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Introduction to IOTA and Injectors

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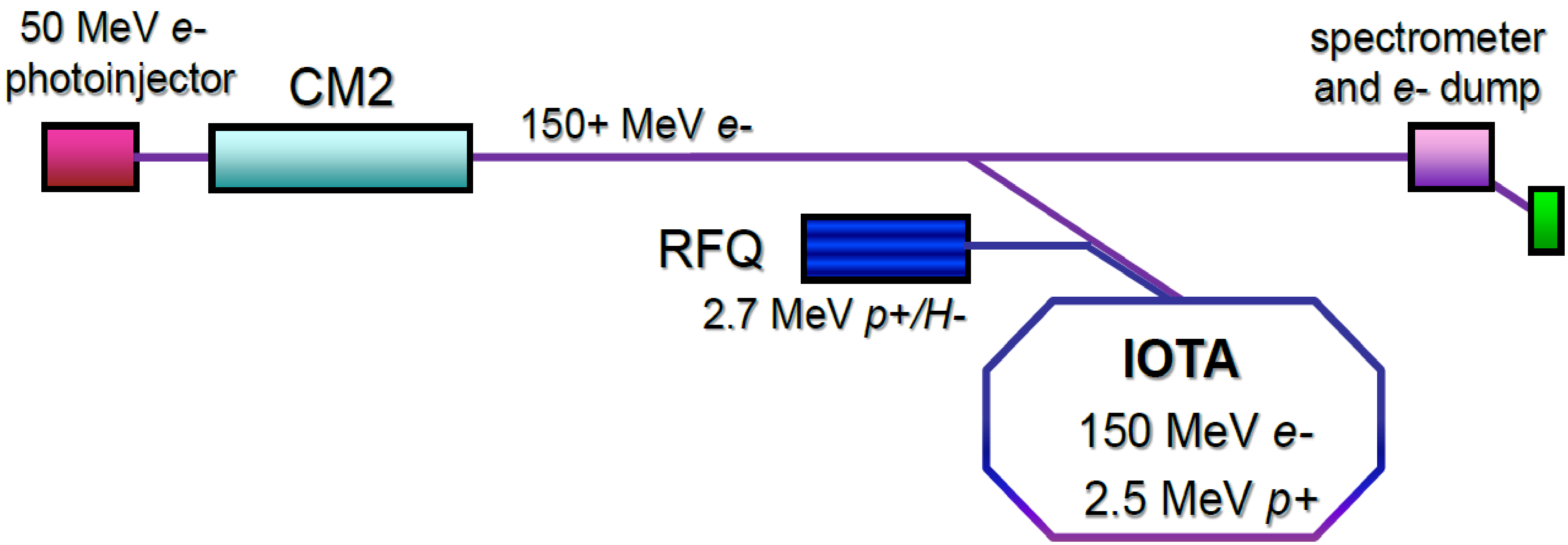
Fermilab
28 April 2015

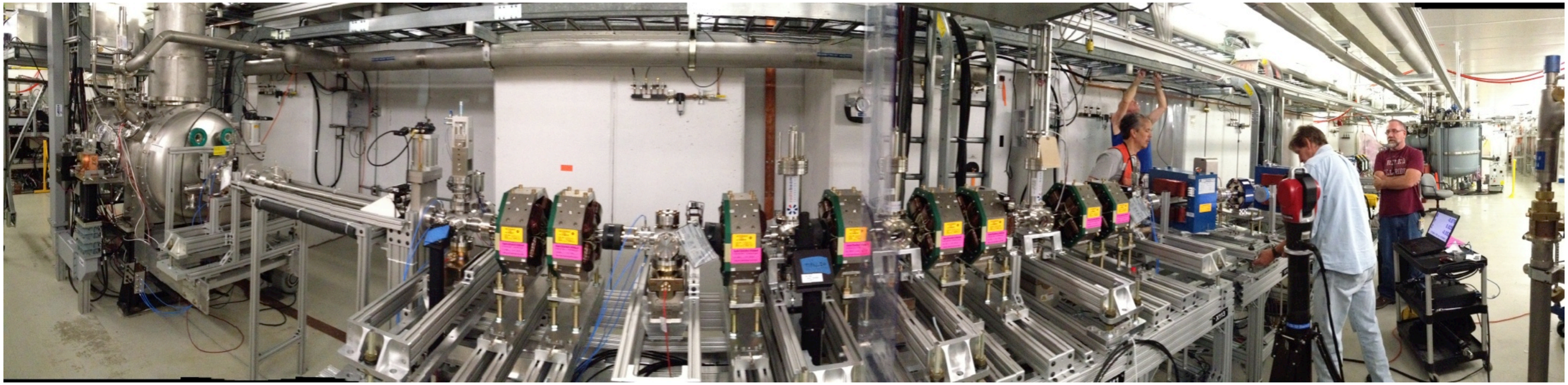
IOTA/ASTA Schematic



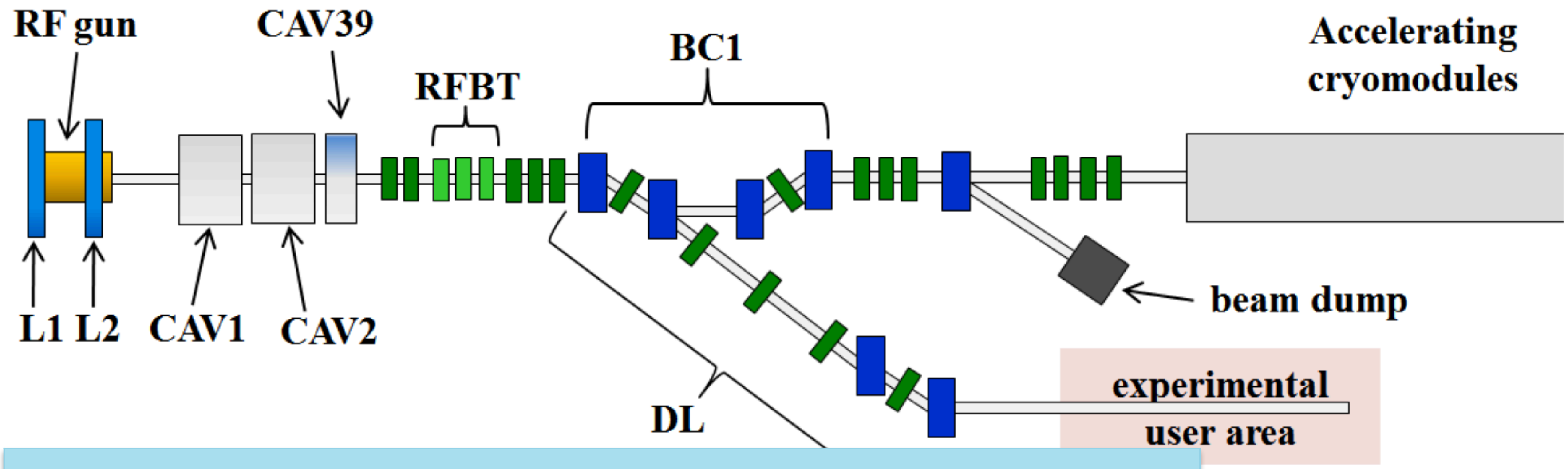
Existing Infrastructure

- **IOTA/ASTA capitalizes on the investments** made by OHEP for highly successful ILC/SRF R&D Program.
- Construction of ASTA (formerly 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 and operating a complete ILC RF unit.
- **Multi-million (>$90M) investment** resulted in the successful commissioning of 1.3 GHz SRF cryomodule (CM2).
  - Beam through low-energy photo injector
  - Facility nears completion
- The **addition of IOTA expands scope** to host high-intensity accelerator research.

ASTA Facility



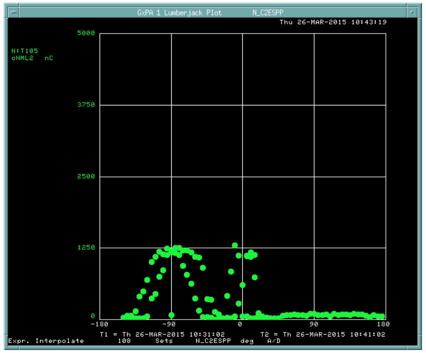
ASTA e$^-$ Injector



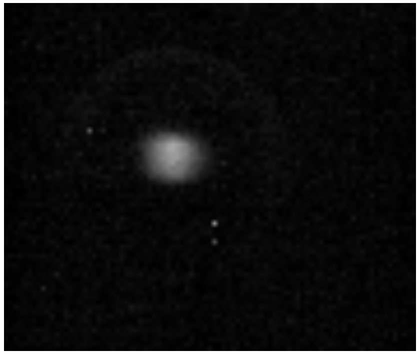
Parameter	ILC nominal	Range
Bunch charge	3.2 nC	10pC to > 20 nC
Bunch spacing	333 ns	<10 ns to 10 s
Bunch train	1 ms	1 bunch to 1 ms
Train rep. rate	5 Hz	0.1 Hz to 5 Hz
Transverse emit.	25 mm-mrad	1 to 100 mm-mrad
r.m.s. bunch length	1 ps	10fs to 10ps
Beam energy	300 MeV	50-300 MeV

First Electrons Through Photoinjector!

- Sign-offs Wednesday, 25 March
- Electrons beyond the gun - Wednesday, 25 March
- Beam after CC2, towards end of line – Thursday, 26 March
- Electrons seen at low energy beam absorber (~20 MeV) – Friday morning, 27 March



Initial CC2
Phase Scan

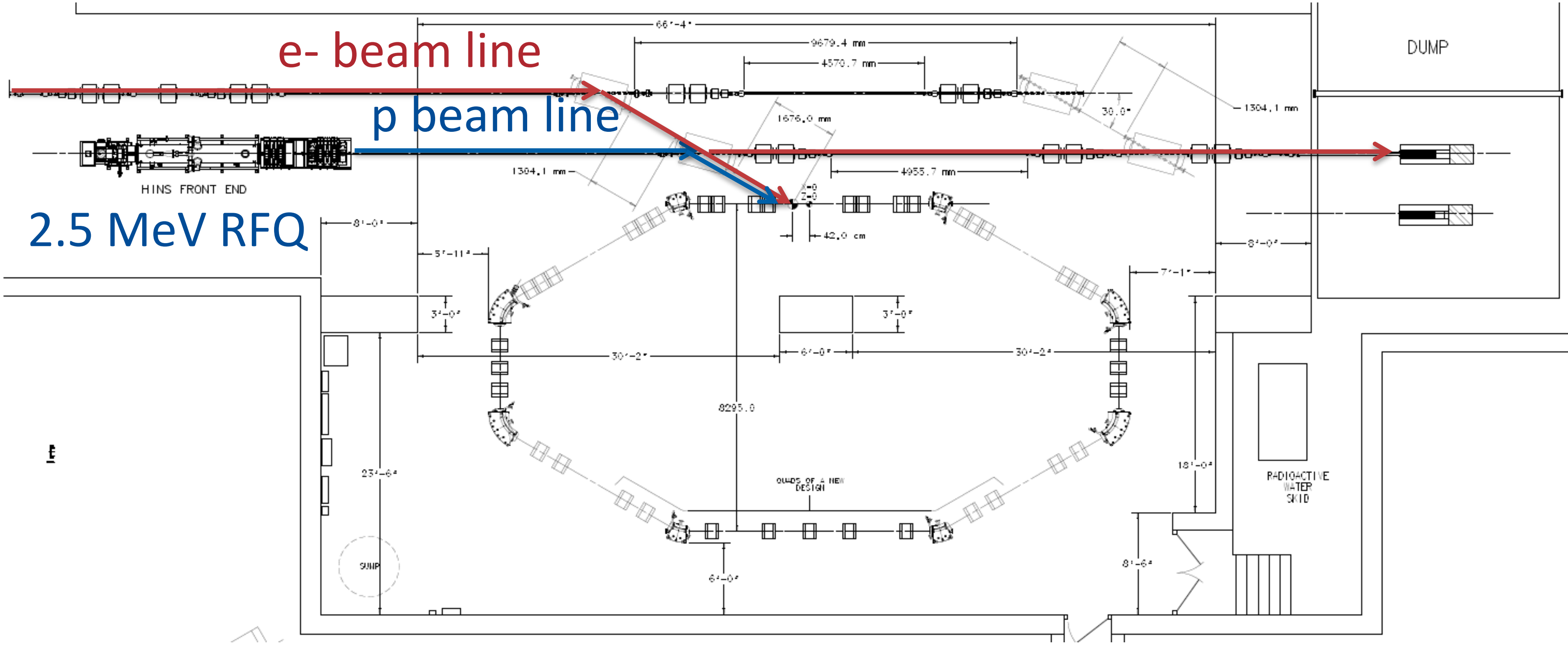


OTR Screen after
22.5° bend

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 discovery potential

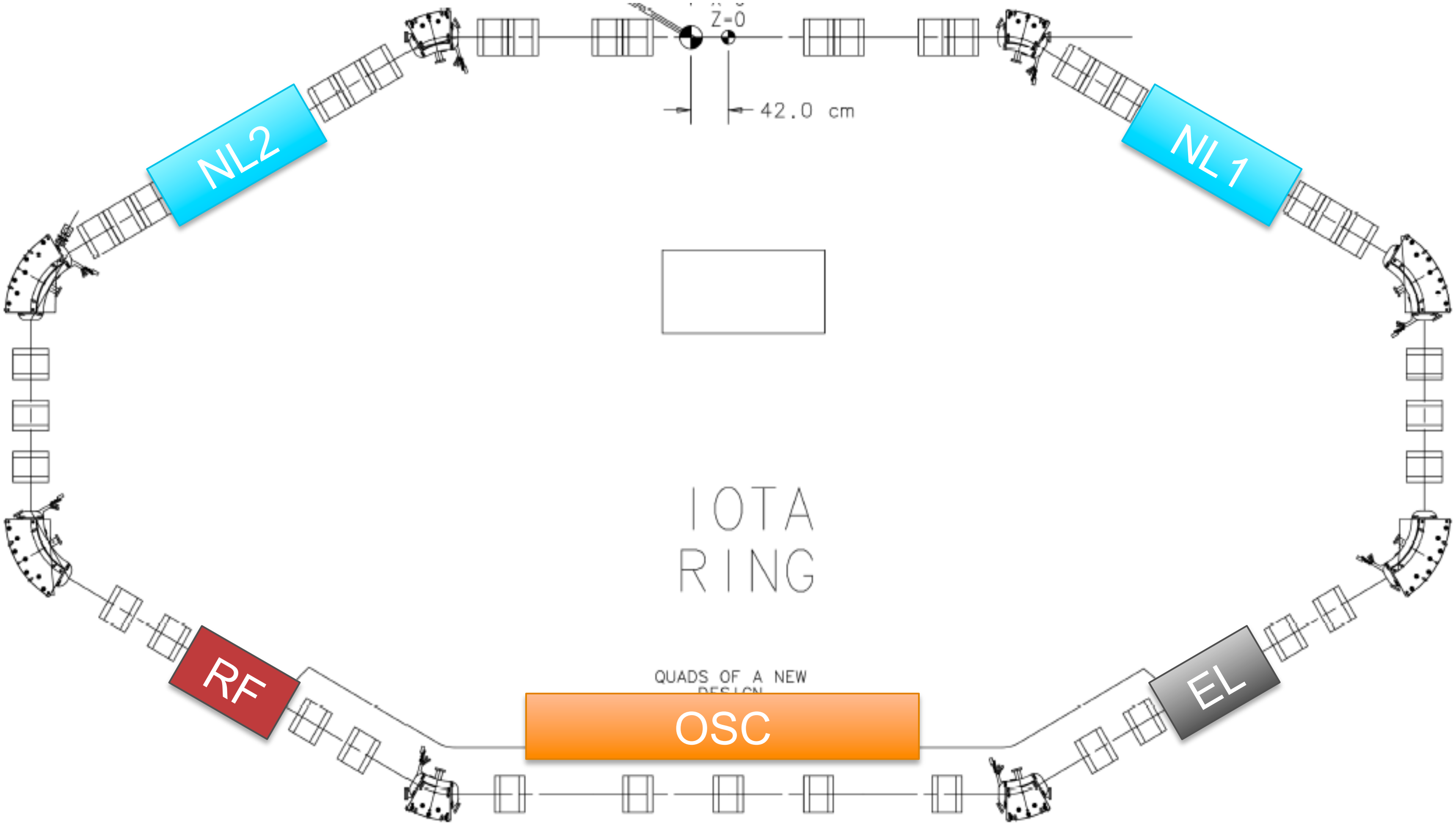
IOTA Ring


e- beam line

p beam line

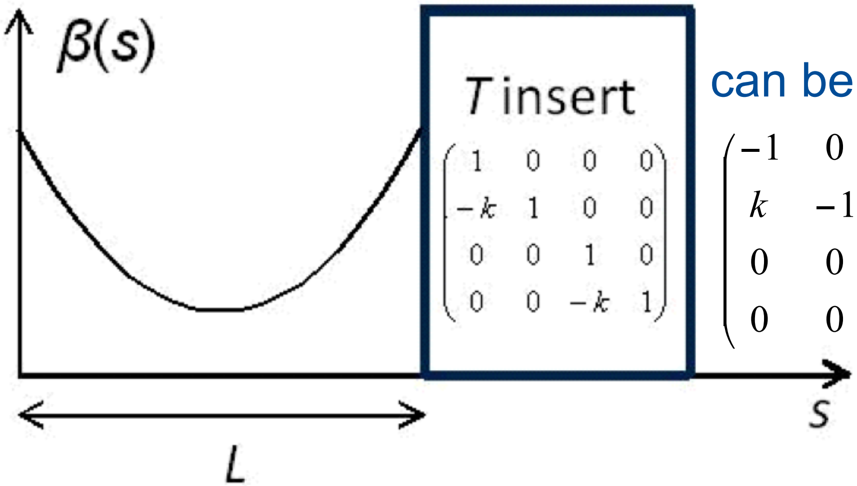
2.5 MeV RFQ

IOTA Layout



Machine Design Principles – 1

1. Start with a round axially-symmetric *linear* lattice (FOFO) with the element of periodicity consisting of
   a. Drift sufficient length
   b. Axially-symmetric focusing block “T-insert” with phase advance n×π



$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ -k & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -k & 1 \end{pmatrix}$$

can be also

$$\begin{pmatrix} -1 & 0 & 0 & 0 \\ k & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & k & -1 \end{pmatrix}$$

2. Add special nonlinear potential *V(x,y,s)* in the drift such that

$$\Delta V(x,y,s) \approx \Delta V(x,y) = 0$$

Machine Design Principles – 2

3 To maximize the attainable tune shift / spread, design for at least 2 elements of periodicity

4 Allow for a second approach to integrability – the Electron Lens

5 Reserve 5 m drift for Optical Stochastic Cooling chicane

6 Decouple transverse and longitudinal degrees of freedom as much as possible
  - Zero dispersion in nonlinear elements
  - Maximize momentum compaction

7 Limit the beta-beating to allow large amplitudes of oscillation for studies with pencil beam

Machine Design Principles – 3

8 Fit in the experimental hall

9 Minimize number of power circuits to reduce cost

10 Minimuze the number of magnets

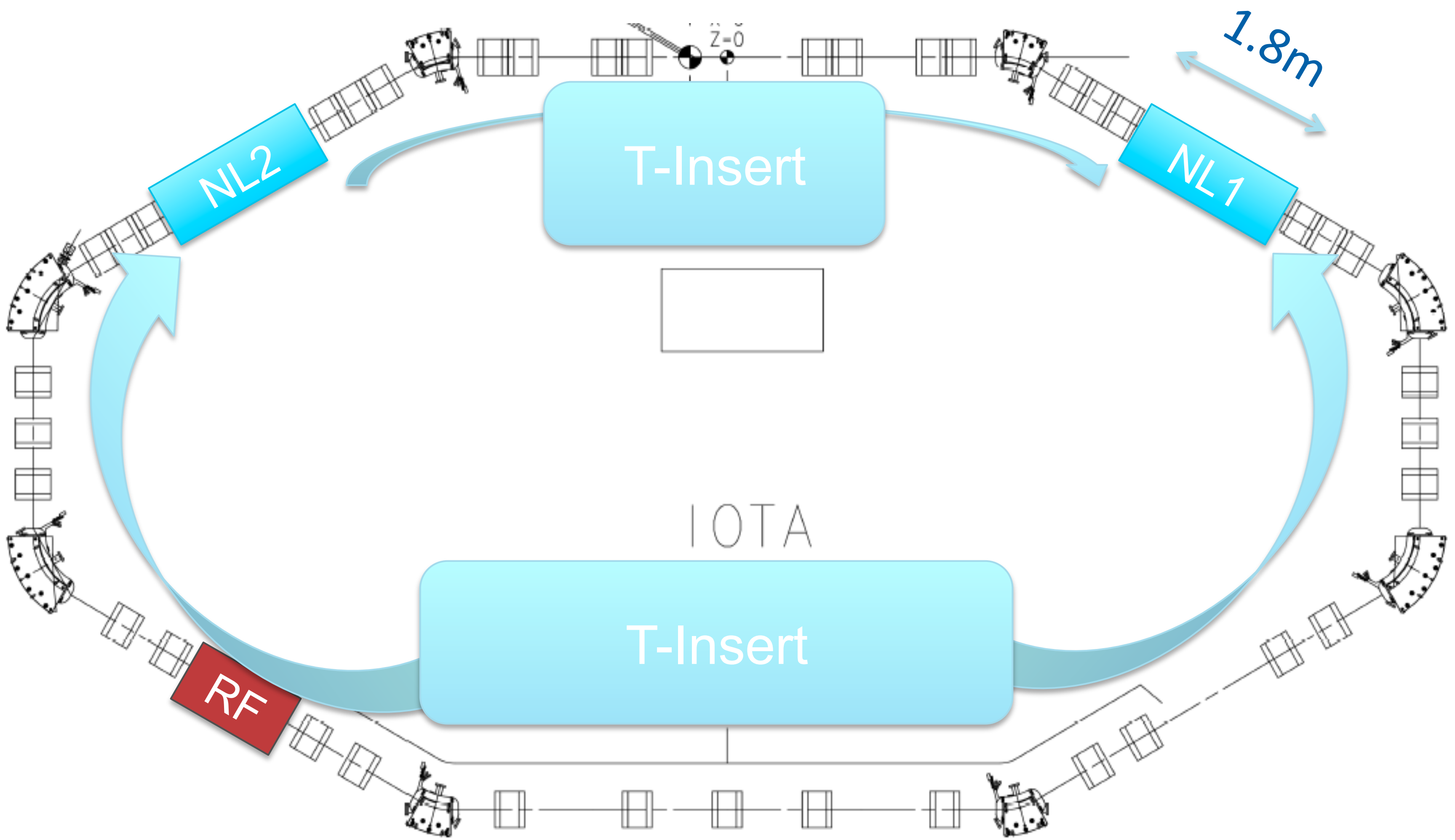
11 Instrumentation/correction to achieve high precision

12 Good vacuum to ensure sufficient beam circulation time

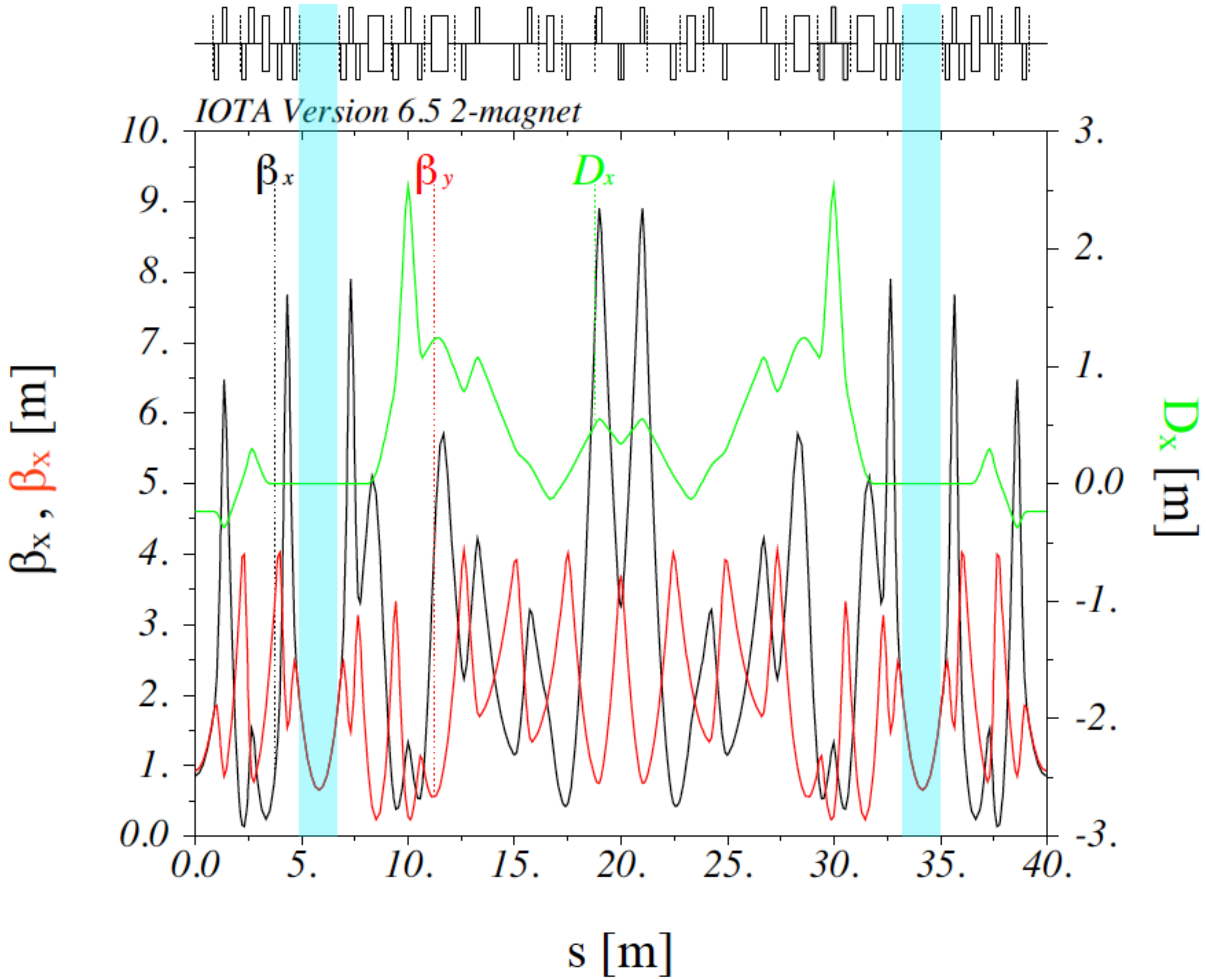
IOTA Optics Options

1. 1 Nonlinear Insert
2. 2 Nonlinear Inserts
3. Electron Lens
4. 2D McMillan
5. Optical Stochastic Cooling

IOTA Option 1 – 2NL



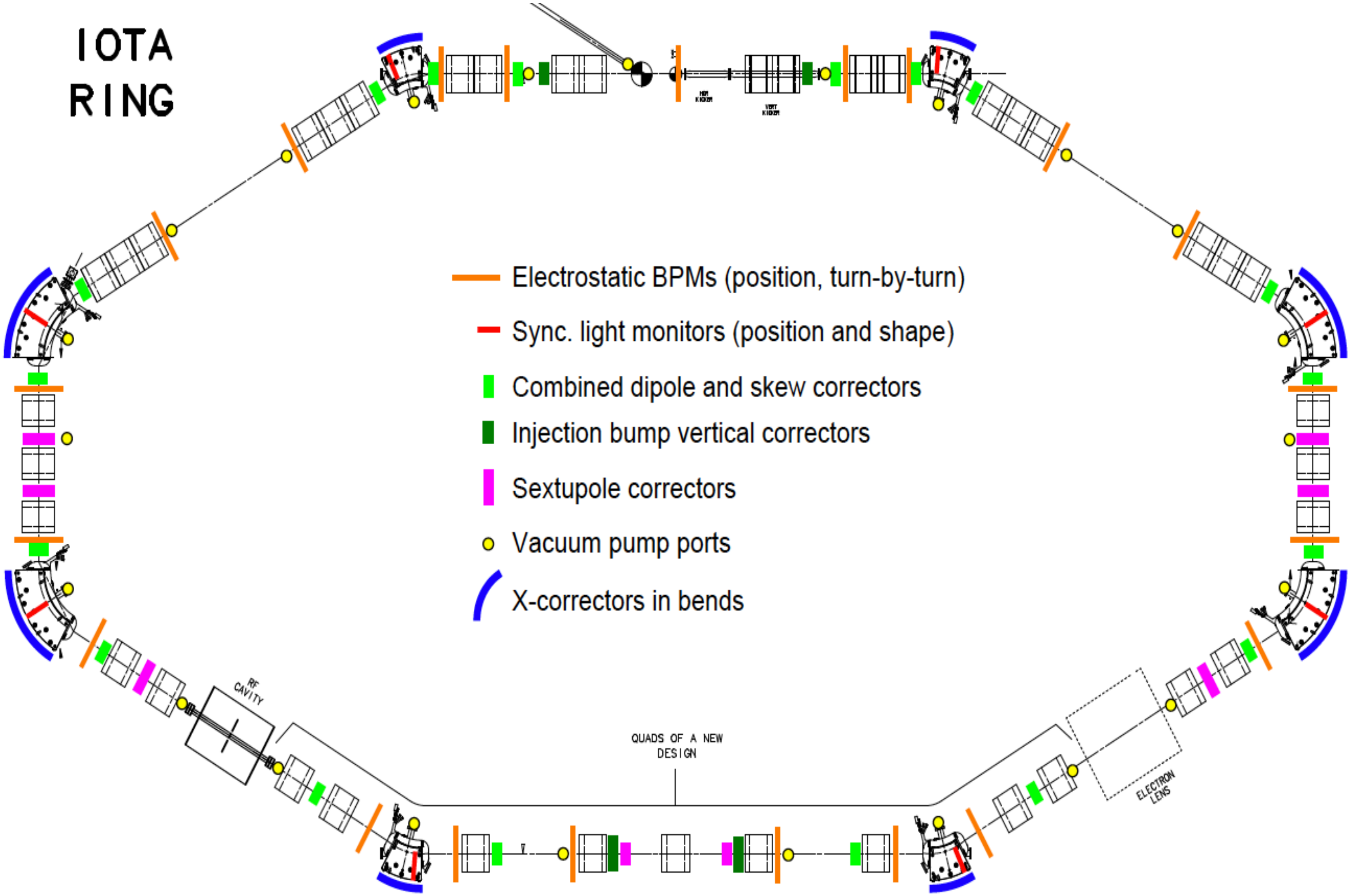
IOTA Option 1 – 2NL



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^-: 0.002 ÷ 0.005
Bunch length, momentum spread	e^-: 12 cm, 1.4×10^{-4}

IOTA Layout



- 🟧 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

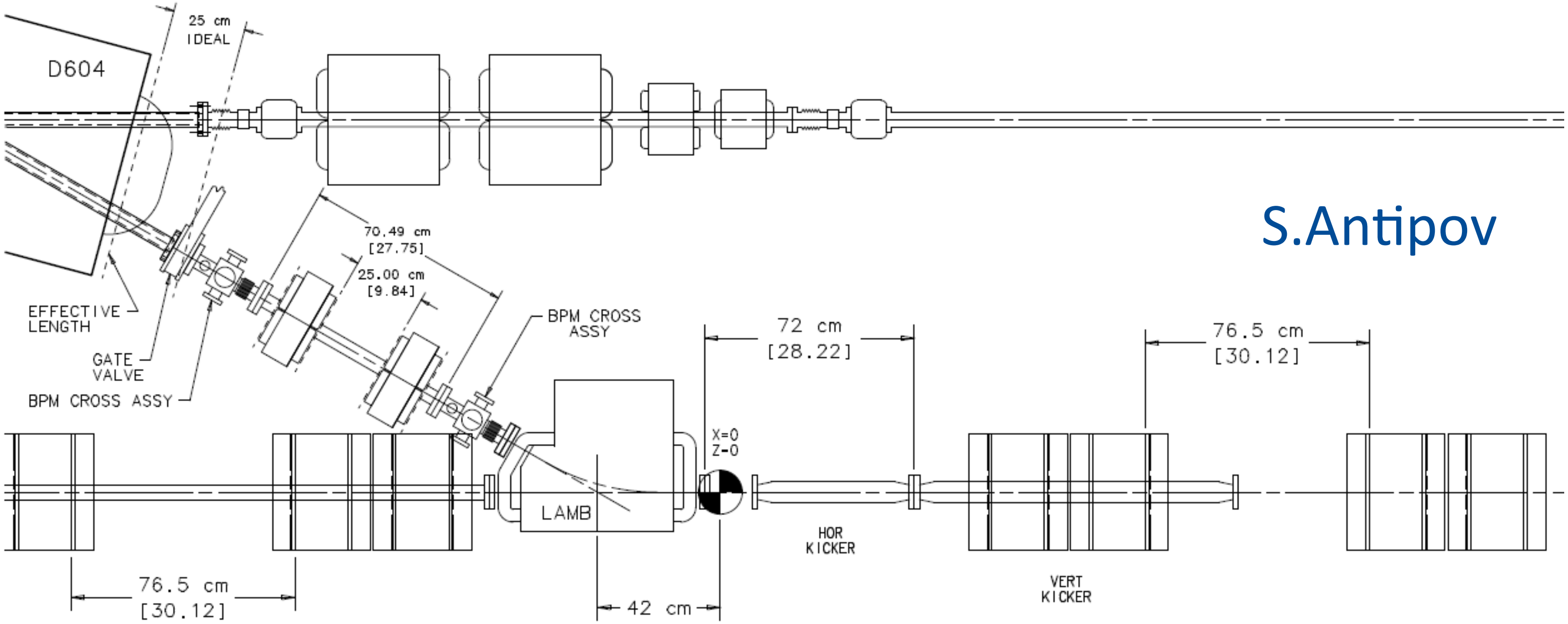
IOTA Elements – 1

- 8 sector bending magnets (4 30-degree, 4 60-degree)
- 39 quadrupole magnets in 26 circuits
- 25 H dipole correctors, 21 V
- 20 skew-quadrupole correctors
- 8 sextupole magnets

- 20 button-type BPMs
- 8 Synchrotron Light ports (CCD cameras, PMTs)
- Current monitor

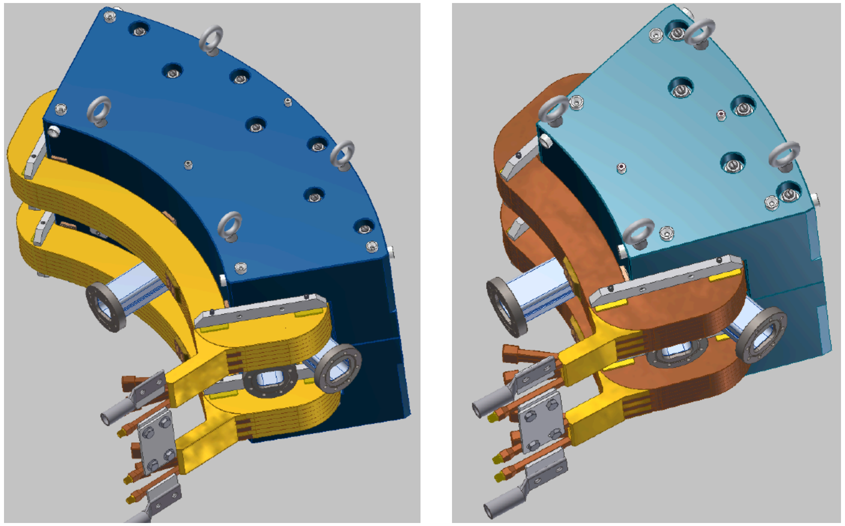
IOTA Elements – 2

- Dual-frequency RF cavity (30 MHz, 2 MHz)
- Single-turn injection
  - Lambertson magnet
  - H and V stripline kicker (also for painting the aperture)



S.Antipov

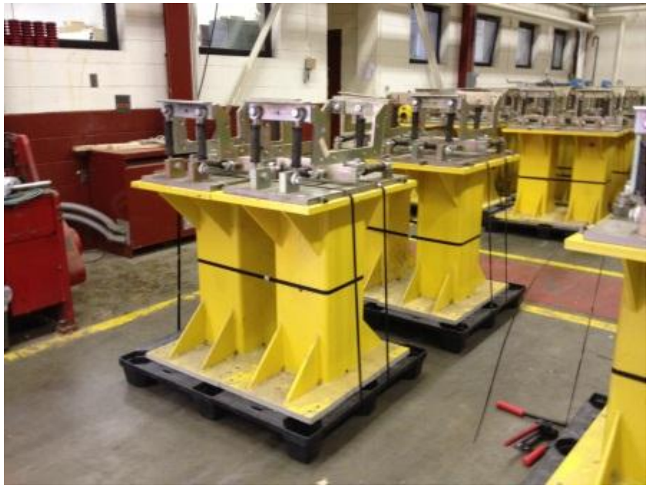
Ring Elements in Hand



Dipole magnets (ordered)

32 quads from **JINR (Dubna)** being measured

Vacuum chambers
for dipoles (received)



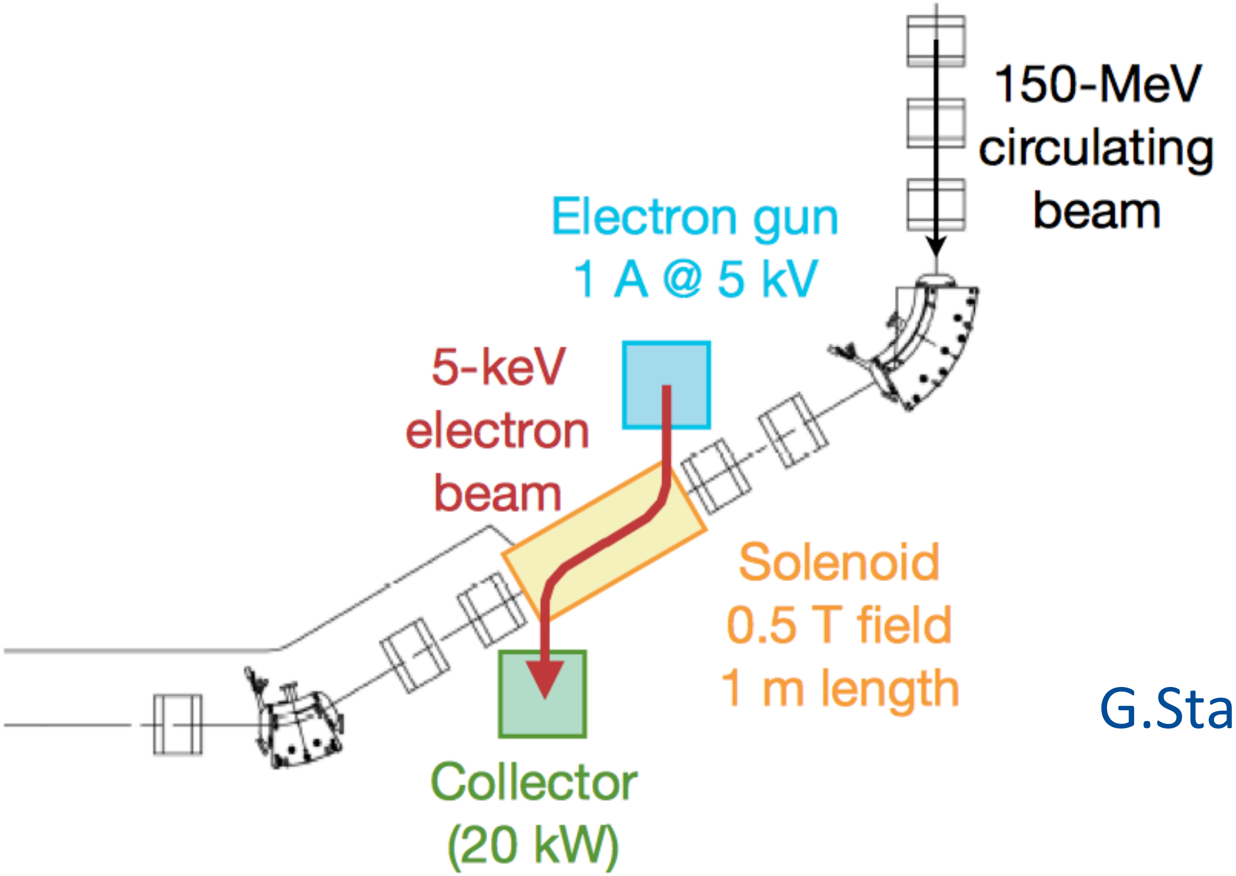
Magnet support stands
from **MIT** (received)

Also:

BPM bodies and electronics
Vacuum system
Dipole power supply
Quad supplies
Corrector power supplies

IOTA Electron Lens

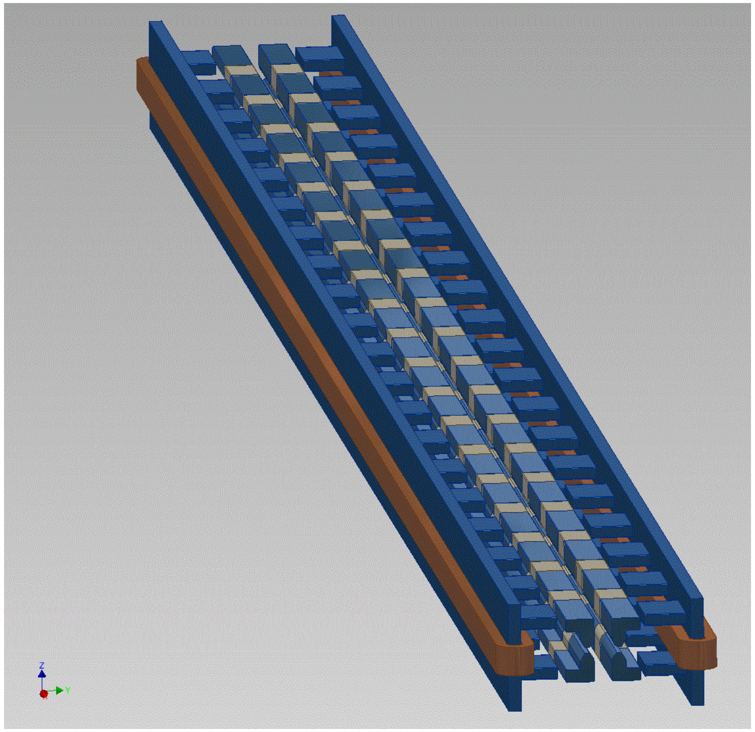
- Capitalize on the Tevatron experience and recent LARP work
- Re-use Tevatron EL components



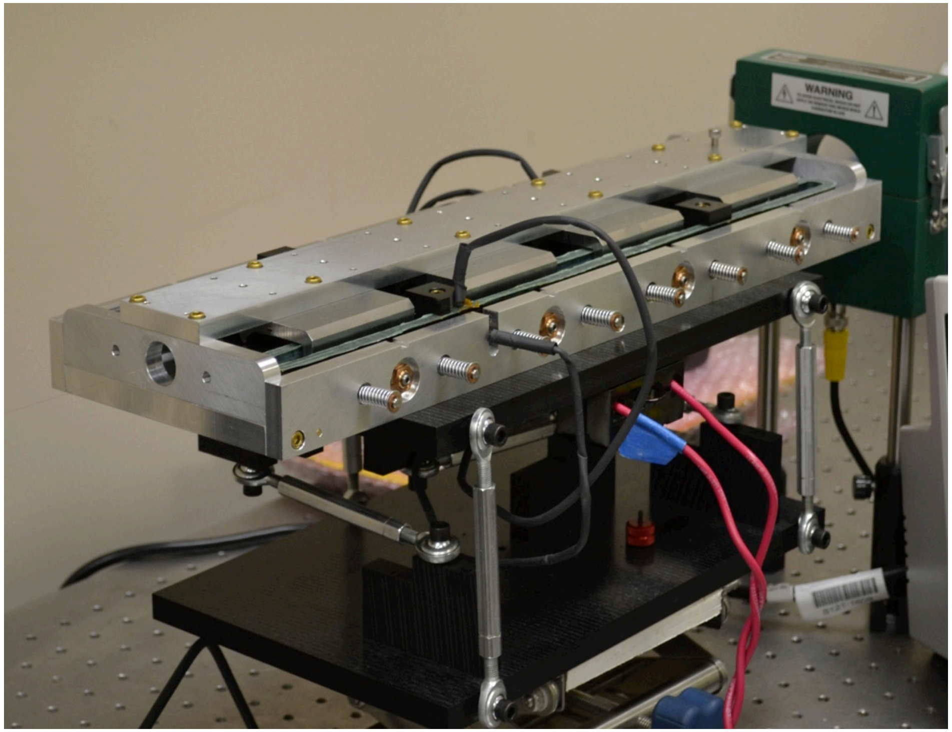
G.Stancari

Nonlinear Magnet

- Joint effort with RadiaBeam Technologies (Phase I and II SBIR)



FNAL Concept: 2-m long nonlinear magnet



RadiaBeam short prototype. The full 2-m magnet will be designed, fabricated and delivered to IOTA in Phase II

IOTA Staging – Phase I

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

- **Achieve large nonlinear tune shift/spread** without degradation of dynamic aperture **by “painting”** the accelerator aperture **with a “pencil” beam**
- 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
- The measure of success will be the achievement of high nonlinear tune shift = 0.25

IOTA Staging – Phase I

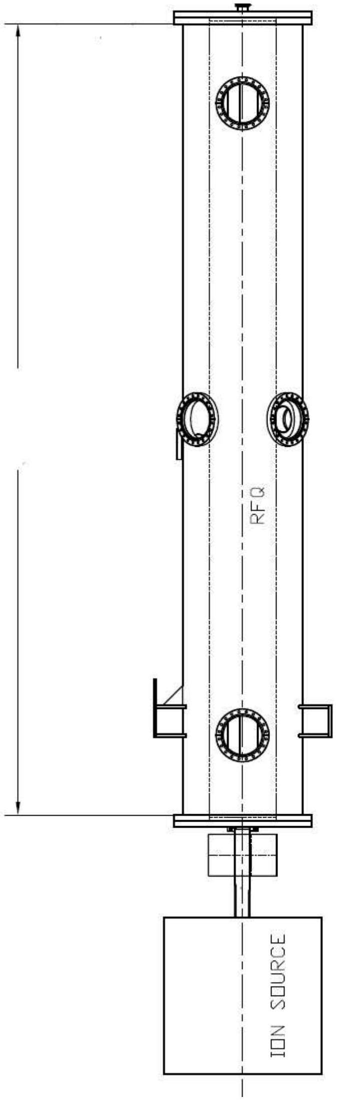
- The magnet quality, optics stability, instrumentation system and optics measurement techniques must be of highest standards in order to meet the requirements for integrable optics
  - 1% or better measurement and control of β-function, and 0.001 or better control of betatron phase
- This is why **Phase I needs pencil e$^-$ beams** as such optics parameters are not immediately reachable in a small ring operating with protons

IOTA Staging – Phase II

After the IOTA commissioning with e-, we will move the existing 2.5 MeV proton/H- RFQ into the ASTA hall to inject protons into the IOTA ring.

- ΔQ_{SC} =0.5 for one-turn injection, multi-turn injection possible
- Allows tests of Integrable Optics with protons and realisti space charge beam dynamics studies

Beam energy	**2.5 MeV**
Beam momentum	70 MeV/c
Relativistic beta	0.073
RF structure	325 MHz
Average beam current	<8 mA
Transverse emit.	0.4 mm-mrad
Momentum spread	3.7×10^{-3}
Pulse rate	0.2-1 Hz
Max. protons per turn	8.8×10^{10}



Plan of Activities and Status

Phase 1: FY15-17

1. Construction of main elements of the ASTA/IOTA facility:
    a) electron injector based on existing ASTA electron linac
        - Low energy injector operational. HE beamline construction in FY15. Connect CM2 and send beam down HE beamline in FY16
    b) IOTA ring
        - Most components procured. Begin assembly in FY16
    c) proton injector based on existing HINS proton source
        - Resurrecting the ion source in FY15, RFQ in FY16
    d) special equipment for AARD experiments.
2. Commissioning of the IOTA ring with electron beam – FY17
3. Study of single-particle dynamics in integrable optics with electron beams.

Plan of Activities – Outlook

Phase 2: FY18-20

1. Commission IOTA operation with proton beams.
2. Carry out space-charge compensation experiments with nonlinear optics and electron lenses.

Phase 3: FY21 and beyond

1. Study the application of space-charge compensation techiques to next generation high intensity machines.
2. Expand the program beyond these high priority goals to allow Fermilab scientists and a broader accelerator HEP community to utilize unique proton and electron beam capabilities of the ASTA/IOTA facility

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