# Integration of ORKA and SY120

T. Kobilarcik

21 June 2012
v2.0

**Abstract**

A conceptual design, allowing simultaneous ORKA and Switchyard 120, is presented.

## 1 Overview

Presently, beam is transfered from the Main Injector to Swithyard via the P1, P2 and P3 lines. P1 transports beam from the MI to F0. P2 transports beam from F0 to F17. P3 transports beam from F17 to A0. The optics for P1, P2, and P3 are the old Main Ring lattice.

The proposed modification extends the Main Ring lattice[1] to B0 (a proposed site for ORKA), and extends the Main Ring lattice further into Switchyard, ensuring cleaner transport.

## 2 Assumptions About the Beam

The beam is assumed to match the lattice af F0. Table 1 lists the initial lattice functions[2]. We assume a $20\pi$ mormalized emmittance (95%), which is equal to $0.491\ mm \cdot mR$ physical emmittance at 120 GeV/c, for horizontal and vertical phase space; we assume no cross-plane correlations.

The beam envelope is the edge calculated from the 95% physical emmittance ($x = \sqrt{\beta \epsilon_{p(95\%)}}$). This is the half-width of the beam.

## 3 Simultaneously Running ORKA and Switchyard

Simultaneously running ORKA and Switchyard is achieved by replacing the last two dipoles in F45 with an electrostatic septum and inserting two Main Injetor style Lambertson magnets (ILA) immediately downstream of F49QD. The

[1] Fermilab-FN-0182

[2] Private communication, David Johnson.

| | x | y |
|---|---|---|
| $\beta$ | 72.628 | 73.110 |
| $\alpha$ | -0.724 | 0.726 |
| $\eta$ | 2.318 | 0.0 |
| $\eta'$ | 0.026 | 0.0 |

Table 1: Initial lattice parameters at F0.

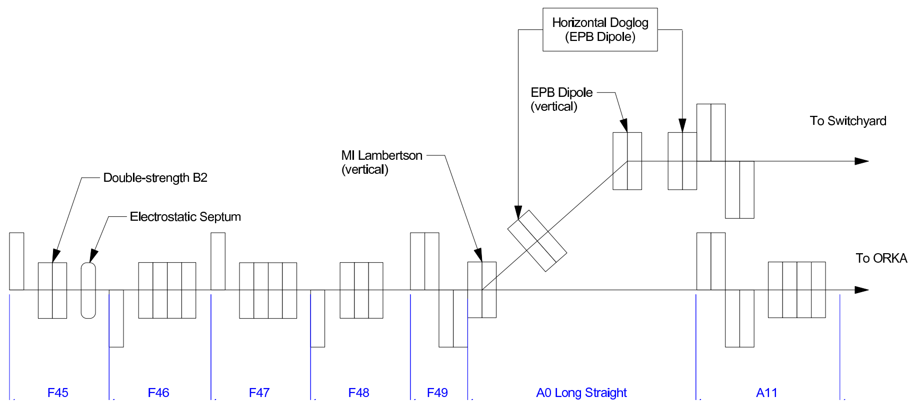



Figure 1: Modified P3 line showing beginning of A Sector (for transport to ORKA) and Swtchyard Transfer Hall.

septum is oriented to split horizontally, while the lambertsons bends vertically. Refer to Figure 1 and figure 2.

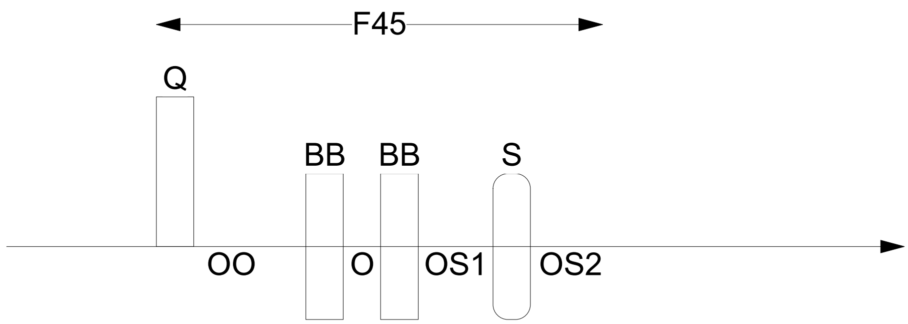
If the septum is run at 100 kV, the seperation between the nominal and deflected trajectories is aproximatly 16 mm. However, if a switchyard-style septum is used (which has a central anode and two cathodes), then each beam is deflected, resulting in a 32 mm seperation. Figure 3 shows the beam and apertures, demonstrating there is suffifient clearance. A single trim magnet, following the septum, will keep the ORKA beam very close to the nominal trajectory.

There are approximately 90° of phase advance between the septum and the first lambetson. As such, the beam entering the lambertson is very nearly para-axial. A pair of EPB dipoles, located 23 m downstream, levels out the beam.

Refering to Figure 1, one also notes a horizontal dog-leg. Powering the four EPB dipoles to 14 kG (1800 amps) results in a 600 mm offset at QA11A – adequate space to continue the Main Ring lattice into Switchyard. One notes that this dog-leg is an exellent candidate for a Switchyard critical device.

Returning to the F45 modifications, the remaining two dipoles must be replaced with two double-strength dipoles. This changes the bend-point, moving the beamline 6 inches inward at A0.

Table 2 lists the elements needed for the new A0 interface.




| | | | |
|---|---|---|---|
| Q | 2.1336 m | OO | 2.1082 m |
| BB | 6.0700 m | O | 0.3048 m |
| S | 3.0480 m | OS1 | 2.6322 m |
| | | OS2 | 1.0000 m |

Figure 2: Block diagram showing modification to F45 half cell.

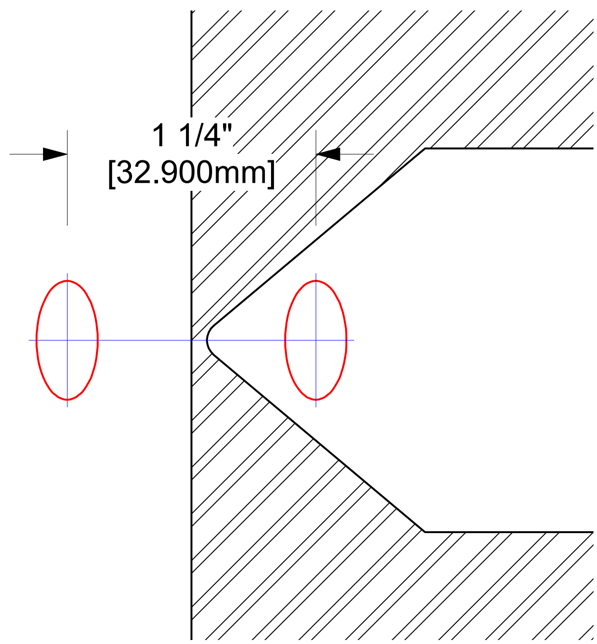



Figure 3: Deflected and undeflected beam overlaid on Main Injector style lambertson.

| Element | Length [m] | Bend Angle [mR] |
|---|---|---|
| FQ49D | 2.1336 | . |
| drift | 1.1308 | . |
| ILA1 | 2.8000 | 7.5 up |
| drift | 0.2048 | . |
| ILA2 | 2.8000 | 7.5 up |
| drift | 10.2784 | . |
| EPB1A | 3.0480 | 10.7 left |
| drift | 0.3048 | . |
| EPB1B | 3.0480 | 10.7 left |
| drift | 0.3048 | . |
| EPB2A | 3.0480 | 7.5 down |
| drift | 0.3048 | . |
| EPB2B | 3.0480 | 7.5 down |
| drift | 14.3048 | . |
| EPB3A | 3.0480 | 7.5 right |
| drift | 0.3048 | . |
| EPB3B | 3.0480 | 7.5 right |

Table 2: New A0 interface for Switchyard. The interface consists of interleaved horizontal and vertical dog legs.

# 4 Beam to ORKA

The Main Ring lattice is rebuilt throughout A-Sector with the following changes:

1. Short (52") Main Ring quadrupole are used in place of long (84") Main Ring Quadrupoles.

2. A48Q is at a different gradient.

3. All A49 quadrupoles are unused.

4. A final-focusing triplet is located immediately after AQ49D.

The first change will be adress in section 4.1; the last three in section 4.2.

## 4.1 A-Sector Optics

Due to availability, the A-Sector lattice will be reconstructed using short (52") Main Ring Quadrupoles. In order to maintain the previous optics the K1 value must be raised from $0.017994884 m^{-2}$ to $0.029096636 m^{-2}$, which implies running the magnets at $2380 Amps$.

Figure 4 shows $\beta_x$, $beta_y$, and $eta_x$ for F-Sector and A-Sector. Onse sees that the F and A Sector lattice functions are adequately close for single-pass beam transport.

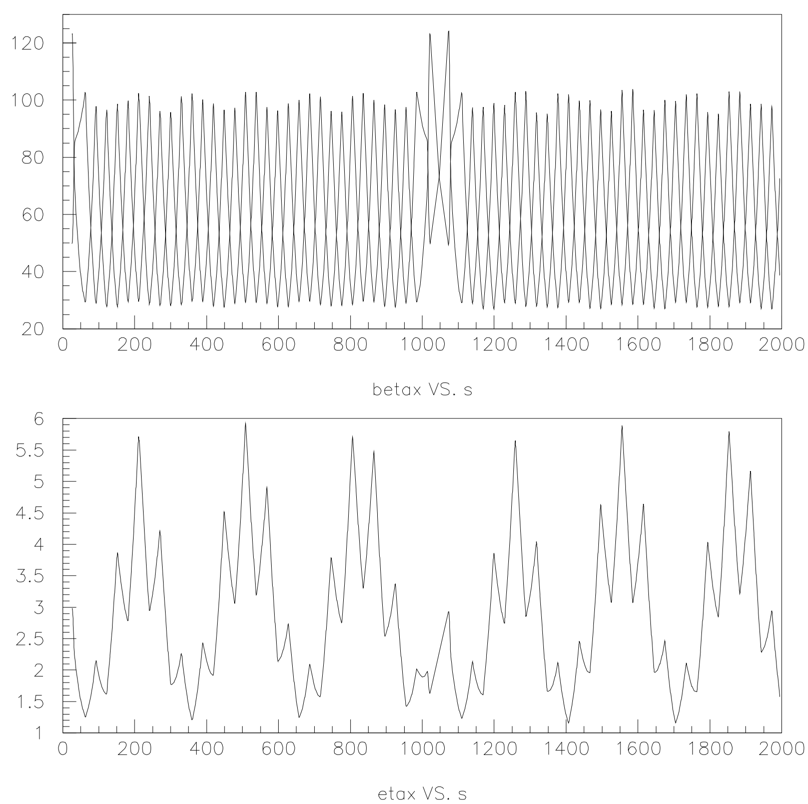



Figure 4: Latice functions (beta above, eta below) for F and A Sectors. The modified A-Sector lattice matches F-Sector adequately for single-pass beam.

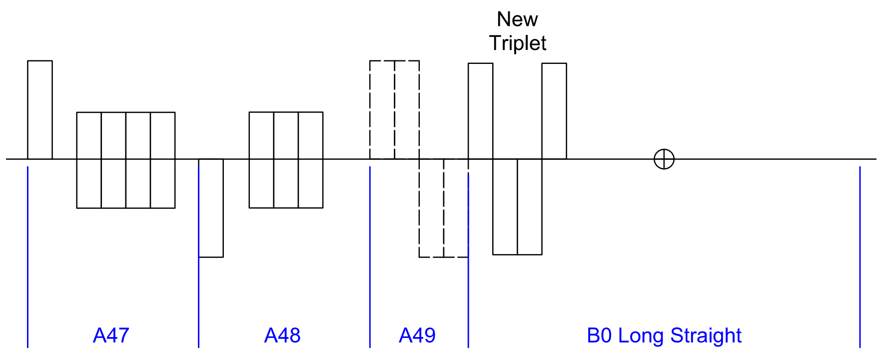



Figure 5: Schematic showing changes for ASector. The focal length of QA48 is changed to match into the new triplet. The A49 quadrupoles are removed.

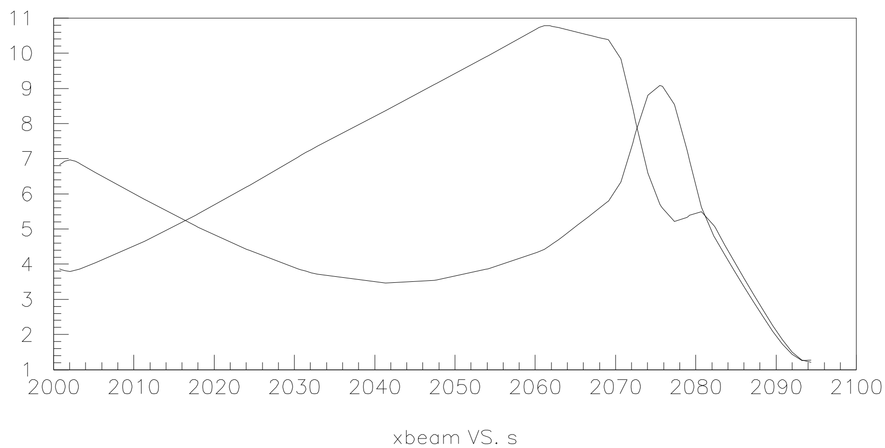



Figure 6: Half-width of 95% emmittance beam envelope through final focusig optics.

### 4.2 ORKA Final Focus Optics

The final focusing optics are acheived by removing the A49 quadrupoles, installing a triplet, and using AQ48 to match (refer to figure 5. The triplet consists of four 4Q120 quadrupoles in a symmetric configuration (FDDF) running the same strength ($K1 = -0.03841 m^{-2}$ (685 A). This results in a 12 m drift space between the last quadrupole and the target — sufficient space for adjusting trims, beam position monitor, etc. The A49 quadrupoles are turned off, allowing the beam to grow in planes, which allows for a symmetric spot (1.2 mm in each plane). Finally, Q48 is used to fine-tune the match. Table 3 lists the values used in this exercise.

This optics solution is presented as a proof-of-principle. As the experiment refines their needs, the optics may be optimized.

| Element | Length [m] | Focal Length [m] |
|---|---|---|
| AQ48 | 1.3208 | 683.9222 |
| drift | 37.7050 | . |
| AQ50A | 3.0480 | 17.3432 |
| drift | 0.3048 | . |
| AQ50B | 3.0480 | -16.8333 |
| drift | 0.3048 | . |
| AQ50C | 3.0480 | -16.8333 |
| drift | 0.3048 | . |
| AQ50D | 3.0480 | 17.3432 |
| drift | 12.1524 | . |
| target | 0.0 | . |

Table 3: Straw-man final focus optics for ORKA. The three B2 dipoles after AQ48 are not listed, although their length is accounted for in the drift space.

| | B2 | ILB | EPB | MRS | 4Q120 | note |
|---|---|---|---|---|---|---|
| Transfer Hall | 0 | 2 | 6 | 0 | 0 | optics have not been worked out |
| A Sector | 125 | 0 | 0 | 31 | 0 | |
| Final Focus | 0 | 0 | 0 | 1 | 4 | begins at F48 |

Table 4: Magnet count.

### 4.3 Magnet Count

Refer to table 4.

## 5 Beam to Switchyard

The electrostatic septa (MSep), which initiate the Meson/Dump Line split, are located at the downstream end of Enclusre B. The two-way Lambertsons (MLam), which completes the Meson/Dump Line splilt, are llocated at teh upstream end of Enclosure C. The Main Ring lattice is extending into Enclosure B, a doublet is added to prepare the beam for the two-way split, and an additional doublet is inseted before MLam to increas stability. The new Main Ring lattice extension into Swithyard will be refered to as "GSector". Figure 7 shows a block diagram of the proposed changes.

### 5.1 Extending the Lattice

Half-cells G11, G12, G13, and G14 are replicated without the bending magnets. This allows one to continue strong-focusing as far into Switchyard as possible. G15 is replaced by a drift (e.i., the quadrupole is eliminated); G16 is replaced by a doublet which orients the beam for splitting by the septum. If a long

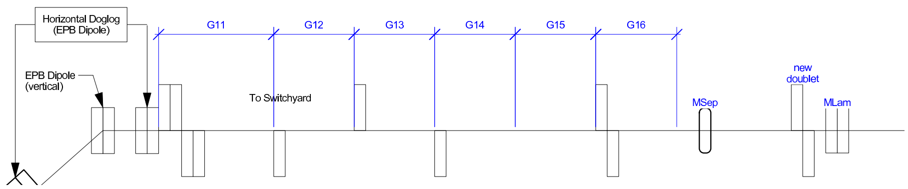



Figure 7: Proposed changes to the front end of Switchyard. The G11 and G12 quadrupoles can be powered from the F-Sector quadrupole bus.

quadrupole can be found for GQ11A, then GQ11A, B, C, D and GQ12 can all be powered from the F-Sector quadrupole bus.

## 5.2 Splitting Station

The splitting station consistes of a dogleg, a single electrostatic septum, a quadrupole doublet, and two Lambertson dipoles.

Figure 8 shows a ray-tracing illustrating the idea. Recall from geometric optics that any ray originating at the focal point, and passing through principal plane, will exit parallel to the optical axis. Thus, if the septum is located at the focal point of the doublet, the trajectory of the split beams will be parallel upon exiting.

Furthermore, if the split ratio is controlled with a dogleg, then the separation between the innermost edges of the split beams will remain constant. This allows one to minimize the separation.

Finally, assuming a vertical split, if the quadrupoles have a D-F configuration in the vertical plane, the first quadrupole will kick the beam away from the central trajectory, allowing one to run the septum at a lower voltage.

The dependancies of the problem are straight-forward: the thickness of magnetic septum of the Lambertson determines the spacing between the split beam; the focal length of the doublet determines the exiting position and angle of the beam; the voltage of the septum is set by this angle, and the position is located where the split beam intersects the central trajectory.

Of course, the horizontal and vertical focusing properties of a quadrupole doublet are not the same. This "mismatch" may be exploited by chosing an optimal location to begin a F0D0, minimized by the use a shorter length quadrupoles, or made more symmetric by replacing the doublet with a triplet (at the expense of increasing the split).

Figure ref:SYPhase shows the simulated split beam immediately downstream of the second quadrupole. TURTLE[3] was used to model the split using the following deck.

```
D1: DRIFT,  L= 1.000;                              !meters
```

[3]D.C. Carey, K.L. Brown, and Ch. Islen, "TURTLE with MAD Input (Trace Unlimited Rays Through Lumped Elements)", SLAC-R-524

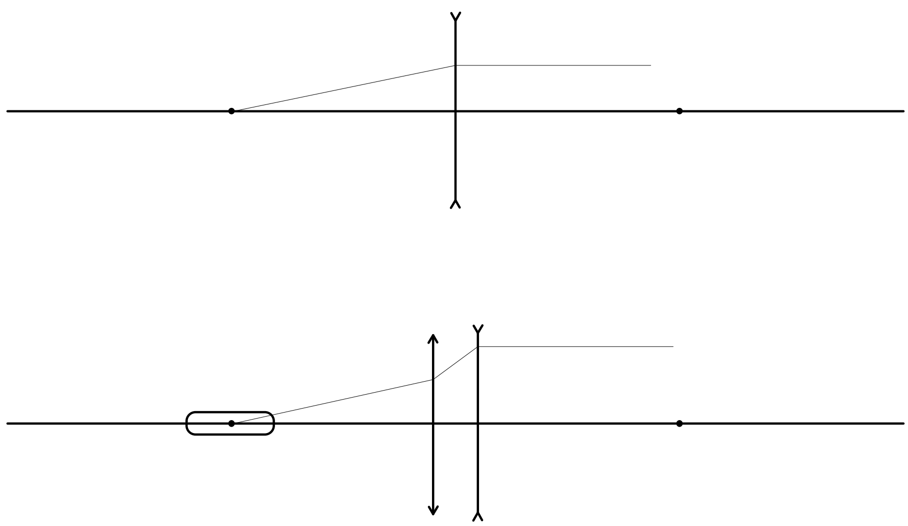


Figure 8: The top figure illustrates a ray, originating at the focal point and passing through the principal plane, being bent parallel to the optical axis. The bottom figure shows an electrostatic septum with its bend point placed at the focal point of a quarupole doublet. The deflected beam will exit the doublet parallel to the central trajectory. The polarity of the quadrupoles in the doublet may be chosen to increase the split.

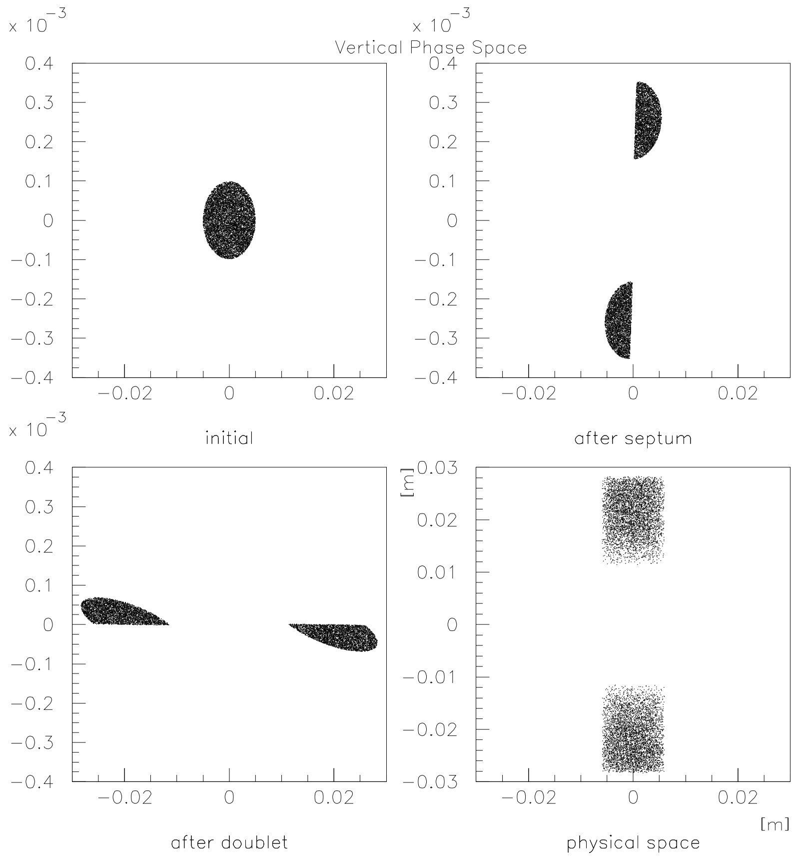



Figure 9: Vertical phase space traced through splitting station. The lower right graph is physical space. Units are *meters* and *radians*.

```
S1: SEPTUM, L= 3.048, VOLT=  0.100, APER=10.0;   !MV and mm
D2: DRIFT,  L=52.0479;
Q1: QUAD,   L= 3.048, GRAD= +0.10048738;         !meters and m^{-2}
DS: DRIFT,  L= 0.3048;
Q2: QUAD,   L= 3.048, GRAD= -0.10048738;
```