Ion Sources and Injectors for HEDP Ion Drivers

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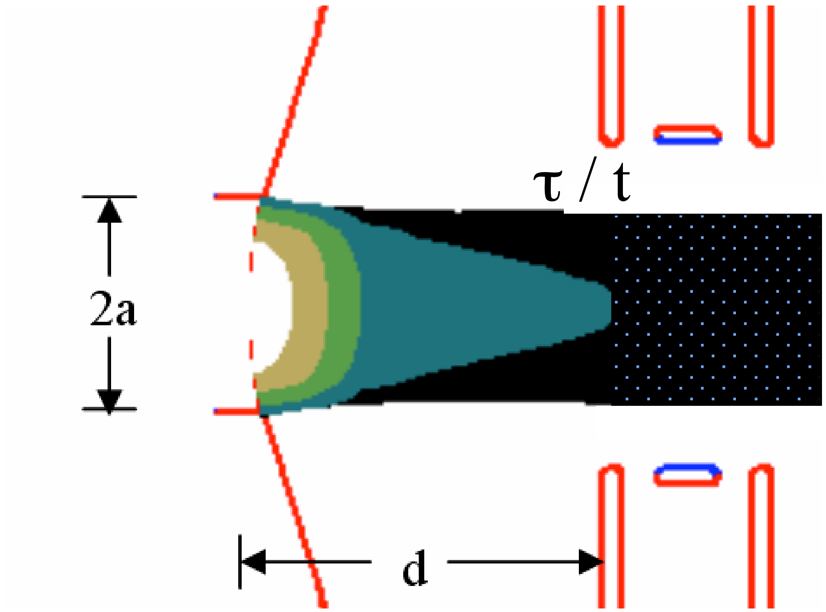
It is a challenge to develop an injector for HEDP

- HEDP requires ~1 μC at the target (beam voltage is limited by the Bragg peak energy).
- At the injector, a100 ns beam pulse requires 10 A current.
- If $\beta = 0.01$ (e.g.1 MV Ne^{+}), the bunch length is 0.3 m, and the line charge density (λ) is 3.3 μC/m.
- This is about 30 times shorter in pulse length and 20 times higher in beam current than the present HIF injector (HCX).
- Multiple beams can reduce the injector requirements.

The challenge (similar to HIF) is to simultaneously achieve high current density and high current

$$\varepsilon_{n,4rms} = 2a\sqrt{\frac{kT_i}{mc^2}} \qquad J = \chi\frac{V^{3/2}}{d^2} \qquad I = \chi\frac{\pi a^2}{d^2}V^{3/2}$$

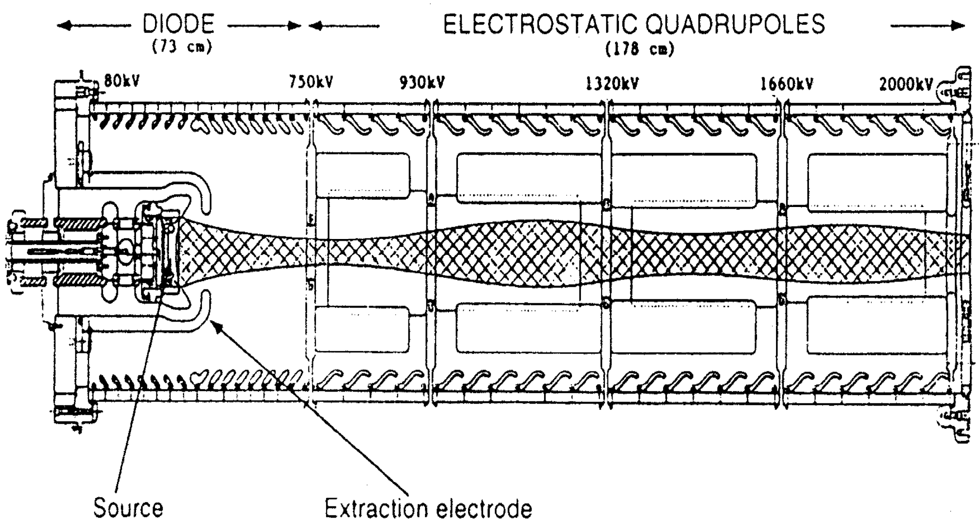


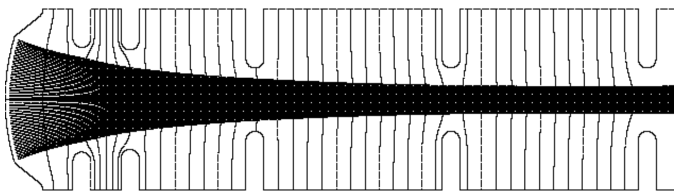
$$V = 100kV\sqrt{\frac{d[cm]}{1\,[cm]}}$$

We need:

- High current density ion source, e.g. $J > 100\ mA/cm^2$.
- High voltage gradient without breakdown, e.g. > 100 kV/cm
- High line charge density beam transport to keep the beam from blowing up.

Examples of a single large diameter beam





Case 1 (HCX size surface source):

1.68 A, 750 kV Li^+ Ion Diode

10.0 cm diam ⇒ J = 21.4 mA/cm^2

25 cm extraction gap ⇒ 30 kV/cm

$\varepsilon_{n,4rms}$ = 0.62 π-mm-mrad (0.25 eV)

Case 2 (small aperture gas source):

0.48 A, 200 kV He^+ Ion Diode

1.5 cm diam ⇒ J = 270 mA/cm^2

3.0 cm extraction gap ⇒ 66 kV/cm

$\varepsilon_{n,4rms}$ = 0.19 π-mm-mrad (0.6 eV)

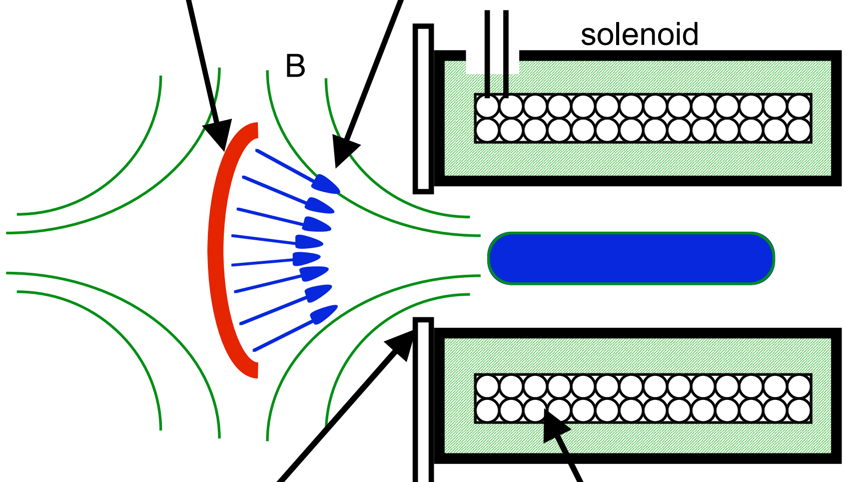
What if we can beat conventional wisdom?

- Hold ultra-high voltage gradient across a large gap using short pulse or magnetic insulation
- Obtain very high current density for a short pulse (from a large surface ionization source)
- Use solenoid focusing for high line charge density transport or use neutralized beam transport at the injector
- Achieve large beam compression e.g. use accel-decel scheme
- Apply innovative beam chopping scheme

A conceptual magnetically-insulated, short pulse, high current ion diode

J > 100 mA/cm^2 when surface T > 1200° C

High voltage gradient and special waveform to control rise time



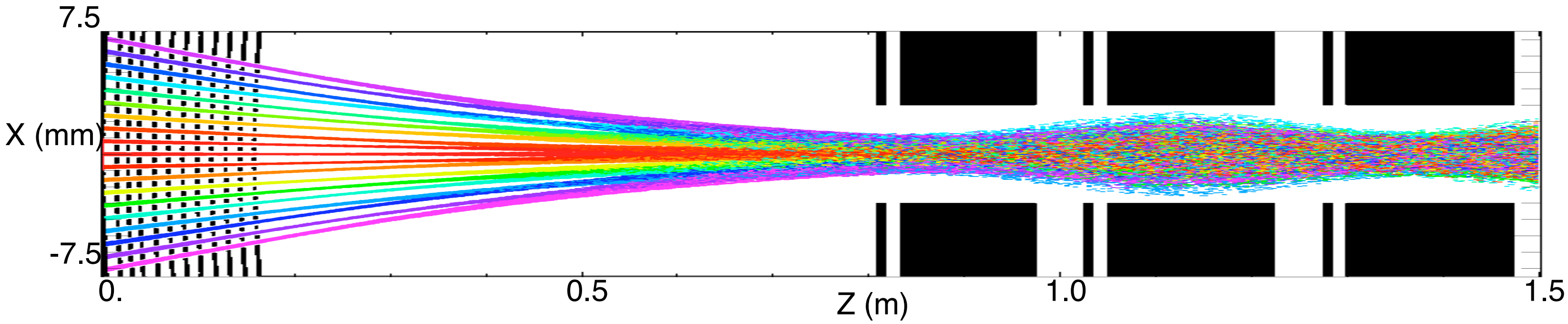
Use the solenoid's fringe field to stop 2nd electrons from reaching the anode

Solenoid focusing provides low energy transport of high line charge density beam

Several case studies by assuming either high current density or high voltage gradient

	Case 3	Case 4	Case 5
Ion species	Li+	Li+	He+
Diode voltage (kV)	175	1000	750
Beam current (A)	0.33	5.00	5.00
Source diameter (cm)	0.8	8.0	8.0
Extraction gap (cm)	1.5	14.4	13.0
Emittance (pi-mm-mrad)	0.05	0.50	1.00
Current density (mA/cm^2)	650	100	100
Voltage gradient (kV/cm)	117	70	56
Comments	normal grad	very high grad	high grad
	very high J	high J	normal J
	tiny spot	best bet	need screen

Use multi-beamlets to increase beam current



- This concept is being studied for multiple-beam HIF drivers because of its advantage in compactness, but size may not be an issue for a single-beam HEDP ion driver.
- The beamlet brightness is reduced by the grid transparency
- It can be scaled to higher beam current.
- The short rise time (due to a small extraction gap) may be the most important advantage here.

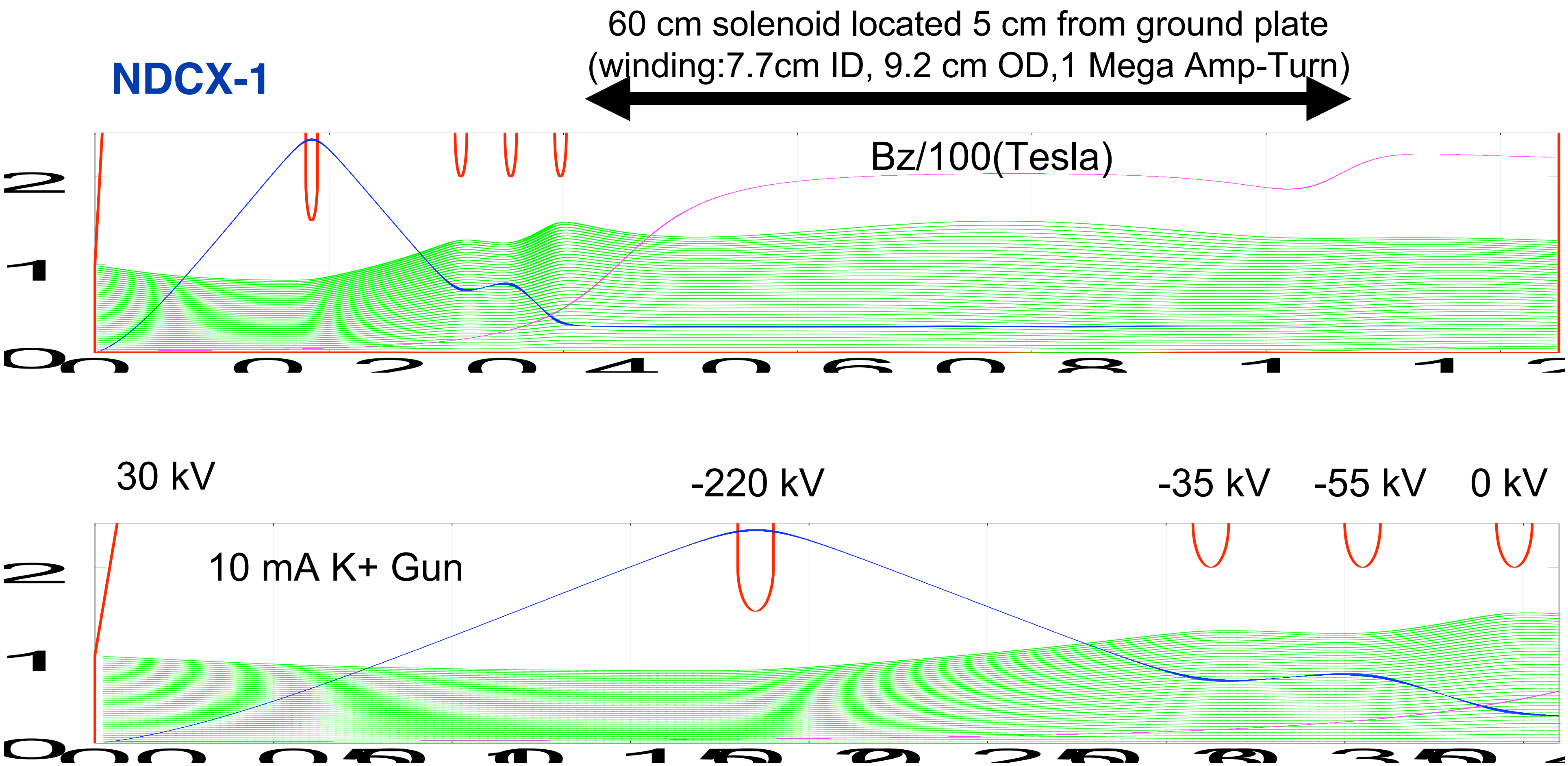
MAP Diode with 700 kV, 1 cm gap, various noble gases

- Magnetic field insulation
- Virtual cathode from circulating electrons
- Neutralized transport with co-moving electrons
- J in kA/cm^2 range but large micro-divergence
- Need to separate out co-moving electrons before further acceleration

An Accel-Decel injector rapidly compresses the beam

- Use a high voltage to extract significant beam current
- Decelerate the ions to longitudinally compress the bunch length while loading it into a solenoid channel
- Do "constant lamda" acceleration to amplify the beam current and shortening the pulse length. A velocity tide can further compress the bunch.
- This method allows the use of a low current ion source to do "load and fire". However, the compression will significantly increase the longitudinal emittance.

A preliminary design of an Accel-Decel injector



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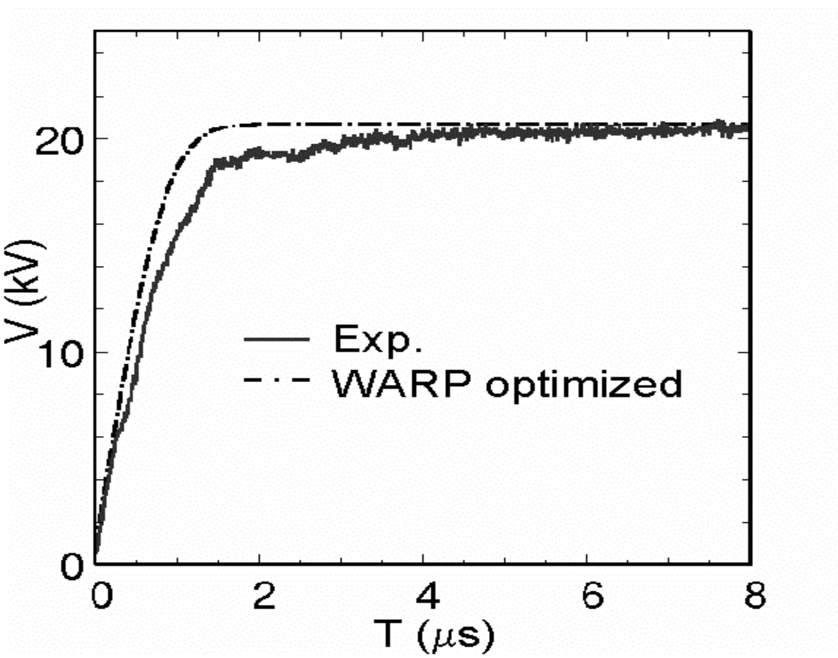
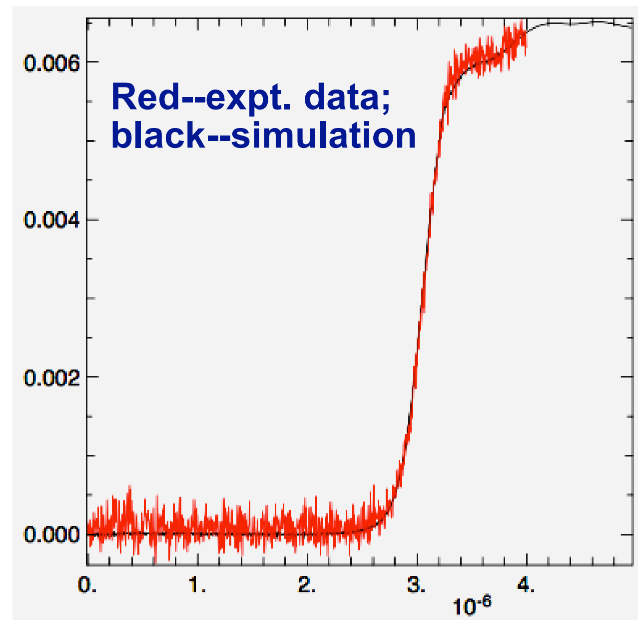
Time-dependent adaptive-mesh simulation shows how to achieve a fast rise time

Applied Diode Voltage



Current at Faraday cup



- The current pulse rises faster than the applied voltage pulse.
- Capacitive coupling softens the signal rise time.
- One dimensional theoretical model:
- Example: 50ns/350ns

Near-term enabling R&D

- High voltage breakdown threshold at 100 ns time scale and as a function of gap distance.
- Magnetic insulation
- High current density Li^+ surface ionization source.
- Large aperture gas source with screen control, and study the rise time.
- Time dependent simulation to examine the rise time and transient effects.