Implementation of Solenoids in Mad-X with application to the LHC

came up by :

- **2nd Mad-X day -> request for solenoid in makethin** (C. Milardi, Daϕne)

Launched follow up.

Idea : implement and apply to the LHC even if the effect is known to be small,
still good to have at least the option to include in first order and be able to turn optionally on/off

- **so far**

magnets from experiments not in standard LHC sequence
Mad-X tracking: trrun.f !---- Solenoid call ttsol(el, track, ktrack) not yet implemented
Sixtrack : not implemented
makethin : solenoids treated dummy element, L=0, k = 0;

Solenoids and Coupling in the LHC

small effect, see Koutchouk et al. CERN-SL-94-33, Part. Accel. 55 (1996) 183–191 (Montreux)

$$\Delta c^{\mp} = -\frac{i}{4\pi}\frac{B_s l}{B\rho}\left(\sqrt{\frac{\beta_y^*}{\beta_x^*}} \pm \sqrt{\frac{\beta_x^*}{\beta_y^*}}\right)$$

0 or 2 for LHC (50 for LEP)

$$\Delta c^{+} = 0 \quad c^{-} = -\frac{i}{2\pi}\frac{B_s l}{B\rho} = -5.3 \times 10^{-3}\, i \quad \text{at 450 GeV for the CMS magnet}$$

for comparison: JPK had in '96: ~3e-3 from 24Tm CMS solenoid and ~3e-2 from random a2 and orbit

Why much less than at LEP where this was a major effect ?

L3 in LEP : $c^{+} \approx 0.8 - 0.2\, i$, $c^{-} \approx -0.9 - 0.4\, i$ at injection

L3 ~ 6 Tm, Aleph 10 Tm, Opal 2.6 Tm, Delphi 5 Tm

LHC ~ 20 times stronger fields at injection (from 22 to 450 GeV)

strongest solenoid , CMS ~ 50 Tm about 4 times stronger than at LEP (JPK assumed 24 Tm)

cmsdoc.cern.ch/cms/TDR/MAGNET/CMS_TDR_10_97/CMS_Pageshtml/chap3.html 4T over 12.5 m

5x less field x 25 for β ratio : Solenoids ~ 100 times less important, nearly negligible

Implementation, Solenoid Transfer Matrix

linear (thick, symplectic) transfer matrix used in Mad-X twiss, mad8, transport

where $k = \frac{eB_0}{2p_s} \quad C = \cos kL \quad S = \sin kL$

$$R_{\rm sol} = \begin{pmatrix} C^2 & \frac{SC}{k} & SC & \frac{S^2}{k} & 0 & 0 \\ -kSC & C^2 & -kS^2 & SC & 0 & 0 \\ -SC & -\frac{S^2}{k} & C^2 & \frac{SC}{k} & 0 & 0 \\ kS^2 & -SC & -kSC & C^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & \frac{L}{\beta^2\gamma^2} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

can be written as product of two matrices, rotation × matrix (looking like a quad focusing in two planes)

$$R_{\rm sol} = \begin{pmatrix} C & 0 & -S & 0 & 0 & 0 \\ 0 & C & 0 & -S & 0 & 0 \\ S & 0 & C & 0 & 0 & 0 \\ 0 & S & 0 & C & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} C & \frac{S}{k} & 0 & 0 & 0 & 0 \\ -kS & C & 0 & 0 & 0 & 0 \\ 0 & 0 & C & \frac{S}{k} & 0 & 0 \\ 0 & 0 & -kS & C & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & \frac{L}{\beta^2\gamma^2} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

rotation by $\phi = kL$ focusing matrix in both x and y

madX implementation, makethin:

normally : thick magnets all become multipoles with L=0.
here : needs extra element thin solenoid
discussed with F.S.: done by extension of existing solenoid element
with extra Lrad, ksl parameters and L=0

Lrad = L_{thick}/n (keep length for special use, as done for other magnets for Synchr. Rad.)

$$ksl = \frac{ks\ L_{thick}}{n}$$

Example.

Thick solenoid, Input to makethin:

```
ssol1: solenoid, at = 1,l:= 2,ks:= 0.5;
```

Output from makethin for 2 slices:

```
sol1..1: solenoid,l:= 0,lrad:= 1,ks:= 0.5,ksl:= 0.5;
sol1: marker;
sol1..2: solenoid,l:= 0,lrad:= 1,ks:= 0.5,ksl:= 0.5;
s: sequence, l = 2;
sol1..1, at = 0.5,l:= 0,lrad:= 1,ks:= 0.5,ksl:= 0.5;
sol1, at = 1;
sol1..2, at = 1.5,l:= 0,lrad:= 1,ks:= 0.5,ksl:= 0.5;
```

Next (proposal for discussion) :

- commit changes to makethin and trrun (A.K.) to cvs repository (could be done this week)
- documentation - writeup started
- add solenoid info to standard LHC optics files (T.R.)
- extend twiss module to treat thin solenoid (F.S.)
- further testing and follow up of some issues found as by-product of this extension
- collaboration with daϕne, C. Milardi plans to come a week before the end of the year