Current Status of Hadronic Physics with

GlueXcitations Experiment at Jefferson Lab

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The George Washington University

(for GlueX Collaboration)

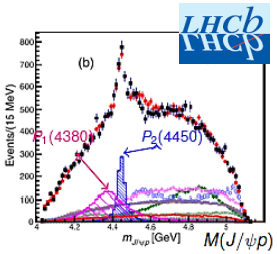
- GlueX Project: Motivation.
- GlueX Experiment.
  - Pseudoscalars.
  - Scalars & Tensors.
  - Vectors.
  - Cascades.
- Summary.

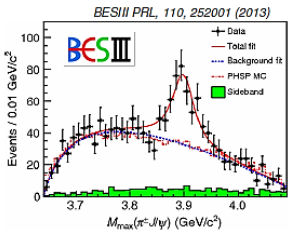
*Supported by DE-SC0016583

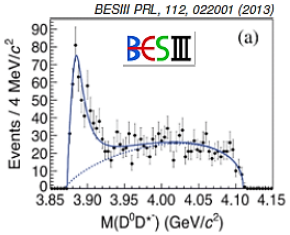
GlueX Project

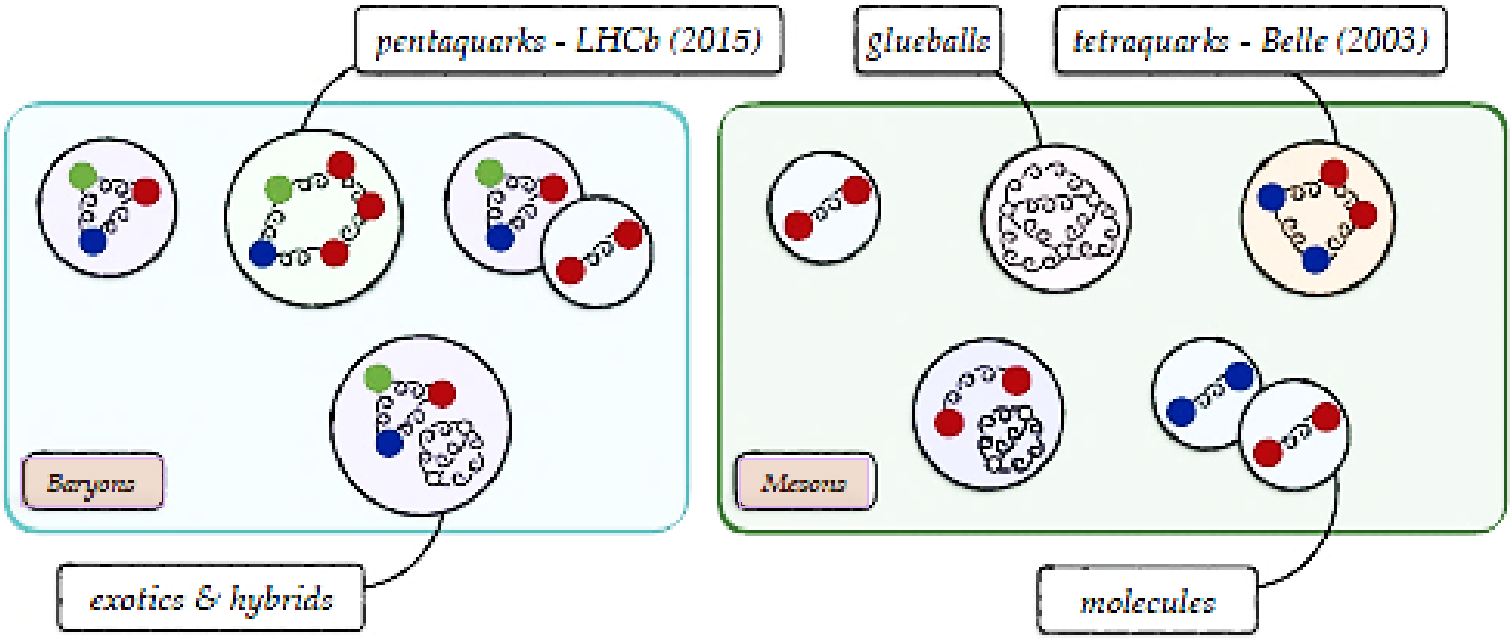
125+ *members*
from ***26*** *institutions*

Hadrons
QCD's rich spectrum







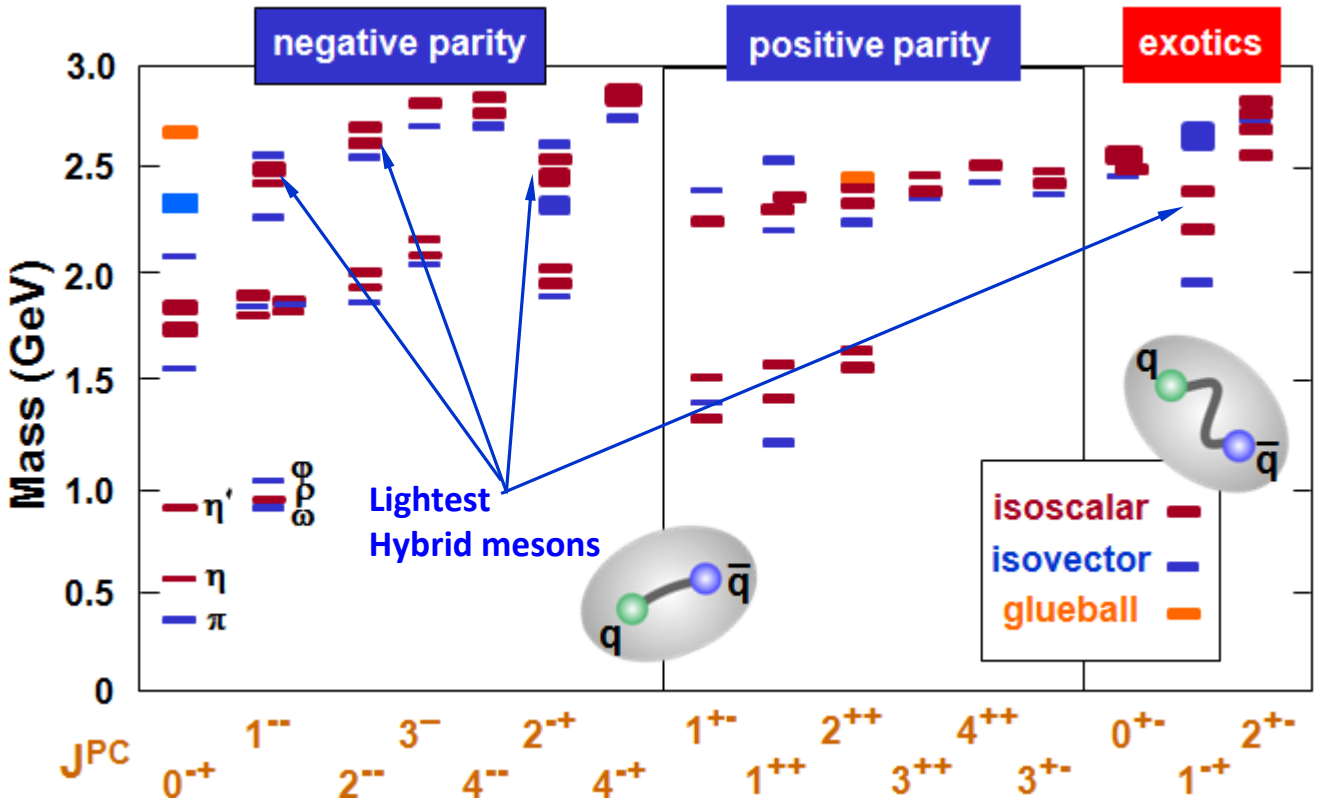


JLab searches: CLAS12 GLUEX

Courtesy of Raúl Briceño, 2018

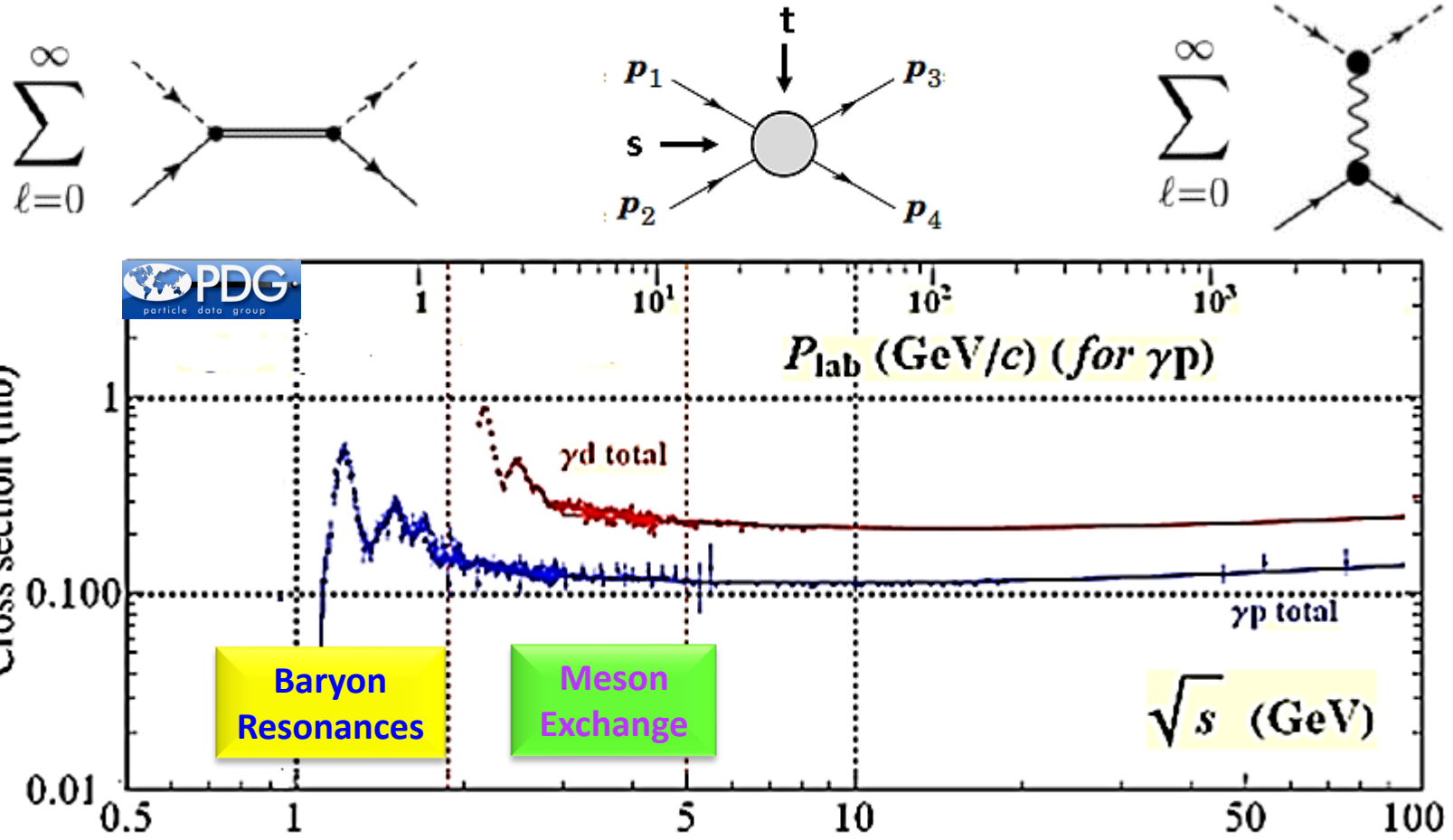
Lattice QCD: Mesons

Primary goal of GlueX experiment is to search for & ultimately map out **spectrum** of **light quark hybrid mesons**.



J.J. Dudek *et al,* Phys Rev D **88**, 094505 (2013)

Low- & High-Energy Dynamics for Meson Photoproduction



Jefferson Lab clas

GLUEX Gluonic Excitations Experiment

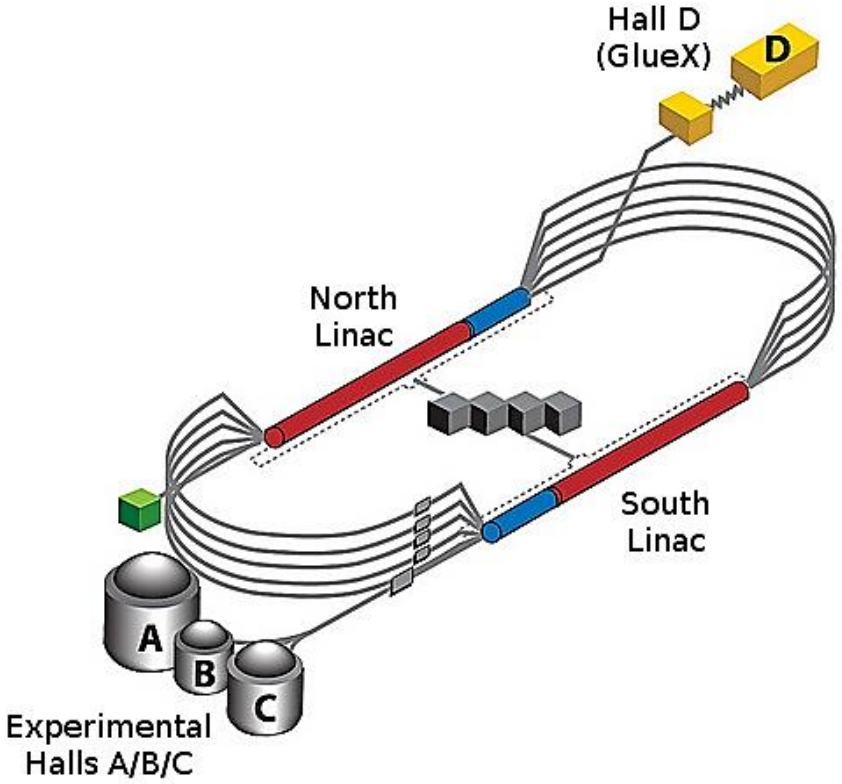
CLAS12

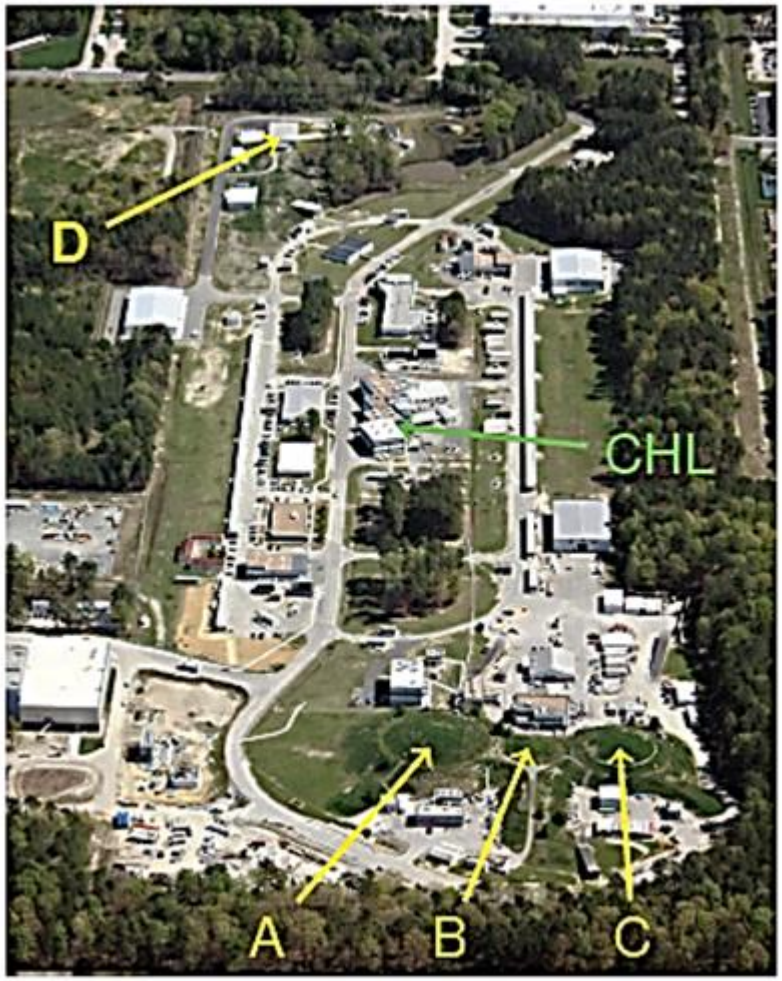
GlueX Experiment

Current Status: Begin by understanding non-exotic production mechanisms.

Type	S	L	J^P
Pseudoscalar	0	0	0^-
Pseudovector	0,1	1	1^+
Vector	1	0,2	1^-
Scalar	1	1	0^+
Tensor	1	1,3	2^+

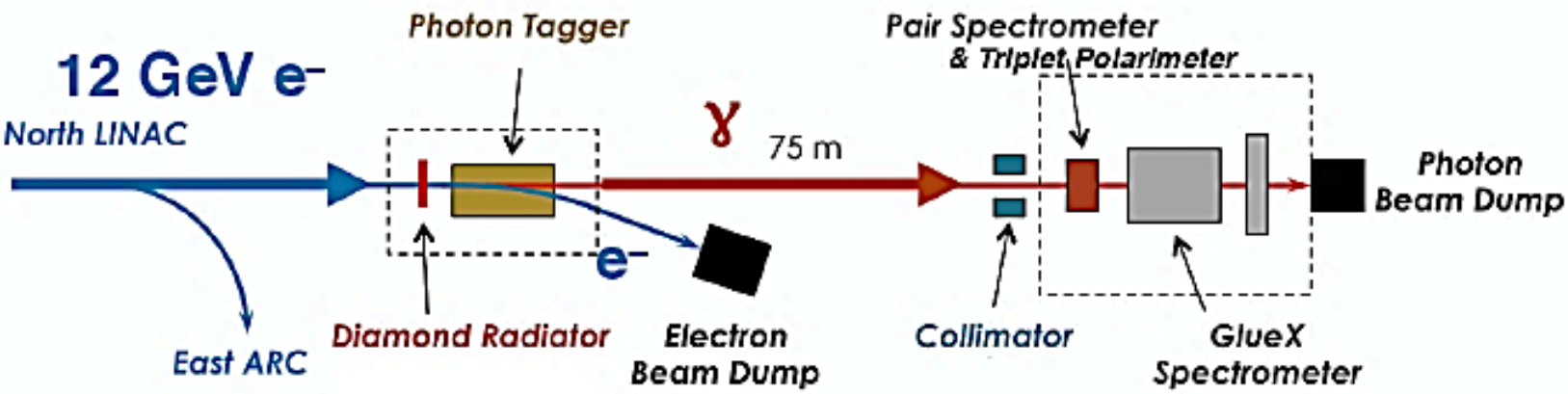
Tatev Monastery, 9th-century

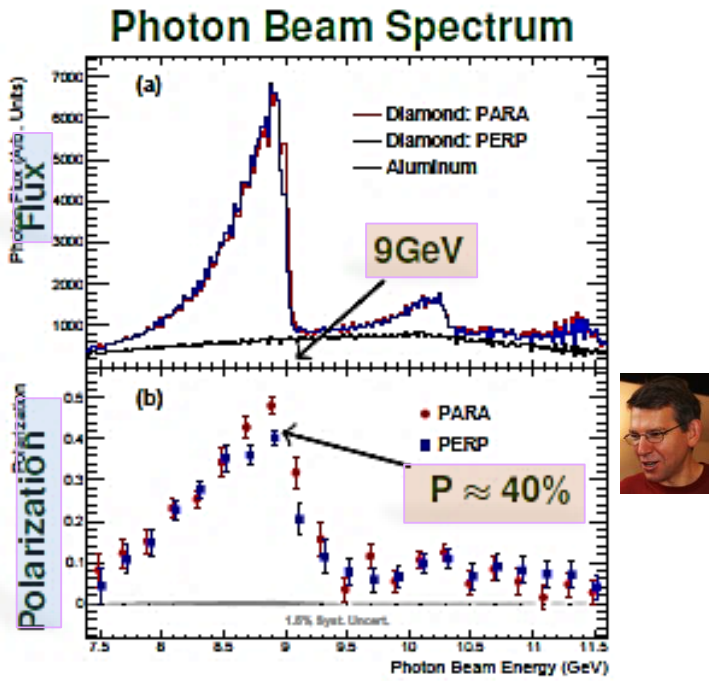


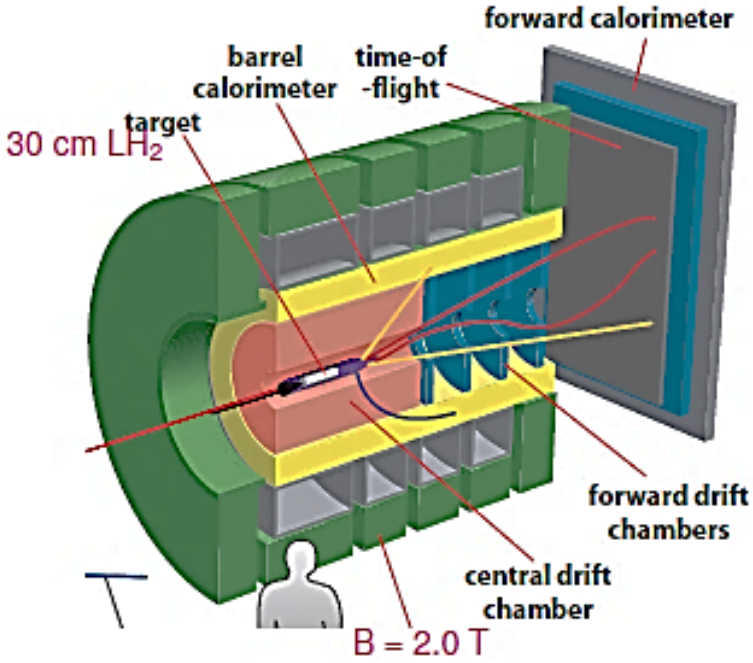


- Accelerator: 2.2 GeV/pass
- Halls A,B,C: e^- 1-5 passes $\leq$11 GeV
- Hall D: e^- 5.5 passes 12 GeV $\Rightarrow$ γ-beam
- Runs 2017-2018: 5.5 passes 11.7 GeV

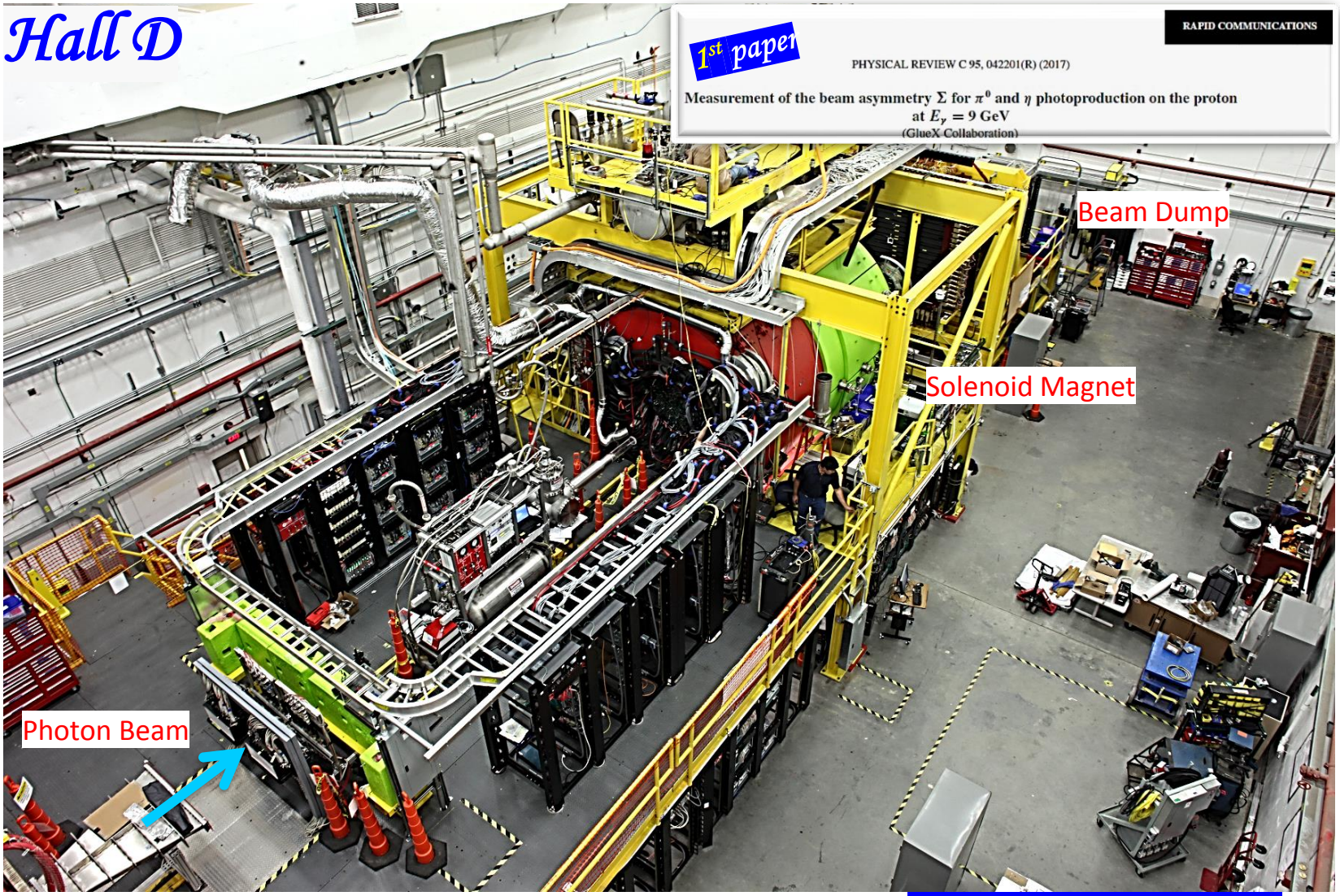
Hall D/GlueX Meson Spectroscopy in Photoproduction







Hall D



1st paper

RAPID COMMUNICATIONS

PHYSICAL REVIEW C 95, 042201(R) (2017)

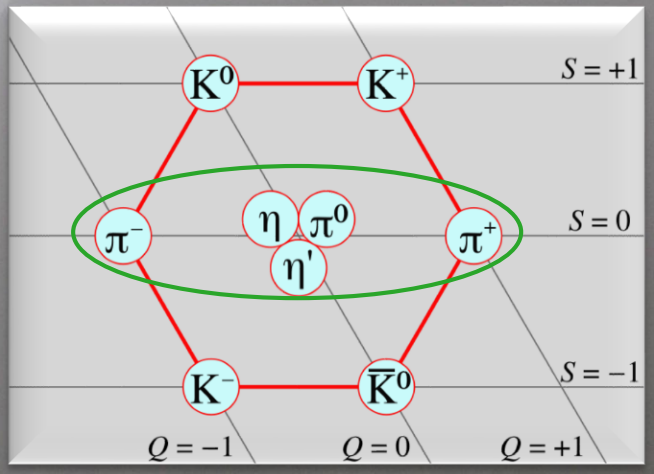
Measurement of the beam asymmetry Σ for π^0 and η photoproduction on the proton at $E_\gamma = 9$ GeV

(GlueX Collaboration)

GlueX Statistics: above 8.2 GeV

- Spring **2016**: **10 pb^{-1}** ⇒ Source for the 1st paper
- Spring **2017**: **45 pb^{-1}**
- Spring **2018**: **100 pb^{-1}**
- Fall **2018**: in progress

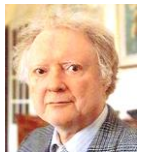
Photoproduction of Pseudoscalar Mesons



$J^P = 0^-$

Regge Pole Model

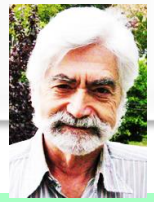
with Regge-cut corrections

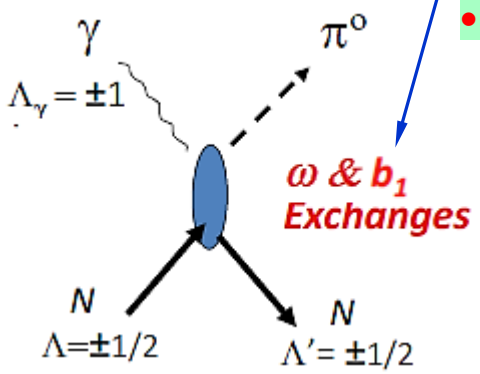


IL NUOVO CIMENTO Vol. XXXII, N. 3 1° Maggio 1964

The Reaction $\gamma + \mathcal{N} \to \pi + \mathcal{N}$ at High Energies

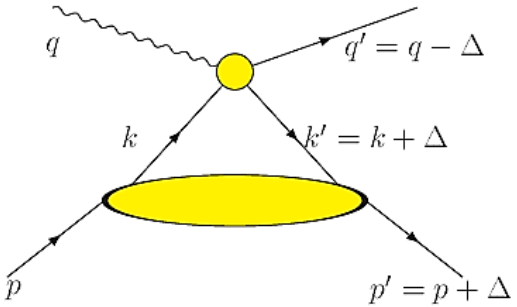
G. ZWEIG





- There were no b_1 mesons back to **1964**.

- **Regge cut** amplitudes are incorporated into some models & are interpreted as re-scattering of on-shell meson-nucleon amplitudes.
- ω-exchange is dominant in π^0 photproduction. That is unique case in **meson photoproductions** – **single** trajectory.



Handbag Model

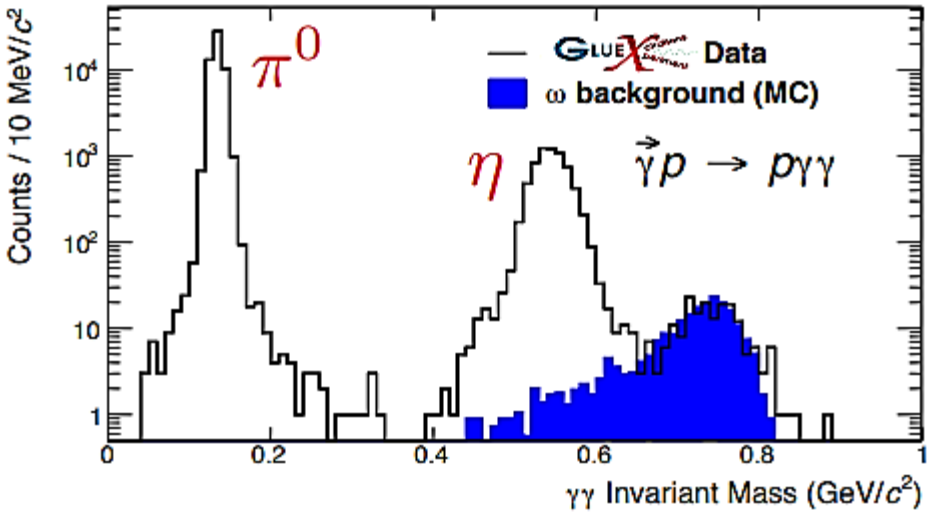
with twist-3 contribution

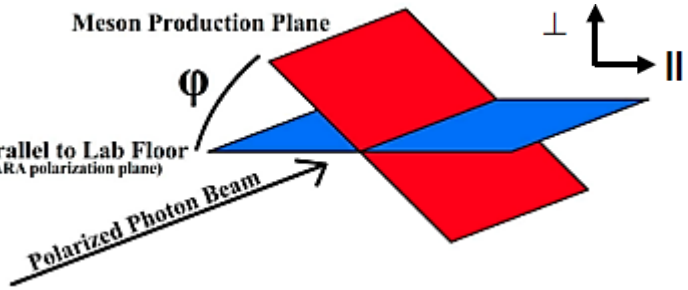
H.W. Huang & P. Kroll, Eur Phys J C **17**, 423 (2000)

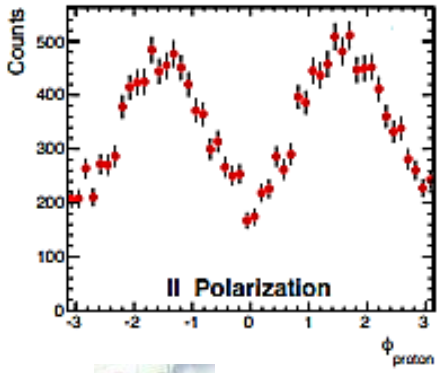
- Reaction is factorized into **two** parts:
  - One quark from incoming & one from outgoing nucleon participate in hard sub-process, which is calculable using **pQCD**.
  - Soft part consists of all other **partons** that are spectators & can be described in terms of **GPD**s.

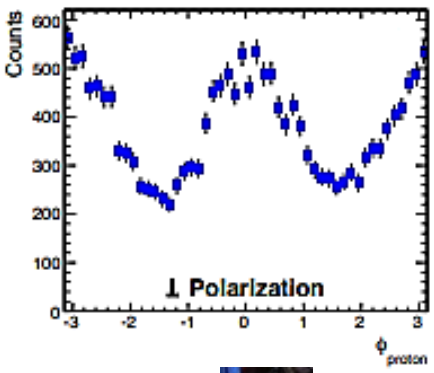
Σ Beam Asymmetry for $\vec{\gamma}p \to p\pi^0$

$$\gamma p \to p\gamma\gamma$$







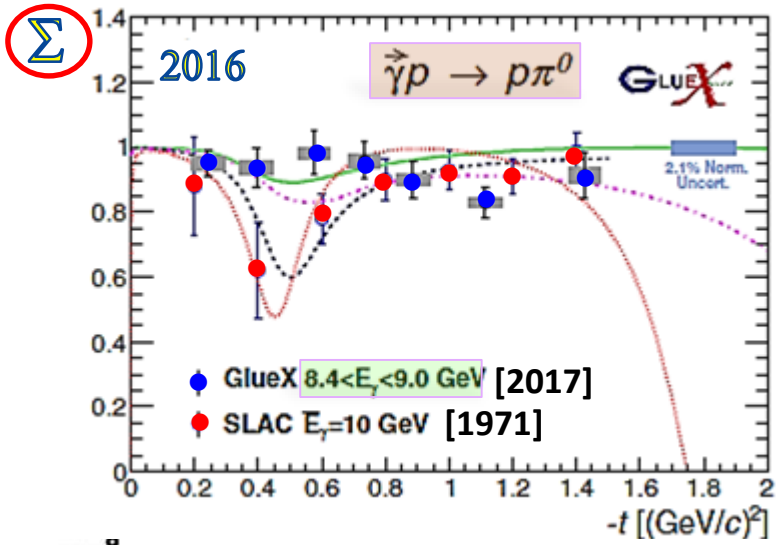


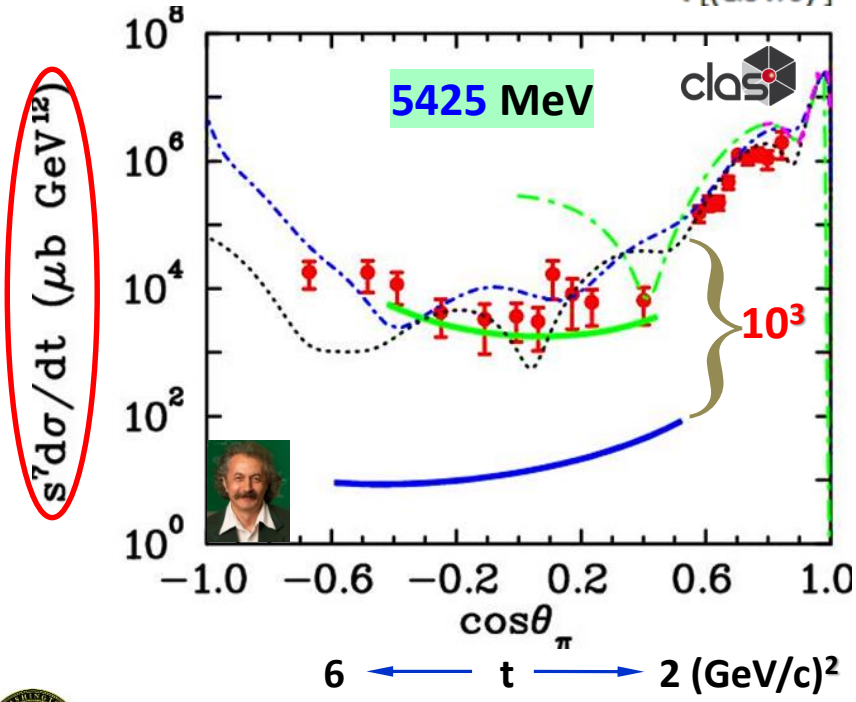
$$\sigma = \sigma_0 \left(1 - P_\gamma \Sigma \cos 2(\phi_p - \phi_\gamma^{\text{lin}})\right)$$

H. Al Ghoul *et al,* Phys Rev **95**, 042201(R) (2017)

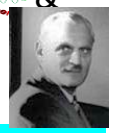
Courtesy of Justin Stevens, 2017

Courtesy of Zhenyu Zhang, 2017





- GlueX Σ closes to **unity**.
- There is some **disagreement** between GlueX & SLAC measurements.



- **Mike Dugger**: At **dip**, SLAC had huge background from **Compton**.
- Preliminary **2017** confirms **2016** data sample.
- **Dip** at |t|~**0.5** (GeV/c)^2 in multiple **Regge** predictions observed.

Goldstein73
Laget11
Mathieu15
Donnachie16

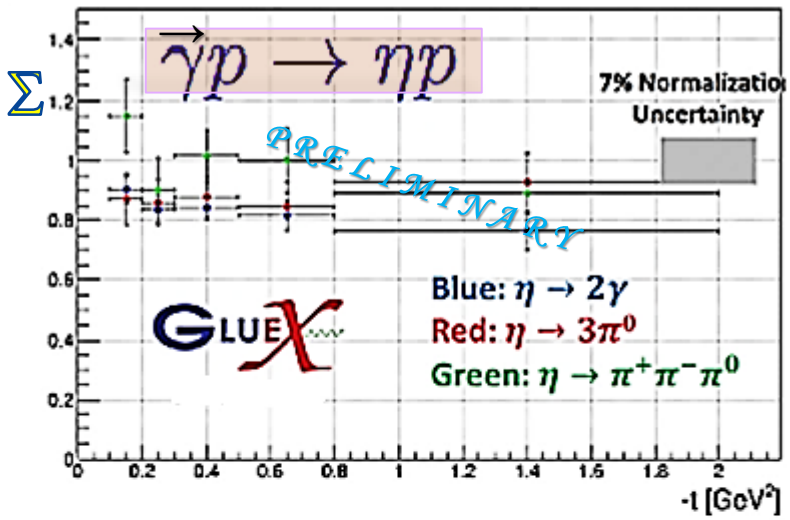
H. Al Ghoul *et al*, Phys Rev **95**, 042201(R) (2017)

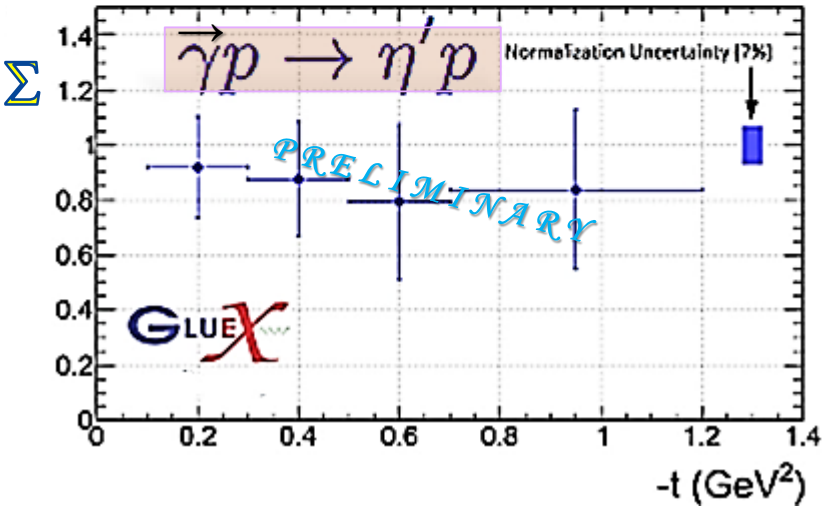
- **Regge** exchange based models for π^0 photoproduction are more consistent with clas experimental data.
- **Size** of angular distribution of measured clas cross sections is greatly **underestimated** by **QCD** based **GPD** mechanism at **s = 11 GeV^2**.
- Numerical studies **reveal** dominance of **twist-3** contribution.

Goldstein73
Laget11
Mathieu15
Donnachie16
Kroll00
Kroll18

M. Kunkel *et al*, Phys Rev C **98**, 015207 (2018)

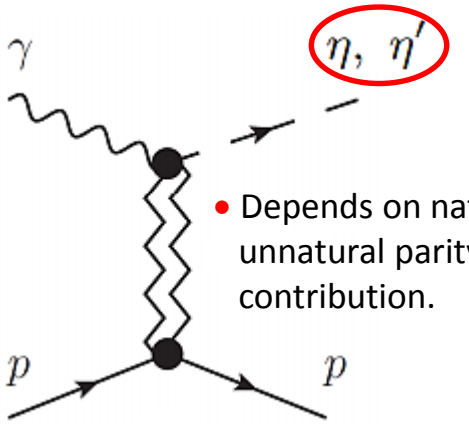
Σ Beam Asymmetry for $\vec{\gamma}p \to \eta p$ & $\vec{\gamma}p \to \eta' p$





- **First** high-energy measurements.
- **Σ** closes to **unity**.
- Preliminary **2017** confirms **2016** data **η** sample.
- Dominated by **vector**-meson exchange.
- Consistent with JPAC predictions.

V. Mathieu *et al,* Phys Lett B **774**, 362 (2017)



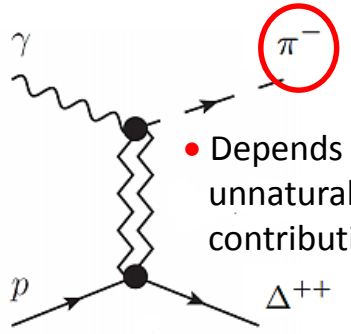
- Depends on natural & unnatural parity meson contribution.

Courtesy of William McGinley, 2018

Courtesy of Teagan Beattie, 2018

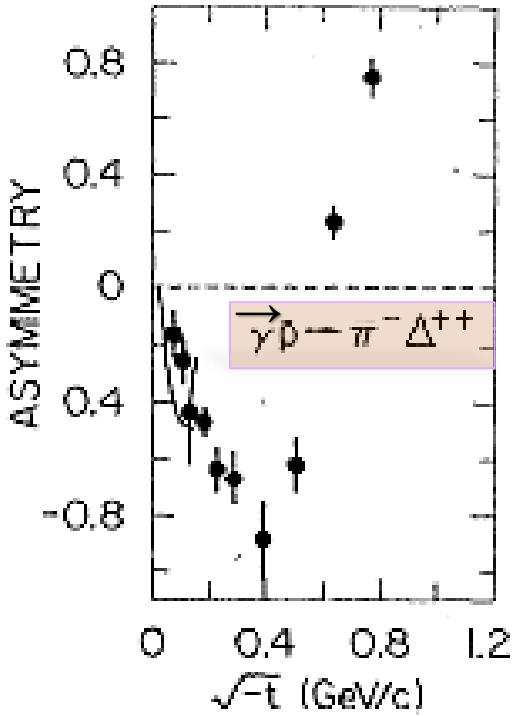
Early Spectroscopy Opportunity

$\vec{\gamma}p \to \pi^-(\pi^+ p)$ or $(\pi^-\pi^+)p$



- Depends on natural & unnatural parity meson contribution.

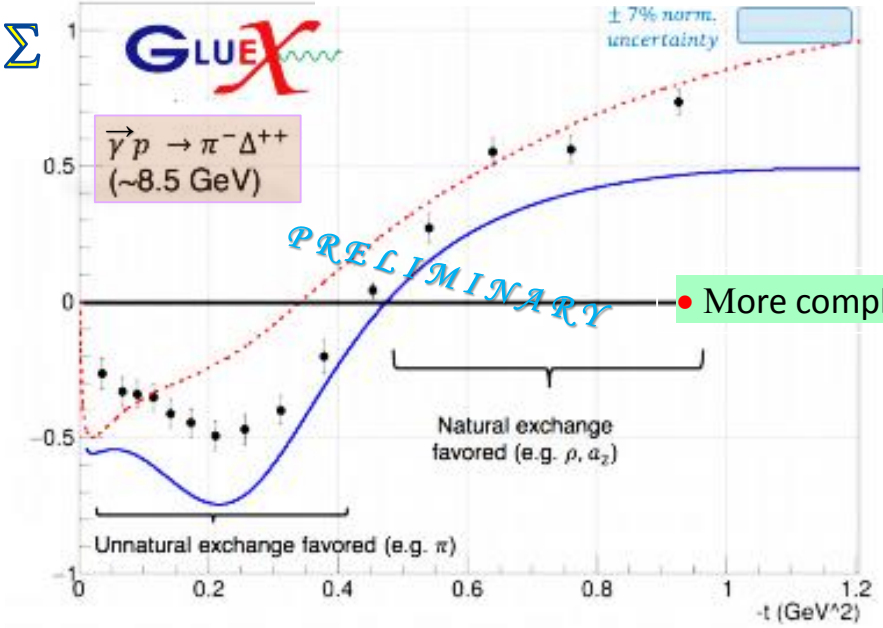
SLAC @16 GeV



D. J. Quinn *et al,* PRD **20**, 15553 (1979)

(16 GeV) B.-G. Yu *et al,* Phys Lett B **769**, 262 (2017)

(8.5 GeV) J. Nys *et al,* Phys Lett B **779**, 77 (2018)

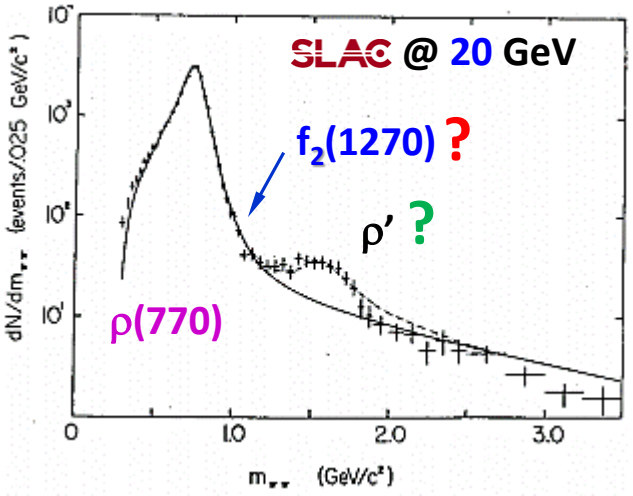


- More complicated **t**-dependence.

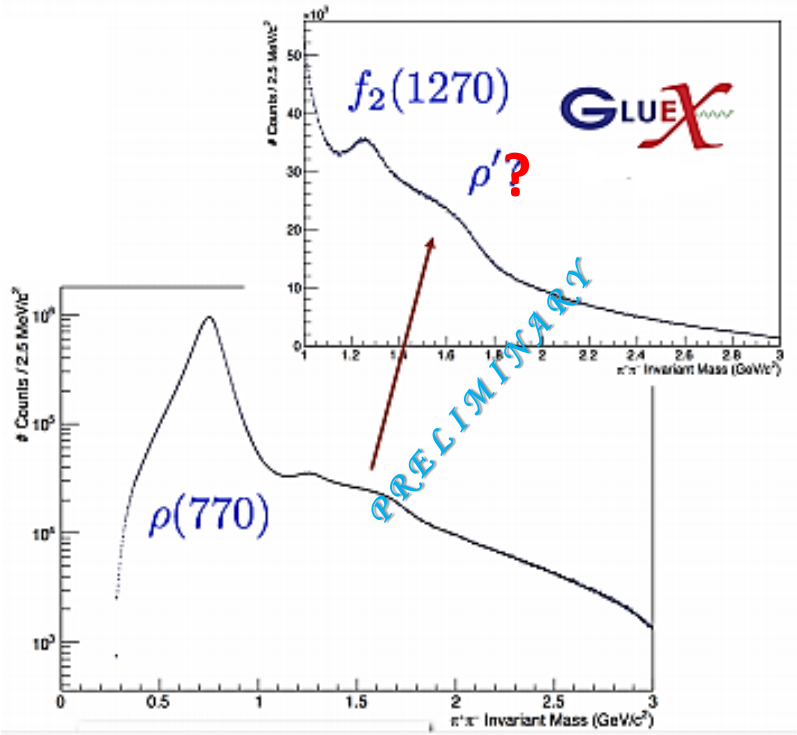
Courtesy of Jonathan Zarling, 2018

Early Spectroscopy Opportunity

$\vec{\gamma}p \rightarrow \pi^-(\pi^+ p)$ or $(\pi^-\pi^+)p$



K. Abe *et al.* Phys Rev Lett **53**, 751 (1984)



Courtesy of Jonathan Zarling, 2018

- Enhancement of GlueX consistent with early SLAC measurements but **1000x** more statistics.

Photoproduction of Scalar & Tensor Mesons

$J^P = 0^+$ $J^P = 2^+$

$a_0(980)$ MASS

VALUE (MeV)	DOCUMENT ID
980±20 OUR ESTIMATE	Mass determination very model dependent

$a_0(980)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
50 to 100 OUR ESTIMATE		Width determination very model dependent			

$a_0(980)$ DECAY MODES

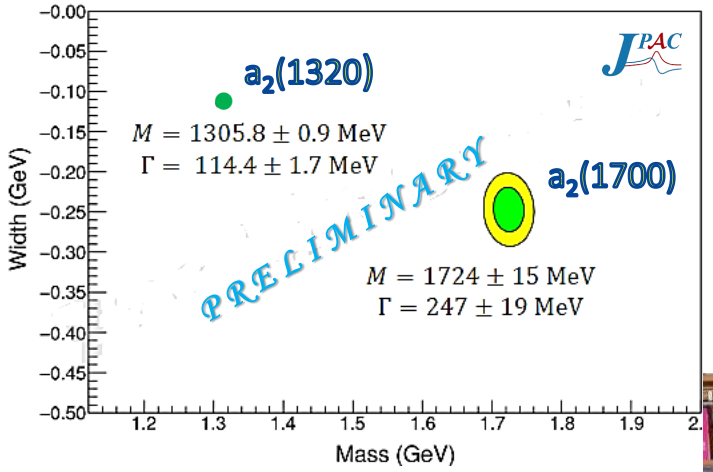
	Mode	Fraction (Γ_i/Γ)
Γ_1	$\eta\pi$	dominant
Γ_2	$K\overline{K}$	seen
Γ_3	$\rho\pi$	
Γ_4	$\gamma\gamma$	seen
Γ_5	e^+e^-	

- **Structure of light scalar meson states is poorly understood.**

Input: COMPASS $\pi^- p \to \eta\pi^- p$ @ **191** GeV/c

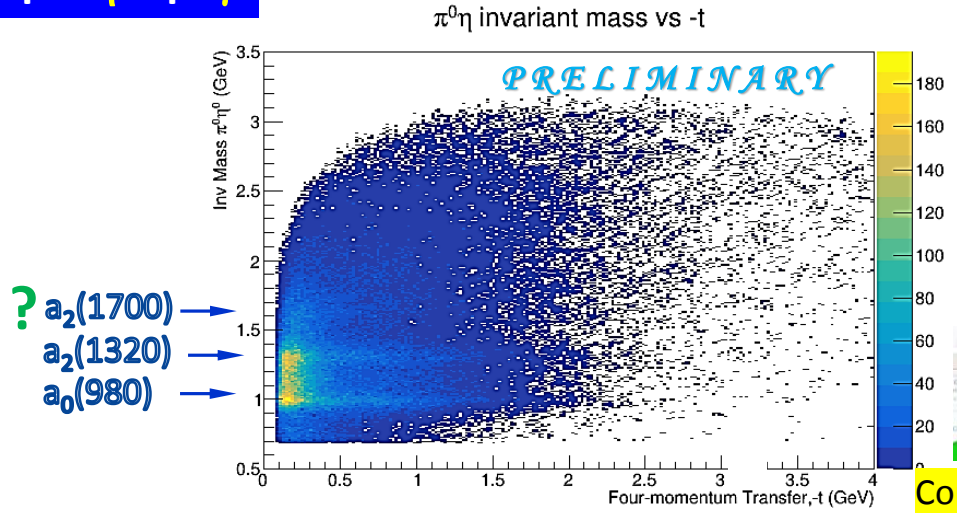
A. Jackura *et al,* Phys Lett B **779**, 464 (2018)

C. Adolph *et al,* Phys Lett B **740**, 303 (2015)



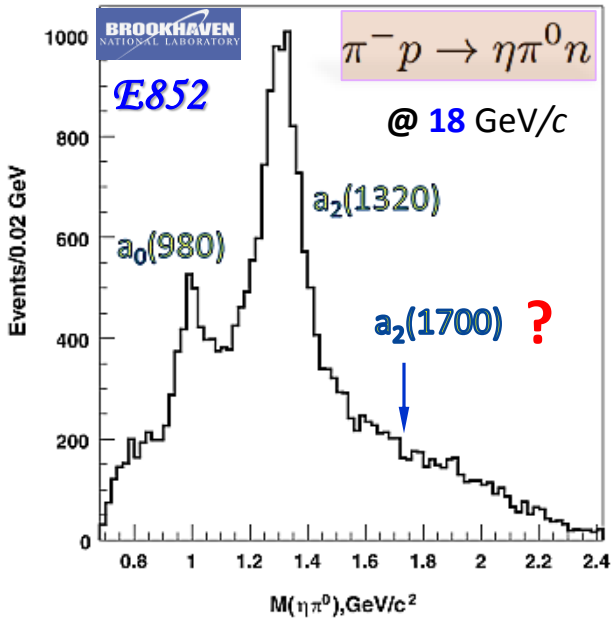
Courtesy of Alessandro Pilloni, 2018

$\gamma p \to p\pi^0\eta \to p4\gamma$

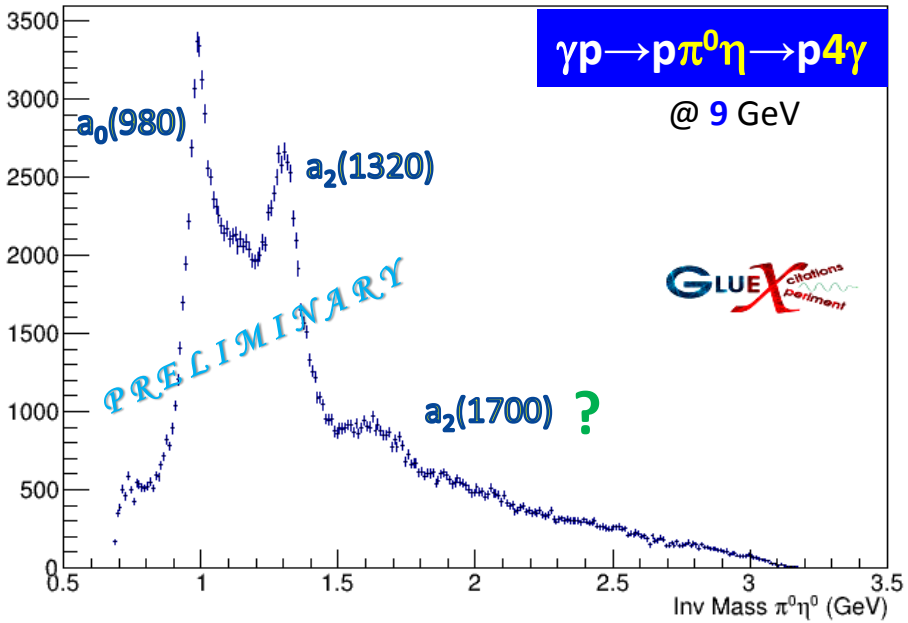


Courtesy of Stuart Fegan, 2018

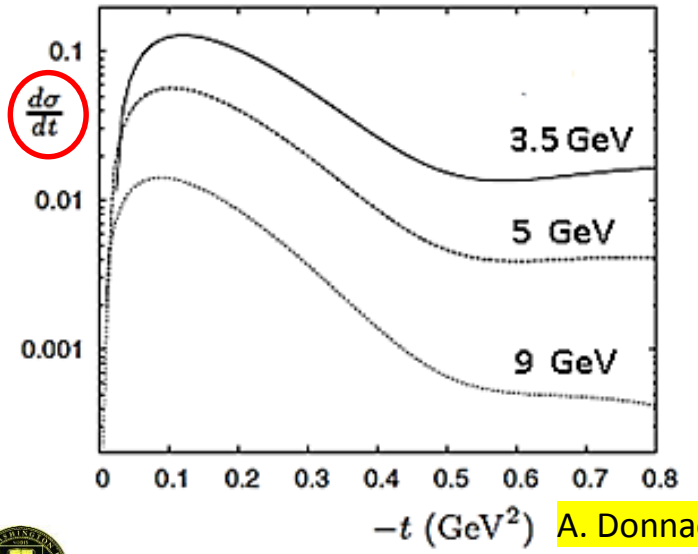
Σ Beam Asymmetry for $\vec{\gamma}p \rightarrow a_0(980)p$



G.S. Adams *et al, Phys* Lett B **657**, 27 (2007)



Courtesy of Stuart Fegan, 2018



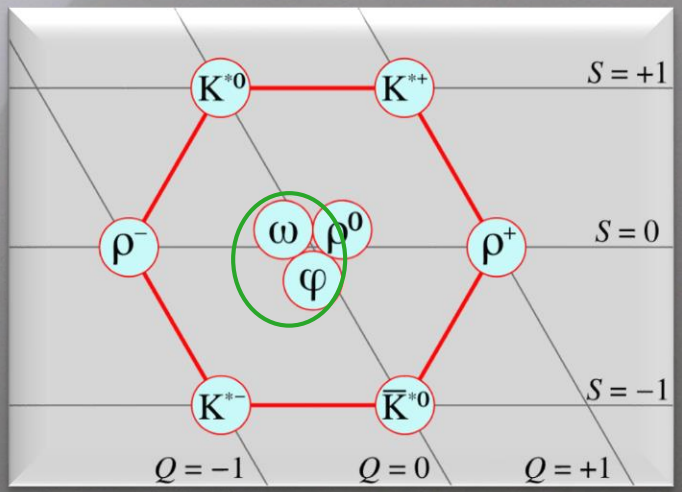
A. Donnachie & Yu. Kalashnikova, Phys Rev C **93**, 025203 (2016)

- Model for a_0 was extend π^0 one to incorporate **Regge cuts**, based on knowledge of π^0 photoproduction.
- One can expect that Σ for π^0 is similar to Σ for a_0.

- GlueX Data are coming in a month or so.
- Theoretical prediction is coming same time.

please stay tuned.

Photoproduction of Vector Mesons

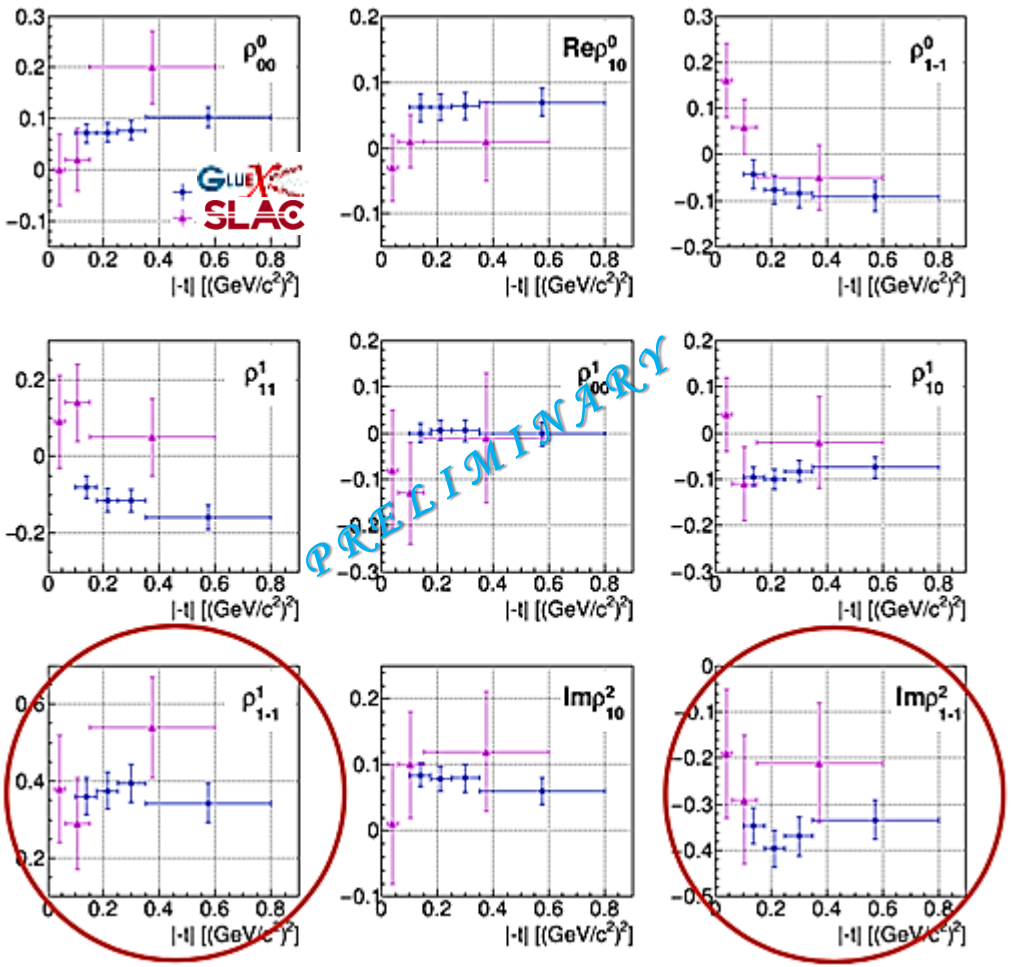


$J^P = 1^-$

$\gamma p \rightarrow \omega p$ $\omega \rightarrow \pi^+\pi^-\pi^0$

- **Spin density matrix elements**: measure transfer polarization from **photon** to **vector meson**.

- Expect contributions from **pseudoscalar** exchange.
- **Consistent** with previous SLAC results.
- Provides **insight** into exchange mechanisms.
- Consistent with **s**-channel **helicity** conservation.



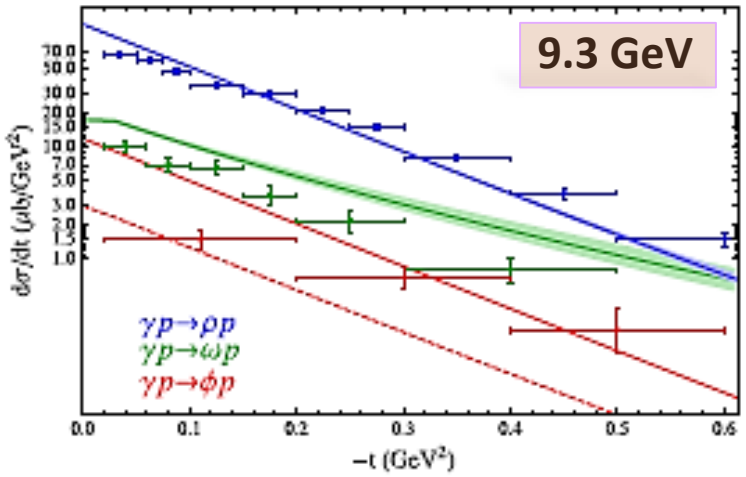
Courtesy of Michael Staib, 2018

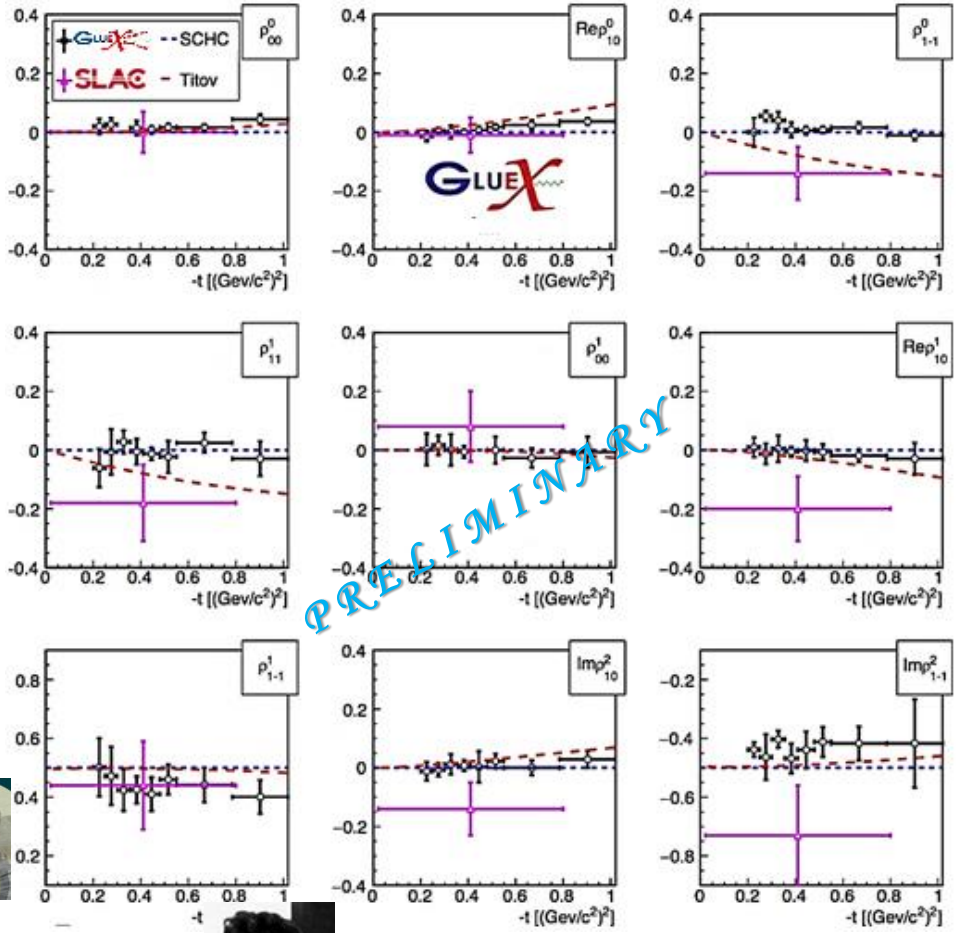
$\gamma p \rightarrow \phi p$ $\quad \phi \rightarrow K^+K^-$

- **Spin density matrix elements**: measure transfer polarization from **photon** to **vector meson**.

SLAC J. Ballam *et al,* Phys Rev D **7**, 3150 (1973)

JPAC V. Mathieu *et al,* Phys Rev D **97**, 094003 (2018)



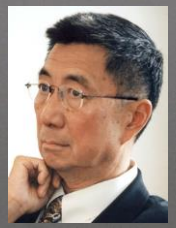


Courtesy of Alex Barnes, 2018

- Consistent with **s**-channel **helicity** conservation.
- Production mechanism dominated by **Pomeron** exchange.

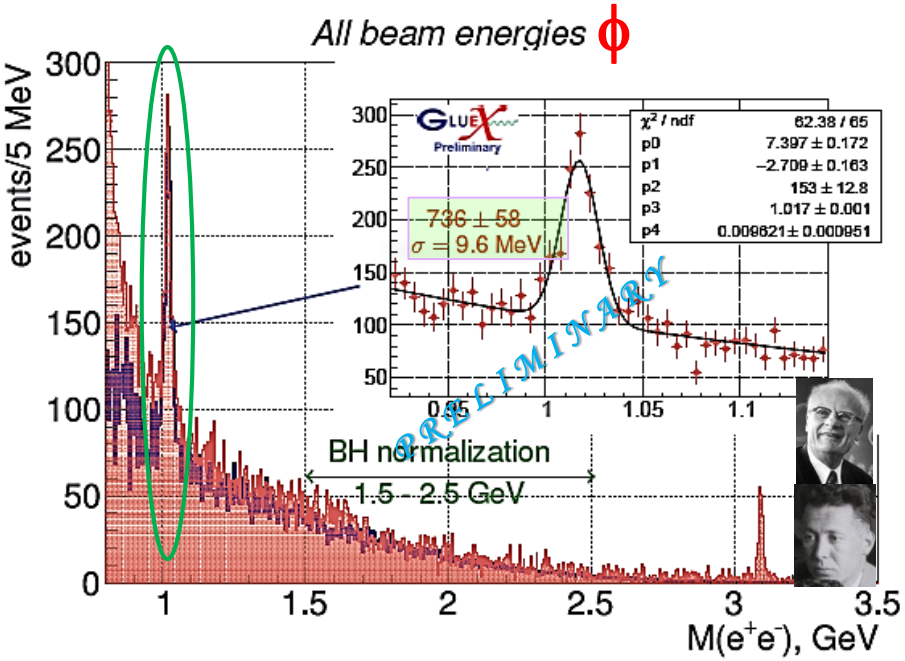
J/ψ Photoproduction at Threshold

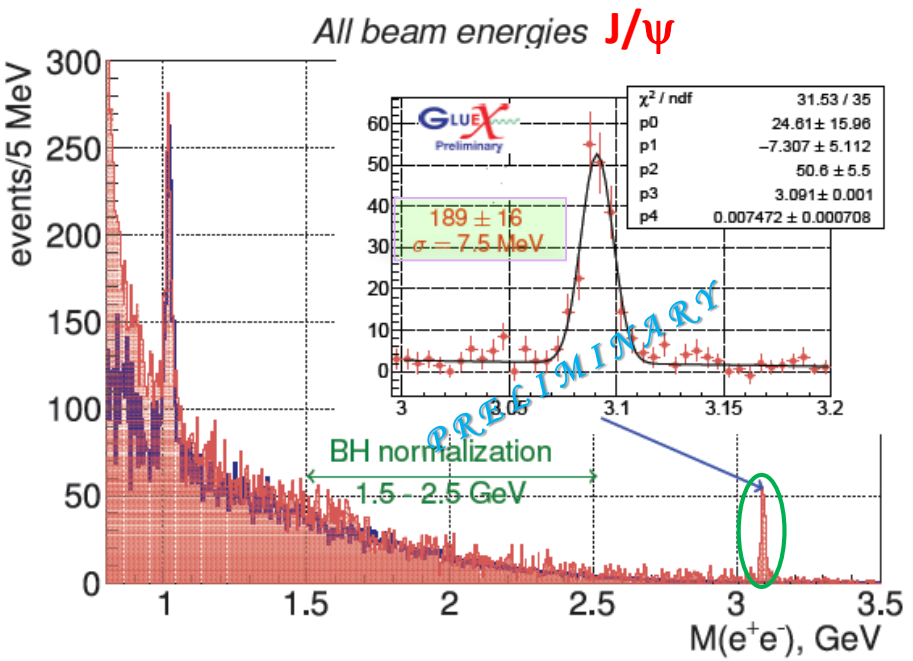
$J^P = 1^-$



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

- Preliminary **cross sections** measured for E_γ = **8.2–12 GeV**
- **Statistics: 2016+2017** data sample (**70 %**)





- Other experiments at Jefferson Lab (CLAS & Hall C) have been scheduled to near future to measure same process.

Courtesy of Lubomir Pentchev, 2018

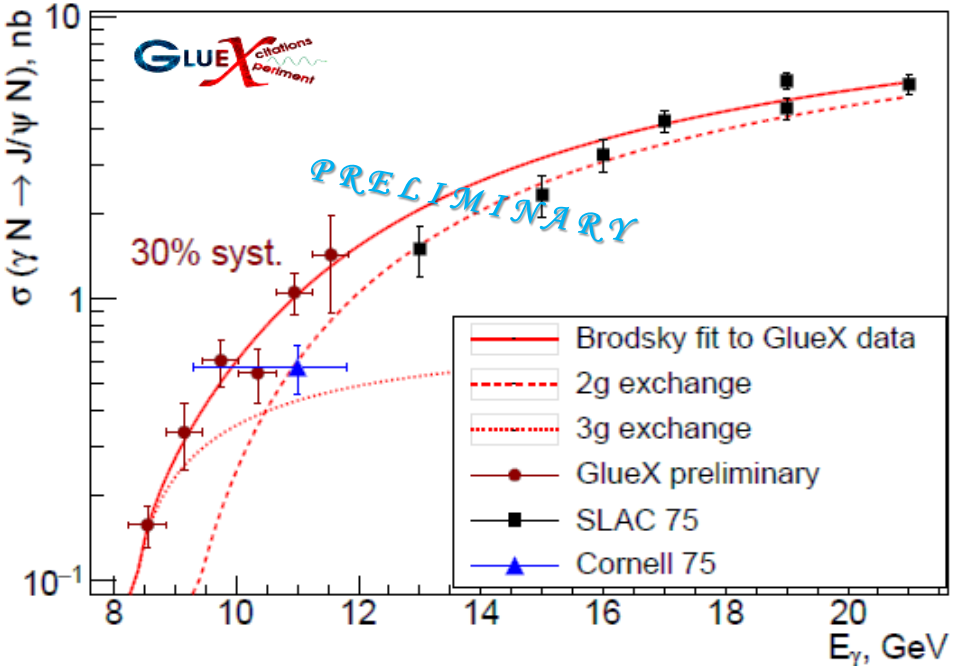
$\gamma + p \rightarrow J/\psi + p$

- Threshold J/ψ provides info on
  - **Multiquark correlations**.

S. Brodsky *et al,* Phys Let B **498**, 23 (2001)

  - **Gluon distributions** in nucleon.

D. Kharzeev *et al,* Eur Phys J C **9**, 459 (1999)



- Best fit using **Brodsky**'s parametrization reproduces GlueX & SLAC data well.

- SLAC

U.Camerini et al, PRL 35 (1975)

Calculated from the measured $\frac{d\sigma}{dt}|_{t=tmin}$ assuming $\frac{d\sigma}{dt} \propto e^{a \cdot t}$, $a = 2.9 \pm 0.3$ GeV^{-2} measured at 19 GeV

-

B.Gittelman et al, PRL 35 (1975)

t-slope $a = 1.25 \pm 0.2$ GeV^{-2} horizontal error bar represents the acceptance

Courtesy of Lubomir Pentchev, 2018

$\gamma + p \rightarrow J/\psi + p$

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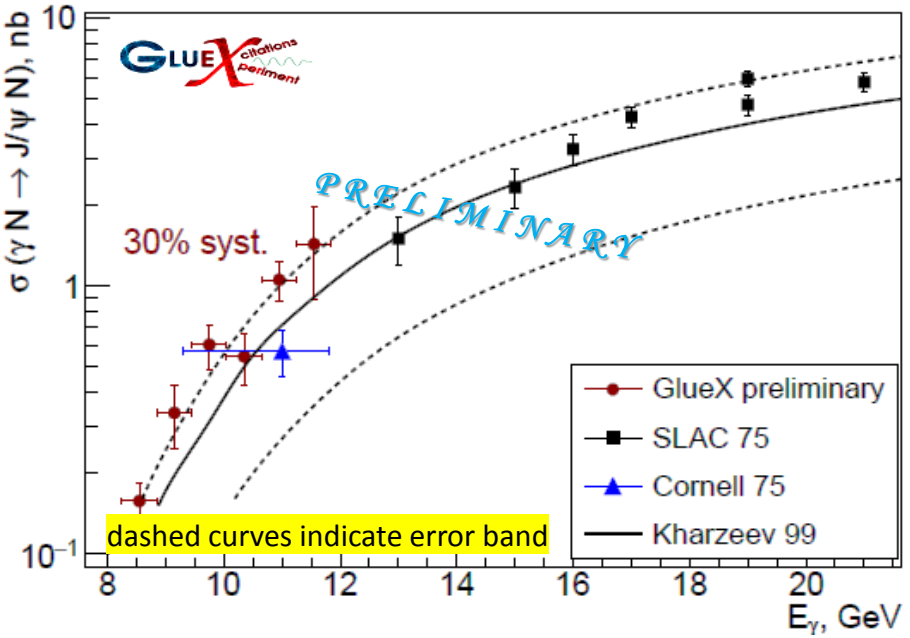
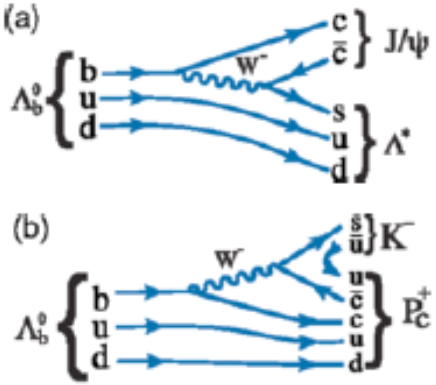


- At **low energies** photoprod **amplitude** is proportional to matrix element of gluon part of trace of QCD energy-momentum tensor evaluated over nucleon state; this quantity arises from **scale anomaly** of QCD.
- Resulting contribution to photoprod **amplitude** is **real !**.
- Low-energy **J/ψ** photoprod data can thus be used to **extract fraction of nucleon's mass** arising from gluons, & corresponding spatial distribution.

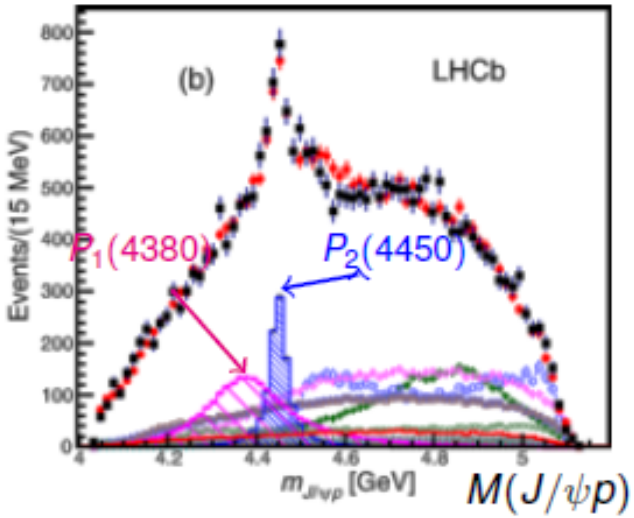
- **SLAC**
  U.Camerini et al, PRL 35 (1975)
  Calculated from the measured $\frac{d\sigma}{dt}|_{t=tmin}$ assuming $\frac{d\sigma}{dt} \propto e^{a \cdot t}$, $a = 2.9 \pm 0.3$ GeV^{-2} measured at 19 GeV
- *B.Gittelman et al, PRL 35 (1975)*
  t-slope $a = 1.25 \pm 0.2$ GeV^{-2}
  horizontal error bar represents the acceptance

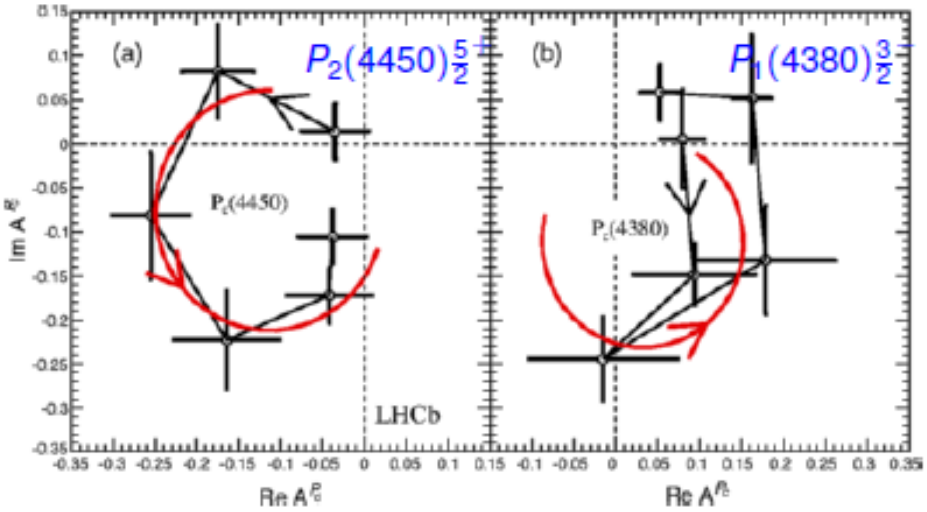
Courtesy of Lubomir Pentchev, 2018

LHCb PRL, 115, 072001 (2015) $\Lambda_b^0 \to K^-(J/\psi p)$



- No indications of $\Lambda^* \to K^- p$ reflections to $J/\psi p$
- PWA leads to two states for $P_c^+ \to J/\psi p$:
  - $M_1 = 4380 \pm 30, \Gamma_1 = 205 \pm 90$ MeV/c^2
  - $M_2 = 4450 \pm 3, \Gamma_2 = 39 \pm 20$ MeV/c^2
- J^{PC}: $(\frac{3}{2}^-, \frac{5}{2}^+)$ or $(\frac{3}{2}^+, \frac{5}{2}^-)$ or $(\frac{5}{2}^+, \frac{3}{2}^-)$

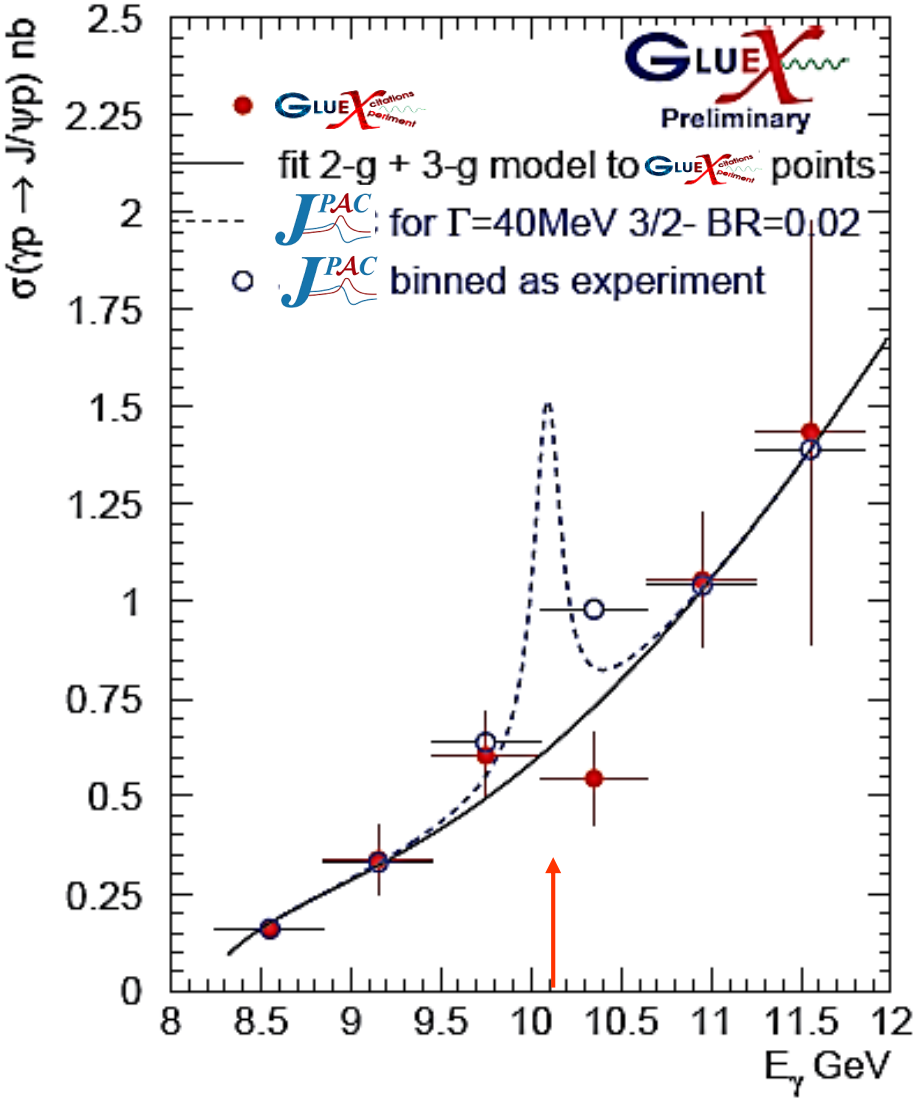




Threshold of $\Sigma_c(2455)\bar{D}^*(2007) = 4462$ MeV/c^2. The only mode detected $J/\psi p$

Courtesy of Eugene Chudakov, 2018

Limit on Pentaquark Production



Fit: 2 + 3-gluon exchange

Brodsky et al, PL 498 (2001)

2 free parameters $\chi^2/ndf = 0.8$

Limit for $P_c(4450)$ $\Gamma = 40$ MeV

JPAC model, assumptions:

$\sigma(10.1) = 0.64$ nb non-reson.

no wide state $P_c(4380)$ added

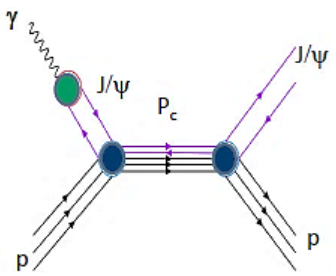
J^{PC}	BR	10.1 ± 0.6 GeV		(2 bins)
		JPAC nb	experiment nb	separation $\sigma(stat)$
3/2-	2.0%	0.81	0.58 ± 0.08	2.9
5/2+	0.7%	0.81	0.58 ± 0.08	2.9

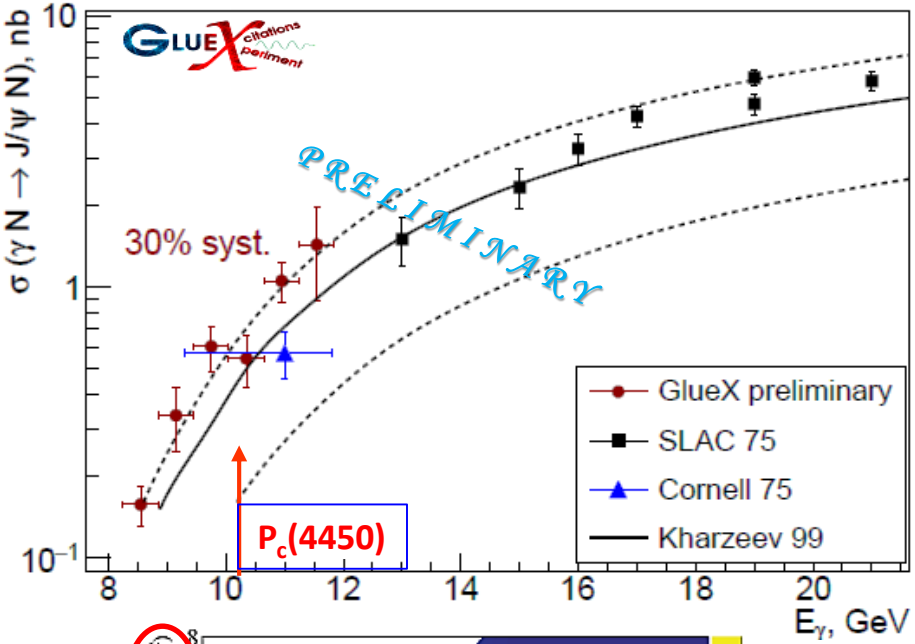
Systematic to be addressed:

- *t* and *s*-channel interference
- VMD model dependence
- The wide state influence

Courtesy of Eugene Chudakov, 2018

$$\gamma + p \rightarrow P(4.45) + p \rightarrow J/\psi + p$$



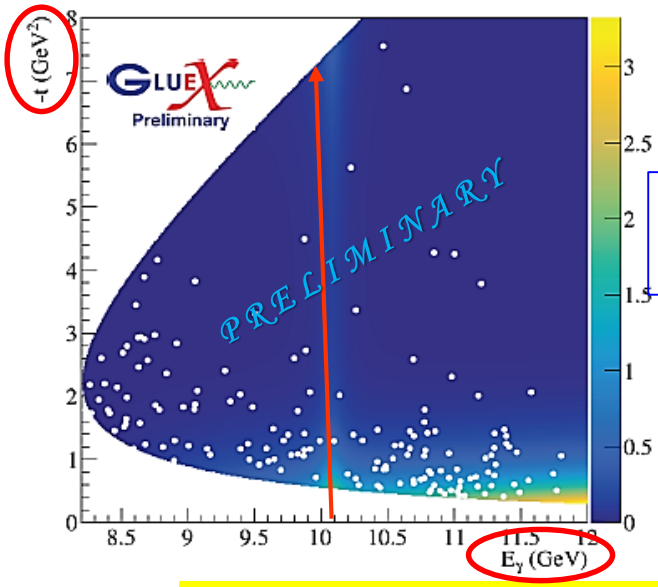


- **No indication** of LHCb **pentaquark**.

R. Aaij *et al*. Phys Rev Lett **115**, 072001 (2015)

While

- **Pentaquark** signal could present itself via **destructive interference** between **resonance** & **non-resonant** background in dominant partial wave.

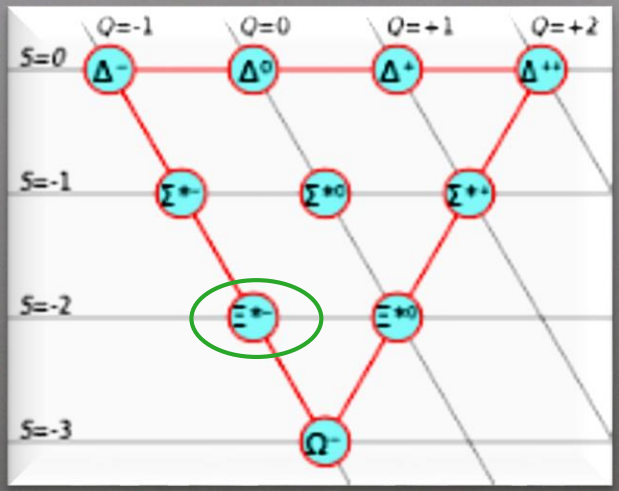


189±16 events

$\sigma \sim \sum |A_i|^2$ $\quad A_i = BW_i + NR_i \times \exp(-i\phi)$

Courtesy of Lubomir Pentchev, 2018

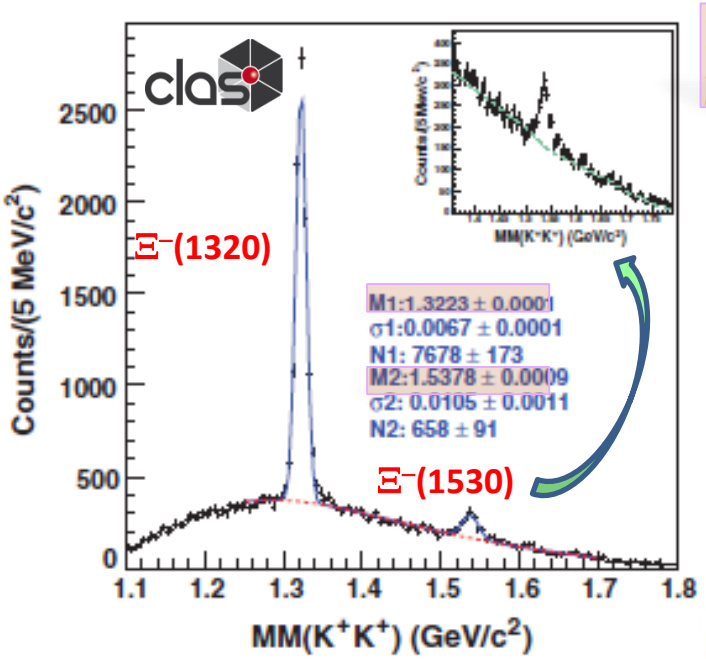
Hyperon Spectroscopy



Bump Hunting

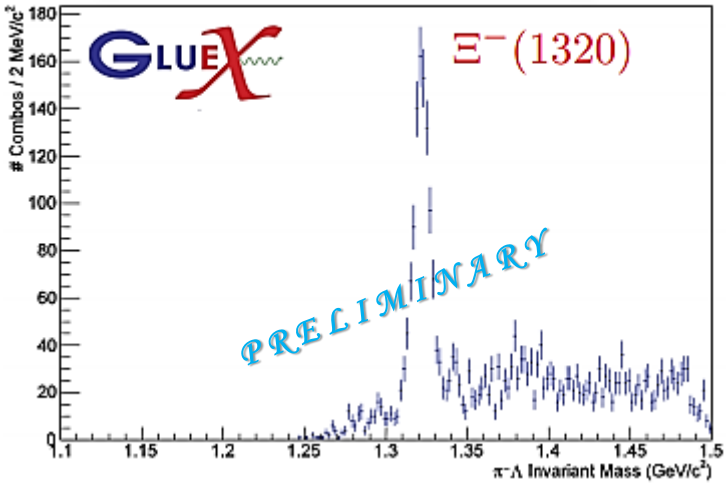
$$\gamma p \to K^+K^+(X)$$
$$\gamma p \to K^+K^+\pi^-(X)$$

@ **2.75** – **4.75** GeV

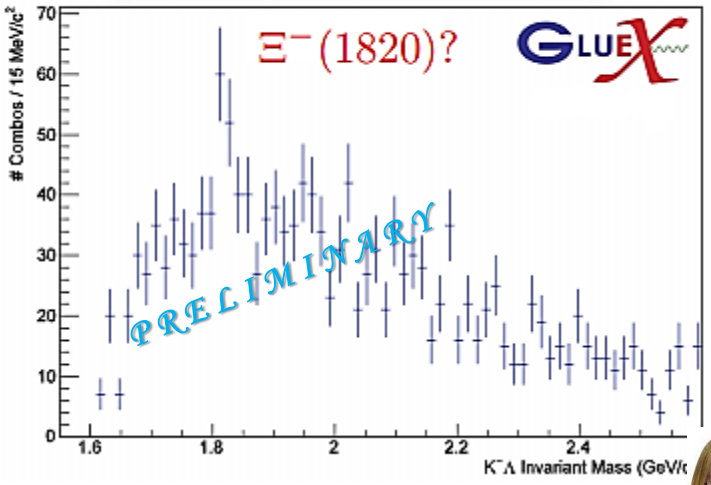


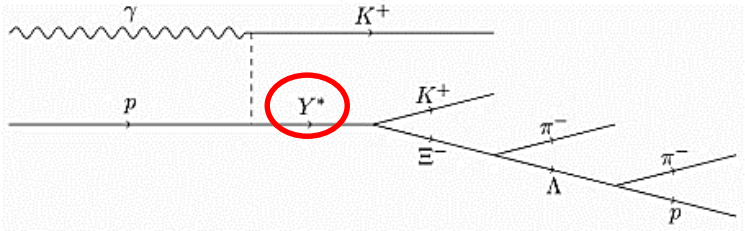
L. Guo *et al,* Phys Rev C **76**, 025208 (2007)

$$\gamma p \to K^+K^+\Lambda\pi^-$$



$$\gamma p \to K^+K^+\Lambda K^-$$





- GlueX collaboration can reconstruct these multi-step reactions.

- Searches in CLAS12 by Very Strange Group.

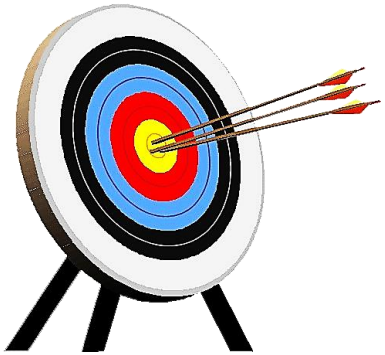
Courtesy of Ashley Ernst, 2018

Summary

``Low intensity" program (**GlueX I**), is expected to be completed in **2018**.

``High intensity" GlueX (**GlueX II** with **DIRC**), will begin subsequently.

Summary



- GlueX experiment is commissioned & initial **meson** program is well underway.
- Early measurements aimed at understanding **meson production mechanism** through polarization observables.
- **First observation** of **charm** at **threshold**, potential limit on pentaquark production.

Շնորհակալություն հրավերի
եւ ձեր ուշադրության համար

Haghartsin Monastery near Dilijan, 13th-century