IBX Ion Source

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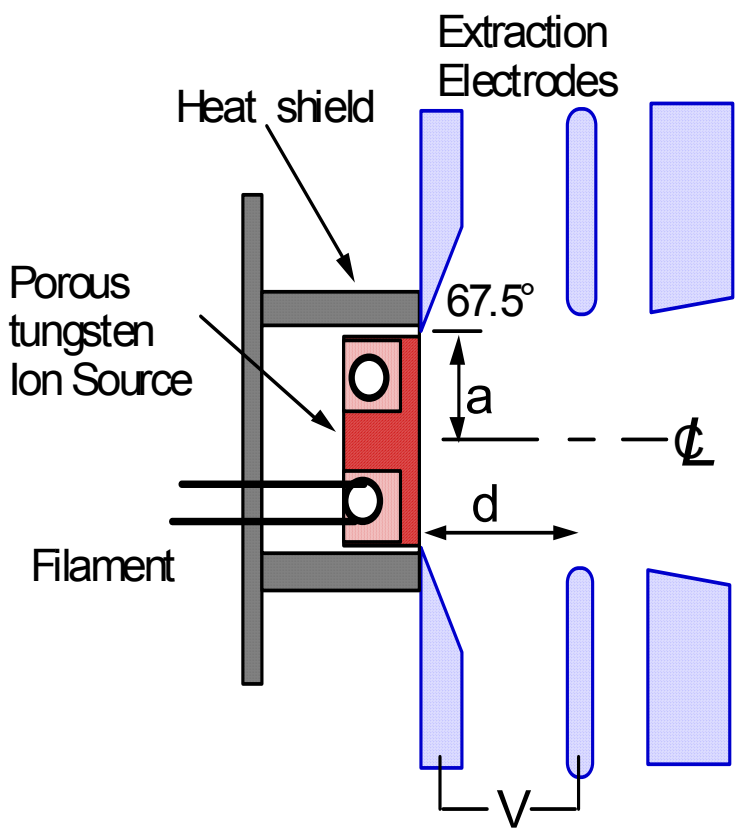
IBX injector specifications

- **Line charge density ≈ 0.2 μC/m** (beam potential > 1 kV) **(~ 0.5 A of K^+).**
- **Ions with mass/charge ≈ 40.**
- **Pulse length ~ 0.2 μs.** (This is a key difference from the 20 μs expected for drivers.)
- **Rise time ~ 10-20% of pulse length.**
- **Normalized edge emittance ≈ 1 π mm-mrad.**
- **Start IBX in FY04 (limited development). Maintain 2-MV injector for HCX experiments.**

Beam extraction scaling law

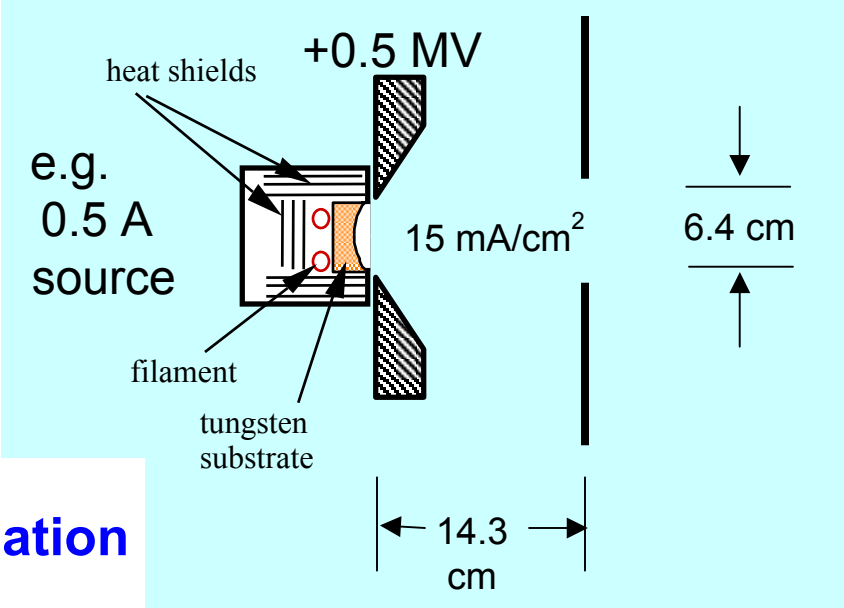
$$J_{CL} = \chi \frac{V^{\frac{3}{2}}}{d^2} \qquad I_{CL} = \pi\chi\left(\frac{a}{d}\right)^2 V^{\frac{3}{2}}$$



- **Space-charge-limited flow in the extraction diode is governed by Child-Langmuir equation.**
  where $\chi = (4\varepsilon_o/9)(2q/M)^{1/2}$
  with q and M being the charge and mass of the ions respectively, a is the aperture radius, d the diode length, and V is the extraction voltage.
- **V is limited by breakdown**
  $V \sim d$ for $d < 1$ cm
  $V \sim d^{0.5}$ for $d > 1$ cm
  so large ion diode needs high V but produces low J.
- **Spherical aberration depends on the aspect ratio a/d (typically < 0.5) thus $I_{max} \sim V^{3/2}$**
- **Conclusion: high current needs large V and d but results in low J, so the brightness is limited.**

The surface ionization source is the best known solution for a large beam

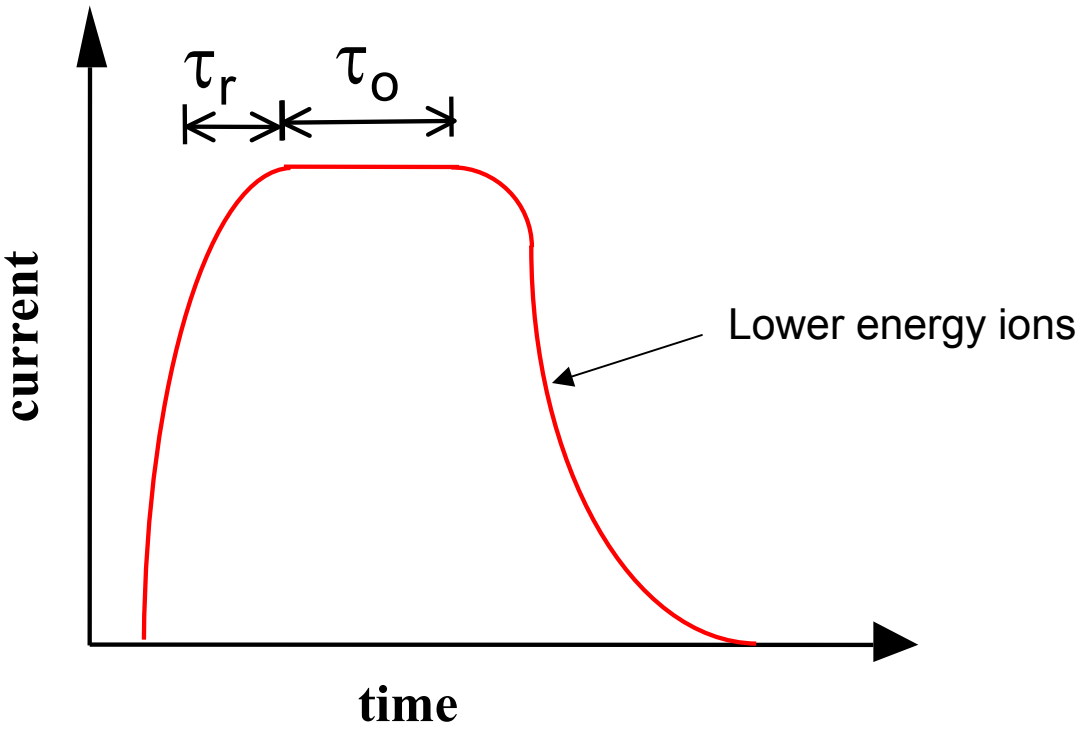
- A surface-ionization source produces alkali metal ions from a solid (possibly large) emitter.
- Ion temperature is only a small fraction of an eV; $J \leq 20$ mA/cm^2.



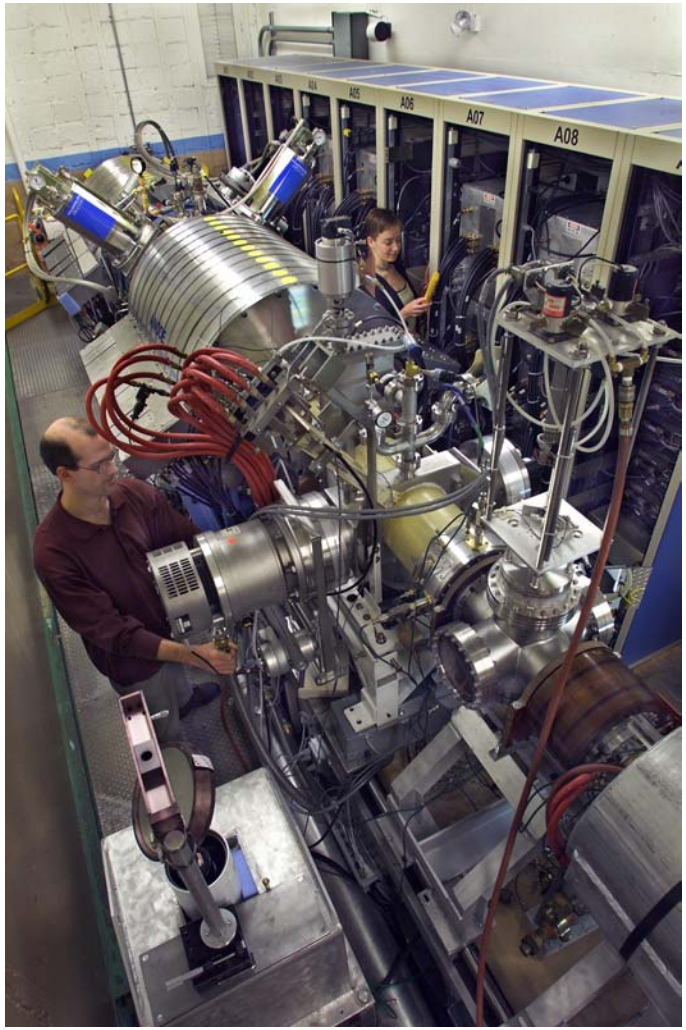
- Issues:
- 1050°C heat management
- Alkali metal vapor contamination
- Life time due to ion and neutral depletion and heater filament

Desired current pulse after the injector

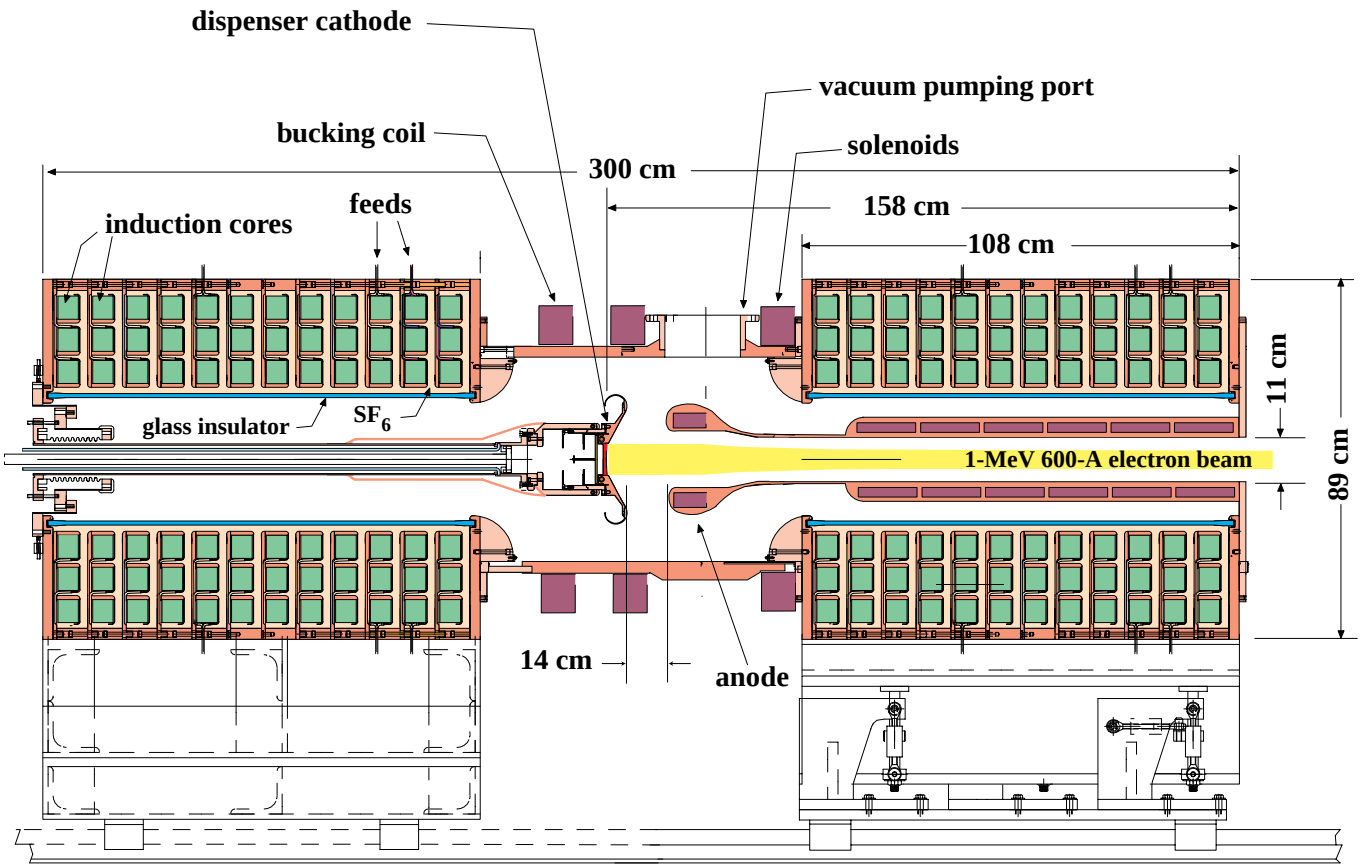
Want $\tau_r < 0.2\ \tau_o$



The RTA injector was built to investigate alternate power sources for HEP linear colliders



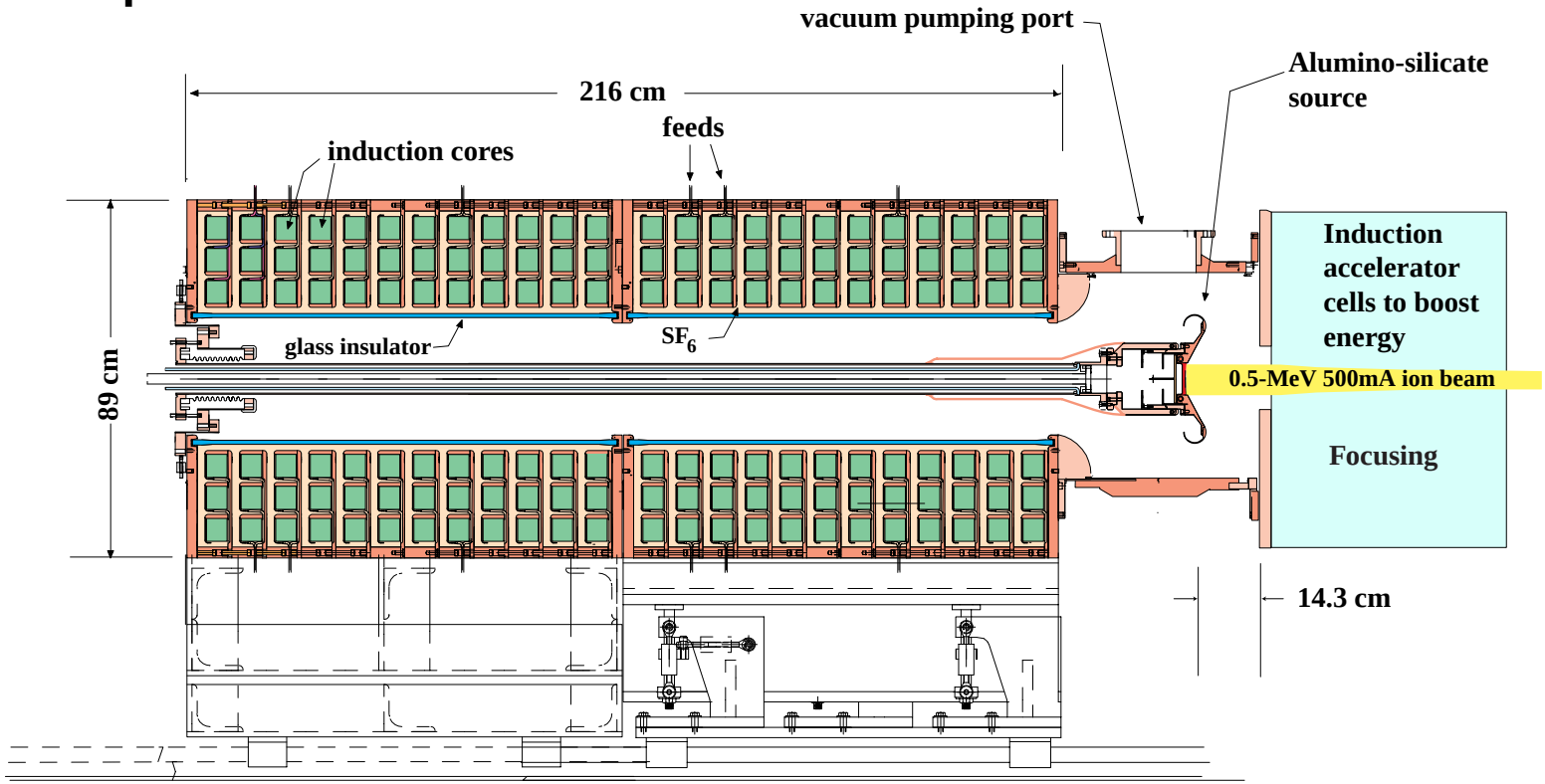
RTA as a 1-MeV 600-A electron gun



72 cores @ 14 kV/core = 1 MV, 2605SC Metglas®, core area = 28 cm^2 , ρ = .75, ΔB = 2.5 T, $\int$ Vds = 375 ns
M-type dispenser 4.4-cm-radius cathode @ 10 A/cm^2 = 600 A, norm. edge emittance = 300 π mm-mrad
Peak cathode shroud surface field = 165 kV/cm, peak non-electrode "cathode" surface field = 100 kV/cm
Ten 15-W drive lines/cell

IBX Source (0.5-MeV, 500-mA, K^+ beam)

Short pulse



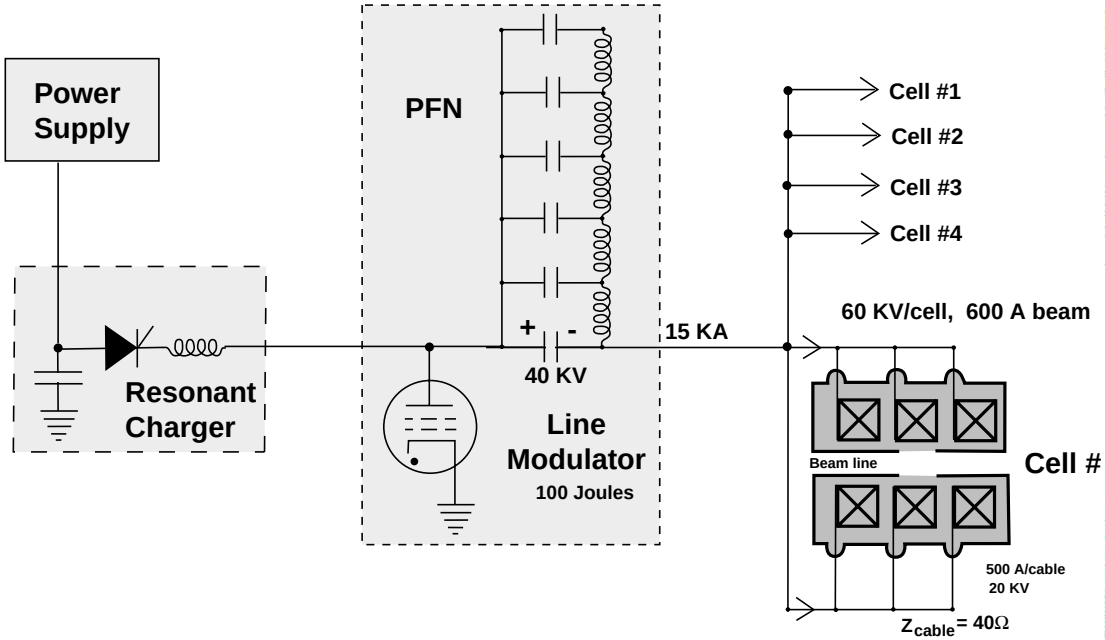
72 cores @ 7 kV/core = 0.5 MV, 2605SC Metglas®, core area = 28 cm^2 , ρ = .75, ΔB = 2.5 T, $\int$ Vds = 750 ns

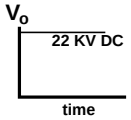
Alumino-Silicate Source, 6.5-cm-diameter cathode @ 15 mA/cm^2 = 500 mA

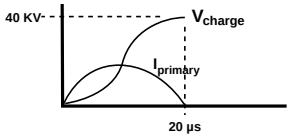
Ion transist time = 275 ns, norm. edge emittance = 1 π mm-mrad

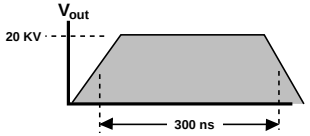
We will need to modify the PFN boards for a longer pulse

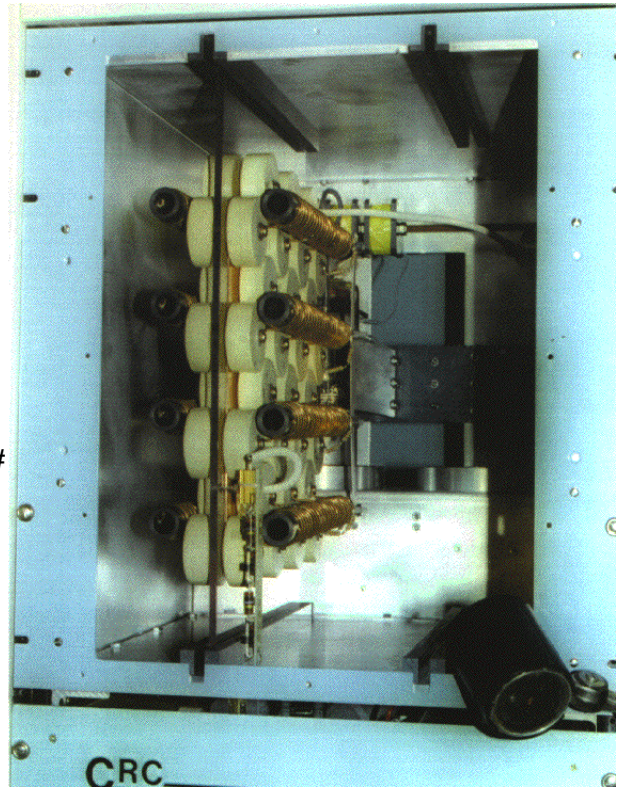
Existing RTA pulsed power system







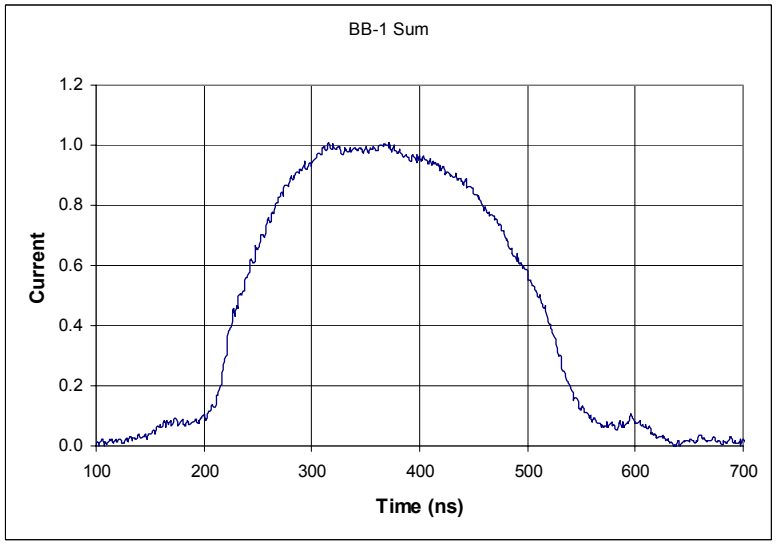




Voltage waveform

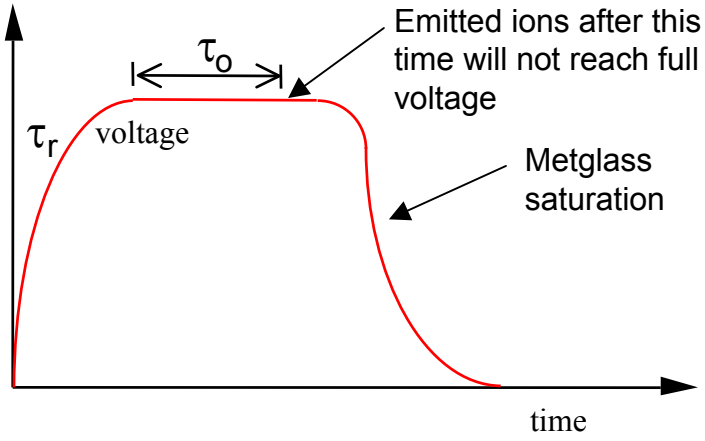
We will need to operate at lower voltage to widen the voltage waveform.

Current from existing RTA injector



Voltage for modified RTA

Ion transist time = 275 ns



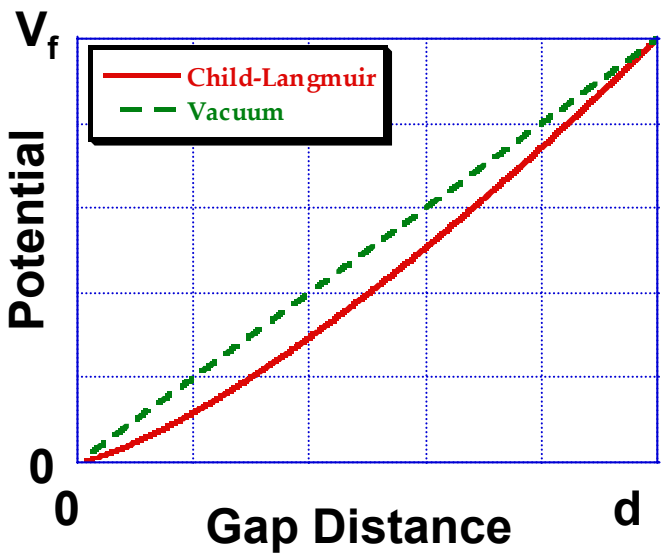
τ_r determined by capacitance

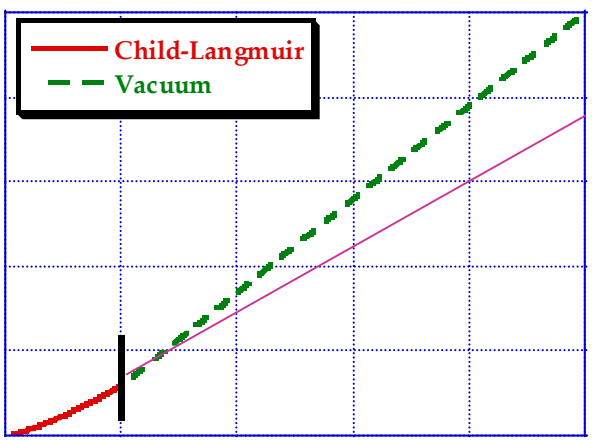
$\tau_r \sim 300$ ns

$\tau_0 \sim 200$ ns

(needs additional study)

Lampel-Tiefenback solution for a 1-D diode





$$V(x=d, t) = V_f \; [4/3 \, (t / t_r) - 1/3 \, (t / t_r)^4]$$

Where $t_r = 3 \, d \, [m/(2qV_f)]^{1/2}$ is the particle transit time with m and q being the mass and charge of the ions.

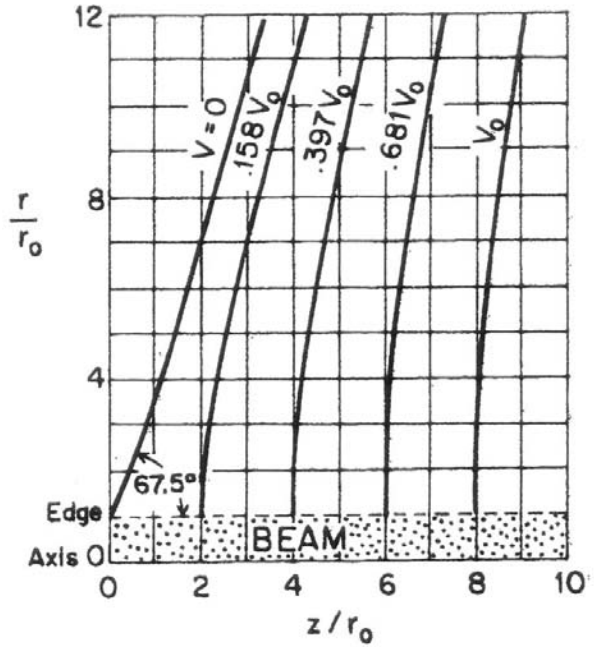
The electric potential behind the beam front is according to Child-Langmuir whereas the potential in front of the beam front is due to a linear vacuum field.

This solution can provide a zero rise-time flat-top current and energy pulse with a long tail. (For J = 3mA/cm2 and d = 30cm, t = 0.6μs.)

The duration of a flat-top is determined by how long the voltage is held constant after reaching the peak value.

Beam voltage will not have a sharp risetime

- **Real extraction optics is 3D.**



- **Particles will be lost in transport during the rise time.**

Issues for single aperture approach

Large current sources require large area sources

- Presently, examining 10-15 cm diameter sources to produce 0.5-1.0 A beams.
- Large beams more prone to spherical aberrations.

Emittance constraint requires ion temperature below 1 eV

- Presently, this restricts source technology to surface ionization type sources, e.g. contact ionizers and aluminosilicates.

Size mismatch between injector and accelerator

- Beam to beam distance at emitter surface is 25-30 cm.
- Beam to beam distance at accelerator is 7-10 cm.
- Requires special matching section to funnel beams together.

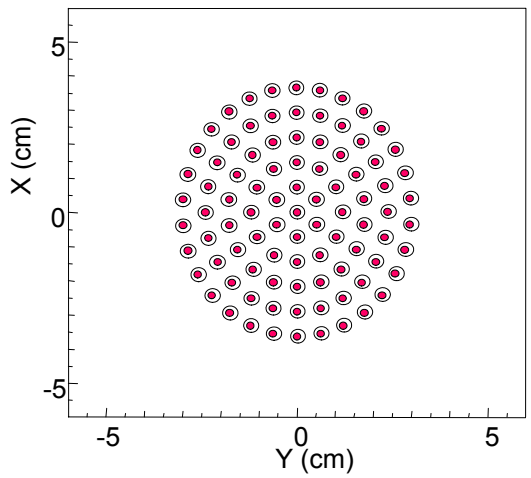
We are beginning to explore a novel compact "merging beamlet" injector concept

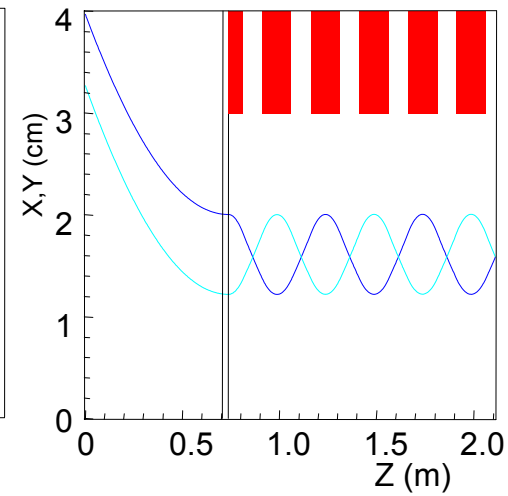
Child-Langmuir:

$$J_{CL} \propto \frac{V^{3/2}}{d^2} \quad \text{and} \quad V \propto d^{0.5\ to\ 1.0}$$

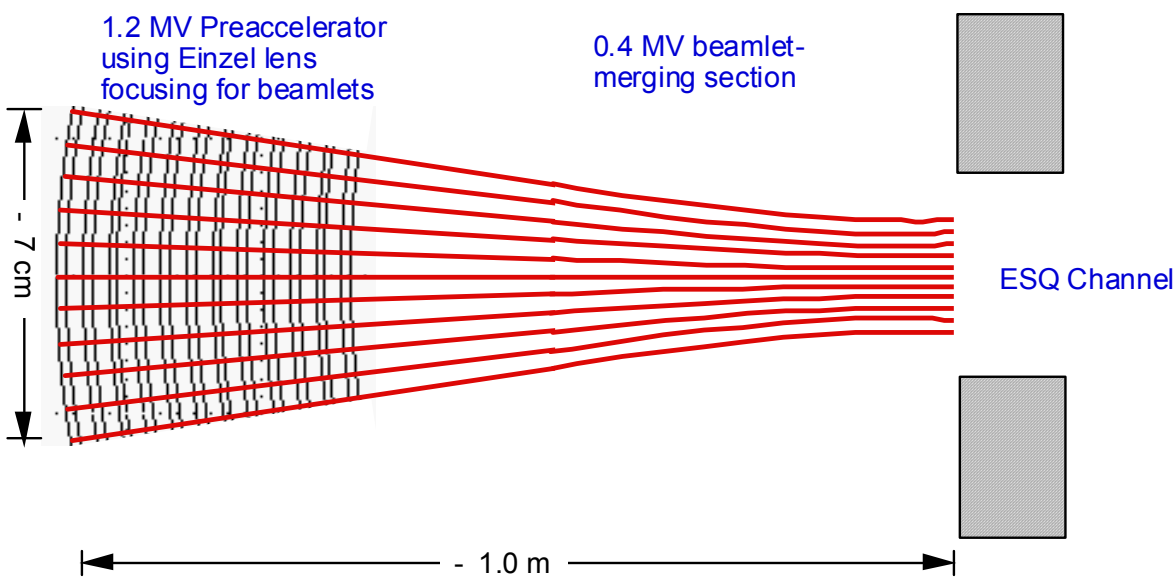
⇒ small multi-aperture sources

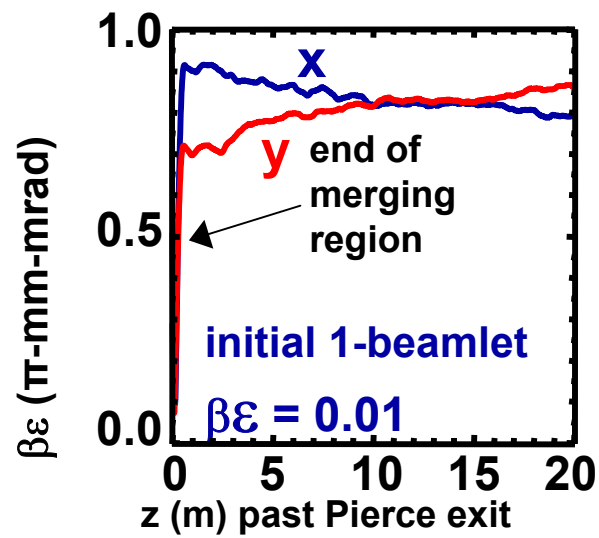
(this Ar source achieved 100 mA/cm^2)





emittance grows due to entrained space

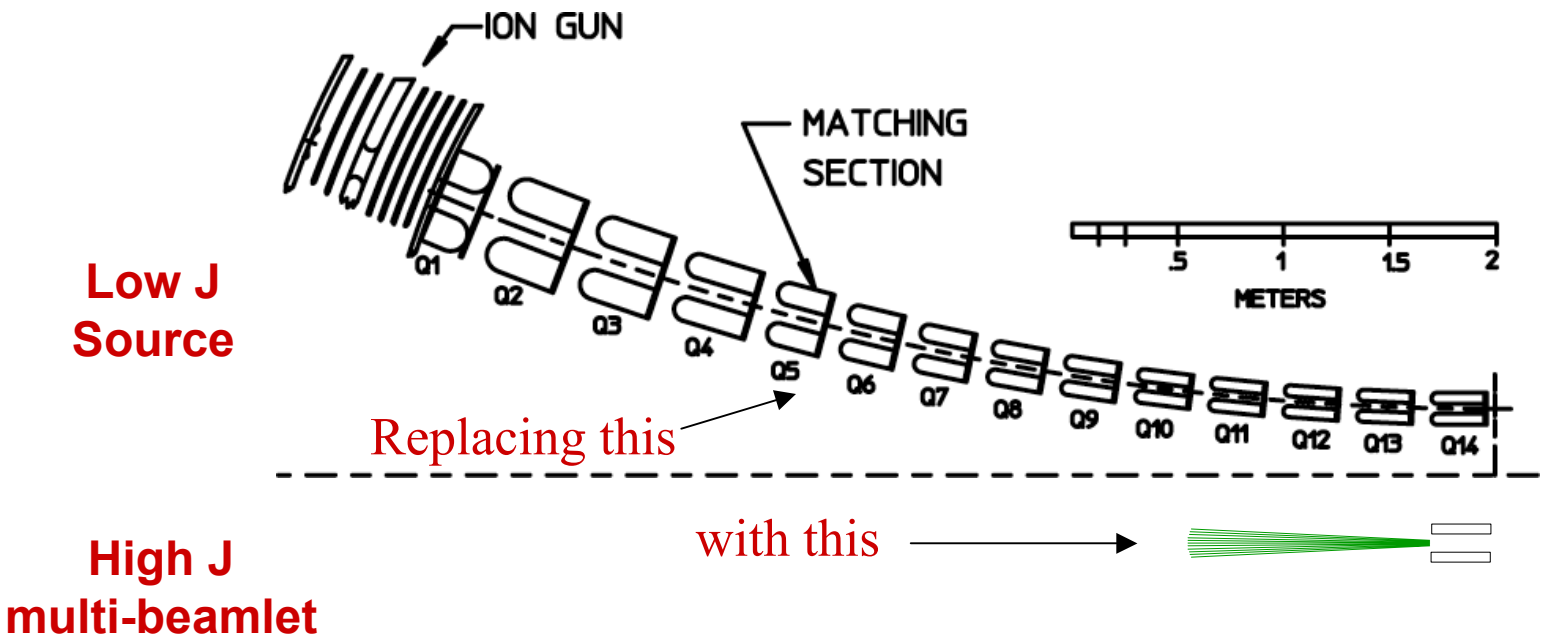




Small gap sources

- **Multiple beamlets (~ 5 mA/beamlet)**
  - **Reduces transit time**
  - **Work at lower voltages**
- **Current experiments on rf plasma source will address if this technology can be used at ion source for HIF applications.**
  - **time for meniscus to stabilize**
  - **Ion temperature**
  - **Ionization state**

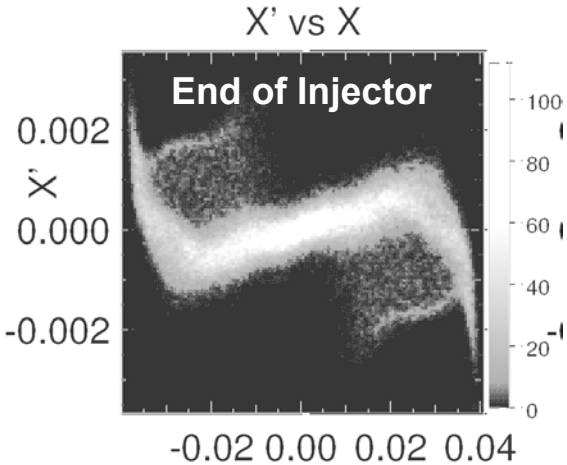
The mini-beamlet approach can drastically reduce the size of a multiple beam injector

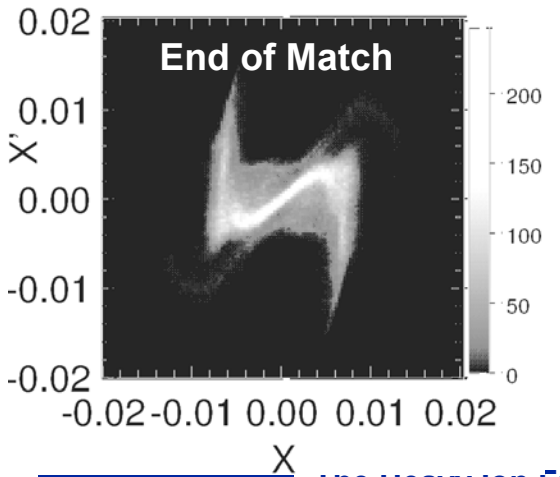


- The merging beamlet approach requires a high current density ion source, but it can tolerate a higher intrinsic ion temperature. So there are more acceptable ion source options.

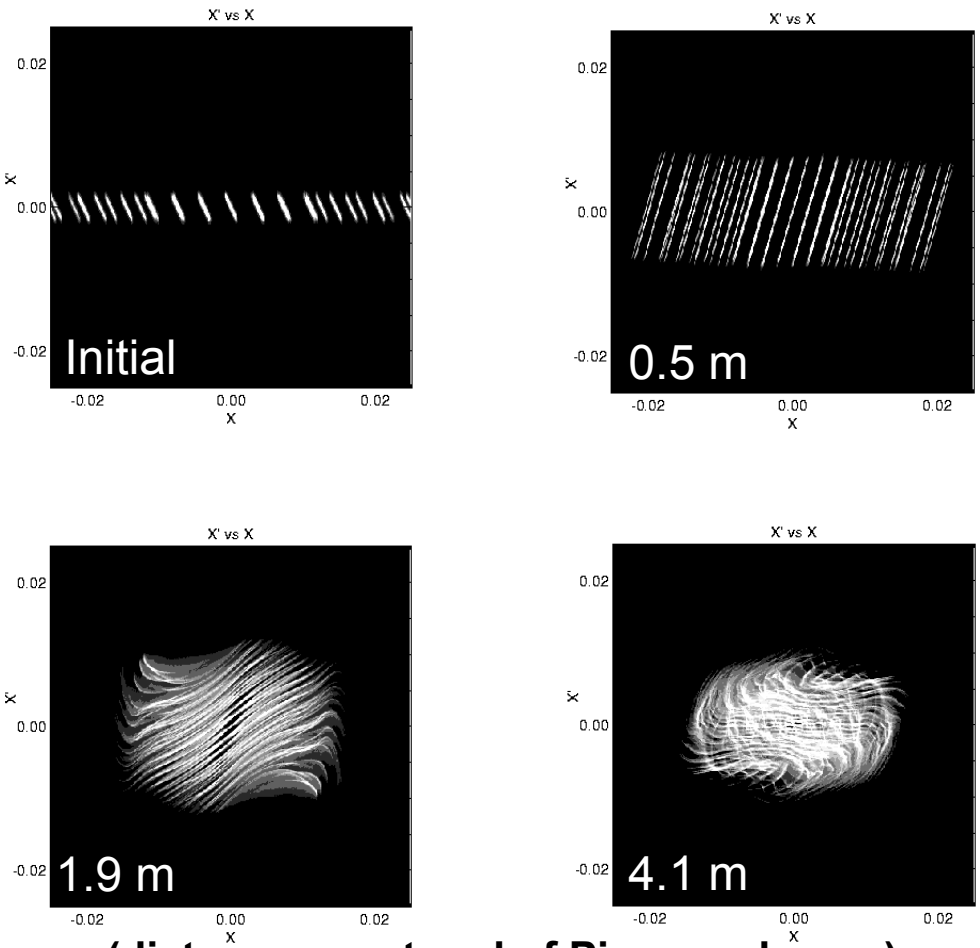
Simulations of two injector approaches: similar emittances, qualitatively different phase spaces

ESQ injector (555 mA)





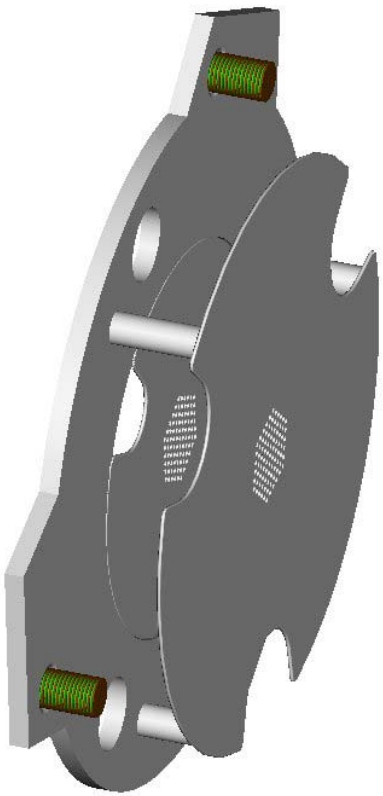
Merging-beamlets injector (572 mA)

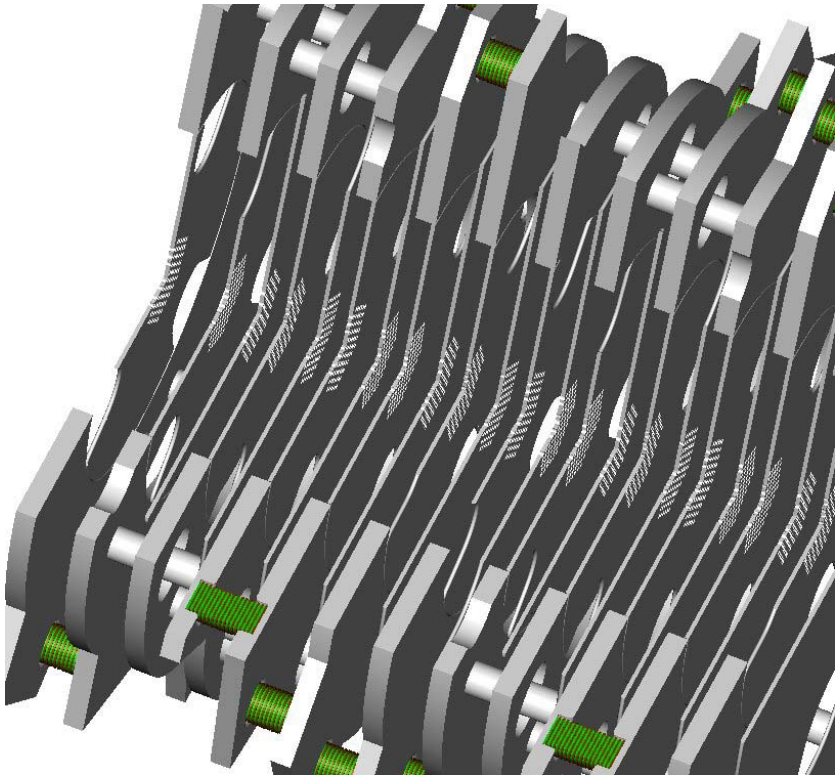


(distances past end of Pierce columns)

Mechanical design for the Einzel lens

Stack using HGI insulators





Summary

- We can provide a 0.5-A, 0.5-MeV, low-emittance, short-pulse, K^+ beam by converting RTA.
- If current experiments with the rf plasma source provide high quality beamlets we would like to use this approach in IBX.