

Symplectified Transfer Matrices across Individual Injector Cryo-Components Derived from 02/03/05 Difference Orbit Measurements

All Entry/Exit points refer to locations inside the design model.
All matrices are in m-rad.

Capture + Cryo-Unit:

From: Entry face of Capture (P= 0.334965 MeV/C)
To: IPM0L01 (P=5.5 MeV/C)

$$\begin{pmatrix} -0.623823 & -0.183197 & 0.0177688 & -0.00861233 \\ -0.157818 & -0.144276 & -0.0058171 & -0.00775912 \\ 0.0212808 & -0.00490488 & -0.578752 & -0.111091 \\ -0.00946495 & -0.00665128 & -0.044886 & -0.114172 \end{pmatrix}$$

On-Diag.Normalized Determinant	1.00309
Off-Diag.Normalized Determinant	-0.00308637
4D Determinant Ratio ¹	1.00154
X-Sub Matrix SVD Condition Number	7.53519
Y-Sub Matrix SVD Condition Number	5.75758
4 X 4 Matrix SVD Condition Number	7.62251

There is considerable uncertainty in this measurement, mainly due to the following:

- The above was derived using only the last 100 keV BPM's. No valid model exists at this point encompassing all 5 BPM's in the uncoupled region due to the phantom solenoid MFA0I01.
- Even with only 3 BPM's the fit of orbit to model was quite poor. The 100 keV line model appears to be worse than a few months ago for orbits of similar amplitude (200-300 microns).
- Nonetheless the above result seems to reasonably reproduce the FOPT implied transport across the CU of fitted orbit coordinates, if one neglects temporarily the validity of the latter. This is why it is used here. If one uses only the last 2 100 keV BPM's in the analysis, the resulting matrix cannot even explain transport of all coordinates across the CU.
- Opening up A1 clearly improved the data quality. Orbit restriction/scraping was still seen in many instances at A2. A repeat of this measurement with A2 opened up would be highly desirable. From recent tests it was also clear that opening up A2 may be the only way to modify the phase advance in 100 keV in a way more friendly to FOPT measurements (in affording more orthogonal kicks).
- Interestingly, if one again ignores the underlying 100 keV model issue, the CU transport is neither very coupled nor very singular. The FOPT orbit however suggests singular transport before capture+CU. Again this begs the question of Injector modeling. We really need to be able to explain single particle optics in the 100 keV line (no cryos) with confidence. The point is, orbit blowup can come as easily from non-cryo components as it can from cryo-components if we can't model the transport correctly.

The outstanding (and most urgent) issues at this point in my opinion are thus:

- **Make 100 keV line model explain the data, or find out why it does not and fix it. Can we ask the Injector modeling team to take this on as a high priority?**
- **Include MFA0I01 into the model. Alex has volunteered to do this. He'll be back next week.**

¹ The Determinant Ratio in the table is defined as $\left[\frac{\det(M_x) \cdot \det(M_y)}{\det(M_{xy})} \right]^{1/4}$, a measure of the XY coupling content in the full matrix.

Cryo-Module:

Not much surprise here. The CM transport has been almost unchanged for the past half-plus year even with energy change. The measurement below basically reproduced the results from the past dozen measurements. The minor difference from past measurements is to a large extent due to the skew quad MQS0L05 being turned off for the first time.

The new addition here is the transport through the first CM (IN03) measured on 02/03. Short of a history on this I can't say how stable this is, but it is unlikely that IN03 & IN04 will conspire to make the total transport stable over time while being unstable separately. The measurement quality in both cases is very good.

The transport across IN04 is then inferred from these 2 measurements. A slight 0.3% momentum difference between the 2 measurements at 0L05, as calculated by the model server (because we tweaked IN03 when IN04 was turned off in order to get beam through the Chicane cleanly), had to be ignored to get this indirect result.

From these matrices it can be seen that the singularity responsible for the blowup, obvious in the overall transport **A**, is really not coming from any individual singular component, but rather from the way all its components are compounded together. This is known as mismatch. The measurement performed here is relevant because it sheds light on how MQJ0L05 and MQS0L05 should really be set to most logically carry the beam envelope (or trajectory) from IN03 to IN04. This piece of information has not been available up to now.

This measurement is also important in providing input to the 12 GeV Injector recirculation design. With the much more stringent operational condition imposed by recirculation, we need to know the real model to a much better degree.

All measurements were made on 02/02-02/03/05
All skew quads in measured sections were turned off.
Quad MQJOL05 was set at -277.81 G

A

From: Entry face of cavity R031 (P=5.5 MeV/C)
To: Exit face of cavity R048 (P=64.9451 MeV/C)

$$\begin{pmatrix} -1.58052 & 5.50264 & 0.260575 & 1.03608 \\ -0.108714 & 0.334808 & 0.00879415 & 0.0950029 \\ -0.243357 & 0.923744 & -0.247615 & -0.520639 \\ -0.0329967 & 0.0609662 & 0.0257164 & -0.22476 \end{pmatrix}$$

On-Diag.Normalized Determinant 0.815273
Off-Diag.Normalized Determinant 0.184727
4D Determinant Ratio 0.902925
X-Sub Matrix SVD Condition Number 476.528
Y-Sub Matrix SVD Condition Number 5.36908
4 X 4 Matrix SVD Condition Number 410.448

B

From: Entry face of cavity R031 (P=5.5 MeV/C)
To: Exit face of cavity R038 (P=34.6519 MeV/C)
Chicane BPMs included in trajectory fit (not very good result)

$$\begin{pmatrix} -0.344419 & 1.62077 & 0.0116645 & 0.0715413 \\ -0.167251 & 0.320078 & 0.0312702 & 0.0107227 \\ -0.0942814 & 0.638081 & -0.568645 & 2.25278 \\ -0.00446822 & 0.0526416 & -0.12049 & 0.194504 \end{pmatrix}$$

C

From: Entry face of cavity R031 (P=5.5 MeV/C)
To: Exit face of cavity R038 (P=34.6519 MeV/C)
Chicane BPMs not included in trajectory fit (better result)

$$\begin{pmatrix} -0.613734 & 2.82274 & 0.0313588 & 0.311705 \\ -0.0576443 & -0.00257574 & 0.0160255 & -0.0184774 \\ -0.0249847 & 0.449559 & -0.444282 & 2.13336 \\ 0.0111389 & 0.0226955 & -0.123231 & 0.221932 \end{pmatrix}$$

On-Diag.Normalized Determinant 1.03512
Off-Diag.Normalized Determinant -0.0351223
4D Determinant Ratio 1.01741
X-Sub Matrix SVD Condition Number 50.7904
Y-Sub Matrix SVD Condition Number 29.2607
4 X 4 Matrix SVD Condition Number 58.6892

D

From: Entry face of cavity R041 (P=34.6519 MeV/C)

To: Exit face of cavity R048 (P=64.9451 MeV/C)

This is indirectly inferred from matrices **A**, **C** above, and model for transport between R038 & R041 including MQJ0L05.

$$\begin{pmatrix} 0.964092 & 2.67388 & -0.303516 & -3.23091 \\ -0.00330432 & 0.482531 & -0.0000213884 & -0.196321 \\ 0.29085 & 0.191735 & 0.718719 & 5.69747 \\ -0.0050035 & 0.201334 & -0.00884504 & 0.589445 \end{pmatrix}$$

On-Diag.Normalized Determinant	0.888452
Off-Diag.Normalized Determinant	0.111548
4D Determinant Ratio	0.942577
X-Sub Matrix SVD Condition Number	17.4771
Y-Sub Matrix SVD Condition Number	70.2864
4 X 4 Matrix SVD Condition Number	85.2181