

# CO<sub>2</sub> Laser R&D

Past: **0.5 TW**  
2 x 5 ps  
5 J

Present: **1 TW**  
5 ps  
5 J

Near future: **5 TW**  
2 ps  
10 J

Future: **50 TW**  
0.5 ps  
25 J

1 MeV

3 → 5 MeV

25 MeV

250 MeV

		Apr. 2009	Feb. 2010	Nov. 2010	Nov. 2011	???
Energy	[J]	5	5	5	10 (IV)	25 (V)
Duration	[ps]	2 x 5 (I)	5 (II)	5	2 (IV)	0.5 (V)
Power	[TW]	0.5	1	1	5	50
$a_0$		1.2	1.7	2.2 (III)	4.9	16
$E_p$	[MeV]	1.5	3 (?)	5	25	250

- I. laser pulse was split into two due to imperfect amplification spectrum
- II. isotopic mixture was used to demonstrate single pulse amplification
- III. improved laser focusing is expected to increase laser intensity
- IV. Ti:Sapphire seed laser is purchased (Sept. 2010) to shorten  $CO_2$  seed to 1 ps. Improved seed pulse contrast would allow better energy extraction.
- V. Additional amplification stage and/or laser pulse plasma chirping/compression need to be developed to reach this stage

Past: **0.5 TW**

2 x 5 ps  
5 J

1 MeV

Present: **1 TW**

5 ps  
5 J

3 → 5 MeV

Near future: **5 TW**

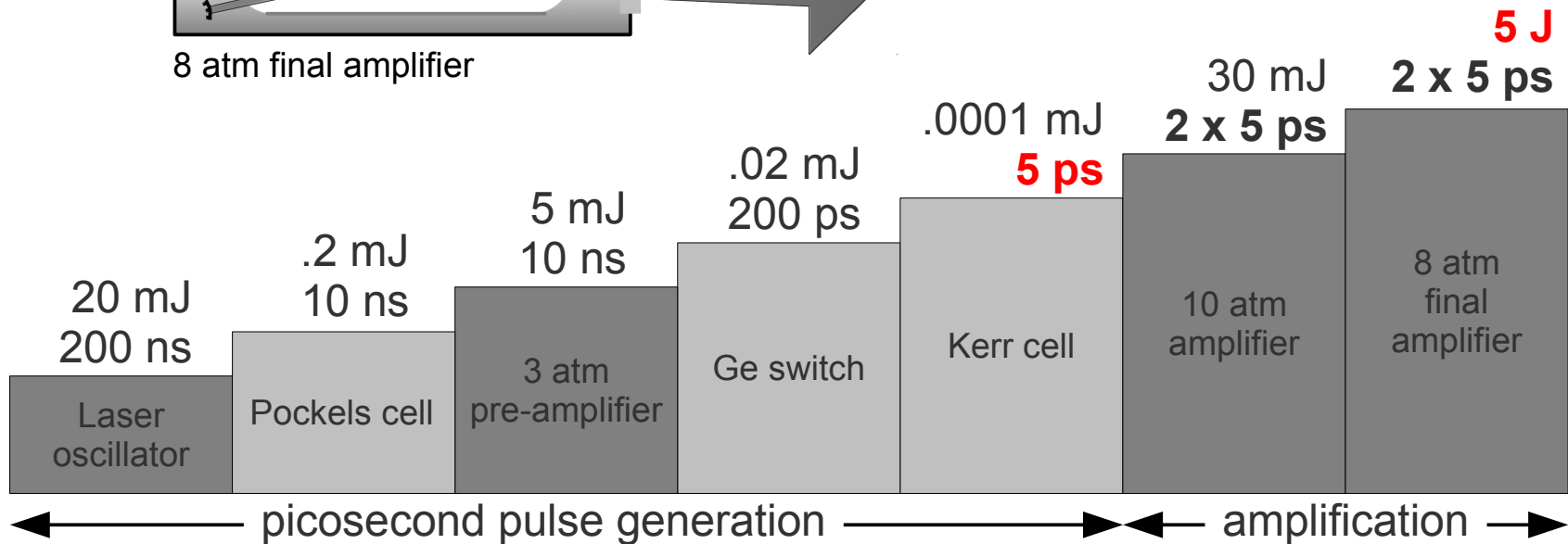
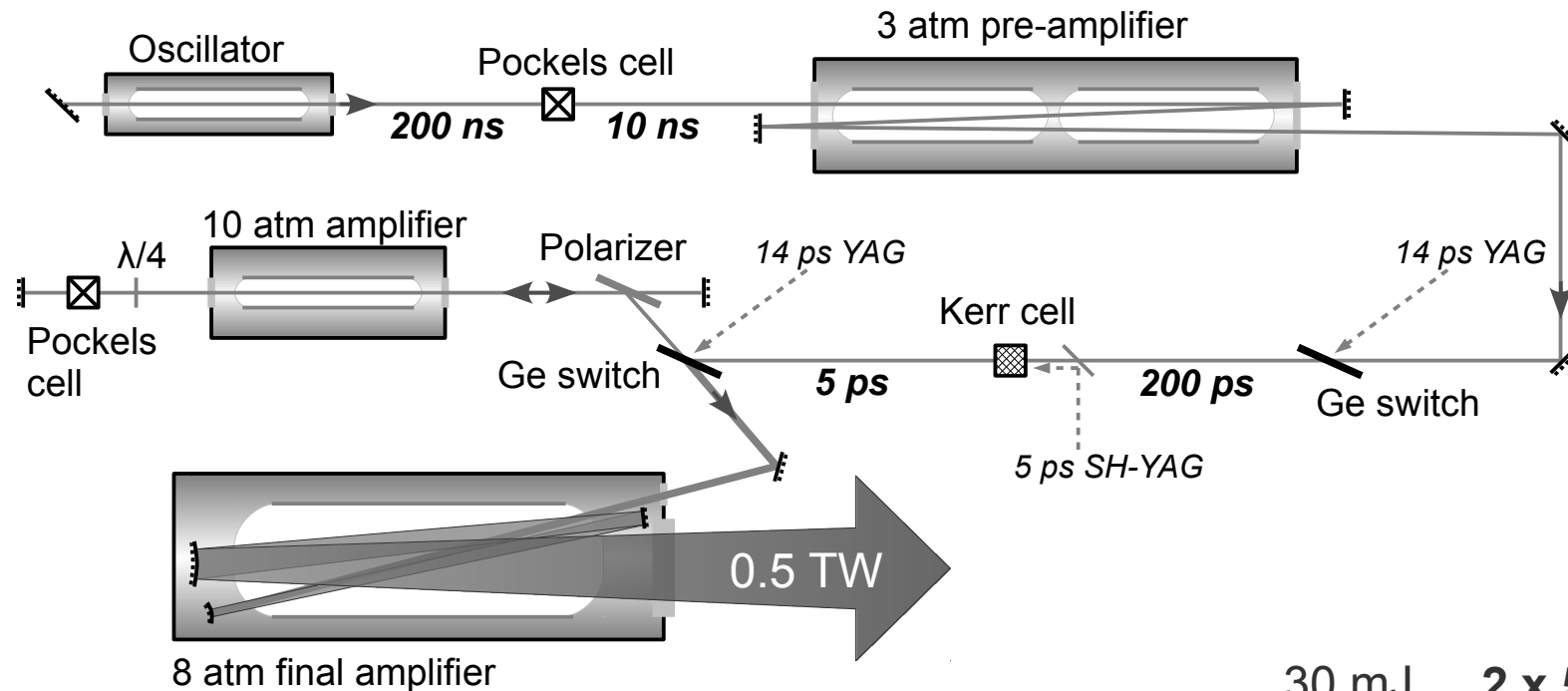
2 ps  
10 J

25 MeV

Future: **50 TW**

0.5 ps  
25 J

250 MeV



Past: **0.5 TW**

2 x 5 ps

5 J

1 MeV

Present: **1 TW**

5 ps

5 J

3 → 5 MeV

Near future: **5 TW**

2 ps

10 J

25 MeV

Future: **50 TW**

0.5 ps

25 J

250 MeV

Spectra

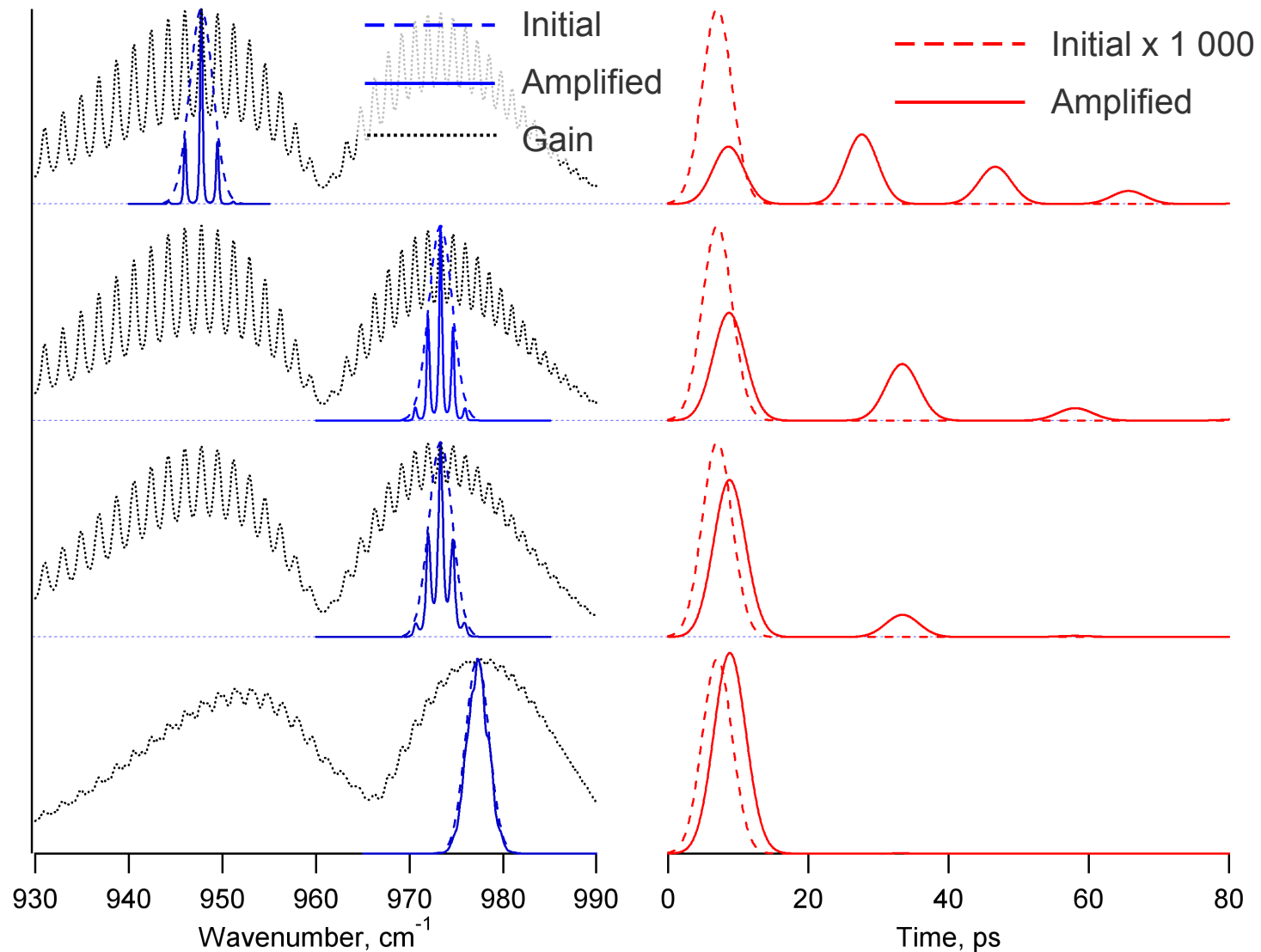
Power

7.5 atm; P-branch

7.5 atm; R-branch

10 atm; R-branch

10 atm; R-branch;  
isotopic gas



Past: 0.5 TW

2 x 5 ps  
5 J

1 MeV

Present: 1 TW

5 ps  
5 J

3 → 5 MeV

Near future: 5 TW

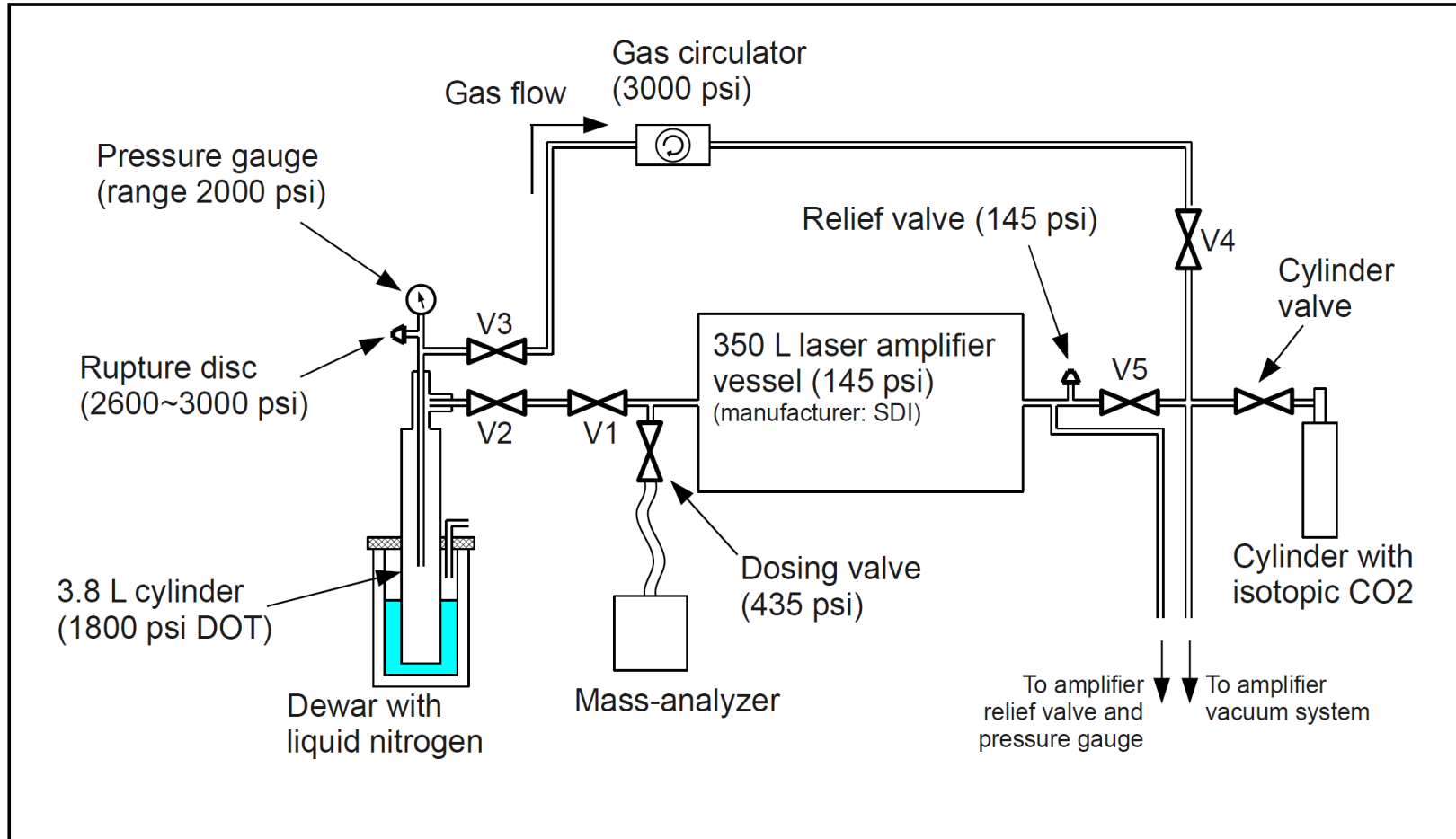
2 ps  
10 J

25 MeV

Future: 50 TW

0.5 ps  
25 J

250 MeV



**Valves** Max working pressure 2500 psi  
**Tubing** Max working pressure 2630 psi; Factor of safety 4 (SS-304, O.D. 3/8", wall thickness 0.028")  
**Fittings** "rated for working pressures higher than the tubing"  
**Maximum pressure in the cylinder (calculated):**  
 1170 psi (room temp.); 118 psi (LN2 temp.)

CO <sub>2</sub> freeze-out setup	
Mikhail Polyanskiy ATF, bldg 820M, ext. 2505	01/04/2010

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2 x 5 ps  
5 J

1 MeV

Present: 1 TW

5 ps  
5 J

3 → 5 MeV

Near future: 5 TW

2 ps  
10 J

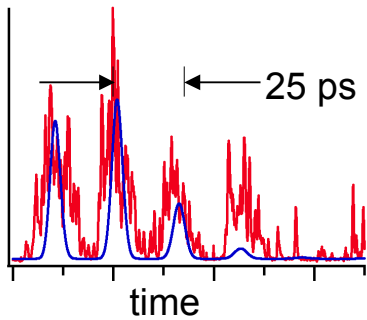
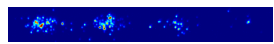
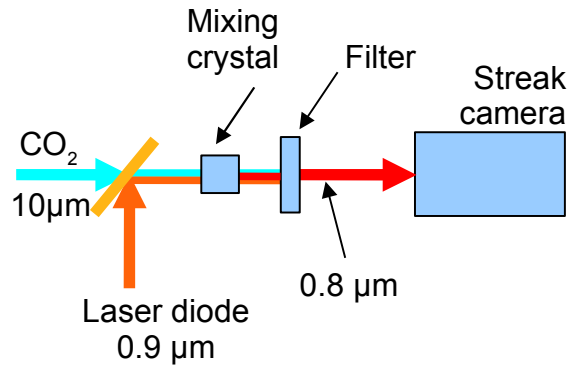
25 MeV

Future: 50 TW

0.5 ps  
25 J

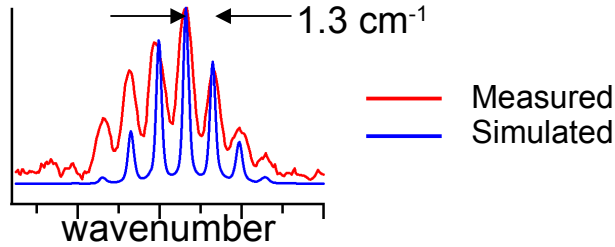
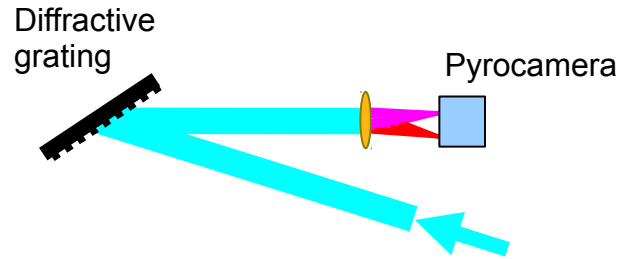
250 MeV

### “Streak camera”



- :) Single-shot
- :( Low resolution (~10 ps)
- :) Train measurements

### “Spectrometer”



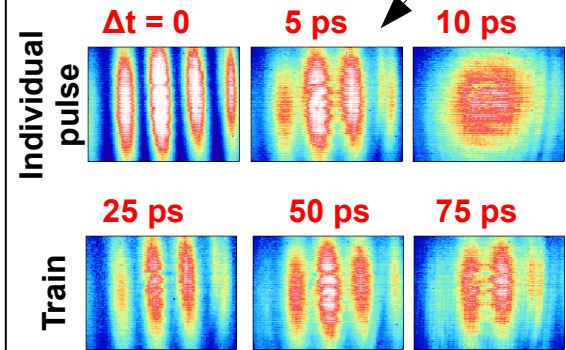
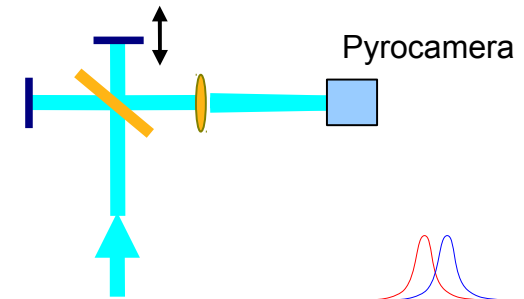
Fourier transform

Total bandwidth  $\Leftrightarrow$  Individual pulse  
sub-ps resolution

Individual lines  $\Leftrightarrow$  Train  
resolution improvement needed

- :) Single-shot
- :) Simple = reliable
- :) Individ. pulse measurements
- ... Train measurements (?)
- :( Indirect method

### “Interferometer”



- :( Multiple-shot
- :) Individ. pulse measurements
- :) Train measurements
- :( Complicated data analysis

Past: 0.5 TW  
2 x 5 ps  
5 J  
1 MeV

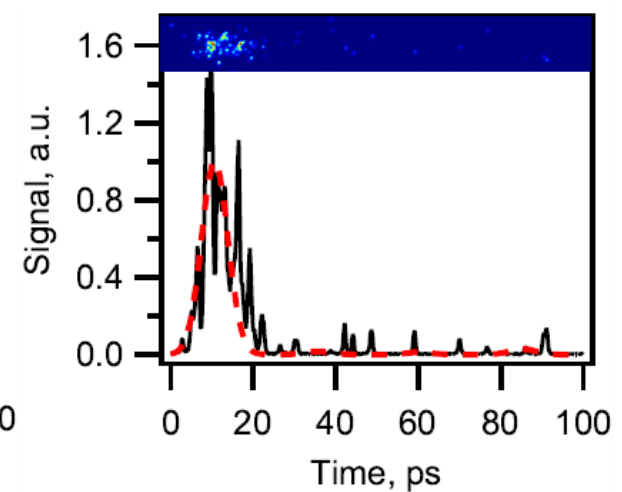
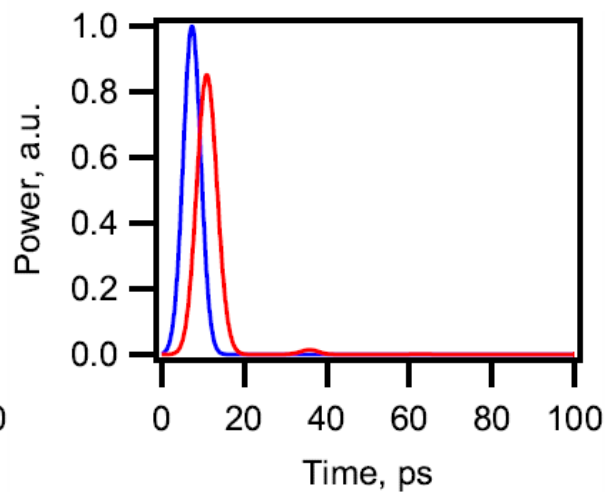
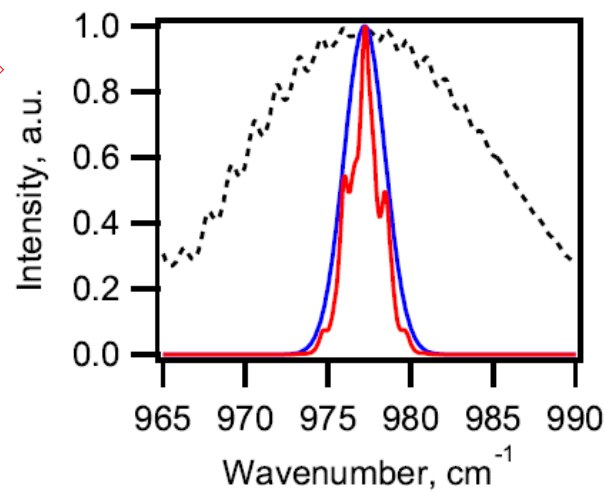
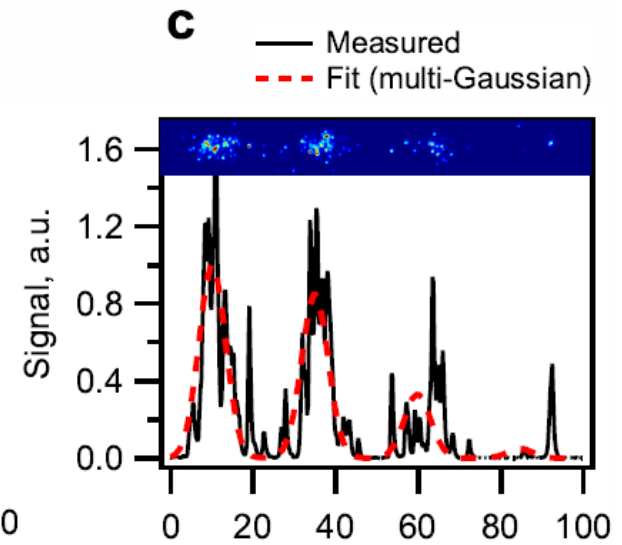
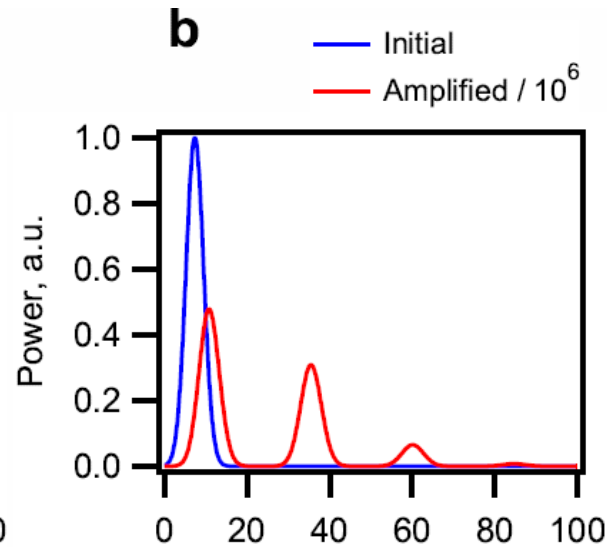
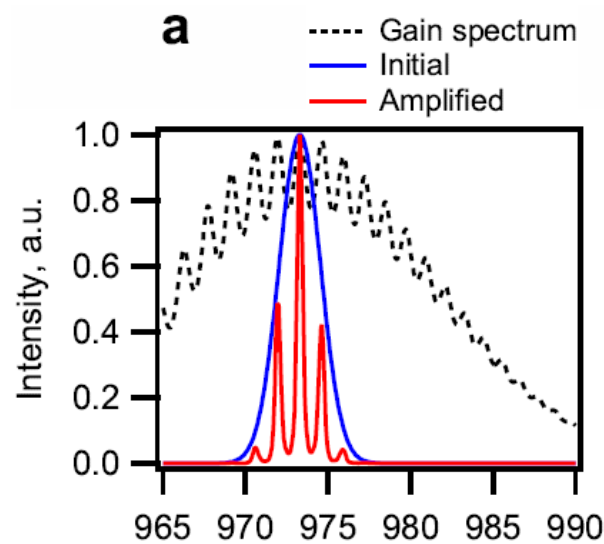
Present: 1 TW  
5 ps  
5 J  
3 → 5 MeV

Near future: 5 TW  
2 ps  
10 J  
25 MeV

Future: 50 TW  
0.5 ps  
25 J  
250 MeV

### Simulations

### Experiment



Natural CO<sub>2</sub>

Isotopic CO<sub>2</sub>

Past: **0.5 TW**

2 x 5 ps  
5 J

1 MeV

Present: **1 TW**

5 ps  
5 J

3 → 5 MeV

Near future: **5 TW**

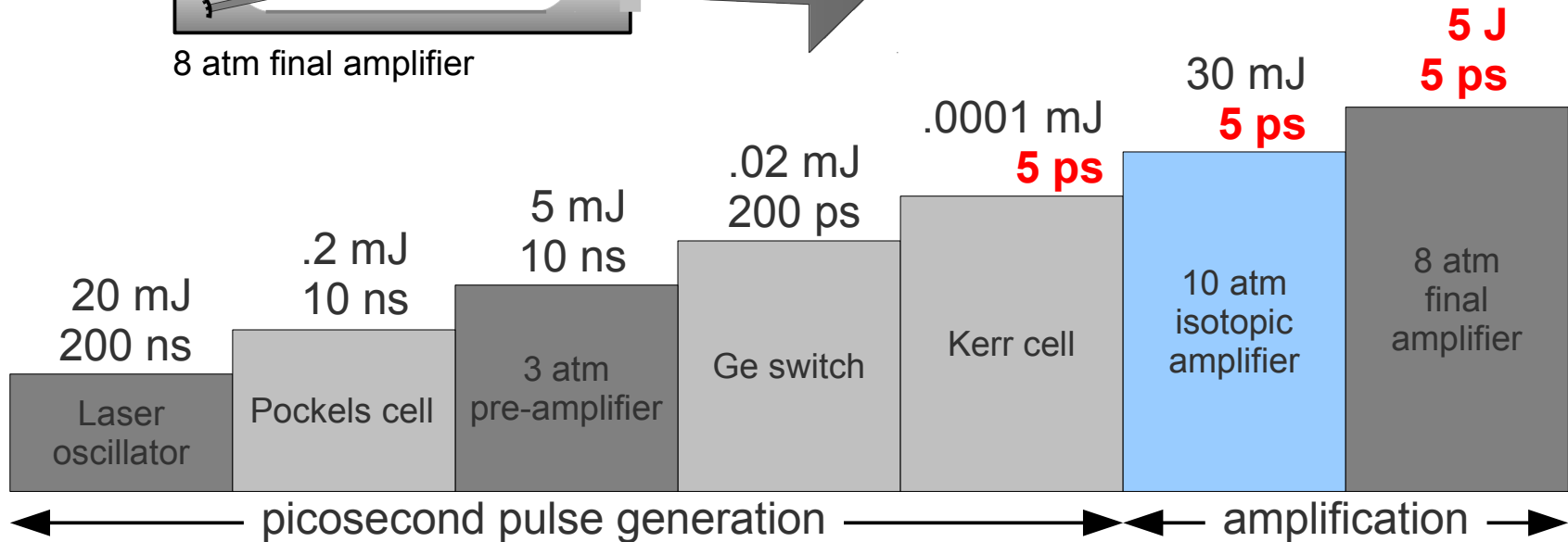
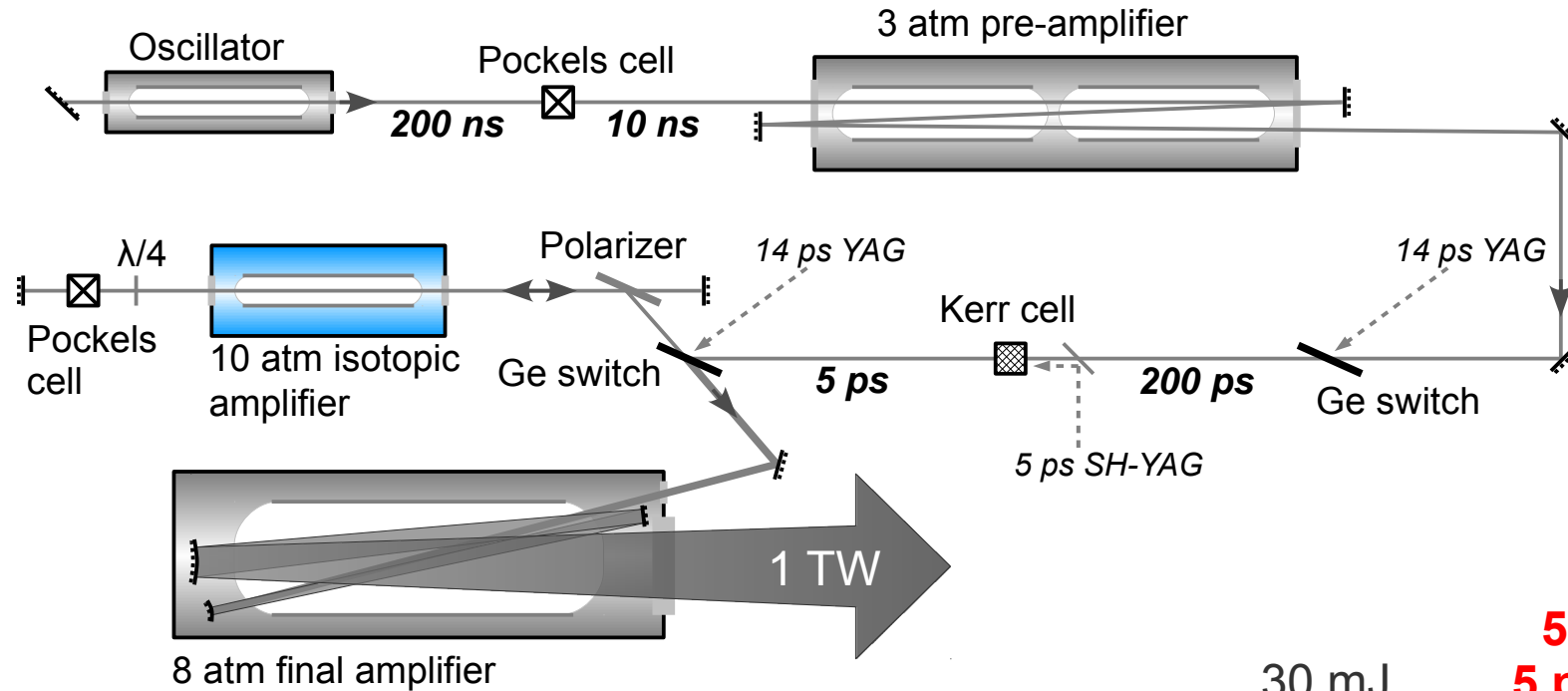
2 ps  
10 J

25 MeV

Future: **50 TW**

0.5 ps  
25 J

250 MeV





Past: **0.5 TW**

2 x 5 ps  
5 J

1 MeV

Present: **1 TW**

5 ps  
5 J

3 → 5 MeV

Near future: **5 TW**

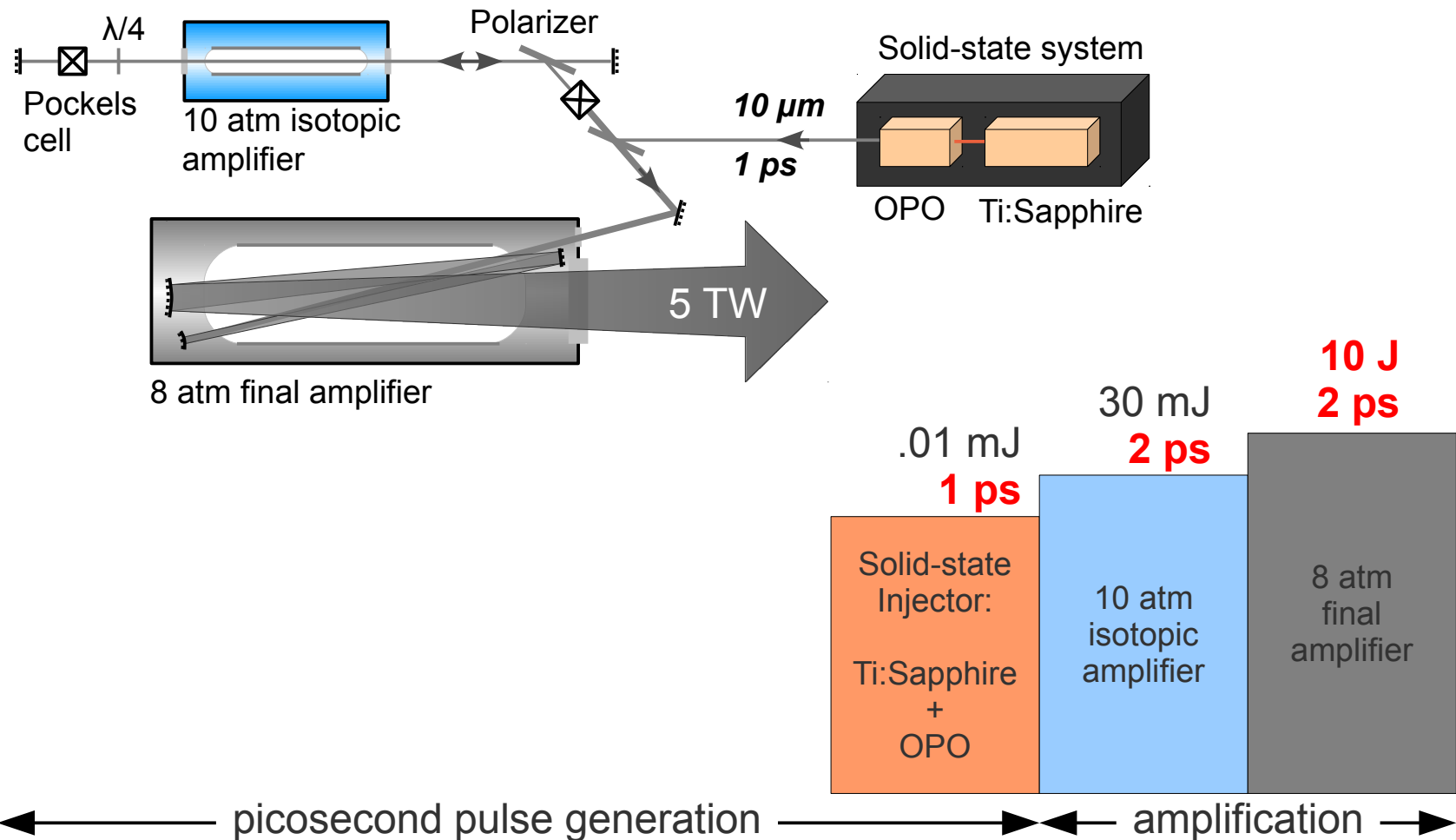
2 ps  
10 J

25 MeV

Future: **50 TW**

0.5 ps  
25 J

250 MeV



Past: **0.5 TW**

2 x 5 ps  
5 J

1 MeV

Present: **1 TW**

5 ps  
5 J

3 → 5 MeV

Near future: **5 TW**

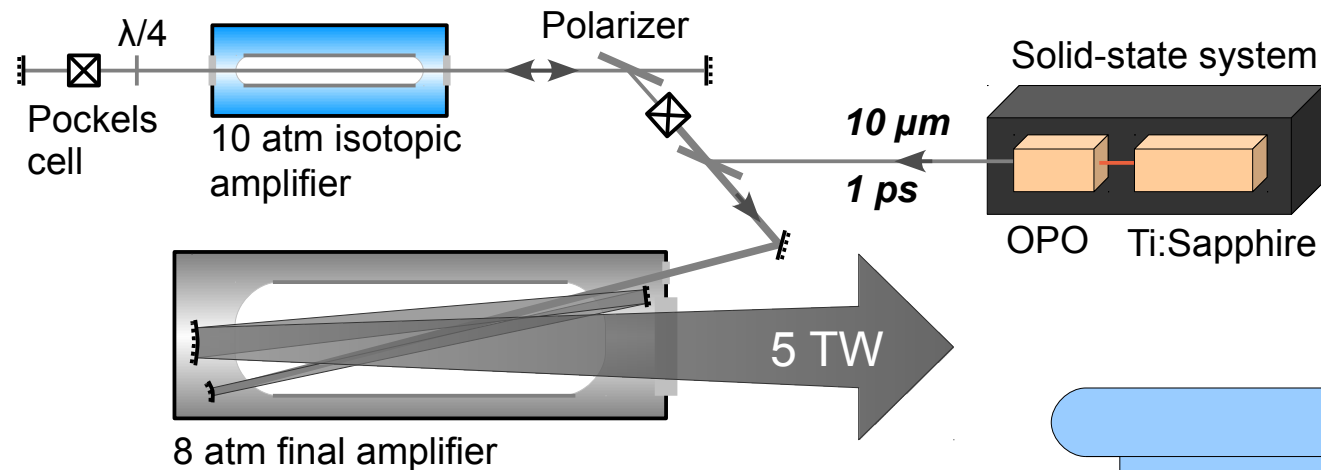
2 ps  
10 J

25 MeV

Future: **50 TW**

0.5 ps  
25 J

250 MeV



Delivery: **Feb. 2011**

- \*\*\*
- *Shorter* injected pulse
  - Higher pulse *contrast*
  - Better *stability*
  - *Simpler* operation

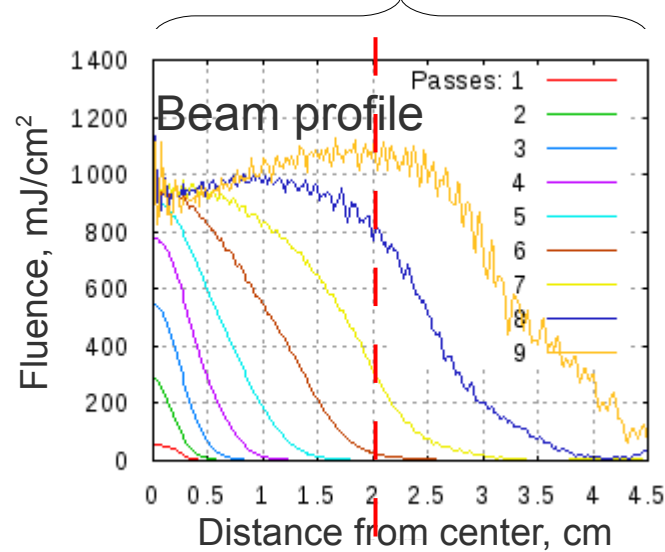
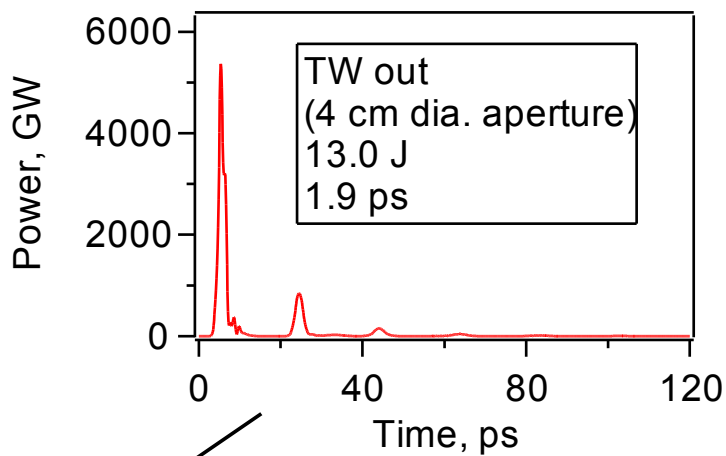
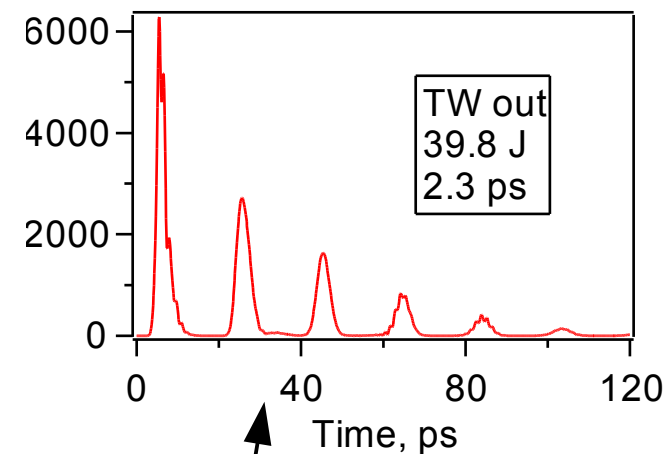
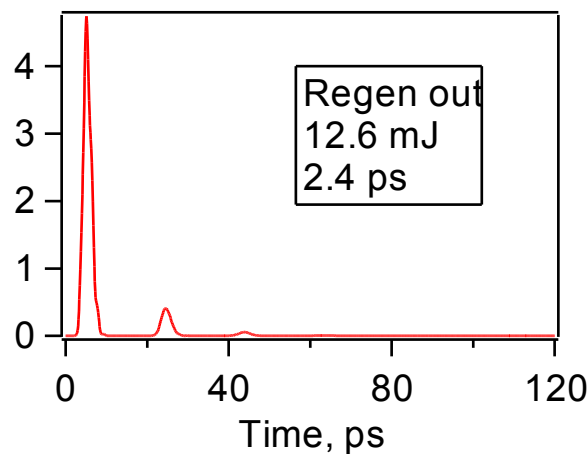
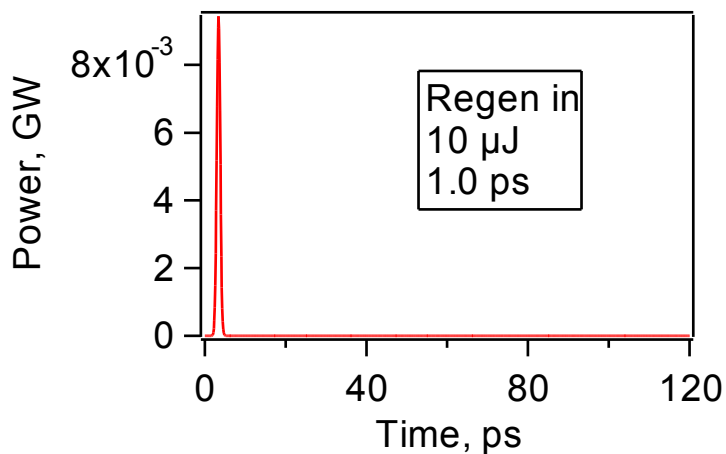
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**1 MeV**

Present: **1 TW**  
5 ps  
5 J  
**3 → 5 MeV**

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**250 MeV**

## Simulations



Pulse shortening due to Stark effect  
in high intensity laser field

Past: **0.5 TW**  
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1 MeV

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0.5 ps  
25 J  
250 MeV

Stark effect based approach

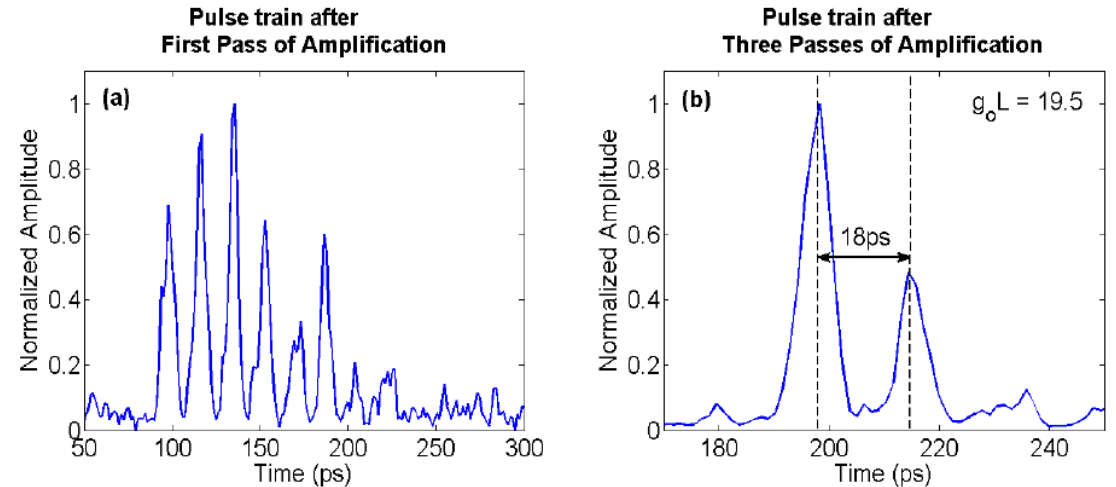
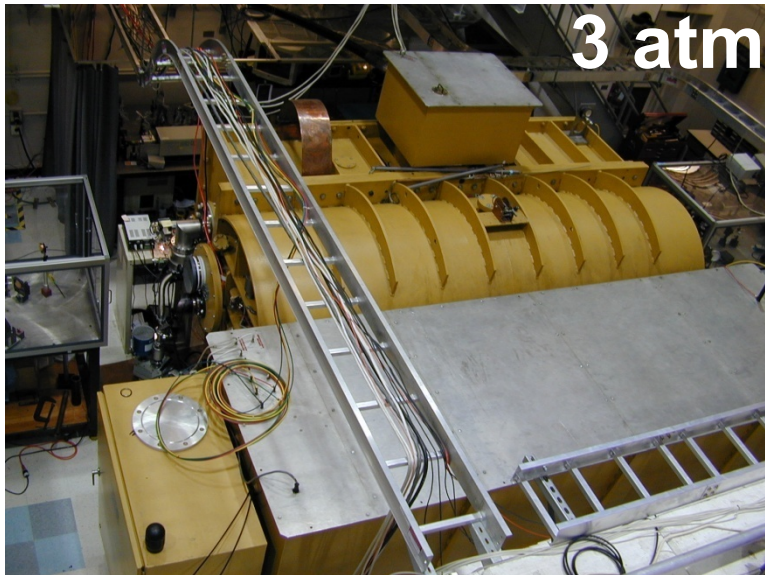


Fig. 6. Temporal profiles of the CO<sub>2</sub> pulses after amplification in the first pass of the final amplifier (a), and all three passes of the final amplifier (b) as measured by the Hadland Photonics (Imacon 500) streak camera.

UCLA

$$45 \text{ J} / 3 \text{ ps} = 15 \text{ TW}$$

D. Haberberger, S. Tochitsky, and C. Joshi. Fifteen terawatt picosecond CO<sub>2</sub> laser system. *Optics Express*, 18:17865–17875, 2010. doi:10.1364/OE.18.017865.

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2 x 5 ps  
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1 MeV

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5 ps  
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2 ps  
10 J

25 MeV

Future: **50 TW**

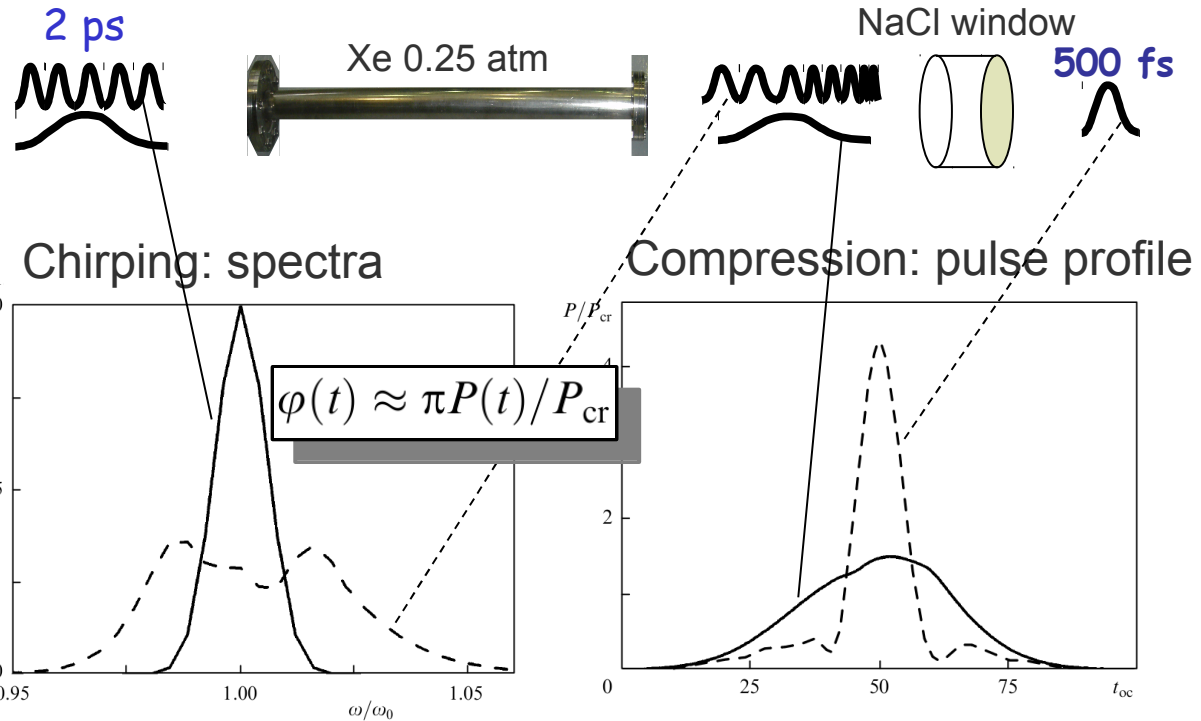
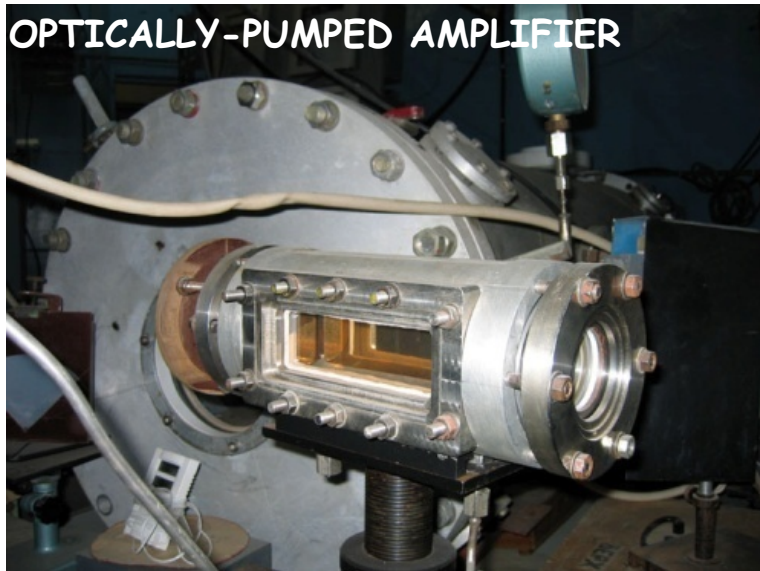
0.5 ps  
25 J

250 MeV

Towards sub-PW...

Additional amplification stage  
and/or laser pulse plasma  
chirping/compression

OPTICALLY-PUMPED AMPLIFIER



Laser-induced ionization shifts phase of the wave resulting in a chirp. Subsequent pulse compression results in 3~4 times pulse shortening.

V. M. Gordienko, V. T. Platonenko and A. F. Sterzhantov. Self-action of a high-power 10- $\mu\text{m}$  laser radiation in gases: control of the pulse duration and generation of hot electrons. *Quantum Electronics*, 39:663-668, 2009. [doi:10.1070/QE2009v039n07ABEH014090](https://doi.org/10.1070/QE2009v039n07ABEH014090).

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0.5 ps  
25 J

250 MeV

## Summary

- Using isotopic  $CO_2$  mixture we eliminated pulse splitting
- Solid state injection will allow to:
  - shorten pulse duration
  - improve pulse contrast
  - reduce downtime
- Possible paths to sub-PW regime being investigated