On MPN link budget penalties

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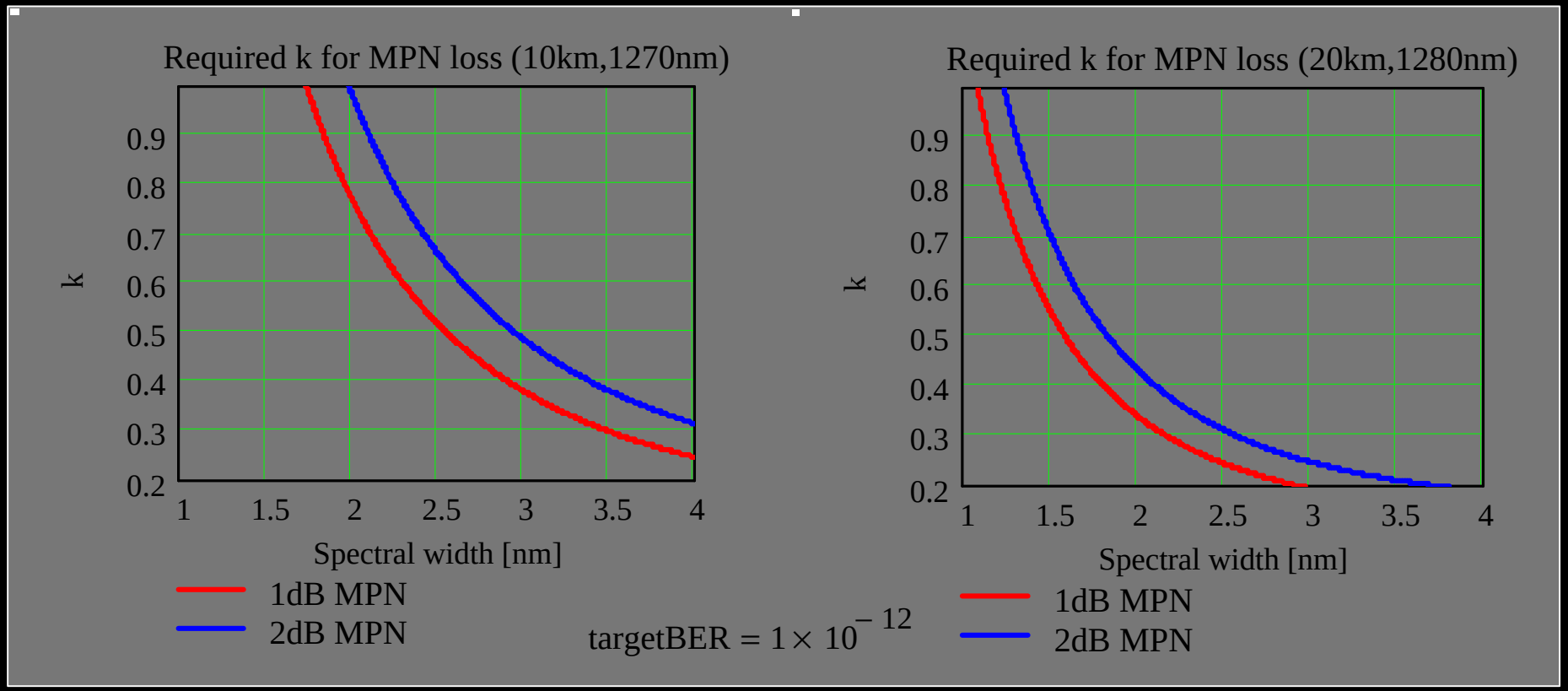
Required k for a given link MPN penalty

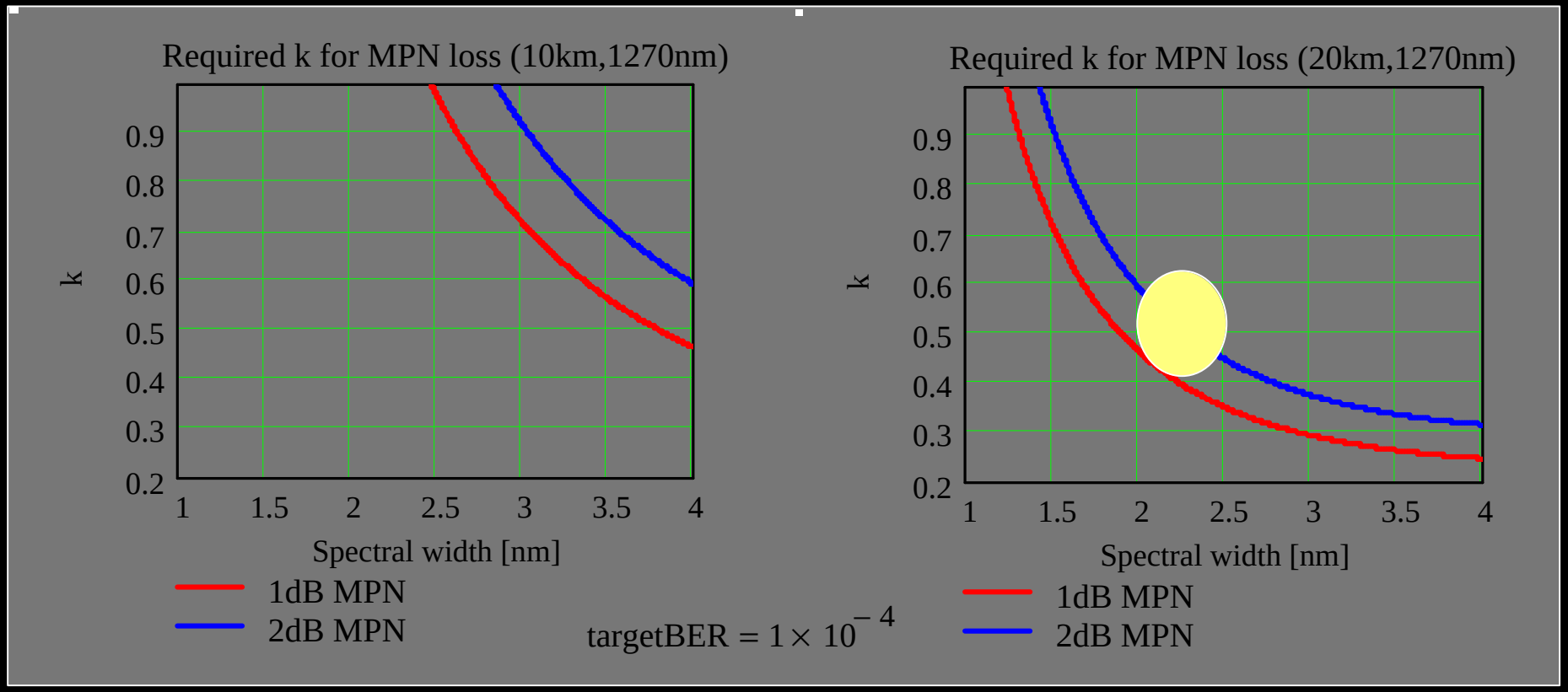
BER=10^{-12}



- 2dB MPN allowance enables additional ~0.5nm D1

Required k for a given link MPN penalty

BER=10^{-4}

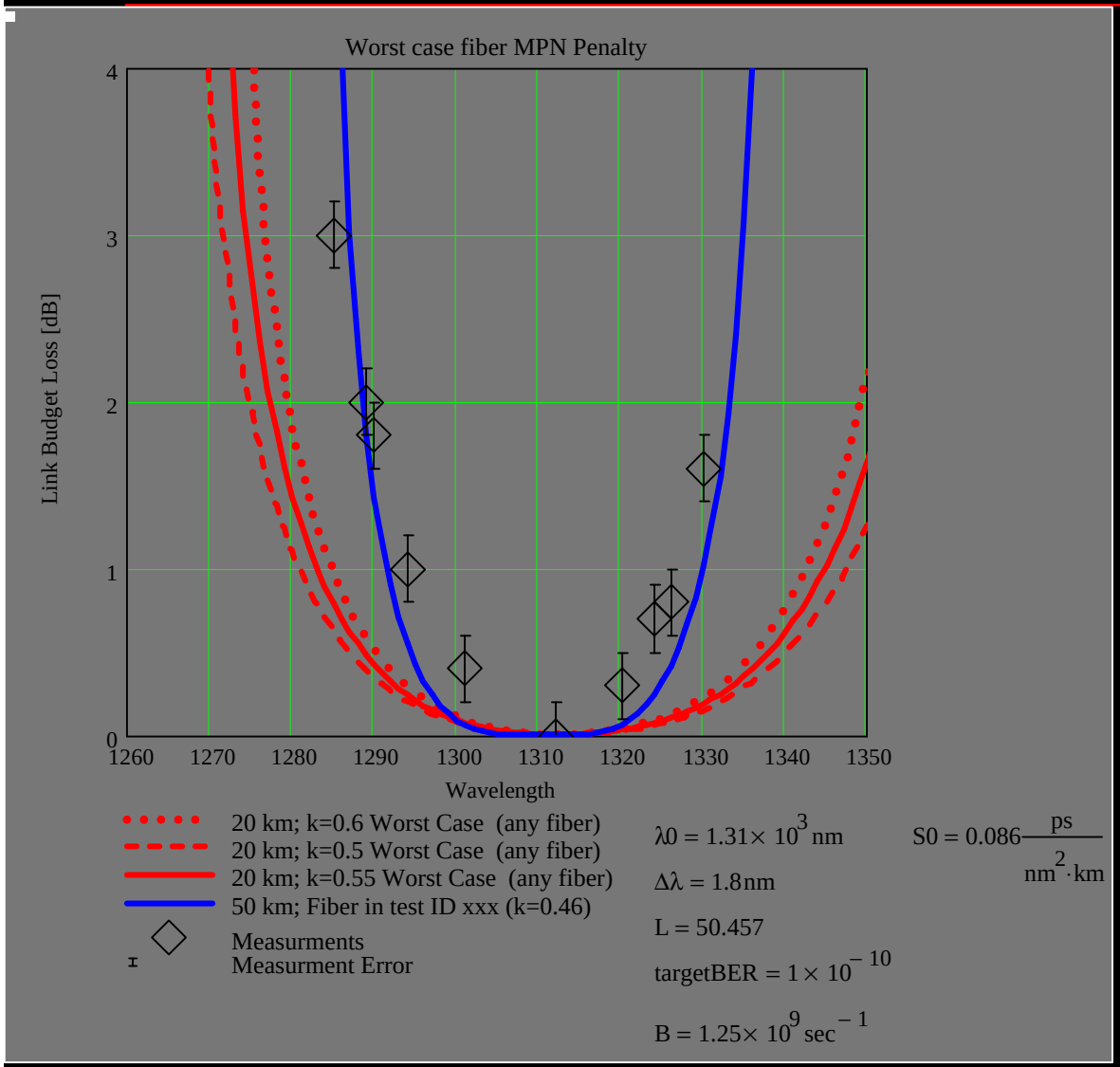


- 2dB MPN @10^{-4} enables 20km

High Sensitivity to Dl measurement

- Manual calculations does not fit auto calculation for test equipment.
- Mistakes due to internal equipment K factors
- Different customers produced different results
- Current re-measurements in agreement with vendor A resulted in drop from 2.6nm to 1.8nm. Strong effect on resultant k !!!

NEW ANALYSIS MPN test results – 50 km (see Appendix 1 for additional conditions)



Worst case assume:

1302nm < λo < 1322nm

So = 0.092 ps/nm^2/km.

Three k values 0.8,0.4,0.3

Measured data (50 km fiber) k < 0.5

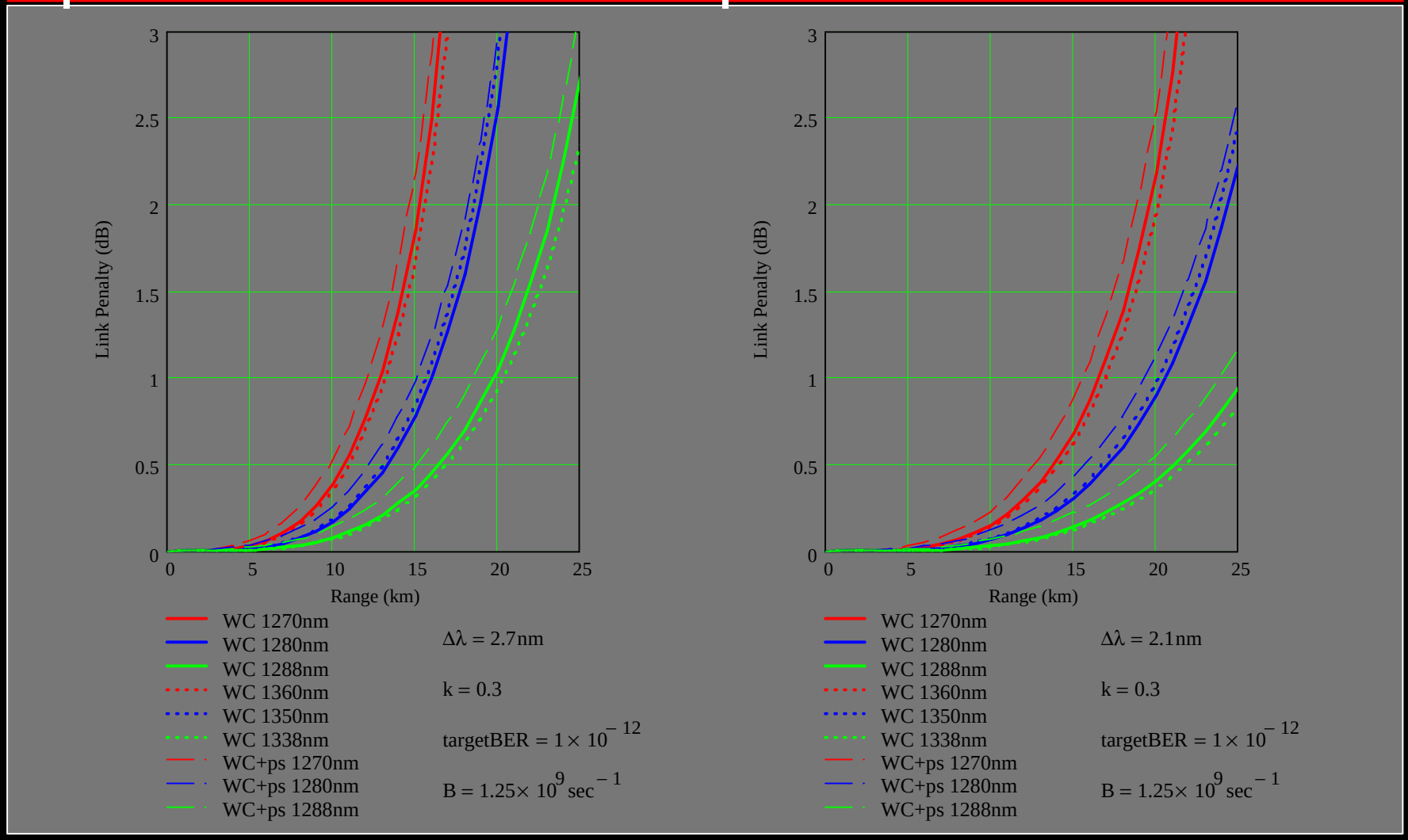
LEAST SQUARE FIT:

K = 0.46

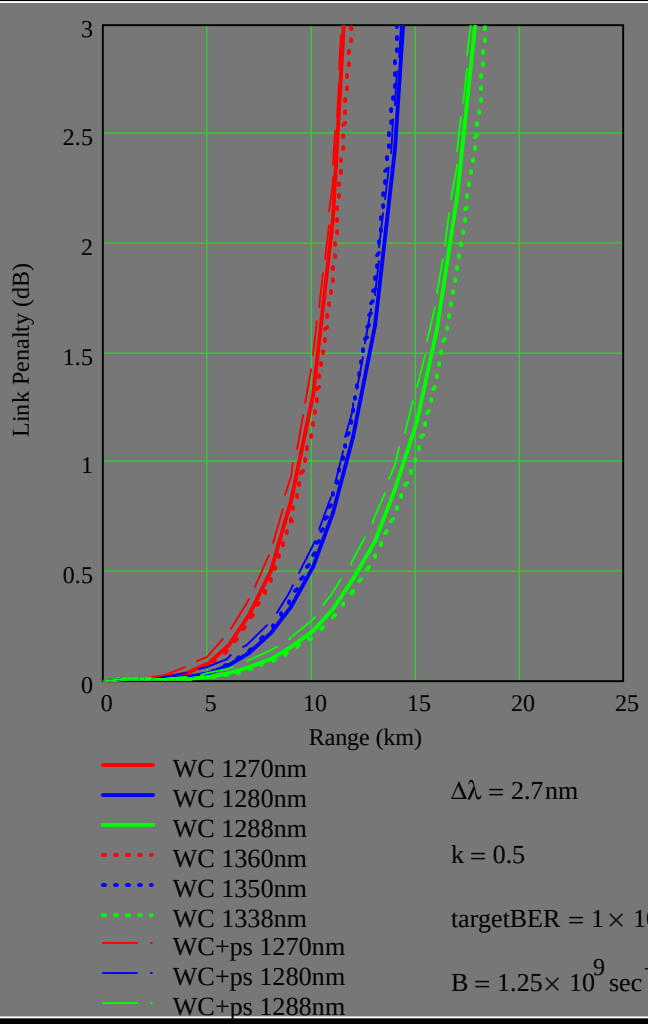
Keys

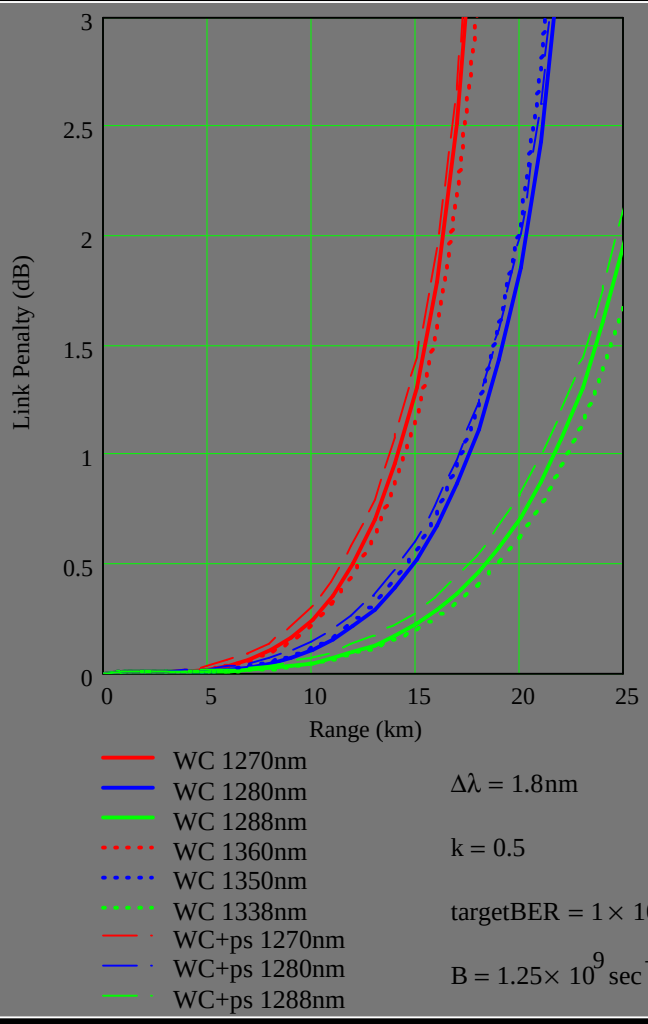
- WC stands for worst case fiber (λ_0 extreme)
- Laser wavelength range:
  - Red – 1260 – 1360 nm
  - Blue – 1280 – 1350 nm
  - Green – 1288 – 1338 nm
- Dashed line for Hot (long wavelength); Solid line for Cold (short wavlength)

Effect of Spectral width - k=0.3, BER = 1E-12, Dl=2.1nm vs. 2.7nm

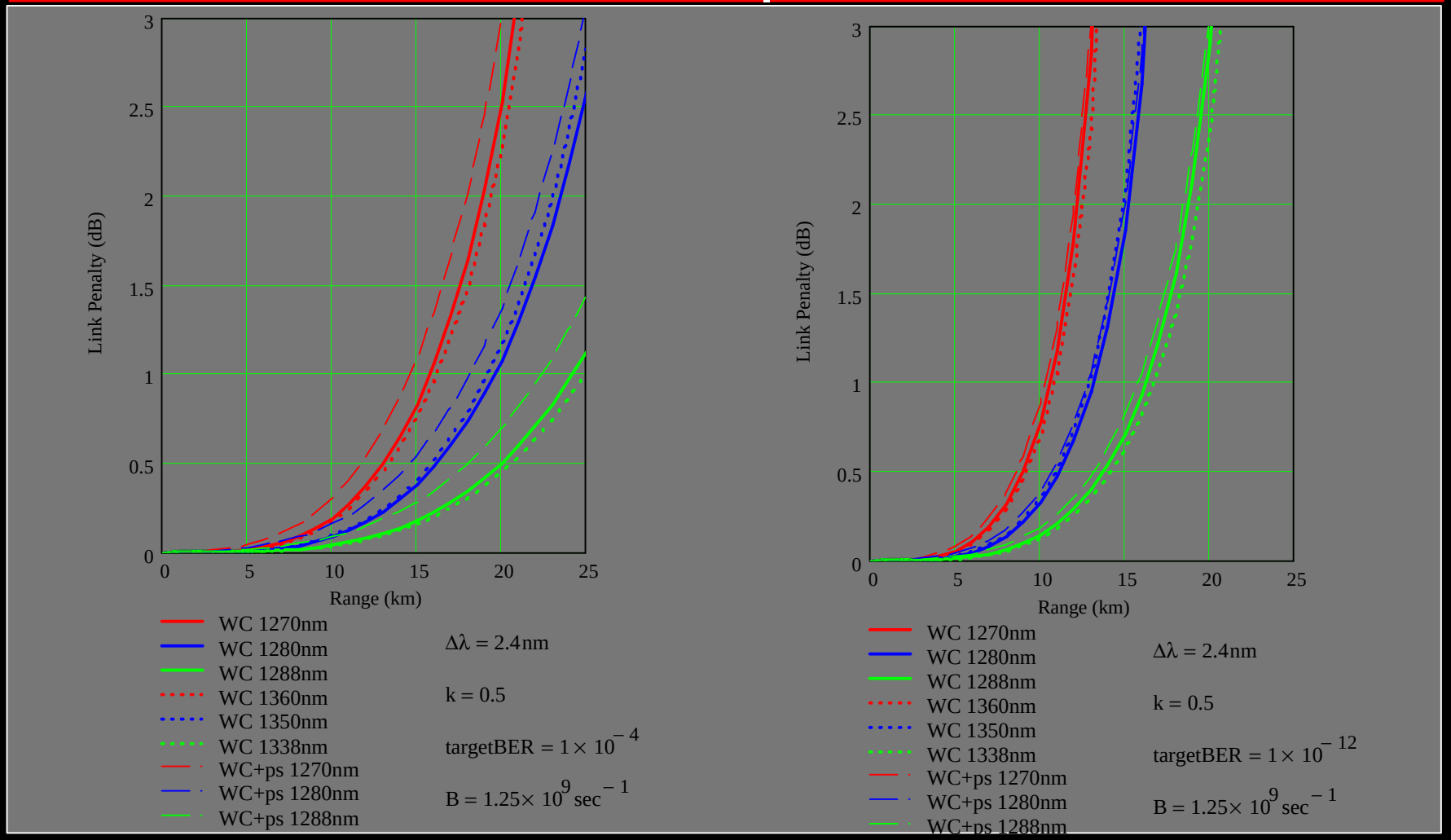


Effect of Spectral width - k=0.5, BER = 1E-12, Dl=1.8nm vs. 2.7nm

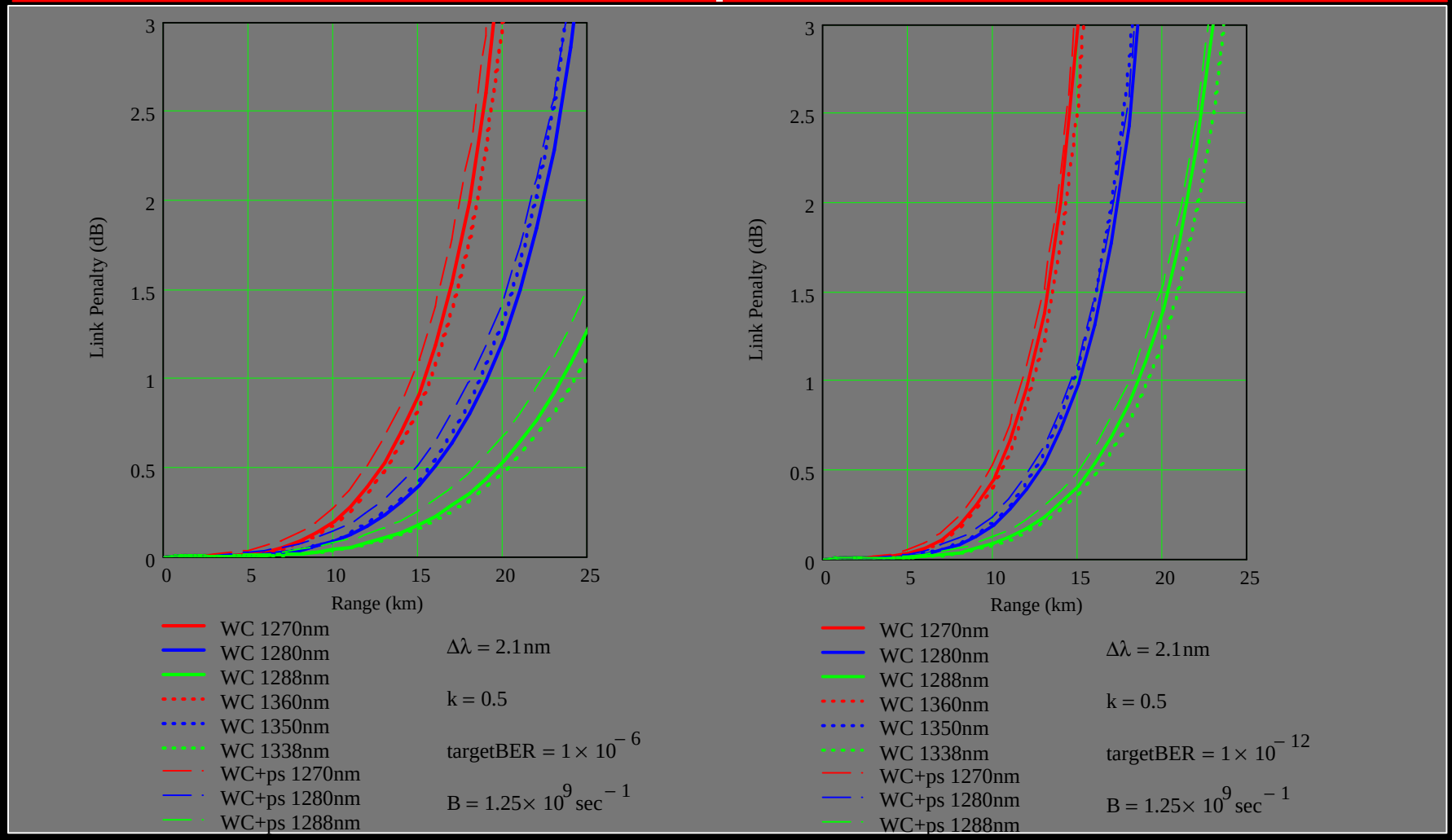




Effect of BER - k=0.5, Dl=2.4nm, 1E-4 vs. 1E-12

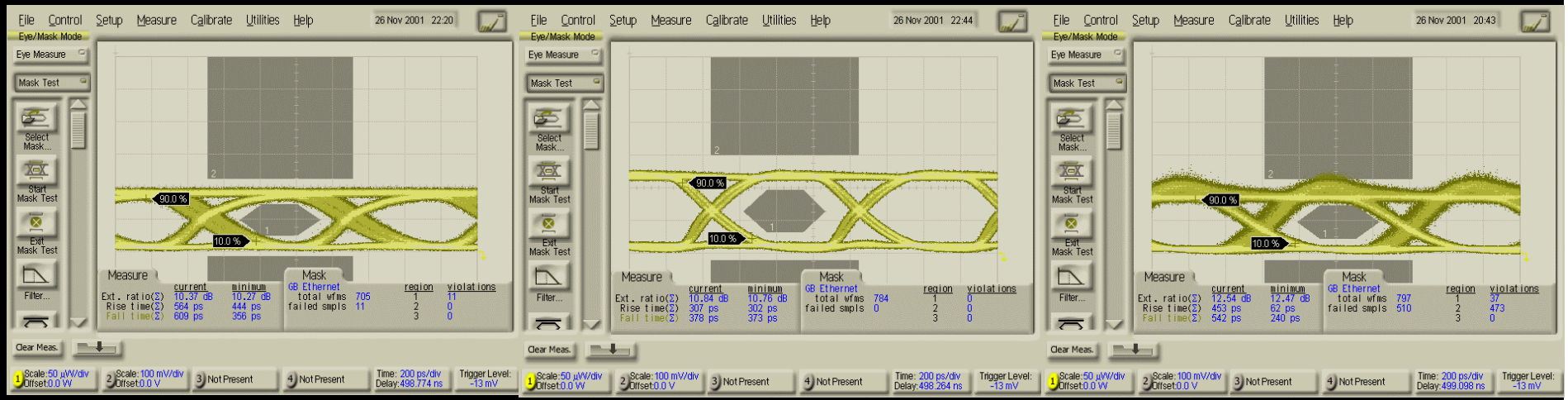


Effect of BER - k=0.5, Dl=2.1nm, 1E-6 vs. 1E-12



Dispersion effect “puzzle”

- Positive Dispersion (“hot”) “spreads” fall time
- Negative Dispersion (“cold”) “spreads” rise time



T2 90C 25 km fiber
fiber$\Delta\lambda$=3.1nm
λ= 1339nm
D= 50 ps/nm

T2 25C 25 km fiber
$\Delta\lambda$=2.6nm
λ= 1311nm
D= -9 ps/nm

T2 -55C 25 km
$\Delta\lambda$=2.6nm
λ = 1279nm
D= -81 ps/nm

- Spectral Plots

Observations

- Assuming FEC works for MPN:
  - K=0.6 enables 10km $\Delta\lambda$=2.7nm
  - K=0.5 enables 20km $\Delta\lambda$=2.1nm BER=10^{-6}
- Enabling 2dB PN penalty adds about 2-4km range

Appendix 1: MPN penalty model equations

Basic MPN equations

$$BER(Q) := 0.5 \cdot \mathrm{erfc}\left(Q \div \sqrt{2}\right)$$

Fiber dispersion

$$D(\lambda) := \overrightarrow{\left[\frac{So}{4} \cdot \left[\lambda - \frac{(\lambda o)^4}{(\lambda)^3}\right]\right]}$$

$$Q := \mathrm{root}\left(\mathrm{targetBER}^{-1} \cdot BER(Q) - 1, Q, 3, 10\right) \quad Q = 6.361$$

$$\beta(L,\lambda) := \pi \cdot B \cdot D(\lambda) \cdot \Delta\lambda \cdot L \cdot km \qquad \sigma_{mpn}(L,\lambda,k) := \frac{k}{\sqrt{2}} \cdot \left(1 - e^{-\beta(L,\lambda)^2}\right)$$

Agraval et.al.

$$\varepsilon(L,\lambda) := B \cdot D(\lambda) \cdot \Delta\lambda \cdot L \cdot km$$

$$\alpha(L,\lambda,k) := 5 \cdot \log\left(\frac{1}{1 - Q^2 \cdot \sigma_{mpn}(L,\lambda,k)^2}\right)$$

$$\alpha_{wc}(L,\lambda,k) := \mathrm{if}\left[(\lambda) > 1312 \cdot nm, \alpha(L,\lambda,k)_0, \alpha(L,\lambda,k)_4\right]$$

Basic MPN equations

Agraval et al, "Dispersion Penalty for 1.3um Lightwave Systems," IEEE Journal of Lightwave Technology, Vol.6, No. 5, pp 620-624, May 1988

Effect of BER - k=0.3, Dl=2.1nm, 1E-10 vs. 1E-12