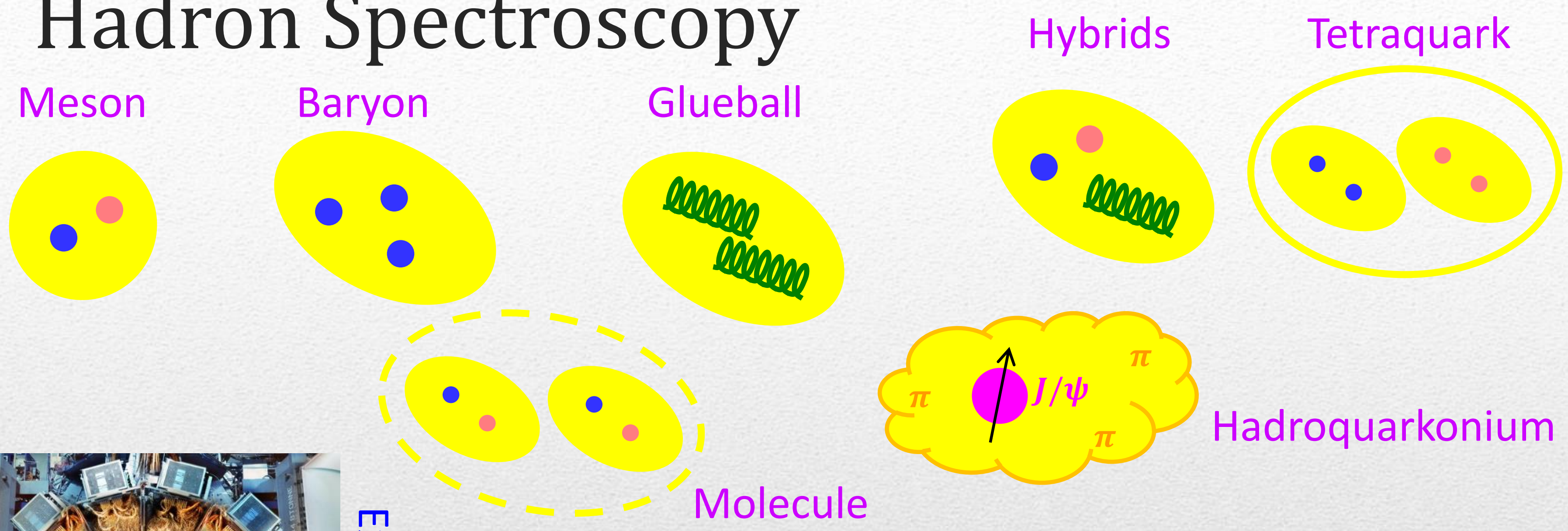
Update on JPAC activities

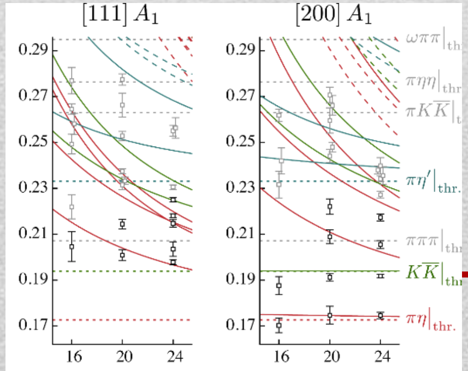
Alessandro Pilloni

CLAS Collaboration Meeting, July 12th, 2018

Hadron Spectroscopy



Experiment

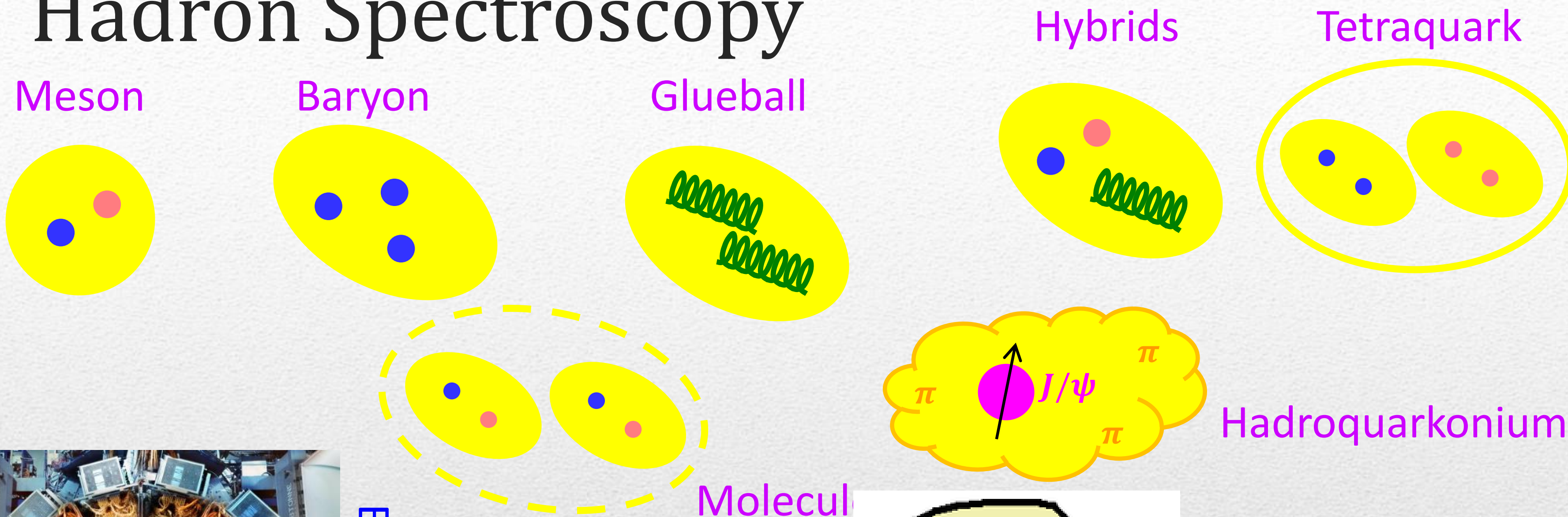


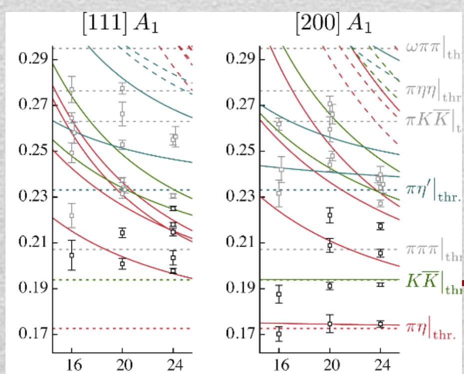
Lattice QCD

Data → Amplitude analysis → Properties, Model building

Interpretations on the spectrum leads to understanding fundamental laws of nature

Hadron Spectroscopy





Experiment

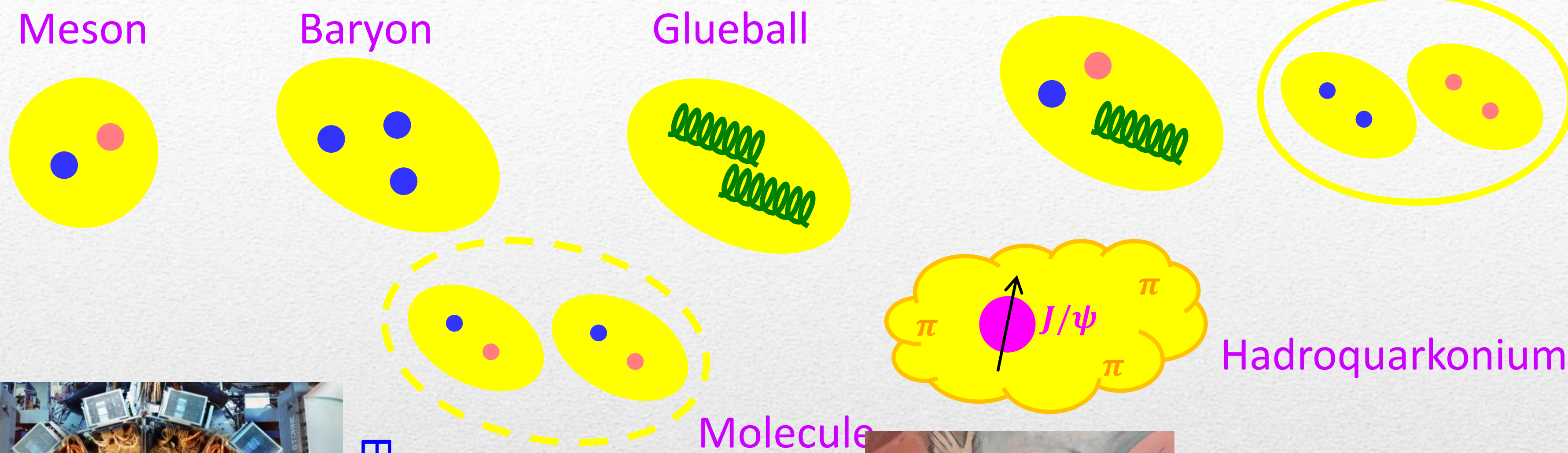
Lattice QCD

Data

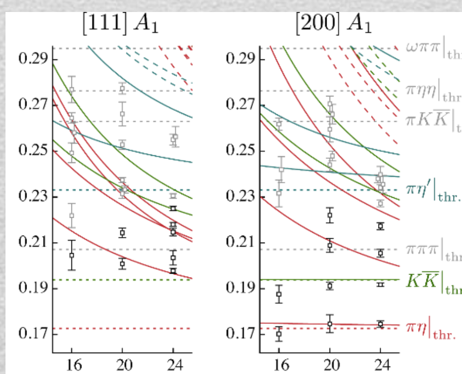
Properties,
Model building

Interpretations on the spectrum leads to understanding fundamental laws of nature

Hadron Spectroscopy



Experiment



Lattice QCD

Data

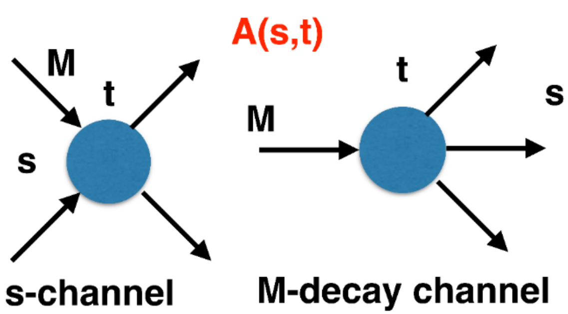
Properties, Model building

Improvement needed! With great statistics comes great responsibility!

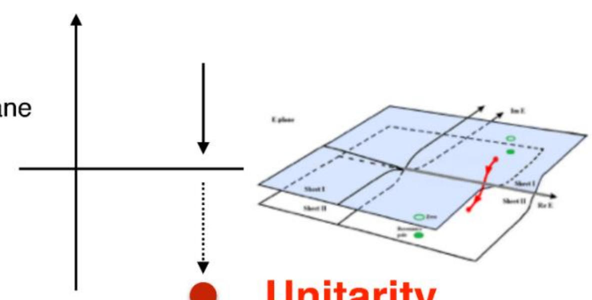
Outline

- Test of Regge Factorization
- Pion Photoproduction with FESR
- What is the formalism to search for resonances?
- Exotic resonances in $\eta\pi$
- (flash) Still Pentaquark photoproduction

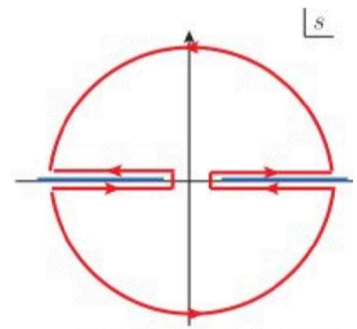
Kindly offered by «The S-matrix principles»



Crossing



Unitarity

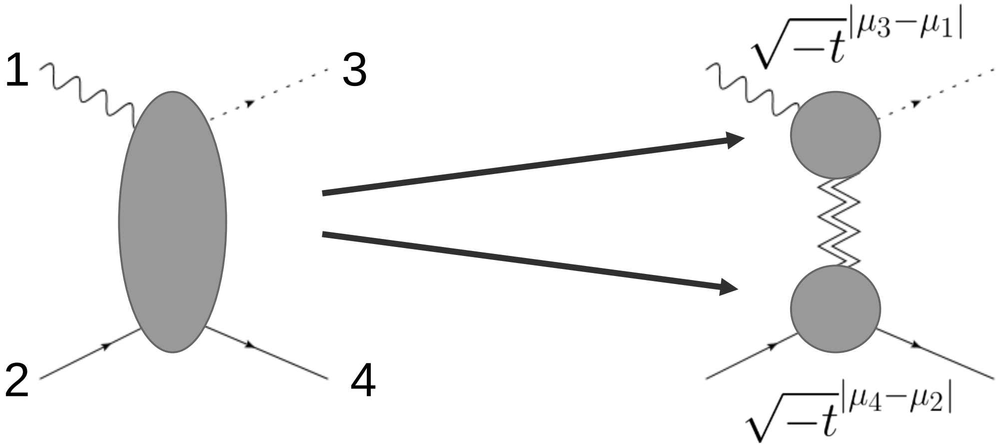


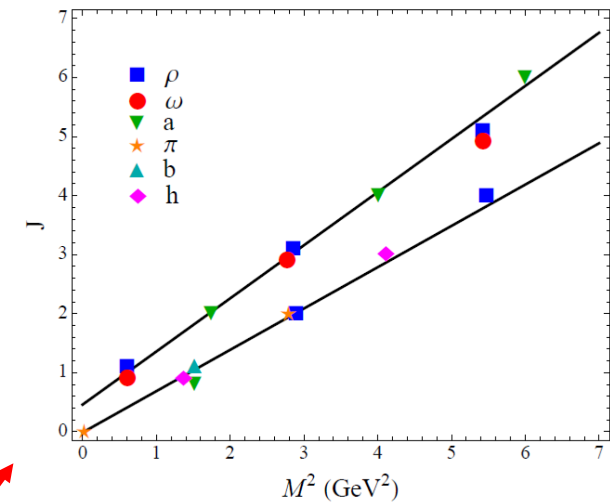
$$f_l(E) = \lim_{\epsilon\to 0} f_l(E + i\epsilon)$$

Analyticity

Factorization at high energies

- Regge poles: coupled-channel effect at high energies
- Contribution from photon and baryon vertex
- Suppresses amplitudes in forward direction ($t = 0$)





$$A_{\mu_4\mu_3\mu_2\mu_1}(s,t) = \beta^{\text{top}}_{\mu_3\mu_1}(t)\beta^{\text{bottom}}_{\mu_4\mu_2}(t)R(s,t)$$

$$s^{\alpha(t)}$$

Global Regge analysis

J. Nys et al. (JPAC), arXiv:1806.01891

- Test the range of validity of factorization, using minimal models (no absorption, no cuts)
- We consider all process with meson beam (more constrained)
- We consider charge exchanges, when no π contributes
- First fit with $SU(3)$ and EXD constraints, then relaxed

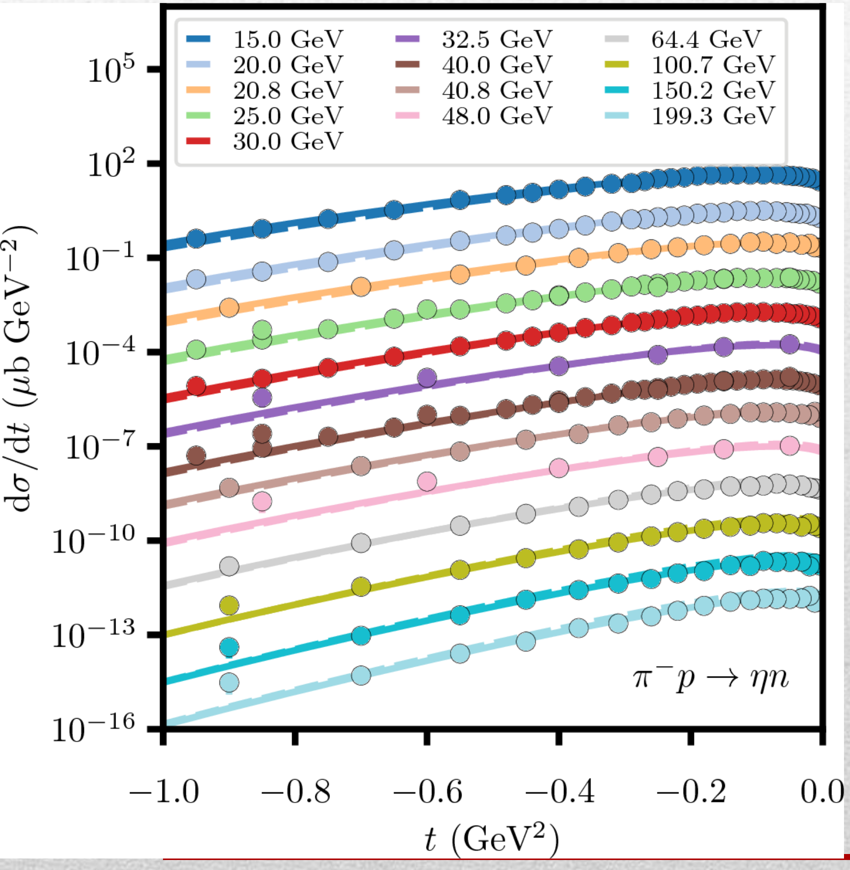
Reaction
$\pi^+ p \to X$
$K^\pm N \to X$
$\pi^- p \to \pi^0 n$
$\pi^+ p \to \pi^0 \Delta^{++}$
$\pi^- p \to \eta n$
$\pi^- p \to \eta' n$
$\pi^+ p \to \eta \Delta^{++}$
$K^+ n \to K^0 p$
$K^- p \to \overline{K}^0 n$
$K^+ p \to K^0 \Delta^{++}$
$K^- n \to \overline{K}^0 \Delta^-$
$K^- p \to \overline{K}^0 \Delta^0$
$K^- p \to \pi^- \Sigma^{*+}$
$K^- p \to \pi^- \Sigma^+$
$K^- p \to \pi^0 \Lambda$
$\pi^+ p \to K^+ \Sigma^{*+}$
$\pi^+ p \to K^+ \Sigma^+$
$\pi^- p \to K^0 \Lambda$
$\pi^- p \to K^0 \Sigma^0$
$K^- p \to \eta \Lambda$
$K^- p \to \eta' \Lambda$
$\pi^- p \to \omega n$
$\pi^+ n \to \omega p$

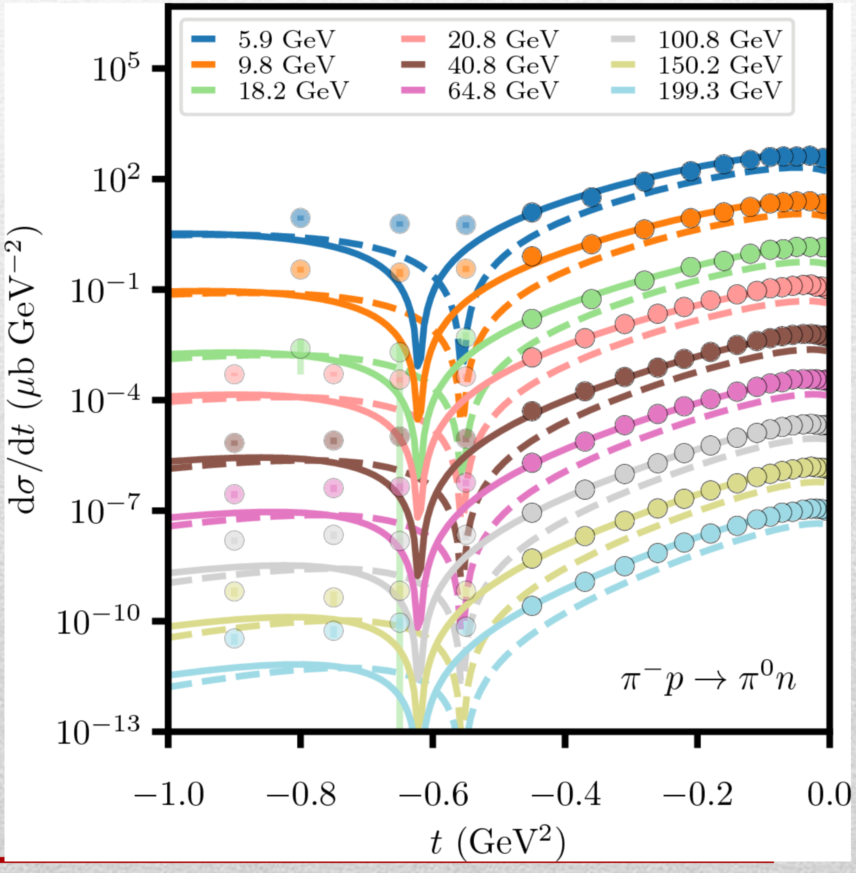
Many different reactions considered

Global Regge analysis

J. Nys et al. (JPAC), arXiv:1806.01891

- η production works fine until $t \sim -0.8~\mathrm{GeV}^2$
- For π the presence of a zero require a more detailed model, things work until $t \sim -0.5~\mathrm{GeV}^2$

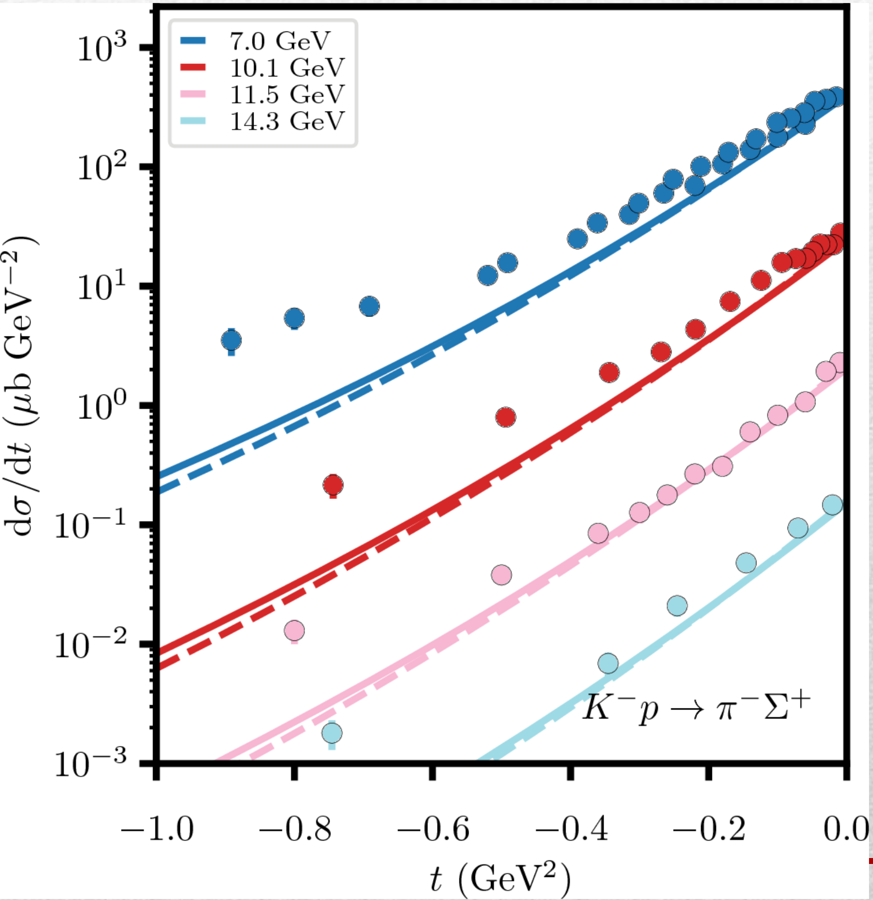


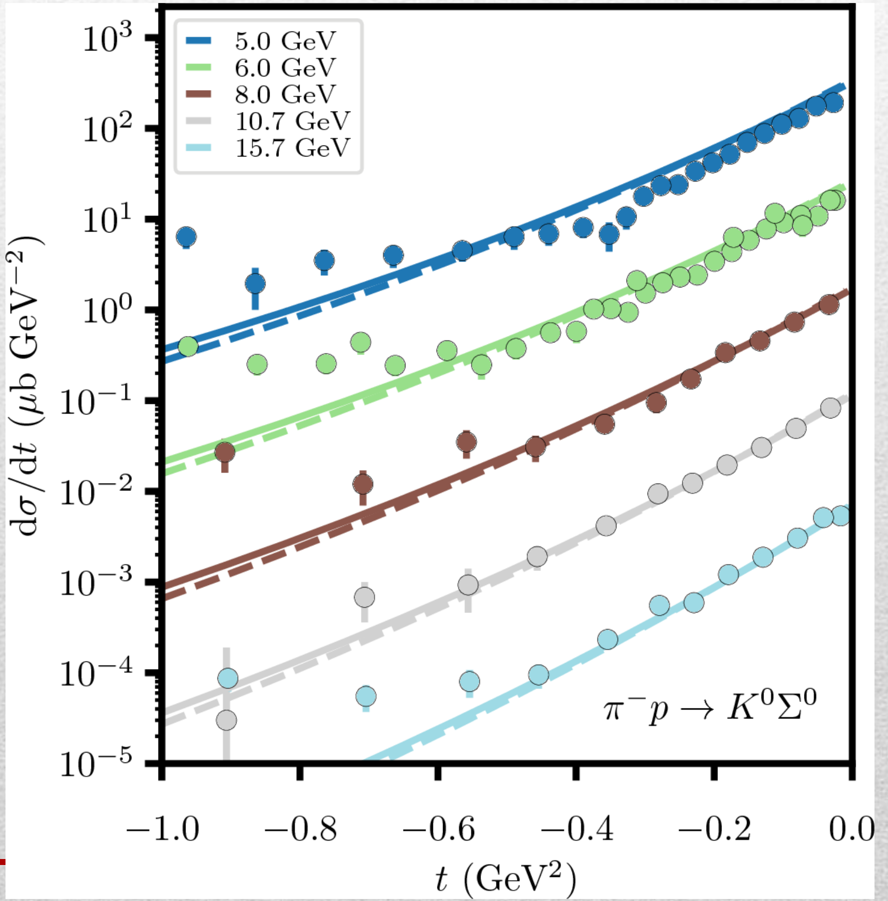


Global Regge analysis

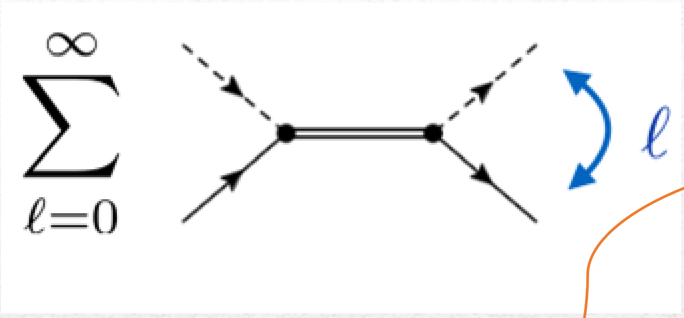
J. Nys et al. (JPAC), arXiv:1806.01891

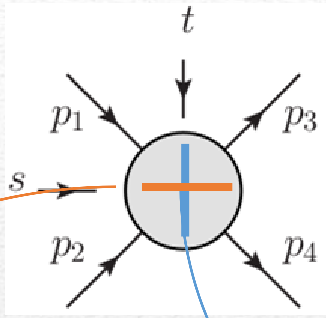
- For strangeness exchange, the behavior is flatted than expected
- Other exchanges (poles, cuts…) needed, hard to constrain
- Trustworthy until $t \sim -0.5\ \text{GeV}^2$

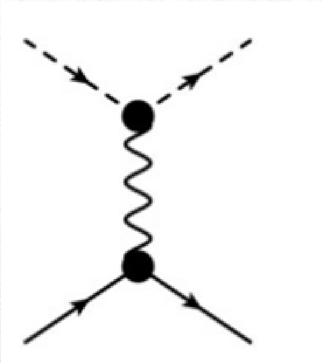


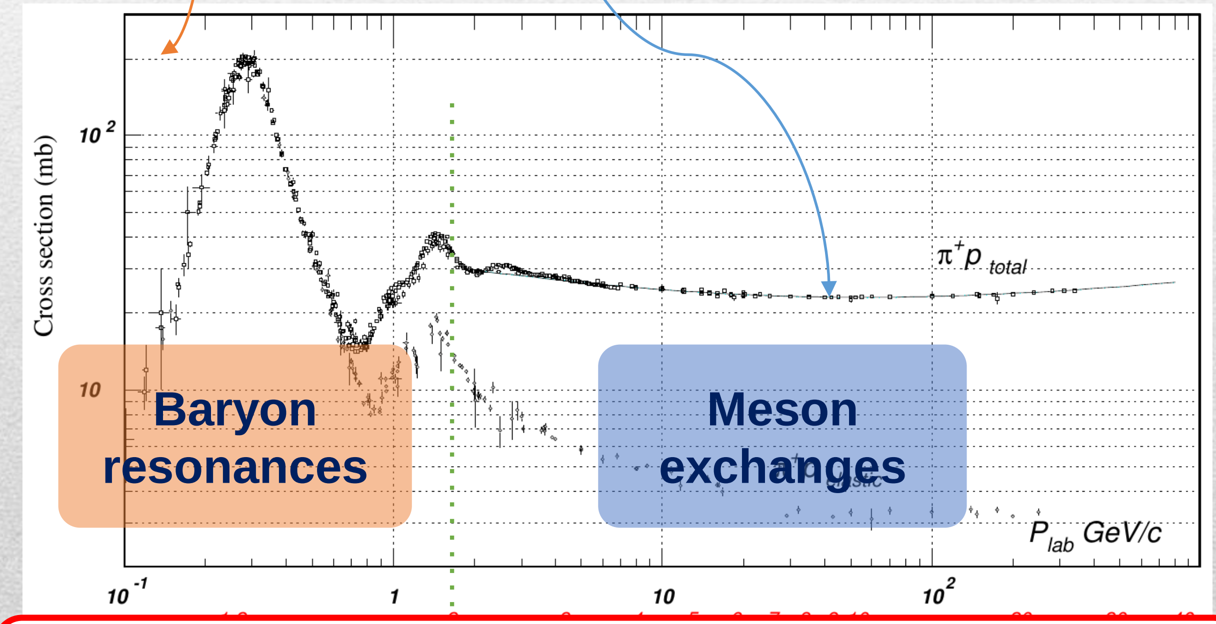


π photoproduction with FESR







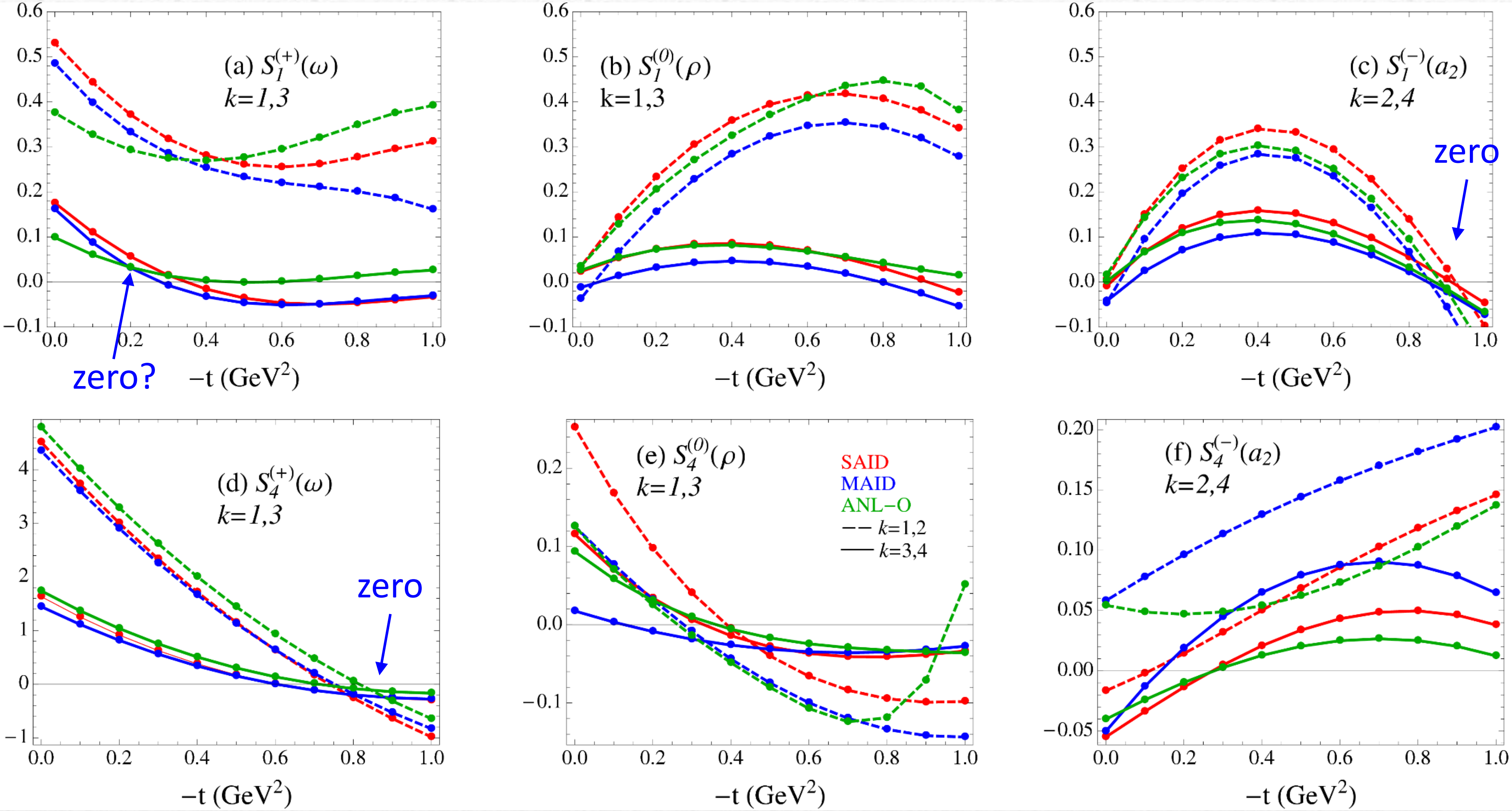


Connect low- and high-energy dynamics

π photoproduction with FESR

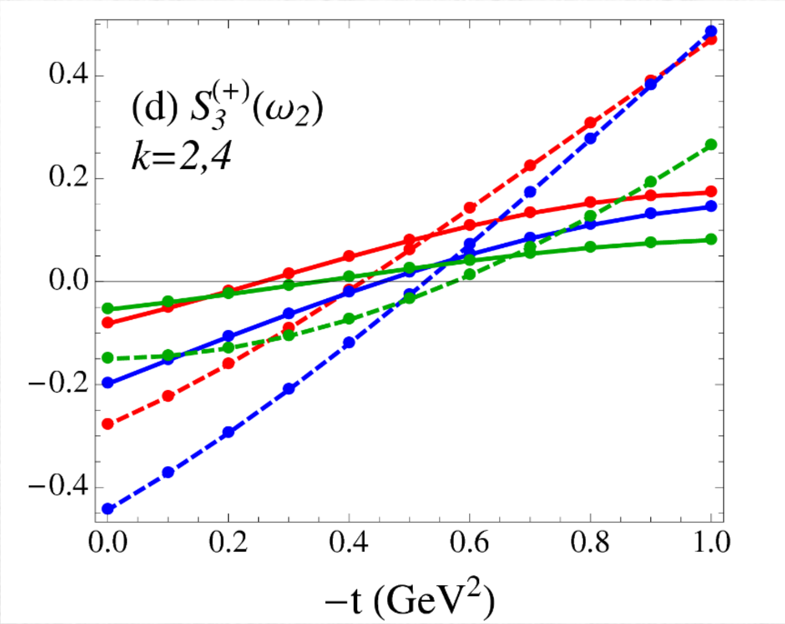
V. Mathieu et al. (JPAC), arXiv:1806.01891

Calculate moments from low energy models



π photoproduction with FESR

V. Mathieu et al. (JPAC), arXiv:1806.01891



FESR can also help improving the low-energy models
For example, models imply an unexpected large contribution from ω_2 exchanges
If that is not the case, the J^P of some resonances (as $N(1680)$) must have reconsidered

What is the formalism to search for resonances?

M. Mikhasenko, AP, J. Nys *et al.* (JPAC), EPJC78, 3, 229
AP, J. Nys, M. Mikhasenko *et al.* (JPAC), arXiv:1805.02113

The literature abounds with discussions on the optimal approach to construct the amplitudes for the hadronic reactions

- Helicity formalism

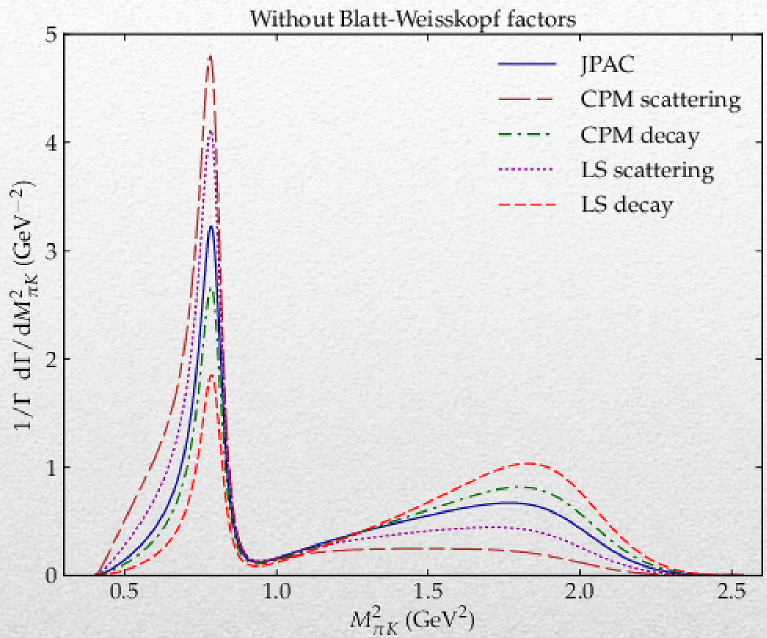
  Jacob, Wick, Annals Phys. 7, 404 (1959)

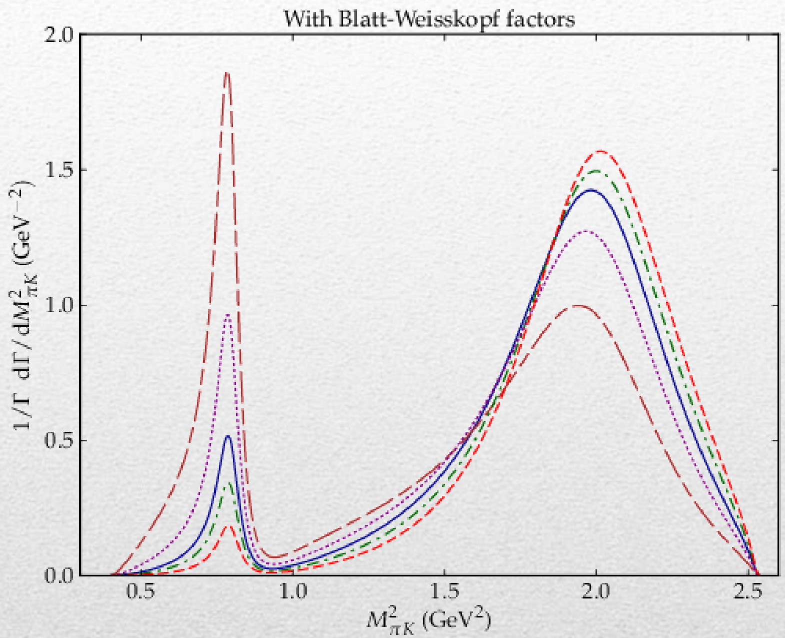
- Covariant tensor formalisms

  Chung, PRD48, 1225 (1993)
  Chung, Friedrich, PRD78, 074027 (2008)
  Filippini, Fontana, Rotondi, PRD51, 2247 (1995)
  Anisovich, Sarantsev, EPJA30, 427 (2006)

The common lore is that the former one is nonrelativistic, especially when expressed in terms of LS couplings
and the latter takes into account the proper relativistic corrections

General expression and comparison





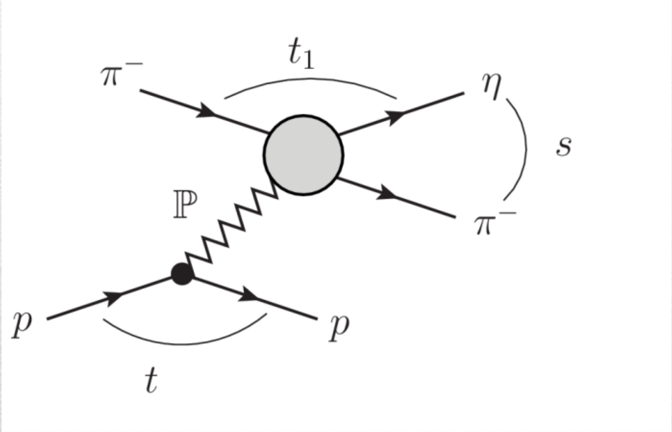
We use analyticity to check the properties of the formalisms on the market
We pointed out some inconsistencies in the Chung/Bonn-Gatchina formalisms

- Violation of crossing symmetry
- Misedintification of some of spin-orbit couplings
- Violation of Mac Dowell (CPT) symmetry

Searching for resonances in $\eta\pi$

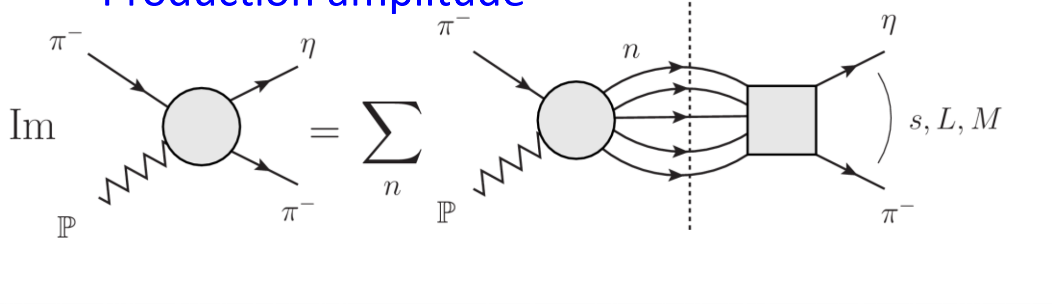
A. Jackura, M. Mikhasenko, AP *et al.* (JPAC & COMPASS), PLB779, 464-472

- The $\eta\pi$ system is one of the golden modes for hunting hybrid mesons
- We build the partial wave amplitudes according to the N/D method
- We test against the D-wave data, where the a_2 and the a_2' show up

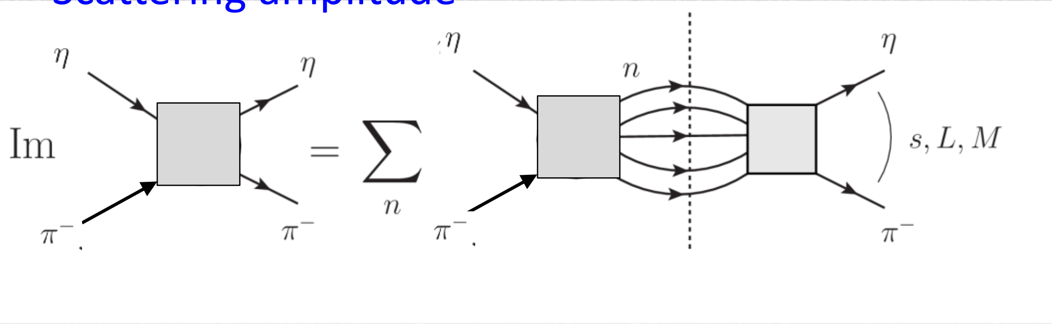


(easier than photoproduction, Factorization well established)

Production amplitude



Scattering amplitude



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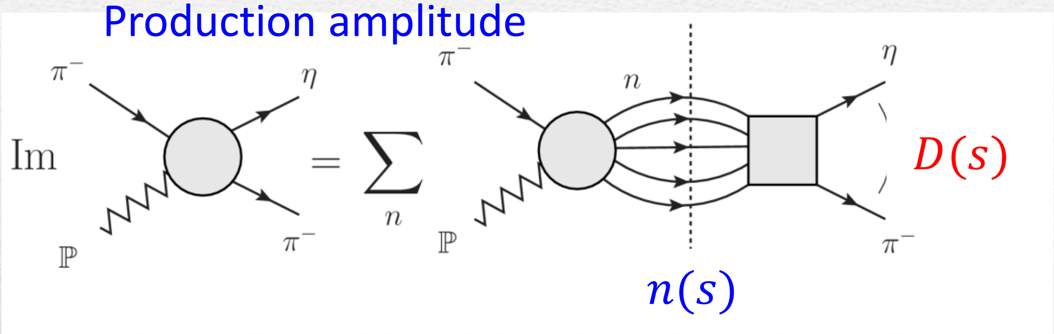
$$t(s) = \frac{N(s)}{D(s)}$$

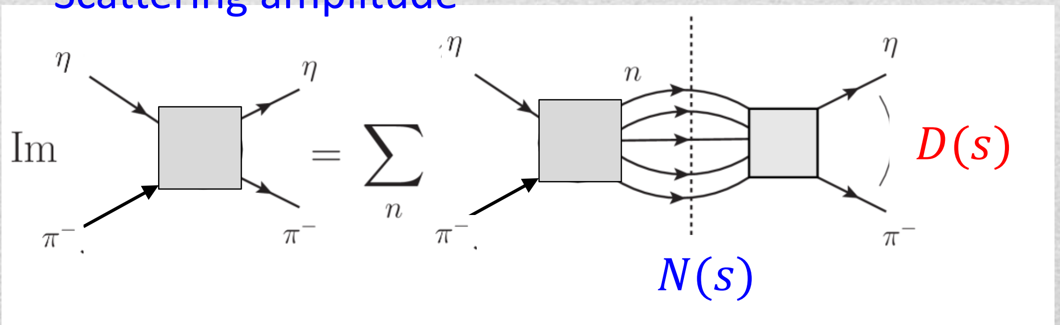
The $D(s)$ has only right hand cuts;
it contains all the Final State Interactions constrained by unitarity → universal

$$\mathrm{Im}\, D(s) = -\rho\, N(s)$$

Production amplitude



Scattering amplitude



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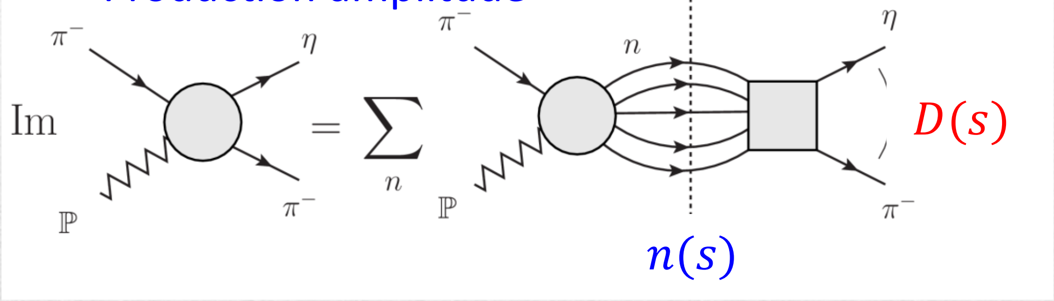
A. Jackura, M. Mikhasenko, AP *et al.* (JPAC & COMPASS), PLB779, 464-472

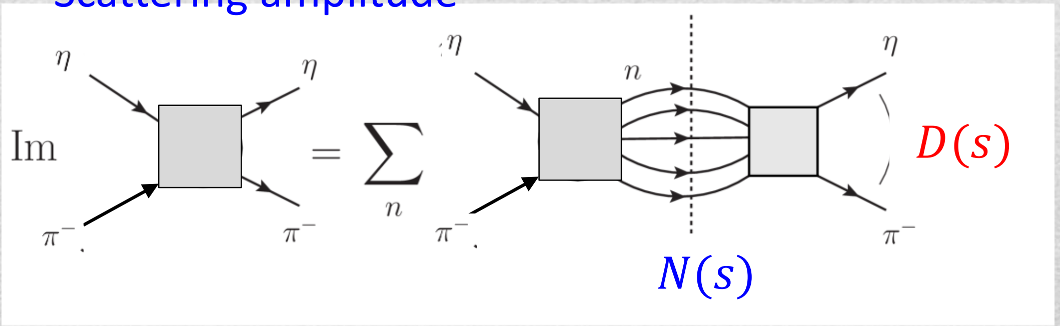
$$t(s) = \frac{N(s)}{D(s)}$$

The $n(s), N(s)$ have left hand cuts only, they depend on the exchanges → process-dependent, smooth

Production amplitude



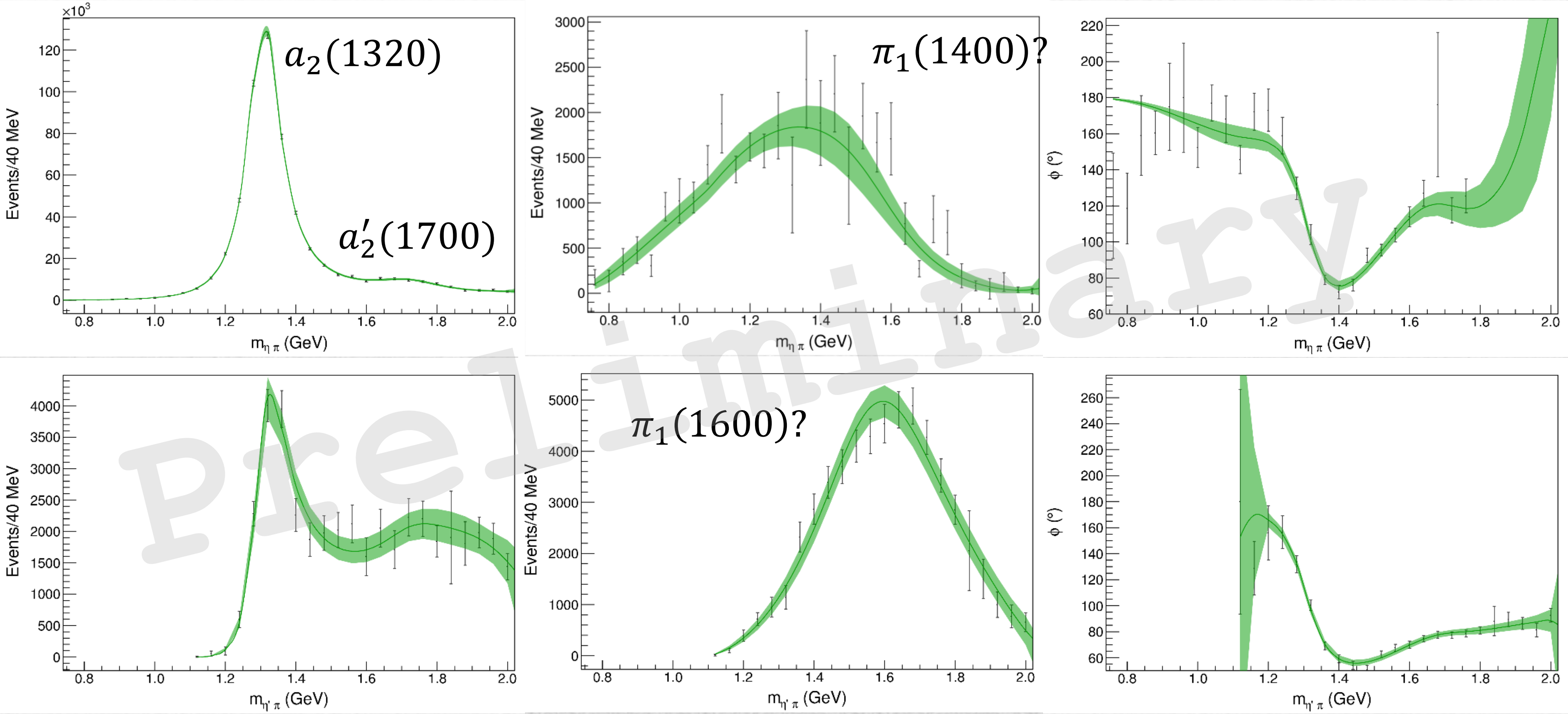
Scattering amplitude



Searching for resonances in $\eta\pi$

- Coupled channel analysis of $\eta\pi$ and $\eta'\pi$ almost completed

A. Rodas, AP *et al.* (JPAC), in preparation



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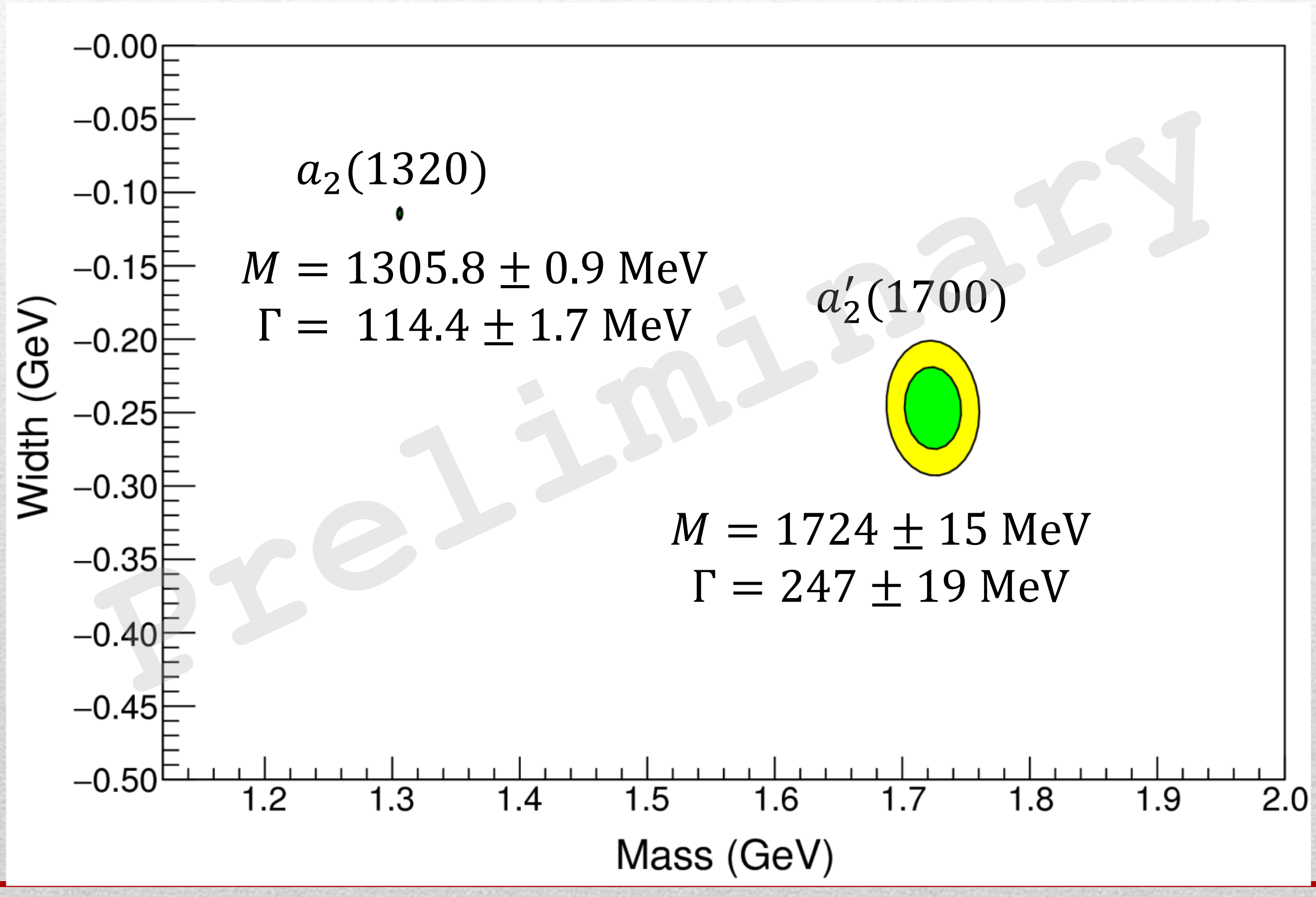
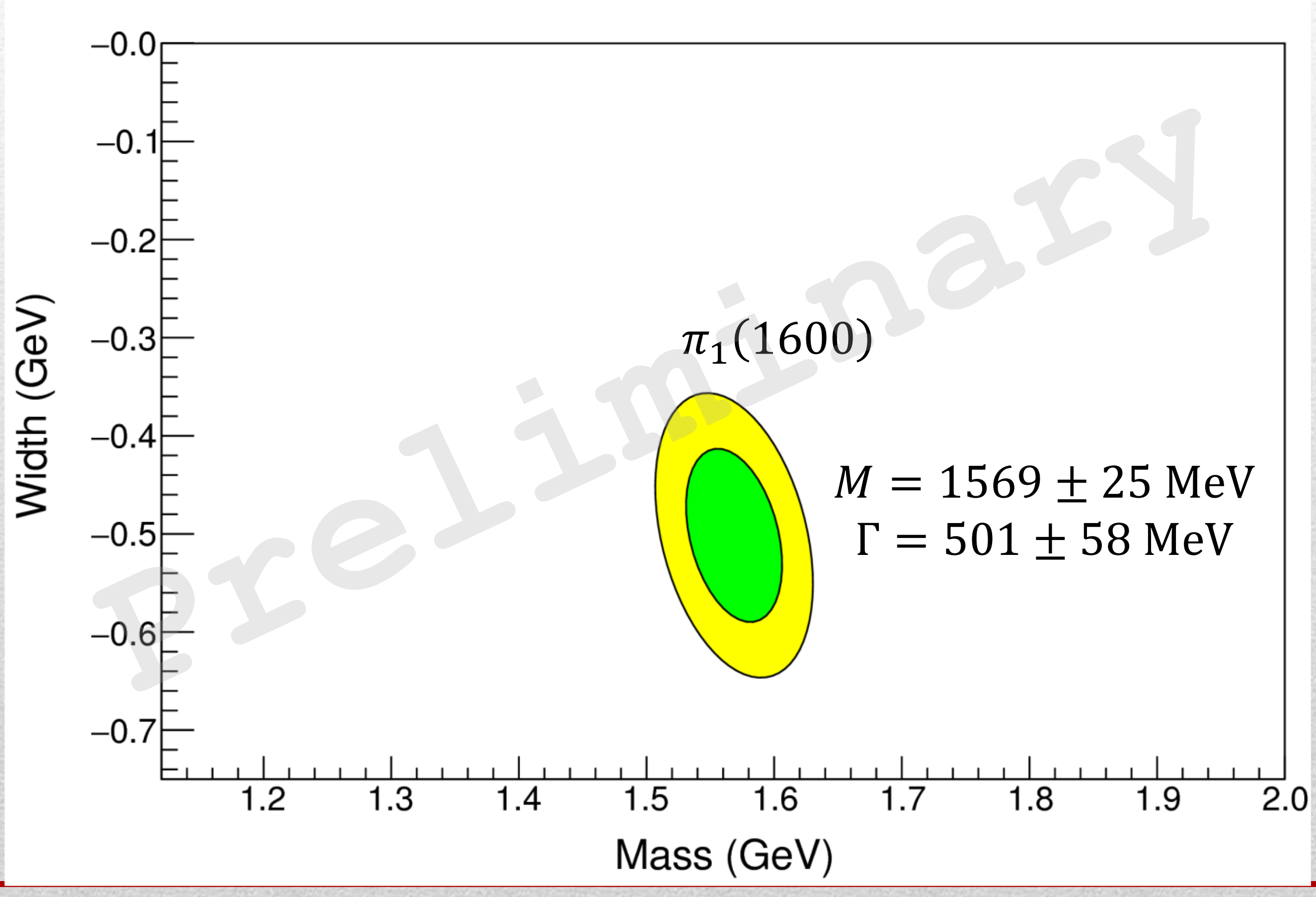


Searching for resonances in $\eta\pi$

- Only one pole needed, to describe seemingly displaced peaks

A. Rodas, AP *et al.* (JPAC), in preparation

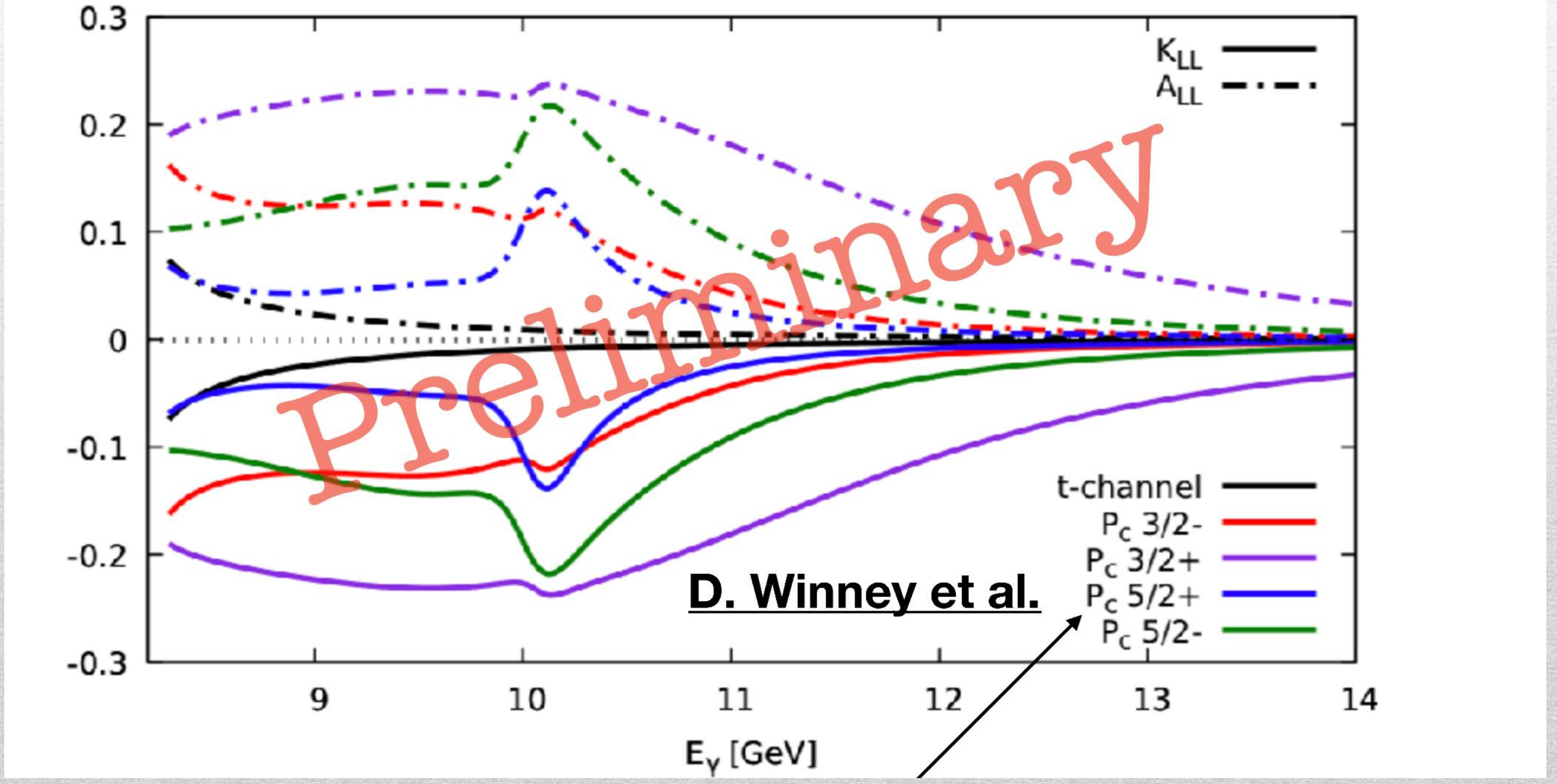


Flash: Still pentaquark photoproduction

Using polarization observables to search the LHCb pentaquark with SBS

D. Winney, C. Fanelli, A. Hiller Blin, AP *et al.* (JPAC), in preparation

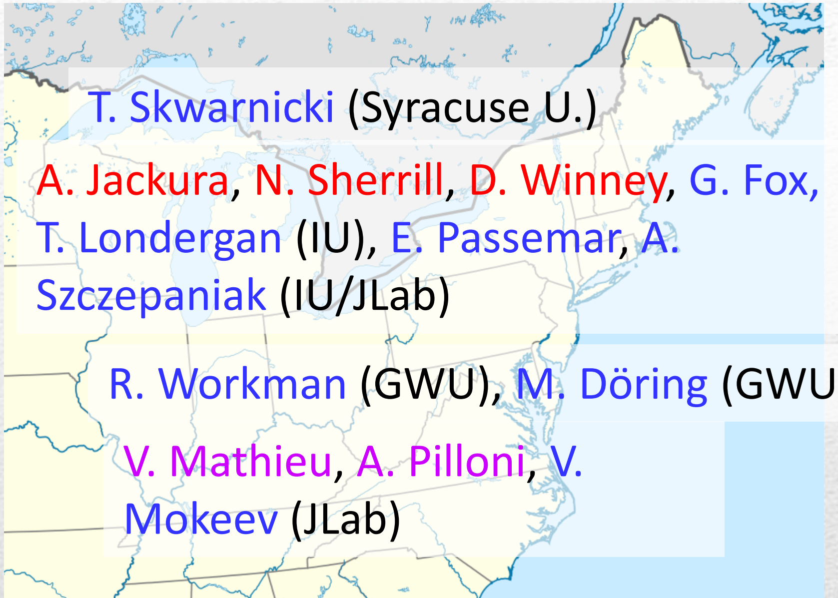
C. Fanelli, L. Pentchev, B. Wojtsekhowski, LoI12-18-001



Joint Physics Analysis Center

- We aim at developing new **theoretical tools**, to get insight on QCD using first principles of QFT (unitarity, analyticity, crossing symmetry, low and high energy constraints,...) to *extract the physics out of the data*
- Many ongoing projects (both for meson and baryon spectroscopy, and for high energy observables), with a particular attention to producing complete reaction models for the golden channels in exotic meson searches

Joint Physics Analysis Center



T. Skwarnicki (Syracuse U.)

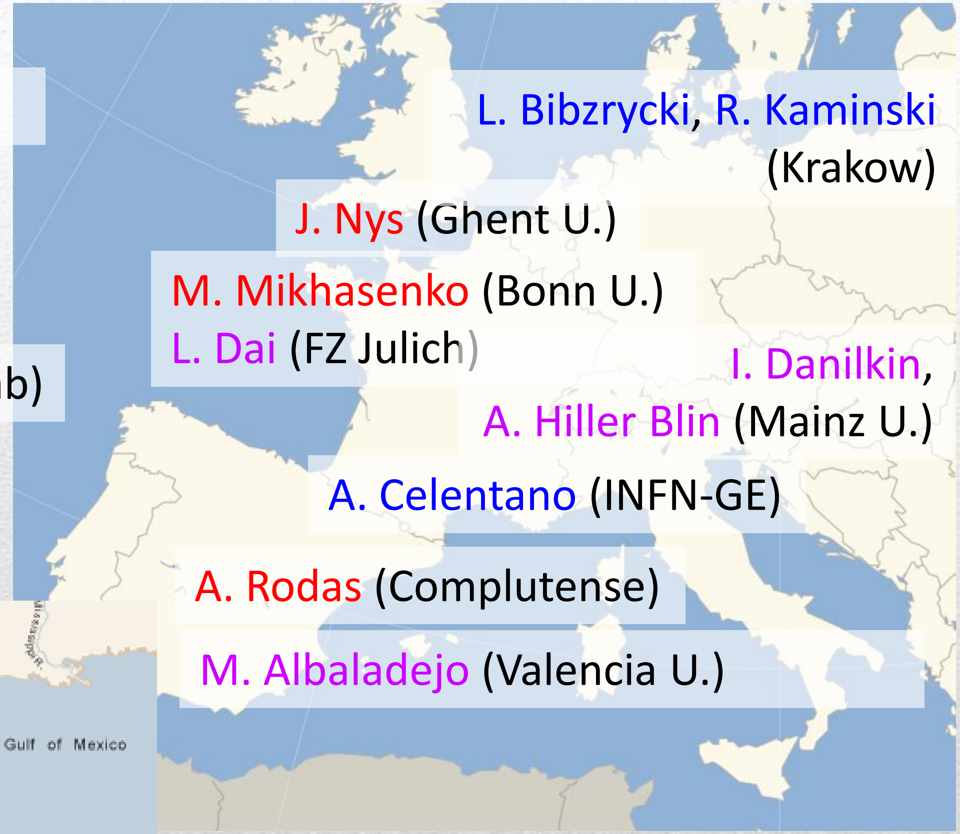
A. Jackura, N. Sherrill, D. Winney, G. Fox, T. Londergan (IU), E. Passemar, A. Szczepaniak (IU/JLab)

R. Workman (GWU), M. Döring (GWU/JLab)

V. Mathieu, A. Pilloni, V. Mokeev (JLab)

P. Guo (Cal. State U.)

J. Castro, C. Fernandez-Ramirez (UNAM)



L. Bibzrycki, R. Kaminski (Krakow)

J. Nys (Ghent U.)

M. Mikhasenko (Bonn U.)

L. Dai (FZ Julich)

I. Danilkin, A. Hiller Blin (Mainz U.)

A. Celentano (INFN-GE)

A. Rodas (Complutense)

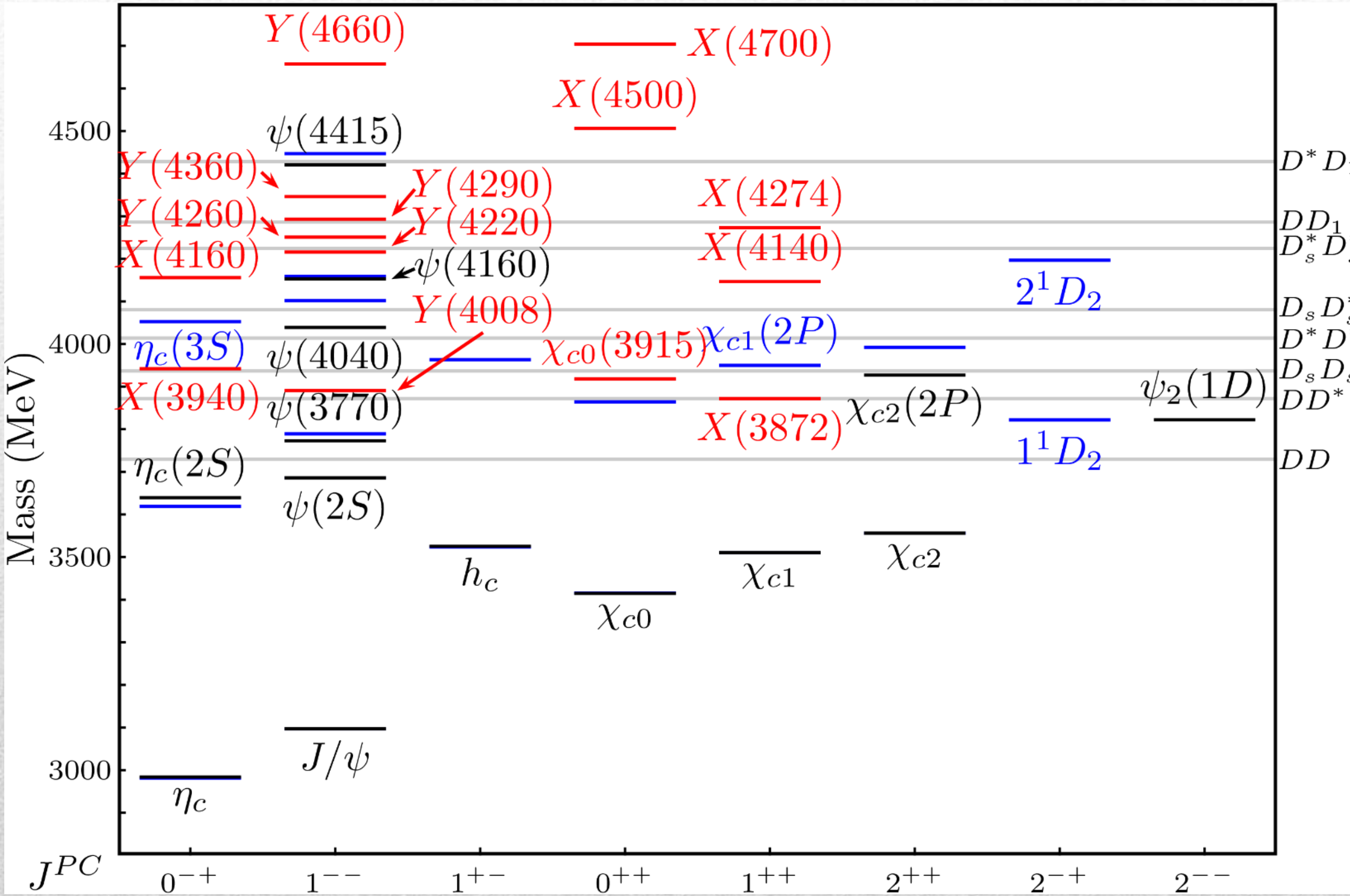
M. Albaladejo (Valencia U.)

Students, Postdocs, Faculties

BACKUP

Exotic landscape

Esposito, AP, Polosa, Phys.Rept. 668



A host of unexpected resonances have appeared

decaying mostly into charmonium + light

Hardly reconciled with usual charmonium interpretation

How helicity formalism works

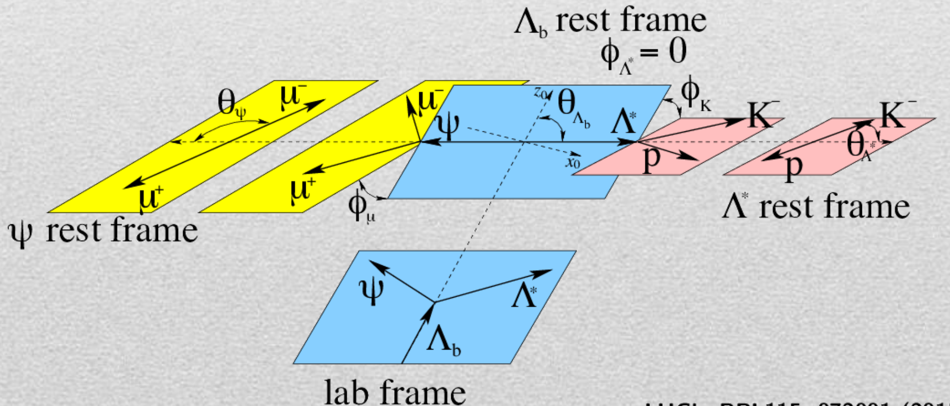
- Helicity formalism enforces the constraints about rotational invariance
- It allows us to fix the angular dependence of the amplitude
- What about energy dependence?

Example: $B \to \psi K^* \to \pi K$

$$\mathcal{M}^{K^*}_{\Delta\lambda_\mu} \equiv \sum_n \sum_{\lambda_{K^*}} \sum_{\lambda_\psi} \mathcal{H}^{B\to K^*_n\psi}_{\lambda_{K^*},\,\lambda_\psi} \delta_{\lambda_{K^*},\lambda\psi}$$

$$\mathcal{H}^{K^*_n\to K\pi} D^{J_{K^*_n}}_{\lambda_{K^*},0}(\phi_K,\theta_{K^*},0)^*$$

$$R_{K^*{}_n}(m_{K\pi}) D^1_{\lambda_\psi,\,\Delta\lambda_\mu}(\phi_\mu,\theta_\psi,0)^*,$$



LHCb, PRL115, 072001 (2015)

Each set of angles is defined in a different reference frame

How tensor formalism works

The method is based on the construction of explicitly covariant expressions.

- To describe the decay $a \to bc$, we first consider the polarization tensor of each particle, $\varepsilon^{i}_{\mu_1\dots\mu_{j_i}}(p_i)$
- We combine the polarizations of b and c into a "total spin" tensor $S_{\mu_1\dots\mu_S}(\varepsilon_b, \varepsilon_c)$
- Using the decay momentum, we build a tensor $L_{\mu_1\dots\mu_L}(p_{bc})$ to represent the orbital angular momentum of the bc system, orthogonal to the total momentum of p_a
- We contract S and L with the polarization of a

Tensor $\times R_X(m)$ which contain resonances and form factors

What do we know?

- Energy dependence is not constrained by symmetry
- Still, there are some known properties one can enforce

$$R_X(m) = B'_{L^X_{\Lambda_b^0}}(p, p_0, d) \left(\frac{p}{M_{\Lambda_b^0}} \right)^{L^X_{\Lambda_b^0}}$$

$$\mathrm{BW}(m | M_{0X}, \Gamma_{0X})\, B'_{L_X}(q, q_0, d) \left(\frac{q}{M_{0X}} \right)^{L_X}$$

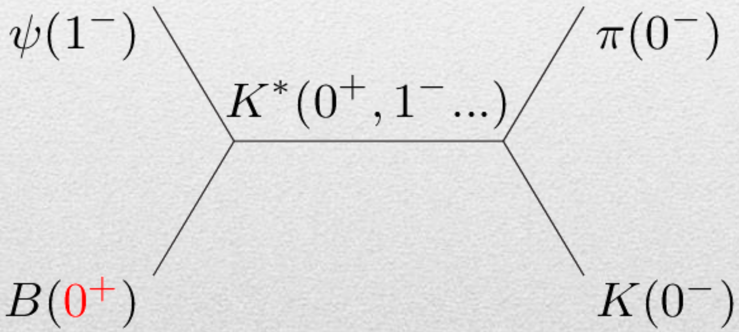
- Kinematical singularities: e.g. barrier factors (known)
- Left hand singularities (need model, e.g. Blatt-Weisskopf)
- Right hand singularities = resonant content (Breit Wigner, K-matrix...)

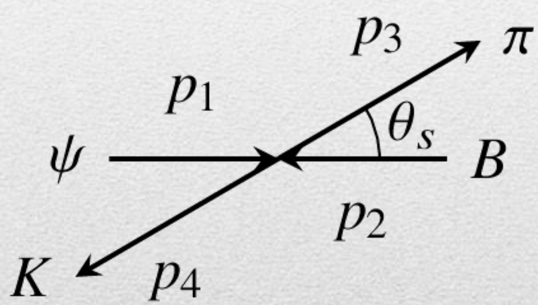
Kinematics

- Kinematical singularities appear because of the spin of the external particle involved
- We can write the most general covariant parametrization of the amplitude as
  tensor of external polarizations $\otimes$ scalar amplitudes
- Scalar amplitudes must be kinematical singularities free
- They can be matched to the helicity amplitudes
- We can get the minimal energy dependent factor
- Any other additional energy factor would be model-dependent

$B \to \psi\, \pi K$

To consider the effect of spin, let's consider $B \to \psi \pi K$
We focus on the parity violating amplitude for the K^* isobars, scattering kinematics





$$p = \text{incoming 3-momentum in the COM} = \frac{\lambda_{12}^{1/2}}{2\sqrt{s}}$$

$$= \frac{\sqrt{[s-(m_1+m_2)^2]\,[s-(m_1-m_2)^2]}}{2\sqrt{s}}$$

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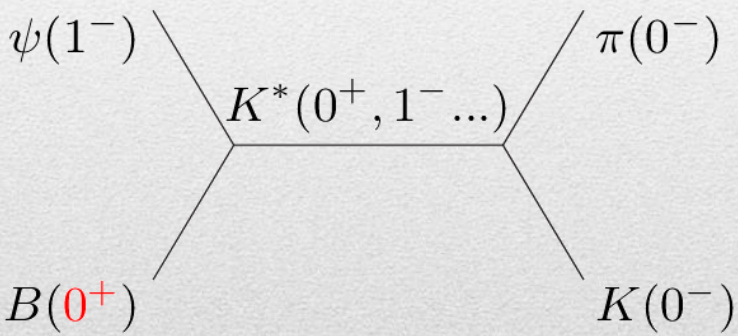

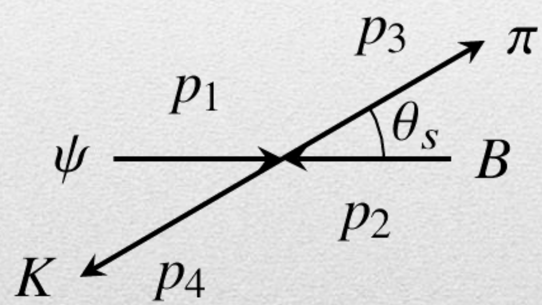

$$q = \text{outgoing 3-momentum in the COM} = \frac{\lambda_{34}^{1/2}}{2\sqrt{s}}$$

$$= \frac{\sqrt{[s-(m_3+m_4)^2]\,[s-(m_3-m_4)^2]}}{2\sqrt{s}}$$

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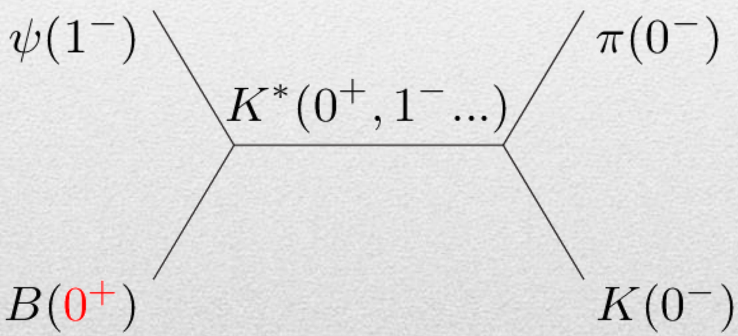
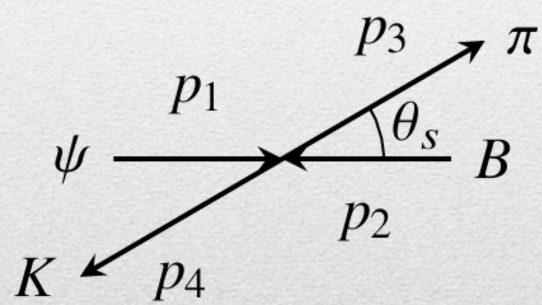




$z_s =$ cosine of the scatt. angle in the COM

$$= \frac{s(t-u) + (m_1^2 - m_2^2)(m_3^2 - m_4^2)}{\lambda_{12}^{1/2}\lambda_{34}^{1/2}} = \frac{\text{polynomial}}{\lambda_{12}^{1/2}\lambda_{34}^{1/2}}$$

Helicity amplitudes

$$A_\lambda = \frac{1}{4\pi} \sum_{j=|\lambda|}^{\infty} (2j+1) A^j_\lambda(s)\, d^j_{\lambda 0}(z_s)$$

$$d^j_{\lambda 0}(z_s) = \hat{d}^j_{\lambda 0}(z_s) \xi_{\lambda 0}(z_s), \qquad \xi_{\lambda 0}(z_s) = \left(\sqrt{1-z_s^2}\right)^\lambda$$

$\hat{d}^j_{\lambda 0}(z_s)$ is a polynomial of order $j - |\lambda|$ in z_s,
The kinematical singularities of $A^j_\lambda(s)$ can be isolated by writing

$$A^j_0 = \frac{m_1}{p\sqrt{s}} (pq)^j \, \hat{A}^j_0 \qquad \text{for } j \geq 1,$$

$$A^j_\pm = q \, (pq)^{j-1} \, \hat{A}^j_\pm \qquad \text{for } j \geq 1,$$

$$A^0_0 = \frac{p\sqrt{s}}{m_1} \hat{A}^0_0 \qquad \text{for } j = 0,$$

Identify covariants

Two helicity couplings $\to$ two independent covariant structures

Important: we are not imposing any intermediate isobar

$$A_\lambda(s,t) = \varepsilon_\mu(\lambda,p_1)\left[(p_3-p_4)^\mu - \frac{m_3^2-m_4^2}{s}(p_3+p_4)^\mu\right] C(s,t) + \varepsilon_\mu(\lambda,p_1)(p_3+p_4)^\mu B(s,t)$$

$$C(s,t) = \frac{1}{4\pi\sqrt{2}}\sum_{j>0}(2j+1)(pq)^{j-1}\hat{A}^j_+(s)\,\hat{d}^j_{10}(z_s)$$

$$B(s,t) = \frac{1}{4\pi}\hat{A}^0_0 + \frac{1}{4\pi}\frac{4m_1^2}{\lambda_{12}}\sum_{j>0}(2j+1)(pq)^j\left[\hat{A}^j_0(s)\hat{d}^j_{00}(z_s) + \frac{s+m_1^2-m_2^2}{\sqrt{2}m_1^2}\hat{A}^j_+(s)\,z_s\hat{d}^j_{10}(z_s)\right]$$

Everything looks fine but the λ_{12} in the denominator
The brackets must vanish at $\lambda_{12}=0 \Rightarrow s = s_\pm = (m_1 \pm m_2)^2$,
$\hat{A}^j_+$ and $\hat{A}^j_0$ cannot be independent

General expression and comparison

$$\hat{A}^j_+ = \langle j-1, 0; 1, 1 | j, 1\rangle g_j(s) + f_j(s)$$

$$\hat{A}^j_0 = \langle j-1, 0; 1, 0 | j, 0\rangle \frac{s+m_1^2-m_2^2}{2m_1^2} g'_j(s) + f'_j(s)$$

$g_j(s_\pm) = g'_j(s_\pm)$, and $f_j(s), f'_j(s) \sim O(s-s_\pm)$
All these four functions are free of kinematic singularity.

Comparison with tensor formalisms ($j=1$)

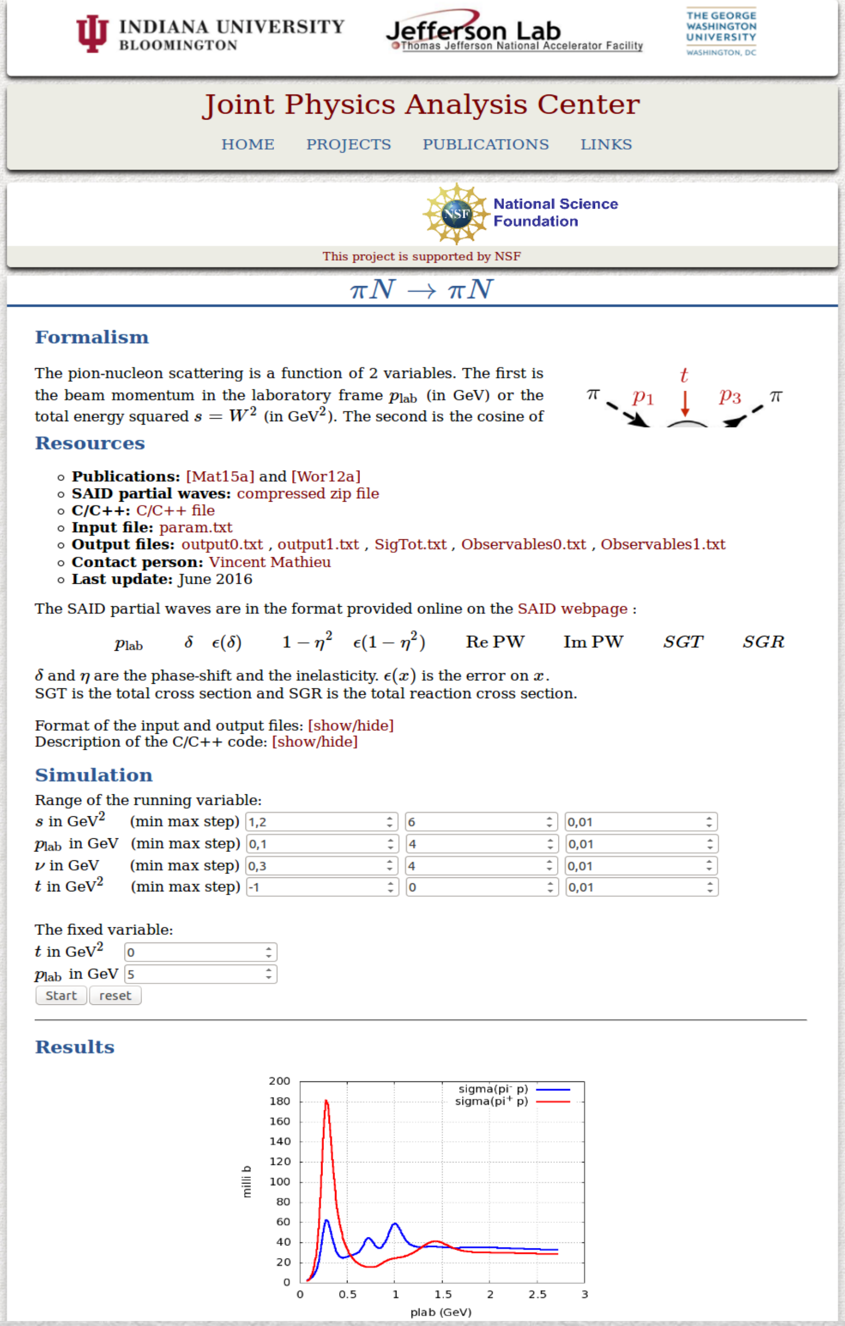
$$g_1 = g'_1 = \frac{4\pi}{3} g_S, \quad f_1 = \frac{2\pi\lambda_{12}}{3s} g_D, \quad f'_1 = -\frac{4\pi\lambda_{12}}{3s}\frac{s+m_1^2-m_2^2}{m_1^2} g_D.$$

If the g_S, g_D are the usual Breit-Wigner, the g', f' are fine

There is no unique recipe to build the right amplitude, but one can ensure the right singularities to be respected

Interactive tools

- Completed projects are fully documented on interactive portals
- These include description on physics, conventions, formalism, etc.
- The web pages contain source codes with detailed explanation how to use them. Users can run codes online, change parameters, display results.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National Science Foundation

This project is supported by NSF

$\pi N \to \pi N$

Formalism

The pion-nucleon scattering is a function of 2 variables. The first is the beam momentum in the laboratory frame $p_{\rm lab}$ (in GeV) or the total energy squared $s = W^2$ (in GeV^2). The second is the cosine of

Resources

- **Publications:** [Mat15a] and [Wor12a]
- **SAID partial waves:** compressed zip file
- **C/C++:** C/C++ file
- **Input file:** param.txt
- **Output files:** output0.txt , output1.txt , SigTot.txt , Observables0.txt , Observables1.txt
- **Contact person:** Vincent Mathieu
- **Last update:** June 2016

The SAID partial waves are in the format provided online on the SAID webpage :

$p_{\rm lab}$ δ $\epsilon(\delta)$ $1-\eta^2$ $\epsilon(1-\eta^2)$ Re PW Im PW SGT SGR

δ and η are the phase-shift and the inelasticity. $\epsilon(x)$ is the error on x.
SGT is the total cross section and SGR is the total reaction cross section.

Format of the input and output files: [show/hide]
Description of the C/C++ code: [show/hide]

Simulation

Range of the running variable:

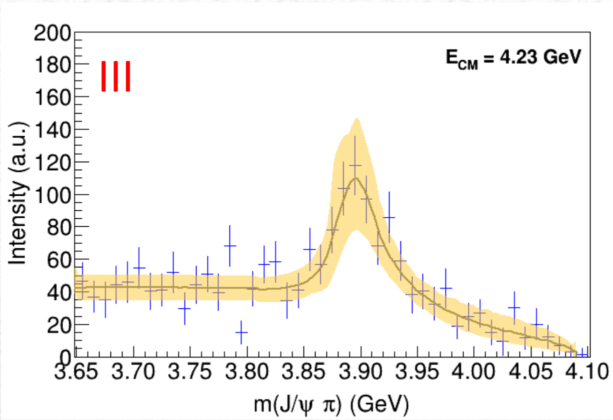
s in GeV^2	(min max step)	1,2	6	0,01
$p_{\rm lab}$ in GeV	(min max step)	0,1	4	0,01
ν in GeV	(min max step)	0,3	4	0,01
t in GeV^2	(min max step)	-1	0	0,01

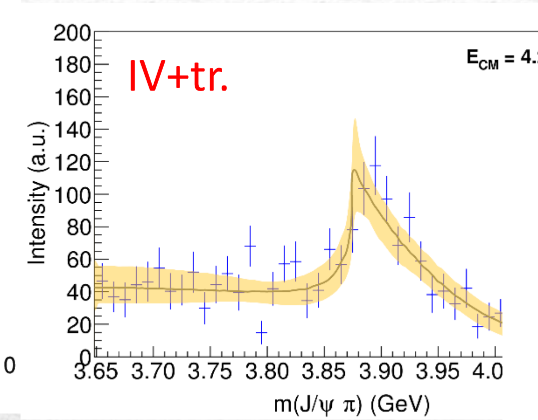
The fixed variable:
t in GeV^2 0
$p_{\rm lab}$ in GeV 5
Start reset

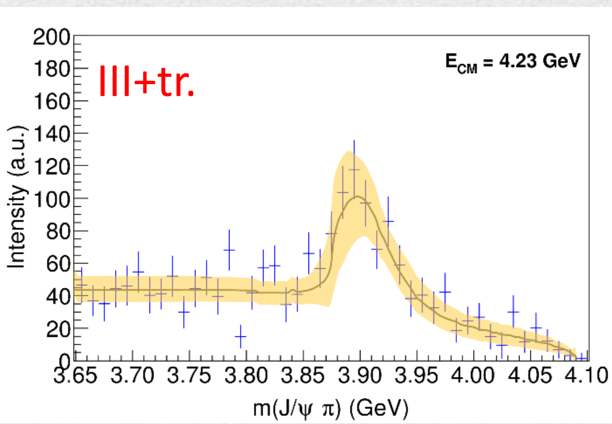
Results

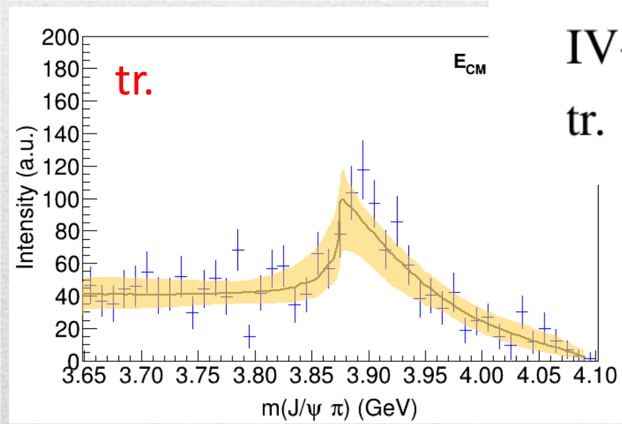
http://www.indiana.edu/~jpac/

Fit summary





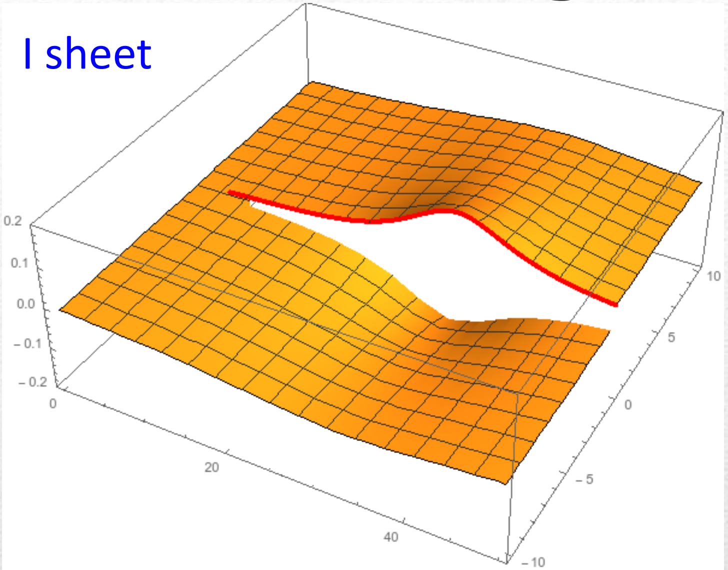


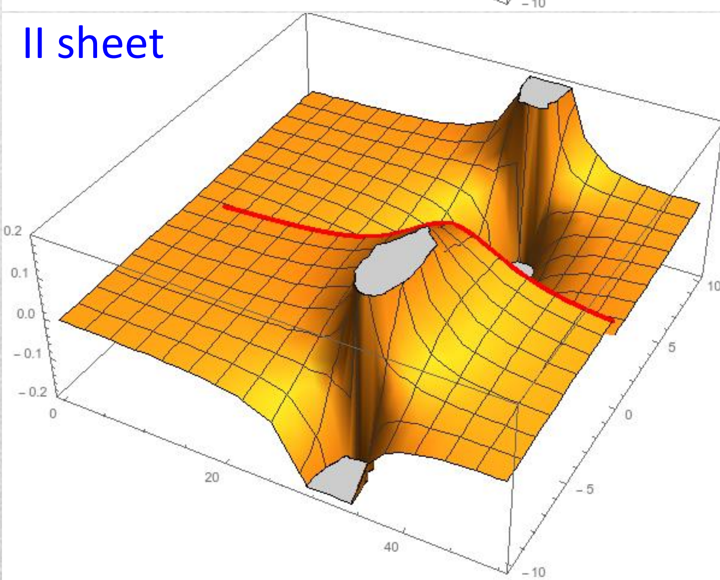


Scenario	χ^2	DOF	χ^2/DOF
III	644	532	1.21
III+tr.	642	532	1.21
IV+tr.	666	532	1.25
tr.	695	532	1.31

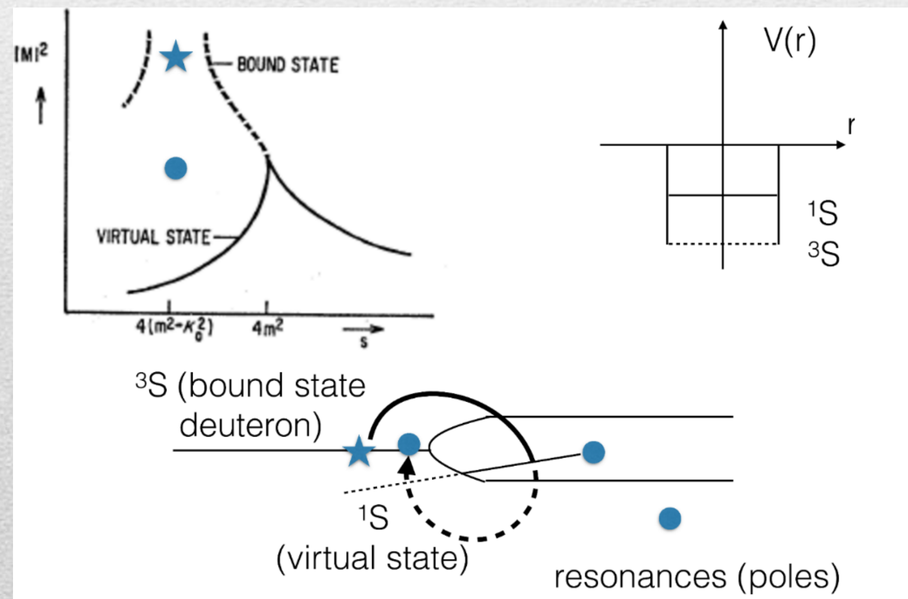
Naive loglikelihood ratio test give a $\sim 4\sigma$ significance of the scenario III+tr. over IV+tr., looking at plots it looks too much – better using some more solid test

Pole hunting

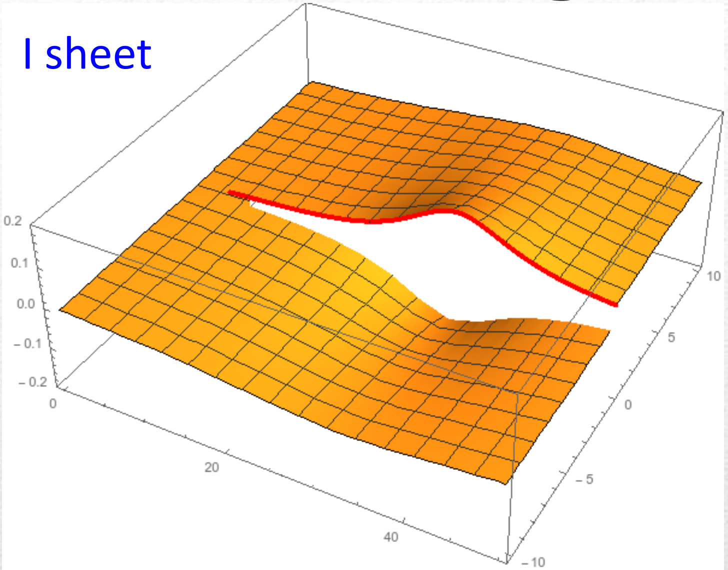


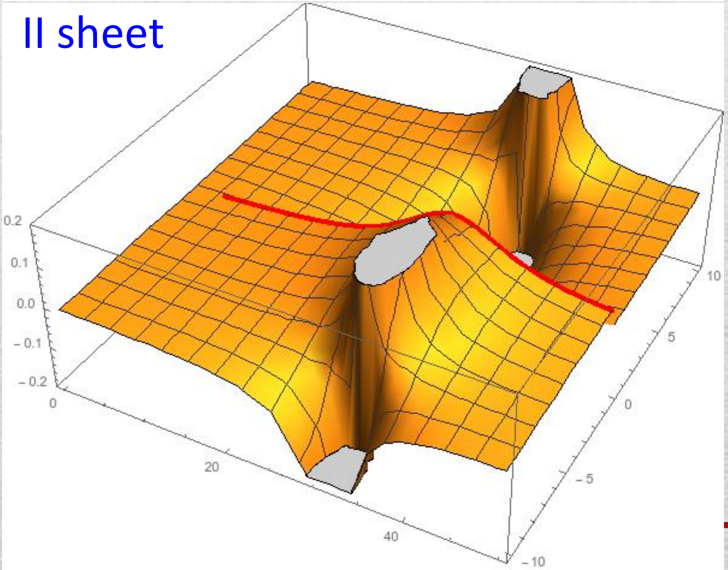


Bound states on the real axis 1st sheet
Not-so-bound (virtual) states on the real axis 2nd sheet



Pole hunting

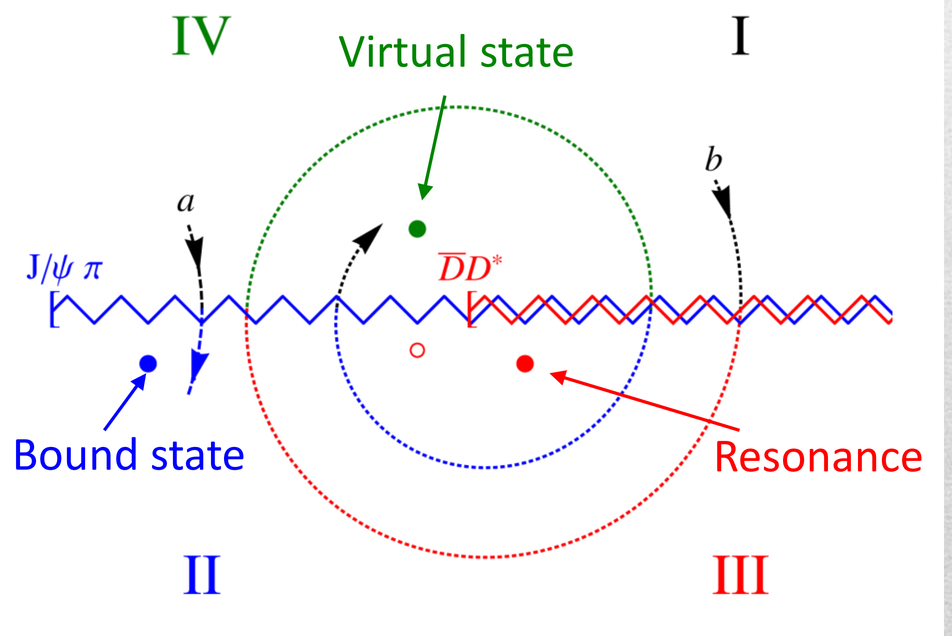




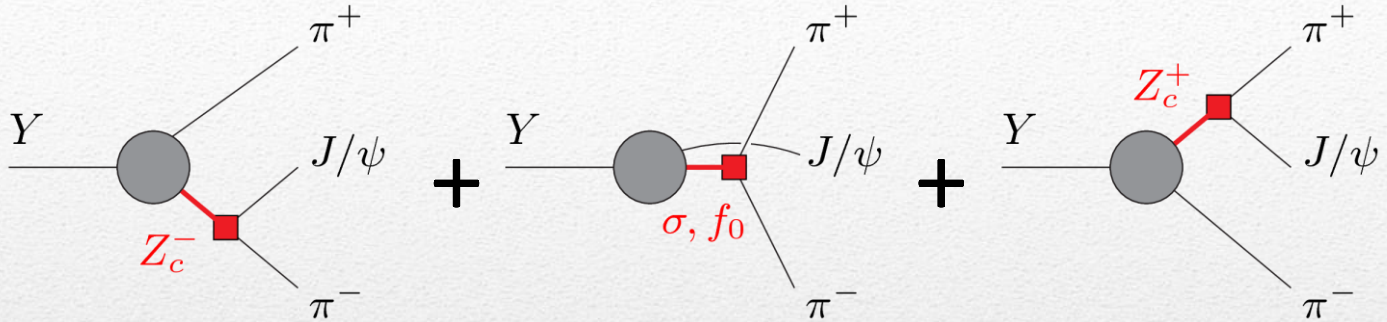
More complicated structure when more thresholds arise: two sheets for each new threshold

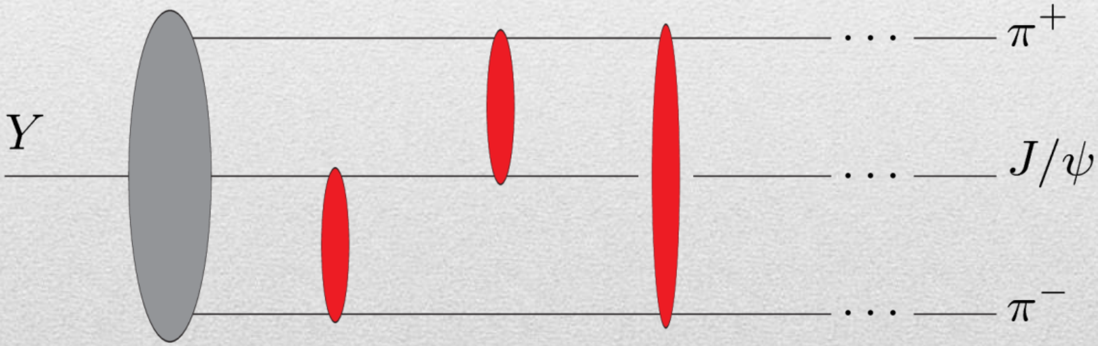
III sheet: usual resonances

IV sheet: cusps (virtual states)



The isobar model





Khuri-Treiman formalism was introduced to describe $K \to 3\pi$

Khuri and Treiman, PR119, 1115

Used recently for several reactions,

Niecknig and Kubis, JHEP 10, 142

Colangelo, *et al.*, PRL118, 022001

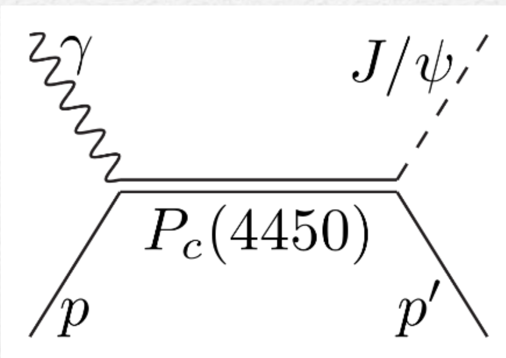
AP *et al.* [JPAC], PLB772, 200

Albaladejo, AP *et al.* [JPAC], 1803.06027

The formalism implements the all-order rescattering in all the 3 channels at once

P_c photoproduction

To exclude any rescattering mechanism, we propose to search the $P_c(4450)$ state in photoproduction.



Hadronic vertex EM vertex

$$\langle \lambda_\psi \lambda_{p'} | T_r | \lambda_\gamma \lambda_p \rangle = \frac{\boxed{\langle \lambda_\psi \lambda_{p'} | T_{\text{dec}} | \lambda_R \rangle} \boxed{\langle \lambda_R | T^\dagger_{\text{em}} | \lambda_\gamma \lambda_p \rangle}}{M_r^2 - W^2 - i\Gamma_r M_r}$$

Hadronic part

- 3 independent helicity couplings,
  $\to$ approx. equal, $g_{\lambda_\psi,\lambda_{p'}} \sim g$
- g extracted from total width and (unknown) branching ratio

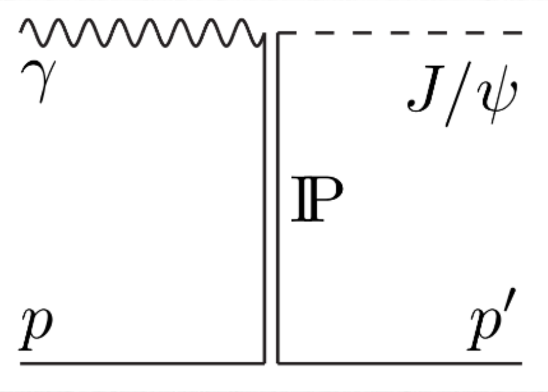
Vector meson dominance relates the radiative width to the hadronic width

$$\Gamma_\gamma = 4\pi\alpha\, \Gamma_{\psi p} \left(\frac{f_\psi}{M_\psi} \right)^2 \left(\frac{\bar{p}_i}{\bar{p}_f} \right)^{2\ell+1} \times \frac{4}{6}$$

Hiller Blin, AP *et al.* (JPAC), PRD94, 034002

Background parameterization

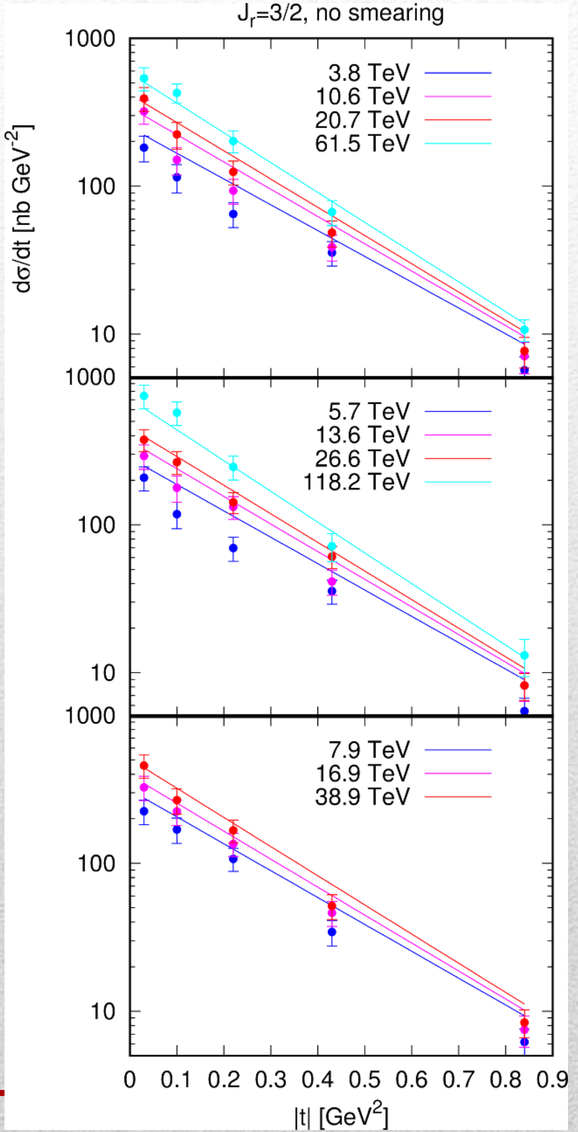
The background is described via an Effective Pomeron, whose parameters are fitted to high energy data from Hera



$$\langle \lambda_\psi \lambda_{p'} | T_P | \lambda_\gamma \lambda_p \rangle = iA \left(\frac{s - s_t}{s_0} \right)^{\alpha(t)} e^{b_0 (t - t_{\min})} \delta_{\lambda_p \lambda_{p'}} \delta_{\lambda_\psi \lambda_\gamma}$$

Asymptotic + Effective threshold

Helicity conservation

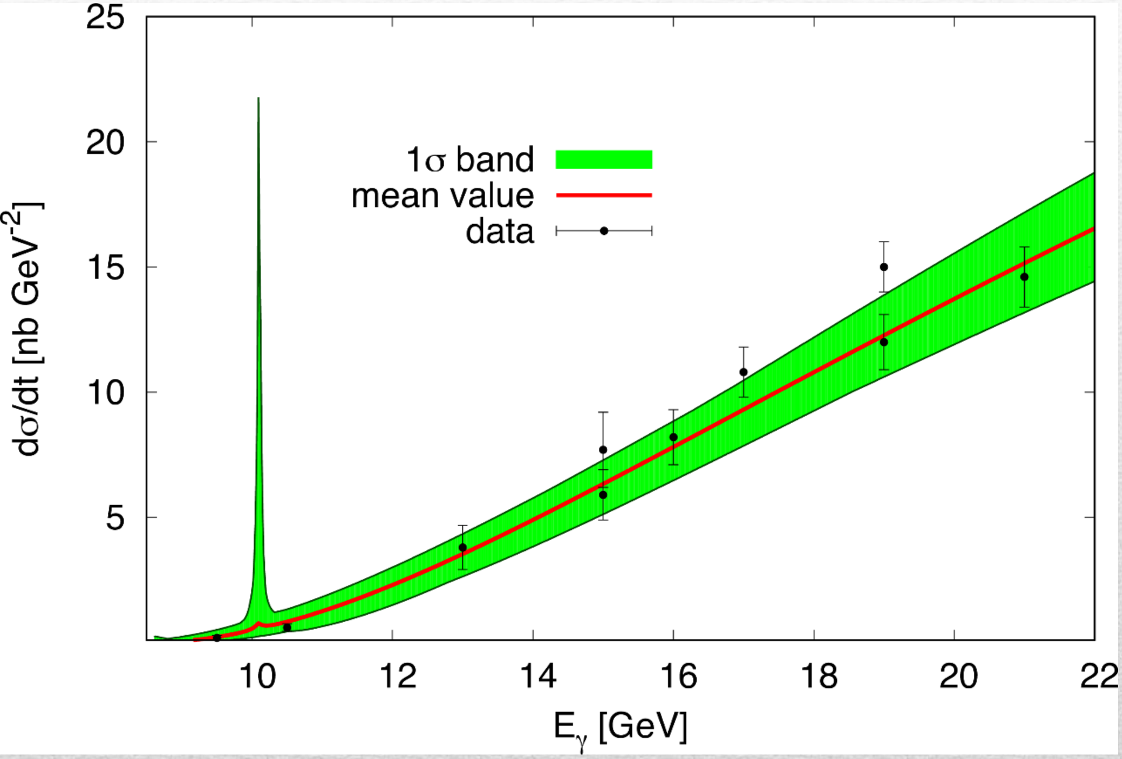


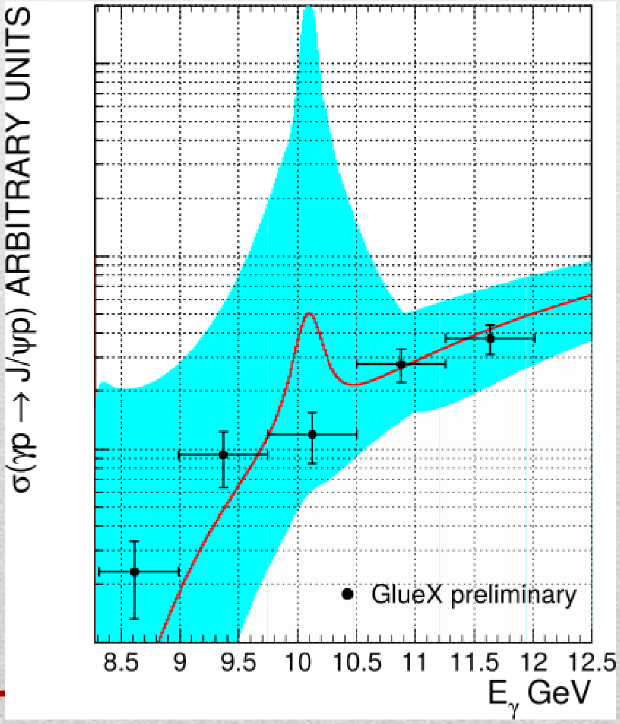
Hiller Blin, AP *et al.* (JPAC), PRD94, 034002

Pentaquark photoproduction

$J^P = (3/2)^-$

σ_s (MeV)	0	60
A	$0.156^{+0.029}_{-0.020}$	$0.157^{+0.039}_{-0.021}$
α_0	$1.151^{+0.018}_{-0.020}$	$1.150^{+0.018}_{-0.026}$
α' (GeV^{-2})	$0.112^{+0.033}_{-0.054}$	$0.111^{+0.037}_{-0.064}$
s_t (GeV^2)	$16.8^{+1.7}_{-0.9}$	$16.9^{+2.0}_{-1.6}$
b_0 (GeV^{-2})	$1.01^{+0.47}_{-0.29}$	$1.02^{+0.61}_{-0.32}$
$\mathcal{B}_{\psi p}$ (95% CL)	≤ 29 %	≤ 30 %





Hiller Blin, AP *et al.* (JPAC), PRD94, 034002

Searching for resonances in $\eta\pi$

The denominator $D(s)$ contains all the FSI constrained by unitarity → universal

$$D(s)_{ij} = (K^{-1})_{ij}(s) - \frac{s}{\pi}\int_{s_i}^{\infty} \frac{\rho_i(s')N_{ij}(s')}{s'\left(s'-s\right)} ds'$$

$$K_{ij}(s) = \sum_R \frac{g_i^R g_j^R}{M_R^2 - s}$$

OR

$$K_{ij}^{-1}(s) = c_0 - c_1 s + \sum_i \frac{c_i}{M_i^2 - s}$$

$$\rho_i(s)N_{ij}(s) = g\frac{\lambda^{(2l+1)/2}\left(s, m_\pi^2, m_\eta^2\right)}{\left(s+\Lambda\right)^7}$$

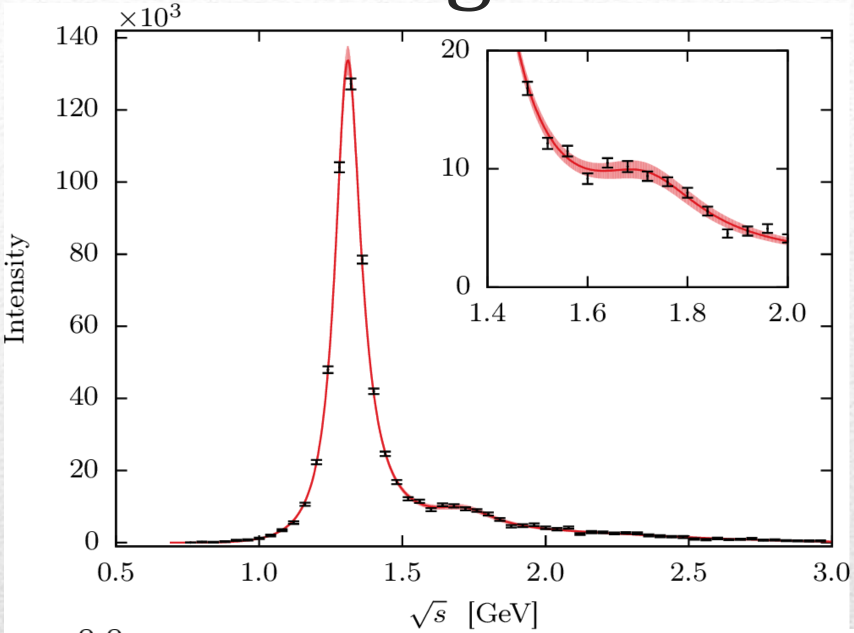
Searching for resonances in $\eta\pi$

The $n(s)$ is process-dependent, smooth

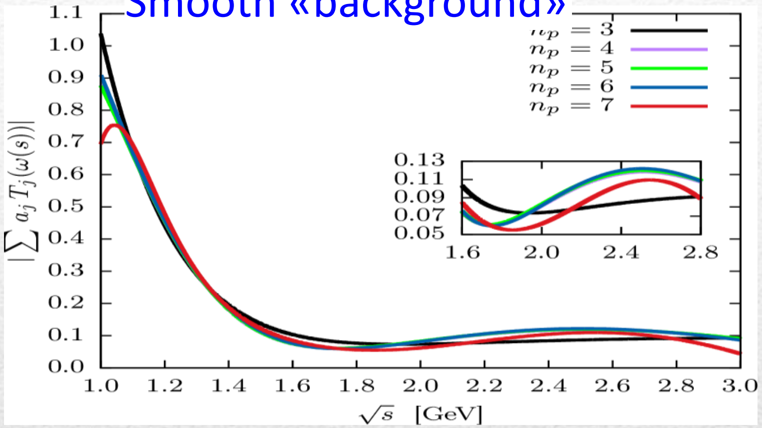
$$n(s) = \sum_j a_j \omega^j(s)$$

$$\omega(s) = \frac{s}{s + s_0}$$

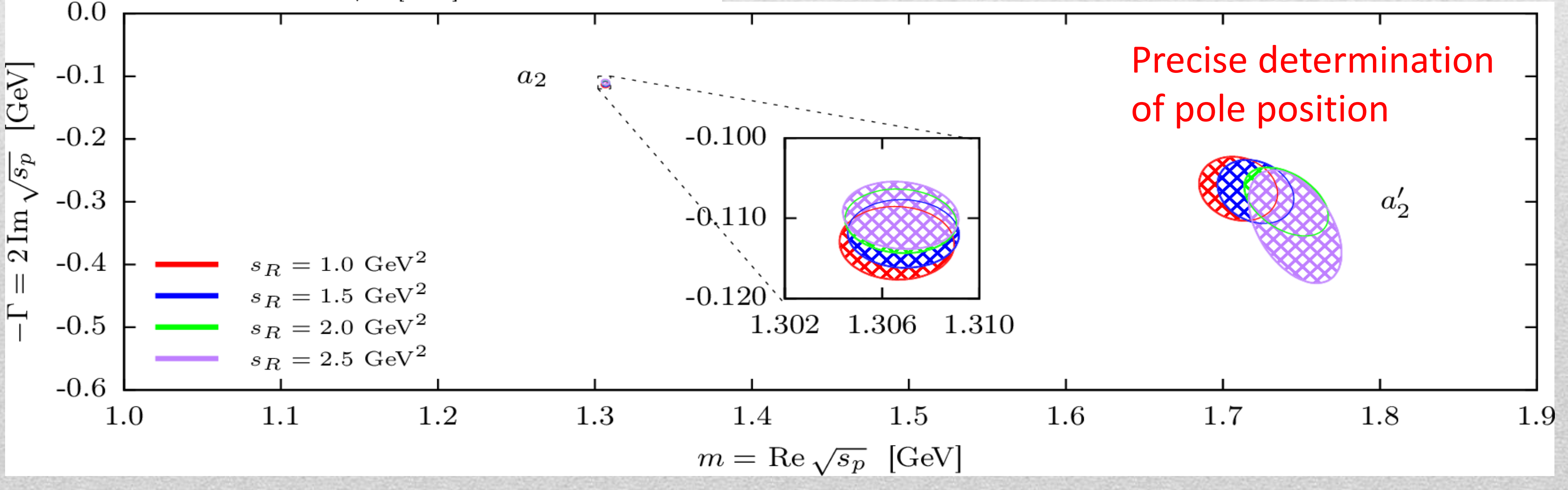
Searching for resonances in $\eta\pi$

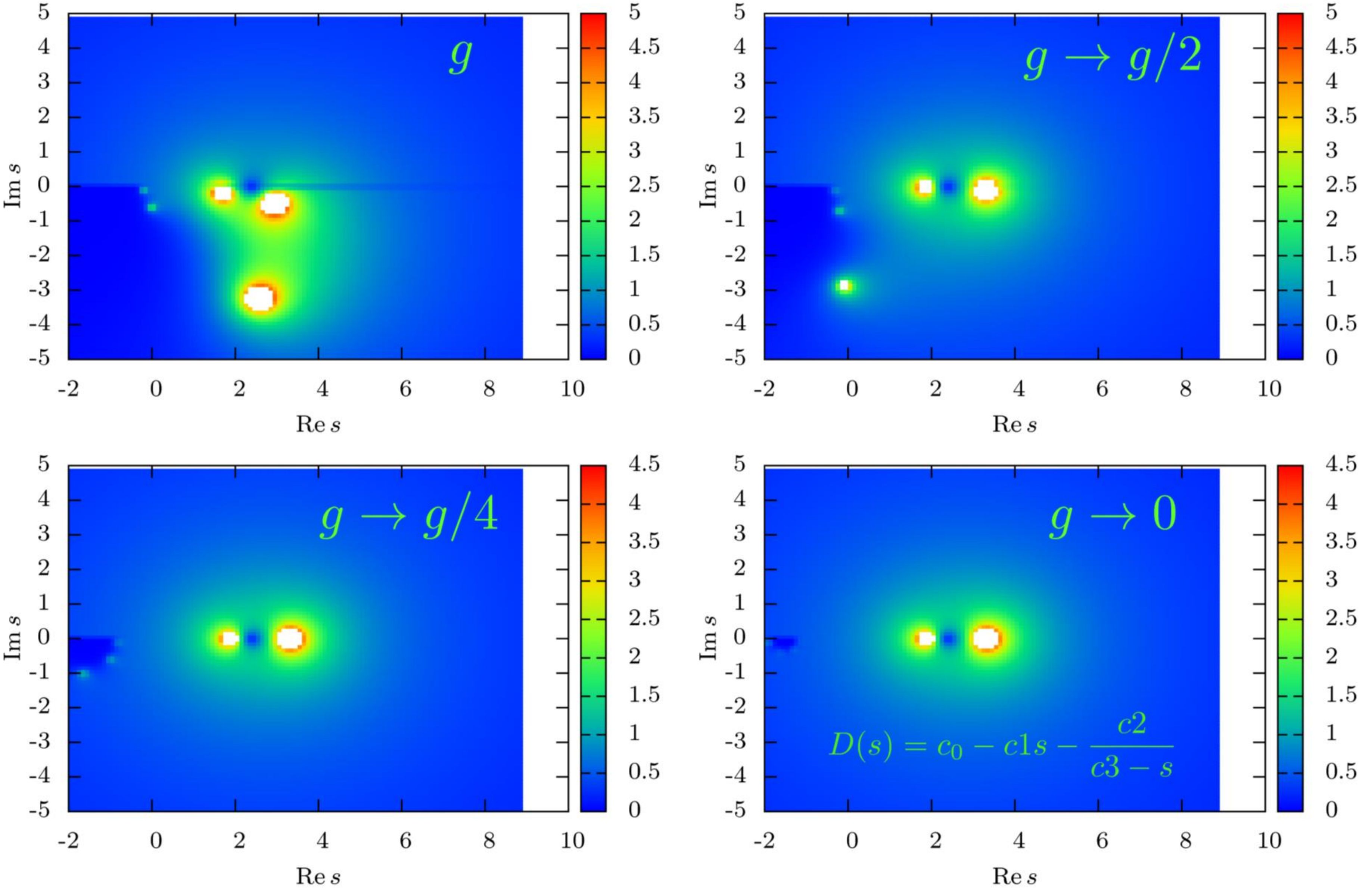


Smooth «background»



Precise determination of pole position



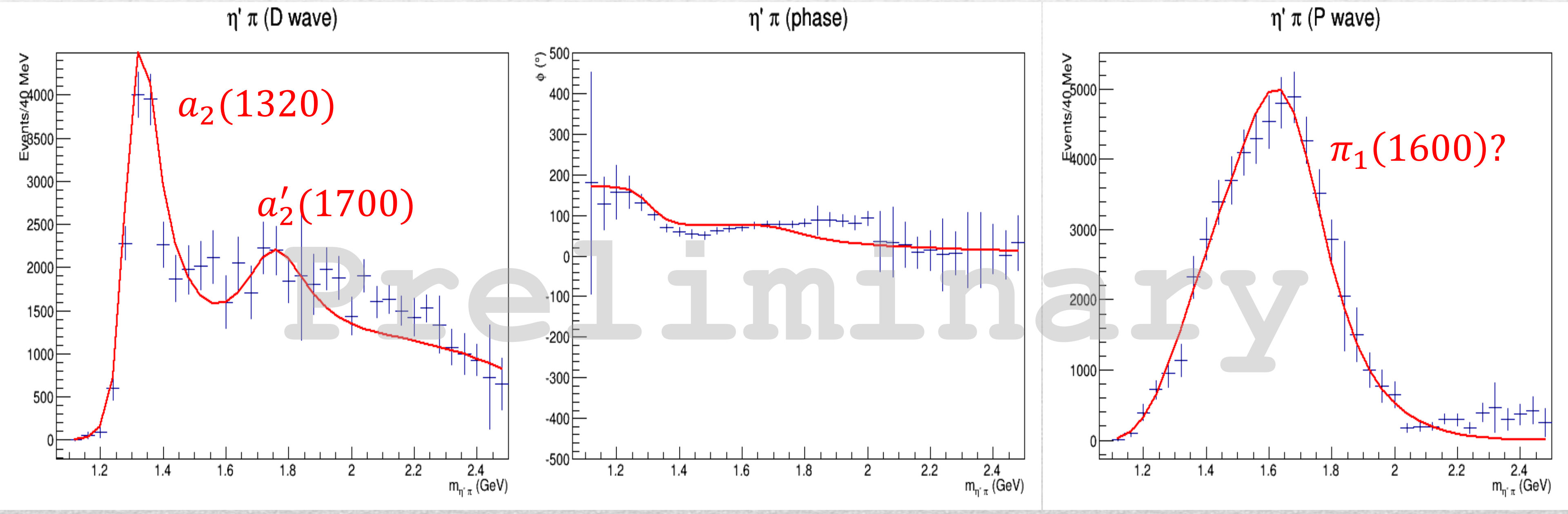


g
$g \to g/2$
$g \to g/4$
$g \to 0$
$D(s) = c_0 - c1s - \frac{c2}{c3 - s}$
Im s
Re s

Searching for resonances in $\eta\pi$

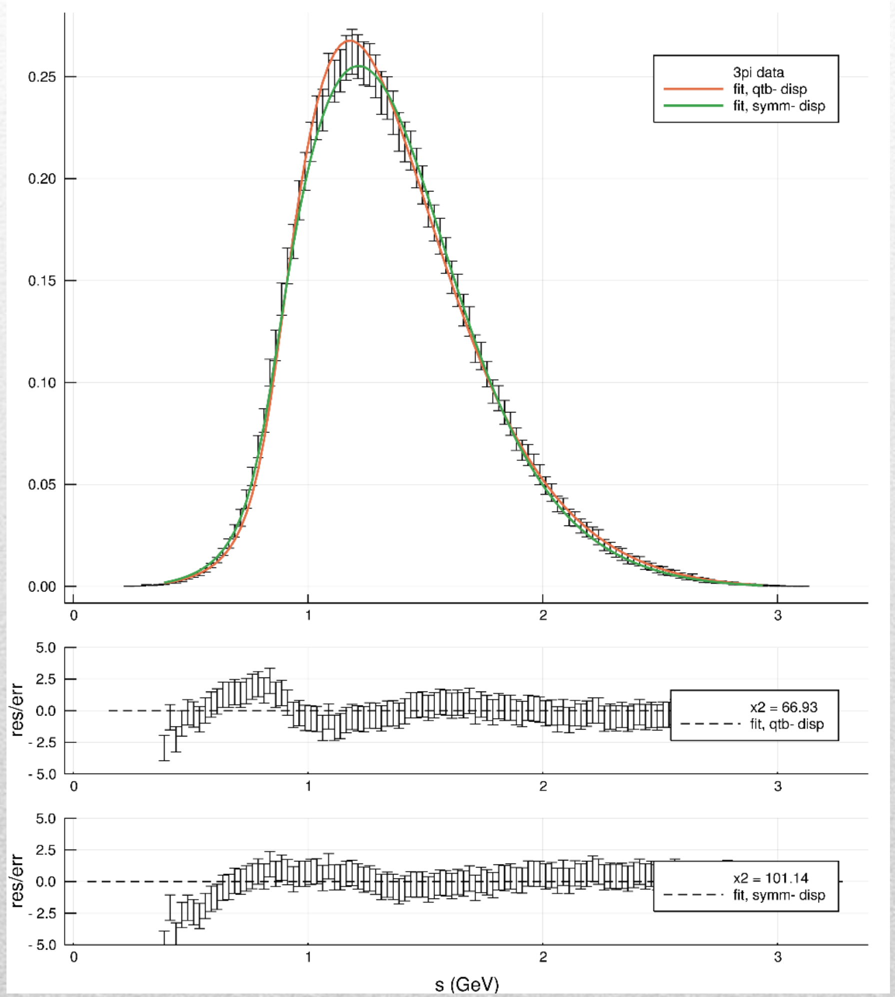
$$m(a_2) = (1307 \pm 1 \pm 6)\ \text{MeV} \qquad m(a_2') = (1720 \pm 10 \pm 60)\ \text{MeV}$$
$$\Gamma(a_2) = (112 \pm 1 \pm 8)\ \text{MeV} \qquad \Gamma(a_2') = (280 \pm 10 \pm 70)\ \text{MeV}$$

- The coupled channel analysis involving the exotic P-wave is ongoing, as well as the extention to the GlueX production mechanism and kinematics



The $a_1(1260)$

M. Mikhasenko, A. Jackura, AP, *et al.*, in preparation



We can use these models to fit $\tau^- \to 2\pi^-\pi^+\nu$ and describe the $a_1(1260)$

The dispersed improved model describes better the data at threshold