POLITECNICO DI TORINO

FF.SS.: THE FAST FIBER SIMULATOR SOFTWARE

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INTRODUCTION

- To design/manage a network, it is **crucial** to predict the performance of a single optical link

- *What about the GN-model?*

LIMITATIONS OF GN-MODEL

- The GN-model have some limitations:
  - Large bandwidths (Raman)
  - Short links
  - Subcarrier multiplexing
  - Low-dispersion fiber
  - Constellation shaping
  - …
- More sophisticated models (EGN) fixes some of these limitations, but not all of them
  - Complexity also increases
- Moreover, these models do not take into account some effects
  - E.g. non-linear phase noise, PMD, …
  - *Crucial* for transceiver design
- Accurate time-domain simulation tools are still very important!

NON-LINEAR SCHRÖDINGER EQUATION

$$\frac{\partial \mathbf{E}(z,\omega)}{\partial z} = -j\overline{\overline{\beta}}(\omega)\mathbf{E}(z,\omega) - \alpha(\omega)\mathbf{E}(z,\omega)$$

$$-j\frac{\gamma}{3}\mathcal{F}\left\{\begin{bmatrix} 3|E_X(z,t)|^2 + 2|E_Y(z,t)|^2 & E_X^*(z,t)E_Y(z,t) \\ E_Y^*(z,t)E_X(z,t) & 3|E_Y(z,t)|^2 + 2|E_X(z,t)|^2 \end{bmatrix}\mathbf{E}(z,t)\right\}$$

Dispersion and PMD (2x2 tensor)
linear <u>random</u> frequency-domain operator

Attenuation
linear frequency-domain operator

Kerr effect
non-linear time-domain operator

- Non-linear vectorial (2x2) equation
- Operators both in time-domain and frequency-domain
- PMD is a random effect

PMD-MANANKOV EQUATION

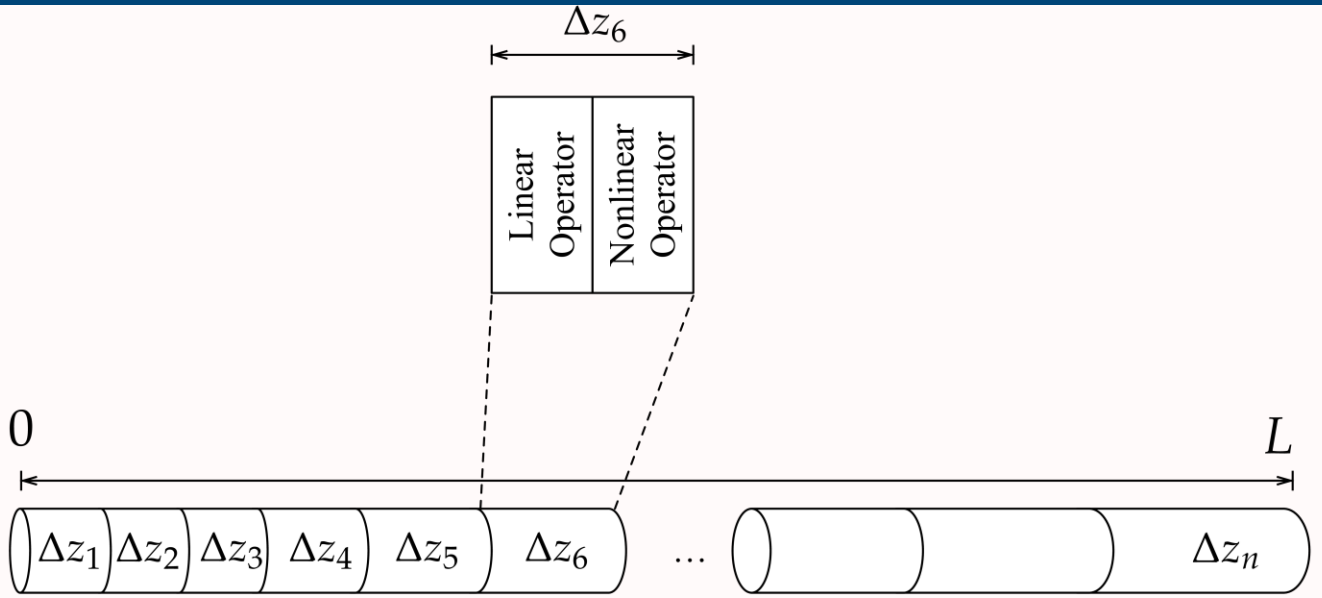
$$\frac{\partial \mathbf{E}(z,\Omega)}{\partial z} = -j\beta_2(\Omega)\mathbf{E}(z,\Omega) - \alpha(\Omega)\mathbf{E}(z,\Omega) - j\frac{8}{9}\gamma\,\mathcal{F}\left\{|\mathbf{E}(z,t)|^2\,\mathbf{E}(z,t)\right\}$$

Linear frequency-domain operator

Non-linear time-domain operator

- Assumes an *average* PMD over a small optical bandwidth around $\omega_0 = \omega - \Omega$
- Equation becomes *scalar* and *deterministic*

SPLIT-STEP FOURIER METHOD



- Assumption: in a small Δz linear and non-linear operators act independently
- For every step, a DFT and IDFT are necessary to apply the steps:
  - Linear in frequency-domain
  - Non-linear in time-domain
- Complexity can still be high for small steps and/or large signals

FF.SS.

- Speed of FFTs can be increased using general-purpose GPU computing (GPGPU)

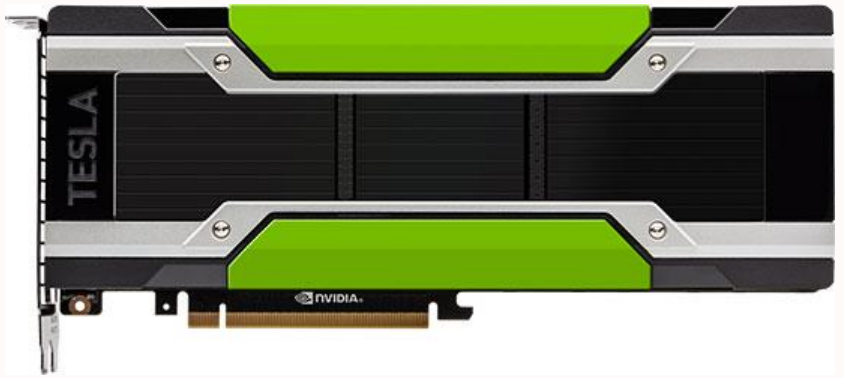
- We called our GPU-powered implementation of the split-step Fourier method **FF.SS. – *Fast Fiber Simulator Software***
- Entirely written in MATLAB with the aid of the Parallel Computing Toolbox
- Solves both the PMD-Manakov equation and the Dual-Polarization NLSE integrating the waveplate PMD model

TESTED HARDWARE

Low-cost desktop-class machine
4-core 3.4 GHz
(Core i7-6700)

High-performance server
2x 6-core 3.4 GHz
(Xeon E5-2643 v3)

TESTED GPUS

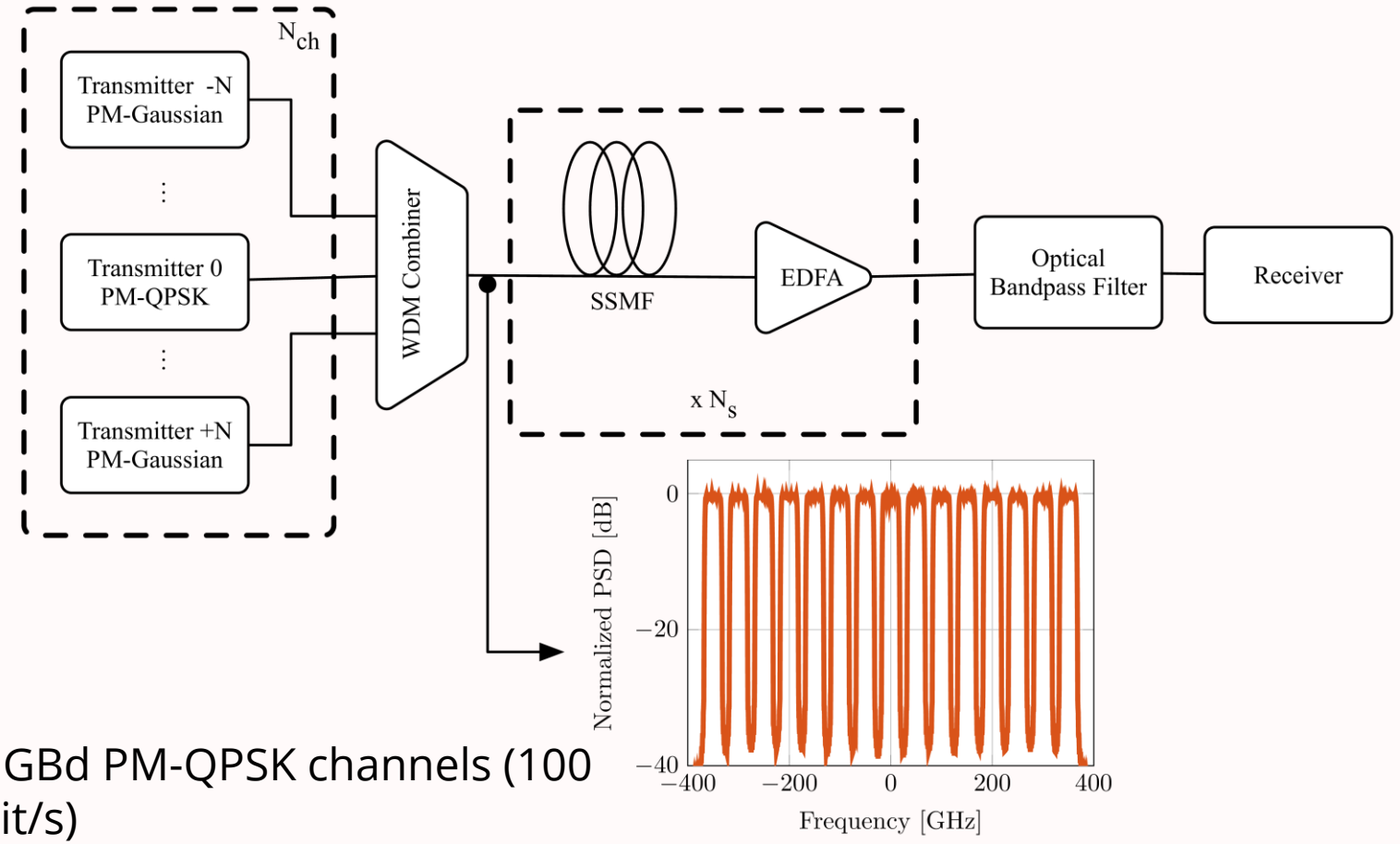


Low-cost “gaming” GPU
NVIDIA GeForce GTX 1070
Pascal architecture (2016) ~$400

High performance GPU
NVIDIA Tesla K40c
Kepler architecture (2012) ~$4,000

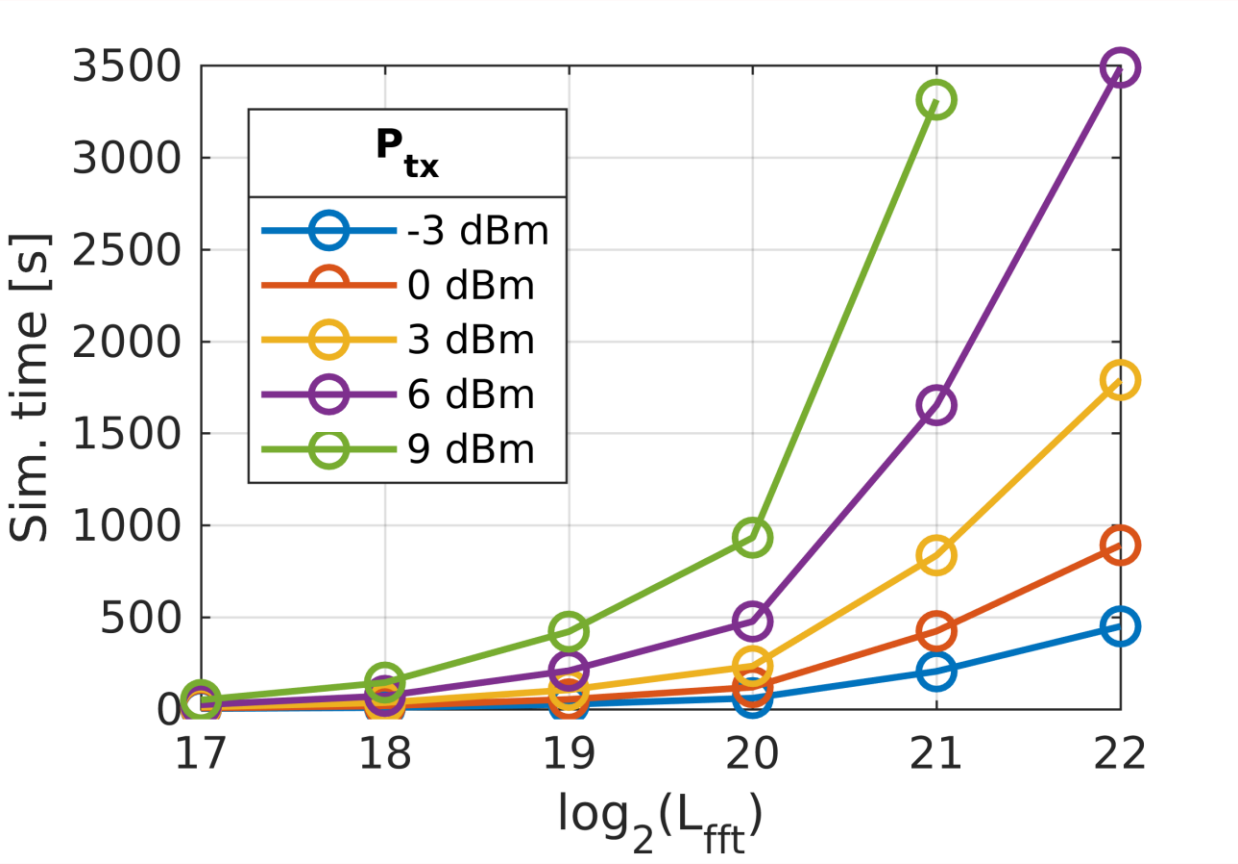
Bonus!
NVIDIA Tesla P100
Pascal architecture (2016)

TEST SCENARIO



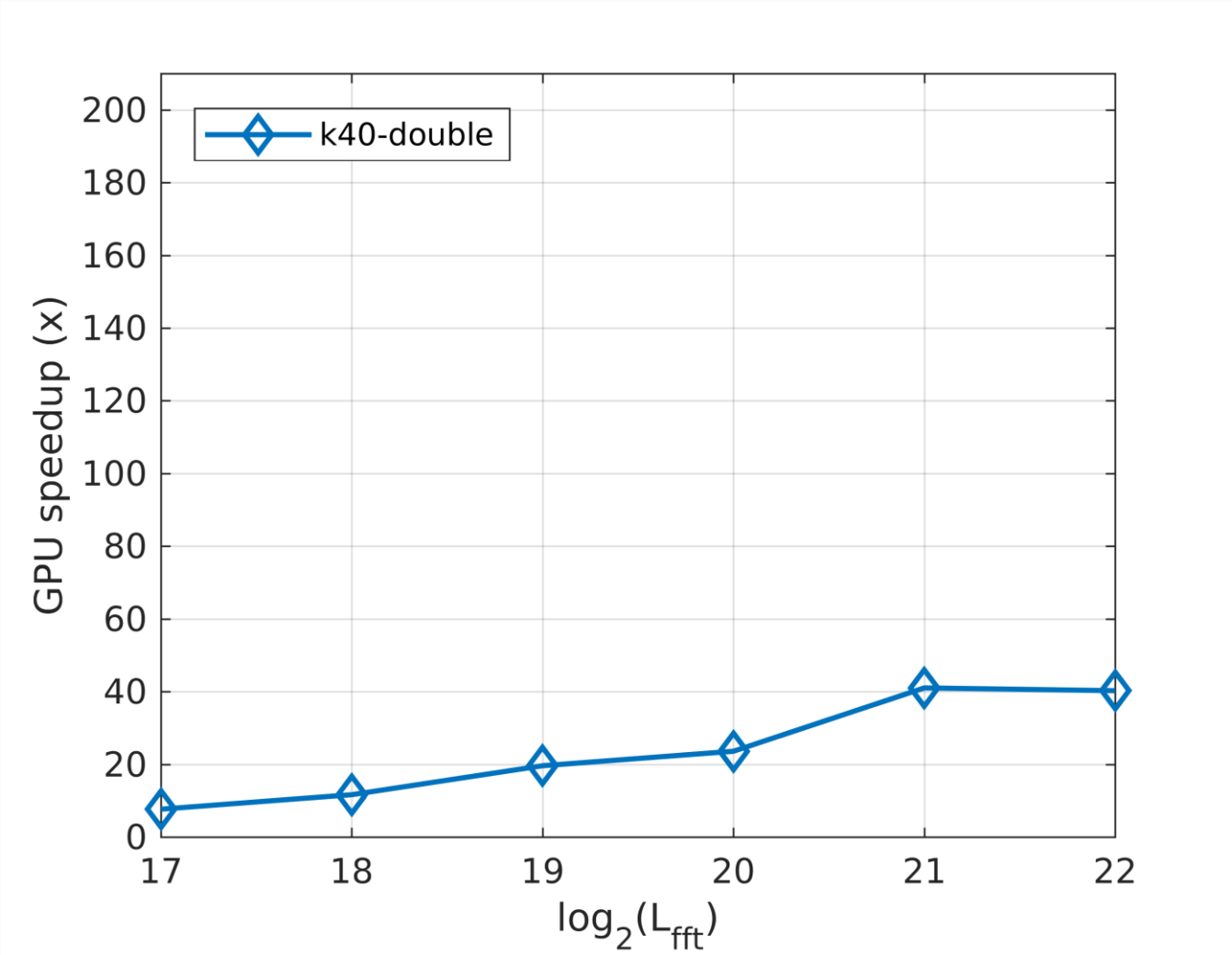
- 32 GBd PM-QPSK channels (100 Gbit/s)
- 100km SMF spans
- Gaussian interfereres to compare results with GN-model

BASELINE (CPU) RESULTS

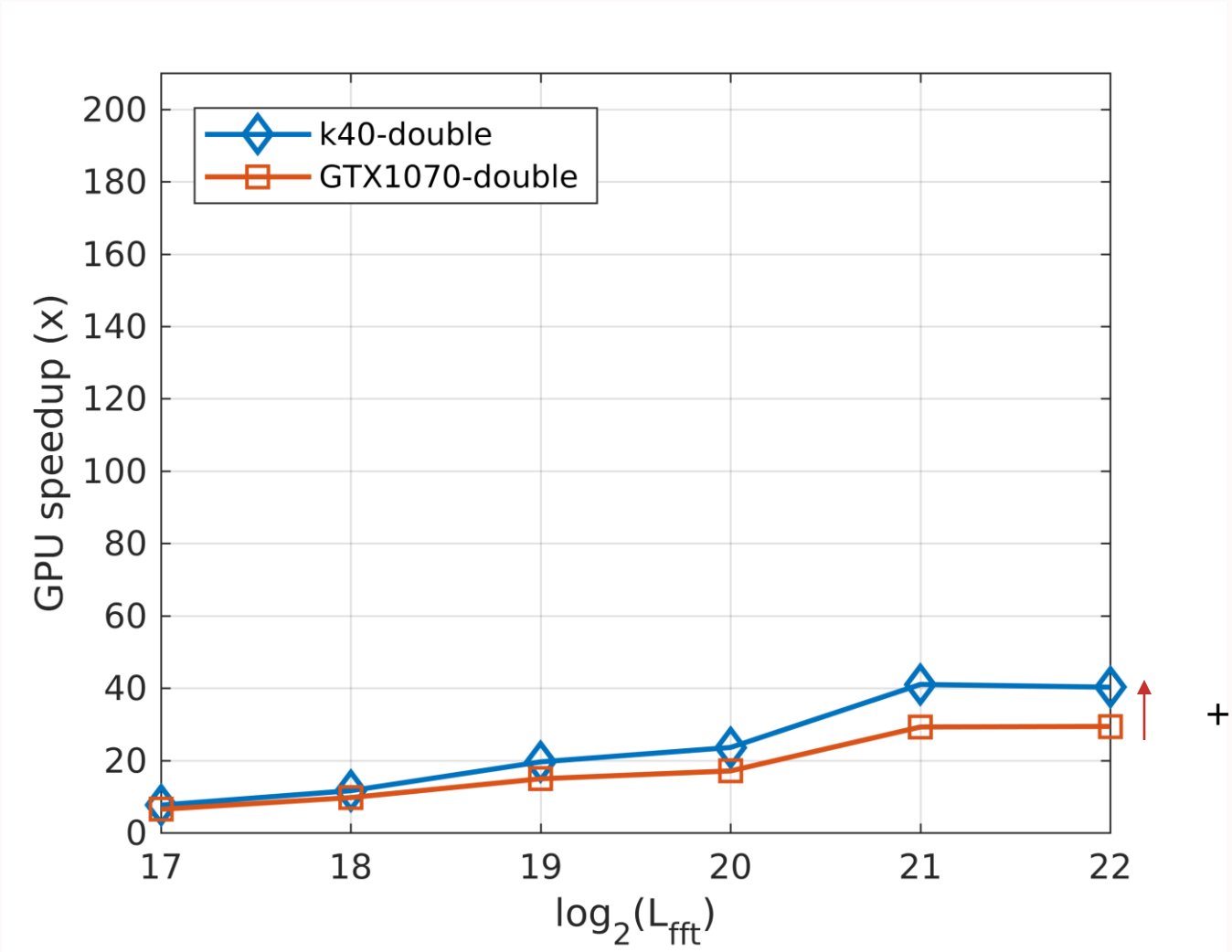


- Time to simulate a single 100-km span
- Executed on the **server** CPU
- Exponential increase with $\log_2(L_{fft})$
- Time increase with total transmit power (smaller steps)

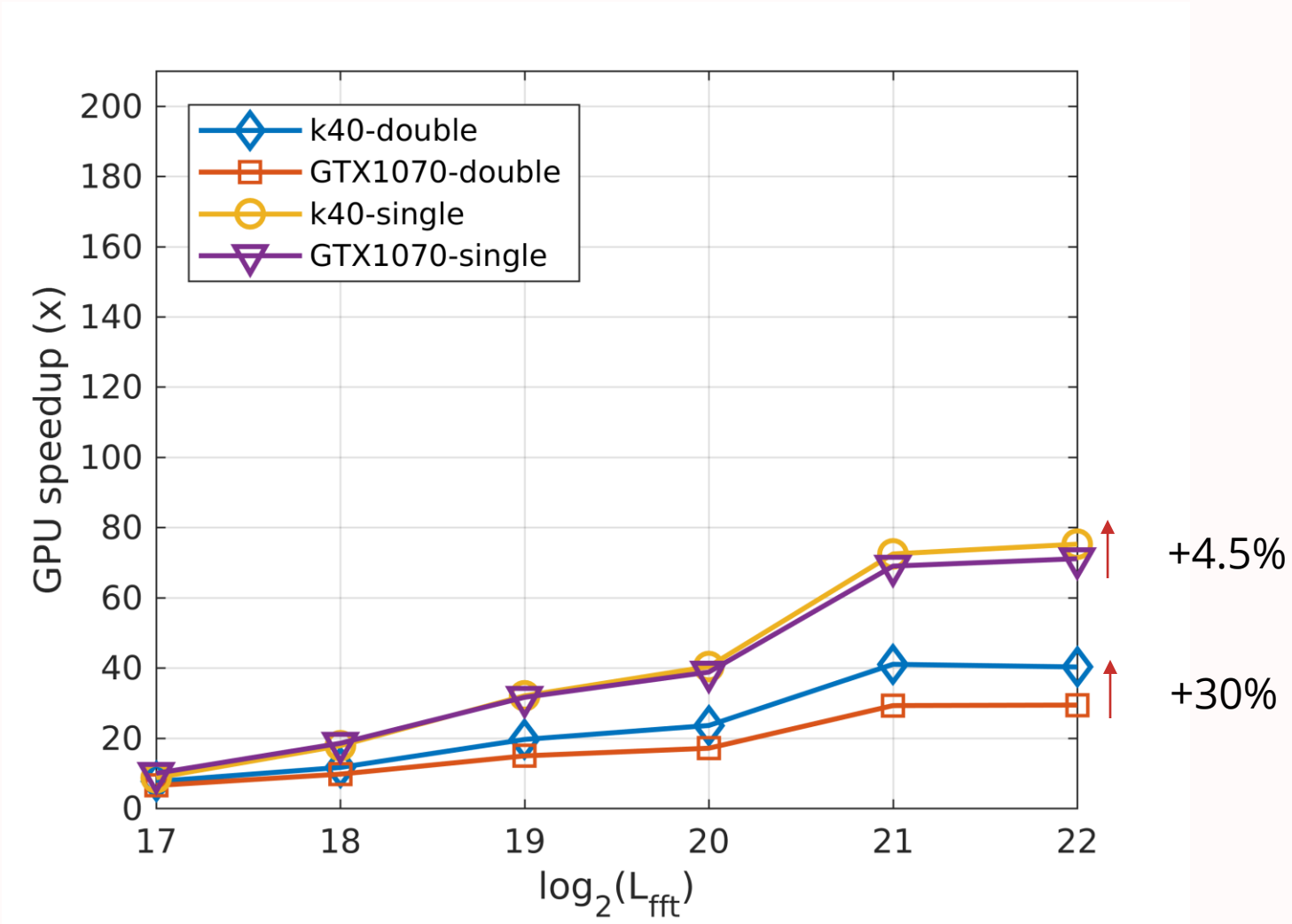
GPU SPEEDUP


k40-double
GPU speedup (x)
0
20
40
60
80
100
120
140
160
180
200
17
18
19
20
21
22
log2(Lfft)

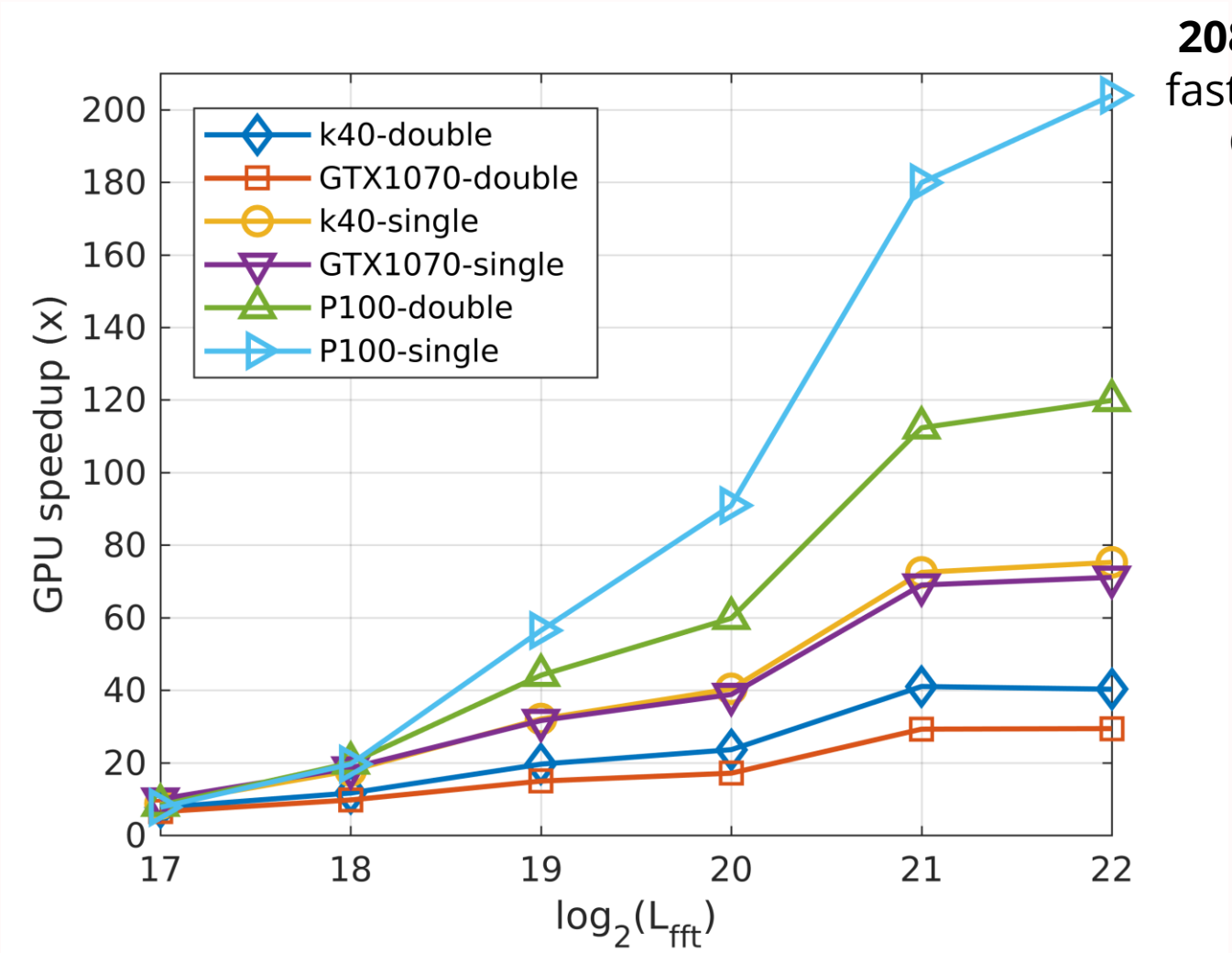
GPU SPEEDUP


k40-double
GTX1070-double
GPU speedup (x)
0
20
40
60
80
100
120
140
160
180
200
17
18
19
20
21
22
log2(Lfft)
+30%

GPU SPEEDUP


k40-double
GTX1070-double
k40-single
GTX1070-single
GPU speedup (x)
0
20
40
60
80
100
120
140
160
180
200
17
18
19
20
21
22
log2(Lfft)
+4.5%
+30%

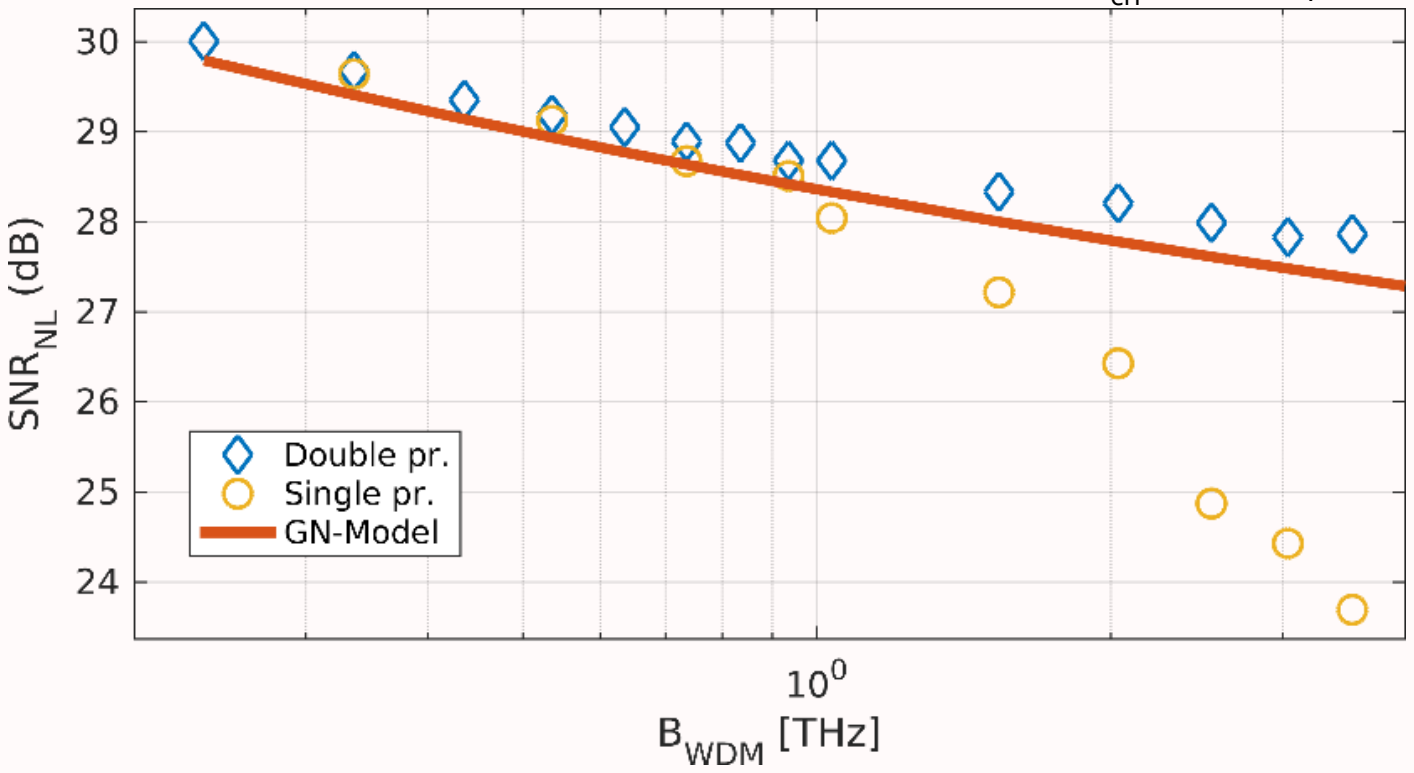
GPU SPEEDUP (BONUS)



208 times faster than CPU!

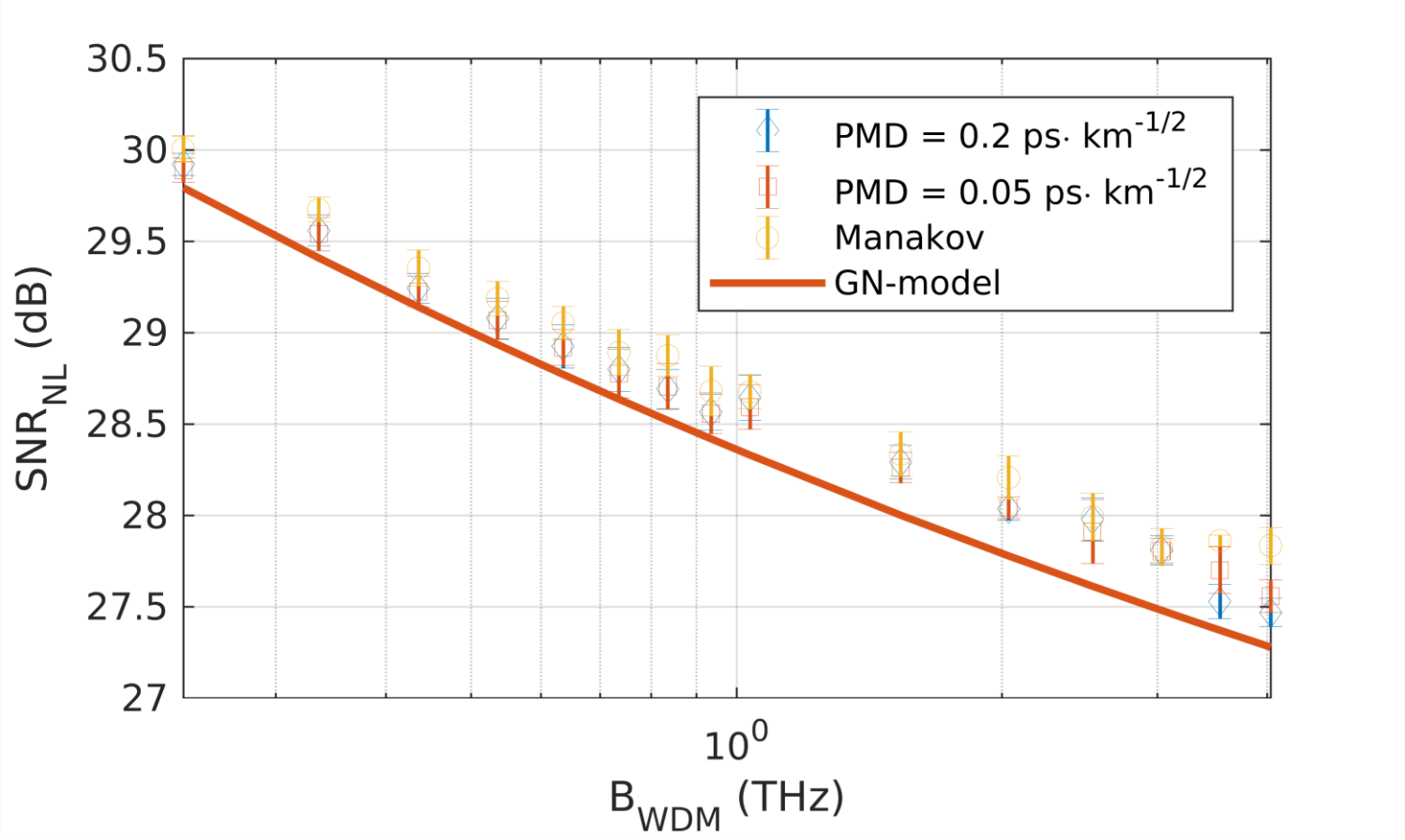
ACCURACY OF SINGLE-PRECISION

P_{ch}=-6 dBm, 30x100km SMF



- Accuracy up up 1 THz of WDM bandwidth, then overestimation of non-linear interference noise
- Double precision is accurate even at 4 THz

BONUS: FULL C-BAND RESULTS



- Accuracy up up **4 THz** of WDM bandwidth (81 WDM channels on 50 GHz grid)
- For this scenario, PMD has negligible effect on NLIN generation

CONCLUSION

- Even though GN-model is good enough for most of use cases, there are cases where it is not sufficient
  - For these cases, full time-domain simulations with SSFM are necessary
- Use of GPUs can **significantly reduce** simulation time
- A low-cost system (desktop + gaming-class GPU) can still provide enormous reductions in simulation time
  - For “heavy” simulations, a server-class GPU is still needed

THANK YOU

We acknowledge NVIDIA Corporation for the donation of the Tesla K40 GPU

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BACKUP SLIDES

STEP SIZE

- Depends on total optical power:

Maximum non-linear phase shift

$$\gamma \Delta z \left(\max_{t,z} |E(z,t)|^2 \right) \leq \xi$$

- A too large step size will overestimate the impact of Kerr effect

DIFFERENCES BETWEEN GTX1070 AND K40