Fermilab R&D Relevant to JLEIC

Mike Syphers, NIU/FNAL
JLEIC Collaboration Meeting
5 April 2017

In partnership with:

Northern Illinois University

Accelerator Physics and Technologies

- Technologies
  - Fermilab Technical Division
    - Magnets
    - Superconducting RF
    - Cryogenic systems
  - Fermilab Accelerator Division
    - Kicker systems
    - Beam instrumentation
- Accelerator Physics
  - Fermilab Accelerator Division (Accelerator Physics Center) / Computing Division
    - collider accelerator physics / optics
    - particle tracking / simulations
    - Machine-Detector Interface
    - MARS calculations — radiation fields, collimation systems
    - e-Cloud calculations, simulations, measurement experience
    - hadron cooling expertise
    - beam and spin dynamics
    - chromatic corrections, etc.

Accelerator Technologies

- Technologies
  - Fermilab Technical Division
    - Magnets — ring, interaction regions, beam lines
      - conventional
      - superconducting — including major dipoles, quadrupoles; helices
      - corrector — both normal & sc, including fast ramping, multi-multipole correctors
    - Superconducting RF cavities — crab cavities
      - ILC-style cavity experience; full infrastructure and test facilities
    - Cryogenic systems
      - decades of experience in superconductivity infrastructure
  - Fermilab Accelerator Division
    - Kicker systems
      - most notably and most recently: kickers for Main Injector/Recycler operation to enable Muon Campus operation; pulsed kickers and magnets for Muon beam production/targetry
    - Beam instrumentation
      - host of instrument development from BPMs, flying wires, IPMs, various wire chamber and ion chamber configurations, etc., plus timing/clock systems and signal processing systems, etc.

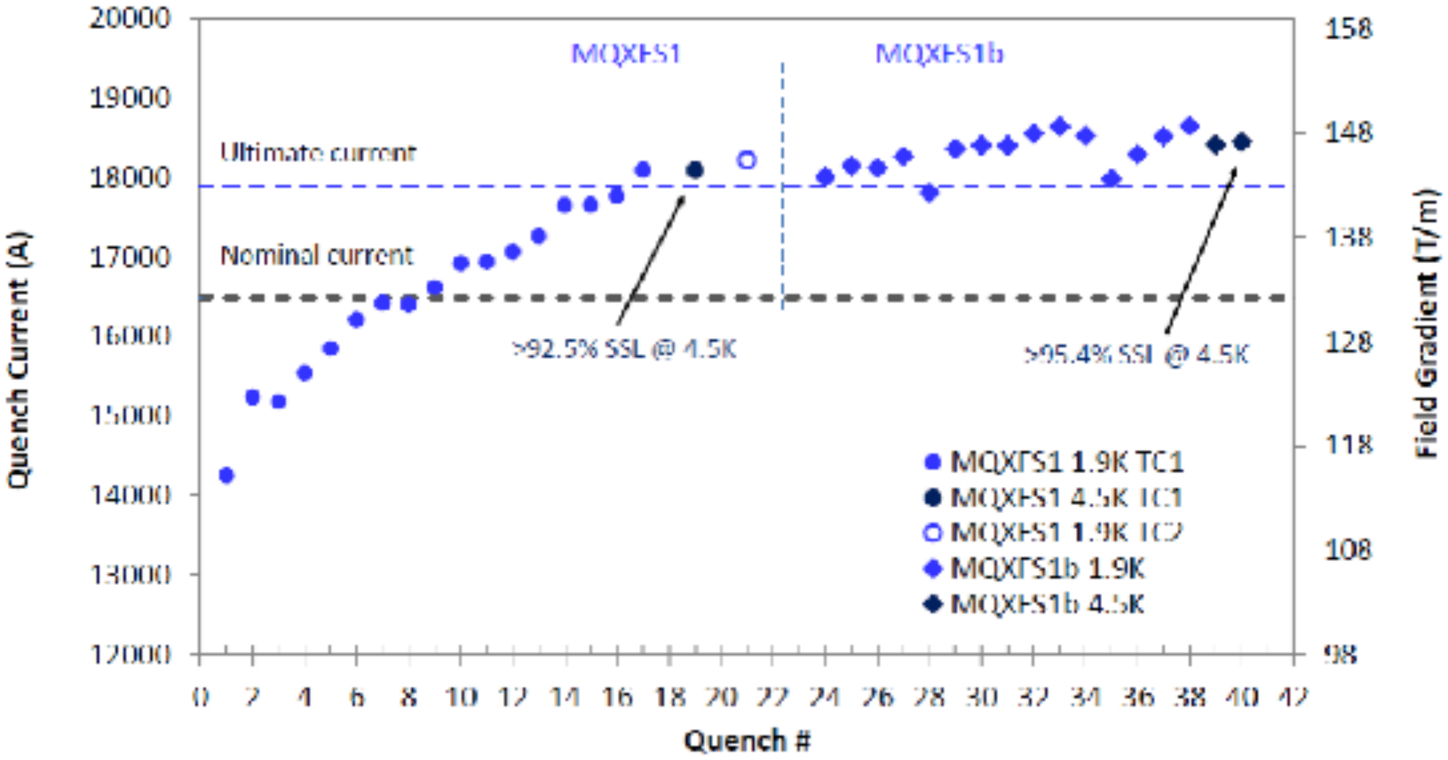
Accelerator Physics

- Accelerator Physics
  - Fermilab Accelerator Division (Accelerator Physics Center) / Computing Division
    - collider accelerator physics / optics
      - many years of collider commissioning, operation, upgrades; simulation, computational efforts
      - chromatic corrections, etc.
    - particle tracking / simulations
      - SYNERGIA/CHEF + much experience with standard codes
    - MARS calculations — radiation fields, collimation systems
      - Tevatron, CDF/D0, SSC, LHC, VLHC, FCC, …
    - Machine-Detector Interface
      - CDF/D0 experience + SSC + LHC experience
    - e-Cloud calculations, simulations, measurement experience
      - experimental efforts in Main Injector/Recycler, code validations; LHC, ILC damping rings efforts
    - hadron cooling expertise
      - antiproton cooling — both e- cooling and stochastic systems; muon cooling development
    - other local relevant beam dynamics
      - spin dynamics — expertise being honed for g-2 beam delivery, analyses
      - heavy ion experience

Selection of on-going R&D at Fermilab

- 16 T Dipole magnet R&D
- Mu2e Solenoid Magnet construction
- Muon g-2 Inflector Magnet upgrade
- SRF R&D
- PIP-II design effort
- MARS development
- SYNERGIA development
- Beam-beam Kicker for e-Cooling (Piot)
- FAST Facility
- IOTA

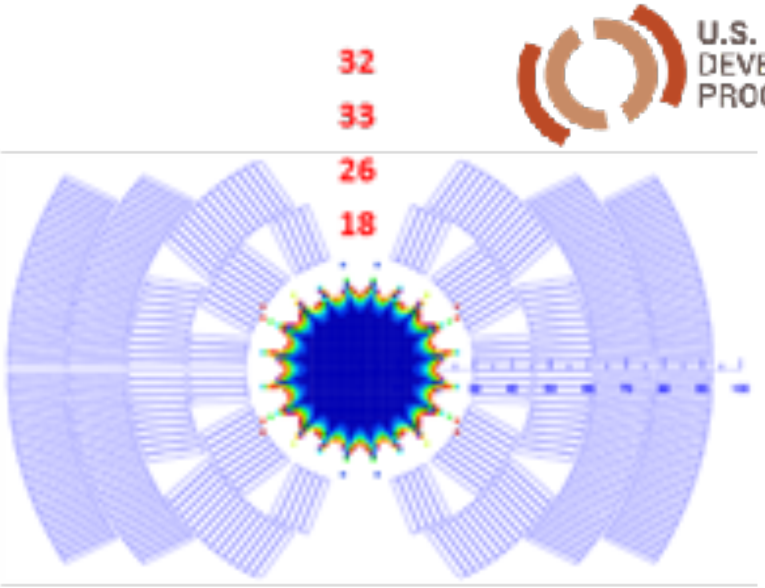
LARP and High Luminosity LHC Accelerator Upgrade Project

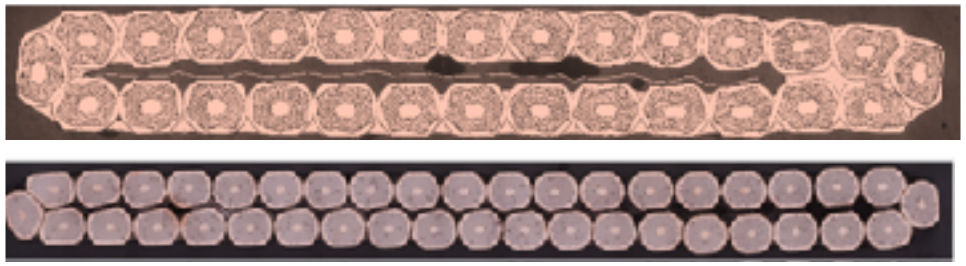


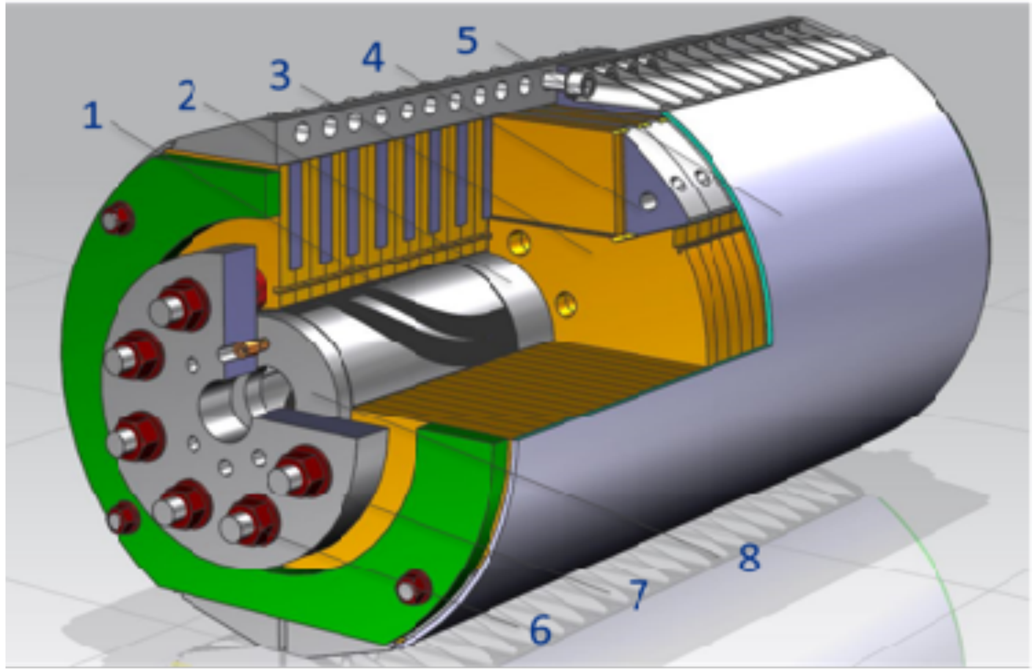
courtesy S. Belomestnykh, FNAL

15 T Dipole demonstrator (baseline)

- Coil:
  - 60-mm ID
  - 4-layer graded coil
- Cable:
  - L1-L2: 28 strands, 1 mm RRP150/169
  - L3-L4: 40 strands, 0.7 mm RRP108/127
  - Insulation: E-glass tape
- Mechanical structure:
  - Thin StSt coil-yoke spacer
  - Vertically split iron laminations
  - Aluminum I-clamps
  - 12-mm thick StSt skin
  - thick end plates and StSt rods
- Cold mass OD<610 mm (VMTF Dewar limit)



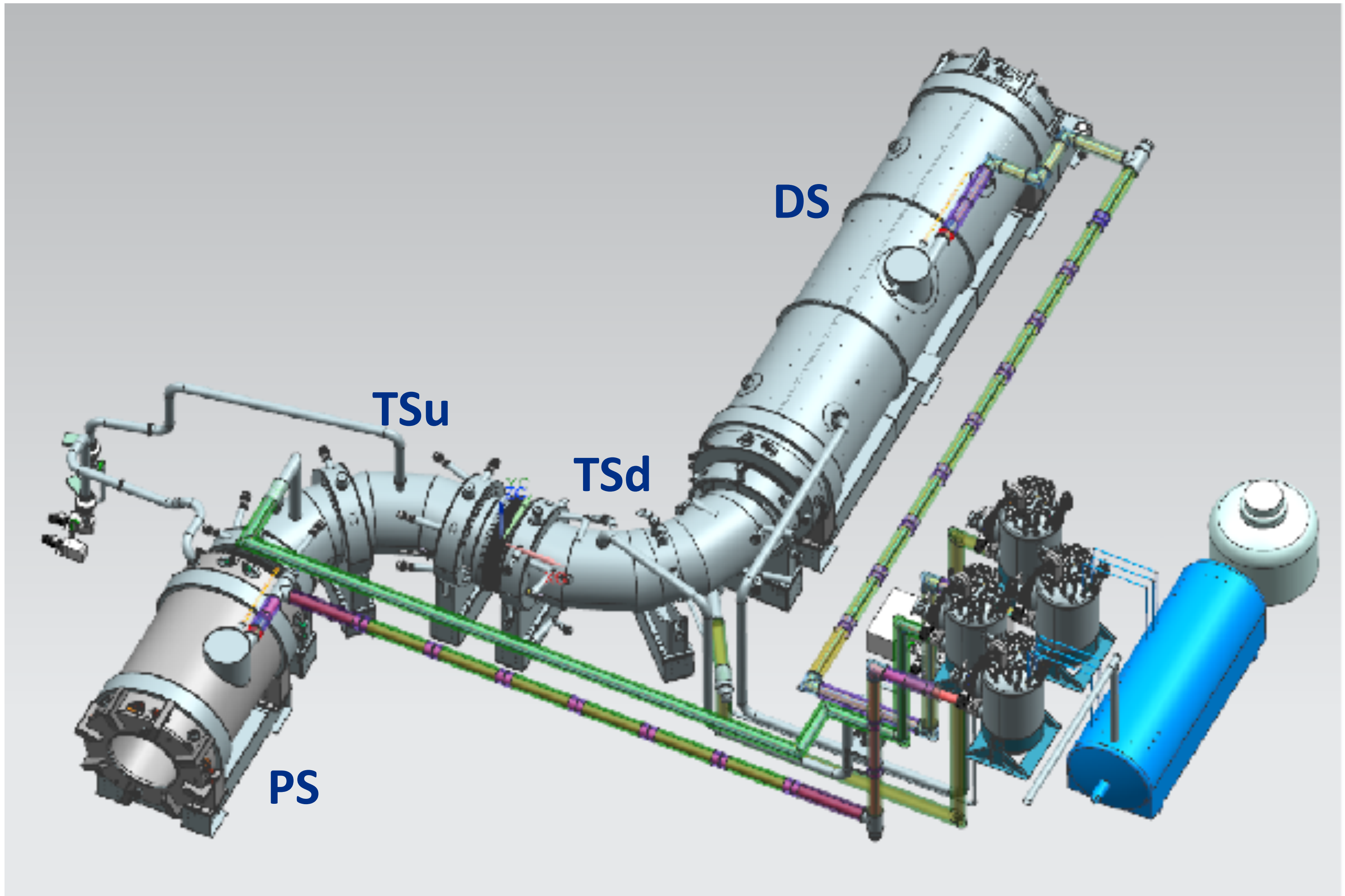


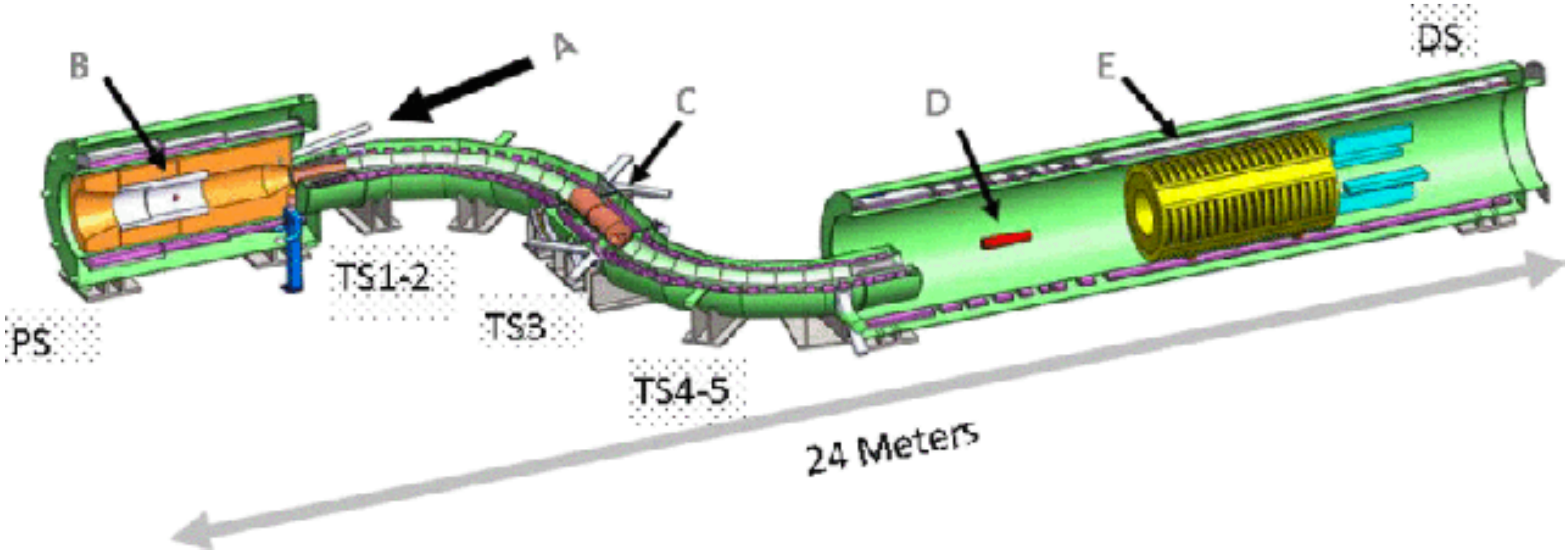


slide courtesy A. Zlobin, FNAL

Mu2e Solenoids

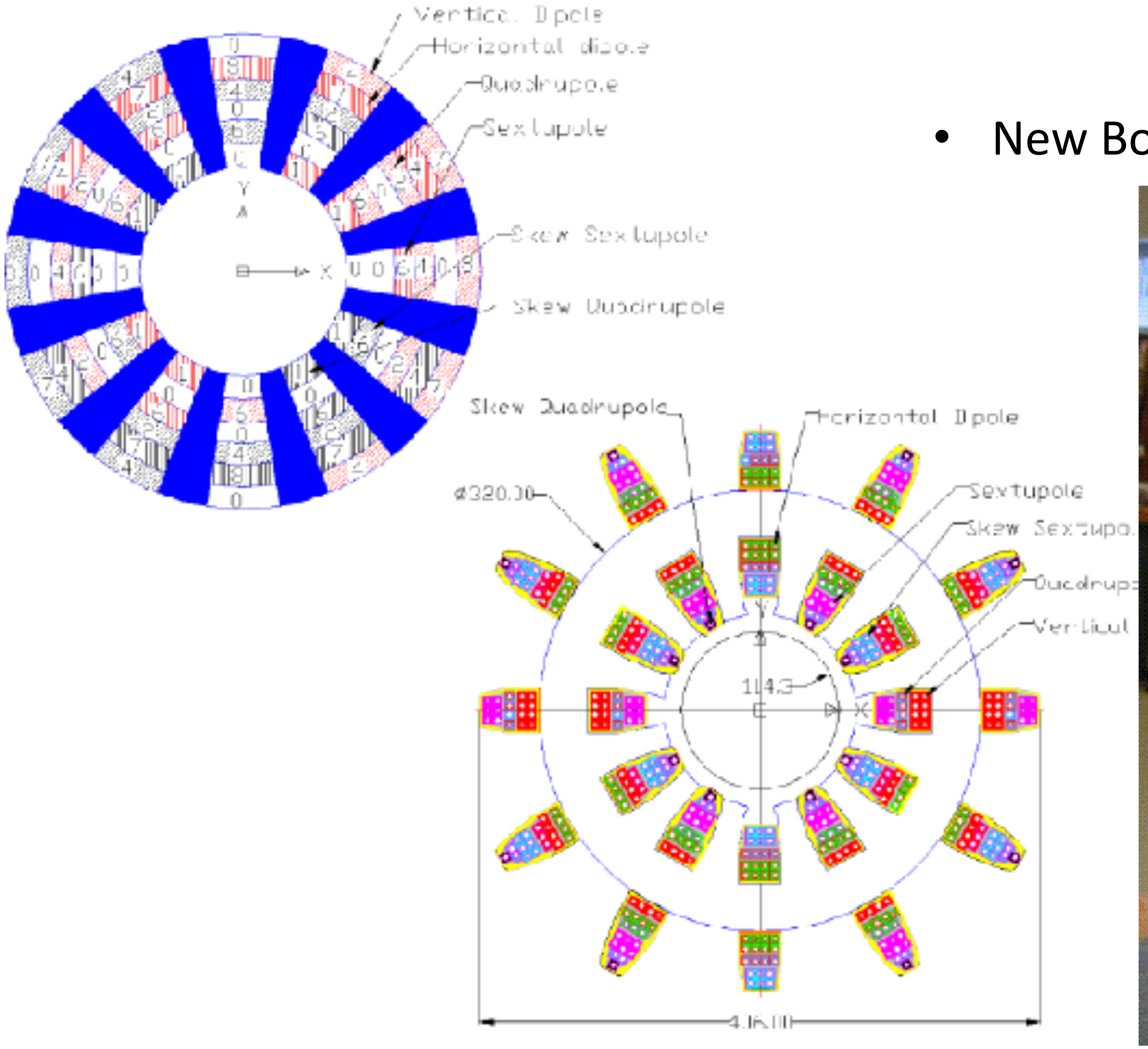
- Capture Solenoid
  - 5 T, 1.7 m ID
- Transport (“S”) Solenoid
  - 3.4 T, 0.9 m ID
- Detector Solenoid
  - 2.2 T, 2.1 m ID



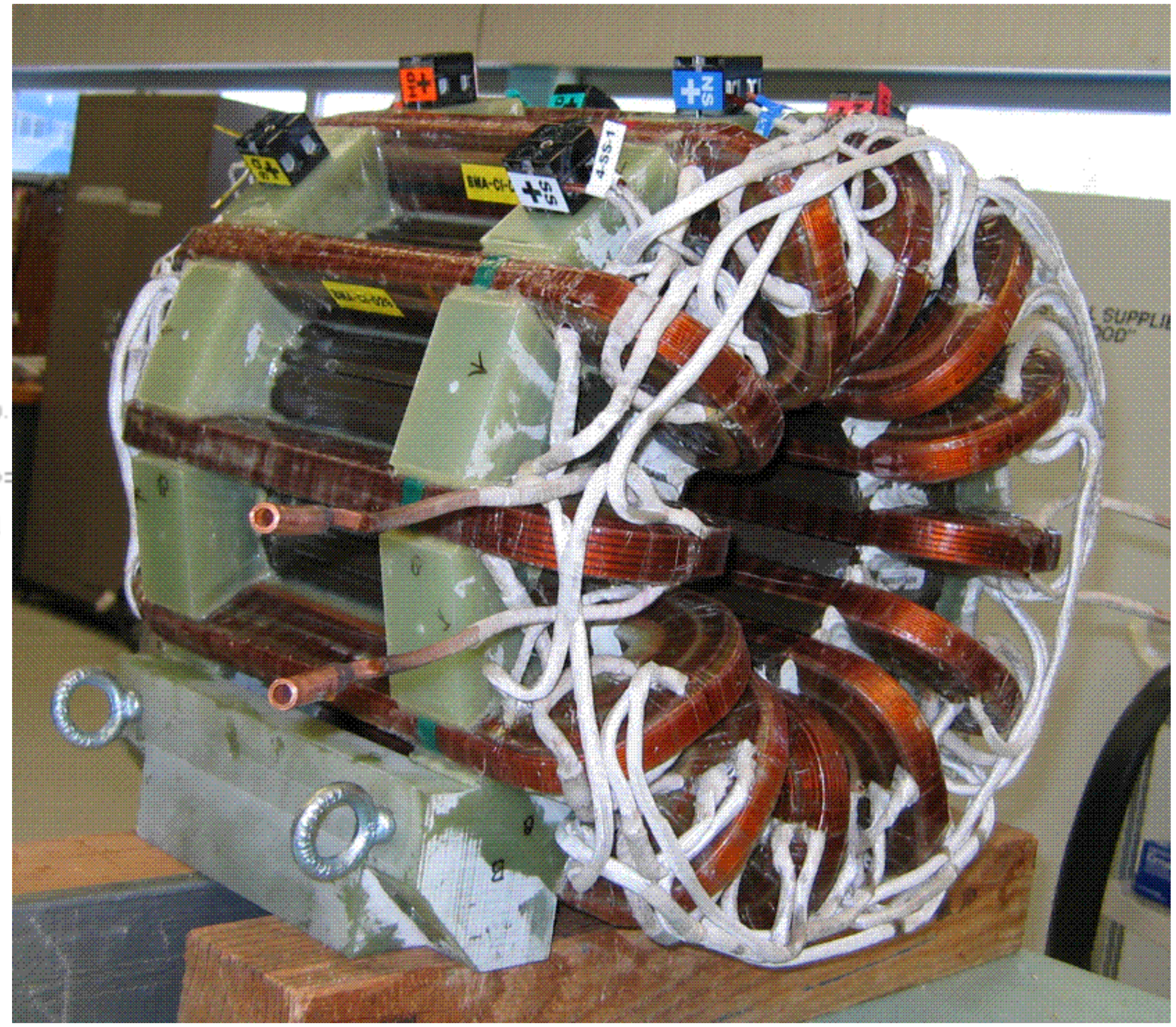


Booster Multipole Correctors

- How to package a variety of correction magnets in limited space that must obey programmable ramping with cycle times of 10’s of milliseconds?

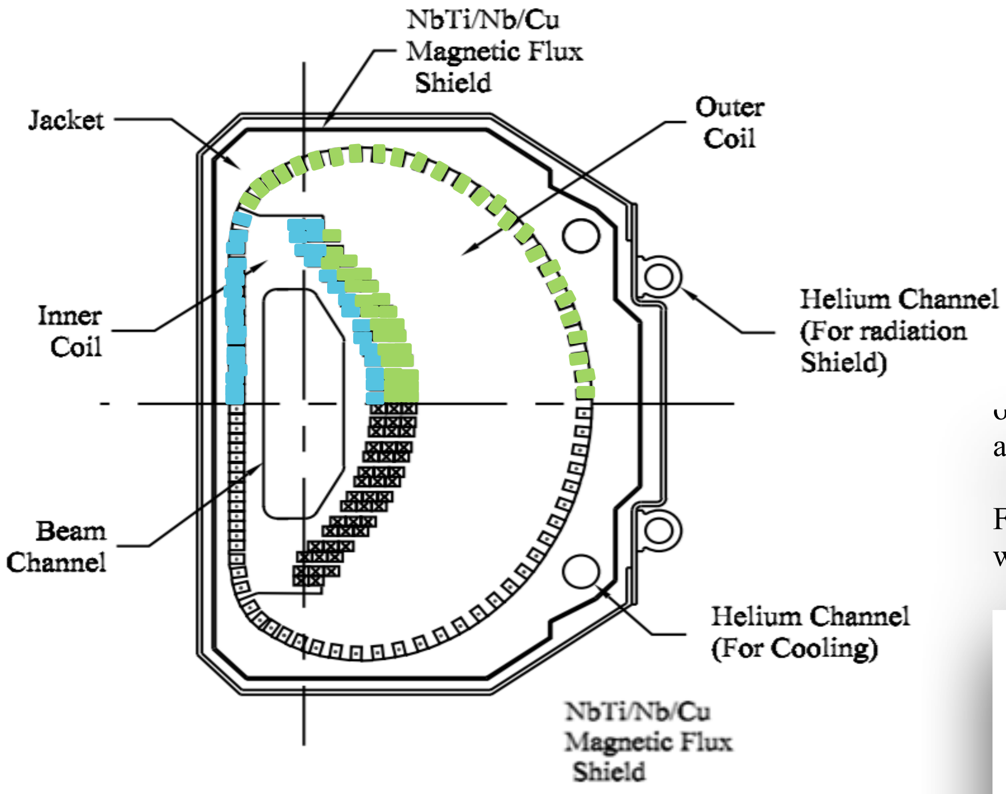


- New Booster Corrector Magnet Package Before Potting

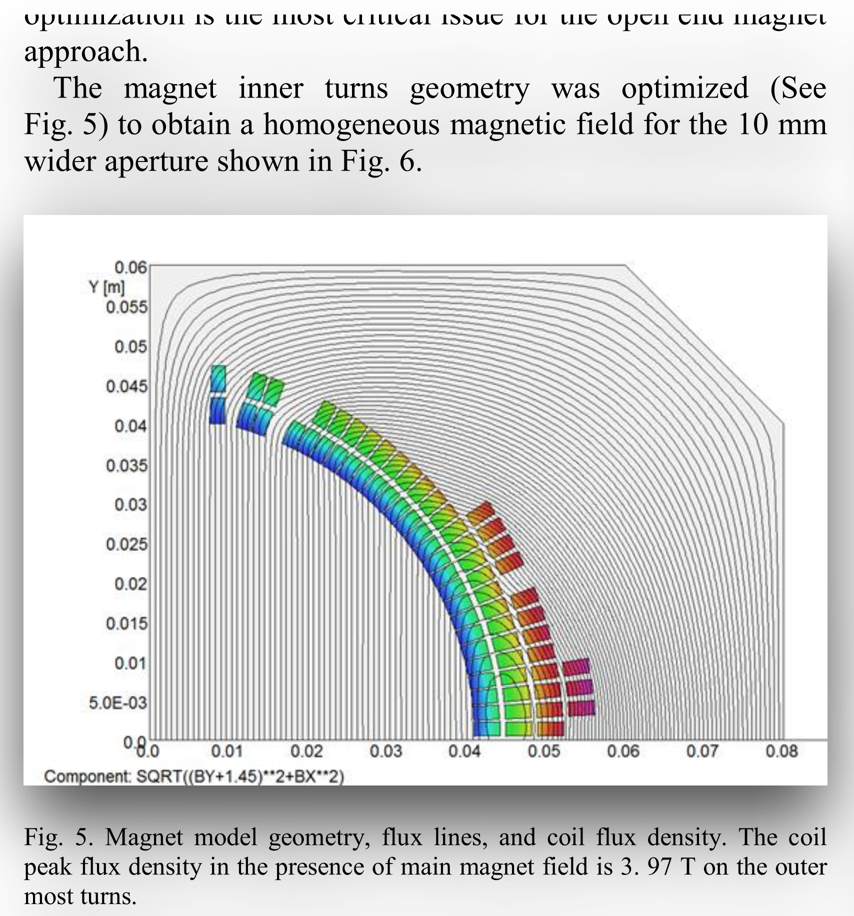


Muon g-2 Inflector Magnet

- How to put an injection septum into a region where the magnetic field otherwise needs to be uniform to ~1 ppm?



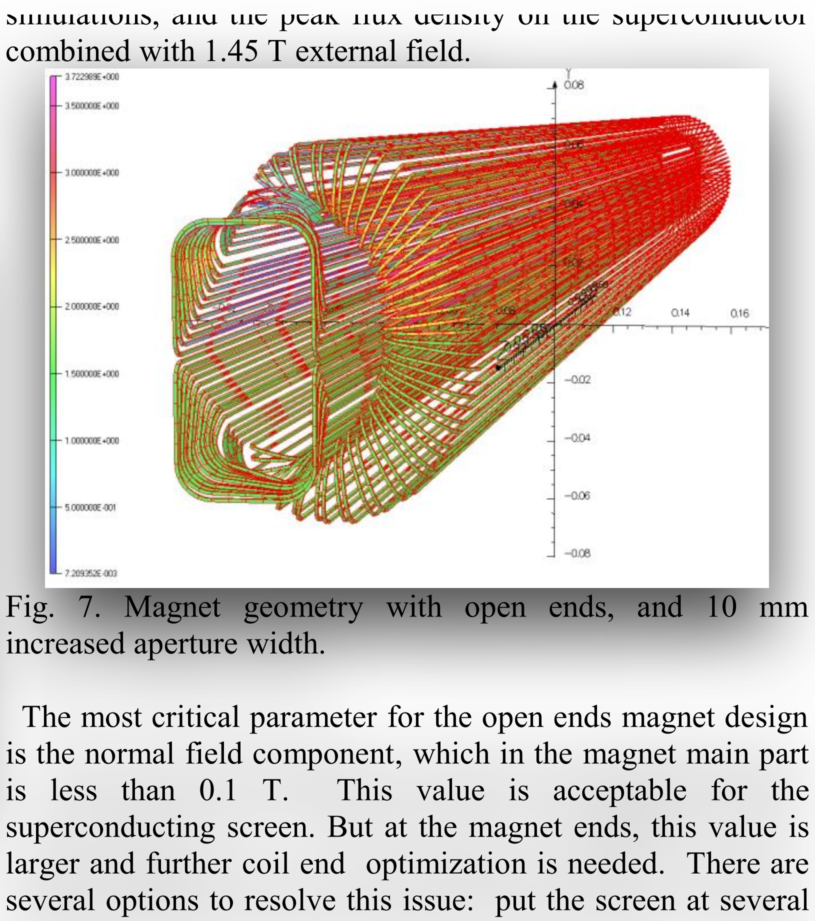
V. S. Kashikhin, et al., fermilab-conf-14-276-td



optimization is the most critical issue for the open end magnet approach.

The magnet inner turns geometry was optimized (See Fig. 5) to obtain a homogeneous magnetic field for the 10 mm wider aperture shown in Fig. 6.

Fig. 5. Magnet model geometry, flux lines, and coil flux density. The coil peak flux density in the presence of main magnet field is 3. 97 T on the outer most turns.



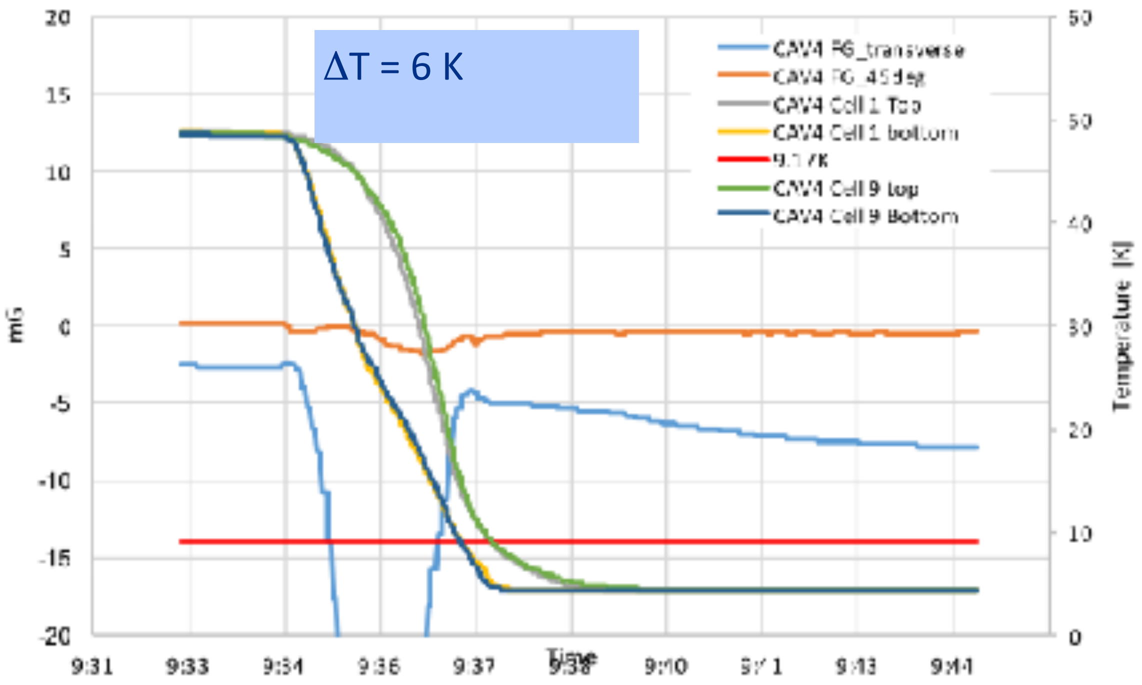
simulations, and the peak flux density on the superconductor combined with 1.45 T external field.

Fig. 7. Magnet geometry with open ends, and 10 mm increased aperture width.

The most critical parameter for the open ends magnet design is the normal field component, which in the magnet main part is less than 0.1 T. This value is acceptable for the superconducting screen. But at the magnet ends, this value is larger and further coil end optimization is needed. There are several options to resolve this issue: put the screen at several

LCLS-II pre-production cryomodule achieved world record on Q_0

Cryomodule in CMTF Test Cave

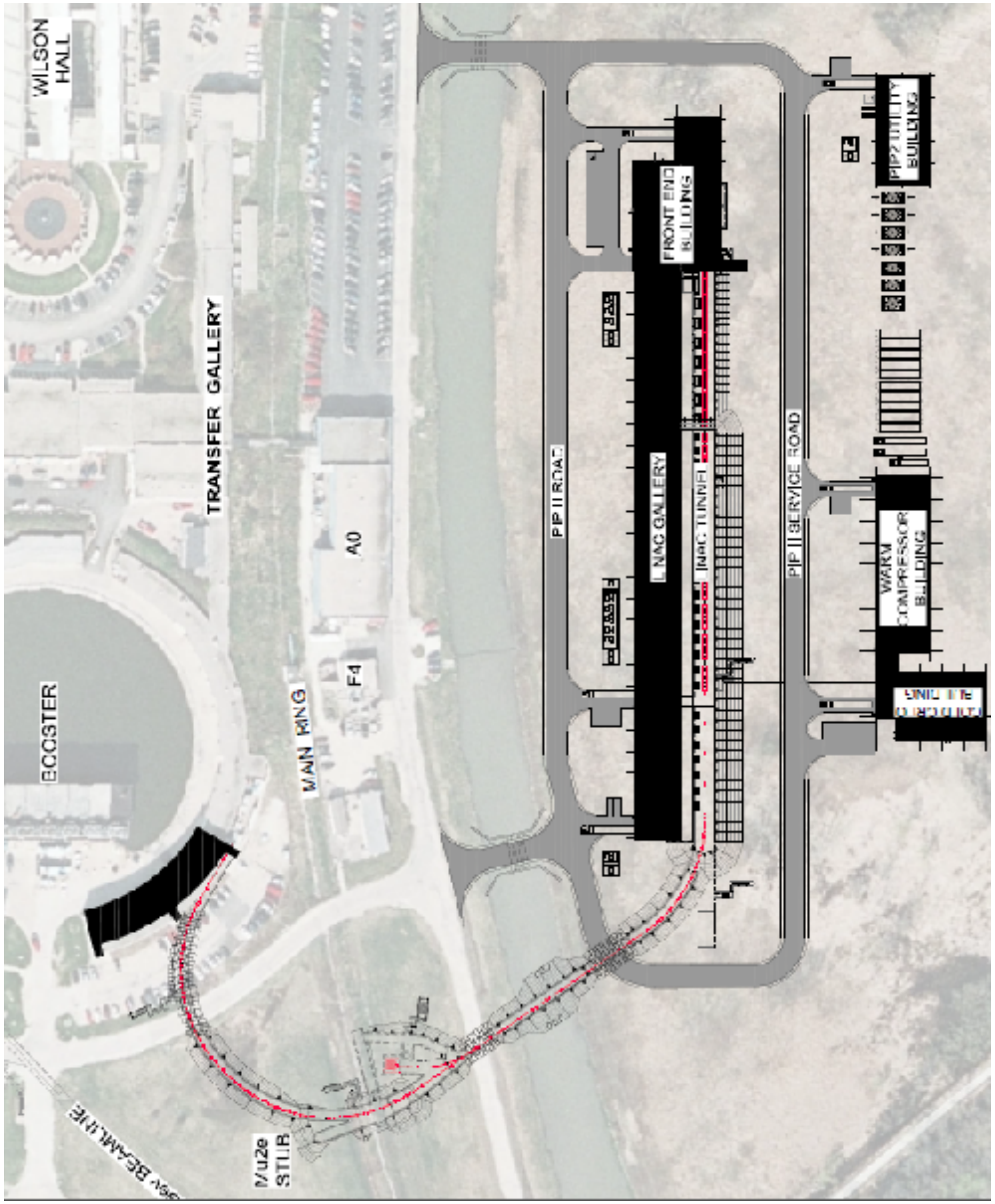


Fast Cool Down Demonstrated

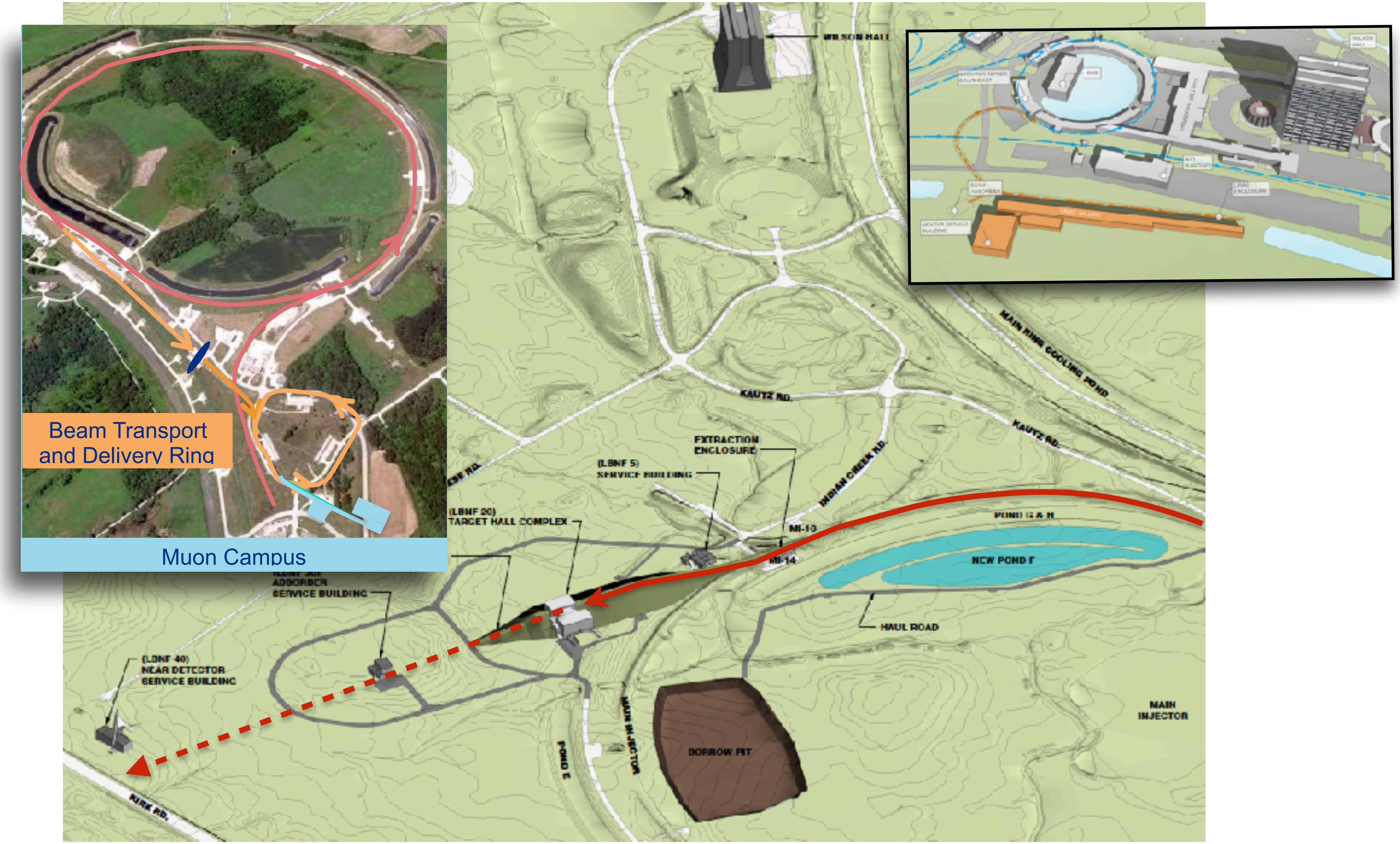
Major PIP-II Components

(from talk by V. Lebedev S. Holmes)

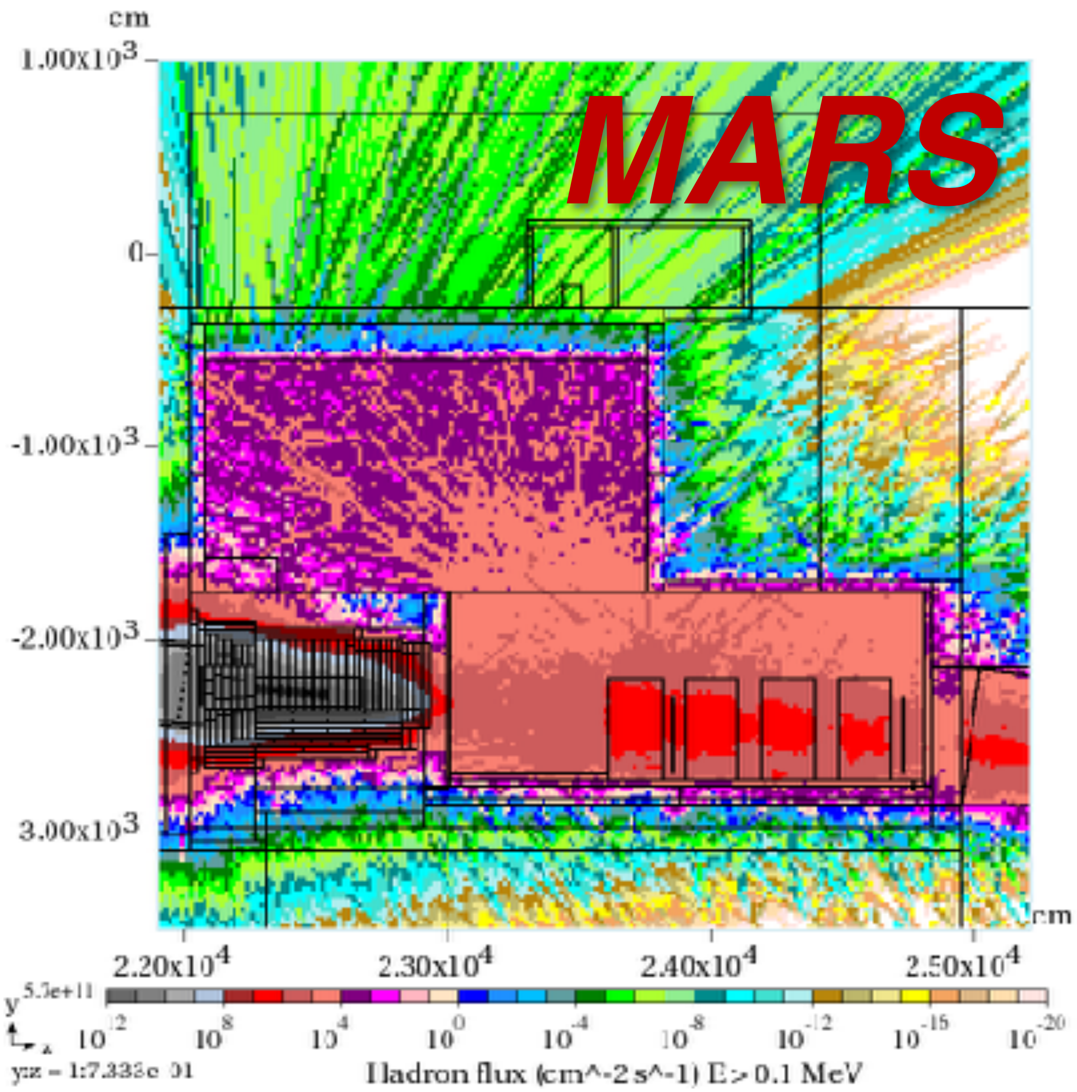
- New 0.8 GeV linac
  - L≈210 m
    - Includes 4 empty slots at the linac end, L≈40 m
      - Possible energy upgrade
  - ~200 m linac extension is accommodated
- New Linac-to-Booster transfer line
  - L≈300 m
  - Compatible with 800 MeV beam to Mu2e
- Upgraded Booster
  - 20 Hz, 800 MeV injection
  - New injection girder
- Upgraded Recycler & MI



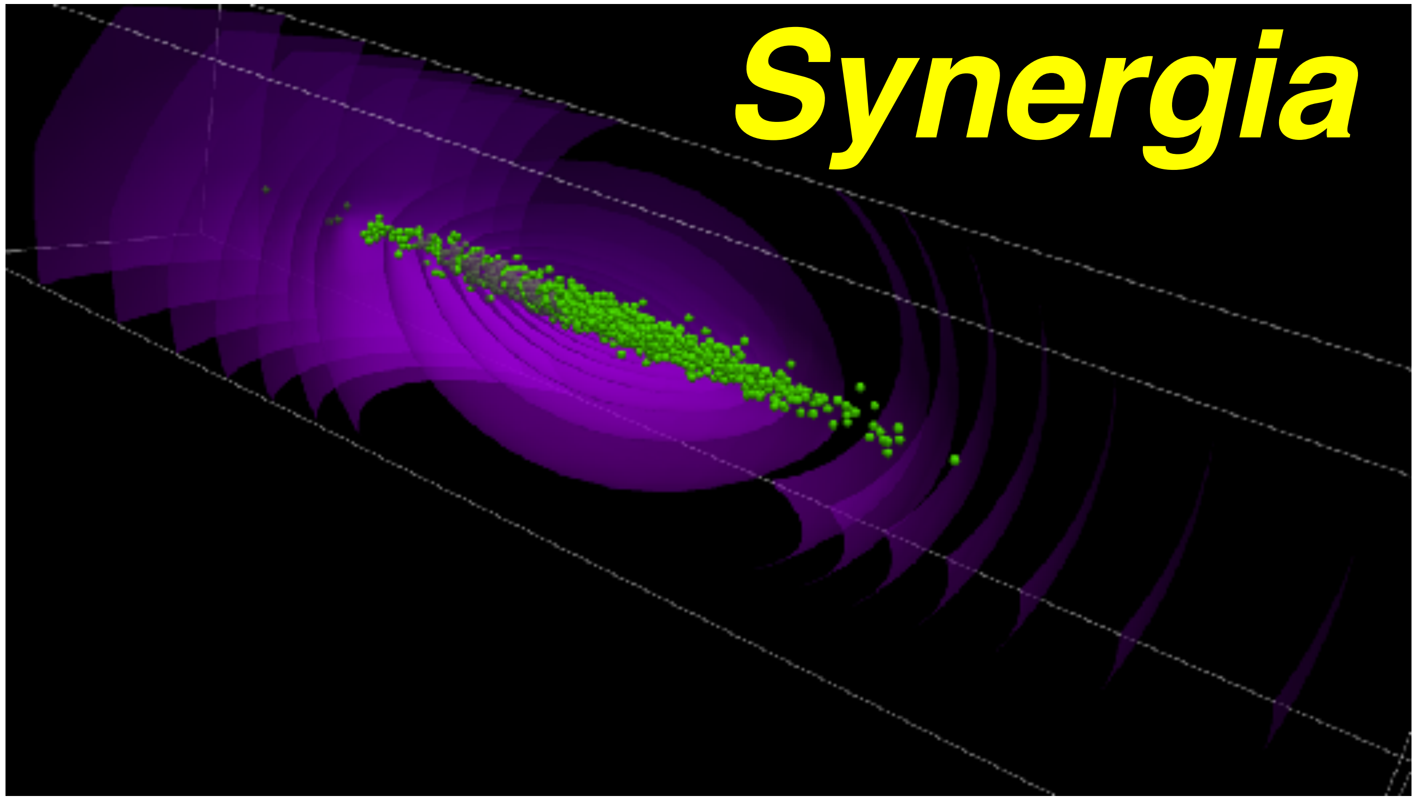
Fermilab Landscape: Muon Campus, DUNE, PIP-II



Accelerator Modeling Tools



- Energy Deposition Simulation
- Developed and supported for > 30 years
- Radiation levels, particle-matter interactions at all energy ranges of interest



- Beam Dynamics Framework
- Developed at Fermilab
- Collective effects/Fully nonlinear single-particle dynamics

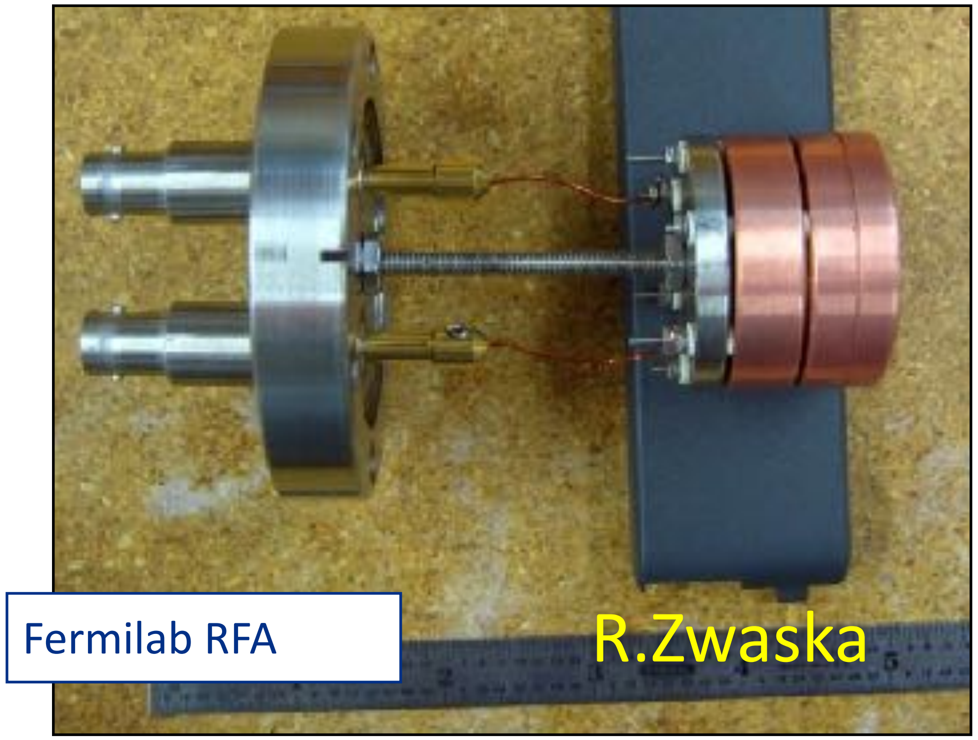
- Modeling Fermilab Machines
- Booster
  - Space charge + wakefields
- Main Injector and Recycler
  - Slip stacking with space charge

Main Injector: e- Cloud Experimental Station

slide courtesy V. Shiltsev

E-Cloud Station in Main Injector :

- 2 experimental Chambers (coated and SS)
  - Test various coatings for ECloud suppression
  - Measure spatial extinction of ECloud
- 3 Fermilab and 1 Argonne RFA
  - Retarding Field Analyzers
  - Directly measure electron flux
- 3 microwave antennas and 2 absorbers
  - Measure ECloud density by phase delay of microwaves
- So far, three materials tested:
  - TiN (2009-10) – suppressed vs. Stainless (5-1000x)
  - α-C (2010-12, from CERN) – similar suppression as TiN
  - DLC (2013-, from KEK) – Awaiting the return of beam



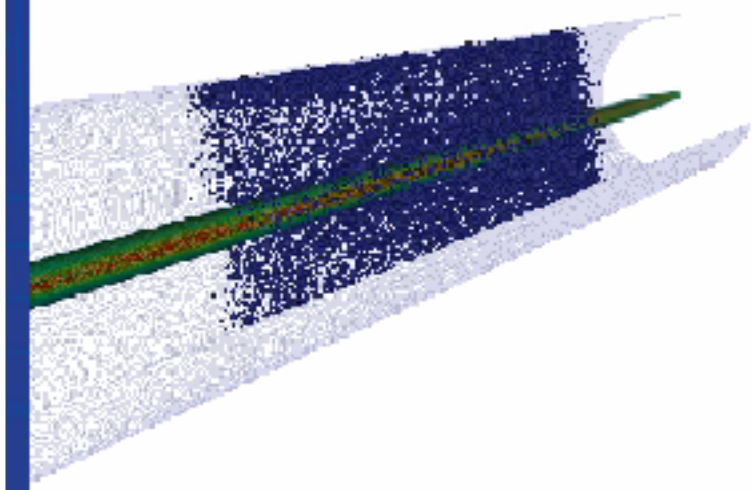
Fermilab RFA

R.Zwaska

Augmented by comprehensive simulations

- Utilization of SYNERGIA and ComPASS tools :
  - *ComPASS VORPAL e-cloud simulation of MI experiments*
- Model microwave experiment (only possible with ComPASS tools), RFA response
- Code comparisons with “standard” tools such as POSINST

P.Lebrun, J.Amundson, P.Spentzouris, et al



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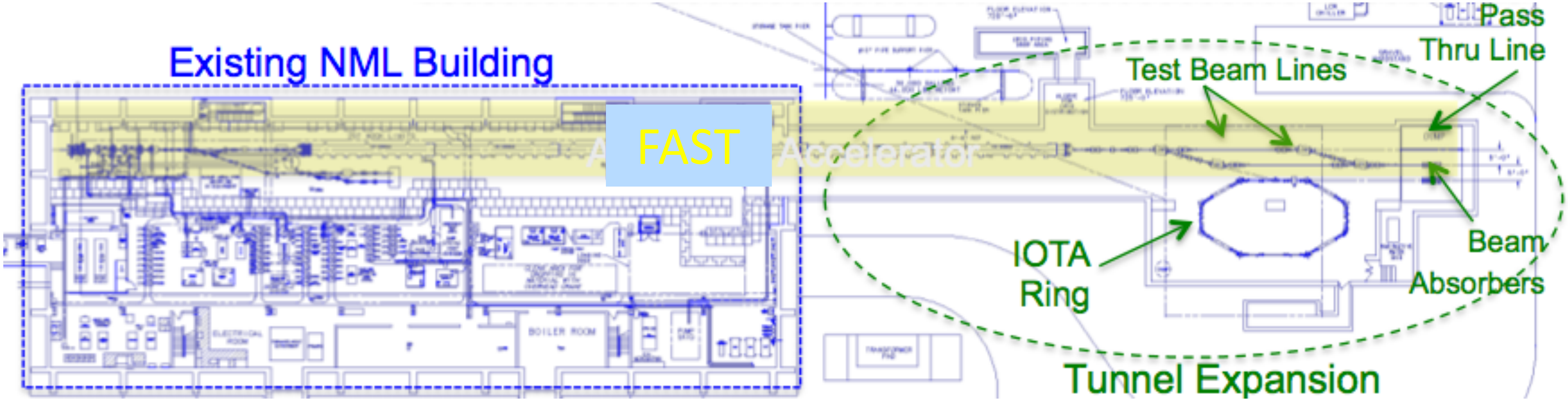
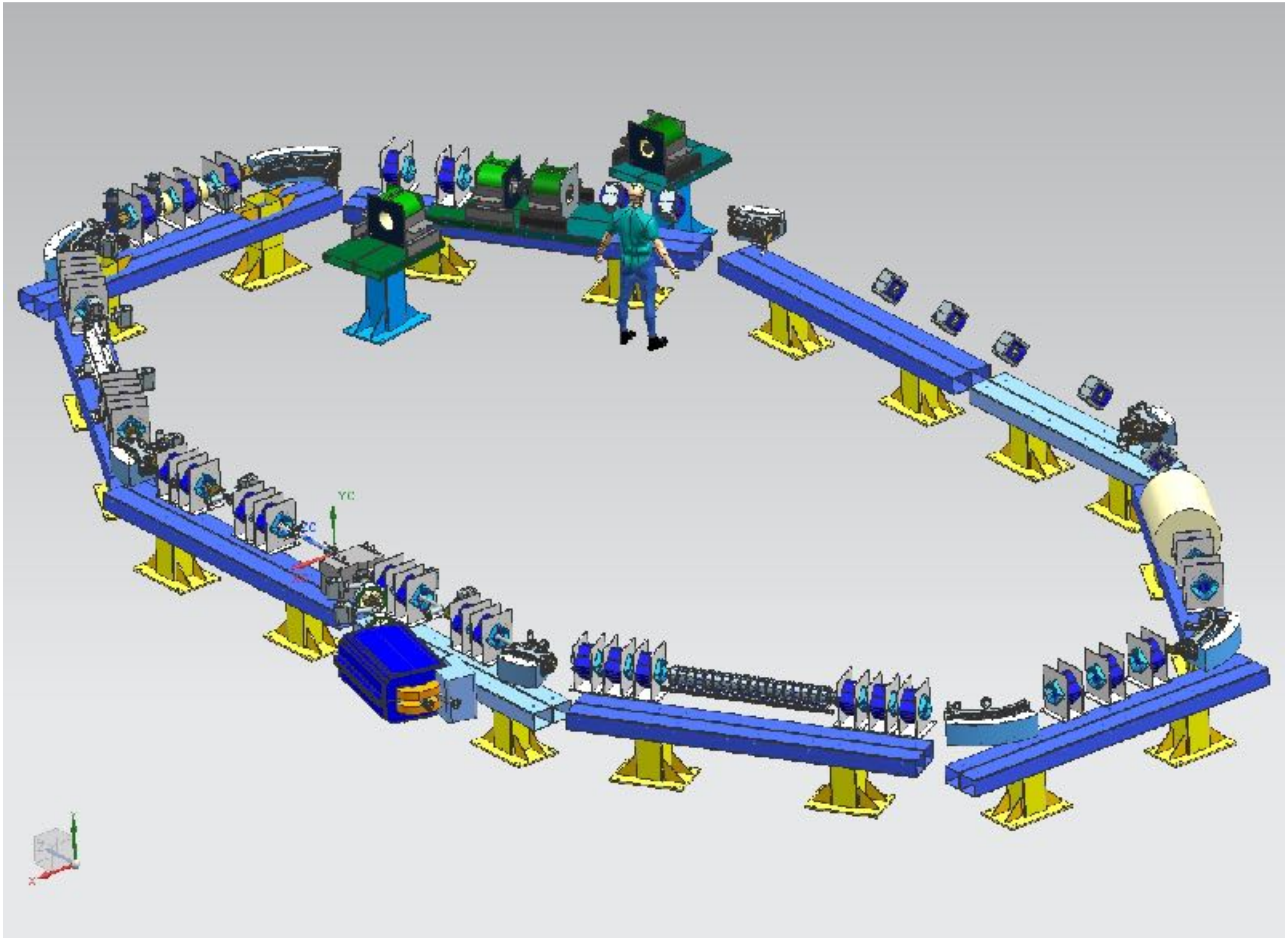
Fermilab Accelerator Science and Technology Facility

formerly ASTA, NML

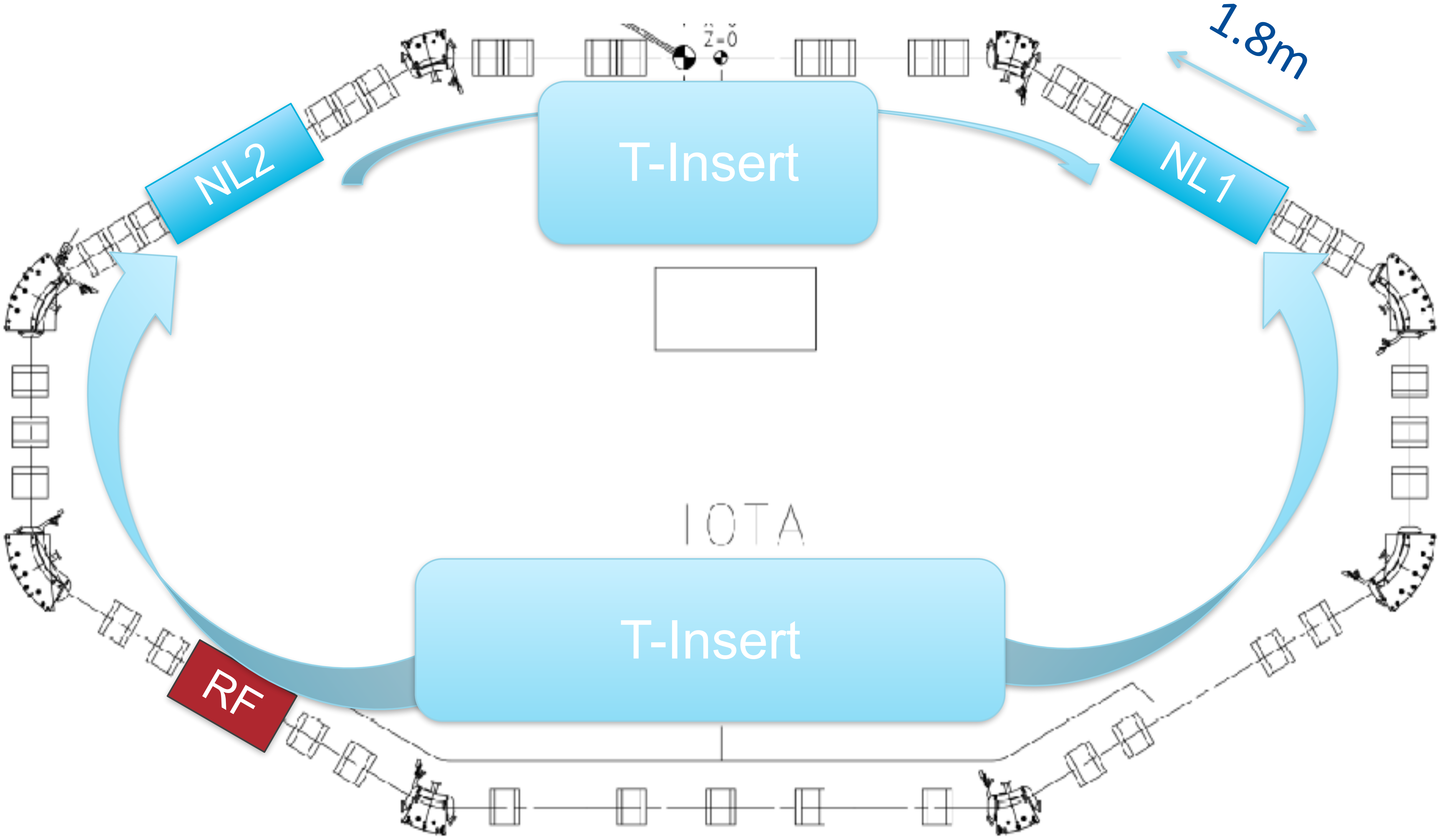
FAST (formerly ASTA, NML)



IOTA Layout

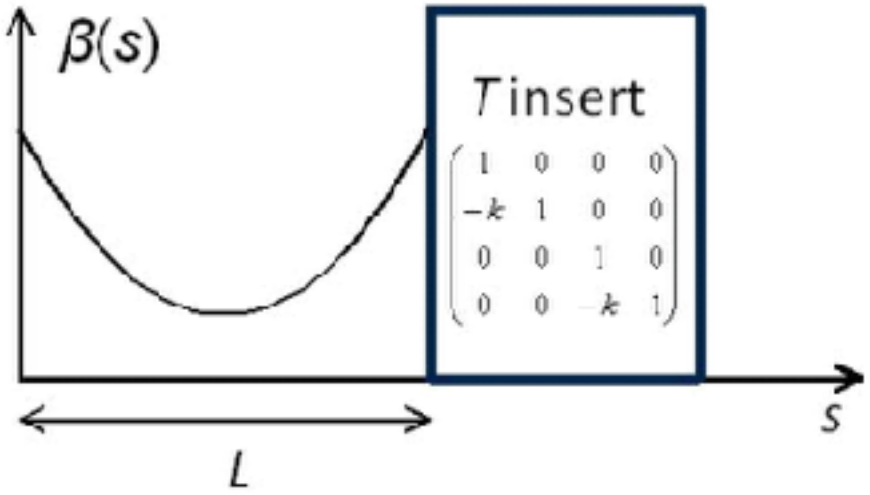


IOTA Optics – 2NL



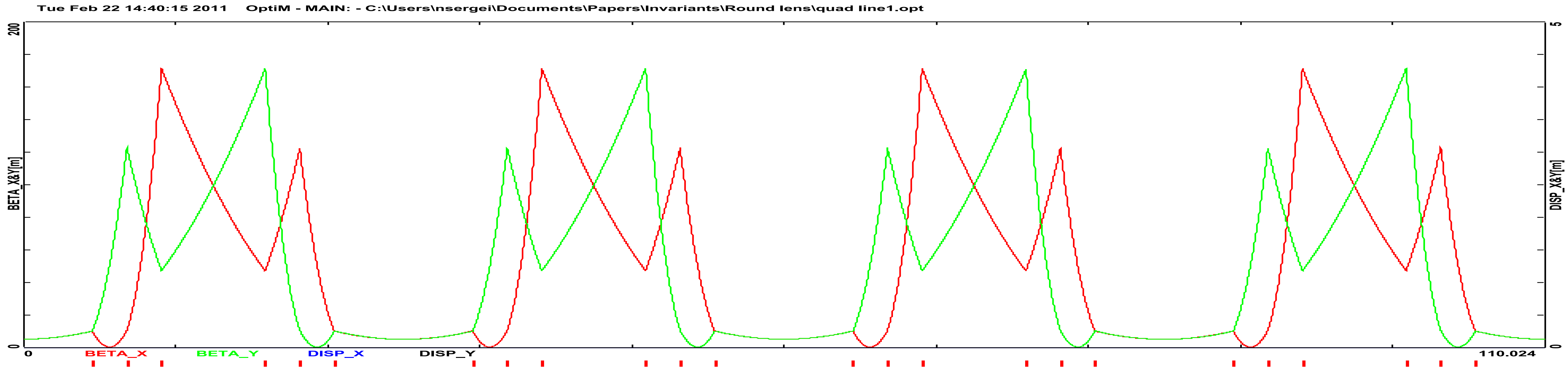
Nonlinear Integrable Optics with Laplacian Potential

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



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

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



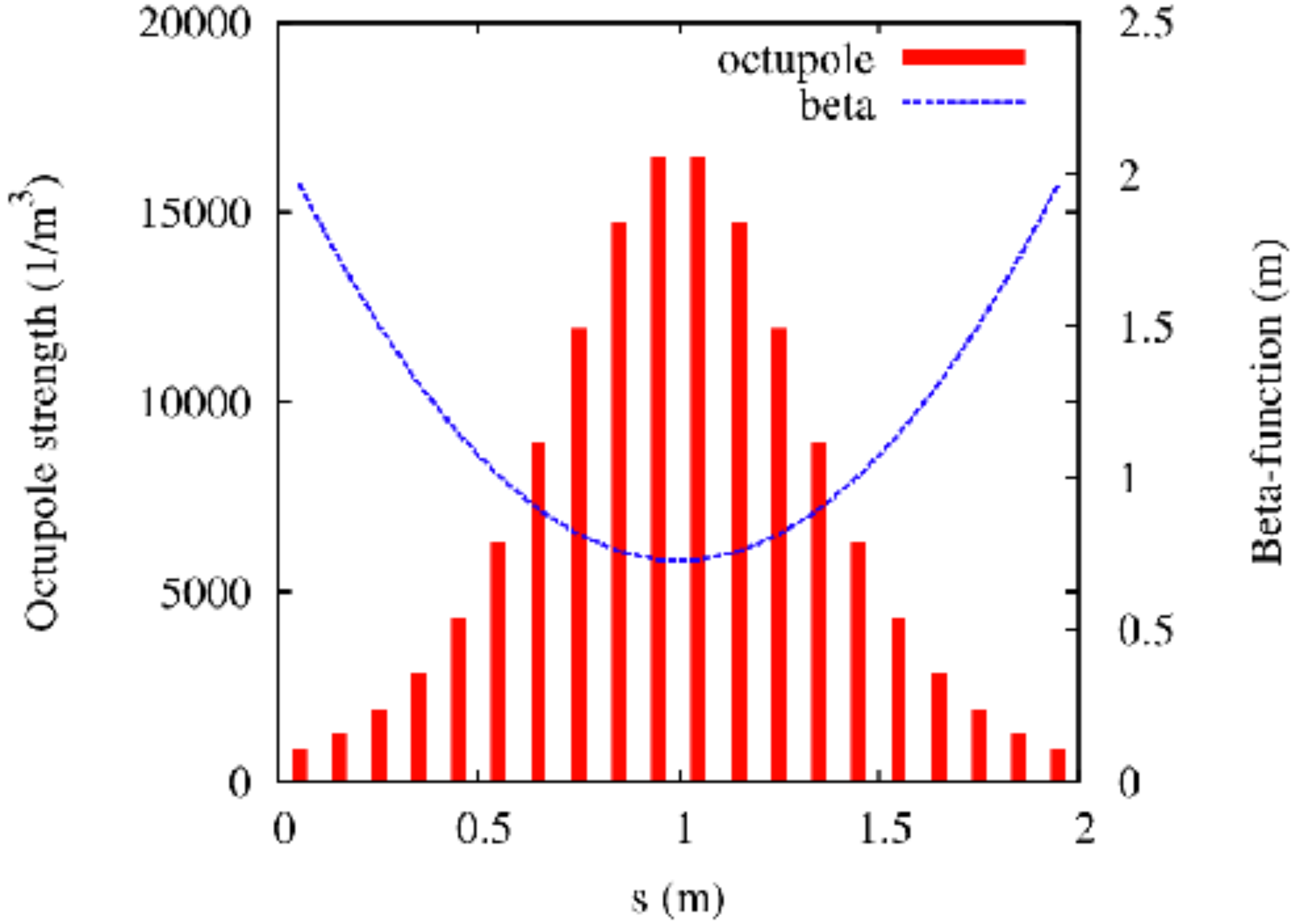
slide courtesy A. Valashev, FNAL

Quasi-Integrable System

- Build *V* with Octupoles

$$V(x,y,s) = \frac{\kappa}{\beta(s)^3}\left(\frac{x^4}{4} + \frac{y^4}{4} - \frac{3x^2y^2}{2}\right)$$

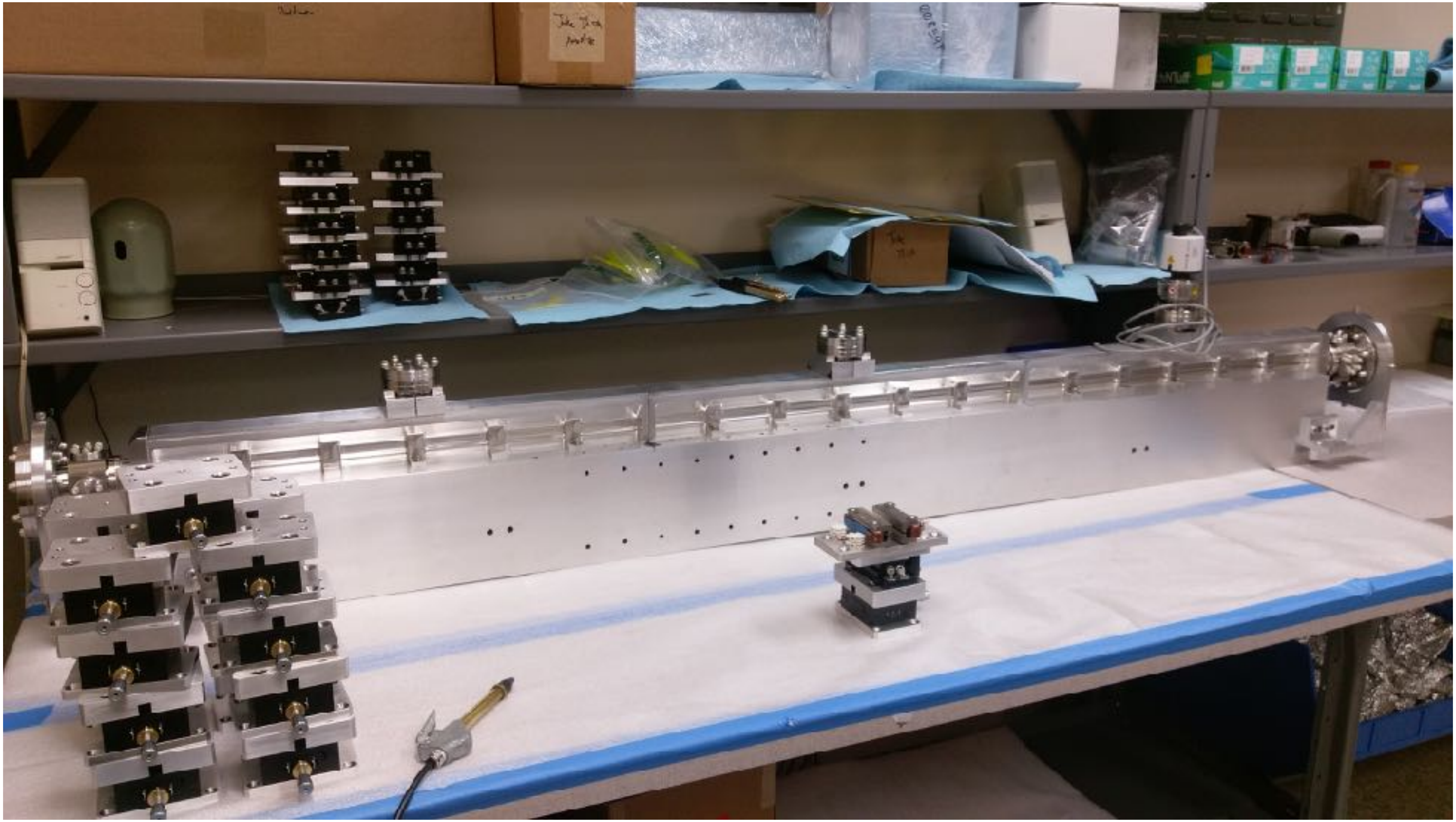
$$U = \kappa\left(\frac{x_N^4}{4} + \frac{y_N^4}{4} - \frac{3y_N^2 x_N^2}{2}\right)$$



$$H = \frac{1}{2}(p_x^2 + p_y^2) + \frac{1}{2}(x^2 + y^2) + \frac{k}{4}\left(x^4 + y^4 - 6x^2y^2\right)$$

- Only one integral of motion – *H*
- Tune spread limited to ~12% of Q_0

Nonlinear Magnet at RadiaBeam (Nov. 2016)



JLEIC and eRHIC Topics for Discussion

- some highlights that struck me, take from slides of Fulvia, Todd of R&D highlight where FNAL can contribute

Identifier	Title	Our Priority	Panel Priority
INJ2	Space charge in ion complex	First	Medium
INJ3	Ion beam formation	First	Medium
BDD3	Nonlinear beam dynamics	Second	Medium
BDD4	Instabilities and feedback systems	Second	Medium
IRS2	Ion and electron ring background and vacuum	Second	Medium
IRS1	IR design and detector integration	Third	High
IRS3	Collimation and machine protection	Third	Low

- plus beam cooling studies

Conclusion

- Fermilab has interest in collaborating with JLEIC / eRHIC

- How to best engage?

- Suggestions