Magnetic Design of FFAG Superconducting Magnets

T. Ogitsu

M. Yoshimoto

M. Aiba

FFAG Magnet
Magnetic Field Requirement

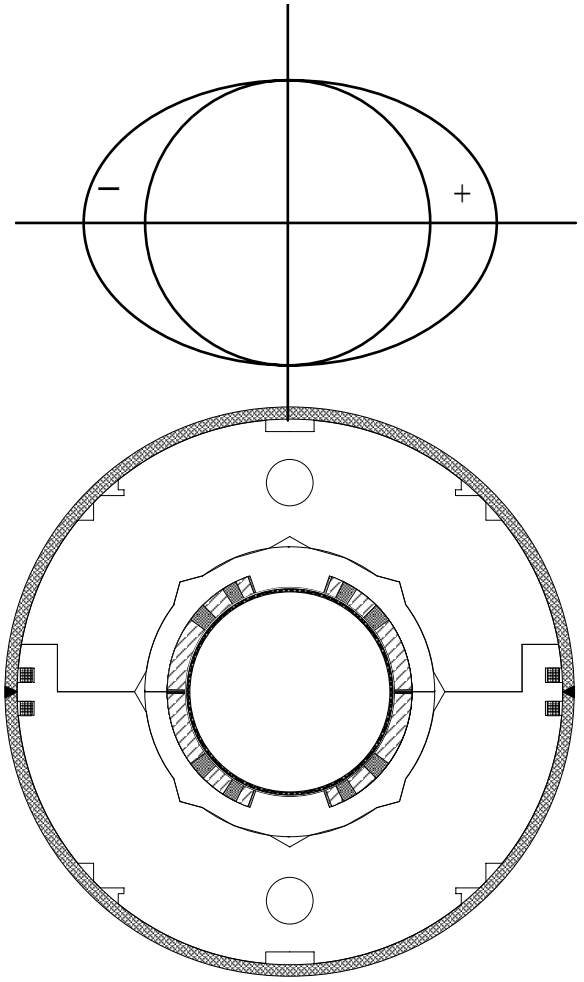
$$B(r) = B_0\left(\frac{r}{r_0}\right)^k$$

*Optics people wants B_0 and k changeable….

- Normal conducting magnet > iron defined field
- Superconducting magnet > current defined field

Conventional SC magnets for Accelerator

- Cosine theta design
  - For example: Dipole
  - Cos(nθ) > 2n-pole magnet
- Well established for
  - Dipole, Quadrupole
    - ~ 8T ~5cm aperture
    - ~5T ~20cm aperture
  - Higher order coils
    - Smaller coils but some are combined with larger main coil



What to do with FFAG field?

What about combination of multipole fields

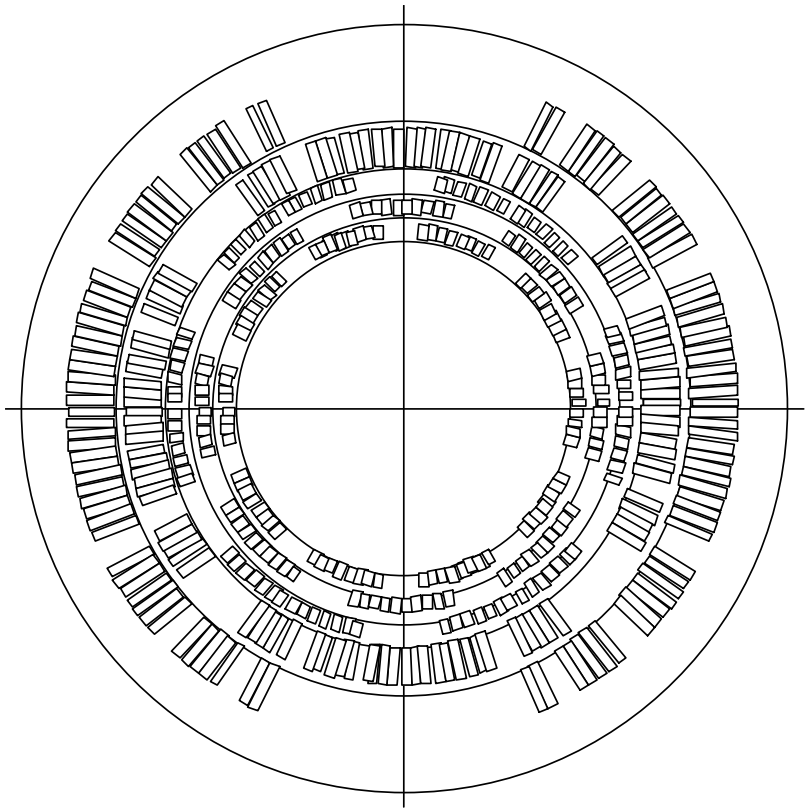
$$B(r) = B_0\left(\frac{r}{r_0}\right)^k$$

$$= B_0 + \frac{k}{r_0}B_0 r + \frac{k(k-1)}{2!\,r_0^{\,2}}B_0 r^2 + \frac{k(k-1)(k-2)}{3!\,r_0^{\,3}}B_0 r^3 + \ldots$$

Combined Multipole Coil?

- Can change B_0 and k in wide range within the conductor limit.
- Can even change the field profile.

- Isn't it too complicated?
  - Magnetic force?
  - Can be expensive...



Let's make it SIMPLE!

Required current distribution

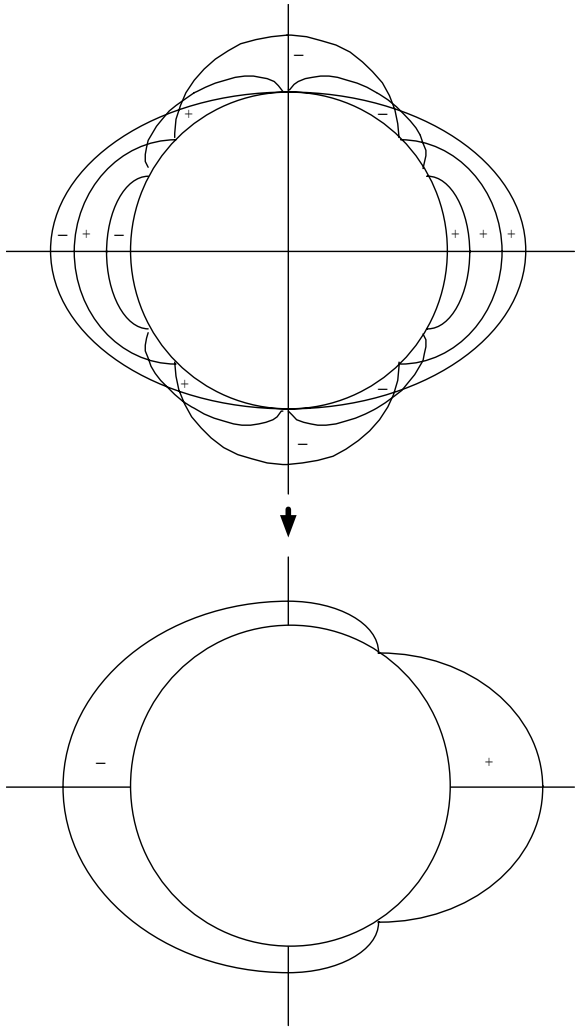
⇓

Sum of all cosine theta current

⇓

Asymmetric Coil

Need R&D!



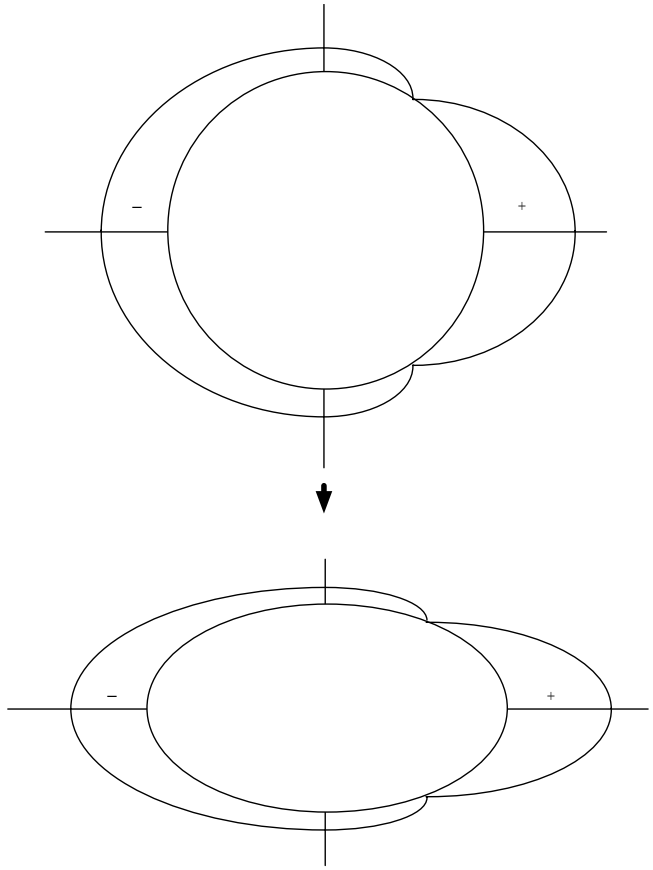
Elliptic Structure

- Large beam excursion
  - Requires large aperture
  - Large Stored Energy
    - Difficult to protect
  - More superconductor
    - More money

⇓

Elliptic Structure

Need R&D as well



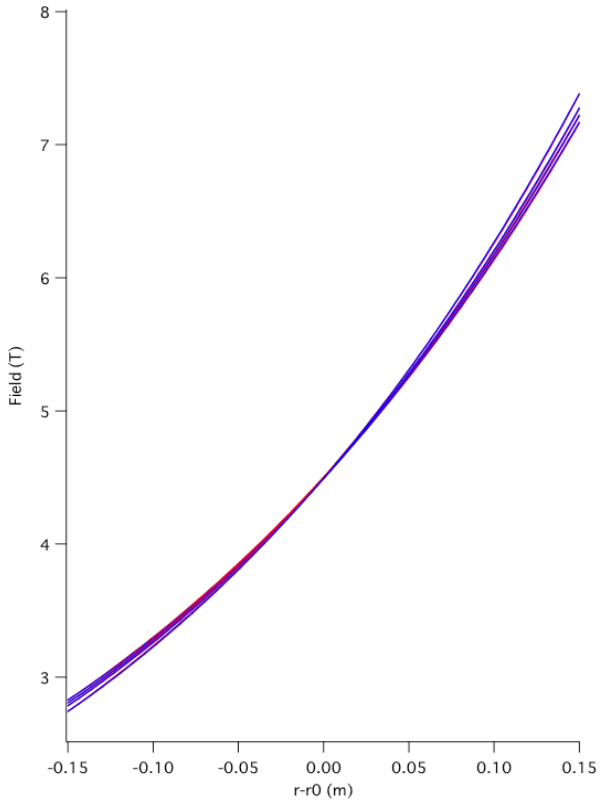
K corrector

- K correction?
  - Does it need to be wide range?
  - If not, first order correction

$$B(r,k+\Delta k) = B_0\left(\frac{r}{r_0}\right)^{k+\Delta k}$$

$$\sim B(r,k) + \frac{dB(r,k)}{dk}\Delta k$$

$$\sim B_0\left(\frac{r}{r_0}\right)^{k} + B_0\left(\frac{r}{r_0}\right)^{k}\ln\left(\frac{r}{r_0}\right)\Delta k$$

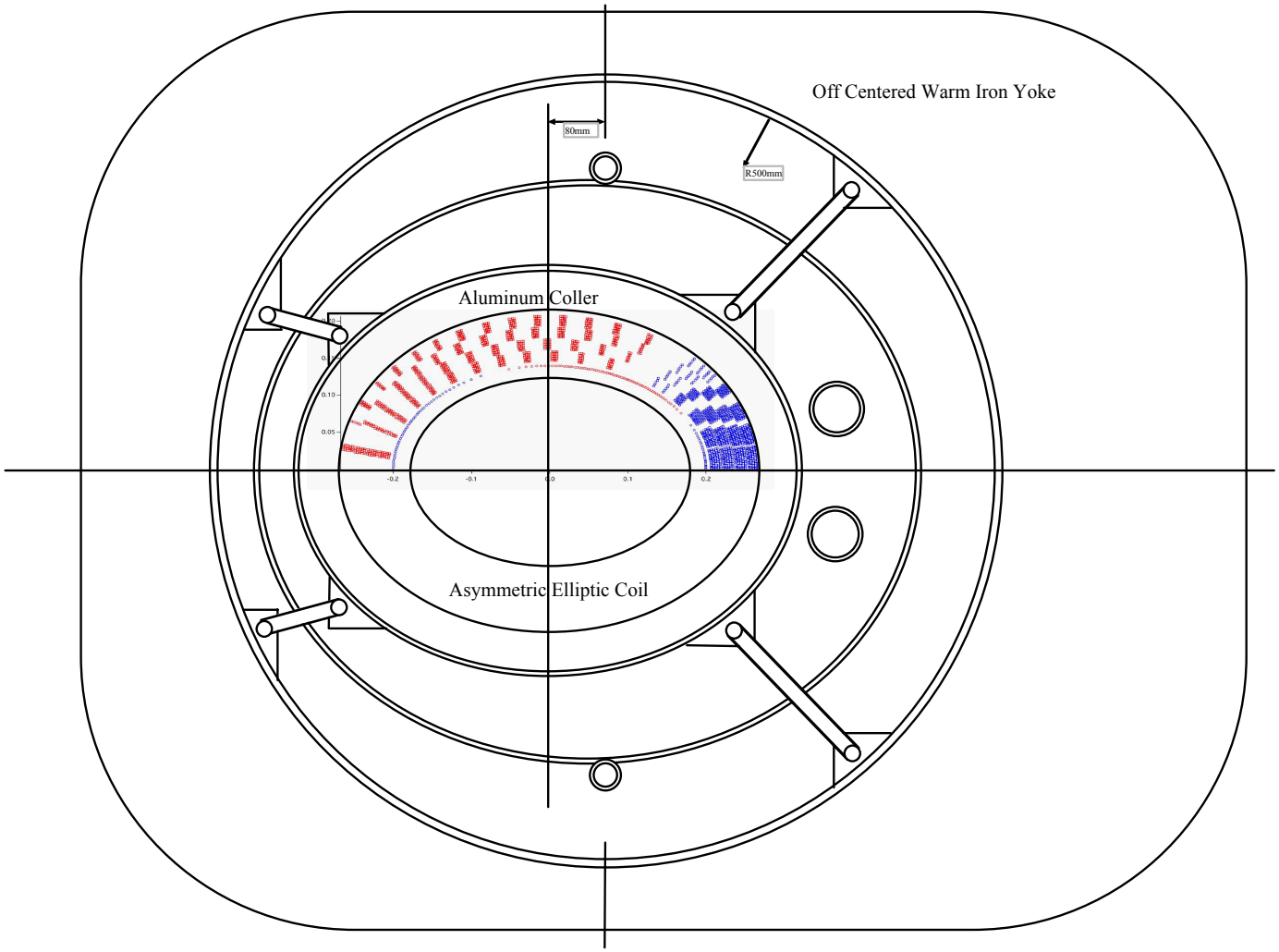


$B_0 = 4.5$, $r_0 = 200$, k = 620, δk = 10, 20, 40
Red lines represent definite equation, while
Blue lines represent first order approximation.

Current distribution can be derived using the same method as that of main coil

Reference Design 1

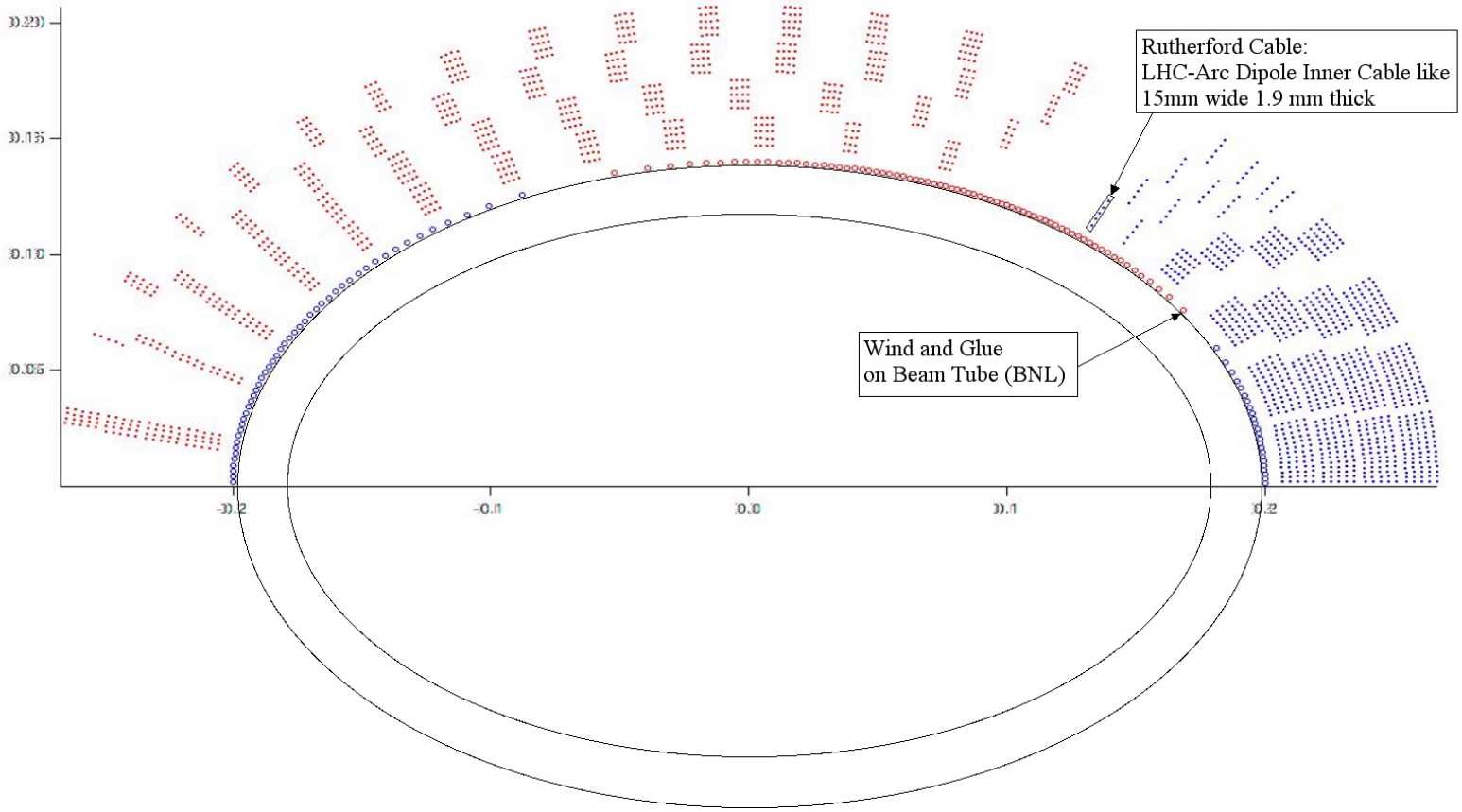
- B_0=5.75T, r_0=200m, k=680, beam excursion 20.3m



1. Main Coil
   - Asymmetric & Elliptic
   - Rutherford Cable 2X15mm
   - Operation Current 7.5kA
   - Stored Energy: ~0.9MJ/m
2. Corrector Coil
   - Wind & glue (BNL)
   - ~10A/delta-K
3. Collar
   - Pre-stress ~80MPa
   - Horizontal EMF ~ 3.7 MN
   - Aluminum collar to gain pre-stress during cool down
4. Iron Yoke
   - Off centered yoke for EMF balance
   - Warm Iron

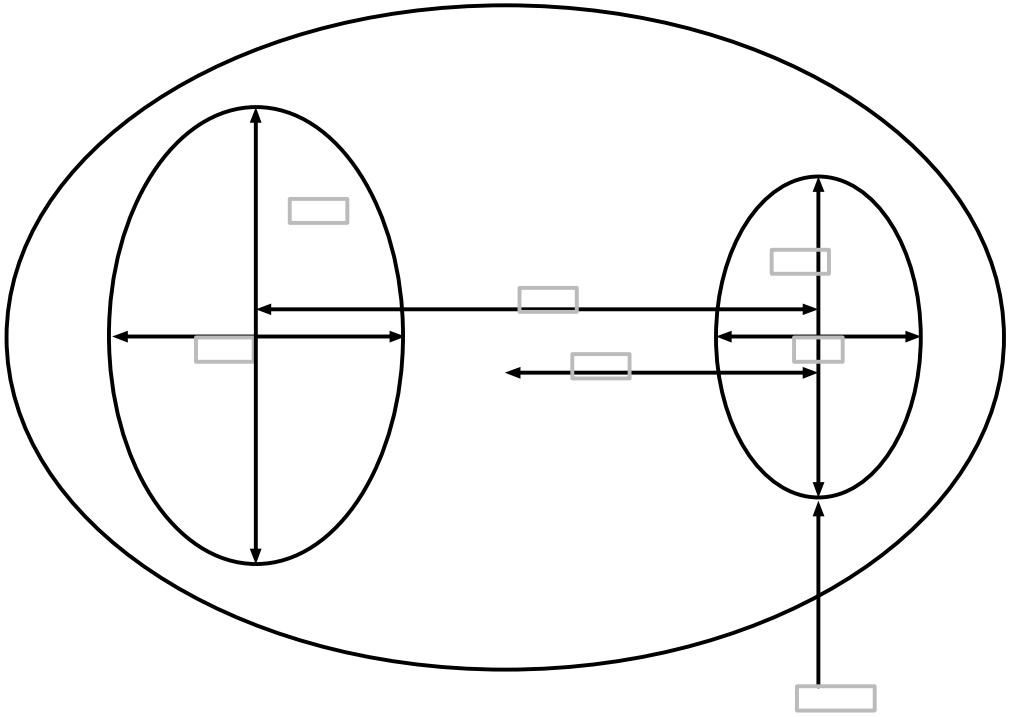
Reference Design 1

Coil Cross Section



Reference Design 1

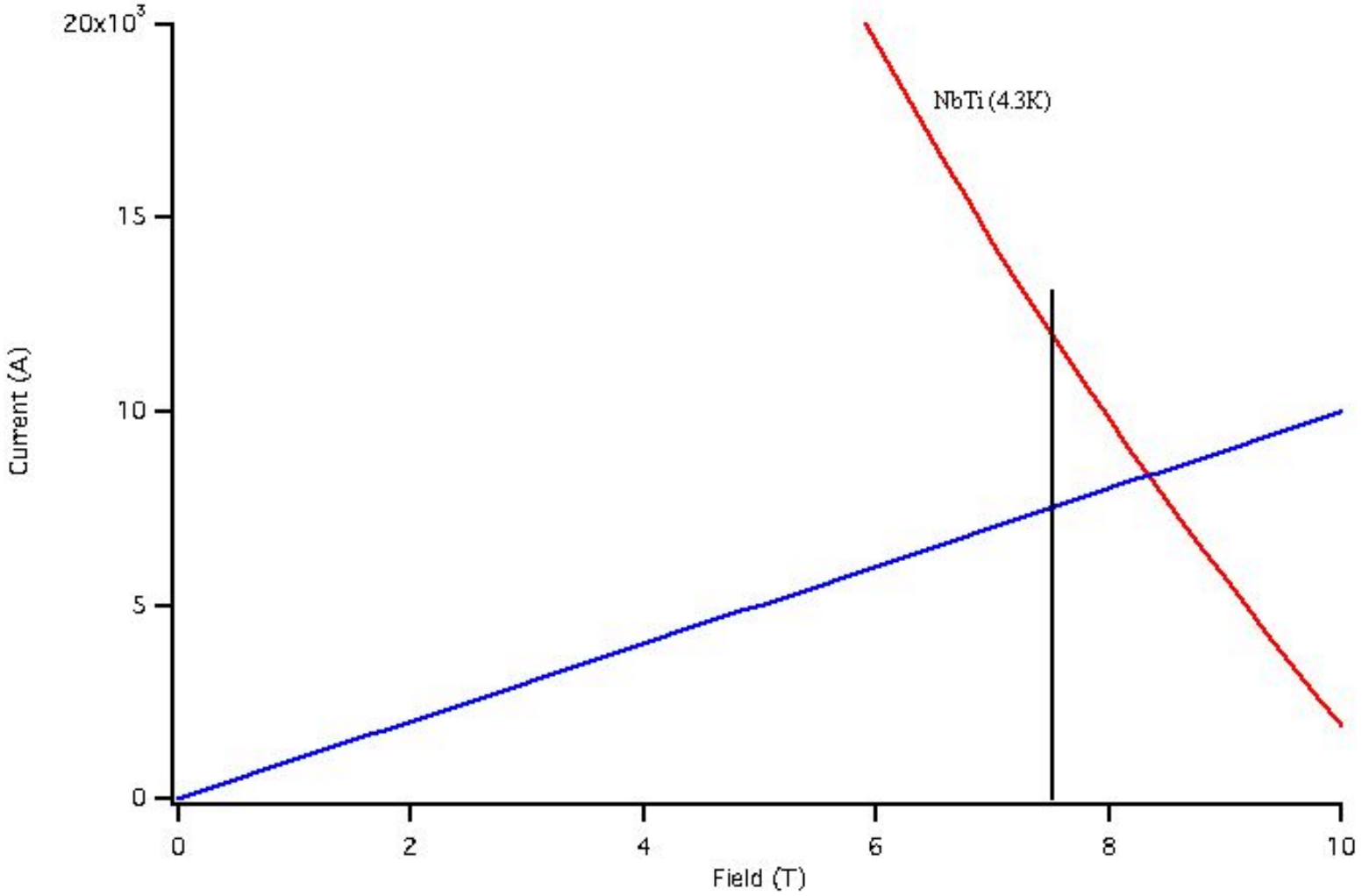
Field Map & Beam Aperture



165mm

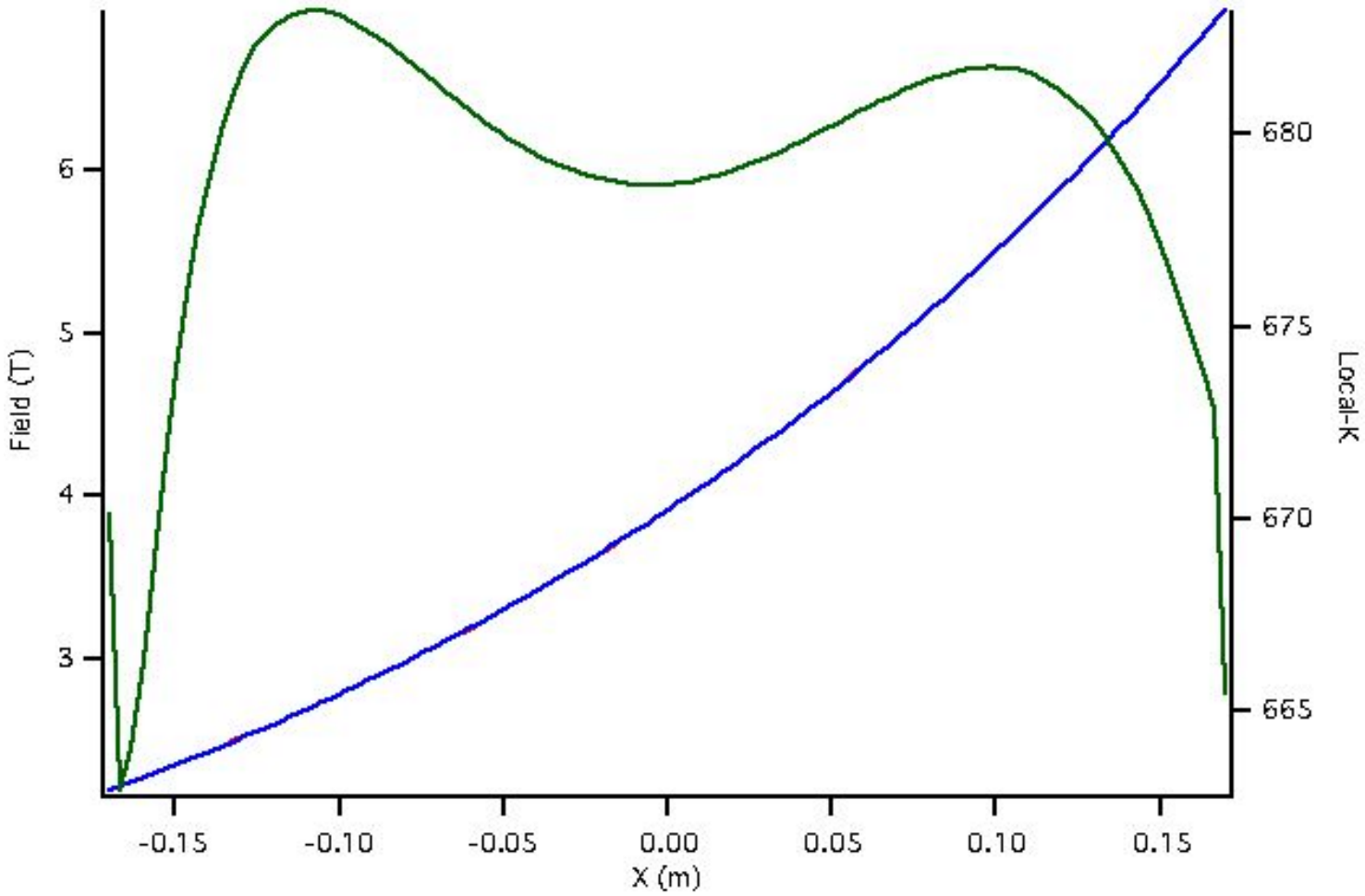
Reference Design 1

Operation Margin

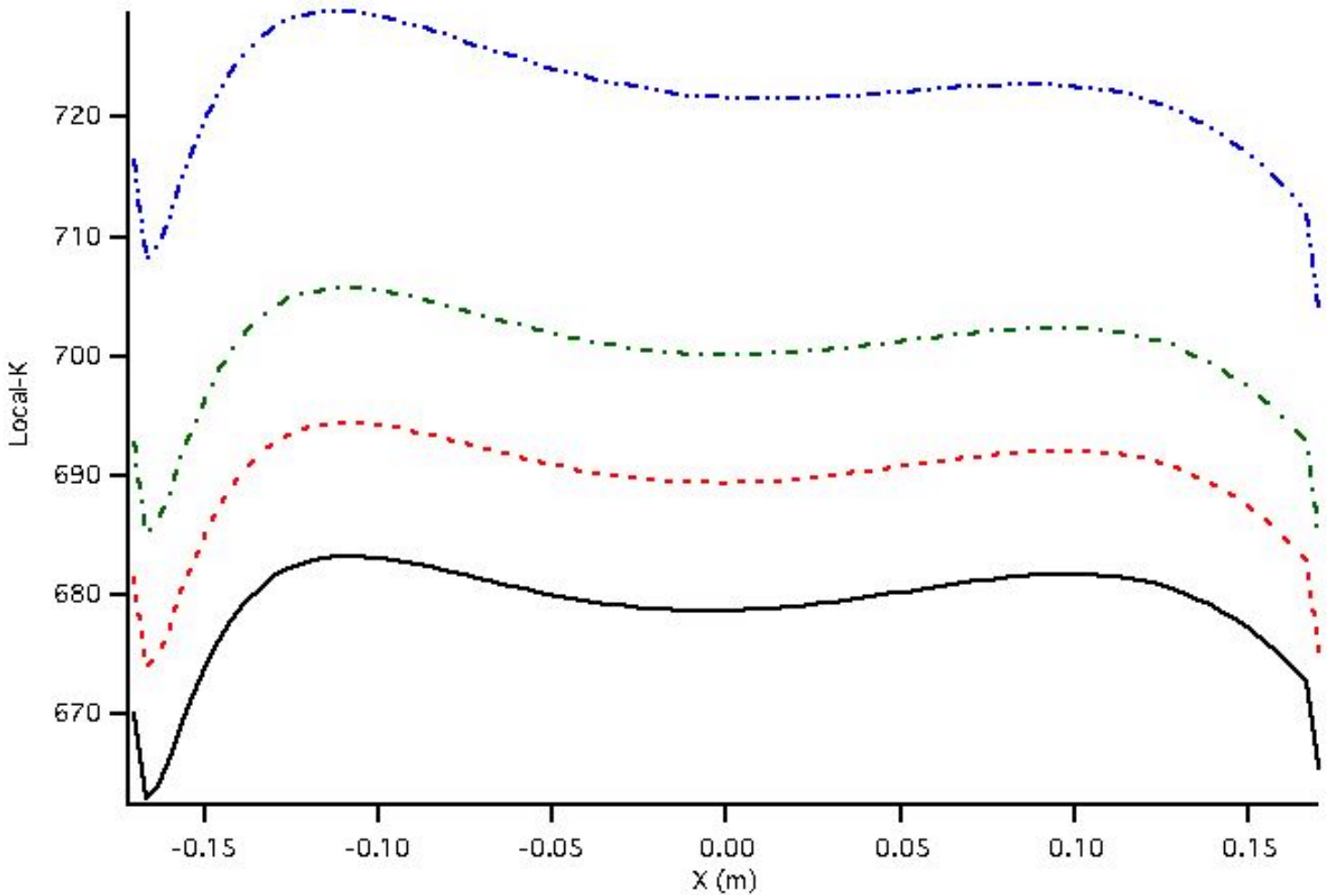


Reference Design 1

Field quality of main coil



Reference Design 1
k corrector

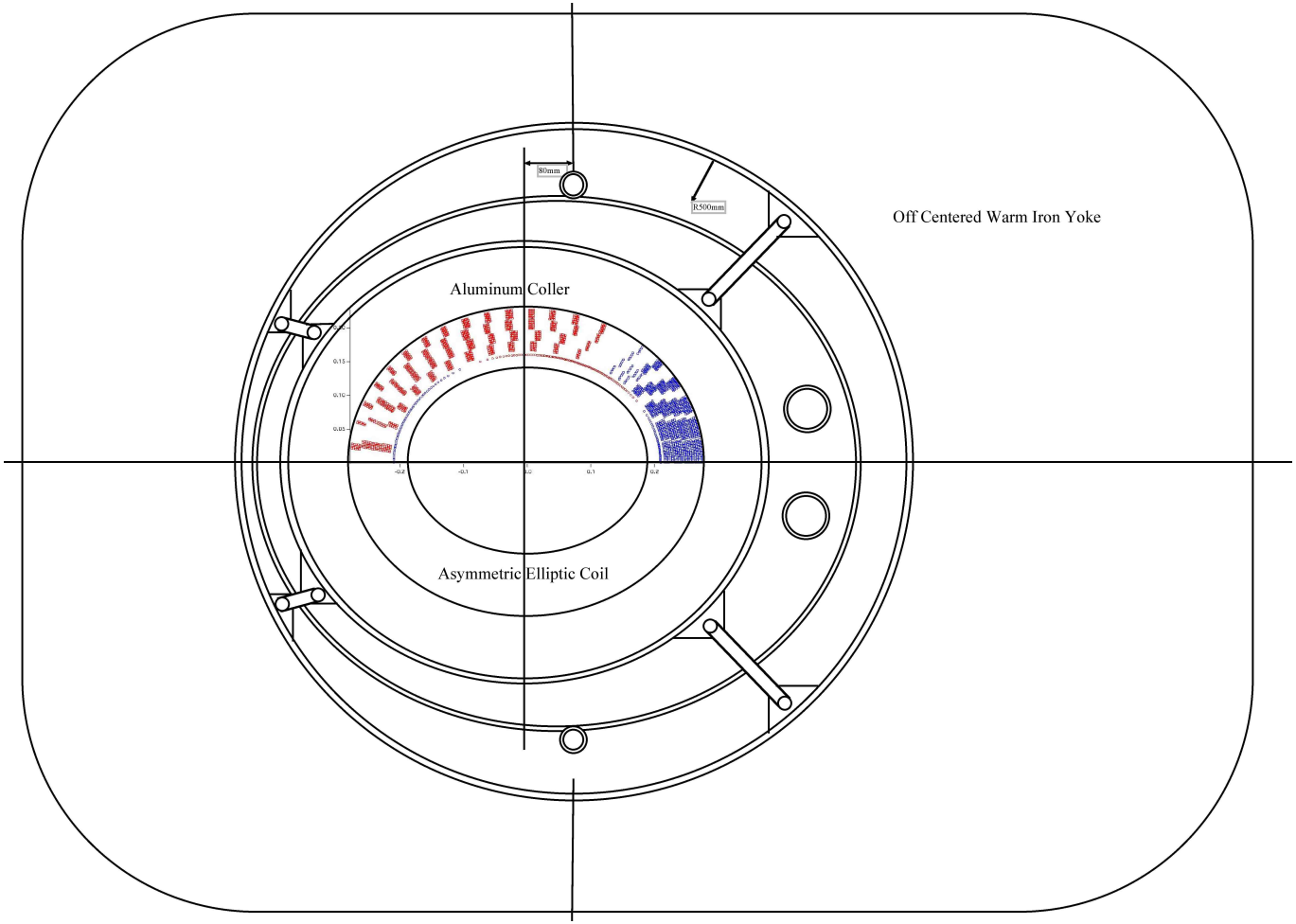


Reference Design 1

- Summary
  - Asymmetric Elliptic Coil
  - Warm Off Centered Yoke
  - First Order Delta-k Correction Coil
- Issues to be studied
  - 3d end design
  - Coupling between main and corrector coil
  - Detailed mechanical analysis
  - Quench protection

Reference Design 2

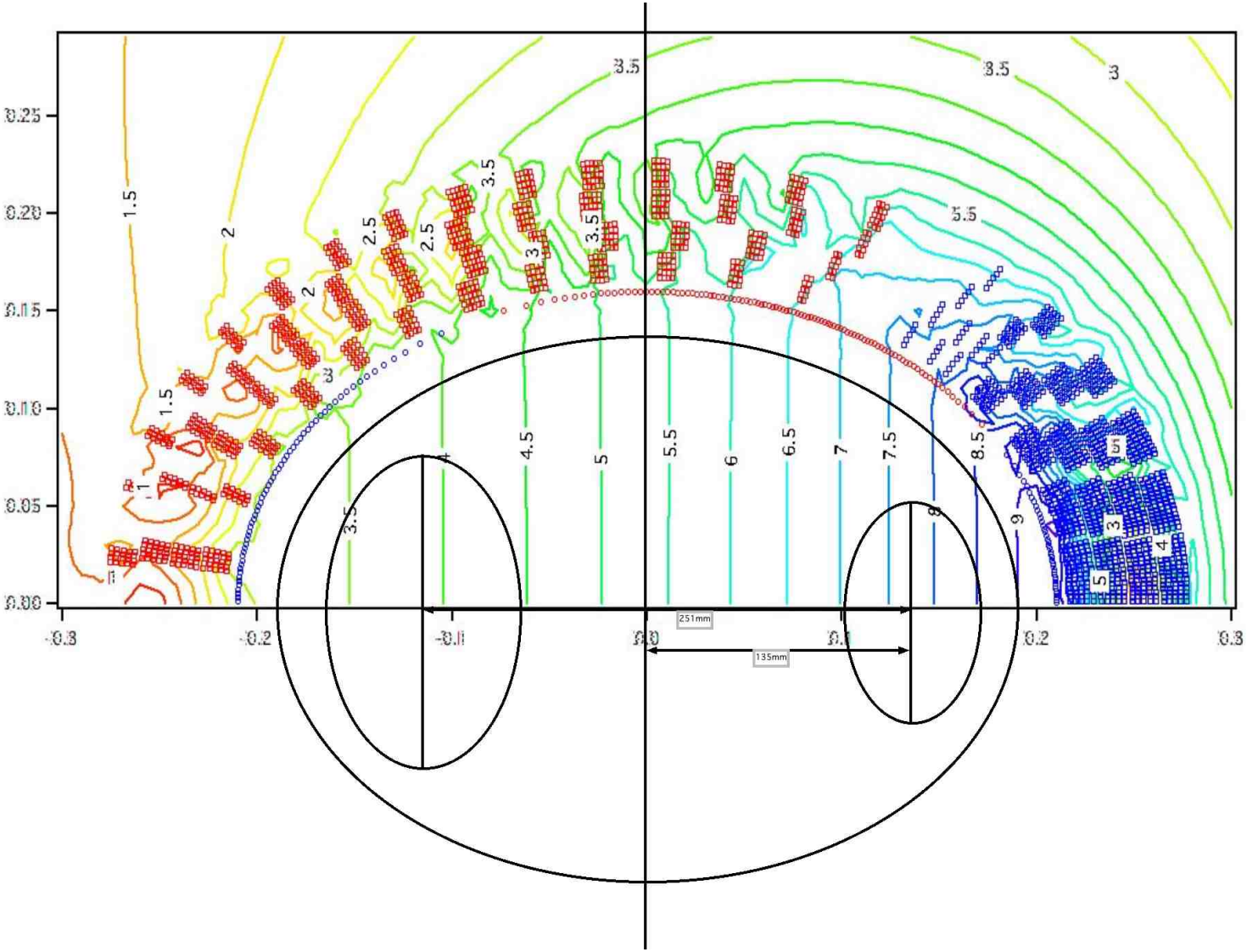
- B_0=7.73T, r_0=120m, k=330, beam excursion 25.1m



1. Main Coil
   - Asymmetric & Elliptic
   - Rutherford Cable 2X15mm
   - Operation Current 9kA
   - Stored Energy 1.5MJ/m
2. Corrector Coil
   - Wind & glue (BNL)
   - 25A/delta-K
3. Collar
   - Pre-stress ~150MPa
     ?need to study insulator?
   - Horizontal EMF ~ 6.4 MN
   - Aluminum collar to gain pre-stress during cool down
4. Iron Yoke
   - Off centered yoke for EMF balance
   - Warm Iron

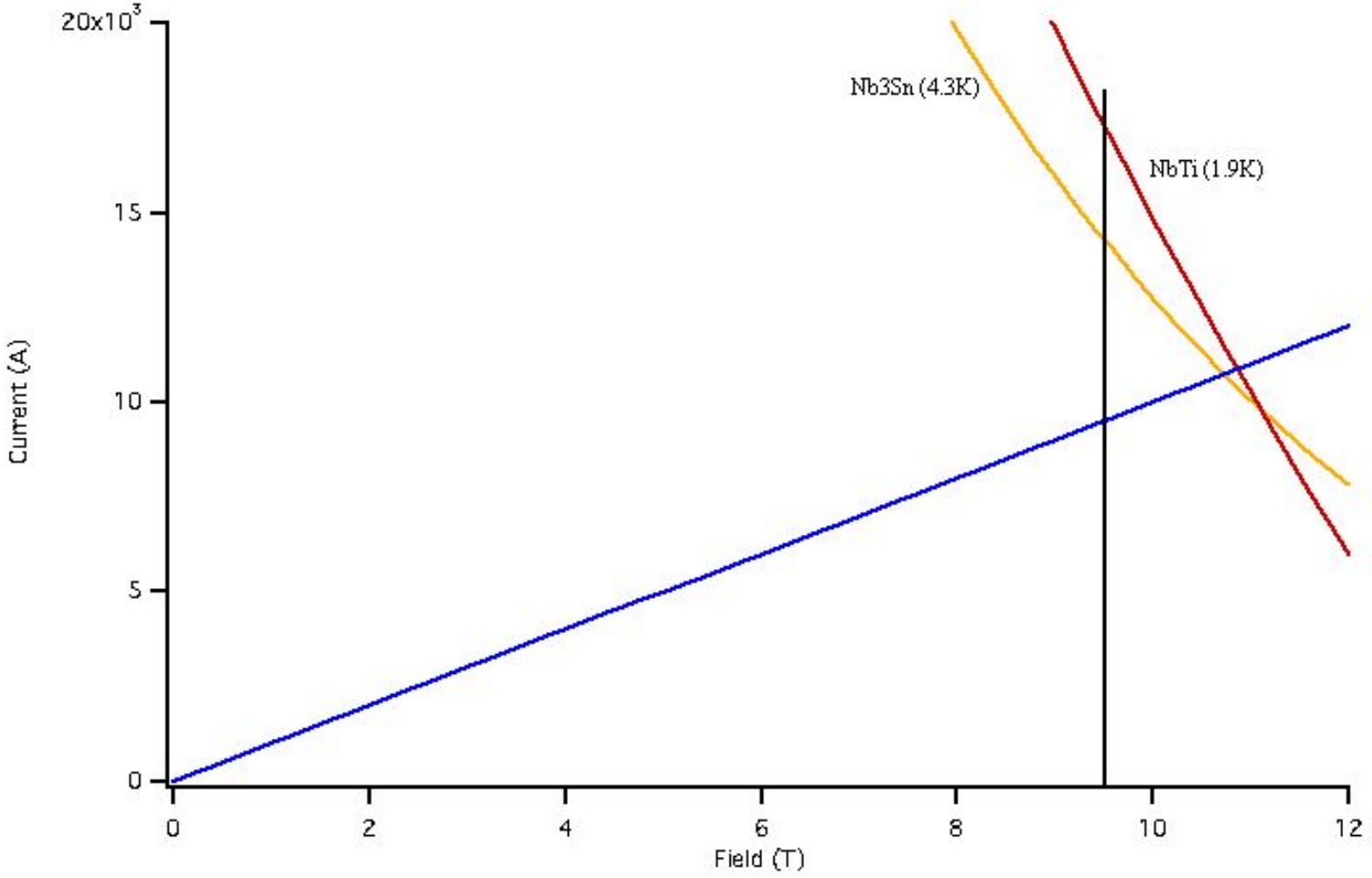
Reference Design 2

Field Map & Beam Aperture



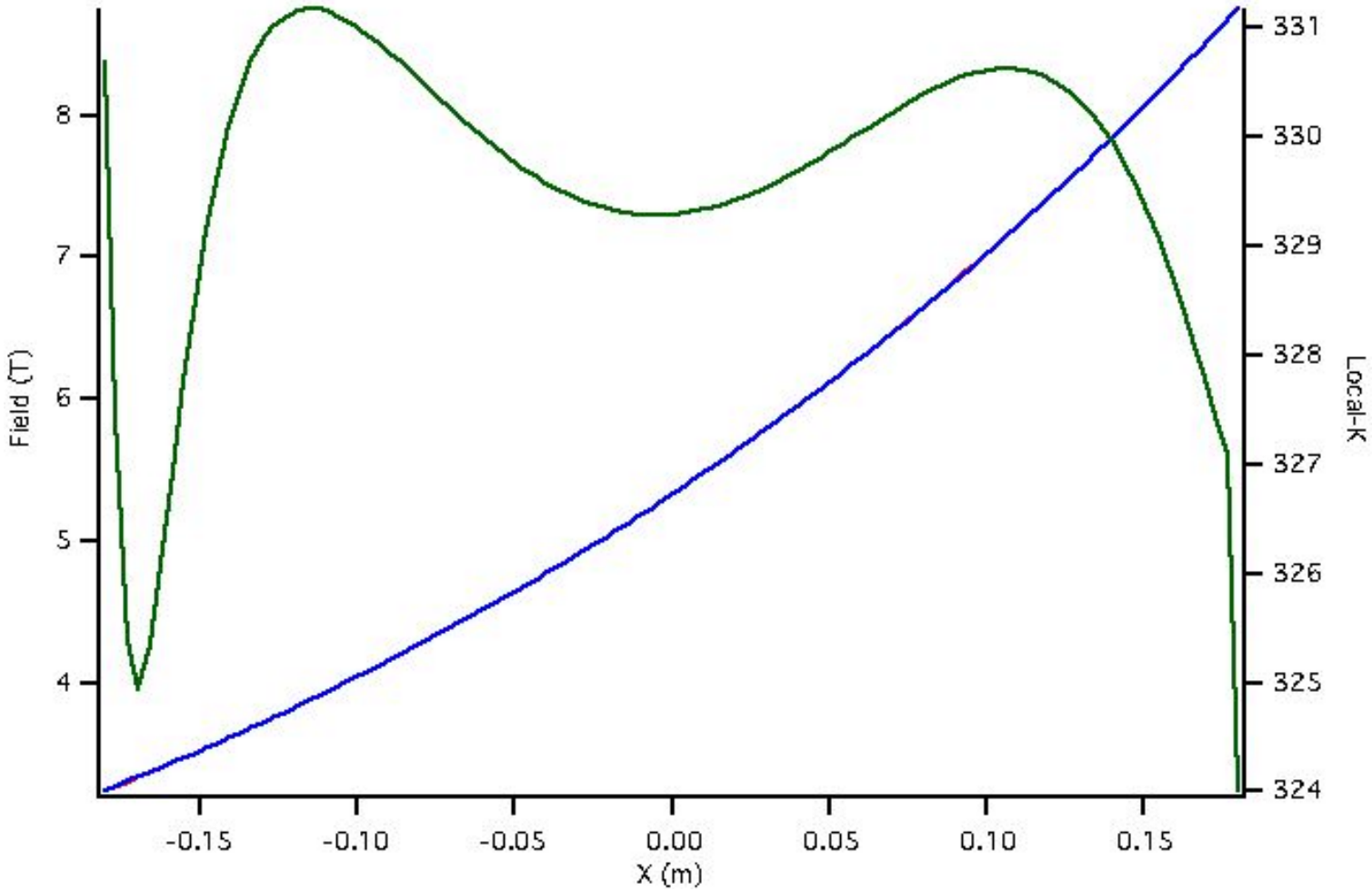
Reference Design 2

Operation Margin

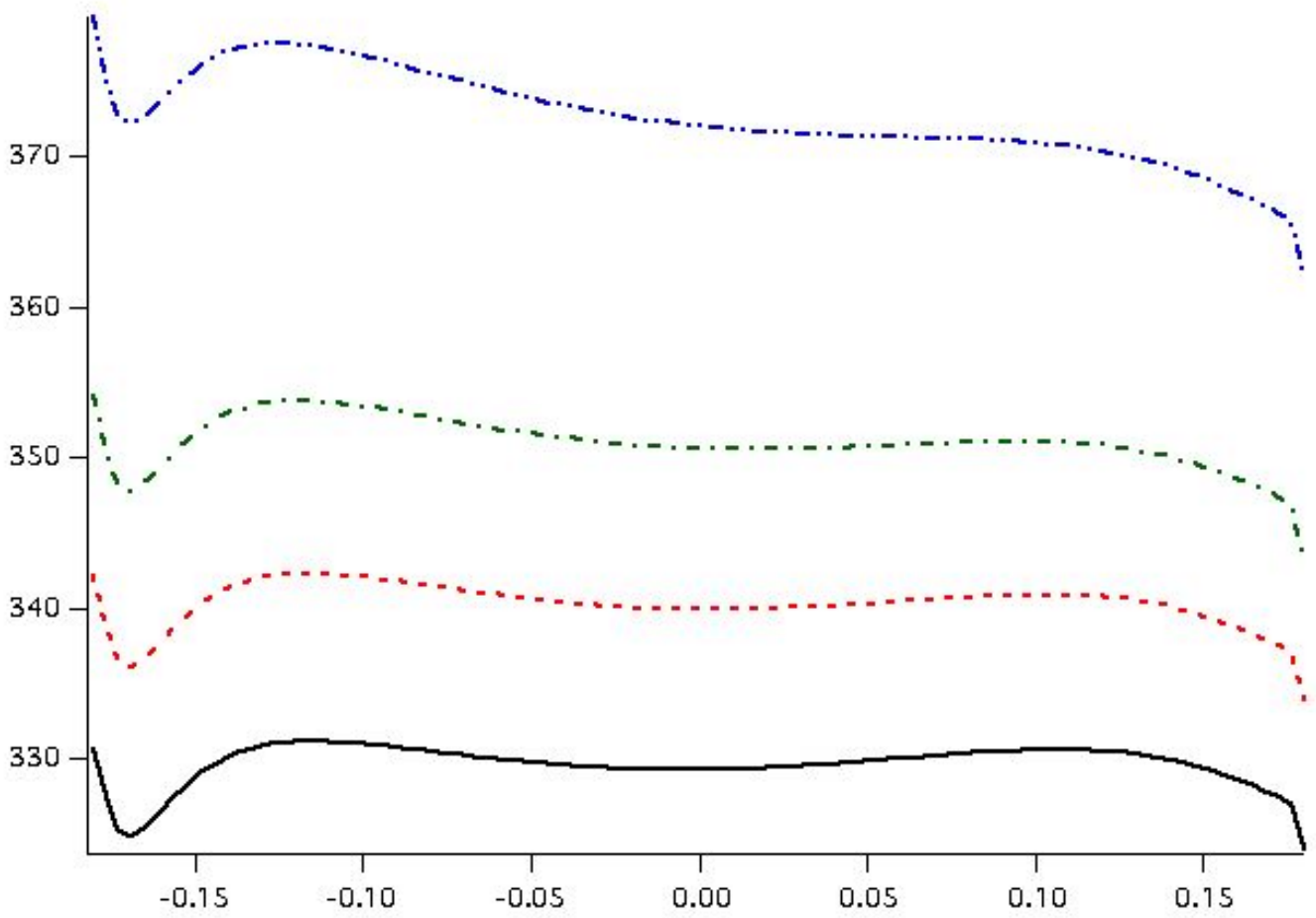


Reference Design 2

Field quality of main coil



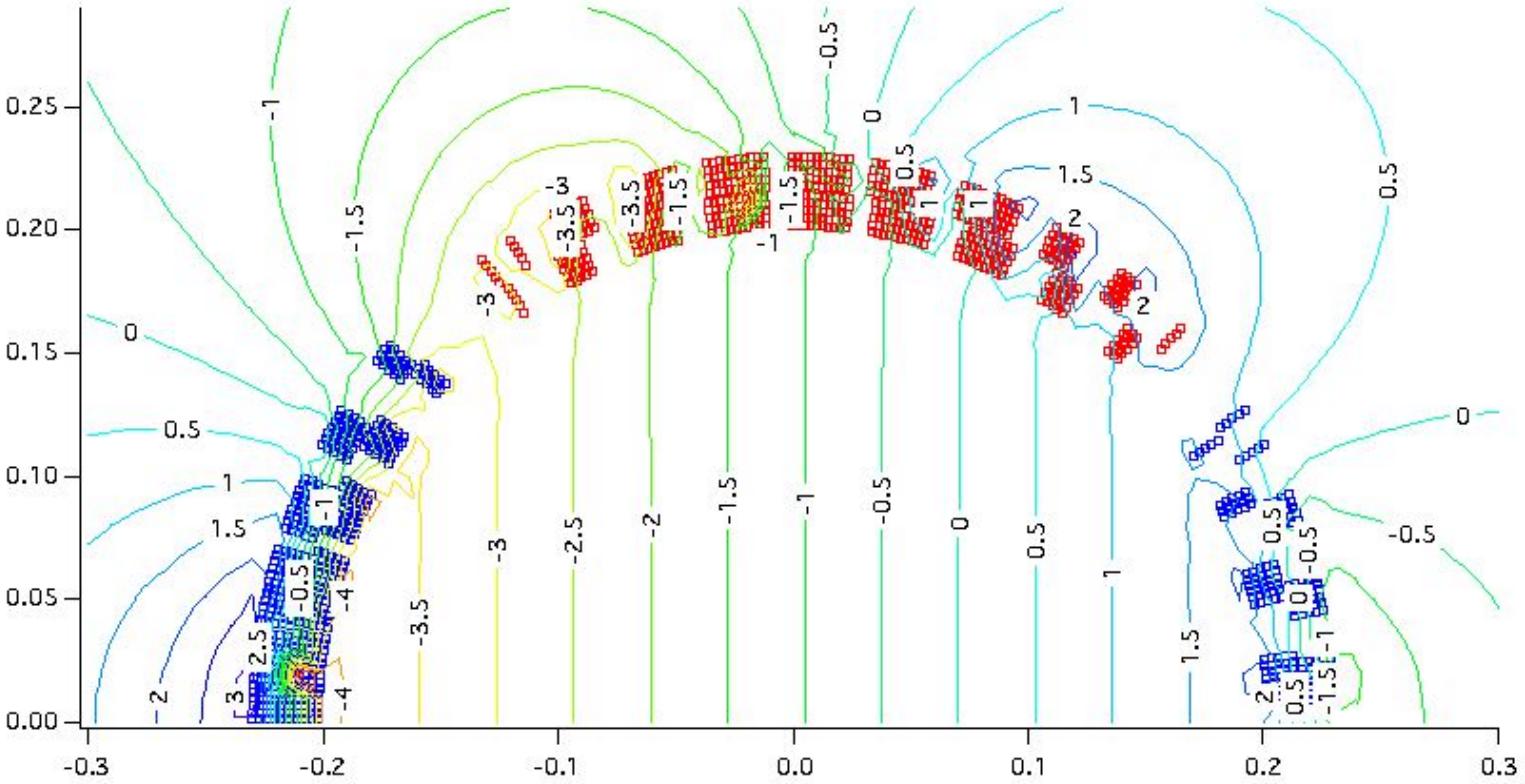
Reference Design 2
k corrector



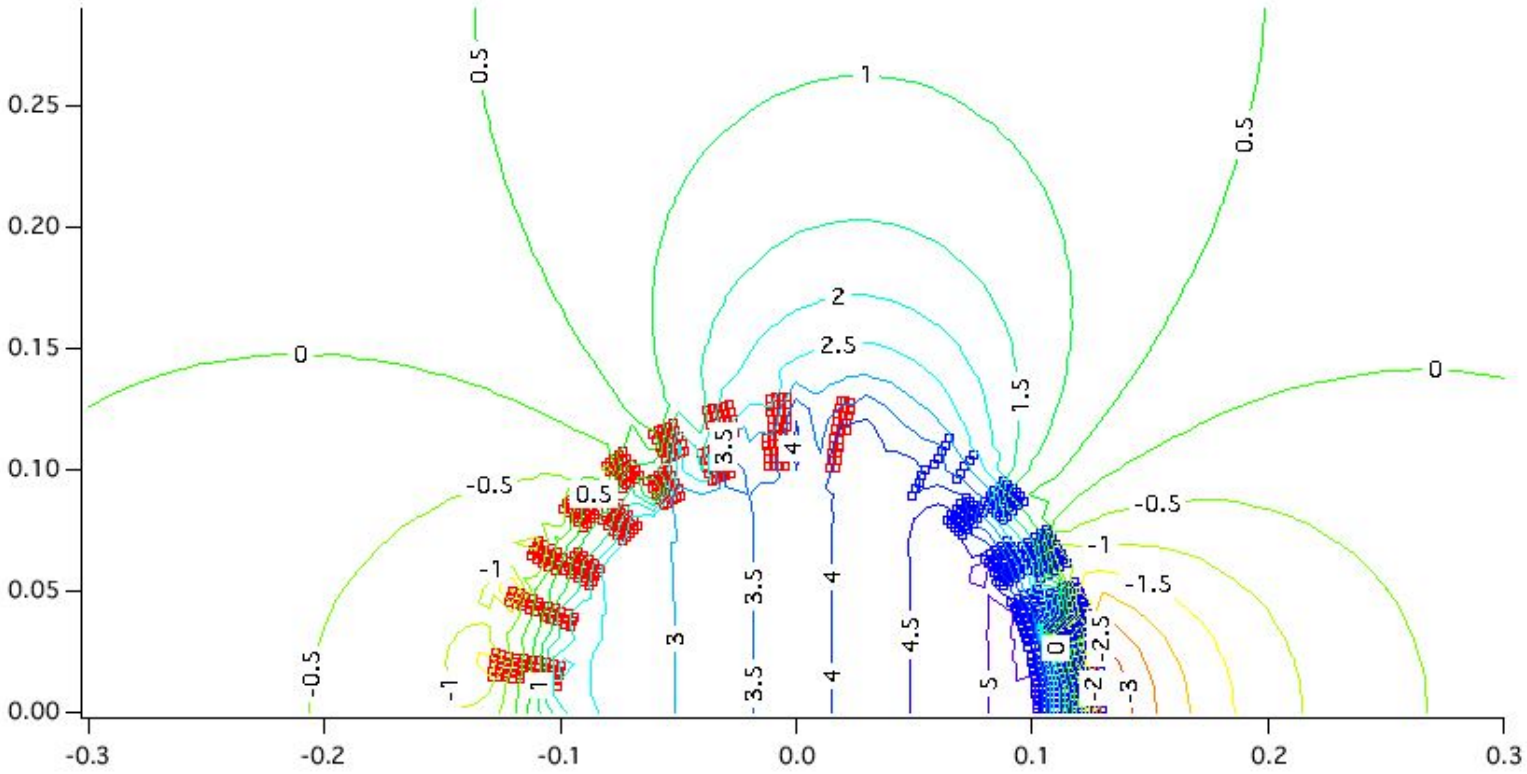
Reference Design 2
Summary

- Reference design 1 concept can be used as well, except.
  - Pre-stress requirement exceed usual Rutherford cable insulation limit…

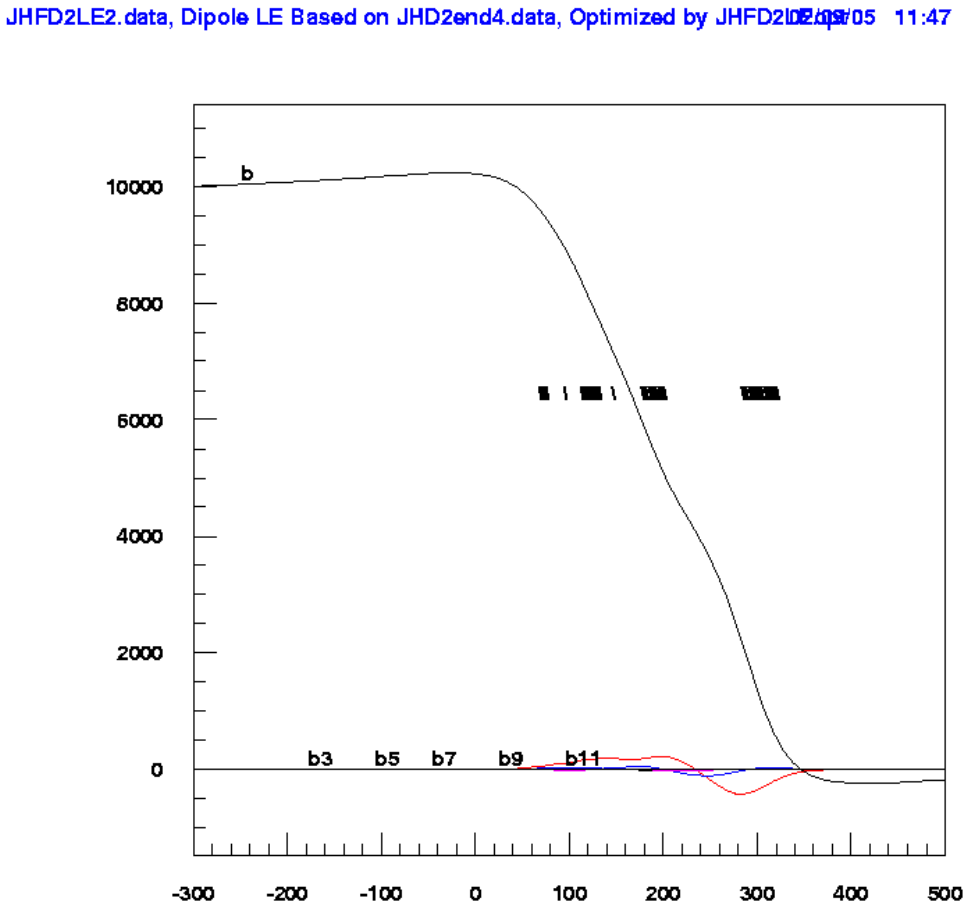
Scott 10-20GeV QF

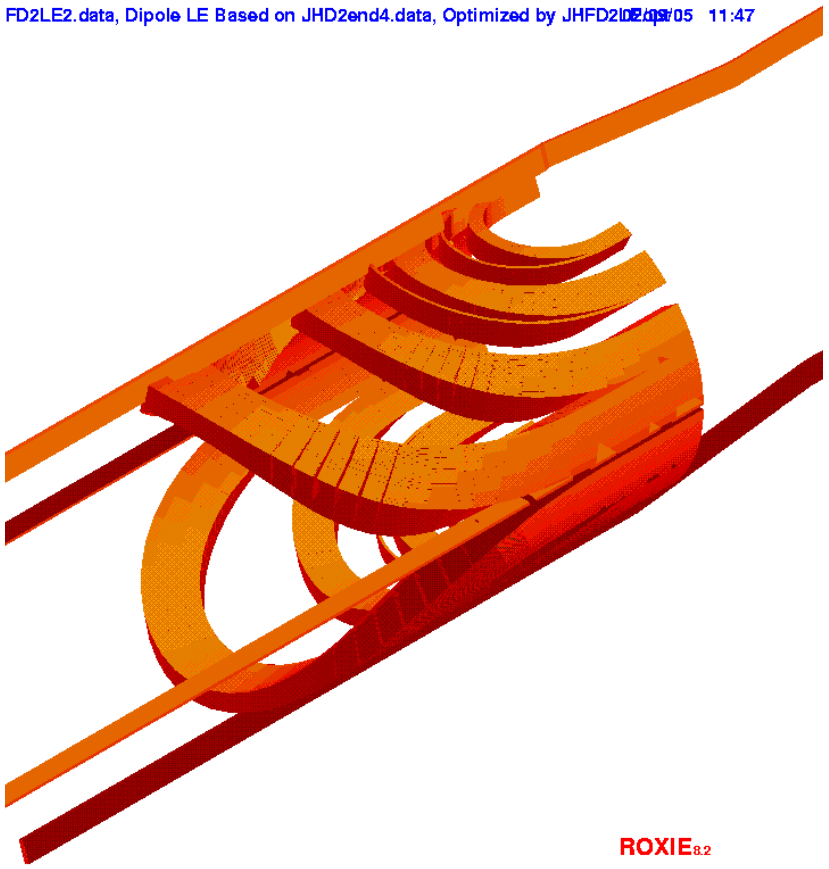


Scott 10-20GeV DF



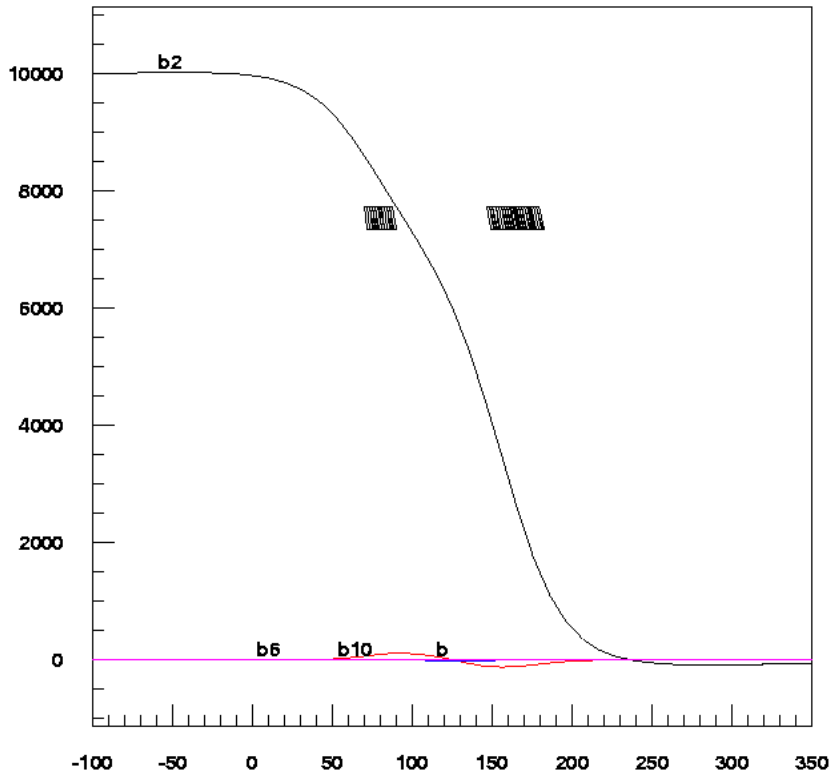
End Dipole Example





End Quad Example

Quad (R=90mm) for JHFNu, LHCDi-Out w/ MQXA ins. Ryoke=125mm, RE Coil 02/11/04 02:37



ROXIE8.2

End Spacer for JHFQ2RE.data 02/11/04 02:34

ROXIE8.2