REDUCTION OF THE BEAM JITTER AT THE PIP2IT TEST ACCELERATOR

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Zoom information

- I will be available for discussions on HB’21 days (October 4-8, 2021) from 8:10 AM to 8:50 AM of Chicago time at
  - Alexander Shemyakin's Personal Meeting Room
  - https://us04web.zoom.us/j/9116726745?pwd=bElpZy9ZVVBhcDEwZ3U3ZFo4d3RoUT09
  - Meeting ID: 911 672 6745
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- Alternatively, you can send me email to
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Abstract

- Analysis of the BPM signals at the H- test linear accelerator PIP2IT showed that a large portion of the scatter in their signals comes in all three planes from the beam jitter.

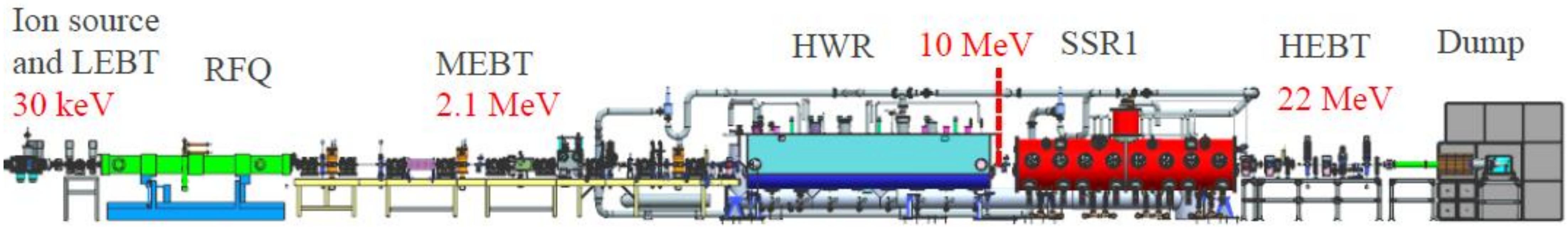
- BPM jitter measurements were compared with orbit responses to oscillating various beamline parameters with a low frequency sine wave.

- The main contributor to the jitter was found to be a low-frequency noise in the input reference to the ion source high voltage (HV) power supply. Filtering this reference signal decreased the rms scatter in BPM readings by a factor of 2-3.

PIP2IT

- PIP-II Injector Test (PIP2IT) is an H- ion linac to test critical elements of the front end of the PIP-II accelerator currently under development at Fermilab.
  - Was assembled and commissioned in several stages in 2014-2021
  - Final parameters: 16 MeV x 2 mA x 0.55 ms x 20 Hz with aperiodic bunch structure

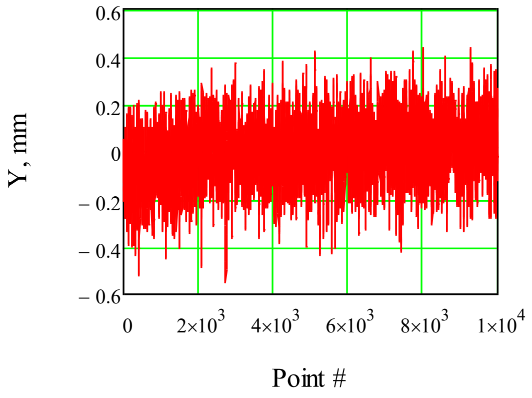
- BPMs reported the scatter in all 3 planes that significantly exceeded the expected electronics noise
  - Not a problem for emittance growth but a significant annoyance in measurements

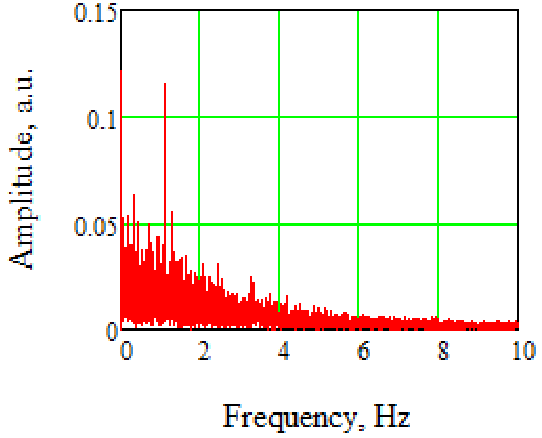


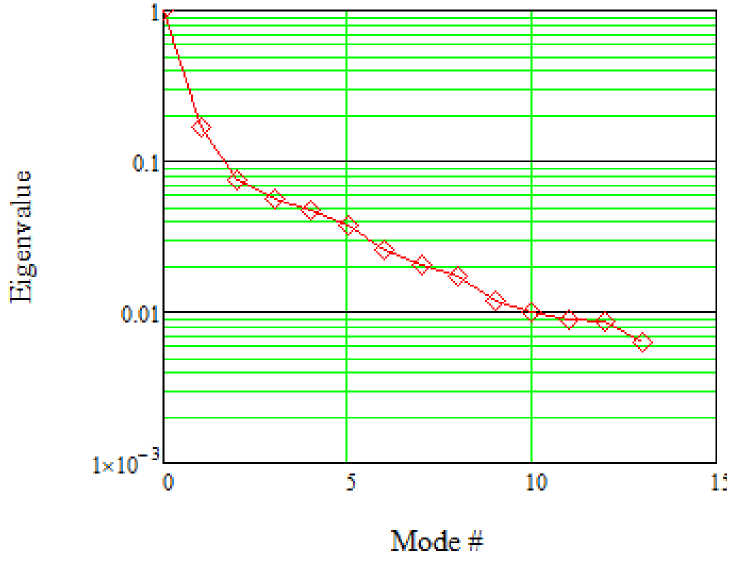
LEBT = Low Energy Beam Transport; RFQ= Radio Frequency Quadrupole; MEBT= Medium Energy Beam Transport; HWR = Half-Wave Resonator; SSR1=Single Spoke Resonator; HEBT = High Energy Beam Transport

Beam jitter

- Analysis of the BPM noise with Singular Value Decomposition (SVD) showed that it comes from the beam jitter, originated upstream of the MEBT. $M = ULV^T$
  - Proposal: compare jitter spacial distribution with responses to IS/LEBT parameters

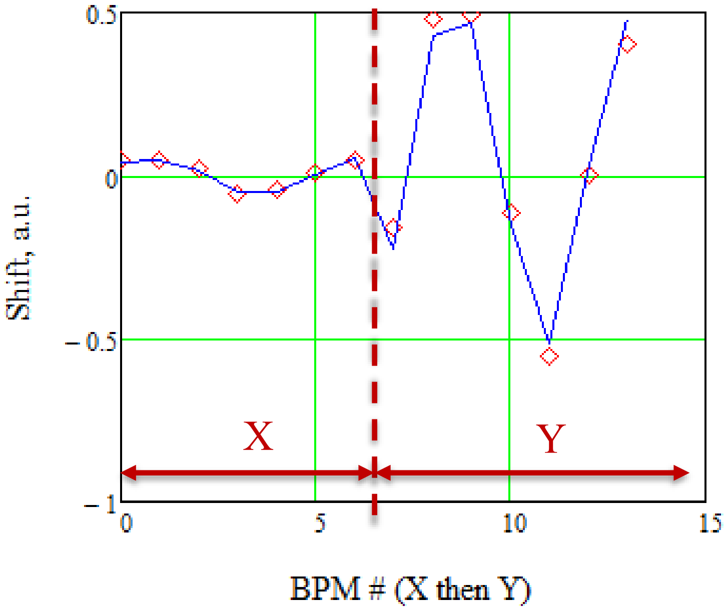






Normalized singular values from SVD analysis of 14 BPM channels.

Top: raw signal in Y channel of BPM #3. Bottom: FFT spectrum of the 1st mode. 1.1 Hz line is prominent.

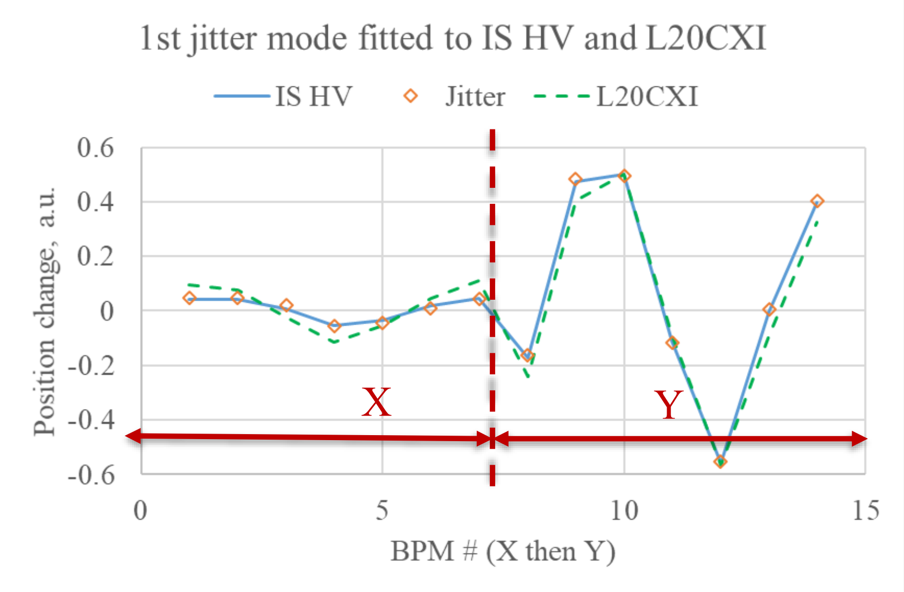


Red markers are the 1st spatial SVD eigenvector. Blue line is the best fit with MEBT betatron modes. The fit gives a vector (x_0, x_0', y_0, y_0') of beam parameters at the RFQ exit.

PIP-II

Comparison with excitations in ion source and LEBT

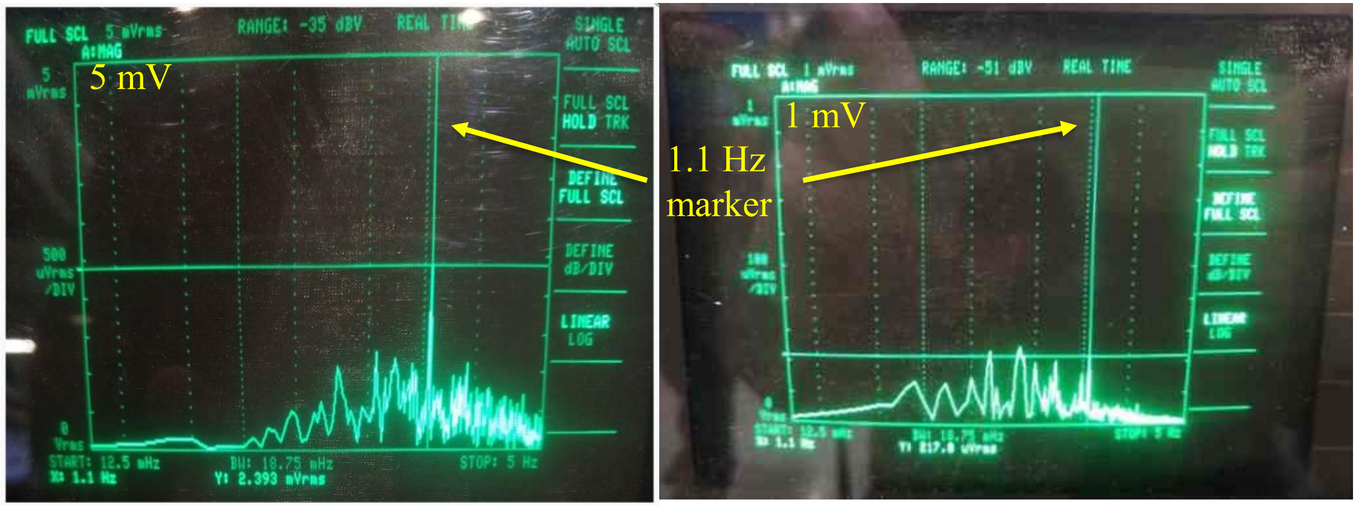
- Responses of the MEBT trajectory to various LEBT/IS parameters were recorded
  - Parameter is changed sinusoidally at 0.25 Hz
  - Amplitudes of 0.25 Hz line in BPM spectra are recorded
- Each trajectory is fitted to MEBT betatron modes
  - =>initial vectors (x_0, x_0', y_0, y_0') at RFQ exit
- Angles between these vectors and the noise vectors are calculated
  - In canonical coordinates
- Conclusion:
  - Jitter comes from the ion source HV
  - Corresponds to 60 V rms out of 30 kV DC



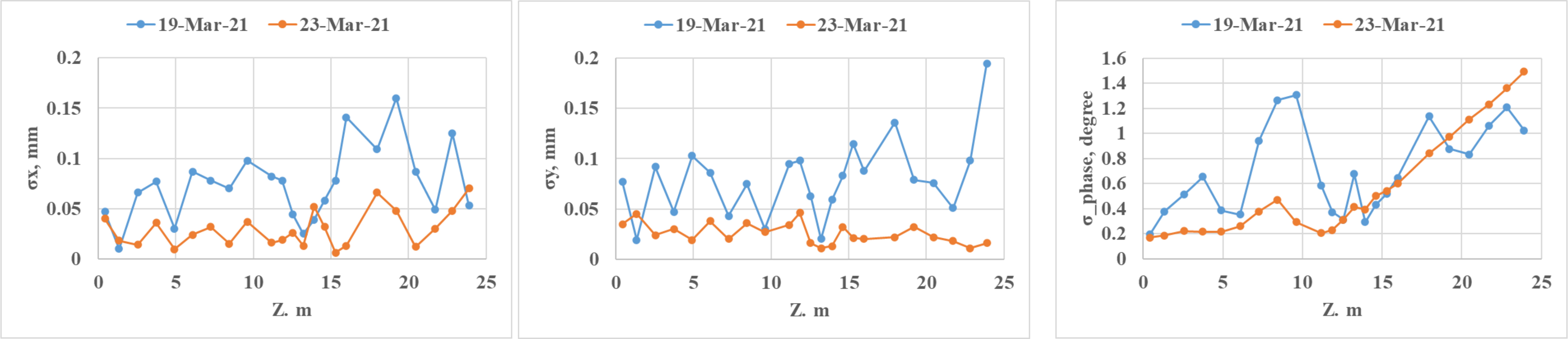
Angles between eigenvectors and vectors of excitations, rad	Mode 1	Mode 2
Ion Source HV	0.018	1.540
P:L00CXI	0.995	0.625
P:L00CXI	0.771	0.849
P:L10CXI	0.590	1.030
P:L10CYI	1.191	0.333
P:L10CYI	1.038	0.485
P:L20CXI	0.025	1.502
P:L20CYI	1.148	0.472
P:L30CXI	1.138	0.386
P:L30CYI	0.663	0.957
LEBT bend	0.366	1.254
LEBT bend	0.344	1.276
LEBT chopper	1.235	0.597

Decrease of the HV noise and BPM scatter

- RC filter was installed at the input reference to the HV power supply
  - The measured HV noise components decreased significantly
  - The beam jitter decreased in all 3 planes by 2-3 times



IS Hv signal from a low-frequency spectrum analyzer before (left) and after (right) installation of the filter. Characteristic 1.1 Hz component decreased by 11 times.



Rms scatter in X, Y, and phase before and after installation of the filter. Beam energy 2.1 MeV.

Recipe to find the source of beam jitter

- Collect BPM data and analyze with SVD
  - If there are no prominent singular values, likely contribution of the beam jitter is small
- Location where spatial eigenvector of the main mode starts to deviate from background indicates the source
- If the jitter source is upstream of where all BPMs are located (as it was at PIP2IT)
    - Check the temporal spectrum for hints (1.1 Hz line at PIP2IT)
  - Record the BPM response to changes in the suspicious parameters by oscillating them and recording the corresponding lines in BPM spectra
    - Allows to overcome noisy signals (at PIP2IT, the rms noise of IS HV readback was 200 V)
  - Fit each orbit response to betatron modes to distill it to single vector (x_0, x_0', y_0, y_0')
    - at RFQ exit for PIP2IT study. Helps to reject bad measurements.
  - Find the orbit response vector colinear with the vector for the measured noise

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