Fermilab U.S. DEPARTMENT OF ENERGY | Office of Science

Beam Line Tuner for the FAST linac

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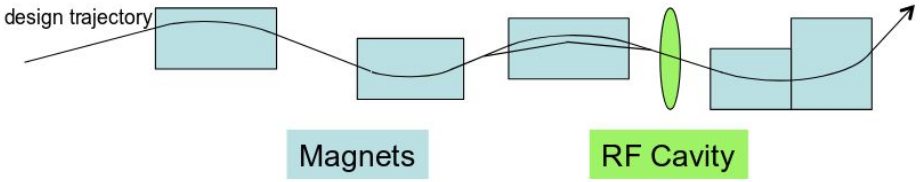
Helen Edwards Internship, Final Presentation, 8/8/2019

Outline

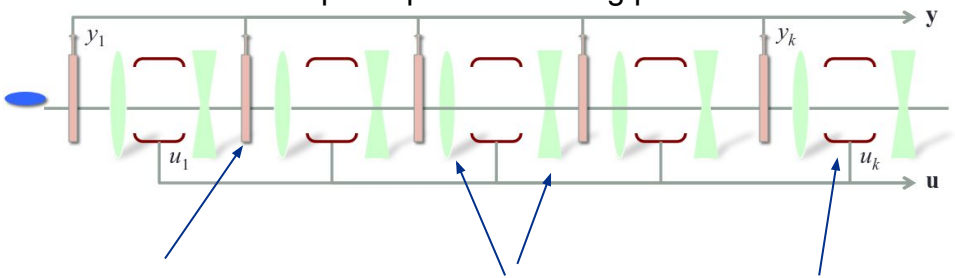
- Motivation
- Studies
- Results & Future Work
- Additional Learnings
- Conclusion

Motivation



Steer beam to have it on desired trajectory

These elements participate in steering process:



Corrector

Quadrupole (should only focus but steers if beam is off center)

Beam Position Monitor (BPM)

Picture credit: USPAS

- Importance to keep beam on design trajectory
- Track beam through linac
- Create beam bumps
- Correct and create simulated beam trajectories

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Studies I: Orbit Correction Algorithm

- Orbit Correction Algorithm: Singular Value Decomposition

$$x = Rq$$

$$q = R^{-1}x$$

Find pseudoinverse of Response matrix

#BPM $\neq$ #Correctors

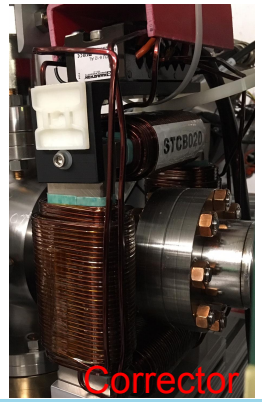
Know which corrector angles we need to achieve certain position offsets

With angles: Calculate new current for correctors

x : Beam Position (BPM) change (m)

q : Corrector kick angle (mrad)

R : Response matrix



Studies I: Orbit Correction Algorithm

- What to do with that?
  - Beam bump
  - Correct beam to a specific setting of BPM readings

  ➔ Elegant simulations

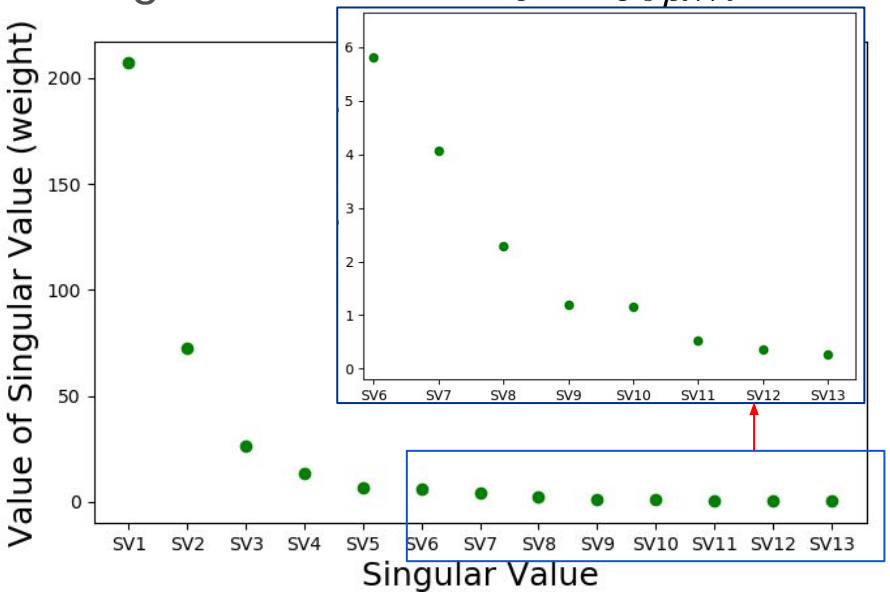
  ➔ Feed in desired positions, try to adjust beam trajectory as good as possible to that

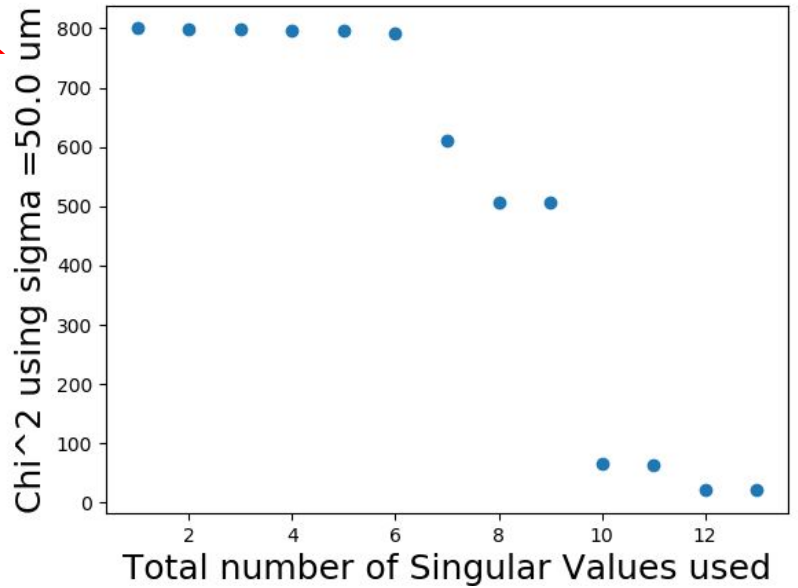
Cryomodule (CM) in linac

Studies II: Analysis of Singular Values (SV):

Example: Beam Bump (location: Before Cryomodule (CM), using 90 m of beamline including 13 correctors and 21 BPM, quads set to zero)

- Goodness of fit increases with amount of SV (if #BPM>#correctors)
- Using BPM resolution $\sigma = 50\mu m$ for χ^2



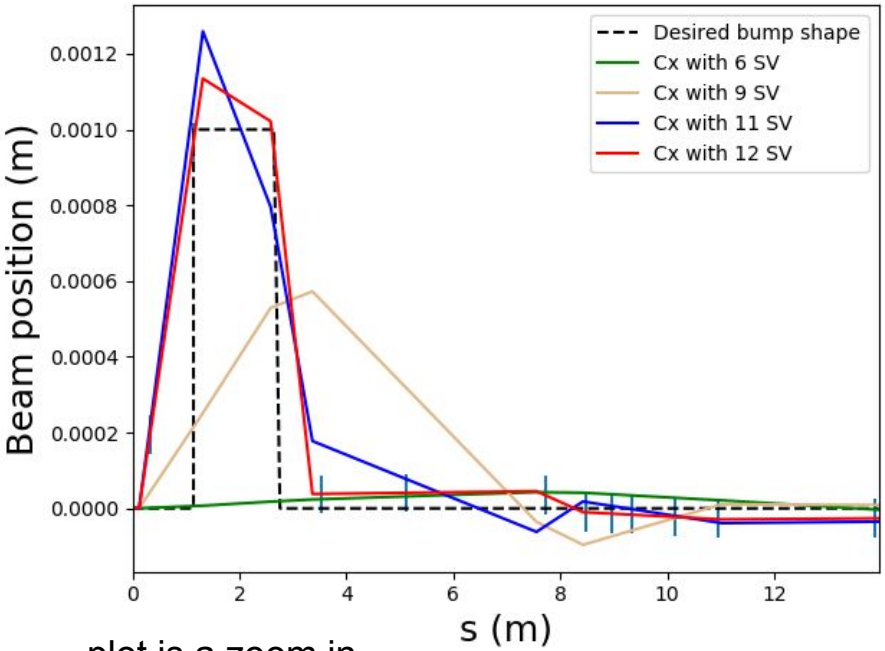


Studies II: Analysis of Singular Values (SV):

Example: Beam Bump (location: Before Cryomodule (CM), using 90 m of beamline including 13 correctors and 21 BPM, quads set to zero)

- 90 m of linac (until H480)
- Quads are off
- If #BPM>#correctors:

  Result gets better while increasing amount of SV with no upper limit



plot is a zoom in bump region

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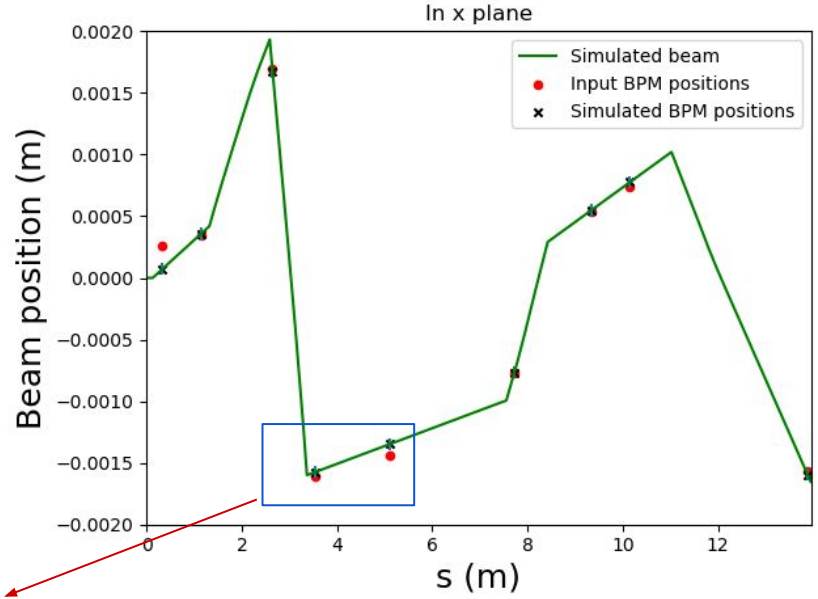
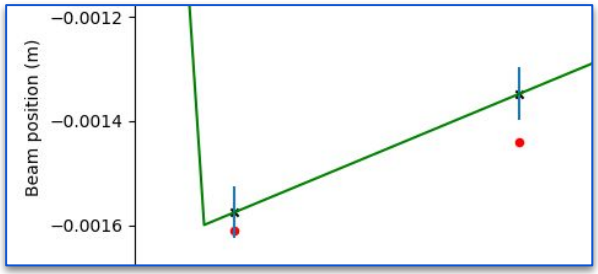
Studies III: Simulate beam trajectory with steering in Injector (before CM)

- Using realistic, simulated lattice containing focussing for injector to CM beamline
- Use BPM measurements from 03/13/2019
- Correct beam to these values
- Output corrector strengths
- Correction not always within error bars





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Results & Future Work

- Results
  - Corrector Strengths
    - Injector beam bump
    - Realistic beam trajectory
- Future Work
  - Improve Elegant lattice files
    - Correspondence with actual linac (model for CM not clear)
  - Turn corrector strengths into magnet current settings
  - Controls interface

Additional Learning

- Learn to work with linux cluster and elegant
- Understand behavior of components in a beam line
- Understand what are the limits and possibilities of steering in a beam line
- Understanding of quad steering
- Understanding of beam based alignment

Conclusion

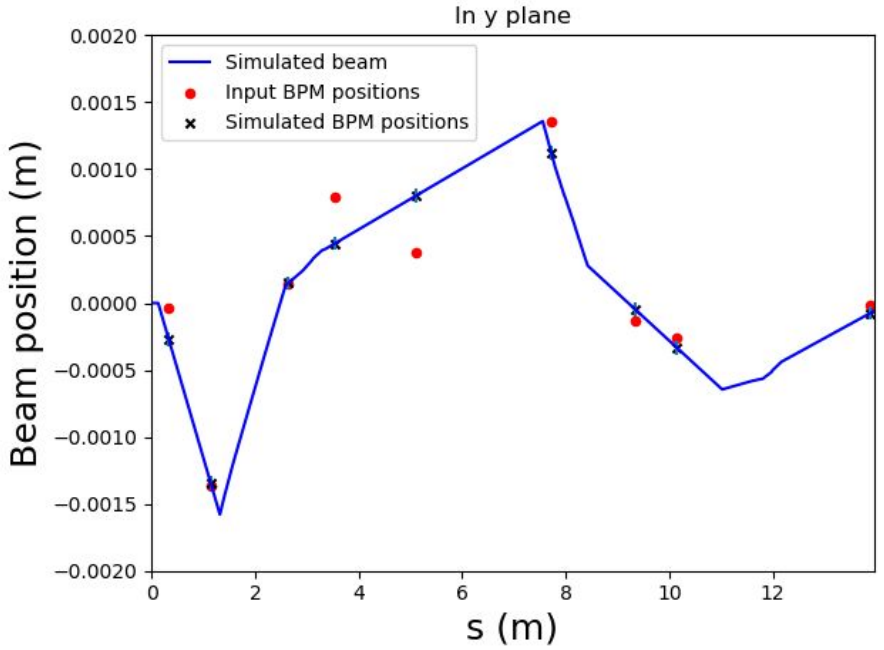
- Learning about beam simulation and tracking
- Outcome: Usable routines

Thank you for your attention!

(...and for your help and for organising!)

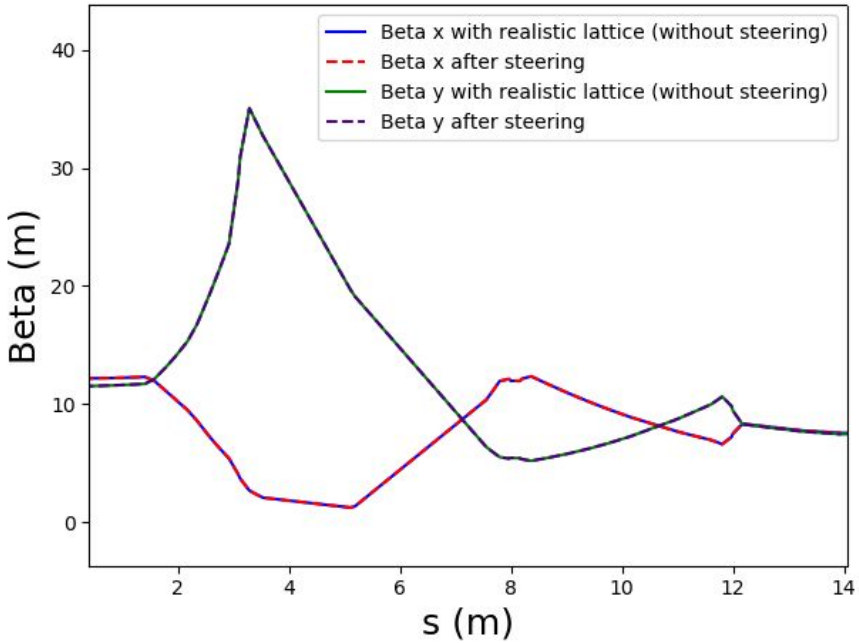
Backup - Steering in y plane

Steering in y plane and x plane works simultaneously



Backup - Steering: beta functions

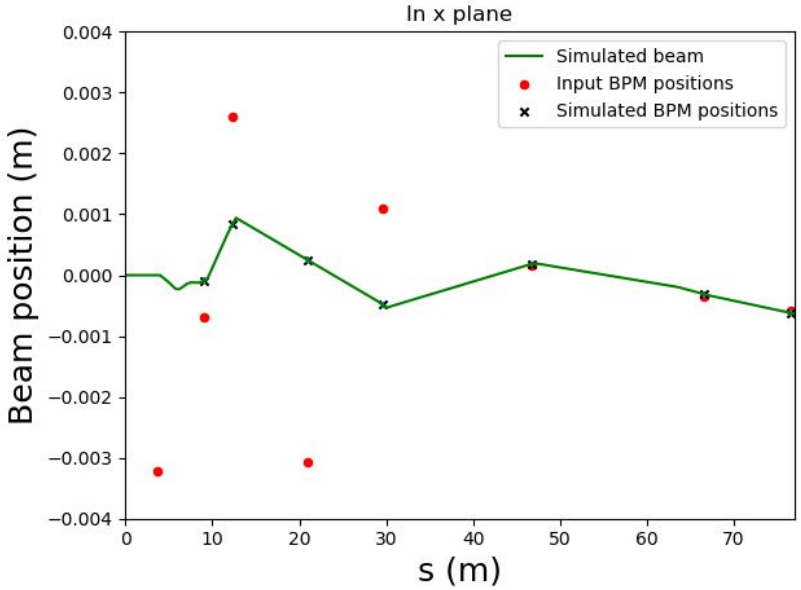
Still more detailed analysis needed but it seems that the steering preserves the beam size.

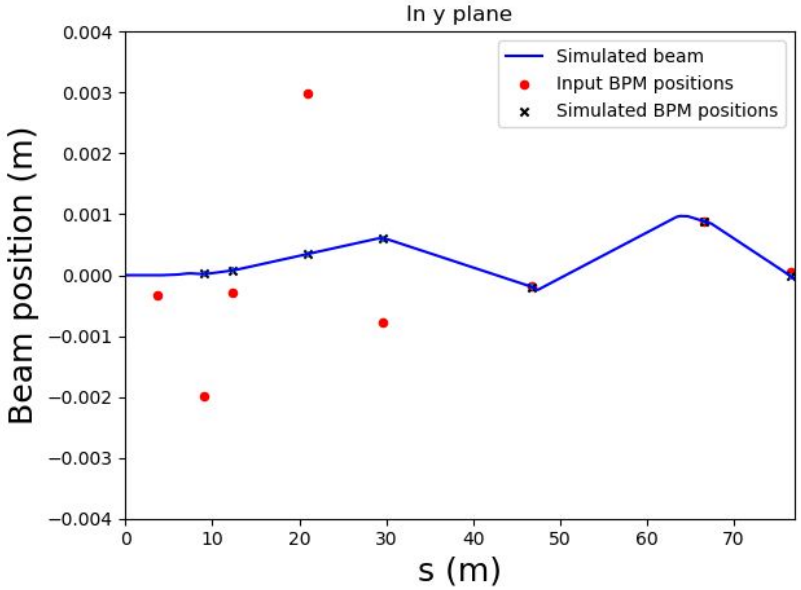


Backup - Steering after CM

- Model for the Cryomodule not clear, problems with steering through the CM
- No correctors directly after the CM, difficult to adjust to first BPMs directly after CM
- Correction further downstream works

Backup - Steering after CM





s=0 means here 0 meters after the CM

Backup
More Details to Singular Value Decomposition (SVD)

Not square matrix: $A = UWV^T$

U : Columns have eigenvectors of AA^T

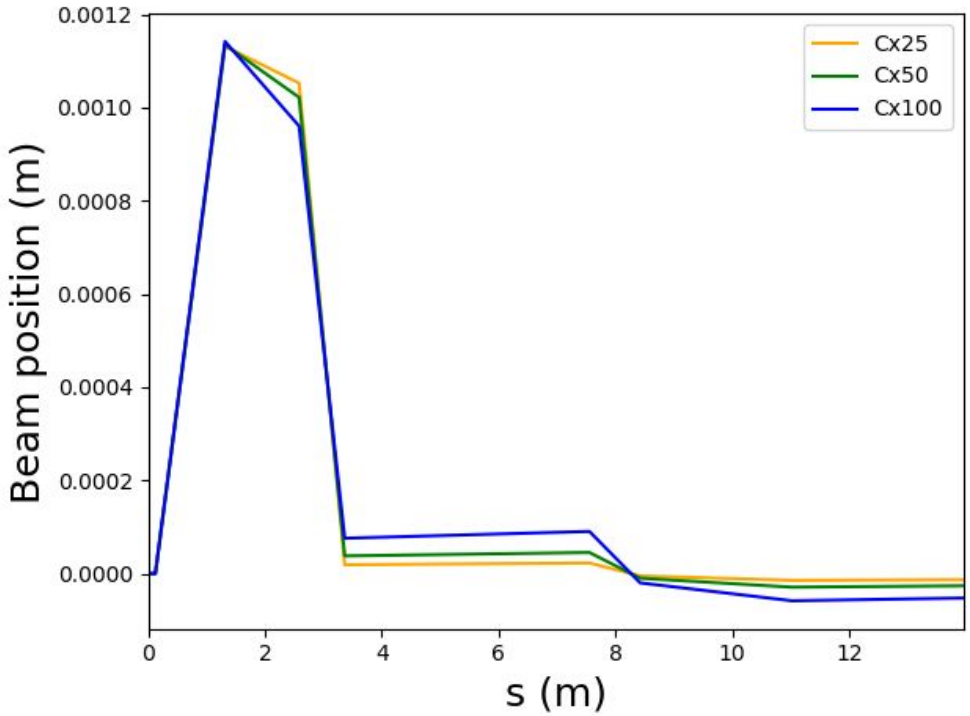
W : Has Singular Values on diagonal, are square root of the eigenvalues of both AA^T and A^TA

V : Rows have eigenvectors of A^TA

Pseudoinverse: $A^+ = V^T W^+ U$

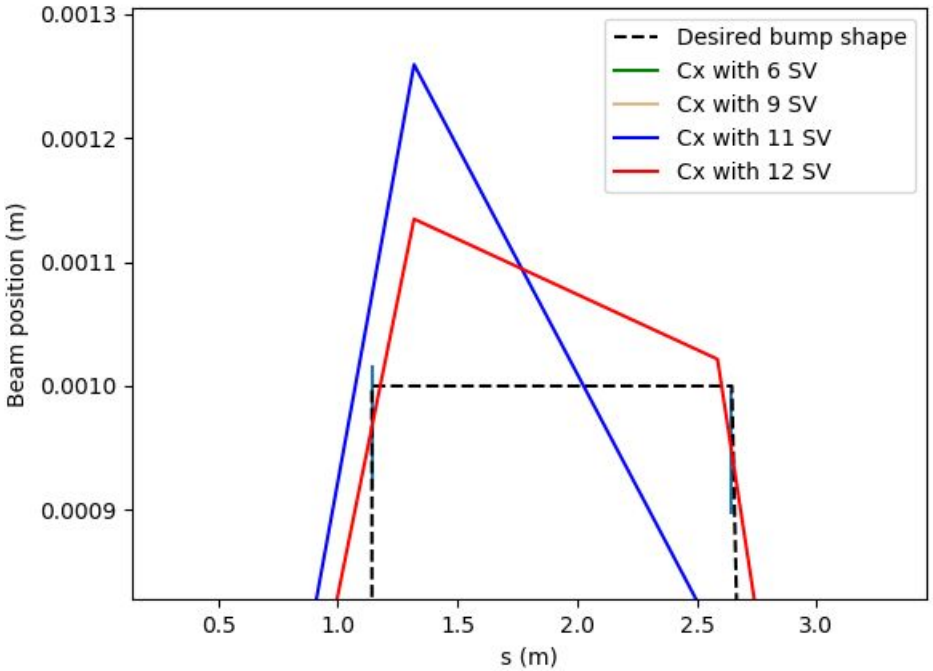
Comparison using different BPM noise levels

Difference of the simulation when using BPM resolution of 25 um, 50 um and 100um



Backup - Zoom of bump

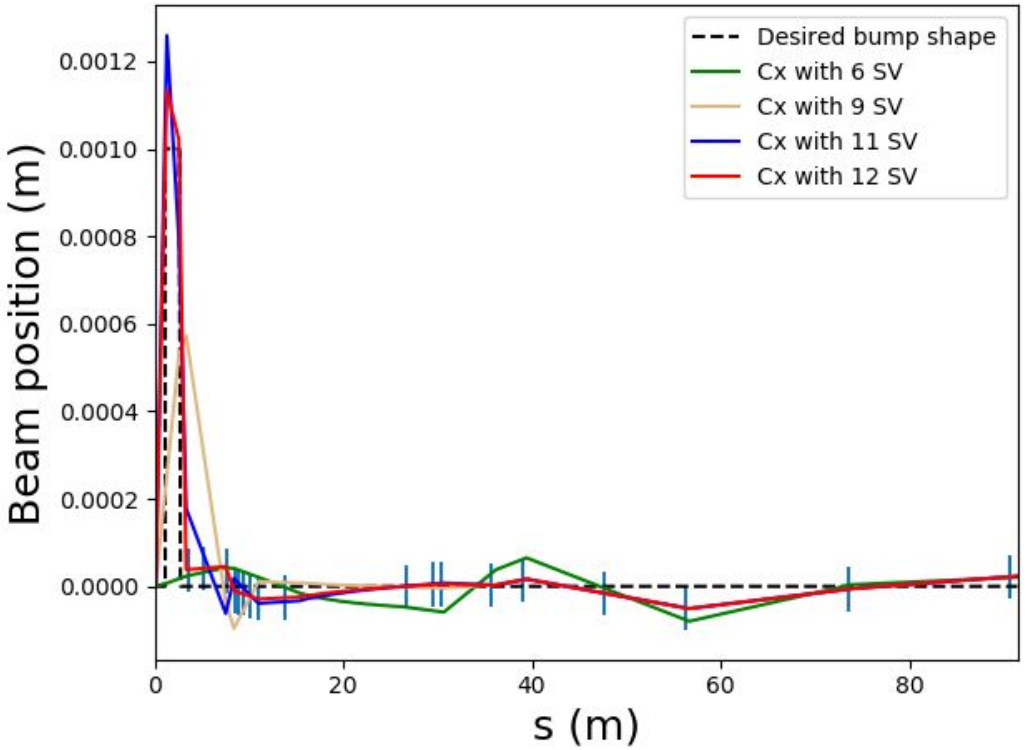
Zoom of bump to show error bars



Backup - Bump with full used beamline

This bump was constructed using 90 m of the linac (until H480).

This part of the beamline has 13 horizontal correctors, hence we get 13 SV.



Backup - Zoom of Chi Squared

Zoom for the Chi Squared Values for the use of 10 to 13 singular values