Benchmark on MUC magnetic field calculation

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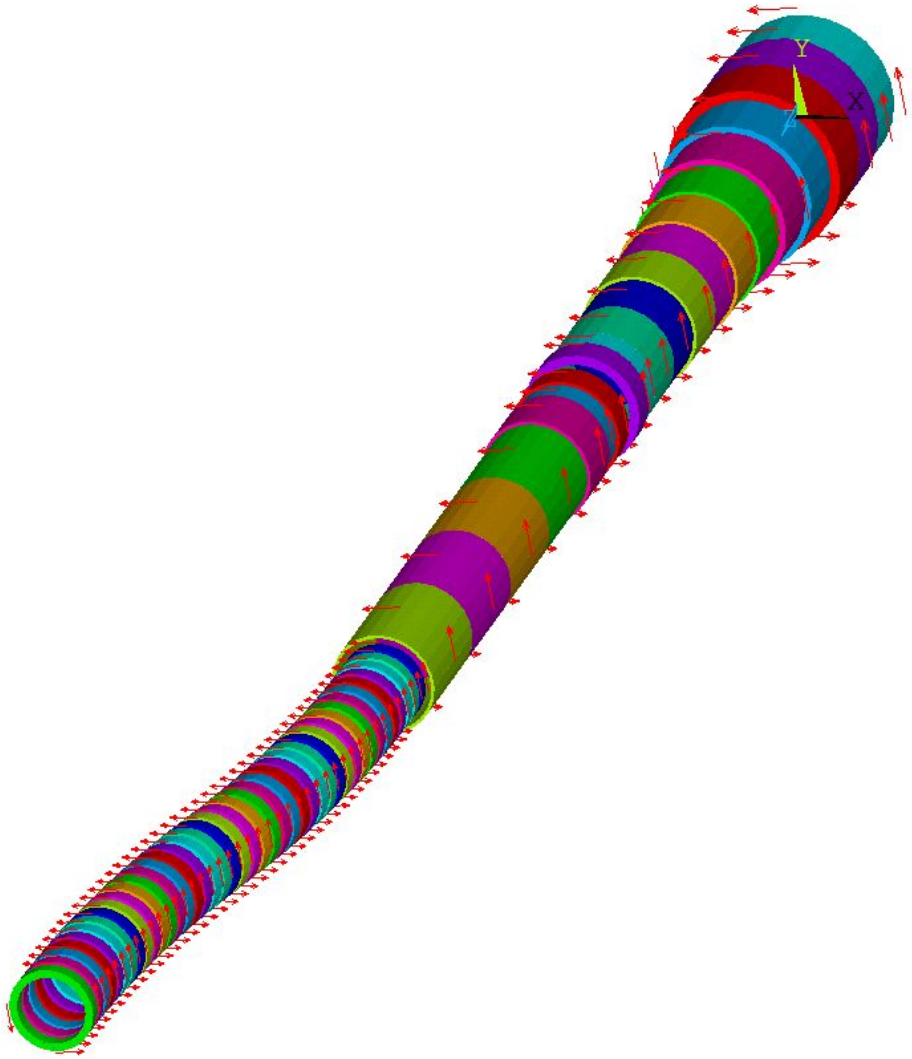
Outline

- Geometry of the tapering and chicane coils implemented
- Spatial components of the magnetic field computed along three paths of points (one path along the coils axis and two oblique off axis paths)
- Three different numerical codes (ANSYS, Current-loop approximation, Daniele C++ code) used to run the simulations
- Four sets of data computed among the three codes and compared
- Conclusions

Geometry

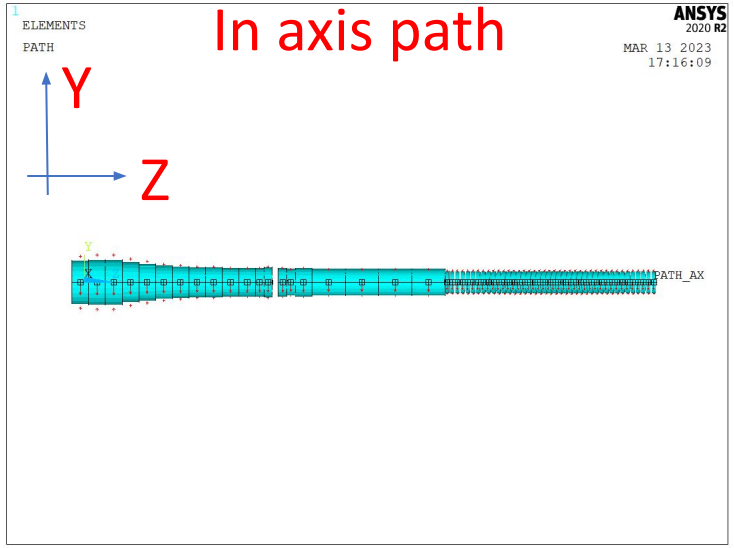


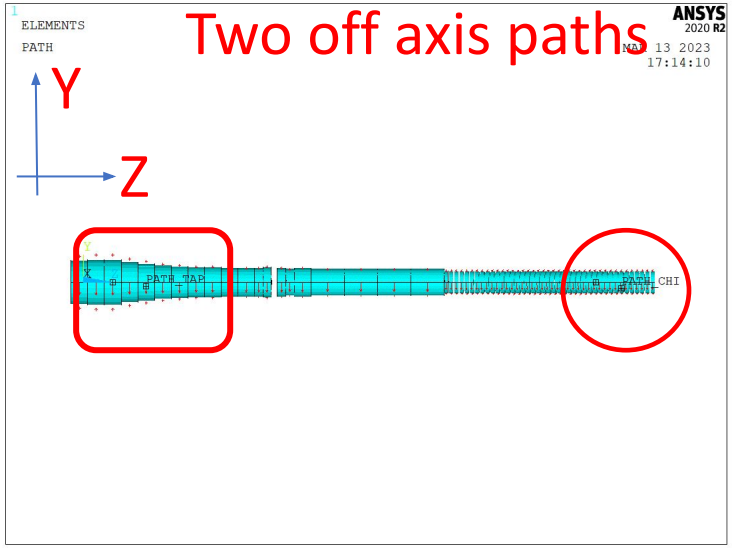
Tapering Coil #	Rc(m)	Zc(m)	DR(m)	DZ(m)	NR	NZ	I(A)
1	0.820	-0.200	0.440	0.800	11	20	60563
2	0.840	0.600	0.480	0.800	12	20	60706
3	0.840	1.400	0.480	0.800	12	20	62848
4	0.780	2.200	0.360	0.800	9	20	58407
5	0.740	3.000	0.280	0.800	7	20	54433
6	0.700	3.800	0.200	0.800	5	20	54360
7	0.680	4.600	0.160	0.800	4	20	52688
8	0.660	5.400	0.120	0.800	3	20	54305
9	0.660	6.200	0.120	0.800	3	20	45720
10	0.640	7.000	0.080	0.800	2	20	54713
11	0.640	7.800	0.080	0.800	2	20	49427
12	0.640	8.400	0.080	0.400	2	10	30671
13	0.660	8.800	0.120	0.400	3	10	44273
14	0.640	9.500	0.080	0.400	2	10	57945
15	0.620	9.900	0.040	0.400	1	10	47690
16	0.640	10.500	0.080	0.800	2	20	34741
17	0.620	11.700	0.040	1.600	1	40	56598
18	0.620	13.300	0.040	1.600	1	40	50989
19	0.620	14.900	0.040	1.600	1	40	48182
20	0.620	16.500	0.040	1.600	1	40	50161

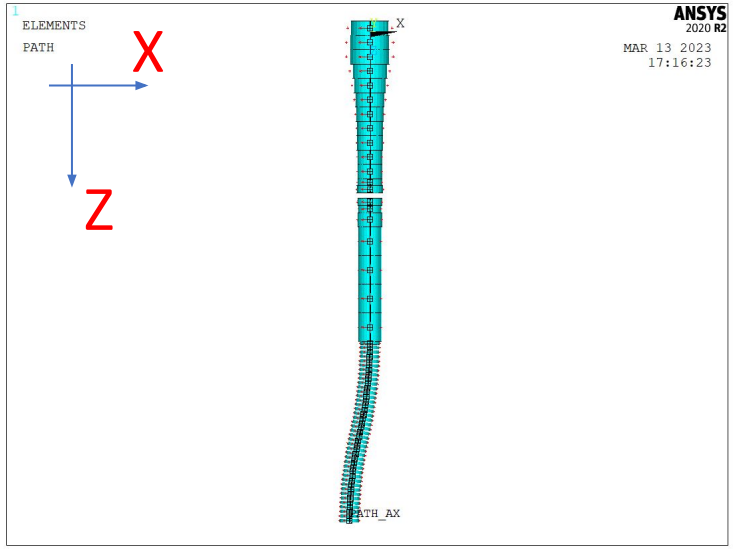
41 Chicane coils:
Inner radius: 430 mm
Outer radius: 530 mm
Length: 180 mm
Current Density: 16.57 A/mm2
Placed at 0.625 deg intervals (250 mm in s)

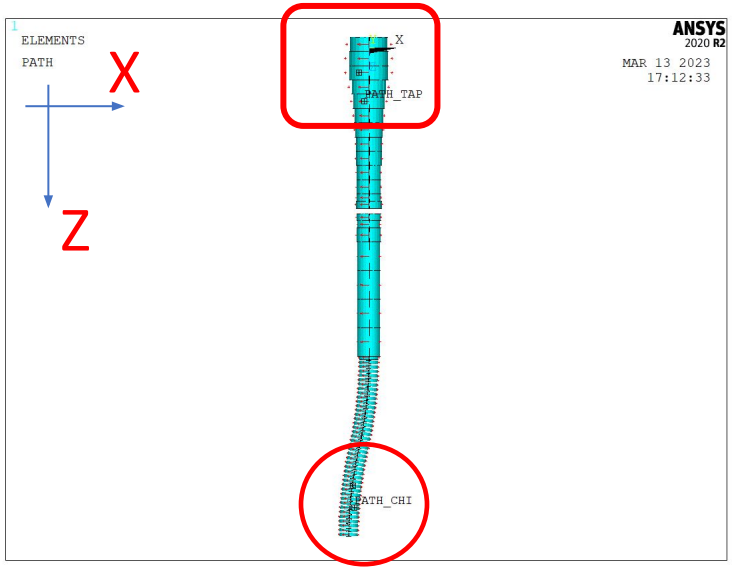
Parameters assumed in C. Rogers past simulations

Paths of points to compute the magnetic field









Numerical codes: ANSYS

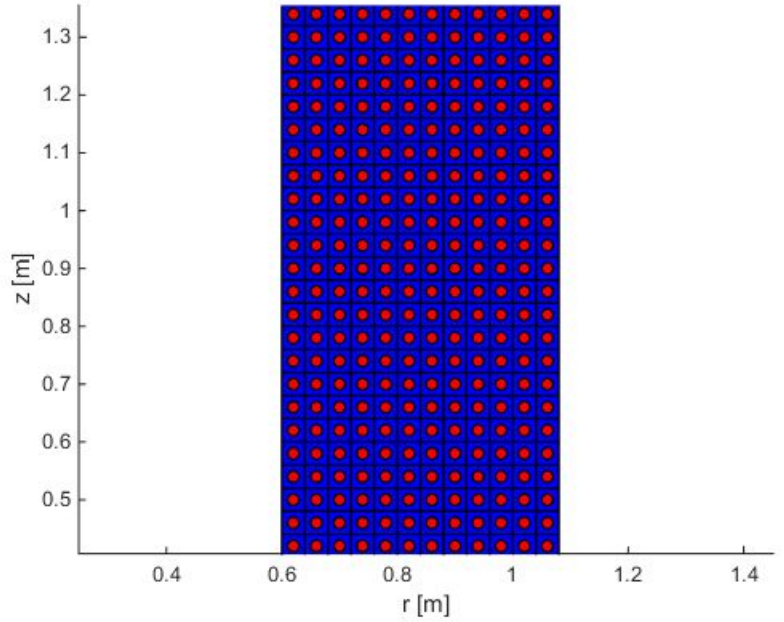
- ANSYS in the case of magnetostatic and linear problems implements a formulation based on the integration of the Biot Savart law *
- It uses a primitive (meshless) current carrying elements (SOURC36)
- Magnetic field can be computed either directly at specific locations or by a finite element mesh made of SOLID96 elements

*Biot-Savart Integration for Bars and Arcs, Miklos Gyimesi et al. IEEE TRANSACTIONS ON MAGNETICS, VOL. 29. NO. 6. NOVEMBER 1993

Numerical codes: Current-loop approximation

- Based on the well-known analytical solution of the magnetic field produced by a current-carrying ring with infinitely small cross section.
- The solution diverges at the source points (fine as long as we are not interested in the field inside the coil).
- Each coil is sub-divided in several loops in radial and vertical directions.

- Each loop is characterized by its radius, center position, direction cosines of axis, and current.
- Straightforward computation of net vertical forces if concentric non-tilted coils.



Numerical codes: Daniele

- The C++ code provides a numerical integration of the Biot Savart law.
- The code has been written ~1 year ago. It was a quick attempt to have a realistic magnetic field to set up simulation.
- Magnetic field can be computed either directly at specific locations or on a cartesian mesh.

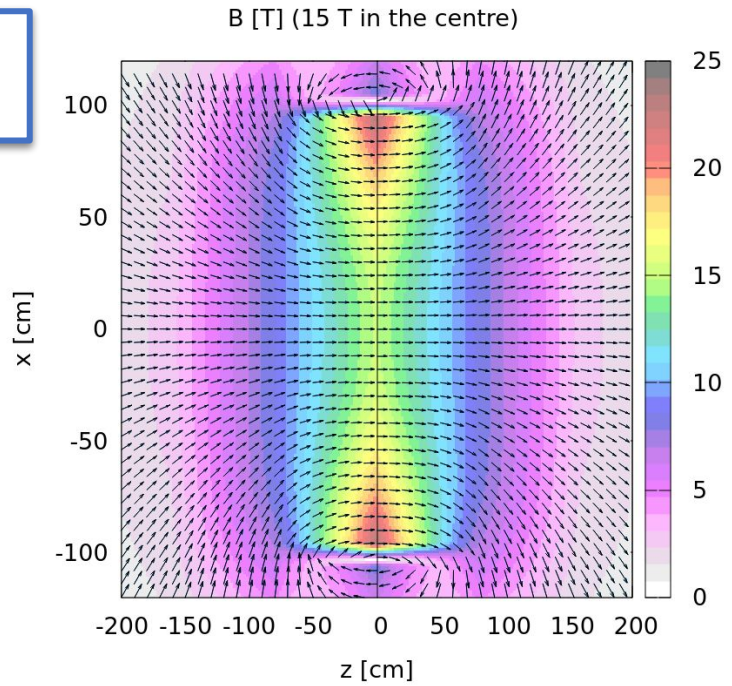
Evaluation of the magnetic field of a single coil

$$\zeta_\pm = z \pm \frac{l}{2},$$
$$h^2 = \frac{4R\rho}{(R+\rho)^2},$$
$$k^2 = \frac{4R\rho}{(R+\rho)^2+\zeta^2},$$

Requires the evaluation of elliptic integrals

$$B_\rho = \frac{\mu_0 I}{4\pi}\frac{2}{l}\sqrt{\frac{R}{\rho}}\left[\frac{k^2-2}{k}K(k^2)+\frac{2}{k}E(k^2)\right]_{\zeta_-}^{\zeta_+},$$

$$B_z = \frac{\mu_0 I}{4\pi}\frac{1}{l}\frac{1}{\sqrt{R\rho}}\left[\zeta k\left(K(k^2)+\frac{R-\rho}{R+\rho}\Pi(h^2,k^2)\right)\right]_{\zeta_-}^{\zeta_+}.$$

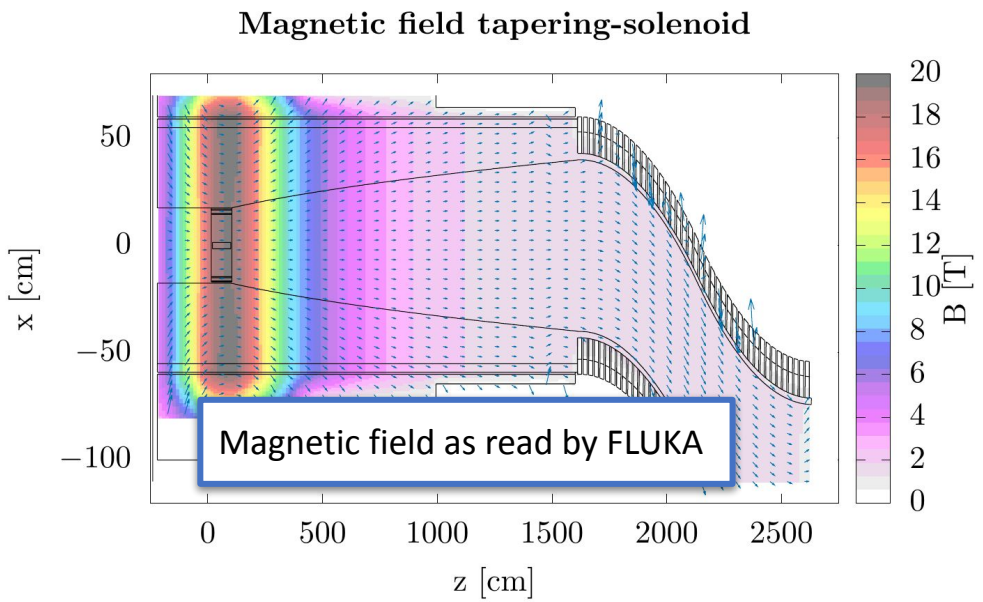


Results to FLUKA

- Magnetic fields can be implemented in FLUKA via dedicated user routines or magnetic cards.
- Using the magnetic cards is less error prone and (in general) the preferred approach.
- It is possible to have 3D cartesian meshes or 2D when dealing with cylindrical symmetry.

```
1031 MGNCREAT         100                                                    TAP
1032 MGNCREAT                                        20        40            &
1033 MGNCREAT         0.0      -200                  80      1700            &&
1034 *
1035 MGNDATA    4.276E-06 4.262E+00  -0.09739 4.261E+00   -0.1948 4.260E+00TAP
1036 MGNDATA      -0.2924 4.258E+00   -0.3901 4.256E+00   -0.4879 4.253E+00 &
1037 MGNDATA       -0.586 4.251E+00   -0.6844 4.24                          &
1038 MGNDATA      -0.8817 4.251E+00   -0.9803 4.25                          &
                                      ...
1299 MGNDATA    1.164E-01 1.260E-01 7.313E-02 6.                            &&
1300 MGNDATA    3.247E-02 5.155E-02 2.907E-02 5.418E-02 2.842E-02 5.380E-02 &&
1301 MGNDATA    2.863E-02 5.232E-02 2.902E-02 5.045E-02                     &&
1302 * STOP DATA SOLENOID TAPERING
1303 MGNFIELD           1                          VACINS     VACIN          TAP
1304 MGNFIELD           1                           COIL1    COIL18          TAP
1305 MGNFIELD           1                            Shld                    TAP
```

Actual snapshot from the FLUKA inputfile.

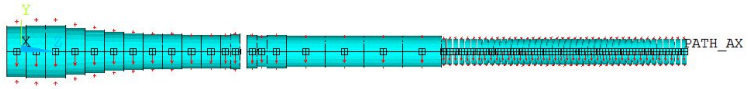


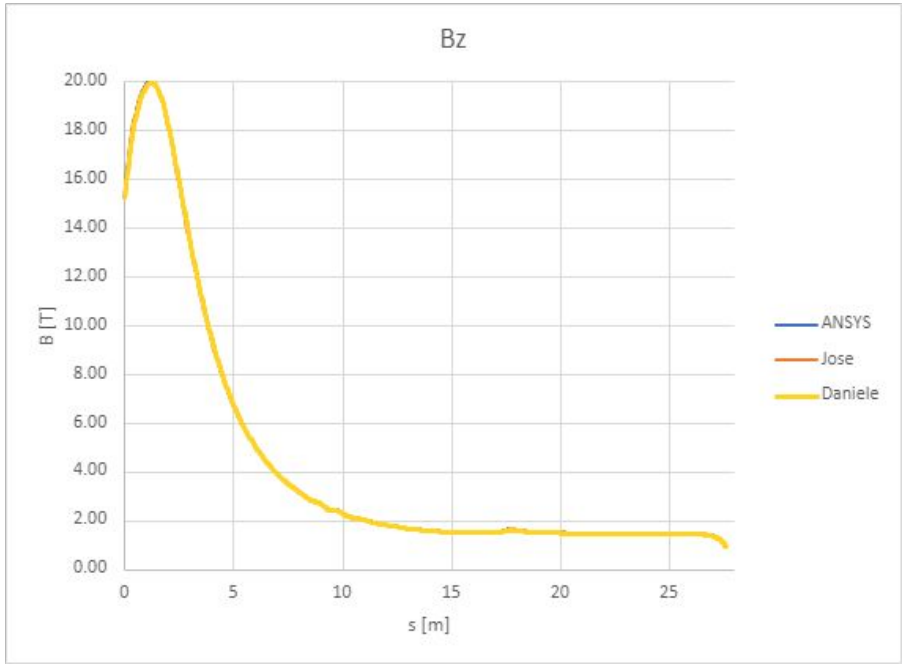
Magnetic field as read by FLUKA

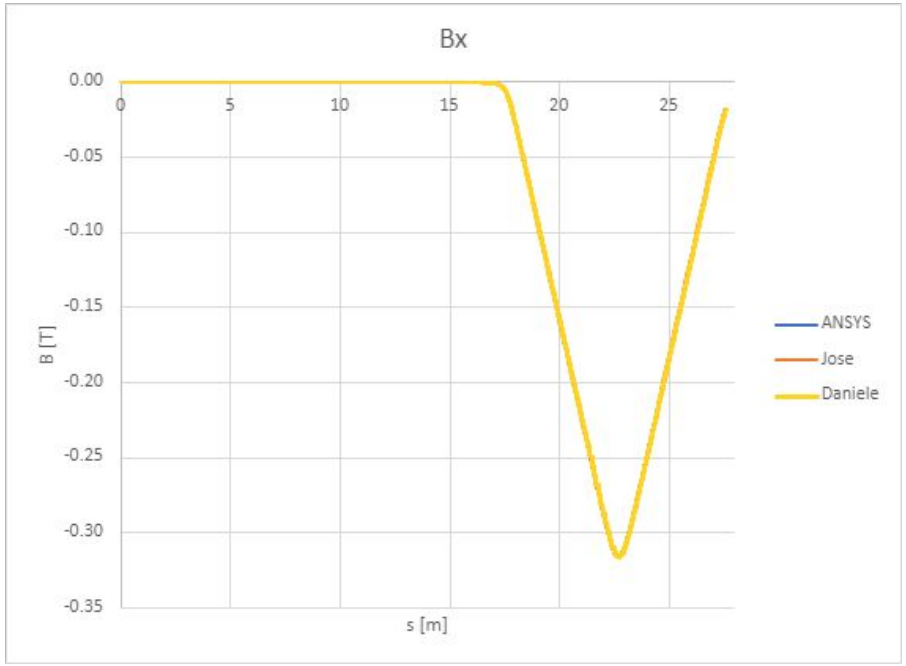
Sets of data

1. in axis points with tapering and chicane coils ON
2. in axis points with only chicane coils ON
3. off axis points in the tapering region with tapering and chicane coils ON
4. off axis points in the chicane region with tapering and chicane coils ON

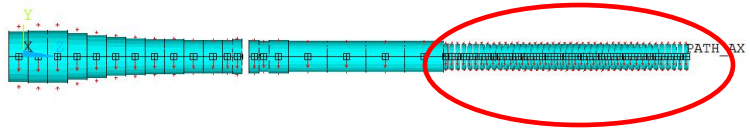
Results: in axis point with tapering and chicane coils ON

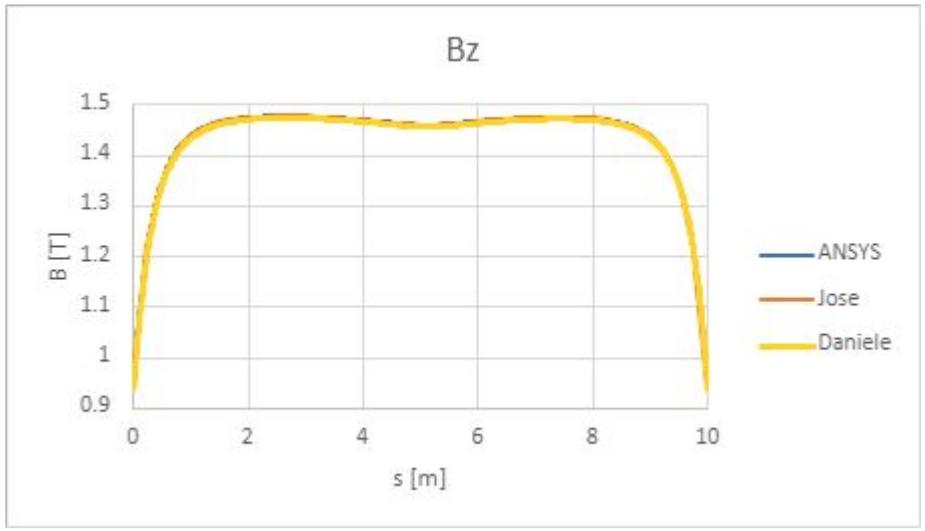


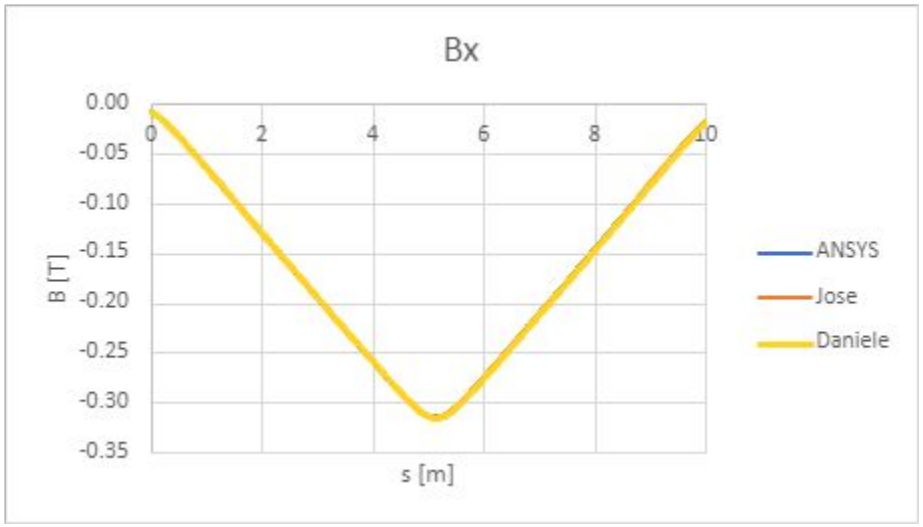




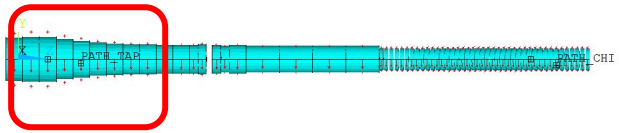
Results: in axis point with only chicane coils ON

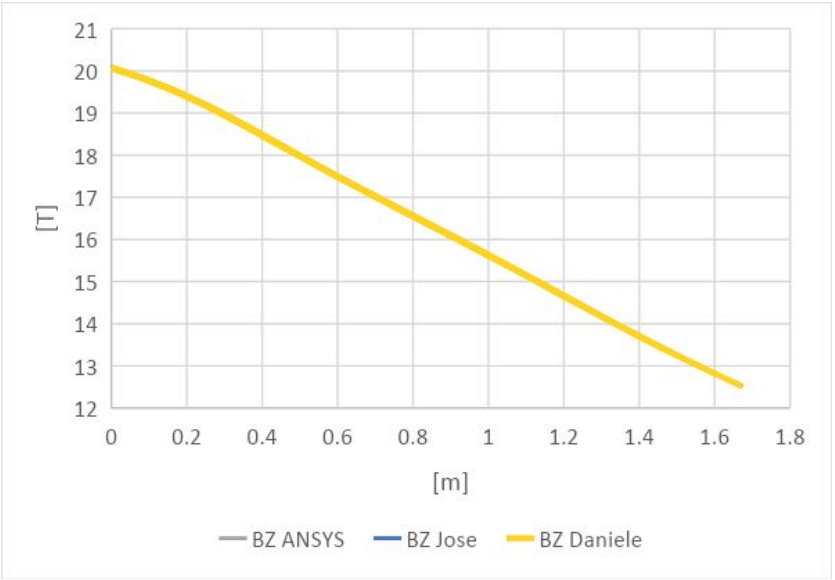


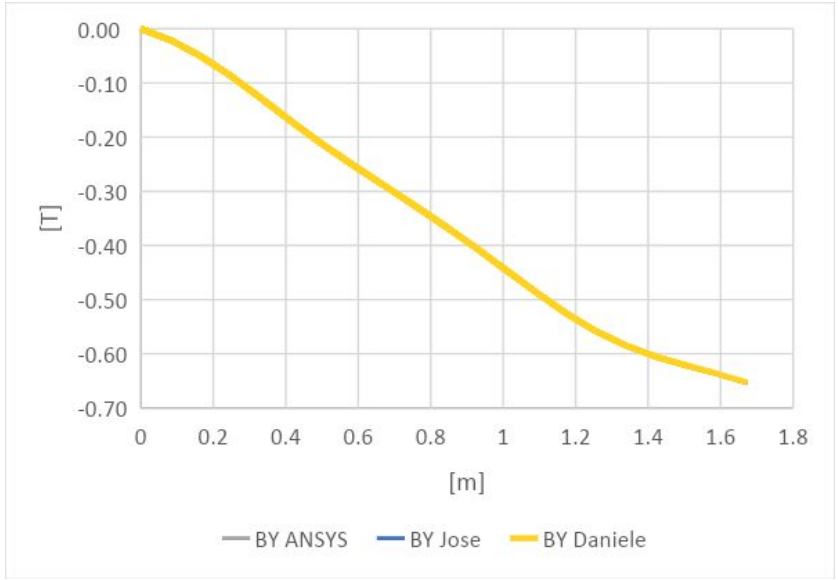


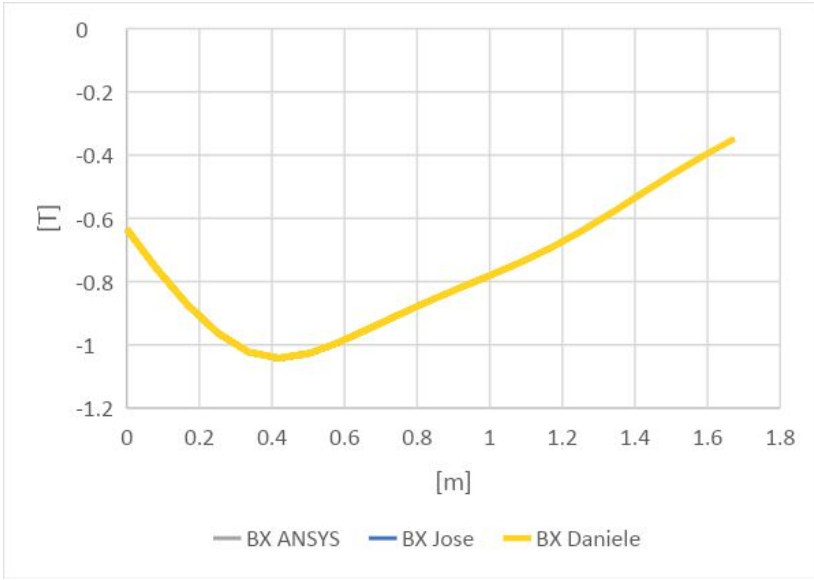


Results: off axis point in the tapering region

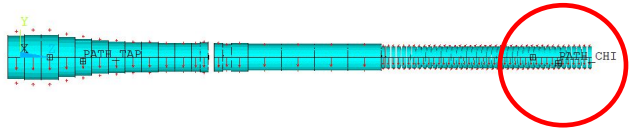


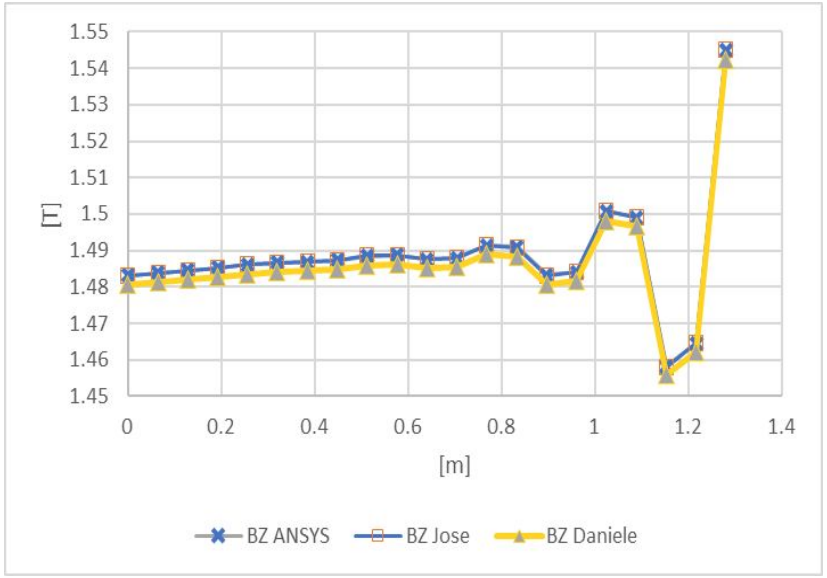


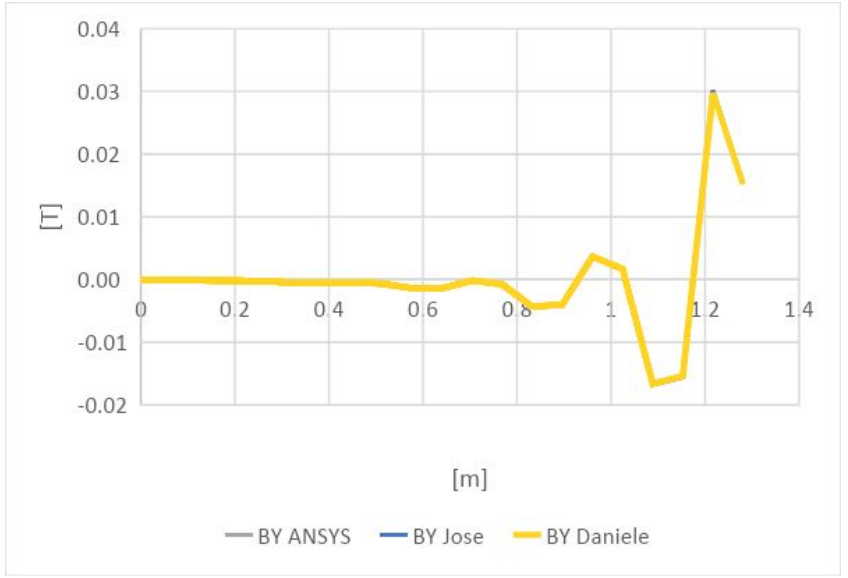


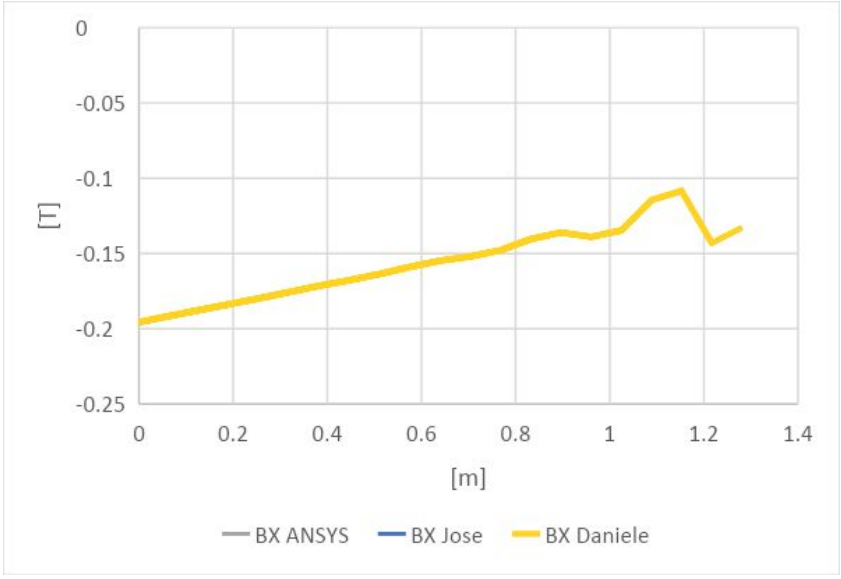


Results: off axis point in the chicane region









Conclusions

- A benchmark exercise has been implemented to validate three different numerical codes used for the design of the MUC
- The three components of the magnetic field have been compared along four different paths
- The benchmark outcome shows that the three codes provide results in a good agreement
- Lesson learnt: to have a satisfactory detail in the field definition, ~100 numerical slices in Daniele's code.
- Final remark: the current assumption of the tapering field follows the inverse cubic field from past MAP studies. Deviation from this function are fine as long as the magnetic field decrease is adiabatic.