Increasing the capture rate of the Rubicon Inverse Free Electron Laser & advanced IFEL

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Advanced Accelerator Concepts 2016

Overview

UCLA

Introduction to Rubicon

- The Rubicon Inverse Free Electron Laser

Motivation

- Results with the single buncher
- Improvements with double buncher scheme

The experiment

- The potential set-up

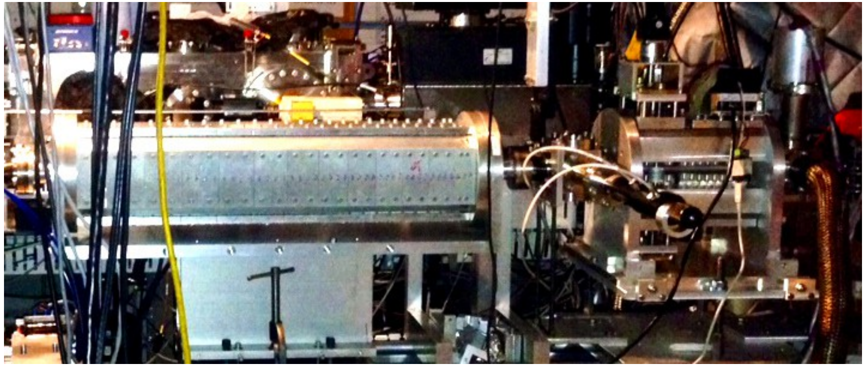
Future plans

- Aemelia: staged IFEL driven ICS experiment for MeV photons

Conclusion

The Rubicon Inverse Free Electron Laser

The IFEL



What is an IFEL?

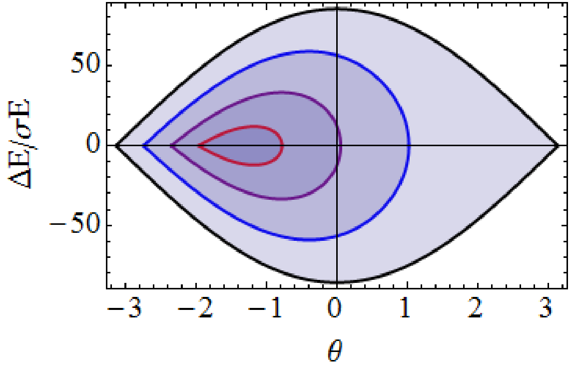
- Resonant energy exchange between a laser and electron beam inside of an undulator: $\frac{\partial \gamma^2}{\partial z} = -2kK_l K \sin(\Psi) = \frac{\partial}{\partial z}\left(\frac{k(1+K^2)}{2k_w}\right)$ $\quad K_l = \frac{e\lambda E(z)}{2\pi mc^2}$ $\quad K = \frac{e\lambda_w(z)B(z)}{2\pi mc}$

gradient phase synchronicity

- Rubicon IFEL: Helical halbach undulator – CO_2 laser seed – BNL ATF
- choose design “resonant” phase and energy to satisfy above equation

Why pre-bunch?

- particles injected near resonant phase and resonant energy will be trapped.
- larger resonant phase (magnitude)
  - → larger gradient
  - → smaller bucket



Pondermotive Bucket

Resonant phase: 0, π/8, π/4, 3π/8

The pre-buncher

Single Buncher

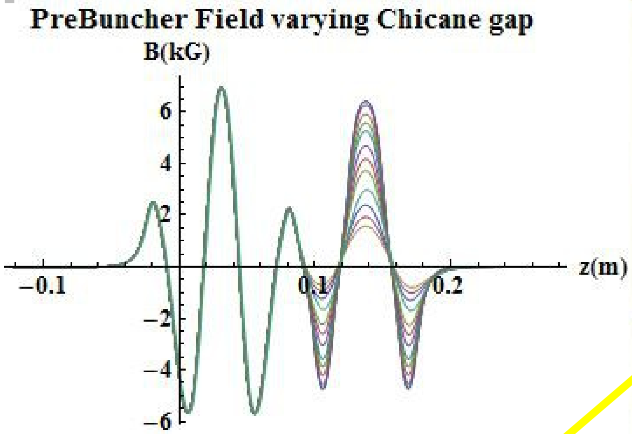
- Single period, planar, halbach undulator

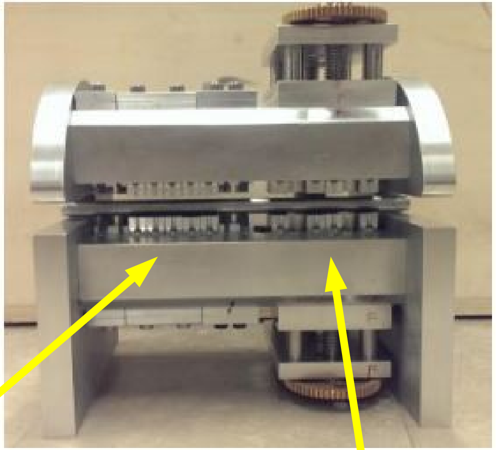
- Permanent magnet, variable gap chicane

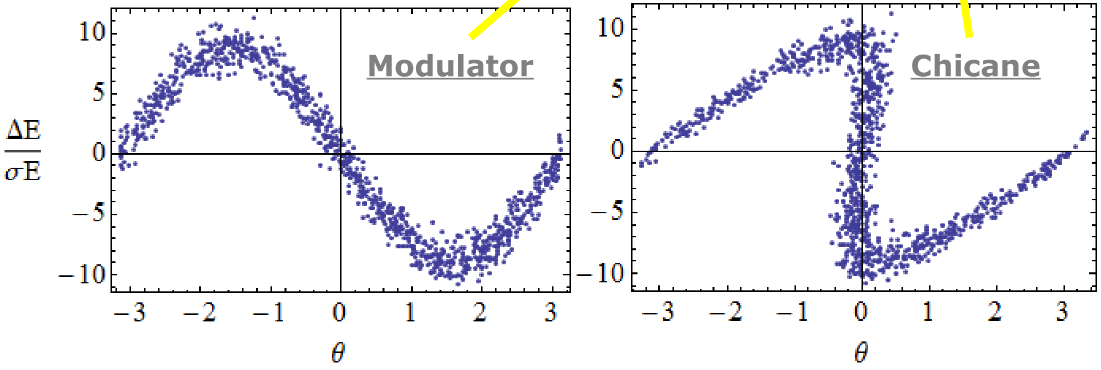
- Laser imparts sinusoidal energy modulation

- Chicane dispersion converts to density modulation

- Chicane delay allows for control of injection phase







Rubicon results

Single Buncher

Rubicon IFEL experiment

- 52 MeV → 95 MeV
- Increased fraction accelerated: 30% → 60%
- Demonstrated emittance conservation

Nocibur high efficiency energy extraction

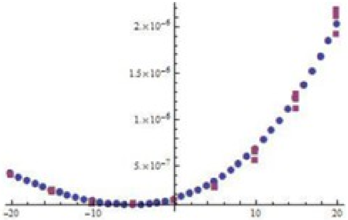
- 65 MeV → 35 MeV
- 45% decelerated – 30% efficiency

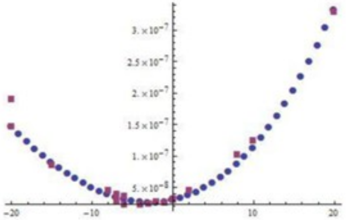
RubiconICS

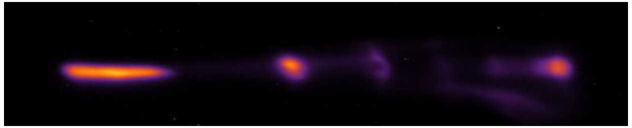
- 12 KeV X-Rays from 80 MeV

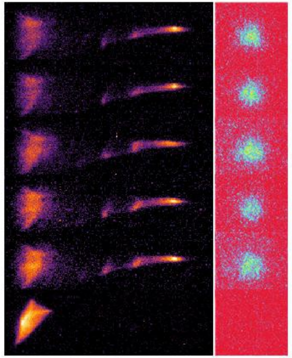
Un- accelerated beam **Accelerated beam**

2.3 µm emittance **2.4 µm emittance**









PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **16**, 010706 (2013)

Cascaded modulator-chicane modules for optical manipulation of relativistic electron beams

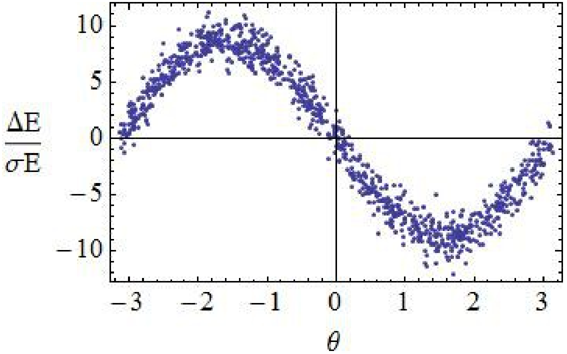
Erik Hemsing and Dao Xiang
SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA
(Received 24 October 2012; published 28 January 2013)

The double buncher

Simple model

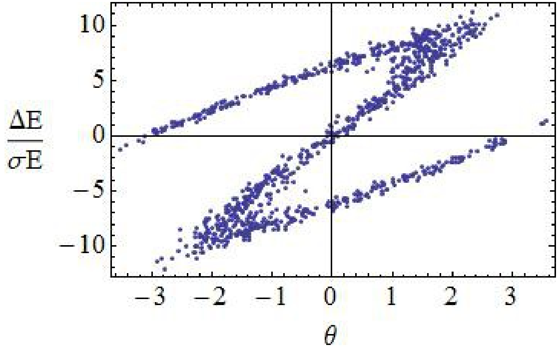
1st modulator

½ period planar undulator (small modulation)



1st chicane

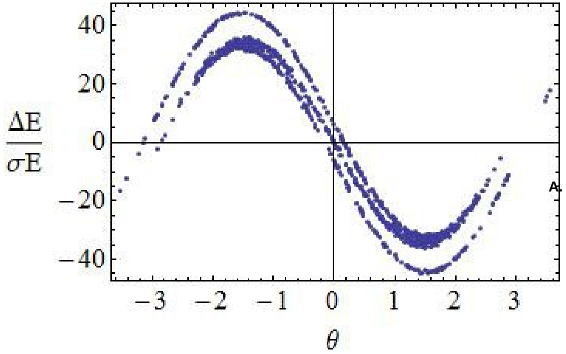
Large R56 chicane compressor (over-rotate)



2nd modulator

1 period planar undulator (large modulation)

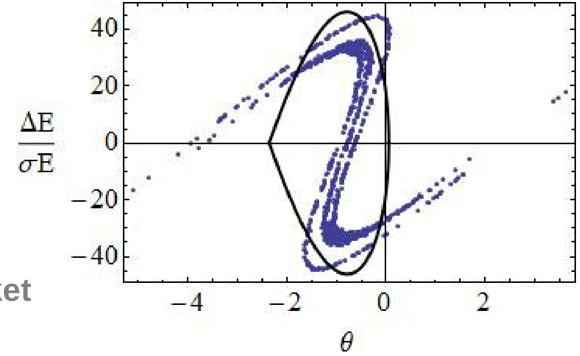
Utilize pre-existing pre-buncher



2nd chicane

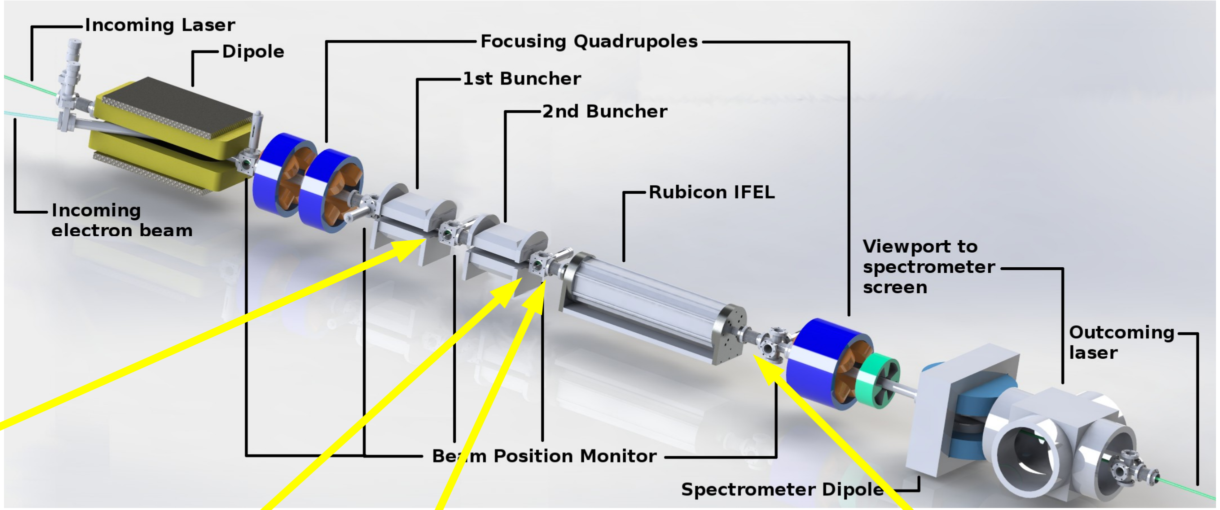
Small R56 chicane compressor (bunch)

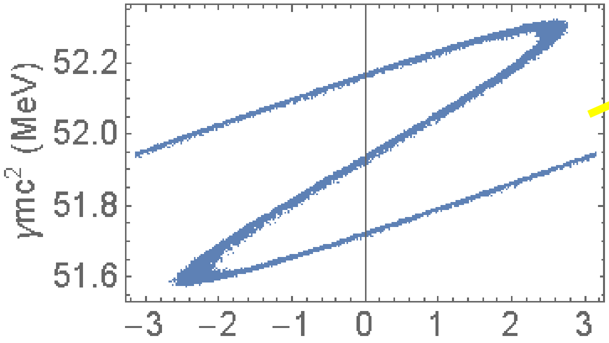
~97% of particles inside of pondermotive bucket

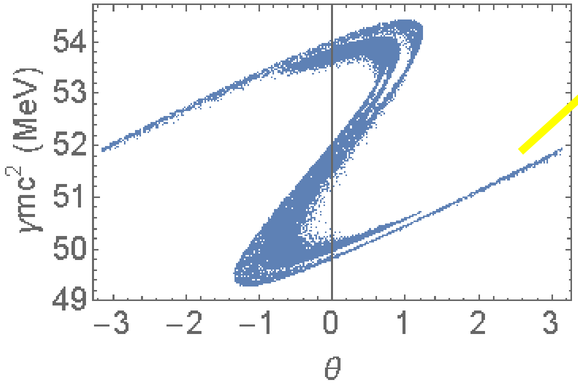


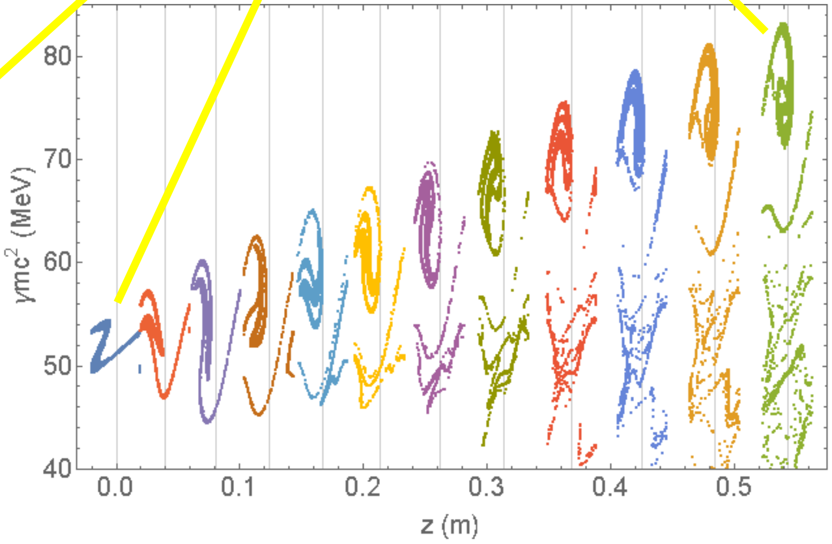
The double buncher

Genesis Simulations







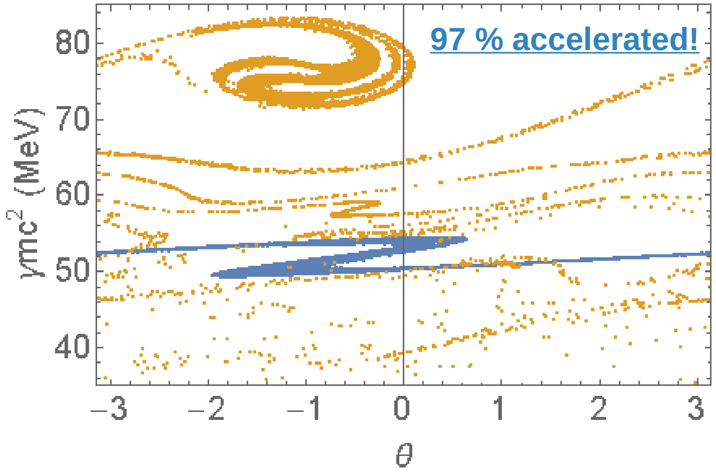


The double buncher

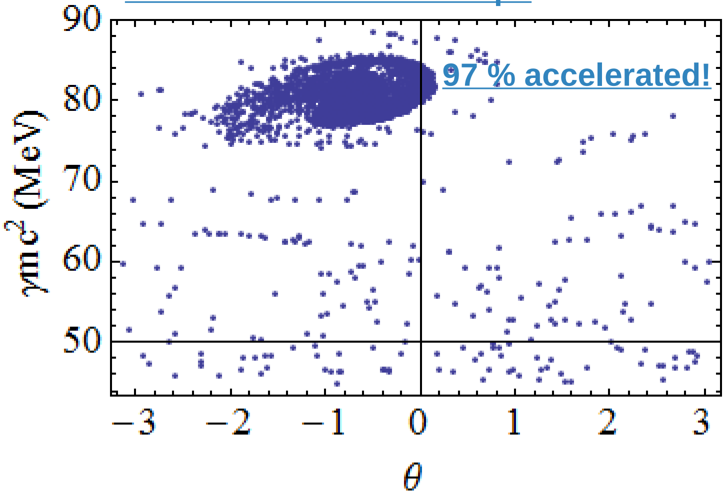
Simulations

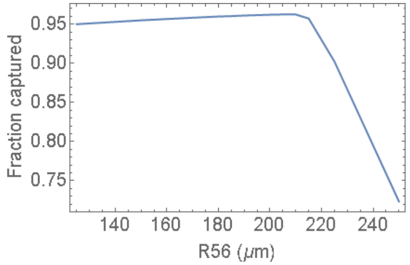
E-Beam energy	**52 → 80 MeV**
emittance	**2 mm-mrad**
σxy (waist)	**100 μm**
Laser Wavelength	**10.3 μm**
Rayleigh Range	**0.55 m**
Laser Waist	**1.4 mm**
Laser Power	**166 GW**
λw (1st modulator)	**0.07 m (half period)**
Chicane 1: R56	**215 μm**
λw (2nd modulator)	**0.05 m (1 period)**
Chicane 2: R56	**80 μm**
period tapering	**0.04 -0.06 m**
K tapering	**2.03-2.56**

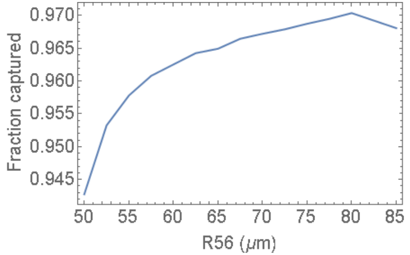
Genesis – 3D Time Dependent

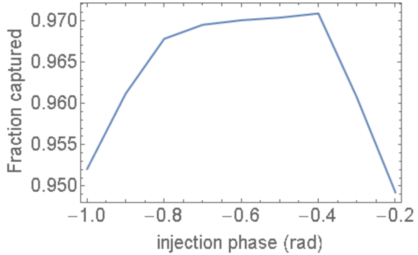


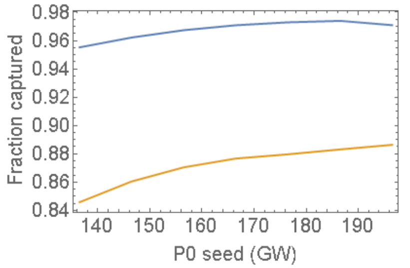
GPT – 3D Radia field maps











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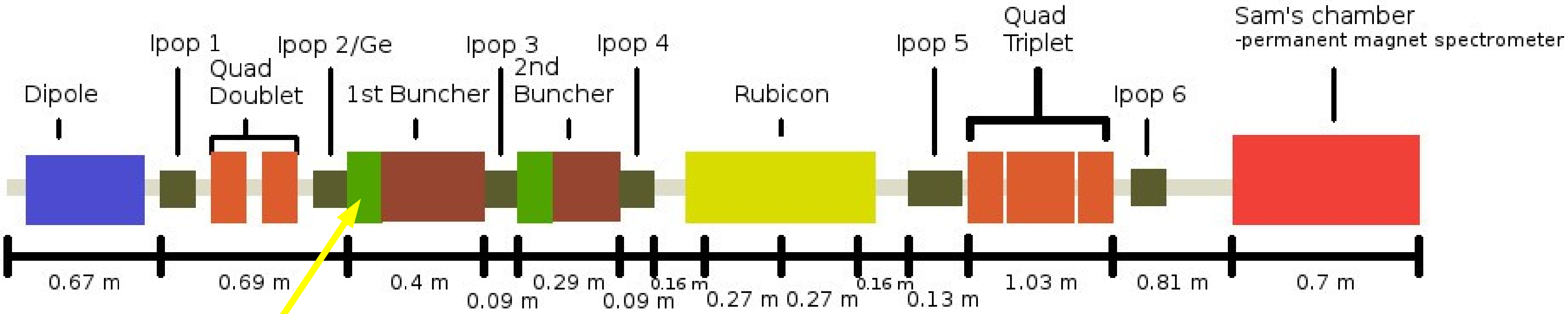
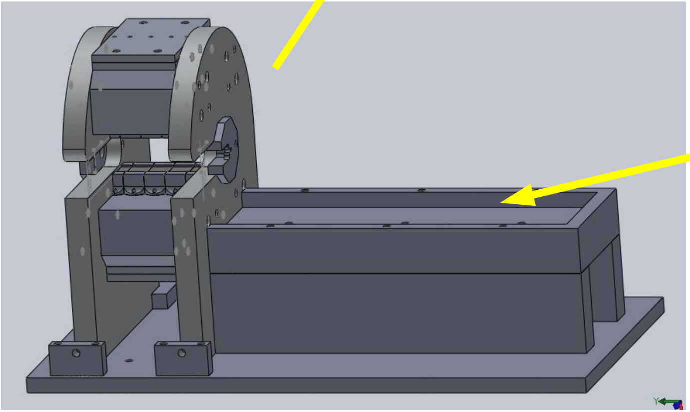
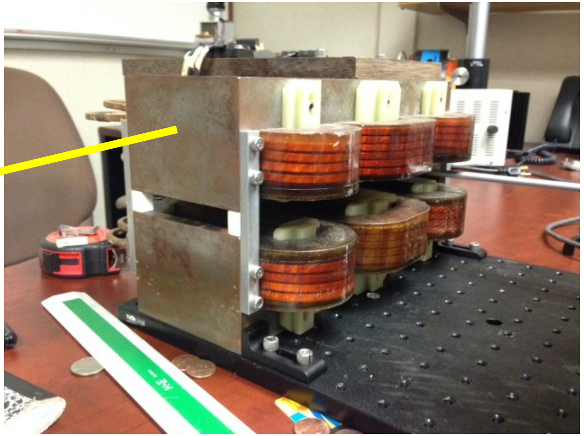
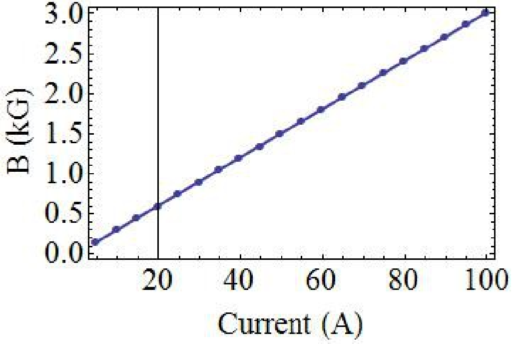
Experiment preparation









The double buncher

Experiment preparation

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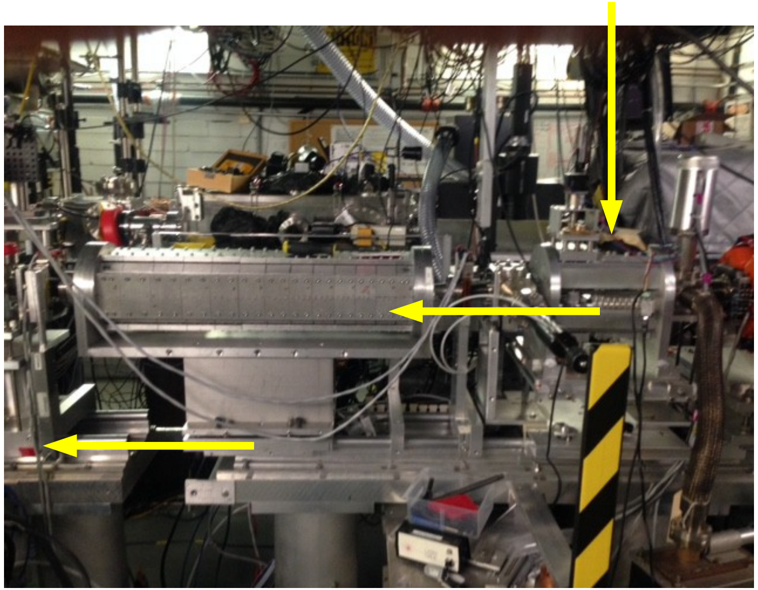
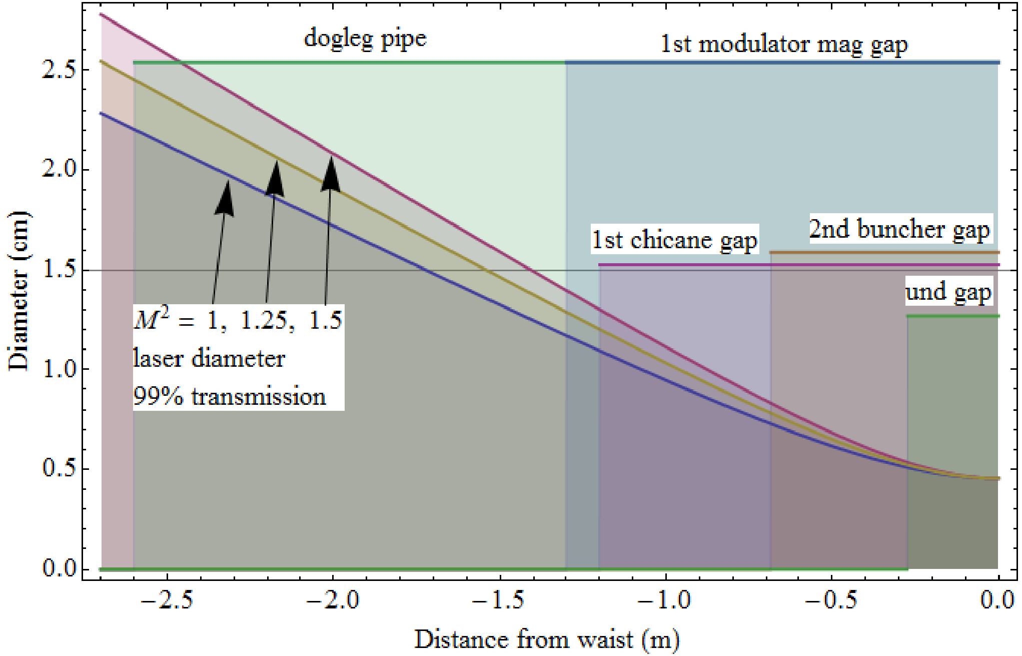
New buncher position





What's next for IFEL research at ATF?

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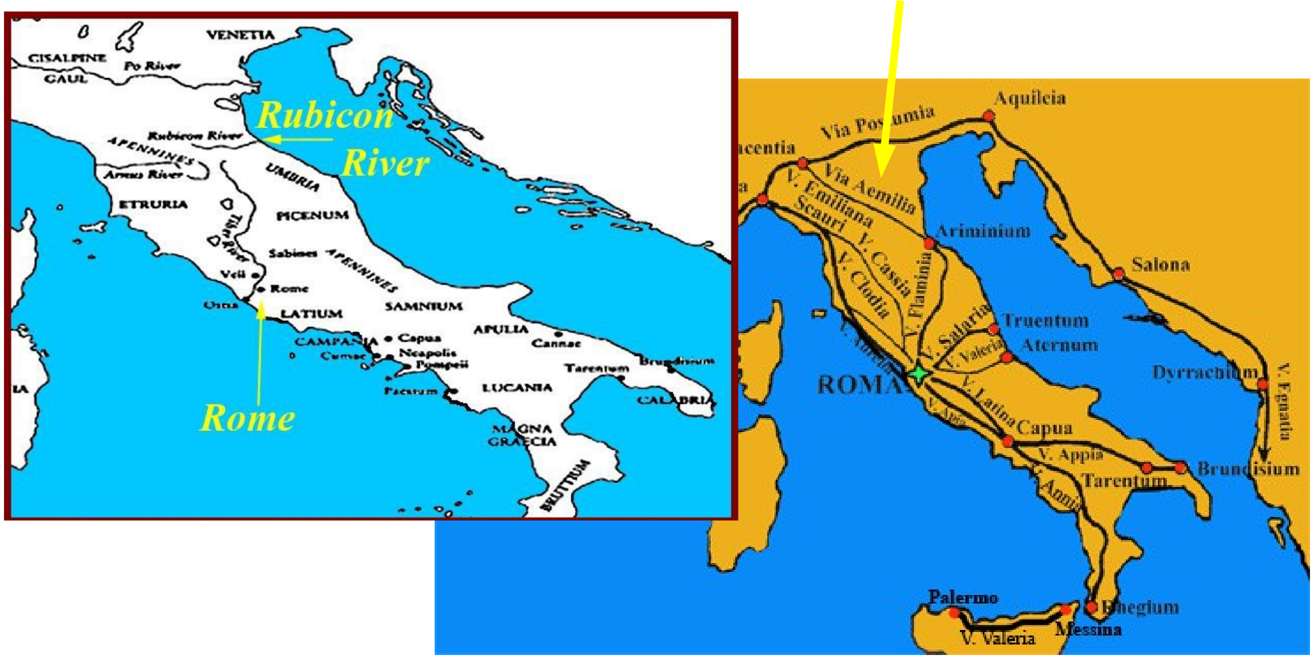
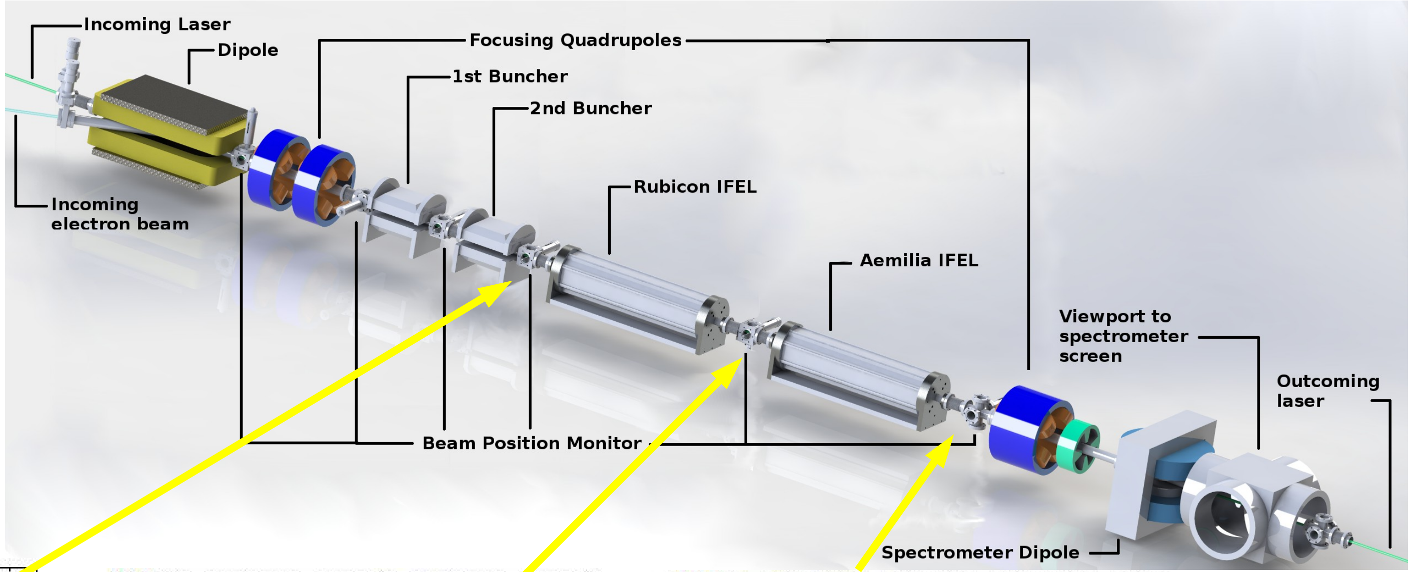
ATF - UCLA
Experiment for
MeV
ICS photons from a
Laser driven
IFEL
Accelerator

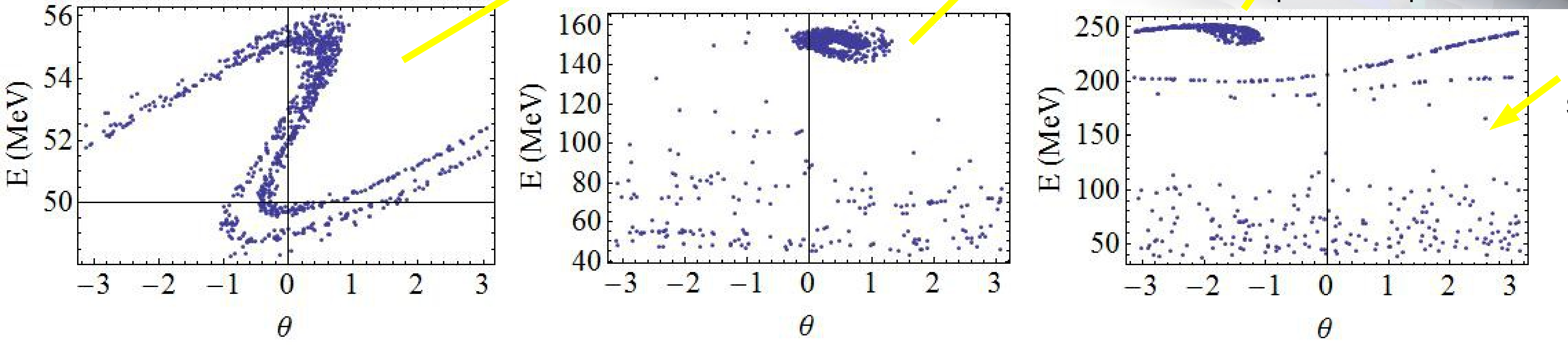
After crossing the Rubicon, Julius Caesar lead his legion down the Via Aemilia. We intend to do the same!



Aemilia

- Add 2nd IFEL stage after Rubicon
- Retune Rubicon for final energy of 150 MeV
- 2nd stage boosts energy to 240-250 MeV
- Use double buncher for high capture

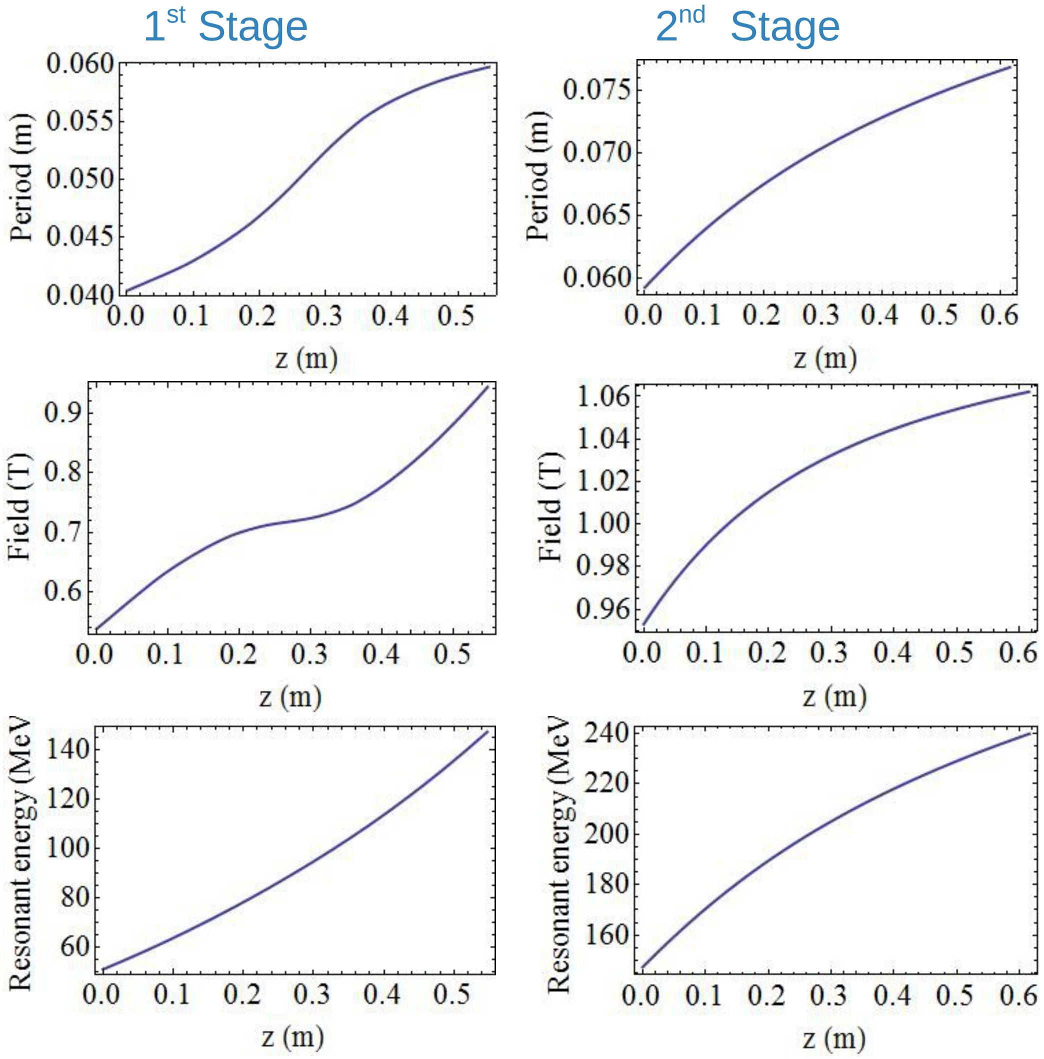




GPT simulations

Aemilia

- tapering designed for 1.75 TW
    - GPT simulations: 2 TW
- stages separated by 0.2 m
- laser waist: 0.1 m after 1st stage (1 mm waist)
- rayleigh range: 0.3 m
- GPT simulations: 70% accelerated
- ICS with 1um YAG laser → $h^*\nu_{ICS} > 1$ MeV



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Aemilia: a difficult experiment

Realizing Aemelia:

- Could be realized on beamline 2:

Would maybe need to remove triplet.

- Laser clipping on dog-leg pipe

- 2 TW CO2 power?

- Control of injection phase

between 1st and 2nd stages

- YAG ICS:

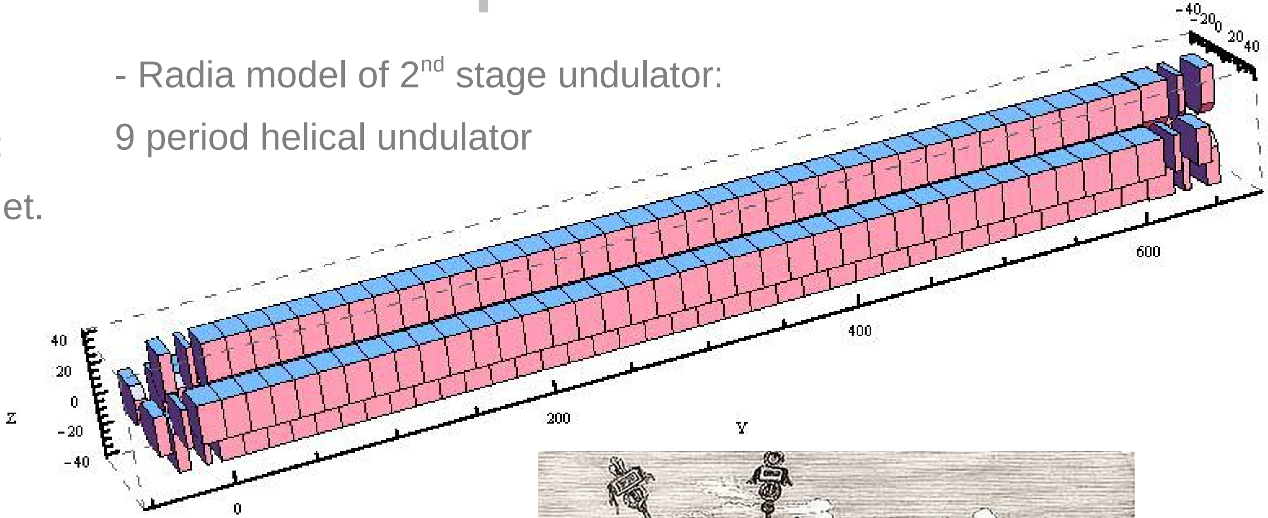
  - focusing of 240 MeV beam

  - timing

  - interaction location?

- Radia model of 2nd stage undulator:

9 period helical undulator



"The die is cast."

Conclusion

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- Using cascaded pre-bunching: potential 97% capture rate
    - Time-Dependent Genesis simulations
    - GPT simulations

- Experiment is realizable at ATF and the second buncher is in production
    - E-beam parameters, laser parameters, beamline layout

- Aemelia: where do we go from Rubicon?
    - 240 MeV output energy ~200 MeV/m gradient
    - potential generation of MeV ICS photons

UCLA

UCLA: P. Musumeci, J. Duris, I. Gadjev, Y. Sakai

ATF: I. Pogorelsky, M. Polyanskiy, M. Fedurin, C. Swinson, M. Babzien, K. Kusche, M. Montemagno, P. Jacob, G. Stenby, B. Malone, M. Palmer

Radiabeam: A. Murokh

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Thanks