Development of the Zeeman Slower for the Ultra-cold Atomic Interference Experiment

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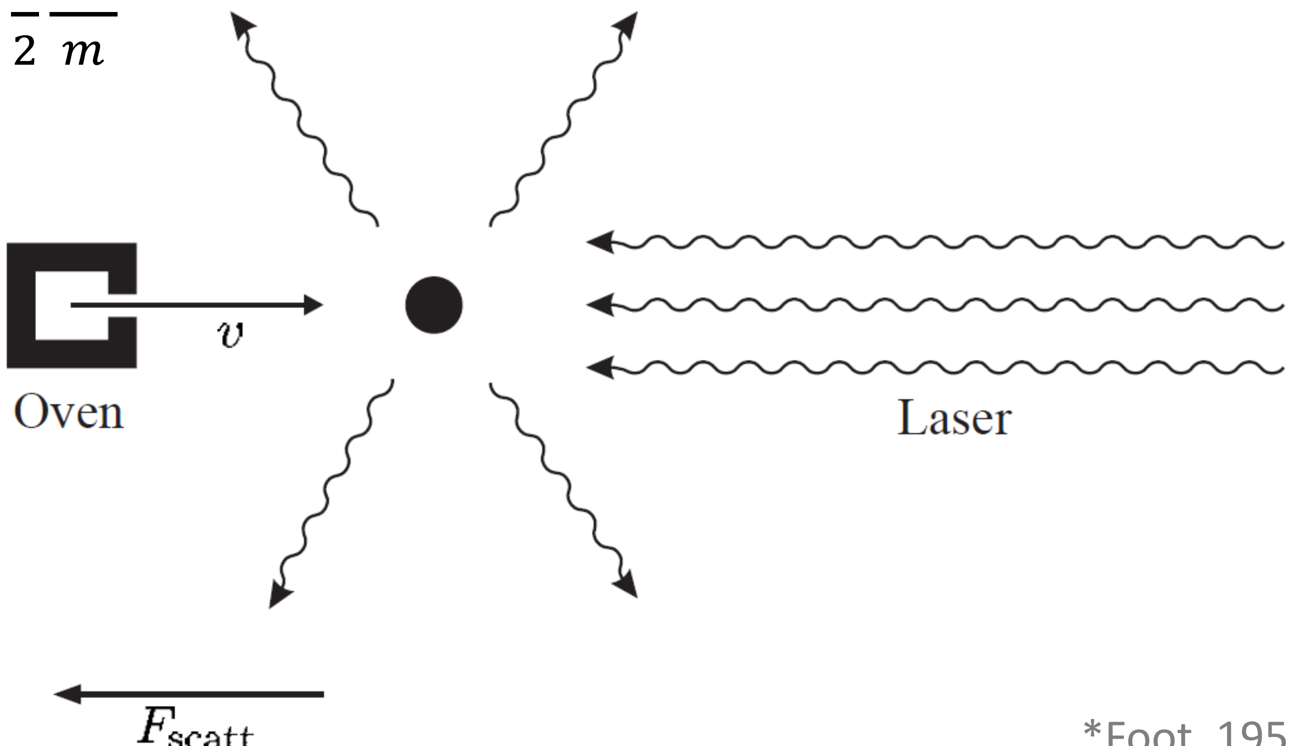
Outline

- Introduction – laser cooling, Zeeman slowers
- Design – optimizing magnetic field
- Construction – winding procedure and techniques
- Results – acquisition of data, compare with expectations
- Simulation – analyzing velocity profile and distribution

Introduction, scattering force

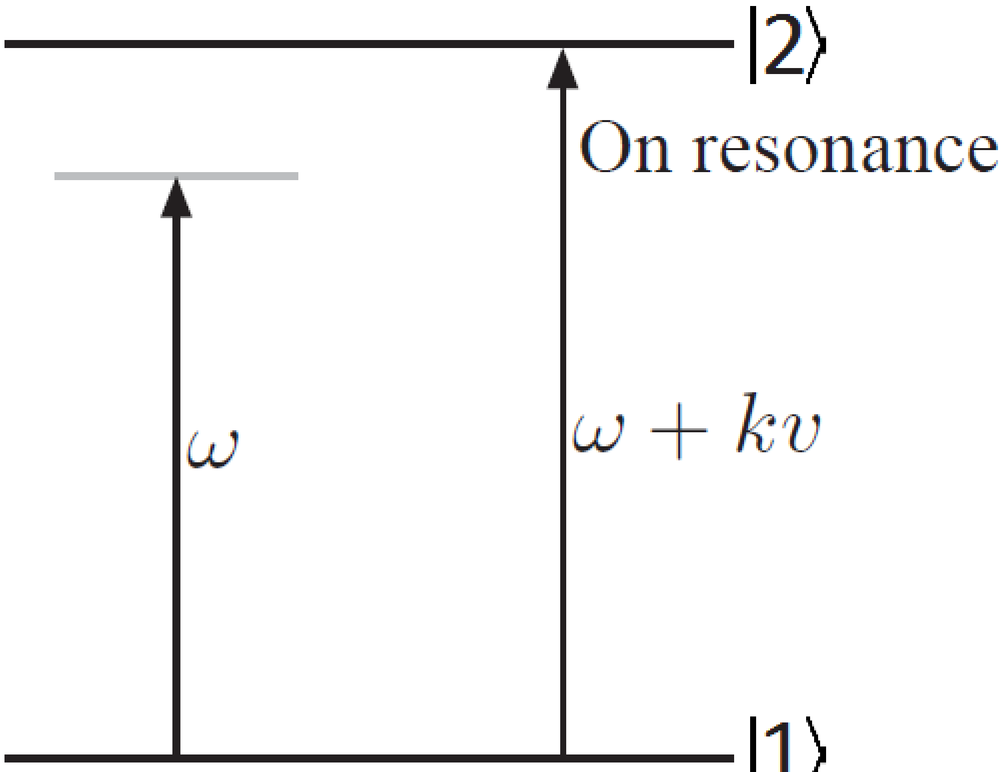
- $F_{scatt} = \hbar k \frac{\Gamma}{2} \frac{s}{1+s+4\delta^2/\Gamma^2}$
  - where $s = I/I_{sat}$
- $a_{max} = \frac{F_{max}}{m} = \frac{\Gamma}{2}\frac{\hbar\, k}{m}$
- $a = f\, a_{max}$



*Foot, 195

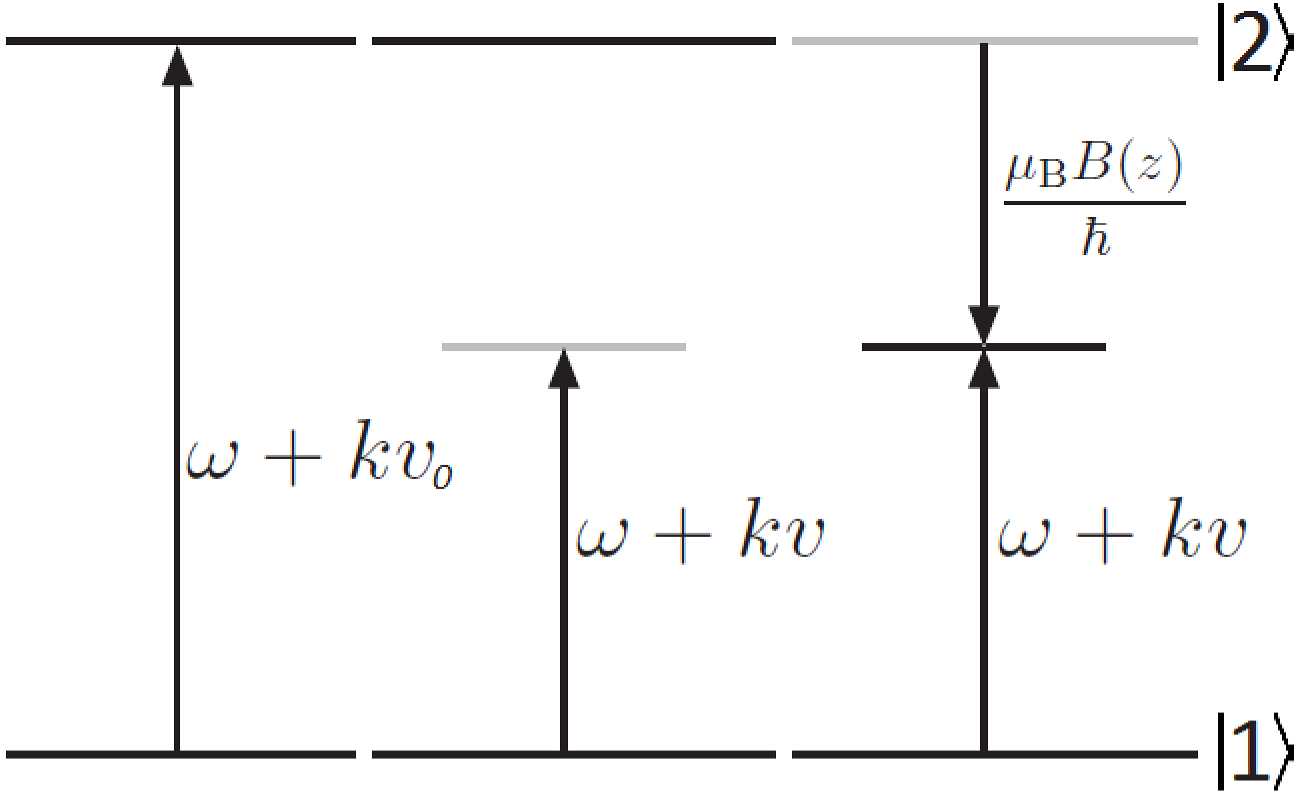
Introduction, Doppler shift

- $\delta = \delta_{lab} + \vec{k}\vec{v}$



Introduction, Zeeman effect

- $\delta = \delta_{lab} + \vec{k}\vec{v} + \frac{\overrightarrow{\mu_B}\,\vec{B}}{\hbar}$



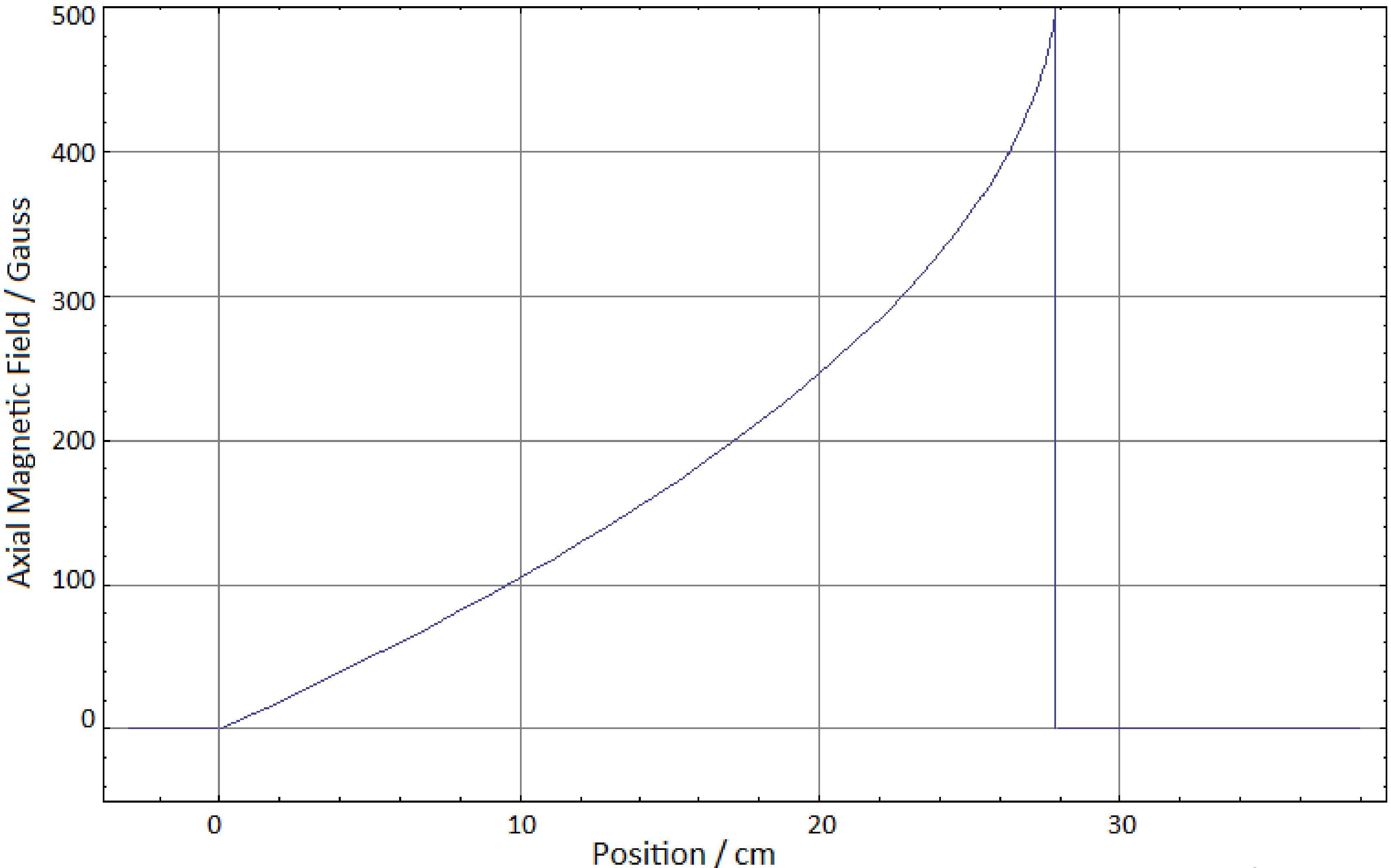
Introduction, derivation

- Constant acceleration
  - $v_0{}^2 = v^2 + 2az$
    - $v_0{}^2 = 2aL$
  - $v = \sqrt{v_0{}^2 - 2az}$
    - $v = v_0\sqrt{1 - z/L}$
    - $\vec{k}\vec{v} = \frac{\overrightarrow{\mu_B}\,\vec{B}}{\hbar}$
  - $B(z) = \frac{k\hbar v_0}{\mu_B}\sqrt{1 - z/L}$

Introduction, slower equations

- Ideal Zeeman slower
  - $a_{max} = \frac{\Gamma}{2} \frac{\hbar\, k}{m}$
  - $v_{capt} = \sqrt{2\, f\, a_{max}\, L}$
  - $B_{max} = \frac{\hbar\, k\, v_{capt}}{\mu_B}$
- $B(z) = B_{max}\left(1 - \sqrt{1 - \frac{z}{L}}\right)$

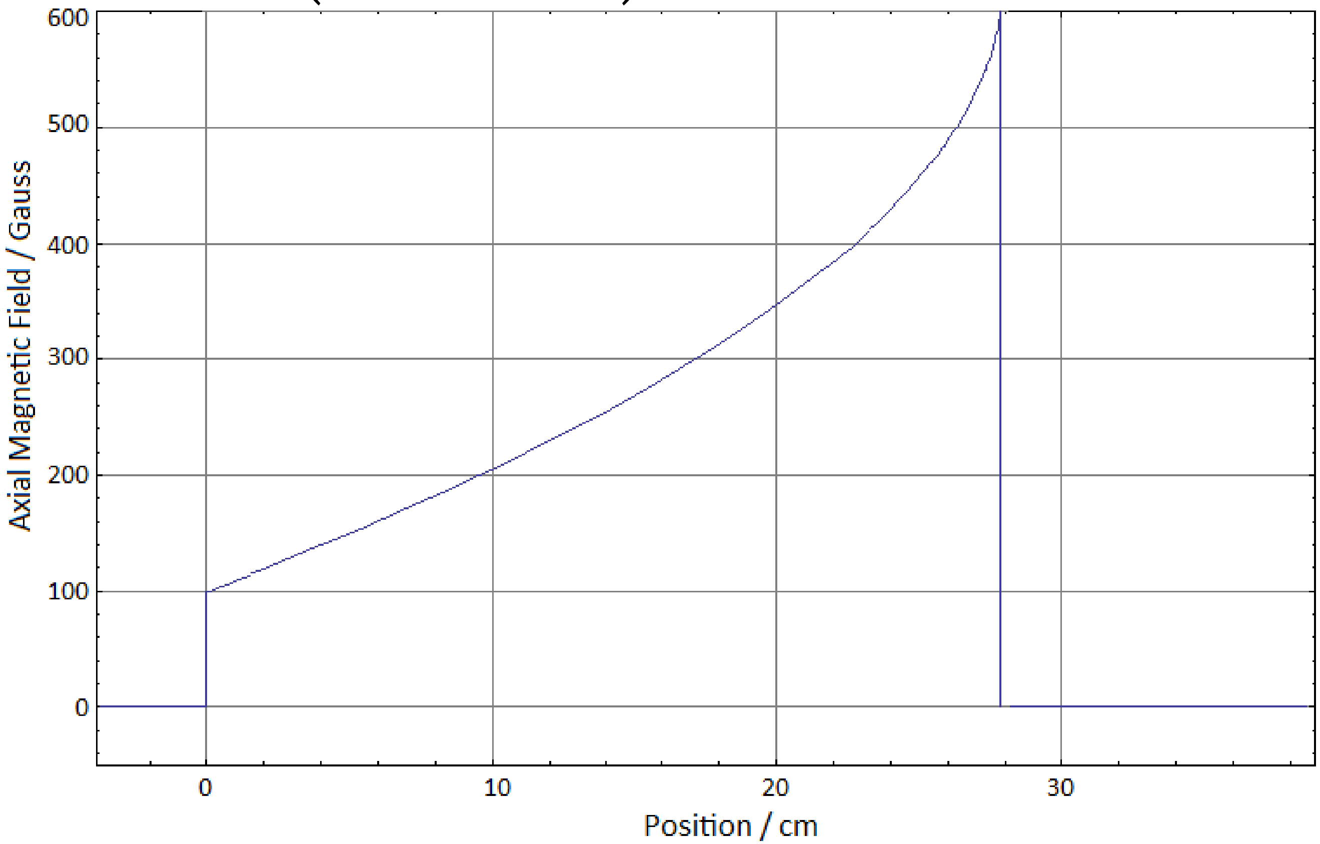
Ideal magnetic field profile



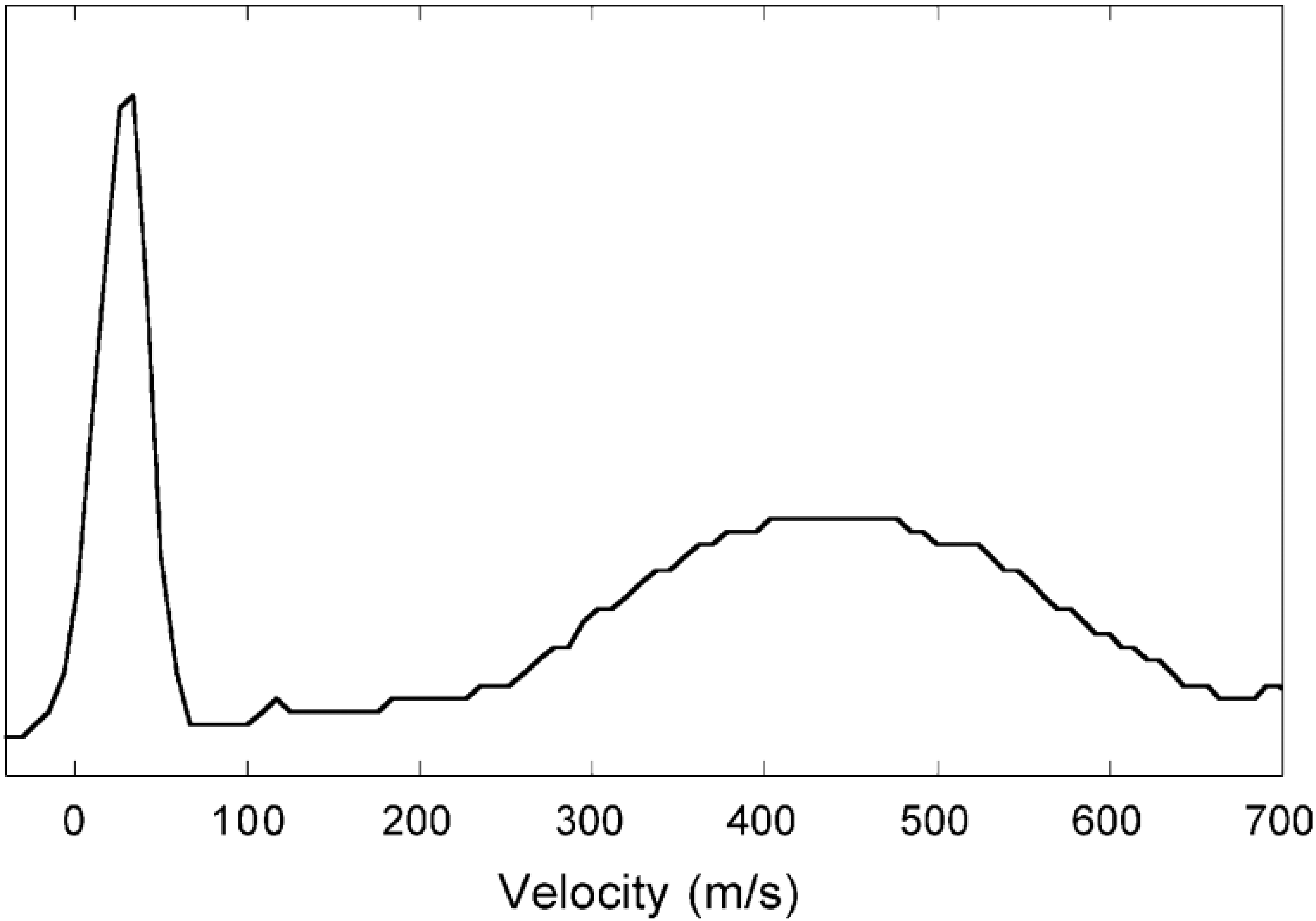
(at 35 Amps)

Ideal magnetic field profile

- Offset layers
  - $B(z) = B_{max}\left(1 - \sqrt{1 - \frac{z}{L}}\right) + B_{off}$



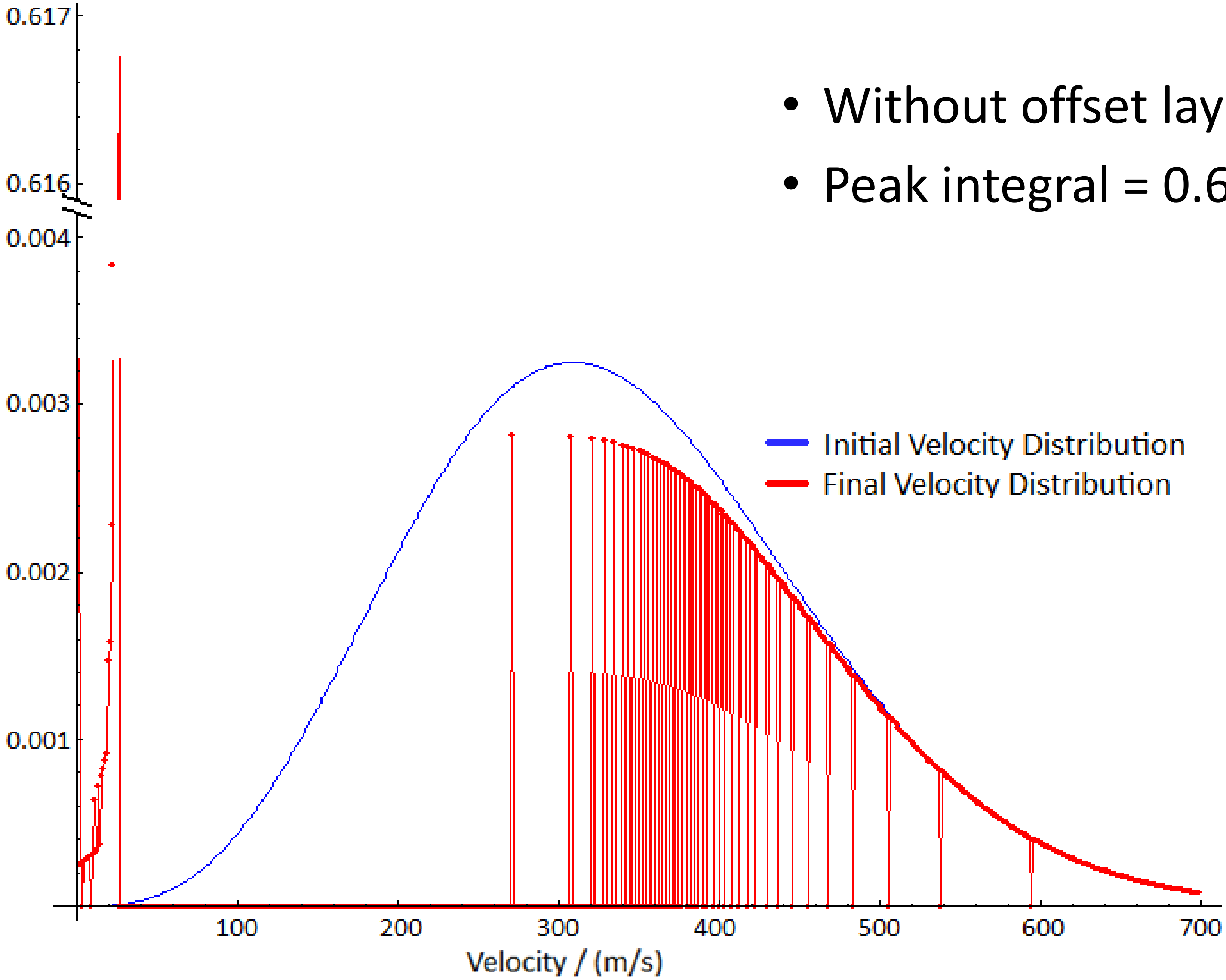
Ideal velocity distributions



*Mayera, Minarik, Shroyer, McIntyre

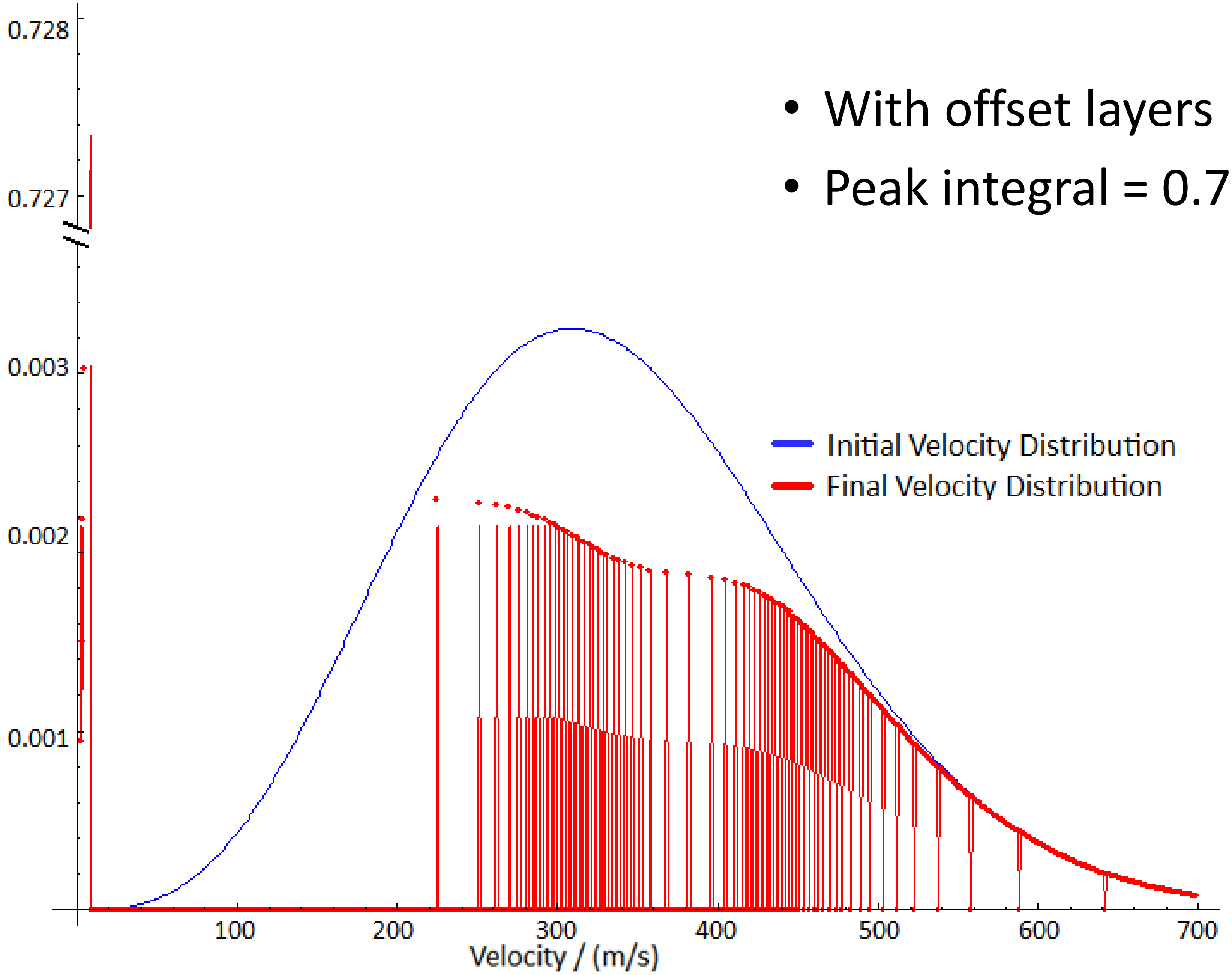
Ideal velocity distributions

- Without offset layers
- Peak integral = 0.66



Ideal velocity distributions

- With offset layers
- Peak integral = 0.76

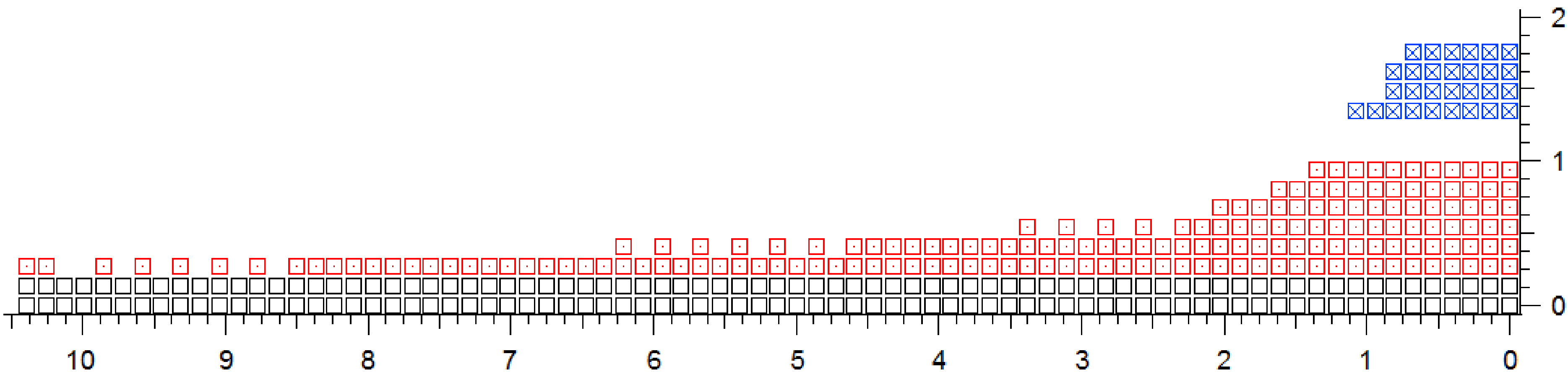


Optimizing the design

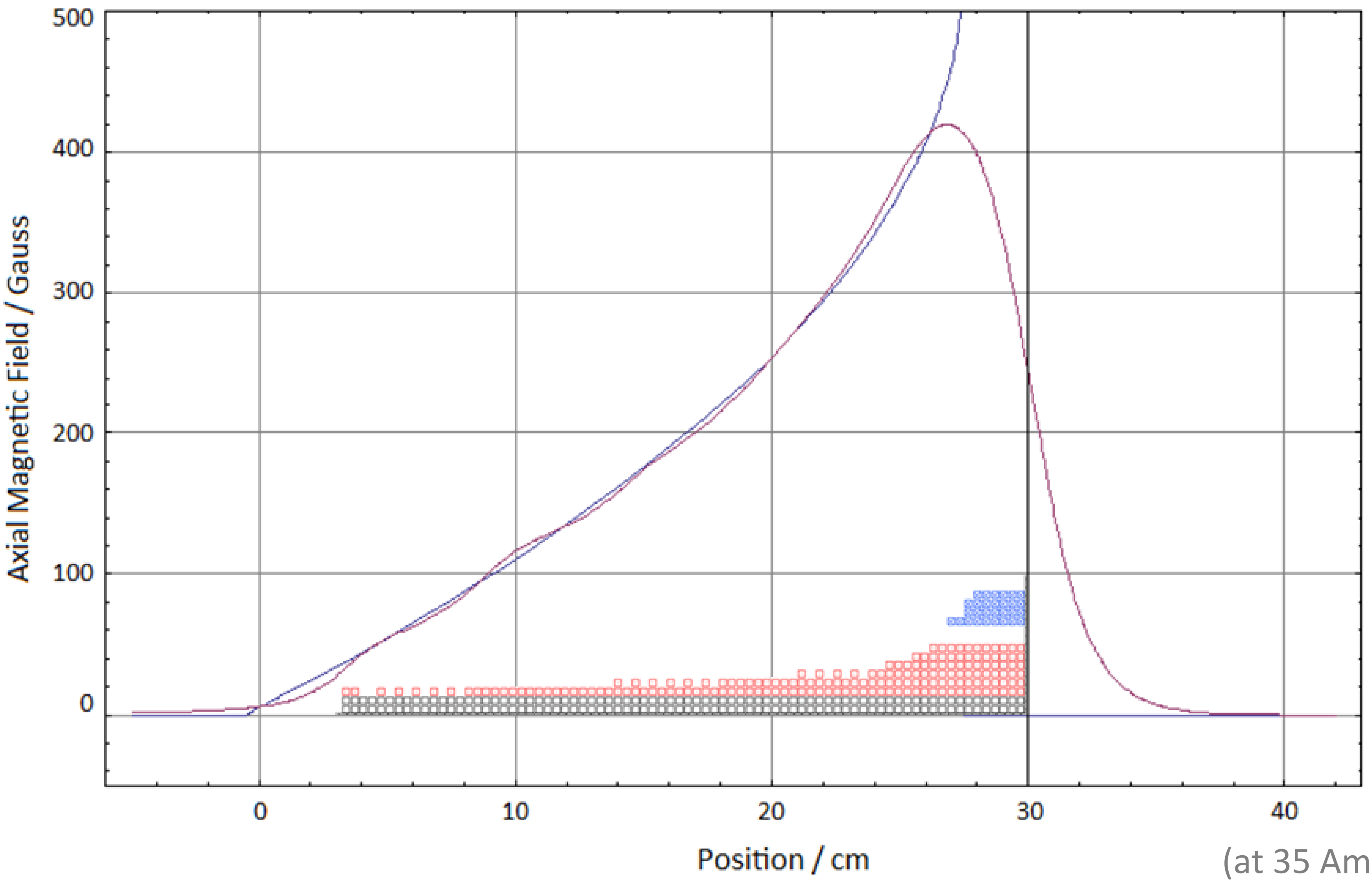
- Axial Magnetic Field of a single coil:
  - $B(z) = \left(\frac{\mu_0\, I}{d}\right) \Big/ \left(1 + \left(\frac{2\, z}{d}\right)^2\right)^{3/2}$
- Summary equation used for optimization:
  - $B(z) = \sum_{j=0}^{l} \sum_{i=0}^{n_j} \left(\frac{\mu_0\, I}{d_j}\right) \Big/ \left(1 + \left(\frac{2\, z_i}{d_j}\right)^2\right)^{3/2}$

Final design, geometry

- Dimensions in inches
  - indicates compensation “reverse” coils
  - indicates normal “forward” coils
  - indicates “offset” coils



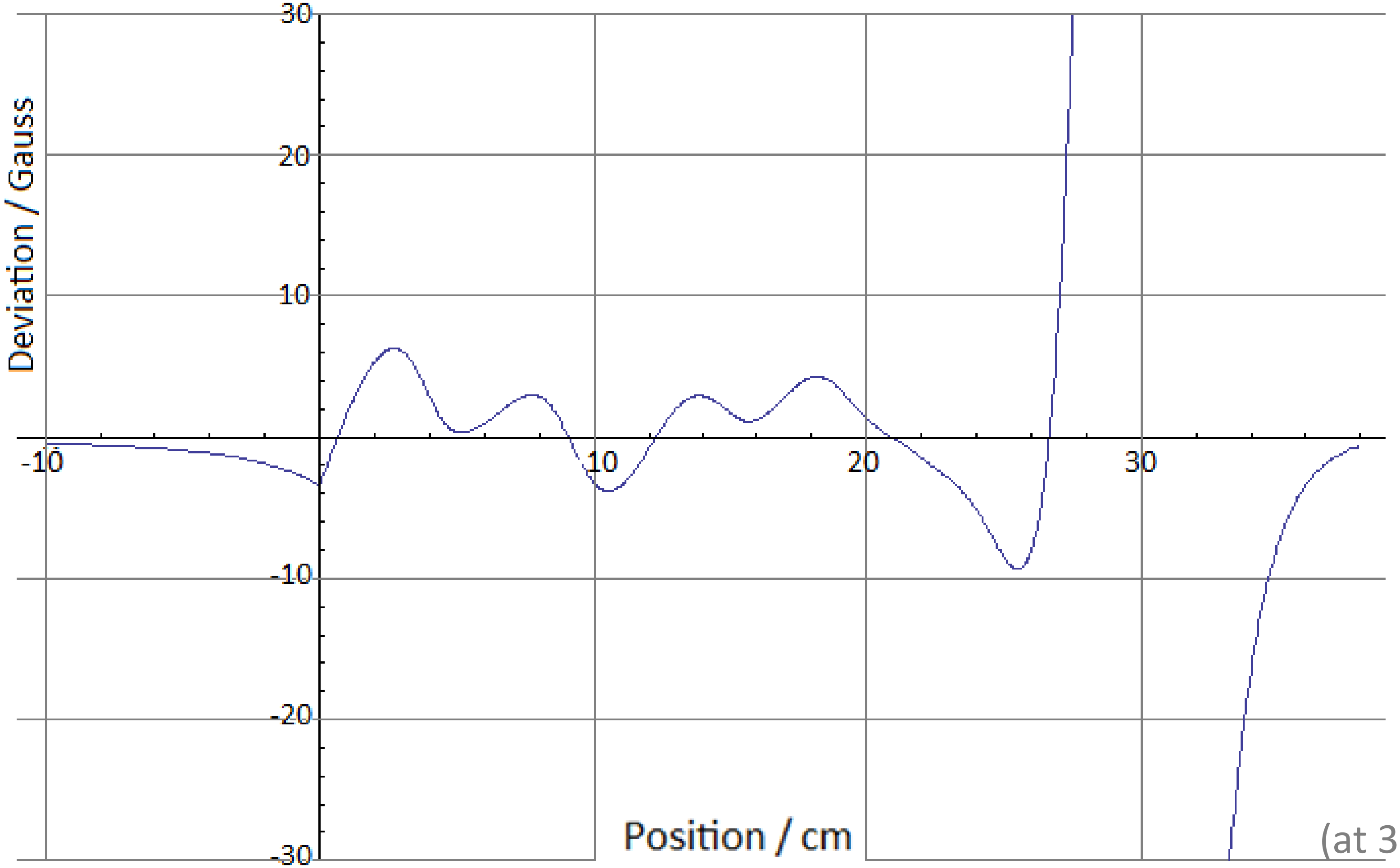
Final design, magnetic field profile



(at 35 Amps)

Final design, magnetic field profile

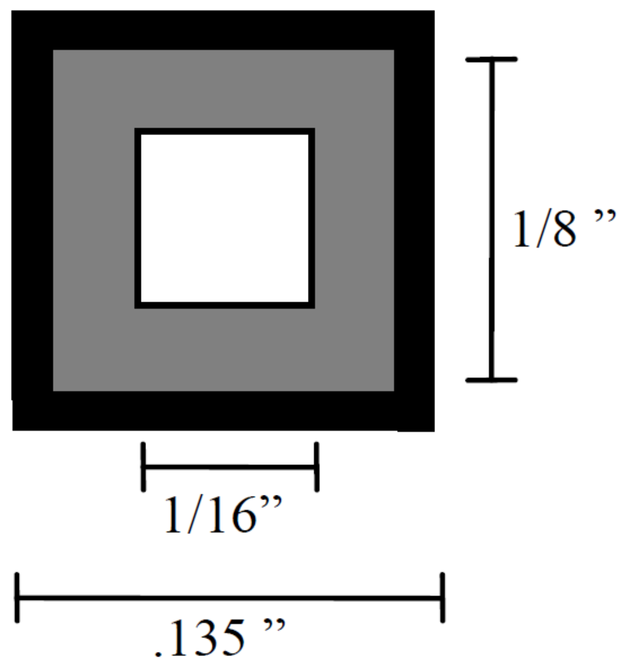
- Deviation from ideal magnetic field



(at 35 Amps)

Winding procedure, materials

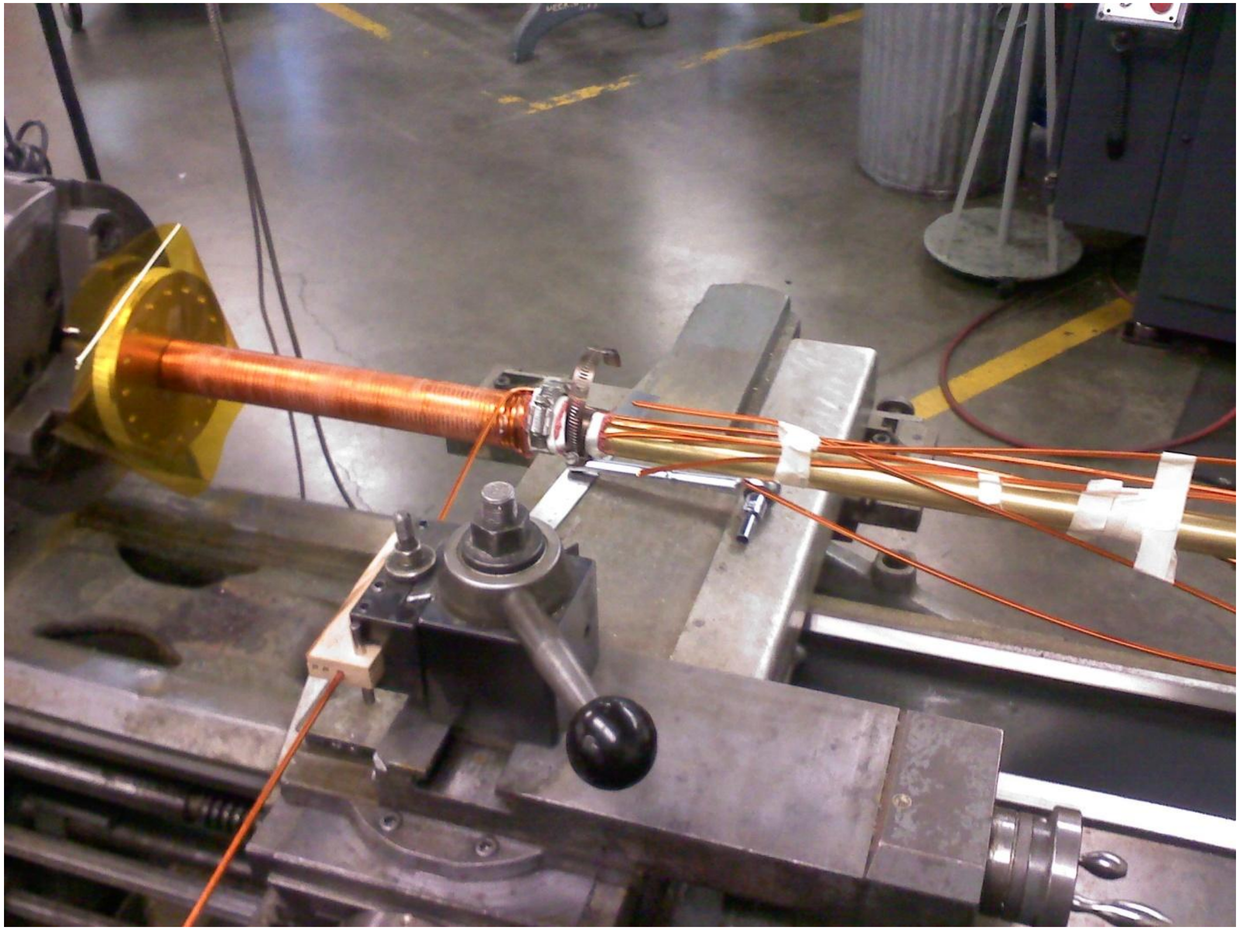
- Specifications of the wire used:
  - Insulated hollow square copper wire
  - Dimensions in inches:



*Maloney

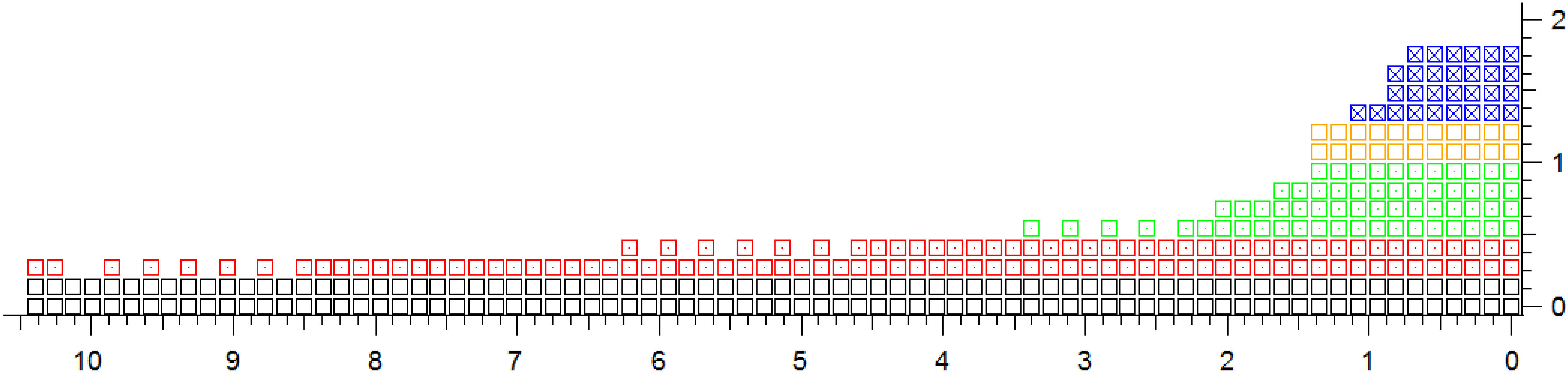
Winding procedure

- General notes on winding:

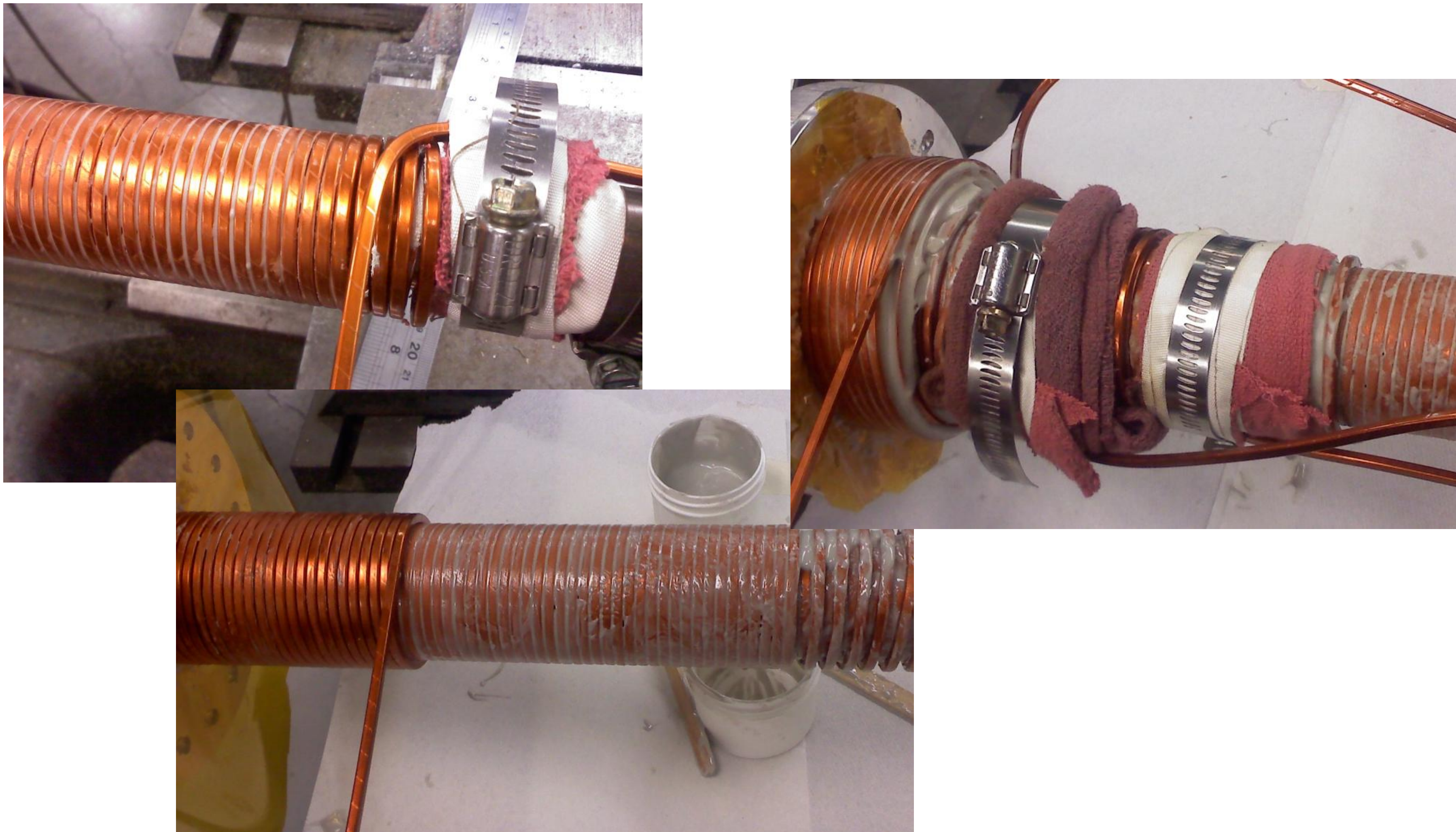


Winding procedure

- Segments of wire, for separate cooling lines

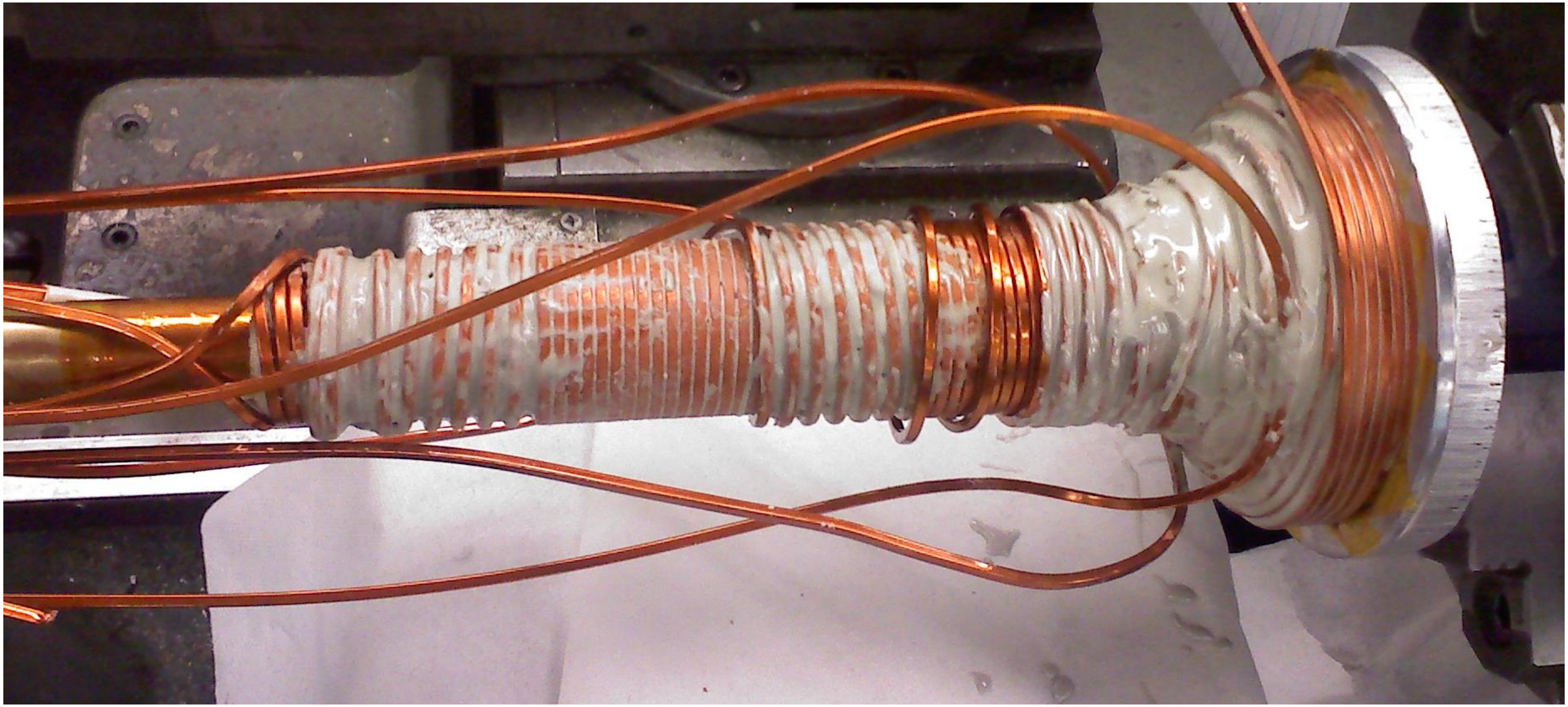


Winding procedure



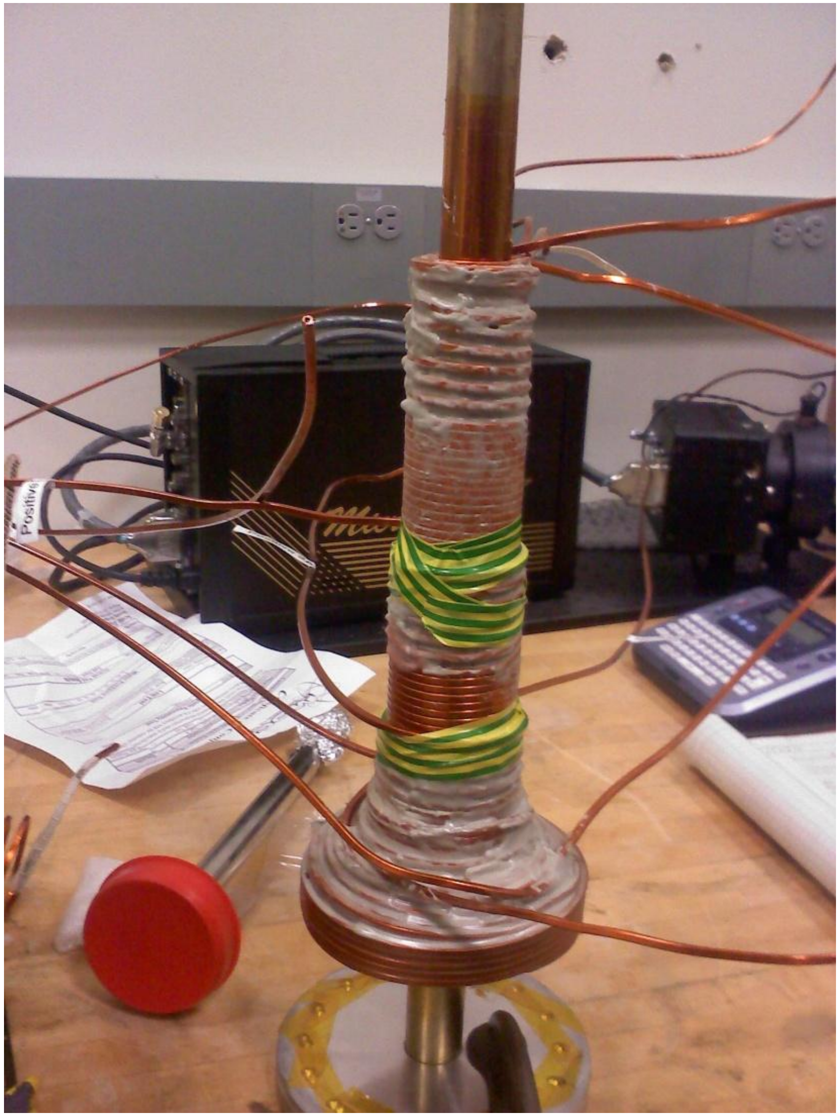
Winding procedure

- Assembly of all layers, drying on the lathe



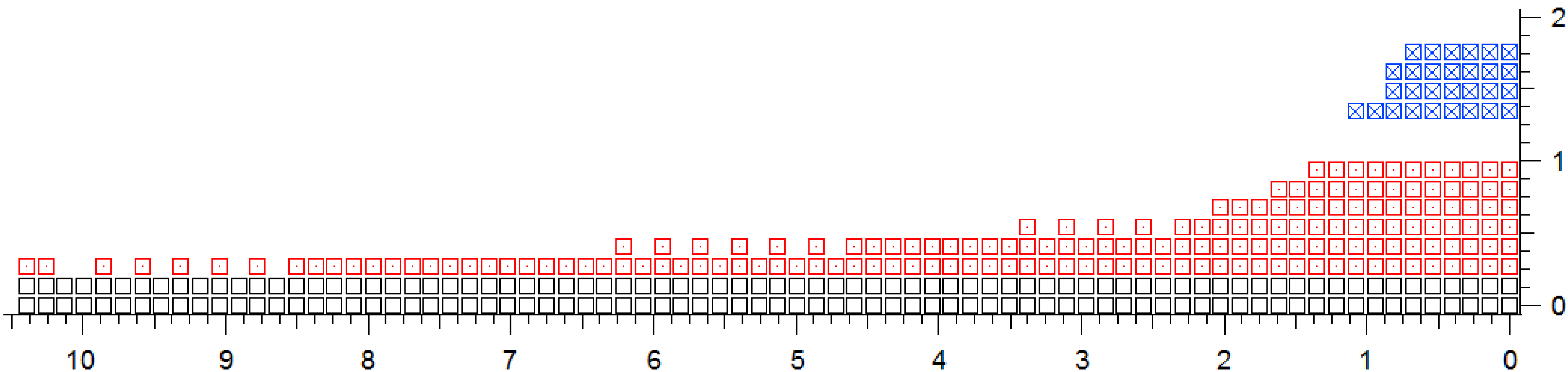
Winding procedure

- Unwrap and label the lead wires
- Check for material flaws



Recall geometric design and terms

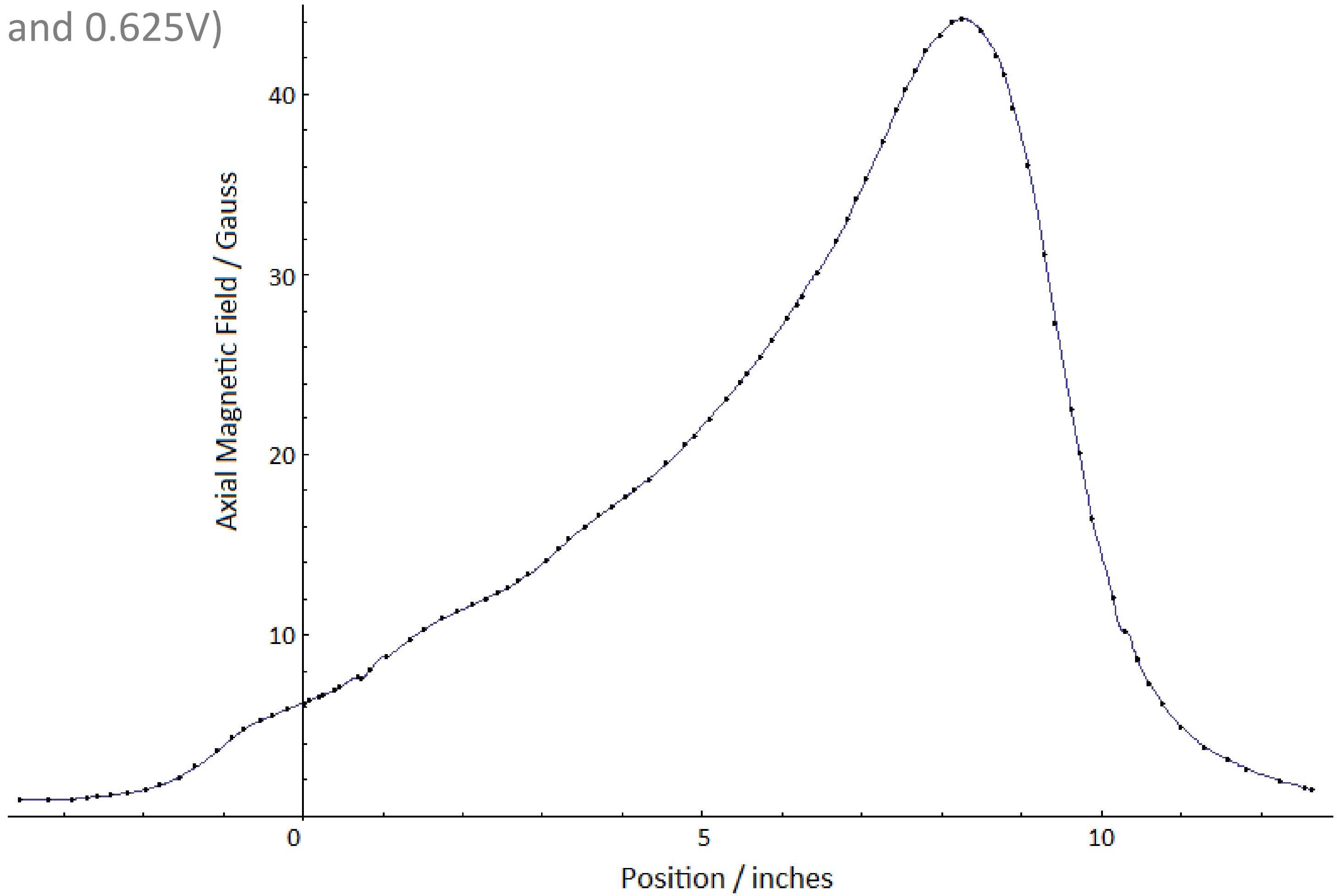
- Dimensions in inches
  - ☒ indicates compensation “reverse” coils
  - ⊡ indicates normal “forward” coils
  - ☐ indicates “offset” coils



Testing, magnetic field profiles

- Forward layers:

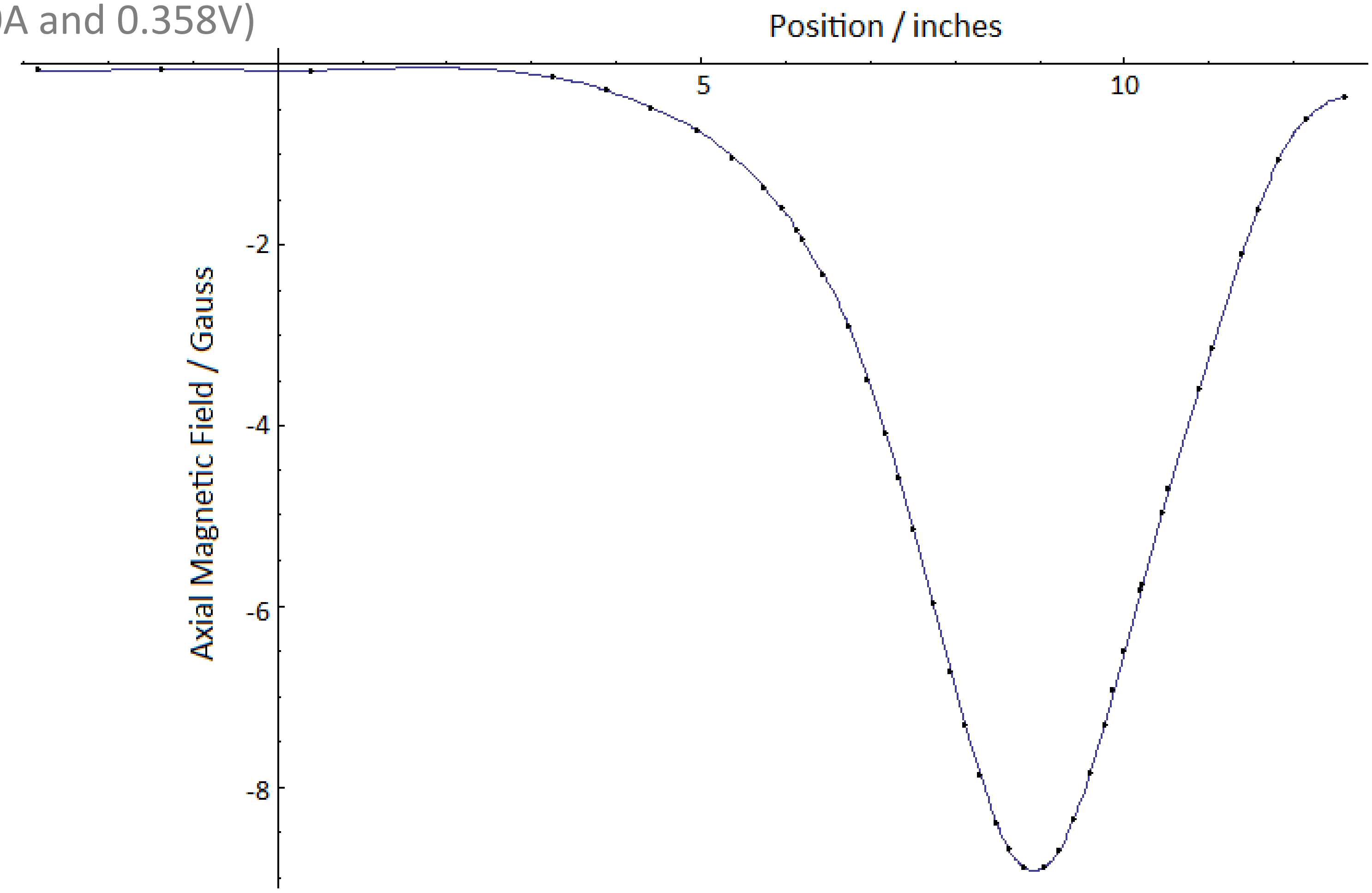
(at 3.00A and 0.625V)



Testing, magnetic field profiles

- Reverse layers:

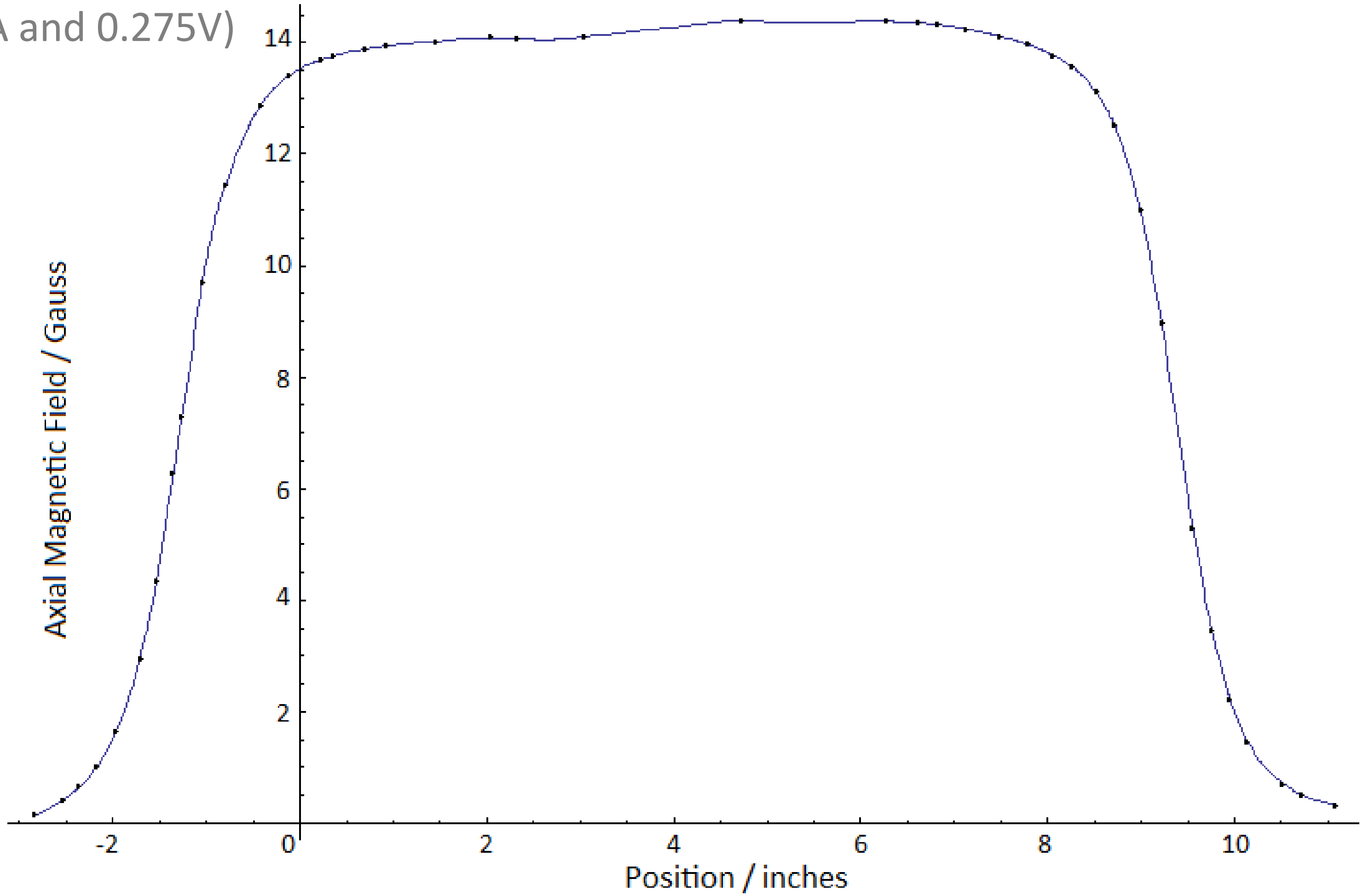
(at 3.00A and 0.358V)



Testing, magnetic field profiles

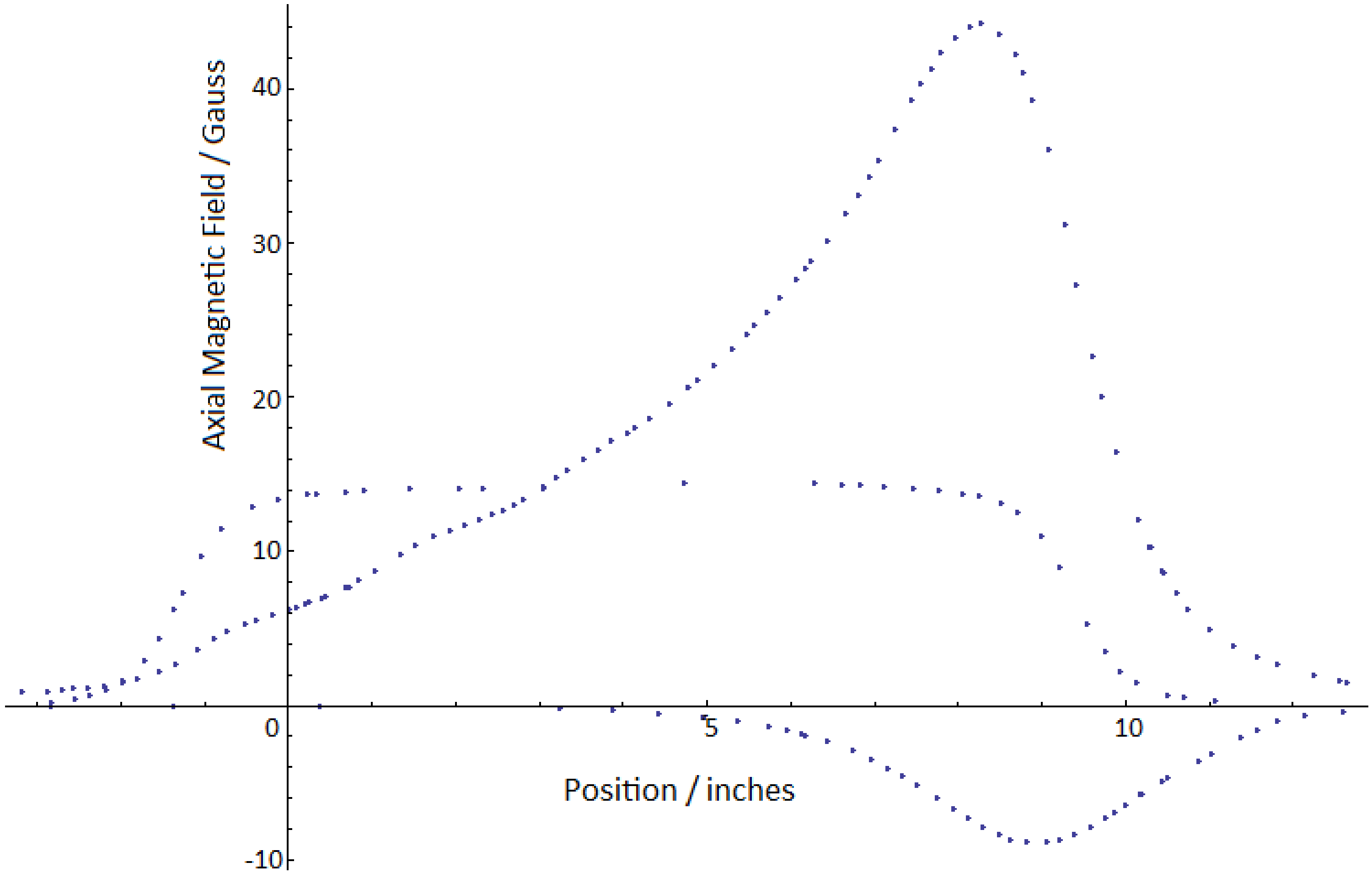
- Offset layers:

(at 2.00A and 0.275V)



Testing, magnetic field profiles

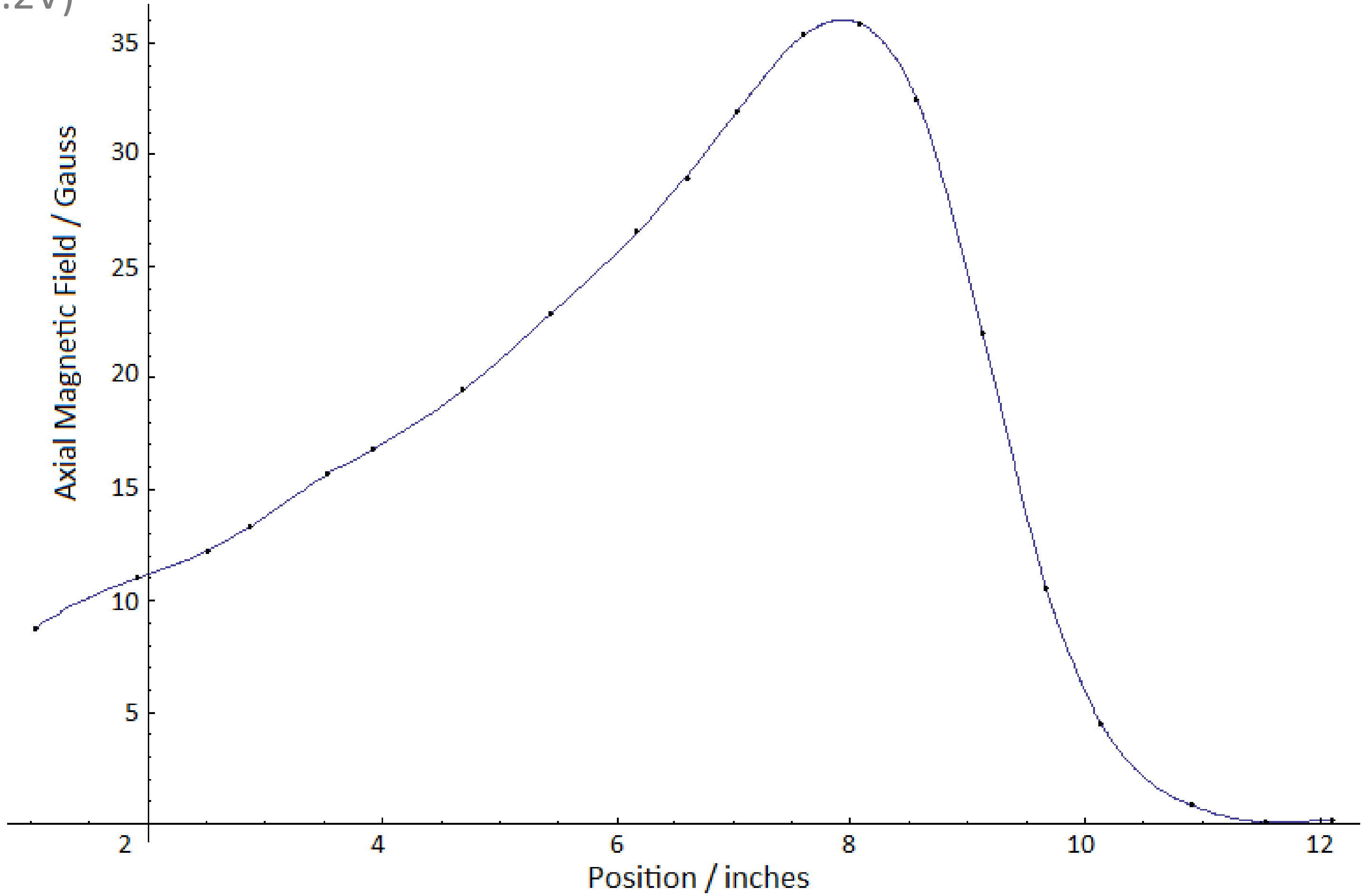
- Relative positions of the above three:



Testing, magnetic field profiles

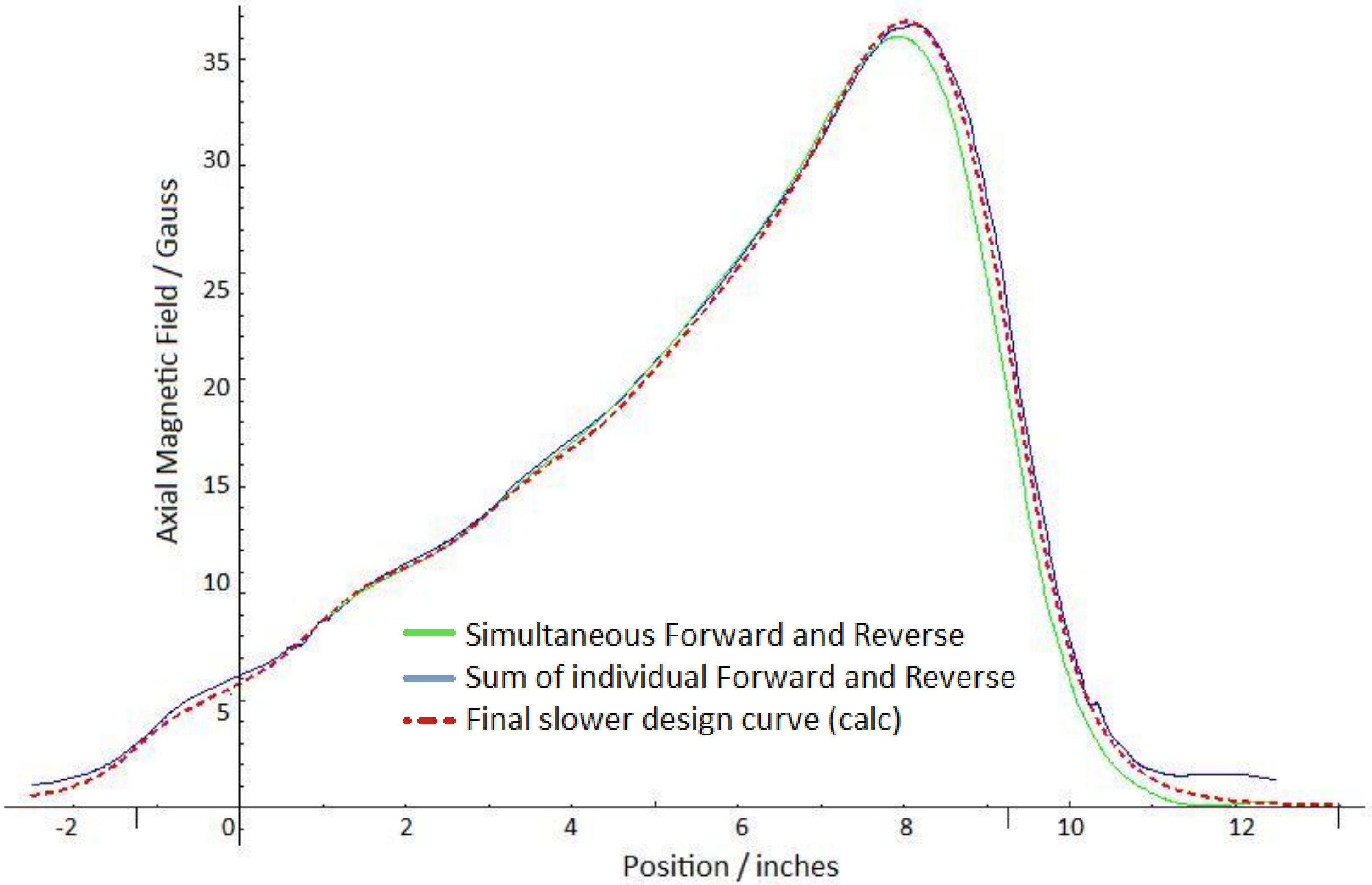
- Simultaneous forward and reverse layers:

(at 3.00A and ~1.2V)



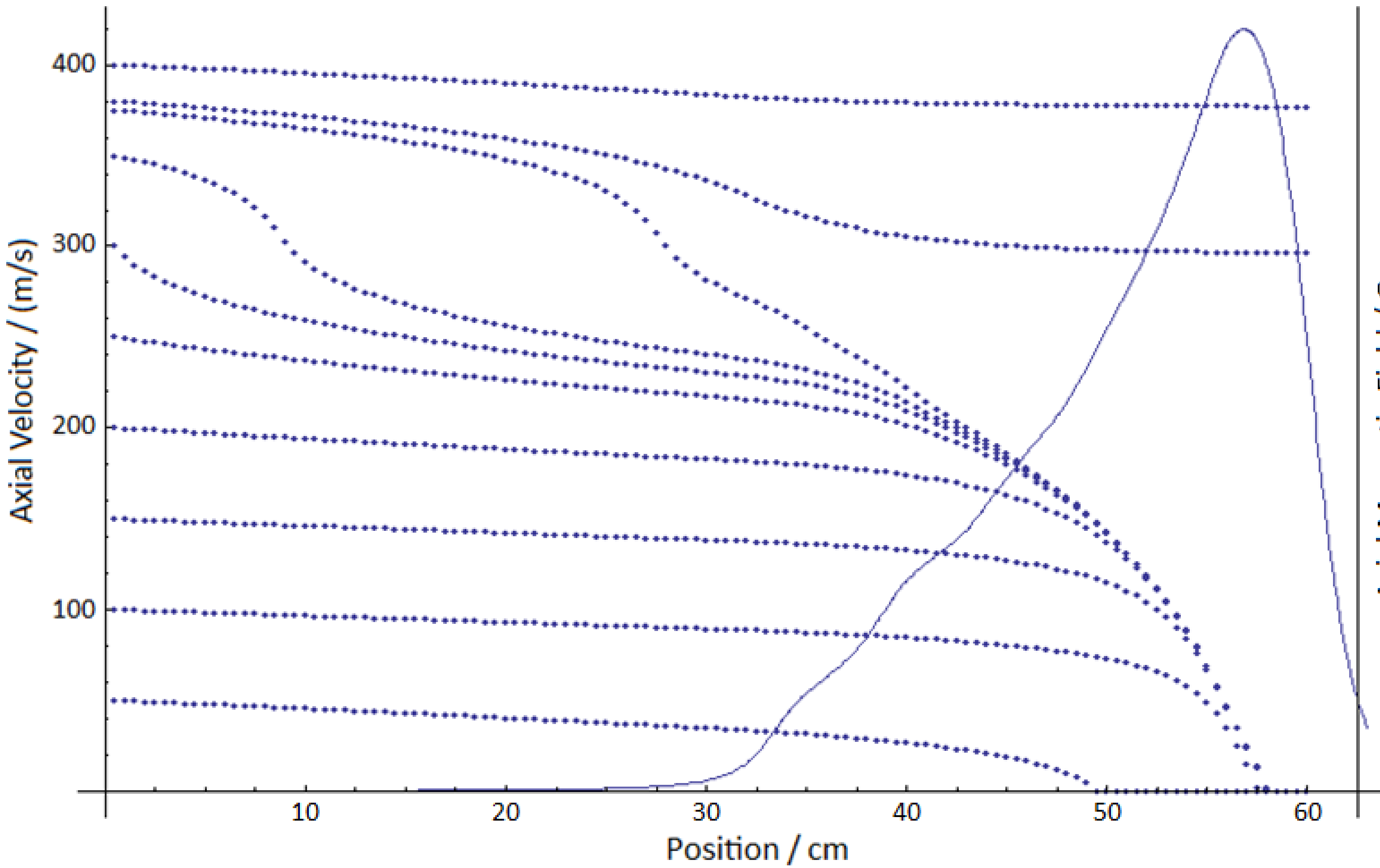
Testing, magnetic field profiles

- Simultaneous forward and reverse layers:



Simulations, velocity profiles

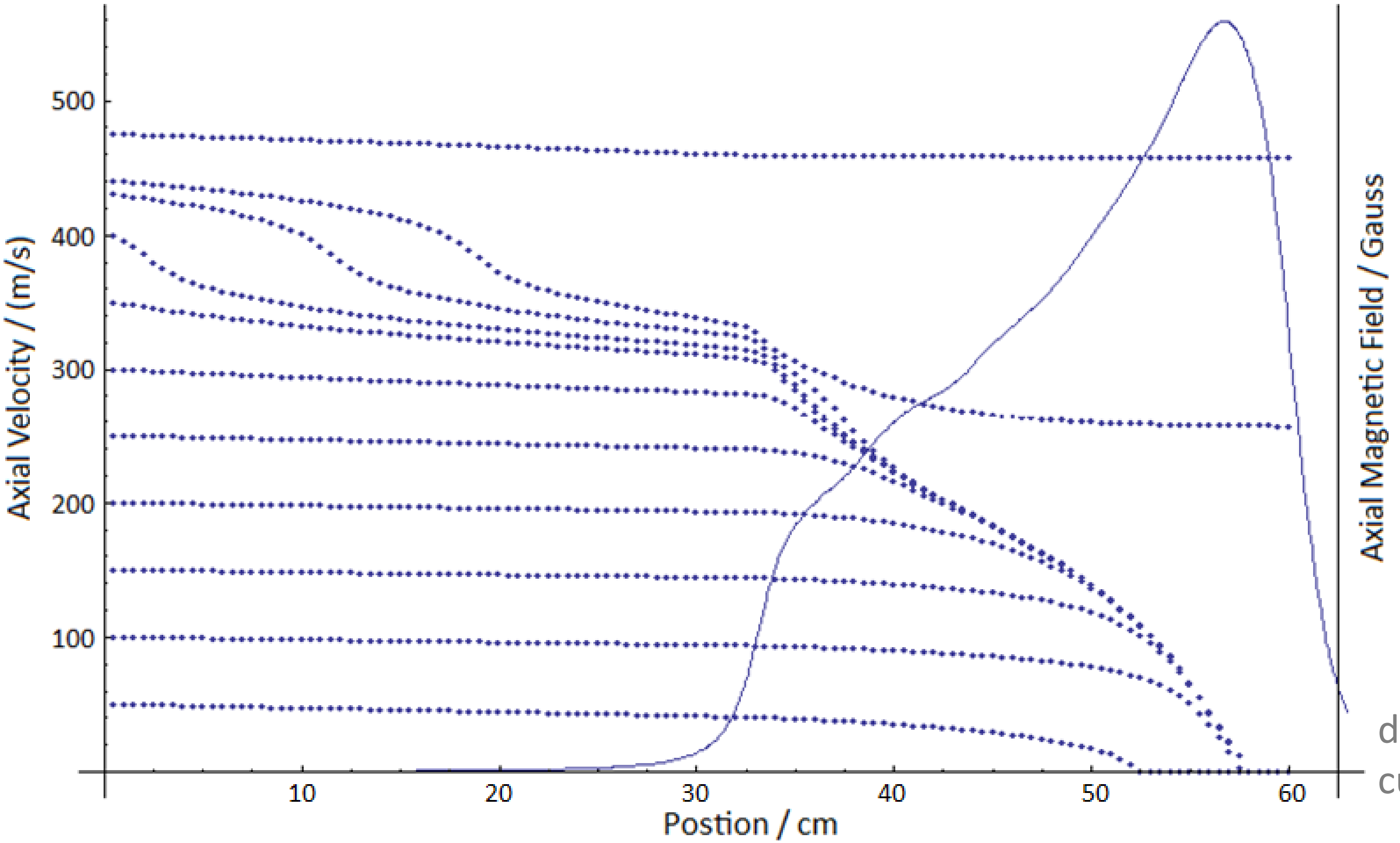
- Position dependent velocity profiles



detuning = 0 Γ
current = 35 A
offset = 0 A

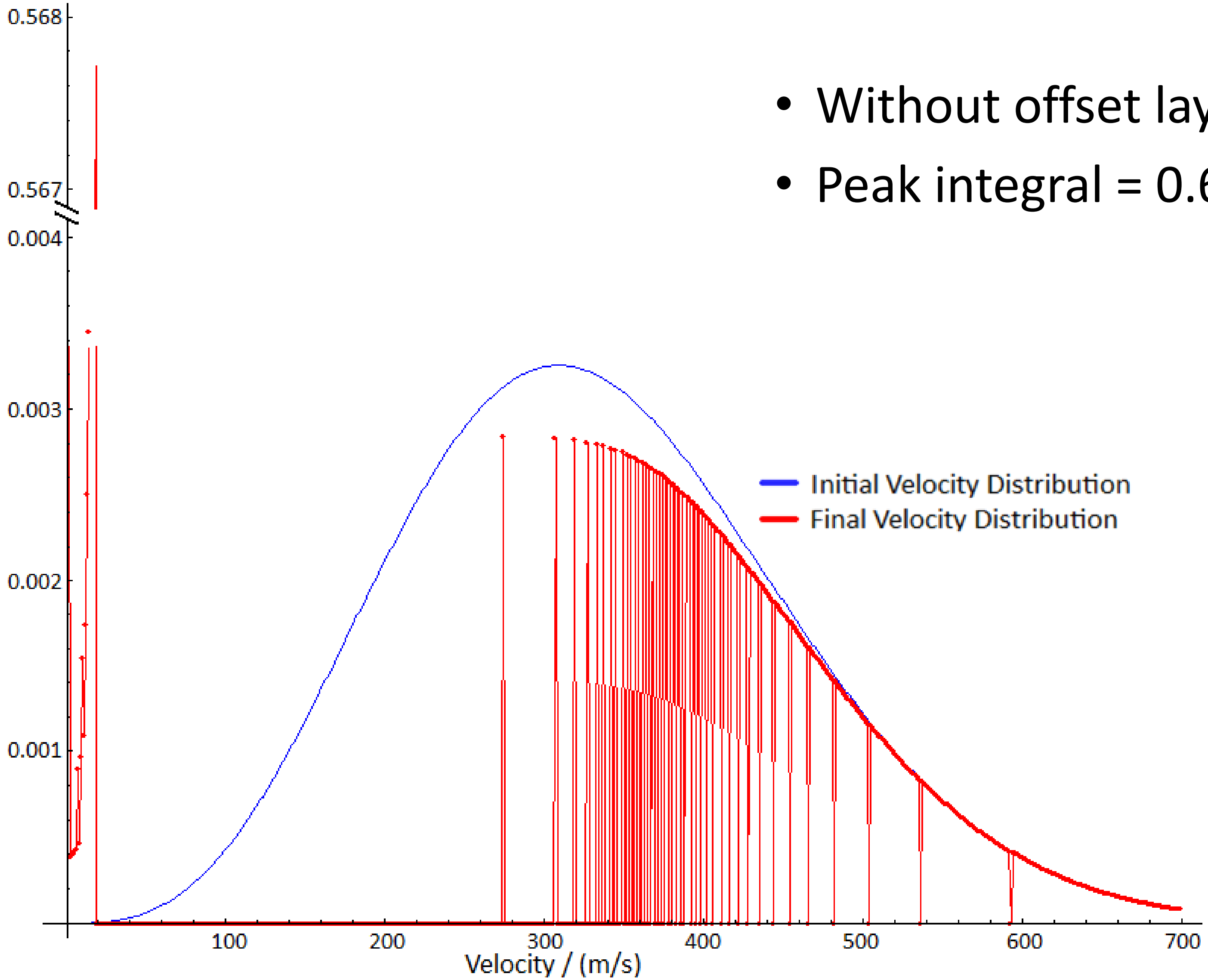
Simulations, velocity profiles

- Position dependent velocity profiles



detuning = -7 Γ
current = 35 A
offset = 20 A

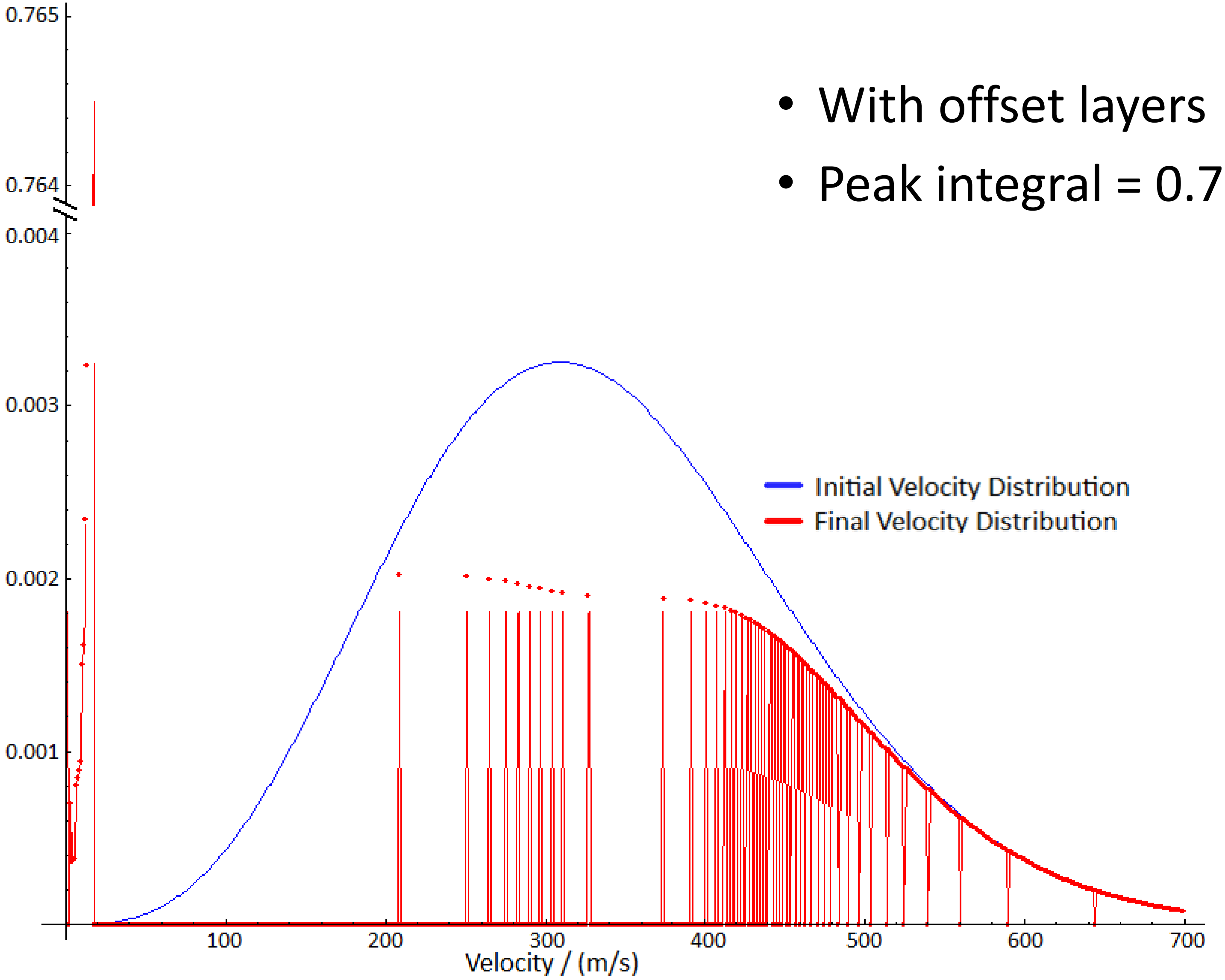
Simulations, velocity distributions



- Without offset layers
- Peak integral = 0.65

Simulations, velocity distributions

- With offset layers
- Peak integral = 0.77



Conclusions and Future Work

- Conclusions
  - Zeeman slower works as predicted
  - Offset field works as expected
- Future work
  - Optimized currents and detuning
  - Additional components for the apparatus
  - Ultra-cold atomic interference experiment

References and Bibliography

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Questions?