Beam size and emittance measurements in LEBT

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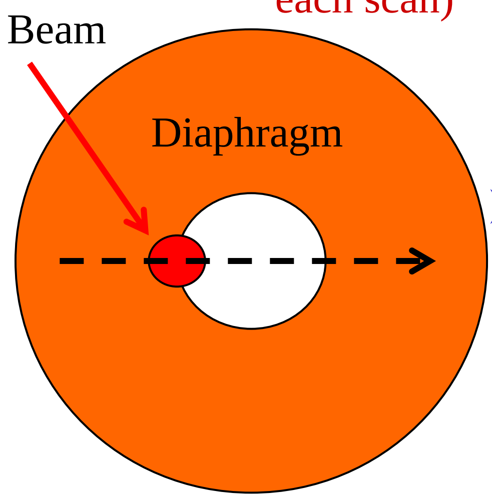
Outline

1. Beam size measurements
2. Solenoid scans
3. Beam loss at the solenoid diaphragm

Principle of beam size measurements

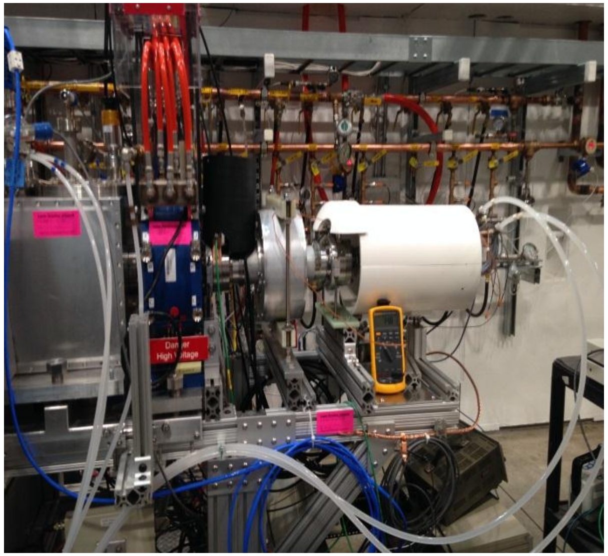
- Beam size can be done in LEBT by scanning the beam over a diaphragm
  - Calibration is done using the known size of the diaphragm ID
    - Essentially, the beam size is measured as a portion of that size
    - Low-current beam is moved through the diaphragm center full swing from full extinction to full extinction
    - Readings of the dipole correctors corresponding ½ of the beam coming through correspond to the beam center being at the diaphragm edge
  - Beam size measurement
    - Beam is moved from the center until 5% of the beam is lost (in two directions each scan)
    - Ideally, 3 scans: to center the beam and to measure the beam size along two axes
    - Procedure is insensitive to rotation inside the solenoid

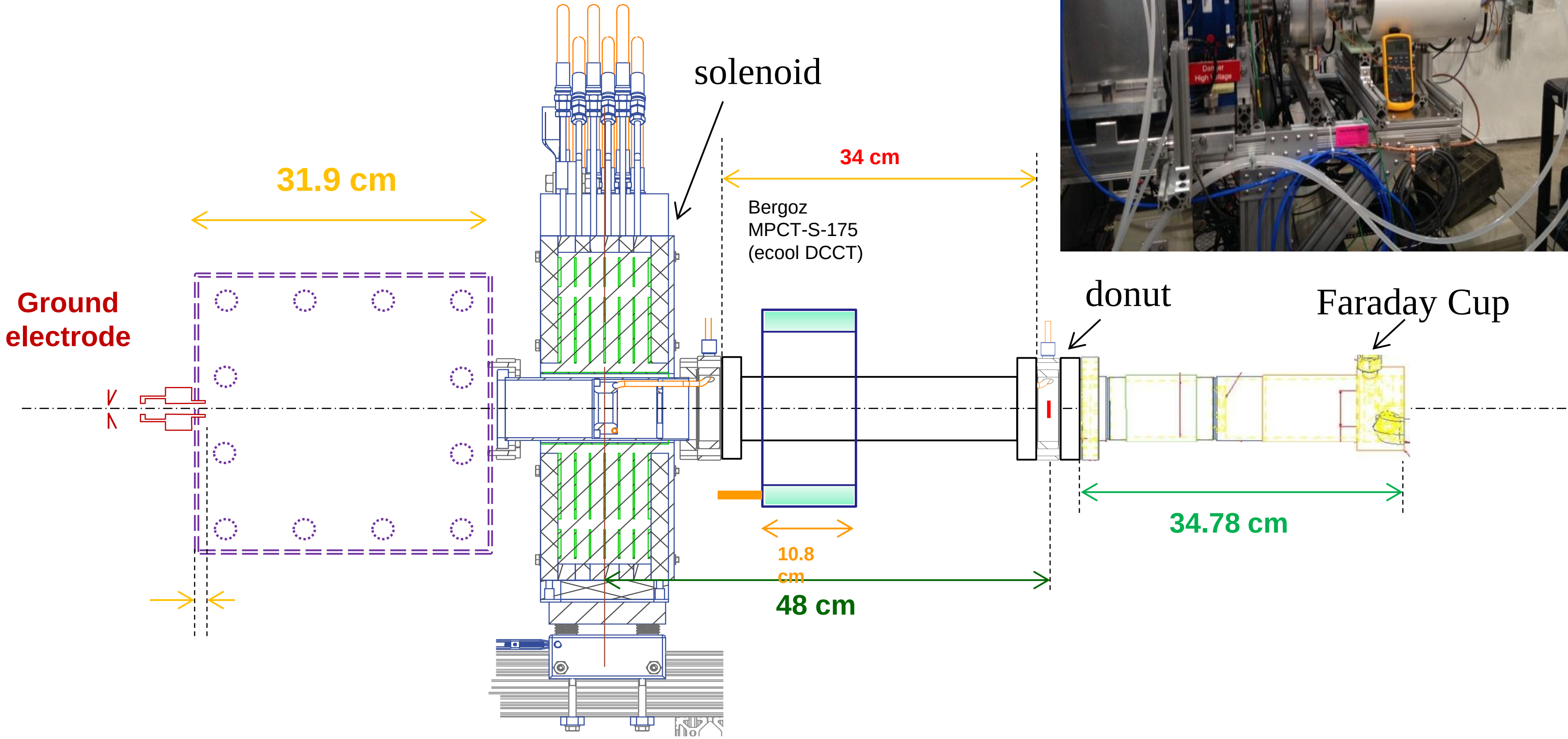


  - Details
    - In practice, used X+Y and X-Y direction because separately correctors are bit too weak
    - measured the distance between 5% loss on both sides and subtracted from the hole diameter (“95%-to-95% size”)

Setup

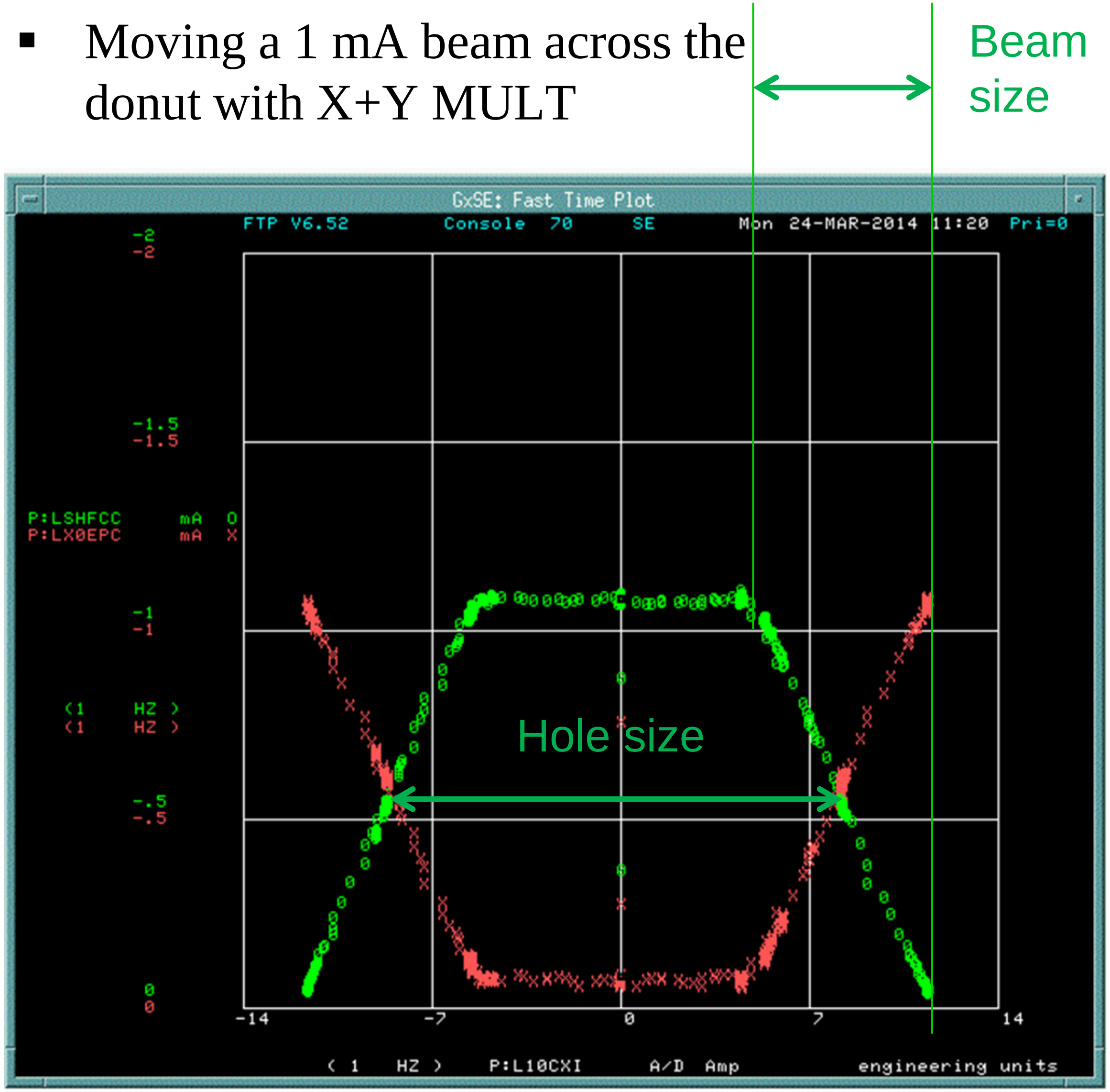
- An electrically isolated diaphragm ("donut") is in front of the Faraday Cup
  - ID=18 mm, length 0.5"= 12.7 mm
  - typically biased by +40V





Example of a measurement

- Moving a 1 mA beam across the donut with X+Y MULT



Horizontal axis: current of the X solenoid corrector, in A. 7.2 mm/div.

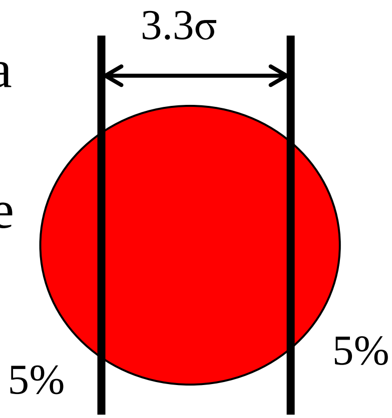
Vertical axes: Green- Faraday Cup current, 0.2mA/div

Red- donut current, 0.2mA/div

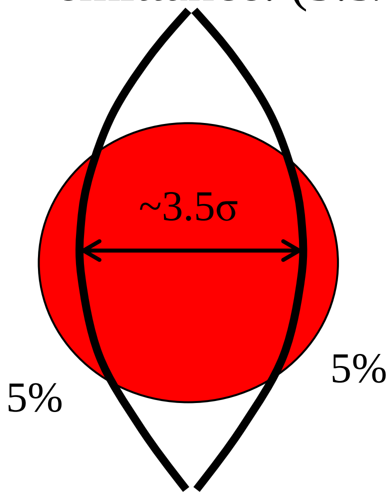
24-Mar-2014, solenoid current is 155A, pulsed beam

Cutting the Gaussian beam

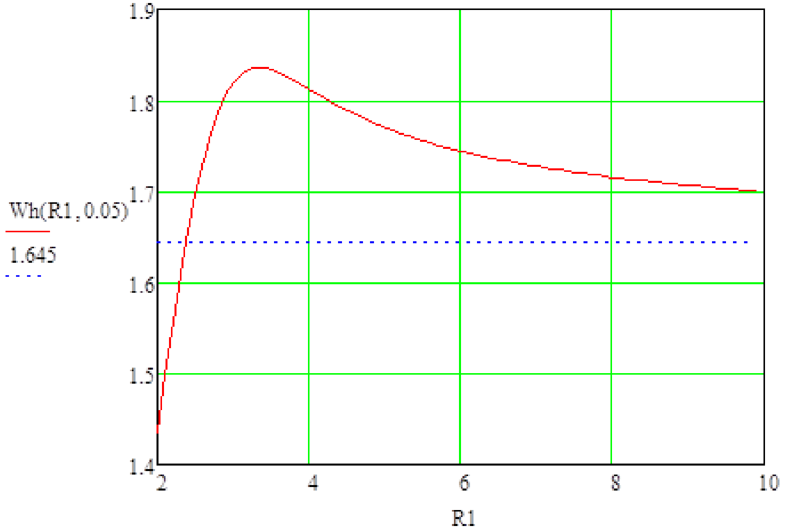
- For a Gaussian axially symmetrical beam, the distance determined by cutting 5% of the beam from two sides by a flat edge is $3.3\sigma_r$



- If beam is cut by the edge of a round diaphragm (each side 5% of the current while centered), the answer depends on the diaphragm radius
  - For ID=18 mm, typical $R/\sigma_r = 3.5 – 9$, and the distance becomes $\sim 3.5\sigma_r$
- In solenoid scans, the results of measurements is for 3σ emittance: $(3.5/2)^2 \approx 3$



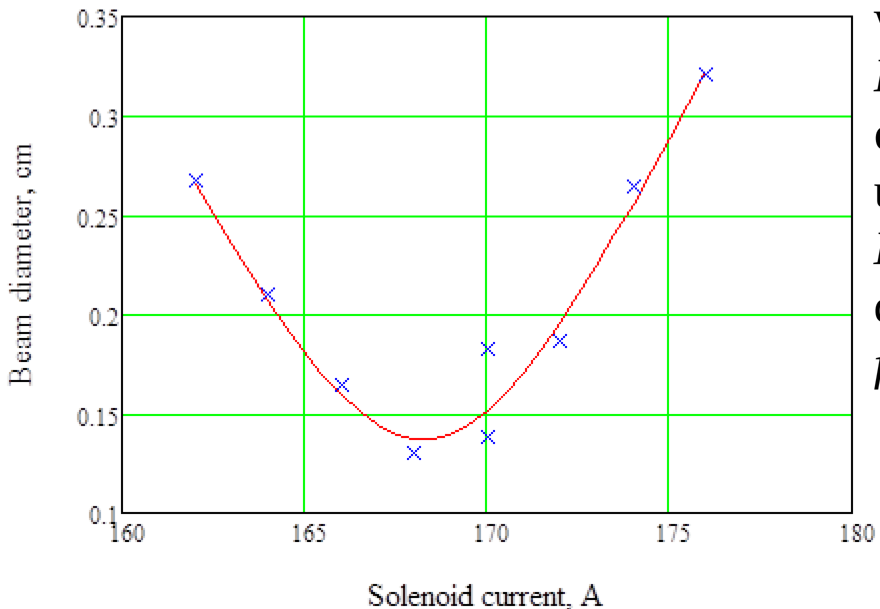
Red: distance from the beam center to the edge of the diaphragm (in σ_r) when 5% of the max current is cut as a function of the hole radius (in σ_r). Blue: flat case (R=∞).



Solenoid scans

- The "95%-to-95%" size is measured at various solenoid current and fitted to a model of a thin lens

$$R = \sqrt{R_0^{\,2} - 2R_0 R_0^{'} L_{sd} + \left(\frac{\varepsilon^2}{R_0^{\,2}} + R_0^{'\,2}\right) L_{sd}^{\,2}}\,;\; R_0^{'} = \frac{R_0}{f(I_{sol})} - \alpha_0$$



where
R_0 is the beam radius in the solenoid,
α_0 is the beam divergence angle upstream of the solenoid,
L_{sd} is the distance from solenoid to donut,
f(Isol) is the solenoid focal length

Example of fitting the measured beam sizes during a solenoid scan. Beam current 5.8mA DC. Fitted emittance is 43 μm, which corresponds to σ_{norm}=0.11 μm (the lowest measured). March 26, 2014.

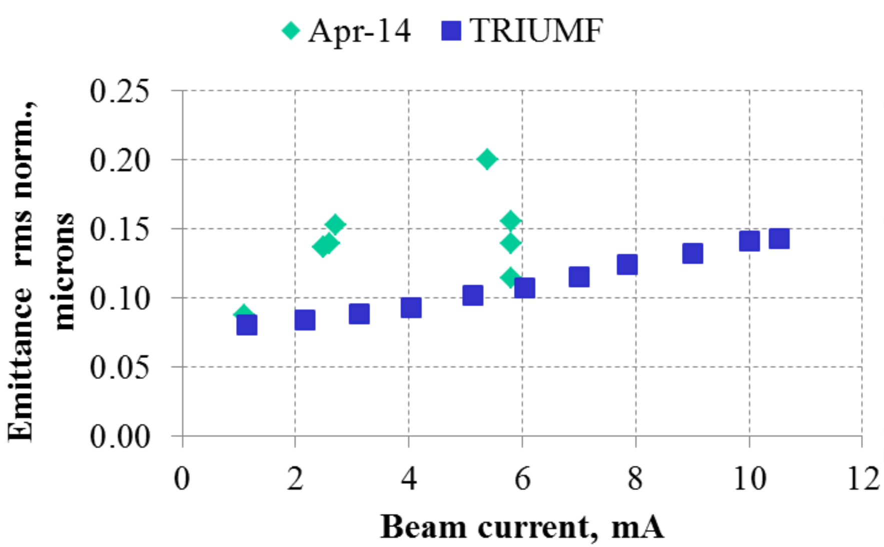
Results

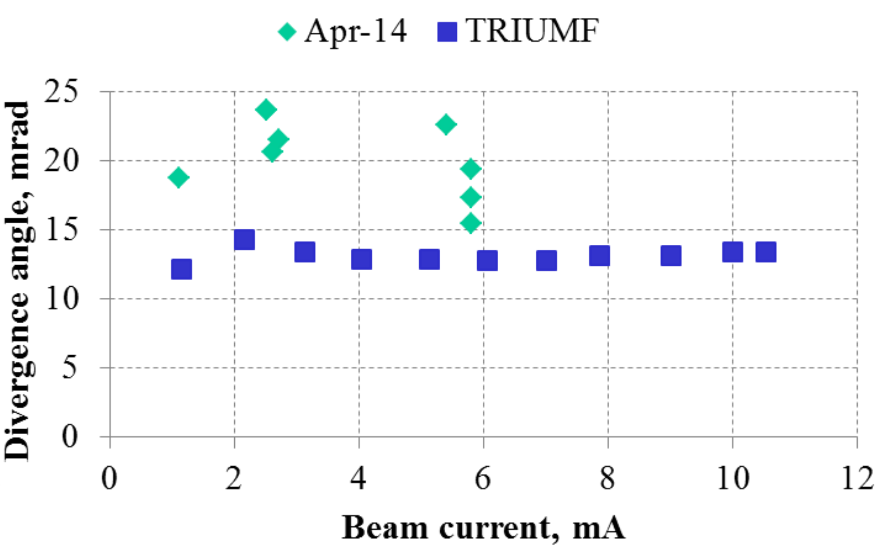
Date	Beam I mA	Angle in solenoid mrad	Radius in solenoid mm	3 sigma Emittance microns	Solenoid current in min. A	Fit rms error mm		IS focus mm
24-Mar-14	1.1	32	17	33	163	0.05		512
25-Mar-14	5.8	27	12	58	167	0.21		457
26-Mar-14	5.8	34	15	43	168	0.13		448
27-Mar-14	2.7	37	19	57	163	0.08		514
27-Mar-14	2.6	36	18	52	163	0.08		513
31-Mar-14	2.5	41	19	51	168	0.10		454
31-Mar-14	2.5	41	19	51	168	0.10		454
2-Apr-14	5.8	30	13	52	168	0.17		450
2-Apr-14	5.4	39	18	75	166	0.11		471
StDev,%		14%	15%	22%	2%	43%		6%

- A large scatter in data. Likely, partly because of the unstable procedure and partly because of not well-controlled ion source conditions
  - Note that scatter of "IS focus"=(Radius)/(Angle) is lower than Angle's and its average coincides with distance from IS to the solenoid
  - Radius in solenoid is close to the radius of the solenoid diaphragm, 19 mm

Comparison with acceptance tests

- Fitted emittance and divergence angle can be compared with the results of the acceptance tests at TRIUMF
  - Both measurements are with DC beam
  - TRIUMF data were recorded with the Allison-type emittance scanner
- Recently measured emittance and angle are larger than at TRIUMF
  - Need to decrease the scatter to make a reliable statement



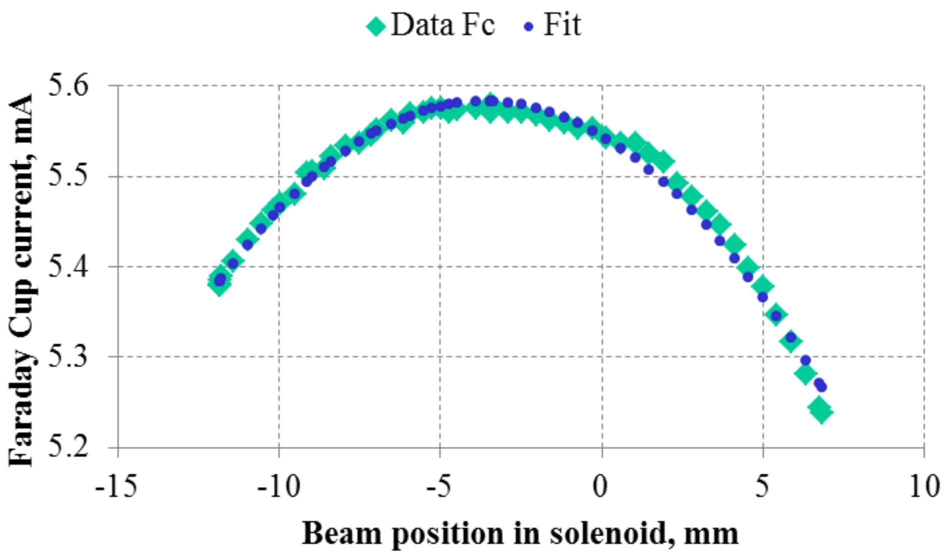


Plans for emittance measurements

- Automate the procedure
  - Find a way to write down a Java code that makes a solenoid scan
  - It should improve reproducibility of the measurements
- Need to design and install a water- cooled diaphragm instead of the donut
  - Presently, overheating the donut limits the rate of measurements
- Tune the ion source to minimize the beam emittance for a given beam current
- Compare results with the pulse mode
- After installation of the Emittance scanner, compare beam parameters measured with two methods

Implications for scraping upstream

- Assuming a Gaussian distribution, for I_{beam}~ 5mA predicted rms beam size in the solenoid is ~9 mm
  - With the radius of the solenoid diaphragm of 19 mm, ~10% of the beam should be scraped
  - Also, variation of the lost current with shifting of the beam center should be parabolic $$I_{FC}(x) = I_{FC\_max} \cdot (1 - \frac{x_{sol}^2}{b^2})$$ with b = 25 mm
- In measurements with the solenoid diaphragm biased by +40V
  - Likely ~10% of beam is scraped
  - However, dependence on the beam shift is week, b_{meas} = 62 mm
  - Tails may be non-Gaussian



Beam to the Faraday Cup as a function of the beam position in the solenoid. The position is re-calculated from IS correctors.

Summary

- Procedure of measuring the beam size by scanning the H- beam over a diaphragm has been tested
  - Needs to be automated for reliability and speed
- Solenoid scans gave first estimations for the beam emittance
  - Large scatter, likely determined both by the procedure and by real variations of beam properties
  - Agrees with TRIUMF measurements within ~50%
- Variation of the beam loss when the beam is moved over the solenoid diaphragm is much weaker than expected
  - May be non-Gaussian tails or errors in calibrations