Progress at BNL on the Linac Compton source Design

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Outline

- Physics motivations (Compton source is needed due to experimental program)
- Linac-CO_2 based source (Overview and numbers)
- Laser cavity (R&D program)
- CO2 laser cavity simulations (Attempts to explain experimental data and predict optimal laser cavity)

Outcomes of first results from LHC

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- There are several possible scenarios that call for different ILC energy depending upon the results of LHC measurements of M_H:
  - 115GeV<M_H<160GeV. In this scenario the ILC could give precision measurements of the Higgs parameters through the $ee \rightarrow Z_H$ channel that requires operation in the center-mass energy range M_Z+M_H=205-250 GeV.
  - 160GeV<M_H <200GeV. The main decay mode is then WW, which is comfortable for the LHC; the ILC would not contribute much in this case.
  - M_H >200GeV. This would require the ILC's precision to resolve contradiction with existing LEP-SLC-Tevatron measurements; the ILC should start operations at ~100 GeV –well below the wiggler-based ILC design energy.

Relevant Energy Thresholds

Did positron source set ILC energy?

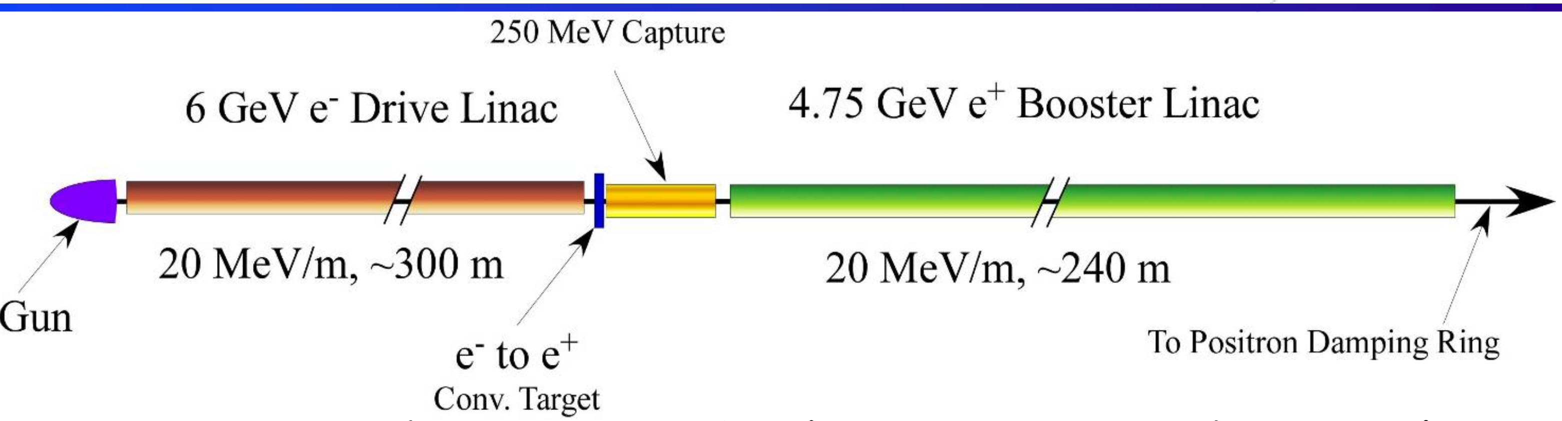
- There are several relevant energy thresholds to be considered: M_Z=91 GeV for Z-boson mass, Higgs mass M_H<200 GeV as is tentatively implied from LEP-SLC-Tevatron measurements, and M_H~350 GeV for Top-quark studies.
- Both Higgs and Top-quark studies do not require 0.5 TeV center-mass energy.
- 150-GeV linac is required before the wiggler for positron production, the 100-GeV linac after the wiggler should be used to decelerate electrons in order to conduct experiments aimed to the Z-boson.
- Compton-based source which is completely independent of the main ILC can optimally fit experimental needs .

Time flexibility

- Who is going to build ILC if it is not going to be build in the next 15 years?
- SuperB factory might be build before ILC and needs very similar beams to ILC
- Staged ILC approach possible with Compton:
  - Injection complex and SuperB
  - M_Z collider at 50GeVx 50GeV
  - M_H collider at 175GeVx 175GeV
  - ILC at at 500GeVx 500GeV

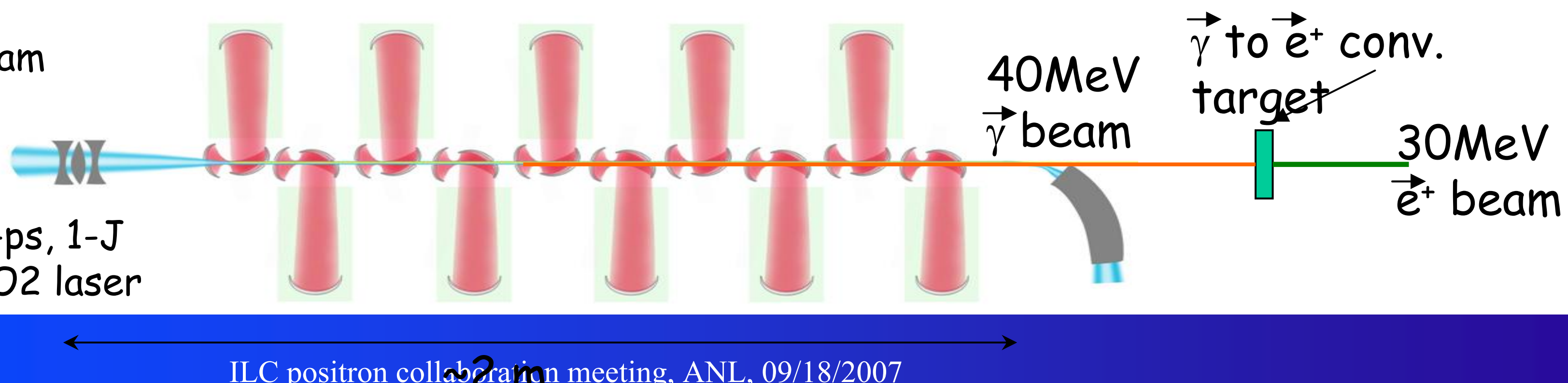
Polarized Positrons Source

Conventional Non-Polarized Positrons:



In the proposal

- Polarized γ-ray beam is generated in Compton backscattering inside optical cavity of CO_2 laser beam and 4 GeV e-beam produced by linac.
- The required intensities of polarized positrons are obtained due to 10 times increase of the "drive" e-beam charge (compared to non polarized case) and 5 to 10 consecutive IPs.
- Laser system relies on commercially available lasers but need R&D on a new mode of operation.
- 5ps, 10J CO_2 laser is operated at BNL/ATF.



Linac Compton Source (LCS): Numbers

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e- beam energy	4 GeV
e- bunch charge	10nC
RMS bunch length (laser & e^- beams)	3 ps
γ beam peak energy	30 MeV
Number of laser IPS	10(5)
Total $N\gamma/Ne^-$ yield (in all IPs)	10(5)
$Ne^+/N\gamma$ capture	2% (4%)
Ne^+/Ne^- yield	0.2
Total e^+ yield	2nC
# of stacking	No stacking

Proposal numbers are in black, Optimistic numbers are in Red

CO_2 Laser system for ILC PPS

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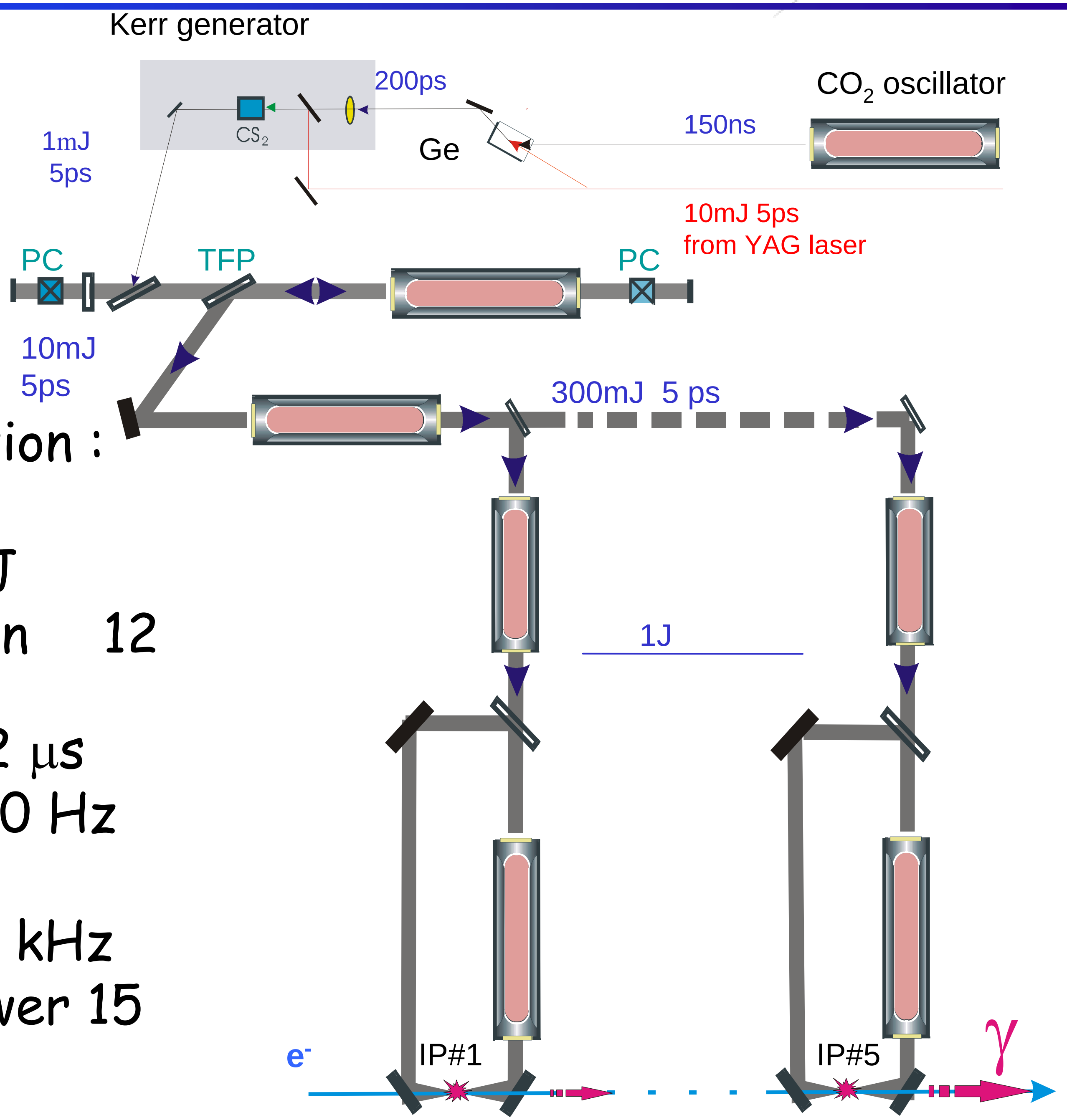

intra-cavity pulse circulation :

- pulse length 5 ps
- energy per pulse 1 J
- period inside pulse train 12 ns
- total train duration 1.2 µs
- train repetition rate150 Hz

- Cumulative rep. rate 15 kHz
- Cumulative average power 15 kW

Excimer laser convertible to CO_2

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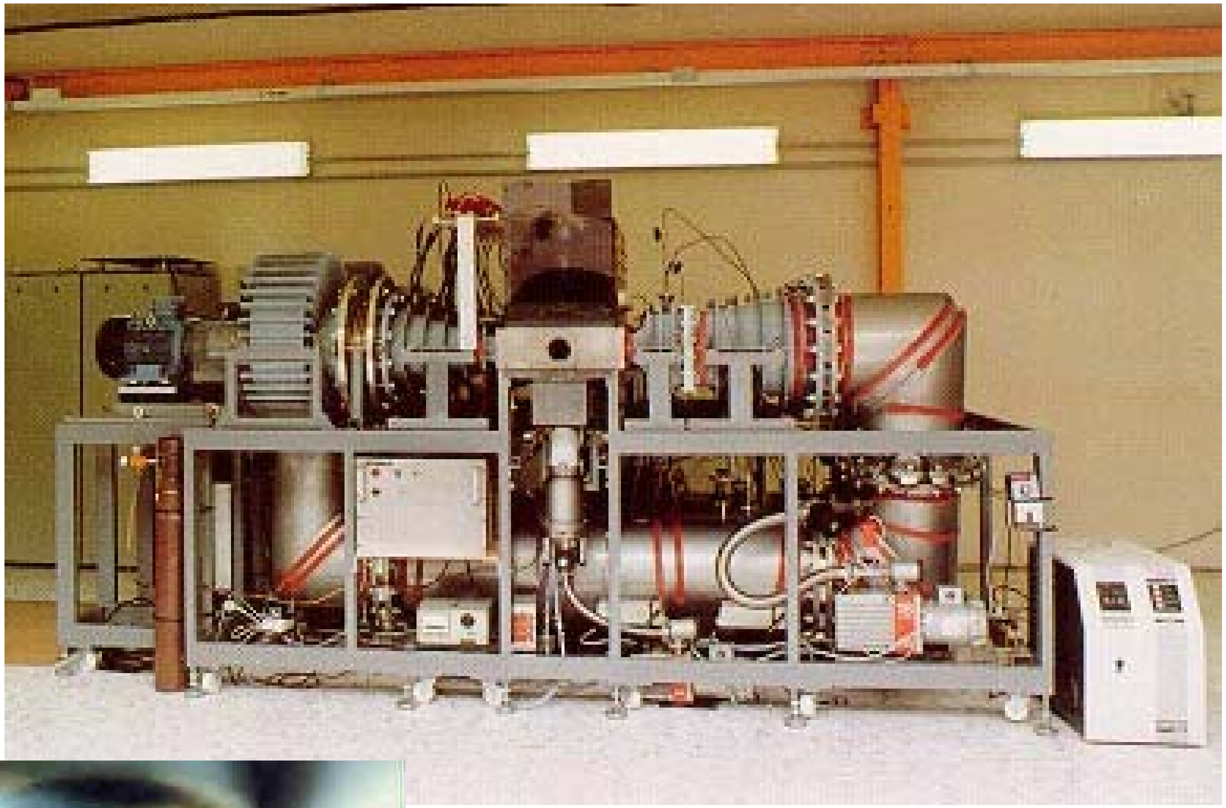
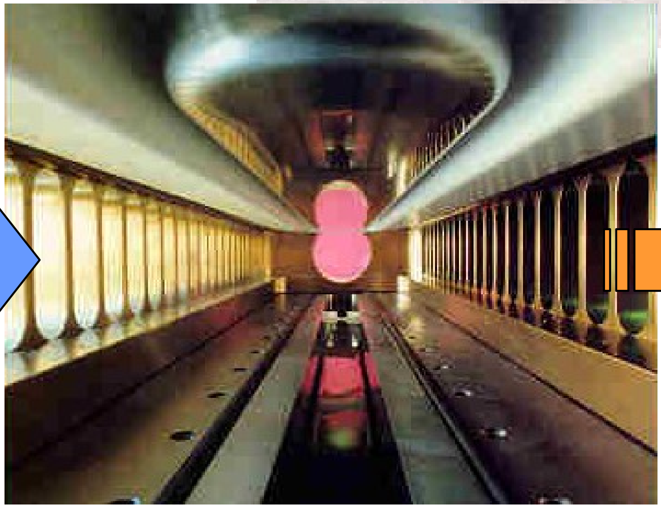
France

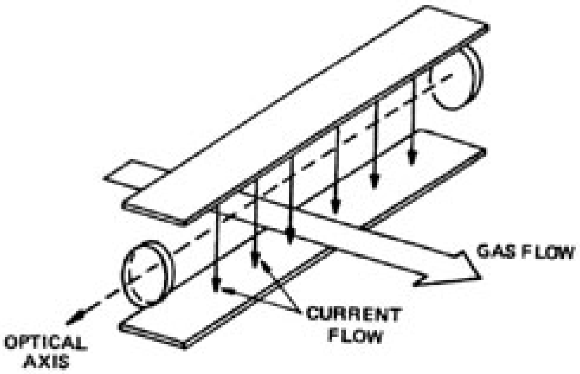
SOPRA



10 J per pulse,
100 Hz repetition rate,
1 kW average power
Price ~5 M$

gas flow

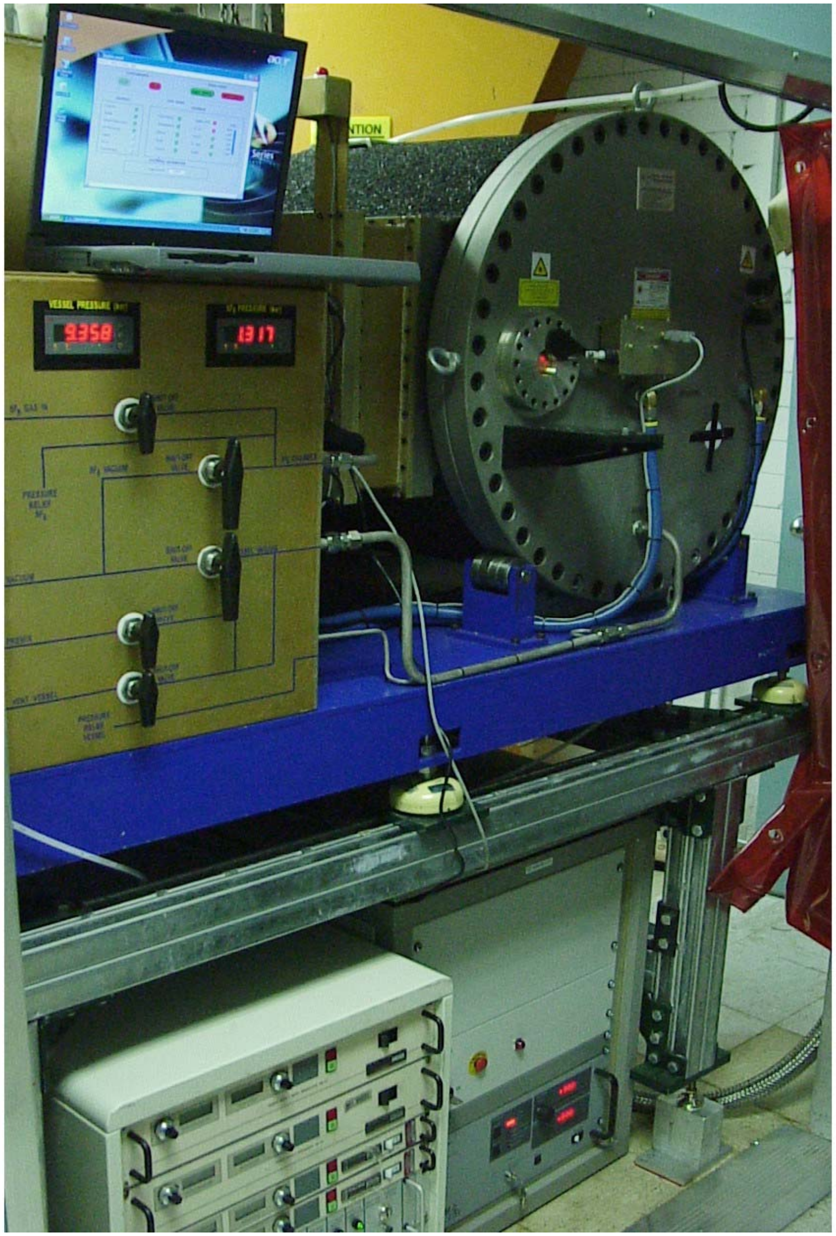




Commercially available high-pressure CO_2 lasers

SCIENTIFIC DEVELOPMENT & INTEGRATION (PTY) LTD

Repetition Rate	20 -500 Hz
Pulse Energy	1.5 J
Beam Size	13 x 13 mm^2
Average Power	750 W
Price	~ 0.5-1.5M$



Collaboration with SDI

Description	HP5/10	HP150/10	HP150/5
Gain (%)	2	~2	~2
Maximum rep. rate (Hz)	5	~150	~150
Electrodes dimens. (cm)	1x2x80	1x2x80	2x2x80
Maximum press. (atm)	10	~10	~5
Pre-ionisation	UV	UV	UV
Time jitter (1σ)	<10ns	<10ns	<10ns
Power Supply	4kW	24kW	24kW

2 year plan to test CO_2 laser cavity at high rep. rate.

Subjects for R&D at BNL

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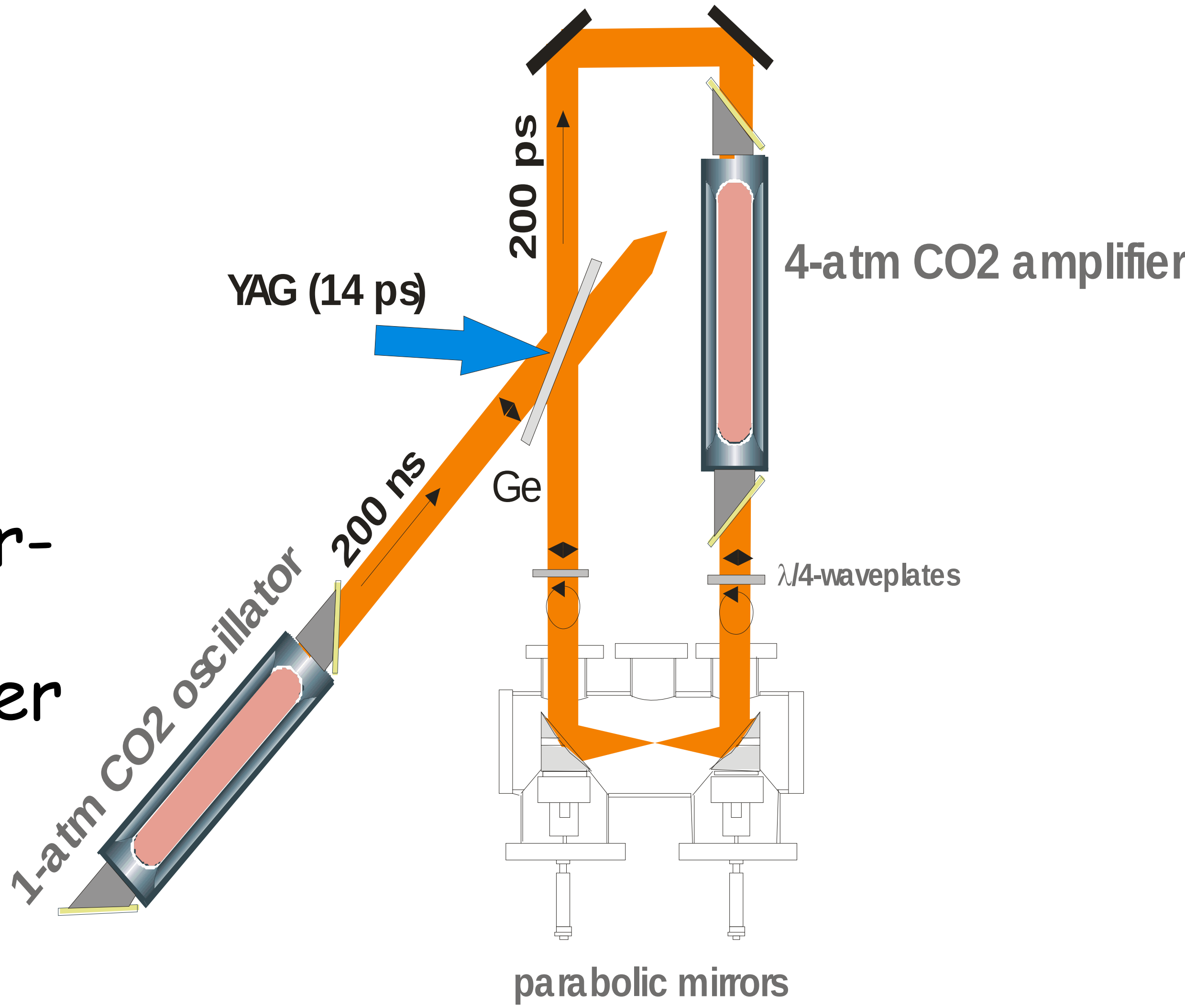
- Optimization of low-loss pulse seeding into the cavity.
- Define requirements to the laser amplifier to support 1-J pulse train.
- Optimization of the amplifier cavity for a uniform pulse train.
- Study optical damage limitations at a high repetition rate.

CO_2 cavity

- Has a potential to increase average intra-cavity power ~100 times at 10.6 microns.

Purpose of the test:

- Demonstration of 100-pulse train inside regenerative amplifier that incorporates Compton interaction point.
- Demonstration of linear-to-circular polarization inversion inside the laser cavity.
- Test of the high power injection scheme



CO_2 cavity: Simplified test setup

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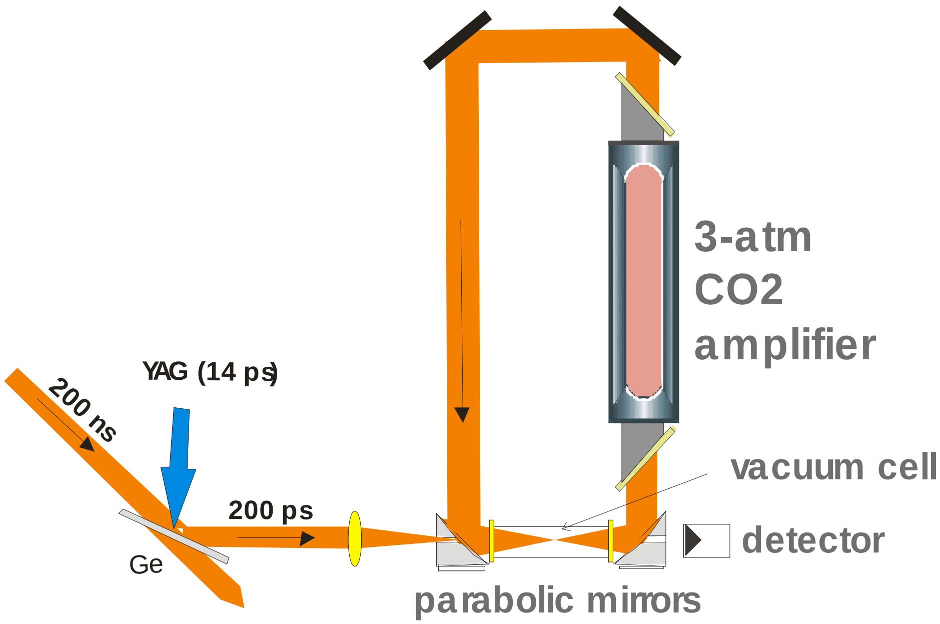
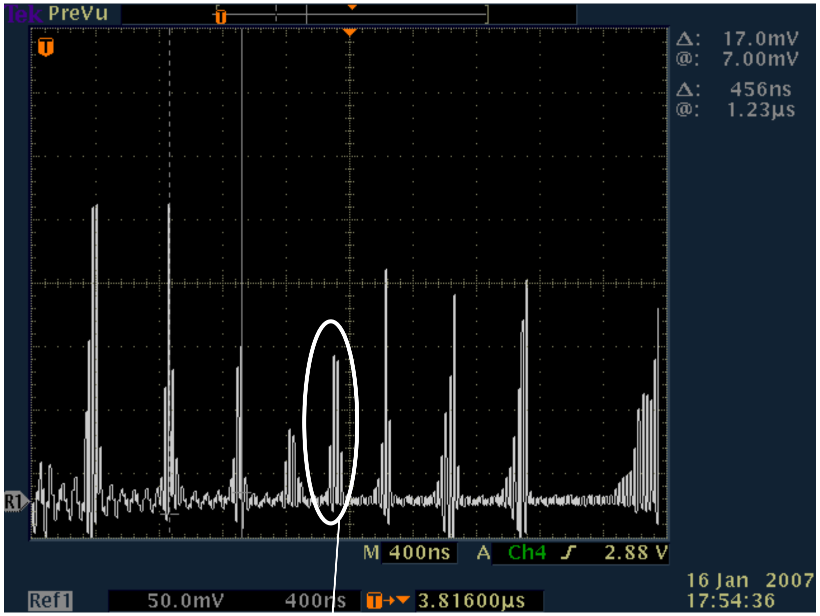
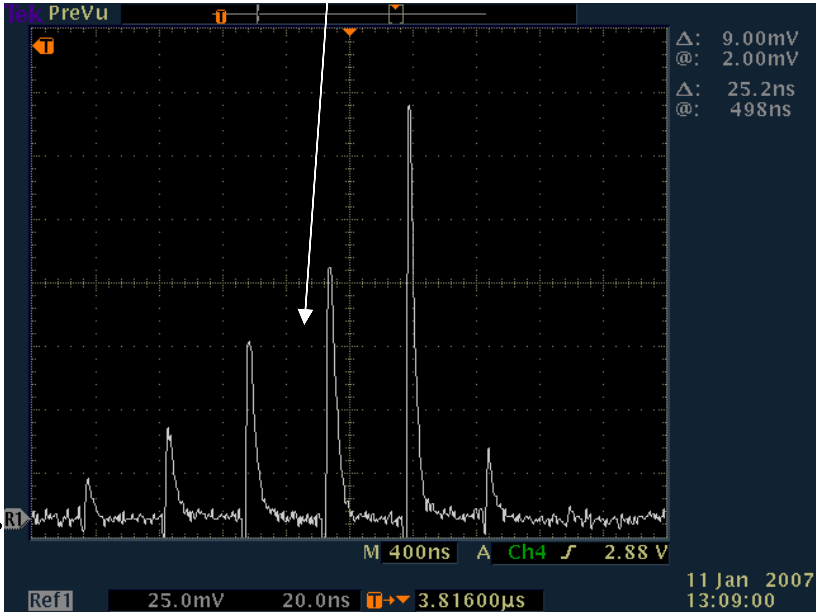




First observations:

- Optical gain over 4 μs
- Misbalanced gain/loss regime results in lasing interruption by plasma
- Single seed pulse amplification continues to the end



The best train uniformity achieved

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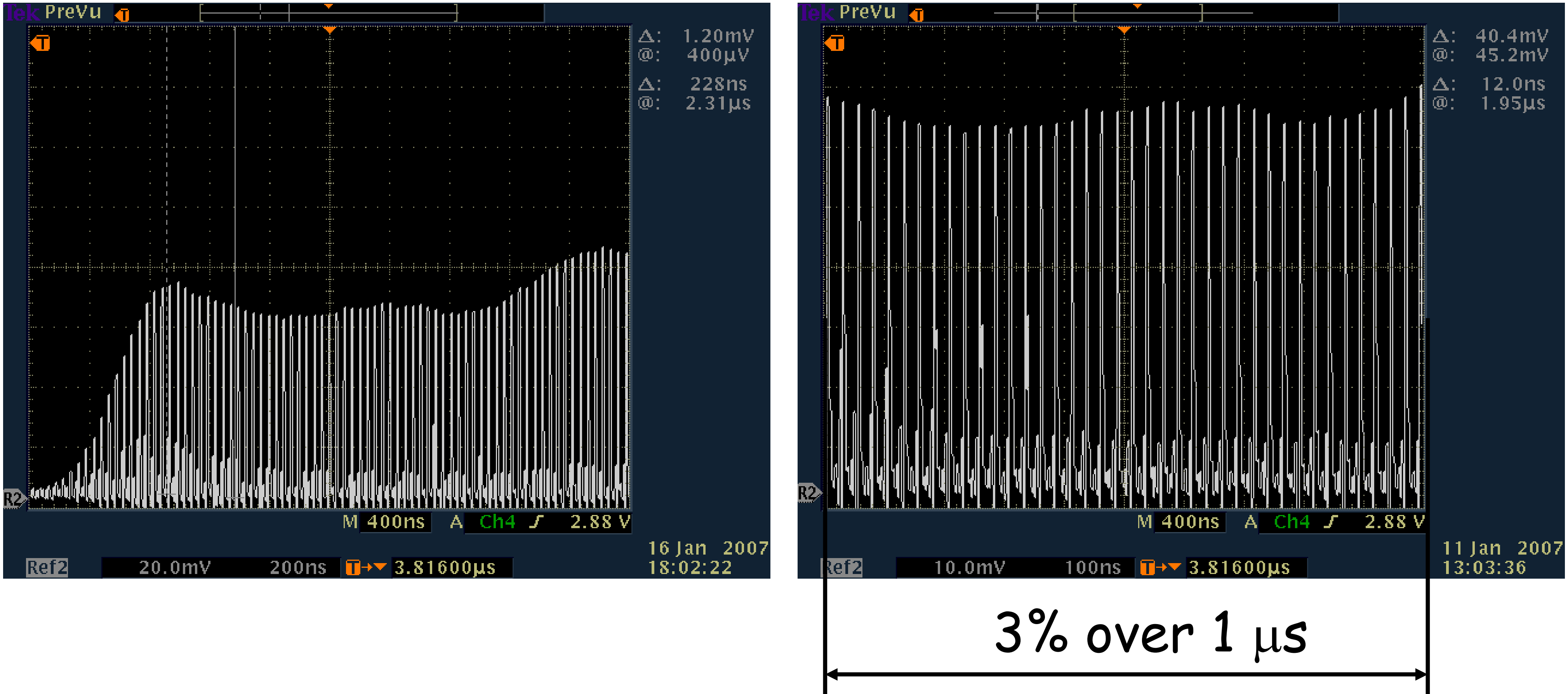
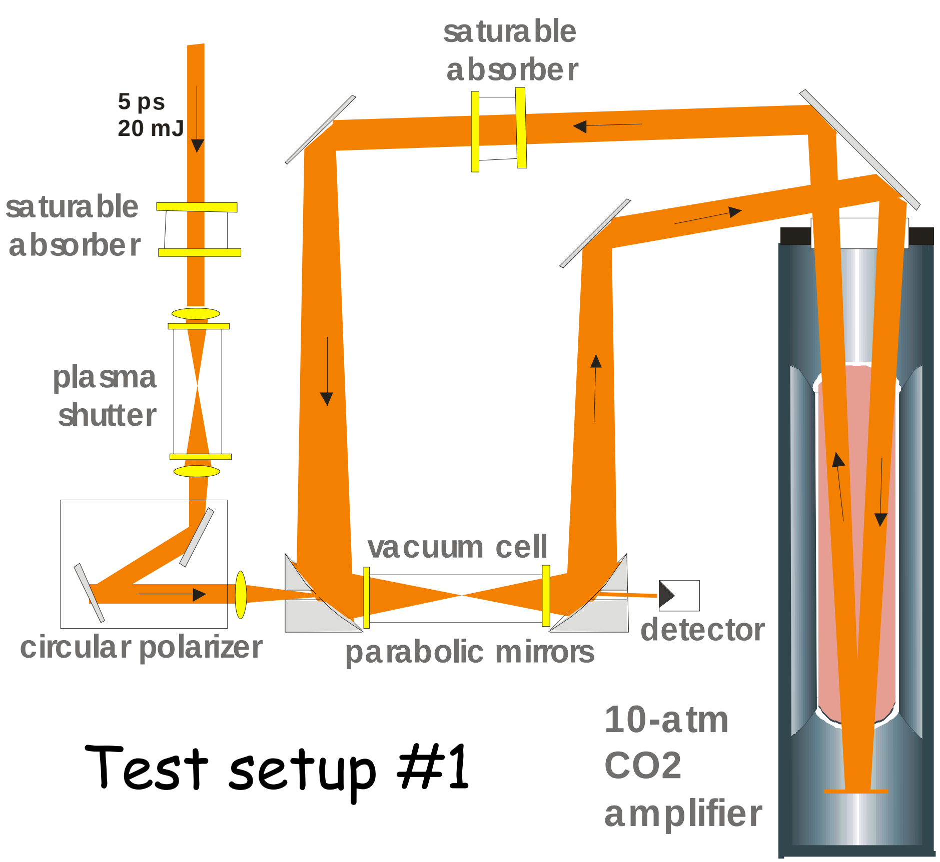


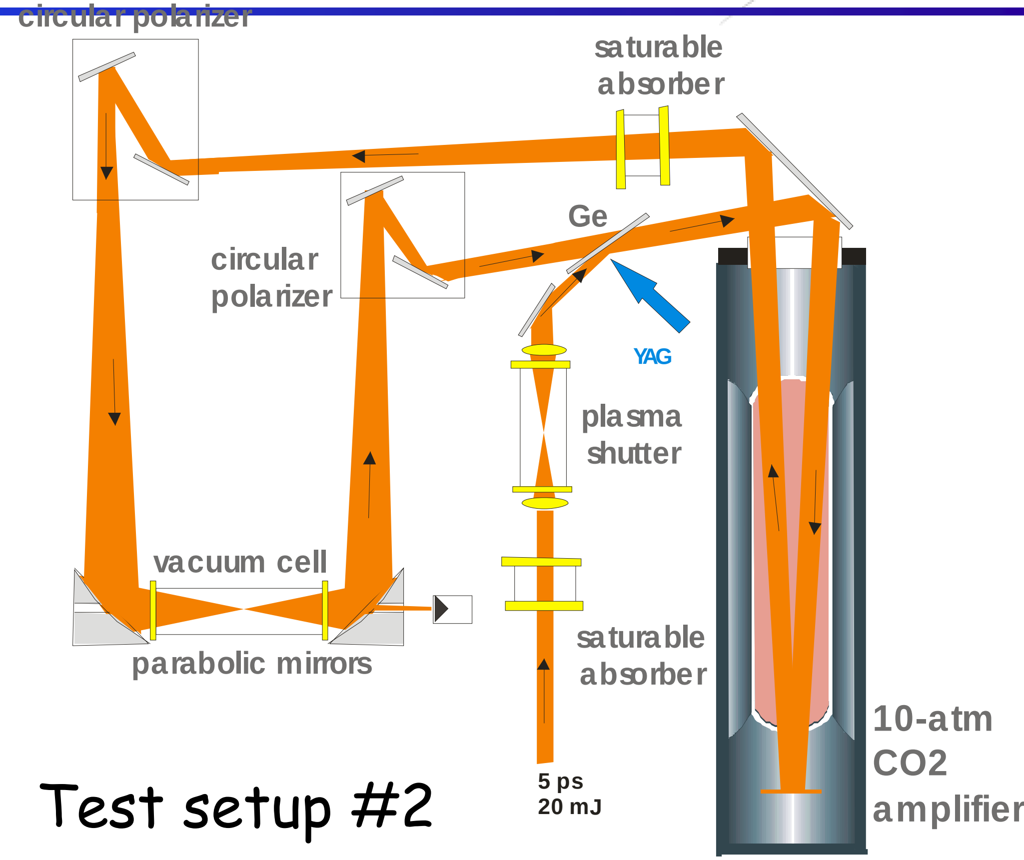
- Very encouraging results obtained with simplified cavity test setup: ~200 ps pulse of the order of 100 mJ circulated for >1 μs.

- Further test would require pulse length monitoring and high pressure or isotope mixture based amplifier (to sustain 5 ps beams).

Compton cavity tests



Test setup #1



Test setup #2

- Simplified scheme
- Injection of circularly polarized beam through a hole in a parabolic mirror in unmatched mode
- Requires using AR transmission windows prompt to optical damage to be explored

- More complex scheme
- Efficient injection of linearly polarized beam via a semiconductor (Ge) optical switch
- Allows using low-damage Brewster windows
- Optical losses and damage thresholds of Ge and circular polarizers to be explored

Assembling multiple interaction points

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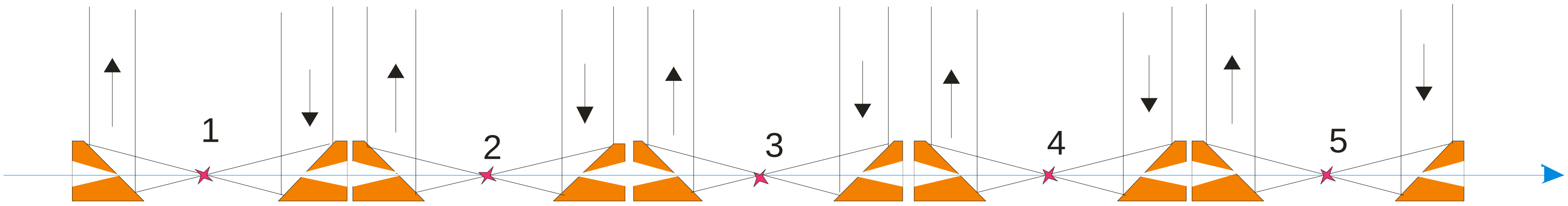
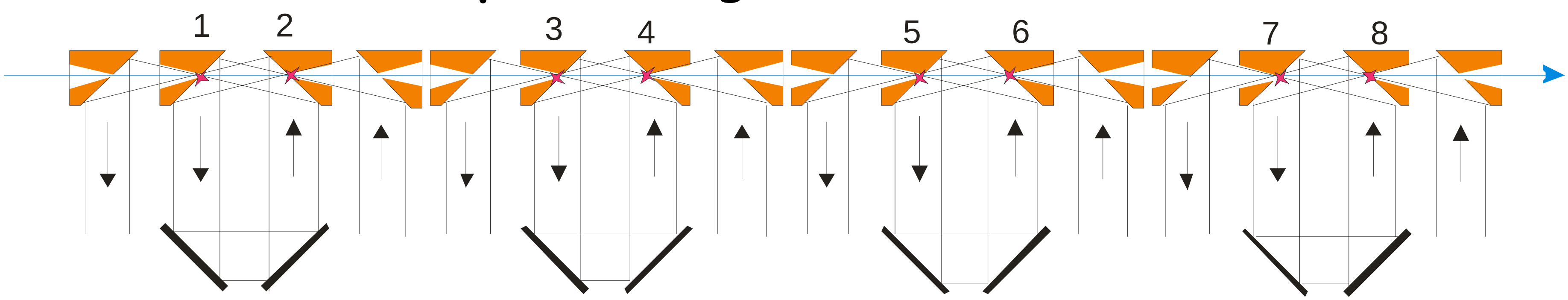
Standard configuration: 5 lasers, 5 IPs



Compact configuration: 4 lasers, 8 IPs



Travel distance between two coupled IPs for the laser pulse is adjusted to interact with two consecutive electron bunches spaces by 12 ns.

Computer modeling of regenerative CO_2 laser amplifier

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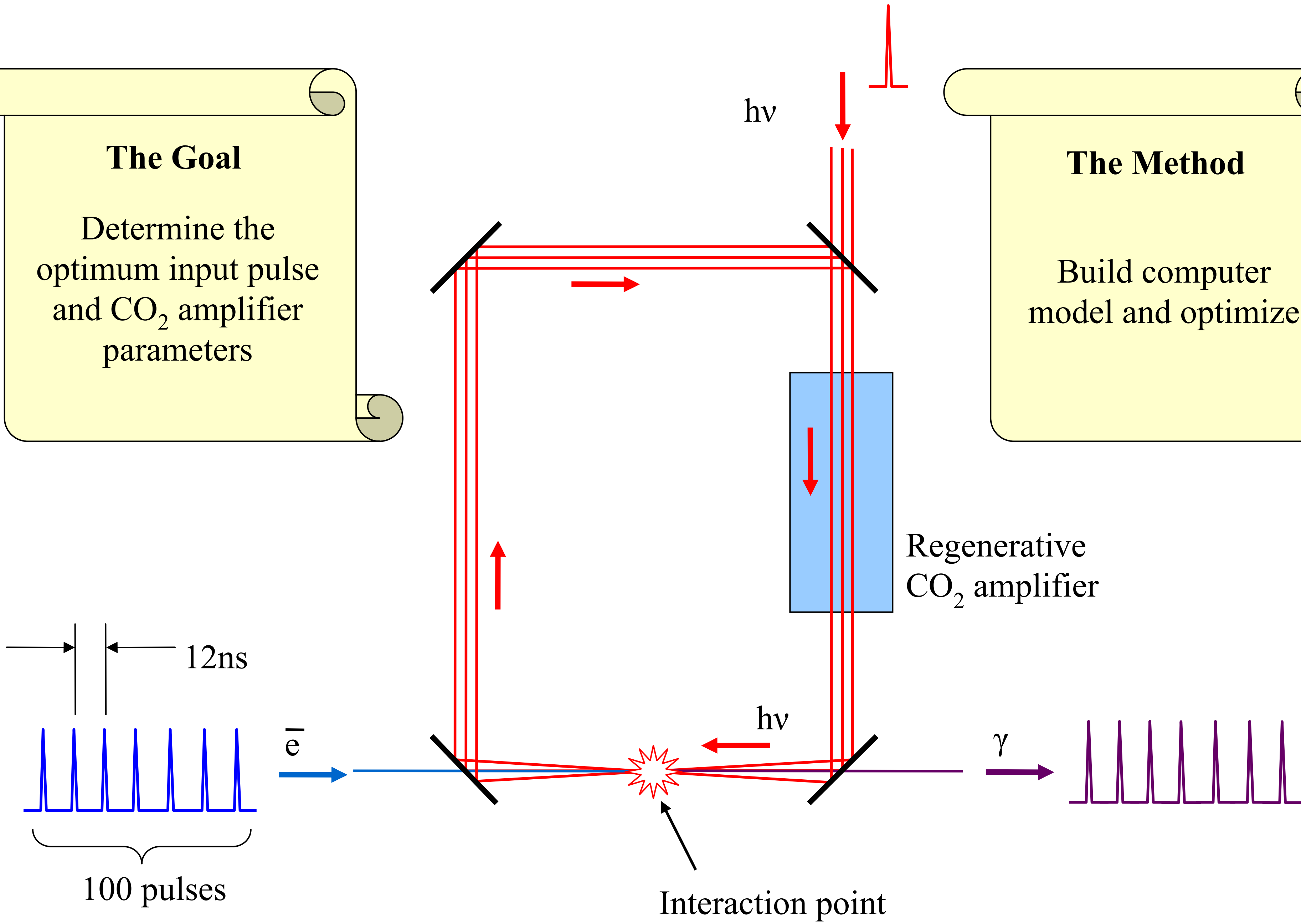
The Goal and The Method

The Goal

Determine the optimum input pulse and CO_2 amplifier parameters

The Method

Build computer model and optimize



CO_2 laser levels, 4-temperature model

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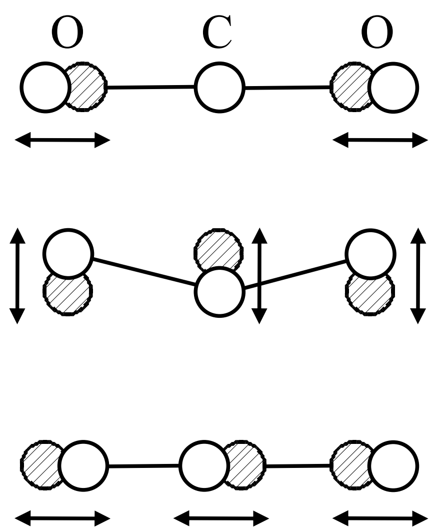
Vibrational modes

CO_2

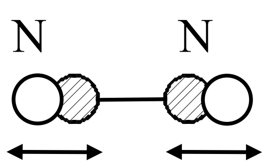


Symmetric stretch ν_1 1388cm^{-1}

Bending ν_2 667cm^{-1}

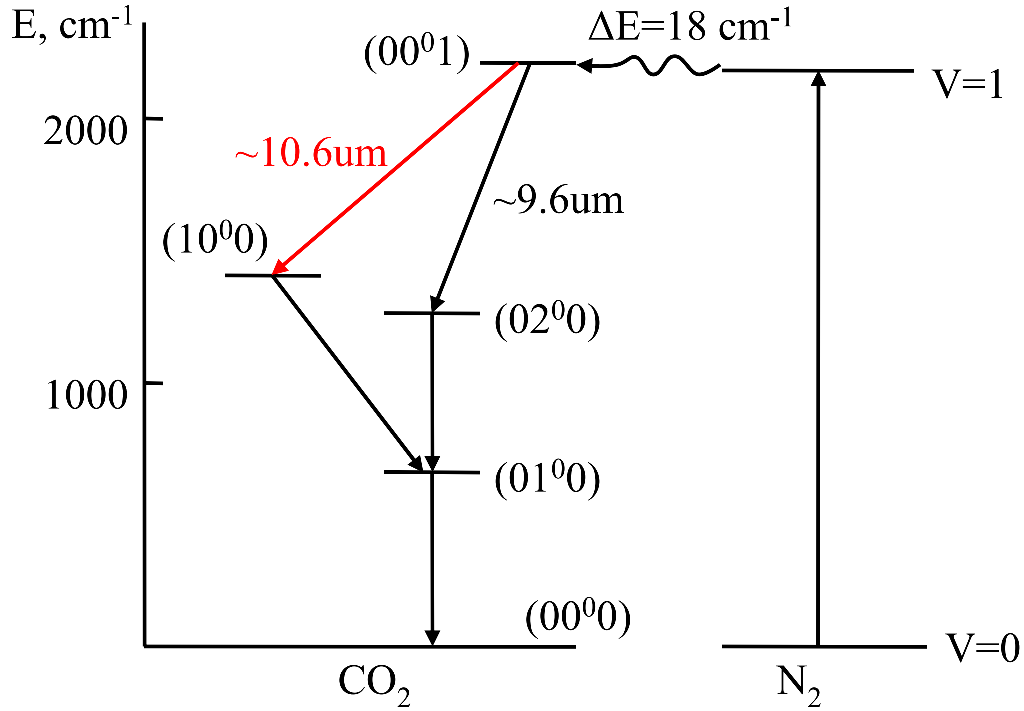
Asymmetric stretch ν_3 2349cm^{-1}

N_2



2331cm^{-1}

Energy level diagram



4-temperature model

T_2: Symmetric stretch and bending CO_2 (coupled by Fermi resonance)

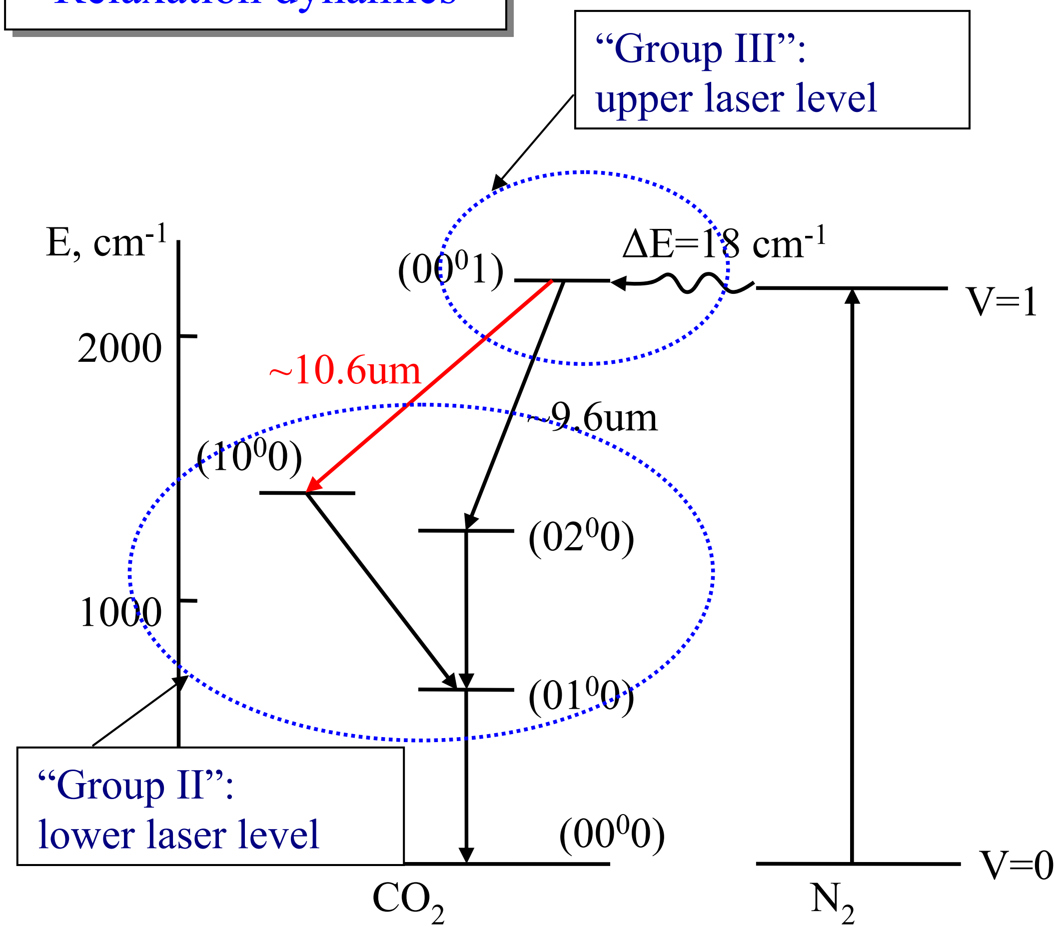
T_3: Asymmetric stretch CO_2

T_4: N_2 vibration

T: Translation and rotation

Dynamics: pumping, relaxation, depletion

Relaxation dynamics

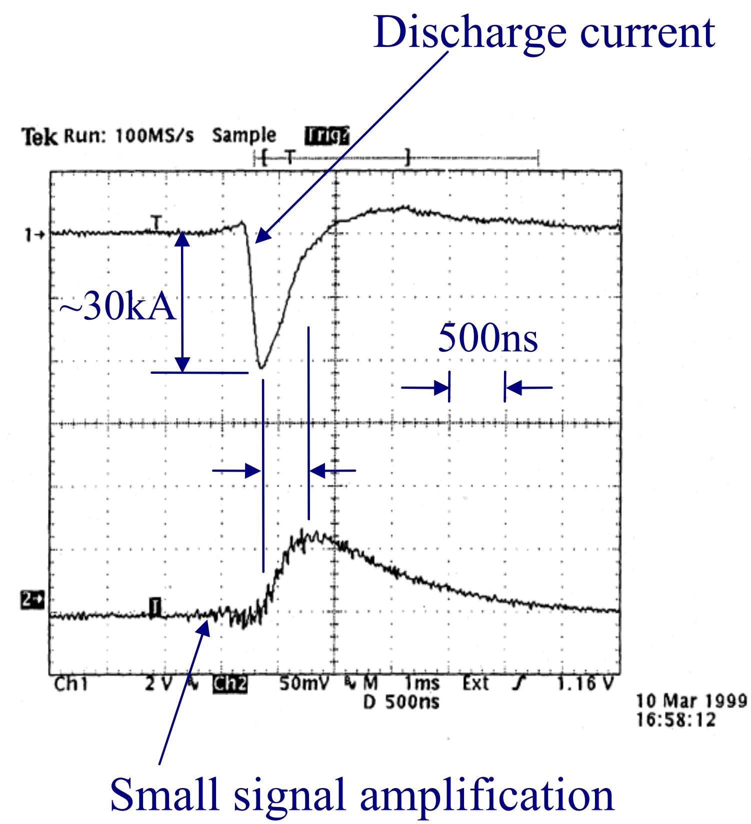


Gas	k_2, torr^{-1}s^{-1}	k_3, torr^{-1}s^{-1}
CO_2	194	350
N_2	650	106
He	3270	85

$k_2 = k_2(T)$, $k_3 = k_3(T)$

T = 300K

Pumping dynamics



Numerical approach

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Main equation

$$2ik\frac{\partial}{\partial z}E = -\nabla_\perp E - 4\pi\frac{\omega^2}{c^2}P,$$

where $$\nabla_\perp = \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}$$

Polarization

$$P = N\sum_j p_j exp(i(\omega - \omega_{R(j-1)})t,$$

N: Number density of CO_2
j: odd numbers enumerating rotational sublevels of level 001
$\omega_{R(j-1)}$:frequency of R(j-1) transition 001-100
p_j: value determined by dipole matrix and density matrix

Numerical equation solving using separating parameters

1) Assuming $E(r,t,z)$ is known for $z<=z_0$, calculate $E(r,t,z_0+\delta z)$ using equation

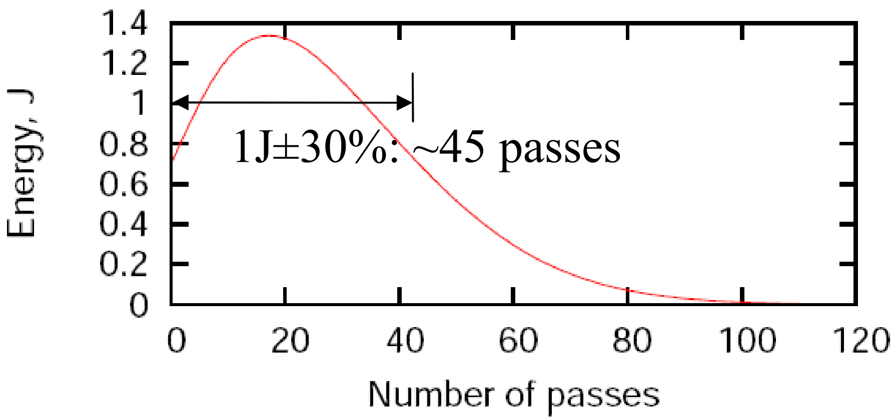
$$2ik\frac{\partial}{\partial z}E = -4\pi\frac{\omega^2}{c^2}P \times 2$$

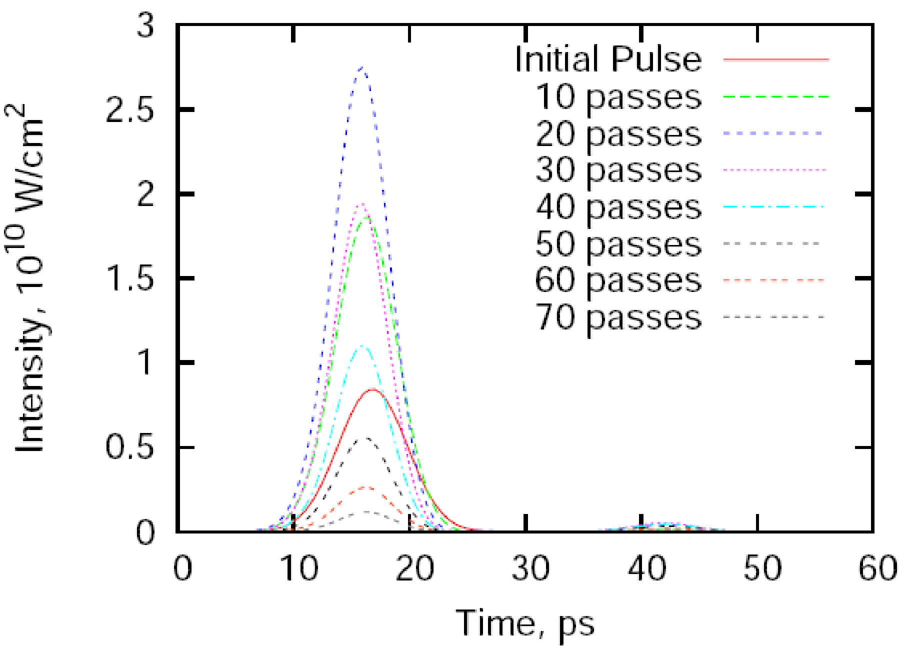
2) Starting from $E(r,t,z_0+\delta z)$, calculate $E(r,t,z_0+2\delta z)$ resolving the equation

$$2ik\frac{\partial}{\partial z}E = -\nabla_\perp E \times 2$$

3) Go to 1)

Preliminary results: "instant" pumping

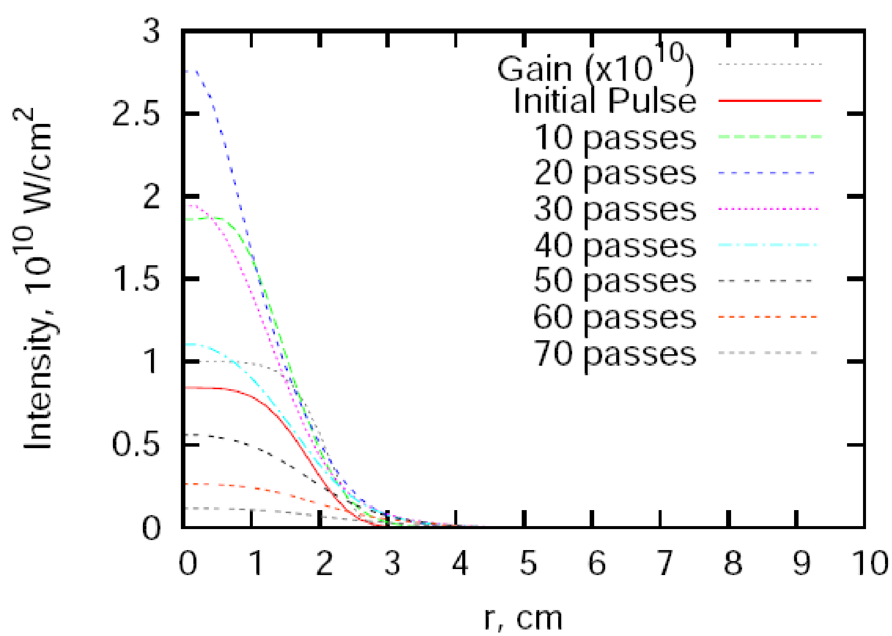




- Initial state of the active medium is determined by specifying the temperatures in 4-temperature model

- No pumping during amplification

- Only relatively short period of constant pulse energy is achievable



Preliminary results: “realistic” pumping

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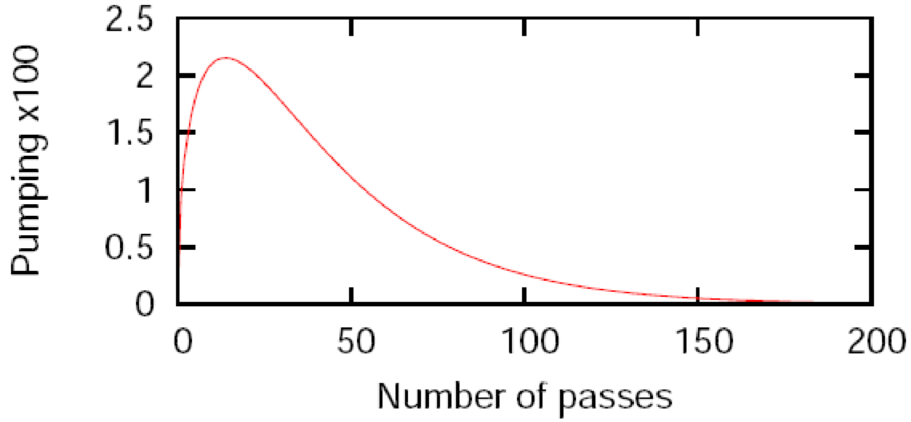
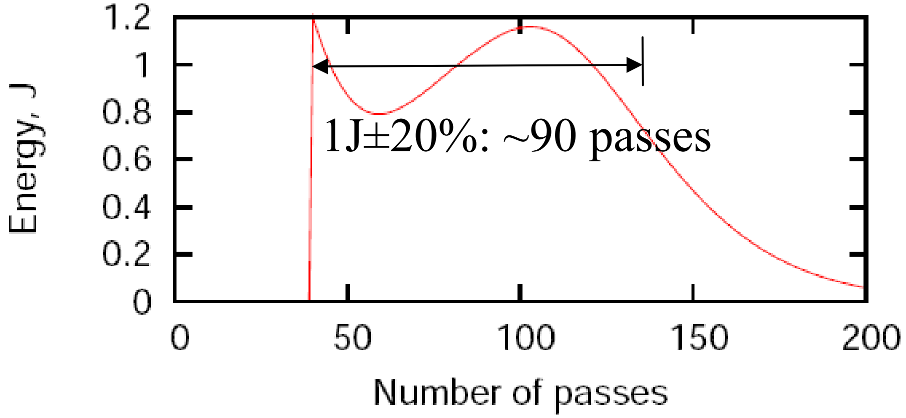
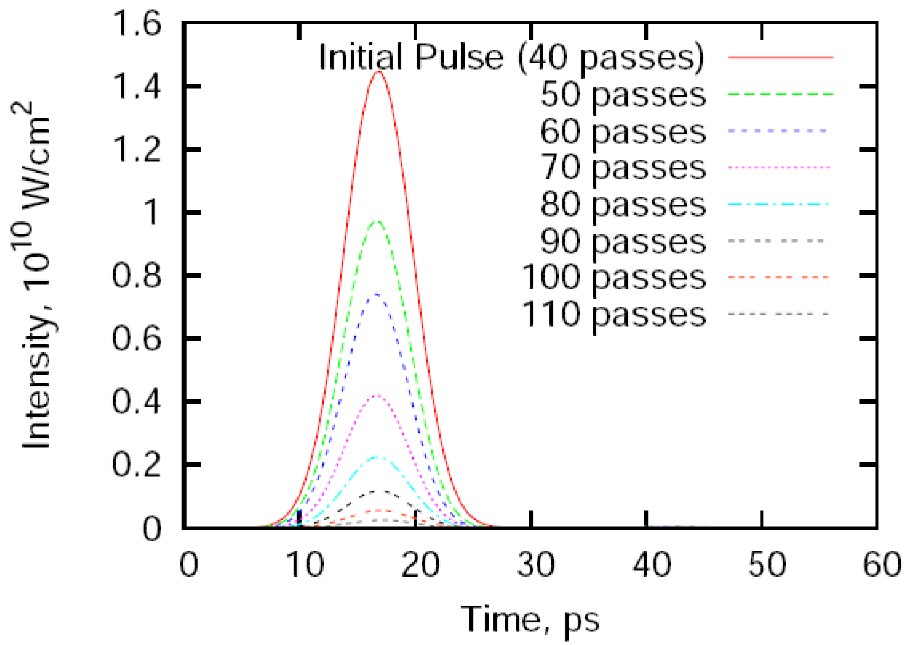
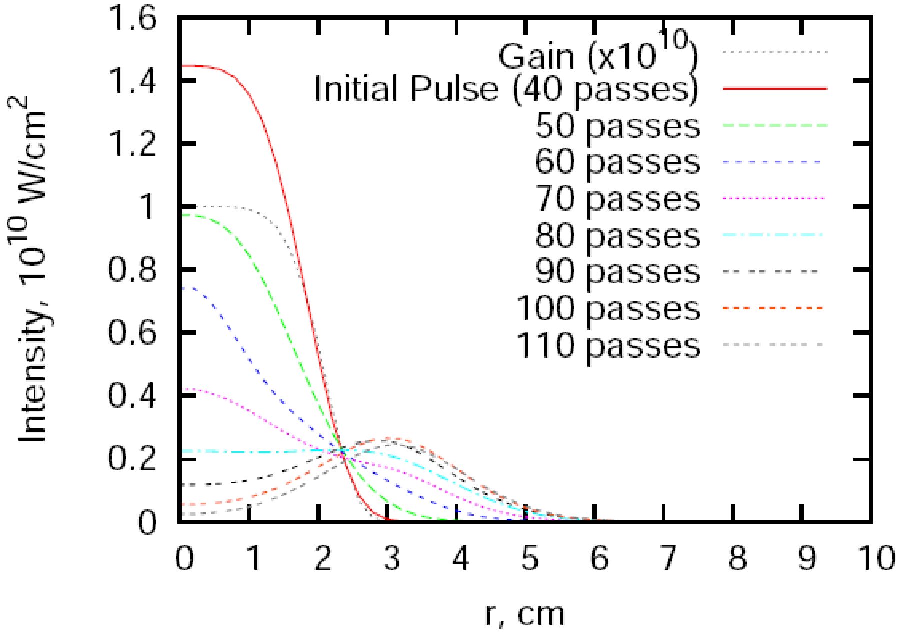




- Pumping dynamics is determined by a real electric discharge

- Longer period of constant pulse energy and smaller energy variation are achievable





Conclusions, problems and future plans

- Initial version of computer code for short pulse regenerative CO_2 amplifier simulation is developed

- Preliminary calculations using "instant pumping" and "realistic pumping" models fulfilled

- Preliminary calculation results assume principal possibility of the realization of proposed regenerative CO_2 amplifier

- "Realistic pumping" code requires further development for more accurately simulation of laser level populations dynamics

- Parametric optimization will be fulfilled after updating the code