NDCX-II Project

Joe Kwan
Project Manager

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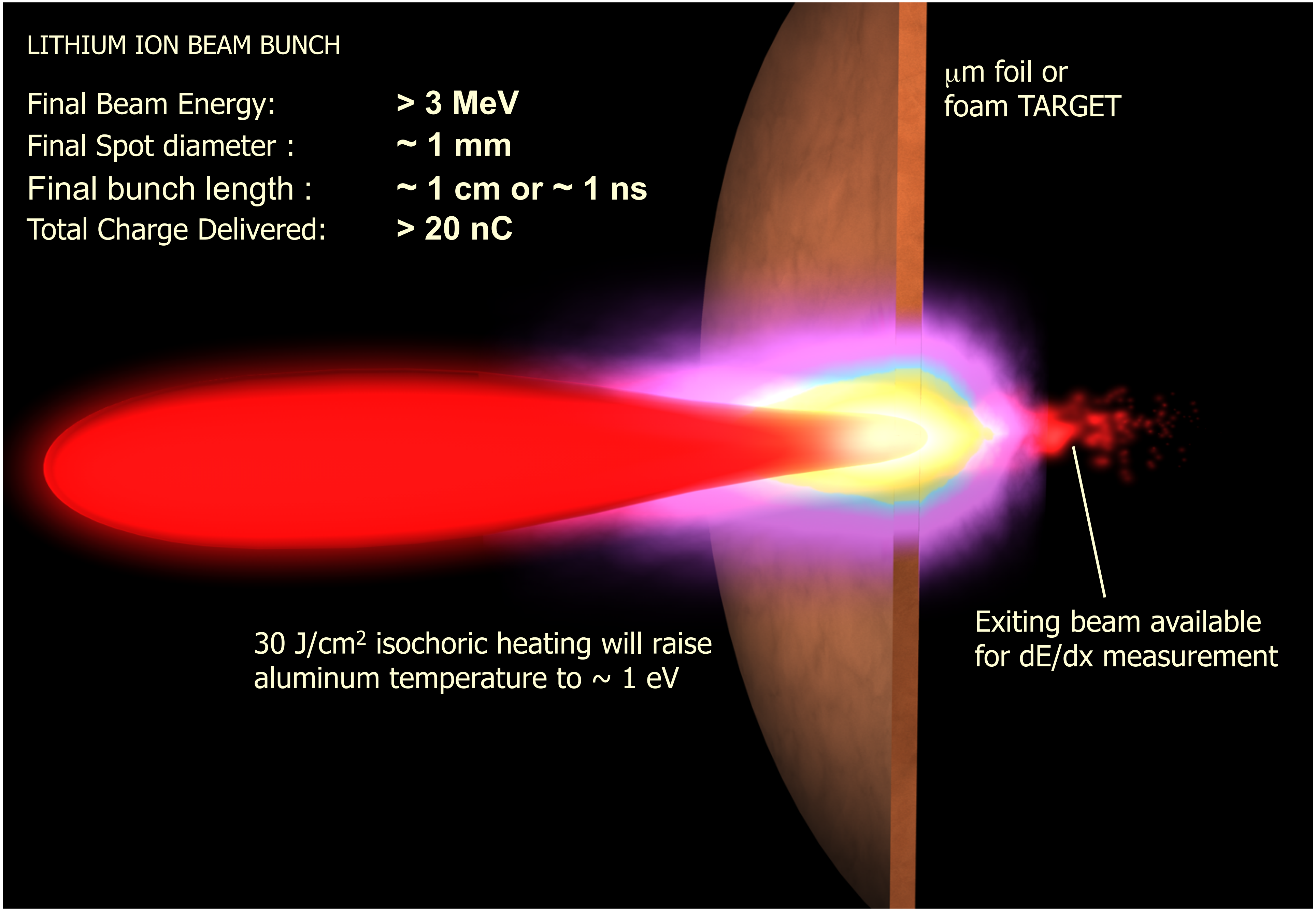
Heavy Ion Fusion and
High Energy Density Physics

Outline

- Scientific Motivation for NDCX-II
- NDCX-II Physics Design
- Accelerator System:
  —Physics
  —Mechanical
  —Electrical
- Project Management
- Summary

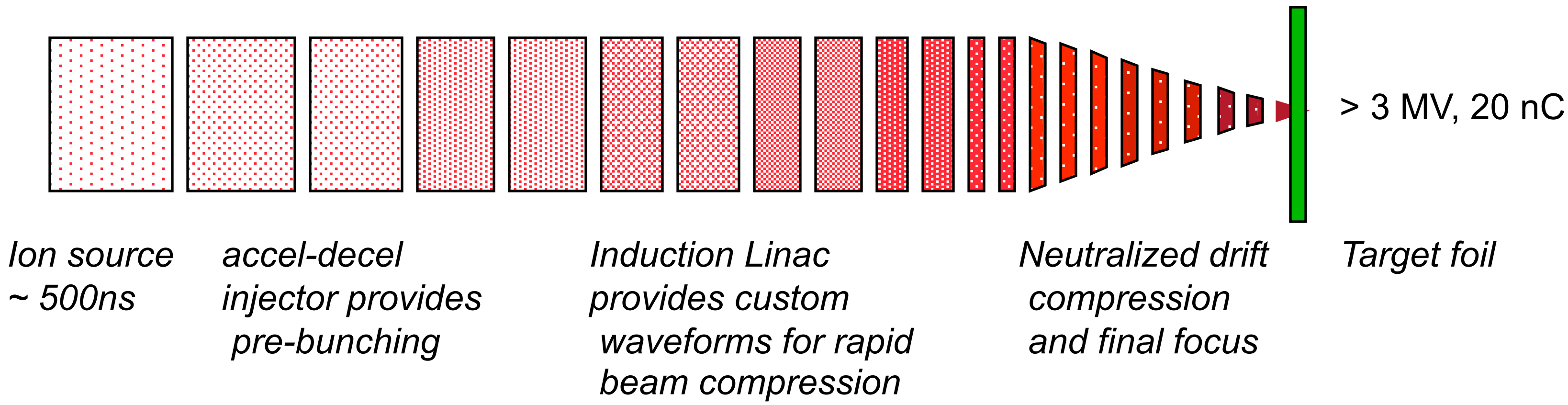
NDCX-II is ideally suited for heating foils to WDM regime



Technical Approaches

- Use an induction accelerator to compress beam pulse quickly down to ~ 1 ns
- Neutralized drift compression and final focus of an intense beam to a small spot
- Reuse the ATA induction cells and utilize an existing building to save cost and construction time
- Design a flexible machine to enable future HIF driver development
- Use the lighter Li ions to optimize the performance of NDCX-II (as limited by cost and schedule)
- Consider solenoids, electric quads and magnetic quads beam focusing and chose the one that is most effective

NDCX-II generates short pulses needed for isochoric heating

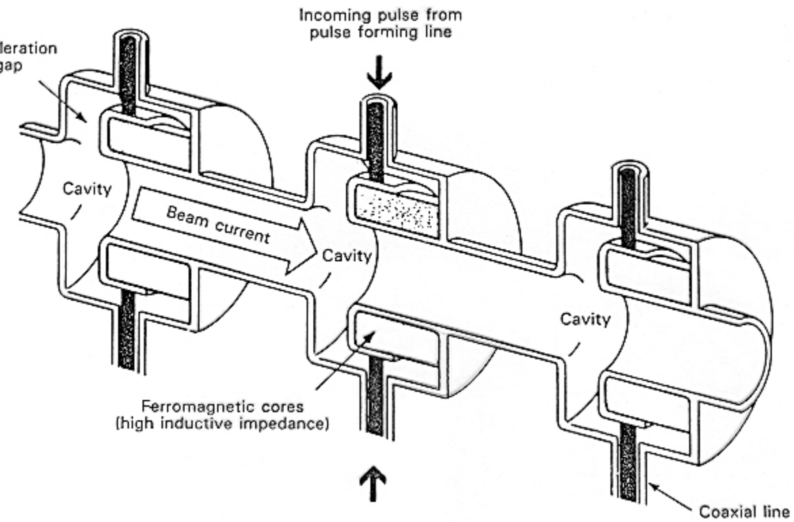


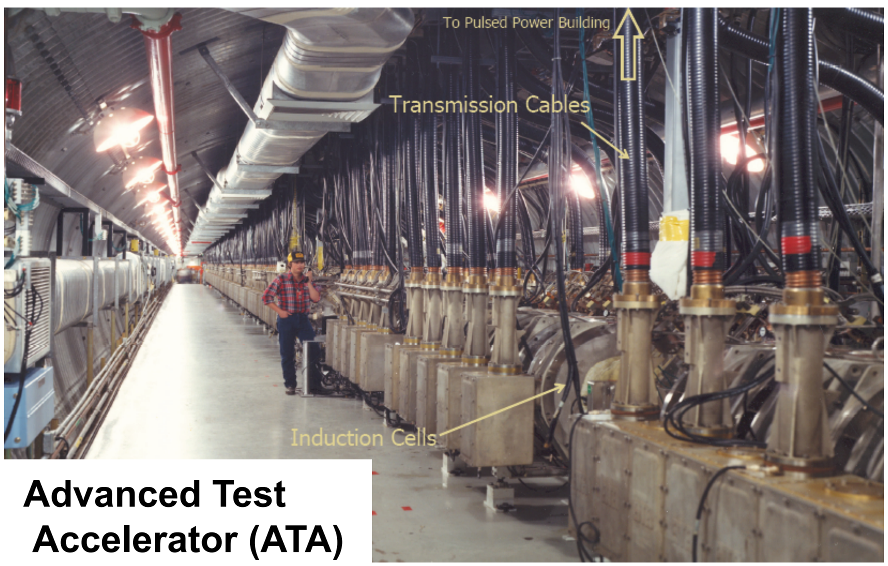
Key design parameters:

- **~100 mA Li^+ Ion source at > 1 mA/cm^2.**
- **Induction cell voltage average gradient 0.25 MV/m (peak 0.75 MV/m).**
- **Build new 2T solenoids for beam transport.**
- **Use existing 8T solenoid for final focus.**

The induction linac is ideal for compressing high-current short-pulse beams

- An induction linac works like a series of transformers using the beam as a "single-turn" secondary.
- Volt-seconds in the core material limits the pulse length.
- Applied voltage waveforms determine the acceleration schedule.





Advanced Test Accelerator (ATA)

DARHT-II

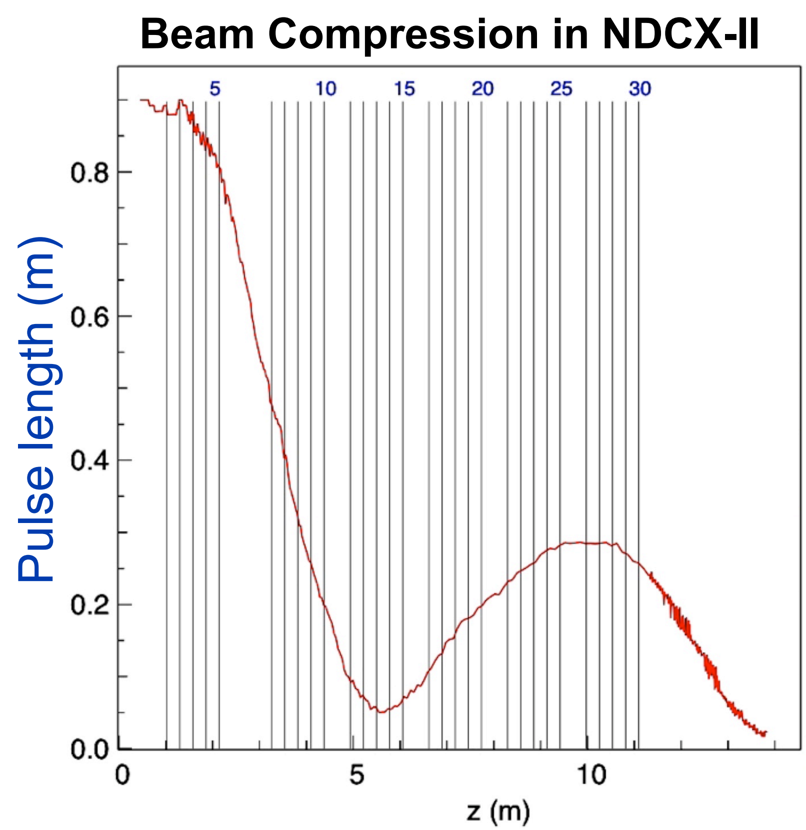
The NDCX-II baseline physics design effectively combines acceleration and compression

- Run 1-D Particle-in-cell (PIC) code with a few hundred particles for design synthesis:
  - Models gaps as extended fringing field.
  - Self-field model guided by results from Warp runs.
  - Can use realistic acceleration waveforms.
  - Also include centroid tracking for study of misalignment effects.
- Run comprehensive PIC code “Warp” for detailed design:
  - 3-D and axisymmetric (r,z) models.
  - Electrostatic space charge and accelerating gap fields included.
  - Time-dependent space-charge-limited emission.
  - Extensively benchmarked against experiments and analytic cases.

See A. Friedman’s paper in this conference

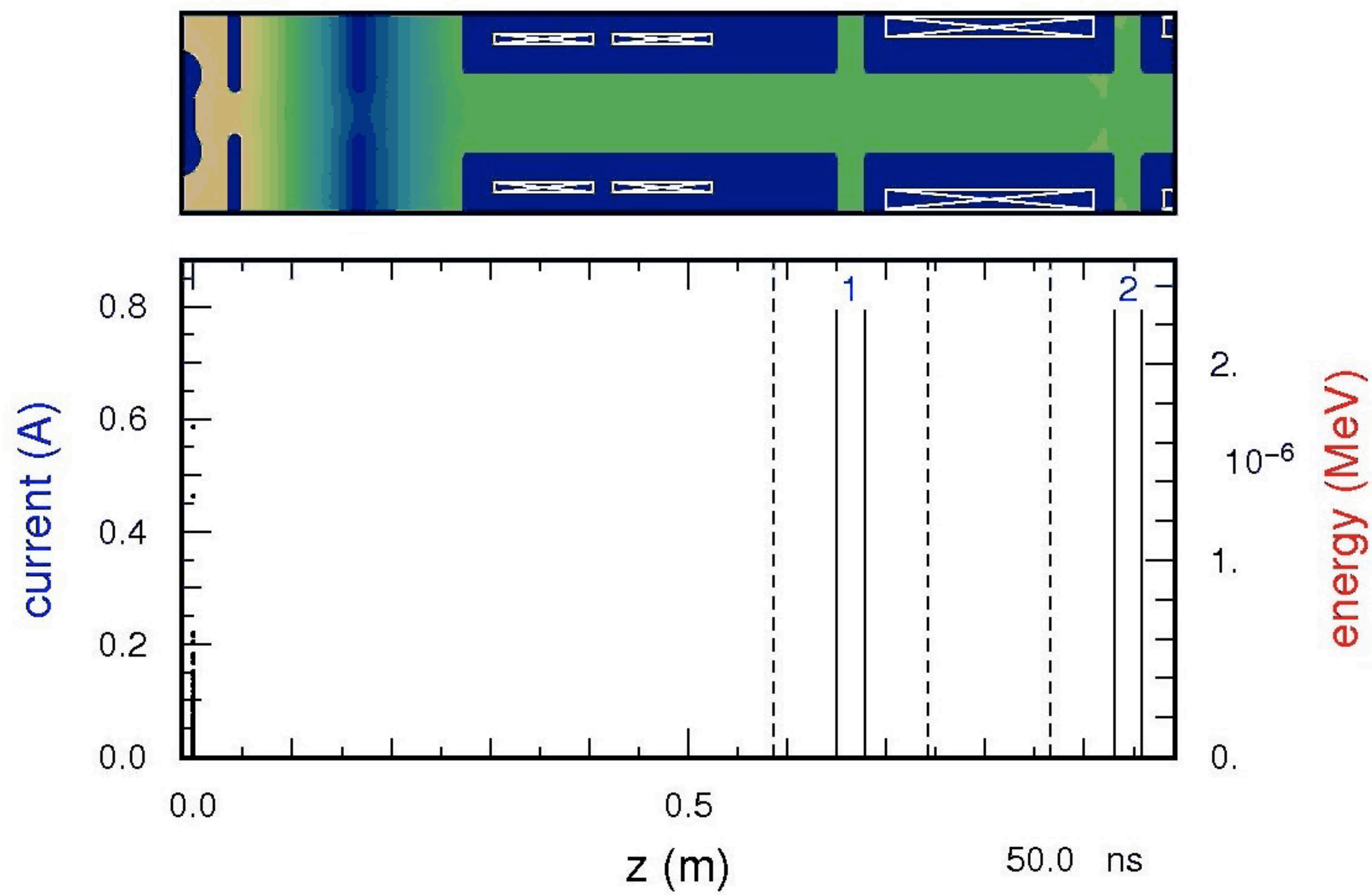
NDCX-II beam experiments are relevant to HIF drivers

- HIF driver-like compression of non-neutral and neutralized beams.
- Explore limits on velocity tilt.
- Employs space charge to remove velocity tilt.
- Longitudinal beam control.
- Chromatic aberration in final focus.
- Possible to add a quadrupole transport section at the end.
- Beam diagnostic development.

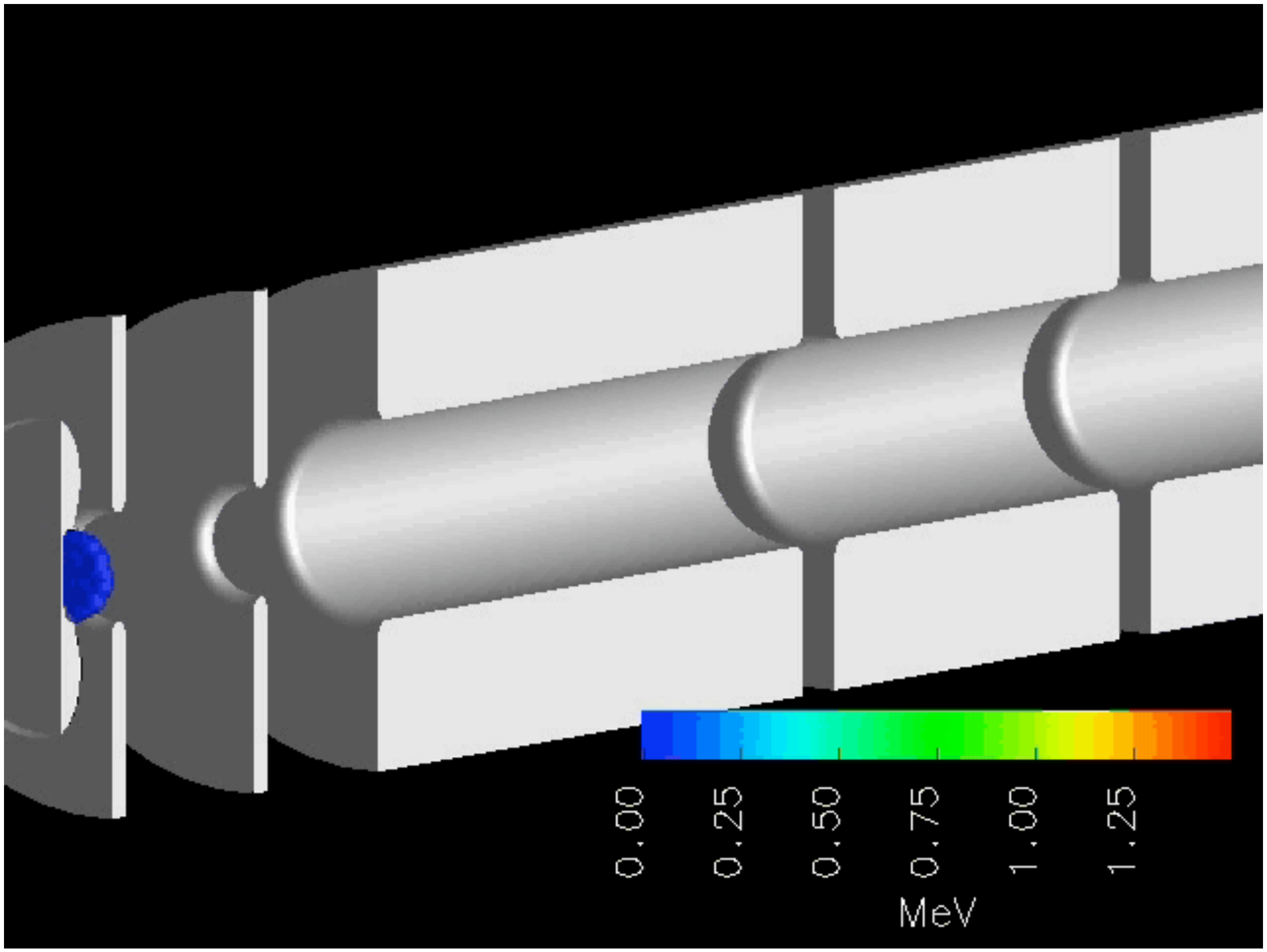


Center of mass z position

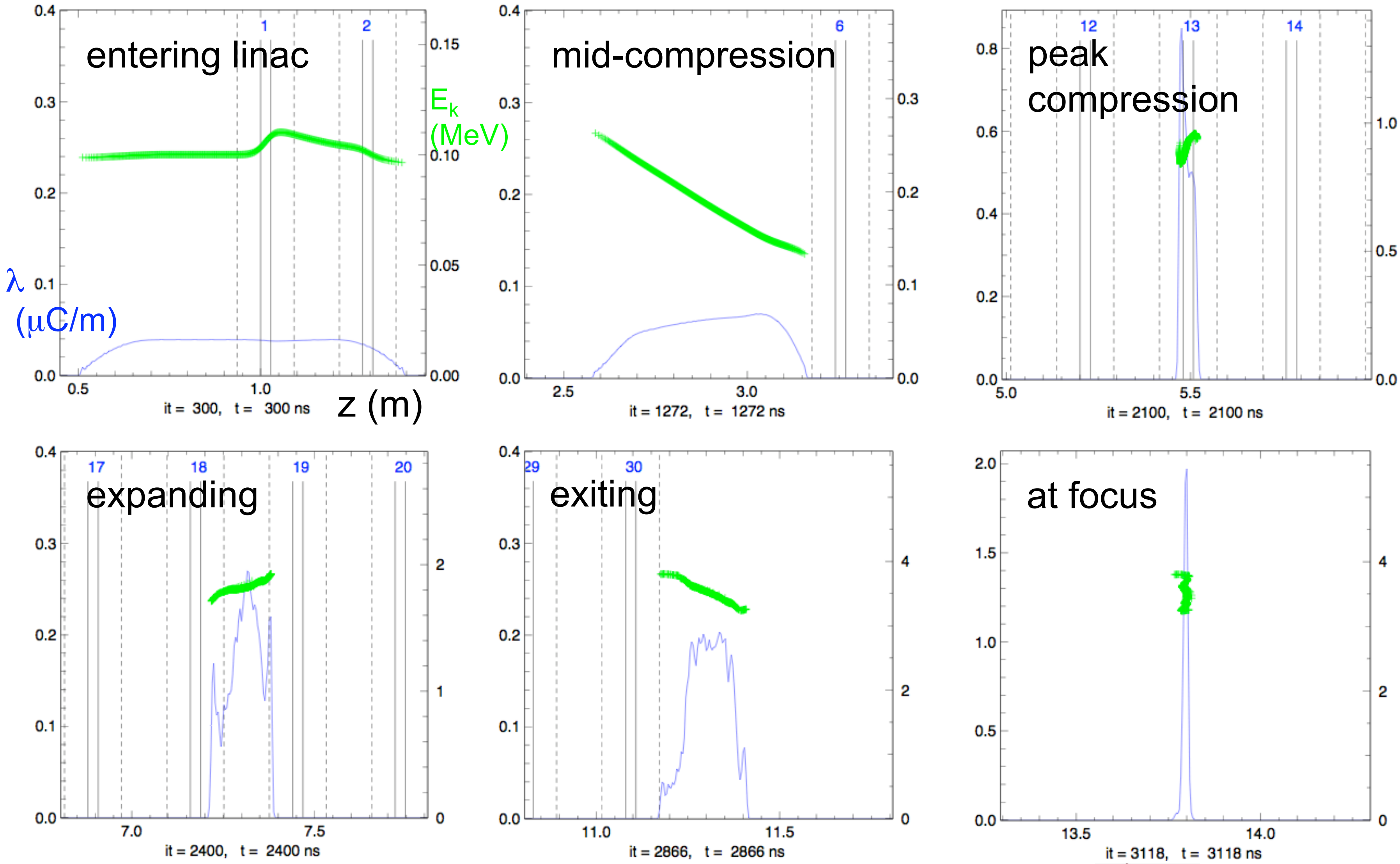
Use the Warp code to simulate the NDCX -II beam in (r,z)



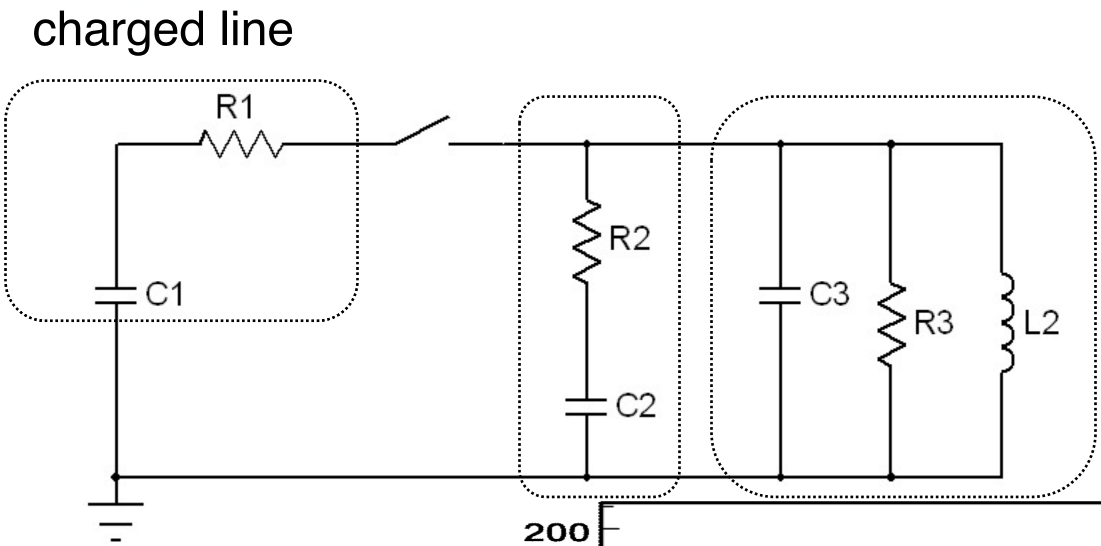
Warp-3D to Simulation for NDCX-II



Evolution of the phase space and the line charge density



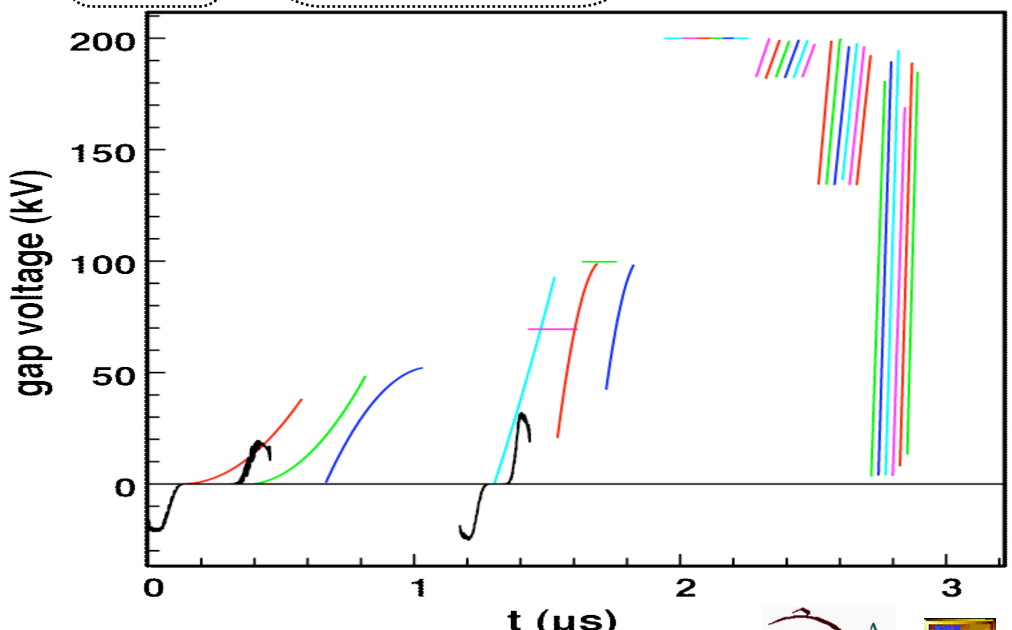
A simple passive circuit can generate a wide variety of waveforms



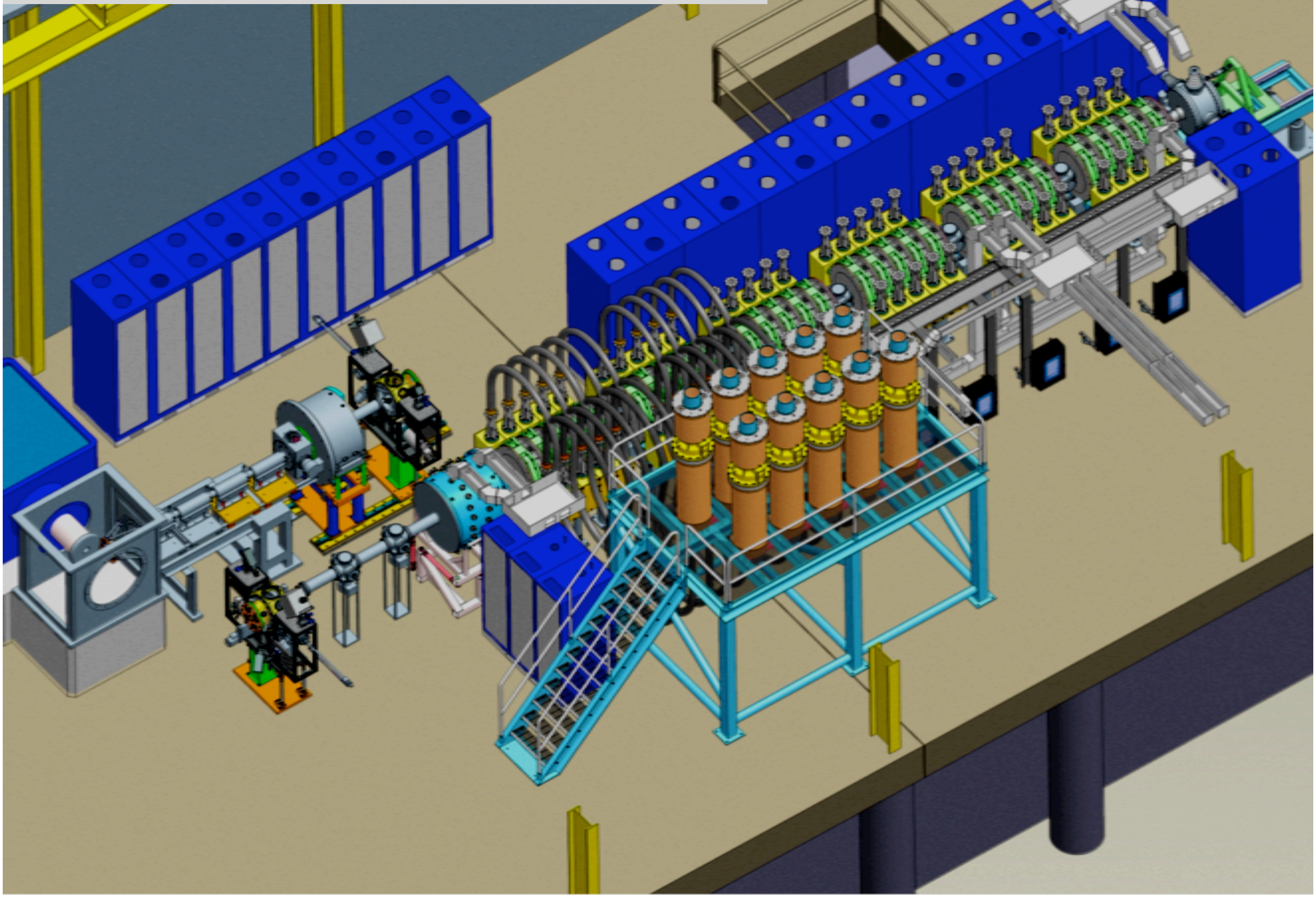
ATA "compensation box"

induction cell & accelerating gap impedance

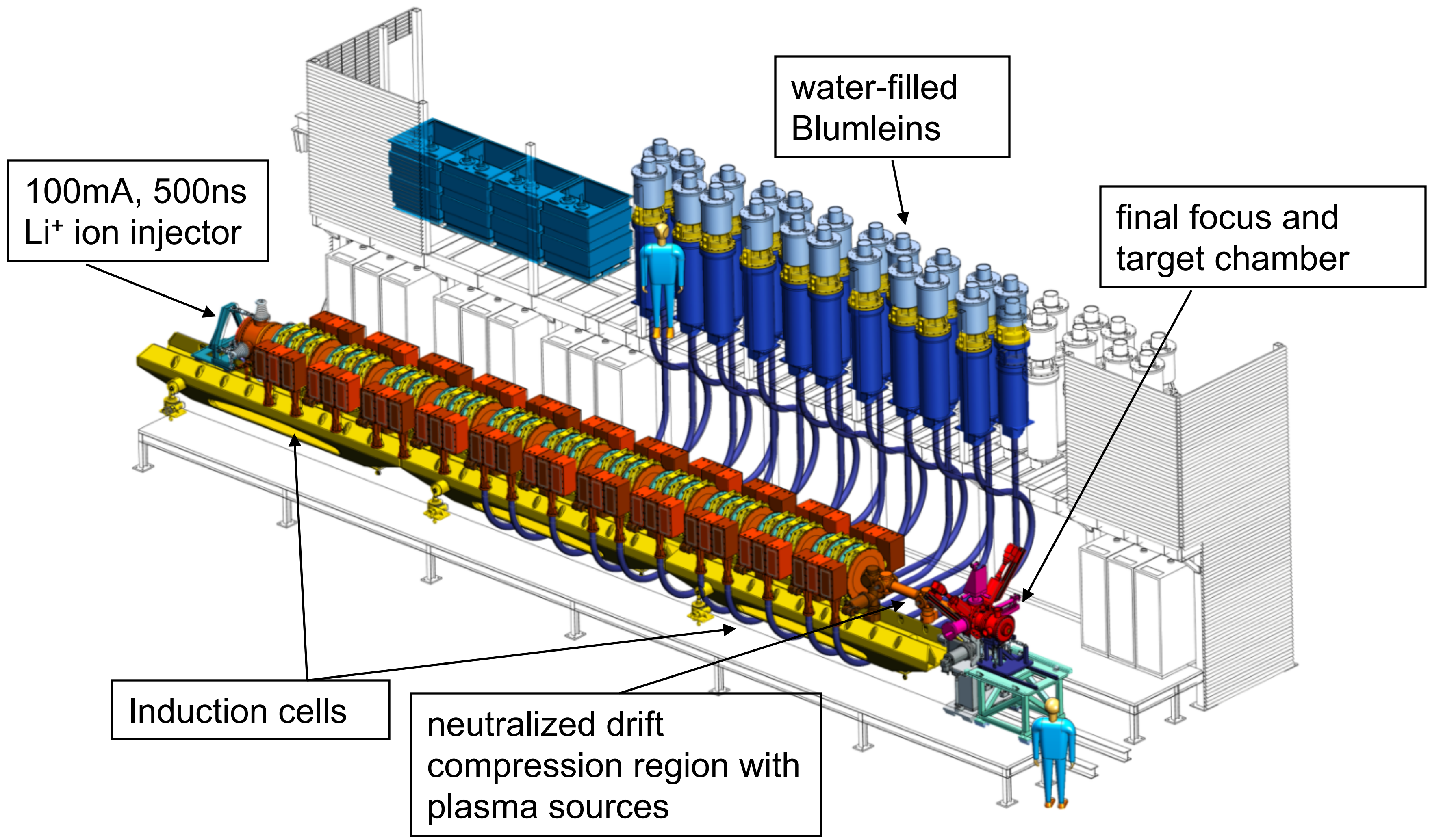
Waveforms needed for NDCX-II



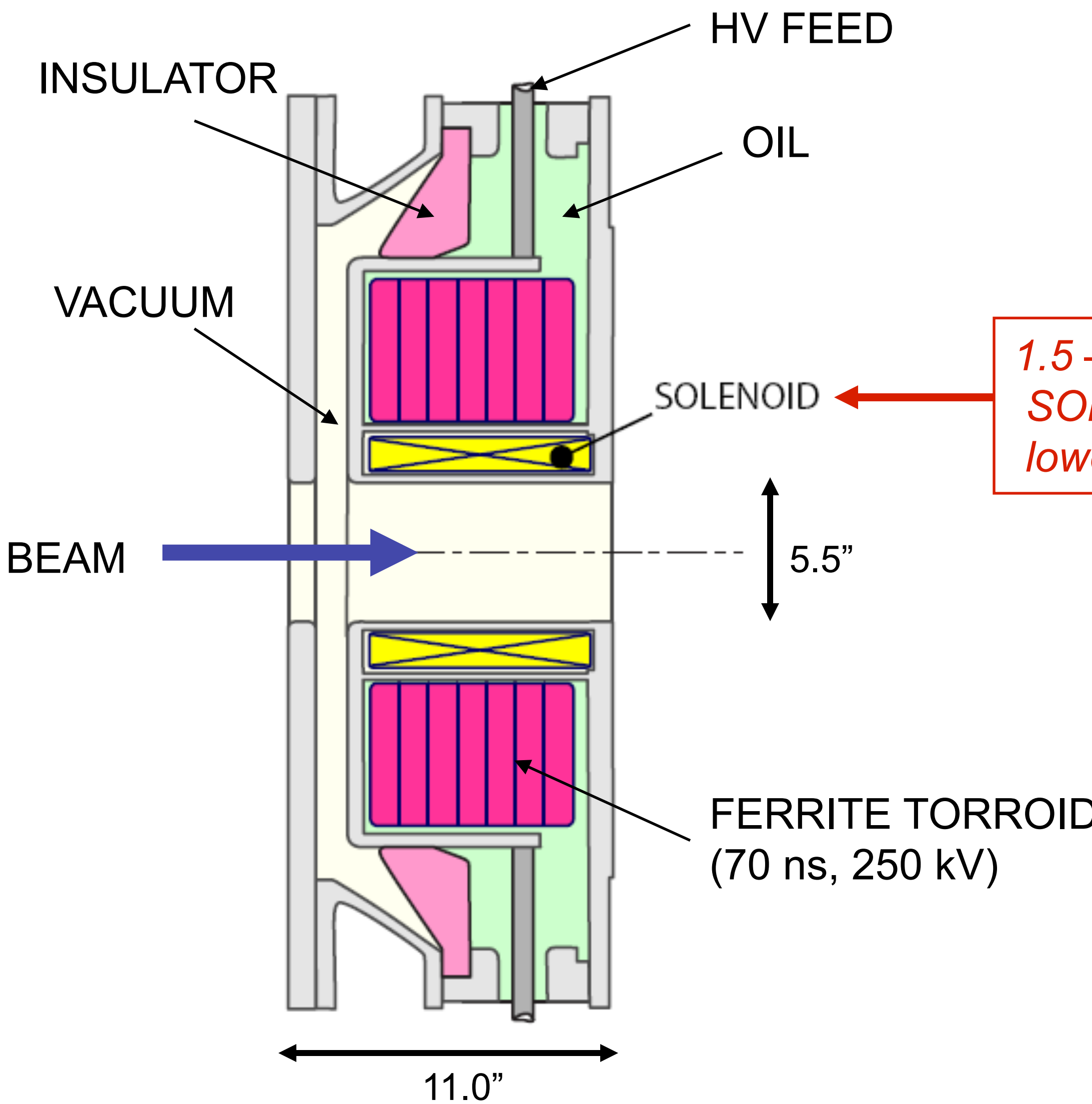
NDCX-II will coexist with NDCX-I in LBNL's Building 58 high bay



NDCX-II Conceptual Design Layout

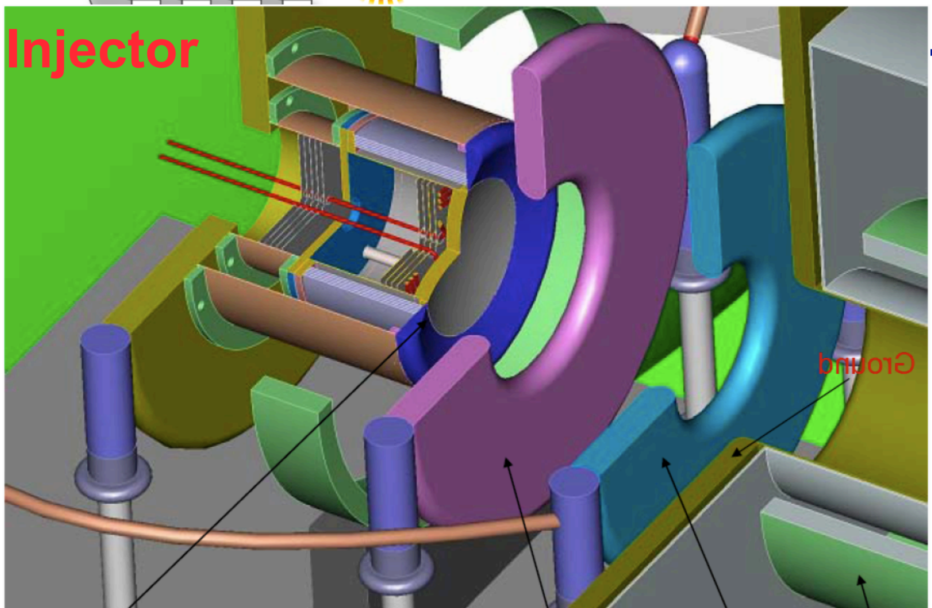


Schematic of the Induction Cell



1.5 – 3 T PULSED SOLENOID (ATA used a lower field dc one)

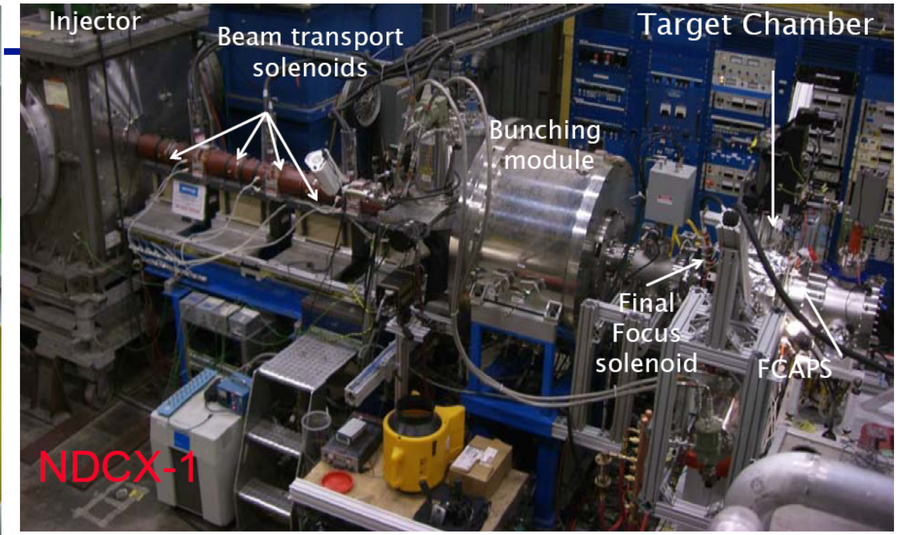
NDCX-II ion source and target are similar to NDCX-I

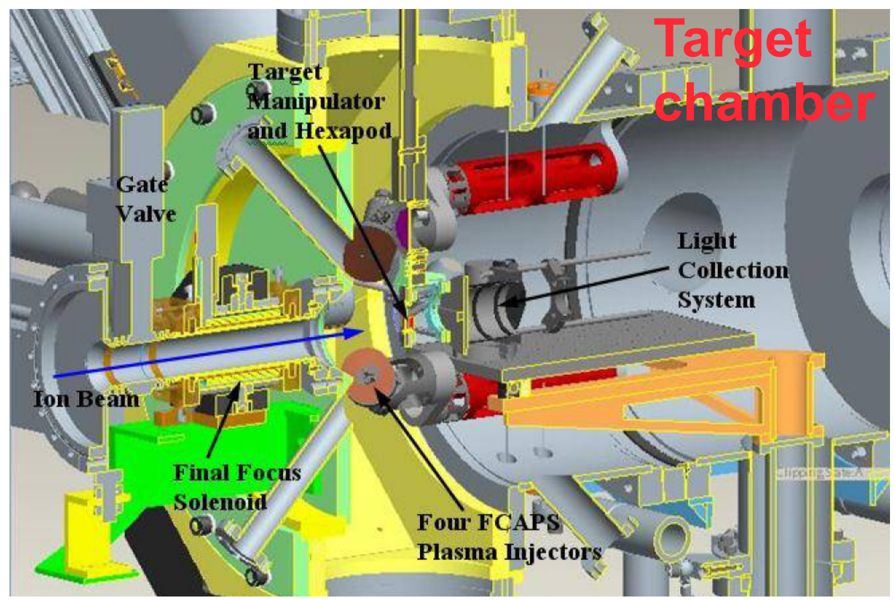


102 kV pulsed source

68 kV DC extraction electrode

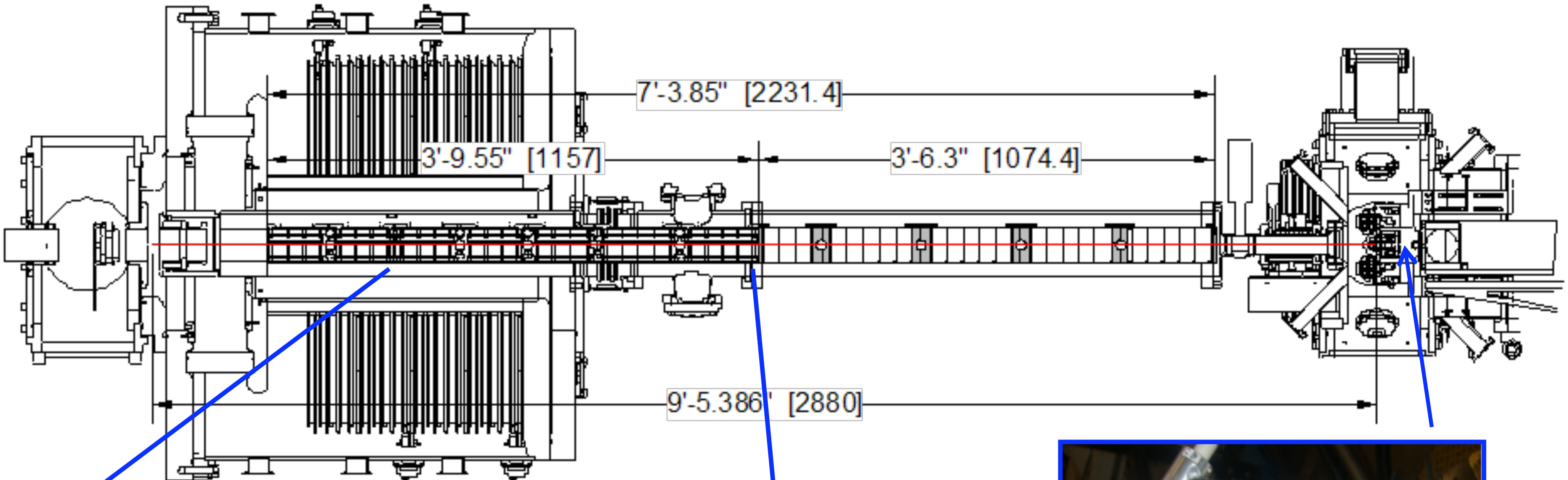
-170 kV DC accel electrode

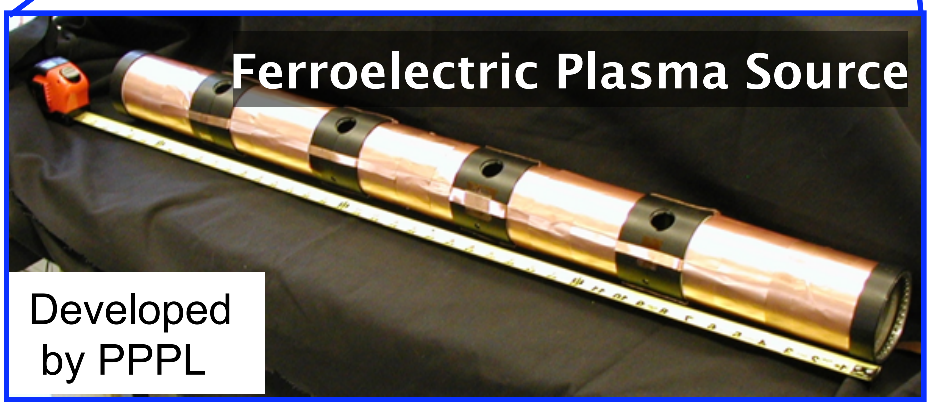




	NDCX-I	NDCX-II
Ion mass	K (A=39)	Li (A=7)
Ion energy	350 keV	> 3 MeV
Focal spot diameter	~ 2 mm	1 mm
Pulse duration	2 – 4 ns	1 ns
Peak current	~ 2 A	~ 30 A

NDCX-II Beam Neutralization is Based on NDCX-I Neutralization Experience





NDCX-II will modify and change configuration of ATA hardware

- Pulsed 3T solenoid instead of 5kG DC solenoid
  - Effect of the solenoid return flux on the available core volt-seconds is being studied on the test stand
- Mismatched load for Blumlein to generate compression waveforms
- Derating the Blumlein output voltage from 250kV to 200kV
  - Higher safety margin on insulators to protect from possible high amplitude reflections which are a result of impedance mismatching
  - Offsets the potential partial saturation of ferrite from solenoid return flux
- DC charging of the switch chassis instead of the CRC system
  - Simpler and adequate for the much lower repetition rate

NDCX-II will modify and change configuration of ATA hardware

- Separate trigger system for each Blumlein instead of distributed Blumlein pulse for triggering many Blumleins
  - Beam transit time is too long for cable delays
  - System jitter using a commercial 100kV trigger generator is being studied on the test stand
- One transmission line between Blumlein and cell
  - Obvious mismatch, but load is not matched either
  - Step-up for nominal flat pulse
  - Simpler installation
  - Feed cell from alternating sides to cancel minor dipole effect
- X and Y corrector for each solenoid
  - Effect of the saturating ferrite during the reset and main pulse on dipole strength is being studied on the test stand

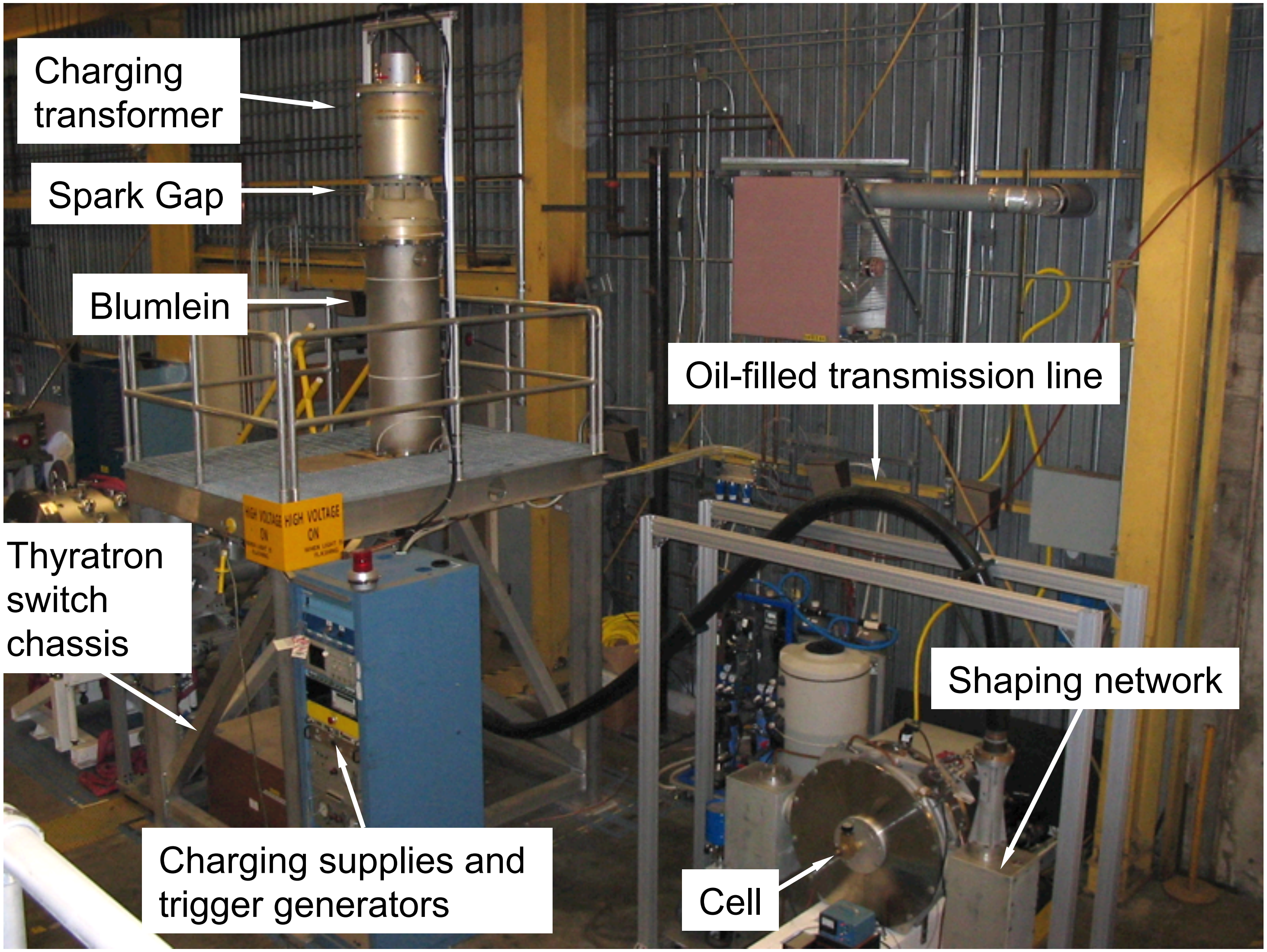
NDCX-II Electrical Systems

- Injector high voltage pulsers (2) and power supply (1) for beam extraction
- Pulsed power systems (34) to produce the acceleration and compression waveforms at the induction cells
  - 10 spark gap switched lumped element or transmission line pulsers
  - 24 ATA Blumleins with shaping elements at cells
- High current pulsers (40) for the transport solenoids in the induction cells and intercells
- Correction dipole pulsers (2 per solenoid)
- Plasma source pulsers
- Control system – 200 power supplies
- Timing and trigger system – 200 triggers
- Data acquisition system – 300 diagnostics
- Interlock system – 100 status monitors

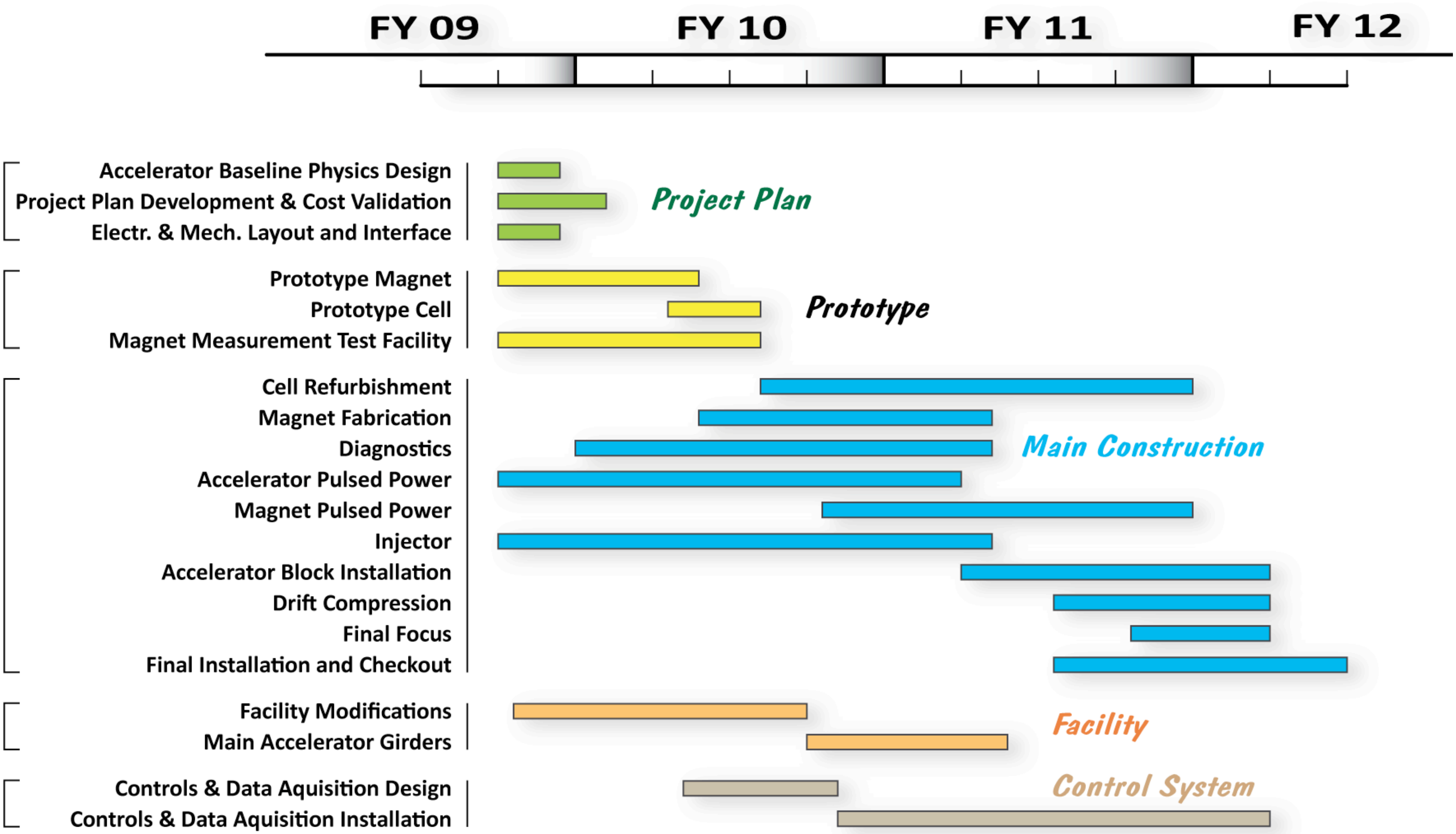
Technical Risk Areas were Identified

- Ion source—Li^+ current density of 1 mA/cm^2 has been demonstrated and has a matched beam solution.
- The injector still needs to be designed to handle the heat problem.
- Custom voltage waveforms for ion acceleration—sensitivity study and test data are underway.
- Solenoid magnet alignment—use state of the art mechanical alignment technique, and provide beam steering correction using dipole coils.
- Shielding of the ferrite core and beam diagnostics from the pulsed solenoid field.

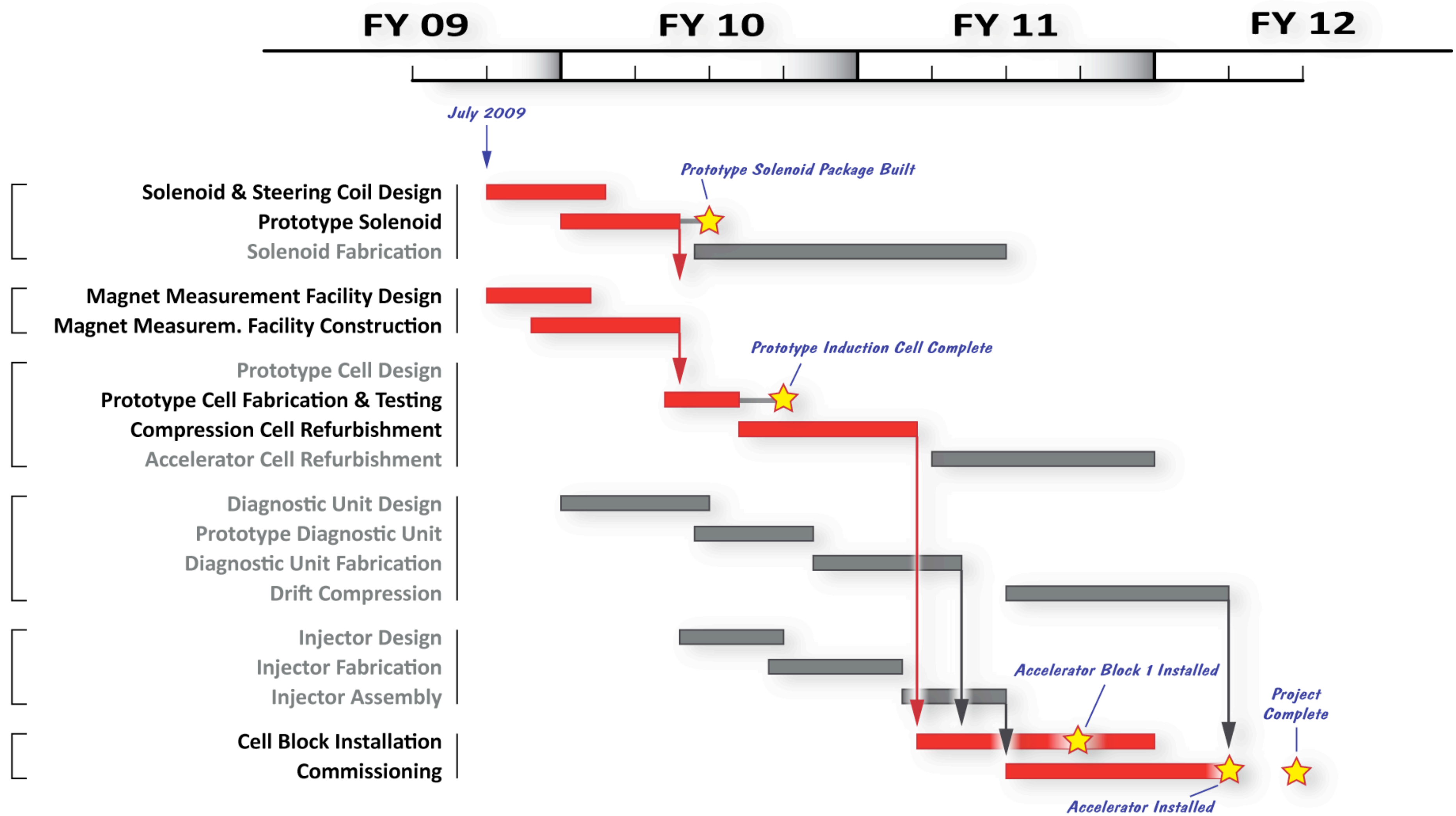
The NDCX-II Test Stand is operational and testing the performance of various hardware components



Overall Schedule



Critical Path Analysis



NDCX-II Project Team

DOE OFES
Dave Goodwin

NDCX-II Project
Project Manager: Joe Kwan
Project Engineering & Controls: Matthaeus Leitner

EH&S
Ken Barat

Project Controls
Denis Peterson
Budget Oversight
Glenna Rogers
Administrative Support
Lynn Heimbucher

Physics Support
Joe Kwan

Ion Source & Injector
Joe Kwan
Prabir Roy
Beam Acceleration / Ion Optics
Alex Friedman
Bill Sharp
Ron Cohen
Dave Grote
Jean-Luc Vay
Beam Neutralization
Erik Gilson
Target & Beam Diagnostics
Frank Bieniosek
Steve Lidia

Mechanical Engineering
Matthaeus Leitner

Ion Source & Injector
Jin-Young Jung
Wayne Greenway
Accelerator Cell & Solenoid
Jin-Young Jung
Diagnostics & Intercell Units
Jeff Takakuwa
Layout, Facility & Alignment
Matthaeus Leitner
Mike Dickinson
Magnet Measurement
Arnaud Madur
Diego Arbelaez
Installation & Refurbishment
Tom Lipton
Tak Katayanagi
Cory Lee
Ahmet Pekedis

Electrical Engineering
Will Waldron

Pulsed Power
Will Waldron
Electrical Coordinator
Bill Abrahams
Electrical Installation
New Hire #2
Craig Rogers
Controls
Company Sub-Contract

Conclusions

- NDCX-II will be a unique ion-driven user facility for warm dense matter and IFE target physics studies.
- The machine will also allow beam dynamic experiments to study high-current drivers.
- The baseline physics design makes optimal use of the ATA accelerator components through rapid beam compression and acceleration.
- The project is $11M. It runs from July 2009 to March 2012.
- NDCX-II is a prerequisite for the Integrated Beam–High Energy Density Physics Experiment in the 2007 DOE Office of Science Strategic Plan.
- With NIF starting operation, now is the time to ramp up effort toward inertial fusion & fusion/fission hybrids.