Update on MDISim tool

Principle and strategy as described earlier

MAD-X sequence --> automatic geometry generation and analytic estimate --> detailed Geant4

Tools for Flexible Optimisation of IR Designs with Application to FCC, IPAC 2015 tupty031

Essential in MDISim

Transformations : CS <--> EU

High numerical precision µm over km or > 10^9 cartesian (Euclidian) coordinates

Developments over the last months :

- **further improving numerical precision**
- **beam generation**
- **solenoid --- work in progress**

Tracking precision

Goal for SR, beam gas detailed simulation with Geant4 : **μm precision over ~ km around IP**.

Tests + developments : test MAD-X sequences, often using single or few BENDS, QUADS

and tracking for a small machine (LEIR) entirely using Geant4, then back from EU to CS

looking at stability of Courant Snyder invariant -- locate growth locations

step by step -- identify and fix precision

Several smaller and **three major steps :**

- **ROOT geometry export**
- **CTUB for RBENDS to eliminate gaps, GEANT4**
- **Magnetic field tracking precision tuning, GEANT4**

Result for LEIR : tracking in LEIR with GEANT4 ; previously lost after few turns

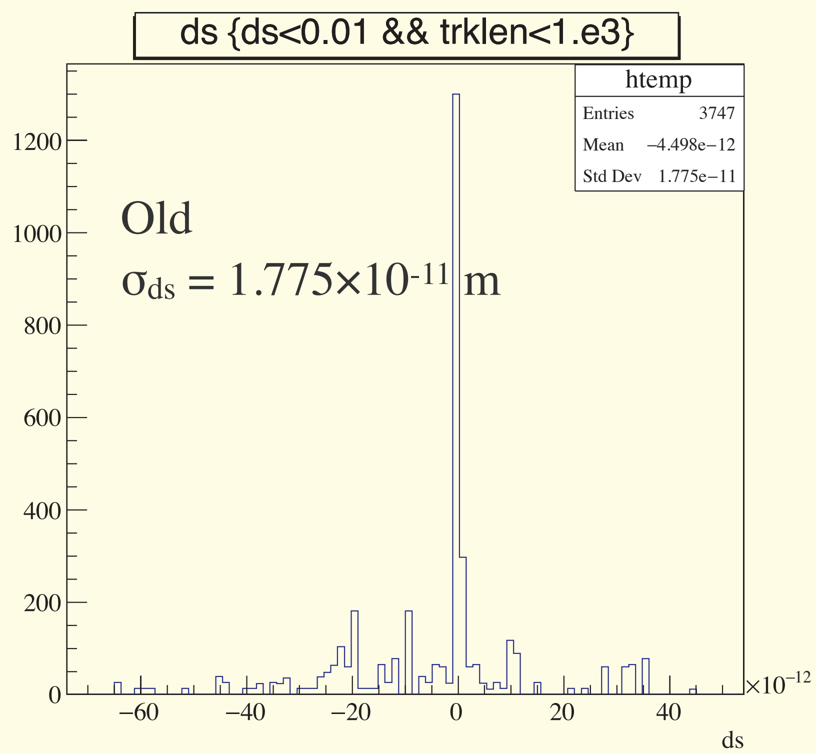
now no more loss (check over 10 km or 127 turns)

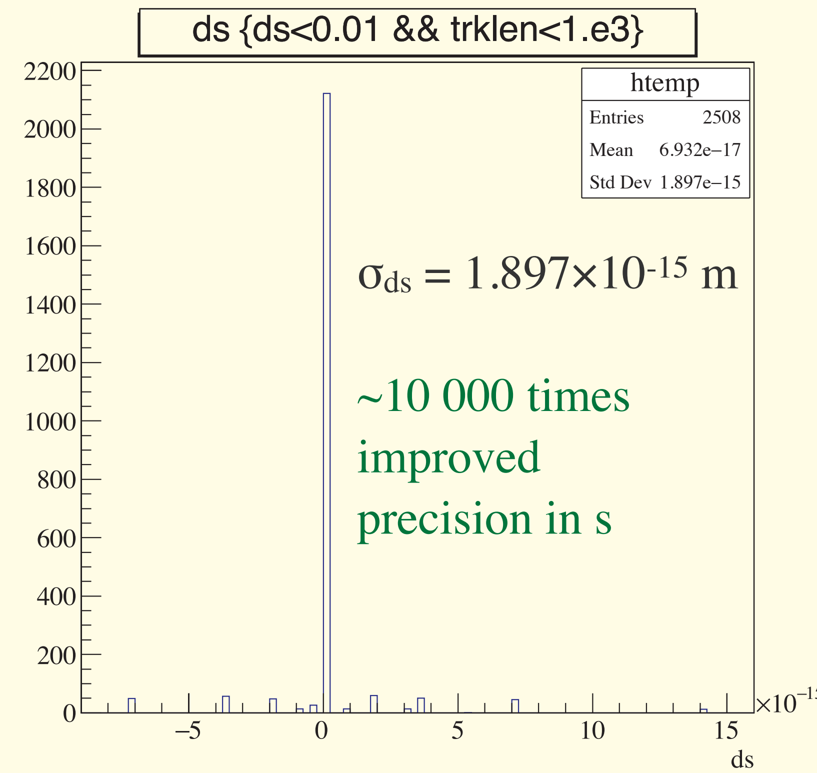
Precision loss in ROOT geometry export

Root exports geometries in various formats   root, C, xml, gdml

```
Example
18.067141635485662 "true" value printed to 17 digits to avoid any loss in precision
18.0671416355      GDML export, used as input to GEANT4
18.067142          C export
1.806714e+01       XML export
```

Reported as Root issue on 21/06/2017 with proposed fix change "%.12g" to "%.17g" in TGDMLWrite.cxx
running since then with "my own" improved root module for geometry generation





difference between GEANT4 and MAD-X track position for LEIR

Magnetic field tracking, Geant4

Using the **improved ROOT GDML export**, angle off by 1.227×10^{-9} after 1st bend in LEIR

GEANT4 magnetic field tracking accuracy can be adjusted :

example : DeltaOneStep = 1.e-05 default, with 1.e-9 angle off by 6.864×10^{-9} , 18× better

Excellent results with :

minEpsilonStep= 5e-08 m maxEpsilonStep= 1e-06 m DeltaOneStep= 9e-11 m

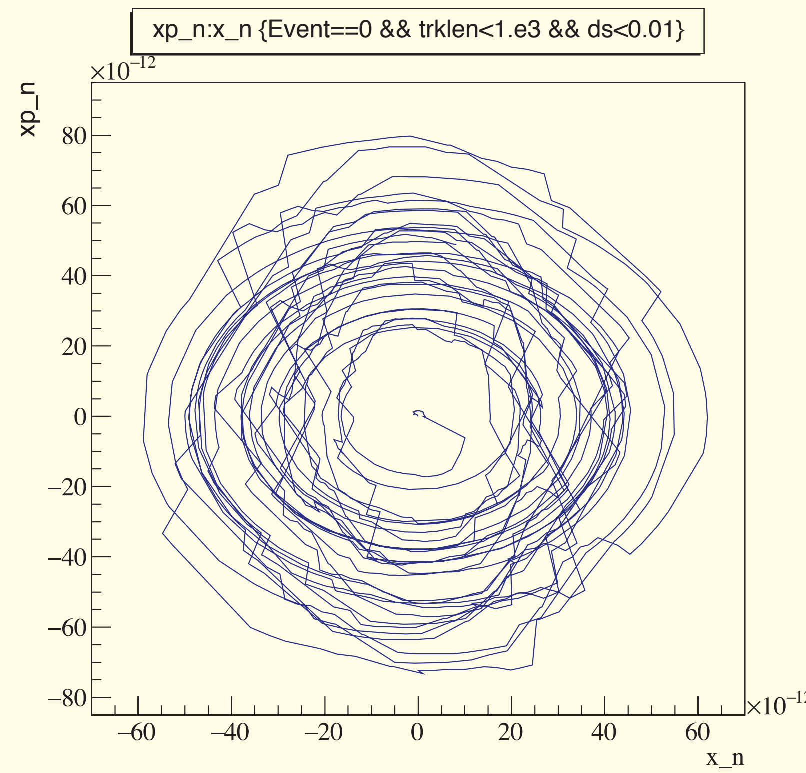
DeltaIntersection=3.6e-11 m.

LEIR normalized x vs x'

tracked over 10 km

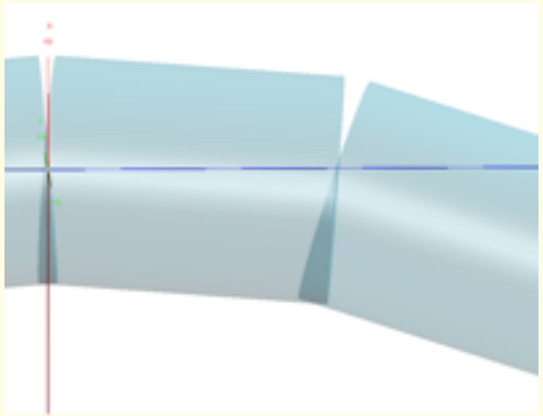
or 127 turns

numerical noise < 10^{-10}

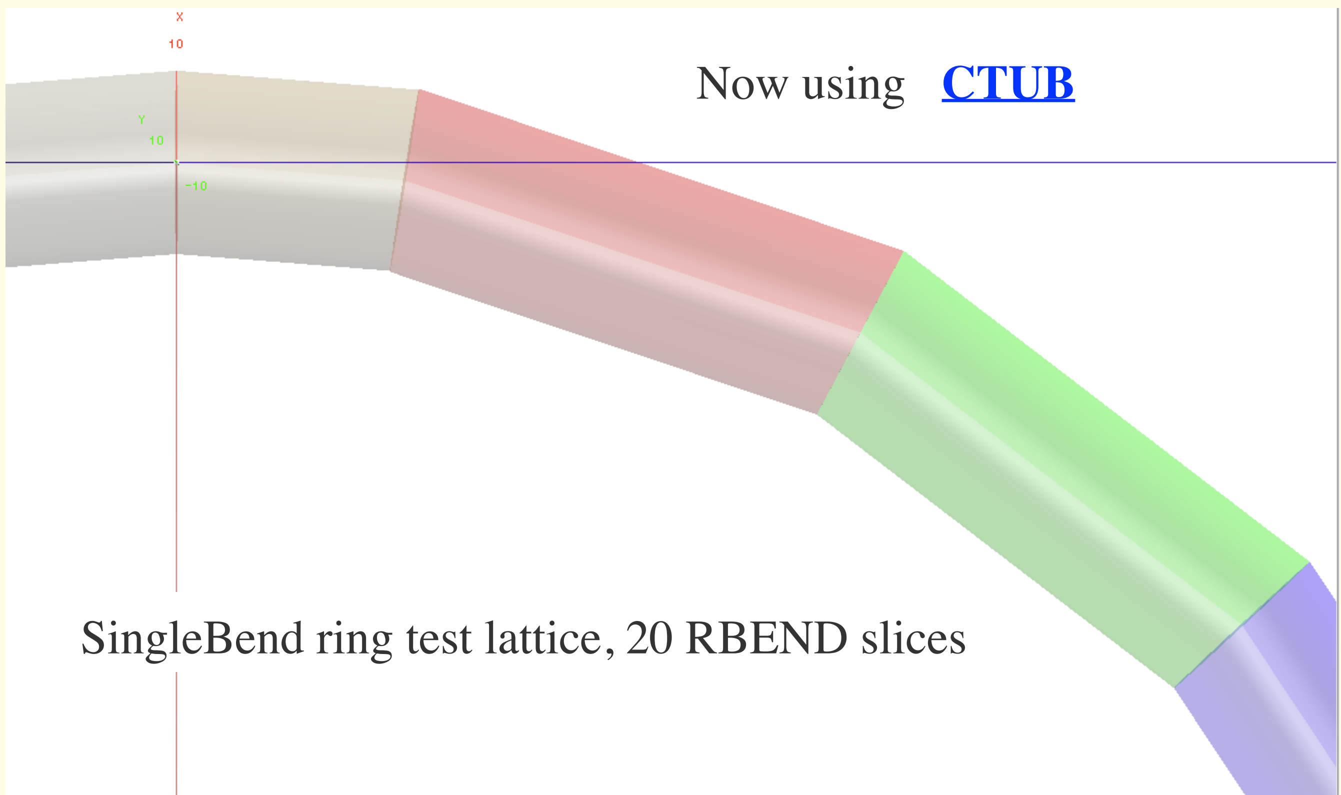


Cut tubes CTUB

Previously using cylindrical tubes as shape for rectangular magnets (and Torus for SBEND)



Issue with transitions -- here clearly visible
for large rings less dramatic



SingleBend ring test lattice, 20 RBEND slices

Beam generation, on Geant4 level

Earlier tests done with pencil beam just pos and direction. **Typical G4 input now**

```
/testem/det/GeomFile   /Users/hbu/www/Geom/fcc_ee_t_202_sol_16_b1.gdml
/testem/det/FieldFile  /Users/hbu/www/Geom/fcc_ee_t_202_sol_16_b1.dat
```

defines all the geometry
beam and field (optics) information

```
# beam shape, 1. means Gauss, other positive means flat to value, negative means constant amplitude at abs value
/testem/det/Gaussx 1
/testem/det/Gaussy 1

#b1    direction
/gun/direction 0 0 1
```

Could be further extended to allow for initial offsets, angles and reading a distribution (in normalized CS)

Beginning of FieldFile, generated by MDISIM, example FCC-ee, b1, 45.6 GeV, asking to start -10m from IP, which got adjusted to the volume boundary at -8.43927 m

```
1   e+
2   45.600000000000001
3     9.5382132385354353e-06   9.5382132385354353e-06   4.2656186370507299e-07   4.2656186370507299e-07   0   0.00037686580617889316
4     0.014999999999997973     0                        0                        -0.12659863625152623     0   -8.4392755075480679
5     15.597594603369464       0                        0                        0                        0   0
6     -0.0054892512183816154   0.06411244973529287      0                        0                        0   0
7     0                        0                        45.607098028511672       0                        0   0
8     0                        0                        -0.069525605184703382    0.021926411528636208     0   0
9     0                        0                        0                        0                        1   0
10    0                        0                        0                        0                        0   1
11  SOL1R1_1_3_sole   SOLENOID     1.0001125105478401   0.013150271395337188   0.
12  SOL2R1_1_4_sole   SOLENOID     1.0001125105478401   -0.013150271395337188  0.
13  QC1R1_1_7_quad    QUADRUPOLE   1.2                  0                      -0.20536990096781343
```

Line 1: particle type with charge in Geant4 (PDG) convention.
Line 2: particle momentum in GeV/c.
Line 3: beam sizes $\sigma_{xn}, \sigma'_{xn}, \sigma_{yn}, \sigma'_{yn}, \sigma_z, \sigma_e$. Normalized in x, y which is $\sqrt{\epsilon_x}, \sqrt{\epsilon_x}, \sqrt{\epsilon_y}, \sqrt{\epsilon_y}, \sigma_z, \sigma_e$
Line 4: θ, ϕ, ψ survey angles and $\mathbf{v}_{\mathrm{eu}}$ eu vector of the starting point taken at the end of a starting volume,
Line 5-10: the transport matrix to the starting point.

Geant4 run with Gauss beam generation

b1 at IP

b2 at IP

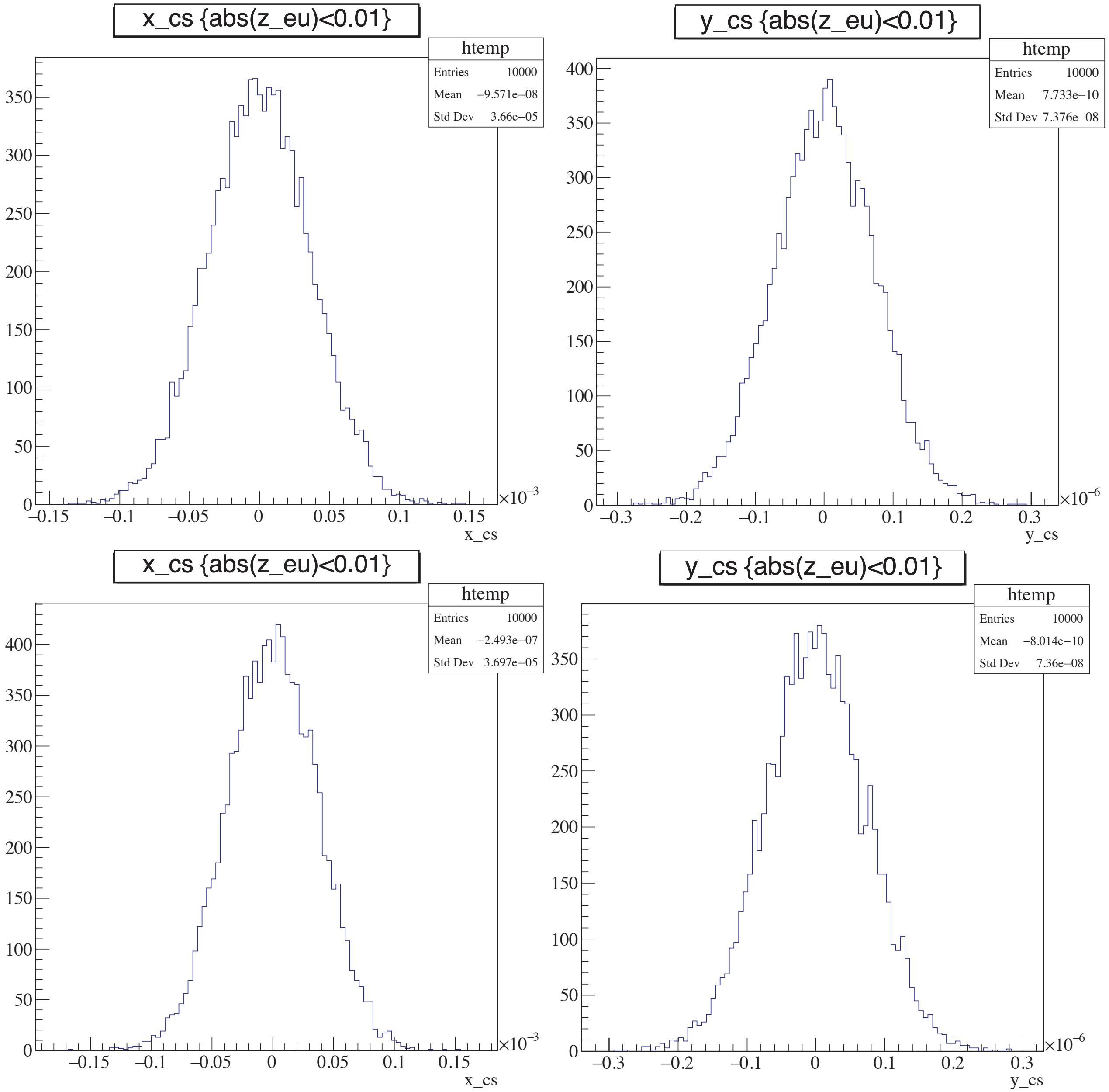


Figure 85: TestEm16 fcc_ee_t_202_nosol tracking from -550 m by 600 m through IP (SR off). Beam sizes at IP. b1 top, b2 bottom. 4/7/2017. Expected from optics $\sigma_x* = 3.66044 \times 10^{-5}, \sigma_y* = 7.32089 \times 10^{-8}$ m.

Solenoid

2T solenoid, 15 mrad crossing angle, transverse component **0.03 Tesla**

at 45.6 GeV nearly **2× stronger than arc bends** (0.0156 T)

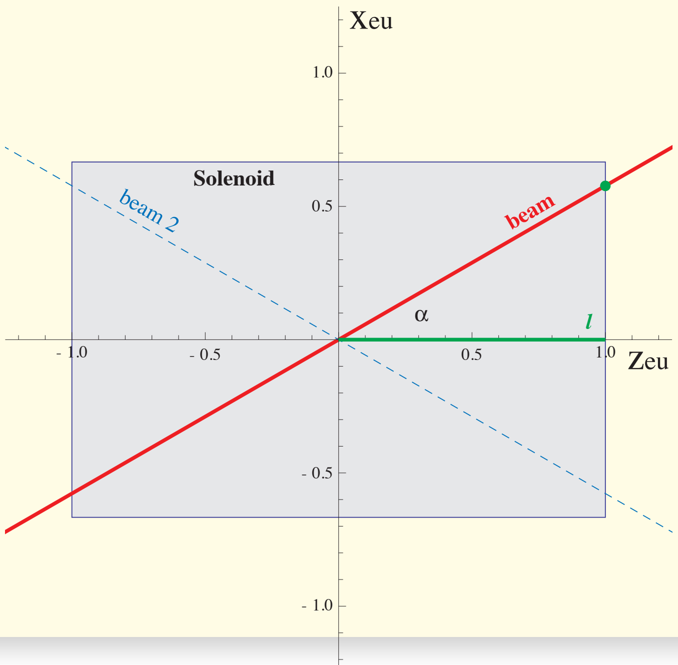
each bunch radiating at top energy some 10^{11} hard photons (Ecr = 611 keV)

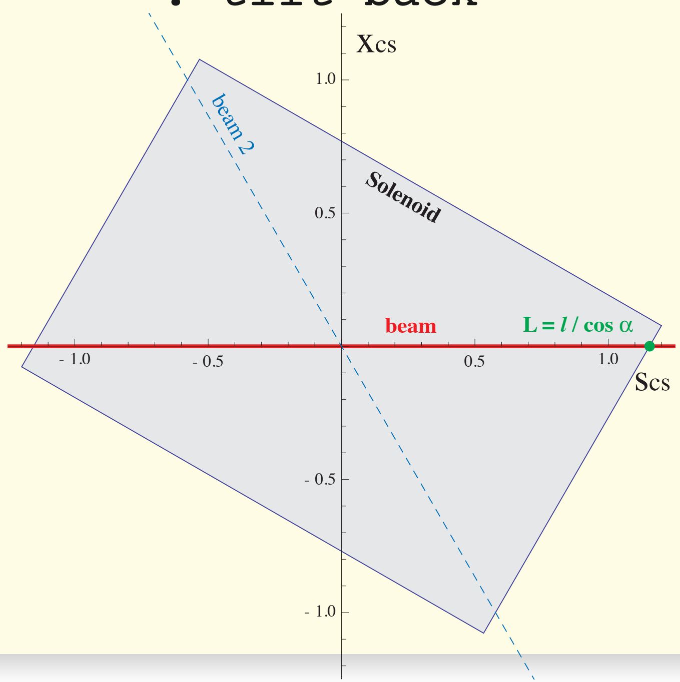
so far missing in MAD-X sequences /afs/cern.ch/user/k/koide/Oide/Lattices/FCCee_z_205_nosol_2.seq

My proposal, shown last week in HSS and FCC-ee optics meeting

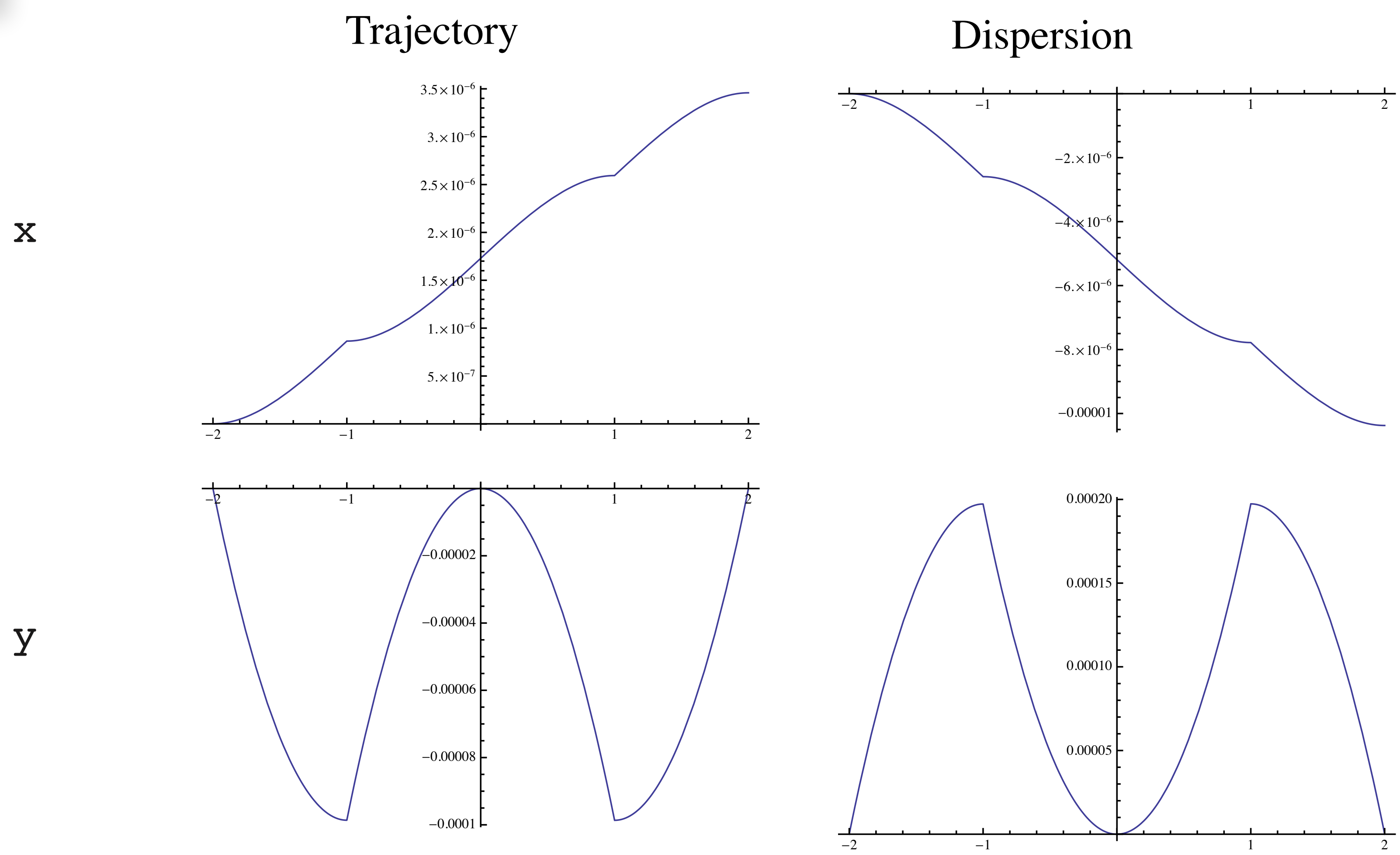
Implementation of tilted solenoid in current MAD-X using a *matrix* *element* TiltX

```
tilt1   :  TiltX(s=0,  px), at=0;          ! tilt beam
Sol1    :  msol            , at:=L/2;
tilt2   :  TiltX(s=L,-px) , at= L;         ! tilt back
```





Solenoid-Antisol. L/R of IR, ±2.000225 m, FCC-ee 45.6 GeV, 2T



From left to right : 1m Anti-solenoid, 1m Solenoid, **IP**, 1m Solenoid, 1 m Anti-solenoid

Dispersion and orbit perfectly compensated by anti-solenoid in y, small residual in x, as seen with SAD

Implementation in MDISim / Geant4, and

comparison Analytic - Helix, SAD, MAD-X, GEANT4 in progress