Study of the ηN scattering amplitude through the associated photoproduction of φ- and η-mesons in the region of the N(1535) resonance*

Matthias Lutz and Madeleine Soyeur

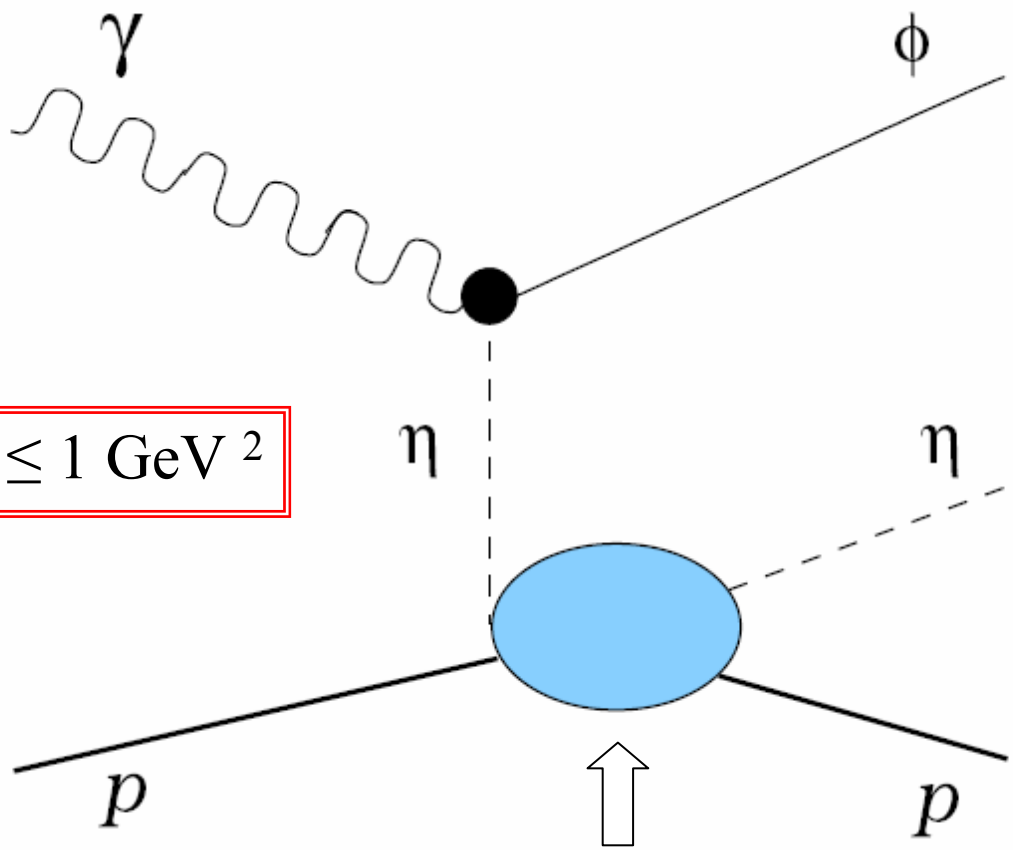
Nucl. Phys. A (2006) in press
nucl-th/0511055

CEA/Saclay
DAPNIA

General idea

$E_\gamma^{Lab} \approx$ 4-5 GeV

$|t| \leq 1$ GeV ^{2}



S11(1535)

CEA/Saclay

DAPNIA

The N(1535) resonance*

Quantum numbers: $I=1/2,\ J^{\pi} = 1/2^{-}$
S11 (πN)

Total width: (150 ± 25) MeV

Main hadronic decay modes:

$N\pi$	35 - 55 %
$N\eta$	30 - 55 %
$N\pi\pi$	1 - 10 %

CEA/Saclay
DAPNIA

Contents

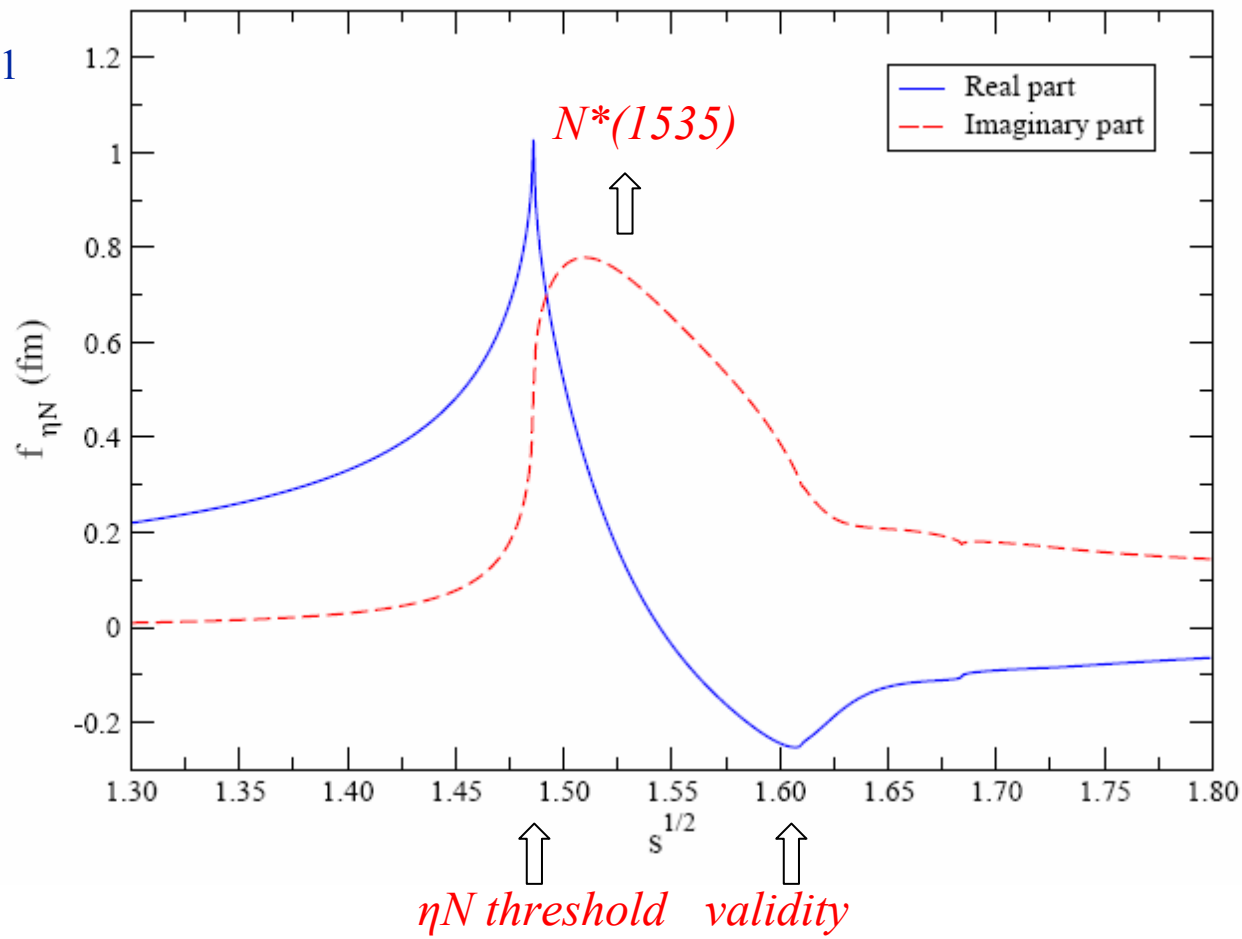
1. The η N scattering amplitude and scattering length
2. Some properties of φ-meson photoproduction
3. t-channel model of the $\gamma p \rightarrow \varphi \eta p$ reaction in the N*(1535) region
4. Numerical results
5. Concluding remarks

CEA/Saclay
DAPNIA

1. The η N scattering amplitude and scattering length (s-wave)

M.F.M. Lutz et al.,
NPA 706 (2002) 431

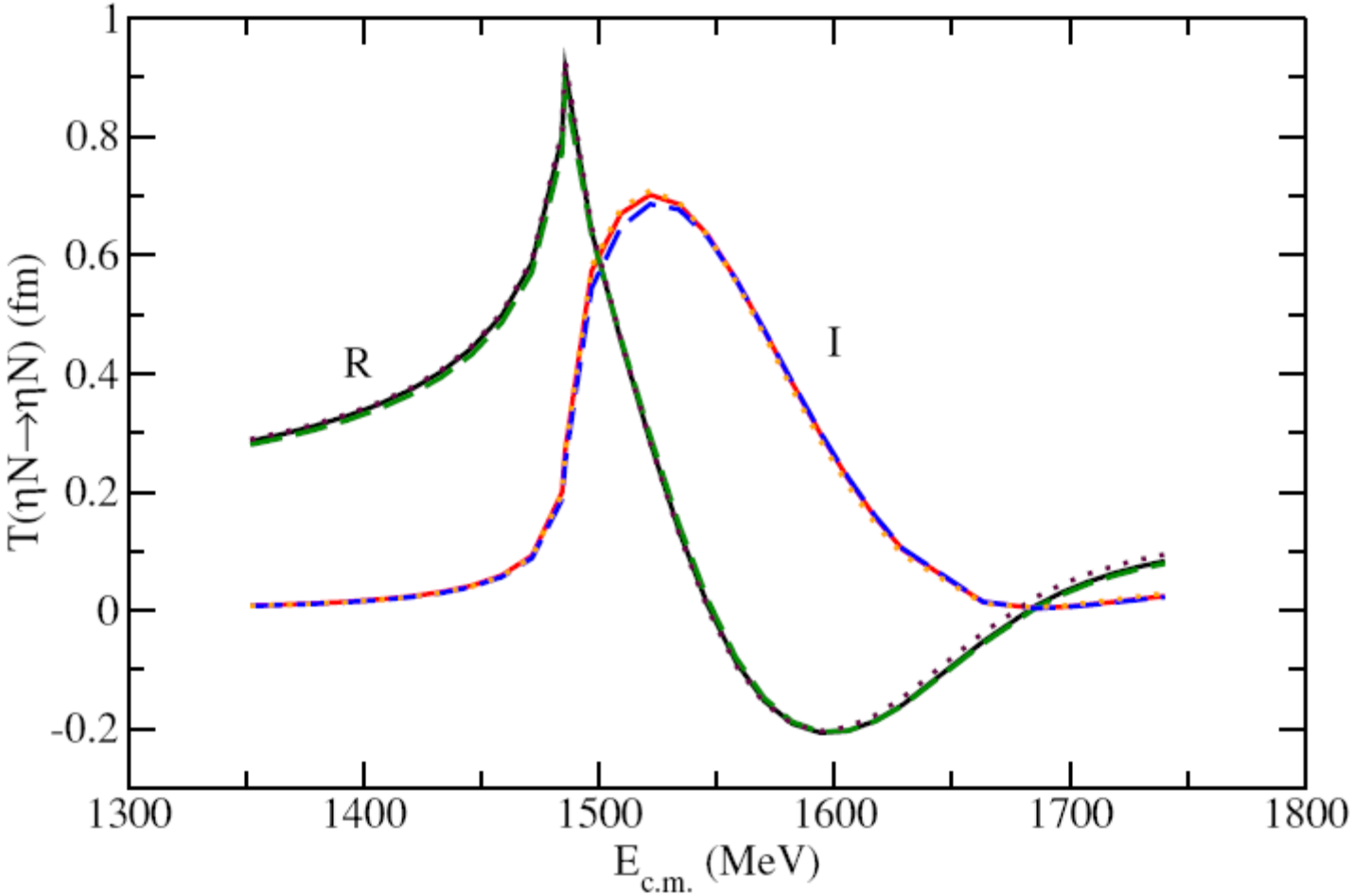
Re $a_{\eta N}$ = 1.03 fm
Im $a_{\eta N}$ = 0.49 fm



CEA/Saclay
DAPNIA

A.M. Green, S. Wycech,
PRC 71 (2005) 014001

K-matrix coupled-channel calculation



CEA/Saclay
DAPNIA

Scattering length:

→ *Quantity strongly linked to the description of the N*(1535) resonance located very close (49 MeV) to threshold*
+ background contribution to the amplitude

No direct measurement from ηN scattering

→ *Indirect determination from η-meson production reactions such as $\pi N \rightarrow \eta N$, $\gamma N \rightarrow \eta N$, $pn \rightarrow \eta d$, $pd \rightarrow \eta\, {}^3He$*

We suggest a new process $\gamma\, p \rightarrow \Phi\, \eta\, p$, dominated by the $\eta N \rightarrow \eta N$ amplitude.

CEA/Saclay
DAPNIA

Dynamics of η-nucleon physics at threshold

- *Coupled-channel dynamics very important*

  ηN couples strongly to $\pi N \rightarrow$ consistent description of $\pi N \rightarrow \pi N$, $\pi N \rightarrow \eta N$, $\gamma N \rightarrow \pi N$, $\gamma N \rightarrow \eta N$, etc ...

- *Re $a_{\eta N} > 0 \rightarrow$ attractive ηN interaction suggesting the possibility of η-nucleus bound states*

  But remember the narrow structure at threshold!
  $\rightarrow$ beware of binding and many-body effects leading to the subtreshold regime

2. Some properties of φ-meson photoproduction

Recent studies of the $\gamma p \rightarrow \varphi p$ reaction at E_γ^{Lab} of a few GeV

- *Data at low $|t|$ (<1 GeV^2)* Forward peak

$E_\gamma^{Lab} \leq$ 2.4 GeV	J. Barth et al., EPJ A 17 (2003) 269	
$E_\gamma^{Lab} =$ 3.5 GeV	K. McCormick et al., PRC 69 (2004) 032203	S10-11
$E_\gamma^{Lab} \leq$ 2.37 GeV	T. Mibe et al., PRL 95 (2005) 182001	

- *Theoretical understanding*

t-channel processes dominate the production dynamics

Meson-exchanges: π, η, scalar mesons

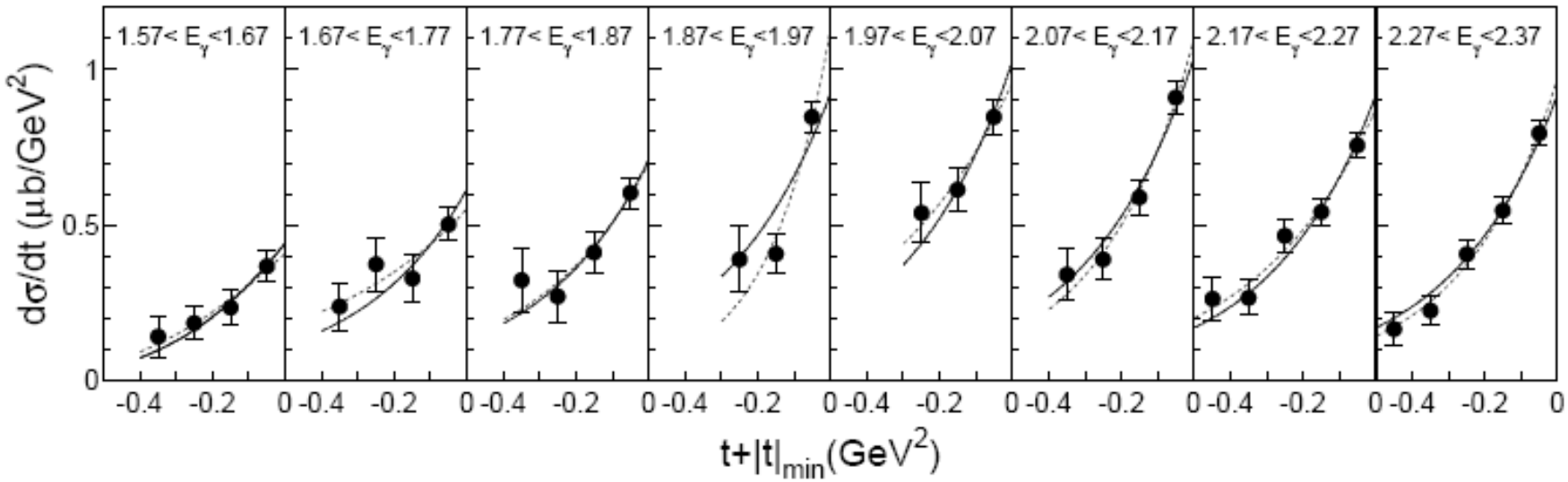
Pomeron-exchange, ….

A.I. Titov and T.-S.H. Lee, PRC 67 (2003) 065205

Large uncertainties (vertices, couplings, …)

CEA/Saclay

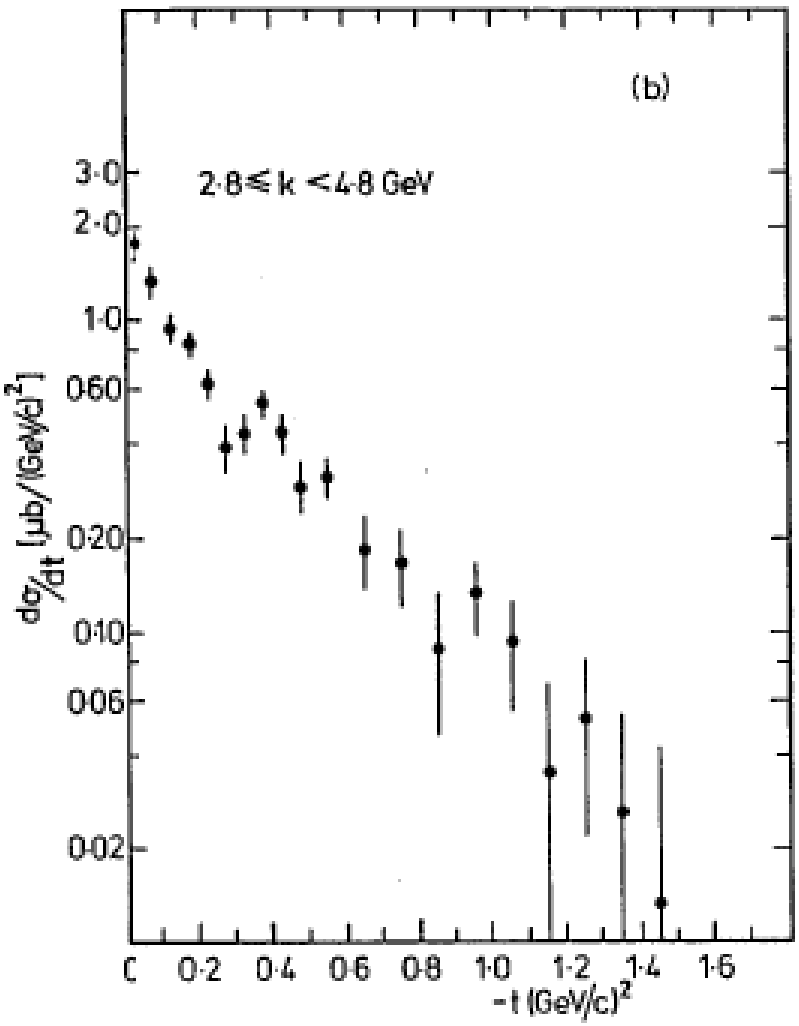
DAPNIA



T. Mibe et al., PRL 95 (2005) 182001

$\gamma p \rightarrow \varphi p$
$E_\gamma^{Lab} \approx 4$ GeV

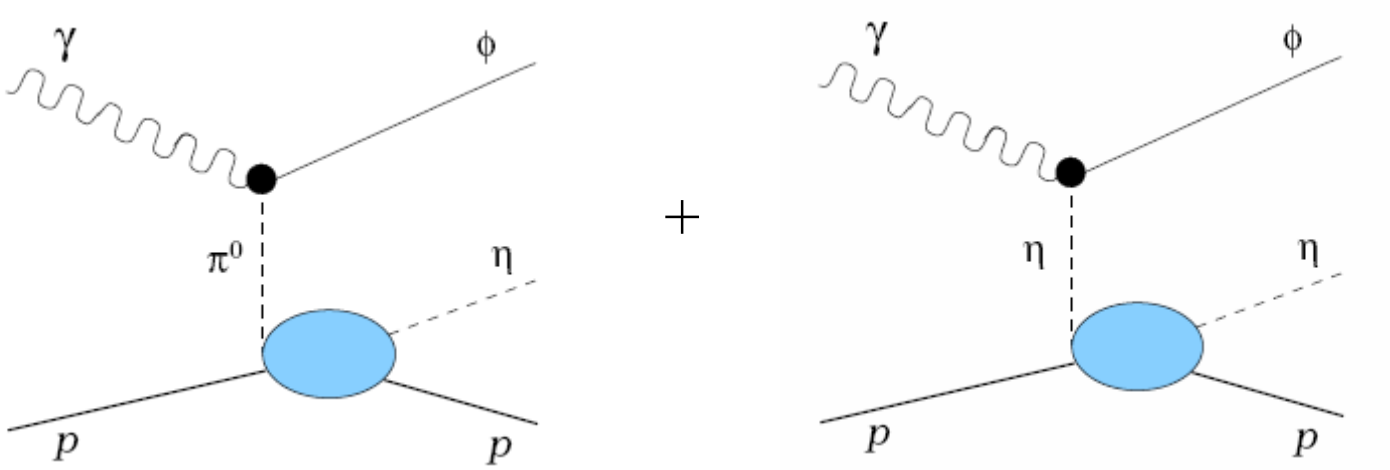
D.P. Barber et al.,
Z. Phys. C 12 (1981) 1



CEA/Saclay
DAPNIA

3. t-channel model of the $\gamma p \rightarrow \varphi \eta p$ reaction in the N*(1535) region

3.1. Diagrams: exchange of pseudoscalar mesons



$|t| \leq 1$ GeV ^{2}

Dynamical inputs: $\gamma\varphi\pi$ and $\gamma\varphi\eta$ vertices

$\pi^0 p \rightarrow \eta p$ and $\eta p \rightarrow \eta p$ amplitudes

CEA/Saclay

DAPNIA

3.2. γφπ and γφη vertices

Anomalous interaction Lagrangian

$$\mathcal{L}^{int}_{\phi\chi\gamma} = e\,\frac{g_{\phi\chi\gamma}}{2m_\phi}\,\varepsilon^{\mu\nu\alpha\beta}\,\phi_\mu\,(\partial_\nu\chi)\,F_{\alpha\beta}$$

$$F_{\alpha\beta} = \partial_\alpha A_\beta - \partial_\beta A_\alpha$$

χ : pseudoscalar field (π, η)

$$\Gamma_{\phi\pi^0\gamma} = (5.24 \pm 0.49)\,keV$$

$$\Gamma_{\phi\eta\gamma} = (55.17 \pm 1.71)\,keV$$

$$|g_{\phi\pi\gamma}| \simeq 0.13$$

$$|g_{\phi\eta\gamma}| \simeq 0.70$$

- *π-exchange contribution to the cross section suppressed by a factor of 29*
- *Sign of the πη interference unknown*

CEA/Saclay

DAPNIA

3.3. $\pi p \rightarrow \eta p$ and $\eta p \rightarrow \eta p$ amplitudes

M. Lutz, Gy. Wolf, B. Friman, Nucl. Phys. A 706 (2002) 431

Selfconsistent and relativistic coupled-channel study of the πN and γN reactions involving the γN, πN, ηN, ρN, ωN, $\pi\Delta$, $K\Lambda$, $K\Sigma$ channels

Kinematics: $1.40 < s^{1/2} < 1.75$ GeV

Only relative s-wave in the vector meson-nucleon final state (also in the ηN channel)

Only relative s- and d-waves in the πN channel (S11, S31, D13, D33 baryon resonances)

CEA/Saclay

DAPNIA

Dynamics: Effective meson-meson-baryon-baryon Lagrangian

Assumptions:

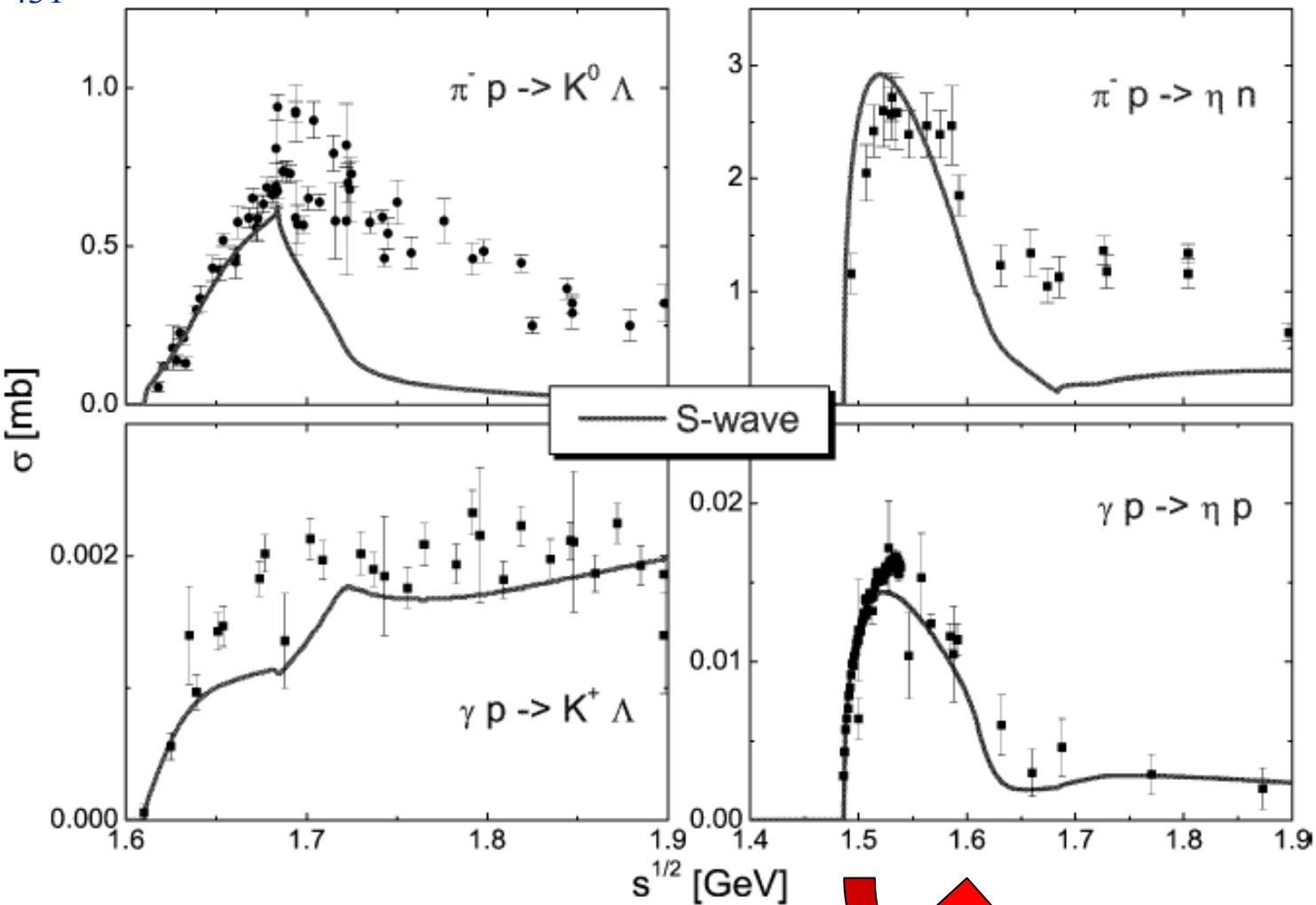
Fundamental fields: photon, mesons, nucleon, Δ(1232)
Baryon resonances (S11, S31, D13, D33):
generated dynamically through Bethe-Salpeter equation
Vector Dominance Assumption (generalized)
to relate amplitudes involving (real) photons to amplitudes involving vector mesons

Fitting procedure: Use all available data (phase shifts, inelasticity parameters, pion-photoproduction multipole amplitudes, inelastic cross sections) to fit the effective Lagrangian parameters (56)

=> Satisfactory fit to the data in the interval $1.40 < s^{1/2} < 1.75$ GeV (or less when higher partial waves matter)

CEA/Saclay
DAPNIA

M.F.M. Lutz et al.,
NPA 706 (2002) 431

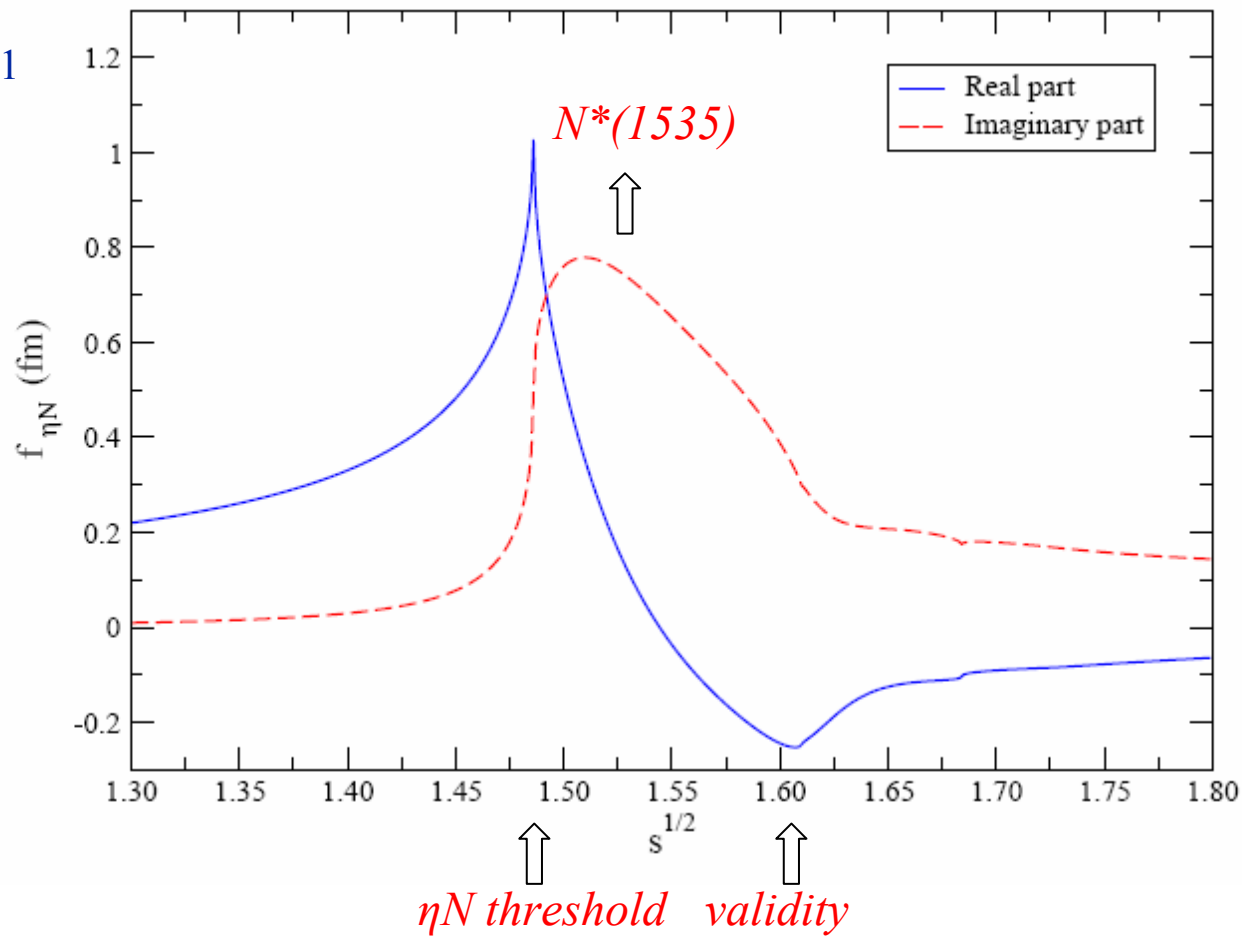


CEA/Saclay
DAPNIA

ηp→ ηp amplitude (s-wave)

M.F.M. Lutz et al.,
NPA 706 (2002) 431

Re $a_{\eta N}$ = 1.03 fm
Im $a_{\eta N}$ = 0.49 fm

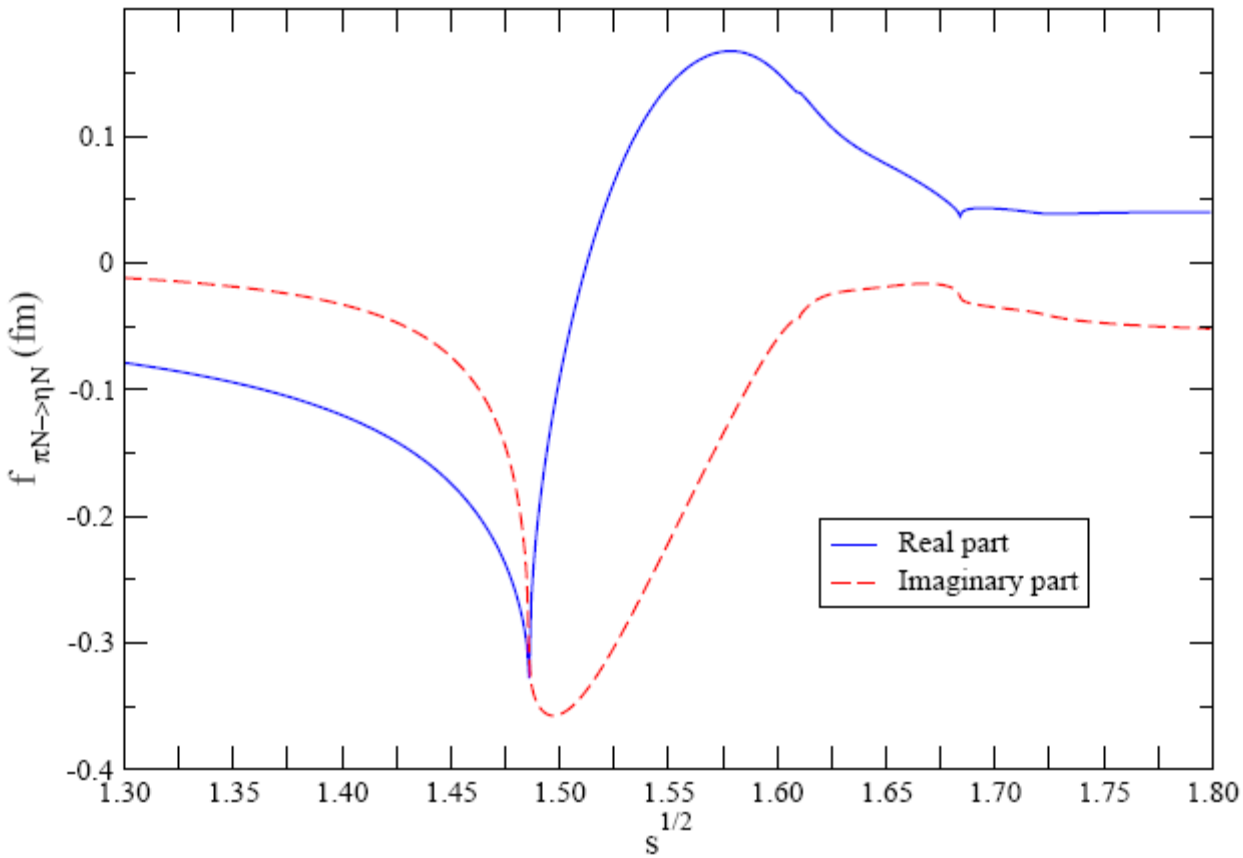


CEA/Saclay
DAPNIA

πp→ ηp amplitude (s-wave)

M.F.M. Lutz et al.,
NPA 706 (2002) 431

πp→ ηp amplitude significantly smaller than the ηp→ ηp amplitude in the threshold region



CEA/Saclay
DAPNIA

3.4. Kinematics

Initial photon energy:

linked to the momentum transfer range

$E_\gamma^{Lab} = 3$ GeV (threshold) $\rightarrow$ $|t_{min}| = 1.2$ GeV^2

$E_\gamma^{Lab} = 4$ GeV $\rightarrow$ $|t_{min}| = 0.38$ GeV^2

$E_\gamma^{Lab} = 5$ GeV $\rightarrow$ $|t_{min}| = 0.26$ GeV^2

$4 < E_\gamma^{Lab} < 5$ GeV to reach sufficiently low momentum transfers for meson-exchange pictures to be valid

CEA/Saclay
DAPNIA

Structure of the π-exchange, η-exchange and πη interference contributions to the cross section for the γp→φηp reaction

$$\sum_{\lambda_\gamma,\lambda,\bar{\lambda}_\phi,\bar{\lambda}} \frac{1}{4} \mid M^{\pi-exchange}_{\gamma\, p\to\phi\,\eta\, p} \mid^2 = \frac{e^2\, g^2_{\phi\pi\gamma}}{4\, m^2_\phi} \frac{(m^2_\phi - t)^2}{(t - m^2_\pi)^2} \frac{1}{2} \sum_{\lambda,\bar{\lambda}} |M_{\pi\, p\to\eta\, p}|^2,$$

$$\sum_{\lambda_\gamma,\lambda,\bar{\lambda}_\phi,\bar{\lambda}} \frac{1}{4} \mid M^{\eta-exchange}_{\gamma\, p\to\phi\,\eta\, p} \mid^2 = \frac{e^2\, g^2_{\phi\eta\gamma}}{4\, m^2_\phi} \frac{(m^2_\phi - t)^2}{(t - m^2_\eta)^2} \frac{1}{2} \sum_{\lambda,\bar{\lambda}} |M_{\eta\, p\to\eta\, p}|^2,$$

$$\sum_{\lambda_\gamma,\lambda,\bar{\lambda}_\phi,\bar{\lambda}} \frac{1}{4} \mid M^{interference}_{\gamma\, p\to\phi\,\eta\, p} \mid^2 = \frac{e^2\, g_{\phi\pi\gamma}\, g_{\phi\eta\gamma}}{4\, m^2_\phi} \frac{(m^2_\phi - t)^2}{(t - m^2_\pi)(t - m^2_\eta)}$$

$$\frac{1}{2} \sum_{\lambda,\bar{\lambda}} (M^+_{\pi\, p\to\eta\, p} M_{\eta\, p\to\eta\, p} \; + \; M^+_{\eta\, p\to\eta\, p} M_{\pi\, p\to\eta\, p}).$$

CEA/Saclay

DAPNIA

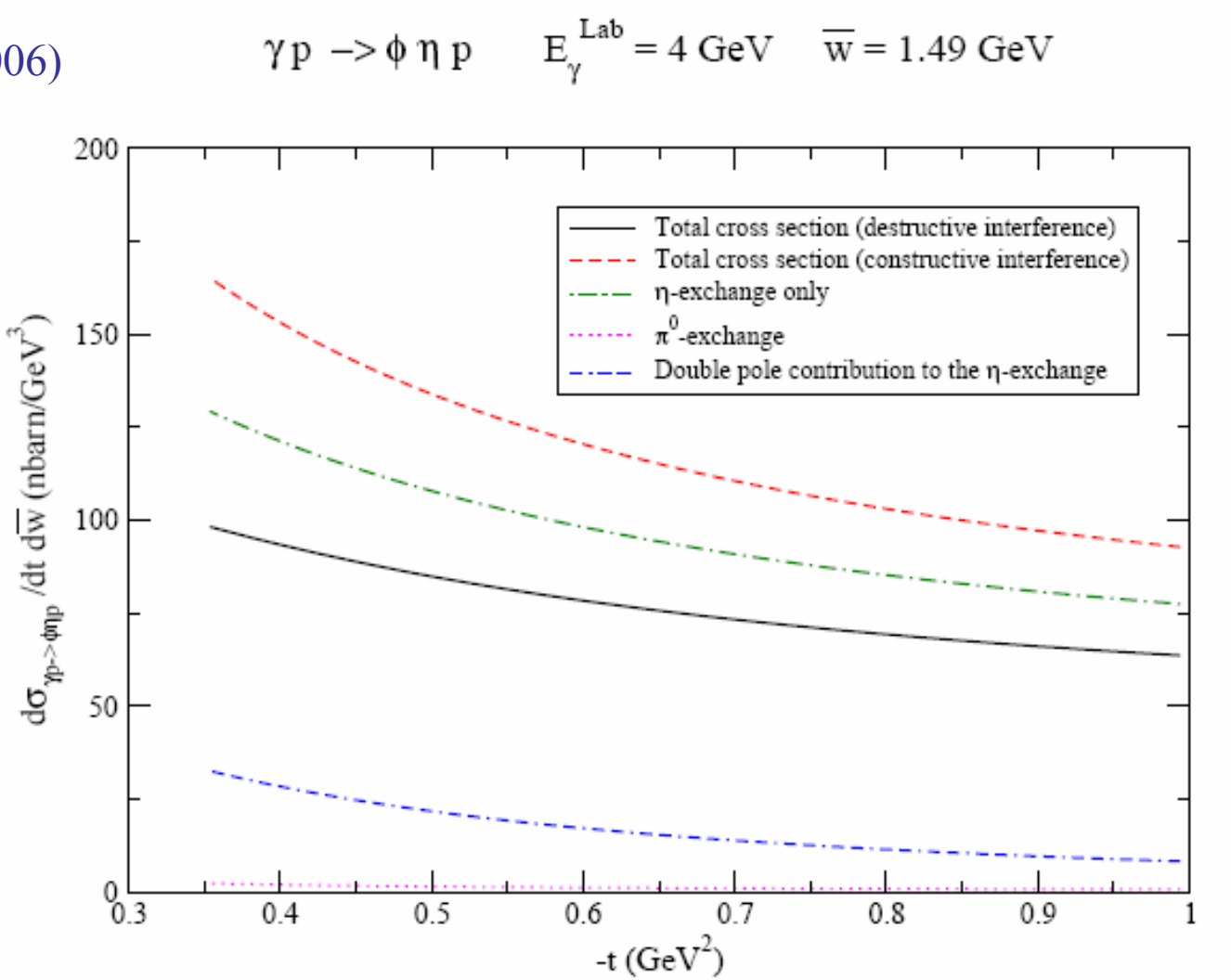
4. Numerical results

-Optimize the choice of the total ηN center of mass energy to be close to the 'spike' of the real part of the ηN →ηN amplitude

$$\overline{w} = 1.49 \text{ and } 1.54 \text{ GeV}$$
(Re + Im) (Im)

- Consider constructive and negative πη interferences
- No γπφ or γηφ form factor (dynamics?)
- No φN final state interaction (large relative momentum)

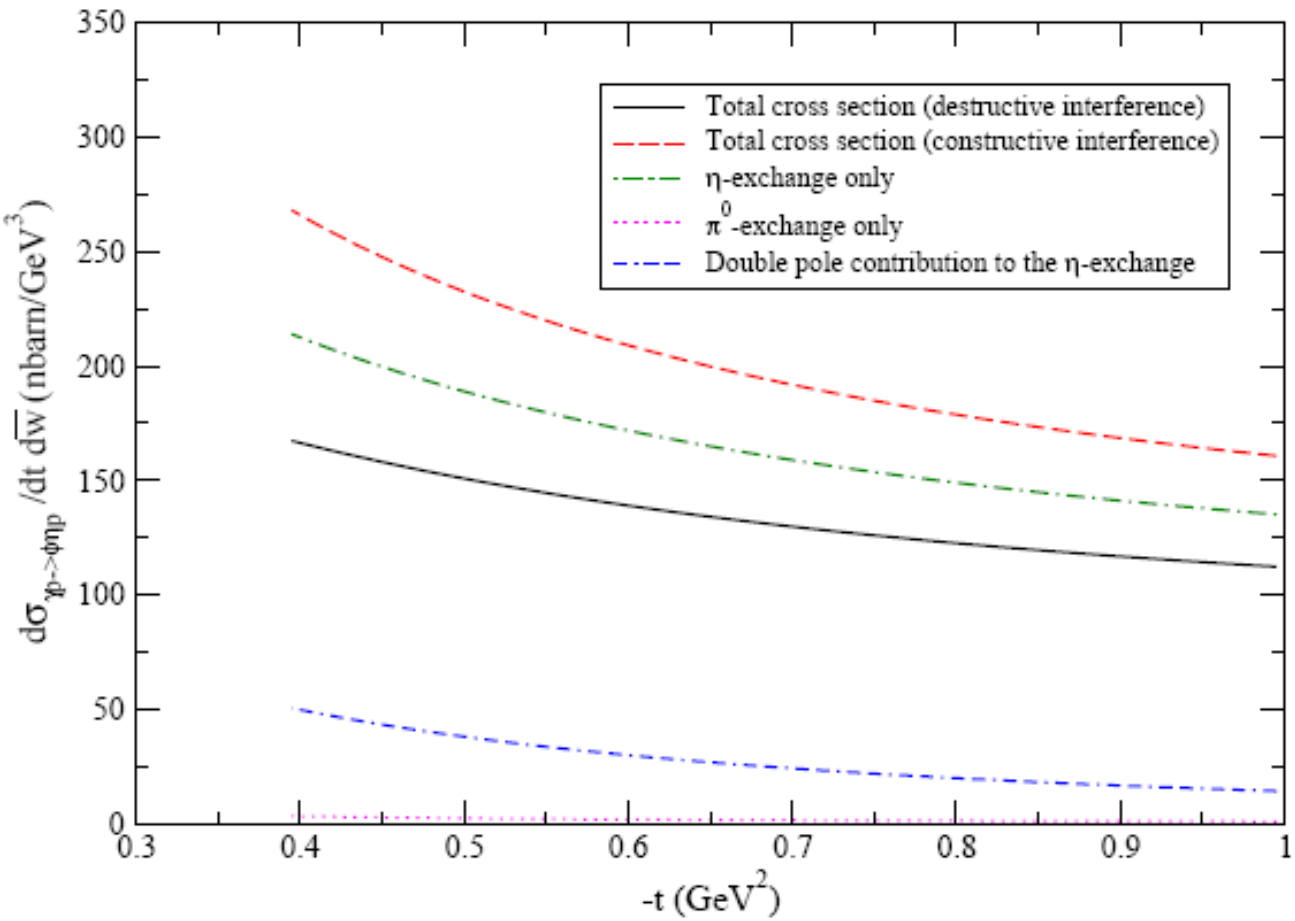
M.F.M. Lutz and M. S.,
nucl-th/0511055
Nucl. Phys. A (2006)



CEA/Saclay
DAPNIA

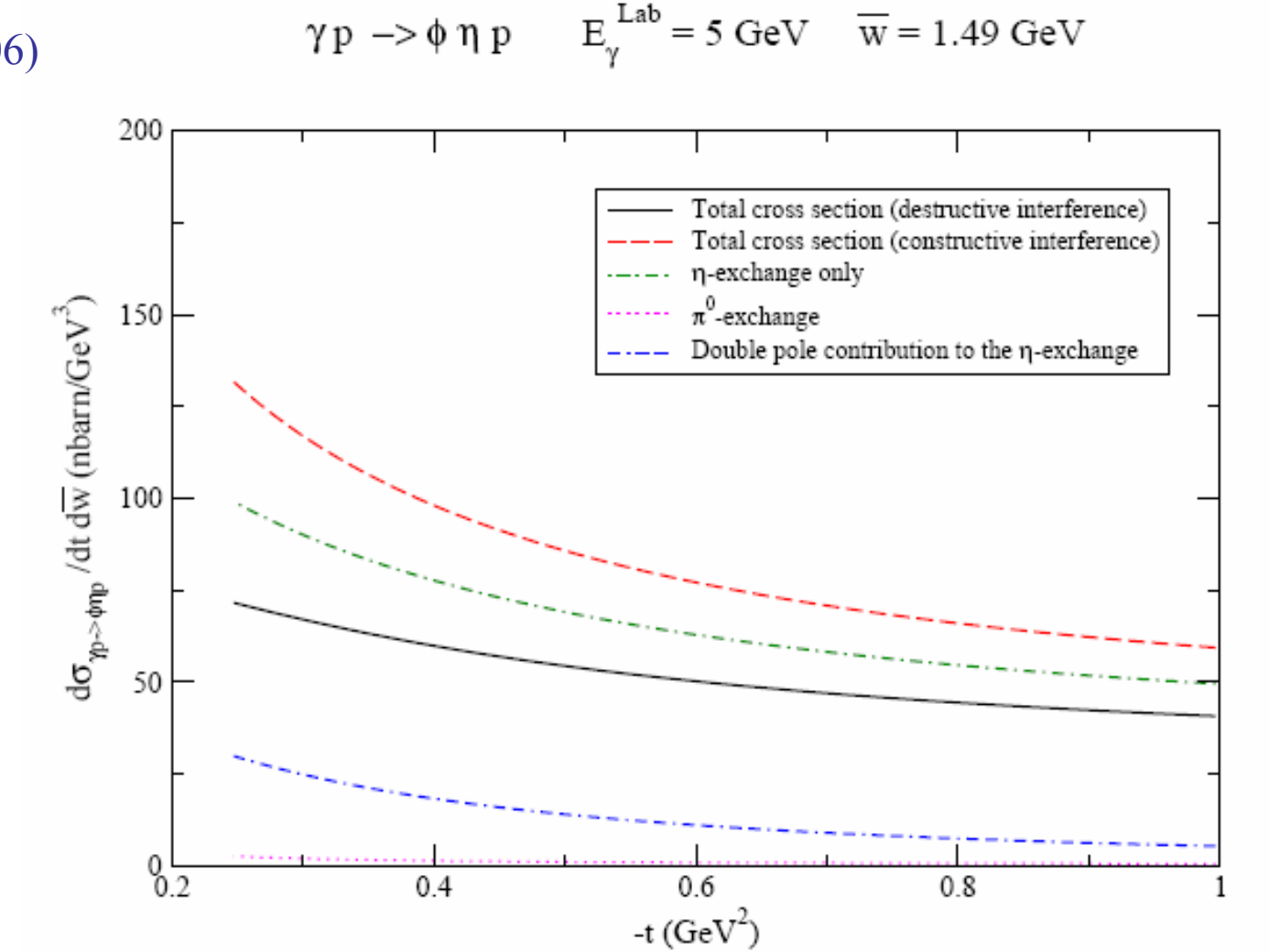
M.F.M. Lutz and M. S.,
nucl-th/0511055
Nucl. Phys. A (2006)

$\gamma p \to \phi \eta p \qquad E_\gamma^{Lab} = 4\ \text{GeV} \qquad \overline{w} = 1.54\ \text{GeV}$



CEA/Saclay
DAPNIA

M.F.M. Lutz and M. S.,
nucl-th/0511055
Nucl. Phys. A (2006)



CEA/Saclay
DAPNIA

5. Concluding remarks

- The $\gamma\, p \rightarrow \varphi\, \eta\, p$ reaction in the N*(1535) region is very sensitive to the $\eta p \rightarrow \eta p$ scattering amplitude in the threshold region.
- The actual magnitude of the $\gamma\, p \rightarrow \varphi\, \eta\, p$ cross section is strongly linked to the relative sign of the $\gamma\pi\varphi$ or $\gamma\eta\varphi$ coupling constants (interference between π- and η-exchanges).
- Accurate data at $E_\gamma^{Lab} \approx$ 4-5 GeV (JLab) involving t-distributions at different ηp invariant masses would clearly contribute to the understanding of the $\eta p \rightarrow \eta p$ scattering amplitude in the threshold region.