The odderon and the spin dependence of proton-proton scattering

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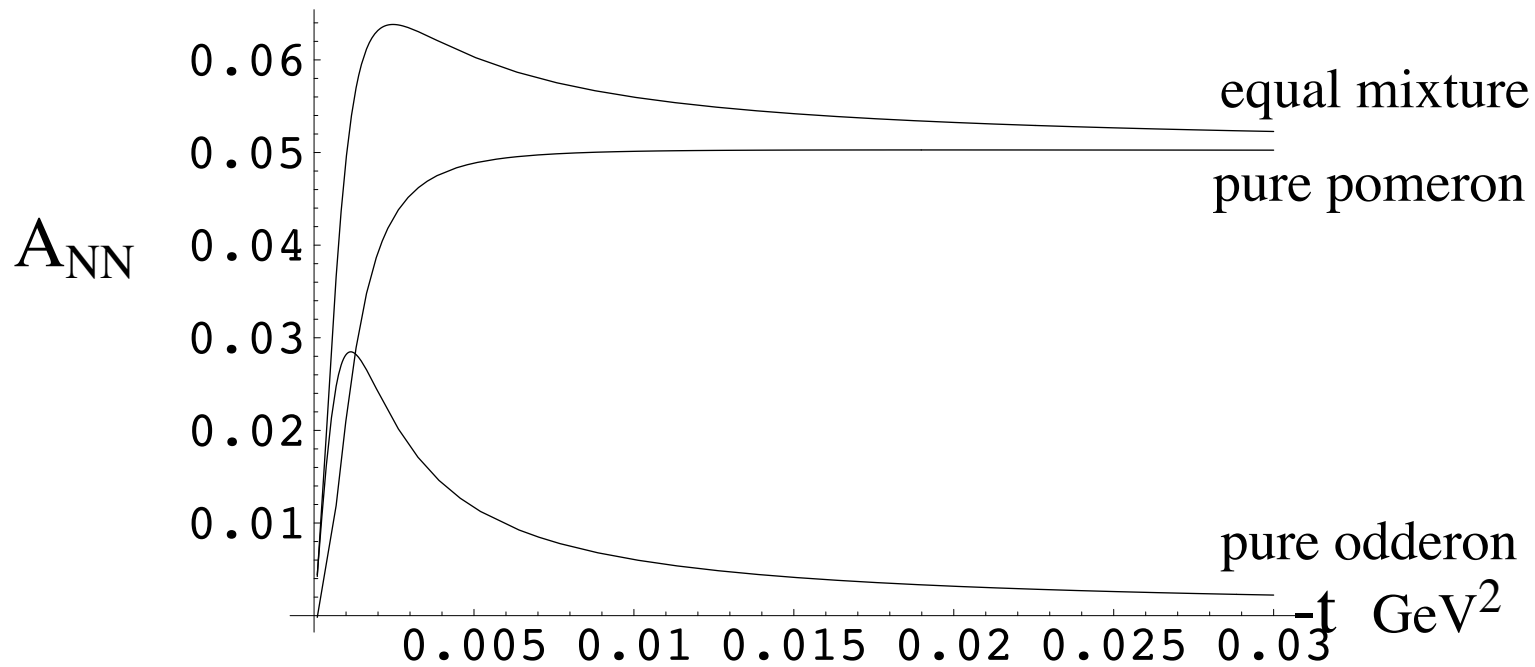
Leader & Trueman PRD 61 077504

The proton-proton helicity amplitudes

$$\phi_1(s,t) = <++|M|++>$$
$$\phi_2(s,t) = <++|M|-->$$
$$\phi_3(s,t) = <+-|M|+->$$
$$\phi_4(s,t) = <+-|M|-+>$$
$$\phi_5(s,t) = <++|M|+->$$

Two important initial state polarization asymmetries

$$A_N \frac{d\sigma}{dt} = -\frac{4\pi}{s^2} Im\{\phi_5 * (\phi_1 + \phi_2 + \phi_3 + \phi_4)\}$$
$$A_{NN} \frac{d\sigma}{dt} = -\frac{4\pi}{s^2}\{2|\phi_5|^2 + Re(\phi_1 * \phi_2 - \phi_3 * \phi_4)\}$$

Buttimore, *ibid.*

Amplitudes are normalized so that

$$\phi_1^{\text{had}} = \frac{s}{8\pi}\sigma_{\text{tot}}(i + \rho)exp(bt/2)$$

The singular electromagnetic amplitudes are

$$\phi_1^{\text{em}} = \frac{\alpha s}{t}\frac{1}{(1 - t/0.71)^2}$$

$$\phi_5^{\text{em}} = -\frac{\alpha s\kappa}{2m\sqrt{-t}}\frac{1}{(1 - t/0.71)^2}$$

$$\kappa = 1.79$$

The parameters in the hadronic amplitudes have s dependence determined from unpolarized scattering

Regge pole couplings: cf. Berger et al PRD 17, 2971

$$\phi_1^{\text{had}} = -\frac{1}{8\pi}\Sigma_R \beta_{nf}^R \beta_{nf}^R \left(s/s_0\right)^{\alpha_R}\left(\exp\left(-i\pi\alpha_R\right)+\mathcal{S}_R\right)/\sin\pi\alpha_R$$

for single flip amplitude, replace

$$\beta_{nf}^R \beta_{nf}^R \longrightarrow \beta_f^R \beta_{nf}^R$$

for double flip amplitude, replace

$$\beta_{nf}^R \beta_{nf}^R \longrightarrow \beta_f^R \beta_f^R$$

I use $\quad \beta_f^R = \tau_R \sqrt{-t/m^2}\, \beta_{nf}^R \quad$ with $\quad \tau_R \quad$ constant

Regge Classification

Class 1 $\tau = P = C$	Class 2 $\tau = -P = -C$	Class 3 $\tau = -P = C$
$\phi_+, \phi_5, \phi_2 - \phi_4$	ϕ_-	$\phi_2 + \phi_4$
$I\!\!P, O, \rho, \omega, f, a_2$	a_1	π, η, b

Table 1: *Classification of pp amplitudes by exchange symmetries and the associated Regge poles.*

cf. Buttimore et al PRD 59, 114010

The Model

- is based on Regge fit to pp scattering over wide energy range (cf. Cudell et al) which fixes non-flip parameters for the Pomeron (simple or multiple pole), a $C = -1$ vector meson (mainly ω) and a $C = +1$ tensor meson (mainly f_2).

- The non-flip amplitude is

$$g_0(s, 0) = g_P(s) + g_f(s) + g_\omega(s),$$

  where the functions $g_R(s)$ have enery dependence and phase determined by standard Regge theory.

- The corresponding flip amplitude is determined by three real, energy independent constants

$$
\begin{aligned}
g_5(s, t) &= \tau(s)\frac{\sqrt{-t}}{m}g_0(s, t) \\
&= \frac{\sqrt{-t}}{m}\{\tau_P\, g_P(s) + \tau_f\, g_f(s) + \tau_\omega\, g_\omega(s)\}.
\end{aligned}
$$

so

$$\tau(s) = \{\tau_P \, g_P(s) + \tau_f \, g_f(s) + \tau_\omega \, g_\omega(s)\}/g_0(s,0)$$

- The two constants in $\tau(21.7) = -0.213 - 0.054i$ determines two relations between the three constants $\tau_P, \tau_f, \tau_\omega$

- We need one more measurement to fix their values. If one measures the "shape" of the raw asymmetry over the CNI region *without knowing the value of P at that energy* one can obtain the needed information:

$$S(p_L) = \frac{P Im[\tau(p_L)]}{P(\kappa/2 - Re[\tau(p_L))]} = \frac{Im[\tau(p_L)]}{\kappa/2 - Re[\tau(p_L)]}$$
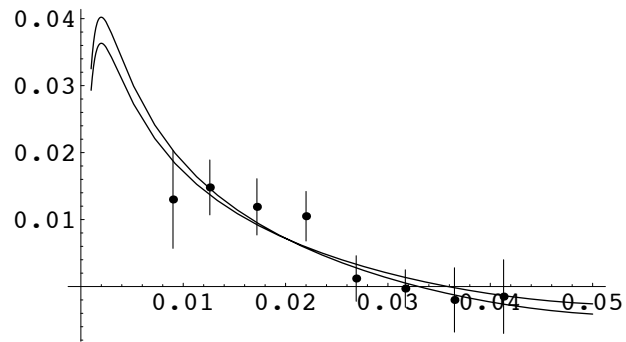
21.7 GeV data and E950 fit with known

 P(upper) and Regge prediction based on fit to

100 GeV data and 21.7 GeV shape (lower)
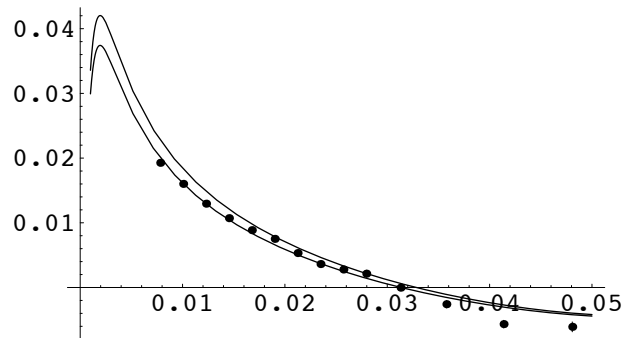
new 100 GeV data, best fit with known

 P(lower) and Regge prediction based on E950 fit

and 100 GeV shape (upper)

$I = 1$ couplings and proton-proton elastic scattering

- Because pp scattering involves the exchange of of $I = 1$ Regge poles, the ρ and the a_2 in particular, we cannot simply use the results above to make predictions for this case. But we can use the beautiful new p-jet data and a couple of reasonable assumptions to achive this. We assume (1) at these energies the proton-proton and neutron-proton unpolarized scattering amplitudes are approximately equal and (2) the two $I = 1$ Regge poles are degenerate with the corresponding $I = 0$ Regge pole of the same Charge Conjugation parity, $C = -1$ for ω, ρ and $C = +1$ for f, a_2. Then we can describe pp scattering in terms of 3-parameters: τ_+, τ_- and the pomeron coupling τ_P. Since we already know τ_P, in some sense, from the pC analysis and we can determine two parameters from the real and imaginary parts of τ obtained by fitting the p-jet data, we are in business.

New p-jet data

A_N vs $-t$
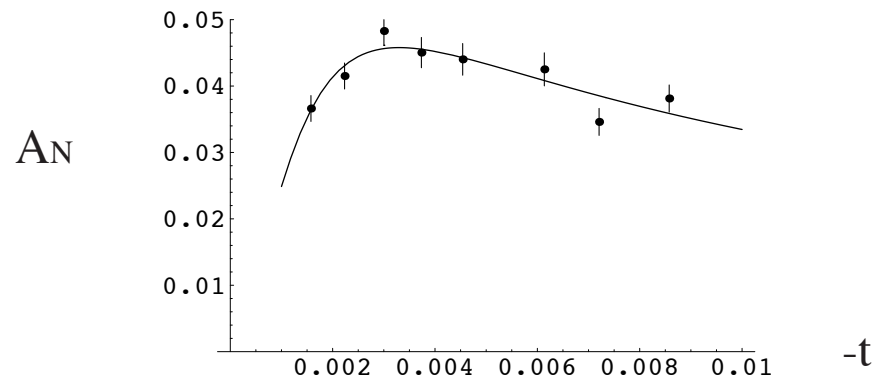
τ from p-jet fit = -0.0625 -0.011 i

τ from E704 fit = 0.185 + 0.024 i

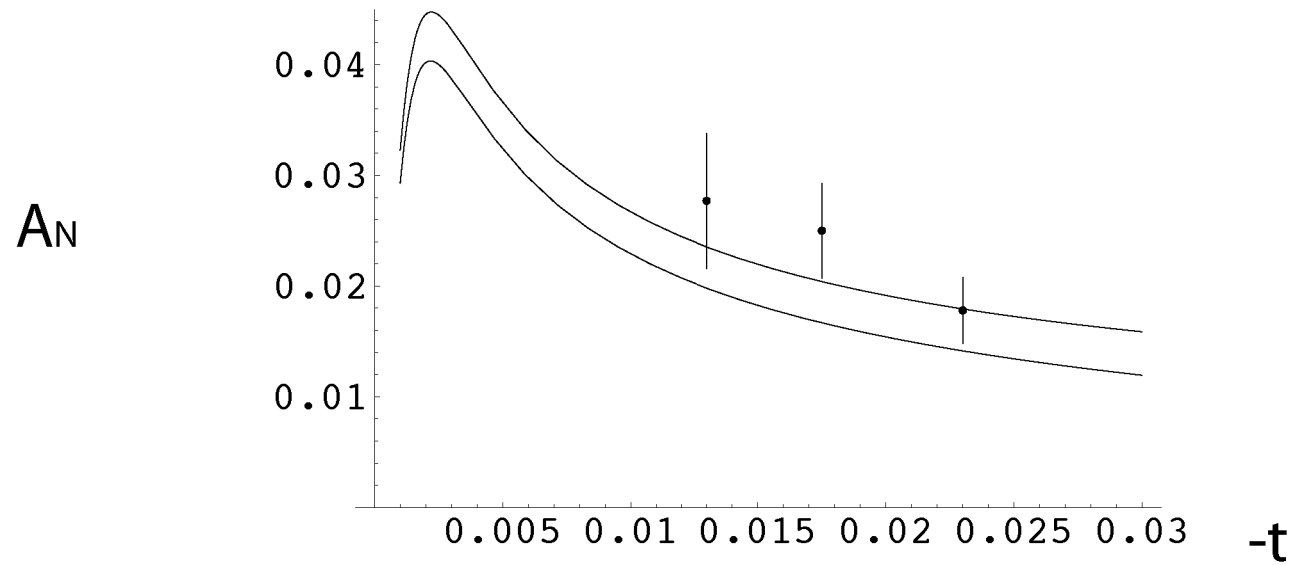# Regge residues in *1/GeV*

non-flip from Cudell et al PR D61:034019
flip from Trueman, Spin2004

	non-flip	*flip*
pomeron	6.95± 0.10	0.626±0.10
C=+	12.73±0.23	-4.12±0.25
C=-	9.65±0.43	10.22±0.77

pp2pp data for A_N compared with
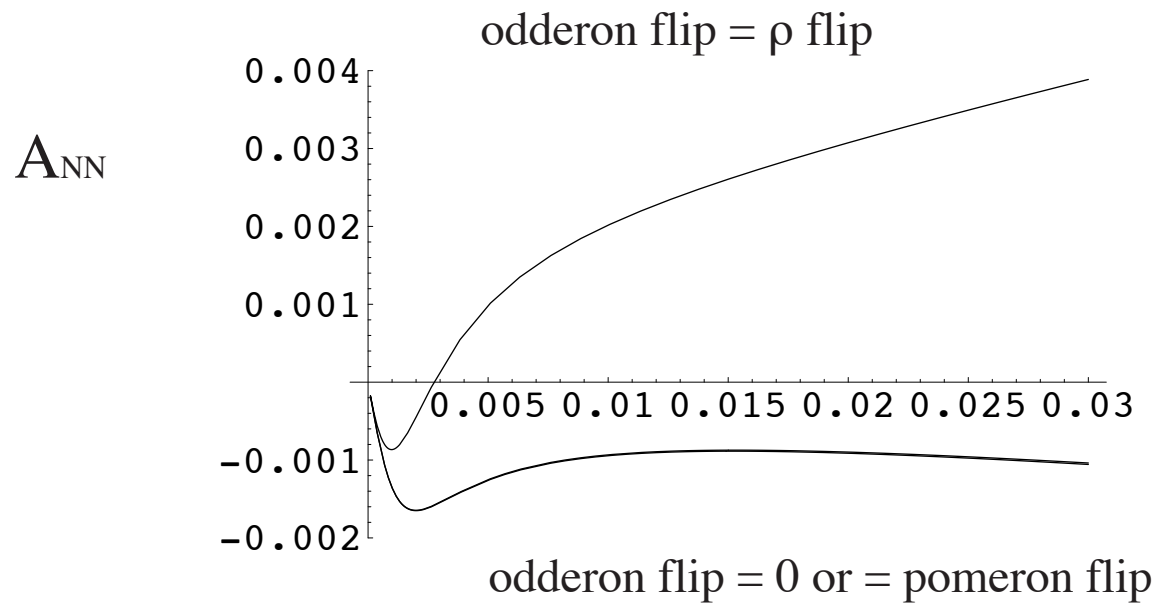prediction of my Regge analysis (lower)
and no hadronic spin flip (upper)

A_N

-t

Odderon pole form assumed for intercept of 1

$$\phi_2^{\mathrm{O}} = \frac{t}{m^2} \frac{1}{8\pi} \beta_f^O \beta_f^O \left(s/s_0\right)$$

Threshold t factors explicitly shown here.
These destroy the CNI enhancement.

Regge pole model prediction for A_{NN}
s=200

odderon flip = ρ flip

A_{NN}

0.004

0.003

0.002

0.001

0.005 0.01 0.015 0.02 0.025 0.03

−0.001

−0.002

odderon flip = 0 or = pomeron flip

To estimate Regge cut associated with odderon use absorption model of Henyey et al, PR 182, 1579

$$\phi_2^{\mathrm{O}}\,cut = -\frac{s\sigma_{\mathrm{tot}}}{4\pi b}(1 - i\rho)\frac{(\beta_f^O)^2}{bm^2}$$

The most important feature of this formula is that the suppression factor of -t has been replaced by the inverse of the slope b .

Cut properties

for pomeron-pole cut

1. Power behavior very close to pole case, up to logs.
Phase the same as pole.

2. *C* and signature the same as pole

3. Both parities present

4. No factorization of residues-<++|M|-->
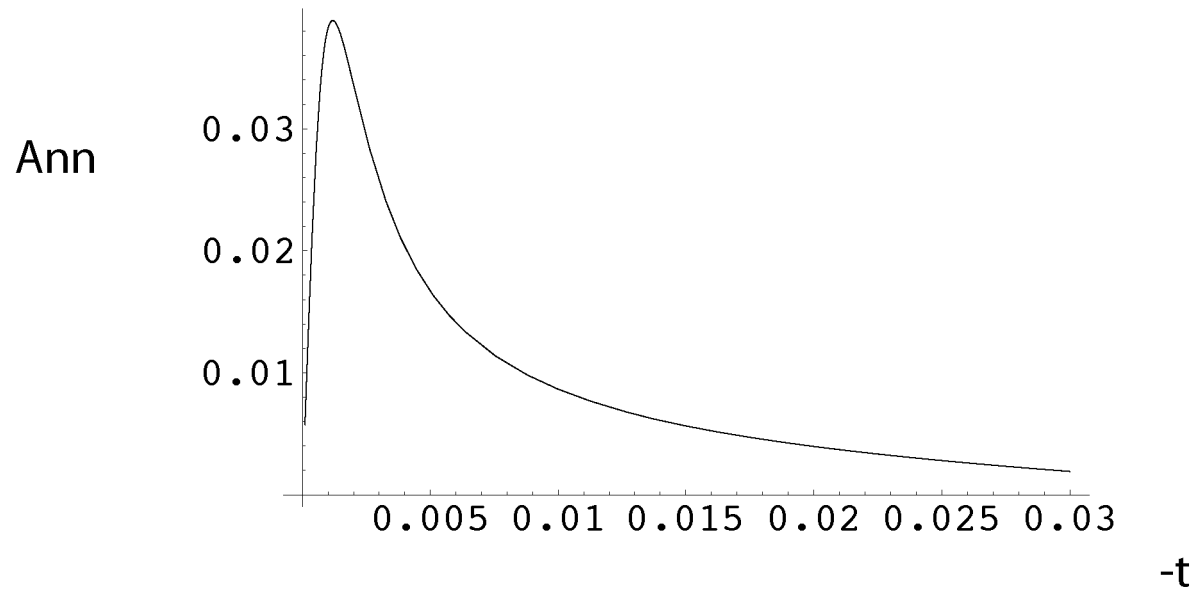so is not forced to vanish at *t*=0

A_{NN} for odderon cut with Regge pole background, odderon flip = ρ flip assumed
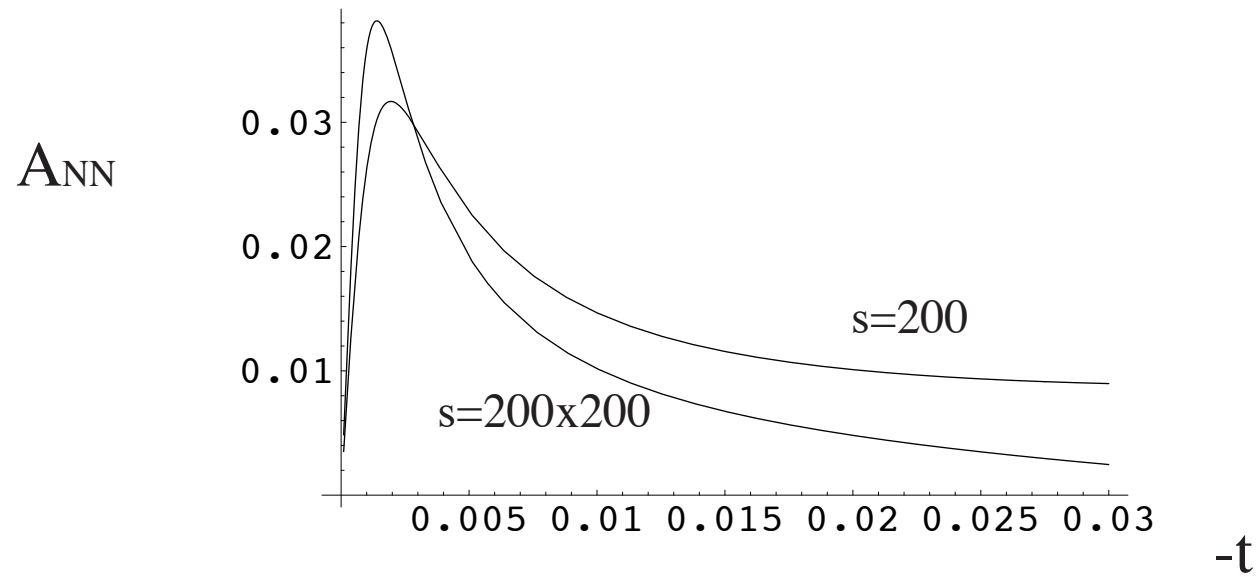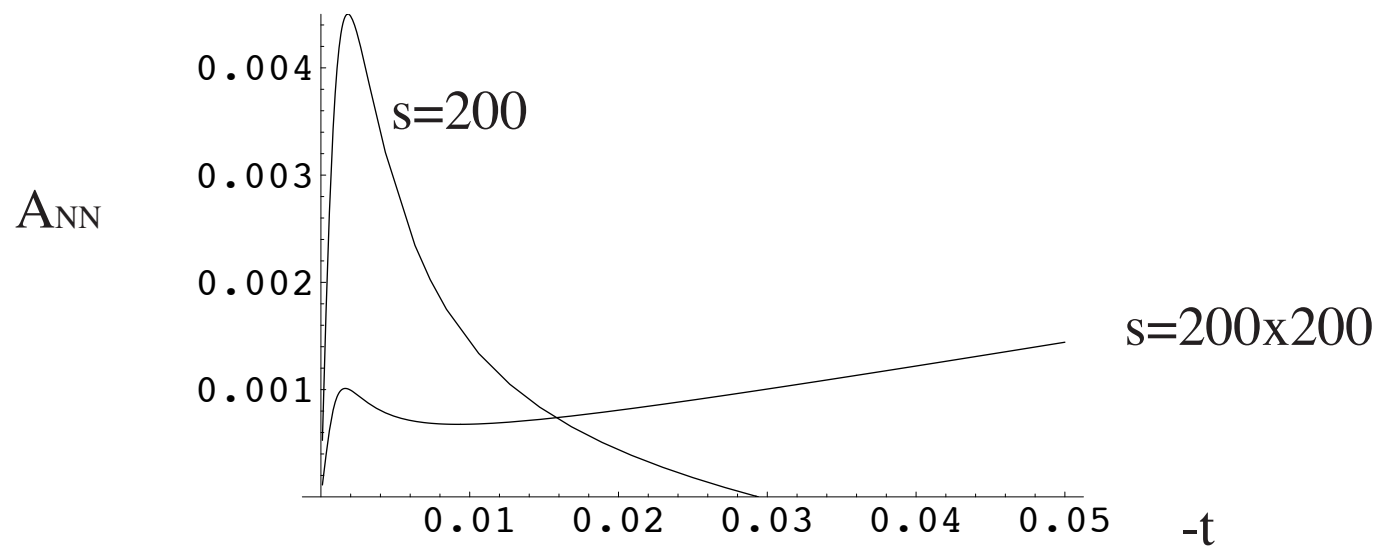
A_{NN} at 200x200 for odderon flip = rho flip (upper) and for odderon flip = pomeron flip (lower)
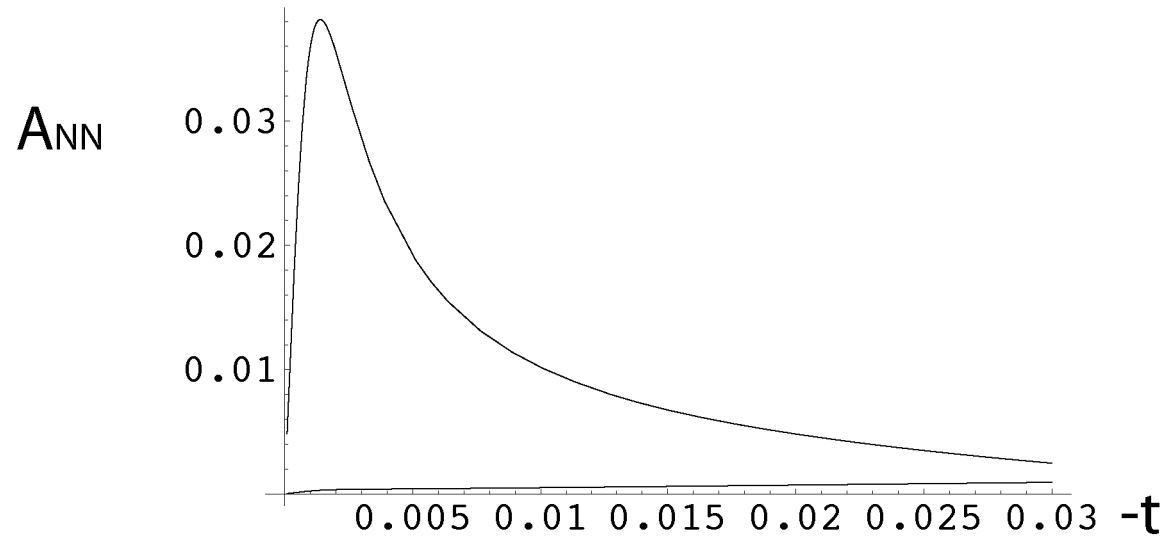
Ann at s = 500x500
Odderon flip residue equal to ρ flip residue

A_{NN} from ρ absorptive cut, no odderon at all

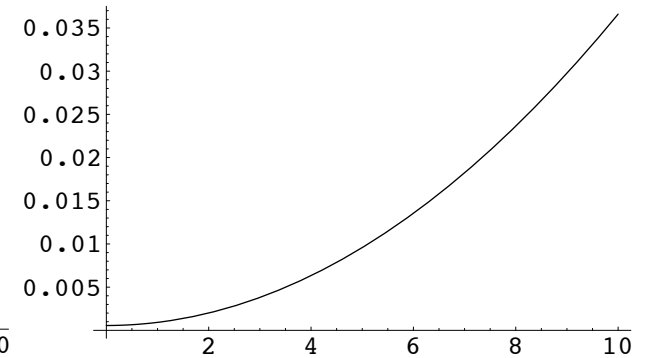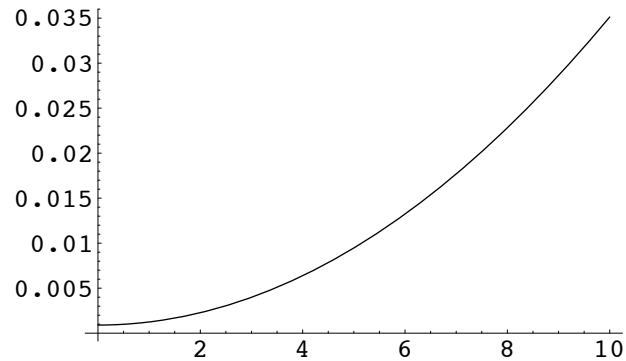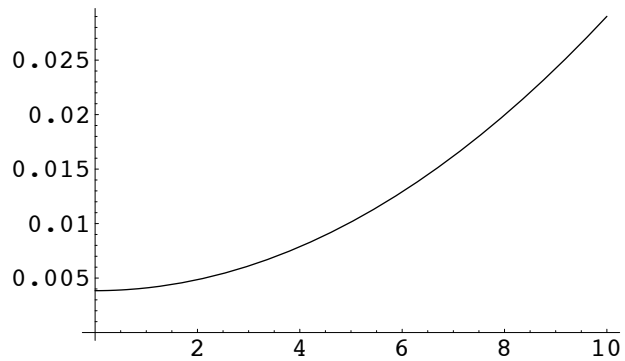Height of Ann peak at t=-0.001 as a function of the Odderon
spin flip coupling at three different energies

s=200

s=200x200

s=500x500

odderon flip coupling

Unsuppressed rho cut included here and in following

Ann(Odderon flip)-Ann(0)/Ann(0)

s GeV^2	Pomeron flip	Rho flip
200	0.0256	6.849
200x200	0.148	39.70
500x500	0.251	67.08

Conclusions

1. If the odderon exists and has a "reasonable" spin-flip coupling there is a good chance of observing it in A_{NN}.

2. The odderon-pomeron cut is essential to producing an observable signal in the small-t region.

3. There is a significant background mainly arising from the ρ-pomeron cut. If the odderon spin-flip is small, but larger than the pomeron spin-flip, measurements of A_{NN} over a wide energy range will be needed to separate out the signal