ASTA:

(Advanced Superconducting Test Accelerator at Fermilab)

Science and Facility Overview and Opportunities for ERL R&D

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Fermilab

ERL-2013
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U.S. DEPARTMENT OF ENERGY

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ASTA Facility

Advanced Superconducting Test Accelerator

(formerly known as NML… now significantly expanded)

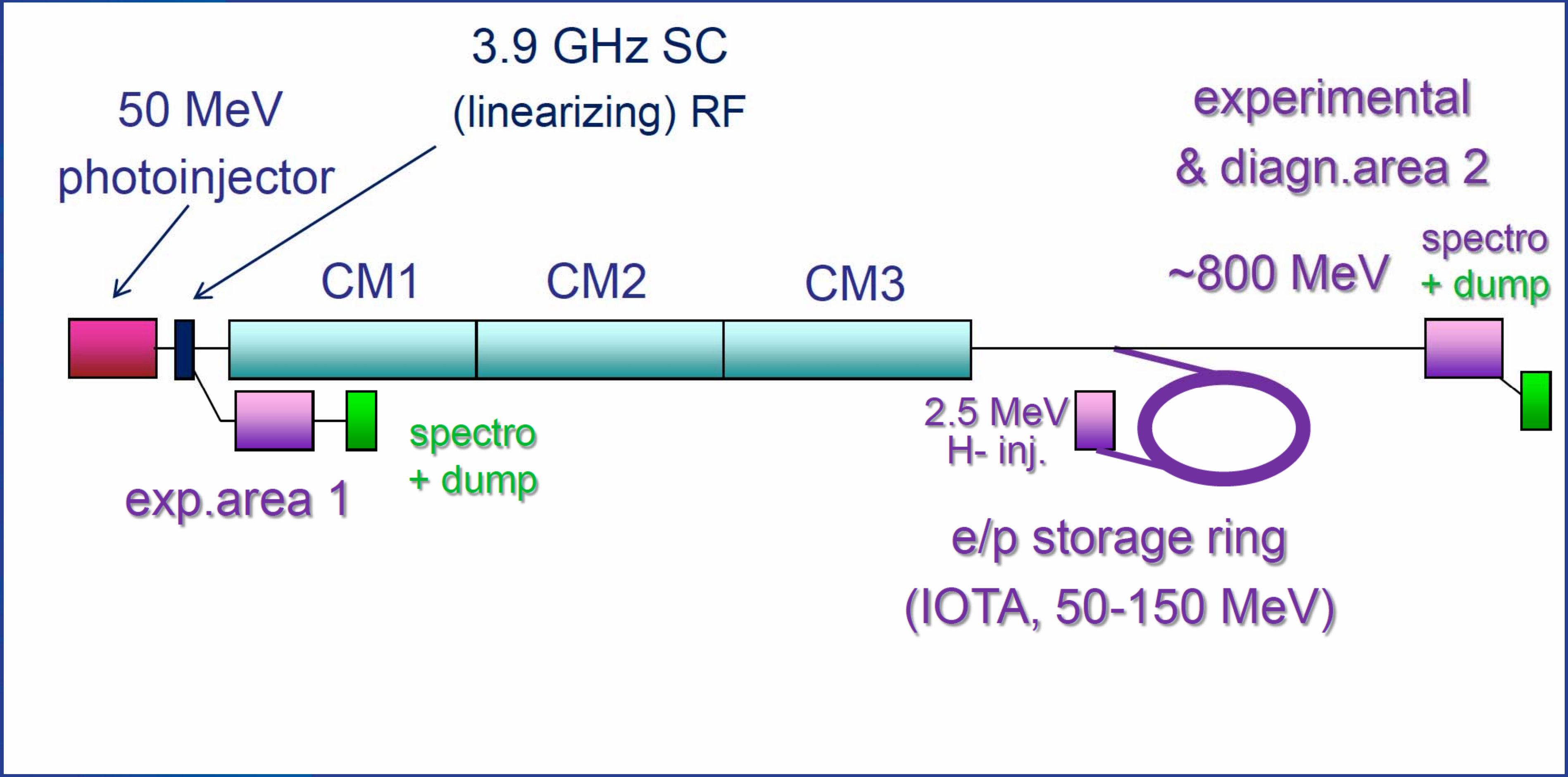
1.3 GHz SC RF Cryomodule transportation to ASTA

Background

- Construction of ASTA (a.k.a. NML) began in 2006 as part of the ILC/SRF R&D Program and later American Recovery and Reinvestment Act (ARRA).
- The Facility was motivated by the goal of building, testing & operating a complete ILC RF unit (3 CMs)
- To date, an investment of about $80M has been made, representing ~80% completion of the facility
- It was recognized early in the planning process that an e- beam meeting the ILC performance parameters was itself a power resource of interest to the wider Advanced Accelerator R&D community.

ASTA → Accelerator R&D Users Facility

ASTA Users Facility (schematically)

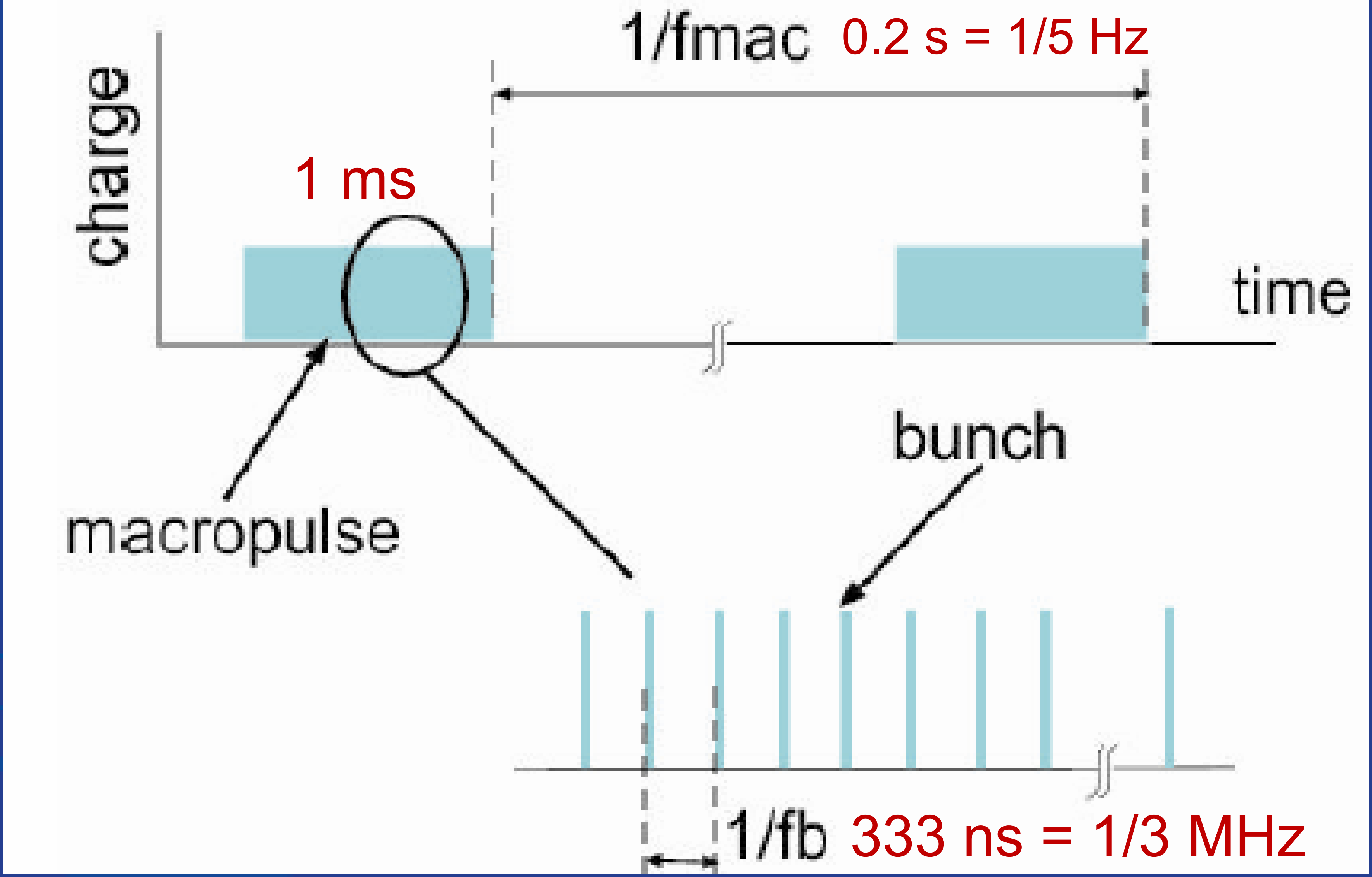


Three Experimental Areas capable of hosting 5-9 experiments at once

Can serve community of 100-150 users (in ~3-5 years)

Beam parameters for EA1-EA3: 50 MeV, 300-800 MeV, IOTA :

ASTA Laser & e-Beam Pulse

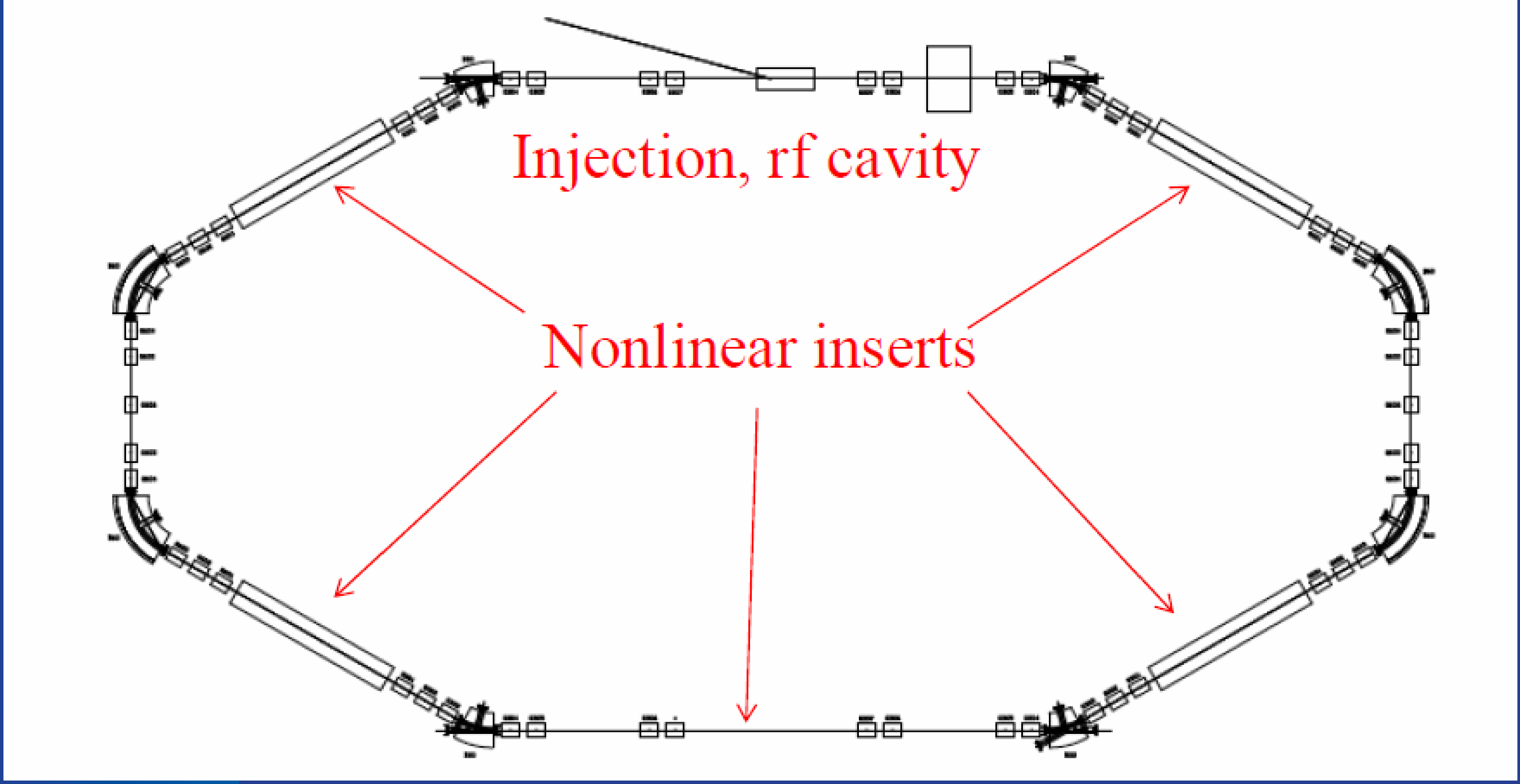


Experimental Areas 1 & 2

Parameter	Value	Range	Unit	Comments
Energy Exp A 1	50	5-50	MeV	maximum determined by booster cavity gradients
Energy Exp A 2	820	50-820	MeV	1500 MeV with 6 cryomodules
Bunch charge	3.2	0.02-20	nC	maximum determined by cathode QE and laser power
Bunch spacing	333	10-∞	ns	laser power
Bunch train *T*	1	1 bunch	ms	maximum limited by modulator and klystron power
Train rep rate	5	0.1-5	Hz	minimum may be determined by egun *T*-regulation and stability considerations
Emittance $_{rms\ norm}$	5	<1 … >100	π µm	maximum limited by aperture and beam losses
Bunch length $_{rms}$	1	0.01-10	ps	min obtained with Ti:Sa laser; maximum obtained with laser pulse stacking
Peak current	3	>9	kA	3 kA with low energy bunch compressor; 9 kA possible with 3.9 GHz linearizing cavity

* 3.2nC × 3000 bunches × 5 Hz × 0.82 GeV = 40 kW

Integrable Optics Test Accelerator IOTA



- Electron mode – beam from SCRF cryomodule (low intensity, low rep rate)
- Proton mode – separate 2.5 MeV H-/p RFQ

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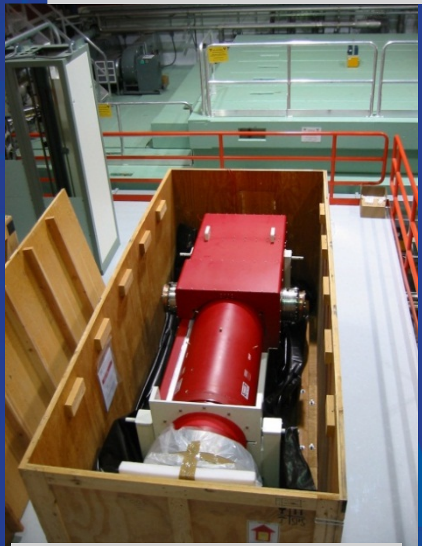
Experimental Area 3: IOTA

Parameter	Value	Unit
Circumference	38.7	m
Bending dipole field	0.7	T
RF voltage	50	kV
Electron beam energy	150	MeV
Number of electrons	$2\ 10^9$	
Transv. emittance r.m.s. norm	2	π μm
Proton beam energy	2.5	MeV
Proton beam momentum	70	MeV/c
Number of protons	$8\ 10^{10}$	
Transv. emittance r.m.s. norm	0.1-0.2	π μm

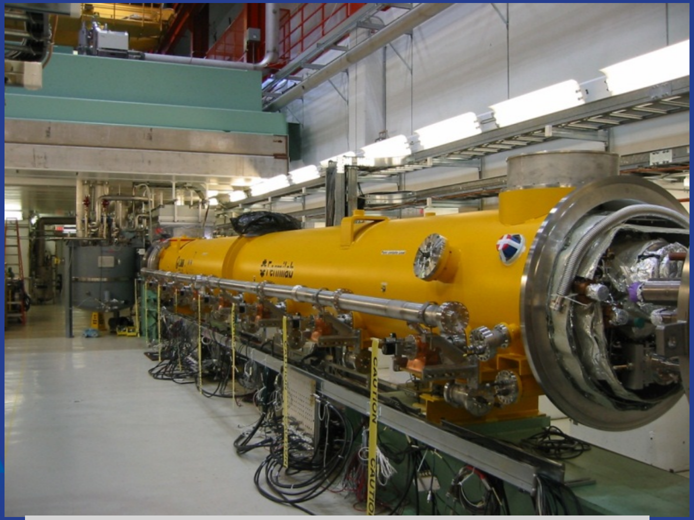
Substantial Investments Have Already Been Made At ASTA

Magnets and Power Supplies: $4M

Beam Dumps: $2M



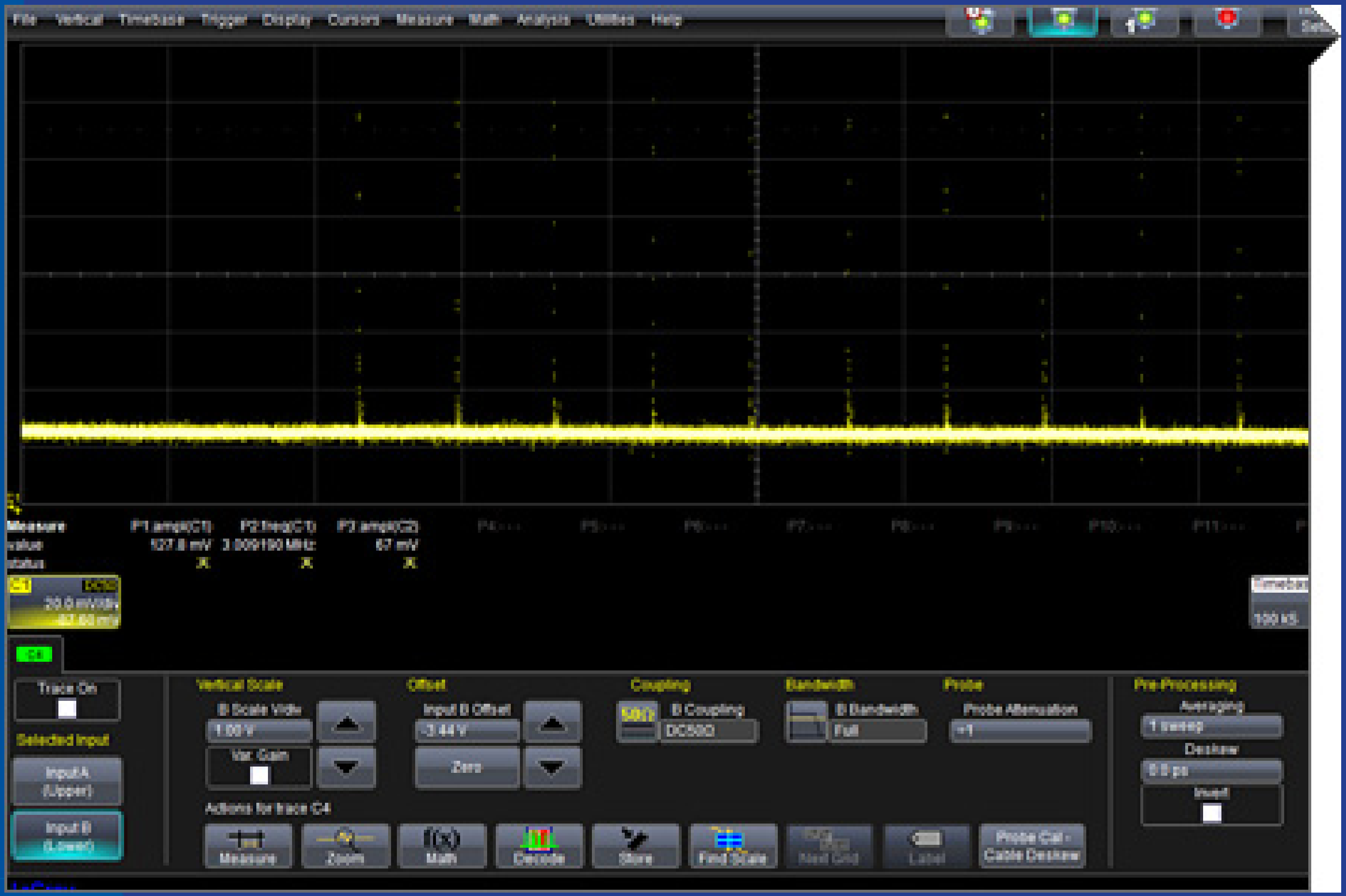
RF Power Systems: $8M



Cryomodules: $15M

Tunnel extension: $4.5M

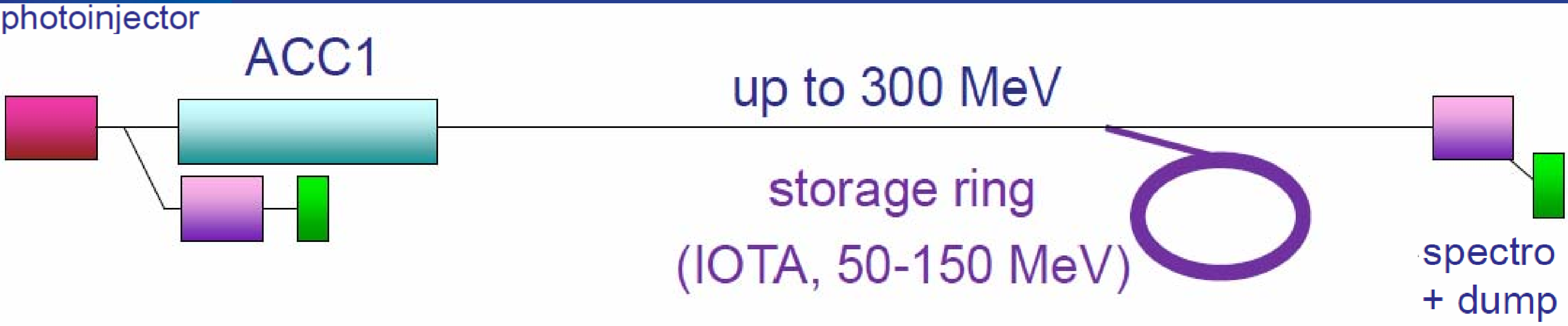
1st Photoelectrons in ASTA (06/20/2013)



- Not yet at full RF power/ energy (3.3MeV vs 5 MeV)
- Not yet full current (Cu cathode used for now, low QE)
- Commissioning ongoing , then beam to 2 SRF cavities 20+20 MeV

ASTA FY14-15 plans (tent.)

Overall – Stage I (“barebone”) facility and experiments



- FY13: Start commissioning 50 MeV PI and install 1st experiments / start SRF CM commissioning
- FY14: 1st experiments at 50 MeV
  RF commissioning of SRF cryomodule
  Install 300 MeV beamline to dump
  Continue IOTA construction
- FY15: More experiments at 50 MeV and 300 MeV beam
  Finish IOTA construction and installation

The ASTA Team

ASTA Team:

ASTA Interim Director, Vladimir Shiltsev

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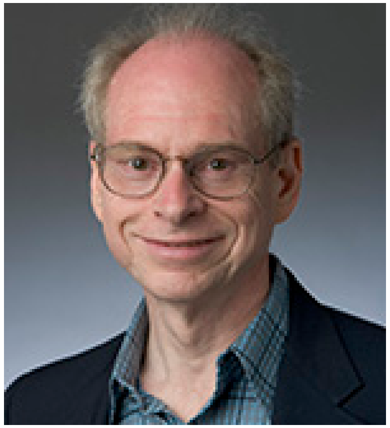

ASTA Program Advisory Committee Chair, Gerald Dugan

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This and more info – see http://asta.fnal.gov/

ASTA Program Advisory Committee

Gerald Dugan (Chair)
Cornell University
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Michael Blaskiewicz
Brookhaven National Laboratory
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John Byrd
Lawrence Berkeley National Laboratory
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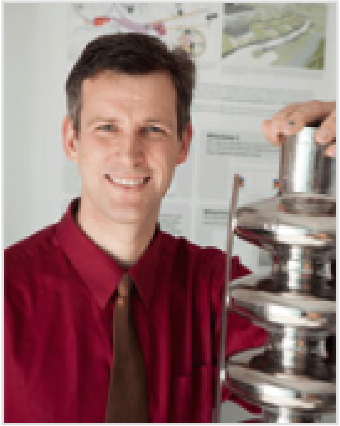

Georg Hoffstaetter
Cornell University
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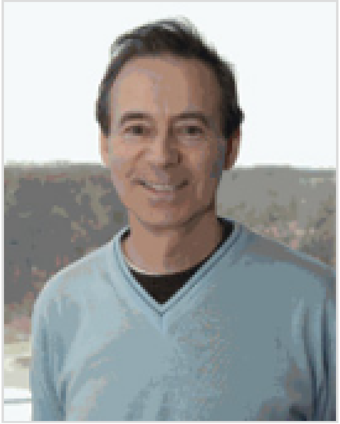

Alexander Zholents
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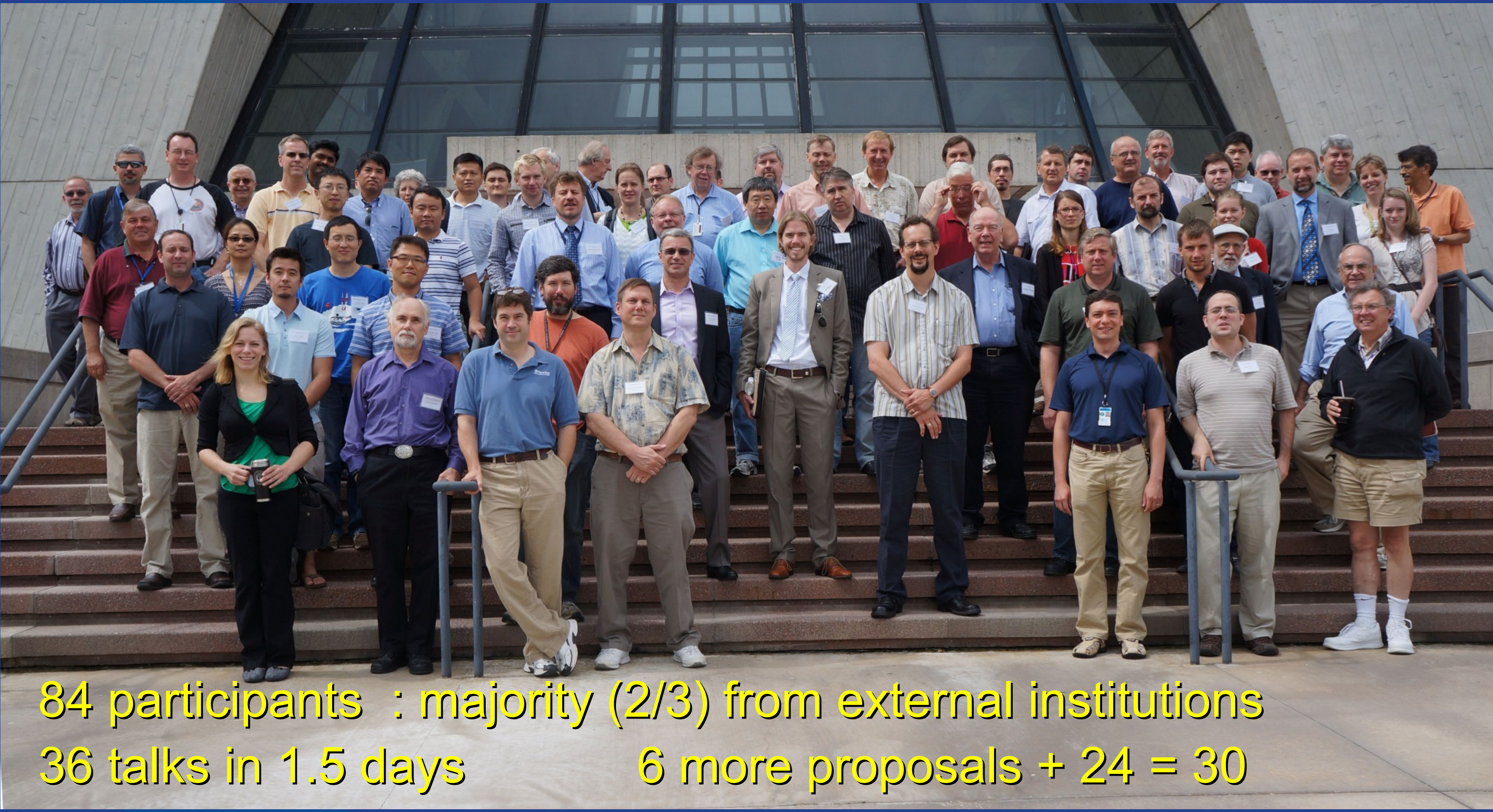
Marco Venturini
LBNL

Richard York
MSU

1st ASTA Users & PAC Meeting (July 23-24, 2013 Fermilab)



84 participants : majority (2/3) from external institutions

36 talks in 1.5 days 6 more proposals + 24 = 30

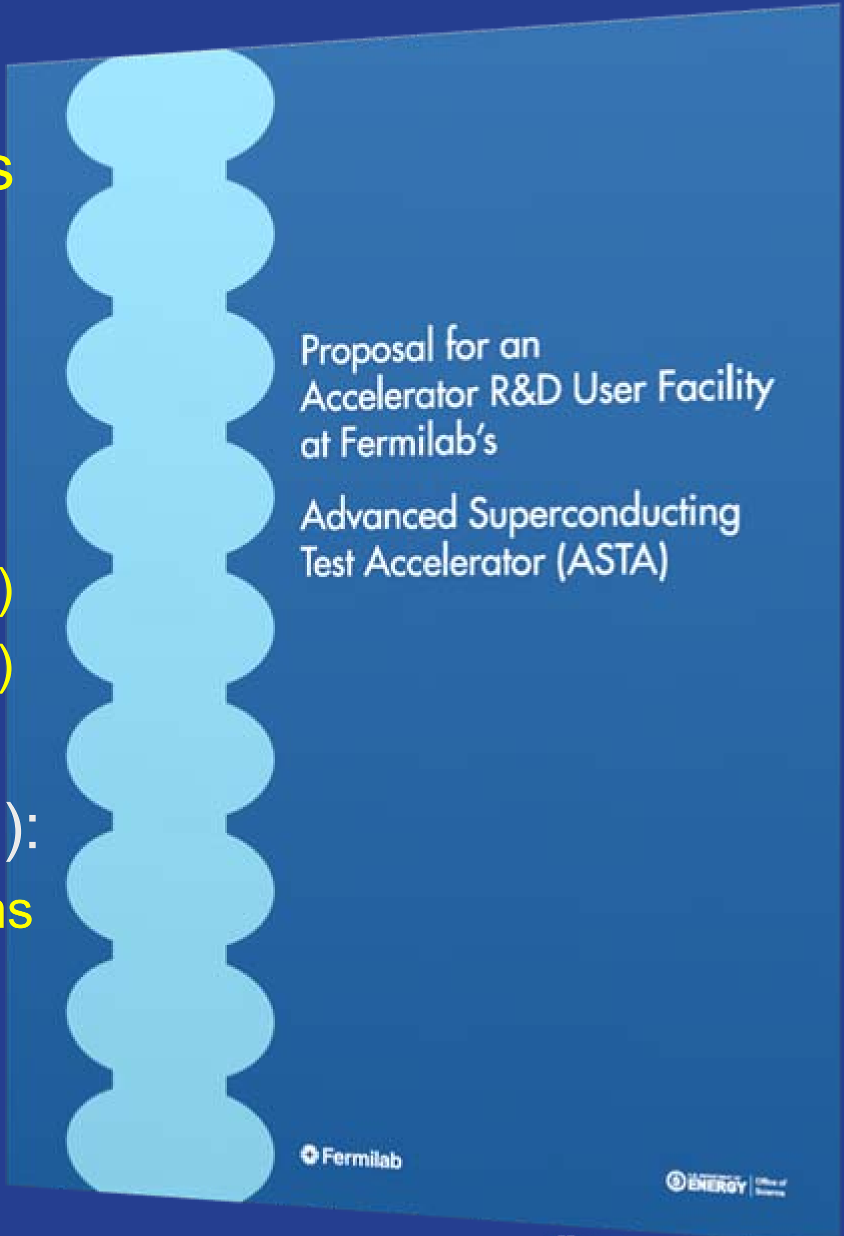
ASTA is Unique Among Accelerator User Facilities in Six Principal Ways

1. **High repetition-rate:** 1 msec long bunch trains, with 3 MHz micro-pulse repetition rate, 3000 bunches per train.
2. **High average power:** at 5Hz - the highest beam power and highest average brightness of any US accelerator test facility
3. **High energy:** ~1 GeV, which is important for a number of photon-science and FEL-related experiments.
4. **Extremely stable beams:** capable of providing exceptional beam stability, which has been demonstrated at FLASH
5. **Superconducting technology:** SRF + beams = nearly all future large scale accelerator facilities
6. **Storage ring:** ASTA incorporates a small, very flexible storage ring, based on innovative optics, capable of supporting a broad range of ring-based advanced beam dynamics experiments

ASTA

As of Sep'2013

- >60 co-authors from 13 institutions
- 30 proposals and growing
  - ~1/2 for HEP (IF, EF, SCRF)
  - ~1/2 – Stewardship and Applications
- At all ASTA experimental areas
  - Exp Area 1 (50 MeV) (12)
  - Exp Area 2 (300-800 MeV) (12)
  - Exp Area 3 (IOTA Ring) (6)
- Broad spectrum of proponents (20):
  - University groups & National Programs
  - SBIR companies & International
  - Large National Laboratories
  - Detector R&D groups

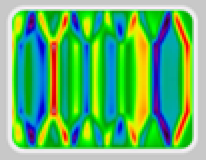


http://asta.fnal.gov/

ASTA Science Thrusts

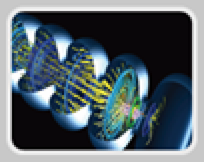
Intensity Frontier of Particle Physics

- Nonlinear, integrable optics
- Space-charge compensation



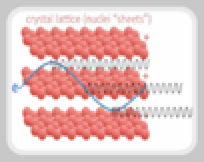
Energy Frontier of Particle Physics

- Optical Stochastic Cooling
- Advanced phase-space manipulation
- Flat beam-driven DWFA in slabs



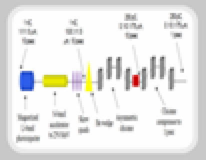
Superconducting Accelerators for Science

- Beam-based system tests with high-gradient cryomodules
- Long-range wakes
- Ultra-stable operation of SCLs



Novel Radiation Sources

- High-brightness x-ray channeling
- Inverse Compton Gamma Ray source



Stewardship and Applications

- Generation and Manipulation Ultra-Low Emittance Beams for Future Hard X-ray FELs
- XUV FEL Oscillator

ASTA Developments

- 2012 - ASTA Proposal developed by Fermilab and prospective users
- Dec 2012 – DoE OHEP briefed on ASTA… encouragment…
- Feb 6-8, 2013 – Fermilab's *Accelerator Advisory Committee* on ASTA:
  - *The AAC strongly encourages FNAL to pursue the ASTA Proposal*.
- Feb 26, 2013 - ASTA Proposal submitted to DOE
- Mar 8, 2013 - ASTA Proposal reviewed by *OHEP GARD* Review panel
- Apr 24, 2013 – NSF/NPS briefed on ASTA
  - "*…very timely*!" – NSF's *"Accelerator Science"* program (June)
- Jun 14, 2013 – ASTA welcomed by *FNAL Users Executive Committee*
- Jun 20, 2013 – First beam from ASTA photoinjector (!)
- Jul 23-24, 2013 - ASTA 1st Users and PAC meeting at Fermilab
- Oct 22-24, 2013 – DOE OHEP review of ASTA Proposal
  - *Together with FACET-II (SLAC) and ATF-II (BNL)*

ASTA Schedule and Operation

- Installation and commissioning schedule by Stage
- Operations schedule (9 months operations/year)
- Assumes funding begins in FY 2014

Stage	Description - following Figures 2, 3, 4 and 5	FY 13 Q1	FY 13 Q2	FY 13 Q3	FY 13 Q4	FY 14 Q1	FY 14 Q2	FY 14 Q3	FY 14 Q4	FY 15 Q1	FY 15 Q2	FY 15 Q3	FY 15 Q4	FY 16 Q1	FY 16 Q2	FY 16 Q3	FY 16 Q4	FY 17 Q1	FY 17 Q2	FY 17 Q3	FY 17 Q4	FY 18 Q1	FY 18 Q2	FY 18 Q3	FY 18 Q4
I.0	as is: photoinjection to low-energy dump																								
I.1	add 50 MeV, experimental area, spectrometer, & dump																								
I.2	add CM #1 (~ 300 MeV), experimental area, and diagnostics area																								
I.3	add IOTA Storage Ring (50-150 MeV)																								
II	add CM #2 and CM #3 (~ 800 MeV)																								
III	add HINS 2.5 MeV H-/proton injector																								
IV	add 3.9 GHz linearizing cavity																								

fabrication & construction (not interfering with beam operations)
installation & commissioning
experimental operations (9 months per year)

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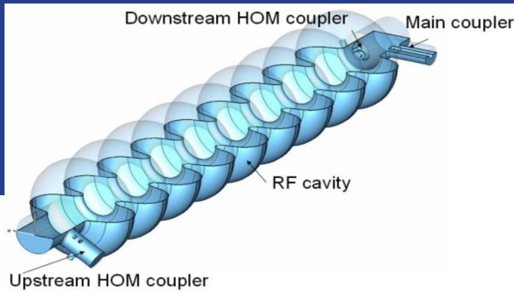
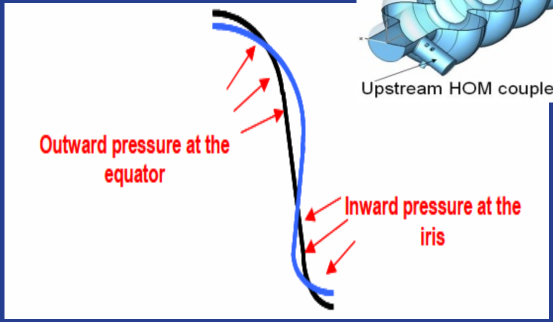
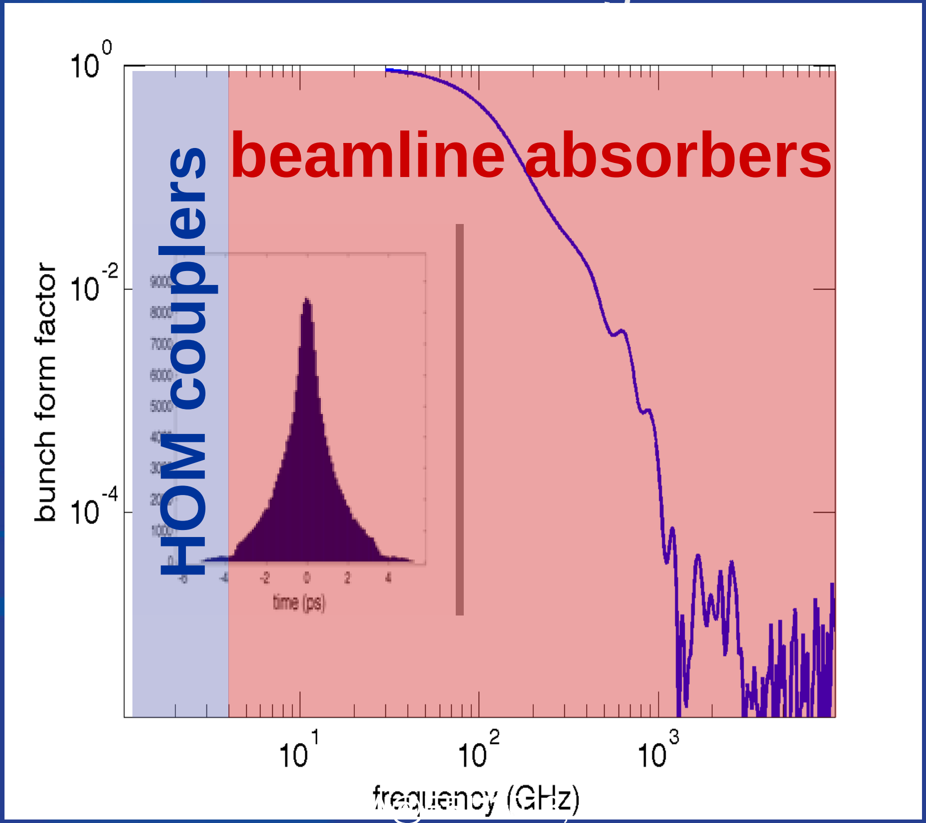
7.4.1 High-gradient SC RF with high-power beam

- **High-gradient operation with beam loading**
  - Field emission,
  - microphonics
  - Lorentz force detuning





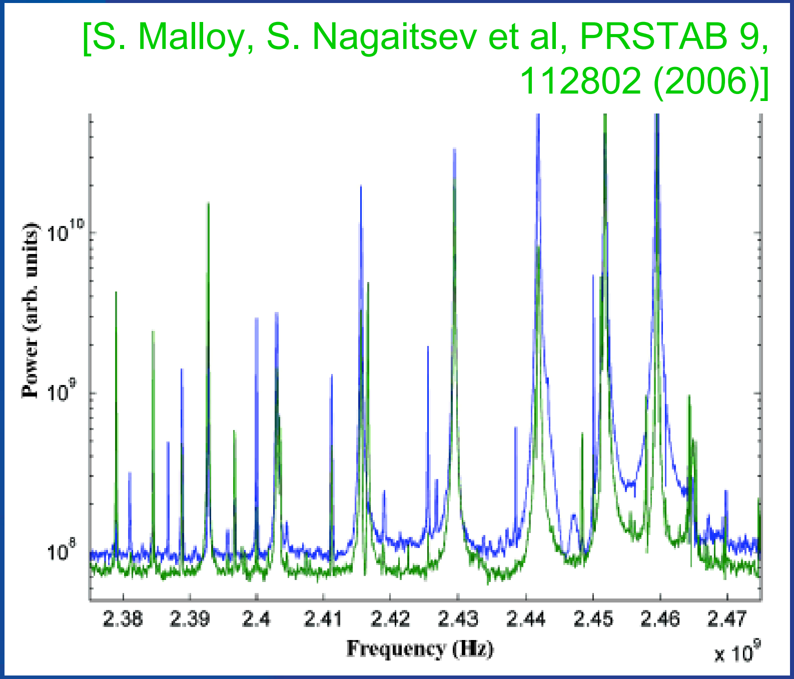


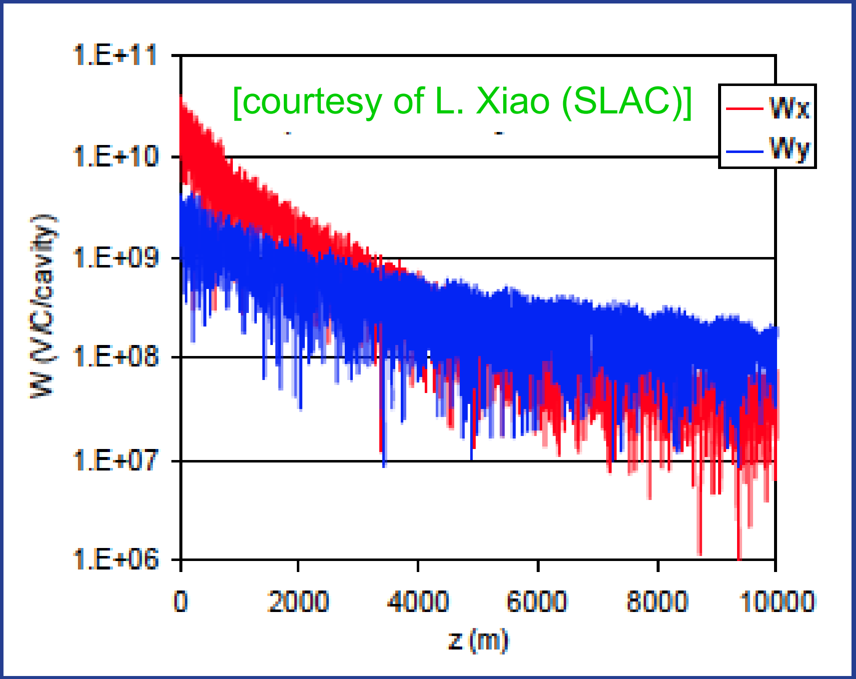
- **High-order modes**
  - spectrum, trapped modes
  - HOM-based BPMs
- **Beam dynamics**
  - Impact of HOM and input RF couplers
  - Multi-bunch effects

7.4.2 Long-range wakefield (HOMs)

[J. Byrd et al., LBNL]

- Beam's trajectory alignment in cavity,
- HOM characterization,
- RF measurements





- Beam measurements
  - bunch-to-bunch BPM
  - charge/position modulation upstream of cryomodule

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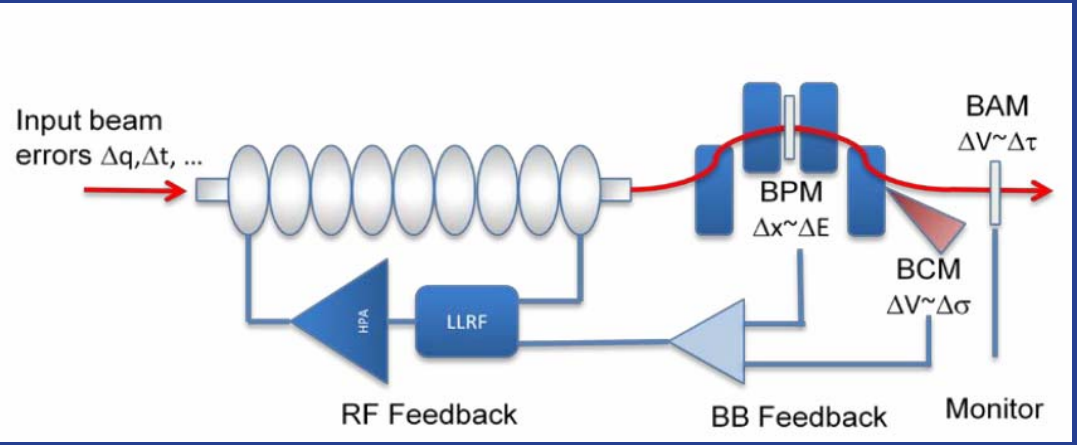
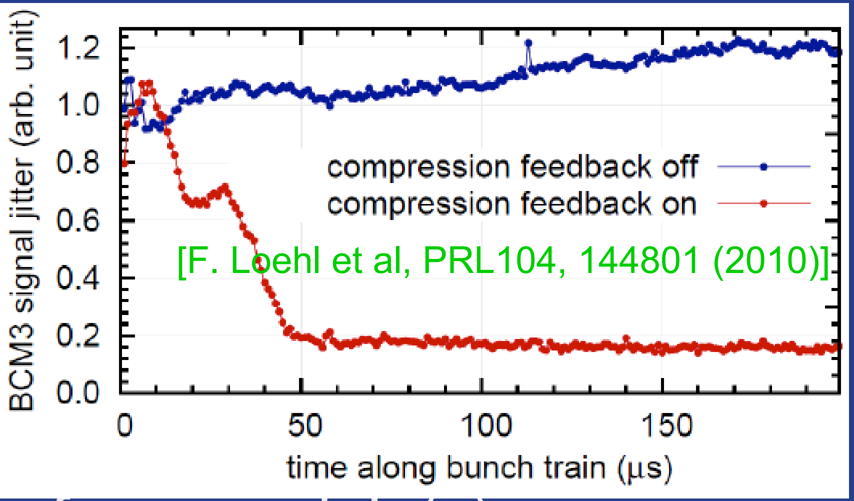
7.4.3 Beam-based linac stabilization

[J. Byrd et al., LBNL]



- High-precision stabilization of SCRF linacs
- Parasitically monitoring of
  - Coherent synchr. radiation (bunch duration),
  - Beam arrival monitor (relative time of flight),
  - BPM in dispersive section (bunch energy).

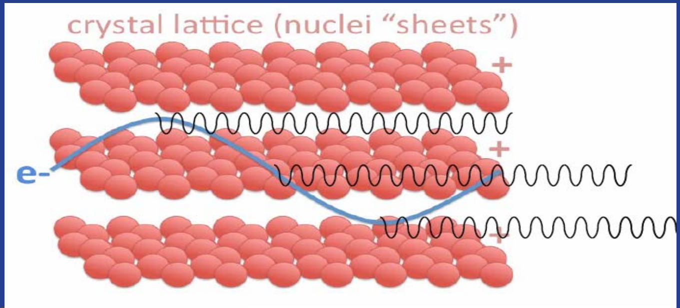


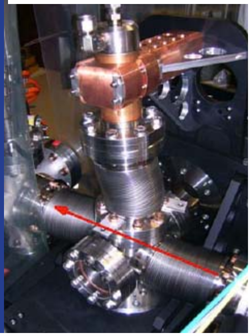
- Apply feedback
- Requires a BC downstream of cryomodule(s).

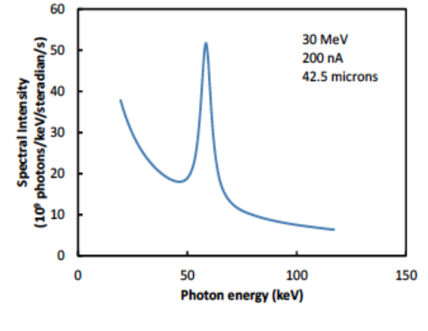
7.5.1 -- Channeling Radiation

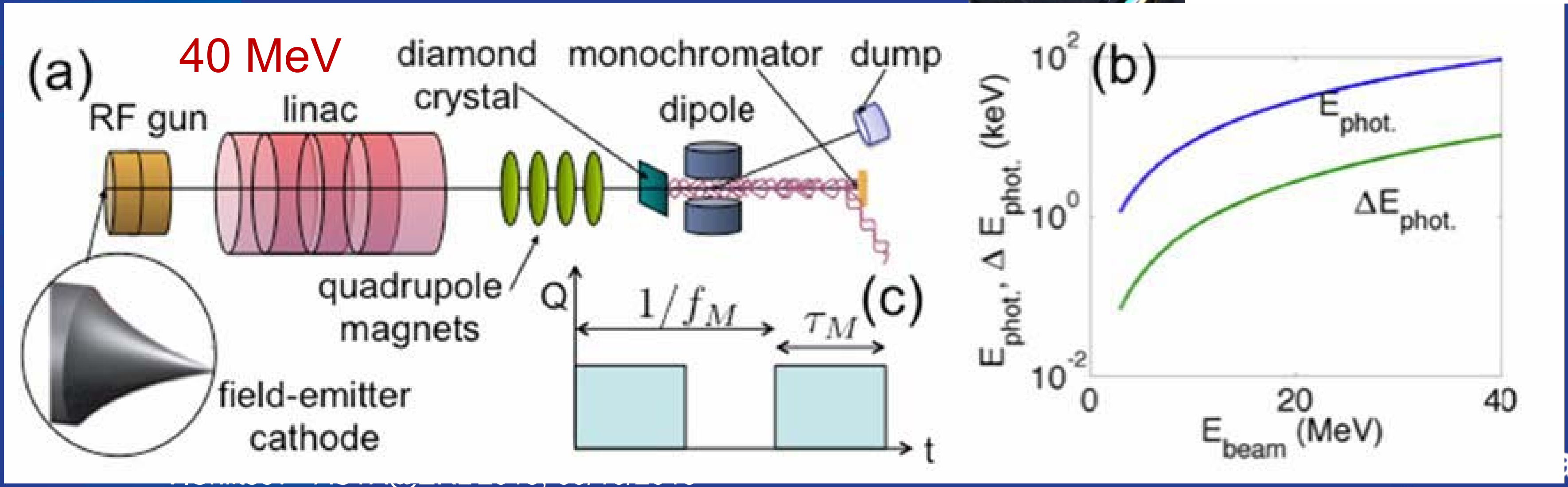
This project aims at producing X-rays at ~80 keV with high-average spectral brilliance.

- Channeling radiation was predicted theoretically by Kumakhov in 1974, and experimentally observed by Terhune and Pantell in 1975.
- Compared with a conventional undulator, channeling radiation requires only a 40-MeV electron beam, rather than a 10-GeV beam to reach the hard X-ray region.





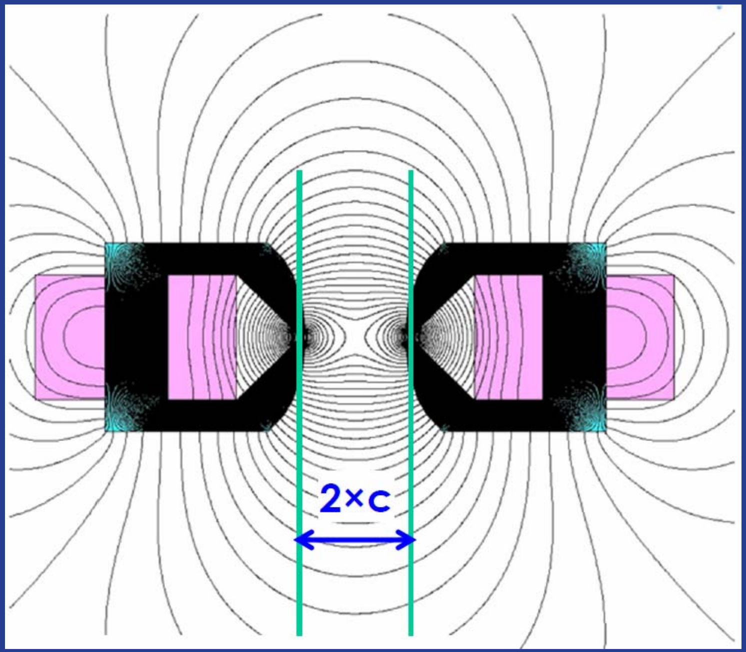




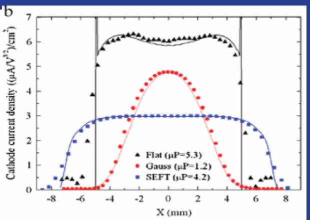
Nonlinear Lenses

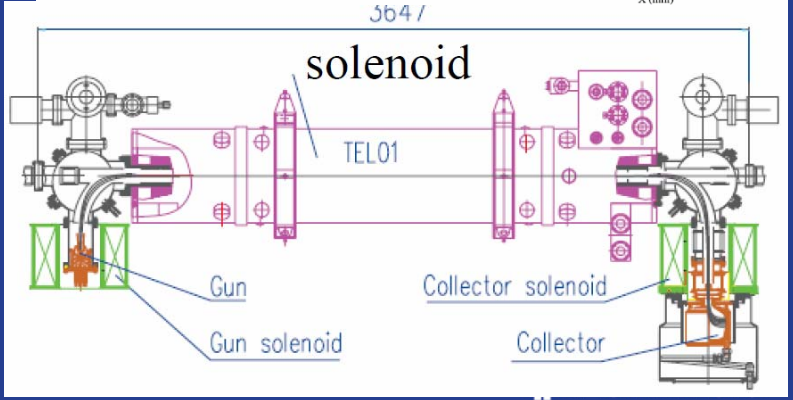
- "Integrable Optics" solutions:
  - Make motion regular, limited and long-term stable (usually involves additional "integrals of motion")
- Can be Laplacian (with special magnets, no extra charge density involved)
- Or non-Laplacian (with externally created charge –e.g. special e-lens or beam-beam

  E(r) ~r/(1+r^2)
- ***Both types will be tested in IOTA***



$$n(r) \propto \frac{I}{\left(ar^2+1\right)^2}$$

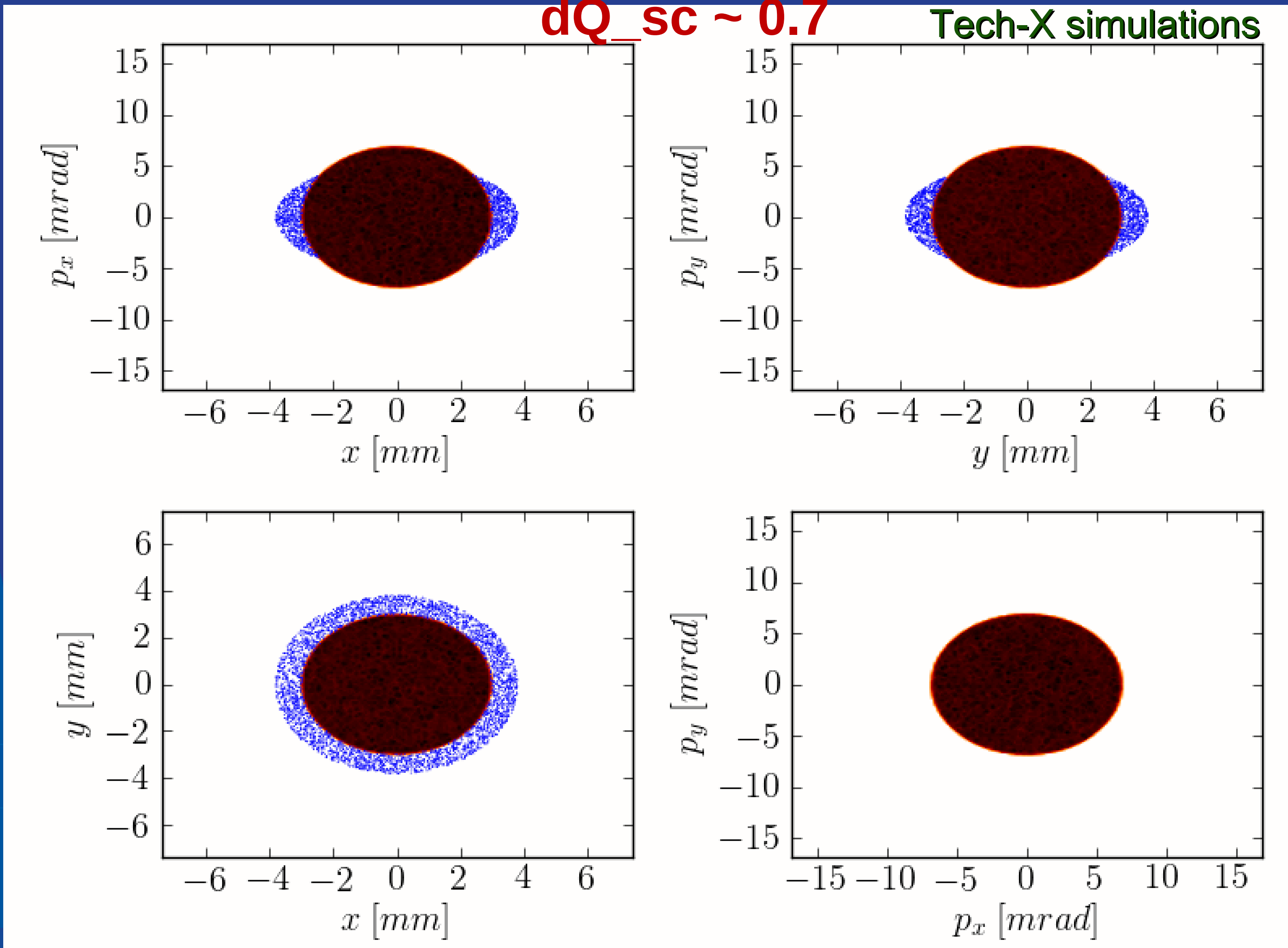




Space Charge Effects in Linear Optics Lattice

System: linear FOFO; 100 A; linear KV w/ mismatch

Result: quickly drives test-particles into the halo

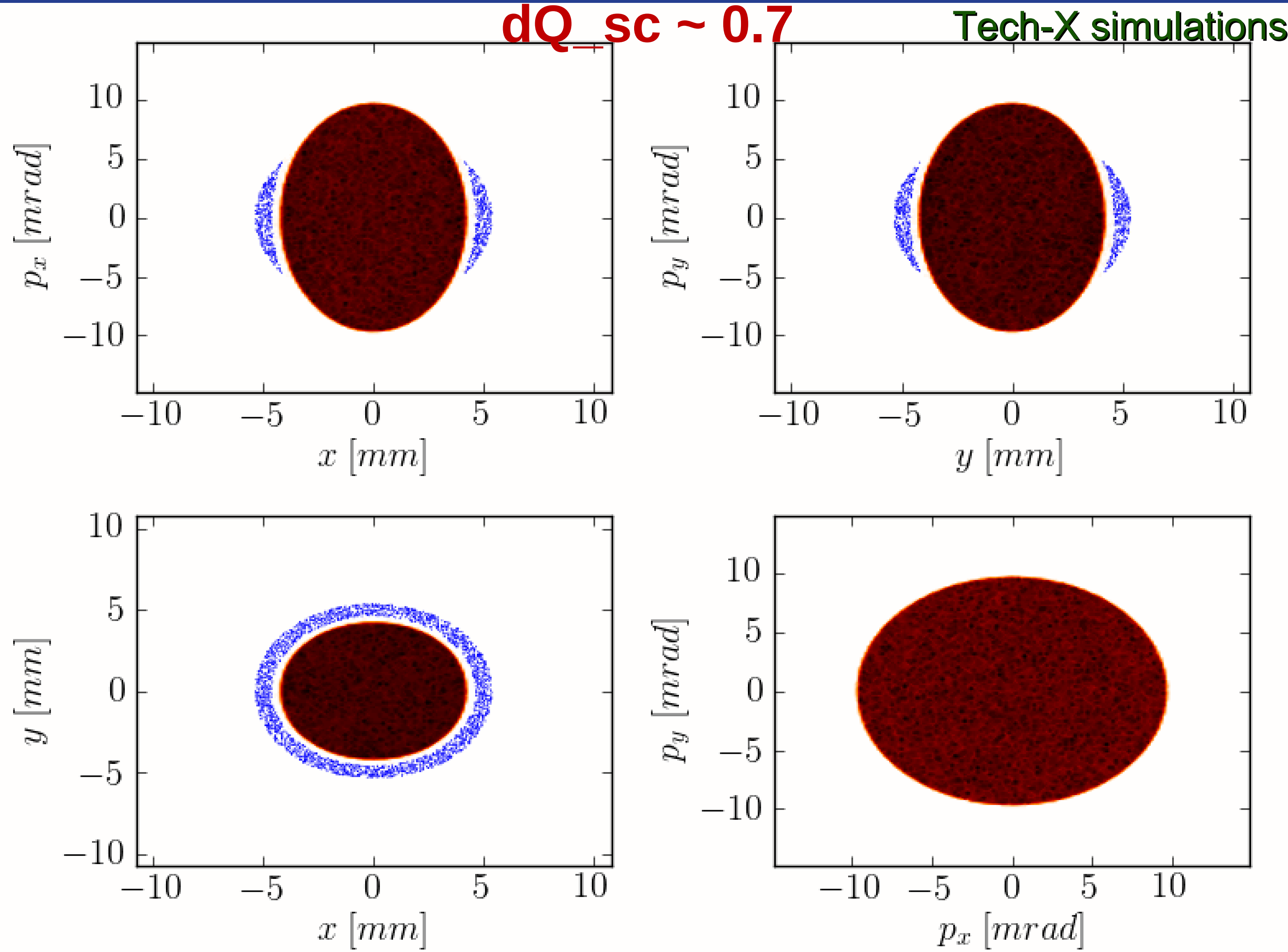


500 passes; beam core (red contours) is mismatched; halo (blue dots) has 100x lower density

Integrable Optics Lattice with Space Charge

System: octupoles; 100 A; generalized KV w/ mismatch

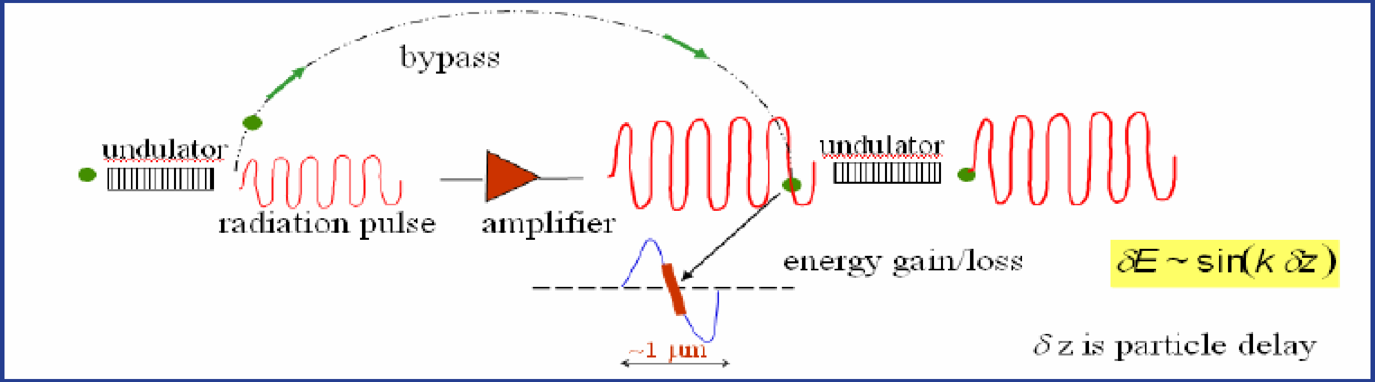
Result: nonlinear decoherence suppresses halo



500 passes; beam core (red contours) is mismatched; halo (blue dots) has 100x lower density

7.3.1 - Optical Stochastic Cooling Experiment

- Goal:
  - Experimental demonstration of the optical stochastic cooling technique (1st – no optical amplifier, then with OPA)

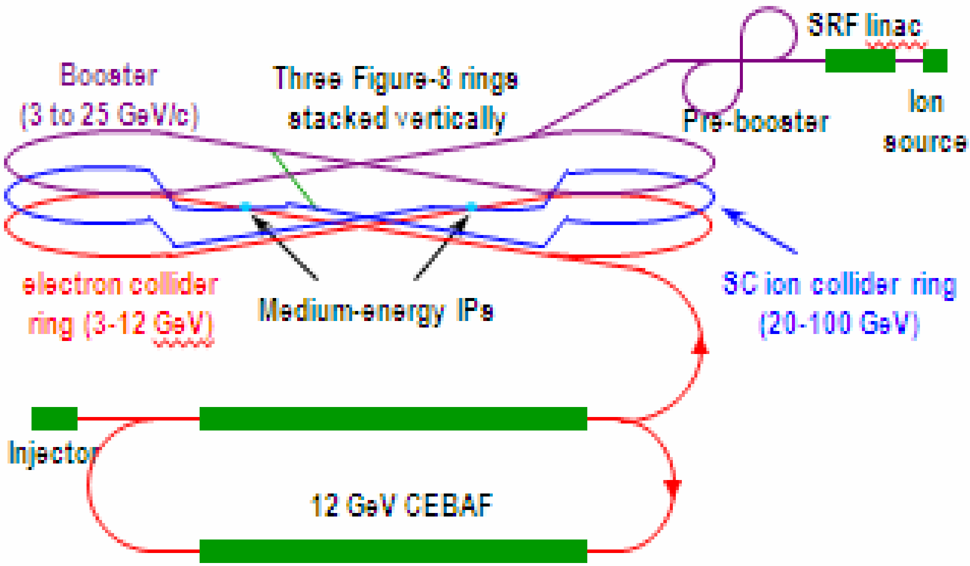


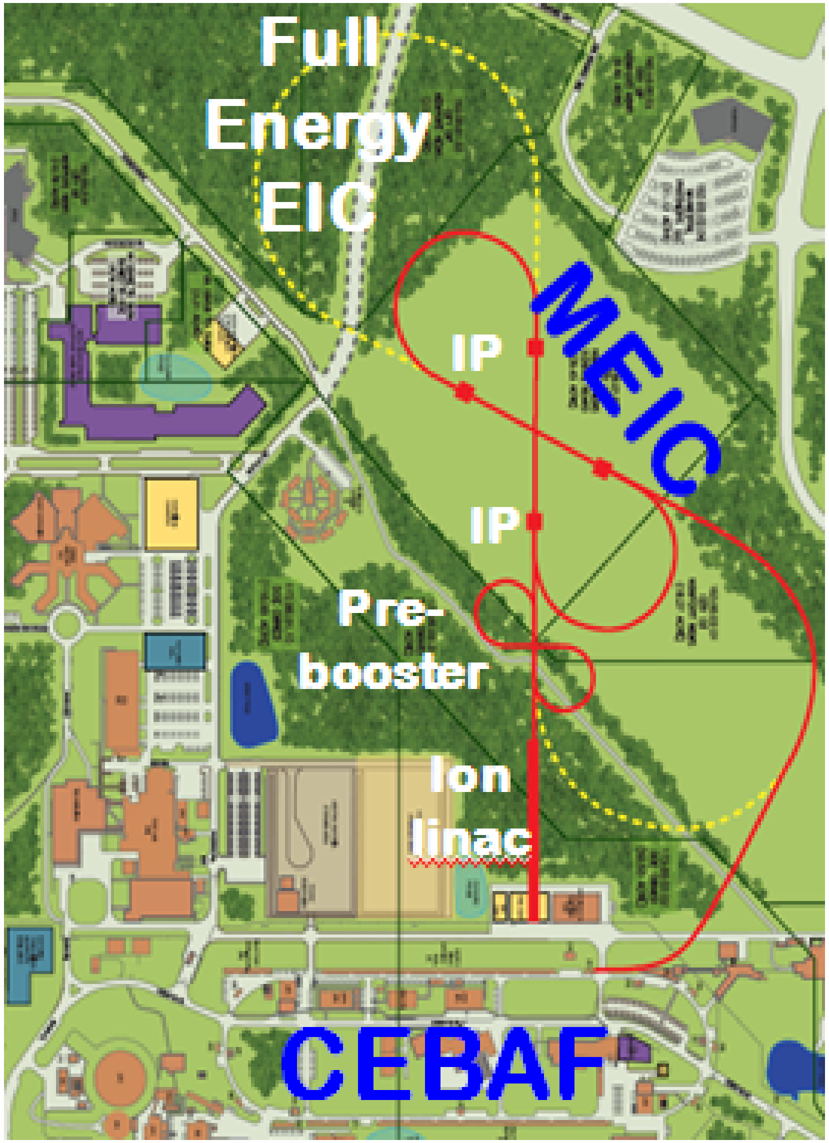
- Why ASTA:
  - Need IOTA – low energy (150 MeV – minimal synchrotron radiation damping) flexible lattice e- storage ring
- Motivation:
  - Cooling for high energy accelerators (e.g. LHC, MC)

Accelerator Science Education at ASTA

- Uniqueness of ASTA as a training ground for future accelerator builders is already widely appreciated :
  - Because of leading edge accelerator technologies available for hand-on experience
  - Breadth of the possible research topics
  - 3 experimental areas to users and round year operation
- Will be a big boost for the field and for Fermilab:
  - Potential already recognized by 20 institutions (support)
  - Many Universities interested in ASTA to expand their accelerator science programs (UC, NIU, IIT, IU, CSU, JAI, Cornell, Wayne State, UMD, MIT… and growing)
  - US Particle Accelerator School – hands on practical training laboratory sessions

MEIC at Jefferson Lab





Energy: e: 3-12 GeV, p: 20-100 GeV, i: 12-40 GeV/u

Ion species: Polarized light ions: p, d, ^{3}He,
Un-polarized light to heavy ions up to A>200 (Pb)

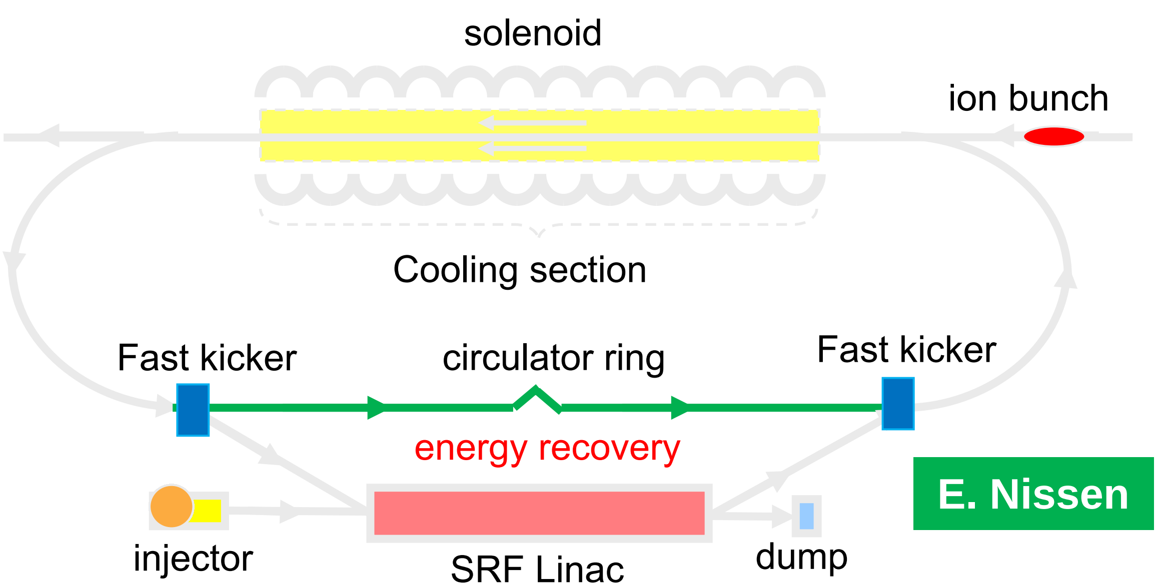
Up to 3 detectors

Luminosity: up to 10^{34} cm^{-2}s^{-1} per interaction point

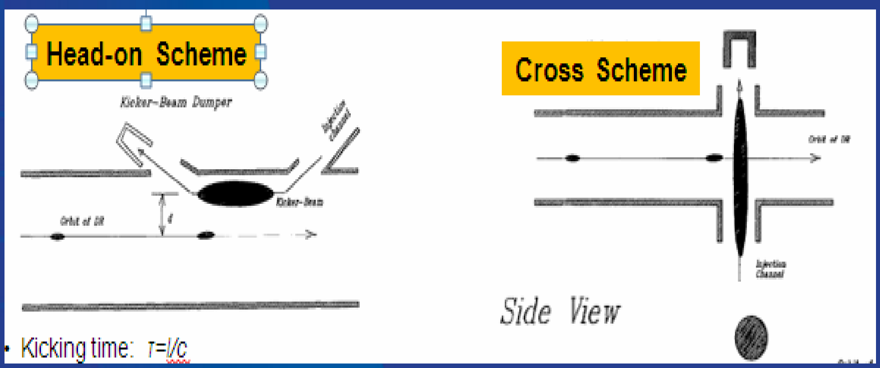
Polarization: All polarizations >70%
At IP: long. for both, trans. for ions only

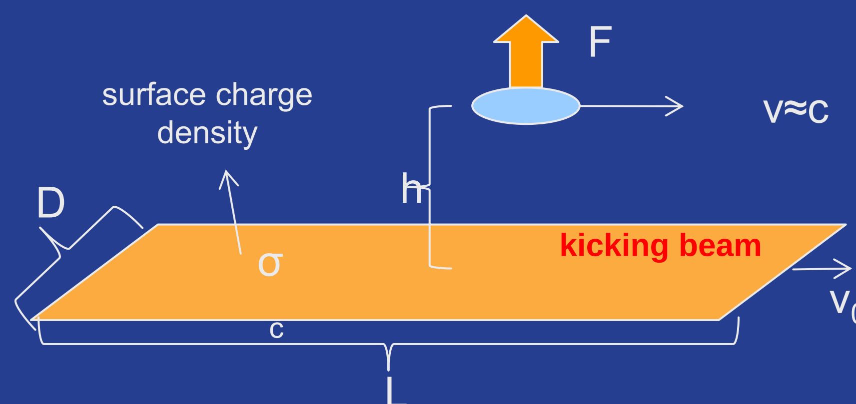
Upgradeable to higher energies & luminosity
20 GeV electron, 250 GeV proton, 100 GeV/u ion

Ultra Fast Beam Kicker for ERL-CCR



- It requires an ultra fast kicker for switching bunches in/out of a CCR
- The kicker must be able to operate at a high repetition rate (~26 MHz)
- Rise/full time must be shorter than sub ns to avoid disturbing the neighboring bunches
- 30 turns → 30-fold saving in the 54 MeV ERL power





Y.Zhang et al (Jlab) – a) proof of principle BBK;

b) flat beam transform; c) energy recuperation CW

Other opportunities for ERL-ralated accelerator R&D at ASTA

We welcome new proposals!!!

- Due to their high average power cw beams, ERLs need nonintercepting diagnostics of all kinds and will eventually have 2-3 GeV so 300-800 MeV is a start.
- <u>**Possible demos with ASTA pulsed high power beams:**</u>
  - 1. CDR for bunch length and beam based feedback at 50 MeV and higher gamma.
  - 2. ODR near field for beam size at 500 MeV and above.
  - 3. OSR from dipoles for beam size and bunch length
  - 4. EOS based diagnostics
  - 5.Undulator radiation diagnostics with U5.0 (should be very relevant to ERL) for bunch length, phase, energy, energy spread, beam position, beam size at micropulse level and sub macropulse.
  - 6. sub ps source for VUV detector tests.
  - 7.Beam based feedback
  - 8. beam arrival monitor development
  - 9. microbunching instability in compressed beams

Summary on ASTA Scientific Potential and Experimental Proposals

ASTA will be a unique Accelerator R&D facility:

- A broad range in beam energies (50-800 MeV)
- High-repetition rate and the highest power beams available
- It offers all the advantages of a modern, SRF-based accelerator
- High beam quality , beam stability, beam brightness
- Arbitrary emittance partition with repartition of phase space
- Linacs and ring, electrons and protons, lasers

ASTA's all 3 exp.areas are good for multiple experiments

- With 50 MeV electrons (EA1)
- With 300-800 MeV electrons and SRF (EA2)
- With 50-150 MeV/c electron and protons in IOTA ring (EA3)

Your Proposals for ASTA Are Very Welcome!!

BACK UP SLIDES

Our Proposal

We propose to establish a proposal-driven Accelerator R&D User Facility at Fermilab's Advanced Superconducting Test Accelerator (ASTA)

To do that requires:

1. Supporting the completion of ASTA in a phased approach:
   - Build out the linear accelerator to ~800 MeV with three Cryomodules
     - associated beam transport lines, dumps and support systems
   - Construct the Integrable Optics Test Accelerator (IOTA)
     - A small, flexible storage ring to investigate beam dynamics of importance to intensity frontier rings
   - In further phases
     - Add proton capability to IOTA (by reusing existing equipment)
     - Increase peak current of compressed electron bunches by installation of 3.9 GHz system
2. Supporting the Operation of an Accelerator R&D User Program
   - Support staff required to operate a 9 month/year proposal-driven Accelerator R&D program

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"1st wave" of ASTA Experiments: FY14

- Neural Neworks in SRF control:
  - Colorado State University
  - 1st SC RF Cryomodule (no beam → with beam)
- X-ray channeling radiator:
  - Vanderbilt and NIU
  - 50 MeV e- beam and highest brightness low-current source
- New non-intercepting beam diagnostics:
  - APC Exp.Beam Phys Dept and AD Instrum. Dept
  - 50 MeV e- beam
- Tagged photons (planning to start)
  - D.Christian , et al with low intensity 50 MeV e-
- Acceleration in Carbon Nanotubes (planning to start)
  - NIU , with 50 MeV e-

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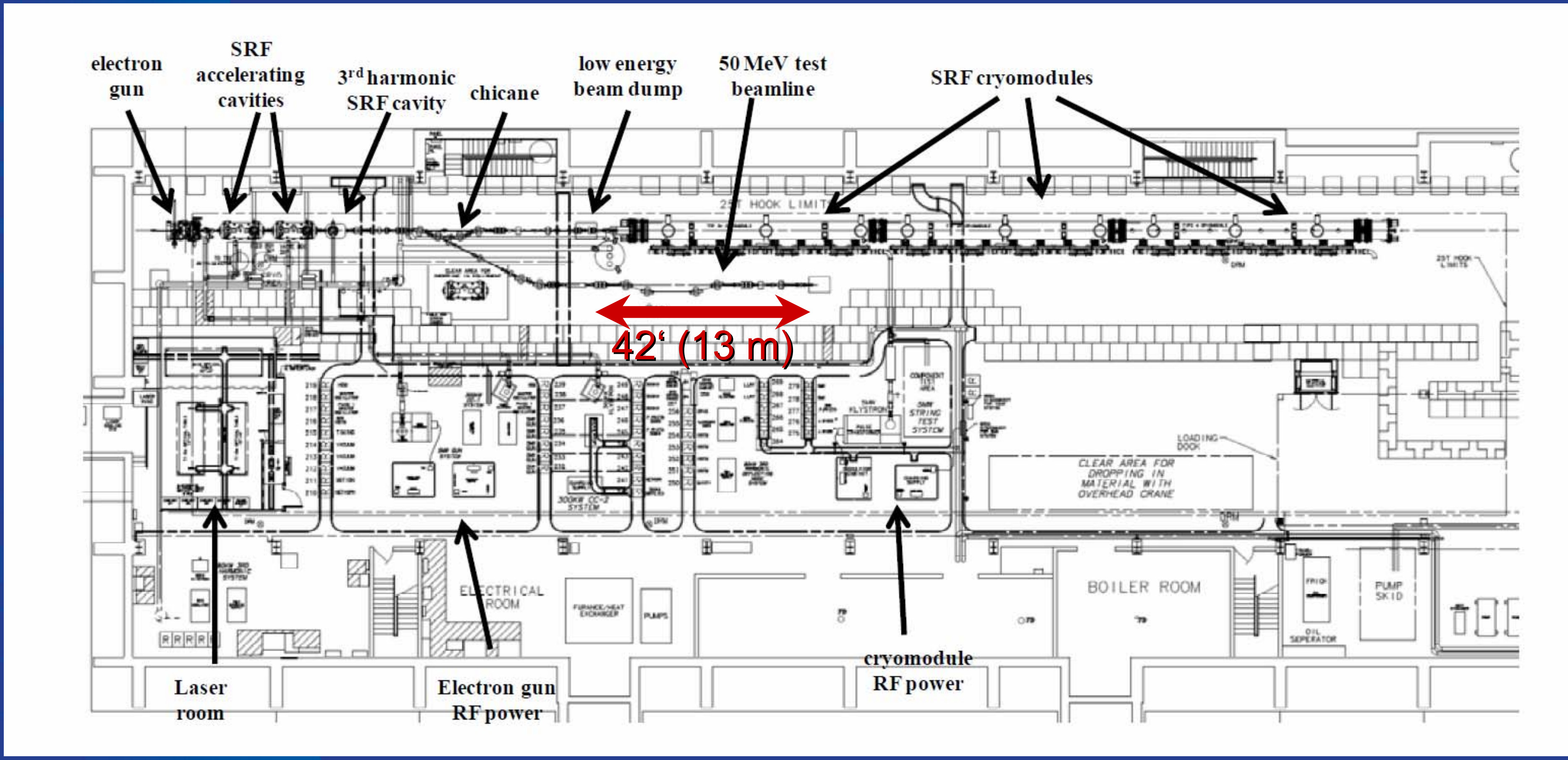
ASTA : Upstream part

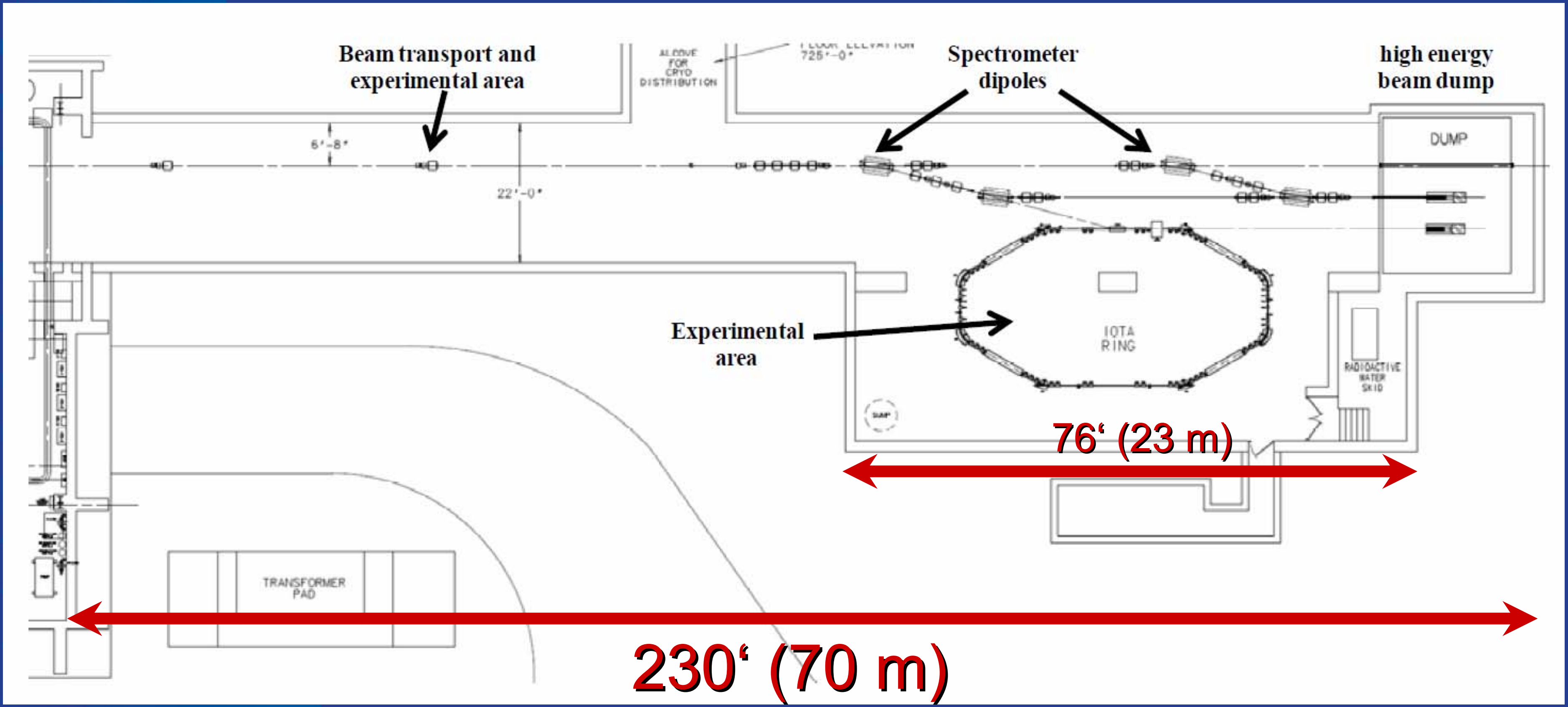


242' (74 m)

- Shows 3 SCRF CMs (1st CM – at Stage I.2, 2 more – Stage II)

Fermilab

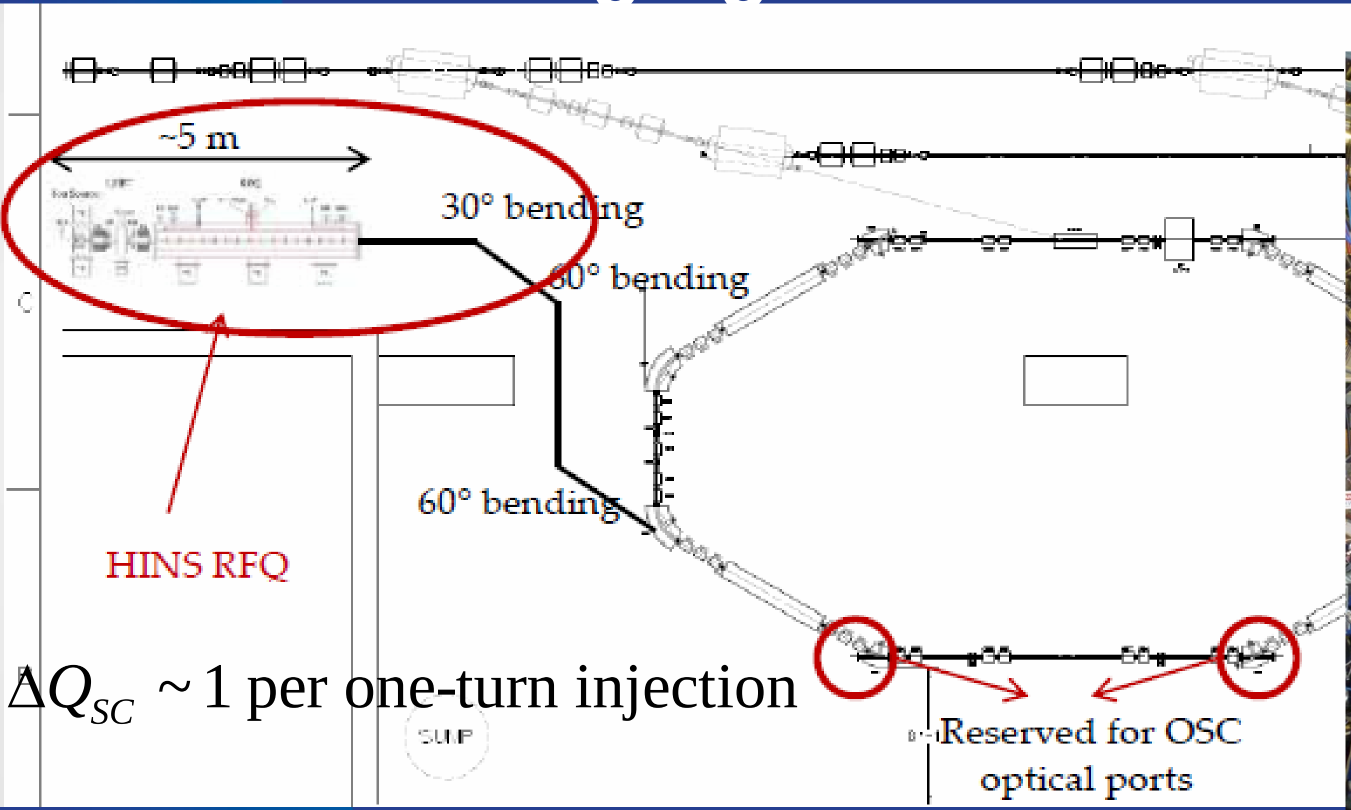
ASTA : Downstream part



- proton RFQ not pictured (Stage III)

Fermilab

7.2.2 – Space Charge Compensation Bringing Protons to IOTA



$\Delta Q_{SC} \sim 1$ per one-turn injection

- Allows tests of Integrable Optics with protons and realistic Space-Charge beam dynamics studies
- Allows Space-charge compensation experiments