TENSOR RESONANCES IN $\eta\pi$ USING COMPASS DATA

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Joint Physics Analysis Center

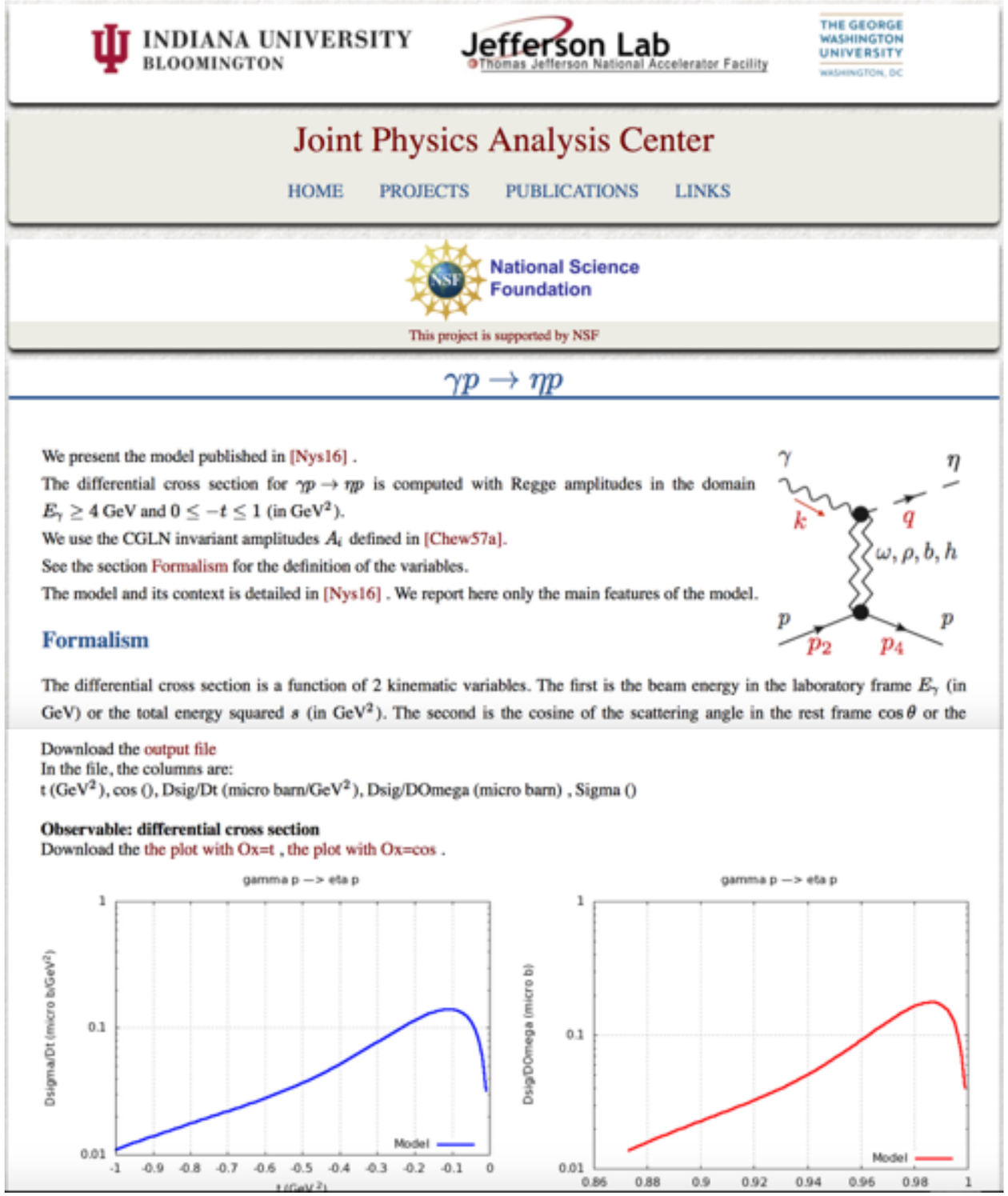
JPAC is a collaboration between theorists, phenomenologists, and experimentalists to provide phenomenological and data analysis tools for hadron physics

In 2015, JPAC began working with COMPASS to develop models satisfying S-matrix constraints for data analysis

$$\pi p \to \eta^{(\prime)} \pi p$$

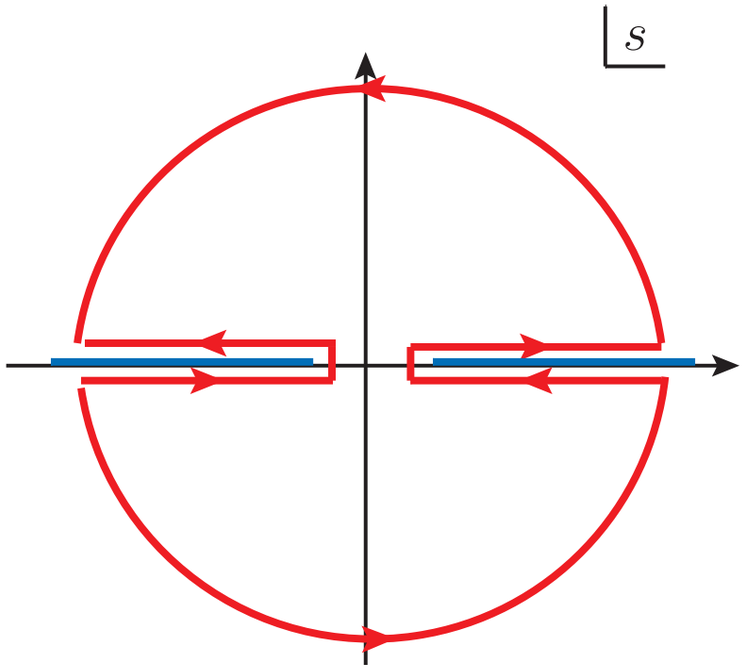
$$\pi p \to (3\pi) p$$

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



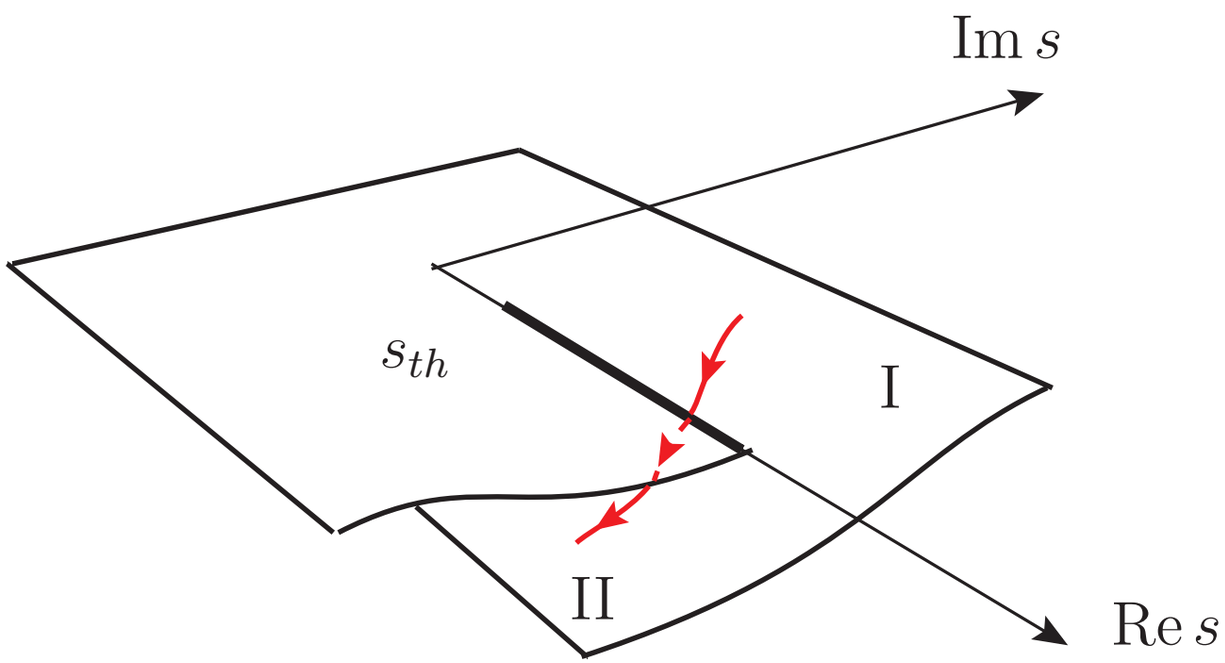
Reaction Theory

Use fundamental physics from relativistic reaction theory (unitarity, analyticity, etc.) to constrain hadronic reaction amplitudes



$$\mathcal{A}(s+i\epsilon,t)-\mathcal{A}(s-i\epsilon,t)\neq 0$$

$$\mathcal{A}(s)=\frac{1}{\pi}\int\frac{\mathrm{Im}\,\mathcal{A}(s')}{s'-s}$$



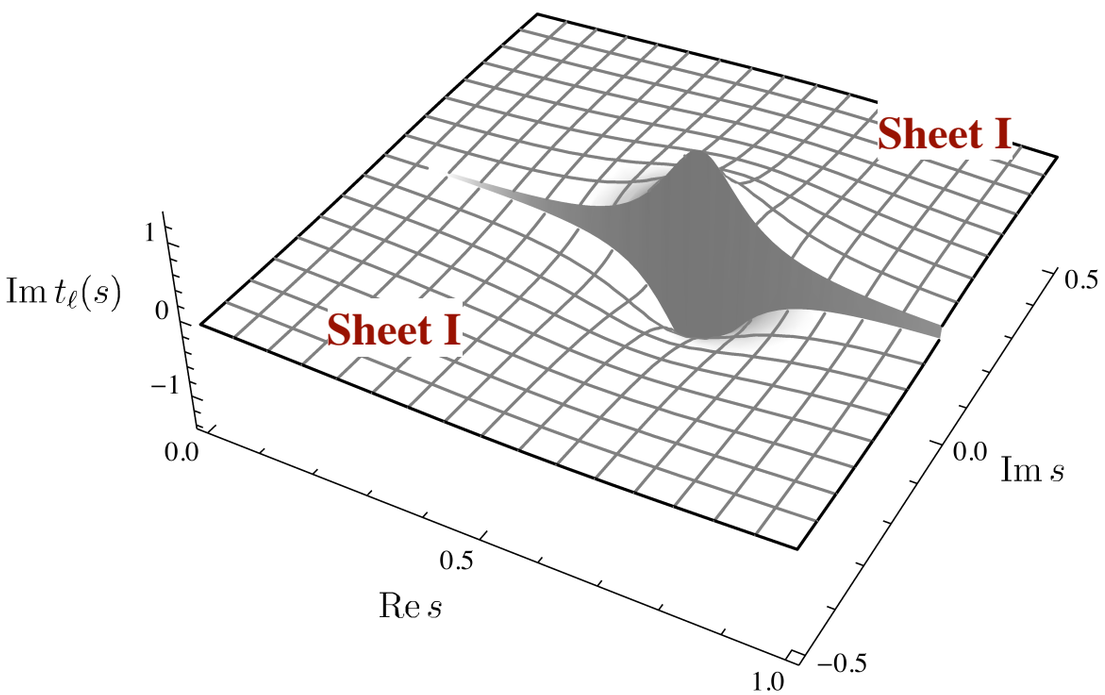
Amplitudes must satisfy these constraints, but the constraints do not fix the dynamics

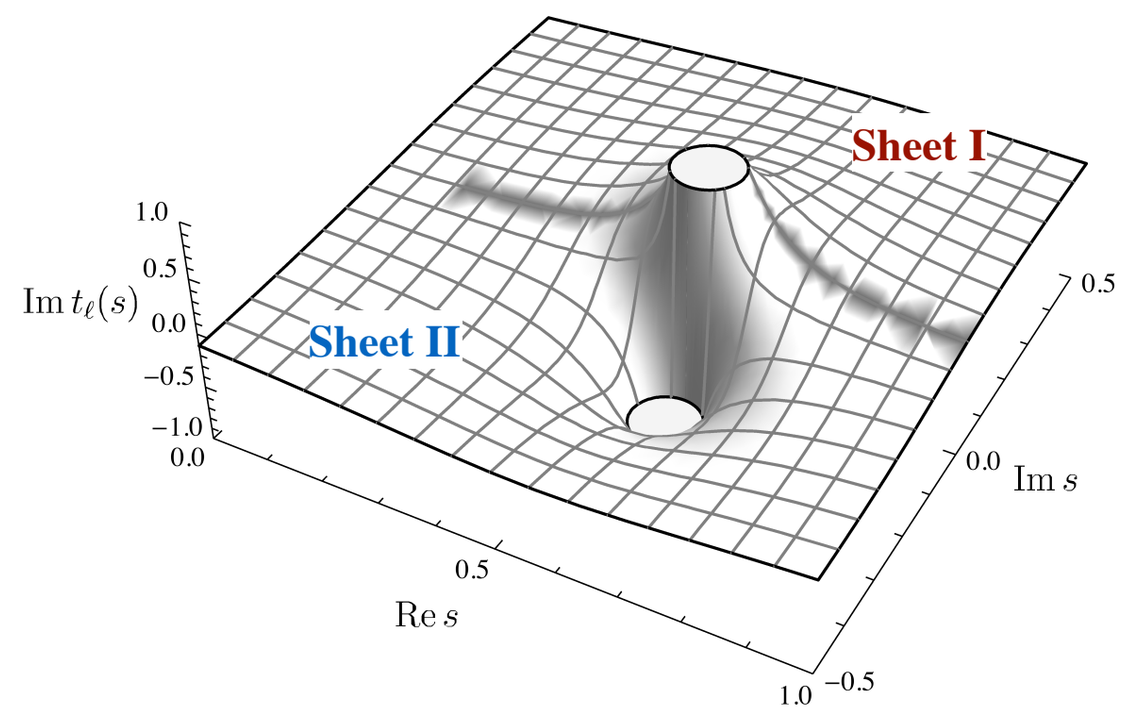
Reaction Theory

Causality implies amplitudes are analytic functions of kinematic variables (energy)

Resonance poles lie underneath unitarity cuts on unphysical Riemann sheets

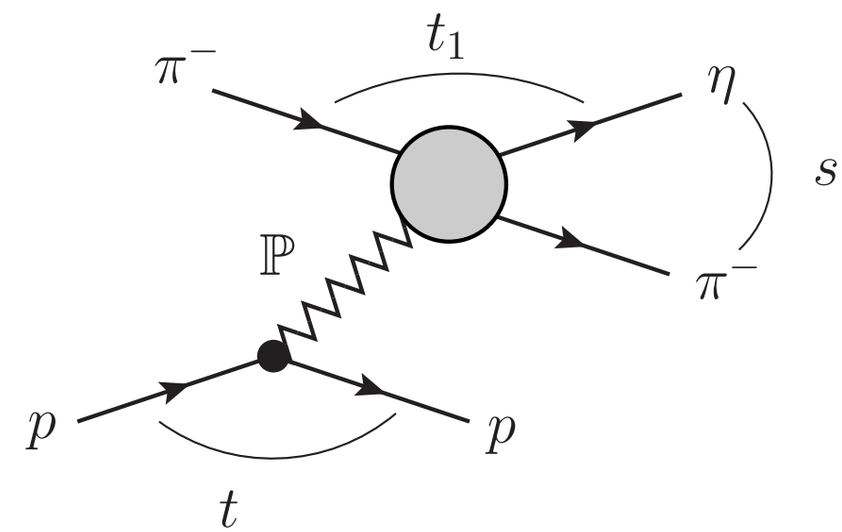
Understanding of amplitude model important when continuing to complex energies





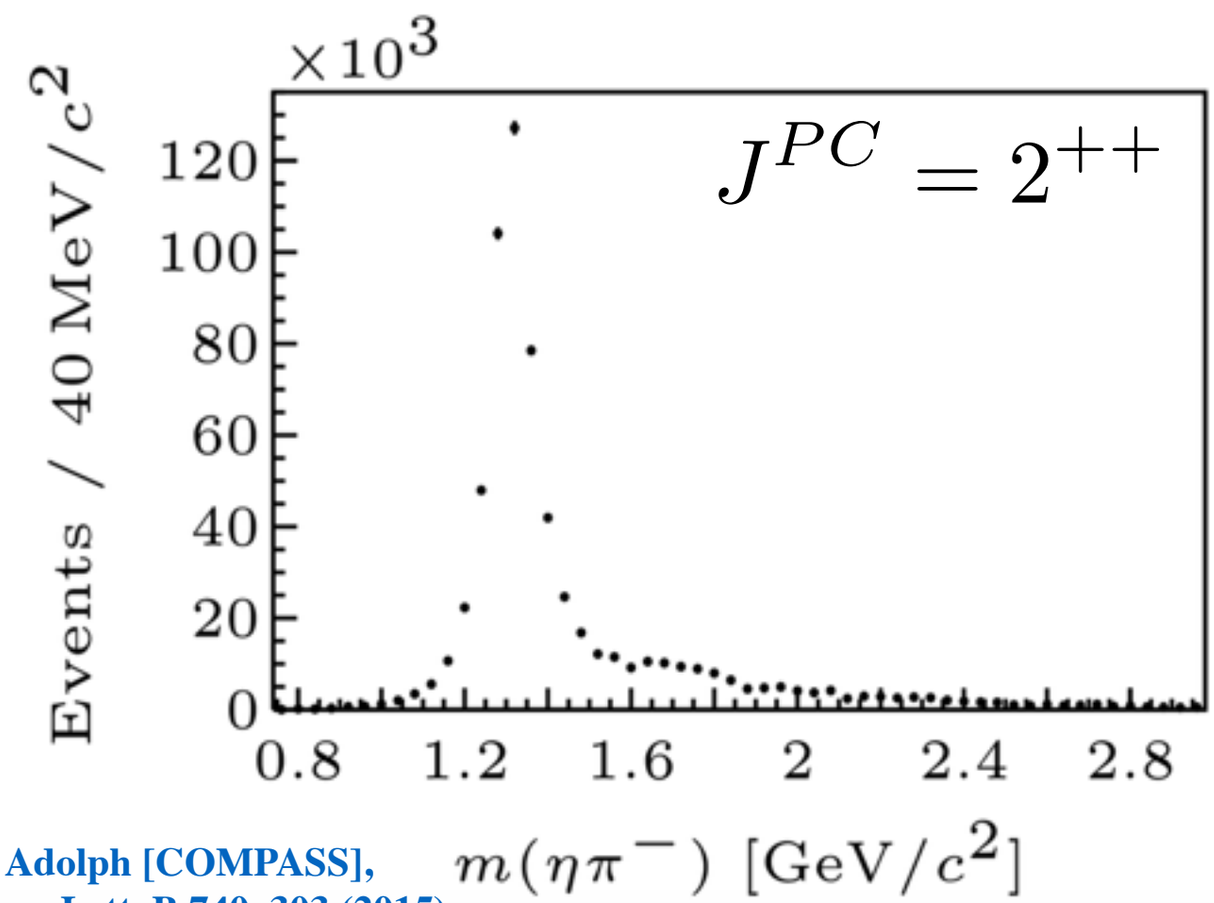
$$\pi\pi \to \rho \to \pi\pi$$

$\eta\pi$ at COMPASS



The $\eta\pi$ system is one of the golden modes for hunting hybrid mesons

As first step toward analysis of whole system, test model on 2^{++} channel



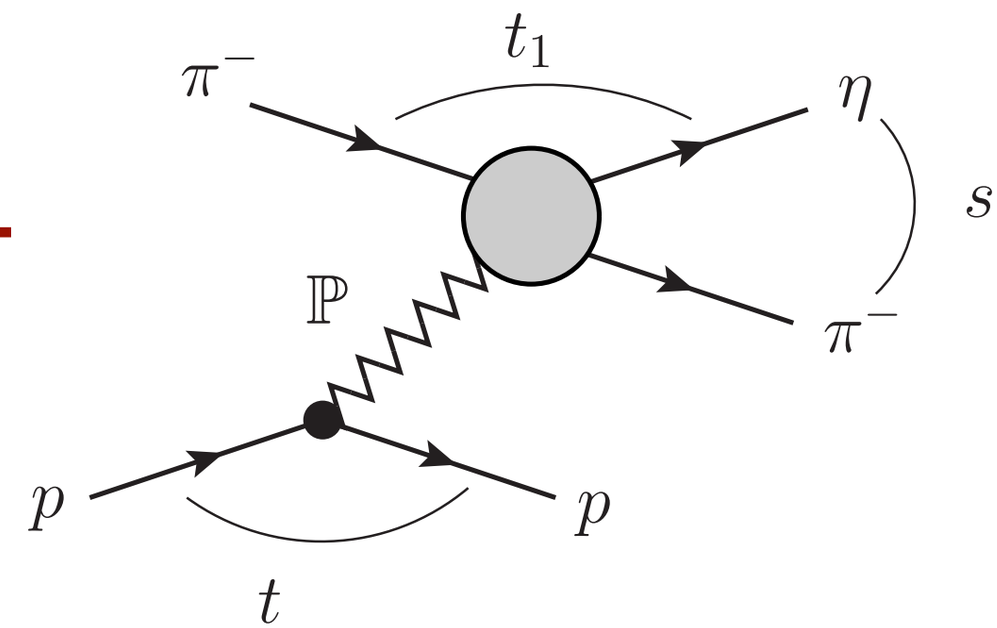
C. Adolph [COMPASS], Phys. Lett. B 740, 303 (2015)

Expect $a_2(1320)$ (Large peak) to be narrow resonance, and try to determine parameters for the excited a_2'

First joint publication between JPAC and COMPASS — Template for future analyses

AJ [JPAC & COMPASS], arXiv:1707.02848

Amplitude Model



$$\frac{d\sigma}{d\sqrt{s}} \propto I(s) = \int_{t_{\min}}^{t_{\max}} dt\, p\, |a(s,t)|^2 \equiv \mathcal{N} p\, |a(s)|^2$$

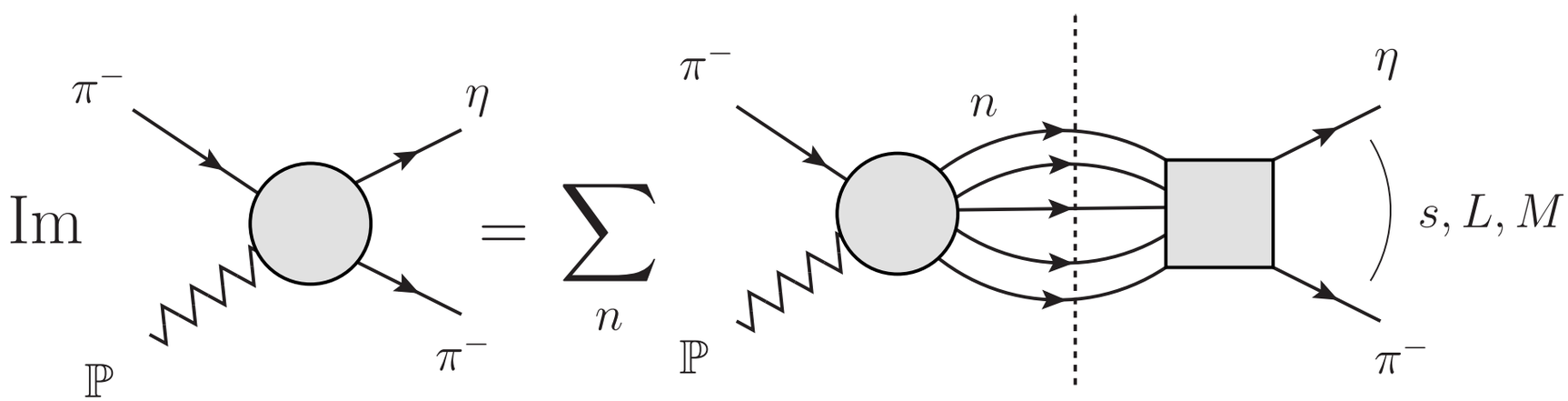
Since no t-dependence, assume flexible parameterization for production mechanism

$$a(s) = p^2 q\, \hat{a}(s)$$

Kinematics taken for Pomeron with vector coupling

$$\mathrm{Im}\, \hat{a}(s) = \rho(s) \hat{f}^*(s) \hat{a}(s)$$

Assume only $\eta\pi$ in intermediate state



Amplitude Model

Use N-over-D method for amplitude model

$$\hat{a}(s) = \frac{n(s)}{D(s)}$$

Production

Rescattering

$n(s)$ is a flexible model for production mechanism, given by

$$n(s) = \frac{1}{c_3 - s} \sum_j^{n_p} a_j \, T_j(\omega(s))$$

Left-hand singularities

$$\omega(s) = \frac{s}{s + \Lambda}$$

$$\Lambda = 1 \text{ GeV}^2$$

Production mechanism should be smooth in resonance region

Amplitude Model

Choose CDD parameterization for pole parameters

Form of CDD guarantees no first-sheet-poles

Left-hand-singularities modeled by pole singularity - parameter s_R corresponds to finite range of strong interactions: $s_R = 1.5\ \mathrm{GeV}^2$

Test different values for s_R to gauge systematics

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

$$D_0(s) = c_0 - c_1 s - \frac{c_2}{c_3 - s}$$

Resonances

$$\rho(s)N(s) = g\,\frac{\lambda^{5/2}(s, m_\eta^2, m_\pi^2)}{(s+s_R)^7}$$

Exchanges

Results of Fit

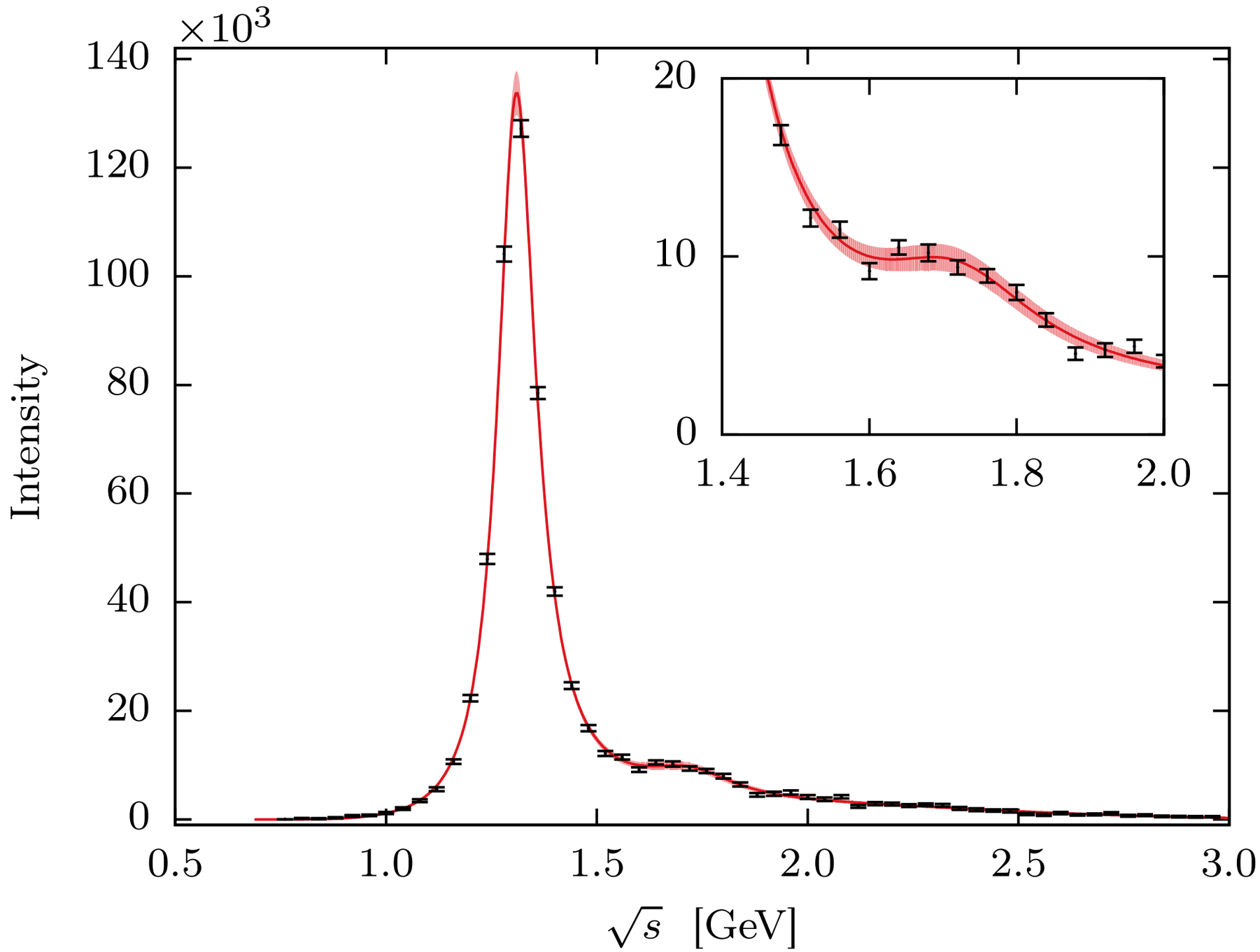
Fit with χ^2

6 terms in production expansion and 2 CDD poles

Statistical error estimates from bootstrap analysis $\chi^2/dof = 1.9$

Denominator parameters			Production parameters $[\mathrm{GeV}^{-2}]$	
c_1	0.532 ± 0.006	GeV^{-2}	a_0	0.471
c_2	0.253 ± 0.007	GeV^{2}	a_1	0.134
c_3	2.38 ± 0.02	GeV^{2}	a_2	-1.484
g	113 ± 1	GeV^{4}	a_3	0.879
			a_4	2.616
			a_5	-3.652
			a_6	1.821

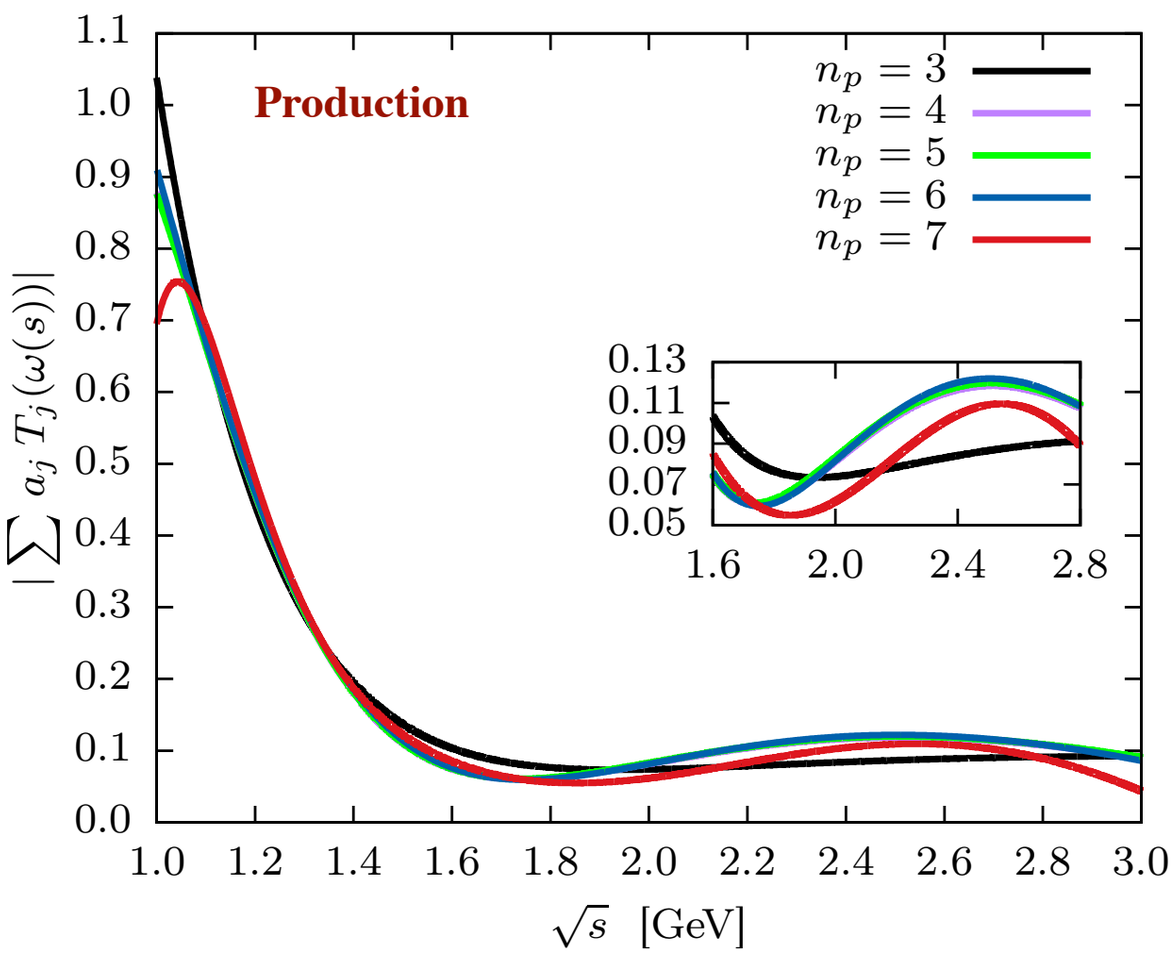
Results of Fit



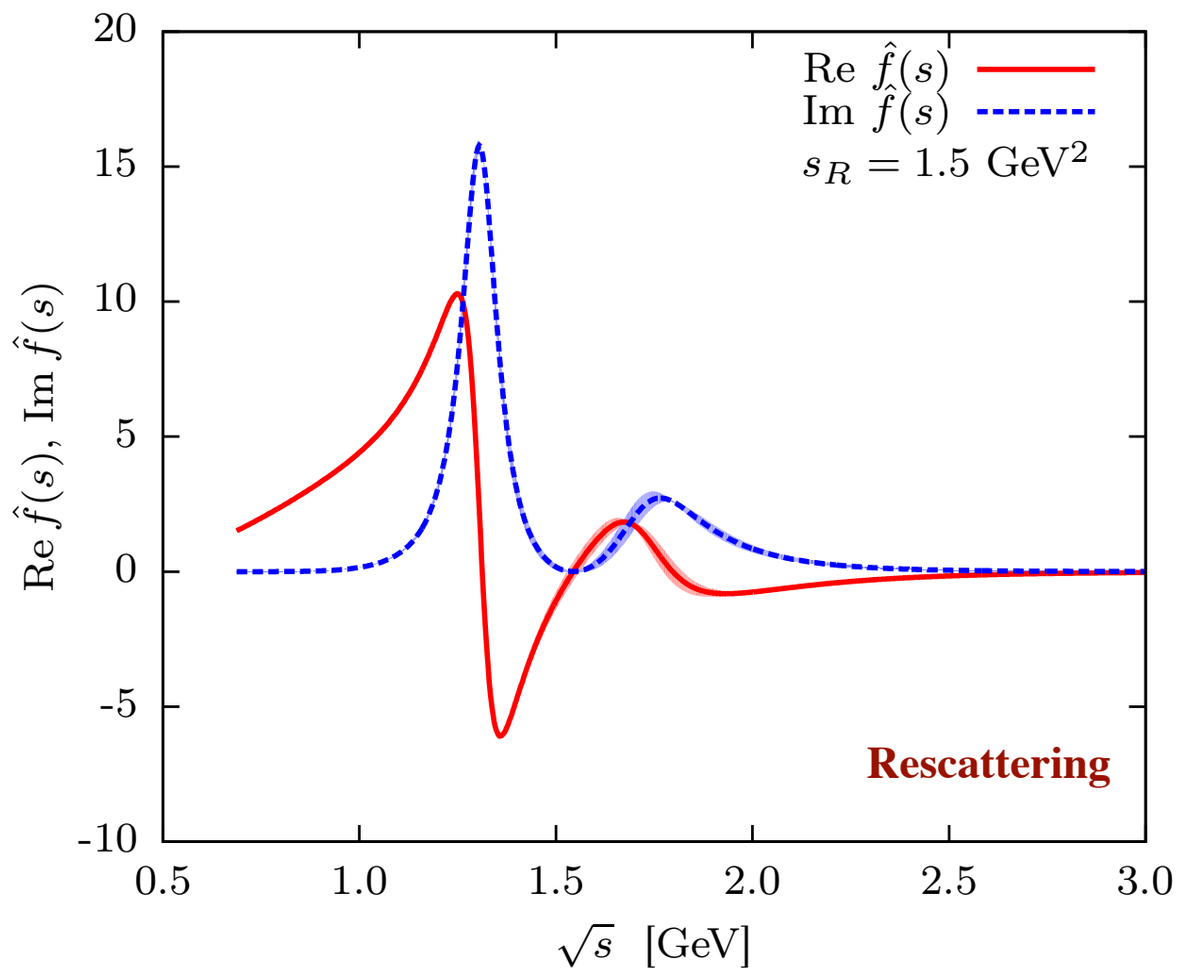
Amplitudes

Production amplitude smooth in resonance region

Low s behavior is suppressed by threshold functions



$$\hat{f} = N(s)/D(s)$$



Pole Positions

Continue amplitude to 2nd sheet to extract pole positions

$$\Longrightarrow \quad D_{II}(s) = D(s) + 2i\rho(s)N(s)$$

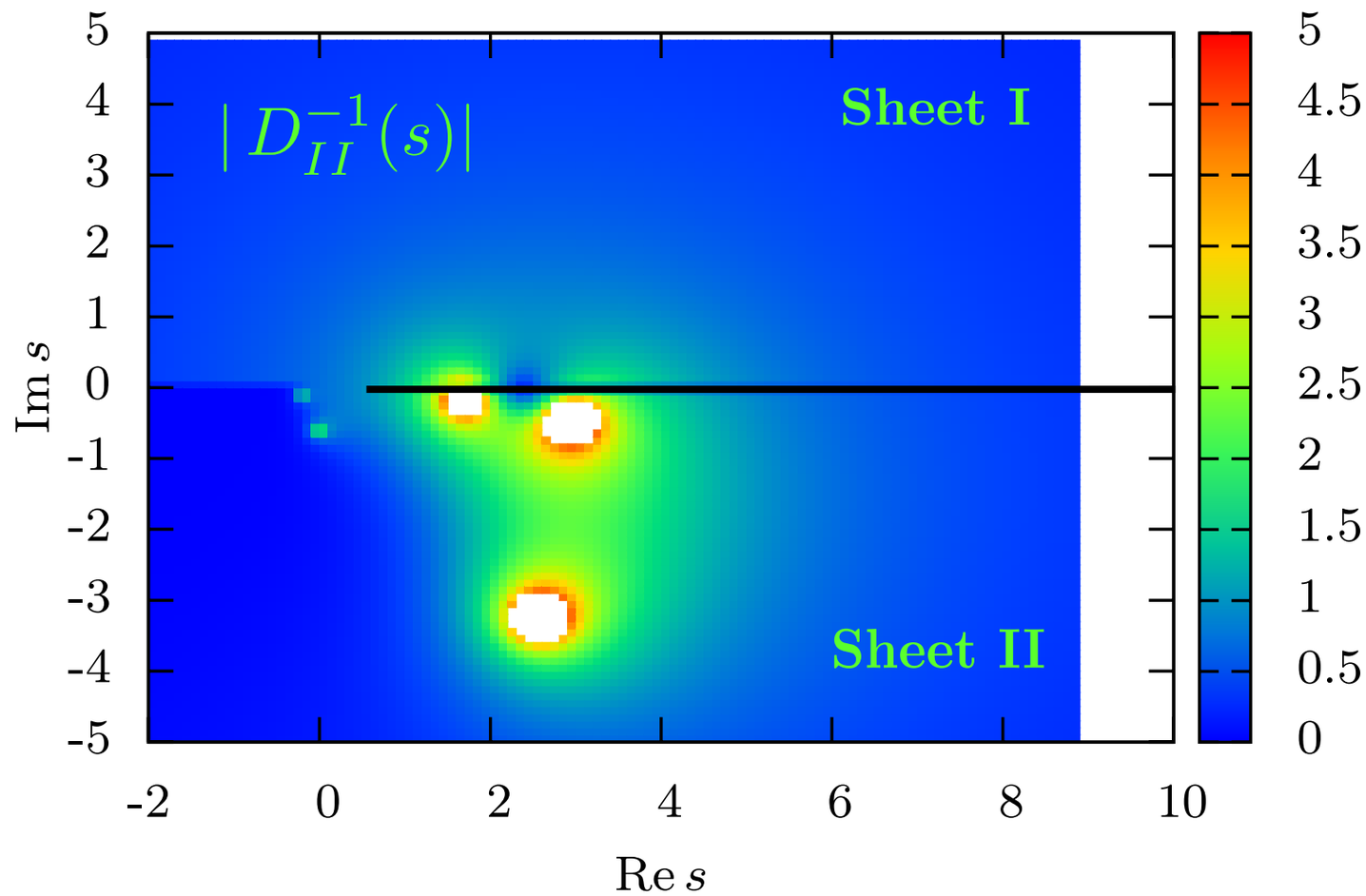
Pole positions

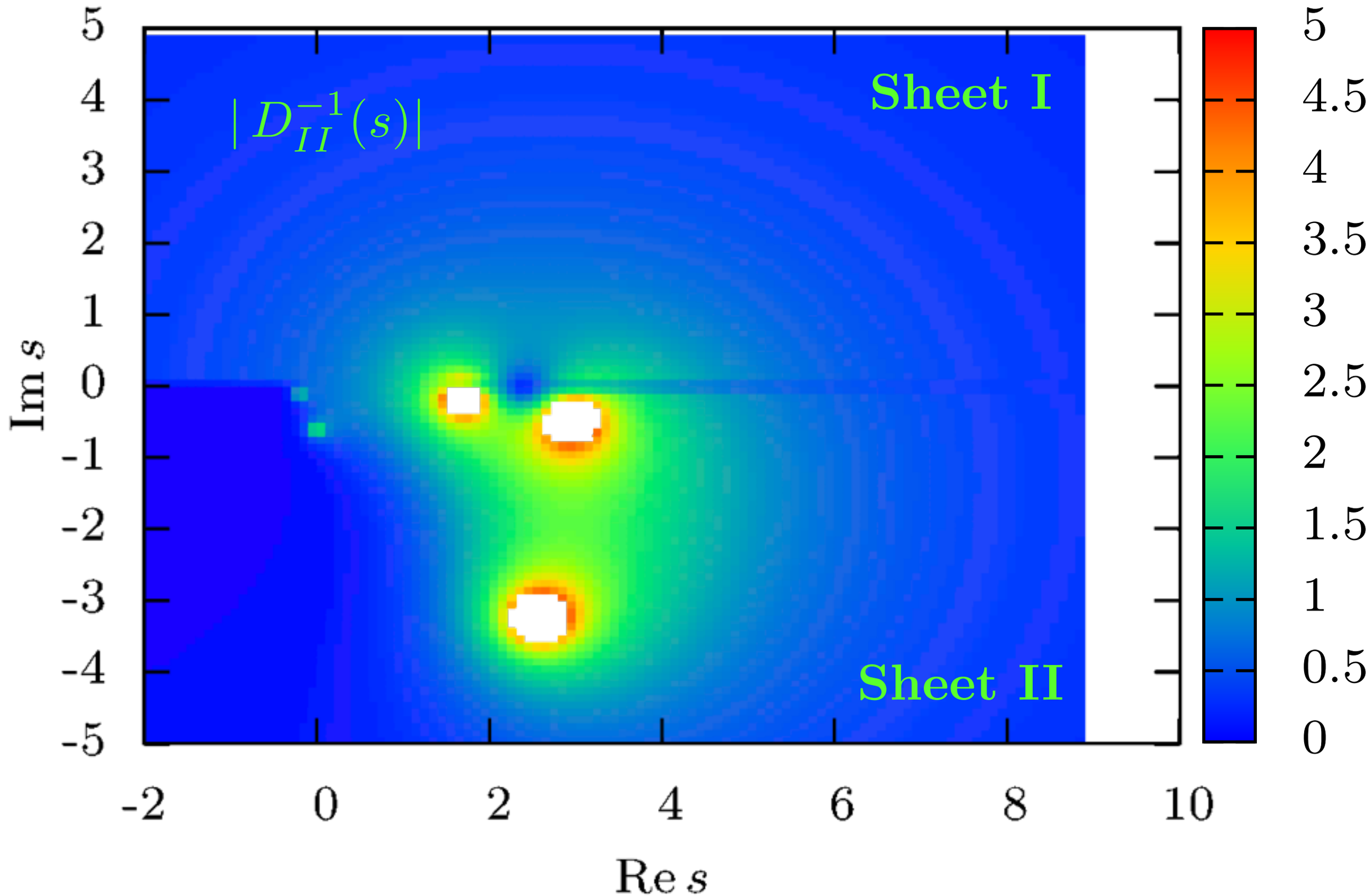
$$D_{II}(s_p) = 0$$

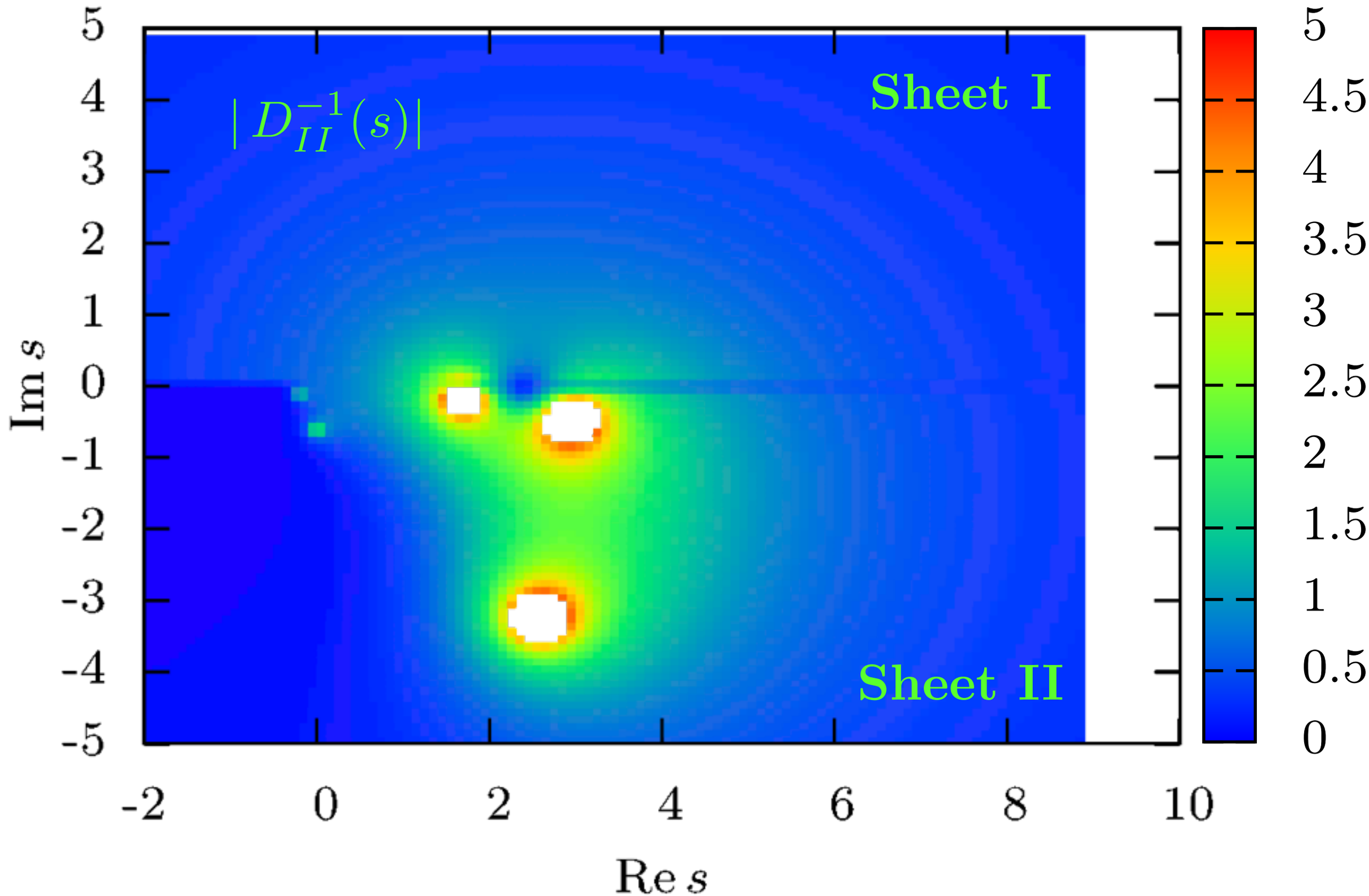
Mass and Width definitions

$$m = \mathrm{Re}\,\sqrt{s_p}$$

$$\Gamma = -2\,\mathrm{Im}\,\sqrt{s_p}$$




$|D_{II}^{-1}(s)|$
Sheet I
Sheet II
Im s
Re s
5
4
3
2
1
0
-1
-2
-3
-4
-5
-2
0
2
4
6
8
10
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0


$|D_{II}^{-1}(s)|$
Sheet I
Sheet II
Im s
Re s
5
4
3
2
1
0
-1
-2
-3
-4
-5
-2
0
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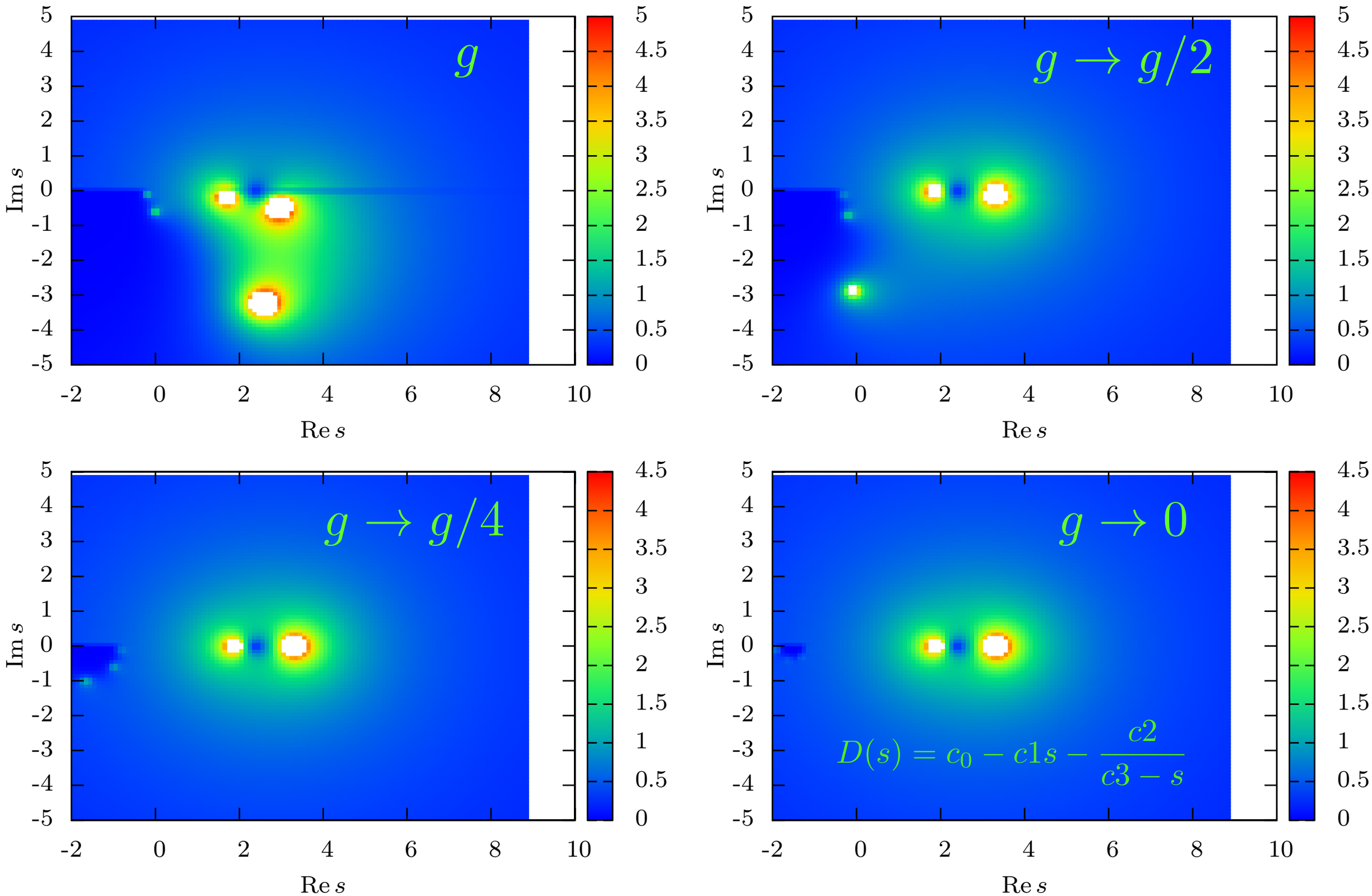
3
2.5
2
1.5
1
0.5
0


g
$g \to g/2$
$g \to g/4$
$g \to 0$
$D(s) = c_0 - c1s - \frac{c2}{c3 - s}$
Im s
Re s

Coupled Channels

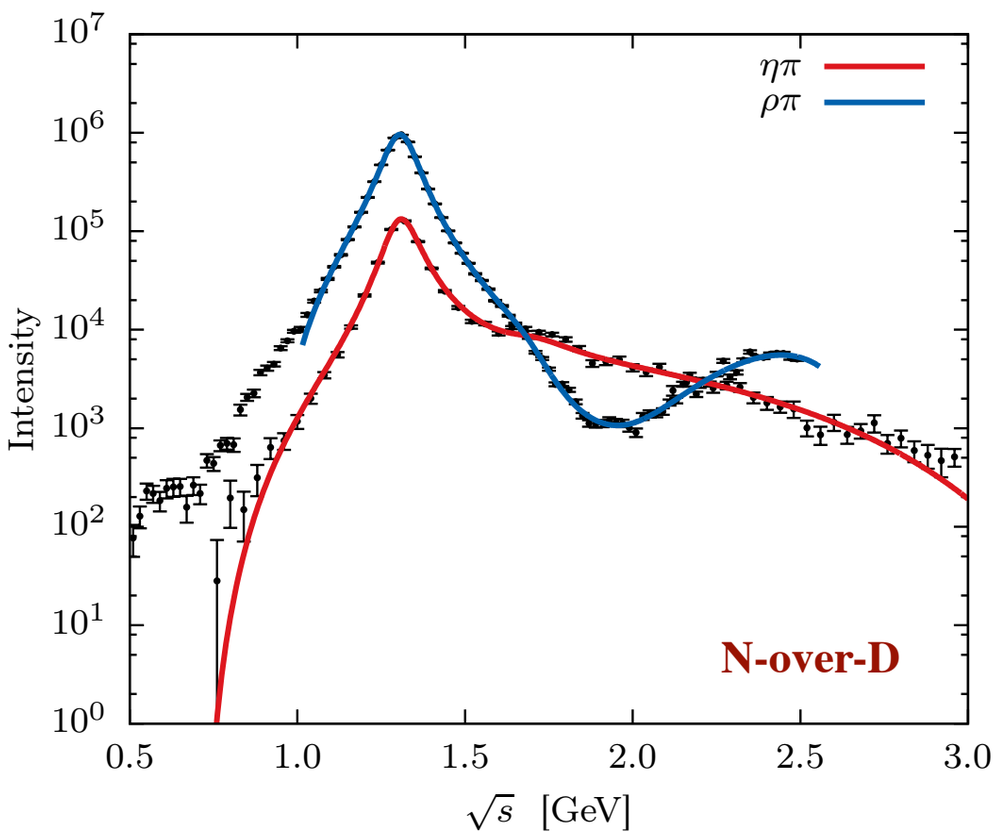
$a_2 \to \rho\pi$ is dominant mode

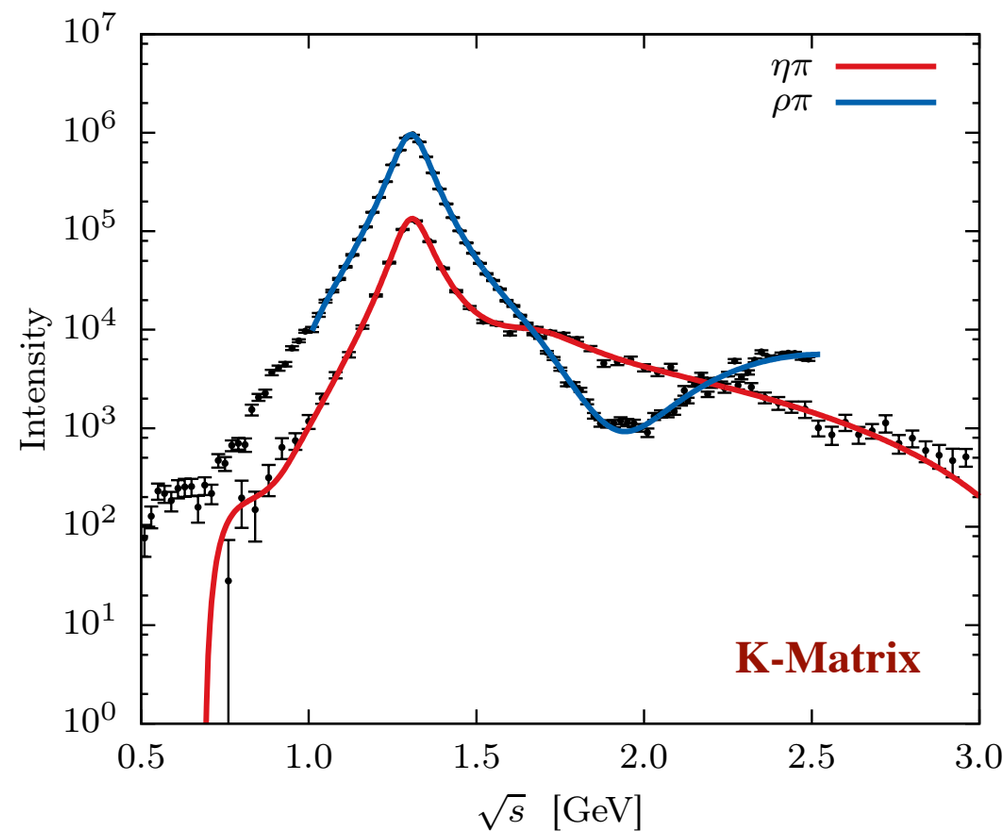
Fit for $\eta\pi$ prefers two a_2 poles

Fit for $\rho\pi$ prefers one a_2 pole

$$\hat{a}_j(s) = \sum_k [D(s)]^{-1}_{jk}(s)\, n_k(s)$$

Pole positions are consistent for single channel approximation

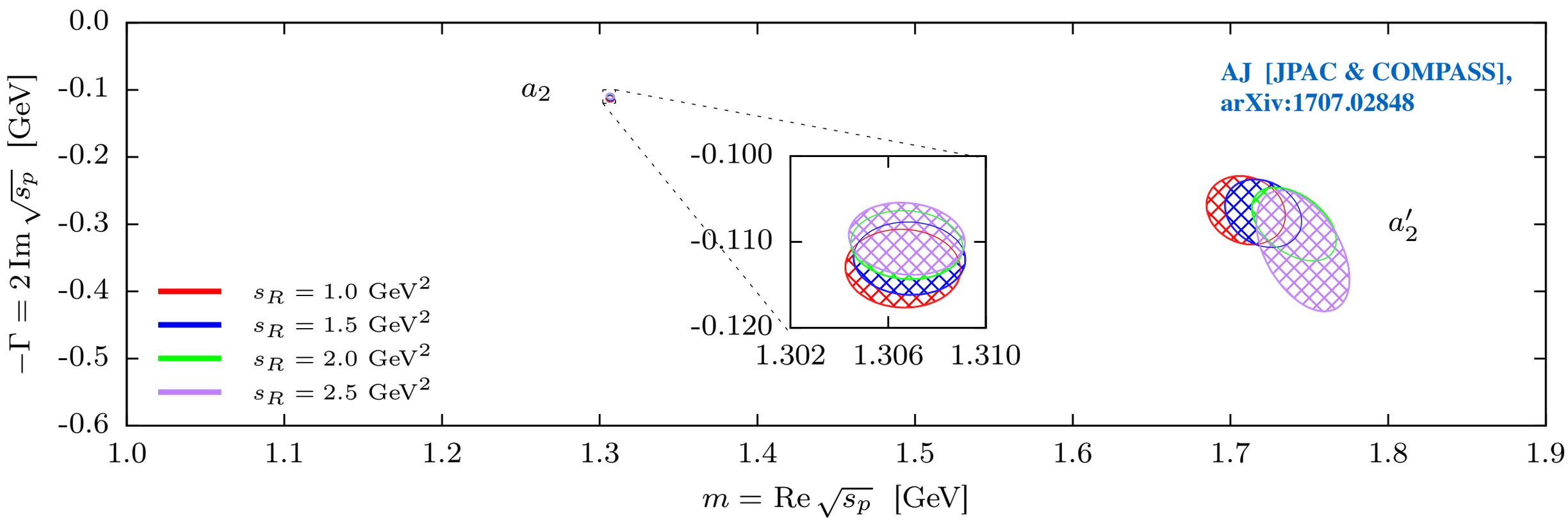




Final Pole Positions

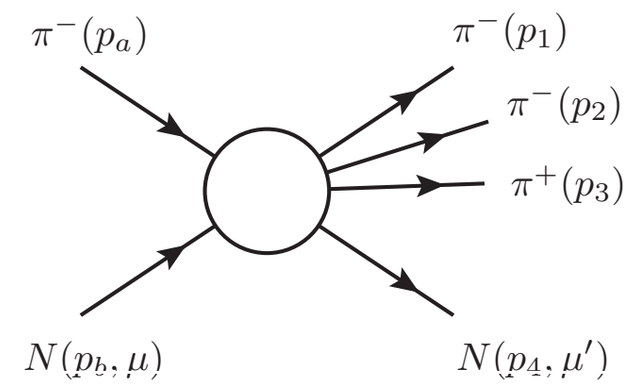
Final pole positions and estimated uncertainties for a_2, a_2'

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



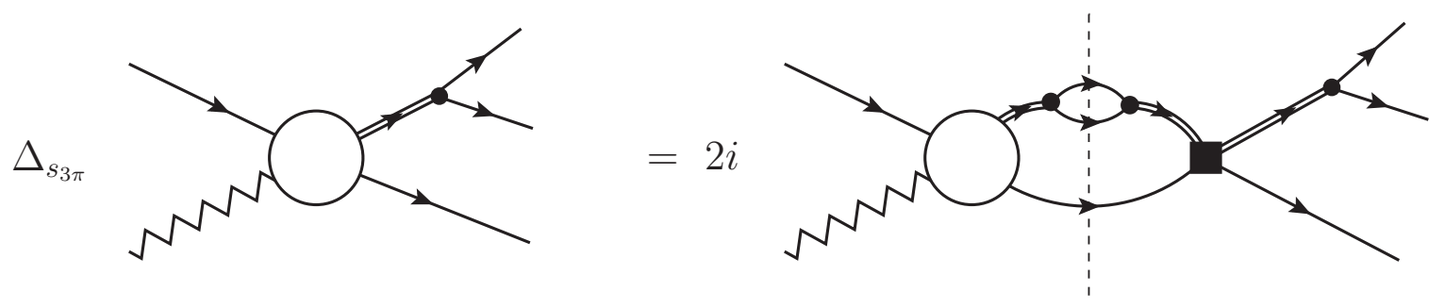
Extensions

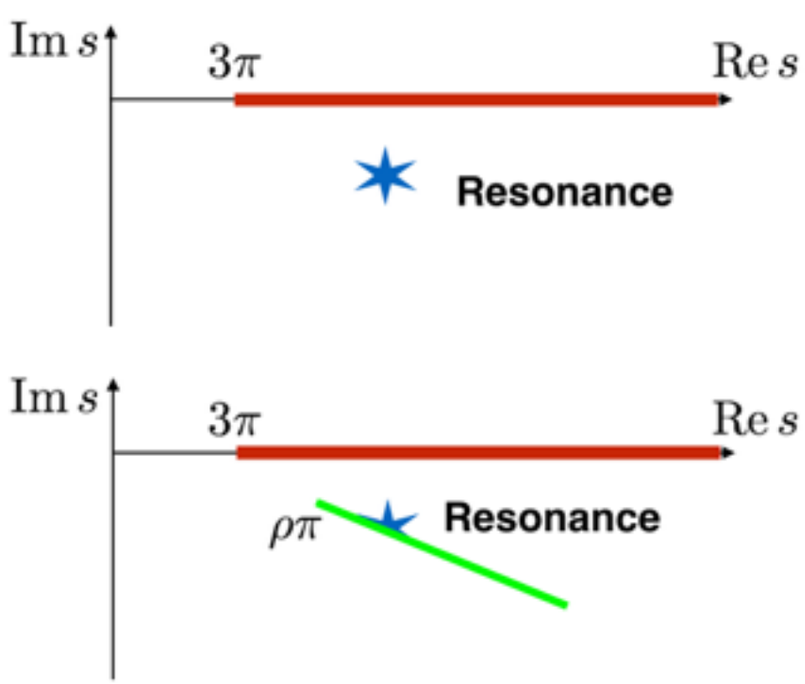
$\pi^- p \to \pi^- \pi^- \pi^+ p$



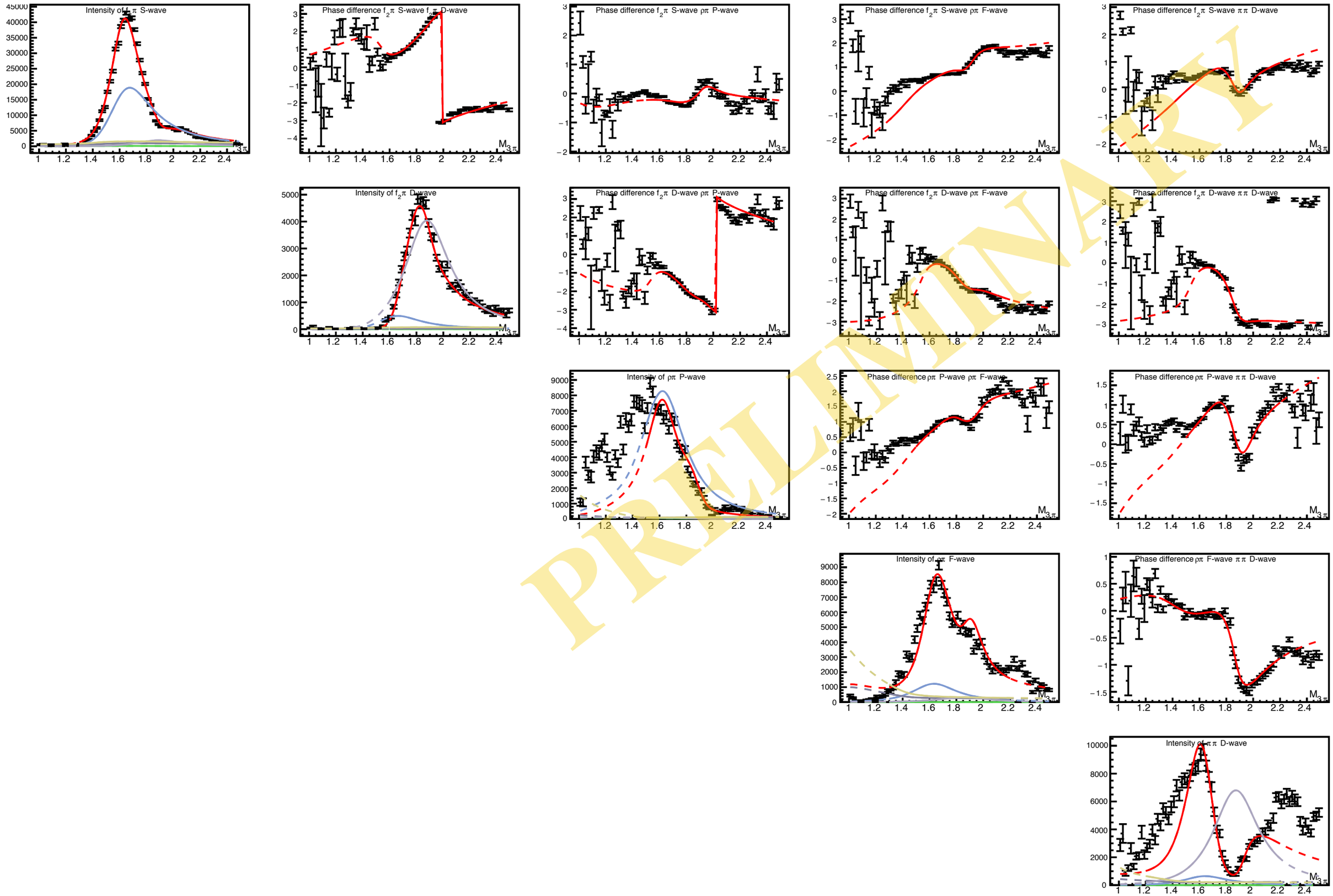
Developed quasi-two-body unitary model
- Assumes isobar is quasi-stable particle

First analysis in $J^{PC} = 2^{-+}$





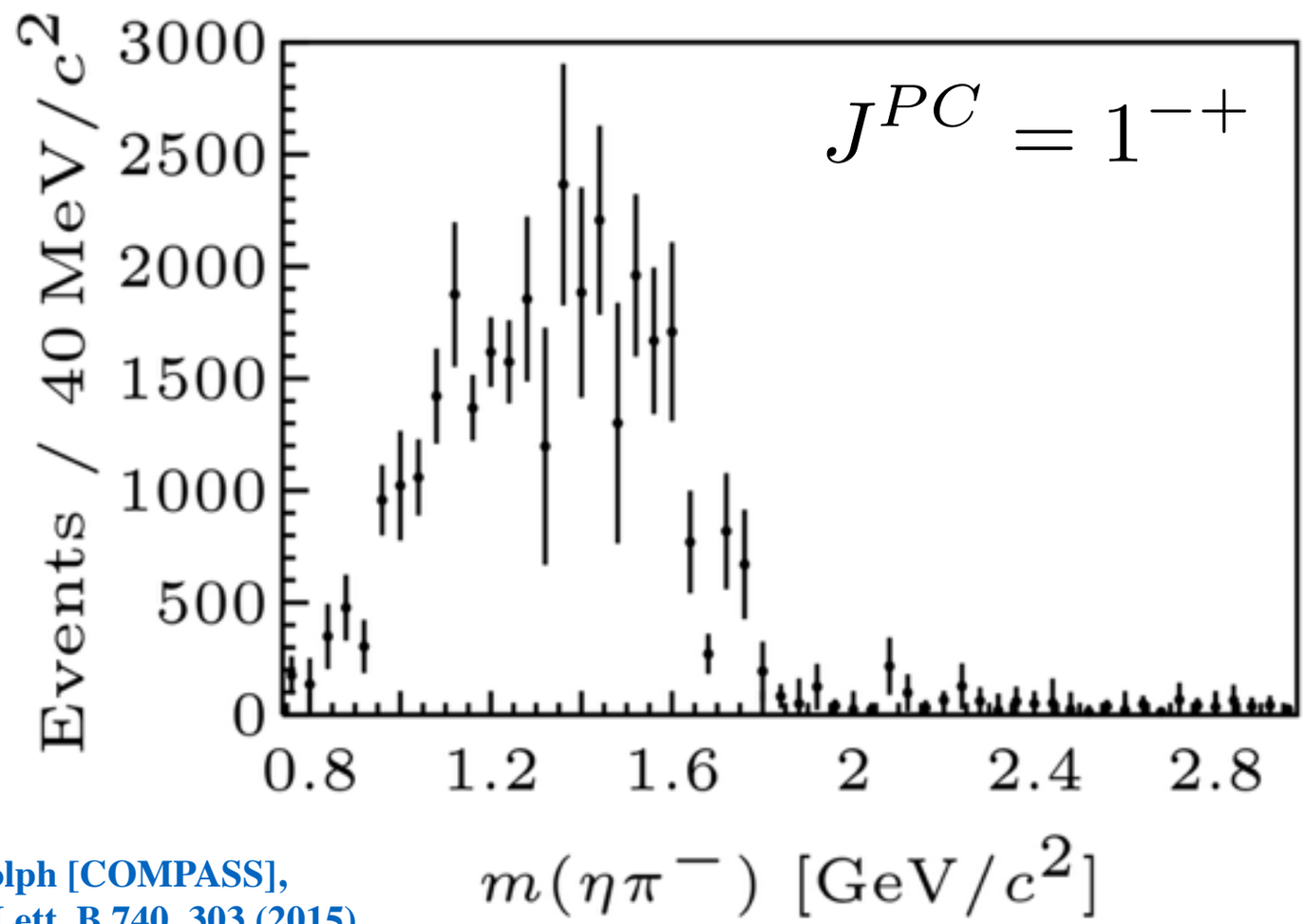
Poles may hide under cuts generated by isobar decay



Exotics at COMPASS

Coupled channel analysis including $J^{PC} = 1^{-+}$

Studies with P-wave on-going



C. Adolph [COMPASS], Phys. Lett. B 740, 303 (2015)

Summary

Active collaboration between theorist and experimentalist to construct analytic models

Have constructed analytic amplitude for the fitting of partial wave intensities and the extraction of resonance pole positions for the D-wave $\eta\pi$ system at COMPASS

Have performed systematic studies on model to understand stability and nature of poles found

Pole positions are consistent with previous COMPASS study

This analysis serves as a template for more detailed on-going analyses

Back-Up

Vector Pomeron Model

Pomeron trajectory intercept $\alpha \approx 1$. As first approximation, treat pomeron as particle with a vector coupling

$$A(\pi p \to \eta \pi p) = \sum_{\lambda} A_{\lambda}(\pi \mathbb{P} \to \eta \pi) V_{\lambda}(p \to \mathbb{P} p)$$

$$V_{\lambda}(p \to \mathbb{P} p) \sim \epsilon_{\mu}(\lambda) \bar{u} \gamma^{\mu} u$$

$$\sim \frac{s_{tot}}{\sqrt{s}} \sin \alpha_{recoil}$$

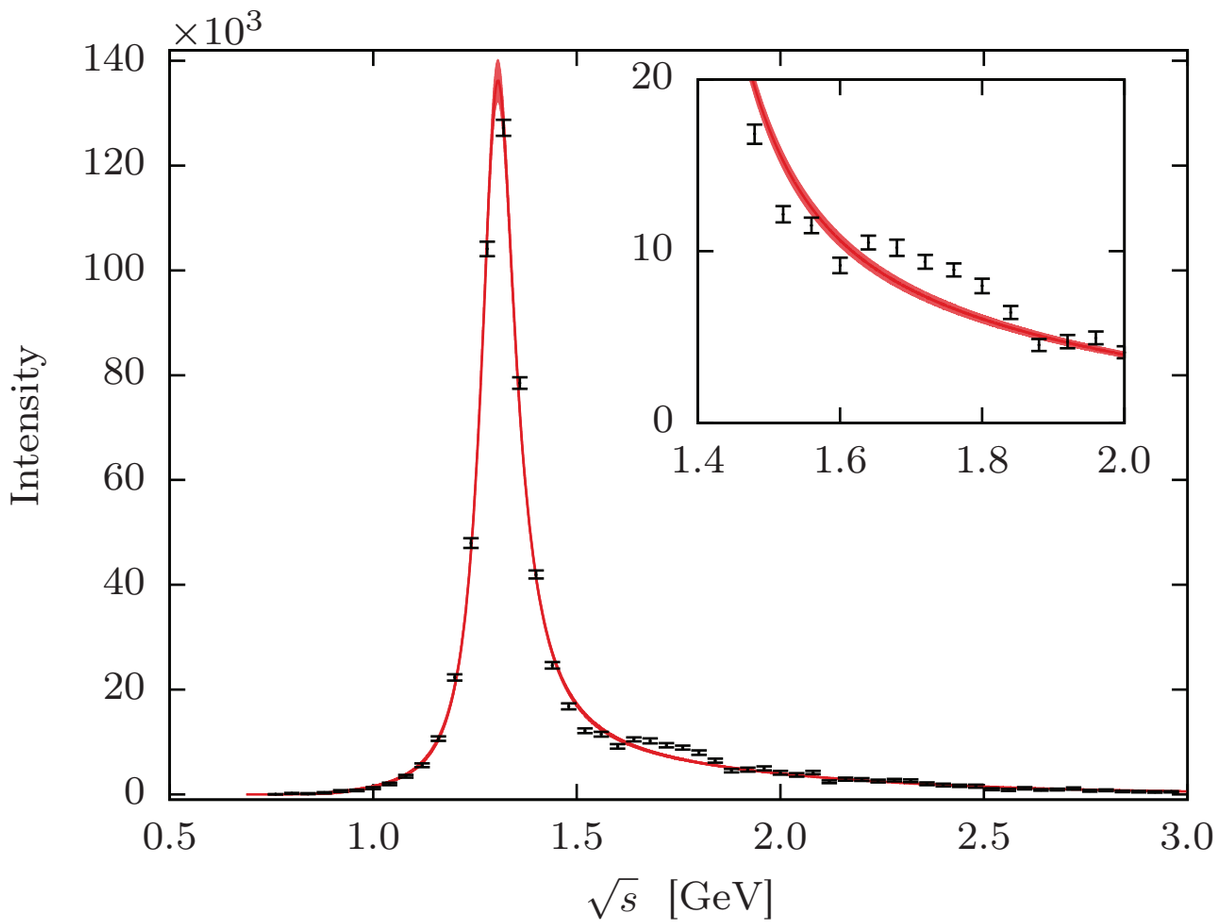
In Gottfried-Jackson Frame

$$s_{tot}, s \to \infty \text{ with } s/s_{tot} \text{ constant}$$

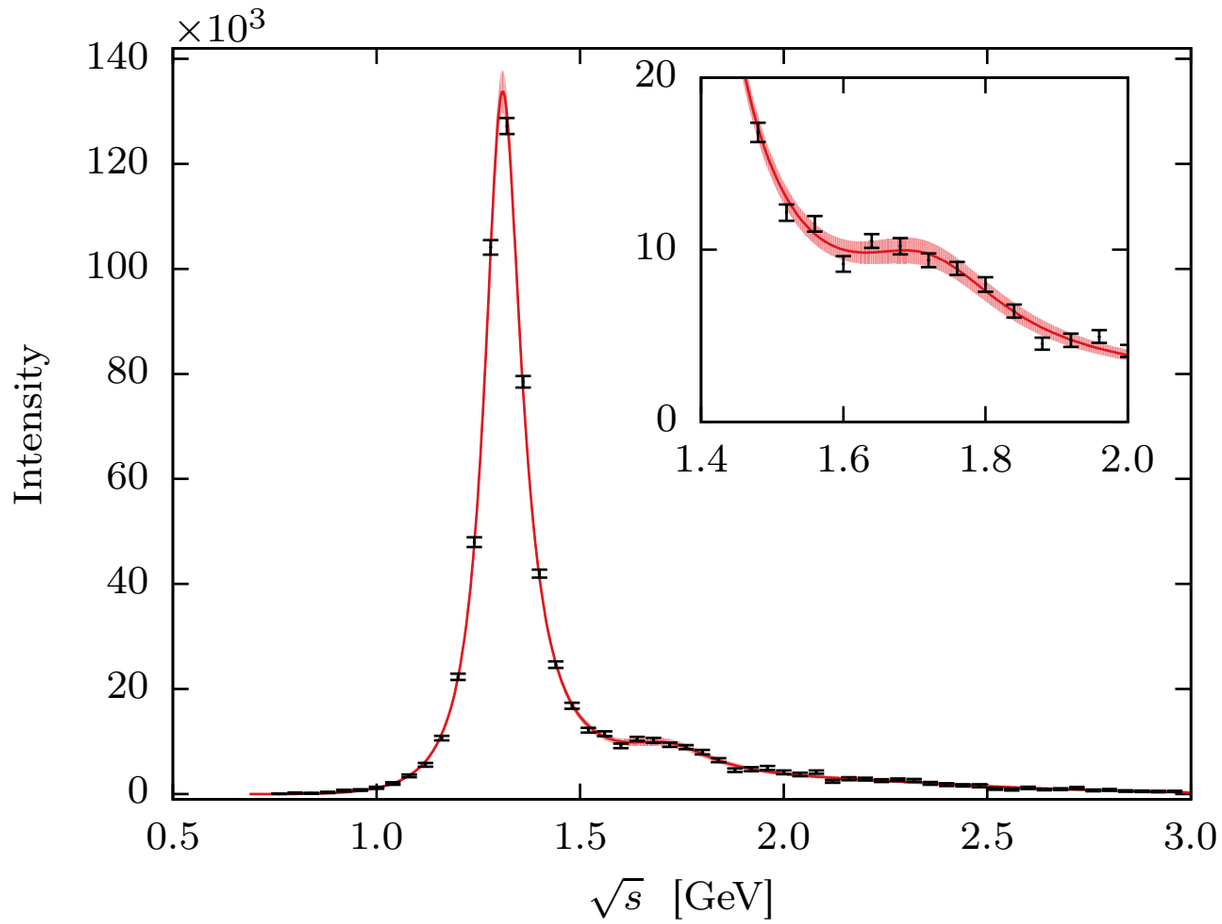
$$\sin \alpha_{recoil} \to \frac{1}{q}$$

Pion-Pomeron momentum

1 CDD vs 2 CDD

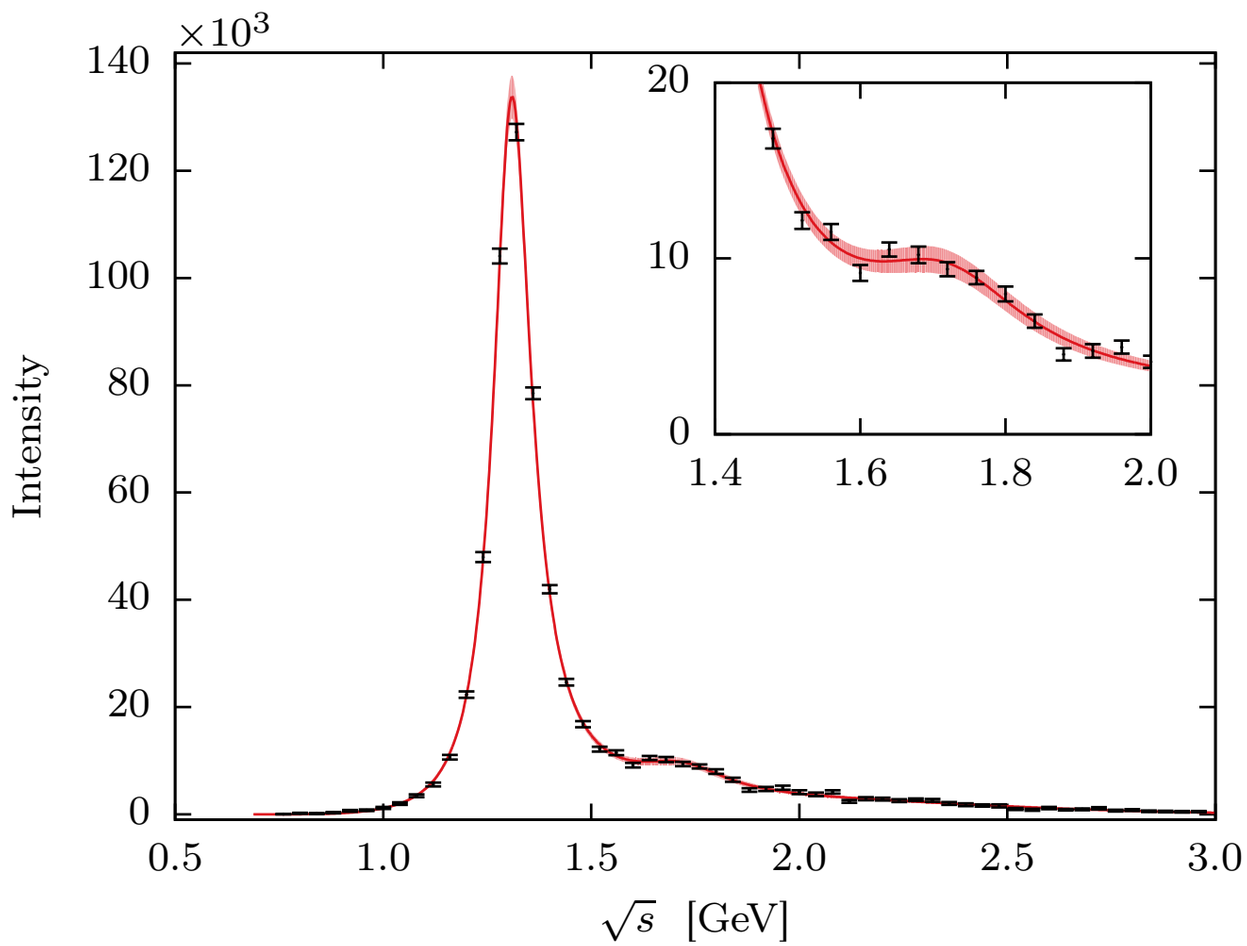


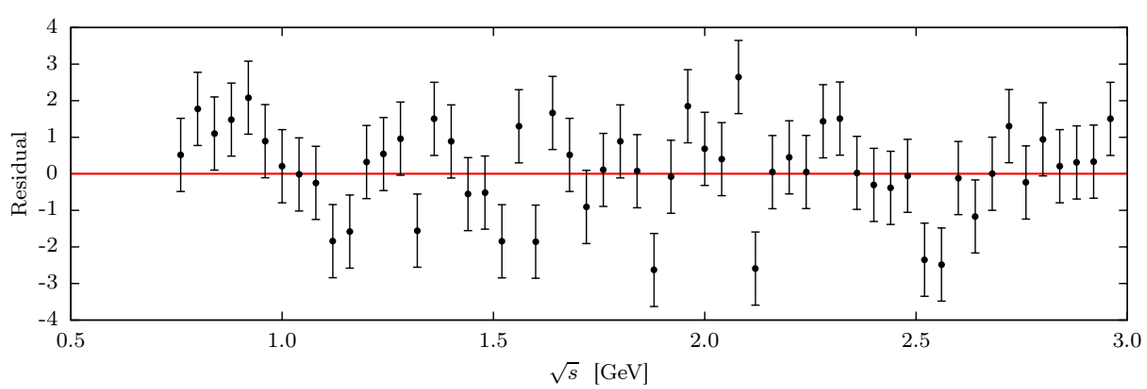
1 CDD pole



2 CDD poles

Residuals



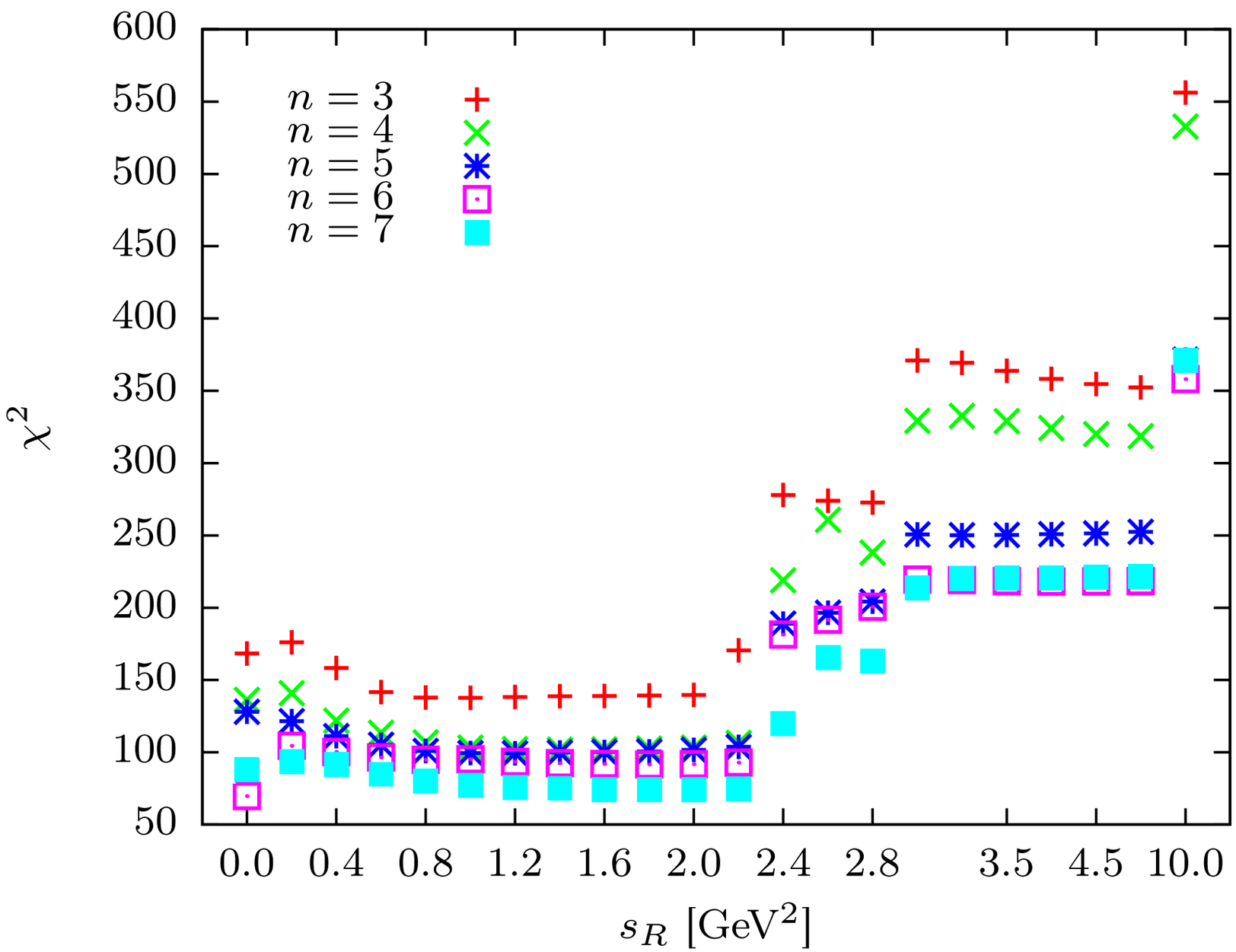


$$Res_j = \frac{O_j - I(s_j)}{\sigma_j}$$

Performed 1 million fits with random starting values for all parameters. Minimum solution was $\chi^2/dof \sim 2$

No clear region where deviation seems systematic

Fixing the Range of Interaction



Preliminary fits at various s_R to determine value

Consistent with range of strong interaction ~ 1 GeV