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Outage probability due to Stimulated Raman Scattering in GPON and TWDM-PON coexistence

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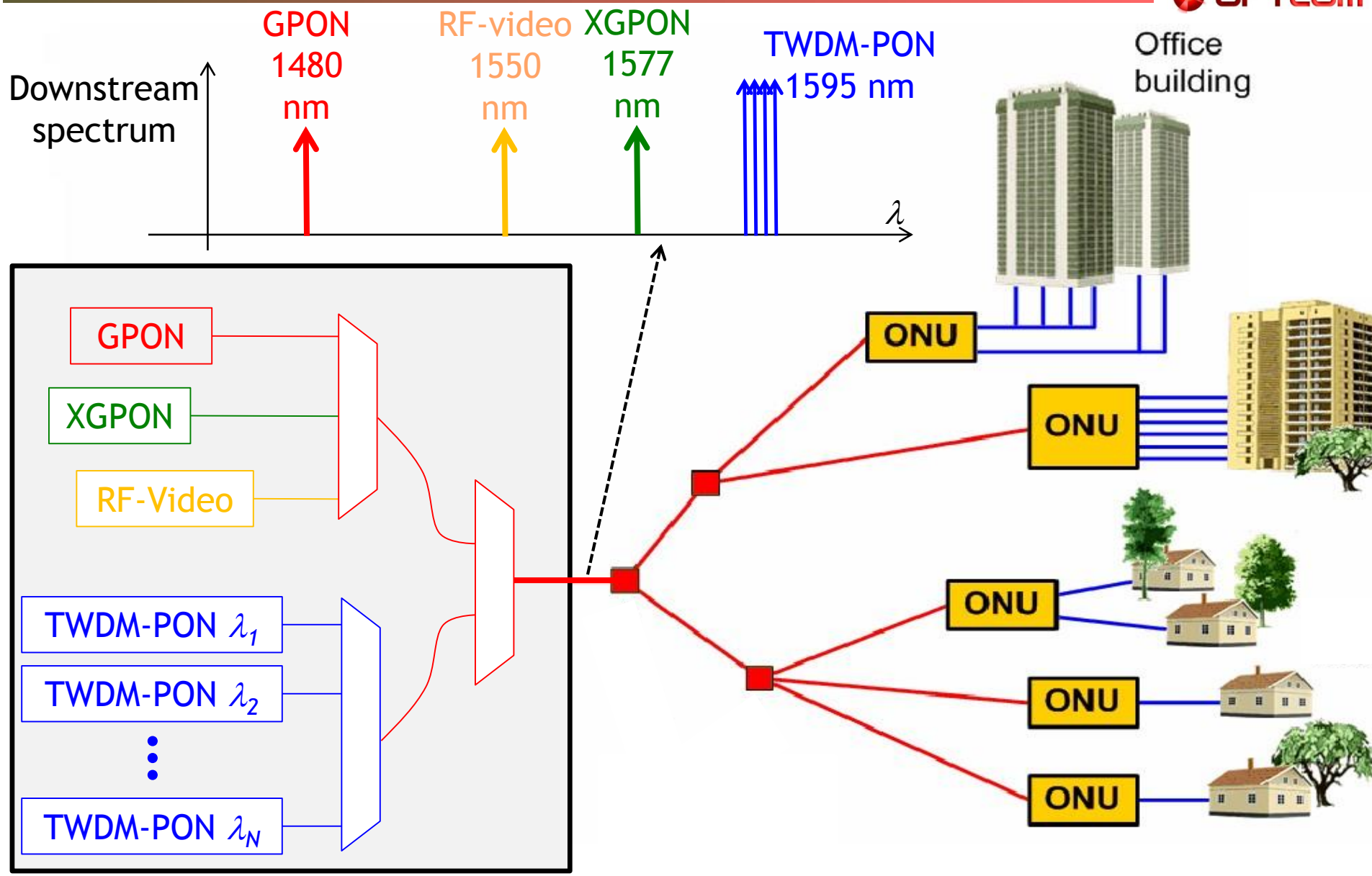
Outline

- The scenario: NGPON2 with full-backward compatibility with previous standard (GPON, XGPON and RF-Video)
- Impairments on GPON due to the Raman depletion induced by TWDM-PON
- Interplay between Raman and Polarization effects
- System design rules for full coexistence

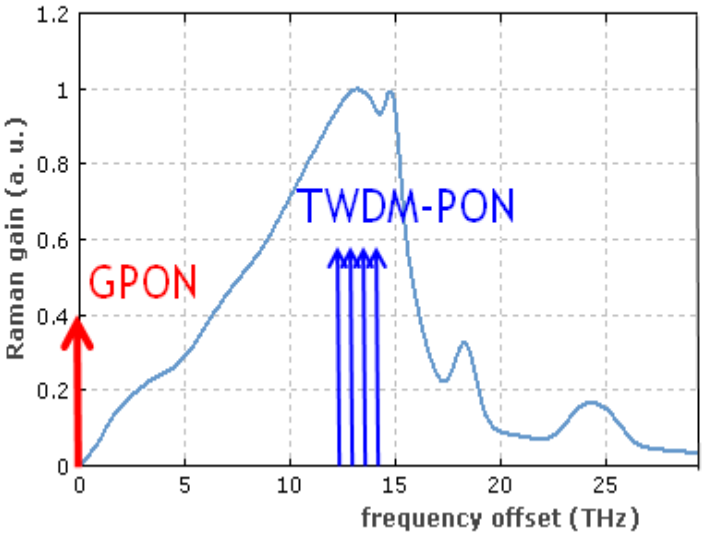
The scenario

Full coexistence scenario



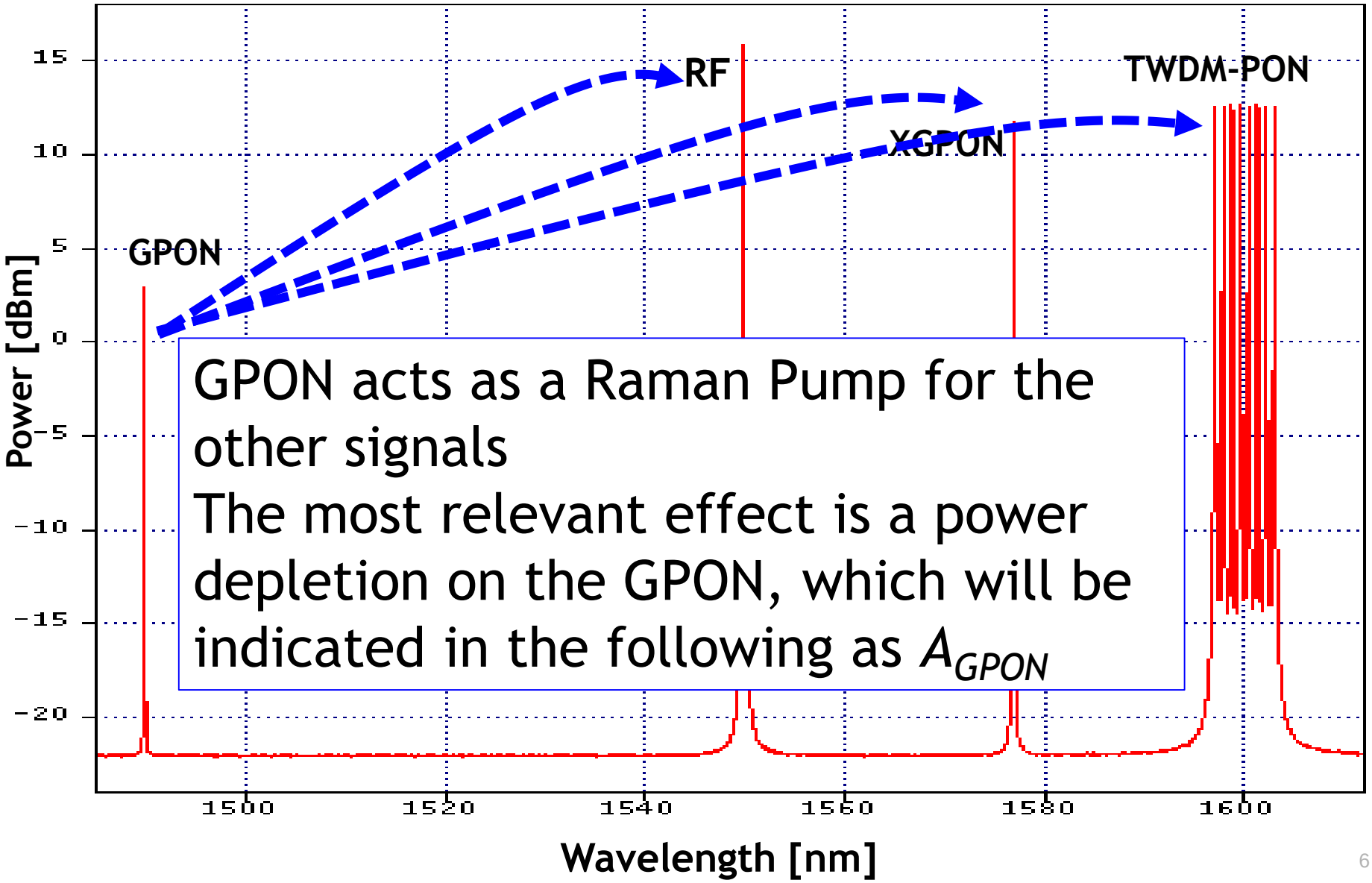
Raman effects in TWDM-PON and GPON

- **TWDM-PON wavelength allocation for the downstream**
  - 4-8 wavelengths around 1600 nm
  - Approximately 110 nm distance from GPON at 1490 nm
- **The problem**: the spectral distance is very close to the maximum efficiency of Raman crosstalk
  - Strong TWDM-PON signals can **deplete** GPON signal in the downstream due to RAMAN nonlinearity by A_{GPON} dB



- We showed in a previous paper that this problem sets a **maximum Tx power level** for TWDM-PON signals
  - This is also under investigation in FSAN

The Raman effect in NG-PON2

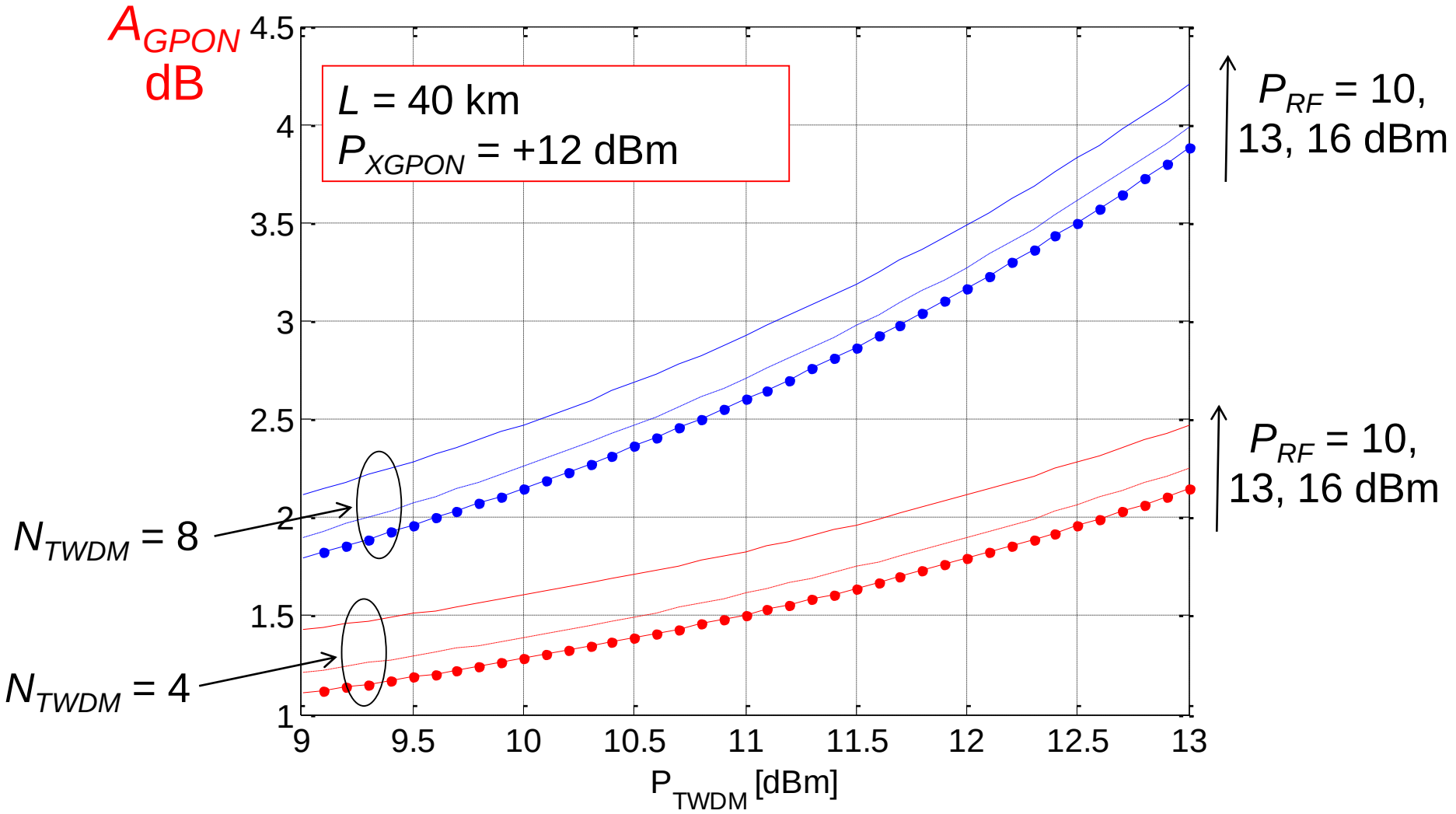


Quick summary on our previous results

Propagation impairments due to Raman effect on the coexistence of GPON, XG-PON, RF-video and TWDM-PON

R. Gaudino[(1)], V. Curri[(1)], S. Capriata[(2)]

A_{GPON} vs. P_{TWDM}



Analytical model

- By re-using the Raman equations that were developed to study distributed Raman amplifiers, the problem can be easily studied analytically

- Our previous results assumed a complete polarization averaging along the fiber link

- This paper extends the treatment considering also **polarization-related effects**

GPON Raman-induced depletion and its interplay with polarization effects induced by PMD

Raman and polarization states

- We focus ONLY on the impact of TWDM-PON over GPON depletion and ONLY on the downstream

- The involved signals relative polarizations states evolve along the fiber in a random way, depending on transmitter polarizations and on fiber PMD

- Also this effect was studied in the past for Raman amplifiers
  - In our scenario, we can re-use the same equations, specializing them to TWDM-PON and GPON interaction

“Polarization averaged case”

Using a simple “polarization averaged” analysis, the TWDM-PON Raman depletion on GPON is estimated as:

$$A_{GPON}^{dB} = 10\log_{10}(e)\left\{C_R \cdot L_{eff} \cdot N_{TWDM} \cdot P_{TWDM}\right\}\ [dB]$$

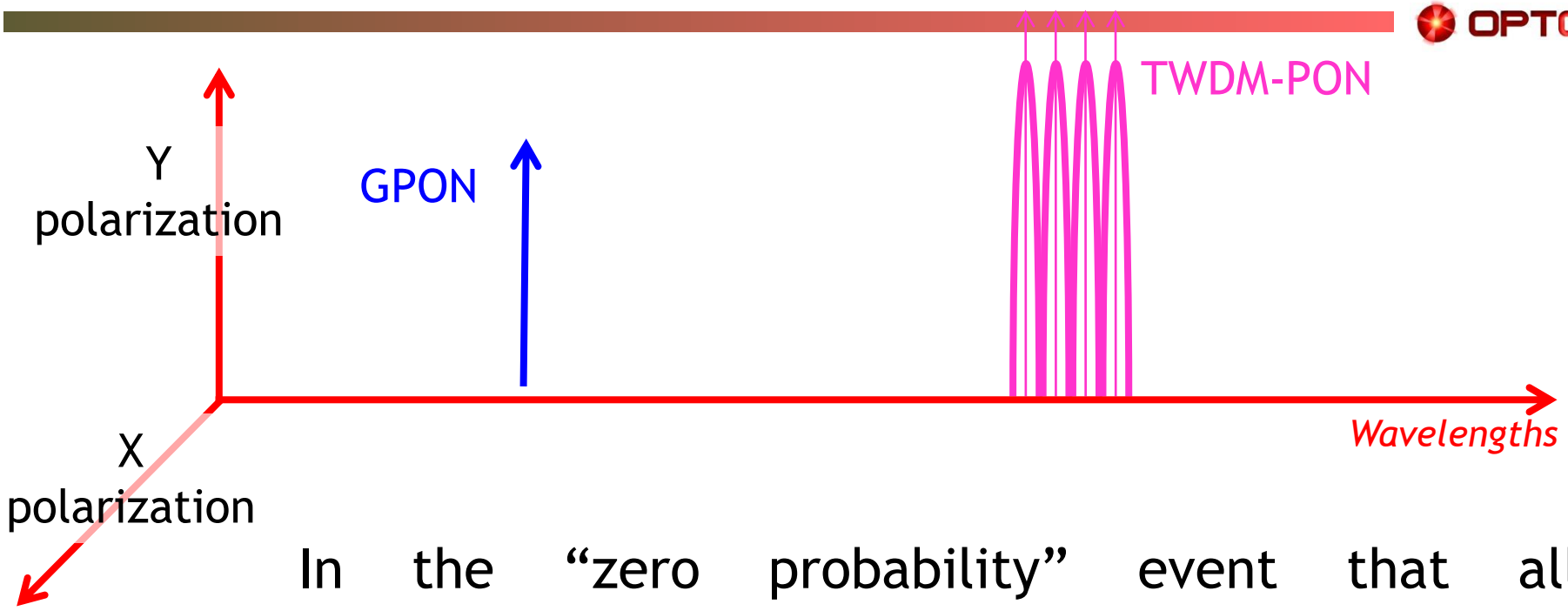
Raman coefficient (at proper spectral distance ≈100nm)

Effective length of downstream fiber link

Number of TWDM channels

Launched power on each TWDM channel

Worst-case: aligned polarizations



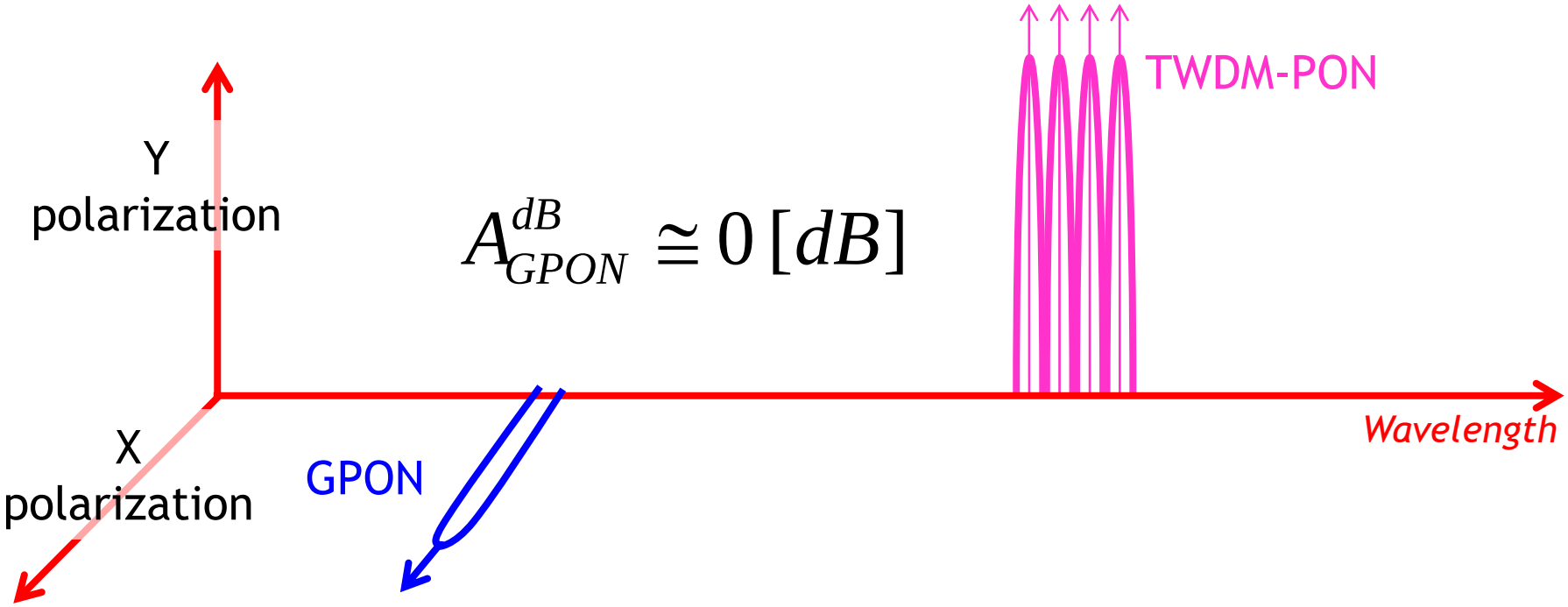
In the "zero probability" event that all wavelengths remain polarization aligned along all the PON downstream span we would have:

$$A^{dB}_{GPON}\Big|_{WC} = \mathbf{2}\cdot 10\log_{10}(e)\left\{C_{R,TWDM}\,L_{e,TWDM}\,N_{TWDM}\,P_{TWDM}\right\}\ [dB]$$

a factor 2 in dB units!!

Best case

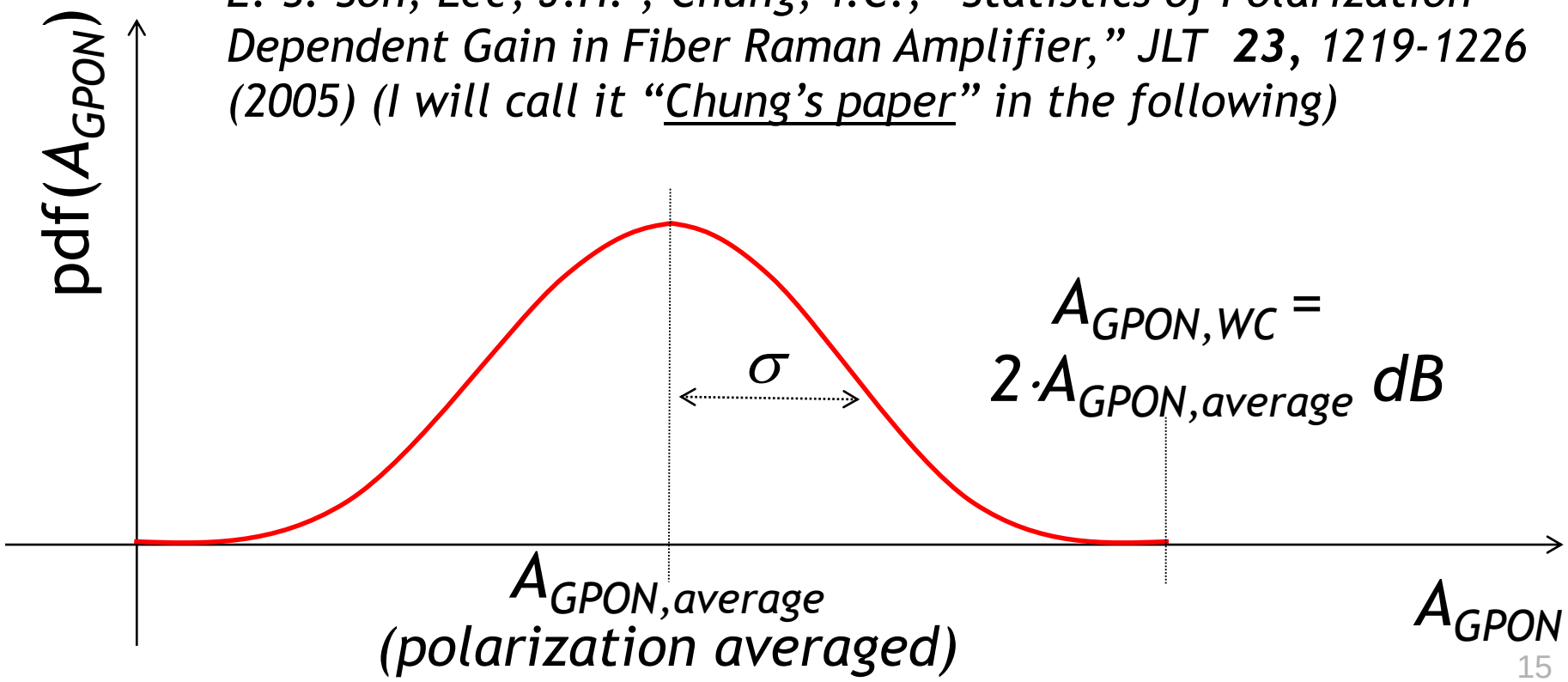
- On the contrary, for the other “zero probability” event in which all TWDM-PON signals are polarization aligned, and the GPON is orthogonal (again over all the fiber span), the Raman depletion for GPON would be almost zero



Realistic case

Considering PMD-related polarization effect, A_{GPON} is thus a random variable with a certain probability density function (PDF)

A very similar situation was studied in details for distributed Raman amplifiers, see for instance:
E. S. Son, Lee, J.H. ; Chung, Y.C., "Statistics of Polarization-Dependent Gain in Fiber Raman Amplifier," JLT ***23****, 1219-1226 (2005) (I will call it "Chung's paper" in the following)*



The general case

$$A_{GPON}^{dB} = [10\log_{10}(e)] \cdot C_R \cdot N_{TWDM} P_{TWDM} \cdot \{L_{eff} + DOP_{TX} \cdot L_{pol}\} \quad [dB]$$

Degree of polarization (DOP) at launch of the aggregated N_{TWDM} TWDM-PON channels

$$L_{pol} = \int_0^L 10^{-\frac{\alpha_{dB}}{10} z} [\hat{s}_{GPON}(z) \cdot \hat{s}_{TWDM}(z)] dz$$

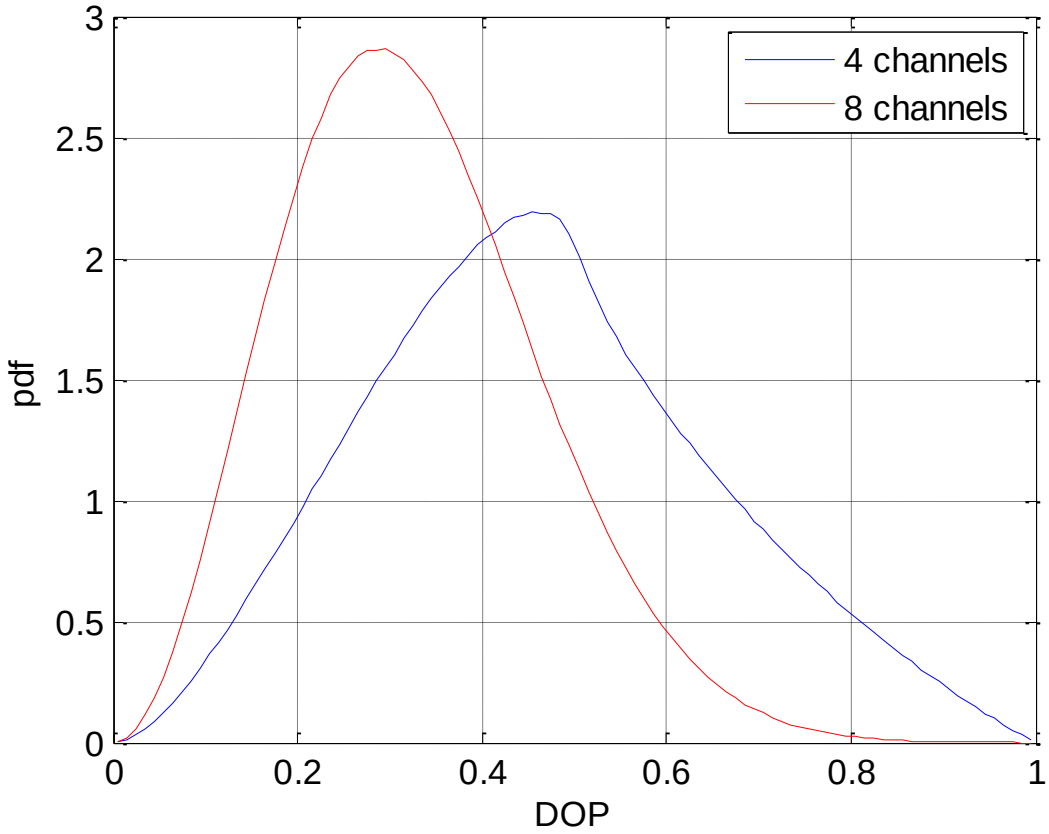
GPON polarization evolution (Stokes vector along fiber length)

TWDM-PON "average" polarization over N_{TWDM} channels

It was demonstrated (in Chung's paper) that L_{pol} is a random process assuming values in $[-L_{eff}, L_{eff}]$ having a truncated zero-mean Gaussian shape, with known variance **depending only on PMD and fiber length**

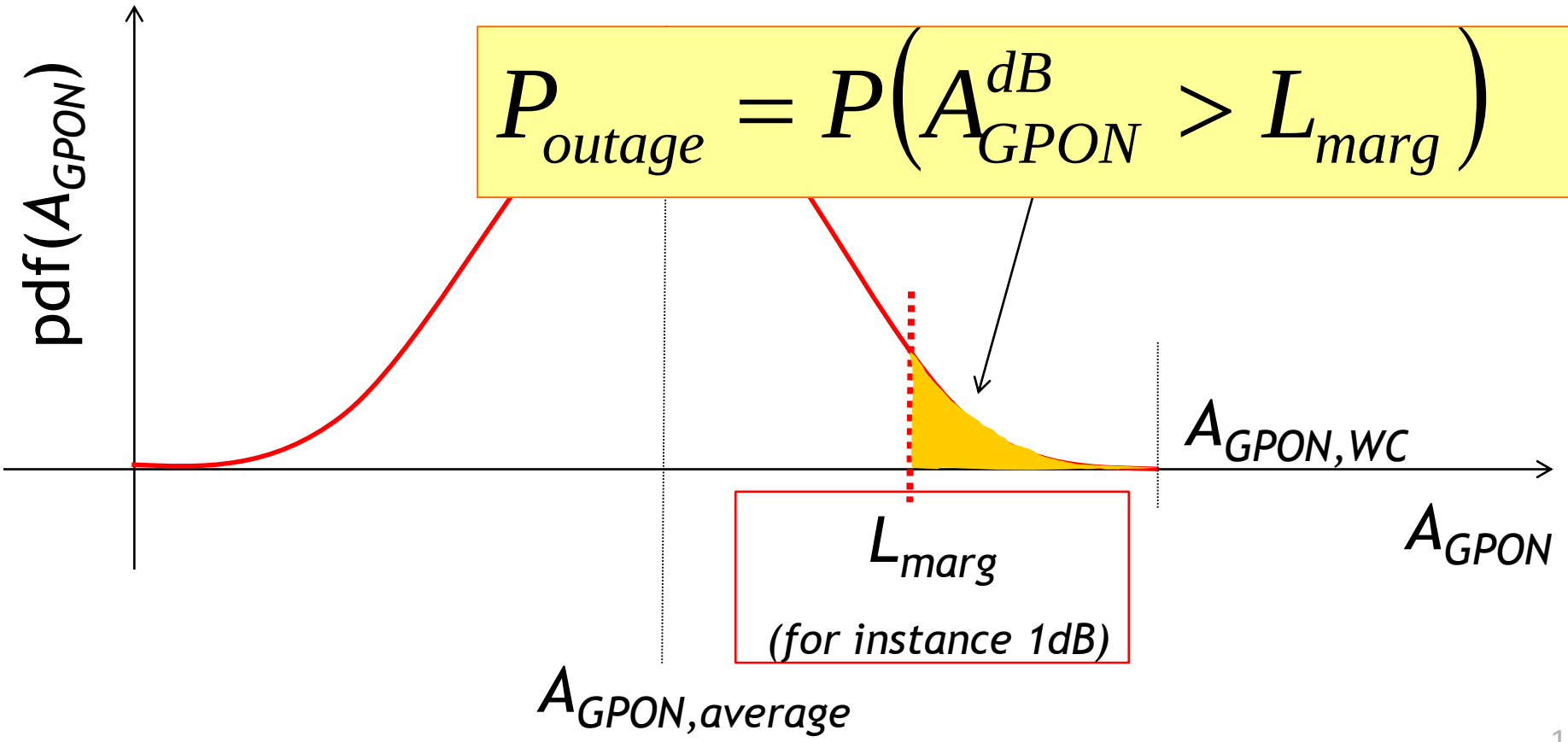
TWDM channels DOP_{TX}

- In a real system, the TWDM channel states of polarization will also be random
- We found its DOP_{TX} probability density function
- It depends ONLY on the number of channels (4 or 8)



Out-of-Service effect on GPON

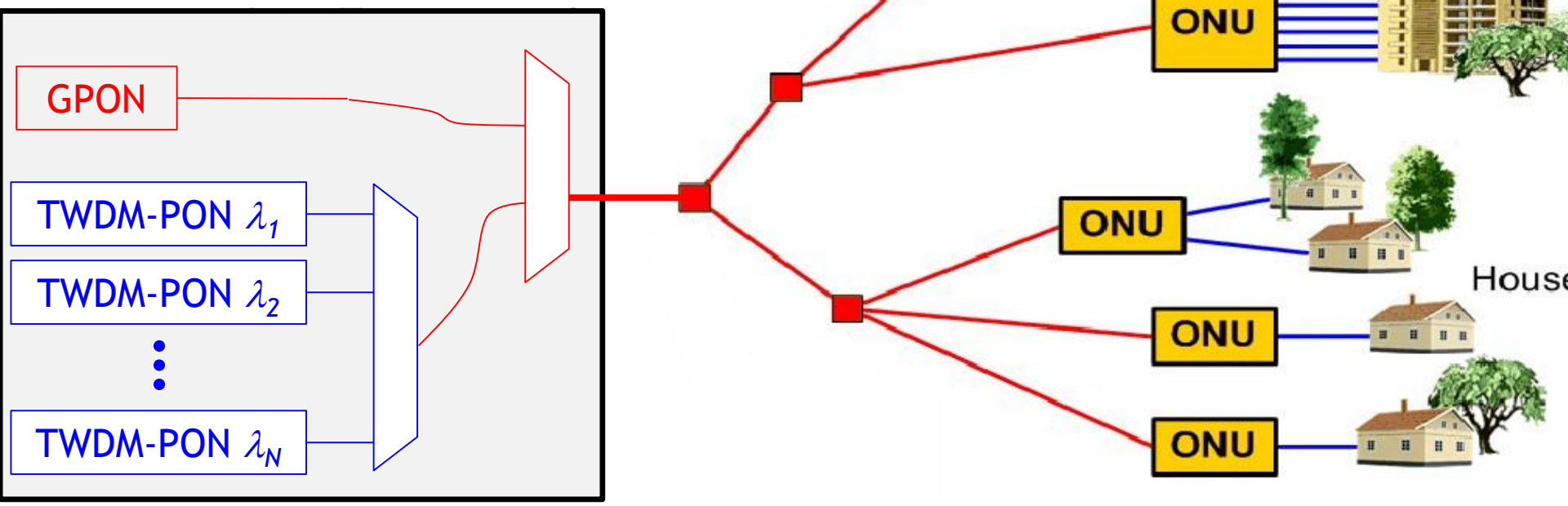
If the maximum margin (L_{marg}) on GPON power budget is smaller than $A_{GPON,WC}$, there exists a probability P_{outage} that the systems goes out-of-service.



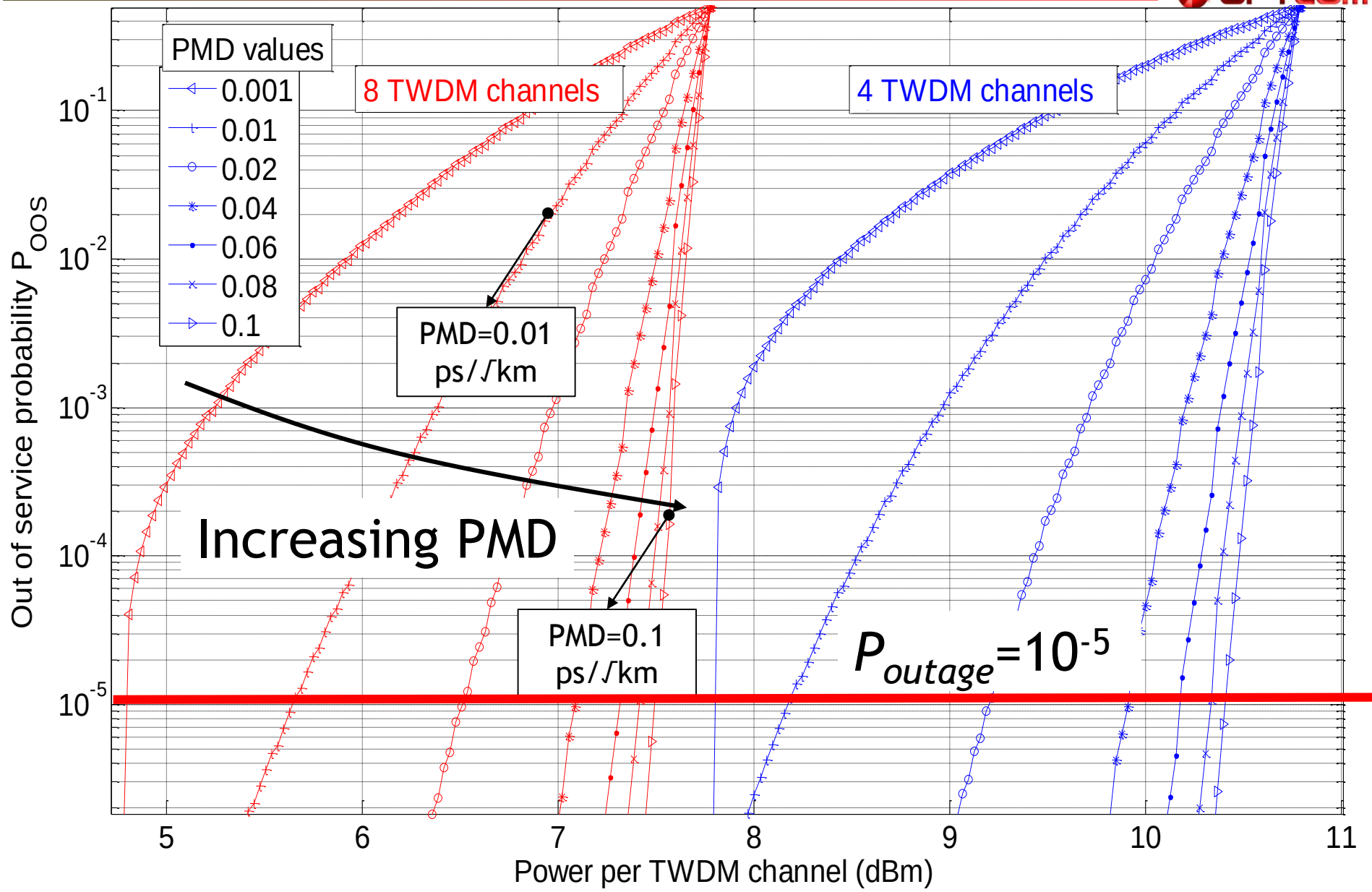
Numerical results

Parameters for the results in the following slides:

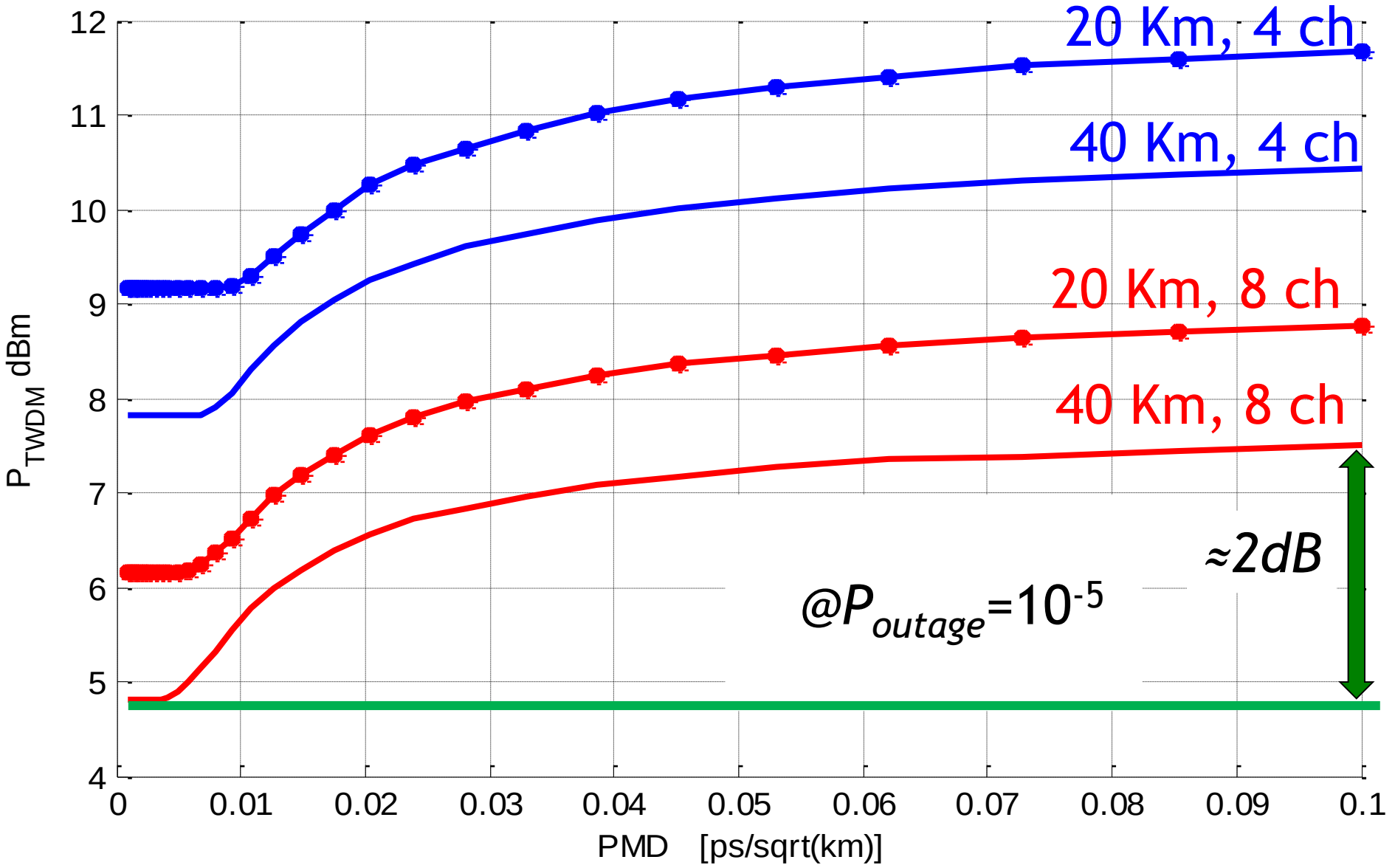
- Margin on GPON: L_{marg} =1dB
- 40 Km, 0.22 dB/Km
- 4 or 8 TWDM channels
- Random DOP_{TX}
- Different PMD values



P_{outage} vs. P_{TX}



Maximum acceptable P_{TWDM}



Conclusion

- Raman depletion sets a maximum value for the TDWM channels TX power
  - For PMD significantly smaller than 0.1 ps/sqrt(Km) a further decrease in maximum power should be accepted in order to have a low out of service probability
  - For very low PMD around 0.01 ps/sqrt(Km) this give around 2 dB decrease in acceptable TDWM power for out of service equal to 10^{-5}

Thank you for your attention!

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