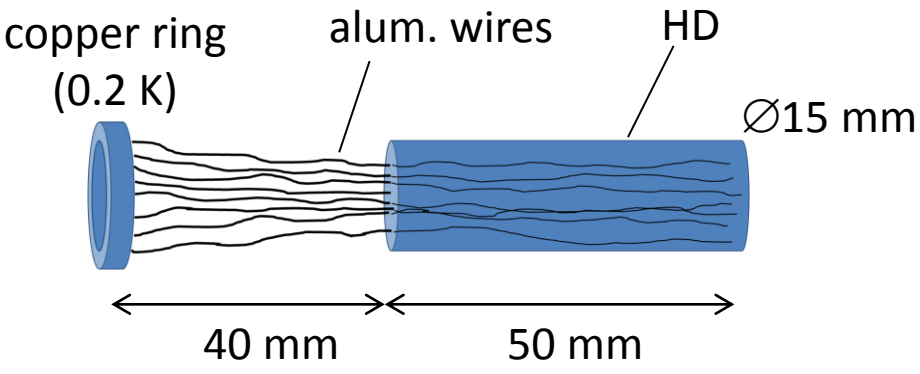
An 11-GeV Raster for Hall B

(designed for eHD)

Rastering during the 2012 eHD tests

- H- and D-polarization losses measured using NMR
- Calculations indicate target cell design and rastering were inadequate
  - Significant heating (Møller scattering)
- Solution for lower power eHD tests and 11 GeV eHD measurements:
  - New target design
  - New raster system



Local Heating of target material

- Electron beam energy deposition
  - Current density → Beam current; Spot size
  - Local irradiation time → Rastering speed
  - Material heat capacities
  - Equilibrium temperature → IBC cooling power; Target heat load
- Electron energy loss: bremsstrahlung
- Electron energy deposition: Møller scattering

target temperature

$$T = \left(\frac{\alpha}{v} + T_o^{\,4}\right)^{1/4}$$

beam and target characteristics

Equilibrium temperature

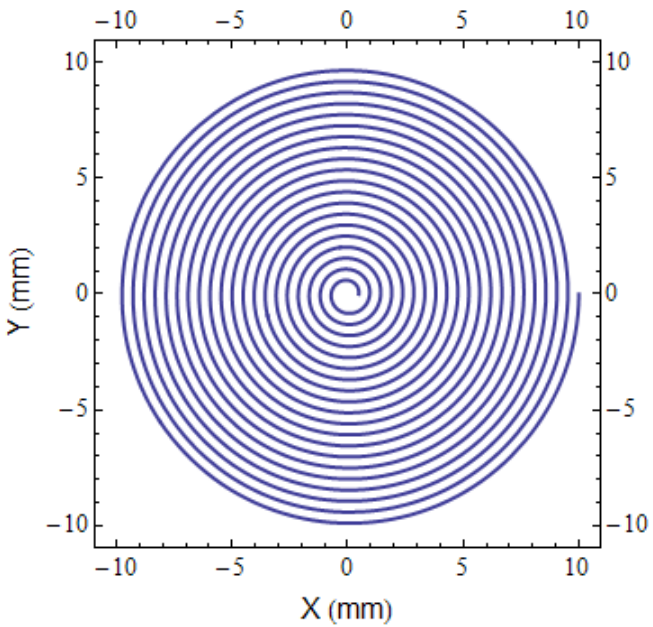
Raster speed (transverse)

Spiral Track Raster Patterns

Operational math: for spiral track, arc element $ds^2 = dr^2 + r^2 d\theta^2$
Condition for uniform irradiation: constant speed $\upsilon = ds/dt$

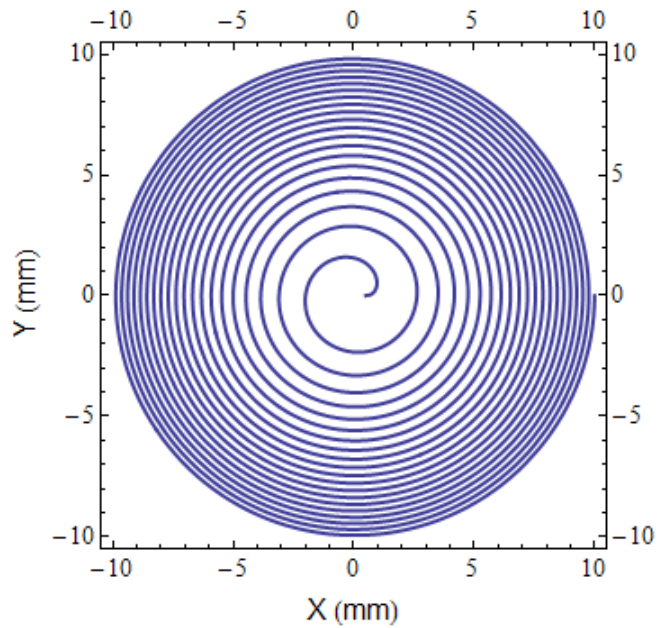
Frequency-modulation

Constant radial pitch: $dr/d\theta$



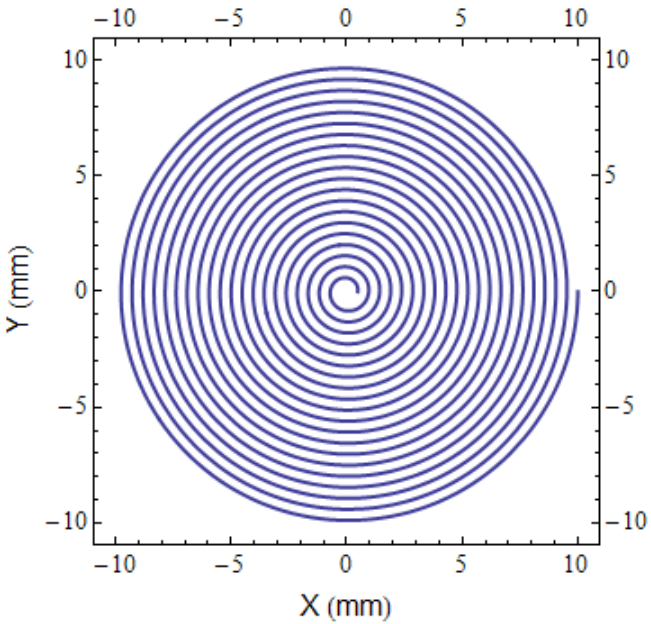
Amplitude-modulation

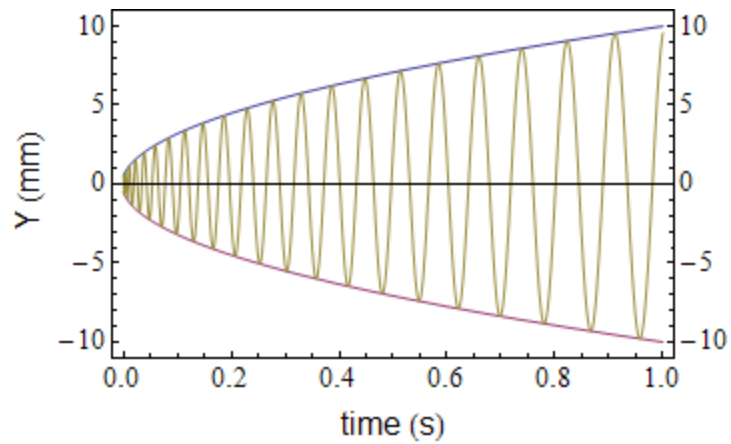
Constant angular speed: $d\theta/dt$

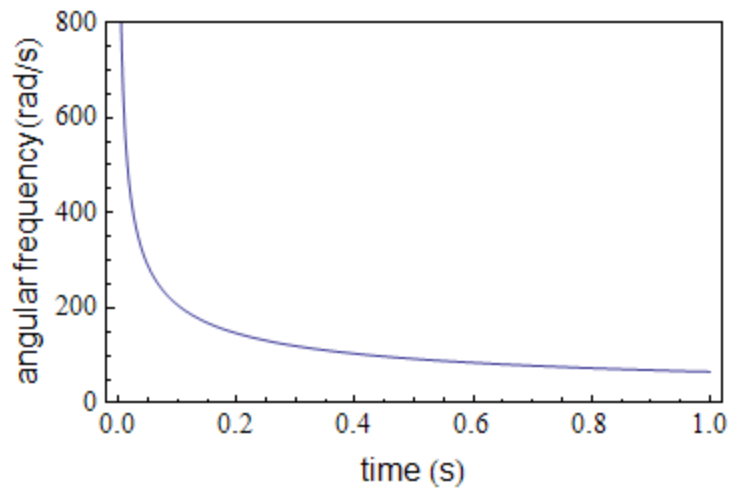


FM-mode rastering

Constant radial pitch d*r*/dθ requires changing angular frequency ω(*t*)

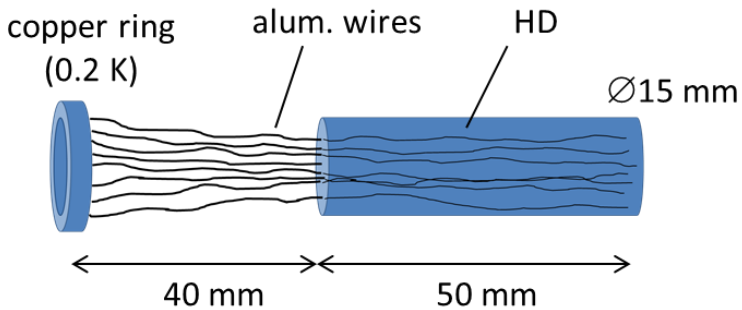


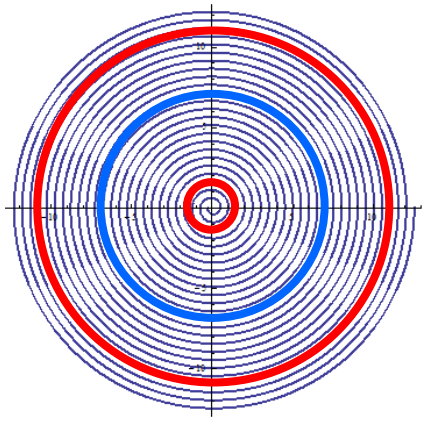




Ø20 mm pattern (R_{min}: 0.5 mm)
20-turns
υ = 0.6 m/s
refresh rate = 0.5 Hz
max freq = 1400 rad/s (220 Hz)

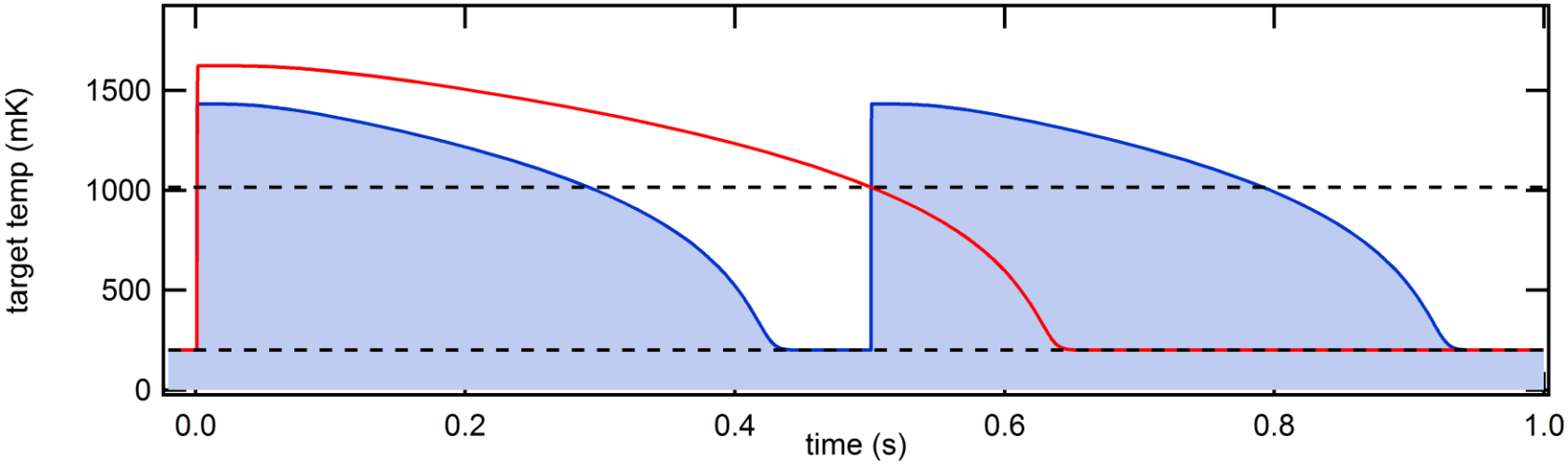
g14 Target with Hall B Slow Raster (Ø10 mm pattern)



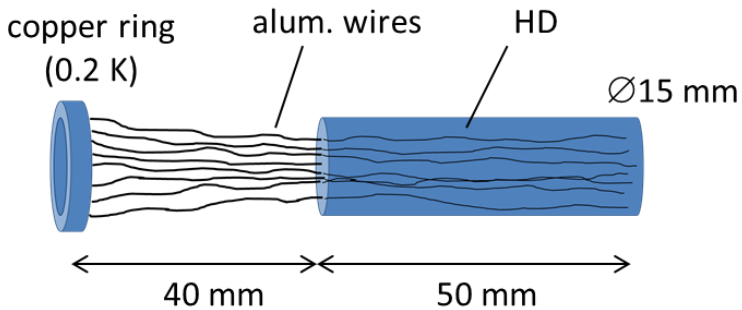


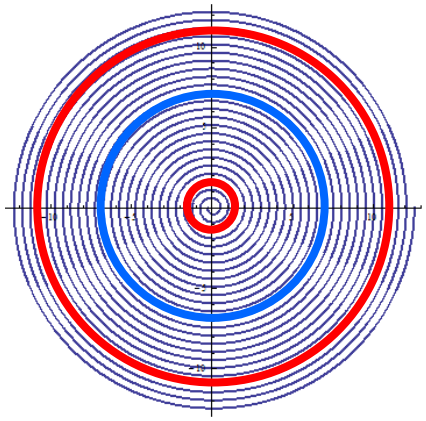
99-turns
υ = 3.1 m/s
refresh rate = 1.0 Hz
max freq = 19.8 kHz

equilibrium temp: 200 mK
max local temp: **1.43 K** / **1.62 K**
steady state temp: **1.02 K**



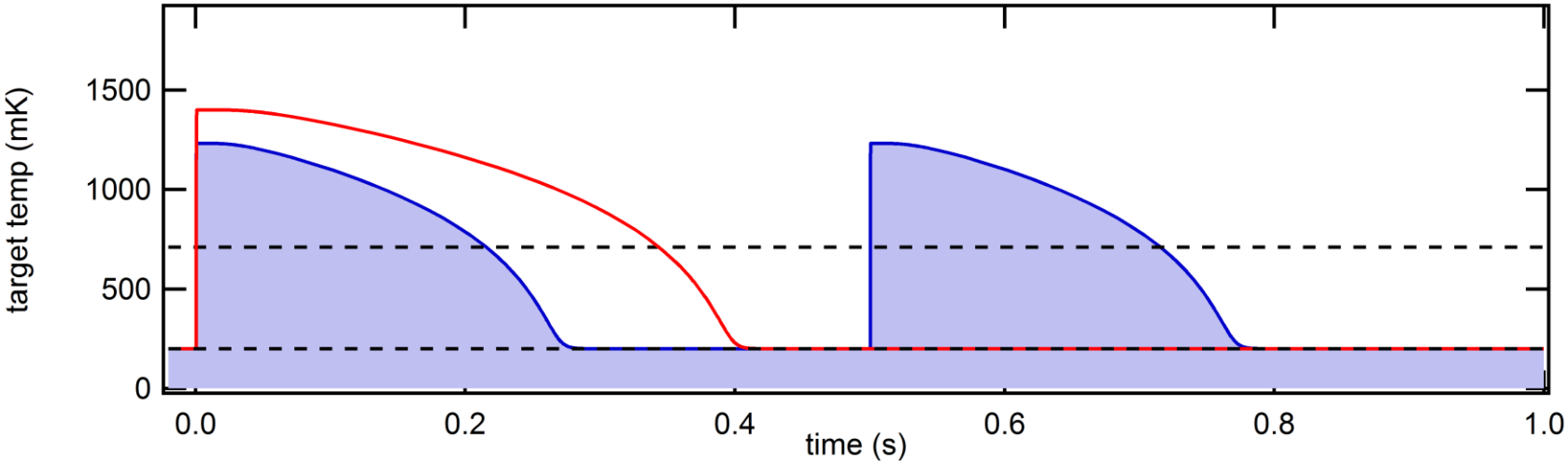
g14 Target with Hall B Slow Raster (Ø15 mm pattern)



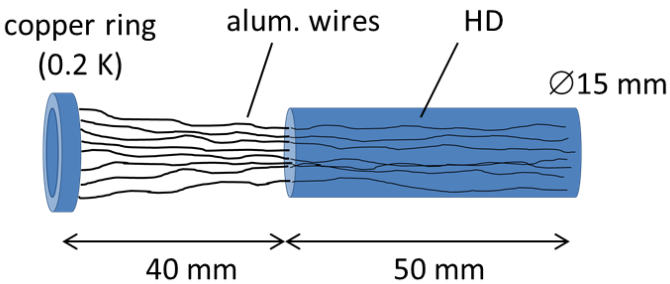


99-turns
υ = 4.7 m/s
refresh rate = 1.0 Hz
max freq = 19.8 kHz

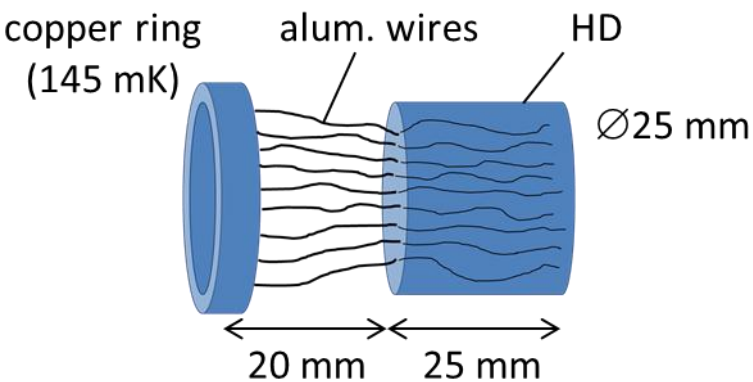
equilibrium temp: 200 mK
max local temp: **1.23 K** / **1.40 K**
steady state temp: **710 mK**



Improved target cell design



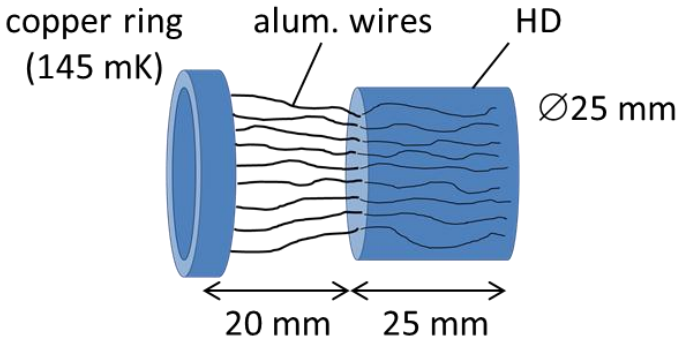
- Shorter wires
- Larger diameter wires
- Half thickness HD

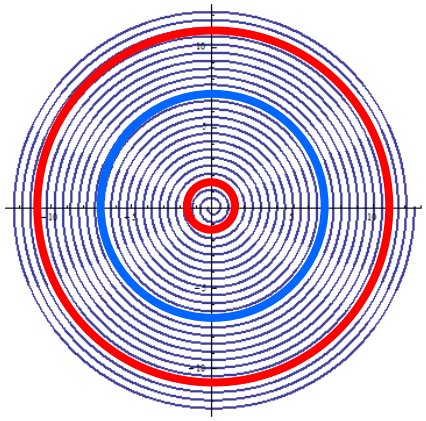


- Lower equilibrium temp
  - Reduced heat load
  - IBC cooling power

- Shorter, thicker aluminum wires for improved thermal conduction

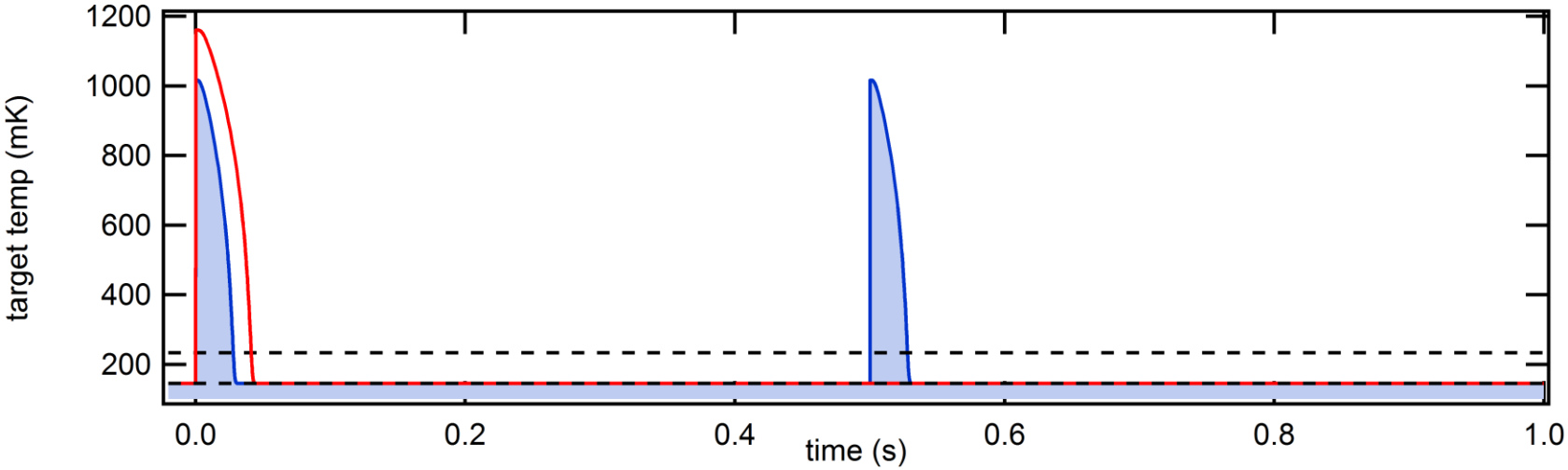
Improved target with Hall B Slow Raster (Ø25 mm pattern)



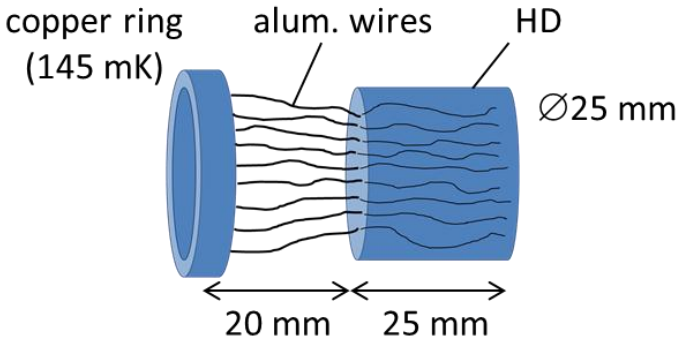


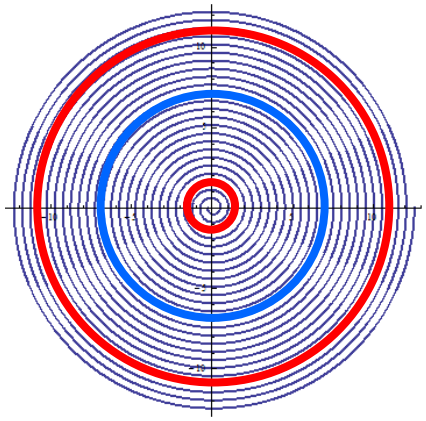
99-turns
υ = 7.8 m/s
refresh rate = 1.0 Hz
max freq = 19.8 kHz

equilibrium temp: 145 mK
max local temp: **1.02 K** / **1.16 K**
steady state temp: **233 mK**



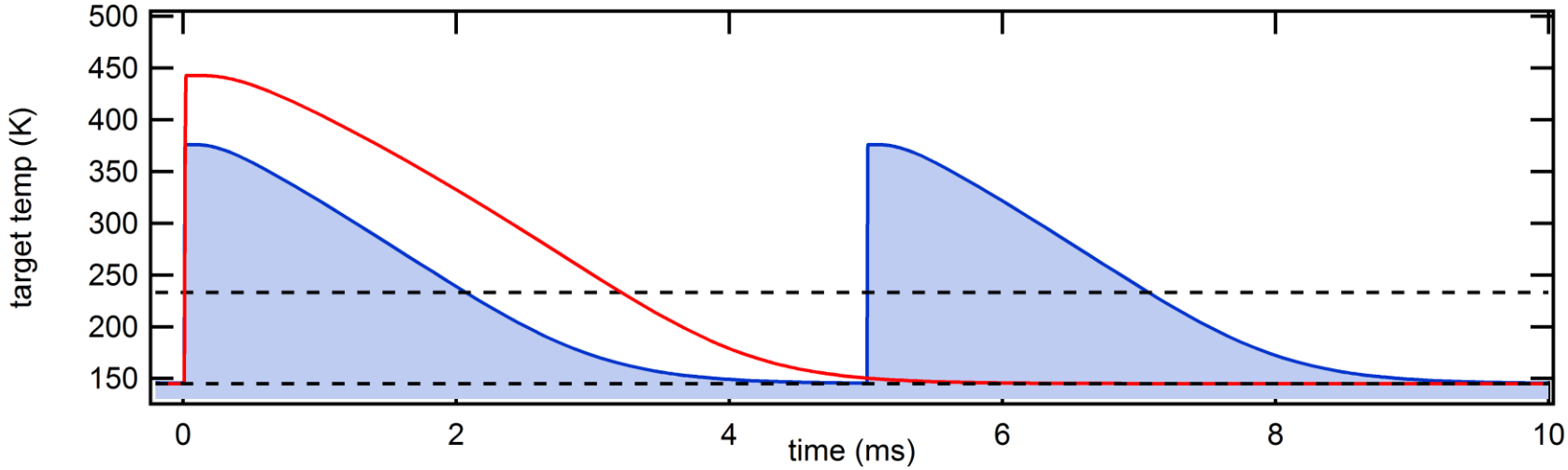
Improved target with Hall B Slow Raster **x100 raster speed**





99-turns
υ = 780 m/s
refresh rate = 100 Hz
max freq = 2 MHz

equilibrium temp: 145 mK
max local temp: **376 mK** / **443 K**
steady state temp: **233 mK**



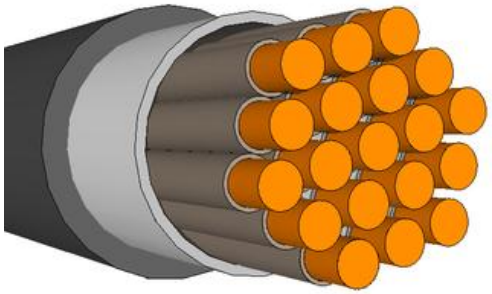
Technical issues with FM-mode rasters

Problems with high-speed FM-mode rasters:

- High peak frequencies
  100 Hz raster speed → 50 kHz sustained AC
  → 2 MHz peak AC
- Magnet drivers / power amplifiers
- High-freq AC generates EMFs in conductors
  (eddy-currents: heating & power losses)

Hall B Slow Raster magnet uses heavy gauge windings

(unsuitable for high-frequency AC)

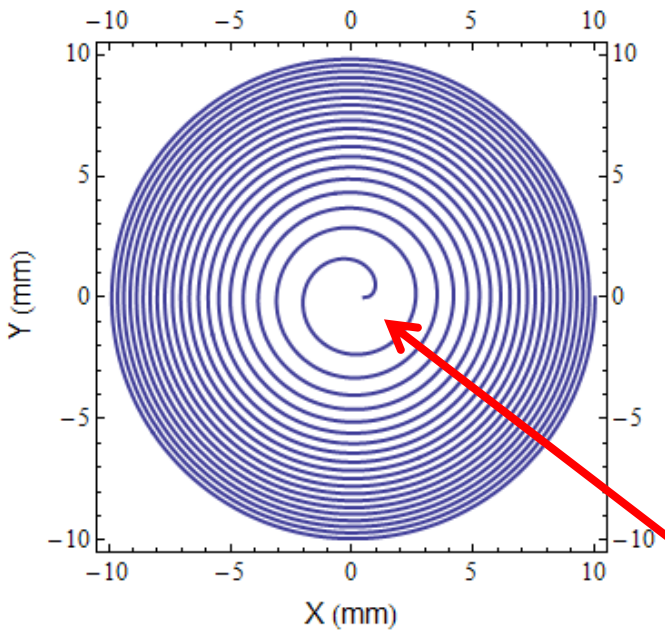


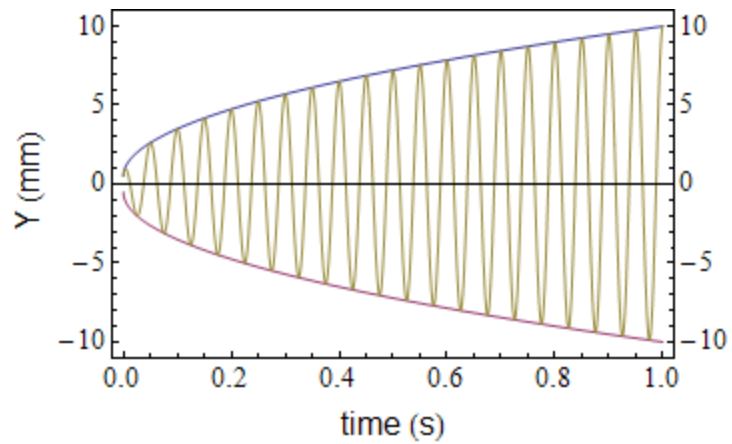
Alternative magnet coil wire: ***Litz cable***
(multiple wire strands, individually insulated)
(operate to ~100 kHz AC)

Unfortunately, 100 kHz << 2 MHz and higher!
(Litz cable not an option for high-speed FM-mode raster)

Amplitude-modulation (AM) rastering

Constant angular frequency $\omega(t)$

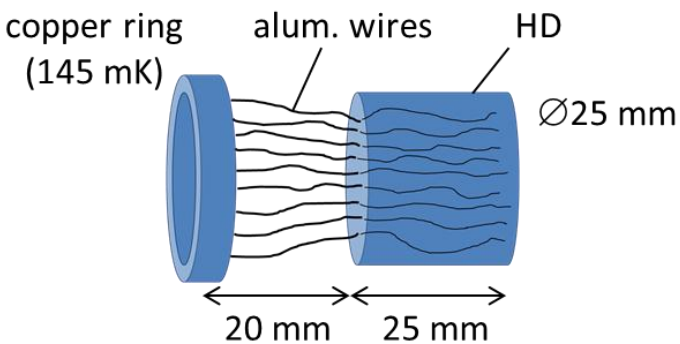


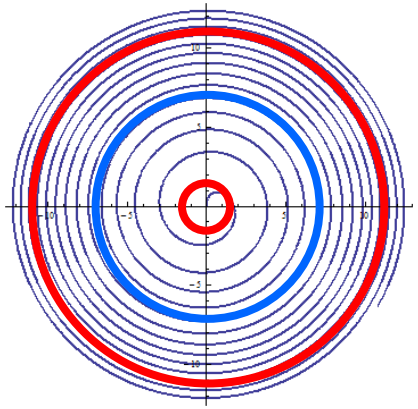


Ø20 mm pattern (R_{min}: 0.5 mm)
20-turns
υ = 0.5 m/s
refresh rate = 0.5 Hz
angular freq = 125 rad/s (20 Hz)

- No high-frequency peaks!
- Problem: non-uniform coverage near center
- Compensate with
  - higher frequency
    (larger than FM-mode sustained frequency)
  - pattern precession

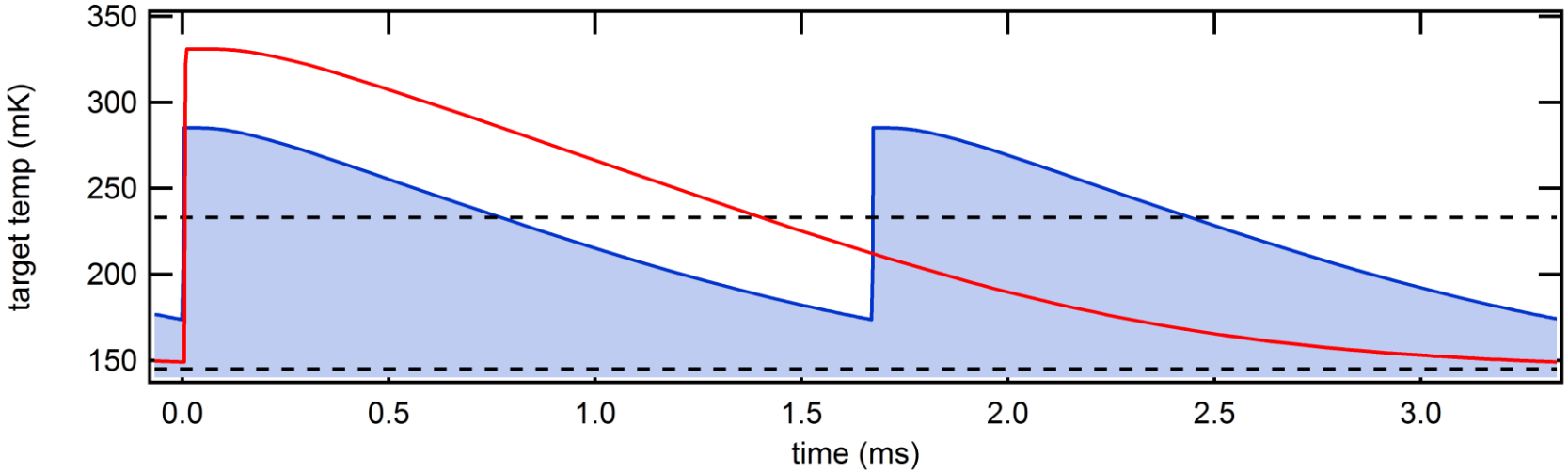
Improved target with AM-mode raster (Ø25 mm pattern)



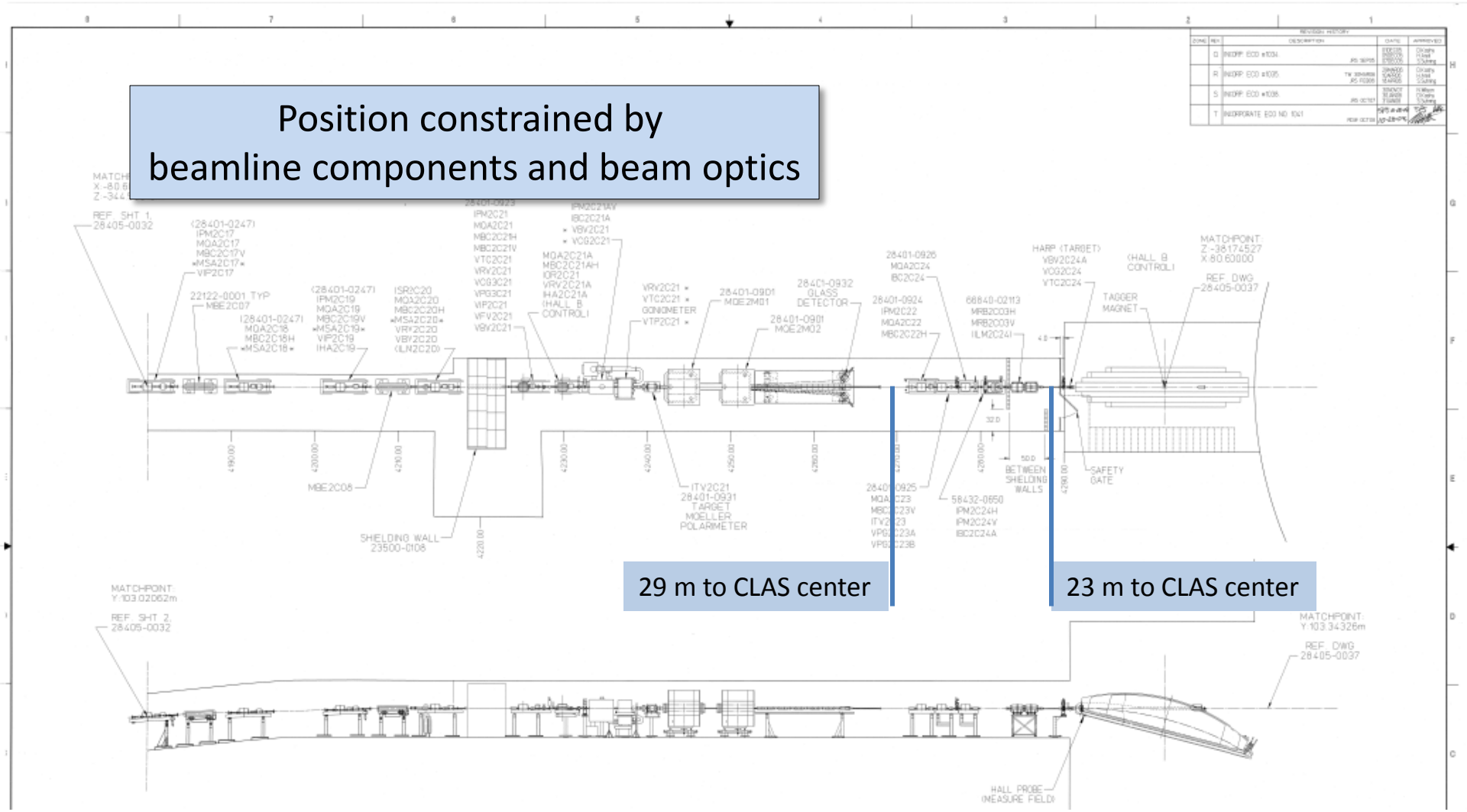


υ = 1885 m/s
refresh rate = 900 Hz
freq = 24 kHz
precession ratio 3:1

equilibrium temp: 145 mK
max local temp: **286 mK** / **331 mK**
steady state temp: **233 mK**

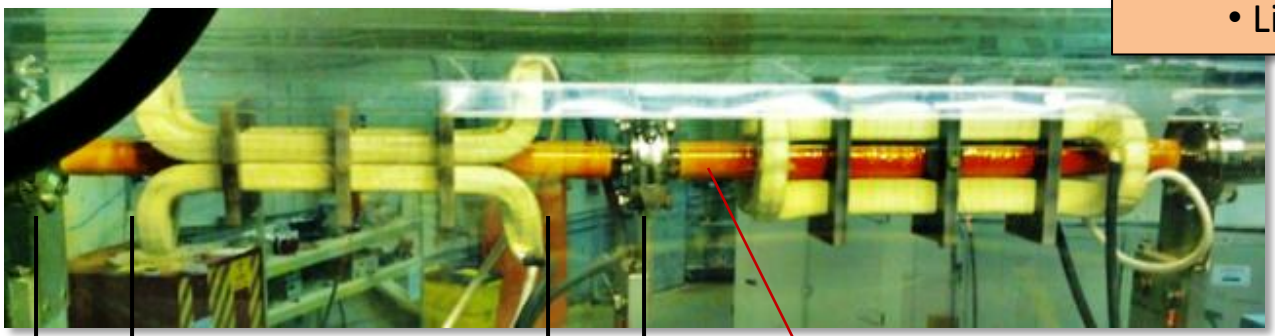


Possible raster positions



Performance of existing 6-GeV fast rasters (Hall A/C)

24 kHz frequency requires:
- air-core
- Litz cables



25 cm
(ℓ_{eff} = 23.7 cm)

~ 40 cm

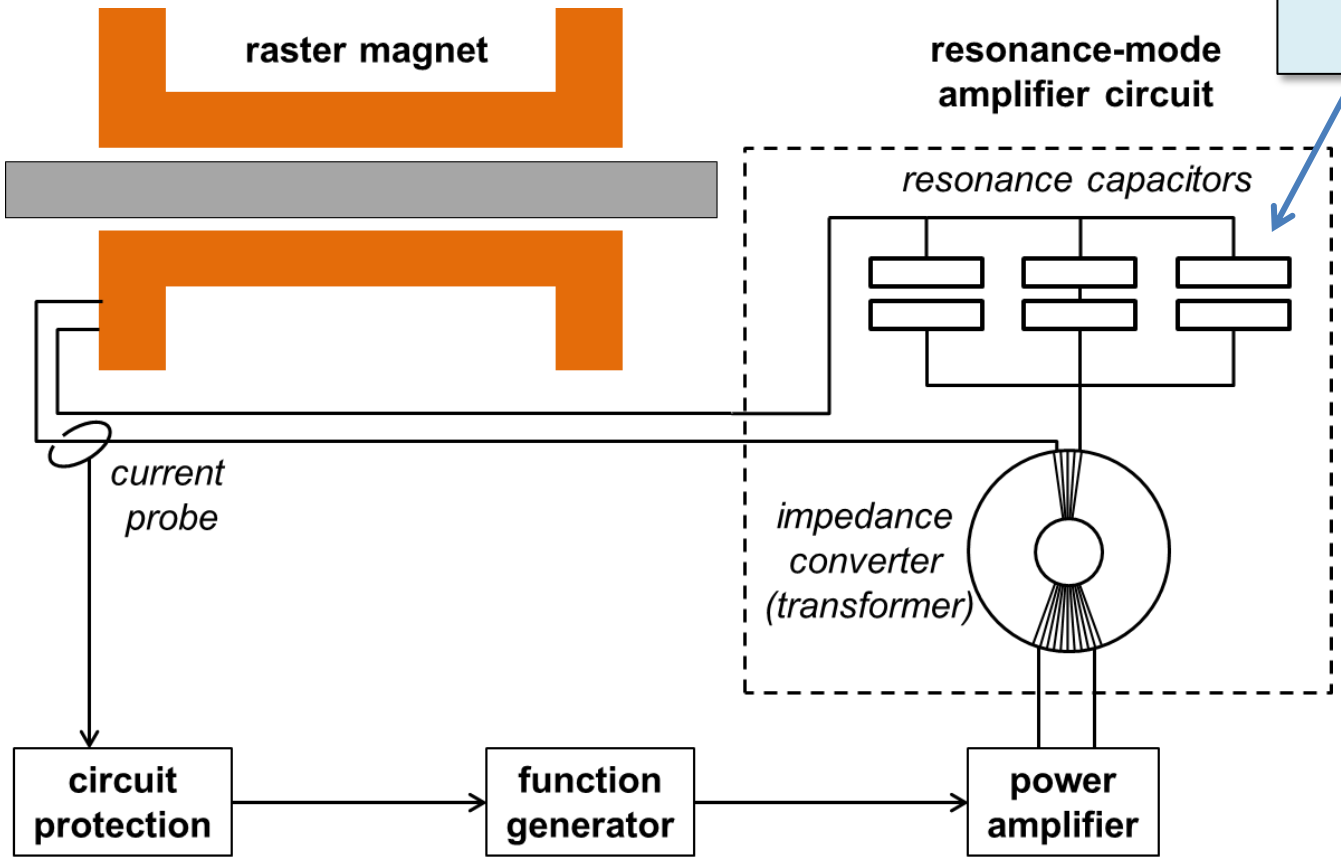
Ceramic beam pipe with thin metal coating inside to conduct the image current of the beam

max bend:	0.353 mrad · GeV
impedance:	L_{DC} = 88 μH
inductive reactance:	@ 25 kHz, X_L = 13.8 Ω
power supply:	500 V adjustable 250 W DC-to-DC converter
	50 A max (40 A nominal during operation)

***Pattern for 1 GeV @ 20 m* → 14.1 mm diameter**

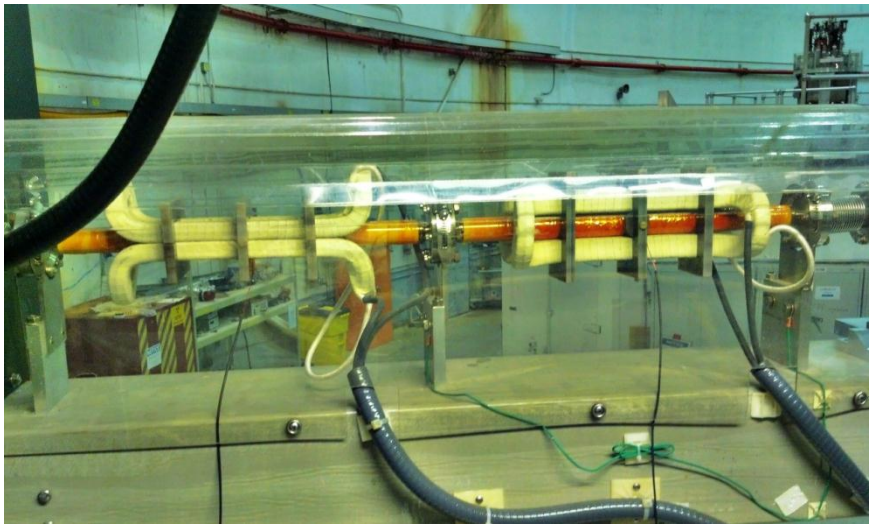
6-GeV raster magnet driver

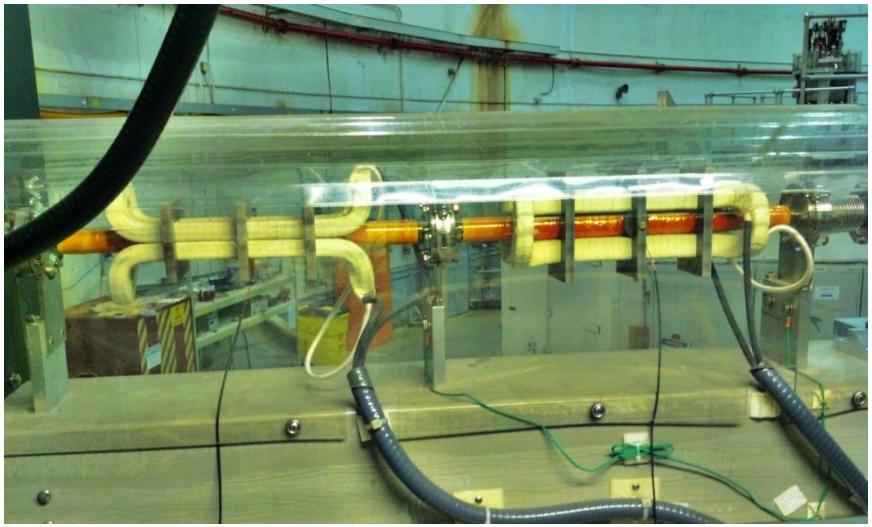
Designed and built by Jlab electronics group (C. Cuevas. et al.)



Components commercially-available

Dual raster configuration for ~1 GeV





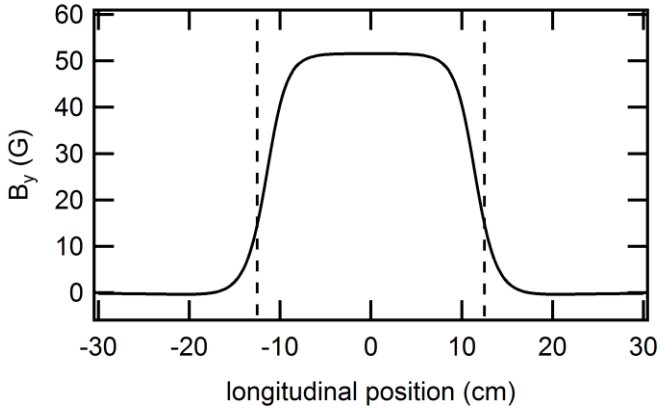
Each fast raster:

<u>0.353 mrad bending</u>

1 GeV @ 20 m → 14.1 mm diameter

For 1 GeV eHD test:

need total 25 mm diameter



Required steps for implementing 6-GeV raster system

- ✓ accumulate existing components:
  - power-amplifier
  - resonance circuit
  - waveform generators
  - magnet coils
- ◦ bench test system 6-GeV raster magnets with resonance-mode power amplifier
- ◦ field measurements (24 KHz) along raster
- ◦ fix layout for components in the Hall
  (magnets, electronics with Pb enclosure, ceramic beam pipe, etc)
- ◦ remote control of raster system in Counting House
- ◦ raster magnet alignment
- ◦ commissioning raster with beam

11-GeV raster development

- Current **Hall A fast raster insufficient** to provide needed bend at 11 GeV
  (pattern for 11 GeV @ 20 m: 2.6 mm diameter for double raster)

- Build new fast rasters based on design from Hall A raster
- Fast switches and function generators usable
- Larger magnets → bigger impedance → better power supplies needed

11 GeV raster requirements @ 20 m

maximum bend: 6.6 mrad · GeV

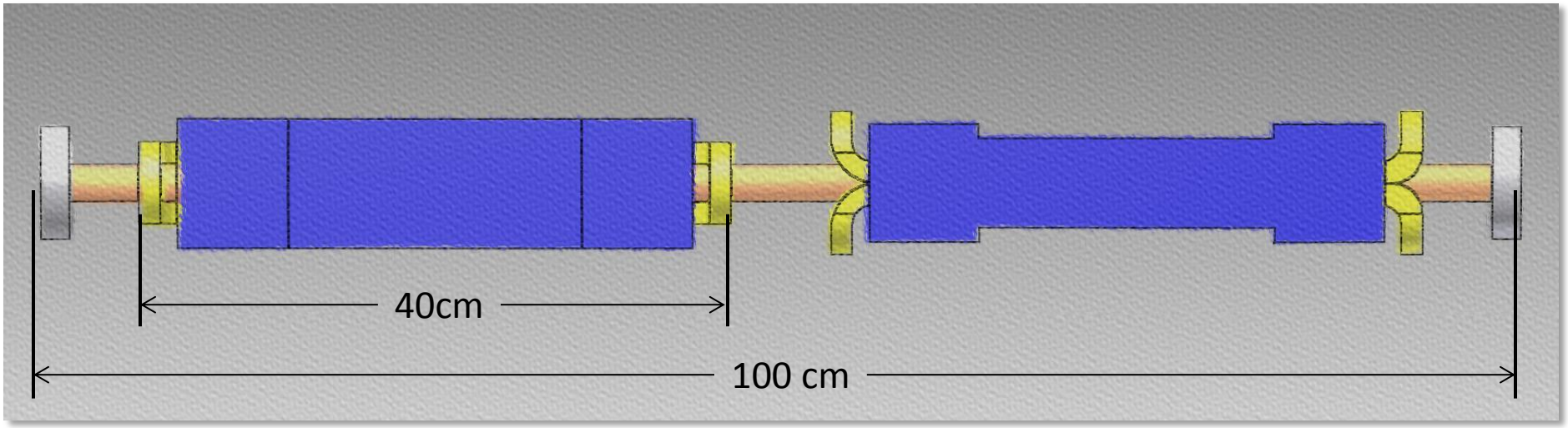
bending power $\propto \int B\, d\ell$ impedance $\propto N^2 I / \ell$

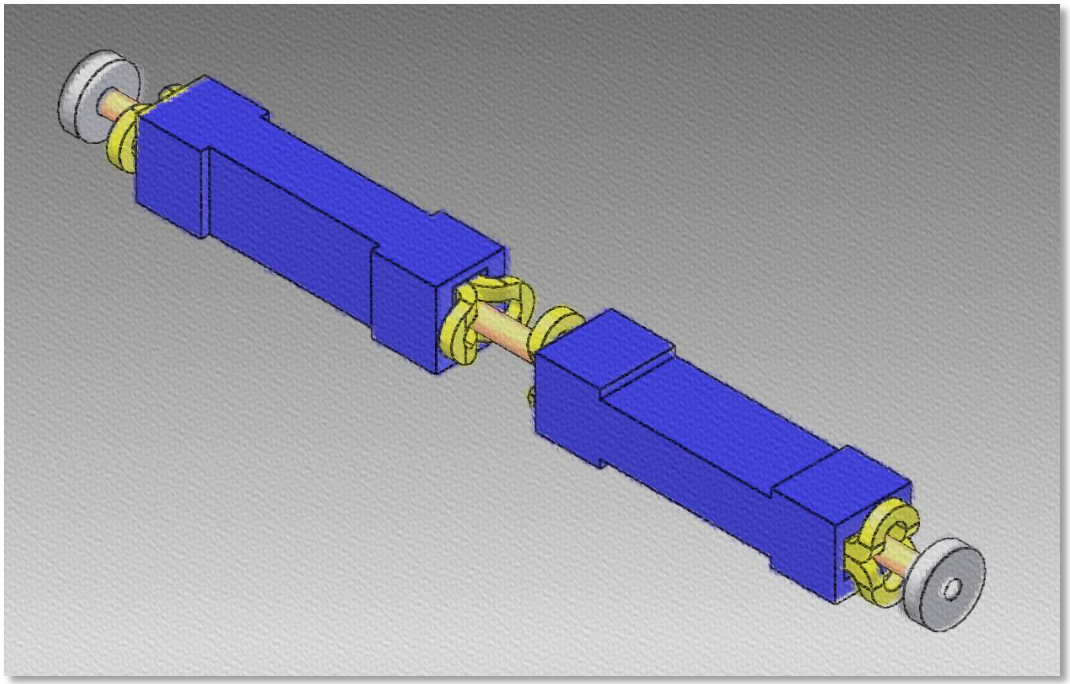
1) ***longer coils:*** 25 cm → 40 cm
2) ***ferrite flux return:*** increase central field by x2
3) ***increase windings:*** 6x current turns

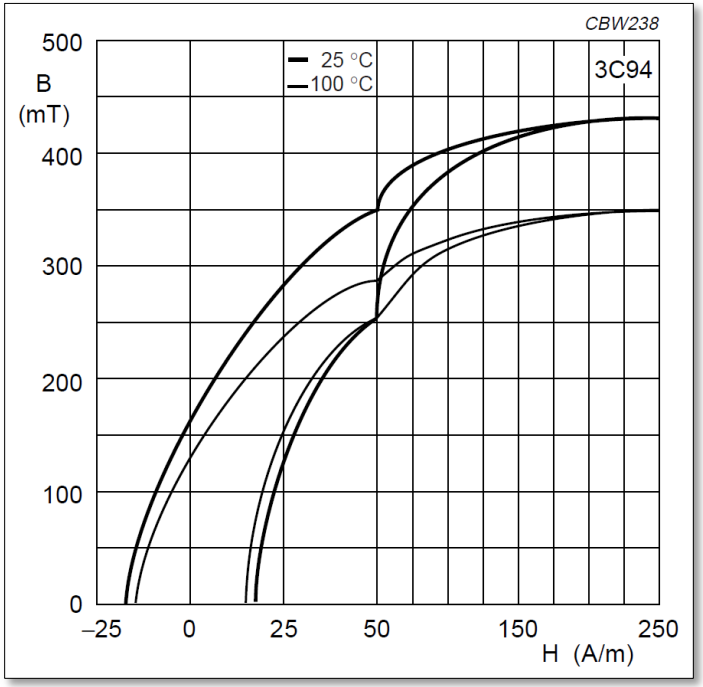
7.16 mrad GeV → 26 mm diameter @ 11 GeV & 20 m

11-GeV raster design

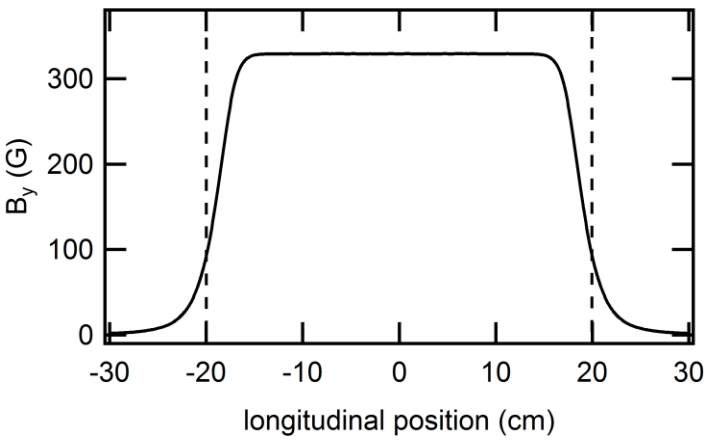
(only one of two raster pairs are shown)

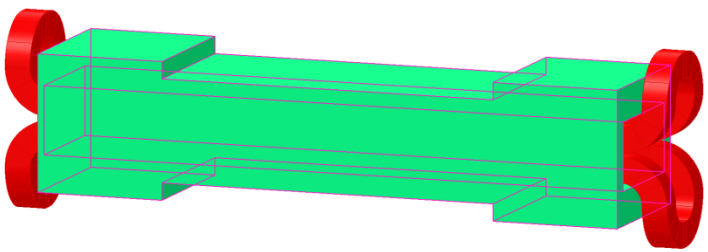


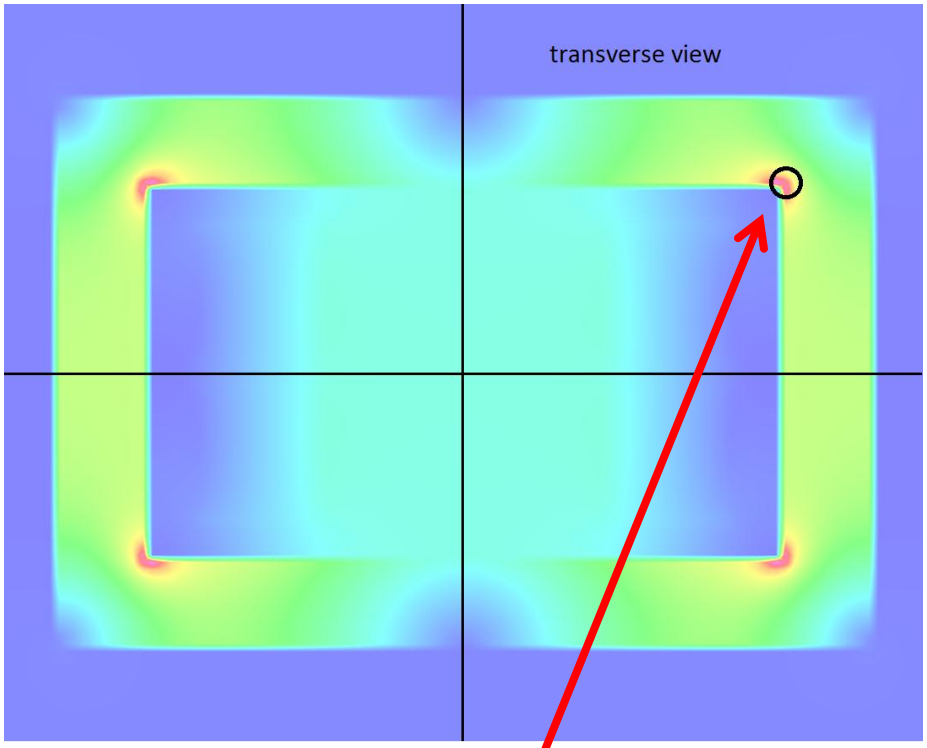


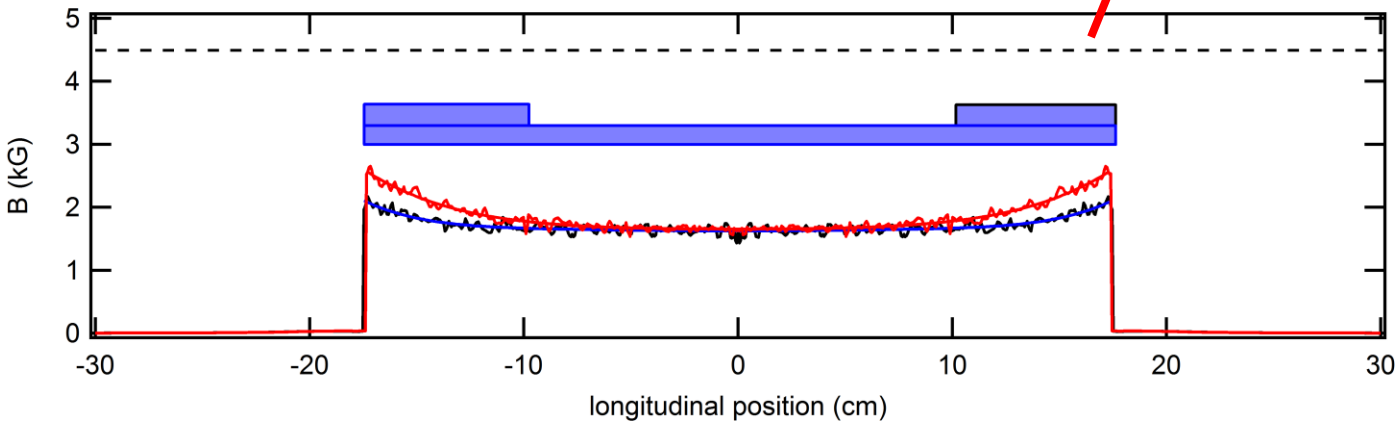


11-GeV raster: Calculated fields









Required steps for implementing 11-GeV raster system

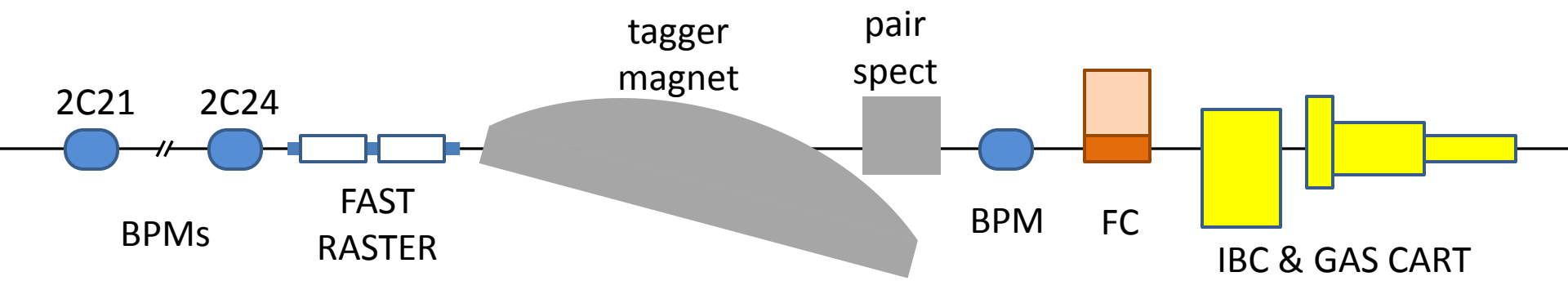
<u>6-GeV raster system components that can be reused:</u>

- Power amplifiers
- Waveform generators
- Resonant-mode circuits
  (require modifications to work with higher Q-value of new coils)

<u>New equipment needed for 11-GeV:</u>

- Magnet coils
- Ferrite yoke
- Ceramic beampipe
- Remote controls

Beamline Components : **Alignment Procedure**



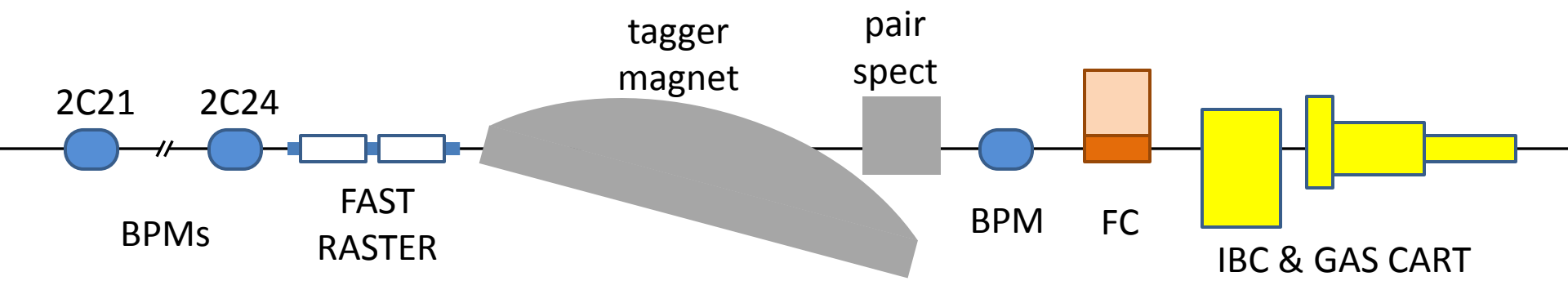
(1) Insert empty target cell in IBC

(2) Run rastered beam with orbit locks OFF and small diameter raster pattern
- increase pattern size until edge of target hit
- re-center beam position
- continue increasing pattern size and re-centering beam until max pattern diameter established

(3) Record values of BPMs as nominal beam position

(4) Turn orbit locks ON and test beam stability

Beamline Components : **Running Procedure**



(1) Insert polarized target in IBC; position FC in beam

(2) Run rastered beam and align using nominal BPM values as reference

(3) Turn orbit locks ON and verify beam position

(4) Block beam, retract FC, unblock beam