JPAC recent results: Determination of the lightest hybrid meson

A.Rodas

Excited QCD 2019, Schladming, Austria

A. Jackura, M. Mikhasenko, A.Pilloni et al. (JPAC & COMPASS), PLB779, 464-472
AR, A.Pilloni et al. (JPAC) Phys.Rev.Lett. 122 (2019) 042002

Joint Physics Analysis Center
Universidad Complutense de Madrid

January 31, 2019

Index

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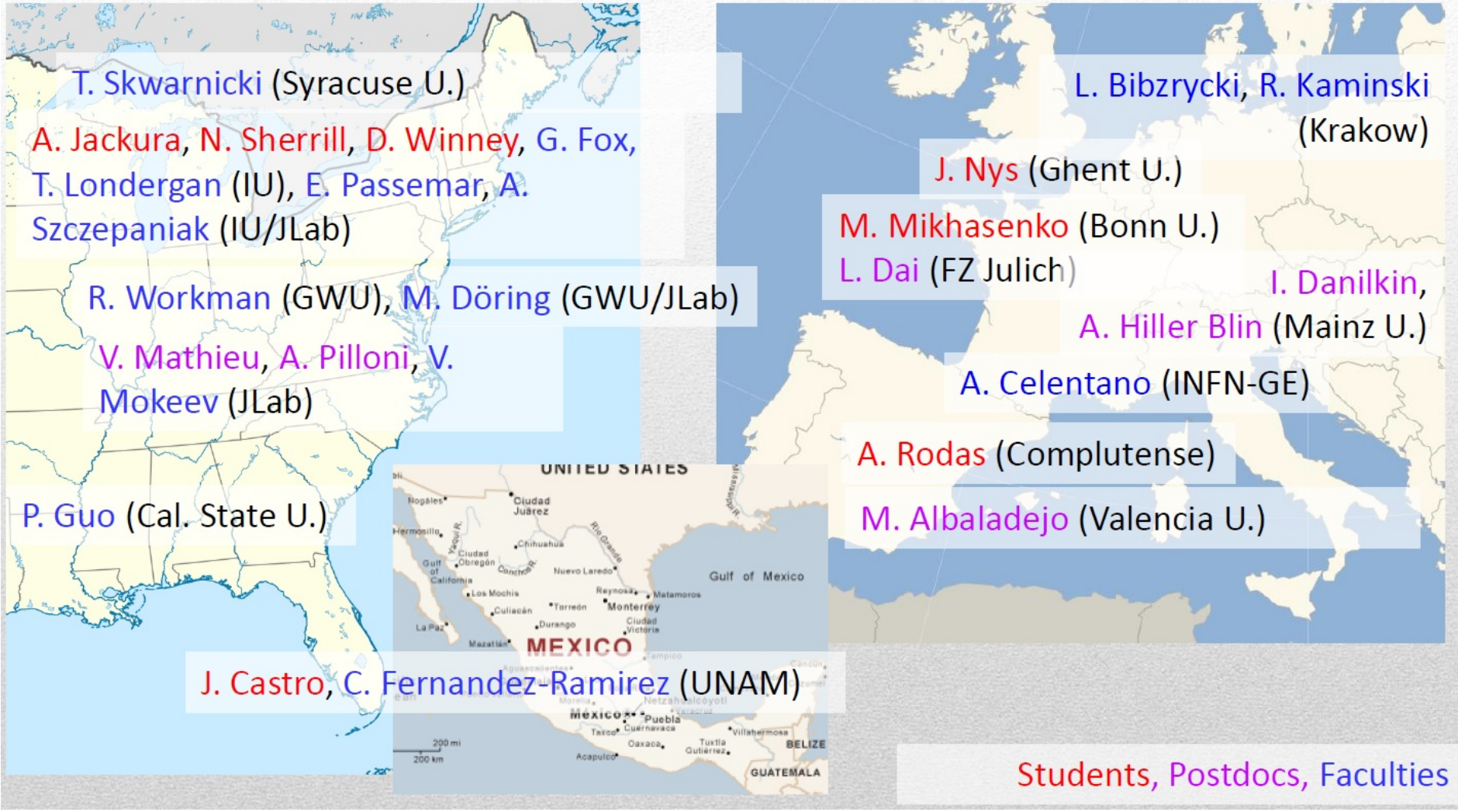

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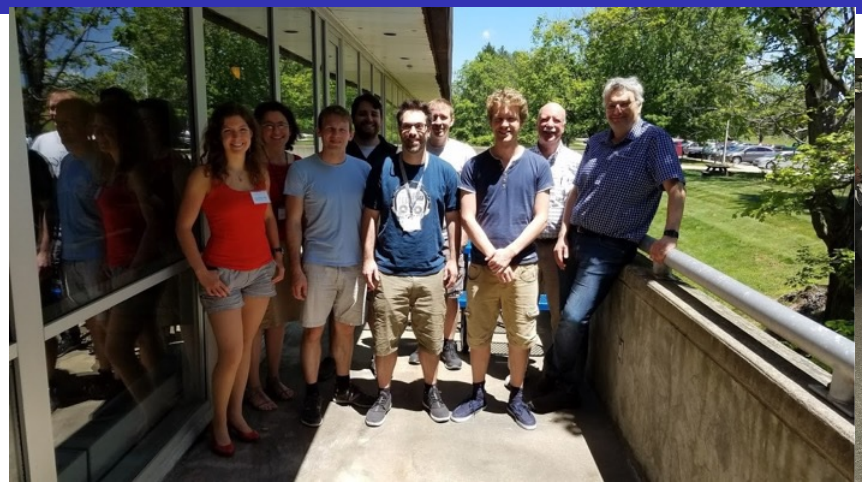

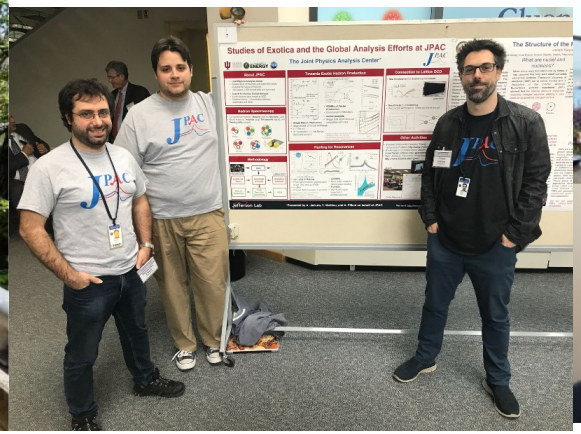

- JPAC: theory, phenomenology and analysis tools in support of experimental data from JLab12 and other accelerator laboratories.

- Contribute to education of new generation of practitioners in strong interactions.

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- Single meson production

  H. Al Ghoul et al. [GlueX], V. Mathieu and J. Nys [JPAC], Phys. Rev. D 94 (2016)034002

- Global analysis

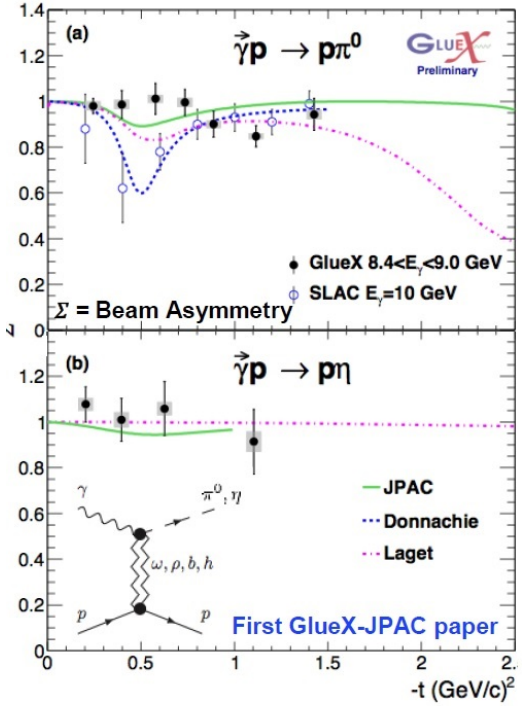
  J. Nys et al. (JPAC), Phys.Rev. D98 (2018) no.3, 034020

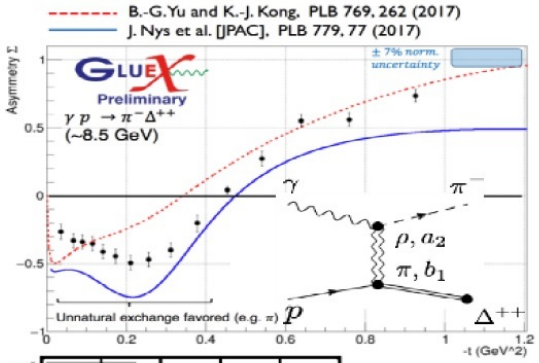
- Regge Phenomenology

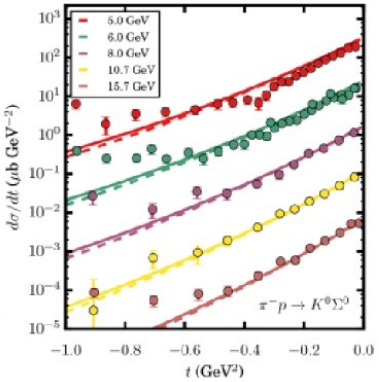
  J. A. Silva-Castro et al. (JPAC), arXiv:1809.01954

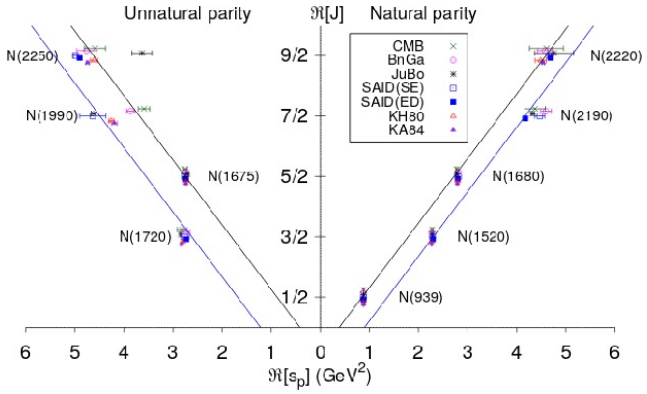
- Pion Photoproduction

  V. Mathieu et al. (JPAC), Phys.Rev. D98 (2018) no.1, 014041









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- $\tau \to 3\pi\nu$

  M. Mikhasenko et al. [JPAC], Phys.Rev. D98 (2018) no.9, 096021

- $Z_c(3900)$

  A. Pilloni et al. [JPAC], Phys. Lett. B 772 (2017)200

- $P_c(4450)$

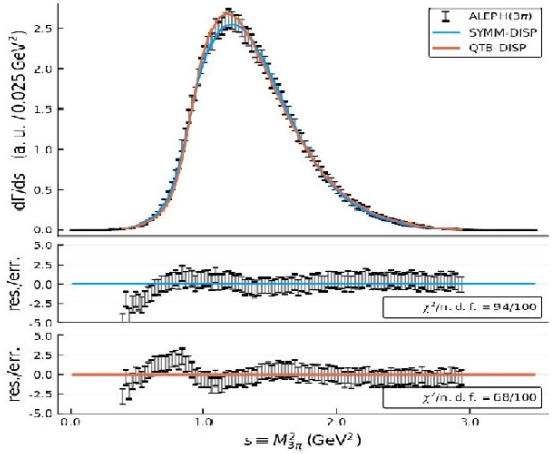
  A. Hiller Blin et al. [JPAC], Phys. Rev. D 94 (2016)034002

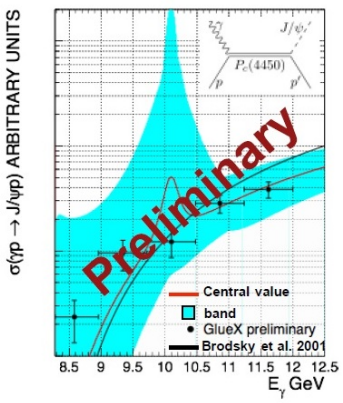
- Right helicity formalism

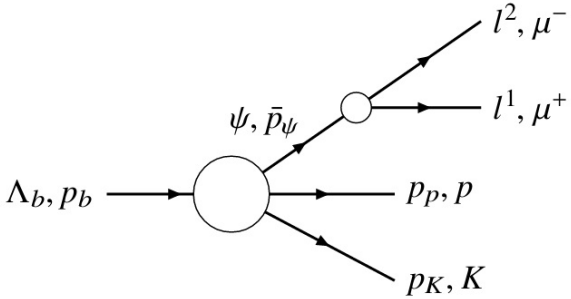
  A. Pilloni et al. [JPAC], Eur.Phys.J. C78 (2018) no.9, 727

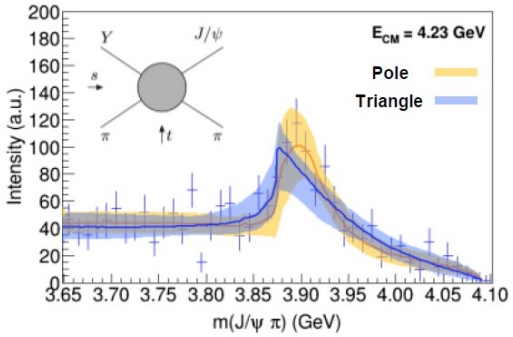
- $3 \to 3$ interactions

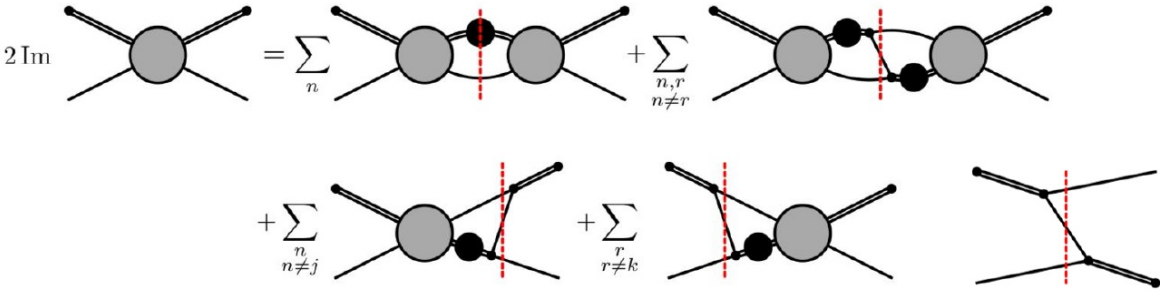
  A. Jackura et al. [JPAC], Eur.Phys.J. C79 (2019) no.1, 56







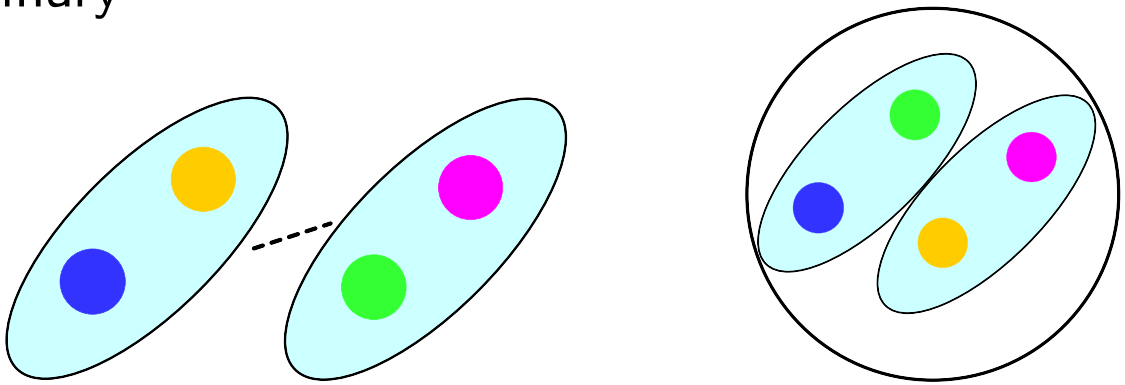




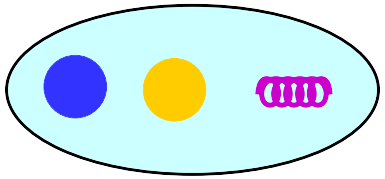
This work: Motivation

- In this talk: Recent analysis on spectroscopy
- Ordinary hadrons $\rightarrow$ first part of the talk

- Not so ordinary

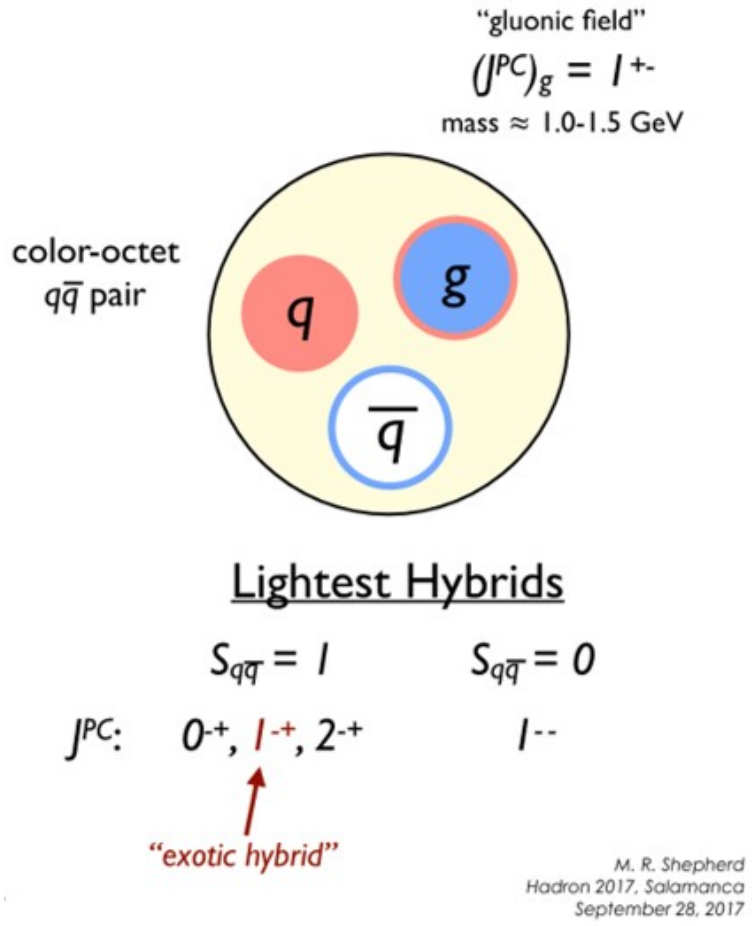


- Hybrid



This work: Motivation

- Only one hybrid expected.
- $J^{PC} = 1^{-+} \rightarrow$ lightest hybrid candidate.



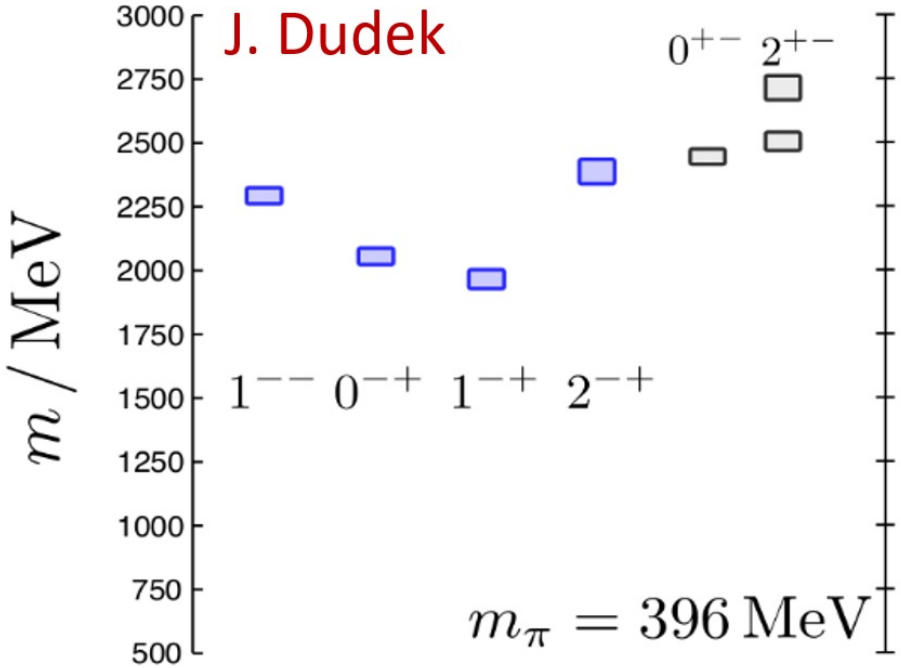
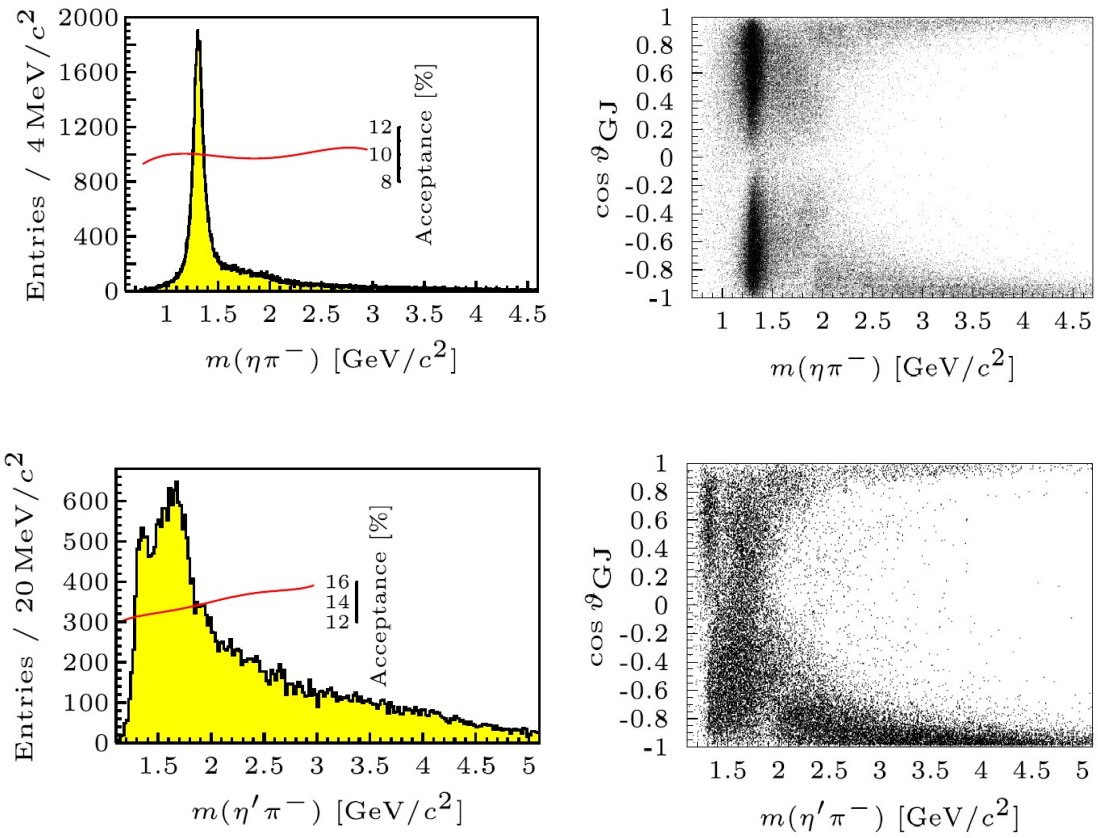


Table of Content

Data: COMPASS experiment

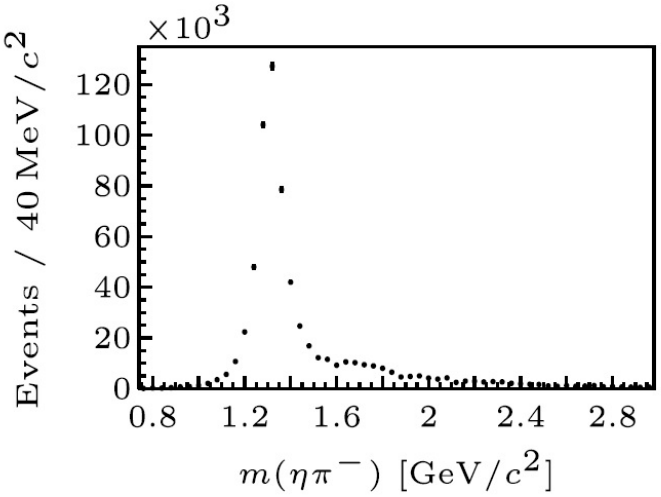
- $E_{Beam} = 190\text{GeV} \Rightarrow$ Peripheral production
- Dominated by $J^{PC} = 2^{++} \Rightarrow$ Ordinary meson.



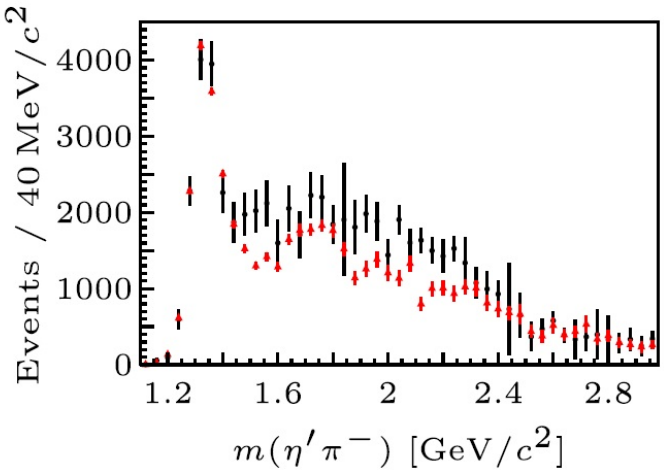
- Asymmetry$\rightarrow$ odd (exotic) waves.
- Dominated by $J^{PC} = 1^{-+} \Rightarrow$ non $q\bar{q}$ quantum numbers.

Status

- Clear $a_2(1320)$ decaying into $\eta\pi$ and $\eta'\pi$?



- Is there a clear $a_2'(1700)$?. What are its parameters?



PDG status

$\pi_1(1400)$ $I^G(J^{PC}) = 1^-(1^{-+})$

$\pi_1(1400)$ MASS	1354 ± 25 MeV (S = 1.8)
$\pi_1(1400)$ WIDTH	330 ± 35 MeV

Decay Modes

Mode		Fraction (Γ_i / Γ)
Γ_1	$\eta\pi^0$	seen
Γ_2	$\eta\pi^-$	seen
Γ_3	$\eta'\pi$	

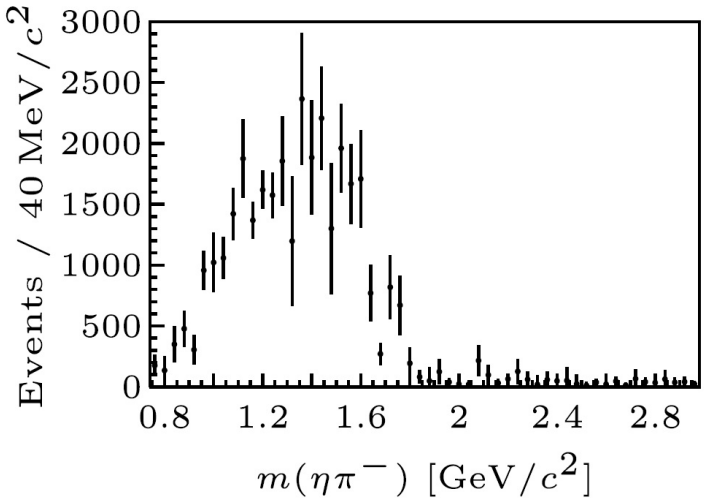
$\pi_1(1600)$ $I^G(J^{PC}) = 1^-(1^{-+})$

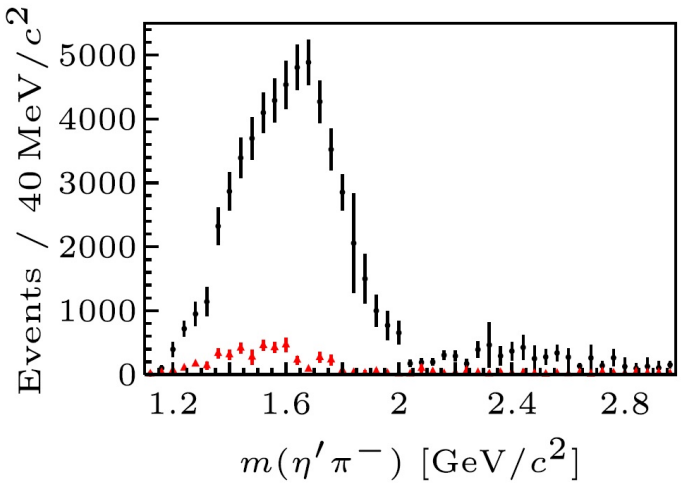
$\pi_1(1600)$ MASS	1662^{+8}_{-9} MeV
$\pi_1(1600)$ WIDTH	241 ± 40 MeV (S = 1.4)

Decay Modes

Mode		Fraction (Γ_i / Γ)
Γ_1	$\pi\pi\pi$	seen
Γ_2	$\rho^0\pi^-$	seen
Γ_3	$f_2(1270)\pi^-$	not seen
Γ_4	$b_1(1235)\pi$	seen
Γ_5	$\eta'(958)\pi^-$	seen
Γ_6	$f_1(1285)\pi$	seen

- PDG reports 2 different resonances

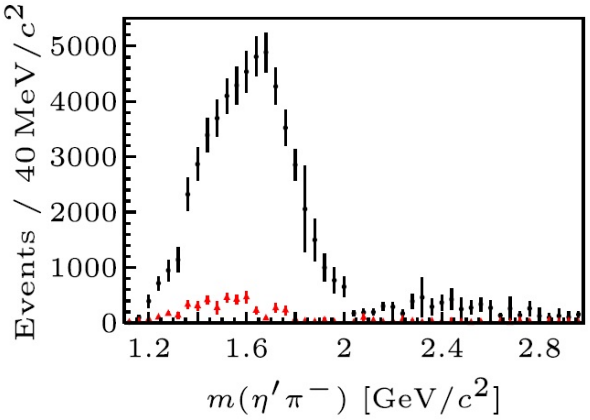




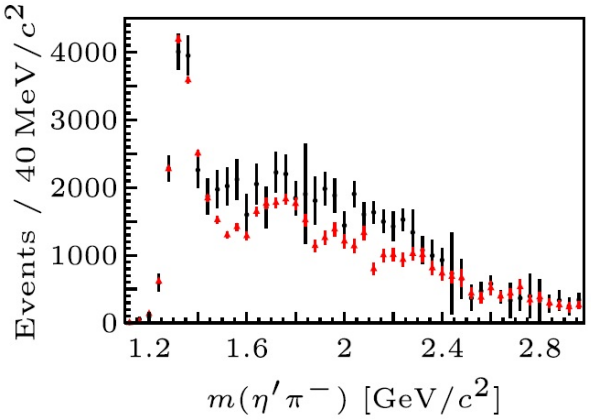
- $\pi_1(1400)$ decaying into $\eta\pi$? Different $\pi_1(1600)$ decaying into $\eta'\pi$?

Partial waves

- Coupling to $\eta\pi$ much smaller than $\eta'\pi \Rightarrow$ Hybrid nature?
- Ordinary mesons have similar couplings.
- Data looks suspicious above 2 GeV.



(a) P-wave, $L = 1$



(b) D-wave, $L = 2$

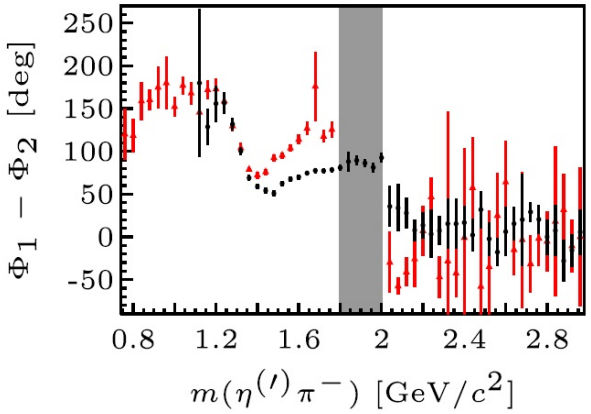
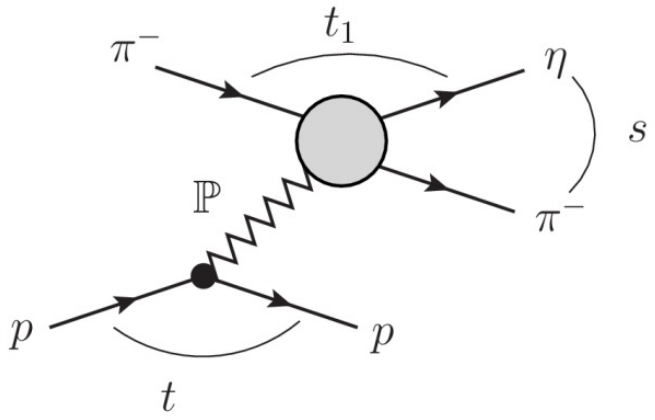


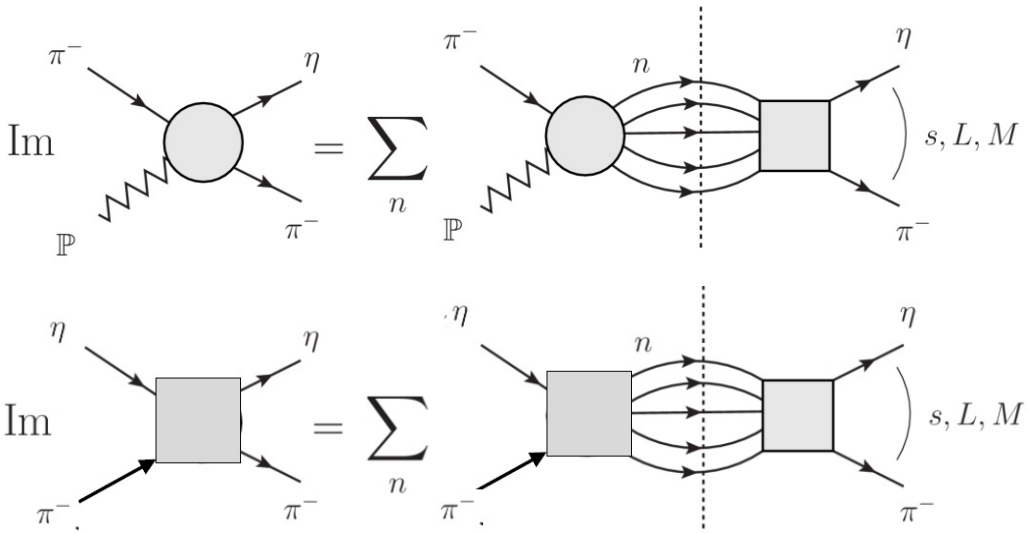
Table of Content

Method

- Peripheral production $\Rightarrow$ factorization of the pomeron $\Rightarrow Ima(s) = \rho(s)t^*(s)a(s)$.



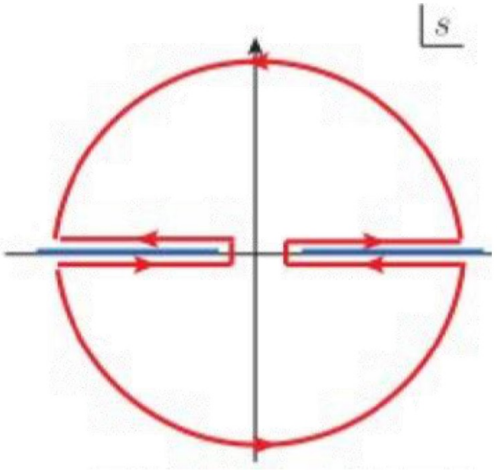
- Amplitude built around $t(s) = \frac{N(s)}{D(s)}$ method $\Rightarrow a(s) = p^2 q \frac{n(s)}{D(s)}$.



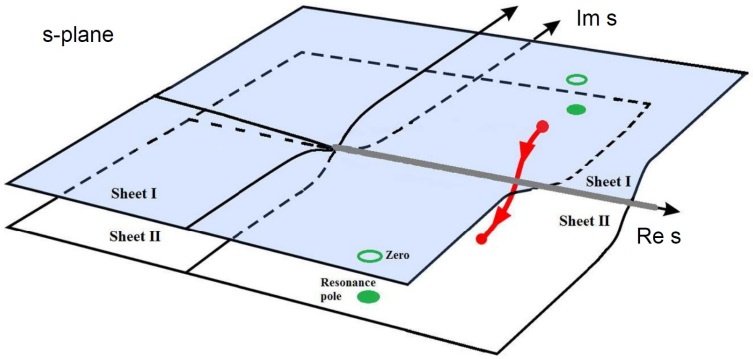
- They are smooth polynomials $n(s) = \sum_j a_j w^j(s)$, where $w(s) = \frac{s}{s+s_0}$.

Method

- N(s) and n(s) are process dependent, they have only left hand cuts.
- D(s) has a right hand cut, altogether $t(s)$ has the correct analytic structure.



- By adding this discontinuity over the RHC one could go to the direct continuous Riemann sheet.



Single channel

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

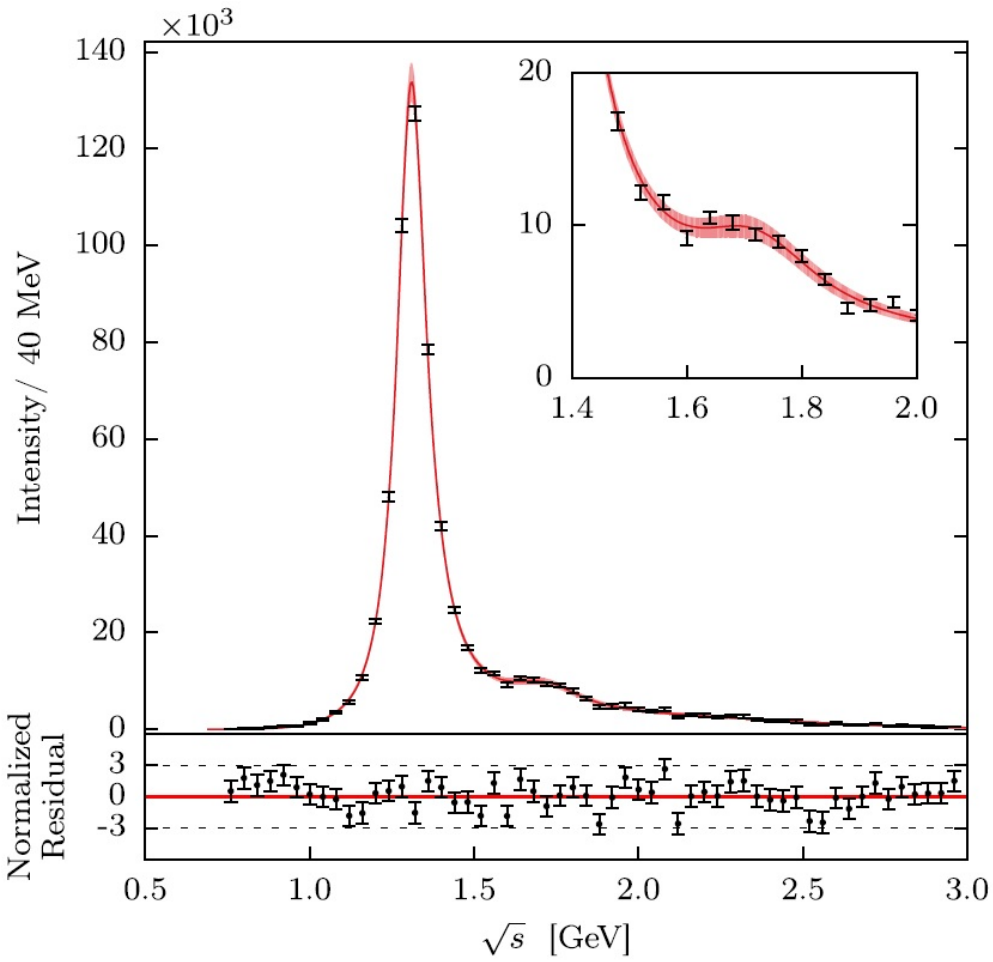
- $Imt(s) = \rho(s)|t(s)|^2 \Rightarrow ImD(s) = -\rho(s)N(s)$, so that

$$D(s) = D_0(s) - \frac{s}{\pi}\int_{s_{th}}^{\infty} ds' \frac{\rho(s')N(s')}{s'(s'-s)},$$

where $D_0(s) = c_0 - c_1 s - \frac{c_2}{c_3 - s} \rightarrow$ CDD poles.

- And $\rho(s)N(s) = g\frac{\lambda^{(2l+1)/2}(s, m_\eta^2, m_\pi^2)}{(s+s_R)^{2l+3}}$.

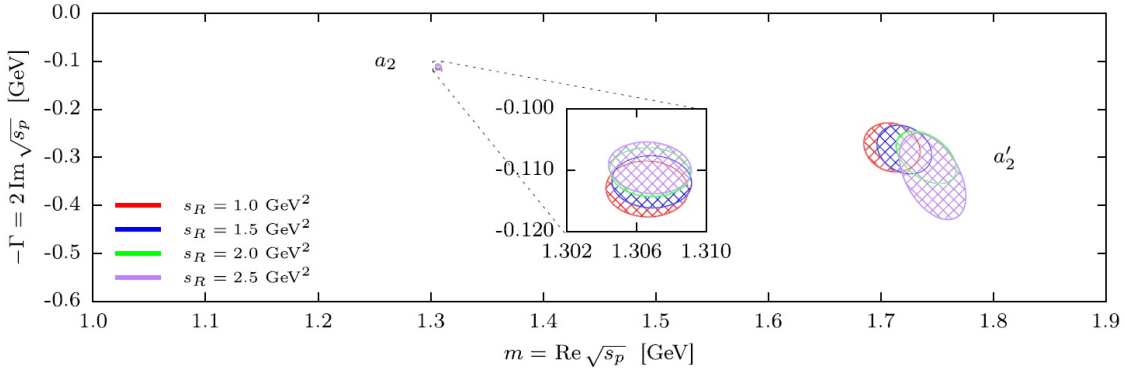
Single channel

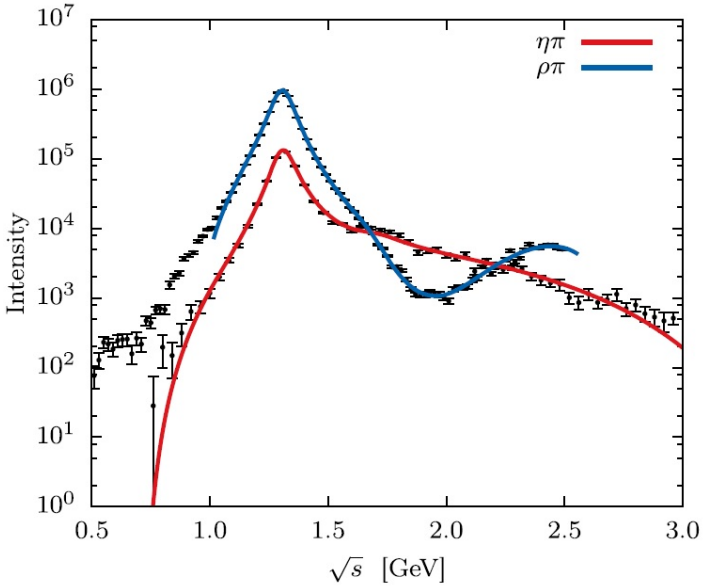


- 12 parameters, $\chi^2 \approx 2$.
- Good description of both peaks, the residuals of the fits follow a Gaussian distribution.

Single channel

- Various systematics
  1. Effective mass of the pomeron.
  2. Different values for N(s) scale parameters.
  3. Including $\rho\pi$ channel.





- $m(a_2) = 1307 \pm 1 \pm 6$ MeV $\quad \Gamma(a_2) = 112 \pm 1 \pm 8$ MeV
- $m(a_2') = 1720 \pm 10 \pm 60$ MeV $\quad \Gamma(a_2') = 280 \pm 10 \pm 70$ MeV

Table of Content

Coupled channel

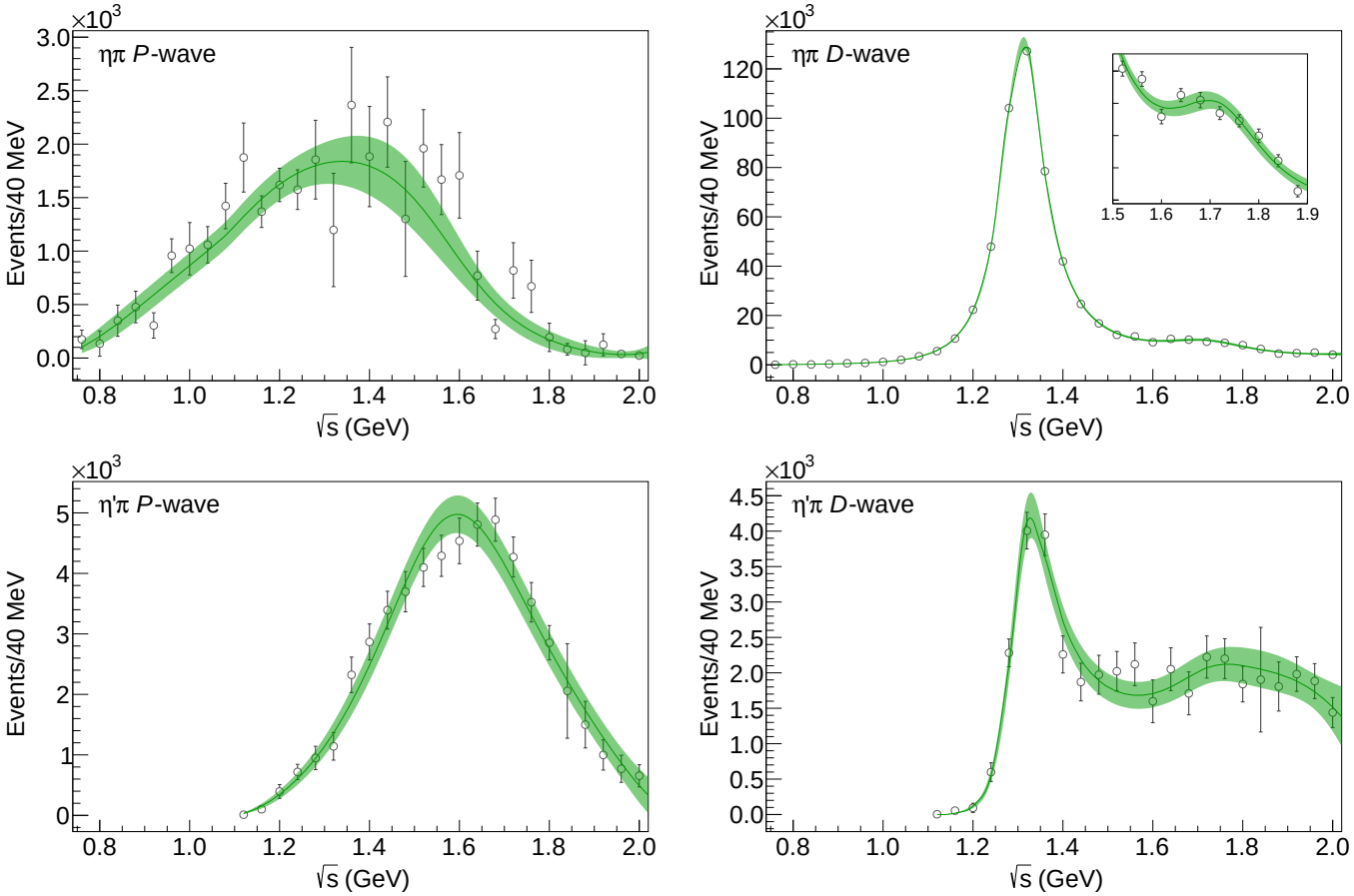
- $\eta^{(\prime)}\pi$ coupled channel up to 2 GeV.
- $\rho\pi$ cannot be included without including big systematic contribution (Deck).
- We use a K-matrix approach with a Chew-Mandelstam phase space.

$$
\begin{aligned}
D^J(s)_{ki} &= (K^J(s)^{-1})_{ki} - \frac{s}{\pi}\int_{s_k}^{\infty} ds' \frac{\rho(s')N^J_{ki}(s')}{s'(s'-s-i\epsilon)}, \\
\rho N^J_{ki}(s') &= \delta_{ki}\,\frac{\lambda^{J+1/2}\left(s', m^2_{\eta^{(\prime)}}, m^2_\pi\right)}{(s'+s_L)^{2J+1+\alpha}} \\
K^J_{ki}(s) &= \sum_R \frac{g^{J,R}_k g^{J,R}_i}{m^2_R - s} + c^J_{ki} + d^J_{ki}\, s.
\end{aligned}
$$

- Just 1 K-matrix pole for the P-wave.

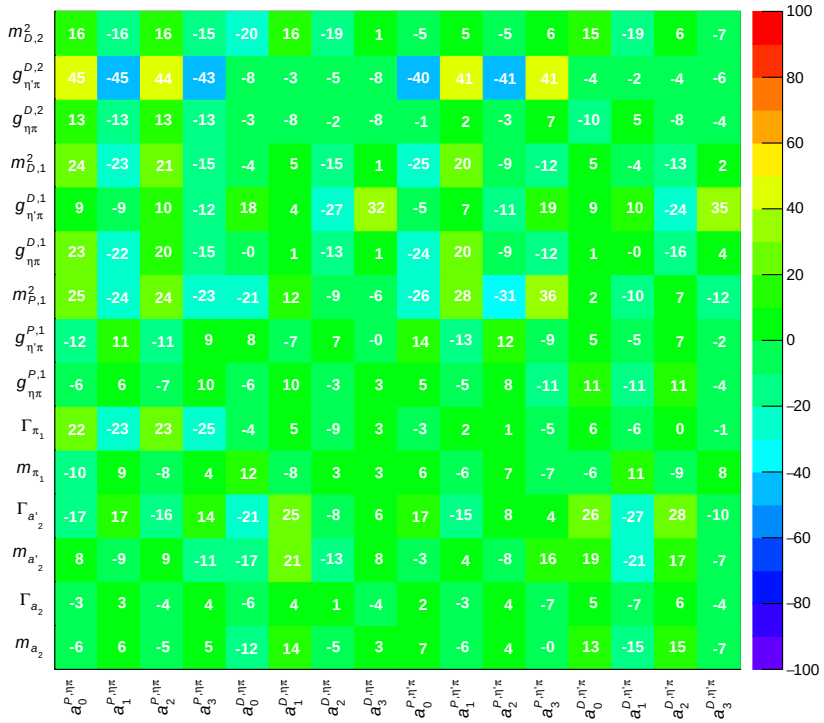
Coupled channel analysis

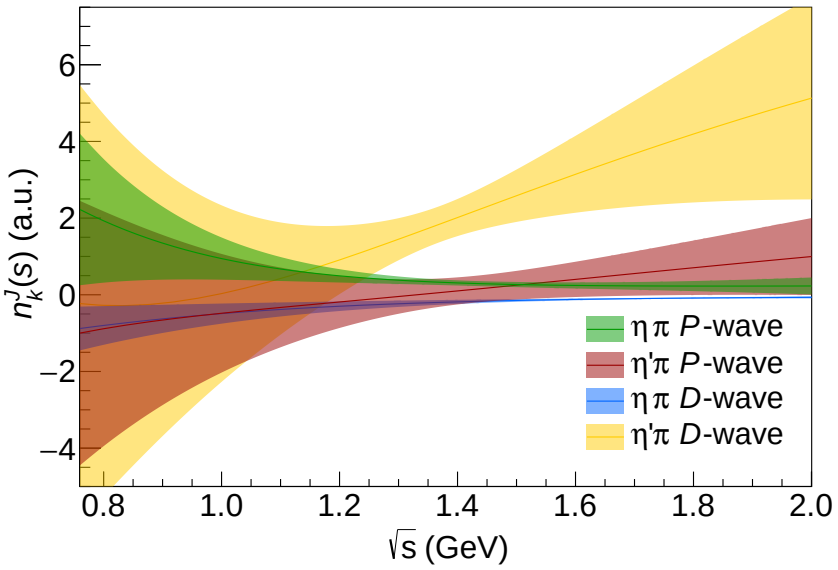
- We use an average of 6 parameters for each figure.
- $\chi^2 \approx 1.3$, no significant deviation for any partial wave.
- 1 K-matrix pole produces 2 different peaks for the P-wave $\rightarrow$ 300 MeV distance.



Coupled channel analysis

- There is no correlation between the numerator $n^J(s)_k$ and denominator $D^J(s)_{ki}$.

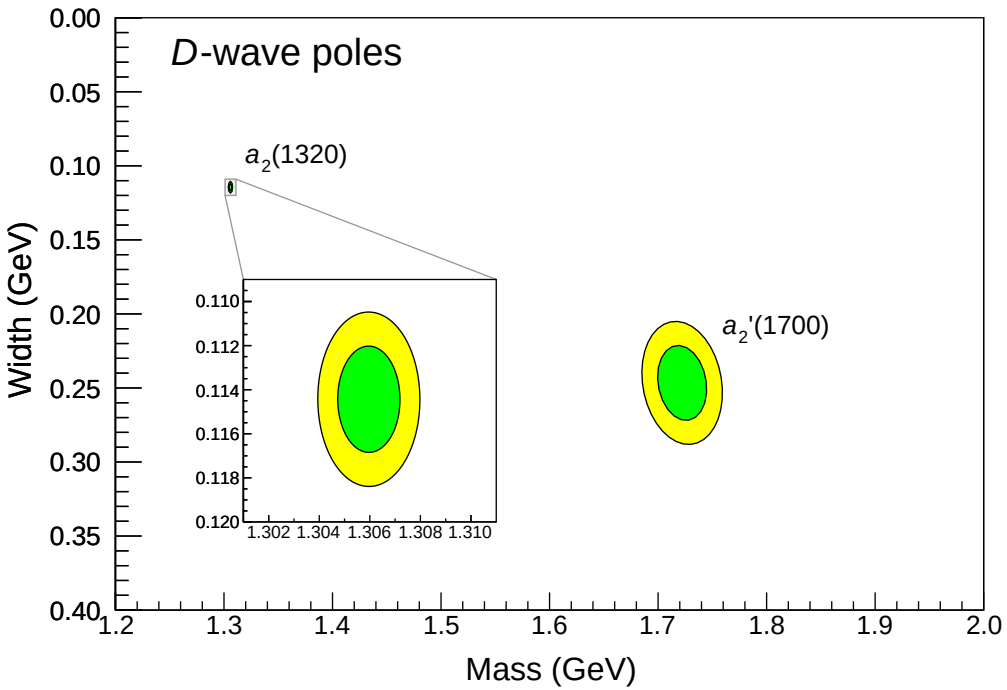


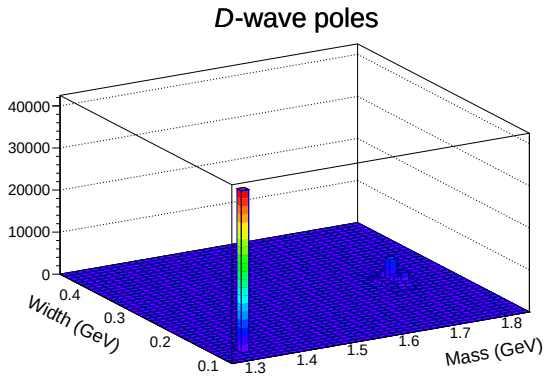


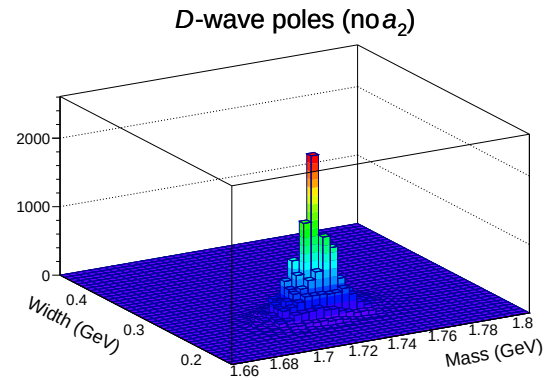
- As explained before, numerator is smooth and process dependant.

Poles

- Statistical uncertainties calculated through bootstraping
- $m(a_2) = 1306.0 \pm 0.8 \pm 1.3$ MeV $\quad \Gamma(a_2) = 114.4 \pm 1.6 \pm 0.0$ MeV
- $m(a_2') = 1722 \pm 15 \pm 67$ MeV $\quad \Gamma(a_2') = 247 \pm 17 \pm 63$ MeV
- Clearly compatible with the single channel case.
- All systematics (diferent LHC masses, numerator models ...) included.

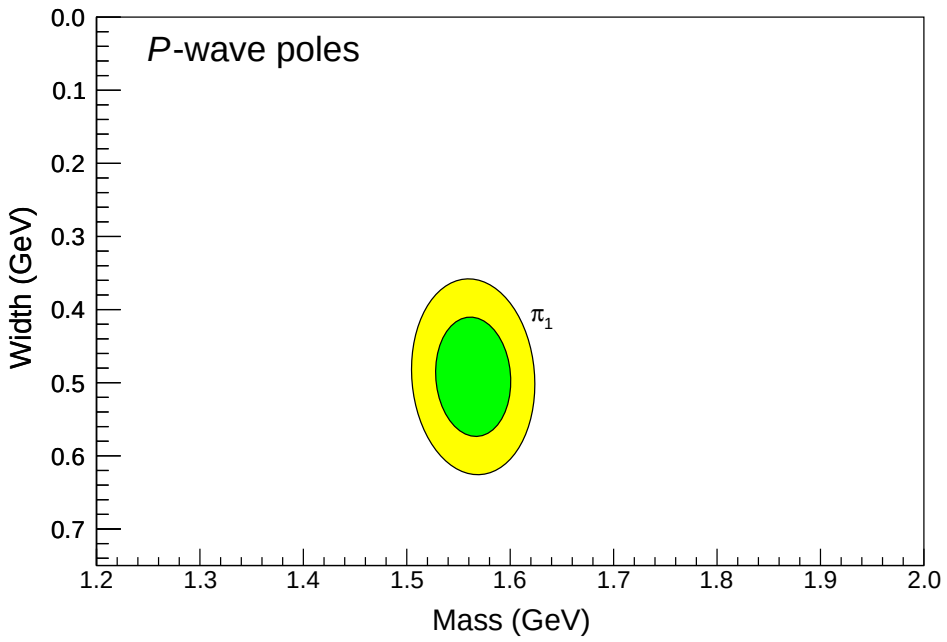






Poles

- Only one pole for the P-wave.
- $m(\pi_1) = 1564 \pm 24 \pm 86$ MeV $\quad \Gamma(\pi_1) = 492 \pm 54 \pm 102$ MeV.



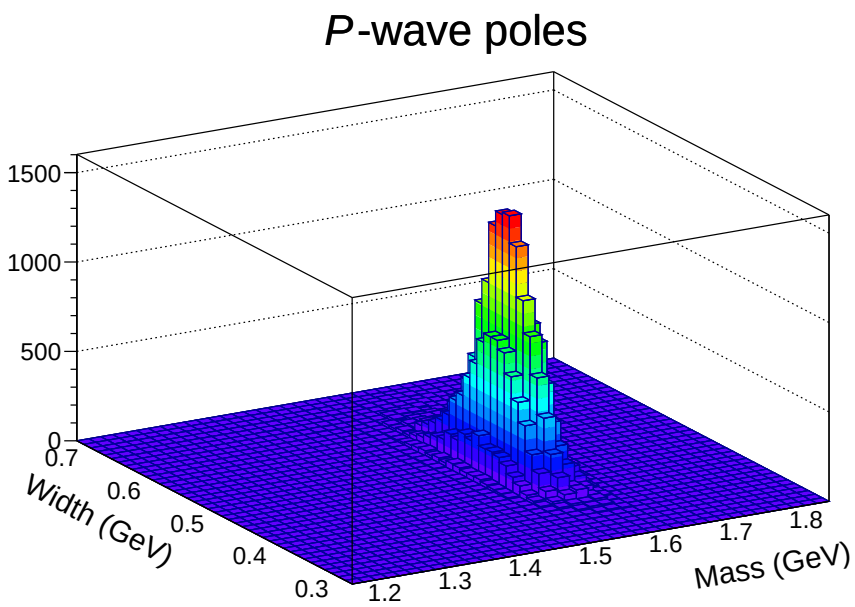
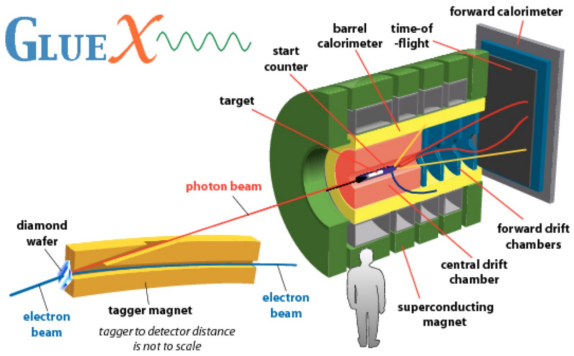
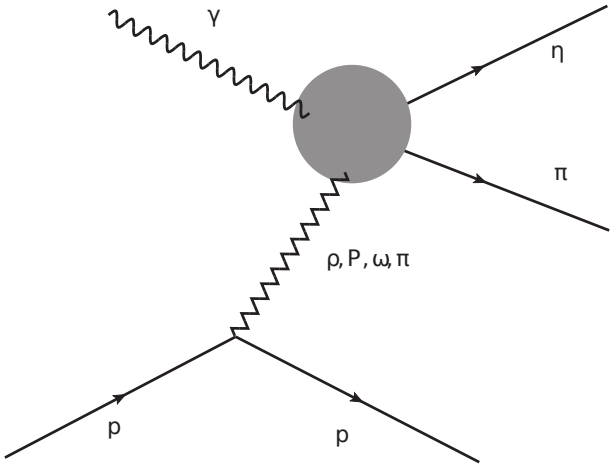


Table of Content

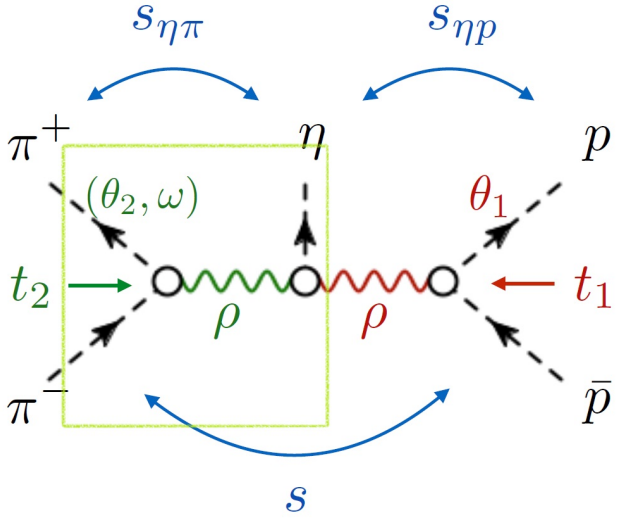
Future project: Hunting hybrids at JLab

- New GlueX/CLAS data?





- $2 \to 3$ finite energy sum rules (FESR)
- $\pi p \to \eta^{(\prime)} \pi p$ at JLAB kinematics.



Summary

- Phenomenological analysis of COMPASS data $\rightarrow$ Analyticity and Unitarity.
- Past: JPAC and COMPASS collaboration to extract the ordinary $a_2(1320)$ and $a_2'(1700)$ resonances.
- This work: New method to analyze also the non-ordinary π_1. Just one resonance contrary to the PDG status.
- Future: Understanding Gluex exchanges.
- Future: Analytic dispersive constraints for $2 \rightarrow 3$.

Thank you for your attention!