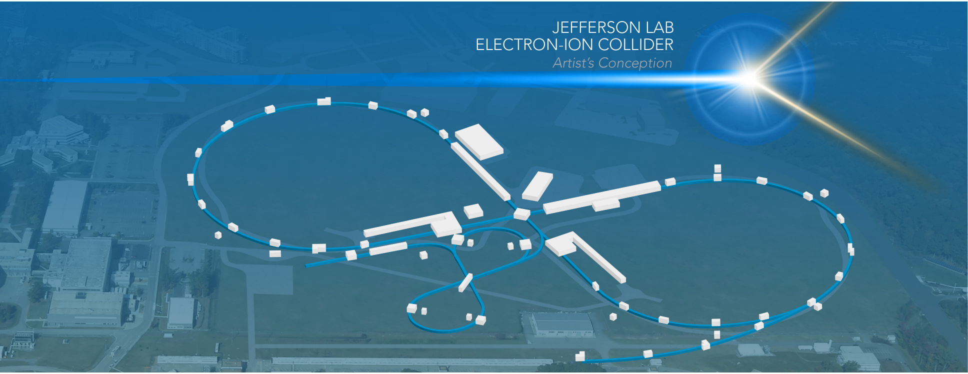
Ideas for a 4.3 MeV magnetized DC cooler for JLEIC



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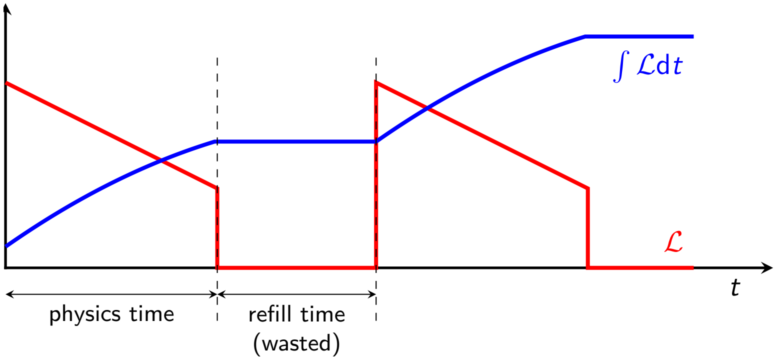
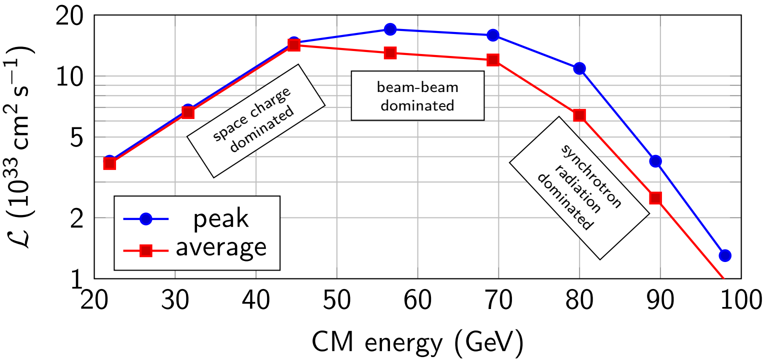
Extra booster ring for beam preparation



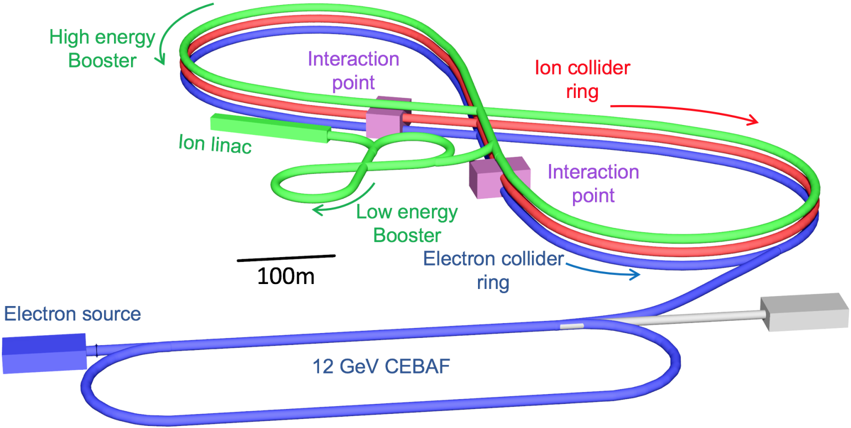
- Maximize $\int \mathcal{L}dt$: renew beam often, but minimize refill time
- Extra ring prepares new beam during physics run
- Initially: total cycle time $\approx 1\,\mathrm{h}$ $\Rightarrow$ constrains cooling time

Emittance requirements

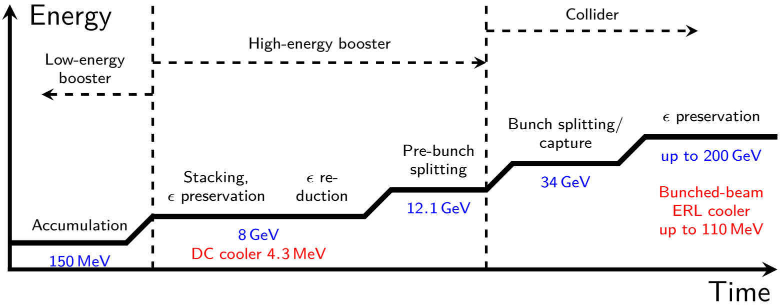


- High luminosity is key feature; cooling mandatory
- Low-energy cooling for low initial ϵ, collision-energy cooling for preservation
- Normalized ICR emittance: $\epsilon_x \approx 0.5\,\mu\text{m}$, $\epsilon_y \approx 0.2\,\mu\text{m}$

JLEIC ring layout



Injection and cooling scheme (protons)



- Discuss only protons for now; other ions are similar/easier
- LEB e-cooling not needed for protons (space charge prevents further emittance reduction at LEB energy)

Beam parameters

HEB proton beam at injection

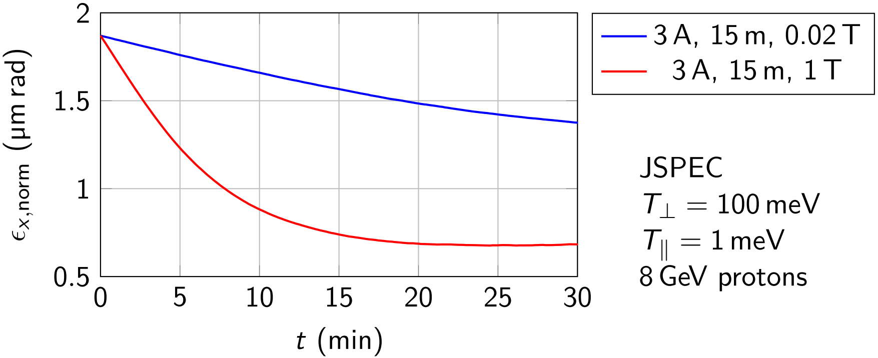
$E_{\mathrm{kin,p}}$	8.0–12.1 GeV
normalized emittance $\epsilon_{x,\mathrm{norm}}$	1.87 µm rad
normalized emittance $\epsilon_{y,\mathrm{norm}}$	1.87 µm rad
energy spread $\delta E/E$	4.7×10^{-4}

HEB electron cooler (as proposed in pCDR)

max. $E_{\mathrm{kin,e}} = E_{\mathrm{kin,p}}/1836$	4.36 MeV	
beam current	3 A	consider reducing
cooler length	15 m	consider increasing
B_z in cooling section	1.0 T	consider reducing
beam diameter	10 mm	

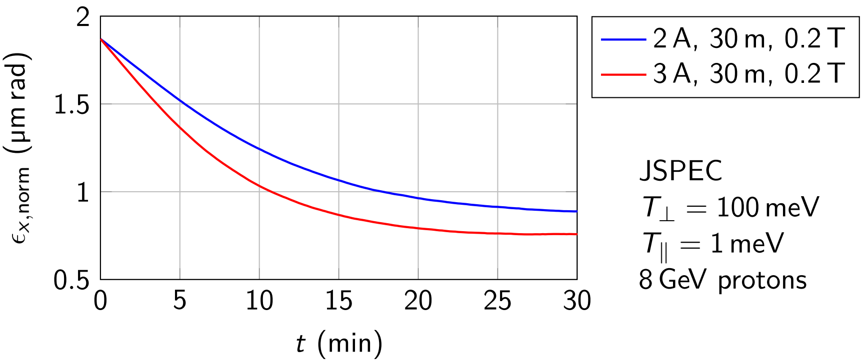
- Can we decrease $\epsilon_{x/y,\mathrm{norm}}$ to ICR values before extraction?

Cooling time (pCDR parameters)



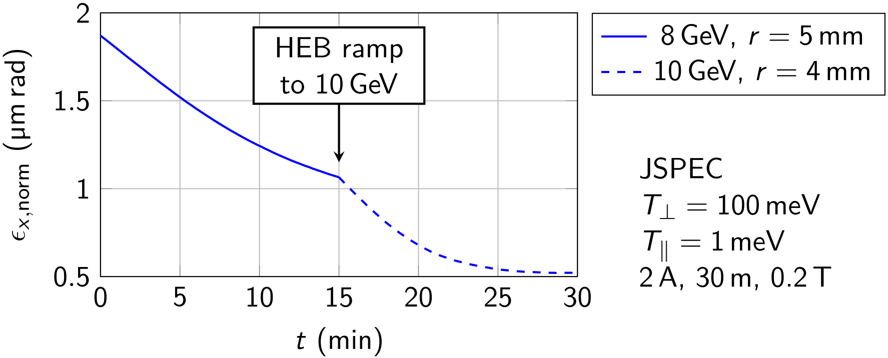
- Predicted performance is good enough at 1 T
- High field makes matching & transport problematic
- But: magnetization mandatory for sufficient cooling rate

Cooling time (relaxed parameters)



- Use longer solenoid ⇒ relaxing the field requirement to 0.2 T works
- Counteract longitudinal bunch compression (simulation pessimistic)

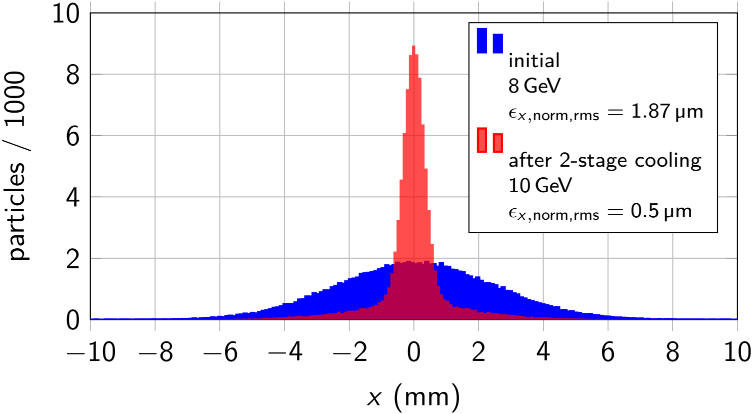
Cooling times (with energy ramp)



JSPEC
$T_\perp = 100\,\text{meV}$
$T_\parallel = 1\,\text{meV}$
2 A, 30 m, 0.2 T

- After ramp: higher $\beta\gamma$, low $\epsilon \Rightarrow$ can decrease cooler beam size
- Initial collision emittance can be reached without ERL cooler
- Requires 5.5 MeV DC cooler, but may be worth it

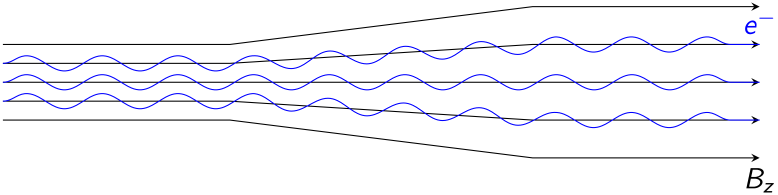
Final ion bunch distribution



- Halo is not cooled away efficiently
- Non-Gaussian shape: ϵ of central region $\ll \epsilon_{\text{rms}}$

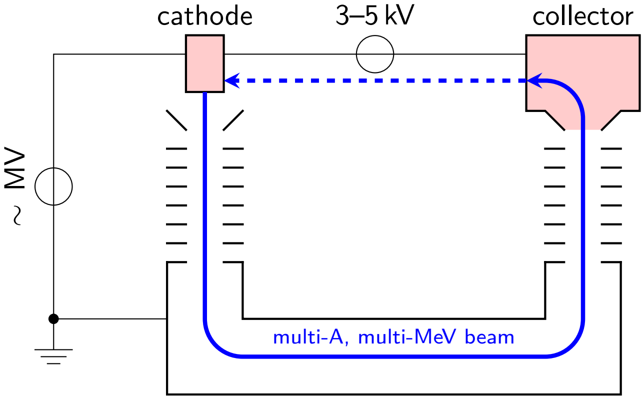
Layout of HEB, possible cooler location

Transport of magnetized beams



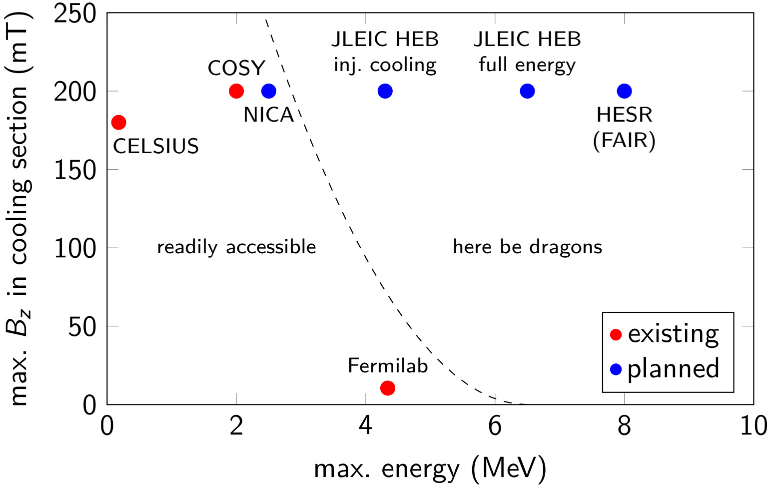
- High B_z at large cathode, quasi-continuous solenoid needed
- Adiabatic field transitions, conservation of enclosed flux
- Optics fundamentally different than betatron
  - No (conventional) ϵ
  - Cylindrical charge distribution (depending on gun), no halo

Energy recovery schematic, power budget



- $P_{\text{collector}} = U_{\text{collector}} I_{\text{beam}} \approx 3\text{–}15\,\text{kW}$
- Total power consumption almost independent of beam power
- Power budget: mostly magnets, a few auxiliary components

A selection of DC coolers



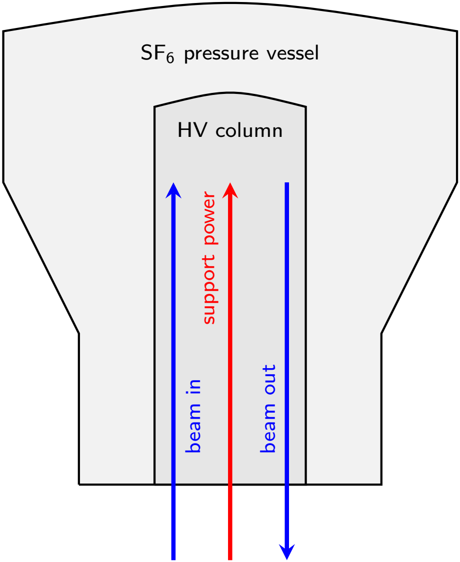
Remarks on history

- Designs start out ambitious and end up conservative
  - Turbine approach considered for a decade and postponed every time (COSY, NICA)
  - SC solenoids considered but never applied (NICA)
  - Beam energy and current may be a compromise (COSY)
- But: Fermilab cooler was innovative and performed well
- Now: identify good trade-off
- Simpler to write parameter table than to build machine

Risk mitigation

- Copy well-established components wherever possible
  - COSY-like gun with segmented + voltage-modulated grid (for BPM and ion-clearing pulses) + beam shaping feature
  - COSY-like high-perveance collector with maximum suppression of secondary current: anti-solenoid, suppressor field, Wien filter, ...
  - Conservative voltage rating of insulators + clearances
- NC pancake cooling solenoid limited in field but may suffice (keep as option)
- HV tank and acceleration column scalable to the extent necessary
- Biggest challenge: transfer of support power to acceleration section

Schematic tank layout



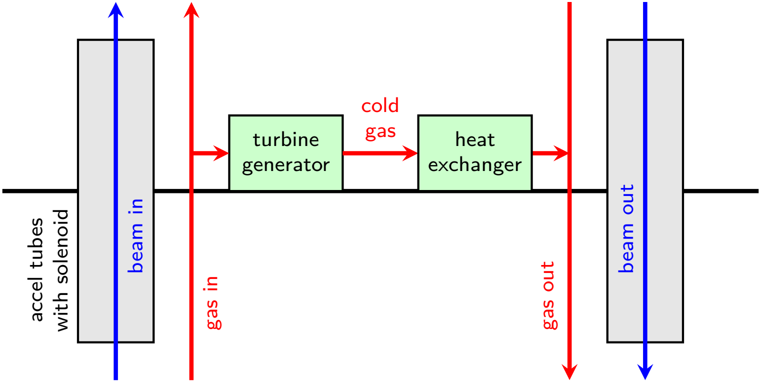
- Energy recovery: equal potentials for accel and decel
- Stack of insulated platforms for magnets and supports
- Scalability of power transfer depends on amount of power and total voltage

Power conversion for magnets and HV

Cooler	Energy (MeV)	HV	Support power
Fermilab	4.3	Pelletron	rotating shafts
COSY	2.0	SMPS	cascade transformer
NICA	2.5	SMPS	cascade transformer

- Cascade transformer good up to 2.5 MV
- Mechanical transmission demonstrated for 4.3 MV but with little power ⇒ What is the limit?
- Needed: modular floating power source
  - Powers magnets and modular HV supply
  - Series connection up to full voltage
  - Extra mechanical HV generator unnecessary
  - Granularity of modules: flexible (e.g. cascade transformer hybrid)

Turbine approach (development by BINP/HIM)



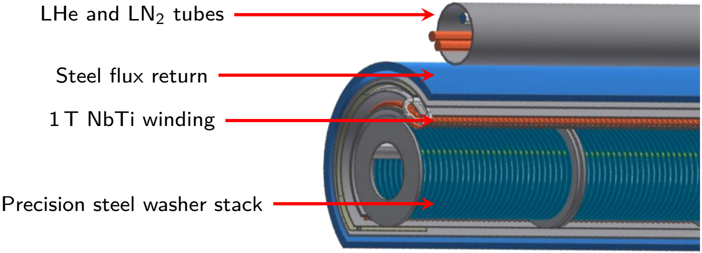
- Modules independent and stackable
- Pressurized gas transports power; efficiency independent of size
- Cold exhaust gas removes heat from loads on platform via HX

HEB cooler design: voltage options

- Why 4.3 MeV? Already demonstrated by Fermilab, but can be increased
- New power conversion concept is needed anyway
- Try to design for 5.5 MeV (10 GeV protons). Numbers are preliminary estimates

	4.3 MeV	5.5 MeV
Length of acc. section (m)	5.0	6.5
Tank height (m)	7.5	9.0
Total height above toroid (m)	8.5	10.0
Tank diameter (m)	4.5	5.0
Coil power in tank (kW)	21	28
Collector power (kW)	10	10
Extra misc power (kW)	1	1
Net total power in tank (kW)	32	39

Cooling solenoid



from: Peter McIntyre et al.: Micro-aligned Solenoid for Magnetized Electron Cooling

- Try to use same module as in CCR
  - Length: 15 m
  - Field straightness: $\approx 1 \times 10^{-5}$ rad
  - Field strength: up to 1 T (superconducting), would operate at 0.2 T
- If it can be used, it dictates the length of the cooling section
- Evaluate space constraints, keep normal-conducting option open

Conclusion and R&D remarks

Design choices

- pCDR parameter set feasible but aggressive
- Explore higher-voltage options for cooler redundancy and more conservative parameter choices

Power conversion schemes

- Turbine platform is not commercialized, still at testing stage in Russia/Germany
- Engineering effort necessary to design a copy of it if we can't readily buy it
- Fallback to rotating rods possible (investigate max power)