HAICU-UBC Development Progress Report

Dec 22, 2023

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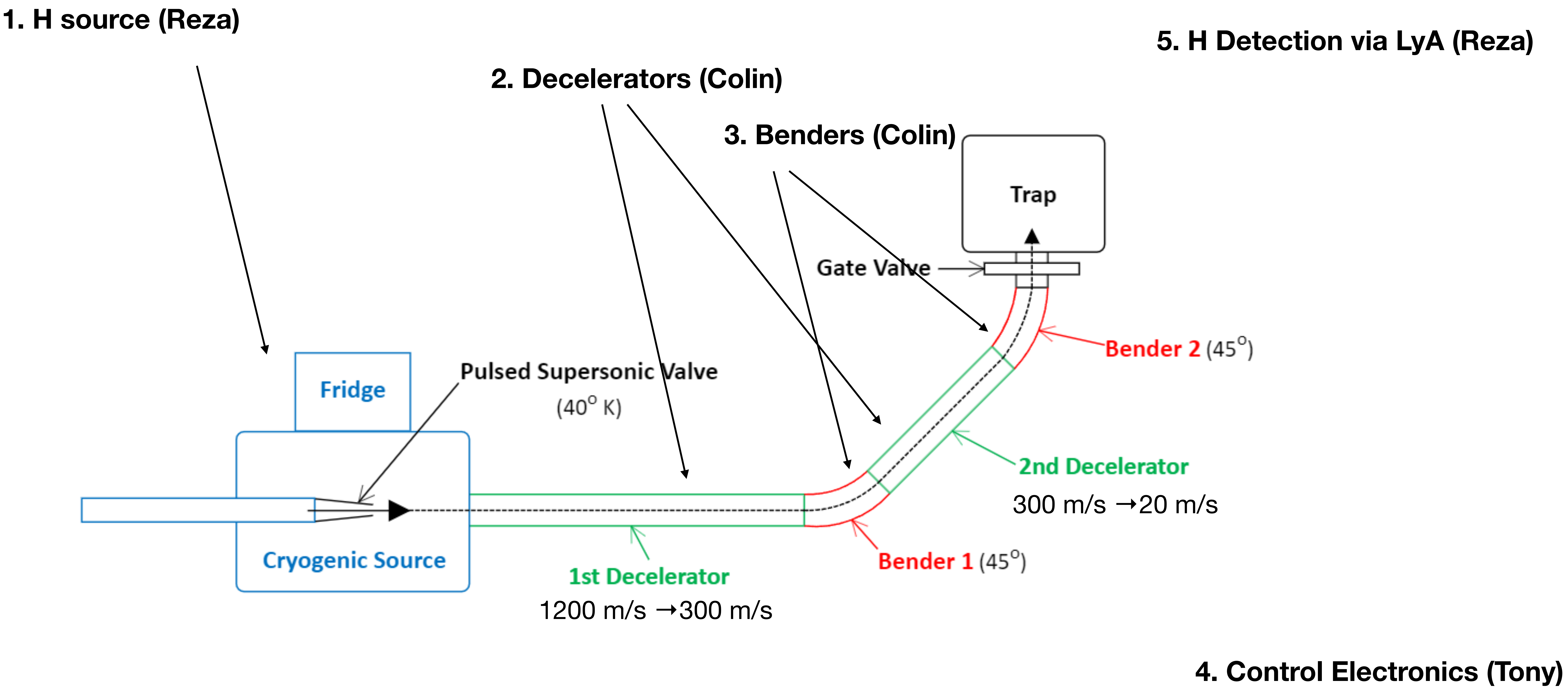
OVERVIEW


1. H source (Reza)
5. H Detection via LyA (Reza)
2. Decelerators (Colin)
3. Benders (Colin)
Trap
Gate Valve
Bender 2 (45°)
Pulsed Supersonic Valve
(40° K)
Fridge
2nd Decelerator
300 m/s →20 m/s
Cryogenic Source
Bender 1 (45°)
1st Decelerator
1200 m/s →300 m/s
4. Control Electronics (Tony)

OVERVIEW

1. H Source Pure H_2 or H_2 in Ne or He supersonic expansion

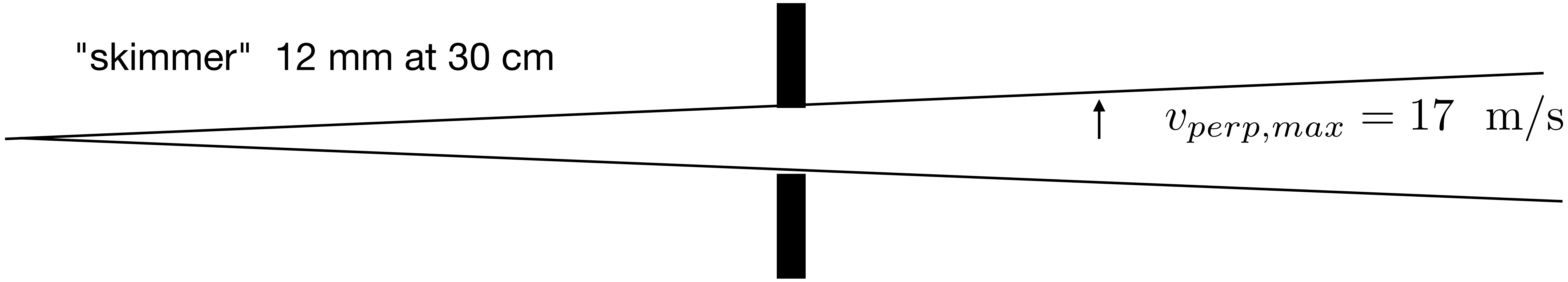
Supersonic beam 30 % H2 in Ne at 100 K, 10 bar : 830 m/s ± 15 m/s H_2 density 2×10^{13} /cc

30 % H2 in He at 30 K, 10 bar : 670 m/s ± 10 m/s H_2 density 6×10^{13} /cc

$$v_{axial} < 20 \ \ \mathrm{m/s}$$

Pulsed gas valve (20 - 100 us opening) : beam length 2 - 8 cm at 800 m/s

"skimmer" 12 mm at 30 cm



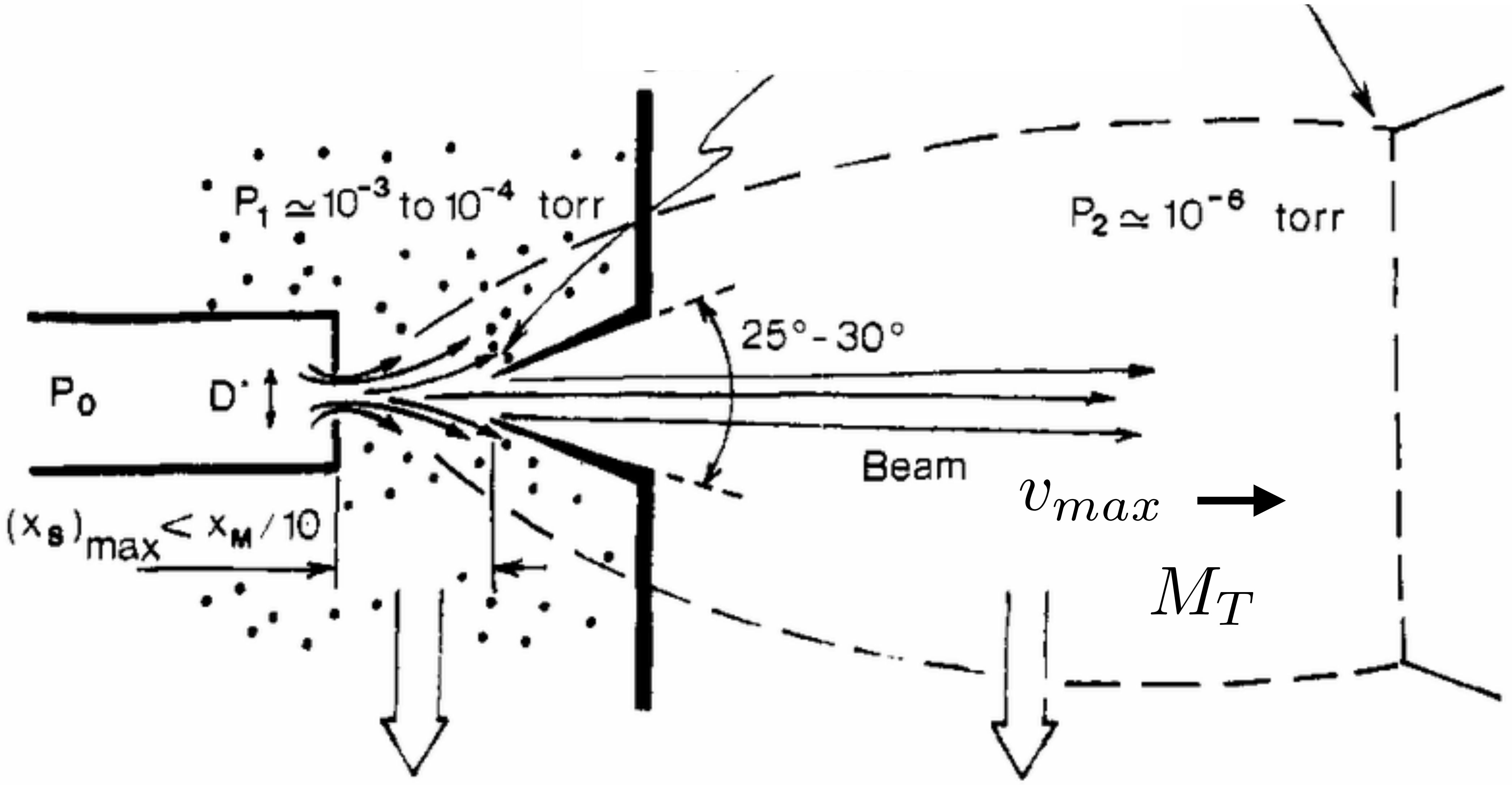
H generation: plate discharge at >2.5 kV

$$H_2 \ \rightarrow \ H + H$$

(expected efficiency > 10 %) **H density (target)** 1×10^{12} /cc

Supersonic beam

1 st Mach disk



nozzle

skimmer

Adiabatic expansion: conservation of total enthalpy

directed mass flow maximum velocity

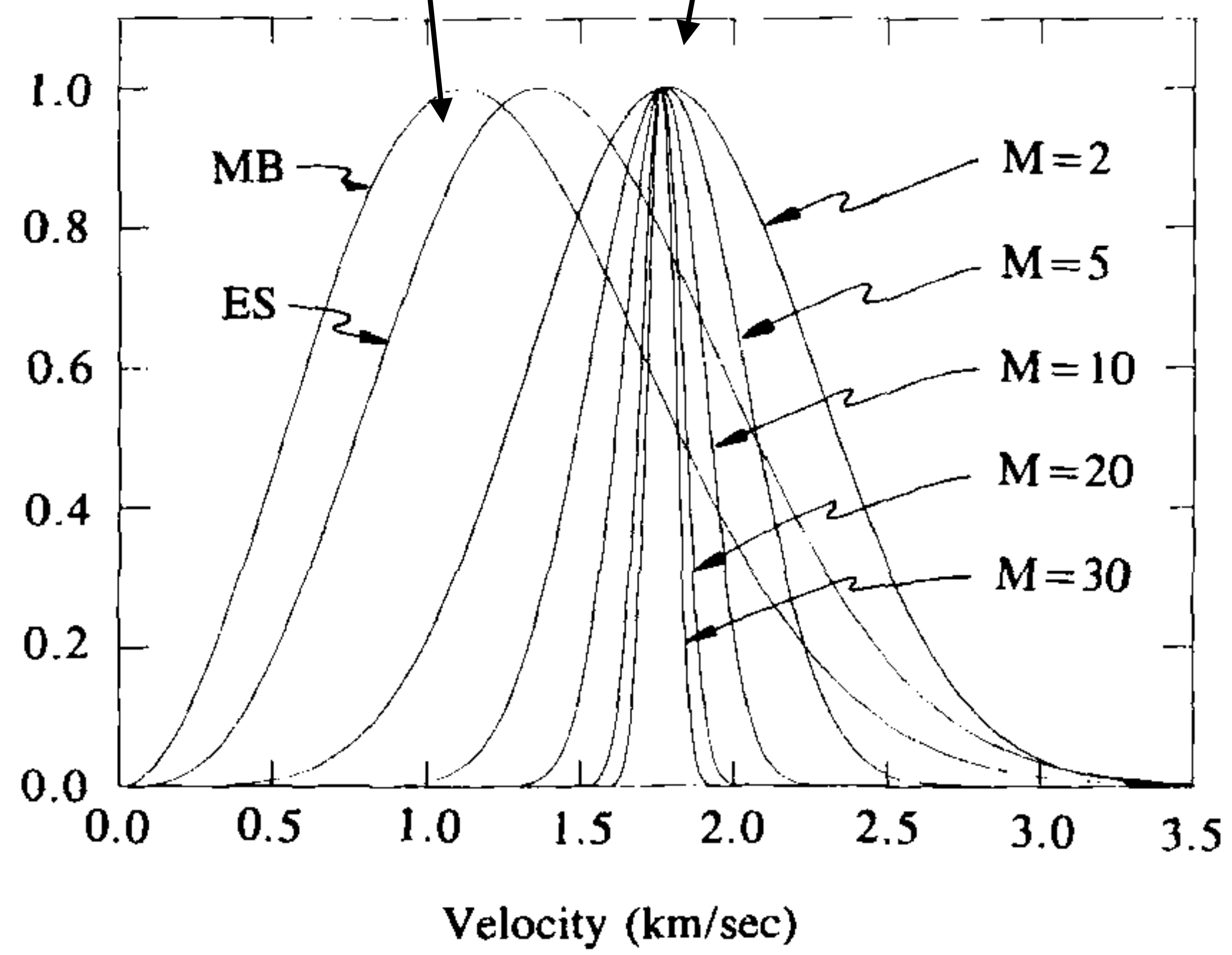
$$v_{max} = \sqrt{\frac{2H(T_0)}{m}} = \sqrt{\frac{2C_pT_0}{m}}$$

$$\frac{T(x)}{T_0} = W^{-1} \qquad \frac{\rho(x)}{\rho_0} = W^{-\frac{1}{\gamma-1}}$$

$$W = 1 + \frac{\gamma-1}{2}M(x)^2$$

Thermal beam

supersonic beam



Mach number

$$M(x) = \frac{v(x)}{a(x)}$$

Speed of sound

$$a(T) = \sqrt{\frac{\gamma RT}{m}}$$

Terminal Mach number

$$M_T = G(\sqrt{2}\sigma\rho_0 D\epsilon)^{\frac{\gamma-1}{\gamma}}$$

- σ effective cross section
- γ heat capacity ratio
- D nozzle orfice diameter
- ρ_0 stagnation density
- ϵ collision efficiency $\epsilon \leq 1$
- G constant

	sound velocity at the nozzle m/s	max velocity m/s	skimmerMach number	skimmer temp/K	skimmer density /m^3	skimmer velocity deviation ~ sqrt(kT/2m} m/s
300 K, 2bar						
He	1019.13	1765.19	394.91	5.77E-03	4.13E+18	2.45
Ne	453.91	786.20	394.91	5.77E-03	4.13E+18	1.09
H2	1316.23	2943.17	64.85	3.56E-01	2.38E+18	27.11
100K, 10 bar						
30% H2 in Ne		827.51		3.70E-02	1.66E+18	18.97

Reza

H Source Summary

Scope

- Generate H beam with > 10^{12} particles/cc at <900 m/s velocity

Progress

- Confirmed that He and Ne gas discharges would work for H generation.
- Optimization is still underway. Limited cooling test due to the size of the current test chamber.

Outlook

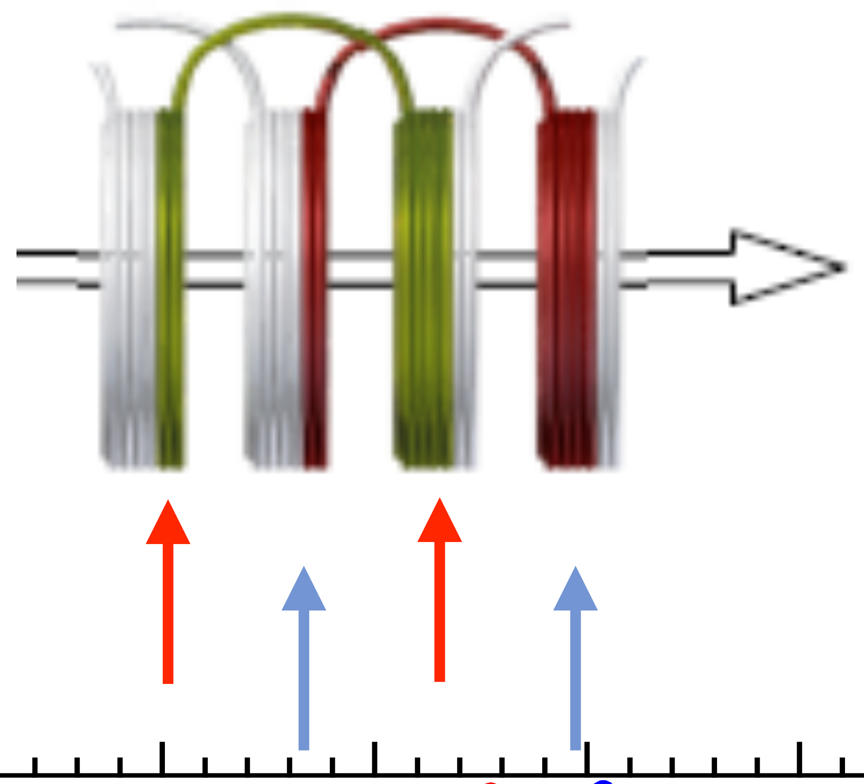
- Refrigerated large source chamber ready to test January 2024.
- Test of higher voltage discharge in January 2023
- Finalize the nozzle condition by February.

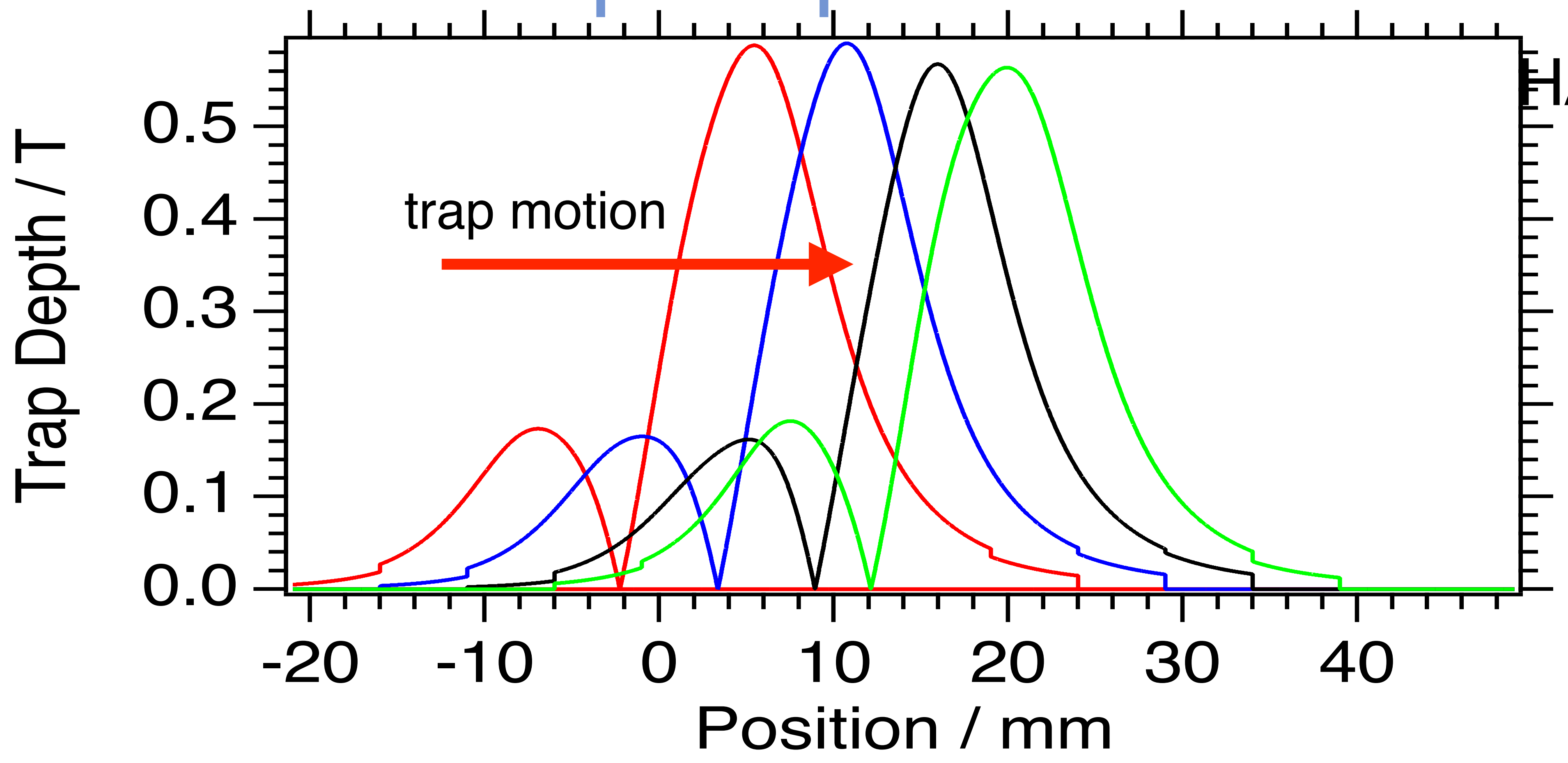
Risks

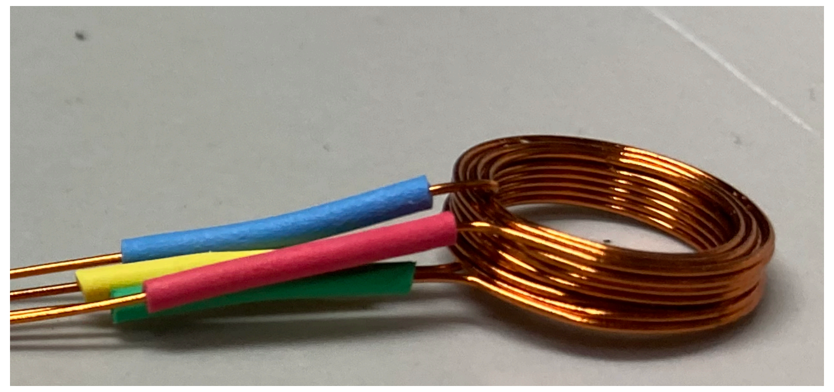
- Optimization is still underway. Difficult to predict final achievable density.
- Long term stability of the discharge nozzle is unknown
- Need to improve laser frequency stability and calibration.

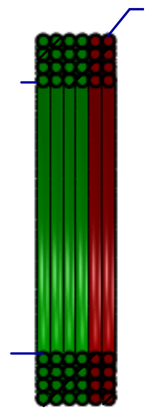
OVERVIEW

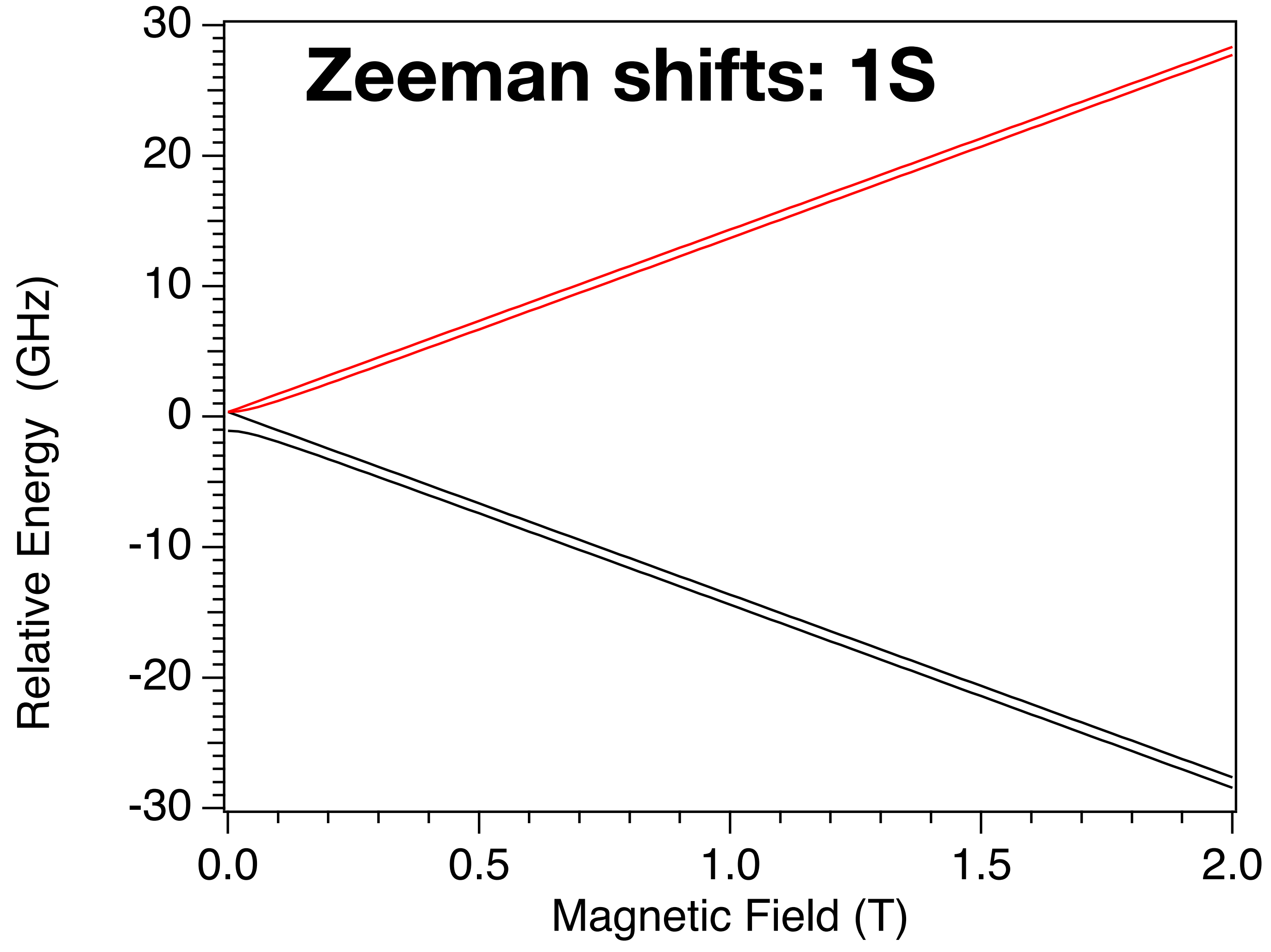
2. Decelerator Moving trap decelerator











$$\frac{dE}{dB} = g_e \mu_B M_s \sim \mu_B$$

$$\sim 0.466 \quad \text{cm}^{-1}/\text{T}$$

Force

$$F = -\frac{dE}{dz} = -\frac{dE}{dB}\frac{dB}{dz}$$

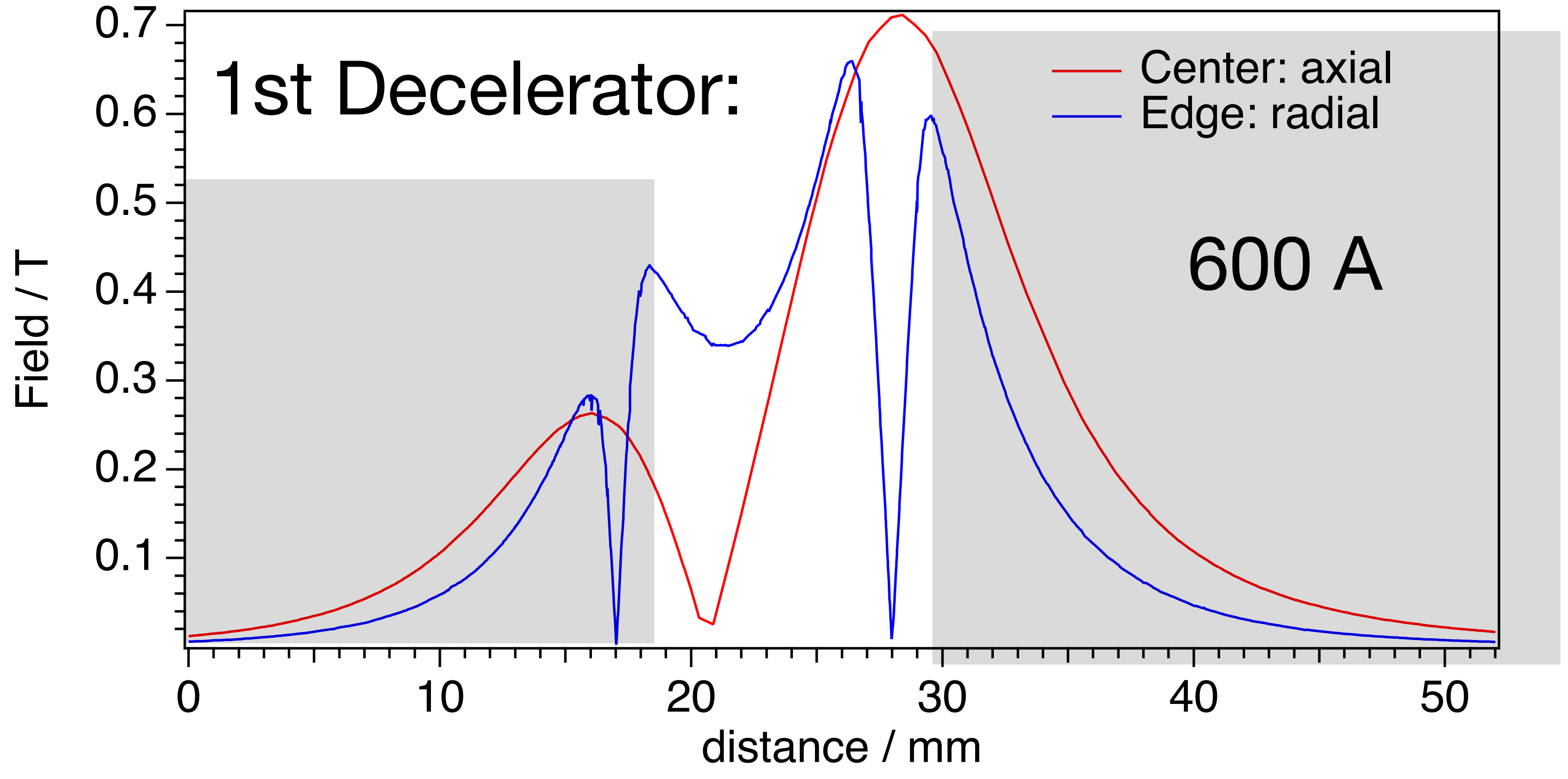
$$\frac{dB}{dz} \sim 100 \sim 170 \quad \mathrm{T/m}$$

HAICU design

1st Decelerator: 12 mm diameter, 2 *4 and 4* 4, 24 AWG

2nd Decelerator: 10 mm diameter, 2 *4 and 4* 4, 26 AWG

trap volume ~ 0.1 cc



Trap condition

$$v_{axial,max} = 46 \quad \mathrm{m/s}$$

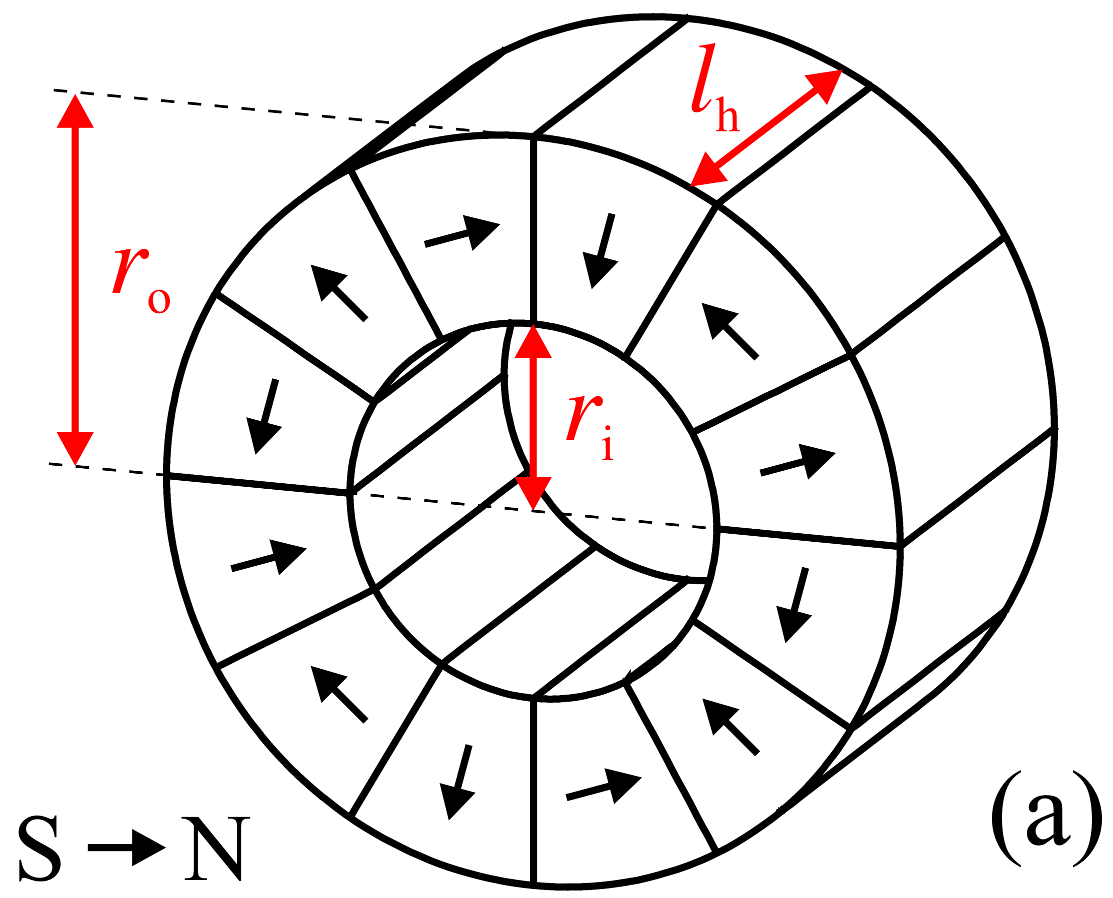
$$v_{radial,max} = 61 \quad \mathrm{m/s}$$

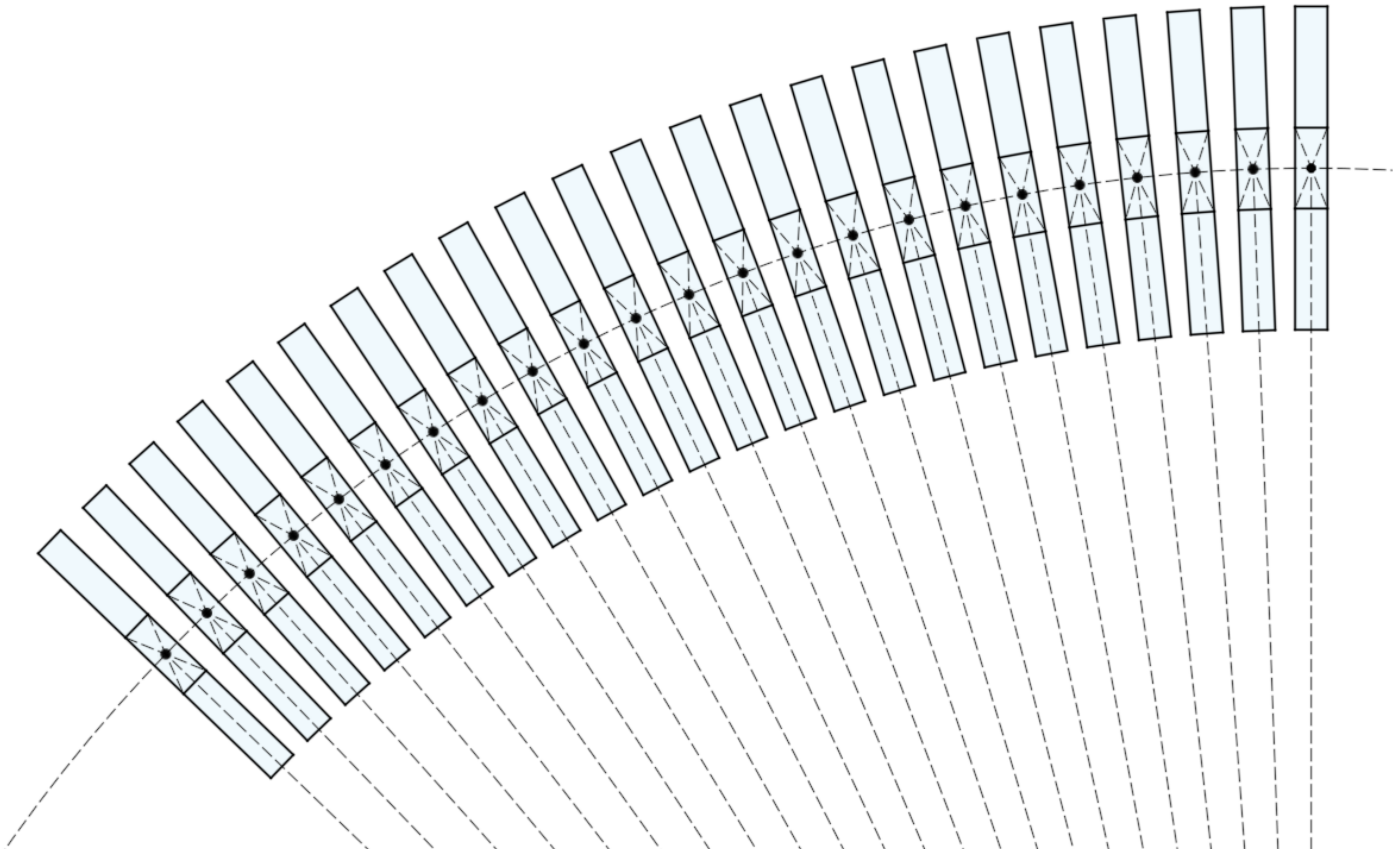
Deceleration efficiency

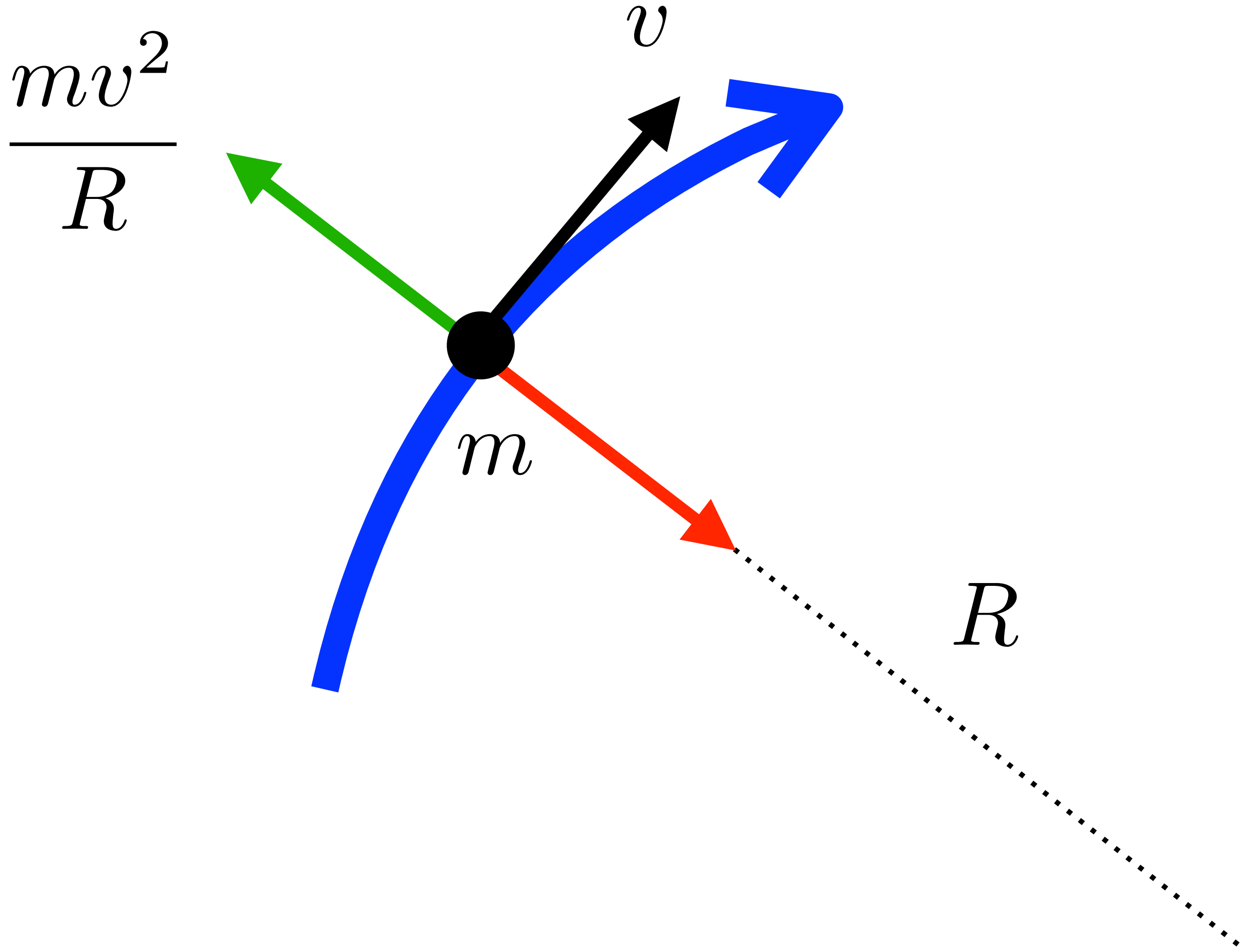
10 - 100 %

OVERVIEW

3. Bender 1   Halbach array permanent magnets







centripetal force $= \dfrac{mv^2}{R}$

transverse magnetic force $= -\dfrac{dE}{dR} = -\dfrac{dE}{dB}\dfrac{dB}{dR} \sim -g_e \mu_B M_s \dfrac{dB}{dR} \sim \mu_B \dfrac{dB}{dR}$

$$\frac{mv^2}{R} = \mu_B \frac{dB}{dR}$$

Maximum velocity $v = \sqrt{\mu_B \dfrac{R}{m}\dfrac{dB}{dR}} = 74.7\sqrt{R\dfrac{dB}{dR}}$

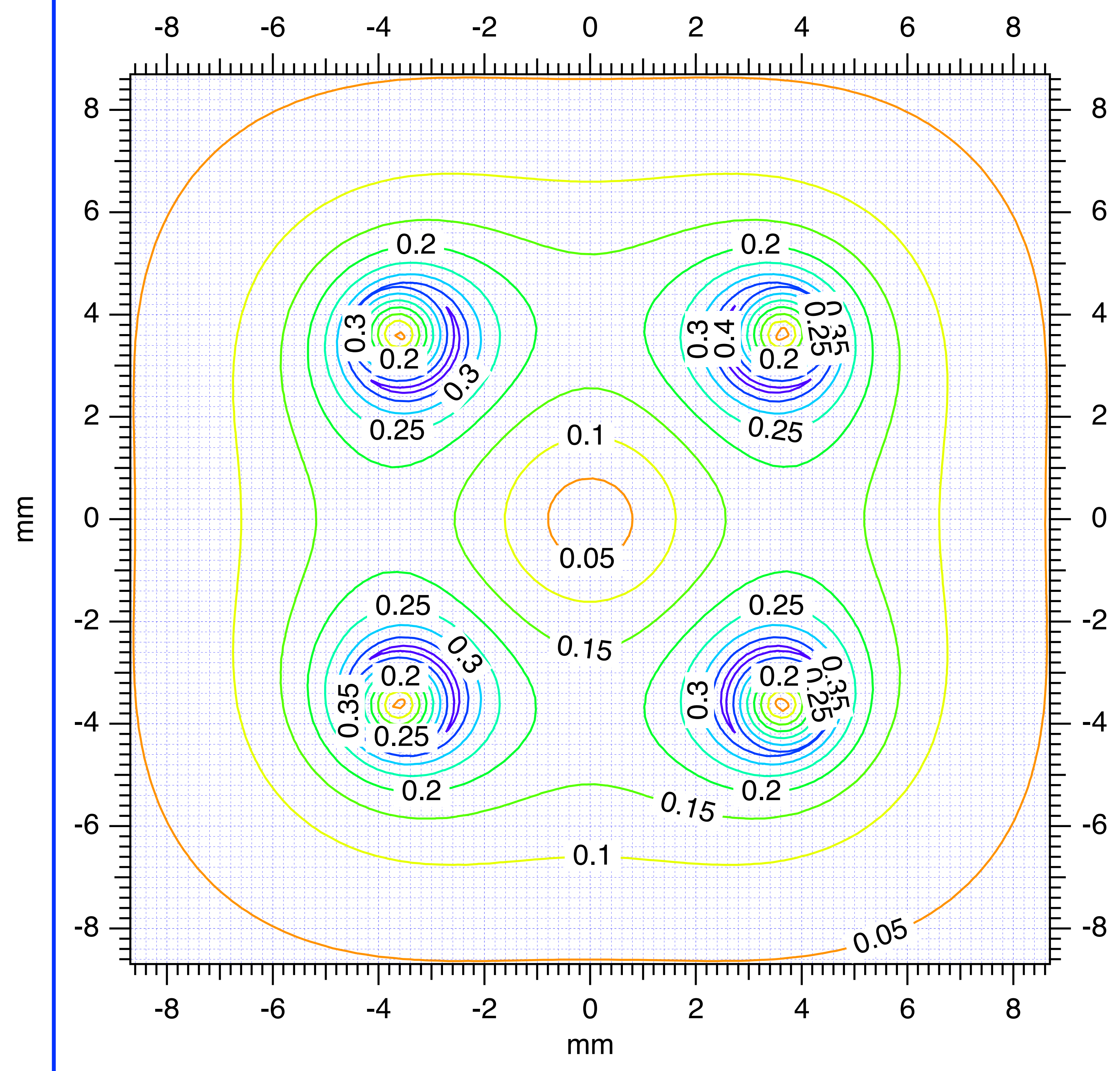
for $m = 1$

$\dfrac{dB}{dR} \geq 110 \quad \mathrm{T/m}$ $v < 360$ [m/s]   **at** $R = 200 \quad \mathrm{mm}$

OVERVIEW

3. Bender 2 quadrupole

quadrupole : 2000 A



0.177T at 4mm

$$\frac{dB}{dR} = 44\ \mathrm{T/m}$$

$$R = 100\ \mathrm{mm}$$

$$v < 156\ [\mathrm{m/s}]$$

Colin

Decelerator and Bender Summary

Scope

- The 1st decelerator 900 m/s →350 m/s, and the 2nd decelerator 350 m/s →20 m/s.

Progress

- Finalized the decelerator and the bender design. Confirmed that the trap moves smoothly.
- Ordered all necessary electrical components. Mechanical design almost completed

Outlook

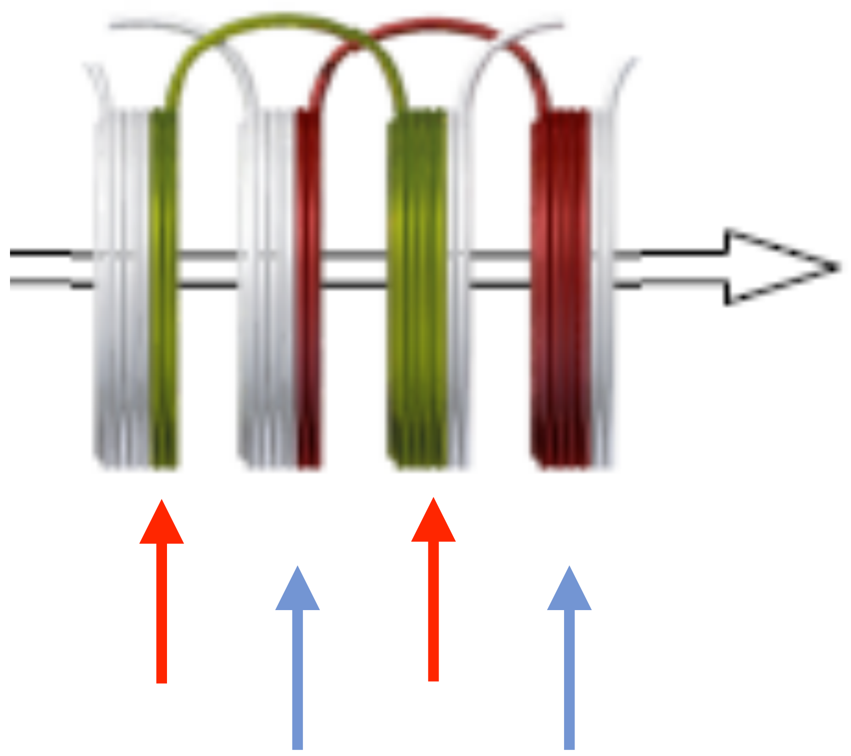
- Finalize the mechanical design by January. Installation of all mechanical components in February.
- Install and assemble all electrical components in February.
- Deceleration test in early March. Optimization during the summer.
- Benders will be tested in January (with CH_3)

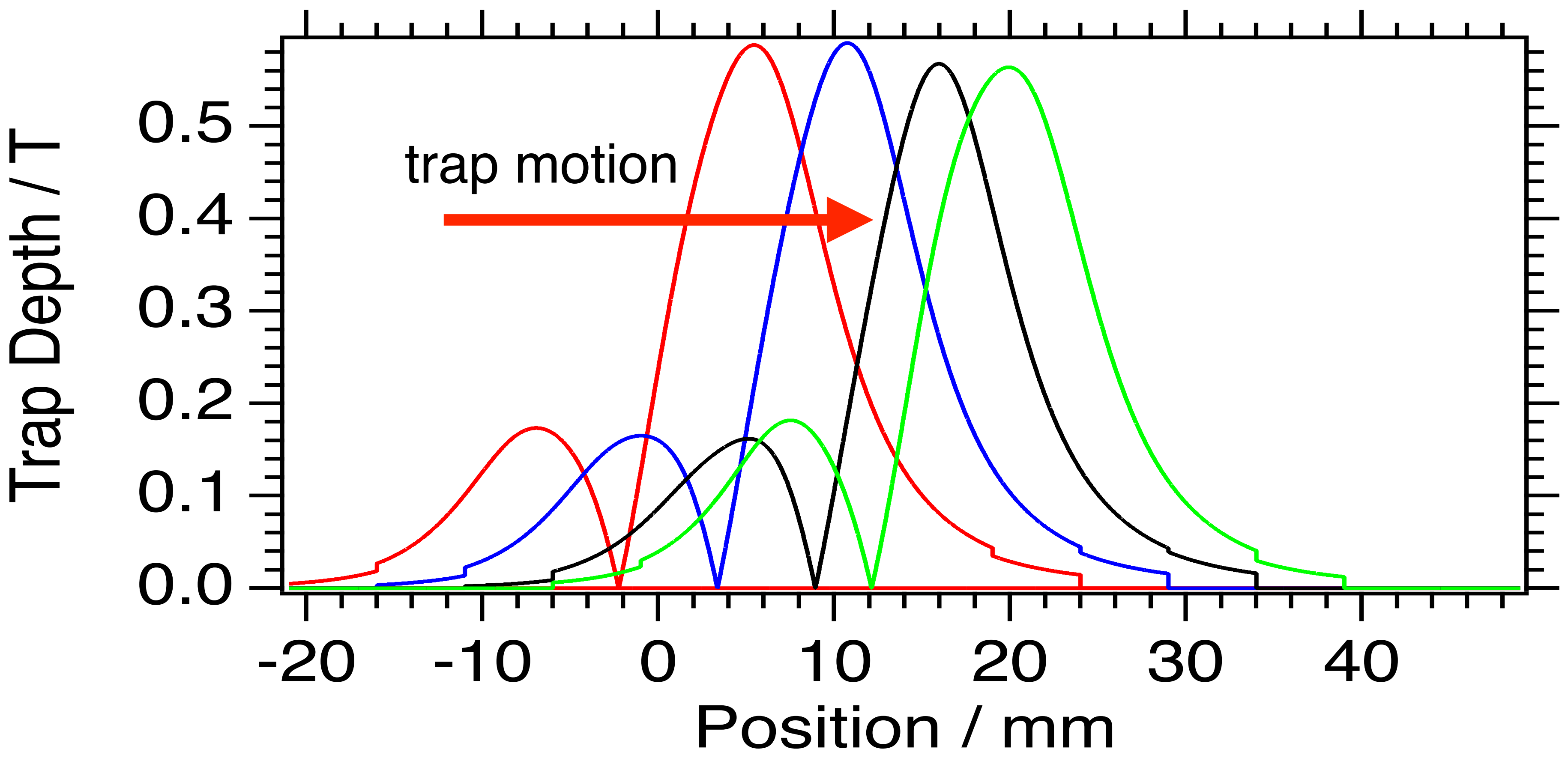
Risks

- No design risk.
- A lot of man power will be needed in February for assembly.
- The bender performance is not well characterized (until January).

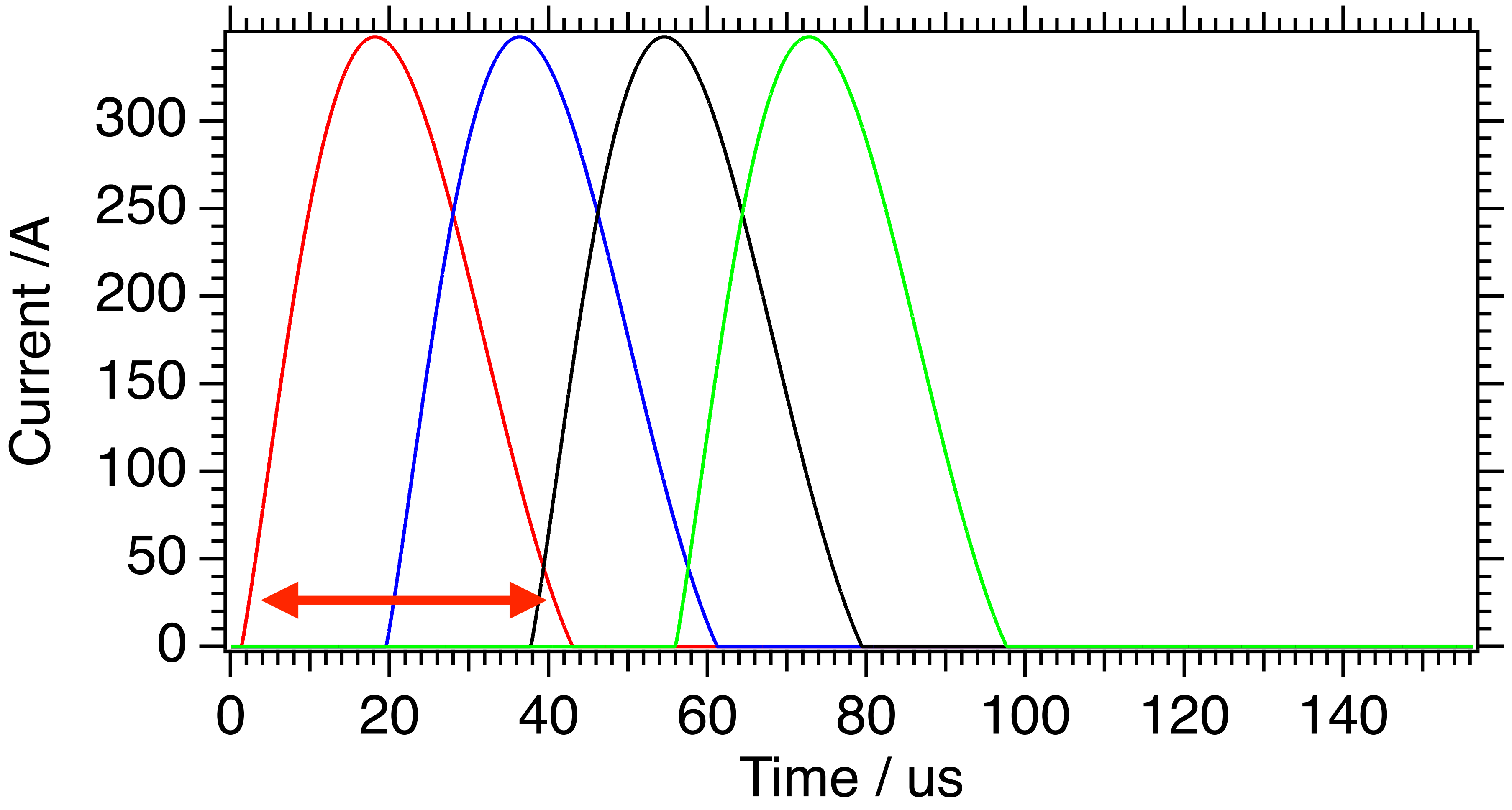
OVERVIEW

4. Control Electronics





5 - 250 us π pulse current



Initial: 1000m/s = 10 us pulse (5 us rise)
Final: 50 m/s (150 mK)= 200 us pulse

Tony

Electronics and System Control Summary

Scope

- 32 TuneBox Sets are required for 900 m/s (each Tunebox drives every 32nd trap).
- 4 banks of discharge boards are needed to provide 32 busbar paths along the decelerator
- 4 FPGA based MLDs (72 output high speed digital pattern generators) drive tuneboxes and discharge boards.

Progress

- The 1st generation system is running in Momose Lab.
- Parts for the 2nd generation are on order. TRIUMF group is migrating current FPGA firmware and PC Side code to Ethernet (currently using USB).

Outlook

- Assembled and ready to test by March.

Risks

- FPGA firmware and PC software development has no set schedule or dedicated resources in the TRIUMF Electronics Development group.
- Need to request >20% FTE of Bryerton between January and March to obtain the new program by the end of March.
- How to combine with other controls

Summary

Outlook

- Momose group will test the deceleration and trapping during the summer time.

Risks

- Relocation from UBC to TRUMF requires a lots of man power. When can we move our system to TRIUMF? Likely Nov 2024, after the 2024 CERN beam time?