COMPETITION OF SPM AND GVD

The SPM effects, discussed up to now, describe the propagation behaviour realistically only for long pulses (i.e. $T_0 > 100\,ps$ in applications) for which the dispersion length L_D is much larger compared both with the fiber lenght L and the nonlinear length L_{NL}

$$L_D \gg L \quad \text{AND} \quad L_D \gg L_{LN}$$

As pulses become shorter and the L_D becomes comparable to L, it becomes necessary to consider the combined effects of SPM and GVD.

New qualitative features arise from the interplay between SPM and GVD. F.i. in the anomalous dispersion regime, the two phenomena may compete in such a way that the pulse propagate without distorsions.

In the normal dispersion regime, the combined effect of GVD and SPM can be used for pulse compression

In this lecture we consider the temporal and the spectral changes that occur when GVD is included in the description of SPM.

The starting point is the NLSE:

$$j \frac{\partial F}{\partial z} - \frac{\beta''}{2} \frac{\partial^2 F}{\partial t^2} + \gamma |F|^2 F = 0$$

The NLSE can be written in a normalized form:

$$j \frac{\partial F}{\partial \xi} = \frac{\mathrm{sgn}(\beta'')}{2} \frac{\partial^2 F}{\partial \tau} - N^2 |F|^2 F = 0 \qquad (15)$$

where we defined $\xi = z / L_D$ $\quad \tau = t / T_0$ $\quad N^2 = \frac{L_D}{L_{NL}} = \frac{\gamma t_0^2}{|\beta''|}$

[In other words, we can also put $T_0 = 1$, $\beta_2 (\beta'') = \pm 1$, Thus $L_D = 1$, and we study the variation of γ.]

The parameter N in eq. (15) rules the relative importance of the SPM and GVD effects on pulse evolution along the fiber.

Dispersion dominates for $N \ll 1$ while SPM dominates for $N \gg 1$. For values of $N \sim 1$ both SPM and GVD play an equally important role during the pulse evolution.

The split step Fourier method can be used to solve numerically the NSE in this case.

We want to consider, as an example, the evolution of the shape and the spectrum of an unchirped Gaussian pulse in normal dispesion regime using $N = 1$ ($\beta_2 = \gamma = 1$, $t_0 = 1$)

The qualitative behaviour in the numerics is quite different from that expected when either GVD or SPM dominates. In particular, we see that the pulse broadens much more rapidly compared with the case $N=0$ (no SPM). This can be understood by noting that SPM generates new frequency components that are red shifted near the leading edge and blue-shifted near the trailing edge of the pulse. As the red components travel faster than blue components ($\beta_2 > 0$) SPM leads to an enhanced rate of pulse broadening compared with that expected from GVD alone. This in turn affects spectral broadening as the SPM phase shift ϕ_{NL} becomes less than that occurring if the pulse shape were to remain unchanged.

The situation is different for pulses propagating in the anomalous dispersion regime of the fiber.

We check numerically. $\rightarrow$ $\left(N=1, \boxed{\beta_2=-1}, \gamma=1, T_0=1\right)$

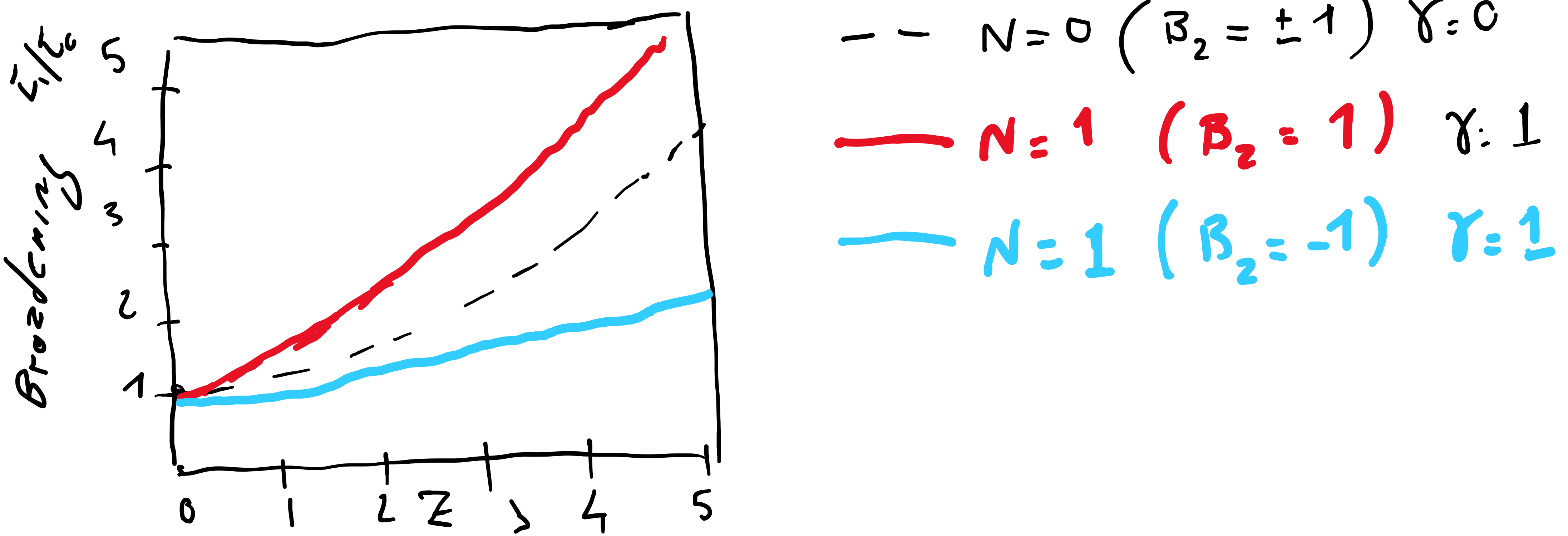
The pulse broadens initially at a rate much lower than that expected in the absence of SPM and it seems to reach a stationary state for $z>4$. At the same time the spectrum narrows rather than broadening expected by SPM in the absence of GVD. This novel behavior can be understood by noting that the SPM-induced chirp is positive while the dispersion-induced chirp is negative for $\beta_2 < 0$. The two chirps nearly cancel each other along the central portion of the gaussian pulse when $L_D = L_{NL}$ $(N = 1)$.

Thus, GVD and SPM compete or cooperate with each other to maintain a chirp-free pulse.

This scenario introduces the soliton evolution (we will see solitons in future lectures).

The numerical figures derived show that the main effect of SPM is to alter the temporal broadening rate imposed on the pulse by the GVD alone.

We can derive the broadening factor as a function of z, for N = 1 when unchirped gaussian pulses are launched into the fiber



The SPM enhances the broadening in the normal dispersion regime and decreases it in the anomalous dispersion regime

I want to underline that it is generally necessary to solve the NLSE numerically to study the combined effects of GVD and SPM. However one can study the problem exploiting approximate analytical tools (but this is not the goal of my lectures).

I invite you to perform numerical simulations with chirped pulses, supergaussian pulses, and SPM with GVD.