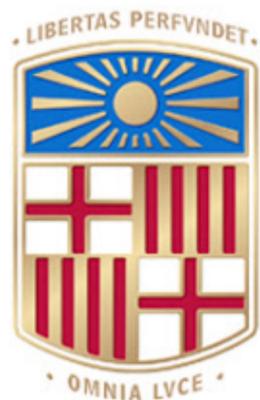


Exotic Mesons in Hadro- and Photo-production

Vincent MATHIEU

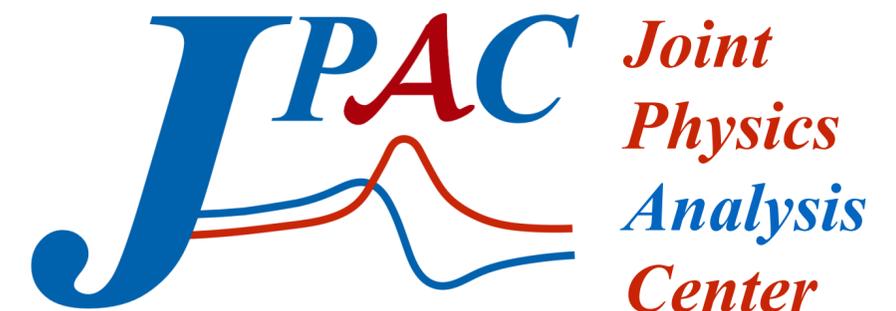
University of Barcelona

Joint Physics Analysis Center
Exotic Hadron Topical Collaboration



UNIVERSITAT DE
BARCELONA

HADNUCMAT
Barcelona, January 2026



Website:

<https://www.jpac-physics.org/>

Shared: Zoom, Slack, Calendar

	Mon 26	Tue 27	Wed 28	Thu 29	Fri 30	Sat
all-day			GlueX Collaboration Meeting			
12:00						
12:24						
13:00						
14:00						
15:00						
16:00	CLAS analyses 16:00–17:00	JPAC meeting iu.zoom.us 16:00 (10:00 G...)	flip-flop iu.zoom.us 16:00–17:00	Bottomonium 16:00–17:00	GlueX/JPAC 16:00 (10:00 G...)	
17:00	A(I)DAP T http...	pi1/KT 17:...		Double Regge GlueX/FESR, b1 production pio...		
18:00				N over D for X(3872) 18:00–19:00		
19:00	pi-Delta 19:00–20:00			Roy-AI 19:00 (13:00 G...)		
20:00					N/D meeting with Sebastian 20:00 (14:00 G...)	
21:00						

The Collaboration

Full Members



Adam Szczepaniak
Indiana University / Jefferson Lab



Alessandro Pilloni
Università di Messina



Alex Akridge
Indiana University



Arkaitz Rodas Bilbao
Old Dominion University /
Jefferson Lab



César Fernández
Ramírez
Universidad Nacional de
Educación a Distancia



Daniel Winney
Universidad Nacional Autónoma
de México



Emilie Passemar
Indiana University



Giorgio Foti
Università di Messina



Gloria Montaña
University of Barcelona



Łukasz Bibrzycki
AGH University of Krakow



Miguel Albaladejo
IFIC-CSIC Valencia



Mikhail Mikhasenko
Ruhr-Universität Bochum



Nadine Hammoud
University of Barcelona



Robert Perry
Massachusetts Institute of
Technology



Sergi González-Solís
University of Barcelona



Vanamali Shastry
Indiana University



Viktor Mokeev
Jefferson Lab



Vincent Mathieu
University of Barcelona



Wyatt Smith
Università di Messina

ExoHad Collaboration

DoE Topical Collaboration: 2023-2027

Website:

<https://www.exohad.org/>

Three Pillars:

Lattice QCD (HadSpec)

Phenomenology (DS, quark model)

Amplitude Analysis (JPAC)



Eric Braaten
Ohio State University



Raúl Briceño
University of California, Berkeley



Jo Dudek
William & Mary



Robert Edwards
Jefferson Lab



Gernot Eichmann
Universität Graz



César Fernández
Ramírez
Universidad Nacional de
Educación a Distancia (UNED)



Christian Fischer
JLU Giessen



Andrew Jackura
William & Mary



Rich Lebed
Arizona State University



Jinfeng Liao
Indiana University



Sebastian Marek Dawid
Indiana University



Vincent Mathieu
University of Barcelona



Emilie Passemar
Indiana University



Alessandro Pilloni
Università di Messina



Arkaitz Rodas Bilbao
Old Dominion University /
Jefferson Lab



Stephen Sharpe
University of Washington



Eric Swanson
University of Pittsburgh



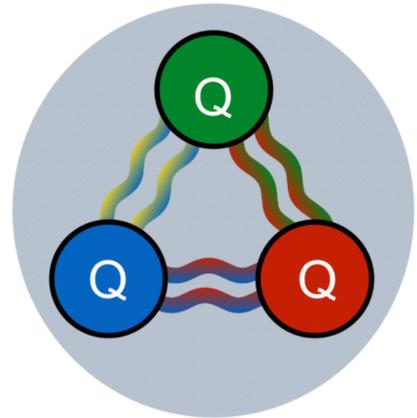
Adam Szczepaniak
Indiana University



Daniel Winney
Universidad Nacional Autónoma
de México

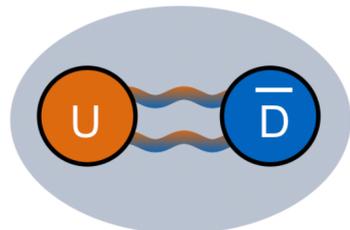
Ordinary and Exotic Hadrons

Ordinary baryons

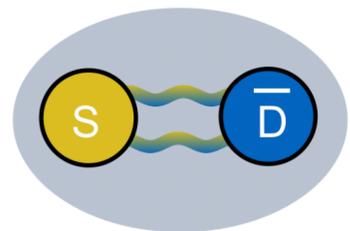


- proton stable
- neutron $\tau \sim 10^3 s$
- baryon Λ $\tau \sim 10^{-10} s$

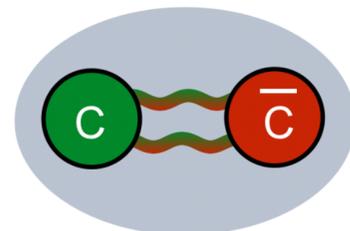
Ordinary mesons



pion $\tau \sim 10^{-8} s$



kaon $\tau \sim 10^{-8} s$



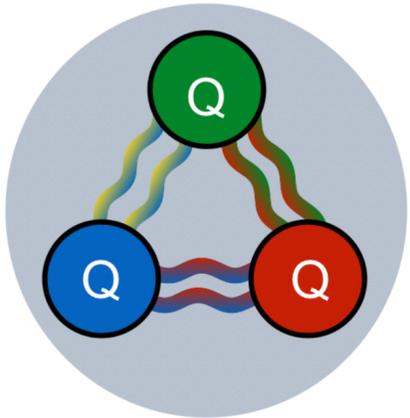
J/ψ $\tau \sim 10^{-20} s$

Q
U
A
R
K
S

UP mass 2,3 MeV/c ² charge 2/3 spin 1/2 u	CHARM 1,275 GeV/c ² 2/3 1/2 c	TOP 173,07 GeV/c ² 2/3 1/2 t
DOWN 4,8 MeV/c ² -1/3 1/2 d	STRANGE 95 MeV/c ² -1/3 1/2 s	BOTTOM 4,18 GeV/c ² -1/3 1/2 b

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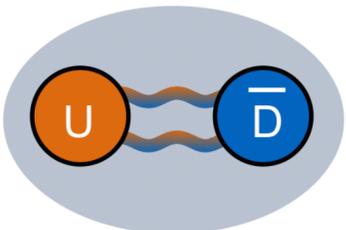


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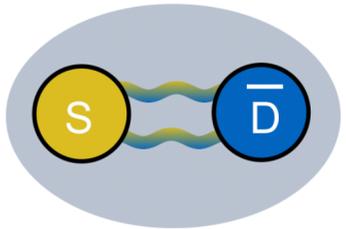
QUARKS

UP mass 2,3 MeV/c ² charge 2/3 spin 1/2 	CHARM 1,275 GeV/c ² 2/3 1/2 	TOP 173,07 GeV/c ² 2/3 1/2
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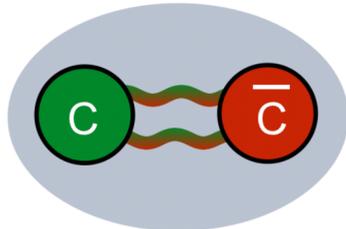
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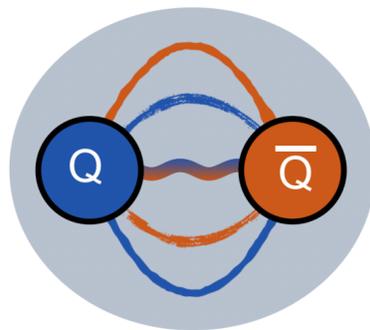
kaon $\tau \sim 10^{-8} s$



J/ψ $\tau \sim 10^{-20} s$

Exotic matter

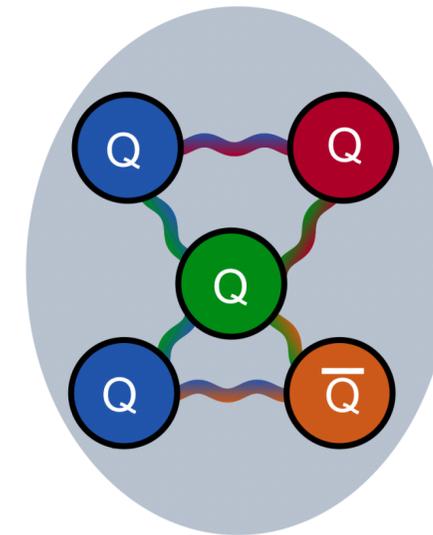
hybrid mesons



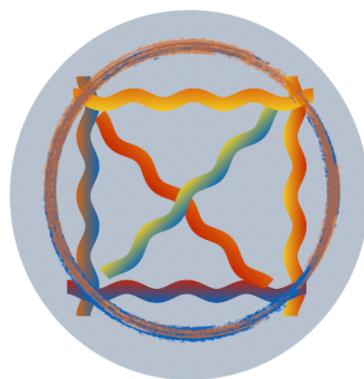
tetraquarks



pentaquarks



glueballs



Discovering Exotic Hadrons

Design and build detectors
Collect data
Build observables
Fit data
Extract pole position,
...

Experiments
Tools

Interpretation

Lattice QCD
Phenomenology
Amplitude Analyses

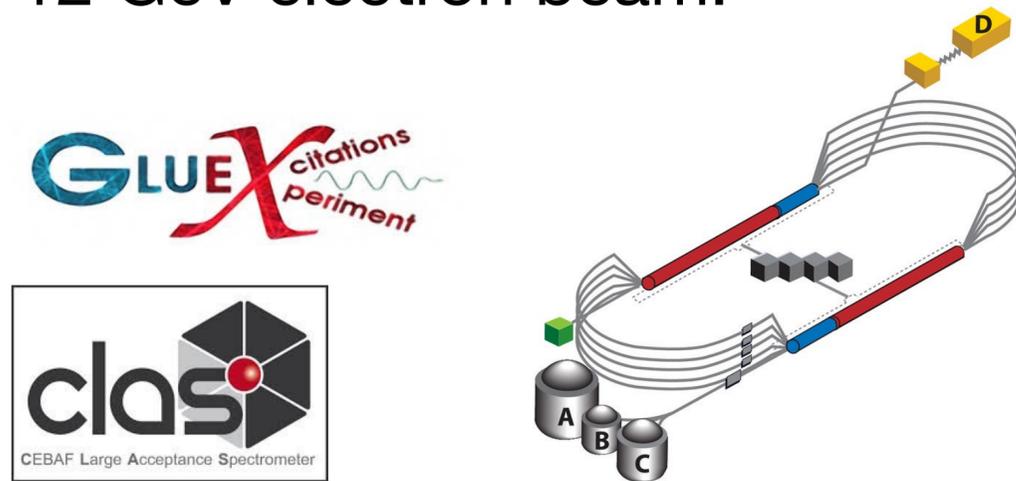
Theory



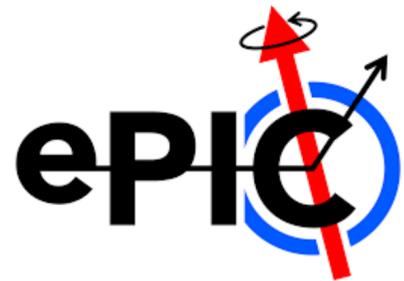
HEP Facilities and Detectors



12 GeV electron beam:



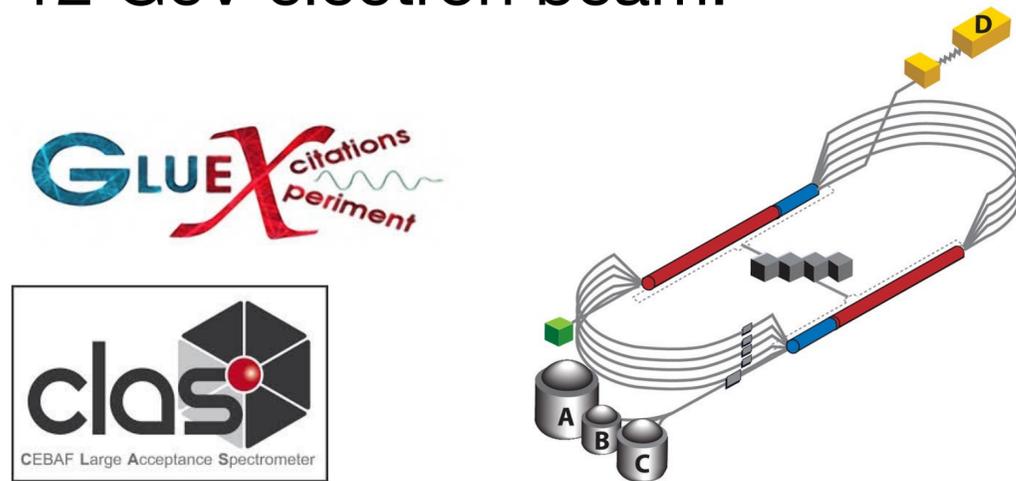
Future Electron-Ion Collider:



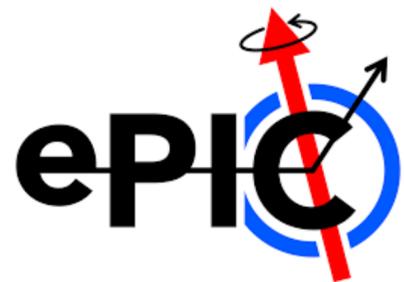
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Proton-proton collisions



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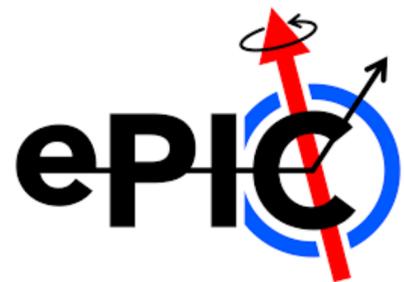
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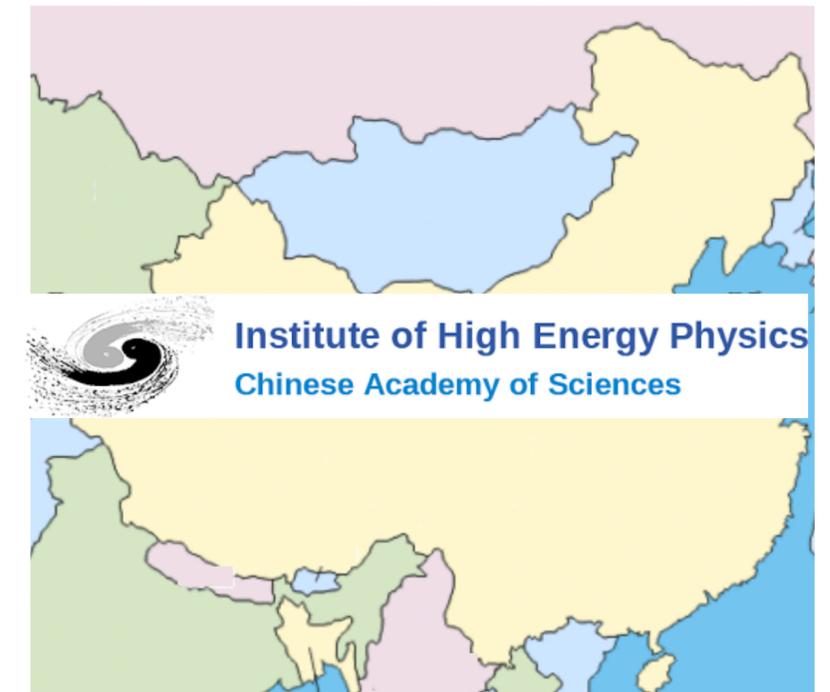
Future Electron-Ion Collider:



Proton-proton collisions



Pion-proton collisions



Electron-positron annihilations
at the J/ψ mass



On the Theory Side

QCD predictions for exotic hadrons properties

Lattice QCD, EFT, quark model, Dyson-Schwinger eqs,...

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Predictions for future measurements

Known measurements, Regge theory, VMD, ...

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Polarization observables, moment expansion, ...

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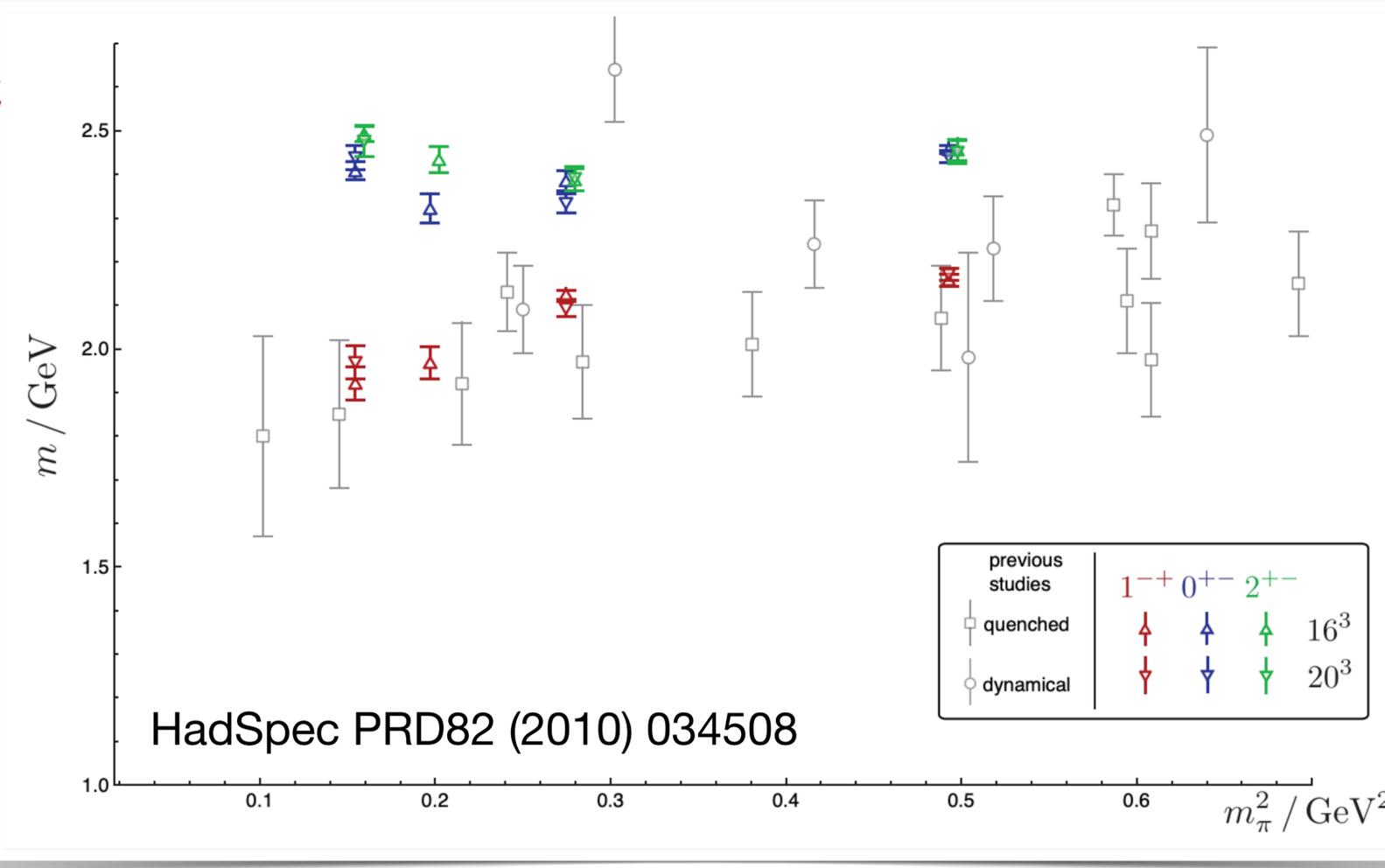
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Lattice QCD on the Lightest Exotic

The lightest isovector exotic meson is the

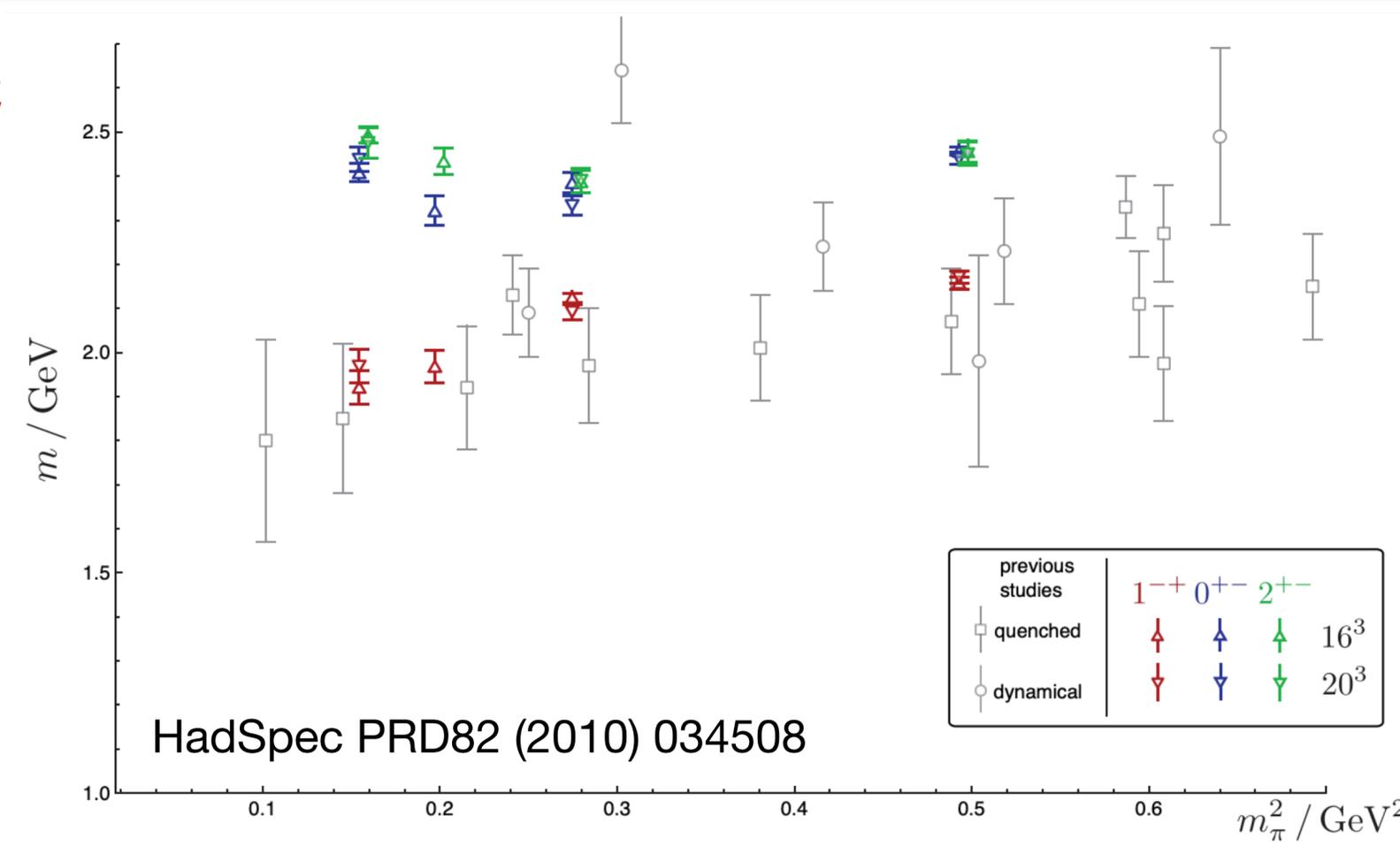
$$\pi_1(1^{-+})$$



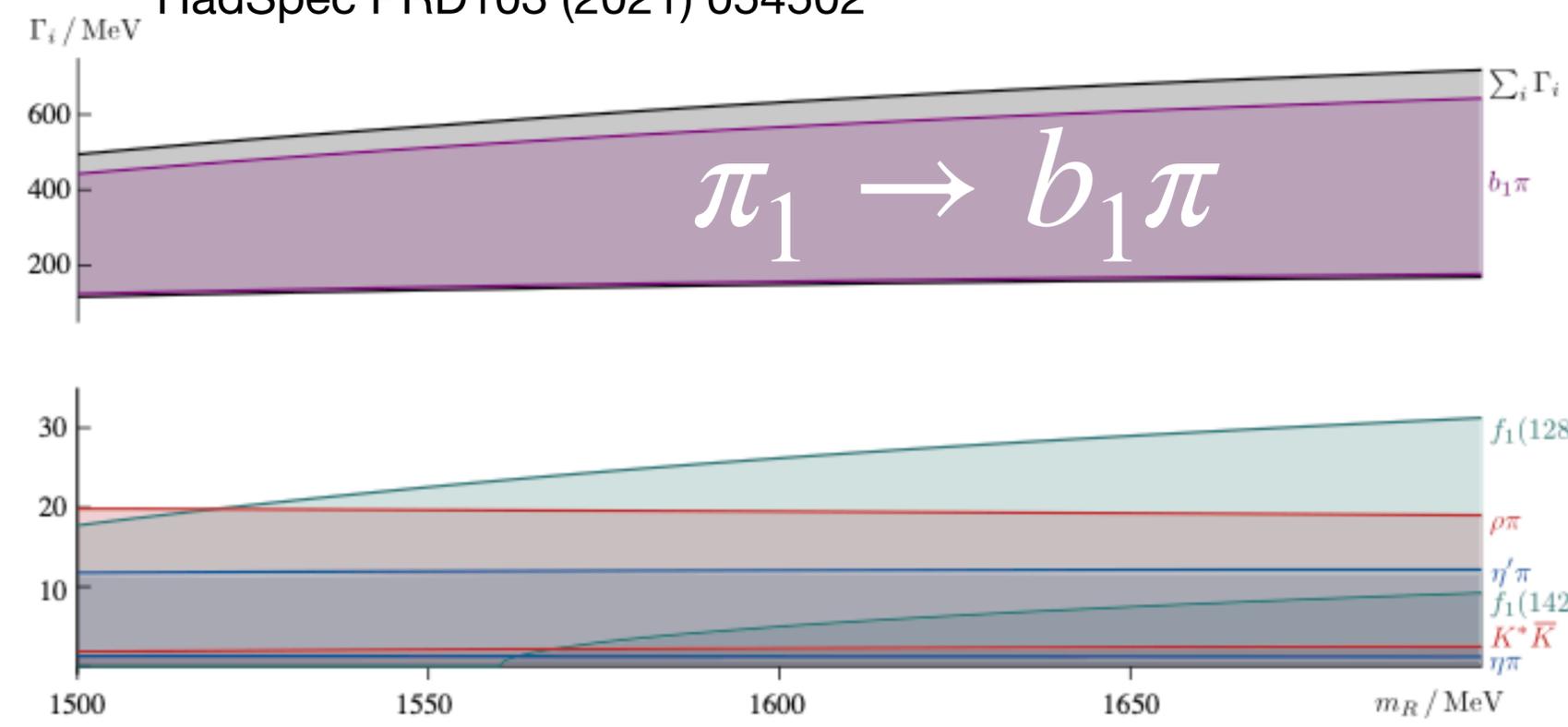
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The lightest isovector exotic meson is the

$$\pi_1(1^{-+})$$



HadSpec PRD103 (2021) 054502



Its main decay channel is $\pi_1 \rightarrow b_1 \pi$

Easiest decay mode is $\pi_1 \rightarrow \eta \pi$

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XYZ Cross Sections @EIC and @JLab22

JPAC PRD102 (2020) 114010

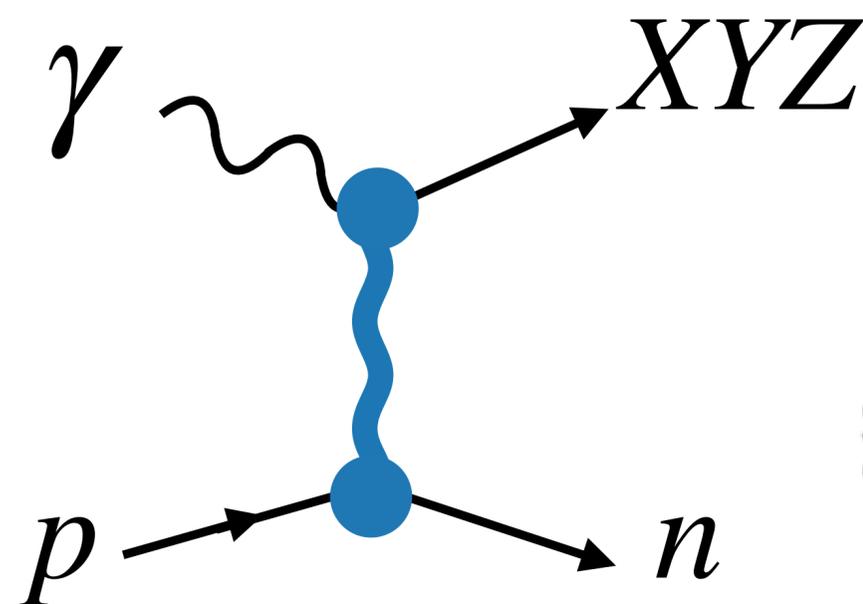
JPAC PRD106 (2022) 094009

JPAC PRD109 (2024) 114035

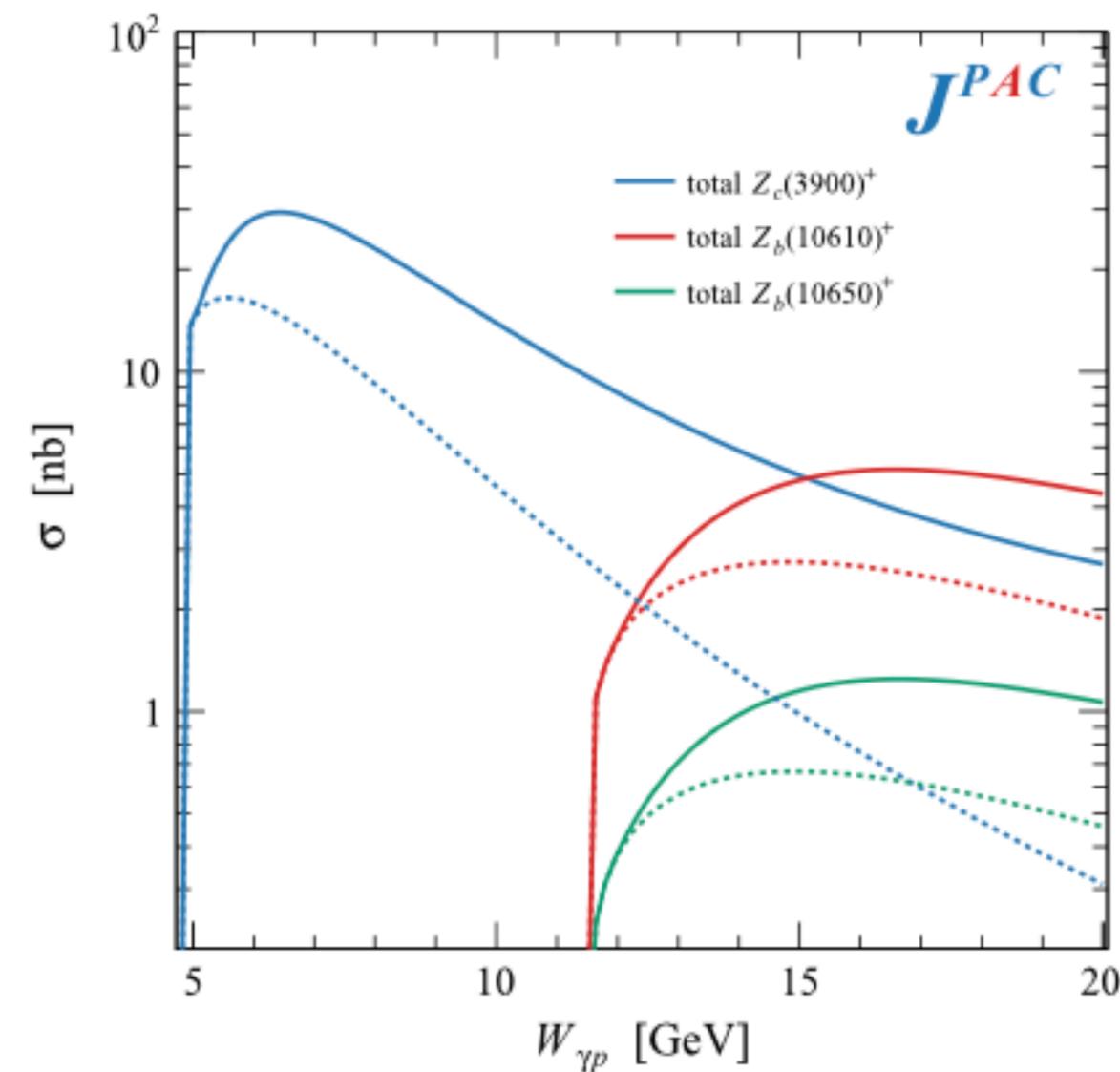
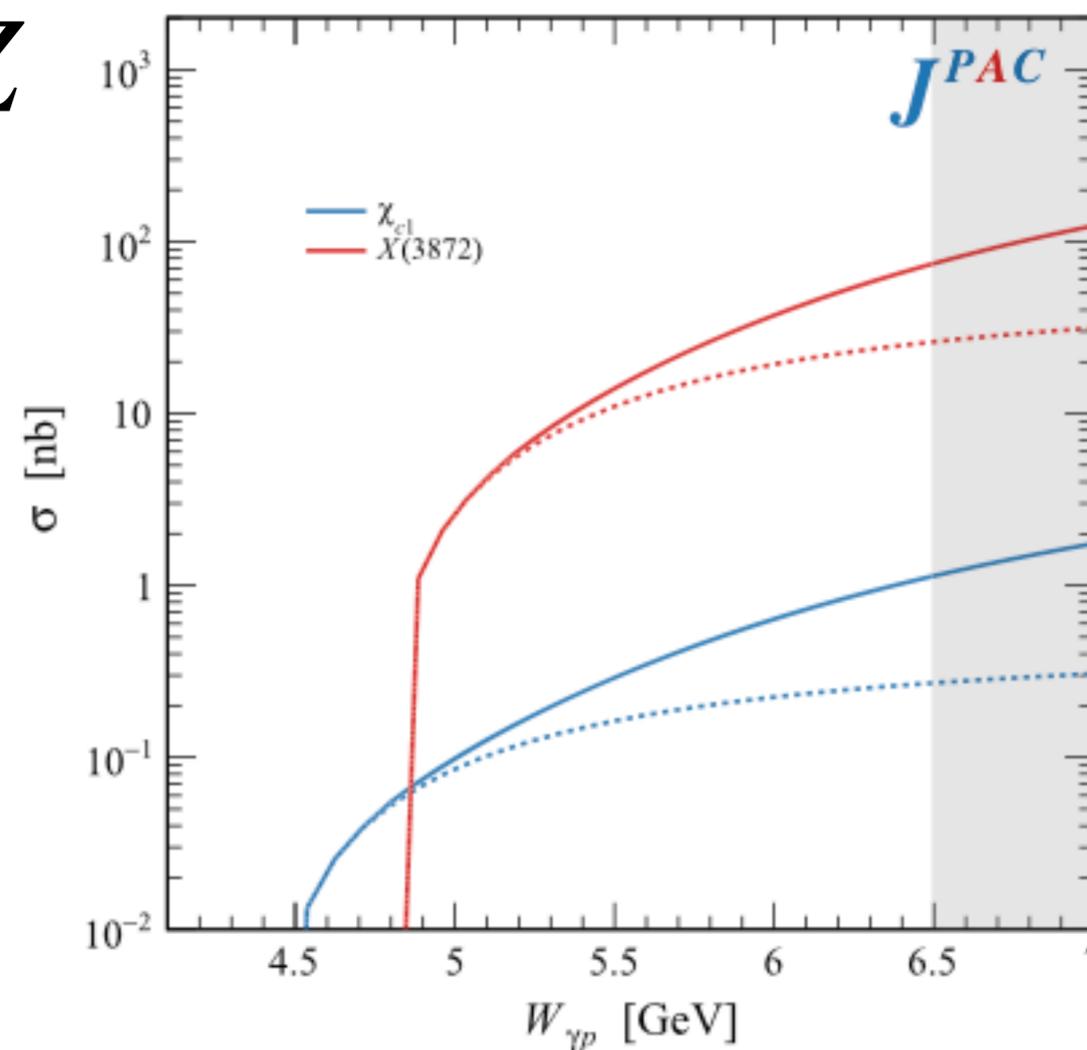
Cross sections prediction for

$X(3872), X(8900), Y(4260)$

$Z_c(3900)^\pm, Z_b(10610)^\pm, Z_b(10650)^\pm$



Exclusive in dashed lines
Semi-inclusive in solid lines



XYZ Cross Sections @EIC and @JLab22

JPAC PRD102 (2020) 114010

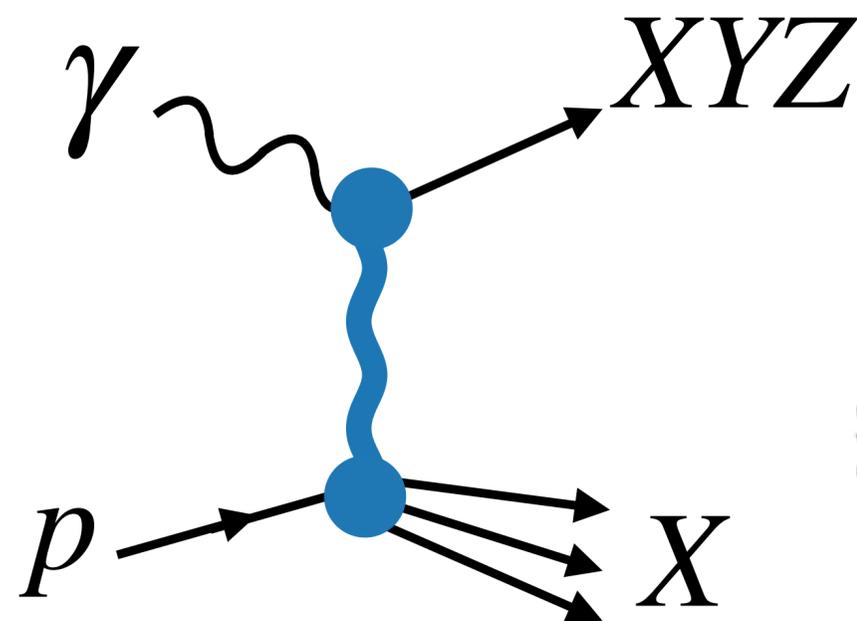
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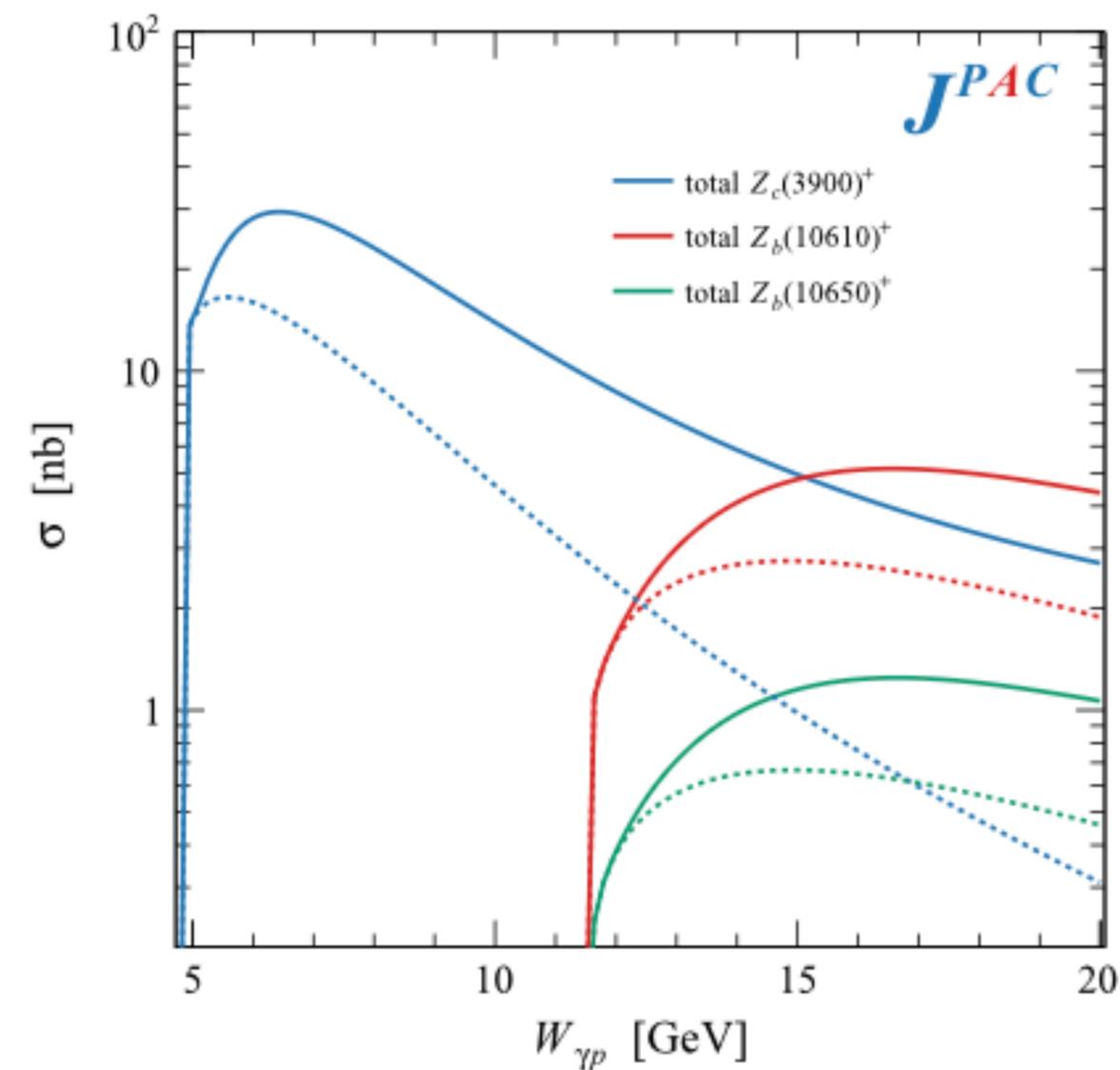
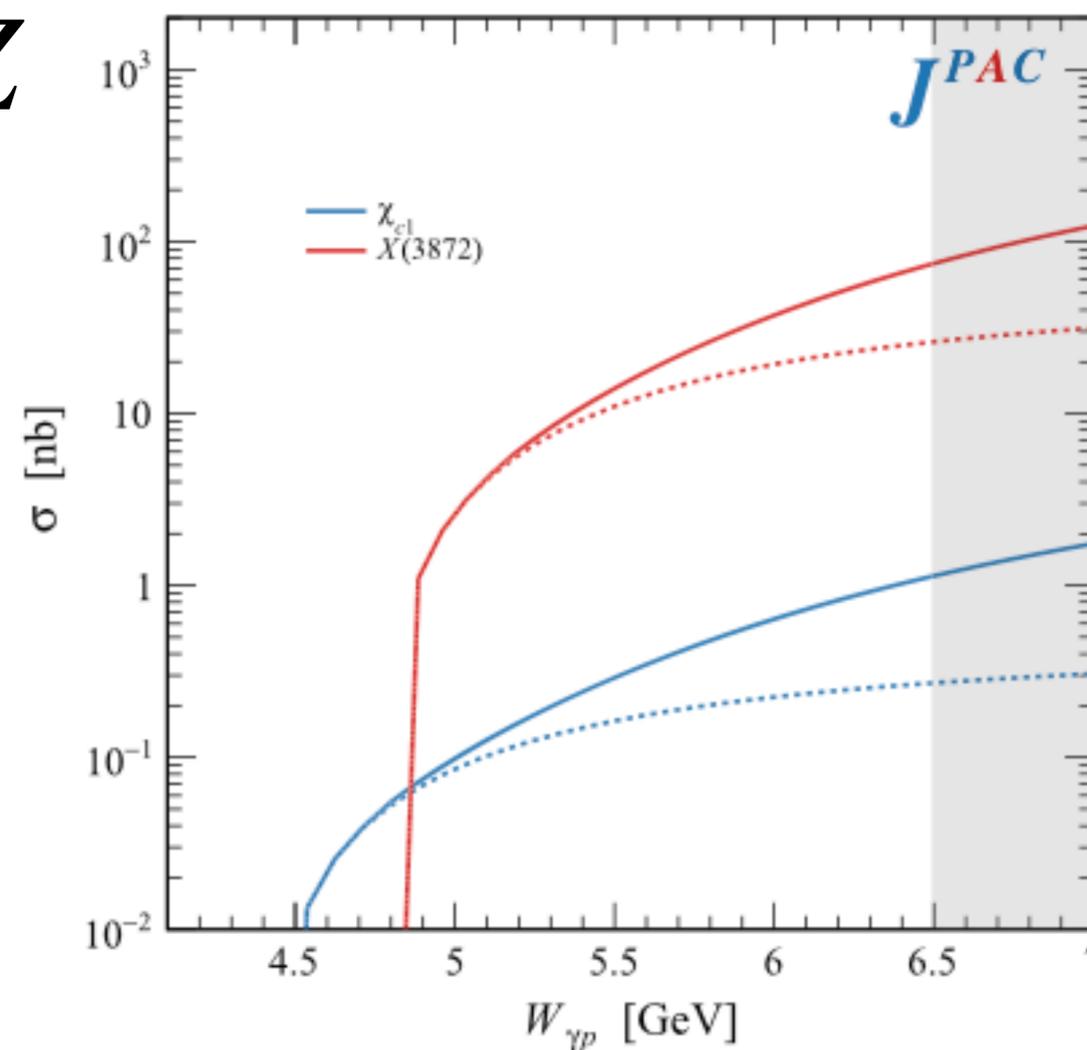
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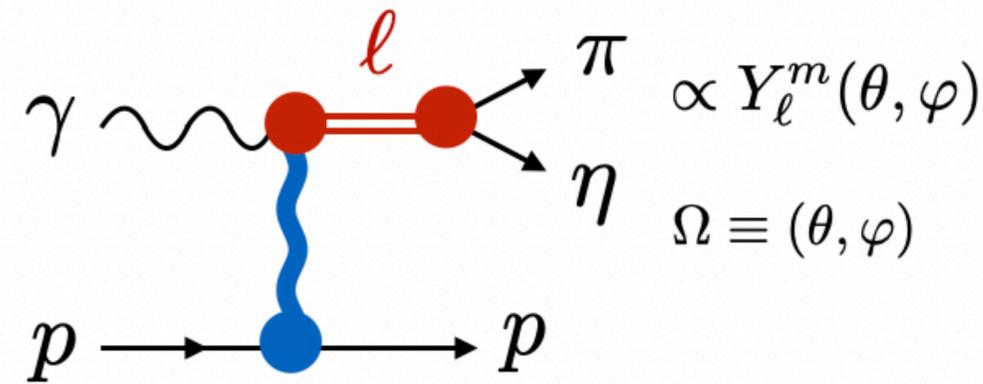
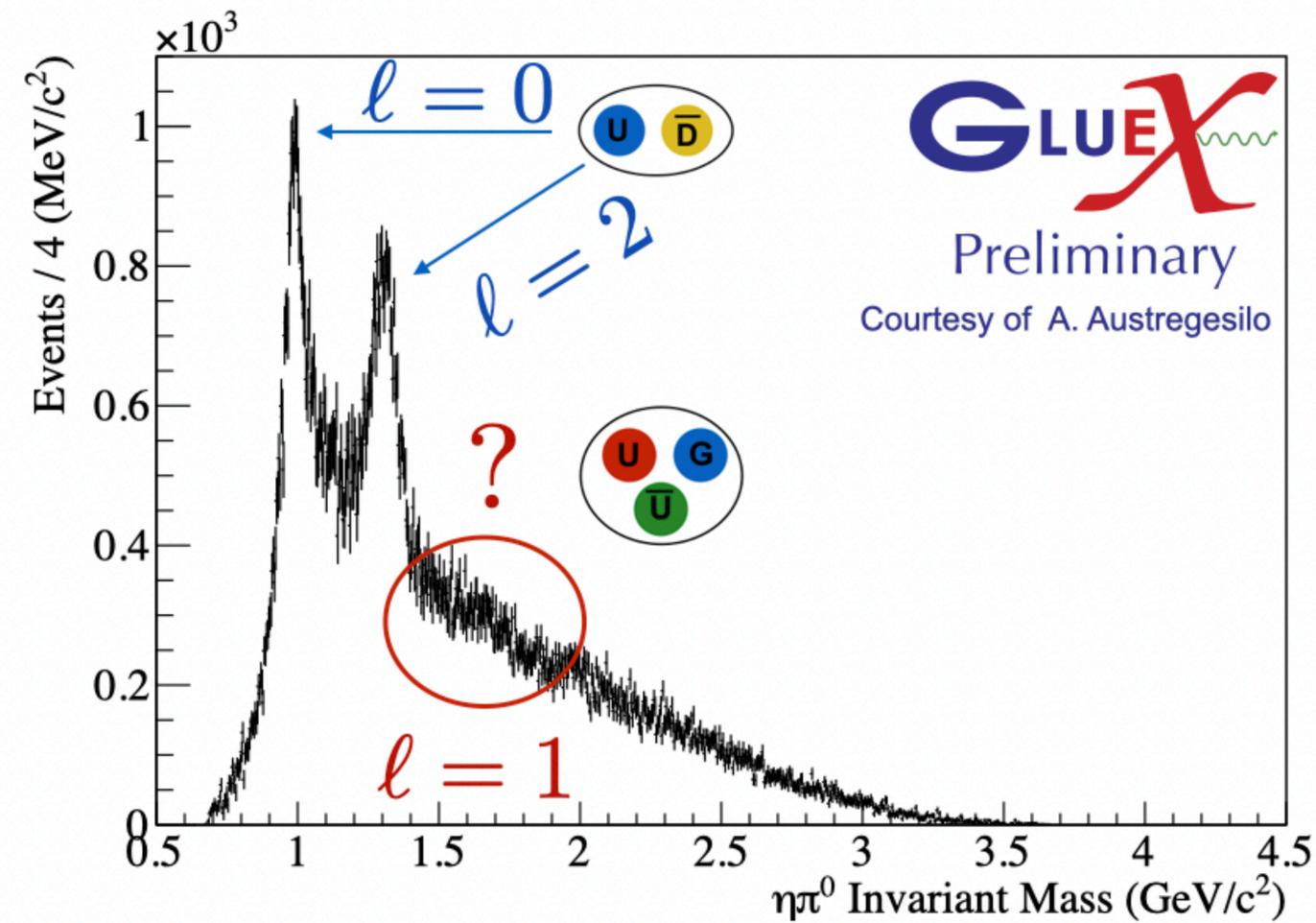
Formalism and interpretation of observables

Polarization observables, moment expansion, ...

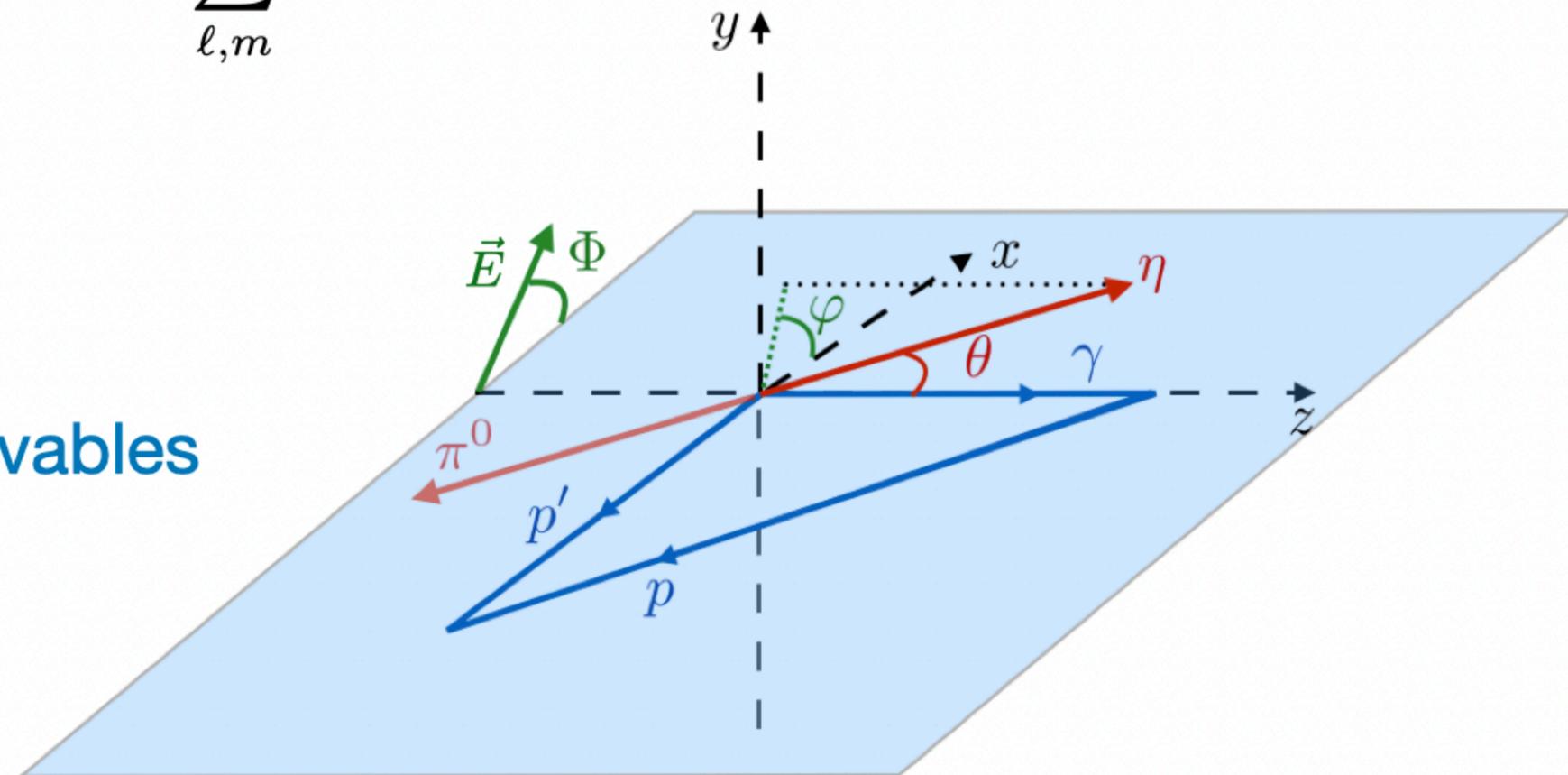
Data analysis

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Angular Distribution



Polarized photon beam



Relations between partial waves and observables

Observables sensitive to exotic mesons

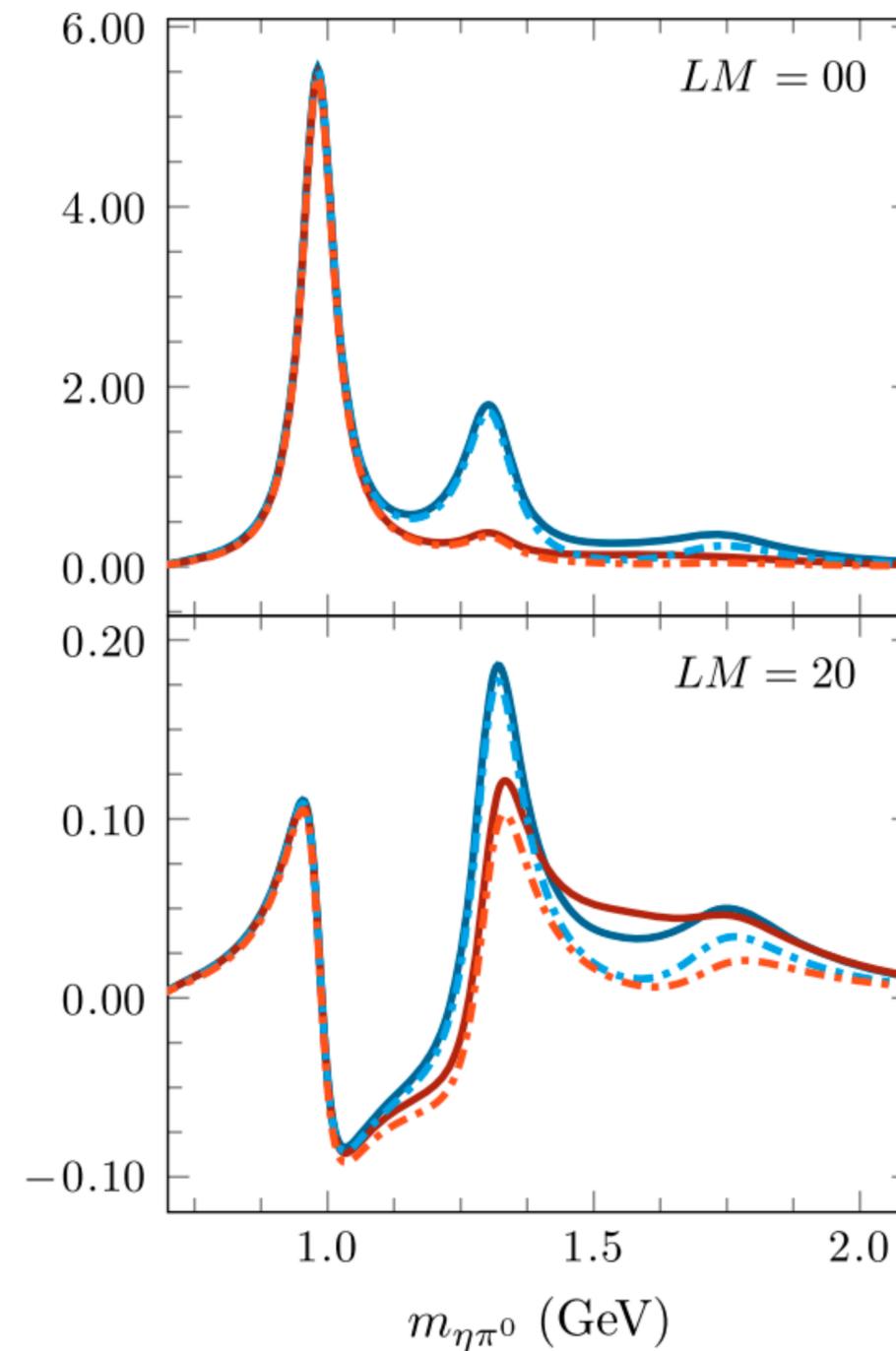
New Observables

Two models:

With exotic meson
(solid lines)

Without exotic meson
(dashed lines)

Combination of moments
very sensitive to the presence
of odd L (exotic) waves



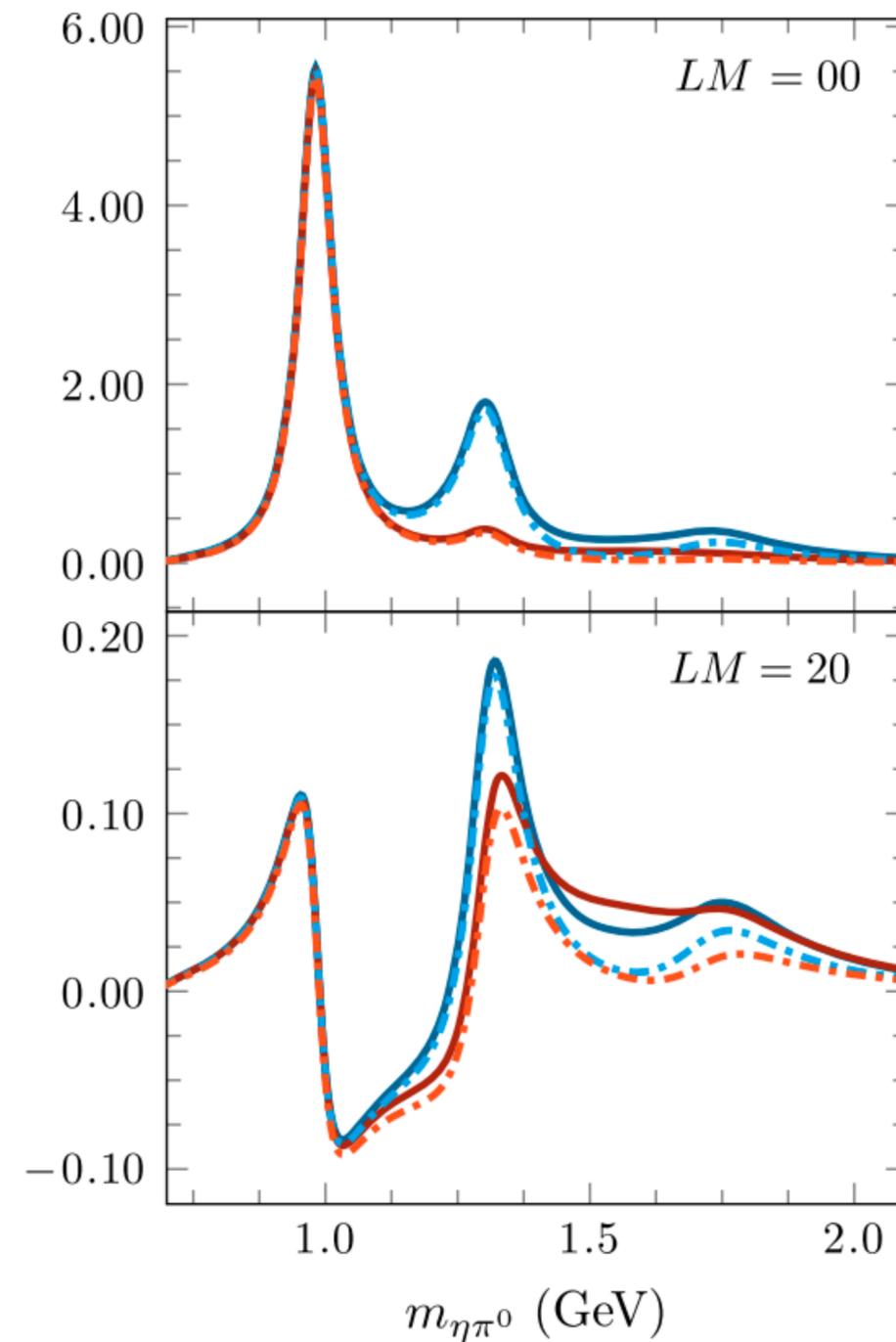
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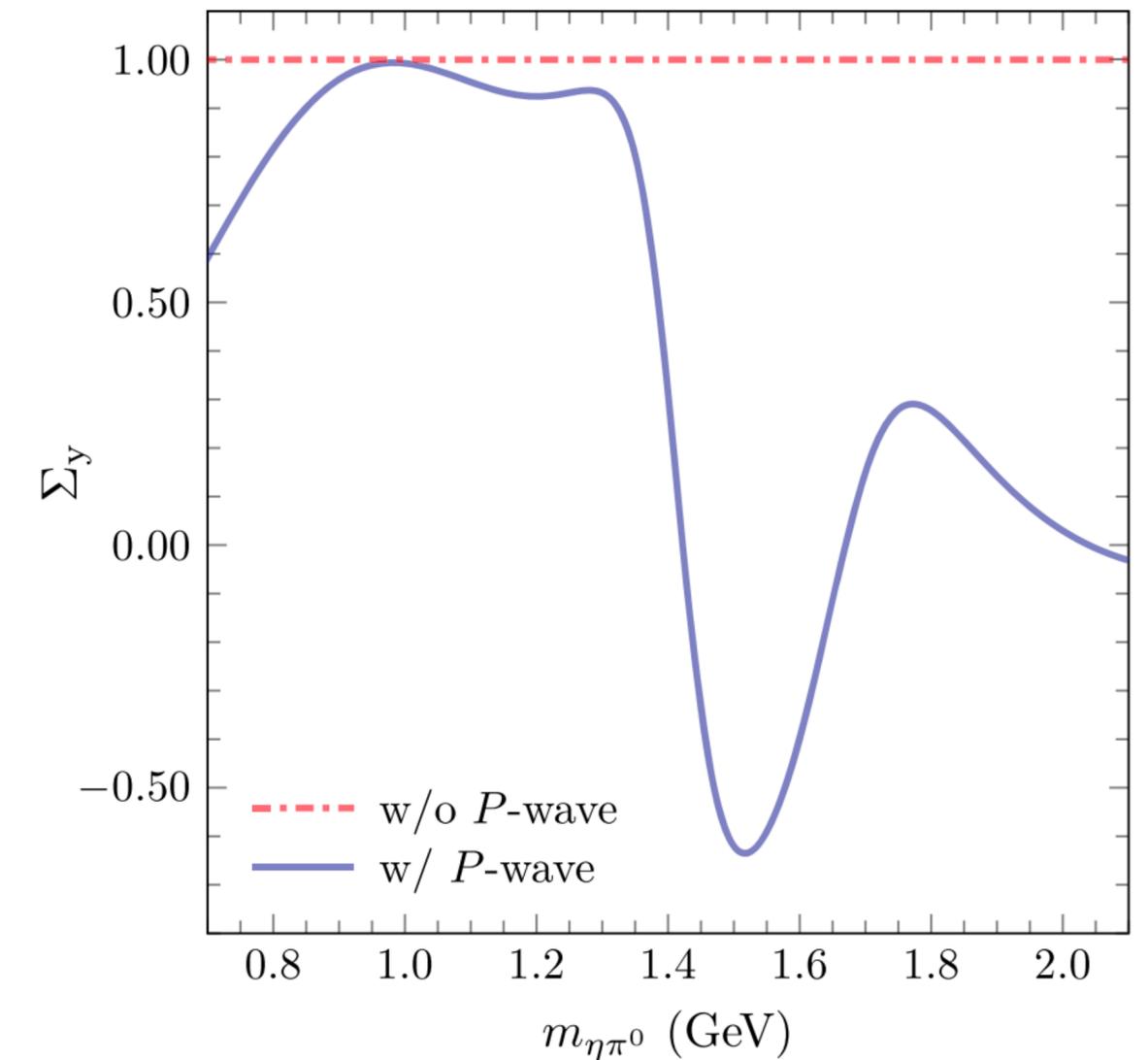
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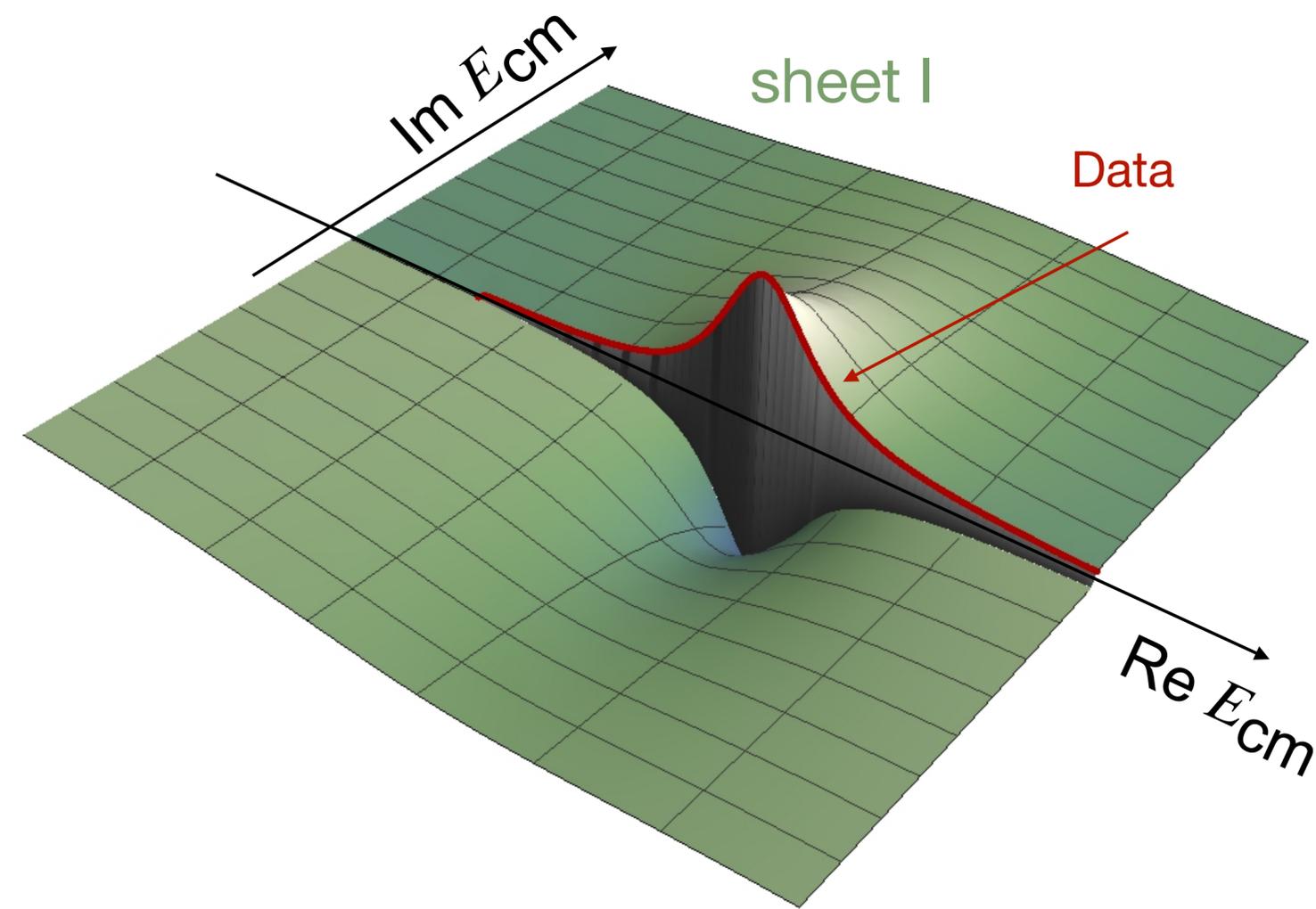
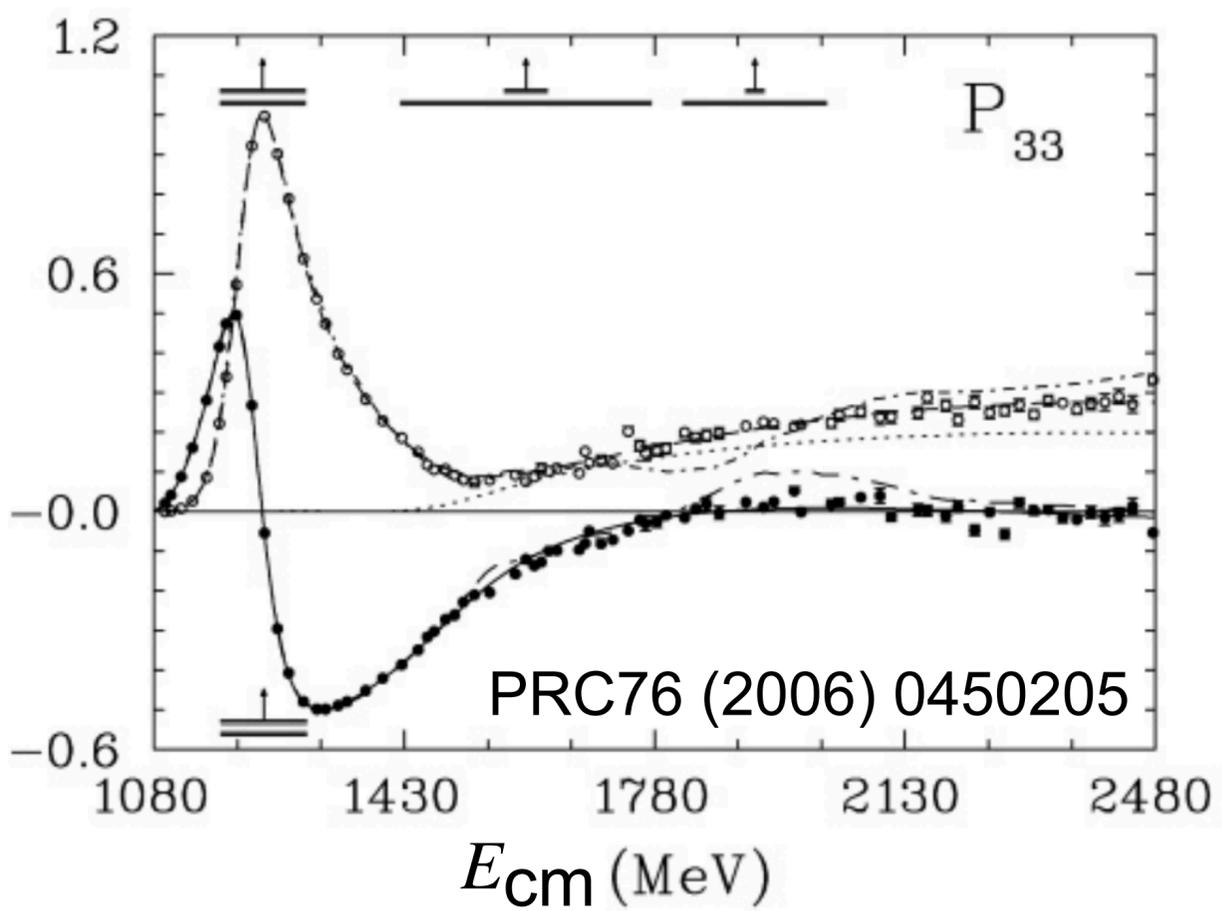
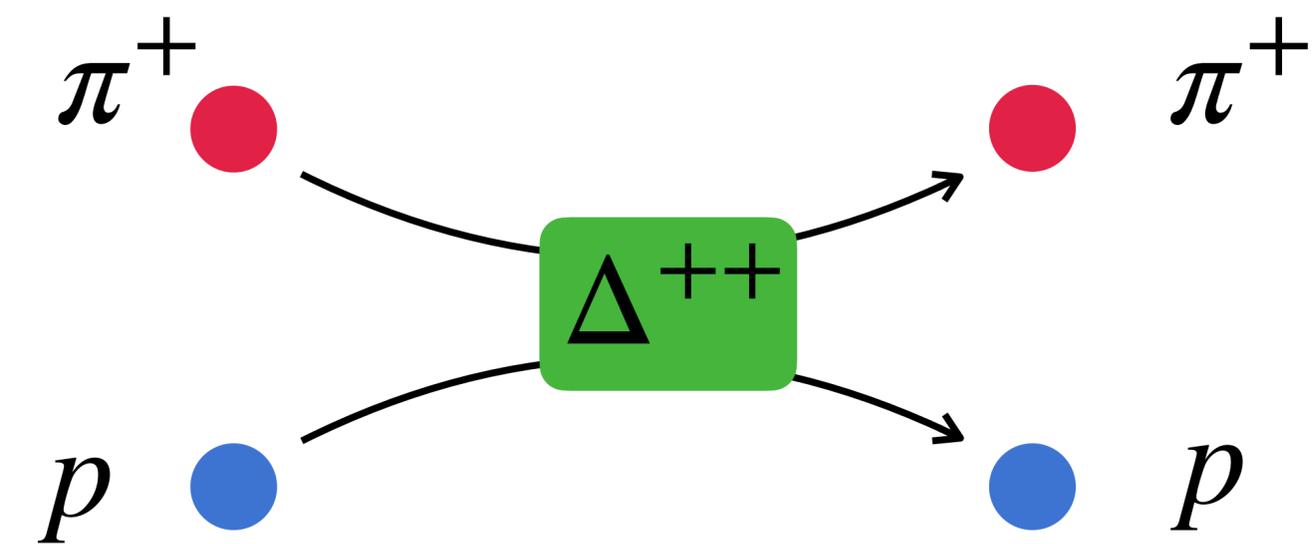
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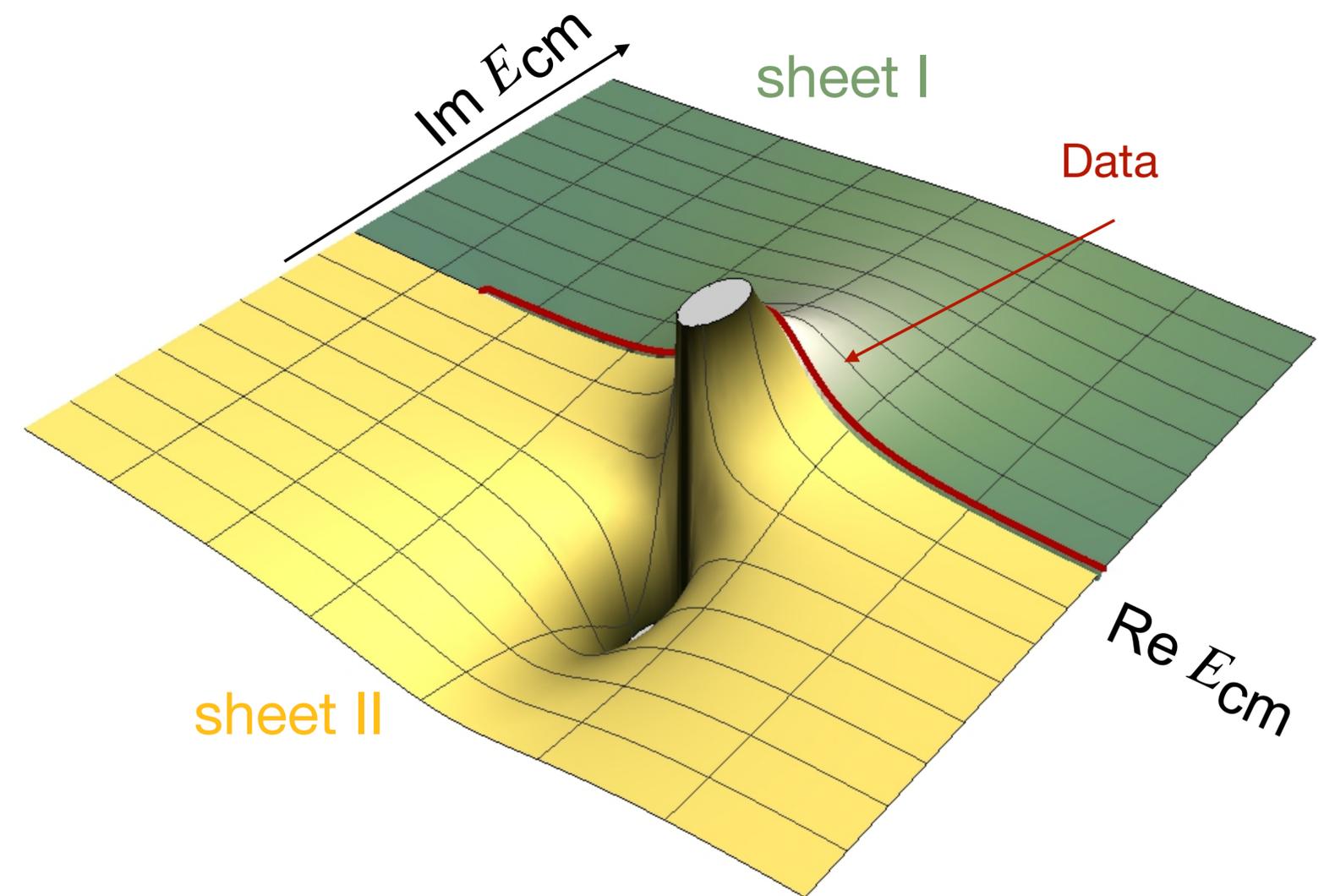
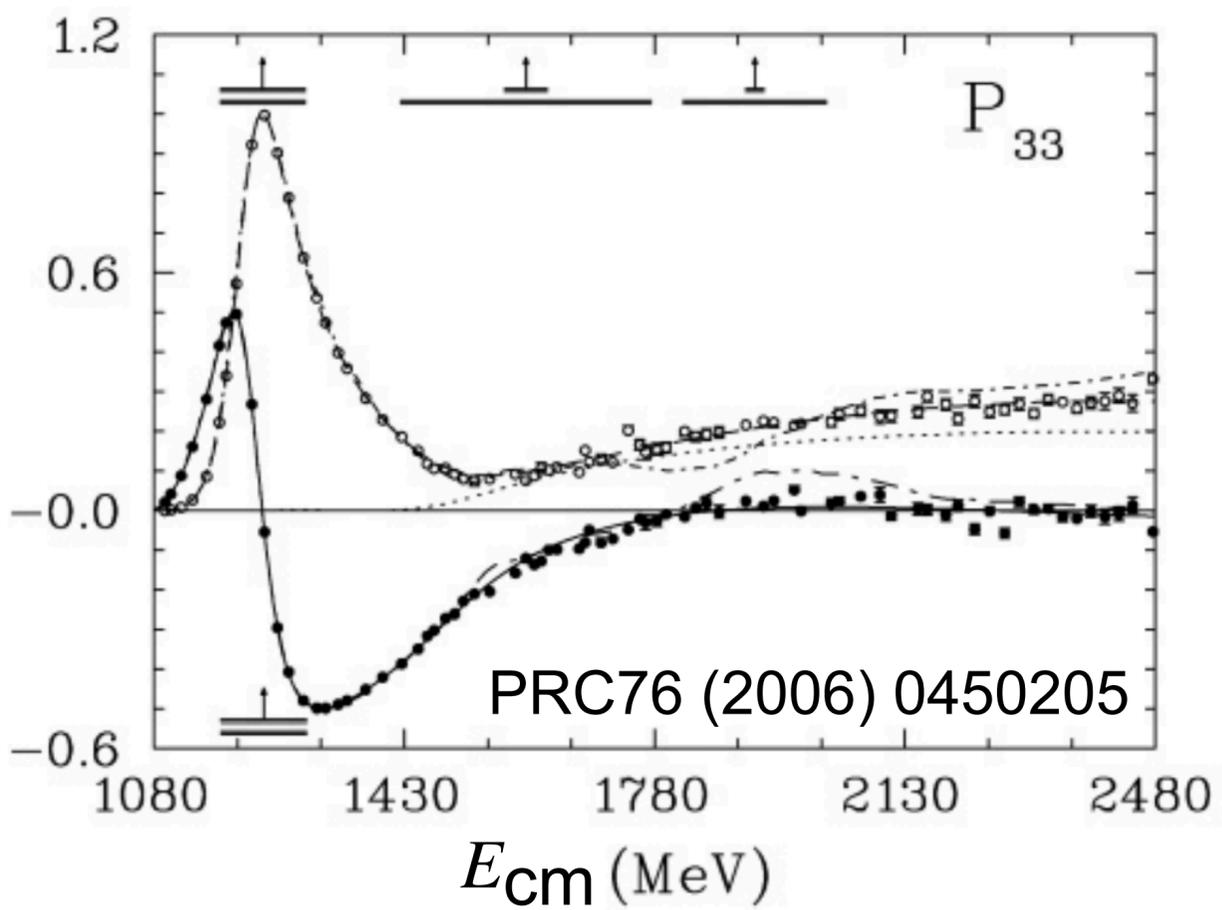
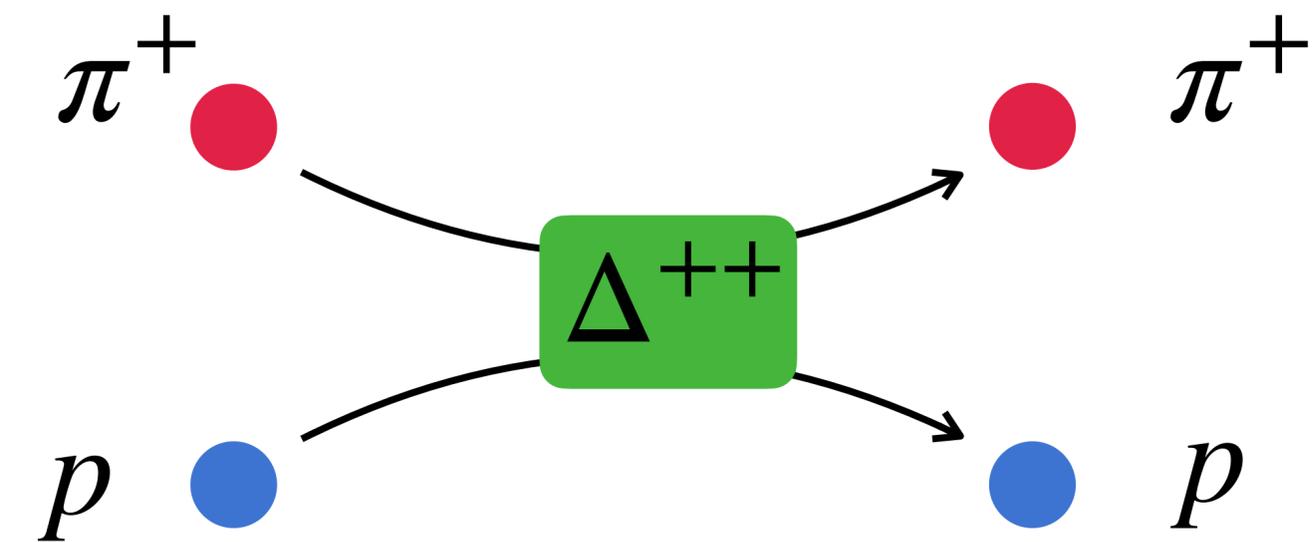
Data analysis

S-Matrix constraints, K-matrix fit...

What's a resonance?

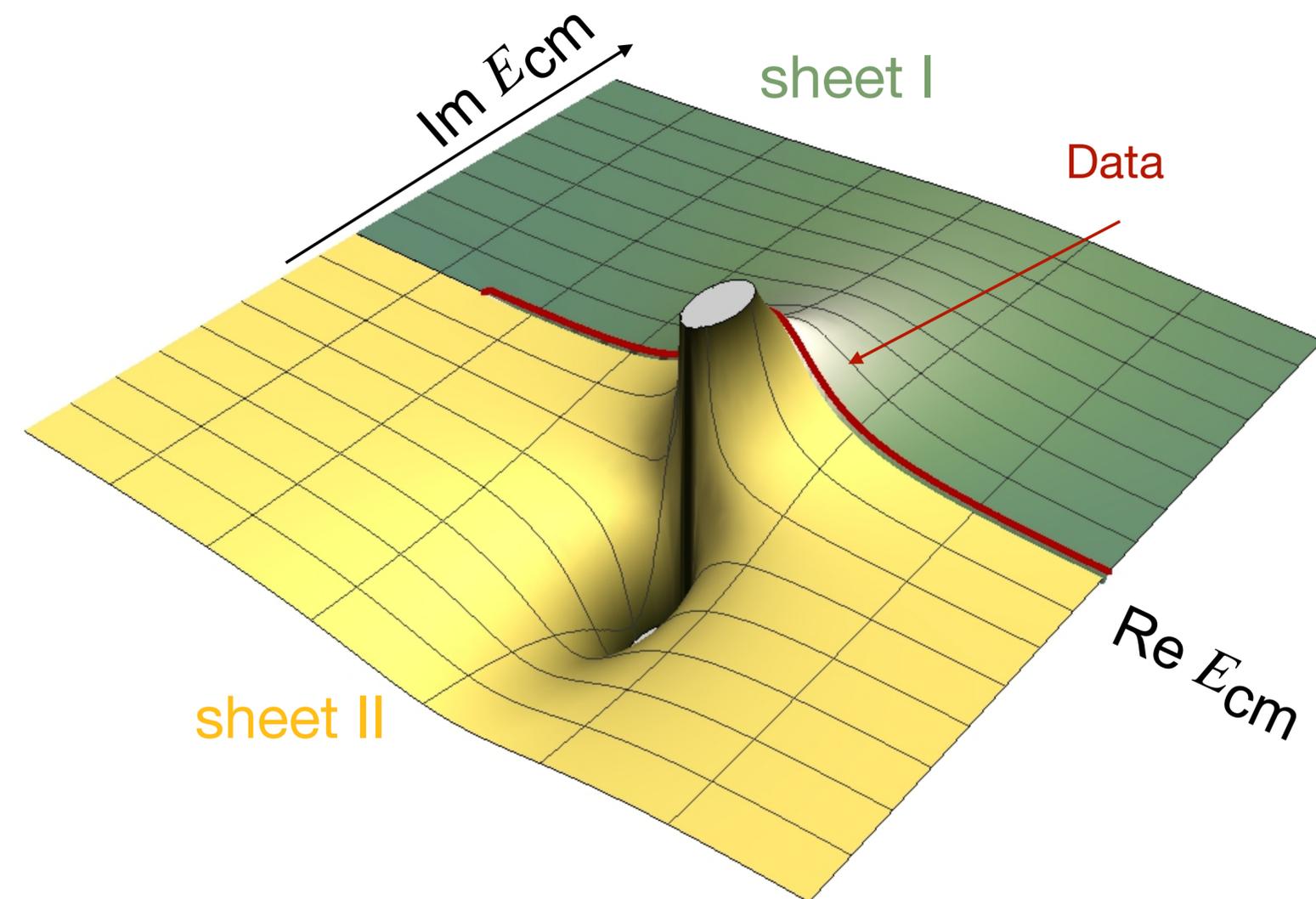
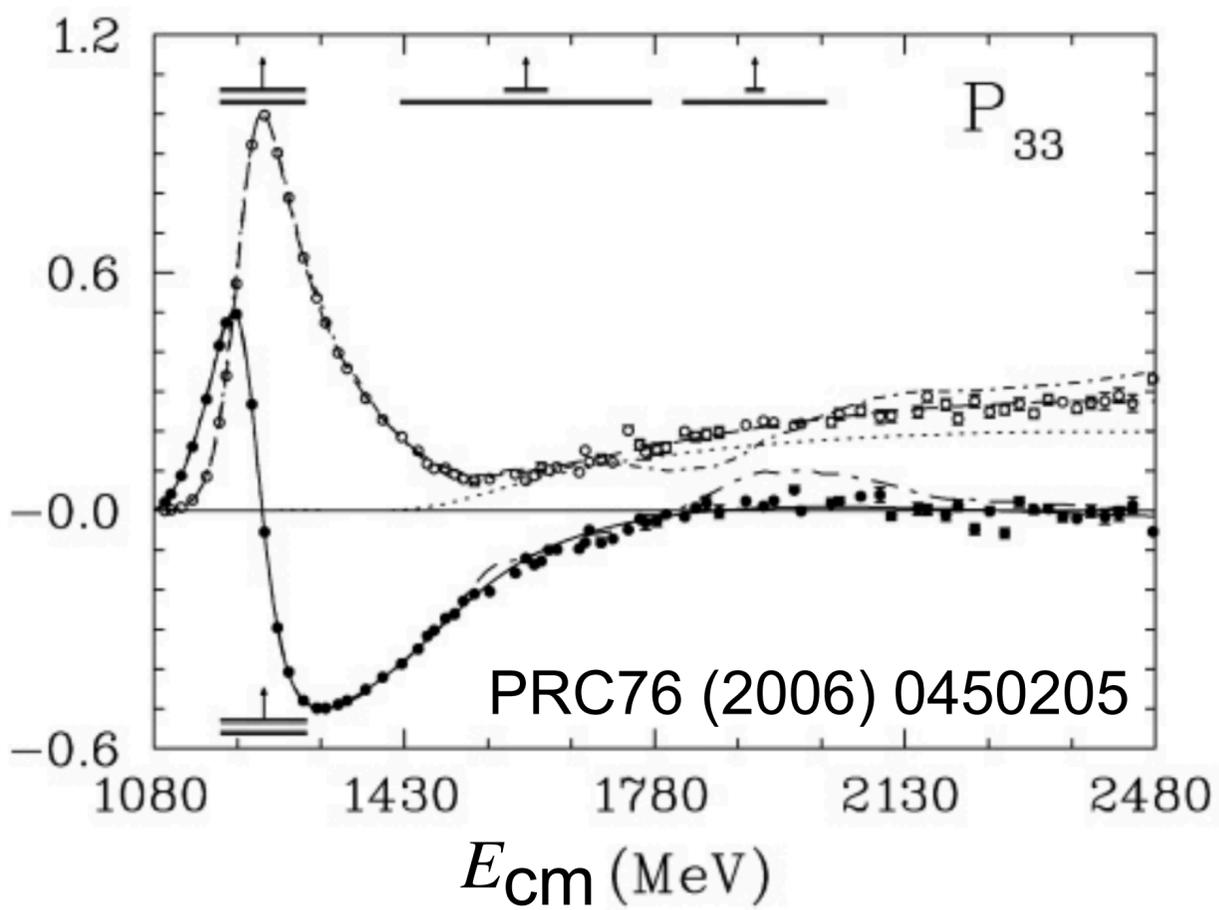
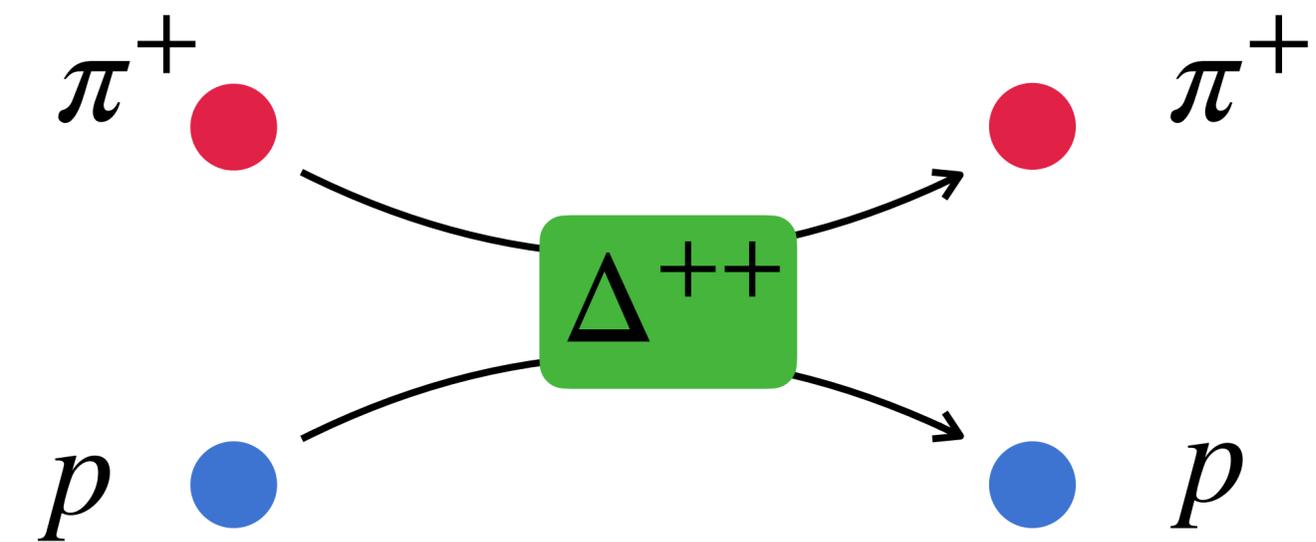


What's a resonance?



Resonances are poles of the scattering amplitude

What's a resonance?



$Im E_{cm}$

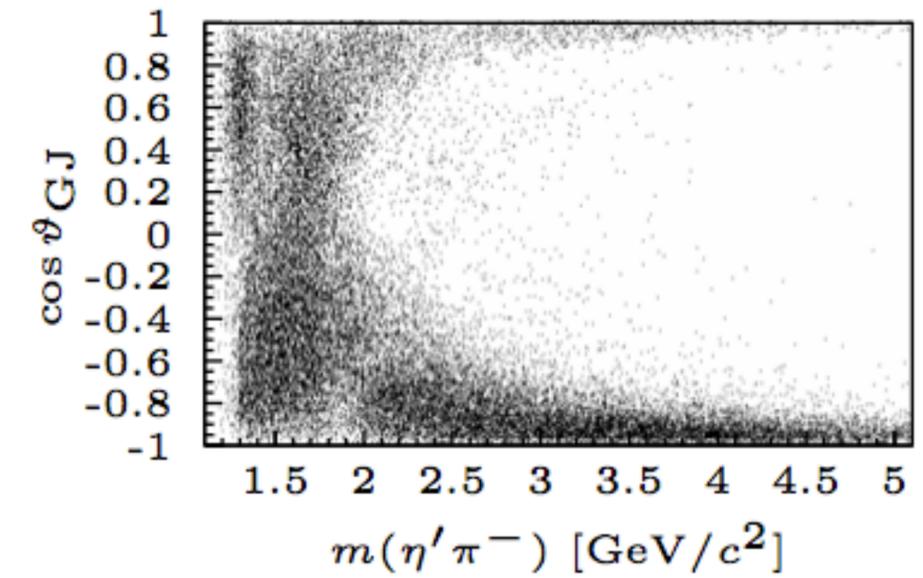
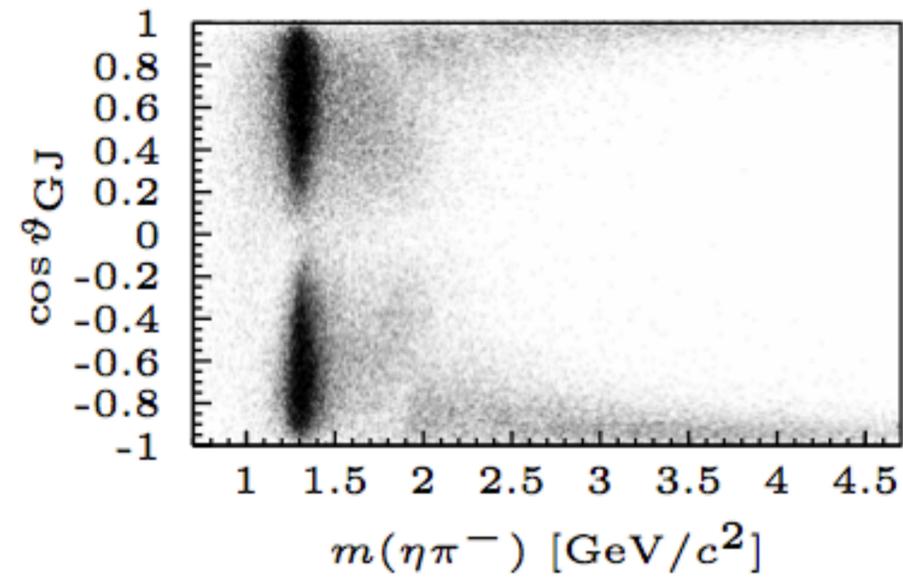
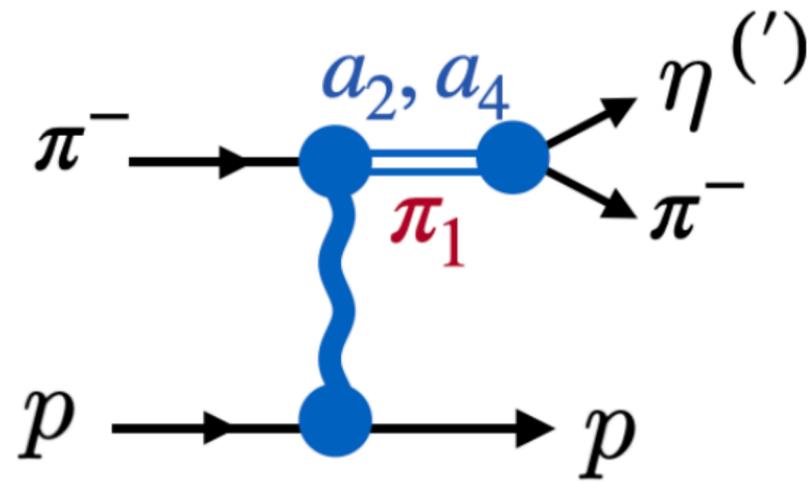
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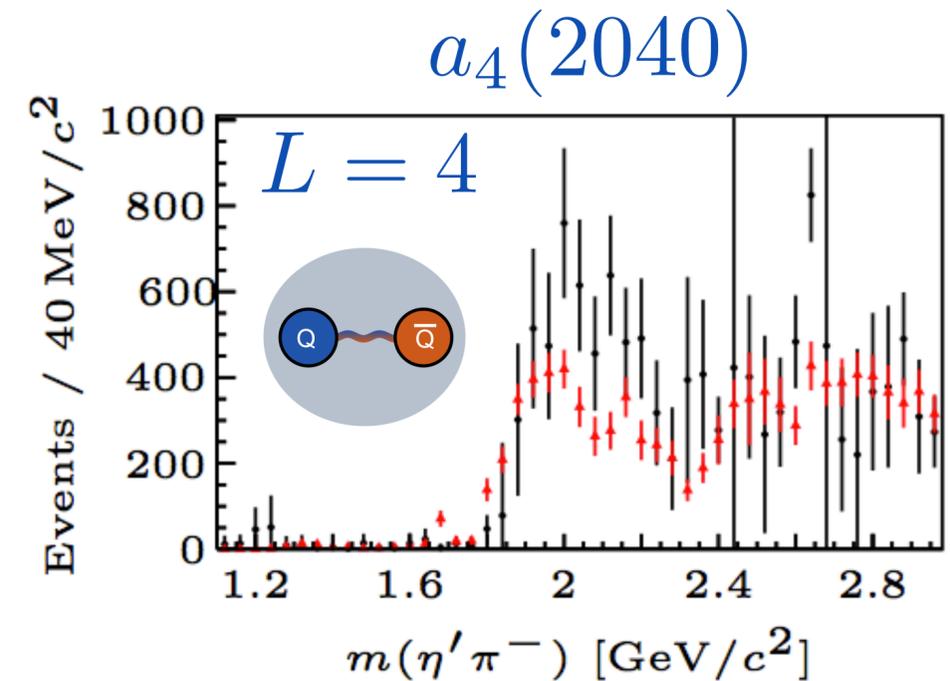
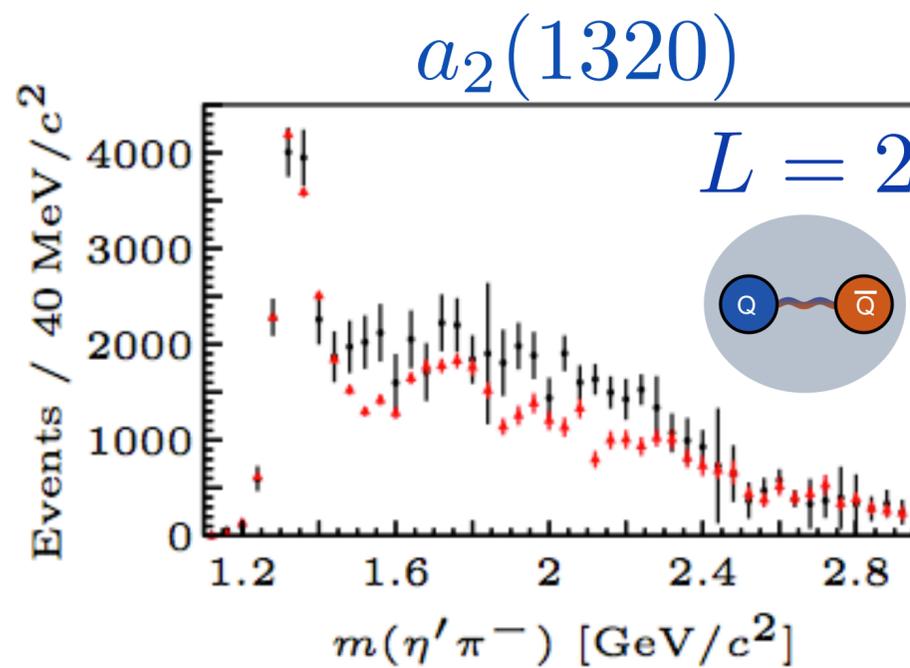
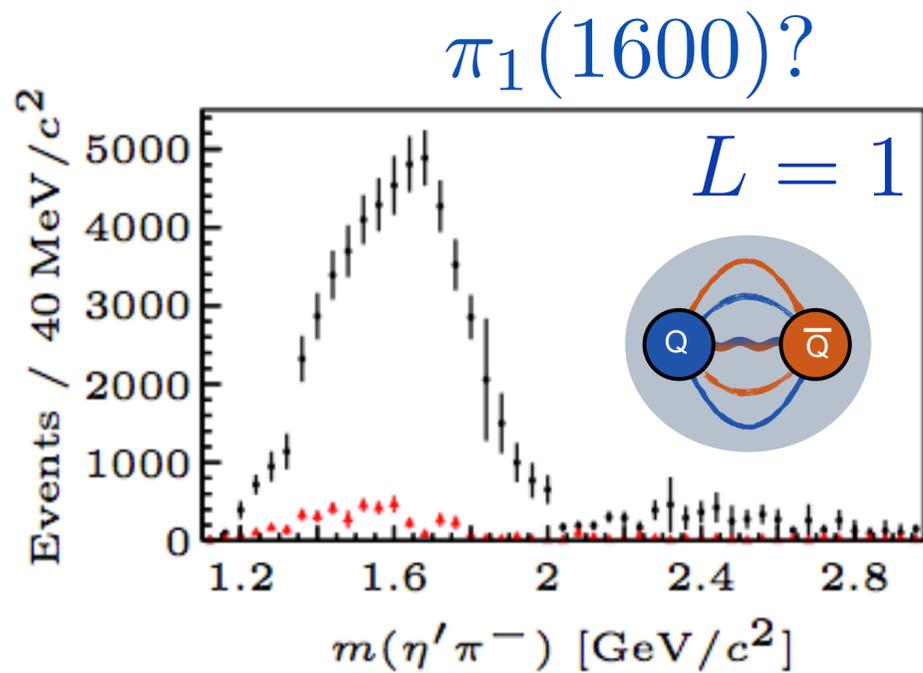
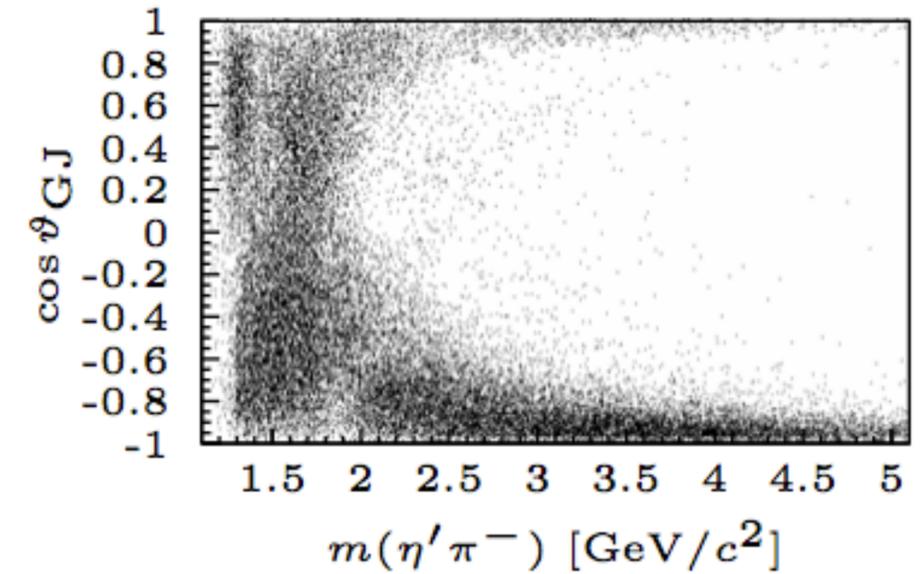
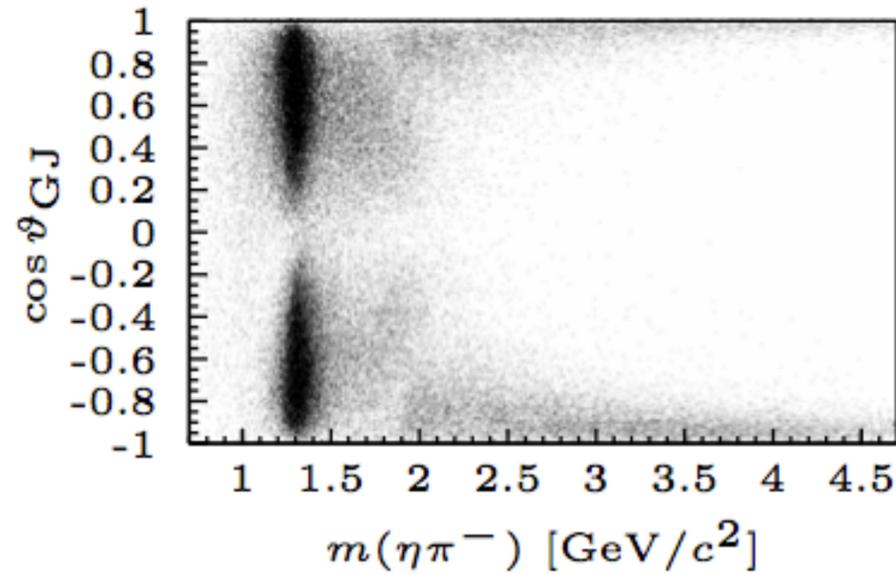
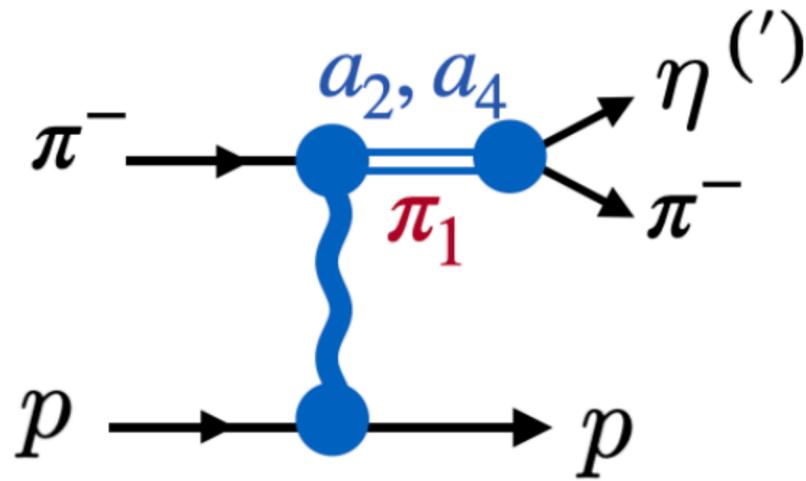
$\times \Delta(1232)$

$Re E_{cm}$

Partial Waves Expansion



Partial Waves Expansion



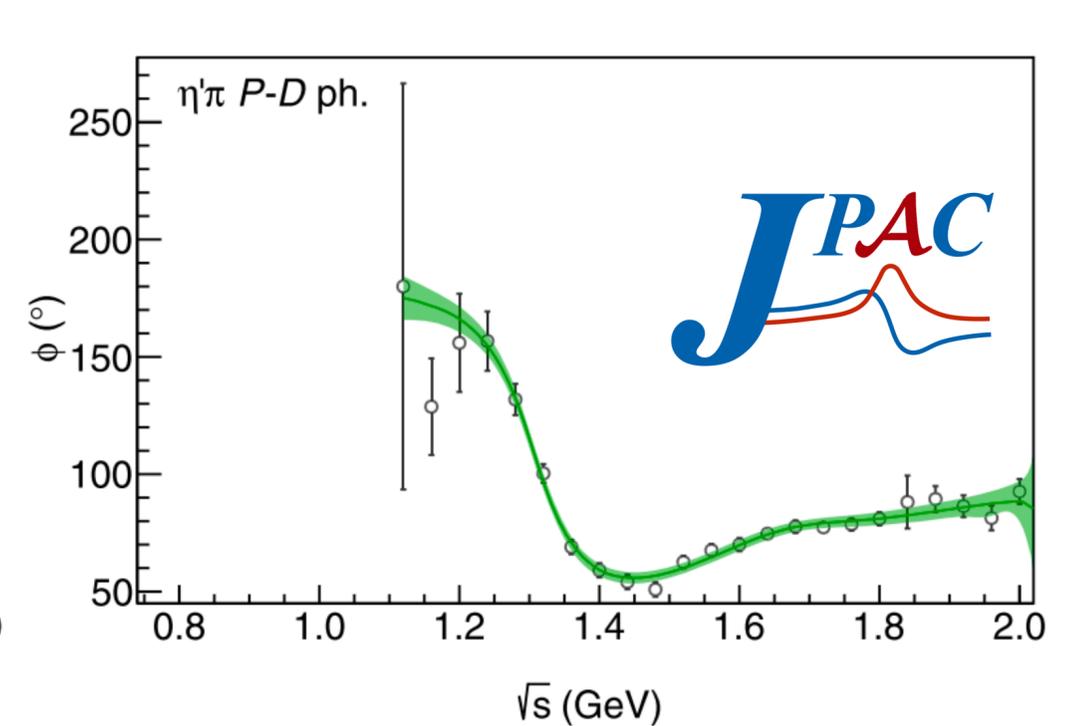
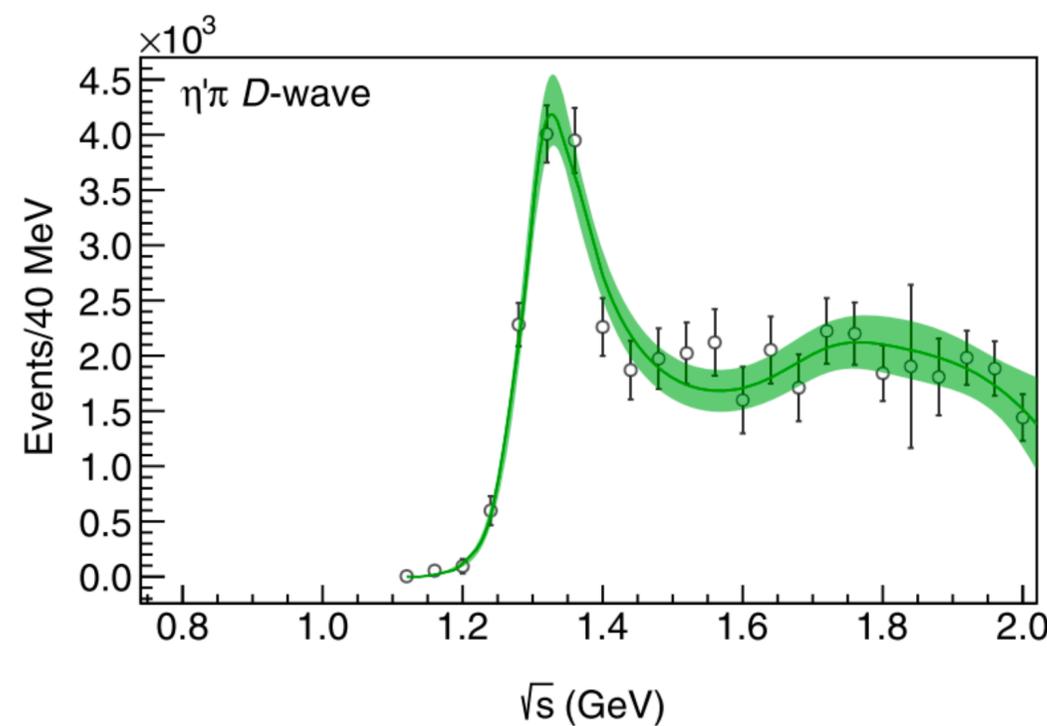
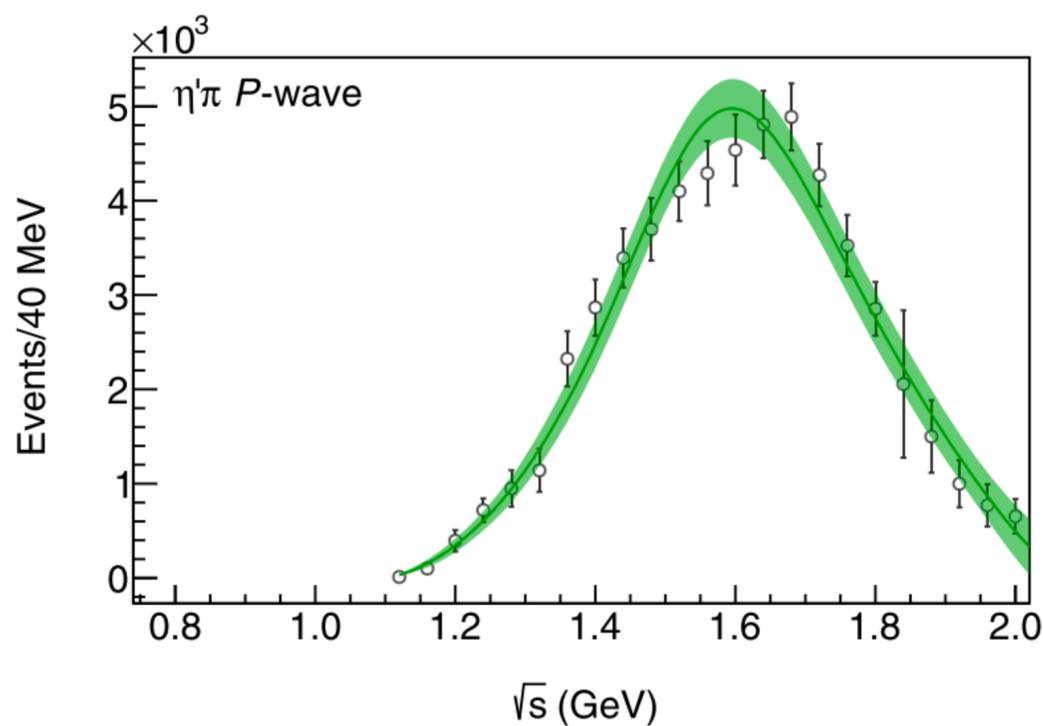
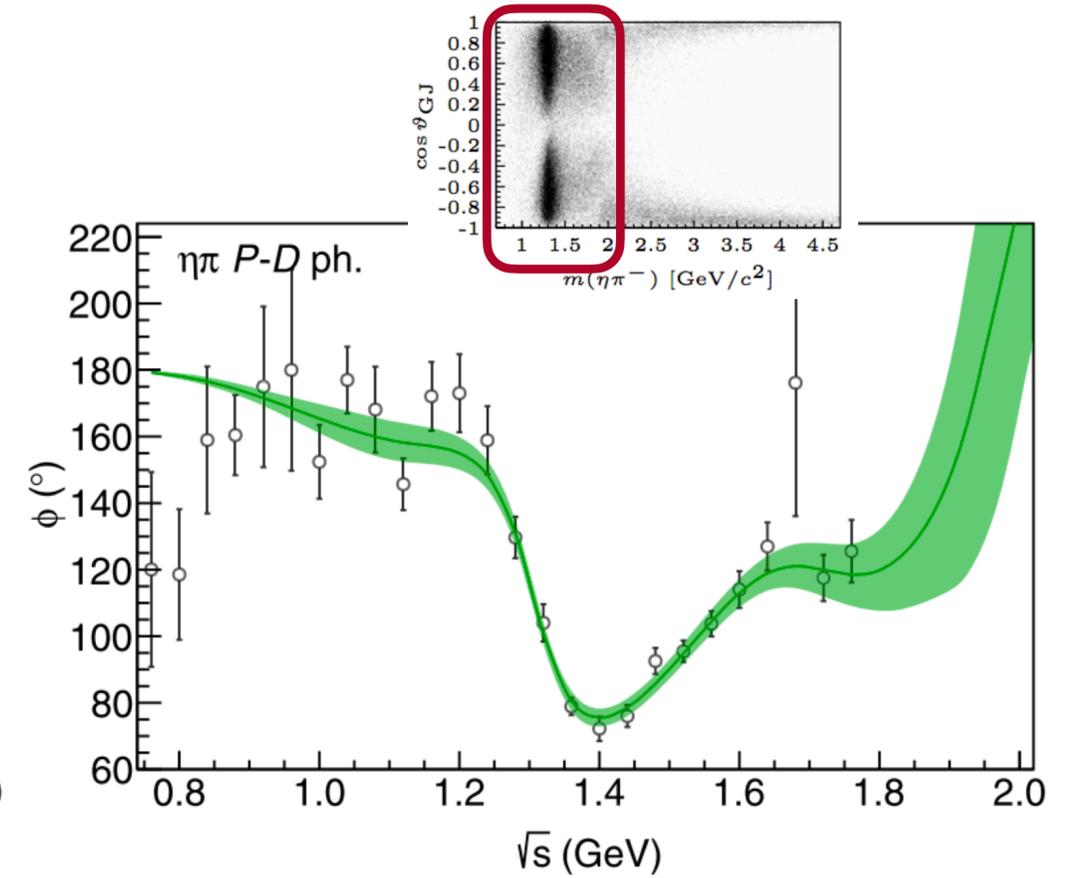
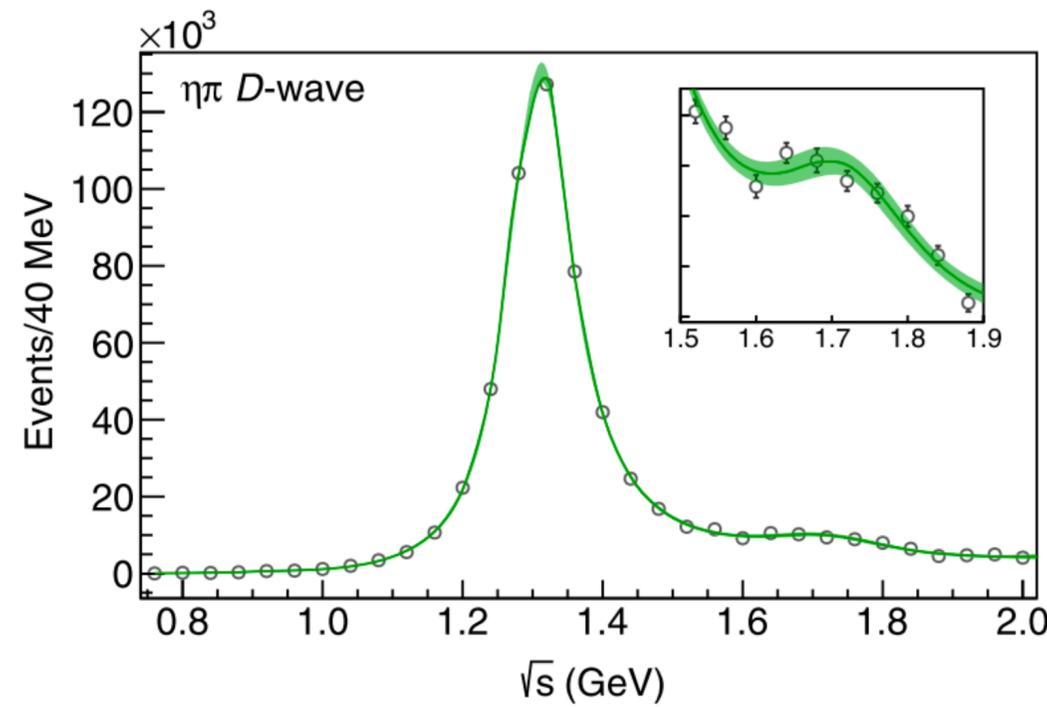
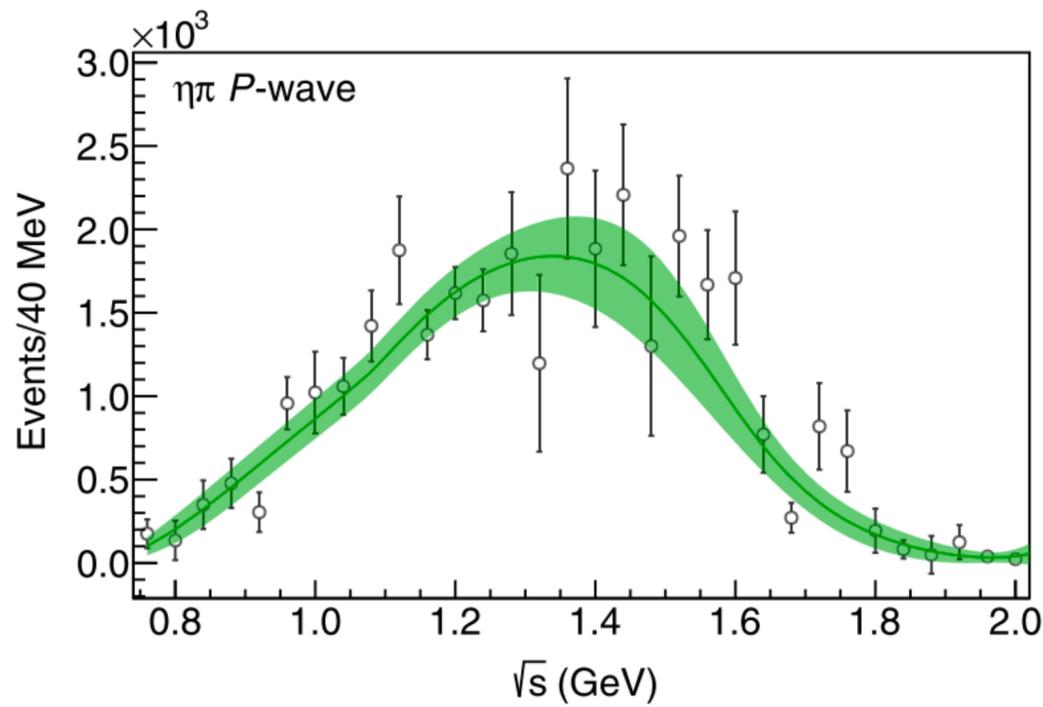
Resonance in angular mom. $L = 1$?

black: $\pi\eta'$
 red: $\pi\eta$ (scaled)

Low Energy Fit of $L = 1,2$

Rodas et al (JPAC) PRL122 (2019)

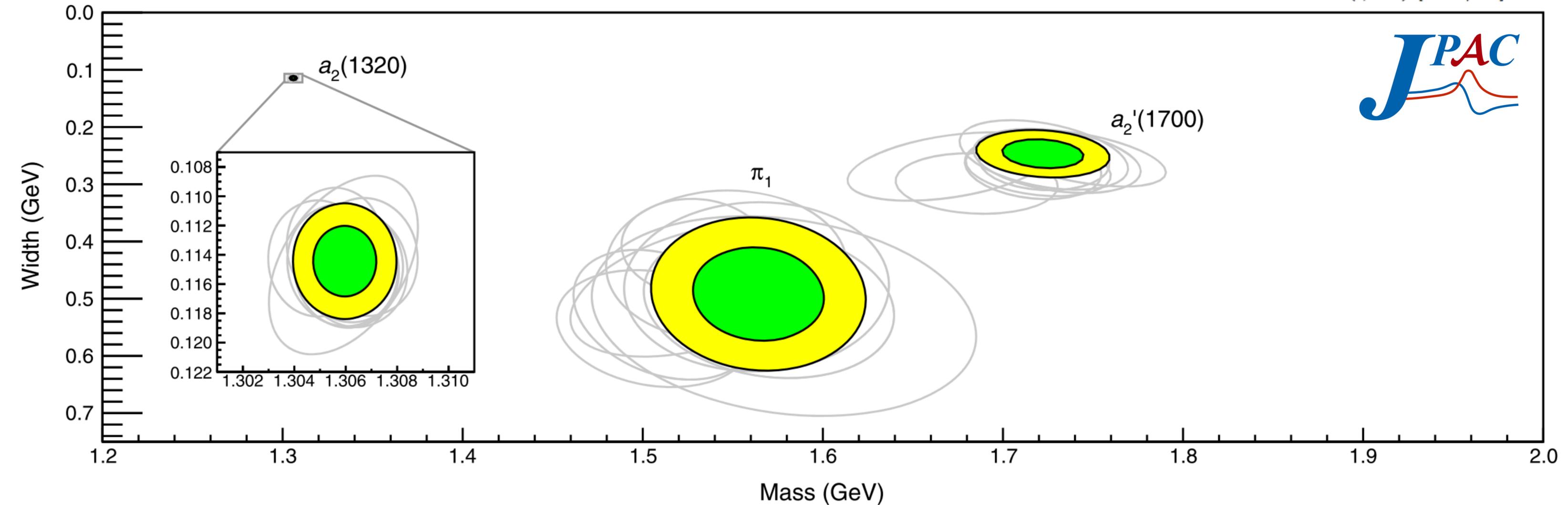
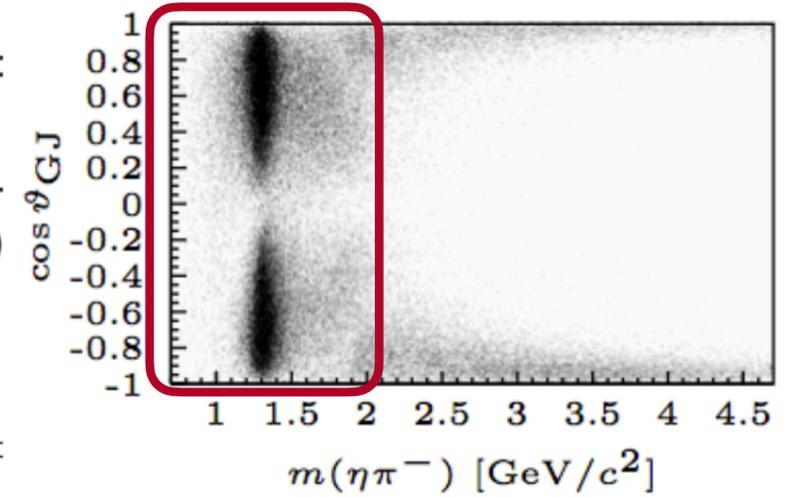
$\pi_1(1400)$ vs $\pi_1(1600)$

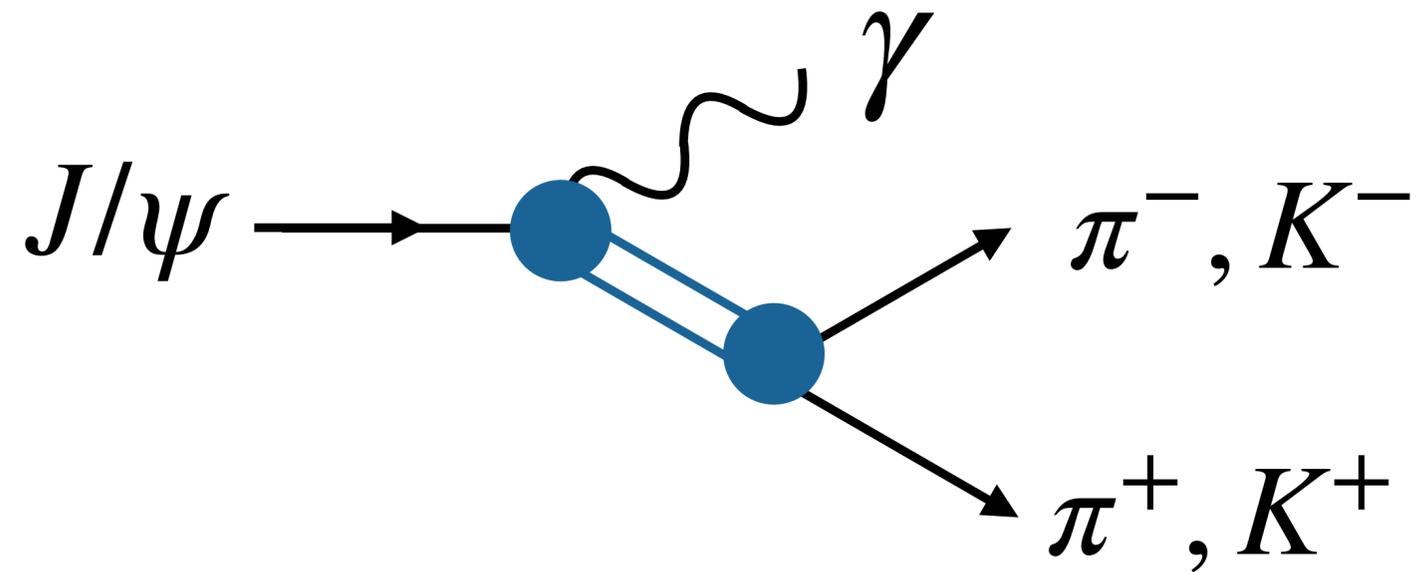


Low Energy Fit of $L = 1,2$

Rodas et al (JPAC) PRL122 (2019)

Poles	Mass (MeV)	Width (MeV)
$a_2(1320)$	$1306.0 \pm 0.8 \pm 1.3$	$114.4 \pm 1.6 \pm 0.0$
$a_2'(1700)$	$1722 \pm 15 \pm 67$	$247 \pm 17 \pm 63$
π_1	$1564 \pm 24 \pm 86$	$492 \pm 54 \pm 102$

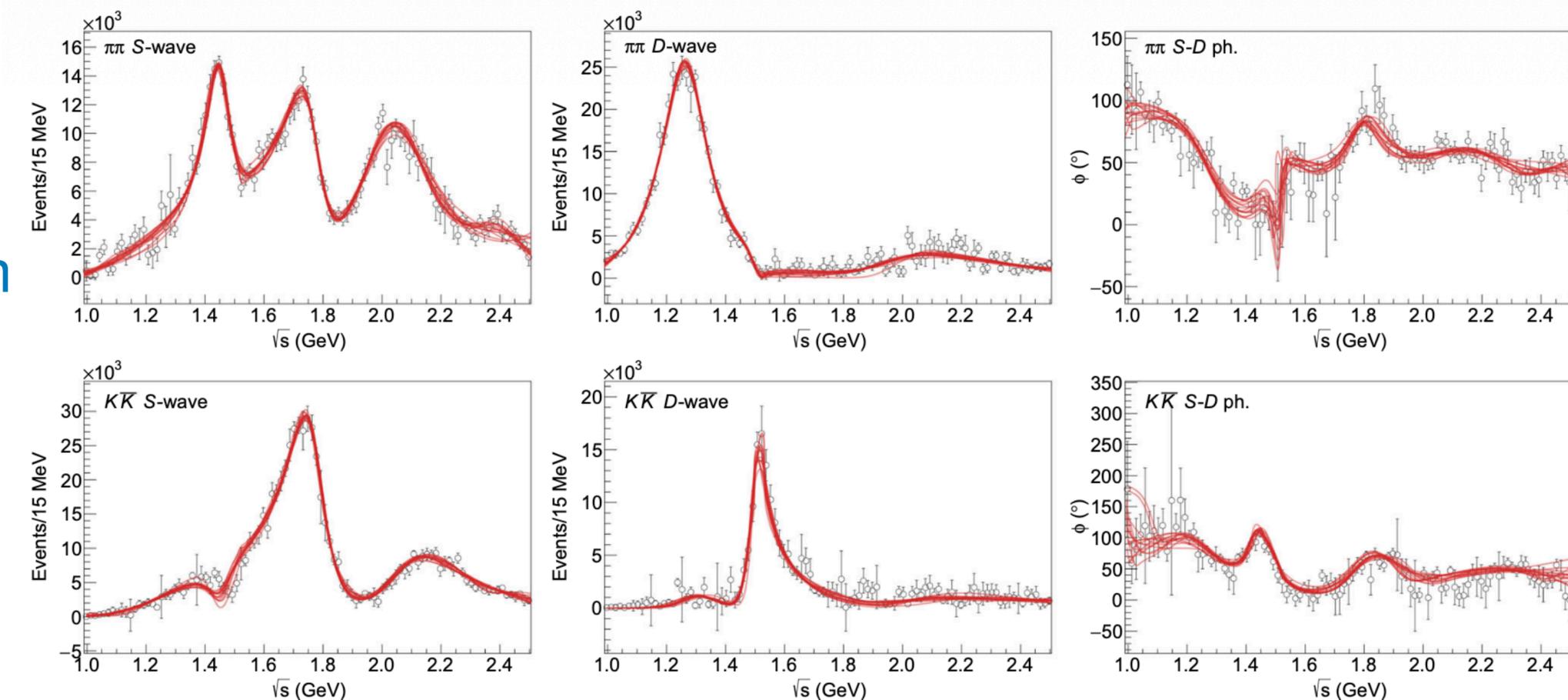




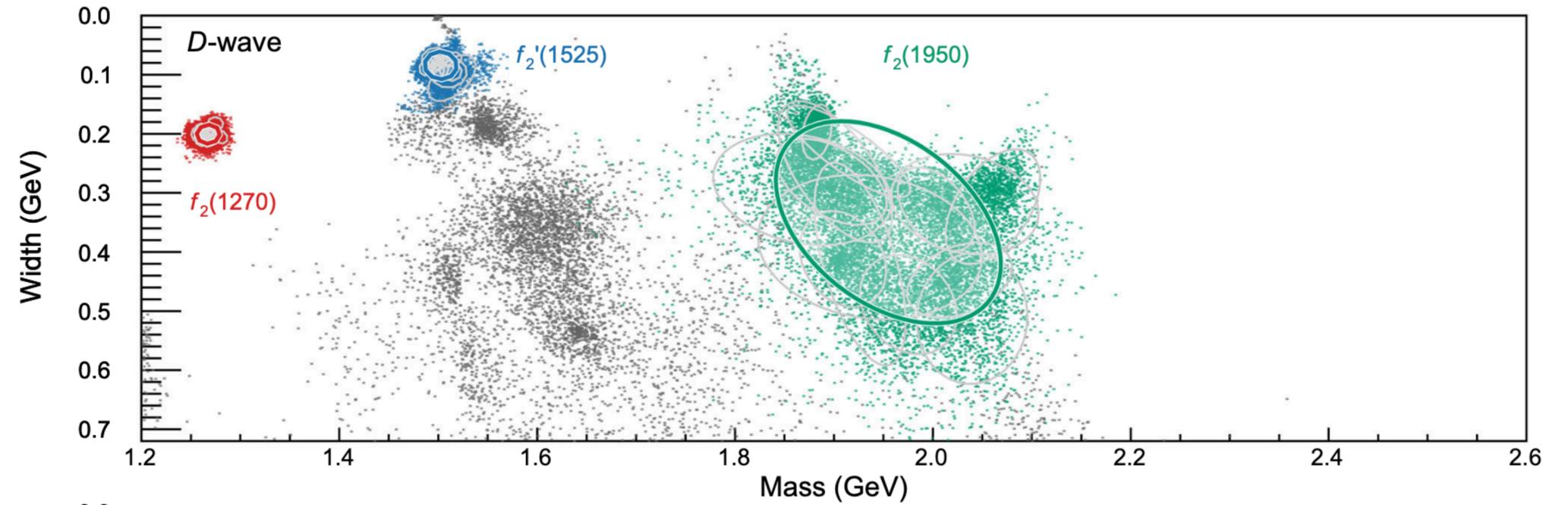
Coupled channels analysis of BESIII data

S-wave hosts rich scalar spectrum

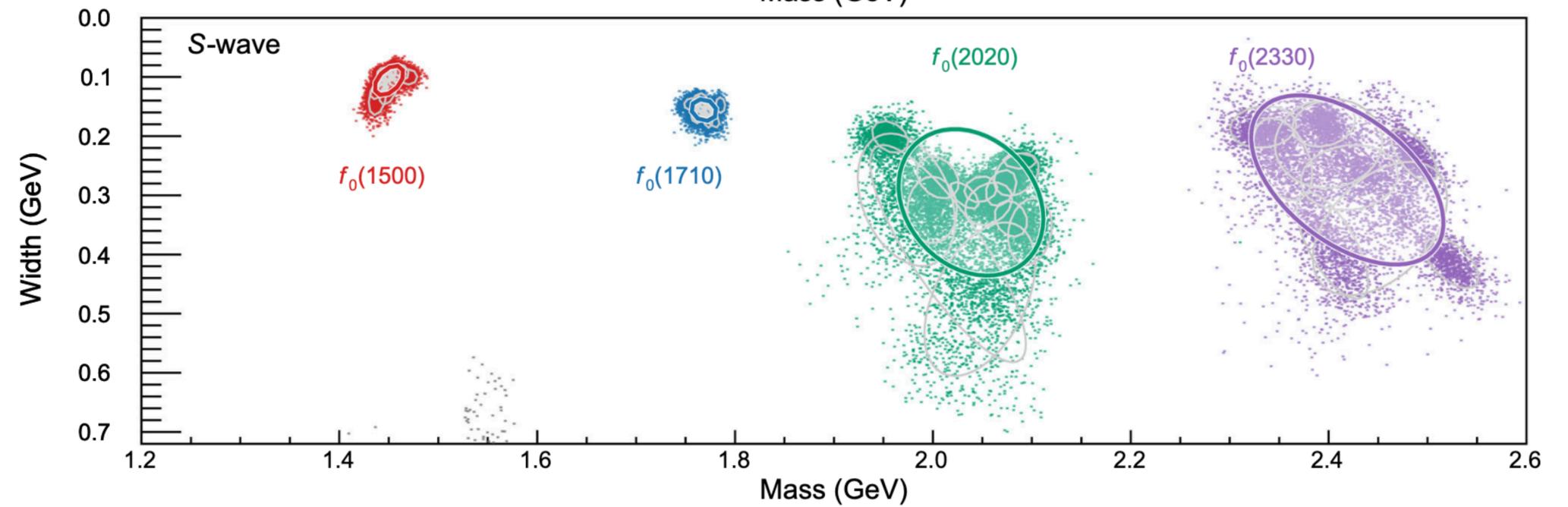
$\eta\eta'$ channel in preparation



D-wave hosts known tensor mesons



S-wave hosts rich scalar spectrum



Summary

QCD predictions for exotic hadrons properties

Lattice QCD, EFT, quark model, Dyson-Schwinger eqs, ...

Predictions for future measurements

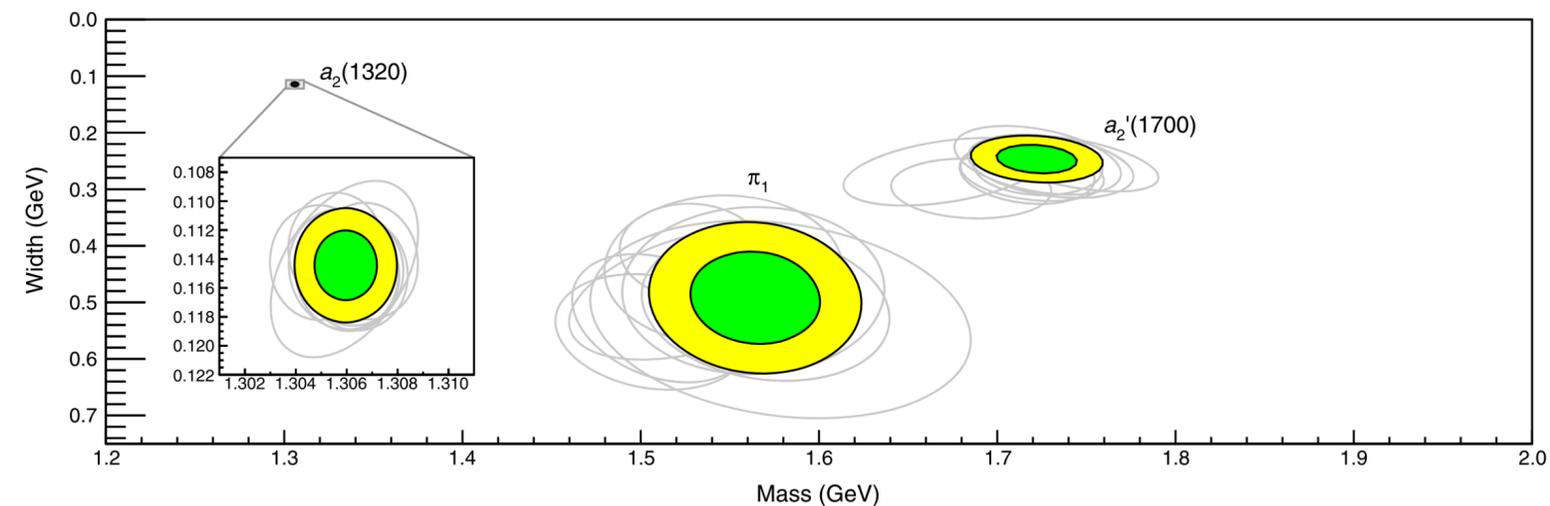
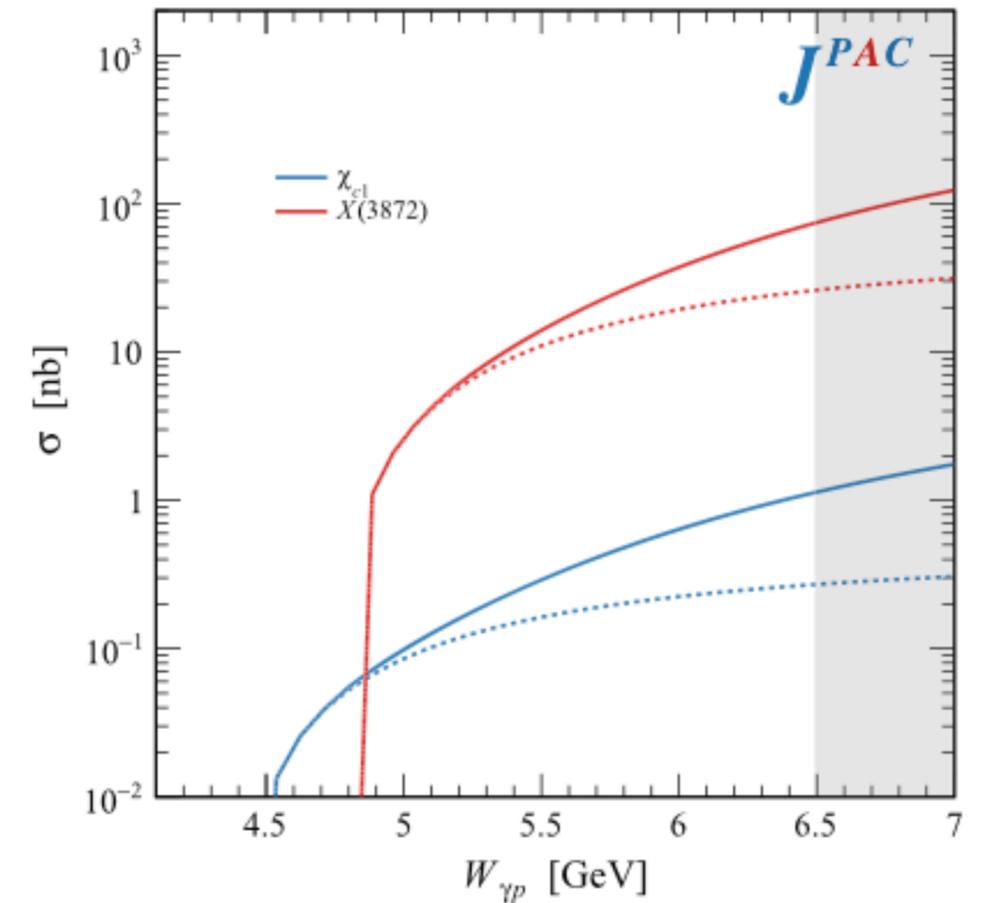
Known measurements, Regge theory, VMD, ...

Formalism and interpretation of observables

Polarization observables, moment expansion, ...

Data analysis

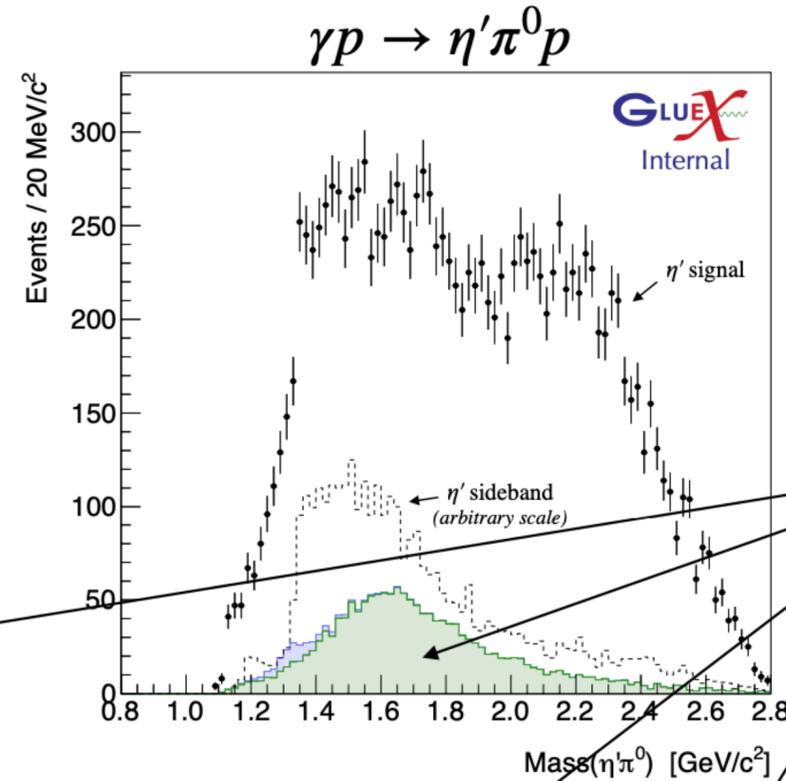
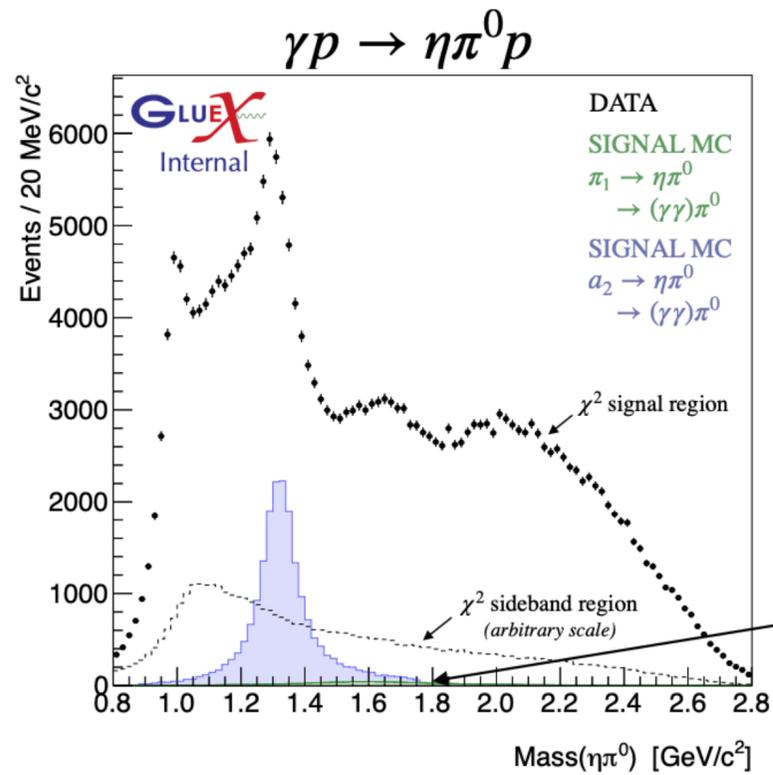
S-Matrix constraints, K-matrix fit...



Backup slides

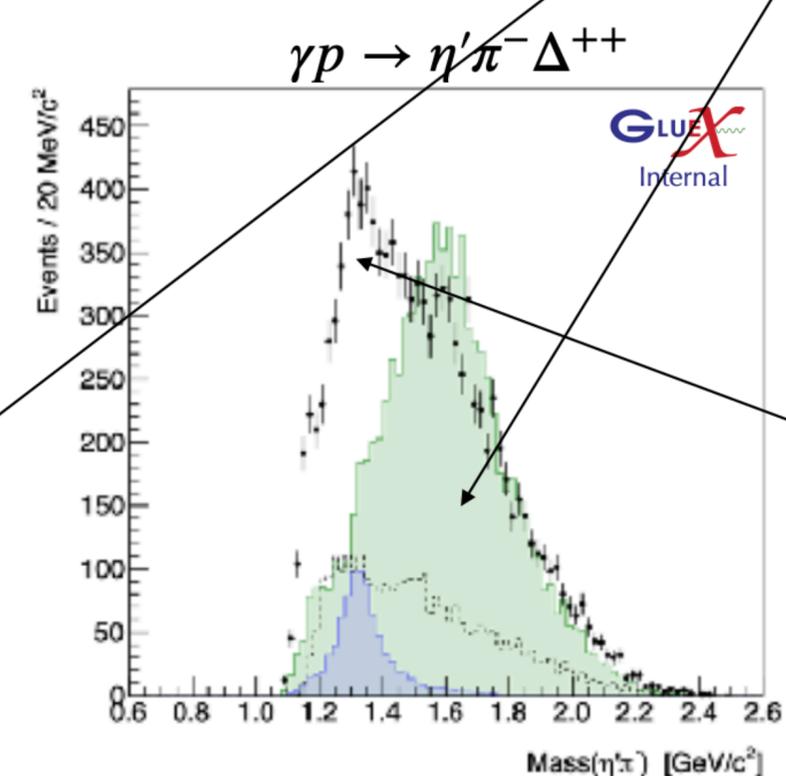
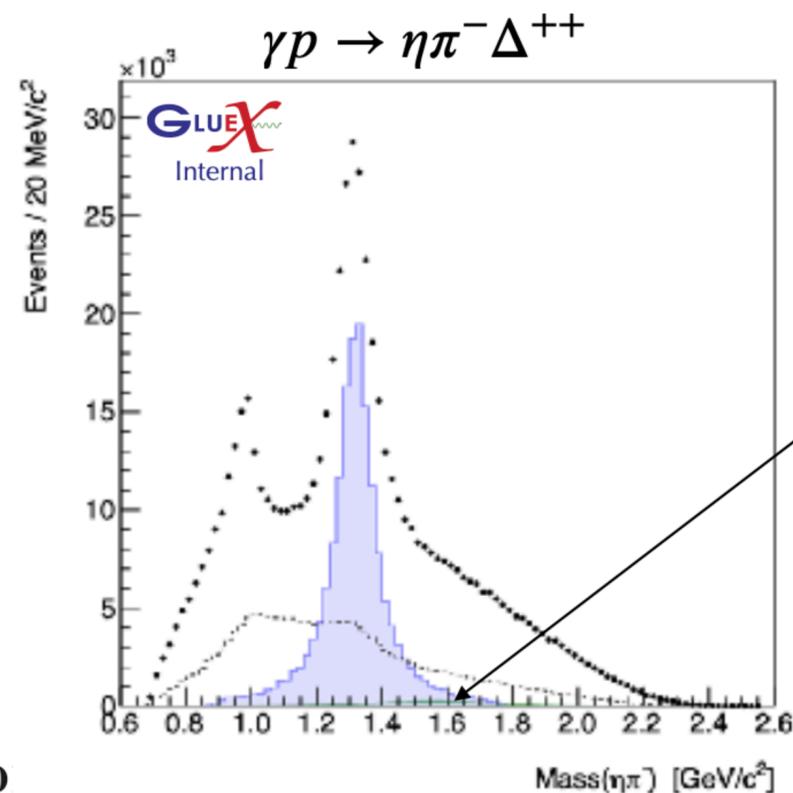
Where (not) to look for the π_1 in GlueX data?

See also GlueX, arXiv:2407.03316



Preliminary upper limits on π_1 contribution

Discovery potential is enhanced if exotic yield is large and the exotic signal is a large fraction of the resonant contribution to a particular reaction.

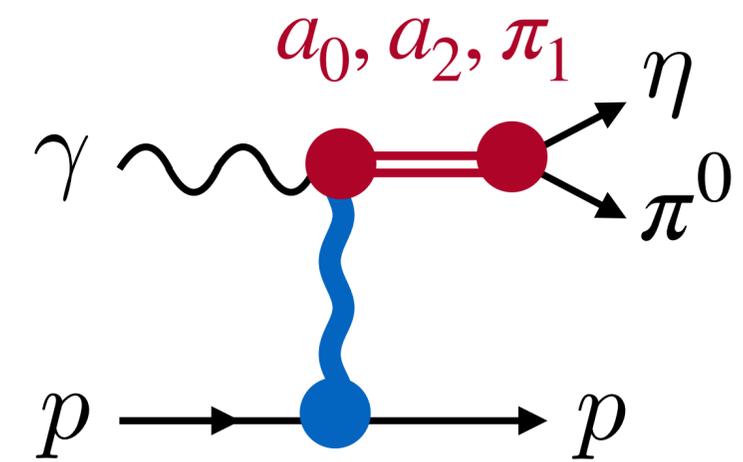


$a_2(1320)$ as a standard candle and interferometer for a π_1 resonance search.

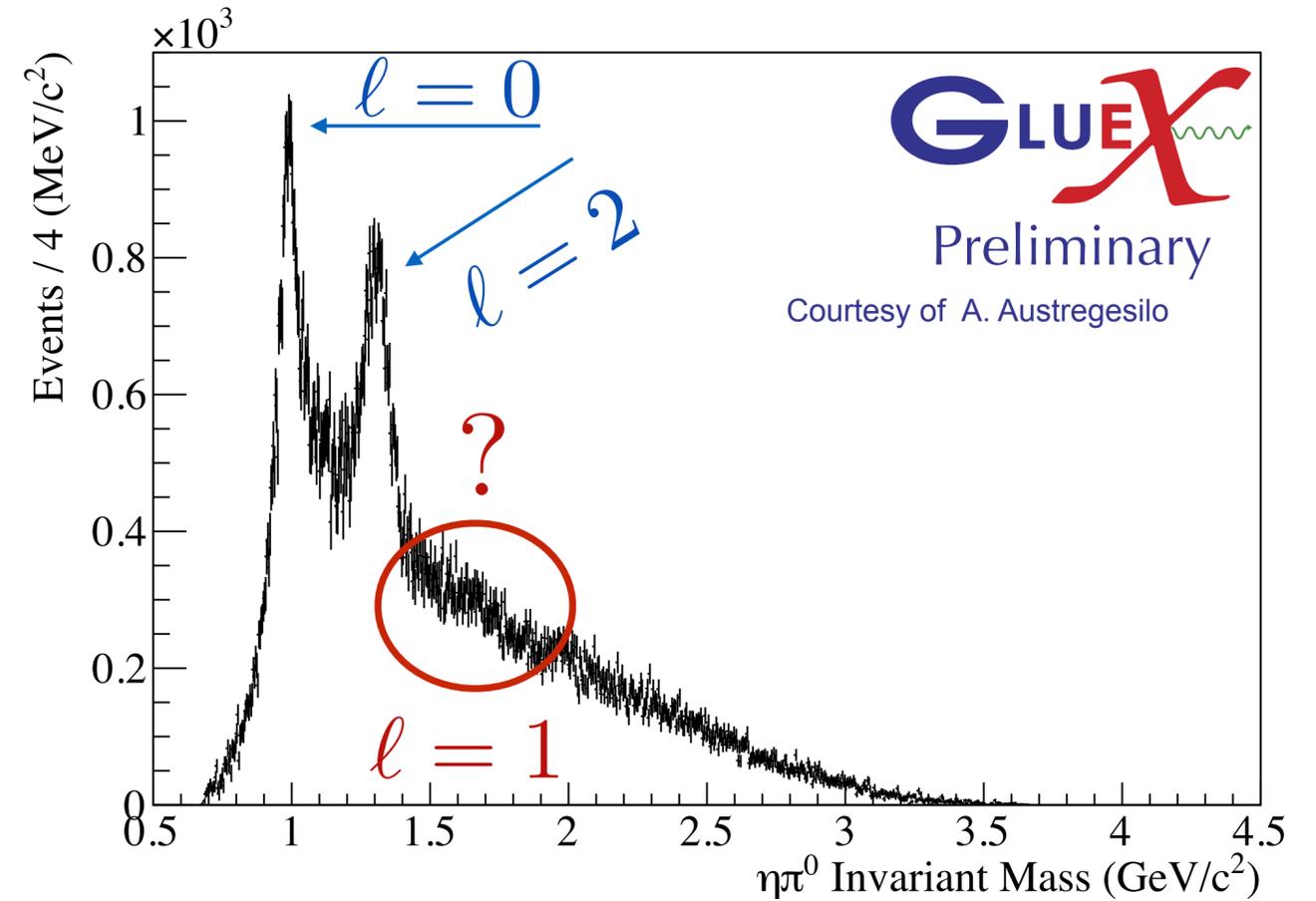
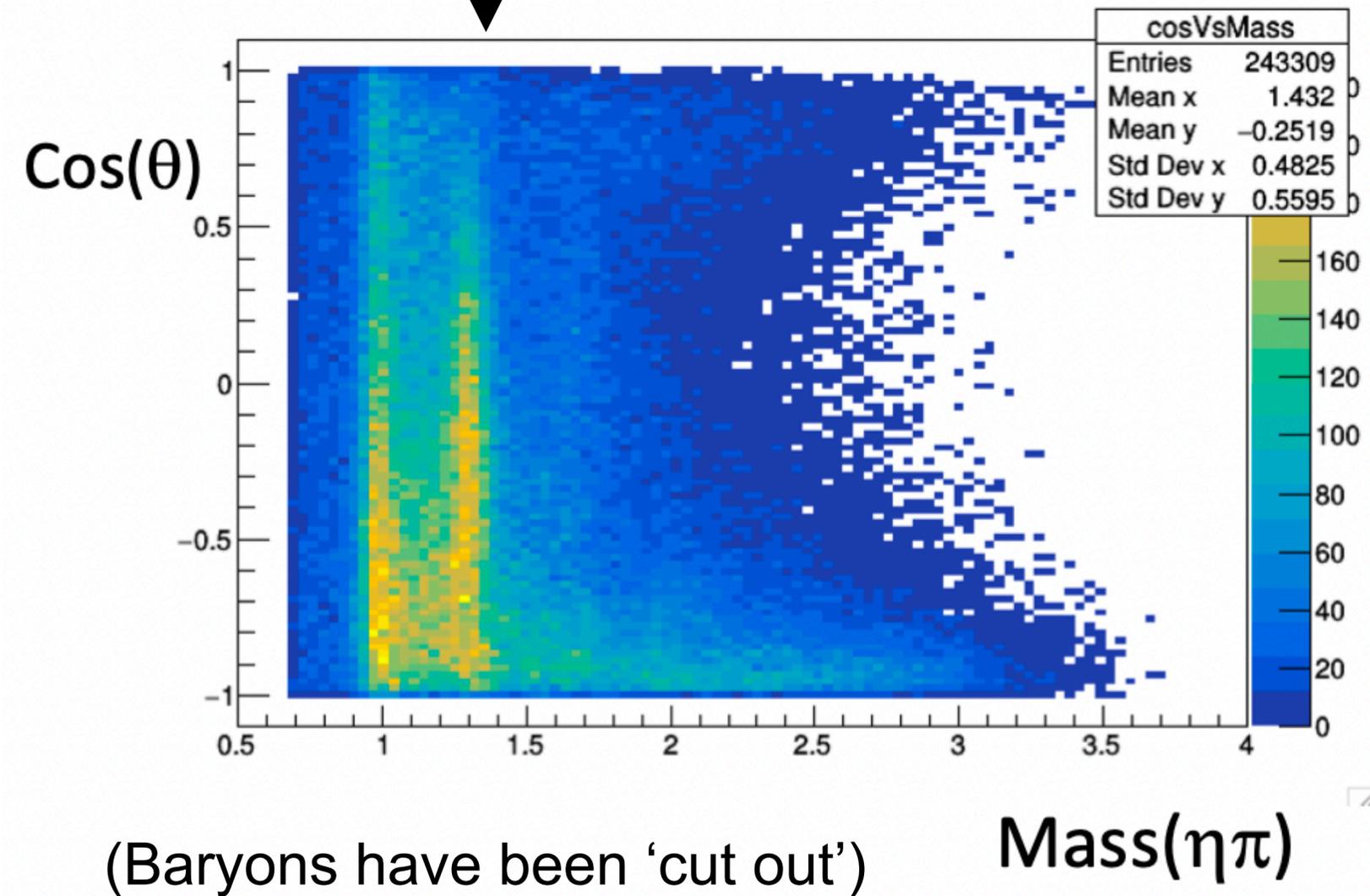
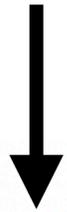


D

$\eta\pi^0$ Photoproduction@GlueX

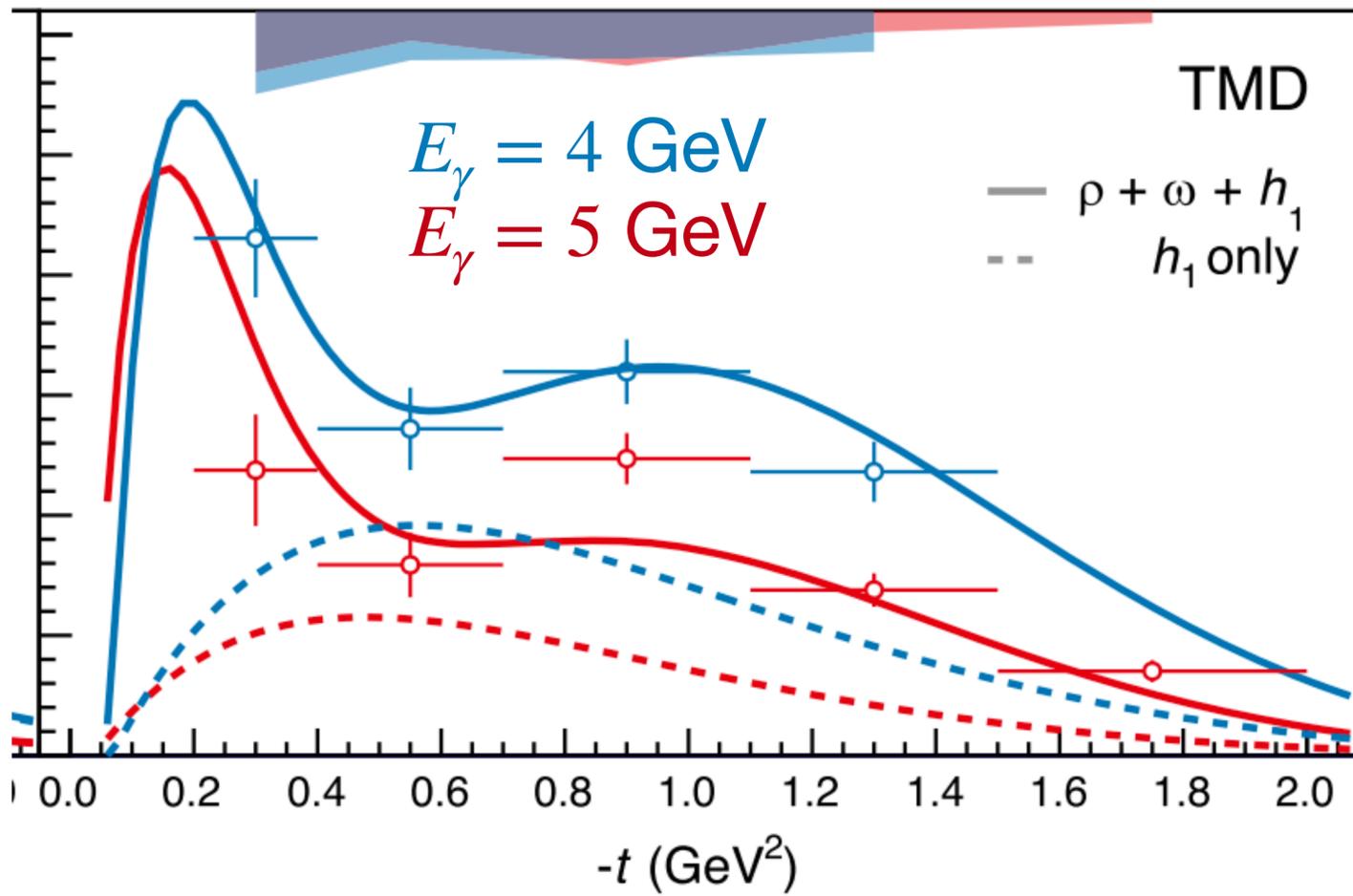


$a_2(1320)$



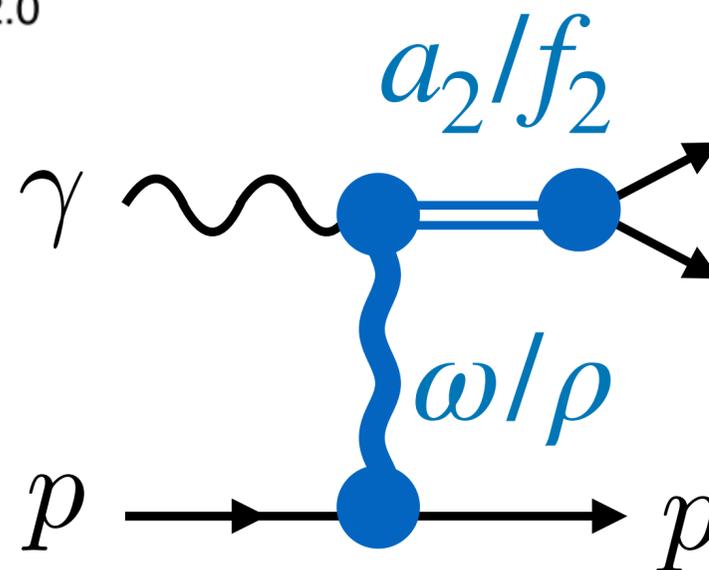
CLAS PRC 102 (2020)

CLAS PRL126 (2021)

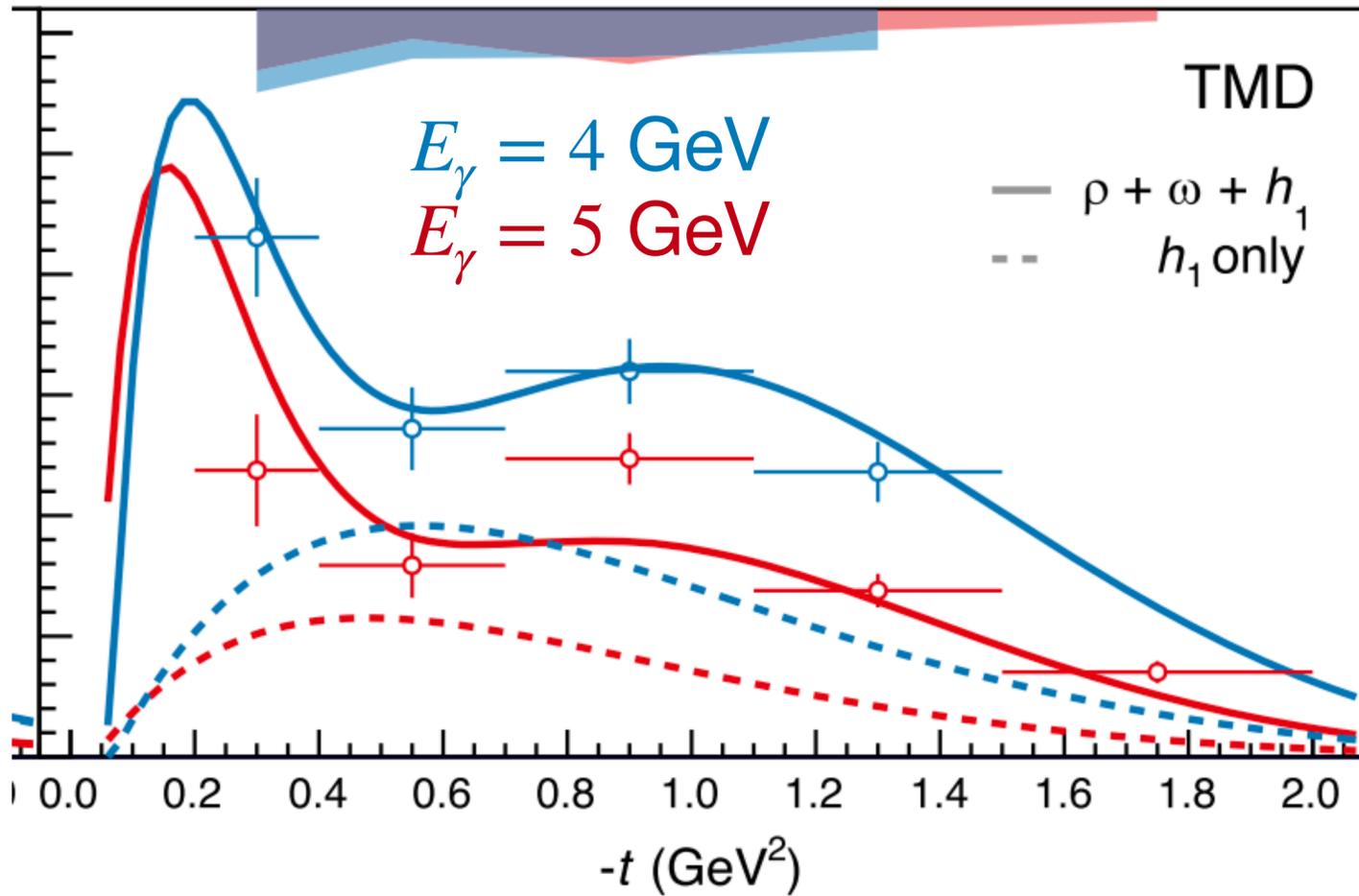


$$\gamma p \rightarrow a_2(1320)p :$$

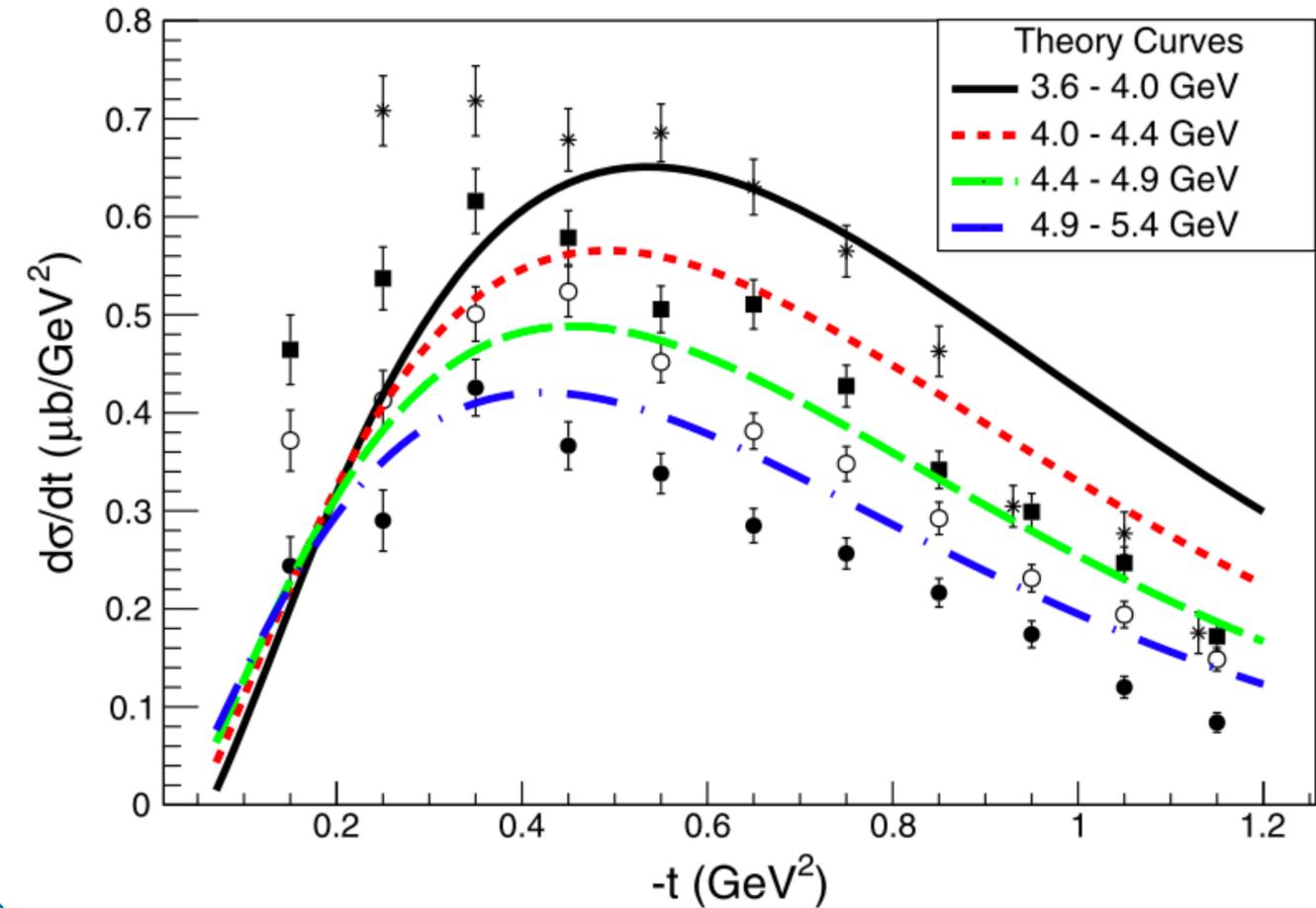
$$\omega + \frac{1}{3}\rho$$



CLAS PRC 102 (2020)

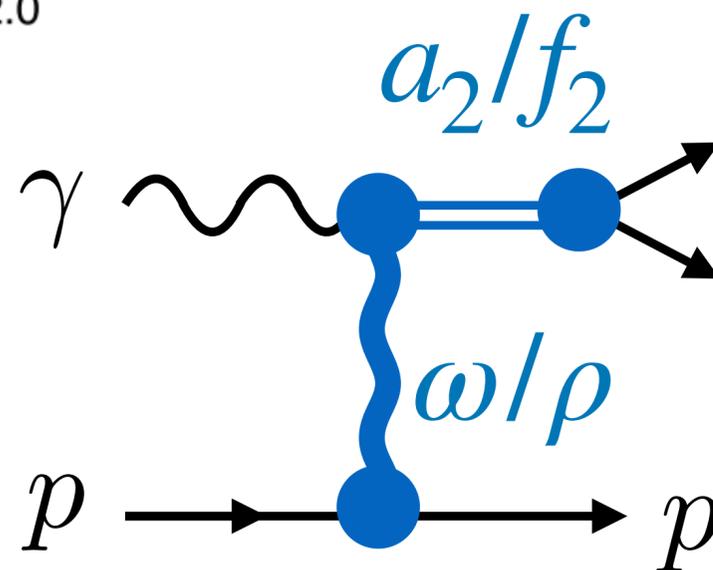


CLAS PRL126 (2021)



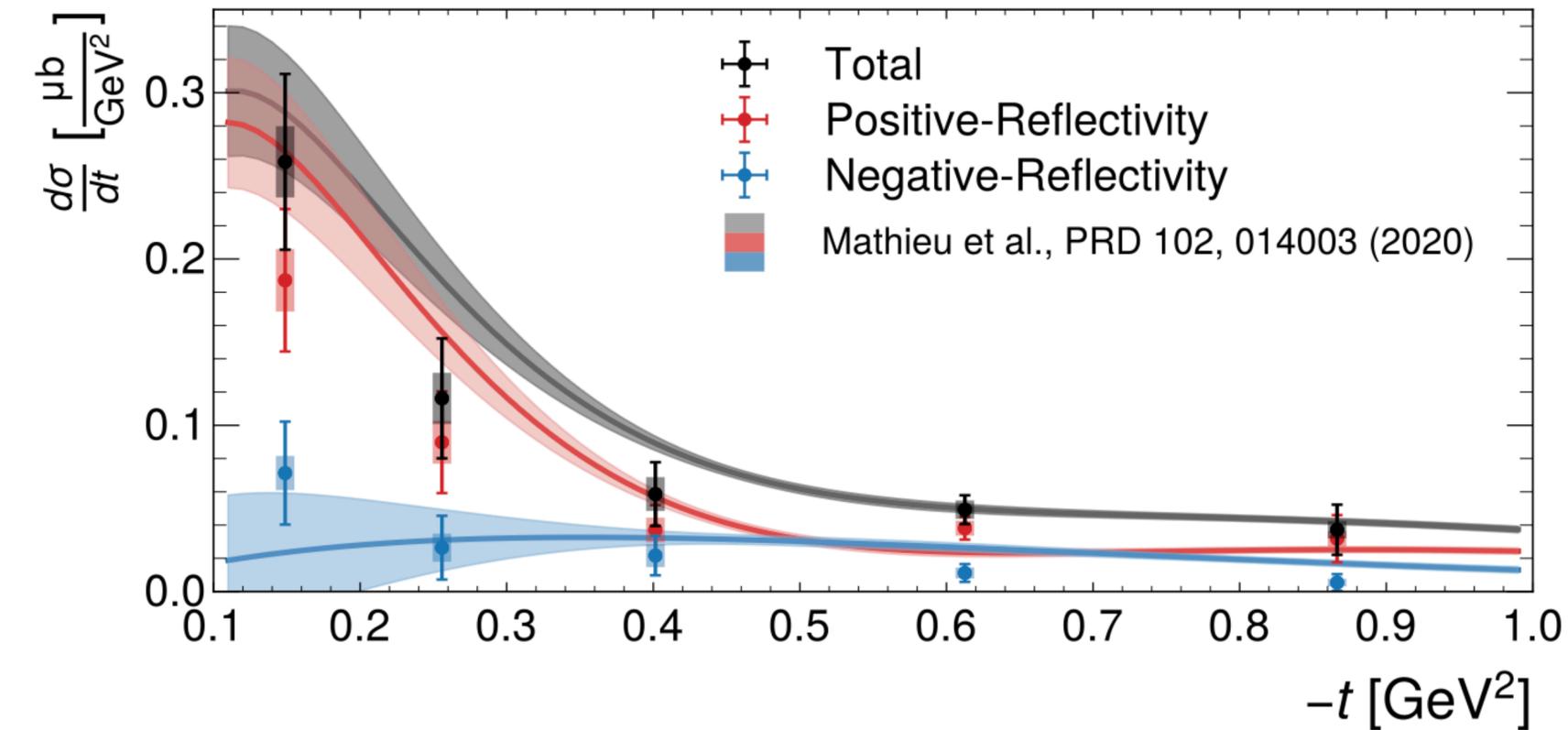
$\gamma p \rightarrow a_2(1320)p :$

$$\omega + \frac{1}{3}\rho$$

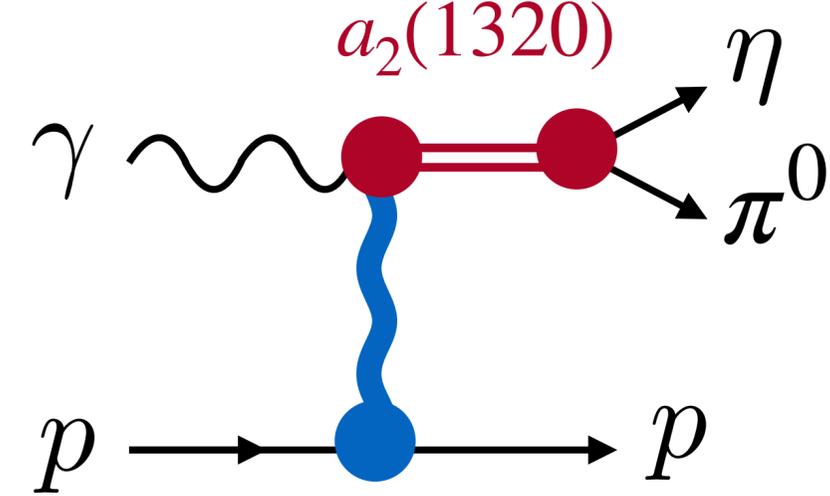


$\gamma p \rightarrow f_2(1270)p :$

$$\rho + \frac{1}{3}\omega$$



Strong $a_2(1320)$ signal in $\pi\eta$



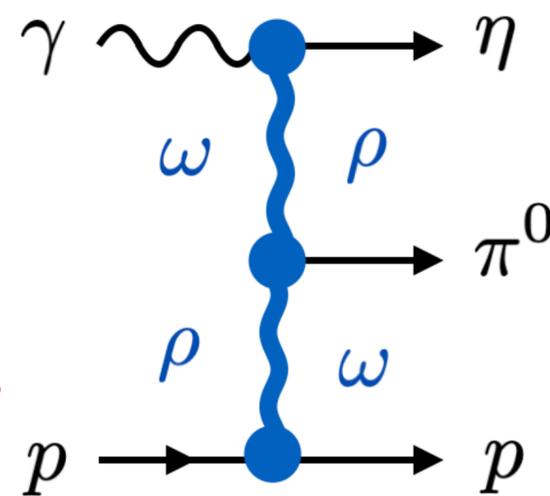
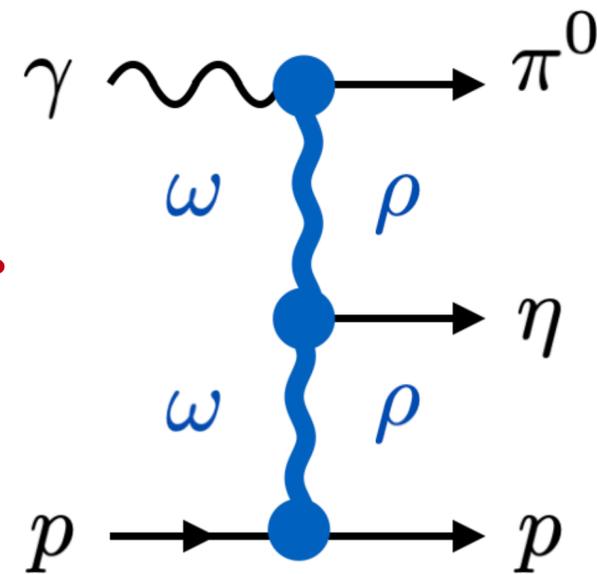
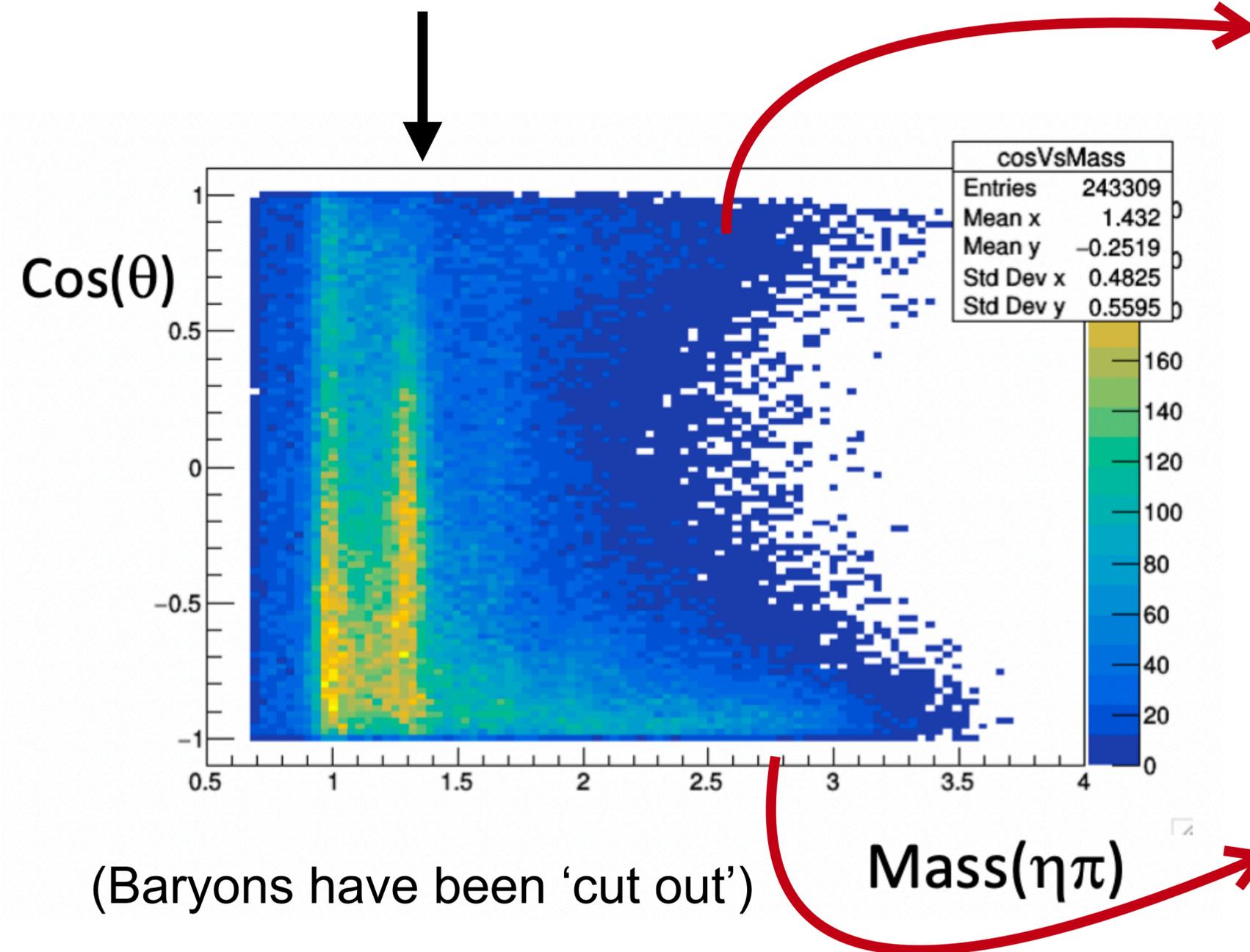
- Production can occur via exchange of
- vector meson (**positive reflectivity**) or
 - axial-vector meson (**negative reflectivity**)

Extraction of the cross-section

Extraction of all D-waves components

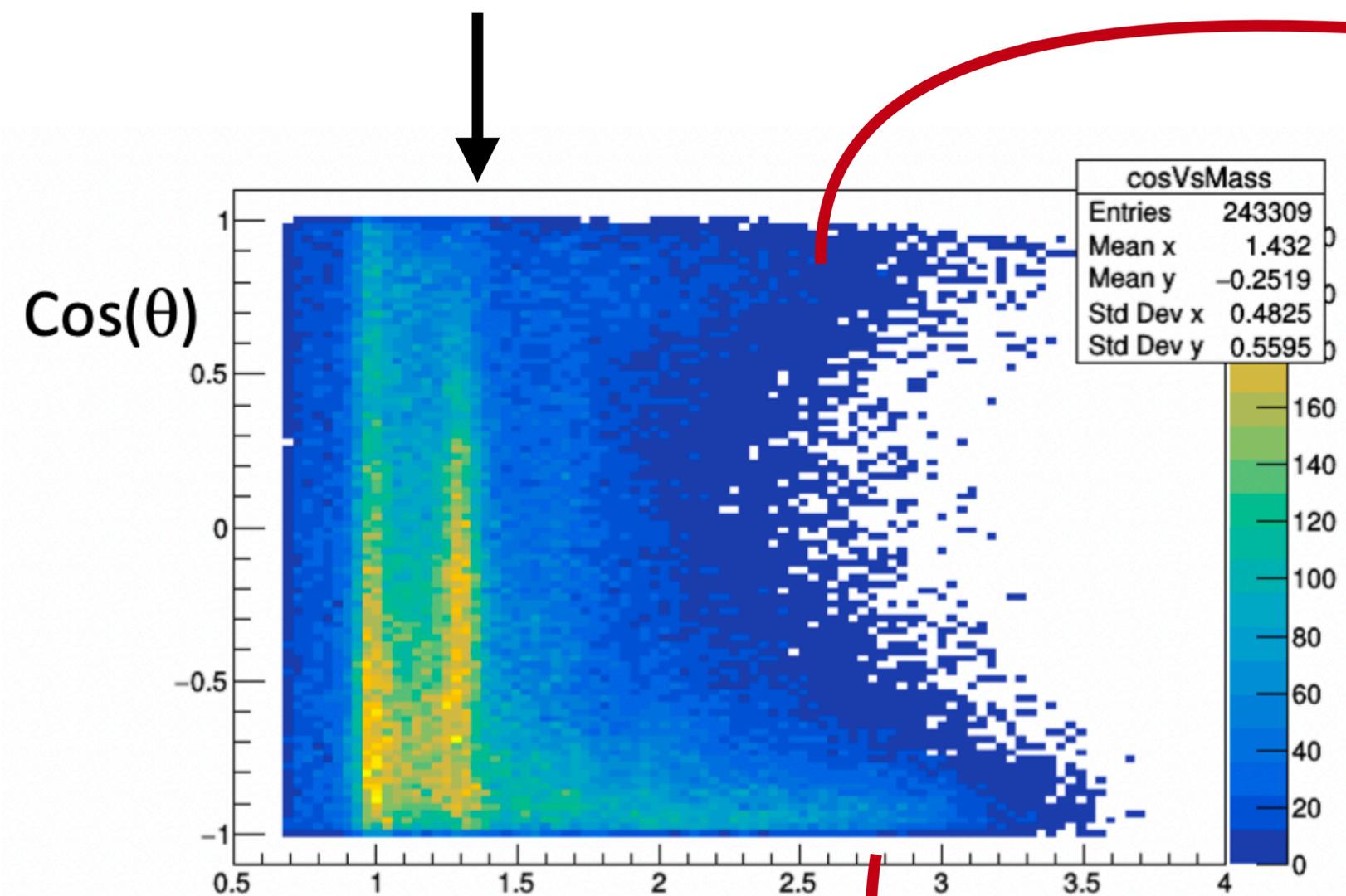
Double Regge @GlueX

$a_2(1320)$



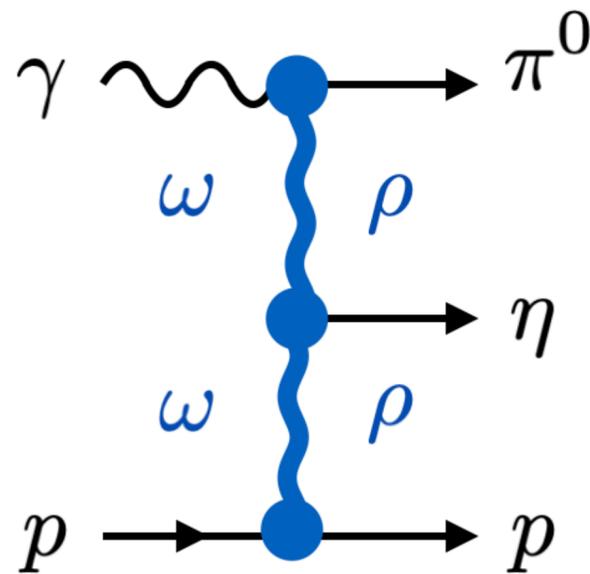
Double Regge @GlueX

$a_2(1320)$



(Baryons have been 'cut out')

Mass($\eta\pi$)

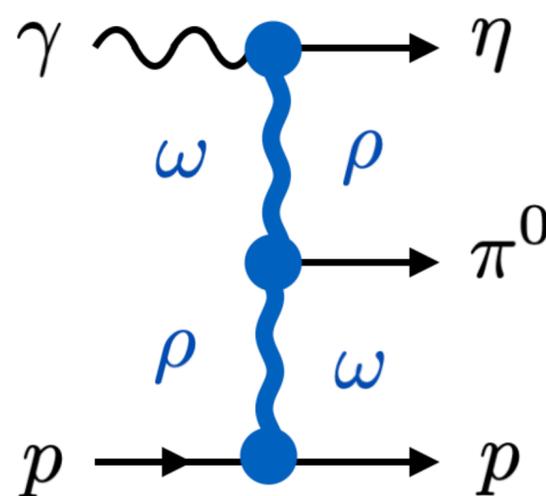


All couplings are known from decays!

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

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

$$\omega \rightarrow (\pi\pi)_\rho \pi$$



Or from SU(3) relations

$$g_{\rho\rho\eta} = g_{\omega\rho\pi} \cos \phi_\eta$$

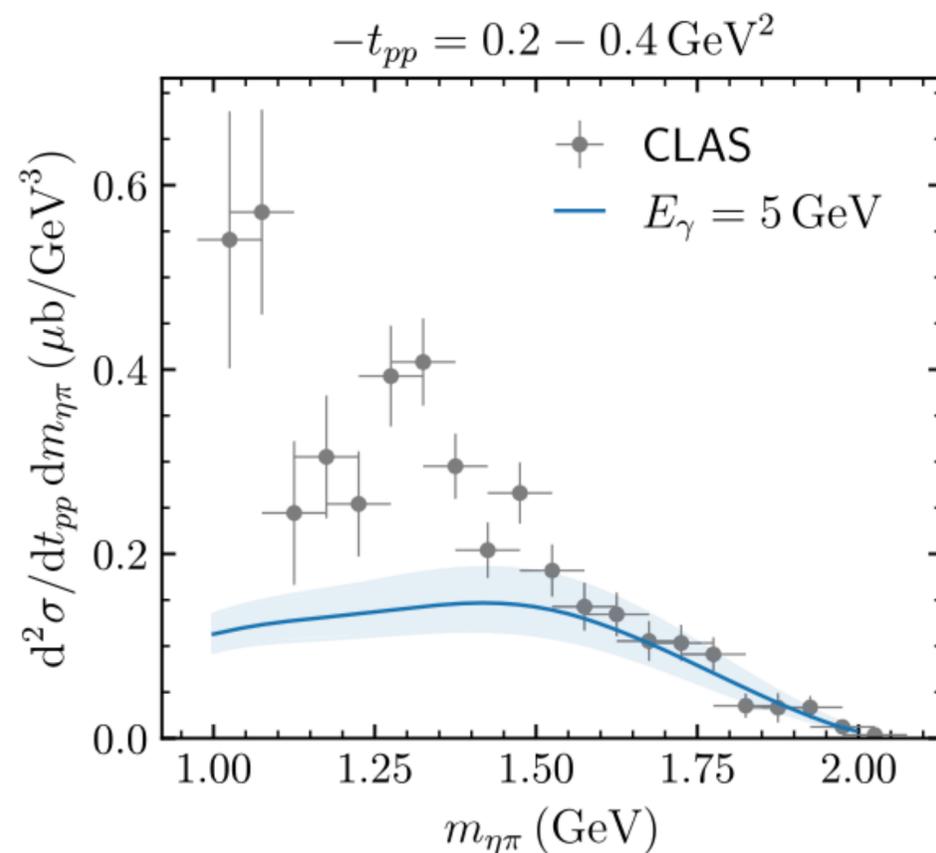
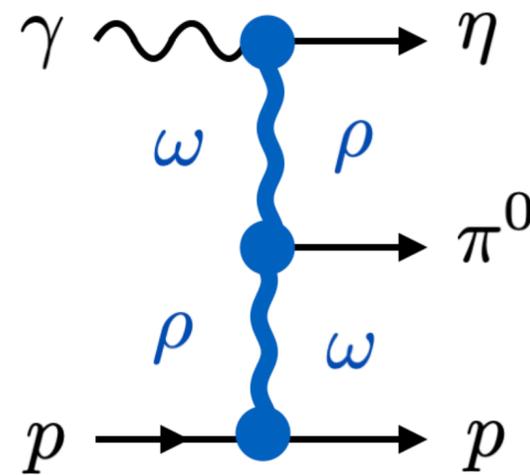
$$g_{\omega\omega\eta} = g_{\omega\rho\pi} \cos \phi_\eta$$

(Analogous formulas for η')

Double Regge @GlueX

Double Regge model including leading Regge poles with no free parameters

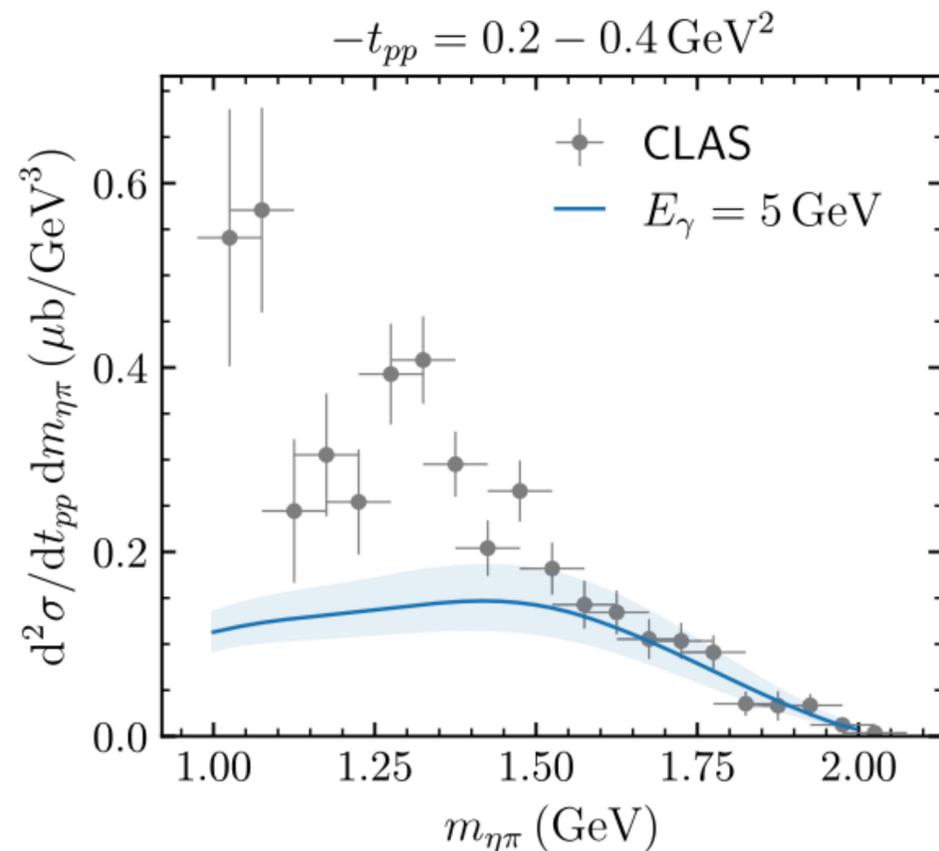
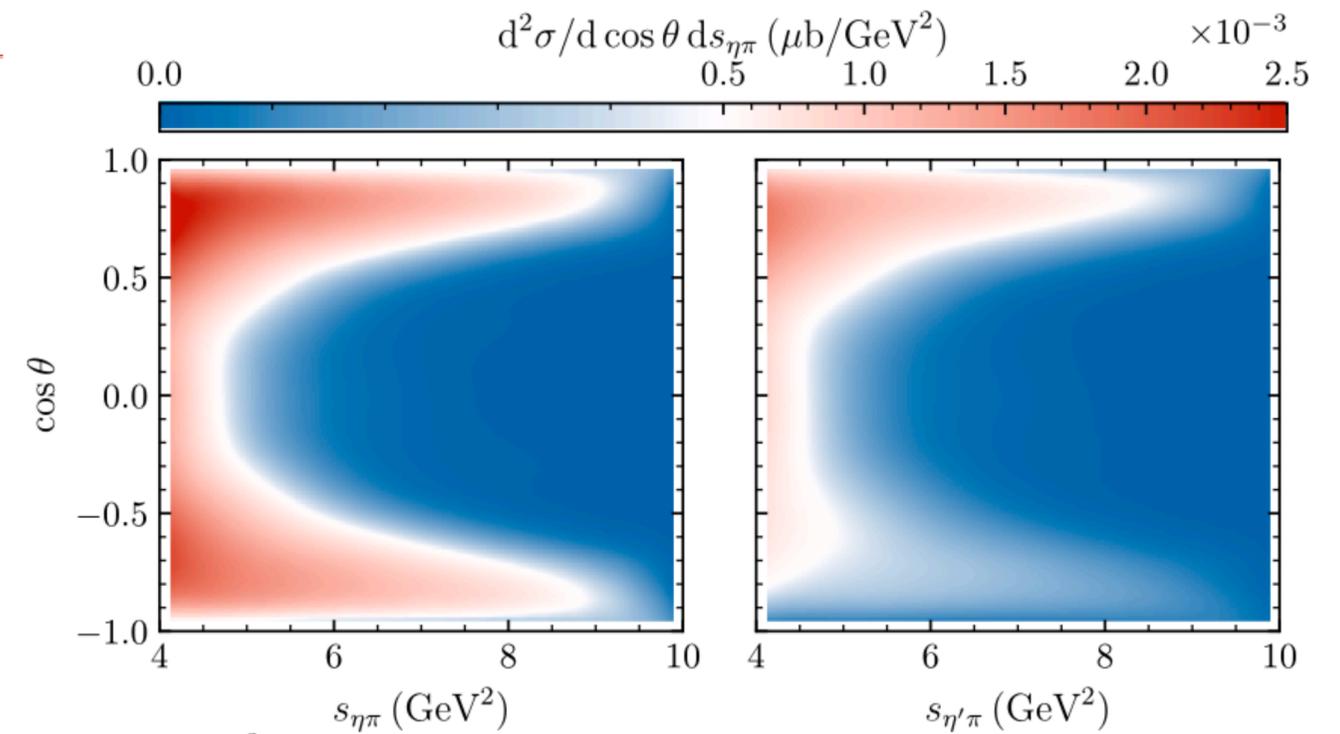
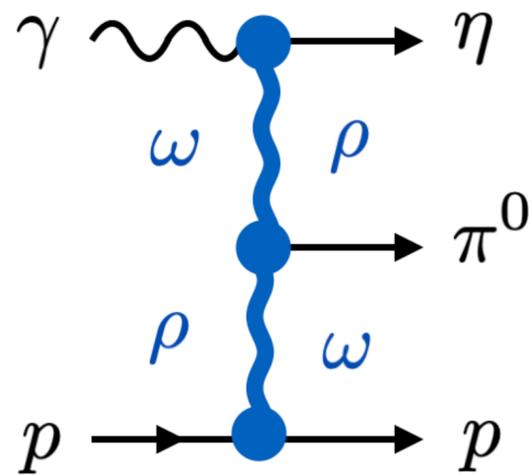
Compare predictions with CLAS data



Double Regge @GlueX

Double Regge model including leading Regge poles with no free parameters

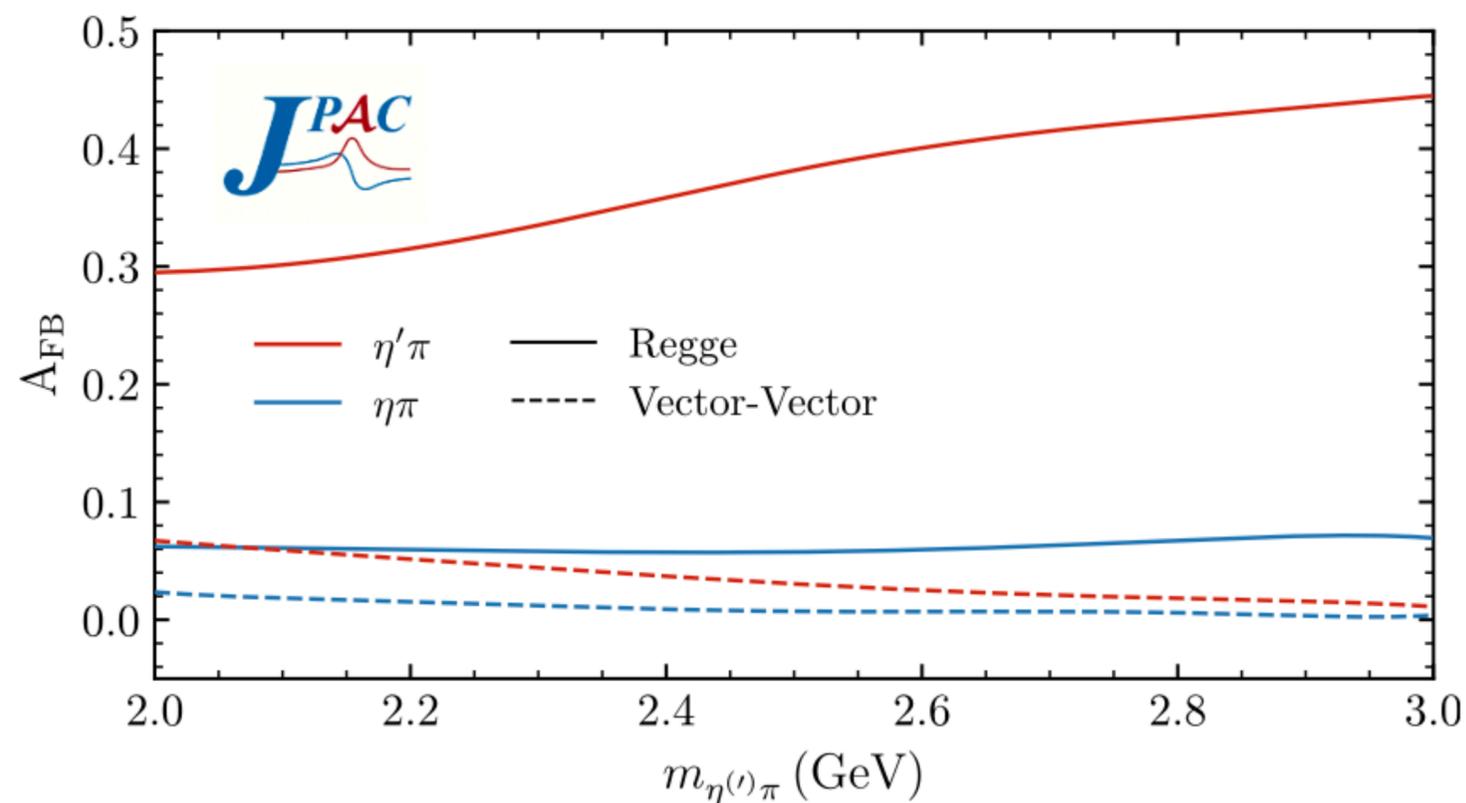
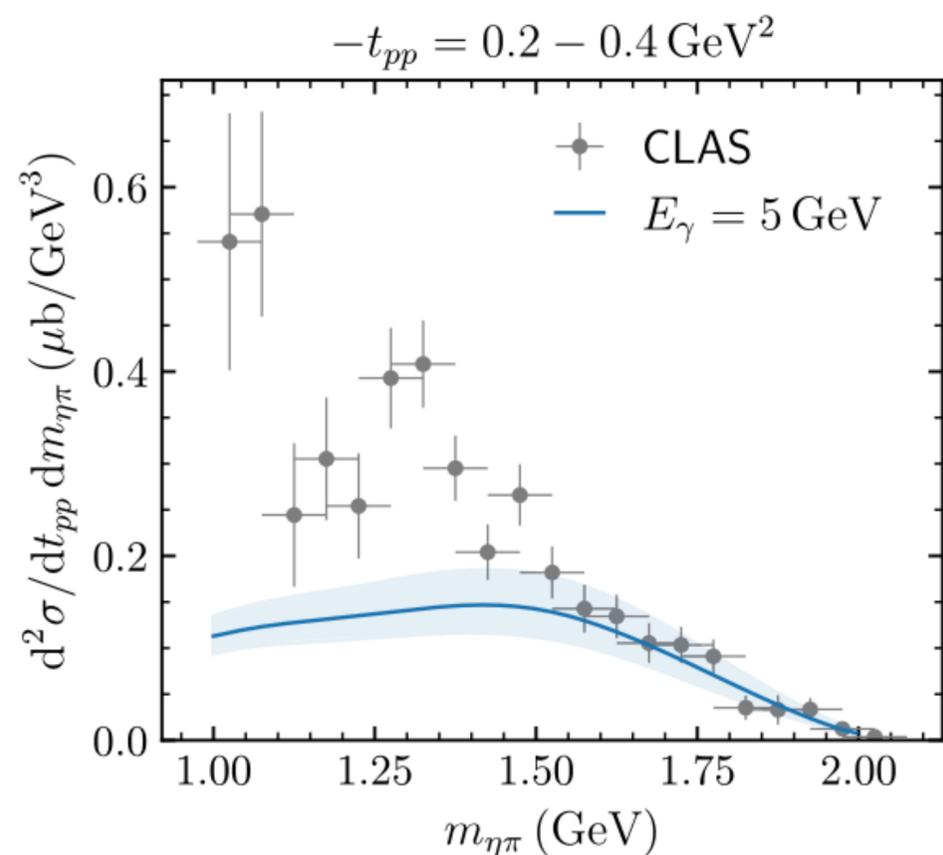
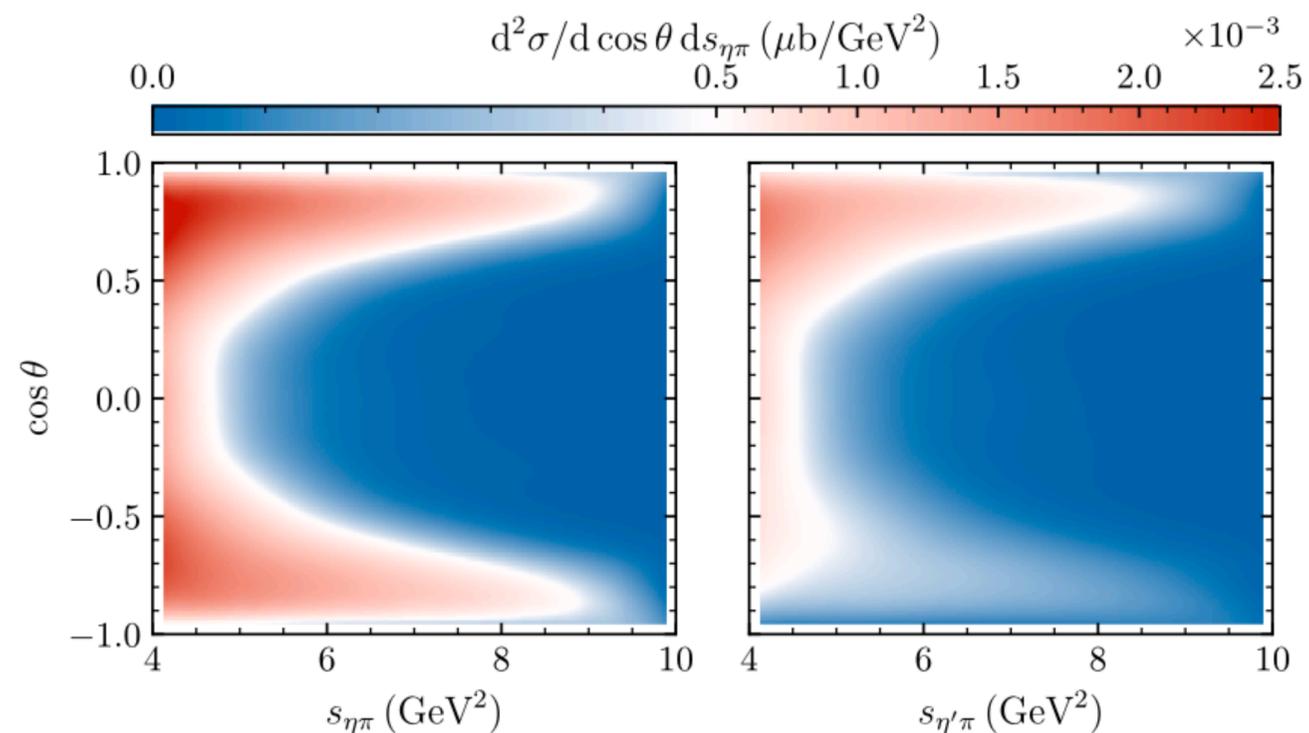
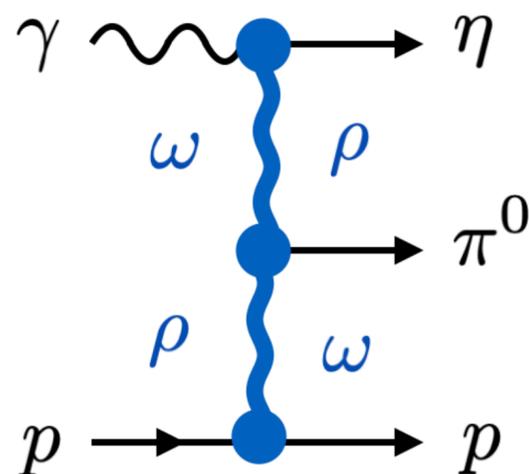
Compare predictions with CLAS data



Double Regge @GlueX

Double Regge model including leading Regge poles with no free parameters

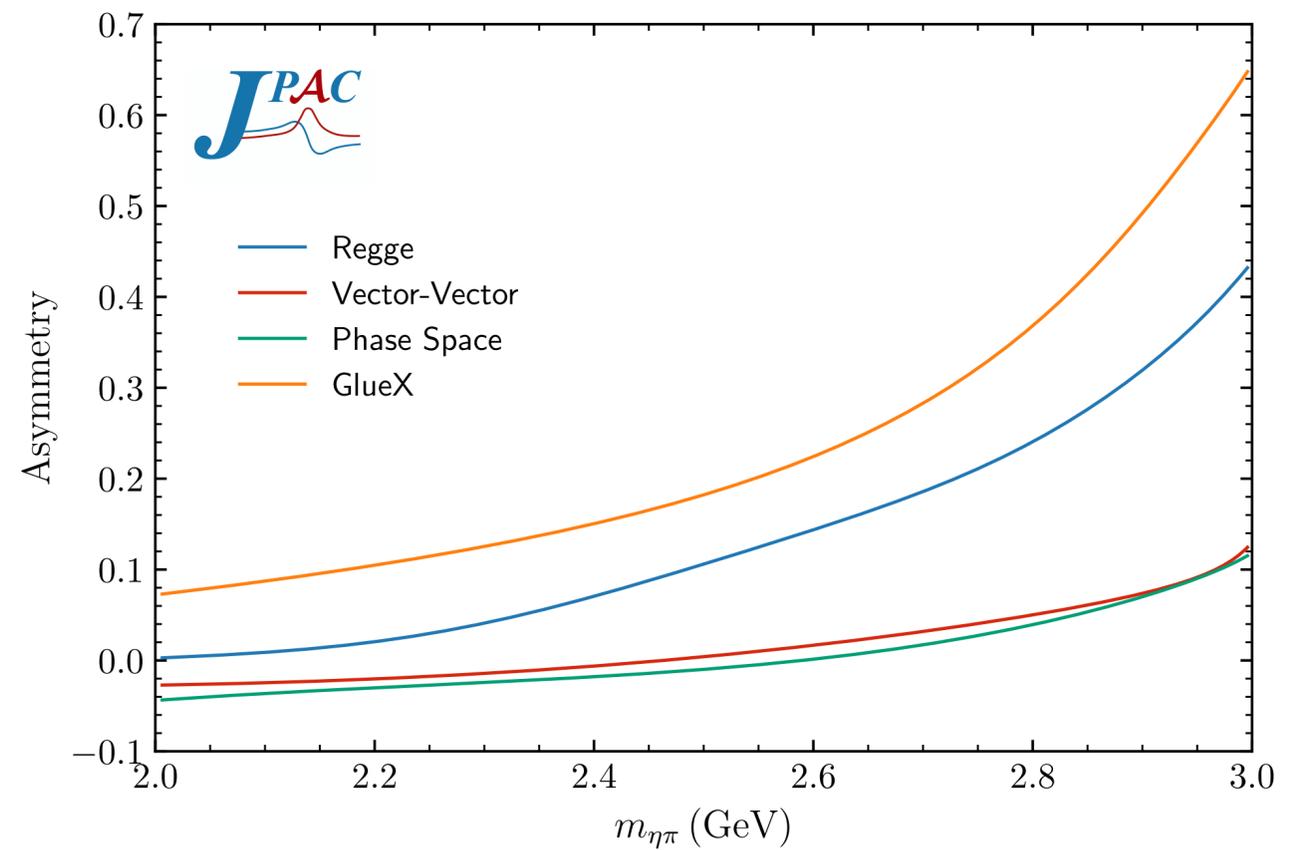
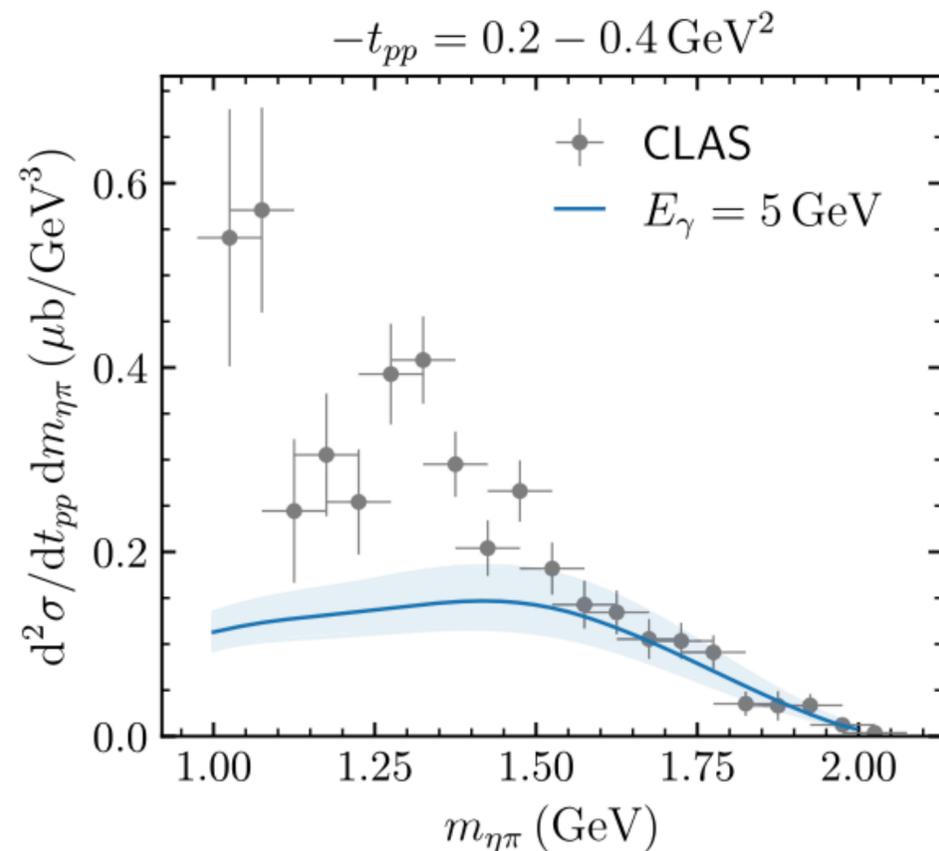
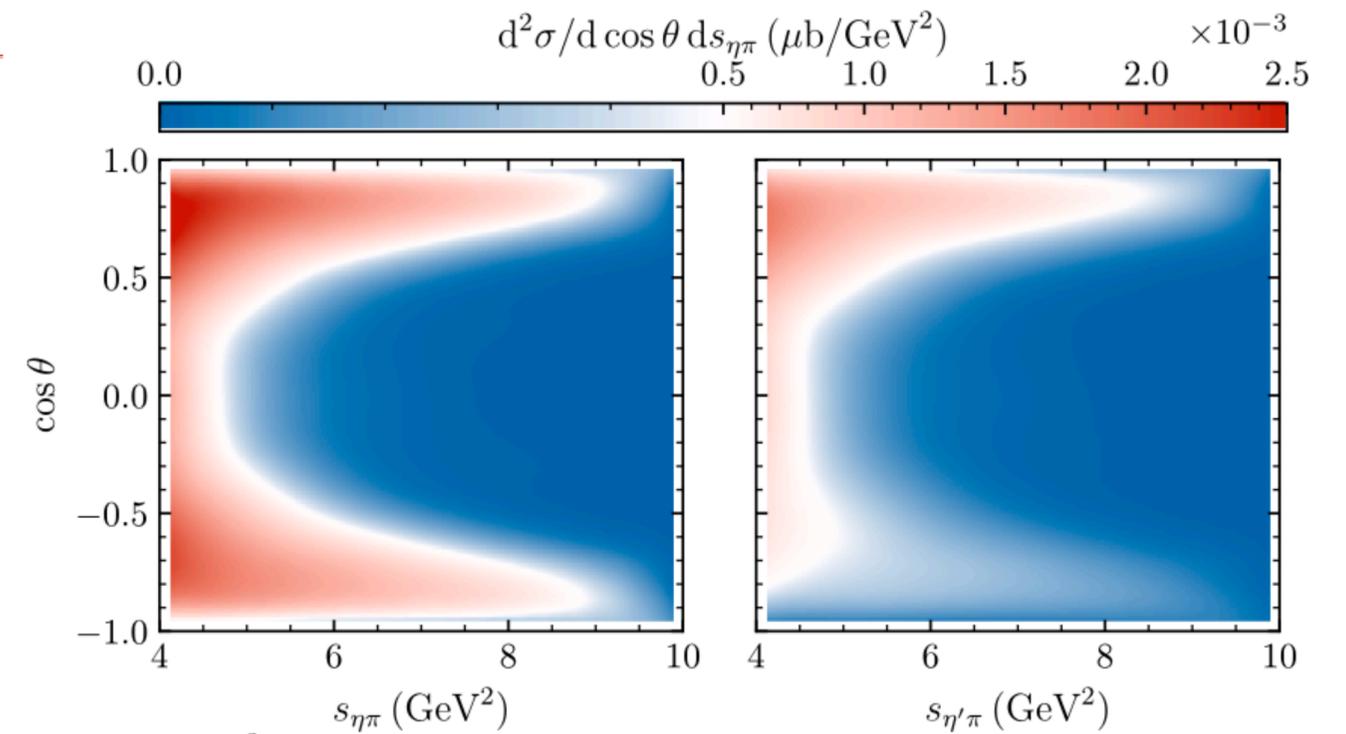
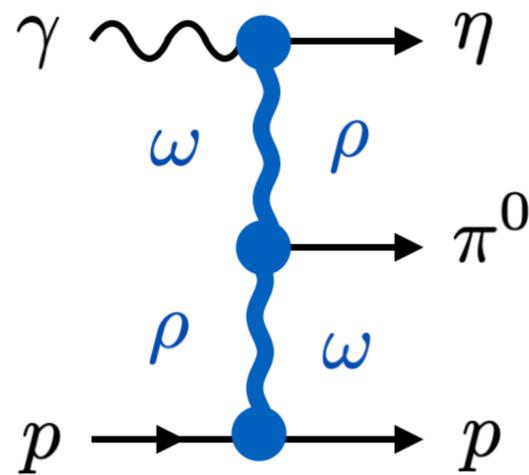
Compare predictions with CLAS data



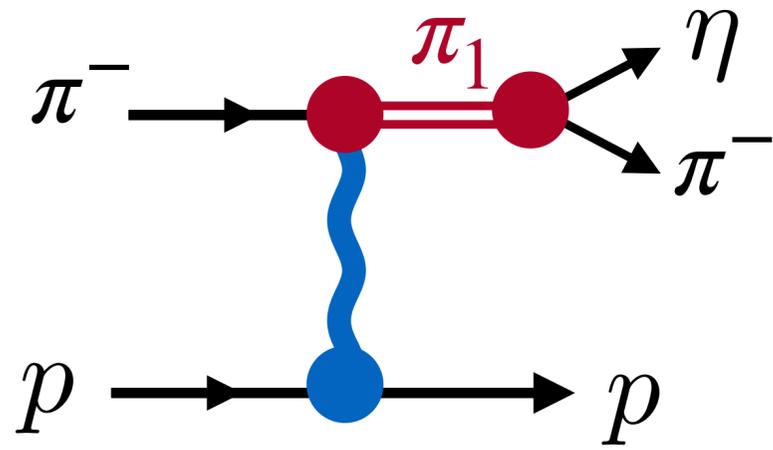
Double Regge @GlueX

Double Regge model including leading Regge poles with no free parameters

Compare predictions with CLAS data

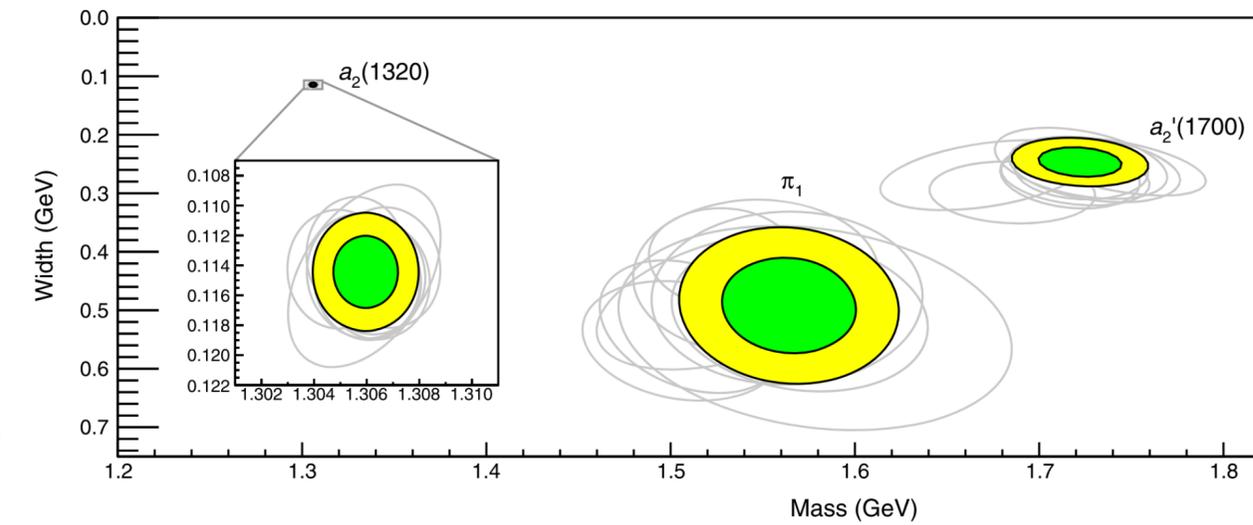


Summary

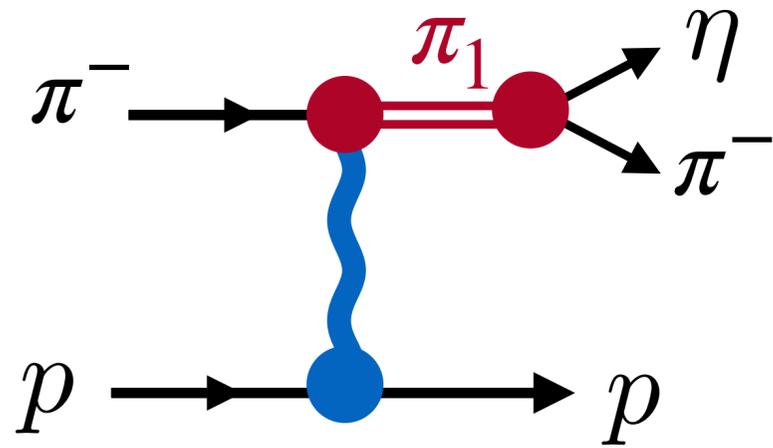


Reaction model for both
single Regge (resonances)
and double Regge region

Two regions connected by FESR

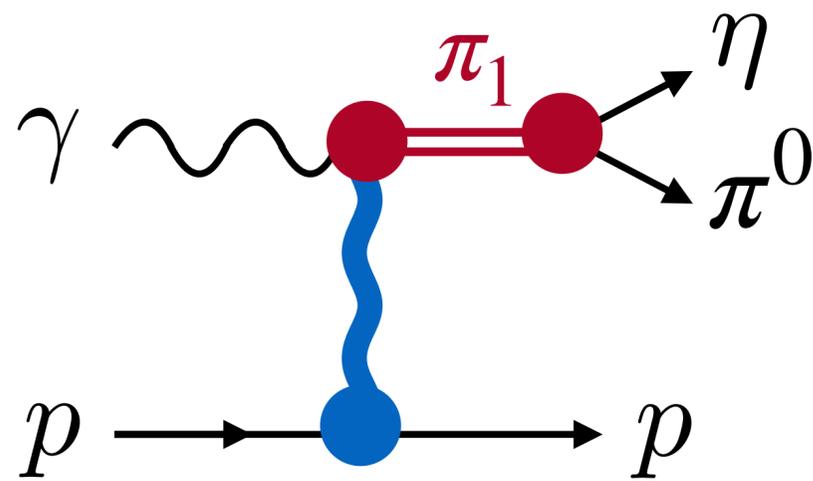
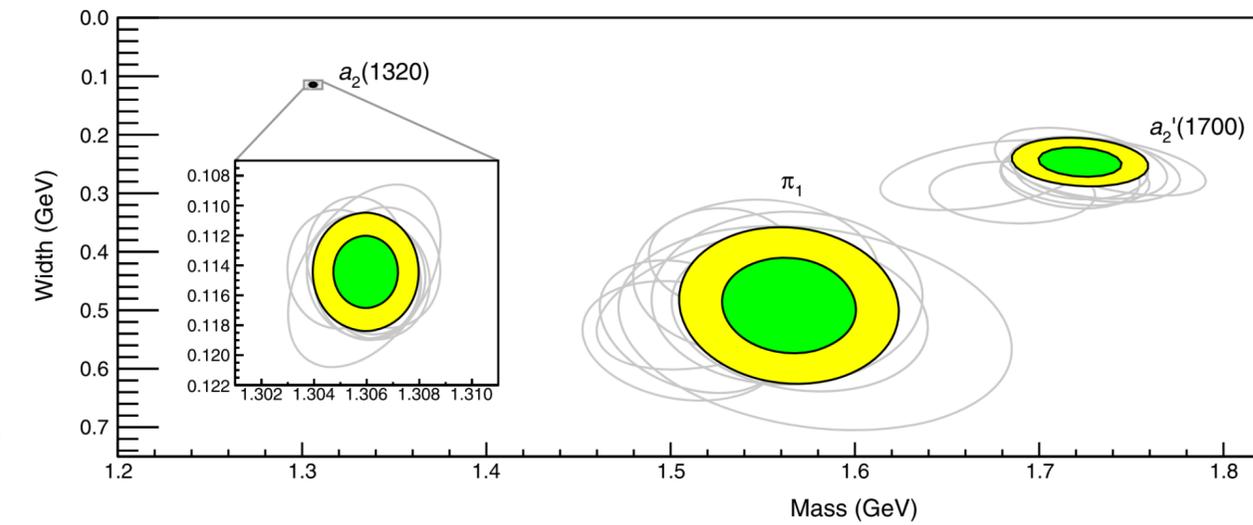


Summary

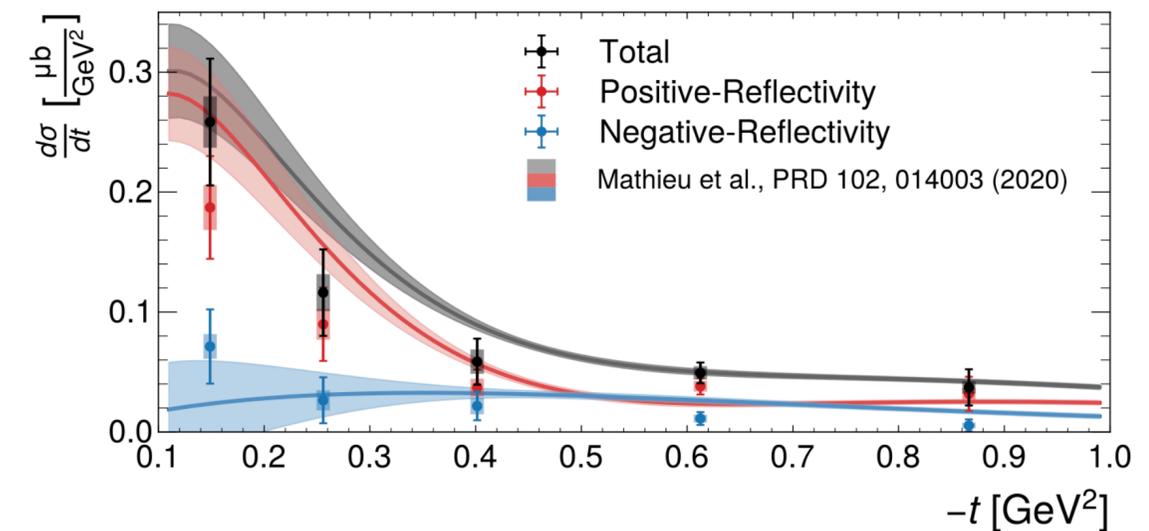


Reaction model for both single Regge (resonances) and double Regge region

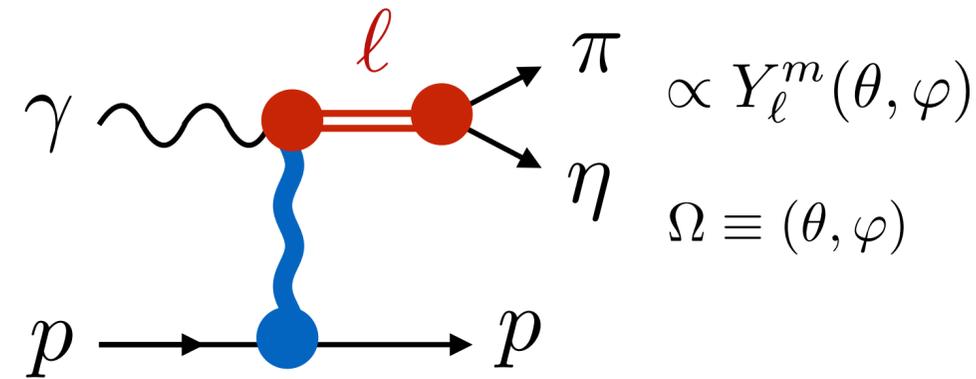
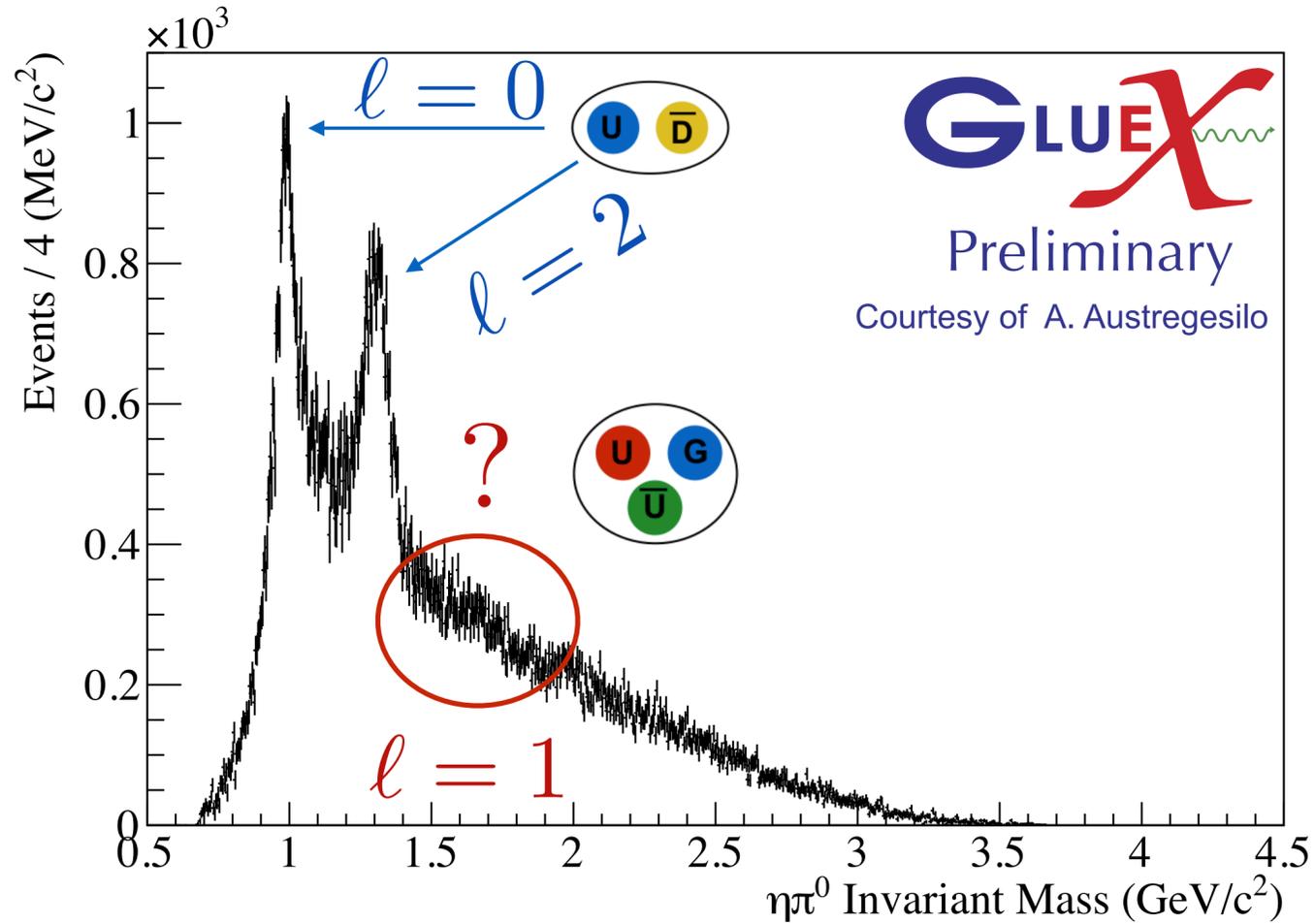
Two regions connected by FESR



Reaction model for both single Regge (only a2 resonance) and double Regge region

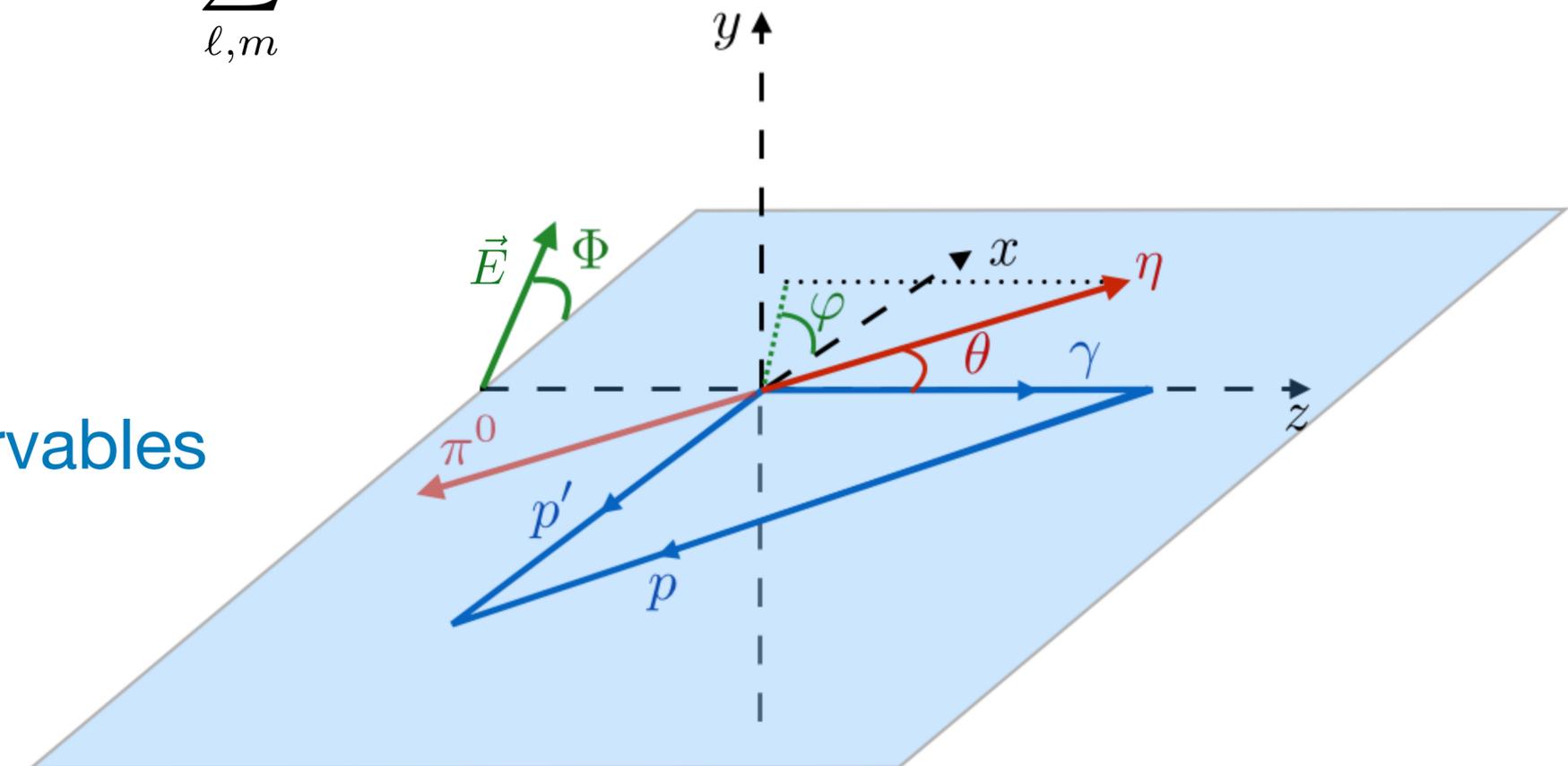


Angular Distribution



Polarized photon beam

$$I(\Omega, \Phi) \sim \left| \sum_{\ell, m} a_{\ell m} Y_\ell^m(\Omega) \right|^2$$



Relations between partial waves and observables

Observables sensitive to exotic mesons