February 11-15 Prague

Possible Superconducting Solenoid Snakes for Nuclotron and NICA

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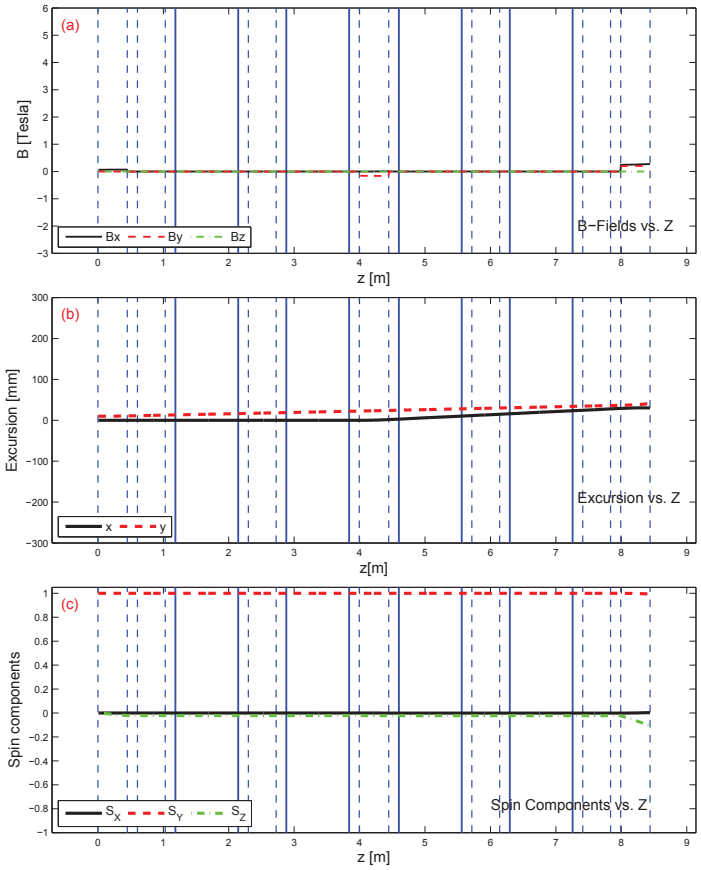
2 GeV Ramped

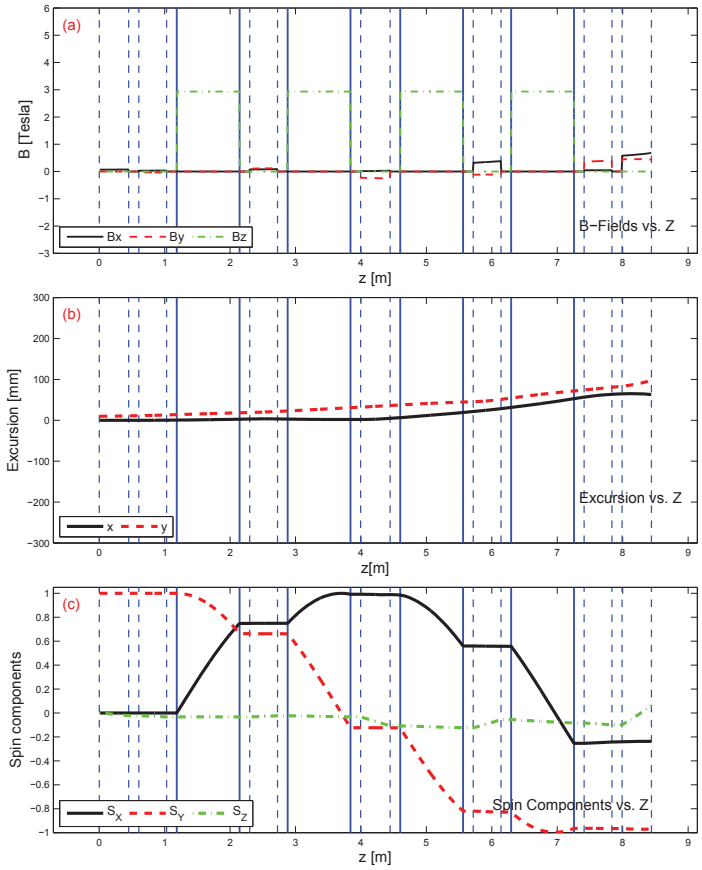
FJK 2GeV vert ramped 7feb14

No Snake Full Set 1 with no Quadrupoles and 001cm displacement of beam



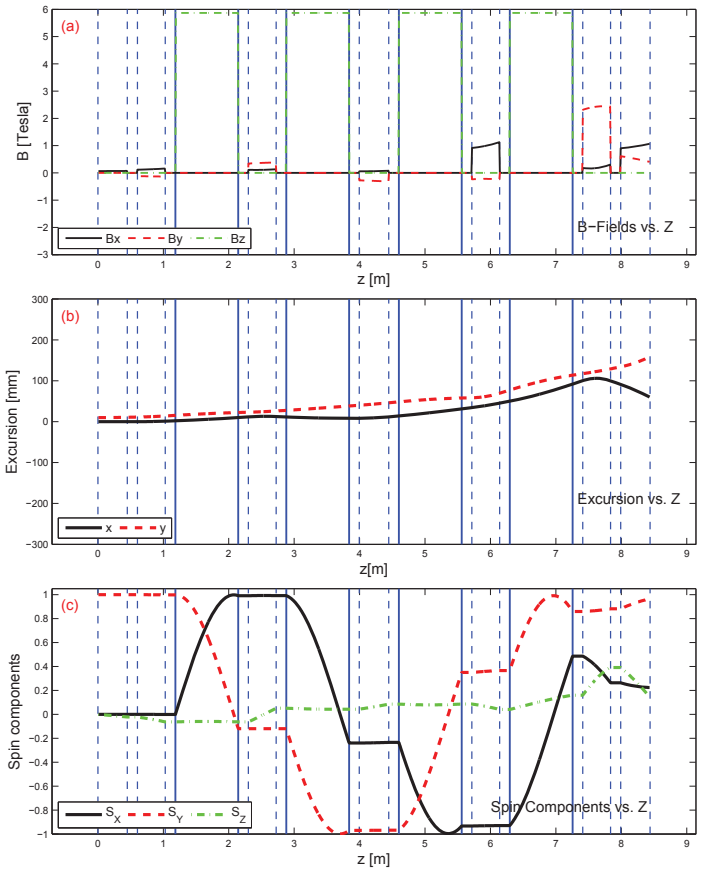
FJK 2GeVvert ramped 7feb14

Half Snake with 3.8883T/m 0.425m and 6.8208T/m 0.425m ramped Quadrupoles and 2.93T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



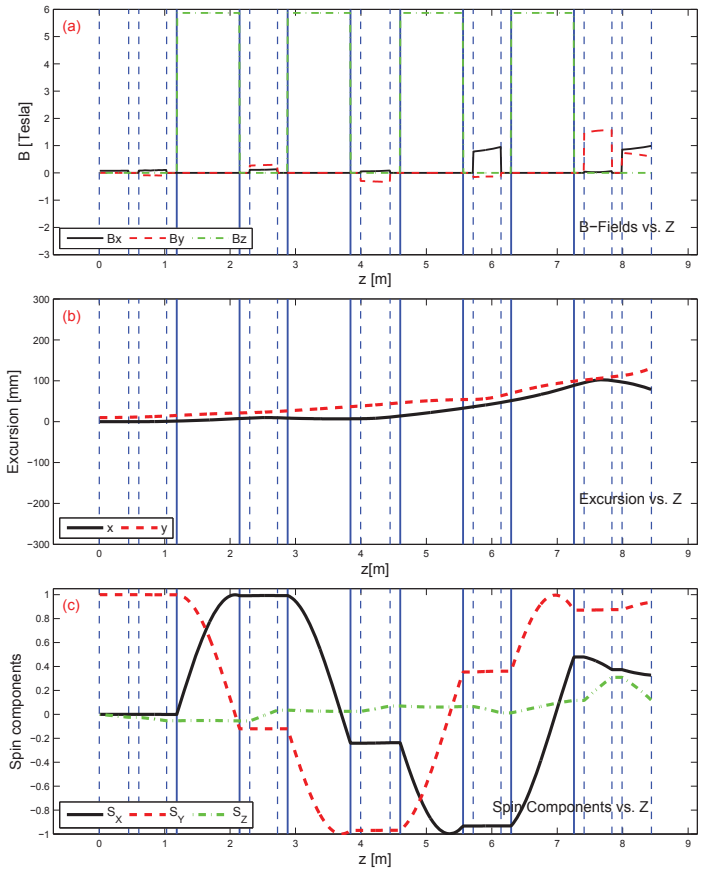
FJK 2GeV vert ramped 7feb14

Full Snake Set1 with 15.015T/m 0.425m and 13.92T/m 0.425m ramped Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



FJK 2GeV vert ramped 7feb14

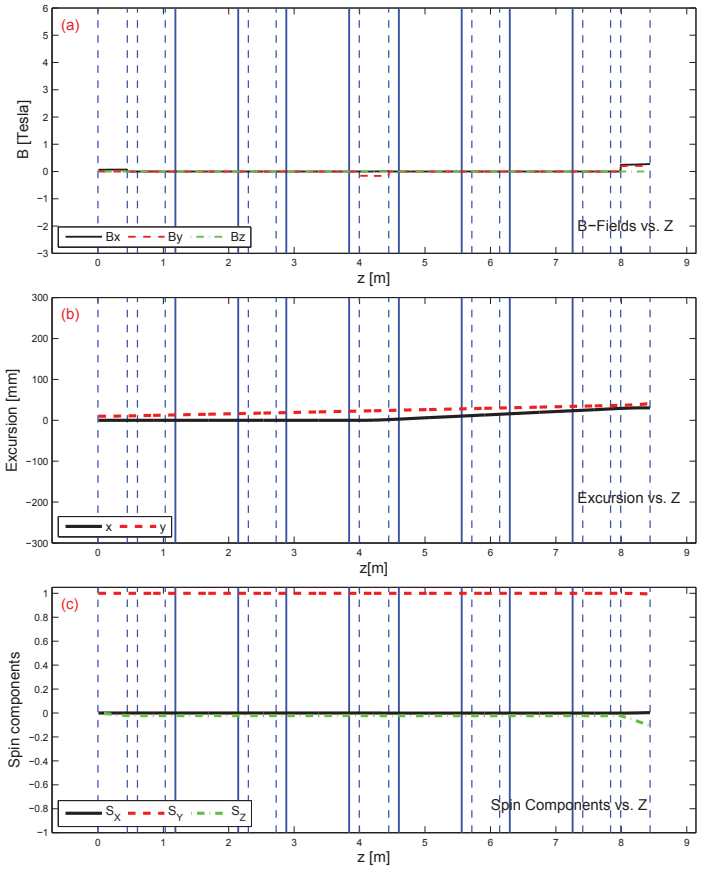
Full Snake Set2 with 10.5421T/m 0.425m and 12.2403T/m 0.425m ramped Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



2 GeV unramped

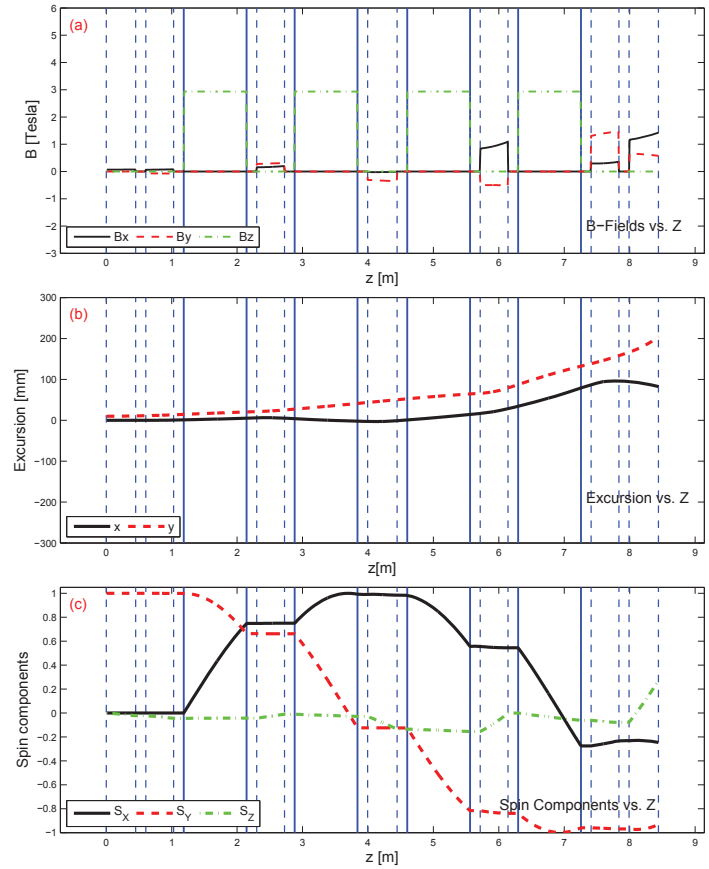
FJK 2GeV vert unramped 7feb14

No Snake Full Set 1 with no skew Quadrupoles and 001cm displacement of beam



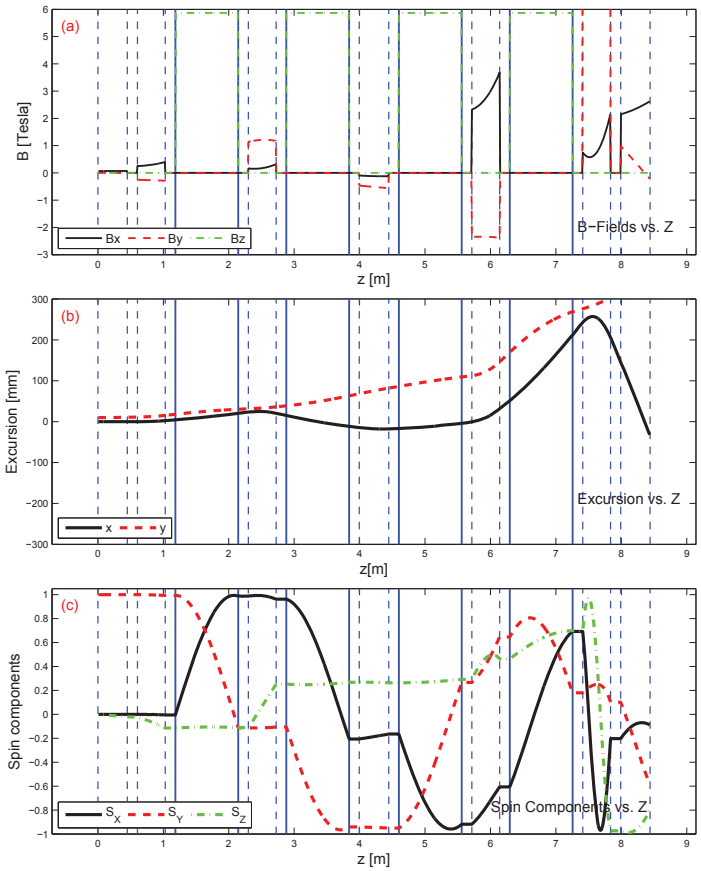
FJK 2GeV vert unramped 7feb14

Half Snake with 8.1914T/m 0.425m and 14.3693T/m 0.425m unramped Quadrupoles and 2.93T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



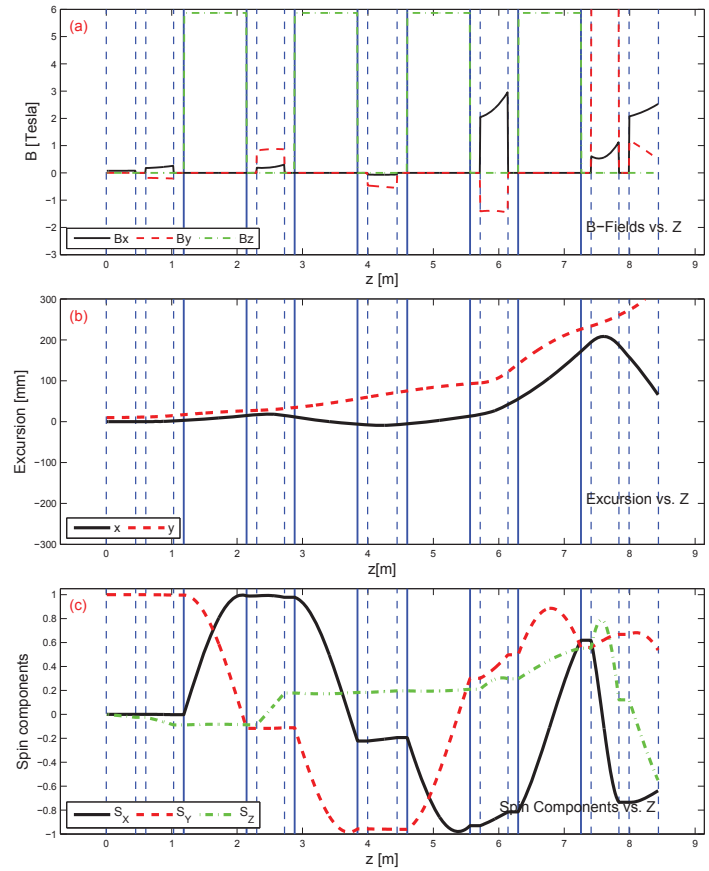
FJK 2GeV vert unramped 7feb14

Full Snake Set1 with 31.6319T/m 0.425m and 29.325T/m 0.425m unramped Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



FJK 2GeV vert unramped 7feb14

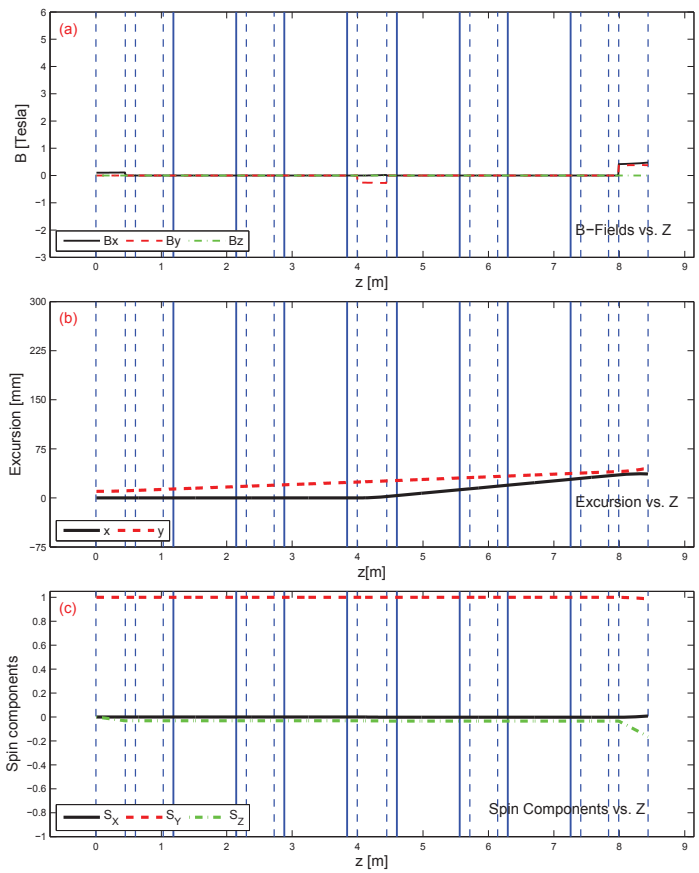
Full Snake Set2 with 22.2088T/m 0.425m and 25.7864T/m 0.425m unramped Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



3 GeV Ramped

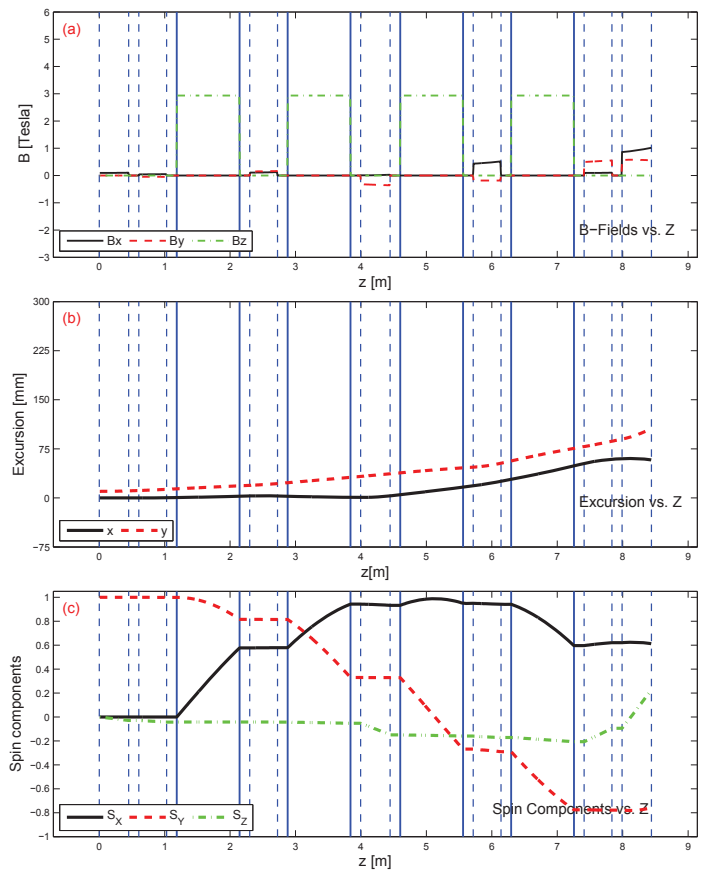
3 GeV vert Ramped JKT 6feb14

No Snake Full Set 2 with no Quadrupoles and 001cm displacement of beam



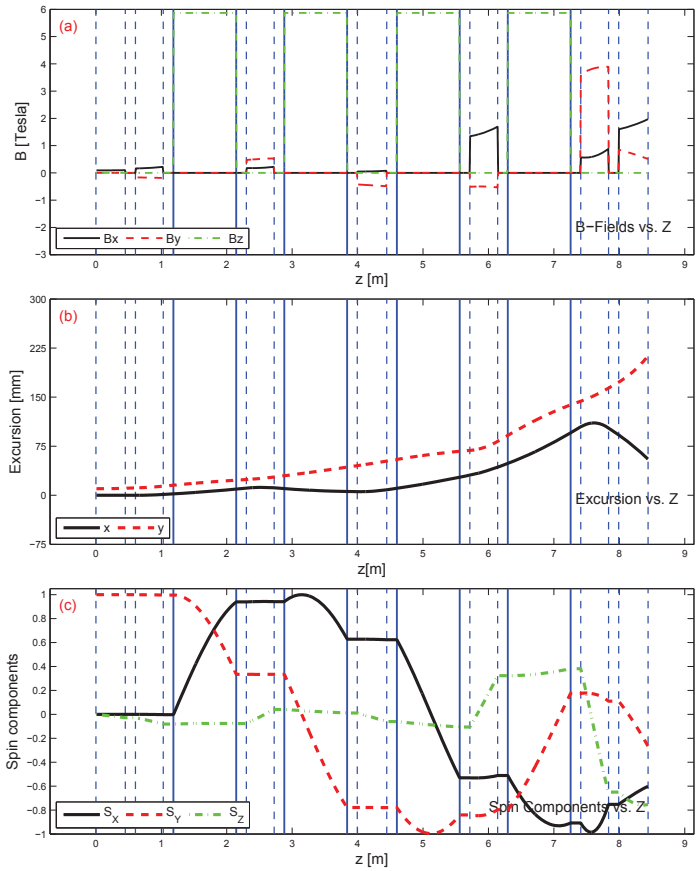
3 GeV vert Ramped JKT 6feb14

Half Snake with 5.3452T/m 0.425m and 9.3764T/m 0.425m Quadrupoles and 2.93T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



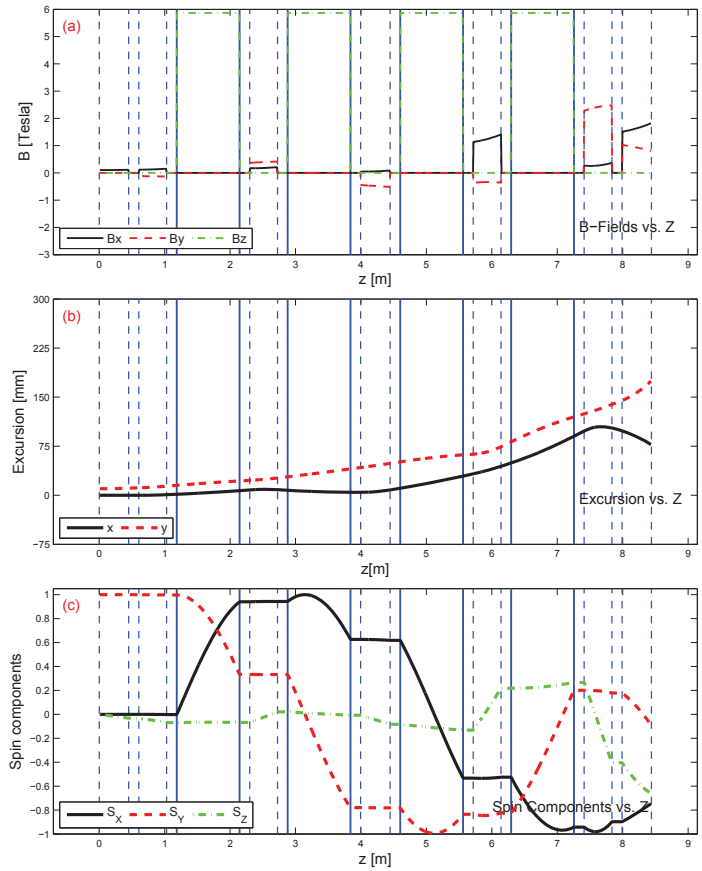
3 GeV Ramped JKT 6feb14

Full Snake Set1 with 20.6408T/m 0.425m and 19.1355T/m 0.425m Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



3 GeV Ramped JKT 6feb14

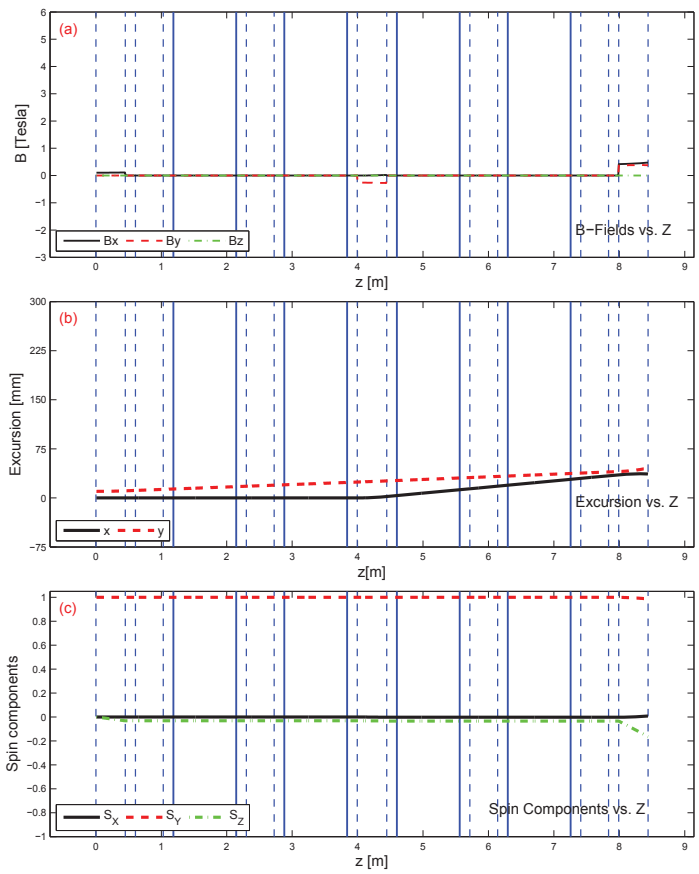
Full Snake Set2 with 14.492T/m 0.425m and 16.8265T/m 0.425m Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



3 GeV unramped

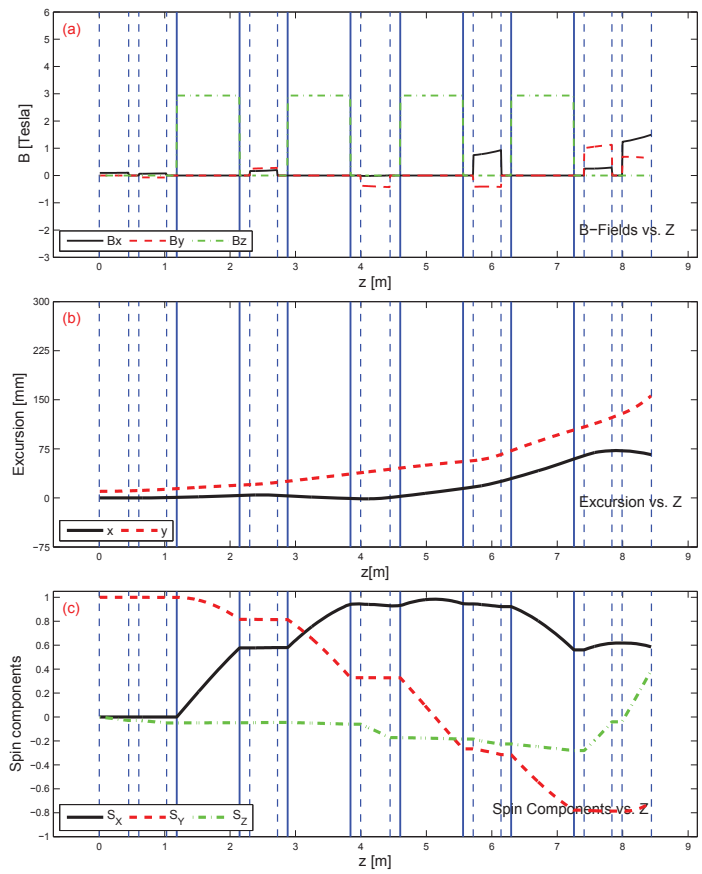
3 GeV vert unramped JKT 6feb14

No Snake Full Set 2 with no Quadrupoles and 001cm displacement of beam



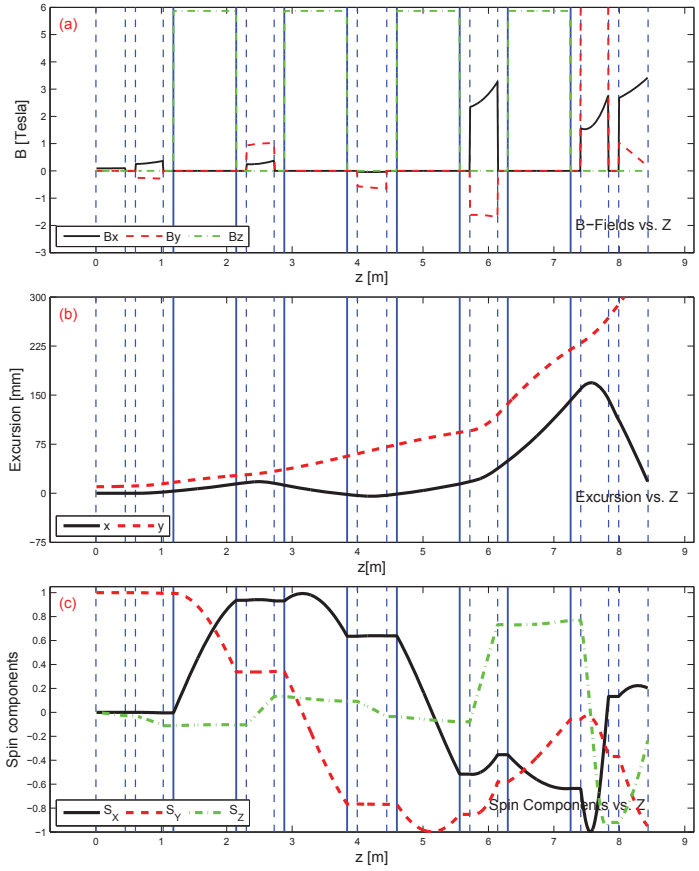
3 GeV vert unramped JKT 6feb14

Half Snake with 8.1948T/m 0.425m and 14.3751T/m 0.425m Quadrupoles and 2.93T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



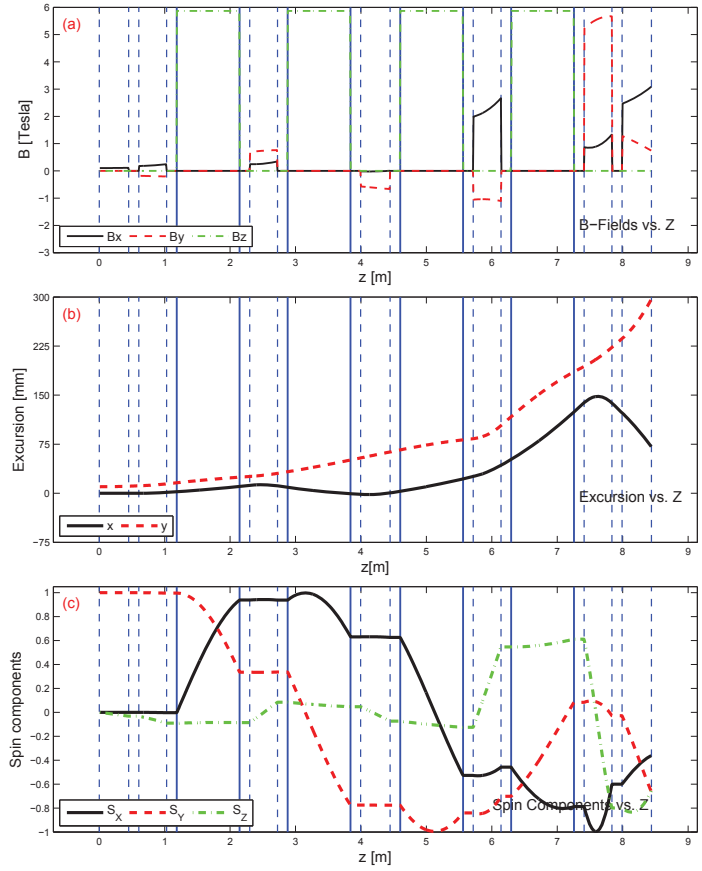
3 GeV unramped JKT 6feb14

Full Snake Set1 with 31.6448T/m 0.425m and 29.337T/m 0.425m Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



3 GeV unramped JKT 6feb14

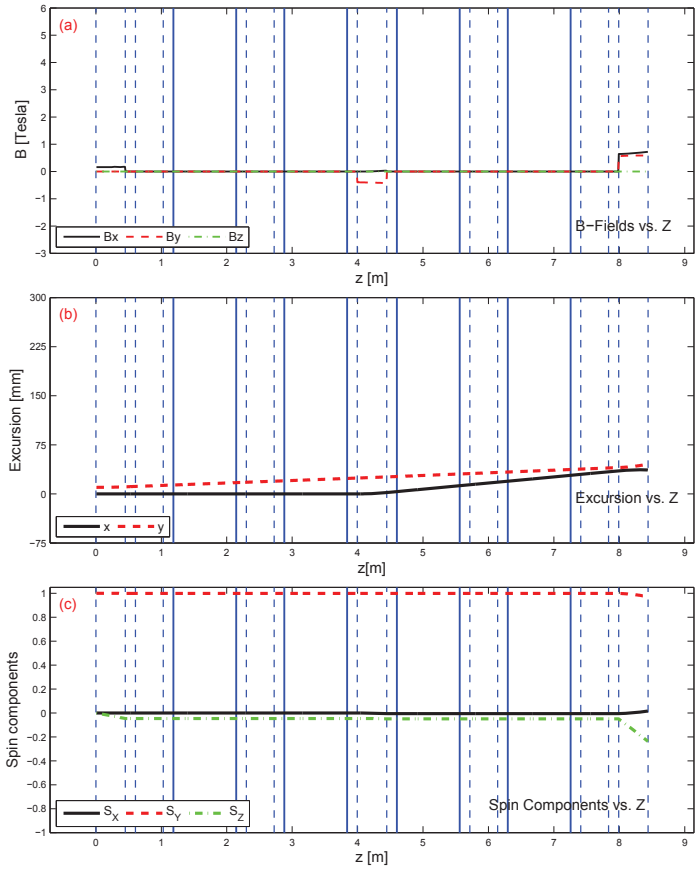
Full Snake Set2 with 22.2179T/m 0.425m and 25.797T/m 0.425m Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



5 GeV

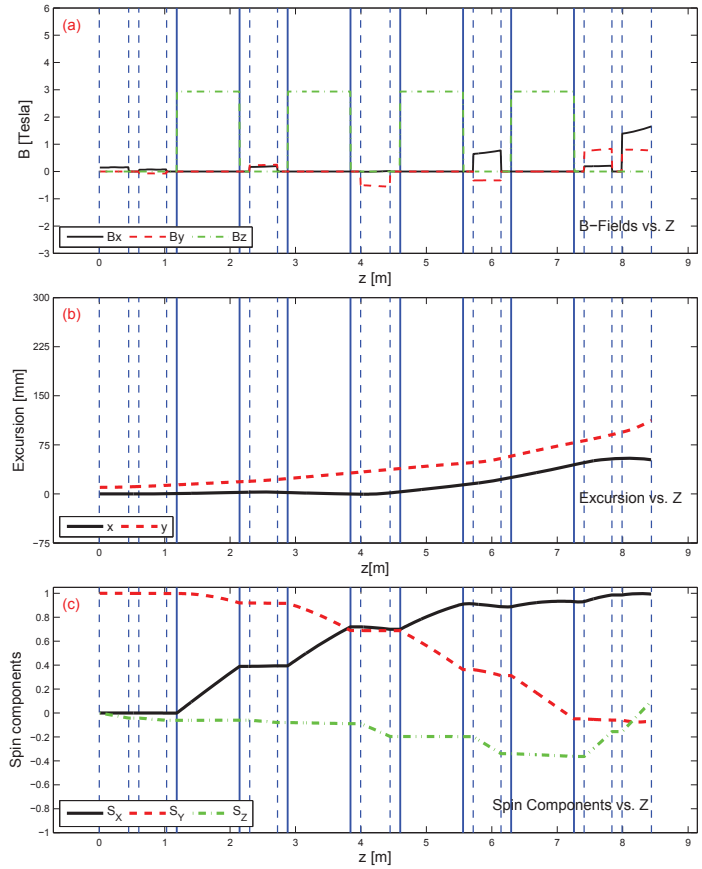
5 GeV vert JKT 5feb14

No Snake Full Set 2 with no Quadrupoles and 001cm displacement of beam



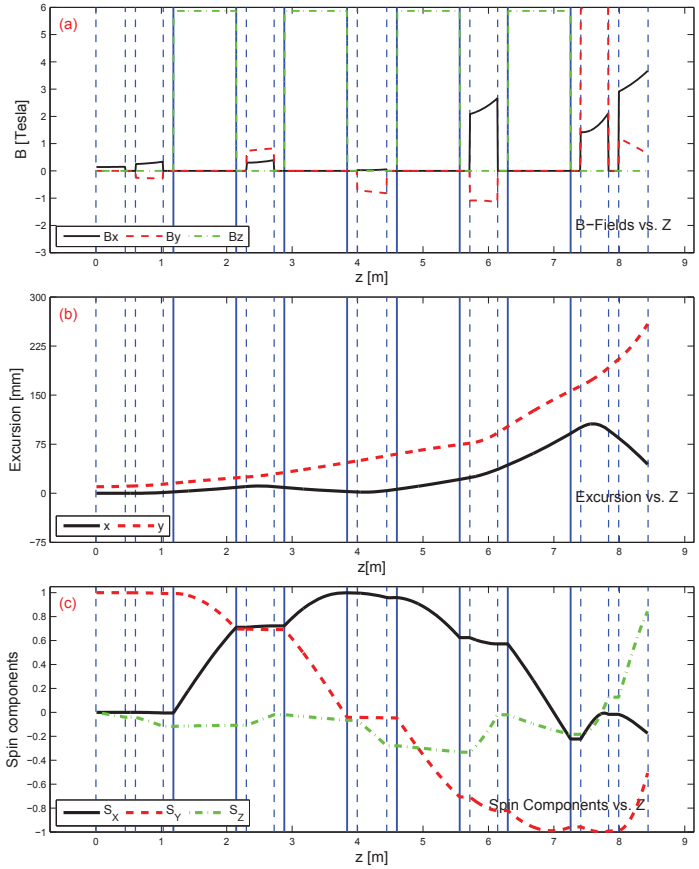
5 GeV vert JKT 5feb14

Half Snake with 8.1948T/m 0.425m and 14.3751T/m 0.425m Quadrupoles and 2.93T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



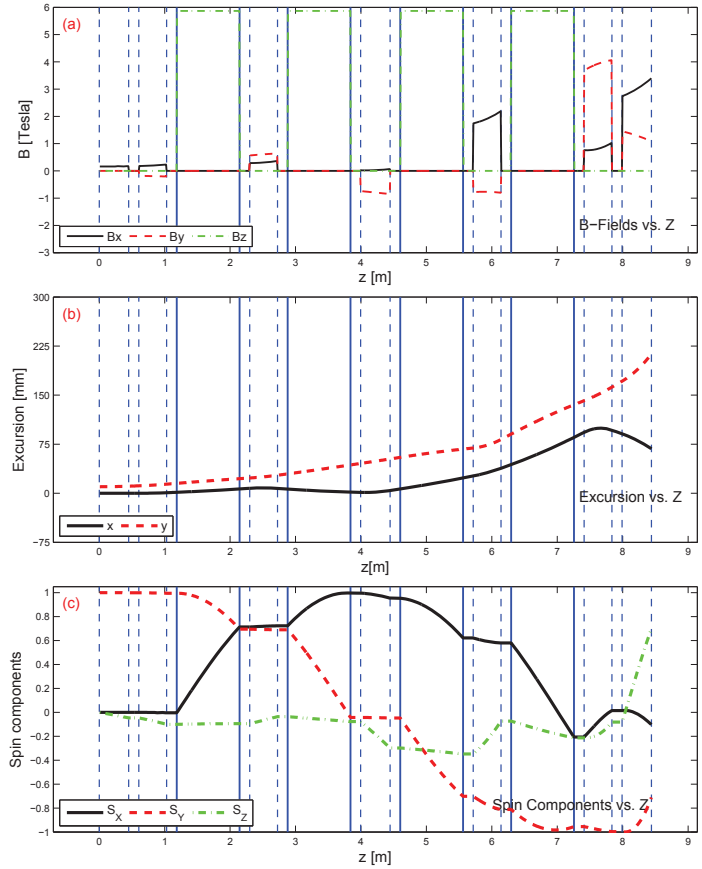
5 GeV JKT 5feb14

Full Snake Set1 with 31.6448T/m 0.425m and 29.337T/m 0.425m Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam

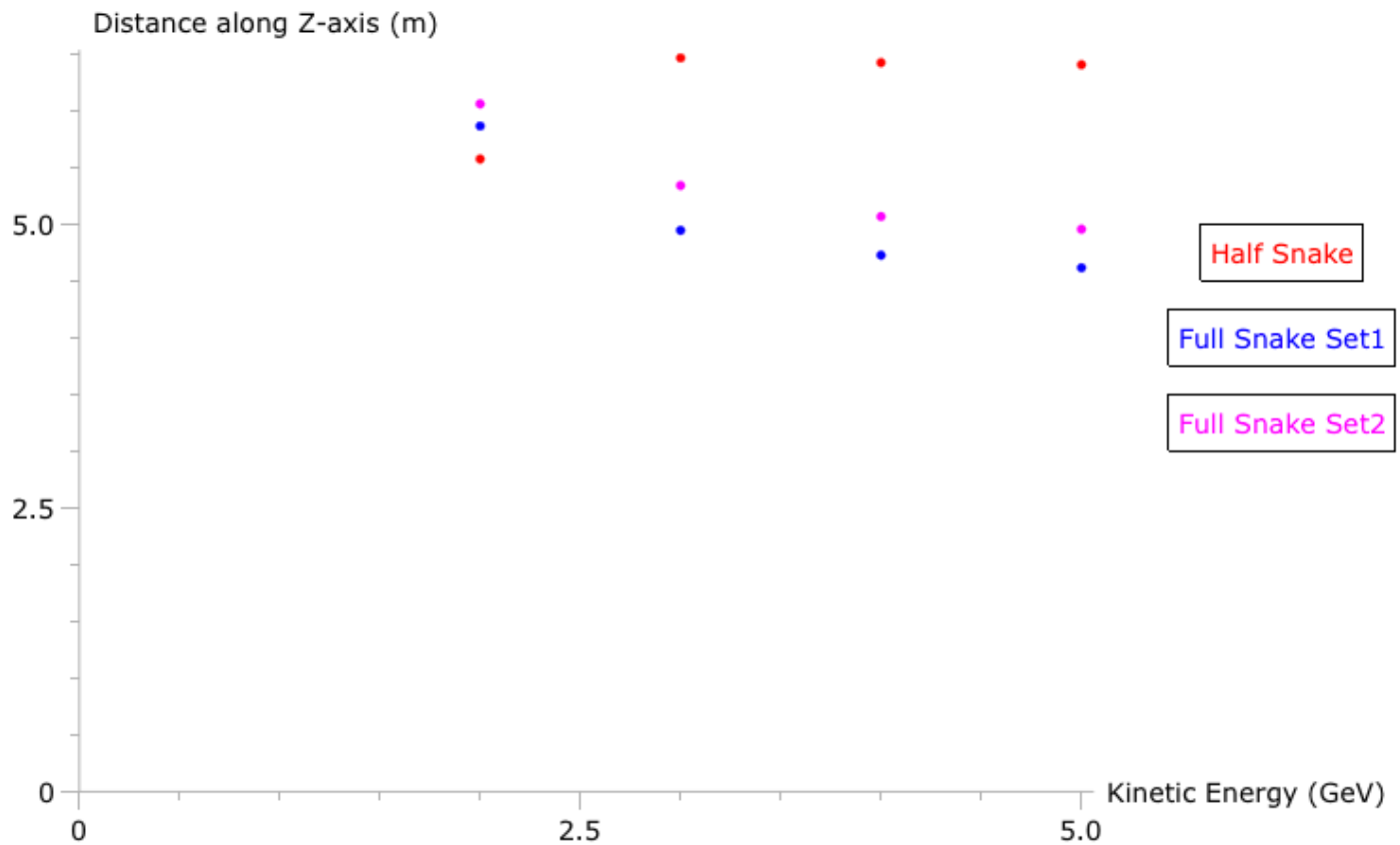


5 GeV JKT 5feb14

Full Snake Set2 with 22.2179T/m 0.425m and 25.797T/m 0.425m Quadrupoles and 5.86T 0.96m Solenoid with 0.155m Gaps and 001cm displacement of beam



Distance Along Z-axis at which Vertical Excursions exceed 6cm versus Kinetic Energy (GeV) JKT 10feb14

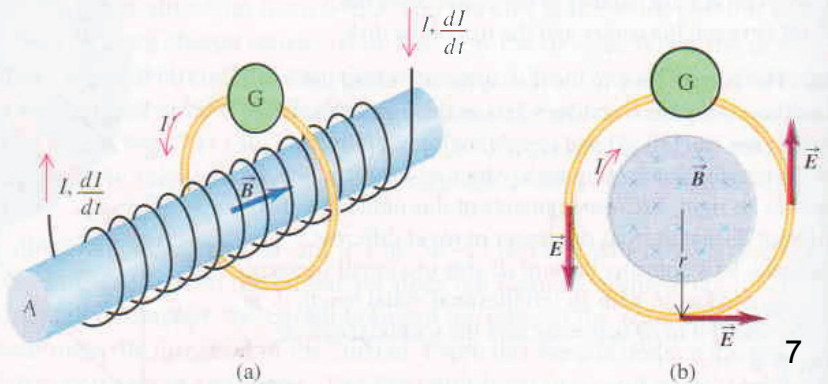


30–4 Lenz's Law

Lenz's law is a convenient alternative method for determining the direction of an induced current or emf. Lenz's law is not an independent principle; it can be derived from Faraday's law. It always gives the same results as the sign rules we introduced in connection with Faraday's law, but it is often easier to use. Lenz's law also helps us gain intuitive understanding of various induction effects and of the role of energy conservation. H. F. E. Lenz (1804–1865) was a German scientist who duplicated independently many of the discoveries of Faraday and Henry. **Lenz's law** states:

> **The direction of any magnetic induction effect is such as to oppose the cause of the effect.**

The "cause" may be changing flux through a stationary circuit due to a varying magnetic field, changing flux due to motion of the conductors that make up the circuit, or any combination. If the flux in a stationary circuit changes, as in Examples 30–1 and 30–2, the induced current sets up a magnetic field of its own. Within the area bounded by the circuit, this field is *opposite* to the original field if the original field is *increasing* but is in the *same* direction as the original field if the latter is *decreasing*. That is, the induced current opposes the *change in flux* through the circuit (*not* the flux itself).



30–15 (a) The windings of a long solenoid carry a current I that is increasing at a rate dI/dt. The magnetic flux in the solenoid is increasing at a rate $d\Phi_B/dt$, and this changing flux passes through a wire loop. An emf $\mathcal{E} = -d\Phi_B/dt$ is induced in the loop, inducing a current I' that is measured by the galvanometer G. (b) Cross-section view.

Possible Solenoid Parameters

For a long solenoid B field = μnI, where n = turns/m, I = current (A) μ = permeability ~ μ_0.
For Nuclotron solenoids with SS core μ~1.002-1.007 B = 4π x 10-7 ~1.2 x 10-6 (mks units).
From *Atomic Energy, Vol. 112, No.2, June 2012, P. 80-89, Kovalenko et al*, Table 1, says for Nuclotron dipoles, B-field for 6 kA is 1.98 T.
From *Kovalenko, DSpin 2013,* dipole field at 6 GeV ~ 1 T, ramp time = 1.67 s.
For dipoles 1 T gives 3 kA; thus assume 3 kA available for solenoid (could be different).
Thus, n = B/ μ_0I = 6/ [μ_0 x 3000]. This 6 T requires 1600 turns/m in each 0.96 m longsolenoid,which, thus needs 0.96 x 1600 turns = 1536 turns
From the Wikipedia website, 96 cm + 1536 turns + r=10cm + rel permeability~1 gives a Solenoid Inductance of L =0.097 H; while 3 kA/1.67s gives dI/dt of 1796 A/s.
From freshman physics, for a pure inductor, the voltage across the inductor is V = L dI/dt ~ 174 V.

ADK 8 feb 2014

Results of Lenz's Law for Ramped Superconducting Solenoids

The Resistance of the copper wire surrounding the superconducting Niobium Titanium filaments is given by:

$$\mathbf{R= r\cdot L_c/A_c \text{ ohm m}}$$

Where **r** is the resistivity of copper, which is ~$\mathbf{2\cdot 10^{-11}}$ ohm at 4.2 K;
while $\mathbf{L_c}$ and $\mathbf{A_c}$ are the copper wire's length **(~1600 m)** and cross section area **(~1cm^2 = 10^{-4} m^2).**
Inserting these numbers gives a resistance in each solenoids' copper part of 90% of the wire cross-section of

$$\mathbf{R\sim 3\ 10^{-4}\ Ohm}$$

The current **I** at ~5 GeV will be about **3000 Amps** in the niobium titanium in the cable.
Lenz's Law says that the current **I'** in the copper of the coil will be **3000 Amps** in the opposite direction.
The power loss in the niobium titanium part of the cable will be **ZERO** because its Resistance is **ZERO**.
However, in the copper part of the wire the power will be

$$\mathbf{P= (I')^2\cdot R \sim (3000\ A)^2 \cdot 3\ 10^{-4}\ Ohm \sim 2.7\ KW}$$

At 4.2 K a few KW would significantly increase the temperature above the level where NiTi stops being super-conducting and might severely damage the solenoids and perhaps any nearby dipoles or quadrupoles as at LHC a few years ago.