Coherent Light Source R&D at MIT

W.S. Graves, F.X. Kärtner, D.E. Moncton (MIT)

Ph. Piot (NIU)

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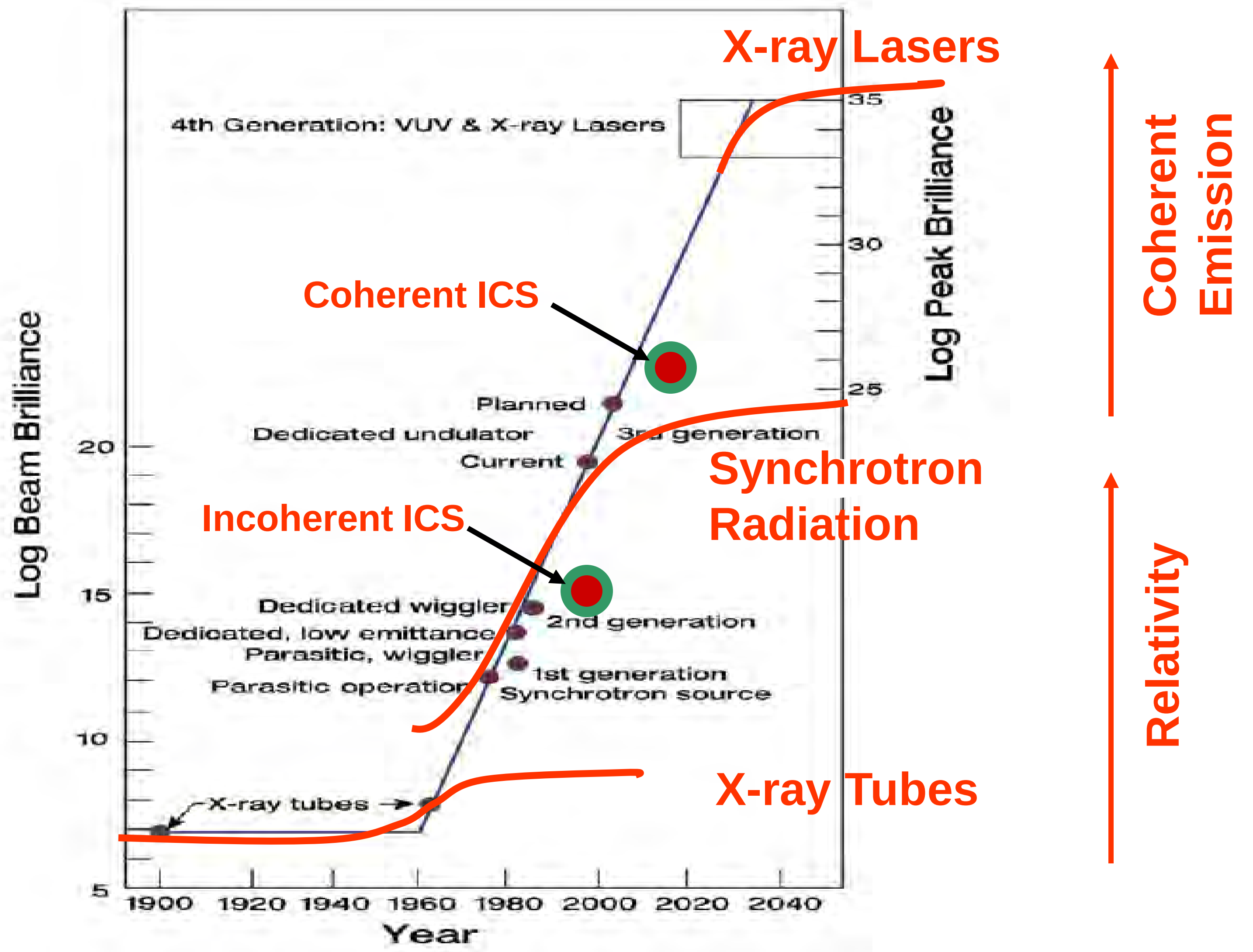
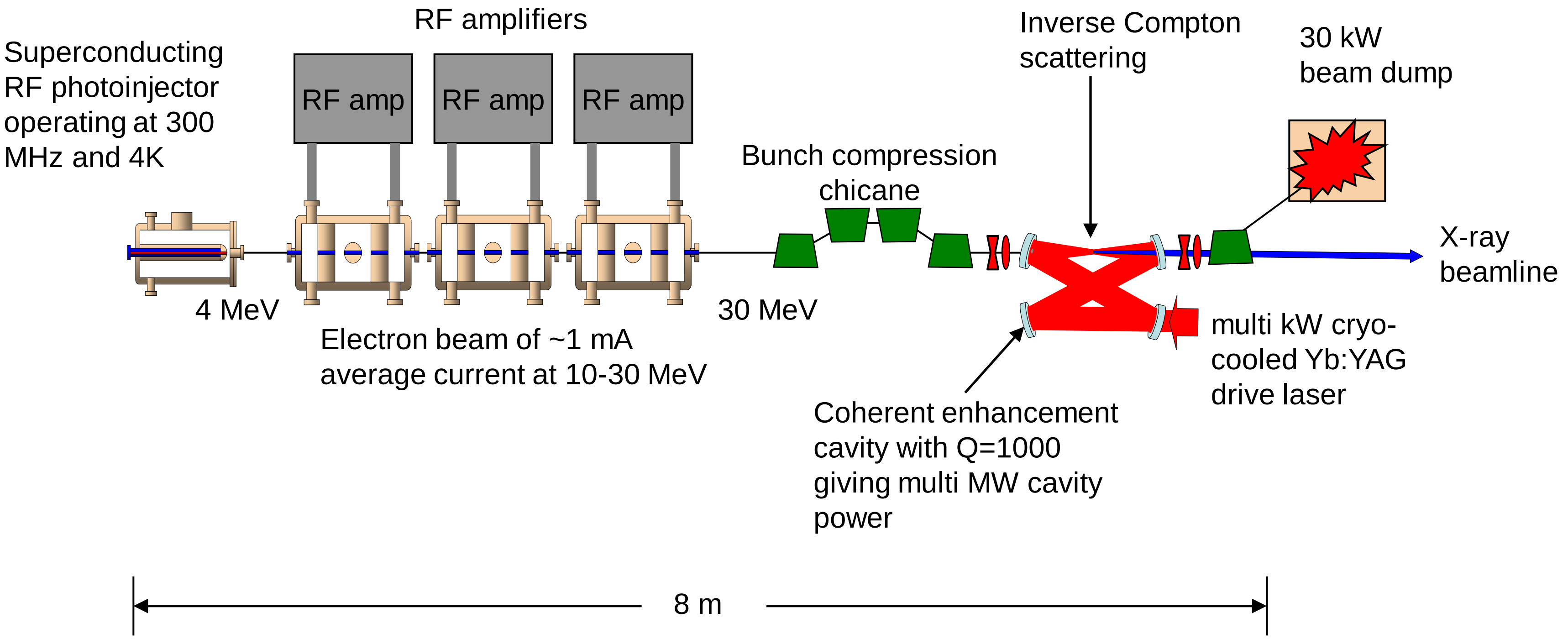
Annapolis, MD

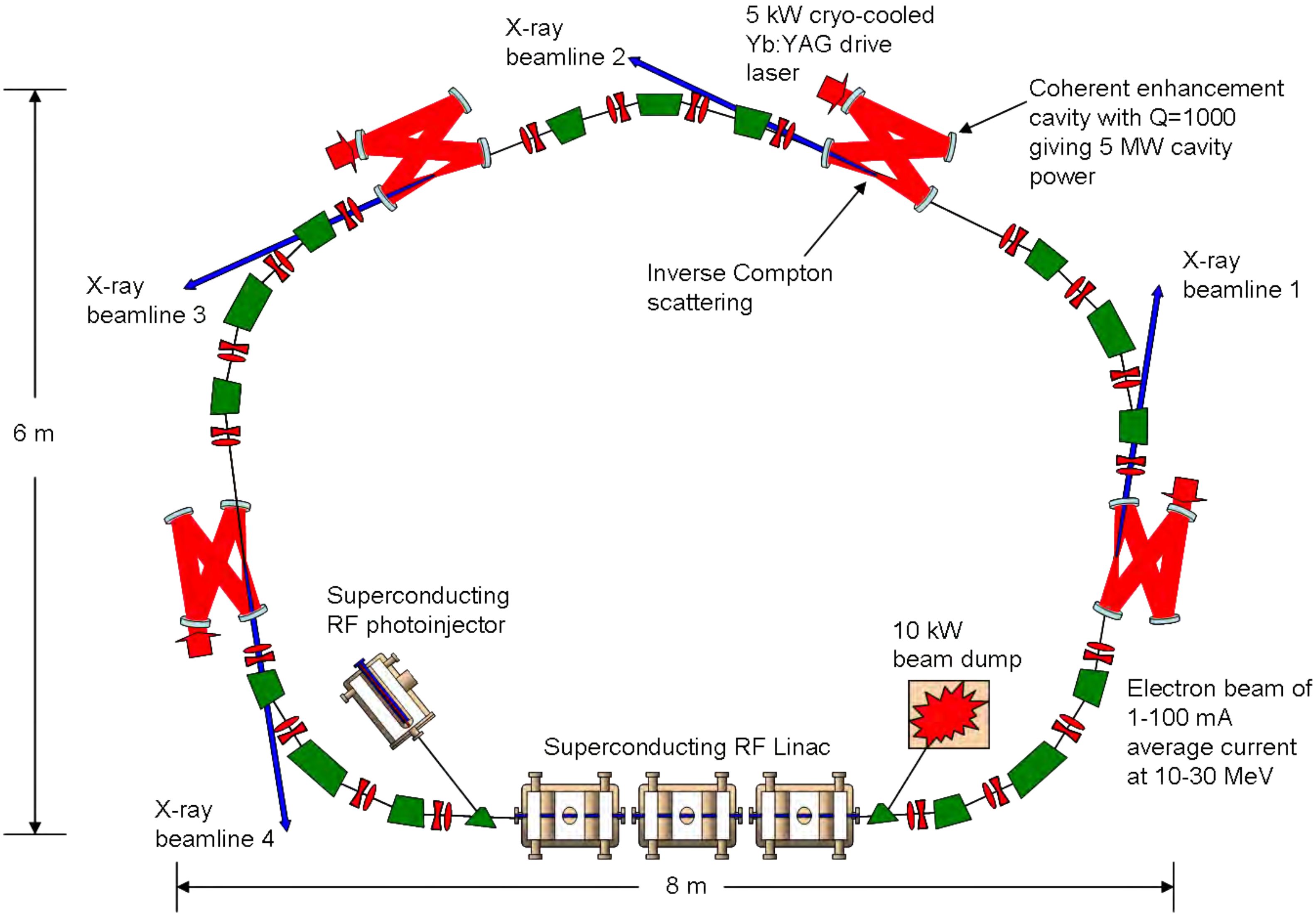
Light Source Performance



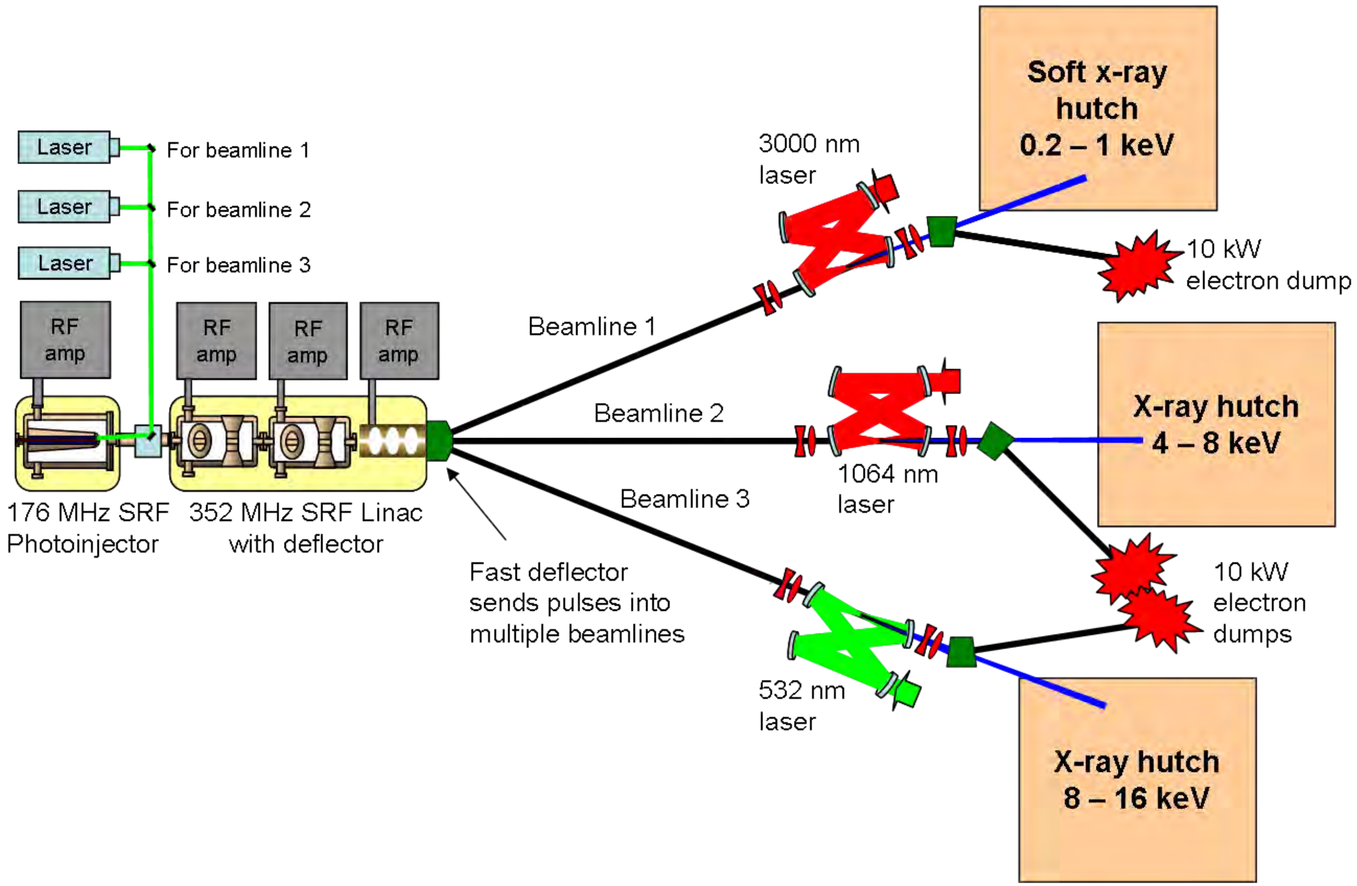
High Repetition Rate ICS with SRF Linac



ERL driving 4 X-ray Beamlines



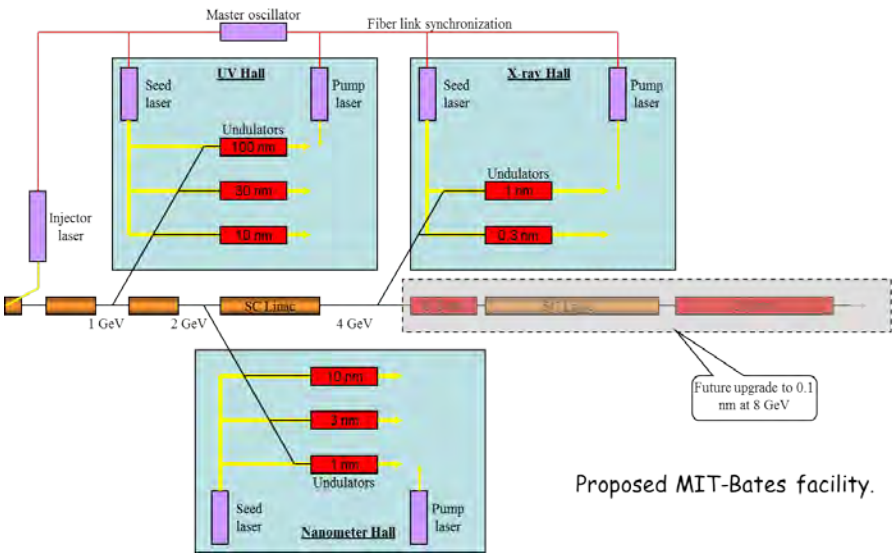
Concept for Multi Beamlines, Multi Independent Energies



Use 3 photocathode drive lasers with different arrival times to generate pulses into multiple beamlines each with independently tunable energy.

FEL Facility Design

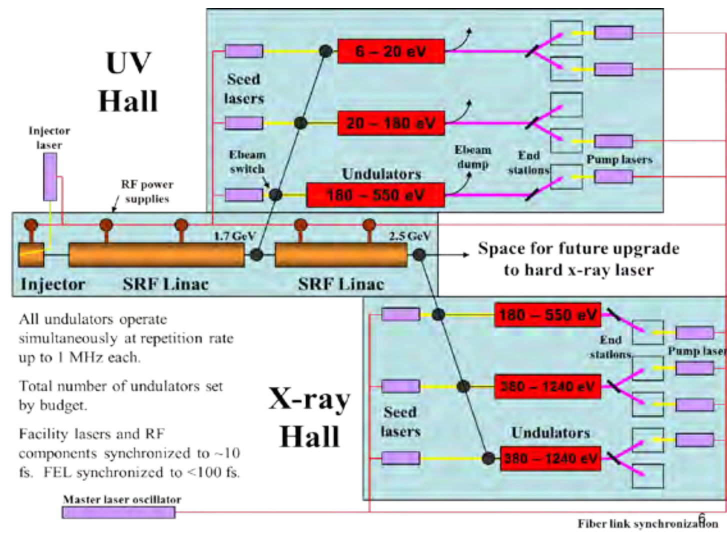
2004 MIT-Bates FEL Proposal



Proposed MIT-Bates facility.

- Many tunable beamlines
- Fully coherent seeded operation
- CW Superconducting RF
- High rep rate
- Lasers tightly integrated

2007 WiFEL Proposal



A next generation light source will adopt many of the concepts pioneered in these designs

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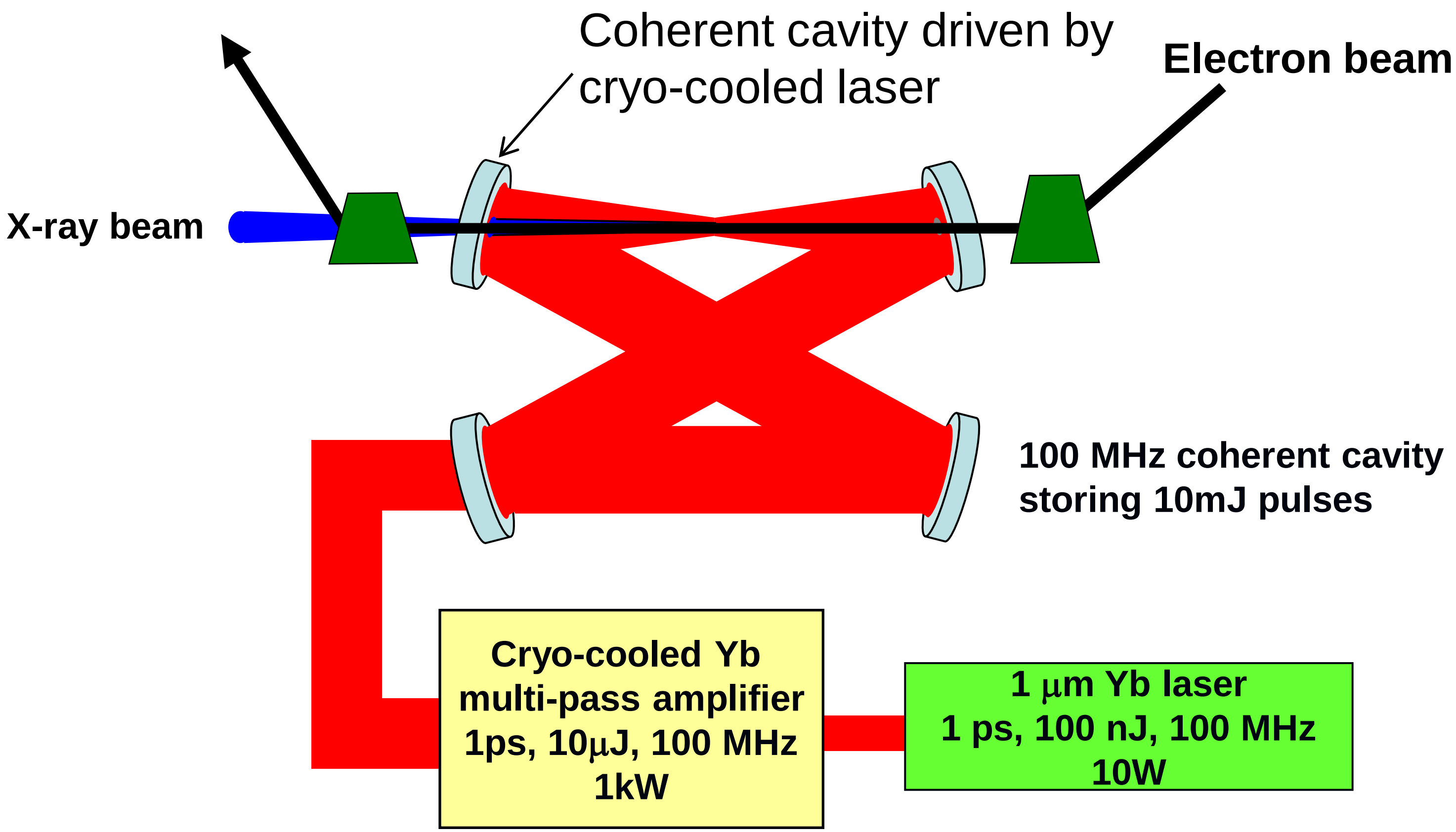
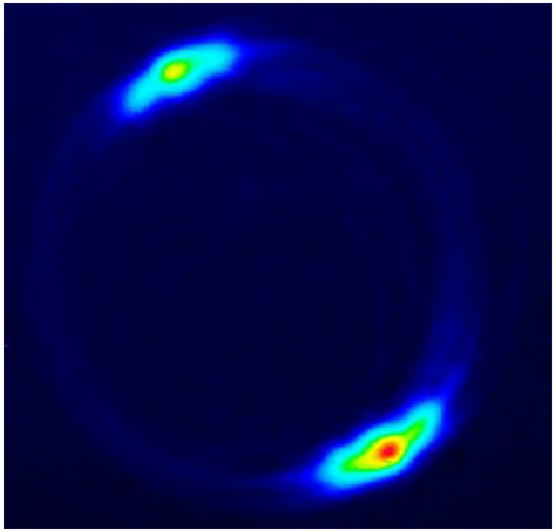
High Power Laser Technology



Coherent cavity stores ~1000X laser amplifier power. Uses Bessel-Gauss ring-shaped modes to avoid mirror damage and oscillator instability.

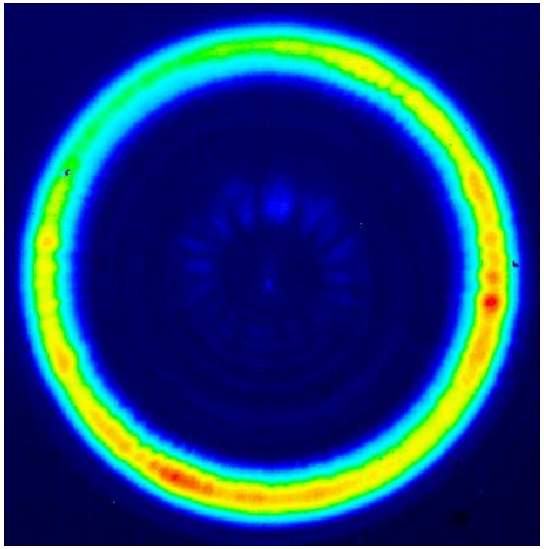
Cavity Results With Two Patterned Mirrors

Misaligned Cavity (sweep)



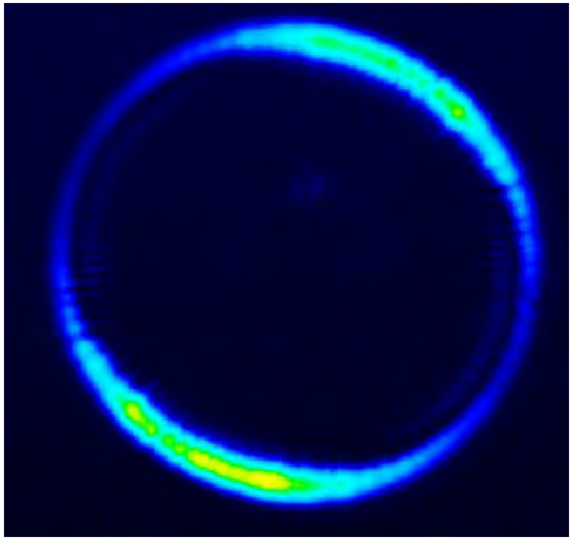
Finesse ~300

Aligned Cavity (sweep)



Finesse ~ 60

Aligned Cavity (locked)



Dramatic finesse drop on alignment (expected finesse ~300)

Transverse profile also changes from sweep to lock—Implication: sweep sums multiple transverse shapes.

Analog to Microwave Cavity

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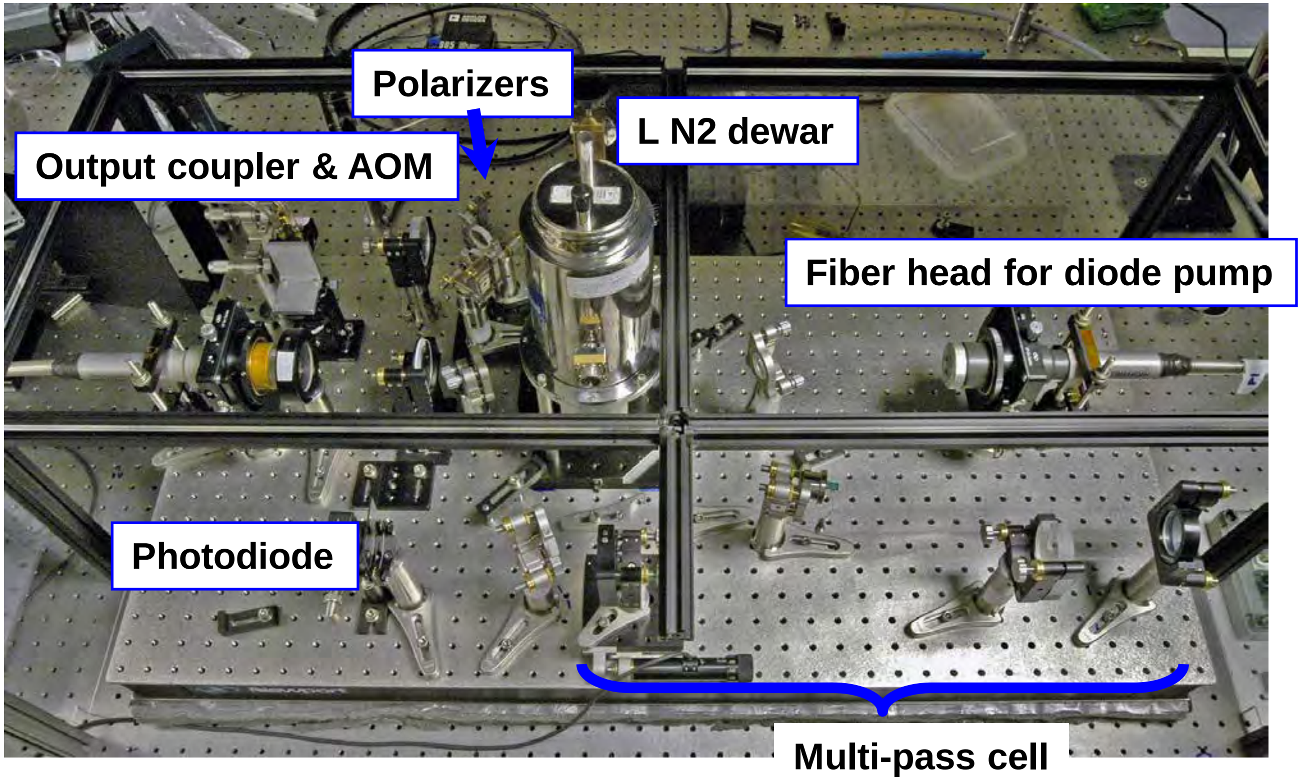
Cryo-cooled Laser Amplifier

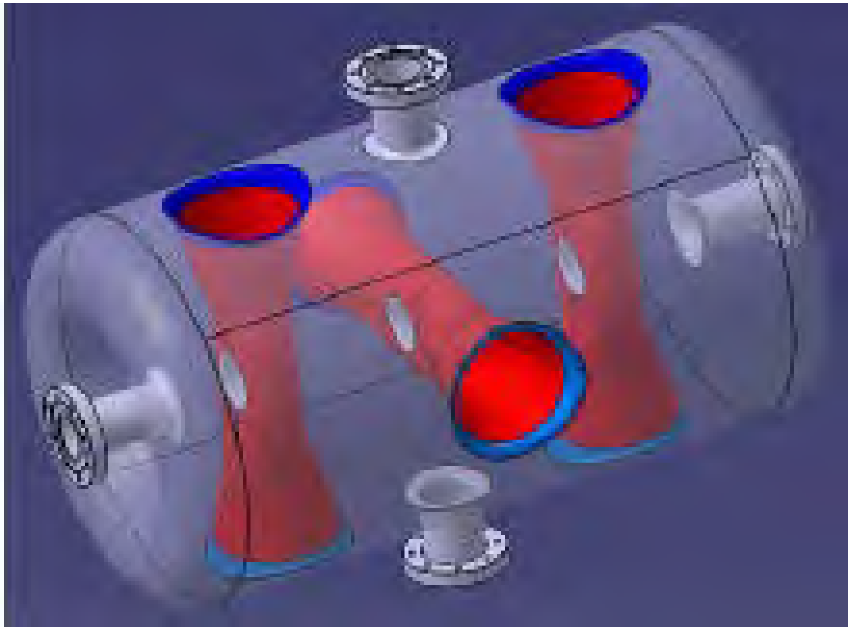
200 W cryo-cooled Yb:YAG

developed at MIT-Lincoln Lab by T.Y. Fan group



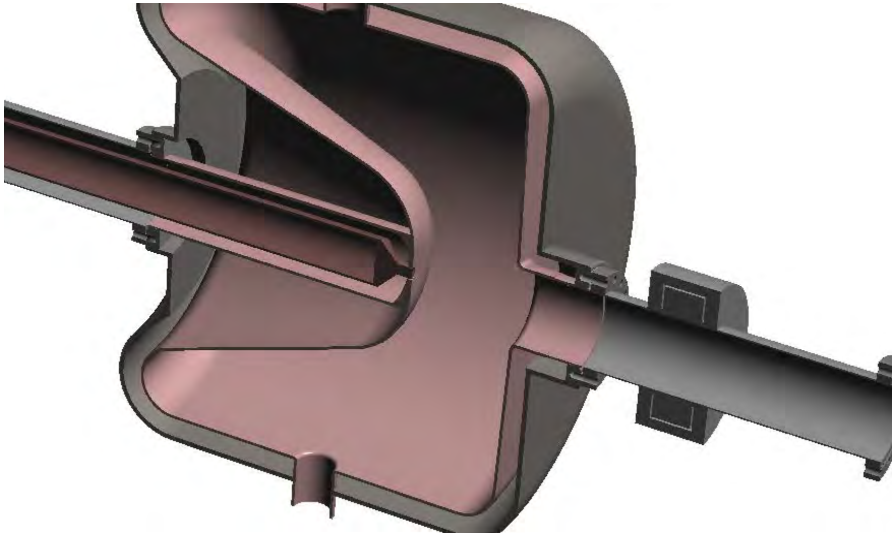
Pursuing R&D on mode-locking and Yb:YLF for sub-ps pulses

Next Generation SRF Cavities at 4K



Spoke cavity development with Jlab

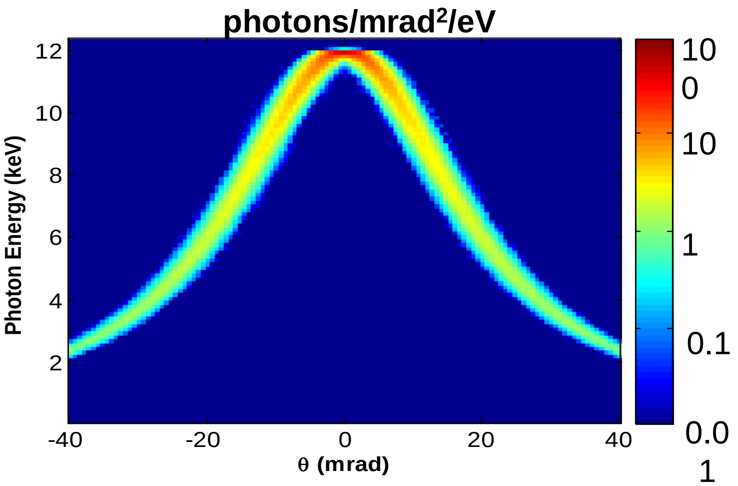
¼-wave resonator gun with UW, Naval Postgraduate School, Niowave Inc, Jlab

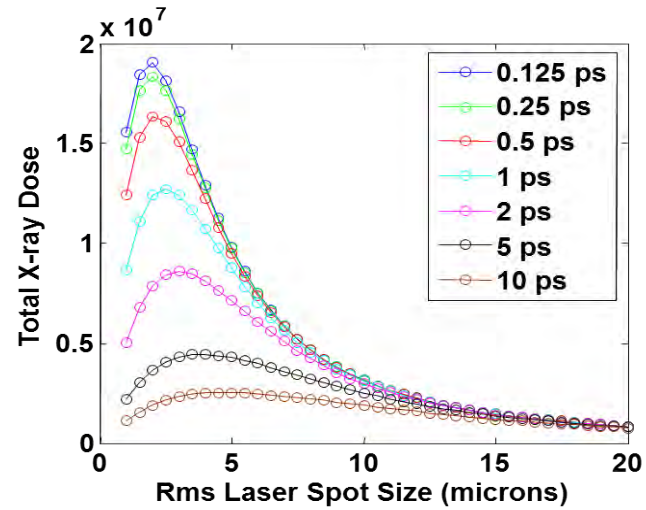


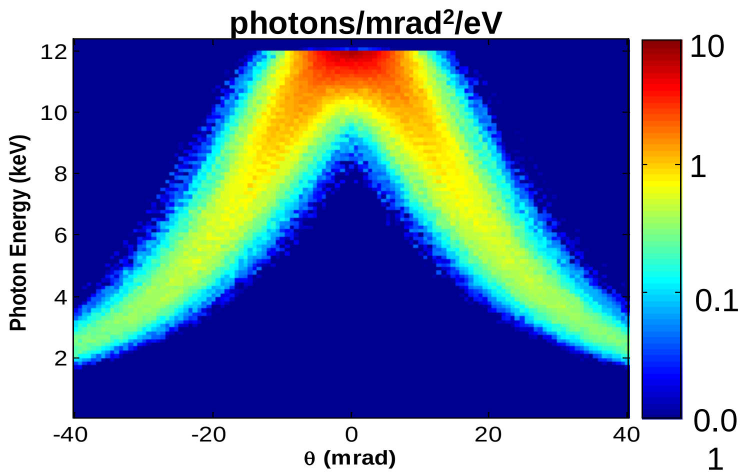
ICS Performance Optimization

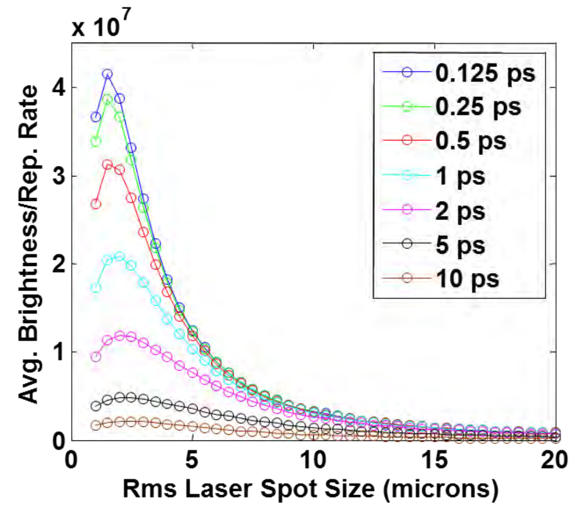
Normalized emittance = 0.3 μm

Winthrop Brown (MIT Lincoln Lab)









Normalized emittance = 1.0 μm

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Coherent X-rays via ICS

New Idea to produce coherent x-rays. No FEL required.

Arrange electrons to have periodic modulation, as if they had been bunched by FEL interaction.

Combine two key technologies: nanocathode array and emittance exchange

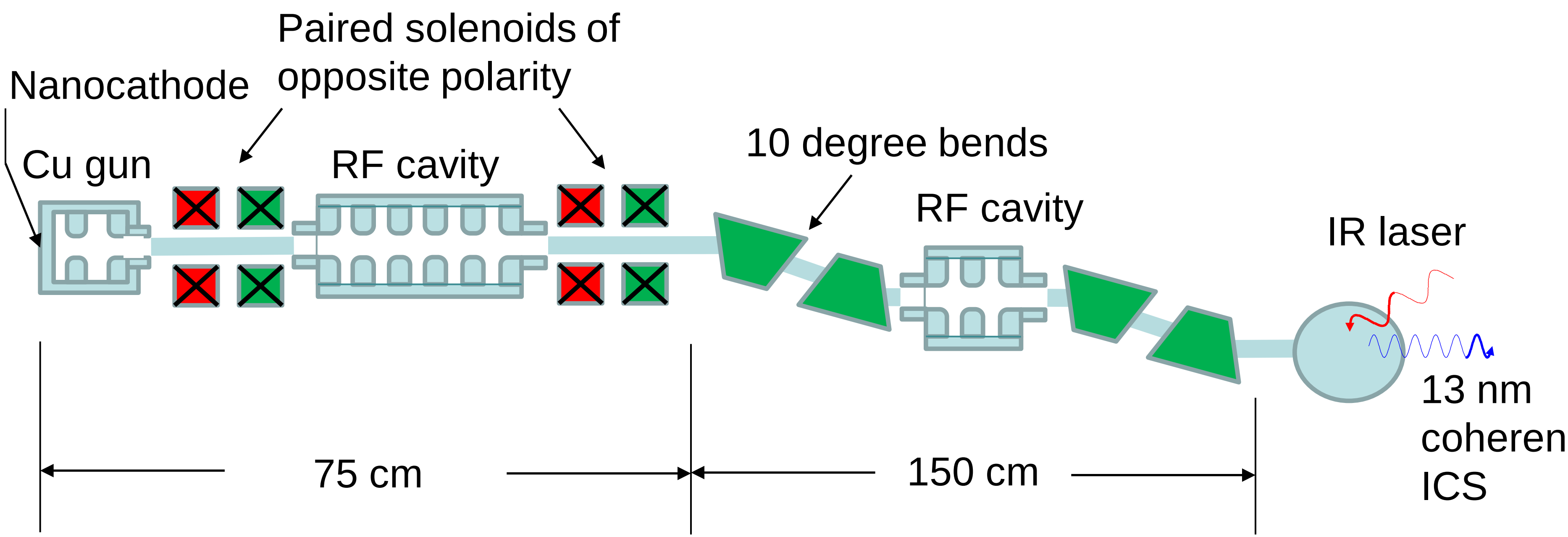
Steps

1. Emit array of beamlets from Field Emission Array nanocathode.
2. Accelerate and focus beamlet array.
3. Perform emittance exchange (EEX) to swap beamlet spacing into longitudinal dimension. Arrange dynamics to give desired period.
4. Coherently bunched beam emits ICS x-rays in phase.

Coherent ICS Example at 13 nm

FEA ⇨ gun ⇨ focus ⇨ emittance-exchange ⇨ coherent ICS

Electron energy ~2 MeV



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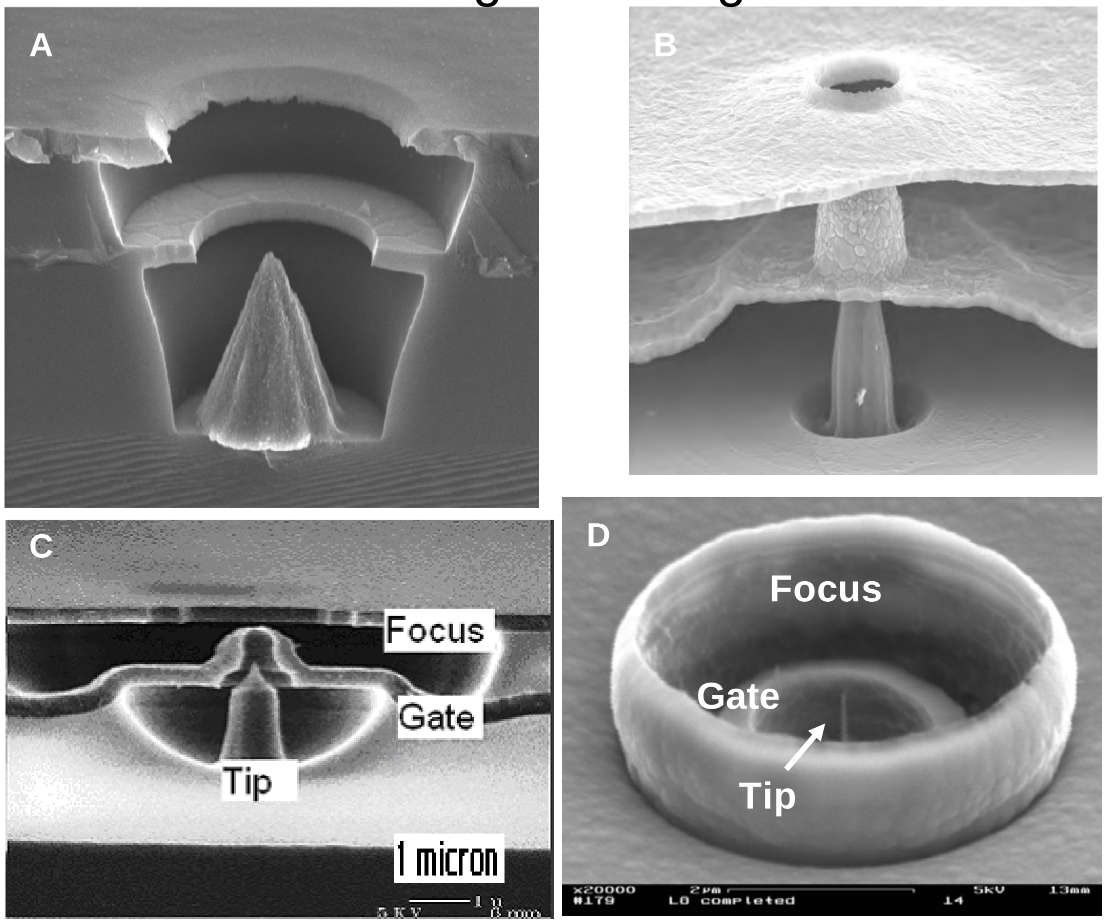
Double Gated Field Emitter Array

for collimating / focusing e-beam

Mo Tip

Si Tip



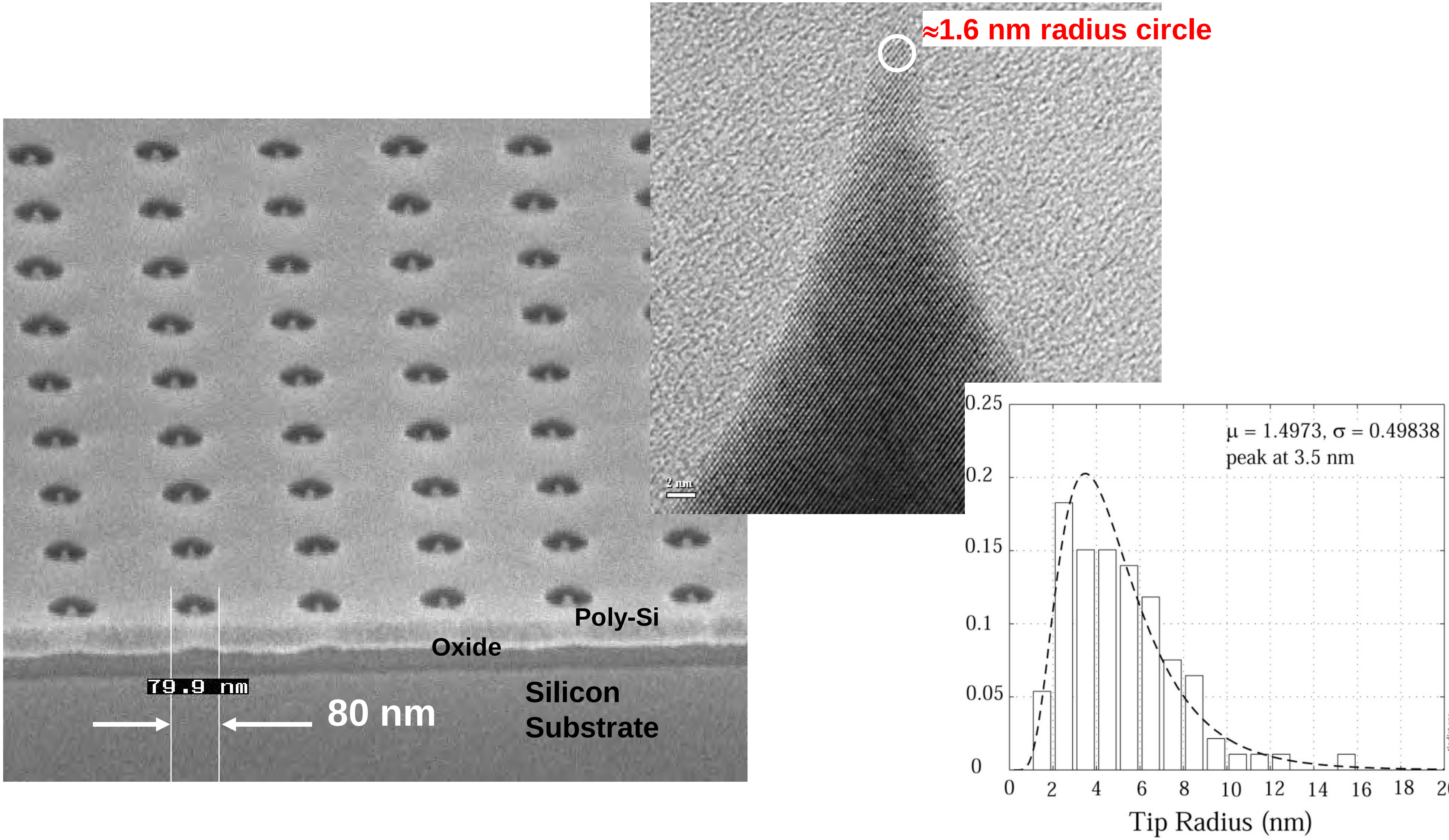
Si Tip

CNT Tip

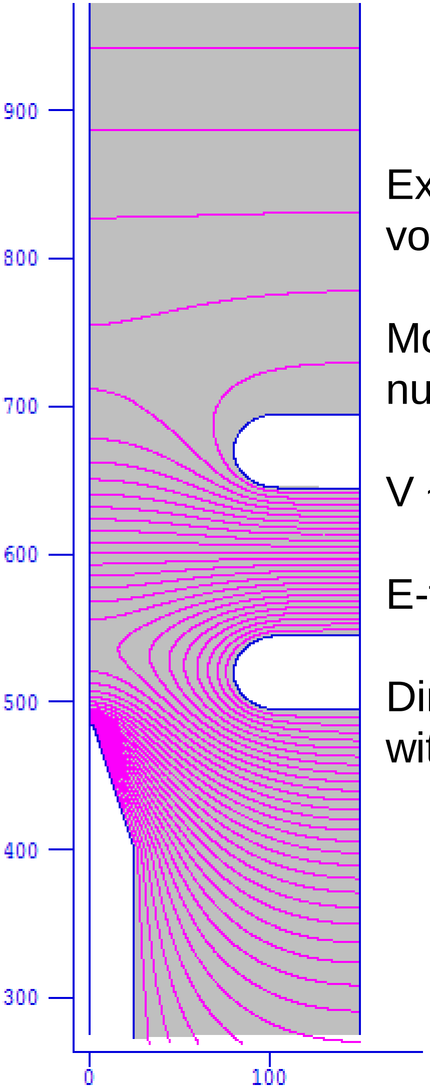
T. Akinwande & L. Velasquez-Garcia, MIT Microsystems Technology Lab

K. Berggren, MIT Nanostructures Lab

Field Emitter Array with 200 nm Pitch



Poisson Model of Tip Electric Field



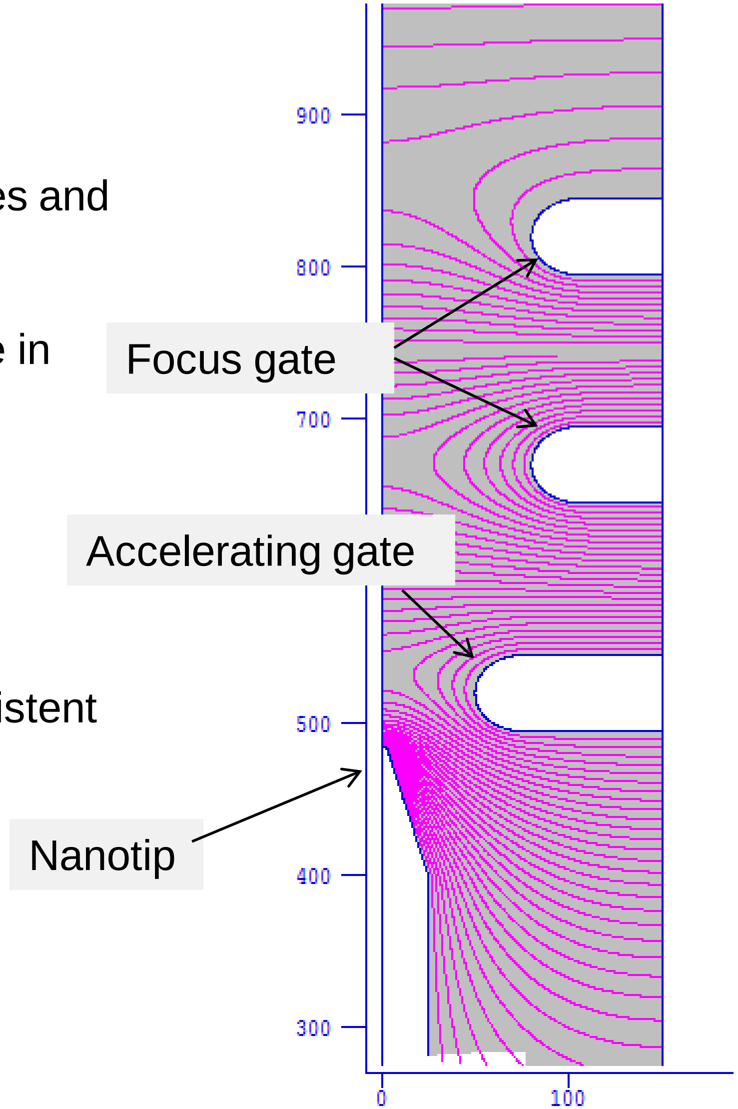
Exploring wide variety of geometries and voltages.

Modeling at nm scale requires care in numerical set up.

V ~ 10-50 V on gates

E-field at tip ~ 10^{10} V/m

Dimensions and voltages are consistent with FEAs produced in the lab



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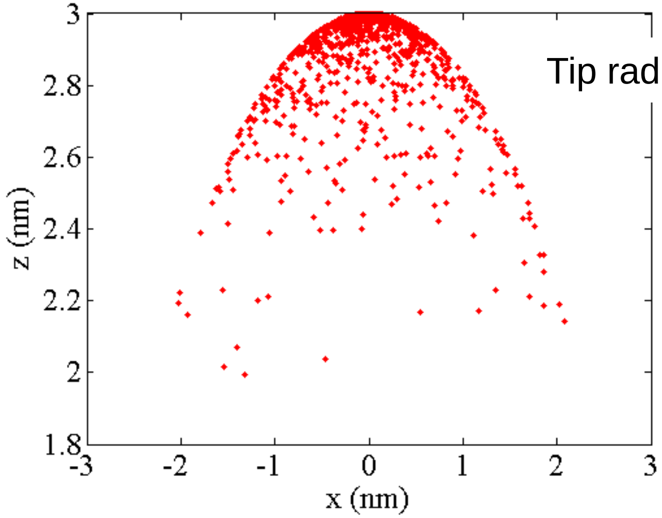
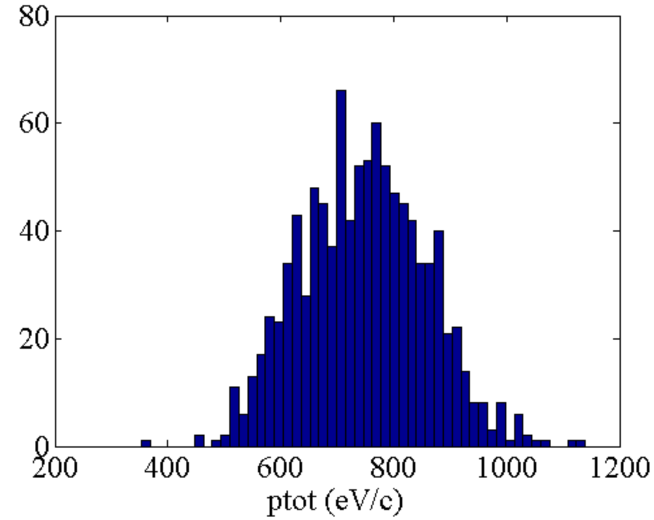
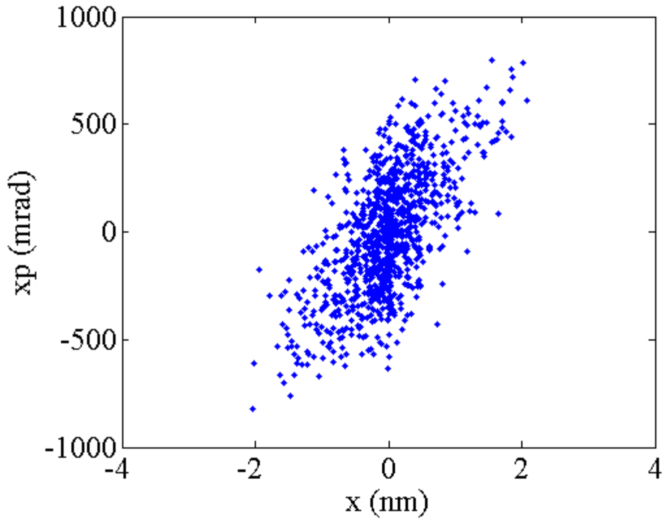
Initial Electron Distribution on Nanotip



Tip radius = 3 nm



Initial K.E. ~ 0.5 eV



sigx = 0.60 nm from F.-N. and surface field
sigpx = 163.17 eV/c

Design x-emittance = 1.93e-13 m-rad
At cathode x-emittance = 1.91e-13 m-rad

Build input distribution for PARMELA

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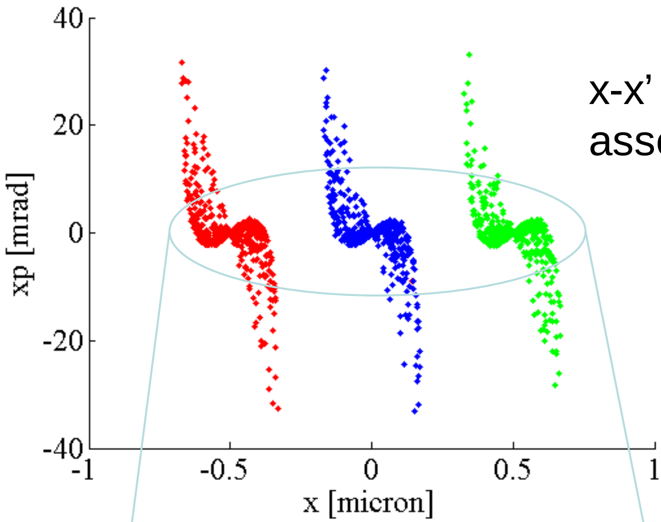
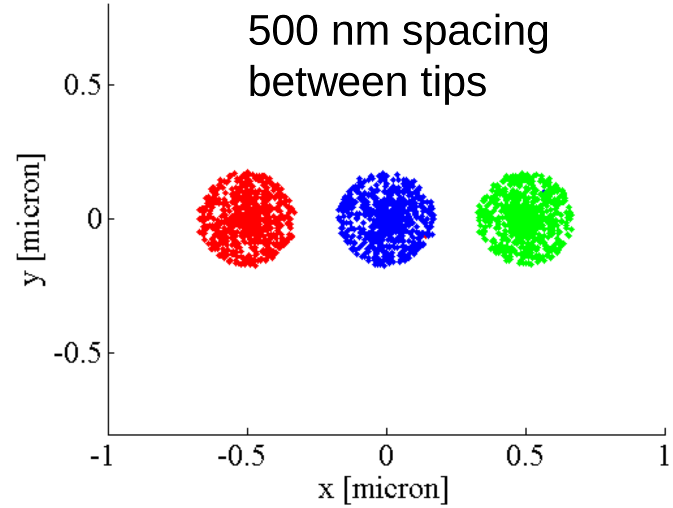
Beam Dynamics of 3X1 Tip Array

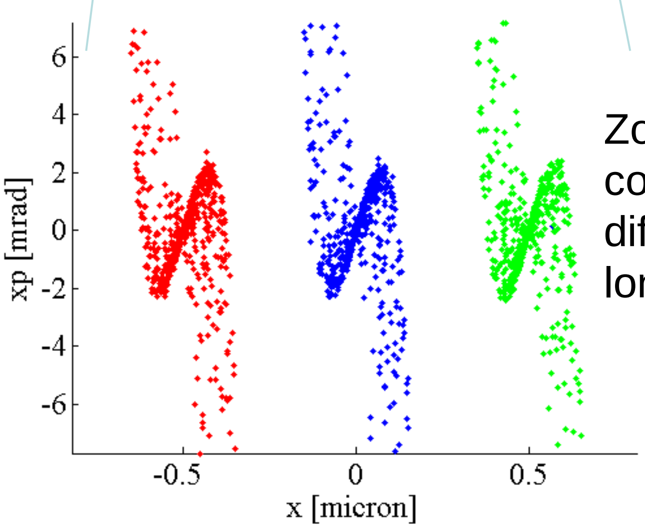
PARMELA tracking results. No space charge



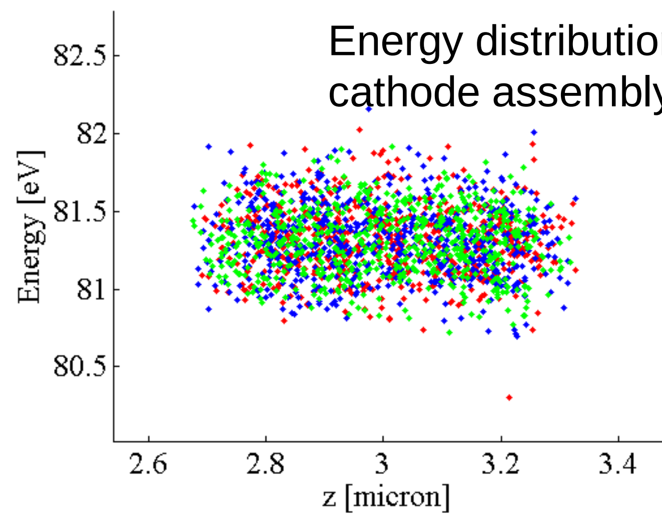
x-x’ at cathode assembly exit



500 nm spacing between tips

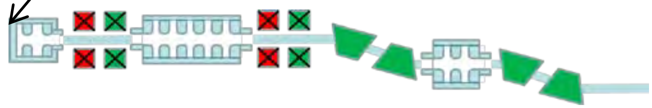


Zoom shows core transport differs from long tails



Energy distribution at cathode assembly exit

You are here



W.S. Graves   August, 2011

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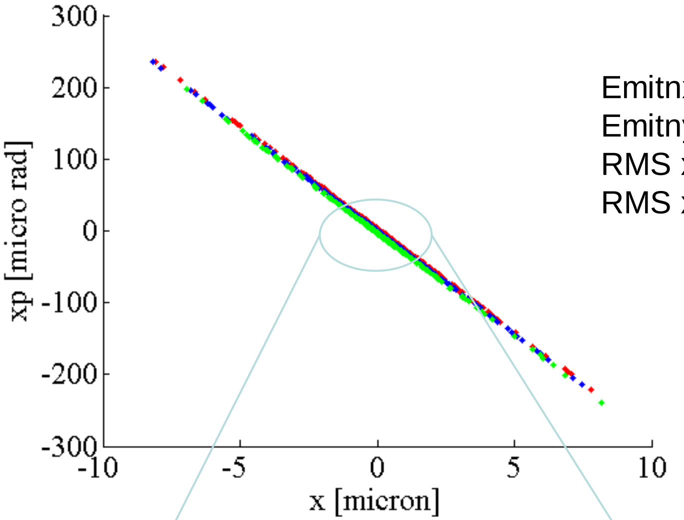
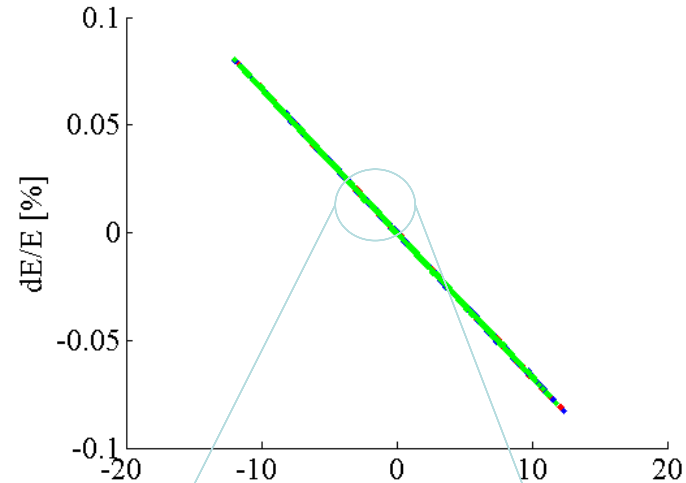
Transverse & Longitudinal Matching to EEX

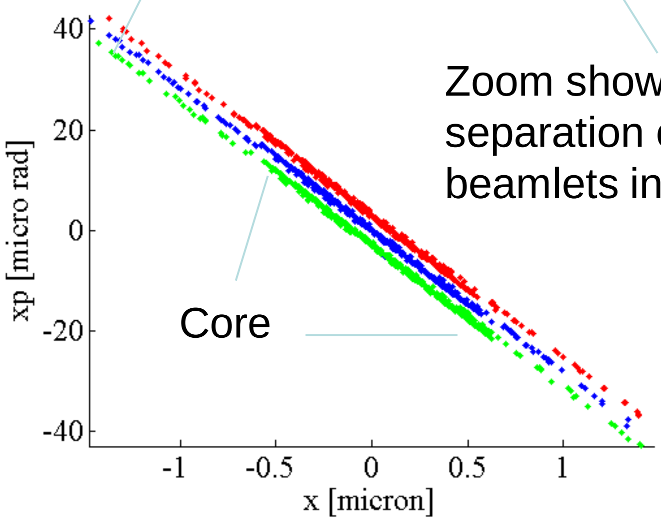
PARMELA tracking results. No space charge



Emitnx = 4.4e-011 m-rad
Emitny = 7.8e-012 m-rad
RMS x size = 1467 nm
RMS x divergence = 42 urad

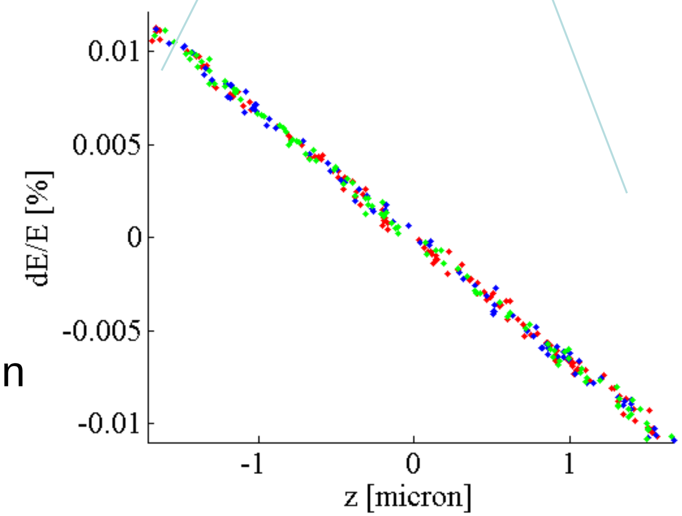


E = 1.8 MeV



Zoom shows separation of beamlets in x-x'.

No beamlet separation in z-z'.



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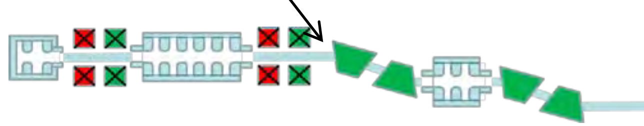

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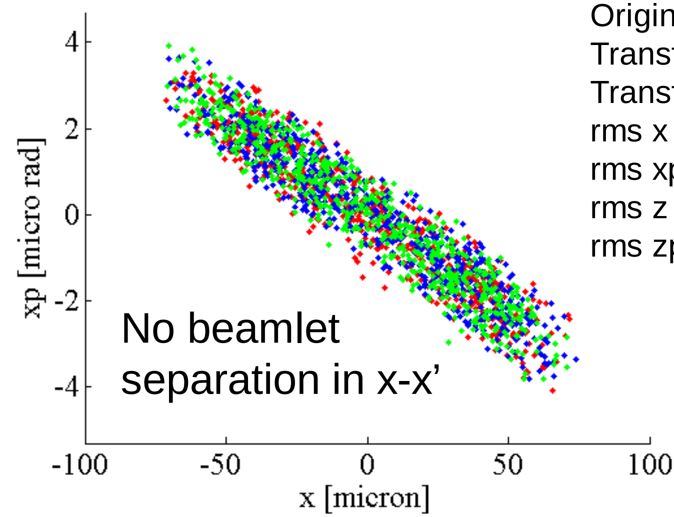
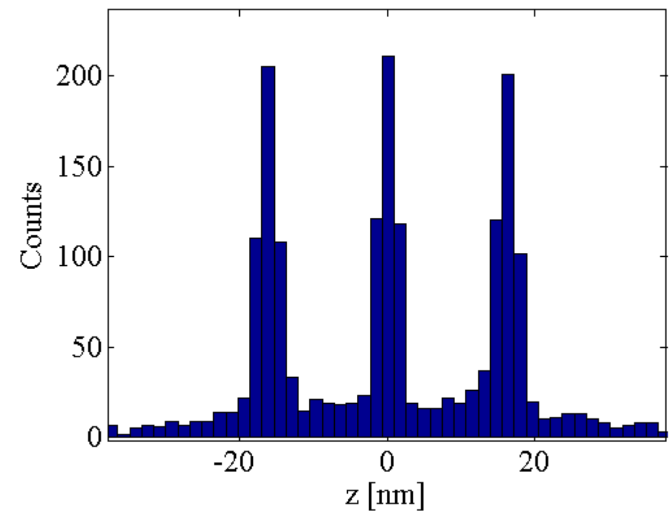
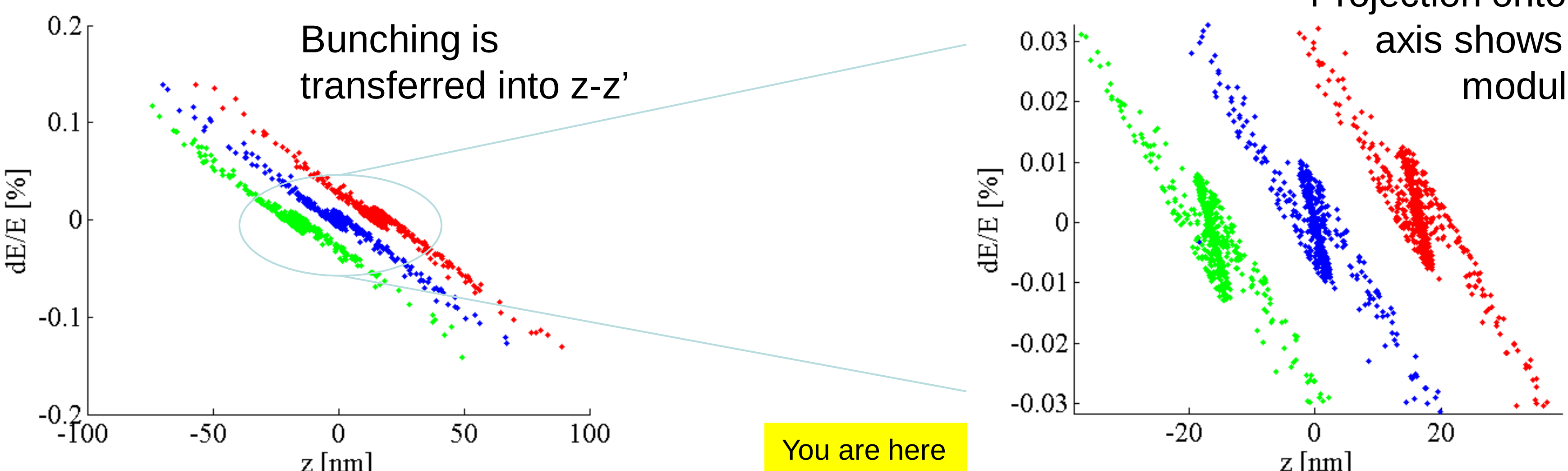
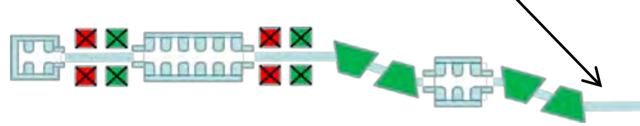
Bunched Beam after Emittance Exchange



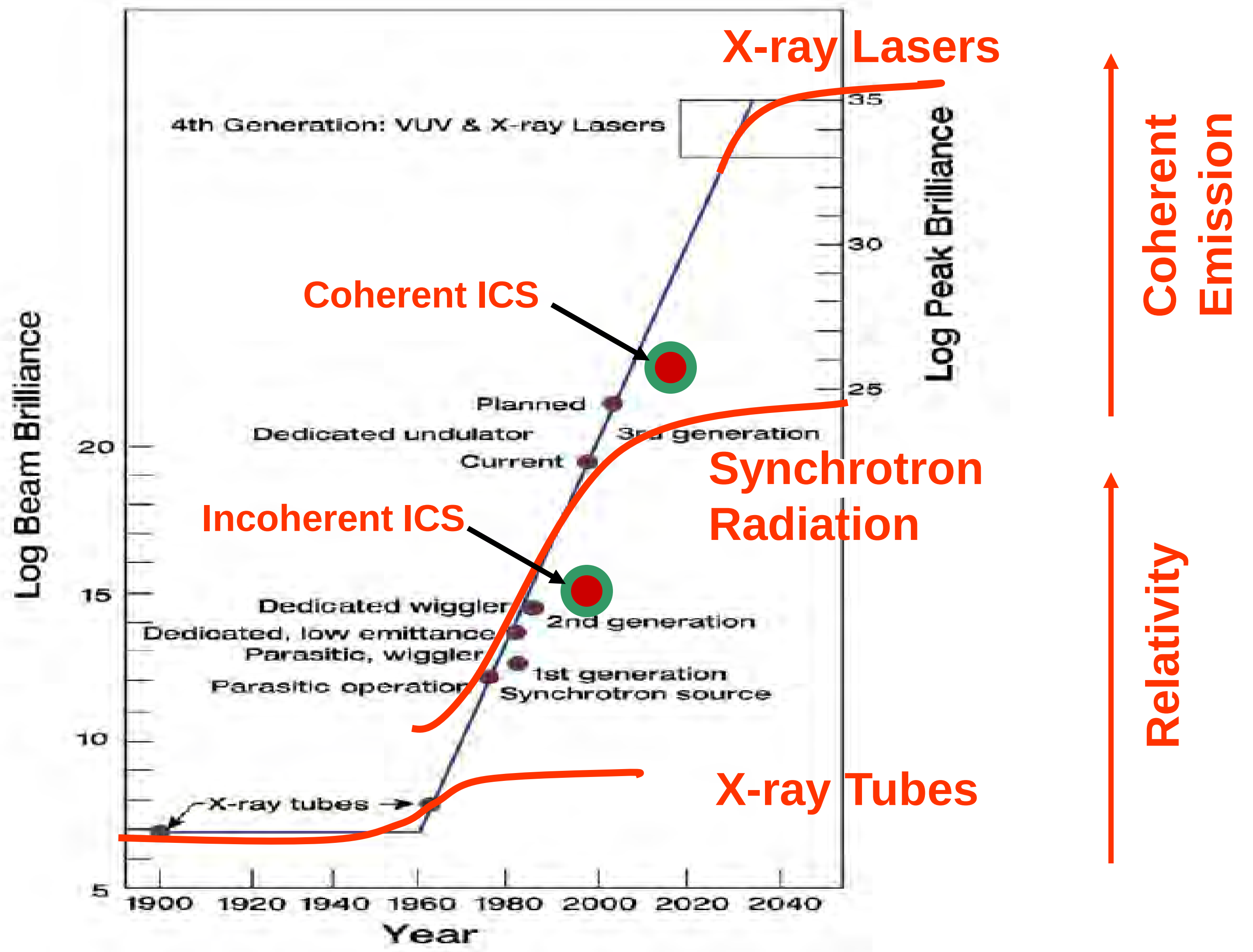
Original emitnx = 4.4e-11
Original emitnz = 2.2e-10
Transformed emitnx = 2.2e-10
Transformed emitnz = 4.4e-11
rms x = 35 micron
rms xp = 1.67 micro rad
rms z = 19.2 nm
rms zp = 2.49e-4 dE/E







Light Source Performance



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Summary

Wide variety of light source activities at MIT

- Optical *femtosecond synchronization*
- High power *ultrafast lasers* for seeding, ICS, as HHG sources
- FEL *facility concepts* including high rep rate, many beamlines, CW stability, FEL dynamics studies
- ICS optimization, *prototyping*, and facility concepts
- 4K SRF *gun and linac development* with Jlab and others
- *Nanocathode* development for high brightness electron beams
- New concepts for *coherent x-ray emission*