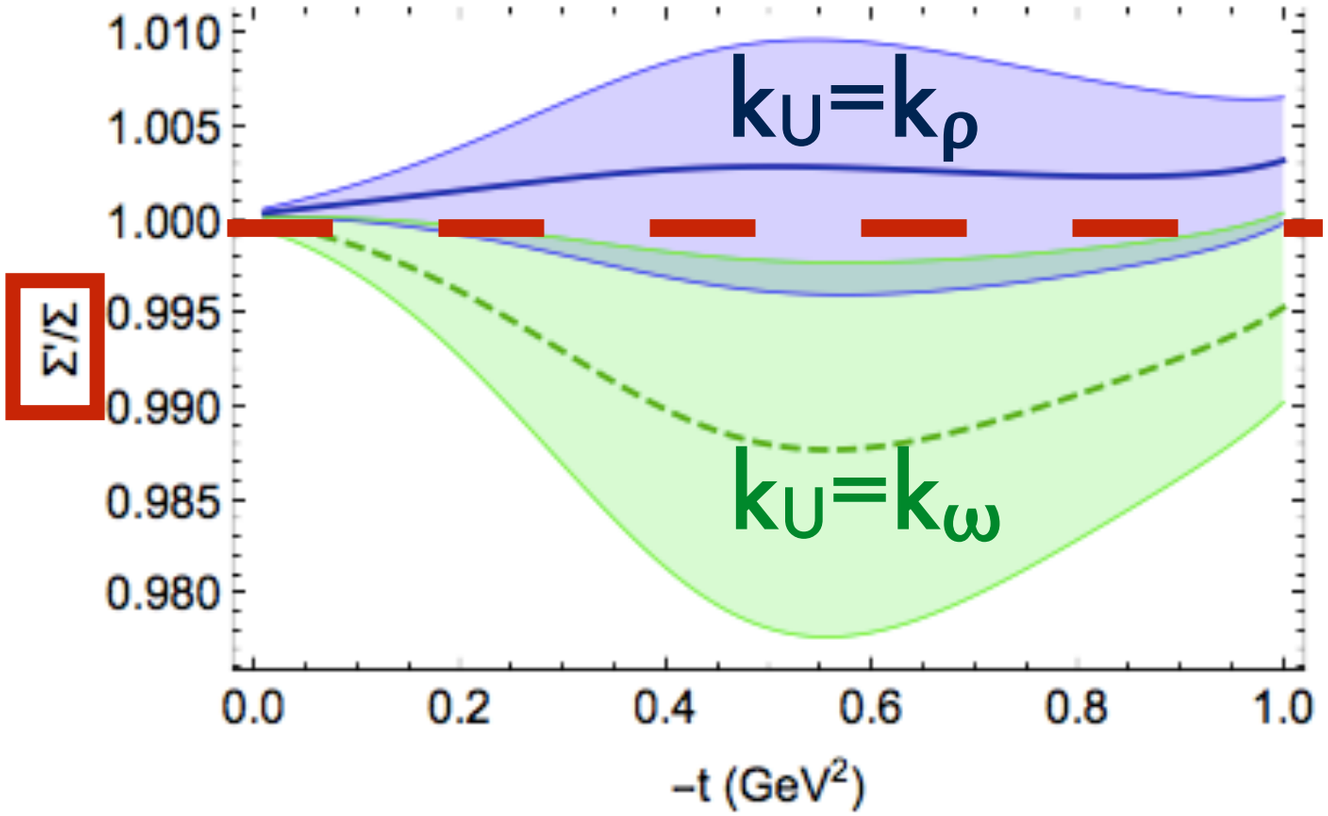
DOI:10.1103/PhysRevC.95.042201

At Regina: γp→pη,pη'

- World η/η' photoproduction data on Σ, Σ′ beam asymmetries & cross sections is sparse or not measured at GlueX energies
- πη and πη' resonances high on list of possibly-accessible exotics/hybrids



Struczinski et al., 1976



V. Mathieu et al. arXiv:1704.07684

$$\eta \to \pi^+\pi^-\pi^0 \ (23\%)$$
$$3\pi^0 \ (33\%)$$
$$\eta' \to \pi^+\pi^-\eta \ (43\%)$$
$$2\pi^0\eta \ (22\%)$$

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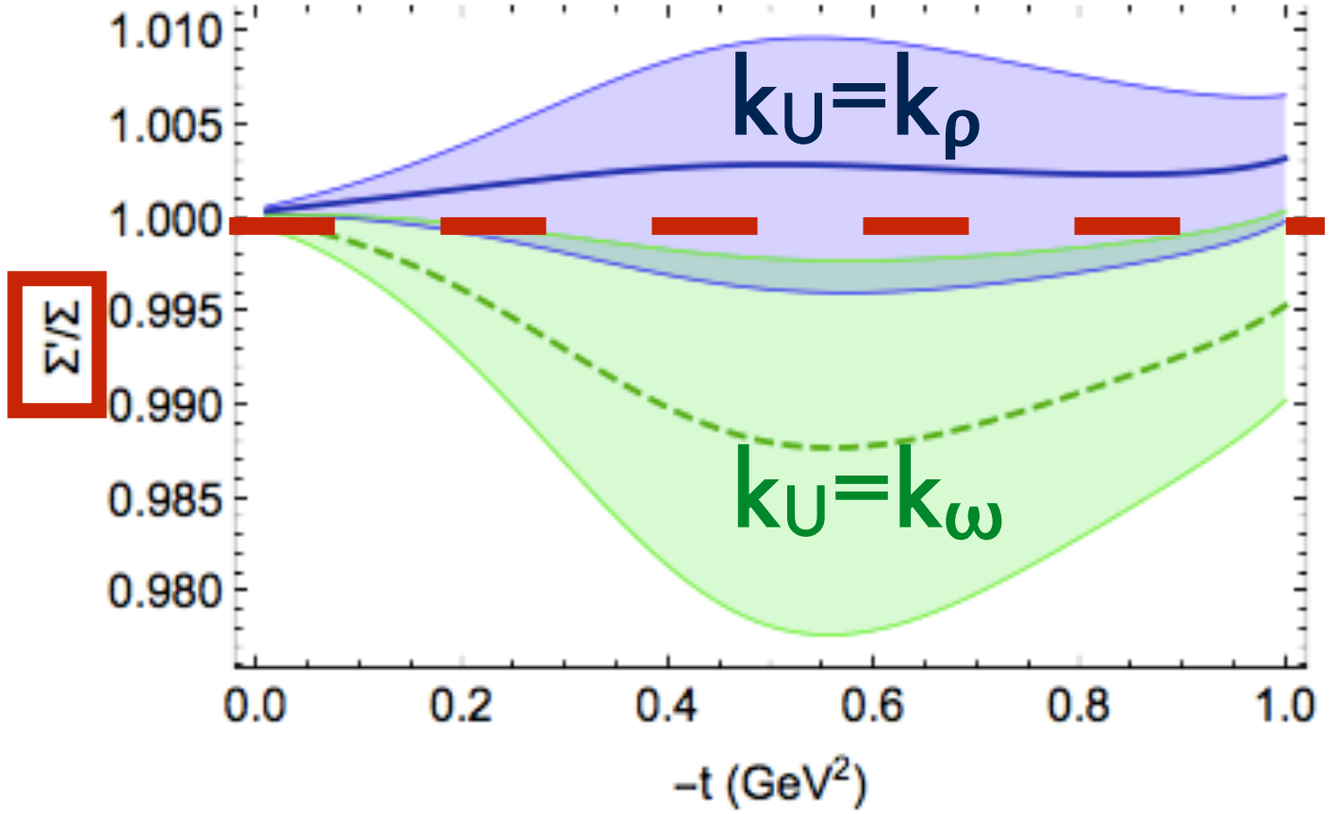

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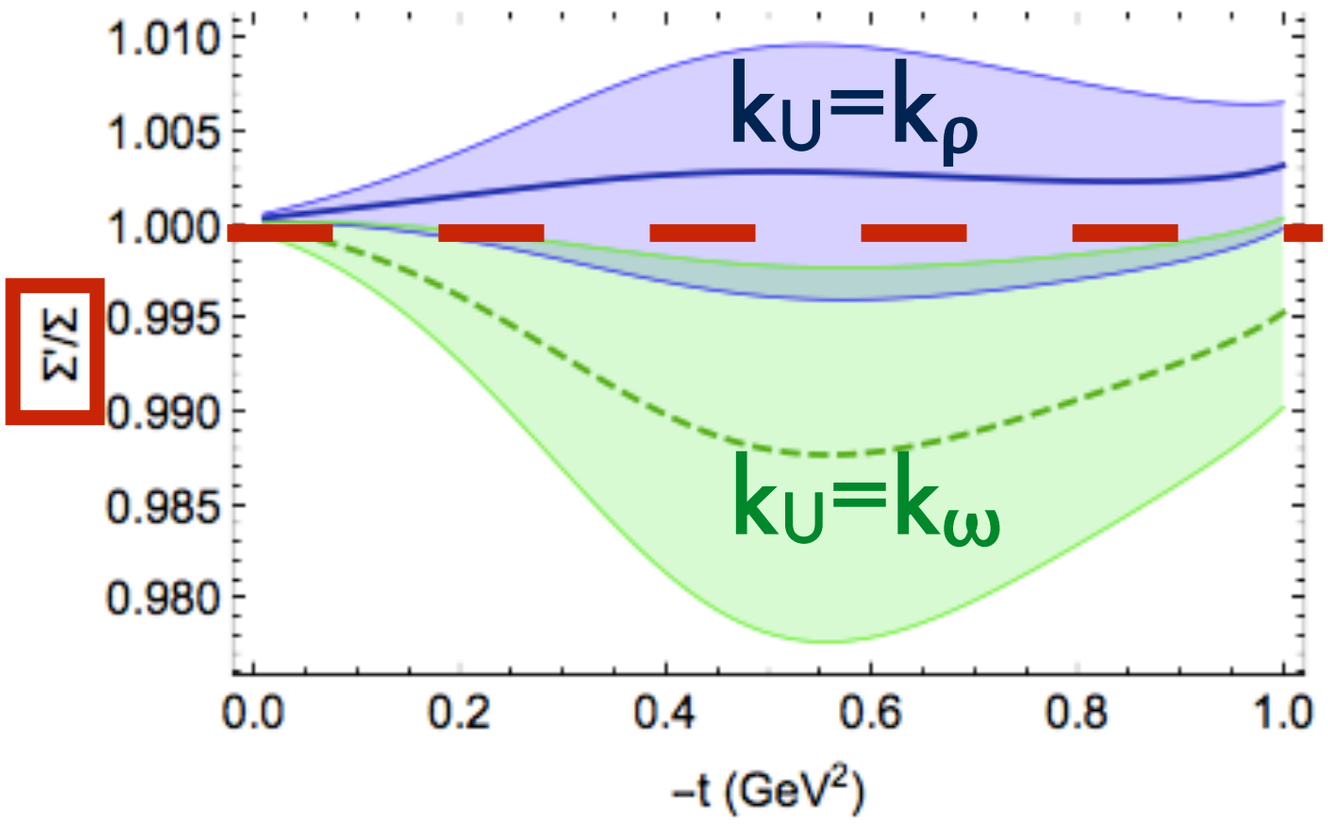
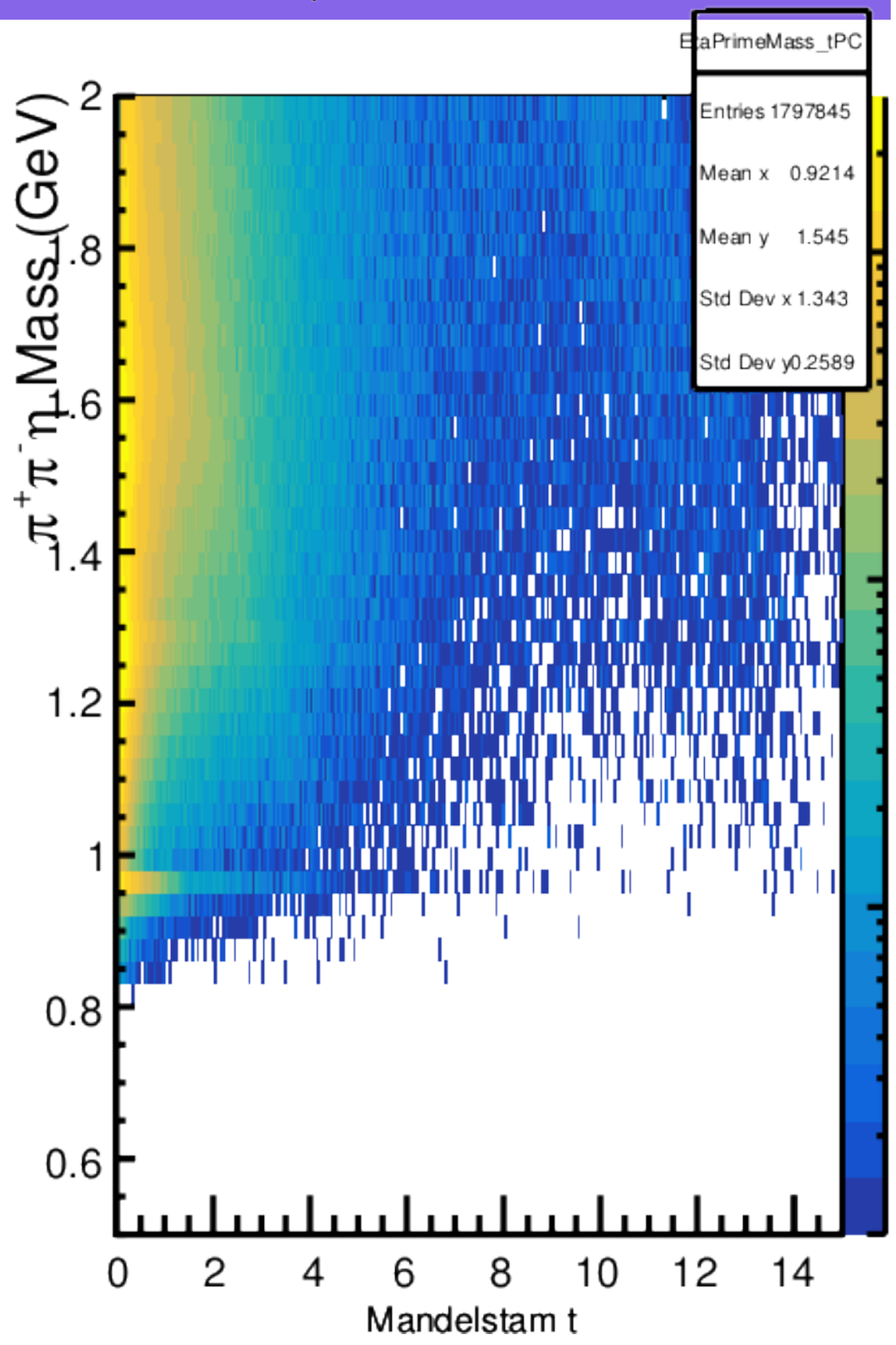
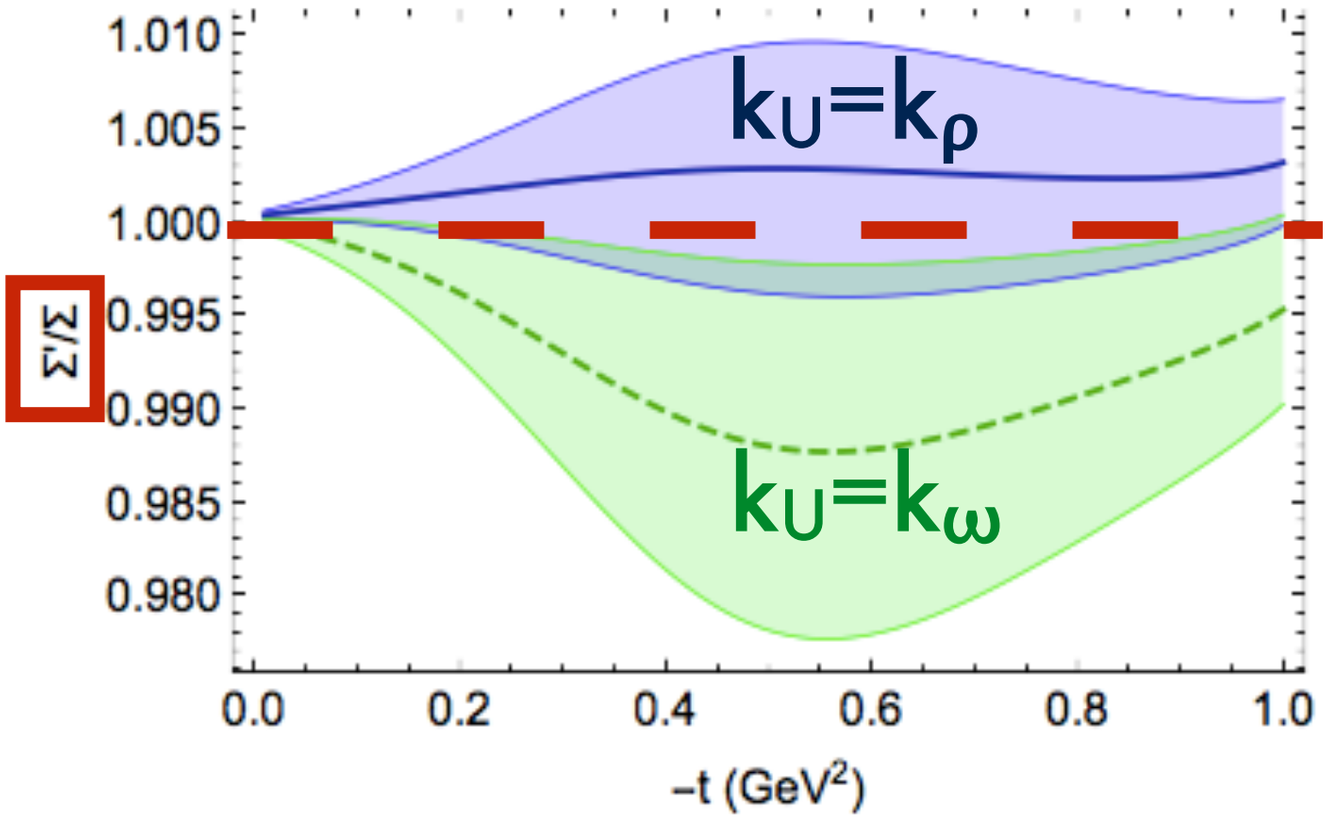


V. Mathieu et al. arXiv:1704.07684



At Regina: $\gamma p \rightarrow p\eta, p\eta'$

- World η/η' photoproduction data on Σ, Σ′ beam asymmetries & cross sections is sparse or not measured at GlueX energies
- πη and πη' resonances high on list of possibly-accessible exotics/hybrids



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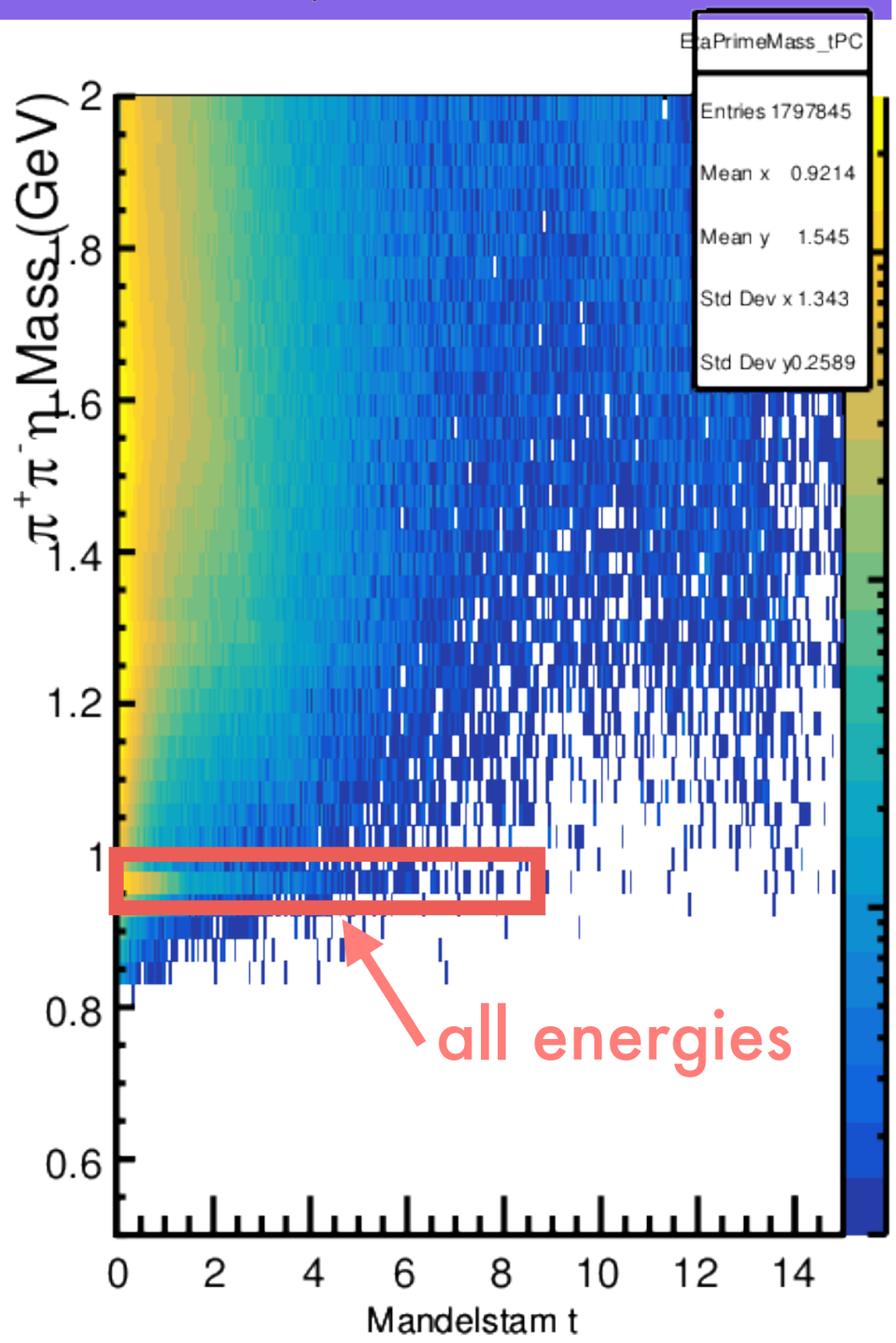

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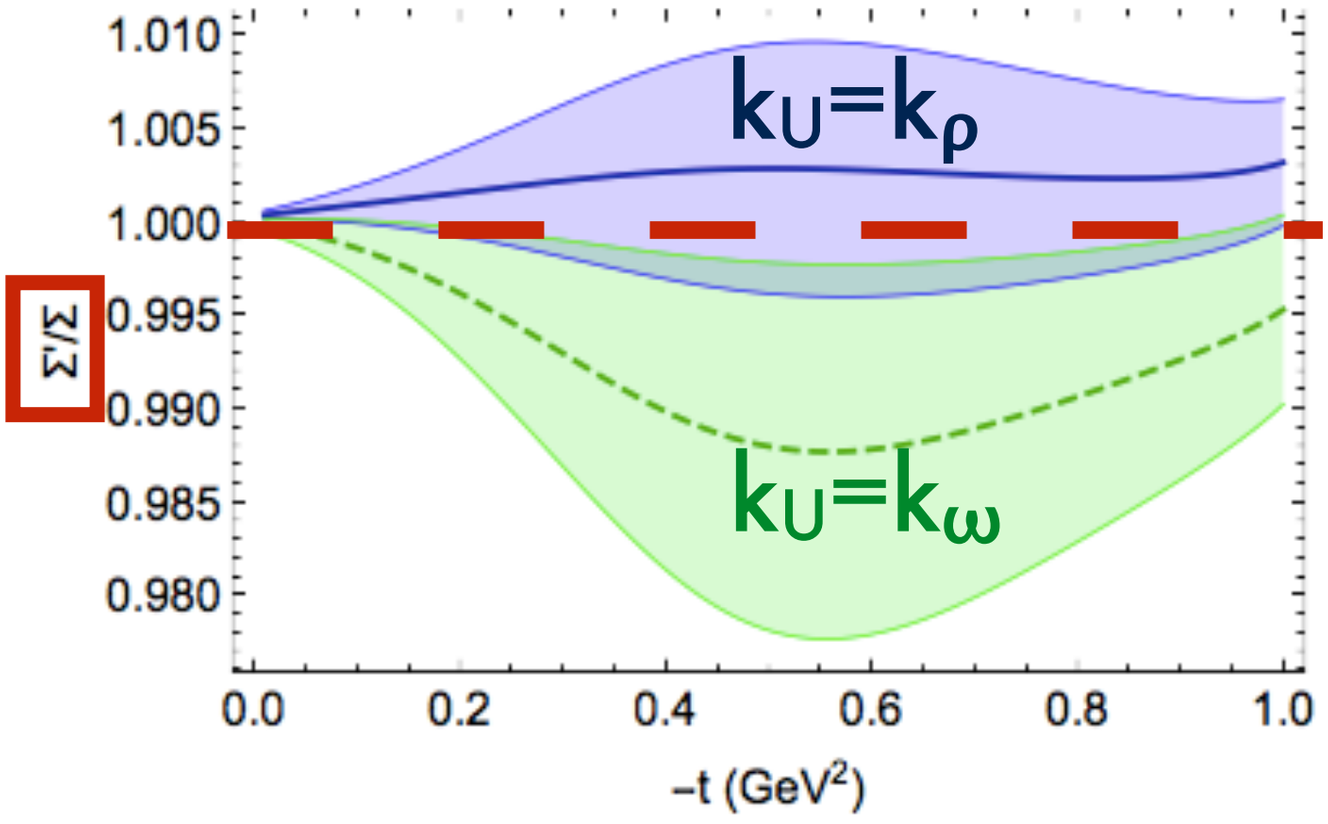

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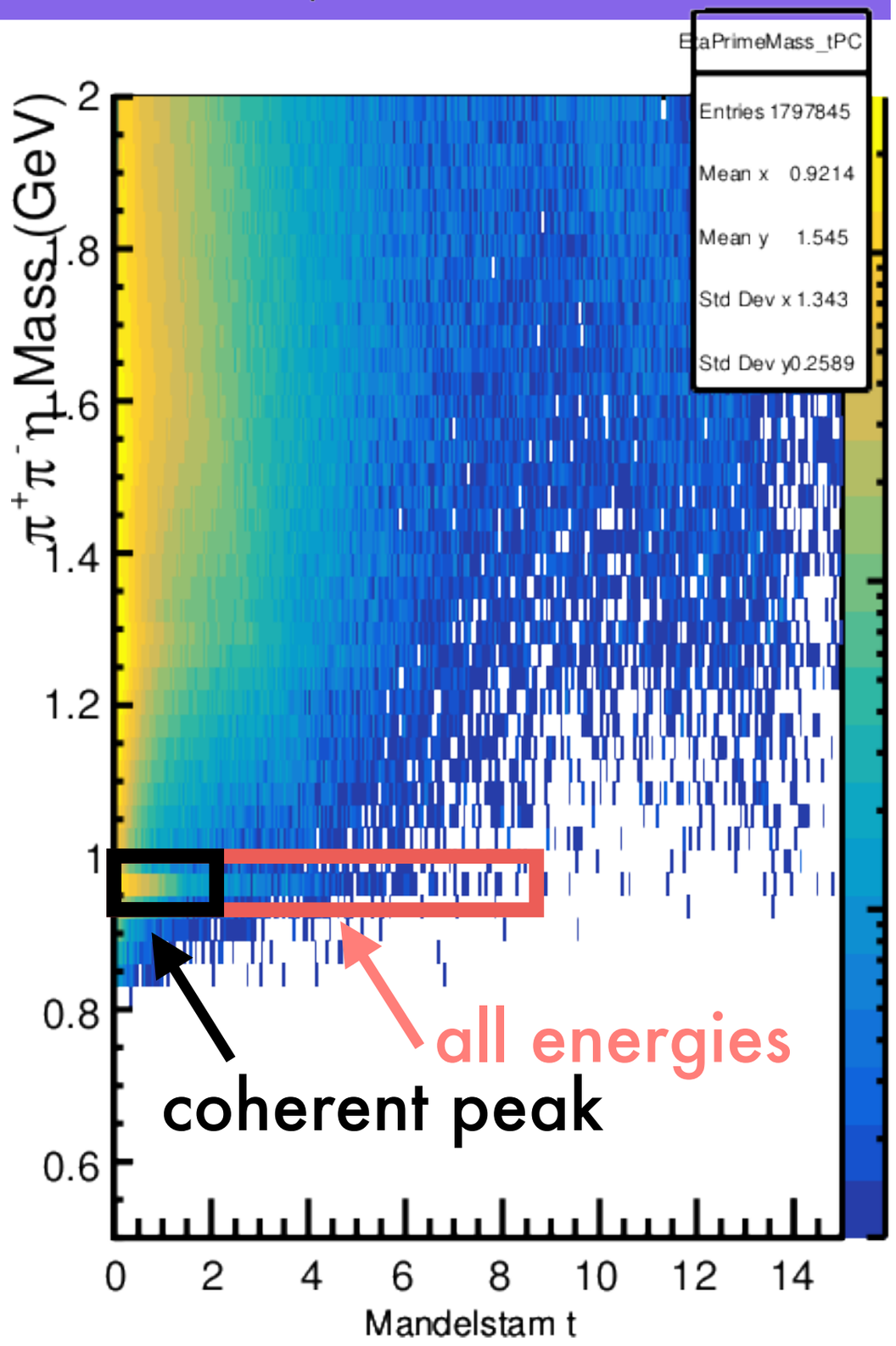


Summary & Outlook

Summary & Outlook

- Gluonic field excitation leads to a **new spectrum** of mesons.

Theory (LQCD) makes detailed hybrid multiplet predictions.

✓Successful commissioning and early physics analyses

✓First production run completed: $\gamma p \to (\rho,\omega,\varphi)p$, $\gamma p \to (\pi^0,\eta,\eta')p$, etc

- Study production mechanism: beam asymmetries, cross sections, spin density matrix elements, PWA
- Comparison with previous measurements and models, plus more
- Detector upgrade for improved K/π separation 2018+
- Other: Primakoff program for η decay width and $\pi^{\pm}$ polarizability

Acknowledgements

LEARN MORE

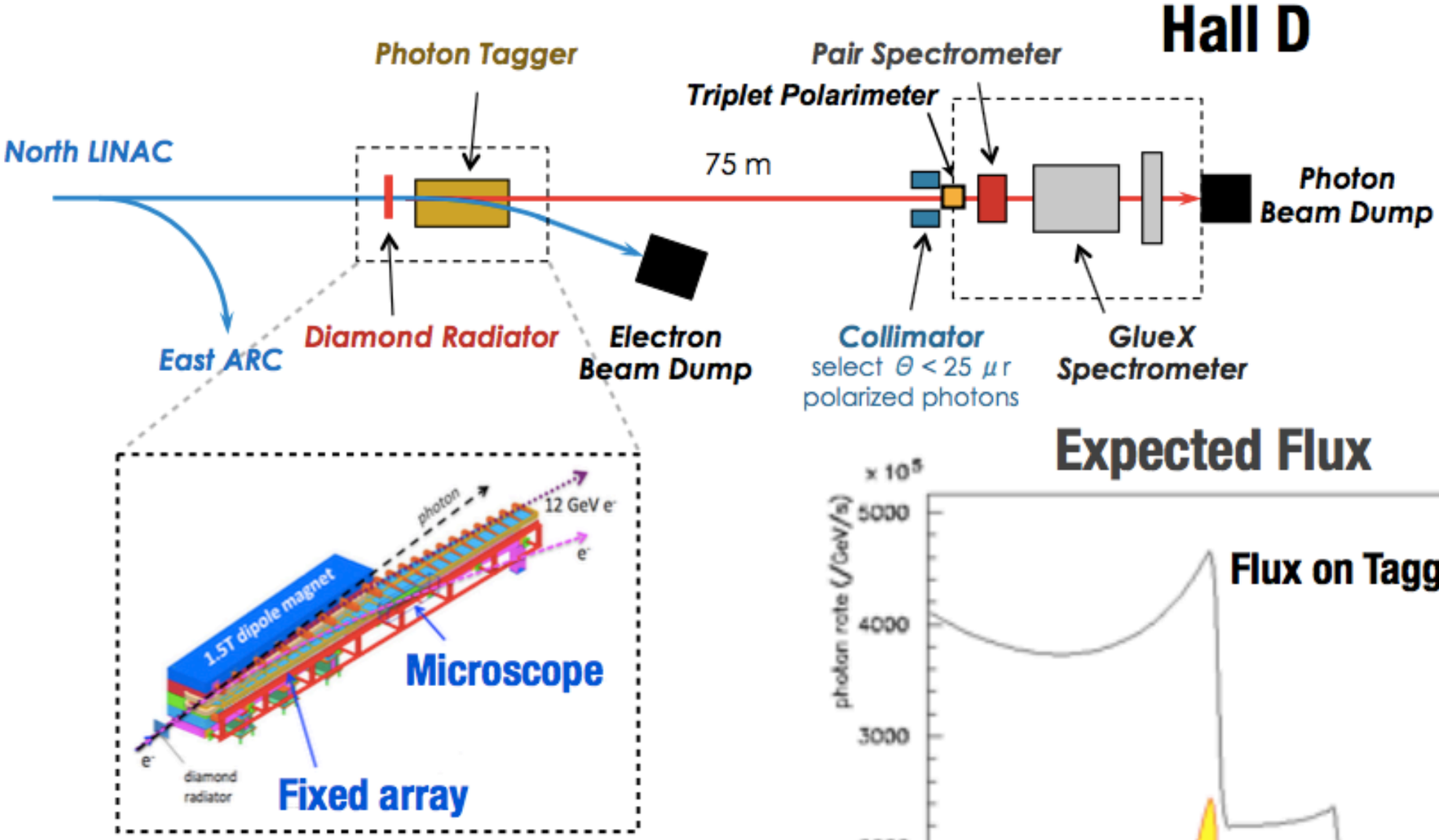
- Particle Adventure
- **portal.gluex.org**
- **www.halld.org**
- **www.gluex.org**

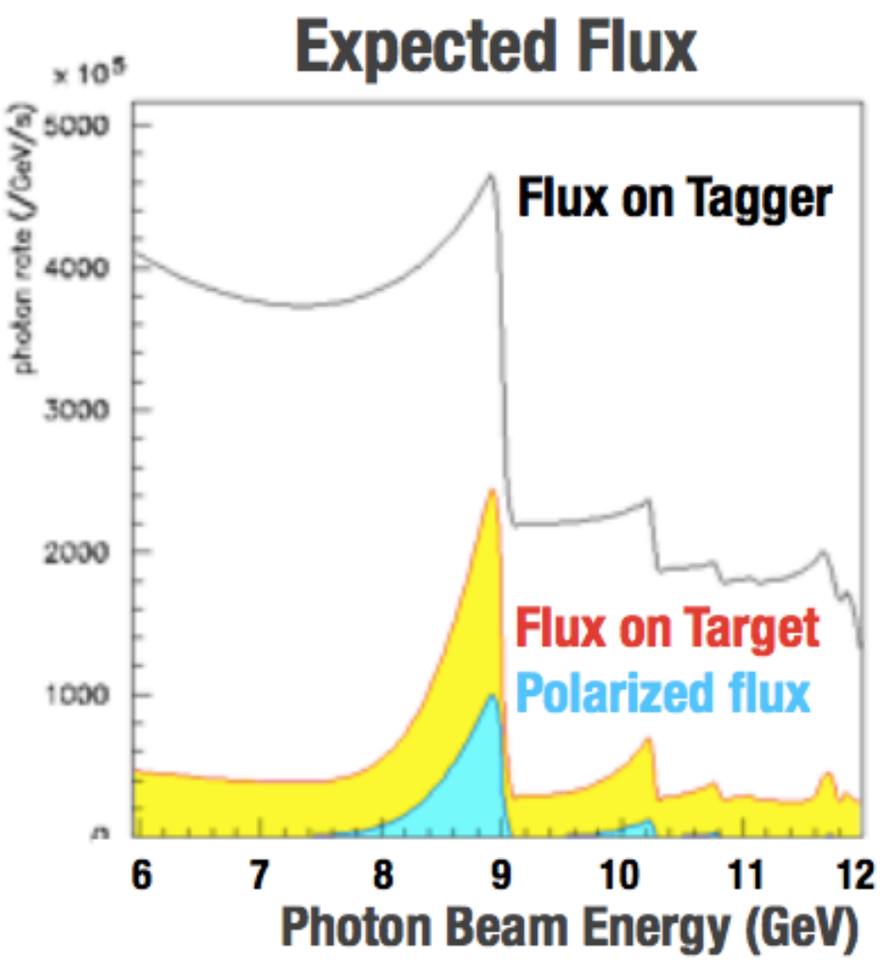
Regina Team members:
T. Beattie, **A. Foda**, G. Huber, G. Lolos, **A. Semenov, I. Semenova**, A.Teymurazyan

Thank you!

Backup Slides

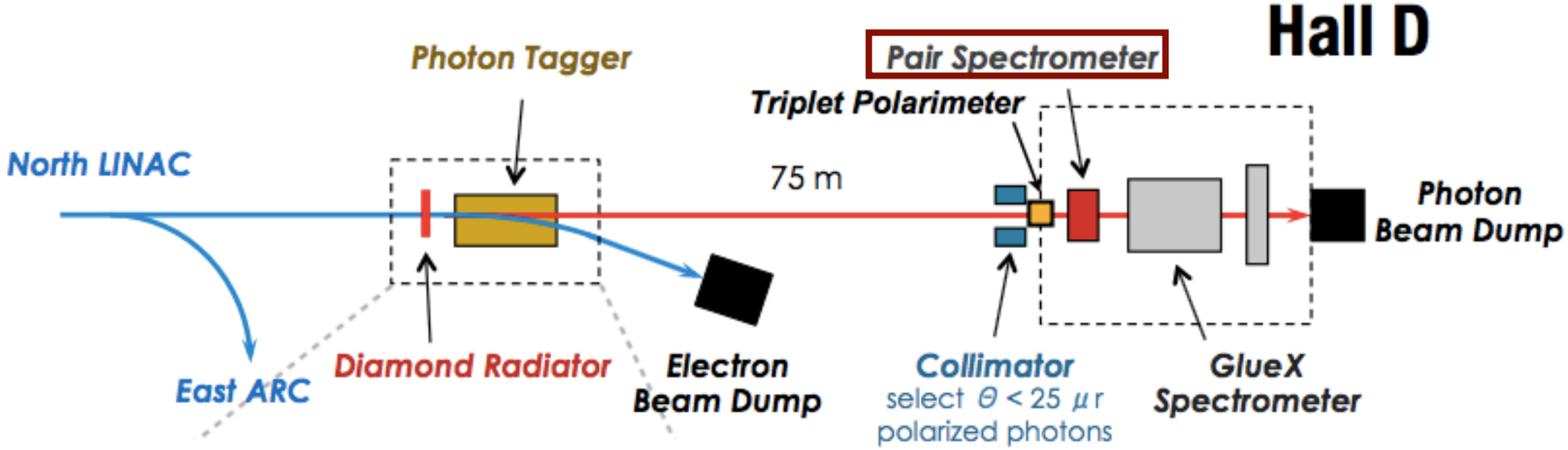
The Beam Line



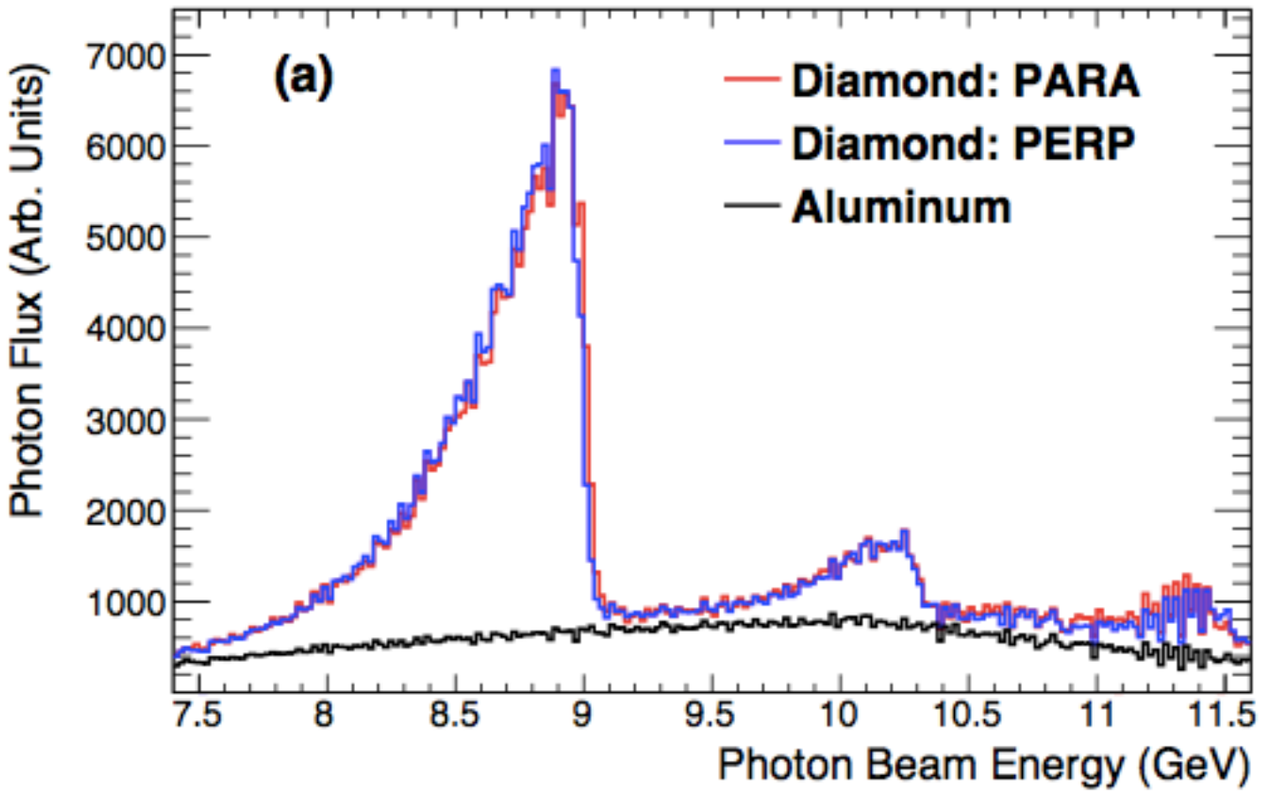


- Linearly polarized photons via coherent bremsstrahlung from diamond radiator
- Design intensity of 10^8 γ/s in coherent peak between E_γ = 8.4 and 9 GeV

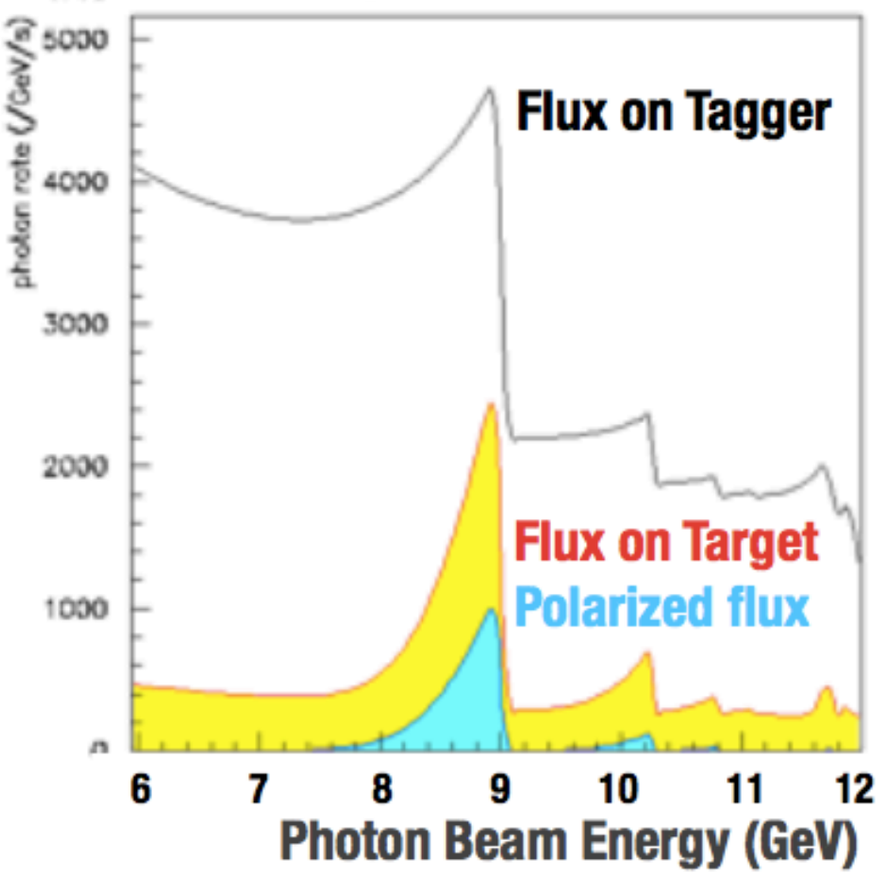
The Beam Line



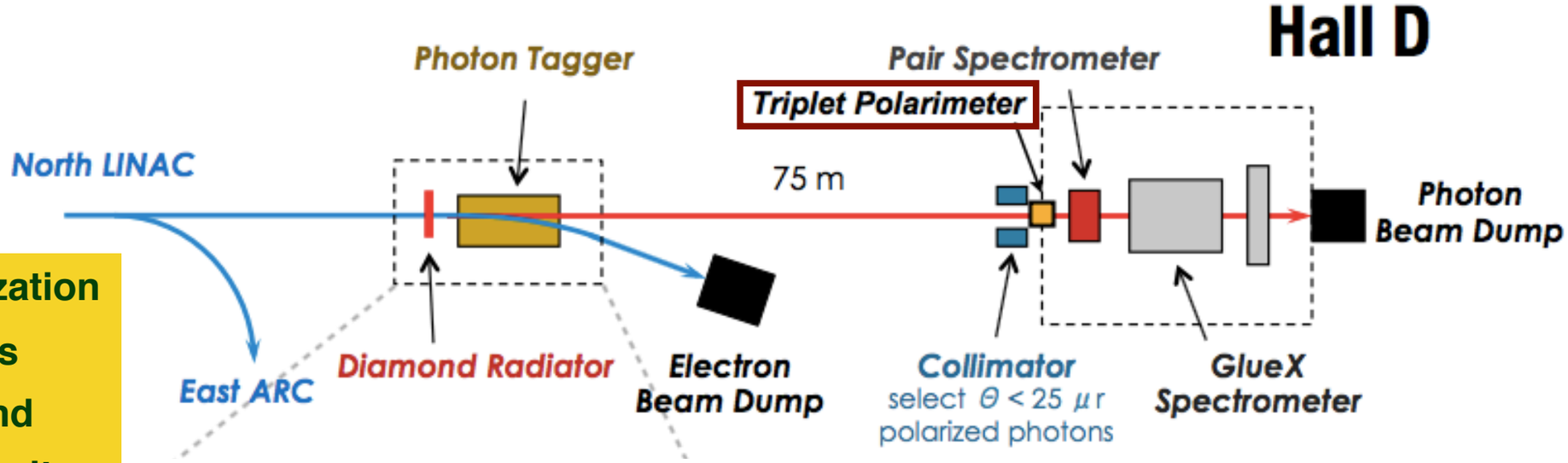
Measured Flux



Expected Flux



The Beam Line



Linear polarization separates natural and unnatural parity

- **Triplet production**

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

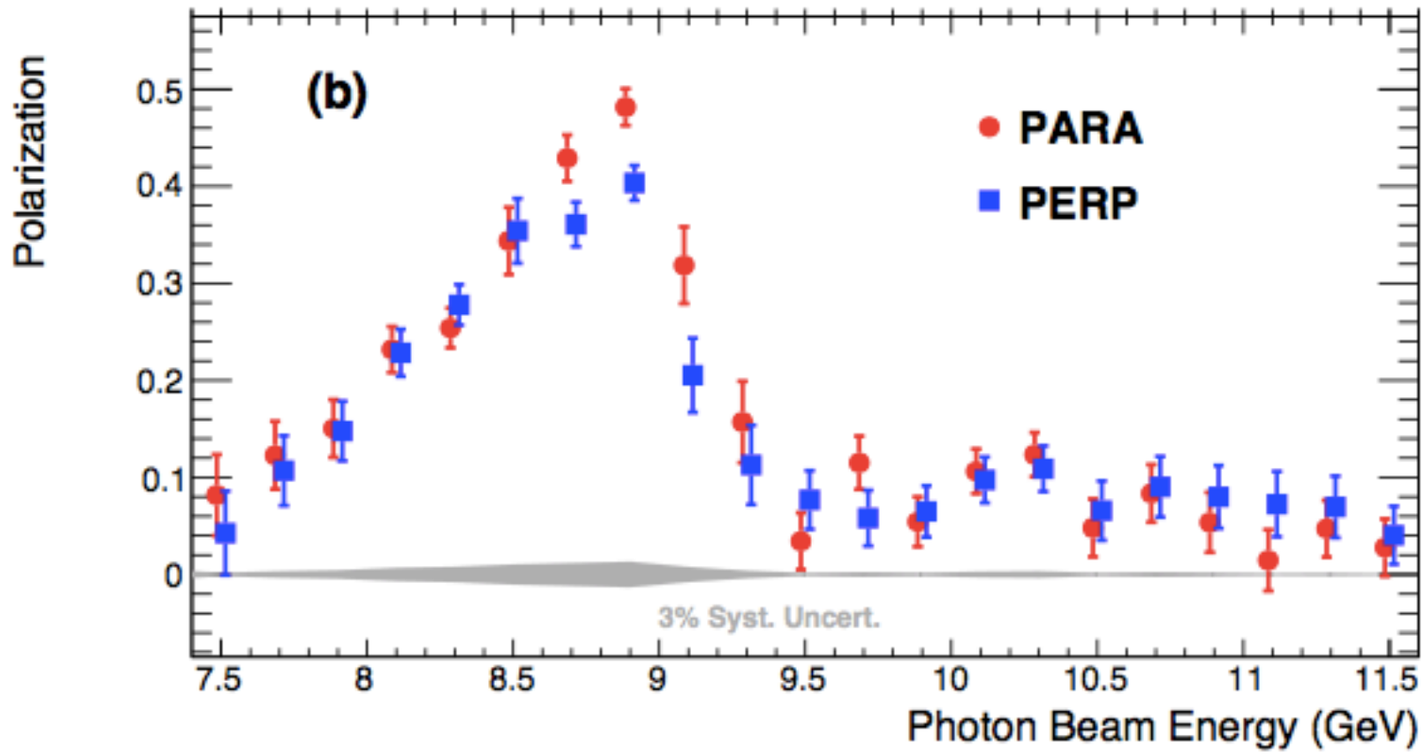
  - Known analyzing power

$$d\sigma \sim 1 \pm P\Sigma cos(2\phi_{e^-})$$

  - Measure beam polarization independent of spectrometer

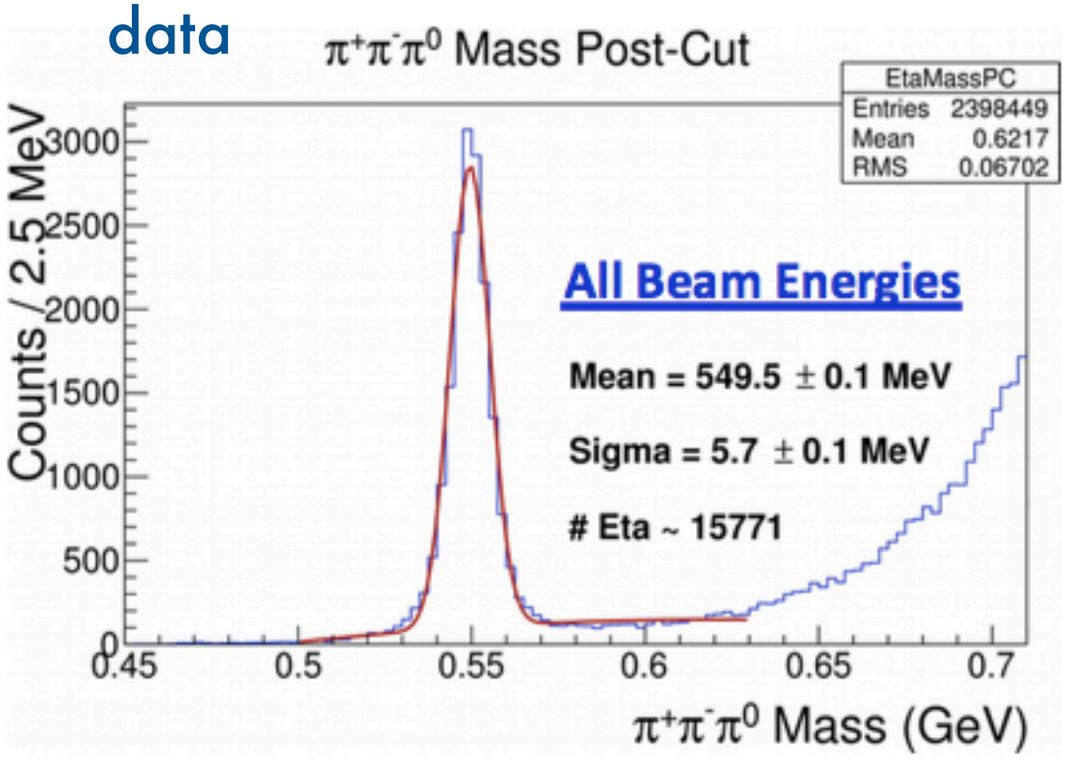
arXiv:1703.07875

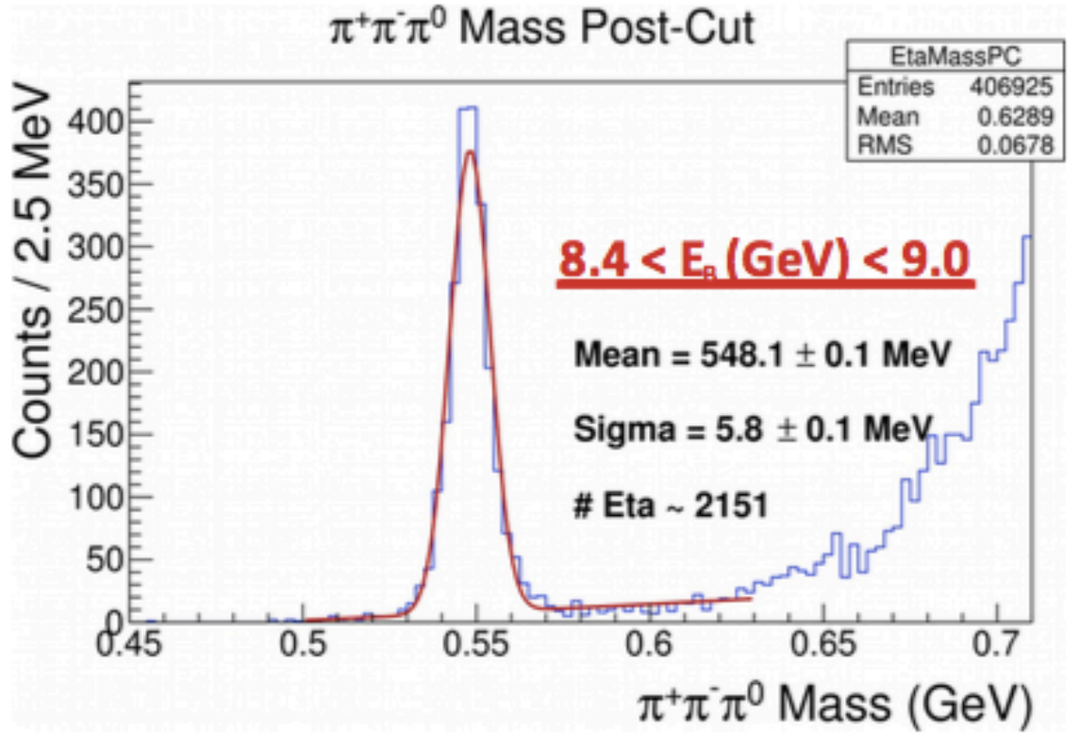
Measured Polarization



Spring 2016 data

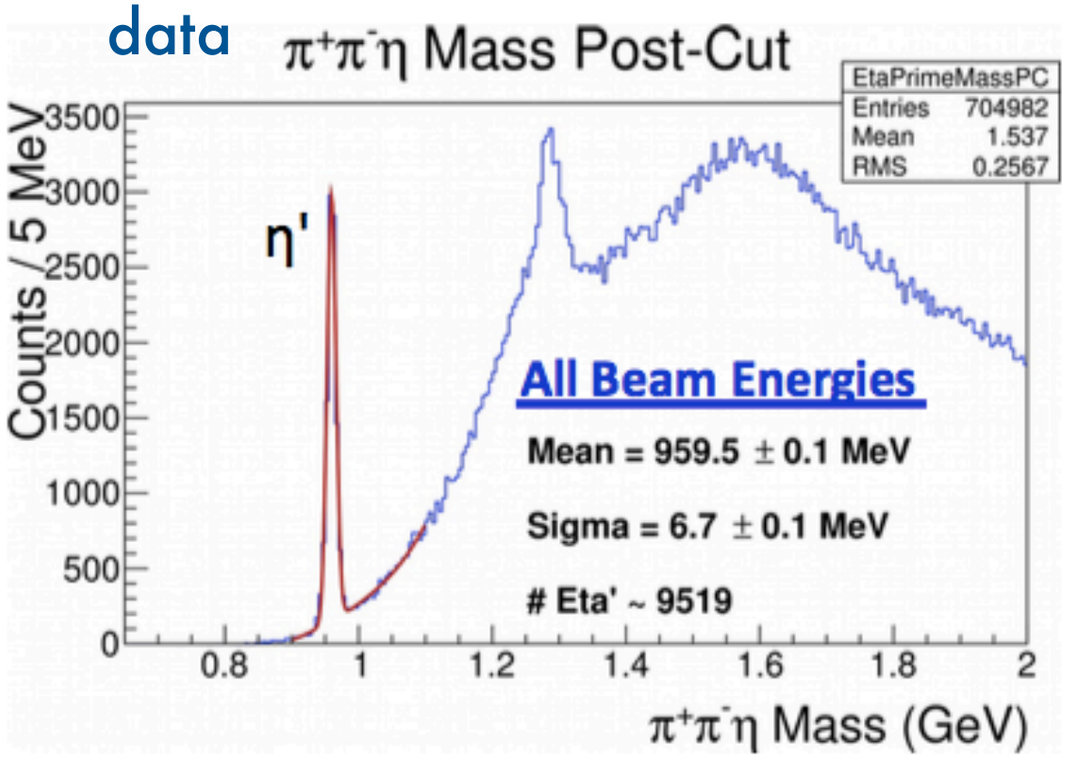
$\eta \rightarrow \pi^+\pi^-\pi^0$ Mass Spectrum

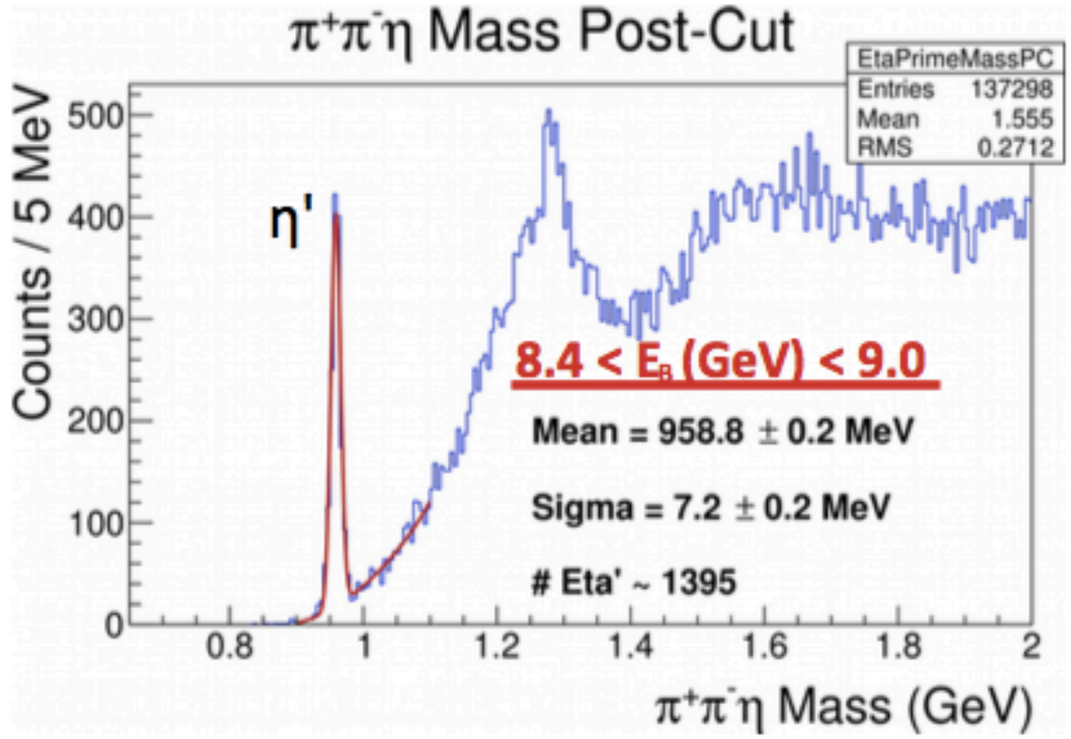




Spring 2016 data

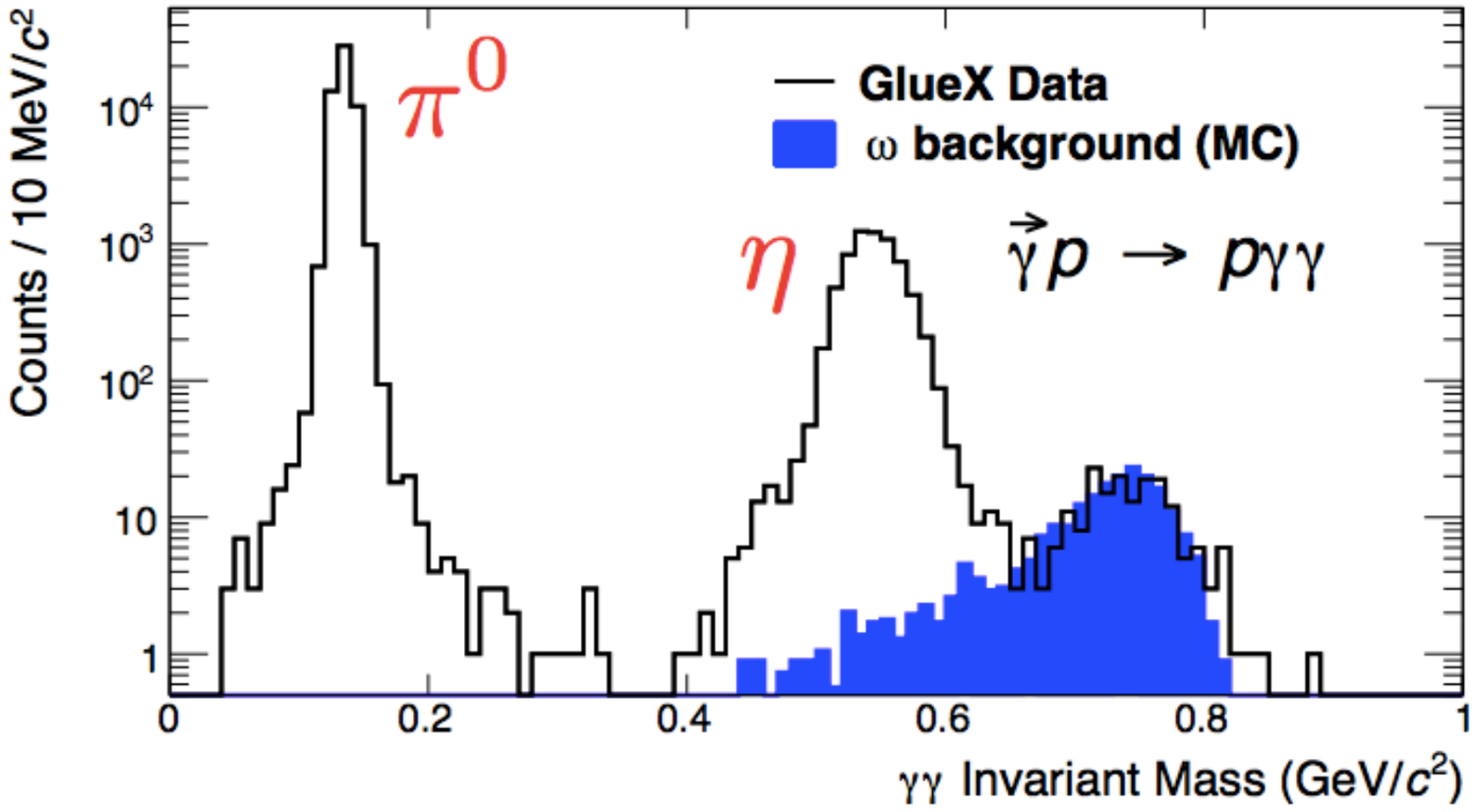
$\eta' \rightarrow \pi^+\pi^-\eta$ Mass Spectrum



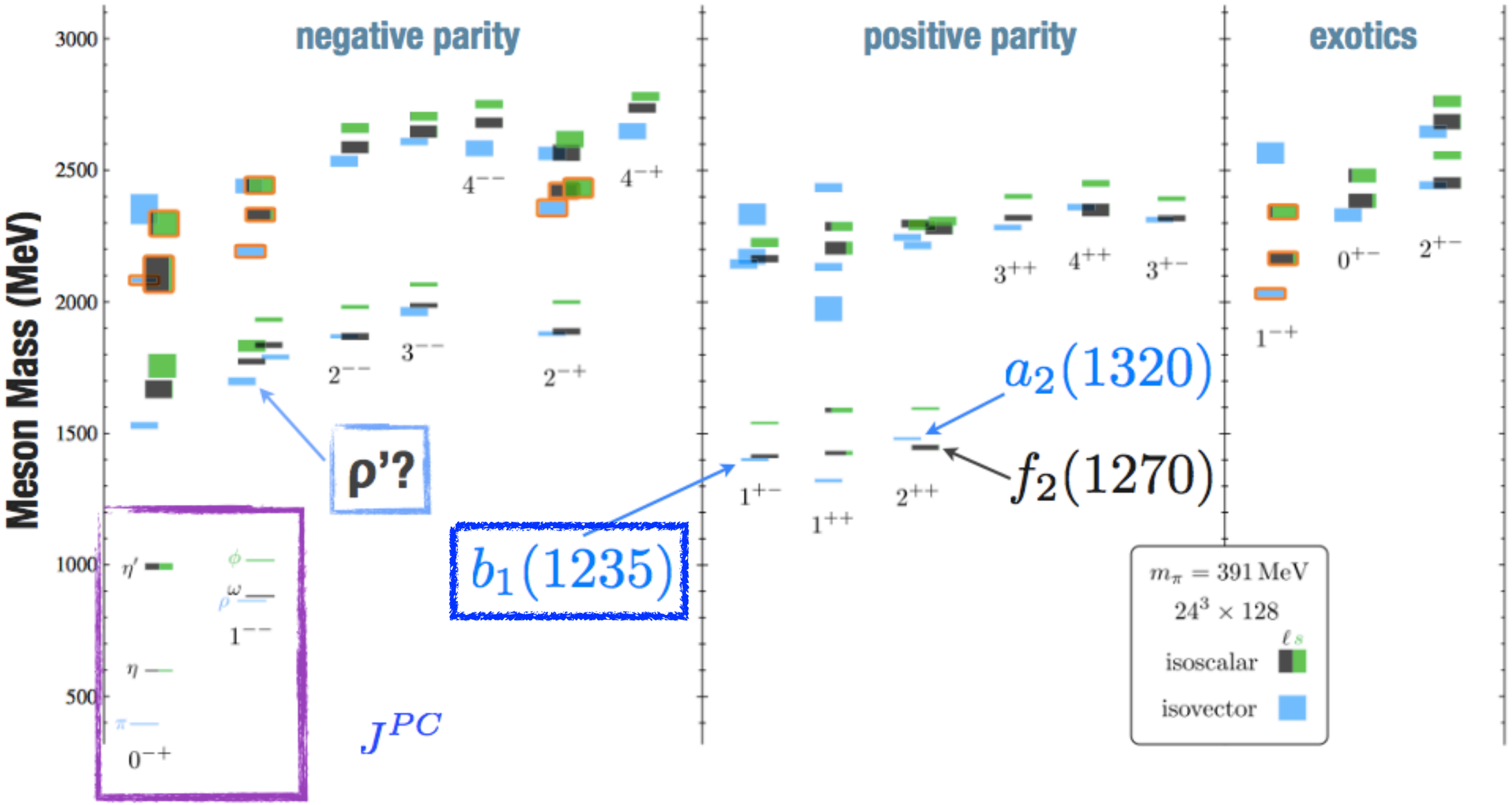


η Background

$$\gamma p \rightarrow p\gamma\gamma$$

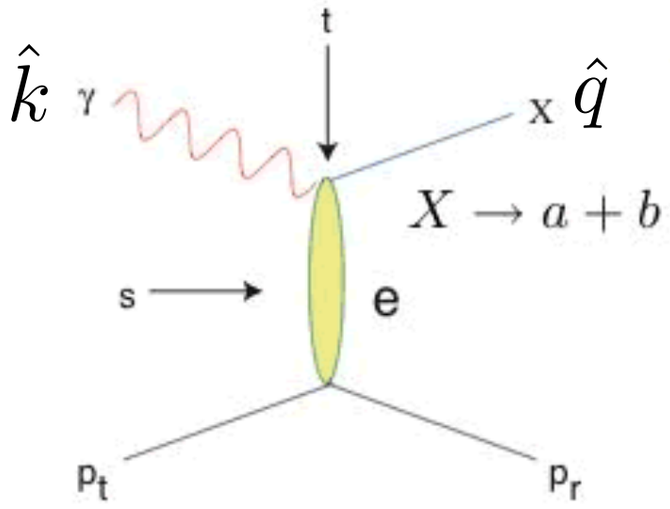


Check the map



- Already studying polarization observables for **"simple" final states**
- Beginning to identify **known mesons** in multi-particle final states

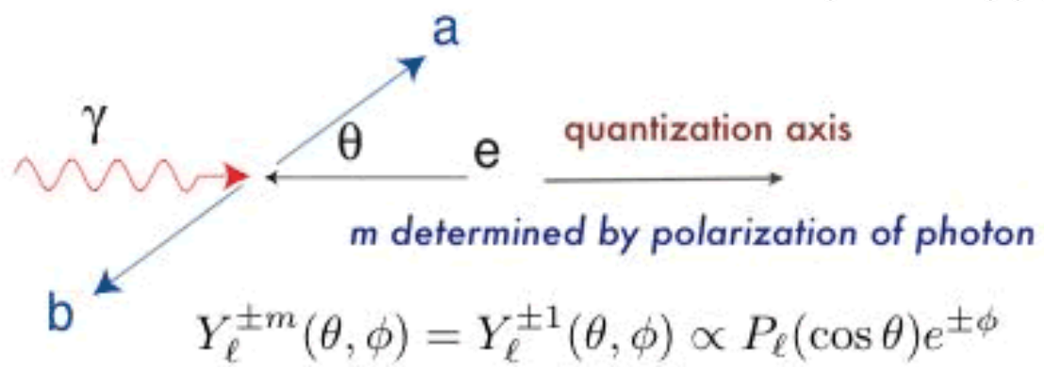
Linear Polarization



assume that X decays into two spin-less mesons: a and b
and that e is also spin-less

$$\epsilon = -cos\phi\hat{n} + sin\phi(\hat{n} \times \hat{k})$$

$$\hat{\boldsymbol{n}} \equiv \hat{\boldsymbol{k}} \times \hat{\boldsymbol{q}}$$



m determined by polarization of photon

$$Y_\ell^{\pm m}(\theta,\phi) = Y_\ell^{\pm 1}(\theta,\phi) \propto P_\ell(\cos\theta)e^{\pm\phi}$$

For circularly polarized photons: m = +1 or m = –1 ➡ $W(\theta,\phi) \propto |P_\ell(\cos\theta)|^2$

For unpolarized photons:
equal mixture of m = +1 and m = –1 ➡ $W(\theta,\phi) \propto |P_\ell(\cos\theta)|^2$

Linear polarization separates natural and unnatural parity

For x - linear polarization: ➡ $W(\theta,\phi) = |Y_\ell^{+1} - Y_\ell^{-1}|^2 \propto |P_\ell(\cos\theta)|^2 \sin^2\phi$

For y - linear polarization: ➡ $W(\theta,\phi) = |Y_\ell^{+1} + Y_\ell^{-1}|^2 \propto |P_\ell(\cos\theta)|^2 \cos^2\phi$

States of linear polarization are eigenstates of parity: access to the nature of the exchange particle.

✓ **Essential to isolate the production mechanism ("e") if X is known**

✓ **A J^{PC} filter if "e" is known (via a kinematic cut)**