# *Hyperon production and polarization with CLAS at JLab*

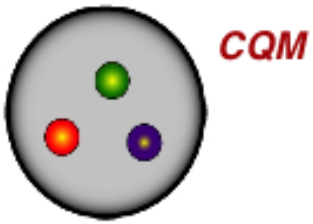
**Sergio Anefalos Pereira**

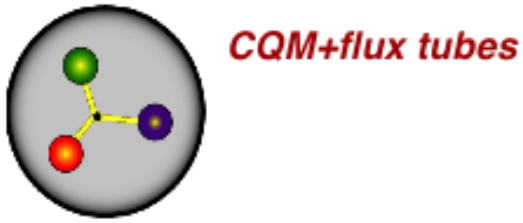
***Laboratori Nazionali di Frascati***
***(for the CLAS Collaboration)***

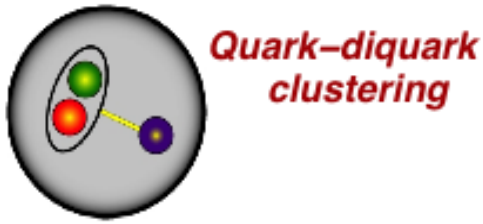
INFN
Istituto Nazionale
di Fisica Nucleare

# Introduction

- A major goal of hadron physics is to probe the structure of the nucleon and its excited states.
  - *The N* spectrum is a direct reflection of the underlying degrees of freedom of the nucleon.*



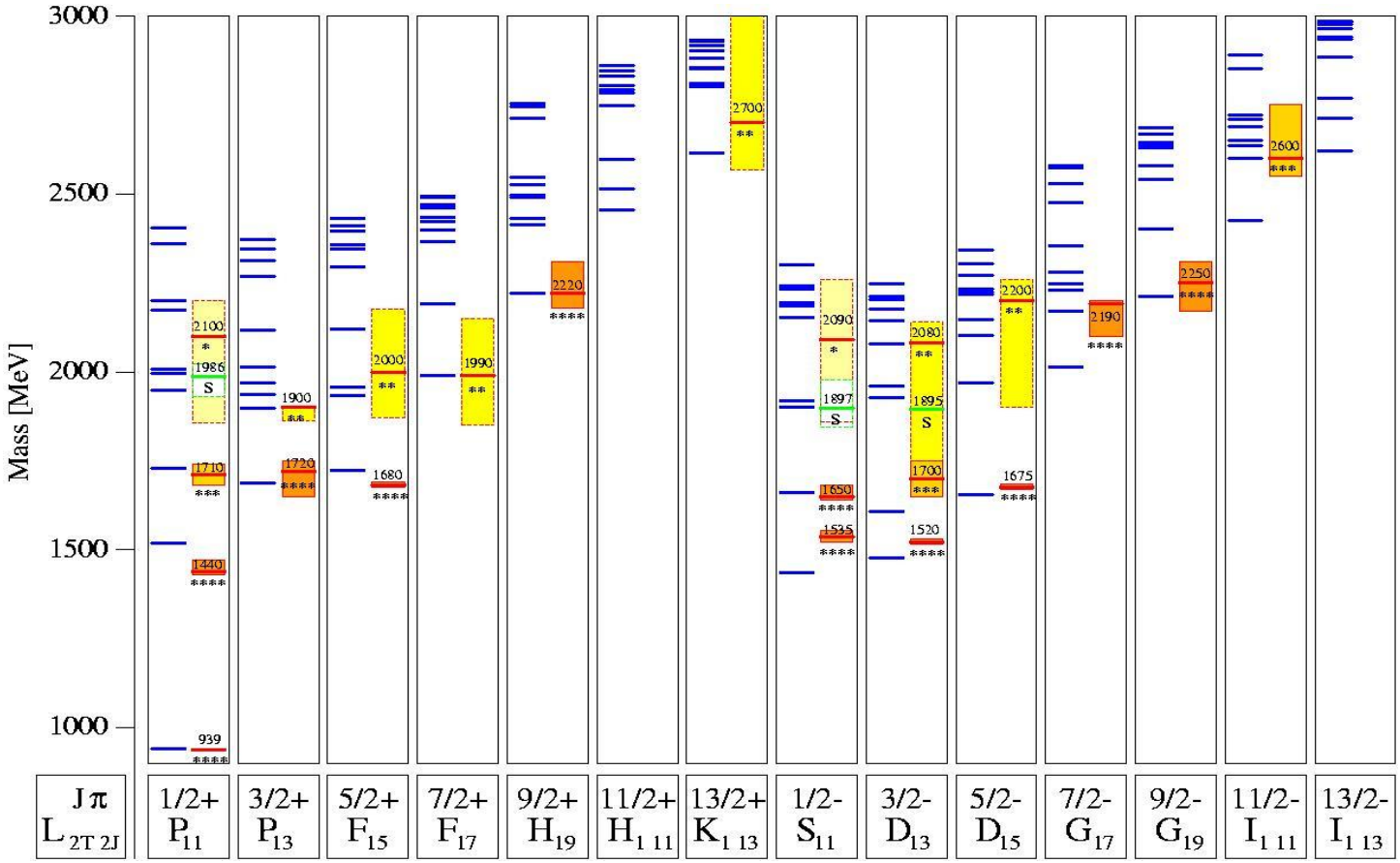

Symmetric Constituent Quark Models predict a higher number of excited states

Quark and flux-Tube Models predict increased number of states

Quark-Diquark models predict fewer states

# Missing Resonances

1. Quark models predict many more baryons that have been observed, “missing” resonances;
2. Many baryon resonances are predicted studying the channels with π, but very few were established;




Löhring, Metsch, Petry, EPJ A10, 395(2001)

The CLAS program is designed to obtain accurate electromagnetic production cross section and spin observables over a broad kinematic range. Strangeness production is an important part of this program.

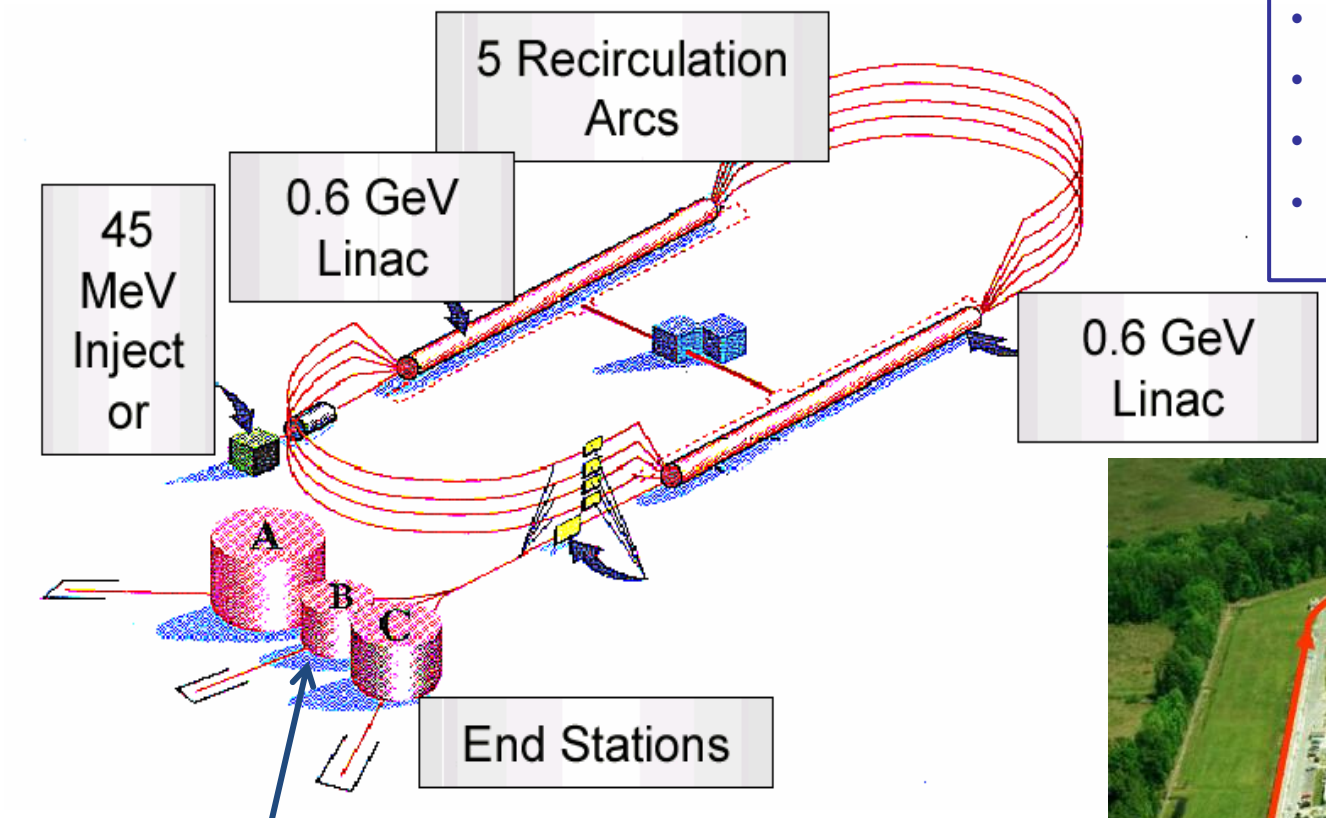
# Why studying KY ?

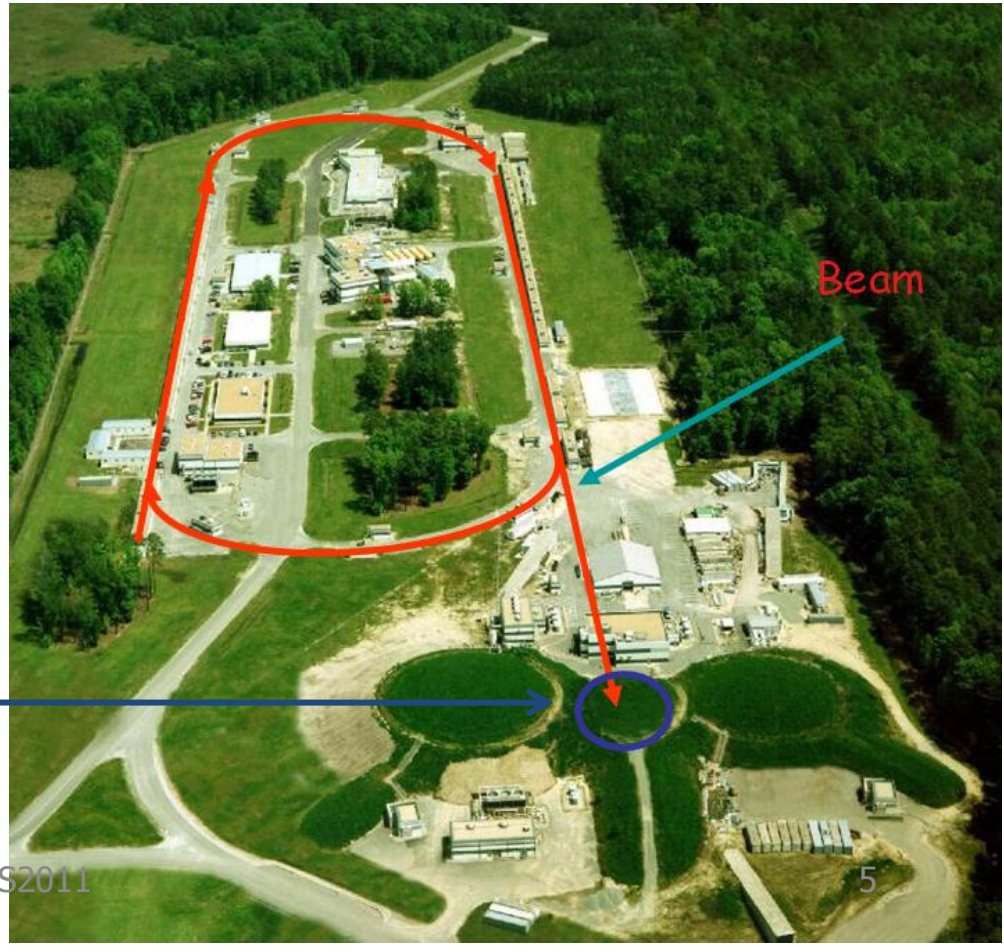
- ✓ To resolve the question of "missing" resonances
  - have information about the structure of the nucleon
  - Couplings of nucleon resonances to KY final states will differ from the $\pi N$, $\eta N$ and $\pi\pi N$ final states.

- ✓ Self-analyzing weak decay of hyperons allows recoil polarization measurements with high statistics:
  - polarization observables are crucial to extract elementary amplitudes high discriminating power against various models
  - one can have access to all observables (not possible with $\pi$ channels)

# JLab Accelerator CEBAF

- Continuous Electron Beam
- Energy 0.8-5.7 GeV
- 200μA, polarization 85%
- Simultaneous delivery to 3Halls




**CLAS**

# Hall B: Cebaf Large Acceptance Spectrometer

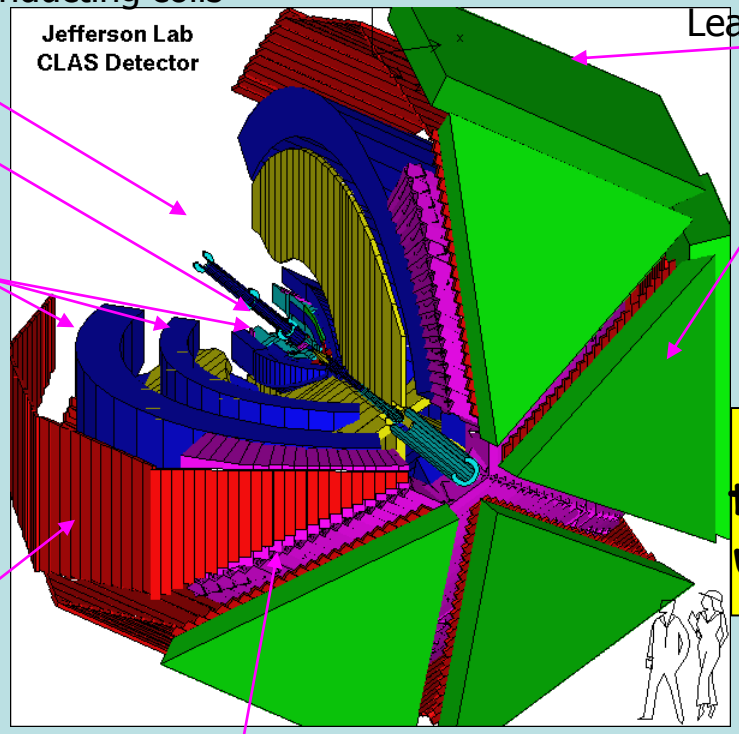
**beam**

**Torus magnet**
6 superconducting coils

**Electromagnetic calorimeters**
Lead/scintillator, 1296 photomultipliers

**Liquid $D_2$ ($H_2$)target +**
$\gamma$ start counter; e minitorus

**Drift chambers**
argon/$CO_2$ gas, 35,000 cells




- Broad angular coverage (**8° ÷ 140°** in LAB frame)
- Charged particle momentum resolution **~0.5%** forward dir

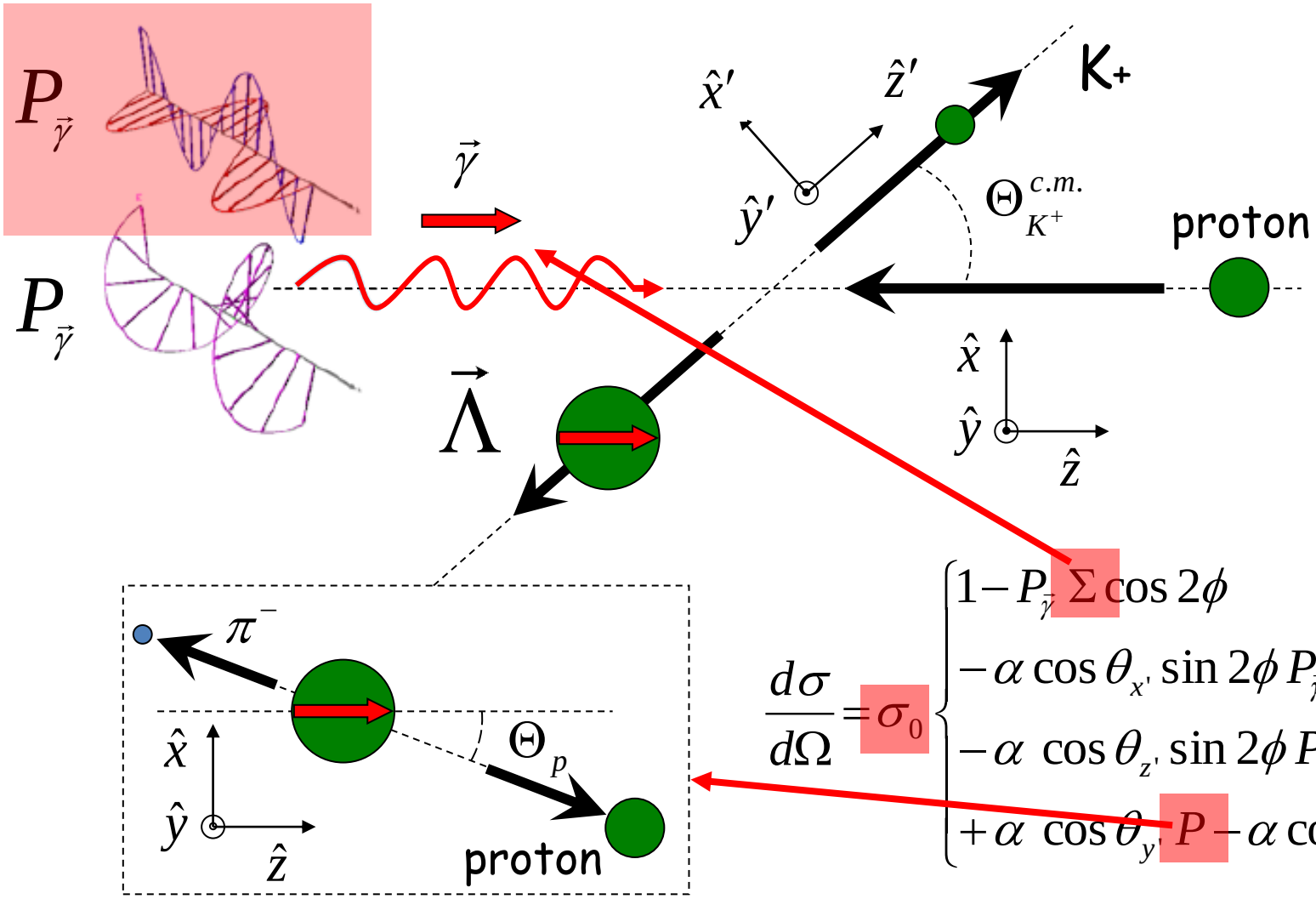
**CLAS is designed to measure exclusive reactions with multi-particle final states**

**Time-of-flight counters**
plastic scintillators, 684 photomultipliers

**Gas Cherenkov counters**
e/$\pi$ separation, 216 PMTs

# Define the Spin Observables

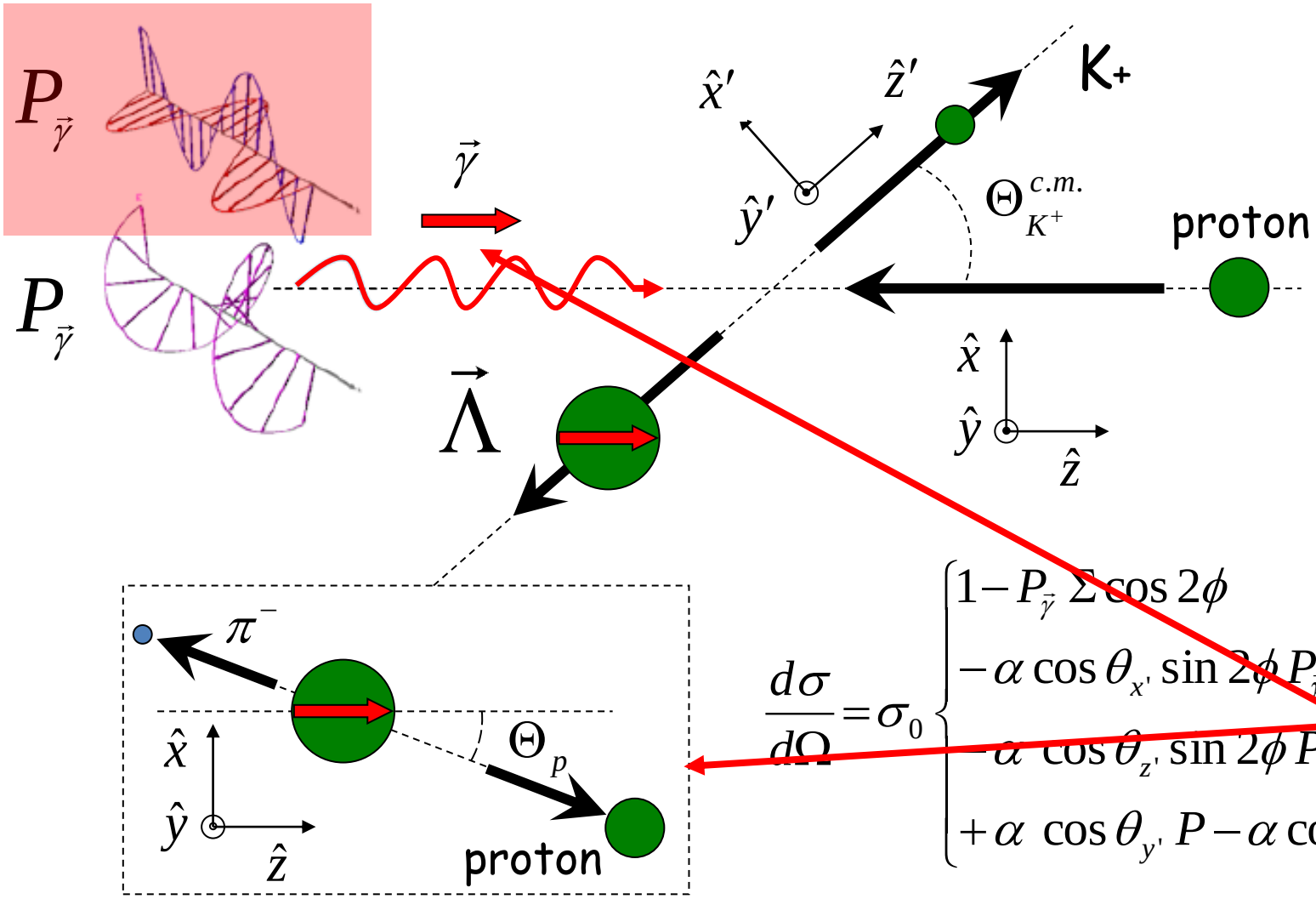
(unpolarized target)




$$\frac{d\sigma}{d\Omega} = \sigma_0 \begin{cases} 1 - P_{\vec{\gamma}}\,\Sigma\cos 2\phi \\ -\alpha\cos\theta_{x'}\sin 2\phi\, P_{\vec{\gamma}}\, O_{x'} - \alpha\cos\theta_{x'}\, P_{\vec{\gamma}}\, C_{x'} \\ -\alpha\cos\theta_{z'}\sin 2\phi\, P_{\vec{\gamma}}\, O_{z'} - \alpha\cos\theta_{z'}\, P_{\vec{\gamma}}\, C_{z'} \\ +\alpha\cos\theta_{y'}\, P - \alpha\cos\theta_{y'}\, P_{\vec{\gamma}}\, T\cos 2\phi \end{cases}$$

# Define the Spin Observables

(unpolarized target)

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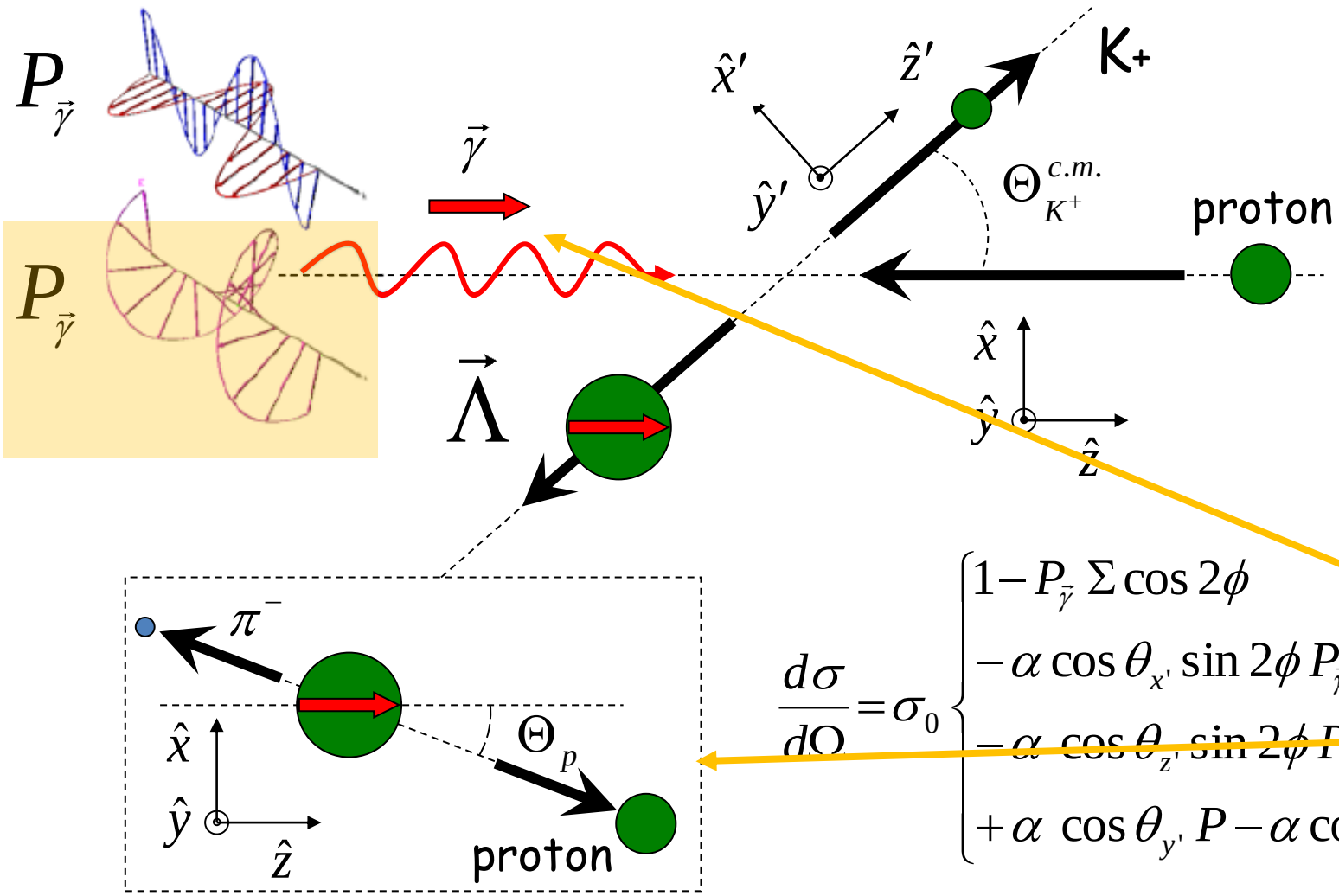
# Define the Spin Observables

(unpolarized target)

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# Polarization observables in pseudoscalar meson production

**4 Complex amplitudes: 16 real polarization observables.**

**Complete measurement from 8 carefully chosen observables.**

**Only hyperon can provide recoil polarization**

**πN** | **KY**

recoil targ γ | γ targ recoil

| Symbol | Transversity representation | Experiment required | Type |
|---|---|---|---|
| $d\sigma/dt$ | $\lvert b_1\rvert^2+\lvert b_2\rvert^2+\lvert b_3\rvert^2+\lvert b_4\rvert^2$ | $\{-;-;-\}$ | $S$ |
| $\Sigma d\sigma/dt$ | $\lvert b_1\rvert^2+\lvert b_2\rvert^2-\lvert b_3\rvert^2-\lvert b_4\rvert^2$ | $\{L(\frac{1}{2}\pi,0);-;-\}$ | $B$ |
| $Td\sigma/dt$ | $\lvert b_1\rvert^2-\lvert b_2\rvert^2-\lvert b_3\rvert^2+\lvert b_4\rvert^2$ | $\{-;y;-\}$ | $T$ |
| $Pd\sigma/dt$ | $\lvert b_1\rvert^2-\lvert b_2\rvert^2+\lvert b_3\rvert^2-\lvert b_4\rvert^2$ | $\{-;-;y\}$ | $R$ |
| $Gd\sigma/dt$ | $2\ \mathrm{Im}(b_1b_3^*+b_2b_4^*)$ | $\{L(\pm\frac{1}{4}\pi);z;-\}$ | $BT$ |
| $Hd\sigma/dt$ | $-2\ \mathrm{Re}(b_1b_3^*-b_2b_4^*)$ | $\{L(\pm\frac{1}{4}\pi);x;-\}$ | |
| $Ed\sigma/dt$ | $-2\ \mathrm{Re}(b_1b_3^*+b_2b_4^*)$ | $\{C;z;-\}$ | |
| $Fd\sigma/dt$ | $2\ \mathrm{Im}(b_1b_3^*-b_2b_4^*)$ | $\{C;x;-\}$ | |
| $O_xd\sigma/dt$ | $-2\ \mathrm{Re}(b_1b_4^*-b_2b_3^*)$ | $\{L(\pm\frac{1}{4}\pi);-;x'\}$ | $BR$ |
| $O_zd\sigma/dt$ | $-2\ \mathrm{Im}(b_1b_4^*+b_2b_3^*)$ | $\{L(\pm\frac{1}{4}\pi);-;z'\}$ | |
| $C_xd\sigma/dt$ | $2\ \mathrm{Im}(b_1b_4^*-b_2b_3^*)$ | $\{C;-;x'\}$ | |
| $C_zd\sigma/dt$ | $-2\ \mathrm{Re}(b_1b_4^*+b_2b_3^*)$ | $\{C;-;z'\}$ | |
| $T_xd\sigma/dt$ | $2\ \mathrm{Re}(b_1b_2^*-b_3b_4^*)$ | $\{-;x;x'\}$ | $TR$ |
| $T_zd\sigma/dt$ | $2\ \mathrm{Im}(b_1b_2^*-b_3b_4^*)$ | $\{-;x;z'\}$ | |
| $L_xd\sigma/dt$ | $2\ \mathrm{Im}(b_1b_2^*+b_3b_4^*)$ | $\{-;z;x'\}$ | |
| $L_xd\sigma/dt$ | $2\ \mathrm{Re}(b_1b_2^*+b_3b_4^*)$ | $\{-;z;z'\}$ | |

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

linearly polarized photons

circ polarized photons

longitudinally polarized target

transversely polarized target

**complete and over-determined**

# 16 Pseudoscalar Meson Photoproduction Observables

For $\gamma + p \rightarrow K^+ \Lambda$:

| | Symbol | Transversity representation | Experiment required |
|---|---|---|---|
| | $d\sigma/dt$ | $\lvert b_1\rvert^2 + \lvert b_2\rvert^2 + \lvert b_3\rvert^2 + \lvert b_4\rvert^2$ | $\{-;-;-\}$ |
| Single Polarization | $\Sigma d\sigma/dt$ | $\lvert b_1\rvert^2 + \lvert b_2\rvert^2 - \lvert b_3\rvert^2 - \lvert b_4\rvert^2$ | $\{L(\frac{1}{2}\pi,0);$ |
| | $T d\sigma/dt$ | $\lvert b_1\rvert^2 - \lvert b_2\rvert^2 - \lvert b_3\rvert^2 + \lvert b_4\rvert^2$ | $\{-;y;-\}$ |
| | $P d\sigma/dt$ | $\lvert b_1\rvert^2 - \lvert b_2\rvert^2 + \lvert b_3\rvert^2 - \lvert b_4\rvert^2$ | $\{-;-;y\}$ |
| Beam & Target | $G d\sigma/dt$ | $2\ \mathrm{Im}(b_1 b_3^* + b_2 b_4^*)$ | $\{L(\pm\frac{1}{4}\pi);$ |
| | $H d\sigma/dt$ | $-2\ \mathrm{Re}(b_1 b_3^* - b_2 b_4^*)$ | $\{L(\pm\frac{1}{4}\pi);$ |
| | $E d\sigma/dt$ | $-2\ \mathrm{Re}(b_1 b_3^* + b_2 b_4^*)$ | $\{C;z;-\}$ |
| | $F d\sigma/dt$ | $2\ \mathrm{Im}(b_1 b_3^* - b_2 b_4^*)$ | $\{C;x;-\}$ |
| Beam & Recoil | $O_x d\sigma/dt$ | $-2\ \mathrm{Re}(b_1 b_4^* - b_2 b_3^*)$ | $\{L(\pm\frac{1}{4}\pi);$ |
| | $O_z d\sigma/dt$ | $-2\ \mathrm{Im}(b_1 b_4^* + b_2 b_3^*)$ | $\{L(\pm\frac{1}{4}\pi);$ |
| | $C_x d\sigma/dt$ | $2\ \mathrm{Im}(b_1 b_4^* - b_2 b_3^*)$ | $\{C;-;x'\}$ |
| | $C_z d\sigma/dt$ | $-2\ \mathrm{Re}(b_1 b_4^* + b_2 b_3^*)$ | $\{C;-;z'\}$ |
| Target & Recoil | $T_x d\sigma/dt$ | $2\ \mathrm{Re}(b_1 b_2^* - b_3 b_4^*)$ | $\{-;x;x'\}$ |
| | $T_z d\sigma/dt$ | $2\ \mathrm{Im}(b_1 b_2^* - b_3 b_4^*)$ | $\{-;x;z'\}$ |
| | $L_x d\sigma/dt$ | $2\ \mathrm{Im}(b_1 b_2^* + b_3 b_4^*)$ | $\{-;z;x'\}$ |
| | $L_x d\sigma/dt$ | $2\ \mathrm{Re}(b_1 b_2^* + b_3 b_4^*)$ | $\{-;z;z'\}$ |

R. Bradford *et al.* Phys. Rev. C **73** 035202 (2006), M.E.McCracken *et.al.*, PRC **81**, 025201 (2010)

C. Paterson *et al.* (Glasgow), to be published

J. McNabb *et al.* Phys Rev C **69** 042201 (2004)

FROST (g9a) under analysis

FROST (g9b) under analysis

C. Paterson *et al.* (Glasgow), to be published

R. Bradford *et al.* Phys. Rev. C **75** 035205 (2007), M.E.McCracken *et.al.*, PRC **81**, 025201 (2010)

FROST (g9b) under analysis

FROST (g9a) under analysis

# *Photoproduction on neutrons (deuteron target)*

- **neutron channels are almost unexplored**
- **add constraints in the resonance extractions.**
- **study Final State Interaction:**
  - **Compare bound proton and free proton results**
  - **Study YN interactions**

# Neutron experiments @ CLAS

**Unpolarized (g10)** **Final data set with several published papers**

- **Target:** **24cm liquid deuterium**
- **Data taking:** **March 13 - May 16, 2004**
- **E($\gamma$):** **0.75-3.58 GeV**
- **Integrated luminosity:** **~ 50 pb$^{-1}$**

$\gamma n\ (p) \rightarrow K^+ \Sigma^- (p)$

neutron cross sections

**Polarized (g13) data process ongoing**

- **Target:** **40cm liquid deuterium**
- **Data taking:** **October 2006 – June 2007**
- **Circular polarized beam**
  - **E$\gamma$ = 0.4 – 2.5 GeV**
- **Linear polarized beam**
  - **E $\gamma$ = 1.1 - 2.3 GeV**
- **Integrated luminosity:** **~ 90 pb$^{-1}$**

$\gamma n\ (p) \rightarrow K^0 \Lambda\ (p)$
$\gamma n\ (p) \rightarrow K^0 \Sigma^0\ (p)$

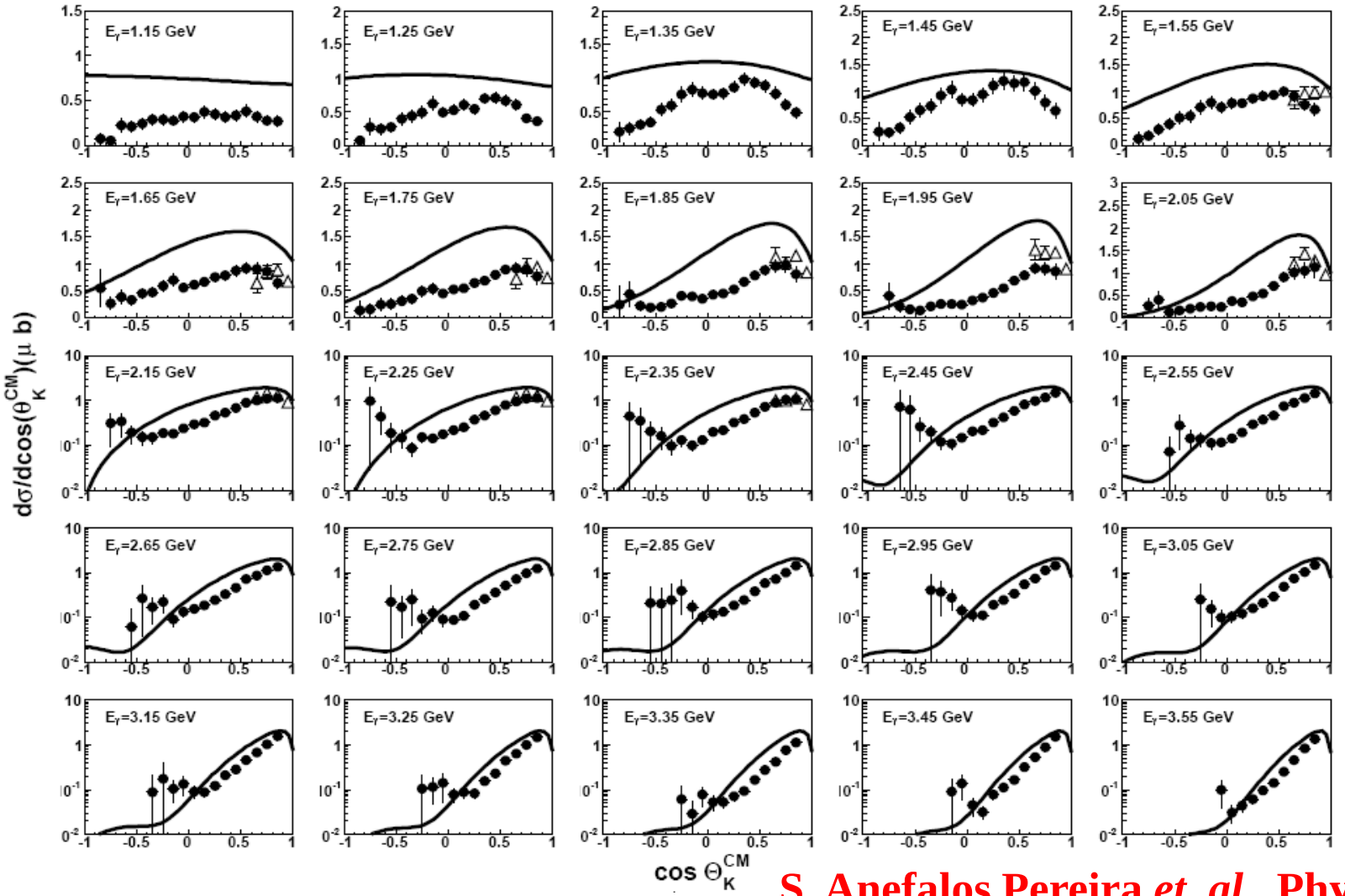
neutron cross sections and spin observables

$\gamma n\ (p) \rightarrow K^+ \Sigma^-\ (p)$
$\gamma n\ (p) \rightarrow K^{+*} \Sigma^-\ (p)$
$\gamma n\ (p) \rightarrow K^{+*} \Sigma^{-*}\ (p)$

neutron cross sections and beam asymmetry

# $\gamma\, n(p) \rightarrow K^+ \Sigma^- (p)$ cross sections

- ● CLAS 2010
- △ LEPS 2006
- — Regge-3 model

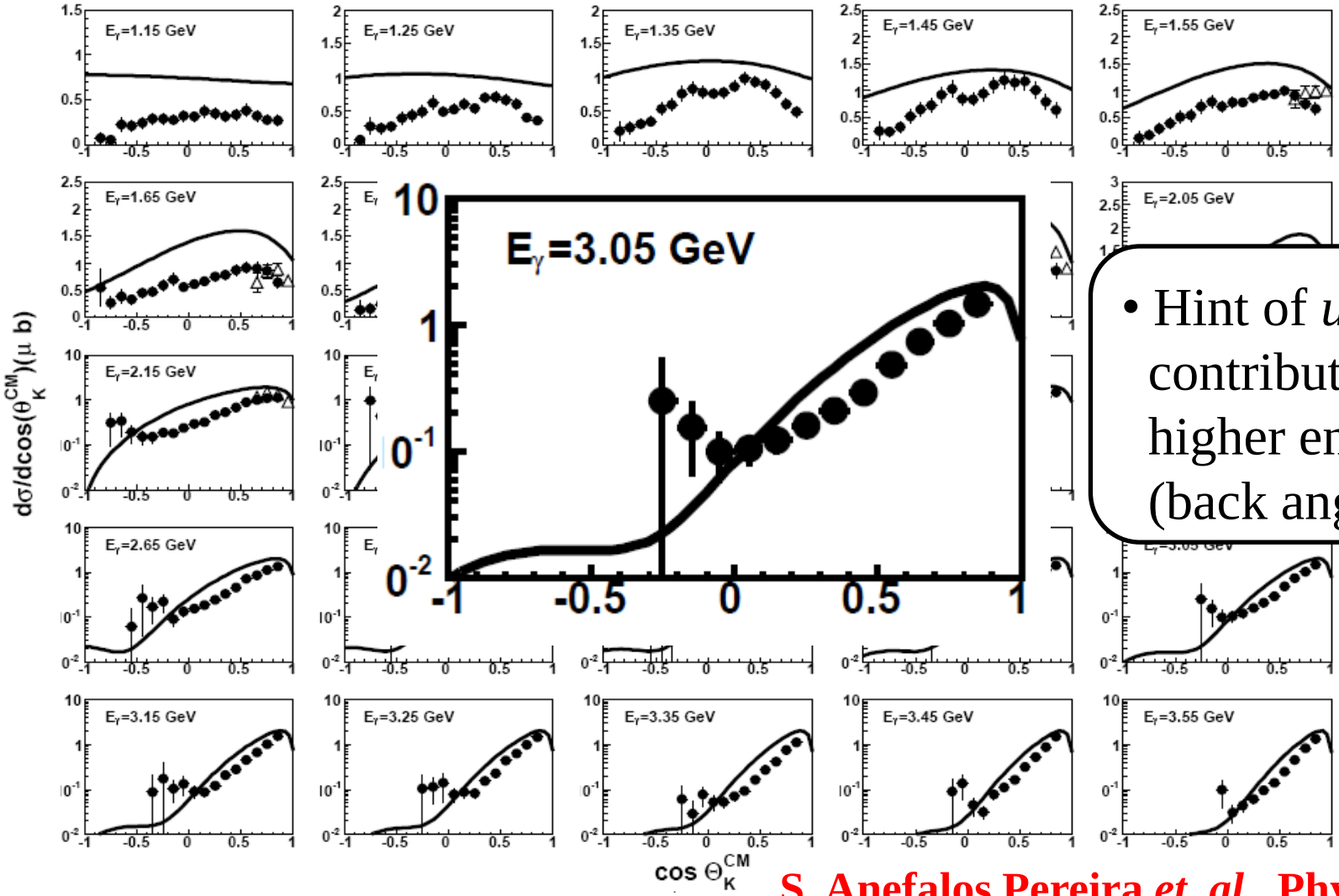



- first "complete" look at hyperon production off neutron
- deuteron target (spectator proton) FSI ~ 10%
- Ghent model with $K^+$ and $K^*(892)$ with no resonances

**S. Anefalos Pereira *et. al.*, Phys.Lett.B 688 (2010)**

# $\gamma\, n(p) \rightarrow K^+ \Sigma^- (p)$ cross sections

- ● CLAS 2010
- △ LEPS 2006
- — Regge-3 model




- first "complete" look at hyperon

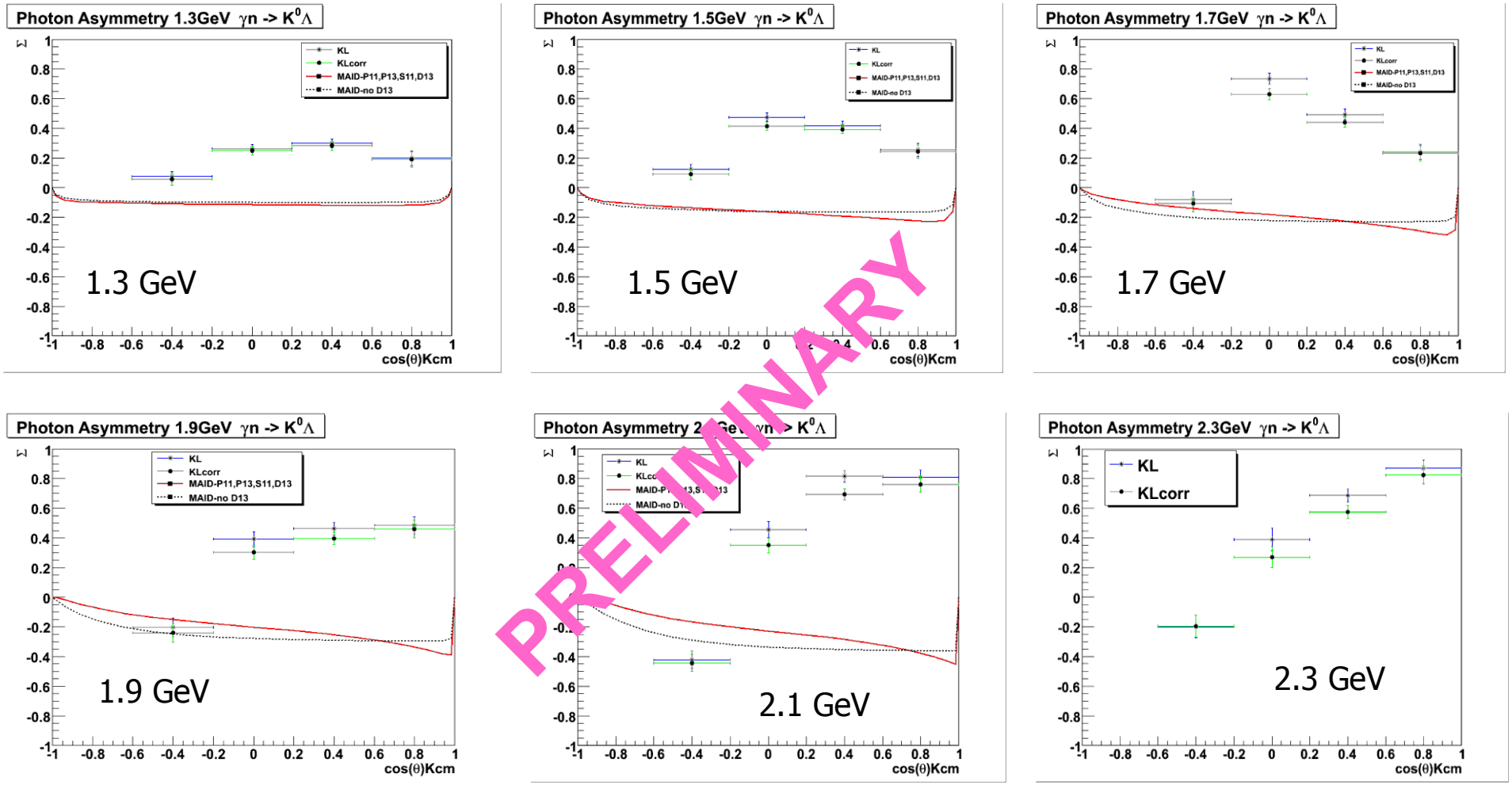
- Hint of *u*- channel contribution for higher energies (back angle rise)

- Ghent model with $K^+$ and K*(892) with no resonances

**S. Anefalos Pereira *et. al.*, Phys.Lett.B 688 (2010)**

# G13 preliminary beam asymmetry results $\gamma n \rightarrow K^0\Lambda$

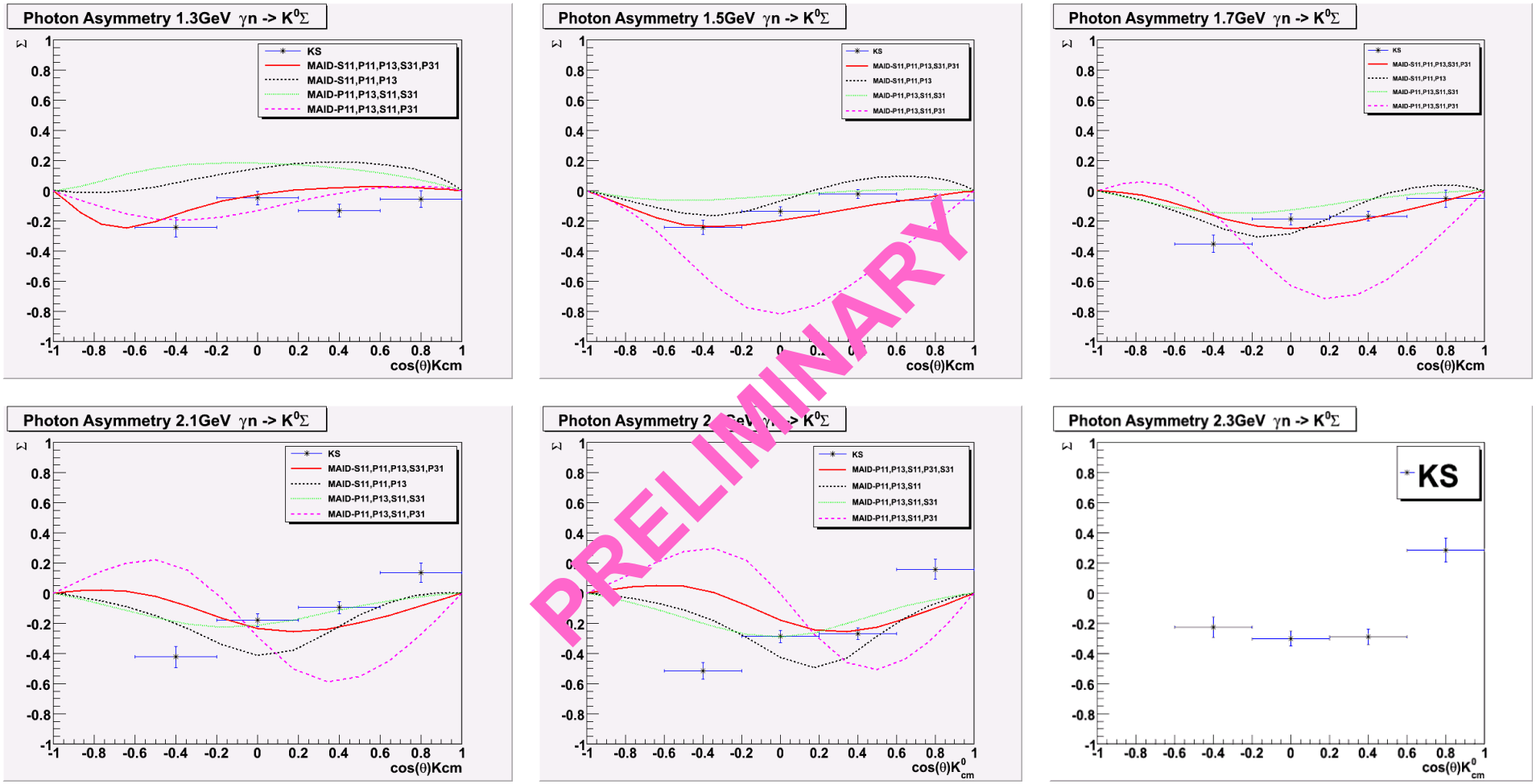
*(Neil Hassal, Glasgow)*




| | |
|---|---|
| KΛ | MAID - P11, P13, S11, D13 |
| KΛ corrected | MAID - no D13 |

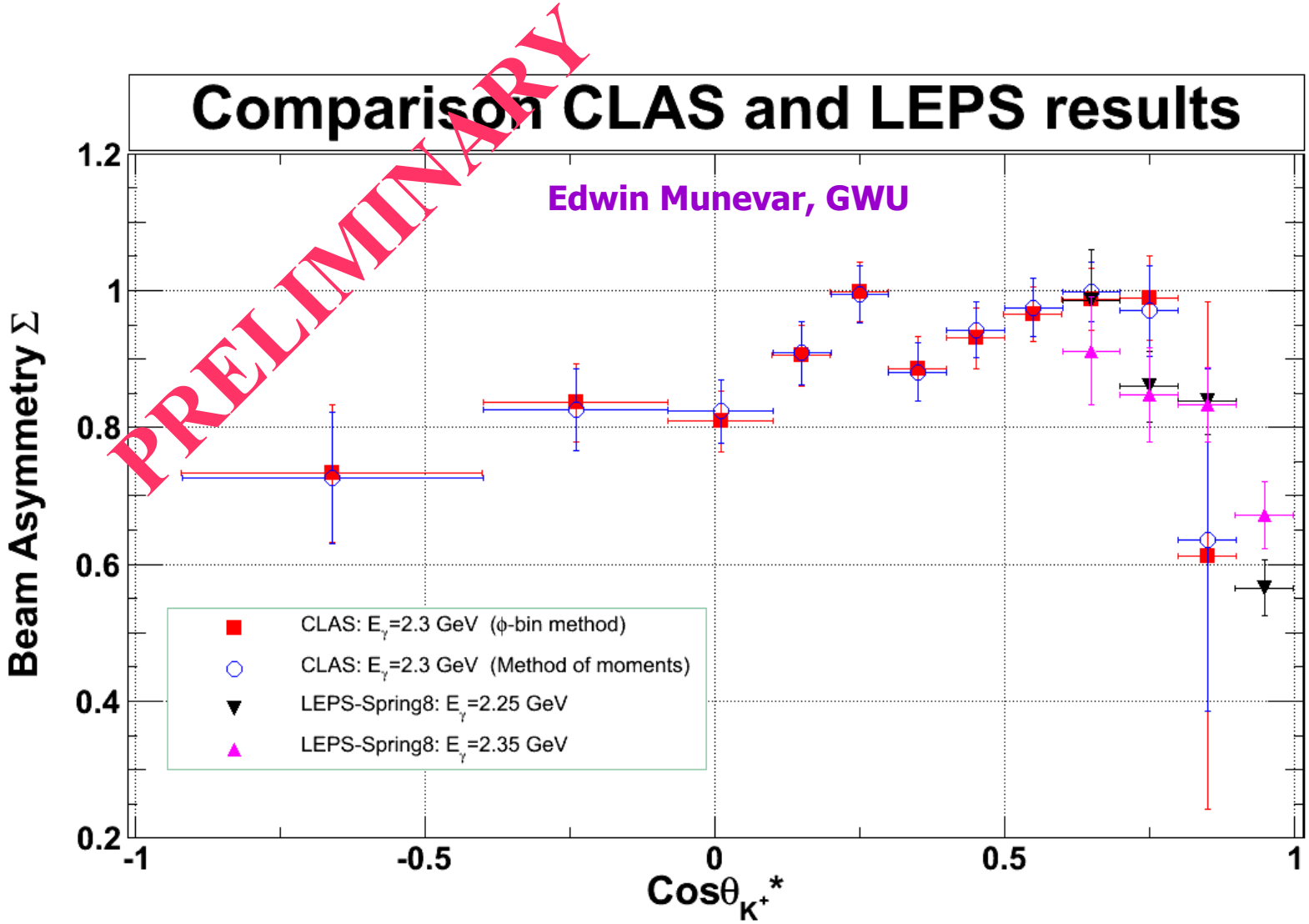
# G13 preliminary beam asymmetry results $\gamma n \rightarrow K^0\Sigma$

*(Neil Hassal, Glasgow)*




| | | |
|---|---|---|
| KΣ | MAID - P11, P13, P31, S11, S31 | |
| MAID – P11, P13, S11, S31 | MAID – S11, P11, P13 | MAID - P11, P13, P31, S11 |

# Measurements on n (Deuterium) target

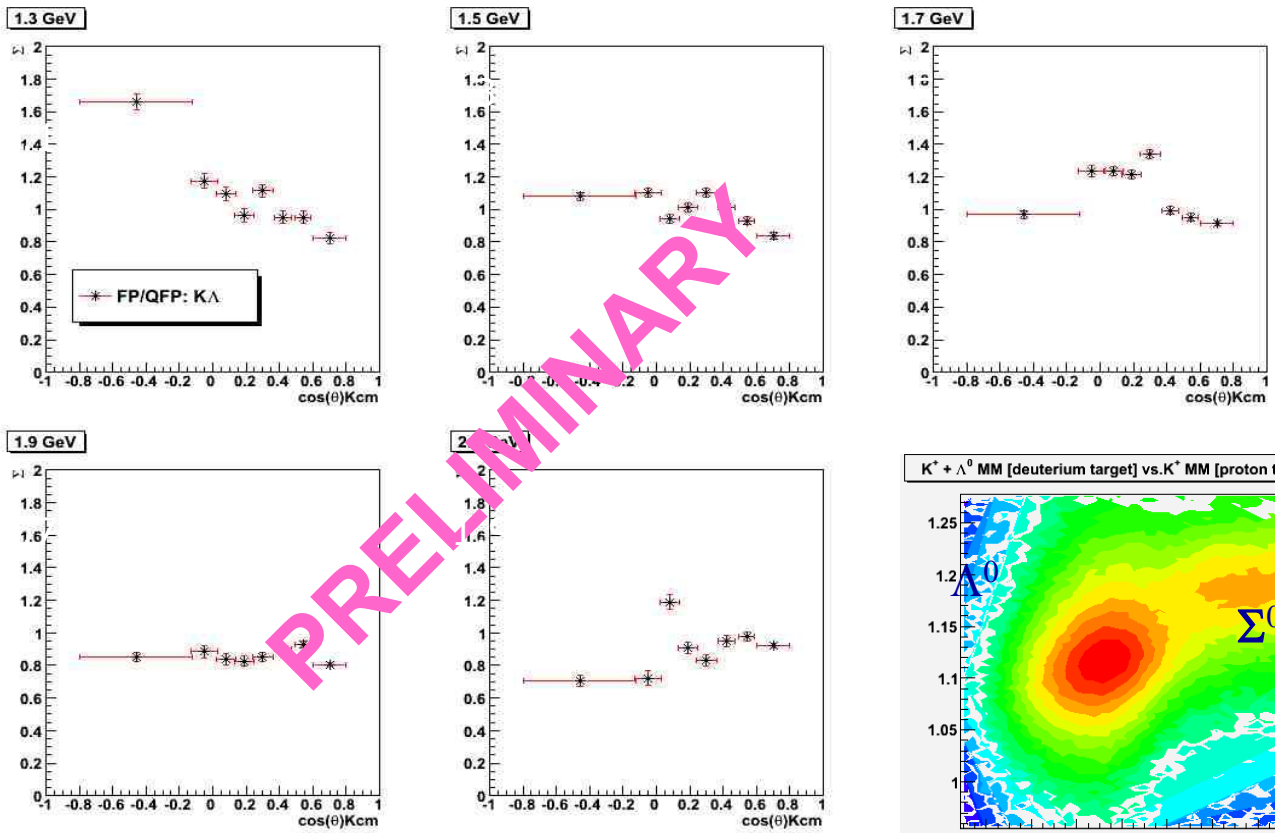



- Circularly and linearly polarized photons on n (g13, Deuterium target)
- $\gamma\, n \rightarrow K^+ \Sigma^-$ analysis for polarization observables underway. Edwin Munevar, GWU

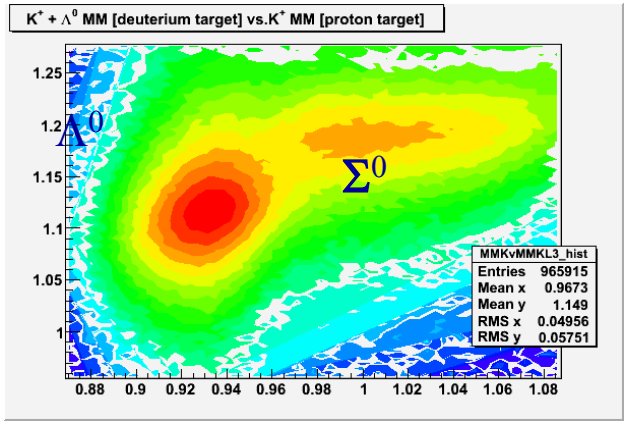
# Rescattering study with G13

**$\gamma p$ (n) –> $K^+\Lambda^0$ (n)** Russell Johnstone, Glasgow
(comparing $H_2$ (g8) and $D_2$ (g13) data)

photon asymmetry Σ ratio (free / quasi-free p)




Indicates that quasi-free neutron is a good approximation to a free neutron




$\cos\theta_{cm}$ (-1.0 to +1.0)

- Free and quasi-free proton
- Quasi free neutron good approx. to free

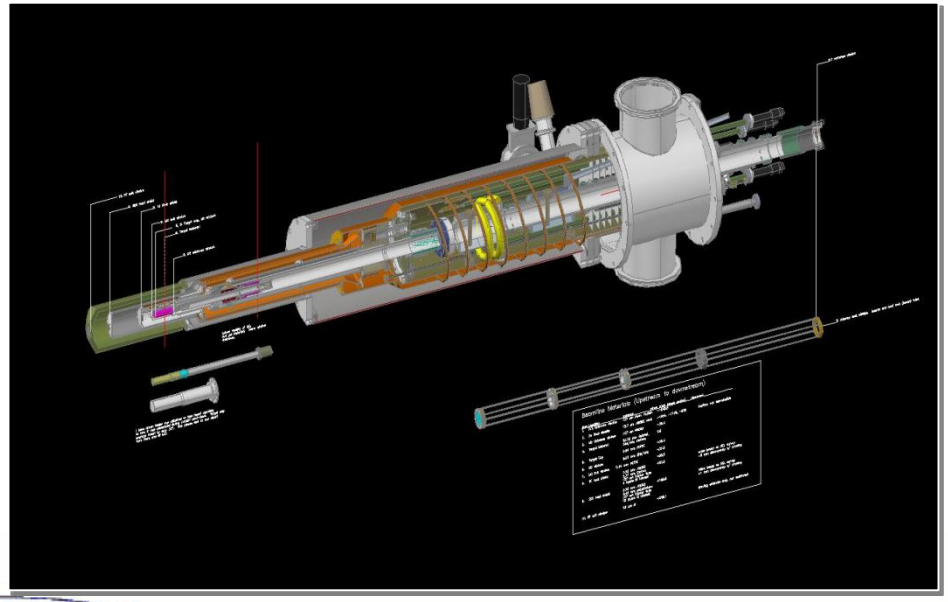
# Summary

- KY photoproduction offer kinematic and analysis advantages in N* physics;
- CLAS detector provides very precise measurements in a broad kinematic range;
- Published CLAS KY results on proton ($\Sigma$, P, $C_x$, $C_z$) and more observables to be published soon ($O_x$, $O_z$,G, E, $L_x$, $L_z$);
- Neutron channels are almost unexplored;
- Deuteron target can be used to study FSI, comparing bound and free proton, as well as YN interactions;
- Cross sections results on the neutron in a wide photon energy and angular range has been obtained with CLAS with g10 experiment. Analysis with g13 data are ongoing and more will come with HD-Ice.

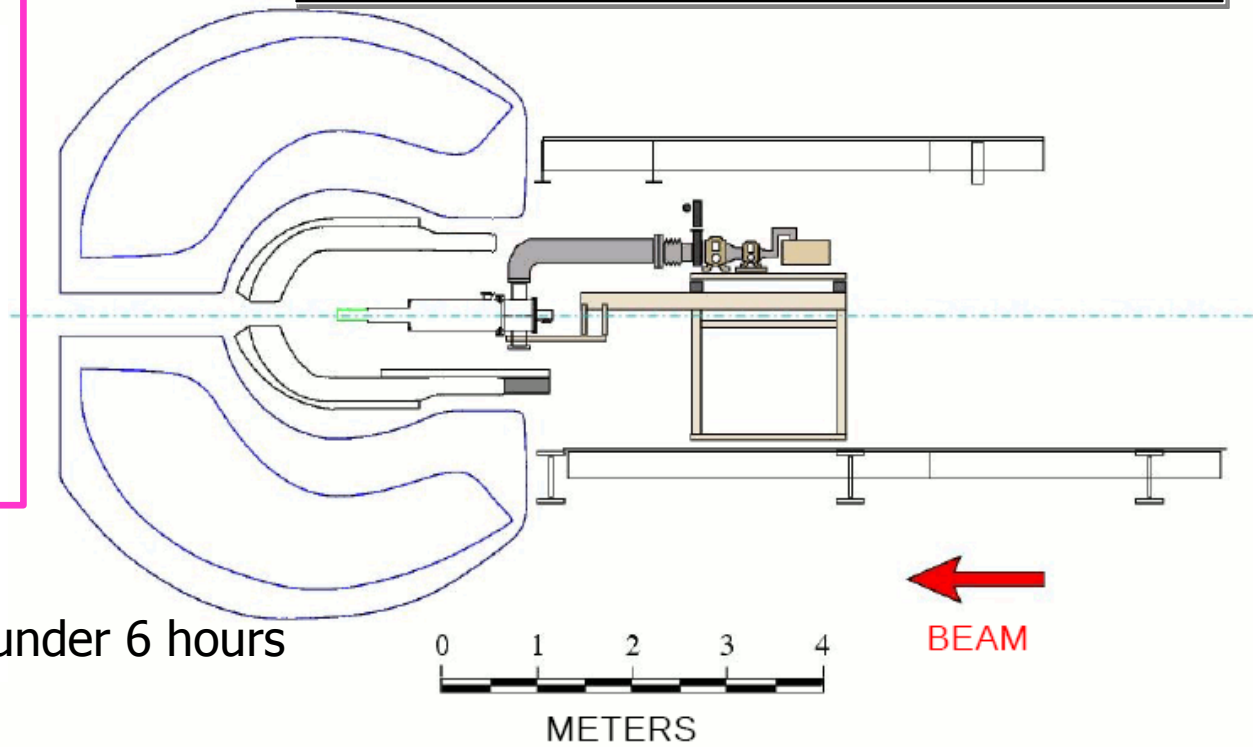
# Backup slides

# FROST

FRozen Spin Target ($C_4H_9OH$ – polarized butanol) with longitudinal and transverse polarization



| | Result | Design |
|---|---|---|
| Polarization | +82%<br>-85% | (80%) |
| 1/e relaxation time | 2800h (+)<br>1600h (-) | (500h) |

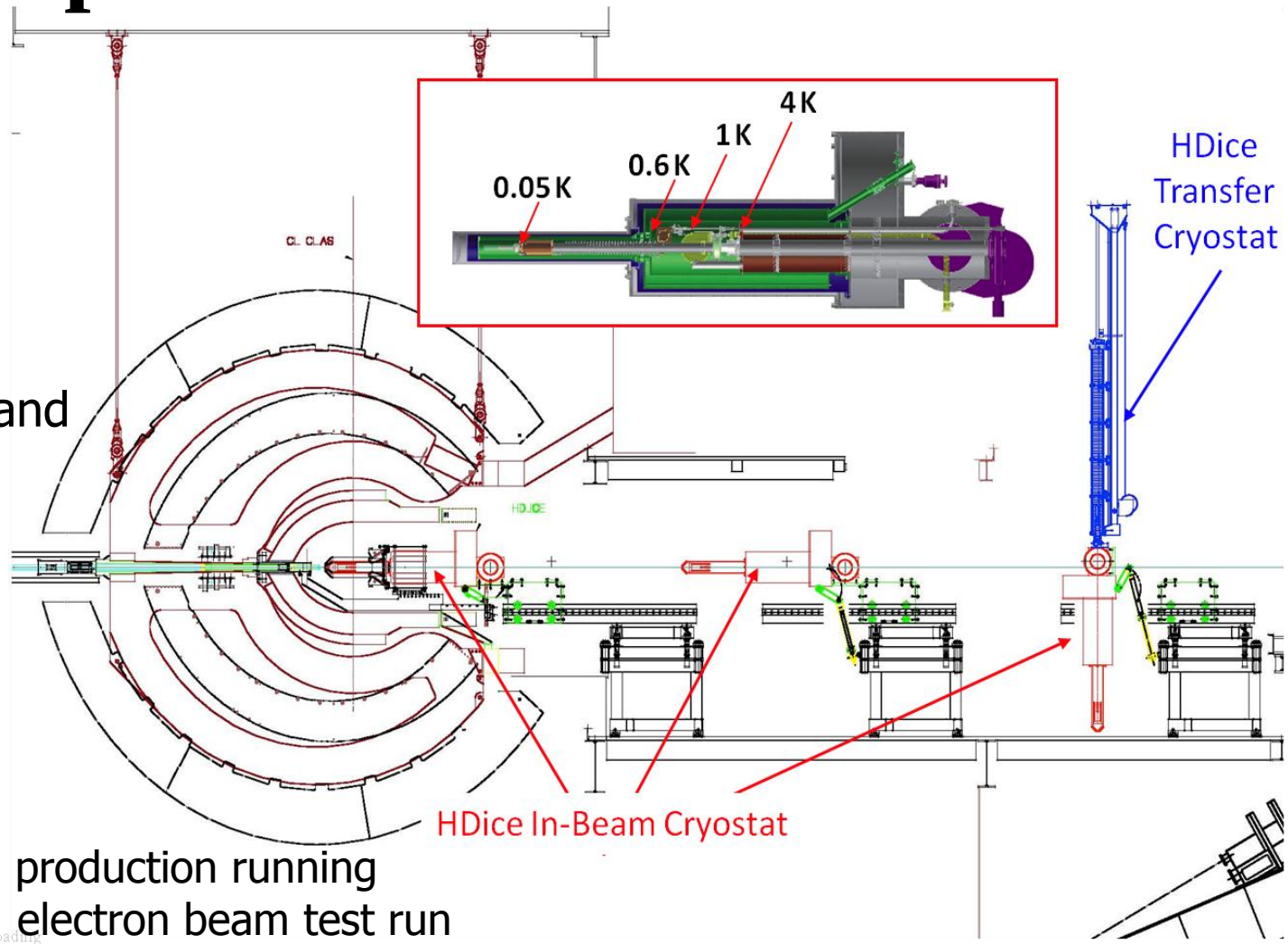



Entire repolarization procedure takes under 6 hours
Take data for 5-6 days

**Excellent reliability!**

# HD-Ice

## target for polarised neutrons

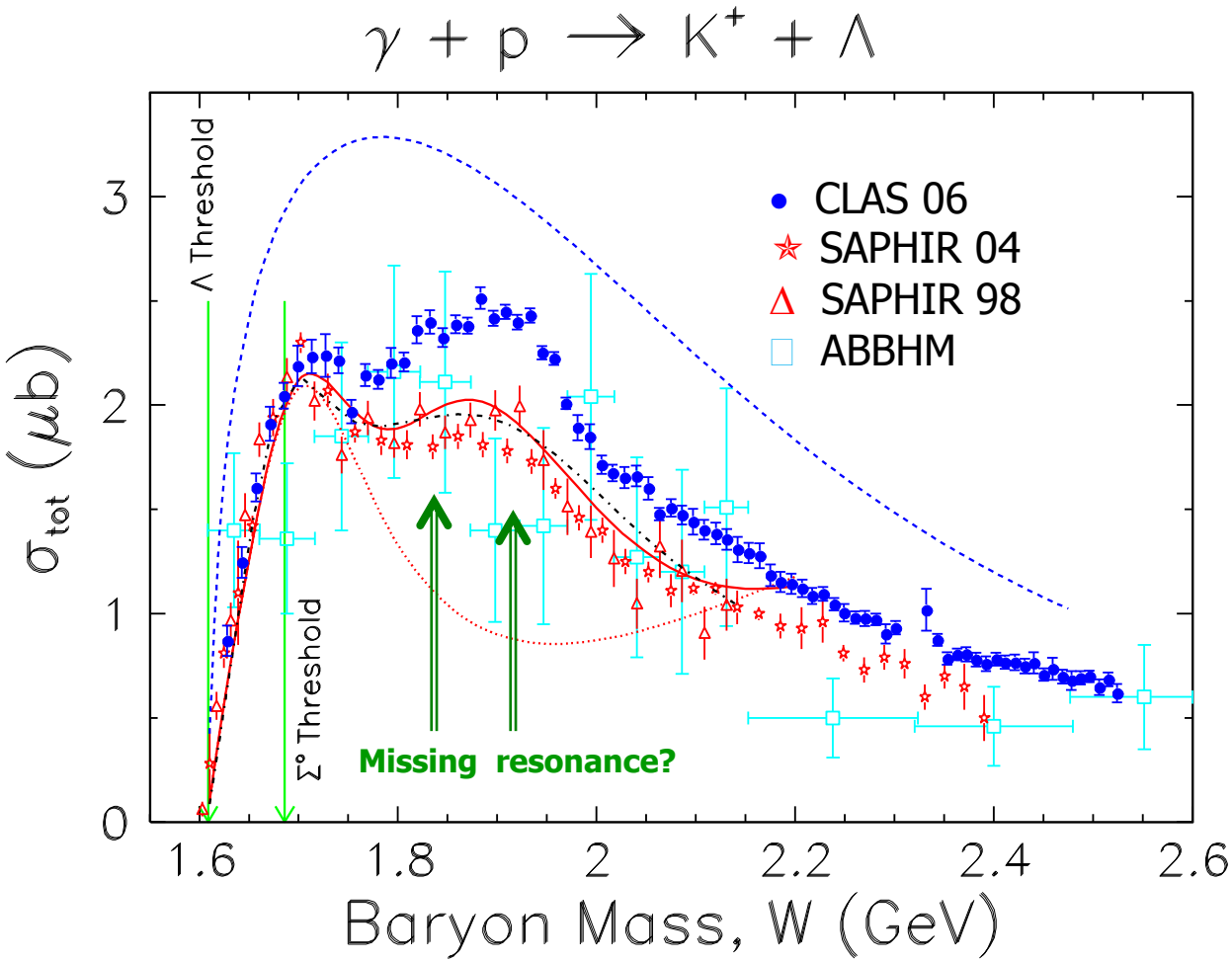



- Designed to run with both photon and electron beams
- New polarized target ($\vec{H}\,\vec{D}$)
- Under construction!
- 04/20 to 05/05/2011 production running
  05/05 to 05/12/2011 electron beam test run

# *Photoproduction on protons*

- **Unpolarized cross sections**
- Single beam polarization
- Recoil polarization
- Double polarization (Beam and Recoil)
  - Circular polarized beam
  - Linear polarized beam

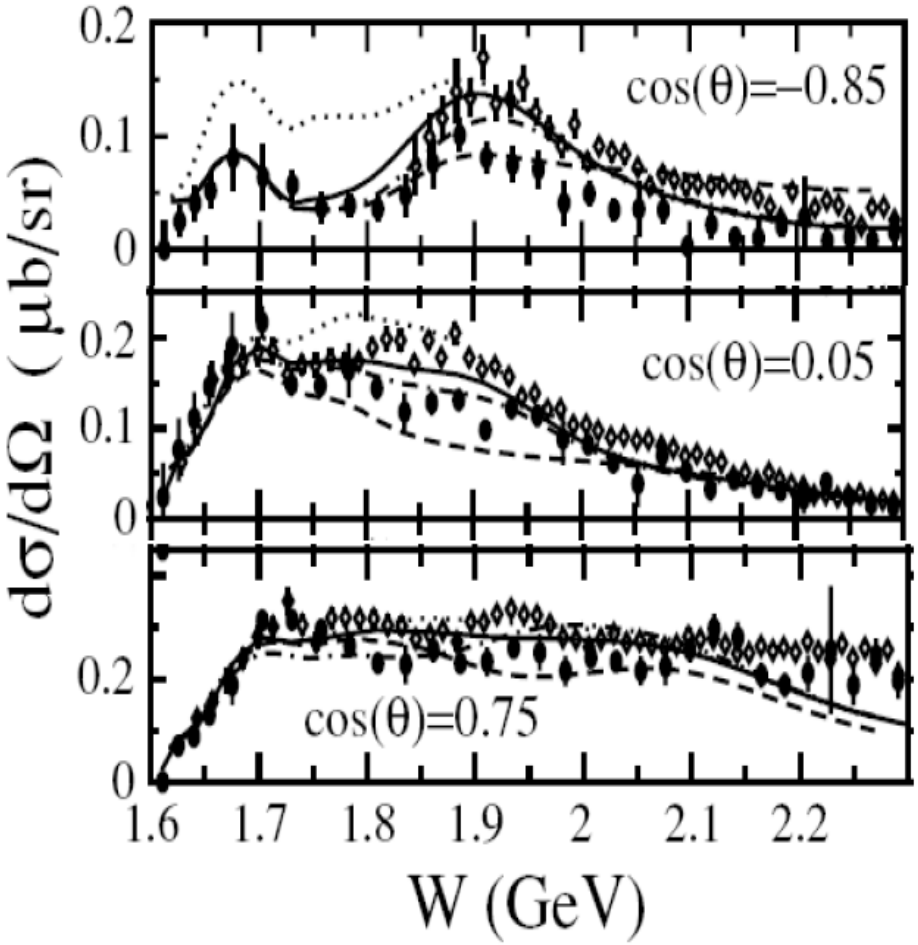
# $\gamma p \rightarrow K^+\Lambda$ Total Cross Sections




- Two bump structure seen
- CLAS/SAPHIR disagreement

R. Bradford *et al*. Phys. Rev. C**73** 035202 (2006)

# Differential cross section of $\gamma p \rightarrow K^+\Lambda$




***Coupled-channel approach by Julia-Diaz et al. (PRC73,055204)***

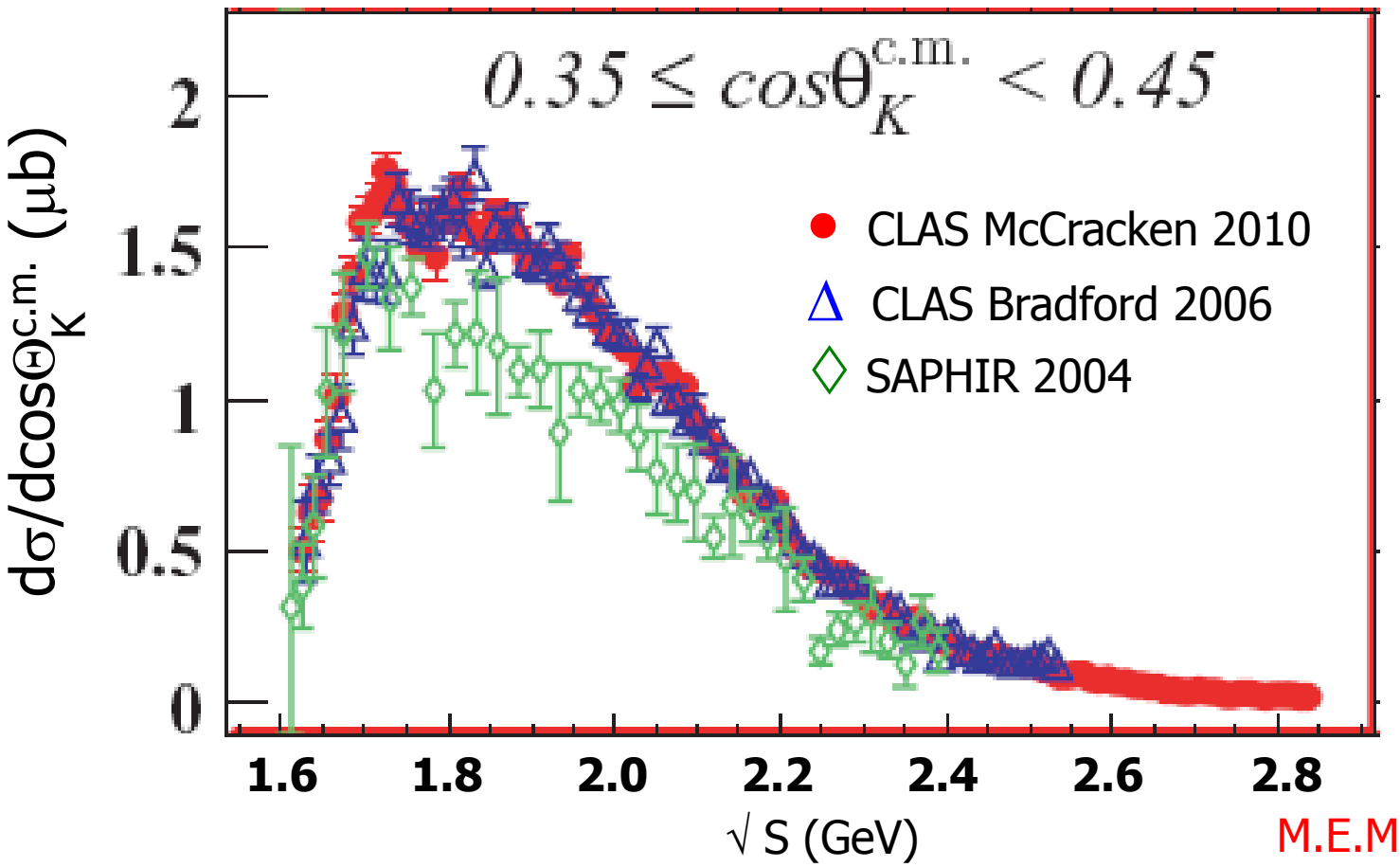
full line: full model with additional $S_{11}$, $P_{13}$ and $D_{13}$ resonances
dotted line: no $S_{11}$ resonance
dot-dashed line: no $P_{13}$ resonance
dashed line: no $D_{13}$ resonance

**Alternative approaches propose other contributions for the resonance-like structure at 1.9 GeV:**

- **$D_{13}$ (**Bennhold & Mart**)**
- **$P_{13}$ (**Nikanov et al.**)**
- **$P_{11}$ (**Ghent model**)**
- **$K\bar{K}N$ bound state (**Martinez Torres et al.**)**

new predicted bound state with a mix of $a_0(980)N$ and $f_0(980)N$

# Differential cross section of $\gamma p \rightarrow K^+\Lambda$

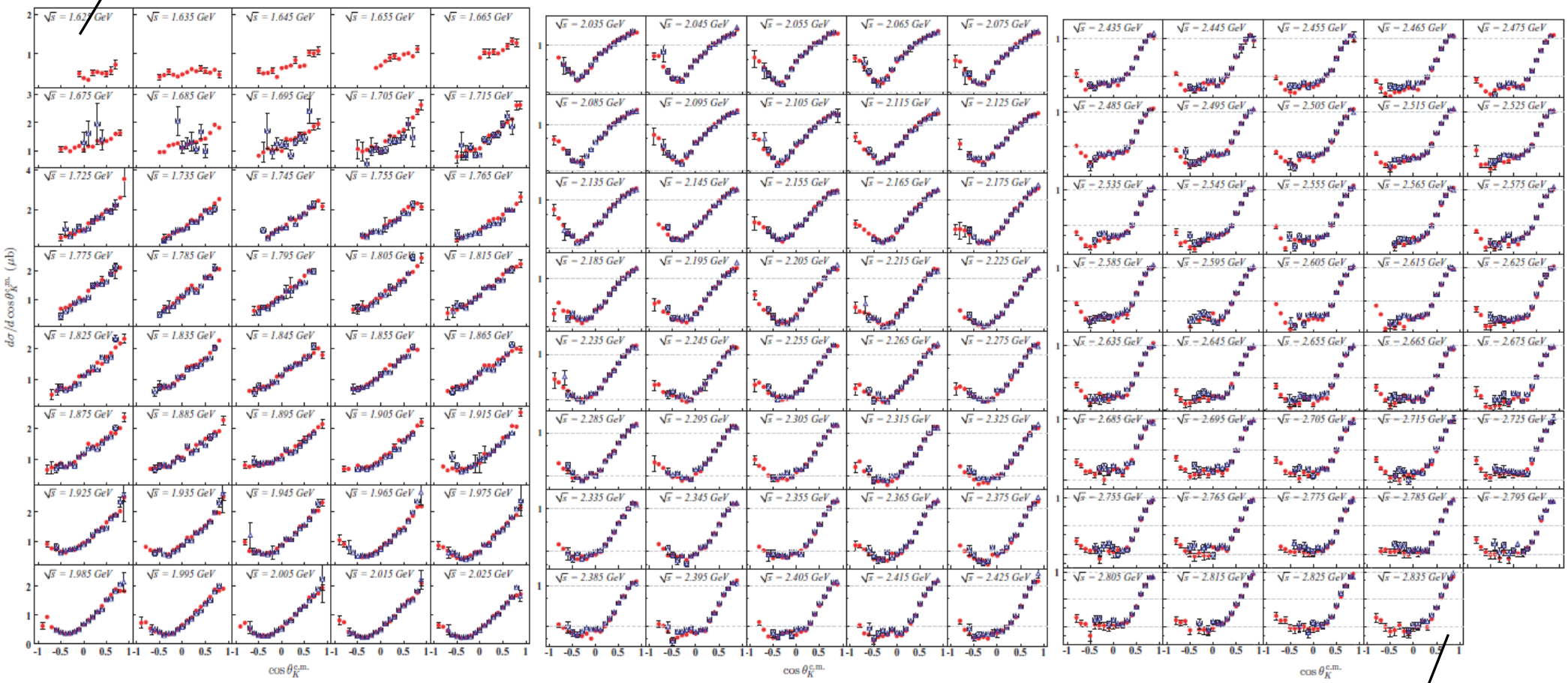



M.E.McCracken et.al., PRC 81, 025201 (2010)

- **broader energy range, better statistics, good agreement between CLAS 2006 (Bradford *et al.*) and new CLAS 2010 data set.**
- **Different data set, different trigger, different analysis chain**

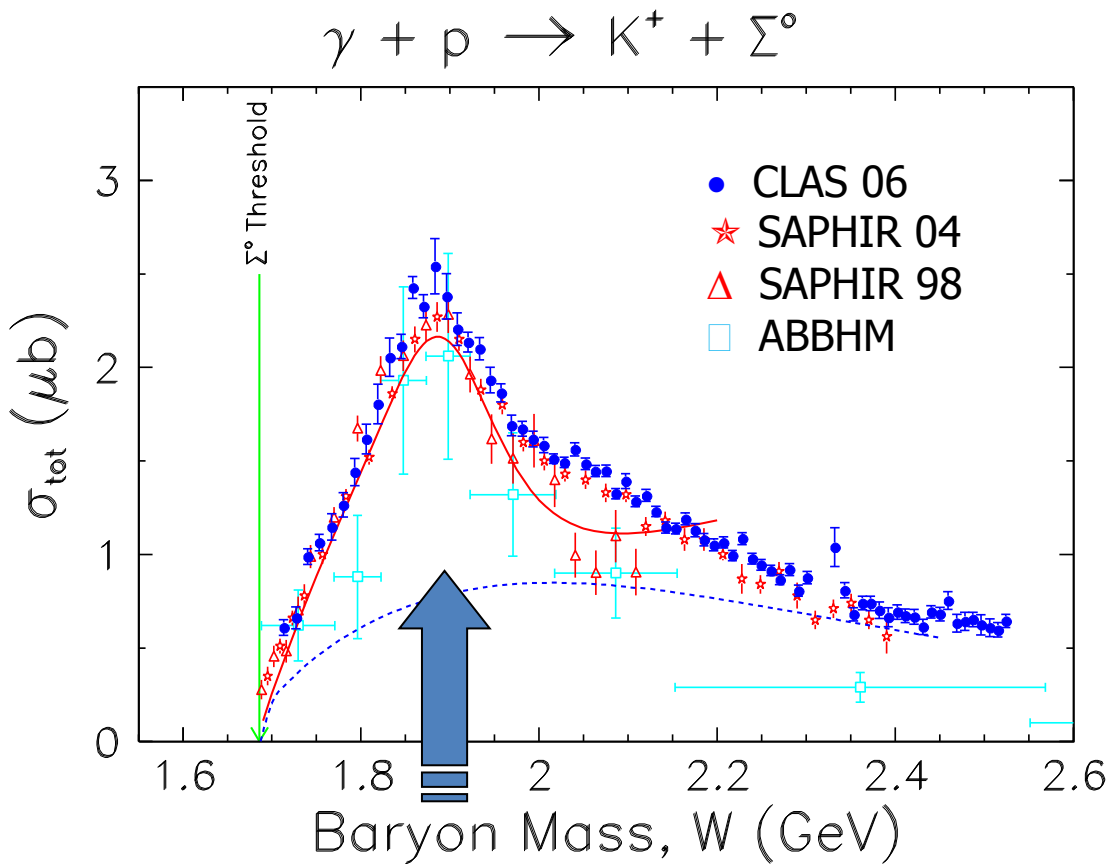
# Differential cross section of $\gamma p \rightarrow K^{+}\Lambda$

**1.62 GeV**




**2.84 GeV**

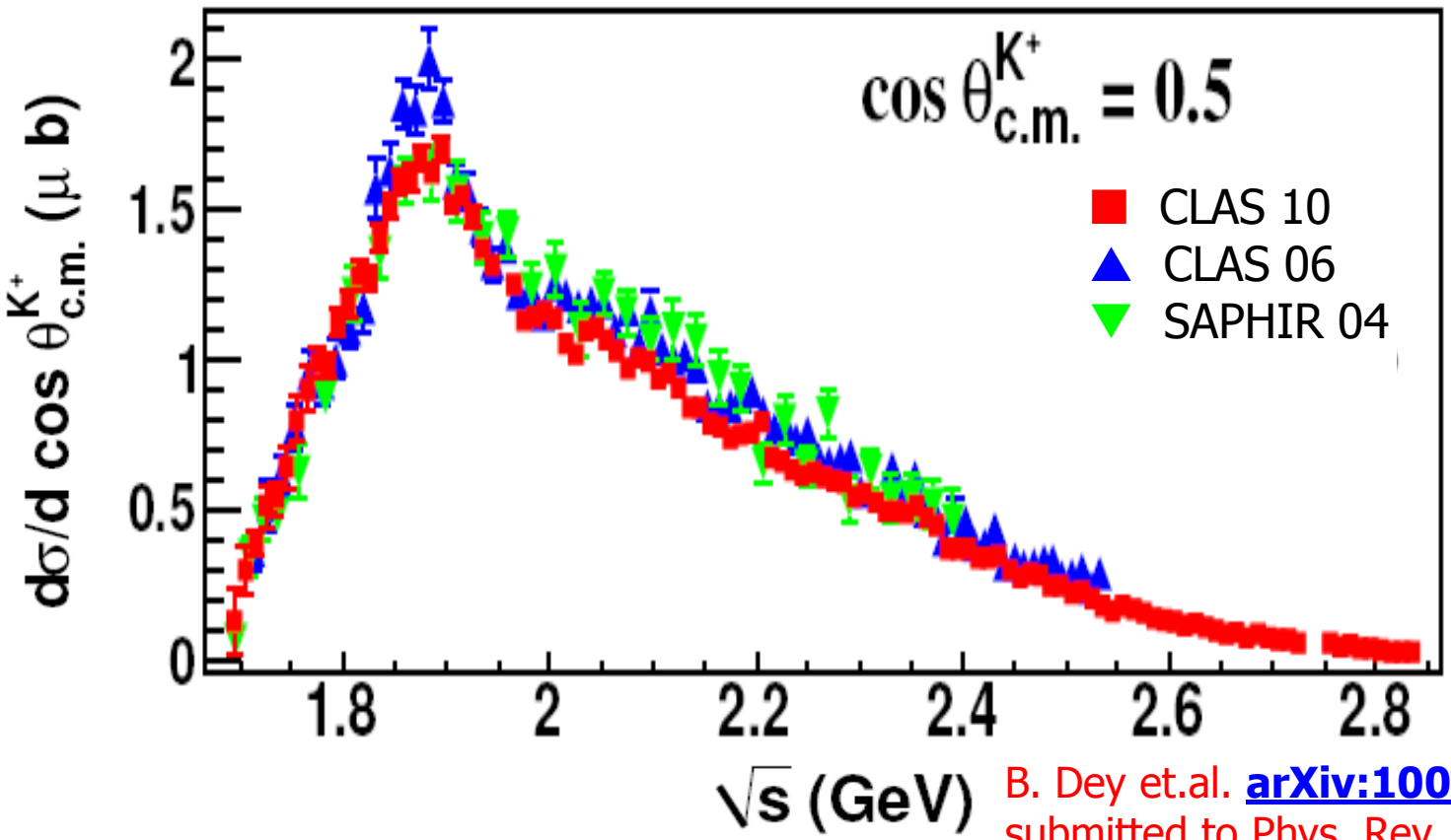
# Total cross section of $\gamma p \rightarrow K^+ \Sigma^0$




R. Bradford *et al.* Phys. Rev. C**73** 035202 (2006)

- **Single-bump: resonance-like structure near 1.9 GeV**
  - **N* & D resonances**
- **Better <u>agreement</u> with SAPHIR than Λ**

# Differential cross section of $\gamma p \rightarrow K^+ \Sigma^0$




B. Dey et.al. **arXiv:1006.0374v2** **[nucl-ex]**
submitted to Phys. Rev. C

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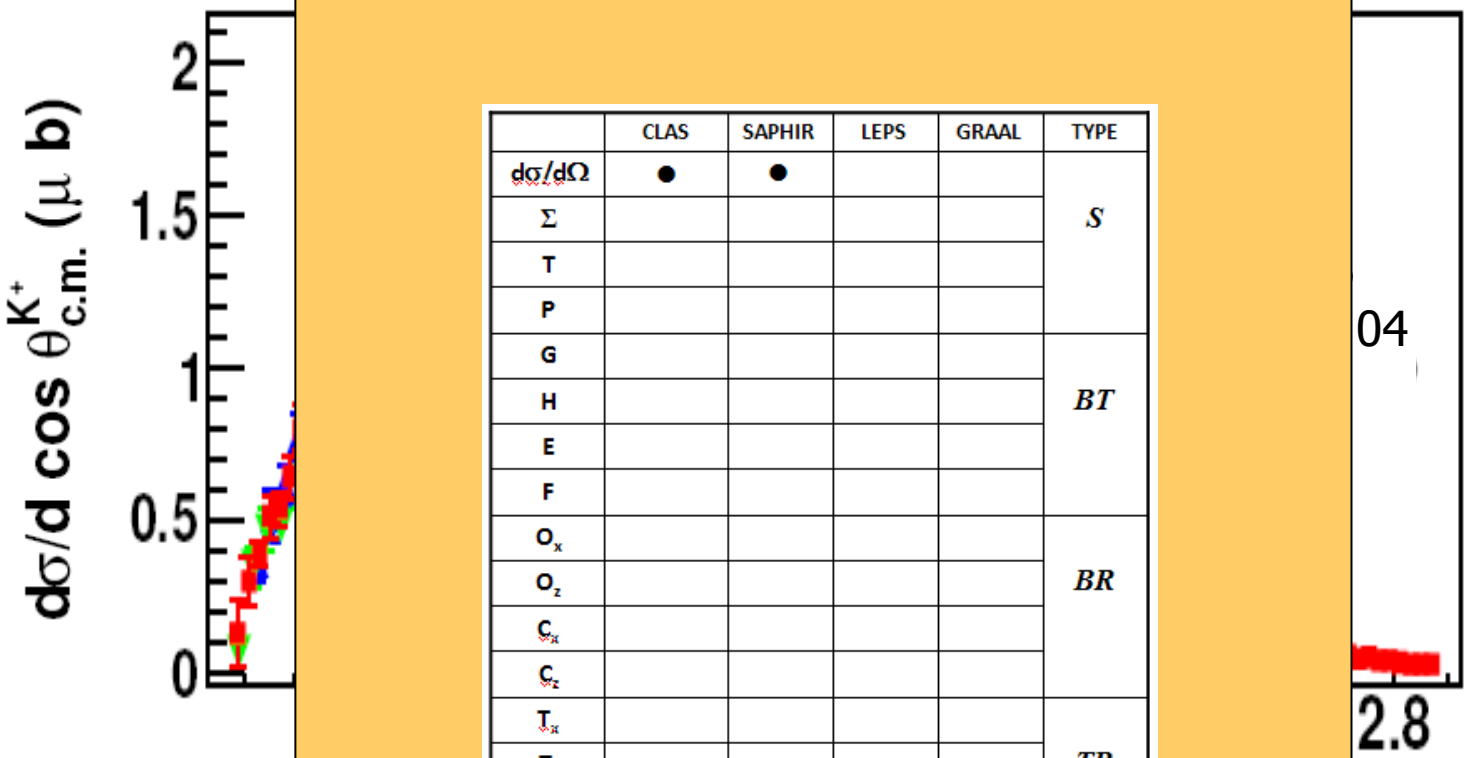


| | CLAS | SAPHIR | LEPS | GRAAL | TYPE |
|---|---|---|---|---|---|
| dσ/dΩ | ● | ● | | | |
| Σ | | | | | *S* |
| T | | | | | |
| P | | | | | |
| G | | | | | |
| H | | | | | *BT* |
| E | | | | | |
| F | | | | | |
| $O_x$ | | | | | |
| $O_z$ | | | | | *BR* |
| $C_x$ | | | | | |
| $C_z$ | | | | | |
| $T_x$ | | | | | |
| $T_z$ | | | | | *TR* |
| $L_x$ | | | | | |
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v:1006.0374v2 [nucl-ex]
. Rev. C

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# *Photoproduction on protons*

- Unpolarized cross sections
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- Recoil polarization
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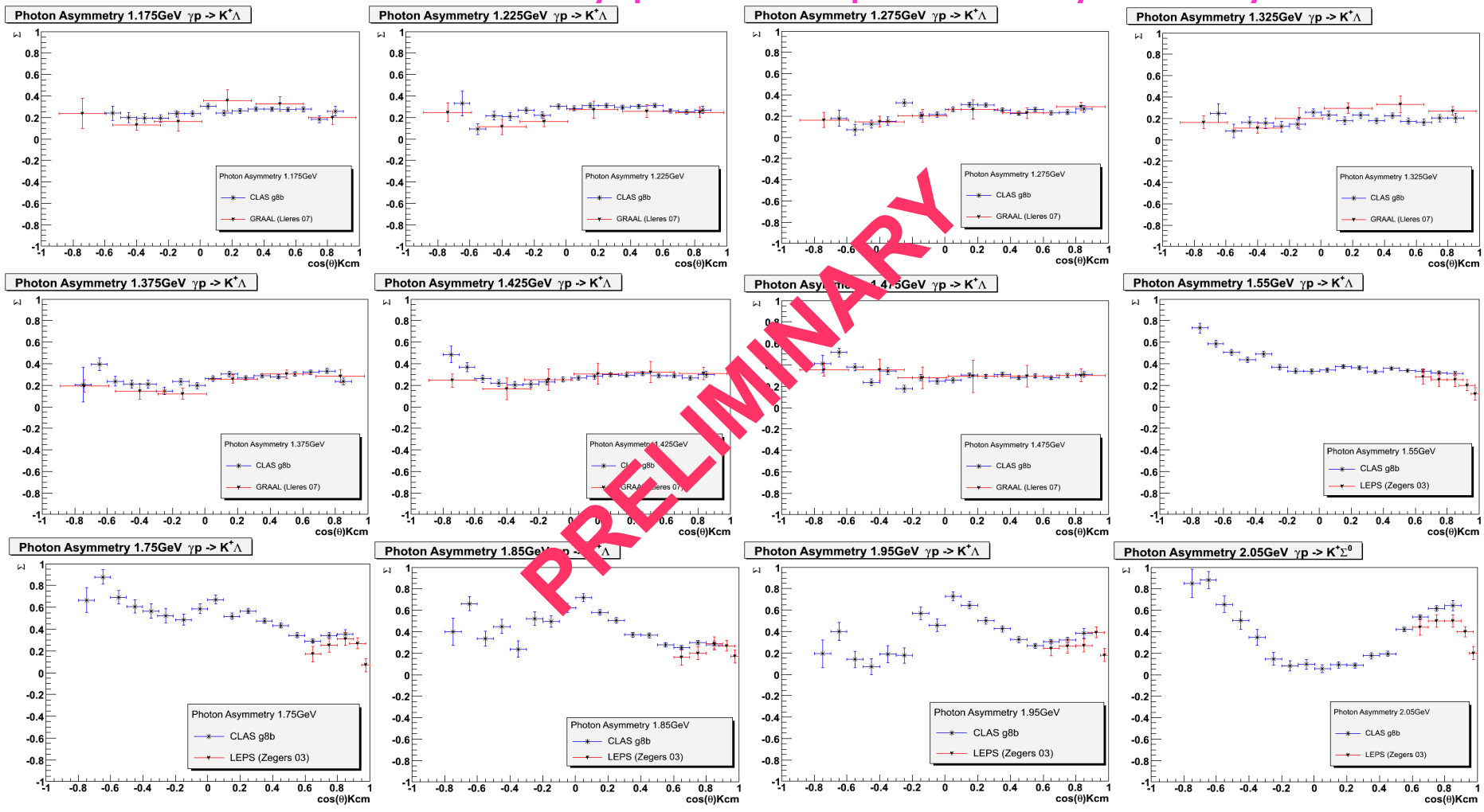
  - Circular polarized beam
  - Linear polarized beam

# CLAS g8b improved results - $K^+\Lambda$

## linearly polarized photon asymmetry




Increase the angular coverage to backward angles

- **Wider range**
- **Improved precision**
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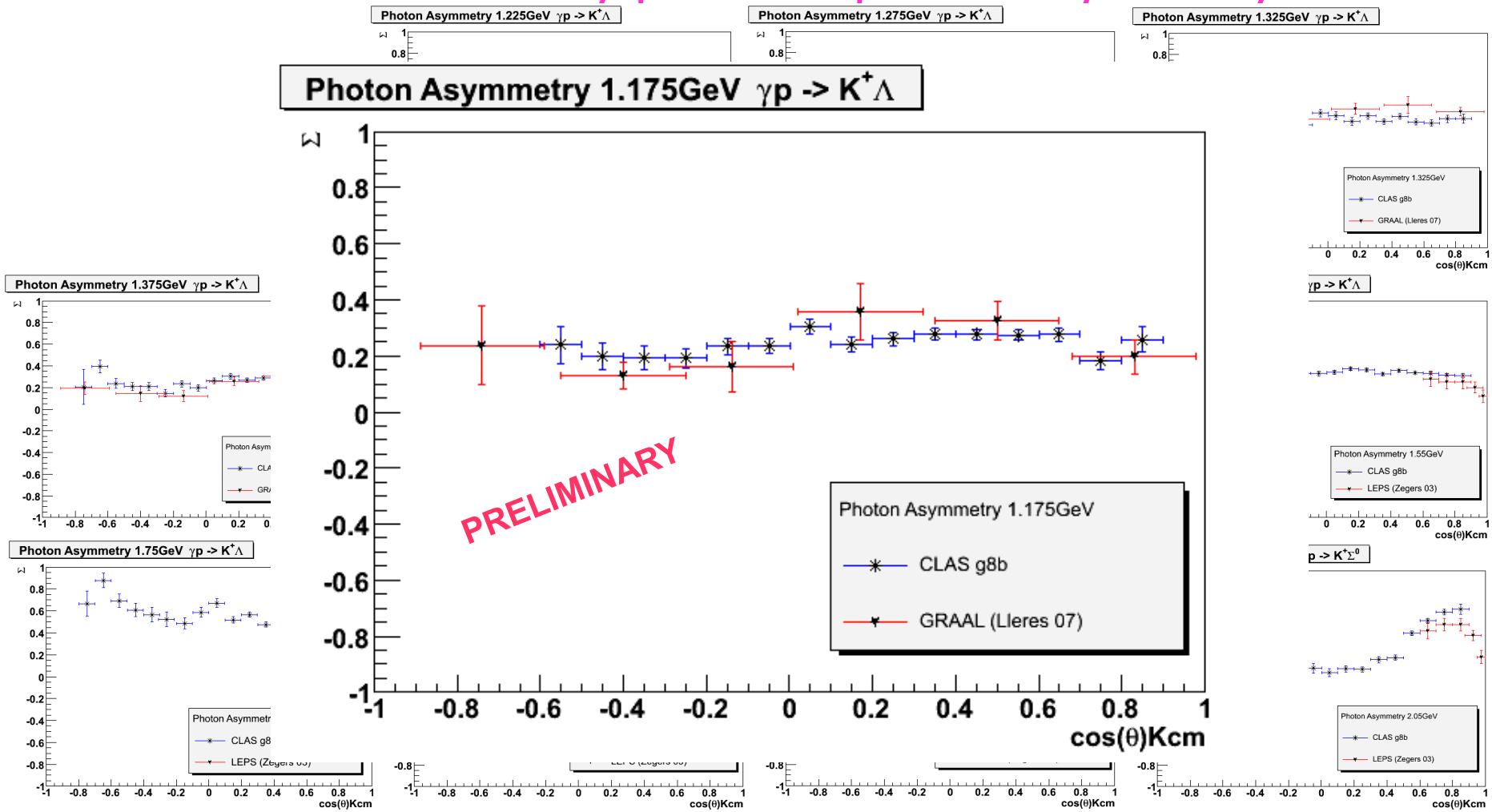


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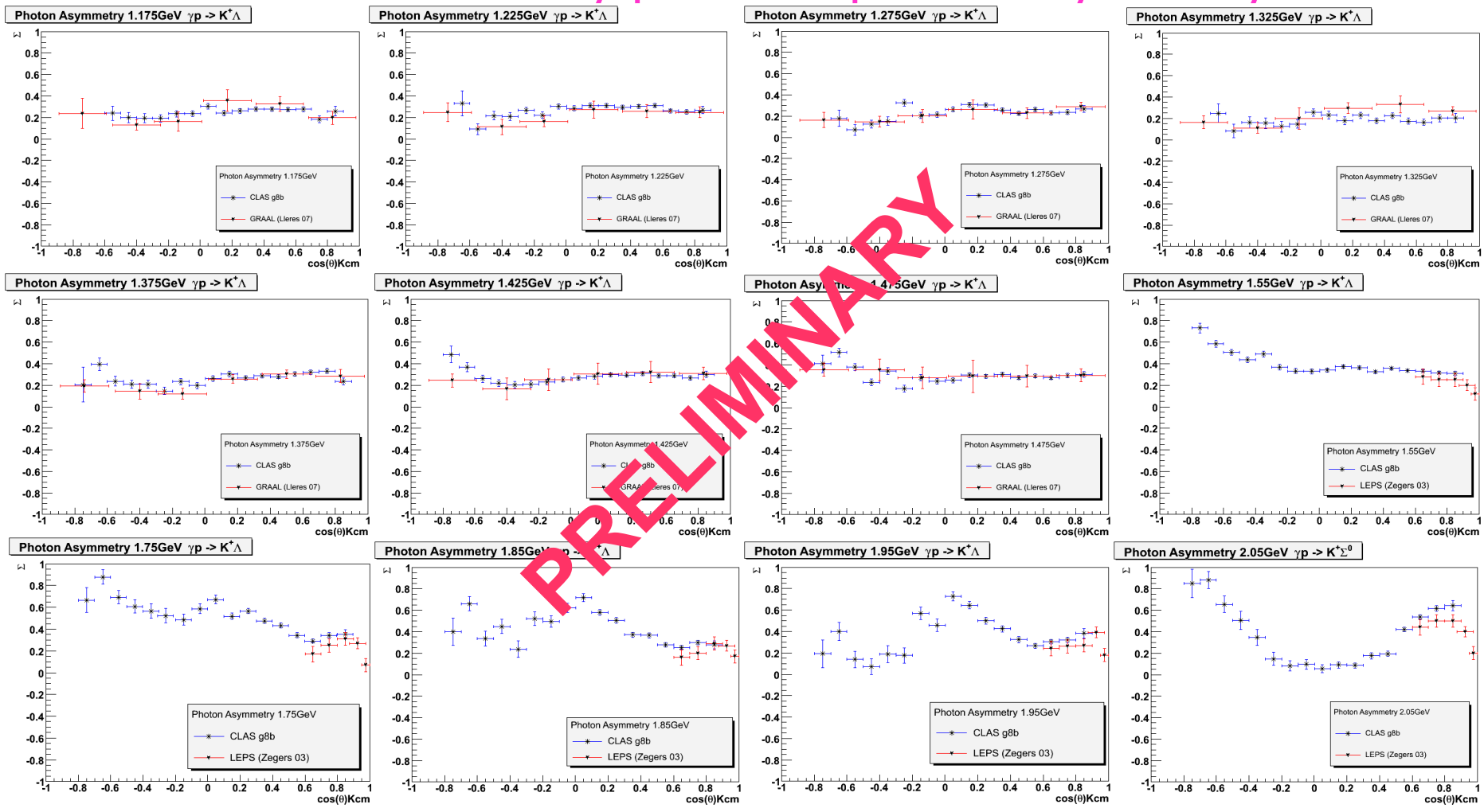


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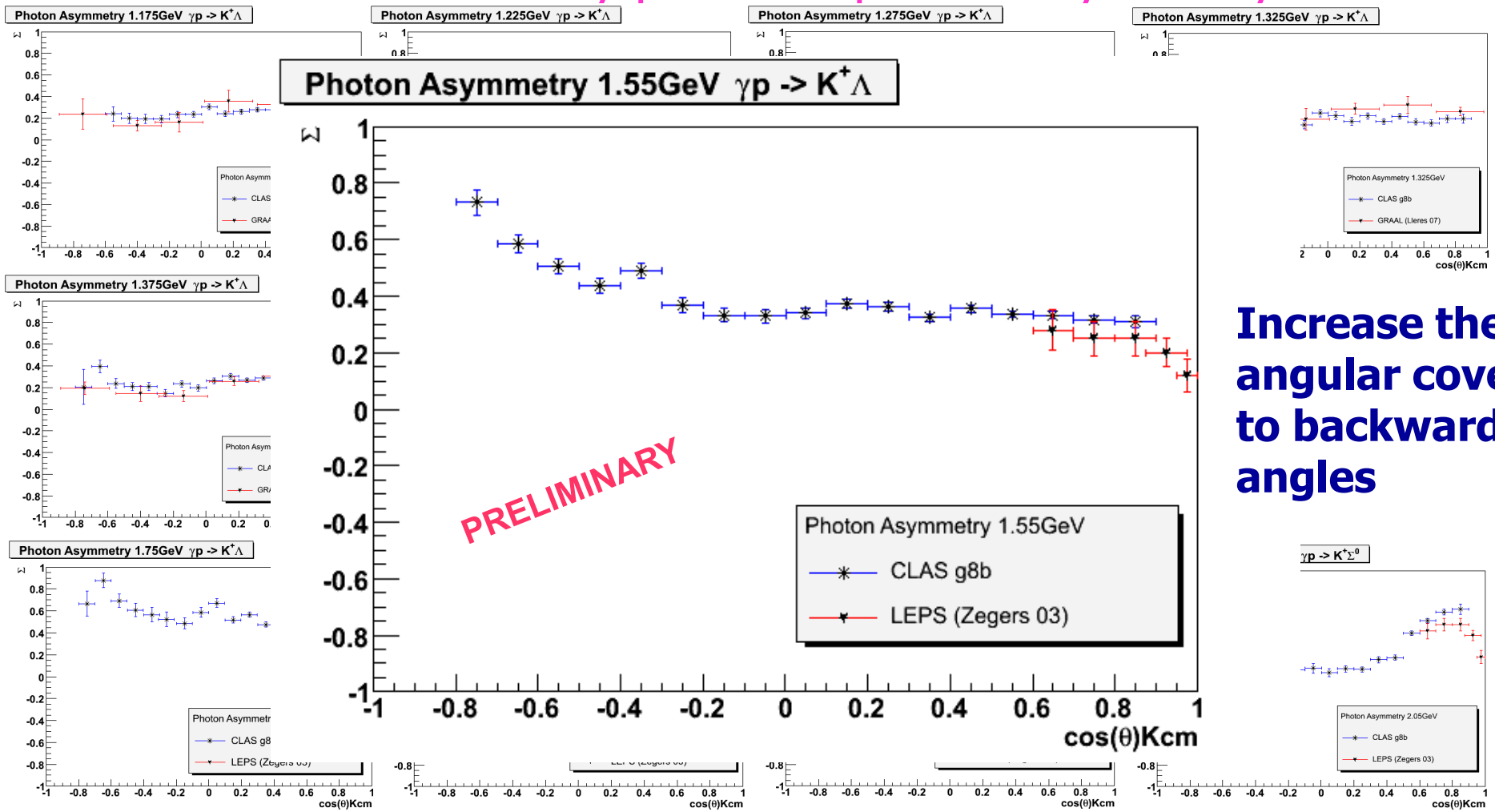


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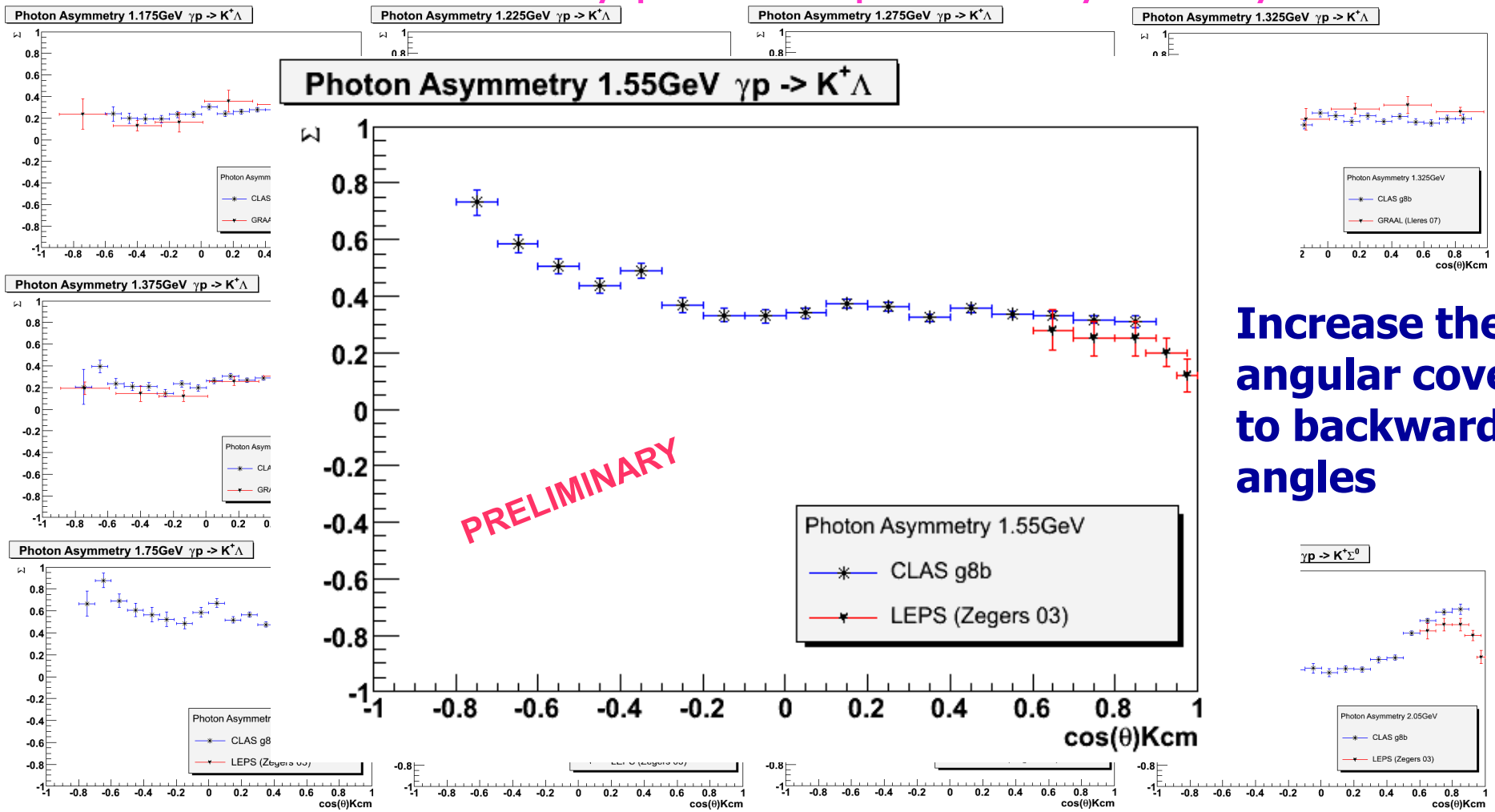


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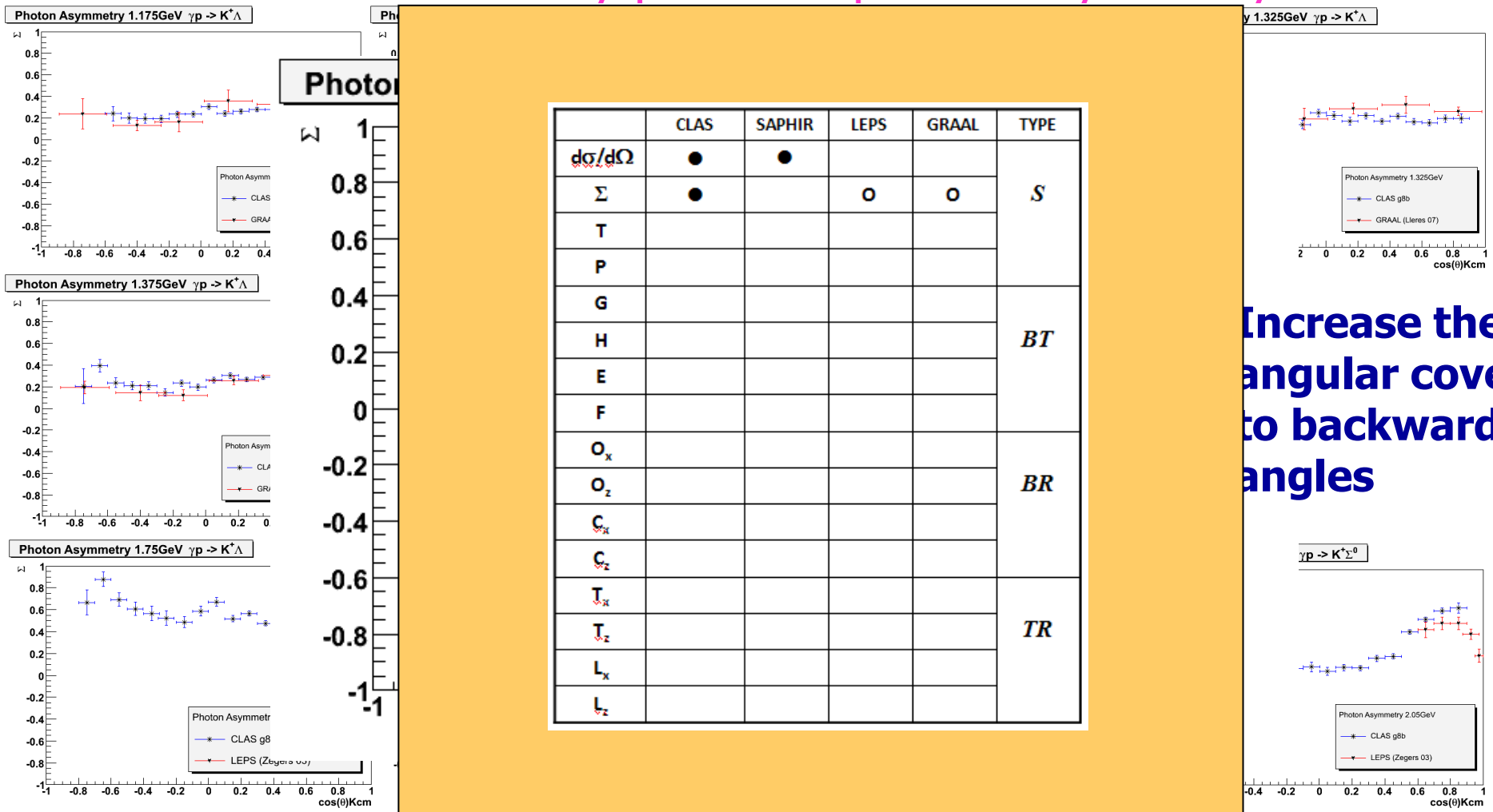


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|---|---|---|---|---|---|
| $d\sigma/d\Omega$ | ● | ● | | | |
| $\Sigma$ | ● | | o | o | *S* |
| T | | | | | |
| P | | | | | |
| G | | | | | |
| H | | | | | *BT* |
| E | | | | | |
| F | | | | | |
| $O_x$ | | | | | |
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| $C_x$ | | | | | |
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| $L_x$ | | | | | |
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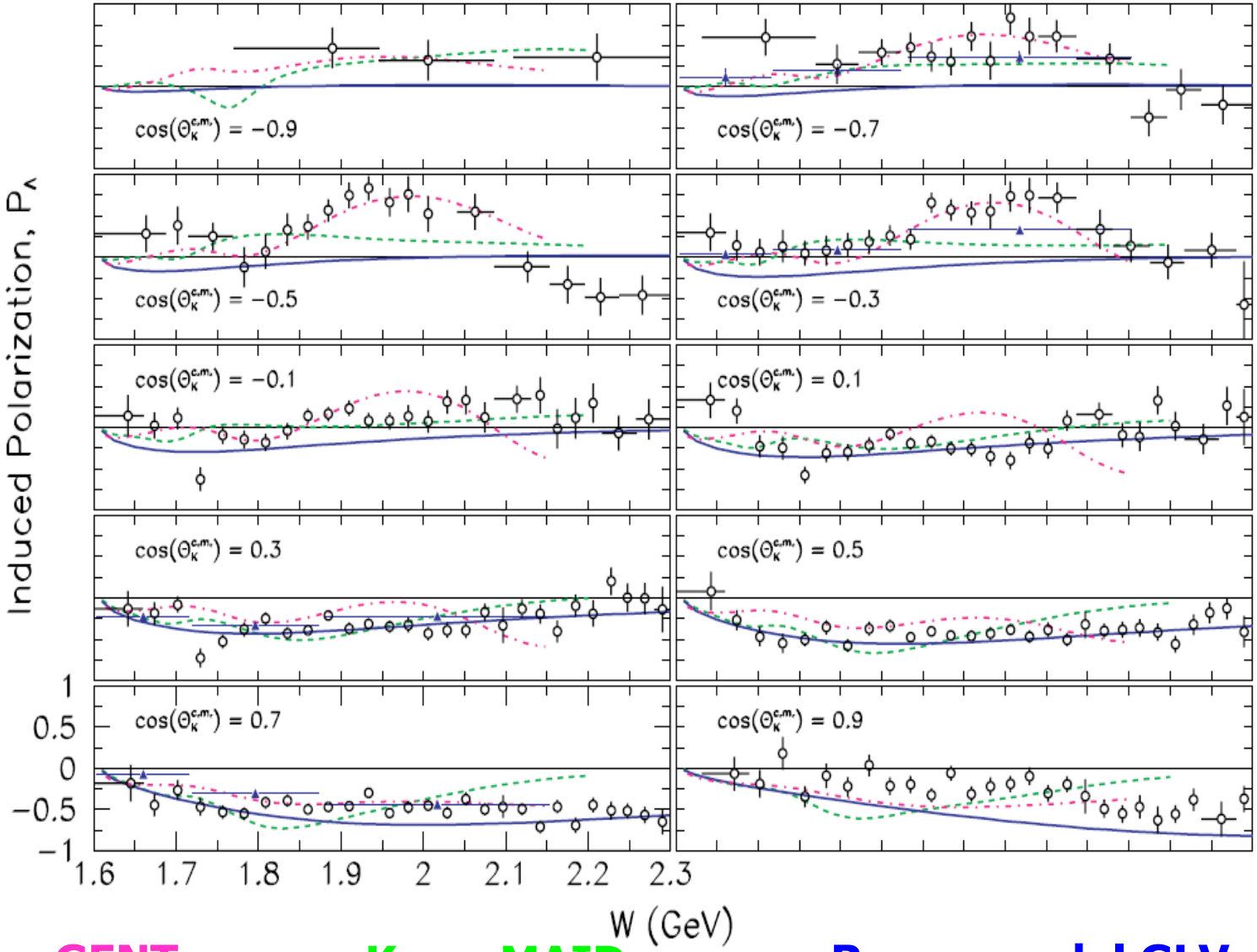


**- - - GENT - - - Kaon-MAID ——— Regge model GLV**

R. Bradford *et al.*, Phys. Rev. C **75**, 035205 (2007).

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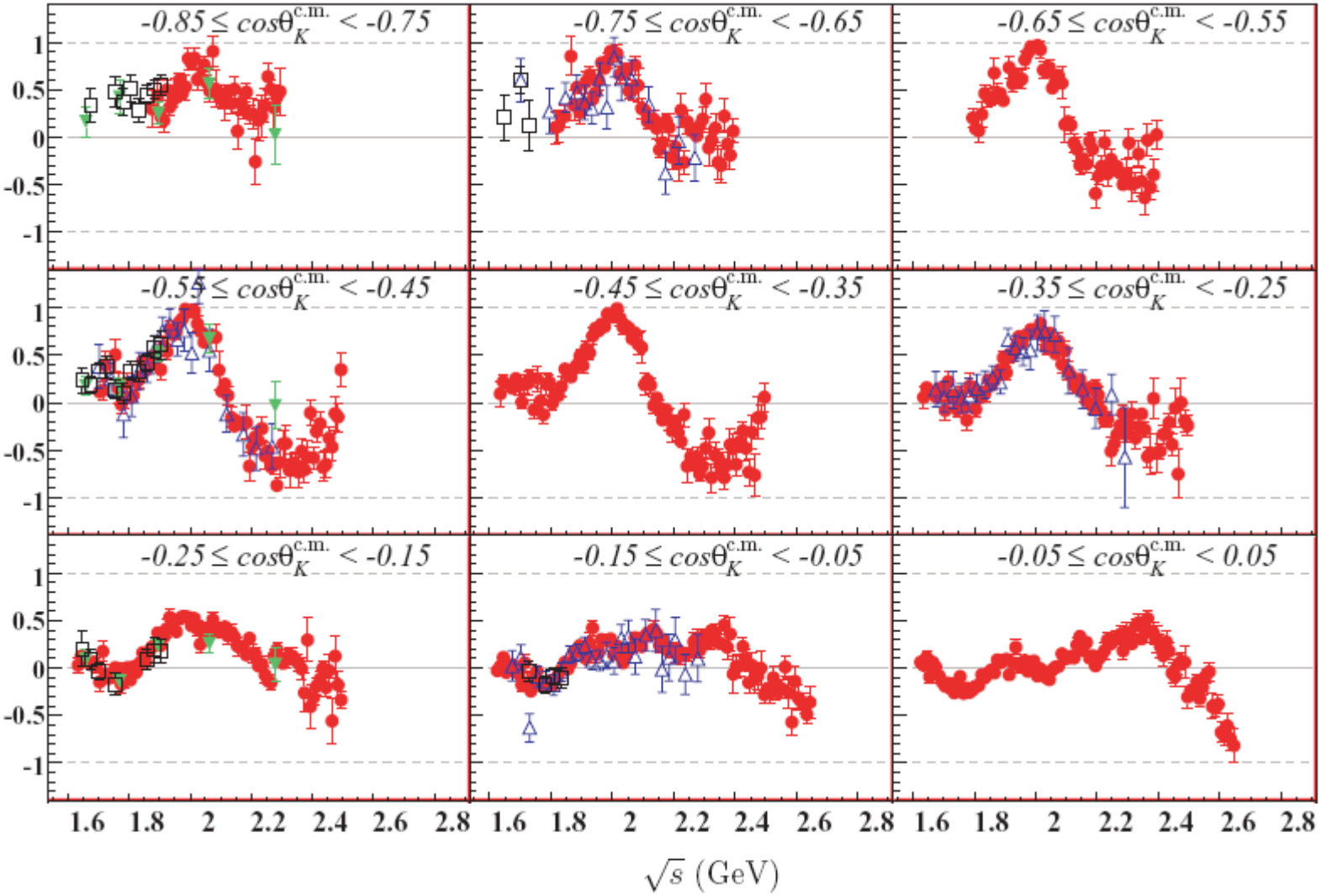
● CLAS McCracken 2010 Δ CLAS McNabb 2004

∇ SAPHIR 2004 ☐ GRAAL 2007

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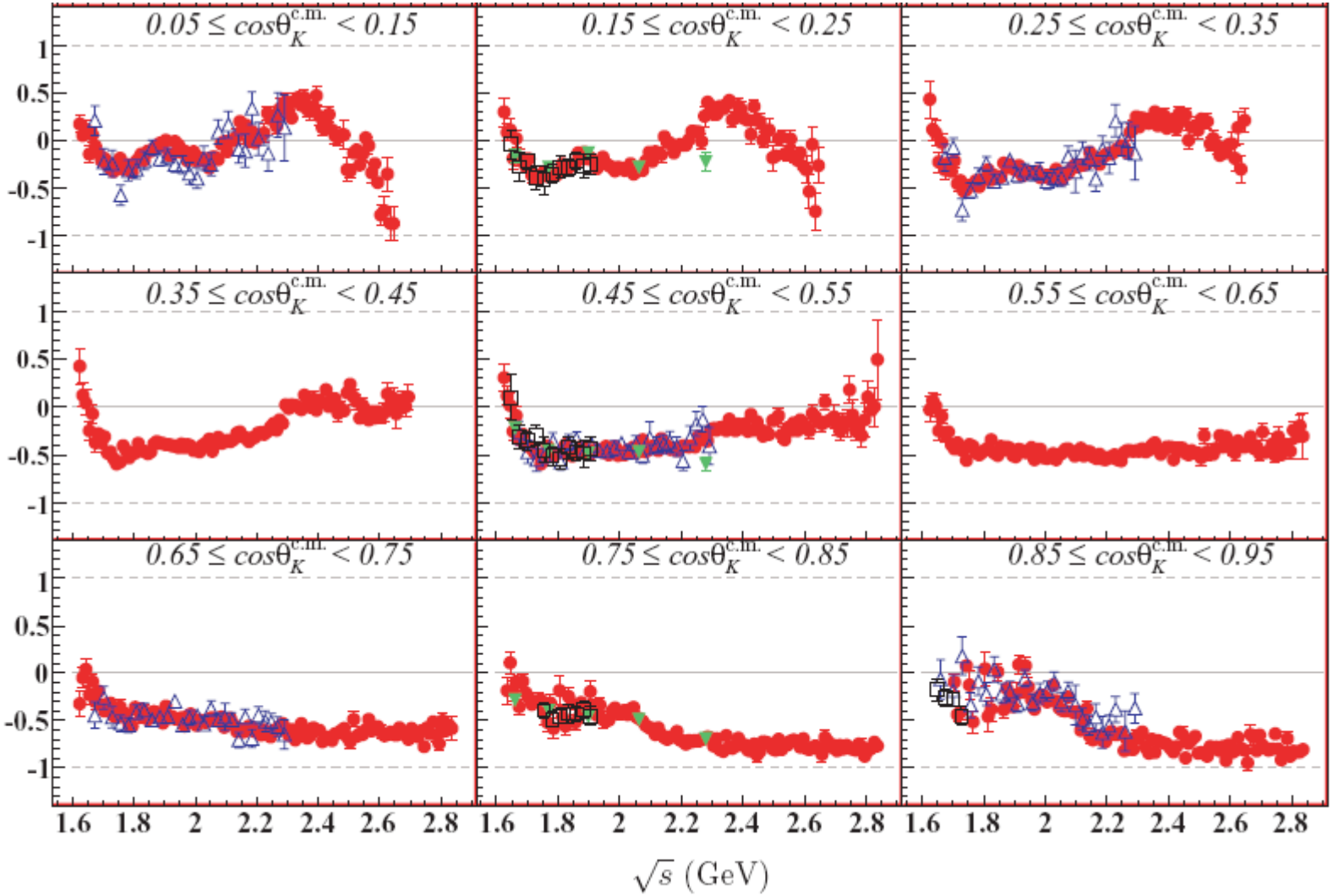


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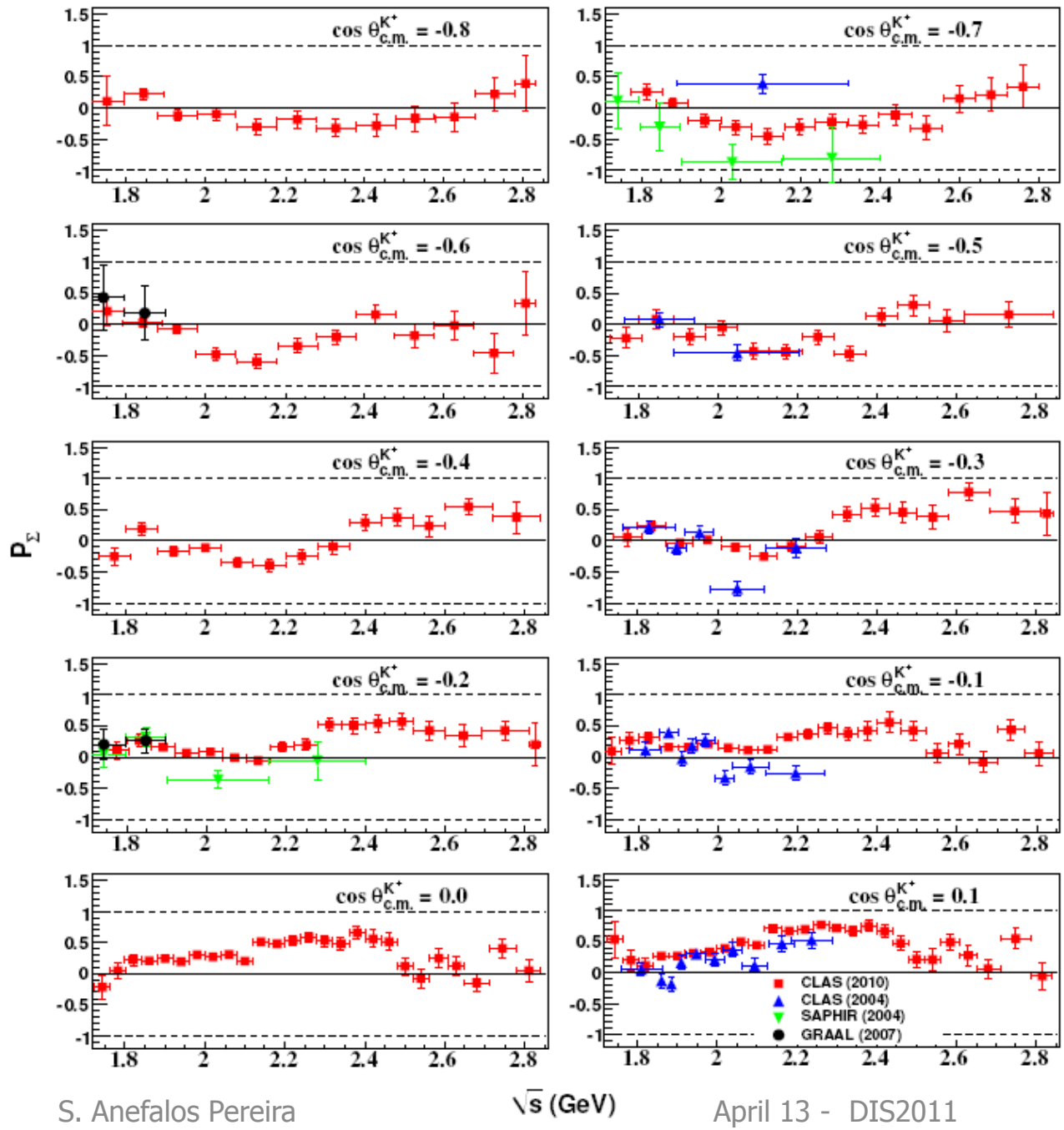


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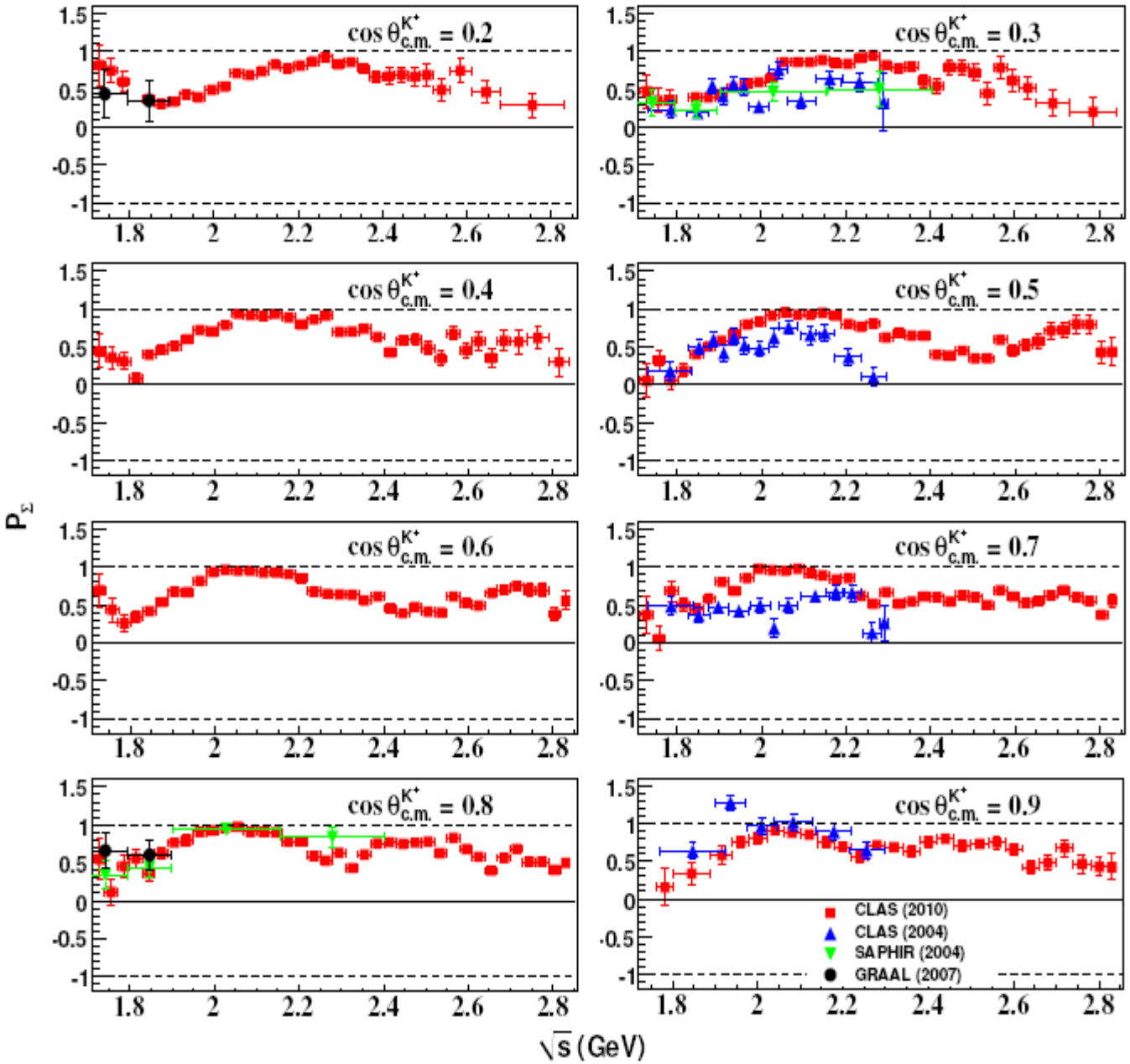


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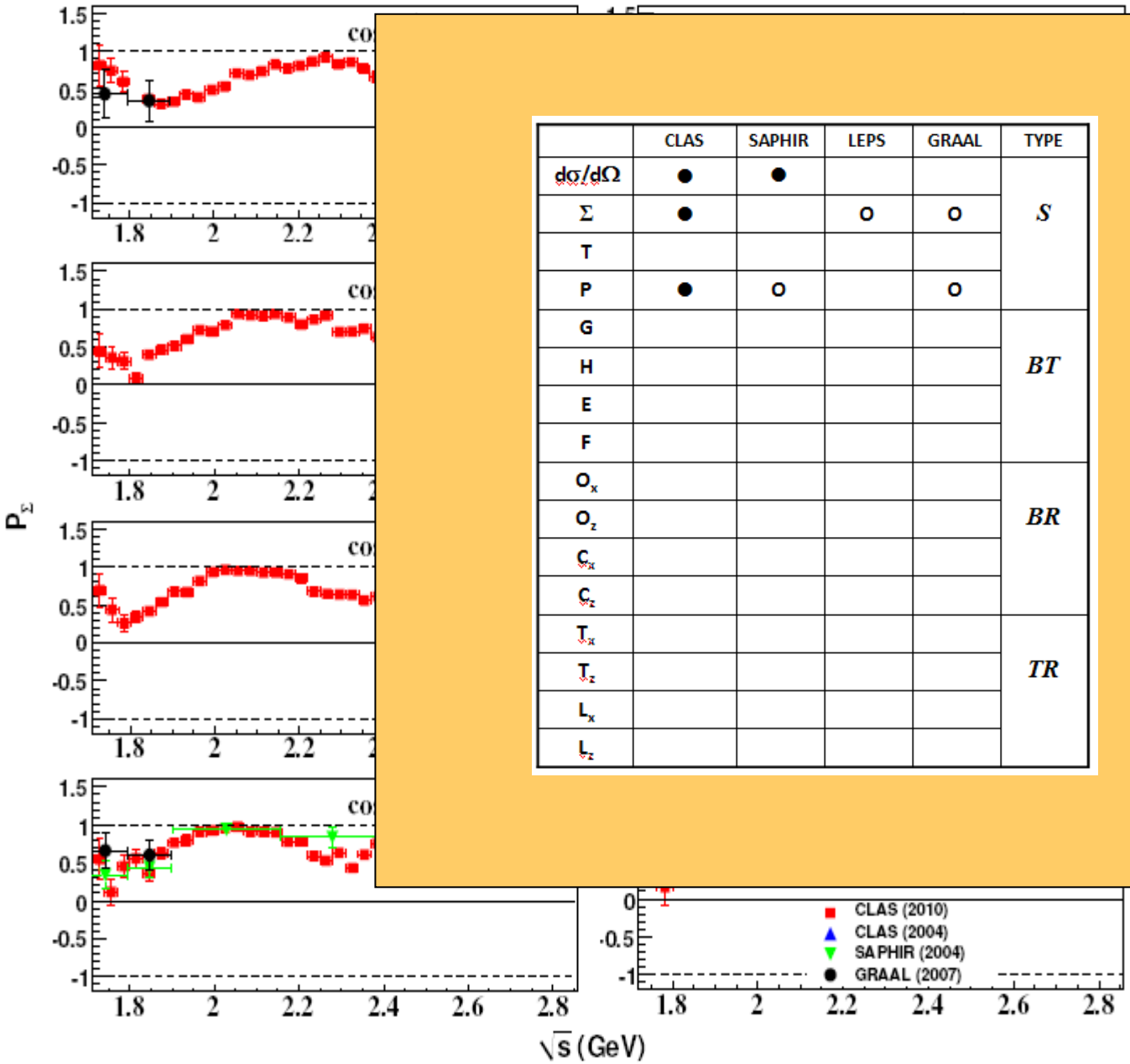


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|---|---|---|---|---|---|
| $d\sigma/d\Omega$ | ● | ● | | | |
| $\Sigma$ | ● | | o | o | *S* |
| T | | | | | |
| P | ● | o | | o | |
| G | | | | | |
| H | | | | | *BT* |
| E | | | | | |
| F | | | | | |
| $O_x$ | | | | | |
| $O_z$ | | | | | *BR* |
| $C_x$ | | | | | |
| $C_z$ | | | | | |
| $T_x$ | | | | | |
| $T_z$ | | | | | *TR* |
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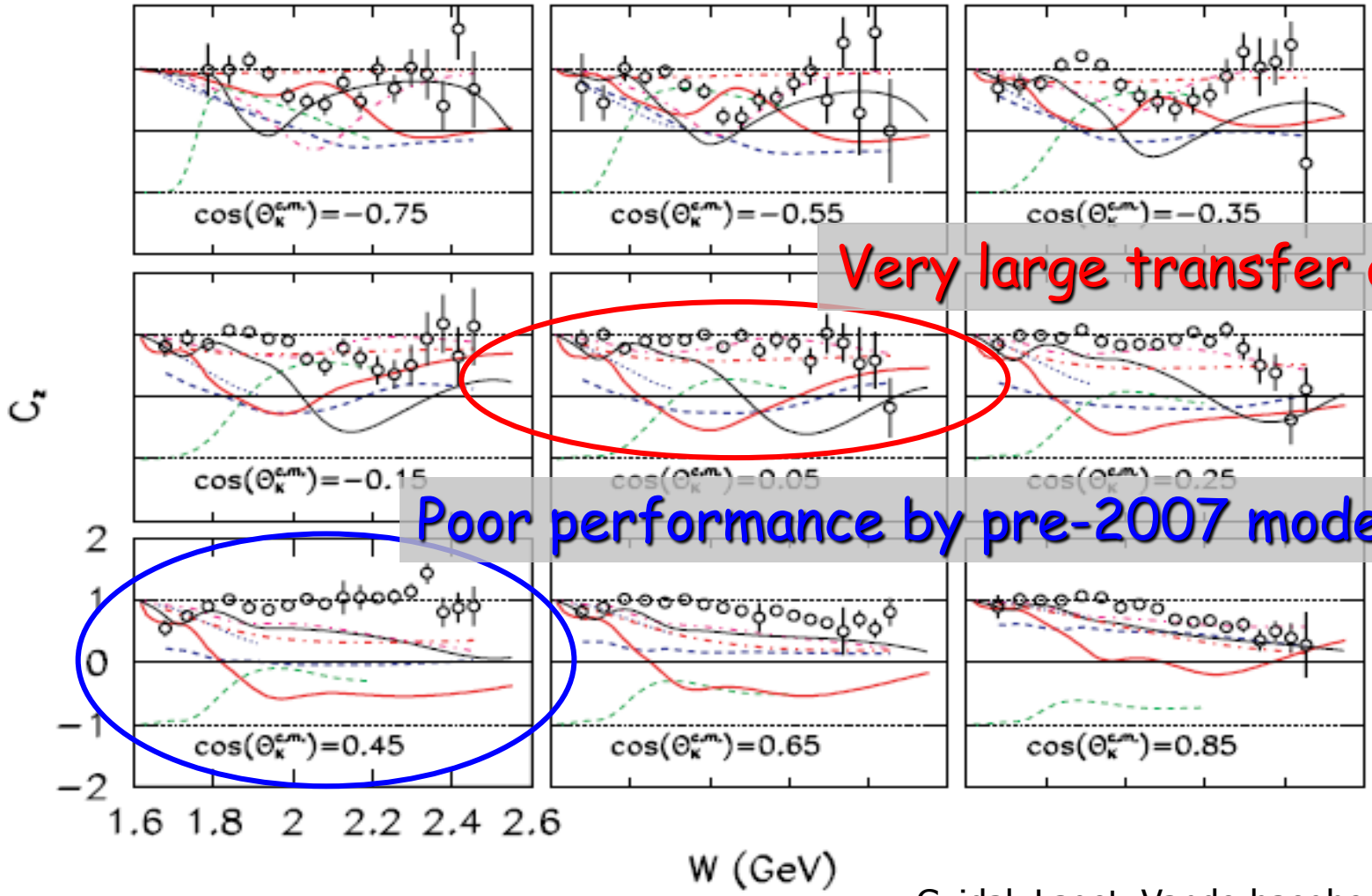
# Results: $C_z$ for $K^+\Lambda$




Very large transfer along z

Poor performance by pre-2007 models

Kaon-MAID
Julia-Diaz, Lee, Saghai,Tabakin
Sarantsev and Nikonov
Guidal, Laget, Vanderhaeghen
Shklyar, Lenske, and Mosel
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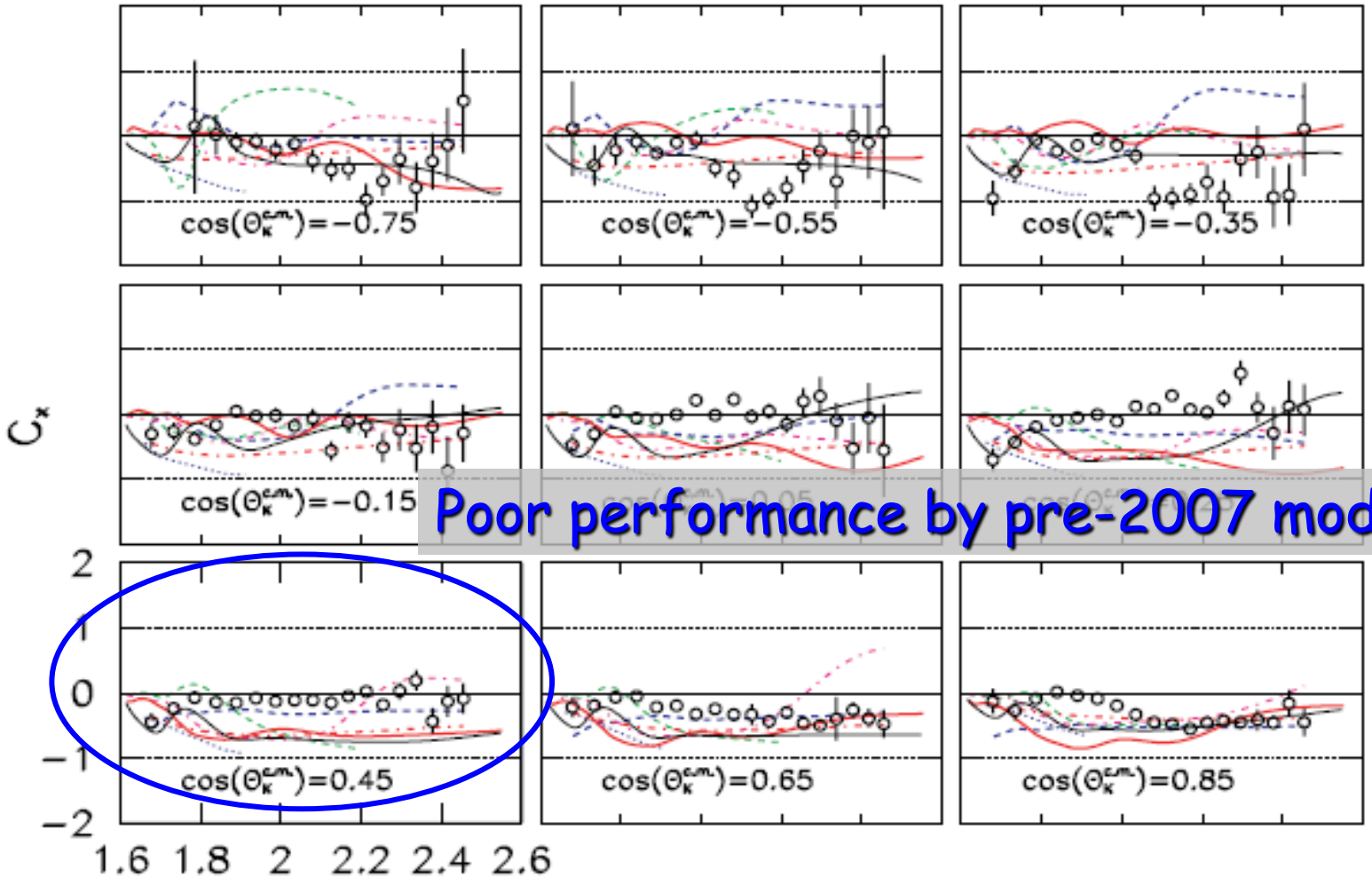


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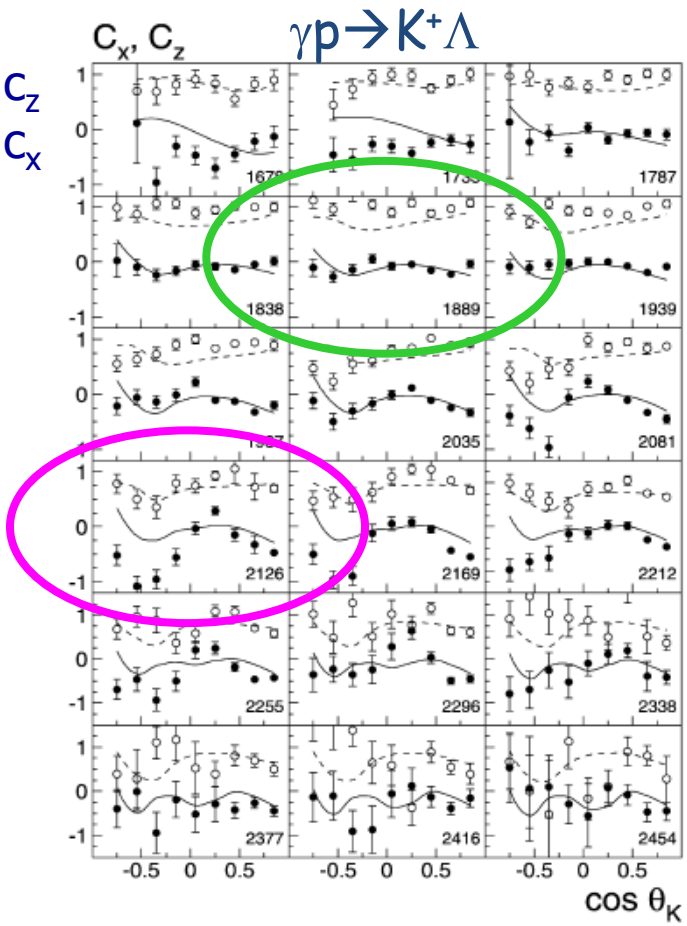
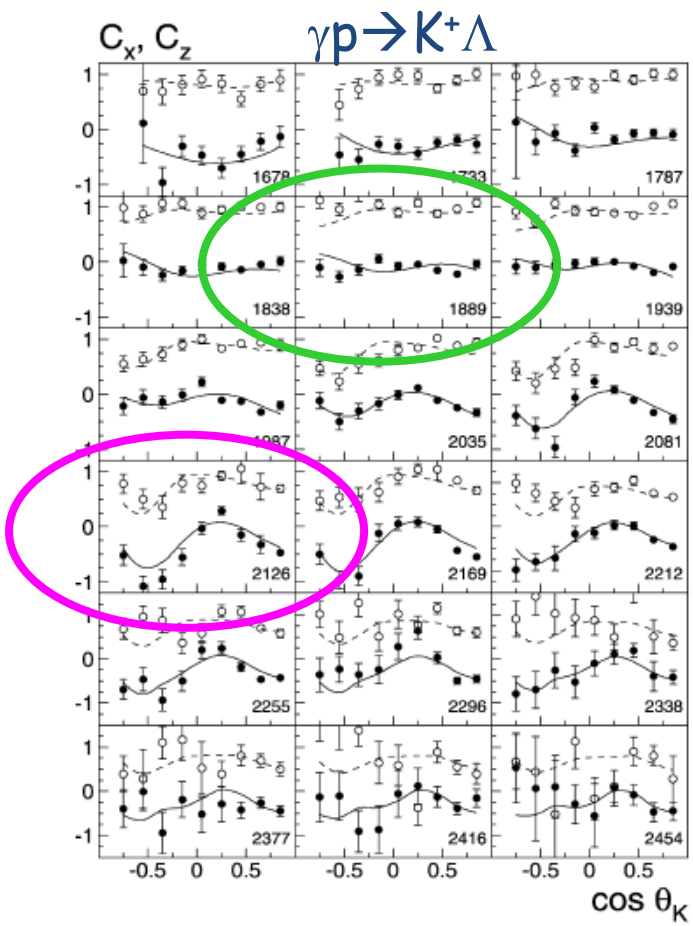
# Effect of including CLAS data in models




- Nikanov *et al*'.'s refit of Bonn-Gachina multi-coupled- channel isobar model
- mix includes:

  $S_{11}$-wave, $P_{13}(1720)$, $P_{13}(1900)$, $P_{11}(1840)$
- $P_{13}(1900)$ is not found in quark-diquark models.

the CLAS data is very important to constraint theoretic models

$C_xC_z$ without $N^*(1900)P_{13}$ $C_xC_z$ with $N^*(1900)P_{13}$

V. A. Nikanov *et al.*, Phys Lett. B **662**, 246 (2008).
see also: A.V. Anisovich *et al.*, Eur. Phys J. A **25** 427 (2005).

E. Santopinto Phys Rev. C **72**, 022201(R), (2005)

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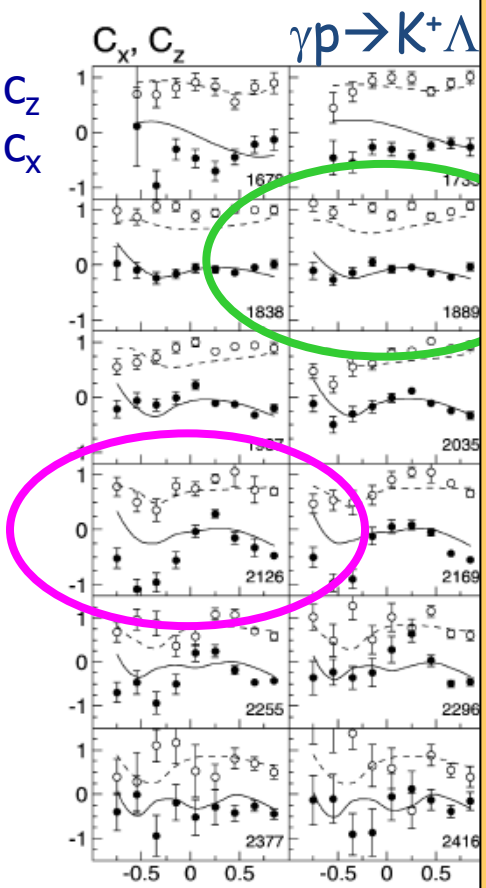


| | CLAS | SAPHIR | LEPS | GRAAL | TYPE |
|---|---|---|---|---|---|
| $d\sigma/d\Omega$ | ● | ● | | | |
| $\Sigma$ | ● | | o | o | *S* |
| T | | | | | |
| P | ● | o | | o | |
| G | | | | | |
| H | | | | | *BT* |
| E | | | | | |
| F | | | | | |
| $O_x$ | | | | | |
| $O_z$ | | | | | *BR* |
| $C_x$ | ● | | | | |
| $C_z$ | ● | | | | |
| $T_x$ | | | | | |
| $T_z$ | | | | | *TR* |
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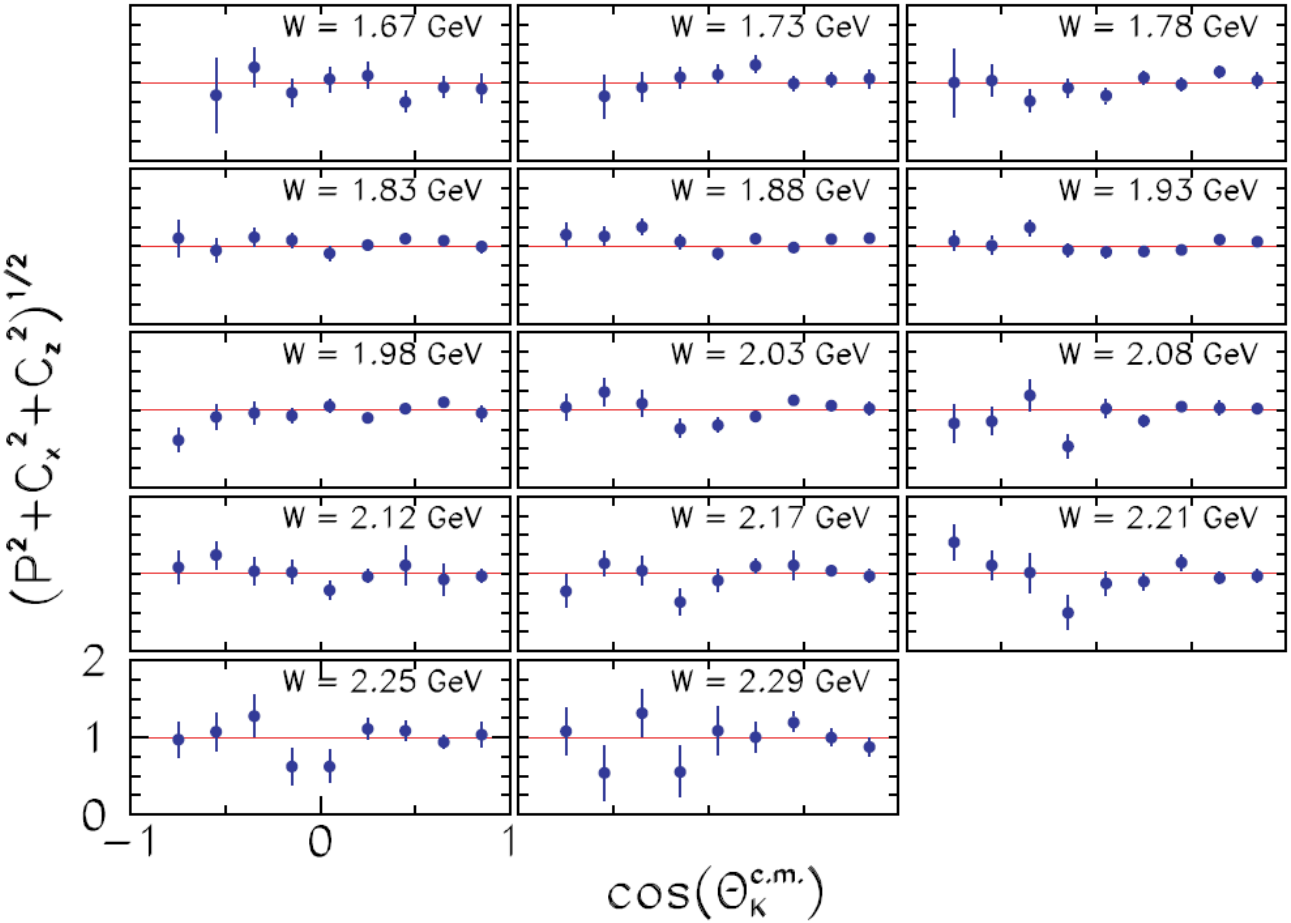
# Total polarization for the Λ




$$R \equiv \sqrt{P^2 + C_x^2 + C_z^2}$$

$$\bar{R} = 1.01 \pm 0.01$$

"Fully Polarized Λ"

Confirmed by GRAAL: A. Lleres *et al.* Eur. Phys. J. A 39, 149 (2009)

- No model predicted this CLAS result.
- For $\Sigma^0$ channel <u>no full polarization</u> has been observed

$$\bar{R}_{\Sigma^0} = 0.82 \pm 0.03$$

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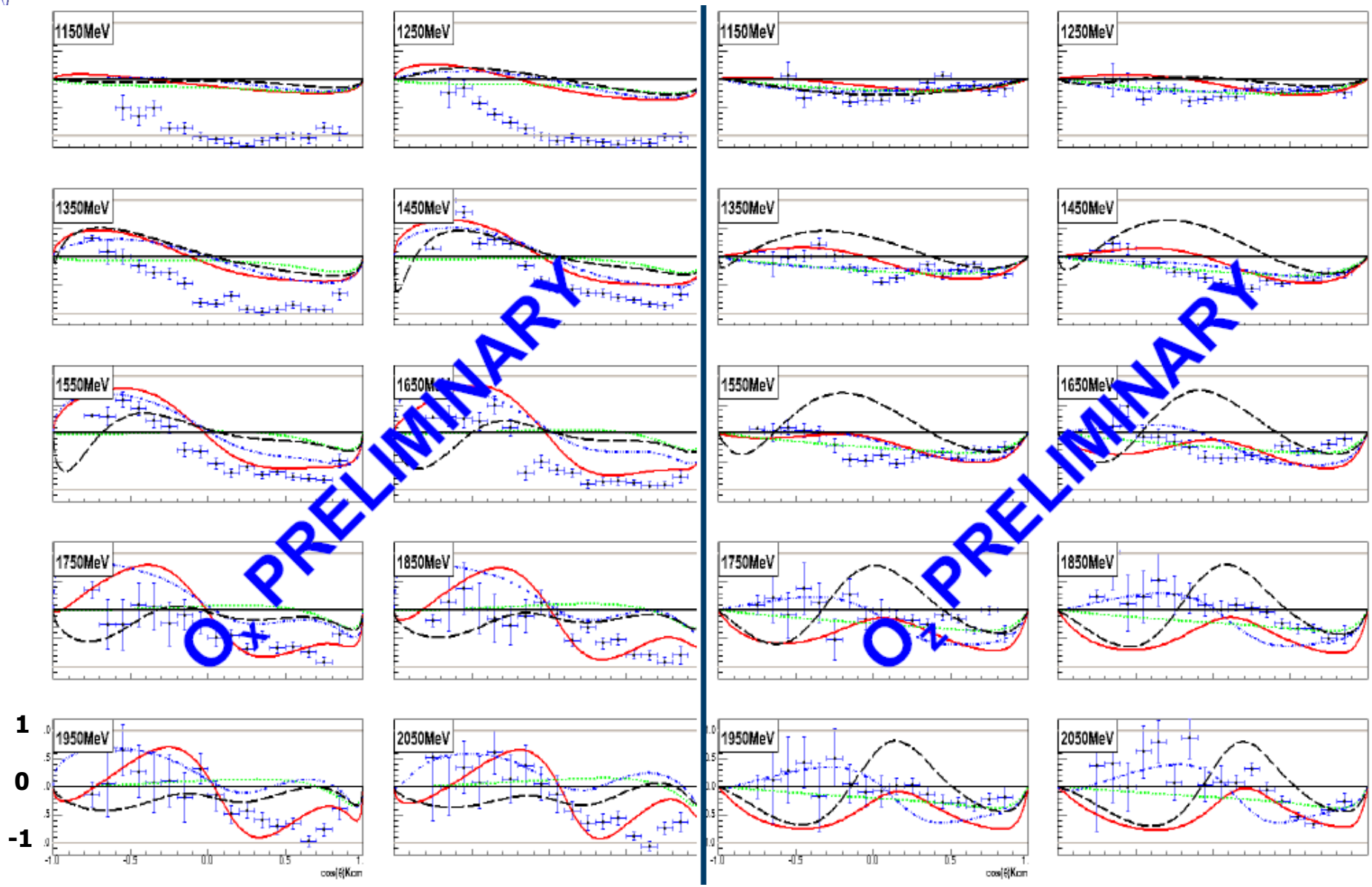


KaonMAID; RPR2-Regge only; RPR2-core; RPR2-w/D13

**Strong differences to the model predictions. These data will improve model capability.**

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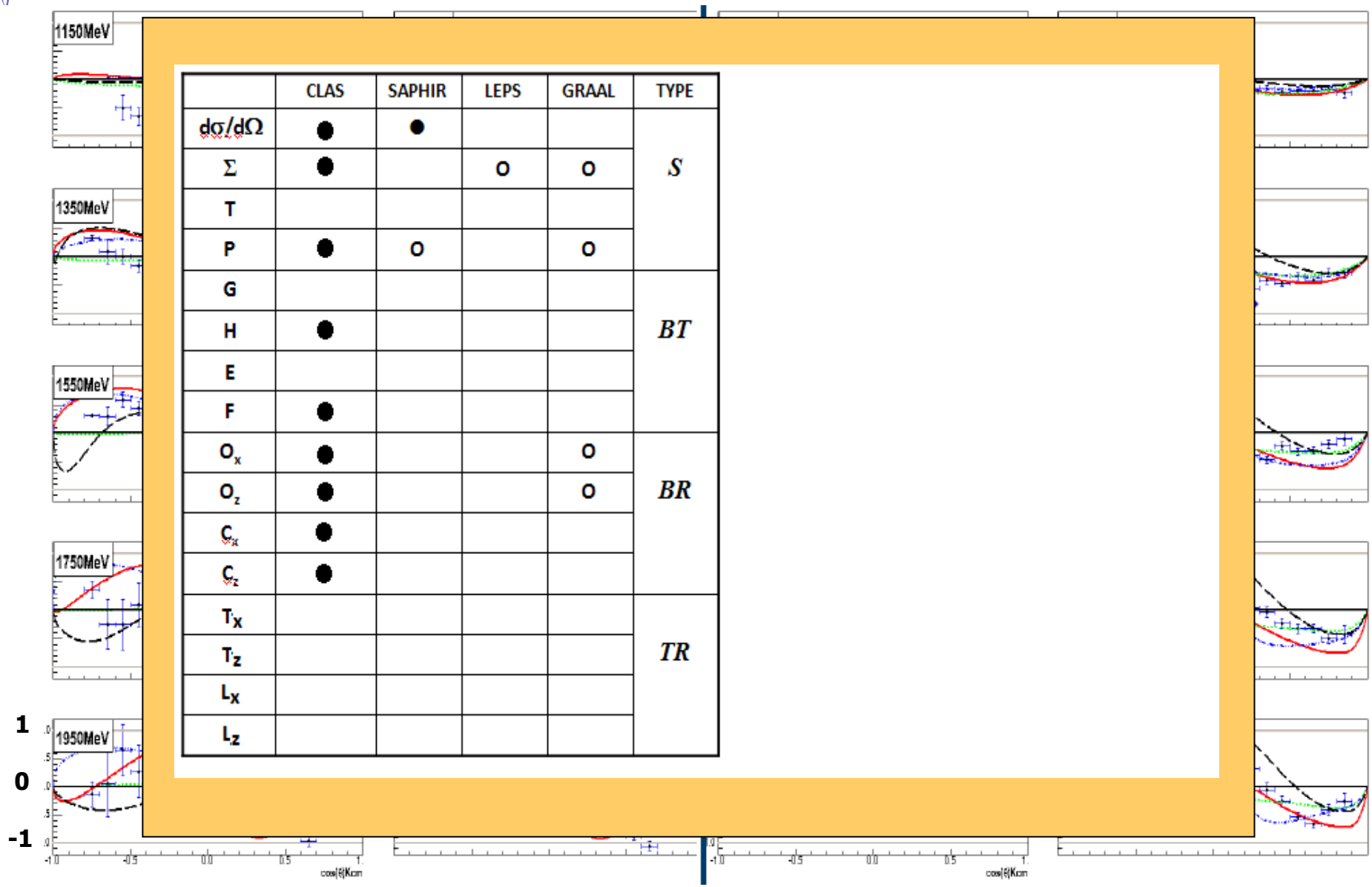


| | CLAS | SAPHIR | LEPS | GRAAL | TYPE |
|---|---|---|---|---|---|
| $d\sigma/d\Omega$ | ● | ● | | | |
| $\Sigma$ | ● | | o | o | *S* |
| T | | | | | |
| P | ● | o | | o | |
| G | | | | | |
| H | ● | | | | *BT* |
| E | | | | | |
| F | ● | | | | |
| $O_x$ | ● | | | o | |
| $O_z$ | ● | | | o | *BR* |
| $C_x$ | ● | | | | |
| $C_z$ | ● | | | | |
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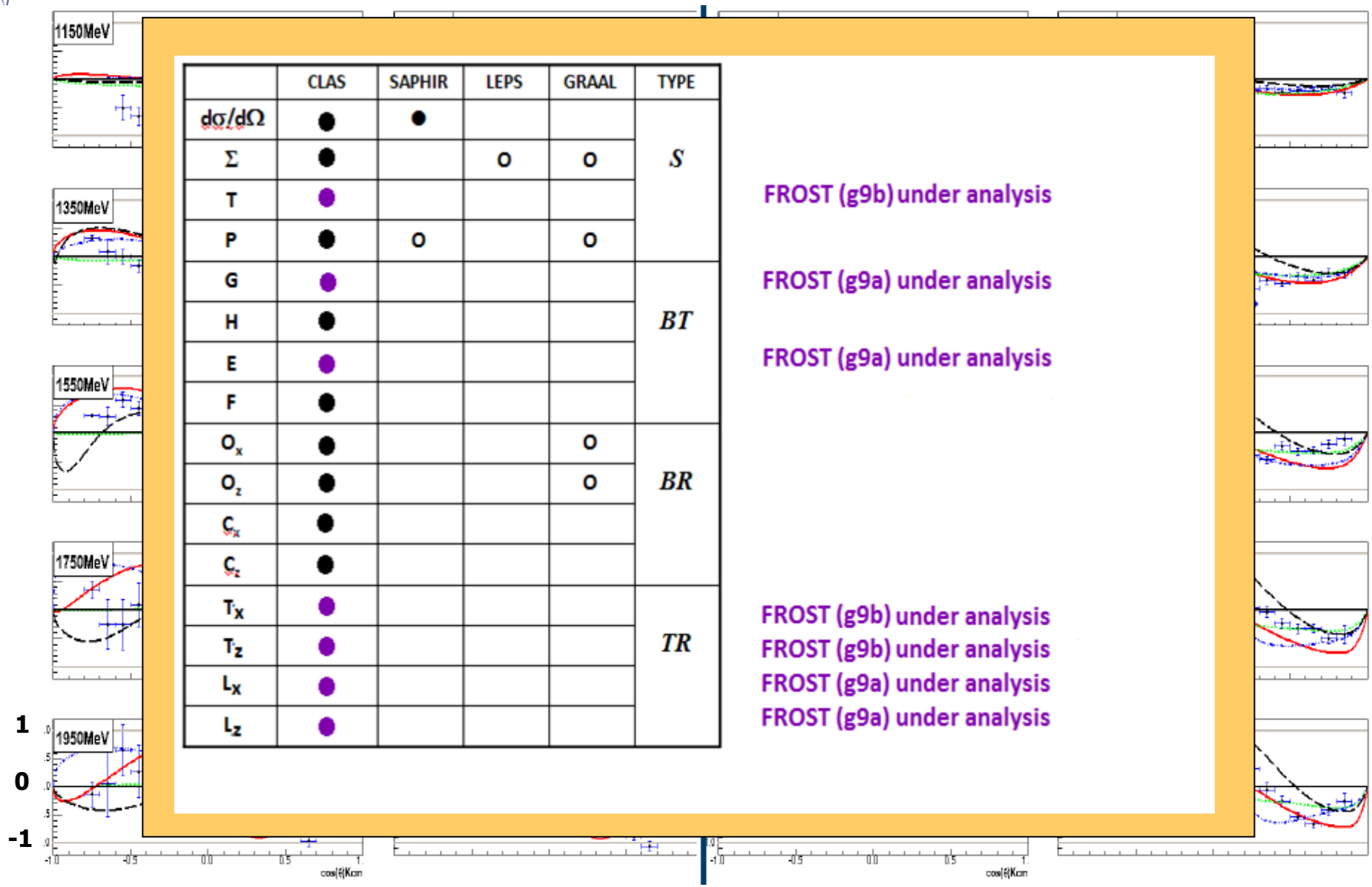


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|---|---|---|---|---|---|---|
| $d\sigma/d\Omega$ | ● | ● | | | *S* | |
| $\Sigma$ | ● | | O | O | | |
| T | ● | | | | | FROST (g9b) under analysis |
| P | ● | O | | O | | |
| G | ● | | | | *BT* | FROST (g9a) under analysis |
| H | ● | | | | | |
| E | ● | | | | | FROST (g9a) under analysis |
| F | ● | | | | | |
| $O_x$ | ● | | | O | *BR* | |
| $O_z$ | ● | | | O | | |
| $C_x$ | ● | | | | | |
| $C_z$ | ● | | | | | |
| $T_x$ | ● | | | | *TR* | FROST (g9b) under analysis |
| $T_z$ | ● | | | | | FROST (g9b) under analysis |
| $L_x$ | ● | | | | | FROST (g9a) under analysis |
| $L_z$ | ● | | | | | FROST (g9a) under analysis |

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