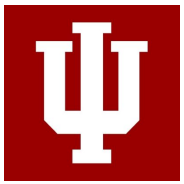
Exotics as a new view on the non-perturbative properties of QCD

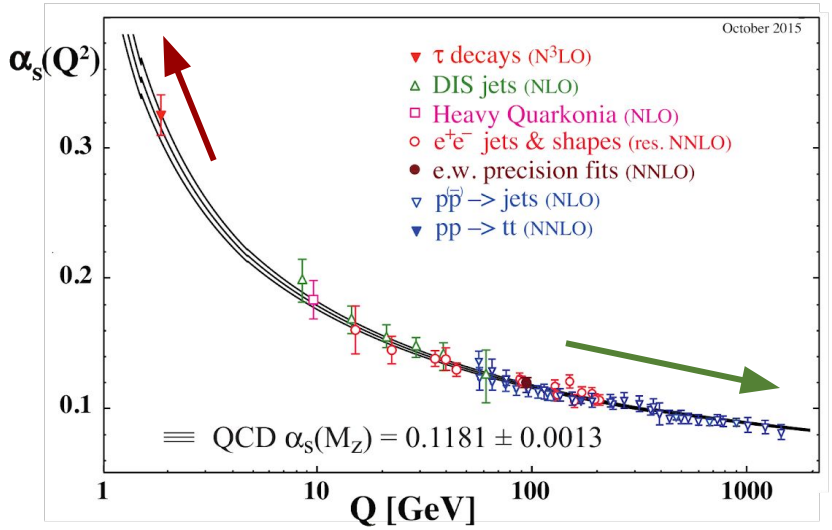
Jannes Nys




Belgian Physical Society, Antwerp, 11/04/2018

Non-perturbative QCD

Numerical methods:
Path integral: lattice QCD



Functional methods:
Perturbation theory

$$\mathcal{L} = \sum_q \bar{\psi}_{q,a}(i\gamma^\mu \partial_\mu \delta_{ab} - g_s \gamma^\mu t^C_{ab} \mathcal{A}^C_\mu - m_q \delta_{ab})\psi_{q,b} - \frac{1}{4} F^A_{\mu\nu} F^{A\,\mu\nu}$$

$$F^A_{\mu\nu} = \partial_\mu \mathcal{A}^A_\nu - \partial_\nu \mathcal{A}^A_\mu - g_s f_{ABC} \mathcal{A}^B_\mu \mathcal{A}^C_\nu$$

Unanswered questions

- Role of glue?
- Why did the quark model work so well up till now?
- Why does it fail in the charmonium sector?
- Can we extract the hadron spectrum directly from QCD?
- …

Which rules govern hadron construction?

Exotic spectroscopy

Quark models are useful for **insight**

Mesons: $q\bar{q}$

$P = (-1)^{L+1}$

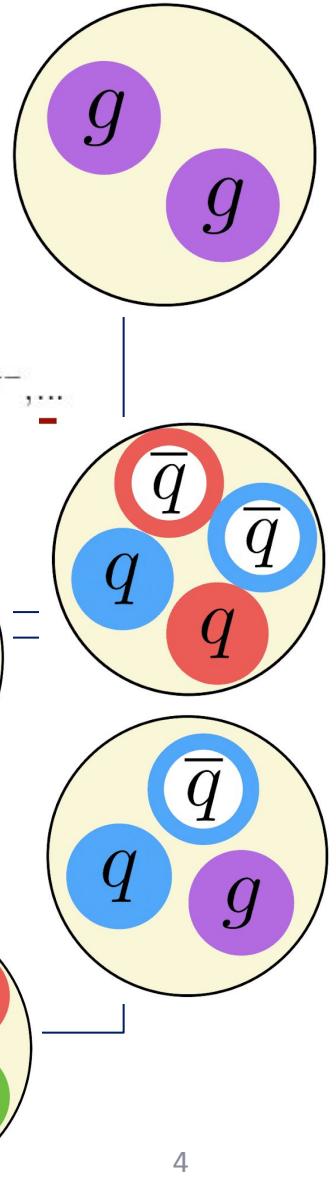
$C = (-1)^{L+S}$

$J^{PC}= 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 1^{++}, 2^{--}, 2^{-+}, 2^{++}, \ldots$

Exotic

$0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

glueballs or hybrid mesons or higher Fock states or molecules



Baryons: qqq

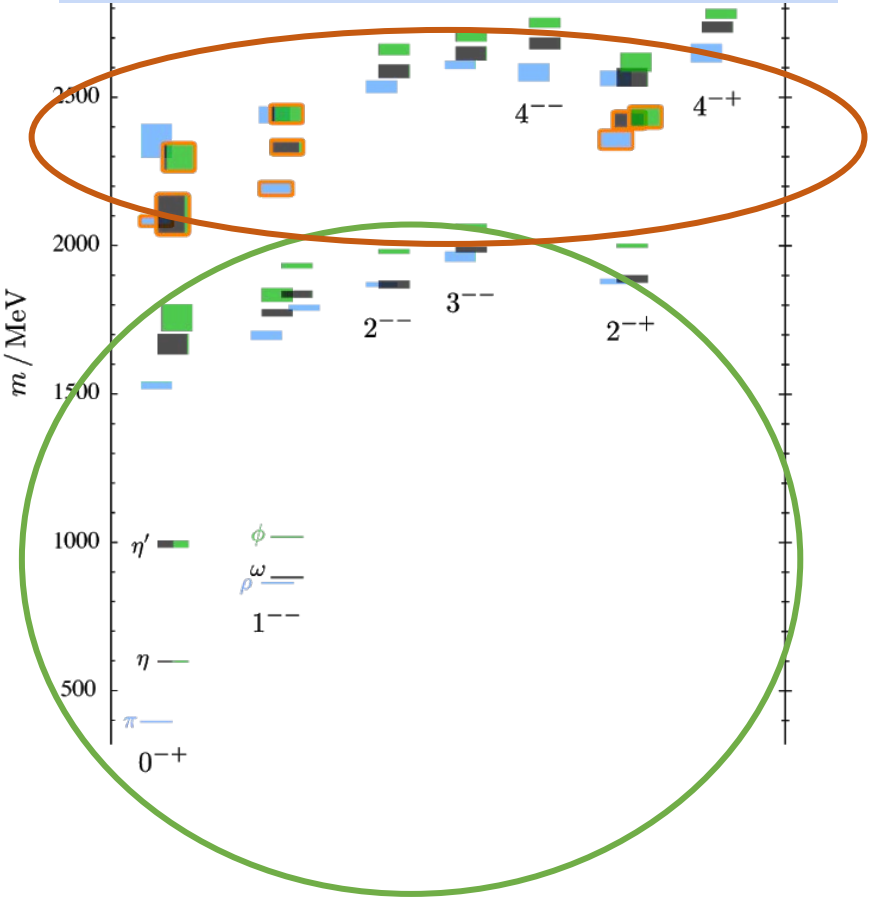
Observation is difficult:

- `exotics' hide in plain sight since they have the same quantum numbers
- Large masses

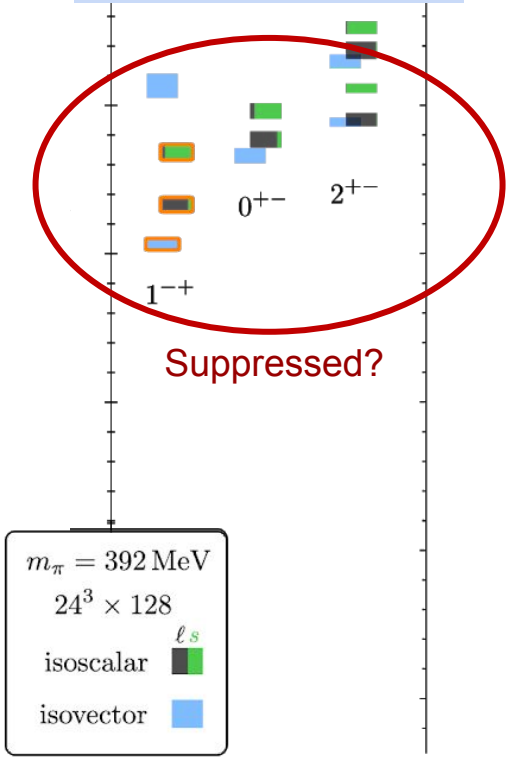
Only structure to distinguish them

Spectroscopy from QCD

Dominant overlap with operators featuring a **chromomagnetic** construction

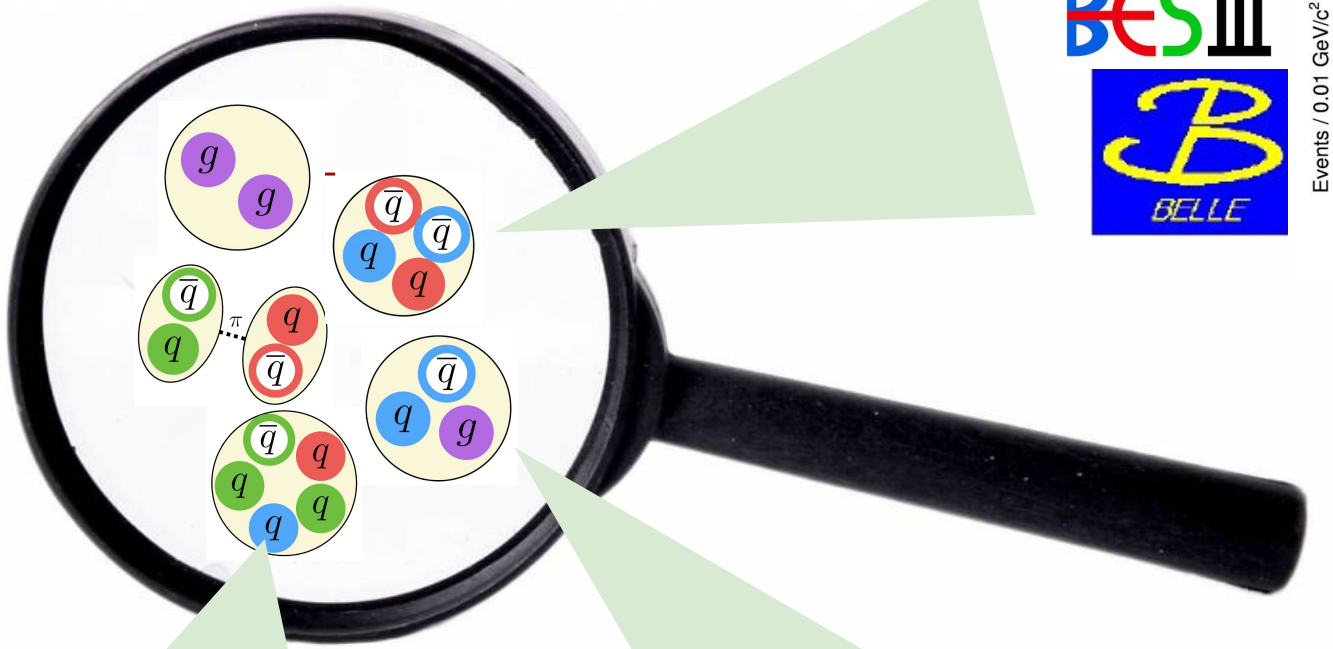


Beyond quark model



Static spectrum from Lattice QCD [Phys.Rev. D88 (2013) no.9, 094505]

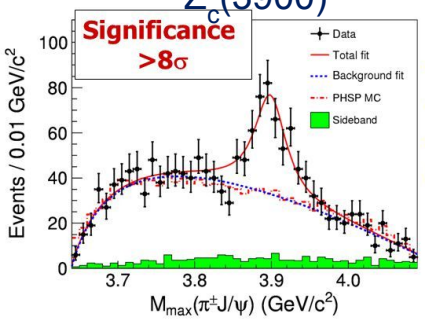
Spectroscopy programs



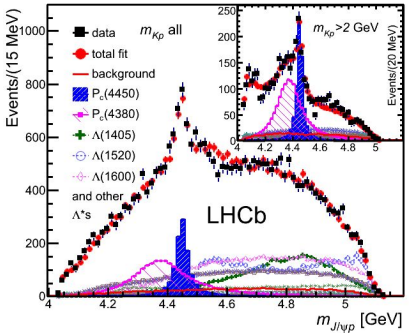
BESIII

BELLE

$Z_c(3900)$



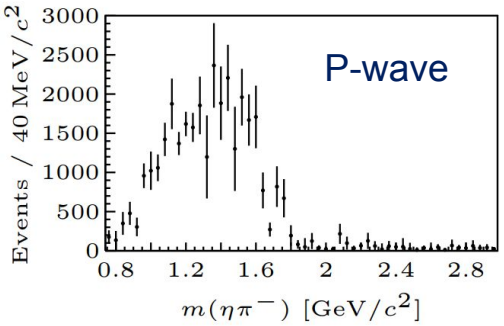
$P_c(4450)$



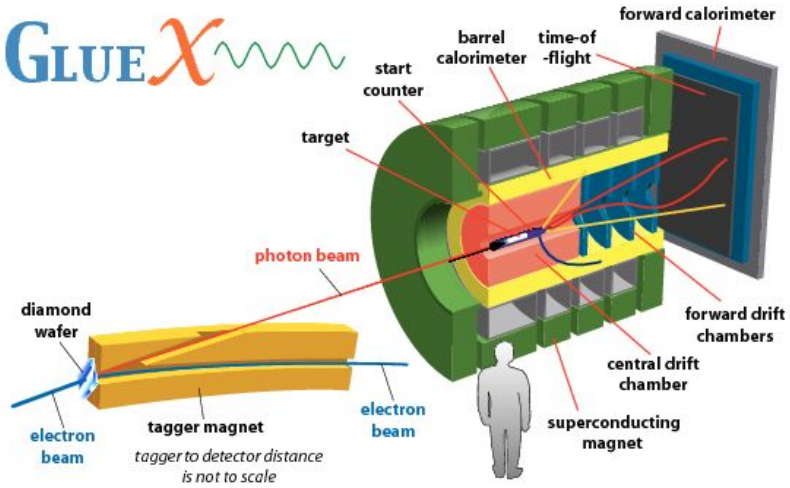
LHCb

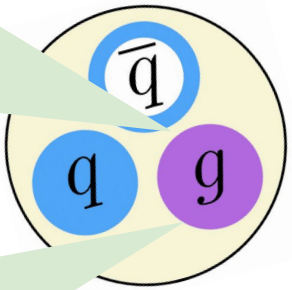
COMPASS

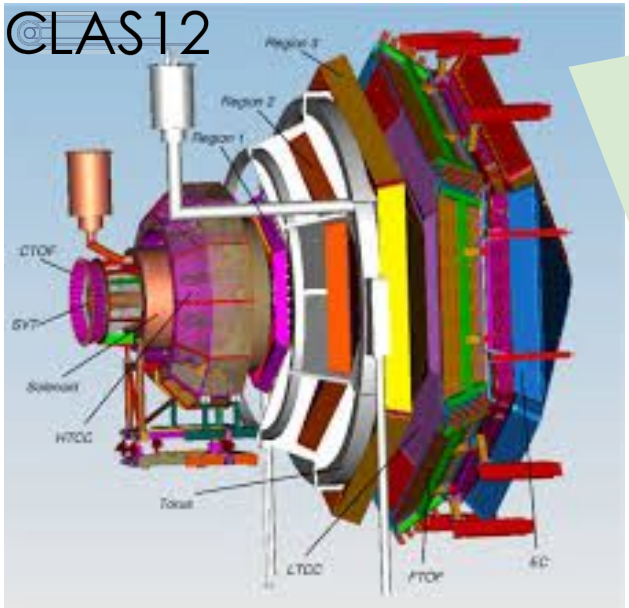
π_1 (?)



Light-quark exotics: experiment

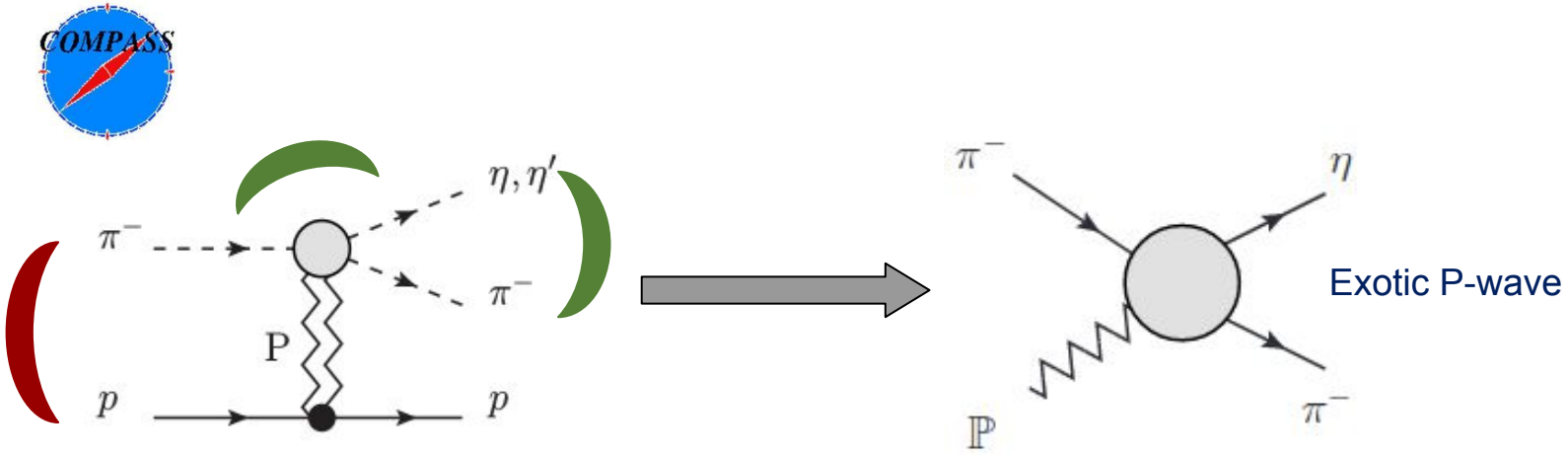






Light-quark exotics: production process

Example: π_1 production



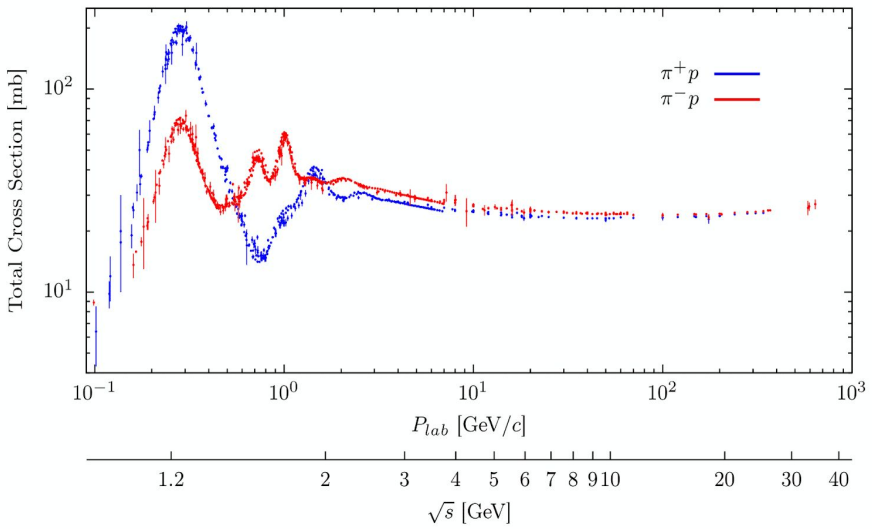
Energy **scale separation**: factorization possible

Knowledge of the production process required to carry out PWA
Multiple production processes required for confirmation

Strategy?

- *How do we extract partial waves?*
  - Knowledge of the production process
- *How do we extract resonances (pole positions)?*
  - QCD? Not a useful tool.
  - S-matrix parametrization

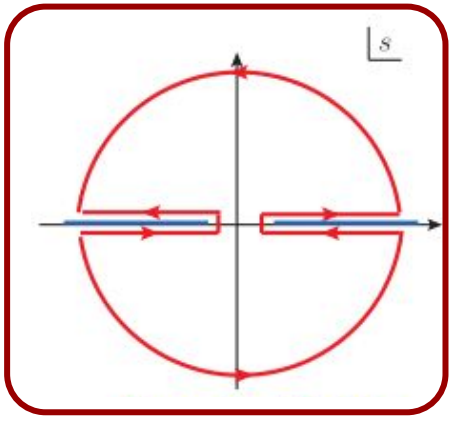
S-matrix theory



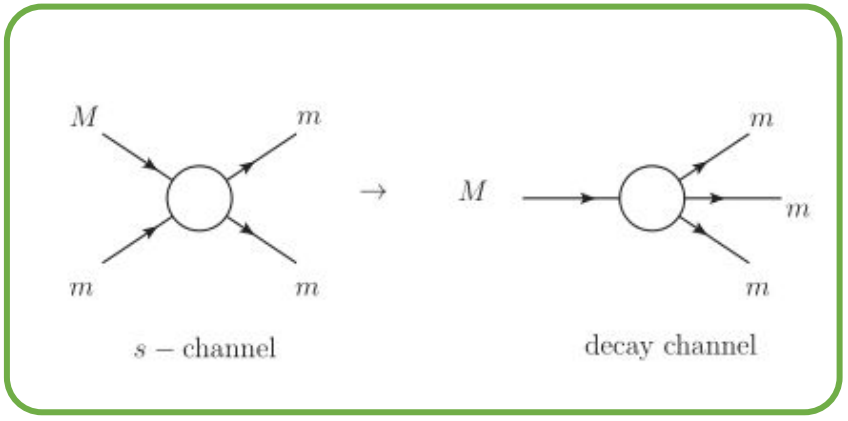
S-matrix theory

Build models: general principles

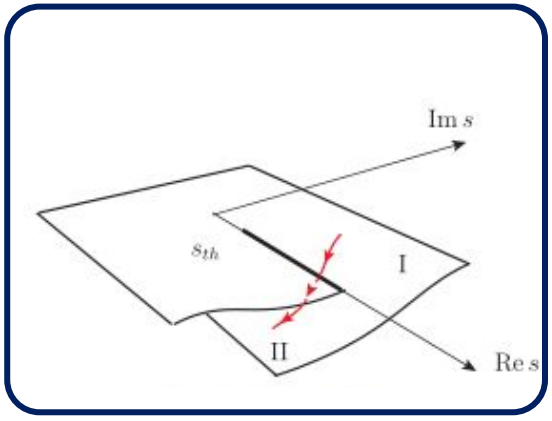
- Analyticity
- Crossing symmetry
- Unitarity
- Lorentz symmetries
- Global symmetries of QCD



ANALYTICITY

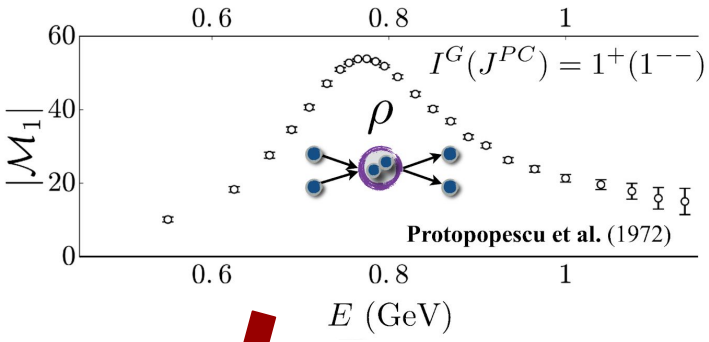


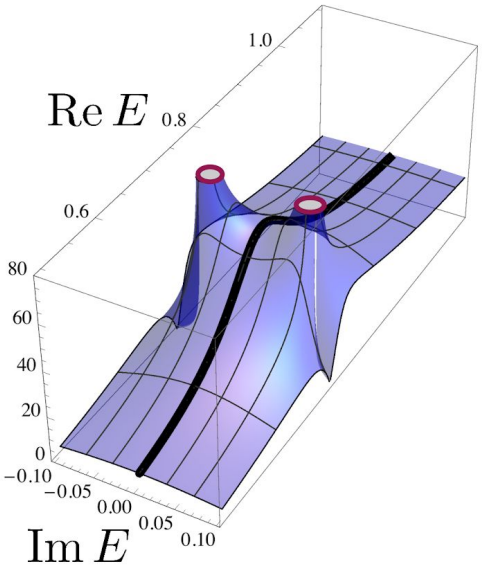
CROSSING SYMMETRY

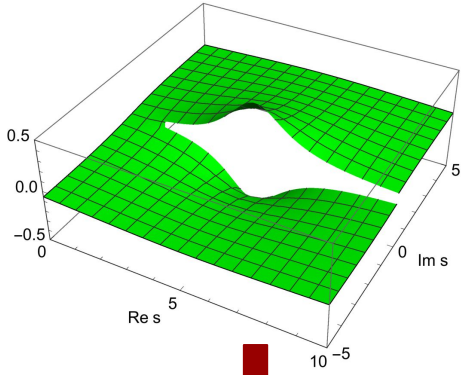


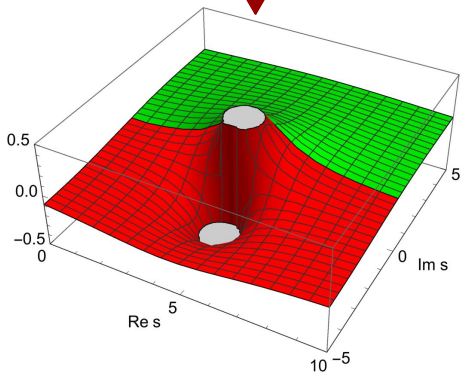
UNITARITY

Resonances = poles

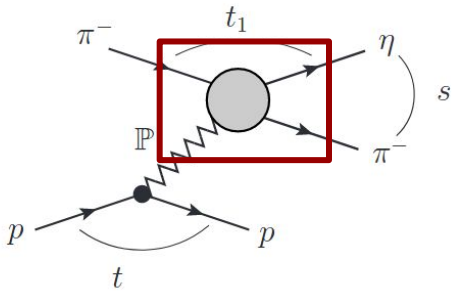




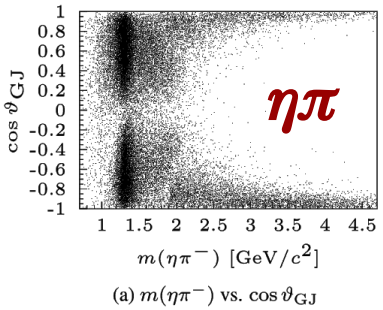




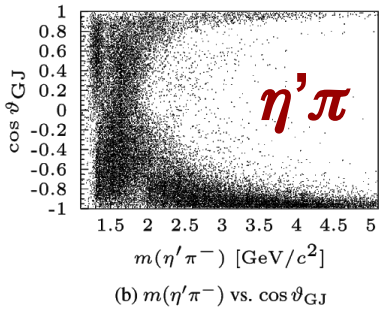
Pole extraction



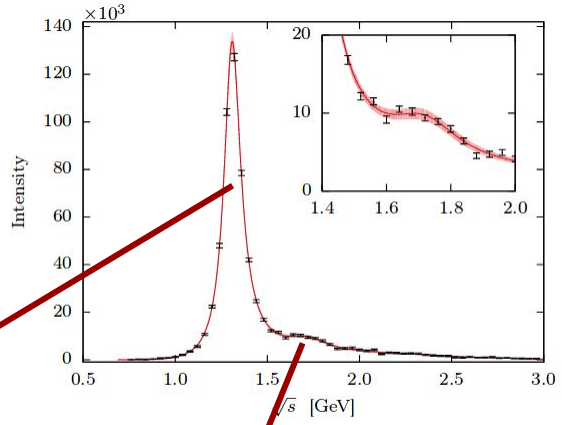
[DATA: COMPASS, PLB (2015) 303]

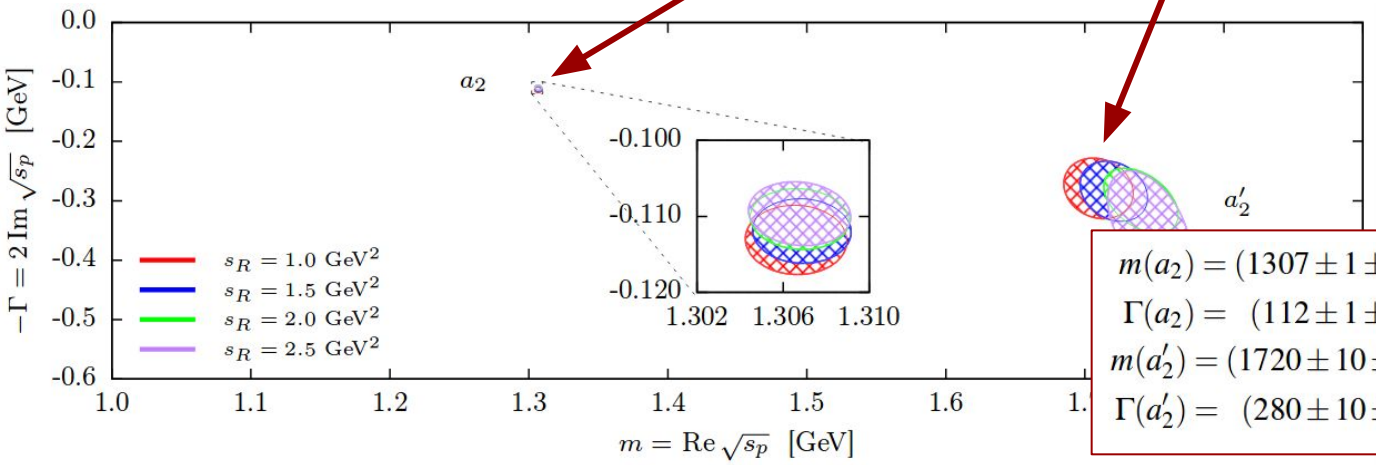


(a) $m(\eta\pi^-)$ vs. $\cos\vartheta_{GJ}$



(b) $m(\eta'\pi^-)$ vs. $\cos\vartheta_{GJ}$



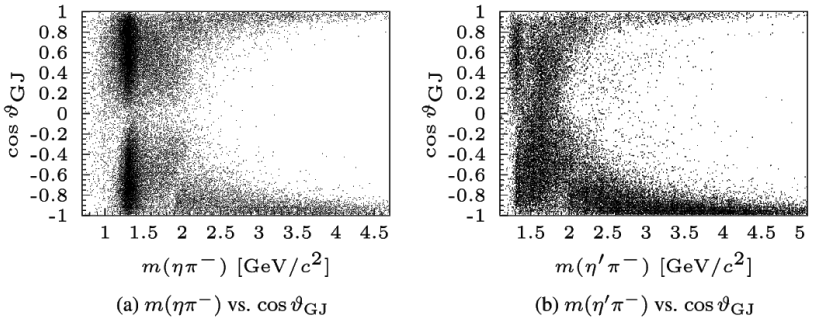


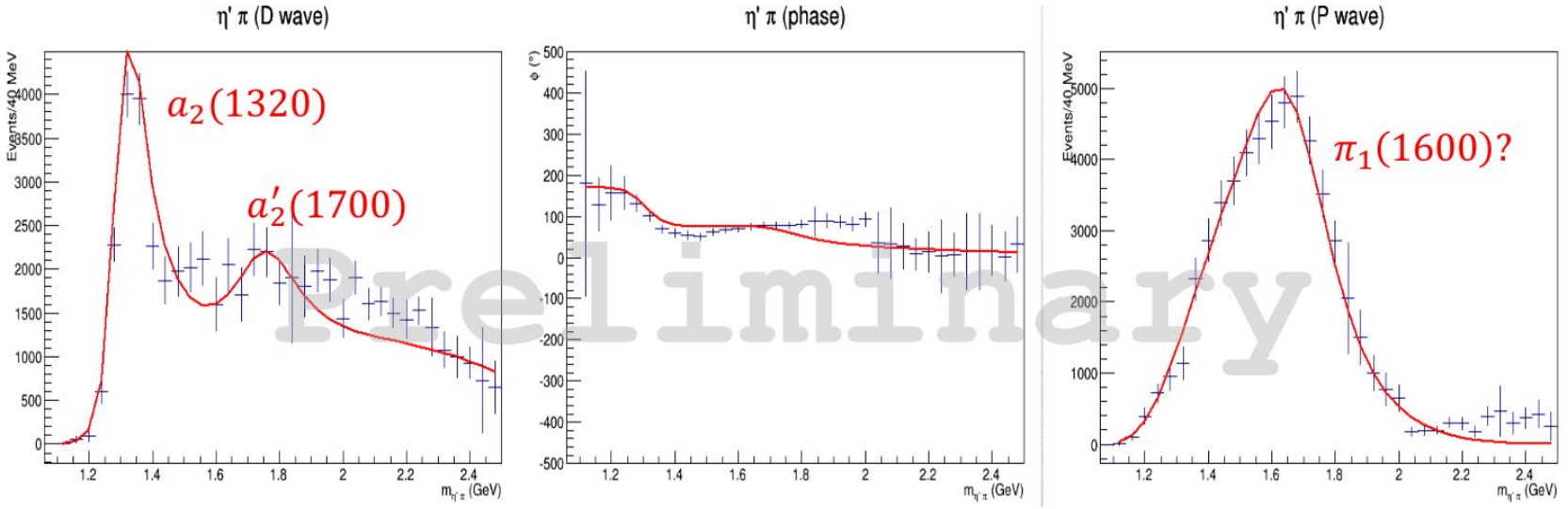
$m(a_2) = (1307 \pm 1 \pm 6)$ MeV
$\Gamma(a_2) = (112 \pm 1 \pm 8)$ MeV
$m(a_2') = (1720 \pm 10 \pm 60)$ MeV
$\Gamma(a_2') = (280 \pm 10 \pm 70)$ MeV

Pole extraction, contd.

- Ongoing analysis for
  - Coupled channels: ηπ and η'π
  - P (**exotic**) and D waves

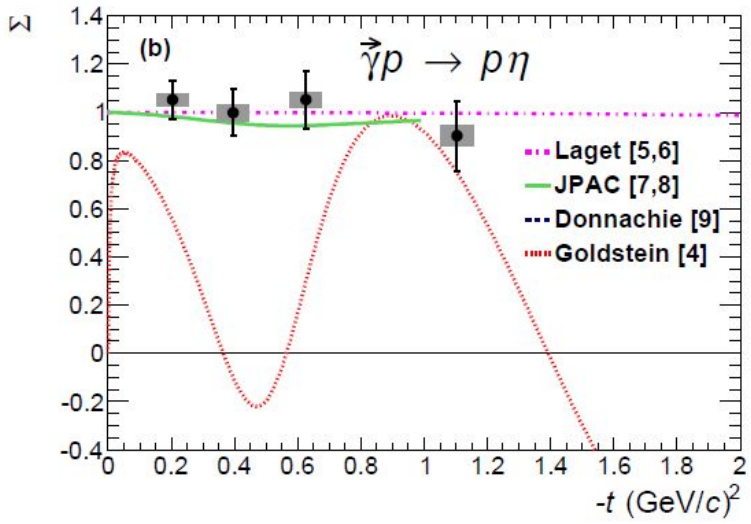
[DATA: COMPASS, PLB (2015) 303]

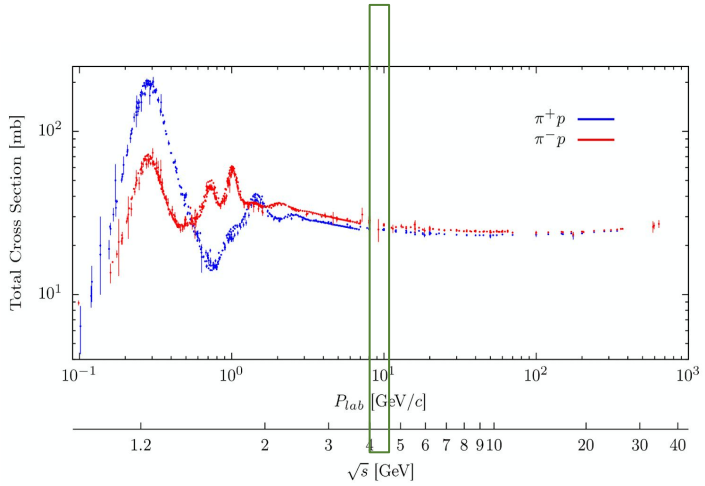


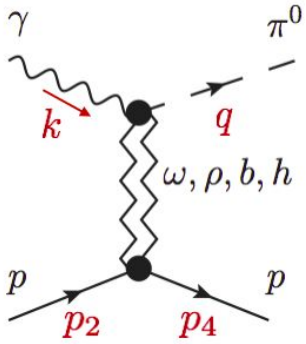


Production process: example

$$\Sigma = +1 \quad : \quad \rho, \omega$$
$$\Sigma = -1 \quad : \quad b, h$$



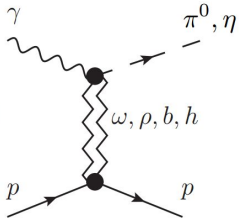


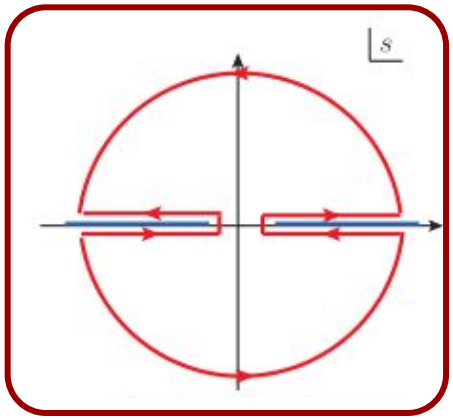


$\pi^0, \eta(0^{-+})$ **have**

same production as

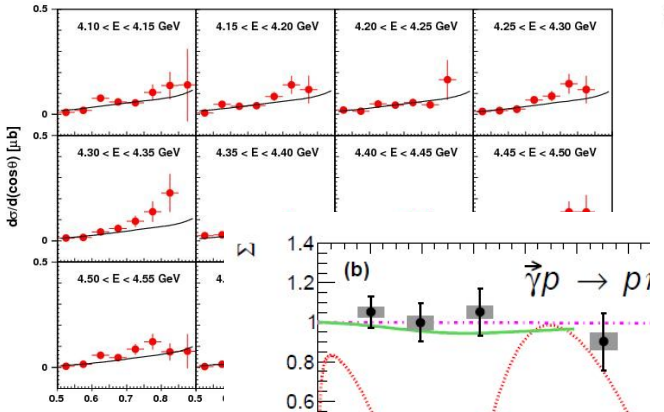
$\pi_1^0, \eta_1(1^{-+})$

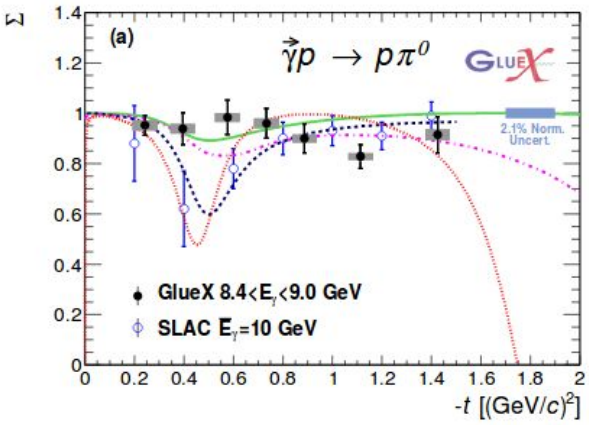


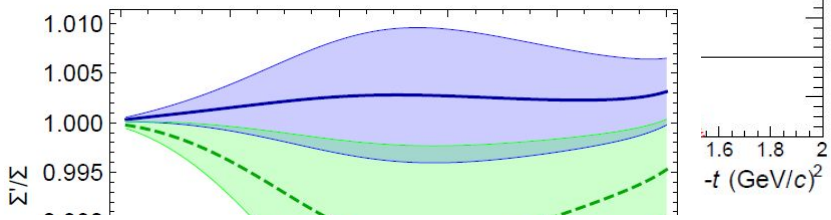


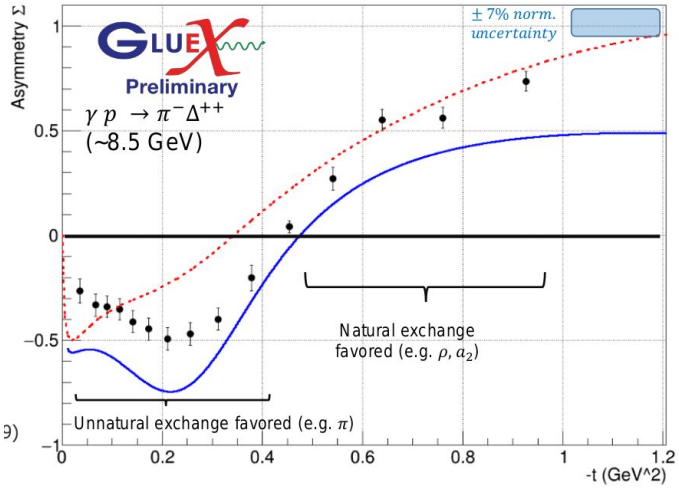
ANALYTICITY

Production process

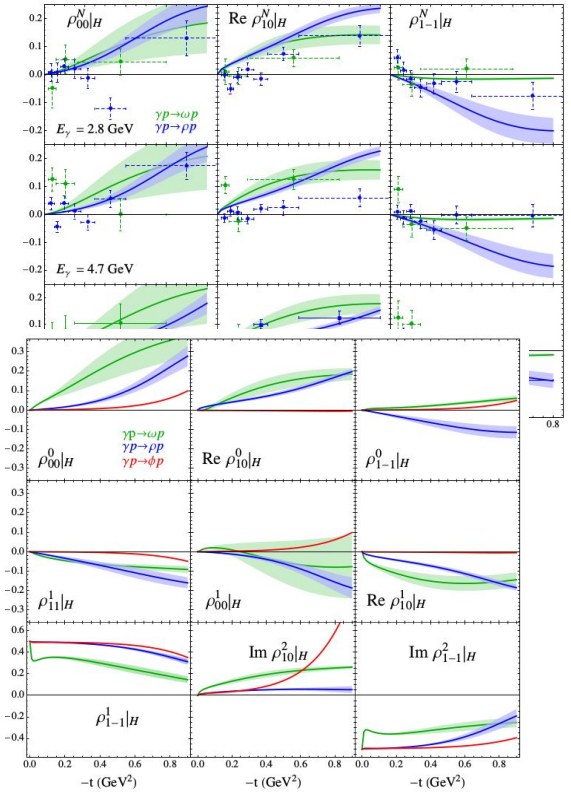


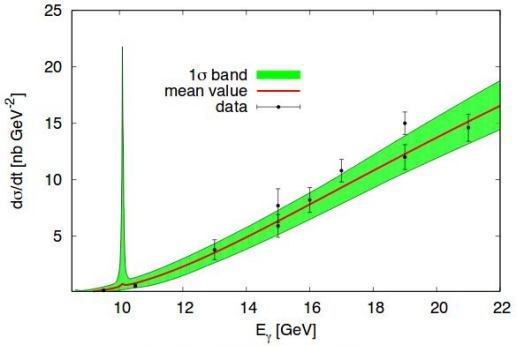




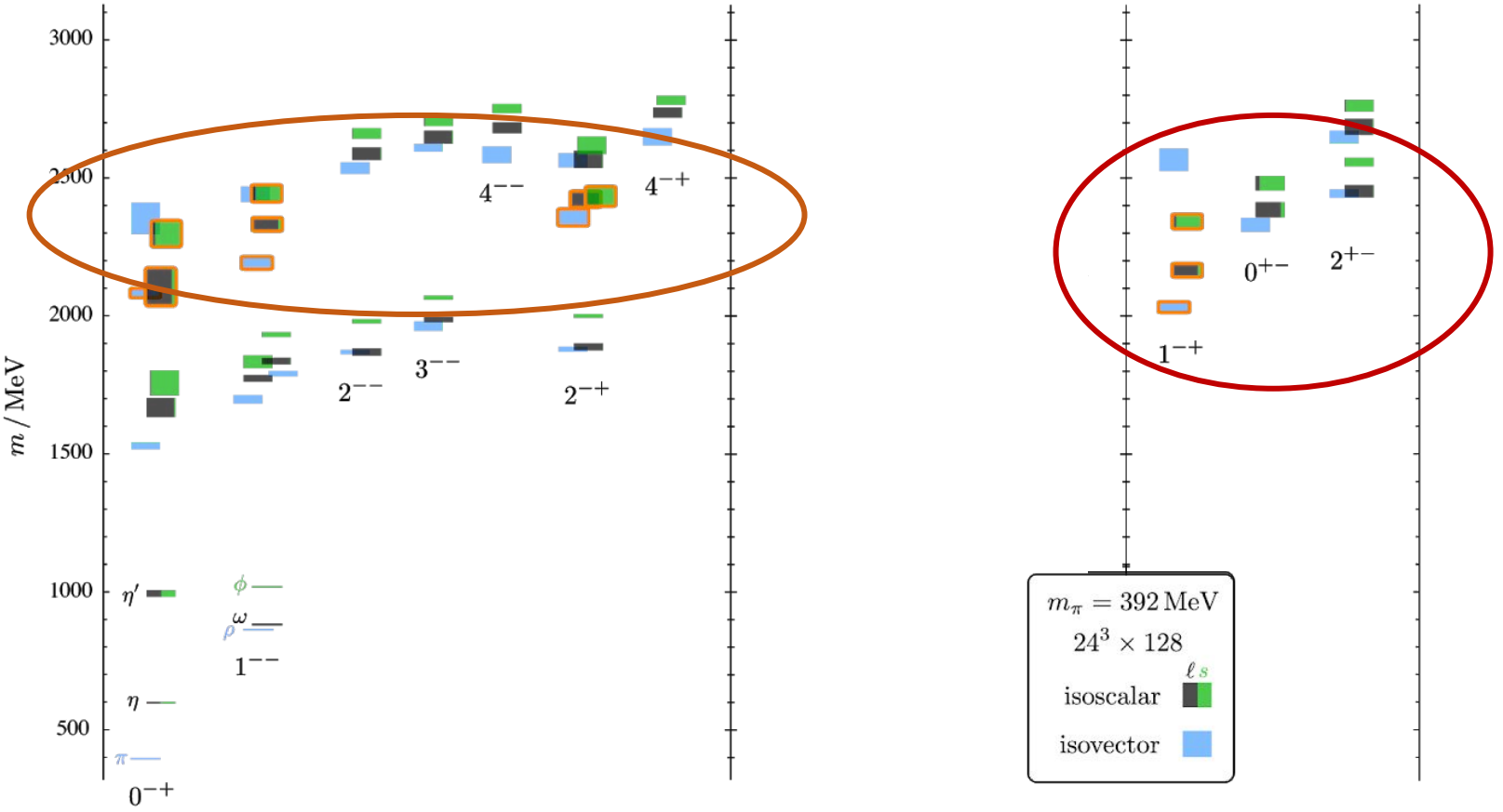


$$\gamma N \rightarrow \pi^{(0,\pm)} N$$
$$\gamma N \rightarrow \eta N$$
$$\gamma N \rightarrow \pi\Delta$$
$$\gamma N \rightarrow \omega N$$
$$\gamma N \rightarrow \rho^0 N$$
$$\gamma N \rightarrow \phi N$$
$$\gamma p \rightarrow P_c \rightarrow J/\psi p$$





Spectroscopy from QCD



Static spectrum from Lattice QCD [Phys.Rev. D88 (2013) no.9, 094505]

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Backup