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Commissioning and Plans of the IOTA Electron Injector

Dan Broemmelsiek

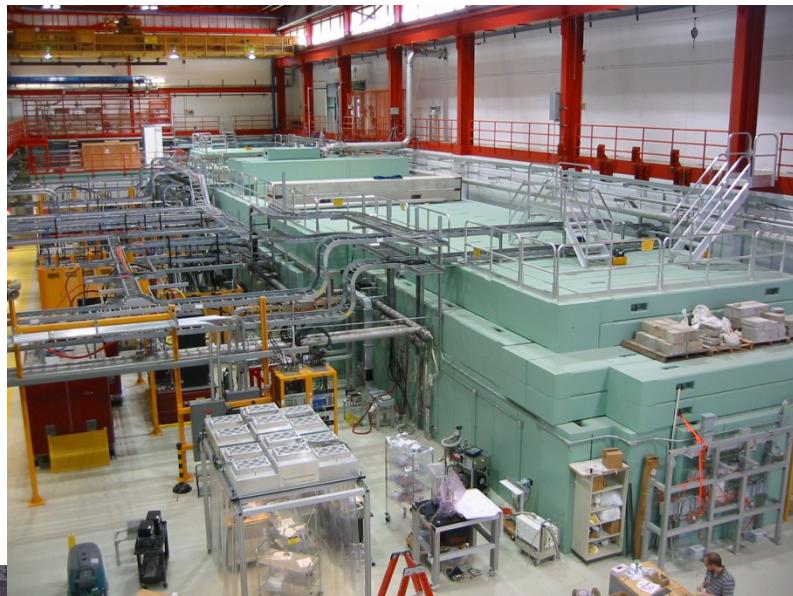
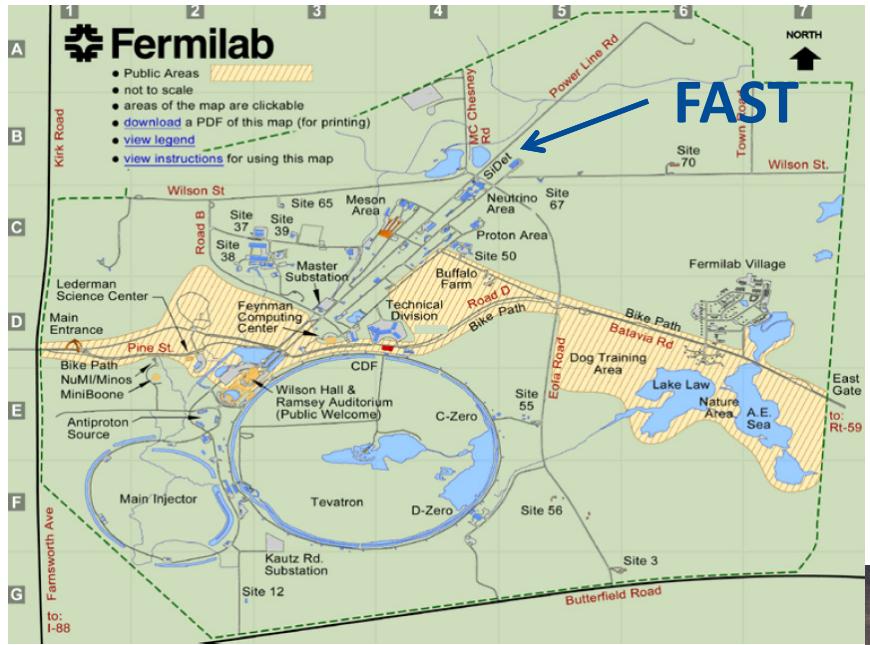
LINAC2016

24 September 2016

Usual Culprits



Location

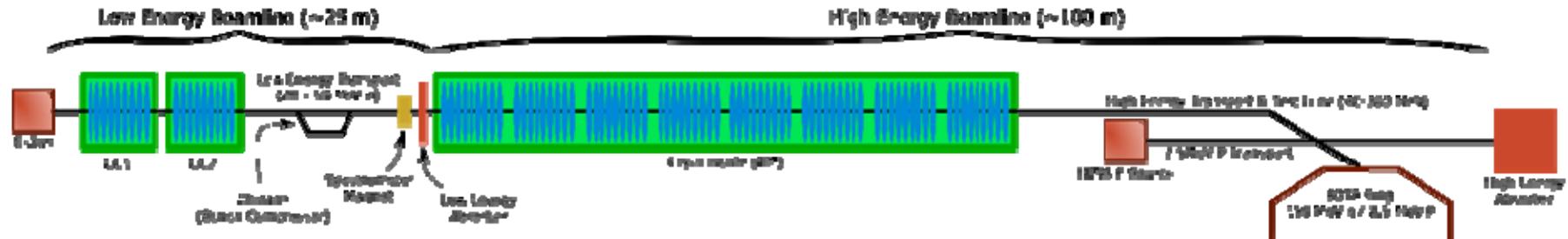


Aerial view courtesy T. Nicol

 Fermilab



IOTA/FAST Facility



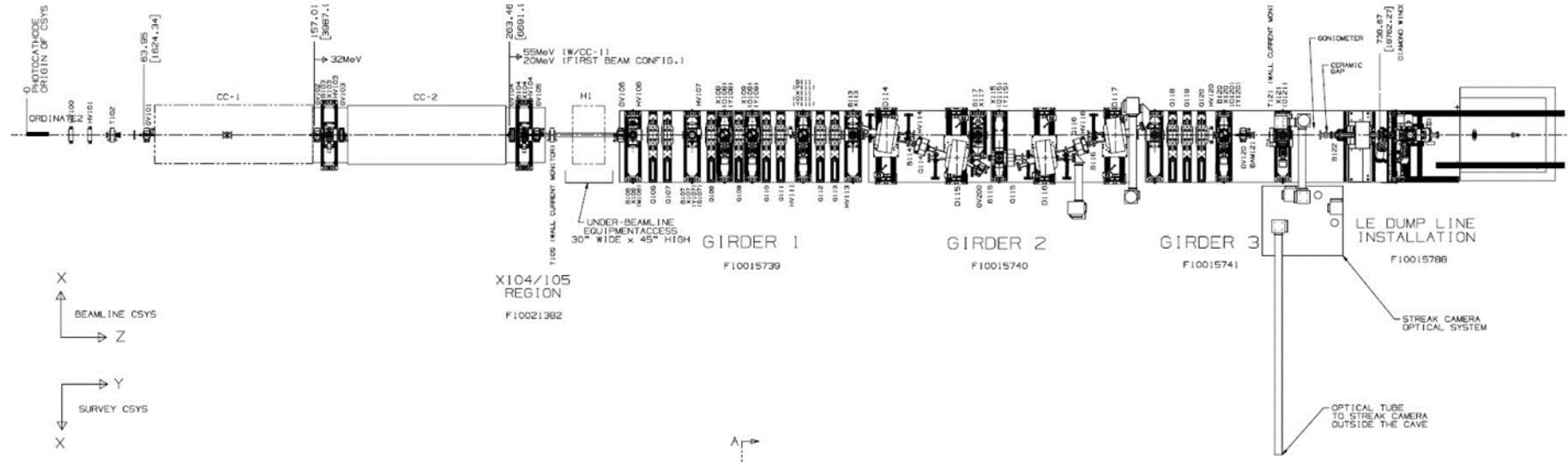
- 50 MeV photoinjector
- 250 MeV ILC cryomodule
- High Energy FODO Lattice Transport Line
- 75 kW Beam Absorber
- Integrable Optics Test Accelerator
- 2.5 MeV Proton Source formerly known as HINS

CM-2 Commissioning



- Harms, et al. in FRAA03, SRF2015
- Average gradient of 31.5 MV/m with only one cavity not meeting this spec.
- “...CM-2 appears to be ready to provide an accelerating voltage of up to 250 MeV.”

Electron Injector



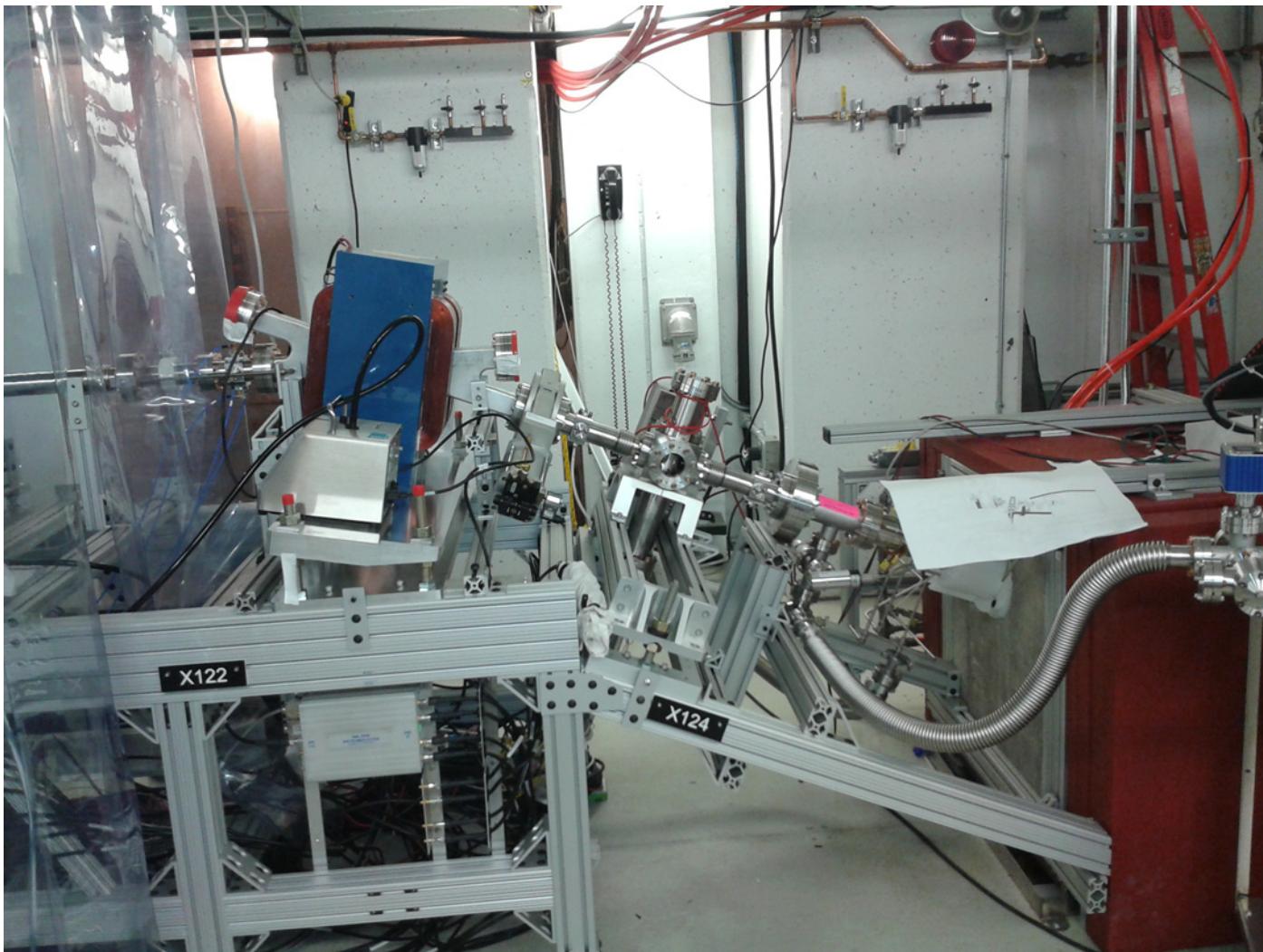
Parameter	Value	Unit
Bunch charge	0.02 – 3.2	nC
Bunch train duration	1	ms
Bunch frequency within train	3	MHz
Number of bunches/train	1 – 3000	
Bunch train frequency	1 – 5	Hz

Gun and Capture Cavities

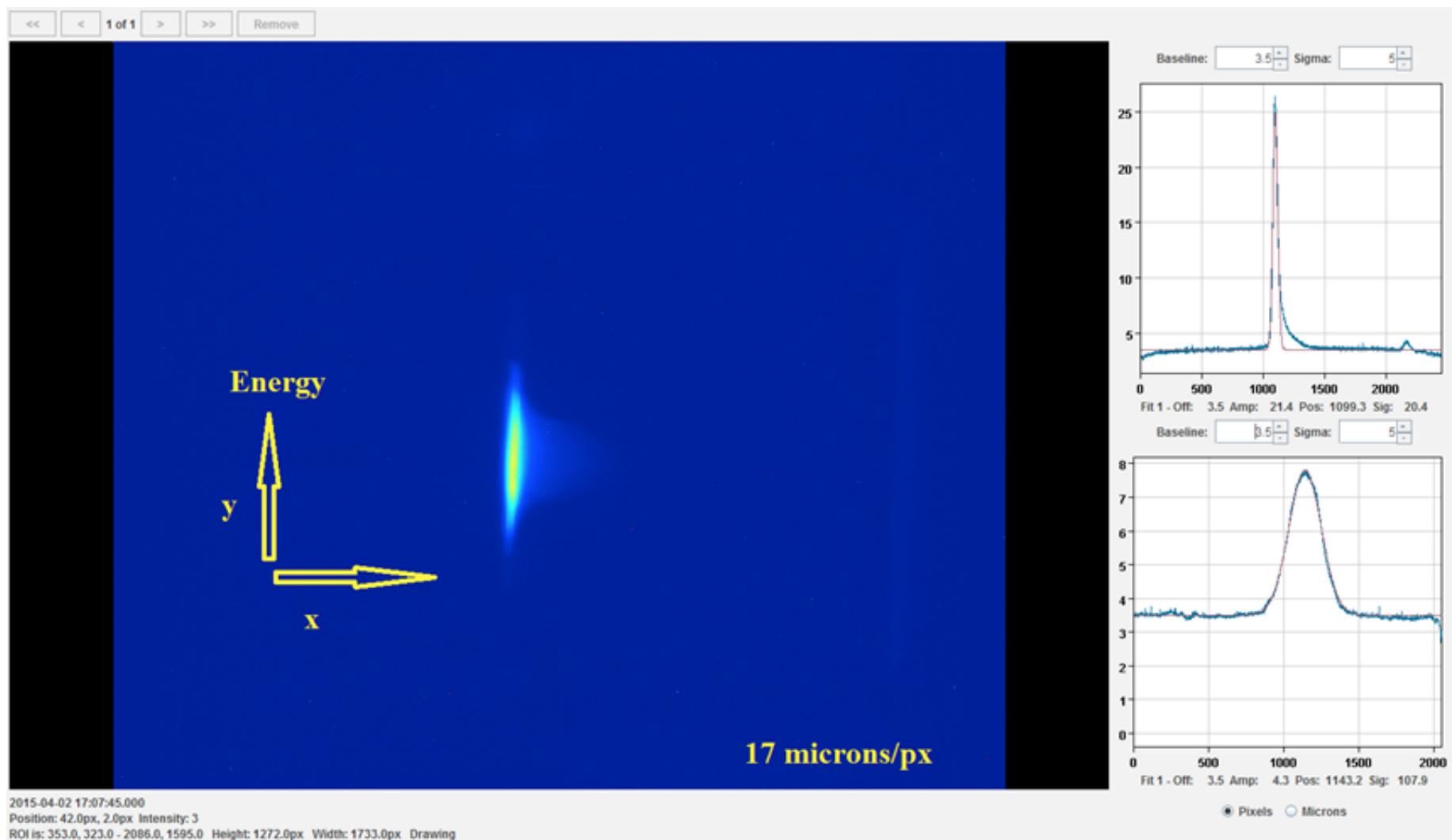
- 1.3 GHz, normal conducting, 1.5 cell RF electron gun
 - Cs₂Te photocathode excited by 263 nm UV laser
 - Gun 42 MV/m, ~4.5 MeV electrons
- Two 1.3 GHz 9-cell SRF cavities
 - CC1 at 27.5 MV/m
 - CC2 at 17 MV/m
 - Parameter scaling, spectrometer based beam energy > 50 MeV



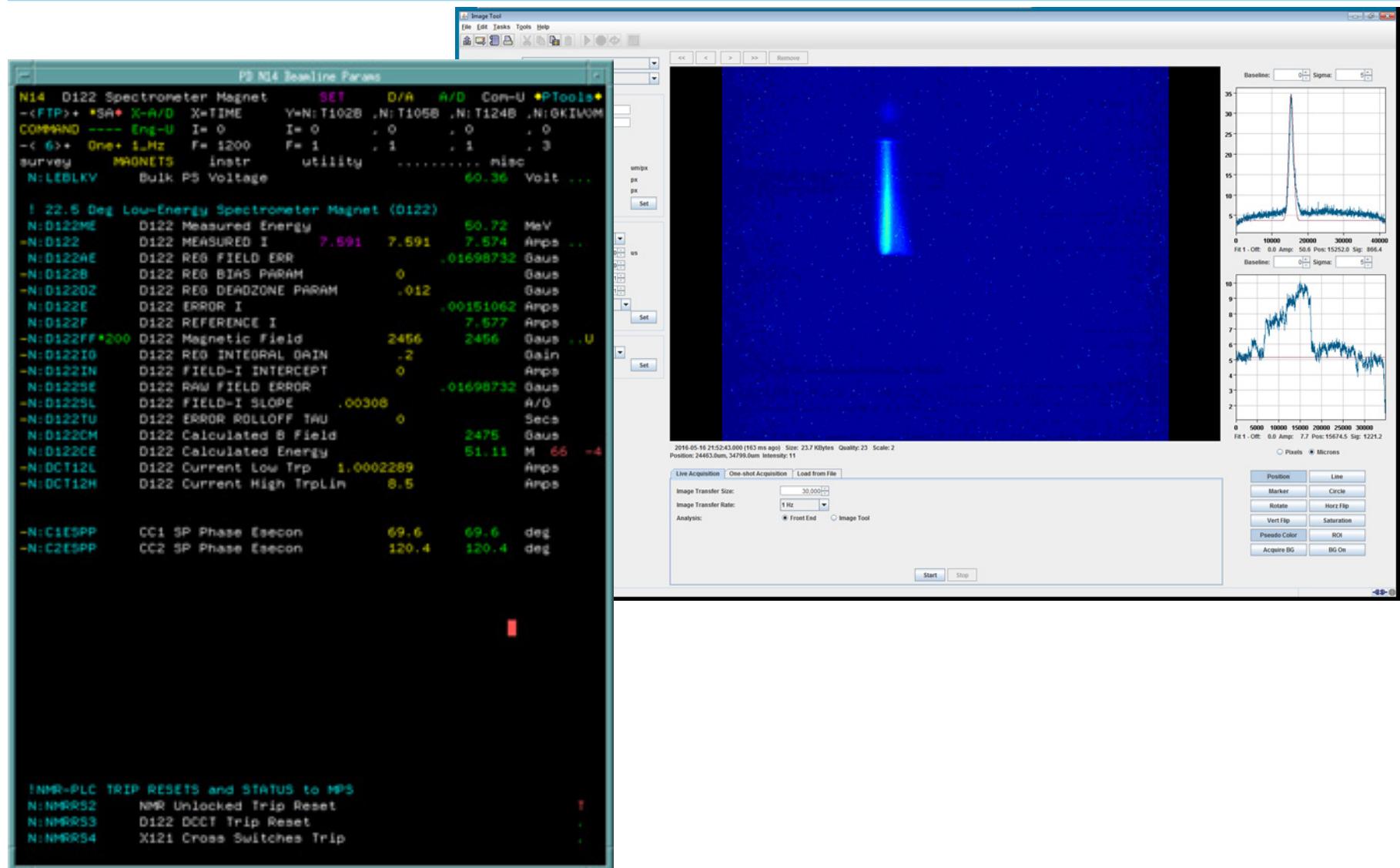
Energy Measurement



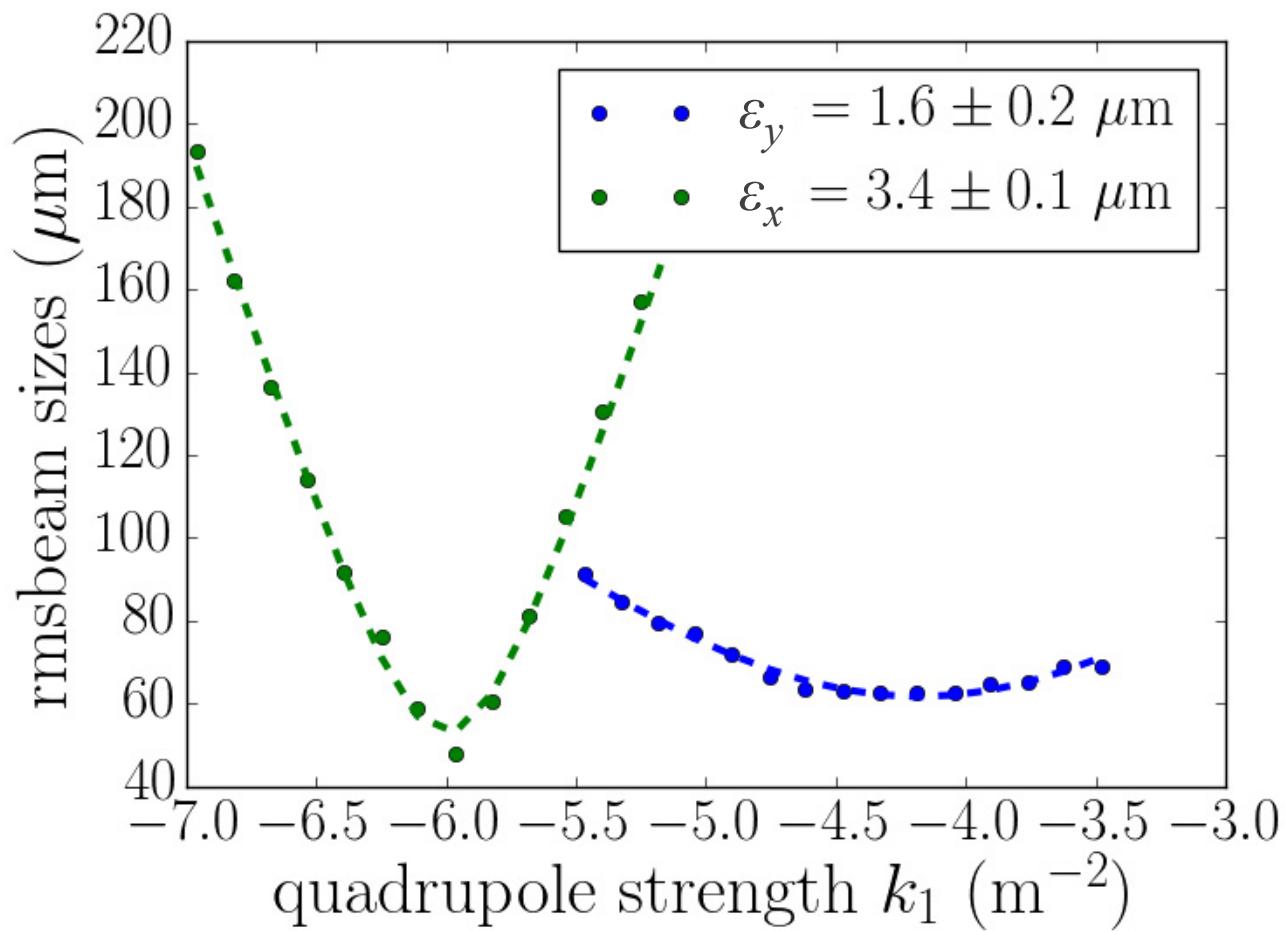
20 MeV April 2015



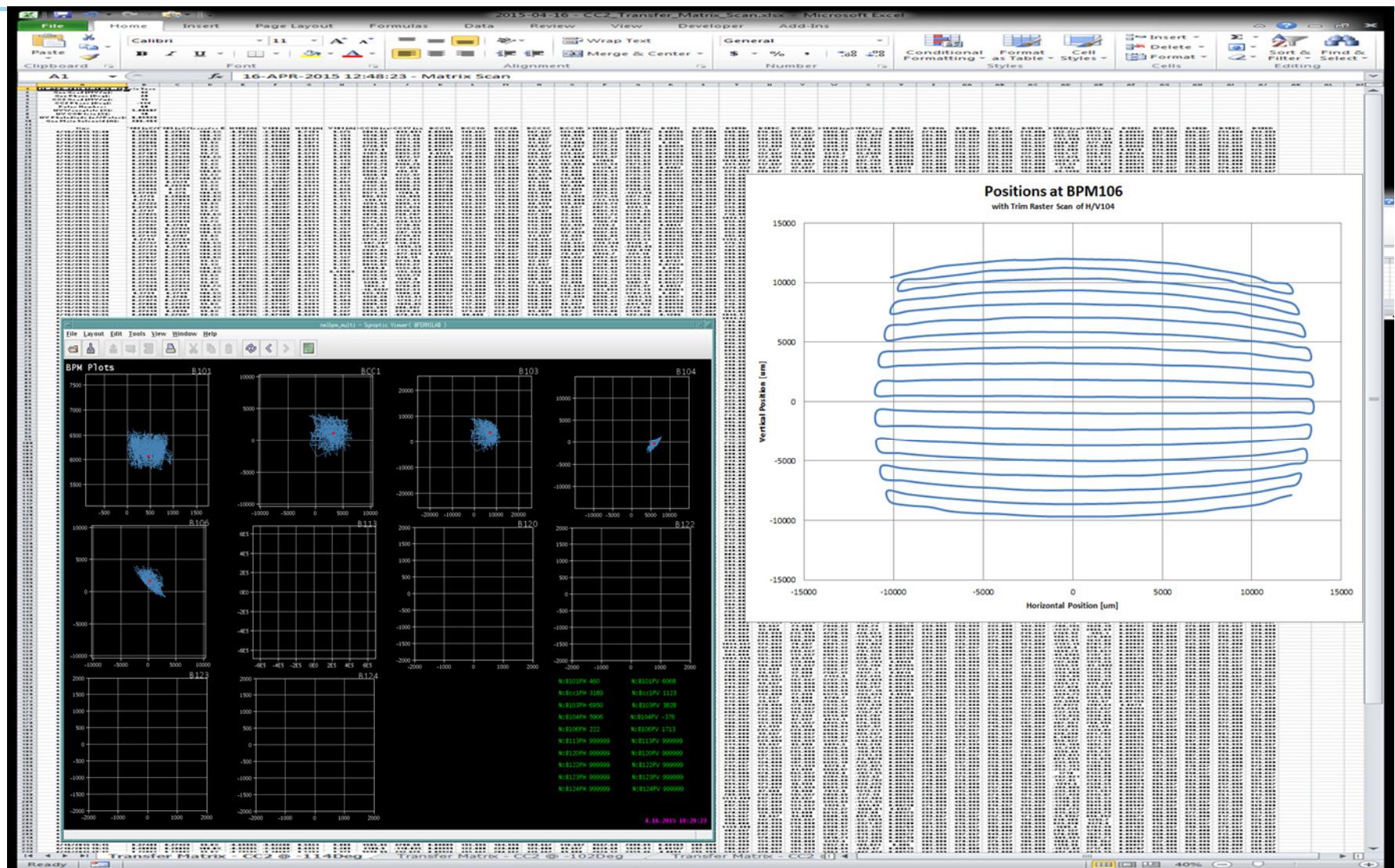
50 MeV May 2016



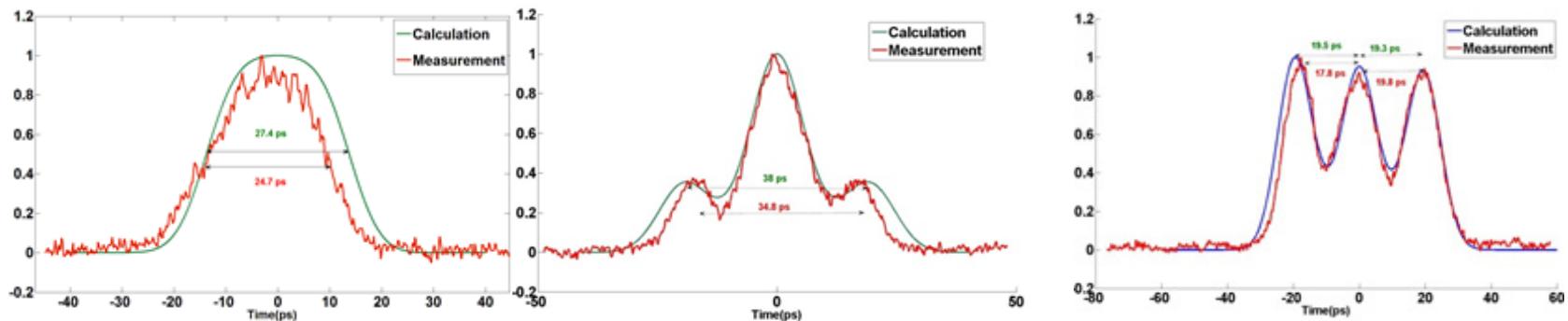
Quad Scan Emittance Measurement, 50 pC



Tesla Cavity Transfer Function Measurement, MOP106018

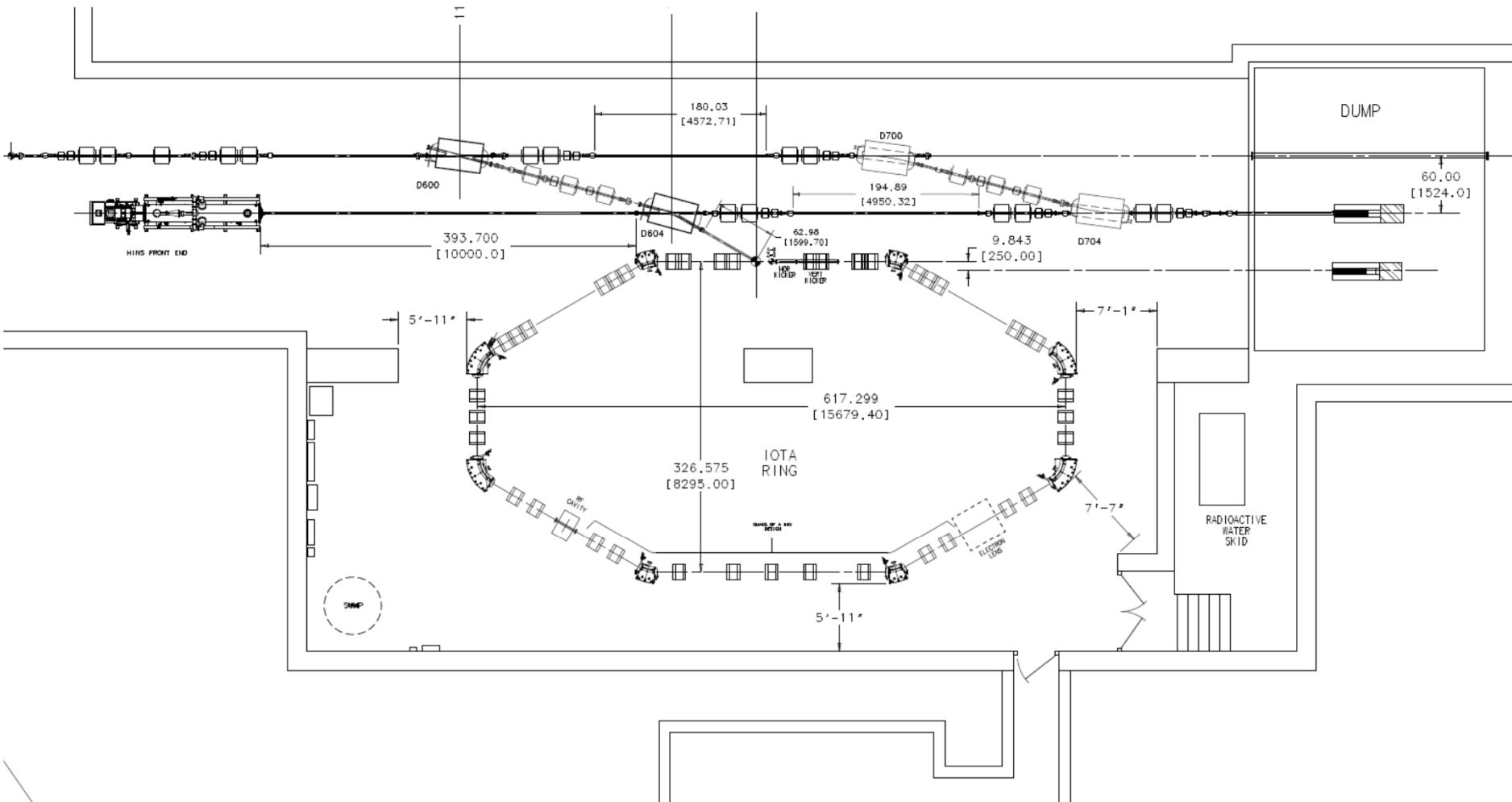


Longitudinal Bunch Shaping, MOPMA043/FEL2015

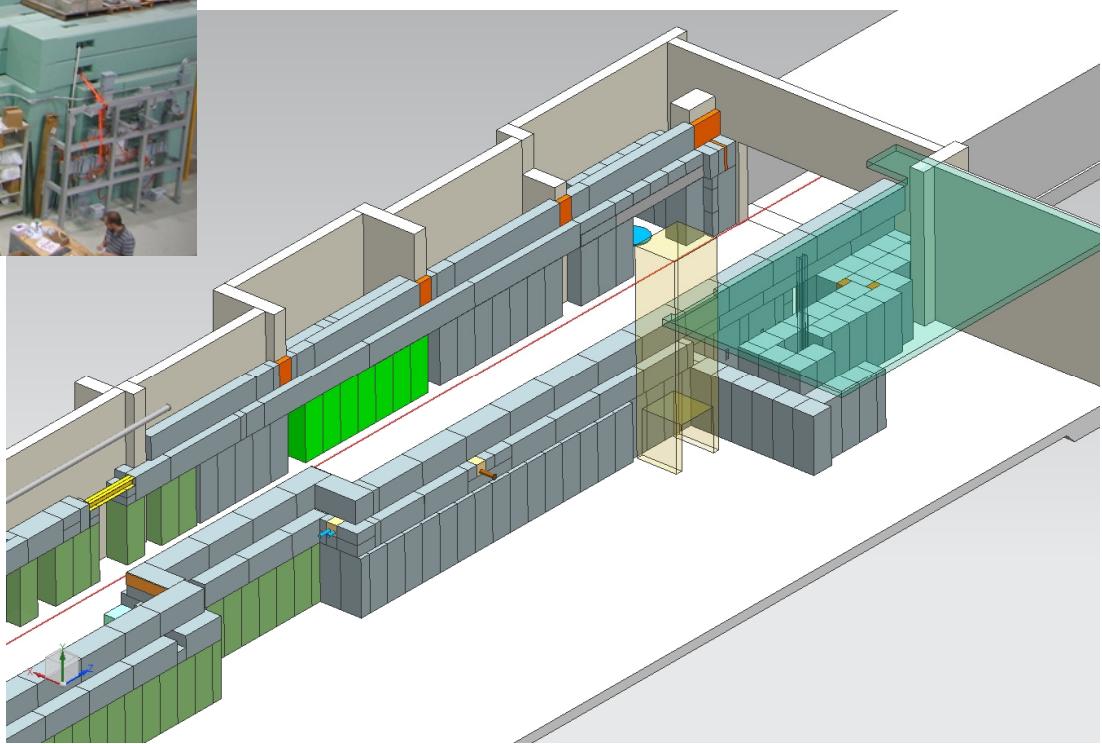


- UV laser shaped at picosecond time-scale
- Study the evolution of density fluctuations

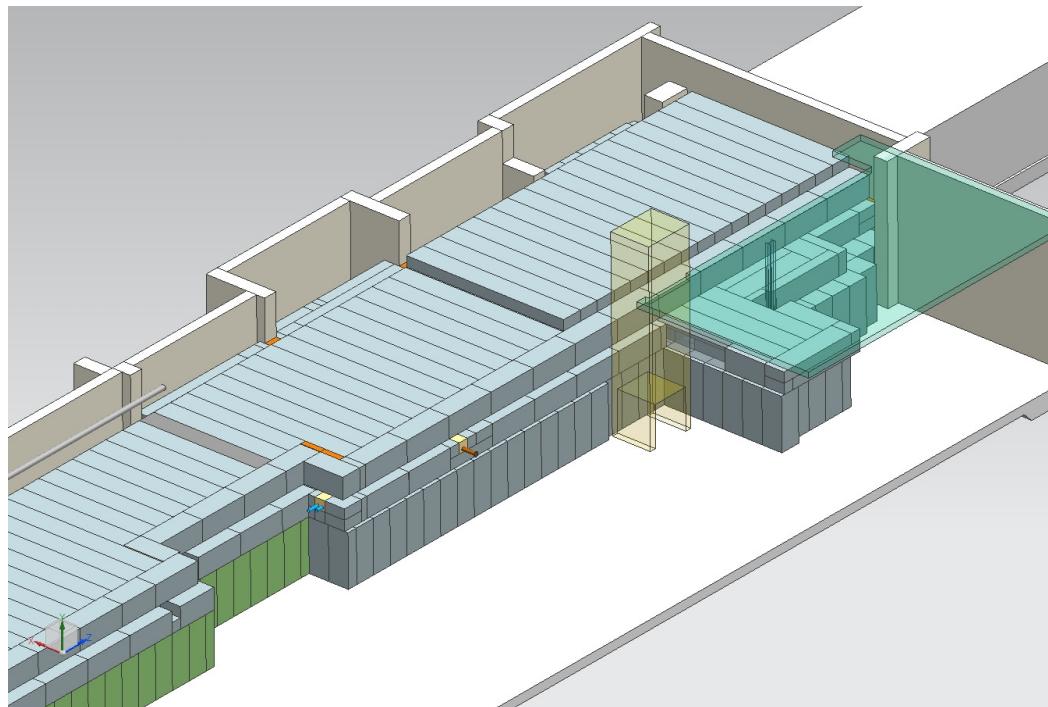
300 MeV to High Energy Absorber



300 MeV Beamline



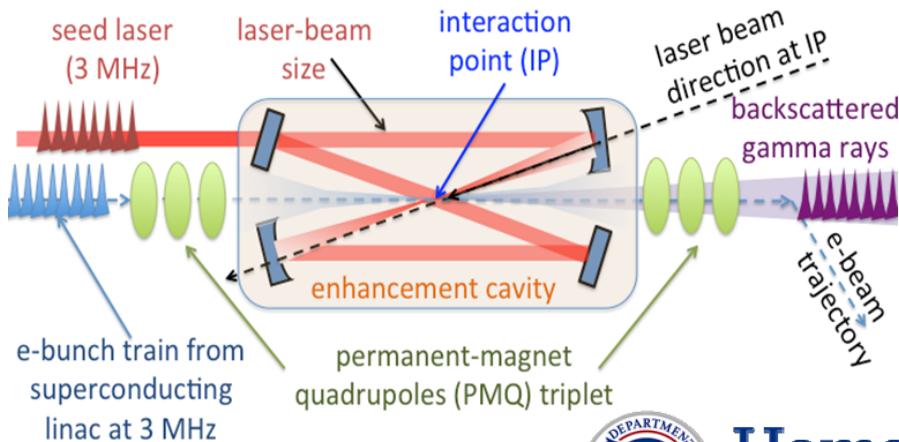
300 MeV Beamline



- Construction well underway
- Finalize designs and procurement

High-rep-rate tunable gamma-ray source

- Inverse Compton scattering of a 300 MeV beam against a high-power infrared laser
- high rep. rate achieved by combining:
 - enhancement IR cavity → high energy IR pulses,
 - beam from SCRF linac → high repetition rate
- high-brilliance γ rays with Watt-level aver. power,
- Application: Nuclear Astrophysics, Nuclear Medicine, Oncology, and Security,
- Collaboration: NIU, Radiabeam & Fermilab



**Homeland
Security**

IOTA Proton Source

- Luckily, we have an extra RFQ just lying around...
- The HINS (“High Intensity Neutrino Source”) was developed as the front end of a pulsed “Project X” 8 GeV proton linac



- Because of cooling problems, it never reached its design pulse rate
- HINS RFQ available for our use
- FY16 working ion source, FY17 working RFQ

HINS Parameters for IOTA

Table 1: HINS Parameters for IOTA

Parameter	Value	Unit
Particle type	proton	-
Kinetic Energy	2.5	MeV
Momentum	68.5	MeV/c
β	.073	-
Rigidity	.23	T-m
RF structure	325	MHz
Current	8	mA
Circumference	39.97	m
Total Protons	9.1×10^{10}	-
RMS Emittance (un-normalized)	4	$\pi\text{-mm-mrad}$
Tune shift	$-.51 \times B$	-
Pulse rate	<1	Hz
Pulse length	1.77	μsec

scrape for higher tune shifts?

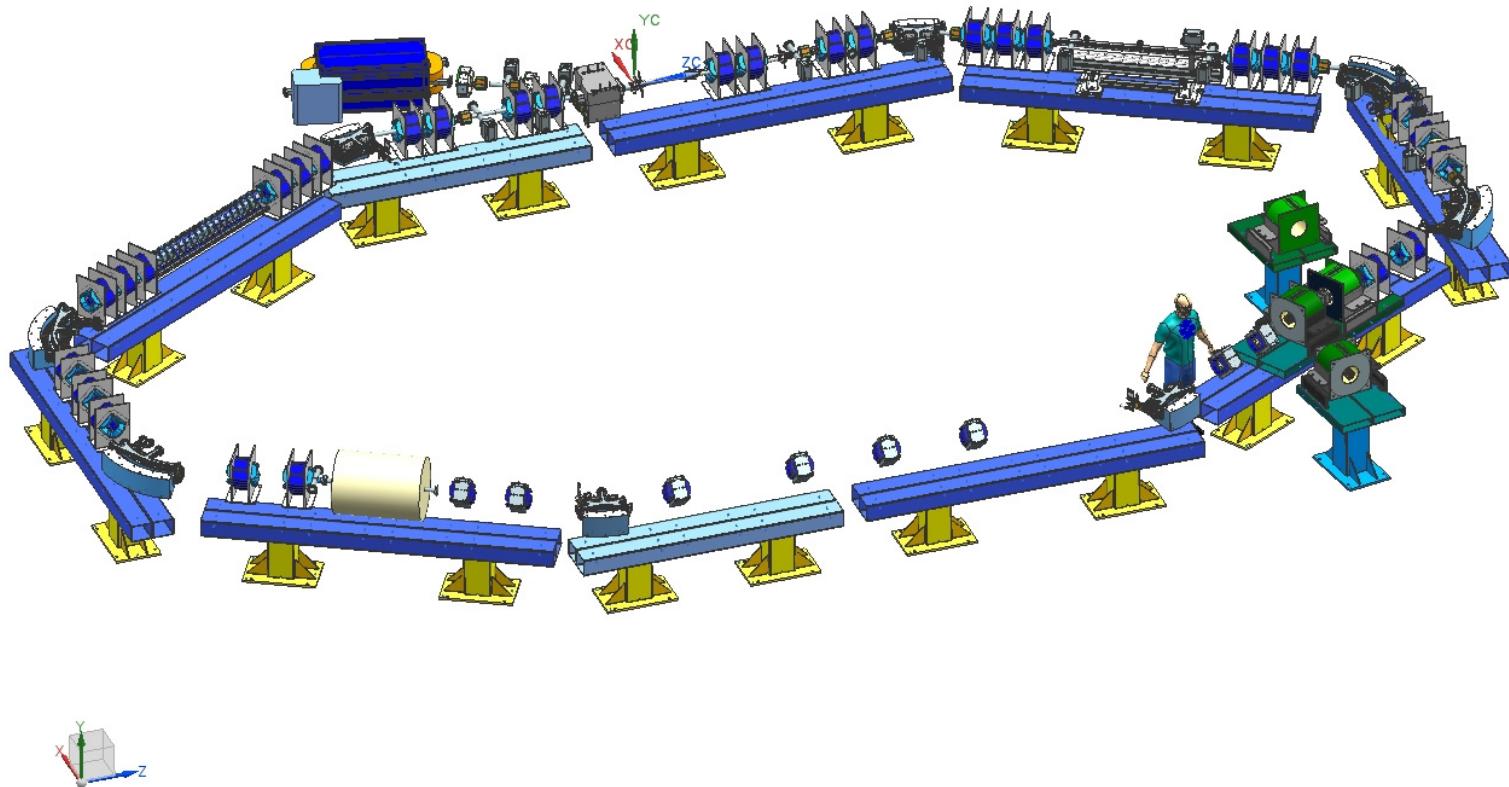
matched to IOTA momentum, but $\beta=.073!$

Demonstrated for 1 ms pulses. Should go to >40 mA for short pulses.

Is this big enough?

Why no one will steal this RFQ from us

IOTA Layout



Integrable Optics Test Accelerator

- **Unique features:**

- Can operate with either electrons or protons (up to 150 MeV/c momentum)
- Large aperture
- Significant flexibility of the lattice
- Precise control of the optics quality and stability
- Set up for very high intensity operation (with protons)

- **Based on conventional technology** (magnets, RF)

- **Cost-effective solution**

- Balance between low energy (low cost) and research potential

IOTA Physics Drivers

1. **Nonlinear Integrable Optics** – Experimental demonstration of NIO lattice in a practical accelerator
2. **Space Charge Compensation** – Suppression of SC-related effects in high intensity circular accelerators
 - Nonlinear Integrable Optics
 - Electron lenses
 - Electron columns
 - Circular betatron modes
3. **Beam collimation** – Technology development for hollow electron beam collimation
4. **Optical Stochastic Cooling** – Proof-of-principle
5. **Electron Cooling** – Advanced techniques

IOTA Parameters

Nominal kinetic energy	e ⁻ : 150 MeV, p+: 2.5 MeV
Nominal intensity	e ⁻ : 1×10^9 , p+: 1×10^{11}
Circumference	40 m
Bending dipole field	0.7 T
Beam pipe aperture	50 mm dia.
Maximum b-function (x,y)	12, 5 m
Momentum compaction	0.02 ÷ 0.1
Betatron tune (integer)	3 ÷ 5
Natural chromaticity	-5 ÷ -10
Transverse emittance r.m.s.	e ⁻ : 0.04 μ m, p+: 2 μ m
SR damping time	0.6s (5×10^6 turns)
RF V,f,q	e ⁻ : 1 kV, 30 MHz, 4
Synchrotron tune	e ⁻ : 0.002 ÷ 0.005
Bunch length, momentum spread	e ⁻ : 12 cm, 1.4×10^{-4}
Beam lifetime	e ⁻ : 1 hour, p+: 1 min

IOTA Staging

- Phase 1
 - Concentrate on the academic aspect of single-particle motion stability using electron beams
 - Achieve large nonlinear tune shift/spread without degradation of dynamic aperture by “painting” aperture with “pencil” beams
 - Suppress strong lattice resonances
 - Investigate stability of nonlinear systems
 - The measure of success will be the achievement of high nonlinear tune shift = 0.25
- Phase 2
 - Allows tests with protons and realistic space charge beam dynamics studies
 - Space charge compensation experiments

IOTA Construction and Research Timeline

	Electron Injector	Proton Injector	IOTA Ring
FY15	20 MeV e^- commiss'd beam tests	Re-assembly began @MDB	50% IOTA parts ready
FY16	50 MeV e^- commiss'd beam tests	50 keV p^+ commiss'd	IOTA parts 80+% ready
FY17	150-300 MeV e^- beam commissioning/tests *	2.5 MeV p^+ commiss'd beam tests @ MDB	IOTA fully installed first beam ? *
FY18	e^- injector for IOTA + other research	p^+ RFQ moved from MDB to FAST *	IOTA commiss'd with e^- Research starts (NL IO)
FY19	e^- injector for IOTA + other research	2.5 MeV p^+ commiss'd beam tests	IOTA research with e^- IOTA commiss'd with p^+
FY20	e^- injector for IOTA + other research	p^+ injector for IOTA	IOTA research with p^+*

- contingent on \$\$: FY17-20 - under current budget scenario...together with OHEP GARD management we explore options to accelerate start of research by 1 year (1.48M\$ supplemental)

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FY20	e^- injector for IOTA + other research	p^+ injector for IOTA <i>beam operations</i>	IOTA research with p^+*

- contingent on \$\$: FY17-20 - under current budget scenario...together with OHEP GARD management we explore options to accelerate start of research by 1 year (1.48M\$ supplemental)

Thank you for your attention.