Sensitivities of Rho Meson SDMEs to Parameters of the JPAC Model

Dave Mack

TJNAF

Abstract

In the JPAC model, the rho SDMEs in the helicity frame at 8.5 GeV beam energy are mainly sensitive to the f2 and Pomeron exchanges, and hence to the corresponding vertex couplings. The f2 contributions dominate the deviations from SCHC, while the Pomeron dilutes them. Since the ratio of Pomeron/f2 increases with beam energy, the deviations from SCHC become quite small by 25 GeV. The 3 unpolarized SDMEs have similar sensitivities to the 6 polarized SDMEs, so might provide useful parameter constraints over the full beam energy range of GlueX. It's not clear to me what's going on with the Natural versions of the SDMEs; while the unnatural versions are indeed relatively small, the natural versions don't show the purity I was naively expecting at 8.5 GeV.

While working on the “light meson results” talk for Hadron 2019, I wondered what physics we can extract from Alexander A’s precise rho SDMEs at https://halldweb.jlab.org/doc-private/DocDB/ShowDocument?docid=4134 .

The JPAC paper **PRD 97, 094003 (2018)** is quite detailed, but there’s no plot to indicate what the dominant contributions are for the rho. There is also no simple explanation why the SDMEs are so different for the omega, rho, and phi even though they’re all $J^{PC} = 1^{--}$ mesons. (See plot on right. Different radiative decay widths at the gamma-X-Vector vertices play an important role, but are only part of the story.)

Fortunately, we have Vincent’s wonderful calculator at http://cgl.soic.indiana.edu/jpac/sdme.php#simu .

In the following slides, I’ll examine the sensitivities of the rho SDMEs at 8.5 GeV.

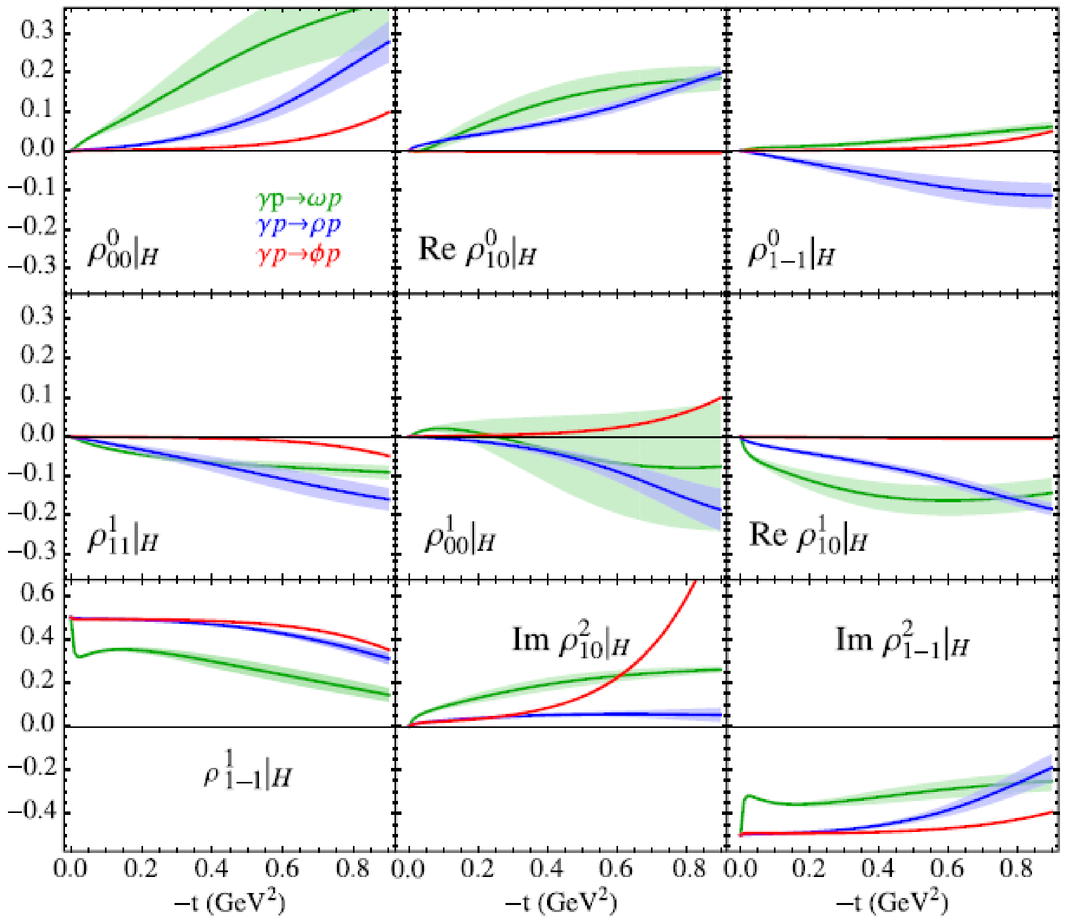
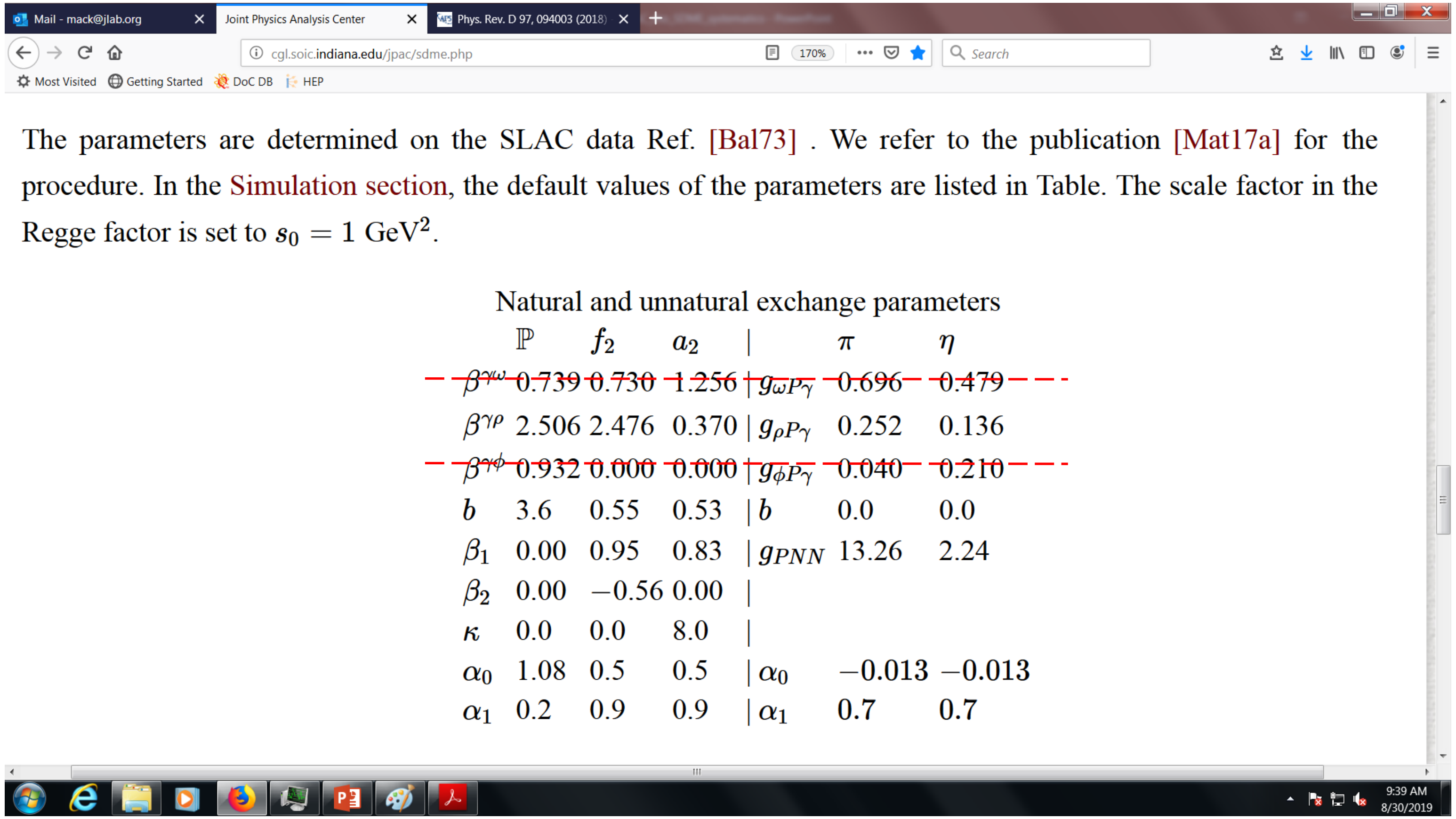


FIG. 8. The SDMEs of ω, ρ^0 and ϕ photoproduction at $E_\gamma = 8.5$ GeV, the average polarized beam energy in the laboratory frame.

Ignoring the gamma-X-omega and gamma-X-phi vertex couplings, it looks like there are 31 parameters potentially affecting rho production.



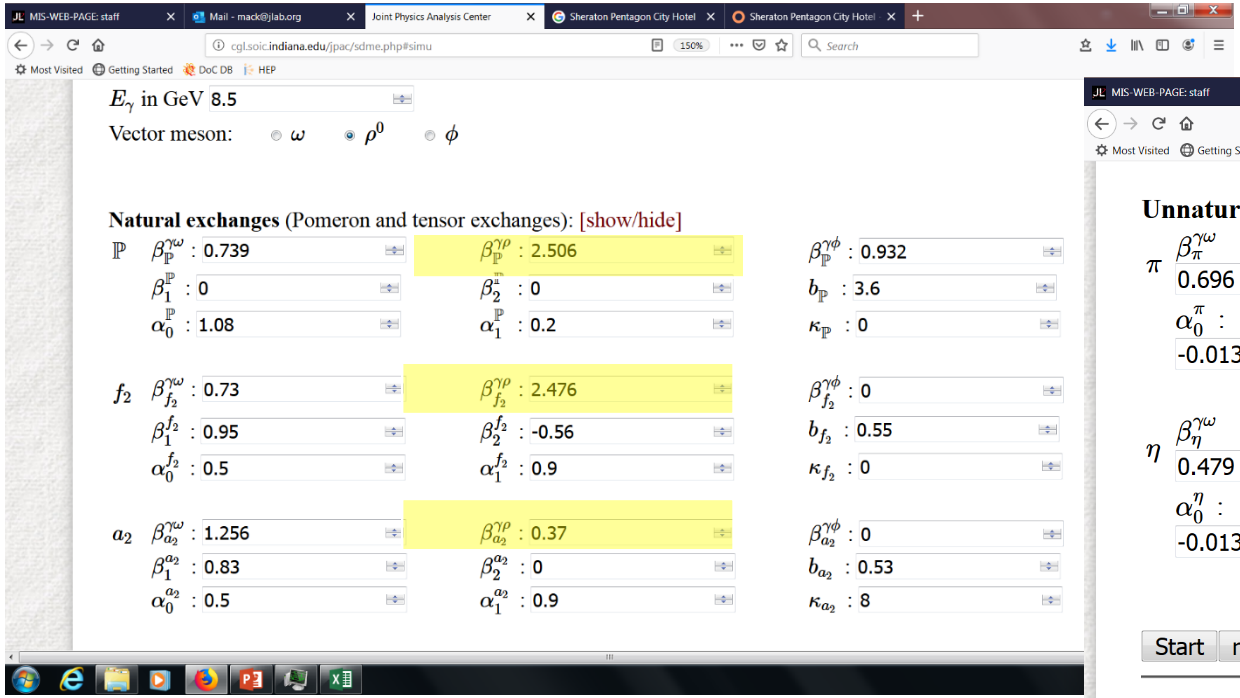
The parameters are determined on the SLAC data Ref. [Bal73] . We refer to the publication [Mat17a] for the procedure. In the Simulation section, the default values of the parameters are listed in Table. The scale factor in the Regge factor is set to $s_0 = 1$ GeV^2.

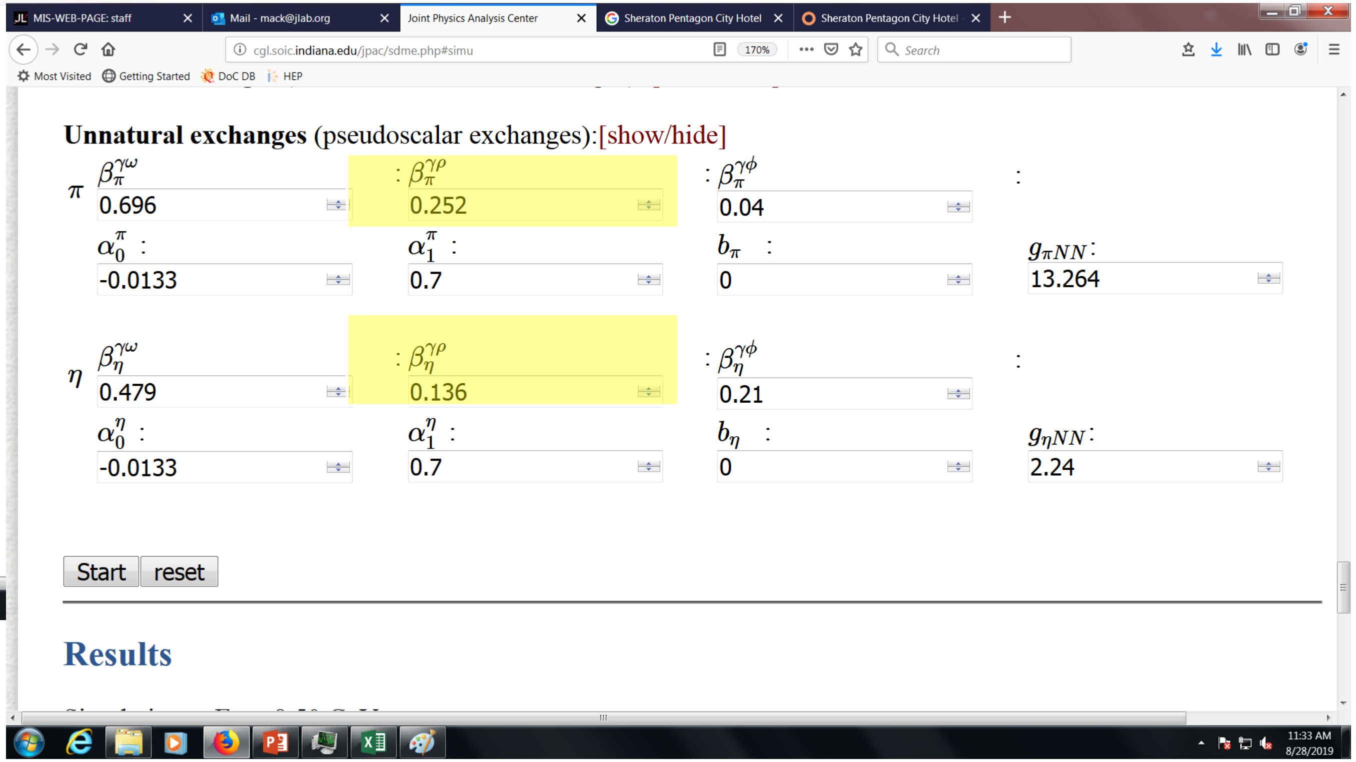
Natural and unnatural exchange parameters

	$\mathbb{P}$	f_2	a_2		π	η
~~$\beta^{\gamma\omega}$~~	~~0.739~~	~~0.730~~	~~1.256~~	~~$g_{\omega P\gamma}$~~	~~0.696~~	~~0.479~~
$\beta^{\gamma\rho}$	2.506	2.476	0.370	$g_{\rho P\gamma}$	0.252	0.136
~~$\beta^{\gamma\phi}$~~	~~0.932~~	~~0.000~~	~~0.000~~	~~$g_{\phi P\gamma}$~~	~~0.040~~	~~0.210~~
b	3.6	0.55	0.53	b	0.0	0.0
β_1	0.00	0.95	0.83	g_{PNN}	13.26	2.24
β_2	0.00	-0.56	0.00			
κ	0.0	0.0	8.0			
α_0	1.08	0.5	0.5	α_0	-0.013	-0.013
α_1	0.2	0.9	0.9	α_1	0.7	0.7

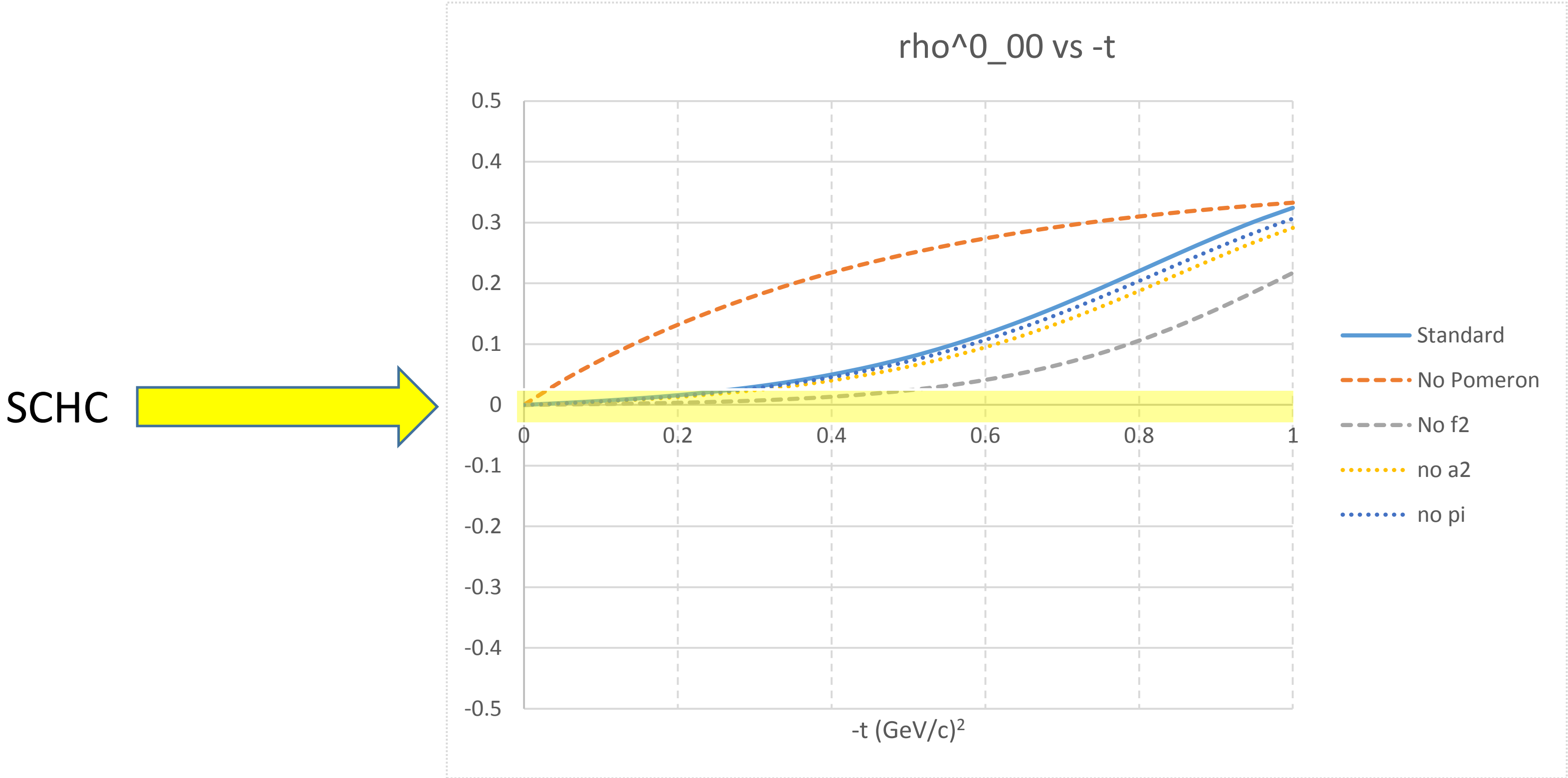
I chose not to play with any lower vertex (ie, N-N-meson) couplings, nor with any Regge trajectory parameters, nor with the b parameters that determine the slopes of the differential cross section dsigma/dt .

To see which exchanges were most important, I set the upper vertex gamma+meson→rho couplings to 0 for the each of the contributions in turn. (These are the beta parameters which have a meson subscript, marked in yellow below.)





This is a plot of a typical rho SDME after setting the upper vertex couplings to zero (one at a time):

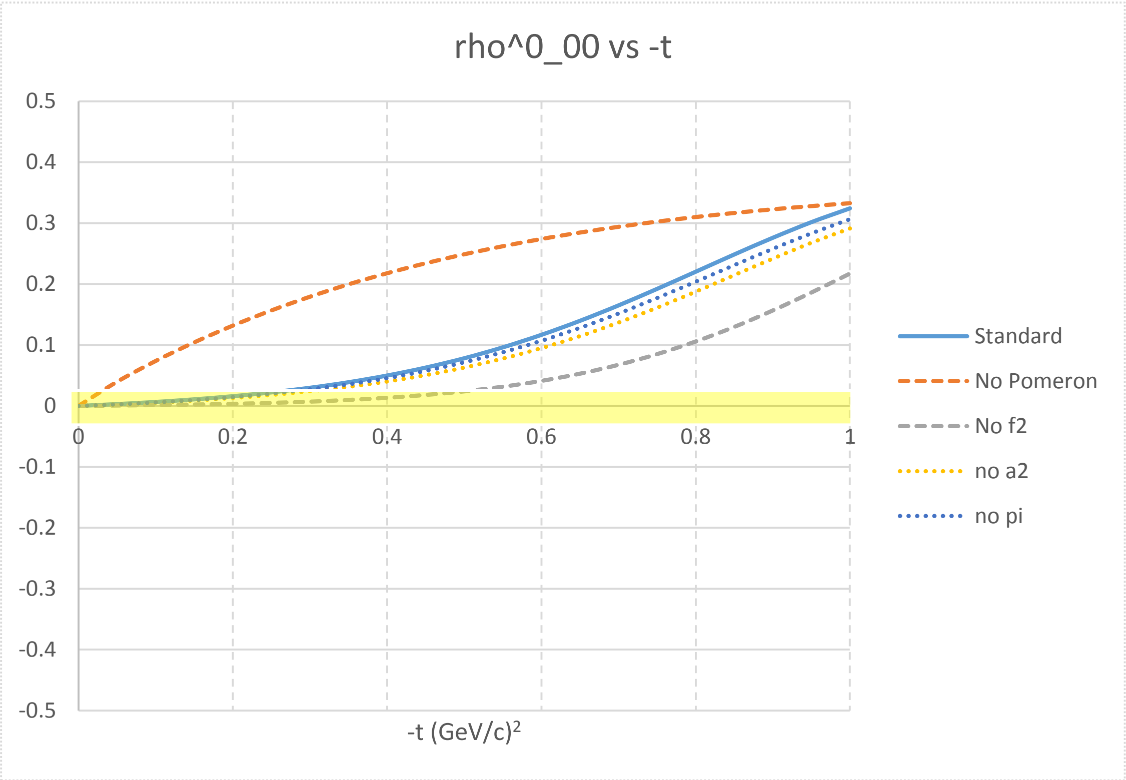


Since all SDME's were impacted similarly, I show only one representative above. (See Backups for all the plots.) For this particular SDME, helicity conservation in the s-channel would be denoted by a horizontal line at 0 . The following statements apply to all 9 rho SDME's:

- The dominant contributions are from natural parity exchange from the Pomeron and f2 . We are very insensitive to other contributions.
- The f2 exchange (see "No Pomeron" curve) tends to break SCHC much more than the Pomeron (see "No f2" curve). Under the JPAC assumptions about the helicity structure of the Pomeron, the latter's role is to dilute the SCHC-violating effects of the f2.
- *One thing we can learn from rho SDME data is the relative strength of the Pomeron and f2 exchanges at this beam energy.*

This is a plot of a typical rho SDME after setting the upper vertex couplings to zero (one at a time):

SCHC



The online calculator gives NAN when I turn off the eta couplings, so there's no curve for "no eta". The contribution will probably be smaller than pi exchange. I'll compile a wish list and send it to Vincent.

Since all SDME's were impacted similarly, I show only one representative above. (See Backups for all.) For this particular SDME, helicity conservation in the s-channel would be denoted by a horizontal line at 0 . The following statements apply to all 9 rho SDME's:

- The dominant contributions are from natural parity exchange from the Pomeron and f2 . This is a huge simplification.
- The f2 exchange (see "No Pomeron" curve) tends to break SCHC much more than the Pomeron (see "No f2" curve). Under the JPAC assumptions about the helicity structure of the Pomeron, the latter's role is to dilute the SCHC-violating effects of the f2.
- *One thing we can learn from rho SDME data is the relative strength of the Pomeron and f2 exchanges at this beam energy.*

For the omega total photoproduction xsect, the GlueX invariant mass region of W ~ 4 lies between the low energy dominance of pi exchange and the high energy dominance of Pomeron exchange.

I haven't found a corresponding plot for rho photoproduction, but Donnachie and Landschoff in PLB 348 (1995) 213-218 confirm that the Pomeron contribution to the total rho cross section rises slowly with energy (s^0.08) while the meson contributions drop steeply with energy (s^-0.45).

It seems GlueX is in an interesting, transitional regime where vector meson photoproduction measurements can constrain both the dominant Regge exchanges as well as the Pomeron.

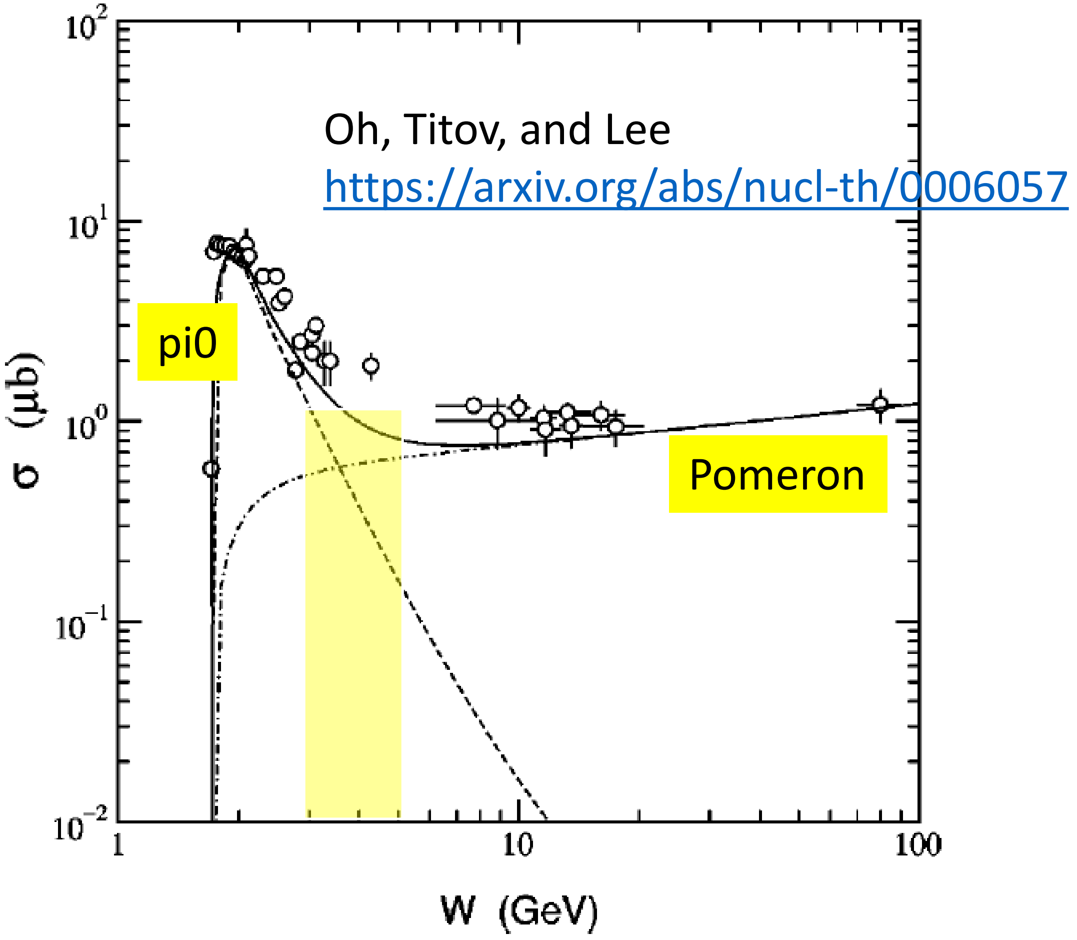


FIG. 3. Total cross sections of $\gamma p \to p\,\omega$ reaction as a function of invariant mass W. The solid curve is from the full calculation and the dotted curve is from the calculation without including Pomeron exchange. The Pomeron exchange contribution is given by the dot-dashed line. Data are taken from Refs. [12,33,34].

At “sufficiently high energies”, the following linear combinations of the SDMEs can project out the Natural and Unnatural exchange contributions in 3+3 terms:

We can then use six SDMEs to get information about the helicity structure of natural and unnatural components:

$$\rho^{N}_{00}{}^{}_{\!\!U} = \frac{1}{2}\left(\rho^0_{00} \mp \rho^1_{00}\right), \tag{B4a}$$

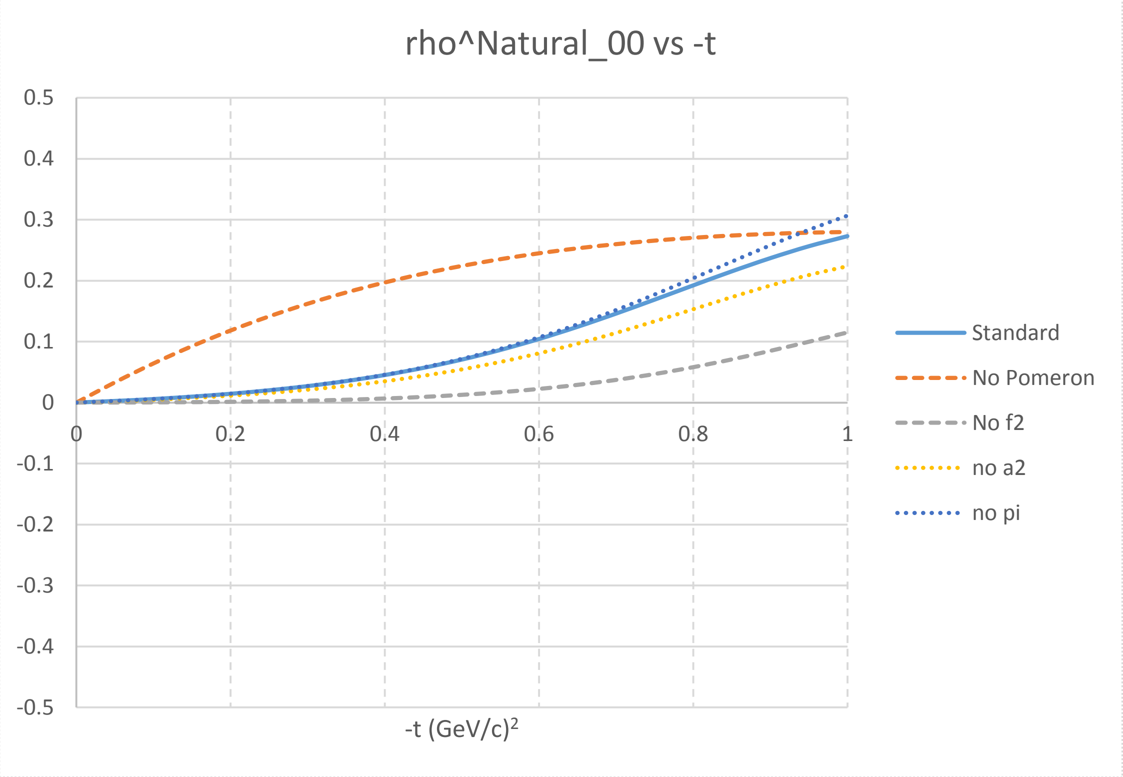
$$\mathrm{Re}\,\rho^{N}_{10}{}^{}_{\!\!U} = \frac{1}{2}\left(\mathrm{Re}\,\rho^0_{10} \mp \mathrm{Re}\,\rho^1_{10}\right), \tag{B4b}$$

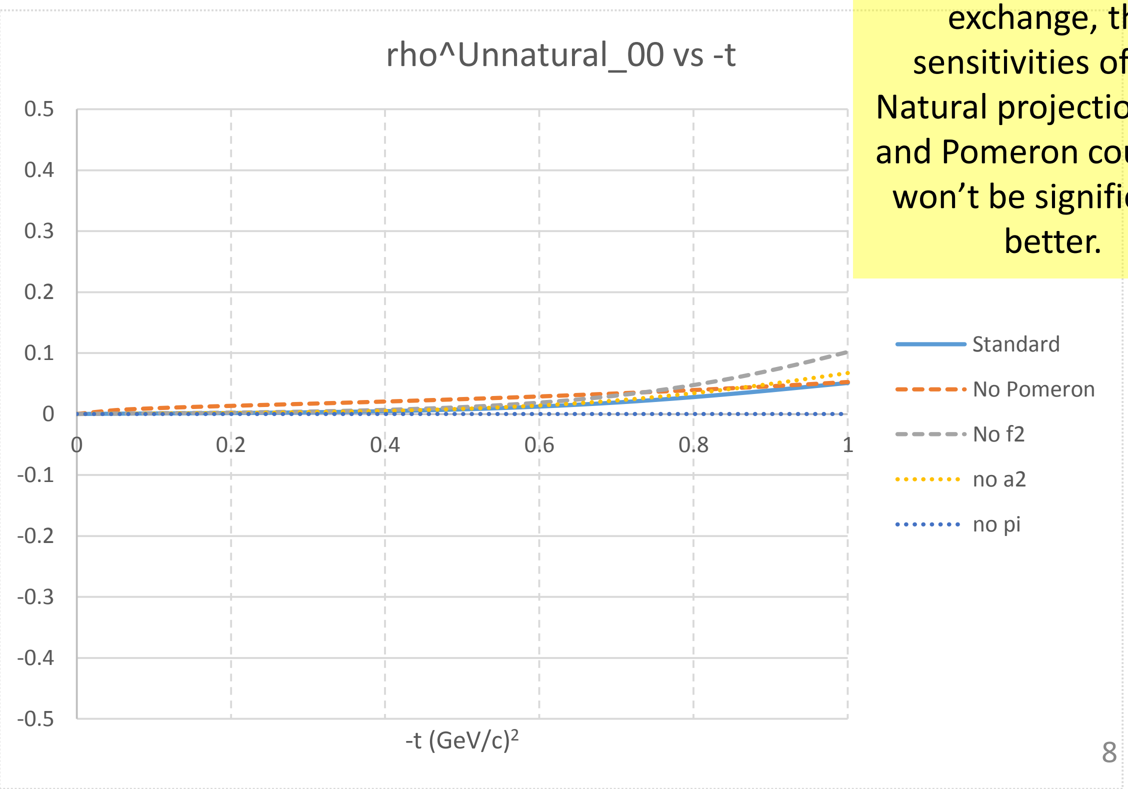
$$\rho^{N}_{1-1}{}^{}_{\!\!U} = \frac{1}{2}\left(\rho^1_{1-1} \pm \rho^1_{11}\right). \tag{B4c}$$

[Mat18a]
V. Mathieu, et al (JPAC),
``Vector Meson Photoproduction with Linearly Polarized Beam,''
arXiv:1802.09403 [hep-ph],

There’s a clear model prediction that Unnatural << Natural. But since the rho SDMEs in this –t range were already dominated by Natural exchange, the sensitivities of this Natural projection to f2 and Pomeron couplings won’t be significantly better.

Here’s one Natural and it’s corresponding Unnatural example, side by side: (see Backups for all)





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$$\rho^{\substack{N\\U}}_{1-1} = \frac{1}{2}\left(\rho^1_{1-1} \pm \rho^1_{11}\right). \qquad \text{(B4c)}$$

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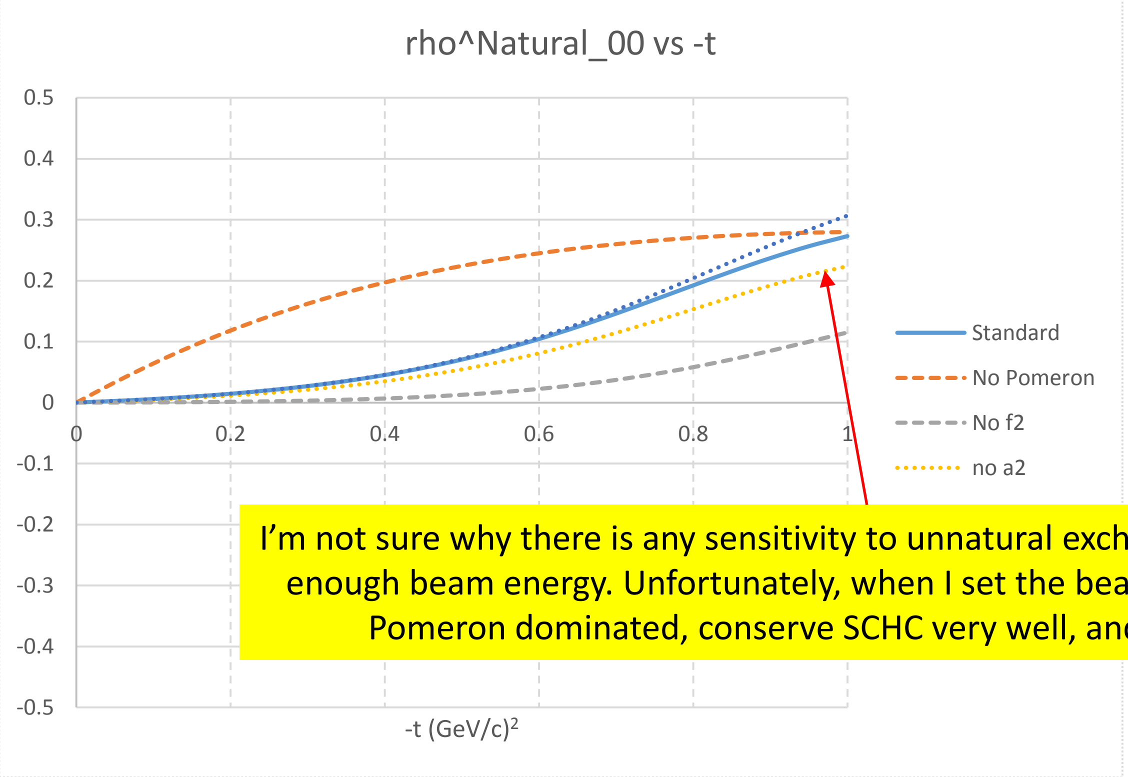
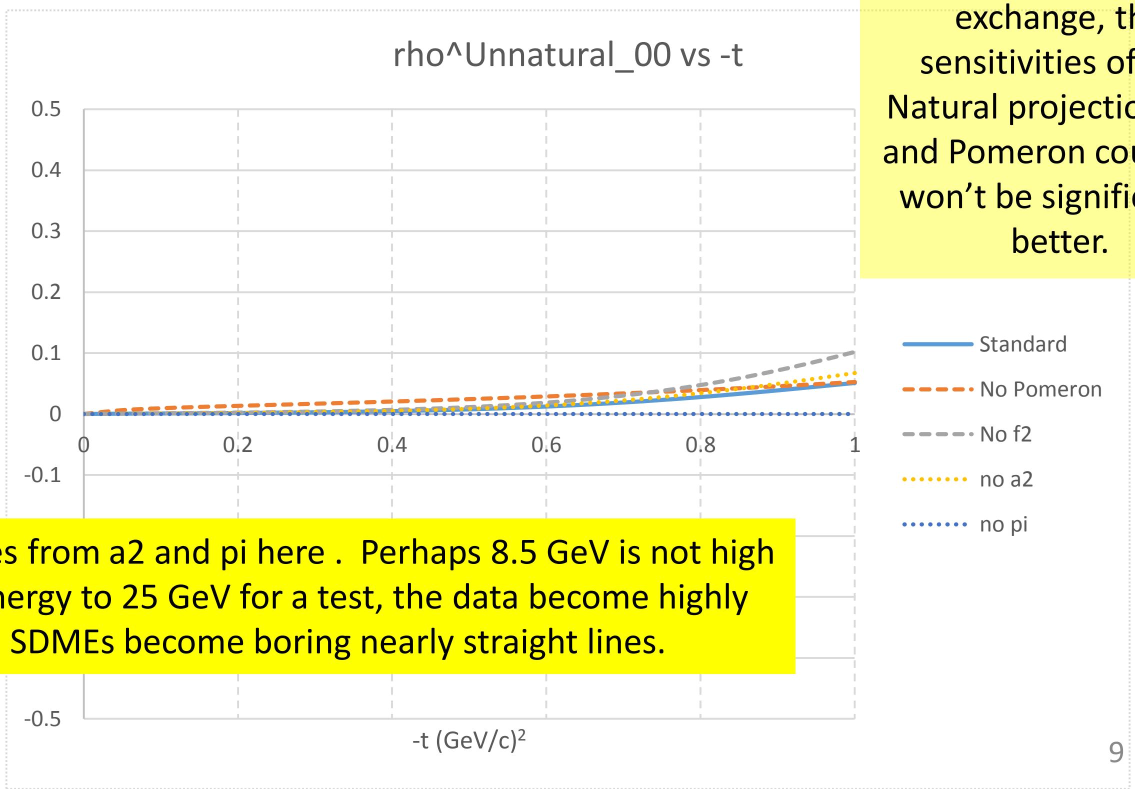
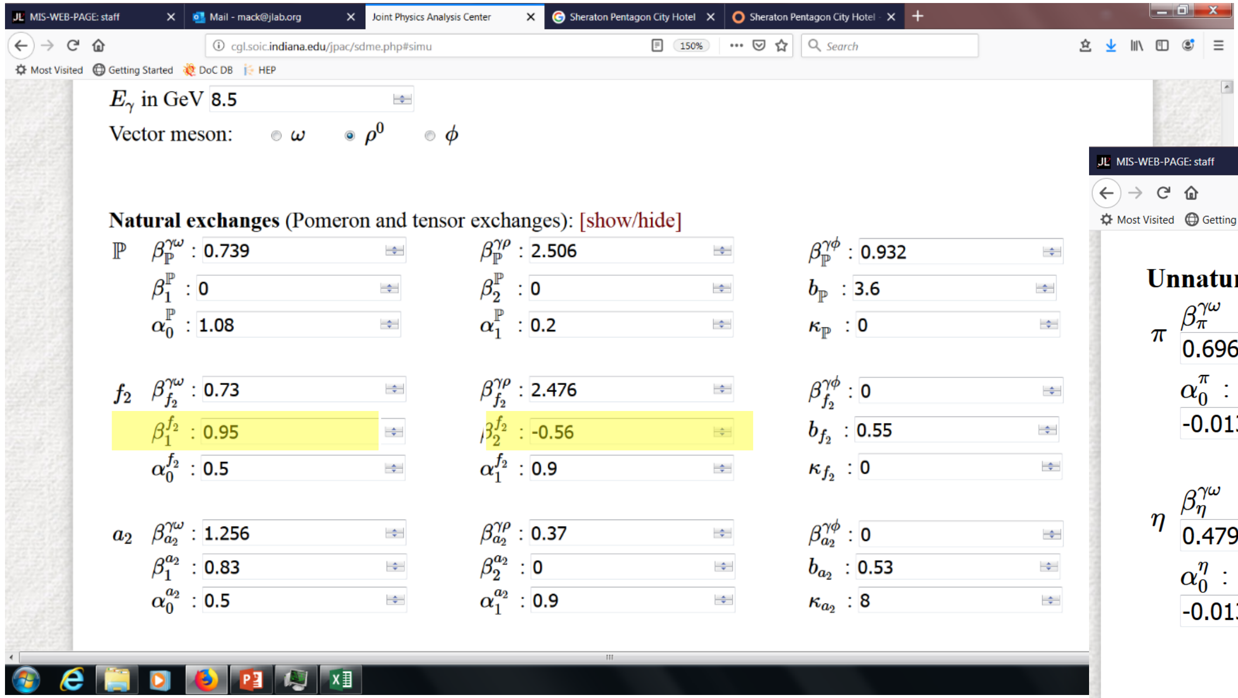


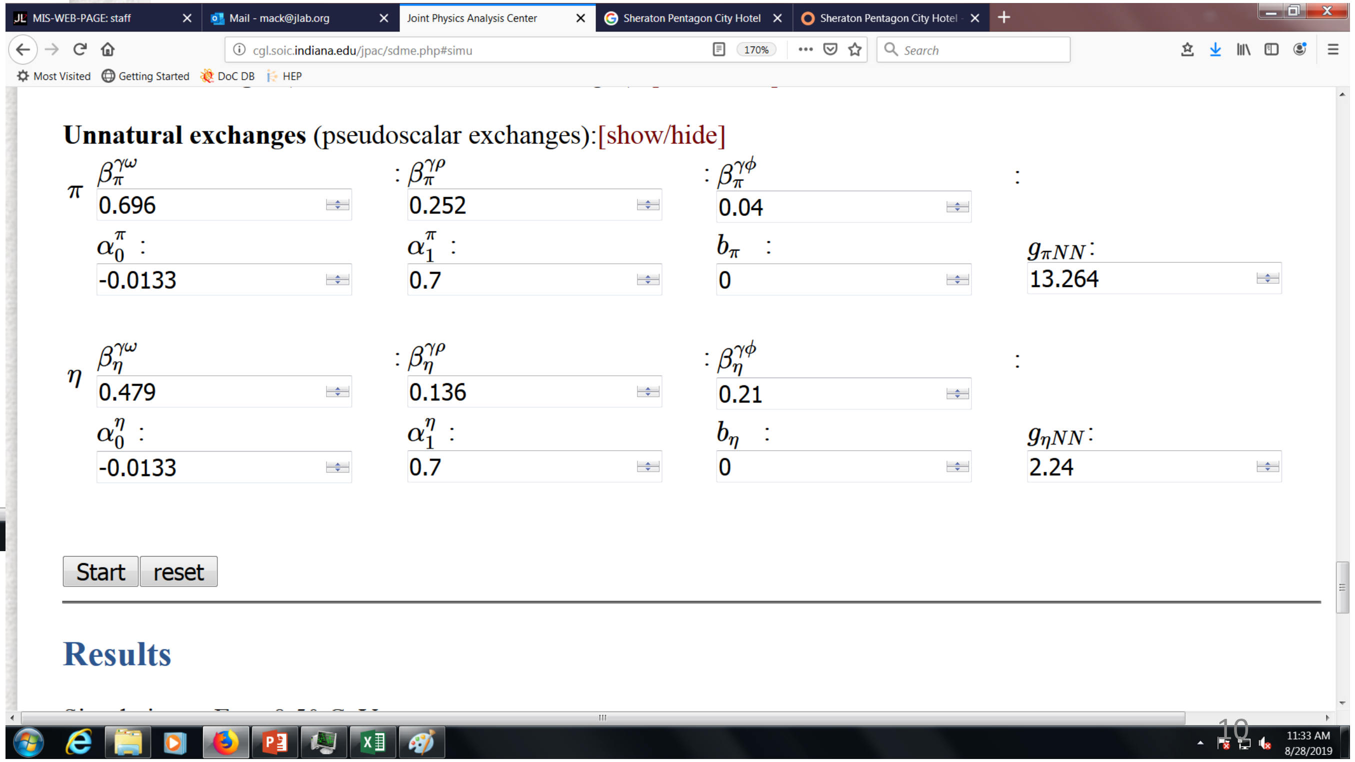


I'm not sure why there is any sensitivity to unnatural exchanges from a2 and pi here . Perhaps 8.5 GeV is not high enough beam energy. Unfortunately, when I set the beam energy to 25 GeV for a test, the data become highly Pomeron dominated, conserve SCHC very well, and the SDMEs become boring nearly straight lines.

If we're only going to study a handful of sensitivities of the SDMEs to model parameters, we definitely want to focus on the f2 and the Pomeron parameters.

So the next test was to set the beta^f2_1 and beta^f2_2 coefficients to zero, one at a time. (These are the single and double helicity flip parameters at the top vertex, respectively.)



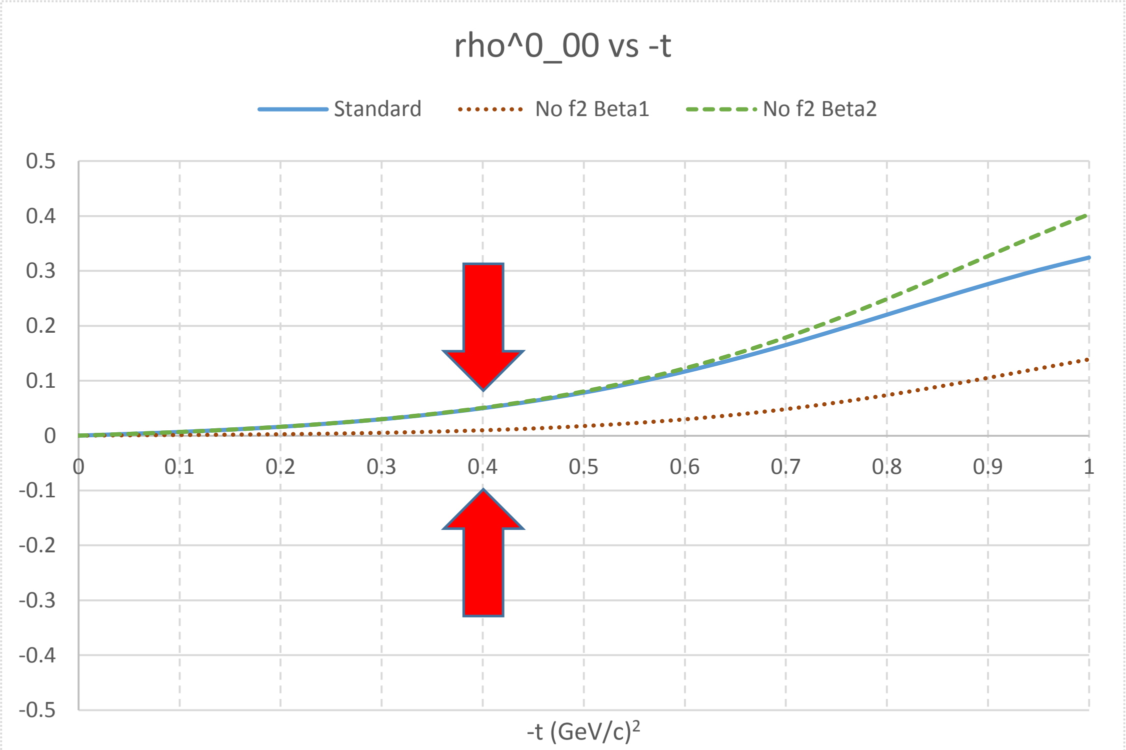


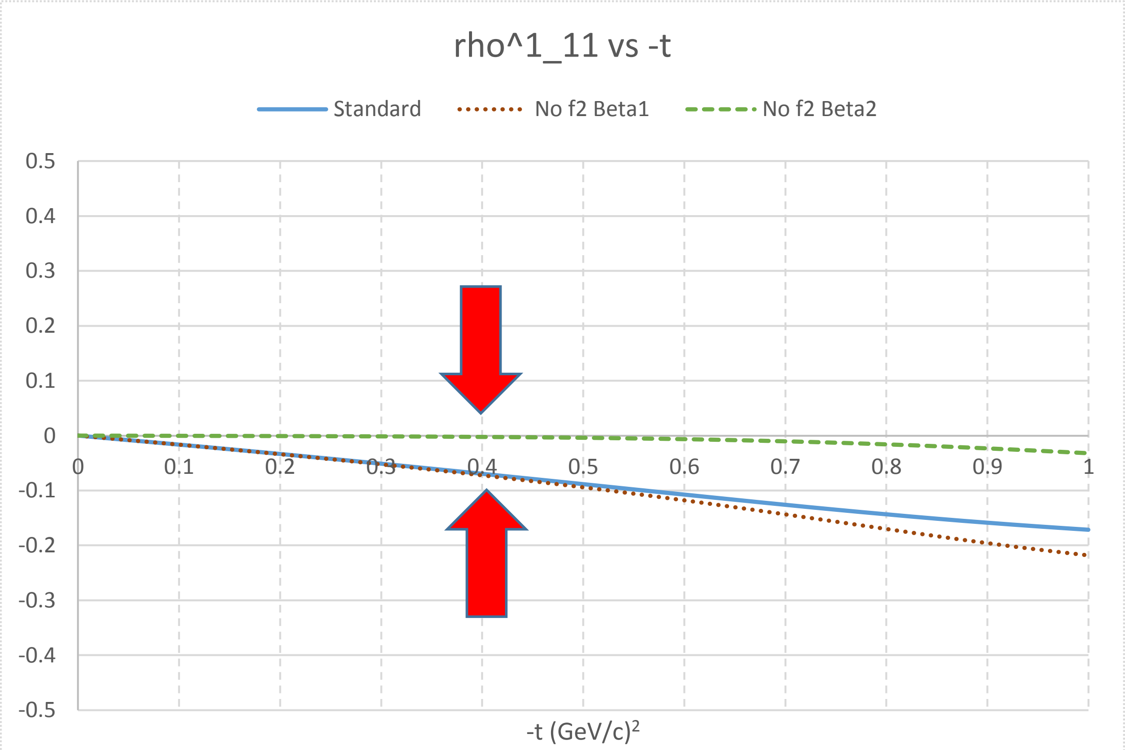
Setting either beta^f2_1 or beta^f2_2 to 0:

6 of the SDMEs behave like the example below left, where deviations from SCHC are dominated by beta^f2_1 . (See Backups for all plots.)

2 of the SDMEs are sensitive to beta^f2_2 while simultaneously being <u>in</u>sensitive to beta^f2_1. (See example below right.)

One SDME is relatively insensitive to <u>both</u> beta^f2_1 and beta^f2_2 : Im(rho^2_1-1)





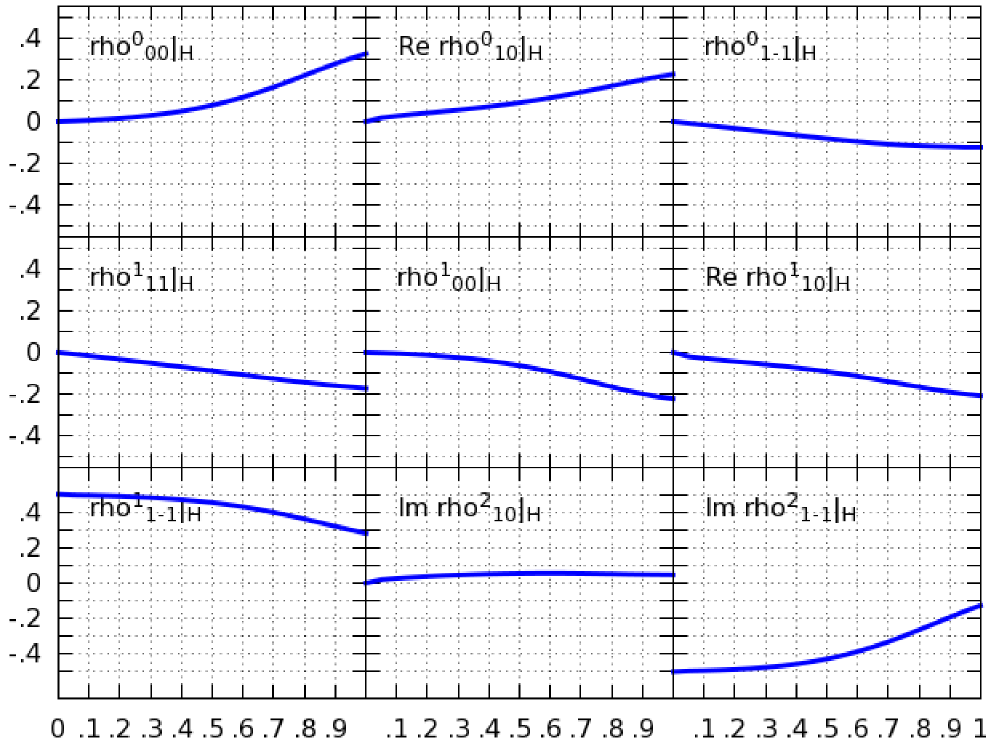
The good news is that it appears one could disentangle the Pomeron/f2 coupling ratio, beta^f2_1 , and beta^f2_2 . It may even be possible to do this with the 3 unpolarized SDMEs alone.

The less-good news is that these effects are small at 8.5 GeV for –t values where there is good agreement between Alexander A's data and the JPAC model. (See https://halldweb.jlab.org/doc-private/DocDB/ShowDocument?docid=4134 .) We would need to control errors at the level of +-0.01 .

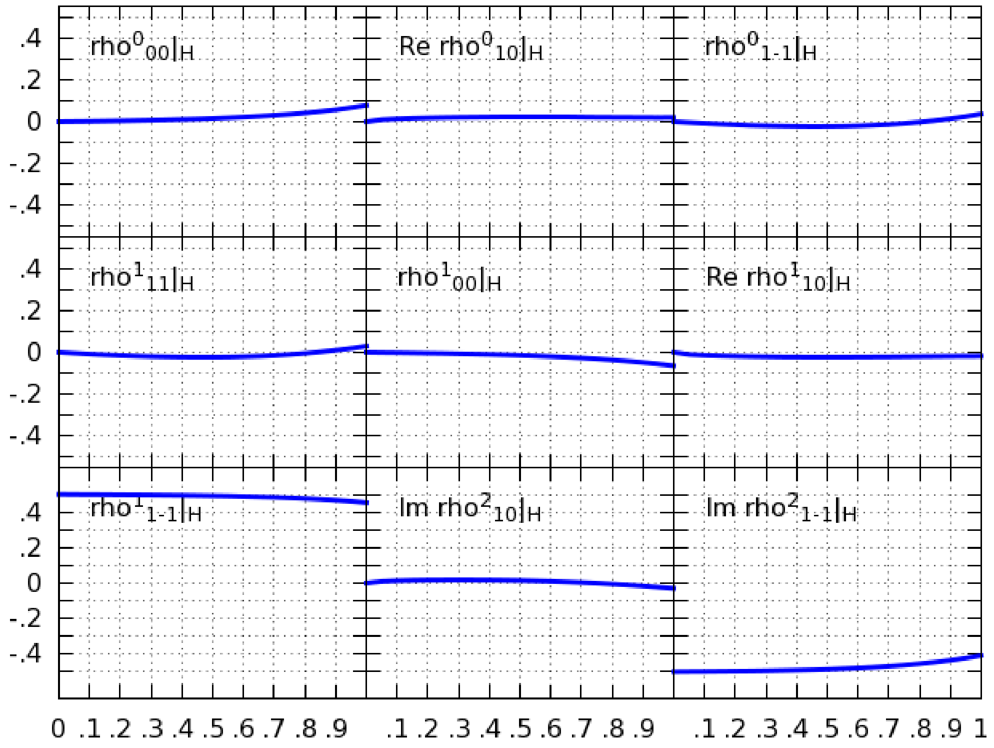
We saw earlier that the dominant contributions are f2 and Pomeron, and that the deviations from SCHC are due to f2 since the standard Pomeron is helicity non-flip. We noted also that relative contribution from the Pomeron increases with beam energy.

This suggests the rho SDMEs in the JPAC model should become boring at higher energies, since they will increasingly conserve helicity in the s-channel. Indeed, this is the case.

8.5 GeV



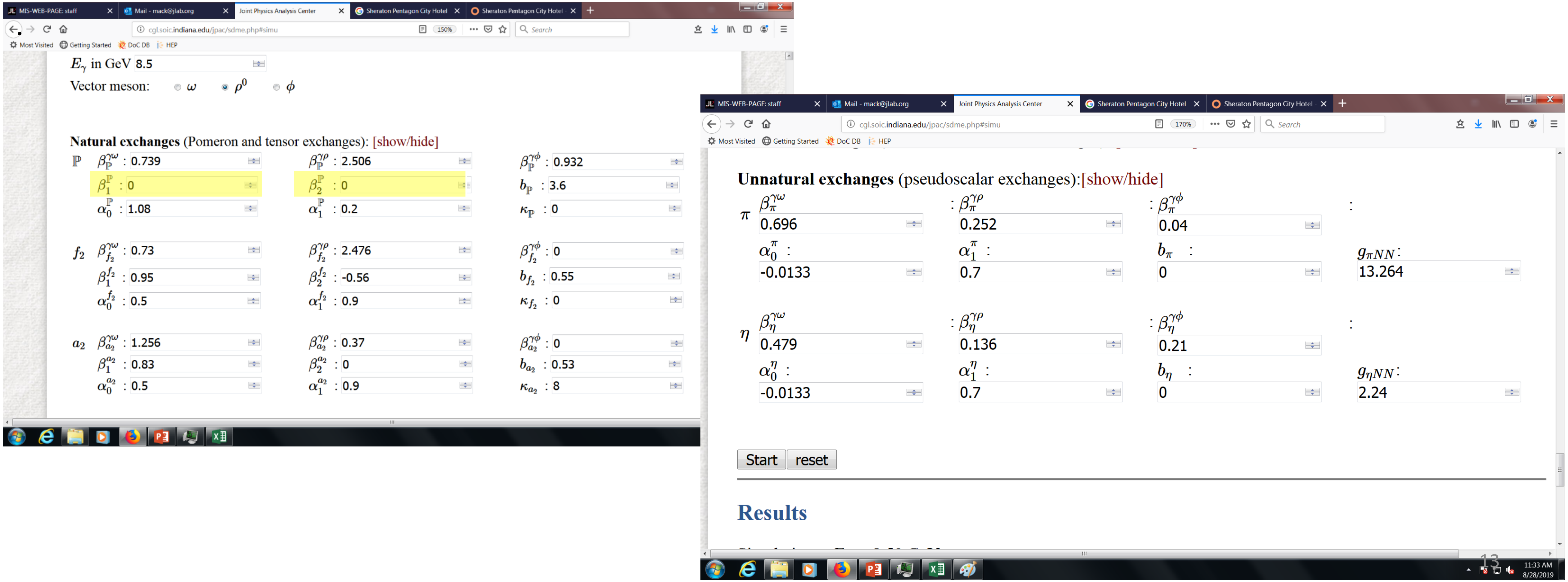
25 GeV



A corollary is that the SDMEs should be a little larger and easier to measure at lower beam energy. That is true, but it’s a modest effect. (Not shown.)

Yet another test was to increase the beta^Pomeron_1 and beta^Pomeron_2 coefficients from 0 to 0.5 , one at a time.
(Just being thorough. This would be a very non-standard Pomeron.)

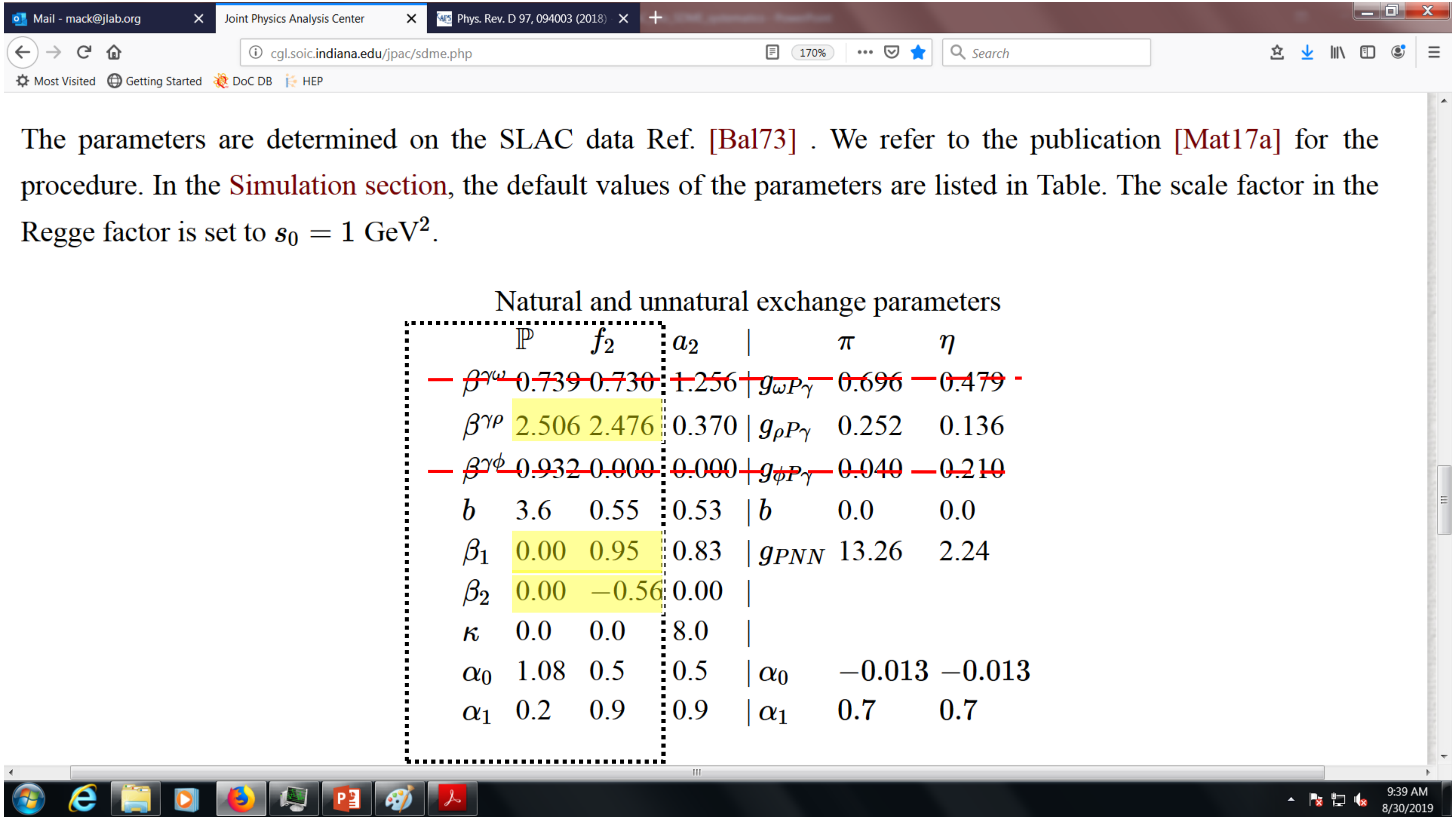
See the Backups and the Excel file for plots. The results seem qualitatively similar to those on the previous slide for the f2 single- and double- helicity flip parameters. It's not clear to me whether it's possible to distinguish, *in fits to single beam energy rho SDMEs alone*, between beta^f2_1 and beta^Pomeron_1 (as well as between beta^f2_2 and beta^Pomeron_2).



Of the 31 parameters potentially affecting rho production, there are “only” 14 involved in the dominant Pomeron and f2 exchanges. (dotted black box)

Discounting the Regge trajectory parameters and the b slope parameters which are probably better determined by xsect data, discounting the nucleon helicity flip kappa parameter to which the SDMEs are reportedly insensitive, then there are 6 parameters whose SDME sensitivities I thought might be interesting.

I have explored the sensitivities of all 6 of these in these slides (yellow).



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Natural and unnatural exchange parameters

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b	3.6	0.55	0.53	b	0.0	0.0
β_1	0.00	0.95	0.83	g_{PNN}	13.26	2.24
β_2	0.00	-0.56	0.00			
κ	0.0	0.0	8.0			
α_0	1.08	0.5	0.5	α_0	-0.013	-0.013
α_1	0.2	0.9	0.9	α_1	0.7	0.7

Summary

- The rho SDMEs are mainly sensitive to the Pomeron and f2 exchanges.

- Relative contributions from the Pomeron increase significantly with beam energy. Since the Pomeron in the JPAC model is helicity non-flip, any f2 helicity-flip dynamics gets diluted away with increasing beam energy. By 25 GeV, the rho SDMEs would be approximately straight lines that conserve s-channel helicity.

- As far as what specific physics might be gleaned:

  i. one could measure the relative strength of the Pomeron and f2 exchanges versus beam energy.

  ii. if errors at the level of +-0.01 can be achieved, we could constrain the helicity flip parameters of the gamma-f2-rho vertices. (The helicity flip strengths seem to be additive, possibly making it meaningless to vary the f2 and Pomeron versions of beta_1or2 simultaneously. Before one could search for subtle deviations from a non-standard Pomeron, it seems one would need rho SDME data over a range of beam energies, or to include omega and/or phi SDMEs in the fits.)

- The 3 unpolarized SDMES appear to contain qualitatively similar information to the 6 polarized SDMEs. Although the redundancy and error cancellation in the polarized SDMEs is valuable, the unpolarized SDMEs are perhaps a way to constrain Pomeron and f2 parameters over the wider GlueX beam energy range 6-12 GeV.

- The nominally “Natural” linear combination of SDMEs seems to contain unsuppressed contributions from the small, unnatural a2 and pi exchanges. (So either I screwed up, or the beam energy isn’t high enough for the Natural projection to work well. The Unnatural version didn’t look too bad, ie, relatively small.)

Backups

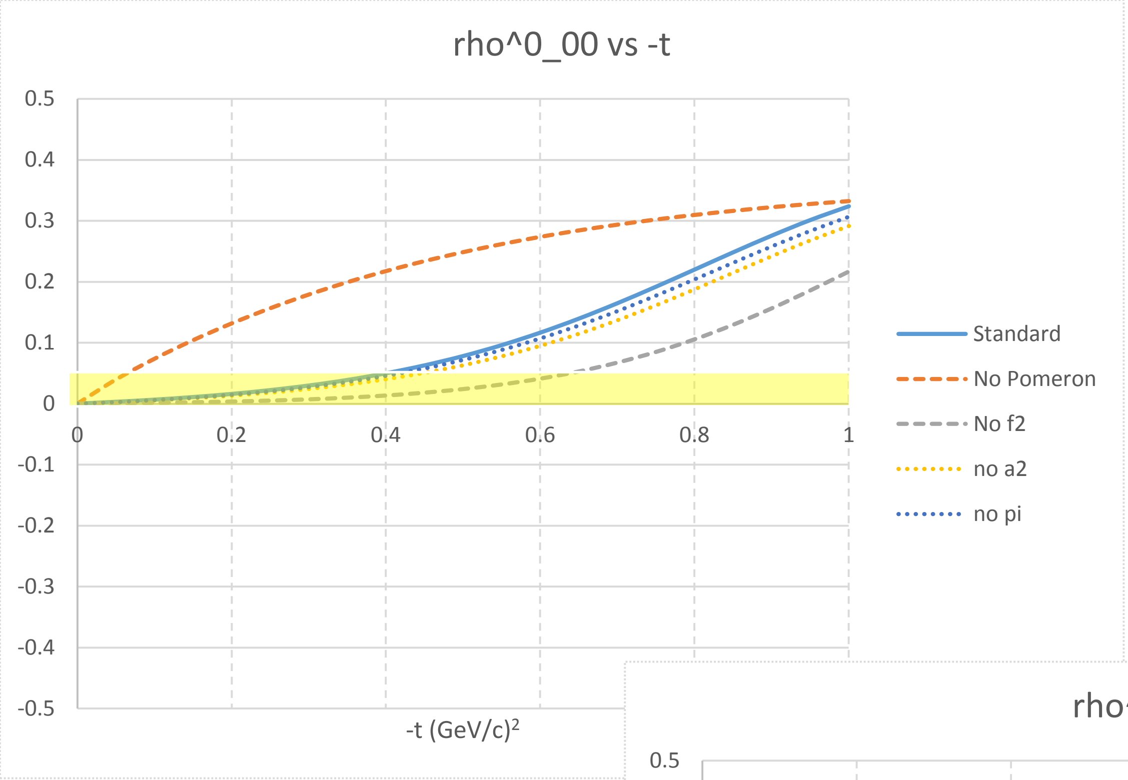
Wish list to discuss with Vincent:

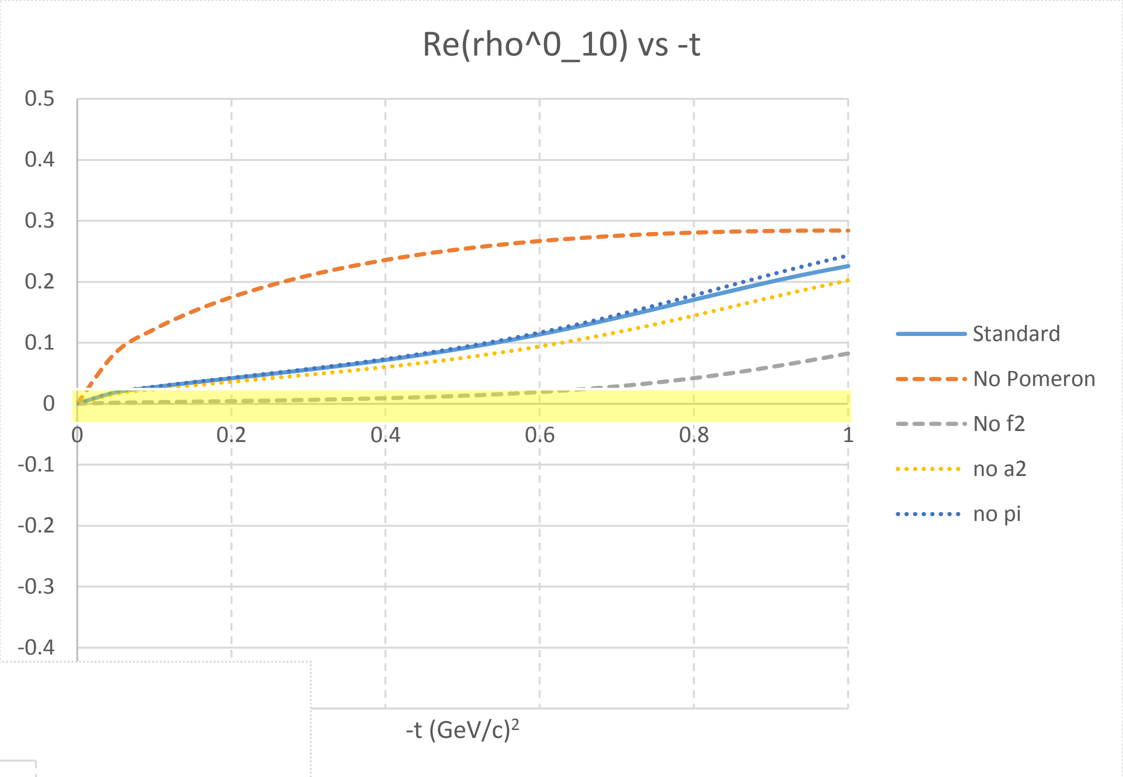
- There's no output if I set eta coupling constant to 0. Can you fix?

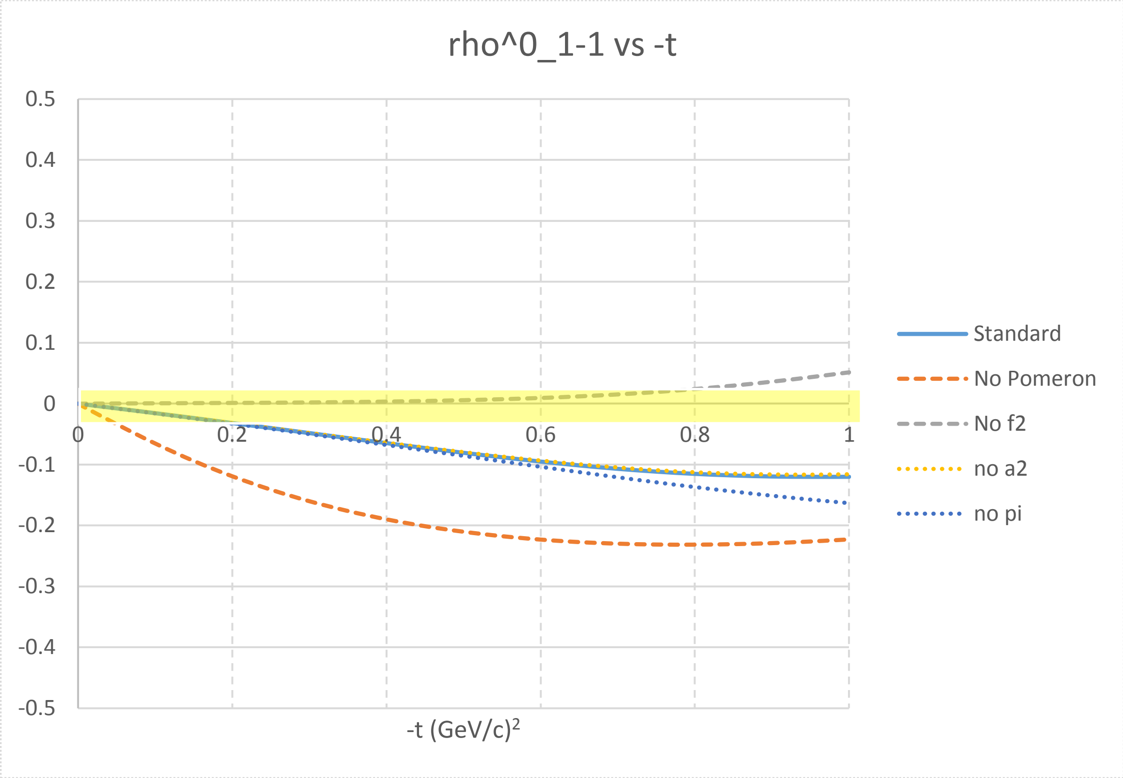
- Can you add dsigma/dt so we can understand the complementarity between SDMEs and xsects for determining the f2 and Pomeron parameters?

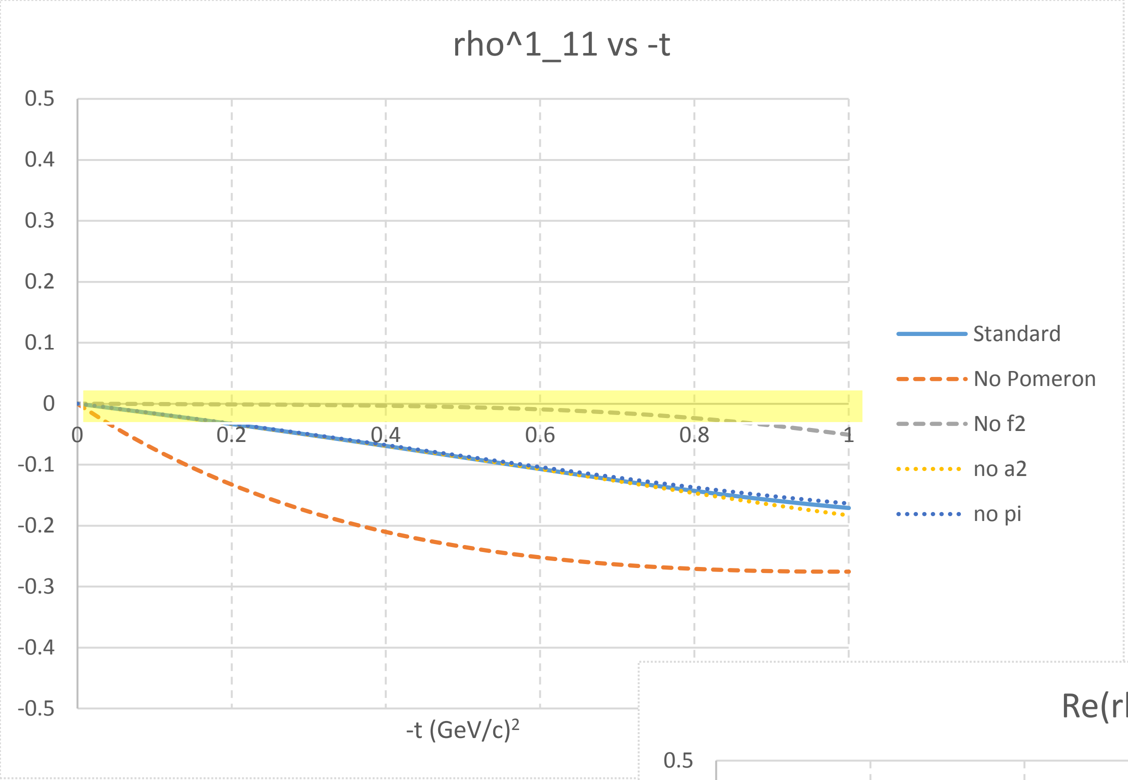
- Why are the SDMEs generally so much larger in the GJ frame? Are we throwing out the baby with the bathwater by sticking to the helicity frame?

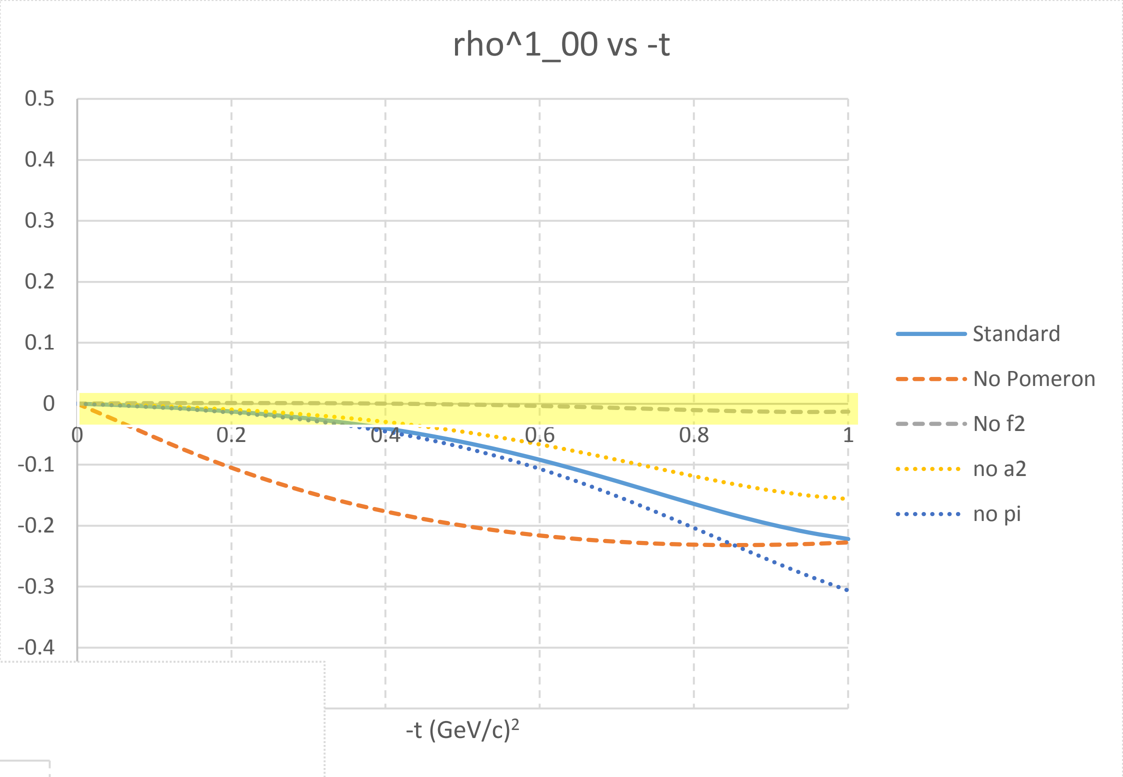
The 9 rho SDMEs
(setting the upper vertex couplings to 0, one at a time)

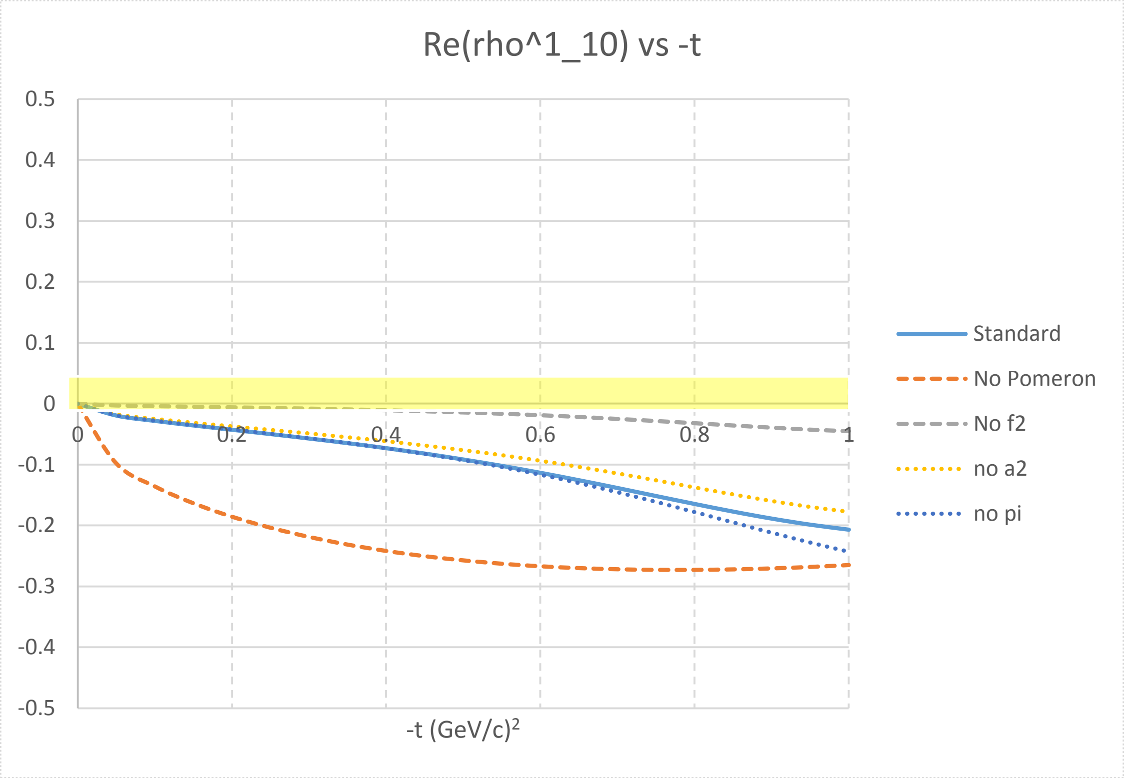

rho^0_00 vs -t
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi

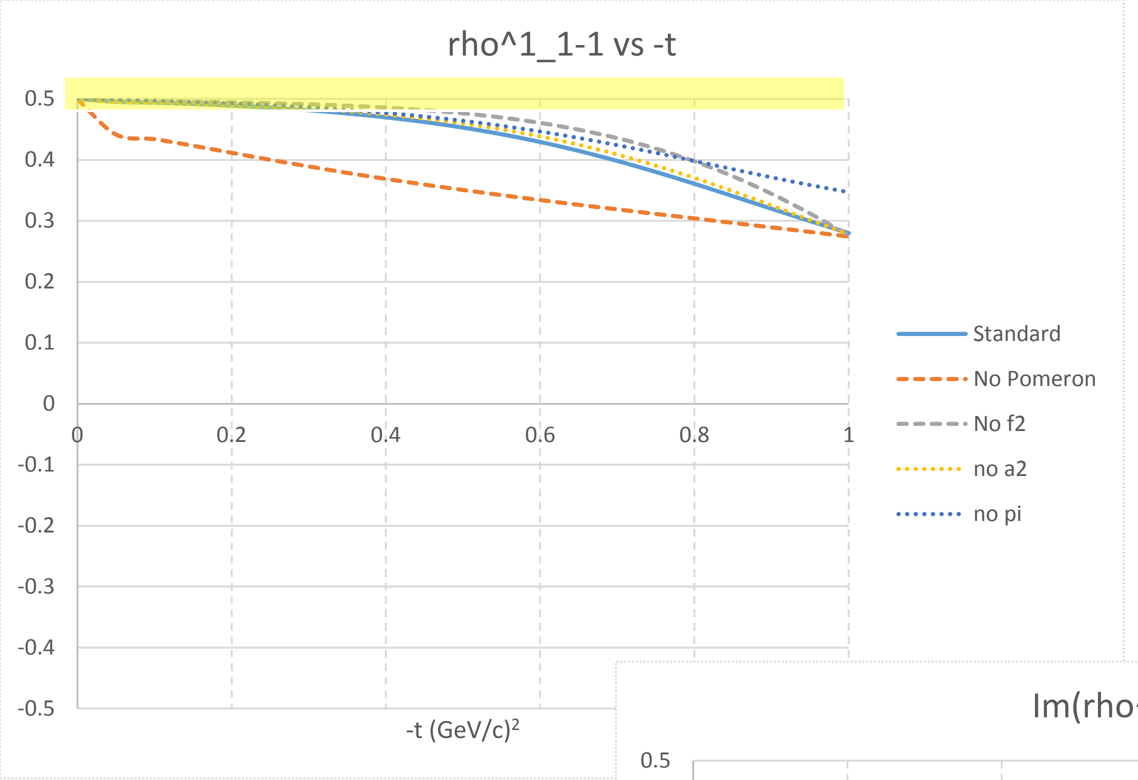

Re(rho^0_10) vs -t
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi


rho^0_1-1 vs -t
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi


rho^1_11 vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi


rho^1_00 vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi


Re(rho^1_10) vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi


rho^1_1-1 vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
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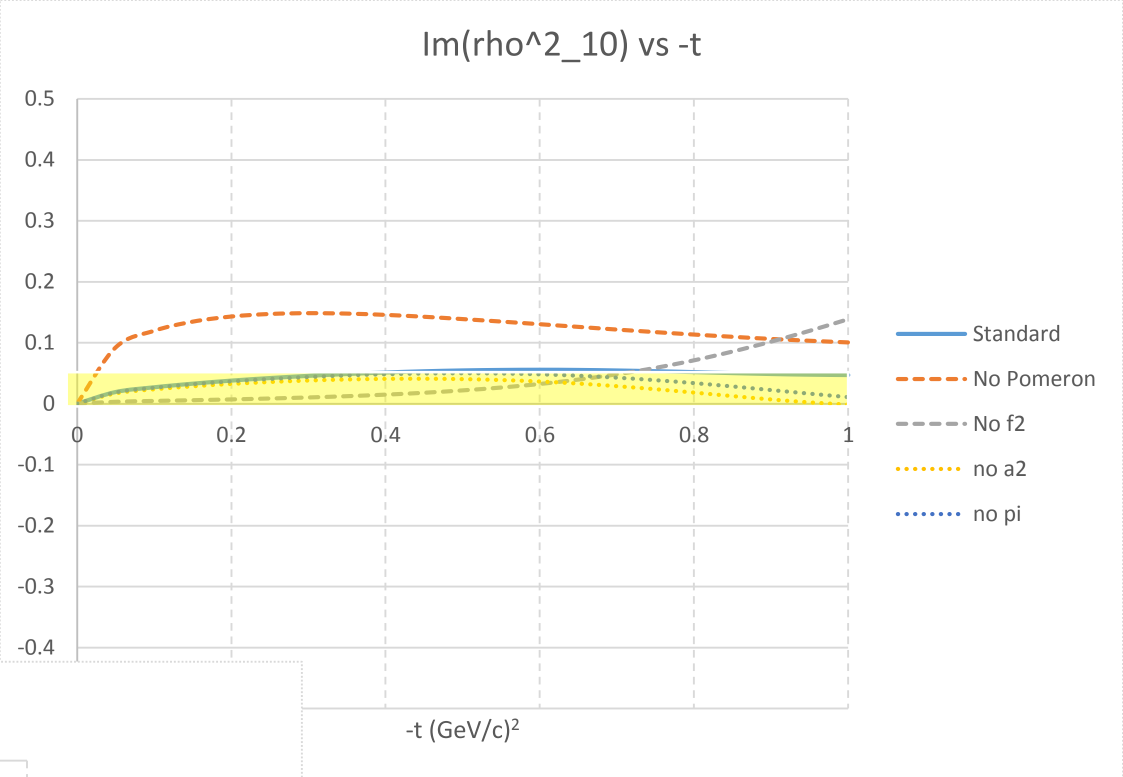
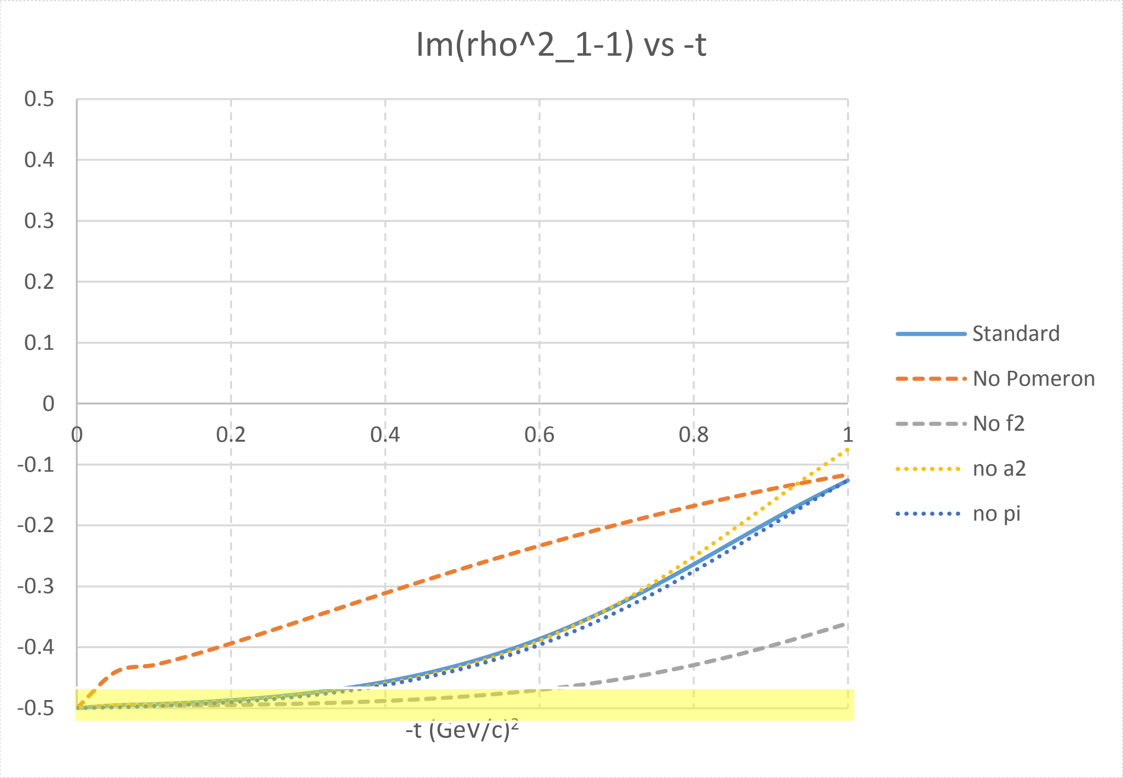
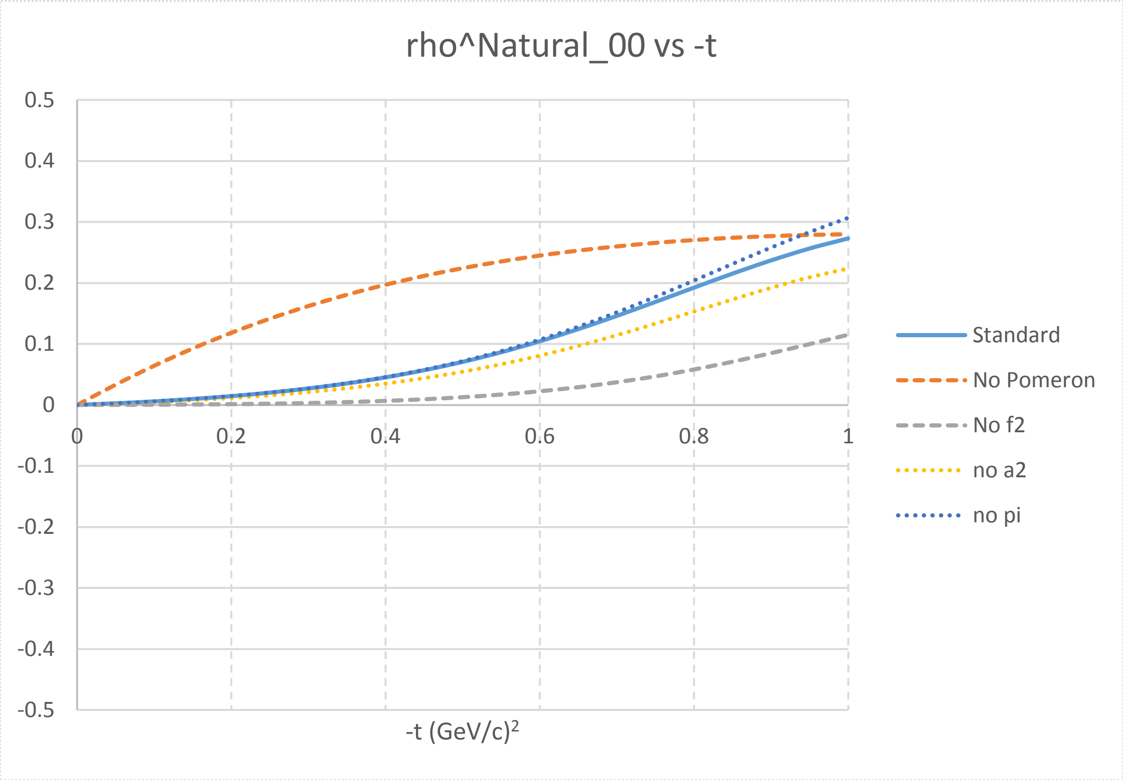
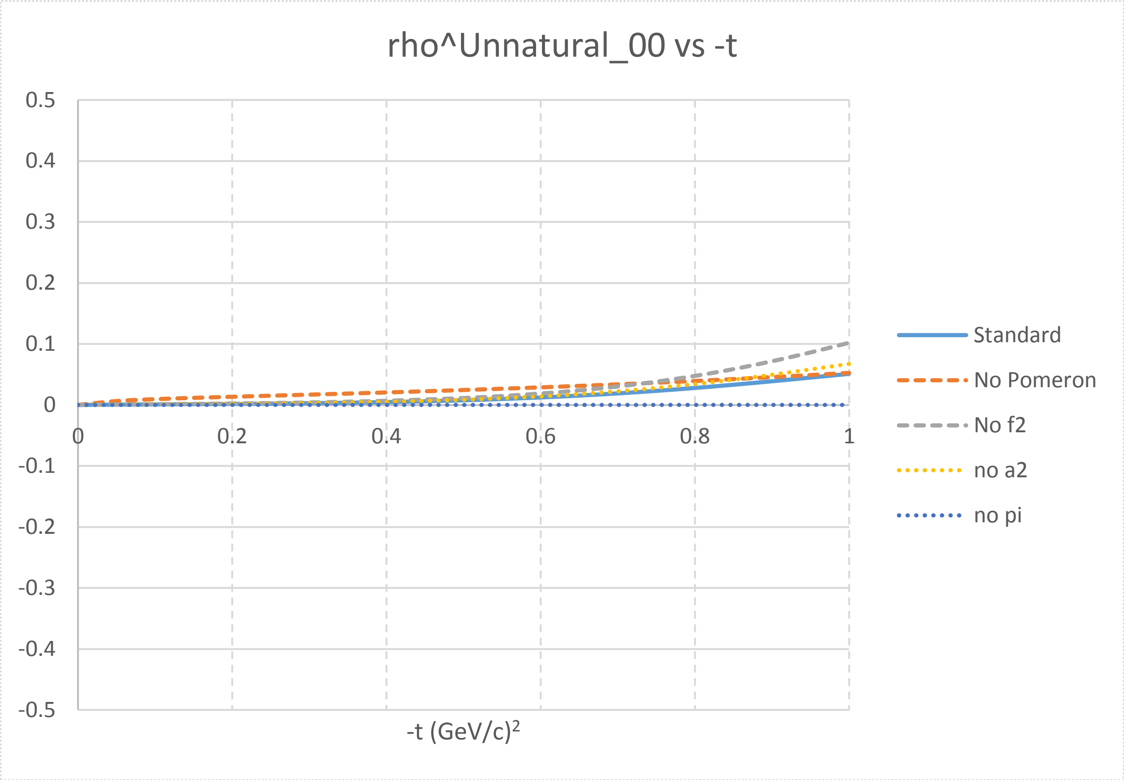
no a2
no pi


Im(rho^2_10) vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi


Im(rho^2_1-1) vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi

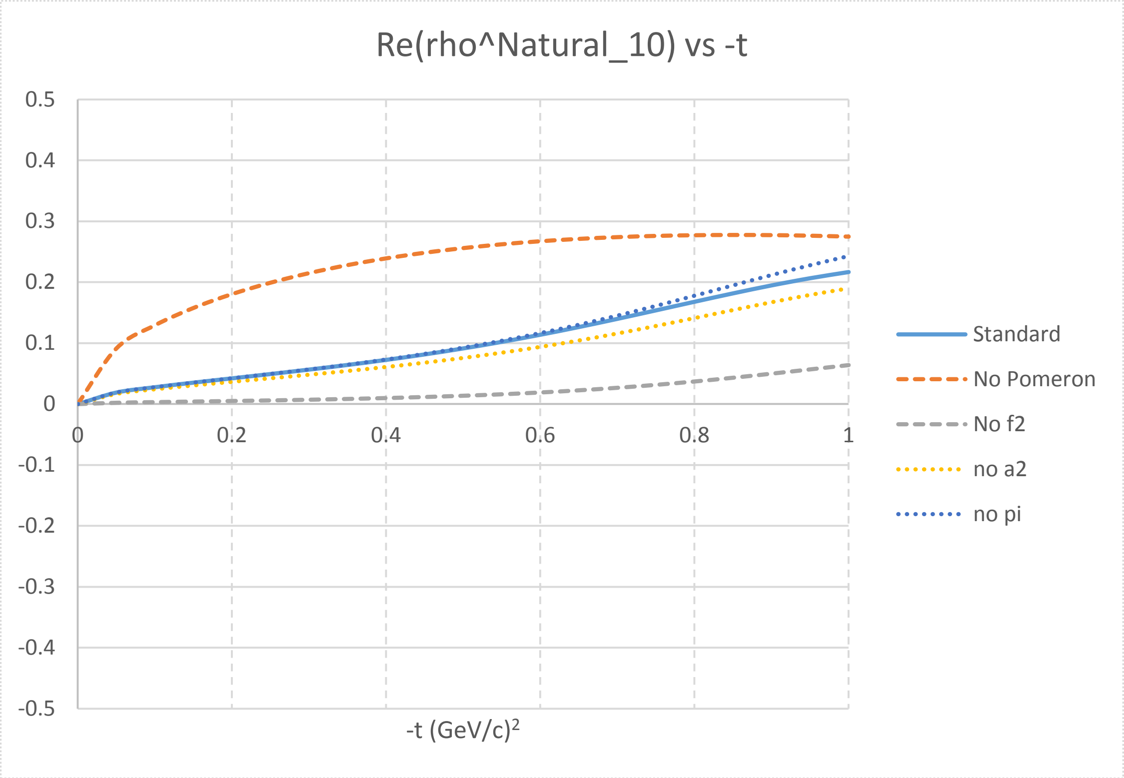
The 3+3 rho (Un)Natural SDMEs

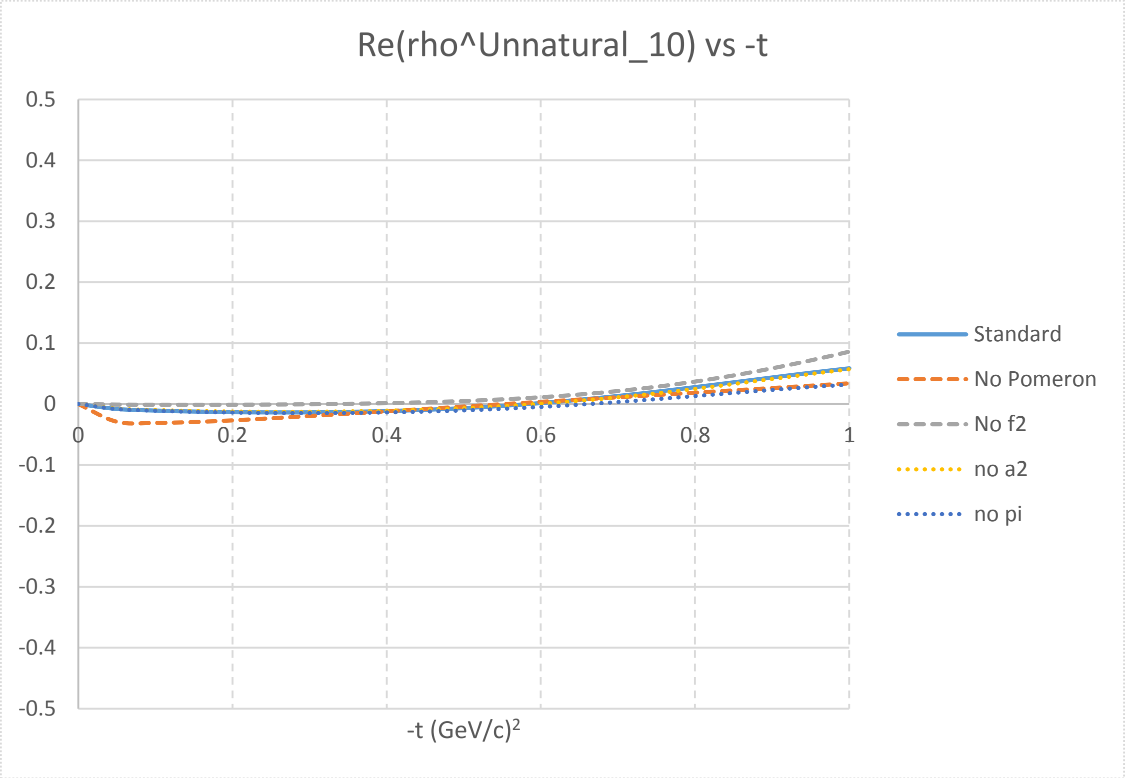


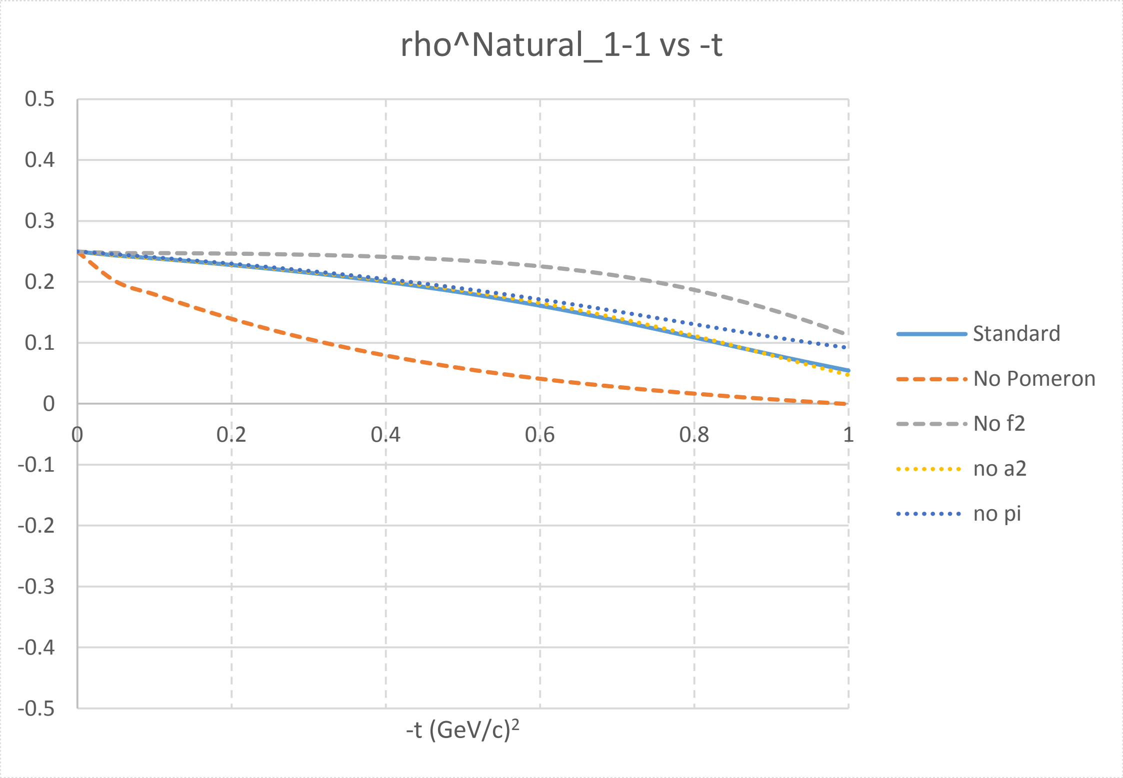


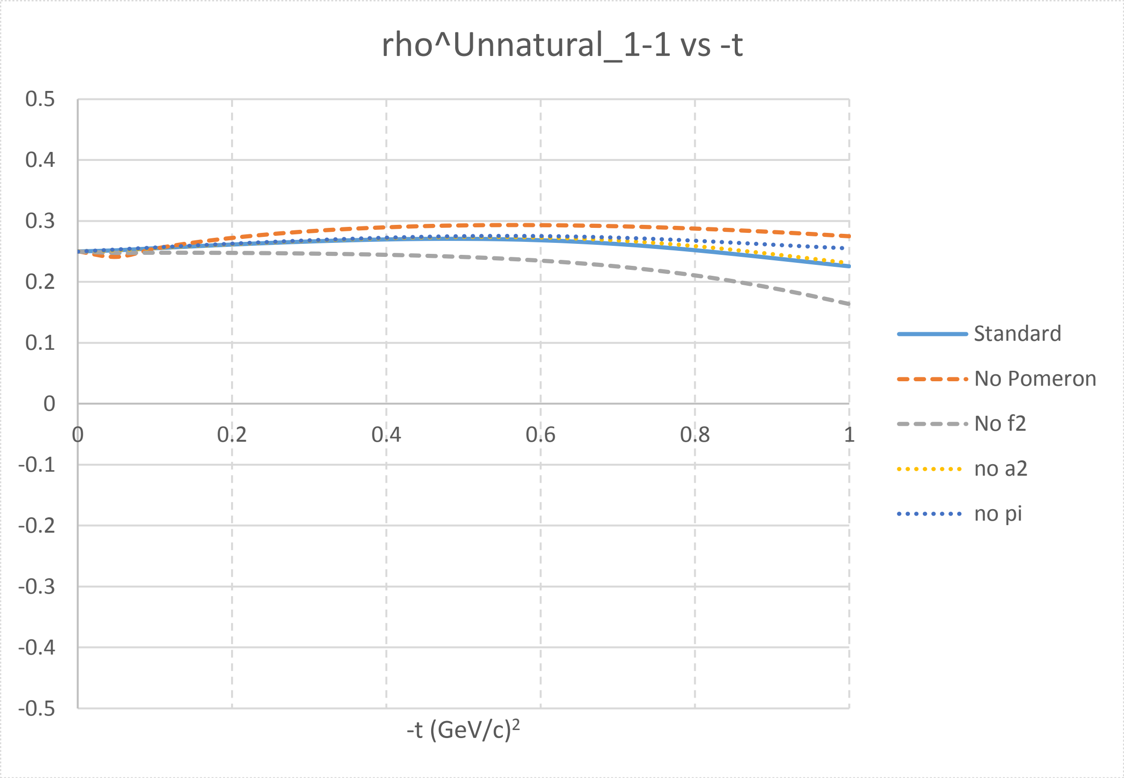
I’m not sure what it means that the unnatural a2 and pi exchanges are making a small contribution to this supposedly “Natural” linear combination. Does it mean the energy isn’t high enough, or a bug, or …?

The “Unnatural” plot is nicely small, but one can see that the Pomeron is making an unexpectedly significant contribution.

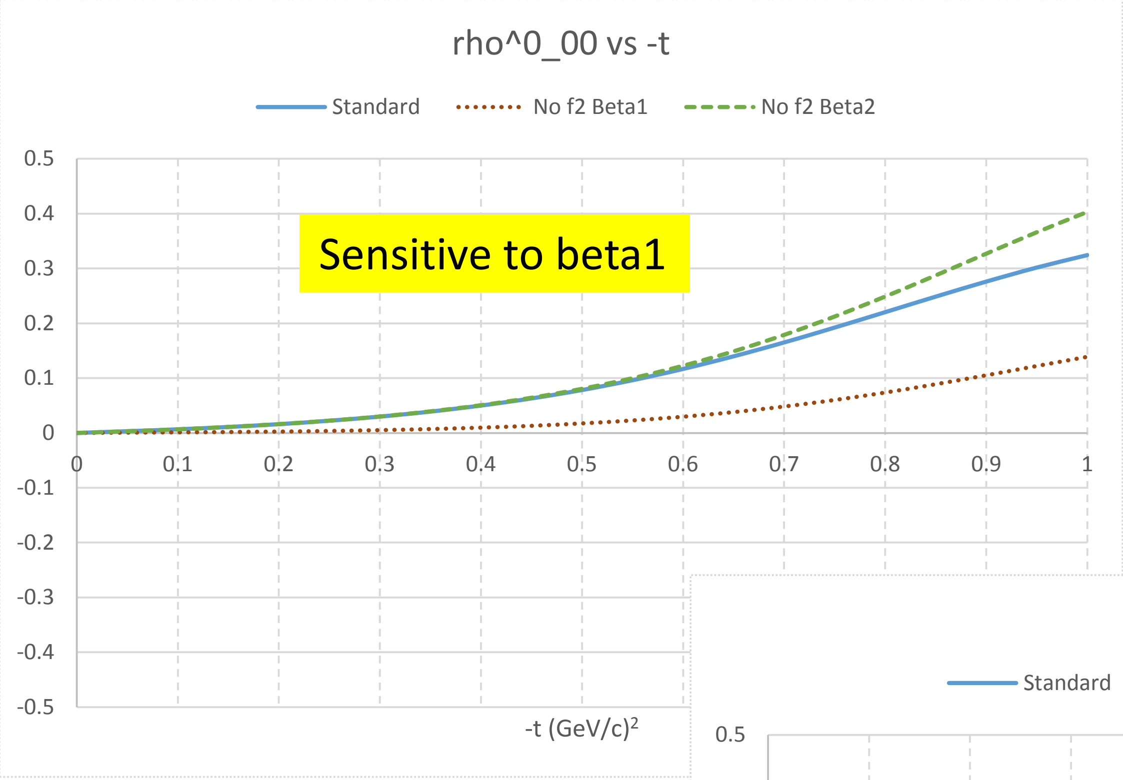

Re(rho^Natural_10) vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi

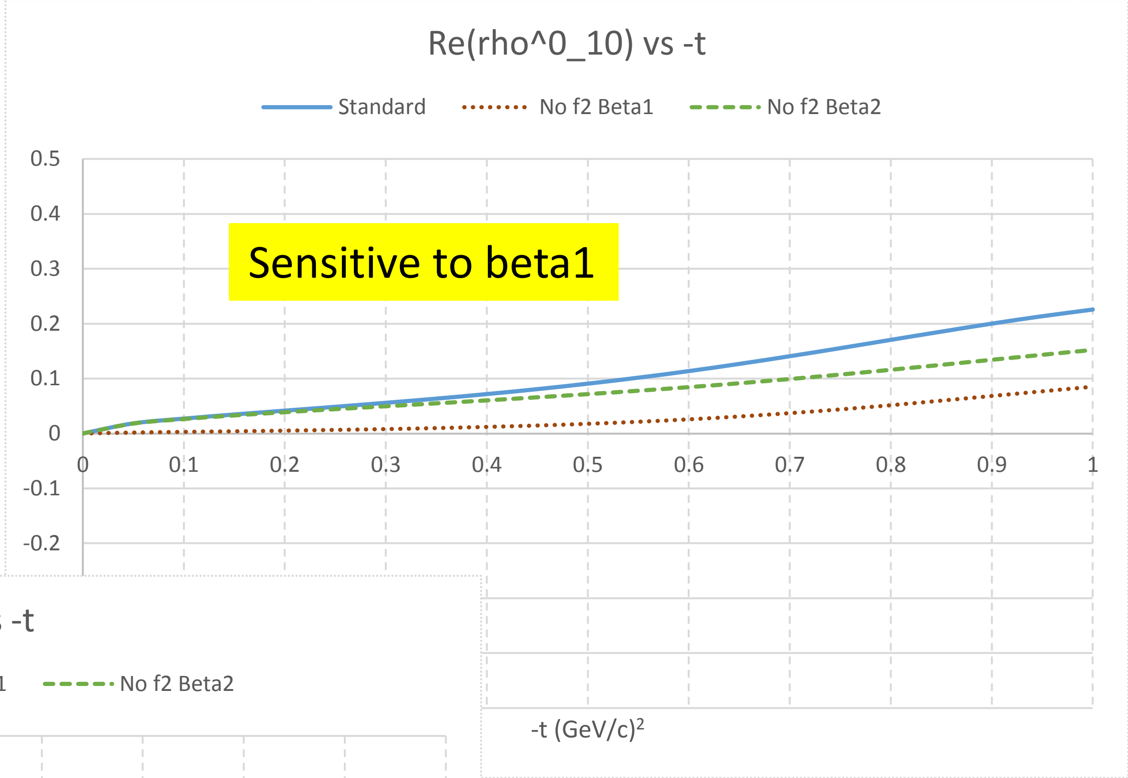

Re(rho^Unnatural_10) vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi

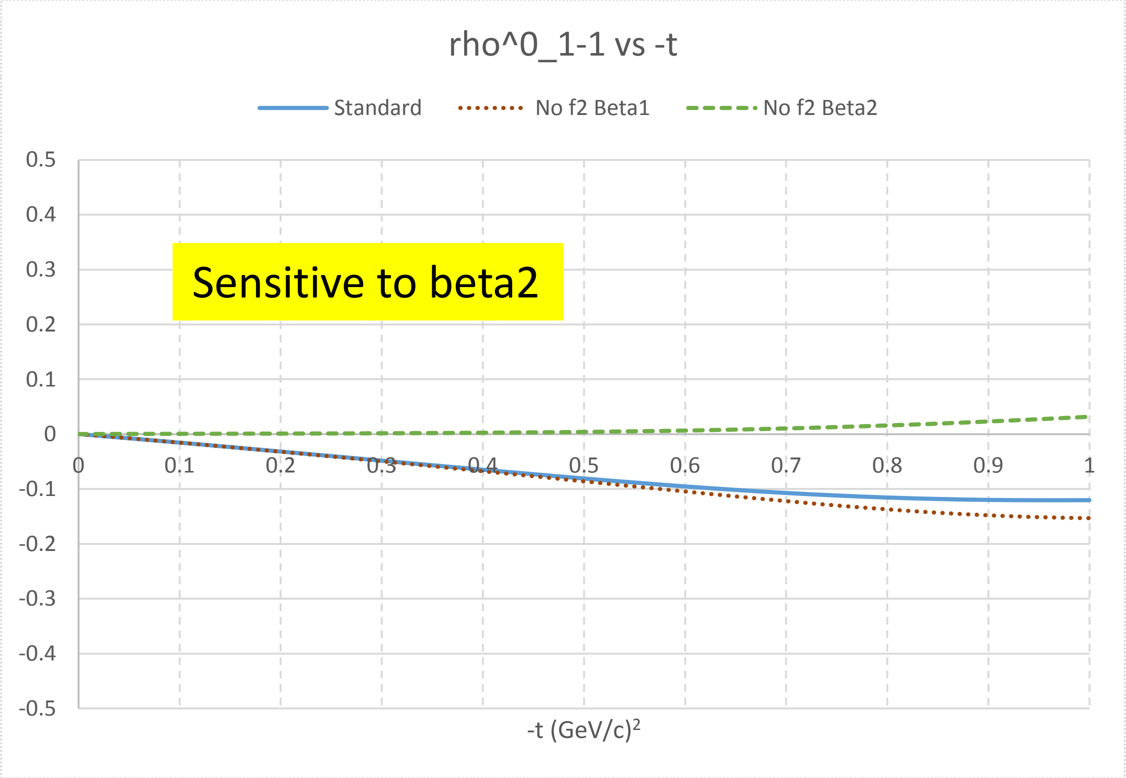

rho^Natural_1-1 vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi

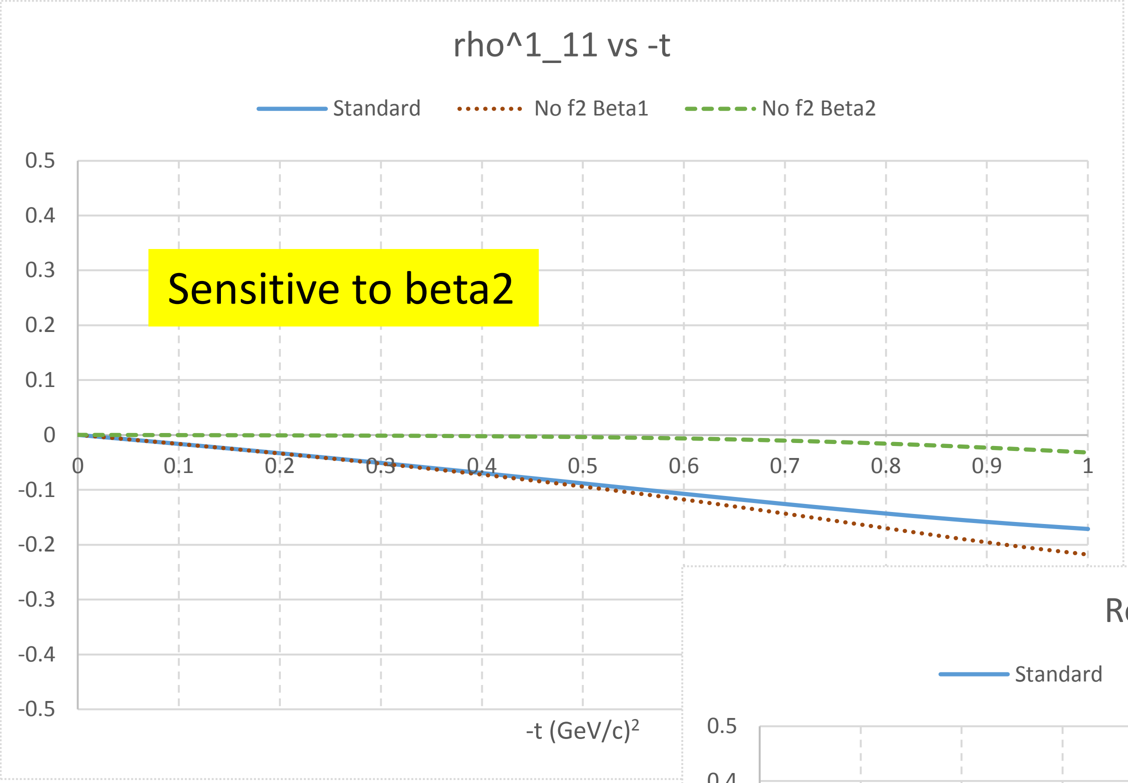

rho^Unnatural_1-1 vs -t
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.2
0.4
0.6
0.8
1
-t (GeV/c)²
Standard
No Pomeron
No f2
no a2
no pi

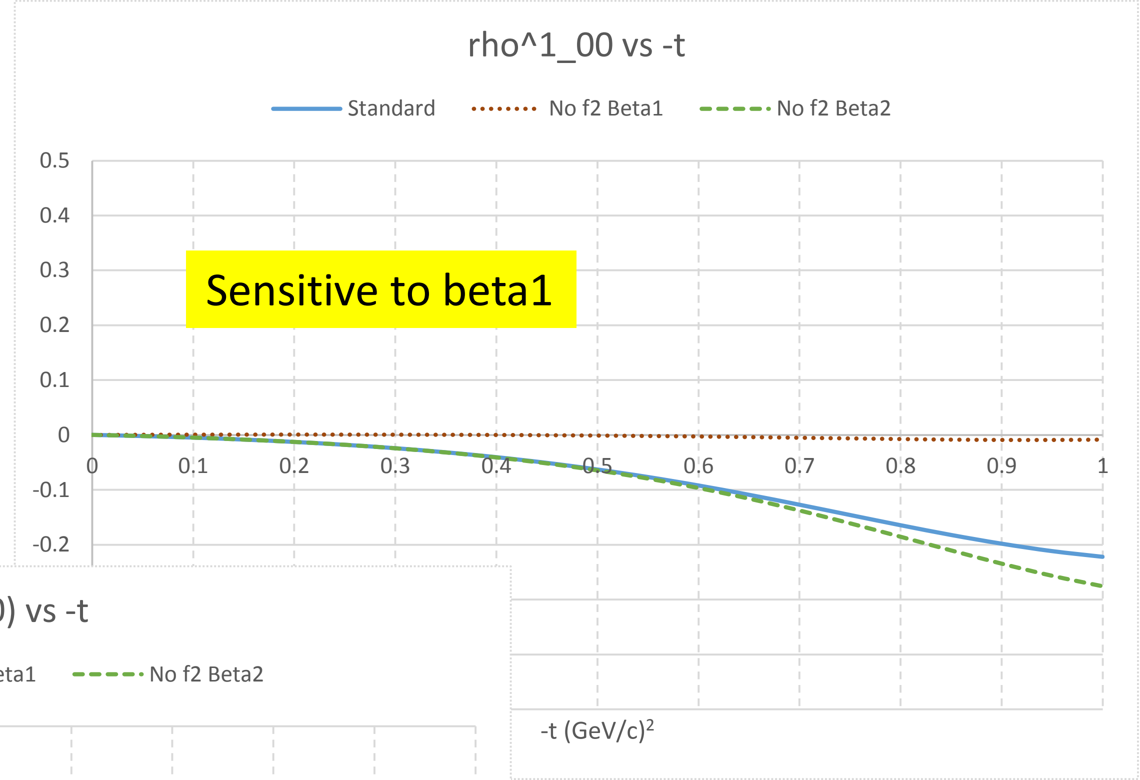
The 9 rho SDMEs
(setting the Beta^f2_1 or Beta^f2_2 coupling to 0)

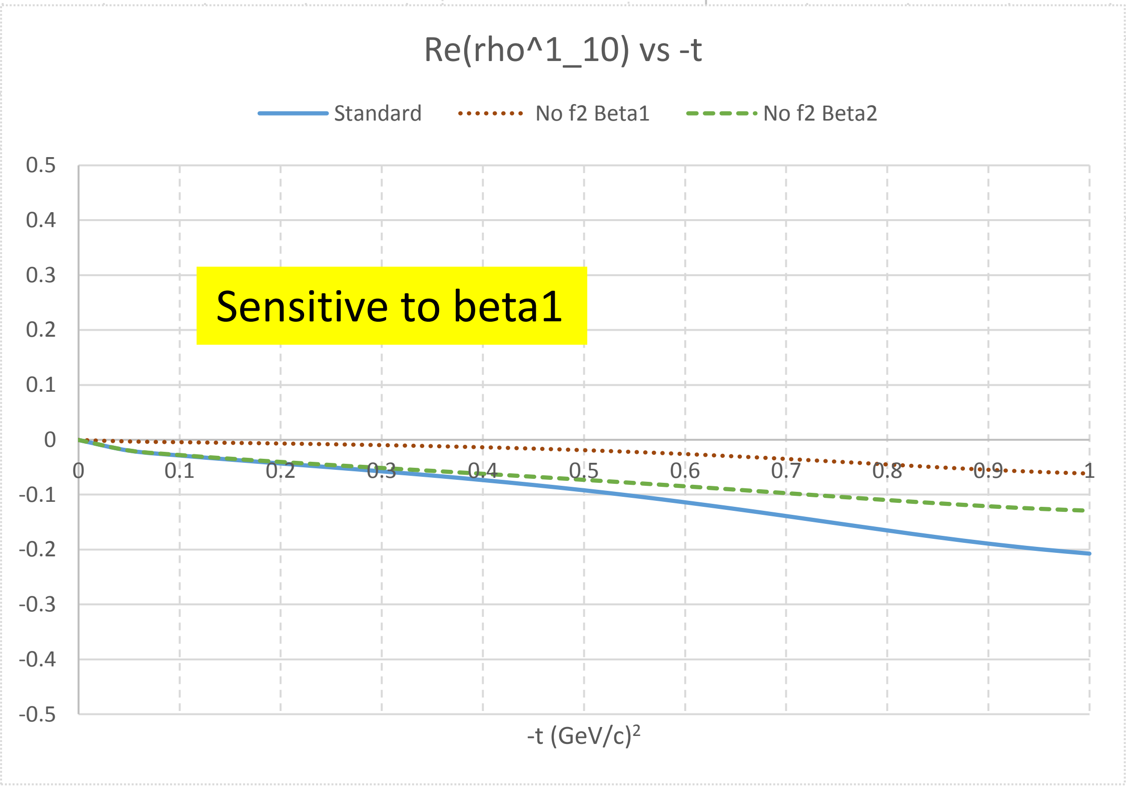

rho^0_00 vs -t
Standard
No f2 Beta1
No f2 Beta2
Sensitive to beta1
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV/c)²

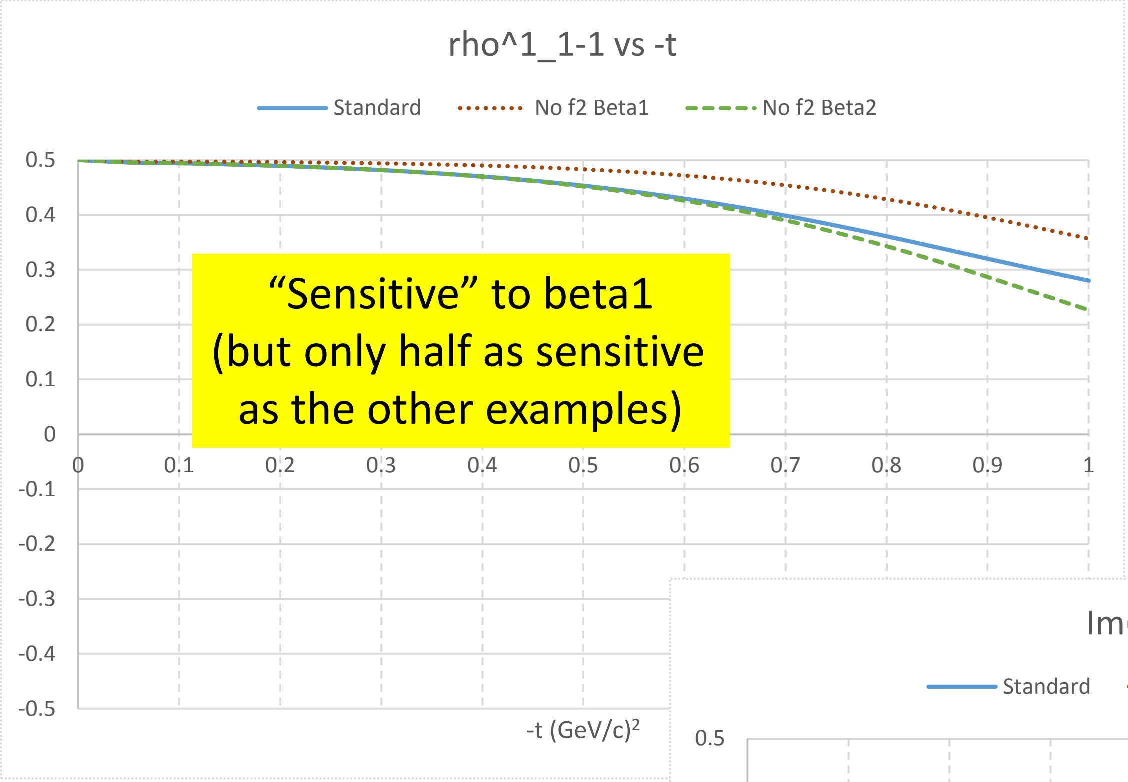

Re(rho^0_10) vs -t
Standard
No f2 Beta1
No f2 Beta2
Sensitive to beta1
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV/c)²

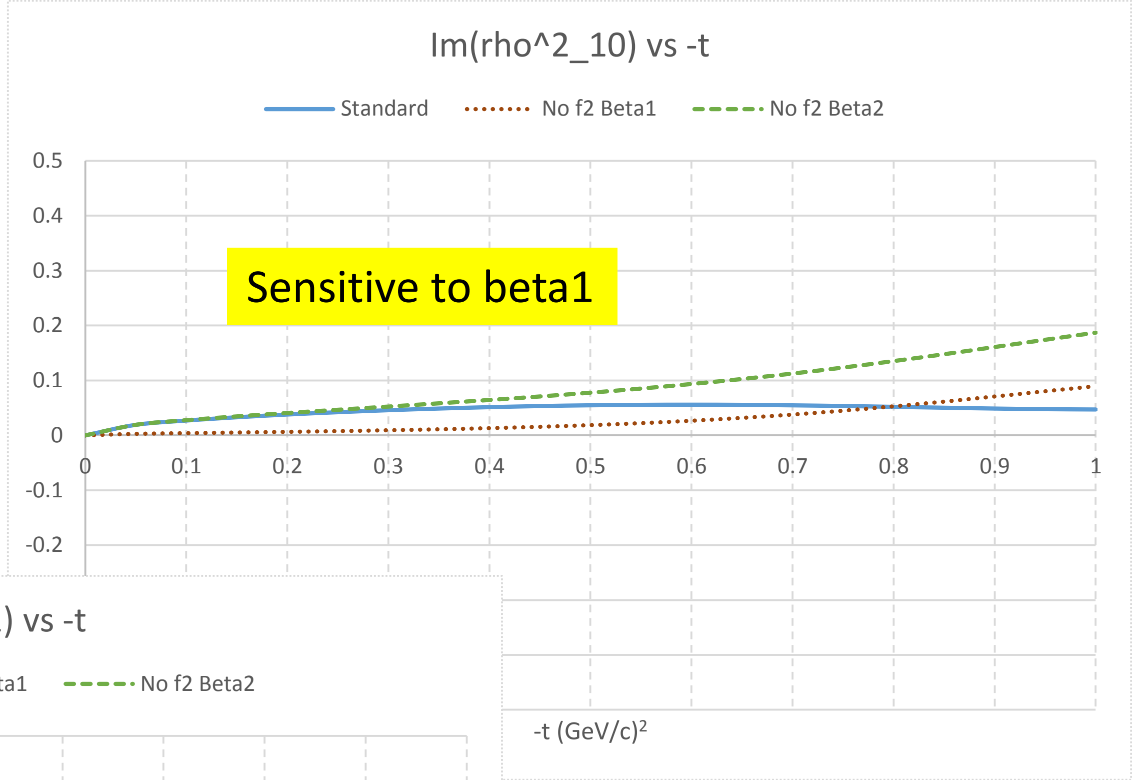

rho^0_1-1 vs -t
Standard
No f2 Beta1
No f2 Beta2
Sensitive to beta2
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV/c)²

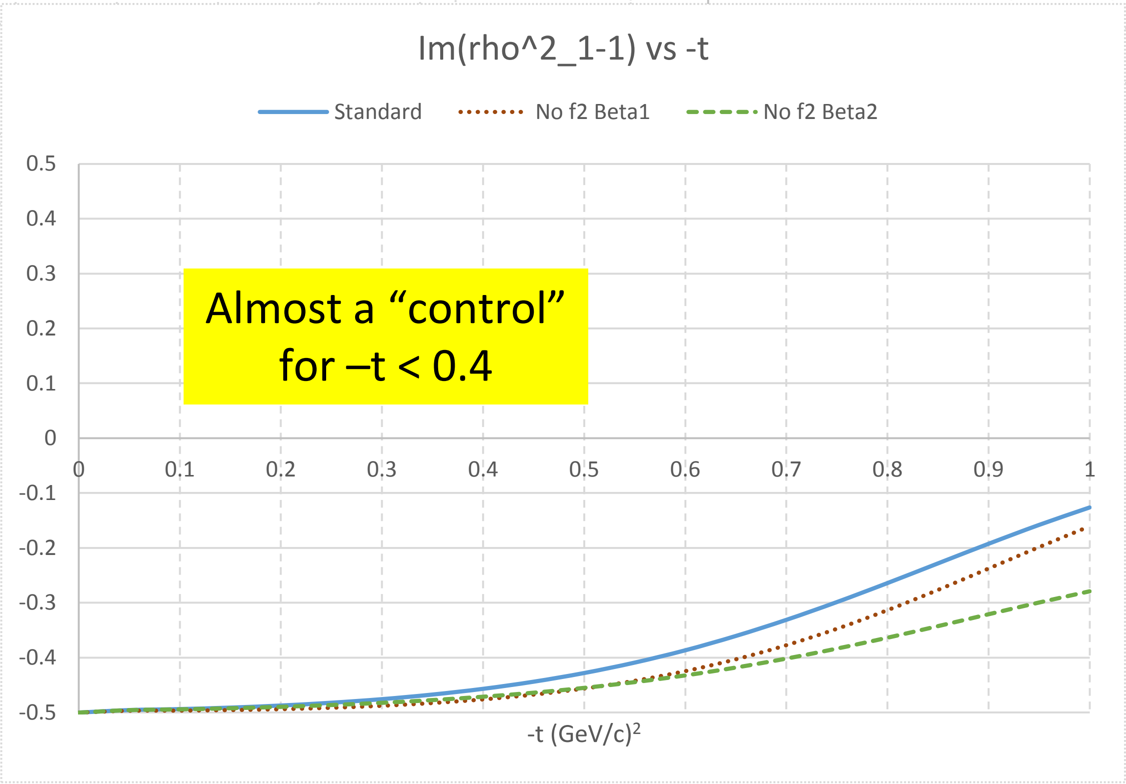

rho^1_11 vs -t
Standard
No f2 Beta1
No f2 Beta2
Sensitive to beta2
-t (GeV/c)²


rho^1_00 vs -t
Standard
No f2 Beta1
No f2 Beta2
Sensitive to beta1
-t (GeV/c)²

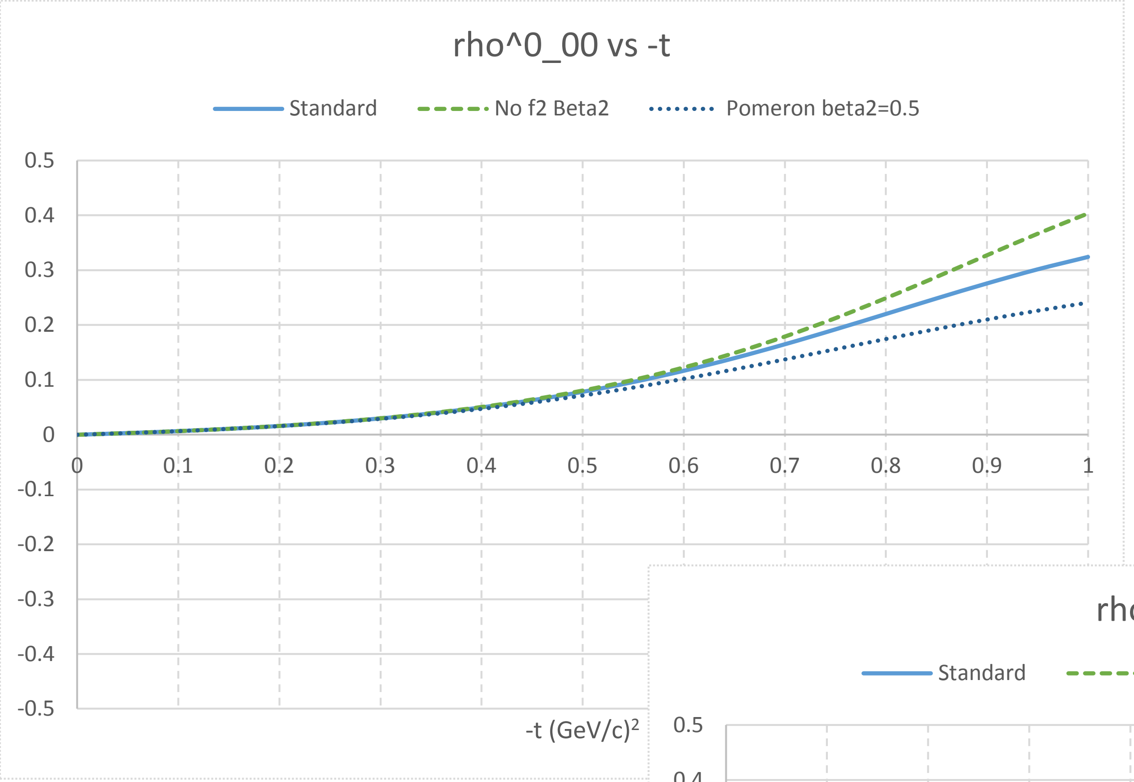

Re(rho^1_10) vs -t
Standard
No f2 Beta1
No f2 Beta2
Sensitive to beta1
-t (GeV/c)²

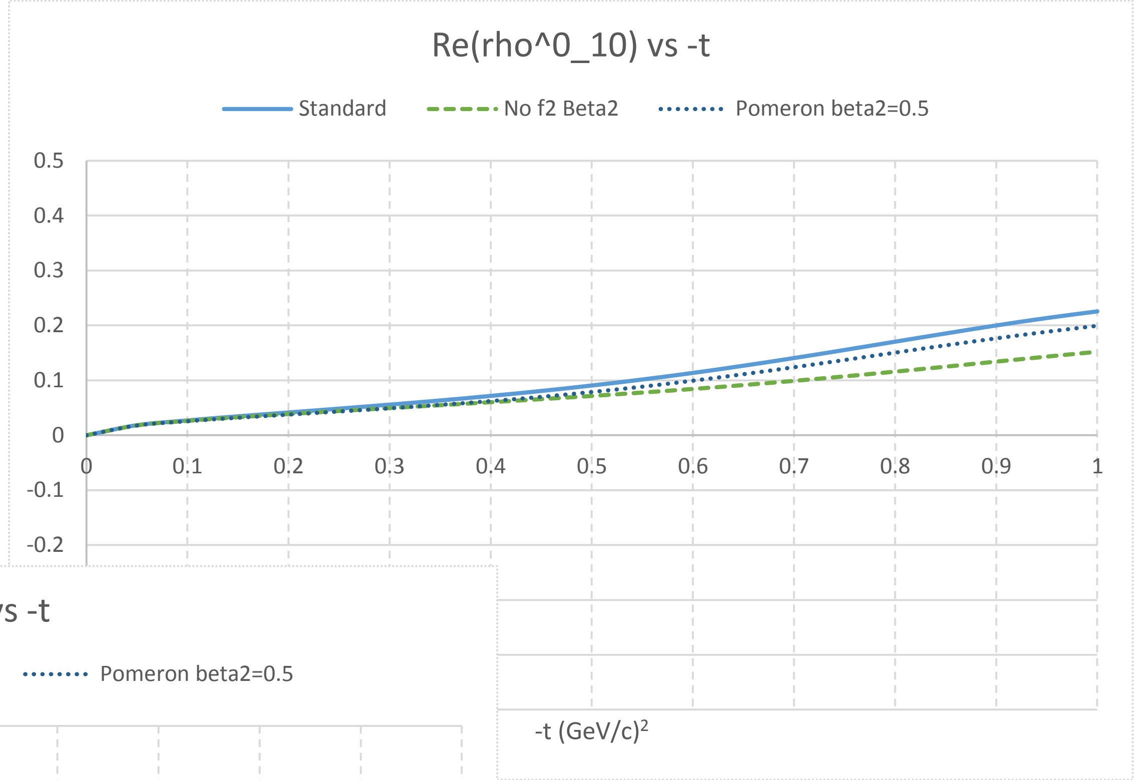

rho^1_1-1 vs -t
Standard
No f2 Beta1
No f2 Beta2
“Sensitive” to beta1
(but only half as sensitive
as the other examples)
-t (GeV/c)²

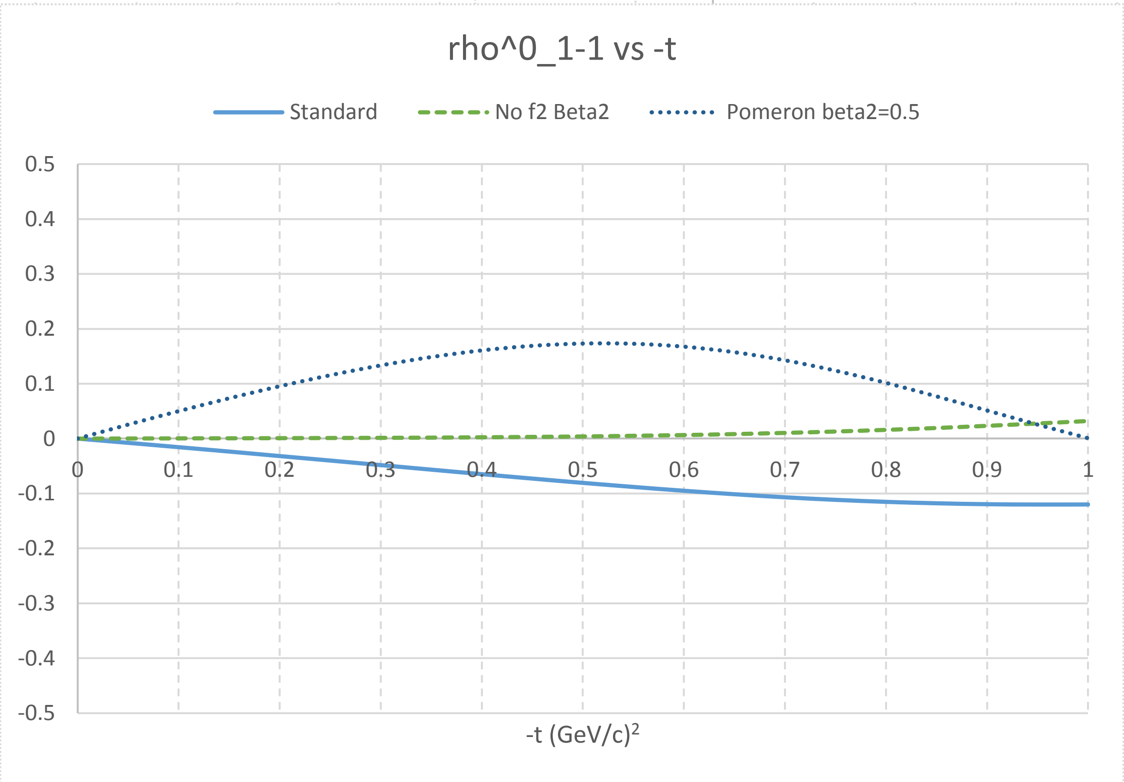

Im(rho^2_10) vs -t
Standard
No f2 Beta1
No f2 Beta2
Sensitive to beta1
-t (GeV/c)²

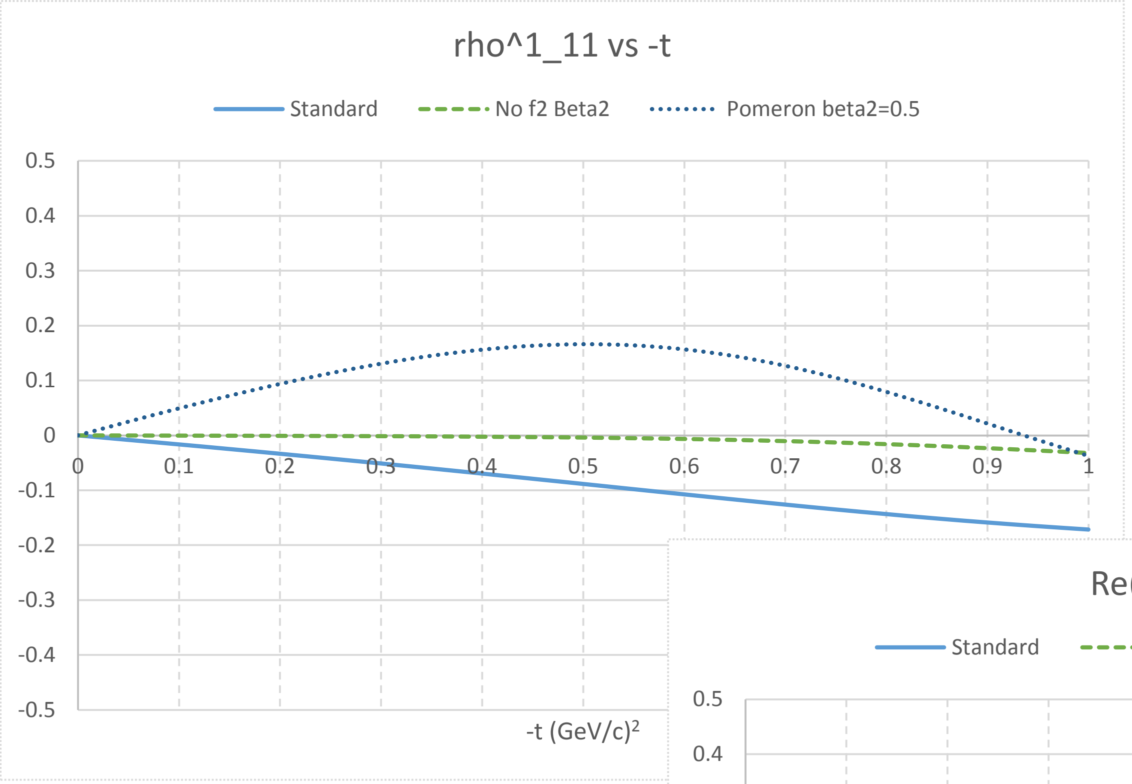

Im(rho^2_1-1) vs -t
Standard
No f2 Beta1
No f2 Beta2
Almost a “control”
for –t < 0.4
-t (GeV/c)²

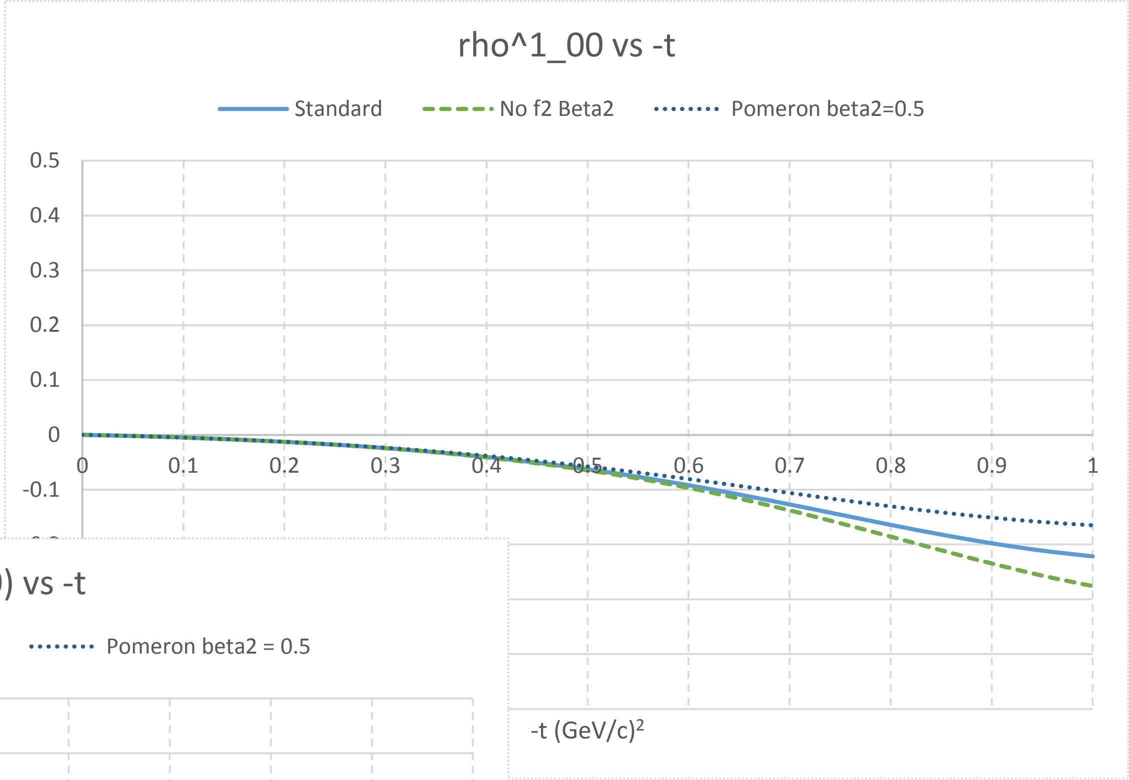
The 9 rho SDMEs
(setting the Beta^Pomeron_2 coupling to 0.5)

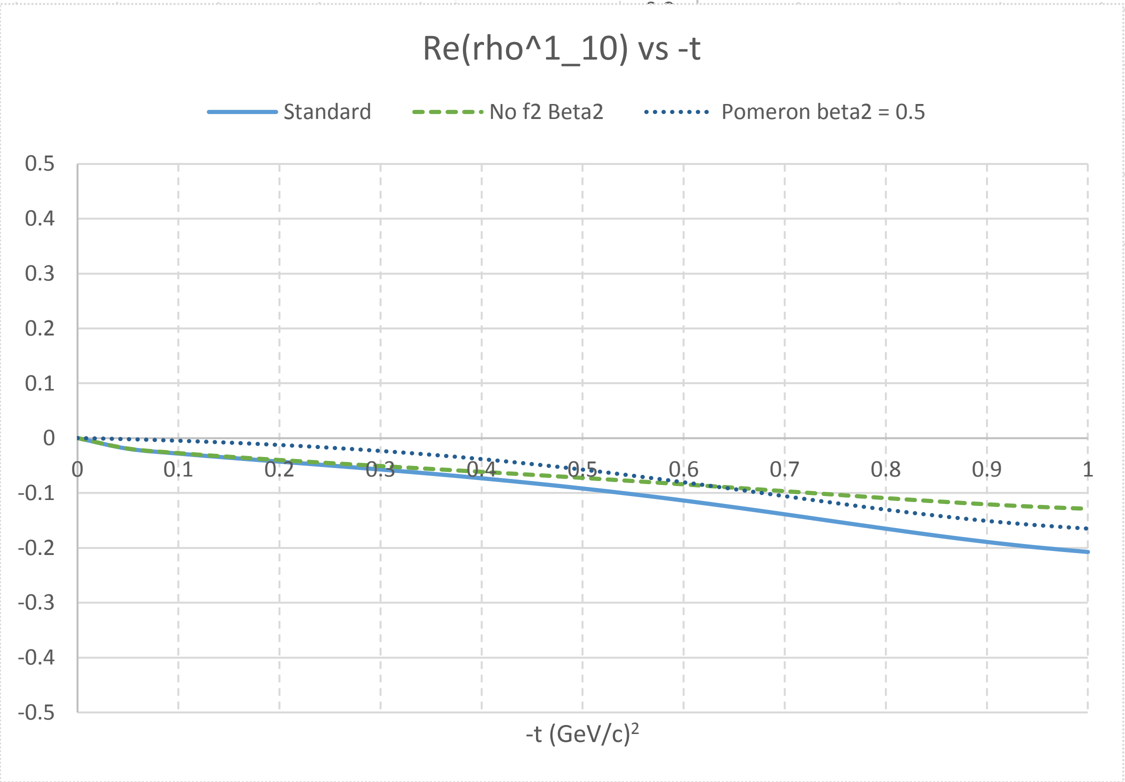

rho^0_00 vs -t
Standard
No f2 Beta2
Pomeron beta2=0.5
-t (GeV/c)²

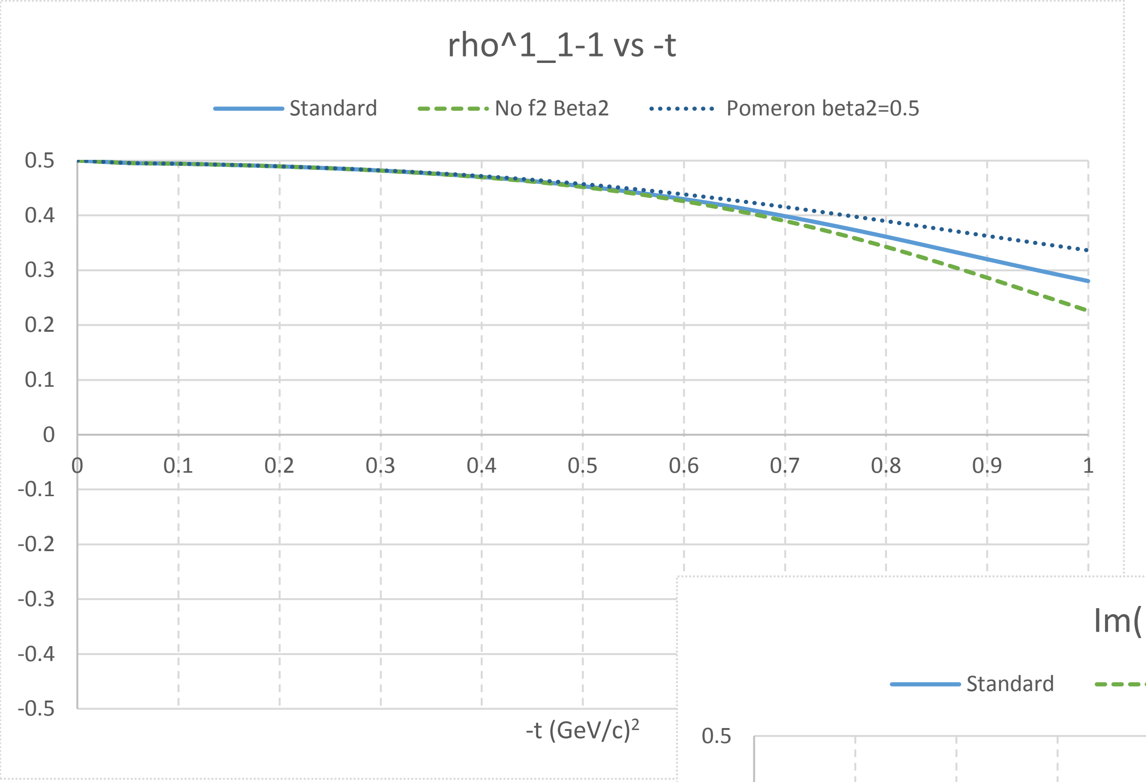

Re(rho^0_10) vs -t
Standard
No f2 Beta2
Pomeron beta2=0.5
-t (GeV/c)²

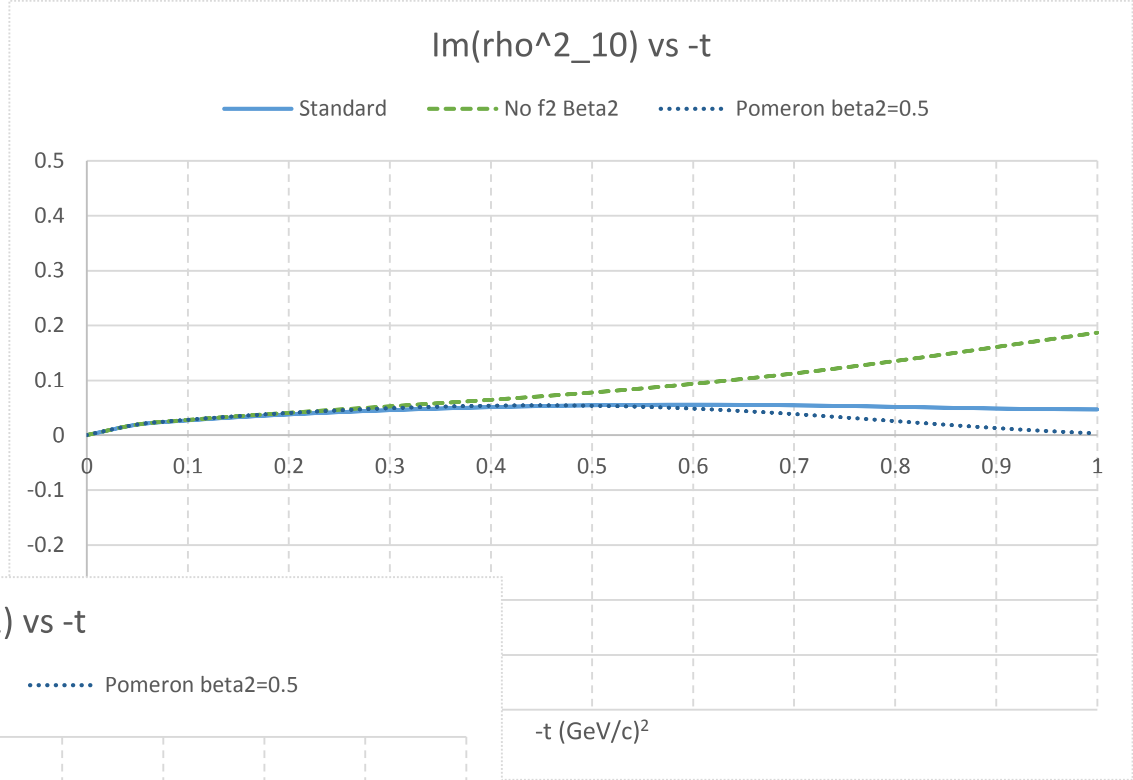

rho^0_1-1 vs -t
Standard
No f2 Beta2
Pomeron beta2=0.5
-t (GeV/c)²

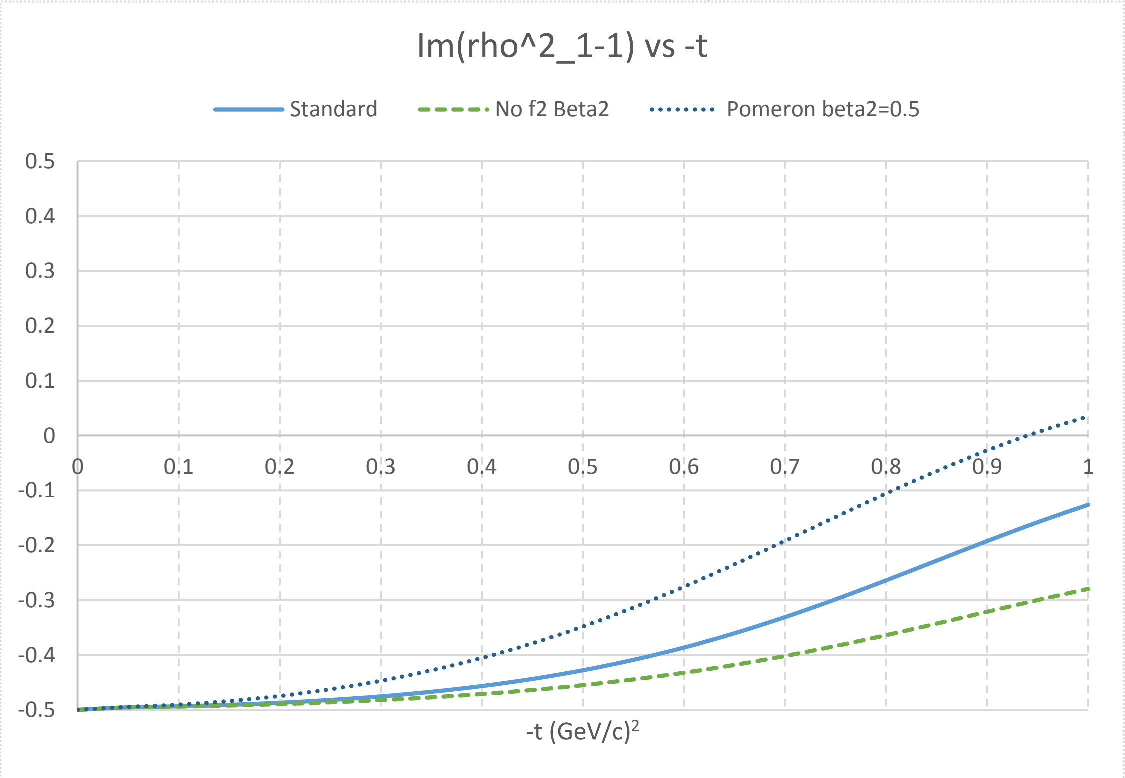

rho^1_11 vs -t
Standard
No f2 Beta2
Pomeron beta2=0.5
-t (GeV/c)^2


rho^1_00 vs -t
Standard
No f2 Beta2
Pomeron beta2=0.5
-t (GeV/c)^2


Re(rho^1_10) vs -t
Standard
No f2 Beta2
Pomeron beta2 = 0.5
-t (GeV/c)^2


rho^1_1-1 vs -t
Standard
No f2 Beta2
Pomeron beta2=0.5
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV/c)^2


Im(rho^2_10) vs -t
Standard
No f2 Beta2
Pomeron beta2=0.5
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV/c)^2


Im(rho^2_1-1) vs -t
Standard
No f2 Beta2
Pomeron beta2=0.5
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV/c)^2