Gigabit PON Upstream Transmission Feasibility - A Statistical Analysis Tool

Y. Lisa Peng   Kendall D. Musgrove
Corning Incorporated

and

Meir Bartur
Zonu Incorporated

IEEE 802.3ah, Raleigh NC
January 2002

CORNING
Discovering Beyond Imagination

Introduction

- Various PON upstream transmission scenario were statistically modeled using Corning SMF fiber distributions and 1310nm FP laser distributions from a well-known Japanese laser manufacture

- Comprehensive system parameter inclusions

CORNING

The Approach - General

- Define important fiber and FP laser link parameters
- Obtain their practical statistical distribution
- Compute the statistical link feasibility based on loss and dispersion limitations
- Evaluate the sensitivity of important link parameters such as split ratio, k factor and BER

CORNING

The Approach - Important Link Parameters

- **Statistical distributions of Corning SMF-28 fiber**
  - **zero wavelength, dispersion slope, loss**
- **Statistical distributions of 1310 FP laser**
  - **center wavelength, spectral width, transmitter power, receiver power,**
- **Other link parameter distributions**
  - **connector, splice, clock recovery, cabled attenuation adder**
- **Discrete parameters, Constants and assumptions**
  - **k - discrete, pick from 0.3 to 0.8**
  - **MPN - allowance of 1 dB or 2 dB**
  - **data rate: 1.25 Gbps**
  - **System margin - 2 dB**
  - **laser temperature impact - will include later**
  - **split ratio - pick from p-t-p, 1x4, 1x8, 1x16 and 1x32**
  - **BER - pick from 10^{-9} to 10^{-12}**

CORNING

The Approach - Calculations

Attenuation limit: $L = \dfrac{P_T - P_R - CR - Cxn - Splc - Splt - M}{\alpha}$

Dispersion (Corning SMF-28): $D(\lambda) = \dfrac{S_0}{4}\left[\lambda - \dfrac{\lambda_0^4}{\lambda^3}\right]$

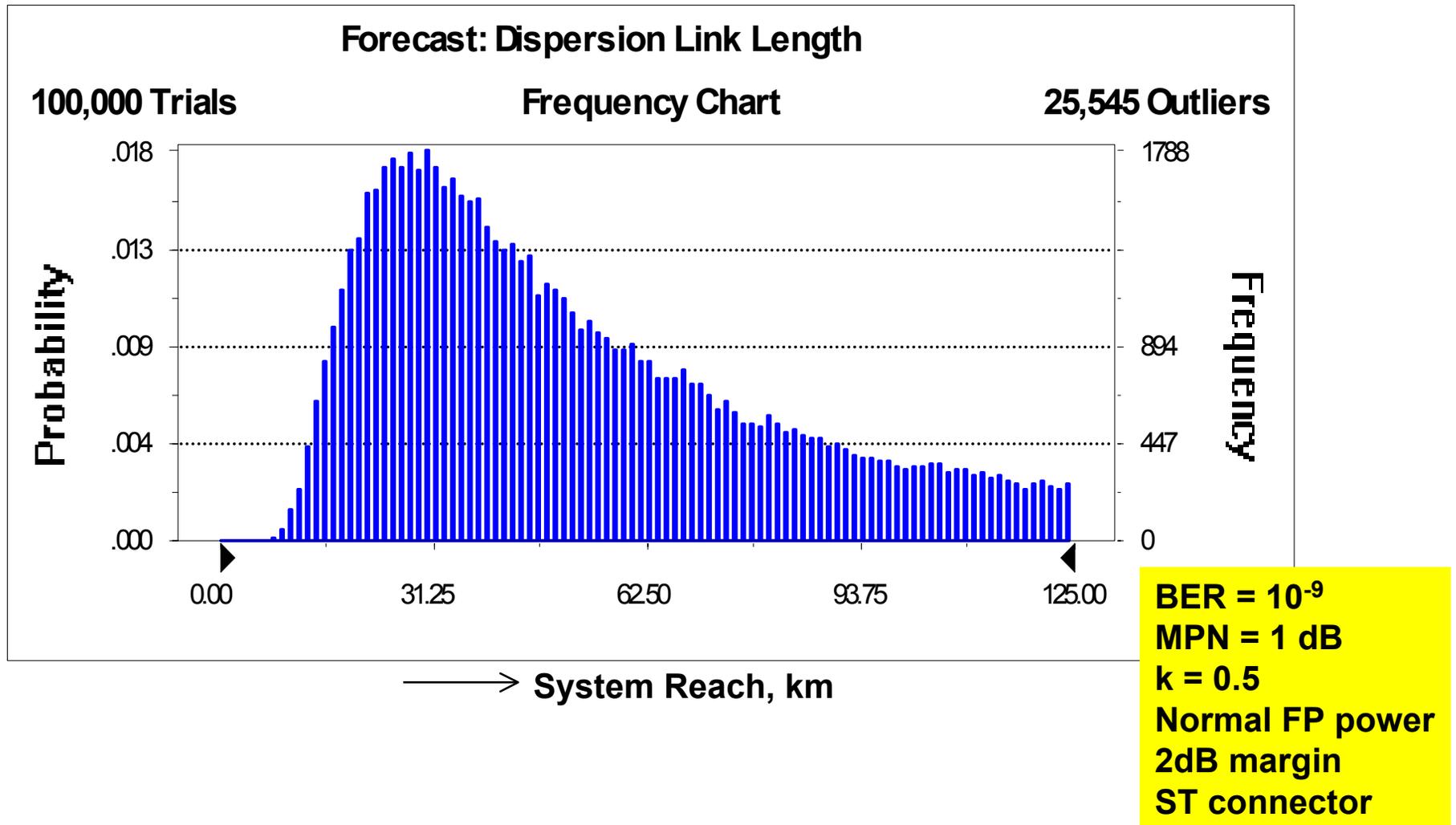MPN limited length: $L = \dfrac{1}{\pi * D * \sigma_\lambda * B}\sqrt{\ln\dfrac{k}{k - r_{mpn}\sqrt{2}}}$

Where r_{mpn} is calculated from: $r_{mpn} = \dfrac{1}{Q}\sqrt{\left[\left(1 - 10^{-\frac{\delta_{mpn}}{5}}\right)\right]}$

Assuming 1dB or 2dB δ_{mpn} system impairment

CORNING

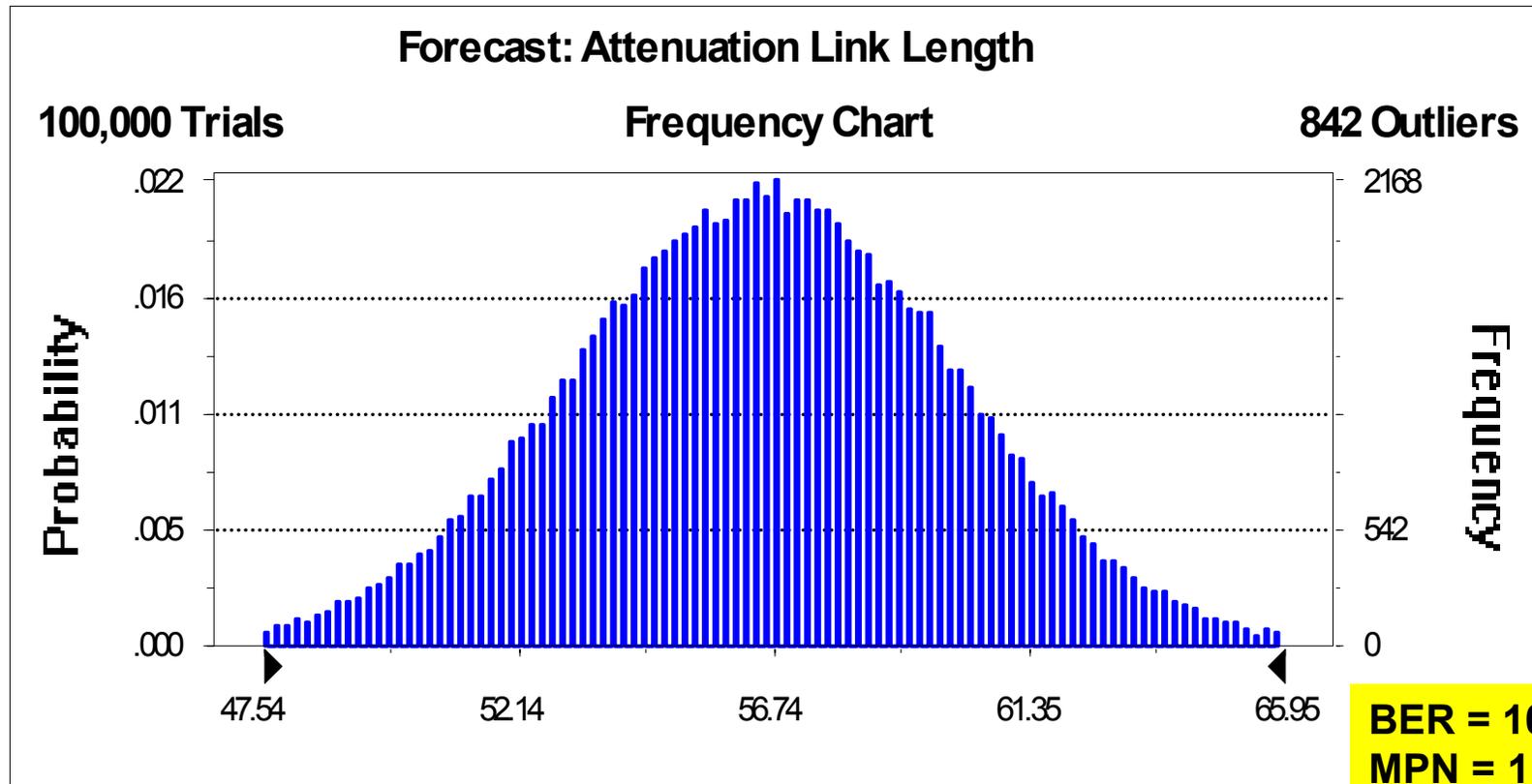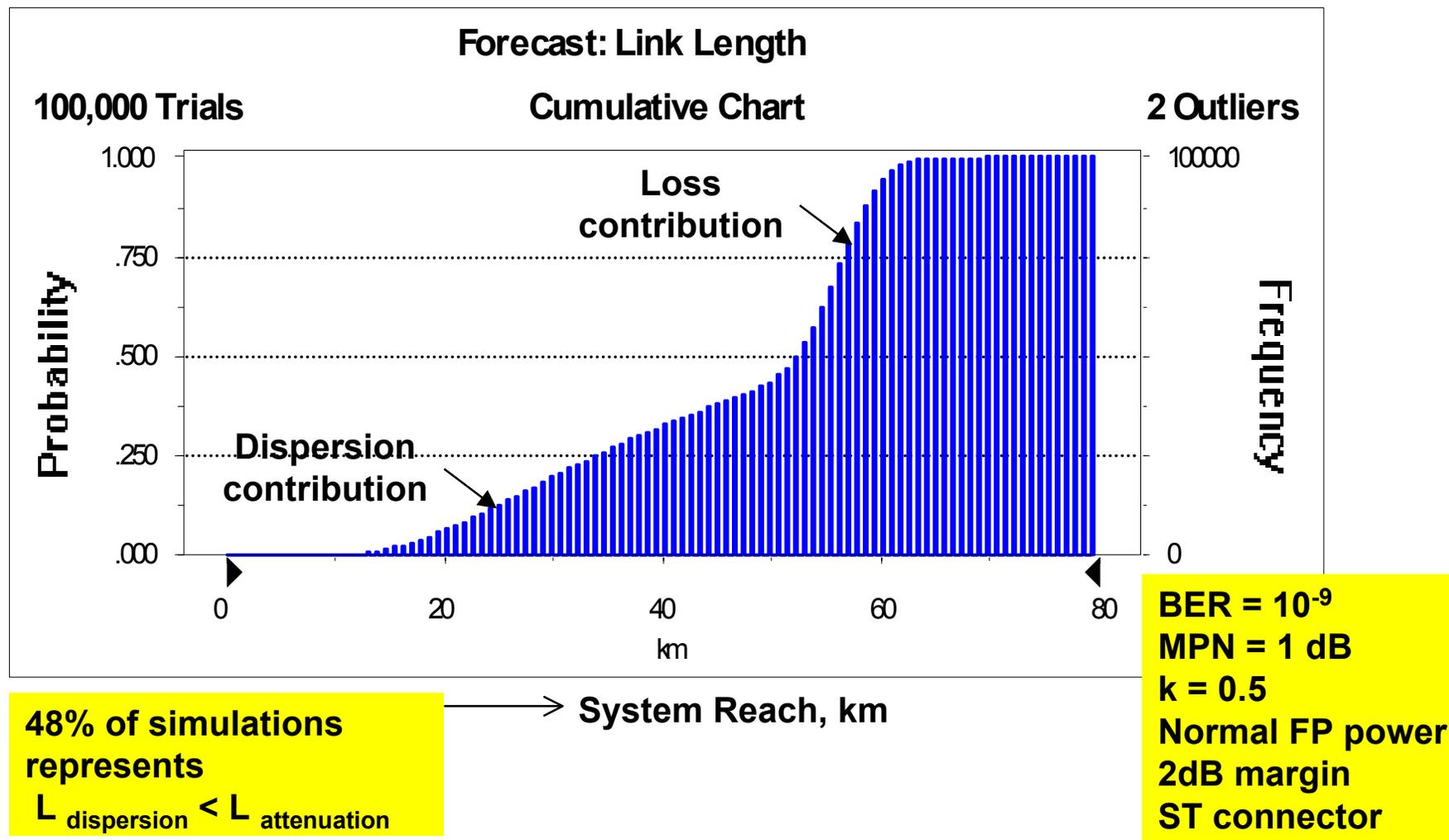# Link Statistical Reach Example -Link Length from Calculated from Dispersion

Forecast: Dispersion Link Length

100,000 Trials — Frequency Chart — 25,545 Outliers

System Reach, km

BER = 10^{-9}
MPN = 1 dB
k = 0.5
Normal FP power
2dB margin
ST connector

CORNING

Link Statistical Reach Example
-Link Length from Calculated from Loss

Forecast: Attenuation Link Length

100,000 Trials   **Frequency Chart**   **842 Outliers**

System Reach, km

BER = 10^{-9}
MPN = 1 dB
k = 0.5
Normal FP power
2dB margin
ST connector

Corning Zonu IEEE EFM Meeting January 2002 Raleigh NC

CORNING

Link Statistical Reach Example -Combined System Reach

Forecast: Link Length

100,000 Trials | **Cumulative Chart** | **2 Outliers**

Loss contribution

Dispersion contribution

System Reach, km

48% of simulations represents
$L_{dispersion} < L_{attenuation}$

BER = 10^{-9}
MPN = 1 dB
k = 0.5
Normal FP power
2dB margin
ST connector

Corning Zonu IEEE EFM Meeting January 2002 Raleigh NC

CORNING

Impact of Split Ratio on Link Failure Rate Probability

BER = 10^{-9}
MPN = 1 dB
k = 0.5
Normal FP power
2dB margin
ST connector

Probability (y-axis)
Range, km (x-axis)

Legend:
- P_t_P Basic-cum
- 1x32 Basic-cum
- 1x16 Basic-cum
- 1x8 Basic-cum
- 1x4 Basic-cum

Corning Zonu IEEE EFM Meeting January 2002 Raleigh NC

CORNING
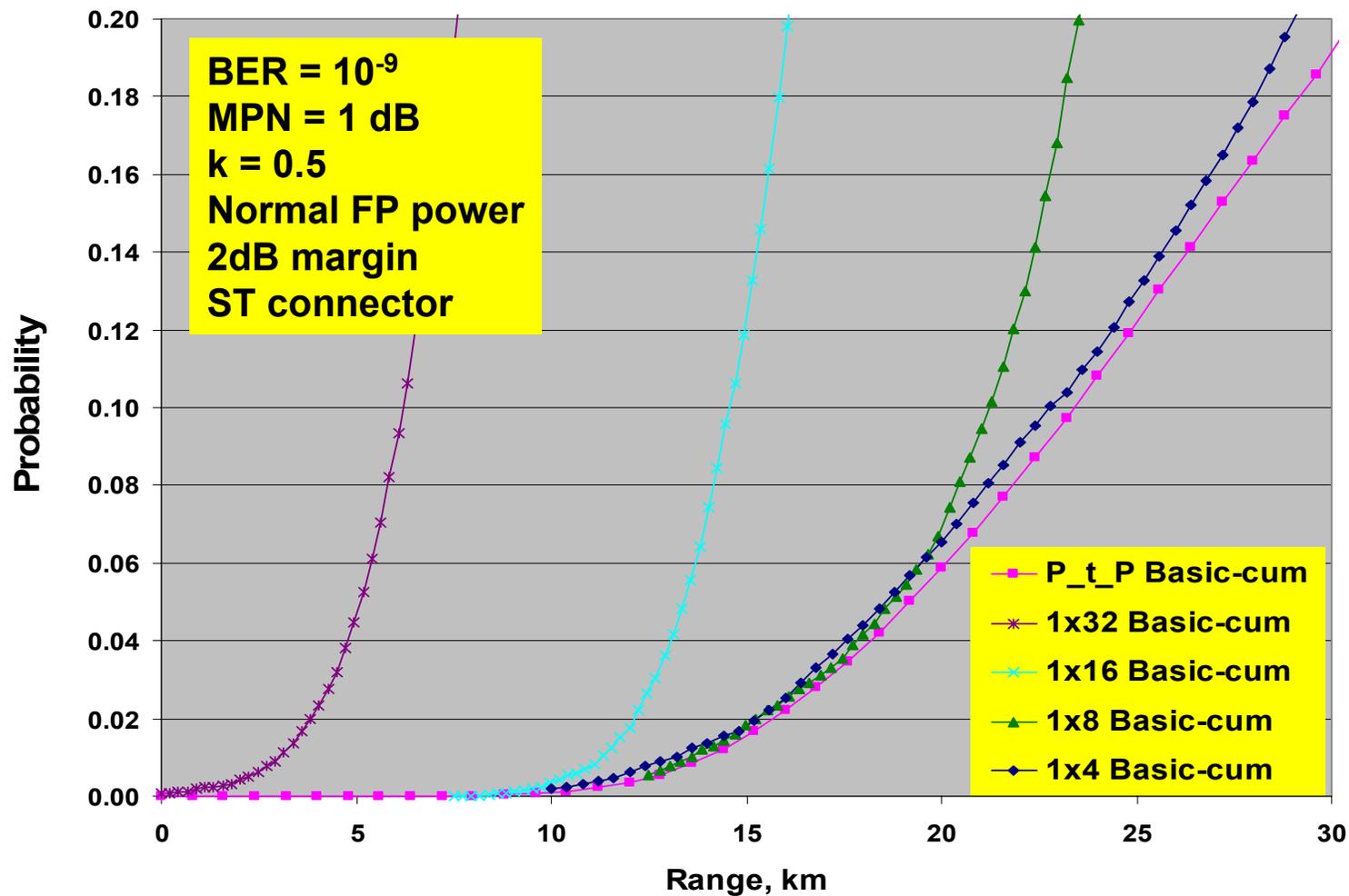
Dispersion and Loss Contributions of Normal Gigabit PONs

PON Split	% Dispersion Limited	% Loss Limited
Point to Point	48	52
1x4	28	72
1x8	16	84
1x16	6	94

BER = 10^{-9}
MPN = 1 dB
**k = 0.5**
Normal FP power
2dB margin
ST connector

CORNING

Impact of k Factor on Link Failure Probability
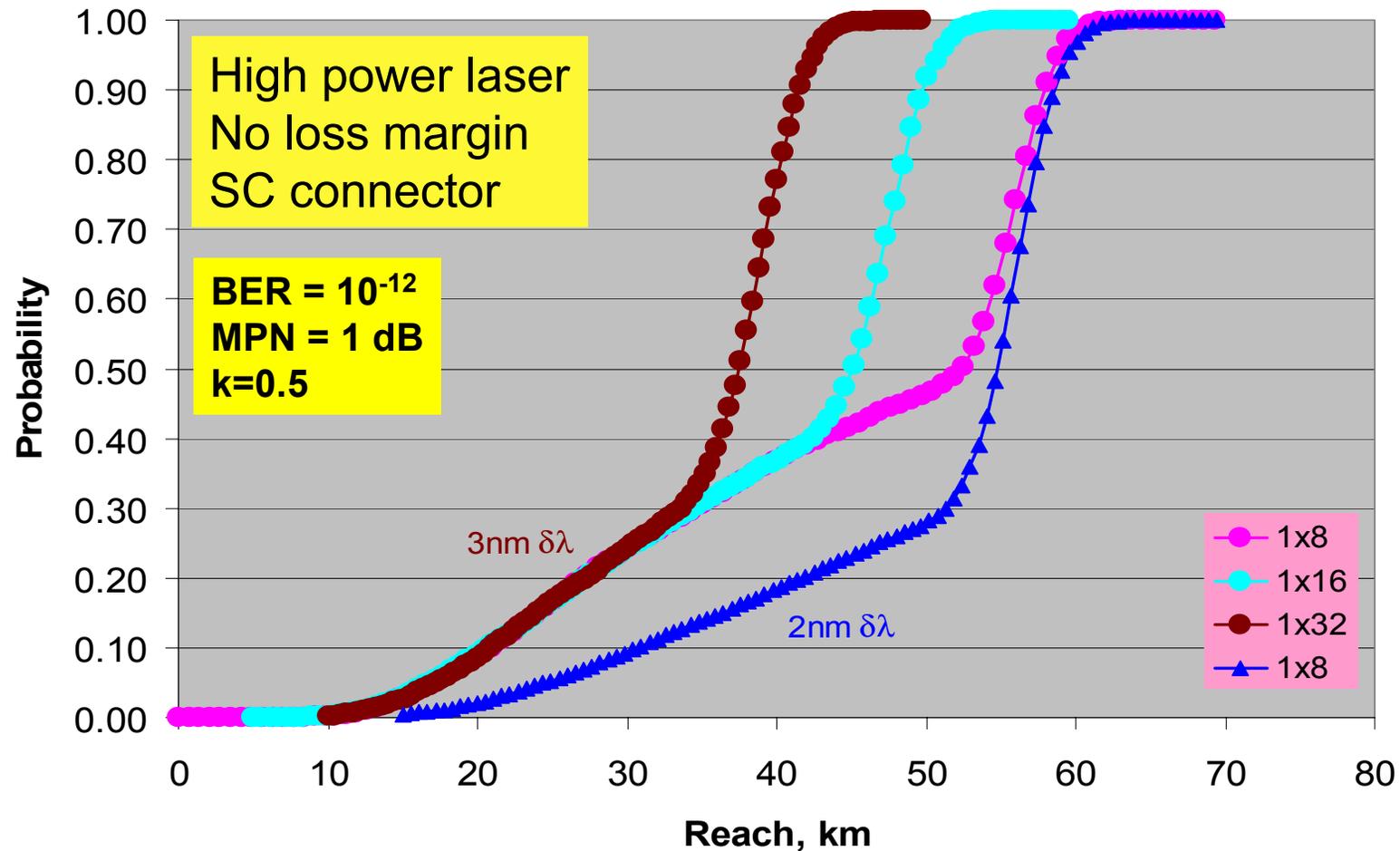
k factor significantly lowers the system reach

1x8 Split
BER = 10^{-12}
MPN = 1 dB
Normal FP power
2dB margin
ST connector

**k increase
from 0.5 to 0.8**

Probability (y-axis)

Range, km (x-axis)

CORNING
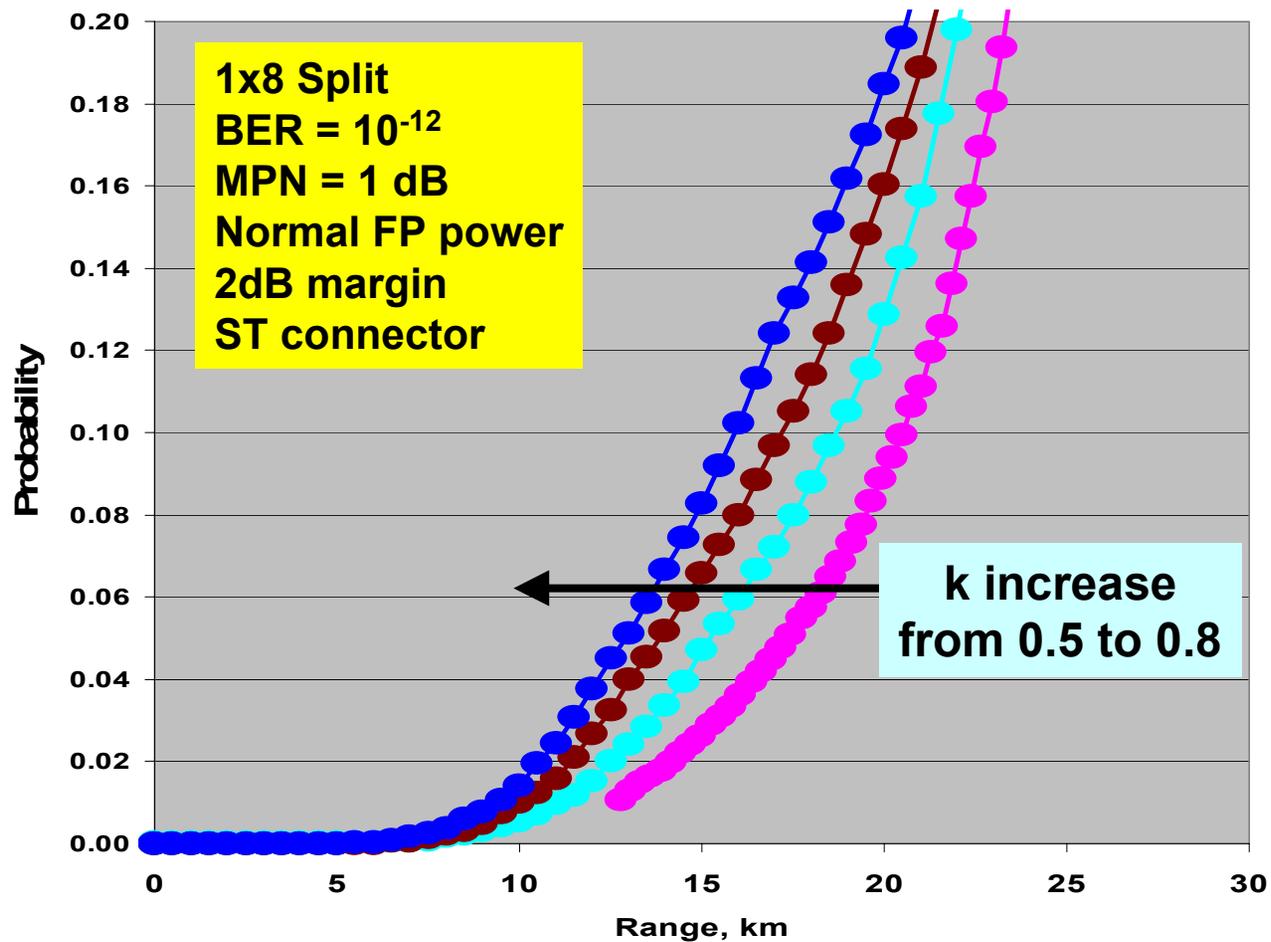
Impact of k Factor on Link Failure Probability

k factor impact bigger in point-to-point systems

P-t-P
BER = 10^{-12}
MPN = 1 dB
Normal FP power
2dB margin
ST connector

k increase
from 0.5 to 0.8

CORNING
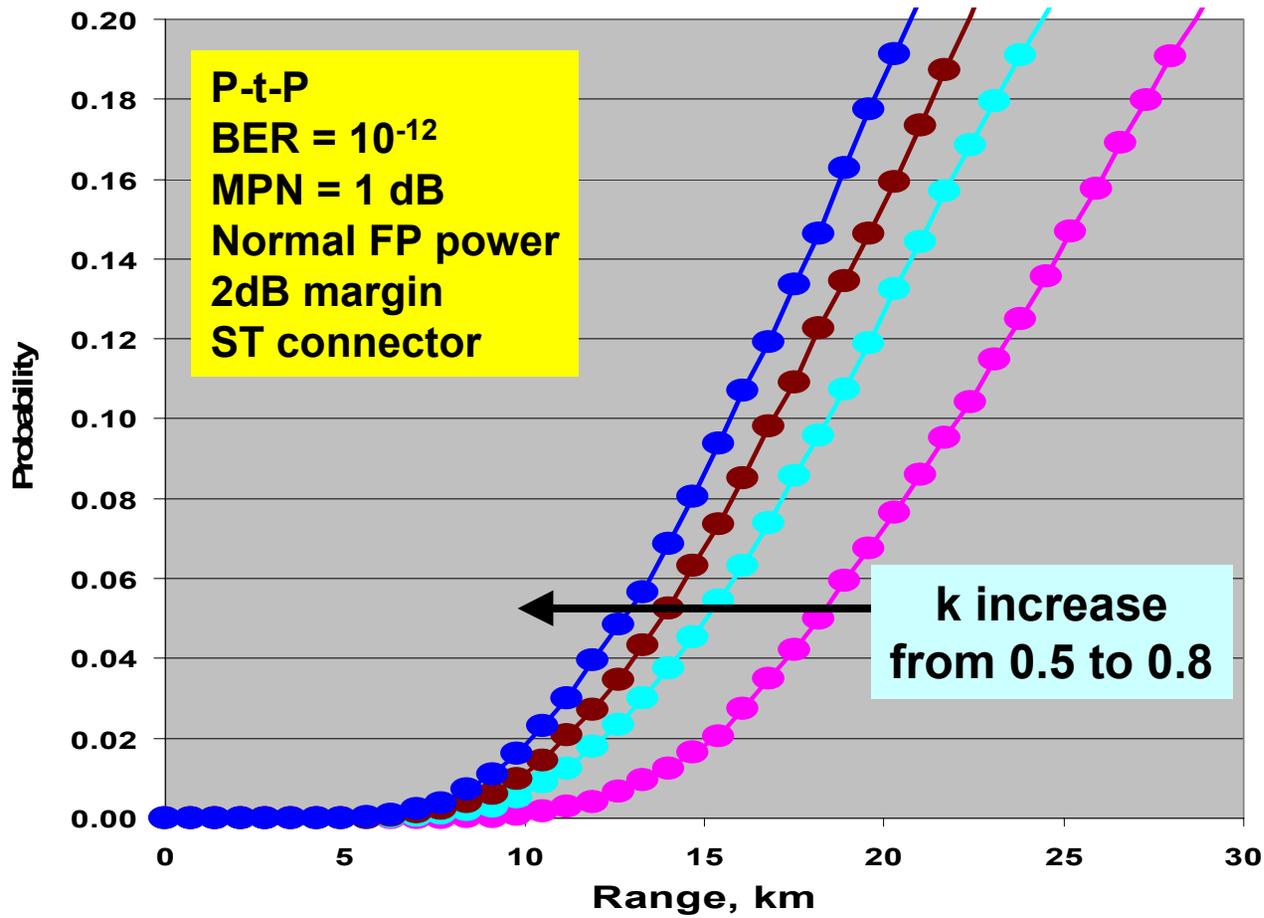
System Can be Strongly Dispersion Limited Even with High Power Lasers

High power laser
No loss margin
SC connector

BER = 10^{-12}
MPN = 1 dB
k=0.5

3nm $\delta\lambda$

2nm $\delta\lambda$

Probability

Reach, km

- 1x8
- 1x16
- 1x32
- 1x8

CORNING

Regular FP LD utilization for high data-rates

- Statistical link power margin model
  - Adopted from AT&T paper ~1995
  - Factors all link parameters based on mean and standard deviation
  - Example (keeping fixed dispersion losses. Using statistical modeling for dispersion gives much better results). Link Margin difference in dB. FP @-2dBm
- Link Budget Power Margin (dB)

Mean – 3σ	Worst Case	(Mean – 2σ) – Worst Case	(Mean – 3σ) – Worst Case	Scenario
5.93	2.4	4.3	3.53	10 km 1:16
0.66	-3.2	4.68	3.86	20 km 1:16
2.78	-0.6	4.15	3.38	10 km 1:32
-2.49	-6.2	4.53	3.71	20 km 1:32

CORNING

High Power FP LD utilization for high data-rates

- Statistical link power margin model
  - Same as previous slide except High Power FP @2dBm

- Link Budget Power Margin (dB)

Mean – 3σ	Worst Case	(Mean – 2σ) – Worst Case	(Mean – 3σ) – Worst Case	Scenario
9.9	6.4	4.3	3.53	10 km 1:16
4.7	0.8	4.68	3.86	20 km 1:16
6.8	3.4	4.15	3.38	10 km 1:32
1.5	-2.2	4.53	3.71	20 km 1:32

CORNING

FP LD utilization for high data-rates

Recommendation:

- Strive for mean/STD data for key parameters.

- Employ Monte-Carlo simulation for dispersion statistics as an integral part of the tool.

- Adopt round-robin testing to reach consensus on MPN and test methodology for inclusion in PMD spec.

Corning Zonu IEEE EFM Meeting January 2002 Raleigh NC

CORNING

Conclusions

- Developed a statistical tool for PON link feasibility evaluation with the flexibility of adjusting various laser, fiber, and link architectural designs

- System capability can be enhanced with statistical design

- Gigabit PON systems may be dispersion limited due to MPN of FP1310 nm lasers at the ONU even at high split ratios and using high powered lasers

CORNING