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WP 8 Task 8.3.

Compact Instrumentation for Larmor labelling applications at the ESS.

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Calculations of intrinsic field integral inhomogeneity for a compact NSE spectrometer

A. Kusmin and C. Pappas

- Why *this* particular problem?
- Methods and Results
- Conclusions - Recommendations

Why “compact” ?

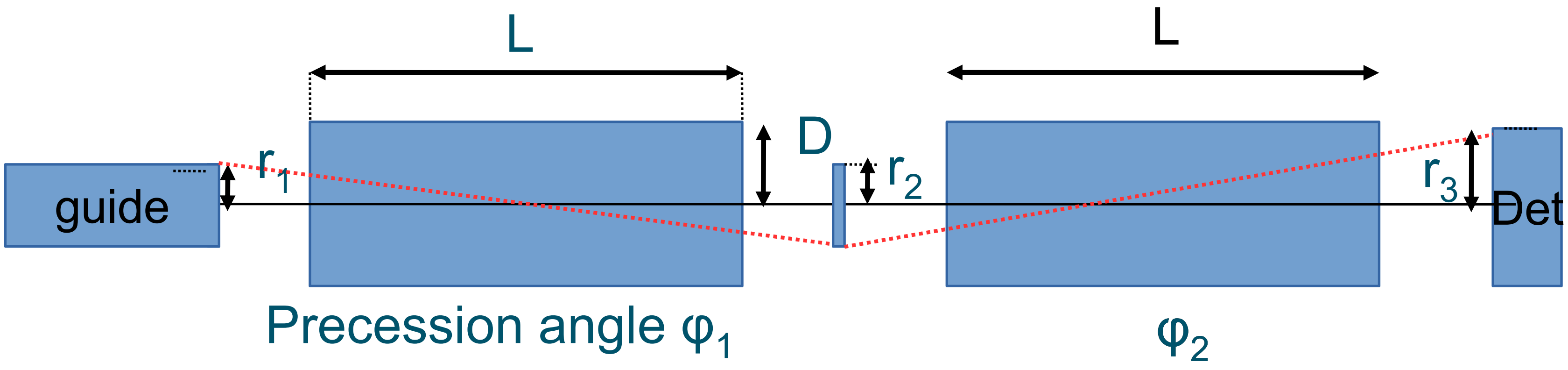
A longer instrument has:

- less intensity (less divergent incident and scattered beam)
- at a spallation source the length leads to a shorter wavelength band, thus also to less intensity

$$\lambda_{max} - \lambda_{min} = \frac{h}{m_n} \frac{1}{L_d f_{\text{pulse}}}$$

- More important gravity effects for longer wavelengths

Why “compact” is bad for NSE ?



For elastic scattering: $\varphi_1 - \varphi_2 = 0$

The Fourier time is given by the magnetic field integral :

$$\tau_{NSE} = \lambda^3 \int |\vec{B}|\, d\ell = \lambda^3 \langle J \rangle$$

And is limited by the magnetic field inhomogeneieties

(J (trajectory) -J_0) must be small ==> minimize $\eta = \langle \Delta J \rangle / J_0$

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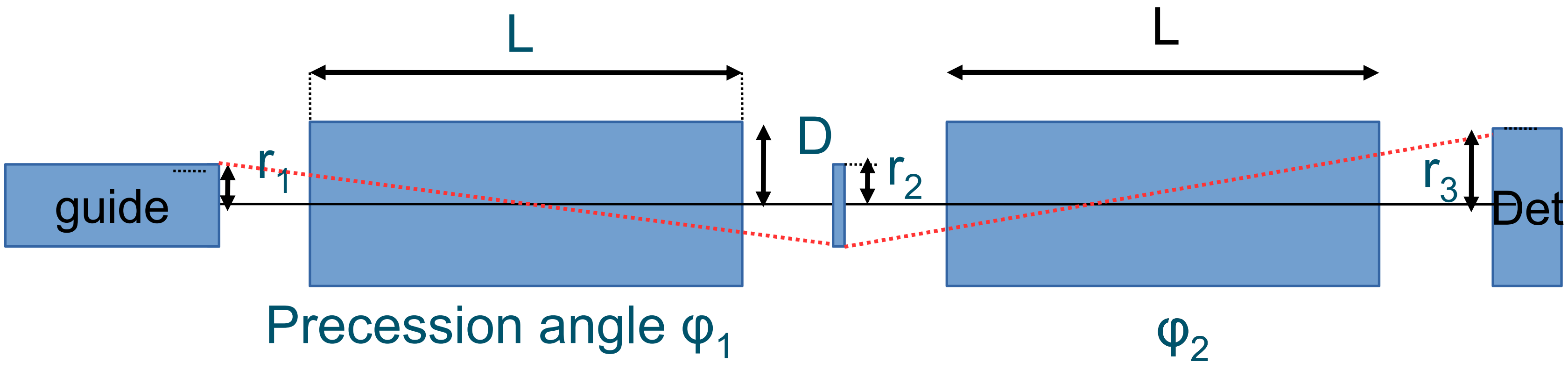
Why “compact” is bad for NSE ?



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$$\tau_{NSE} = \lambda^3 \int |\vec{B}|\, d\ell = \lambda^3 \langle J \rangle$$

$$\eta_{SOL} = \frac{r^2}{2DL}$$ Mezei (D – coil diameter)

$$\eta_{OFS} = \frac{1}{2}\left[\frac{\pi r^2}{L}\right]$$ Zeyen optimal field solenoid

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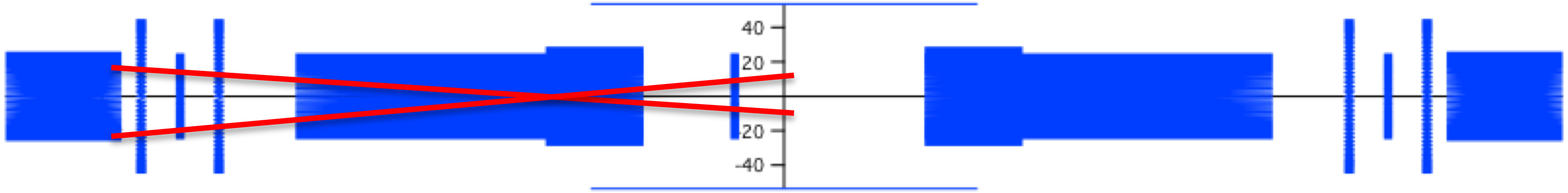
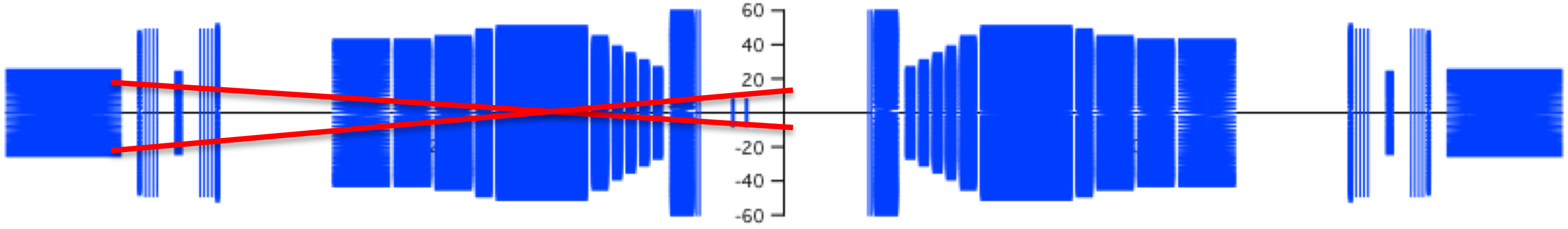
IN15 designs (after Bela Farago)

Field integral 0.26 Tm (old)



Field integral 1.06 Tm (new)



Historically:

- NSE instruments use solenoids with intrinsic η ≈ 10^{-3}-10^{-4}

  main coil length: 2 m (the smallest is 1.2 m at SNS)

  Fresnel coils lead to η ≈10^{-6}

  BUT

  they are at the limit (high currents, positioning accuracy)

- OFS (Zeyen) leads to a reduced Intrinsic η

  BUT is not often used

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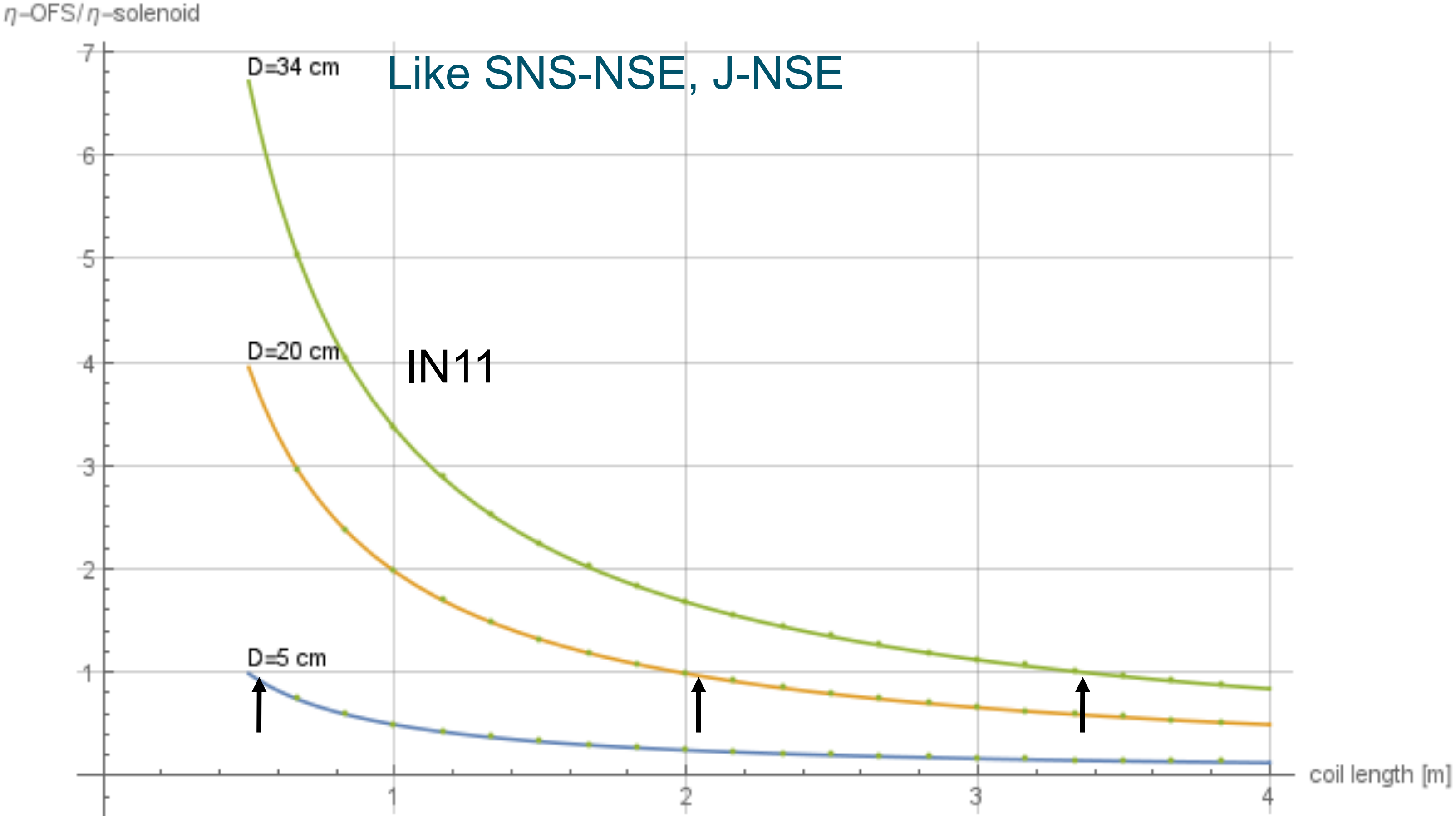
OFS vs. solenoid



Like SNS-NSE, J-NSE

IN11

For OFS to be better than solenoids a coil must be **longer than 2 m**

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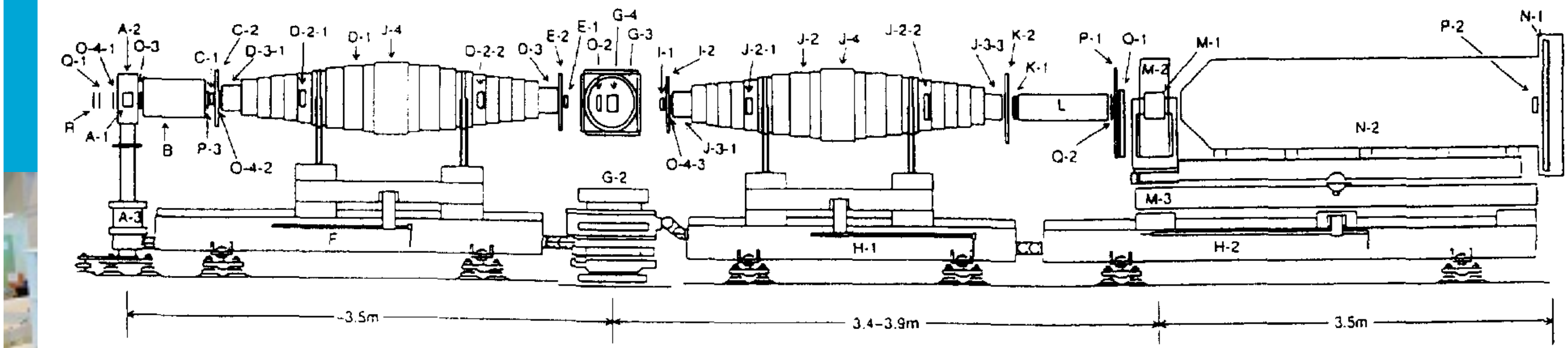
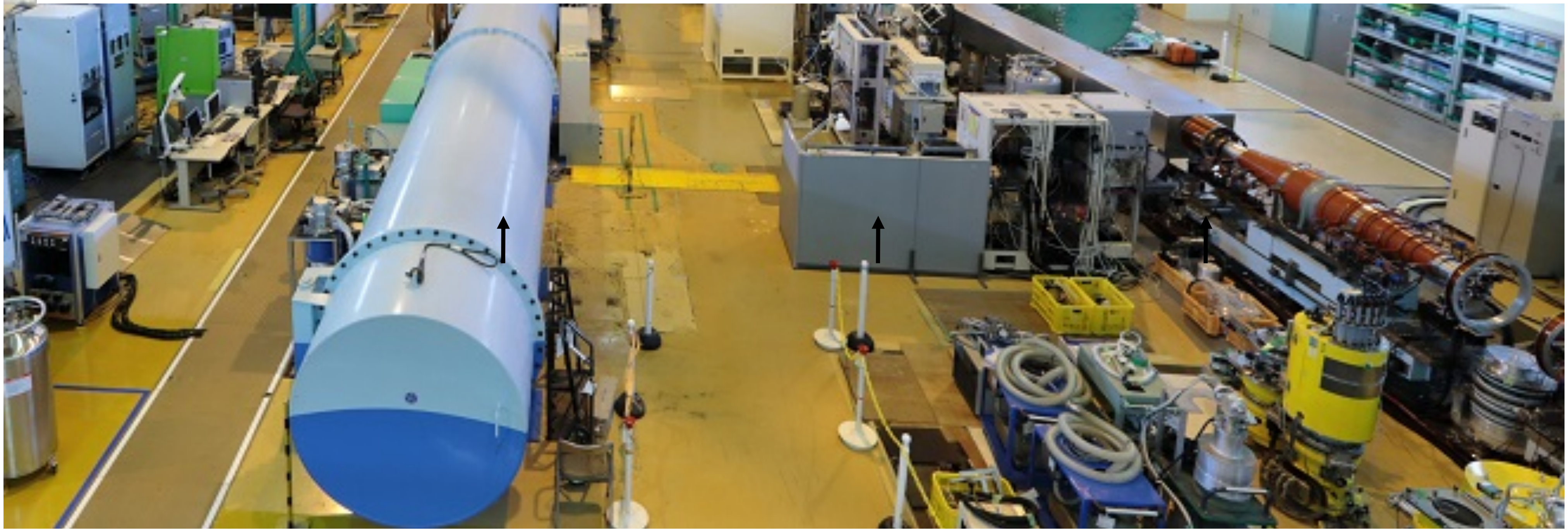
OFS vs. solenoid

NSE@JRR-3, NIMA 1995



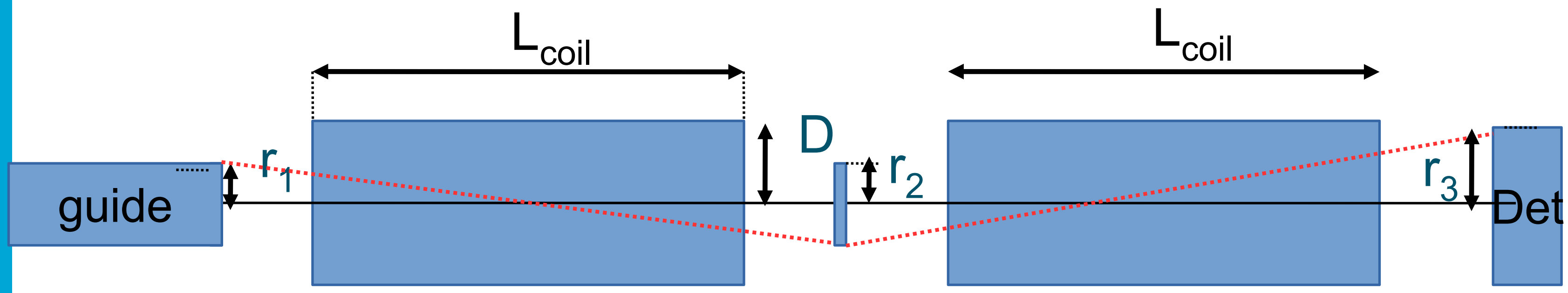


Again look at NSE and solenoids

The parameter space: moderator size, guide exit size, sample size, coil length, coil diameter etc

- look at the region of the parameter space **for short coil length to increase flux while keeping intrinsic η**

- effect of the pancake moderator at ESS
  - => smaller incident beam height
  - => shorter coils may be OK



Methods and tools

Calculation of flux for a particular instrument geometry:

using McStas, VITESS etc

Magnetic field calculations

- RADIA (ESRF) + Mathematica: for coils, analytical
  fast and cheap compared to specialized software
- Infolytica MagNet: for electromagnets
  used by e.g. Michel Thijs, following talk

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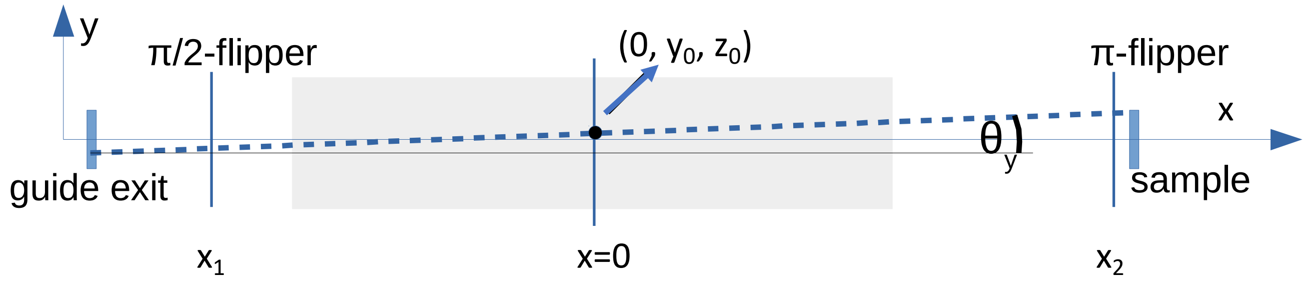
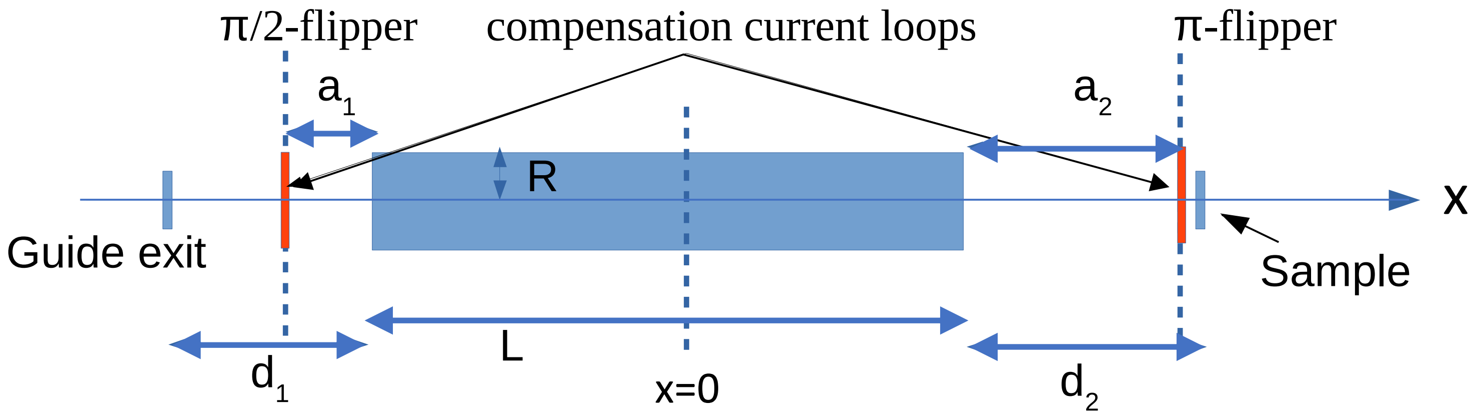
Results

Consider the first arm of an NSE spectrometer





The symmetry with respect to x =0 is quantified by the parameter

$$s = (d_1 + L/2)/(d_1 + L + d_2)$$

$$s = 1/2 \text{ for the symmetric case } d_1 = d_2$$

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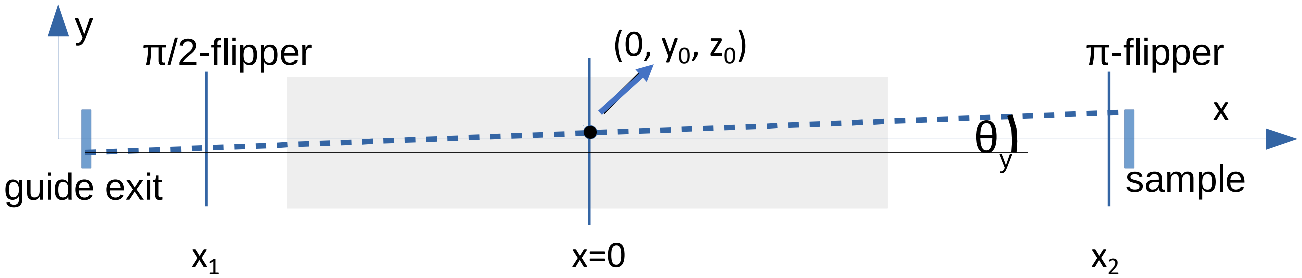
Results

Starting point: the total magnetic field integral between the $\pi/2$ and the π flipper at the symmetry axis $J_0 = \int B_{(x,0,0)}(x)\,dx$



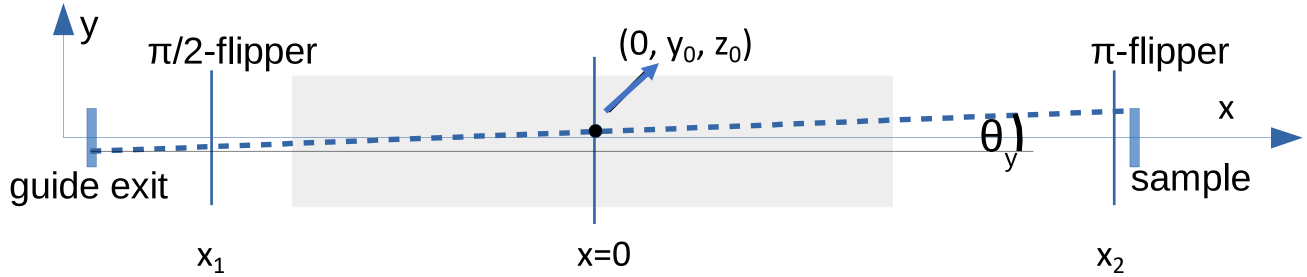
The magnetic field inhomogeneities have been calculated for :

- parallel trajectories $H = \int \beta(x)\,dx$,
- the divergence of the beam $G = J_0/2 + \int [x^2 \beta(x)]\,dx$, and
- the crossed term $U = \int x\,\beta(x)\,dx$

with $\beta(x) = \frac{1}{8}\frac{1}{B_x(x)}\left(\frac{\partial B_x(x)}{\partial x}\right)^2 - \frac{1}{4}\,\frac{\partial^2 B_x(x)}{\partial^2 x}.$

Results

Starting point: the total magnetic field integral between the $\pi/2$ and the π flipper at the symmetry axis $J_0 = \int B_{(x,0,0)}(x)\, dx$



Consider the differences in the magnetic field integral

$$\Delta J = J - J_0 = H\, r_0^2 + G\, \tan^2\theta + 2\, U \left[y_0 \tan\theta_y + z_0 \tan\theta_z\right],$$

with $r_0^2 = y_0^2 + z_0^2$.

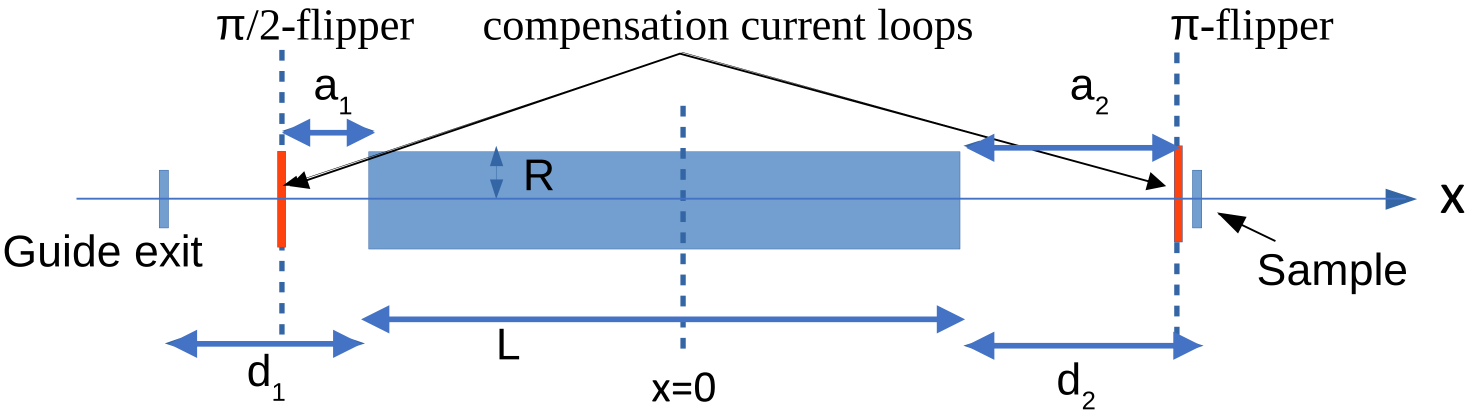
and their variance: $\langle \Delta J^2 \rangle = H^2 \langle r_0^4 \rangle + G^2 \langle \tan^4\theta \rangle + 4HG\, \langle r_0^2 \tan^2\theta \rangle +$

$$4HU\, \langle r_0^2 \left[y_0 \tan\theta_y + z_0 \tan\theta_z\right] \rangle + 4GU\, \langle \tan^2\theta\, \left(y_0 \tan\theta_y + z_0 \tan\theta_z\right) \rangle +$$

$$4U^2 \left[\langle \left(y_0 \tan\theta_y\right)^2 \rangle + \langle (z_0 \tan\theta_z)^2 \rangle + 2 \langle y_0 z_0 \tan\theta_y \tan\theta_z \rangle \right]$$

Results

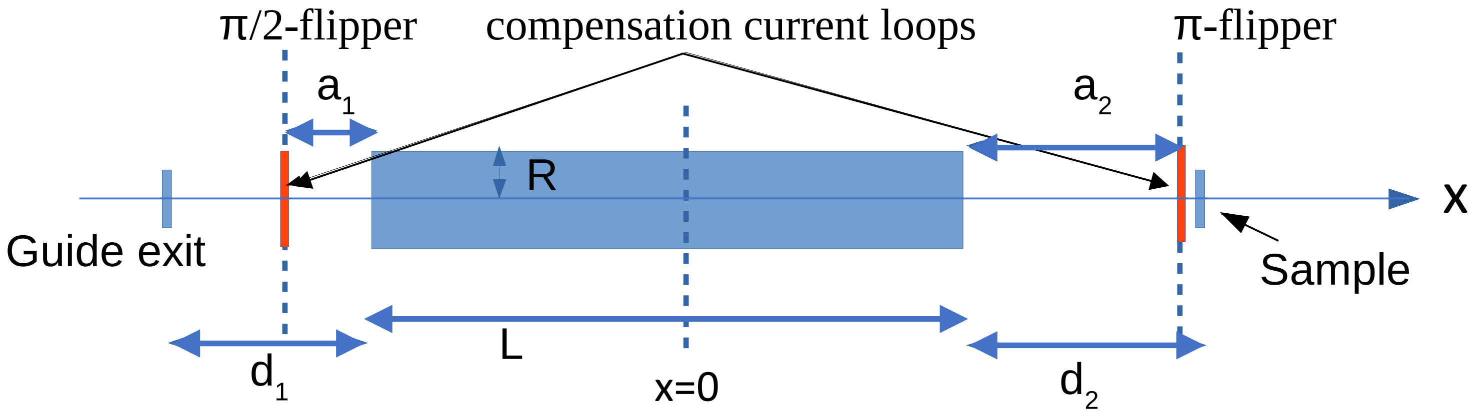
Consider the first arm of an NSE spectrometer

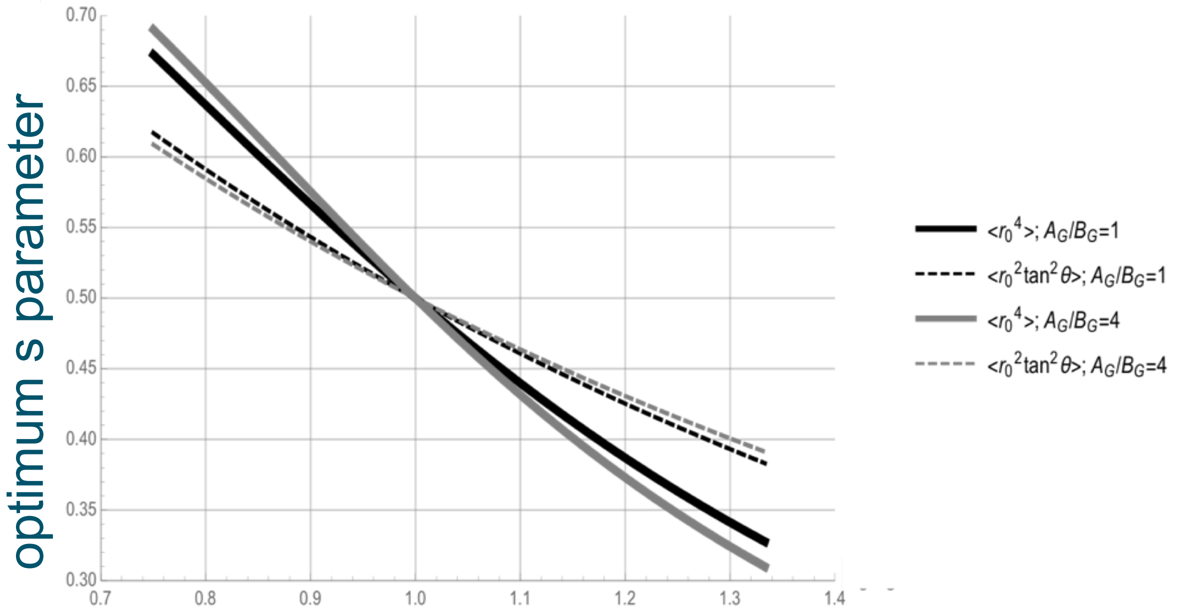


trajectories between randomly selected points connecting the guide exit and the sample

Results

Consider the first arm of an NSE spectrometer





A_S/A_G : the ratio of sample over guide exit widths

optimum s not the same

for smaller or larger

A_S/A_G ratios.

$$s = (d_1 + L/2)/(d_1 + L + d_2)$$

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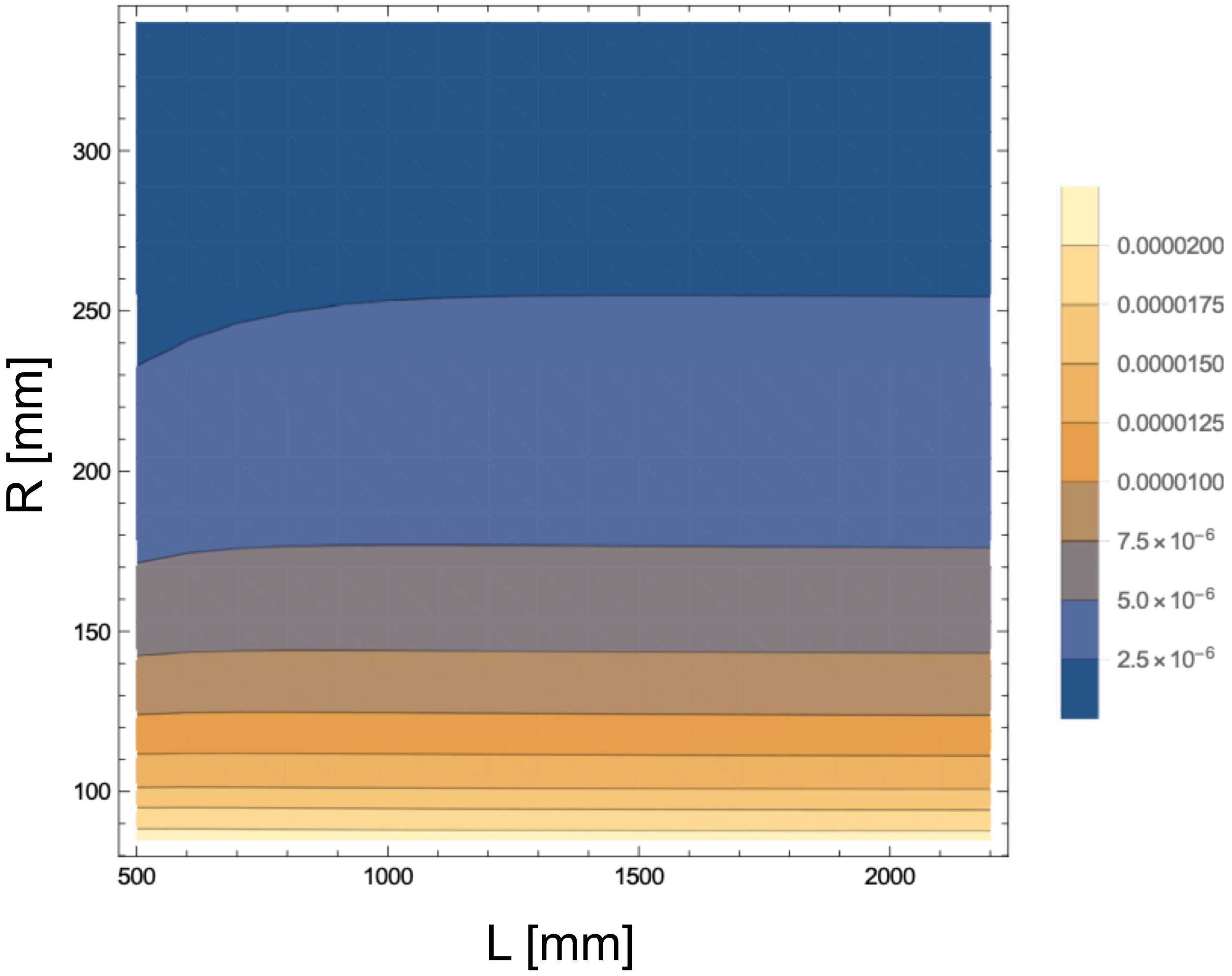
Results

Minimization of intrinsic magnetic field inhomogeneities
Case of weak asymmetry $a_1 = 0.3\ \mathrm{m}$ *and* $a_2 = 0.5\ \mathrm{m}.$



parallel trajectories

$$F_0 = H^2$$

$$H = \int \beta(x)\,dx,$$

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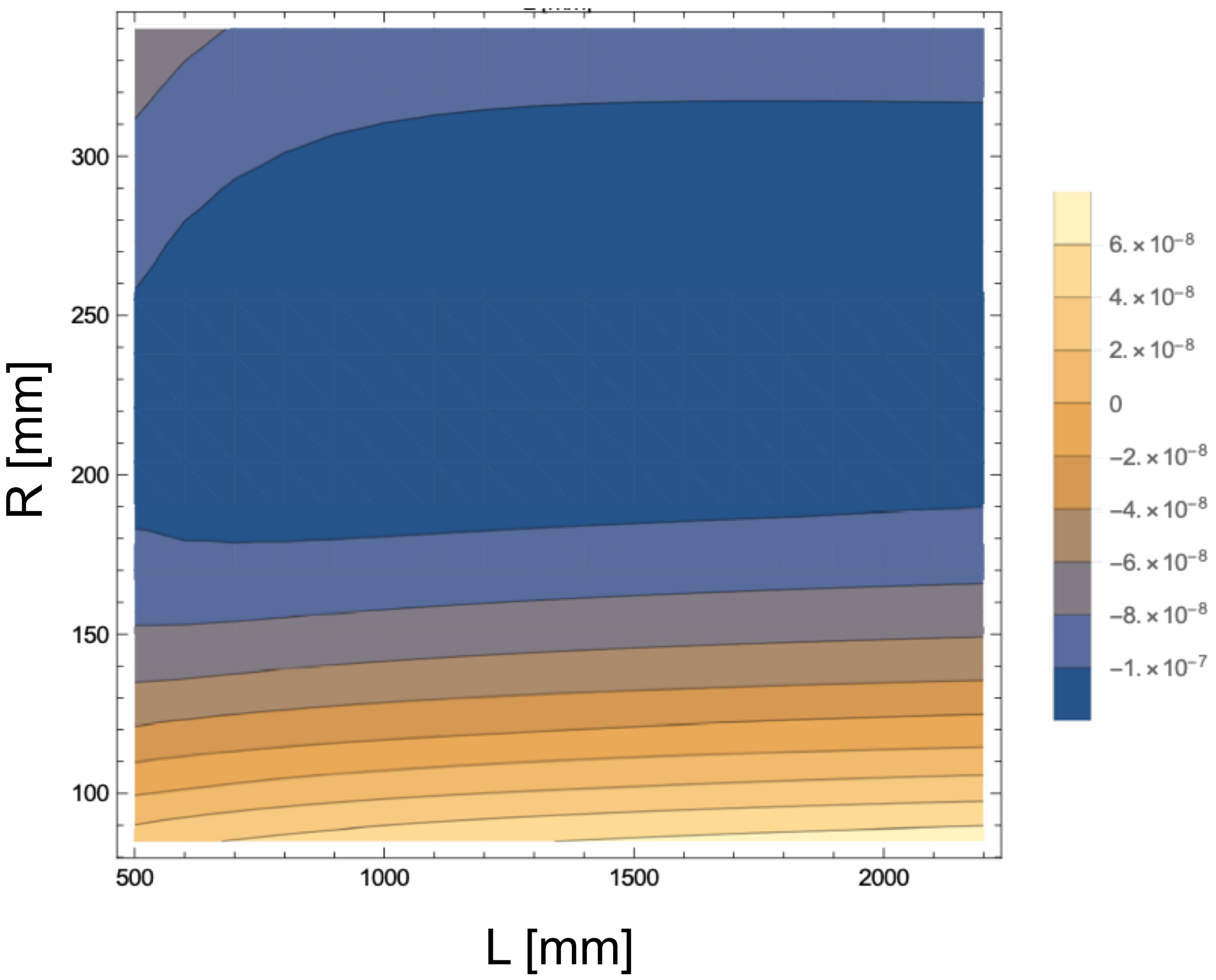
Results

Minimization of intrinsic magnetic field inhomogeneities
Case of weak asymmetry $a_1 = 0.3\ \mathrm{m}$ *and* $a_2 = 0.5\ \mathrm{m}.$



Other contributions

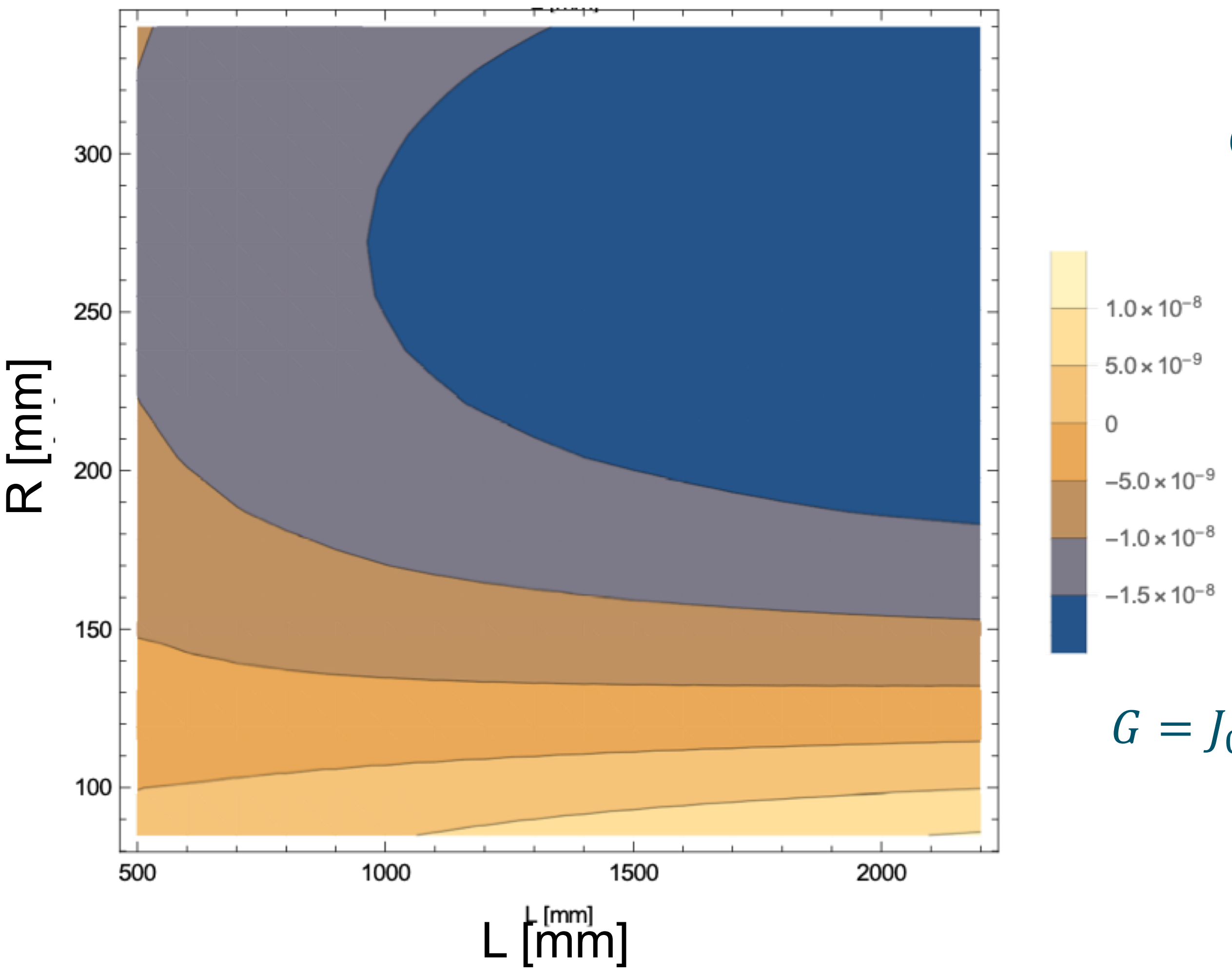
$$F_1 = 4HU/L_{tot}$$

$$U = \int x\,\beta(x)\,dx$$

$$H = \int \beta(x)\,dx,$$

Results

Minimization of intrinsic magnetic field inhomogeneities
Case of weak asymmetry $a_1 = 0.3\ \mathrm{m}$ *and* $a_2 = 0.5\ \mathrm{m}.$



Other contributions

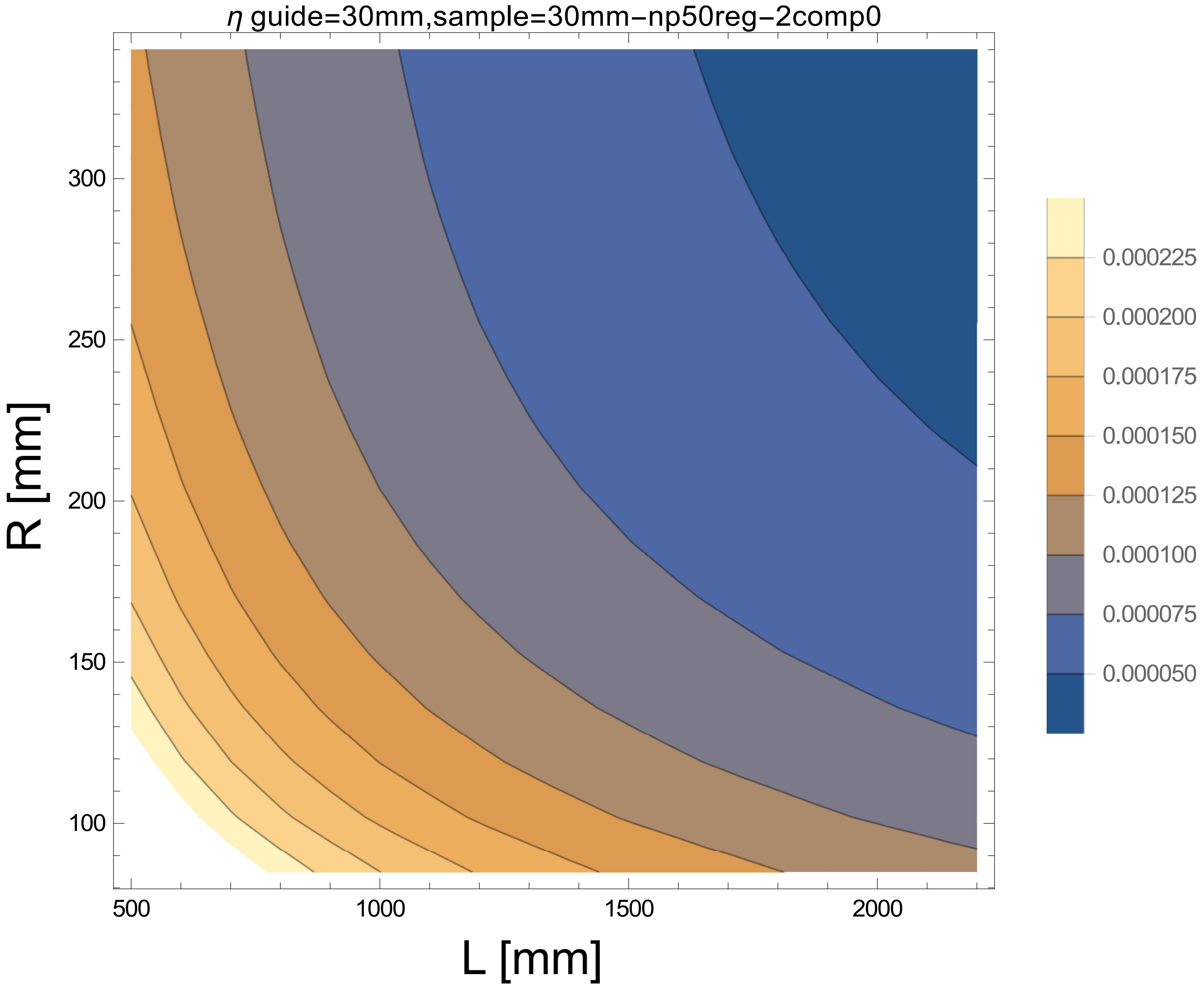
$$F_3 = 4GU/L_{tot}^3$$

$$U = \int x\,\beta(x)\,dx$$

$$G = J_0/2 + \int [x^2\beta(x)]\,dx$$

Results

For a homogeneously divergent beam



Conclusions - Recommendations

- circularly shaped sample and guide cross sections lead to lower field integral inhomogeneities in comparison to the square ones.
- rectangular cross-sections with a height over width ratio, of e.g. 1:4 increase the field homogeneity by at least 30 %.

better than for circular beam cross sections !

- Thus the choice of beam cross sections that mimic the “pancake moderator” beams seems to significantly improve the magnetic field integral homogeneities of a NSE spectrometer.

Conclusions – Recommendations

BUT

- inhomogeneities become worse for shorter coils
- in order to reach long Fourier times, the length of the instruments cannot be reduced.

THUS

- NSE spectrometers will perform better at the ESS, as the required magnetic field integral corrections (through Fresnel coils) will be weaker, but they will not be more compact than e.g. at the ILL or FRM2.