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SIMULATIONS of OFF-MOMENTUM PARTICLE TRAJECTORIES along DAΦNE OPTICS

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Abstract

The principal aim of this work is the study of the off-momentum particles along the Daϕne Optics. We did the tracking of all those particles that are supposed to be generated in one of the two Interactions Points, as a result of the collisions between electrons and positrons that do not success to produce Φ particles. The majority of these particles are destined to die along the machine path, impinging on the vacuum chamber, generating secondary particle showers. In order to evaluate correctly the points along the line on which the off-momentum particles are lost and to estimate successively their contribution to the background around the Interaction Region of Daϕne, we used the BDSIM code. This code conjugates the capabilities of fast particle tracking in accelerators, as more standard optics codes do (MAD), with that of simulating, by means of Monte Carlo techniques, the interaction of the lost particles with matter. All the results of the analysis developed up to now are illustrated in this note. The results of this analysis are useful for defining the suitable locations along the Daϕne optics of the $\gamma\gamma$ tagger detectors, in the frame of the Kloe2 program for studying the $\gamma\gamma$ Physics at DaΦne.

1 The objective of the work: Tracking the Off-Momentum Particles along the Daϕne Collider

This work has been done in the frame of the Kloe2 project that wants to study the $\gamma\gamma$ physics at Daϕne. In order to properly allocate the detectors for the $\gamma\gamma$ tagger, we need to track accurately the off-energy particles[1] inside the machine. In particular the region of the DaΦne collider, in which we are interested for estimating the particle tracks, starts at the interaction Point (IP) and ends at the exit of the first bending dipole. In figure 1 we reported the mechanical layout of part of the transfer lines in which we are interested, while the detailed description of the position of all the magnetic components of these lines is shown in figure 2. Of the two lines shown in the cited figures, the lower one is the positron short line, that we used for the simulations. The quadrupole, sextupole and corrector dipole coefficients used in the calculations have been reported in table 1, for all the magnetic elements along the positron short line considered in our model.

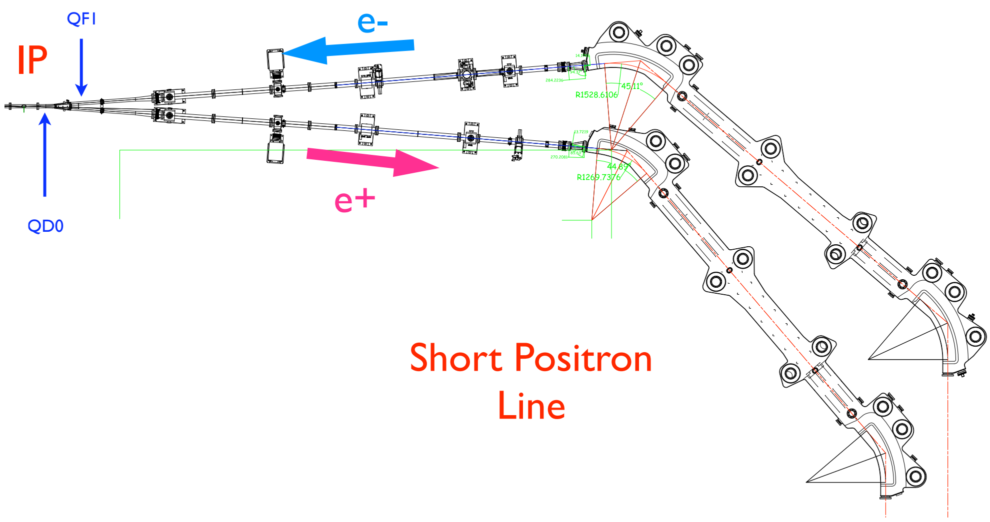


Figure 1: Mechanical Layout of DaΦne Main Rings: from IP up to Wigglers

1.1 Tracking calculations by BDSIM code

The MAD[1] code, similarly to many other optics codes, is strictly thought to study the optical properties of the nominal beam (that one for which the magnetic elements are set) and for this reason, a validation for off-energy transport is usually not required. The error

[1] Particles having energy lower than 510 MeV

ELEMENT	LENGTH	TYPE	k1 $[m^{-2}]$	k2 $[m^{-3}]$	angle on nominal [mrad]
QD0	0.23	quad (def)	-16.979	-	46
QF1	0.24	quad(foc)	+7.284		0
CHVPI101	0.155	kicker	-	-	hkick=0 vkick=0.
quaps101	0.3	quad (def)	-1.1432		
DCPS101 +MDHCPS101	0.328	kicker dipole	- -	- -	hkick=0 vkick=0 9.42478(0.54^o)
quaps102	0.3	quad (foc)	+2.51	-	-
quaps103	0.3	quad (def)	-1.6786	-	-
SXPPS101	0.1	sextupole	-	0	
QSKPS101 +CHVps101	0.2	Skew-quad	 -	- -	- -
dipole (BS)	0.9952	dipole	-	-	783.44(44.884^o)

Table 1: Magnetic Elements on Positron Short Line

in the tracks of off-momentum particles comes from the approximate methods used for transporting these particles trough the magnetic elements, that have been set for nominal design momentum. This error could become important as much as the particle energy is apart from the nominal one. In this frame, the necessity to have a tool that allows to calculate with the same reliability the nominal and the off-energy particle tracks and, at the same time, the need to use a code that allows to calculate directly the interaction of particles with matter have determined the choice of the BDSIM[2] code. Moreover, the BDSIM code has been structured in such a way to introduce in direct way the magnetic element coefficients derived from the MAD input model, thanks to the fact that the it uses the same parameters and same kind of information (in input syntax) of the MAD input for the description of the optics line. Last but not least, in the BDSIM code the particle tracks are calculated by solving the equations of motion, taking into account the Lorentz force in presence of magnetic field. This makes the BDSIM results a reference for the comparison of the MAD estimations for those cases in which the magnetic elements are in a solenoidal field[2]. A more detailed description of BDSIM structure and functionalities has been reported in the following subsection.

[2]In MAD code, normally these cases are treated by discretizing the magnetic elements in such a way to introduce the solenoidal field contribution as multipole elements (of 0 length) in between the real magnetic element parts.

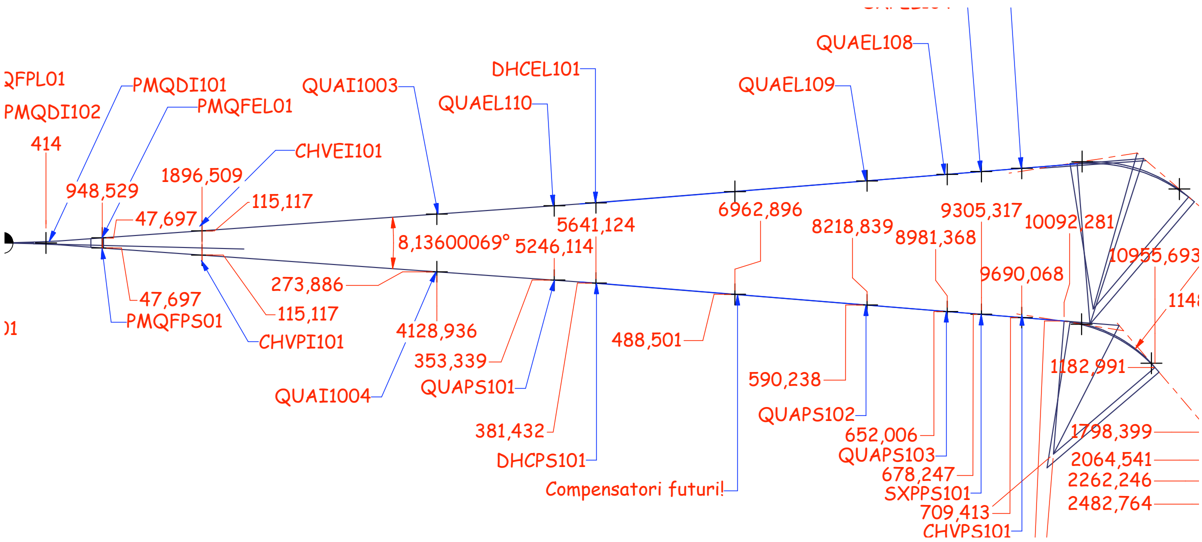


Figure 2: Magnetic Layout of half straight section of one interaction region of the DaΦne collider

1.1.1 Brief Description of BDSIM Code

BDSIM is a Geant4[3] extension toolkit for simulation of particle transport in accelerator beamlines. It allows to represent, in a flexible and fast way, typical accelerator components and calculate the tracking of the beam particles as well as the secondary showers produced by interaction of lost particles (with respect to the nominal centered beam) with matter. The principal advantage of using BDSIM consists essentially in the fact that it is a tracking code that combines fast accelerator-style tracking in the beam-pipe with traditional Geant-style tracking in materials. The main motivation that brought to the development of the BDSIM code was, in fact, the need of having a code for accelerators to study the background for the beam delivery system of the Compact Linear Collider (CLIC at cern) and later of the International Linear Collider (ILC).

While MAD calculates tracking by using map (matrices) transfer techniques, in BDSIM a new approach is adopted inside the beam-pipe: the track is calculated using an analytical solution of the equations of motion (that is the differential equations of motion are solved without Runge Kutta numerical algorithm). By using the analytical solution directly, a significant time saving is obtained over more usual Geant approach of solving locally for a step in a magnetic field. Once outside the beampipe, tracking defaults to the useful Geant approach where steps are calculated from local field (if present) using Runge Kutta techniques and material interactions are included in full.

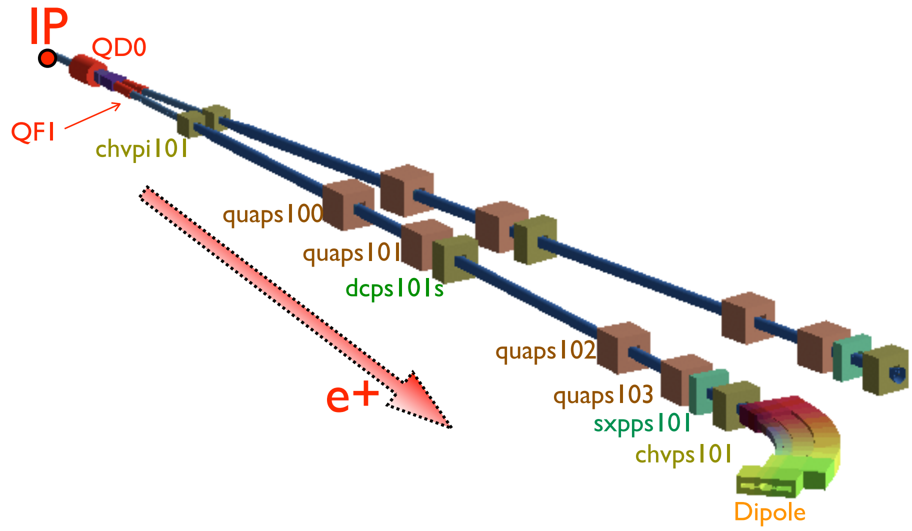


Figure 3: whole BDSIM model: from IP up to Dipole

2 Description of the BDSIM Model used for Tracking the Particles in the DaΦne Positron Line

Simulations have been done with BDSIM for tracking particles in the short positron line (PS) of DaΦne, from IP up to the outlet of the first bending dipole (see figure 3). In figure 4 the BDSIM model of half Daϕne straight section has been reported. In this figure two lines with a relative angle of about 8 degree are distinguishable: one for electrons and other one for positrons. These two lines are geometrically symmetric respect to the Global Z axis (the bisector of the angle between the two lines). Since we are not interested, for the moment, in the secondary showers [3] produced in the windings of the various magnetic elements around the beam-pipe, the description of these elements has been preserved only in the room that they occupy. This is the reason for which all quadrupoles, sextupoles and bending correctors are simply described as hole boxes.

On the contrary, the whole beam-pipe and the permanent quadrupoles (QD0 and QF1) have been accurately reproduced both from the point of view of geometry (geometrical shape and dimension) and material[4].The mechanical and magnetic parameters for QD0 and QF1[4] are summarized in the table 2.

The accuracy in the description of the geometry of the transfer lines is of funda-

[3]The secondary showers will be estimated in a second phase of the project for studying the background around the Daϕne interaction region

[4]Permanent quadrupole are made of SmC: physics and nuclear properties of this material have been defined and implemented in the code by the code developers, following our request .

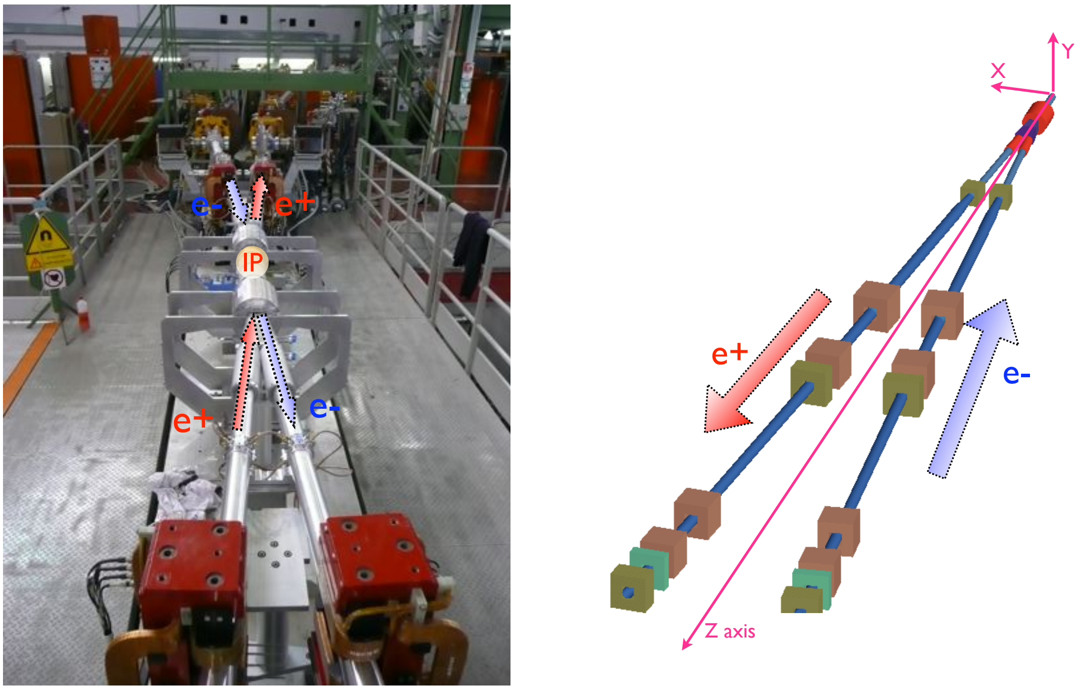
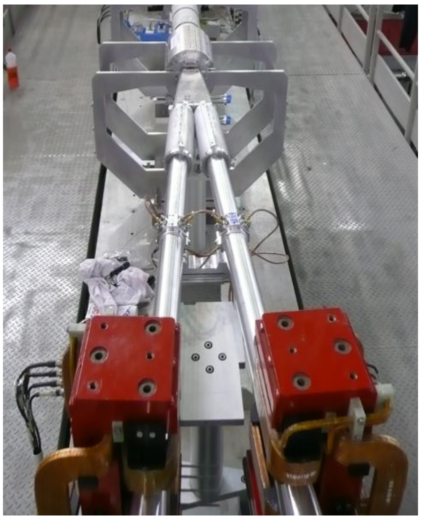


Figure 4: BDSIM Model of half of one straight section in DAΦNE collider

mental importance in order to evaluate with high precision the points in which the off-momentum particles are lost: in figure 6, the comparison between technical designes and BDSIM model of a part of the straight lines have been reported, as an example of the accuracy achieved in our model (see also figure 5).

In the IP of the DaΦne collider, since the last upgrade of 2008, the electron and positron bunches head on with an angle of 50 mrad. All those beam particles that don't success to produce ϕ particle and don't loose whole energy, continue in their path. The permanent quadrupole QD0 (the closer one to the iteration point) has the main goal to redirect the positrons and electrons in their own transfer lines. This means that the nominal particles enter the QD0 with an offset in the X direction and, being QD0 defocusing in the horizontal plane, it affects the trajectory in such a way to bend it. In particular the quadrupole coefficient has been designed to bring the nominal particle (510 MeV) exactly on the center line of the QF1, that is rotated of about 71 mrad (4 degree) respect to the QD0 axis (see a sketch in figure 7, where, on a front view of the splitter exit,in the BDSIM model, the positrons and electrons directions have been reported).

The model: technical details. The geometry of the line in the BDSIM model has been reproduced, choosing to use instead of the predefined elements, special geometry drivers: a set of C++ classes that implement accelerator components (so called 'SQL elements").



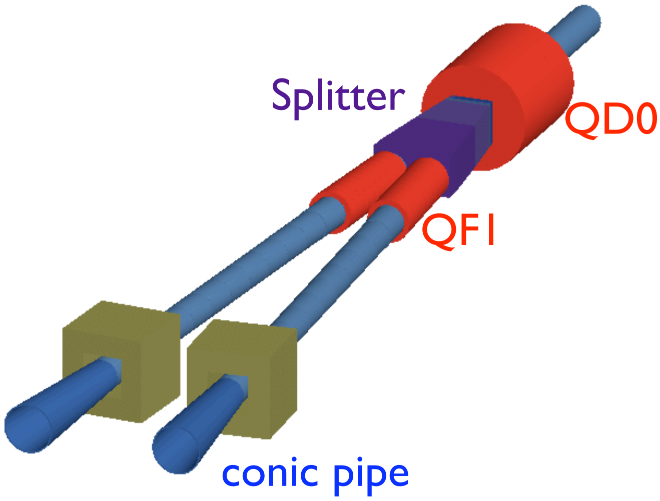


Figure 5: Zoom around splitter

This detailed representation requires to create files with “sql’ extension , that are called by the main program when the command “use,line” is executed. The calculation with BDSIM is managed by a gmad file (that is a text file with extension ‘gmad’) in which, with a syntax, that is pretty well similar to the one used for MAD input file, we can:

- Define the transfer-line (as a sequence of all elements)
- Describe the beam properties (several bunch formats are allowed for compatibility with other simulation code:guineapig-bunch,guineapig-slac, etc.).
- Activate the physics modules and various calculation options (like stoptrack to disable the radiation interaction with matter, when it is required, especially to save cpu time,ThresholdCut Charged,ThresholdCut Photons,SynchRadOn,etc).

In order to collect all the information we need for reconstructing the particle tracks, we used the “marker” element. This is a special element that has no effect on the beam but allows to identify a position in the beam line. This means that a sampler will be placed where the marker has been declared along the element sequence in order to collect all the informations we wish to have on the particle hits: energy, path length, time of flight, tarck-ID, parent-ID, etc. In particular, for our scope, we have collected the following values in ASCII output formats:

- PT: the kind of particle that impinges on the marker (-11 is the PDG code for positron)
- E[GeV] the energy of the particle

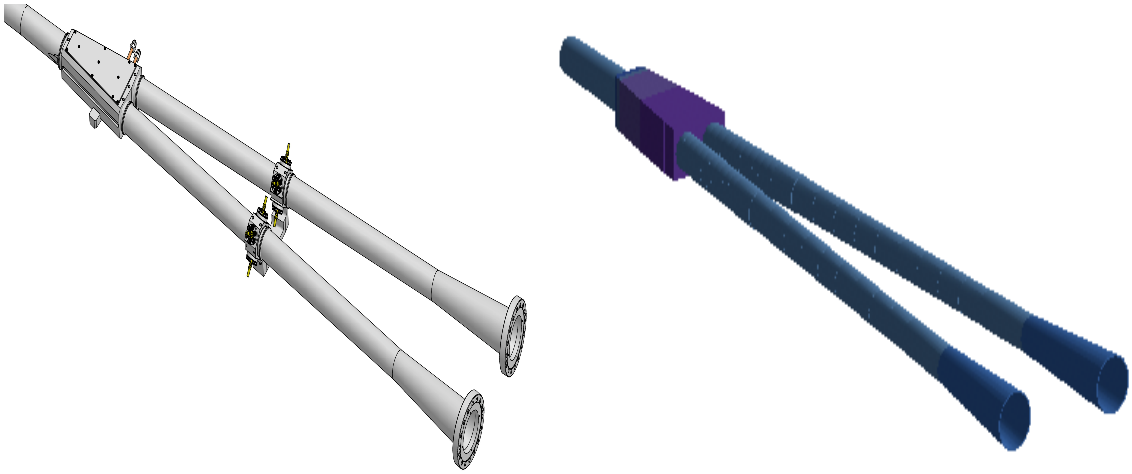


Figure 6: A detail of the beam pipe ending with conic profile. Cad on the left and BDSIM model on the right

- X[m] Global X position: absolute horizontal displacement
- Y[m] Global Y position: absolute vertical displacement
- Z[m] or S[m]: absolute Z axis or the longitudinal coordinate, respectively
- Xp[rad] Global angle in X-Z plane
- Yp[rad] Global angle in Y-Z plane

Along the line we did a very narrow discretization (by using vertical plane perpendicular to the absolute Z axis) in correspondence of all the magnetic elements, in order to be able to insert so many markers as we need to reconstruct as accurately as possible the curvature of the off-energy trajectories. On the contrary, it has not been necessary to discretize in fine way the drift elements in absence of magnetic field, the track being in this case a straight line. Figure 8 shows a 3D view of the discretization of the Daϕne straight section, in which the position of the plane markers is easily recognizable.

3 Analysis of the Simulation Results

The simulations done with Bdism have been developped trough the following steps:

1. Calculation of the nominal energy (510 MeV) particle trajectory (in terms of absolute reference coordinate system) for checking that this one matches exactly the central axis of the transfer line on the technical design.

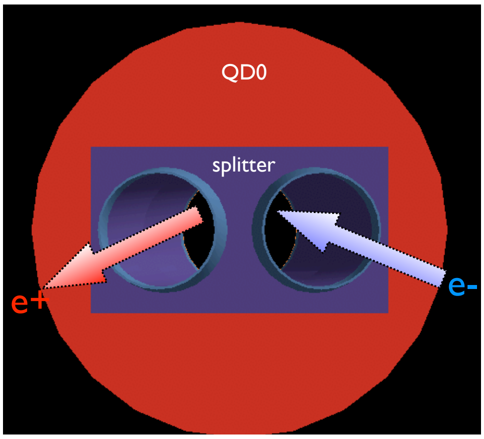


Figure 7: Front view of the splitter exit: a sketched representation of the electron and positron directions

2. Track of the off-momentum particles supposed to be produced at the IP with -25 mrad with respect to the absolute Z axis of the machine (that is in the same direction of the nominal 510 MeV particle)

3. Identification of the zone in which the off-momentum particles are lost, as dependent on the particle energy. In particular, this task has determined the following items:

   - Identification of the lower and higher energy particles that die in between QD0 and QF1 inside the Kloe detector (with and without solenoidal field). The results of these calculations define the Low Energy Tagger positioning (LET).
   - Identification of particles that are lost before entering in the bending dipole, defining the so called Middle Energy Tagger (MET zone: between magnetic elements quaps100 and sxxps101.)
   - Identification of the minimum energy of the off-momentum particles that can survive after the bending dipole . This defines the High Energy Tagger region (HET zone), in absence of the solenoidal field)[5].

4. Study of the modification of the off-momentum particle tracks in dependence of the starting angle at the IP.

[5]This work is still in progress.

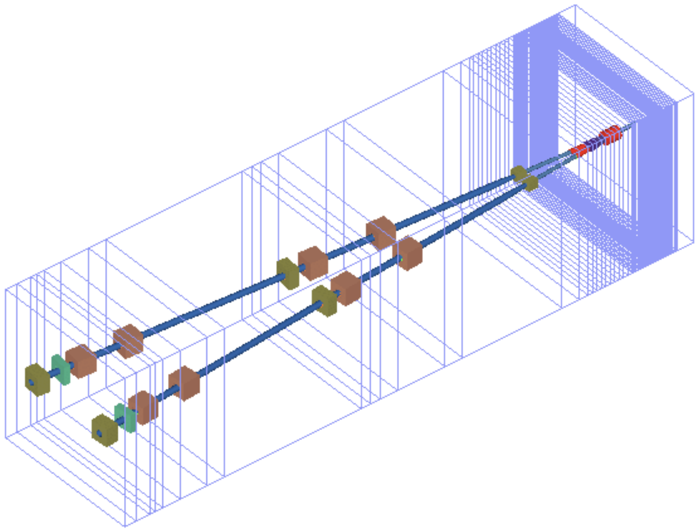


Figure 8: Bdsim Element Discretization Details

5. Analysis of the qualitative and quantitative effect of the solenoidal Kloe field on the particle tracks; at present time this effect has been studied only in the LET region.

For clarity, it seems opportune to point out that the definition of Low, Middle and High energy in the classification of the zones for the $\gamma\gamma$ detector allocation comes from the energy range of the impinging leptons (positrons or electrons). The complement to 510 MeV of the lepton energy, is the remaining energy of the photons that are produced by electron scattering in the IP, according the following reaction:

$$e^+e^- \to e^+e^- \gamma^*\gamma^* \to e^+e^- + X$$

where X is some arbitrary final state allowed by conservations laws. So that the attribute " Low", "Middle" and " High" refer essentially to the reaming energy of electrons or positrons after the collision.

Nominal track. As first part of our analys, we calculated the tracking of the nominal particle, a positron of 510 MeV energy, to check that it fits exactly with the QF1 line[6]. This preliminary check is needed in order to be confident that the transfer line has been correctly modelized (right value of the QD0 quadrupole coeffiient, k_{qd0}, and correctness in positiong the center of all the magnetic elements).

[6]We define the QF1 line the part of transfer line on which QF1 is mounted. This is rotated of about 4 degree respect to the absolute Z axis (coincident with the QD0 axis)

Parameters	QD	QF1
quantity	2	4
Minimum clear inner radius (mm)	33	30
Inner Radius (mm)	34	30.5
Maximum outer radius (mm)	100	45
Magnetic length (mm)	230	240
REM physical length (mm)	230	240
Maximum mechanical length (mm)	240	250
Nominal gradient (T/m)	29.2	12.6
Integrated gradient (T)	6.7	3.0
Good field region radius (mm)	20	20
Integrated field quality dB/B	5.00E-04	5.00E-04
Magnet material type	SmCo2:17	SmCo2:17
Magnet construction	2 halves	2 halves
REM stabilization temperature (C)	150	150

Table 2: Low β Permanent Magnet Quadrupole

The coordinate X, Y, Z respect to the Global reference system [7], calculated with BDSIM, have been reported on the technical design of the beam-pipe boundary: the nominal particle track results to be actually centered on the concerned transfer-line. This is shown, in figure 9, where the blue line in the middle of the beam-pipe is the nominal trajectory, in 3D view, while figure 10 shows the horizontal projection (on X-Z plane) of the nominal track, from IP up to 10 m along absolute Z axis,(this time, the nominal track is the red curve). The nominal track has been calculated connecting the hit points (black dots in the pictures) on the sampler markers.

Off-momentum tracks As a second step, we calculated the trajectories of all particles with energy from 5 MeV up to 510 MeV with a step advance of 5 MeV[8]. Initially, all this particles have been considered to be fired at the IP with the same angle of the nominal one (-25 mrad, with respect to the absolute Z axis). The results of the simulations have been summarized in the table 3, in which we reported the global Z coordinate along the beam transfer line on which particles of different energy impinge. Particles with energy lower than 260 MeV impinge on the internal side of the beam pipe (with reference to the central point of the whole DAΦNE machine, as shown in figure 11), on the contrary particles having energy in the range 260-325 MeV impinge on the external side of the bam-pipe

[7]Normally in the BDSIM standard output the coordinates are the longitudinal s and the local x and y. In order to have the absolute ones we modified the src file BDSOutput.cc and recompiled the Bdsim version

[8]Technically the fired beam particles are specified by a file in which the the beam definition is given according the $guinea - slac$ format: E[GeV] x[rad] y[rad] z[μm] x[nm] y[nm]

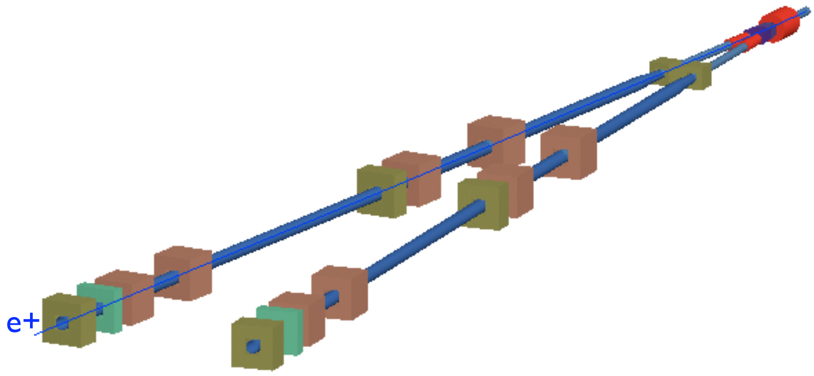


Figure 9: Nominal trajectory along the straight section in the BDSIM model of Daϕne Interaction Region: blu line in the middle of the upper line

Energy Range[GeV]	Distance fro IP[m]	description
0-0.150	0-0.529	from IP to end of QD0
0.155-0.22	0.529-0.786	inside the splitter (between QD0 and QF1)
0.225-0.255	0.786-0.8.36	inside QF1
0.260-325	from 3.4-7.6	between quaps100-quaps102

Table 3: Schematic identification of the zone where off-momentum paricles are lost along the line in absence of solenoidal field (in this table the results refer to particles of all energy but having at IP a global X-Z angle of -25 mrad)

(in the region between quaps100 and quaps102), as shown in figure 12. All particles with $E \geq 327MeV$ enter in the dipole (see figure 13), but only particles with $E \geq 430MeV$ exit the dipole, as it is shown in figure 23. This allows to identify respectively the Low, Middle and High Energy Tagger Zones in the Daϕne Machine, as represented in schematic way, in figure 15.

Finally, even if we do not report in this note the study of the interactions of lost particles with matter , for the sake of thoroughness, we reported in picture 16 an example of simulation[9] of interaction of 200 MeV positrons with matter: red line are secondary electrons and green lines are photons.

3.1 More detailed calculations of particle tracks in the LET zone

In figure 17, the Z positions of the hits on the beam pipe for all the off-momentum particles 1m around the IP (LET zone) have been reported as function of energy. In this calculation

[9]For the Monte Carlo simulations the em-standard module of Geant4 have been chosen, threshold-CutCharged = 0.0001 * MeV and thresholdCutPhotons = 0.0001 * MeV

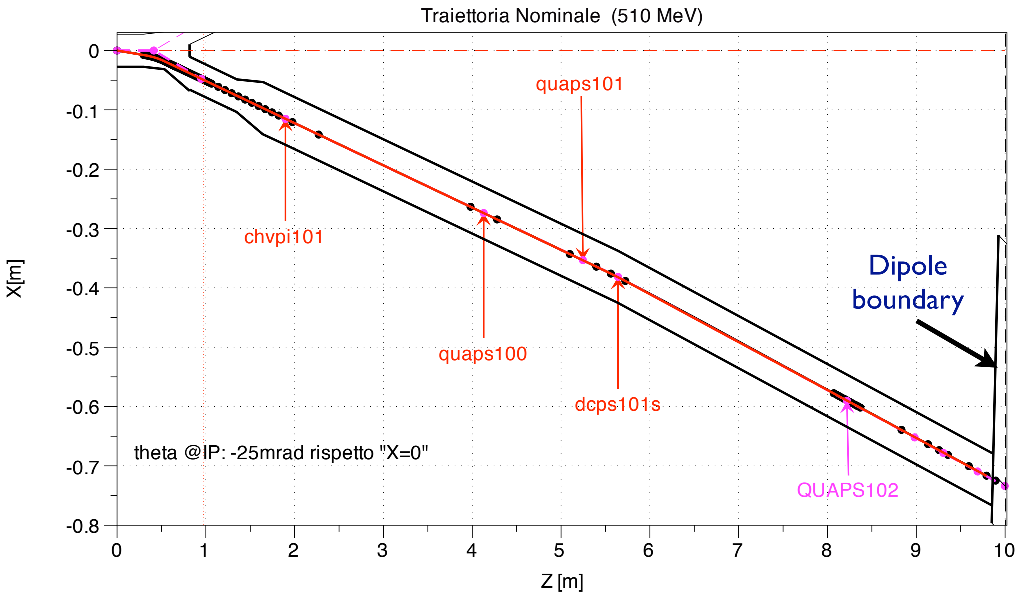


Figure 10: Projection in the horizontal plane of the nominal track. The red curve is the interpolation of the absolute X calculated by BDSIM for a 510 MeV particle, along the PS short line

we considered all particles starting to move from the IP in the same direction of the nominal track (-0.25 mrad wrt Z axis). The effect of the starting angle on the hits has to be taken into account in order to have a complete analysis. In figure 18 the same plot have been reproduced for all energies and several starting angles at the IP[10] from 0 to -60 mrad (this last value being determined by the geometrical acceptance, determinad by the solid angle identified by the lines joining the IP to the downward boundaries of QD0 inner pipe). Because this plot, at a first look, could be not easy to understand, we try to explain in which way it has to be read and used, taking into consideration, for example, the -20 mrad labeled curve. This curve says that all particles that start in the IP with -20 mrad and having energy lower than 0.02 GeV die before entering QD0 quadrupole. Instead, those having energy between 0.02 and 0.12 GeV die inside QD0. The particle of -20 mrad and energy between 0.12 and 0.18 GeV die in the splitter zone before entering in QF1. All those -20 mrad trajectories with energy between 0.18 and 0.195 GeV die in QF1. Finally, particles with -20 mrdad at the IP and $E \geq 0.195$GeV are bent by the QF1 in such a way to be transported far away the QF1 quadrupole. Summarizing, we can assert that, among

[10]In this preliminary studies the real beam energy and space distribution at the IP has not yet taken into account, but it is underway

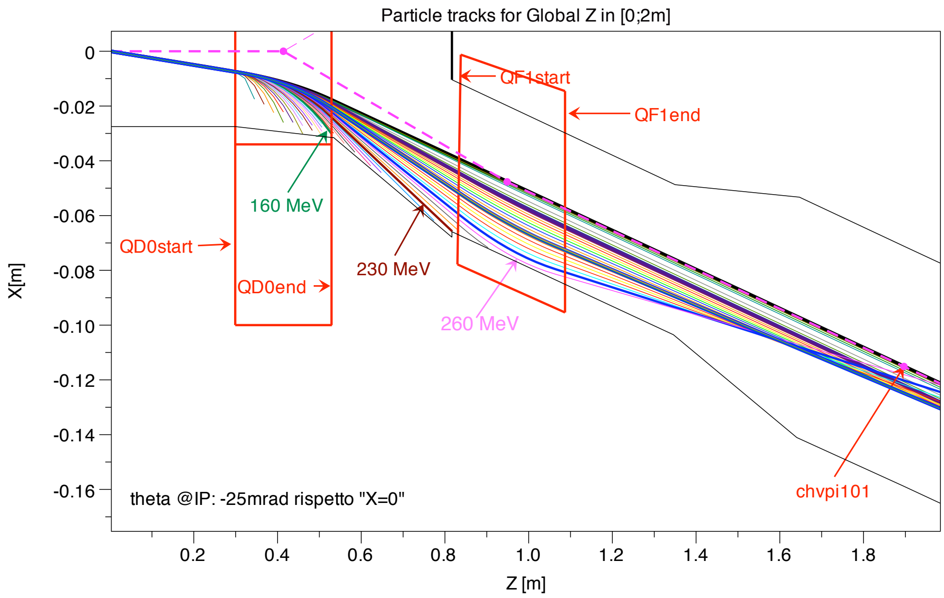


Figure 11: LET: particles with $E \leq 230 MeV$ die before entering QF1 quadrupole. Particles with $E \geq 260 MeV$ exit the QF1 quadrupole

all particles starting at IP with -20 mrad, only those having $E \leq 0.195$ GeV die in the LET zone, impinging on the beam-pipe, towards the center of the Daϕne collider.

On the same plot, the 0 mrad curve have been also reported just as a further check of goodness of the tracking calculations: no matter of whatever energy they have, all particles starting to travel with global angle equal to 0 mrad from IP always impinge on the middle of the splitter, where the two QF1 lines (for positrons and electrons) start to splitt. This is because the particles are not deflected by QD0 quadrupole, as a consequence of entering on its axis.

Furthermore, all particles starting to move from IP with global negative angle in X-Z plane greater in module than 45 mrad ever die before exiting QD0, whatever energy they have. So that we can assert that we couldn't never see along the QF1 lines particles that born in the IP with a negative angle that differs of more than -20 mrad, respect to the nominal trajectory.

To conclude this analysis, in figure 14 we reported the angle of incidence (in the horizontal plane X-Z) that particles have before impinging on the vacuum chamber. This angle is due to the effect of the bending action of the permanent quadrupoles.

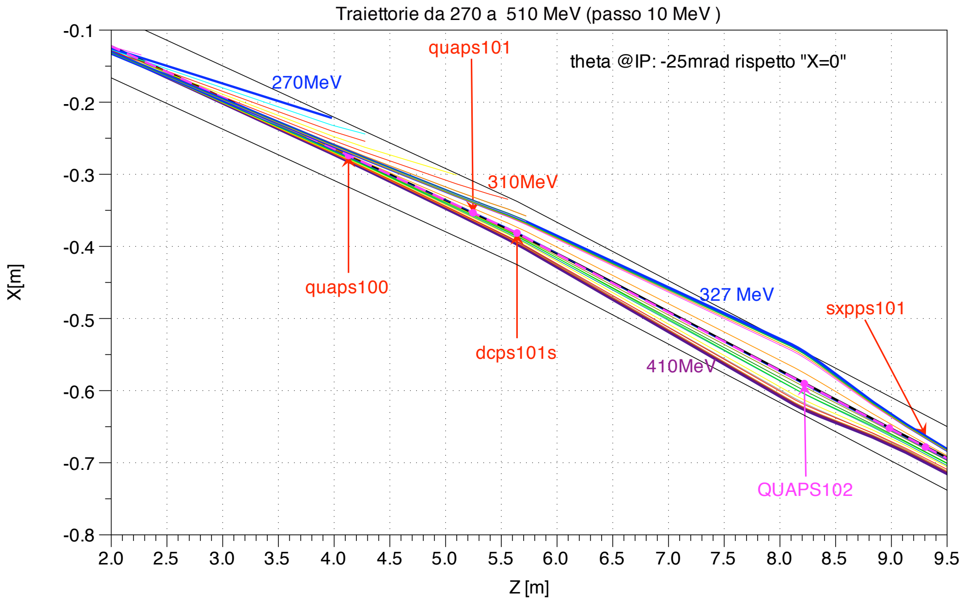


Figure 12: MET: Trajectories of particles with energy comprised between 270 and 510 MeV. Particles with E$\geq$ 327 MeV enter the dipole. Particles with $270MeV \leq E \leq 327MeV$ die on the external side of the pipe between quaps100 and quaps102

3.2 Tracks inside the Bending Dipole

The model of dipole in BDSIM has required a lot of work, both for the complexity of geometry of this component and both for the fact that BDSIM has been essentially thought to work for linear machine. The main difficulty in constructing the geometry in BDSIM comes from the positioning of markers inside the dipole (needed to collect the informations needed for reconstructing the off-momentum trajectories), due to the fact that the standard plane markers are foreseen to be perpendicular to the global Z axis, while the main geometrical axis of the vacuum chamber inside the dipole rotates along an arc length of about 40.5^o. The construction of the dipole model with BDSIM has required a preliminary work of schematization (by the Inventor cad) of the esecutive technical designs in order to reproducing in effective way the more important geometrical details, neglecting only those that could not affect the track results, as it could be verified by figure 19, 20, 21, showing respectively the technical and the schematization designs of the dipole.

It is worthwhile to point out that two main strategies have been followed to realize the dipole model: the first one managing the geometry by means the implemented options in BDSIM and the second one defining new marker elements inside the code creating a modified version of the code. These ways of proceeding are completely independent and

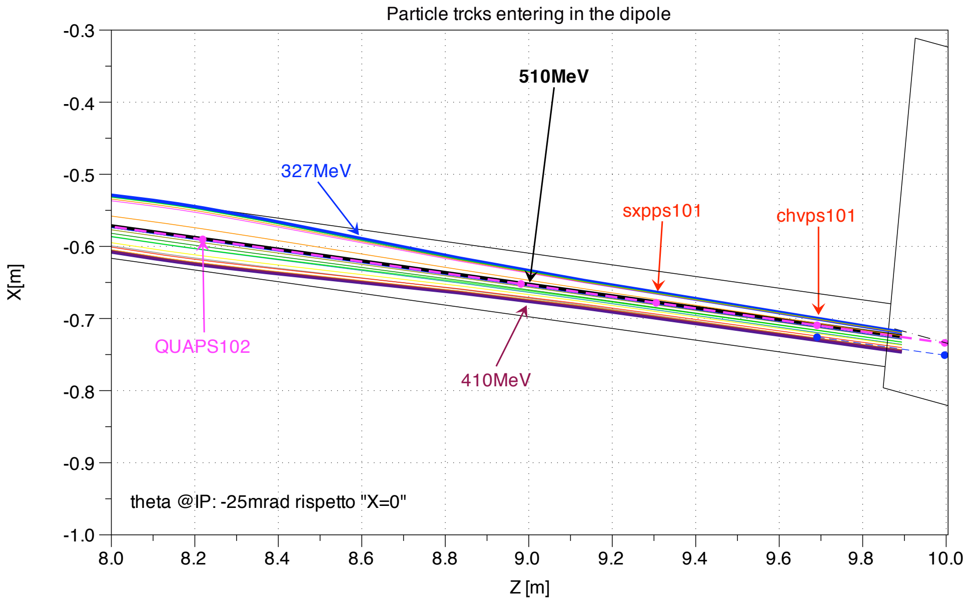
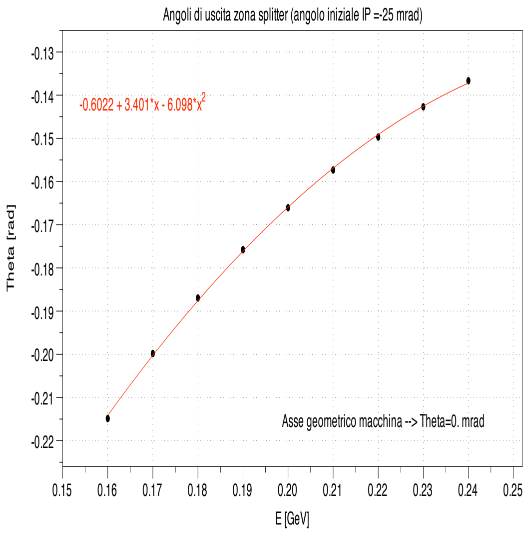


Figure 13: Particles arriving to the dipole inlet. All particles with $E \geq 327 MeV$ enter into the dipole

have produced two unrelated models of the dipole. The results from the two models are in perfect agreement and this successful comparison allowed us to validate the simulations. In figure 22, one of the two models has been shown.

The map of the magnetic field inside the dipole has been introduced defining the absolute vertical component equal to 1.33 T inside the vacuum chamber for an overall arc length of 40.5^o. This corresponds, essentially, to apply the bending field in the circular region of the vacuum chamber, that extends in between the two straight sections, that are, respectively, the inlet and at the outlet of the dipole (as shown in figures 20, 21). The applied field drives the nominal particle to describe a circle having a radius of curvature equal to 1.269 m (less than the geometrical radius of the dipole vacuum chamber equal to 1.4 m). This means that the center of curvature of the nominal track is displaced with respect to the center of curvature of the circular vacuum chamber of the bending dipole.

Simulation of particle tracking inside the bending dipole As result of the simulations we found that all particles with energy greater than 327 MeV up to 510 MeV enter the dipole, but among these only particles with $E \geq 430 MeV$ are able to arrive at the dipole exit, in correspondence of the flange where the HET should be placed (see figure 24 and 25). We estimated the distance from the nominal track of the other particle hits along the



angoli di uscita delle particelle che nascono nell'IP con -25mrad

Energia[MeV]	Theta [rad] (deg) rispetto X=0
160 MeV	-0.214877 (-12.31)
170 MeV	-0.199821 (-11.45)
180 MeV	-0.186962 (-10.71)
190 MeV	-0.175781 (-10.01)
200 MeV	-0.166065 (-9.51)
210 MeV	-0.157333 (-9.01)
220 MeV	-0.1497 (-8.57)
230 MeV	-0.142796 (-8.18)
240 MeV	-0.136671 (-7.83)

Figure 14: Angle of incidence respect to the global Z axis that the particles have when impinge on the transfer line in the LET zone (in absence of solenoidal field)

line on which the HET detector is foreseen to lay, as shown in figure 24. We found that it should exist a correlation between the energy and position for all particles impinging on the HET detector. This correlation is reported in figure 26. We have to stress that these results are referred to particles of all energies but that move from IP with a global reference angle of -25mrad.

4 Estimation of the Effect of the Kloe Field on the Trajectories in LET zone

The above discussed results have been obtained in absence of the solenoidal magnetic field of the Kloe detector. This detector is foreseen to work, during the collision runs, with a magnetic field of nominal central value equal to 0.52 T. The exact map of the magnetic field of Kloe reported in figure 27: in this plot the intensity of the magnetic field has been reported as function of the global Z coordinate, while in the transversal section of the beam-pipe the field is quite well uniform. The analysis of trajectory modification by the Kloe magnetic field has required to redefine the BDSIM model in such a way to introduce properly the magnetic global longitudinal component B_Z in all the elements inside the Kloe region (about 2 m from the IP). This has ben done with a new fine discretization also in the drift elements, in order to reproduce the exact trend of the magnetic field (fringe at the end) and to follow the curvature (both in the horizontal and vertical plane YZ) of the tracks. We expected that, due to the vertical component of the Lorenz force, the trajectories are no more planar but start to make a spiral moving also in vertical plane.

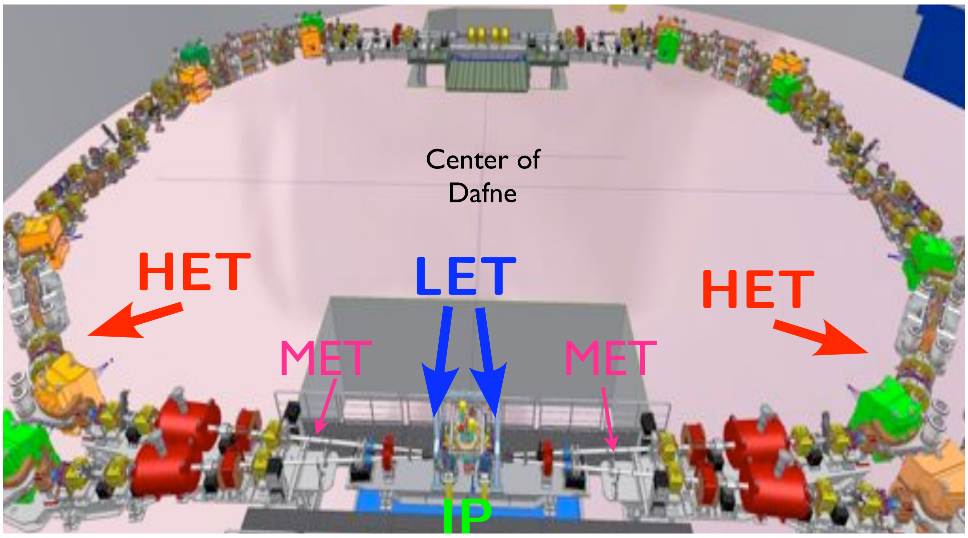


Figure 15: Identification of LET, MET and HET zones in the Daϕne Collider Layout.

Validation of BDSIM model with Kloe field. As starting point of the analysis, a validation of the modified BDSIM model has been necessary and it has been successfully performed, comparing the track of the nominal 510 MeV positron with the corresponding one estimated by the MAD code. This comparison (shown in figure 28) has been done, for the moment, in the region from the IP up to the QF1 outlet. This is because a compensator (permanent dipole), that should be placed just after QF1, has been designed to take again the nominal track on the beam axis, but the insertion of this element in the BDSIM model is not yet completed[11]. As we can see in figure 28, the nominal tracks calculated by BDSIM code and by MAD code agree perfectly. This makes us confident in having properly inserted the solenoidal field in BDSIM. In figure 29, a 3-dimensional view of the 510 MeV trajectory, inside a 1m range from the Kloe IP, is reported together with its projections on the three cartesian planes. The maximum displacement at the end of QF1 is about 2.5 mm in the vertical direction, while the displacement in the horizontal one is essentially the same we found without solenoidal field.

Calculation of off-momentum particle tracks with Kloe field. We estimated how much the trajectories in the LET region could be affected by the Kloe solenoidal field (0.52 T), comparing them to the ones estimated in absence of Kloe field. The figures 31,32 report the results of tracking calculations for particles, having energy from 5 MeV

[11] Afetr to have inserted the compensators the update of all the magnetic coefficients for the elements in the downward line has to be done, extracting the final tuned paramaters from the Mad input

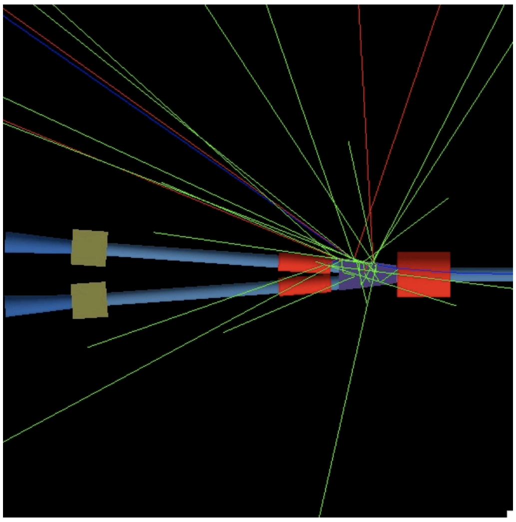


Figure 16: Secondary shower produced by 200 MeV positron impinging on splitter

Enegy	**Impact Z [m] without Kloe Field**	**Impact Z [m] with Kloe Field**	**Δ [cm]**
160 MeV	0.532297	0.537893	0.5596
180 MeV	0.563	0.575	1.1722
200 MeV	0.61918	0.636547	1.7354
220 MeV	0.788837	0.79726	0.8423
240 MeV	0.856076	0.827335	0.6719

Table 4: Effect of Kloe field on several off-momentum track projections on the horizontal plane, sin the zone 1m around the IP (LET region)

up to 510 MeV by step of 5 MeV, in presence of the Kloe field in the LET zone. As we can see the particles move also in the vertical plane (global Y-Z) and a maximum vertical displacement of about 17 mm is reached at a distance of about 1m from the IP from those particles that start to move from IP with energy equal to 270 MeV.

In figure 33 the maximum Y displacement , 1 m apart from IP, is reported as function of the particle energy for $E \geq 10$MeV. In spite, all particles with very low energy ($E \leq 10$ MeV) inverte their motion because of twisting effect due to the solenoidal field. For this reason, they collide on the beam-pipe below the horizontal plane.

Finally, the effect of the solenoidal field on the projection of the tracks in the horizontal plane (XZ) is to increase little bit the global absolute Z coordinate where the particles are lost: in other words off-momentum particles collide little bit later and displaced in vertical plane. The modifications of the impact points due to the Kloe field are

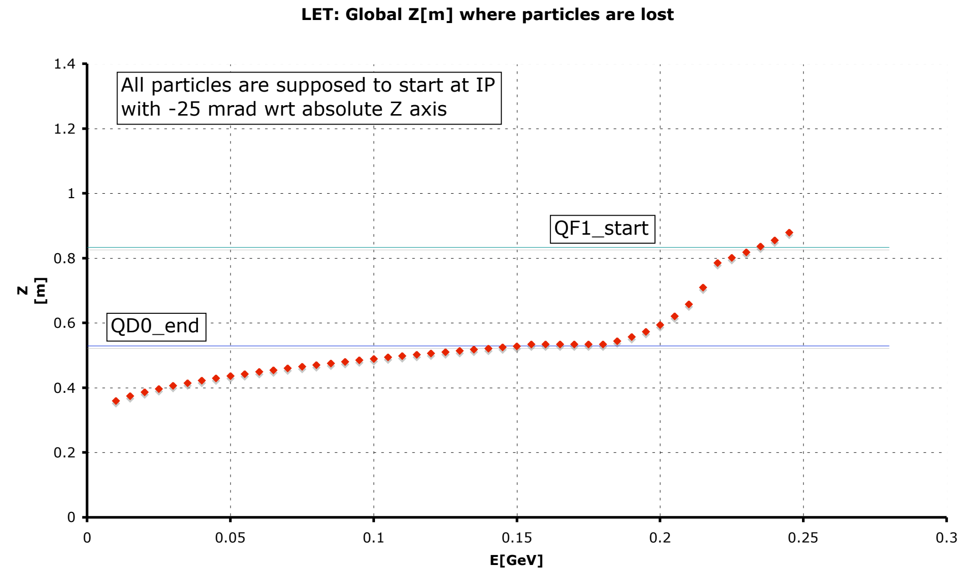


Figure 17: Z on which particles hit the beam pipe versus Energy in the LET zone (up to 1.5 m from the Daϕne collider Interaction Point)

summarized for several off-momentum particles in table 4.

5 Conclusion

The results of this study clearly show that, taking into account the constraints coming from the structure of Daϕne , three different tagging detectors can be placed :

- A detector for final leptons with low energy (LET) located in the region between the machine quadrupoles QD0 and QF1s. According to the tracking, the energy of the scattered leptons arriving on this detector is in the interval (160 230) MeV. Let us note that this detector will be completely inside KLOE and, thus, immersed in a 5 kG solenoidal magnetic field.
- A detector for final leptons with intermediate energy (MET) extending from 2 m up to about 8 m from the IP , i.e. outside KLOE. In this configuration this detector should tag the scattered leptons with energy between 270 MeV and 325 MeV.
- A detector for final leptons with high energy (HET) located at the exit of the first bending magnet of the machine (about 11 m from the IP). The energy of the scattered particles arriving up this point are comprised between 430 and 490 MeV (the

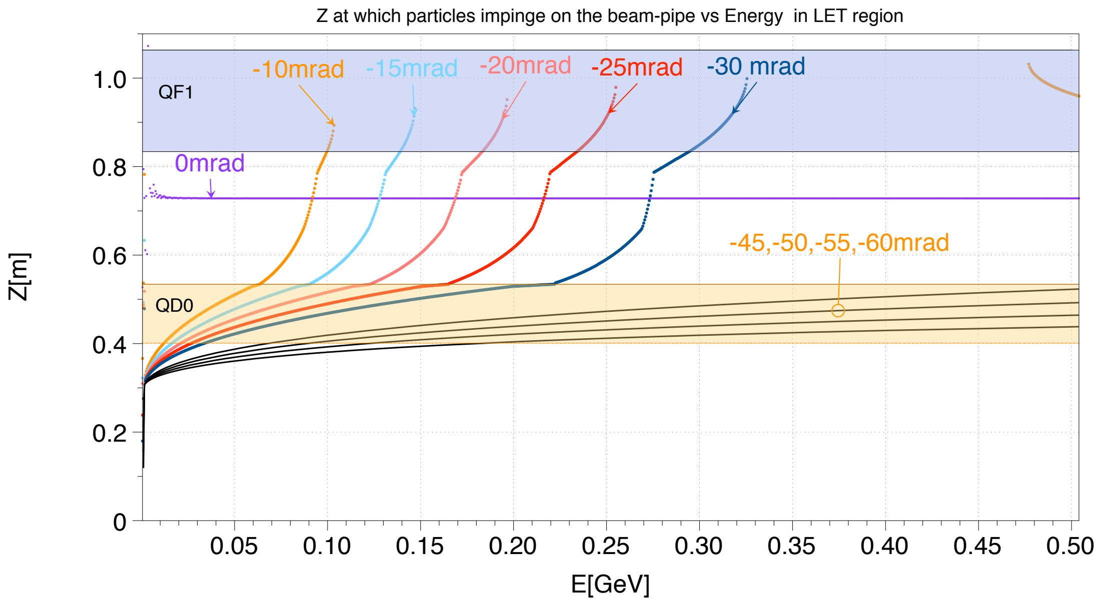
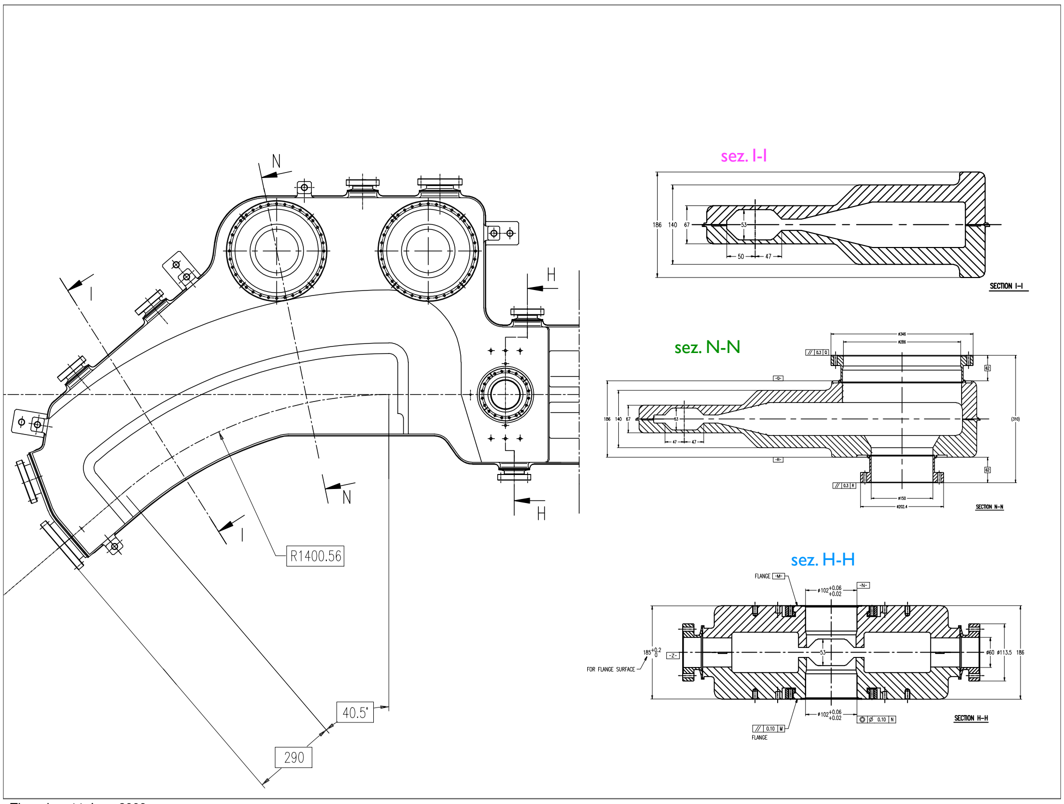


Figure 18: LET zone: Global Z on which particles hit the beam pipe as function of energy and parametrized in the value of starting angle at IP.

upper limit of this interval is determined by the fact that the proper operation of Daϕne requires that nothing can be at a distance less than 3 cm from the main orbit).

6 Acknowledgment

We would like to express mainly our gratitude to Dr. C.Milardi for the fundamental collaboration she offered to us, allowing to be constantly updated about the optics changements in the Daϕne optics. A special thank to A. Piazza for having supplied his fundamental technical support, redesigning the dipole model that has been inserted in BDSIM code, by means of Inventor Software. His precious work has been done in addition to his main fellowship activities. Finally, we want to thank Dr. Theo Demma for the useful conversations we had with him.



Thursday, 11 June 2009

Figure 19: Cad technical dipole designs

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[2] I. Algapov et al.“*The BDSIM Toolkit*”,EUROTeV-Report-2006-014-1.

[3] S. Agostinelli,“ *Geant4 a simulation toolkit* Nuclear Instruments and Methods in Physics Research Section A: Volume 506, Issue 3, 1 July 2003, Pages 250-303

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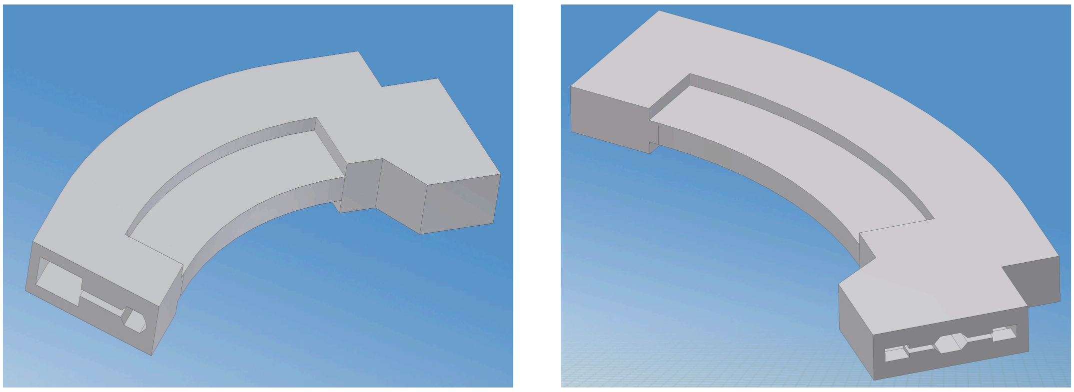


Figure 20: 3D back and front view of the dipole schematization used to construct the dipole model in BDSIM

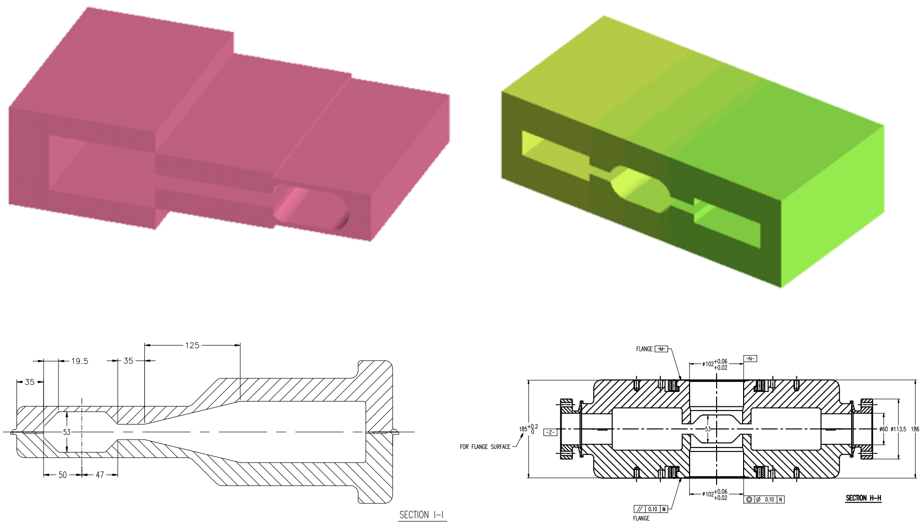


Figure 21: BDSIM cross section models of inlet and outlet dipole straight cross sections

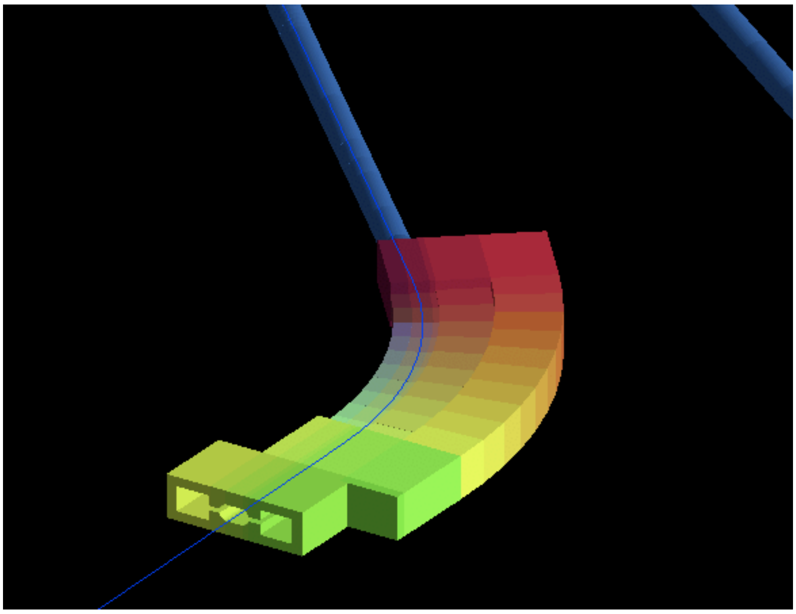


Figure 22: BDSIM Model of the dipole at the end of the straight section. The blu line is the nominal track

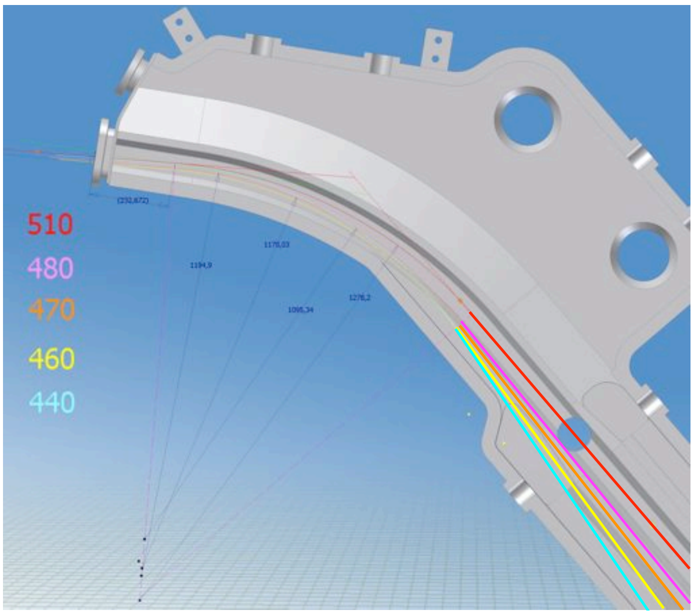


Figure 23: Off-momentum particles surviving after the dipole ($E \geq 430MeV$)

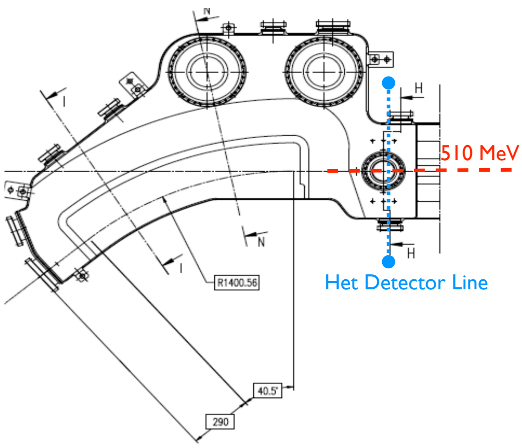


Figure 24: Identification of position of the HET detector at one of the exit flanges of the first bending dipole after the IP

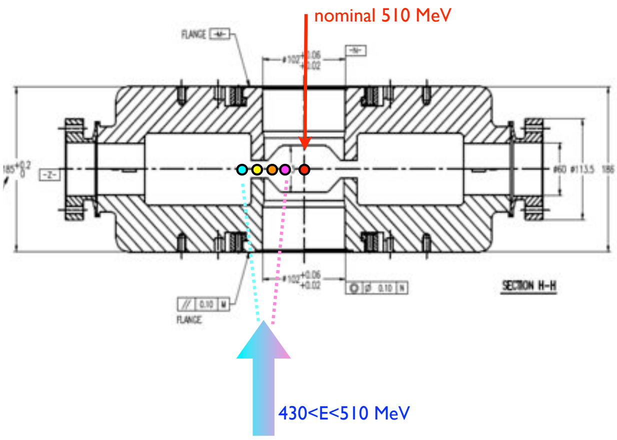


Figure 25: Transversal cross section of the dipole zone where the HET detector should be inserted. The colored circles are a sketch of the hit of the off-energy particles;

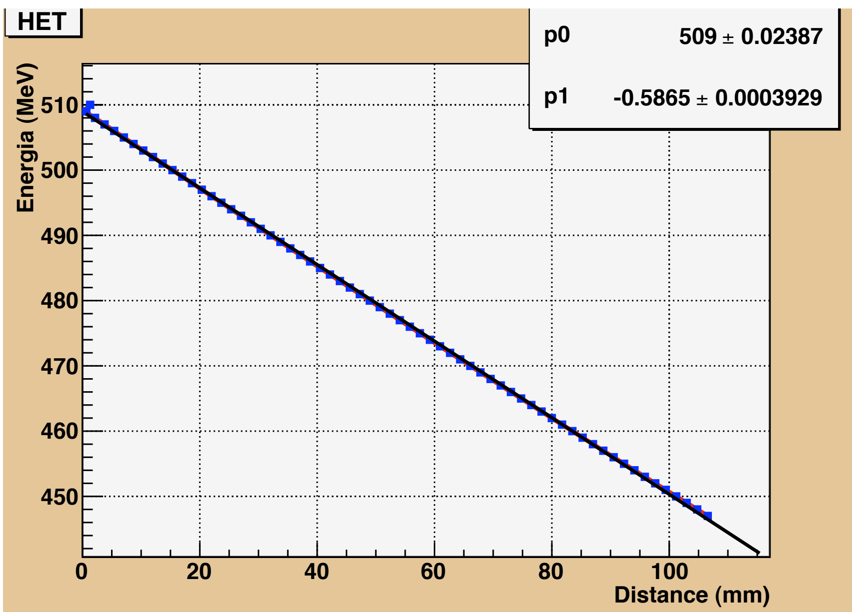


Figure 26: Correlation between Energy and Position of the impact points of the particles on the HET detector. The distance in mm is taken from the nominal 510 MeV hit along the HET line detector.

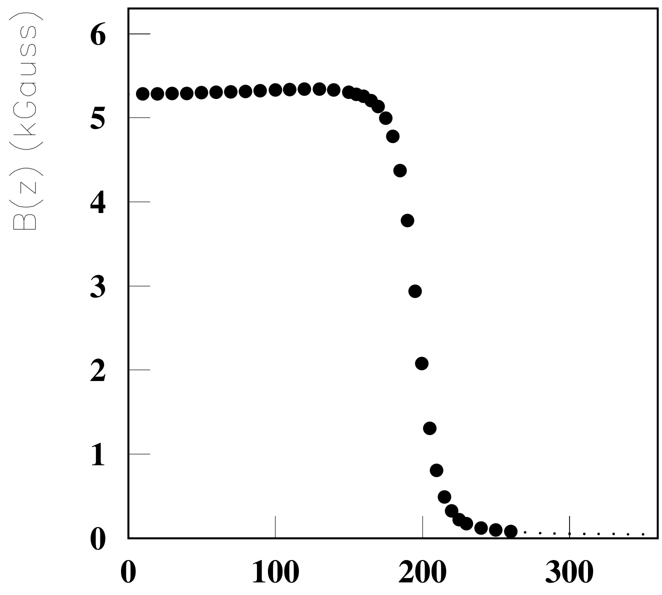


Figure 27: Magnetic field of Kloe

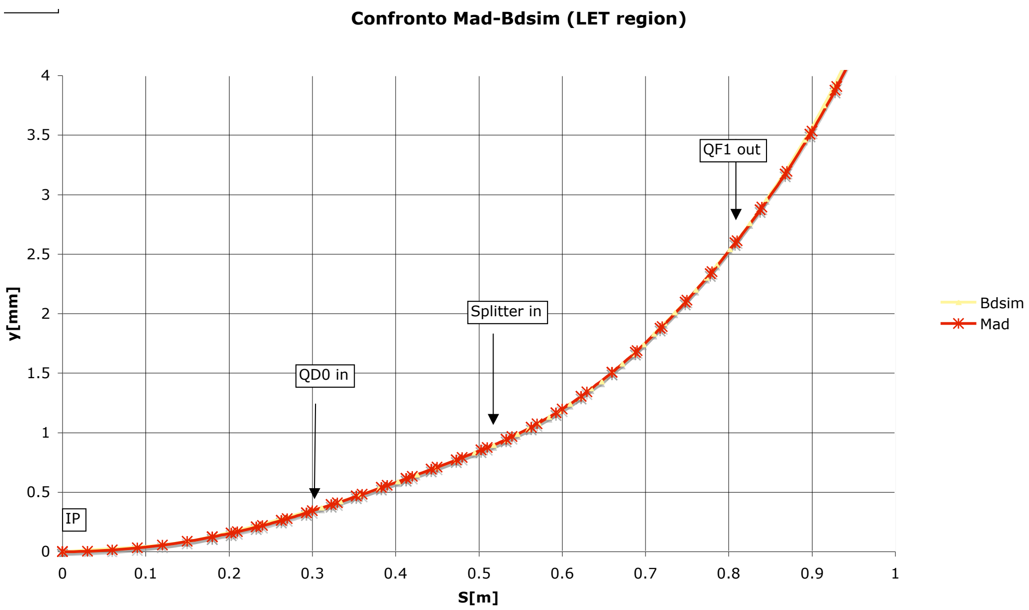


Figure 28: Comparison between MAD and BDSIM. Vertical displacement of the nominal trajectory (510 MeV) due to KLOE field

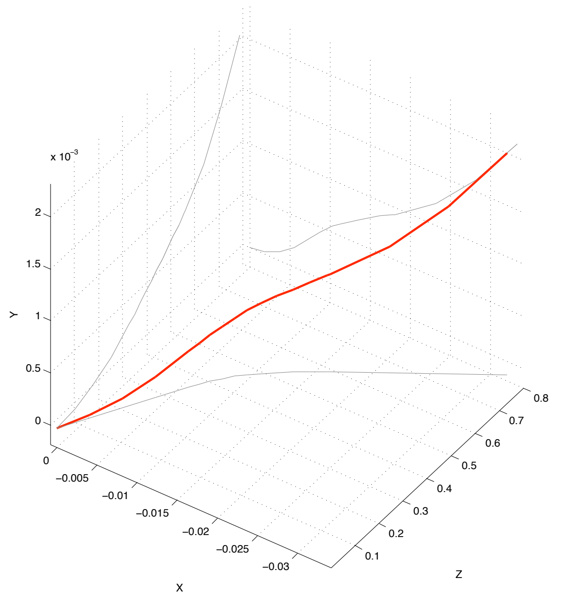


Figure 29: 3D view of nominal trajectory before entering QF1 quadrupole in presence of the solenoidal KLOE field

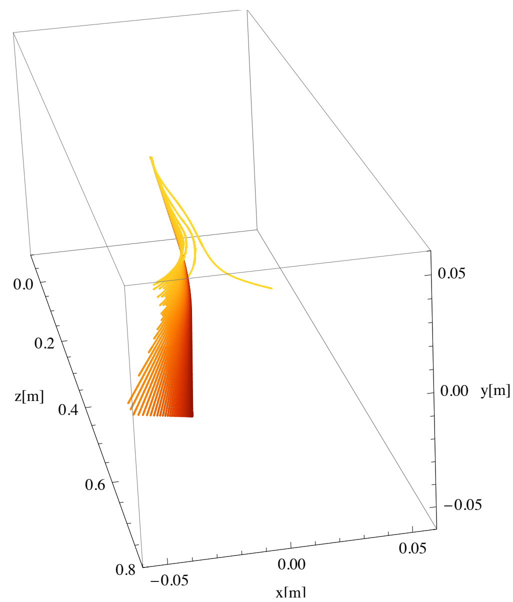
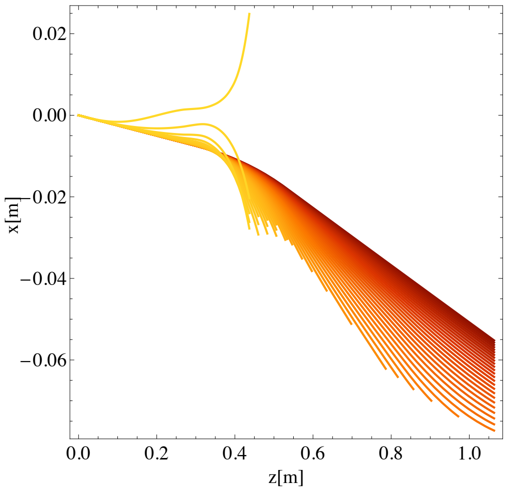


Figure 30: 3D-Plot of all particle trajectories from 5MeV a 510 MeV by step of 10 MeV



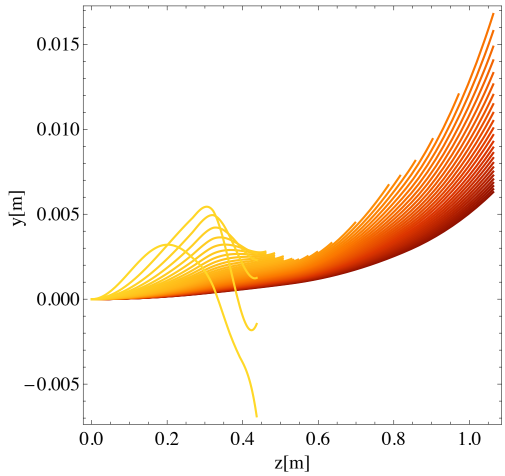


Figure 31: Projections on the X-Z plane of all the particle trajectories in presence of the solenoidal Kloe field. The color scale goes from 5 MeV (yellow) to 510 MeV (red curve) by 10 MeV step

Figure 32: Projections on the Y-Z plane of all the particle trajectories in presence of the solenoidal Kloe field. The color scale goes from 5 MeV (yellow) to 510 MeV (red curve) by 10 MeV step

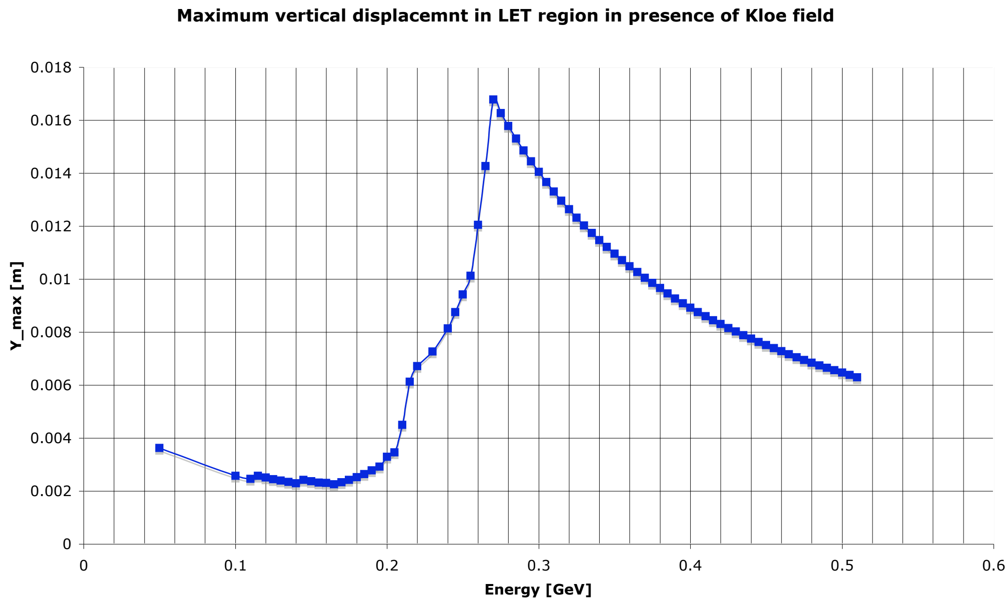


Figure 33: Maximum vertical displacement of tracks, as a function of particle energy, in the LET region due to the Kloe solenoidal field