

Study of Hyperons with CLAS and CLAS12

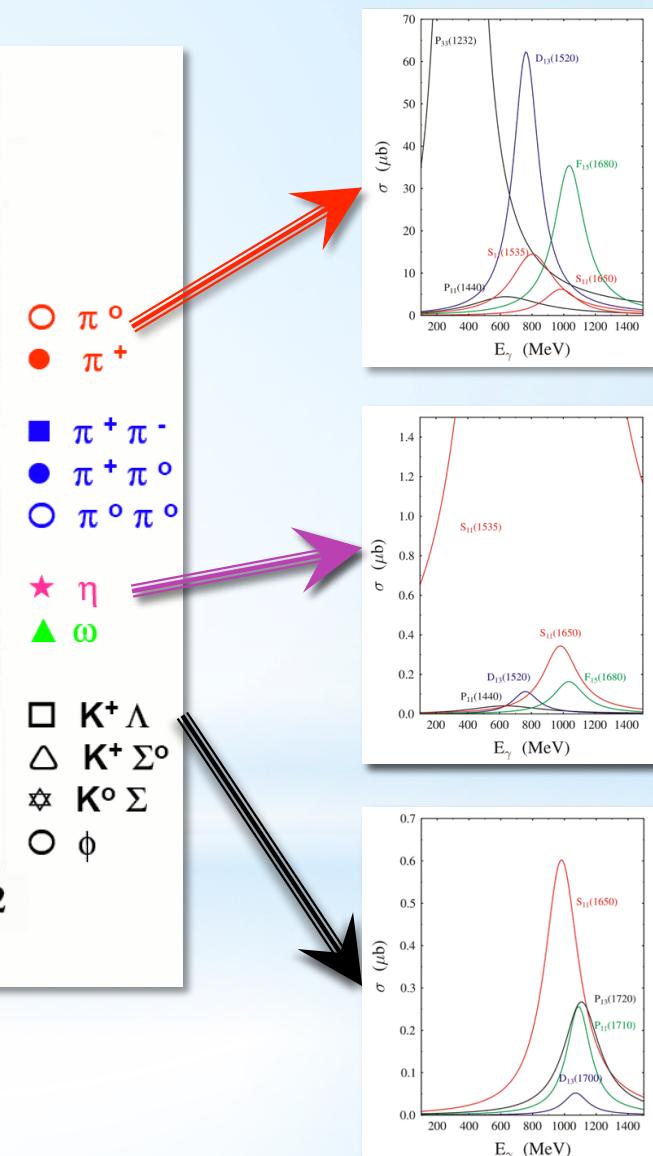
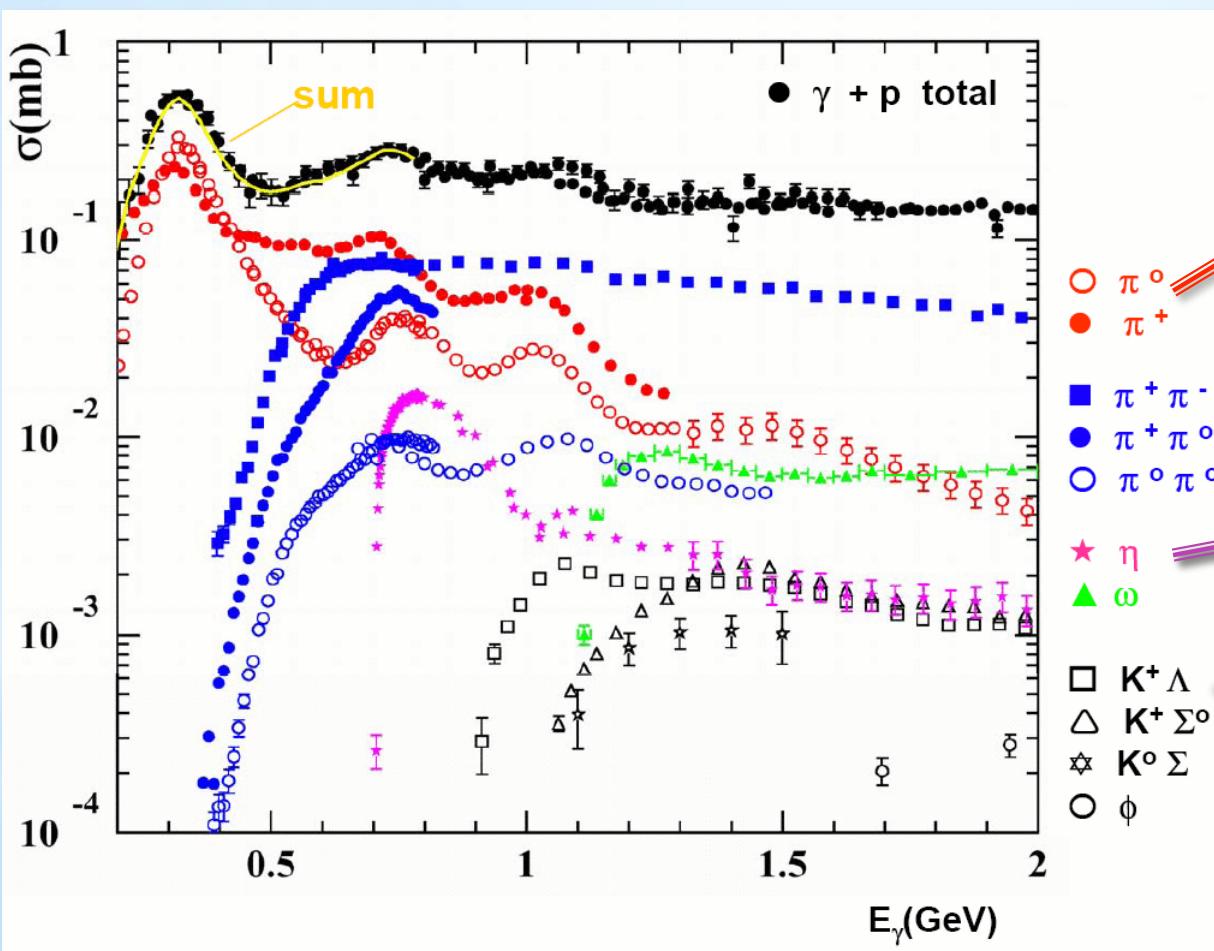
Eugene Pasyuk

Jefferson Lab

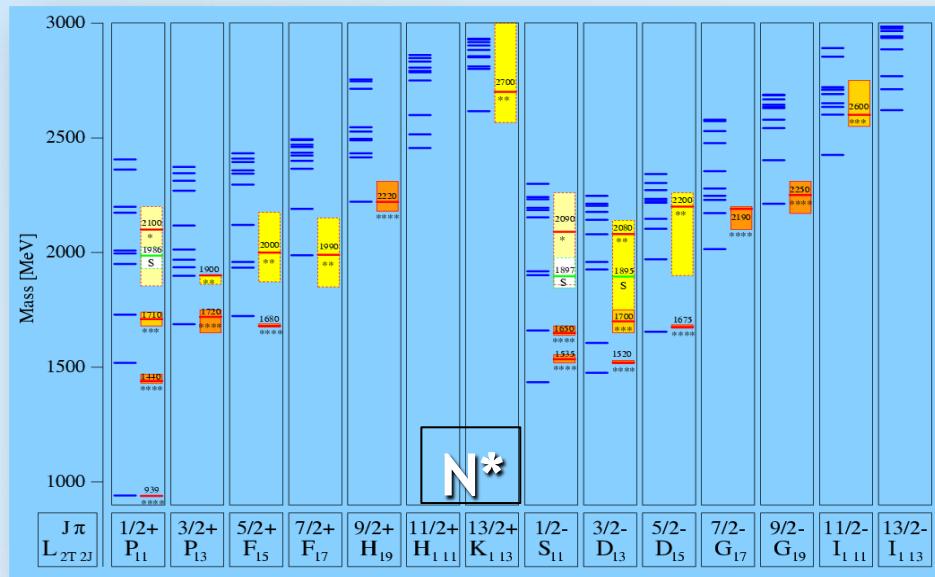
for the CLAS Collaboration



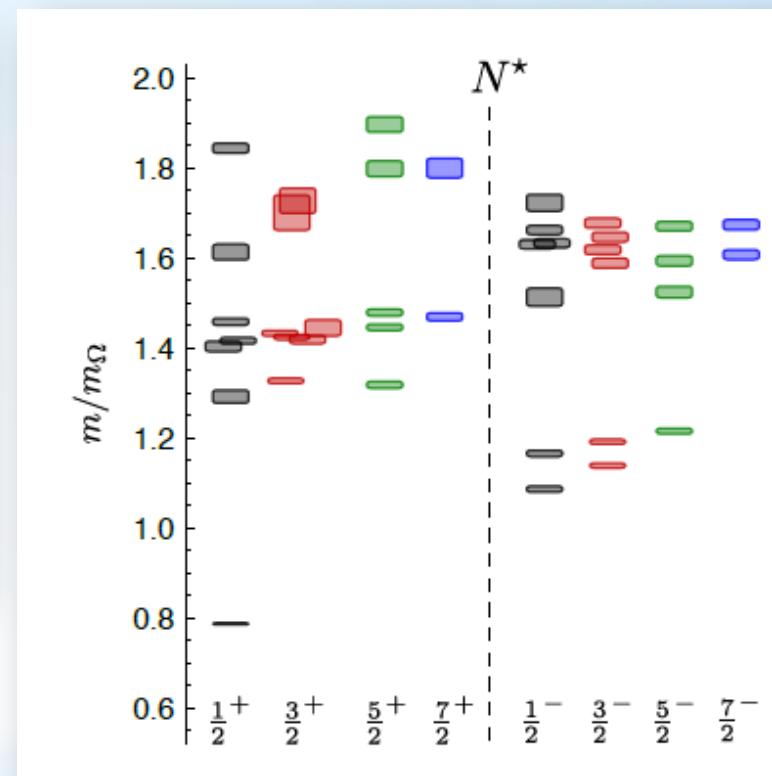
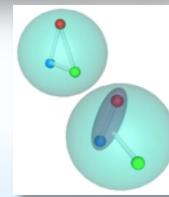
* Photonuclear cross sections



* Baryon Resonance Spectrum



Constituent quark model



- * Masses, widths, and coupling constants not well known for many resonances
- * Most models predict more resonance states than observed

Lattice QCD

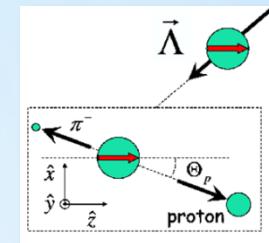
* Polarization observables in pseudoscalar meson production

4 Complex amplitudes: 16 real polarization observables.

Complete measurement from 8 carefully chosen observables.

πN has large cross section

but in KY recoil is self-analysing 😊



πN			Symbol	Transversity representation	Experiment required	Type	KY		
recoil	targ	γ					γ	targ	recoil
		→	$d\sigma/dt$	$ b_1 ^2 + b_2 ^2 + b_3 ^2 + b_4 ^2$	$\{-; -; -\}$	S			
		→	$\Sigma d\sigma/dt$	$ b_1 ^2 + b_2 ^2 - b_3 ^2 - b_4 ^2$	$\{L(\frac{1}{2}\pi, 0); -; -\}$				
		→	$Td\sigma/dt$	$ b_1 ^2 - b_2 ^2 - b_3 ^2 + b_4 ^2$	$\{-; y; -\}$				
		→	$Pd\sigma/dt$	$ b_1 ^2 - b_2 ^2 + b_3 ^2 - b_4 ^2$	$\{-; -; y\}$				
		↑	$Gd\sigma/dt$	$2 \operatorname{Im}(b_1 b_3^* + b_2 b_4^*)$	$\{L(\pm\frac{1}{4}\pi); z; -\}$	BT			
		↑	$Hd\sigma/dt$	$-2 \operatorname{Re}(b_1 b_3^* - b_2 b_4^*)$	$\{L(\pm\frac{1}{4}\pi); x; -\}$				
		↑	$Ed\sigma/dt$	$-2 \operatorname{Re}(b_1 b_3^* + b_2 b_4^*)$	$\{C; z; -\}$				
		↑	$Fd\sigma/dt$	$2 \operatorname{Im}(b_1 b_3^* - b_2 b_4^*)$	$\{C; x; -\}$				
		→	$O_x d\sigma/dt$	$-2 \operatorname{Re}(b_1 b_4^* - b_2 b_3^*)$	$\{L(\pm\frac{1}{4}\pi); -; x'\}$	BR			
		→	$O_z d\sigma/dt$	$-2 \operatorname{Im}(b_1 b_4^* + b_2 b_3^*)$	$\{L(\pm\frac{1}{4}\pi); -; z'\}$				
		→	$C_x d\sigma/dt$	$2 \operatorname{Im}(b_1 b_4^* - b_2 b_3^*)$	$\{C; -; x'\}$				
		→	$C_z d\sigma/dt$	$-2 \operatorname{Re}(b_1 b_4^* + b_2 b_3^*)$	$\{C; -; z'\}$				
		→	$T_x d\sigma/dt$	$2 \operatorname{Re}(b_1 b_2^* - b_3 b_4^*)$	$\{-; x; x'\}$	TR			
		→	$T_z d\sigma/dt$	$2 \operatorname{Im}(b_1 b_2^* - b_3 b_4^*)$	$\{-; x; z'\}$				
		→	$L_x d\sigma/dt$	$2 \operatorname{Im}(b_1 b_2^* + b_3 b_4^*)$	$\{-; z; x'\}$				
		→	$L_z d\sigma/dt$	$2 \operatorname{Re}(b_1 b_2^* + b_3 b_4^*)$	$\{-; z; z'\}$				

I. S. Barker, A. Donnachie, J. K. Storrow, Nucl. Phys. B95 347 (1975).

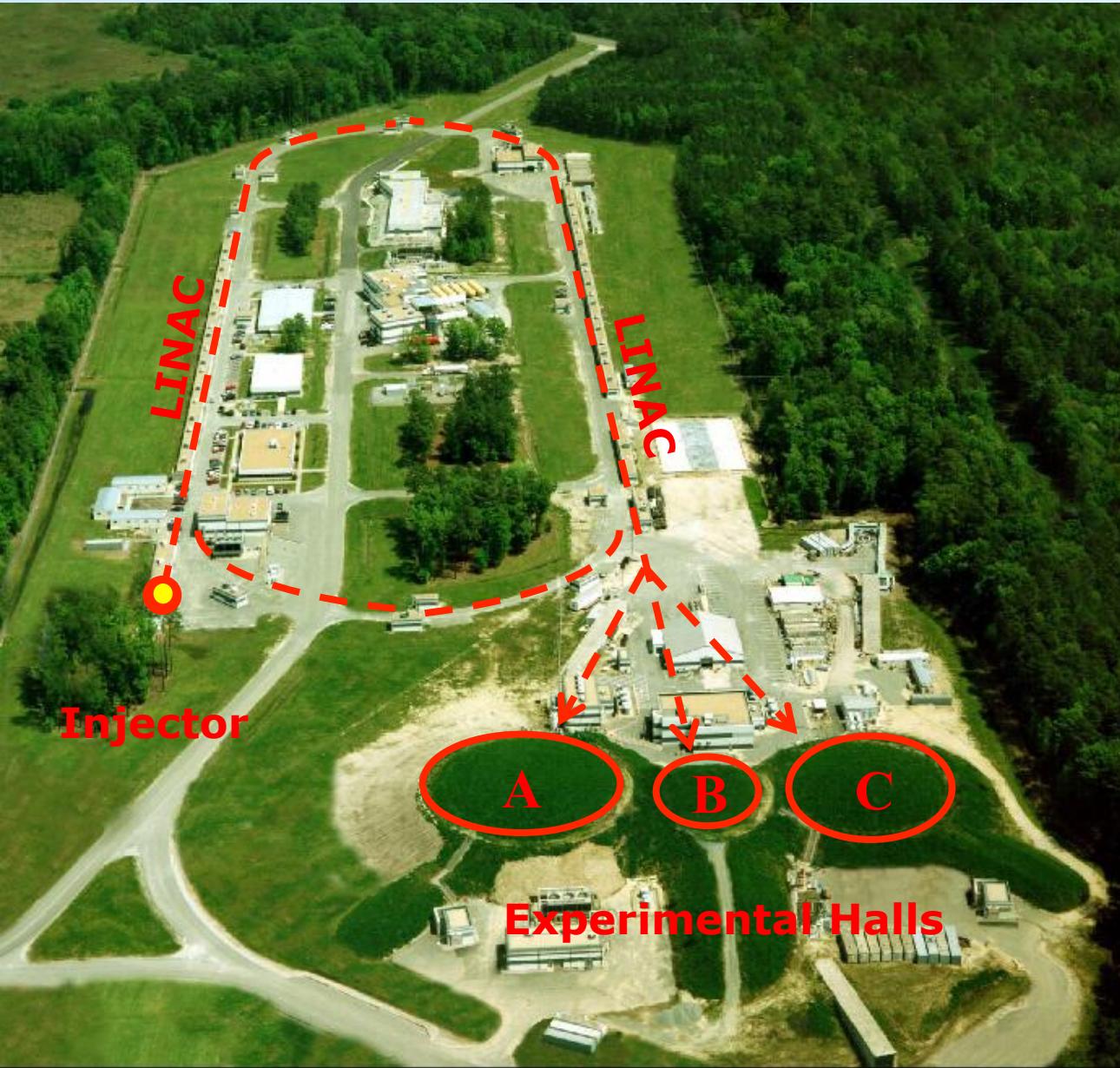
↷ circ polarized photons

↔ linearly polarized photons

↑ longitudinally polarized target

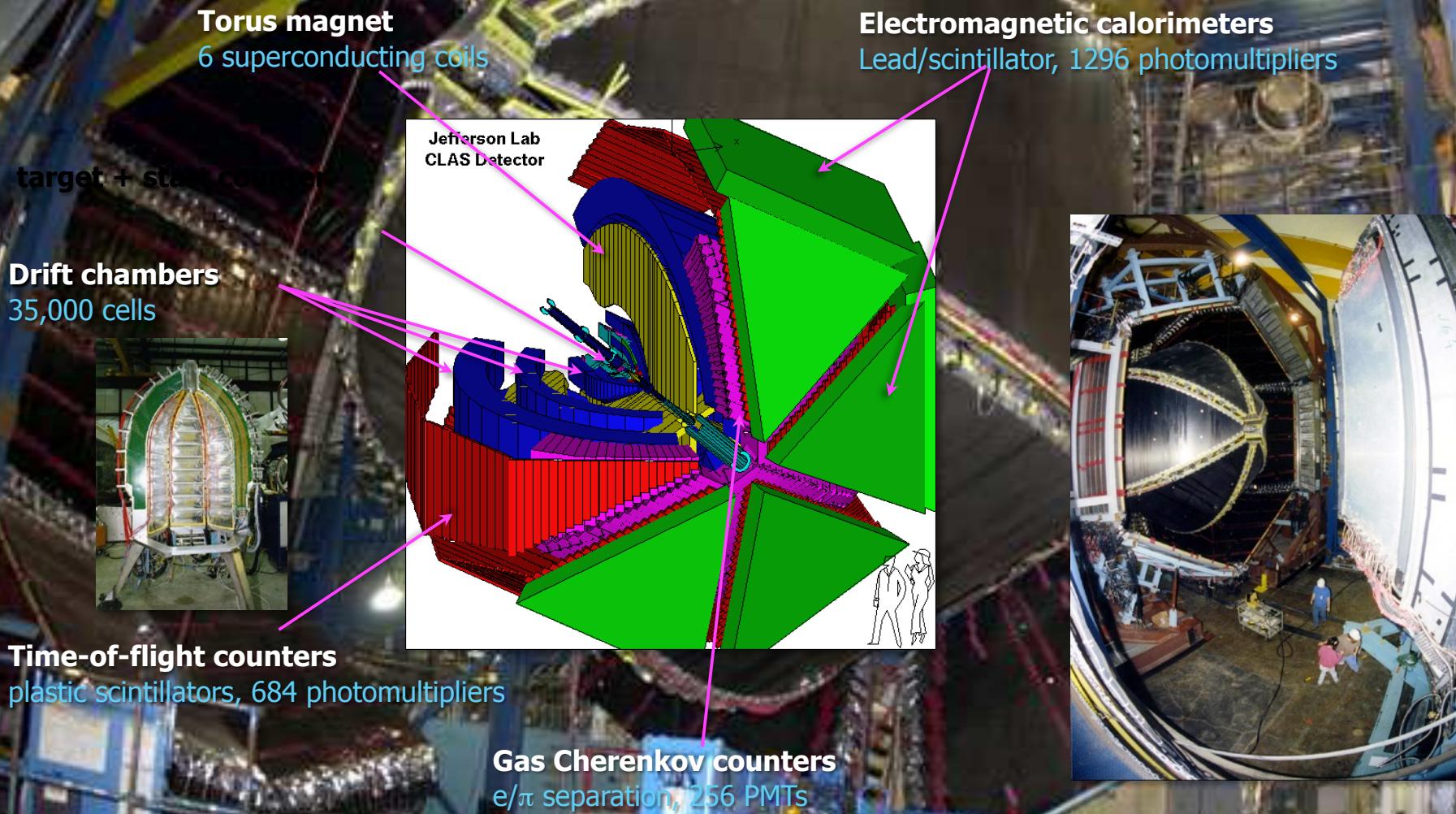
→ transversely polarized target

Complete, and over-determined

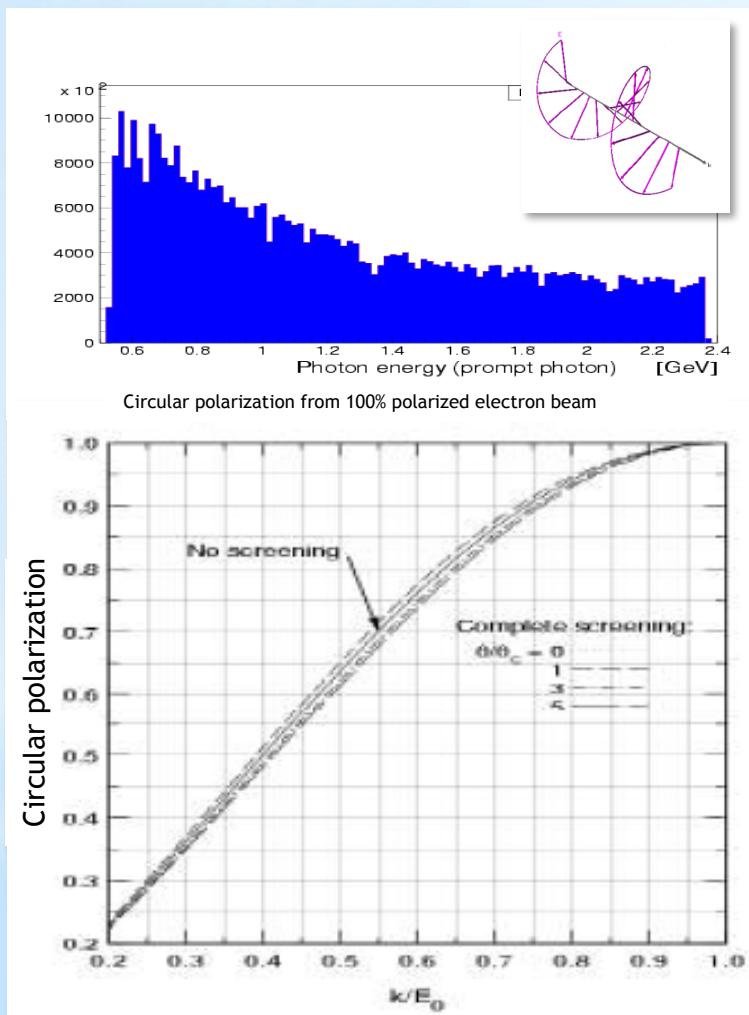


- * E: 0.75 - 6 GeV
- * I_{max} : 200 μ A
- * Duty Cycle: 100%
- * $\delta E/E$: 2.5×10^{-5}
- * Polarization: $\geq 85\%$
- * Simultaneous distribution to 3 experimental Halls

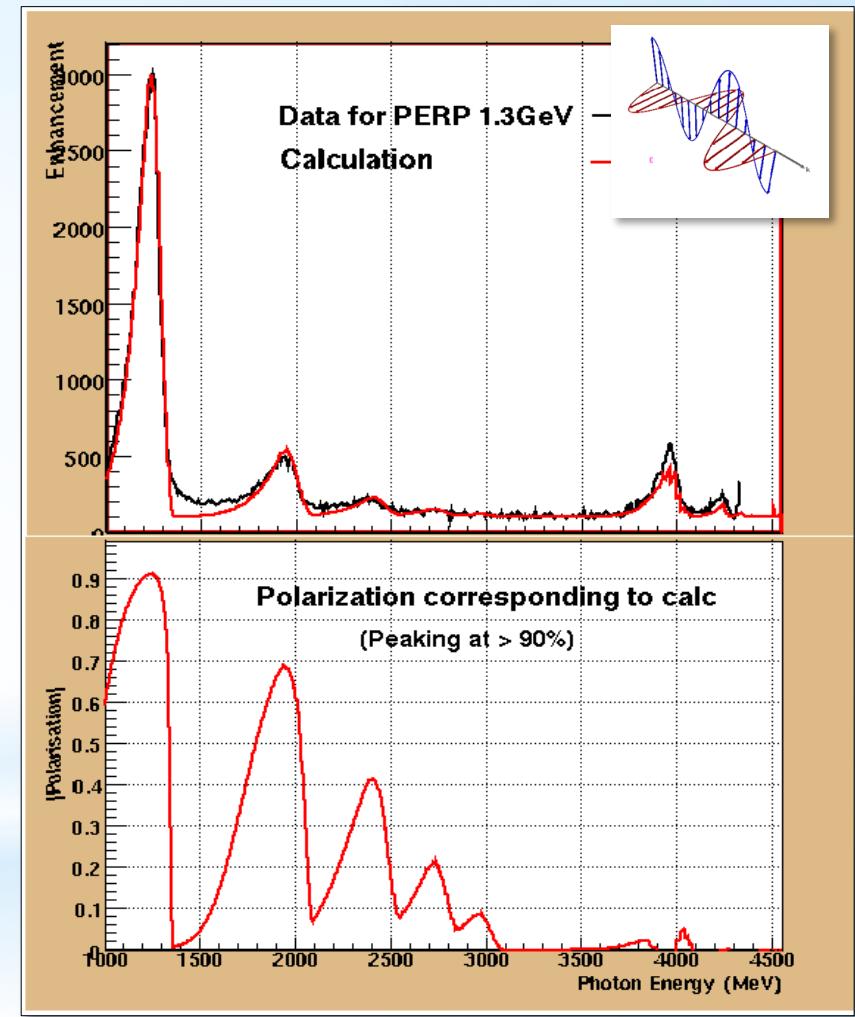
* CEBAF Large Acceptance Spectrometer 1997-2012



* Polarized photon beam



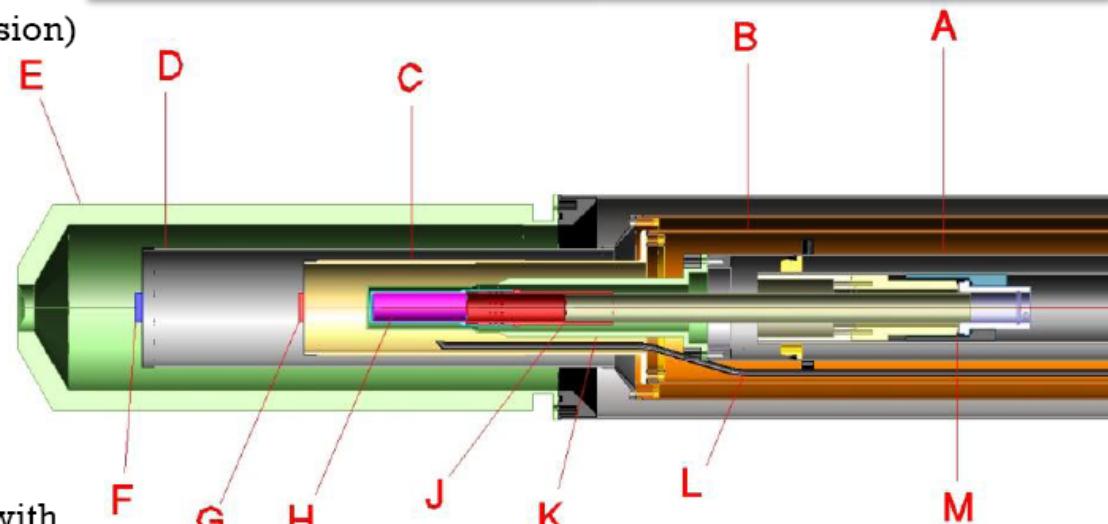
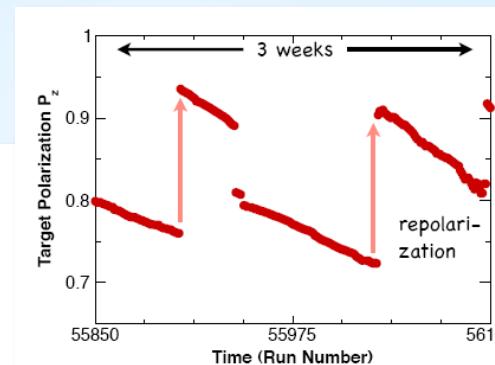
Circularly polarized beam produced by longitudinally polarized electrons



Linearly polarized photons: coherent bremsstrahlung on oriented diamond crystal

The FroST target and its components:

- A: Primary heat exchanger
- B: 1 K heat shield
- C: Holding coil
- D: 20 K heat shield
- E: Outer vacuum can (Rohacell extension)
- F: CH₂ target
- G: Carbon target
- H: Butanol target
- J: Target insert
- K: Mixing chamber
- L: Microwave waveguide
- M: Kapton coldseal



Performance Specs:

Base Temp: 28 mK w/o beam, 30 mK with

Cooling Power: 800 μ W @ 50 mK, 10 mW @ 100 mK, and 60 mW @ 300 mK

Polarization: +82%, -90%

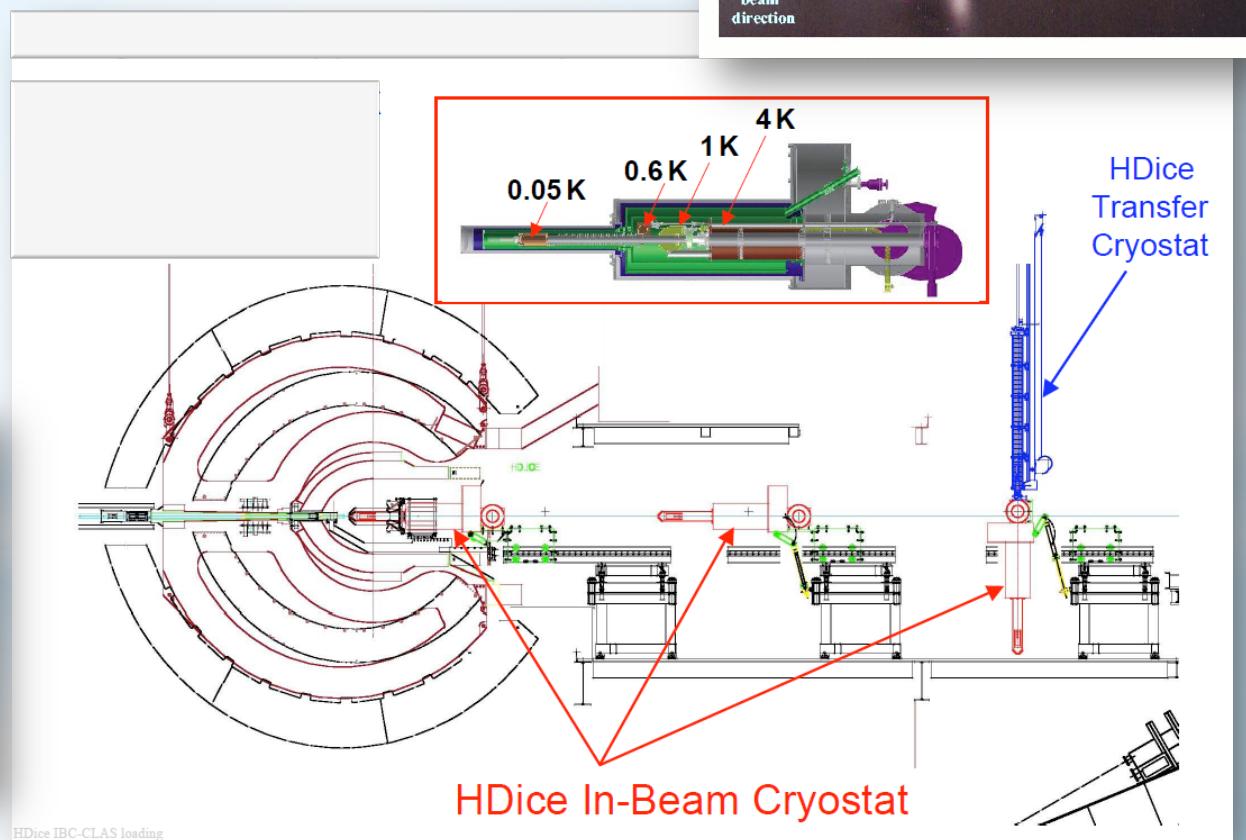
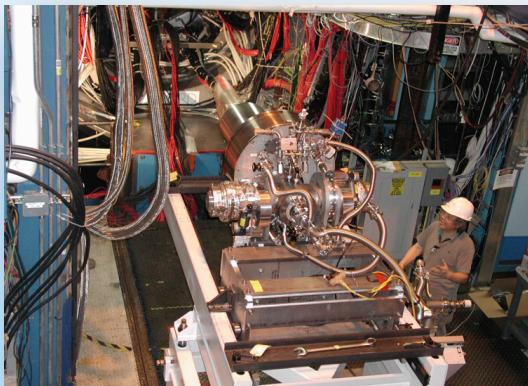
1/e Relaxation Time: 2800 hours (+Pol), 1600 hours (-Pol)

Roughly 1% polarization loss per day.

* HDIce polarized target

HDIce Solid Deuterium-Hydride (HD) - a new class of polarized target

- * Polarized at very high magnetic field and very low temperature
- * Transferred to in-beam cryostat
- * Spin can be moved between H and D with RF transitions
- * All material can be polarized with almost no background

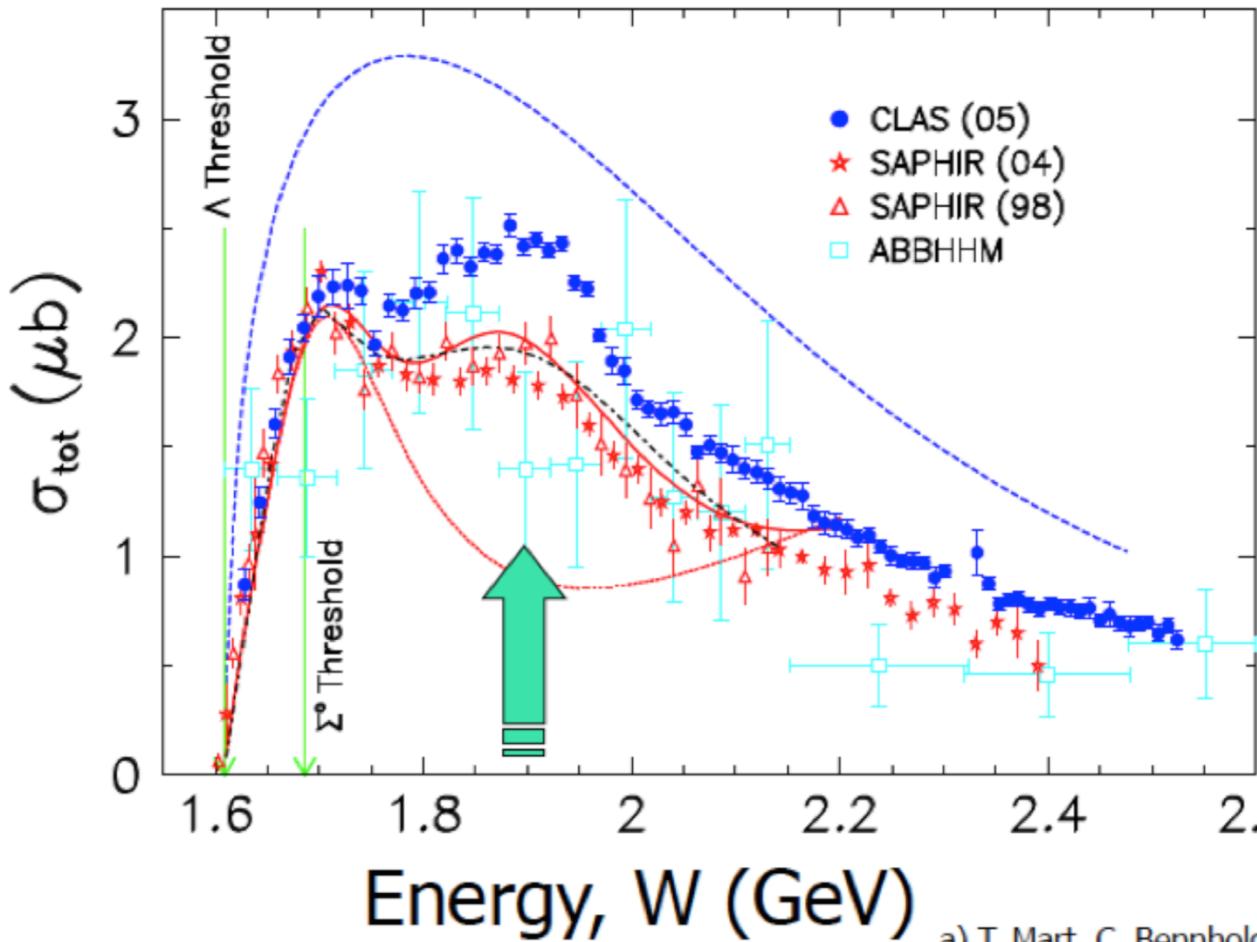


* What we measure with CLAS

- * $\gamma p \rightarrow \pi^0 p, \pi^+ n$
- * $\gamma p \rightarrow \eta p$
- * $\gamma p \rightarrow \eta' p$
- * $\gamma p \rightarrow K Y (K^+ \Lambda, K^+ \Sigma^0, K^0 \Sigma^+)$
- - * $\gamma p \rightarrow \pi^+ \pi^- p \omega p, \rho p, \phi p$

- * $\gamma n \rightarrow \pi^- p$
- * $\gamma n \rightarrow \pi^+ \pi^- n$
- * $\gamma n \rightarrow \Sigma^- K^+, \Lambda K^0$
- * $\gamma n \rightarrow \omega n$

* $\Lambda p \rightarrow K^+ \Lambda$ Cross Section



- Two-bump structure seen
- Resonance-like structure at 1.9 GeV:
 - D_{13} (Bennhold & Mart)^a
 - P_{13} (Bonn-Gachina)^b
 - P_{11} (Ghent "RPR" model)
 - $\bar{K}KN$ bound state (Valencia model)^d
 - Coupled-channel effects (Giessen)^e

a) T. Mart, C. Bennhold, Phys Rev C **61**, 012201(R) (1999).

b) V. Nikanov *et al.*, Phys Lett B **662**, 245 (2008).

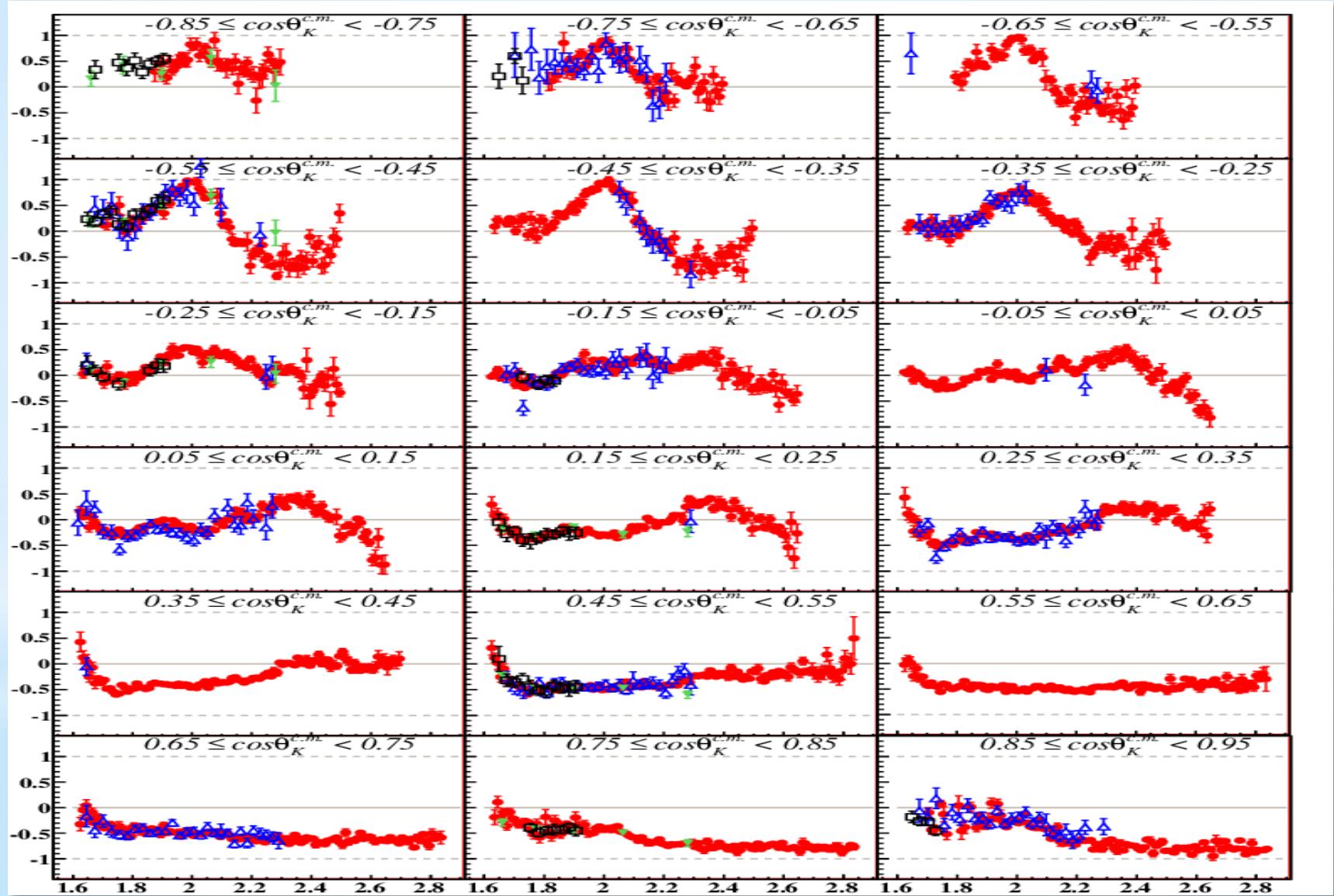
c) T. Corthals, *et al.*, PRC **73**, 045207 (2006).

d) A. Martinez-Torres, *et al.*, Eur. Phys J. **A41**, 361 (2009).

e) R. Shyam, O.Scholten & H.Lenske, PRC **81**, 015204 (2010).

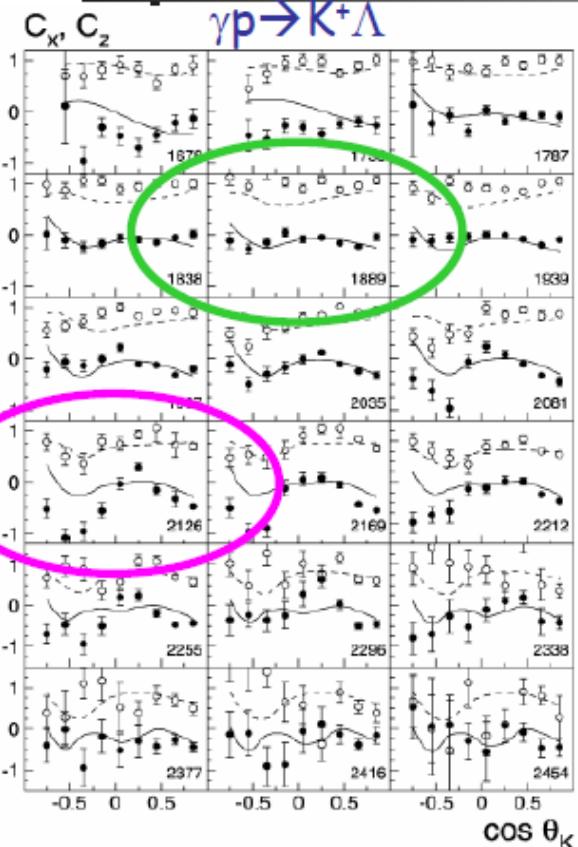
- L. Bradford *et al.* Phys. Rev. C**73** 035202 (2006)
 L. H. Glander *et al.* Eur. Phys. J. A**19** 251 (2004)

* Λ induced polarization

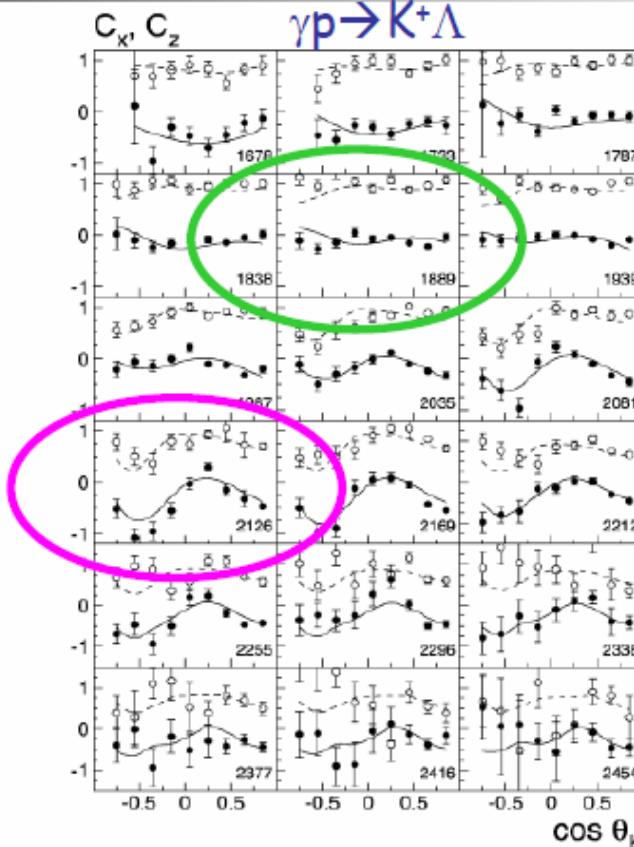


M. E. McCracken *et al.*, PRC 81, 025201(2010)

* $\chi p \rightarrow K^+ \Lambda$: C_x/C_z



$C_x C_z$ without $N^*(1900)P_{13}$



$C_x C_z$ with $N^*(1900)P_{13}$

Bradford et al.

Nikonov *et al'.*'s refit of Bonn-Gachina multi-coupled-channel isobar model

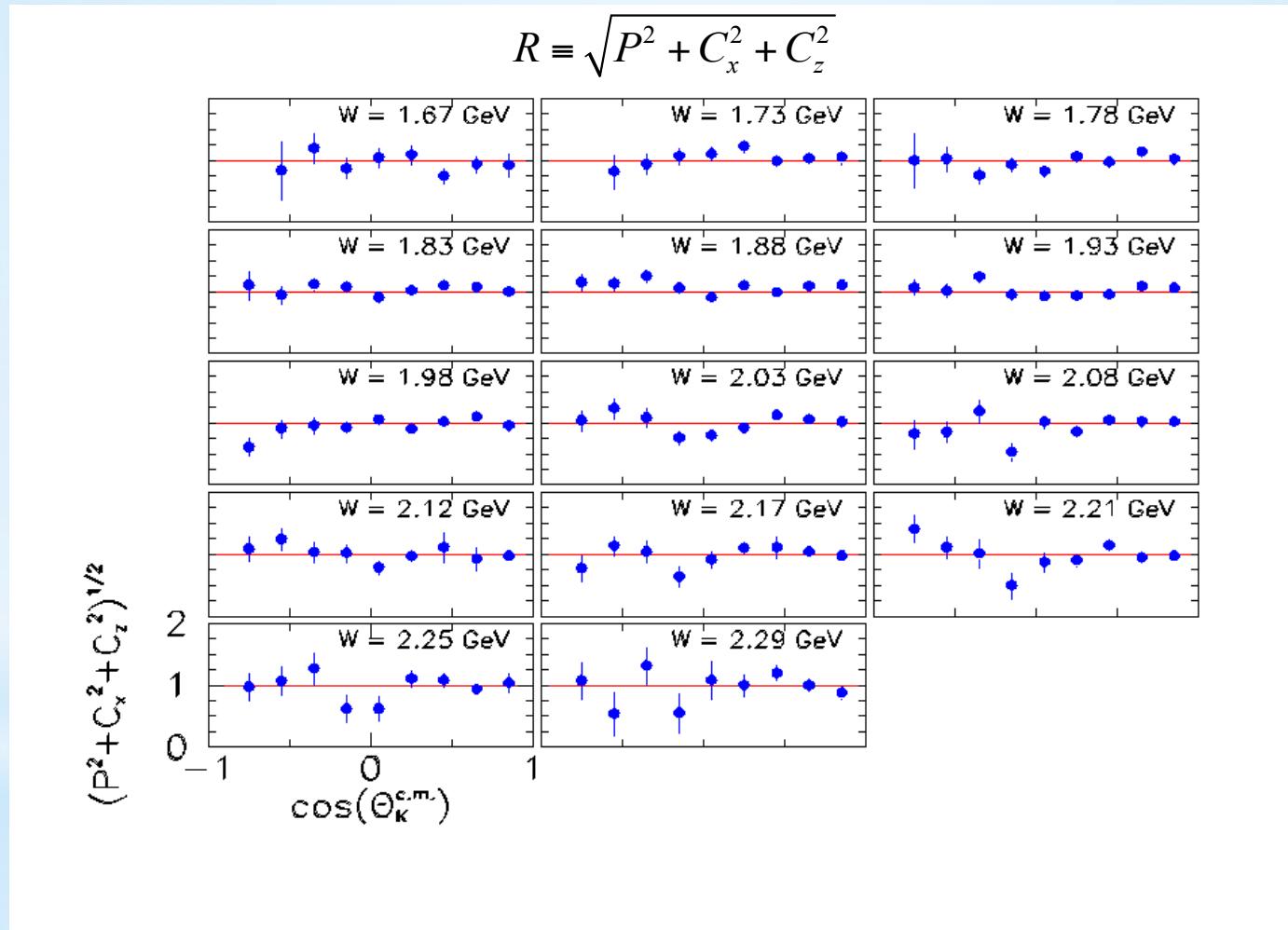
mix includes: S11 wave, P13(1720), P13(1900), P11(1840)

$K^+ \Sigma^0$ cross sections also better described with P13(1900)

Promote this “missing” resonance from ** to *** status.

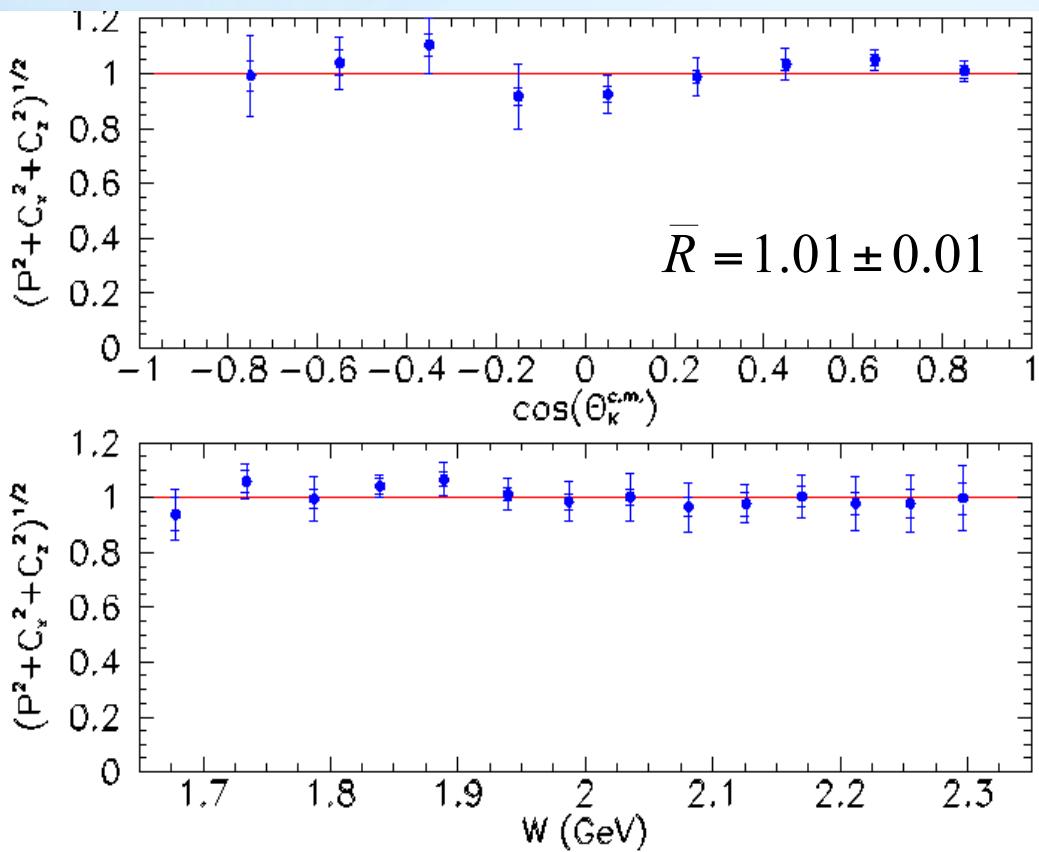
P13(1900) is found in (qqq) quark models, but not in quark-diquark models

* R Values for the Λ



The Λ appears 100% polarized when created with a fully polarized beam.

* Average R values



- * Energy and angle averages are consistent with unity.
- * No model predicted this CLAS result.

* Status of meson photoproduction

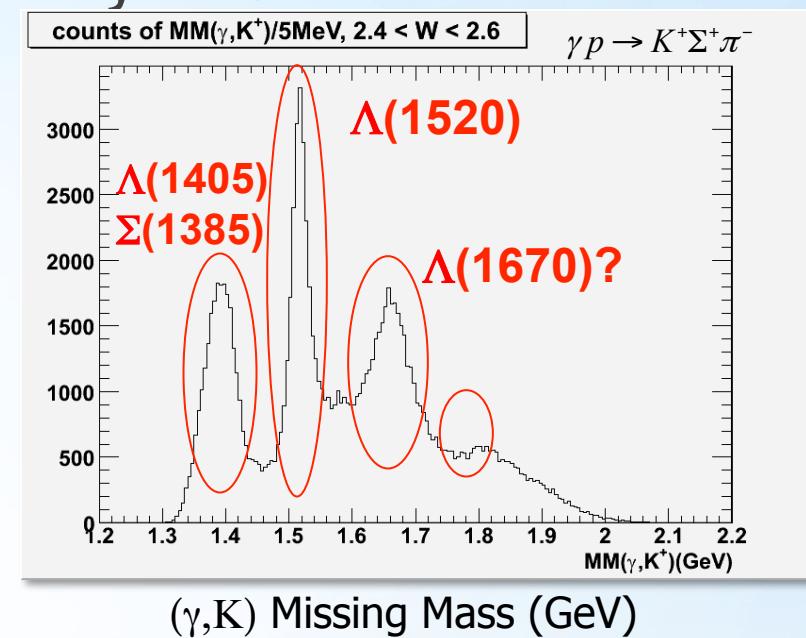
	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
Proton target																
$p\pi^0$	✓	✓	✓	✓	✓	✓	✓	✓								
$n\pi^+$	✓	✓	✓	✓	✓	✓	✓	✓								
$p\eta$	✓	✓	✓	✓	✓	✓	✓	✓								
$p\eta'$	✓	✓	✓	✓	✓	✓	✓	✓								
$p\omega$	✓	✓	✓		✓	✓	✓	✓								
$K^+\Lambda$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^+\Sigma^0$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^+$	✓	✓	✓	✓	✓	✓	✓	✓								
“Neutron” target																
$p\pi^-$	✓	✓	✓		✓	✓	✓	✓								
$p\rho^-$	✓	✓	✓		✓	✓	✓	✓								
$K^+\Sigma^-$	✓	✓	✓		✓	✓	✓	✓								
$K^0\Lambda$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓														

✓ - published ✓ - acquired

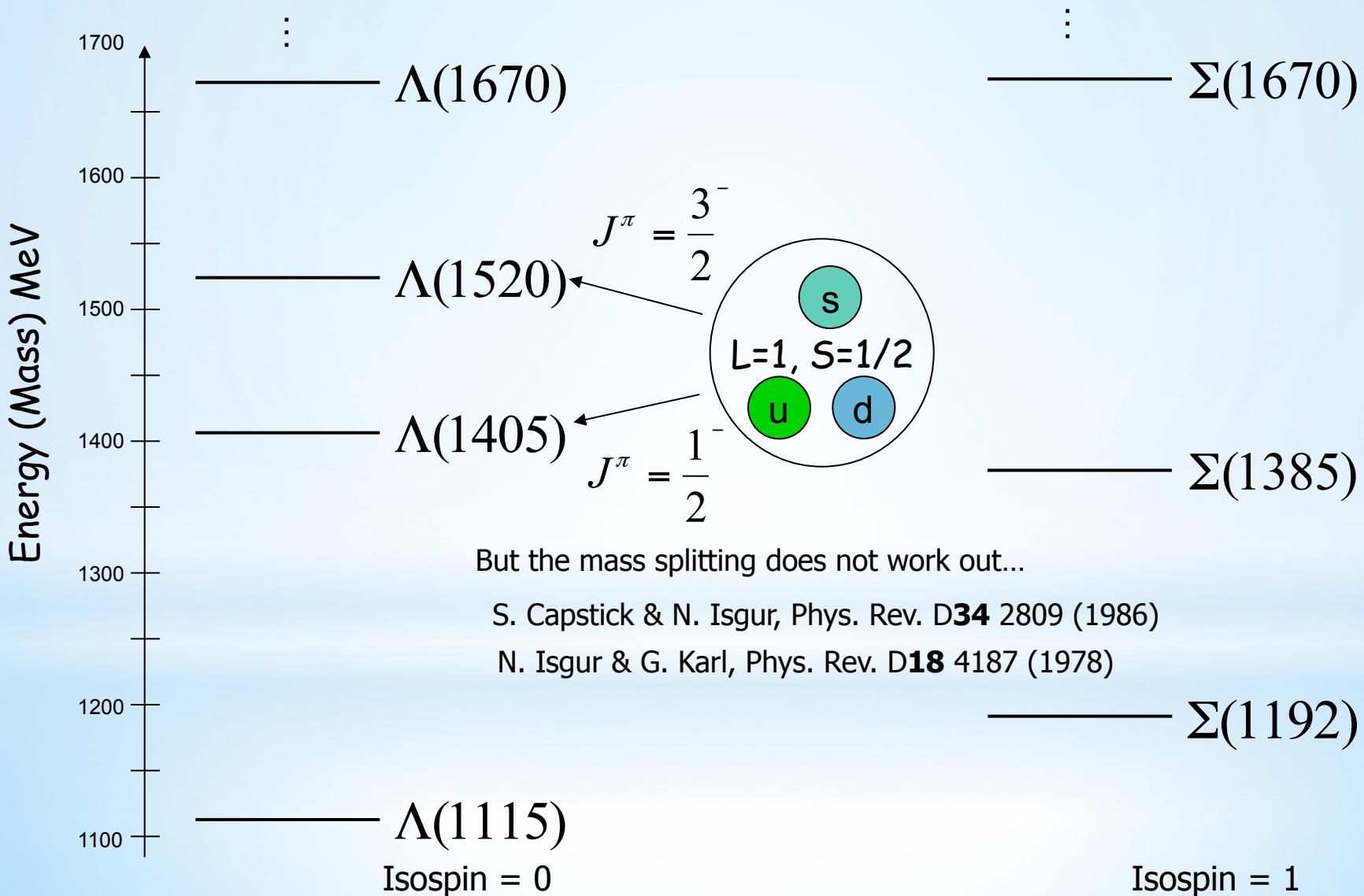
* What “is” the $\Lambda(1405)$?

Shape is an issue since its discovery in 60's

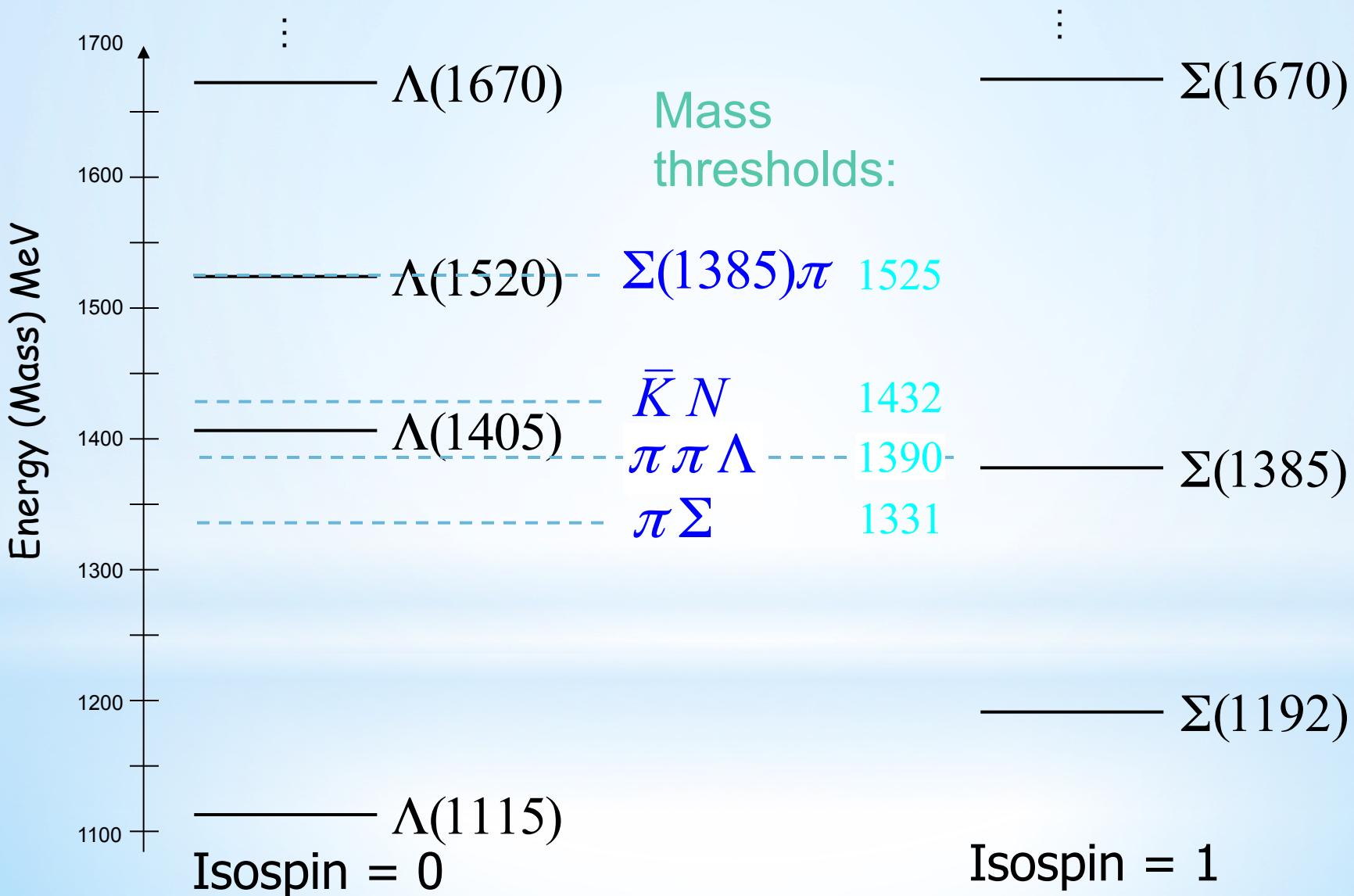
- * SU(3) singlet 3q state
 $I=0, J^\pi = \frac{1}{2}^-$
- * KN sub-threshold bound state
- * Gluonic $J^\pi = \frac{1}{2}^+$ hybrid (udsg)
- * Dynamically generated resonance, via unitary meson-baryon channel coupling



* The Low-Mass S=-1 Hyperons



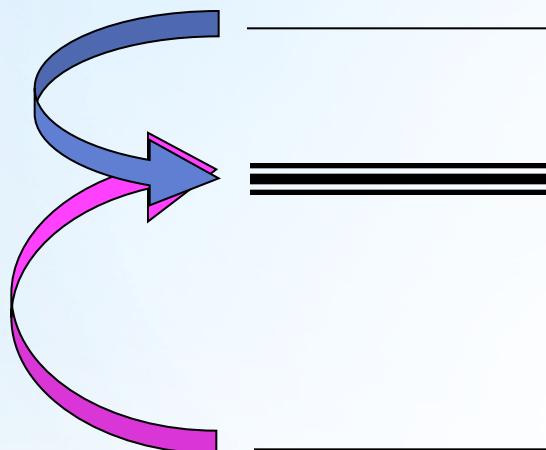
* The Low-Mass S=-1 Hyperons



* Dynamical State Generation

Do the “ground state” mesons and baryons attract strongly enough to form meson-baryon “molecular” bound states or unbound resonances?

Bound state



$\bar{K}N$

$\Lambda(1405)$

Resonance

Channel Coupling:

$$|1\rangle = |\bar{K}N, I=0\rangle$$

Feynman diagram for channel coupling. A dotted line labeled \bar{K} enters from the left, and a dotted line labeled N enters from the bottom. They interact at a vertex with a solid line labeled K_{11} . From this vertex, two solid lines emerge: one labeled \bar{K} going up-left and one labeled N going up-right.

$$K_{11} = \frac{3}{2f^2}(\sqrt{s} - M_N)$$

From chiral SU(3)
effective field theory

$\sum \pi$

$$|2\rangle = |\pi\Sigma, I=0\rangle$$

Feynman diagram for channel coupling. A dotted line labeled π enters from the left, and a dotted line labeled Σ enters from the bottom. They interact at a vertex with a solid line labeled K_{22} . From this vertex, two solid lines emerge: one labeled π going up-left and one labeled Σ going up-right.

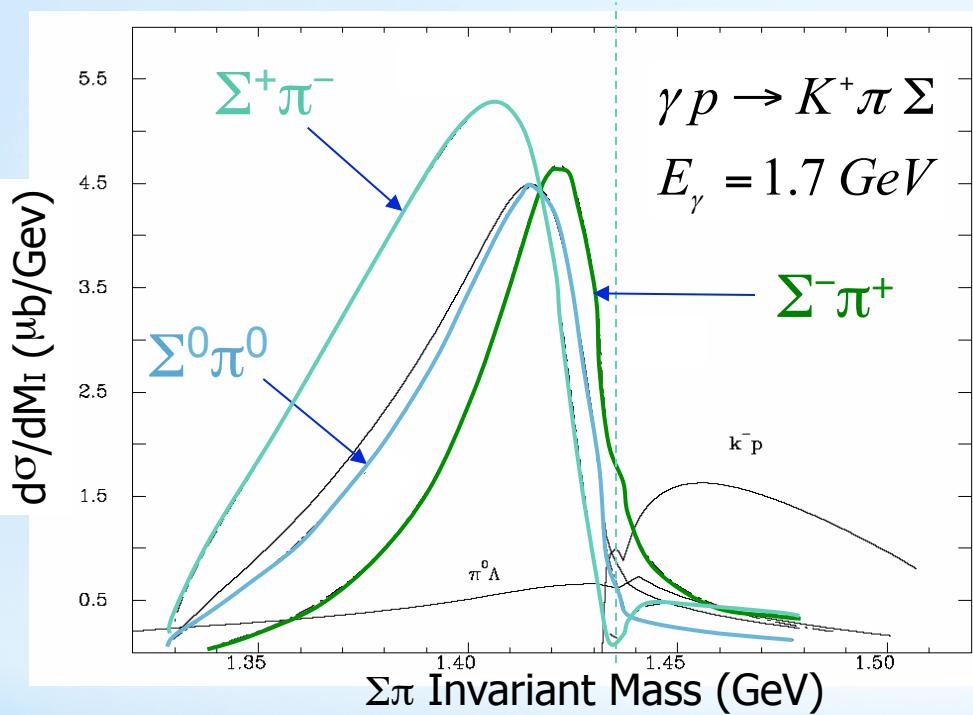
$$K_{22} = \frac{2}{f^2}(\sqrt{s} - M_\Sigma)$$

Feynman diagram for channel coupling. A dotted line labeled \bar{K} enters from the left, and a dotted line labeled N enters from the bottom. They interact at a vertex with a solid line labeled K_{12} . From this vertex, two solid lines emerge: one labeled π going up-left and one labeled Σ going up-right.

$$K_{12} = \frac{-1}{2f^2}\sqrt{\frac{3}{2}}\left(\sqrt{s} - \frac{M_N + M_\Sigma}{2}\right)$$

Graphic: W. Weise

* Chiral Unitary Models



$$\frac{d\sigma(\pi^+\Sigma^-)}{dM_I} \propto \frac{1}{2}|T^{(1)}|^2 + \frac{1}{3}|T^{(0)}|^2 + \frac{2}{\sqrt{6}} \text{Re}(T^{(0)}T^{(1)*}) + O(T^{(2)})$$

$$\frac{d\sigma(\pi^-\Sigma^+)}{dM_I} \propto \frac{1}{2}|T^{(1)}|^2 + \frac{1}{3}|T^{(0)}|^2 - \frac{2}{\sqrt{6}} \text{Re}(T^{(0)}T^{(1)*}) + O(T^{(2)})$$

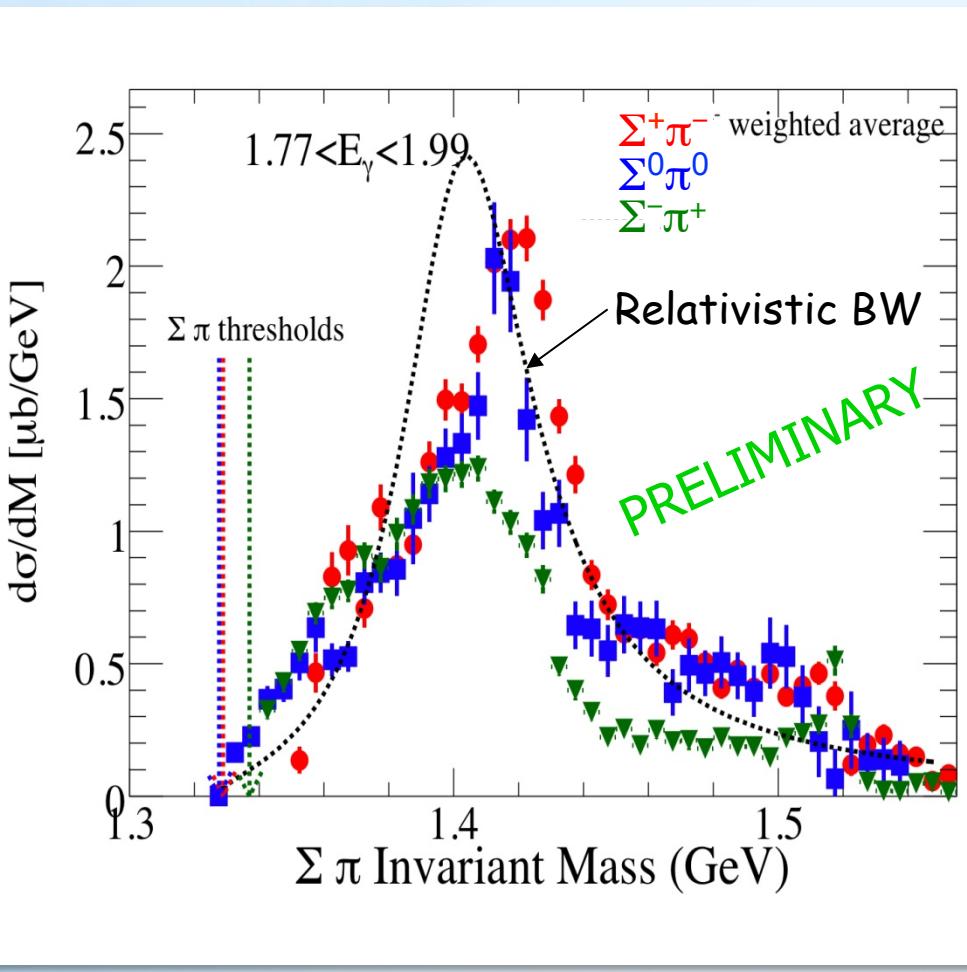
$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_I} \propto \frac{1}{3}|T^{(0)}|^2 + O(T^{(2)})$$

Mass distribution of the “ Λ (1405)” predicted to depend on $\pi\Sigma$ decay channel

- * Model with $I = 0$ and $I = 1$ amplitudes
 - * Chiral Lagrangian + Channel Coupling
 - * $I(\pi\Sigma) = \{0,1\}$ - not in an isospin eigenstate
 - * Interference between $I=0$ and $I=1$ amplitudes modifies mass distributions
 - * no energy or angle dependence
- * Inspired CLAS experiment

J.C. Nacher, E. Oset, H. Toki, & A. Ramos,
Phys. Lett. B **455**, 55 (1999).

* CLAS result for $\Lambda(1405)$

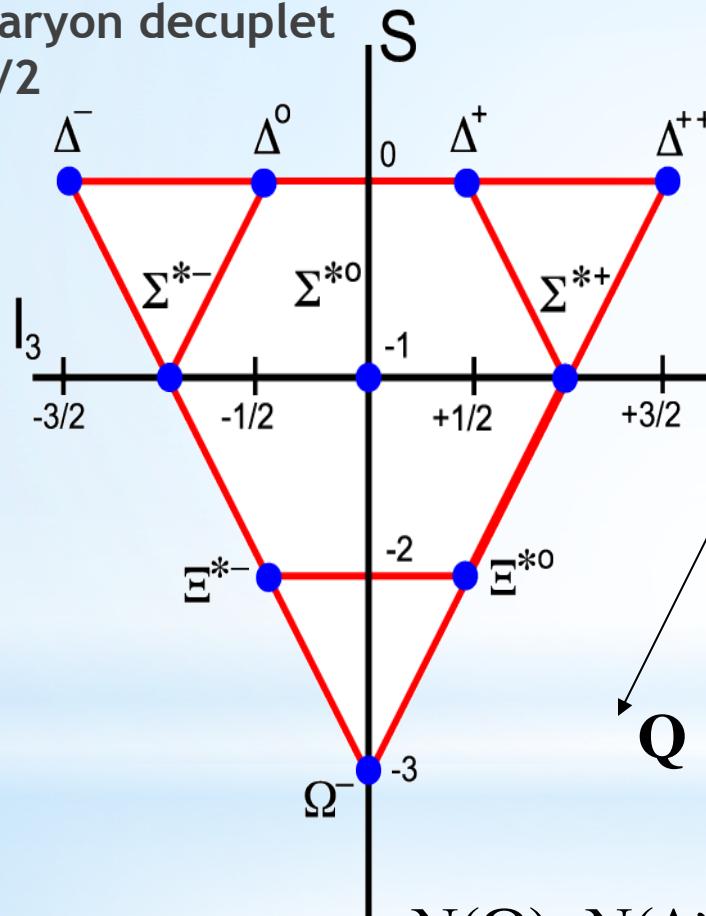


- * Decay-channel asymmetry of $\Lambda(1405)$ lineshape confirmed
- * Asymmetric among the three charge states → not a pure isospin $I=0$ process (decomposition in progress...)
- * Subtracted backgrounds: $\Sigma(1385)$, $\Lambda(1520)$, $K(892)$
- * Direct Spin-parity measurement: $J^\pi = \frac{1}{2}^-$
- * Line shapes depend on photon energy and kaon angle

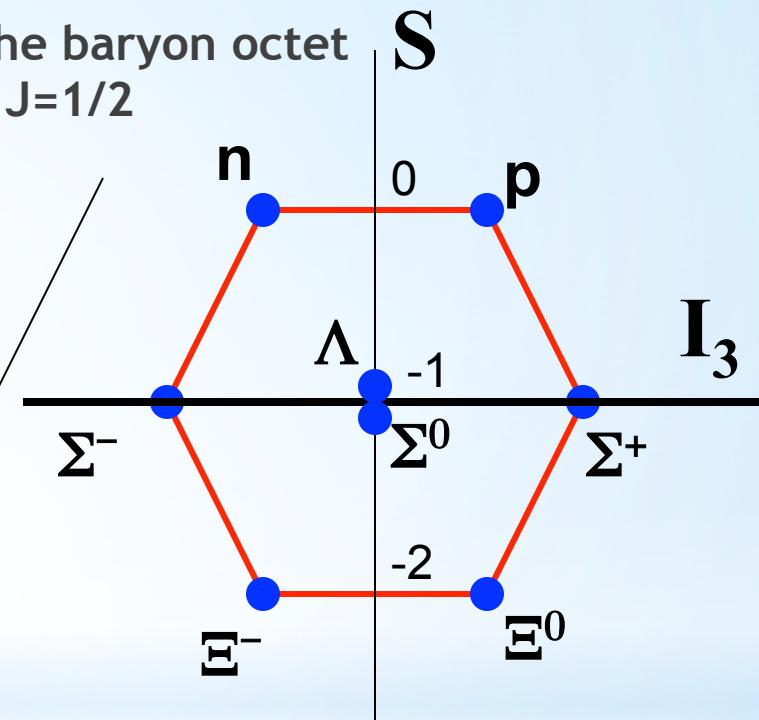
Note that “sign” of the charge asymmetry is opposite to Nacher *et al* prediction

* Baryon ground states

The baryon decuplet
 $J=3/2$



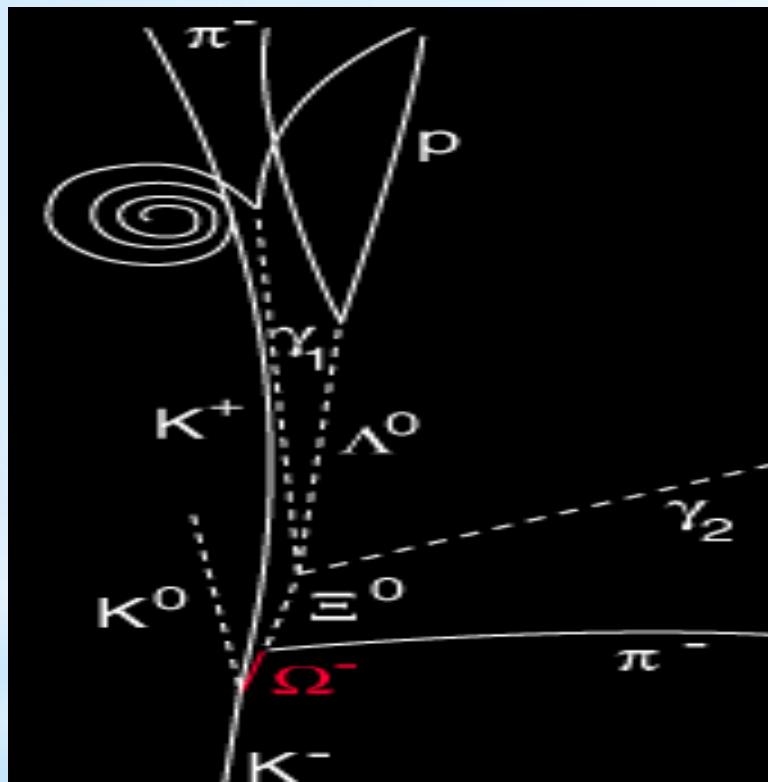
The baryon octet
 $J=1/2$



$$N(\Omega) = N(\Delta^*)$$

$$N(\Xi) = N(N^*) + N(\Delta^*)$$

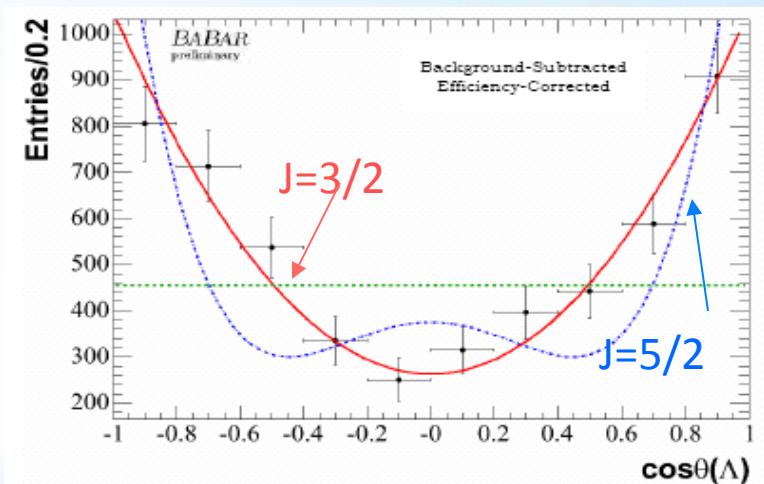
* History of Ω^- (sss) Baryon



Barnes et al, PRL 12:204, 1964,

$$K^- p \rightarrow K^0 K^+ \Omega^-$$

First measurement of $J(\Omega^-)$
at SLAC: $\Xi_c^0 \rightarrow \Omega^- K^+$, $\Omega^- \rightarrow \Lambda K^-$



$$J(\Omega^-) = 3/2, \text{ if } J(\Xi_c^0) = 1/2$$

Aubert et al, PRL.97:112001, 2006

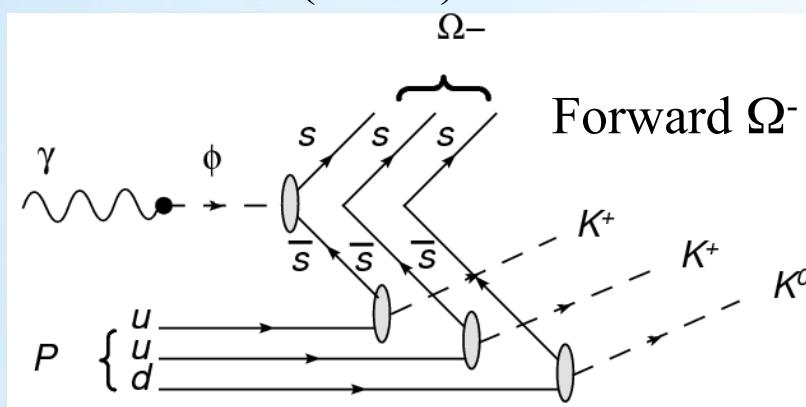
* Excited (PDG***) Ω/Ξ Baryons (half a century later)

	$(J)^P$	M(MeV)	Γ (MeV)
$\Omega(2250)$? ?	2250	
$\Xi(1530)$	$(3/2)^+$	1530	9.1
$\Xi(1690)$	$(1/2?)^?$	1690	<30
$\Xi(1820)$	$(-3/2?)^-$	1823	24
$\Xi(1950)$	$(?)^?$	1950	60
$\Xi(2030)$	$(\geq 5/2)^?$	2025	20

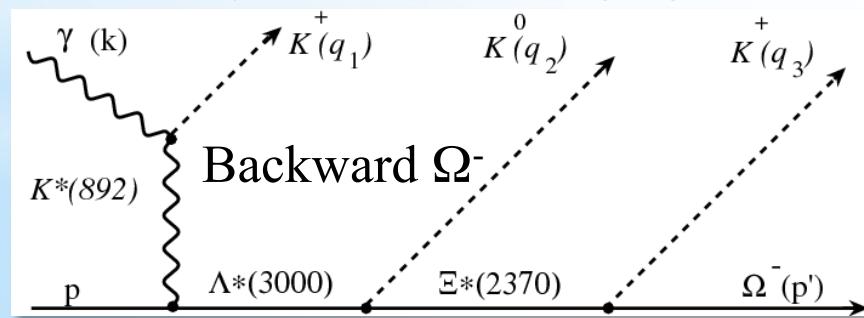
- * Very few Ω/Ξ baryons have been identified in the last 50 years
- * Even fewer have their quantum numbers determined
- * Mass splitting measurement for Ξ needs corroboration
- * Kaon beam was the primary source for the discoveries
- * Photon beam could be a powerful alternative

* Ω^- (sss) Cross section and production mechanism

A. Afanasev (VMD):

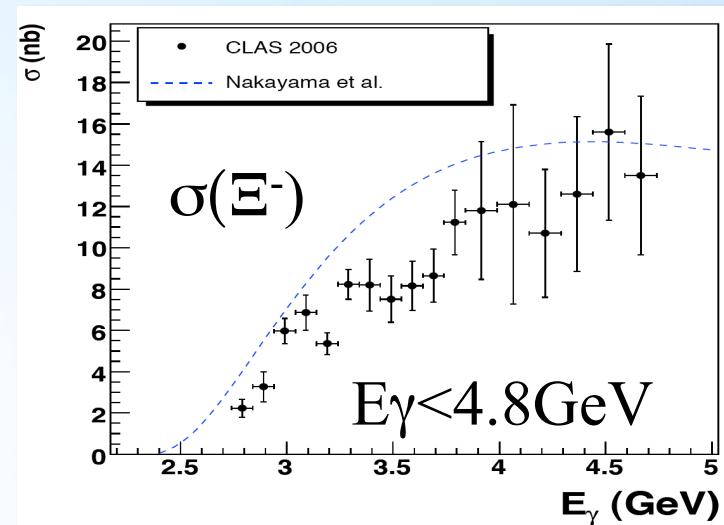
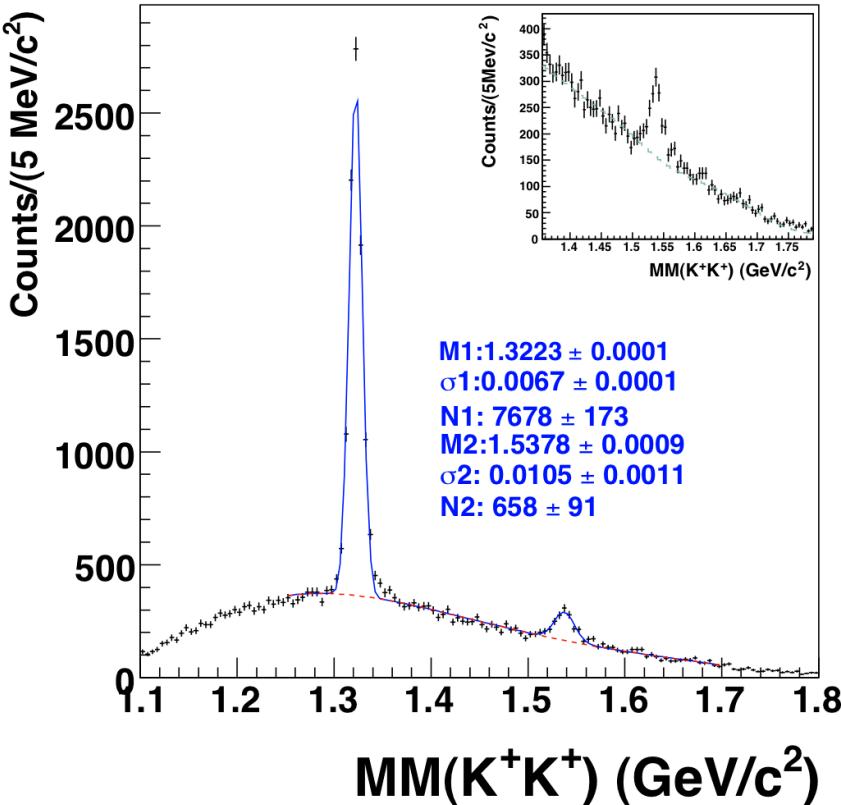


V. Shklyar (Effective Lagrangian)



- * Production mechanism for Ω^- in photoproduction unknown but extremely interesting: **None of the constituent quark (s) is from the target** ($\Delta S = -3$)
- * Models imply different angular distributions
- * Various models predict $\sigma \sim 0.3\text{-}2\text{nb}$ at $E_\gamma \sim 7\text{GeV}$
- * SLAC upper limit: 17nb@20GeV
Abe et al, PRD32, 2869 (1985)

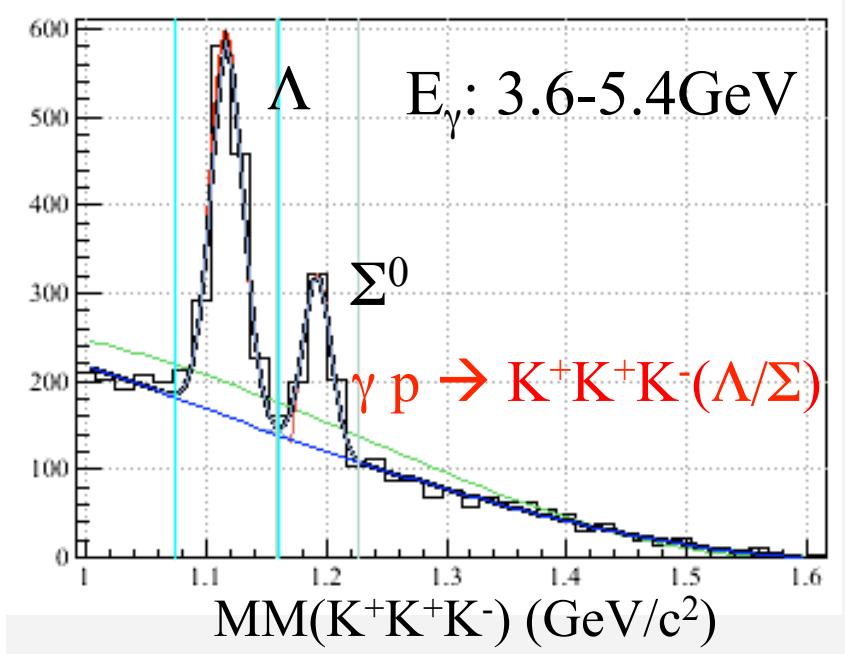
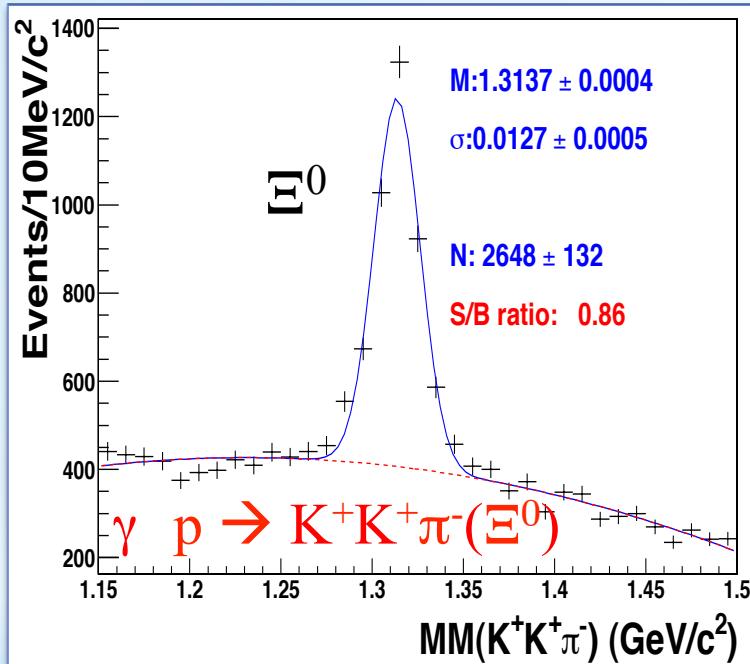
* Cascade cross section



* Don't see anything beyond first excited state.

* Search for Excited Cascade Resonances

$$E^* \rightarrow \pi^- E^0, \Lambda/\Sigma K^-$$

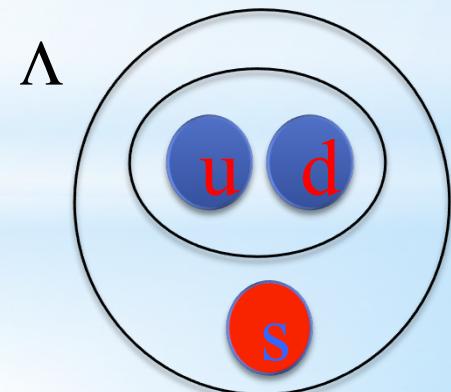
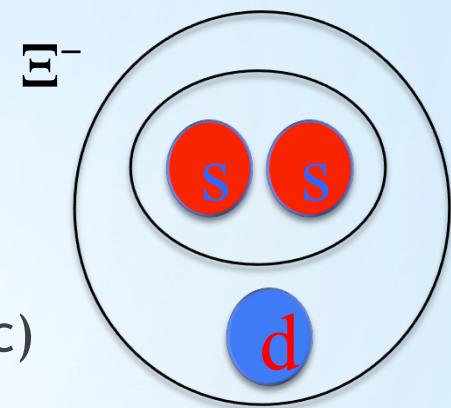
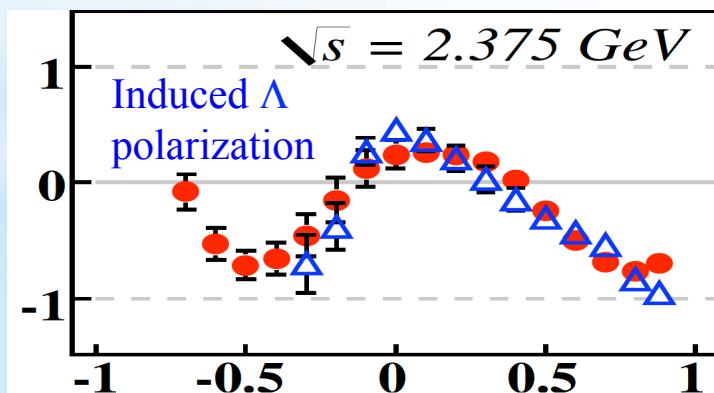


- * $E^0/\Lambda/\Sigma$ decay chain not detected (can not determine J^ρ)
- * Limited by beam energy

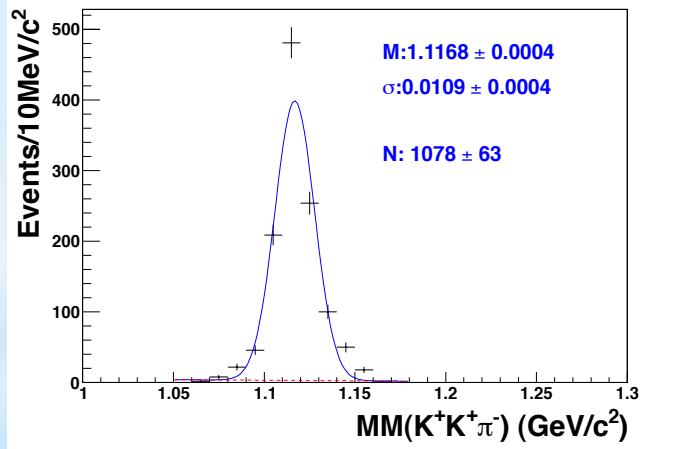
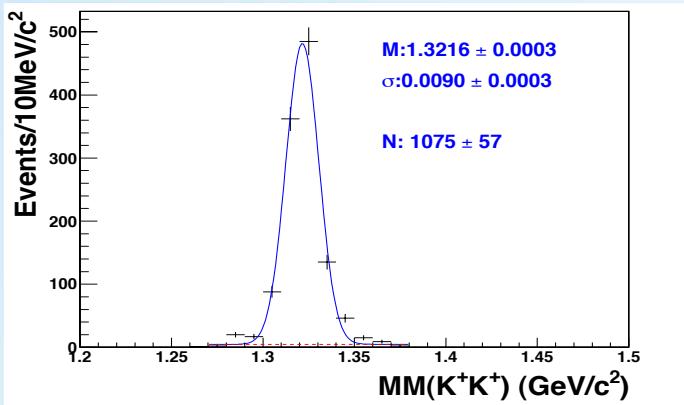
We NEED CLAS12: predicted cross sections at higher E_γ , better acceptance ...!

* Hyperon Polarization

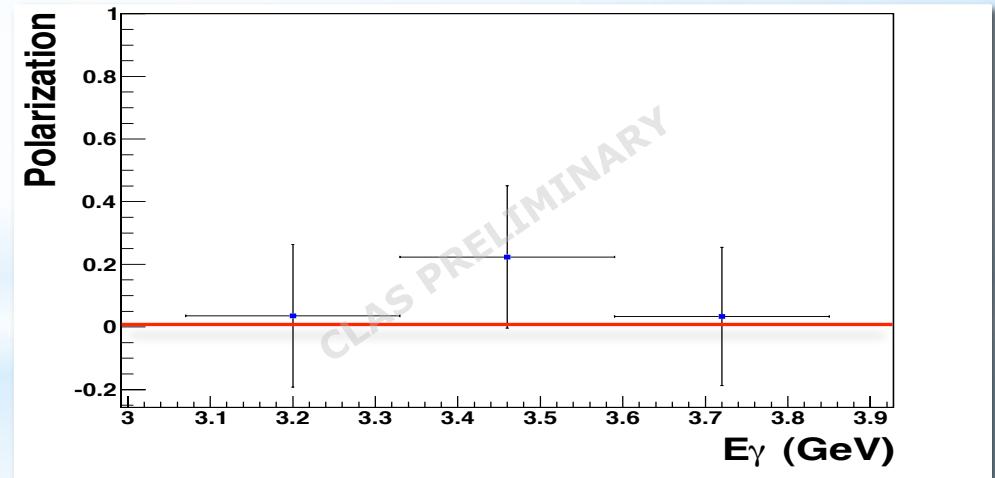
- * Diquark models:
 - * “Good” diquark: isospin 0 and spin 0
 - * $\Lambda((ud)s)$ polarization comes from s
 - * $\Xi(u/d(ss))$, polarization comes from u/d?
- * Purpose of studying Ξ polarization
 - * Probe production mechanism (hadronic/partonic)
 - * Understand the origin of hyperon polarization



* Ξ^- Induced Polarization in Photoproduction

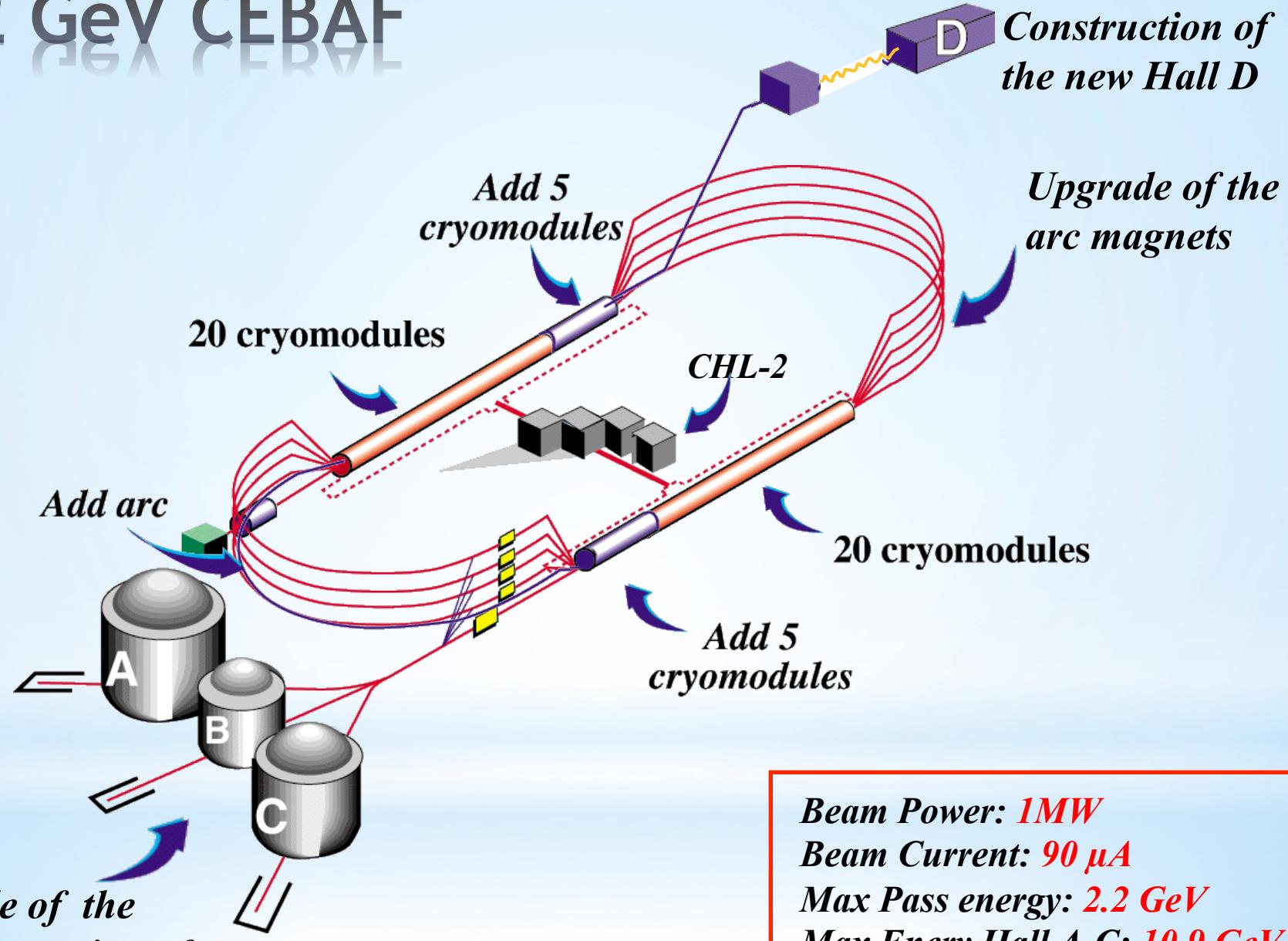


- Data virtually background free (double kinematic constraints)
- Without beam/target polarization, Ξ^- should not be polarized, if our naïve di-quark picture is correct,
- Statistics limited to study $P(\cos\theta^*)$



CLAS12 (with FT): polarization transfer for Ξ^-
 $P_\gamma(10\text{-}85\%)$, known on a event by event

* 12 GeV CEBAF



Beam Power: 1MW
Beam Current: 90 μ A
Max Pass energy: 2.2 GeV
Max Energy Hall A-C: 10.9 GeV
Max Energy Hall D: 12 GeV

Forward Detector:

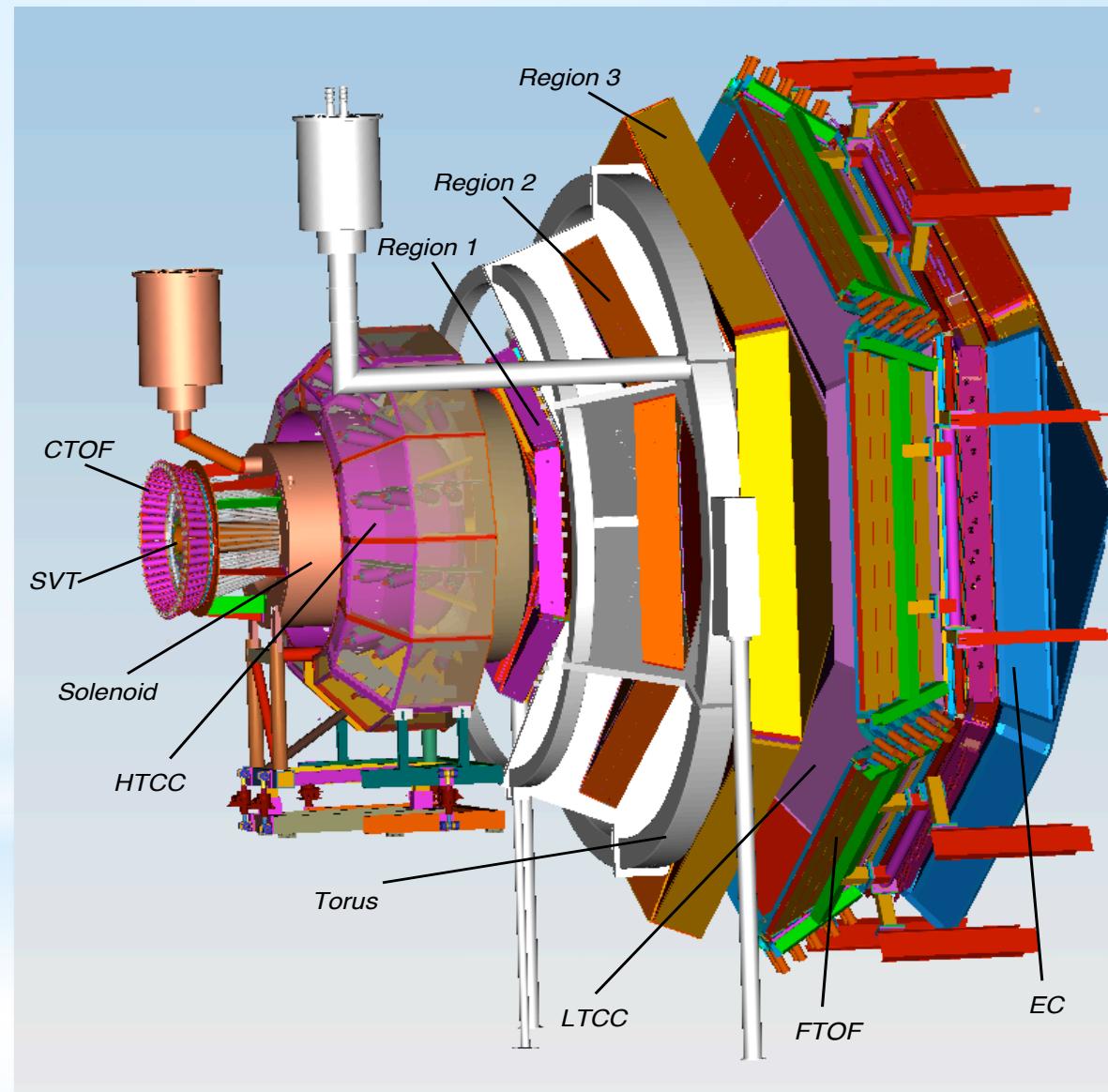
- TORUS magnet
- Forward SVT tracker
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Preshower calorimeter
- E.M. calorimeter (EC)

Central Detector:

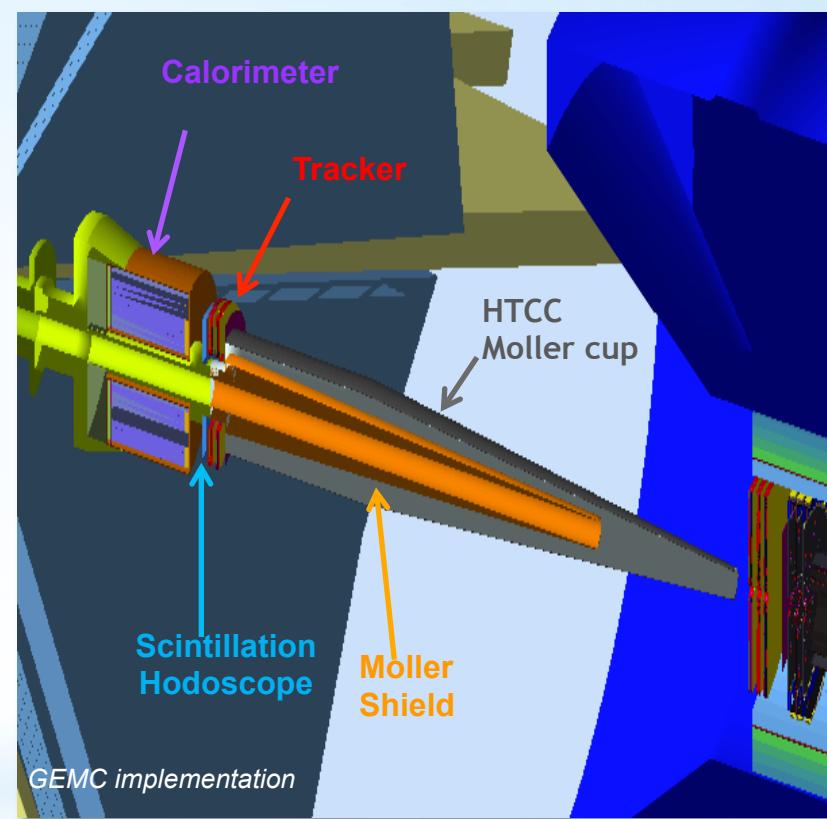
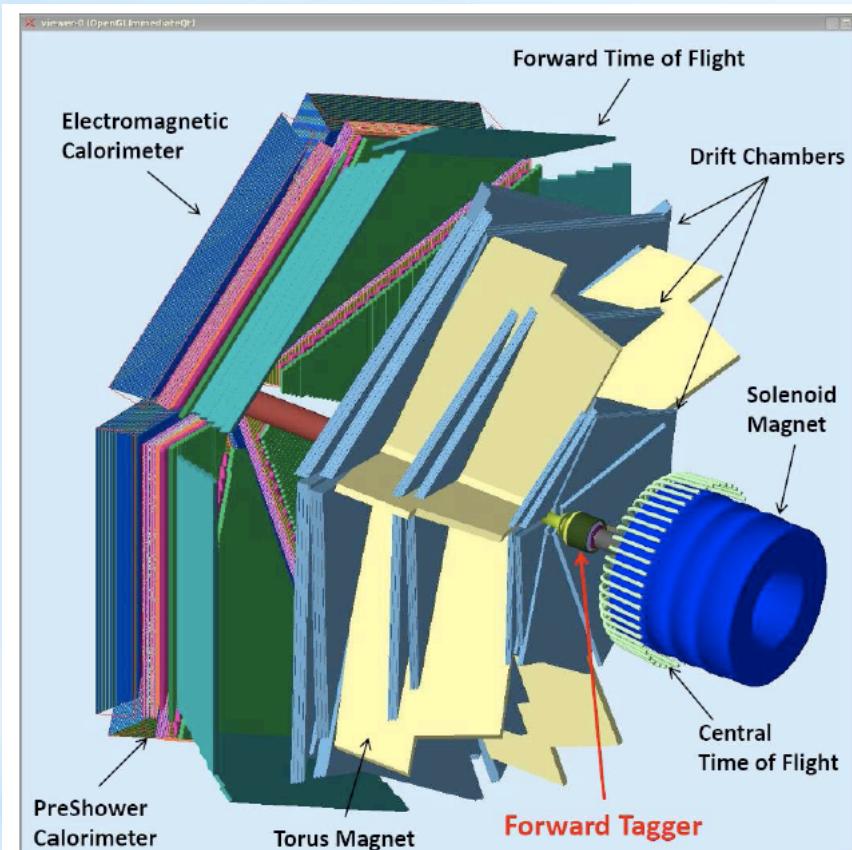
- Barrel Silicon Tracker
- SOLENOID magnet
- Central Time-of-Flight

Proposed upgrades:

- Micromegas (CD)
- Neutron detector (CD)
- RICH detector (FD)
- Forward Tagger (FD)



* CLAS12 Forward tagger(FT)



E_e : 0.5-6.0GeV
 θ_e : 2.5°-4.5°
 E_γ : 5.0-10.5GeV
 P_γ : 10-85%
 Q^2 : 0.01-0.3GeV²

* Conclusions

- * Electromagnetic production of strangeness is an important part of CLAS program and will remain as such after upgrade to CLAS12.
- * What makes it different from production in high energy collisions is a possibility to do this exclusively and get access to production mechanism which in turn helps to understand properties.
- * Strange particles are no less stranger today than they were half century ago when they were discovered. More we look at them, more “strange” properties we see.