Summer Student Project Report

First steps towards geometry optimization for Spectrometer Straw Tracker of SHiP detector

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Annotation. This report contains details of CERN Summer Student project which was performed for SHiP experiment (Search for Hidden Particles). The main aim of the project is optimization of Spectrometer Straw Tracker (SST) geometry implemented in FairSHiP simulation program.

Short description of the future SHiP experiment. SHiP (Search for Hidden Particles) is a future experiment aiming to explore a GeV-mass region of hidden particle sector [1]. There are a number of observations which are not explained within SM, one of them is the dark matter observation. There are also a number of SM extensions proposing good candidates for dark matter particles, some of them predict existence of Heavy Neutral Leptons (HNL). HNL extends the SM by three right-handed neutral leptons, N_i , where i = (1, 2, 3). The SHiP experiment is proposed to use SPS proton beam to produce HNLs with GeV-scale masses. The theories predicting HNL in this mass range allow to solve major SM problems, however this mass region is not explored yet [1].

One of promising theoretical models with HNLs in GeV-scale is νMSM - Neutrino Minimal Standard Model [2,3]. In the νMSM the HNL and SM neutrino mixing gives rise to HNL $N_{2,3}$ production in weak decays of heavy mesons. The same mixing gives rise to the decay of the HNLs to SM particles. Examples of HNL production in D and D_s decays are shown in fig. 1 (a,b), along with examples of $N_{2,3}$(c,d) decays [4].

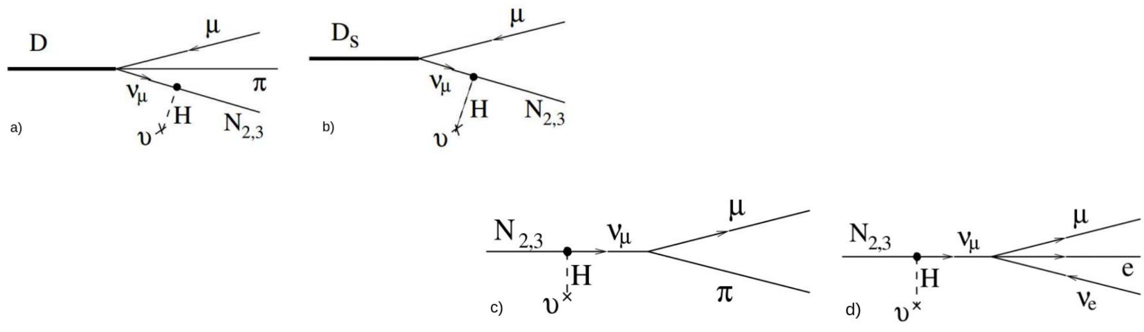


Figure 1. Example of HNL production in D (a) and D_s (b) decays. Example of $N_{2,3}$ decays (c,d) [4].

Decays of type (fig. 1, c) are of high practical interest due to clear final states. SHiP detector should measure precisely secondary particles and reconstruct the decay vertex and mass of HNL particle. This can be implemented with a precise tracker in magnetic field. A scheme of SHiP experiment is shown in fig. 2.

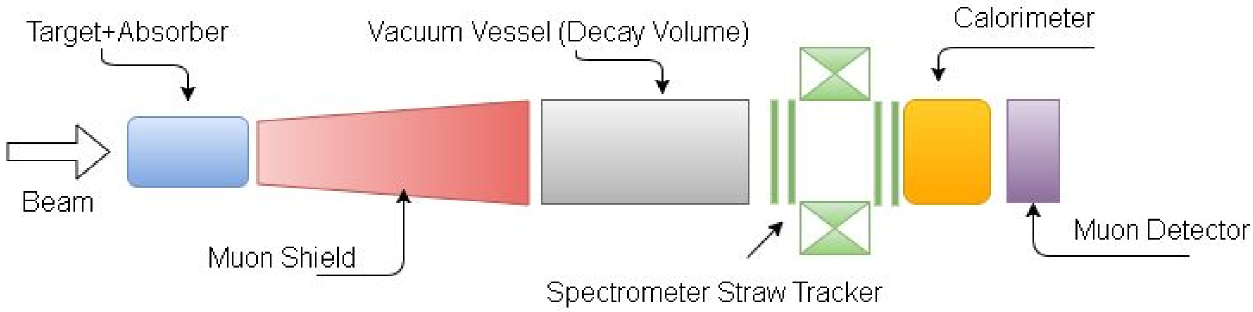


Figure 2. Scheme of SHiP experiment.

In SHiP the corresponding detector is located at the end of Vacuum Vessel (Decay Volume) and is called Spectrometer Straw Tracker (SST) [5]. The aim of SST is to reconstruct precisely tracks of charged particles (products of HNL decays) to obtain the decay vertex, particles momentum and invariant mass of HNL. The current report is focusing on preparations for optimization studies of the SST geometry.

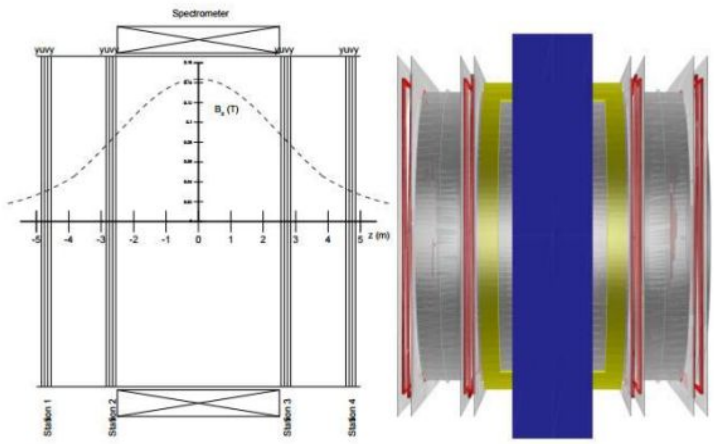


Figure 3. SST scheme (left) and SST 3D model (right) [5].

SST basic concept. The basic concept of SST is shown in fig. 3. SST will consists a dipole magnet with a large aperture, and two tracker stations at each side of the magnet. Each station will consist of 4 parts called “Views”, providing measurements of vertical (Y) or “inclined” (U, V) coordinates, organized in the following order: Y-U-V-Y. Each View will be divided into 2 Planes, each of them with 2 Layers of straw tubes. Schematic view of SST is presented in fig. 4.

Tracking stations should have a high spatial resolution and minimum contribution to multiple scattering of the detected particles and should operate in vacuum. To satisfy all the requirements the tracker planes can be constructed from thin PolyEthylene Terephthalate tubes (PET) [5].

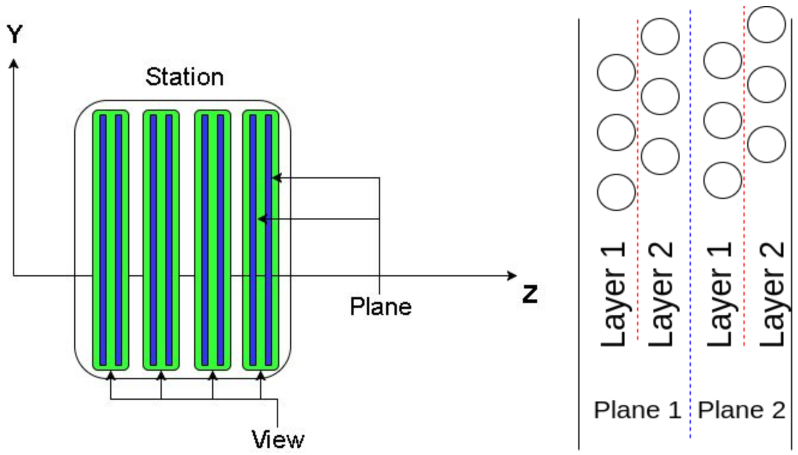
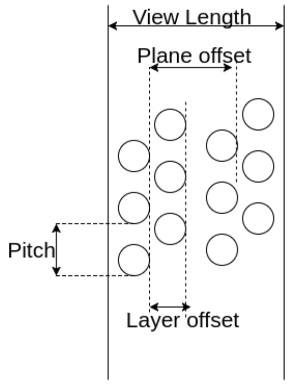


Figure 4. Schematic of SST station (left). Each station consists of 4 Views of 2 Planes, each Plane consists of 2 Layers of straw tubes. Right drawing shows a single View in more details.

As SST must measure particle tracks with high resolution and high efficiency, one needs to define the most optimal parameters of tracker stations. The parameters considered for the optimization in this project are the longitudinal dimensions of SST parts:



- Layer offset (equal to Layer length along Z axis)
- Plane offset (equal to Plane length along Z axis)
- View offset (equal to View length along Z axis)

These SST parameters are shown in fig. 5. For SST optimization we need to find the parameter values providing good efficiency, spatial and momentum resolutions. Within this project limits on these parameters coming from the general SHiP detector geometry are studied.

Figure 5. Definition of SST View parameters.

Simulation software. As usual, MC (Monte-Carlo) simulation is used to study the detector performance. There is already working simulation software for SHiP experiment, FairShip, which includes an event display with 3D visualisation of geometry. The simulation and reconstruction procedures also available within FairShip. FairShip is written in pyROOT, stored on github (https://github.com/ShipSoft/FairShip).

Project content. The preparation stage for geometry optimization studies includes the following steps:

1) Development of event display macros to produce automated geometry snapshots of SST volumes and implementation of volume overlap checking procedure.
2) Defining the boundary values for SST parameters in the current SHiP detector geometry.

The developed procedures and obtained results will be used in my future work on SST geometry optimization.

Geometry visualization and volume overlap checking procedures. New functions have been added to EventDisplay:

1) Automatic high resolution snapshots of objects of interest (Magnet, Decay Volume, SST Stations, Views, etc) in two camera views.
2) Volume overlap checking procedure.

Definition of boundary values of SST parameters in the current SHiP detector geometry.

As mentioned above, the most important SST geometry parameter is View length. The View volume is an envelope for other daughter volumes and, in turn, defines limits of their longitudinal dimensions.

Changing View length we should check for overlaps with neighbor SHiP volumes. The nearby objects are: Decay Volume at the left side, Time Detector at the right side and Magnet in the center. Calculating the boundary coordinates of these volumes by applying the above procedure of the volume overlaps check give us possible SST longitudinal dimensions shown in Fig. 6.

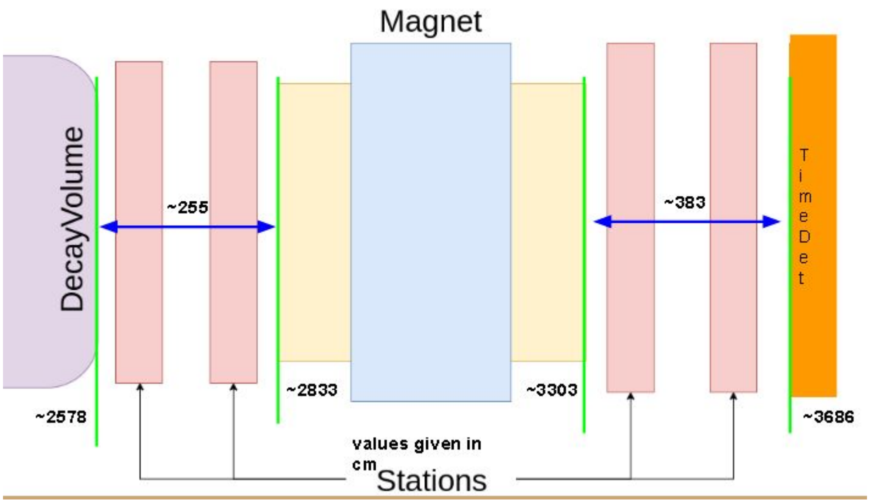


Figure 6. Boundary coordinates (Z axis) of DecayVolume, TimeDet and Magnet.

As shown, we have 255 cm of free space for Stations 1 and 2, and 383 cm of free space for Stations 3, 4. So, the future geometry optimization studies (including studies of detector performance dependence on SST longitudinal dimensions and positions) can be performed in 3 possible ways:

1) Using given fixed positions of SST Stations. In this case the maximum length of a single View is 10 cm.
2) Changing positions of SST Stations we can increase a View length up to 31 cm.
3) Changing also the Magnet position we will reach 39 cm of maximum value for View length.

For all three cases the new geometry has been implemented with the new maximum View length and checked for volume overlaps. As it was expected, no overlaps were found. Fig. 7 shows the implementation of the first case. As it is seen, the fixed position of Station 1 does not allow to increase View length over 10 cm due to Vacuum Vessel wall.

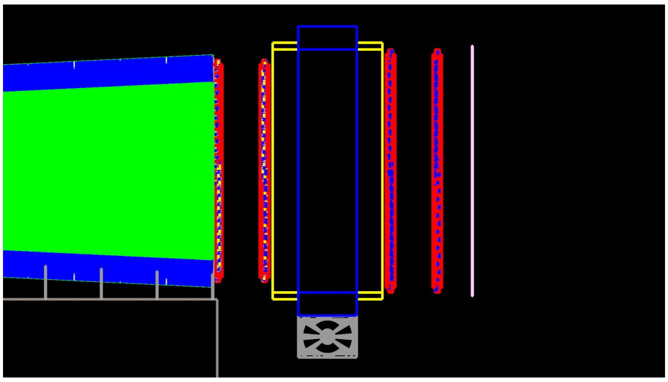


Figure 7. Unchanged positions of Stations, applied View length value is 100 mm. No overlaps found.

Fig. 8 a, b show implementations of case 2 and 3 respectively with the corresponding maximum values of View length.

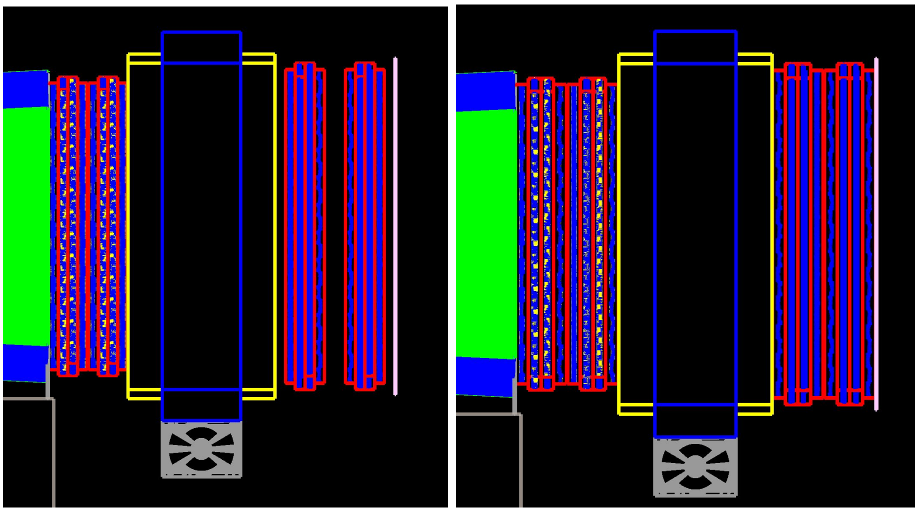


Figure 8. Changed positions of Stations, applied View length value is 310 mm (left). Changed positions of Stations and Magnet, applied View length value is 390 mm (right). No overlaps found.

As for other parameters of SST, Layer offset and Plane offset are dependent from the View length, and then, should be checked to be inside the View volumes. The maximum value of the View length allow to scan the above parameters to find their optimal combination giving the best possible SST performance.

Conclusion. First steps towards SST geometry optimization were taken in order to prepare for future studies. Optimal visualization of SST parts and automatic check for overlapping volumes have been implemented. The maximum possible sizes of SST Views are defined in the current SHiP detector geometry.

As next steps studies of detector performance as a function of SST longitudinal parameters will be performed in the future.

Sources list.

1) W. Bonivento et.al, Proposal to Search for Heavy Neutral Leptons at the SPS, 2013, arXiv:1310.1762 [hep-ex]
2) T. Asaka, S. Blanchet and M. Shaposhnikov, The νMSM, Dark Matter and Neutrino Masses, 2005, arXiv:hepph/0503065.
3) T. Asaka and M. Shaposhnikov, The νMSM, Dark Matter and Baryon Assimetry of the Universe, 2005, arXiv:hep-ph/0505013.
4) Sergey Alekhin et.al, A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case, 2016, arXiv:1504.04855 [hep-ph]
5) SHiP Collaboration, A facility to Search for Hidden Particles (SHiP) at the CERN SPS, 2015, arXiv:1504.04956 [physics.ins-det]