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Optics Measurement at PXIE-MEBT

Arun Saini, A. Shemyakin

PIP-II Technical Meeting

23 February 2016

Outline

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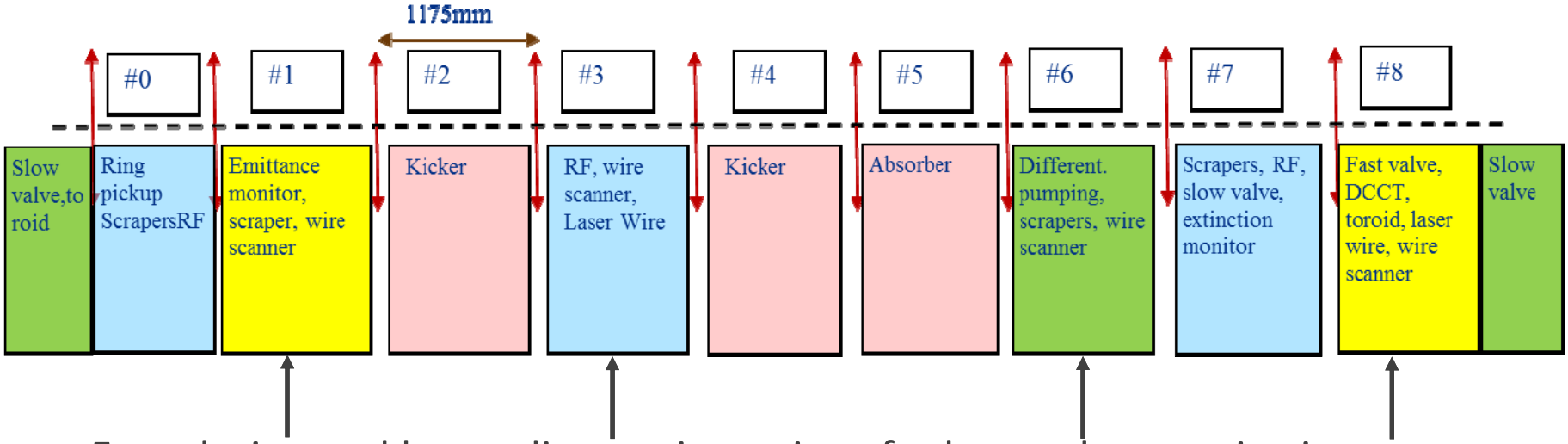
- Optics Measurement
  - Differential Trajectory Analysis
  - Requirements.
- Optics with Pencil Beam
- Summary

MEBT Overview



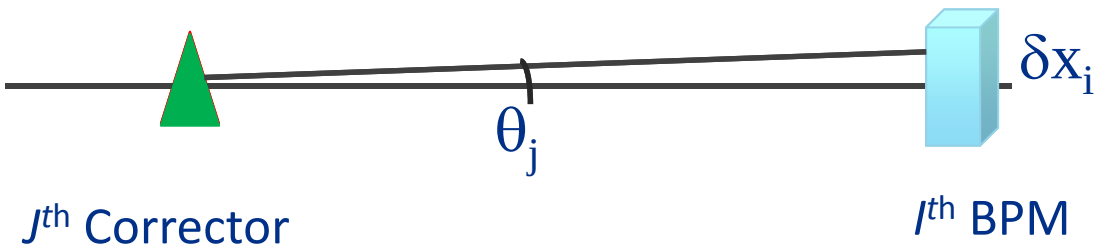
- Four designated beam diagnostic sections for beam characterization:
  - Transverse beam profile measurement
    - Scrapers, Wire scanners, Laser wire.
  - Longitudinal beam profile measurement
    - Fast Faraday Cup
  - Beam energy measurement using *Time of Flight method*
  - Transverse phase portrait using *Allison monitor*
- Each magnet package (2 doublets and 7 triplets) includes BPM and set of *x* and *y* steering correctors.

Beam Optics Measurements

- Principle objective of beam optics measurement is to acquire better knowledge about beam line and implementing this knowledge to prepare a optical model that predict beam trajectory with minimal discrepancy.
- Differential trajectory analysis is used for transverse optics measurement at PXIE-MEBT.
  - Measured shift in beam position with variation in corrector currents.
  - 5 data points will be taken at given location.
  - JAVA based program will be used to automate this process.
    - Sunny Rao is writing this program.
- OPTIM a beam dynamics code will be used to prepare the optics model of beam line.

Differential Trajectory Scheme (1):

Procedure: Current setting in steering corrector is changed and resulting orbit difference with respect to nominal orbit is measured in subsequent BPMs.



- Correctors/Steering magnets deflects the beam with an angle θ and beam response is measured in following BPMs.
- Change in beam orbit in BPMs is related with deflection angle by response matrix R:
  - $$\delta x_i = R_{ij}\theta_j$$
  - for *N* no. of BPMs and *M* no. of correctors :

$$\begin{pmatrix} \delta x_1 \\ \delta x_2 \\ \dots \\ \delta x_N \end{pmatrix} = R \begin{pmatrix} \theta_1 \\ \theta_2 \\ \dots \\ \theta_M \end{pmatrix}$$

Differential Trajectory Scheme(2)

$$\begin{bmatrix} x_2 \\ x_2' \end{bmatrix} = \mathbf{M}_{1\to 2} \cdot \begin{bmatrix} x \\ x' \end{bmatrix}$$

$$\begin{bmatrix} x_1 \\ x_1' \end{bmatrix} \longrightarrow \begin{bmatrix} x_2 \\ x_2' \end{bmatrix}$$

$$\mathbf{M}_{1\to 2} = \begin{bmatrix} \sqrt{\beta_2/\beta_1}\,(\cos\Delta\mu + \alpha_1 \sin\Delta\mu) & \sqrt{\beta_1\beta_2}\,\sin\Delta\mu \\ \sqrt{1/\beta_1\beta_2}\,[(\alpha_1-\alpha_2)\cos\Delta\mu - (1+\alpha_1\alpha_2)\sin\Delta\mu] & \sqrt{\beta_1/\beta_2}\,(\cos\Delta\mu - \alpha_2 \sin\Delta\mu) \end{bmatrix}$$

- A Linear optical model is prepared based on transfer matrices of beam line elements.
- Beam orbit is computed based on optical model.

Differential Trajectory Scheme(3)

- Measured trajectory is compared with optical model prediction and model is corrected to minimize discrepancy.
- Primary sources of discrepancy :
  - Good field region of quadrupoles
    - FRS values is 23 mm
  - Calibration of power supplies
  - BPMs offset with respect to magnetic axis.
  - Quadrupole misalignment
- *K-modulation* method to estimate quadrupole and BPM offset

$$\delta\theta = \Delta K l \ \delta x$$

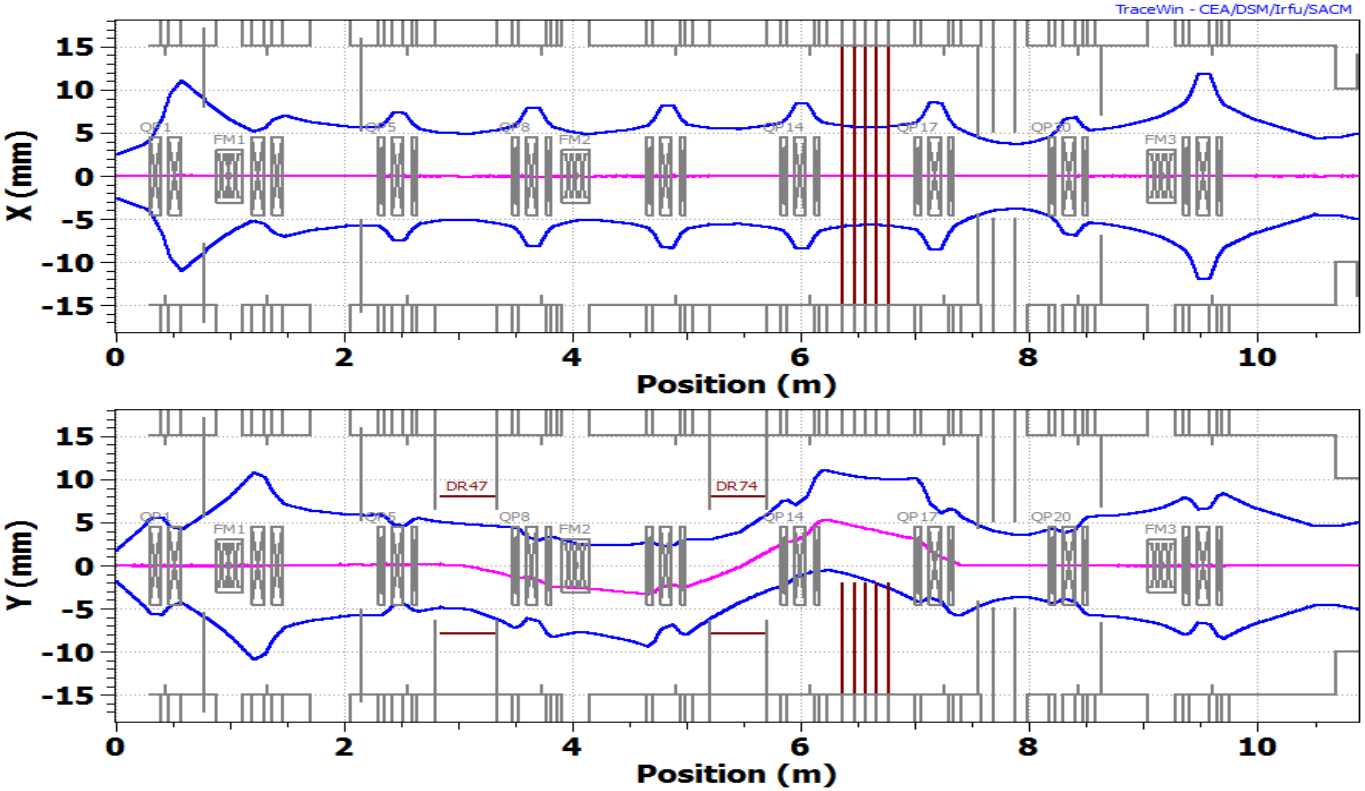
- ΔK is variation in quadrupole strength, *l* is length of quadrupole and δx is initial offset at quadrupole.

Requirements for Differential Orbit Measurement

- Beam pulse length of 10 us with repetition rate of 20 Hz will be used for measurement.
- Good relative alignment of quadrupole and BPMs
  - Minimal allowed relative transverse offset between quadrupole magnetic axis and BPM axis is 50μm.
- In order to achieve good signal to noise ratio beam will be shifted in range of 1–3 mm.
  - Good area radius for BPM is 5 mm.
  - Should be able to resolve beam shift within ~1%
- No beam losses during optics measurement
  - Beam losses will change beam centroid.
  - Result in background noise and therefore degrade signal to noise ratio.
- Aperture limitation in MEBT put stringent constraint on achievable beam shift and may result in beam losses.
  - Using pencil beam for optics measurement is the solution. (Will discuss later).

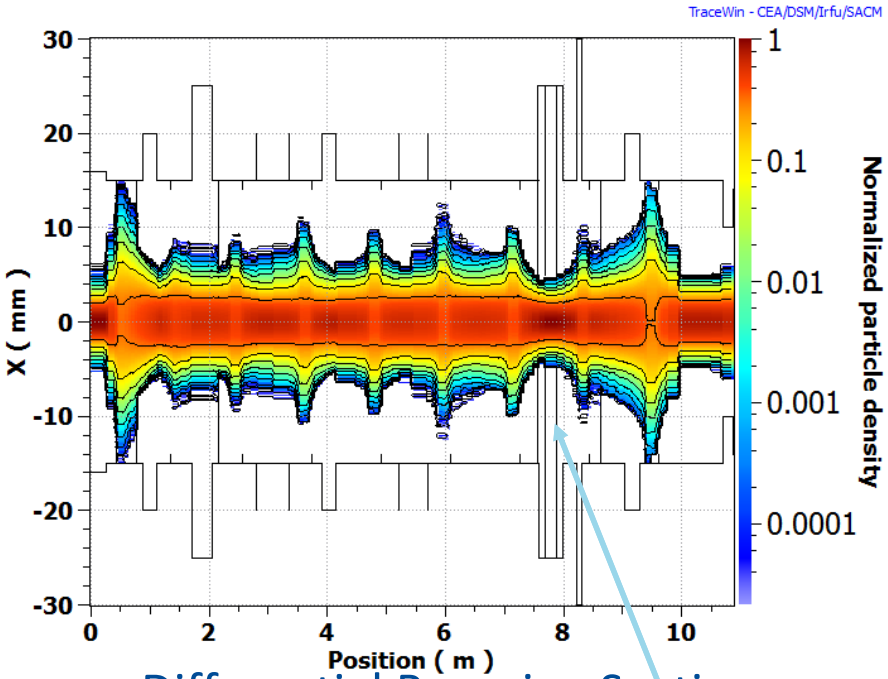
Nominal 3 RMS Beam Envelope in MEBT

Passing Beam: Kicker On

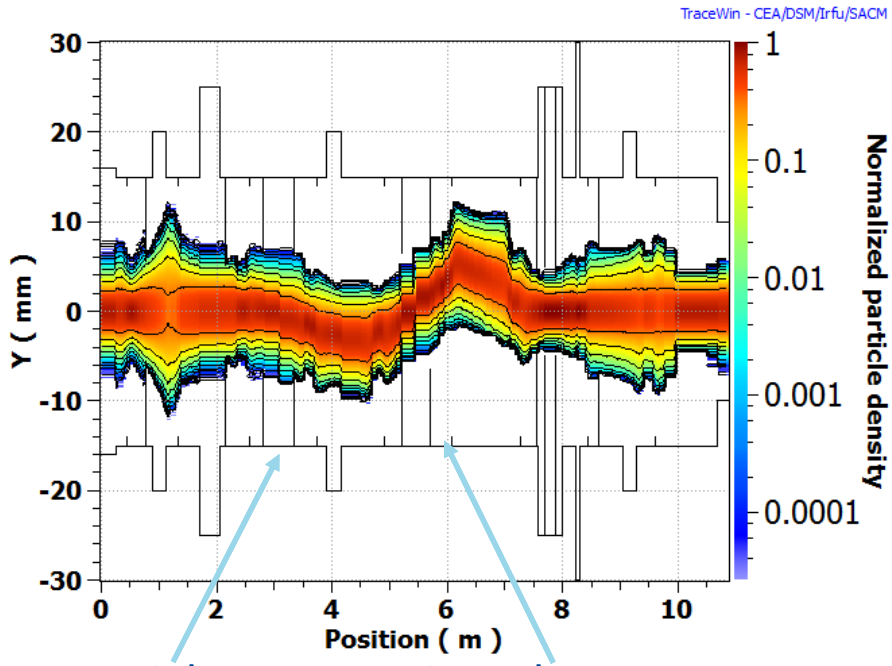


- No uncontrolled beam losses.
- Scrapers are inserted for nominal operation.
- Beam losses at designated places: Scrapers, absorber and kicker protection plates.

Beam density along MEBT:



Differential Pumping Section



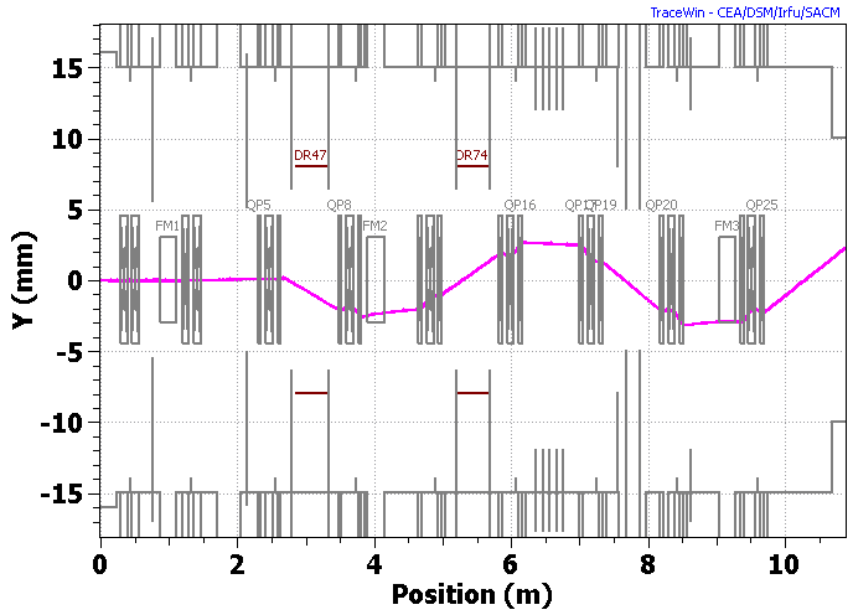
Kicker protection plates

- Differential pumping section (DPS) and kicker protection plates are primary aperture limitation in MEBT.
  - Half aperture to beam RMS size ratio is 3.5 and 3.8 at kicker plate and differential pumping section.
  - Half aperture to beam RMS size ratio at kicker plate is reduced to 2.2 if centroid shift is included
- Beam excitation may results in beam losses.

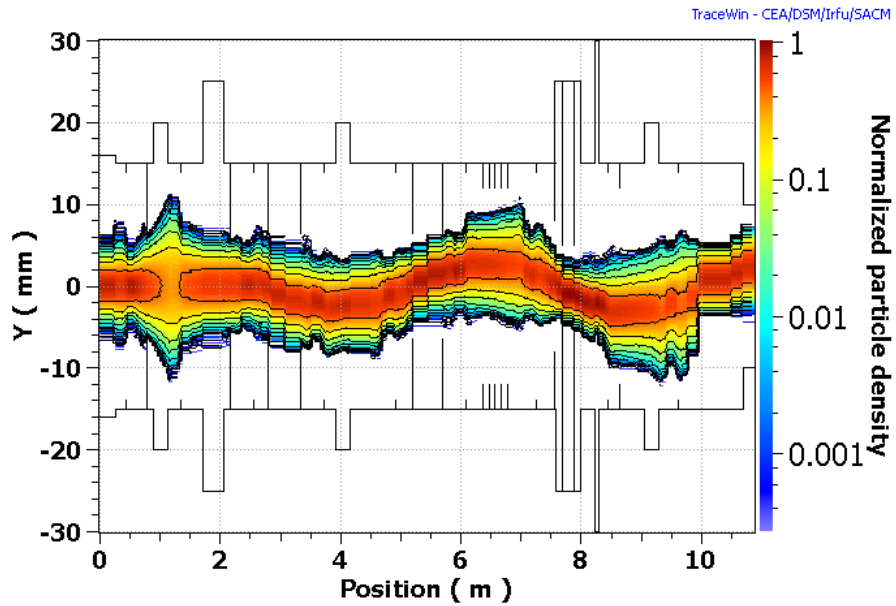
Beam Excitation

- Beam centroid is excited in vertical direction by +/- 2mm using a corrector after first triplet.
- Scrapers 3 & 4 are pulled out to avoid beam losses.
- Kicker are turned off

Beam Centroid after excitation



Particle Density after excitation



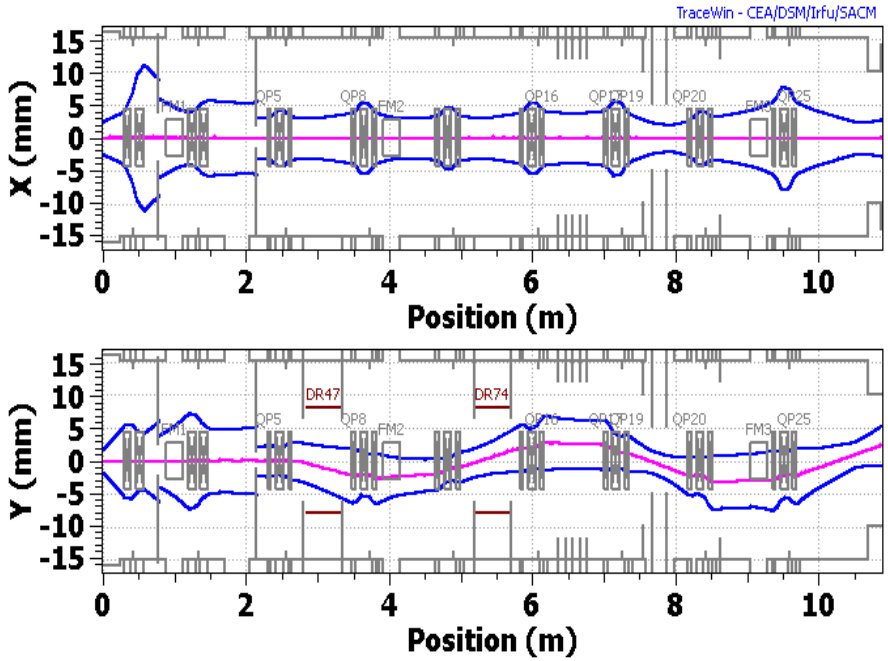
- Beam losses are observed at kicker protection plates and DPS.
  - 0.4 % beam losses at kicker plates and 0.01% in DPS.

Measurement using Pencil Beam

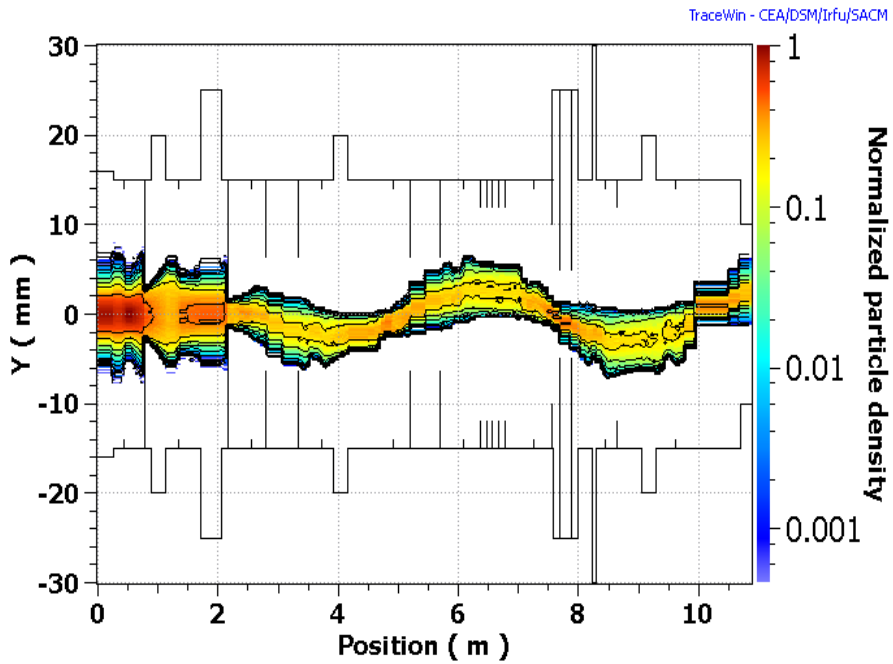
- Using a pencil beam for optics measurement reduces possibility of beam losses.
  - Most of BPMs can be utilized to take data in this mode.
- Pencil Beam is generated using first two beam scraper sets.
- 80 % beam is intercepted and rest of beam (1mA) is tracked through rest of MEBT.
  - Beam pulse length of 10 us with repetition rate of 20 Hz will be used for measurement.
  - According to MEBT-BPM's FRS, BPMs can operate effectively for beam current of range 0.5 mA to 10 mA.
- All other settings (Fields in Quadrupoles, cavities etc.) are kept nominal.

Beam Optics with Pencil Beam

3 RMS Beam Envelope



Beam density along MEBT



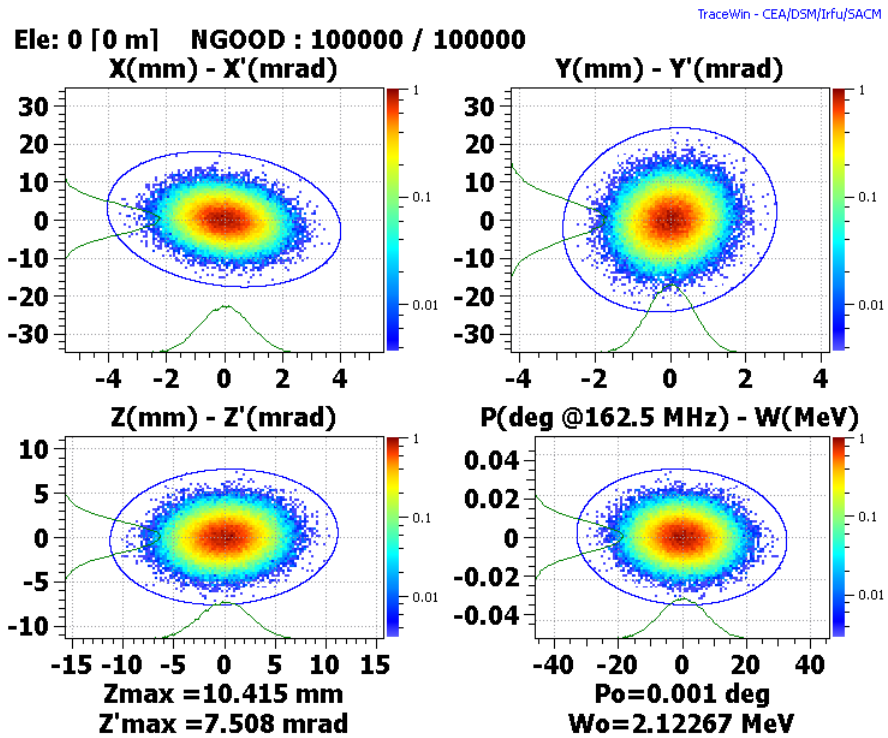
- No beam losses at kicker plates and differential pumping section even after beam excitation by 2 mm in vertical direction.

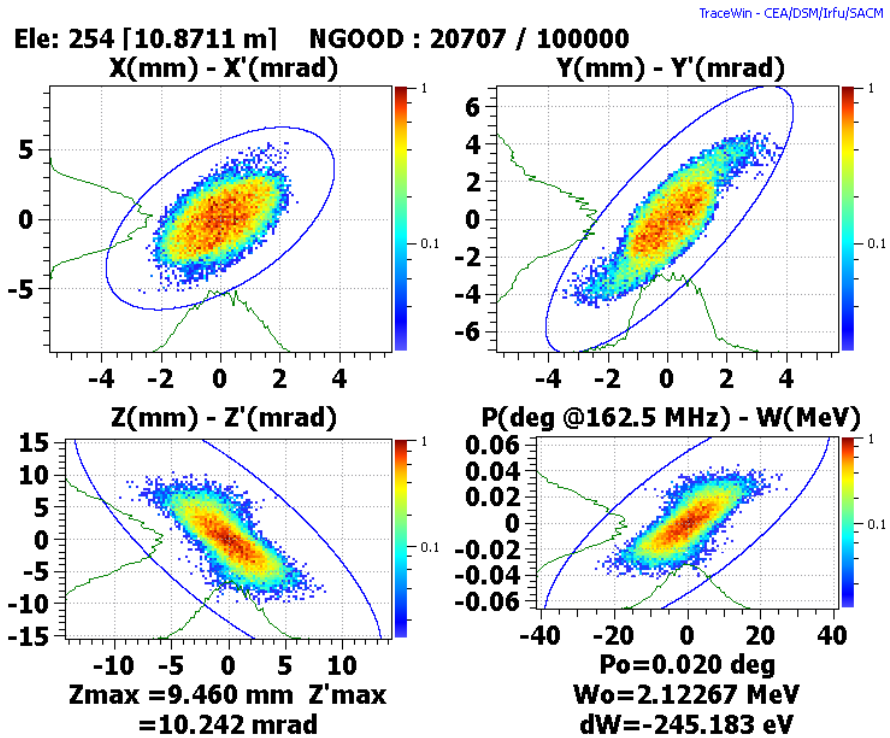
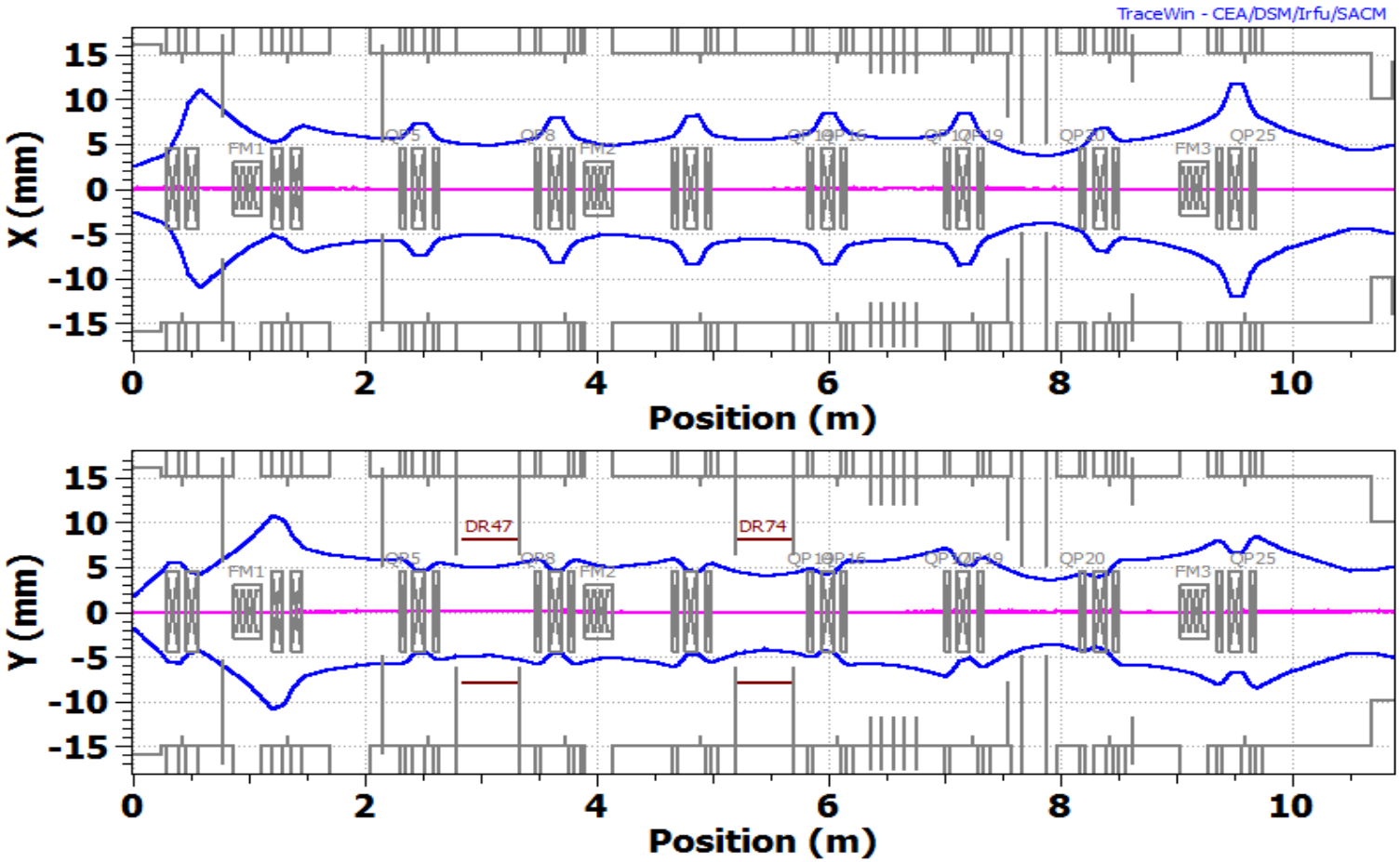
Summary and Conclusion

- Optics measurement in MEBT will be performed using differential trajectory analysis.
  - A Java based automated program will be used
- Aperture limitation particularly in vertical plane results in beam losses and therefore keep stringent constraint on beam excitation.
- Pencil beam generated using first two set of scrapers
  - Will enable optics measurement without beam losses and hence allow to keep same aperture limitation in MEBT.

Additional Slides: Will Remove later

Phase portrait





Passing Beam Kicker Off