MCenter Secondary Beamline for NOvA Test Beam

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ABSTRACT

A modified MCenter secondary beamline tune is presented to serve the new NOvA test beam experiment that will run in downstream MC7 after Summer Shutdown 2018. By matching to the effective post-target beam ellipse, as determined by Monte Carlo simulation, the secondary beamline is tuned to achieve the experiment's desired secondary flux and momentum bite. Some basic operational details regarding the experiment are also discussed.

Experiment Overview

The NOvA test beam experiment seeks to calibrate NOvA scintillator detectors with a well-understood tertiary beam. The tertiary beamline, pictured in **Figure 1**, provides per-particle tracking, momentum, and species tagging, and is inspired by the design of the LArIAT and MINVERvA test beam tertiary lines[1].[2]

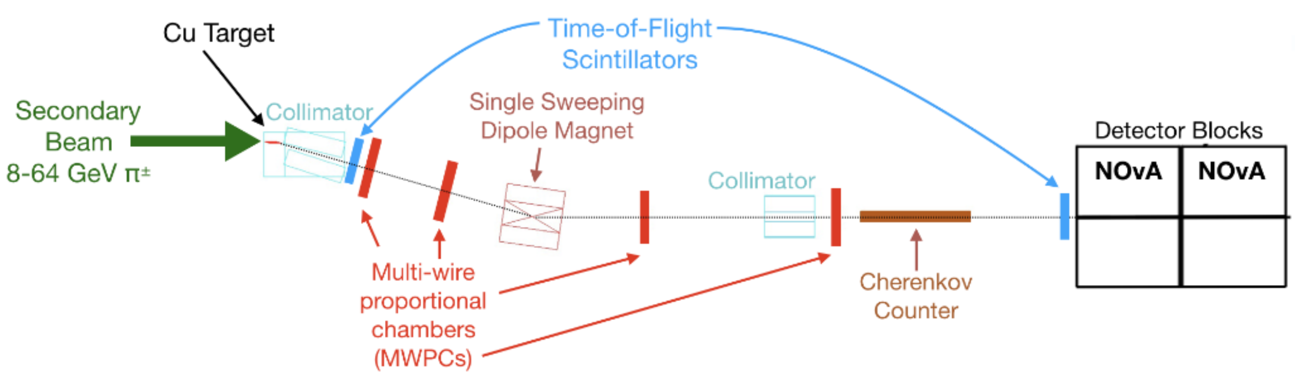

Figure 1. An overview of the NOvA test beam tertiary beamline and detector apparatus.

The experiment is located in the downstream end of the MC7 enclosure. Illustrated in **Figure 2**, this location represents a significant downstream shift to the required focal point of the MCenter secondary beam. The experiment has installed a six-inch diameter Helium-filled beam pipe filling most of the beam path in MC7 up to the target to reduce multiple scattering. To run beam in this configuration, the LArIAT target, located just upstream of the start of the Helium pipe, must be rolled and locked out of the beam path.

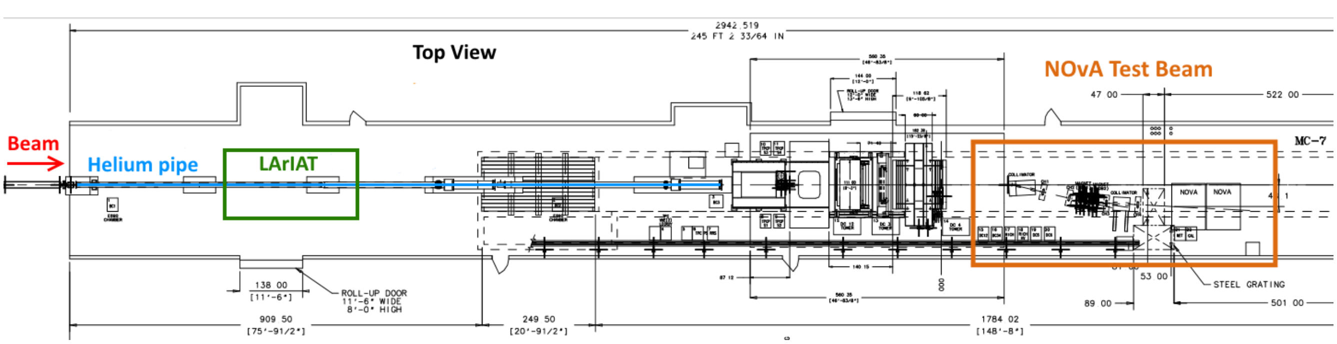

Figure 2. Experiment location in the MC7 enclosure.

The experiment requires a secondary beam flux of 1E6 per spill at mean 64 GeV/c momentum on a 3 cm square cross-section target. In particular, secondary particles that miss the target should be minimized to reduce background in the detectors.

Secondary Beamline

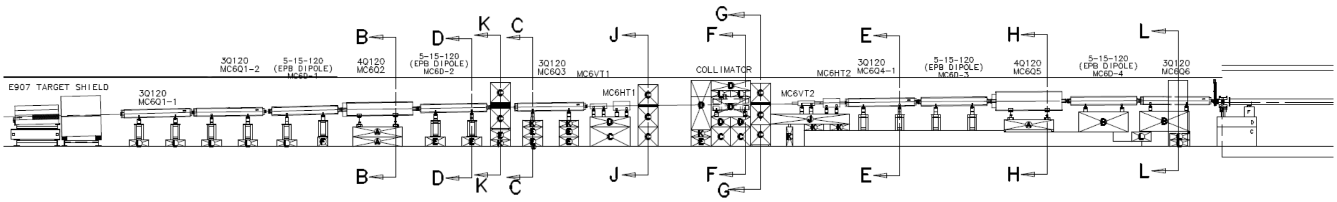

Figure 3. Secondary beamline tune to focus 64 GeV/c secondaries on the NOvA test beam target.

The secondary beamline begins with a 1 cm square Copper target in the MC6 enclosure. Consisting of two quadrupole triplets, four vertical main dipoles, four corrector dipoles, several fixed collimators, and one adjustable-gap vertical collimator, the secondary line is designed to provide a variable momentum bite secondary beam.[3] Currently, the operational momentum range is 1-80 GeV/c with an adjustable bite down to a few percent.

A Monte Carlo model using G4Beamline[4] was created to determine the effective beam ellipse after the target and initial fixed collimator. This model includes the target, surrounding shield, and collimator immediately following the target, and is pictured in **Figure 4**. This model was adapted from work by Fermilab 2017 Summer Intern Livio Verra,[5] with help from NOvA experimenter Junting Huang.

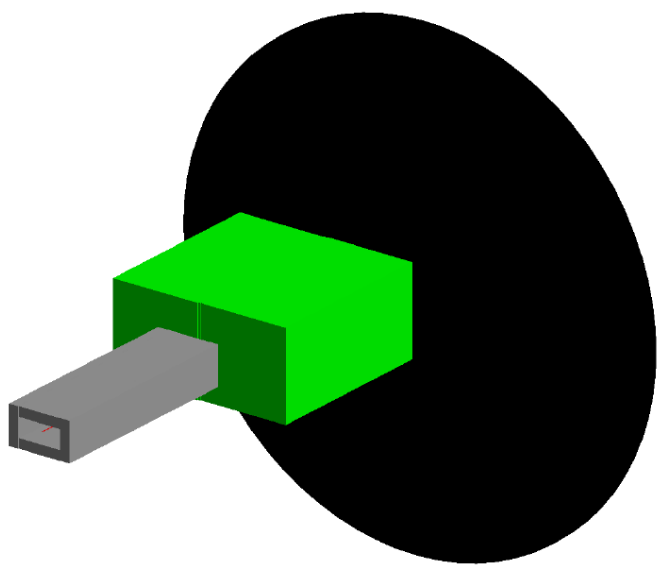

Figure 4. G4Beamline Monte Carlo model of the MC6 target (red), shield (grey), fixed collimator (green), and a large virtual detector (black).

The momentum and species distribution as read by the virtual detector are plotted in **Figure 5** for 6E6 120 GeV protons on target, after applying a cut to keep only protons, pions, kaons, and muons.

To tune the secondary beamline for maximum transmission, the effective ellipse for the secondary beam is computed. By first applying an arbitrary one-percent momentum bite cut on the data from **Figure 5** around the desired central momentum of 64 GeV/c, the elliptical parameters α, β, and ε can be found using the beam matrix relationship in *Eq. 1*, shown in the horizontal plane but identical in the vertical.

$$\Sigma = \varepsilon \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix} = \begin{pmatrix} <x^2> & <xx'> \\ <xx'> & <x'^2> \end{pmatrix} \tag{1}$$

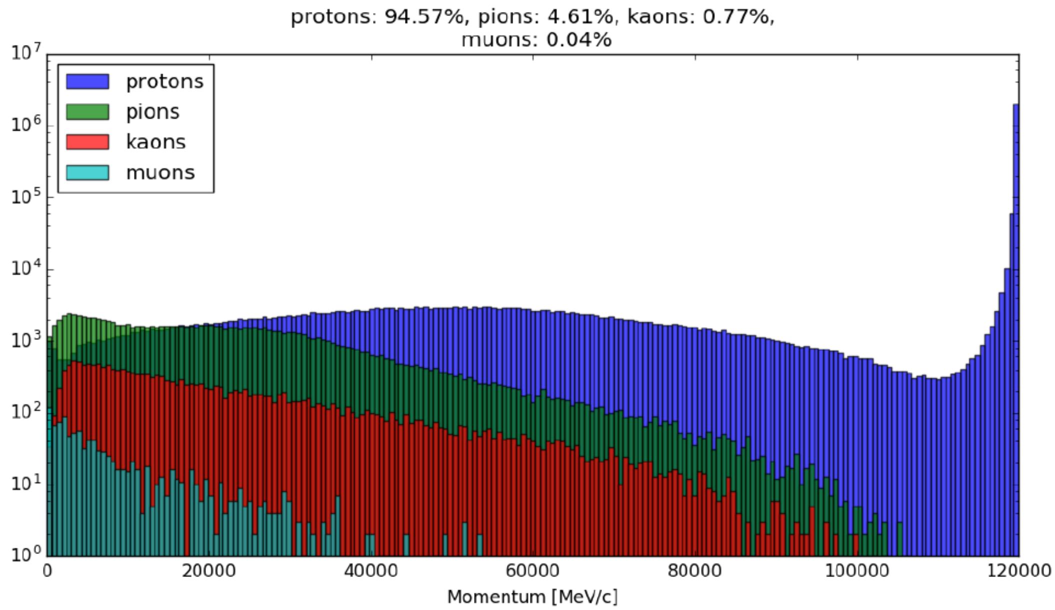

Figure 5. Momentum distribution for select particle species off the MC6 target for 6E6 120 GeV protons on target.

Solving for the parameters of interest, the elliptical parameters are expressed in terms of the statistical second moments of the beam distribution. Again, the following equations are identical for both horizontal and vertical parameters.

$$.\varepsilon = \sqrt{<x_1^2><x_1'^2> - <x_1 x_1'>^2} \qquad \alpha = -\frac{<xx'>}{\varepsilon} \qquad \beta = \frac{<x^2>}{\varepsilon} \tag{2}$$

Figure 6 shows the transverse phase space particle data from the target simulation after a one-percent momentum bite cut around 64 GeV/c

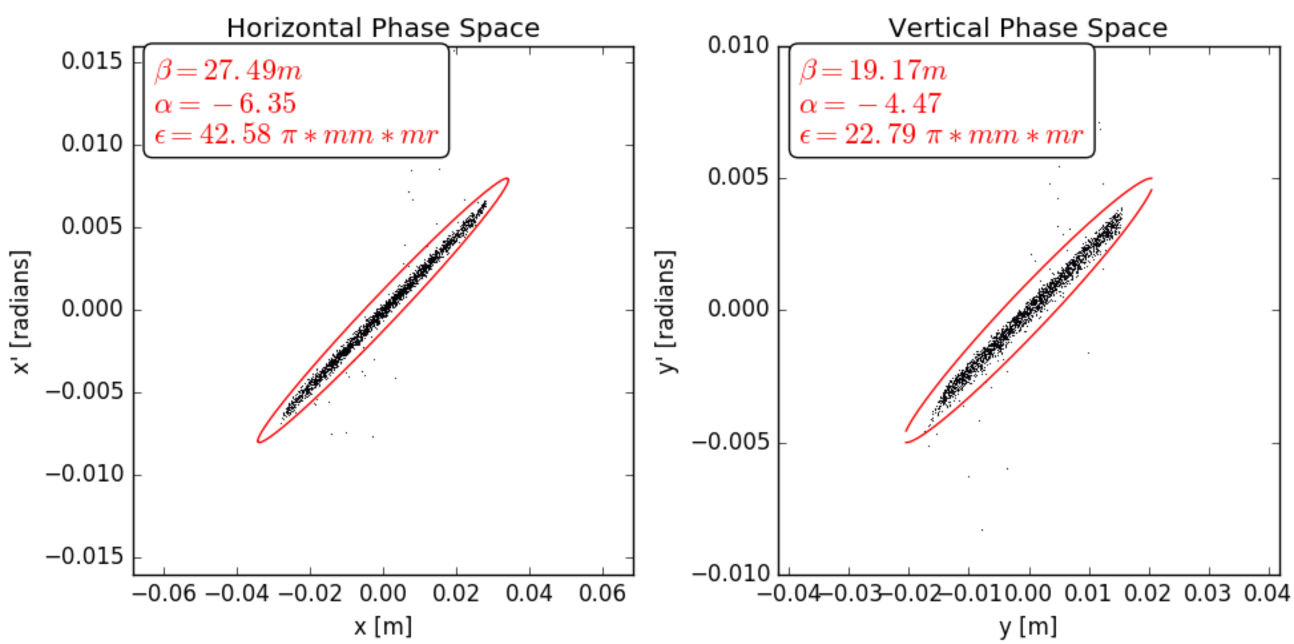

Figure 6. Transverse phase space data from the target Monte Carlo simulation with one-percent momentum bite cut around 64 GeV/c. The effective ellipse is shown in red with the associated computed parameters.

The elliptical parameters computed with *Eq. 2* and plotted in **Figure 6** provide the initial beam conditions for a MADX[6] model that optimizes the quadrupoles to achieve a focal point at the NOvA target. The MADX optimizer is also instructed to minimize the vertical beta function at the momentum collimator MC6CV while maximizing the vertical dispersion; this ensures that MC6CV is primarily absorbing the off-momentum particles. The results of the MADX optimization are plotted in **Figure 7**, with the end of the plot representing the NOvA target. While an ideal tune would have zero dispersion at the target, there is a small amount of residual vertical dispersion in this tune ; it will be shown later that the requested beam spot size on target is still achieved regardless.

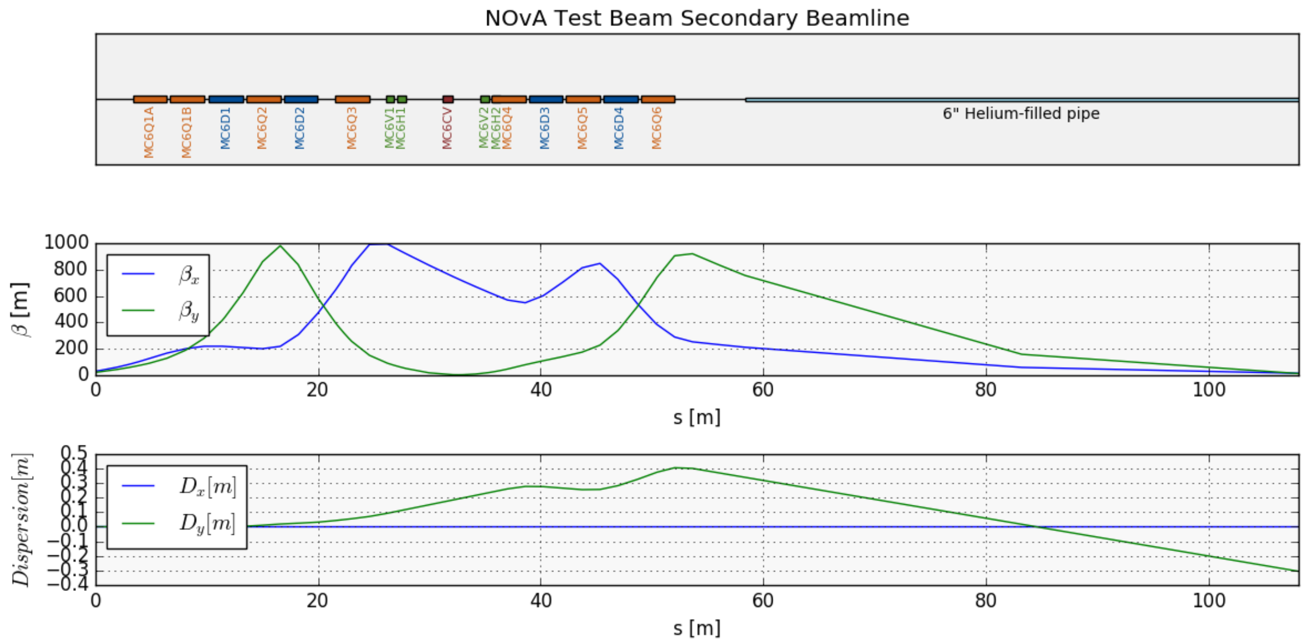

Figure 7. Secondary beamline tune to focus 64 GeV/c secondaries on the NOvA test beam target. The target is situated at the very end of the plot.

Table 1 shows the quadrupole currents for the NOvA test beam tune as recommended by the MADX optimizer. Overall, the operating mode for NOvA only differs slightly from the LArIAT tune that has been operational for the past few years.

Quad	LArIAT	NOvA
MC6Q1	22.59	19.32
MC6Q2	-658.60	-642.83
MC6Q3	38.45	37.34
MC6Q4	-29.93	-29.57
MC6Q5	424.44	429.96
MC6Q6	-41.00	-39.78

Table 1. Comparison of quadrupole currents [Amps] for LArIAT operation and new NOvA test beam tune.

The quadrupole field gradients determined by the MADX model are then applied to a full G4Beamline simulation of the target, secondary beamline, and all fixed collimators, to verify performance of this tune. Now the only cuts made after the target are to keep protons, pions, and kaons, which is what NOvA is interested in seeing; no momentum cuts are made for this model. The momentum collimator MC6CV is set to a vertical aperture of 10 mm, and the resulting beam on target is shown in **Figure 8**.

With the tune recommended by MADX, slightly more than 90% of the secondary beam impinges on the NOvA target with an RMS momentum spread of about 1.5 GeV/c. The production ratio of secondaries on target per proton on the MC6 target is 1.75E-4, so to achieve the requested secondary rate of 1E6 per spill, the primary beam intensity on target needs to be 5.75E9 per spill. The current operating conditions of the MCenter beamline allow a maximum beam intensity on target of 2E11 per spill, so achieving the beam as requested by NOvA appears well within the capabilities of the beamline.

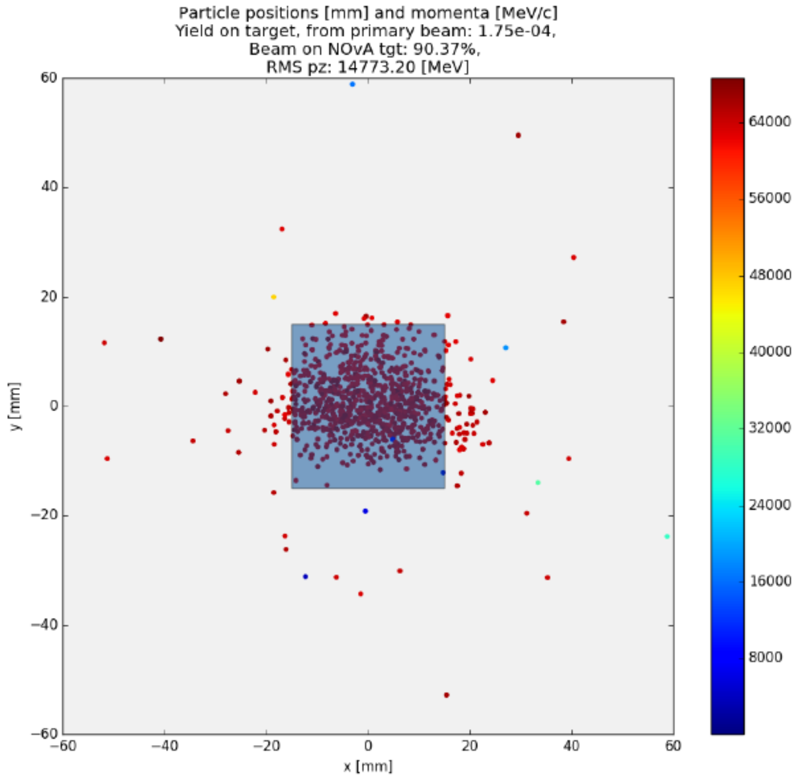

Figure 8. Beam on target from full secondary beamline Monte Carlo model with NOvA 3 cm square target superimposed on the plot. Particle color in this plot represents total momentum in MeV/c.

References

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