



RESULTS FROM THE 6D DIAGNOSTICS TEST BENCH AT SNS

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Acknowledgements

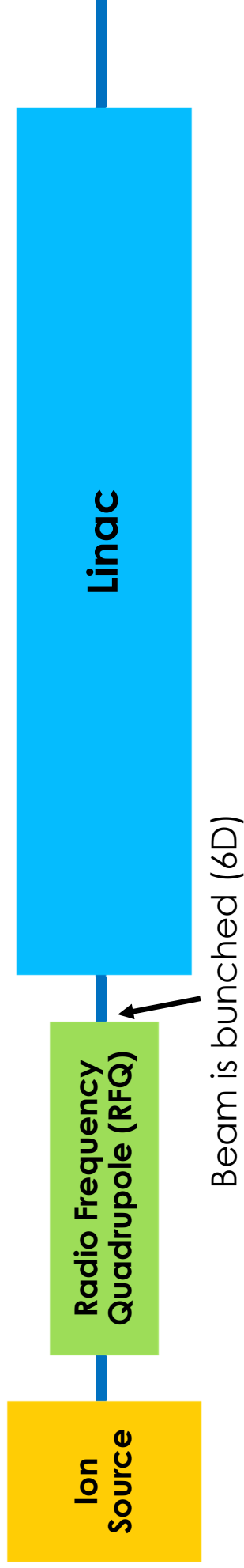
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Outline

- Motivation
 - The SNS Front End
 - Six Dimensional Phase Space
- Experiment
 - Concept
 - The Beam Test Facility
 - Bunch Shape Monitor
- Results
 - Energy Correlation

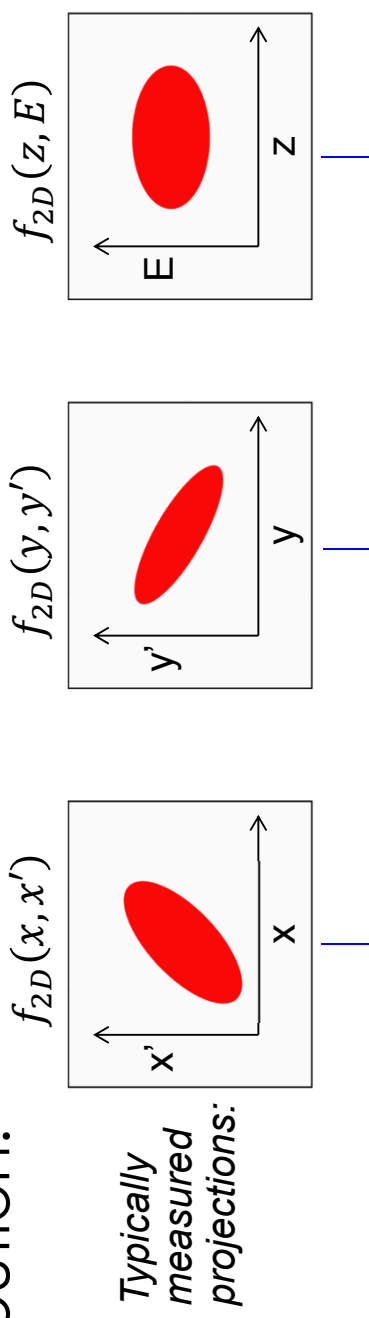
SNS Front End



- Simulations fail at predicting evolution in the SNS linac.
- Single pass system – initial distribution matters.
- An inaccurate initial distribution might be the problem in simulations.

Six Dimensional Phase Space

- Typical scans only measure (x, x') , (y, y') , or (z, E) .
- The three separate 2D phase spaces are combined to create a 6D distribution.



$$f_{3*2D} = f_{2D}(x, x') * f_{2D}(y, y') * f_{2D}(z, E)$$

Six Dimensional Phase Space

- These scans cannot show any correlations between variables not measured together.
 - Ex. No (x, y') or (y, z) .
- The only way to truly know the initial distribution is to measure all six parameters simultaneously.

$$f_{2D}(x, x') * f_{2D}(y, y') * f_{2D}(z, E) \neq f_{6D}(x, x', y, y', z, E)$$

Assumes all cross-terms = 0

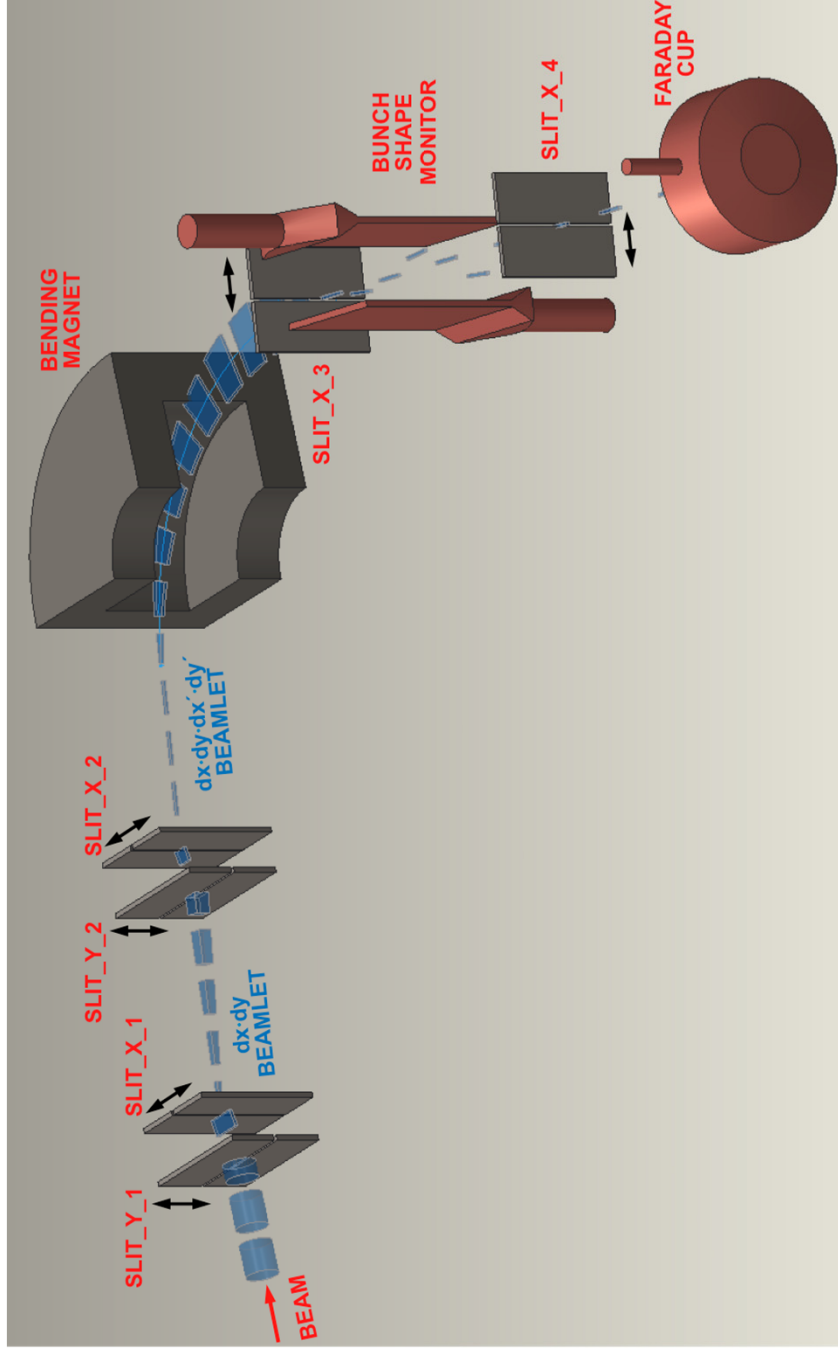
Includes cross-terms:

$[(x, y), (x, y'), (x, z),$
 $(x, E), (y, x') \dots]$

Six Dimensional Phase Space

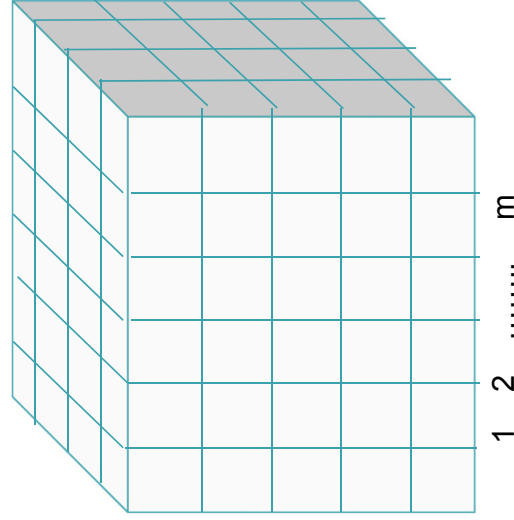
- Correlations – a dependence of one variable on another
 - Ex. The energy spread of particles looks different depending on the horizontal position: $f_E(x)$.
- Correlations could exist due to:
 - Skew magnets
 - Solenoid focusing
 - Space charge

Full Six Dimensional Scan - Concept



Challenges

- Each slit reduces signal strength $\sim 1/20$.
- Each dimension exponentially increases the scan time.
 - Time makes the scan hard to accomplish at a big user facility.

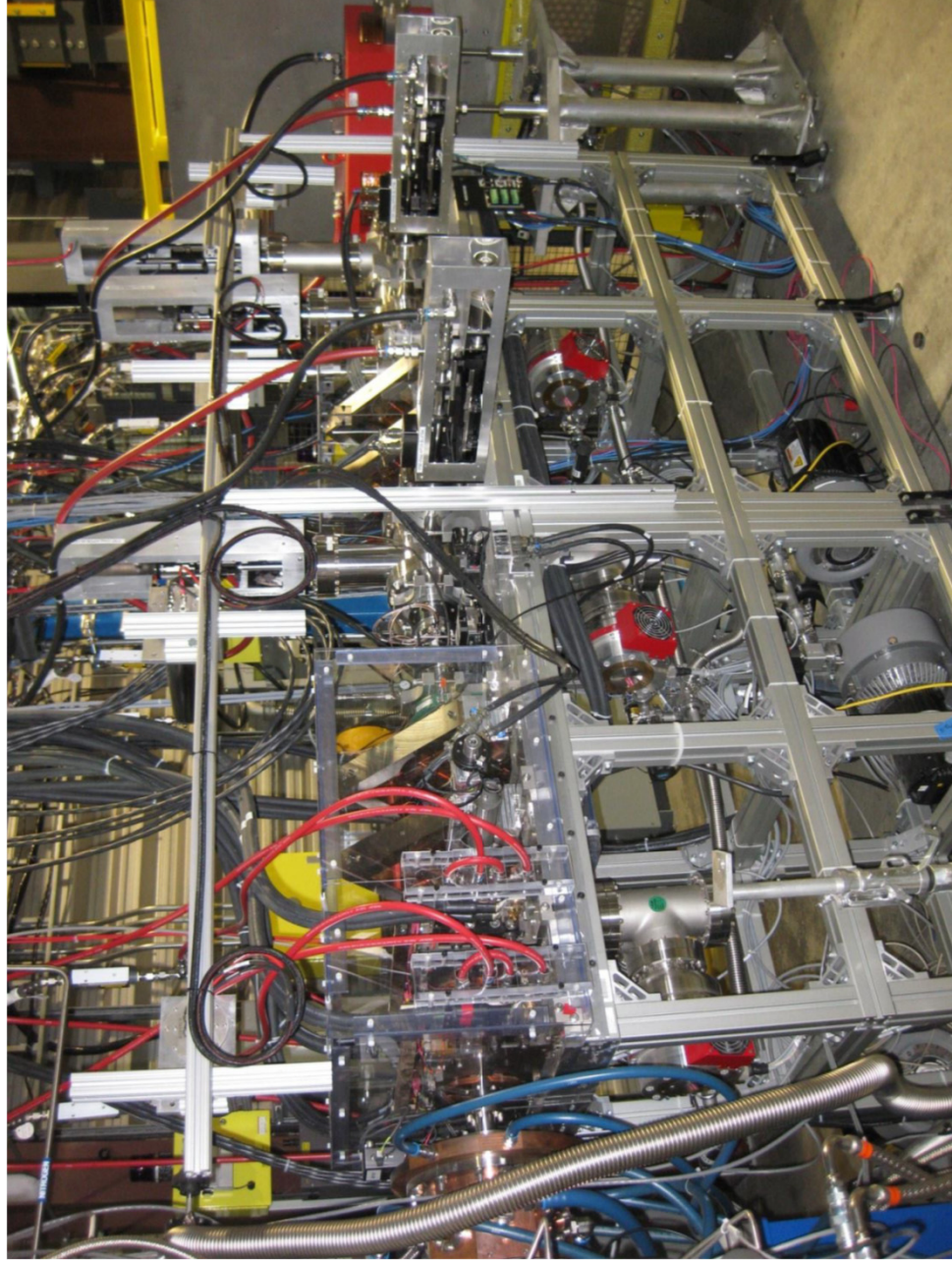


$$N_{bins} = m^D$$

For a coarse measurement: $m = 10$ } $\rightarrow N_{bins} = 10^6$
 $D = 6$

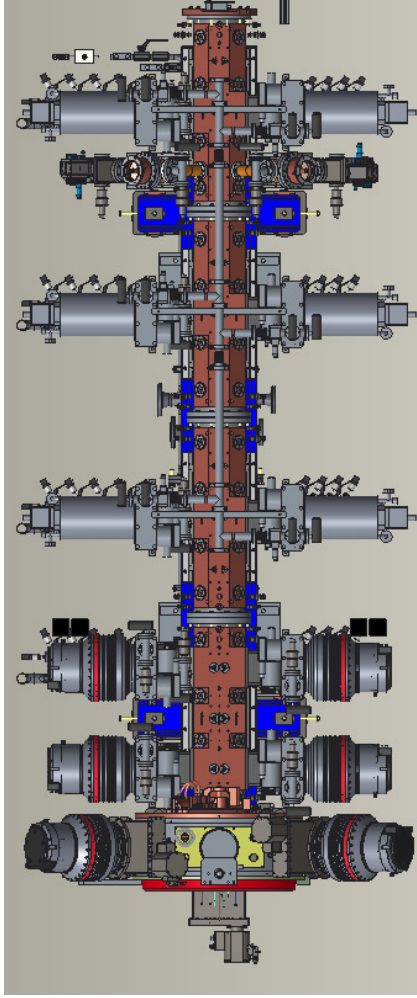
Scan rate 1 step/sec: 10^6 sec = 280 hrs
Scan rate 10 step/sec: 10^5 sec = 28 hrs

Beam Test Facility

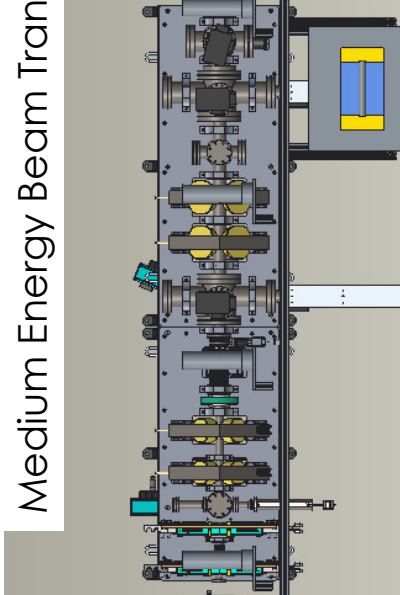


Beam Test Facility

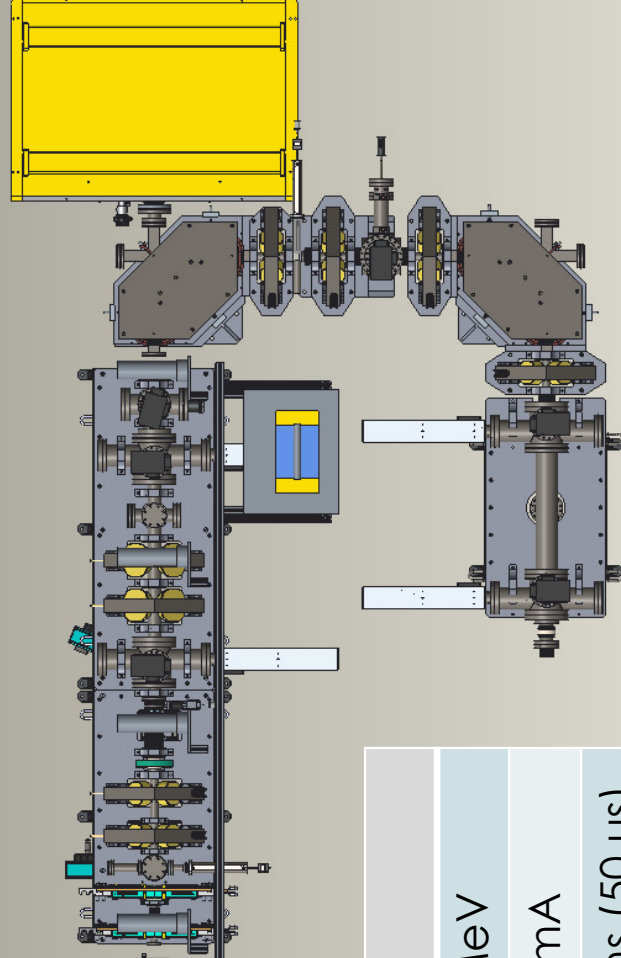
Radio Frequency Quadrupole (RFQ)



Ion Source

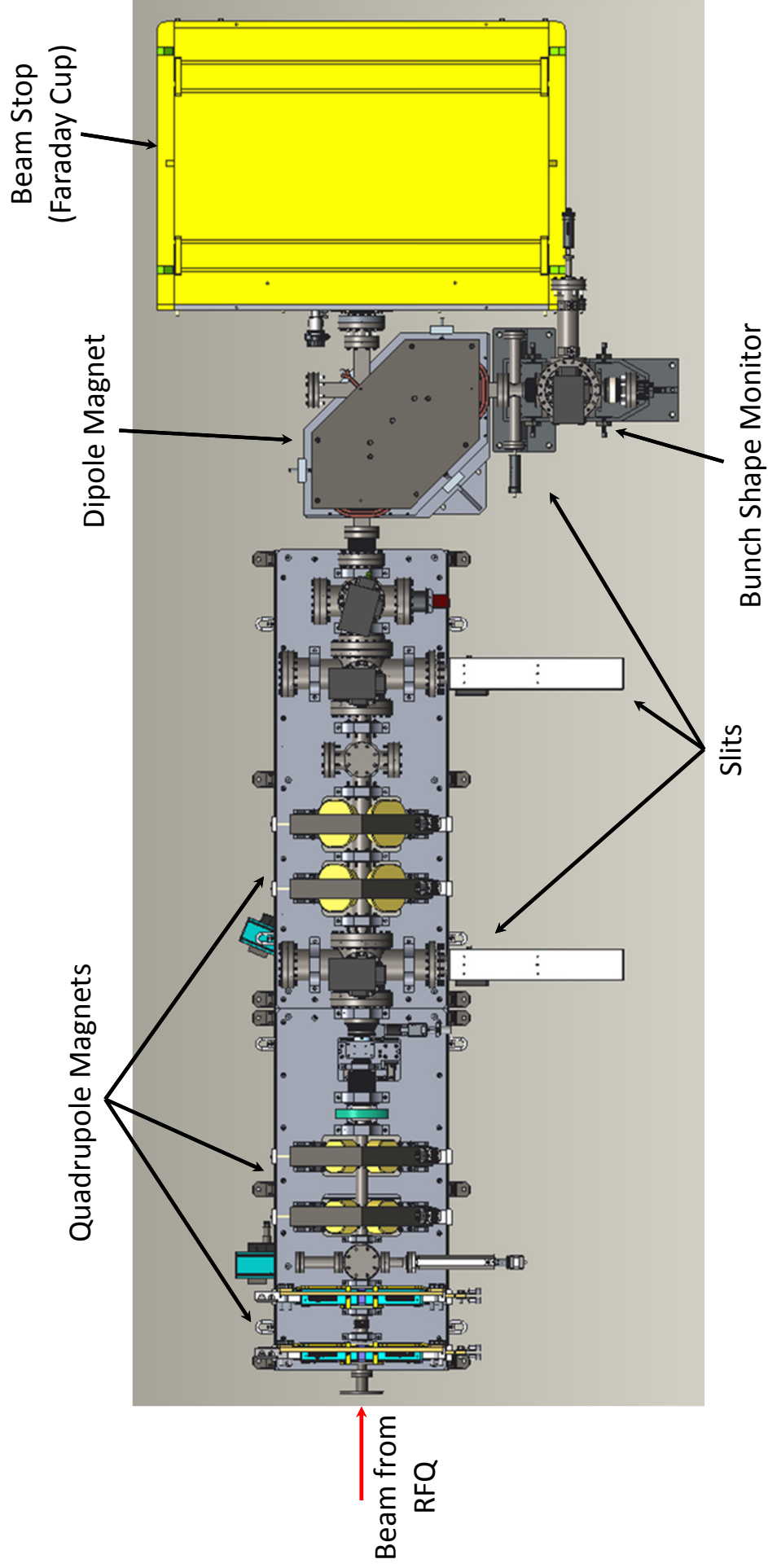


Medium Energy Beam Transport (MEBT)

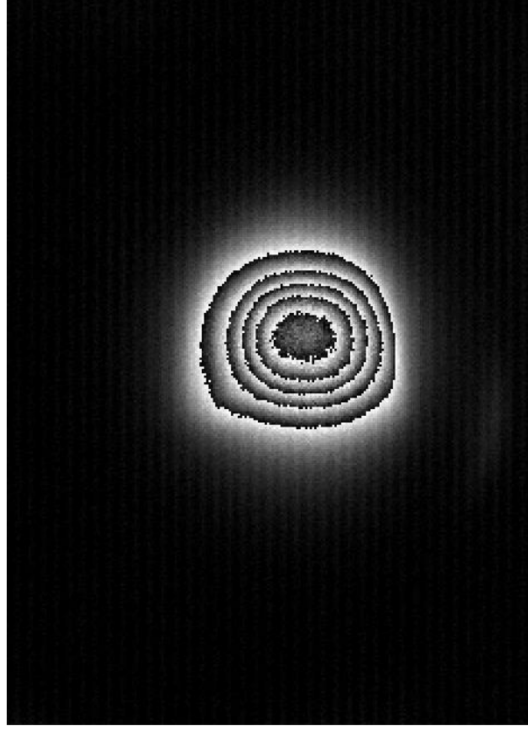
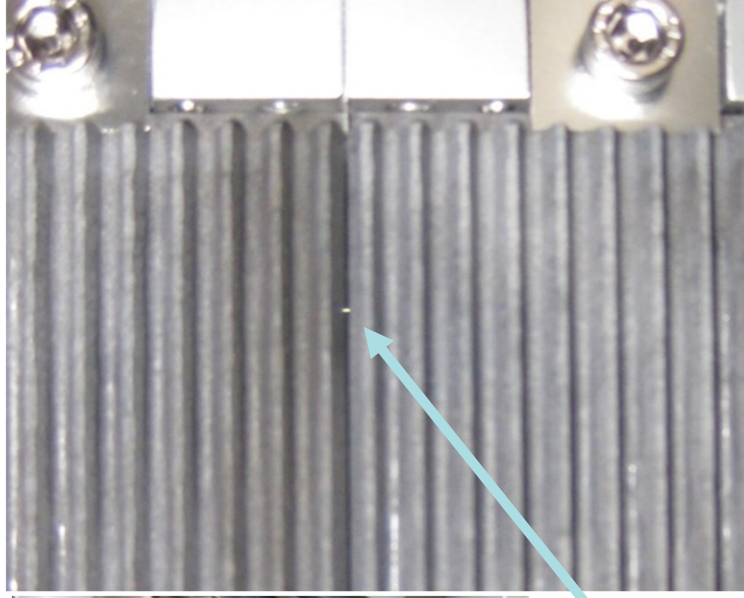
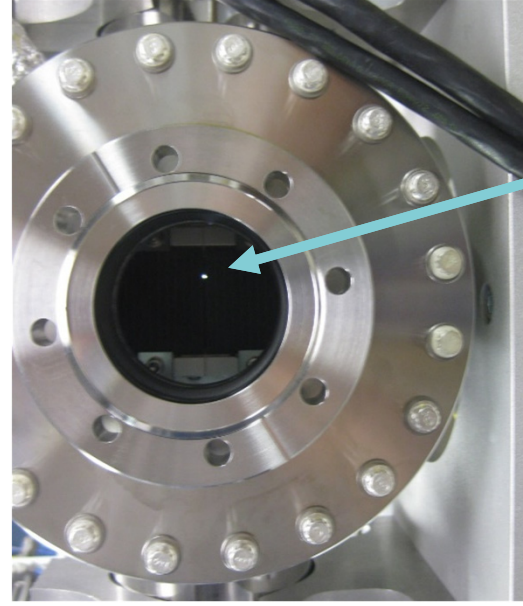


Particles	H ⁻
Energy	2.5 MeV
Current	< 50 mA
Pulse width	< 1 ms (50 μs)
Rep rate	≤ 60 Hz (10 Hz)
Beam Power	< 7.5 kW

Beam Test Facility (MEBT)



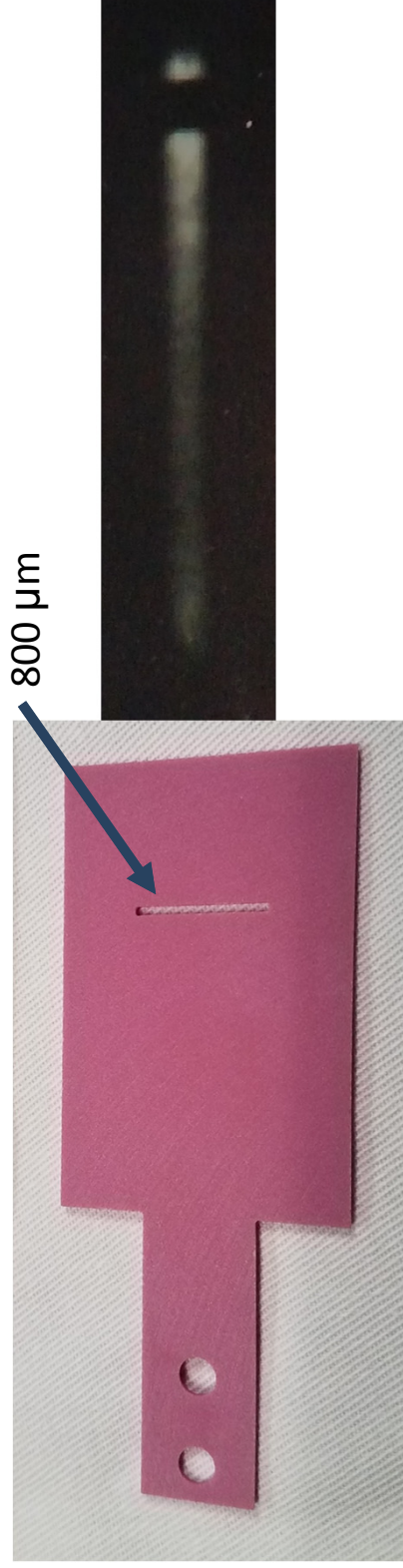
Transverse Slits (x, y, x', y')



200 μm x 200 μm

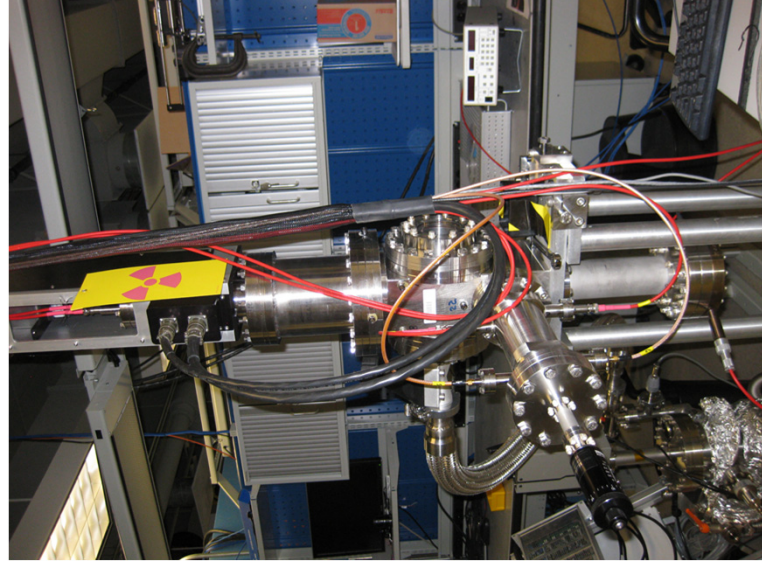
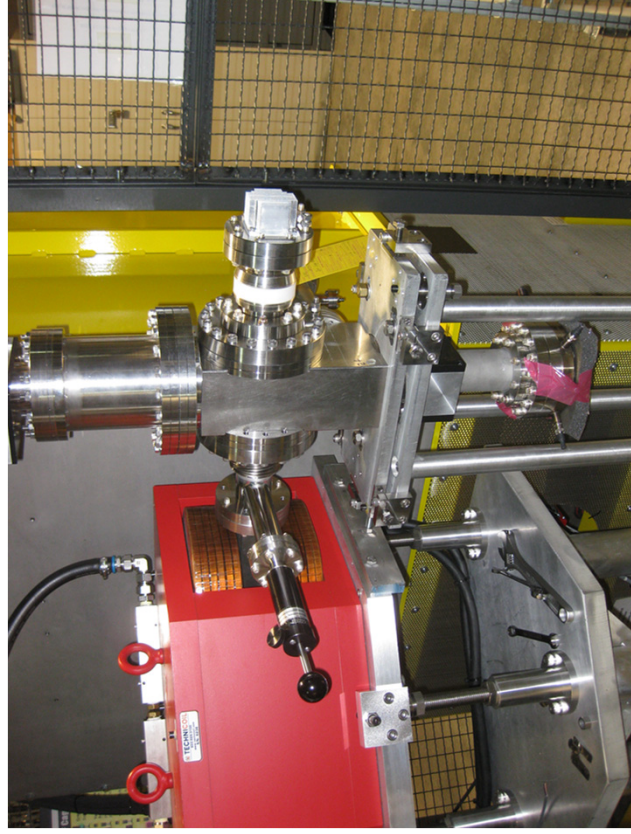
Energy Slit/Screen

- Screens allow measuring an entire dimension at once greatly decreasing scan time.
- The energy slit doubles as a screen.

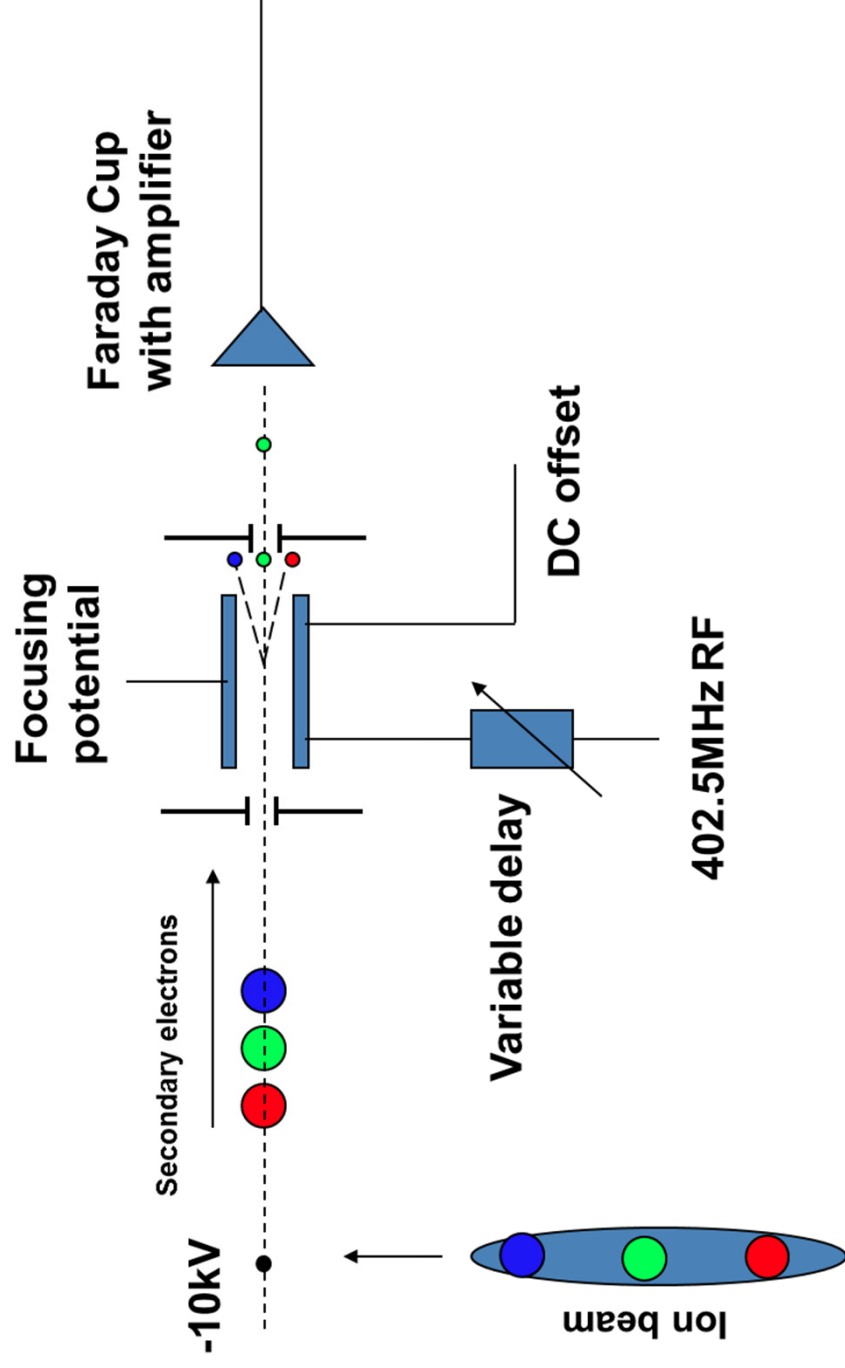


Bunch Shape Monitor

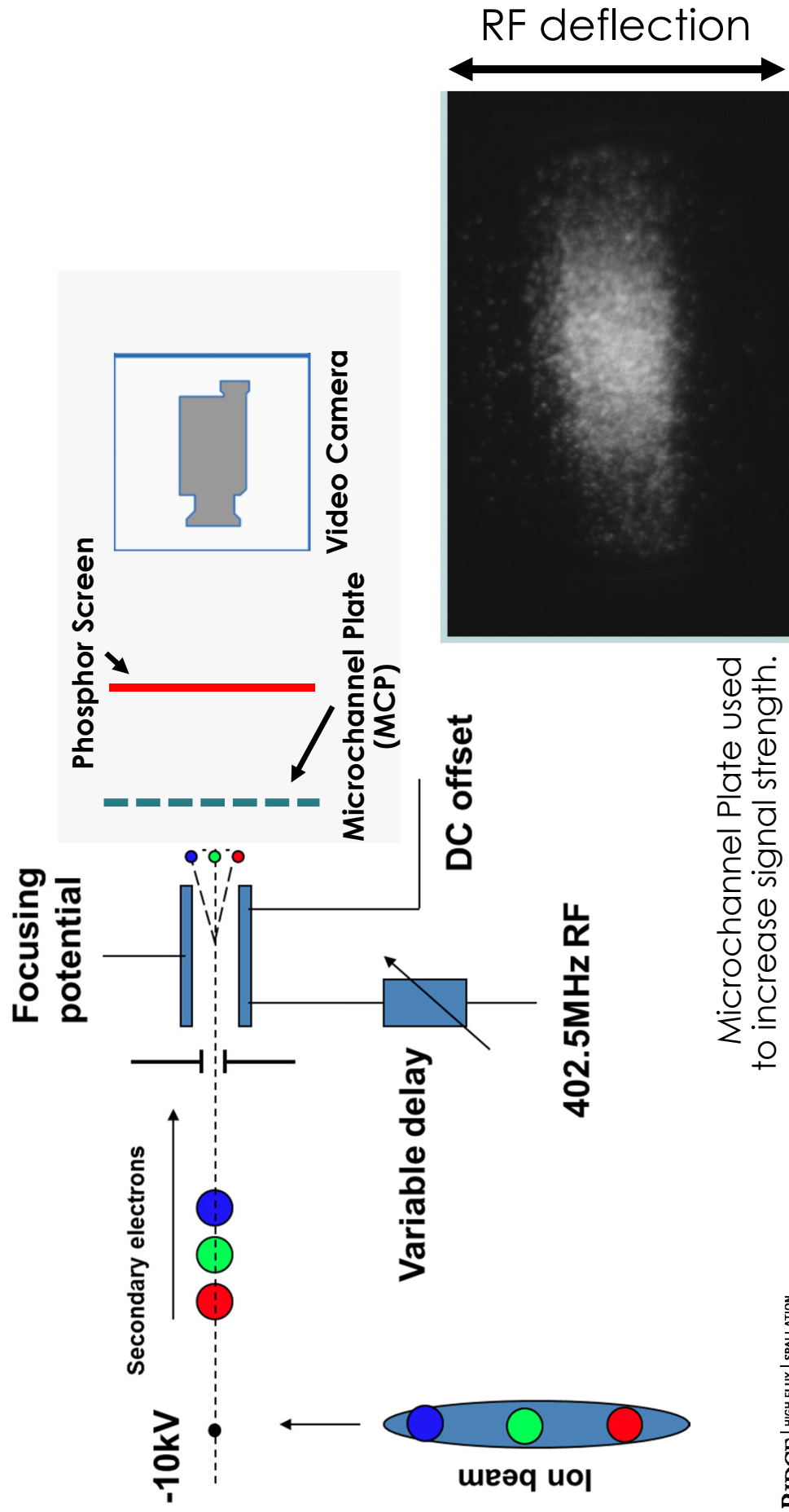
Protons are too heavy to easily deflect, so a Bunch Shape Monitor is used to deflect electrons.



Bunch Shape Monitor



Bunch Shape Monitor



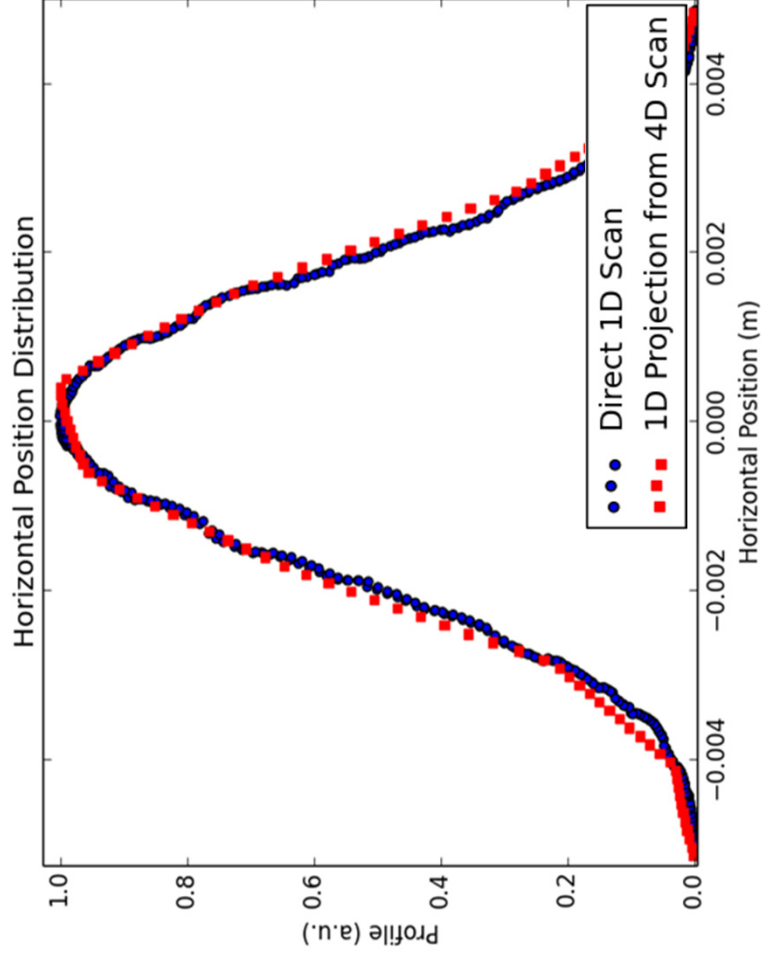
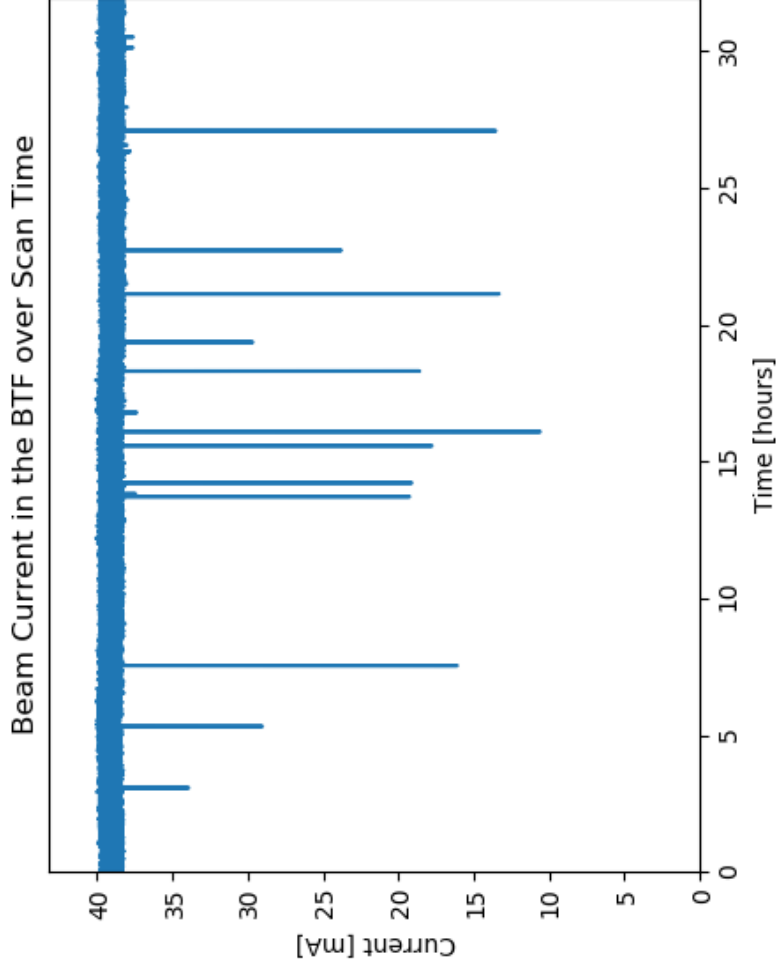
Microchannel Plate used to increase signal strength.

Scan Results

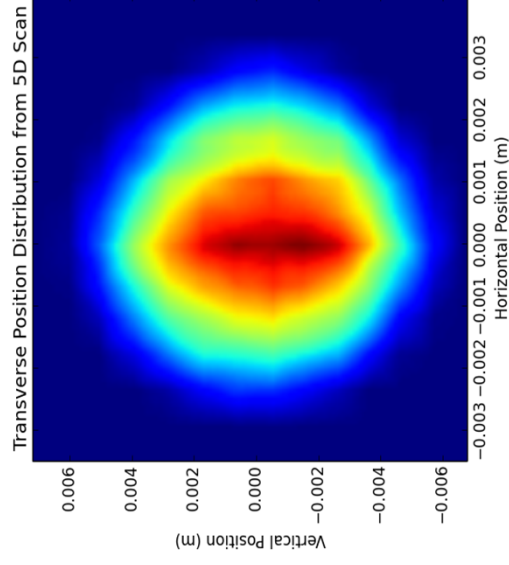
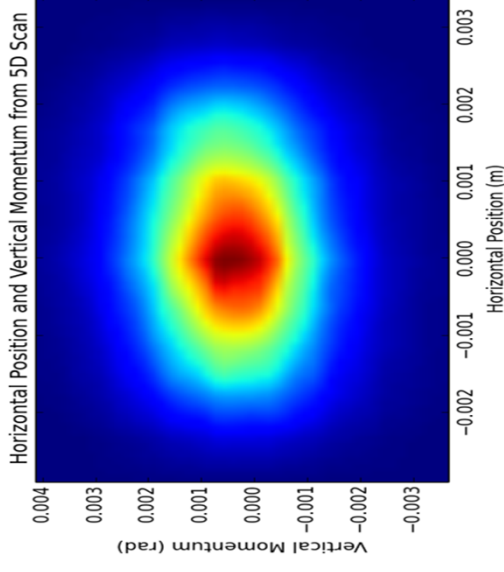
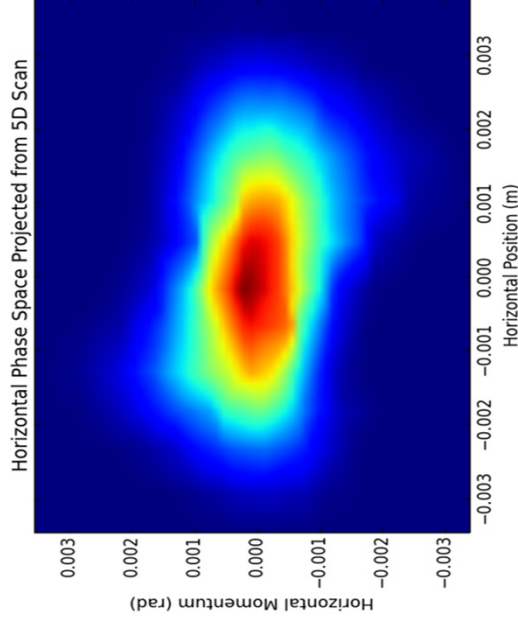
- For 5D and 6D scans, screens decrease the scan time and greatly increase the number of data points.

Typical Scan Results	One Dimension	Two Dimensions	Four Dimensions (x, y, x', y')	Five Dimensions (x, y, x', y', E)	Six Dimensions
Time (Example)	< one minute	~ 10 minutes	4 hrs 50 min	4 hrs 40 min	32 hrs
Data Points (Example)	~50	~1300	~88000	~2.5 x 10 ⁹	~5.6 x 10 ⁶
Total Number of Scans	50	40	10	20	1

Beam Stability

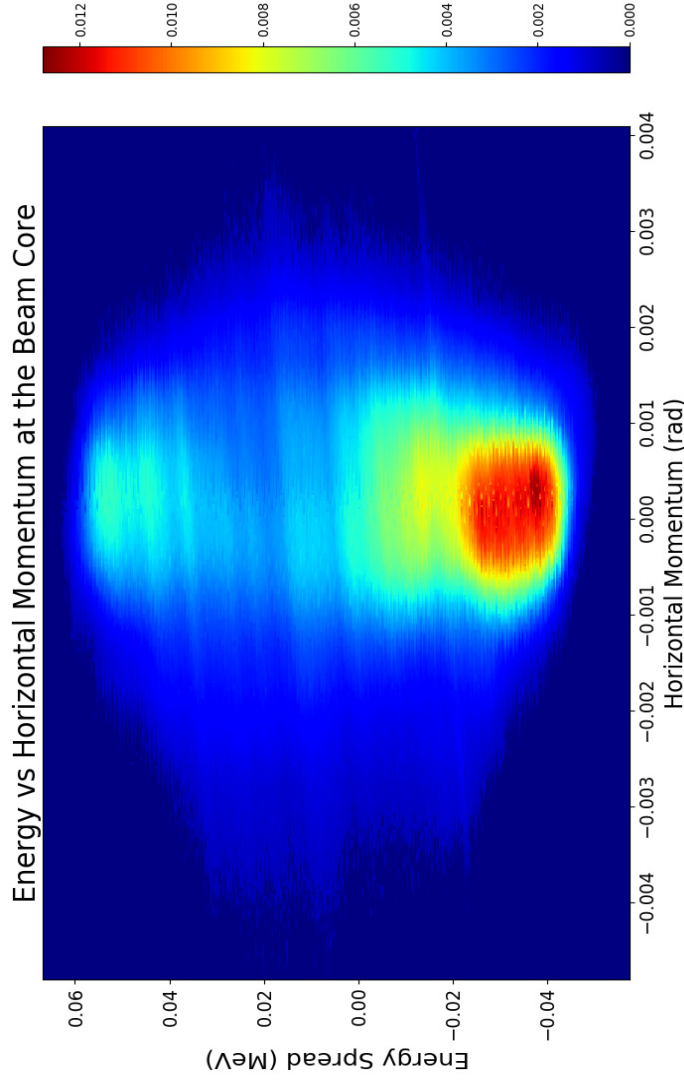


Results



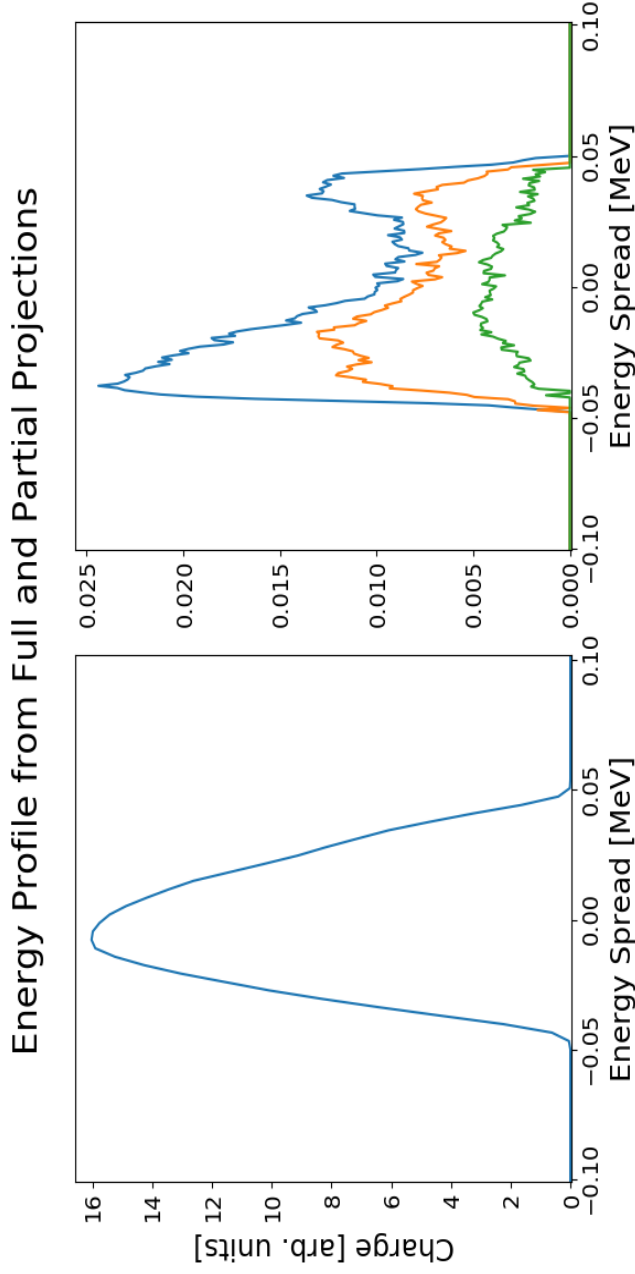
- A few subsets from a 5D scan

Results



- Scan was made with x , y , and y' slits fixed at the center
- A similar relation occurs between energy and each transverse variable.

Results

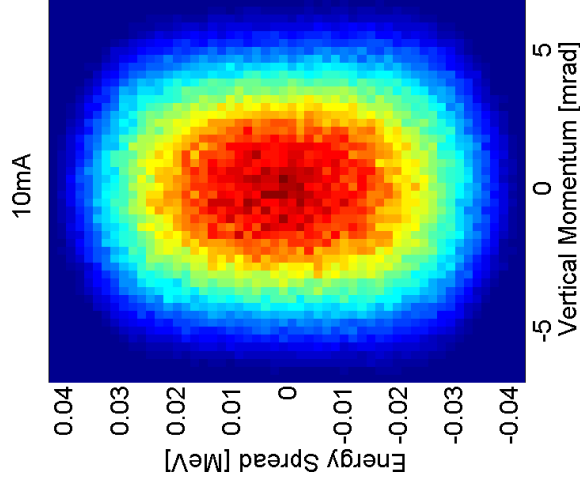
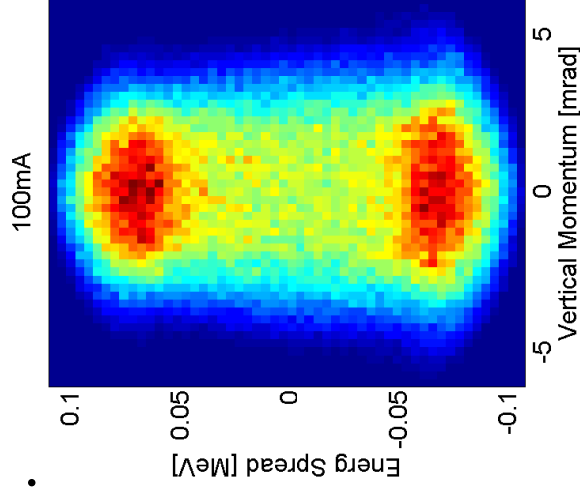


- Left: Integrated energy spread from 5D scan.
- Right: Energy spreads near the beam core at different x' .

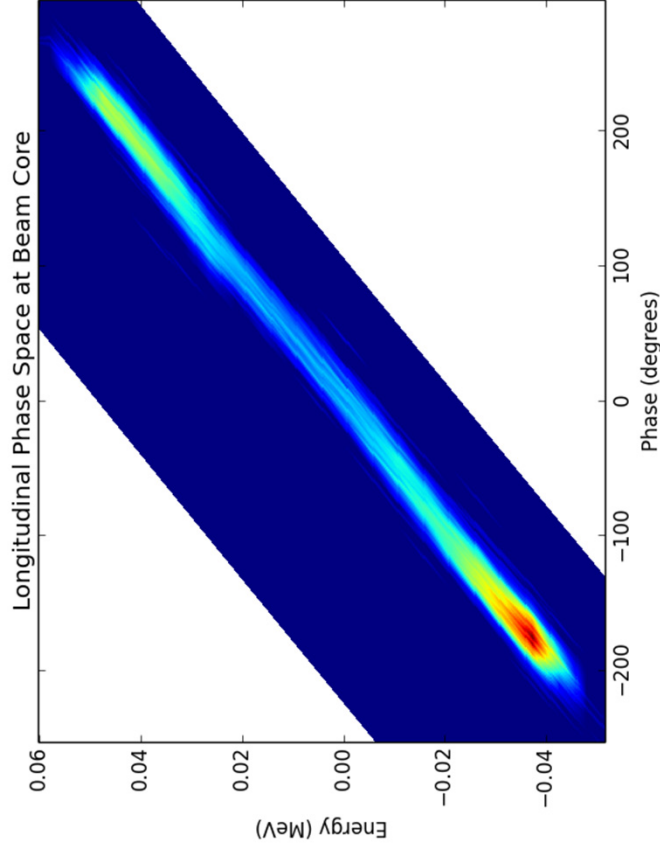
The shape of the energy spread depends on transverse variables:
This proves that correlations exist outside the typical 2D subsets.

Simulations

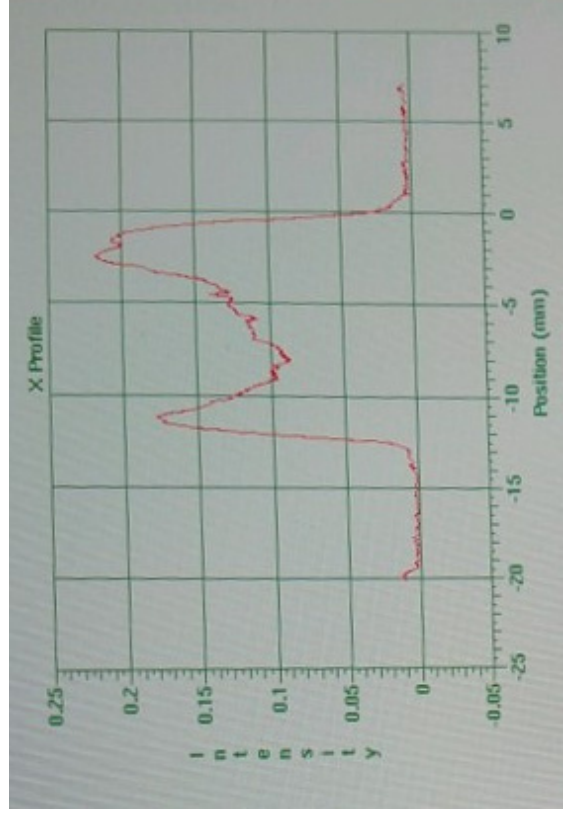
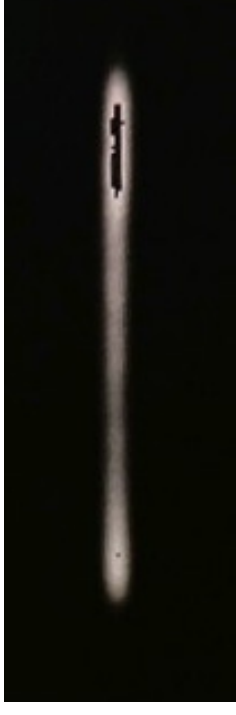
- Able to replicate phenomenon in simulation (PARMILA) but needs higher than realistic current.
- Beam current dependency shows the phenomenon is related to space charge.



Results



- Left: Longitudinal Phase Space

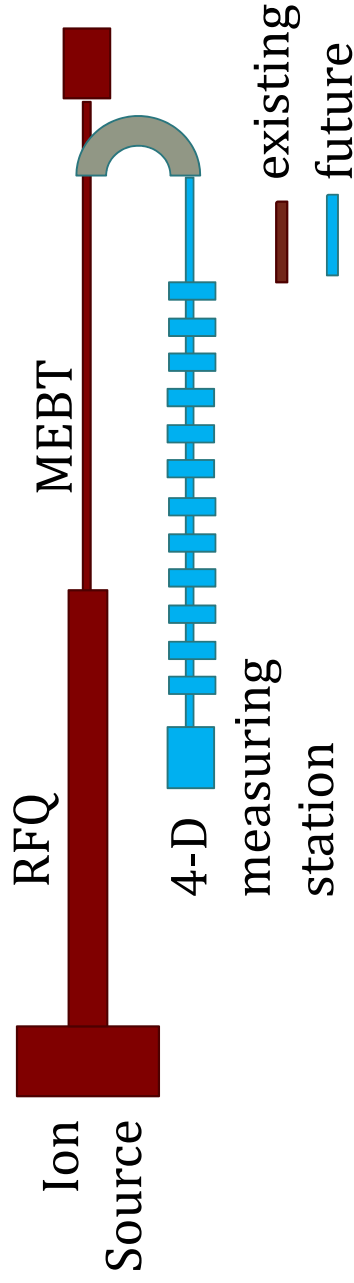


- Right: Energy screen using a different RFQ

Measured with the transverse slits fixed at the center.

Future Work

- The beam line is being extended with more diagnostics at the end.
- This will allow a comparison of beam evolution between simulation and measurement using the correct starting distribution.



Thank You