A Simplified Magnetic Field Tapering and Target Optimisation for the Neutrino Factory Capture System

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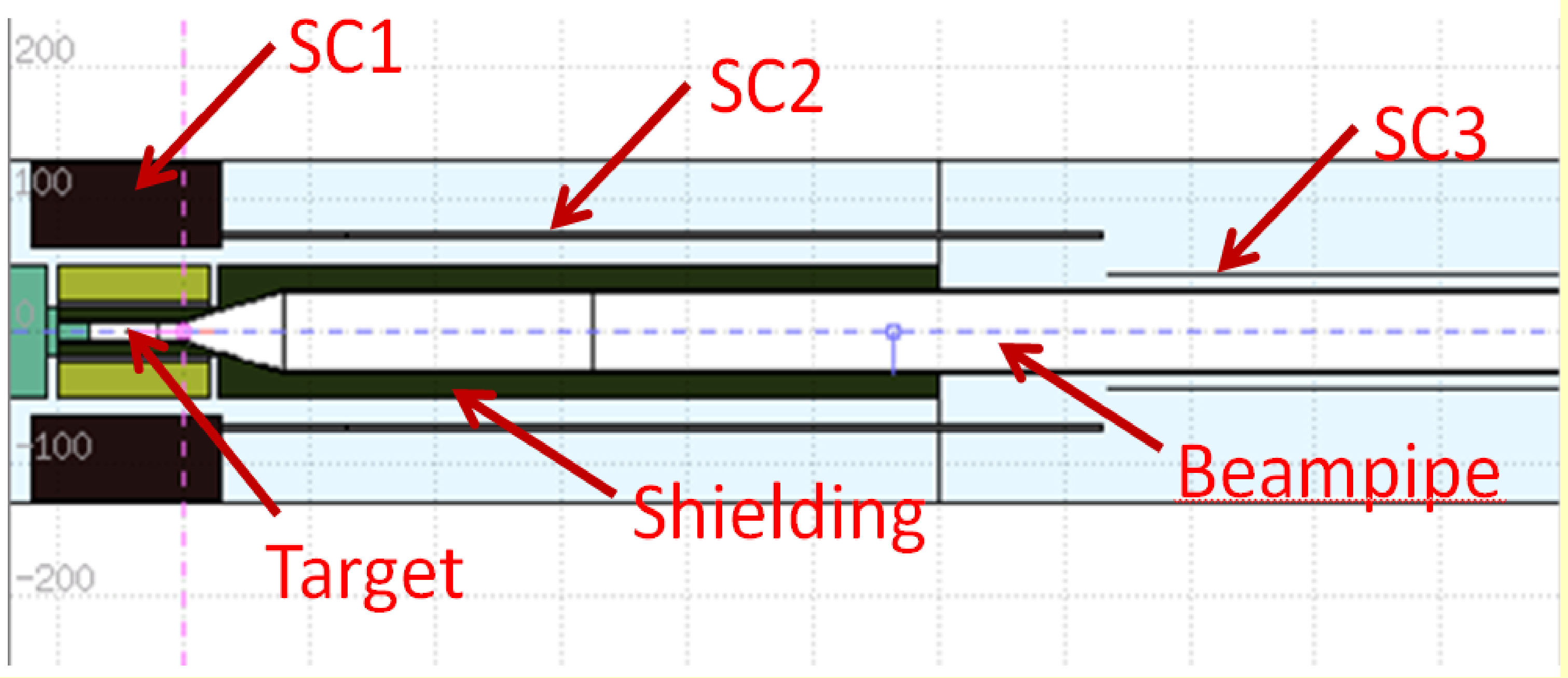
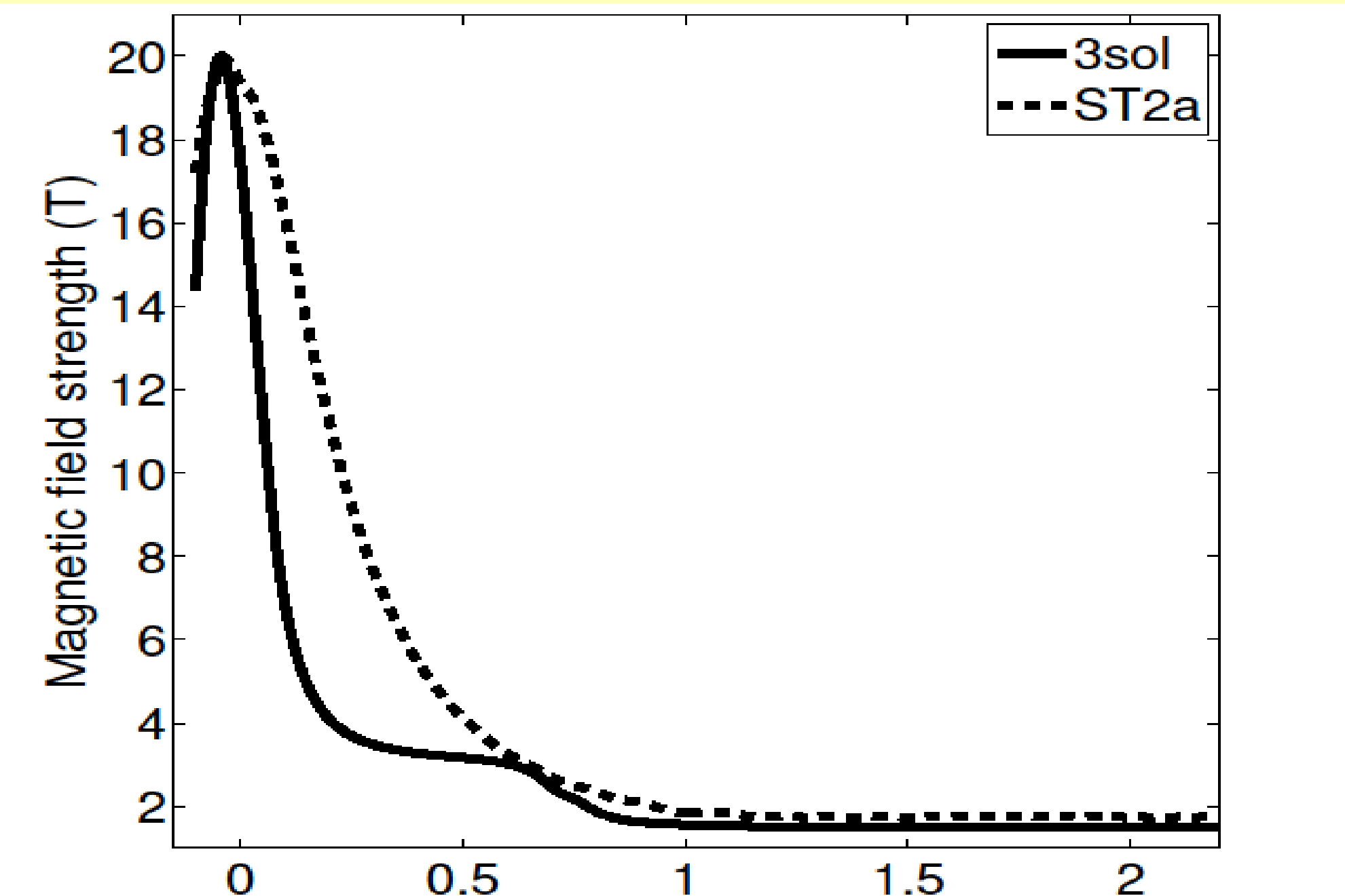
THE NEUTRINO FACTORY (REF: HTTPS://WWW.IDS-NF.ORG/WIKI/FRONTPAGE/DOCUMENTATION/IDR)

In a Neutrino Factory, a 4 MW proton beam with a kinetic energy between 5 and 15 GeV interacts with a free floating liquid mercury jet target in order to produce pions which after capturing are let to decay forming a muon beam, input to the front-end accelerator system of the facility. The baseline capturing layout consists of a series of normal and superconducting solenoids producing a tapered magnetic field from 20 T, near the target, down to 1.5 T at the entrance of the drift pion decay section. An alternative layout is studied, where the magnetic field is rapidly squeezed from 20 T to 1.5 T using only three solenoids. This new layout showed to produce similar, and even slightly better performance than the baseline, having the additional advantage of being simpler and could potentially be made more robust to radiation. We report on further optimisation studies taking into account the beam interaction path length in the mercury jet and shape fluctuations of the jet. G4beamline was used for simulations.



Left: 3 solenoid (3SOL) layout: SC1, SC2 and SC3 are the superconducting solenoids. The beampipe is the region in the center, the radius is r_{b1}=75 mm in the 20 T region around the target, then in the conical region it increases to r_{b2}=274 mm.

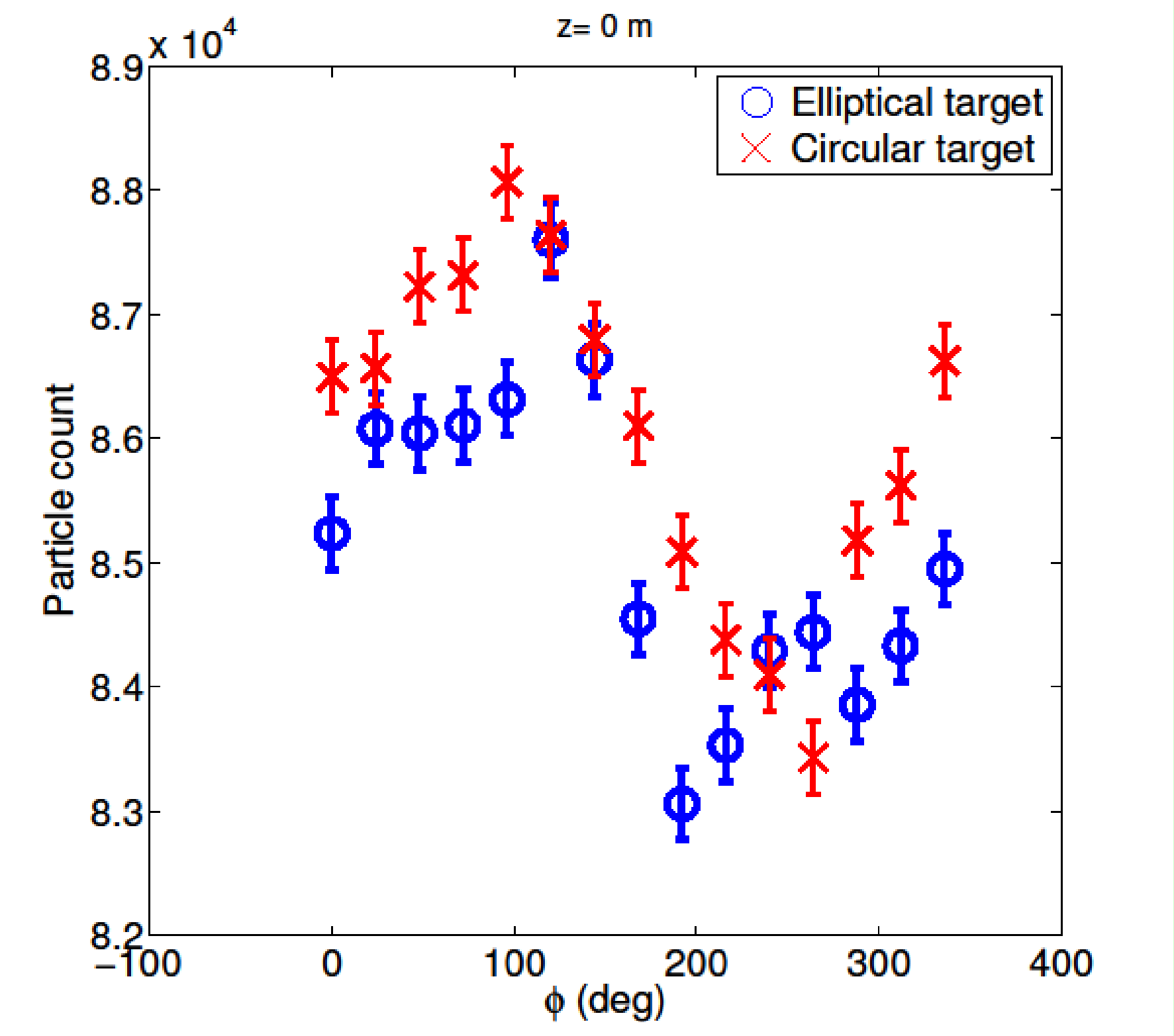
Right: Magnetic fields of 3SOL and the ST2a layout.



ELLIPTICAL VS. CIRCULAR JET

The distorted jet was simulated by increasing the height and squeezing the width, compared to the circular jet with radius r=5 mm, to form an elliptically shaped jet. Here it's assumed that the height increases to 1.2r when in a 20 T field. The major semi-axis of the ellipse should be a=6 mm, therefore and from conservation of mass for the jet, the minor semi-axis is calculated to be b=4.2 mm.

The polar angle between the beam and target is fixed to θ_{BT} =30 mrad while the azimuth angle is varied from φ ϵ[0, 360] deg, in steps of 24, using the target reference frame. The results show a particle count variation of 5.5 % for both cases and the elliptical jet has a lower count, on average. The particle count are done downstream of the jet in the plane at position z=0 mm, or at 375 mm from its centre.



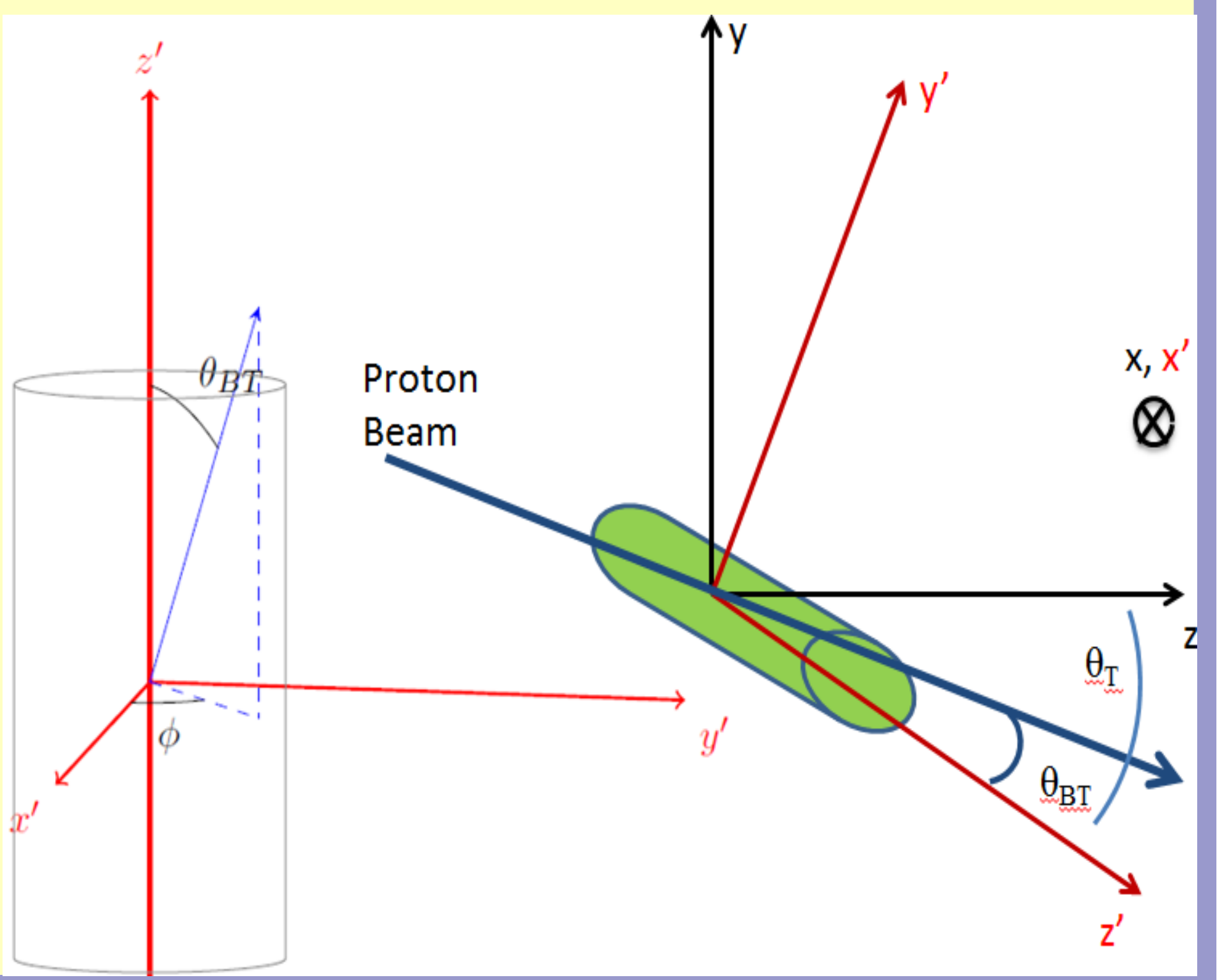
THE MERCURY JET AND THE PROTON BEAM

- 8 Gev proton beam with σ=1.5 mm
- The jet is tilted θ_T=96.68 mrad

Left: the angle definitions of θ_{BT} and φ in the target reference frame.

Right:the target reference frame rotation.

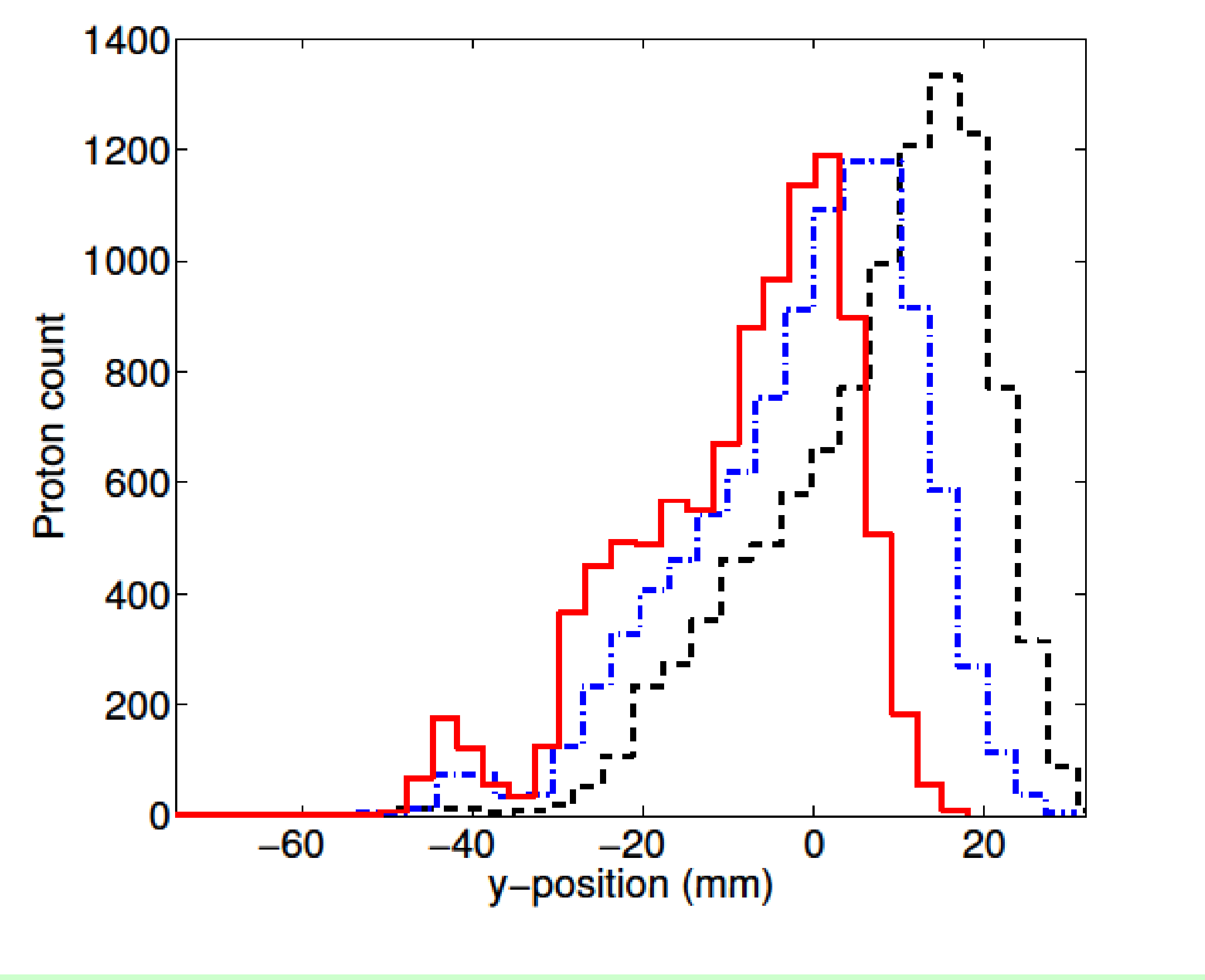
around the x-



PROTON BEAM AND JET INTERACTION REGION

The jet is now circular. The figure shows the distribution of the y-position of each individual proton interaction point in the jet. The black dashed line is the case for φ=0 from the figure above, for the circular jet. The distribution peak is off-centered in the positive y-direction.

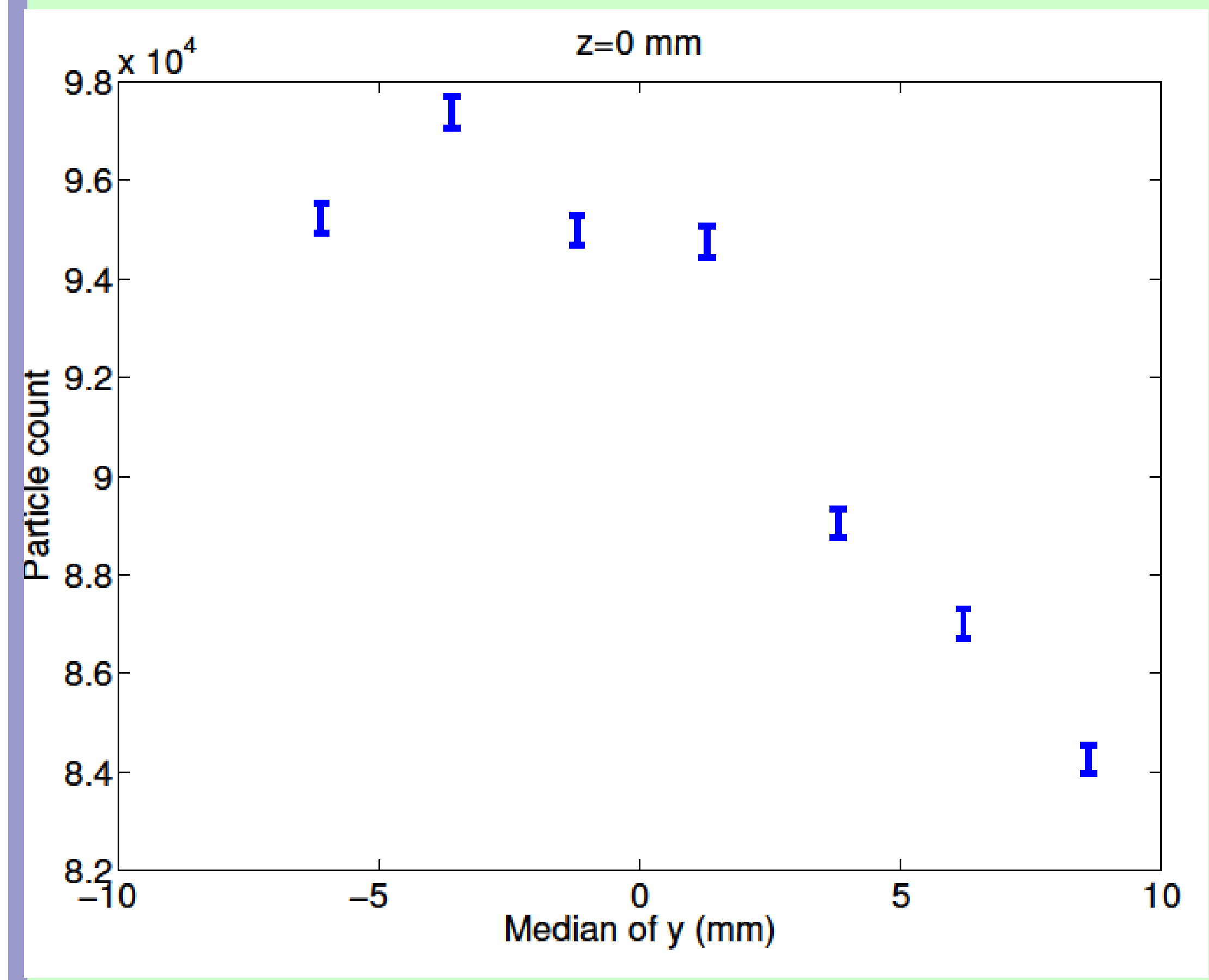
The secondary particles are therefore produced in the upper part of the beampipe, i.e. out of the focal centre therefore more particles will be lost from scraping in the shielding.



The distribution peak was therefore shifted towards the center by making the proton beam enter the jet at a lower y-position. Then the secondary particles will have a smaller radial distribution, thus potentially increasing the muon yield at the front-end.

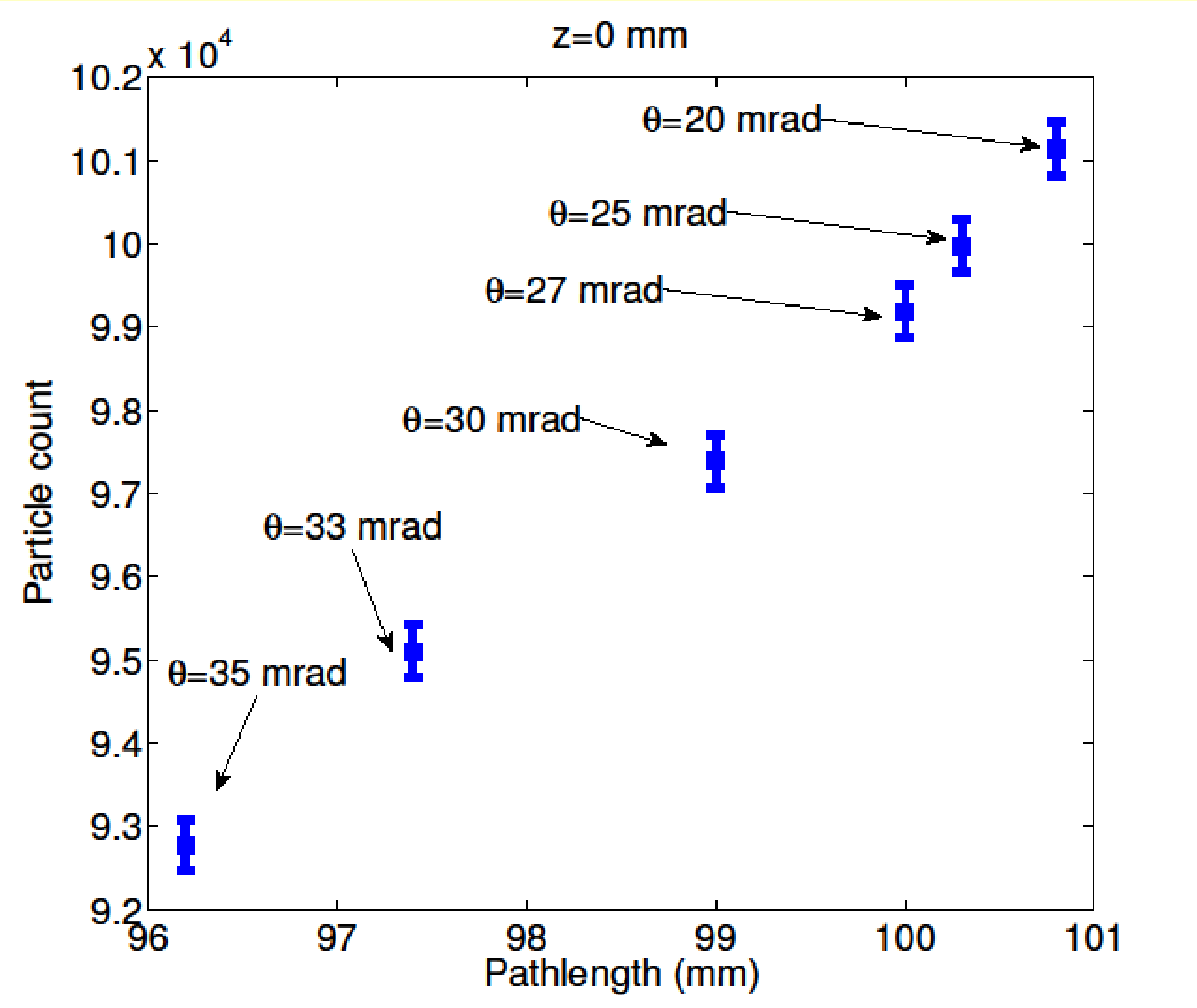
In addition it makes the spreading of the energy deposition more even such that the upper part of the shielding doesn't get the peak of the radiation.

The black dashed line has median 8.6 mm, the blue dash-dotted line has median 1.25 mm and the red line median -6.1 mm and can also be found in the figure below.



The y-distribution is skewed and non-gaussian, the median was therefore chosen over the mean to indicate the central tendency. The figure shows the particle count with respect to the median value of the y-distribution. The maximum particle count was found when the median was –4 mm.

INCREASING THE INTERACTION LENGTH

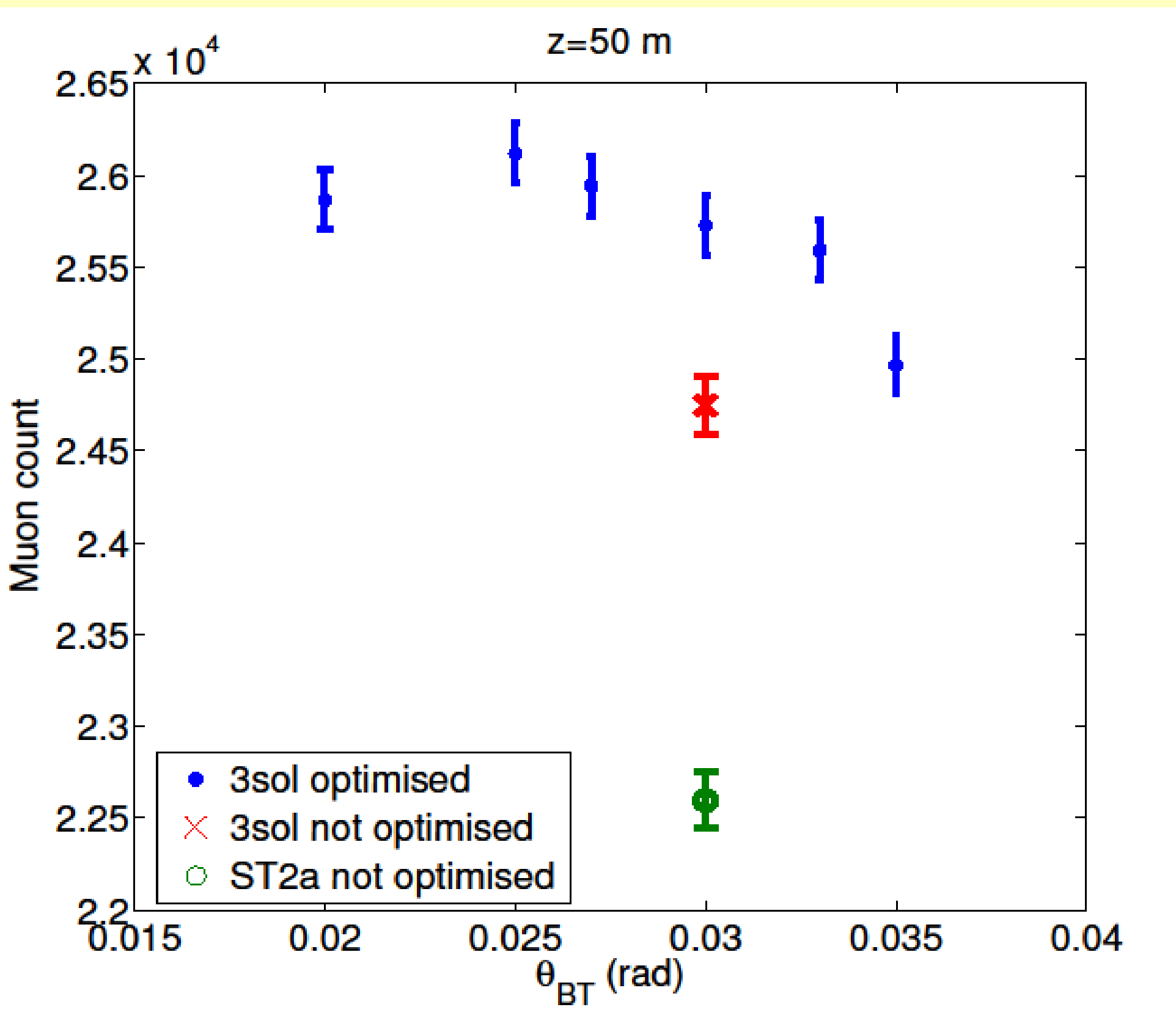


To increase the interaction region length (pathlength) and the particle production further, the angle θ_{BT} is varied from 20 to 35 mrad, while keeping the optimal median y value of -4 mm.

The particle count increases for a longer pathlength, the highest average pathlength found was 100.8 mm and the particle count is then increased another 6.8 % compared to the lower left figure and giving a total increase of 17.3 % compared to the maximum value from the figure under the title Elliptical vs. Circular Jet.

MUON YIELD AT THE FRONT-END

In summary the production of the secondary particles has now been centered in the beampipe and the pathlength increased.



The particle count has thus far been found in the plane at z-position=0 mm, 375 mm downstream of the jet center . To make sure the optimisation increases the output of the front-end, the particle flux is now found at z=50 m, where acceptance cuts are applied.

The results are compared to the ST2a layout. The non-optimised 3SOL and ST2a both used the settings giving the maximum value from the figure in Elliptical vs. Circular Jet.

CONCLUSION

Optimisation studies of the proton beam interaction with the mercury jet target have been performed in the 3SOL layout. Changing the jet shape from a cylinder to an ellipse alters the particle production slightly, a decrease of a few percent is expected.

It is found that the muon yield could be maximised if the secondary particles are produced in the center of the beampipe. The optimal angle between beam and target was found to be θ_{BT} =25 mrad to get the longest pathlength and therefore the highest particle flux. Combining these optimisations give an increased muon count of 5.5 % (16 %) compared to the non-optimised 3SOL (ST2a).