The NDCX-II Engineering Design

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for the NDCX-II Project Team

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The Heavy Ion Fusion Science Virtual National Laboratory

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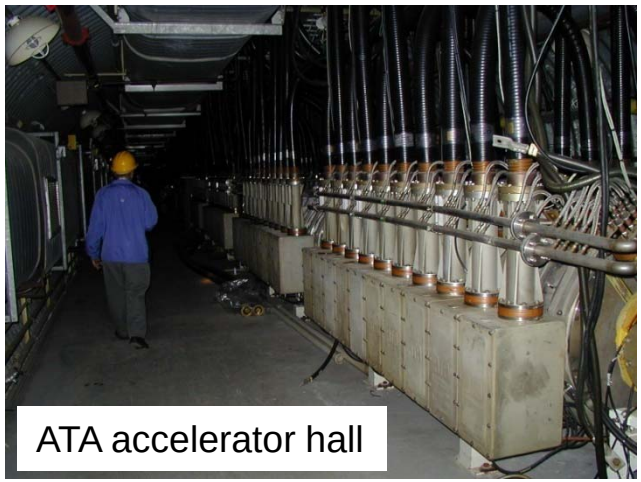
The Neutralized Drift Compression Experiment (NDCX-II) is a user facility which is currently being commissioned for ion-beam-driven high energy density physics and heavy ion fusion science research.

- The 11M$ construction project was started in July 2009 and completed in March 2012
- NDCX-II uses the same neutralized drift compression technique used on NDCX-I, but with a higher energy beam
- See John Barnard's talk on Wednesday for planned HEDP experiments

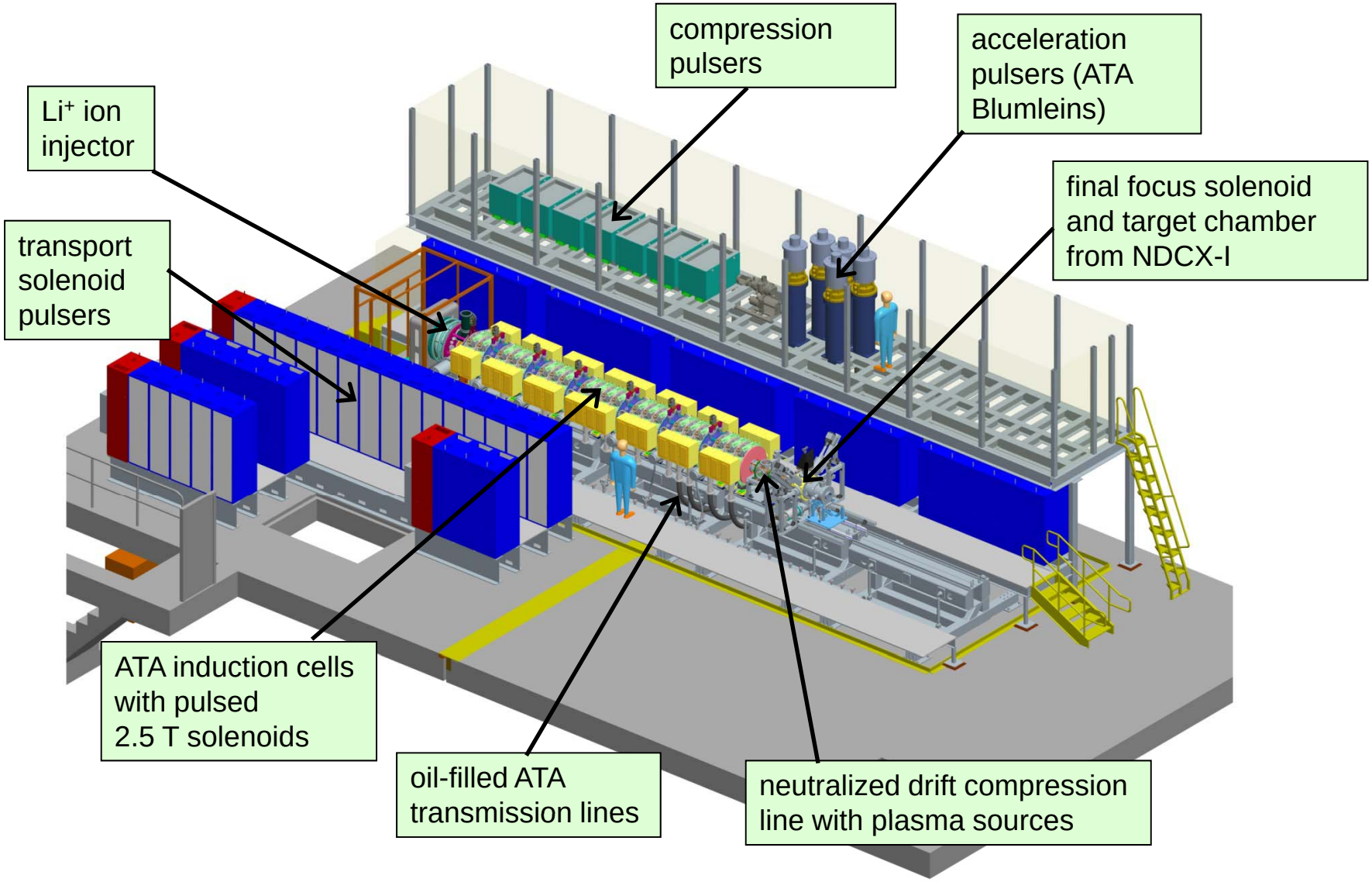
	NDCX-I (bunched beam)	NDCX-II (expected performance)
Ion species	K+ (A=39)	Li+ (A=7)
Charge	15 nC	50 nC total 25 nC within 2 x FWHM
Ion kinetic energy	0.3 MeV	1.2 MeV
Focal radius (50% of beam)	2 mm	0.6 mm
Duration (bi-parabolic measure = √2 FWHM)	2.8 ns	0.9 ns
Peak current	3 A	36 A
Peak fluence (time integrated)	0.03 J/cm2	13 J/cm2
Fluence w/in 0.1 mm diameter, w/in duration		8 J/cm2
Est. max. central pressure in Al target		0.07 Mbar
Est. max. central pressure in Au target		0.18 Mbar

- Induction cells and pulsed power hardware from the decommissioned Advanced Test Accelerator (ATA) at LLNL were refurbished and modified for use on NDCX-II

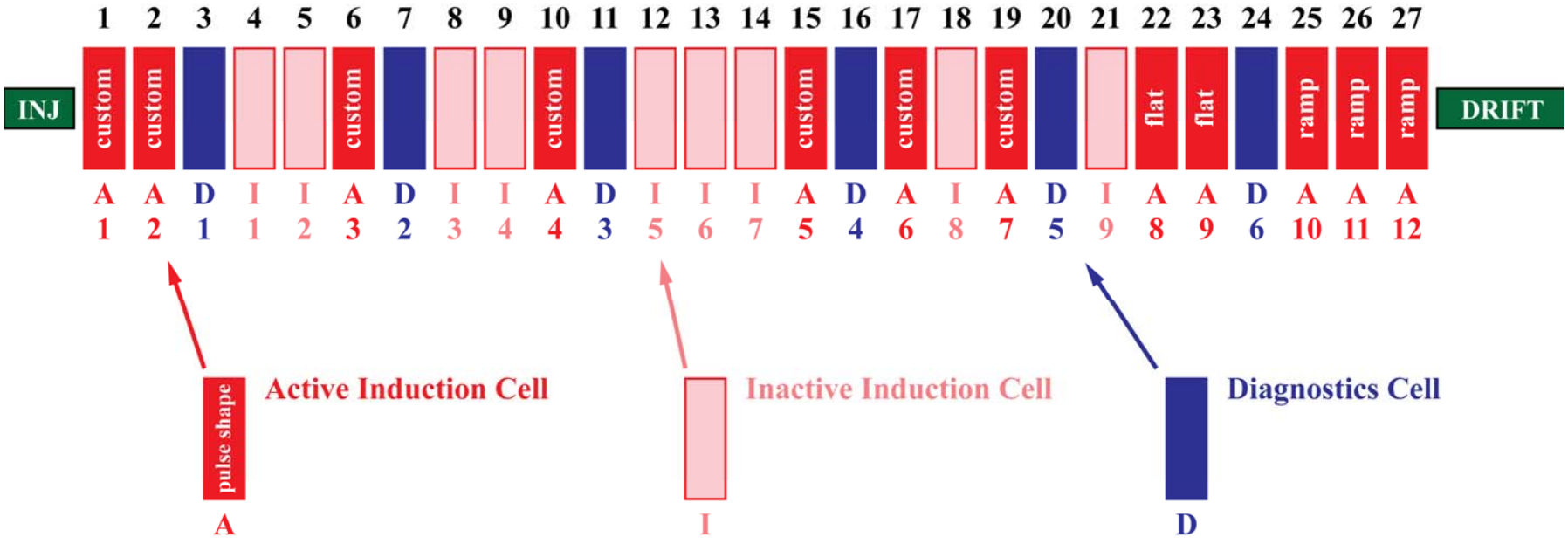

ATA accelerator hall

ATA power supply hall

NDCX-II Facility Layout in Building 58A at LBNL

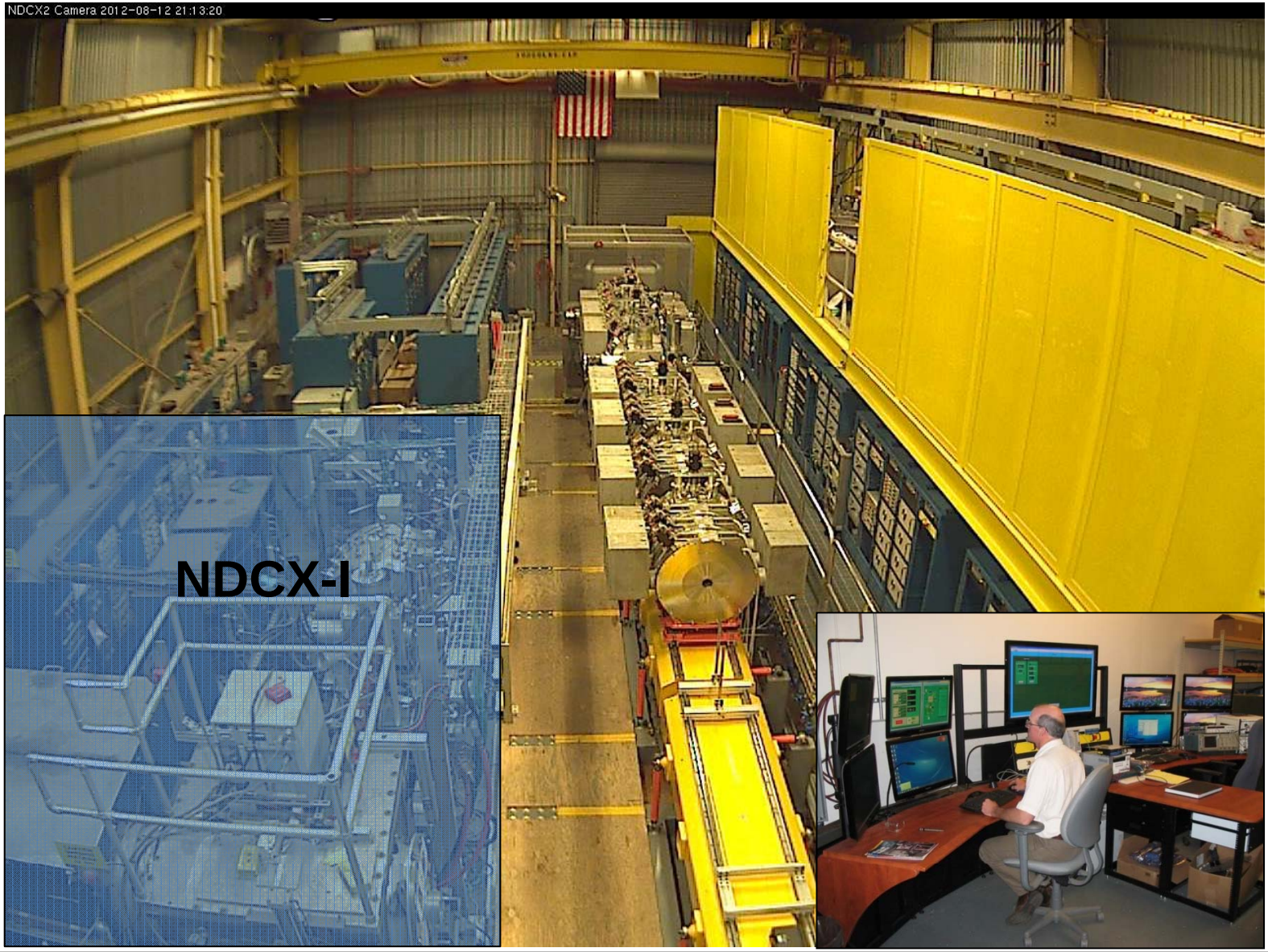


27 Cell Baseline Configuration (11m)

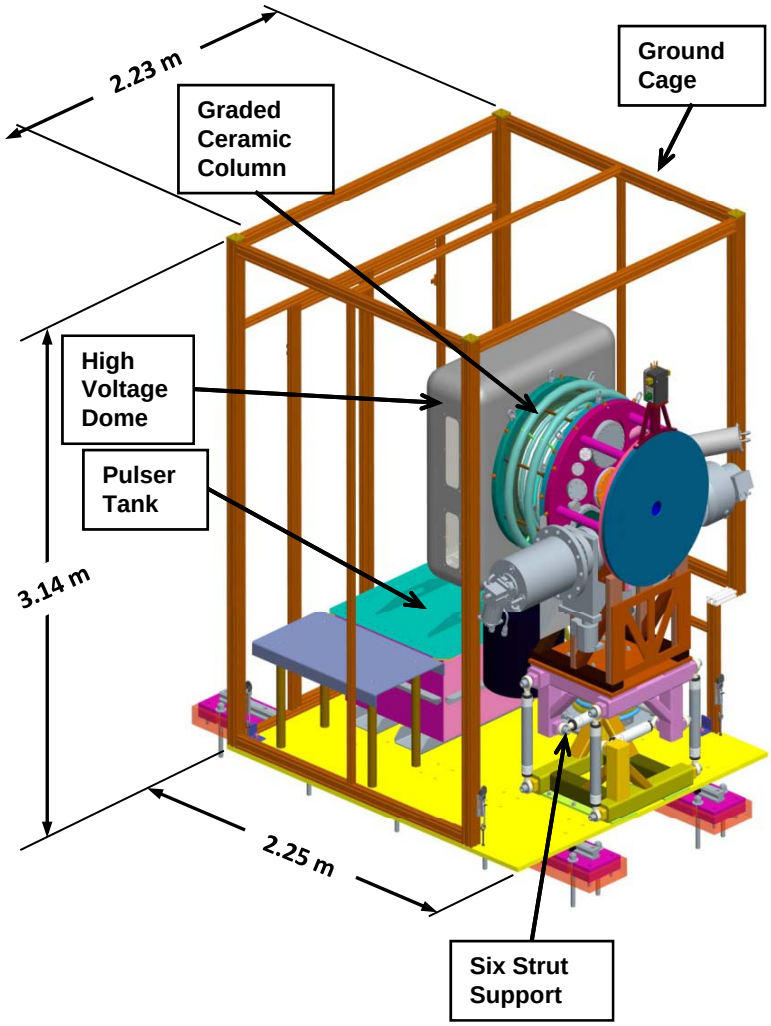


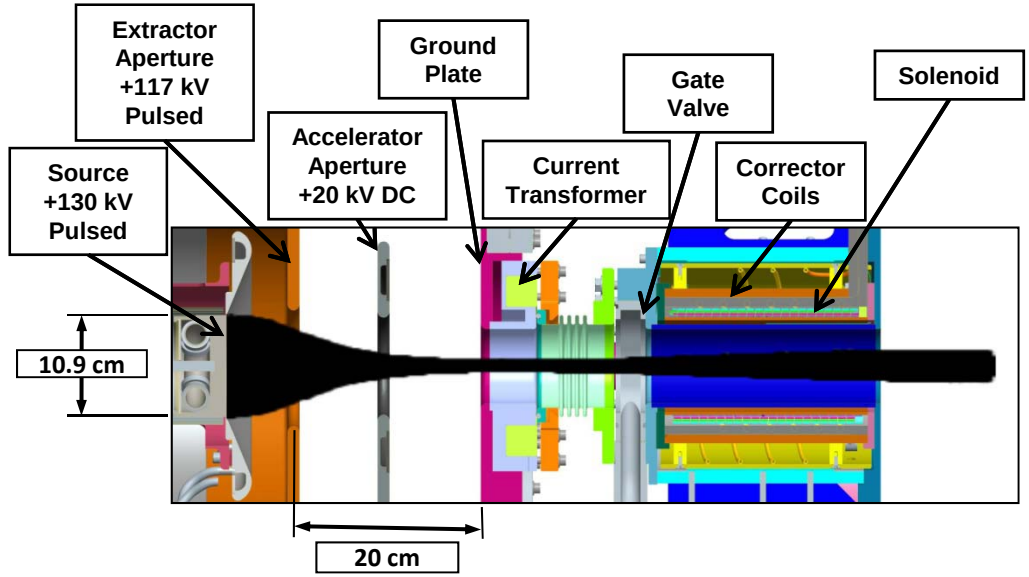
- 27 lattice periods after the injector
- Includes 12 active induction cells
- Reconfigurable
- Upgradable to higher energy with additional cells

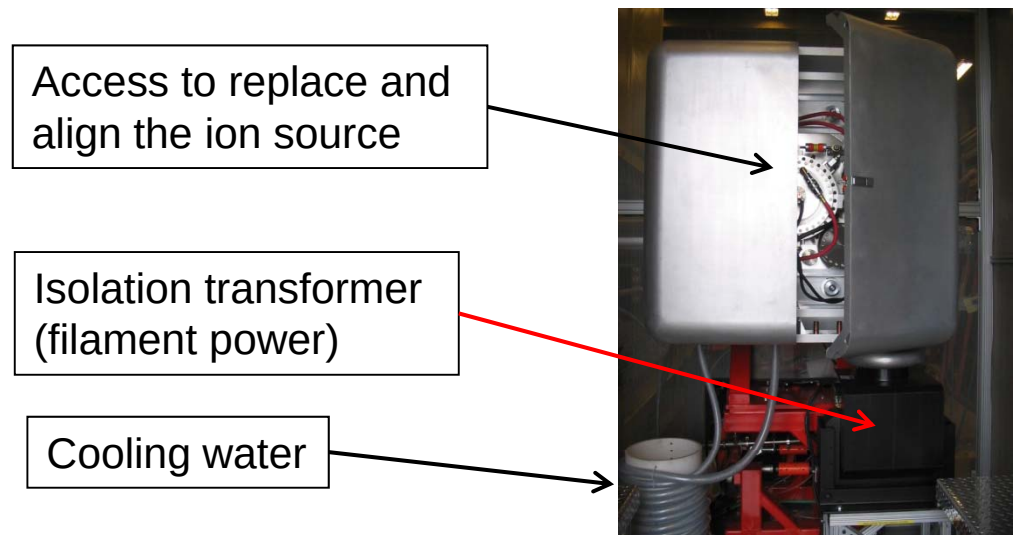
The construction phase is complete and NDCX-II is currently in the commissioning phase with the injector and 11 cells.



Lithium Ion Source and Injector

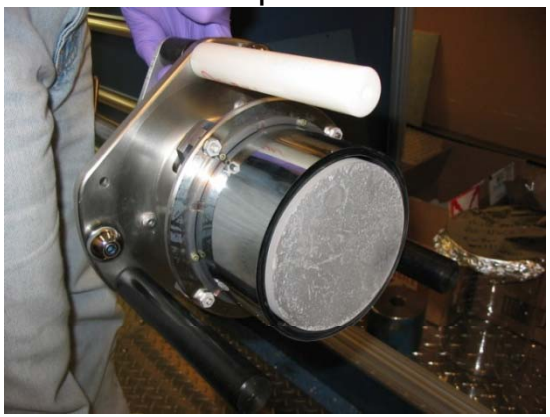




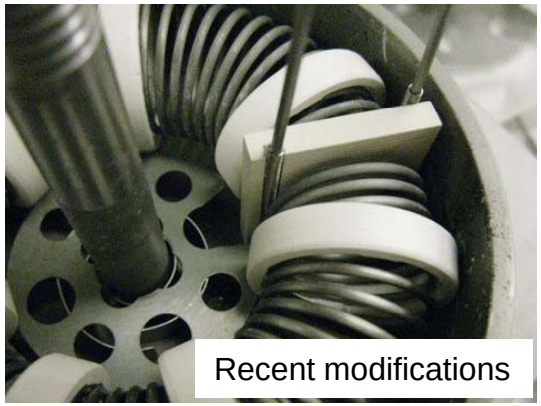


Lithium Alumino-Silicate Ion Source

- Fabricated at LBNL
- 1 mA/cm^2 current density
- A tungsten filament suspended by boron nitride insulators is required to operate at ~2000ºC to heat the source to ~1275ºC
- Filament and source lifetimes are areas of ongoing development to increase from 40-80 hours
- See talks by Prabir Roy and Steve Lidia on Wednesday for more lithium ion source development and performance details



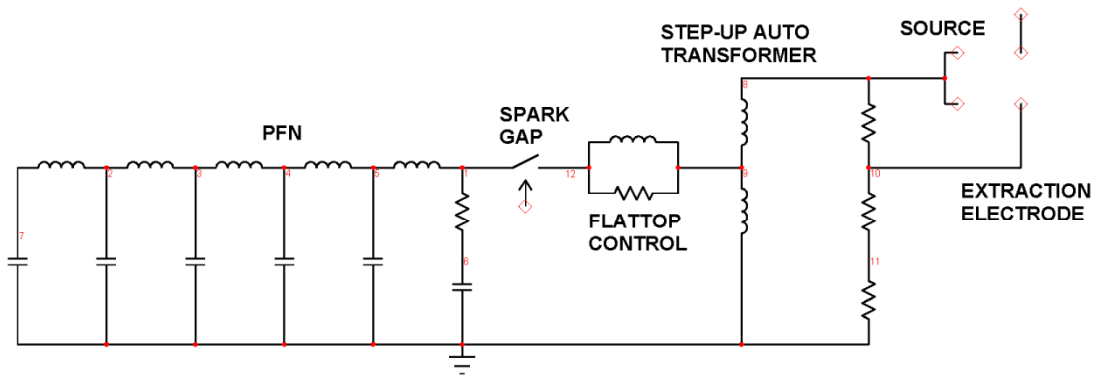
Original design after failure

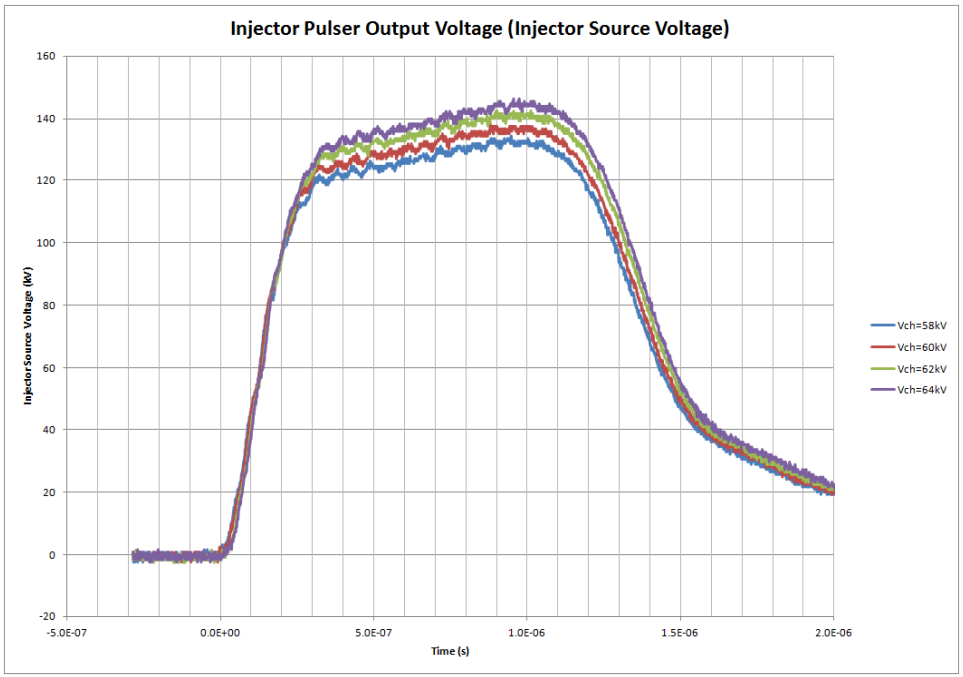


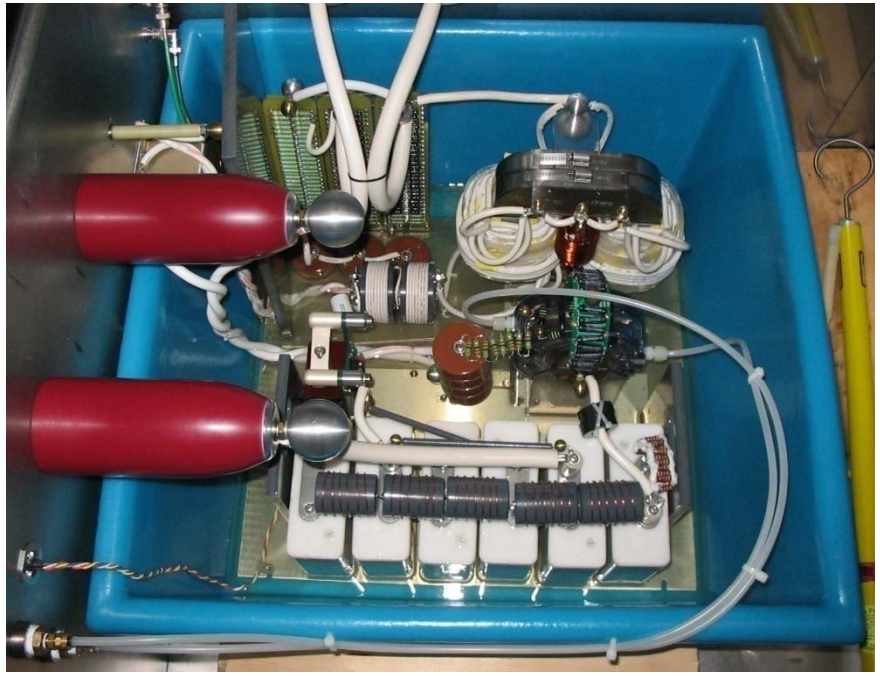
Recent modifications

The high voltage pulser for the injector is a spark gap switched pulse forming network with a tunable ramp or flat top.

- 130kV
- 1.25us FWHM
- 3 shots / min
- Oil insulation

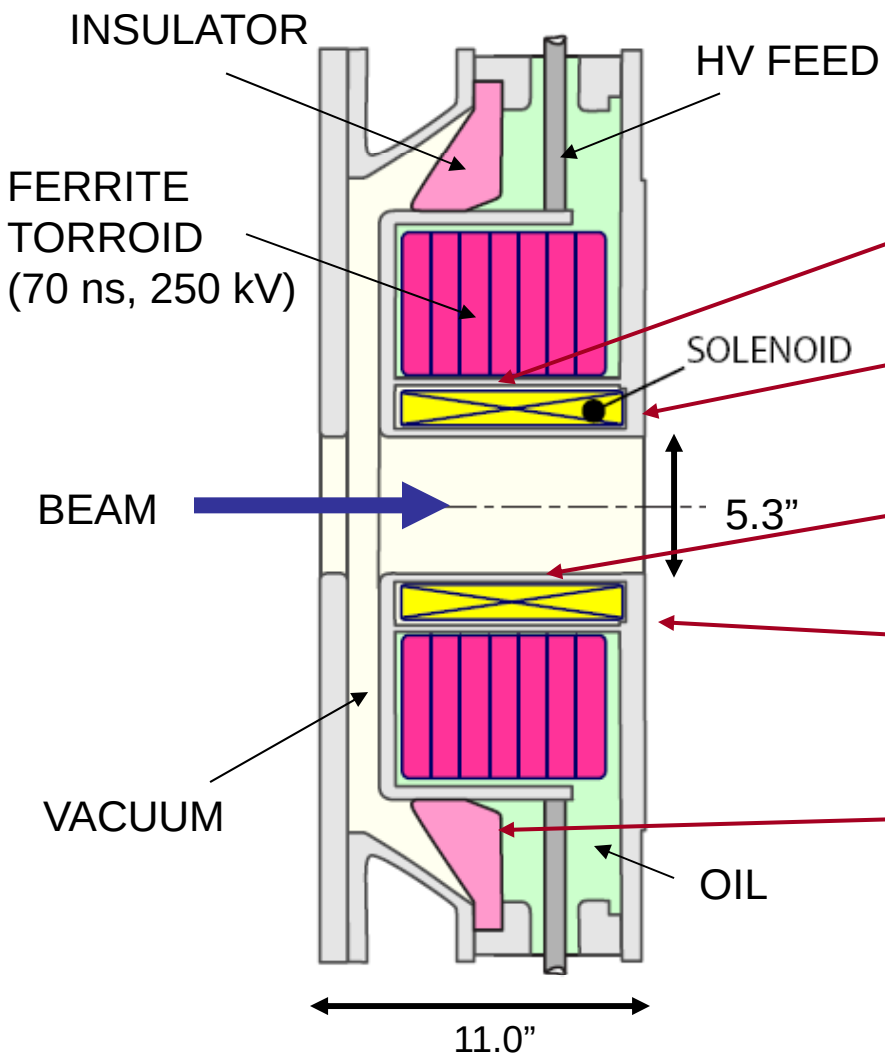






The accelerator cells are from ATA but have been modified with a high field pulsed solenoid.

Original ATA Design

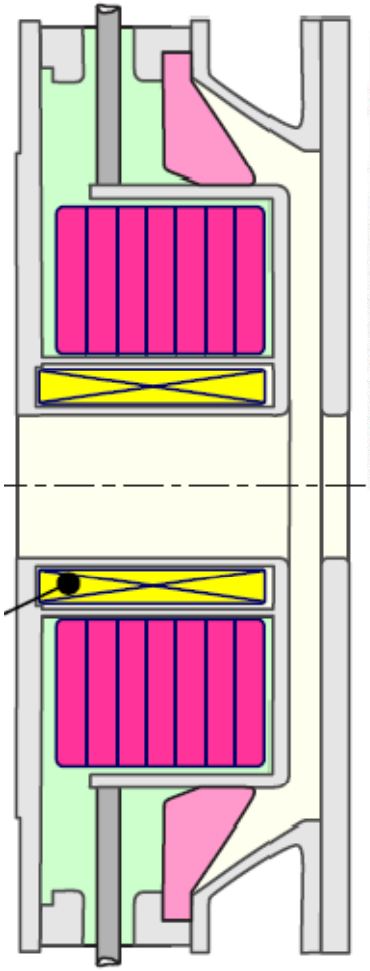


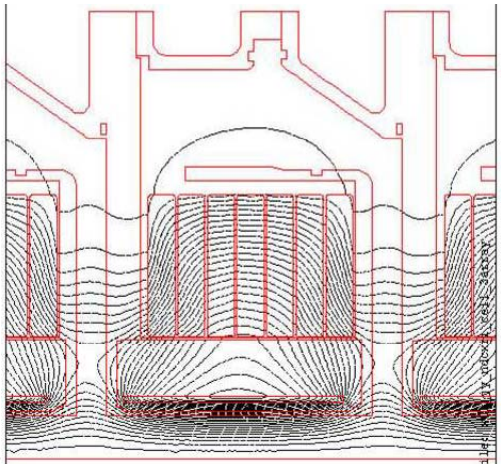
Modifications for NDCX-II:

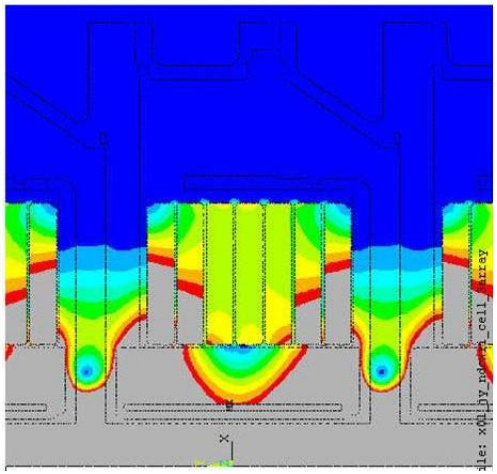
- **Added Cu cylinder to shield the ferrites from the solenoid return flux**
- **Replaced with 2.5 T pulsed solenoid**
- **Reduced beam tube diameter to 3.1”**
- **Used thinner flanges to reduce eddy currents**
- **Used new Rexolite insulator**

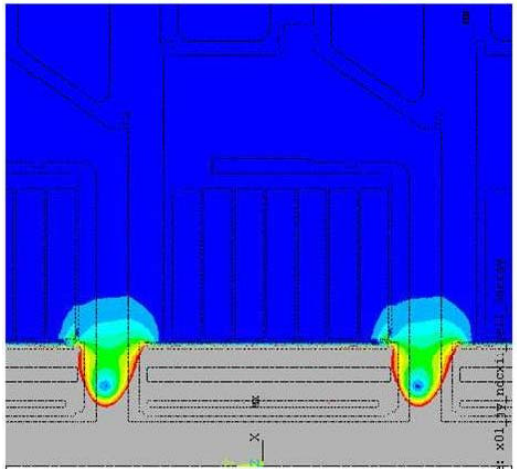
A copper cylinder was required around the pulsed solenoid to keep the magnetic field from saturating the ferrite toroids.

modified with copper shield







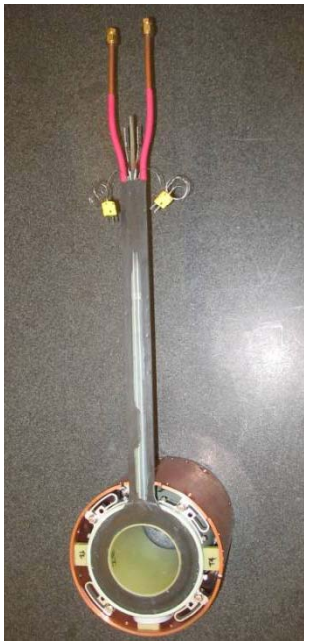


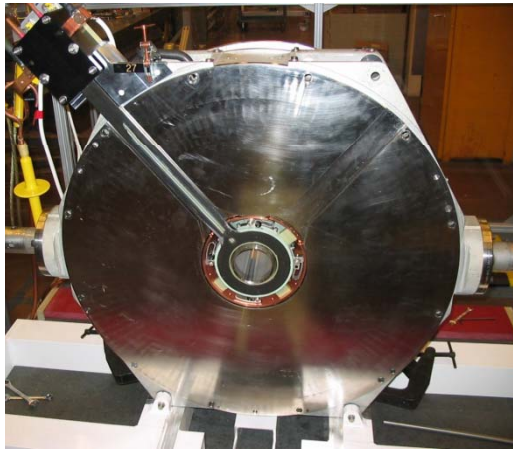
- Eddy currents in the end plates direct the solenoid return flux into the ferrite toroids
- Magnetic field in the gray area is larger than 0.3T (where the ferrite saturates)
- Ferrite does not saturate after the copper cylinder is added just inside the toroids

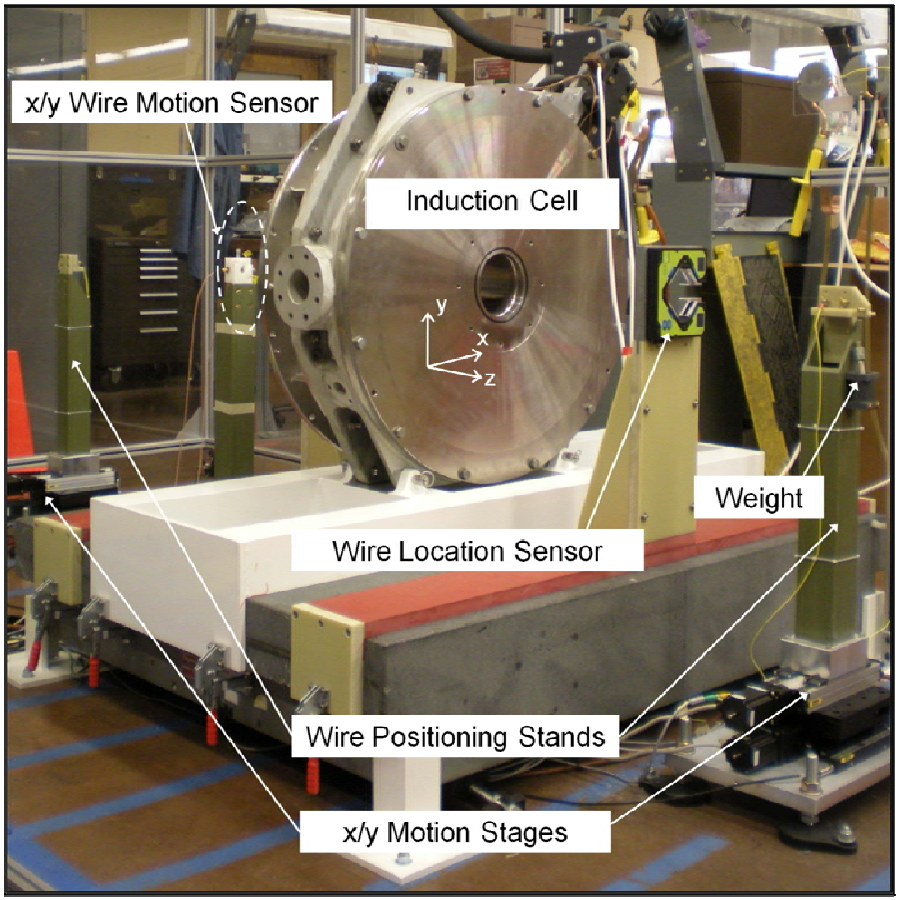
The pulsed transport solenoids were characterized using a stretched wire measurement and the tilt and offset were minimized within the cell assembly before welding.

- After measurement and adjustment, typical solenoids are welded into cells with <1mrad of tilt and < 250um offset

- The fiducials on the top of the cell are mapped to the magnetic axis so that the accelerator can be aligned

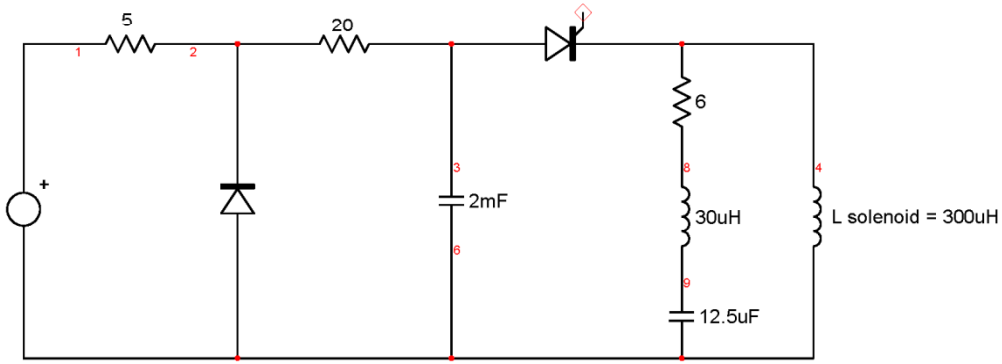


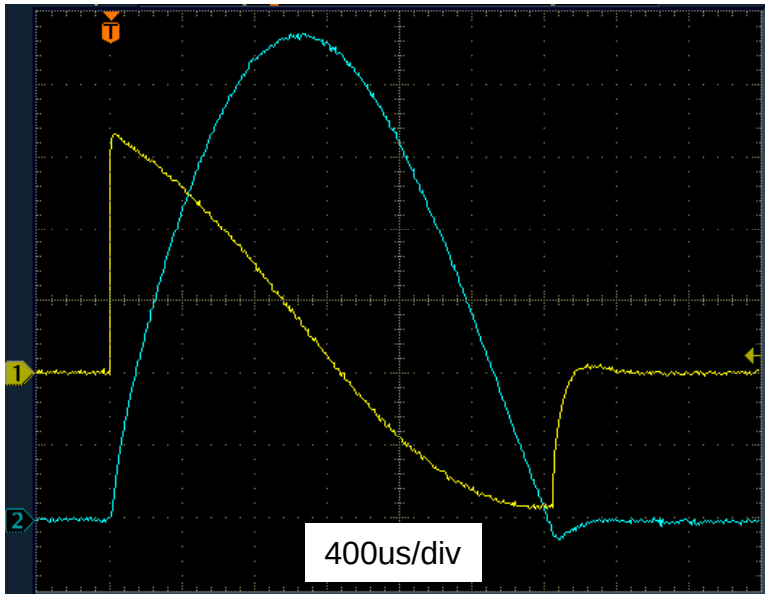




The high current pulsers which drive the transport solenoids are SCR switched capacitors.

- ~3kV, ~7kA for 2.5T (cooling limited)
- 2.4ms half sine of current
- 1 shot / 20sec

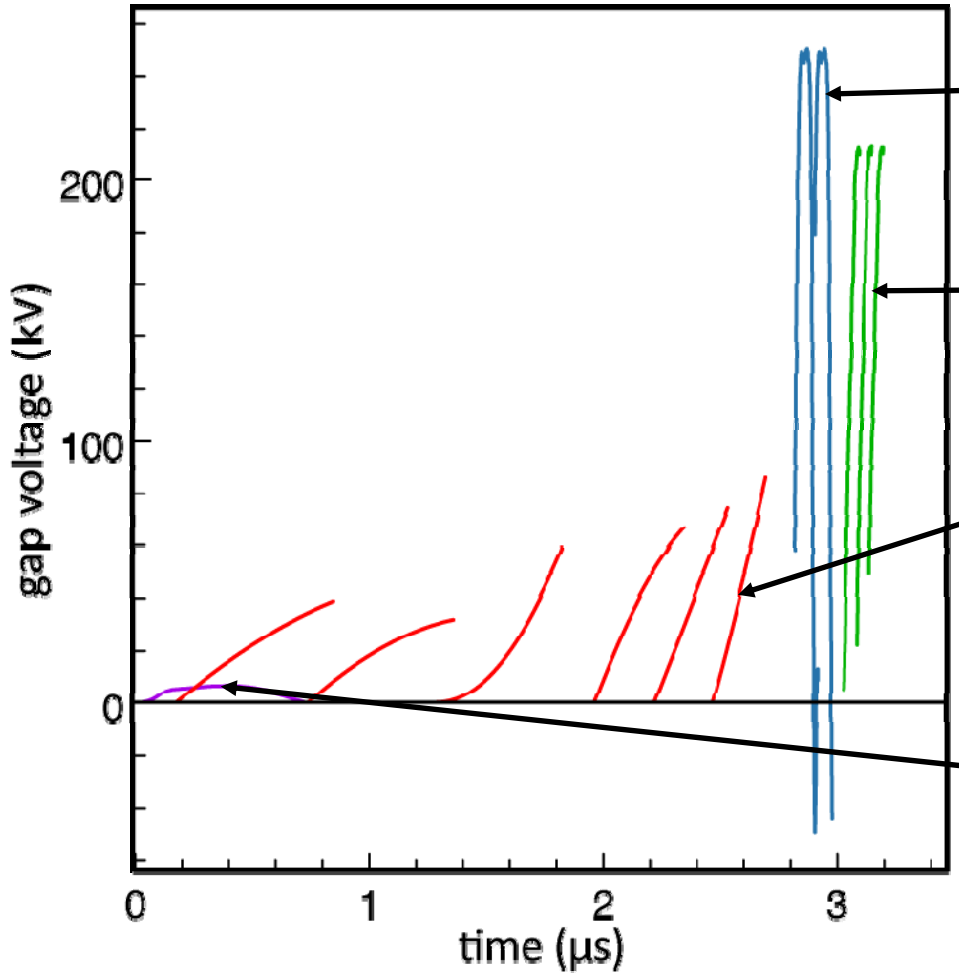




Yellow = pulser output voltage (1kV/div)

Blue = pulser output current (1kA/div)

Compression and accelerating voltage waveforms are either long-pulse moderate-voltage or short-pulse high-voltage (Blumleins)



250 kV "flat-top" measured waveform from test stand

200 kV "ramp" measured waveform from test stand

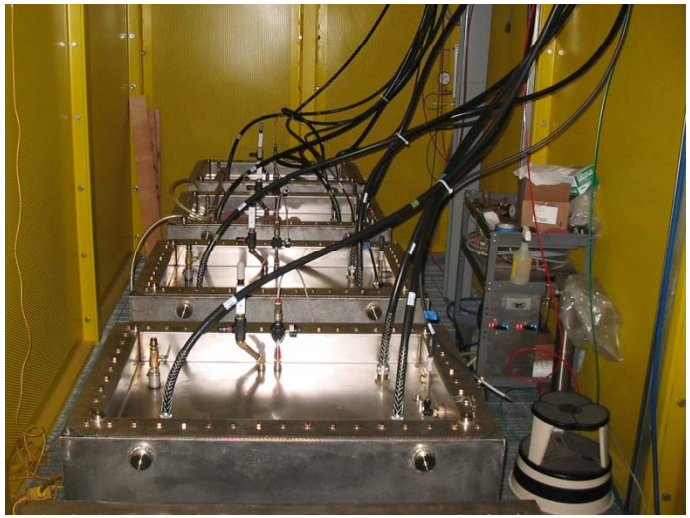
"shaped" for initial bunch compression (scaled from measured waveforms)

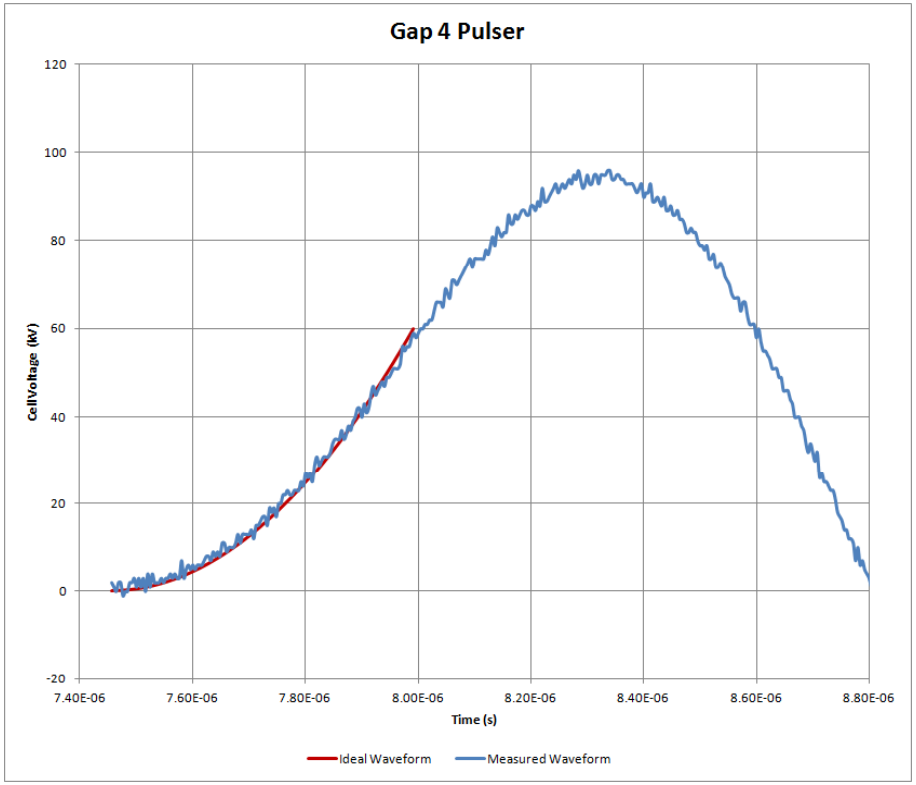
"shaped" to equalize beam energy after injection

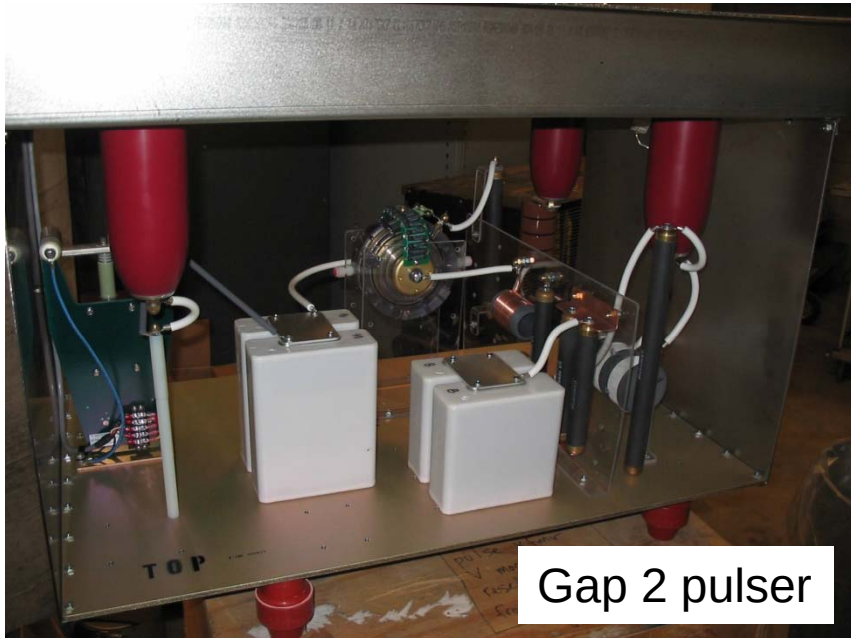
See Dave Grote's talk on Tuesday and Alex Friedman's talk on Wednesday for details of beam dynamics and simulations

The pulsers used for most of the compression waveforms are tunable spark gap switched lumped element pulsers.

- 40-90kV peak
- 300-700ns ramp
- 1 shot / 20sec
- 2-3ns jitter
- Common platform for easy reconfiguration



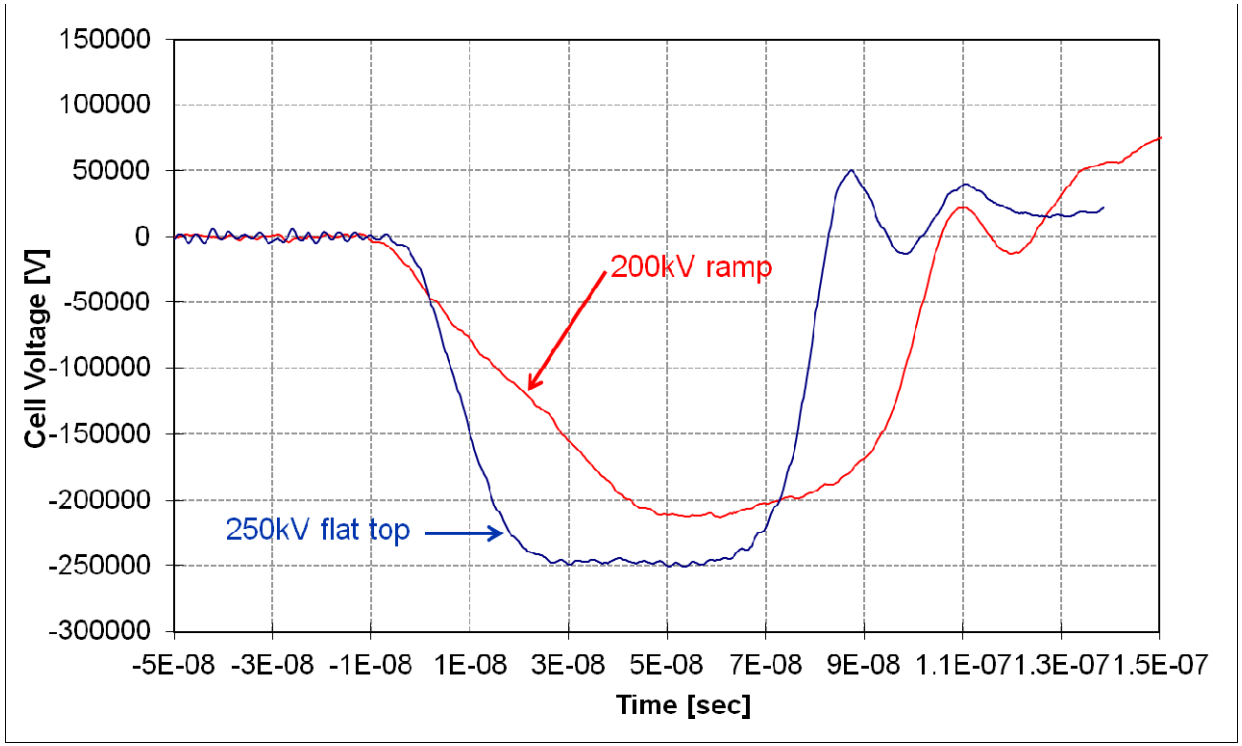


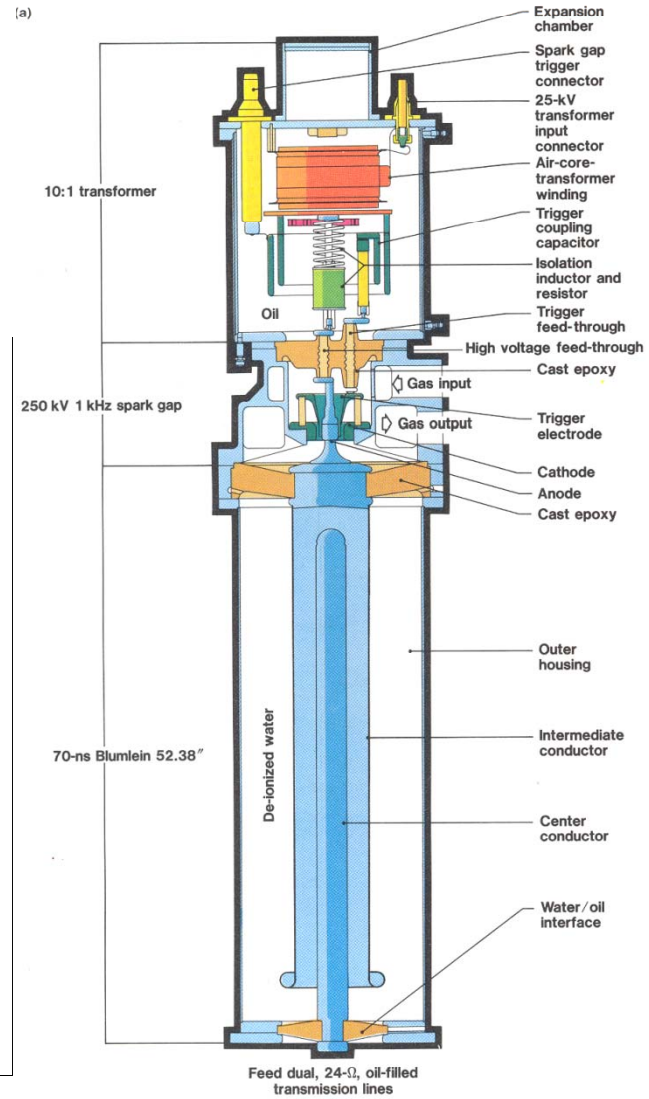


Gap 2 pulser

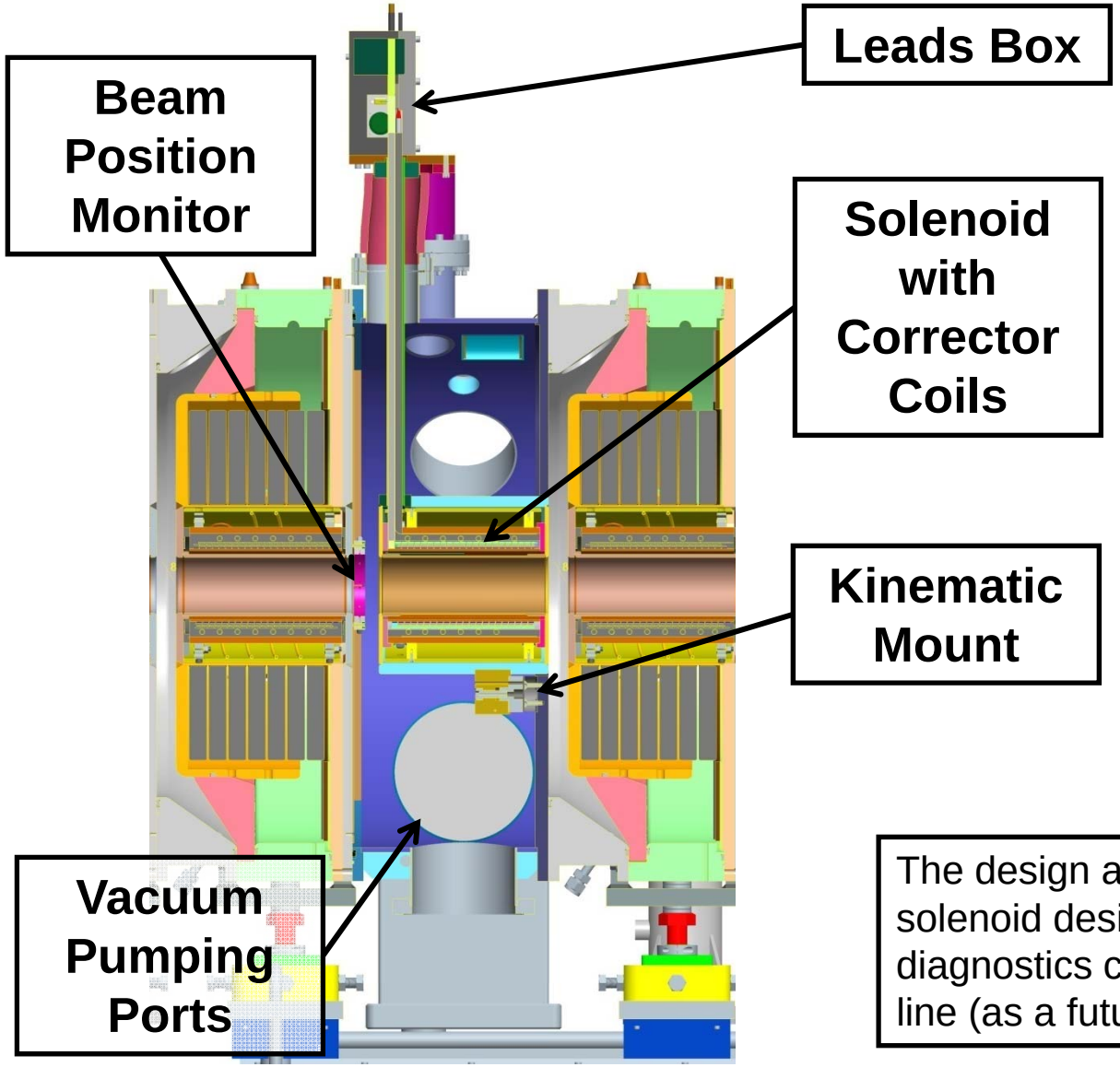
The pulsers used for most of the acceleration waveforms are Blumleins from ATA which have been refurbished.

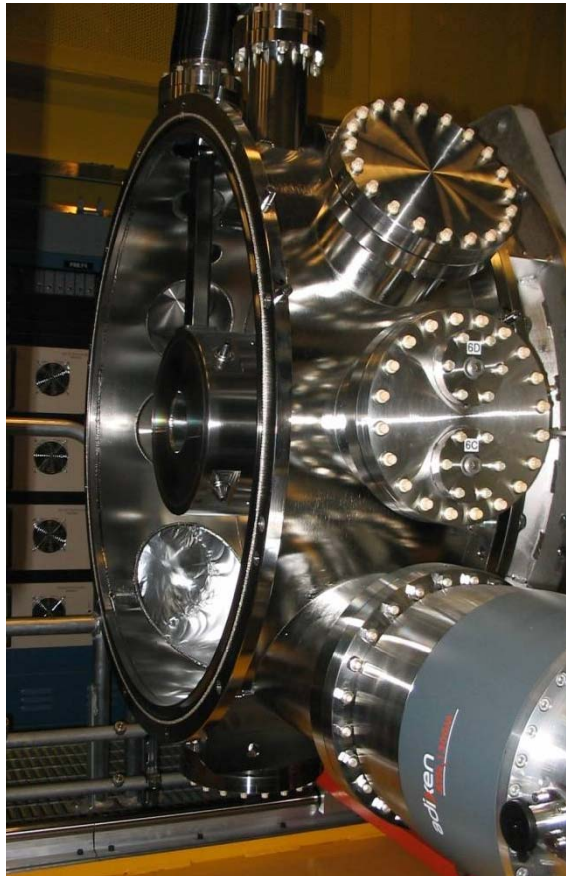
- 250kV, 70ns FWHM flattop
- 200kV, <70ns ramp
- 1 shot / 20sec
- 2-3ns jitter





The diagnostic cells provide vacuum pumping ports and beam diagnostic access along the accelerator.

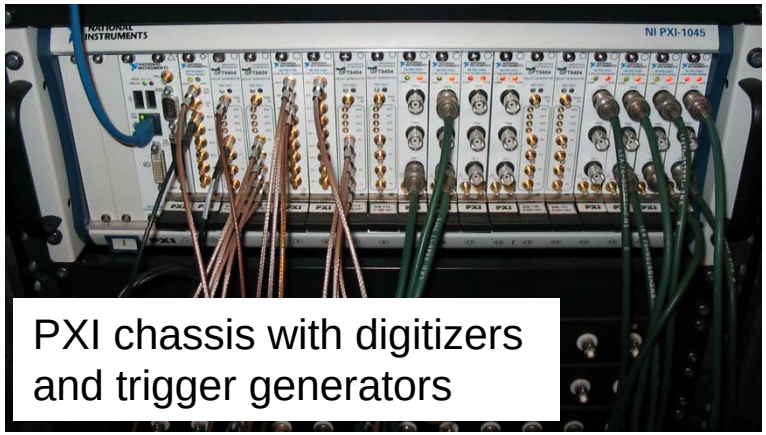




The design accommodates a removable solenoid design so that intercepting beam diagnostics can be inserted into the beam line (as a future modification)

The control and data acquisition systems operate under National Instruments LabVIEW as the user interface

- Timing System - Commercially available PXI-based 10MHz clock synchronization hardware and trigger generators from National Instruments
- Data Acquisition System - Commercially available PXI-based 60MHz and 500MHz digitizers from National Instruments
- Machine Protection System (not beam-related) - Vacuum system PLC and machine status monitoring and control through industrial I/O modules and LabVIEW
- Personnel Protection System (high voltage hazards) - 24V relay-based interlock system
- The data archiving system is implemented using Apache Cassandra (open source, scalable)

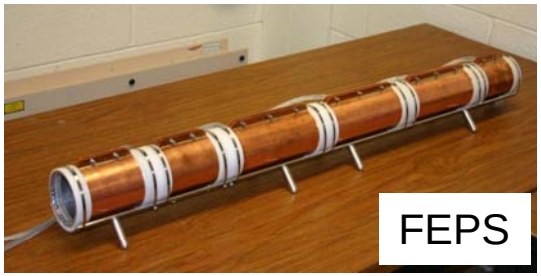


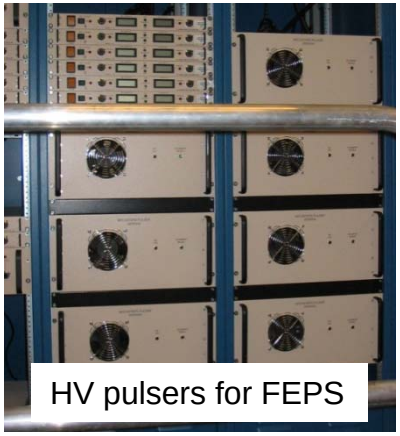
PXI chassis with digitizers and trigger generators

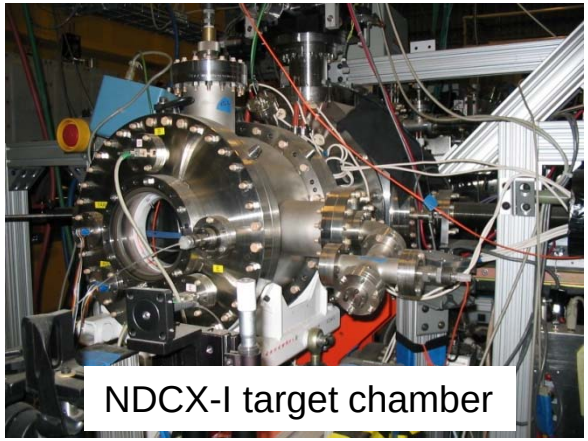
PLC and industrial I/O

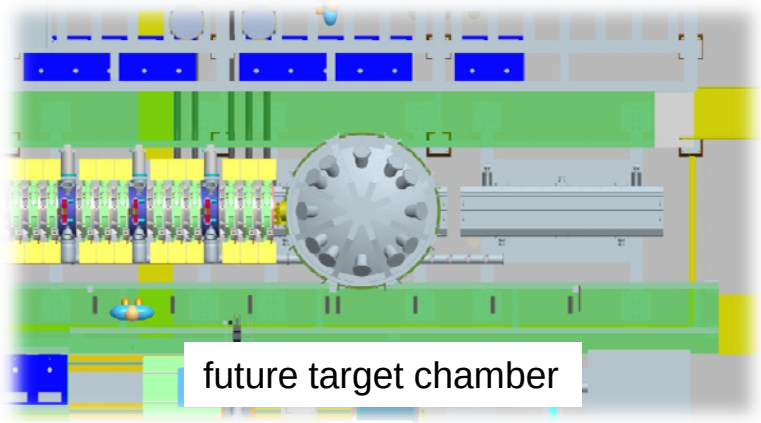
Neutralizing Drift Section Plasma Sources and the Target Chamber

- The ferroelectric plasma source (FEPS) and pulsers from PPPL for the neutralizing drift line are similar in design and performance to those used on NDCX-I
- Plasma source details – see Erik Gilson's talk on Thursday
- The final focus solenoid and 0.6m diameter target chamber from NDCX-I will be used until the planned 2.4m diameter target chamber is funded (chamber design used on Trident, Titan, and MECI)









Conclusion

- The lithium ion source current requirement made the injector design challenging by requiring a large ion source area at very high operating temperature
- Significant modifications were made to the ATA accelerator cell hardware to meet the NDCX-II focusing and acceleration requirements
- Flexible pulsed power systems were developed to generate the required compression and acceleration waveforms
- Further development of the ion source assembly continues improve the lifetime and reliability
- Commissioning activities are underway with initial experiments expected to begin in June 2013