Pseudoscalar and Scalar Meson Photoproduction Interpreted by Regge Phenomenology

Igor Strakovsky

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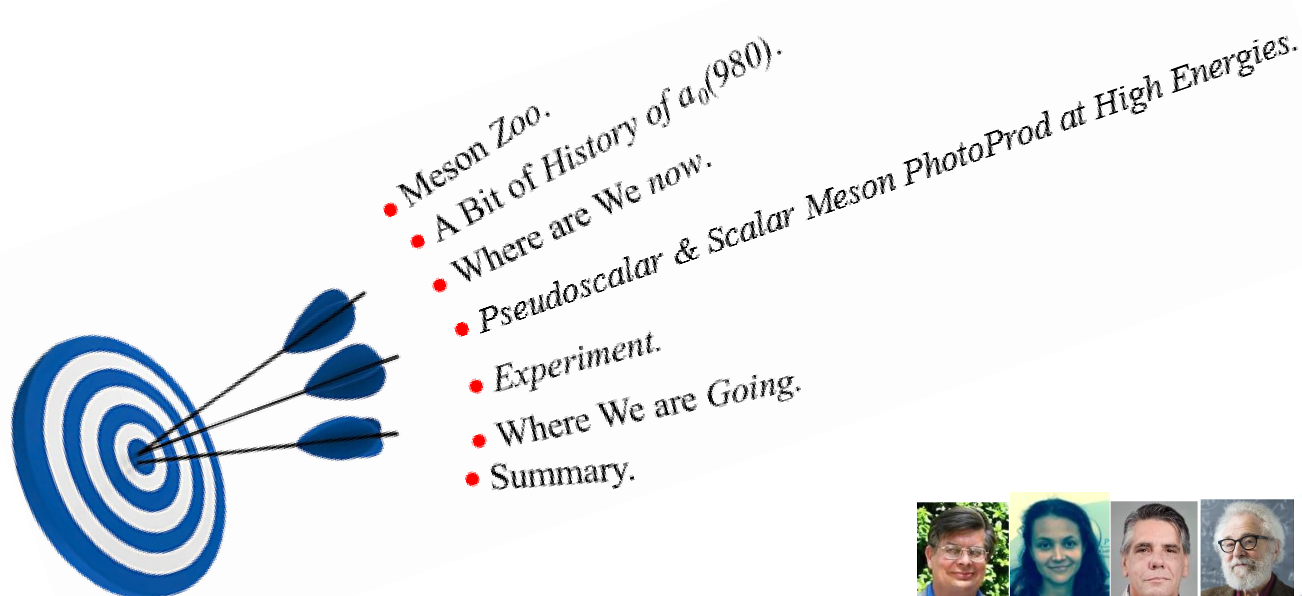
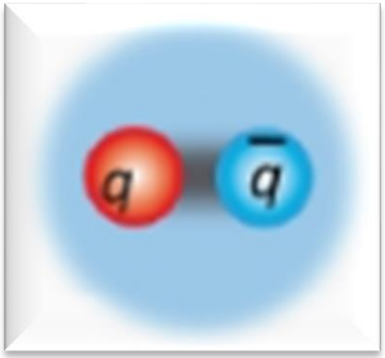


IIS, W. Briscoe, O. Cortes, M. Dugger, G. Goldstein, V. Kashevarov, A. Schmidt, P. Salazzo, & Byung-Geel Yu, Phys Rev C **107**, 015203 (**2023**)

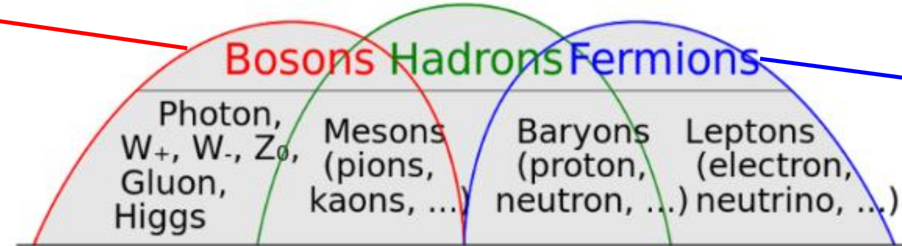
Supported by DE-SC0016583

Meson Zoo

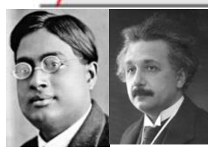


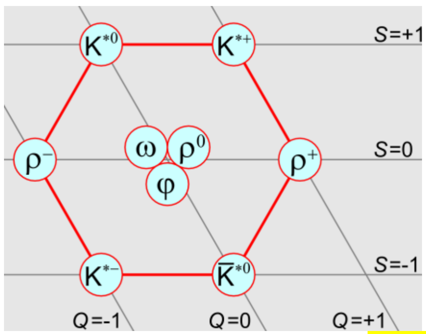
Breakthrough

BE statistics applies only to particles not limited to single occupancy of same state – that is, particles that do not obey *Pauli* exclusion principle restrictions. Such particles have integer values of spin & are named ***bosons***.



FD statistics applies to identical & indistinguishable particles with half-integer spin (1/2, 3/2, *etc*.), called ***fermions***, in thermodynamic equilibrium.



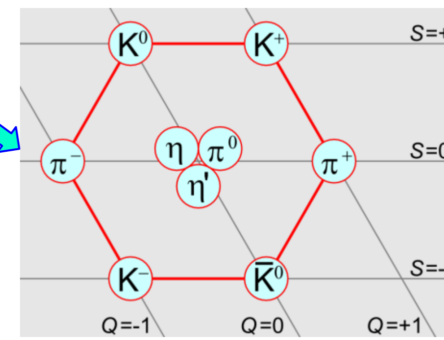


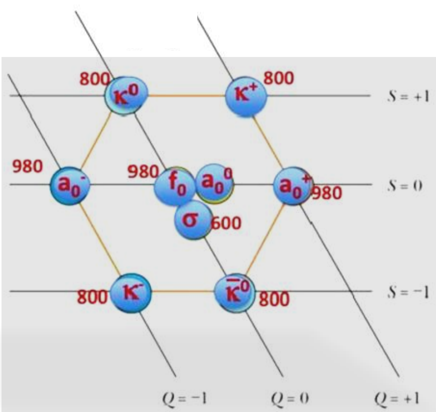
Spin — *Orbital Angular Momentum* — *Total Angular Momentum & Parity*

SU(3) Meson	S	L	J^{PC}
Pseudoscalar	0	0	0^{-+}
Pseudovector	0, 1	1	1^{+-}
Vector	1	0, 2	1^{--}
Scalar	1	1	0^{++}
Tensor	1	1, 3	2^{++}

$h_1(1170)$, $b_1(1235)$..

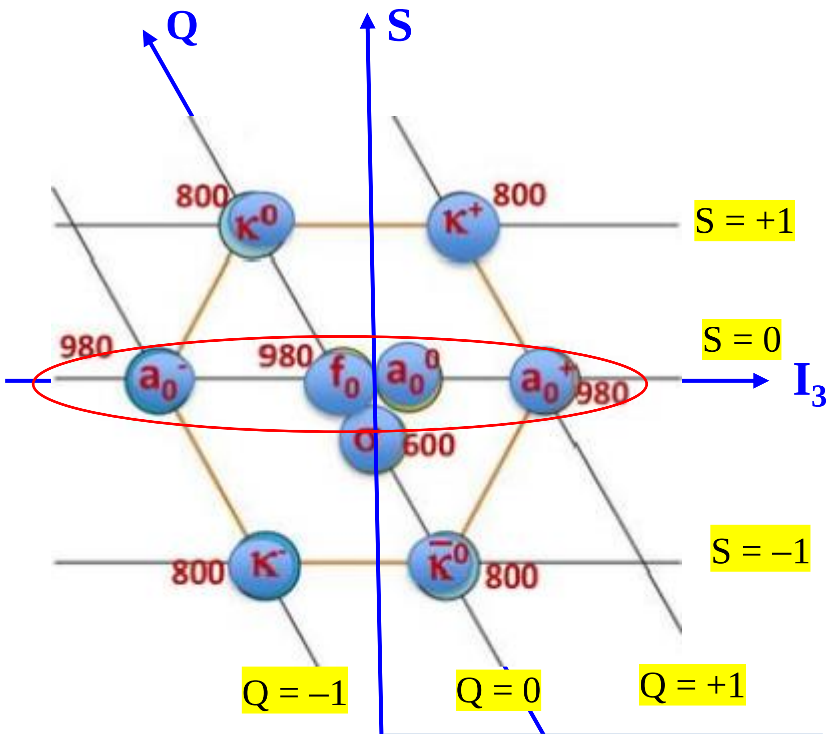
$f_2(1270)$, $\omega_3(1670)$…





Study of Scalar $a_0(980)$-Mesons

SU(3): $J^{PC} = 0^{++}$ *Nonet*



- *Scalar* a_0 family is *triplet*: a_0^-, a_0^0, & a_0^+.
  as ***pseudoscalar*** *pion* family: π^-, π^0, & π^+.
- Structure of *light scalar* mesons
  (*spin* zero, even *parity*) is poorly understood.
  2q state of ***P***-wave multiplet

$$a_0^0 = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}, \quad a_0^+ = u\bar{d}, \quad a_0^- = d\bar{u}$$

  4q state

$$a_0^0 = \frac{s\bar{s}(u\bar{u} - d\bar{d})}{\sqrt{2}}, \quad a_0^+ = s\bar{s}u\bar{d}, \quad a_0^- = s\bar{s}d\bar{u}$$

- Large *widths* mean states have significant overlap with background.
- Further complicated by proximity to $K\bar{K}$ & thresholds while $\eta\pi$ *decay* is dominant.

$$M = a_0 + a_1 Y + a_2 \left[I(I+1) - \frac{1}{4} Y^2 \right]$$

I *– isospin,* ***S/Y*** *– strangeness (hypercharge),* a_i *– free prmts.*

- This phenomenological formula works with accuracy of 5%.

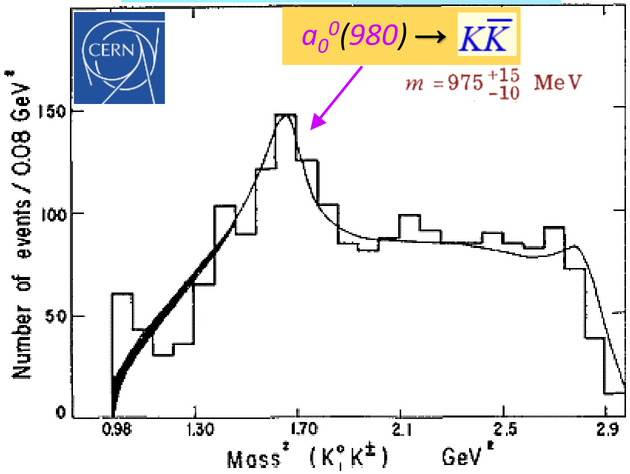
- Mixing be able to shift some masses for *Gell-Mann-Okubo mass* formula.

A Bit of History of $a_0(980)$ Triplet

First Observations of Scalar $a_0(980)$

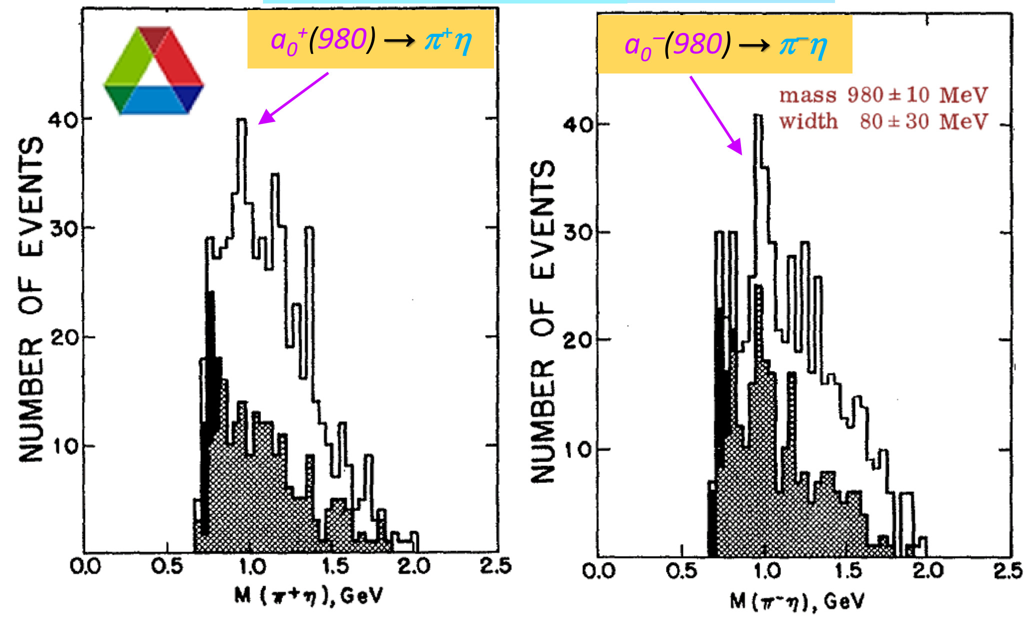
Bump Hunting

$\bar{p}p \to K_1^0 K^\pm \pi^\mp$ @ 1.2 GeV/c



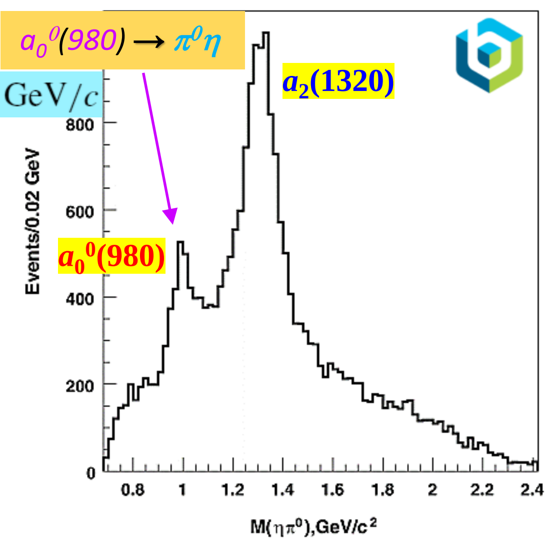
A. Astier *et al*, Phys. Lett. B **25**, 294 (1967)

$K^- + p \to \Lambda + \pi^+ + \pi^- + \eta$ @ 5.5 GeV/c



R. Ammar *et al*, Phys Rev Lett **21**, 1832 (1968)

$\pi^- p \to \eta\pi^0 n,\ \eta \to \pi^+\pi^-\pi^0$ at 18 GeV/c

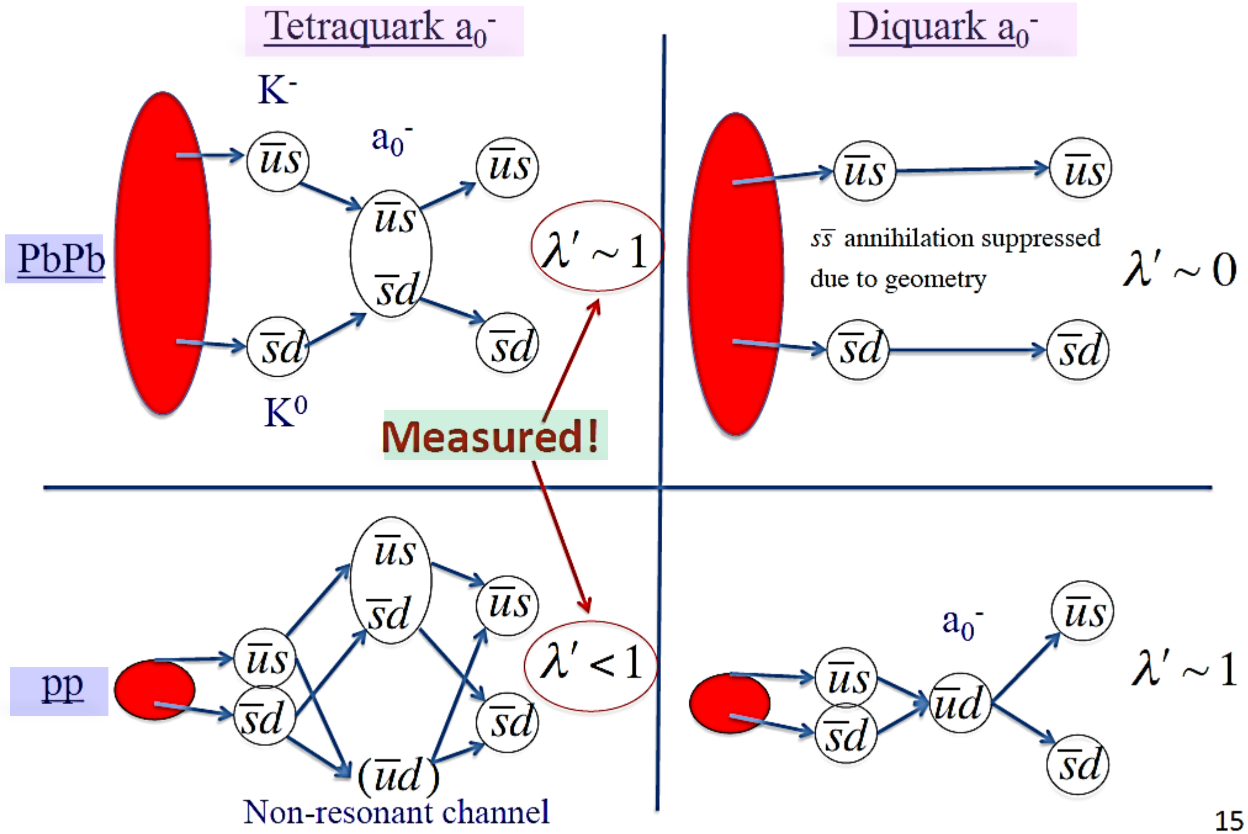


G.S. Adams *et al*, Phys Lett B **657**, 27 (2007)

Nature of $a_0(980)$

Tetraquark vs *Diquark*

$\lambda' \equiv \lambda_{K^0K^-}/\lambda_{KK}$ for $\bar{u}s\bar{s}d$ vs. $\bar{u}d$ a_0^- expected from geometry



Courtesy of Thomas Humanic, **2021**

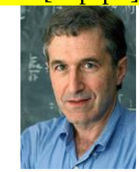
Suplemento de la Revista Mexicana de Fısica **3,** 0308039 (**2022**)

- Result is strongly *model* dependent
  - it seems to be based on *heuristic* idea that ***4q*** states are "larger" than $\bar{q}q$ states
- Analysis does not seem to take account of fact that ***a_0*** requires description in $K\bar{K}$ & $\pi\eta$ channels.

Courtesy of Bob Jaffe, **2022**

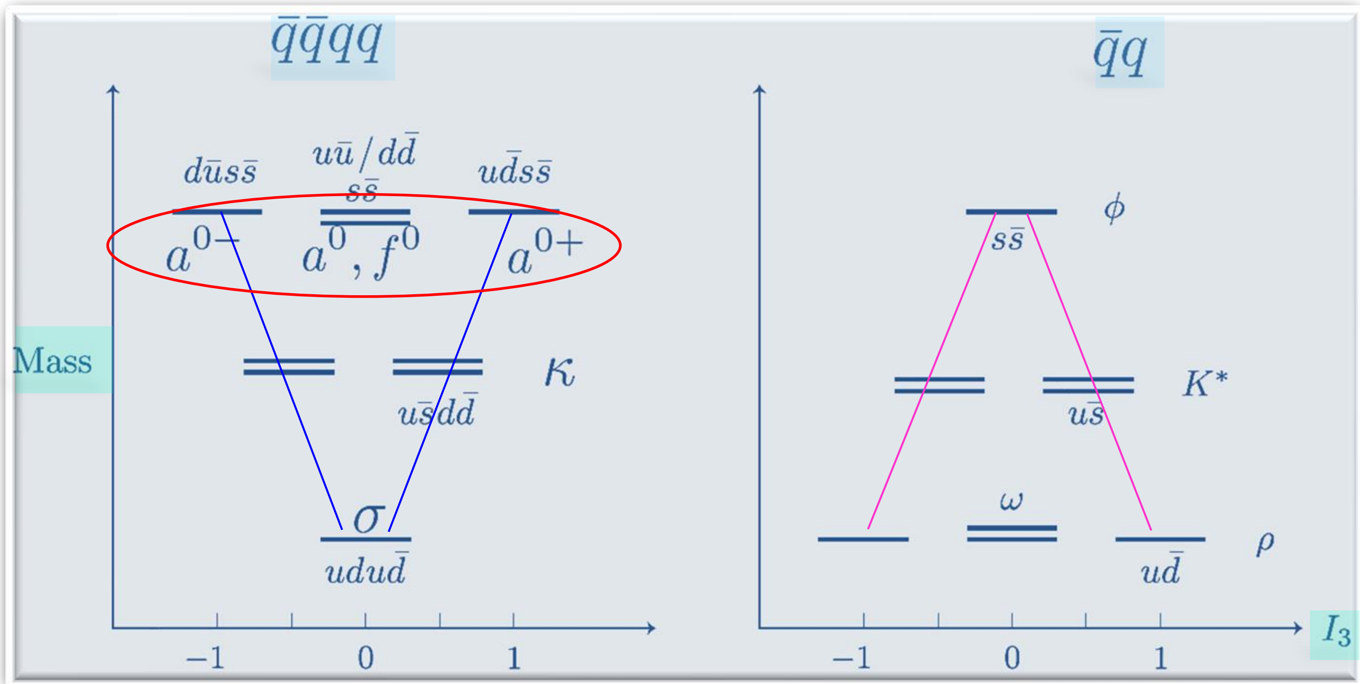
Scalars vs Vectors or Eyewitness of 4q Exotics ?

R.J. Jaffe, Phys Rev D **15**, 267 (**1977**)
arXiv: **00**01123 [hep-ph]
arXiv: **07**01038 [hep-ph]



Inverted mass hierarchy tetraquarks
Scalar Mesons

Ordinary meson states
Vector Mesons



- Very different mass *hierarchy*.
- Possibly suggesting *4q tetraquark*.
- Structure of ***scalar*** mesons.

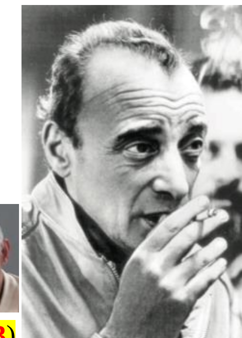
- *Certainly, there is no clear distinction between 4q & ``meson molecule'' categories.*

"I like the conclusion that the a_0 is a multi quark state." Courtesy of Bob Jaffe, **2022**

Scalars vs Pseudoscalars

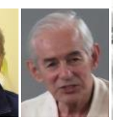
- *Scalar* mesons *$f_0(980)$* & *$a_0(980)$* play a fundamental role in *Gribov's confinement theory* –
  $f_0(980)$ & *$a_0(980)$* as eye-witnesses of confinement.

- Within framework of this approach, these states correspond to lowest energy levels of
  light quarks inside ***Dirac's*** see ($T_{kin} > 0$) while *pseudoscalar* mesons η & π correspond to next level.
  Scalars: singlet: $f_0(980)$ & triplet: a_0^-, a_0^0, a_0^+
  Pseudoscalars: singlet: $\eta(548)$ & triplet: π^-, π^0, π^+



- *Gribov's theory* predicts that *scalars* are *weakly* absorbed since *pseudoscalars* have
  small size of **~0.2** fm.
  It requires *experimental study*.



F.E. Close, Y.L. Dokshitzer, V.N. Gribov, V.A. Khoze, & M.G. Ryskin, Phys Lett. B **319**, 291 (**1993**)

- There is *mass difference* between charged & neutral *pions* (**4** MeV).
- It is caused:
  - by current mass difference of ***u***- & ***d***-quarks (this difference should not affect masses of π or a_0).
  - by ***Coulomb*** field created by electric charge (this value depends on (decreases with) radius of meson.
- Nobody reported such *mass difference* for a_0-triplet.

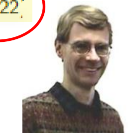
- There is no (or **very small**) *mass difference* between ***f*** & ***a***.
- While there is **significant** *mass difference* between η & π.
  - That is because π is ***Goldstone boson***.

M.G. Ryskin & IIS, LoI for TRIUMF experiment, **1991**
*Production and properties of the scalar mesons **$f_0(975)$** and **$a_0(980)$***

Where are We Now

What is Known about Scalar $a_0(980)$

Citation: R.L. Workman *et al.* (Particle Data Group), Prog.Theor.Exp.Phys. **2022**, 083C01 (2022)



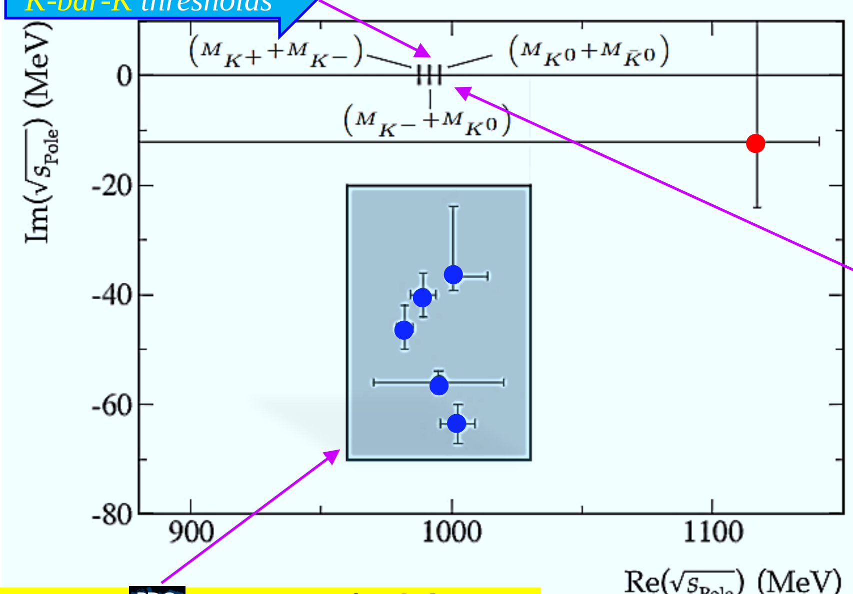
PDG $a_0(980)$

$I^G(J^{PC}) = 1^-(0^{++})$

$a_0(980)$ T-MATRIX POLE $\sqrt{s}$

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
(960–1030) − *i* (20–70) OUR ESTIMATE (see Fig. 64.2 in the review)			
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$(989 \pm 5) - i(40 \pm 5)$	[1] BUGG 08A	RVUE	$\overline{p}p$ annihilation data
$(1117^{+24}_{-320}) - i(12^{+43}_{-12})$	[2] PELAEZ 04A	RVUE	$\pi\pi \to \pi\pi$, $\pi K \to \pi K$
$(982 \pm 3) - i(46 \pm 4)$	[3] ABELE 98	CBAR	$0.0\ \overline{p}p \to K^0_L K^\pm \pi^\mp$

K-bar-K thresholds

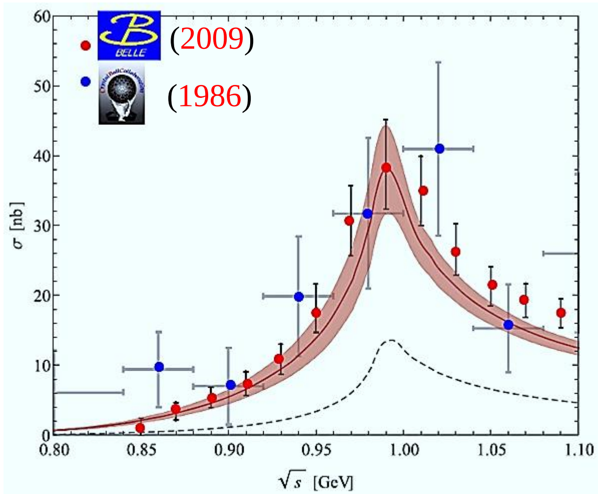


Grey area *is* PDG estimation of *pole* location.

- PDG does not have details about $a_0(980)$ triplet.
- $a_0(980)$ couples strongly to channels $\pi\eta$ & $K\overline{K}$.
- Independent of ***any*** model, $K\overline{K}$ component must be large in $a_0(980)$ WF, since mass of $a_0(980)$ lies very close to opening of $K\overline{K}$ channel, to which it strongly couples.
- Shape of $a_0(980)$ strongly depends on $K\overline{K}$ threshold.

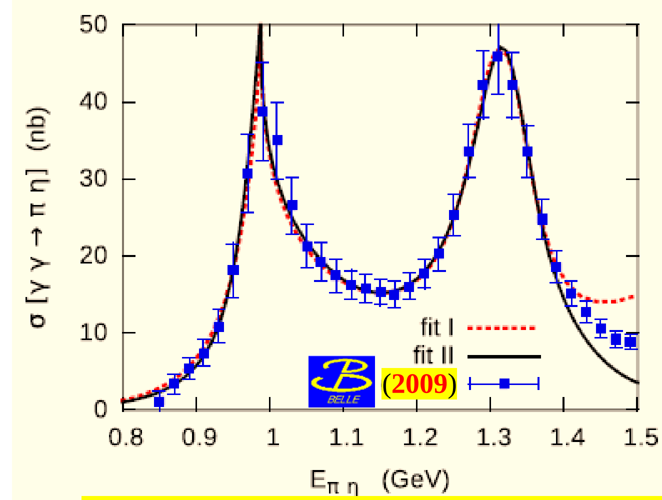
More about $a_0(980)$

$\gamma\gamma \to \eta\pi, K\bar{K}$



I. Danilkin, O. Deineka, & M. Vanderhaeghen, Phys Rev D **96**, 114018 (**2017**)

$$\sqrt{s_{a_0}^{IV}} = (1.12^{-0.07}_{+0.02}) - \frac{i}{2}(0.28^{+0.08}_{-0.13})\ \text{GeV}$$

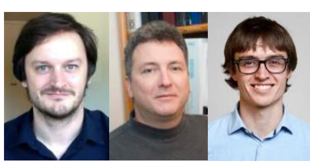


Junxu Lu & B. Moussallam, Eur Phys J C **80**, 436 (**2020**)

$$m - i\Gamma/2 = 1000.7^{+12.9}_{-0.7} - i\,36.6^{+12.7}_{-2.6}\ \text{MeV}$$

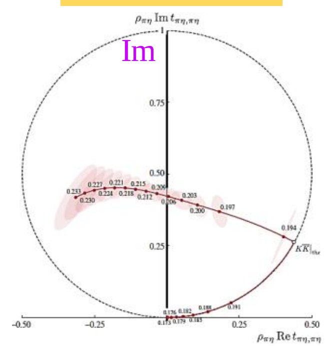
hadspec

$$\sqrt{s_0} = \left((1177 \pm 27) + \frac{i}{2}(49 \pm 33)\right)\ \text{MeV}$$

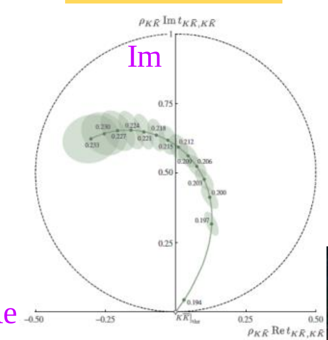


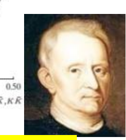
J.J. Dudek, R.G. Edwards, & D.J. Wilson, Phys Rev D **93**, 094506 (**2016**)

$a_0(980) \to \eta\pi$



$a_0(980) \to K\bar{K}$



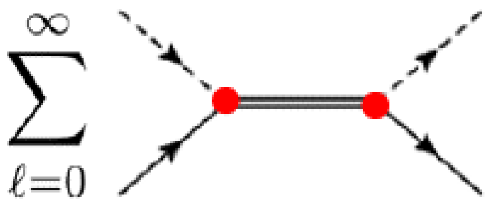


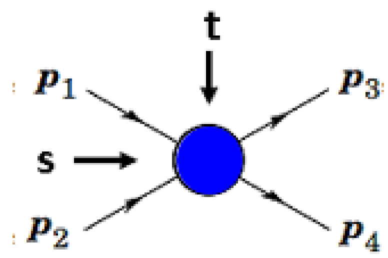
- More data with a_0 will help to solve this puzzle.

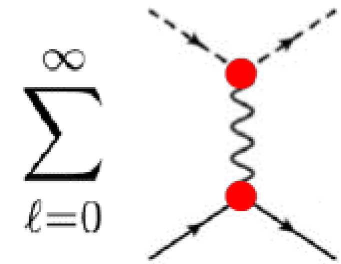
J.-R. Argand, ``*Essai Sur Une Maniere de Representer les Quantites Imaginaires Dans les Constructions Geometriques*'' (Sans nom d'auteur, Paris, **1806**), Vol. **I**, 78.

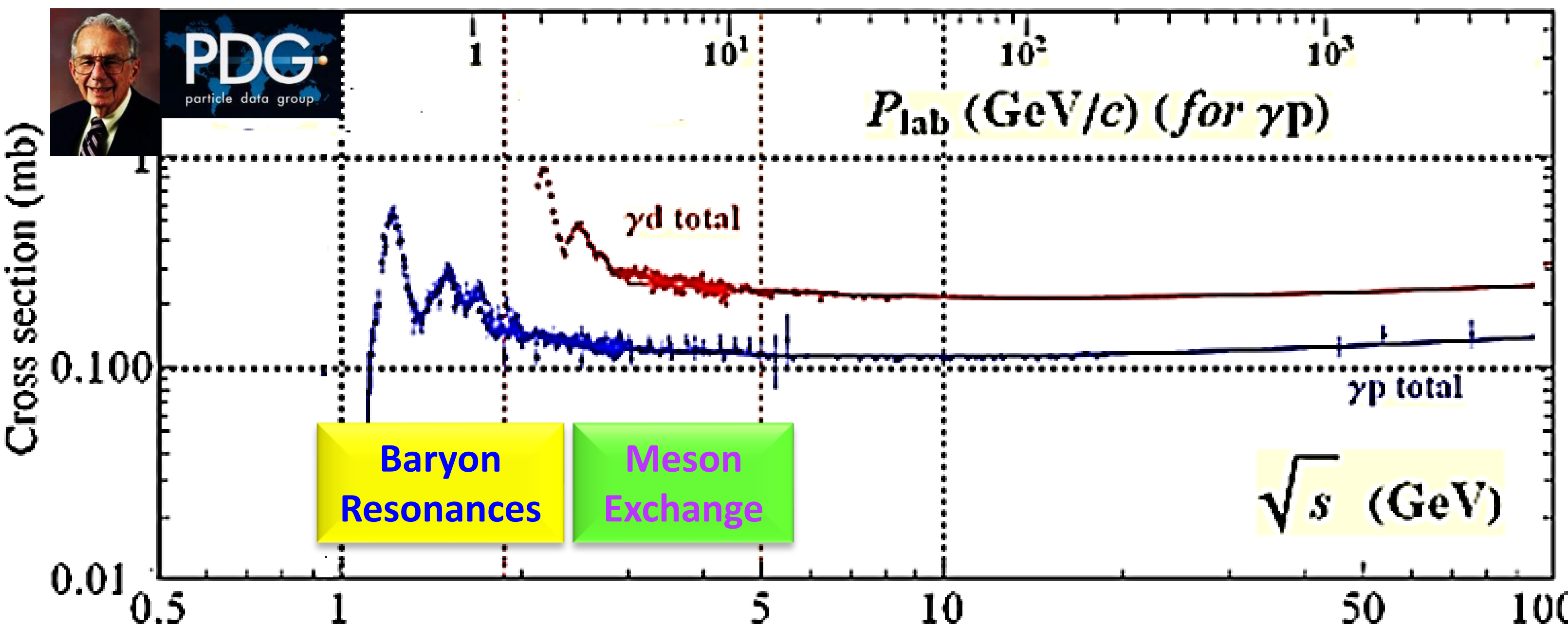
Pseudoscalar & Scalar Meson Photoproduction @ High Energies

Low- & High-Energy Dynamics for Meson Photoproduction





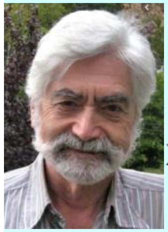




E_γ (max) = 23 TeV

Jefferson Lab · clas · CLAS12 · GlueX

Meson Photoproduction @ High Energies & Regge-Cut Model



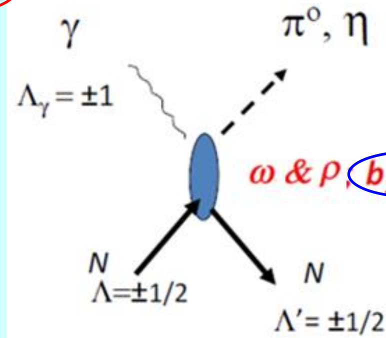
IL NUOVO CIMENTO VOL. XXXII, N. 3 1° Maggio 1964

Reaction $\gamma + \mathcal{N} \to \pi + \mathcal{N}$ at High Energies (*).

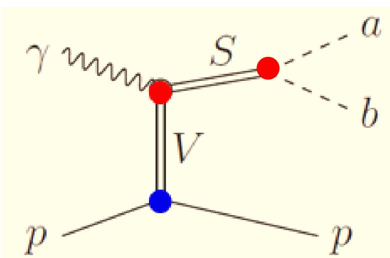
G. ZWEIG

California Institute of Technology, Synchrotron Laboratory - Pasadena, Cal.

(ricevuto il 22 Ottobre 1963)



- There were no b_1 & h_1 mesons back to **1964**.



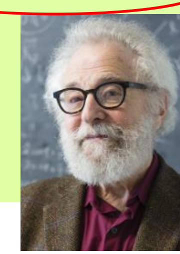
PHYSICAL REVIEW D VOLUME 7, NUMBER 3 1 FEBRUARY 1973

π^0 Photoproduction in a Weak-Regge-Cut Model*

Gary R. Goldstein and Joseph F. Owens III

Department of Physics, Tufts University, Medford, Massachusetts 02155

(Received 9 March 1972)



PHYSICAL REVIEW C 93, 025203 (2016)

Photoproduction of $a_0(980)$ and $f_0(980)$

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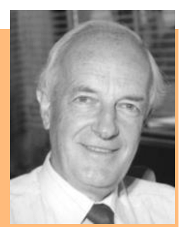
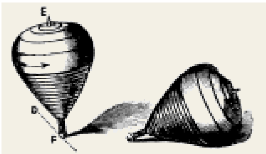
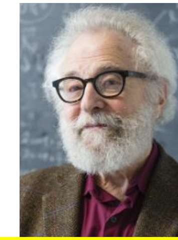
(Received 15 October 2015; published 16 February 2016)



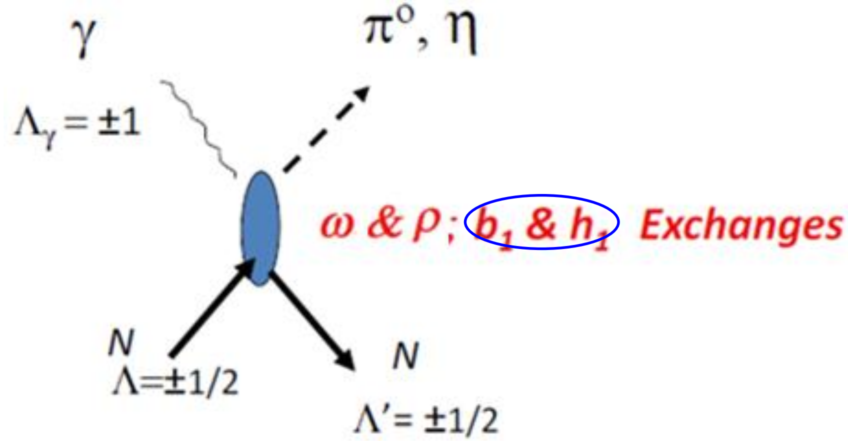
- @ sufficiently high beam energies, *t*-channel processes are dominant, & *t*-dependence of observables can be studied free from lower energy background.
- Measurements of *cross sections* & *beam asymmetries* can provide constraints to models.
- For example, magnitude & sign of *beam asymmetry* can indicate dominance of exchange process.



Pseudoscalar photoproduction
$\gamma + p \rightarrow (\pi^0 \text{ or } \eta) + p$



G.R. Goldstein & J.F. Owens III, Phys Rev D **7**, 865 (1973)



$$\frac{d\sigma}{dt} = \frac{\pi}{2sk^2} \sum_{i=1}^{4} |\, f_i \,|^2;$$

- 4 helicity amps

$$f_{\Lambda_\gamma,\,\Lambda;\,0,\,\Lambda'} \text{ for } \gamma(q,\,\Lambda_\gamma)+N(p,\,\Lambda) \rightarrow \pi^0(q')+N(p',\,\Lambda');$$

$$f_1 = f_{+1,+\frac{1}{2};0,+\frac{1}{2}},\; f_2 = f_{+1,+\frac{1}{2};0,-\frac{1}{2}},\; f_3 = f_{+1,-\frac{1}{2};0,+\frac{1}{2}},\; f_4 = f_{+1,-\frac{1}{2};0,-\frac{1}{2}}$$

f_1 & $f_4 \propto \Delta^1$; $f_2 \propto \Delta^0$; $f_3 \propto \Delta^2$

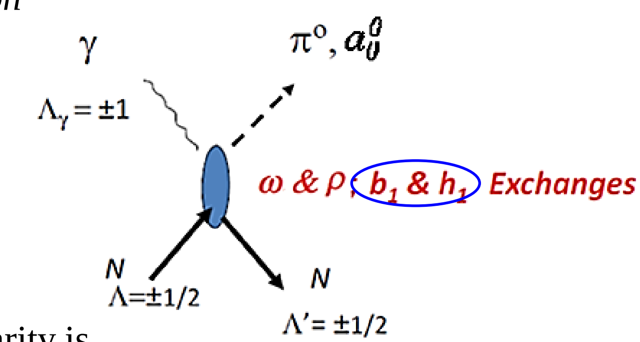
Courtesy of Gary Goldstein, **2017**

$\vec{\gamma} p \to p\pi^0$ *vs.* $\vec{\gamma} p \to p a_0^0$

Regge pole exchange:

$$f_1 = f_{1+,0+}$$
$$f_2 = f_{1+,0-}$$
$$f_3 = f_{1-,0+}$$
$$f_4 = f_{1-,0-}$$

where $\mathbf{f}_{ab,\,cd}$ is amplitude for photon with *helicity* ***a*** striking target nucleon of *helicity* ***b*** & producing *spin-zero meson* & nucleon with *helicity* ***d***.



- In limit of asymptotic energies, we can define following set of amplitudes of definite ***t***-channel parity

$$f_1^{\pm} = f_1 \pm f_4$$
$$f_2^{\pm} = f_2 \mp f_3$$

where natural (unnatural) parity is indicated by superscript **+** (**–**).

- Then combinations that have leading positive or negative ***t***-channel parity are constructed in same way for *pseudoscalar* (π^0) & *scalar* (a_0^0) production.

- How we define ***C***-parity.
  - For π^0 that restricts exchange ***C***-parity to *negative*. Hence ρ & ω for *vector* exchange (J^{PC}: 1^{--}) & b_1 & h_1 for *pseudovector* exchange (J^{PC}: 1^{+-}). Both have negative ***C*** .
  - For a_0^0, ***C***-parity is also *negative*, but parity is *opposite*. That implies that *axial* & *polar* vector exchanges are *switched*. Hence *polarized beam photon asymmetry* Σ will behave *oppositely* for a_0^0 as for π^0.

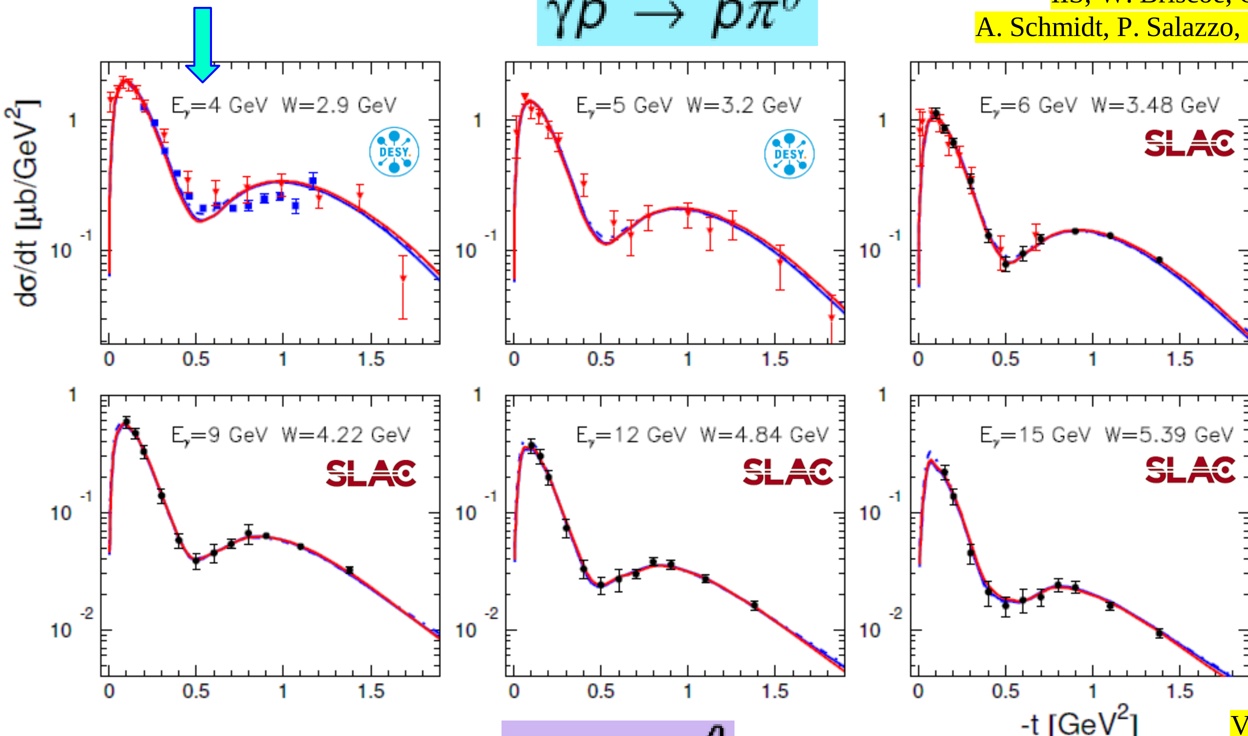
Courtesy by Gary Goldstein, 2022

Experiment

Cross Sections' Dip @ |t| ~ 0.5 GeV²

$\gamma p \rightarrow p\pi^0$

IIS, W. Briscoe, O. Cortes, M. Dugger, G. Goldstein, V. Kashevarov, A. Schmidt, P. Salazzo, & Byung-Geel Yu, Phys Rev C **107**, 015203 (2023)



There is ***dip*** in ***ds/dt*** @ |t| ~ 0.5 GeV² for both ***pseudoscalar*** & ***scalar*** mesons.

dσ/dt, *Σ*(SLAC), *T*, & *P* ——

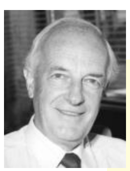
dσ/dt, *Σ*(GlueX) — · —

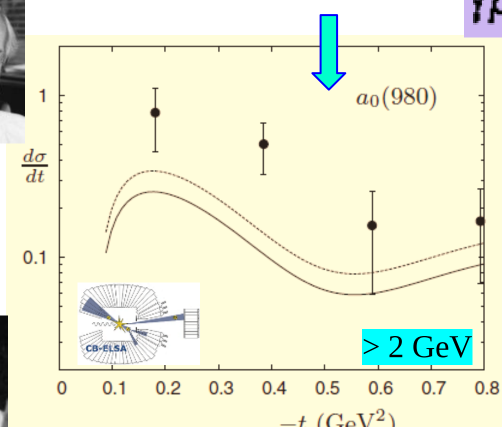
dσ/dt, *Σ*(GlueX), *T*, & *P* – – –

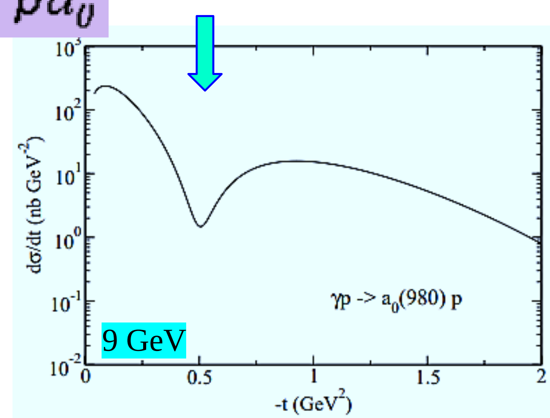
V.L. Kashevarov *et al* Phys Rev C **96**, 045207 (2017)

Courtesy by Viktor Kashevarov, October 2022

$\gamma p \rightarrow p a_0^0$







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

M.L.L. da Silva and M.V.T. Machado. Phys Rev C **86**, 015209 (2012)

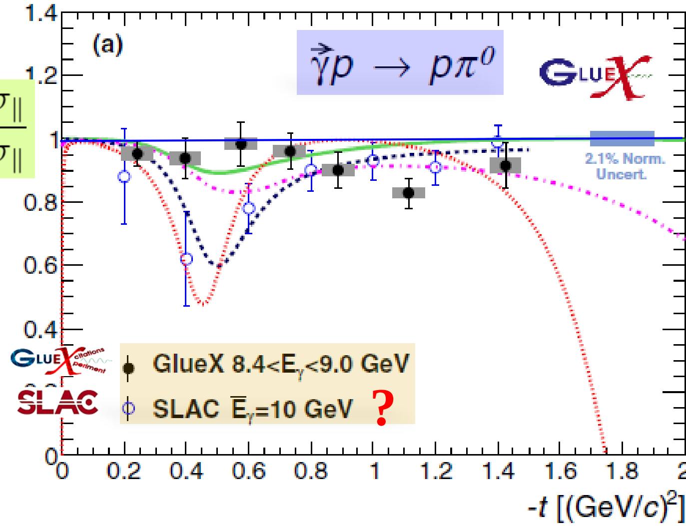
1st GlueX Paper

Asymmetry for Pseudoscalar Photoproduction

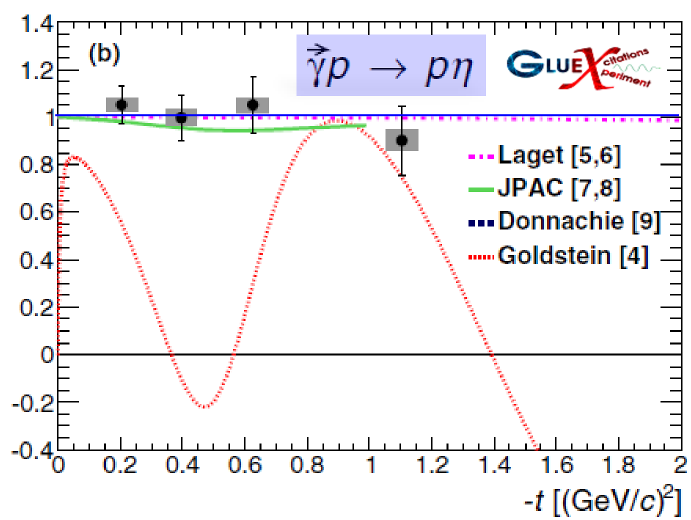
H. Al Ghoul *et al*, Phys Rev C **95**, 042201R (2017)

Σ

$$\Sigma = \frac{d\sigma_\perp - d\sigma_\parallel}{d\sigma_\perp + d\sigma_\parallel}$$



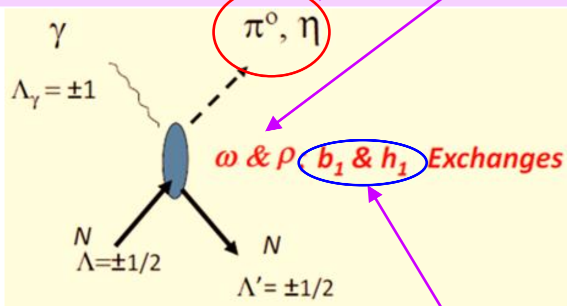
Σ



- *Natural* parity – *UnNatural* parity asymmetry

- π^0 & π^+ are different.
- It is ***EM*** transition. So, *isospin* arguments are not valid.
- There is additional π^+ exchange, dominant @ small ***t***.

- Leading role by *vector Natural parity* meson exchange ⟶ Σ = +1

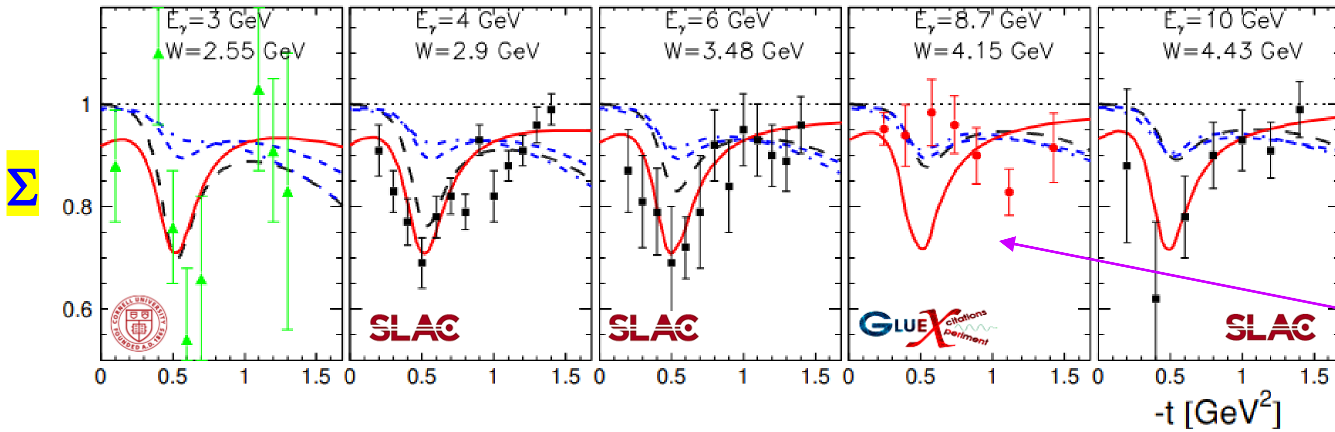


- Adding *pseudovector UnNatural parity* meson exchange ⟶ Σ < +1

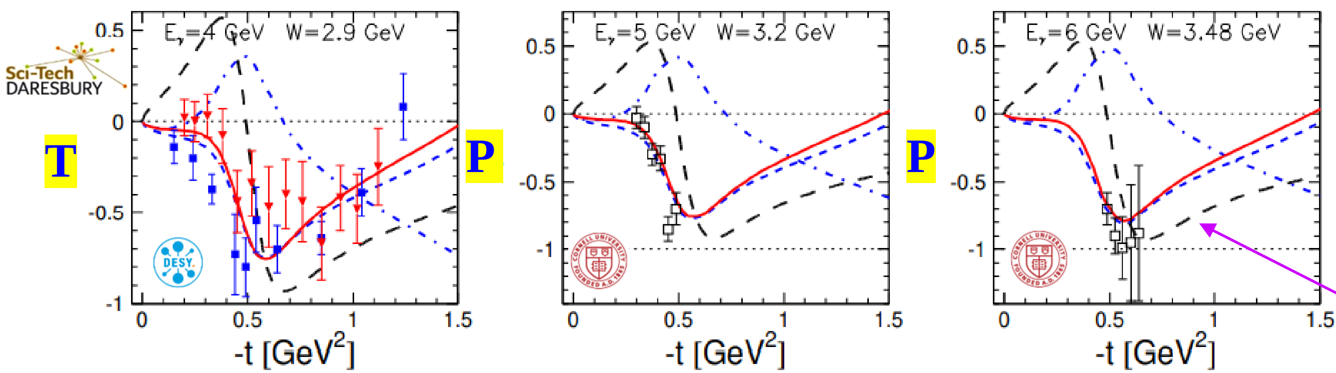
- b_1 & h_1 **Regge** *trajectories* are *1/2* unit below ρ & ω. So, there is $s^{1/2}$ difference. It means that contribution from b_1 & h_1 goes down vs energy.

Fit for $\gamma p \rightarrow p\pi^0$

IIS, W. Briscoe, O. Cortes, M. Dugger, G. Goldstein, V. Kashevarov,
A. Schmidt, P. Salazzo, & Byung-Geel Yu, Phys Rev C **107**, 015203 (2023)



- Why energy sequence **3** to **10** GeV is broken @ **9** GeV.

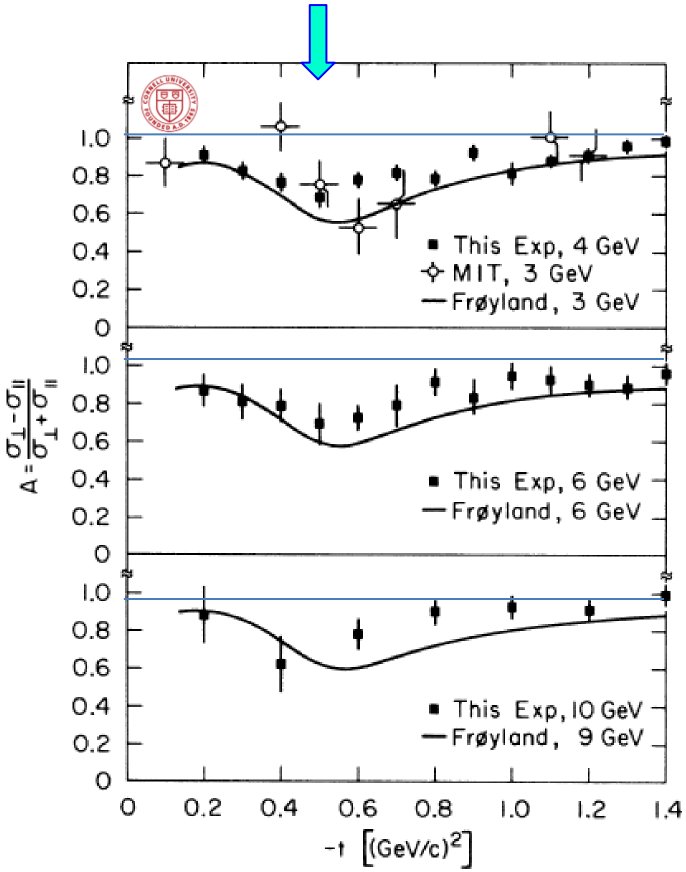


dσ/dt, *Σ* (SLAC), *T*, & *P* ———
dσ/dt, *Σ* (GlueX) — · —
dσ/dt, *Σ* (GlueX), *T*, & *P* — — —

V.L. Kashevarov *et al*
Phys Rev C **96**, 045207 (2017)
Courtesy by Viktor Kashevarov,
October 2022

B.G. Yu, T.K. Choi, & W. Kim, Phys. Rev. C **83**, 025208 (2011)

SLAC $\vec{\gamma} p \to p\pi^0$



R. L. Anderson *et al*, Phys Rev D **4**, 1937 (1971)

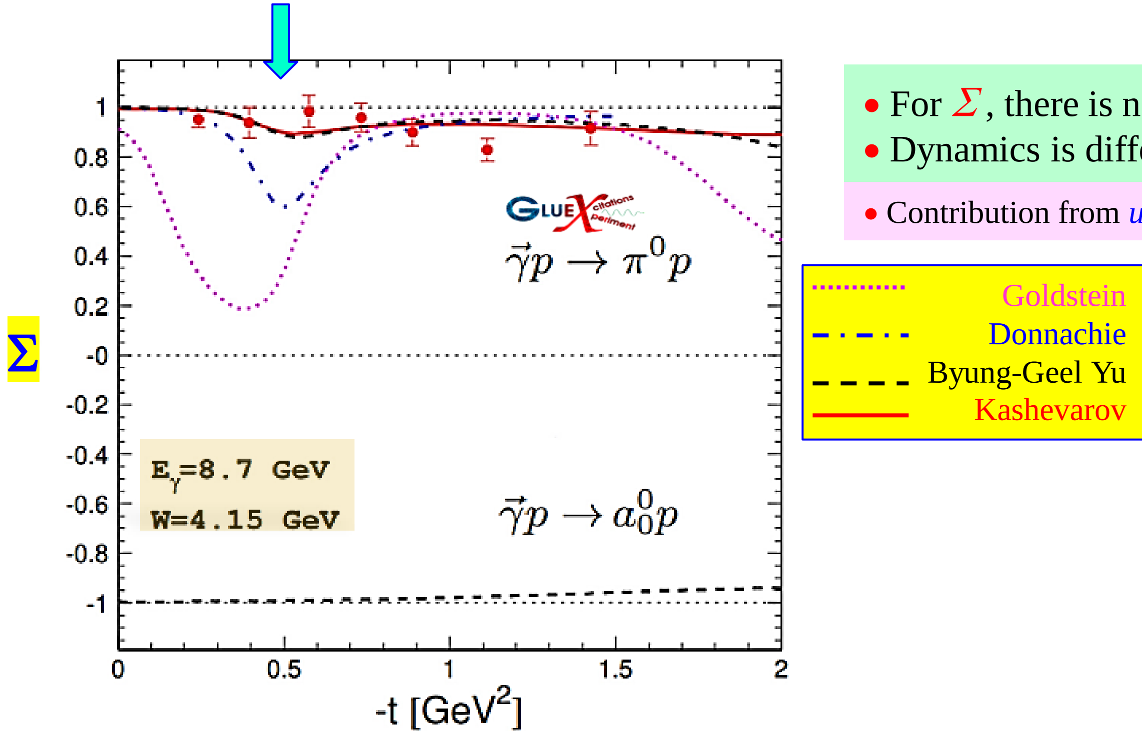
Since the experimental resolution was not sufficient to separate π^0 photoproduction from proton Compton scattering, it was necessary to make a further correction by subtracting the appropriate Compton contribution.

The slight change from our earlier publications is due to the improved subtraction of the Compton contribution. The extracted π^0 cross section in the dip depends very critically on this correction. For example, at 15 GeV and $t = -0.5$ (GeV/c)^2, two-thirds of the observed yield is due to Compton scattering. Whereas we earlier had to rely upon a theoretical estimate for this correction, experimental values can now be used directly. It is important to note that the experimental setup was nearly the same for the two experiments, hence there are practically no systematic errors attached to this correction.

since the dip region at the highest energies is difficult to fit and requires such a large Compton subtraction, we have made coincidence measurements using the technique described in the next section (but with unpolarized photons).

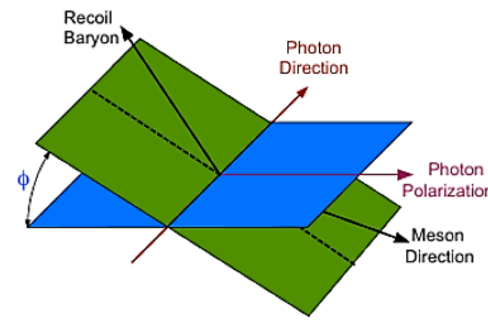
Courtesy by Mike Dugger, 2022

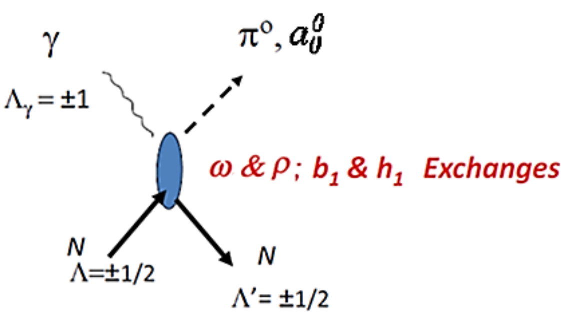
$\vec{\gamma}p \to p\pi^0$ & $\vec{\gamma}p \to pa_0^0$



- For Σ, there is no *mirror* reflection between π^0 & a_0^0.
- Dynamics is different.

- Contribution from *unnatural parity* meson exchange should be *small* ?





- Neutral a_0^0 photoproduction will have **4** *helicity* amps, just like π^0.
- They satisfy same kind of *parity* relations up to *sign*.
- So, for leading (|t| / s) approximation.
  There are + & – combinations that have definite *parity* in t-channel.

- Thus, there will be simple **+1** (for π^0) or **–1** (for a_0^0) predictions for Σ for *vector* meson exchanges.

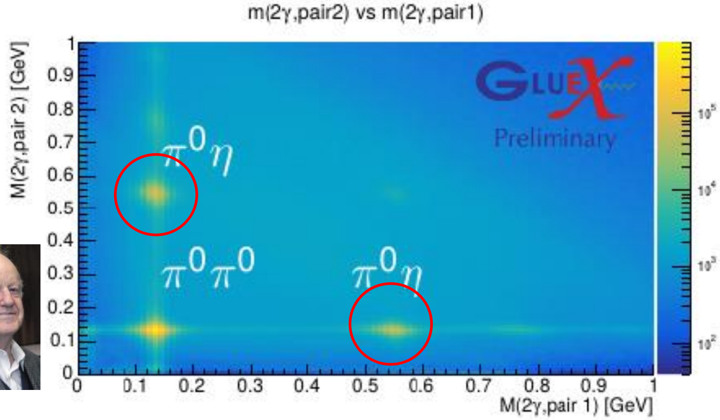
Courtesy by Gary Goldstein, 2022

- To determine dynamics, cross section for a_0^0 is *in order*.

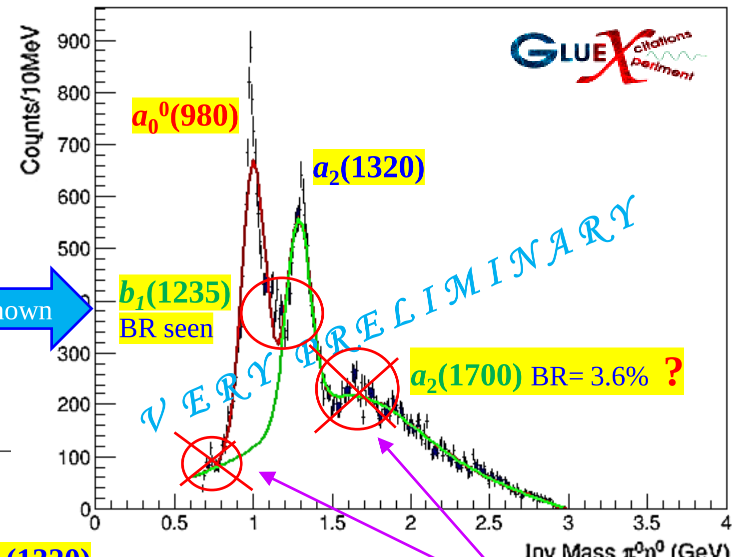
$\gamma p \rightarrow a_0^0(980)p \rightarrow (\eta\pi^0)p \rightarrow (\gamma\gamma\gamma\gamma)p$

- Beam asymmetry of ***ηp*** is useful ***first*** measurement to make in this system.
- Possible to inform models of ***scalars*** producing this final state.
- ***No obvious exotic*** seen, so far, full GlueX phase statistics may allow binning @ ***small angles***.

Luminosity (2016–2017) = 70 pb^{-1}



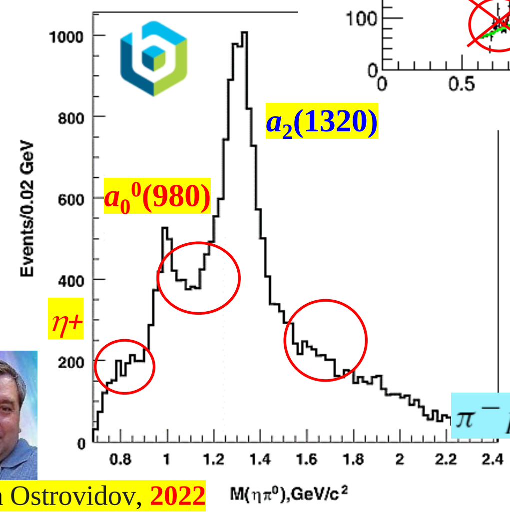
Xsection is unknown



Courtesy by Stuart Fegan, 2020
Courtesy by Malte Albrecht, 2022

Backgrounds of interest

1. ω⇒πγ⇒3γ
2. ππ⇒4γ
3. b1 ⇒ [ω⇒πγ] π ⇒ 5γ
4. η ⇒ πππ ⇒ 6γ
5. η′⇒ ηππ ⇒ 6γ
6. f1(1285) ⇒ ηππ ⇒ 6γ
7. [a2(1320)⇒ηπ] π ⇒ 6γ



$\pi^- p \rightarrow \eta\pi^0 n,\ \eta \rightarrow \pi^+\pi^-\pi^0$ at 18 GeV/c

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

Courtesy by Sasha Ostrovidov, 2022

Background for $\gamma p \rightarrow a_0^0(980)p \rightarrow (\eta\pi^0)p \rightarrow (\gamma\gamma\gamma\gamma)p$

Citation: R.L. Workman *et al.* (Particle Data Group), Prog.Theor.Exp.Phys. **2022**, 083C01 (2022)

$a_2(1320)$

$I^G(J^{PC}) = 1^-(2^{++})$

$a_2(1320)$ MASS

VALUE (MeV)	*DOCUMENT ID*
1318.2±0.6 OUR AVERAGE	Includes data from the 4 datablocks that follow this one.

Error includes scale factor of 1.2.

$a_2(1320)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	3π	(70.1 ±2.7) %	S=1.2
Γ_2	$\rho(770)\pi$		
Γ_3	$f_2(1270)\pi$		
Γ_4	$\rho(1450)\pi$		
Γ_5	$\eta\pi$	(14.5 ±1.2) %	

Citation: R.L. Workman *et al.* (Particle Data Group), Prog.Theor.Exp.Phys. **2022**, 083C01 (2022)

$b_1(1235)$

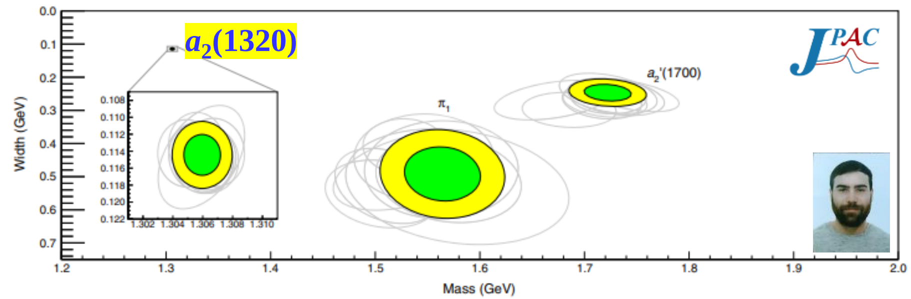
$I^G(J^{PC}) = 1^+(1^{+-})$

$b_1(1235)$ MASS

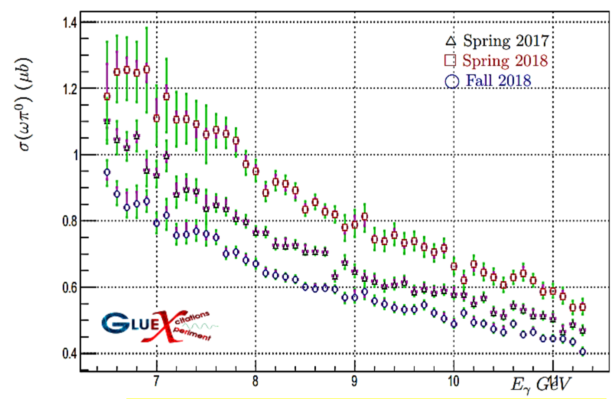
VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
1229.5± 3.2 OUR AVERAGE		Error includes scale factor of 1.6.				See the ideogram below.
1225 ± 5		WEIDENAUER	93	ASTE		$\bar{p}p \rightarrow 2\pi^+ 2\pi^- \pi^0$
1235 ±15		ALDE	92C	GAM2		38,100 $\pi^- p \rightarrow \omega\pi^0 n$
1236 ±16		FUKUI	91	SPEC		8.95 $\pi^- p \rightarrow \omega\pi^0 n$
1222 ± 6		ATKINSON	84E	OMEG	±	25–55 $\gamma p \rightarrow \omega\pi X$
1237 ± 7		ATKINSON	84E	OMEG	0	25–55 $\gamma p \rightarrow \omega\pi X$
1239 ± 5		EVANGELIS...	81	OMEG	−	12 $\pi^- p \rightarrow \omega\pi p$

$b_1(1235)$ DECAY MODES

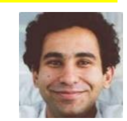
	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$\omega\pi$	seen	



A. Rodas *et al*, Phys Rev Lett **122**, 042002 (**2019**)



Ahmed Foda, PhD Thesis, Regina U. **2021**



$\omega(782)$ DECAY MODES

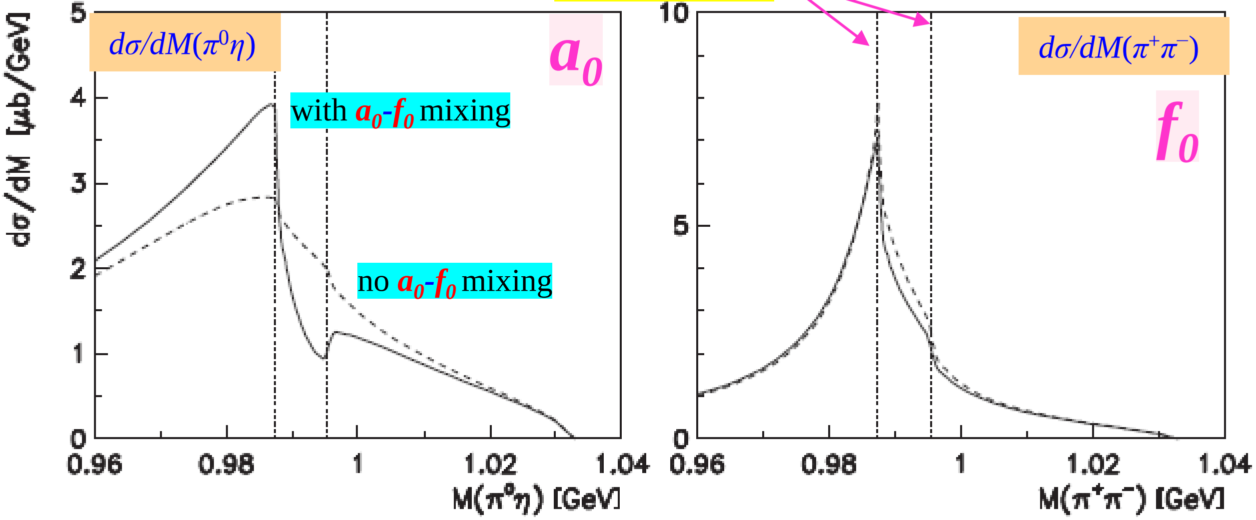
	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	$\pi^+\pi^-\pi^0$	(89.2 ±0.7) %	
Γ_2	$\pi^0\gamma$	(8.35±0.27) %	S=2.2

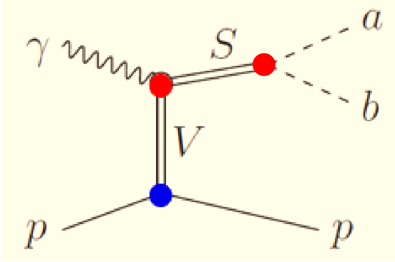
Photoproduction & Mixing Effects of Scalar a_0 & f_0 Mesons

V.E. Tarasov, W.J. Briscoe, W. Gradl, A.E. Kudryavtsev, & IIS, Phys Rev C **88**, 035207 (**2013**)

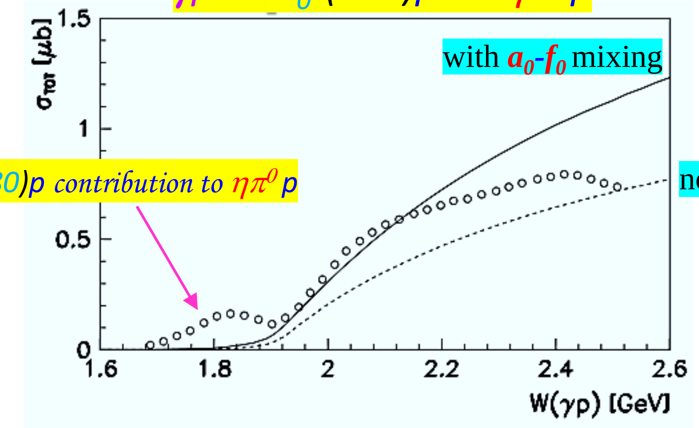
E_γ = **1.6** GeV

$K\bar{K}$ thresholds





$\gamma p \longrightarrow a_0^0(980)p \longrightarrow \eta\pi^0 p$

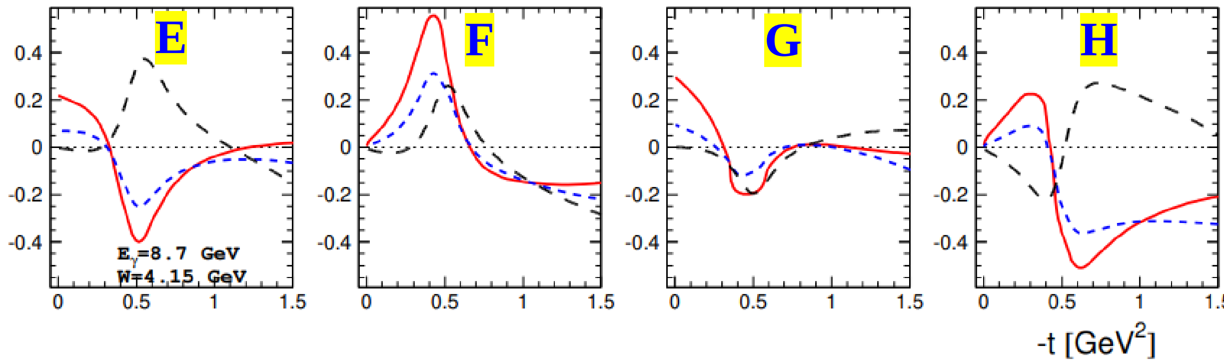


Where We are Going

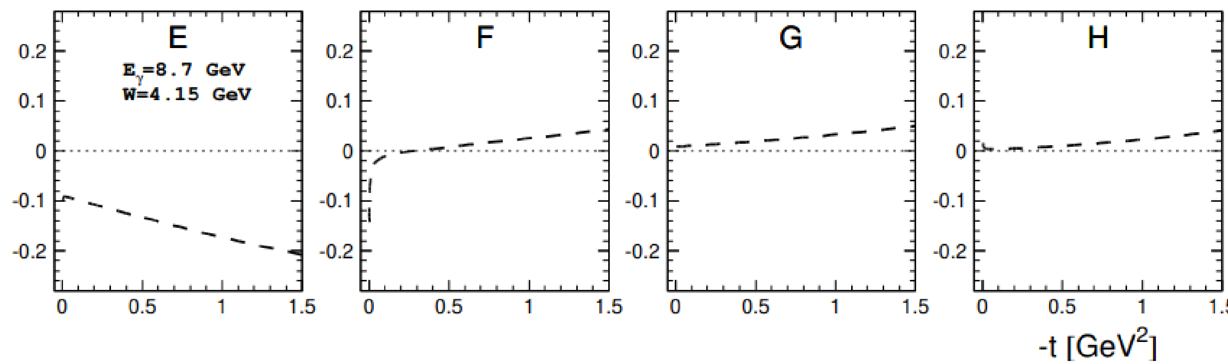
Predictions for Pseudoscalars & Scalars

IIS, W. Briscoe, O. Cortes, M. Dugger, G. Goldstein, V. Kashevarov,
A. Schmidt, P. Salazzo, & Byung-Geel Yu, Phys Rev C **107**, 015203 (2023)

$\gamma p \rightarrow p\pi^0$



$\gamma p \rightarrow p a_0^0$



$d\sigma/dt$, Σ(SLAC), T, & P ———
$d\sigma/dt$, Σ(GlueX), T, & P - - -

Courtesy by Viktor Kashevarov, October 2022

— —

Courtesy by Byung-Geel Yu, October 2022

- Future study is in order to understand dynamics.

- There is ***dip*** @ |t| ~0.5 GeV^2 in *dσ/dt* @ both ***pseudoscalar*** & ***scalar*** mesons.

- There are no correlations between **dips** in *dσ/dt* & *Σ*.

- Leading role is by *vector Natural parity* (*ω* & *ρ*) meson exchange ⟶ *Σ* = **+1** (for *π^0*) & **–1** (for ***a_0^0***)

- Adding *pseudovector UnNatural parity* (***b_1*** & ***h_1***) meson exchange ⟶ |*Σ*| < **1**

- ***b_1*** & ***h_1*** **Regge** *trajectories* are ***1/2*** unit below *ρ* & *ω*. So, there is ***$s^{1/2}$*** difference.
  It means that contribution from ***b_1*** & ***h_1*** goes down vs energy.
  Very little known about these *pseudovector* mesons.

- Status of dip in *Σ* for *π^0* is still uncertain.

- SLAC *dip* region for *Σ* had serious background contributions,
  & it was plausible that data might be unreliable in *dip* region.

- To evaluate this *Σ* case (why energy sequence **3** to **10** GeV is broken @ **9** GeV),
  we performed *three* fits to compare with.

- All previous (before GlueX *Σ* came) ***theoretical calculations*** were under *influence* of SLAC *dip* in *π^0*.

- Low energy (**7** GeV) GlueX *Σ* data for *π^0* photoproduction may help to solve this puzzle.