High Power Compact Fiber Chirped Pulse Amplifiers at 1558-nm using Er/Yb LMA Fibers and Chirped Volume Bragg Grating Compressors

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Outline

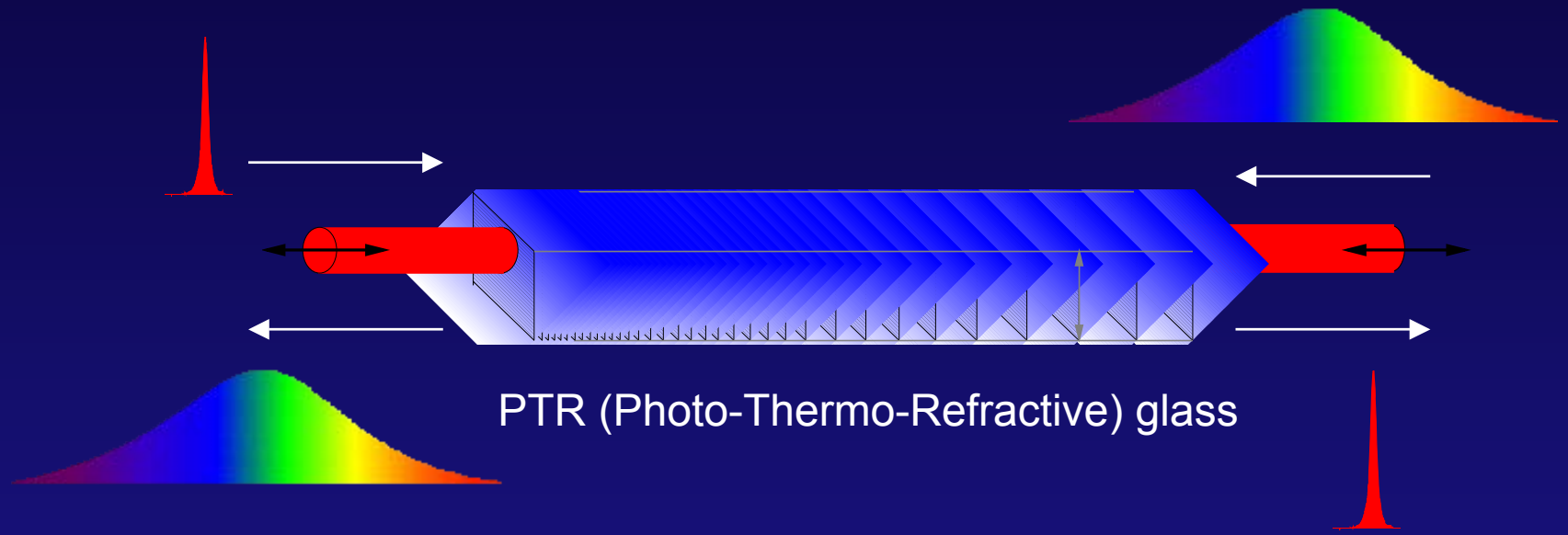
- Introduction
- Chirped Volume Bragg Grating (CVBG) stretchers/compressors
- Compact high power fiber CPA at 1558-nm based on CVBG
  - High power Er/Yb fiber amplifiers
  - CVBG power handling characteristics
  - PM and non-PM CVBG compressor configurations
- Summary

Motivation

- Current Fiber CPA techniques:
  - Diffraction-grating compressors → Large and complex
  - Fiber Bragg grating compressors
  - Hollow-core PCF compressors

  → Low pulse energies (< 1-μJ)
- New CVBG pulse compression technology:
  - Compact & robust/simple alignment
  - Potential for both high-power and high pulse energy scaling

Chirped Volume Bragg Grating (CVBG) Stretcher/Compressor



- Rely on Bragg reflection $\lambda_B = 2n\Lambda(z)$
  - Same as FBG
- mm-large apertures
  - Main difference from FBG

Chirped Volume Bragg Grating

- Long stretched pulses 0.1 – 1 ns

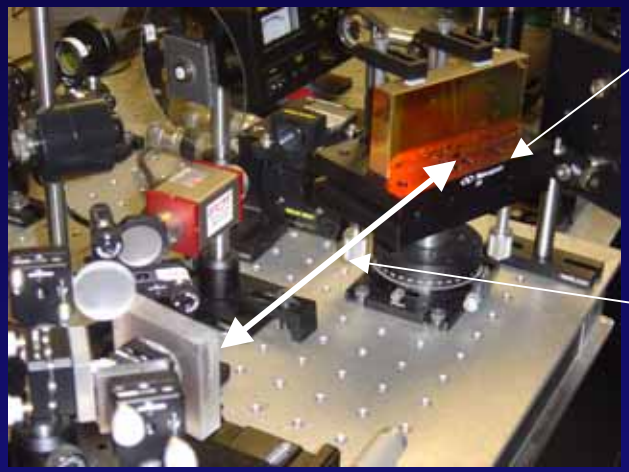
  (1-cm – 10-cm long CVGB)

Stretched pulses 80-100ps

- > mJ pulse energies (both extractable and compressible)
- High power/energy handling capacity
- High efficiency (>90 %)
- Compact and robust
- Reciprocal stretching and recompression

High average power
(15W recompressed)

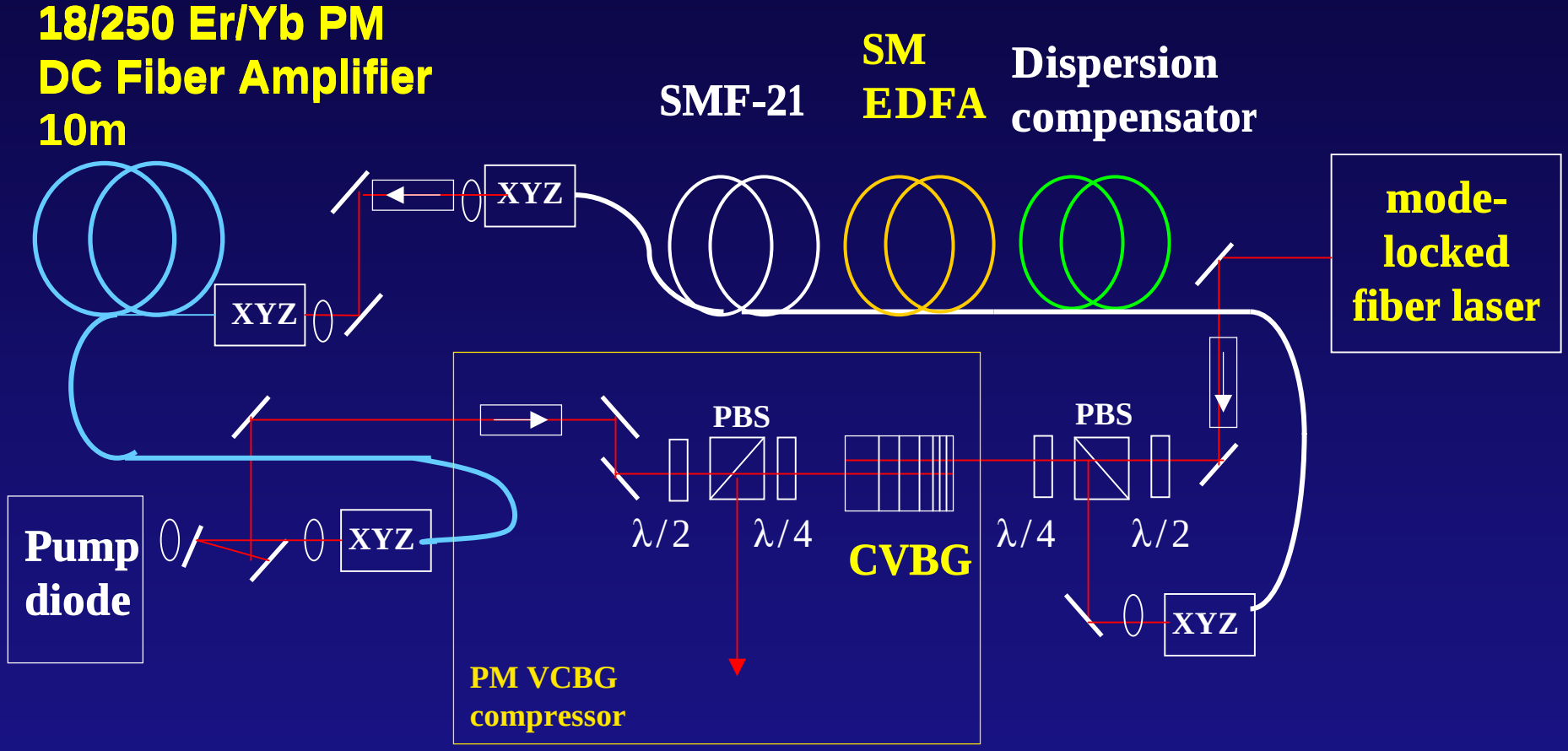
Comparison between Conventional and CVBG Compressors



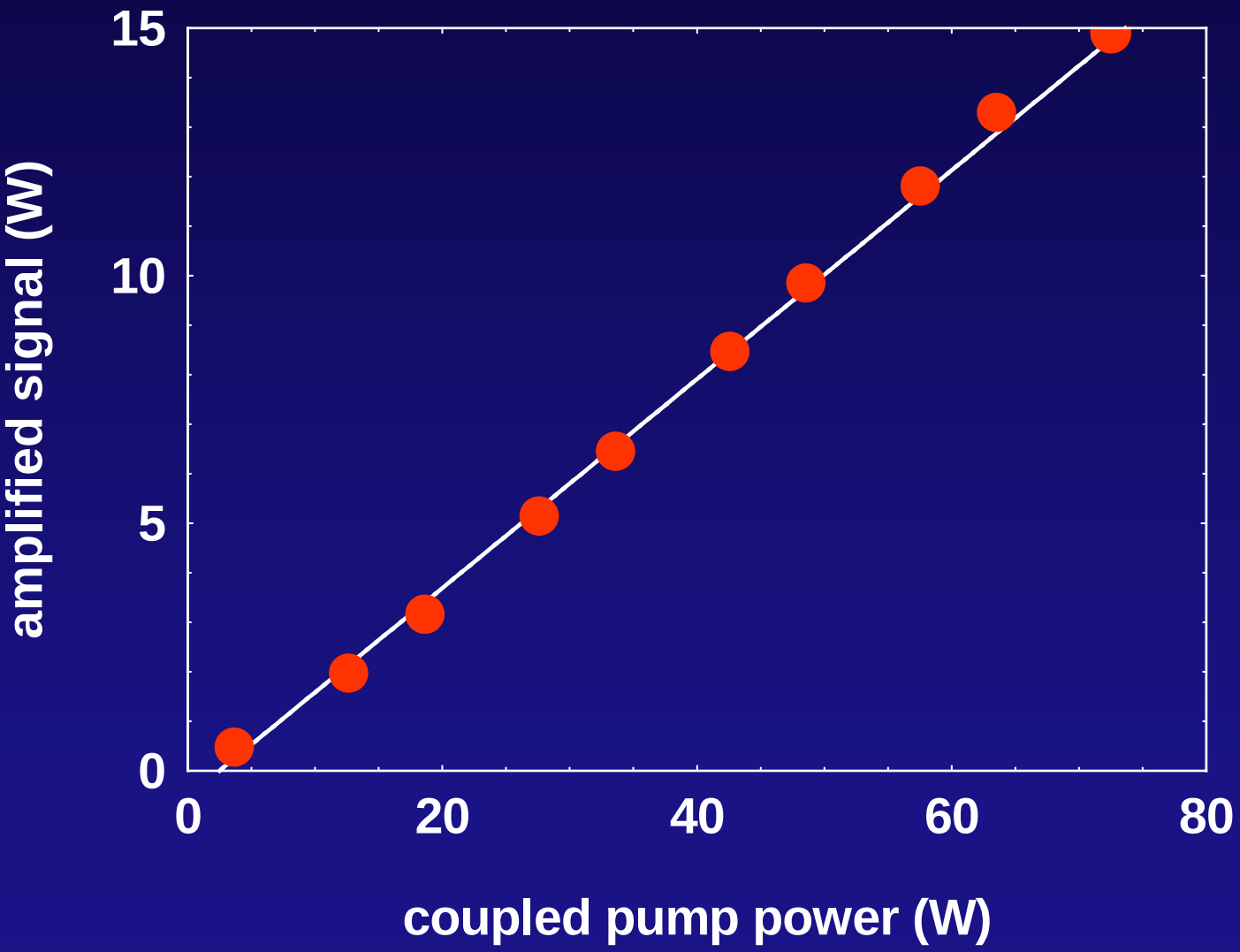
Conventional Grating Compressor

Chirped Volume Grating Compressor

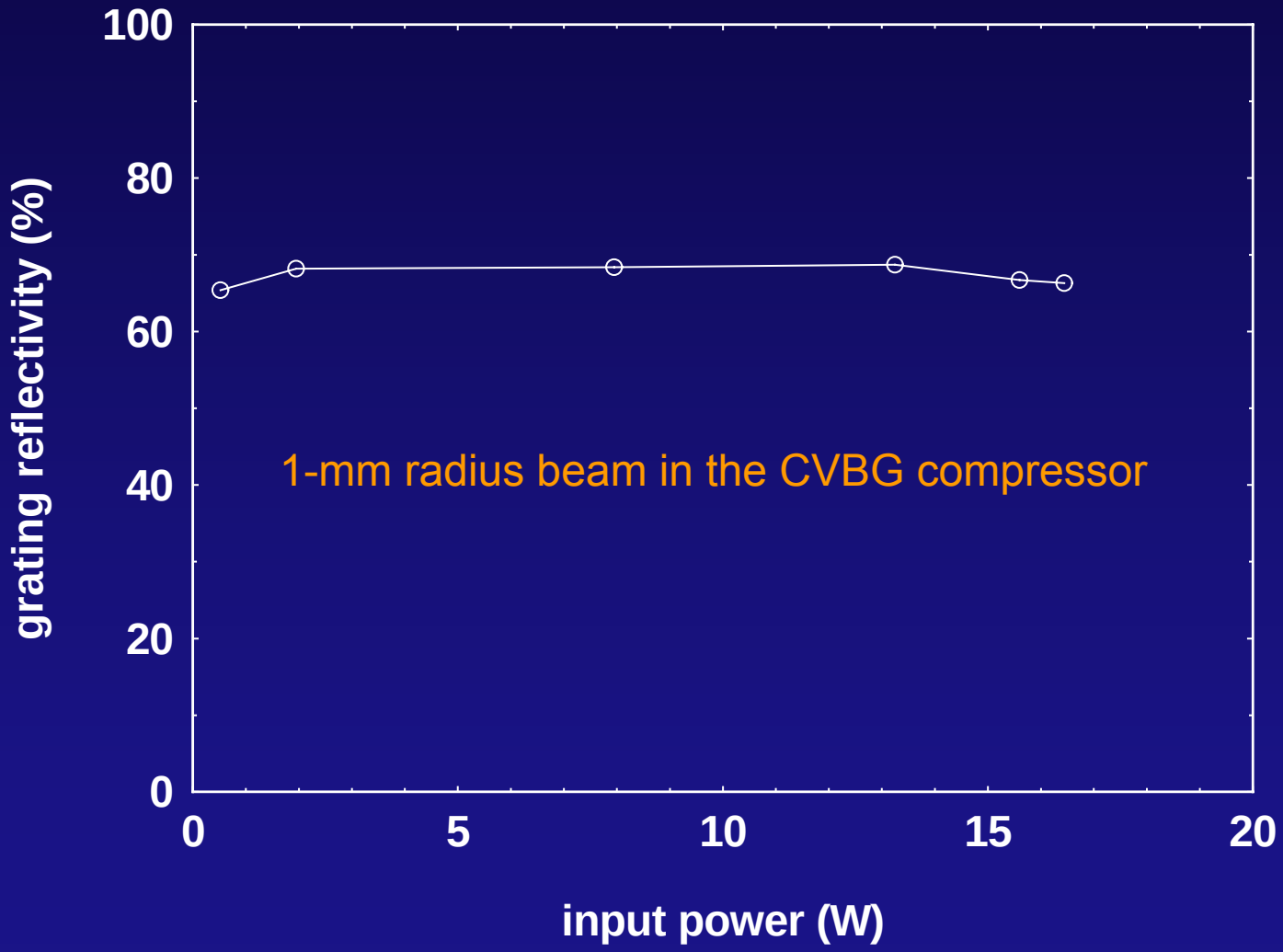
PM-Fiber CPA Set-up



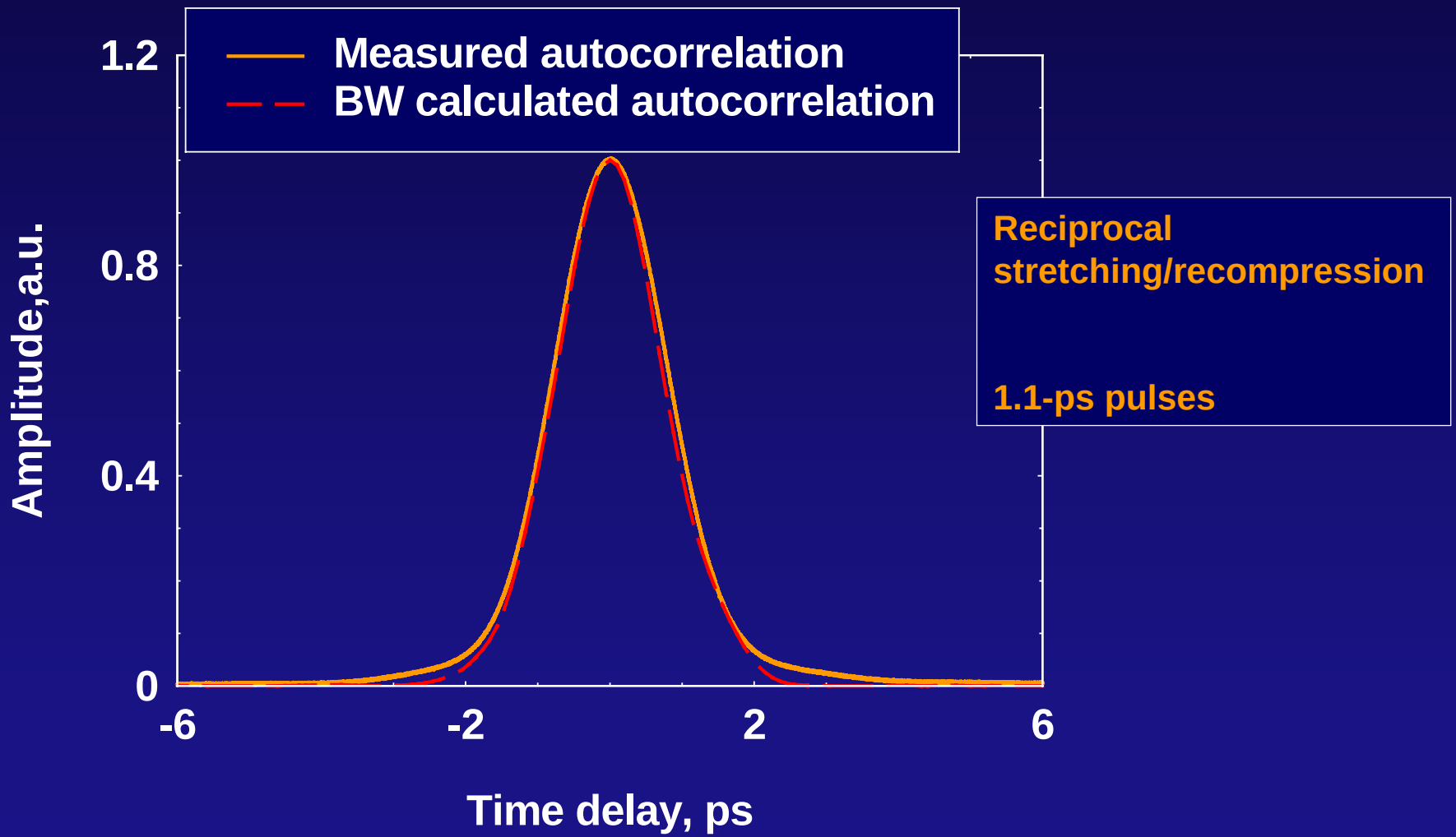
Amplified 1558-nm signal



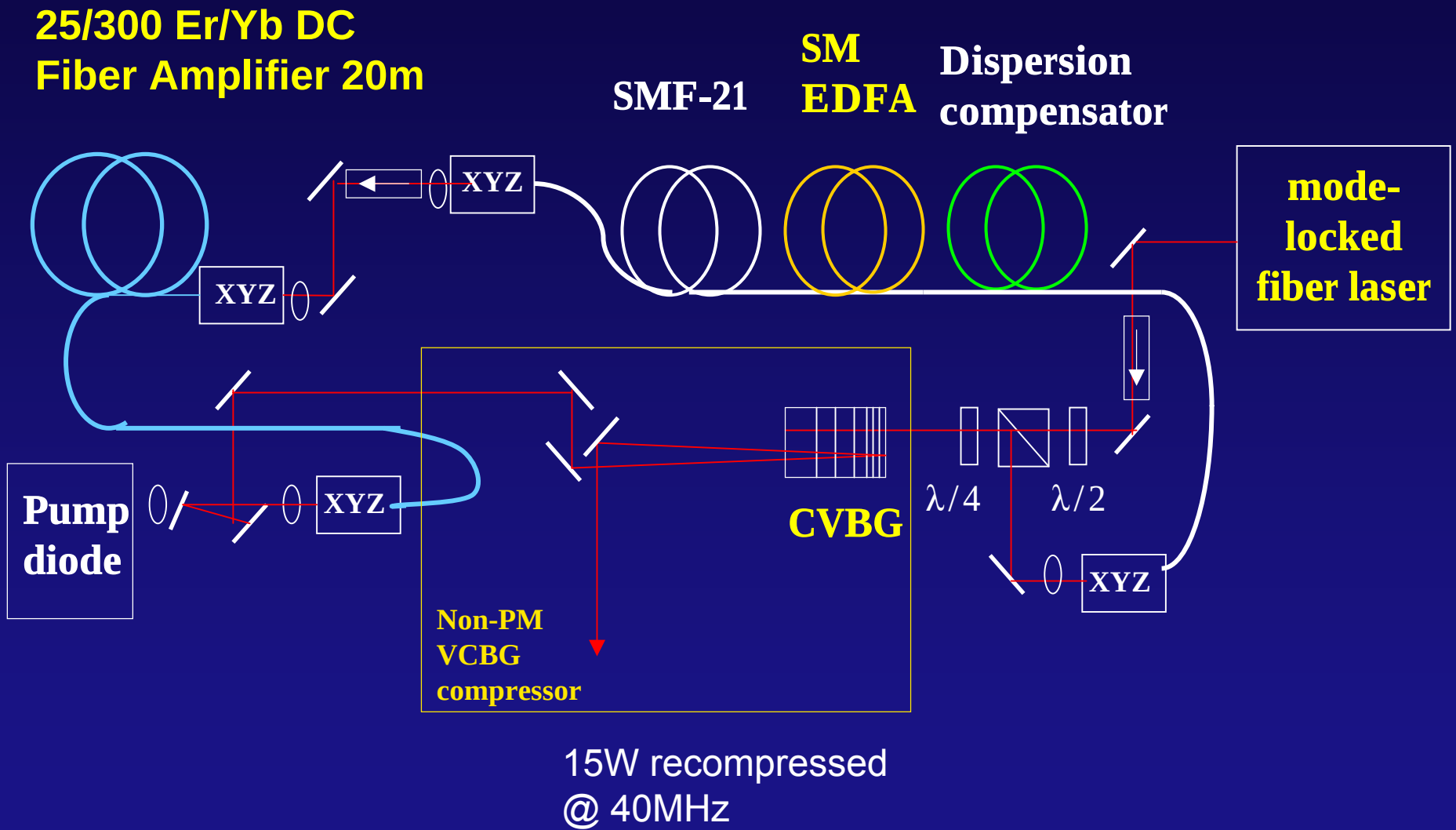
Grating reflectivity is power independent



Recompressed Pulse (@ 6-W recompressed power)

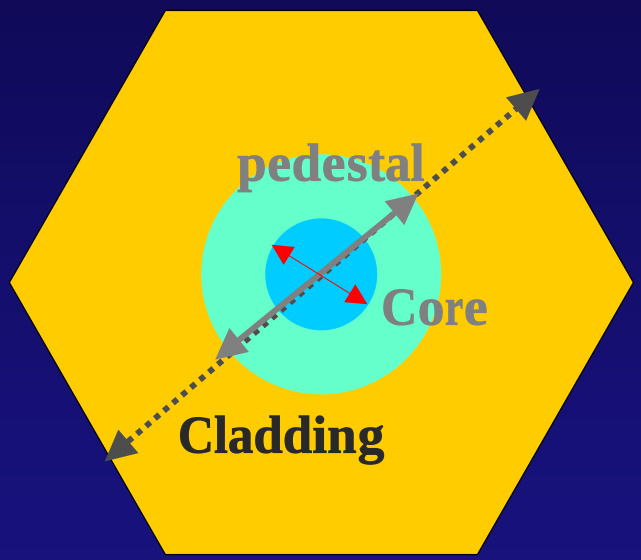


Non-PM Fiber CPA Set-up

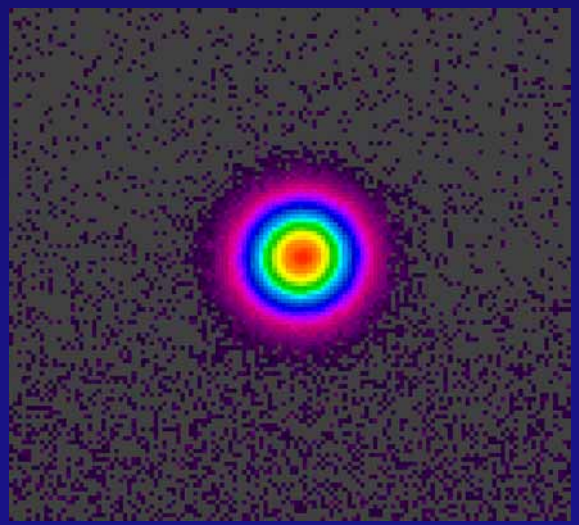


15W recompressed
@ 40MHz

2nd Stage Fiber Amplifier

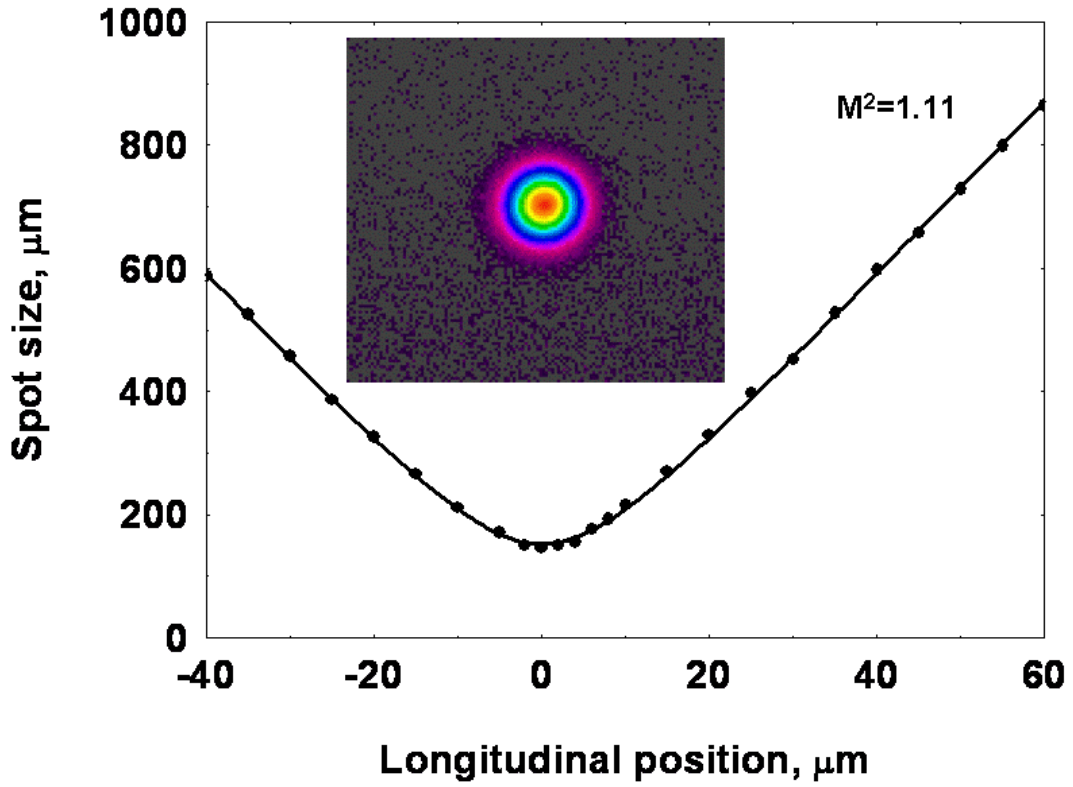


- Er-Yb co-doped
- Core: 25μm, 0.1NA
- Cladding: 300 μm, 0.46NA
- Single transverse mode output:

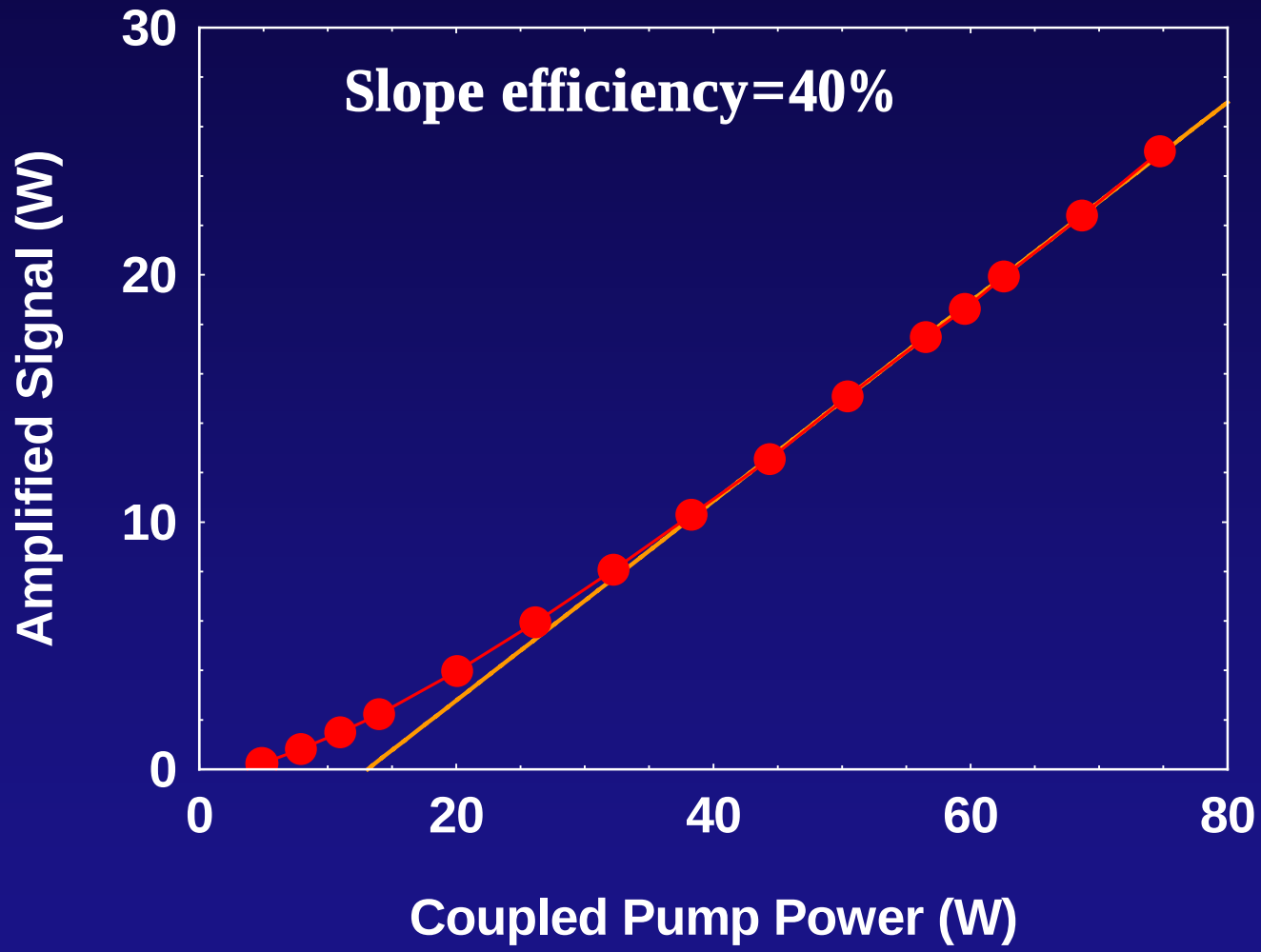


Fiber made under AFRL LADERA Program

Mode quality



Amplified 1558-nm Signal



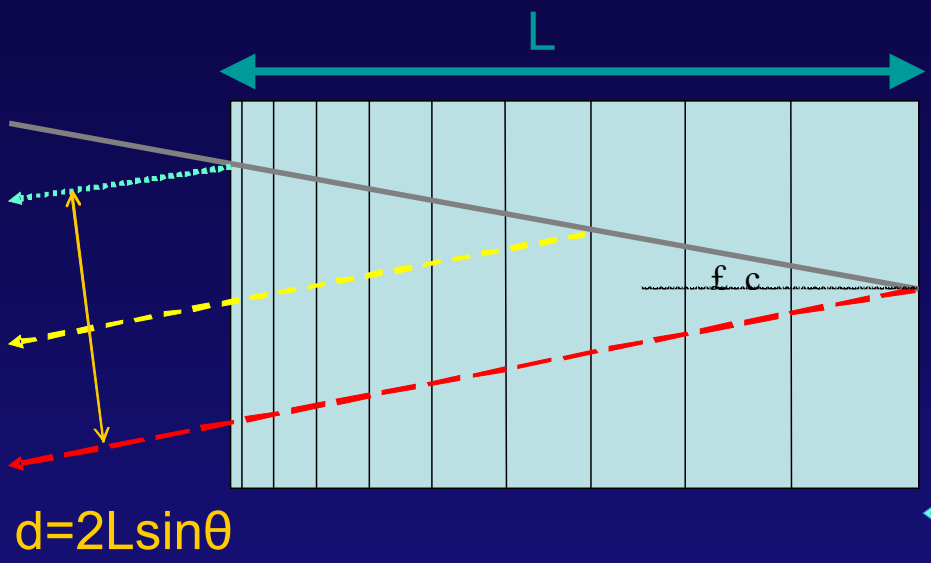
Max Power: 26W

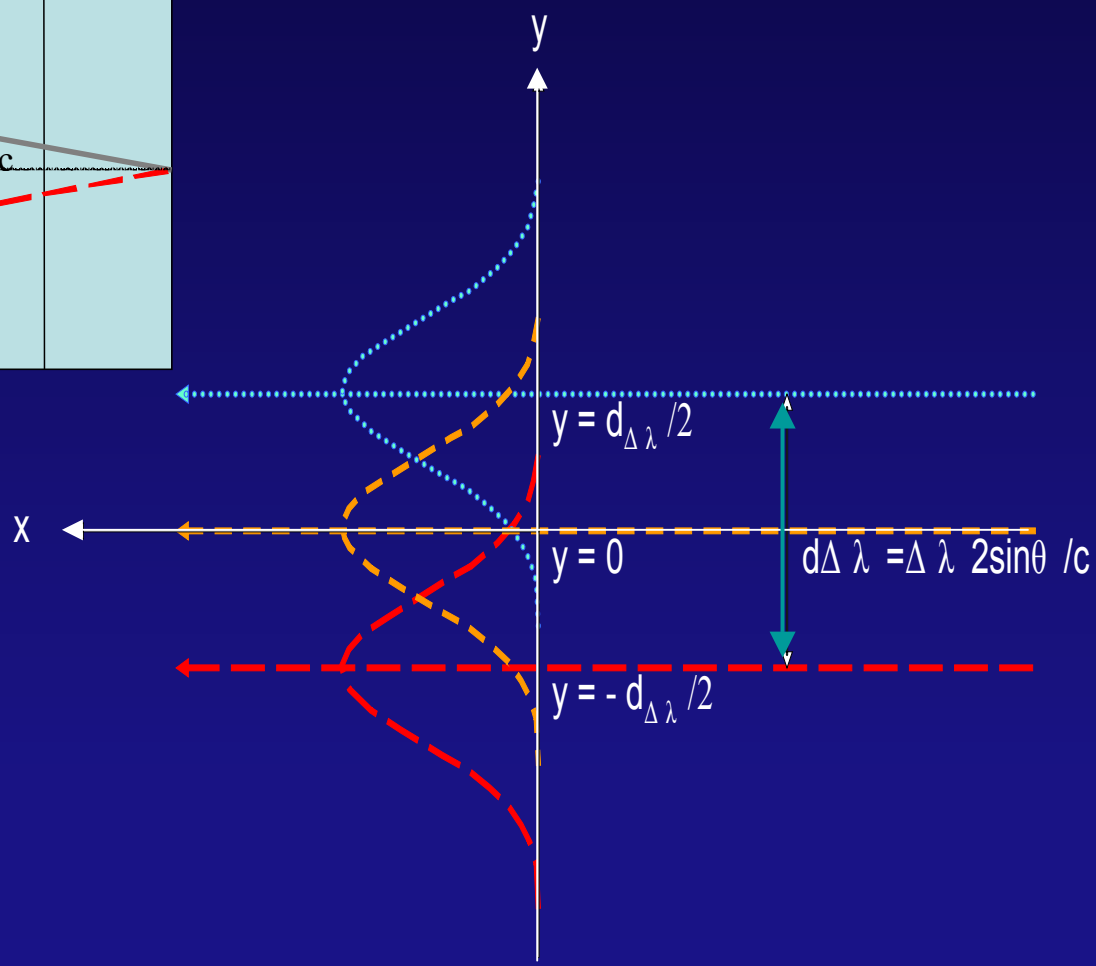
Rep Rate: 40MHz

Stretched Pulse Duration: 80-ps

1-μm ASE: 15W

Spatial Chirp for Tilted Incidence





$d = 2L\sin\theta = 2\Delta\lambda \sin\theta / c$

c: chirp rate

Spatial Chirp for Tilted Incidence (con't)

$$I(y) = I_0 \int_{y-\frac{d_{\Delta\lambda}}{2}}^{y+\frac{d_{\Delta\lambda}}{2}} \exp\left(-2\frac{r^2}{{w_0}^2}\right) dr = \frac{\sqrt{\pi}}{2} w \cdot erf\left(2\frac{y+\frac{d_{\Delta\lambda}}{2}}{w_0}\right) - \frac{\sqrt{\pi}}{2} w \cdot erf\left[-\left(2\frac{y-\frac{d_{\Delta\lambda}}{2}}{w_0}\right)\right]$$

1/e^2 beam-width w'

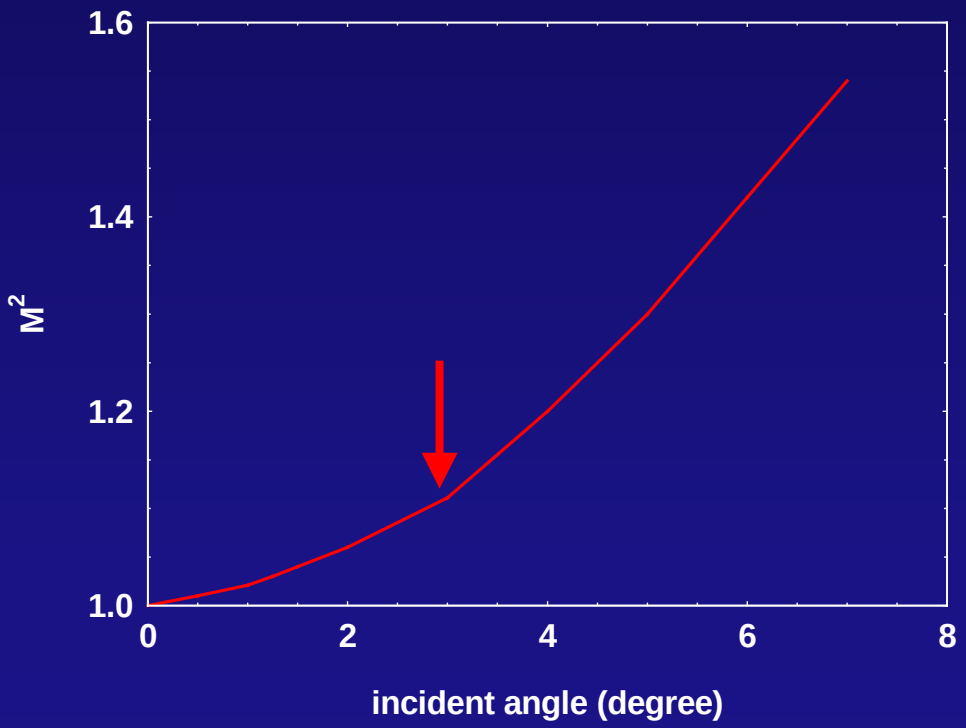
Chirp rate: 7.5nm/cm

Incident beam-radius: 1-mm

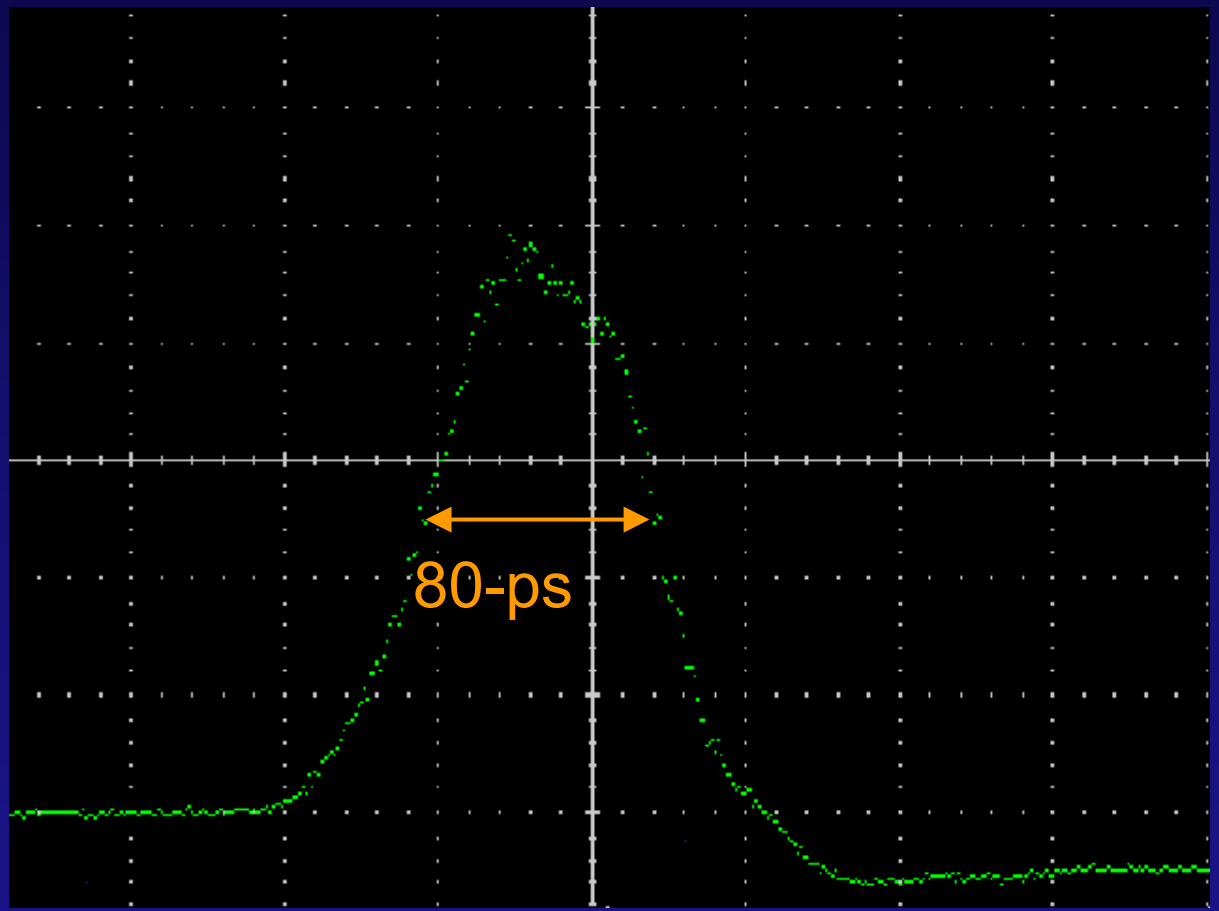
$M^{2'} = w'/w_0$

Incident angle < 3°

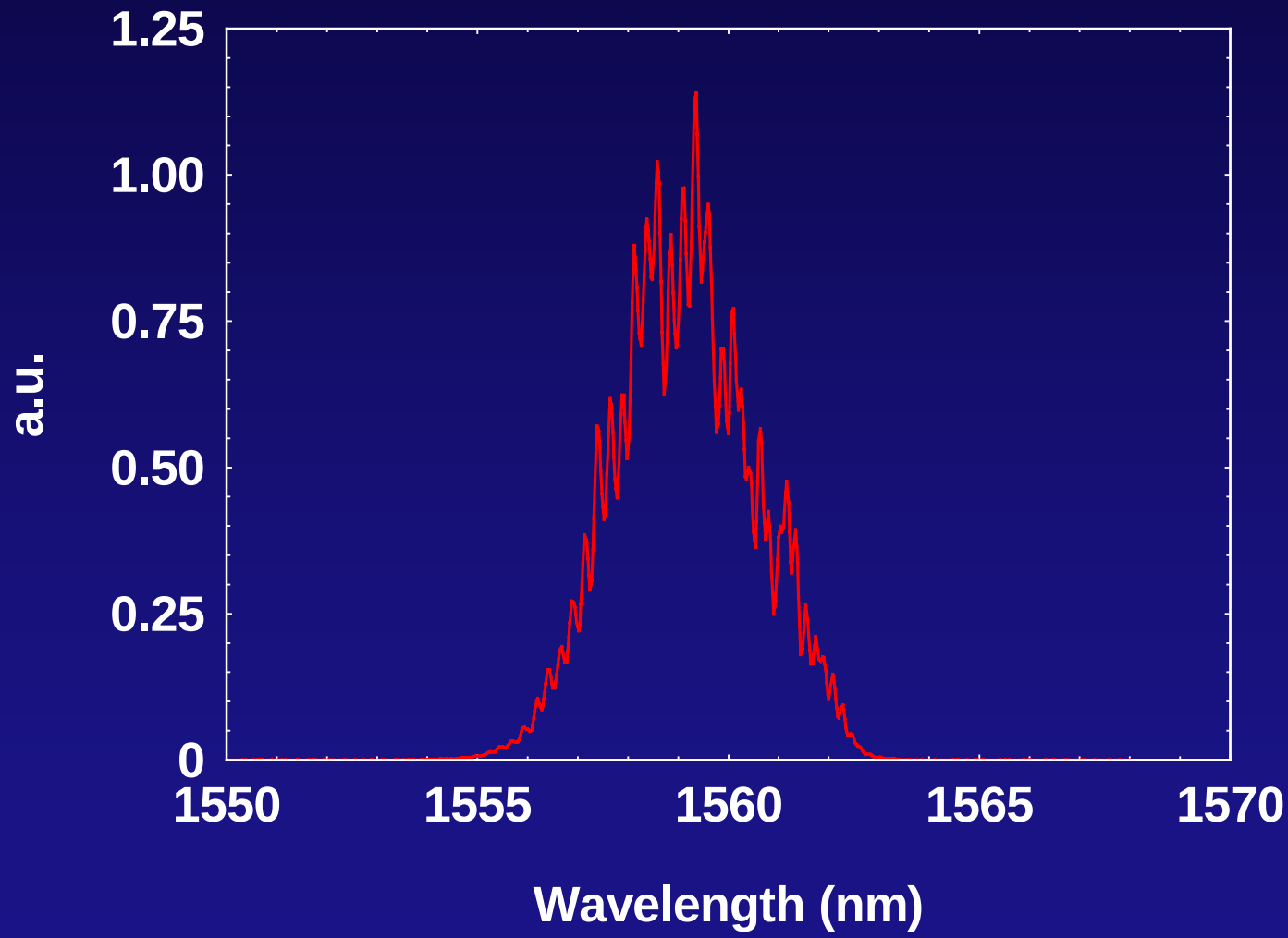
→ $M^{2'} < 1.11$



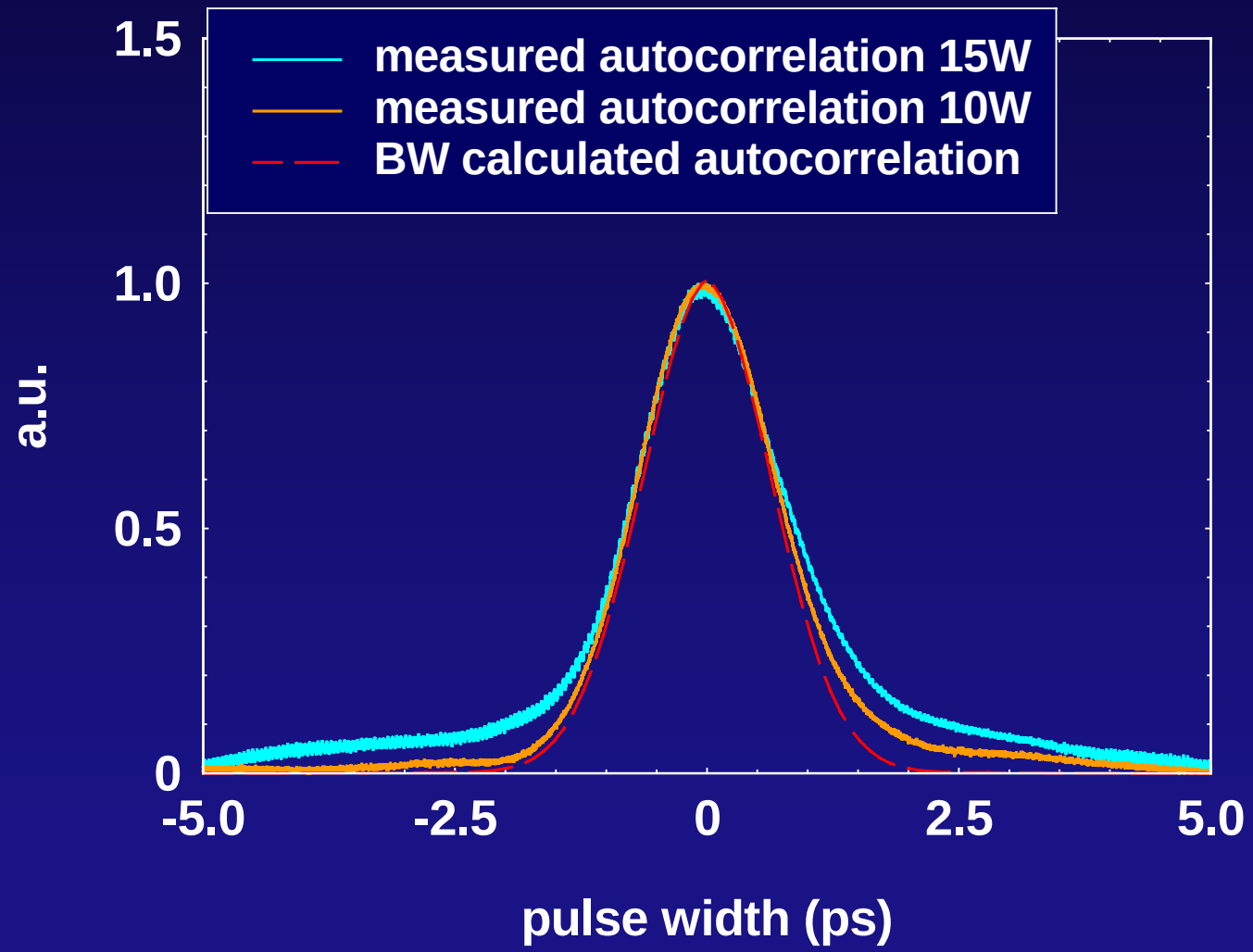
Stretched Pulse: 80-ps



Recompressed Pulse Spectrum



Recompressed Pulse : 1.1-ps



Self-Phase Modulation Distortion

- SPM induces a phase shift, which is equivalent to the action of a dispersive device with corresponding dispersion order *

$$\beta_n^{SPM} = P_0 \gamma z_{eff} \left. \frac{d^n (\tilde{U}_o^2 \left| \tilde{U}_{nom}(\omega) \right|^2)}{d\omega^n} \right|_{\omega=0}$$

→ pulse shape distortion

$\beta_4 \sim 0.2(ps^4) \rightarrow \Phi_{peak} = 0.3 = P_0 \gamma Z_{eff}$

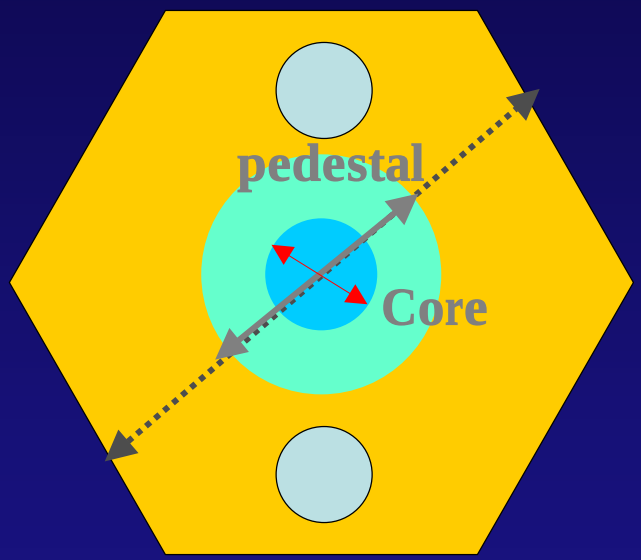
**Ultrashort-Pulsed Fiber Amplifier in "Ultrafast Lasers: Technology and Applications", M. E. Fermann, A. Galvanauskas and G. Sucha, eds,.*

CVBG Energy Scalability

- Photo-Thermo-Refractive (PTR) glass damage threshold >10-J/cm^2 for ~1-ns pulses

- Volume grating clear aperture 5mmx5mm
  - 1-J damage threshold for ~1-ns pulses (4mm beam diameter)
  - Multi-mJ damage threshold for sub-picosecond pulses
    - Recently demonstrated 200-μJ 1-ps recompressed pulsed using CVBG at 1064-nm

PM Version of Er/Yb Fiber Amplifier



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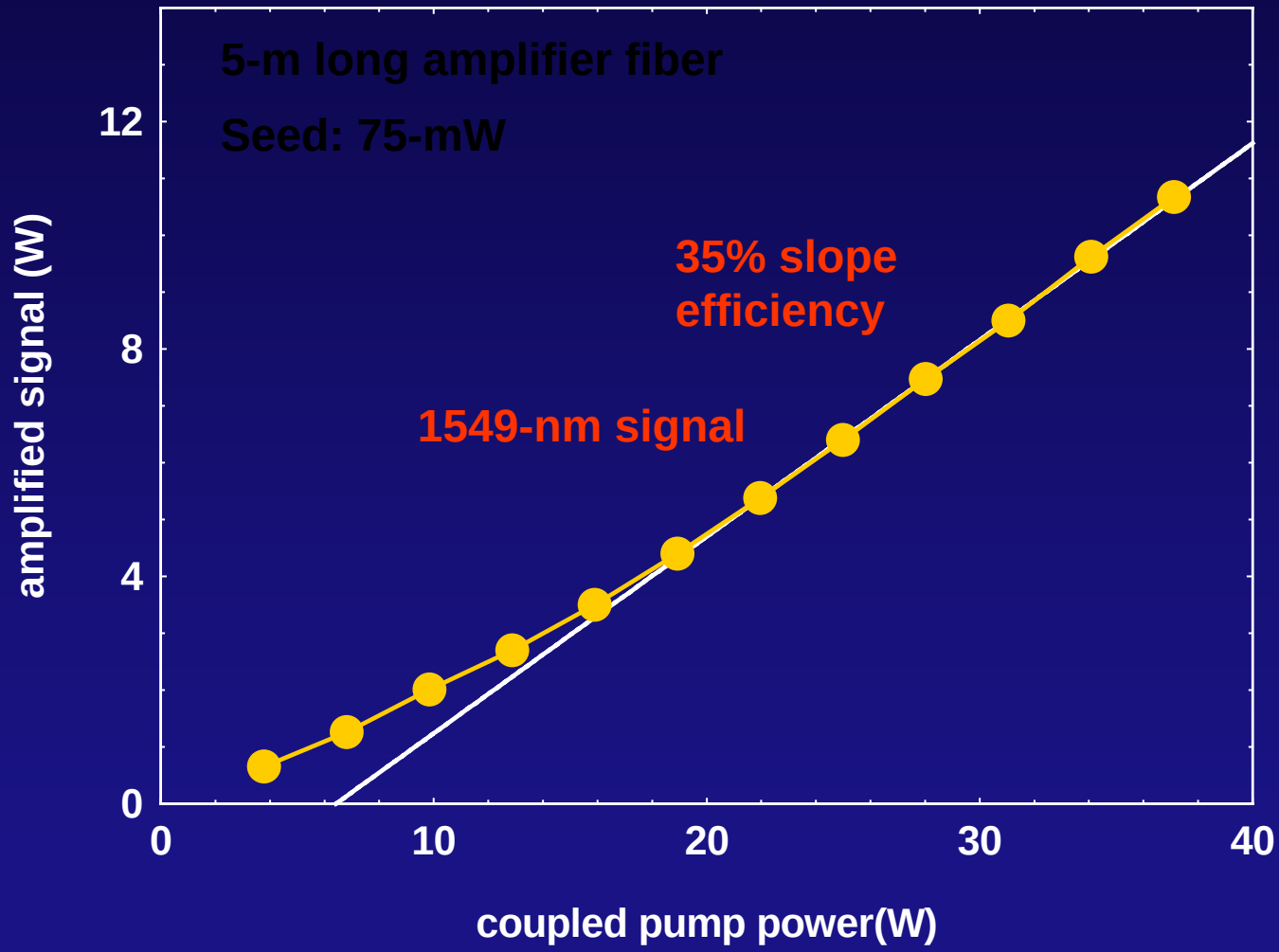
Power characteristics



- Polarisation extinction ratio:
  - 13-16dB

Summary

- 25-um Er/Yb LMA (non-PM and PM versions)
- High power compact fiber CPA using novel CVBG stretchers and compressors
- 15-W average power (recompressed), 1.1-ps pulsed fiber CPA system