Advanced Accelerator Concepts

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A University Group with Collaborations at National Laboratories

Neutrino Factories and muon colliders: Led collaboration simulation/theory group for a few years. Co-chair of NuFact'00 Workshop and on SPC many years. Member of the collaboration executive committee.

- ➡Theory and design of ionization cooling channel design (FNAL,BNL,LBNL, CERN)

- ➡Theory of optical stochastic cooling for muons (LBNL)

High gradient structure test at MIT 30GHz FEL [LLNL/LBNL/CERN]

Fluctuational diagnostics @ATF/BNL [Catravas Thesis]

Plasma channel accelerators [LBNL]

Ongoing collaborations with AFRD/LBNL groups [CBP: optical beam manipulations; VNL: WARP simulations for beams and anti-Hydrogen plasmas]

A wide range of Advanced Accelerator Research Activities

Muon beams

*Muon ionization and optical stochastic cooling: theory, simulation, design and optimization

Plasma-based accelerator concepts

*EIT, ion acceleration, and connections between beam/plasma and atomic physics
*Theory for plasma channels: Q, R/Q, break-up instabilities, simulations
*Autoresonant beatwave excitation
Simulation and theory of beam-plasma dynamics, connections to astrophysics

Radiation Sources

Theory and experiment on FEL RF power sources, high gradient structure testing
*Single shot bunch length and other radiation based diagnostics
Beam phase space manipulations (e.g., conditioning)
*Theory of high harmonic cascade FELs
Magnetic radiation guiding

Storage Rings

Coupled mode theory of bunch lengthening with potential well distortion
Instability control in rings using variable chromaticity

Beam Physics Analogs

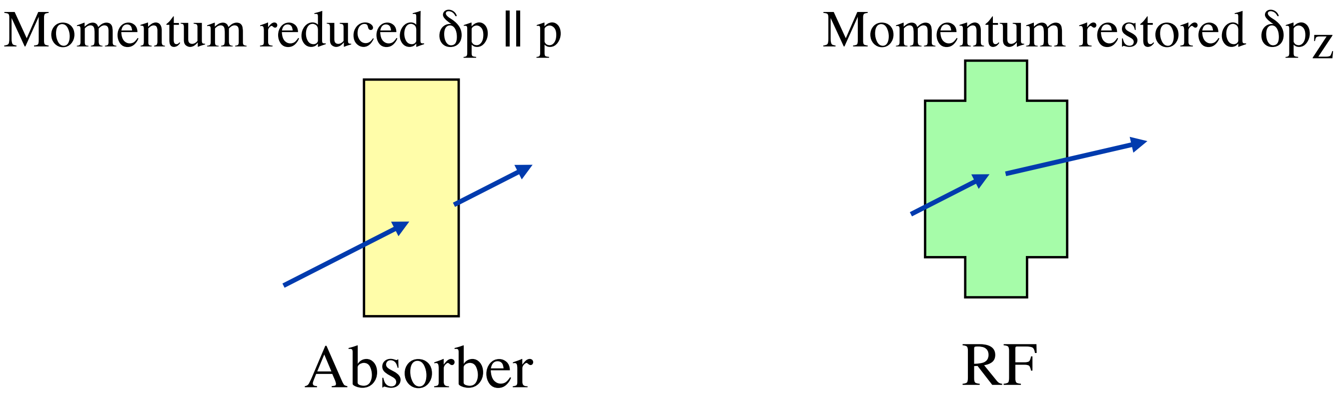
Study of beam physics analogs (virtual cathodes, two-stream instabilities, nonlinear phase space structures) in nonneutral plasma systems.

University Connections

Initiation of the MIT advanced accelerator program and UCB campus program

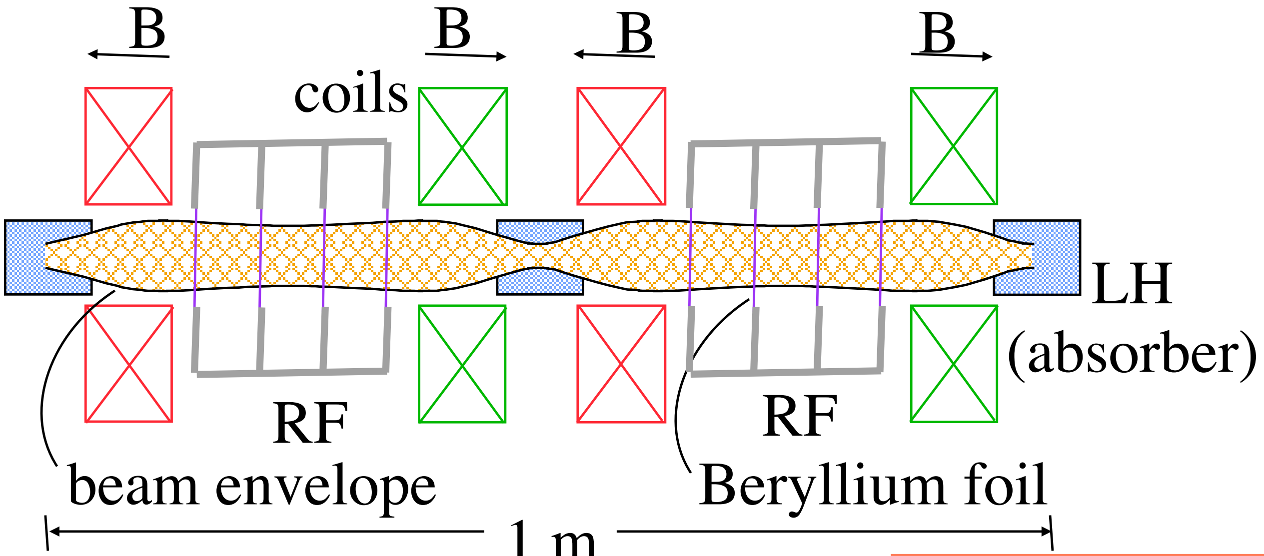
Muon Ionization Cooling

- Muons produced in a large 6-D phase space volume that must be decreased.
- Cooling in L~cτμ~660m.
- Ionization cooling (Skrinsky&Parhomchuk,81).



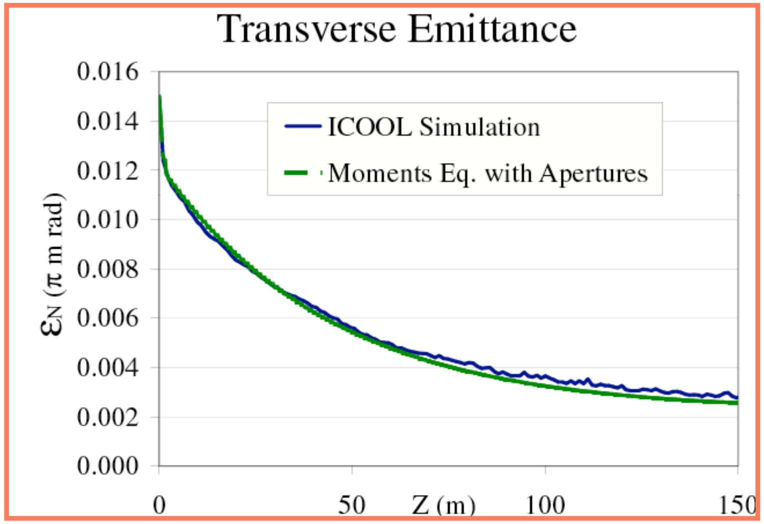
Need to fight multiple scattering and longitudinal blowup

Theoretical Advances: faster design, benchmarking, and better understanding



The old method: particle tracking

The new alternative:
track moments for speedup x1000

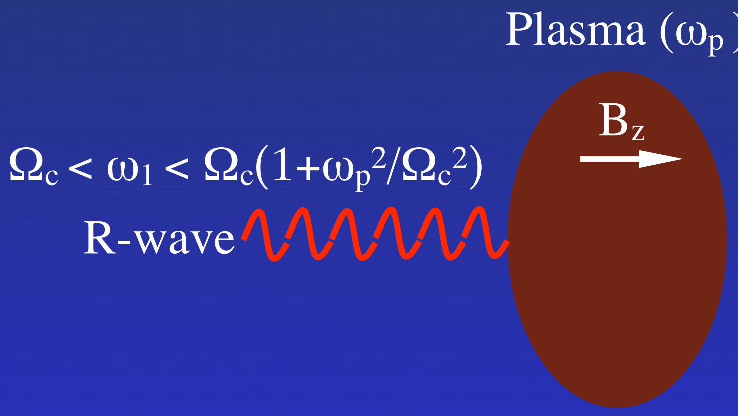


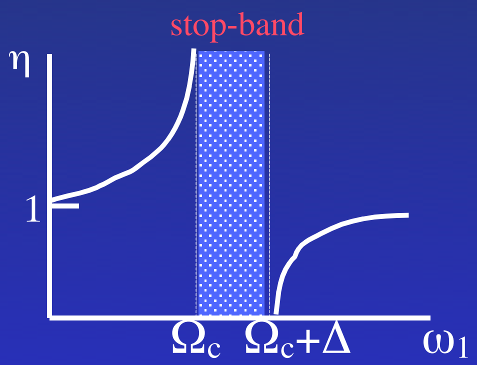
Penn (200)

EIT in Magnetized Plasma: Applications to ion acceleration, pulse compression

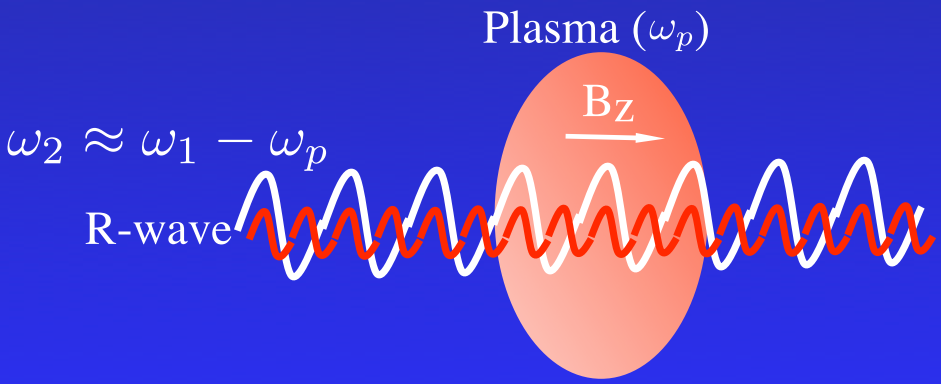
(in presence of longitudinal, static, solenoidal field)

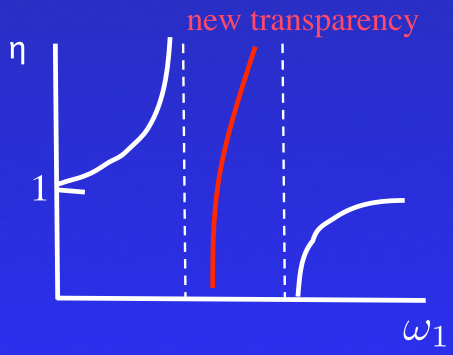
weak probe in absorption band: $\Omega_c \leq \omega_p \leq \Omega_c + \Delta$





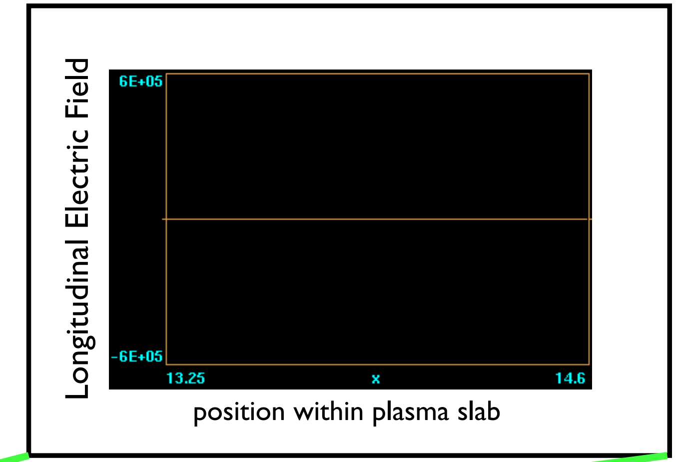
weak probe in presence of intense pump:

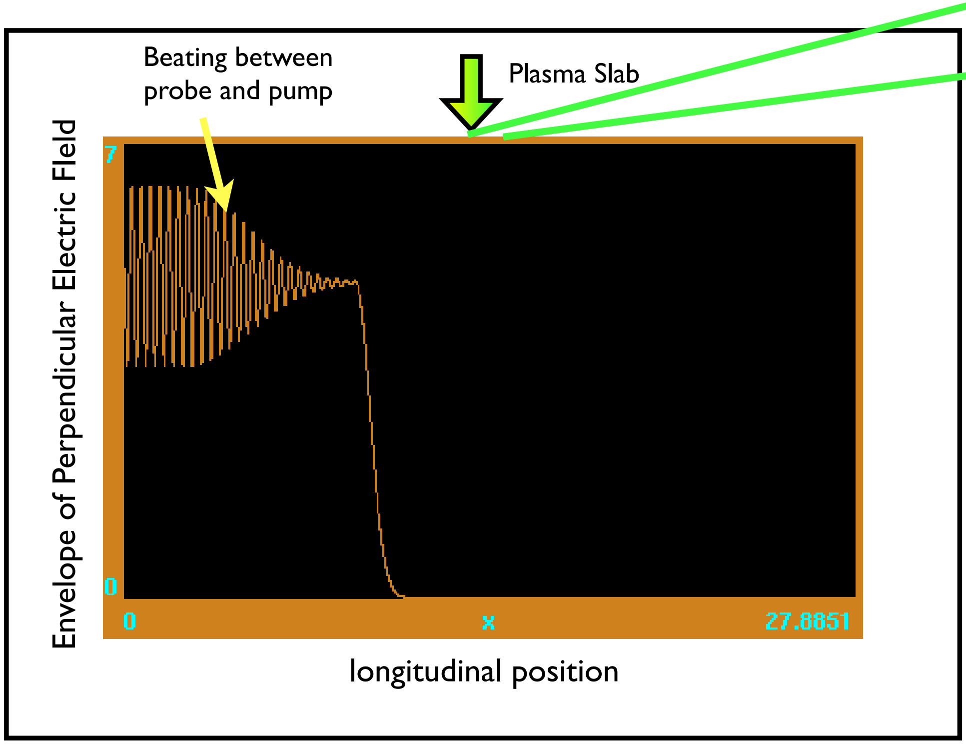




EIT in Plasma:
A possible ion accelerator

1D XOOPIC simulation





Plasma wave has
low phase velocity
['slow light']

$$\omega_1 = \Omega_c = \omega_2 + \omega_p$$

Shvets, JW 2002,
Shvets,Hur, JW 2003
Shvets,Tushentsov, et al 2005

$$a_1 = 0.005,\ a_2 = 0.05,\ \omega_1 = \Omega_c,\ \omega_2/\Omega_c = 0.7,\ \omega_p/\Omega_c = 0.3,\ \Delta z = 6 \times 2\pi c/\Omega_c$$

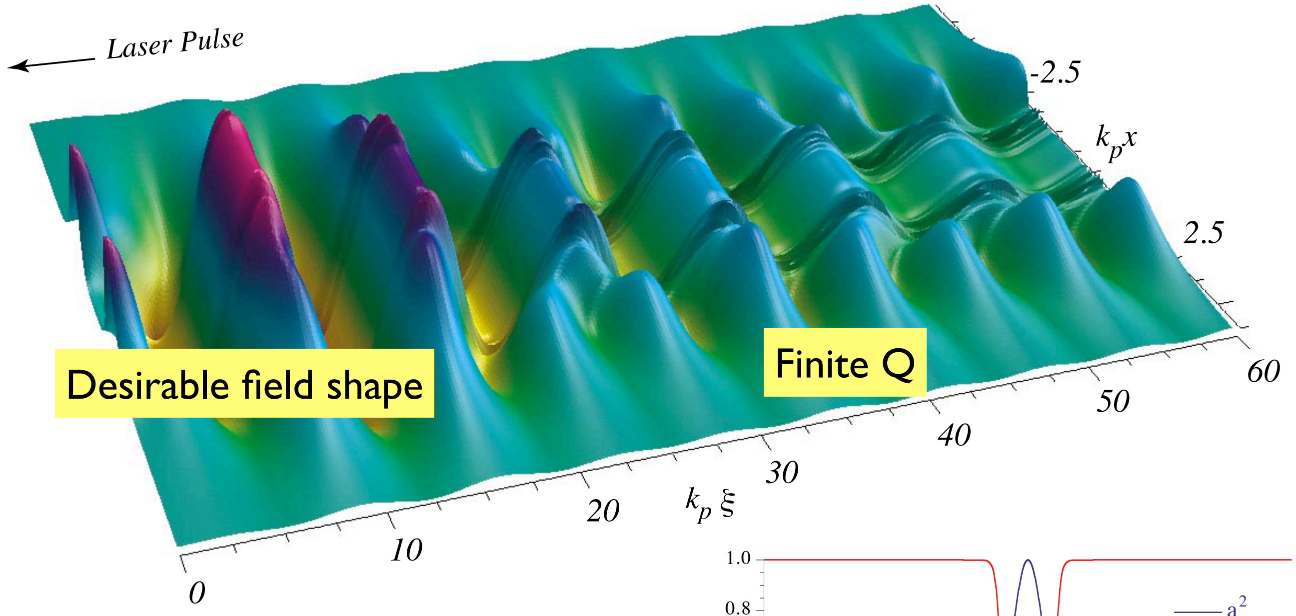
Some parallels between atomic and plasma physics

opportunities for cross-fertilization?

Annular atomic traps	Storage ring dynamics
EIT	EIT
Raman Scattering	Raman Scattering
Stimulated/Spontaneous Emission/LASER	Stimulated/Spontaneous Emission/FEL
quasi-particles/ elementary excitations	collective modes
energy/momentum conservation	resonance conditions
quanta/quasiparticle conservation	Manley-Rowe relations (wave action conservation)
WKB approximation	WKB/asymptotics
Adiabatic theorems/invariants	Adiabatic theorems/invariants
Landau-Zener Transitions	Mode Conversion
STIRAP	Adiabatic Passage/Autoresonance

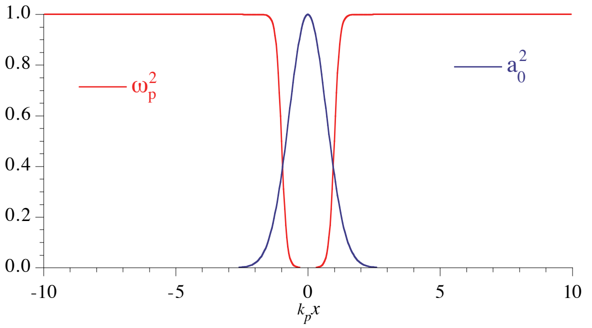
Longitudinal Wake Field

Numerical Solution of the Linearized Cold Fluid Equations



Desirable field shape

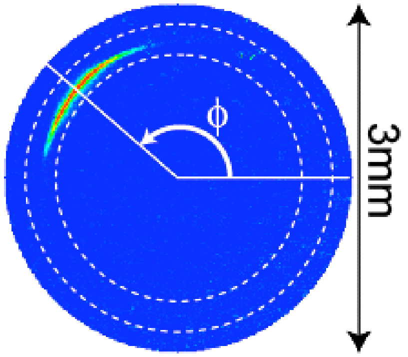
Finite Q

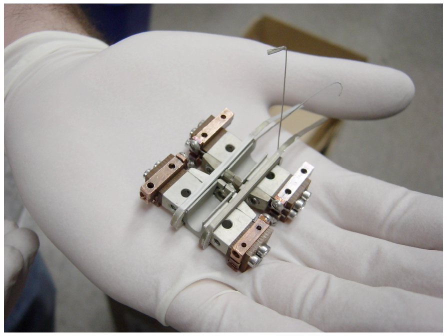


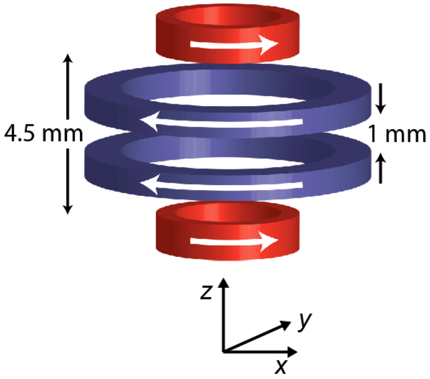
B. A. Shadwick, J.S. Wurtele, UC-Berkeley 1997

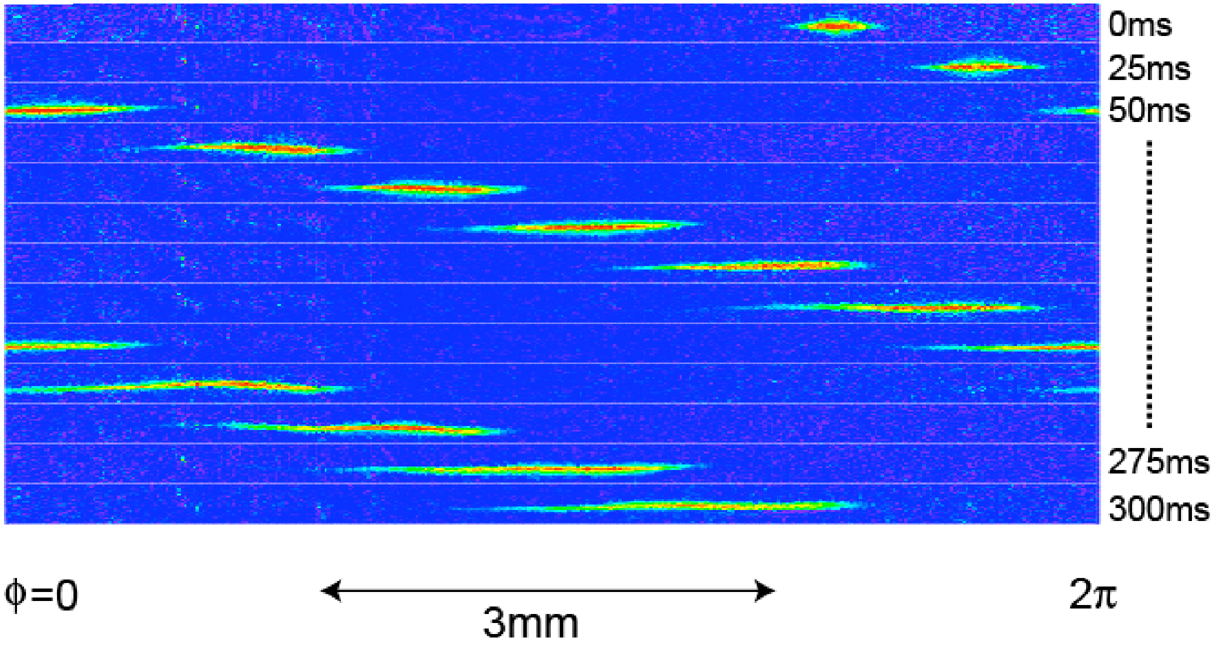
Connections to other fields:
Annular Atomic Traps ---Mini Storage rings

(Stamper-Kurn, et al (PRL 2005))









Robust PBWA Excitation

- Traditional Plasma Beat Wave Acceleration is very sensitive to resonant at ω_p
- Autoresonance sweeps beat frequency through resonance ⇒ insensitive to exact density

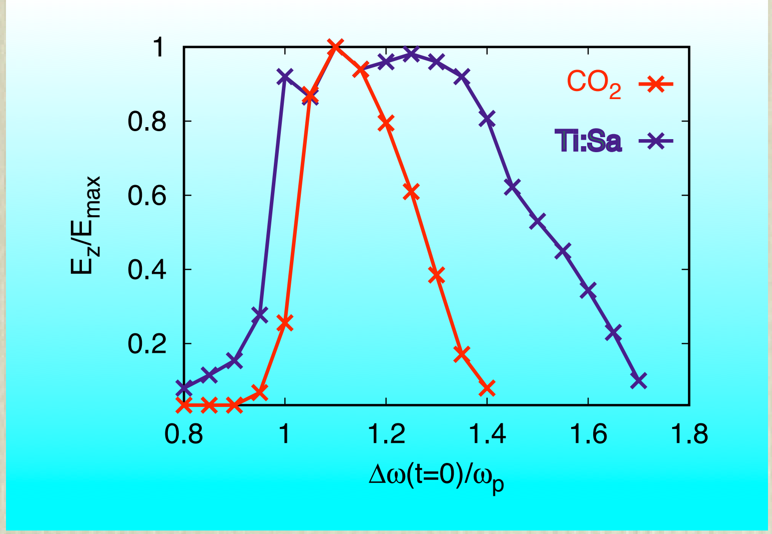
Lindberg et al., PRL (2005)

CO_2 system -

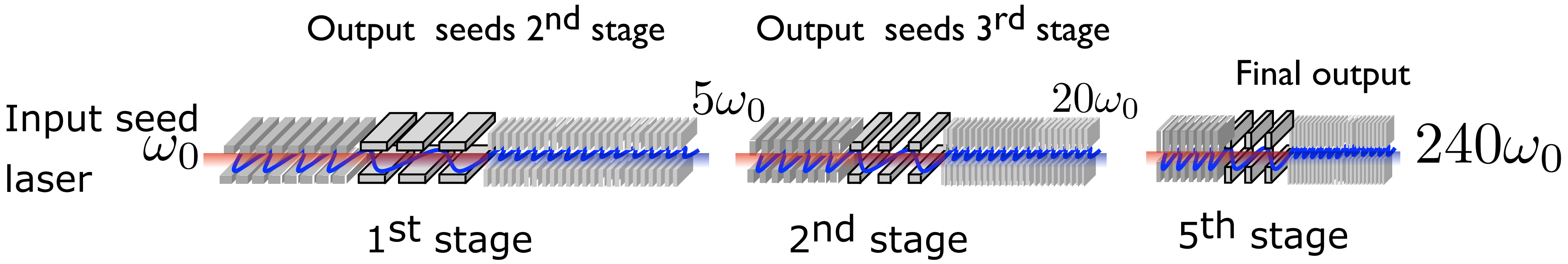
$8-10$ GeV/m fields with $\pm 20\%$ variations in density

Ti:Sa system -

~ 250 GeV/m fields with $\pm 35\%$ variations in density



Radiation Generation in a Harmonic Cascade Low-Gain FEL



Output seeds 2nd stage

Output seeds 3rd stage

Final output

Input seed laser ω_0

$5\omega_0$

$20\omega_0$

$240\omega_0$

1st stage

2nd stage

5th stage

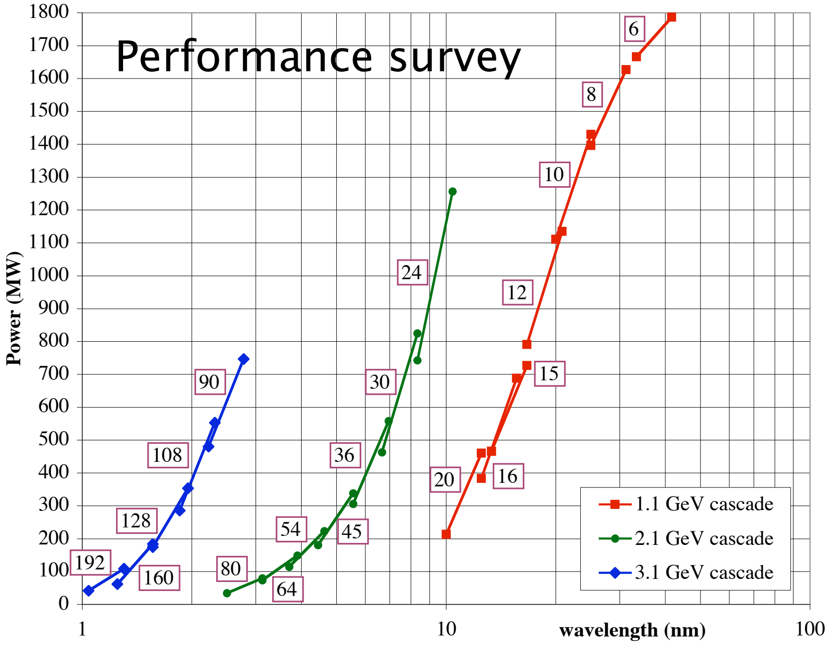
- Number of stages and harmonic of each to be optimized during study.
- Bunching ever more difficult at higher harmonics
- Fresh electrons at each radiator
- Limited by beam quality.

Designs (NOT HEP funded) used FEL simulations Ginger and Genesis: eikonal field + particles. [Zholents, Fawley, Penn et al.]

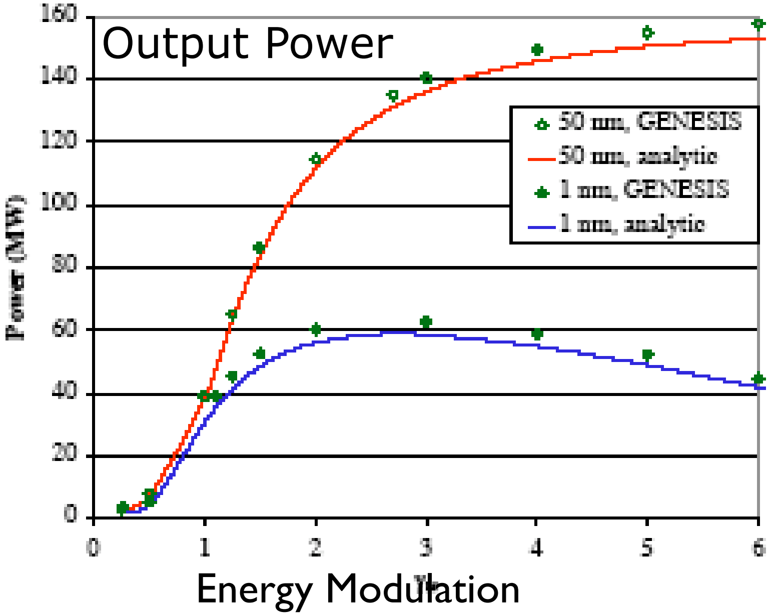
Wiggler schematic courtesy W. Graves

Variational Principle Reduces FEL Low Gain Harmonic Generation from Simulation to Optimization.

Optimization: Spontaneous emission couples to transverse mode that maximizes beam energy loss



Simulation and theory agree



CBP FEL group 2005

Experiment and theory for fluctuational diagnostic: Single pass bunch length measurement BNL/ATF

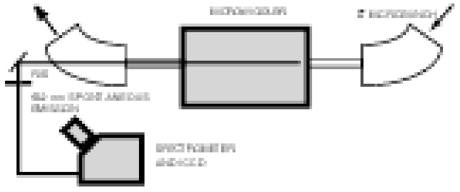
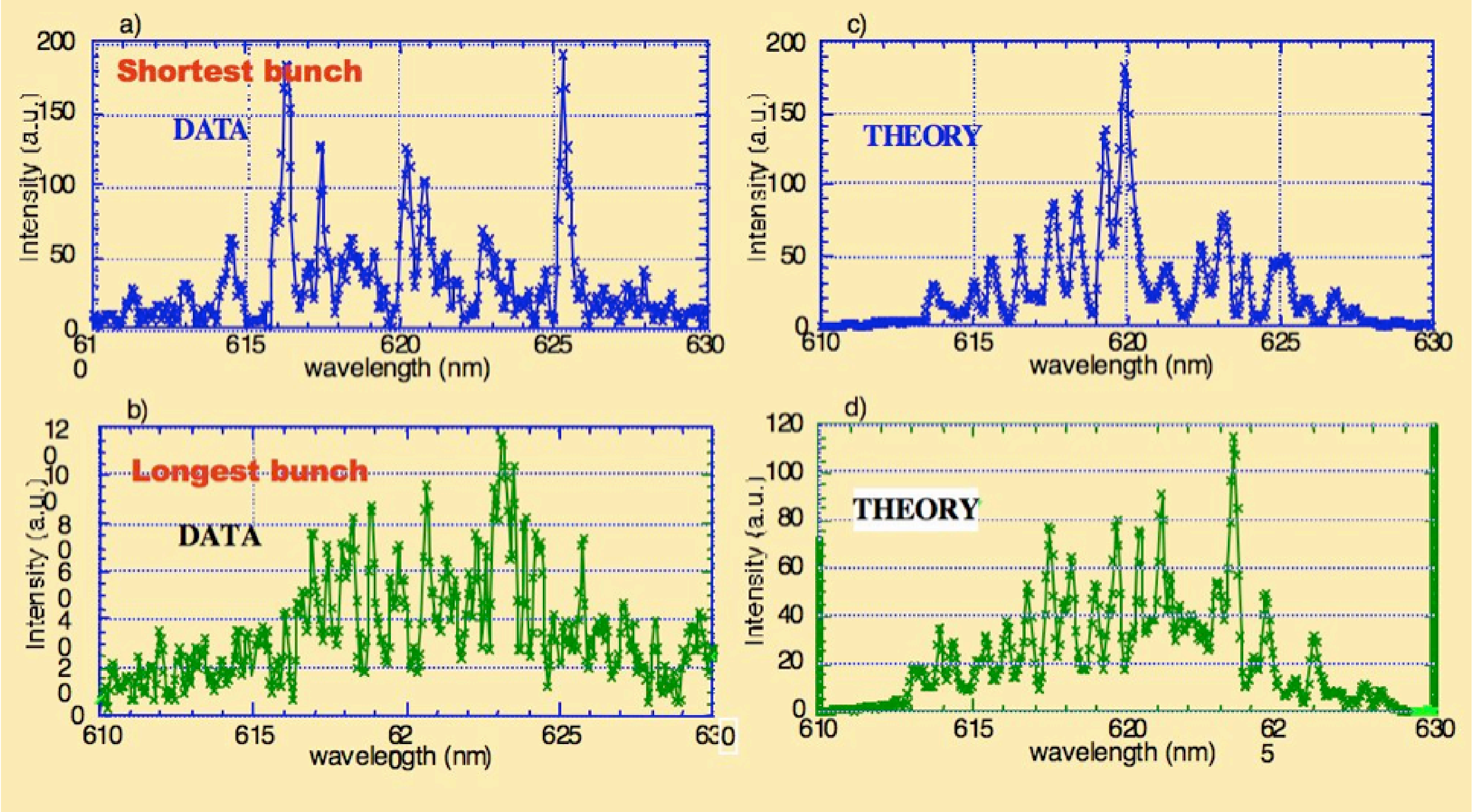


FIG. 1. Experimental setup.

Zolotorov and Stupakov (96)
Catravas Ph.D. [MIT](98)
Catravas et al., PRL (99)

Data and theory for 2ps and 6ps bunch lengths



Conclusions

- The advanced technology R&D program must include an innovative, diverse, intellectually vigorous University program
- Scientific understanding of beam physics should be a central goal of the U.S. DOE advanced accelerator research program on a par with the goal of developing accelerator technology.
- University programs serve as a bridge between the accelerator research community and the rest of the scientific community.

"Sustain and Strengthen the nation's traditional commitment to long term basic research..."

> "Increase the federal investment in long term basic research by 10% a year over the next 7 years..."
>
> "Allocate at least 8% of the budget of federal research agencies to discretionary funding that would .... be focused on catalyzing high-risk high-payoff research"

from the NRC Report, "*The Gathering Storm: Energizing and Employing America for a Brighter Economic Future"* [2005]