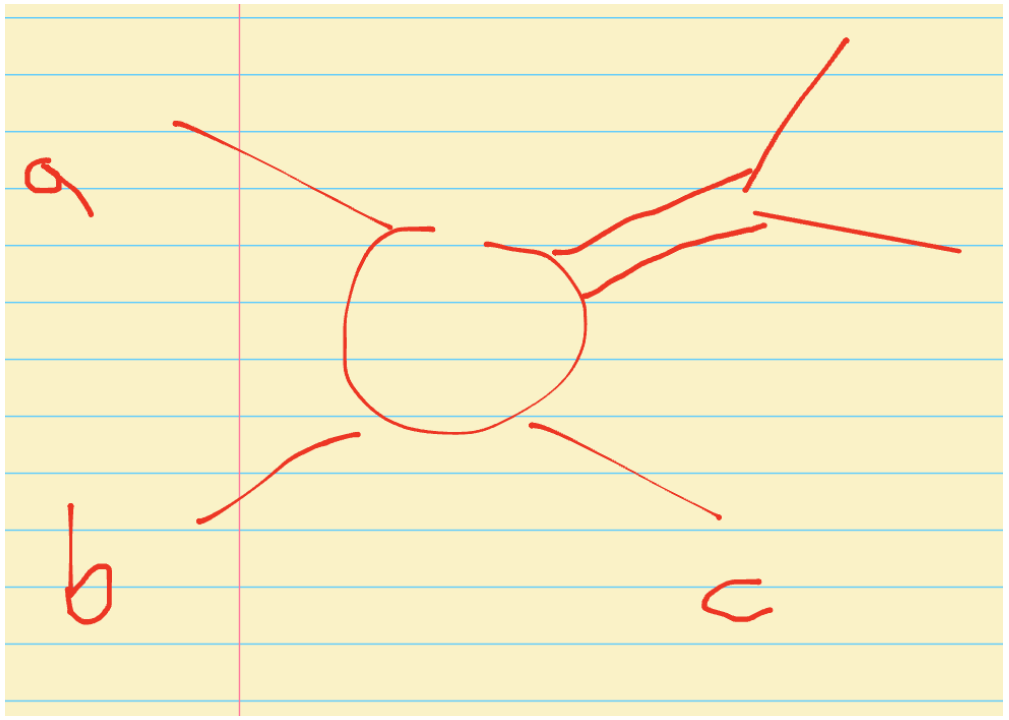
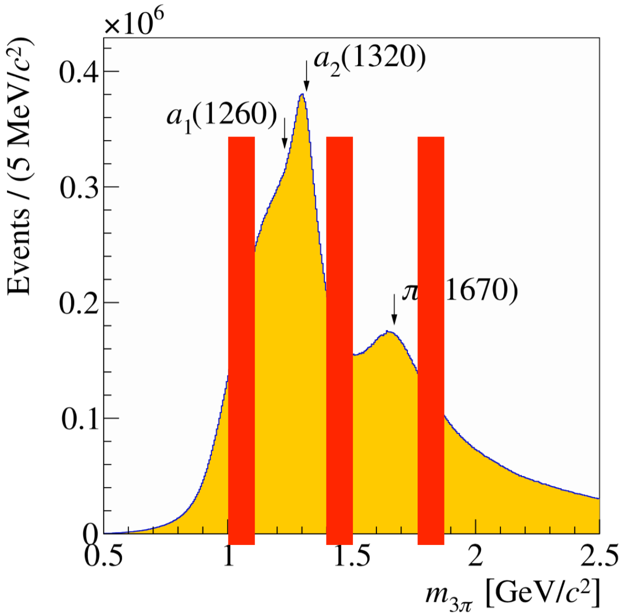
Production of (strange) resonances (Importance of production)

Adam Szczepaniak (IU/JLab)



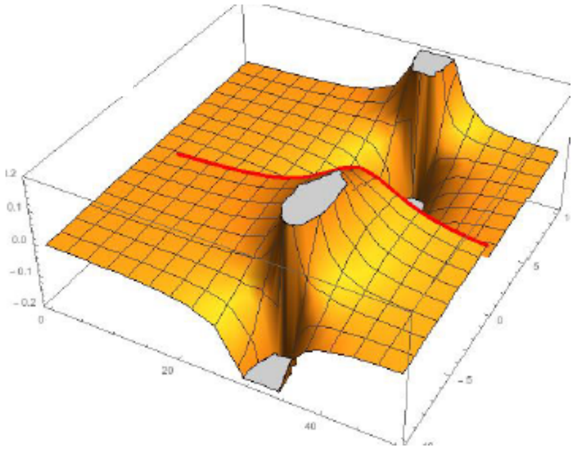
- A few general remarks; amplitude analysis, interpretation of the experiment and theory.
- Physics of quasi-elastic photo-production : π/K exchange
- Consequences for spectroscopy

Nature/QCD : kinematical variables are real



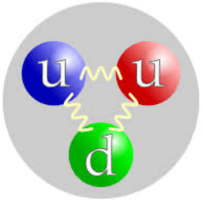
Less predictive power ✗
Some physical interpretation ✗
Minimally biased ✓

Dynamics : complex variables



Predictive power ✓
Physical interpretation ✓
(within the model! ✗)
Biased by the input ✗

Physical interpretation: models



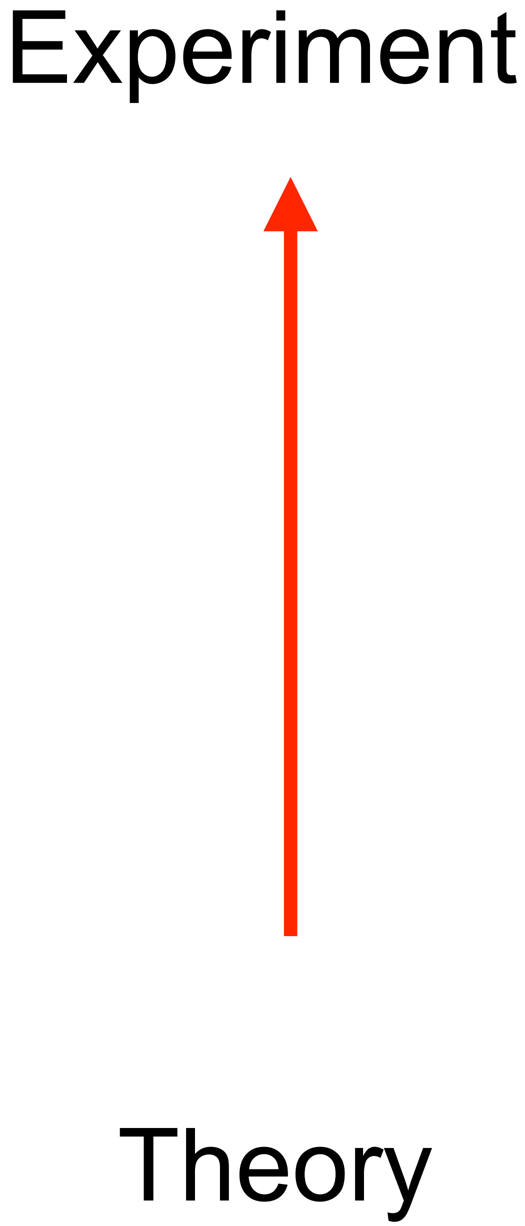
In practice

1. Covariant amplitudes fit data $A(s,t)$, Physically: satisfy complicated unitarity relations

2. Partial waves $A_l(s)$ satisfy simple unitarity relations, directly related to physics but have complicated analytical properties.

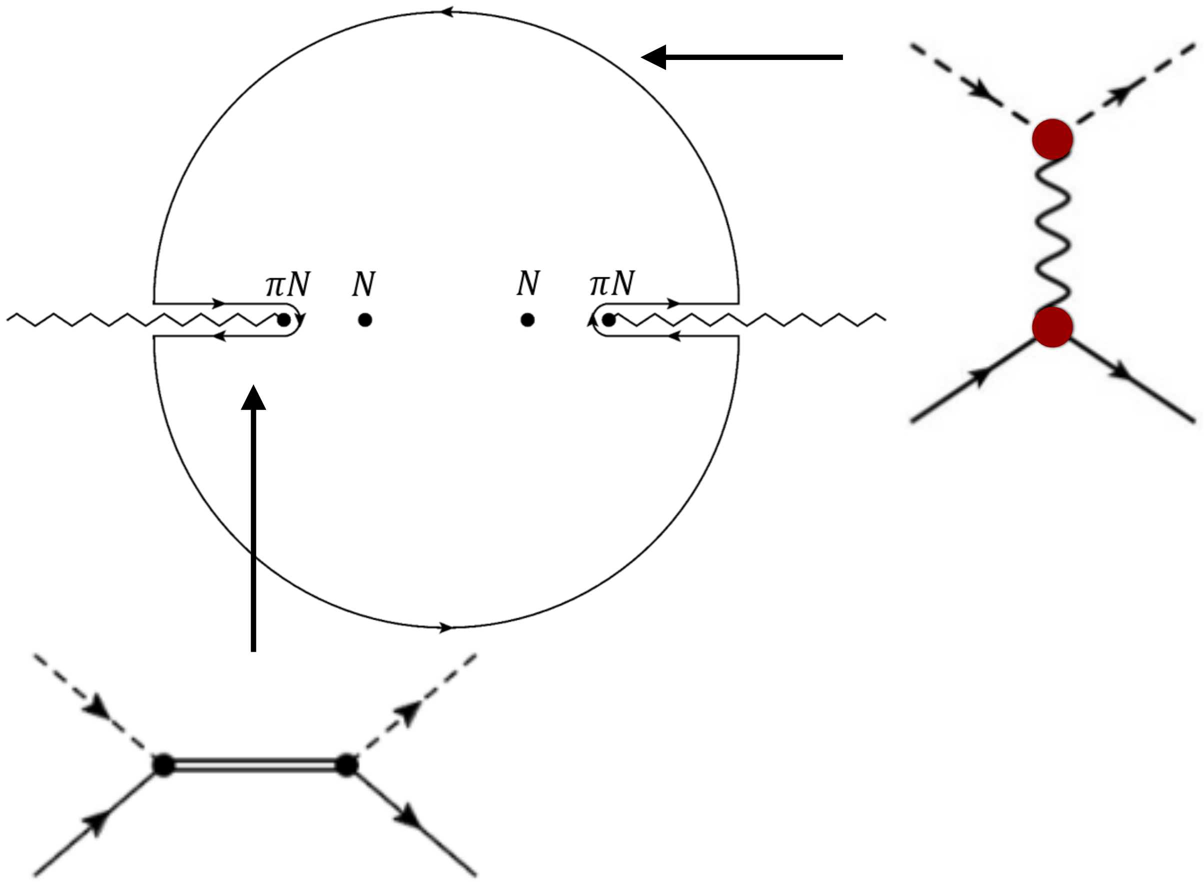
3. Ultimately physics is determined by singularities in energy and in angular momentum

$$A_l(s) = A(s, l)$$


Experiment

Theory

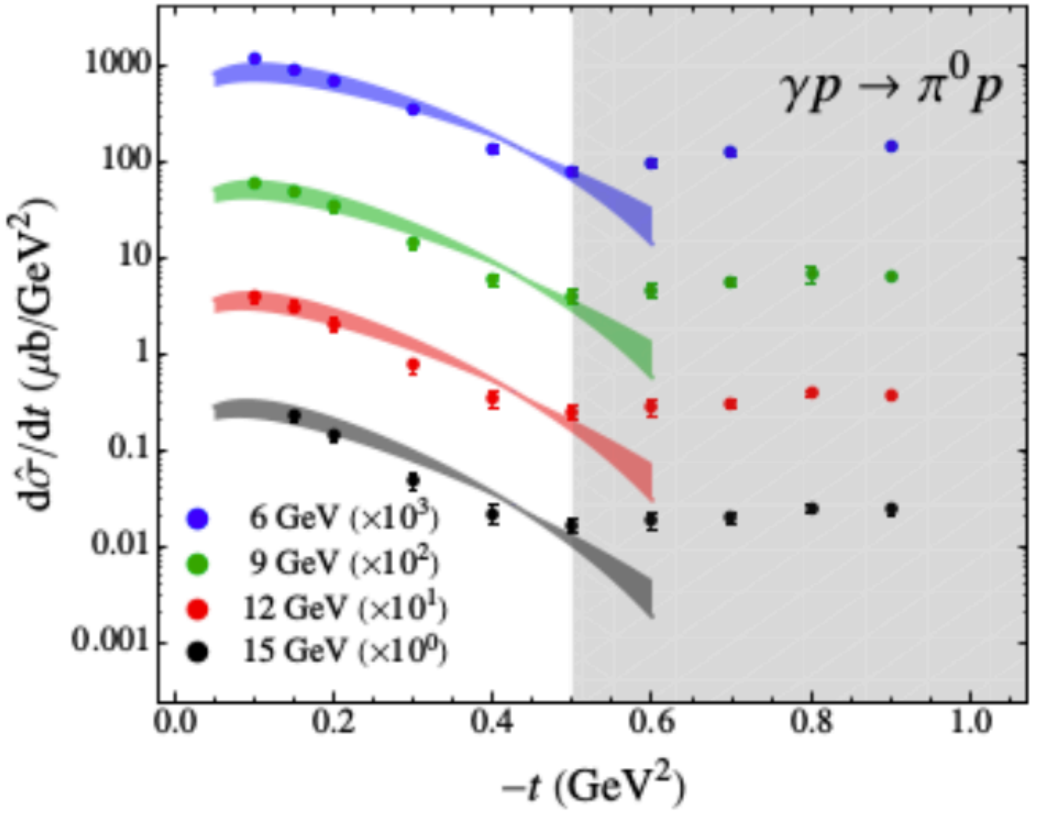
Finite Energy Sum Rules



$$\int_0^{\Lambda} \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu = \beta_i(t)\frac{\Lambda^{\alpha(t)+k}}{\alpha(t)+k}$$

$$\boxed{\beta_i(t) = \frac{\alpha(t)+k}{\Lambda^{\alpha(t)+k}}\int_0^{\Lambda} \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu}$$

- High s-data calculated from s-channel p.w.a

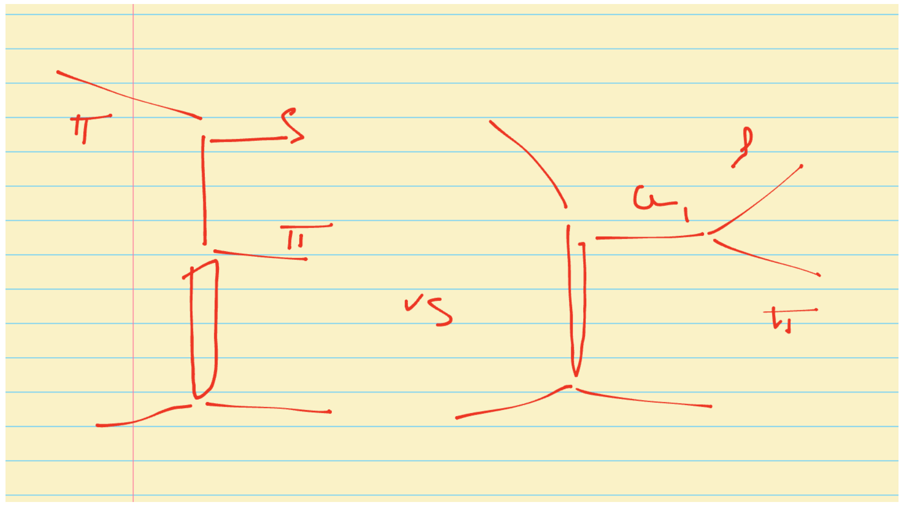


V.Mathieu, et al. (JPAC) 2018

- Resonance parameters (low-s) can be constrained by high-s data

t/s duality

M.Aghasyan et al. COMPASS (2018)



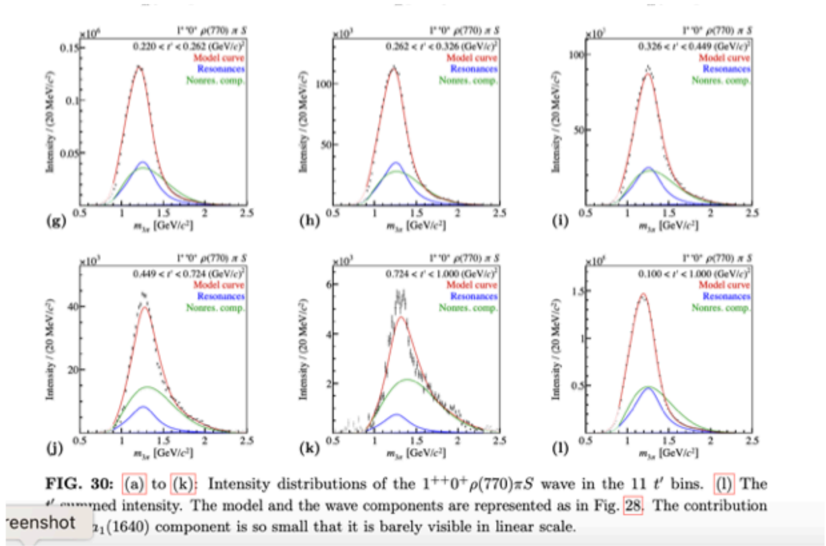
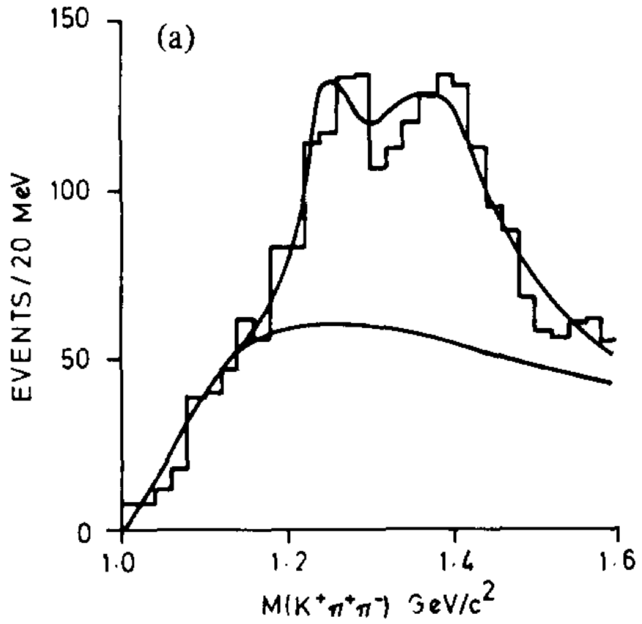


FIG. 30: (a) to (k): Intensity distributions of the $1^{++}0^+\rho(770)\pi S$ wave in the 11 t' bins. (l) The t'-summed intensity. The model and the wave components are represented as in Fig. 28. The contribution $a_1(1640)$ component is so small that it is barely visible in linear scale.

- The $a_1(1260)$ was for some time confused with the pion exchange

- Analogous $K\pi\pi$ analysis: duality between $K_1(1270), K_1(1400), K_1(1650)(?)$ K-exchange



M.G.Bowler et al. (CERN 1973)

Compare with 720 K events at COMPASS (see S.Wallner)

On the nature of $\Lambda(1405)$

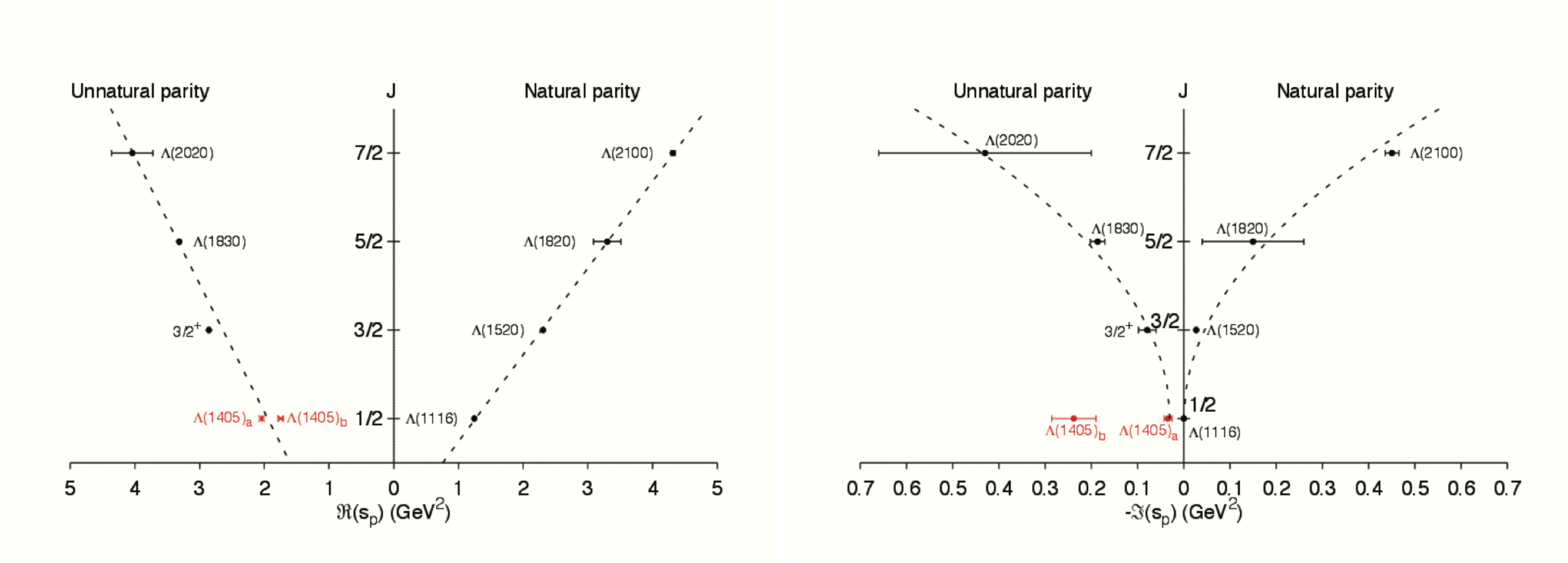
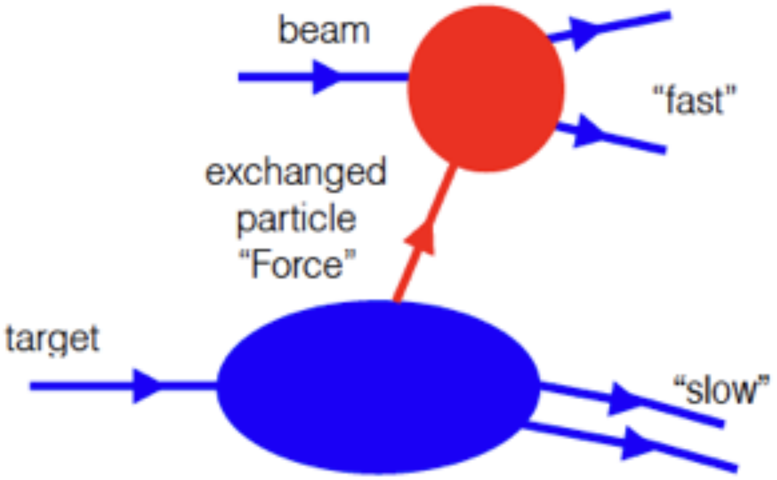


Figure 2: Leading Regge trajectories for the Λ resonances. Dashed lines are displayed to guide the eye.

C.Fernandez-Ramirez, et al. (JPAC) (2016)

In peripheral production (s vs t channel pwa)

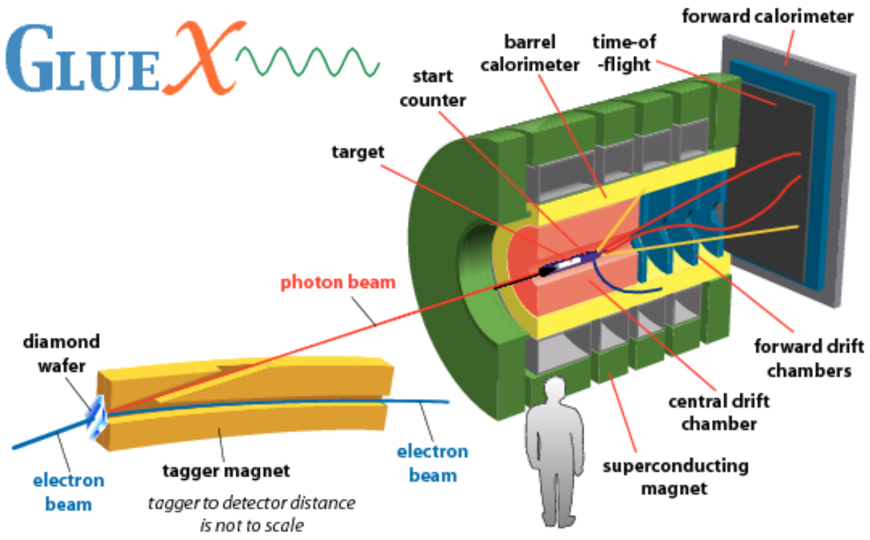


$$A(s,t) = \sum_l (2l+1) A_l(s) P_l(t)$$

For large s, $A_l(s)$ are small
(tails of resonances)

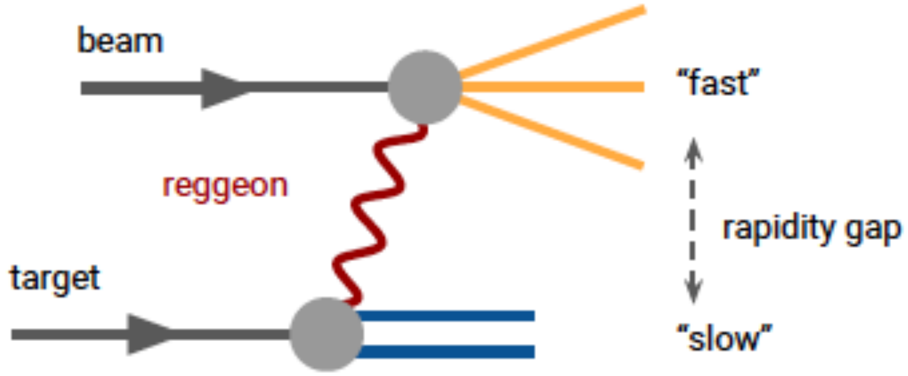
$$A(s,t) = \sum_l (2l+1) A_l(t) P_l(s)$$

The t-channel p.w. with
largest $l_{eff} = \alpha(t)$
dominates



Global Regge analysis

- Test Regge pole hypothesis and estimate corrections (daughters, cuts)



- Rege poles : Factorizable residues
  t-dependent phase
  Shrinkage of the forward peak

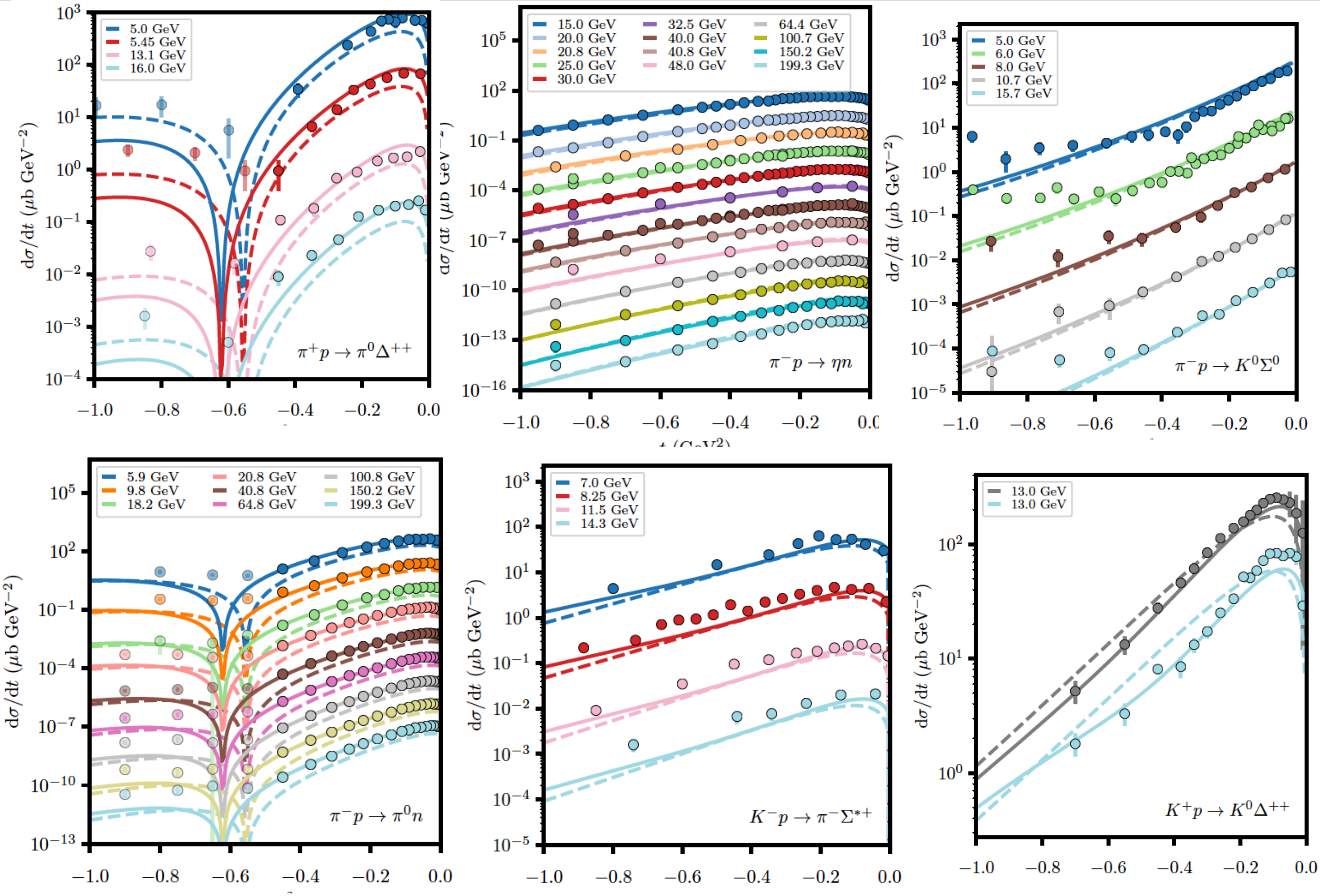
$$A_{\lambda_i} = \sqrt{-t}^{|\lambda_1-\lambda_3|}\sqrt{-t}^{|\lambda_2-\lambda_4|}\beta^{e}_{\lambda_1\lambda_3}\beta^{a}_{\lambda_2\lambda_4}A_R(s,t)$$

$\lambda_i =$ t-channel helicities

Data =1271 points, N_{par} = 6 SU(3) couplings, 1 mixing angle, 2 exp. slopes)

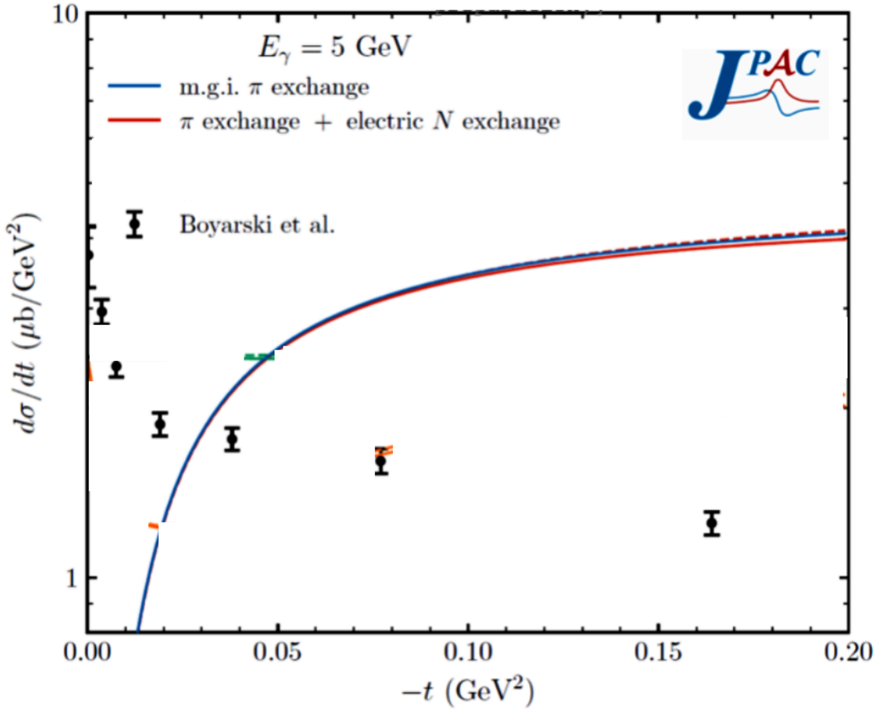
Except pion, pomeron exchange.

Global Regge pole analysis



“Specific” analysis : π/K exchange

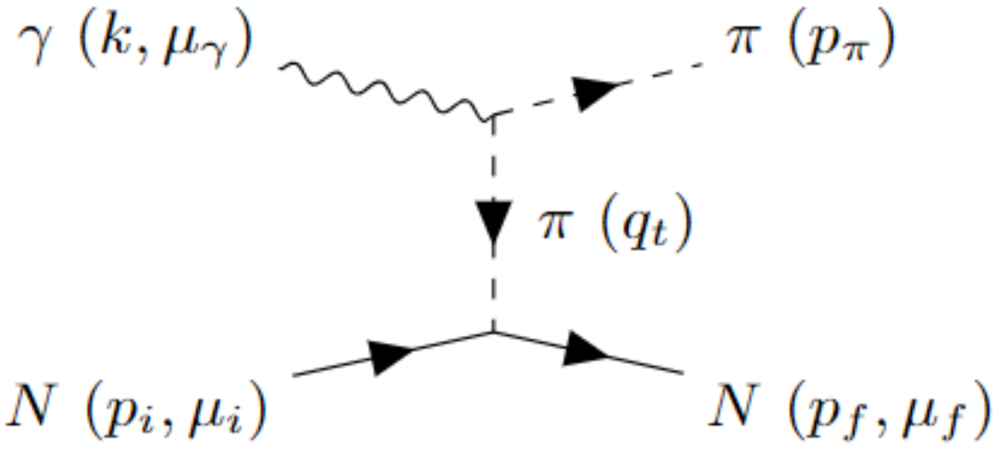
- At low-t charge exchanges reactions should be dominated by $\pi(K)$ exchanges
- Constraints from QCD, chiral, SU(3) symmetry.
- Relevant for light and heavy flavor pheno. (e.g. XYZ’s)
- But there are still open issues
  - What is pion exchange ?
  - What happens at t~0



G.Montana et al. (JPAC) in preparation

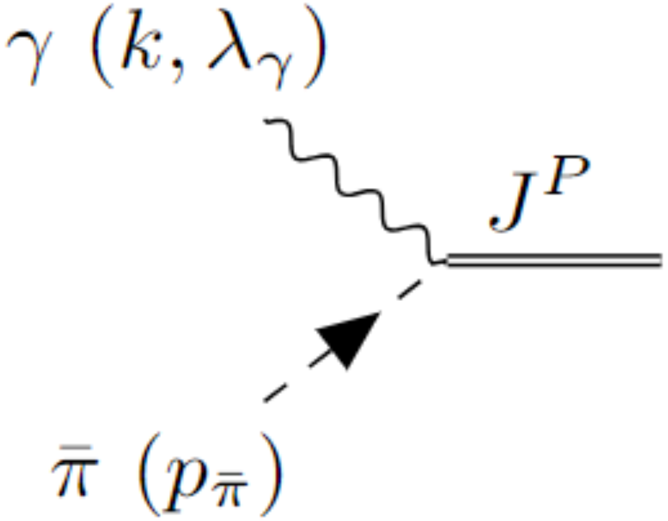
"Specific" analysis : π/K exchange

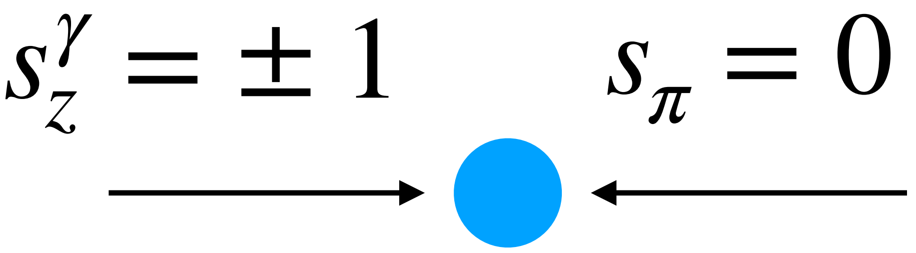
$$A_{\lambda_i}(s,t) = \sum_J (2J+1) A^J_{\lambda_i}(t) d^J_{\lambda_2-\lambda_4,\lambda_1}(\theta_t)$$



In $\gamma p \to \pi^+ n\ (K^+ Y)$, t-channel p.w. with $J^P = 0^-$ has the singularity closest to the physical region, but …

$\pi(K)$ contribution to t-channel vanishes !

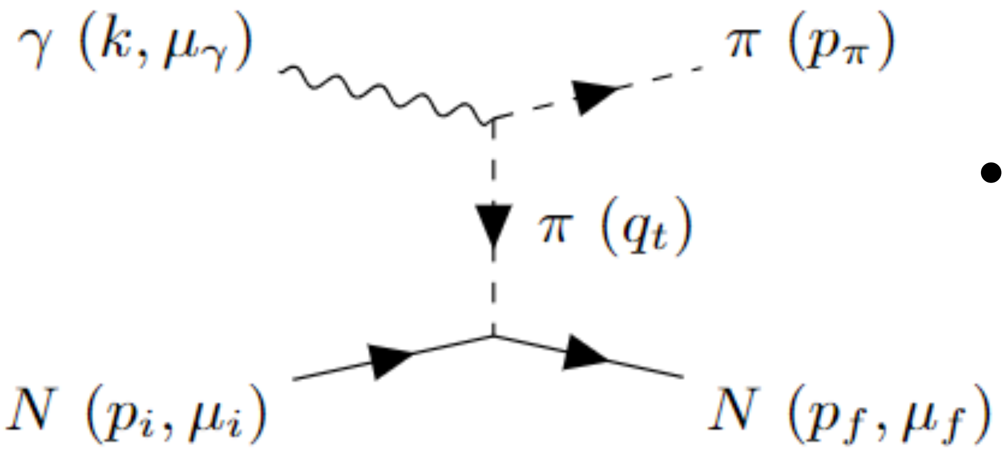




$s_z^\gamma = \pm 1$ $\quad$ $s_\pi = 0$

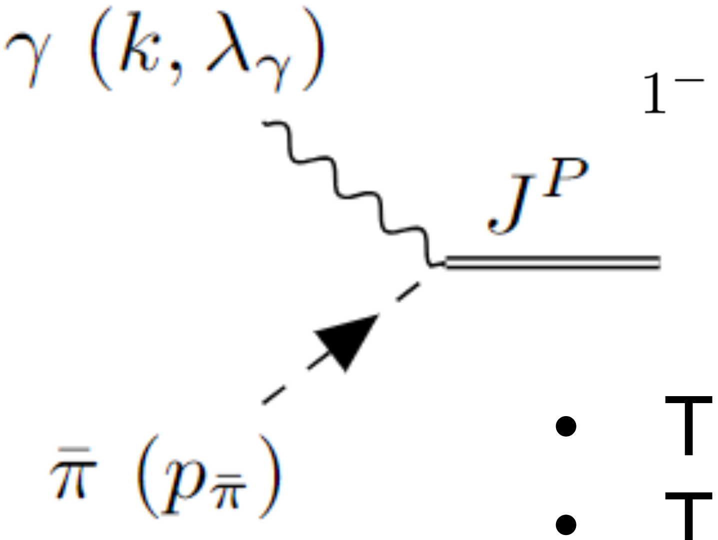
M_π would have to be ± 1

Pion/kaon exchange



- The s-channel amplitude finite $O(s^{J=0})$: Where does it come from ?

- s/t-channel amplitudes are related (Wigner rotation) this means there has to be a Regge pole near $J \sim 0$ in the t-channel p.w.



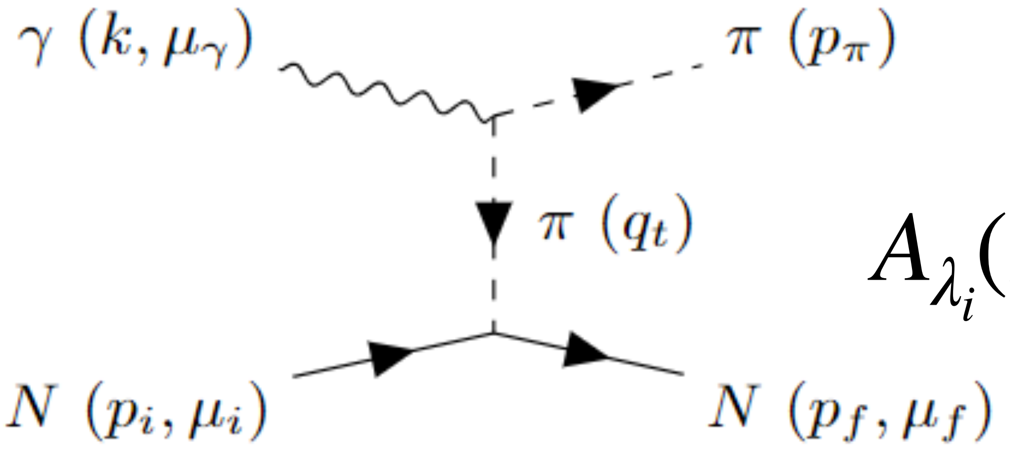
$$1^- \otimes 0^- = 1^+ \begin{cases} L = 1 & \text{for} \quad J = 0 \\ L = \{J-1, J+1\} & \text{for} \quad J \geq 2 \end{cases}$$

one L

vs two L's

- This is manifested as singularity in J of the p.w.a
- The ∞ times 0 from kinematics = finite

Pion/kaon exchange



$$s + u = 2M^2 + m_\pi^2 - t$$

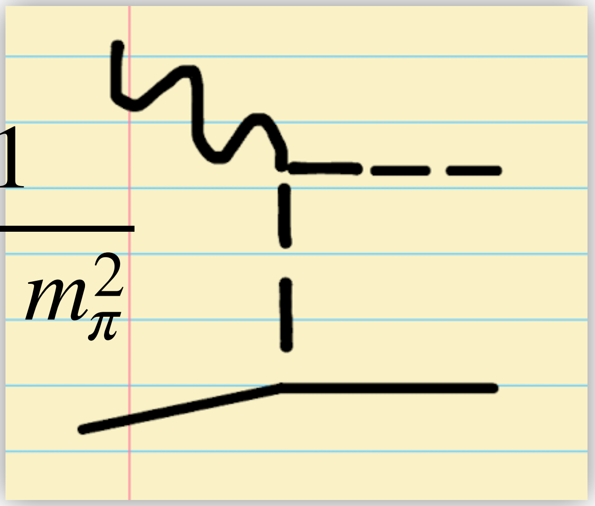
$$A_{\lambda_i}(s,t) = \sum_J (2J+1) A^J_{\lambda_i}(t) d^J_{\lambda_2-\lambda_4,\lambda_1}(\theta_t)$$

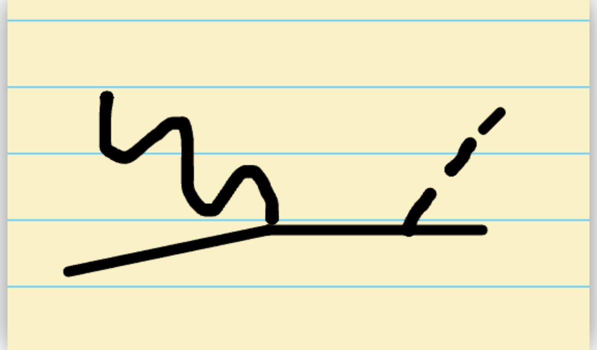
$$A^J_{\lambda_i}(t) \sim \frac{1}{J}\frac{1}{J - \alpha_\pi(t)}$$

$$d^J_{\lambda_2-\lambda_4,\lambda_1}(\theta_t) \to J\frac{t - m_\pi^2}{s-u}$$

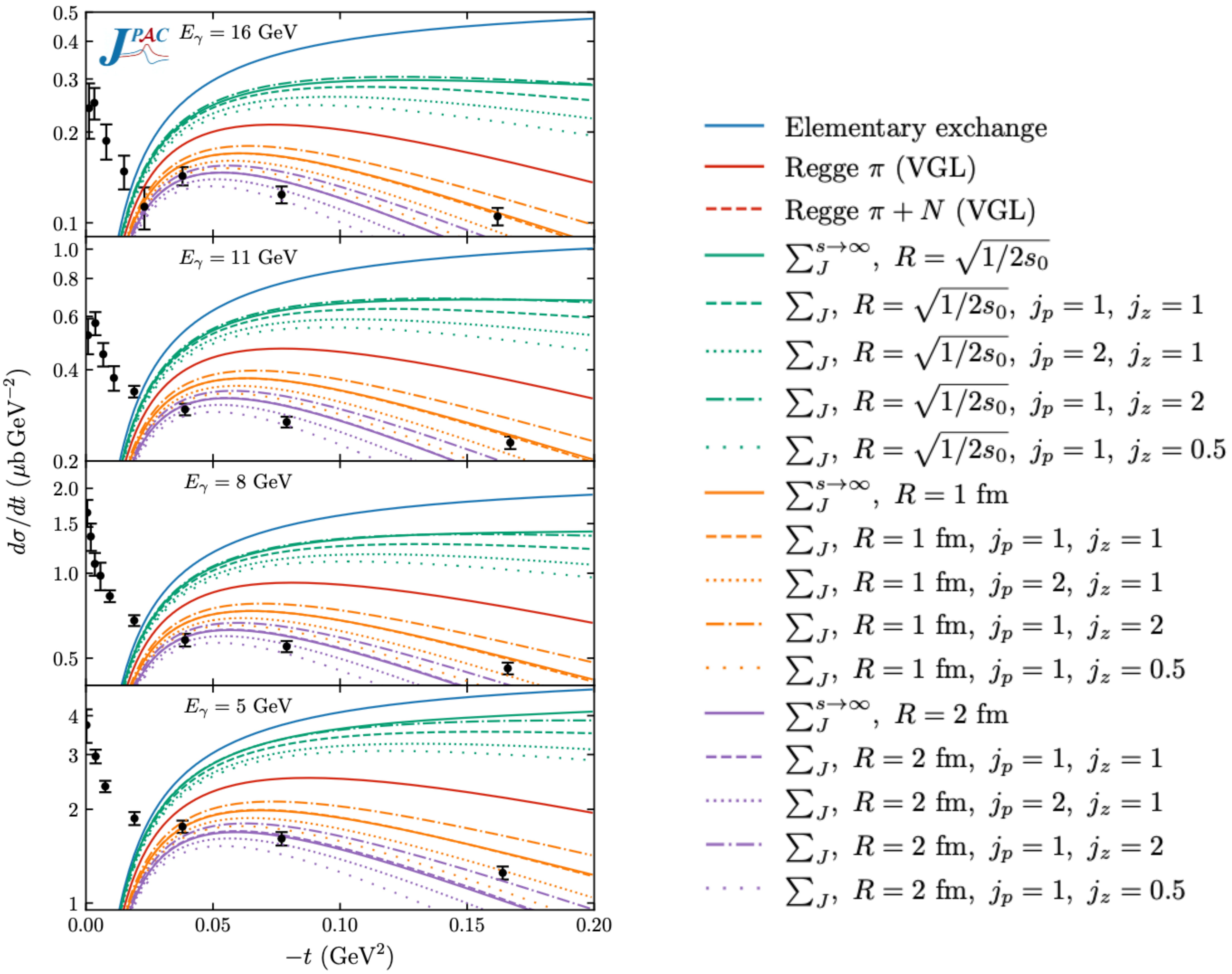
t-channel =A x d = nucleon pole (s-channel) !

$$\frac{1}{t - m_\pi^2}$$





$$\frac{1}{s - M^2}$$

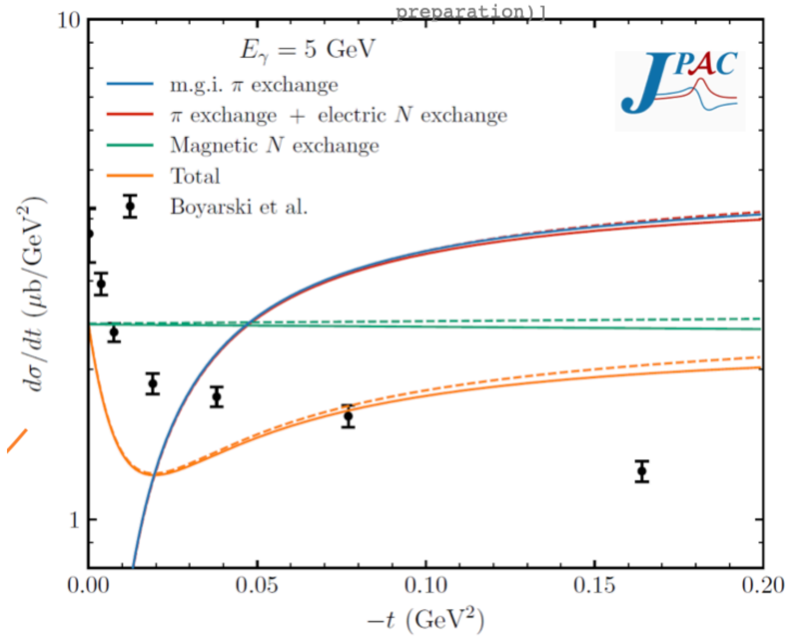

JPAC
$E_\gamma = 16$ GeV
$E_\gamma = 11$ GeV
$E_\gamma = 8$ GeV
$E_\gamma = 5$ GeV
$d\sigma/dt$ (μb GeV^{-2})
$-t$ (GeV^2)
0.5
0.4
0.3
0.2
0.1
1.0
0.8
0.6
0.4
0.2
2.0
1.5
1.0
0.5
4
3
2
1
0.00
0.05
0.10
0.15
0.20
Elementary exchange
Regge π (VGL)
Regge $\pi + N$ (VGL)
$\sum_J^{s\to\infty}$, $R = \sqrt{1/2s_0}$
$\sum_J$, $R = \sqrt{1/2s_0}$, $j_p = 1$, $j_z = 1$
$\sum_J$, $R = \sqrt{1/2s_0}$, $j_p = 2$, $j_z = 1$
$\sum_J$, $R = \sqrt{1/2s_0}$, $j_p = 1$, $j_z = 2$
$\sum_J$, $R = \sqrt{1/2s_0}$, $j_p = 1$, $j_z = 0.5$
$\sum_J^{s\to\infty}$, $R = 1$ fm
$\sum_J$, $R = 1$ fm, $j_p = 1$, $j_z = 1$
$\sum_J$, $R = 1$ fm, $j_p = 2$, $j_z = 1$
$\sum_J$, $R = 1$ fm, $j_p = 1$, $j_z = 2$
$\sum_J$, $R = 1$ fm, $j_p = 1$, $j_z = 0.5$
$\sum_J^{s\to\infty}$, $R = 2$ fm
$\sum_J$, $R = 2$ fm, $j_p = 1$, $j_z = 1$
$\sum_J$, $R = 2$ fm, $j_p = 2$, $j_z = 1$
$\sum_J$, $R = 2$ fm, $j_p = 1$, $j_z = 2$
$\sum_J$, $R = 2$ fm, $j_p = 1$, $j_z = 0.5$

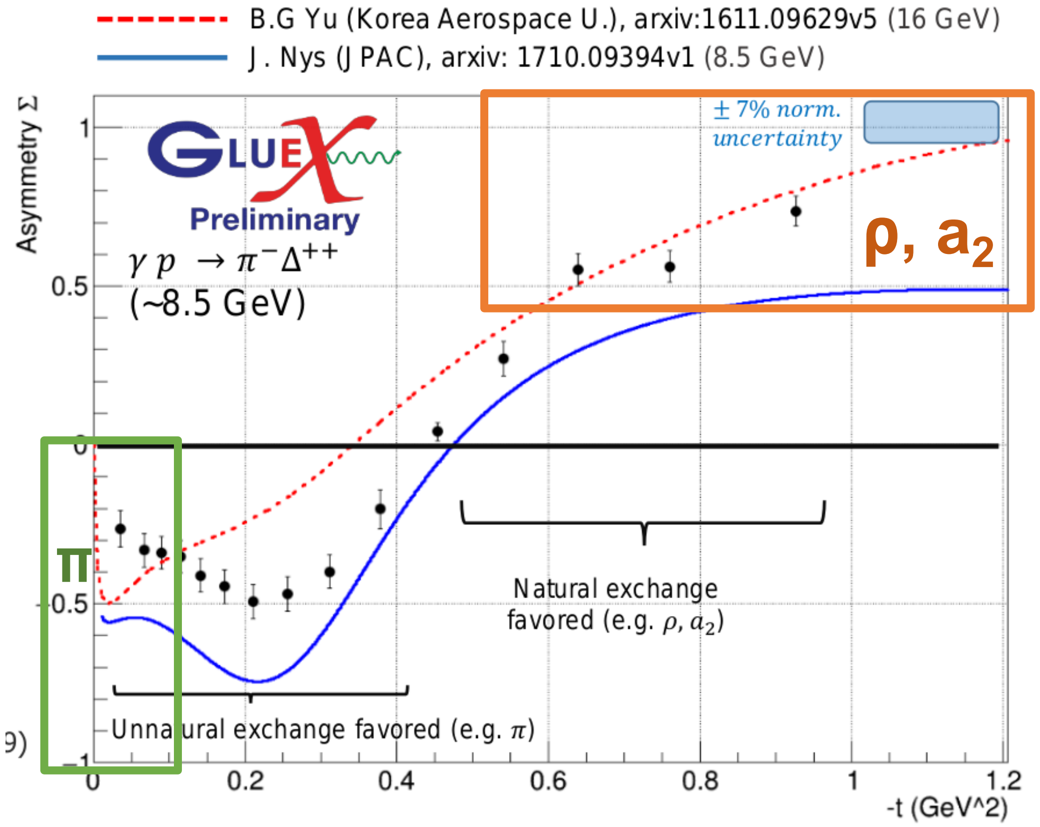
Pion/Kaon exchange

- The J=0 pole is equivalent to nucleon contribution (current conservation)
- As it should be : there is no need to mix s- and t-channel amplitudes

$$\frac{-t}{\mu^2-t} = 1+\frac{-\mu^2}{\mu^2-t}$$

[G.Montana et al. (in preparation)]

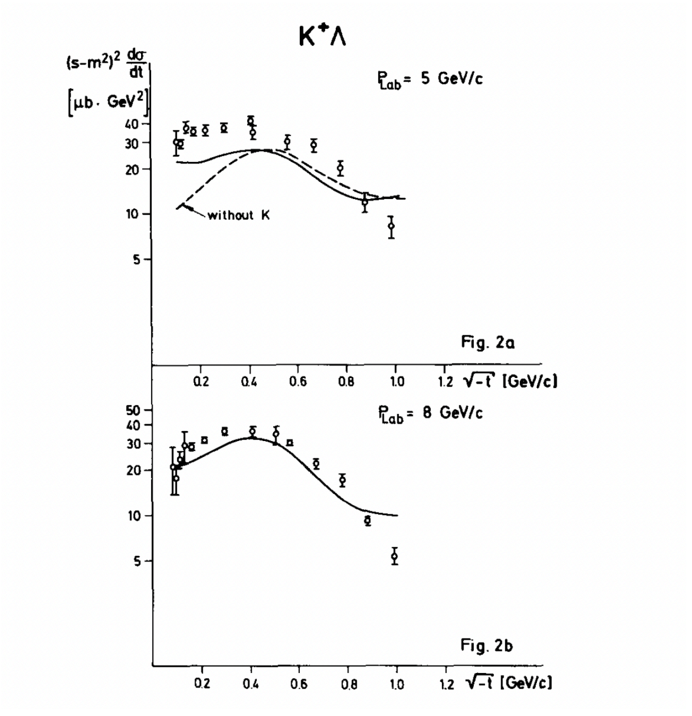




- Photo-production is the "cleanest" probe of OPE.
- At higher-t natural exchanges dominate

- At t~0 other interesting phenomena: absorption, cuts, conspiracy between pion and nucleon poles etc. (stay tuned)

K photoproducton



A.M.Boyarski et al. SLAC (1969) (exp)
N.Levy et al. (1973)

- Low-t vs. high-t physics : K vs K* exchanges
- SU(3) relations
- Factorization breaking effects : need low-t, $|-t'| < m_K^2 \sim 0.25\, GeV^2$

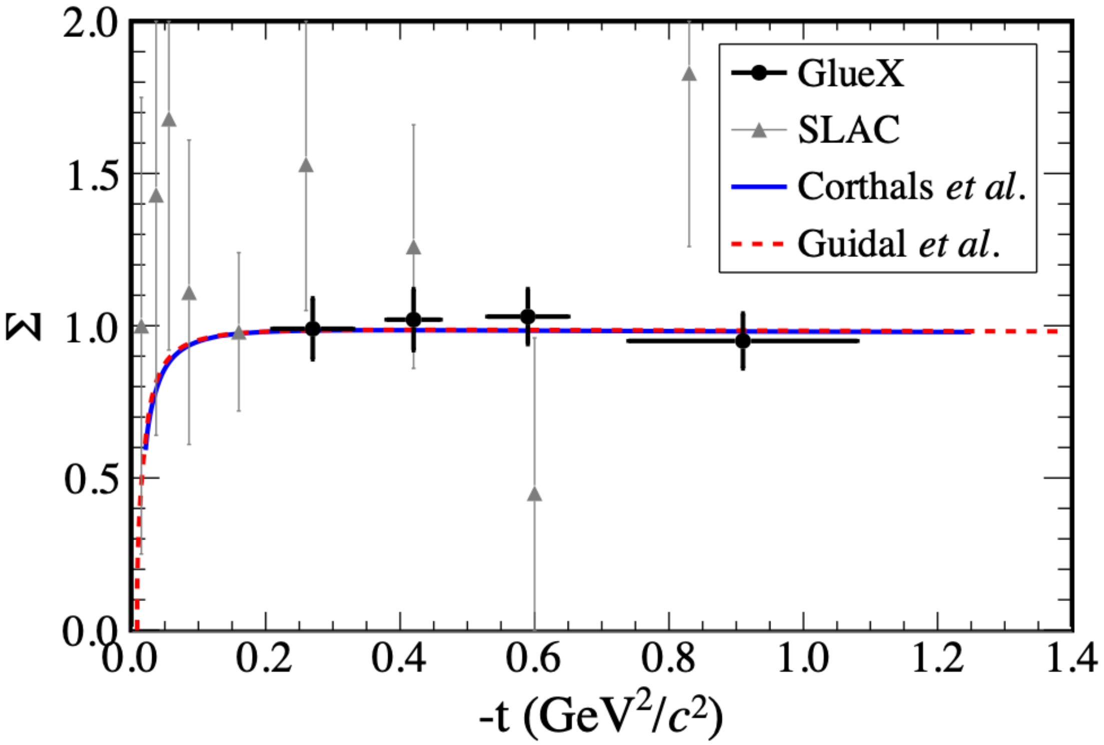


FIG. 10. The beam asymmetry Σ for $\vec{\gamma} p \to K^+ \Sigma^0$ as a function of $-t$. The results from the 0/90 and -45/45 data sets are averaged (solid circles) where horizontal error bars indicate the RMS widths of the t bins and vertical error bars represent statistical and systematic uncertainties added in quadrature. An additional 2.1% overall relative polarization uncertainty is not included. The triangles are previous SLAC results [2] at $E_\gamma = 16\,\text{GeV}$, the curves show predictions from RPR-2007 [6, 7] (solid) and Guidal *et al.* [5] (dashed) at $E_\gamma = 8.5\,\text{GeV}$.

J.Hernandez talk

Lambda SDEM's

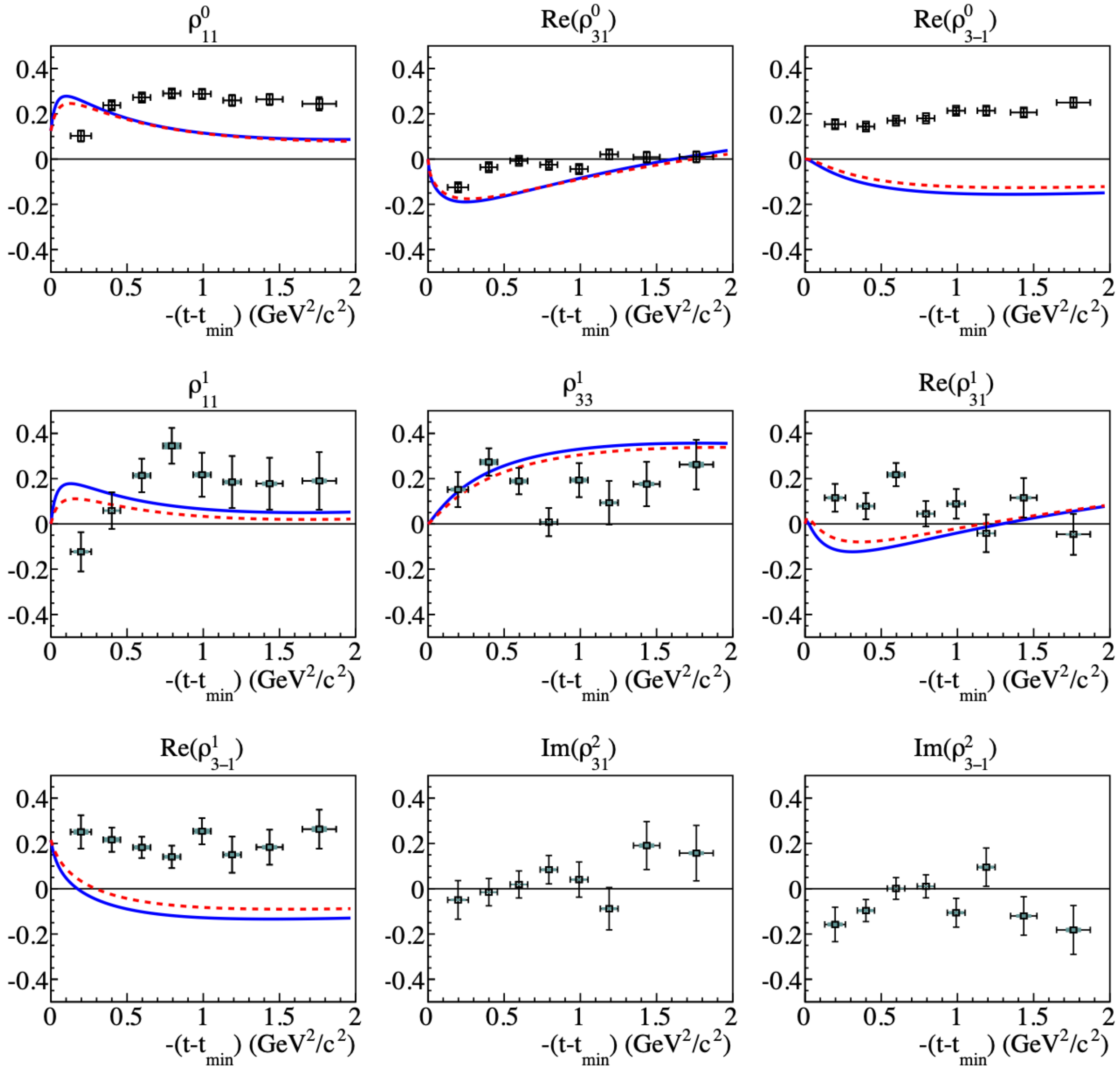


FIG. 7. Spin density matrix elements and predictions by Yu and Kong (based on Ref. [14]), using parameters based on data from CLAS [9] and LEPS [6, 7] (blue solid) and using parameters based on data from LAMP2 [5] and SLAC [4] (red dashed). The vertical error bars show the statistical uncertainty, the blue shaded boxes the scaling uncertainty from the polarization, and the black boxes the remaining systematic uncertainties combined in quadrature. The horizontal error bars show the RMS widths within the $-(t - t_0)$ bins.

S.Adhikari, et al. GlueX 2022

- SDME's can be used to test Regge pole dominance, e.g. ρ^2 vanishes if resides factorize

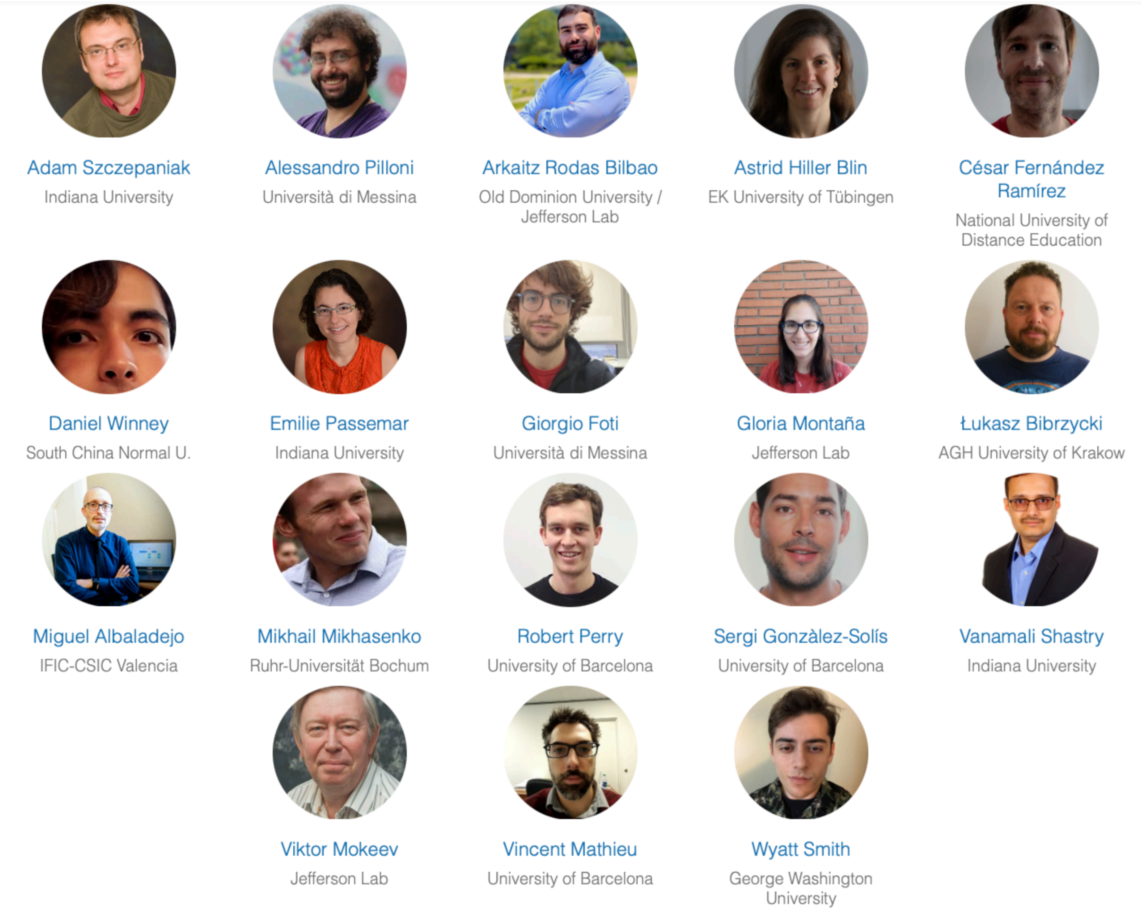
- Models need to be scrutinized

Summary

- (Quasi) elastic production: determines Regge exchanges

- Use Regge theory to correlate resonance production with resonance decays, e.g. FESR's

- One pole, two pole, etc. structures should be understood in terms of trajectories they belong to



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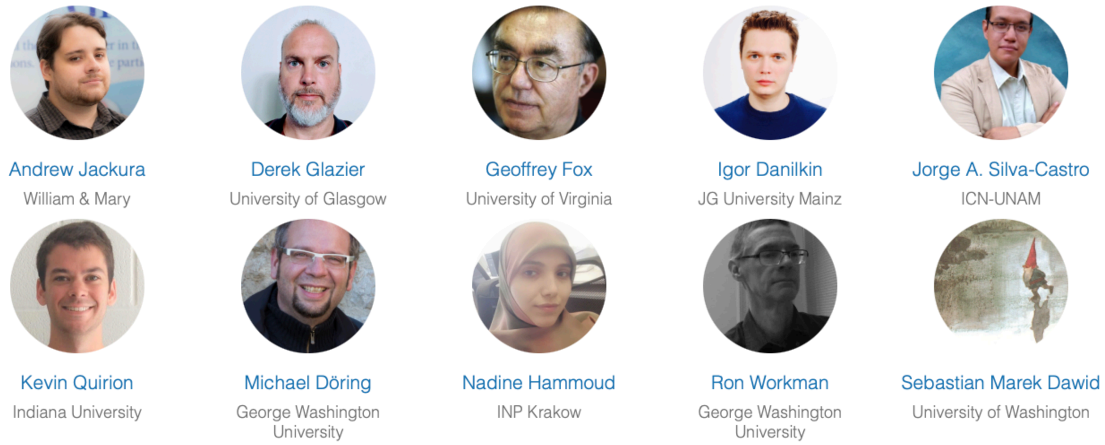

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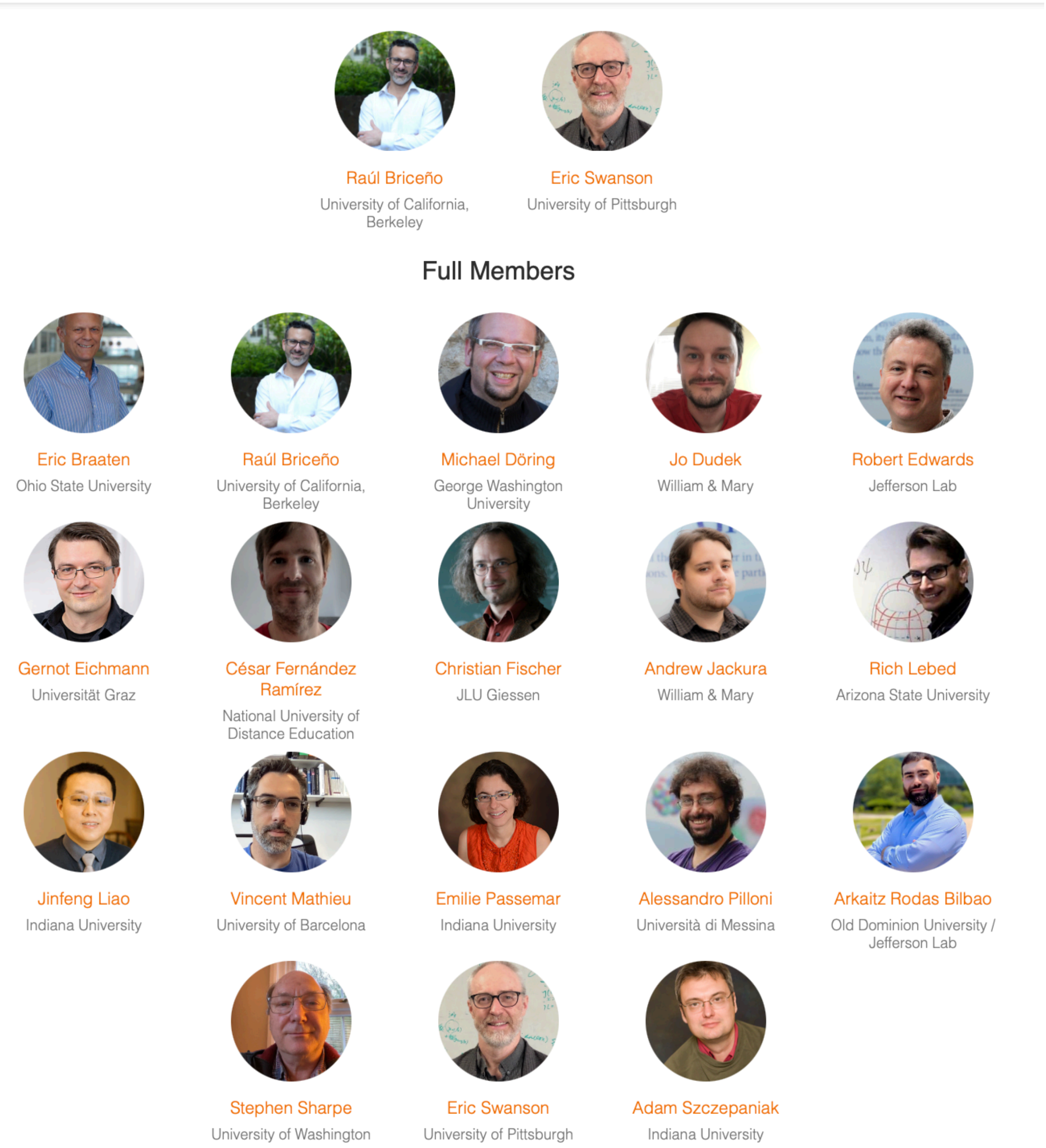

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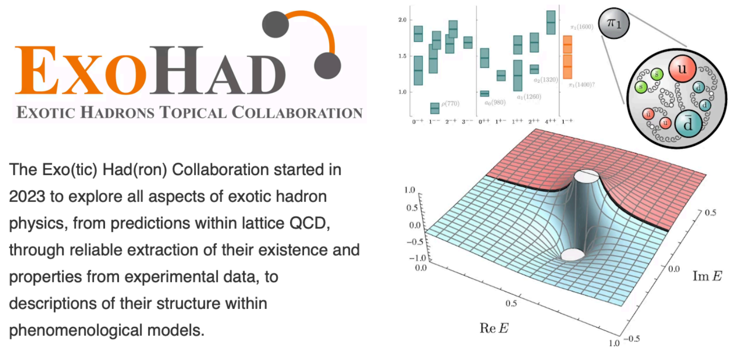

ExoHad
Exotic Hadrons Topical Collaboration

The Exo(tic) Had(ron) Collaboration started in 2023 to explore all aspects of exotic hadron physics, from predictions within lattice QCD, through reliable extraction of their existence and properties from experimental data, to descriptions of their structure within phenomenological models.

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