A_1^n Polarized ^{3}He magnetic field and gradients: update looking at Q1

- Tosca modeling: Steve Lassiter
- Gradient calculations: Vladimir Nelyubin

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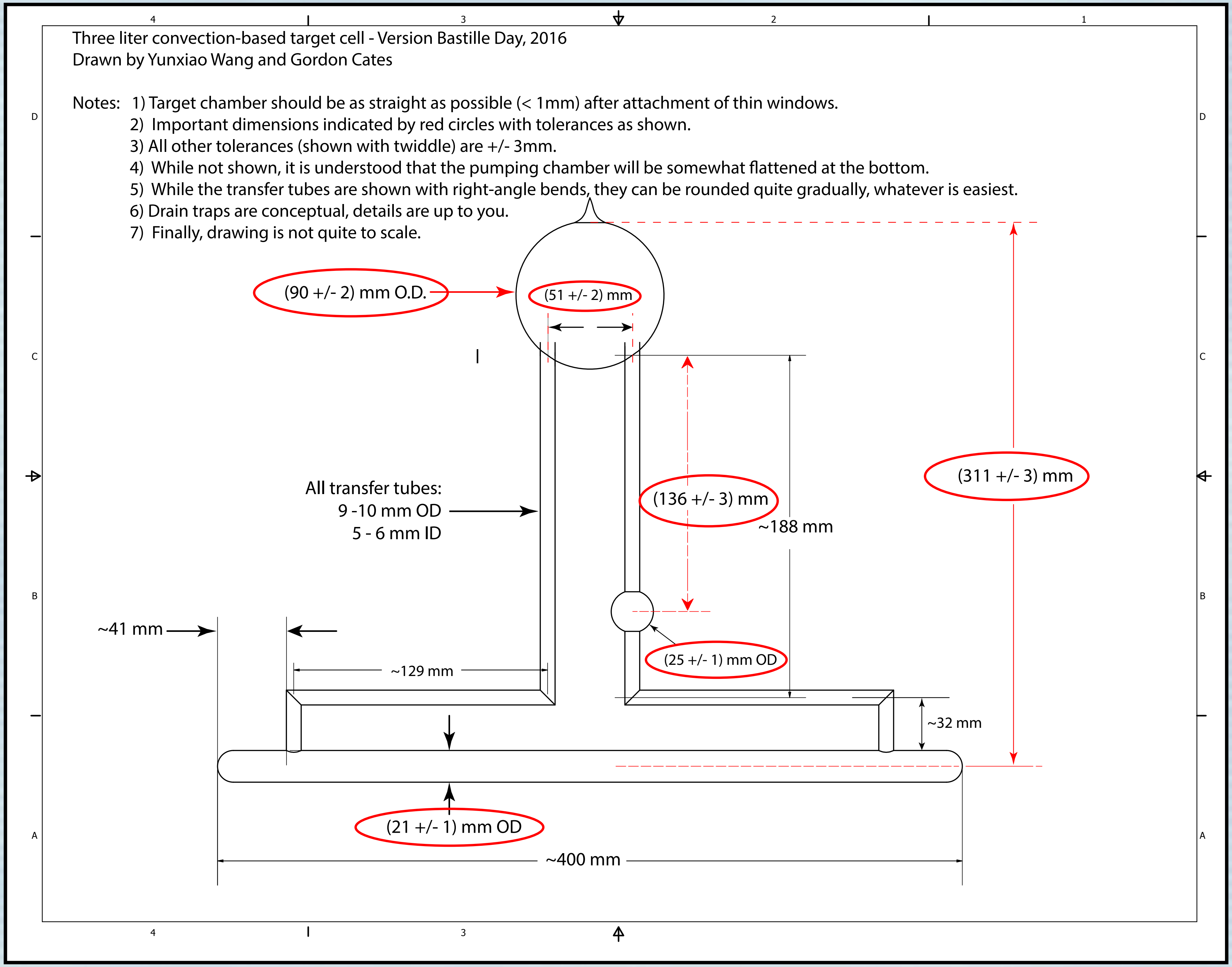
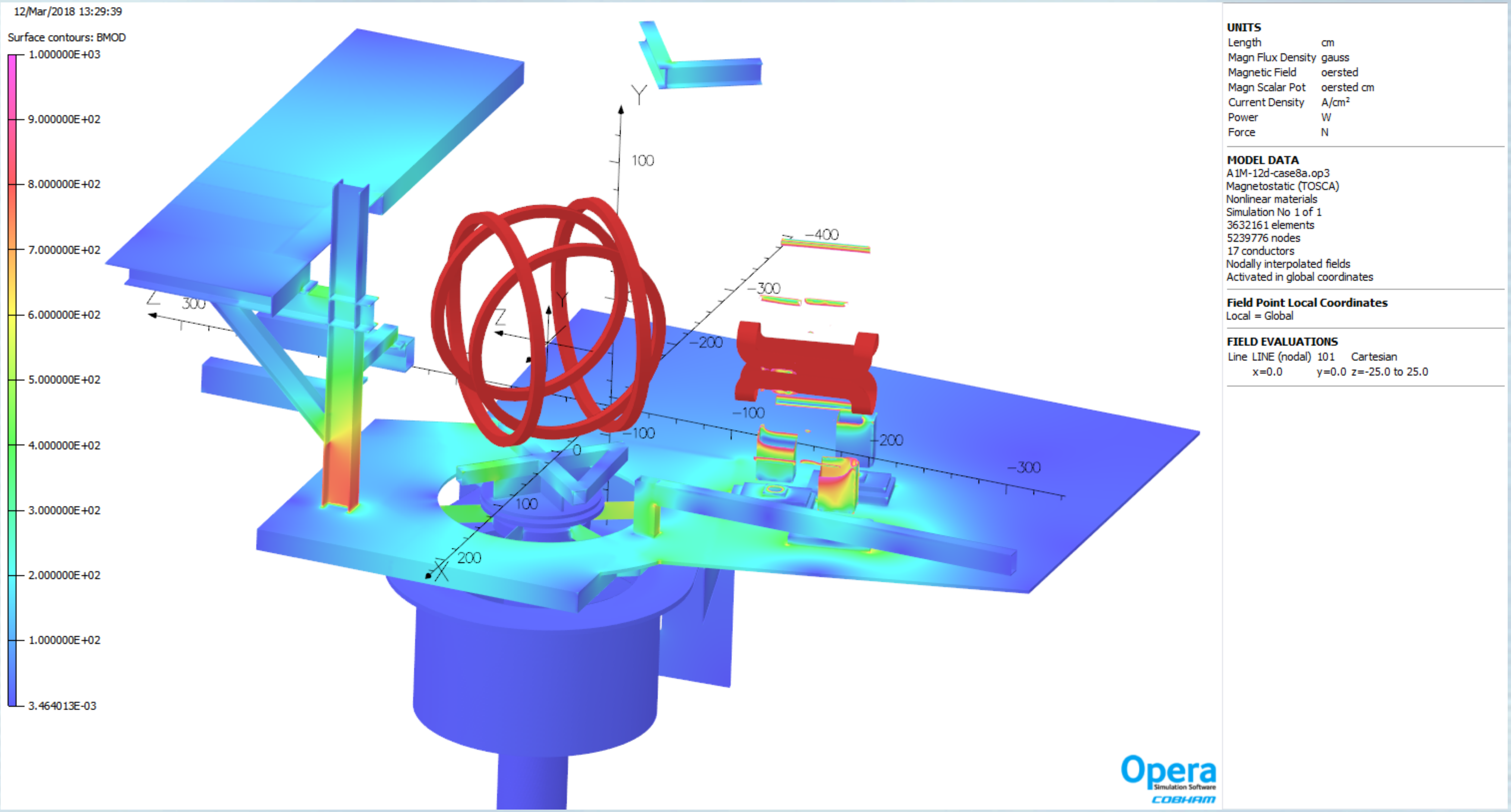
Design of the Hall C convection target



Note that the pumping chamber extends from roughly 22.1cm to 31.1 cm above the center of the target chamber.

Parameters in Steve's Tosca model



Configuration shown above is with Helmholtz coils set for longitudinal running, and the HB correction coils are not turned on (although they are for the plots I will show).

Parameters in Steve's Tosca model for the (single, B_z) case I will show.

- SHMS at 12.5 degrees to beamline
- Helm-Holtz coils orientated at 45 degrees
- Helm-Holtz configured for Bz or Bx field
- HB set at 7.5 GeV/c
- HB correction coils (when used) set to 25AT/cm^2
- Steel structure uses BH curve of mild average steel.
- Tosca model has 5.2 million nodes and 3.6 million quadratic tetrahedral elements.
- Solving time is of the order of 7.5 hours to reach a solution with an RMS error of 5.7% for B fields.

Comment: I believe that this is the setting for resonance production, and is probably a worst case.

Spin relaxation due to magnetic field inhomogeneities under static conditions

- High polarization requires limiting spin-relaxation due to <u>all</u> mechanisms well below the spin-exchange rate.
- Spin relaxation due to magnetic field inhomogeneities under static conditions (that is, not during polarimetry measurements) is due to specific components of the magnetic field inhomogeneities, as described below.

$$\frac{1}{T_1} = D\,\frac{|\vec{\nabla} B_x|^2 + |\vec{\nabla} B_y|^2}{B_z^2}$$

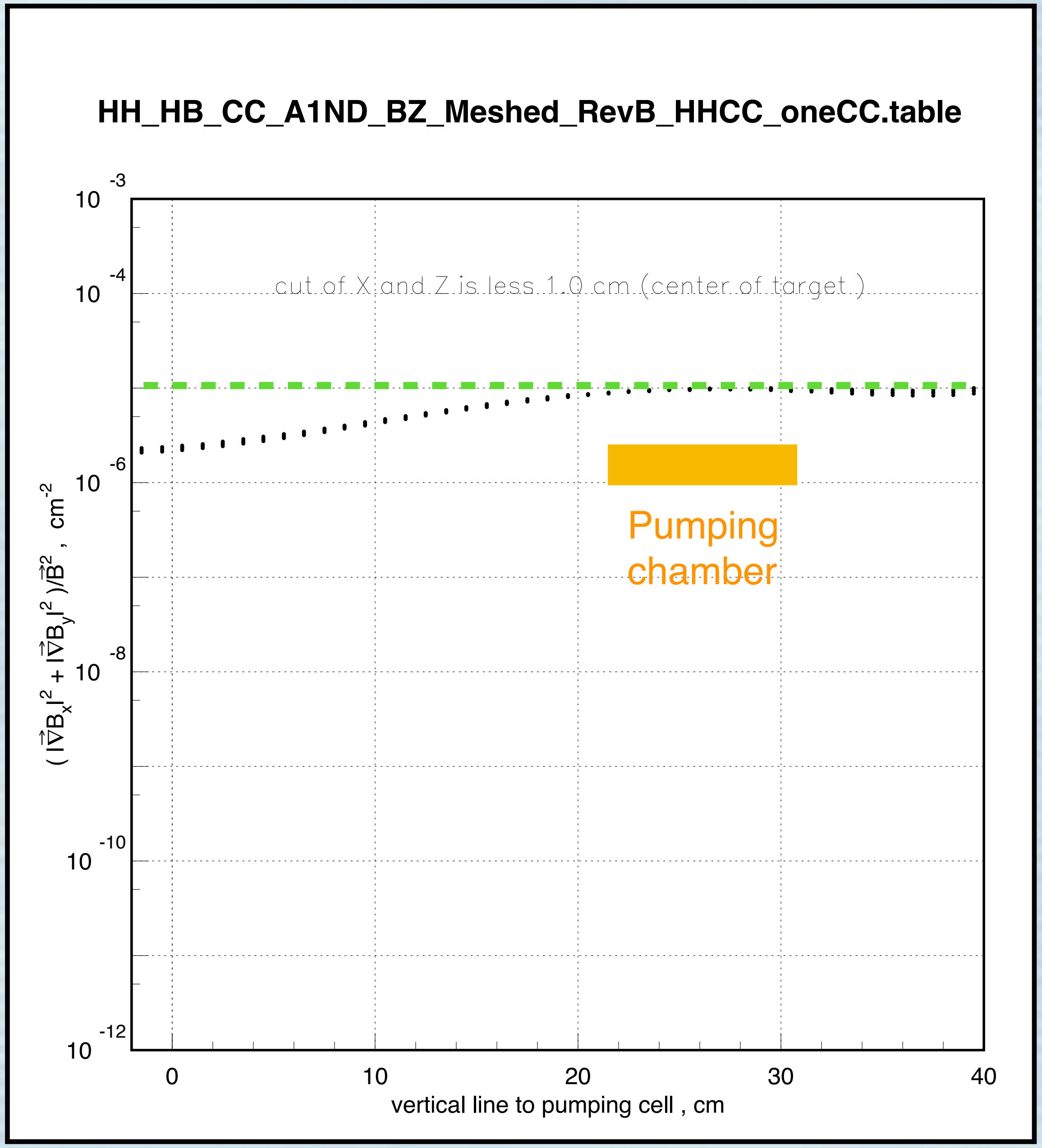
Here $1/T_1$ is the spin relaxation rate, D is the self-diffusion coefficient of ^{3}He, and the magnetic field is assumed to be in the z-direction.

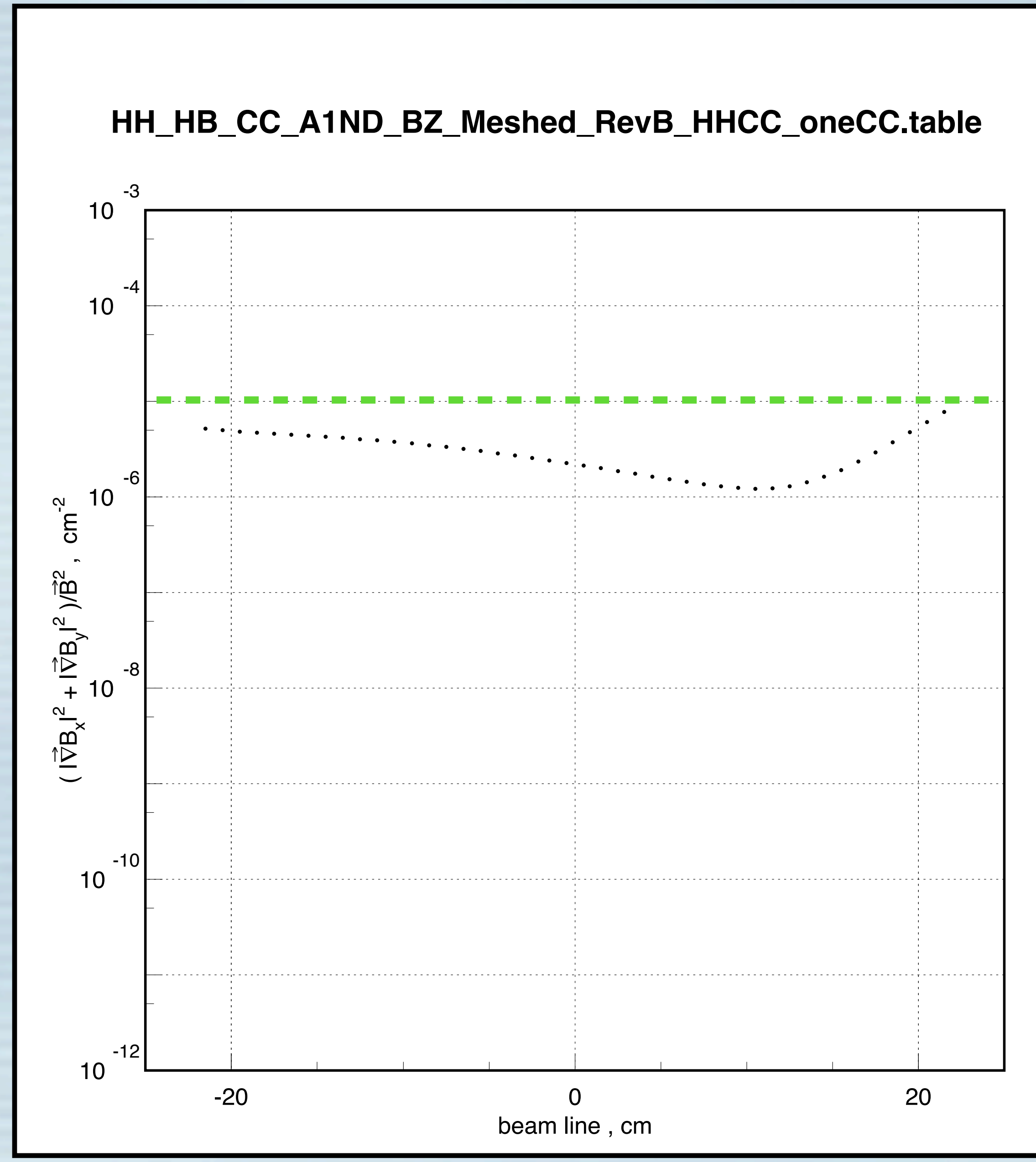
For simplicity, we will assume that a ^{3}He density of 10 atm STP. Under this assumption, D = 0.2 cm^2/s. For example:

$$If \quad \frac{|\vec{\nabla} B_x|^2 + |\vec{\nabla} B_y|^2}{B_z^2} = 10^{-5}\,\mathrm{cm}^{-2}, \quad 1/T_1 = 1/139\,\mathrm{hrs}$$

A good cell, in the absence of beam, might have an intrinsic value of $1/T_1$ = 1/40 hrs. Thus, a value of 10^{-5} cm^{-2} would certainly impact performance, but would not be the dominant factor. At a value of 10^{-6} cm^{-2}, the effects of the inhomogeneities are insignificant.

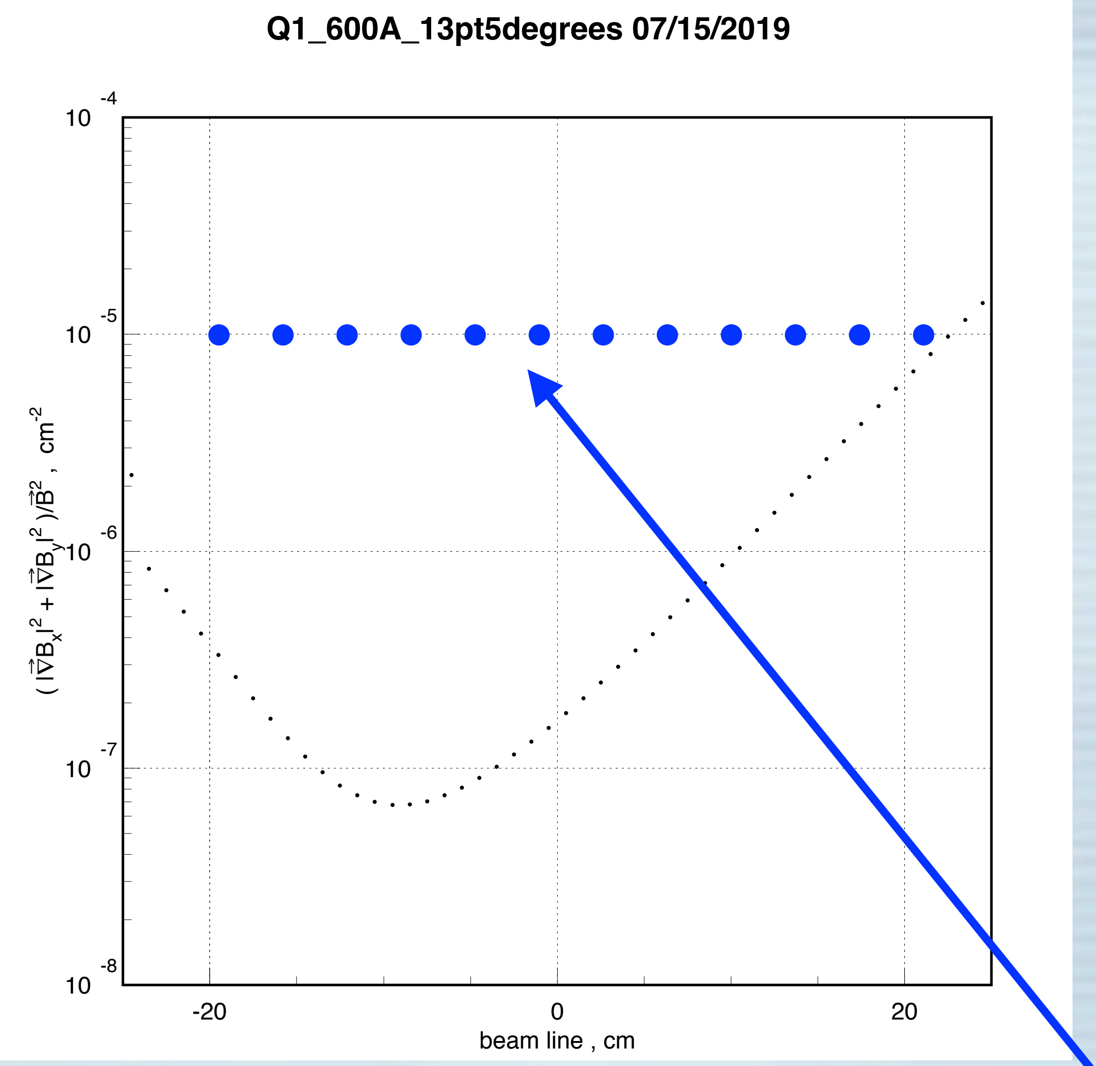
Gradients relevant to static conditions

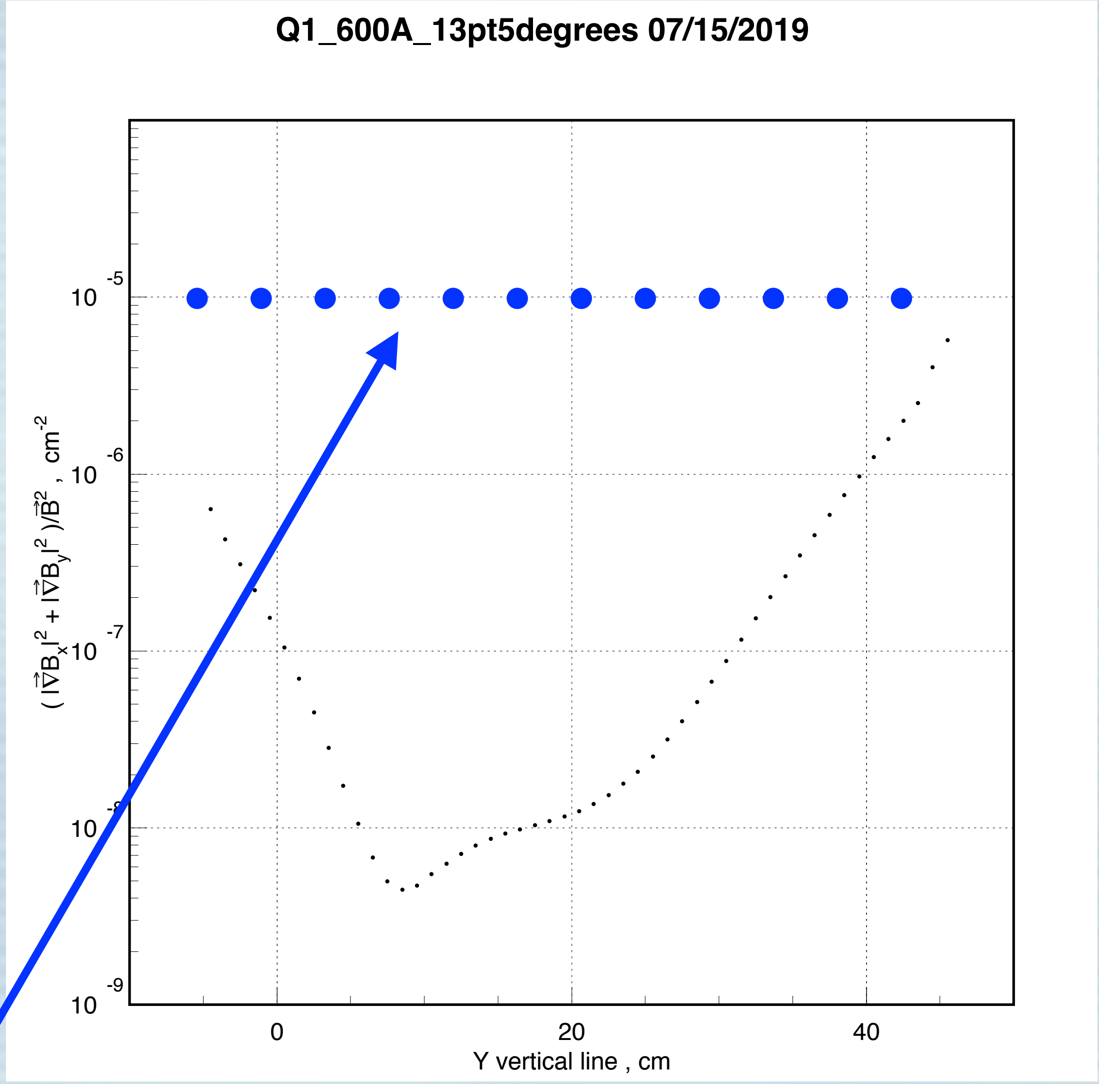




Green dotted lines indicate gradients that result in $1/T_1 = 1/139$ hours

Contribution from Q1 at 600A with HMS at 13.5 degrees (static conditions)



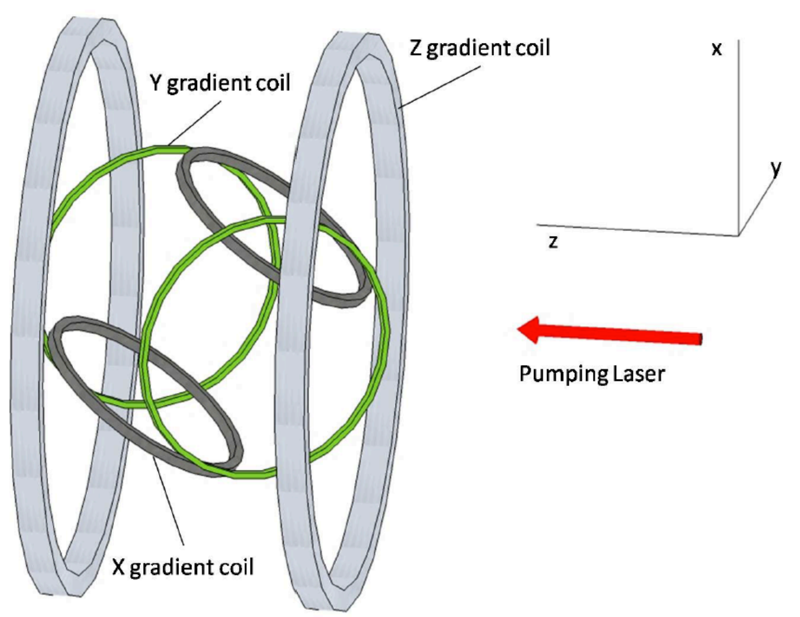


Dotted blue lines shows level that would create spin relaxation at the level of 1/139 hrs

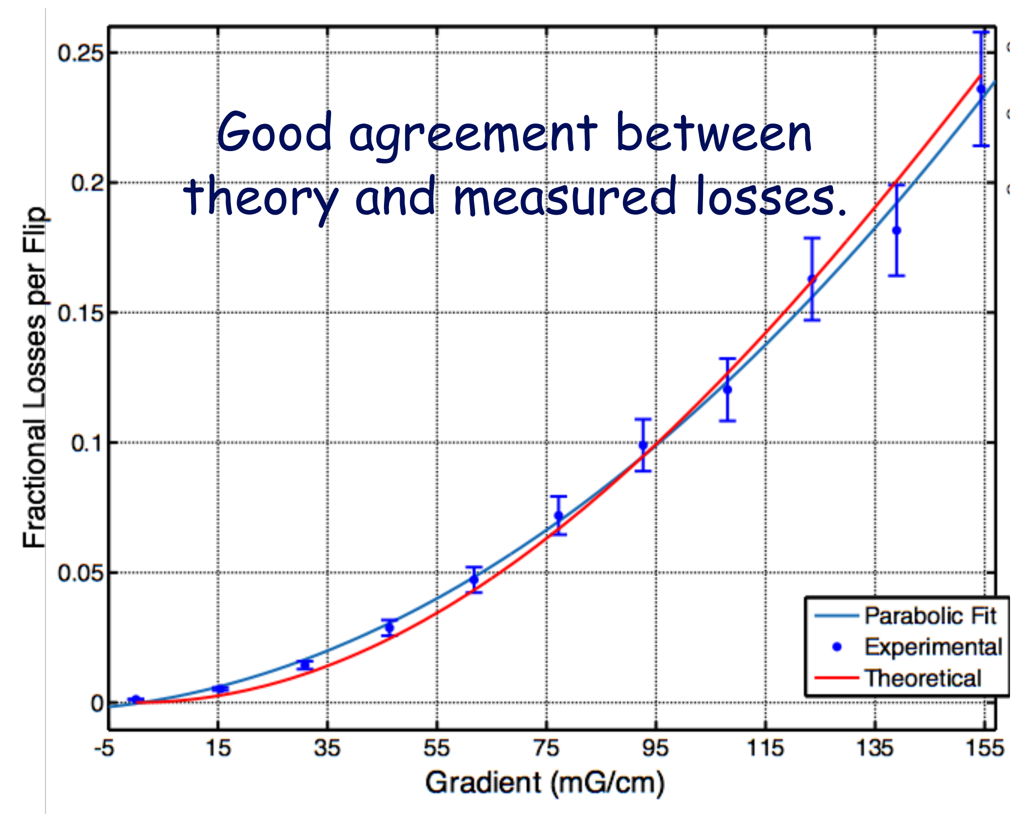
Spin relaxation during NMR AFP
(used during polarimetry)

During an "AFP sweep", all spins in the target are flipped by 180 degrees. The key issue here is the fractional loss of polarization per flip.

$$\text{fractional relaxation} = \frac{|\vec{\nabla} B_z|^2}{B_1^2} D \, \frac{\pi B_1}{2(\partial B_z/\partial t)}$$



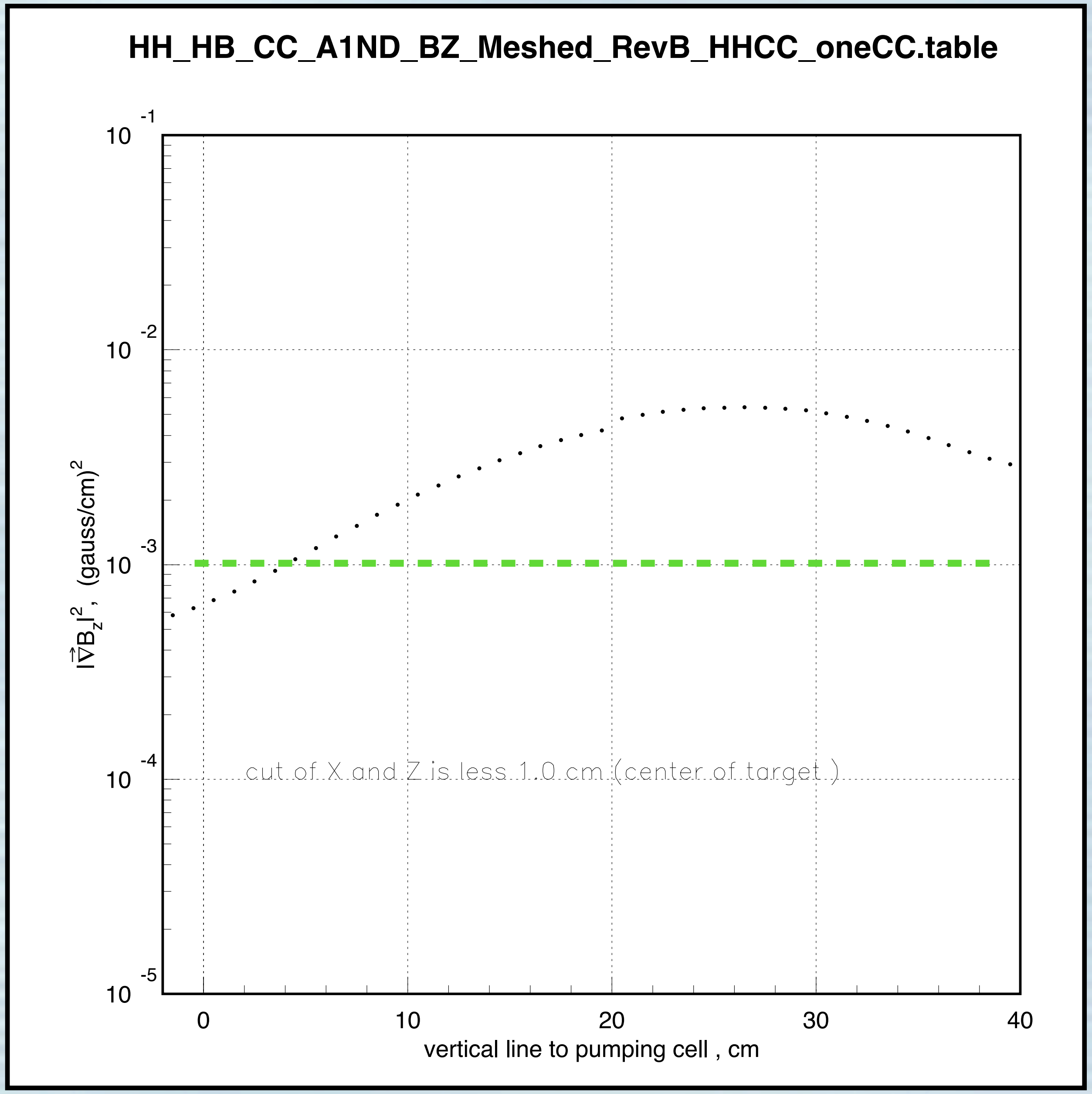
Coils used for test

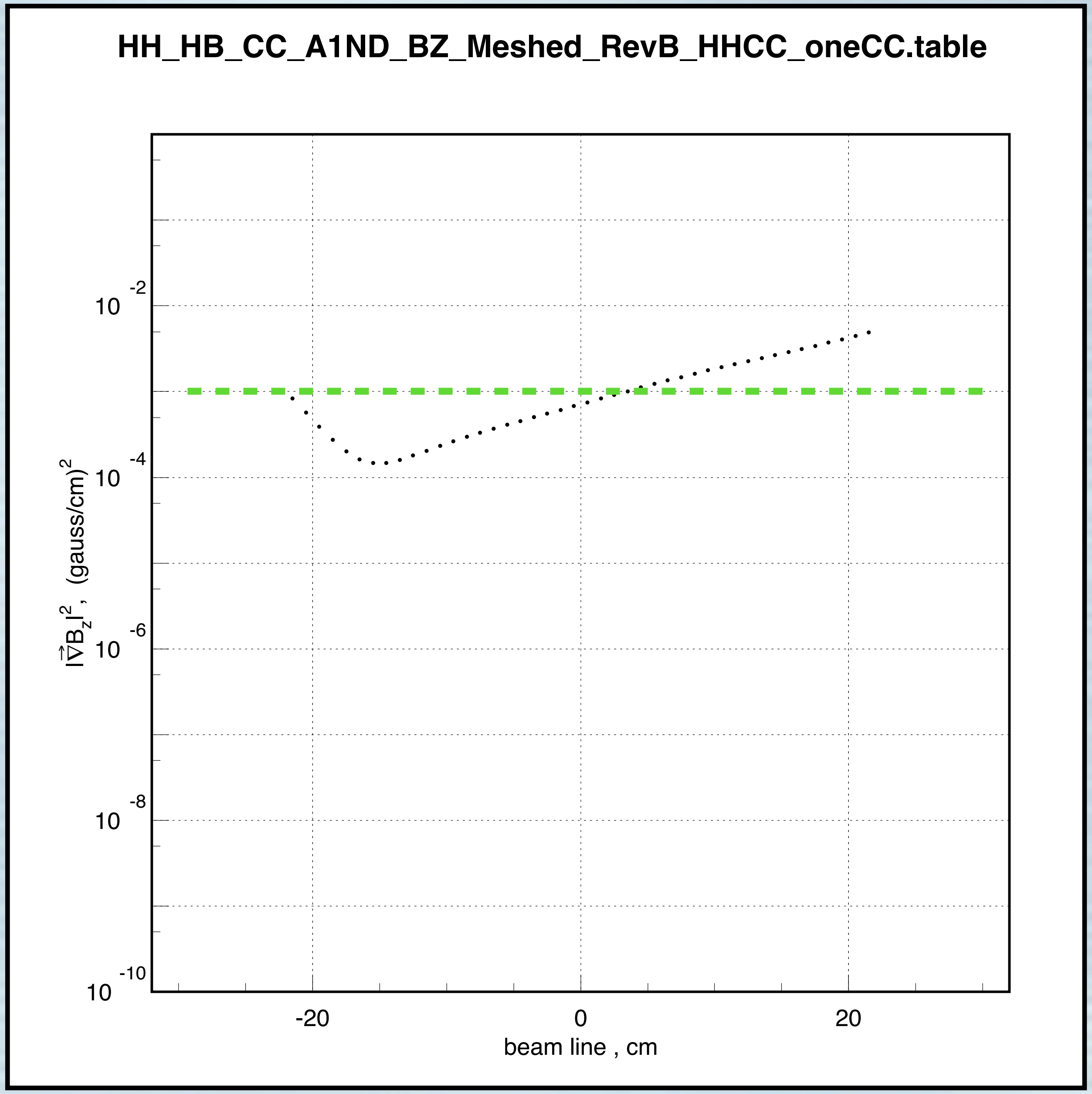


$$If \quad |\vec{\nabla} B_z|^2 = 10^{-3}\,\mathrm{G}^2/\mathrm{cm}^2, \qquad loss = 0.5\%$$

For a value of 10^{-2} G^2/cm^2, the loss would be 5%, which would be an extreme, possibly livable, condition.

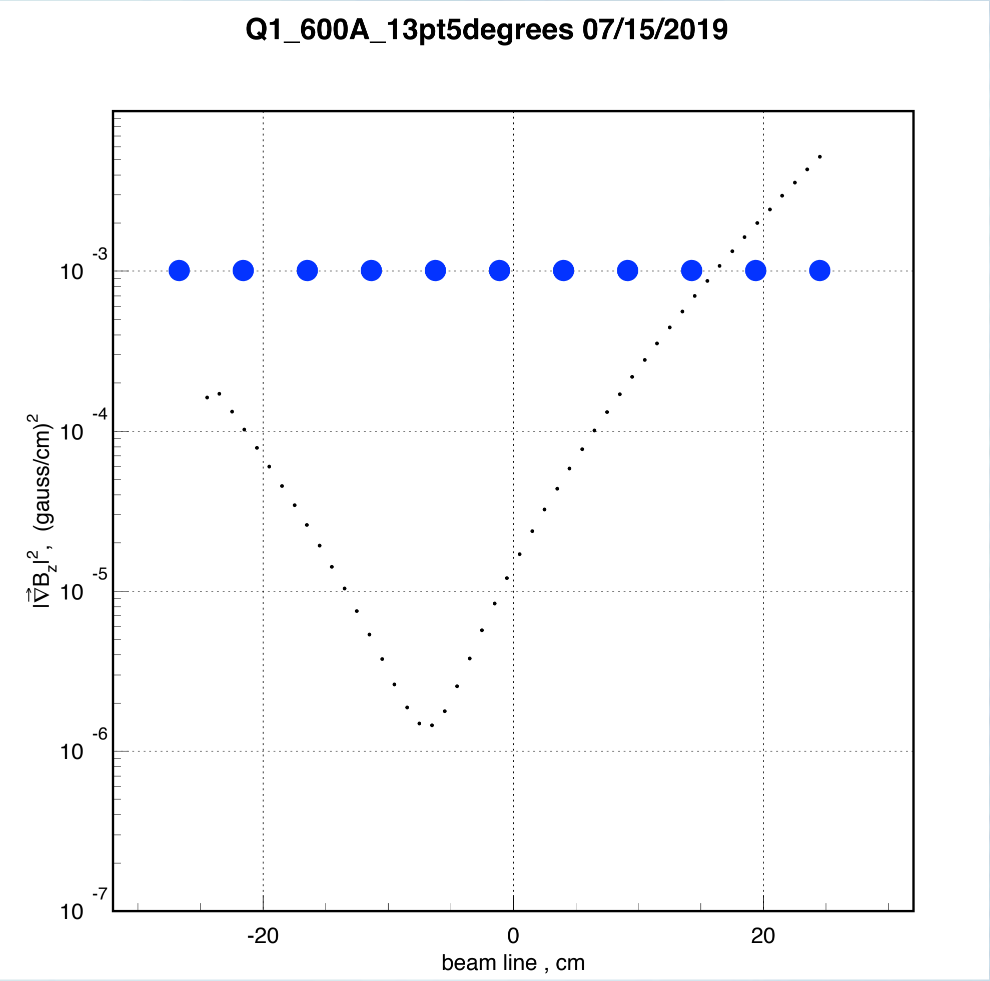
Gradients relevant to AFP conditions

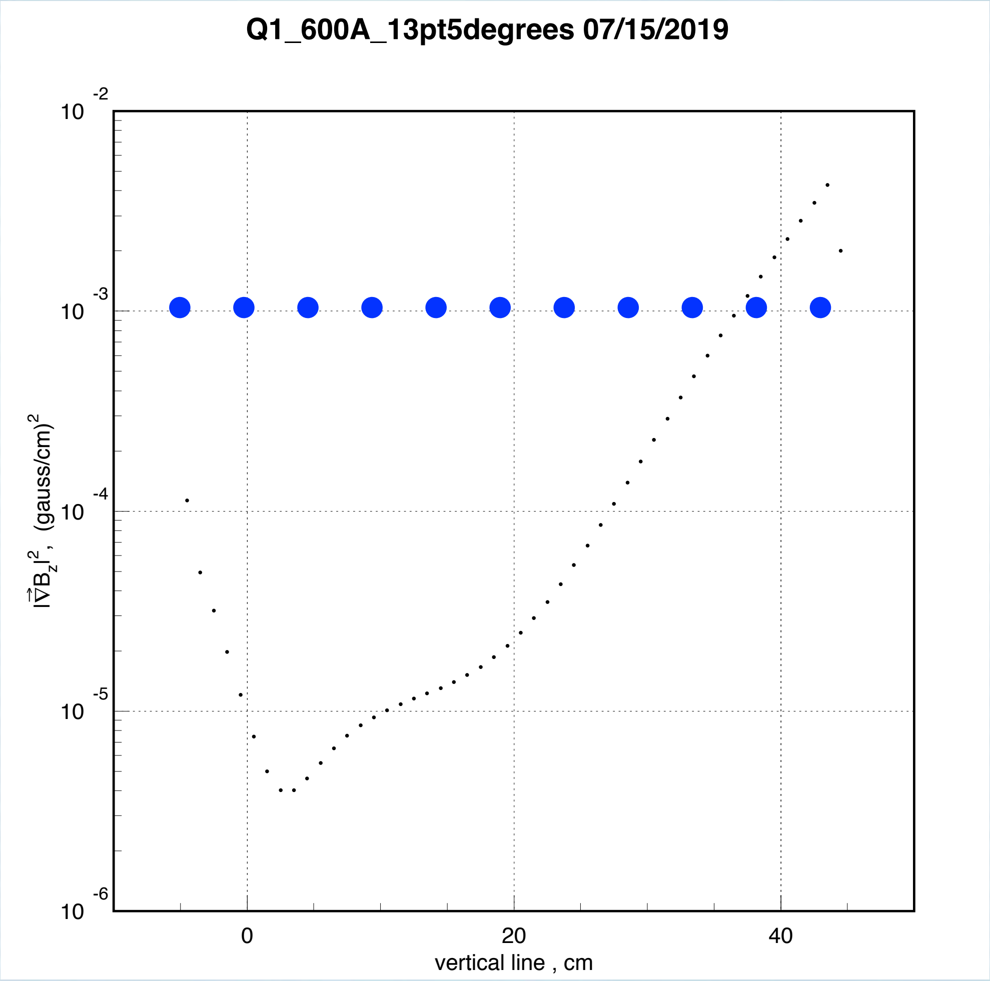




The dashed green line shows the gradient at which losses (per flip) are 0.5%.

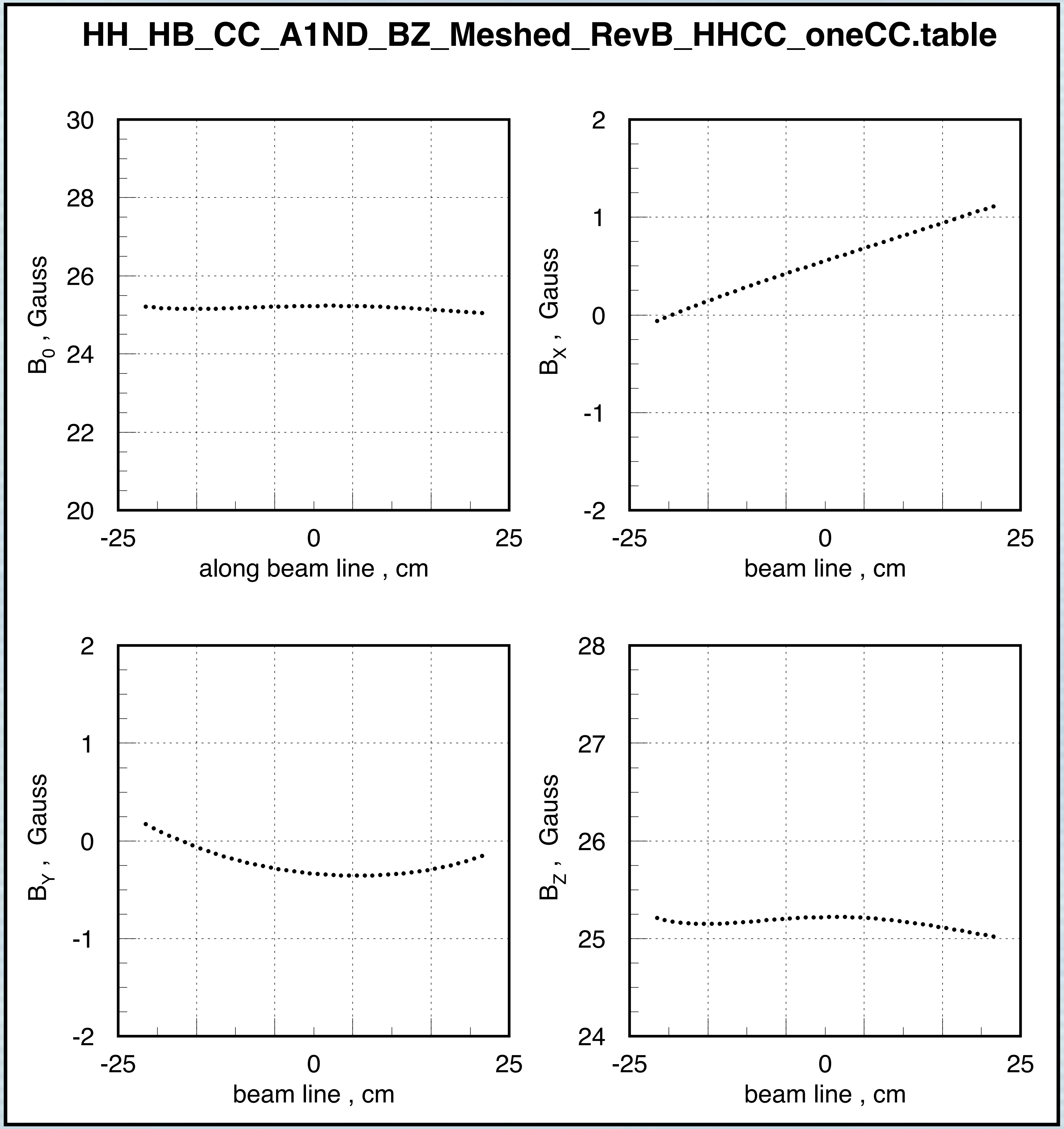
Contribution from Q1 at 600A with HMS at 13.5 degrees (AFP conditions)





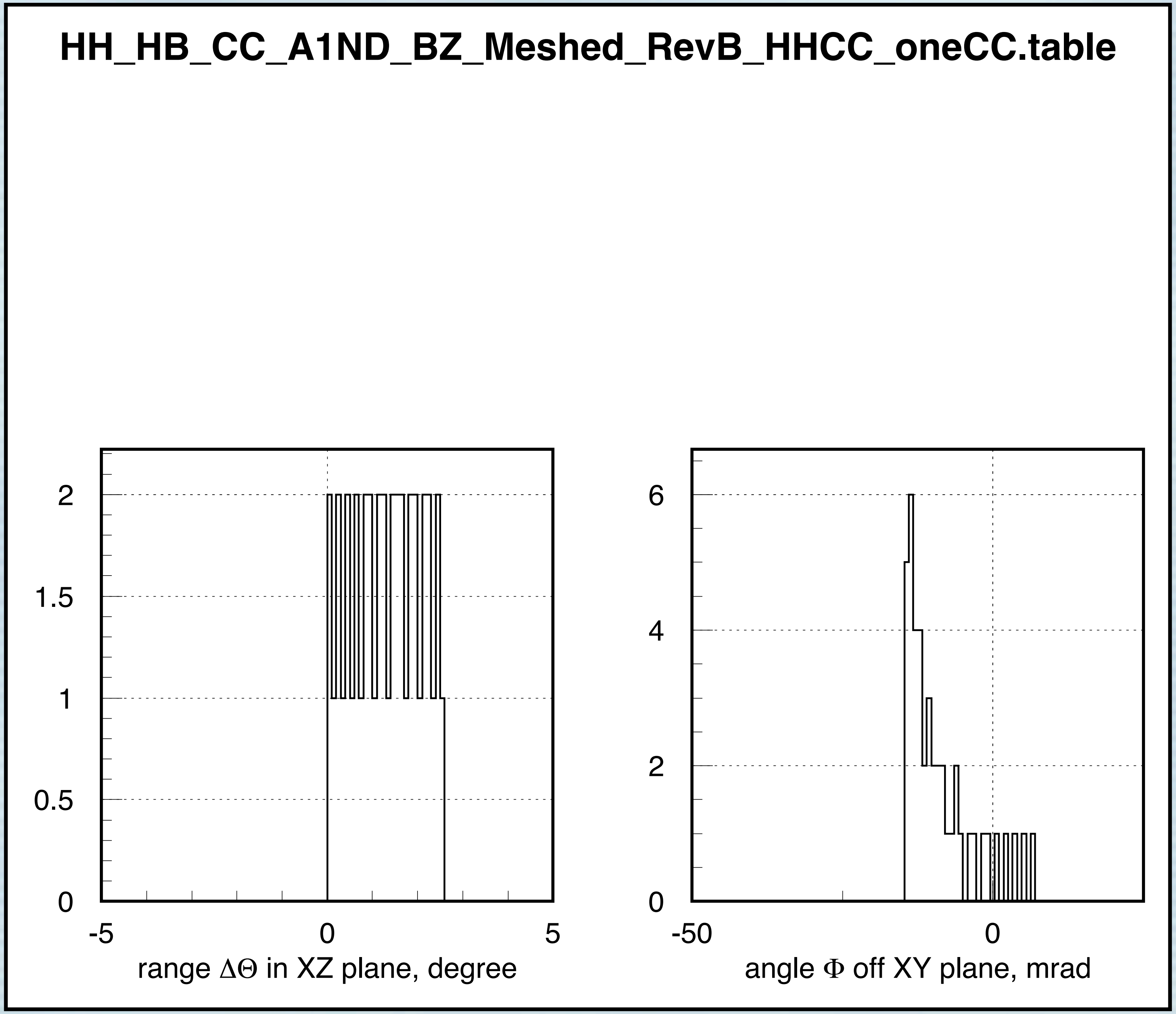
The dashed blue line shows the gradient at which losses (per flip) are 0.5%.

Field components along the target cell



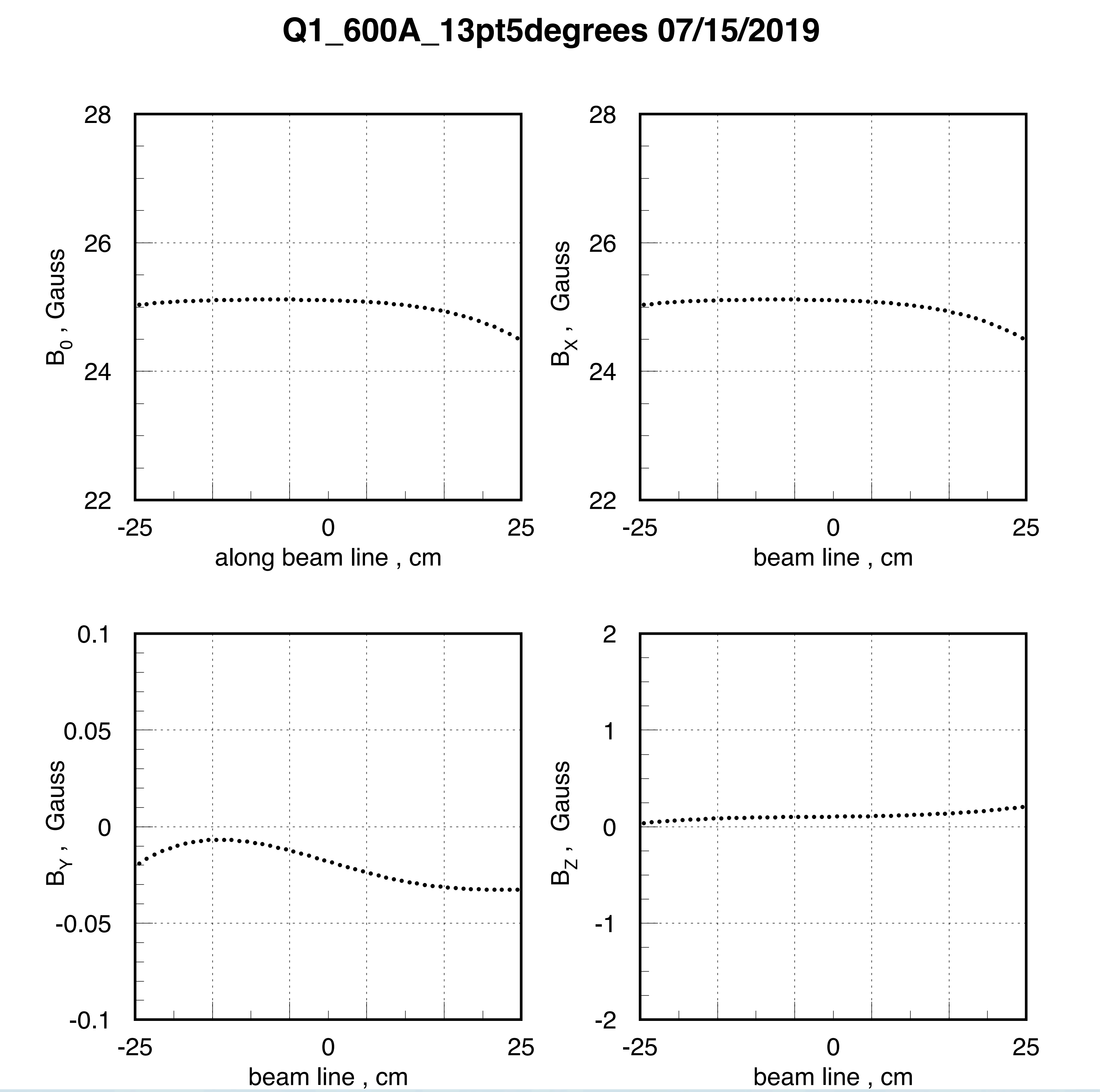
For the configuration shown, the HB correction coil is on and one gradient compensation coil is on.

Angles

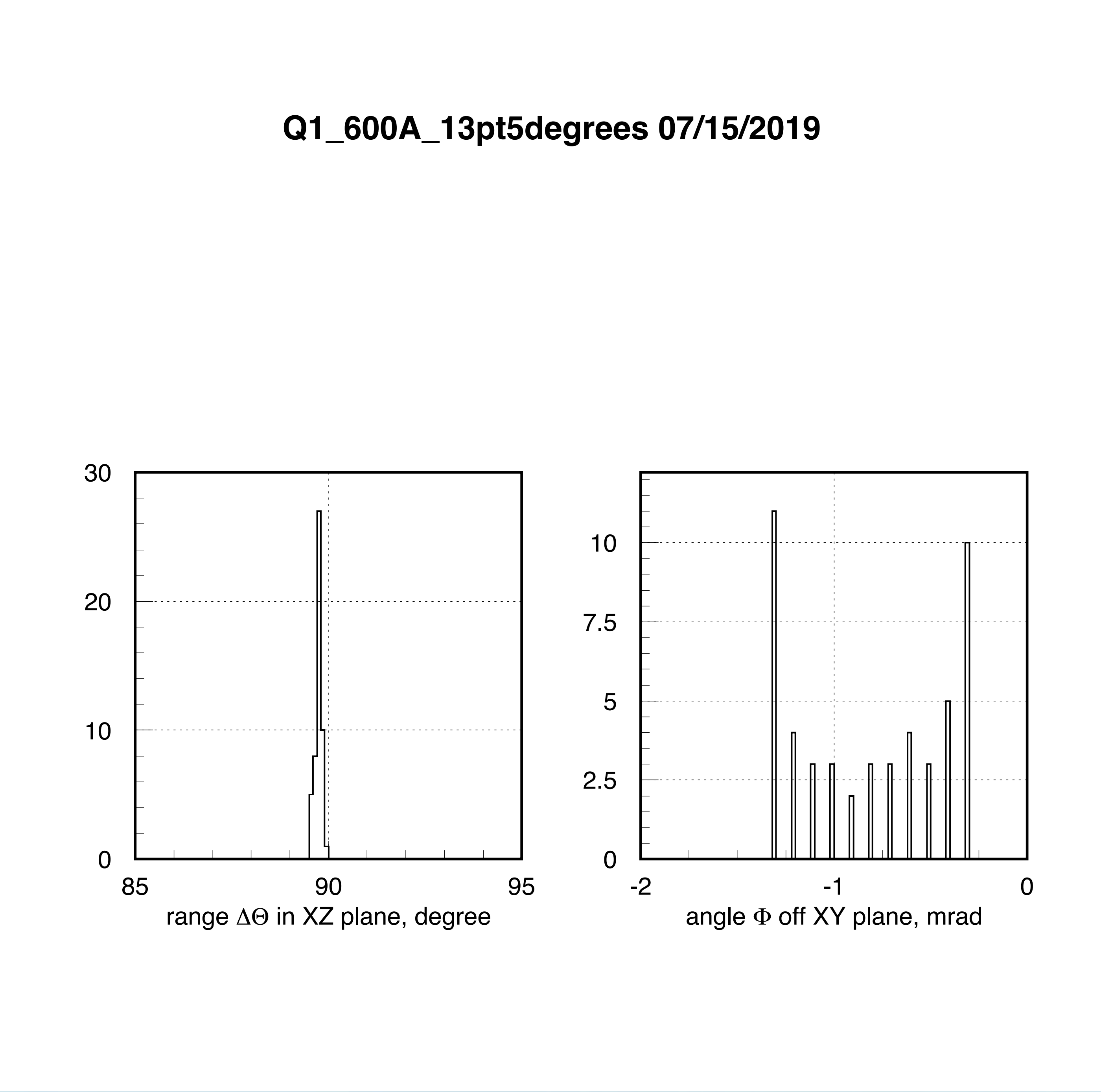


HH_HB_CC_A1ND_BZ_Meshed_RevB_HHCC_oneCC.table
2
1.5
1
0.5
0
-5
0
5
range ΔΘ in XZ plane, degree
6
4
2
0
-50
0
angle Φ off XY plane, mrad

Field components along the target cell (Q1 contribution)



Angles (Q1 contribution)



Summary

- Under static conditions, the gradients look quite good.
- For AFP conditions, losses are a bit excessive for the worst-case scenario, but we will limit measurements by using the pNMR system.
- Contributions from Q1 were studied as per request from ERR, and look quite small.
- If needed, additional gradient coils can be added. However, since the case presented is likely a worst case, it is likely that they will not be needed.