Advanced Accelerator R&D at BNL

R B Palmer 2/16/06

AARD Sub-Panel

I will discuss

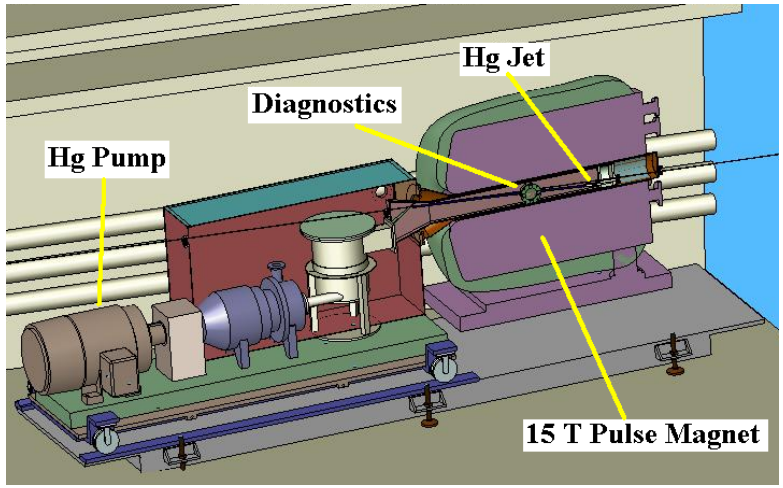
- Neutrino Factory & Muon Collider R&D
- Fixed Field alternating Gradient (FFAG) Studies
- Solid Target Radiation Studies
- Accelerator Test Facility (ATF) Experiments

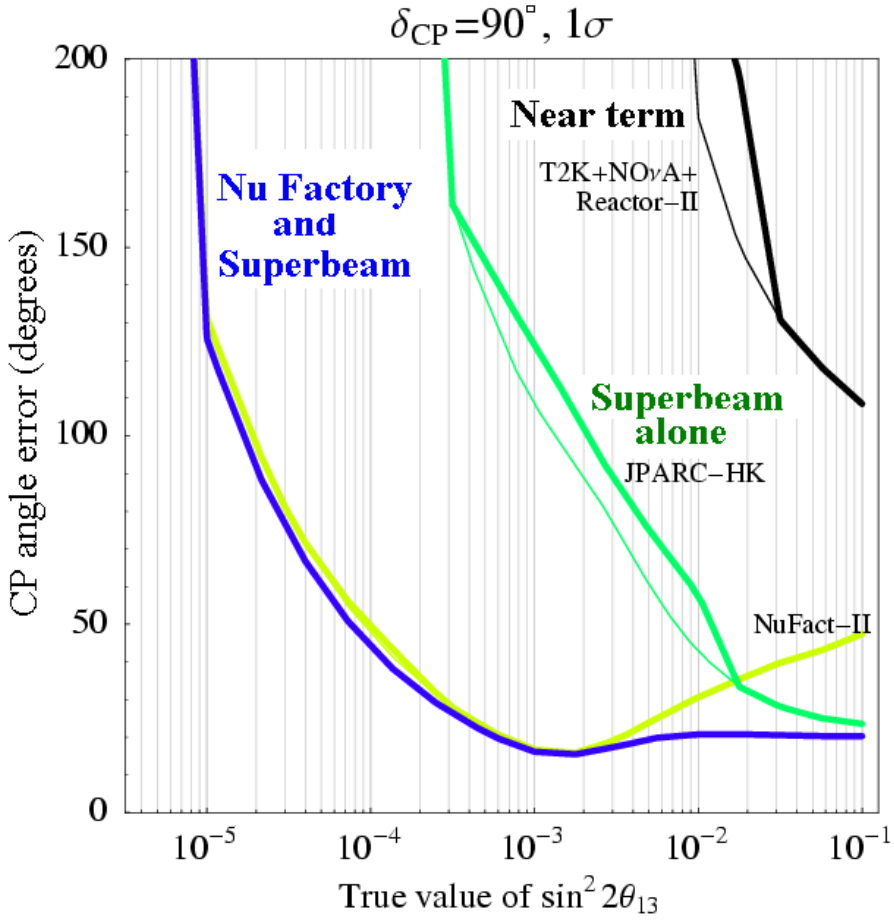
Yakimenko will discuss

- Accelerator Test Facility (ATF) Facility
- RF Guns & Energy Recovery Linacs (ERL)
- Optical Stochastic Cooling

Neutrino Factory Studies

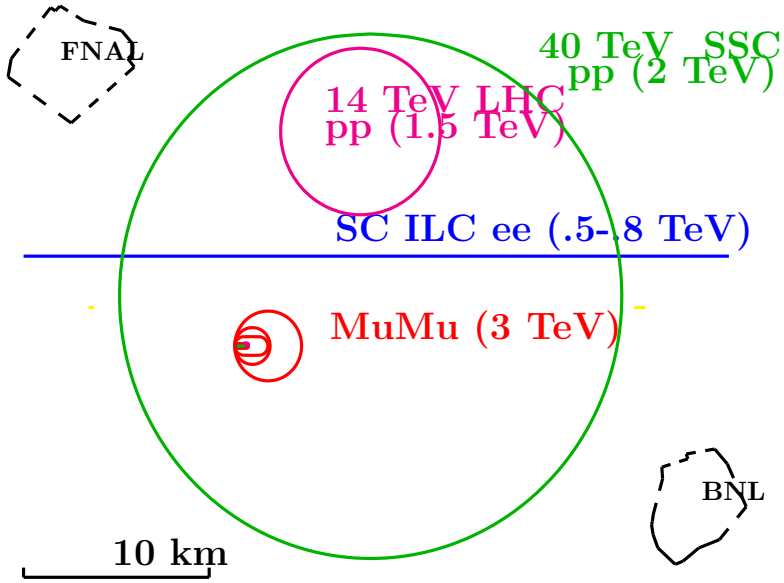
- Part of Neutrino Factory & Muon Collider Collab (NFMCC) (Zisman Talk)
- Lower Backgrounds than Conventional Beams
- Only way to study CP Violation if θ_{13} small
- Main BNL Efforts:
  - Design and Simulation
  - CERN Hg Jet Target Exp





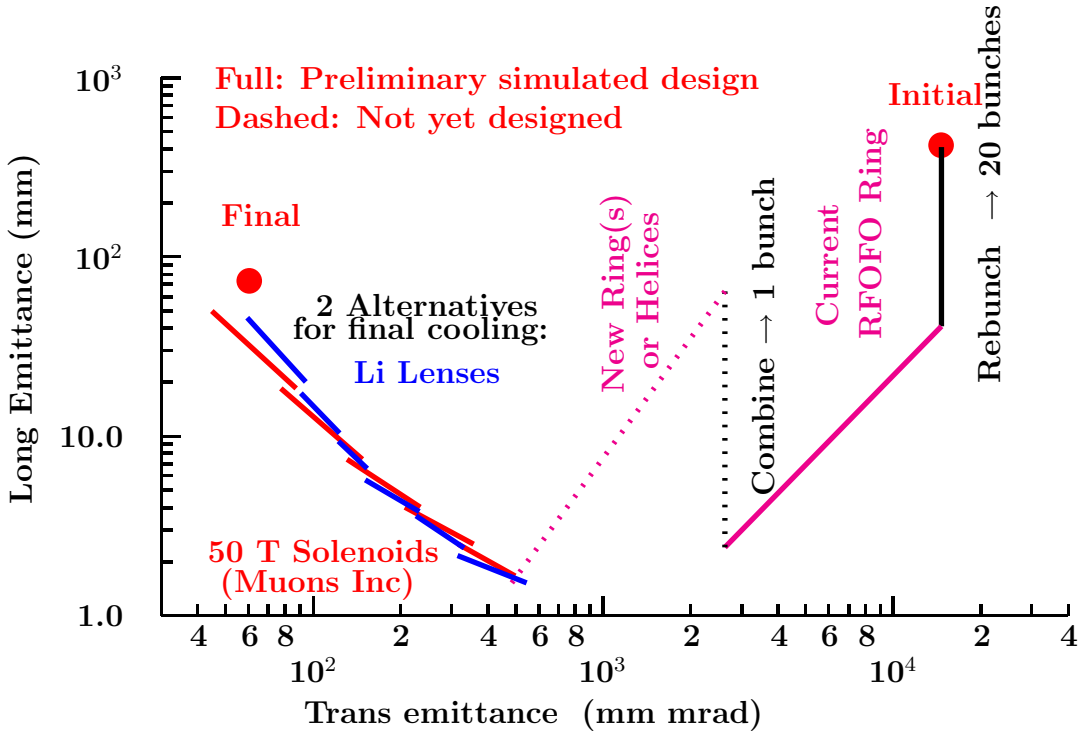
Errors in CP angle δ

Muon Collider Studies



- Part of NFMCC (Zisman Talk)
- Muons are point like
- Same physics as e^+e^-, plus $\sigma \longrightarrow$ Higgs $\times$ 40,000
- And 40,000 less radiation
- So Muon Colliders circular & much smaller

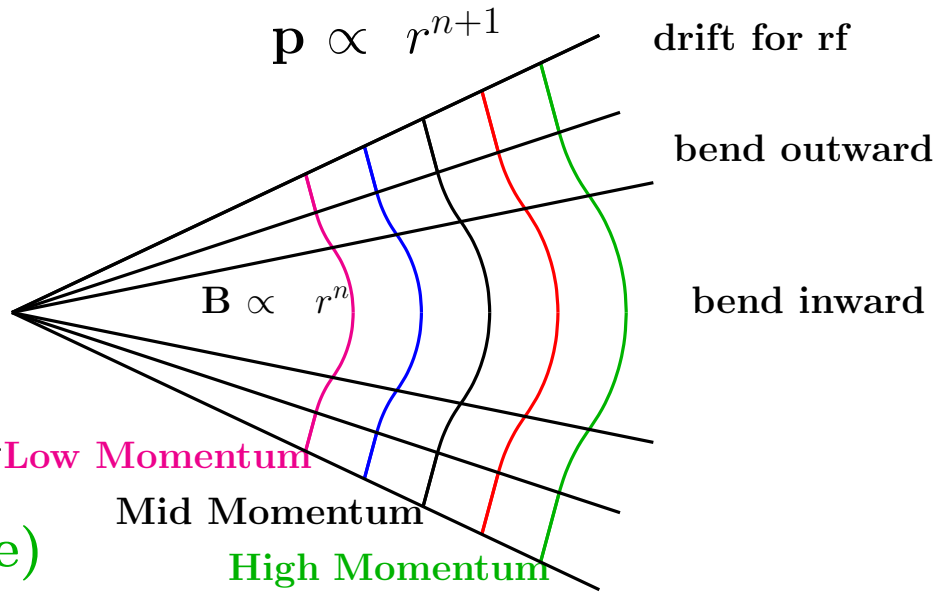
- Main BNL Effort:
  - Required Cooling Design
    Substantial progress
    Example of Scheme $\longrightarrow$



Fixed Field alternating Gradient (FFAG) Studies

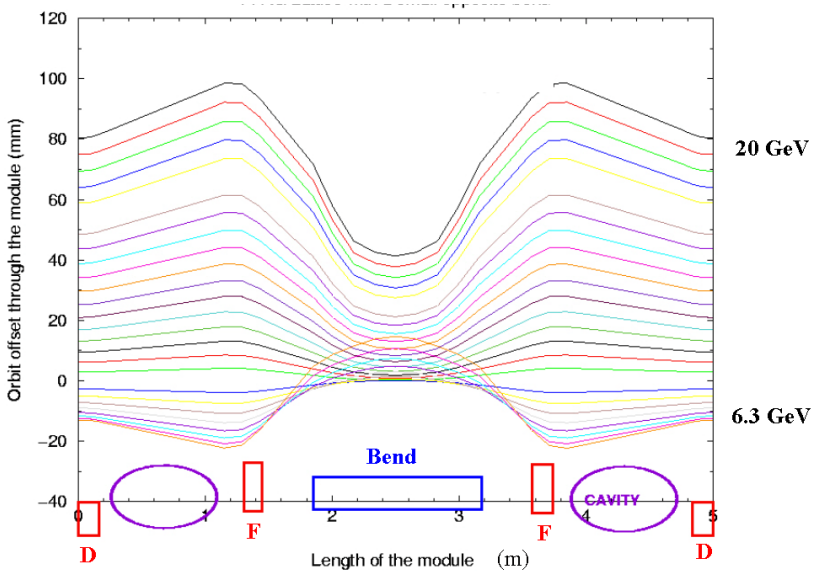
a) Scaling Designs

- Δp limited only by aperture
- Tune independent of momentum
- But large magnet apertures
- Non-isochronous
- Several operating examples in Japan



b) Non-Scaling (Carol Johnstone)

- Orbits are not similar, but closer together than in scaling
  $\longrightarrow$ smaller apertures
  $\longrightarrow$ more isochronous
- But tunes not constant



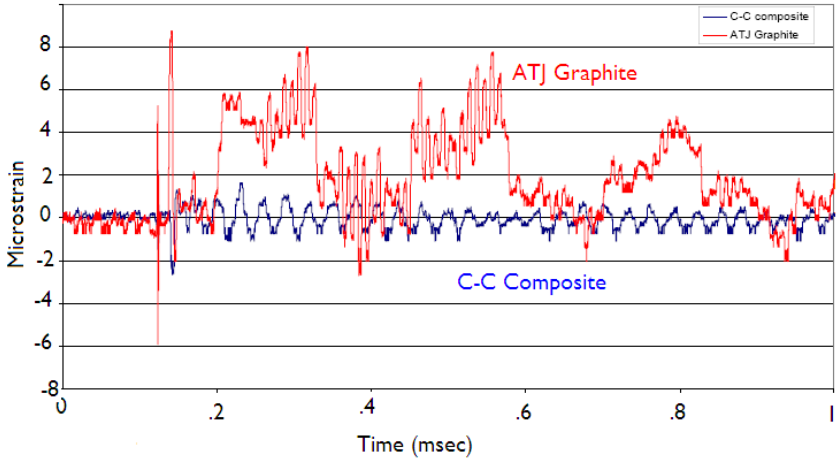
Applications

Medical, Waste Disposal, Muon Acc
Proton Booster, AGS Doubler

BNL involved in Design Studies

Solid target Studies

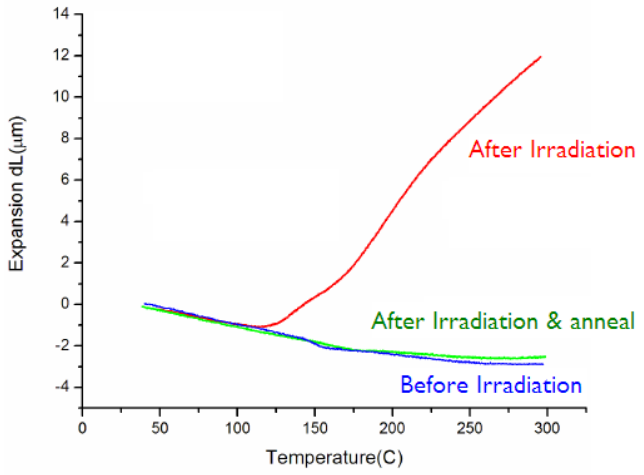
- Target Shocks in AGS Beam
- Study effect of radiation on strength & thermal expansion
- Many Materials
  Vascomax, AlBe, C-C Composite, Invar, Ti alloy, Nickel on Al,Gum metal



Shock for Graphite & C-C

Interesting results

- For both C-C Composite & Invar
- Low Temp Coef. cuts shock
- Radiation spoils Low Temp Coef.
- But annealing restores it



Thermal expansion of C-C: before, after rad, after anneal

Accelerator Test Facility (ATF)

- **World's only Accelerator Physics User Facility**
  Open to proposals from anywhere
  Approval by Scientific Program Director (Palmer)
  With advice from ATF Program Advisory Committee
  Program carried out by ATF Facility Director (Yakimenko)

- **For study of interactions between beams and laser radiation**
  But has done many experiments beyond this

- **Facility consist of:**
  1. 60 MeV electron beam with world record small emittance
  2. Terra Watt CO_2 laser
  3. Multiple beam lines in experimental hall
  4. A range of available experimental equipment
  5. A small permanent staff to help users

These studies are on Basic Accelerator Physics, with possible applications in many fields - Nuclear Physics, High Energy Physics, Material Sciences, Medical applications, Industry etc.

Interactions of Beams and Radiation

- **Fields in Laser foci are very High** $\mathcal{E} > 100$ **GeV/m**
- **But they are transverse and usually do not accelerate**

Theorem (Lawson, Woodward, Palmer) :

No Linear Acceleration ($\Delta E \propto$ field $\mathcal{E}$)
In Vacuum
Far from Materials ($L \gg \lambda$)

Acceleration only if:

Condition	Name	Field/Energy limit
Nearby Structure	Linac	Breakdown
Wiggler Field	Inverse FEL	Synchrotron Rad
Solenoid Field	Cyclotron	Synchrotron Rad
Uniform Dielectric	Inverse Cherenkov	Breakdown
Periodic Dielectric	Inverse Transition	Breakdown
Plasma	Wake, Beat Wave	Plasma density
Non-Linear ($\Delta E \propto \mathcal{E}^2$)	Pondremotive	Synchrotron Rad

Each of these is the inverse of a Radiation Source

ATF Experiments Studying such Interactions

All known mechanisms have been studied either as
1) Radiation Source, that must decelerate the beam; or
2) The inverse process: Acceleration

'STRUCTURE'	LIGHT SOURCE	ACCELERATION
Periodic Structure	#8 & #13 Smith Purcell	#3 Laser grating #27 Micro-Structure
Wiggler	#11 Spiking in FEL #10 Harmonic Generation FEL #24 SASE	#2 Inverse FEL #20 STELLA Staged IFEL
Solenoid		#25 Cyclotron
Dielectric		#6 Inverse Cherenkov #19 Dielectric Wake
Transition	#29 TR Diagnostic #18 Parametric X-Rays	
Plasma	# Laser Plasma UV Source	#32 Plasma Wake #22 Acceleration and Focusing Proposal: Ion Beam
Non-Linear	#5 Non-Linear Compton #22 Picosecond Compton	Proposal: Non-Linear Acc.

Acceleration Experiments without Laser Source

TECHNOLOGY	EXPERIMENT
Plasma Wake Field	#31 Plasma Multibunch Wake
Active Medium	#30 PASER

Diagnostics and Technology Experiments

TECHNOLOGY	EXPERIMENT
Wigglers	#1 Micro-undulator #12 Pulsed wiggler
Beam Detection	#14 Profile Imaging #16 Micro Beam Position Monitor #21 Smith Purcell Bunch Length Determination #23 Super-Fast Optical Beam Detector #28 MINOS Beam Monitor
Photocathode Gun	#9 Quantum Efficiency Measurements #15 RF Gun Test Program
Other	#17 Computer control System #26 Beam pulse compression

9 Examples out of 32 Experiments

Technology

- #23 Ultra-fast detection of relativistic particles

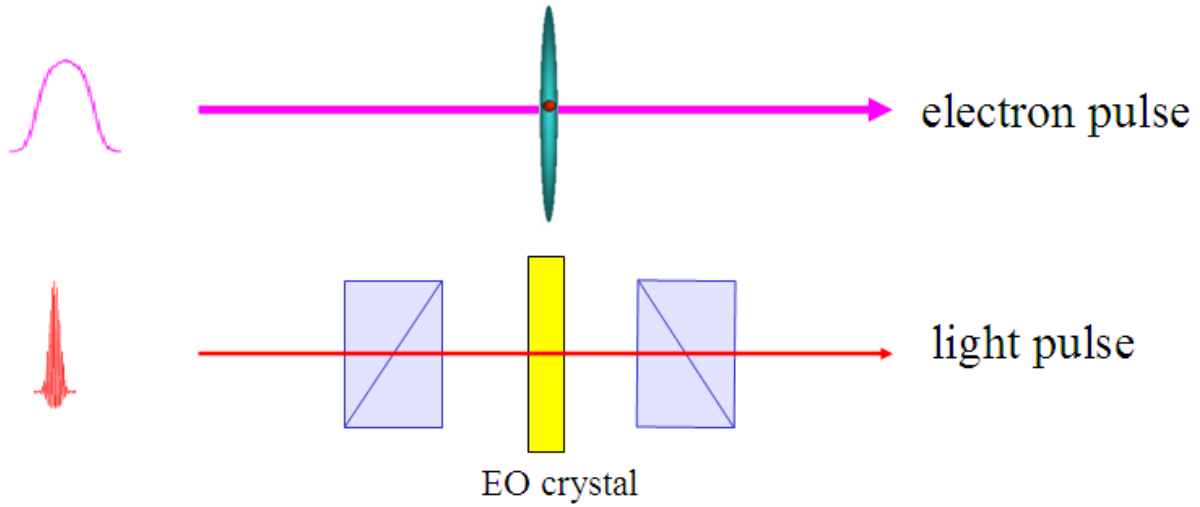
Radiation Sources

- #10 High Gain Harmonic Generation FEL
- #22 Compton Scattering off picosec e beam
- # Laser Induced Plasma EUV Source

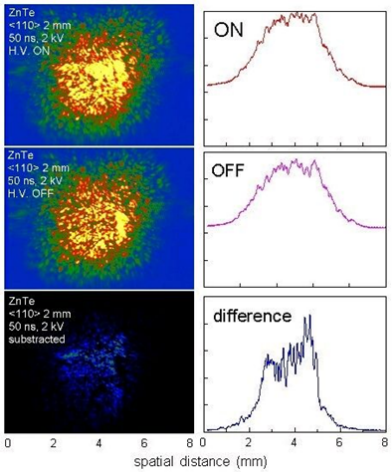
Acceleration

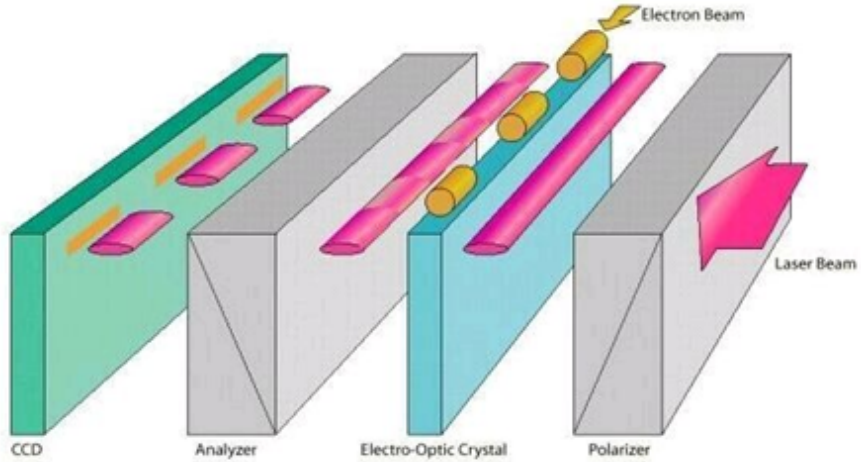
- #10 Short Inverse FEL (IFEL)
- #20 Staged Electron Laser Acceleration STELA
- #22 Acceleration in a Plasma Column
- New: High-brightness picosecond ion beam source
- New: Non-Linear Vacuum Laser Acceleration

#23 Ultrafast detection of relativistic particles



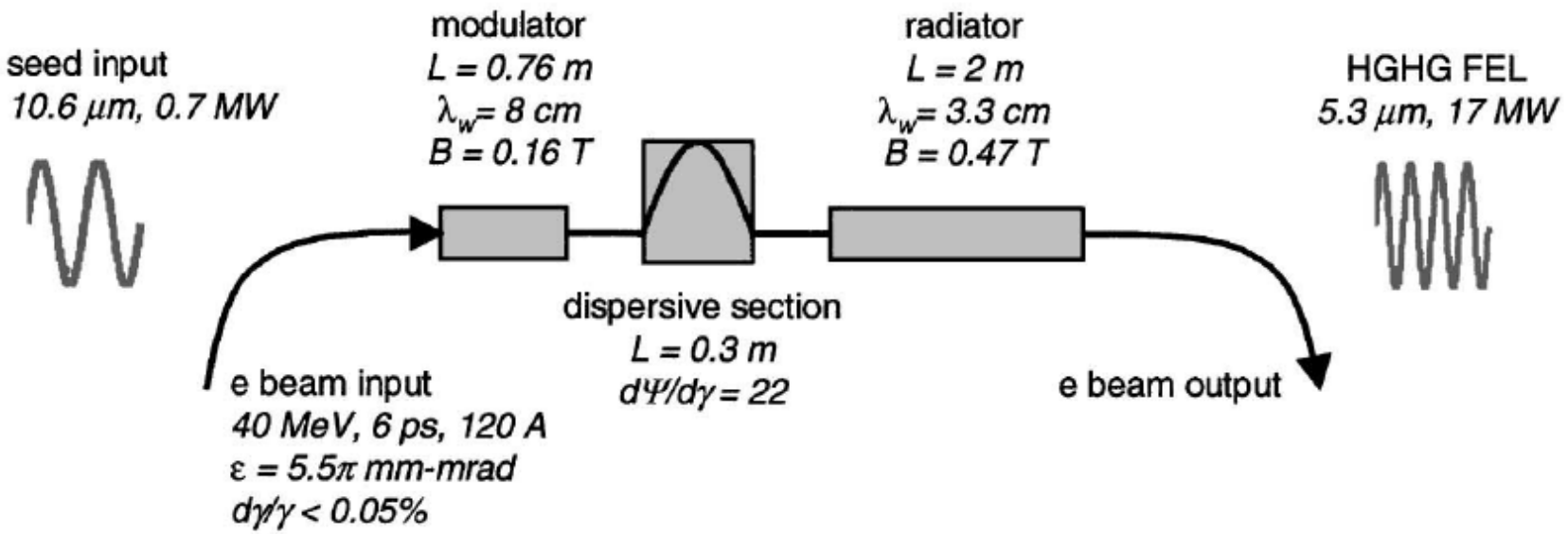
- As fast as the laser pulse: fempto seconds
- Transverse geometry gives time to spacial conversion
- Initial tests without beam



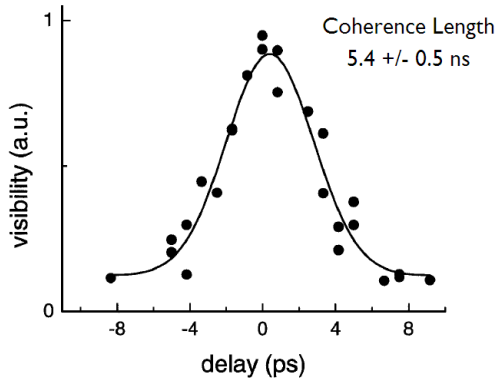


#10 High Gain Harmonic Generation FEL

- Alternative to Self Amplified Spontaneous Emission (SASE)



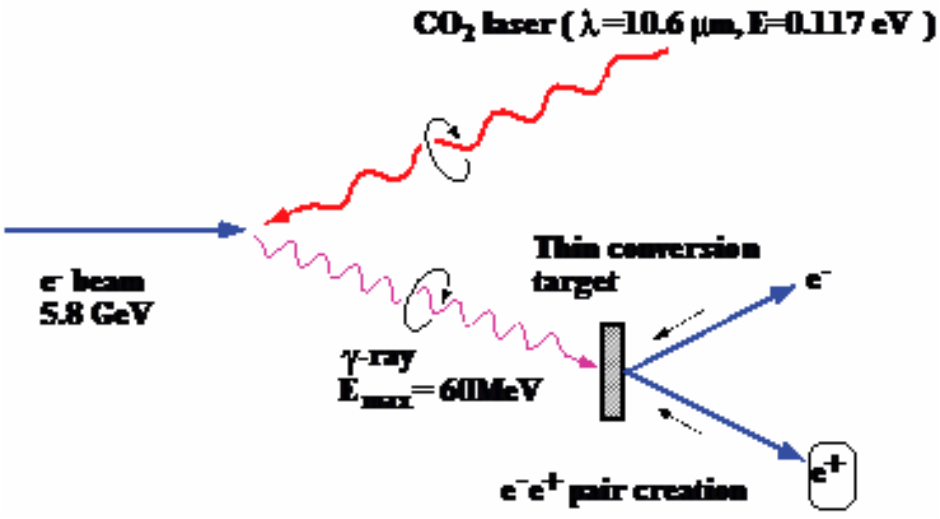
- Modulation at lower freq. has higher harmonic components
  5.3, 2.6, 1.7 μm from 10.6 μm
- Selected higher harmonic then amplified i
  5.3 μm in this demonstration
- Phase and coherence length from seed las
  10,000 times better than SASE

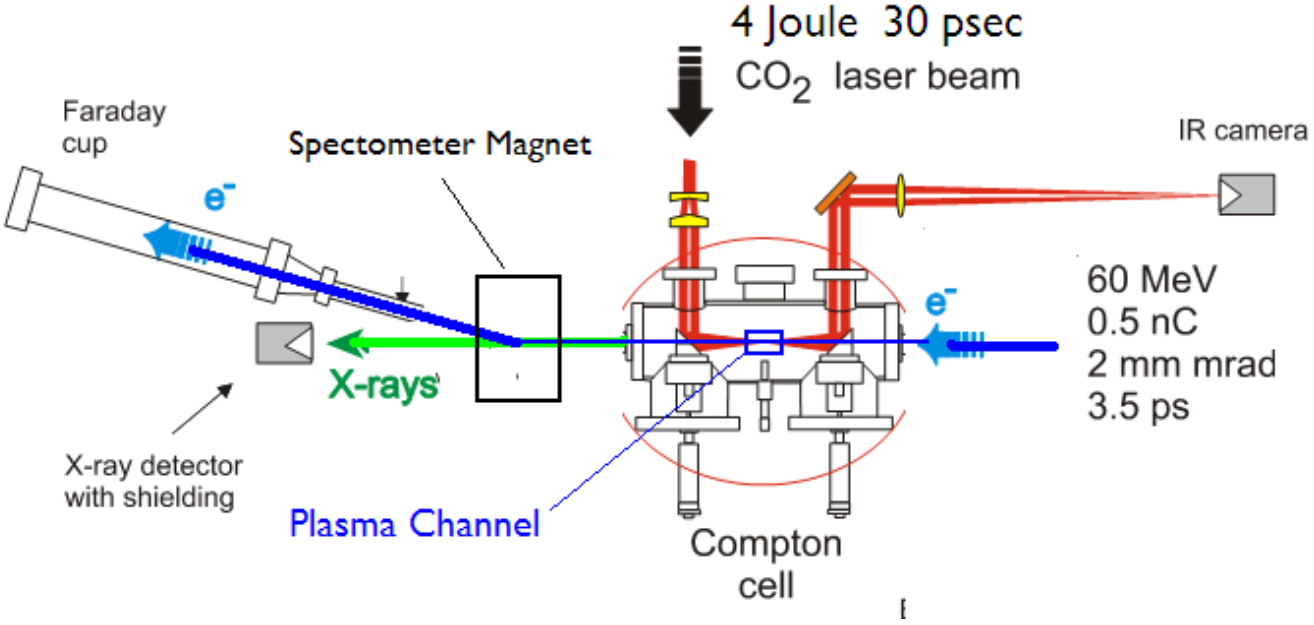


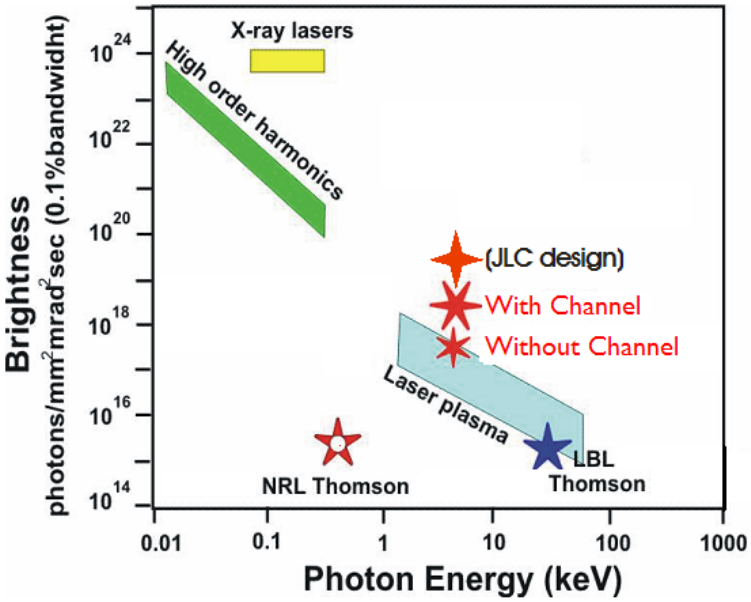
#22 Compton Scattering off picosec e beam

Waseda U, Tokyo Metro U, KEK, UCLA

- Prototype the Polarized Positron Source for JLC
- Interaction Increased by Plasma channel extends Raleigh depth of focus to channel Length
- Observed Second harmonic





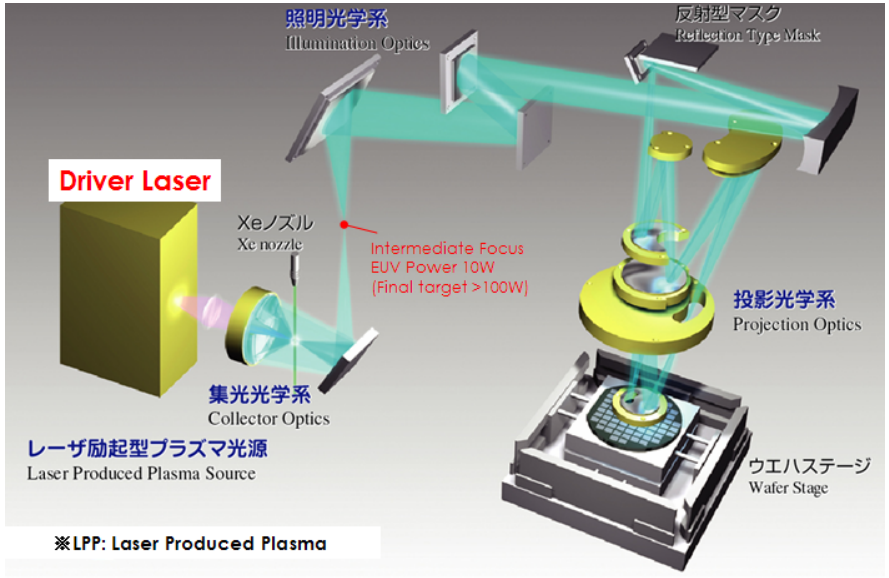


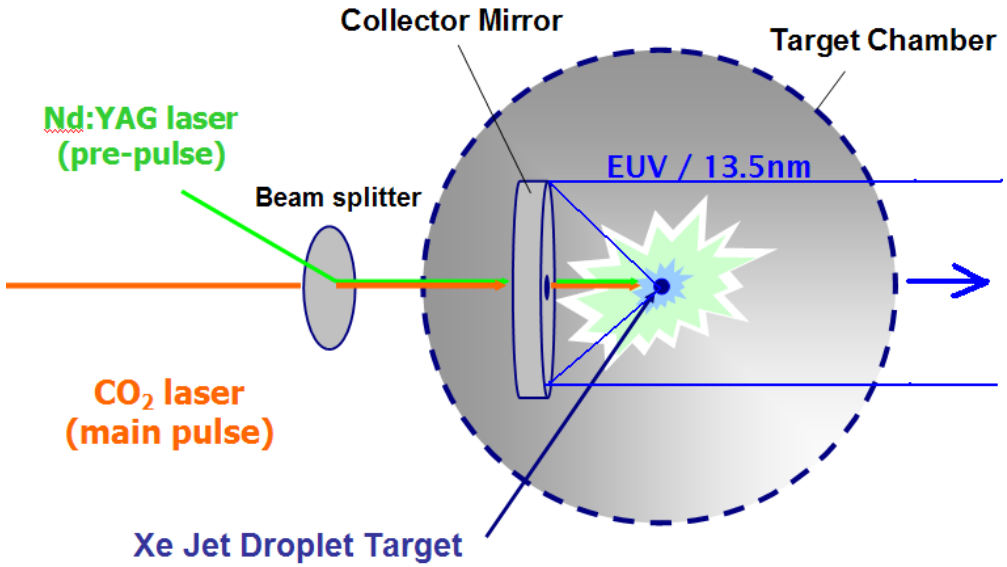
World record Brightness Upgraded laser should reach JLC Design

Laser Induced Plasma EUV Source (no beam)

(Feasibility Study finished)

EUVA, Hiratsuka, Japan; Univ. of Miyazaki; BNL



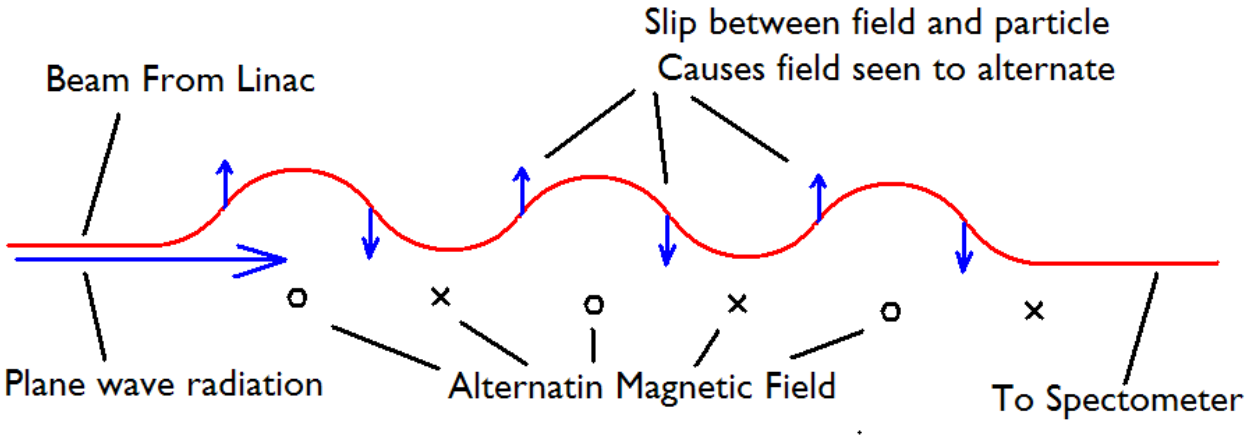


Study yield vs laser power and pulse length

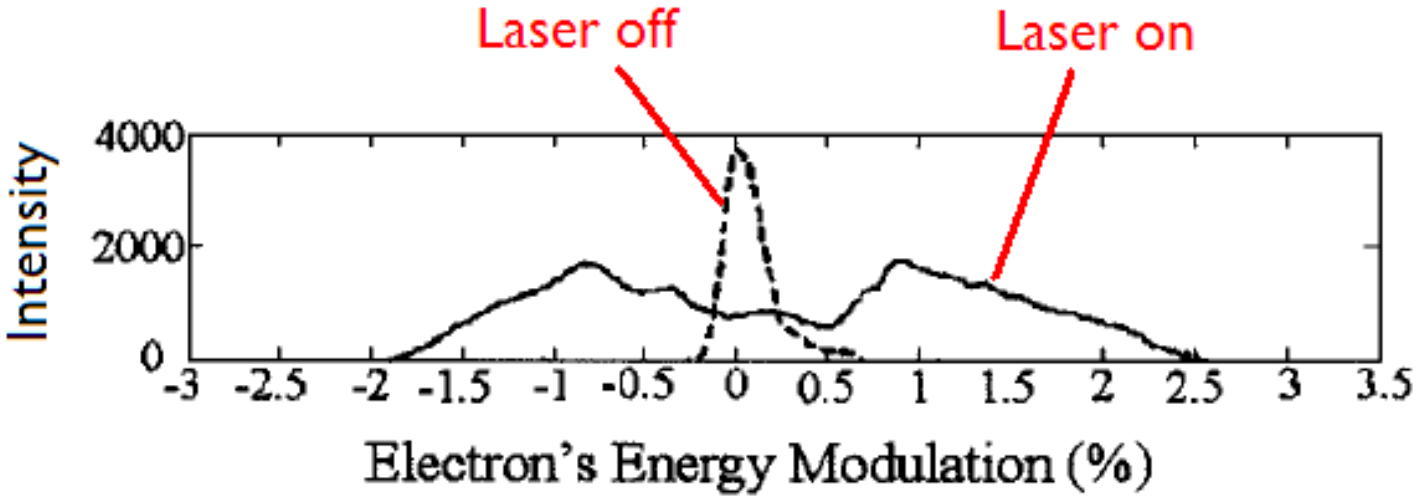
- New and unexpected line of research for ATF
- Establishes practicality of "disposable" structures - as suggested for acceleration

Single Stage Acceleration Studies

Short Inverse FEL



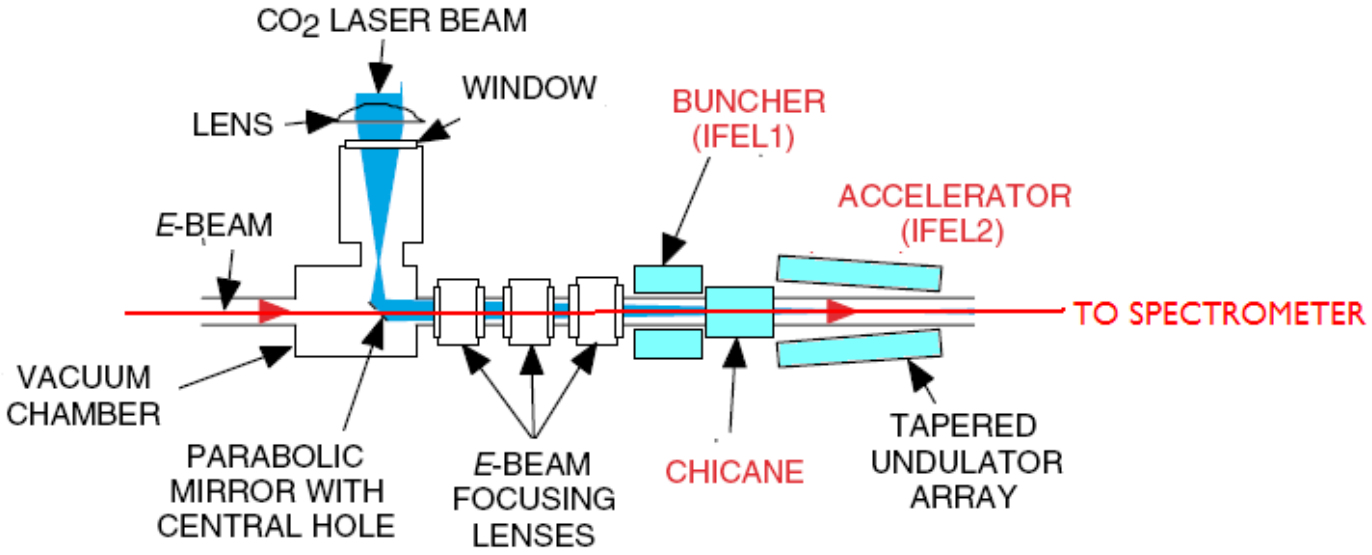
In a simple short interaction of a field and a beam, depending on phase, there will be acceleration of deceleration depending on phase



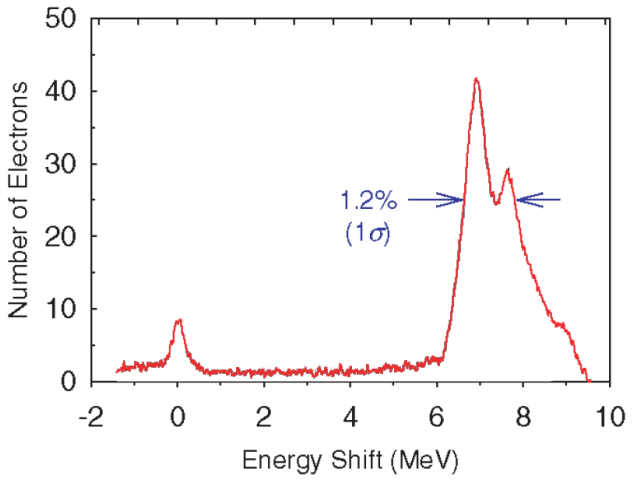
Two Stage Acceleration Study

Acceleration without Deceleration Requiring Phasing

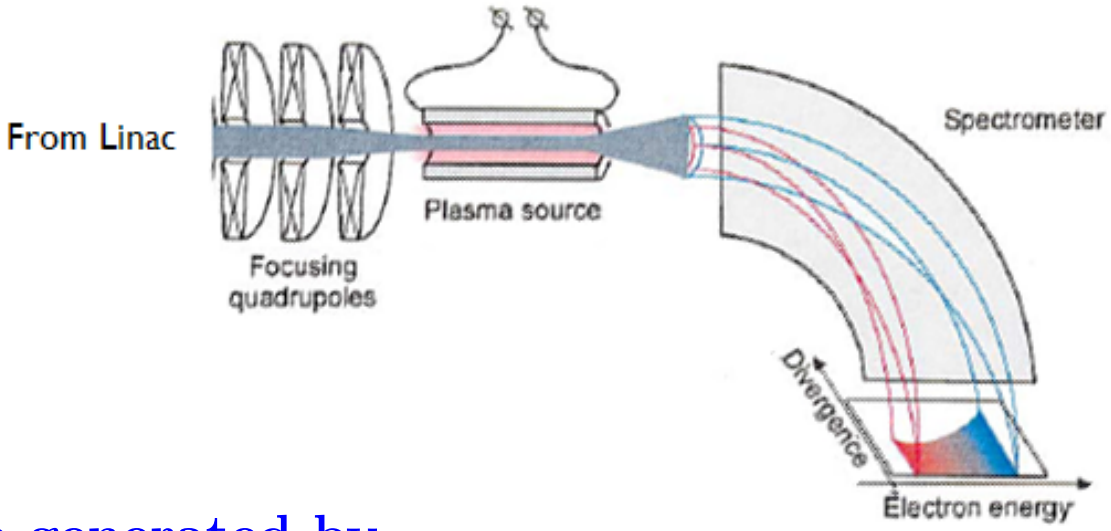
#20 Staged Electron Laser Acceleration STELA



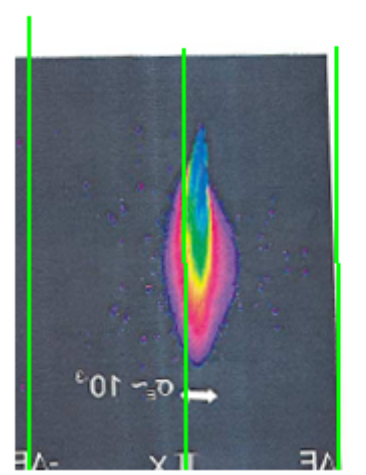
1. Beam energy modulated by CO2 light in IFEL #1
2. Chicane bunches beam
3. Phase set in IFEL #2 to accelerate bunches



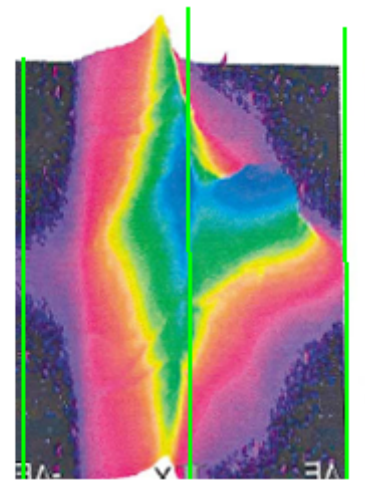
#22 Wake Acceleration in a Plasma Column (no laser)



- Wake generated by front of beam
- Accelerates the tail
- 0.6 MeV Max Acceleration
- in 17 mm
- 35 MeV/m
- Accelerated beam is also focused



No Plasma

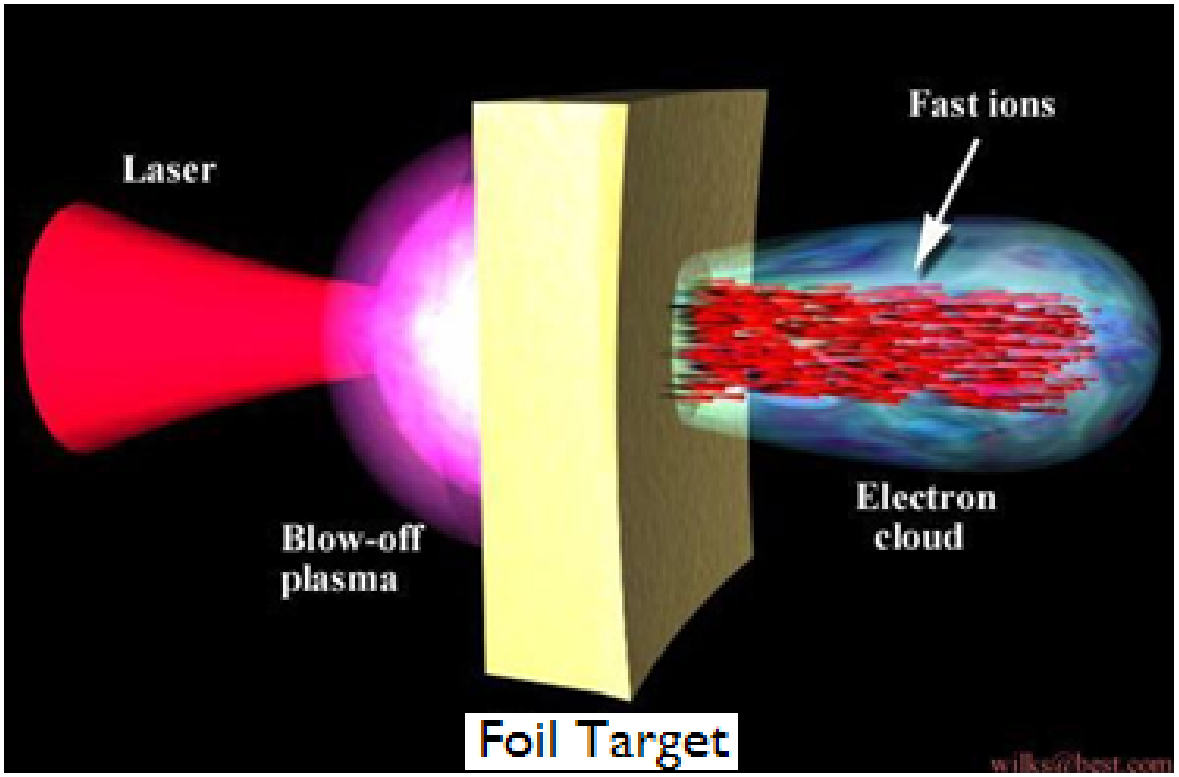


With plasma

High-brightness picosecond ion beam (no beam)

(Stony brook, BNL, TU Darmstadt)

1. Laser heating makes plasma
2. Pondramotive force accelerates electron out the back
3. Electric field extracts ions
4. effect $\propto \lambda$



Experiment Requests 10 J in 1 ps $\rightarrow$ 10 TW (as planed)

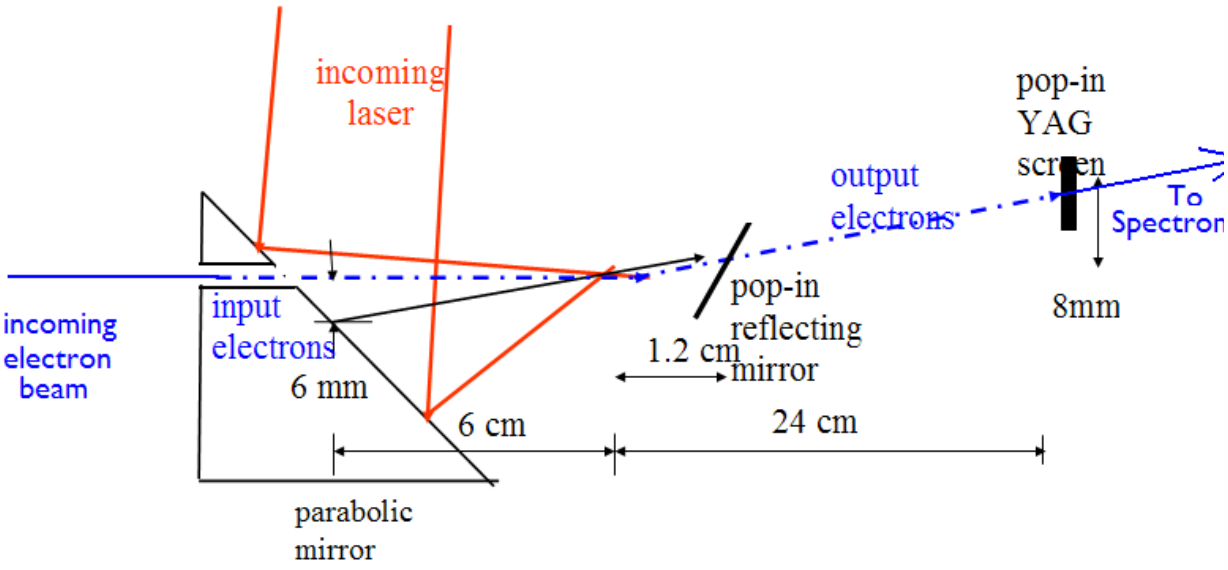
Potential short-term applications:

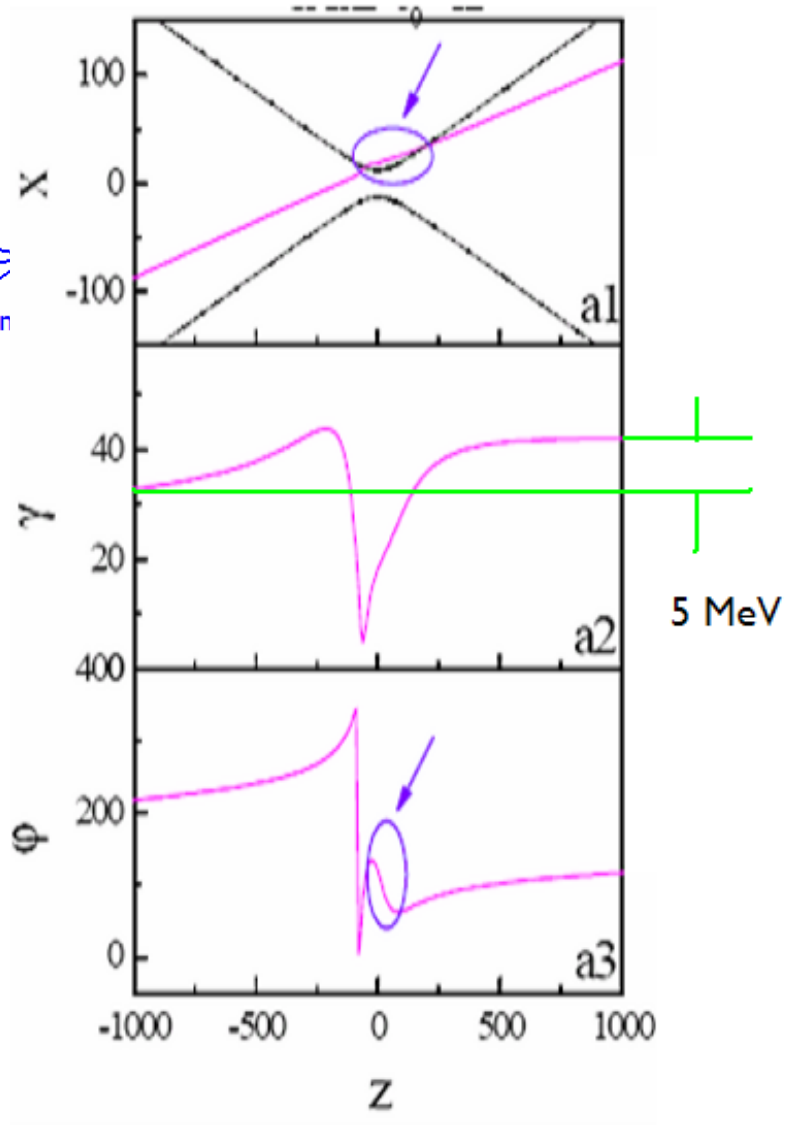
- Activation source for PET
- Ion injector for RHIC with 10-100 times better emittance

Proposal: Non-Linear Vacuum Laser Acc

(Feasibility Study Started)

UCLA; Fudan, China; BNL



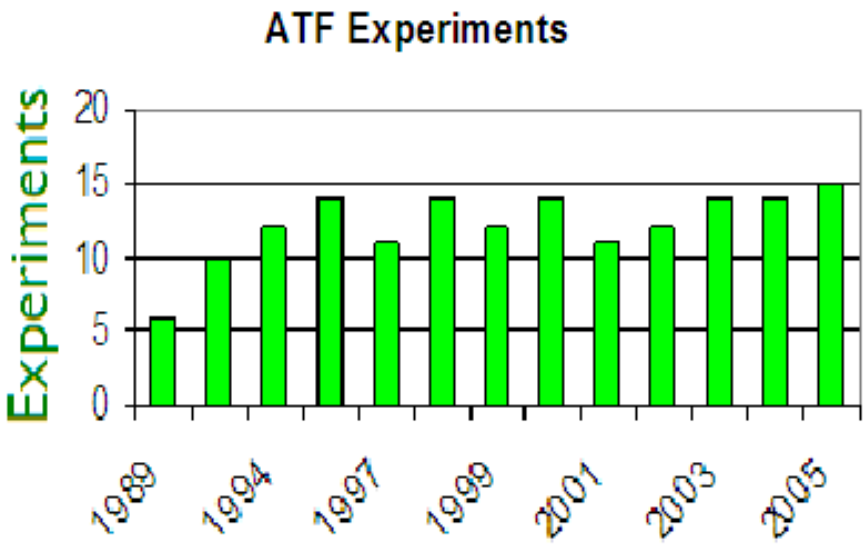


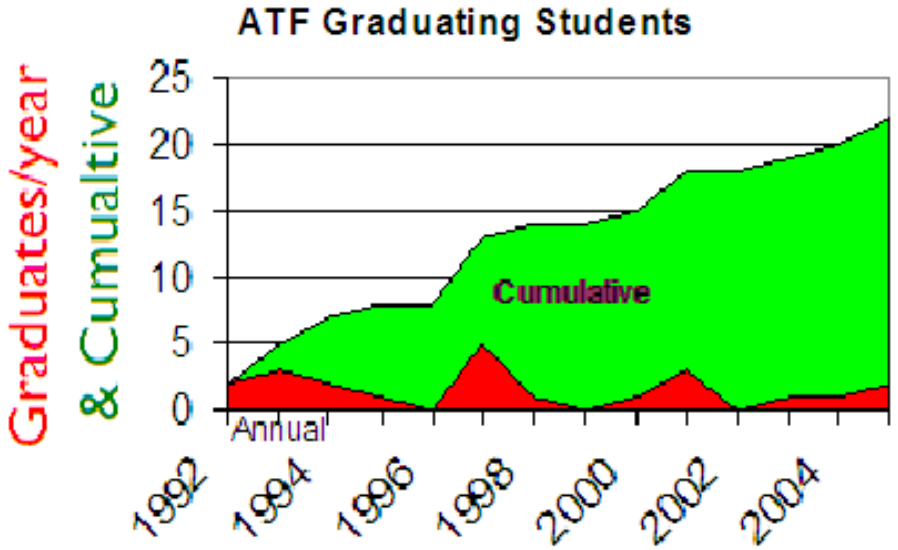
- At low $\mathcal{E}$ ΔE's cancel
- at large $\mathcal{E}$ beam deflected cancelation fails

Requires 10 J 1 ps at 15 MeV (should be available soon)

- **Would demonstrate new mechanism**
- **Possible record gradient: 5 MeV in 250 μm $\rightarrow$ 20GeV/m**

Statistics



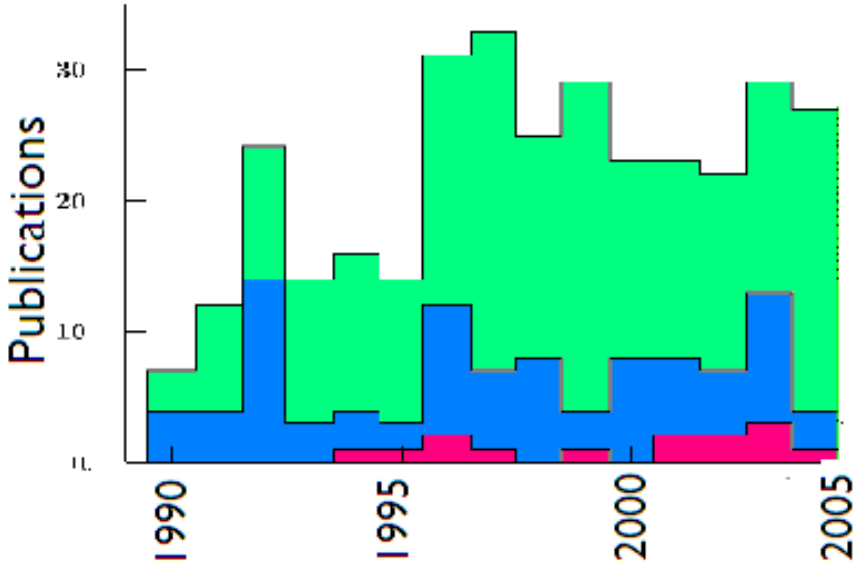


1000 Hours/year

15 Completed Experiments

11 Active Experiments

3 Feasibility Studies



237 Conf Reports

91 Refereed Papers

15 Letters PRL & APL

Conclusion

- **Study of Neutrino Factory (Physics)**
  Only way to study CP if θ_{13} small
- **Study of Muon Collider (Physics)**
  Possible Energy Frontier Machine
- **Study of FFAGs (Physics & CAD)**
  Many possible applications
- **Study of Targets (Physics & Energy Science)**
  Many applications
- **Accelerator Test facility:**
  - Developing New Diagnostics and Technologies
  - Exploring New Radiation Sources
  - Testing Very Advanced Accelerator Methods
  - Education

Exciting and Fundamental Studies