

# PAM4 Transmission and MPN

Re: Comment IDs 4 and 10 against D1.1

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IEEE P802.3cm 400 Gb/s over Multi-mode Fiber Task Force

# Mode Partition Noise Penalty for PAM4

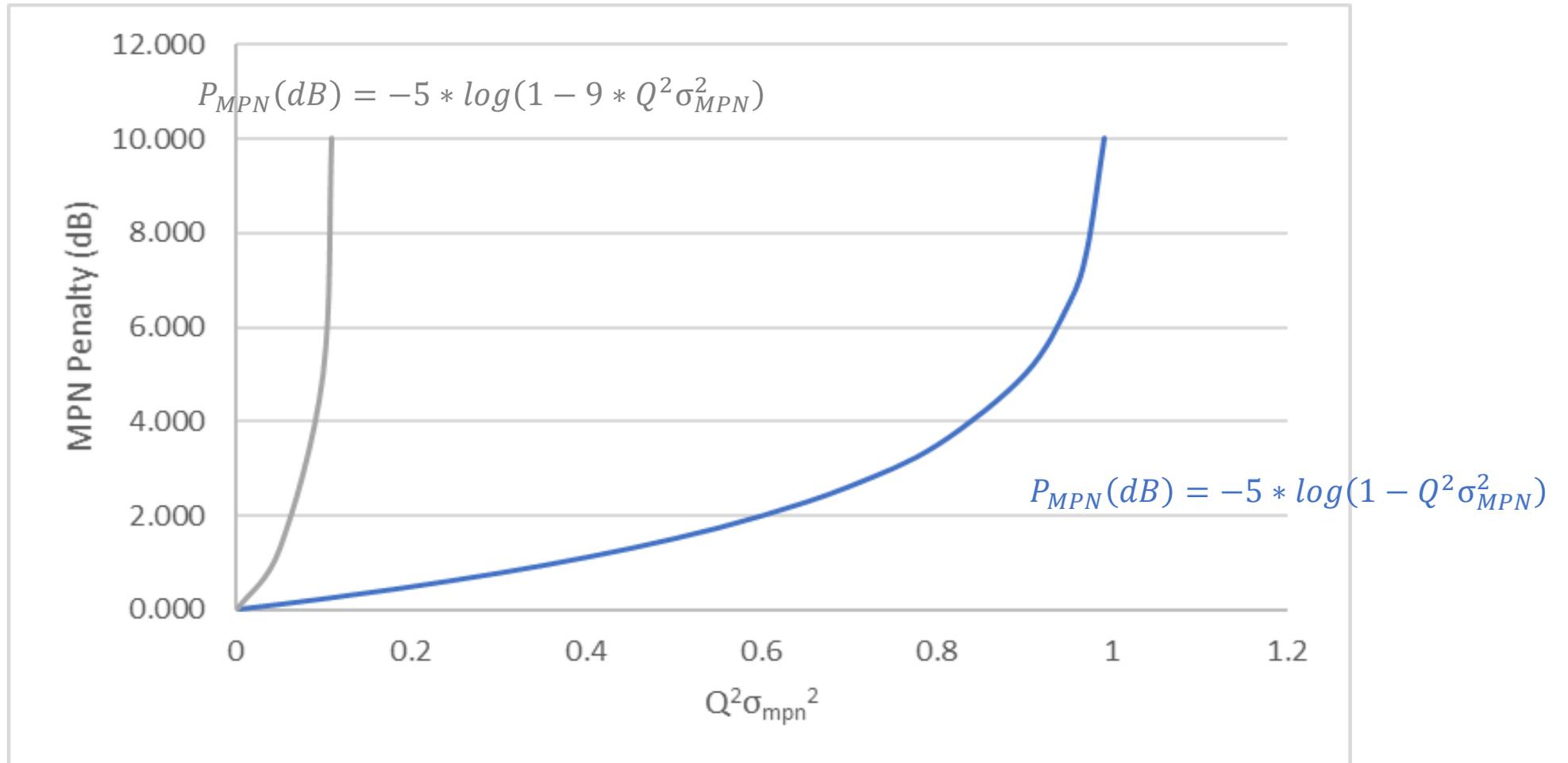
$$P_{MPN}(dB) = -5 * \log(1 - 9 * Q^2 \sigma_{MPN}^2)$$

$$\sigma_{MPN}^2 = \frac{1}{2} k^2 (\pi B)^4 (D^4 L^4 \Delta\lambda^4)$$

Lasky, et. al., "Optoelectronics for Data Communications", 1995.

- Factor of 9 for PAM4
- Equivalent to
  - 3x k
  - 1.75x L, D, or spectral width
- Length and spectral width have same impact on MPN
- Double length = double spectral width
- 300 m w/ 0.3 nm = 150 m w/ 0.6 nm
- Other penalties don't scale the same

# Factor of 9 causes MPN to blow up



Factor of 9 makes estimation of k less forgiving

# Experimental Setup

- 100G BiDi transceiver on eval board
- 2 wavelength channels, 850 and 910 nm with 50 Gbit/s PAM4
- Test at 10°C and 31°C
- Transmission measurements over OM5 fibers with EMB values close to spec
- Back-to-back up to 300 m over OM5
- Compare total transmission penalty to MPN penalty predicted by model with 4<sup>th</sup> power dependence on spectral width and fiber length

# Starting with 0.4 dB predicted penalty, scale to match experiments

$$MPN(dB) = 0.4 * \left( \frac{Spectral\ Width}{0.6\ nm} \right)^4 * \left( \frac{Fiber\ Length}{150\ m} \right)^4 * \left( \frac{Q}{3.414\ dB} \right)^2$$

0.4 dB MPN penalty with:

- 0.6 nm Spectral Width
- 150 m OM5 fiber
- Q = 3.414 dB

## Estimates of budget with minor noise penalties

10GBASE-SR		100GBASE-SR4			400GBASE-SR8			400G-4.2 D1.0		400G-4.2 better Tx		400G-4.2 125 m	
Spreadsheet example		Estimates for two k values			As in P802.3cd	Pessi-mistic	Opti-mistic	Pessi-mistic	Opti-mistic	Pessi-mistic	Opti-mistic	Pessi-mistic	Opti-mistic
PAM- (no. levels)		2						4					
No. eyes		1						3					
Qmin		7.0345	3.8906					3.414					
TDP, TDEC or TDECQ	dBo	3.9	4.3		4.5	4.5		4.5		3.84	4.06	4.00	4.16
Total penalty	dBo	4.2	4.3	4.11	4.60	4.95	4.80	5.41	5.05	4.50	4.50	4.50	4.50
Signalling rate	GBd	10.3125	25.78125					26.5625					
Reach	m	300	100		100			150		150		125	
Spectral width	nm	0.29	0.6		0.6	0.6		0.6		0.6		0.6	
MPN penalty	dBo	0.1	0.14	0.02	0.02	0.15	0.09	0.55	0.31	0.41	0.25	0.25	0.15
MN penalty	dBo	0.3	0.11	0.03	0.08	0.30	0.22	0.36	0.24	0.25	0.19	0.25	0.19
Combined	dBo	0.4	0.24	0.05	0.10	0.45	0.30	0.91	0.55	0.66	0.44	0.50	0.35
MPN k, also used for MN		0.3	0.3	0.1	0.0296	0.1	0.075	0.1	0.075	0.1	0.075	0.1	0.075
TDP, TDEC or TDECQ w/o Pmpn		3.8	3.92	4.04	4.5	4.5	4.5	4.5	4.5	3.84	4.06	4.00	4.16
Rate*reach*spectral width		897	1547		1594			2391	2391	2391	2391	1992	1992
MPN noise	rel. OMA outer	0.01247	0.0257	0.0086	0.0030	0.0090	0.0068	0.0171	0.0128	0.0171	0.0128	0.0130	0.0098

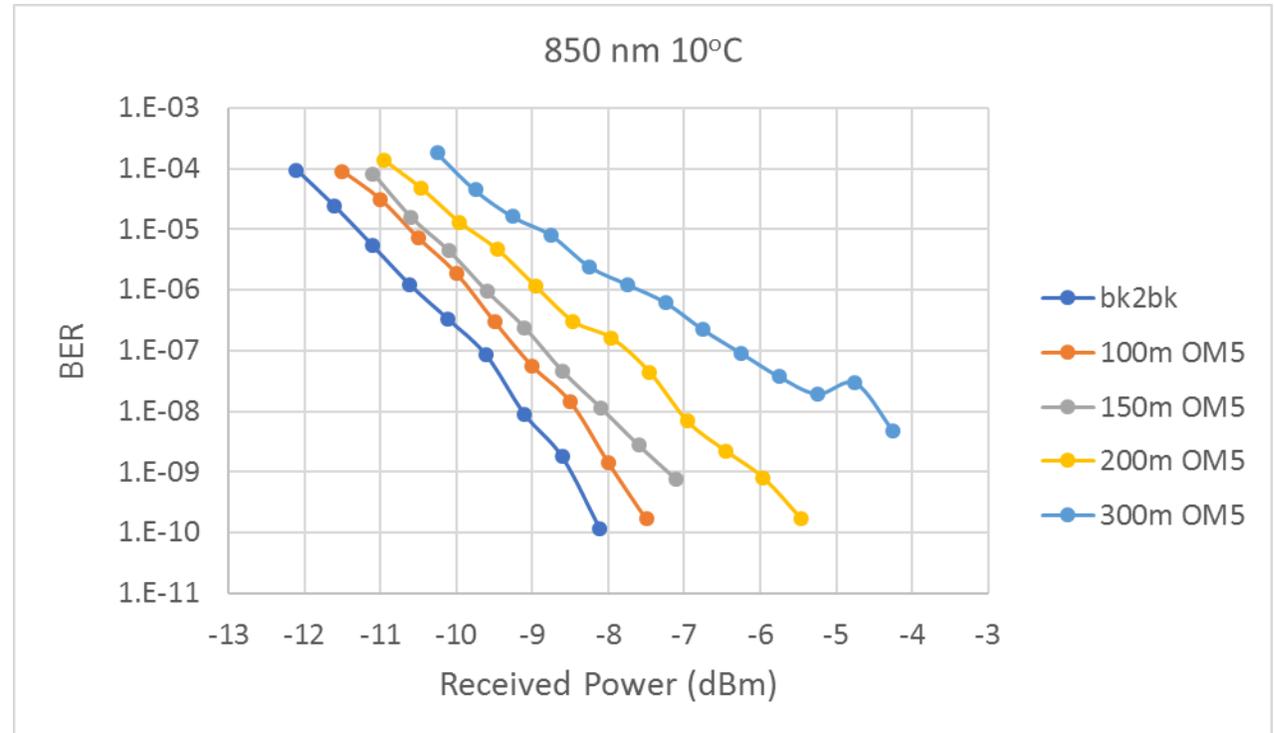
Start with the penalties and k factor in 10GBASE-SR. Compare 100GBASE-SR4, where estimated Pmpn and Pmn are low because PAM2 and FEC

In right hand columns, assume k is 0.1 or 0.075. Scale the 10G/25G noises and predict the penalties for 802.3cm MMF: around 0.4 to 0.9 dB, bringing the total penalty to around **4.9 dB to 5.4 dB, which is too high**. There is only 0.1 dB in the budget for these penalties

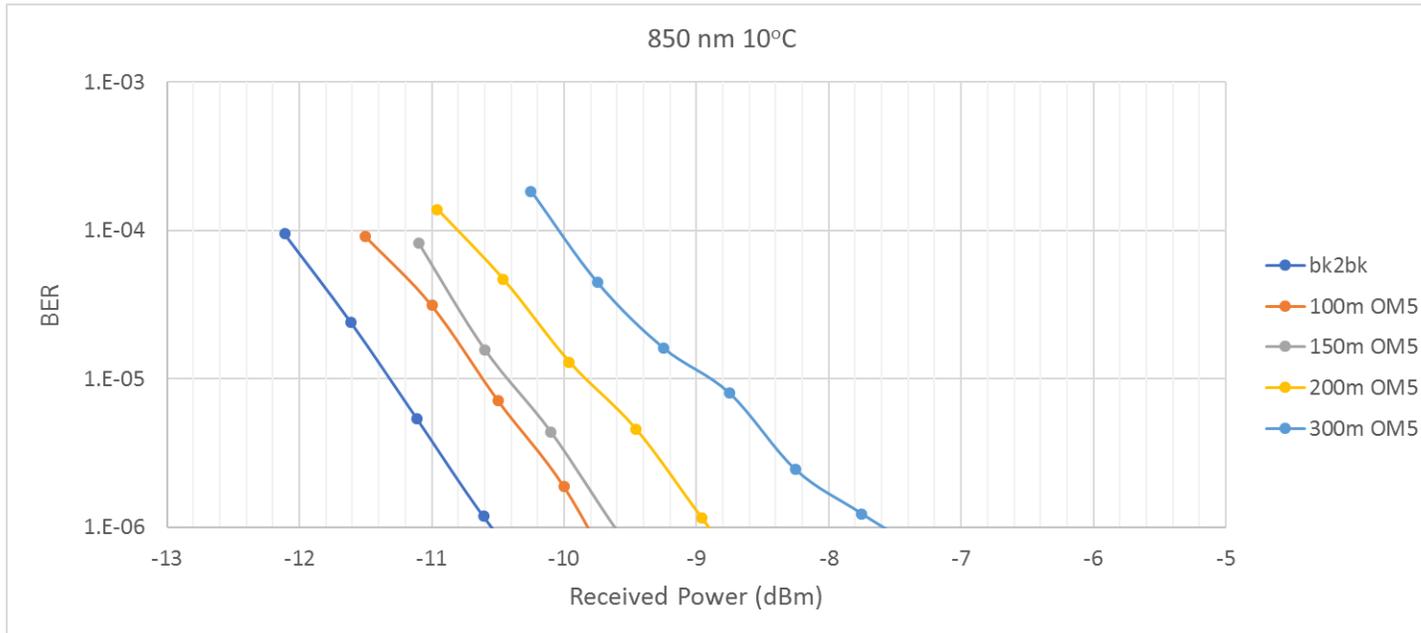
The modal noise penalty could be higher or lower for all columns together – need new information

# 850 nm 10°C

- RMS Spectral Width = 0.331 nm
- Center wavelength = 854.6 nm
- Fiber EMB @ 850 nm = 4875 MHz\*km
- EMB spec = 4700 MHz\*km



# 850 nm 10°C

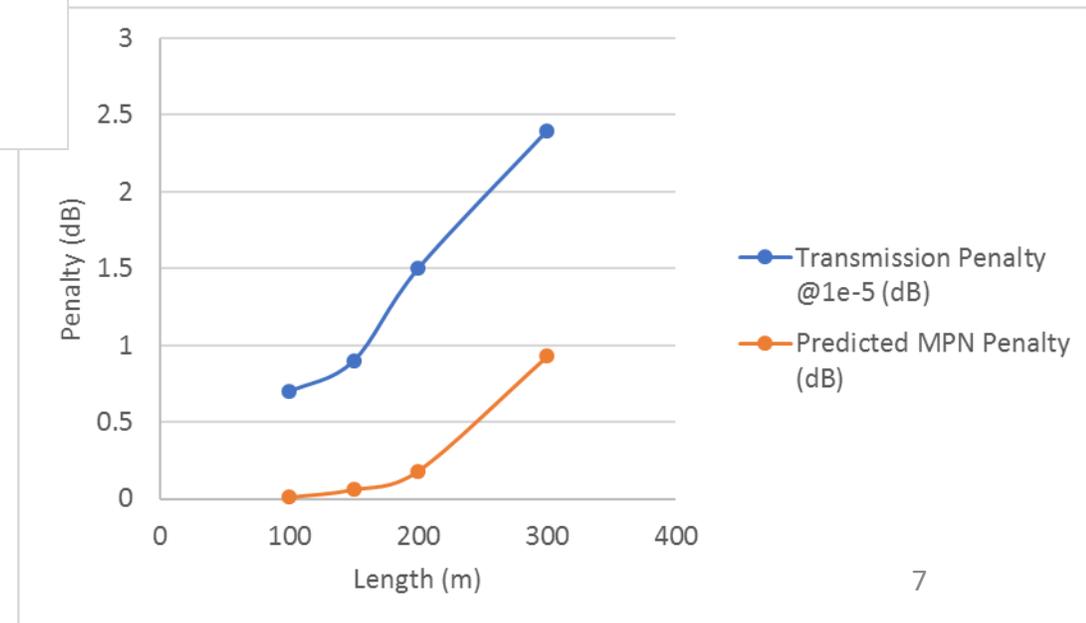


Length (m)	Transmission Penalty @1e-5 (dB)	Predicted MPN Penalty (dB)
100	0.7	0.01
150	0.9	0.06
200	1.5	0.18
300	2.4	0.93

Predicted MPN penalty grows faster than measured total penalty

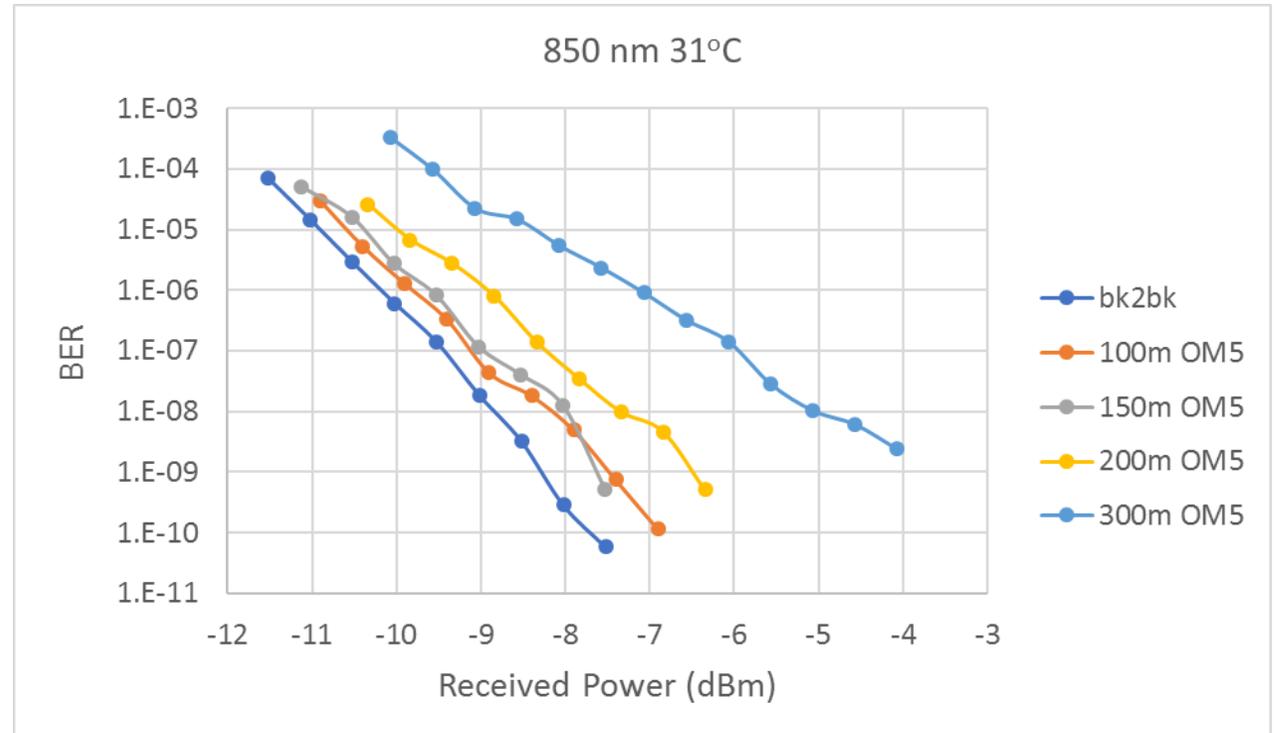
Transmission penalty is from

- Modal dispersion
- Chromatic dispersion
- MPN
- RIN
- etc.

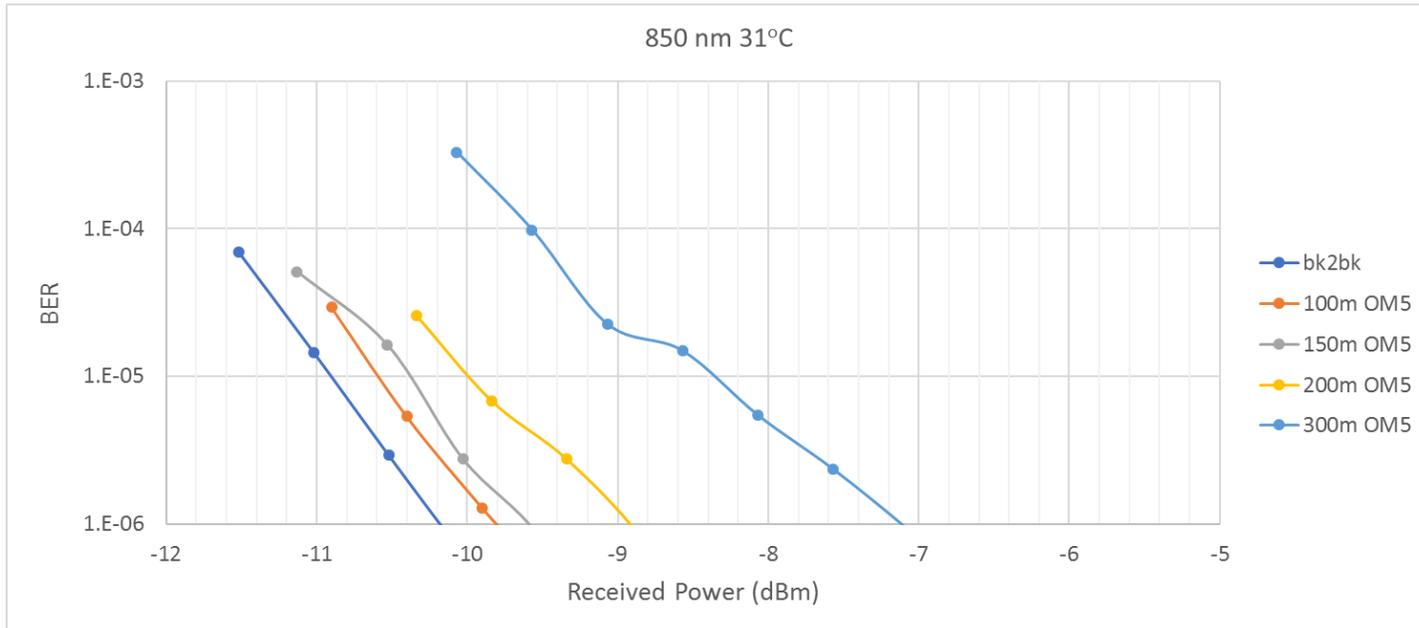


# 850 nm 31°C

- RMS Spectral Width = 0.312 nm
- Center wavelength = 855.82 nm
- Fiber EMB @ 850 nm = 4875 MHz\*km
- EMB spec = 4700 MHz\*km



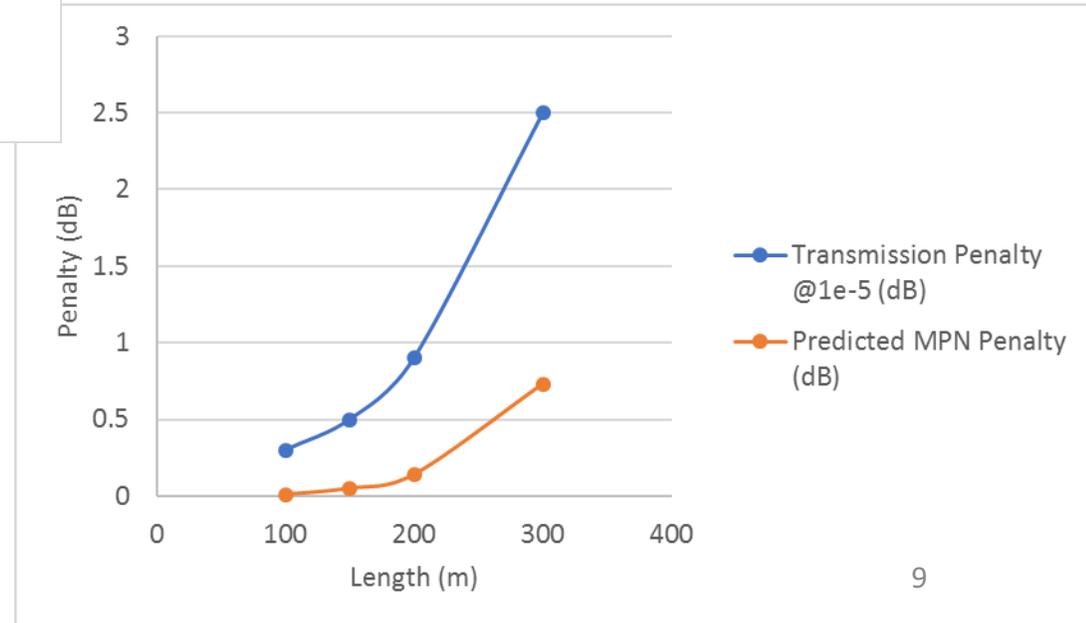
# 850 nm 31°C



Length (m)	Transmission Penalty @1e-5 (dB)	Predicted MPN Penalty (dB)
100	0.3	0.01
150	0.5	0.05
200	0.9	0.14
300	2.5	0.73

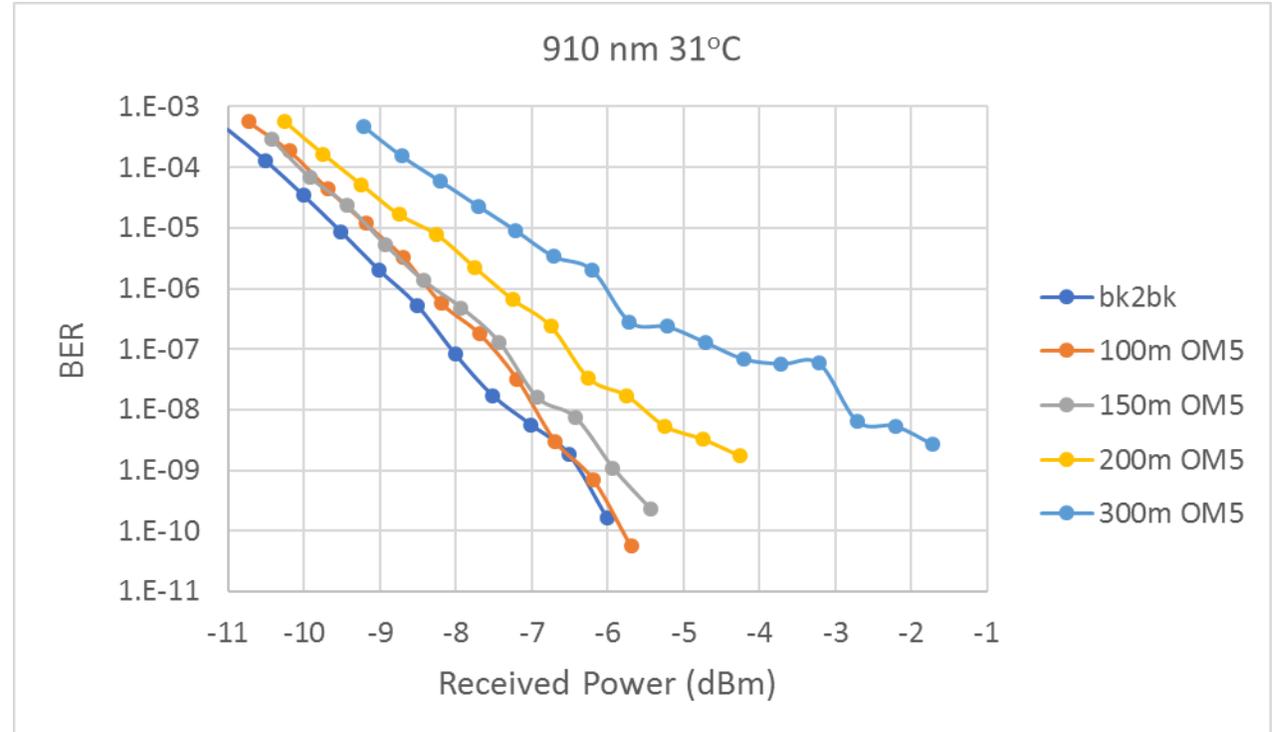
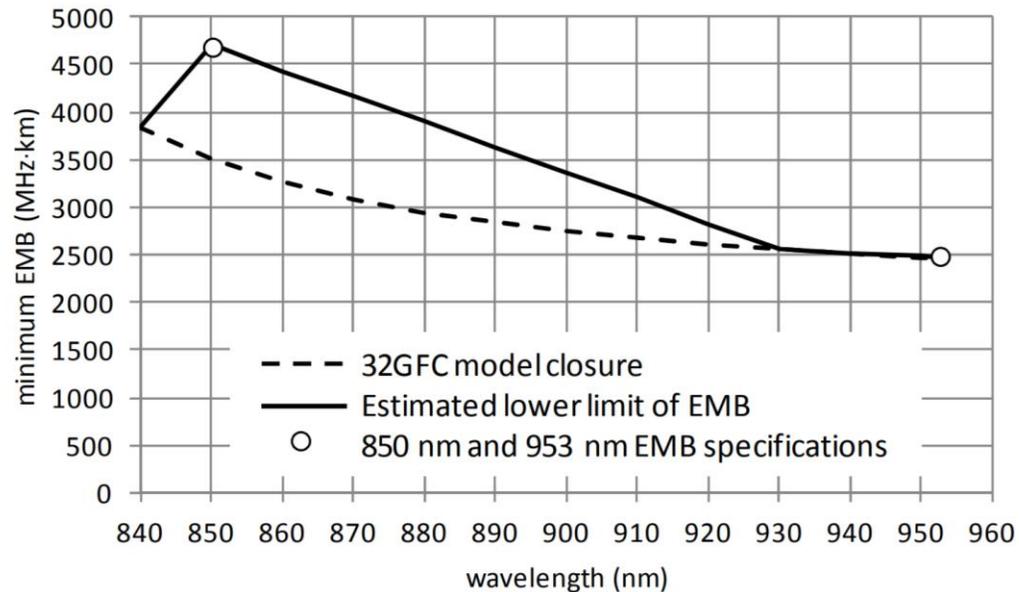
Transmission penalty is from

- Modal dispersion
- Chromatic dispersion
- MPN
- RIN
- etc.

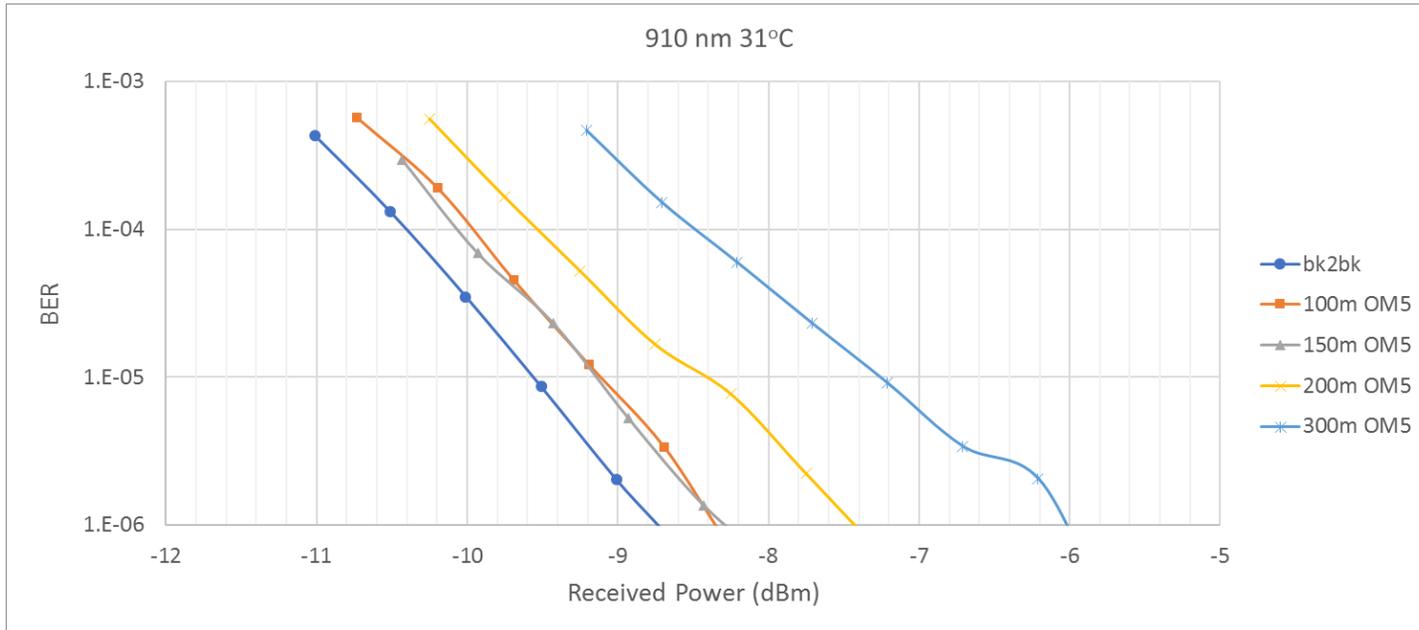


# 910 nm 31°C

- RMS Spectral Width = 0.38 nm
- Center wavelength = 906.6 nm
- Fiber EMB @ 910 nm = 3900 MHz\*km
- EMB guidance ~ 3100 MHz\*km



# 910 nm 31°C

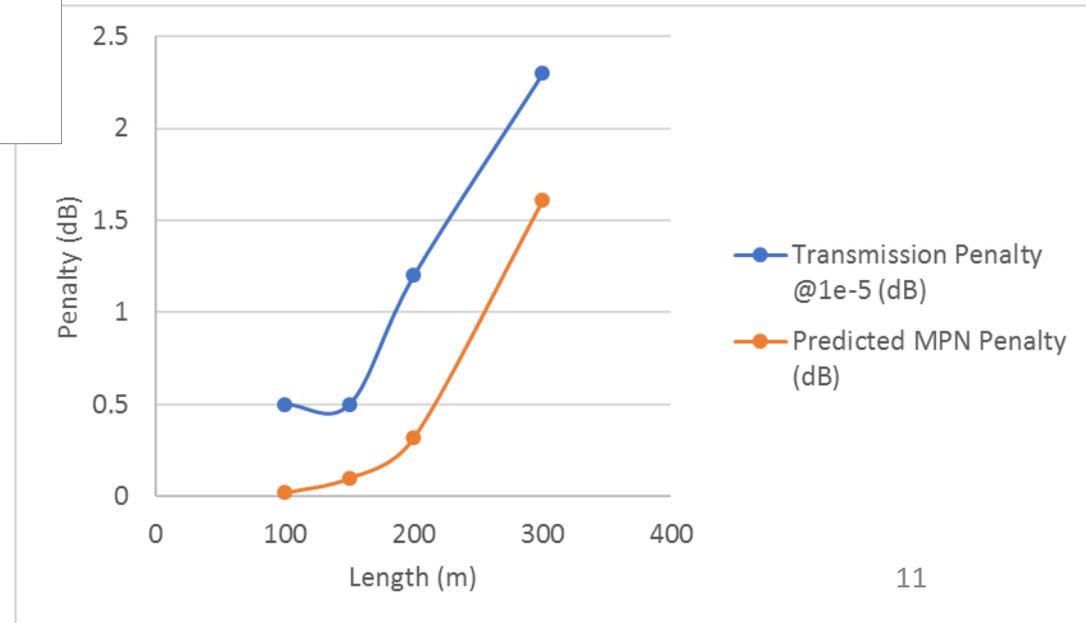


Length (m)	Transmission Penalty @1e-5 (dB)	Predicted MPN Penalty (dB)
100	0.5	0.02
150	0.5	0.1
200	1.2	0.32
300	2.3	1.61

Predicted MPN penalty approaches total measured penalty

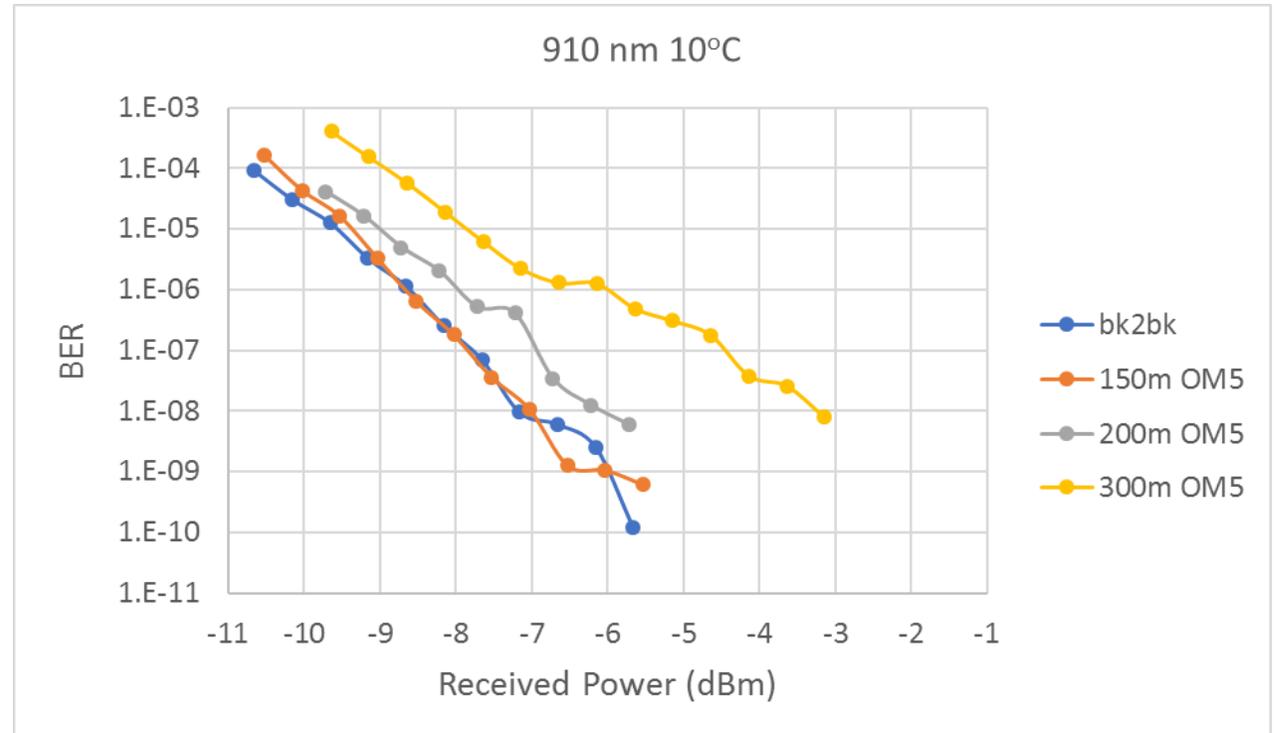
Transmission penalty is from

- Modal dispersion
- Chromatic dispersion
- MPN
- RIN
- etc.

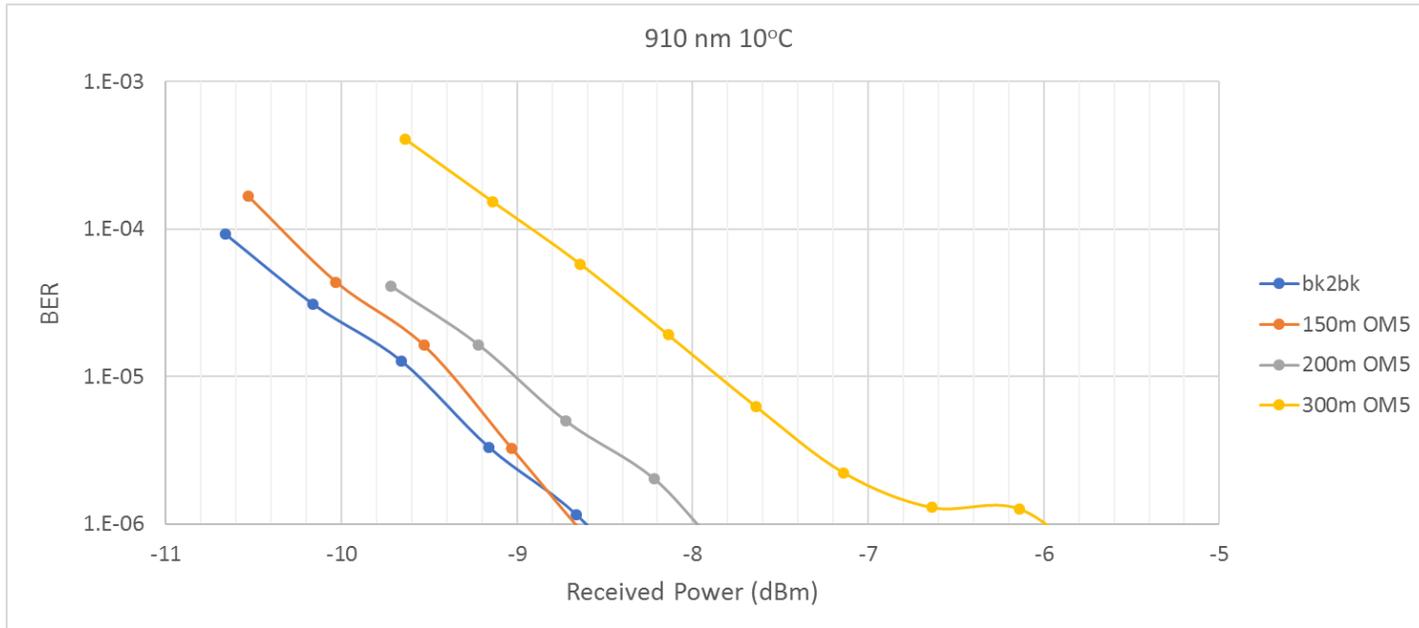


# 910 nm 10°C

- RMS Spectral Width = 0.41 nm
- Center wavelength = 903.5 nm
- Fiber EMB @ 910 nm = 3900 MHz\*km
- EMB guidance ~ 3100 MHz\*km



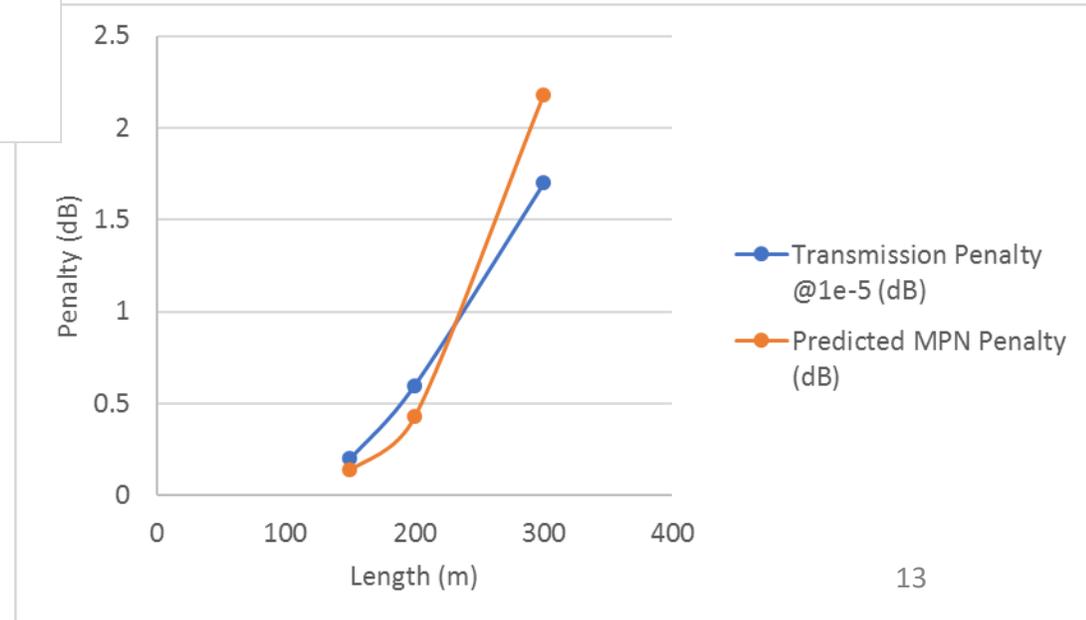
# 910 nm 10°C



Length (m)	Transmission Penalty @1e-5 (dB)	Predicted MPN Penalty (dB)
150	0.2	0.14
200	0.6	0.43
300	1.7	2.18

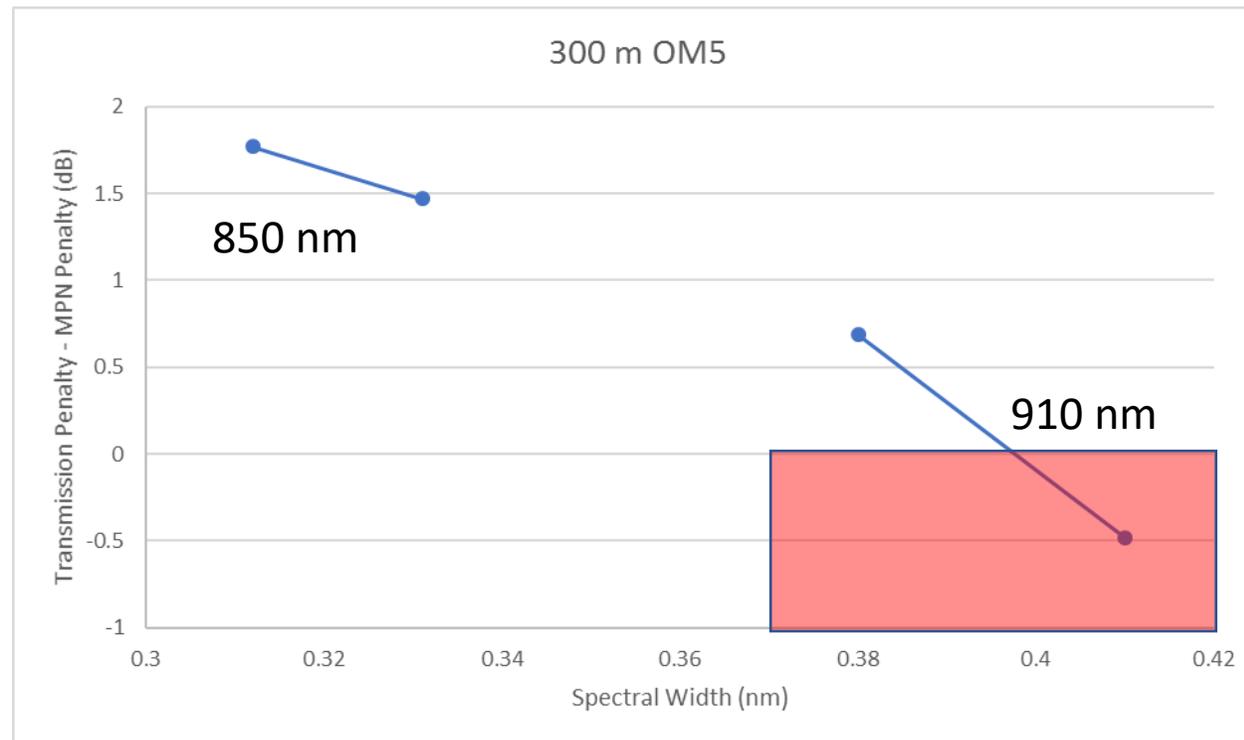
Predicted MPN penalty exceeds total measured penalty > 250 m  
 Transmission penalty is from

- Modal dispersion
- Chromatic dispersion
- MPN
- RIN
- etc.



Wider spectral widths lead to greater discrepancy between measured transmission penalty and predicted MPN penalty

- As the spectral width increases, the predicted MPN penalty increases
- MPN increases faster than measured penalty
- Starting at  $\sim 0.38$  nm, MPN penalty is greater than total penalty



Not physically possible

Worst measured transmission penalty at 300 m = 2.5 dB

- 850 nm channel, 0.31 nm spectral width
- 850 nm channel, 0.33 nm spectral width penalty = 2.4 dB
- Total transmission penalty for 0.65 nm spectral width over 150 m would be at most 2.5 dB
  - MPN and CD scale w/ spectral width and length
  - Modal dispersion, does not scale w/ spectral width
  - Actual penalty would be lower than 2.5 dB

# Conclusions

- PAM4 Transmission Experiments indicate that MPN penalty is lower than predicted at high predicted values of MPN