Fermilab

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Status of IOTA and Proton Injector

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FAST/IOTA Scientific Program Meeting

6 June 2017

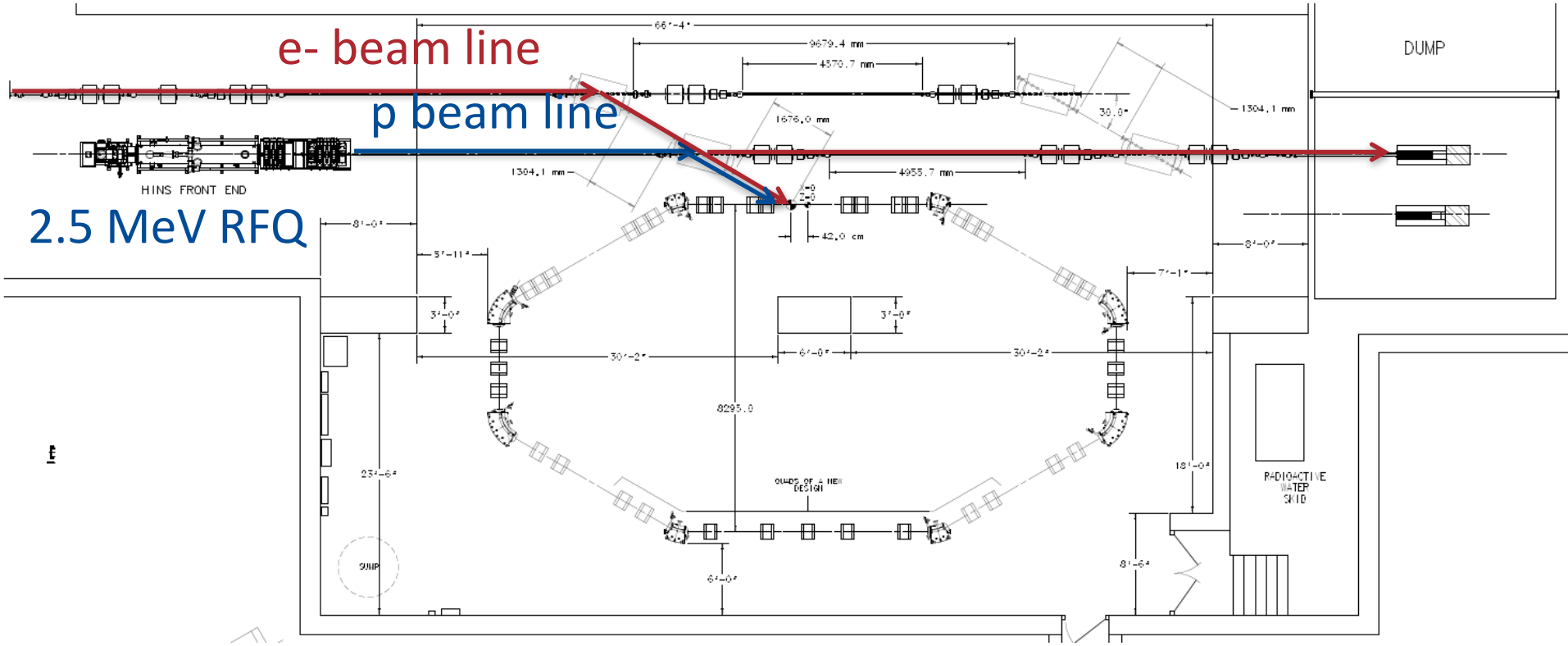
Integrable Optics Test Accelerator

- **Unique features**:
  - Can operate with either electrons or protons (up to 150 MeV/c momentum)
  - Large aperture
  - Significant flexibility of the lattice ← A.Romanov's talk
  - 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

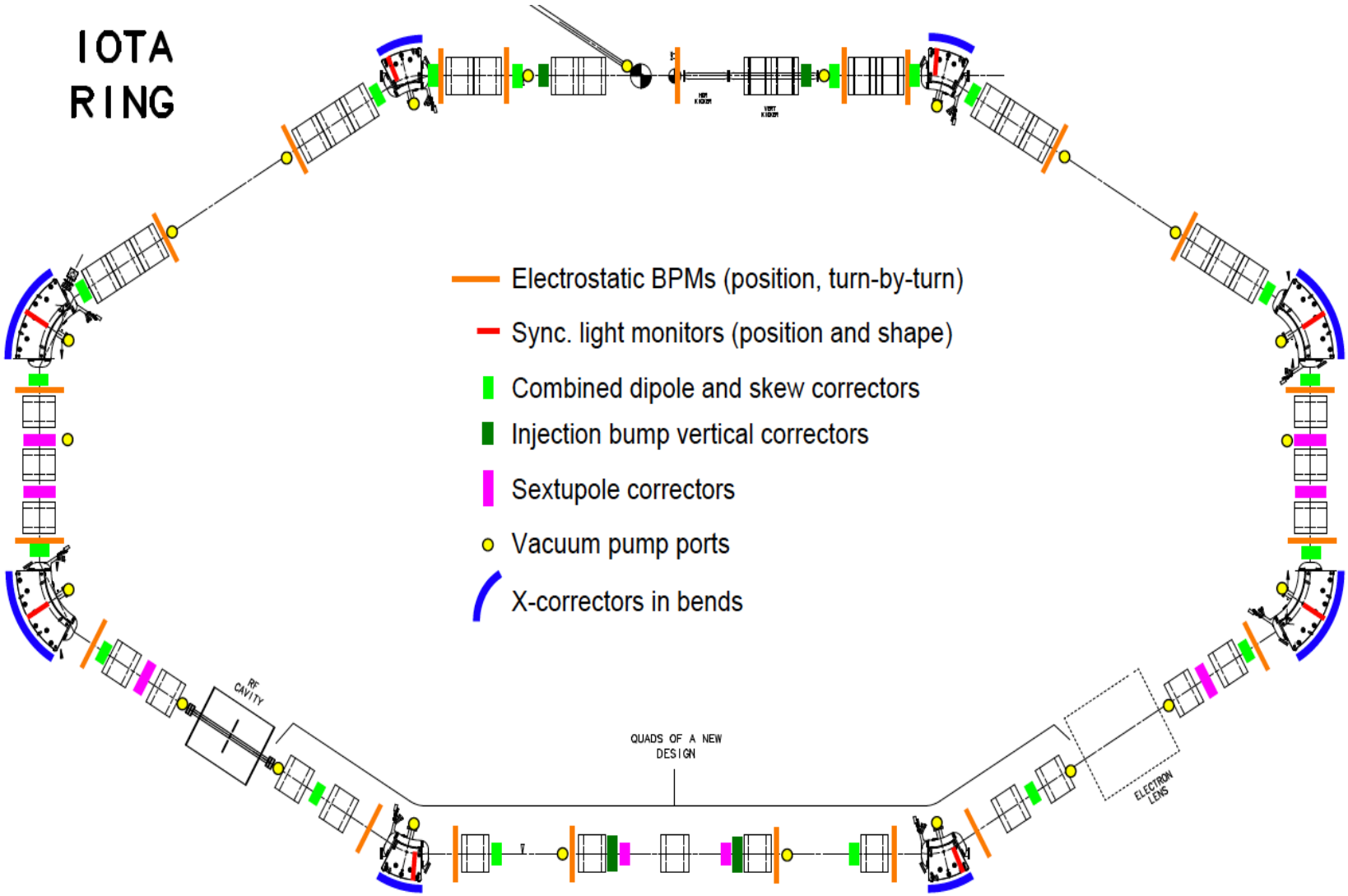
IOTA Parameters

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 μm, p+: 2μm
SR damping time	0.6s (5×10^6 turns)
RF V,f,q	e^-: 1 kV, 30 MHz, 4
Synchrotron tune	e^-: 2×10^{-4} ÷ 5×10^{-4}
Bunch length, momentum spread	e^-: 12 cm, 1.4×10^{-4}
Beam lifetime	e^-: 1 hour, p+: 1 min

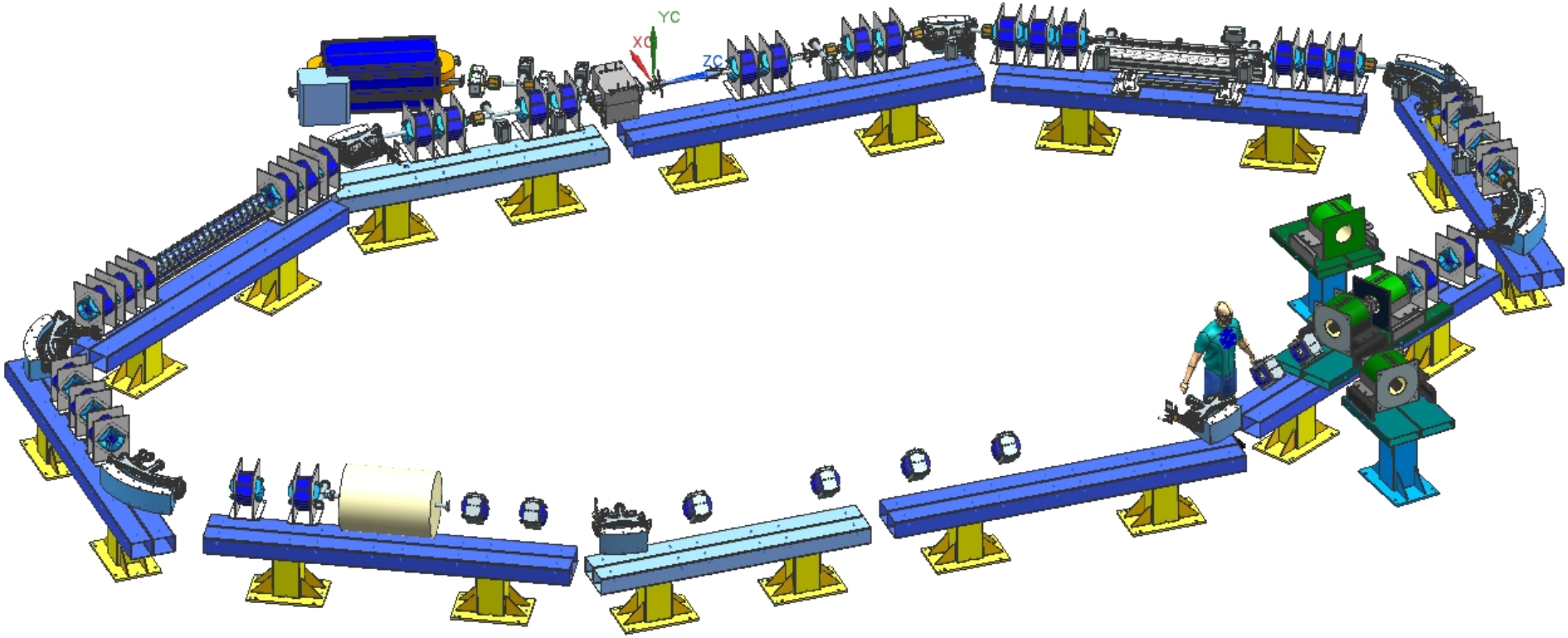
IOTA Ring

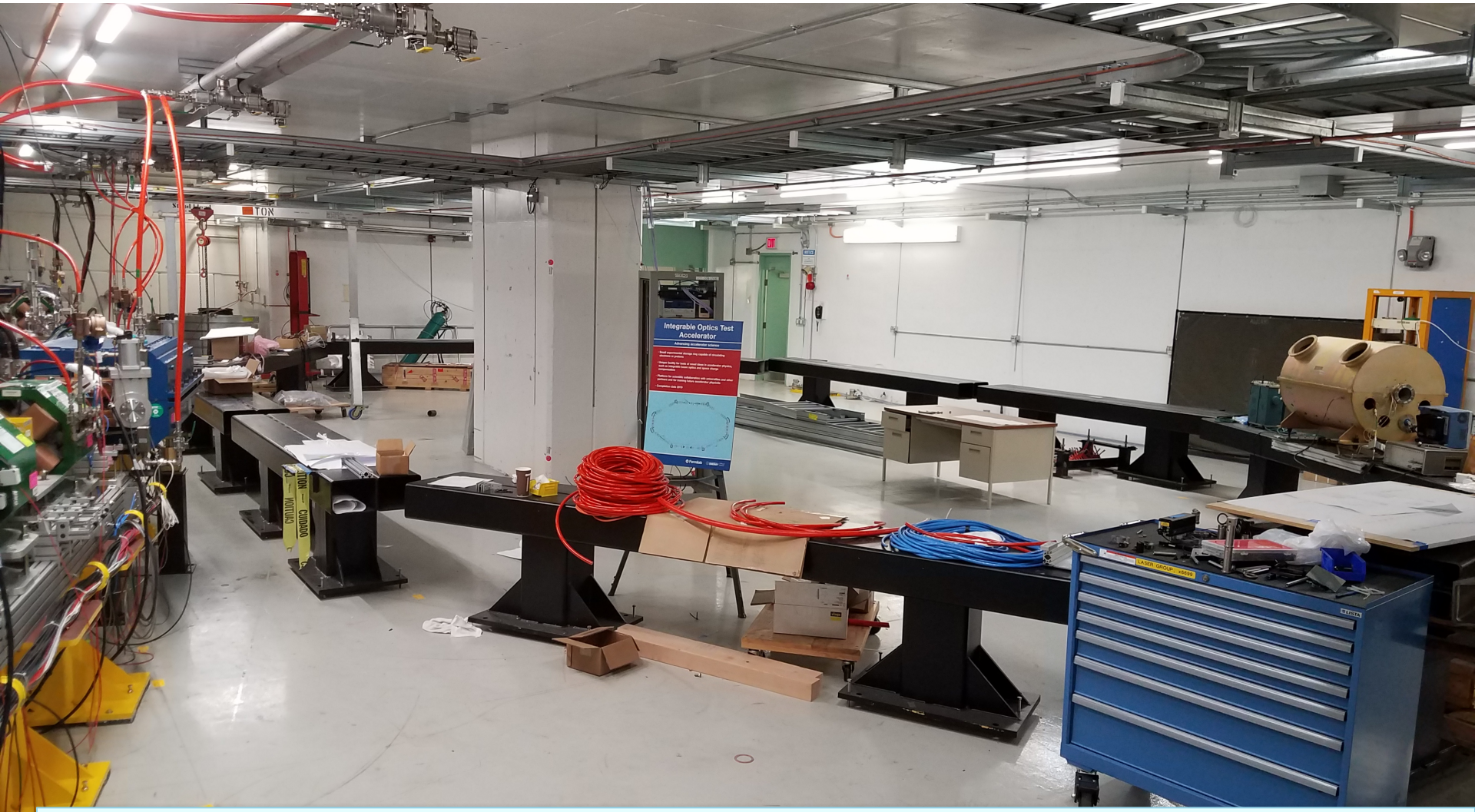

e- beam line
p beam line
2.5 MeV RFQ
HINS FRONT END
DUMP
9679.4 mm
4570.7 mm
1676.0 mm
1304.1 mm
4955.7 mm
42.0 cm
8295.0
RADIOACTIVE WATER SKID

IOTA Layout


IOTA
RING
Electrostatic BPMs (position, turn-by-turn)
Sync. light monitors (position and shape)
Combined dipole and skew correctors
Injection bump vertical correctors
Sextupole correctors
Vacuum pump ports
X-correctors in bends
RF CAVITY
QUADS OF A NEW DESIGN
ELECTRON LENS

IOTA Layout

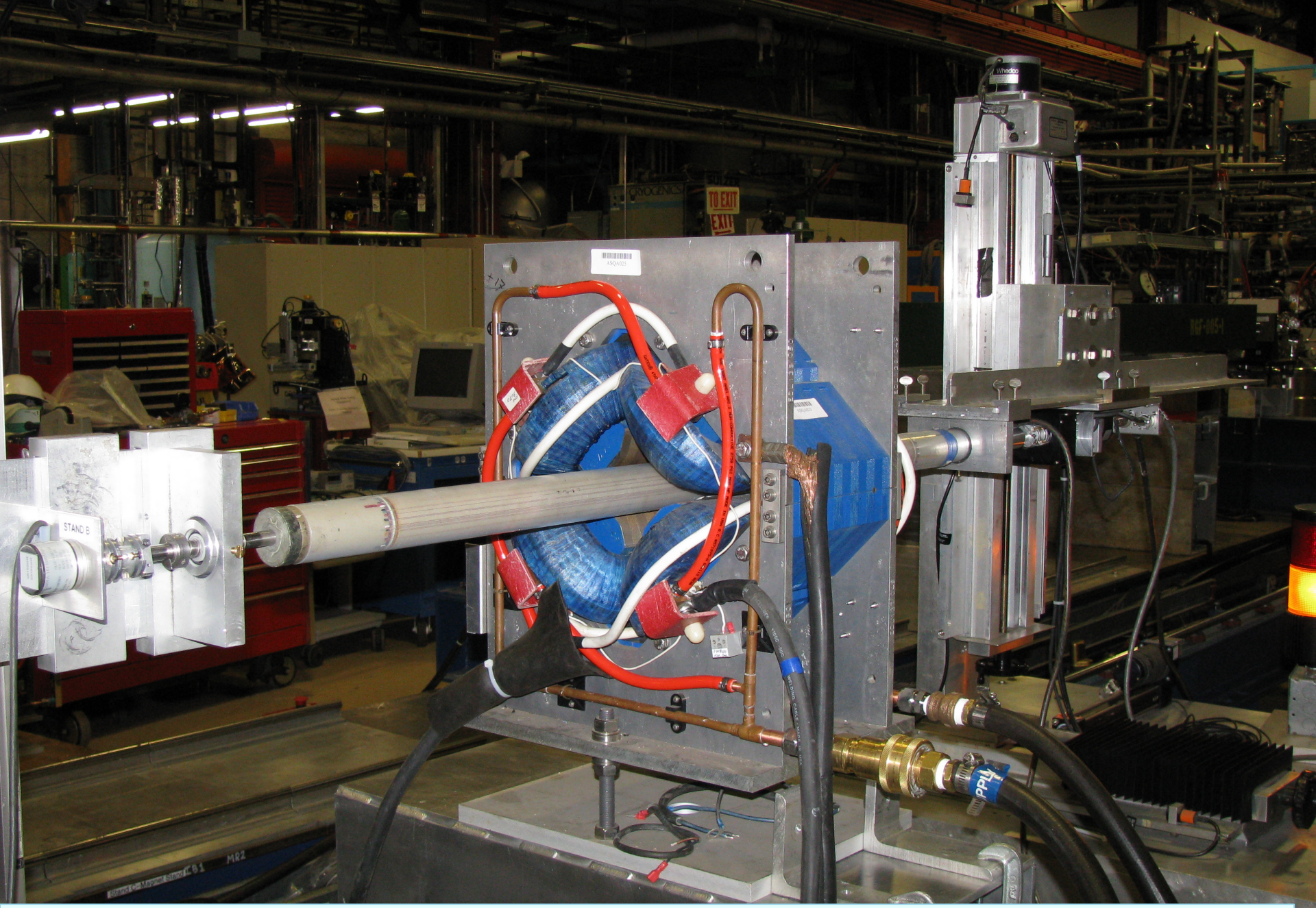




Girders rough-aligned.

30-deg. dipole. All dipole magnets (8+2 spares) received, tested. Applying modifications/corrections. Ready to install 6/2017.

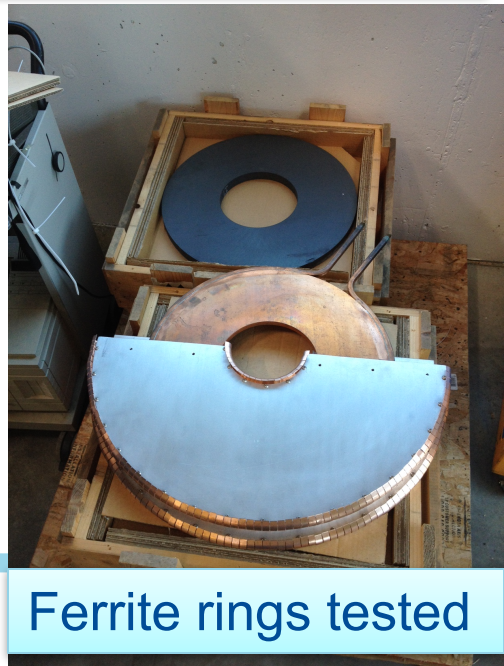
‘Dubna’ quadrupoles (32) – 30 refurbished



20 quadrupoles referenced and multipole harmonics measured

Pbar RF cavity refurbished, tested.

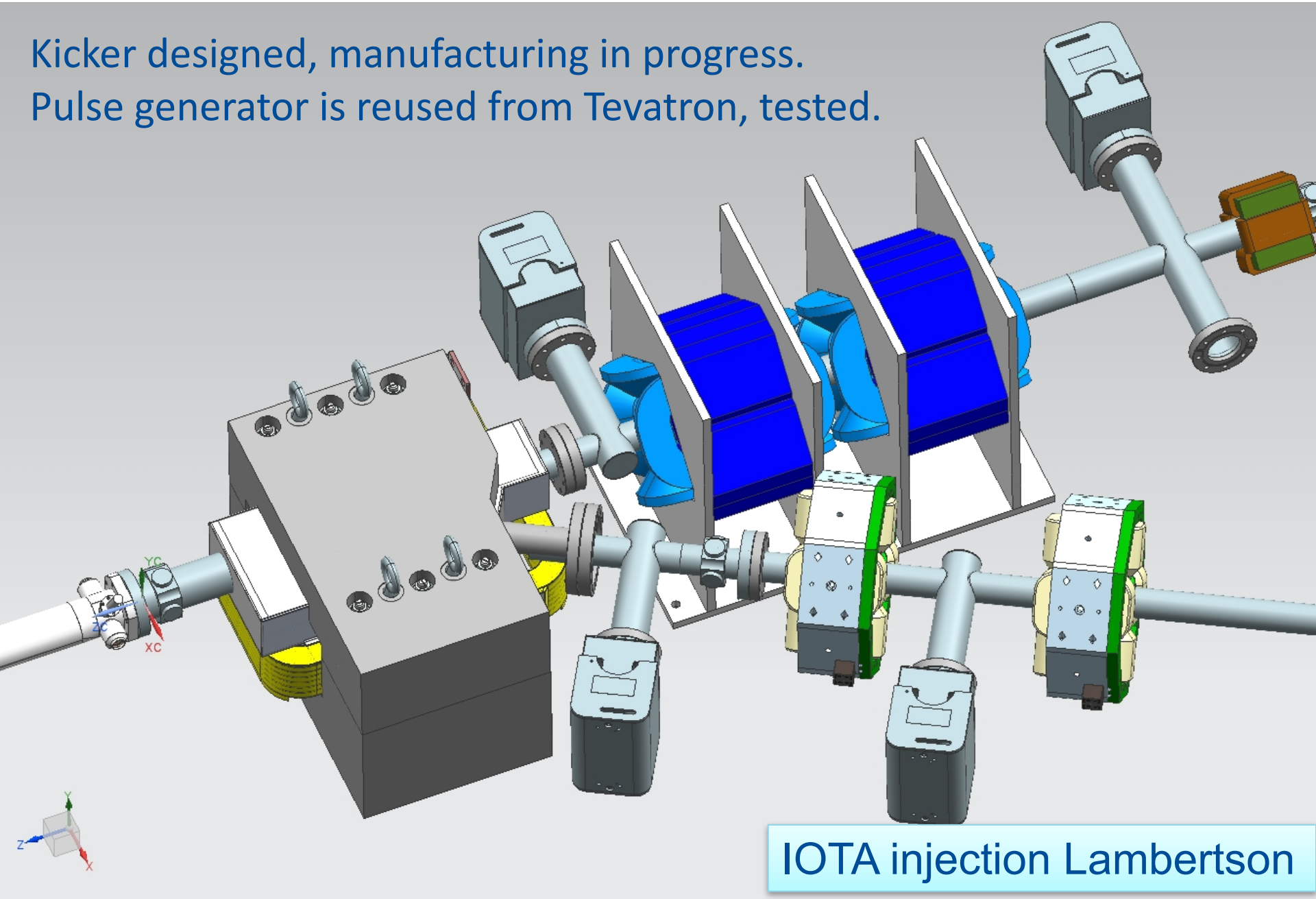
Double ceramic chamber received



Ferrite rings tested

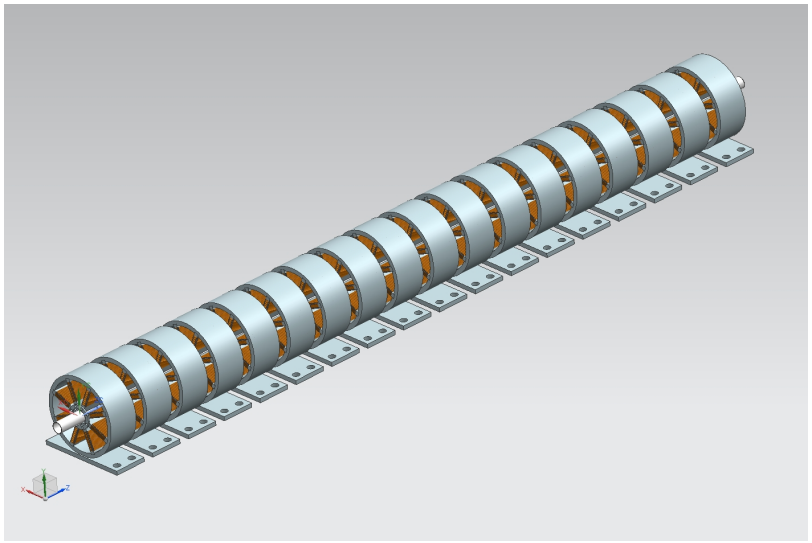
IOTA Injection Lambertson – Design complete, drafting and fabrication in progress

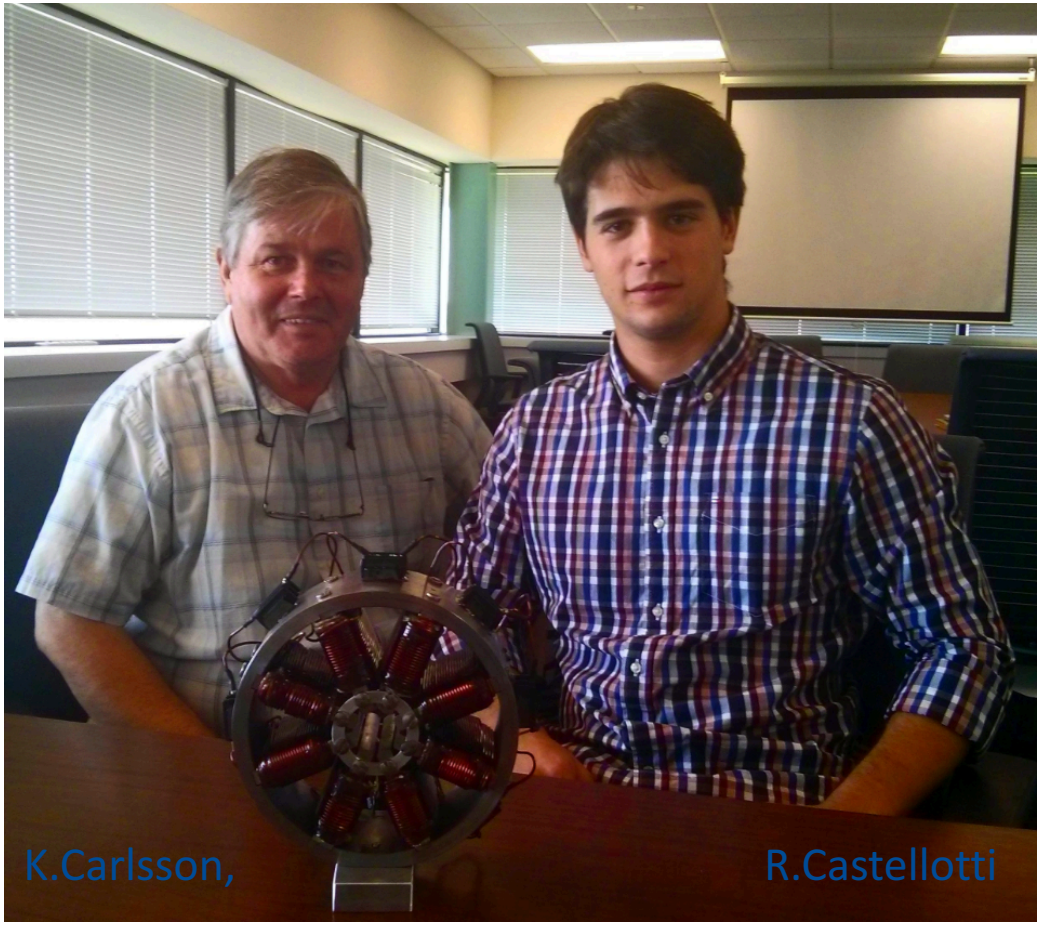
Kicker designed, manufacturing in progress.
Pulse generator is reused from Tevatron, tested.



IOTA injection Lambertson

Octupoles for Quasi-Integrable System

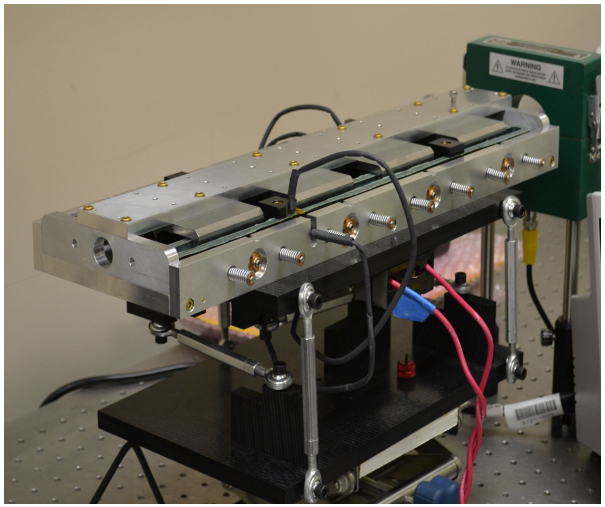




Summer engineering internship project. Prototype built in 2015,
All 18 magnets assembled in 2016.

Nonlinear Magnet

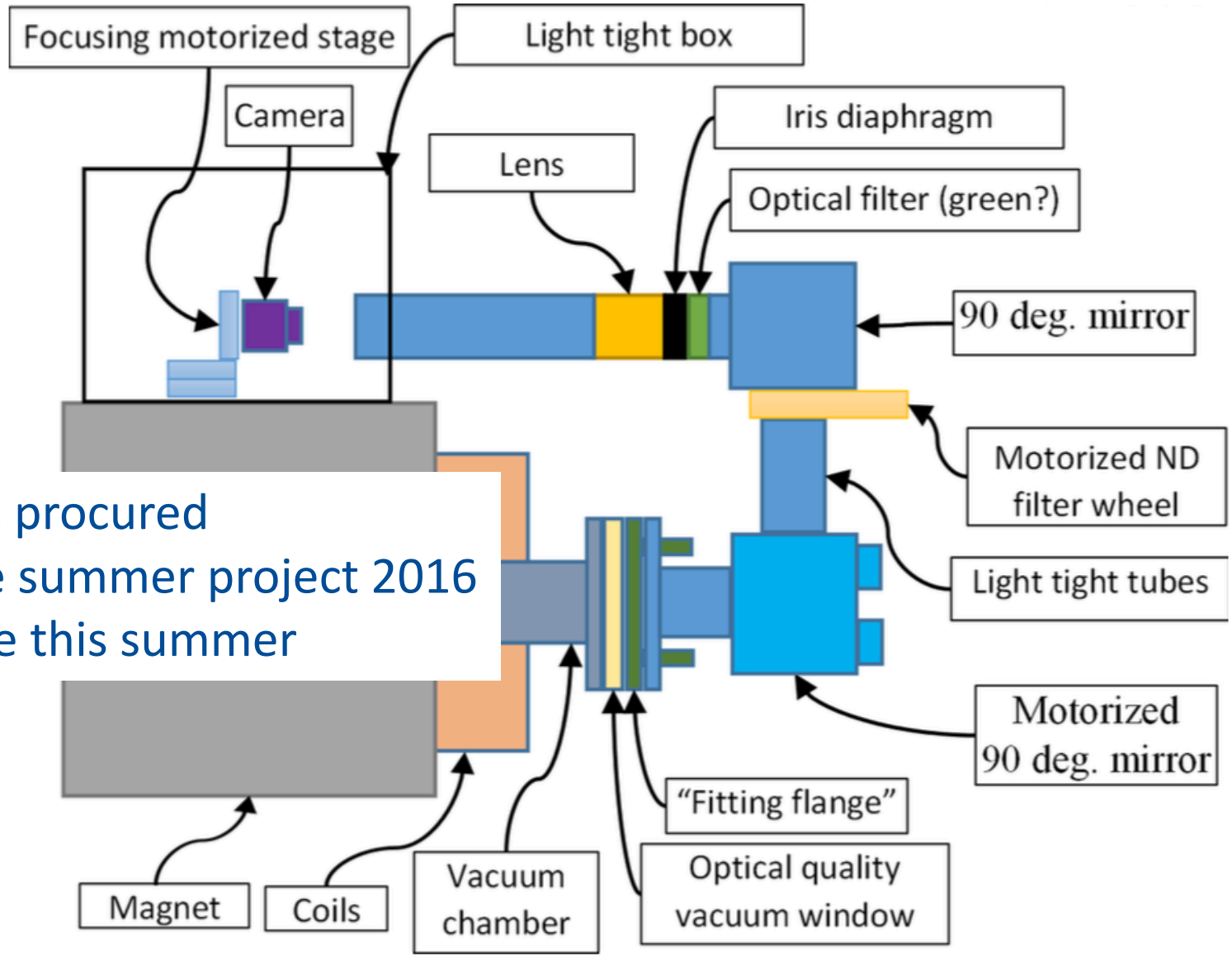
- Design by RadiaBeam Technologies (Phase I and II SBIR)



Phase I – short prototype

Phase II – full 1.8-m long magnet. Delivered !

Synchrotron Light Based Diagnostics – summer internship project



Components procured

1st Prototype summer project 2016

2nd prototype this summer

Figure 19: Schematic view of beam diagnostics stand based on synchrotron radiation.

IOTA Systems

- Power supplies purchased, installed.
- Vacuum system:
  - Dipole alum. chambers manufactured.
  - Vacuum pumps and gauges purchased.

IOTA Components Summary

Item	status
Dipole magnets	6/2017
Dipole stands	✓
Quadrupoles ASQA	✓
Quadrupoles RB	6-8/2017, staged
Quadrupole stands	6/2017
Correctors	6-8/2017, staged
Sextupoles	design
Sextupole stands	design
Octupoles	✓
Octupole stands	6/2017
RF cavity	✓
Lambertson	8/2017
Kicker modules	12/2017

Item	status
Dipole vac. chambers	✓
Straight vac. chambers	8-10/2017
BPM bodies	✓
Dipole PS	Installed, to be tested
Quadrupole PS	✓
Corrector PS	✓
RF amplifier	✓
Kicker pulser	12/2017
SR monitors	3/2018
BPM electronics	4/2018
Vacuum pumps	for e- operation
Vacuum gauges	✓

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 – C.Hall, C.Mitchell, J.Eldred's talk
   - Electron lenses – G.Stancari's talk
   - Electron columns
   - Circular betatron modes
3. **Beam collimation** – Technology development for hollow electron beam collimation
4. **Optical Stochastic Cooling** – Proof-of-principle – V.Lebedev's talk
5. **Electron Cooling** – Advanced techniques

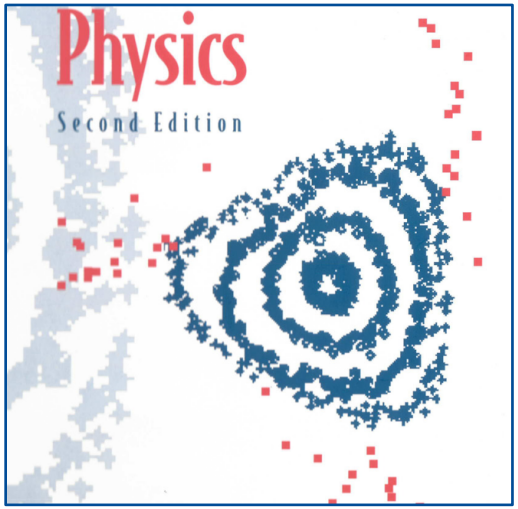
- **Laser-Plasma Accelerator** – Demonstration of injection
- **Quantum Physics**

IOTA Staging – Phase I

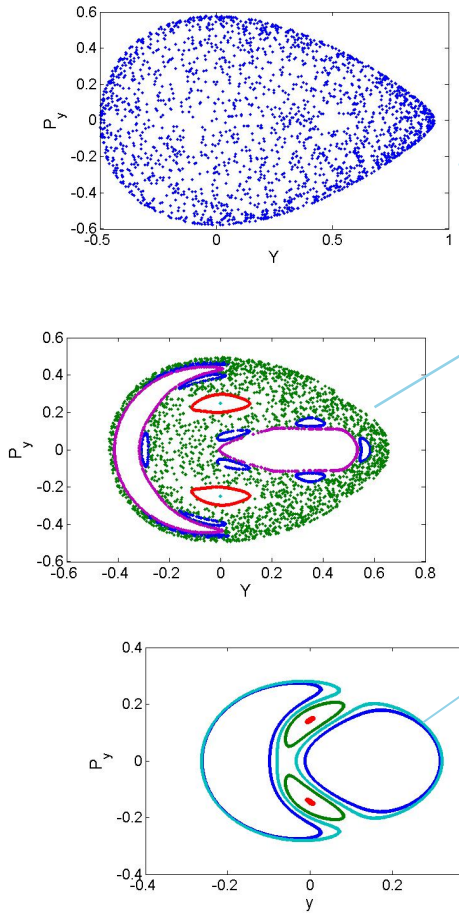
Phase I will concentrate on the academic aspect of single-particle motion stability using e-beams

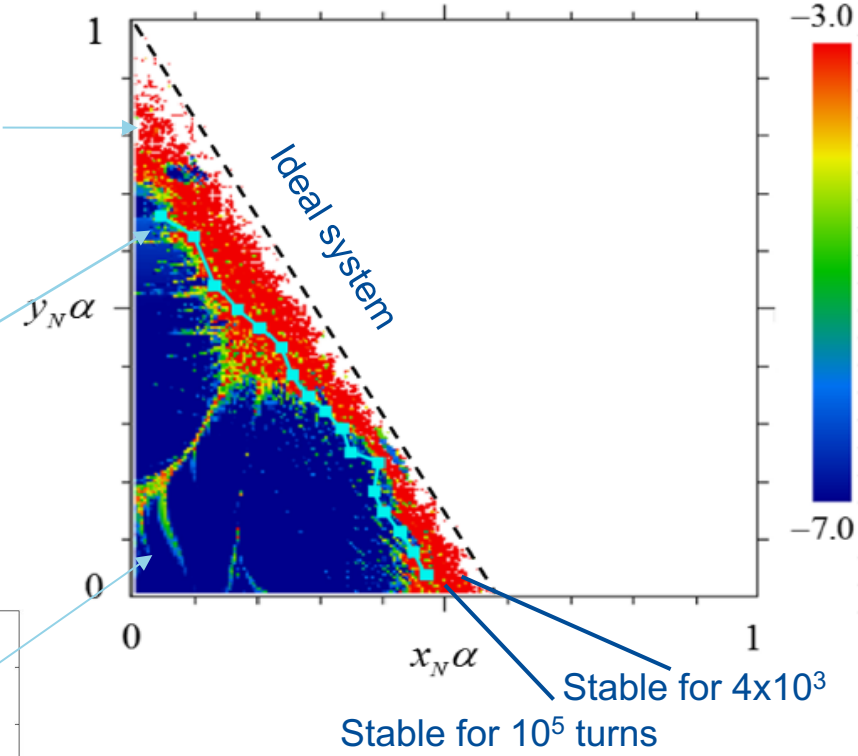
- **Achieve large (0.25) nonlinear tune shift/spread** without degradation of dynamic aperture **by "painting"** the accelerator aperture **with a "pencil" beam**
  - Electron beam ideal for the purpose
  - No space charge or other intensity-related effects
- Suppress strong lattice resonances = cross the integer resonance by part of the beam without intensity loss
- Investigate stability of nonlinear systems to perturbations, develop practical designs of nonlinear magnets

Poincare Maps and FMA



Poincare map of the betatron motion near a 3rd order resonance $3Q_x = 11$ at IUCF on the cover of S. Y. Lee, *Accelerator Physics*
D. D. Caussyn, *et. al*, *Phys.Rev.* A46, pp. 7942-7952, 1992





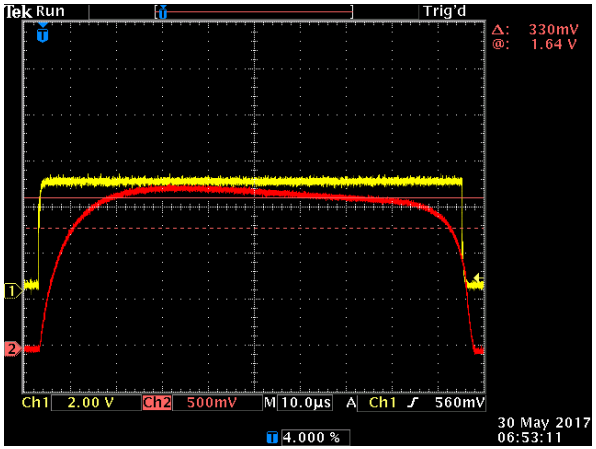
Plots for Henon-Heiles system
Courtesy S.Antipov IPAC-2017

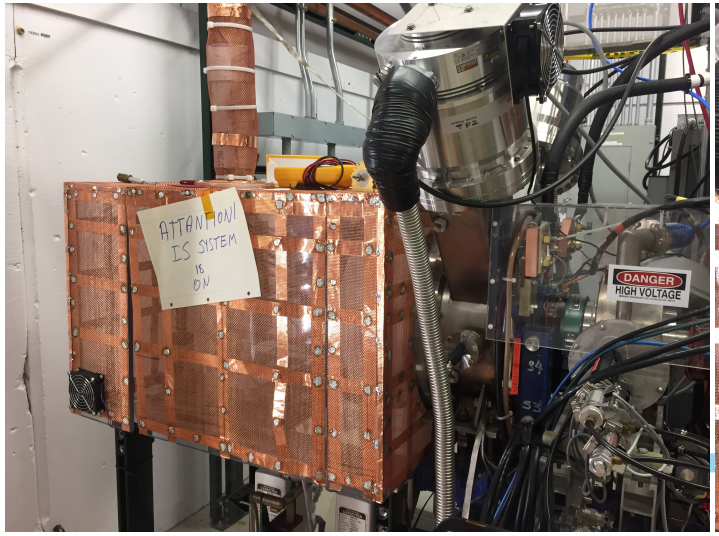
IOTA Staging – Phase II

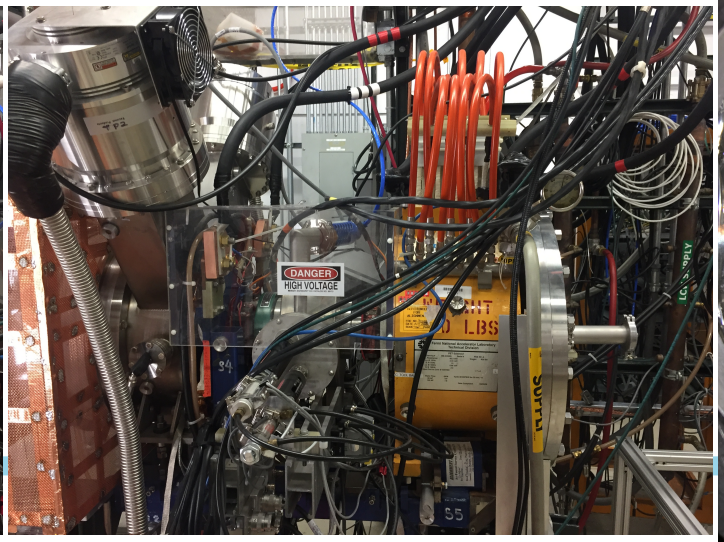
- Recommission the existing 2.5 MeV proton/H- RFQ to inject protons into IOTA
  - Low energy & high intensity → strong space charge
    - $\Delta Q = -0.5$ for one-turn injection
    - Multi-turn injection possible
  - Low energy → tolerance to losses
- Allows tests of Integrable Optics with protons and realistic space charge beam dynamics studies
- **Allows space charge compensation experiments**

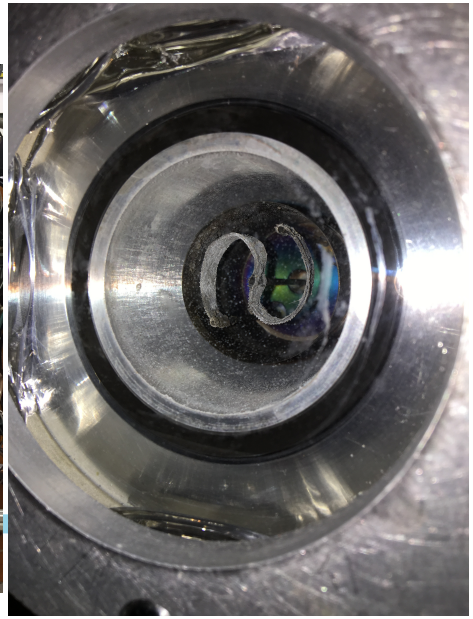
Status of Ion Source

- A lot of work has gone into resurrecting the HINS ion source
  - H.Piekarz, K.Carlson, D.Edstrom, M.Obrycki, S.Hays, S.Morrison
- Hydrogen is flowing and an arc has been established from the filament.
- Waiting on final electrical approval to extract beam
  - Scheduled for Thursday









Plans for Ion Source

- Original Plan:
  - Commission RFQ in MDB using original klystron and modulator
  - Move to FAST
- New Plan:
  - Move RFQ to FAST as soon as practical to free up space in HINS cave
  - Install magnet and Allison detector to separate species and characterize and optimize source in HINS cave
    - ~ remainder of CY 2017
  - Move source to FAST, and commission entire system in situ, using new klystron and modulator
    - ~CY 2018/2019, as allowed by funding and manpower

Summary

- IOTA installation commenced. Expect 80% installed in FY17
- Plan for commissioning with electron beam in summer of 2018
- First IOTA experiments on nonlinear integrable optics with e- in good shape
  - Simulations well advanced
  - Nonlinear magnet delivered
  - Octupole channel manufactured
- Proton injector recommissioning is progressing
  - Arc in the H- source achieved, beam from source this week
  - RFQ commissioning in 2019
- Lab priorities and availability of support labor may impact schedule