Simulating the Beam-line at ISOLDE

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Mentors:
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Isotope Separator On Line

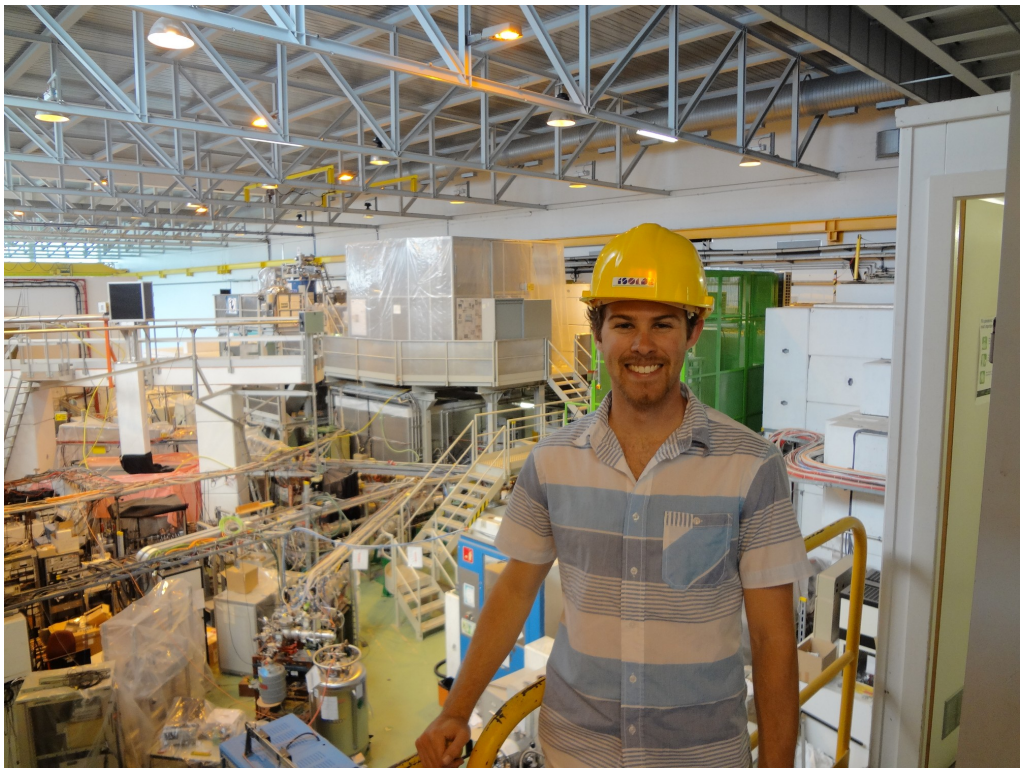

Figure : Part of the ISOLDE facility.

ISOLDE is an isotope mass separator which produces large varieties of radioactive ion beams.

Isotope Separator On Line

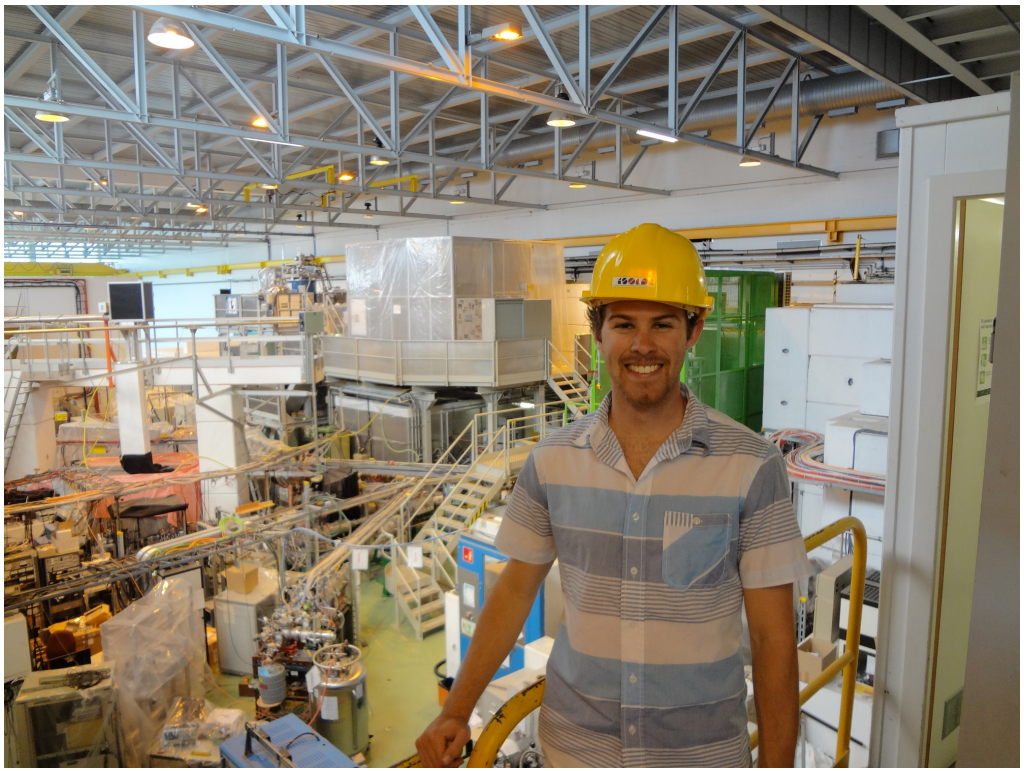

Figure : Part of the ISOLDE facility.

Over 700 nuclides of nearly 70 different elements have been produced (from $Z = 2$ to 88).

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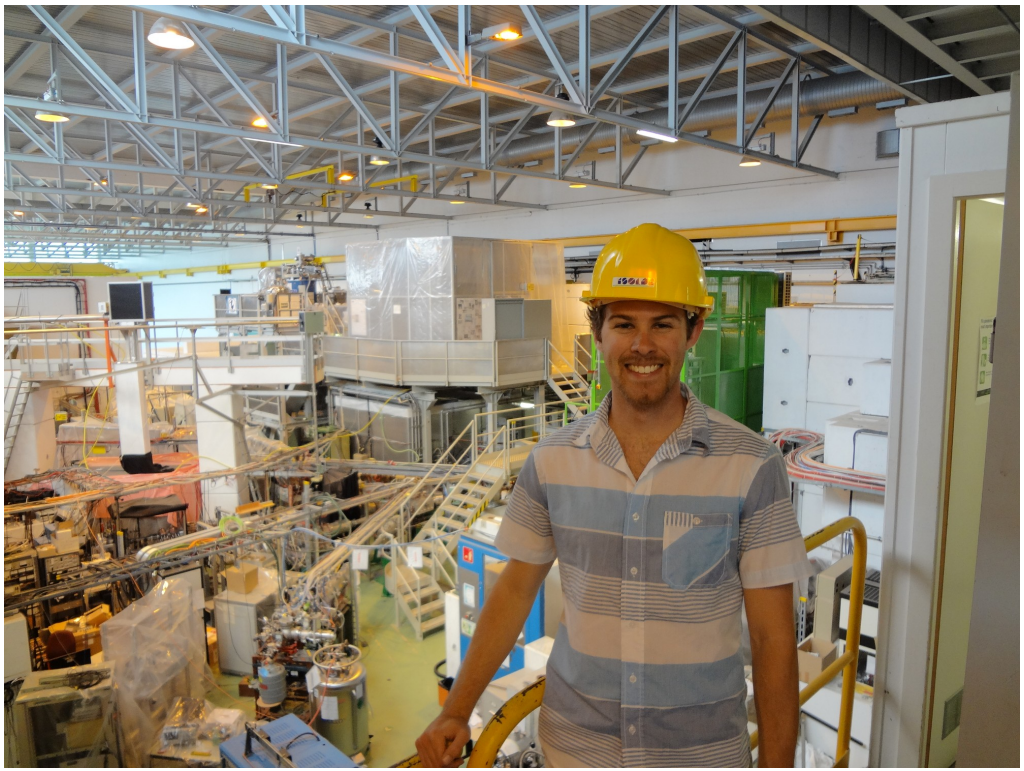

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Applications:

1. Nuclear and Atomic Physics
2. Solid-State Physics
3. Astrophysics
4. Weak-Interaction Physics
5. Materials Science
6. Life Science

Project Goal

We need to maximize the matching along the beam-line so that more particles reach the target at the end.

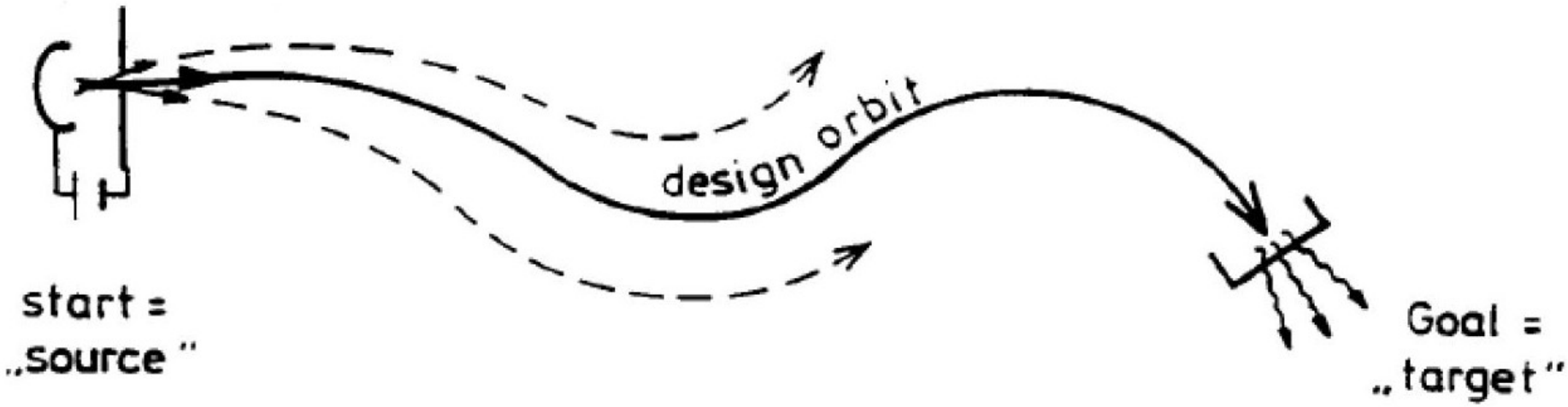

Figure : by Schmüser Rossbach

→ Automate this proceedure.

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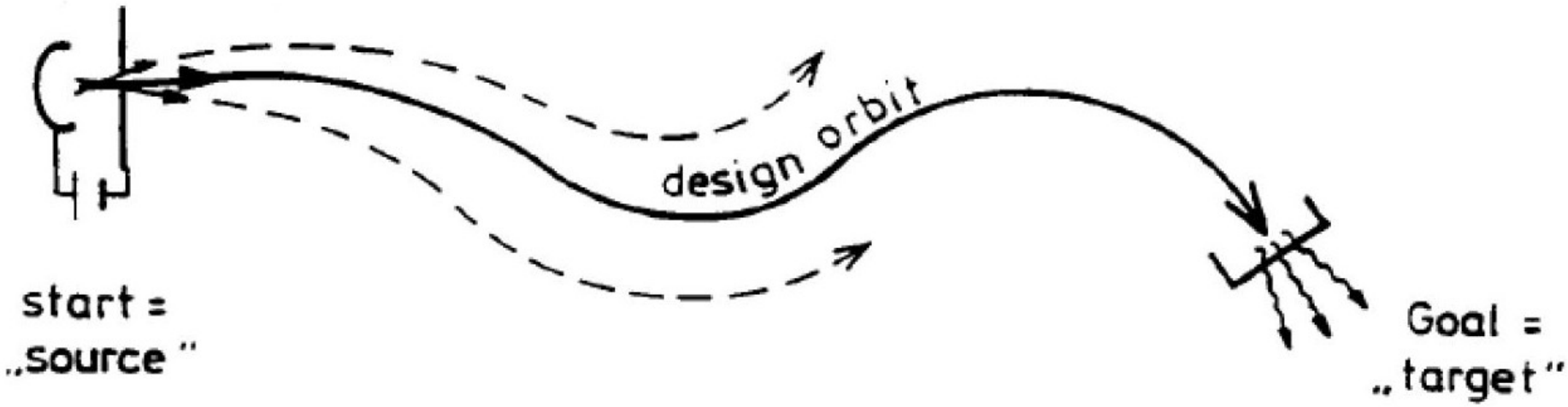

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The Beam-line

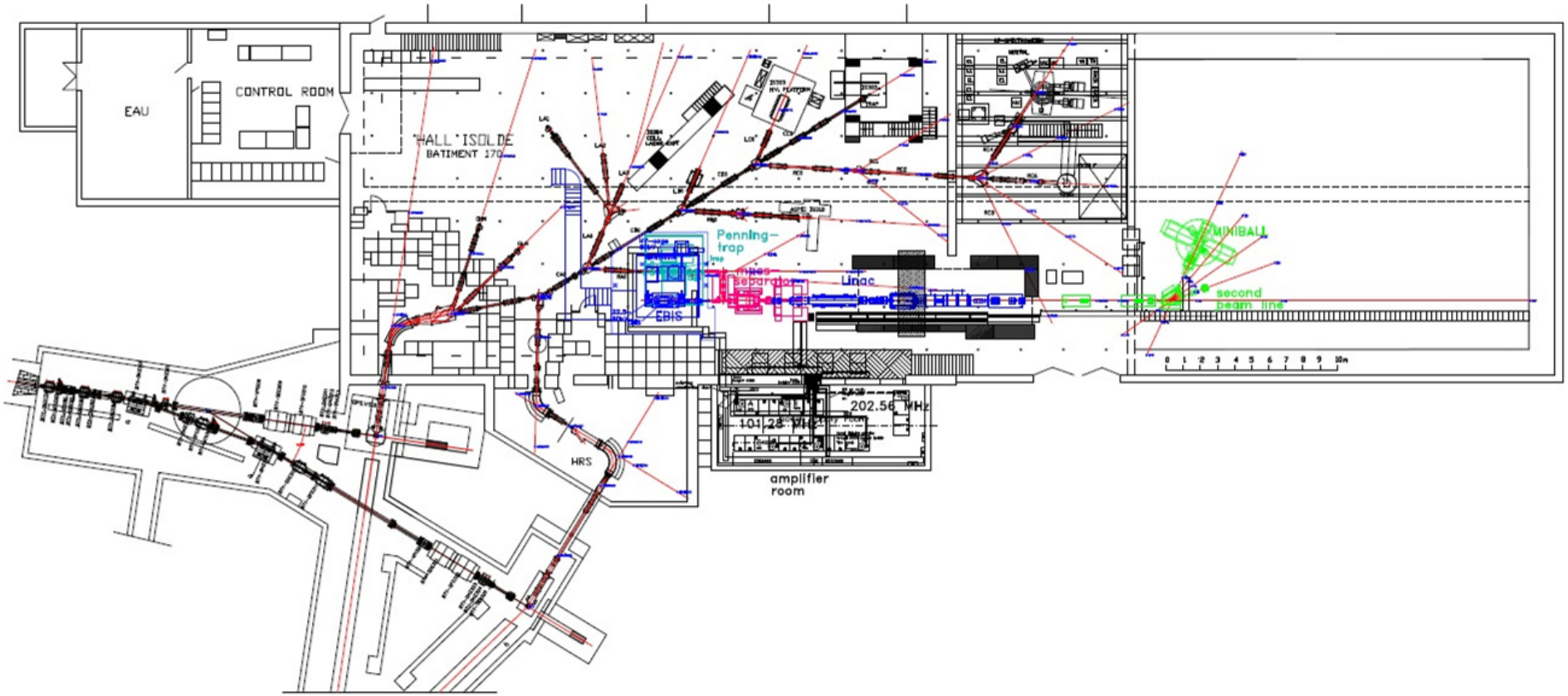

Figure : ISOLDE Blueprint.

The Beam-line

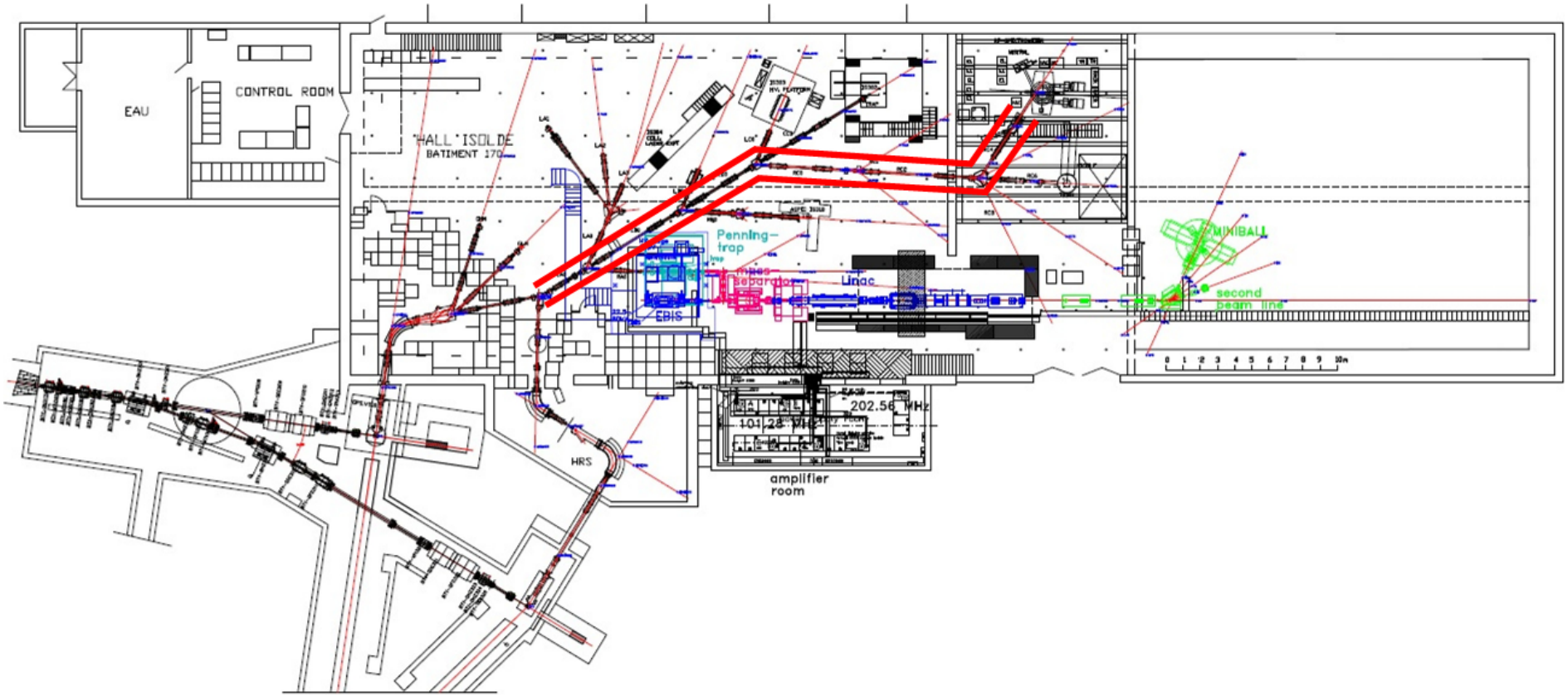

Figure : ISOLDE Blueprint. (My section of the beam-line)

The Beam-line

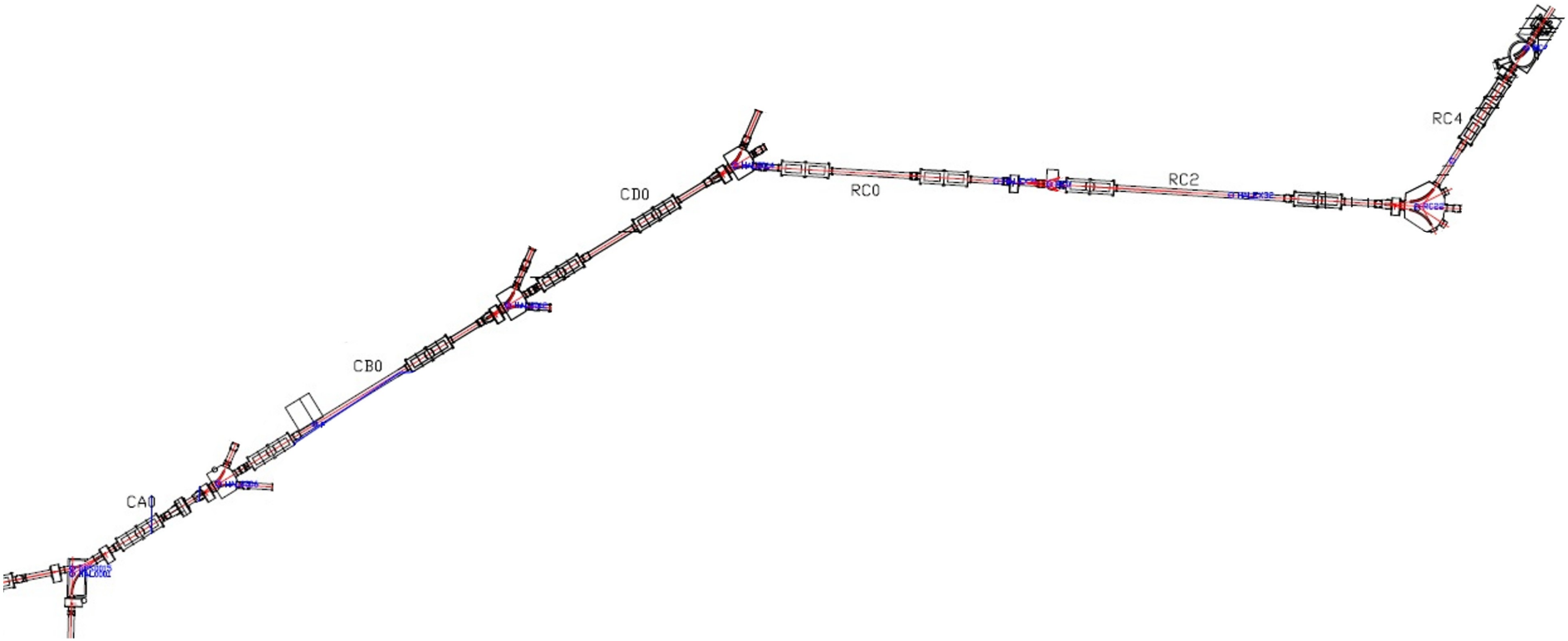

Figure : My section of the beam-line.

The Beam-line

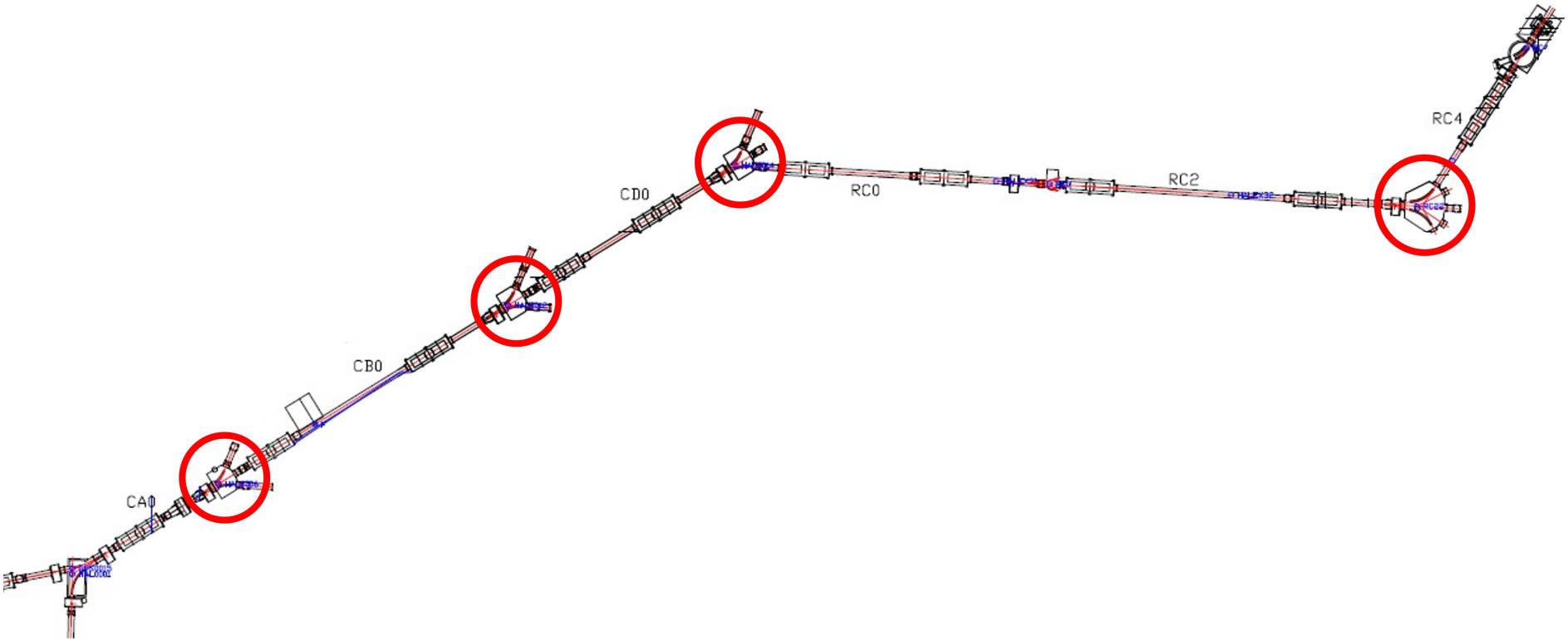

Figure : The kickers and switchyards.

MAD - Methodical Accelerator Design

Designed at CERN, MAD-X was made for the design and simulations of particle accelerators.

It allows the addition and specification of beam-line components and magnets, and will track particles traveling through them.

Choosing a Coordinate System

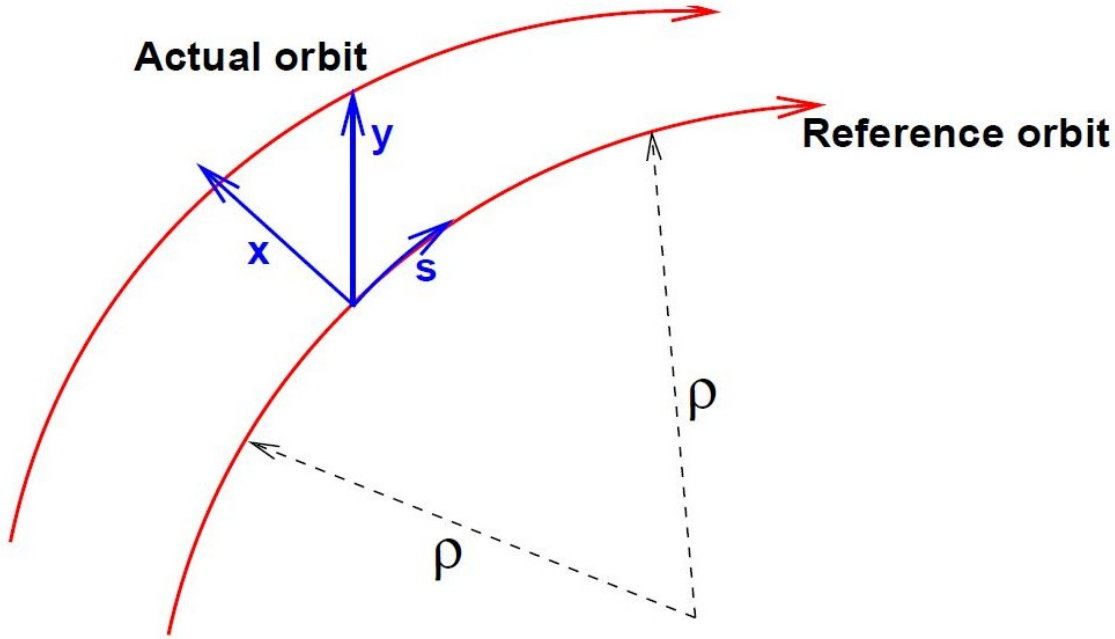

Figure : s, x, and y are orthogonal unit vectors. ρ is the radius of the curve.

Inside of the beam-line, particle motion is described along an idealized reference orbit.

The Coordinate Vector & Transfer Matrix

$$\vec{x} = \begin{vmatrix} x \\ x' \\ y \\ y' \\ l \\ \delta \end{vmatrix} = \begin{vmatrix} \text{horizontal spatial deviation} \\ \text{horizontal divergence} \\ \text{vertical spatial deviation} \\ \text{vertical divergence} \\ \text{longitudinal deviation} \\ \text{momentum deviation} \end{vmatrix} = \begin{vmatrix} [mm] \\ [mrad] \\ [mm] \\ [mrad] \\ [mm] \\ [{}^{0}/_{00}] \end{vmatrix}$$

$$\mathbf{R} = \begin{vmatrix} (x|x) & (x|x') & \dots & (x|\delta) \\ (x'|x) & (x'|x') & \dots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ (\delta|x) & \dots & \dots & (\delta|\delta) \end{vmatrix}$$

The Coordinate Vector & Transfer Matrix

In order to go from an initial state to a final state, we operate on it with the transfer matrix **R**:

$$\vec{x}_f = \mathbf{R}\vec{x}_i$$

Building a Mathematical Beam-line

Each element we add has its own particular transfer matrix.

Imagine the following channel:

drift + quadrupole + drift + dipole + drift

The final position of the particle is simply

$$\vec{x}_f = \mathbf{R}_{drift} \cdot \mathbf{R}_{dipole} \cdot \mathbf{R}_{drift} \cdot \mathbf{R}_{quadrupole} \cdot \mathbf{R}_{drift} \cdot \vec{x}_i$$

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Problems with MAD-X

We can *almost* accurately model our beam with this software, but there are two major problems:

1. MAD-X is not reliable for electrostatic components.
2. The transfer matrices for two components, the kicker and switchyard, are *not* included in the code.

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Our Solution

1. First we build the components with AutoCAD.

2. Feed the files to another program, SIMION, to add the physics to the design and to calculate the transfer matrices based off of the geometry.

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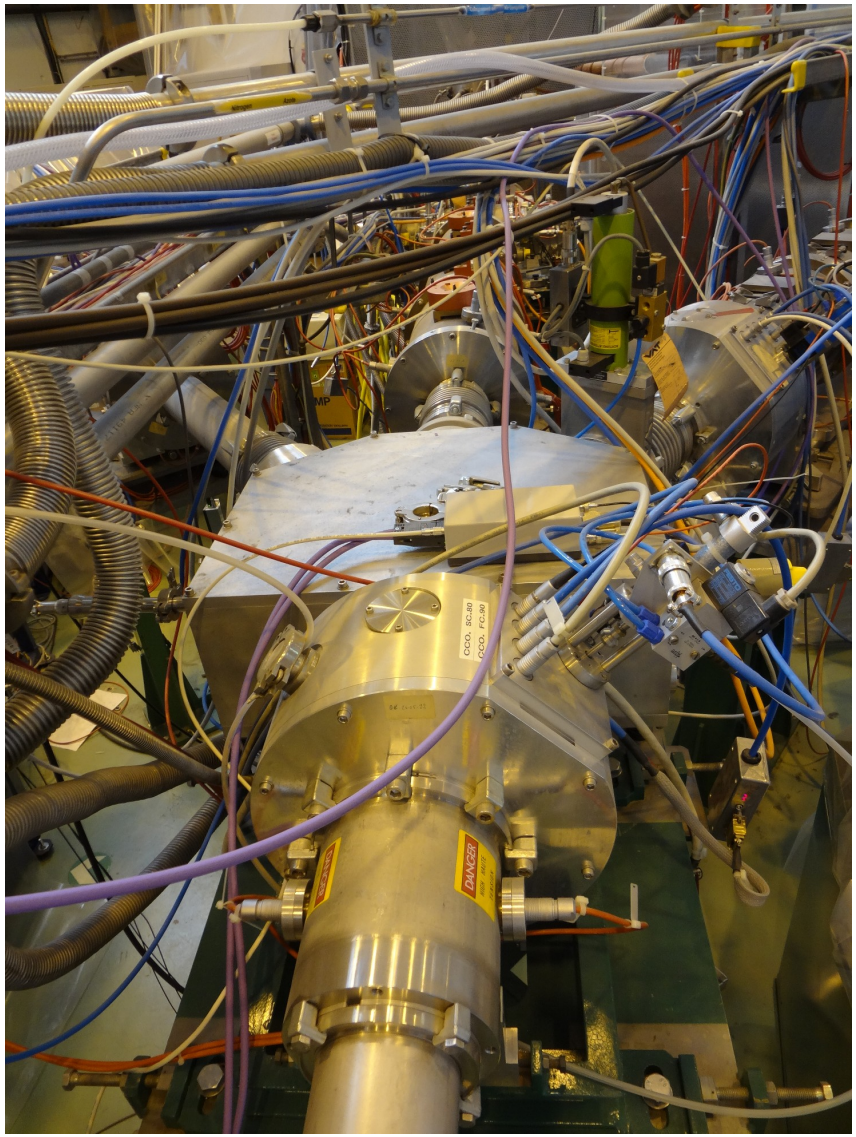
The Kicker, Switchyard, and Quadrupole



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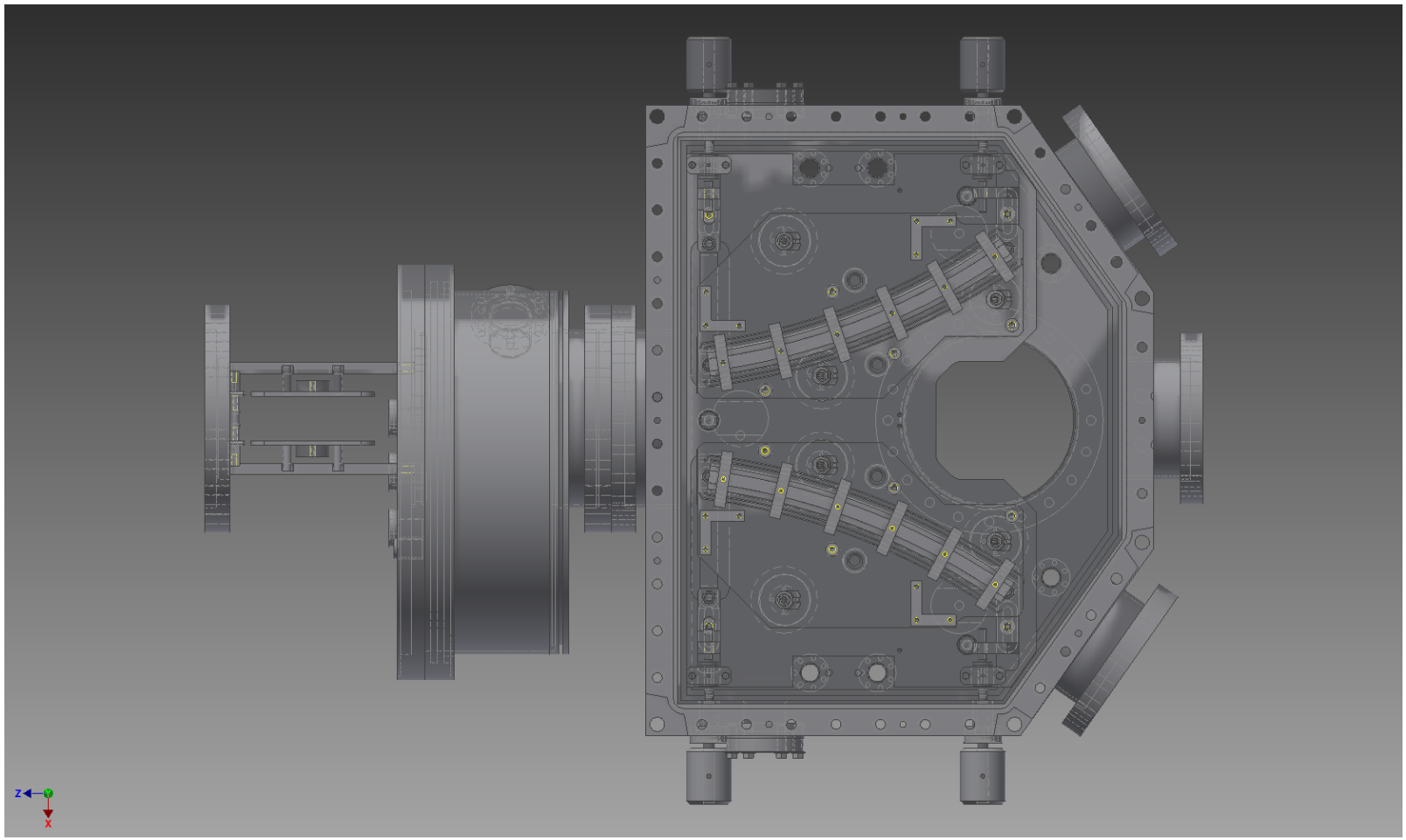

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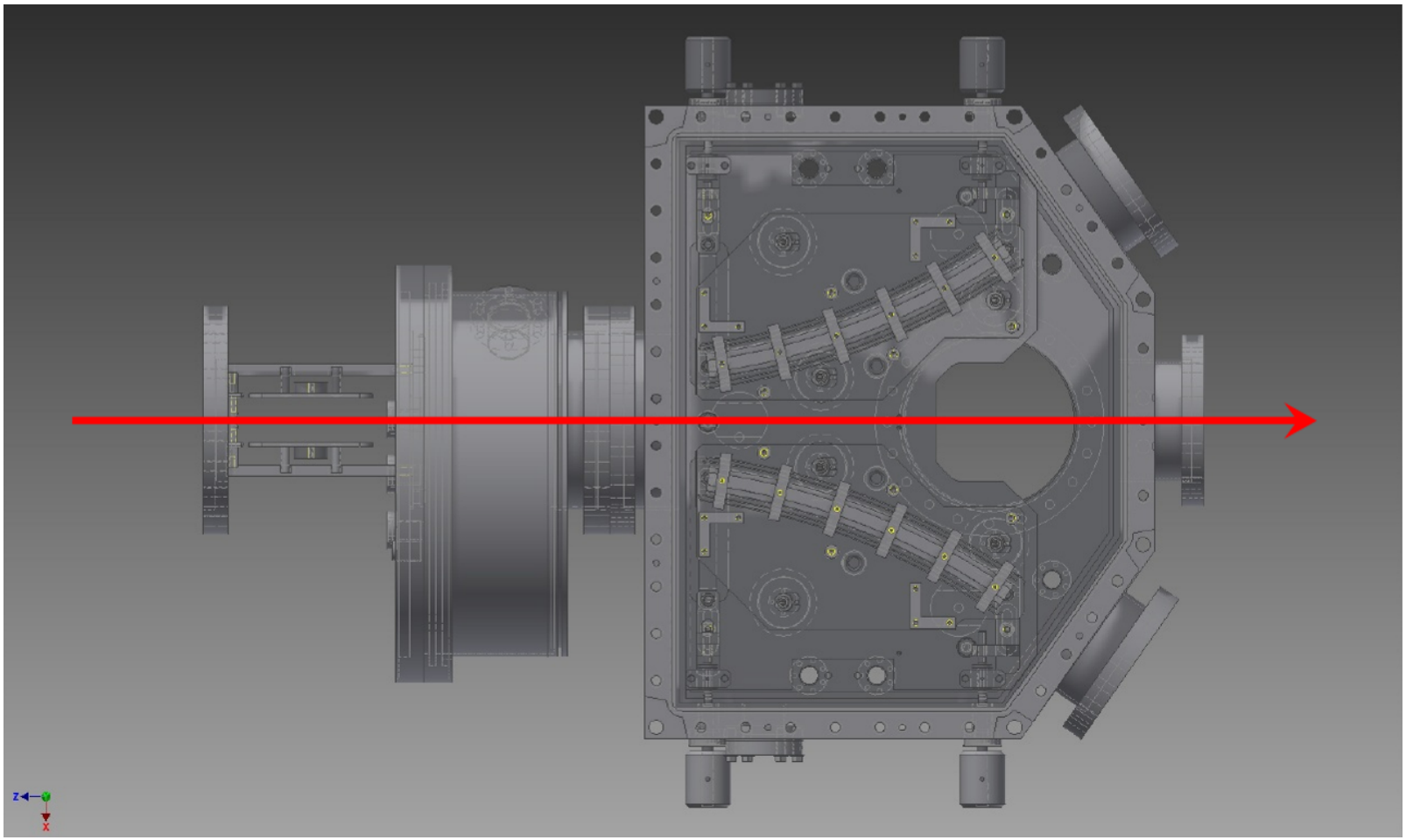

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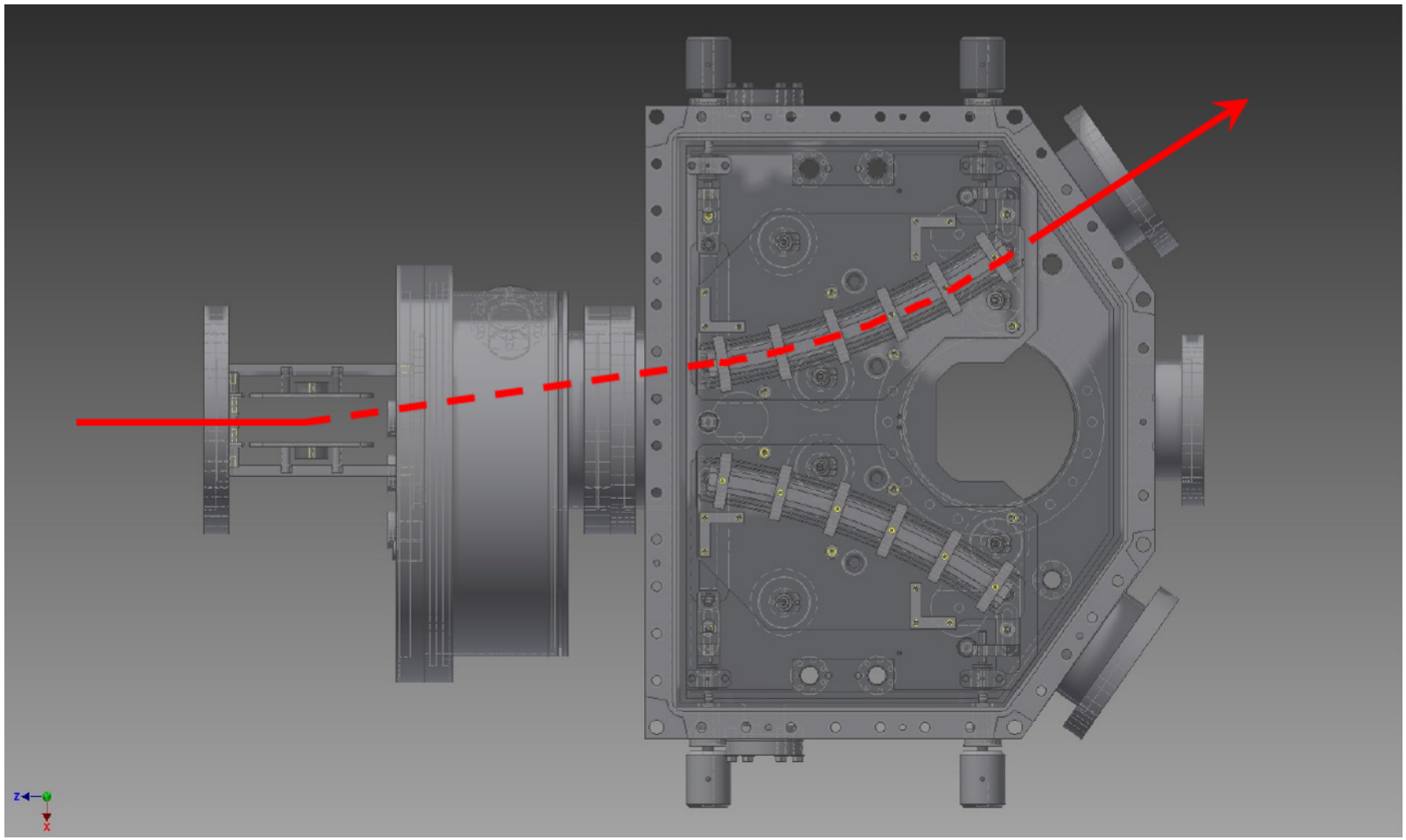

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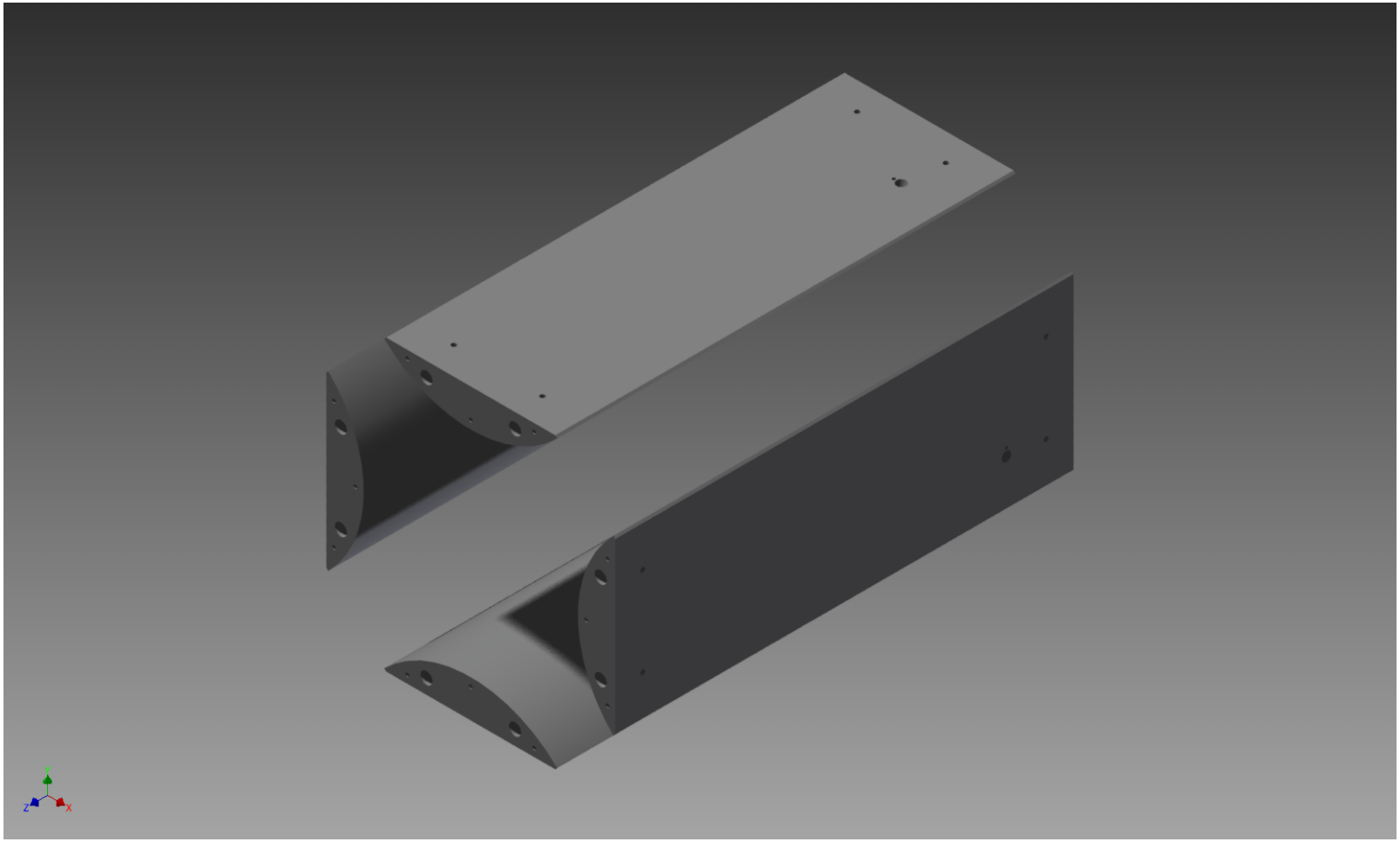
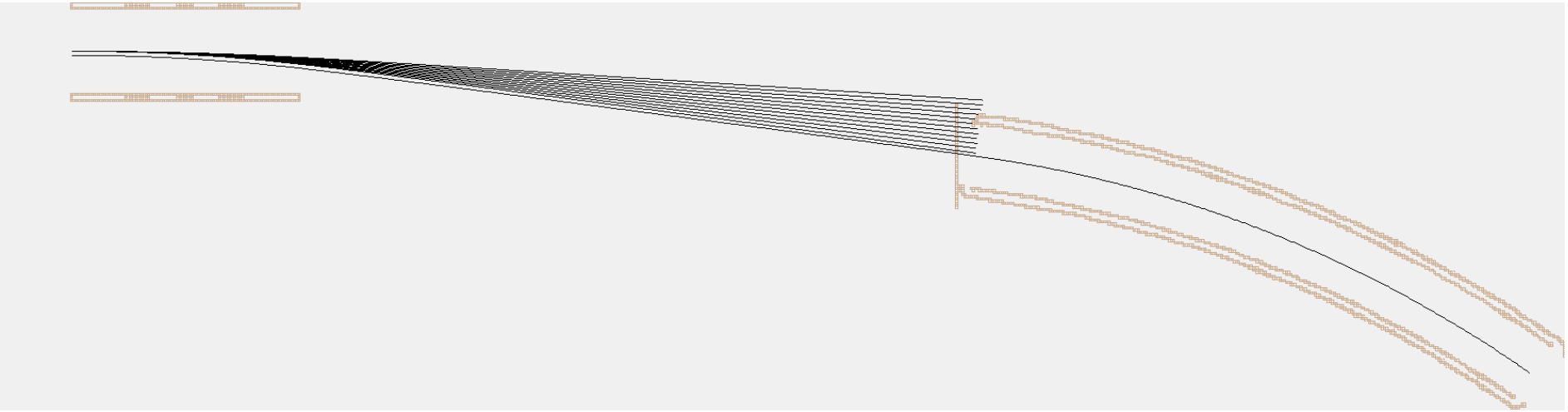


Extracting the Transfer Matrices

Final result example output from SIMION:



Given 1 proton at 50 keV:

- kicker plate voltages: $\pm 2067.69V$
- deflector plate voltages: $\pm 2421.79V$

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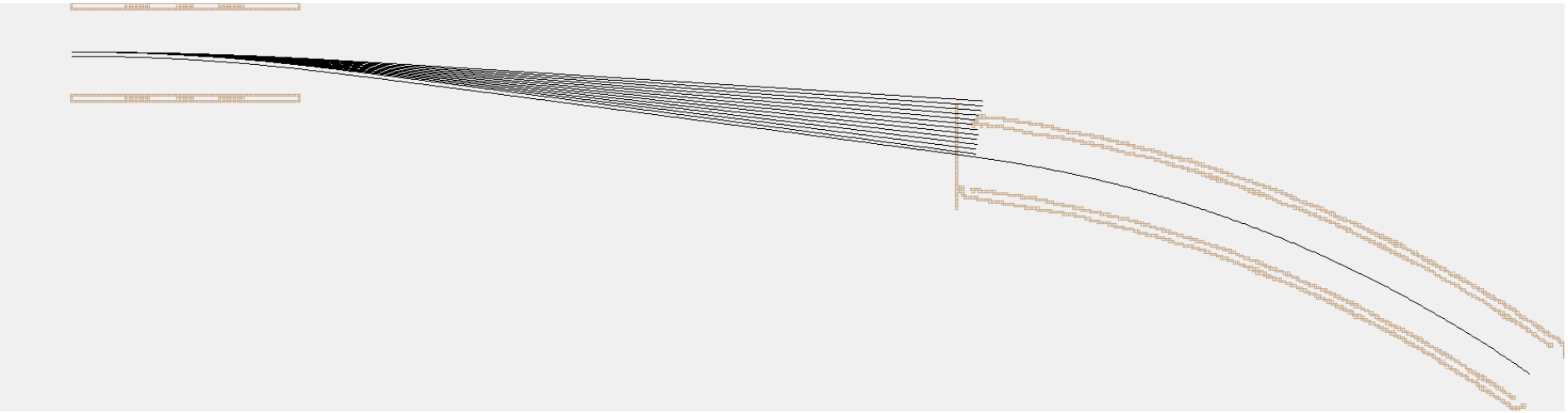

The resulting transfer matrix:

$$\mathbf{R} = \begin{vmatrix} 0.928447 & 0.682261 & -0.025918 & -0.104912 \\ -0.546270 & 0.105721 & -0.054838 & -0.057641 \\ -0.026533 & -0.001919 & 0.999794 & 0.713014 \\ -0.083600 & -0.003370 & -0.004589 & 0.964268 \end{vmatrix}$$

Future Steps

1. Continue extracting the transfer matrices from SIMION.
2. Incorporate these into the MAD-X simulations.
3. Automate MAD-X so that any scientist can specify a particle type and initial conditions, and know what the strengths of the magnets should be set at.

There is plenty of more work to do, but it is the first step towards making the ISOLDE matching procedure more efficient.

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Questions?

Special thanks to...