POLITECNICO DI TORINO

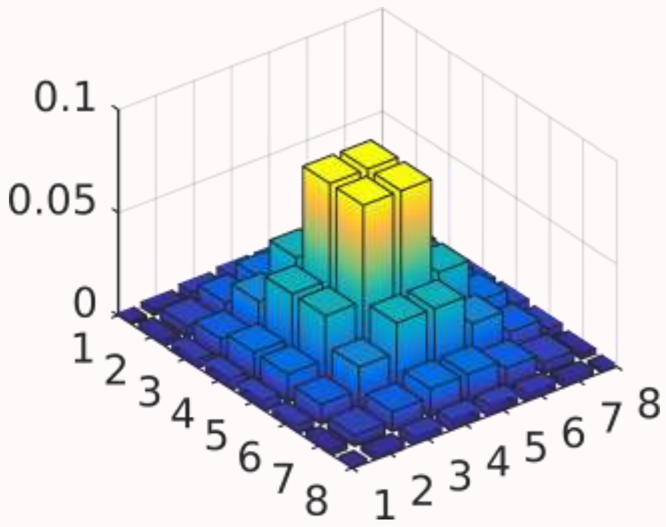
RESIDUAL NON-LINEAR PHASE NOISE IN PROBABILISTICALLY SHAPED 64-QAM OPTICAL LINKS

DARIO PILORI[1], FABRIZIO FORGHIERI[2] AND GABRIELLA BOSCO[1]

1. DEPT. OF ELECTRONICS AND TELECOMMUNICATIONS (DET), POLITECNICO DI TORINO, 10129 TORINO, ITALY
2. CISCO PHOTONICS ITALY S.R.L., 20871 VIMERCATE, ITALY

INTRODUCTION

- Probabilistic constellation shaping (PCS): powerful technique to increase receiver *sensitivity* (plus data rate flexibility)
  - Optimal constellation in an AWGN channel is the Gaussian constellation
  - PCS “mimics” a Gaussian by transmitting with *higher probability* central constellation points



- But: theoretical larger propagation penalties due to constellation-dependent Kerr effect

A. Carena *et al.*, Optics Express **22**(13), pp. 16335-16362 (2014)

IMPACT OF KERR EFFECT

- According to the EGN model, NLI increases with

$$\Phi = \frac{\mathbb{E}\{|a|^6\}}{\mathbb{E}^2\{|a|^2\}} - 2$$

Constellation	Φ
QPSK	-1
64-QAM	-0.62
Gaussian	0

SHAPING

  - This introduces additional NLI if a constellation is shaped
- **But**: most of additional NLI was found to be non-linear phase noise (NLPN)
- At large symbol rates (i.e. 32 GBaud), this NLPN is well compensated by standard phase recovery (CPE) algorithms
  - Reducing the symbol rate impact will be higher

R. Dar and P.J. Winzer, J. Lightwave Technol. **35**(4), 903-930 (2017)
D. Pilori *et al.*, J. Lightwave Technol. **36**(2), 501-509 (2018)

GOAL OF THIS WORK

- Measure propagation performances of **PS 64-QAM** at low symbol rates
  - We expect theoretical gain due to symbol rate optimization (SRO)
  - At the same time, we expect higher penalties due to non-linear phase noise

- Compare it, in the same scenario, with uniform **16-QAM** and **32-QAM** at the same *net data rate*
  - We assumed an ideal 20% FEC

- Extract and analyze non-linear phase noise from simulations without ASE

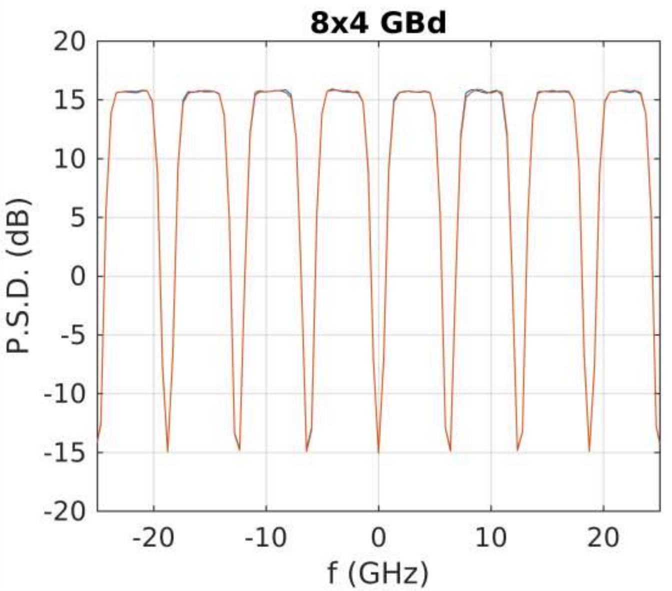
L. Bertignono *et al.*, proc. OFC 2017, paper M3C.2

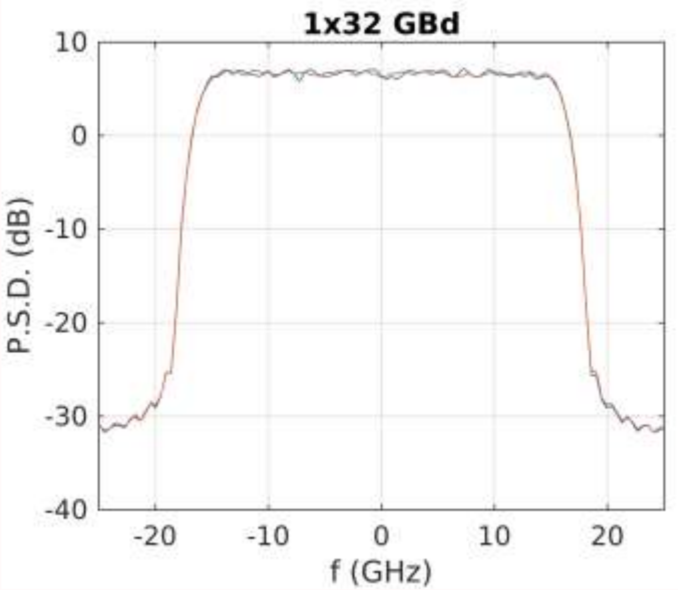
P. Poggiolini *et al.*, J. Lightwave Technol. 34(8), pp. 1872-1885 (2016)

CHOICE OF SYMBOL RATE

- To carry out a fair comparison we kept *fixed*:
  - Total optical bandwidth
  - Relative channel spacing
  - <u>Total bit rate</u> is also constant
- Same laser phase noise: **2.5 kHz / GBaud**

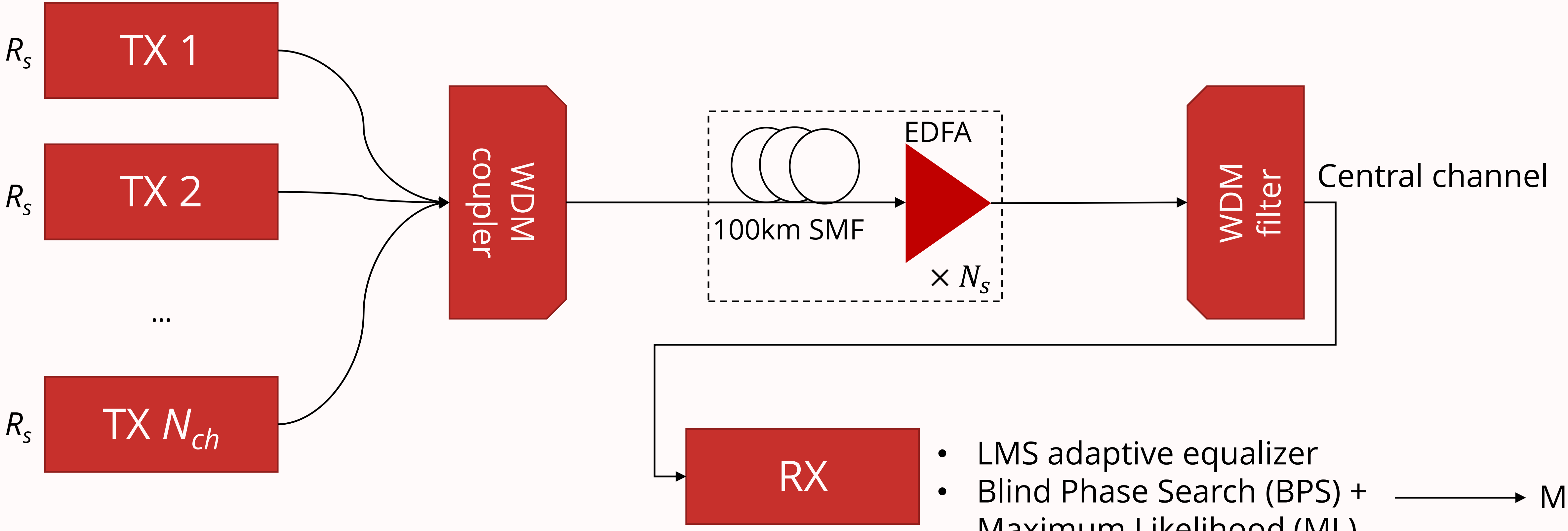
- The reference single-channel case is:
  - R_s=32GBaud, Δf=50GHz, N_{ch}=15 channels, ρ=15%
- We reduced symbol rate to 16, 8 and 4 GBaud





SIMULATION BLOCK SCHEME

- PS 64-QAM
- 32-QAM
- 16-QAM

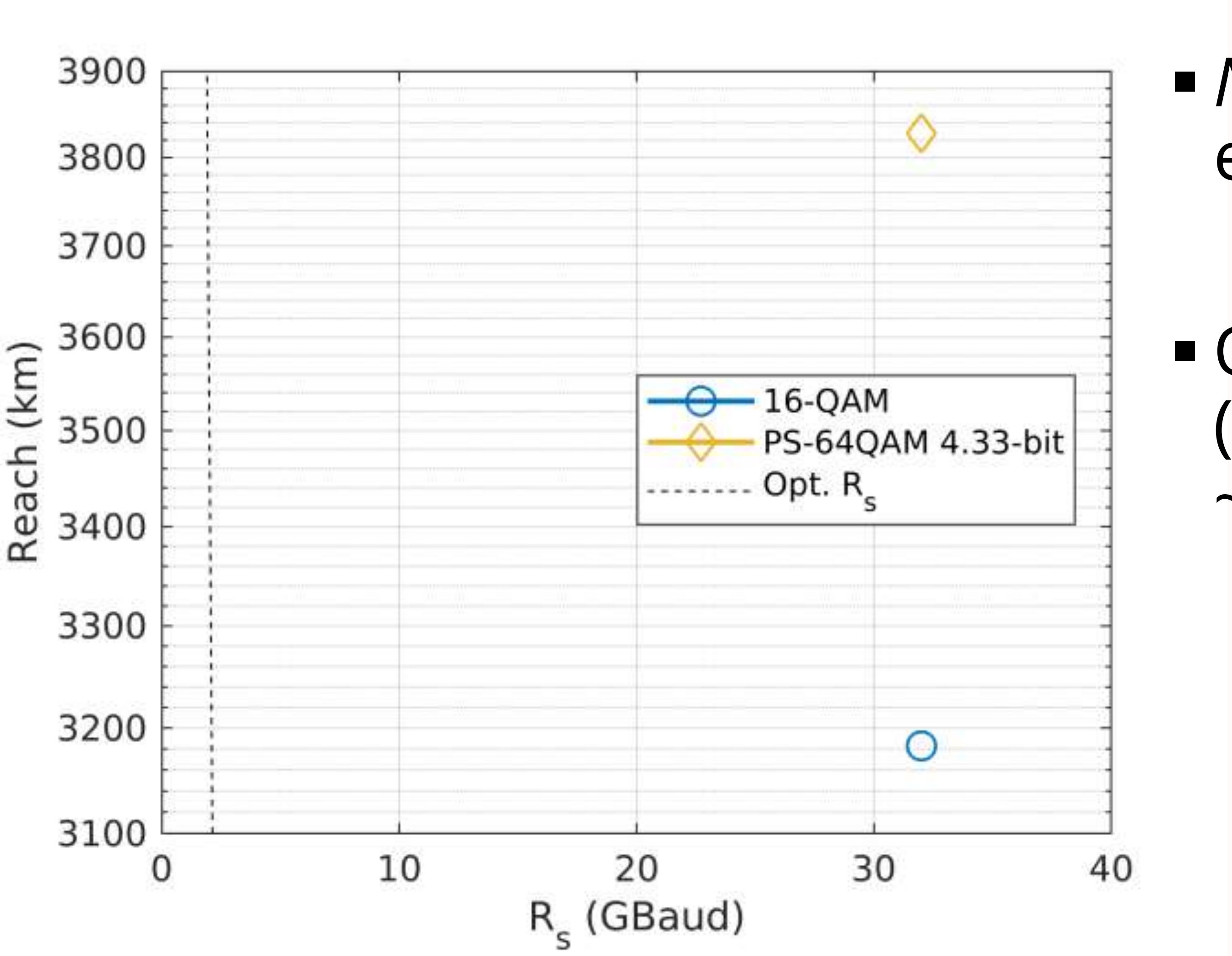


- LMS adaptive equalizer
- Blind Phase Search (BPS) + Maximum Likelihood (ML) phase estimation

→ MI

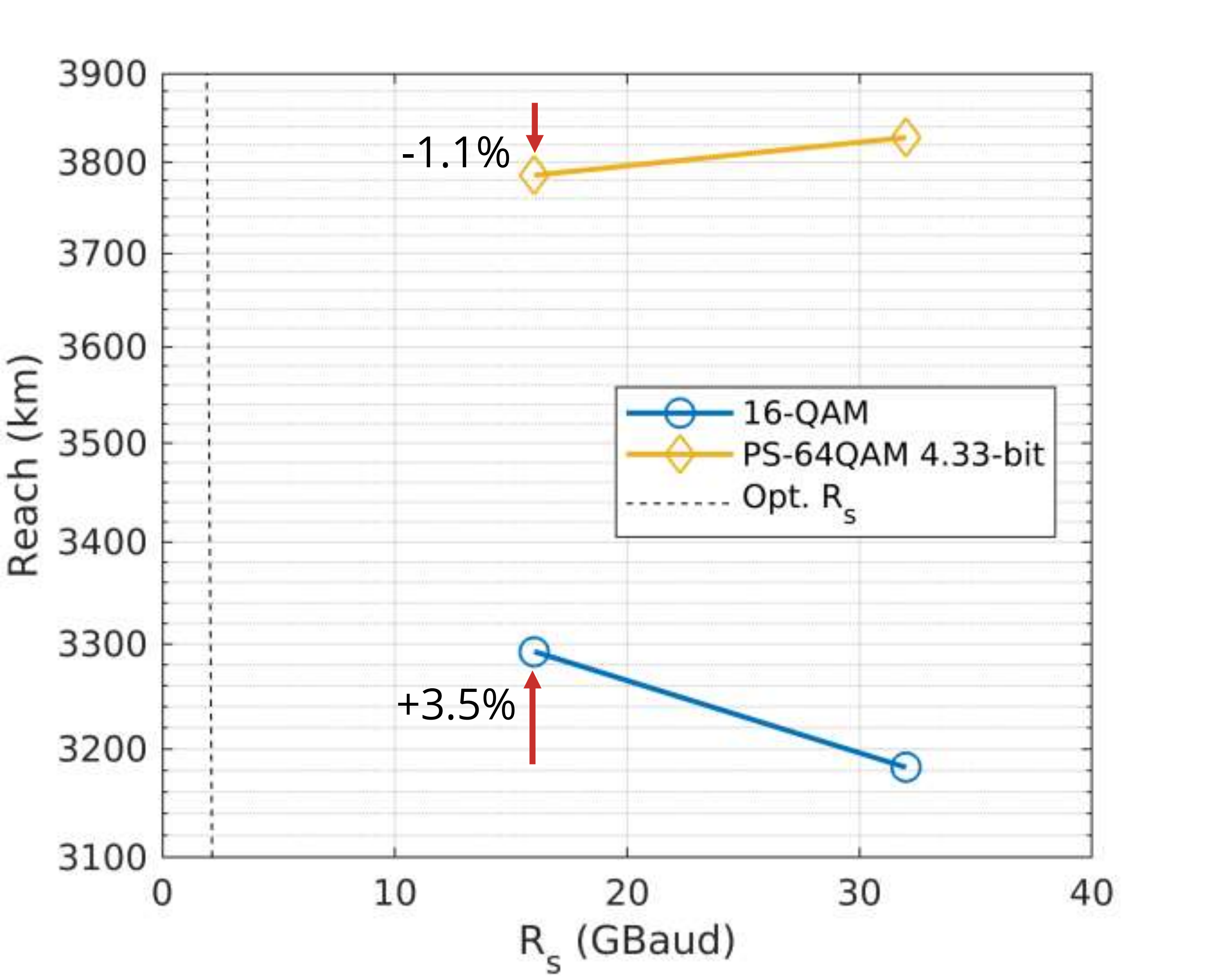
MAXIMUM REACH RESULTS

MAXIMUM REACH RESULTS: 16-QAM VS PS 64-QAM

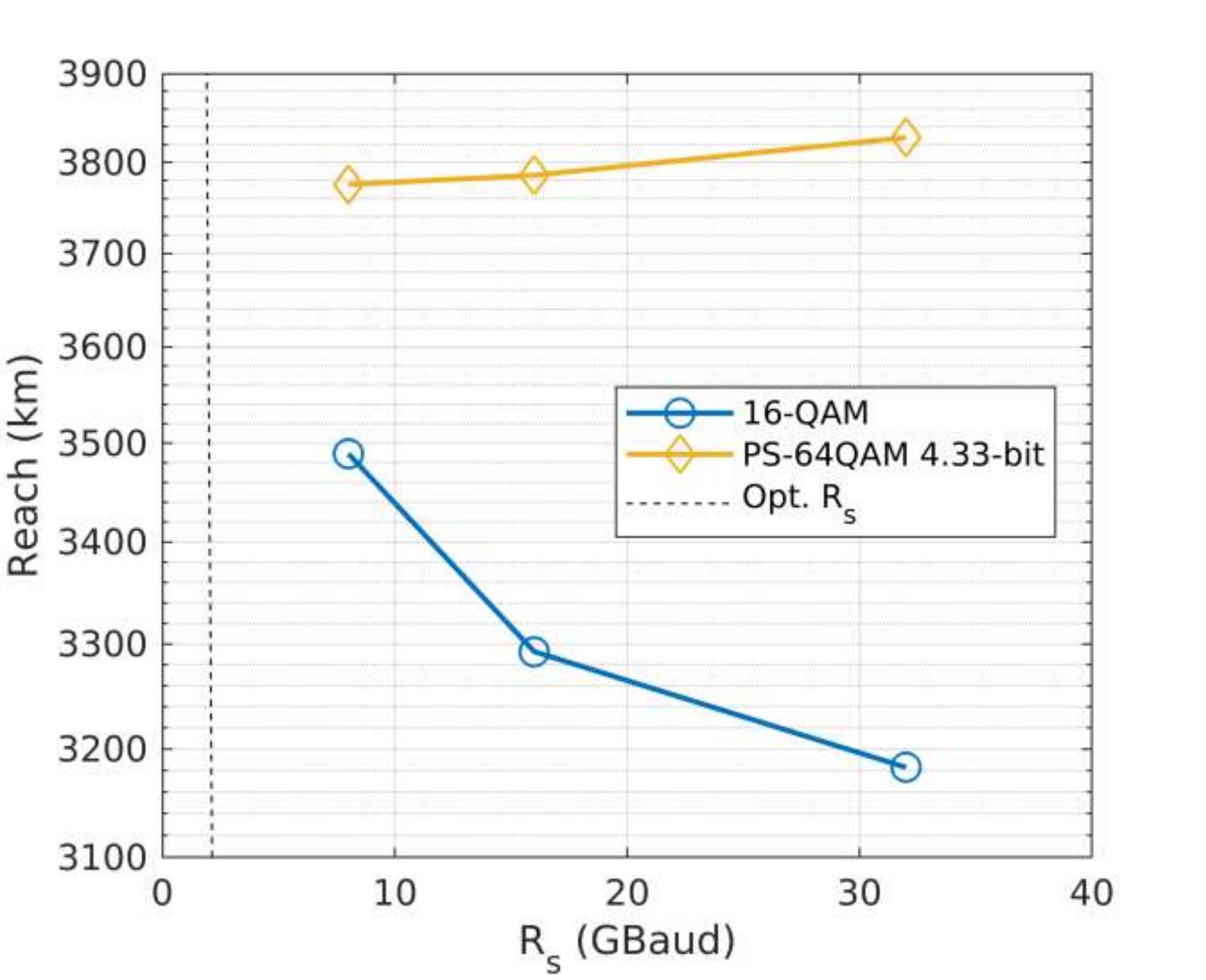


- *Net* (i.e. post-FEC) spectral efficiency: **3.33** bit/symb
- Optimal symbol rate (according to EGN model) is ~ **2 GBaud**
  - We expect that reducing the symbol rate reach will increase

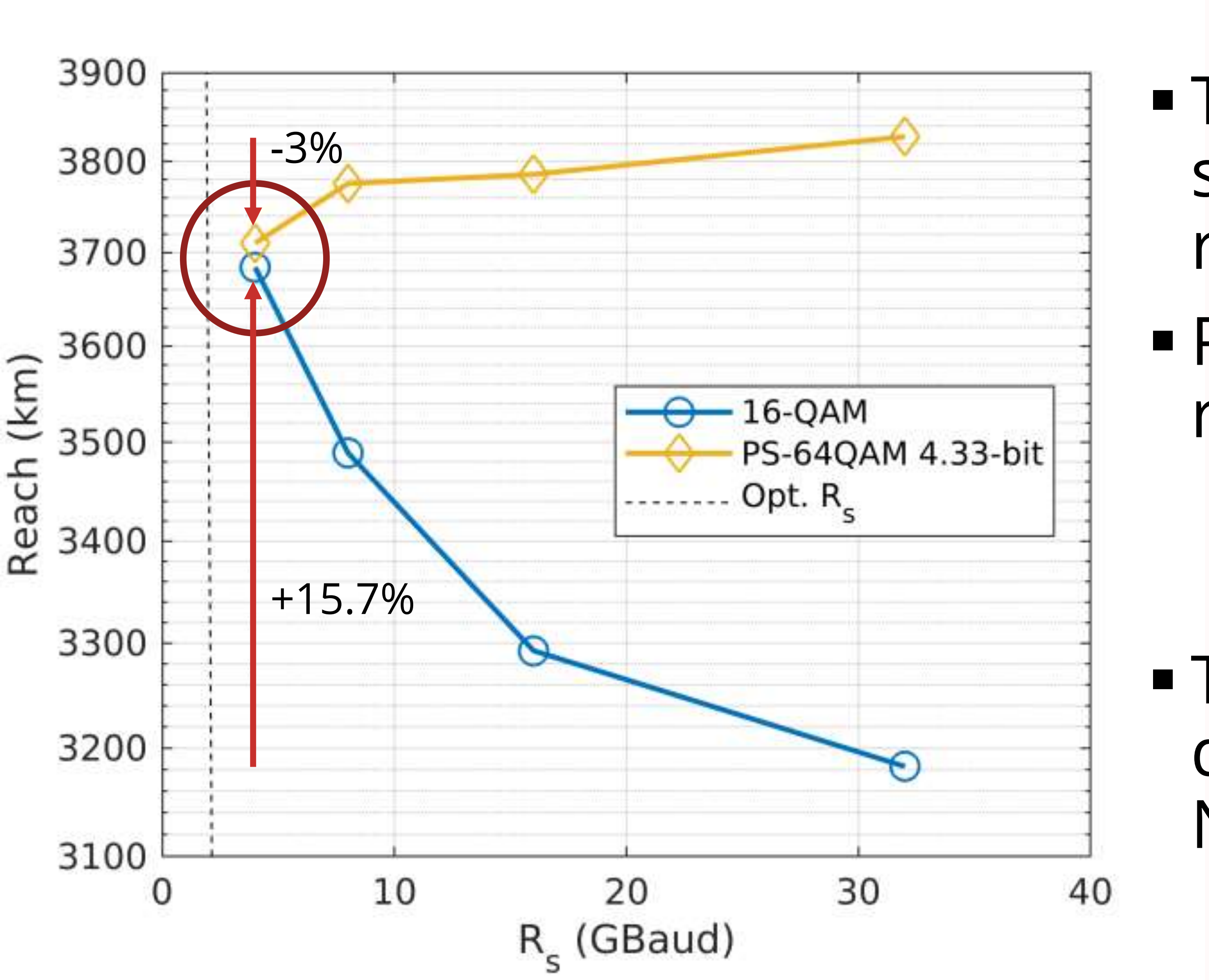
MAXIMUM REACH RESULTS: 16-QAM VS PS 64-QAM



MAXIMUM REACH RESULTS: 16-QAM VS PS 64-QAM

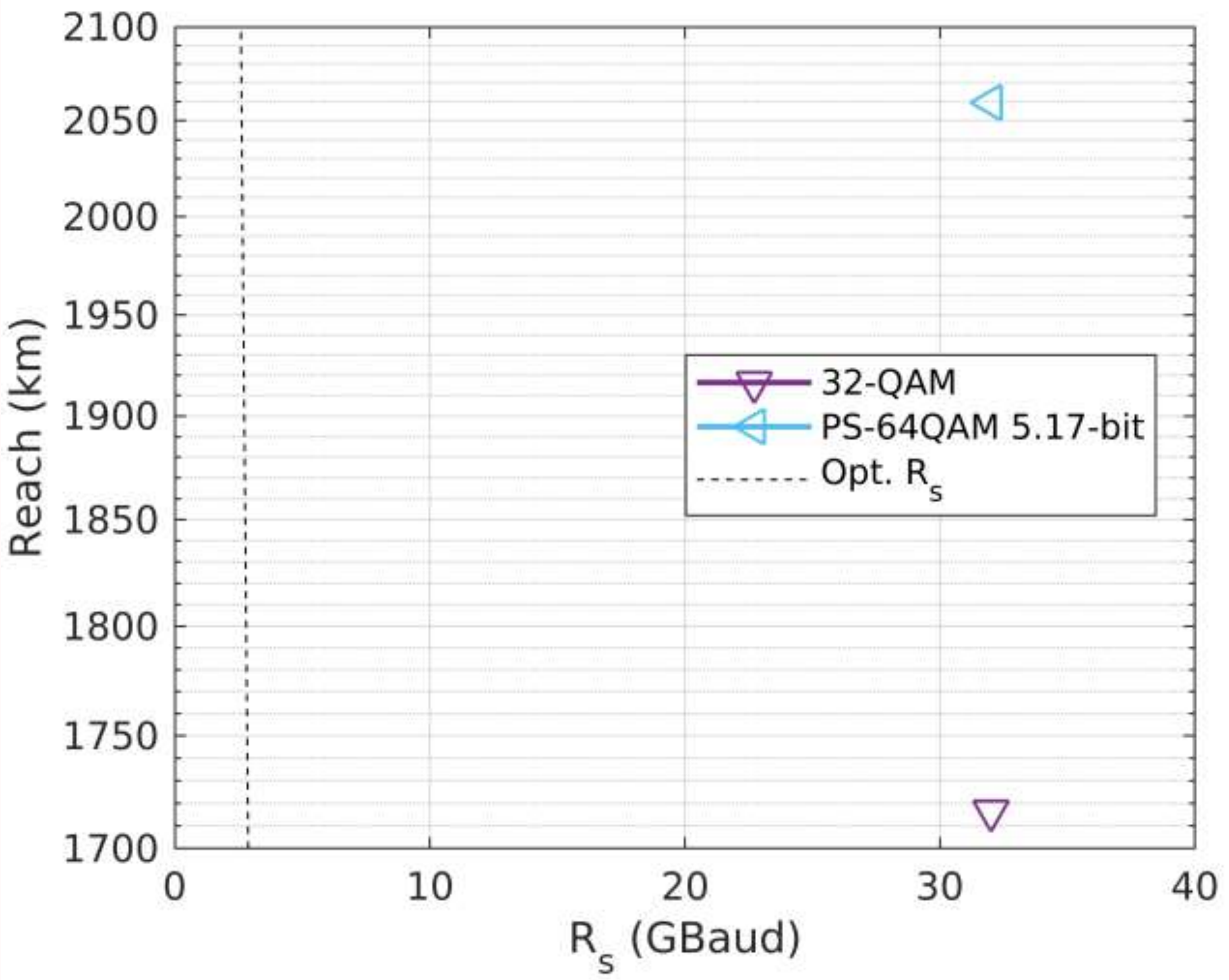


MAXIMUM REACH RESULTS: 16-QAM VS PS 64-QAM

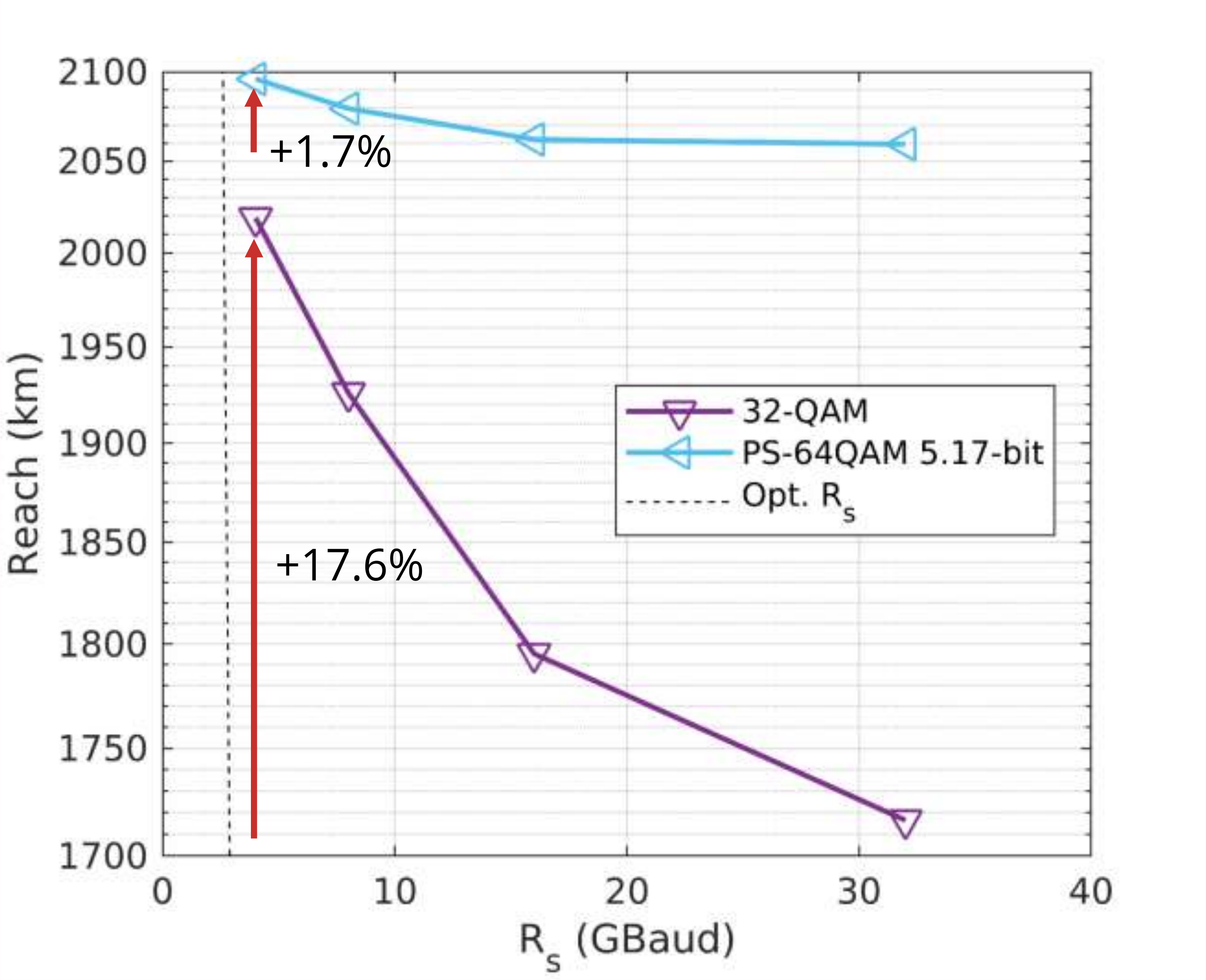


- Towards the optimal symbol rate 16-QAM has a reach **gain** of 15.7%
- PS-64QAM has instead a reach **loss** of 3%
  - 4 GBaud: almost same reach
- This is due to constellation-dependent NLI (mainly NLPN)

MAXIMUM REACH RESULTS: 32-QAM VS PS 64-QAM



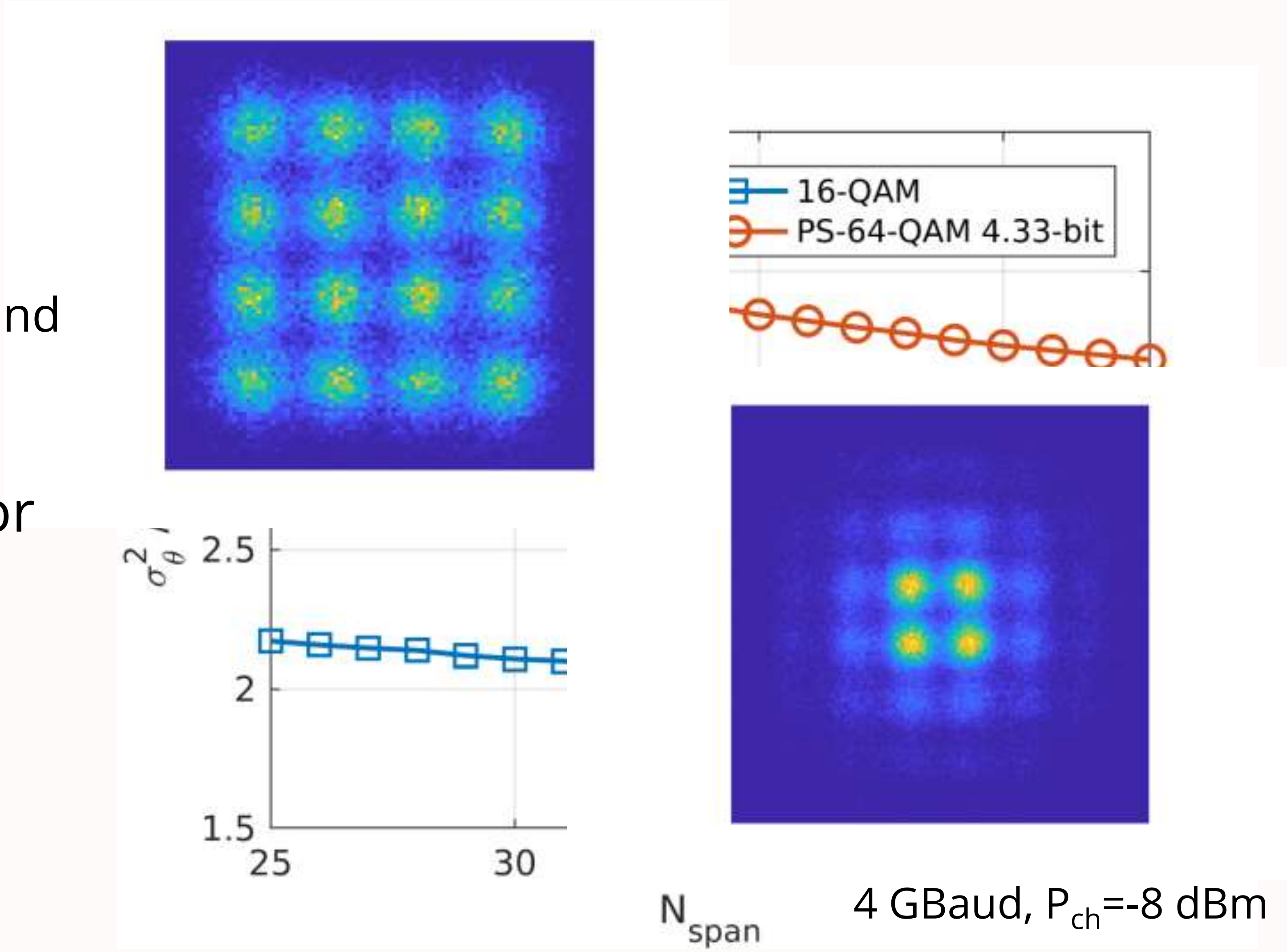
MAXIMUM REACH RESULTS: 32-QAM VS PS 64-QAM



ANALYSIS OF NON-LINEAR PHASE NOISE

NLPN ANALYSIS

- Measurement of the so-called "non-circularity index" of the constellation
  - 0 dB means that noise is perfectly Gaussian, higher numbers correspond to residual phase noise
- Simulations without ASE noise nor laser phase noise and no CPE
- PS-64-QAM, as expected, has higher NLPN

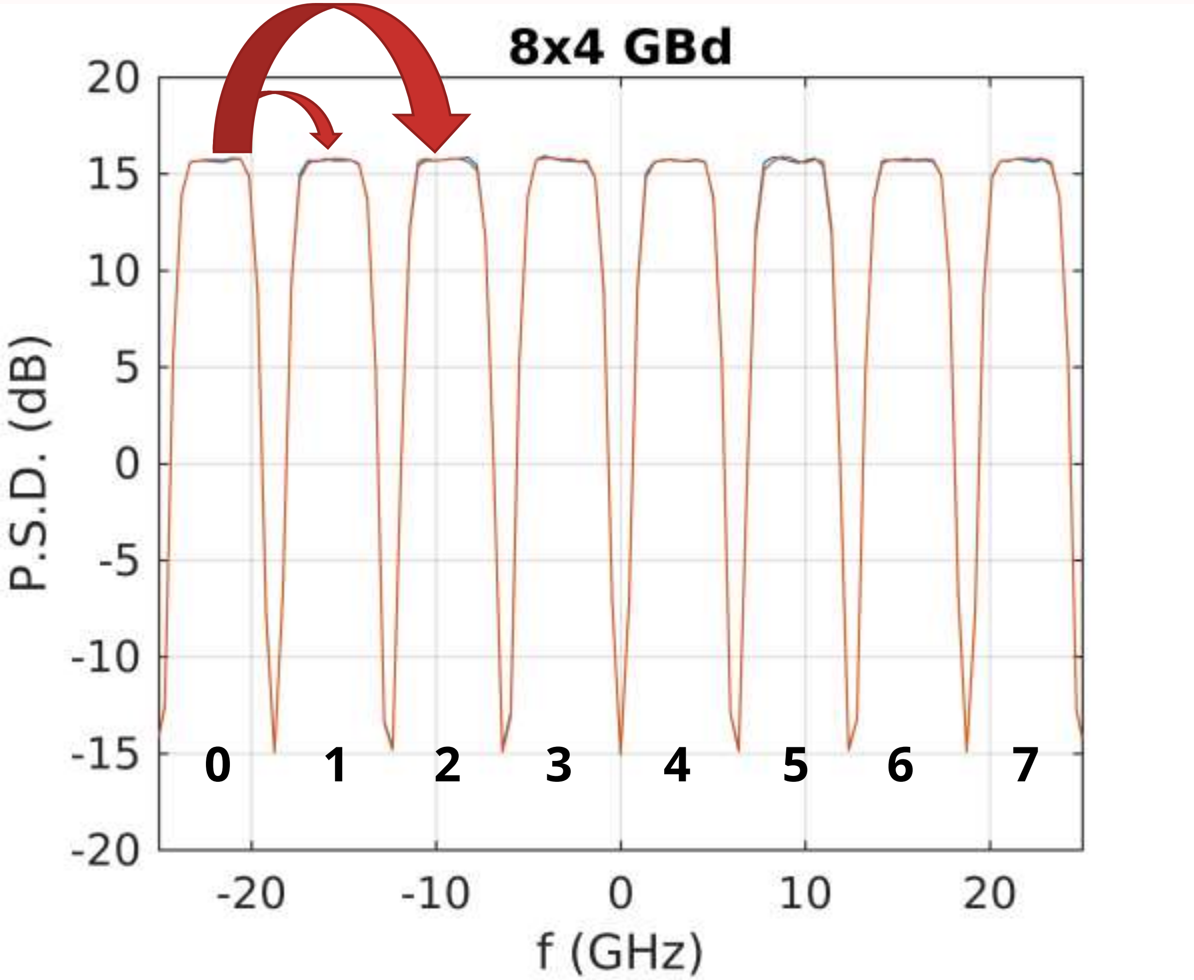


4 GBaud, P_{ch}=-8 dBm

P. Poggiolini and Y. Jiang., *J. Lightwave Technol.* **35**(3), 458-480 (2017).

NLPN CORRELATION

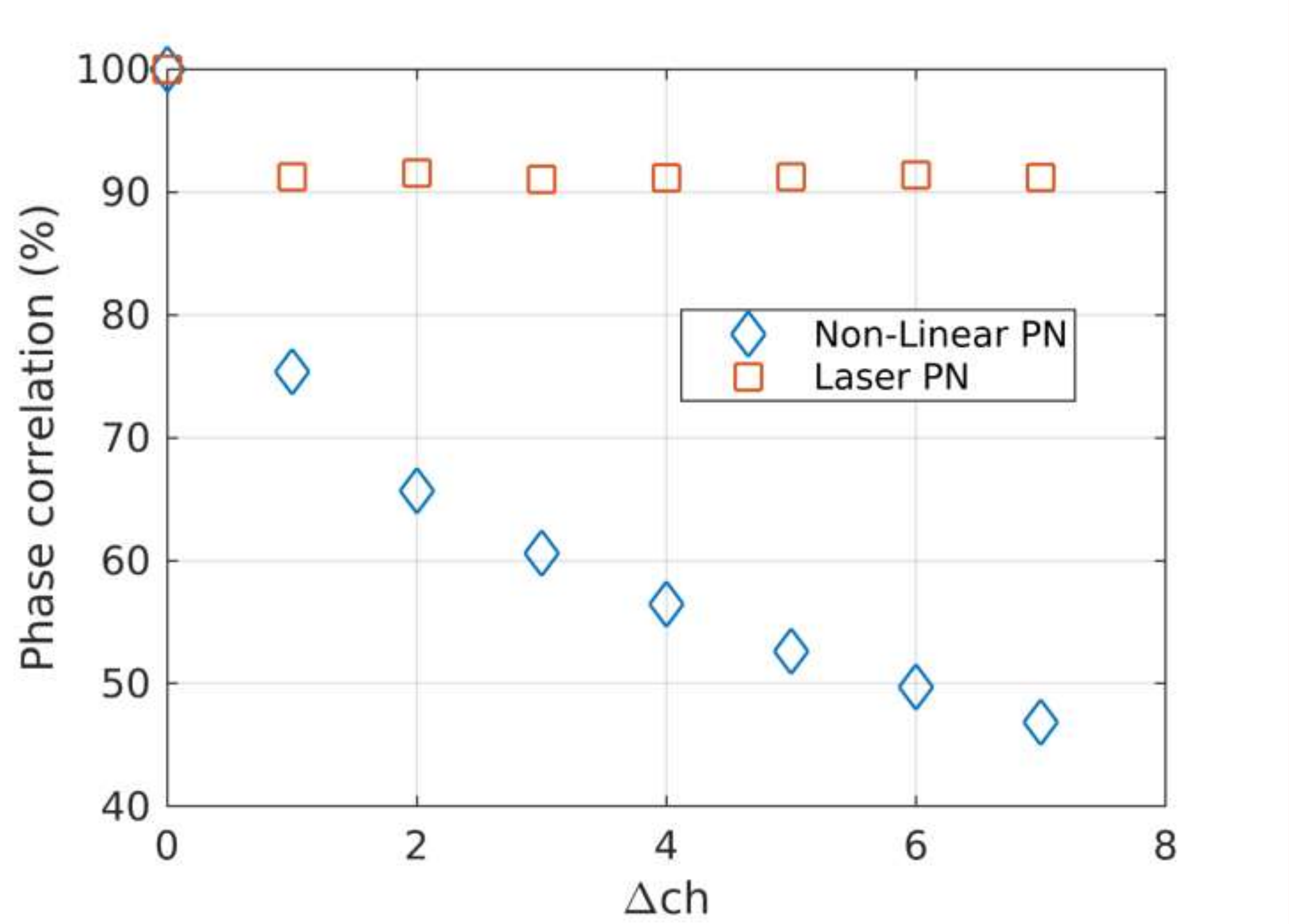
- NLPN could be compensated by **joint processing** of several channels
- We extracted NLPN from **8** channels at the **center** of the WDM spectrum
  - Simulations were run without ASE noise
- We then measured Pearson's correlation coefficient between leftmost WDM channel **0** and the others



NLPN CORRELATION AMONG SUBCARRIERS

- Correlation is a function of the (relative) **frequency difference** between channels, since measurements have been taken at the center of the WDM spectrum

- While with laser phase noise correlation high, correlation **strongly decreases** with bandwidth for NLPN



CONCLUSIONS

- At **low symbol rates**, PS-64-QAM is affected by strong non-linear phase noise (NLPN) with short memory
  - Standard (BPS+ML) phase recovery algorithms are not able to fully compensate for it

- Correlation between NLPN affecting neighbor WDM channel **strongly decreases** with bandwidth
  - This makes difficult to design a CPE algorithm that jointly processes several channels

THANK YOU

DARIO.PILORI@POLITO.IT

BACKUP SLIDES

REACH FOR DIFFERENT LAUNCH POWER