Pushing Graz SLR from 2 kHz to 10 kHz repetition rate

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From 2 kHz to 10 kHz

Overview

- Basic problems & limitations of higher repetition rates
  - #1: Overlap of transmit / receive pulses
  - #2: Signal / Noise ratio for LEO & HEO satellites
  - Question: What is the best (or highest ?) repetition rate ?

- Technical problems, some solutions in Graz:
  - Boosting the High-Q-Laser
  - Adding the Riga ET for 10 kHz
  - Keeping the Graz ET for 2 kHz (out of these 10 kHz)
  - Routing of 2 kHz & 10 kHz start- and stop-pulses

- Setup and test results

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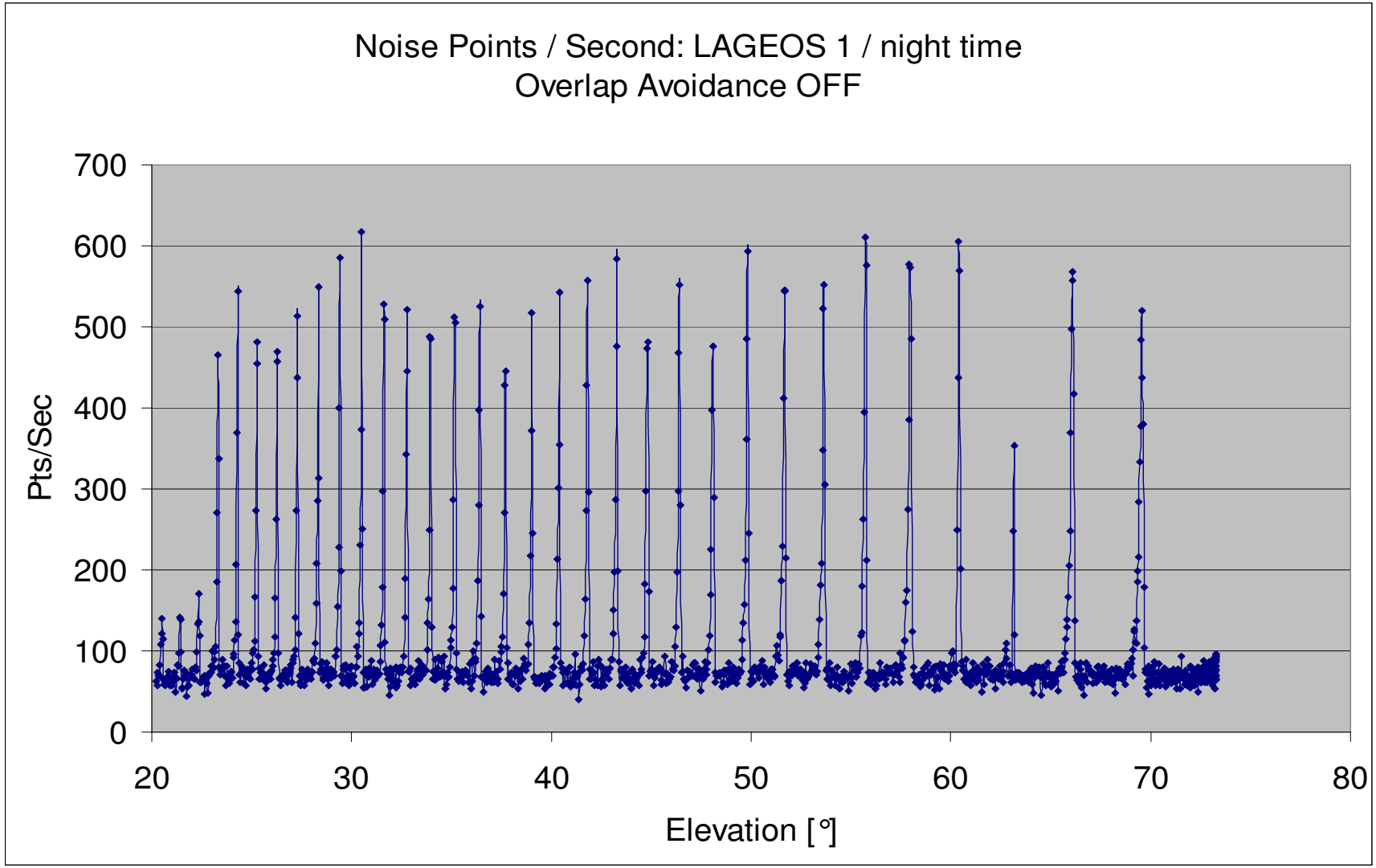
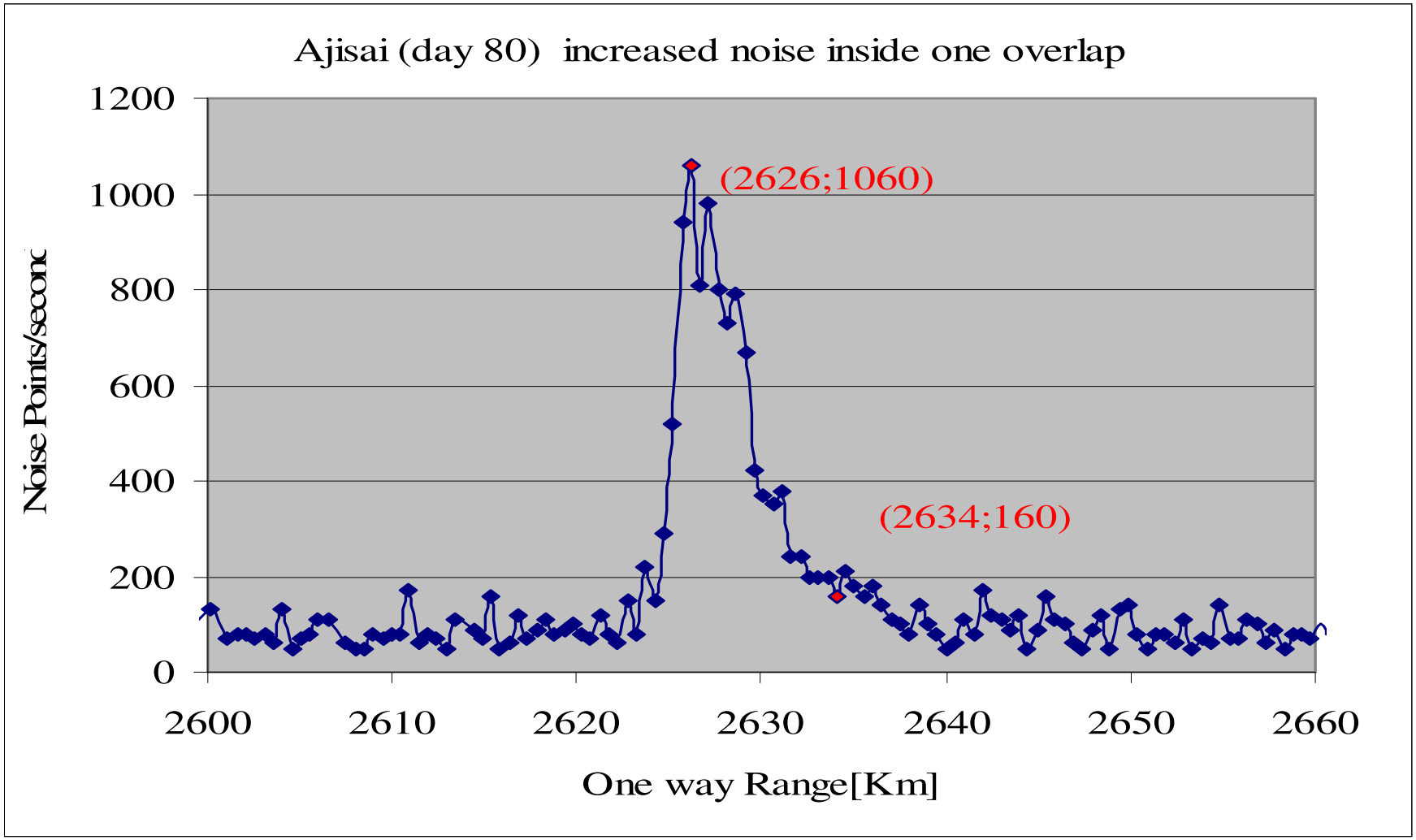
Basic problem #1: Overlaps



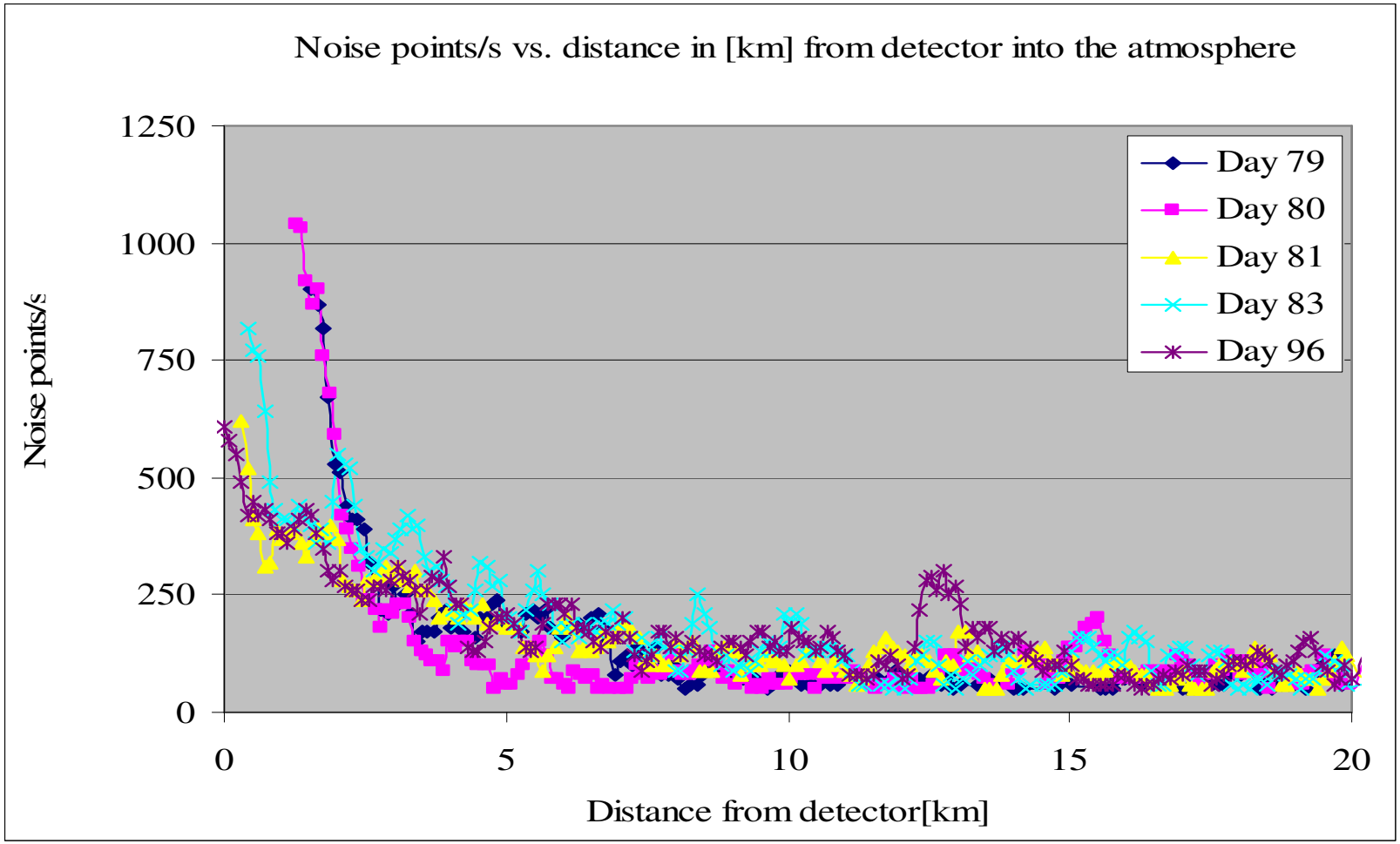
At 2 kHz: Overlap occurs at every 75 km range difference

Graz / 400 µJ: During Overlaps > 50% noise



During OVERLAP: Noise increases from 100 Hz to 1 kHz ☹
(Overlap Avoidance switched OFF)

If Overlap Avoidance is switched OFF…



Overlap backscatter: From distances up to 5 km; sometimes more …

The Overlap Problem

- Overlap between transmit / receive pulses:
  - Strong backscatter from first 5 km of atmosphere;
  - Sometimes still backscatter from up to about 8 km of atmosphere
  - Depends on elevation, actual atmospheric conditions etc.
  - Should be avoided with Single Photon Systems (which are *needed* for high rep rate systems with their low energy/shot)

- This limits the maximum repetition rate to about < 20 kHz
  - Above that: Intrinsic / continuous backscatter
  - Might become more tolerable with very low energy/shot
  - Avoidable if transmit / receive telescope are separated (some 10 m)

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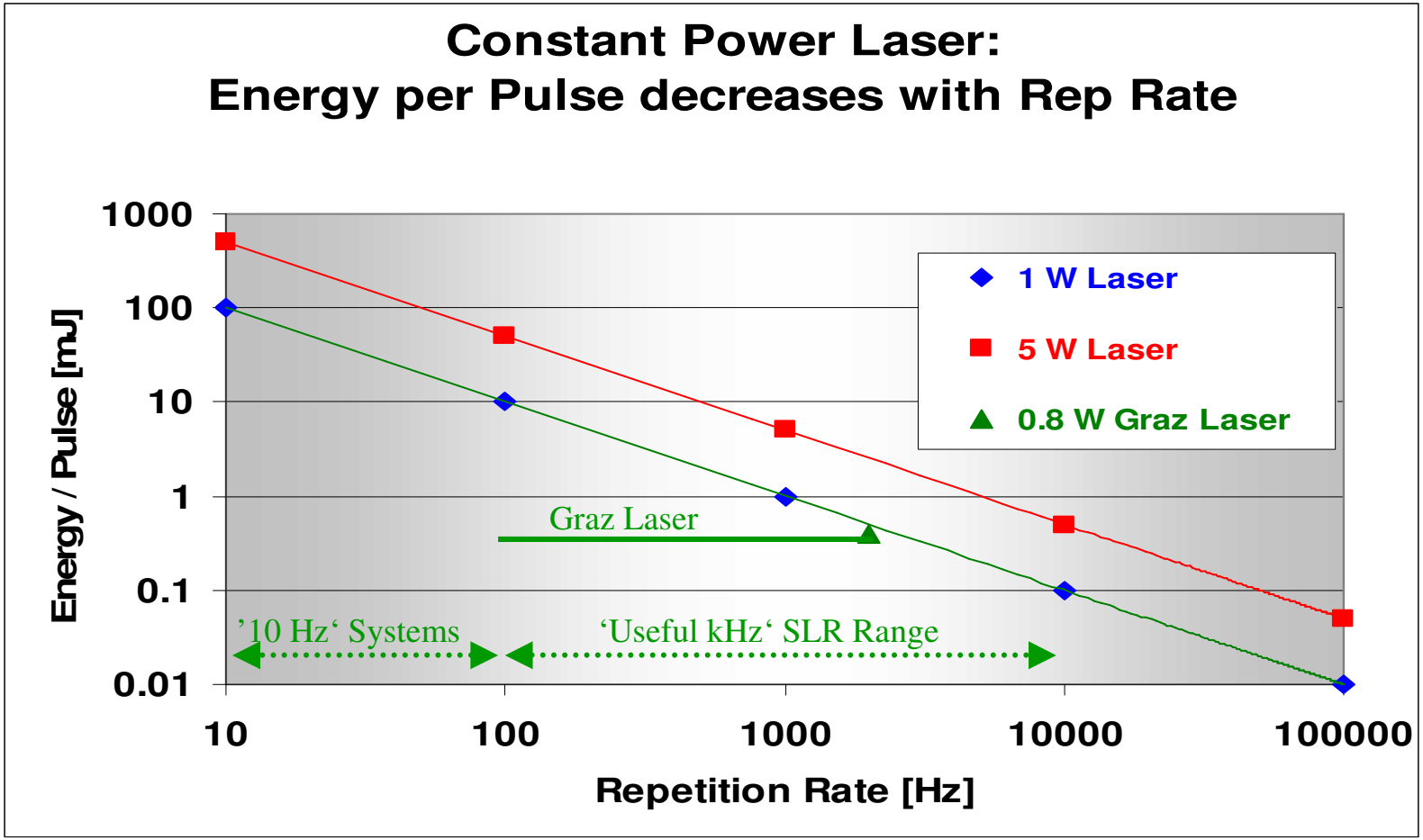
Basic problem #2: Signal / Noise Ratio



Graz Laser: Constant ENERGY Laser (0.4 mJ)

Wanted: Constant POWER Laser: Not (yet) available (?)

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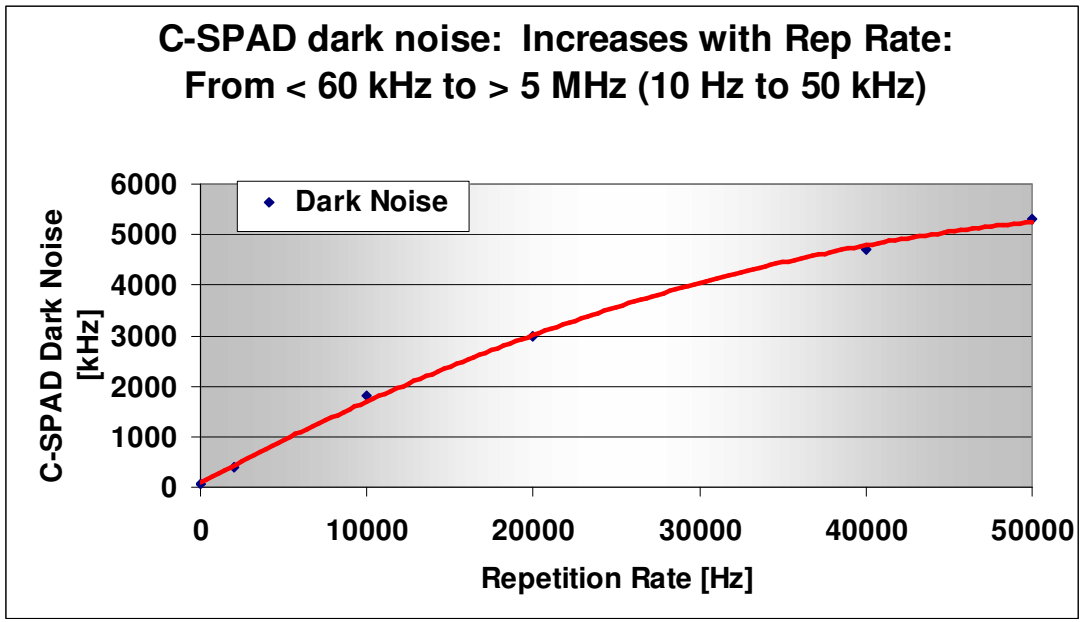
Another limitation: Signal / Noise Ratio

- Increasing the laser rep rate: Energy per shot decreases: => *Decreases signal ☹*
- Increasing the laser rep rate: Noise increases: => *Increases noise ☹*
  - Each Range Gate can produce a noise point (20-50% in Graz daylight)
  - SPAD dark noise increases: from 60 kHz@10 Hz to >5000 kHz@50 kHz

- *Decreasing* signal ☹ => **S/N Ratio ↓↓**
  Increasing noise ☹
- Return identification gets difficult at low S/N ratios



C-SPAD: Dark Noise increases with repetition rate:

e.g. 3 MHz noise at 20 kHz

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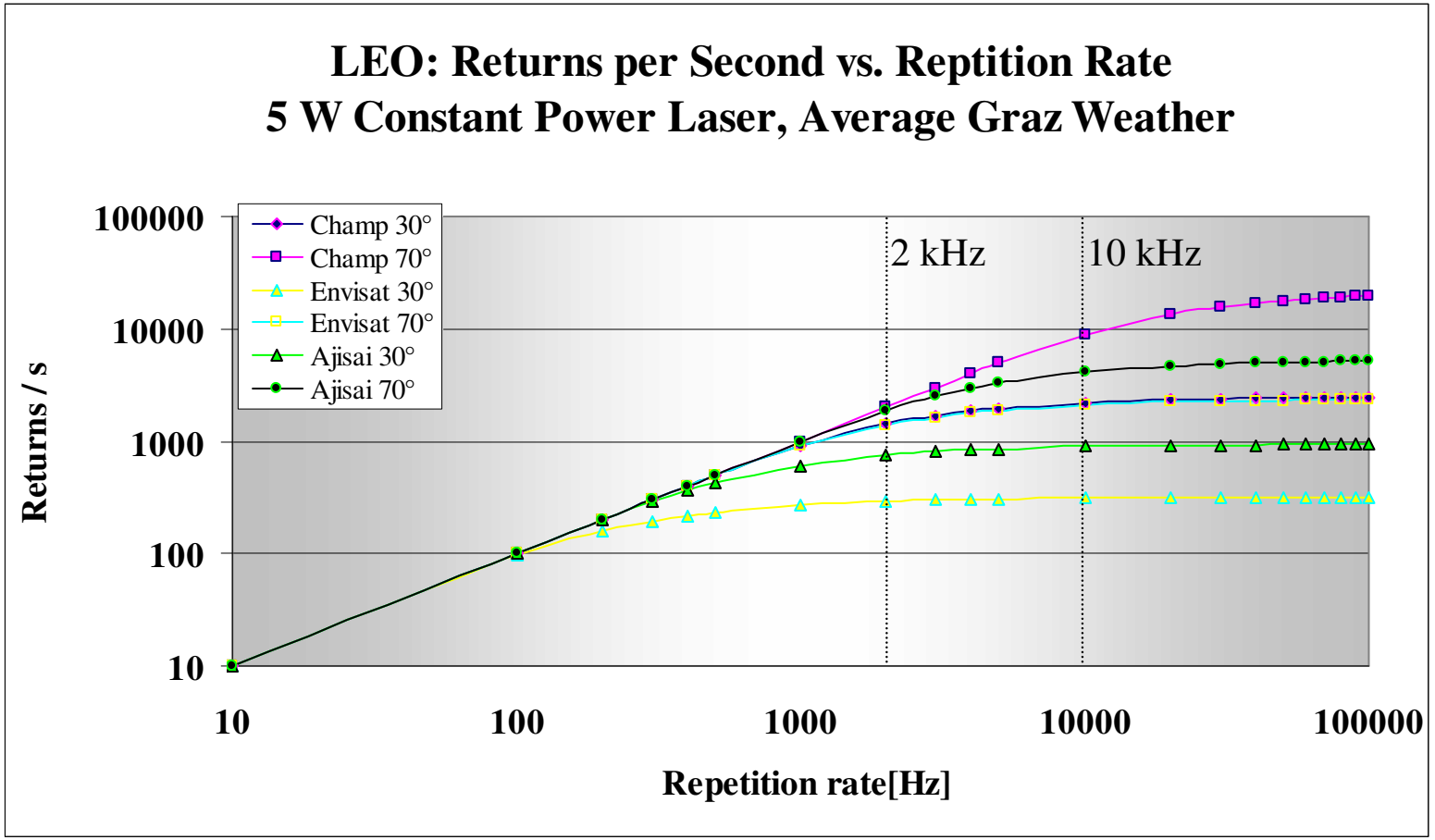
LEO: How many returns per second can we expect ???



Assumed: 5 W Constant Power Laser / C-SPAD / Graz Atmosphere:
LEO: Significant increase of returns / s at least until 10 kHz

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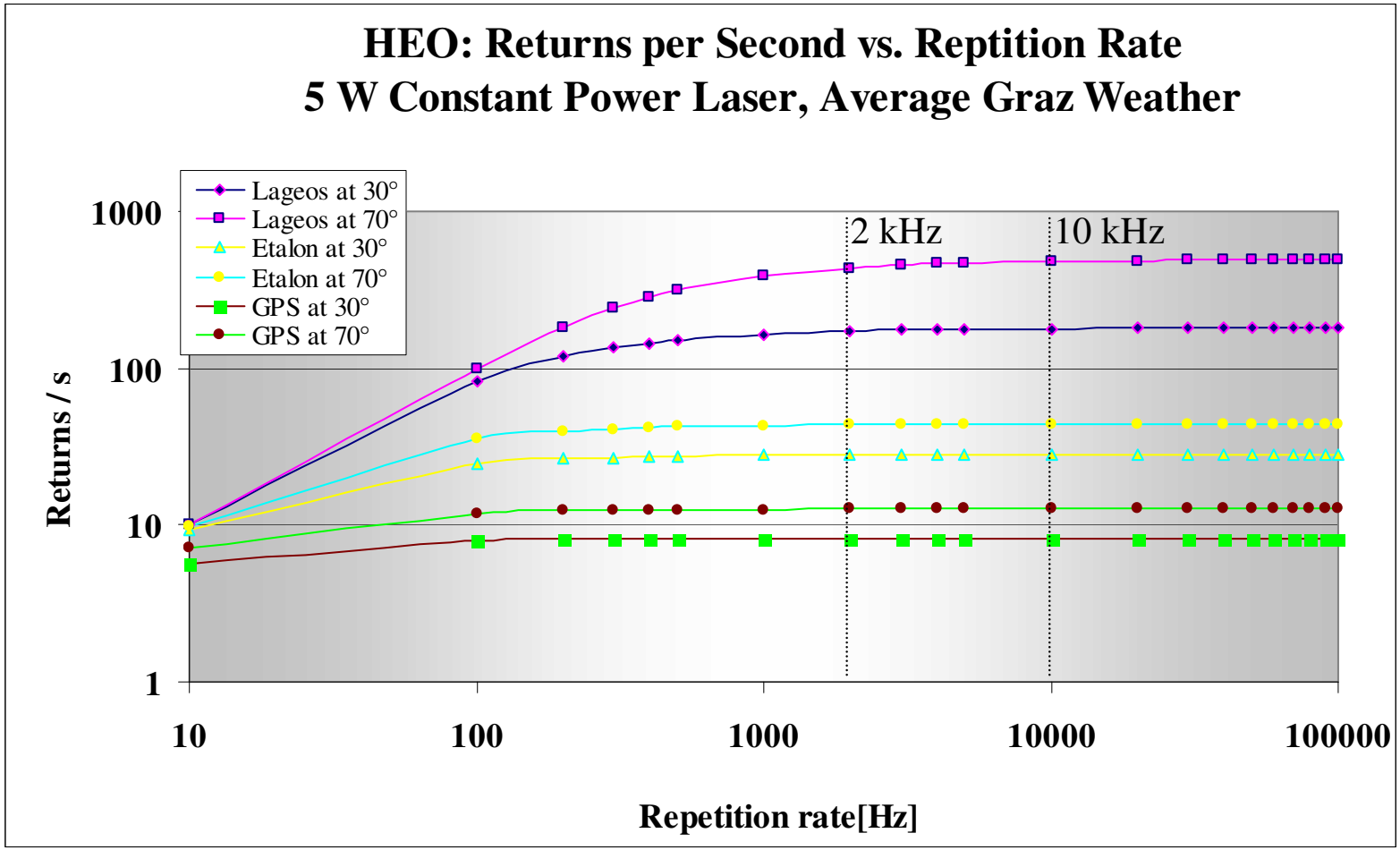
HEO: How many returns per second can we get ???



Assumed: 5 W Constant Power Laser / C-SPAD / Graz Atmosphere:

HEO: NO increase of Returns / s above a few 100 Hz;
LAGEOS: NO increase of Returns / s above a few kHz

From 2 kHz to 10 kHz

Preliminary Conclusions for higher repetition rates:

- 10 kHz Laser Repetition Rate is a good compromise
  - Overlaps still can be avoided
  - Direct increase of returns per second for LEO
  - Still some increase for LAGEOS
  - Limited additional value for HEO satellites (but 2 kHz still okay here)

- Can be achieved in Graz with minor changes, no big investments ☺
  - Boosting the High-Q-Laser: Needs only a new Pockels Cell Driver
  - Needs Riga ET for 10 kHz: Already available
  - Needs an additional Windows PC
  - Needs a new PDM (Pulse Distribution Module)

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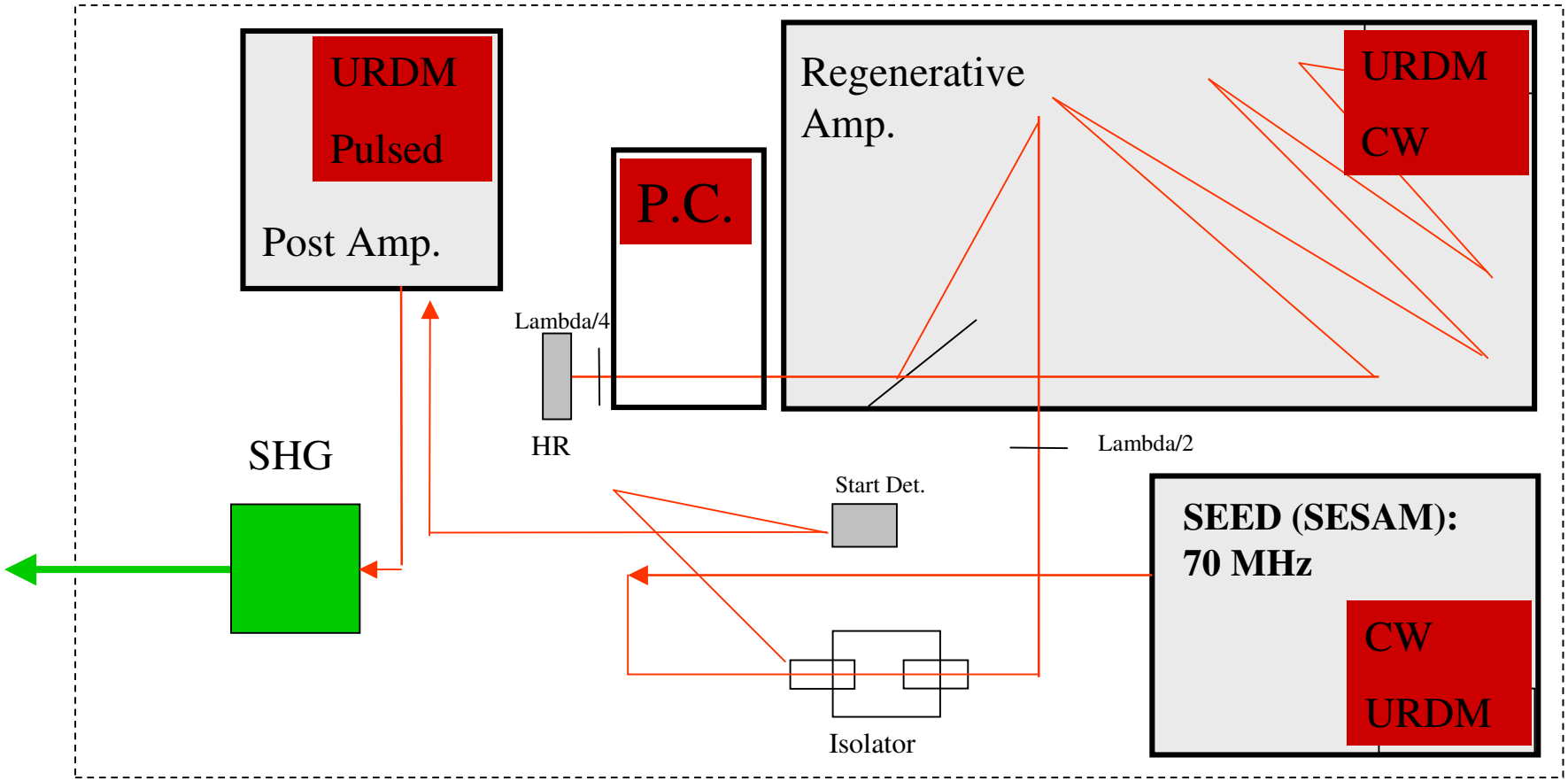
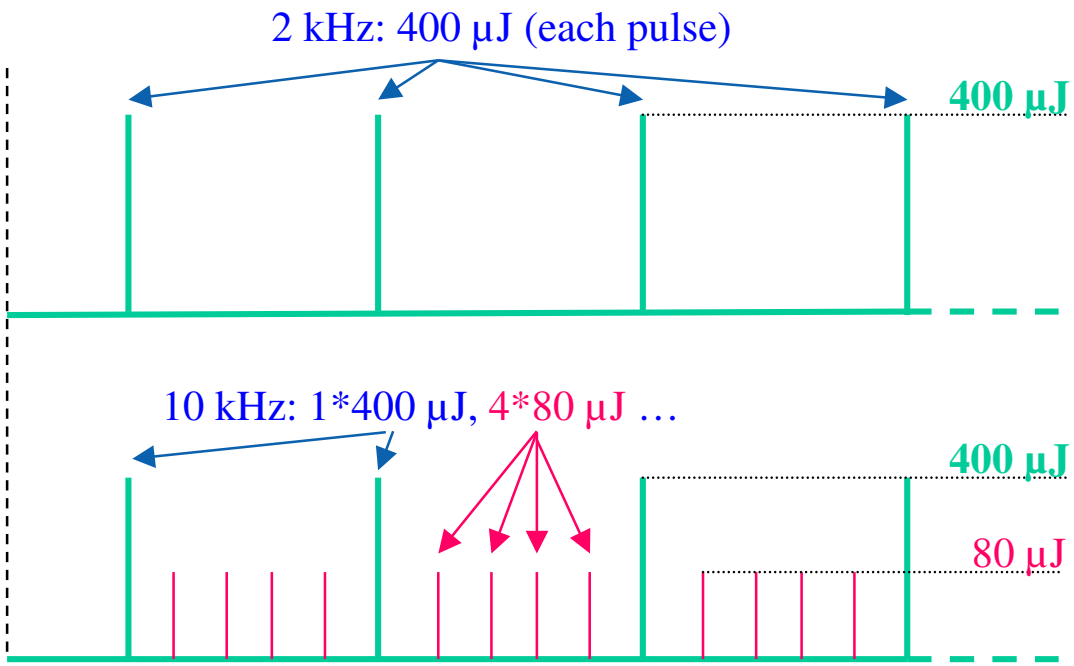
Graz 2 kHz Laser: Limits for higher Rep Rates

Oscillator + Regenerative Amp: CW Pumped => Could deliver up to ≈ 50 kHz !!!
But: Original Pockels Cell: 5 kHz max; replaced by new Pockels Cell: 10 kHz max.
Post Amp: Pulsed Pumping: 2 kHz max. limited; no way to increase it ….



Post Amp: Remains at 2 kHz; Osc.+ Regen: 10 kHz

- Osc. + Regen. Amp.: CW Pumped => generating pulses at 10 kHz
- Post Amp: Pulsed Pumping: Remains at 2 kHz max
- New Pockels Cell installed: Allows up to 10 kHz (Regen. Amp.)
- Therefore: Pulses with alternating energy:
  - 1 pulse amplified by post amp: 400 µJ
  - Next 4 pulses NOT amplified by post amp: 80 µJ



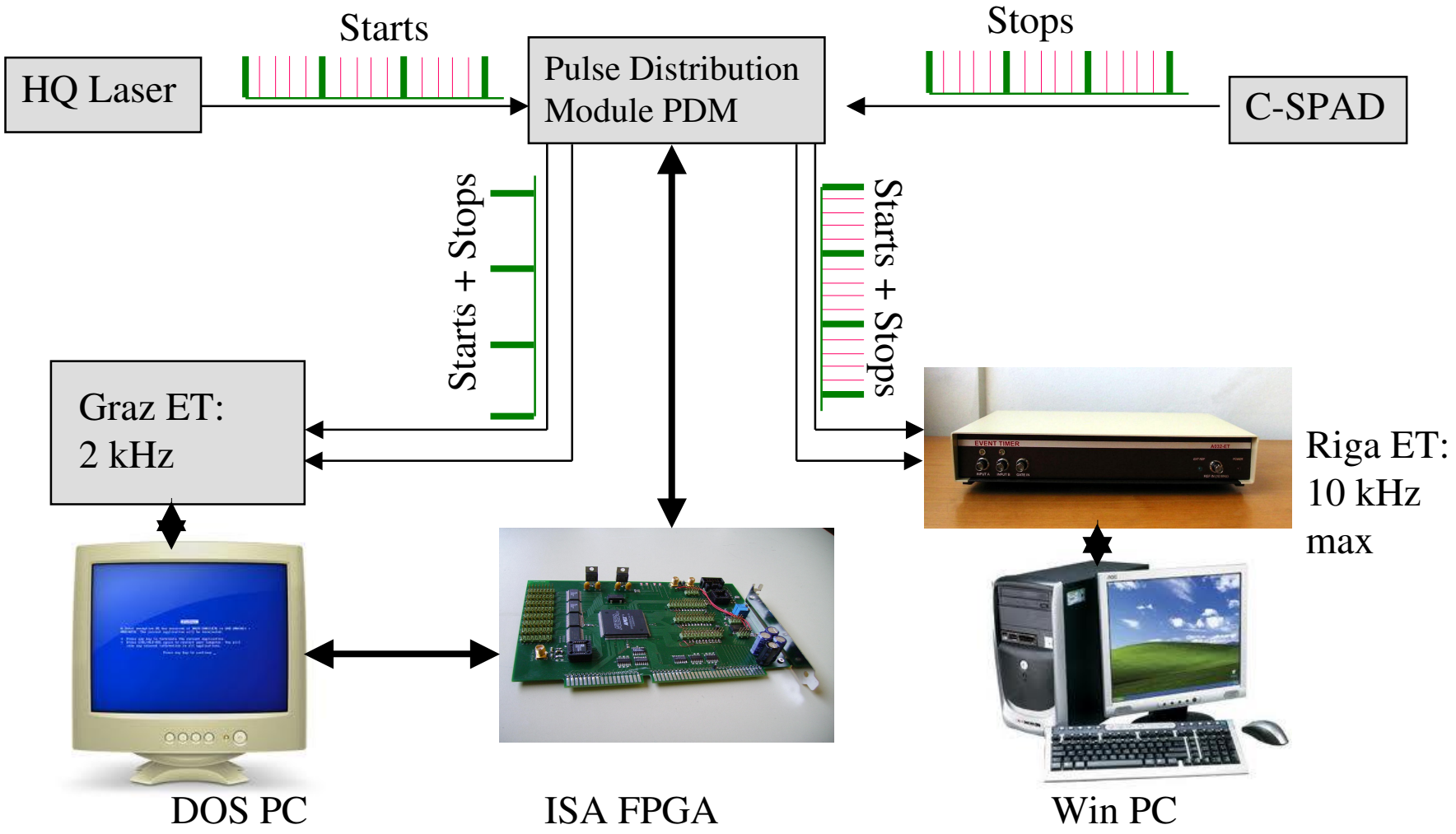
Standard HQ Laser: 2 kHz

400 µJ / Pulse; **0.8 W**

Upgraded HQ Laser: „10“ kHz

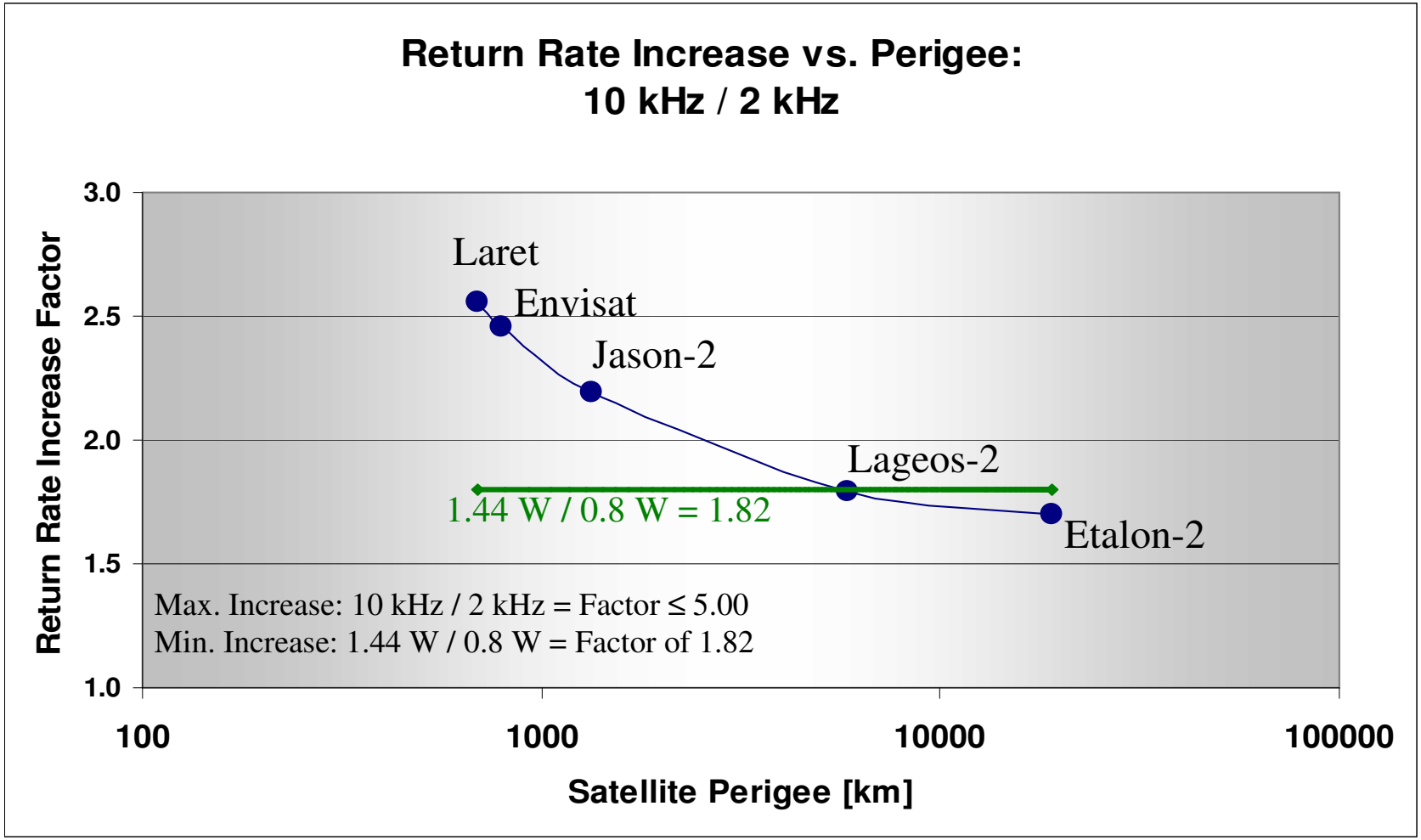
400 µJ / 80 µJ Pulse; **1.44 W**

Graz: 10 kHz Setup …



Start/Stop pulse colors: Symbolic to indicate STRONG (green) and WEAK (red) pulse energy …

First test results with Graz 10 kHz SLR



1.44 W @ 10 kHz / 0.8 W @ 2 kHz = 1.82; for Single Photons, we will arrive at this ratio;
For Single Photon Satellites (HEOs and LAGEOS): Theoretical Factor 1.82 expected;
For Multi –Photon Satellites (LEOs): The Factor will increase, according to received energy (distance …)

First test results with Graz 10 kHz SLR

- Graz 10 kHz system is still under test – no 10 kHz NPs yet distributed
- DOS programs still ‚see' a 2 kHz system – Win PC handles RIGA / „10" kHz

What we expect from High-Q-Laser et al:

CONSTANT POWER LASER; e.g. 5 W:

100 Hz / 50.0 mJ for HEO satellites

10 kHz / 0.5 mJ for LEO satellites

New Dome in Graz – but still „old“ 2 kHz…