Amplitude analyses for extraction of N* parameters and JPAC effort on JLab Physics

Vincent MATHIEU

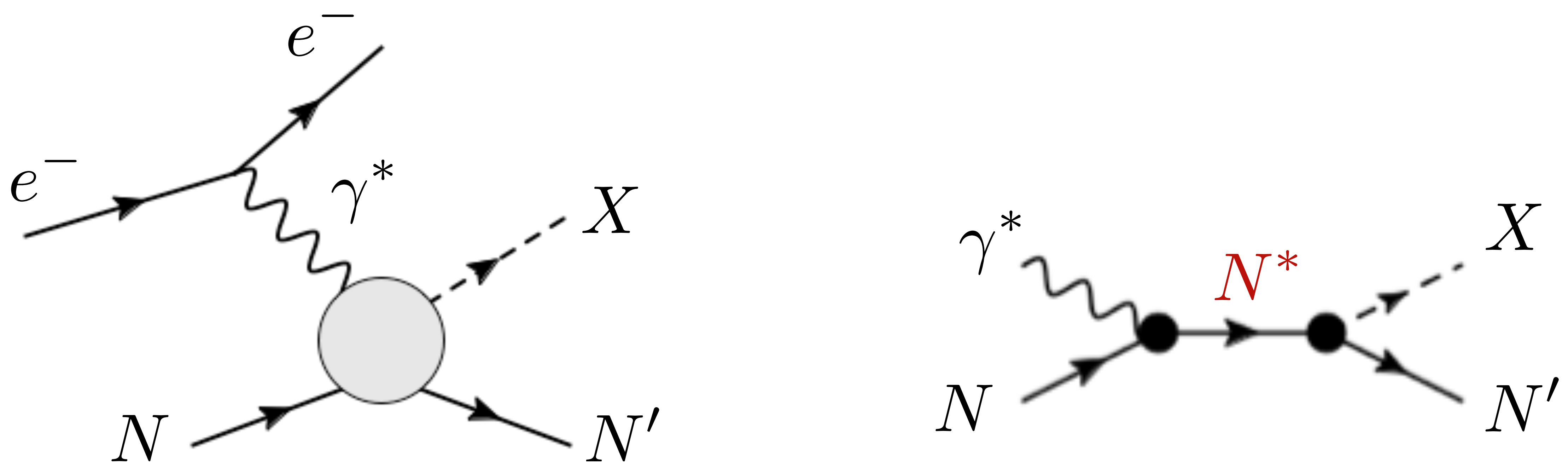
Indiana University
-
Joint Physics Analysis Center

N* meeting
JLab - June 2017

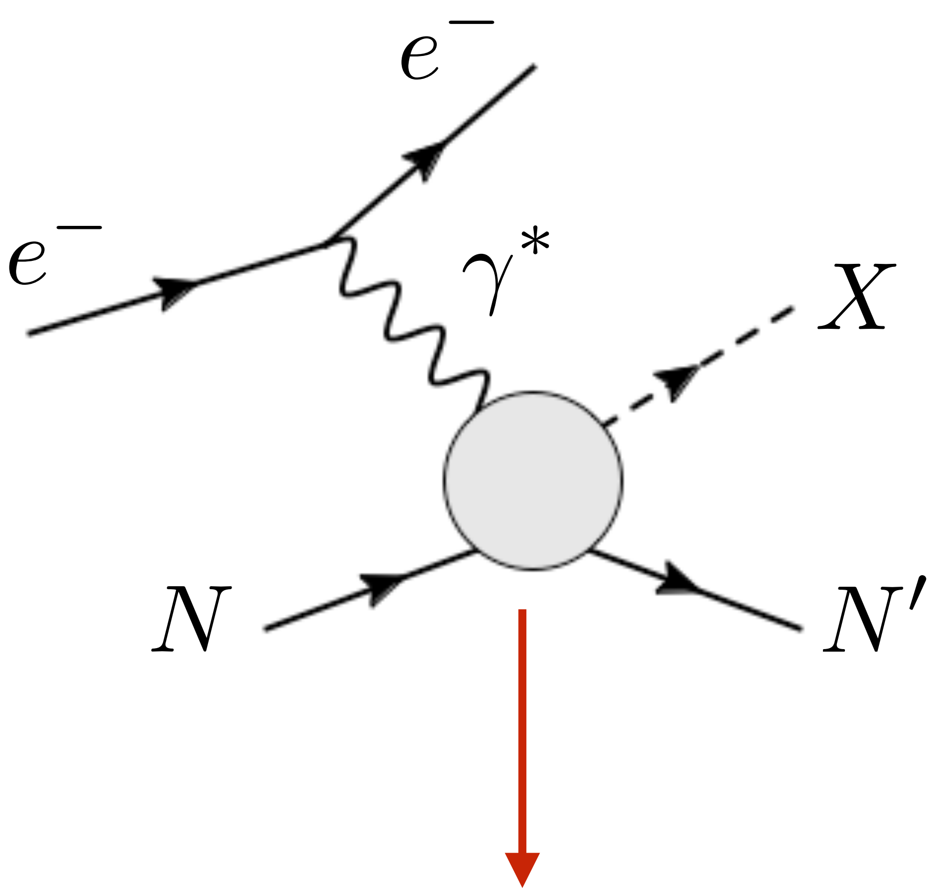
INDIANA UNIVERSITY

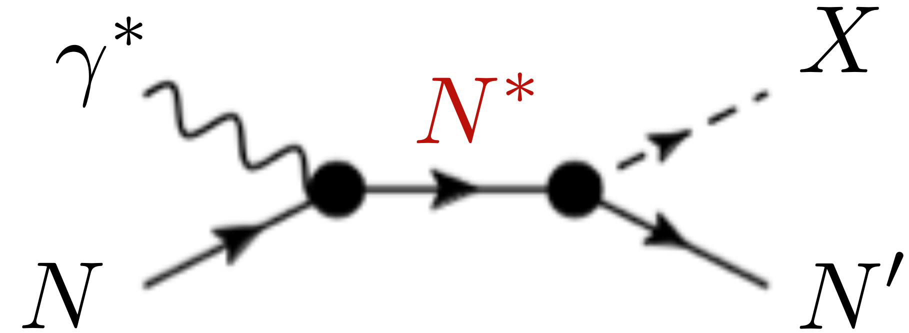
Jefferson Lab
Thomas Jefferson National Accelerator Facility

Motivations



Motivations



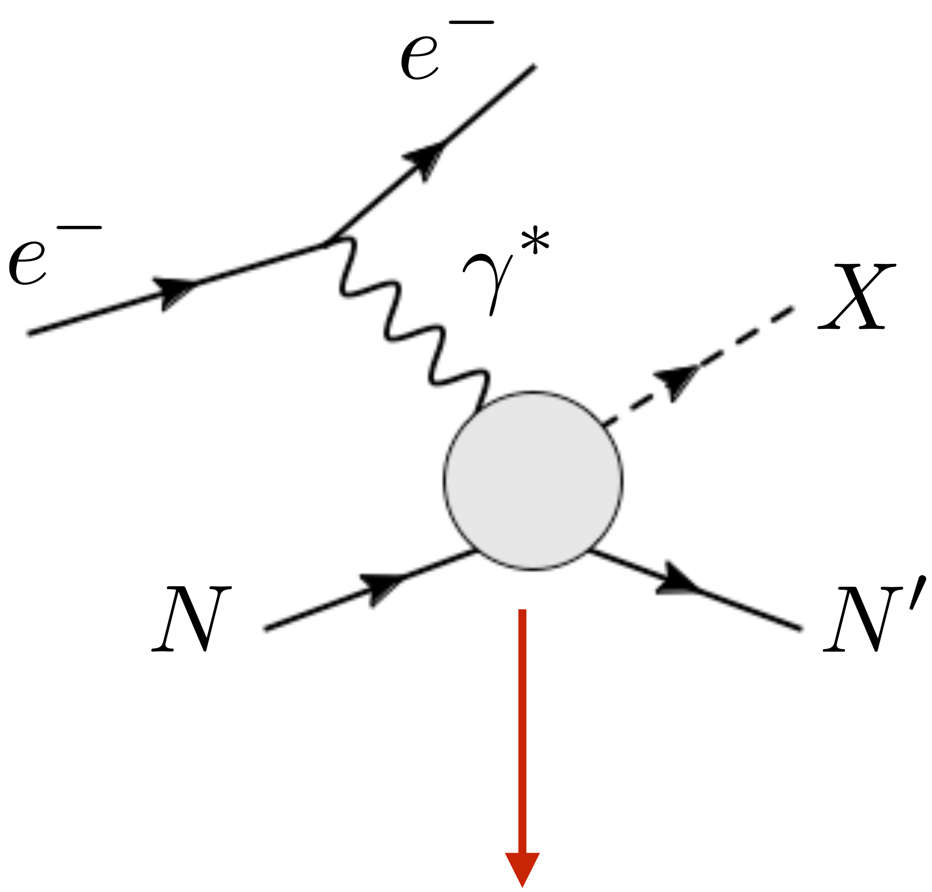


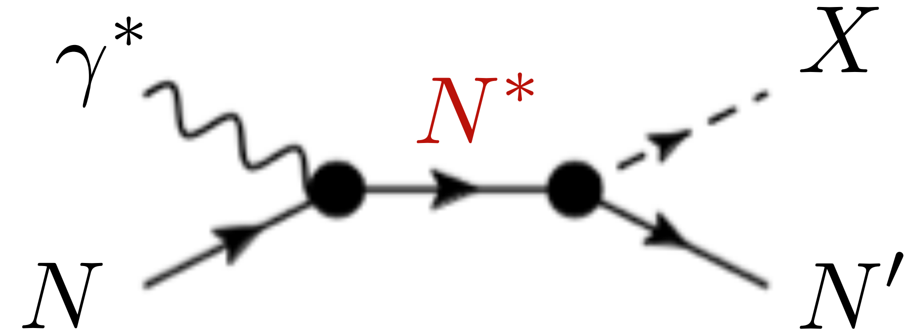
$$A_{\lambda_\gamma,\lambda_N;\lambda'_N}(q^2, E, \theta)$$

6 functions of 3 variables

→ **Need data and constraints**

Motivations





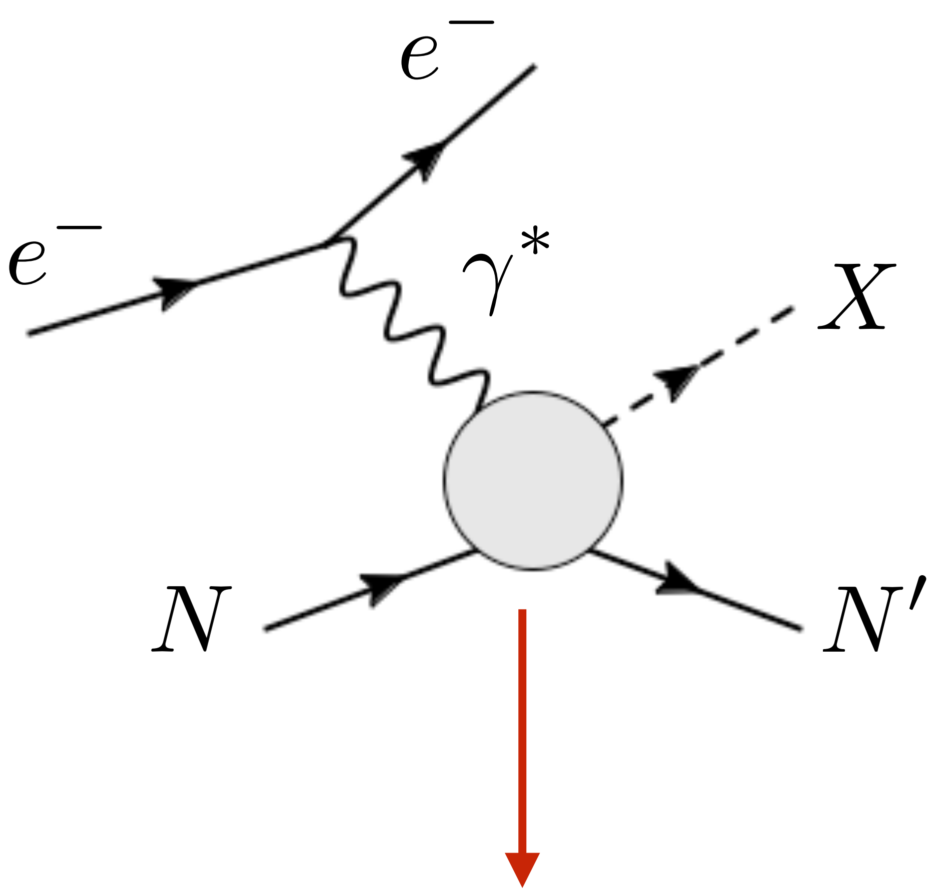
$$A_{\lambda_\gamma,\lambda_N;\lambda'_N}(q^2, E, \theta)$$

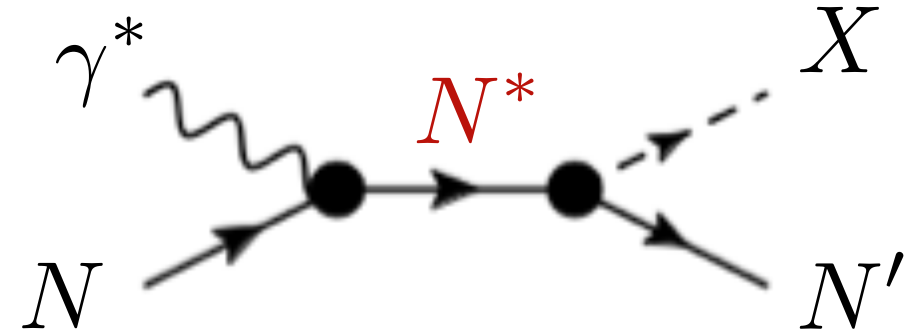
6 functions of 3 variables

$\longrightarrow$ **Need data and constraints**

Constraints from S-Matrix principles and from QCD

Motivations





$$A_{\lambda_\gamma,\lambda_N;\lambda'_N}(q^2, E, \theta)$$

6 functions of 3 variables

$\longrightarrow$ **Need data and constraints**

Constraints from S-Matrix principles ~~and from QCD~~

cf other talks

Outline

Constraints from S-Matrix principles:

- **Unitarity**

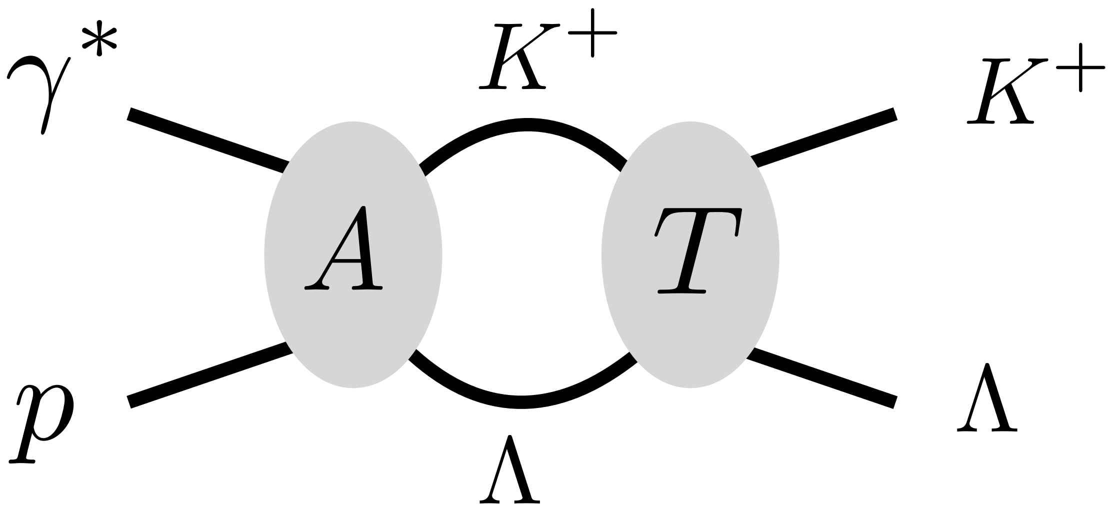
implemented in analysis

- **Analyticity**

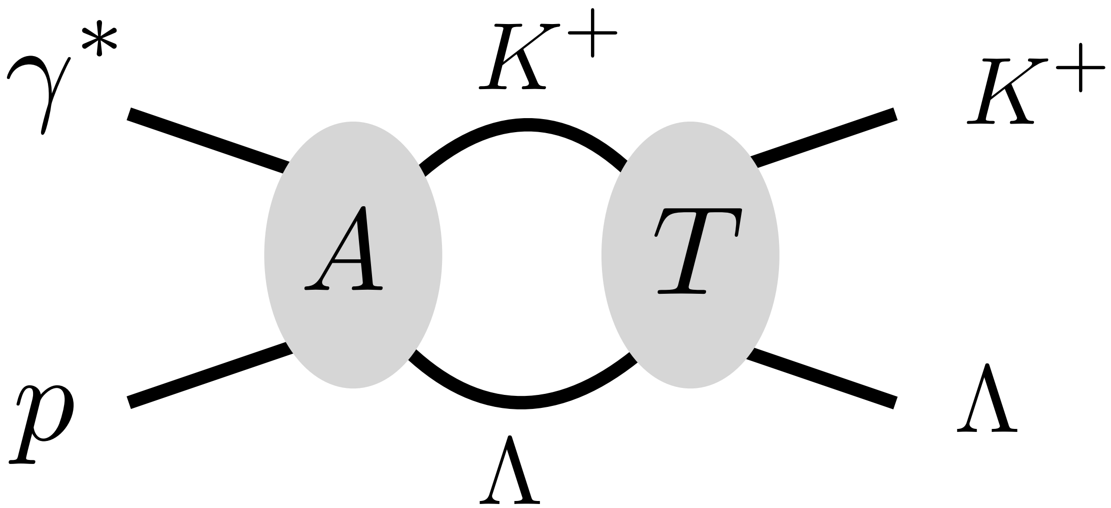
not implemented in analysis
examples: $\gamma p \to \pi^0 p, \eta p$

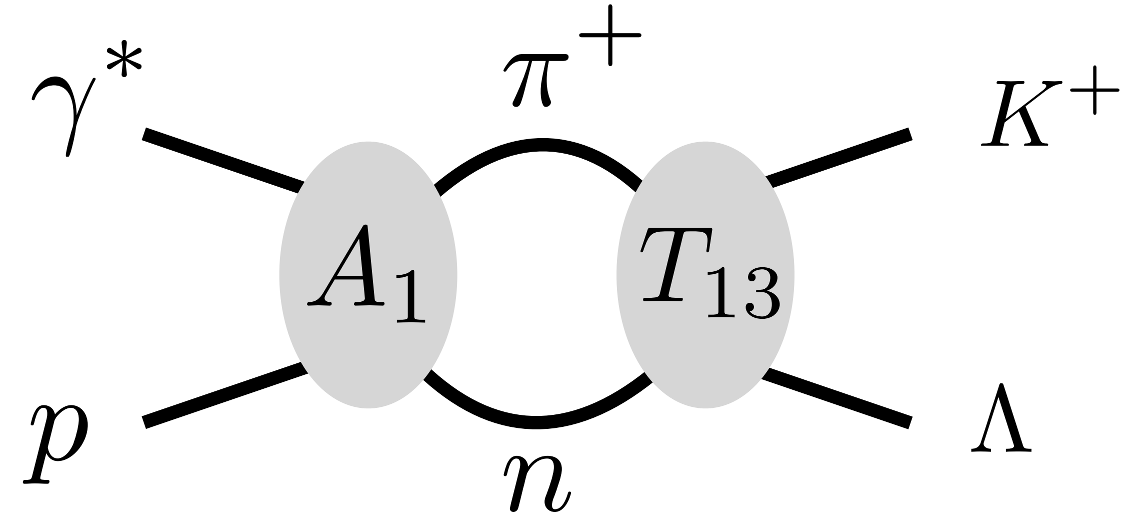
- **N* trajectories**

Unitarity

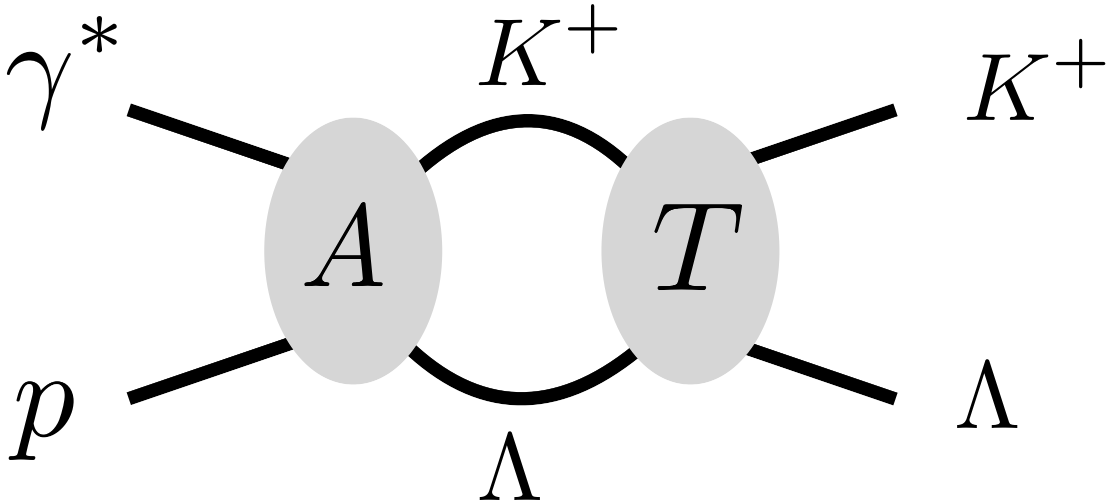


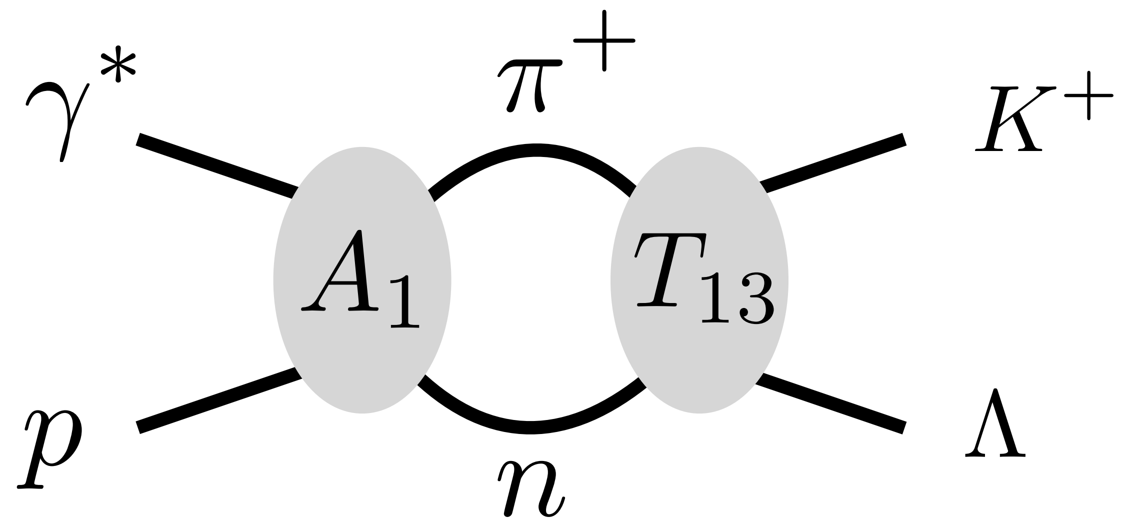
Unitarity

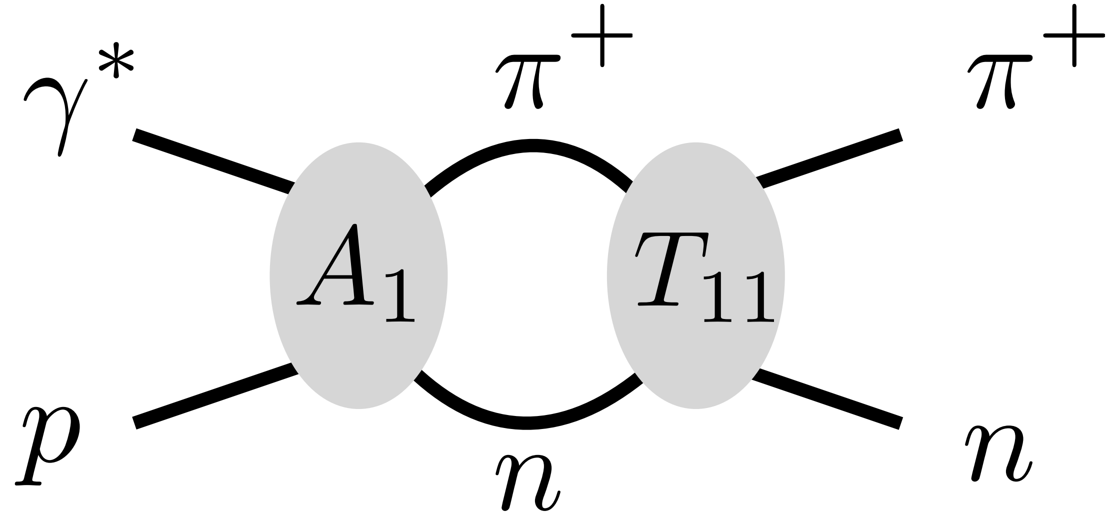




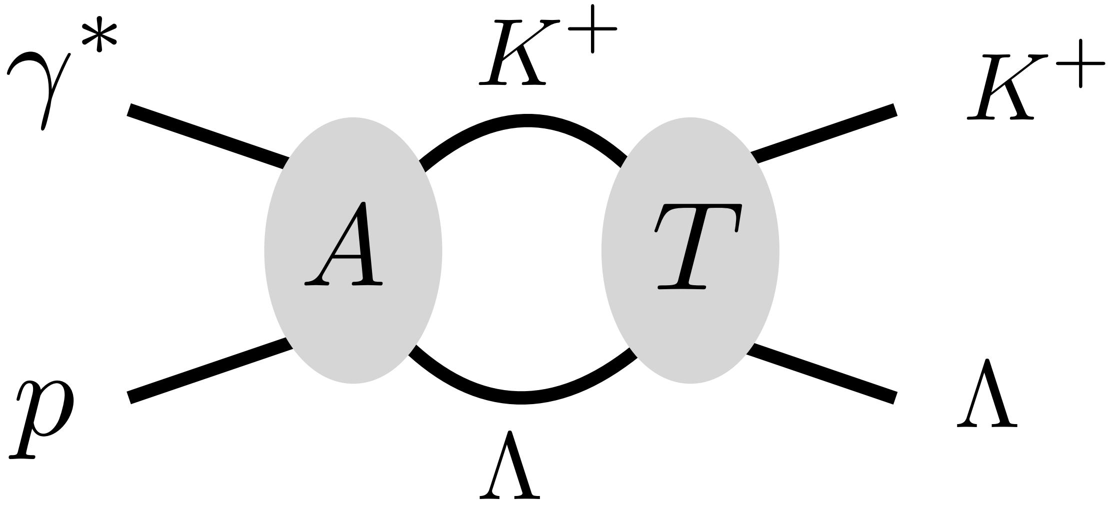
Unitarity

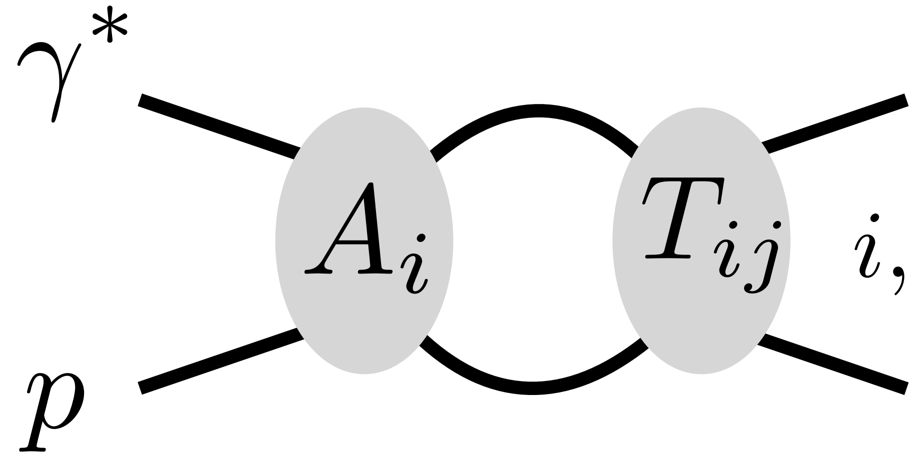

γ^*
K^+
K^+
A
T
p
Λ
Λ


γ^*
π^+
K^+
A_1
T_{13}
p
n
Λ


γ^*
π^+
π^+
A_1
T_{11}
p
n
n

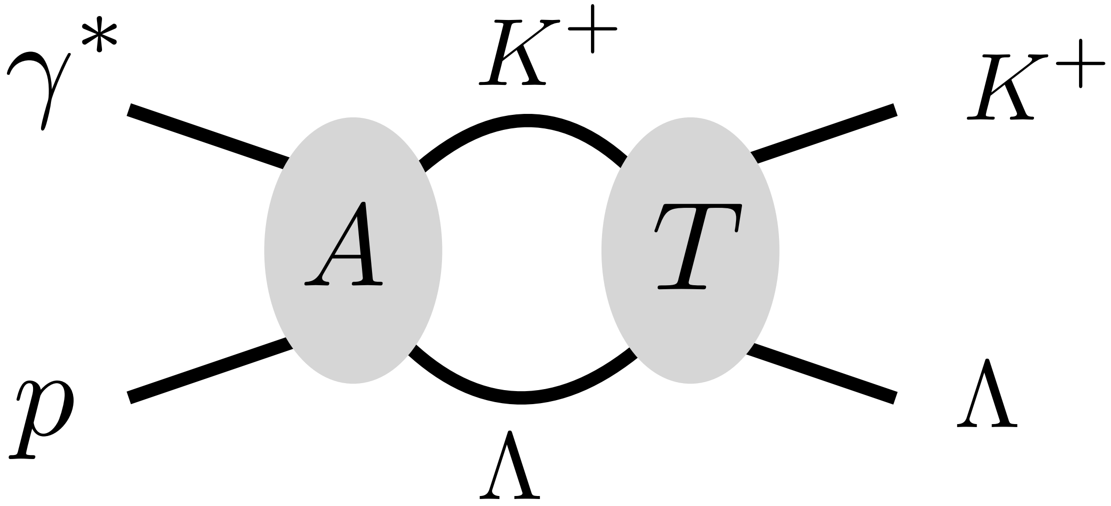
Unitarity

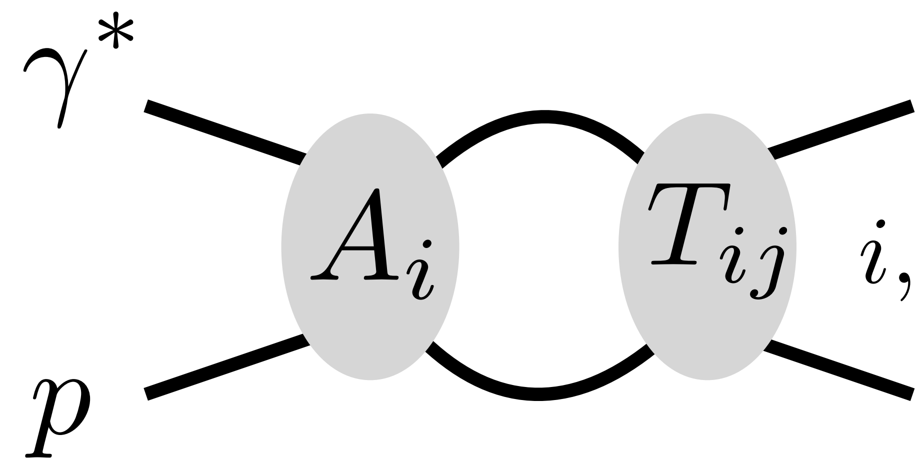




$i, j = \begin{matrix} \pi & \eta & K^+ \\ N & p & \Lambda \end{matrix}$

Unitarity





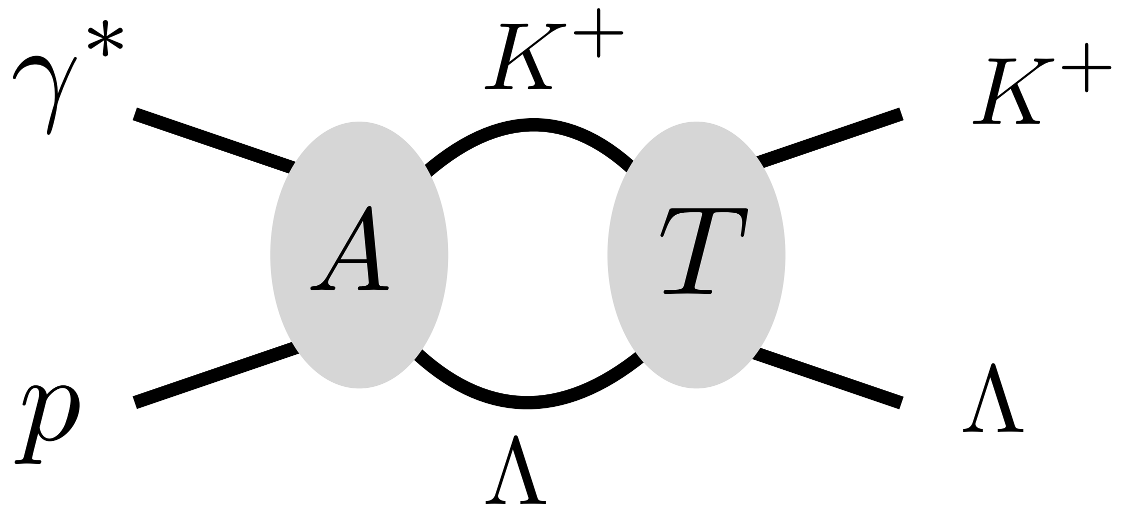
$$i, j = \begin{matrix} \pi & \eta & K^+ \\ N & p & \Lambda \end{matrix}$$

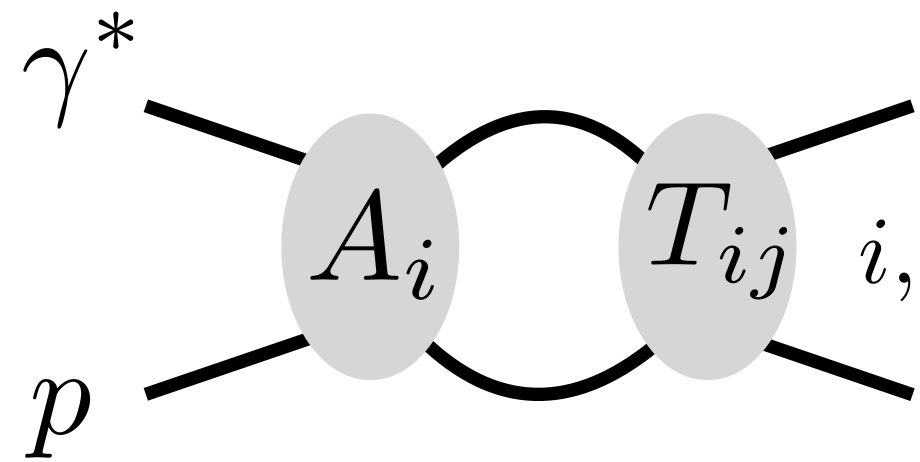
Partial wave expansion

$$T^{ij}_{\lambda;\lambda'}(s, q^2, \theta) : \quad f^{ij}_{\ell\pm}(s, q^2) \qquad (s = E^2_{\mathrm{cm}})$$

$$A^{i}_{\lambda_\gamma\lambda;\lambda'}(s, q^2, \theta) : \quad E^{i}_{\ell\pm}(s, q^2), M^{i}_{\ell\pm}(s, q^2), S^{i}_{\ell\pm}(s, q^2)$$

Unitarity





$i, j = \begin{matrix} \pi & \eta & K^+ \\ N & p & \Lambda \end{matrix}$

Partial wave expansion

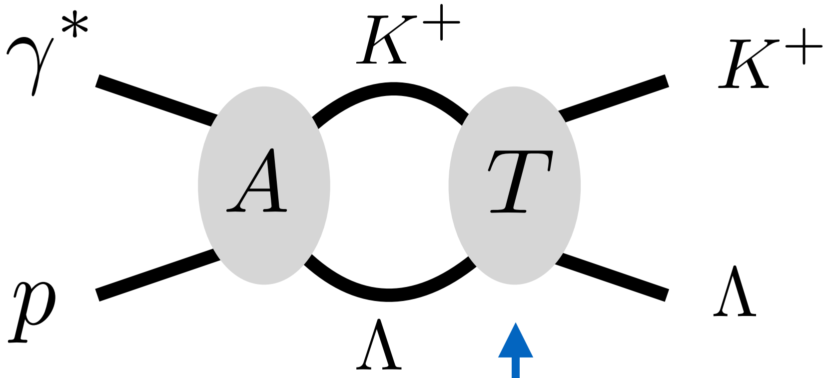
$$T^{ij}_{\lambda;\lambda'}(s, q^2, \theta) : \quad f^{ij}_{\ell\pm}(s, q^2) \qquad (s = E^2_{\text{cm}})$$

$$A^{i}_{\lambda_\gamma\lambda;\lambda'}(s, q^2, \theta) : \quad E^i_{\ell\pm}(s, q^2), M^i_{\ell\pm}(s, q^2), S^i_{\ell\pm}(s, q^2)$$

$$\boxed{\mathrm{Im}\ E^j_{\ell\pm}(s, q^2) = \sum_i E^i_{\ell\pm}(s, q^2) f^{ji*}_{\ell\pm}(s)\ \theta(s - s_i)}$$

$s_n =$ **threshold channel n**

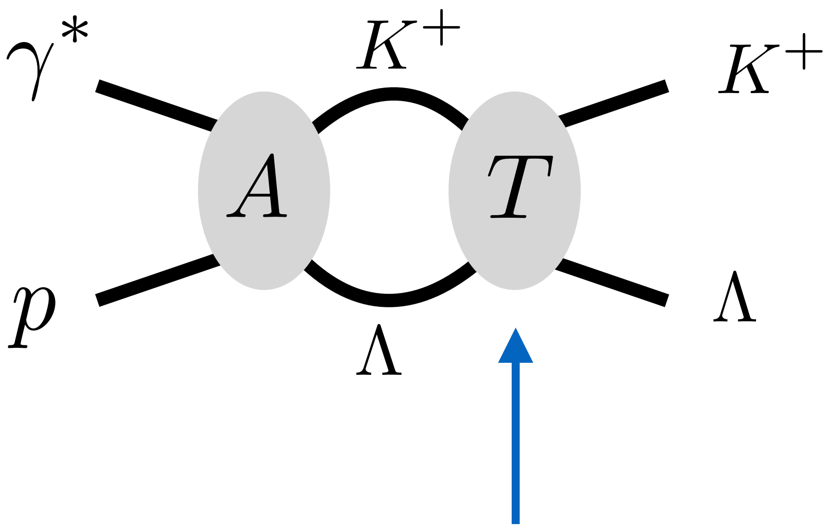
Unitarity



$$\mathrm{Im}\, E^{j}_{\ell\pm}(s,q^2) = \sum_i E^{i}_{\ell\pm}(s,q^2)\boxed{f^{ji*}_{\ell\pm}(s)}\,\theta(s-s_i)$$

hadronic amplitudes as input

Unitarity



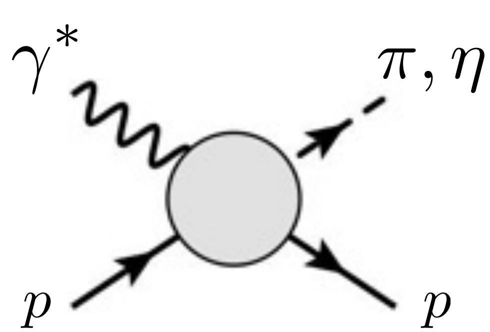
$$\mathrm{Im}\ E^j_{\ell\pm}(s,q^2) = \sum_i E^i_{\ell\pm}(s,q^2)\boxed{f^{ji*}_{\ell\pm}(s)}\,\theta(s-s_i)$$

hadronic amplitudes as input

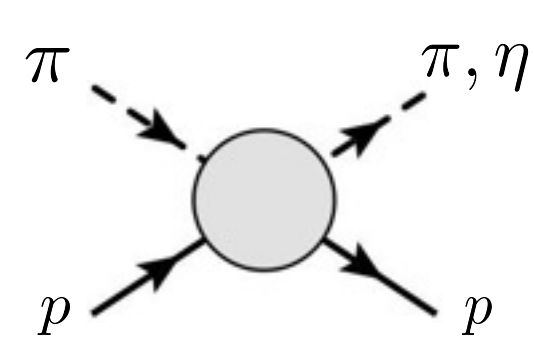
Possible solution of unitarity

$$E^j_{\ell\pm}(s,q^2) = e_{\ell\pm}(s,q^2) f^{1j}_{\ell\pm}(s)$$

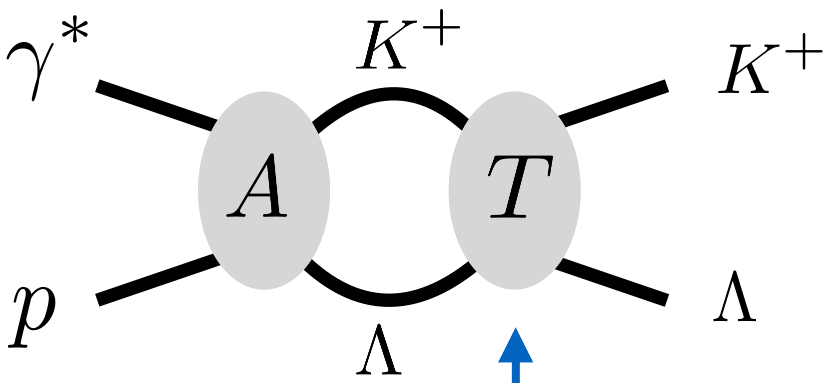
pole positions (mass & width)
do not change



$= e_{\ell\pm}(s,q^2)\times$



Unitarity



$$\boxed{\mathrm{Im}\; E^{j}_{\ell\pm}(s,q^2) = \sum_i E^{i}_{\ell\pm}(s,q^2)\boxed{f^{ji*}_{\ell\pm}(s)}\,\theta(s-s_i)}$$

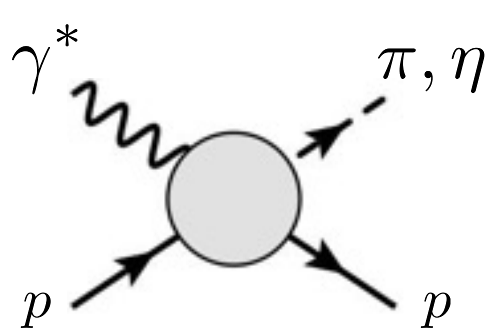
hadronic amplitudes as input

Possible solution of unitarity

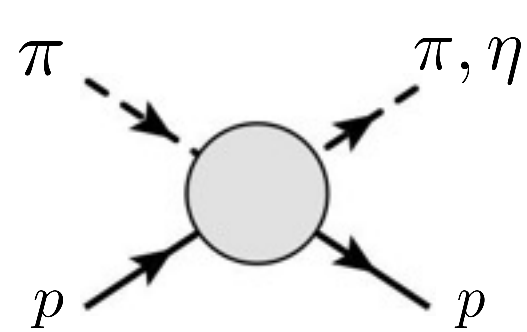
$$E^{j}_{\ell\pm}(s,q^2) = e_{\ell\pm}(s,q^2) f^{1j}_{\ell\pm}(s)$$

pole positions (mass & width) do not change

$$e_{\ell\pm}(s,q^2) = e_{\ell\pm}(0,q^2)\ \mathrm{polyn.}(s)$$



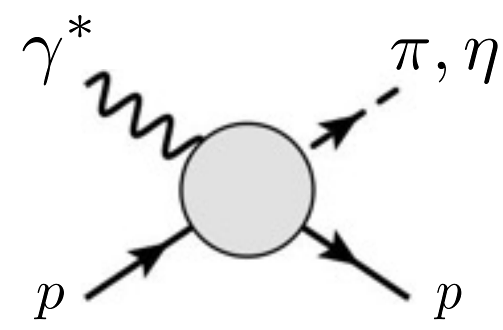
$= e_{\ell\pm}(s,q^2)\times$



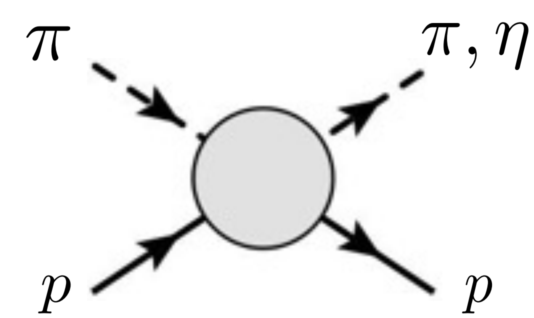
Unitarity

Possible solution of unitarity

pole positions (mass & width) do not change

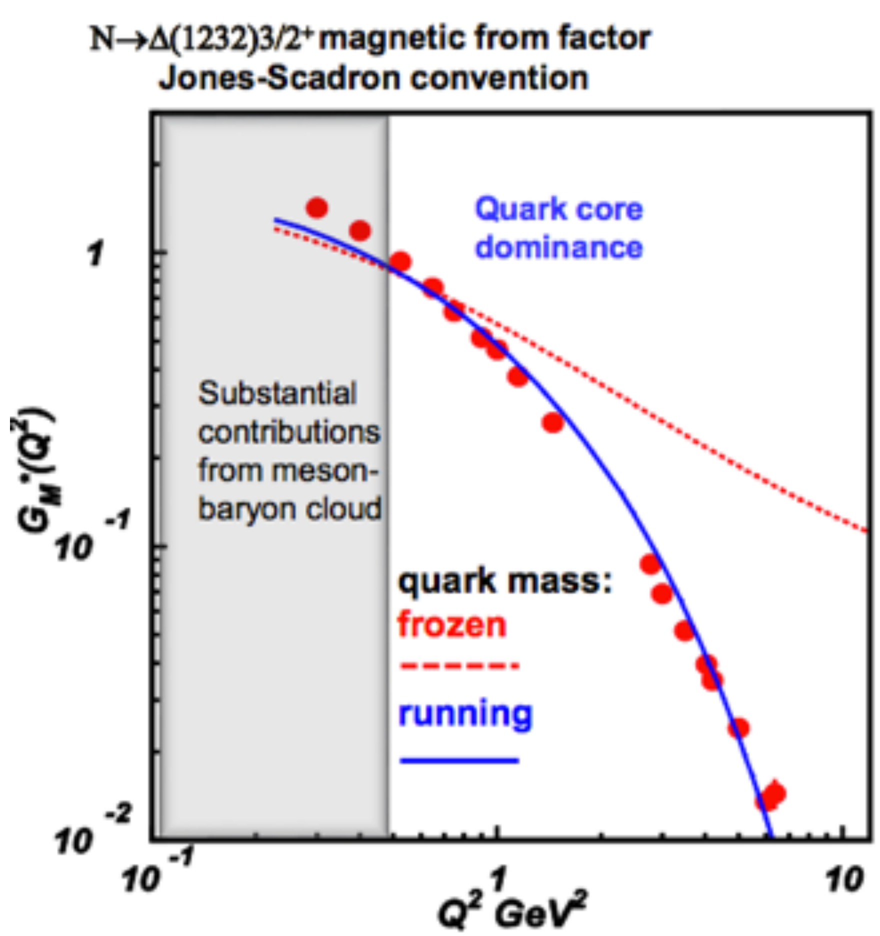


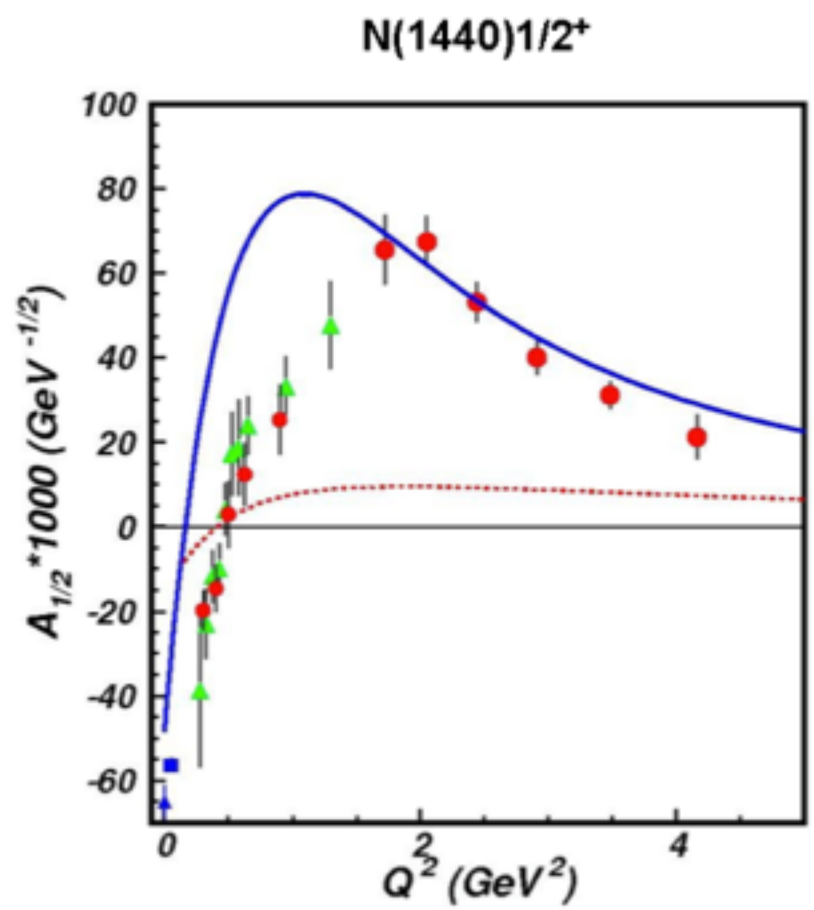
$= e_{\ell\pm}(s, q^2) \times$



$$E^j_{\ell\pm}(s, q^2) = e_{\ell\pm}(s, q^2) f^{1j}_{\ell\pm}(s)$$

$$e_{\ell\pm}(s, q^2) = \boxed{e_{\ell\pm}(0, q^2)}\,\mathrm{polyn.}(s)$$





CLAS: Present & Future

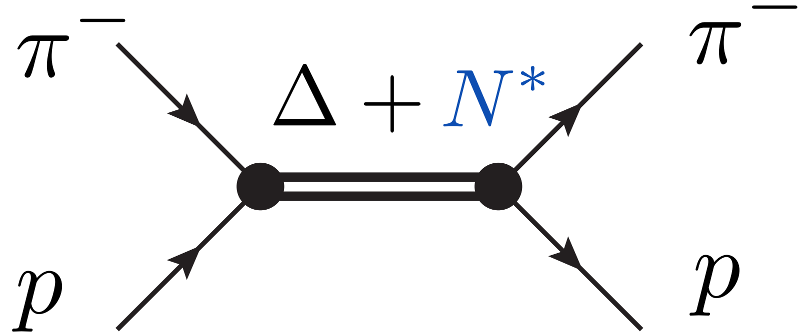
Hadronic final state	Covered W-range, GeV	Covered Q^2-range, GeV^2	Measured observables
$\pi^+ n$	1.1-1.38 1.1-1.55 1.1-1.7 1.6-2.0	0.16-0.36 0.3-0.6 1.7-4.5 1.8-4.5	$d\sigma/d\Omega$ $d\sigma/d\Omega$ $d\sigma/d\Omega$, A_b $d\sigma/d\Omega$
$\pi^0 p$	1.1-1.38 1.1-1.68 1.1-1.39	0.16-0.36 0.4-1.8 3.0-6.0	$d\sigma/d\Omega$ $d\sigma/d\Omega$, A_b,A_t,A_{bt} $d\sigma/d\Omega$
ηp	1.5-2.3	0.2-3.1	$d\sigma/d\Omega$
$K^+\Lambda$	thresh-2.6	1.40-3.90 0.70-5.40	$d\sigma/d\Omega$ P^0, P'

Hybrid Baryons E12-16-010	Search for hybrid baryons (qqqg) focusing on 0.05 GeV^2 < Q^2 < 2.0 GeV^2 in mass range from 1.8 to 3 GeV in $K\Lambda$, $N\pi\pi$, $N\pi$ *(A. D'Angelo, et al.)*
KY Electroproduction E12-16-010A	Study N* structure for states that couple to KY through measurements of cross sections and polarization observables that will yield Q^2 evolution of electrocoupling amplitudes at Q^2<7.0 GeV^2 *(D. Carman, et al.)*

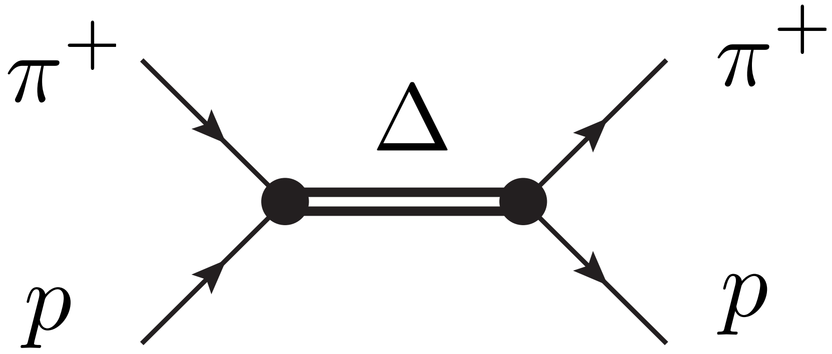
Run Group conditions:
E_b = 6.6 GeV, 50 days
E_b = 8.8 GeV, 50 days

Analyticity

$\pi^- p :$



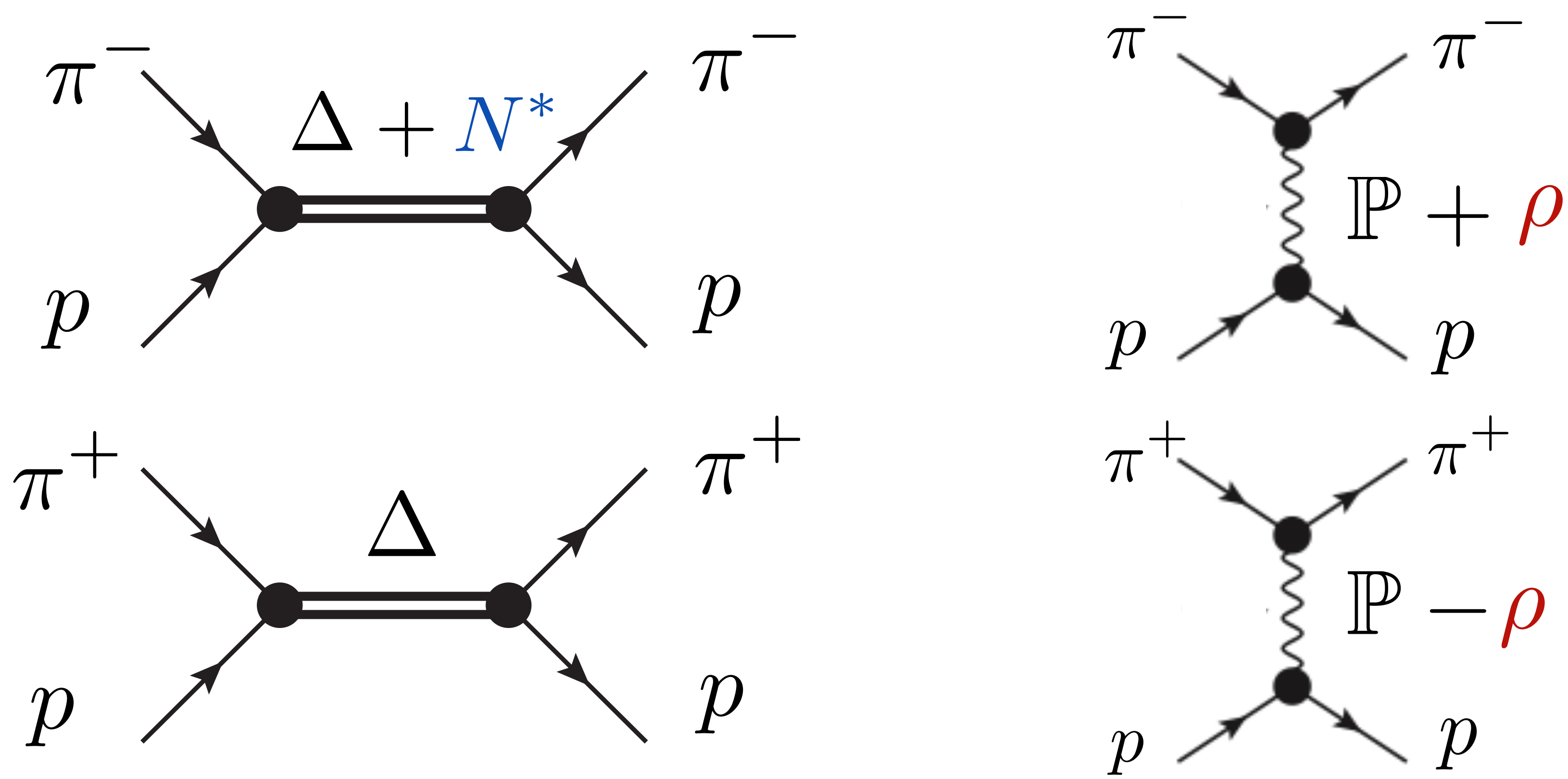
$\pi^+ p :$



Analyticity

$\pi^- p :$

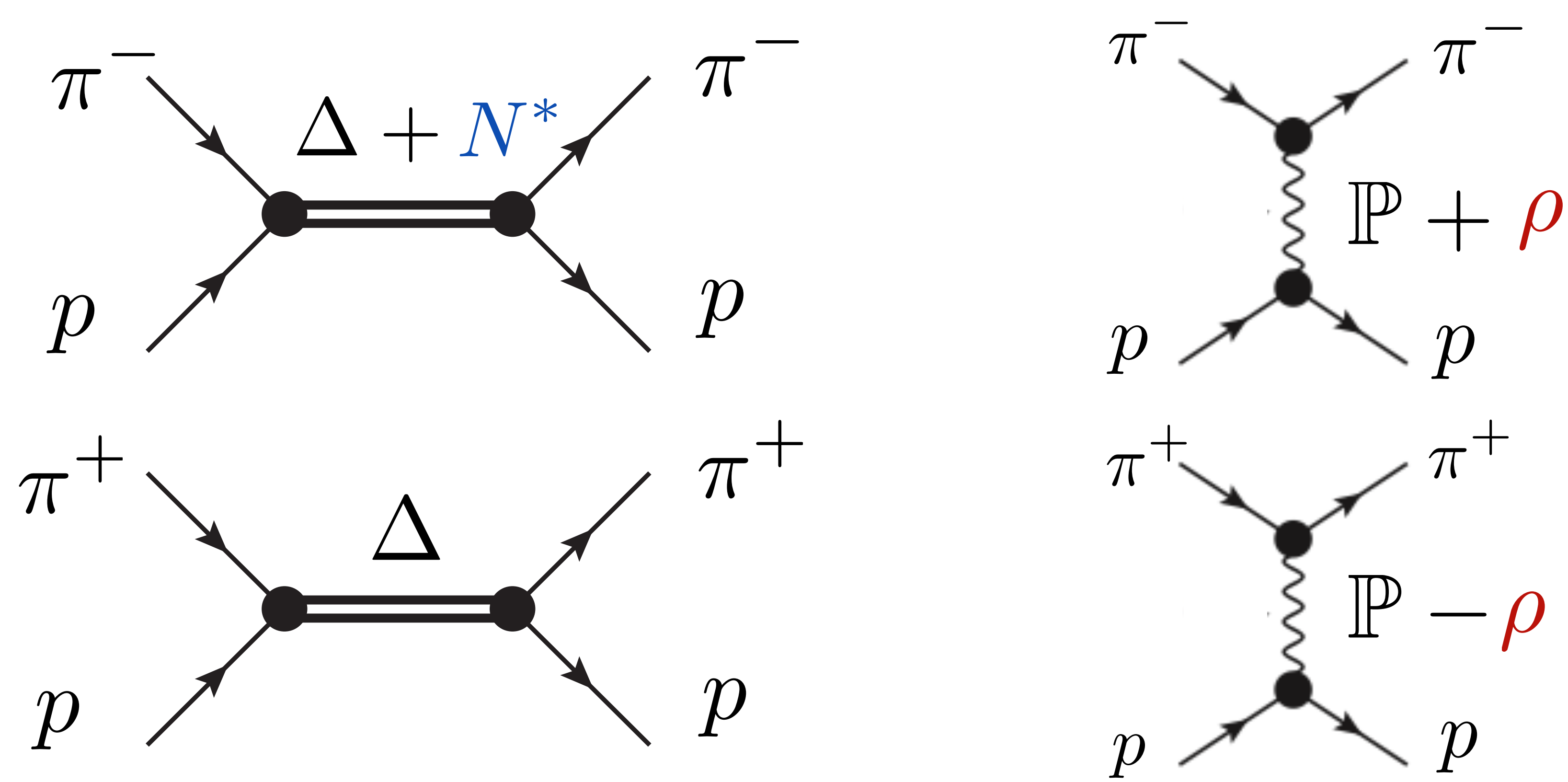
$\pi^+ p :$

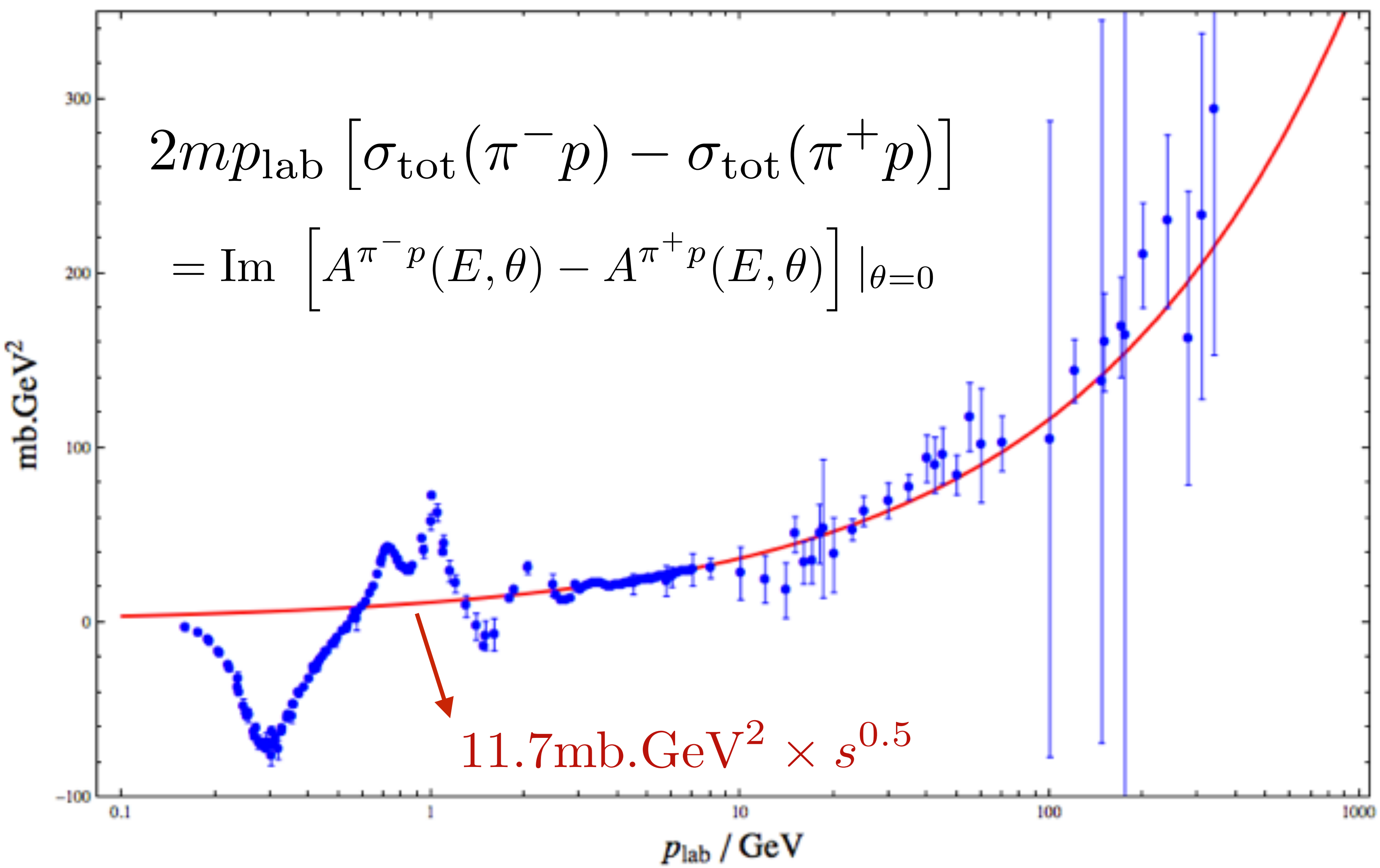


Analyticity

$\pi^- p :$

$\pi^+ p :$

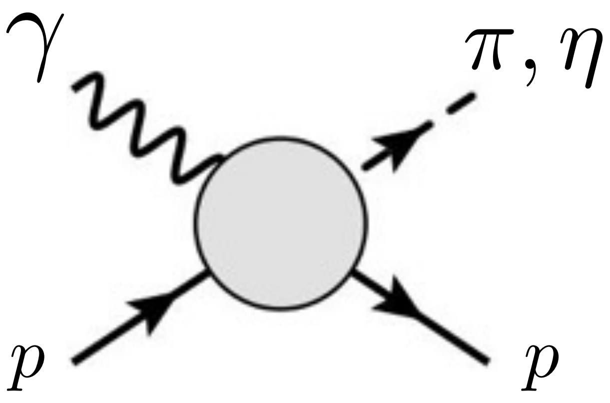




$$\langle N^* \rangle \stackrel{?}{=} \langle \rho \rangle$$

Analyticity

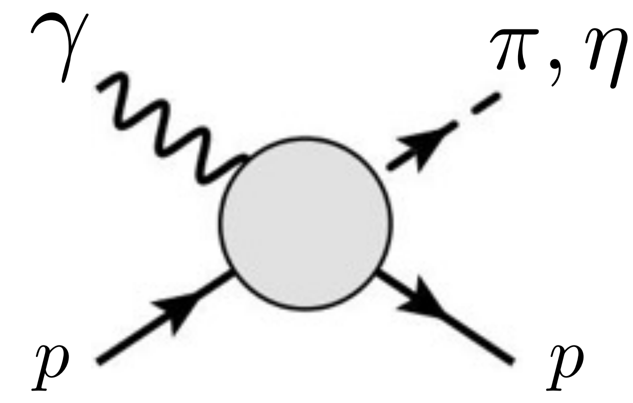
$$\int_0^{\Lambda} \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu = \beta_i(t)\frac{\Lambda^{\alpha_i(t)+k}}{\alpha_i(t)+k+1} + \ldots$$



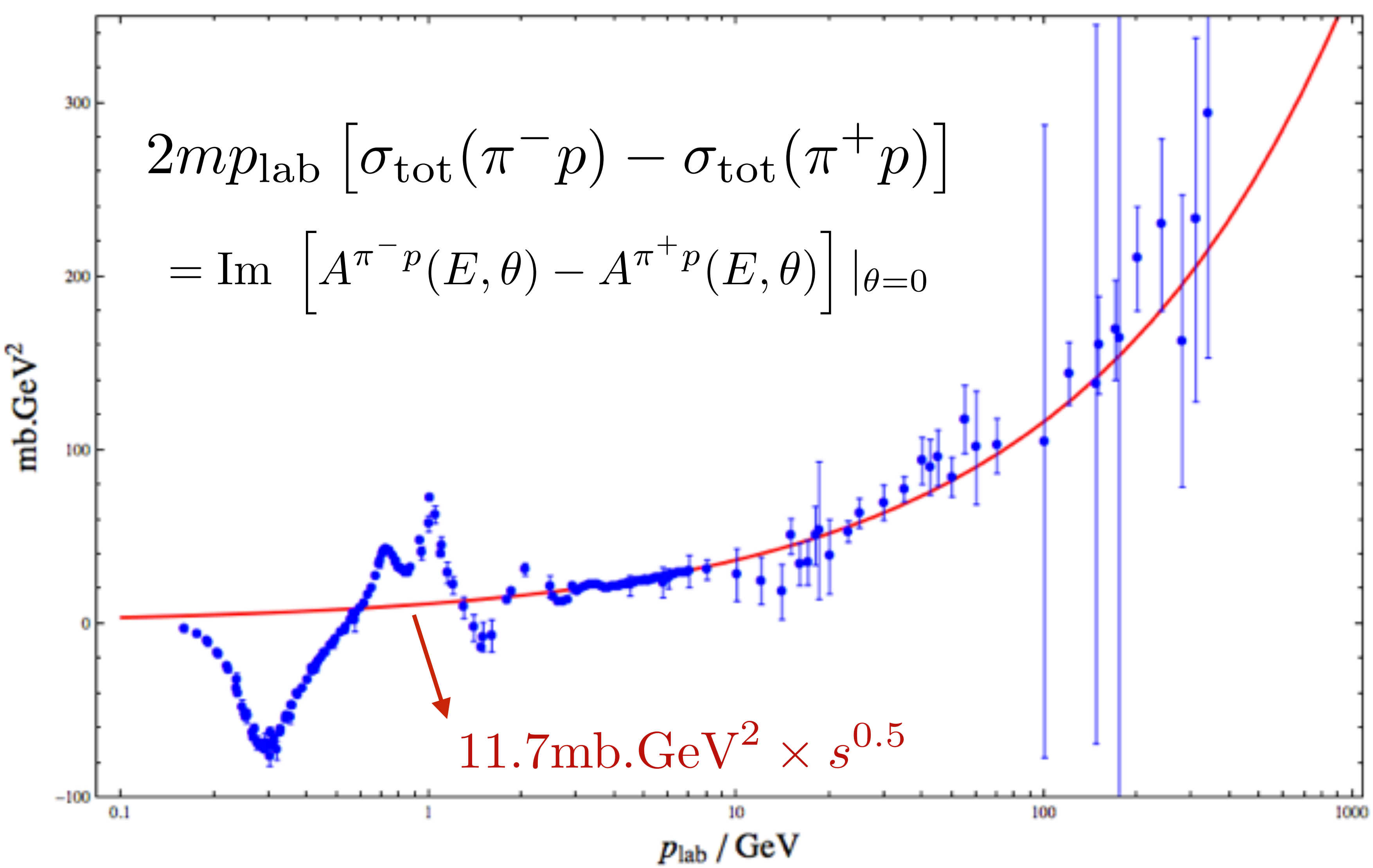
$$\nu = (s-u)/2$$

Analyticity

$$\int_0^{\Lambda} \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu = \beta_i(t)\frac{\Lambda^{\alpha_i(t)+k}}{\alpha_i(t)+k+1}+\ldots$$



$$\nu = (s-u)/2$$

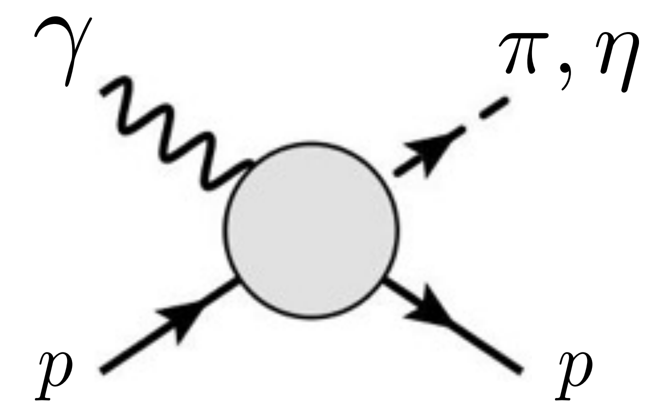


$$\langle N^* \rangle \stackrel{?}{=} \langle \rho \rangle$$

Finite Energy Sum Rules

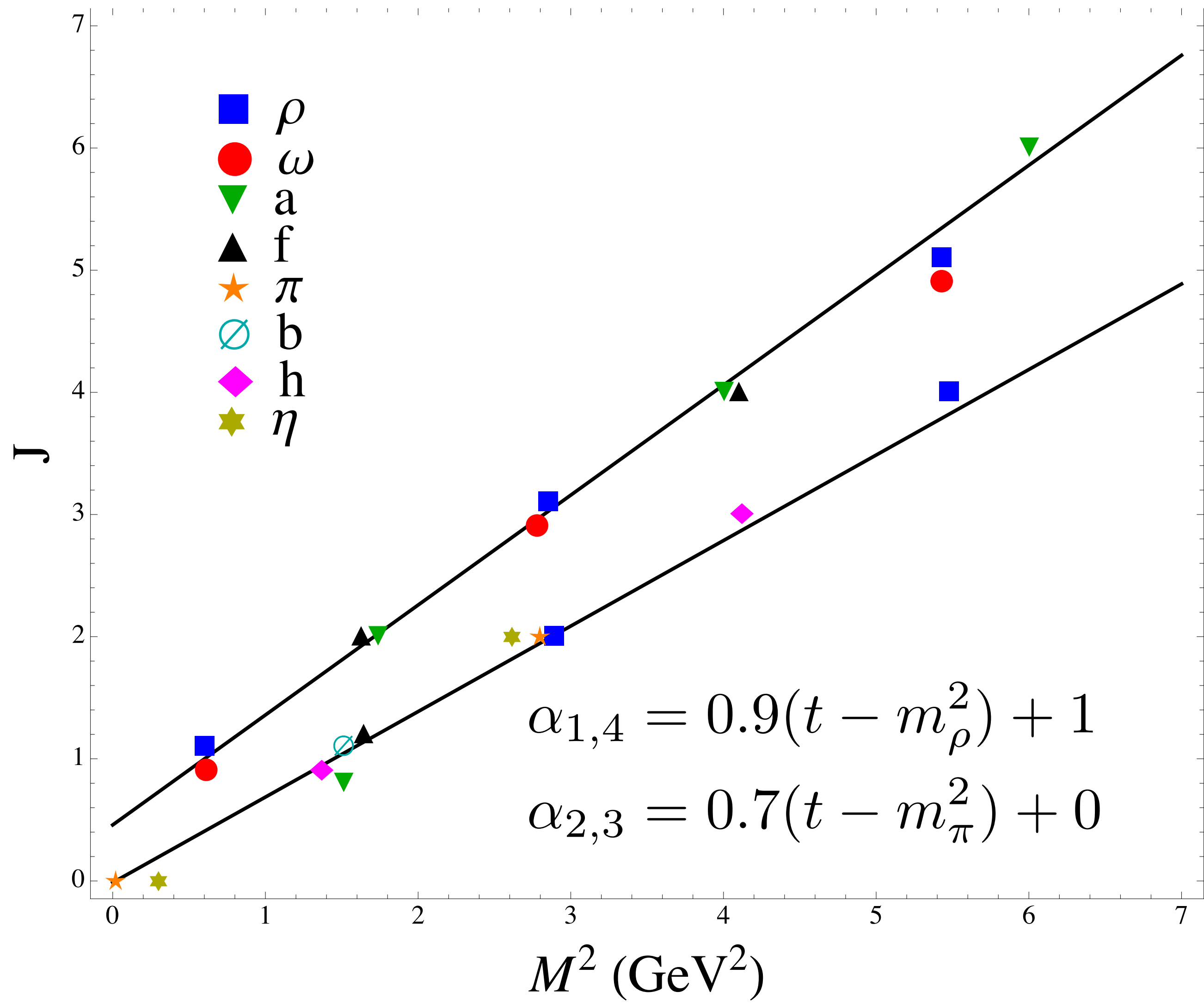
$$\nu = (s-u)/2$$

$$\underbrace{\int_0^\Lambda \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu}_{S_i(t,k)} = \beta_i(t)\frac{\Lambda^{\alpha_i(t)+k}}{\alpha_i(t)+k+1} + \dots$$



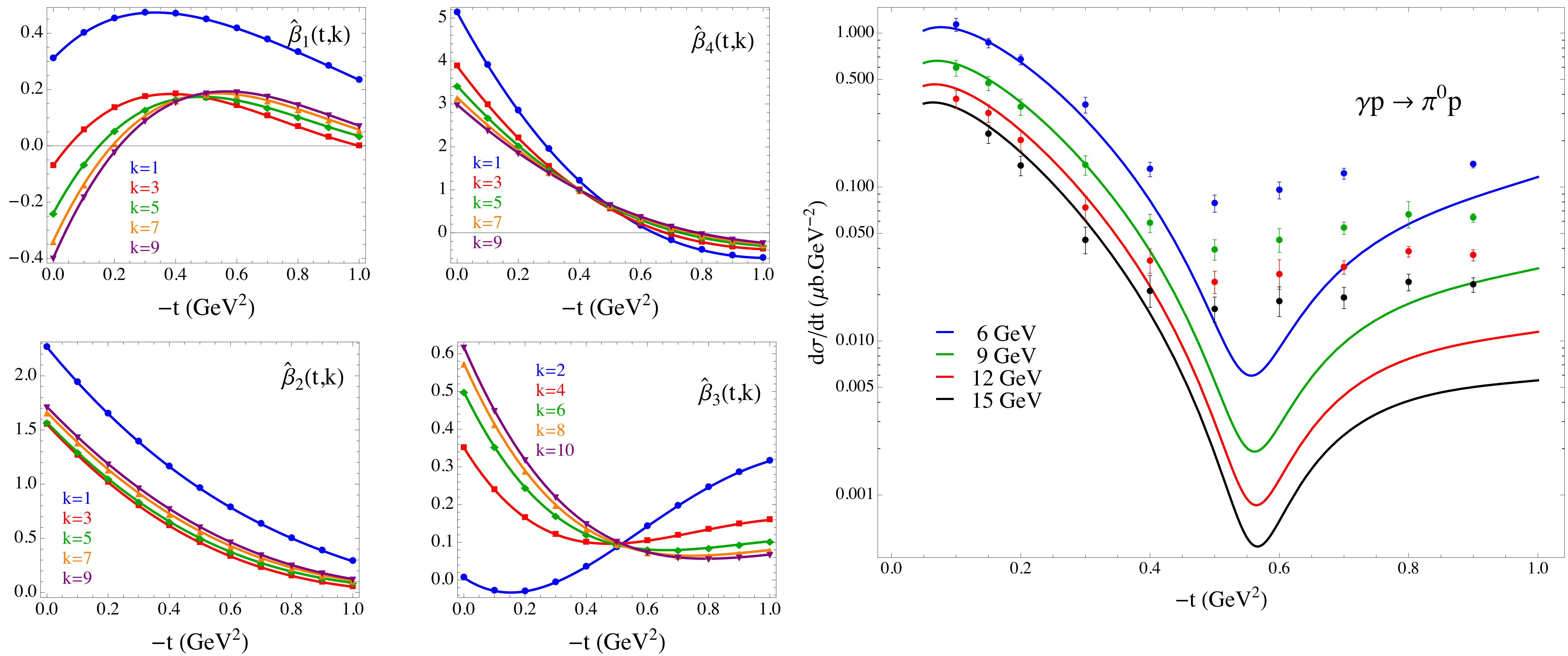
Can we predict the residues ?

$$\widehat{\beta}_i(t) = S_i(t,k)\frac{\alpha_i(t)+k+1}{\Lambda^{\alpha_i(t)+k}}$$
$$= \beta_i(t) + \mathcal{O}(1/\Lambda)$$



VM et al (JPAC), in preparation

$\gamma p \to \pi^0 p$



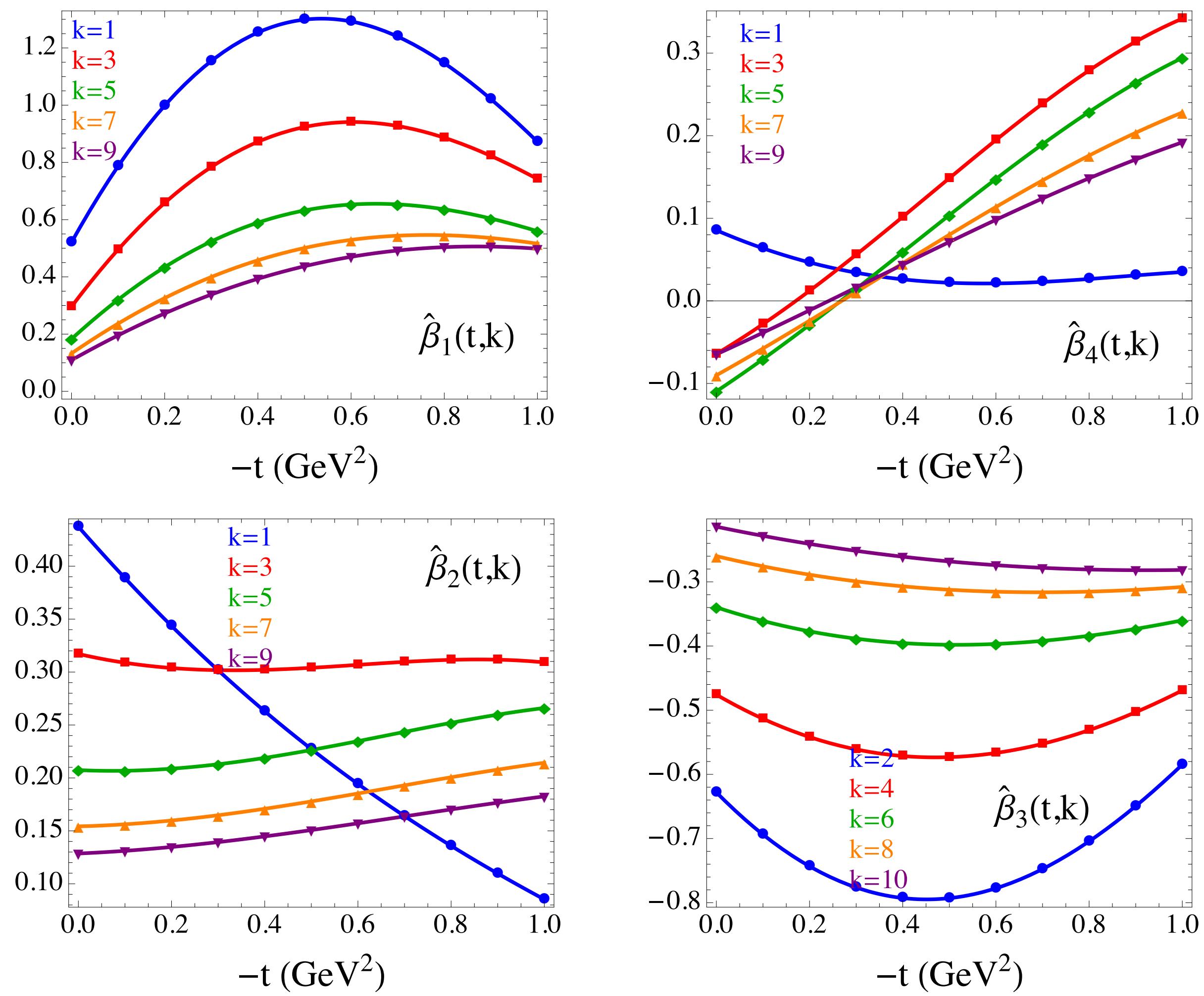
SAID (R. Workman et al) used for the low energy models

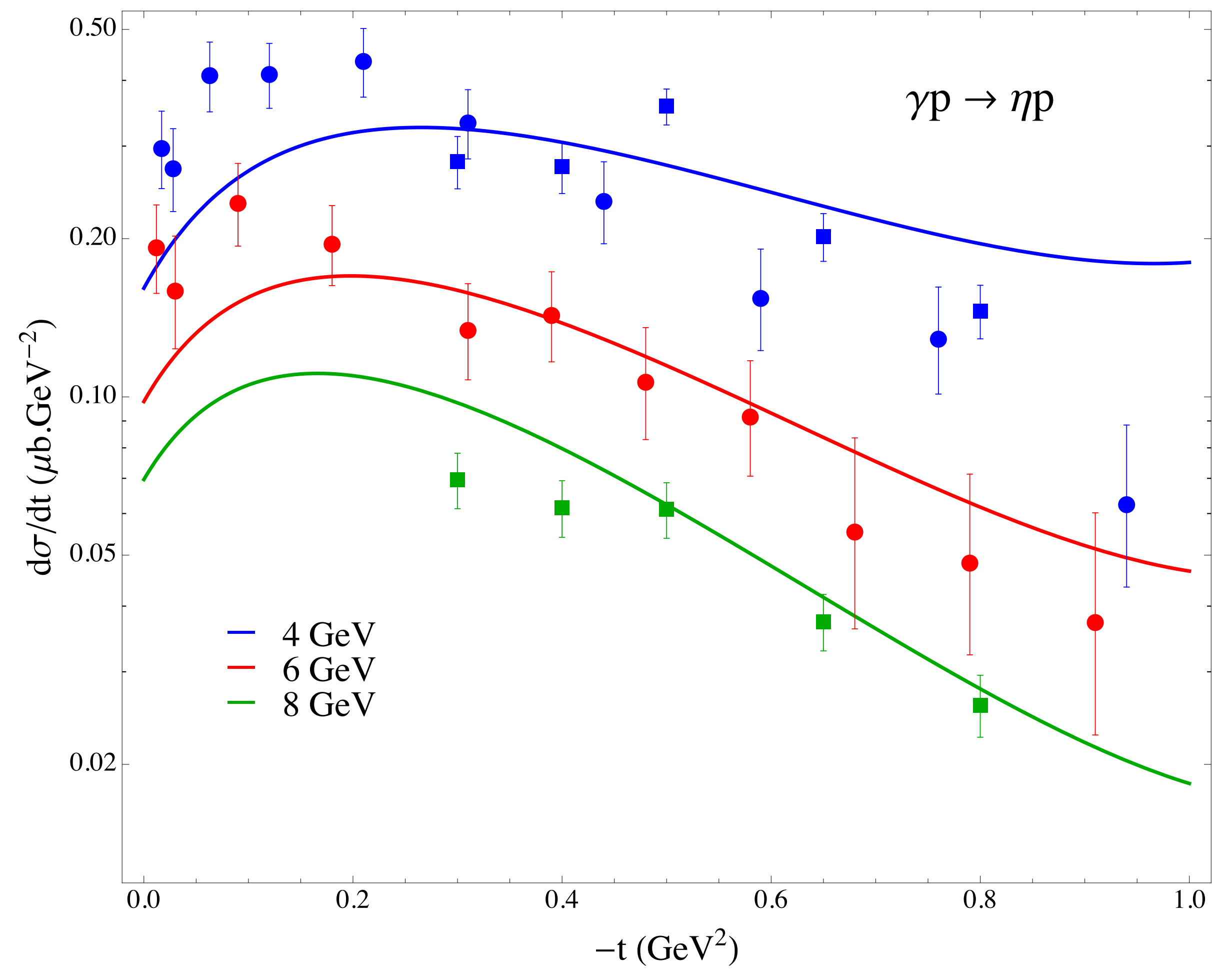
effective residues almost k-independent

Good prediction of t-dependence at high energy

VM et al (JPAC), in preparation

$\gamma p \to \eta p$





MAID (L. Tiator et al) used for the low energy models

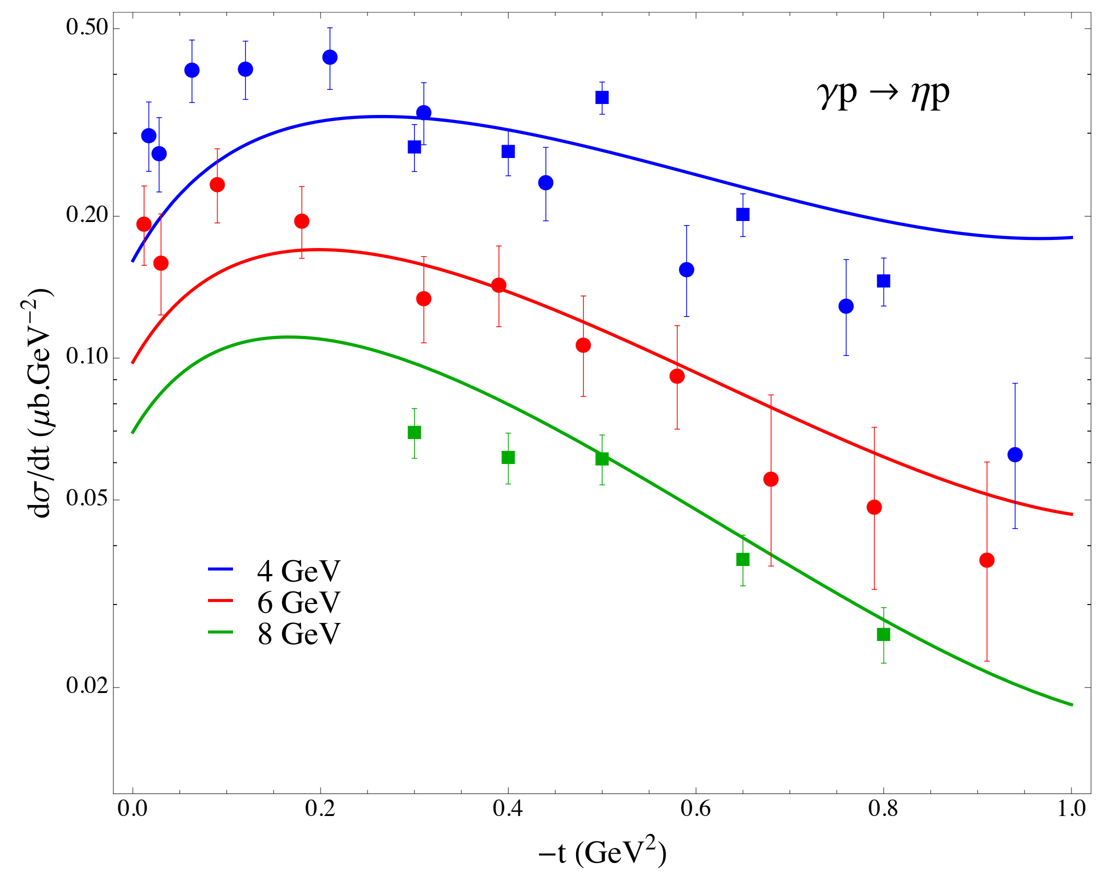
effective residues not k-independent

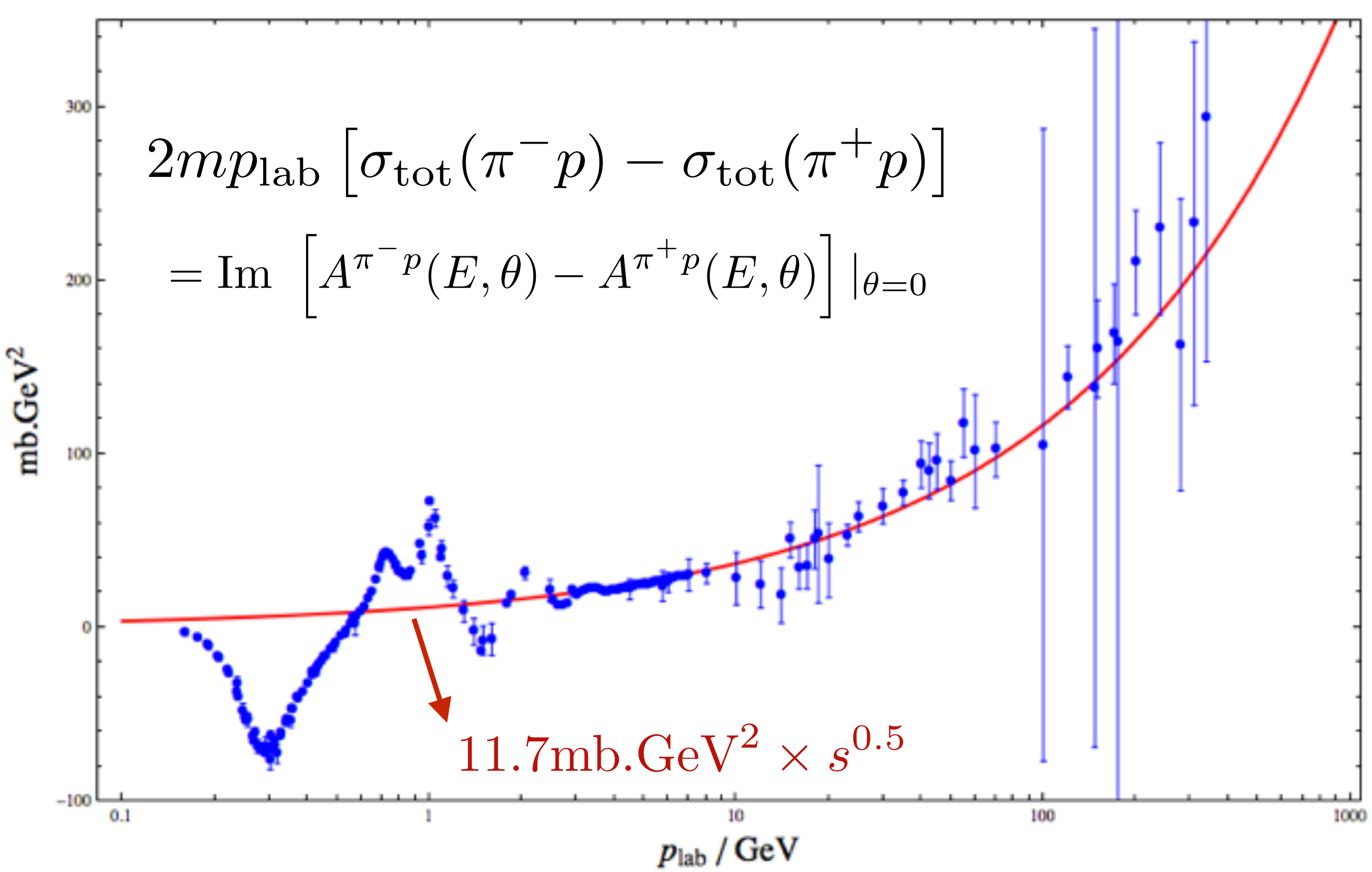
Good prediction of t-dependence at high energy

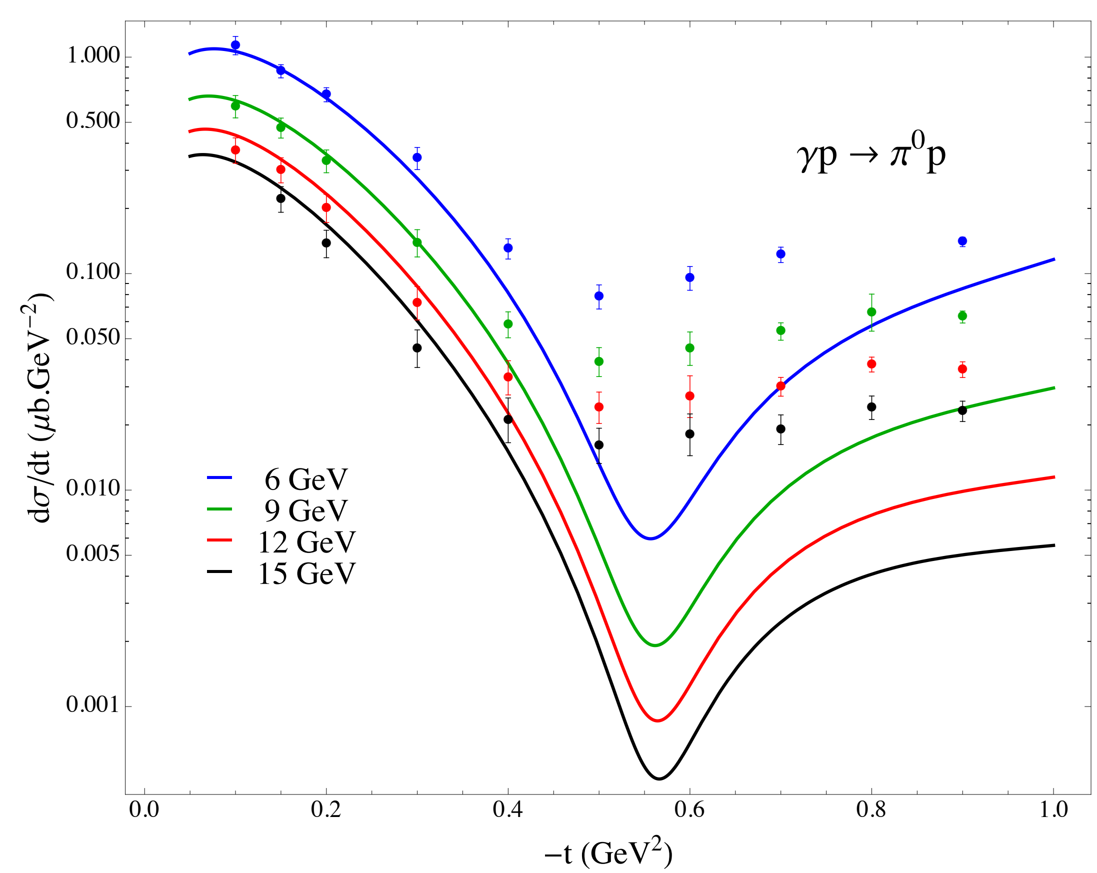
VM et al (JPAC), in preparation

input **prediction**

$$\int_0^{\Lambda} \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu = \beta_i(t)\frac{\Lambda^{\alpha_i(t)+k}}{\alpha_i(t)+k+1}$$

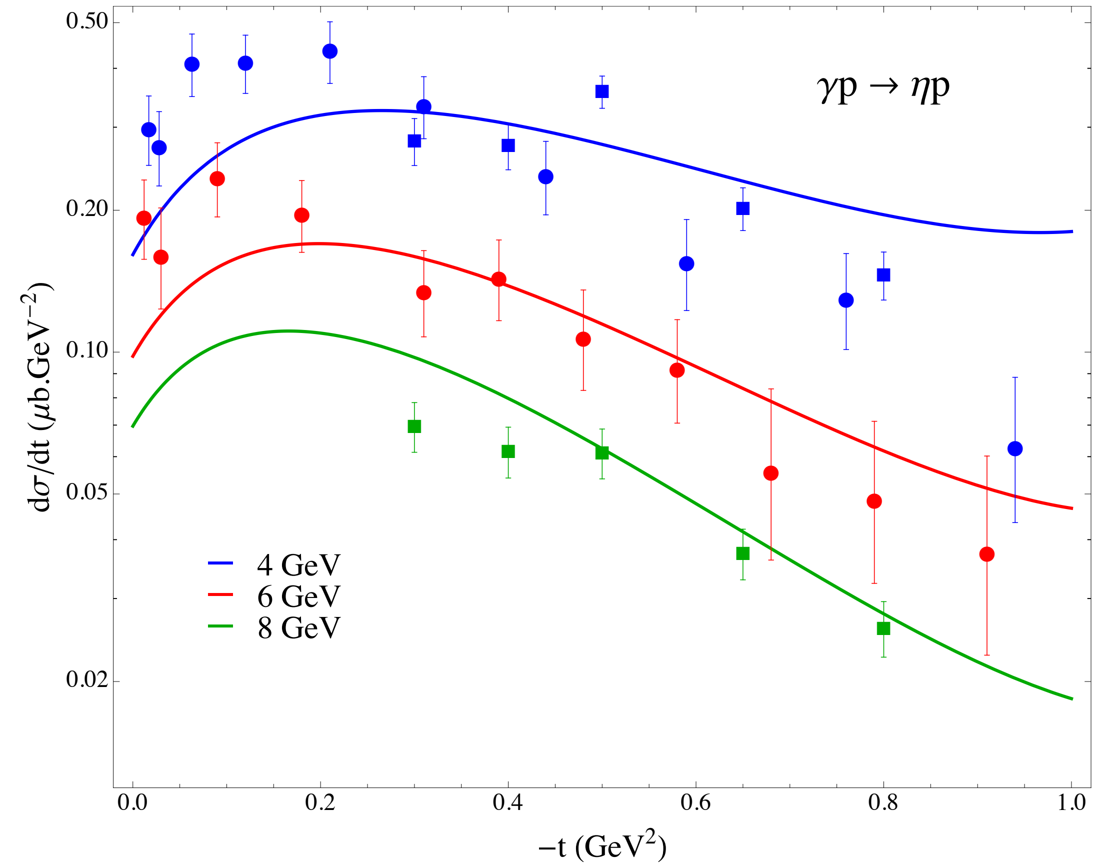


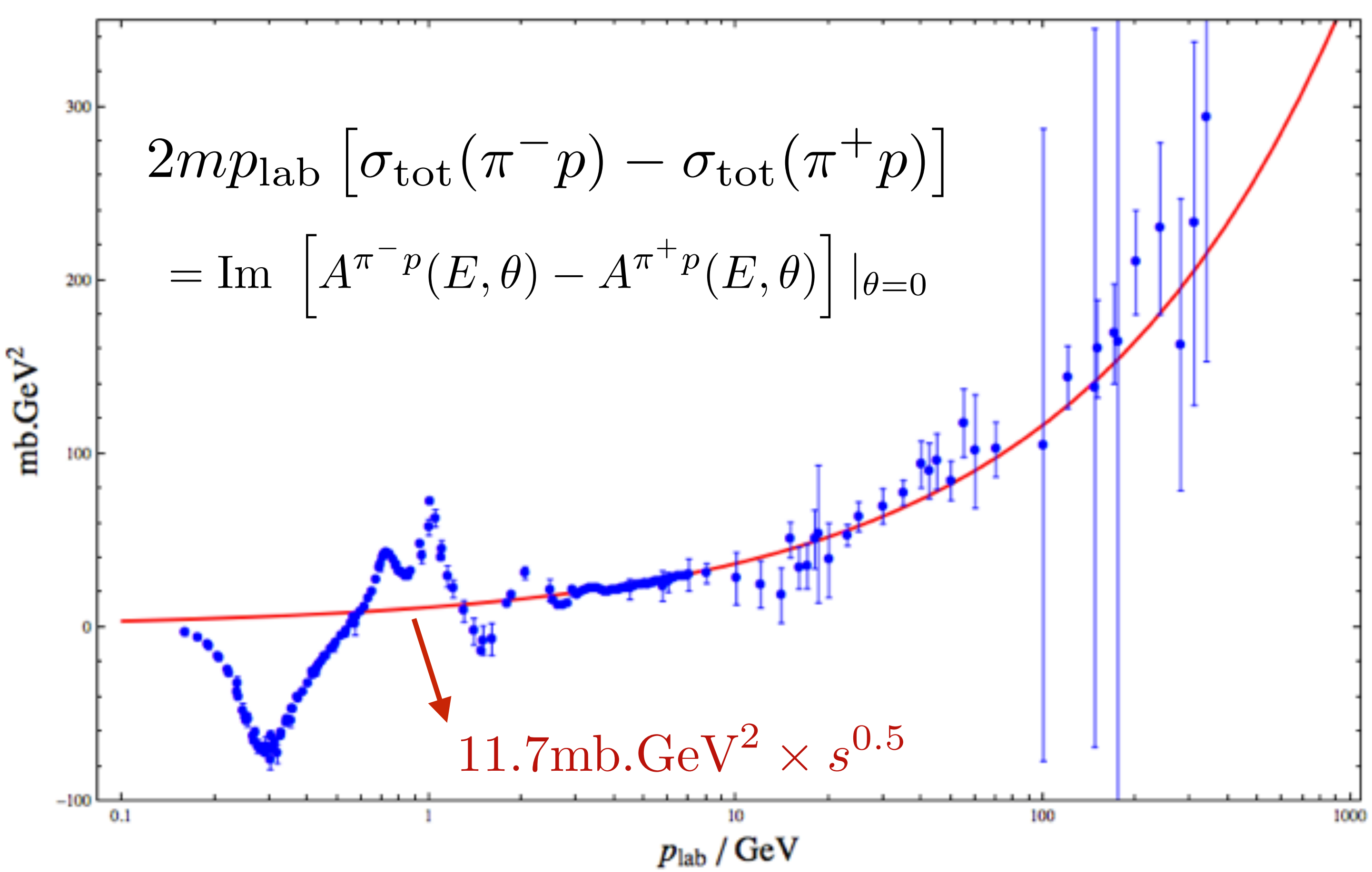


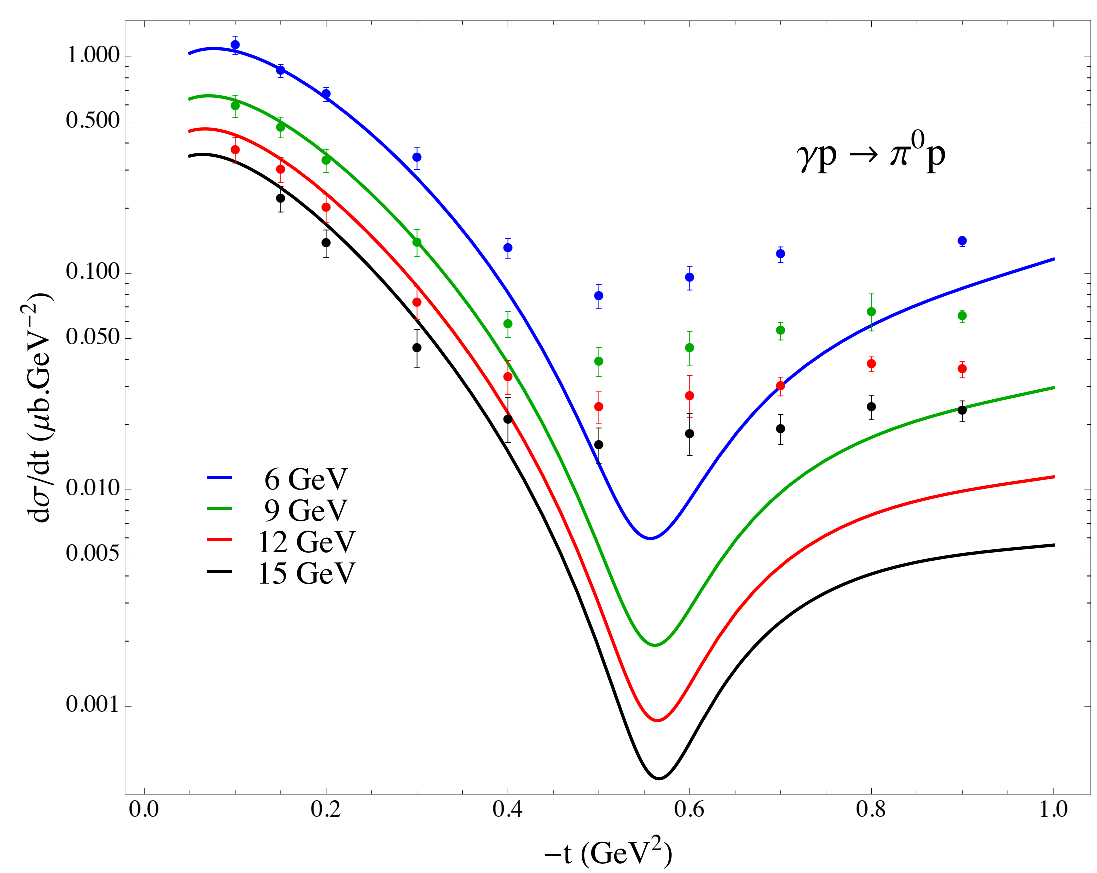


input input

$$\int_0^{\Lambda} \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu = \beta_i(t)\frac{\Lambda^{\alpha_i(t)+k}}{\alpha_i(t)+k+1}$$





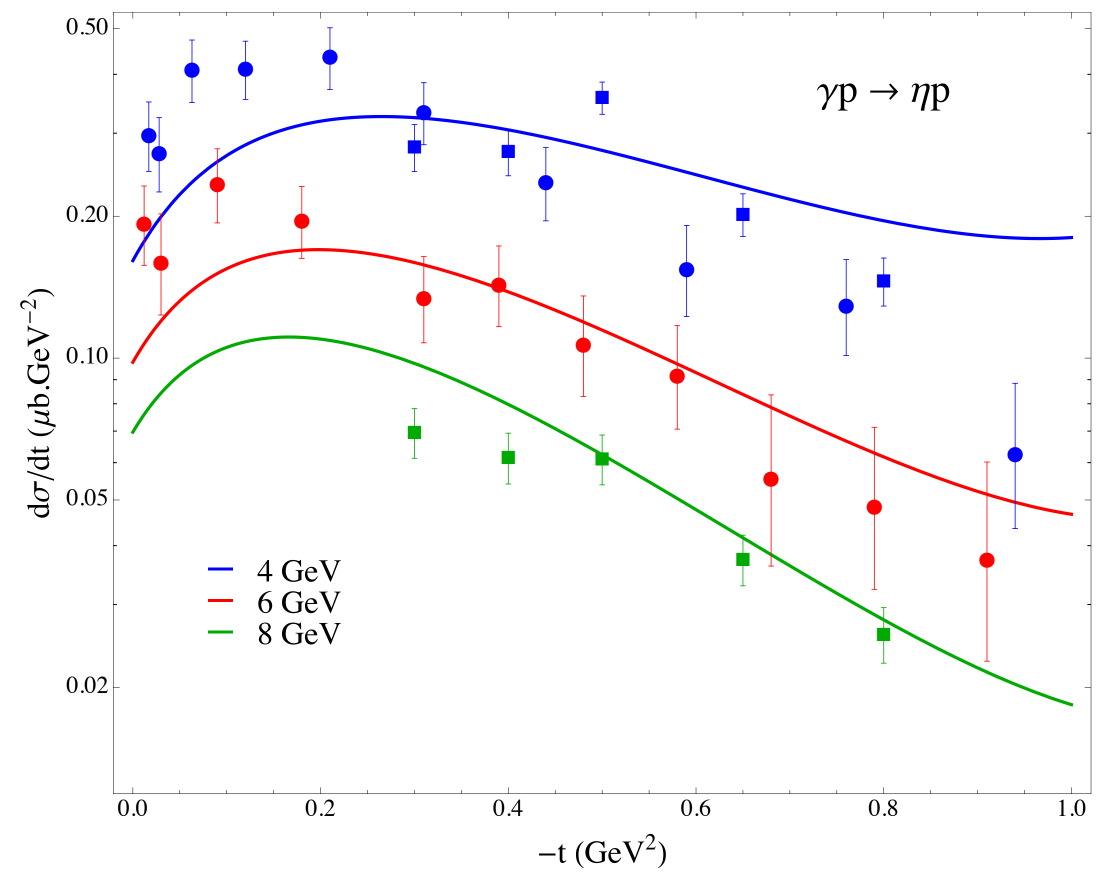


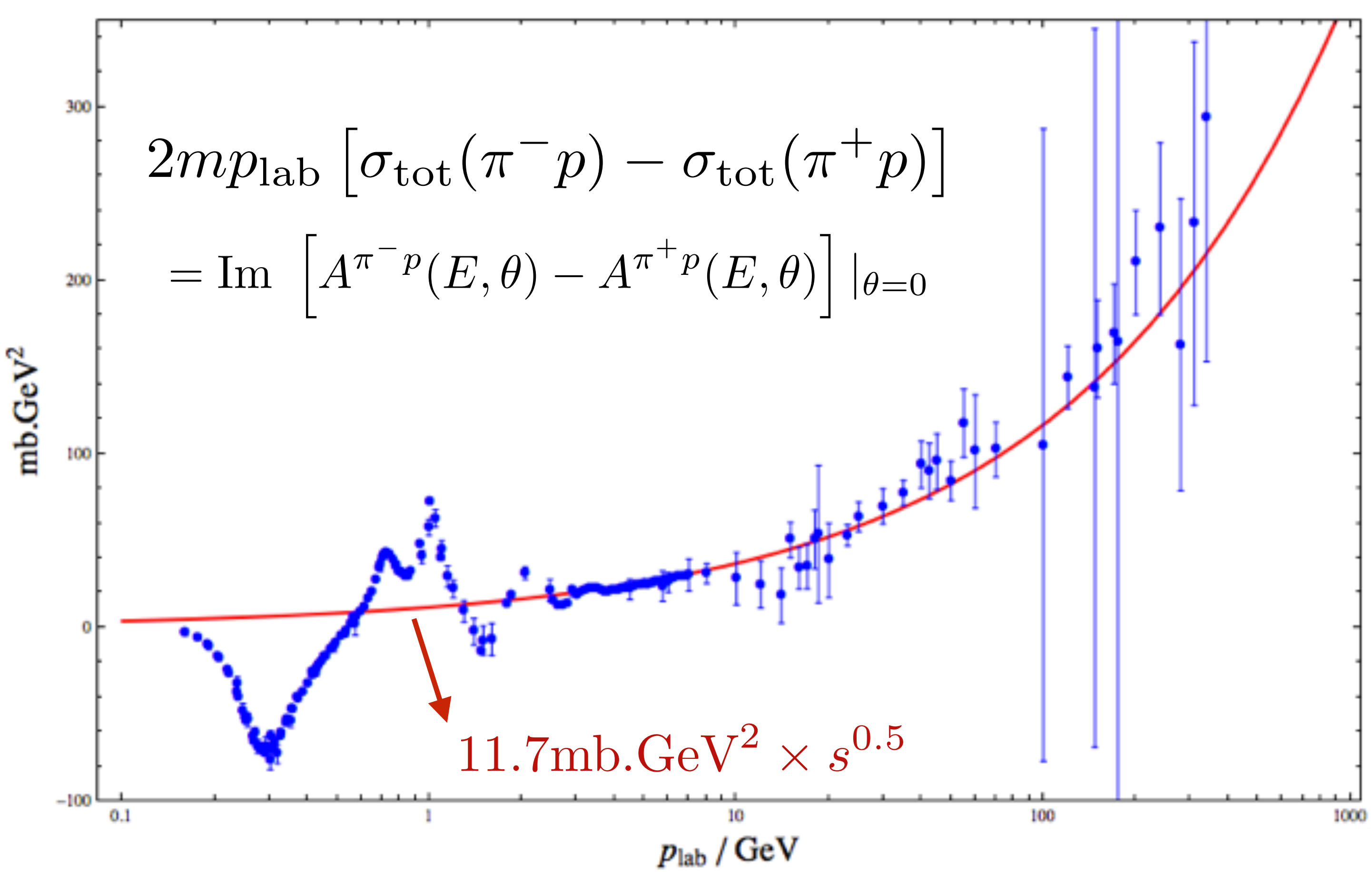
input input

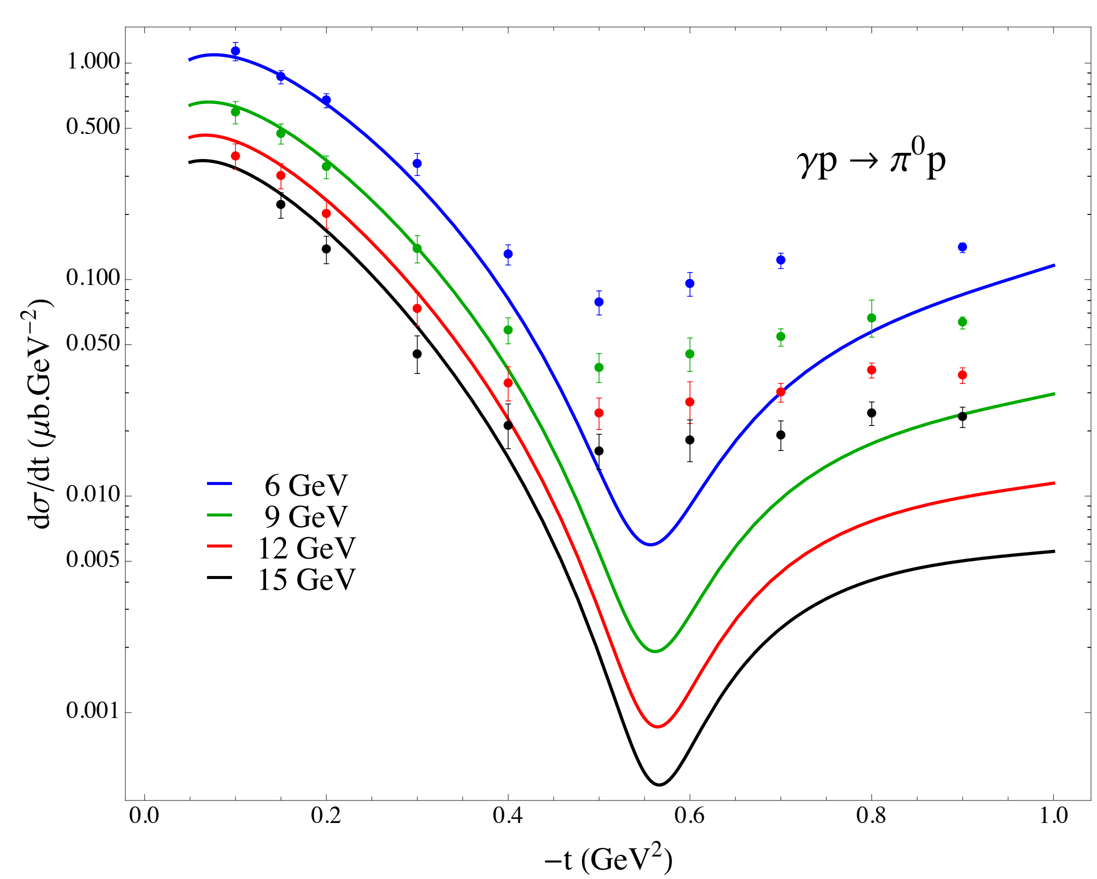
$$\int_0^\Lambda \mathrm{Im}\ A_i(\nu,t)\nu^k d\nu = \beta_i(t)\frac{\Lambda^{\alpha_i(t)+k}}{\alpha_i(t)+k+1}$$

Use high energy data to constraint low energy models

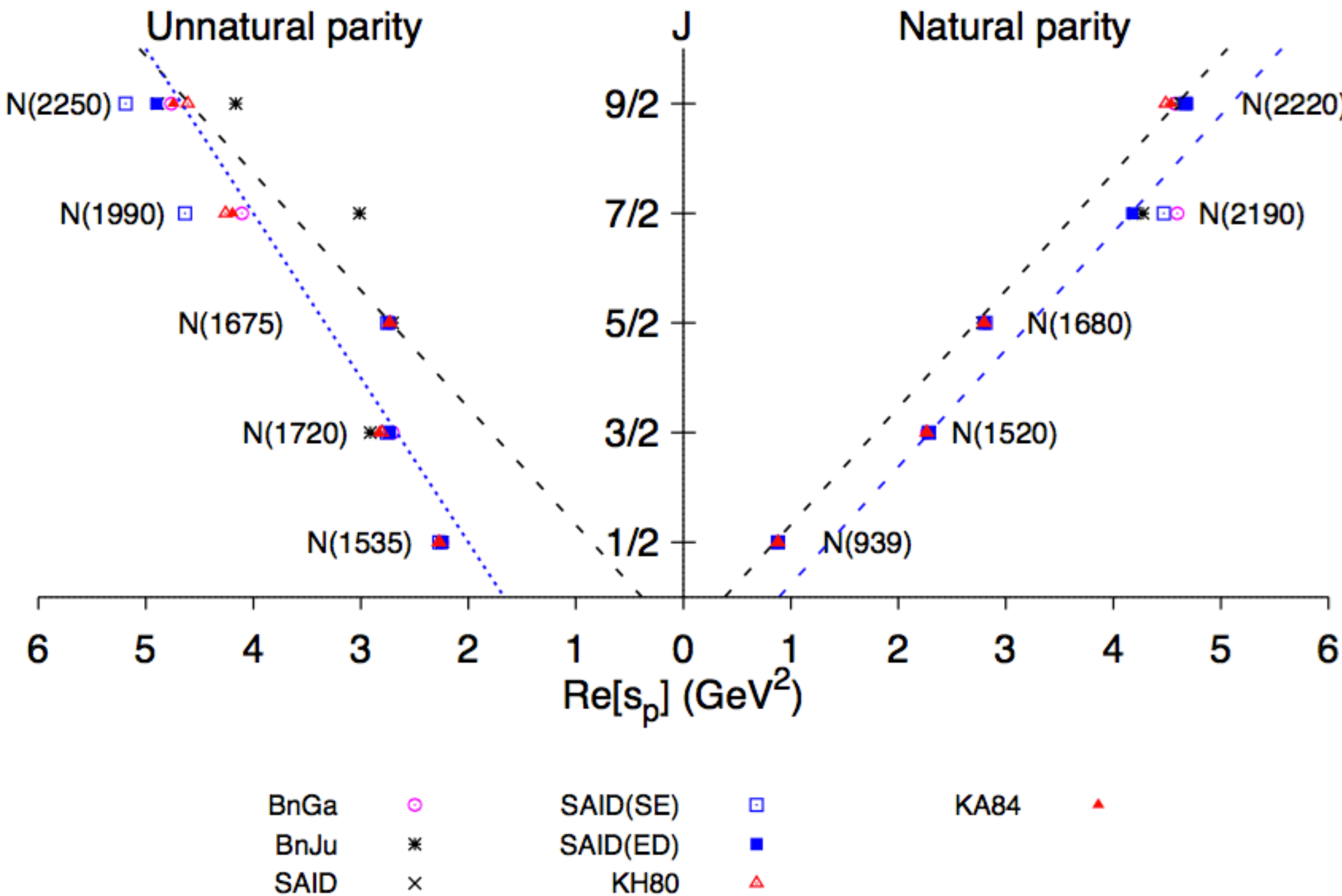
FESR as a penalty in the fit







Regge Trajectories



C. Fernàndez-Ramìrez et al (JPAC) in preparation

INDIANA UNIVERSITY BLOOMINGTON

Jefferson Lab
Thomas Jefferson National Accelerator Facility

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

Joint Physics Analysis Center

HOME PROJECTS PUBLICATIONS LINKS

U.S. DEPARTMENT OF ENERGY

National Science Foundation

JPAC acknowledges support from DOE and NSF

INDIANA UNIVERSITY

Interactive webpage: http://www.indiana.edu/~jpac/index.html

Indiana University

- **Adam Szczepaniak** Professor
- **Geoffrey Fox** Professor
- **Emilie Passemar** Professor
- **Tim Londergan** Professor
- **Vincent Mathieu** Postdoctoral researcher
- **Ina Lorenz** Postdoctoral researcher
- **Andrew Jackura** PhD student

Jefferson Lab

- **Michael R. Pennington** Professor
- **Viktor Mokeev** Professor
- **Vladiszlav Pauk** Postdoctoral researcher
- **Alessandro Pilloni** Postdoctoral researcher

George Washington University

- **Ron Workman** Professor
- **Michael Doring** Professor

Universidad Nacional Autonoma de Mexico

- **Cesar Fernandez-Ramirez** Professor

Johannes Gutenberg University, Mainz

- **Igor Danilkin** Postdoctoral researcher

Bonn University

- **Misha Mikhasenko** PhD student

University of Valencia

- **Astrid Hiller Blin** PhD student

Ghent University

- **Jannes Nys** PhD student

INDIANA UNIVERSITY BLOOMINGTON

Jefferson Lab

Thomas Jefferson National Accelerator Facility

THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

Joint Physics Analysis Center

HOME PROJECTS PUBLICATIONS LINKS

U.S. DEPARTMENT OF ENERGY

National Science Foundation

JPAC acknowledges support from DOE and NSF

INDIANA UNIVERSITY

Interactive webpage: http://www.indiana.edu/~jpac/index.html

Photoproduction:

1. High energy model for η' beam asymmetry photoproduction: $\gamma p \to \eta^{(\prime)} p$ page
2. High energy model for η photoproduction: $\gamma p \to \eta p$ page
3. High energy model for π^0 photoproduction: $\gamma p \to \pi^0 p$ page
4. High energy model for J/ψ photoproduction: $\gamma p \to J/\psi p$ page

Hadroproduction:

1. Pion-nucleon scattering:
   - Amplitudes $\pi N \to \pi N$ amplitude page
   - Finite energy sum rules $\pi N \to \pi N$ FESR page
2. Kaon-nucleon scattering: $\bar{K}N \to \bar{K}N$ page

Light meson Decay:

1. η meson into three pions: $\eta \to 3\pi$ page
2. vector meson into three pions: $\omega, \phi \to 3\pi$ page

INDIANA UNIVERSITY

Interactive webpage: http://www.indiana.edu/~jpac/index.html

Resources

- **Publication:** [Nys16]
- **C/C++ observables:** C-code main, Input file, C-code source, C-code header, Eta-MAID 2001 multipoles
- **C/C++ minimal script to calculate the amplitudes:** C-code zip
- **Data:** Dewire , Braunschweig
- **Contact person:** Jannes Nys
- **Last update:** November 2016

$$\gamma p \to \eta p$$

Run the code

E_γ in GeV 9

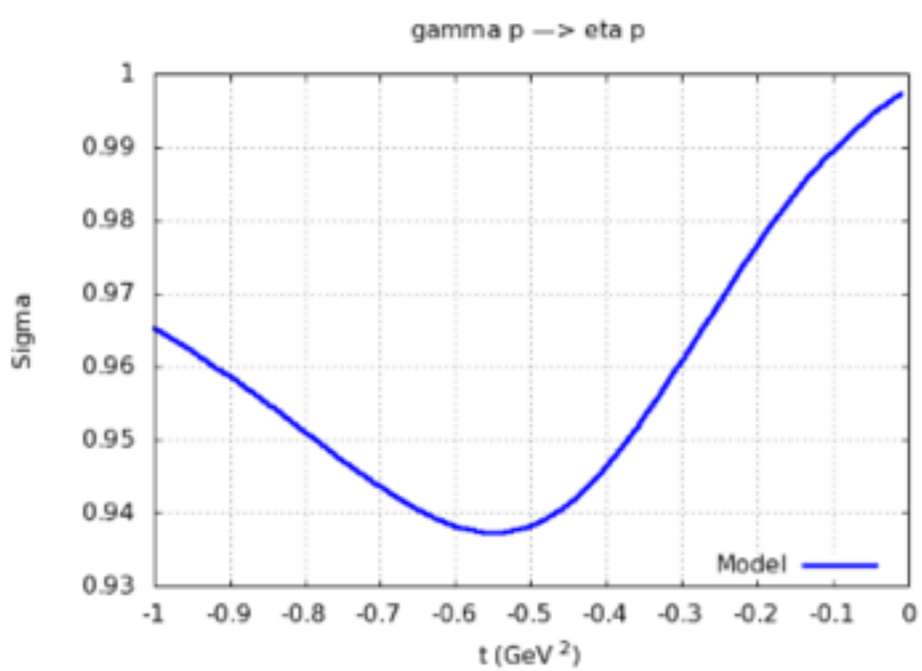
t cos

t in GeV^2 (min max step) -1 0 0.01

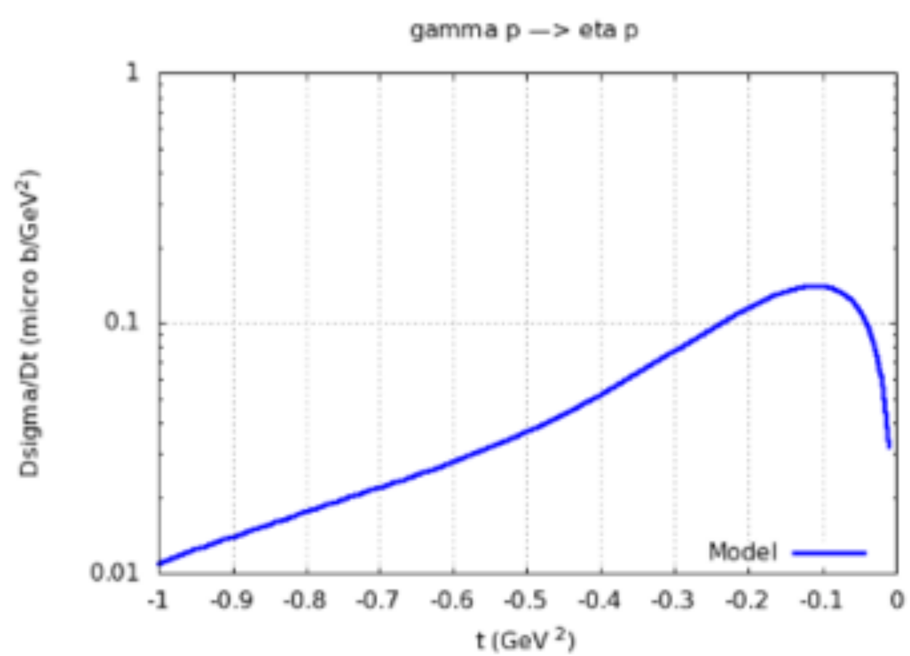
$\cos\theta$ (min max step) 0.85 1 0.01

Start reset

Observable: photon beam asymmetry
Download the the plot with Ox=t , the plot with Ox=cos .



Observable: differential cross section
Download the the plot with Ox=t , the plot with Ox=cos .



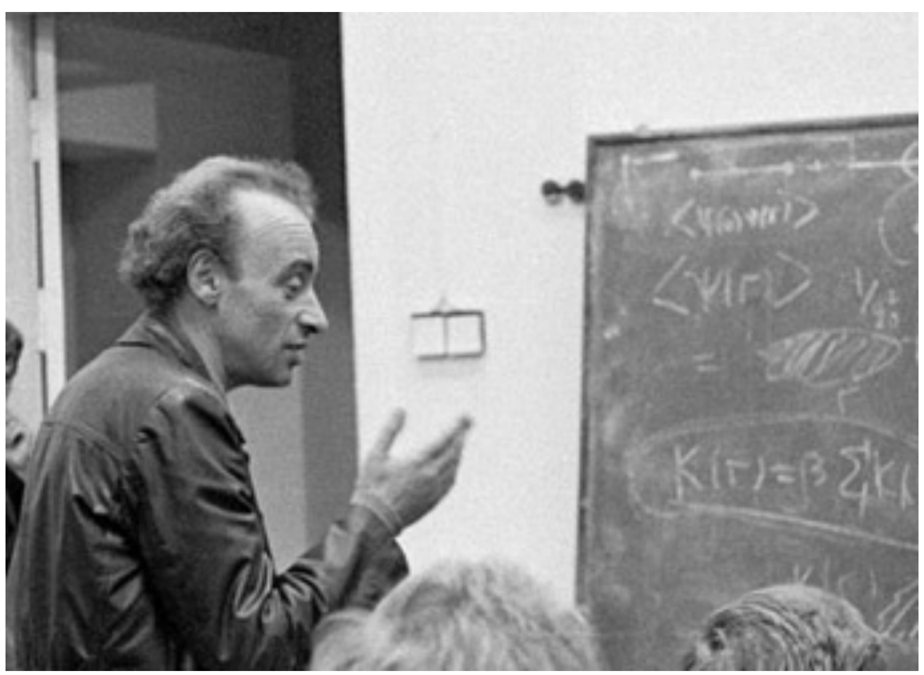
http://www.indiana.edu/~ssrt/

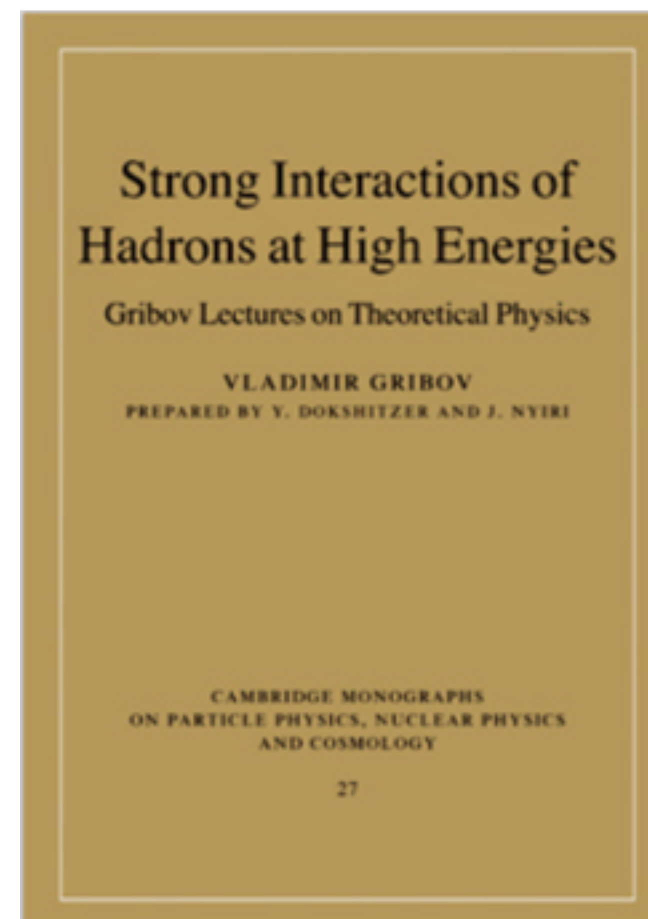
INDIANA UNIVERSITY

2017 International Summer Workshop on Reaction Theory

June 12-22, 2017, Bloomington, Indiana, USA

HOME LECTURERS PROGRAM REGISTRATION VENUE ACCOMMODATION VISA INFORMATION TRANSPORTATION LOCAL INFORMATION PARTICIPANTS RESOURCES CONTACT





Lectures will be live-streamed and recorded