Compton/Linac based Polarized Positrons Source

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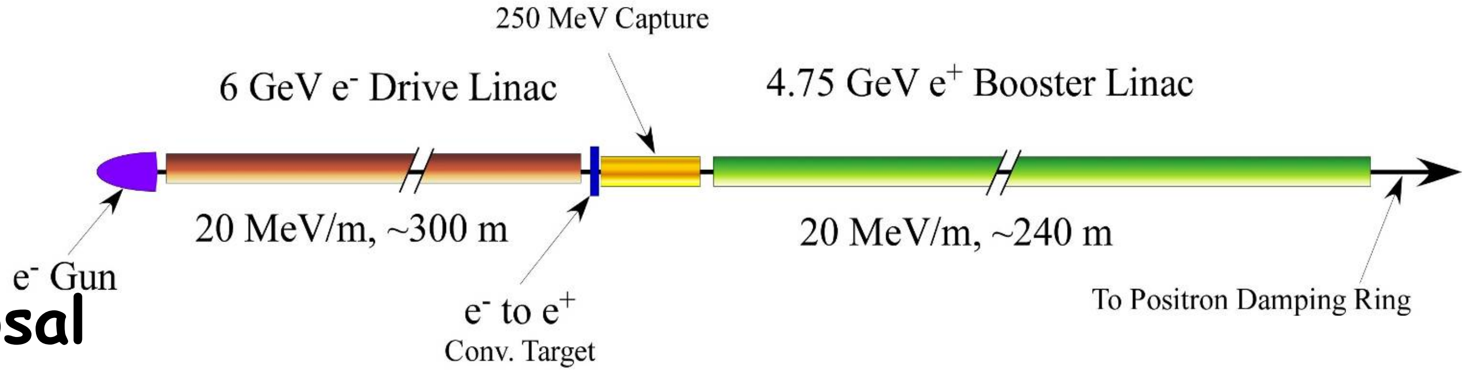
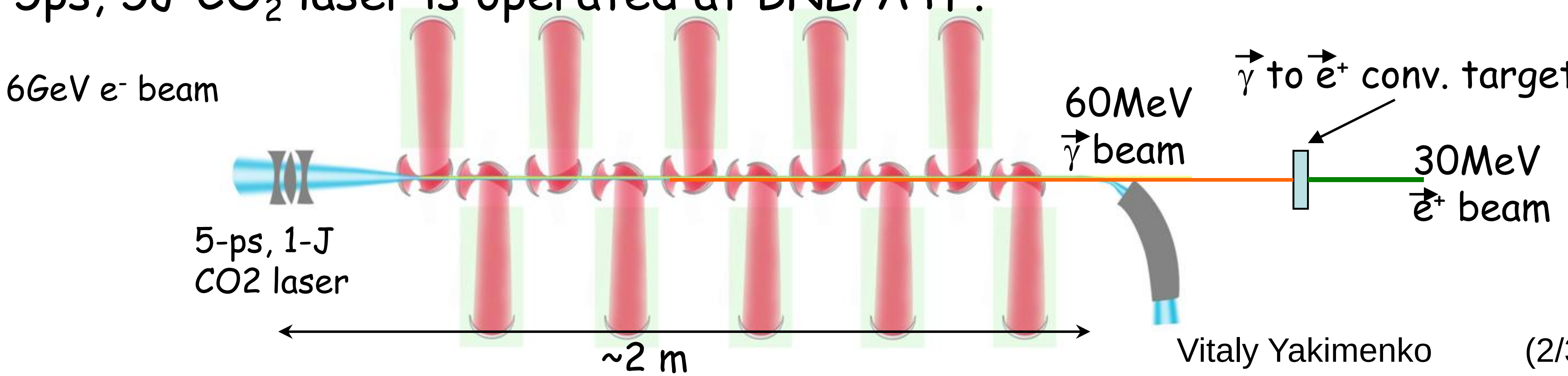
Polarized Positrons Source

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

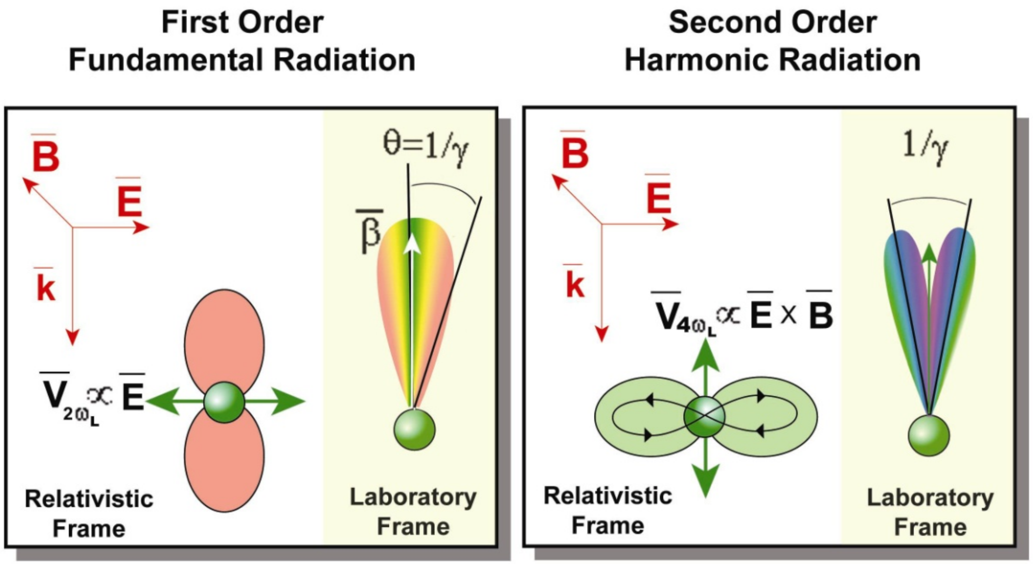


Linac Compton Source: Numbers

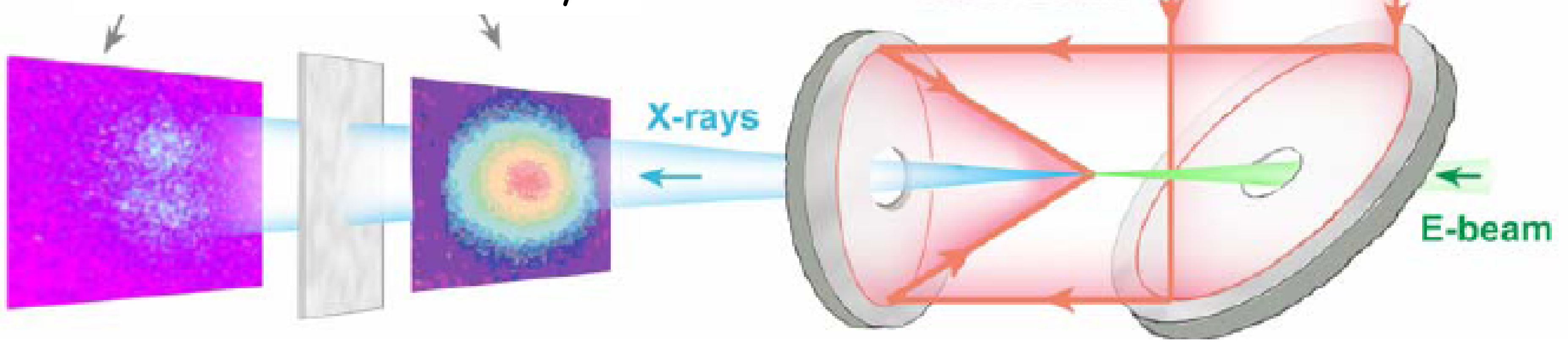
	ILC	CLIC	SuperB
Required e^+/sec	$3\ 10^{14}$	$1.2\ 10^{14}$	$3.2\ 10^{11}$
Required beam format	2856@5Hz	354@50Hz	1600@5min
Source beam format	286@50Hz		50@50Hz
Required e^+ /bunch	$3nC/2\ 10^{10}$	$1nC/6\ 10^{9}$	$20pC/1.2\ 10^{8}$
e- beam energy	6 – 4 GeV		
γ beam peak energy	60 - 30 MeV		
$Ne^+/N\gamma$ capture	2%		
e- bunch charge	15nC	5nC	1nC
bunch length (laser&e^- beams)	3 ps		
Number of laser IPS	10	10	1
Total $N\gamma/Ne^-$ yield (in all IPs)	10	10	1
Ne^+/Ne^- yield	0.2	0.2	0.02
# of stacking	No stacking		

Compton Experiment at ATF

- More then 10^8 of x-rays/per pulse were generated in the experiment N_X/N_{e-} ~ 0.35 in 2006- limited by laser/electron beams diagnostics
- Interaction point with high power laser focus of ~30mm was tested.
- Nonlinear limit (more then one laser photon scattered from electron) was verified..



Real CCD images
Nonlinear and linear x-rays



Compton based PPS with CO2 laser

- No positron accumulation is needed:
  - Efficient head-on collision due to higher divergence of CO2 beam.
  - 10 μm CO2 beam has 10x number of photons per laser energy.
  - 750 W average power industrial laser.
- Easier target and efficient positron capture:
  - Beam format changed in the injector from 2820 bunches @5 Hz to 282 bunches @50 Hz (3μs @50 Hz is more natural for warm RF and short pulse CO2 laser).
  - 40MV/m gradient in post target linac is possible.
  - Efficient collimation due to strong energy / divergence correlation of the gamma beam in the Compton scattering.
- Doable laser:
  - Commercially available components (designed for 750W@500Hz; needed 750W@50Hz).
  - Low repetition rate model (10Hz) is operational at ATF as an amplifier of 2-200 ps beam (laser cavity mode with 5ps pulse is needed).
- **Can be add-on option for non-polarized linac source.**

Choice of parameters

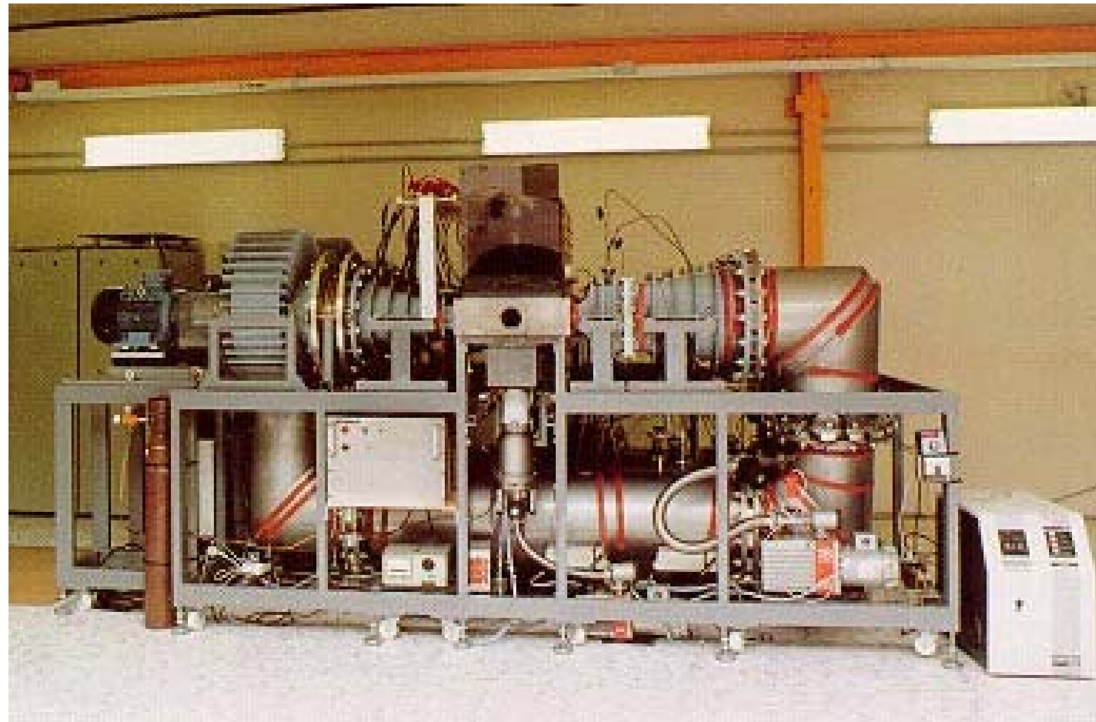
$$N_{\vec{\gamma}} = \frac{N_e N_{\vec{\varphi}}}{S}\sigma_C$$

N_γ, N_e and N_ϕ are the numbers of γ-rays, electrons and laser photons, S is the area of the interacting beams and σ_C is the Compton cross sections

- ~40 μm laser focus is set by practical considerations of electron and laser beams focusing and requires ~5 ps long laser pulses
- Nonlinear effects in Compton back scattering limit laser energy at ~2J
- Pulse train structure of 2820 bunches @ 5 Hz is set by main linac. We change it to 282 bunches at 50Hz. This mode is more natural for warm RF and lasers.
- ~300ns bunch spacing in the main linac will be changed in the dumping ring in any design. 6-12 ns bunch spacing is selected for optimal current in the drive linac and to match the inversion life time of the laser 12ns *282 bunches = 3.4 μs.
- Train of ~10 nC electron bunches is required to produce 10^{12} polarized gammas per bunch. (~1 γ-ray per 1 electron per laser IP)
- Conversion efficiency of polarized gammas into captured polarized positrons is estimated at ~2% and is subject of optimization.

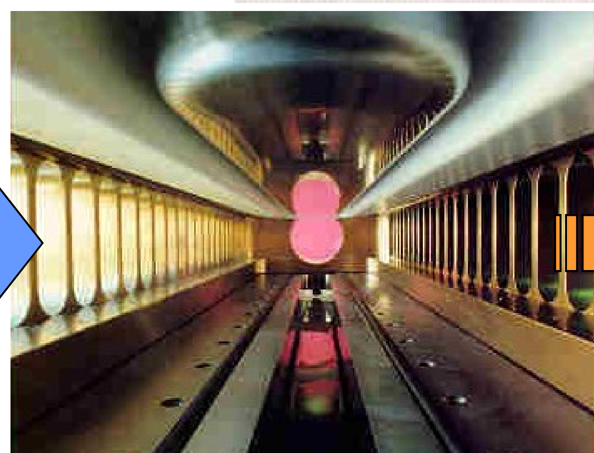
Excimer laser convertible to CO_2

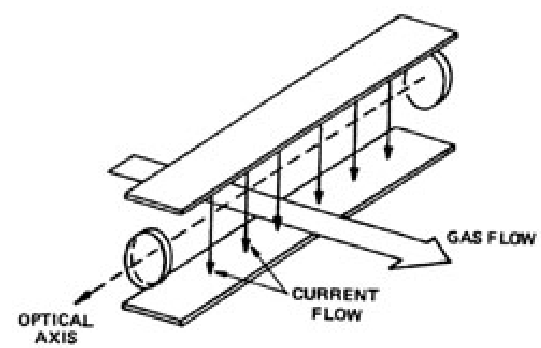
France



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

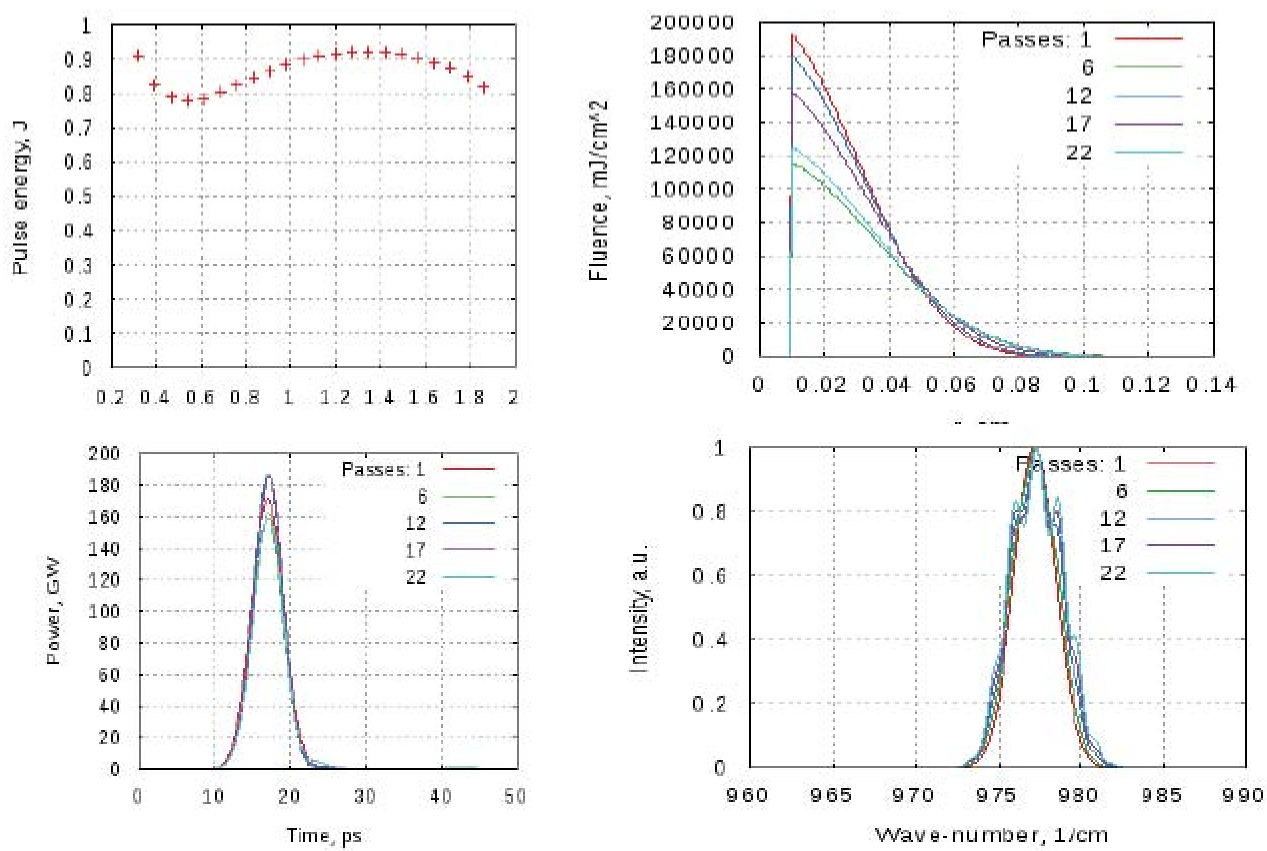
gas flow





CO2 Laser Re-Circulation

- Simulations demonstrate good beam quality preservation for a re-amplified laser pulse over the duration of the macro-bunch.



Monoenrgetic ion beam by Radiation Pressure Acceleration from H_2 gas jet

$$E_{max}\left(MeV\right)\sim a_0^{\ 2}$$

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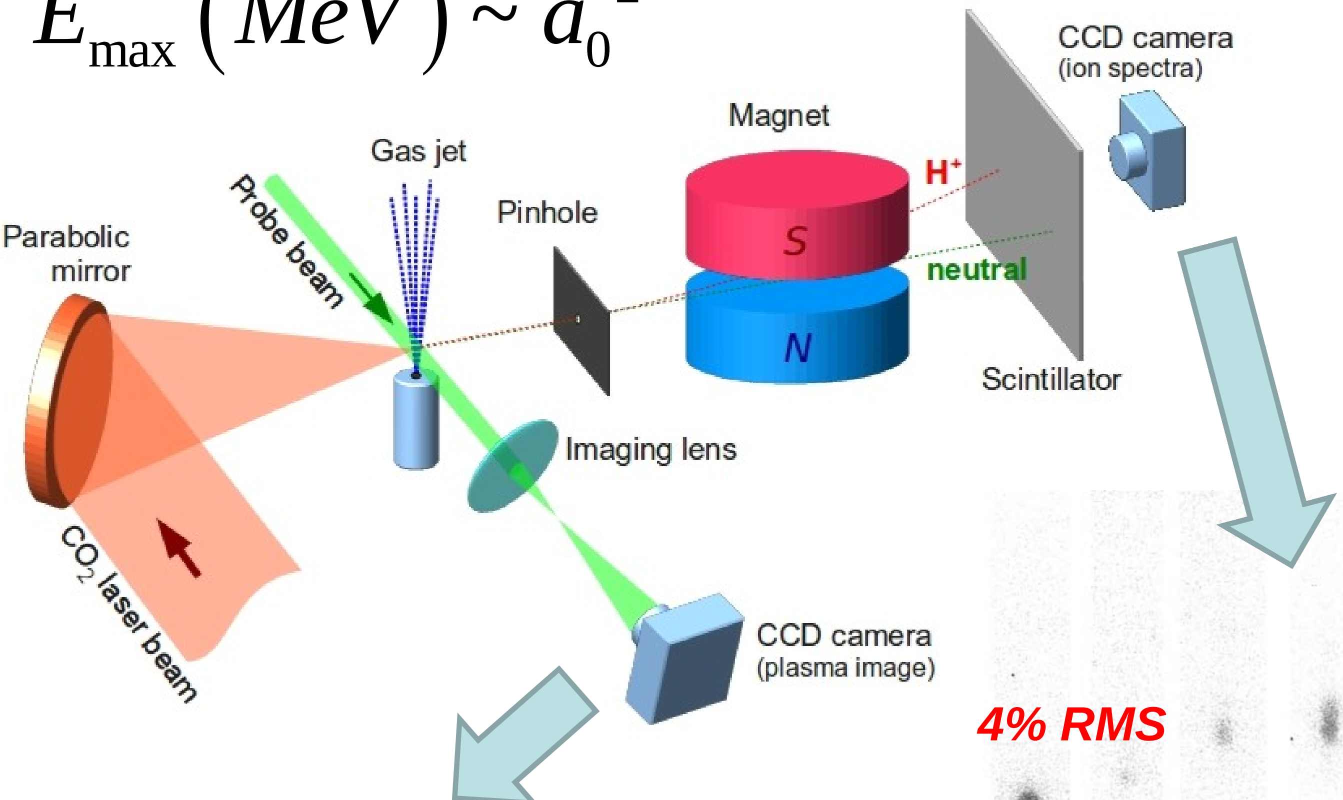
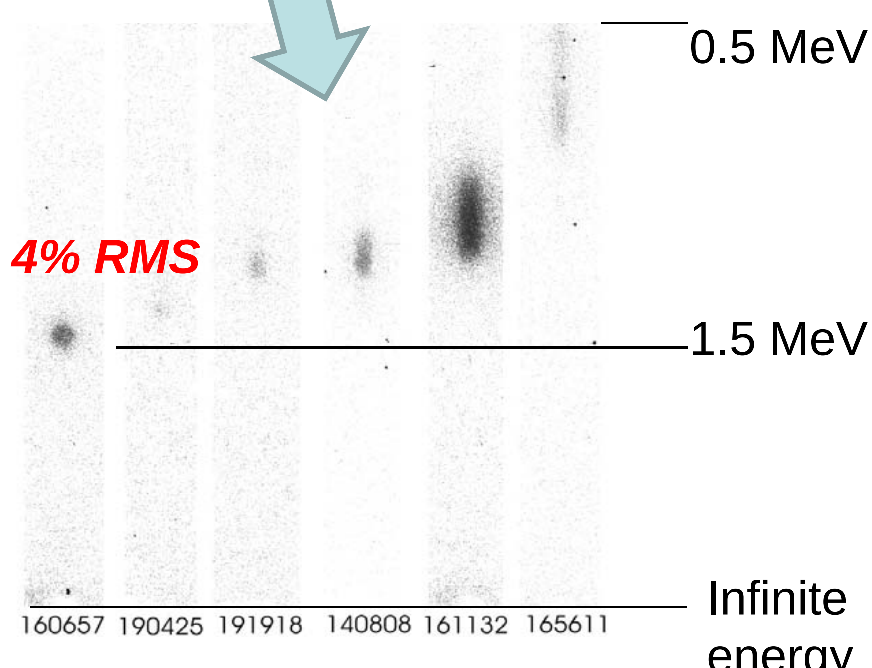
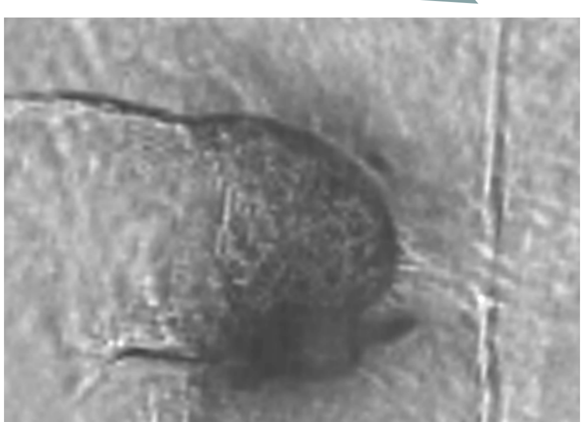






Past: **0.5 TW**
2 x 5 ps
5 J
1 MeV

Present: **1 TW**
5 ps
5 J
3→5 MeV

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

Futur
0.5 ps
25 J

		Apr. 2009	Feb. 2010	Nov. 2010	Nov. 2011	??
Energy	[J]	5	5	5	10 (IV)	2
Duration	[ps]	2 x 5 (I)	5 (II)	5	2 (IV)	0.
Power	[TW]	0.5	1	1	5	5
a_0		1.2	1.7	2.2 (III)	4.9	1
E_p	[MeV]	1.5	3 (?)	5	25	2

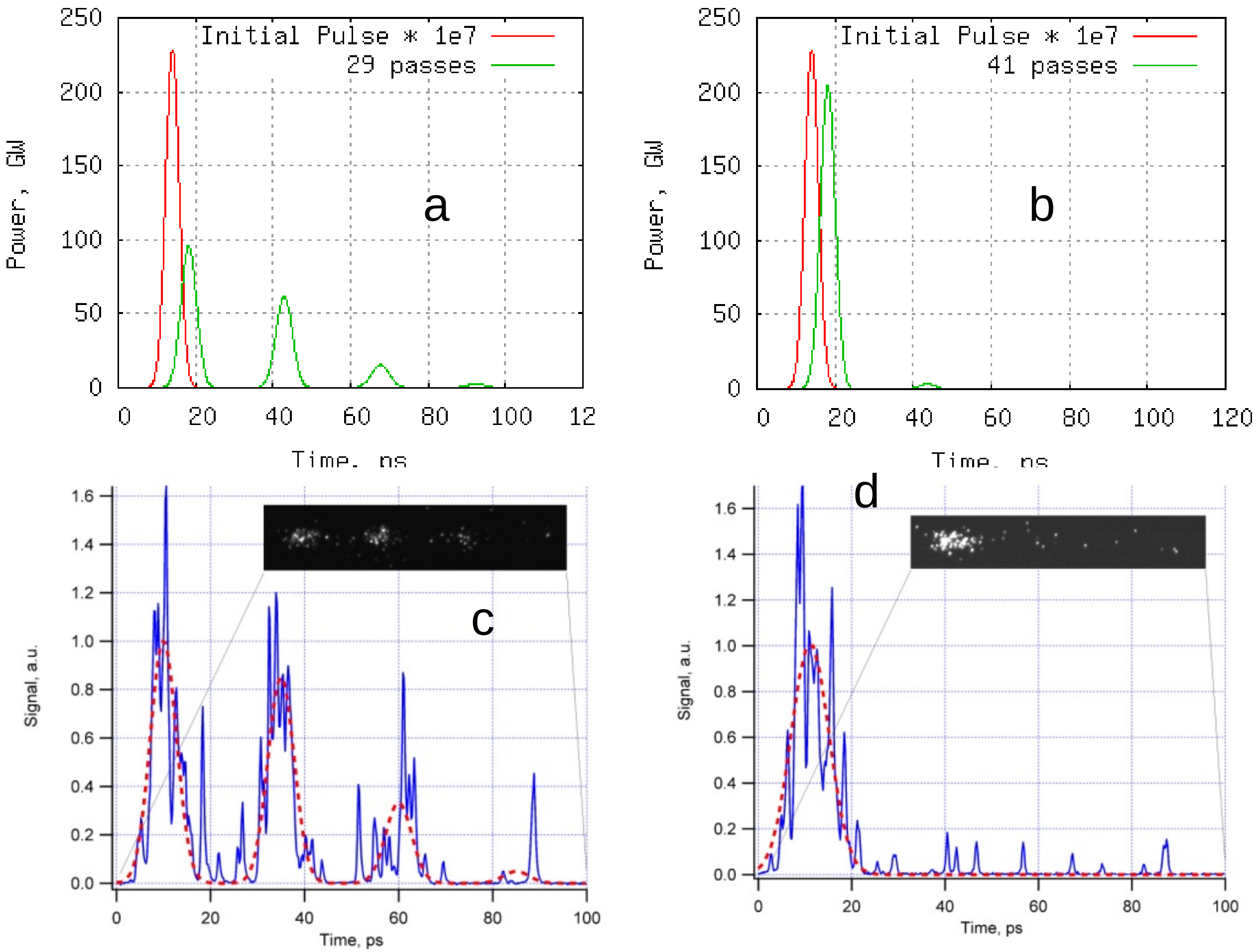
I. laser pulse was split into two due to imperfect amplification spectrum

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 see

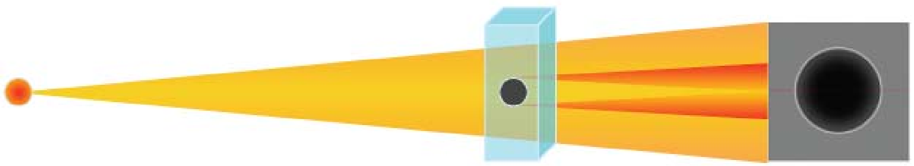
Single 5 ps pulse amplification

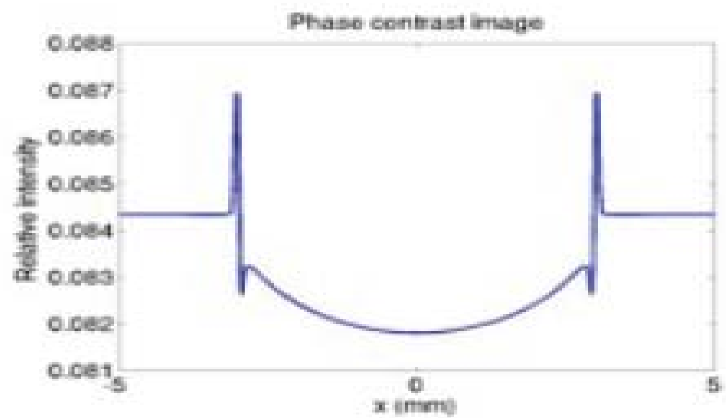


Time structure a 5-ps laser pulse circulating in a laser amplifier : (a) and (b) simulated for a regular 10-atm laser gas composition and for the 10-atm multi-isotope laser; (c) experimental result (streak camera trace) for a 5-ps laser pulse amplified in a 10-atm regenerative CO_2 laser filled with regular gas; (d) same for the laser with isotopic gas mixture.

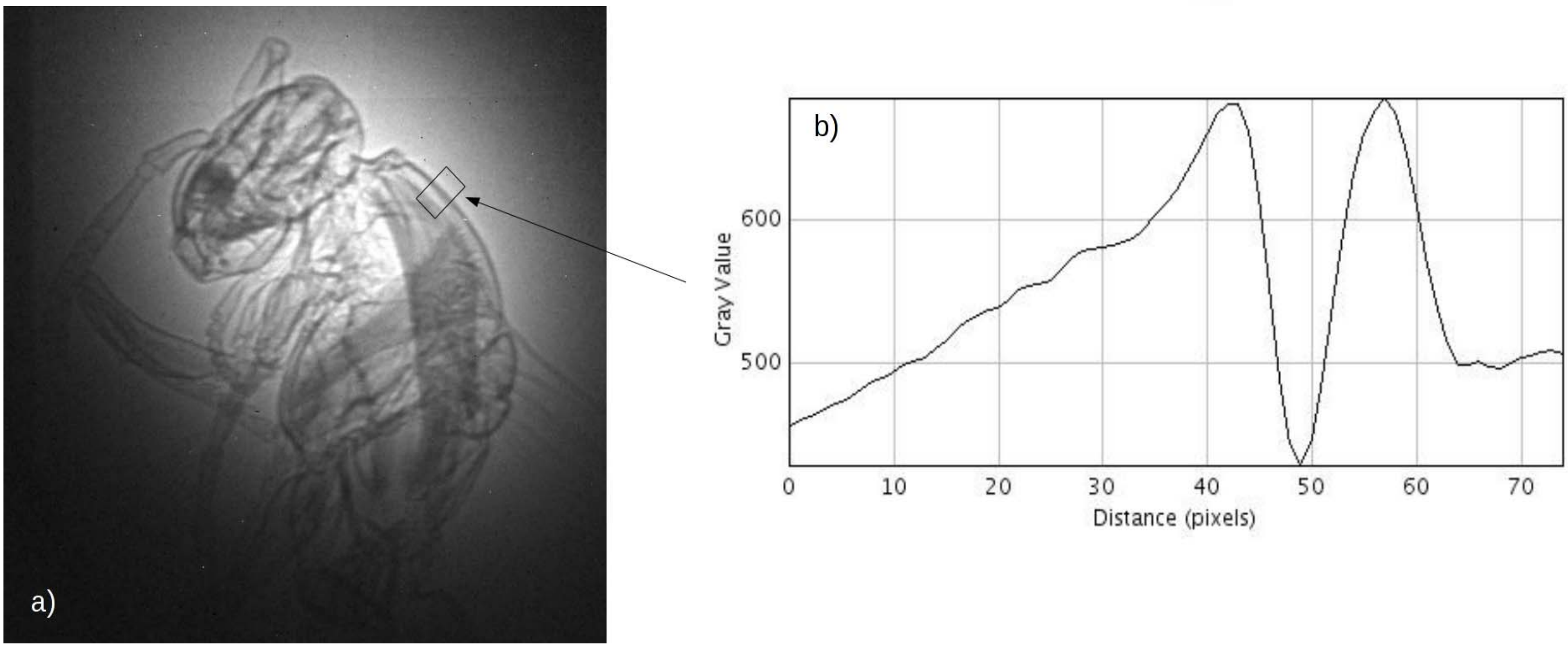
Phase contrast imaging using Compton X ray beam

Phase contrast imaging (INFN),
First proposed by Snigirev (1995)





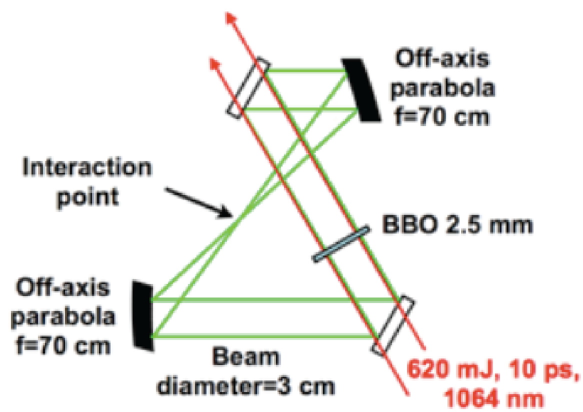
Single shot measurements at ATF

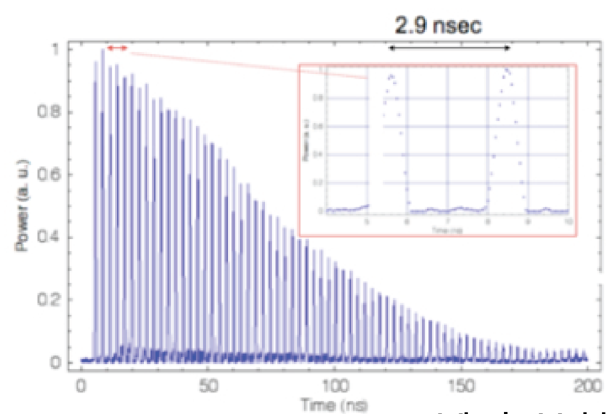


Compton with recirculated 1 μm laser
(RadiaBeam, funded by DOD)

Laser Recirculation

- Several different techniques were studied; we chose:
  - Recirculation Injection by Nonlinear Gating (RING)
    - Developed at LLNL [I. Jovanovic et al]
- Advantages: simple, inexpensive, can handle high power
- Disadvantage: “ring-down”
- Challenges: timing, alignment, maintaining good laser focus through many recirculations



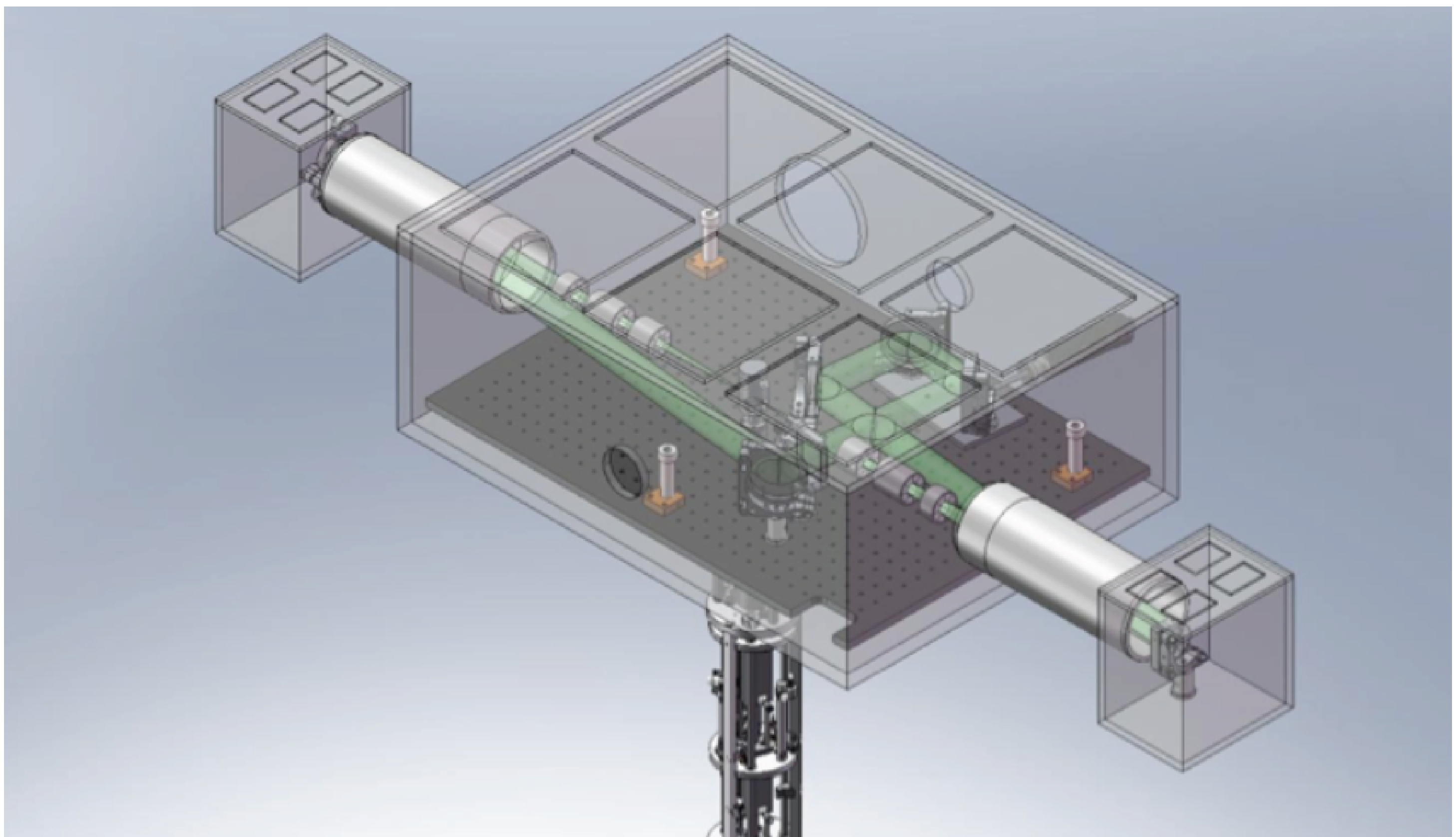


Compton with recirculated 1 μm laser

(RadiaBeam, funded by DOD)

Project overview

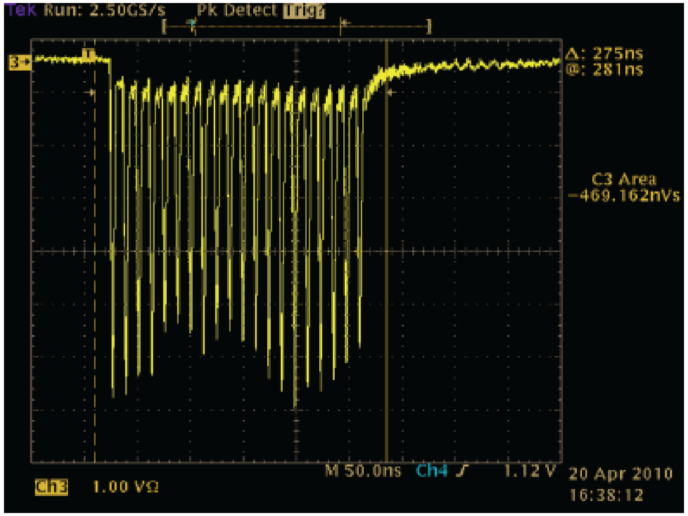
- RING will be implemented inside the vacuum box. Electron beam is focused to the IP with PMQs.

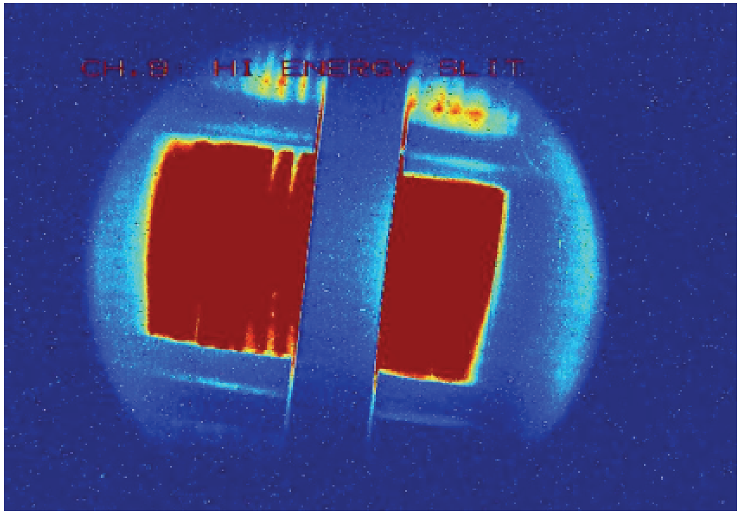


Compton with recirculated 1 μm laser
(RadiaBeam, funded by DOD)

Bunch Train Generation

- In preparation 20 pulses bunch train, 300 pC each beamlet has been generated (April 2010).
- Next experimental run will focus on beam loading mitigation and radiation hardening test of the RING dielectric mirrors.





Conclusion

- Linac based Compton source can reach required intensities without stacking and is an attractive upgrade option for a conventional source.
- Requires
  - development of CO2 regenerative cavity,
  - high repetition rate operations
- There is an active program to use highest Compton X ray peak flux for single shot user experiments:
  - Started with High efficiency conversion ~1x ray / 1 electron, Spatial distribution of second harmonic (U. Tokyo, KEK)
  - Phase contrast imaging (INFN)
  - Diffraction scattering on the crystal (UCLA)
- There is an active CO2 development program at ATF
  - required for ILC pulse parameters and amplifier bandwidth is demonstrated
  - Gradual increase of the single pulse intensity is the main goal.