Tomography of the horizontal phase space of a slow resonant extracted proton beam

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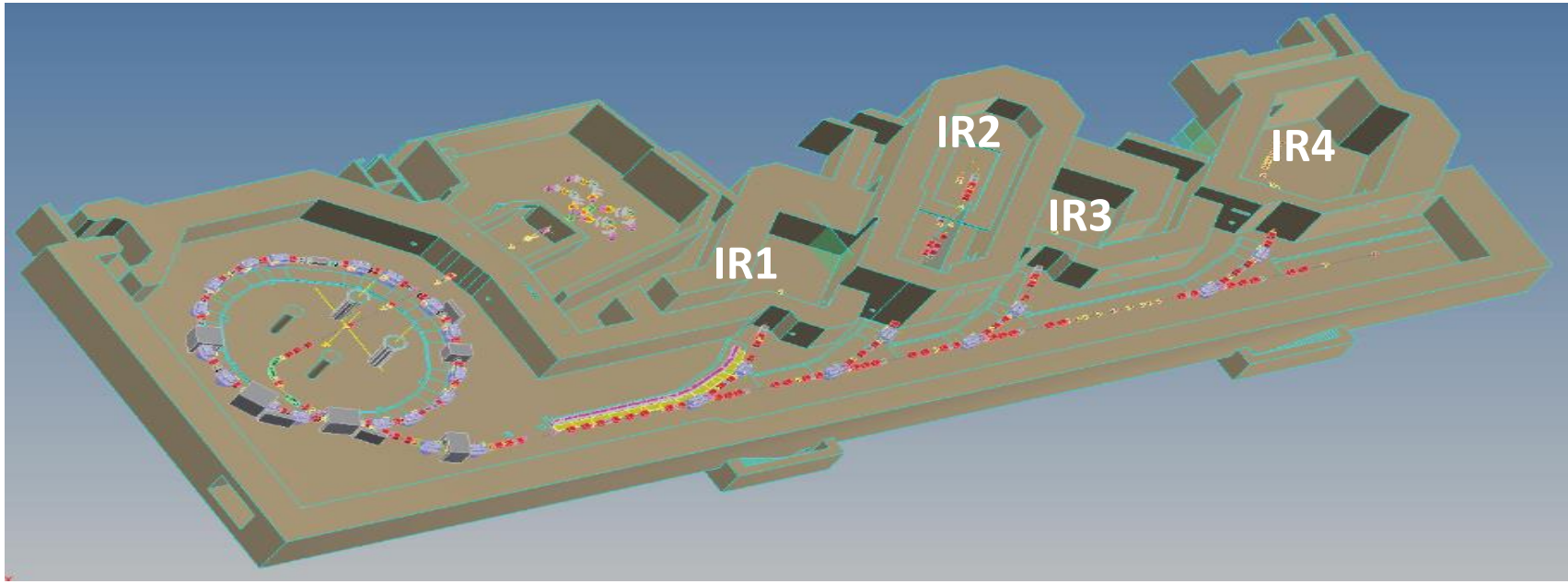
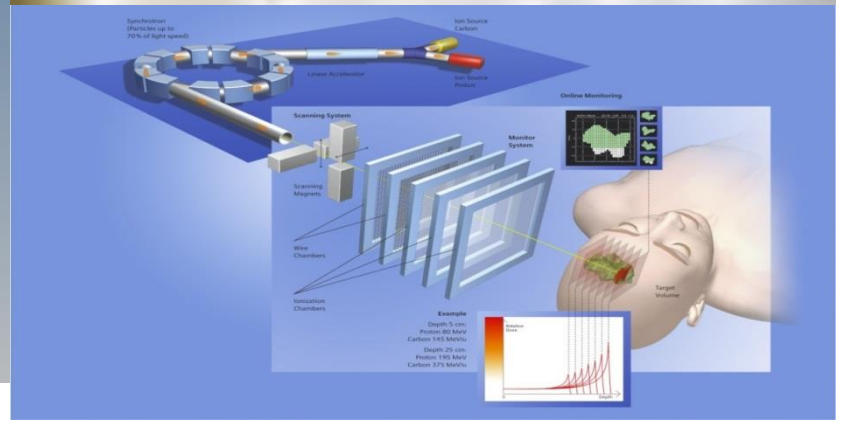
on behalf of Alexander Wastl

Slow Extraction Workshop – 2017 – CERN

MedAustron Ion Therapy Facility

Wiener Neustadt, Austria





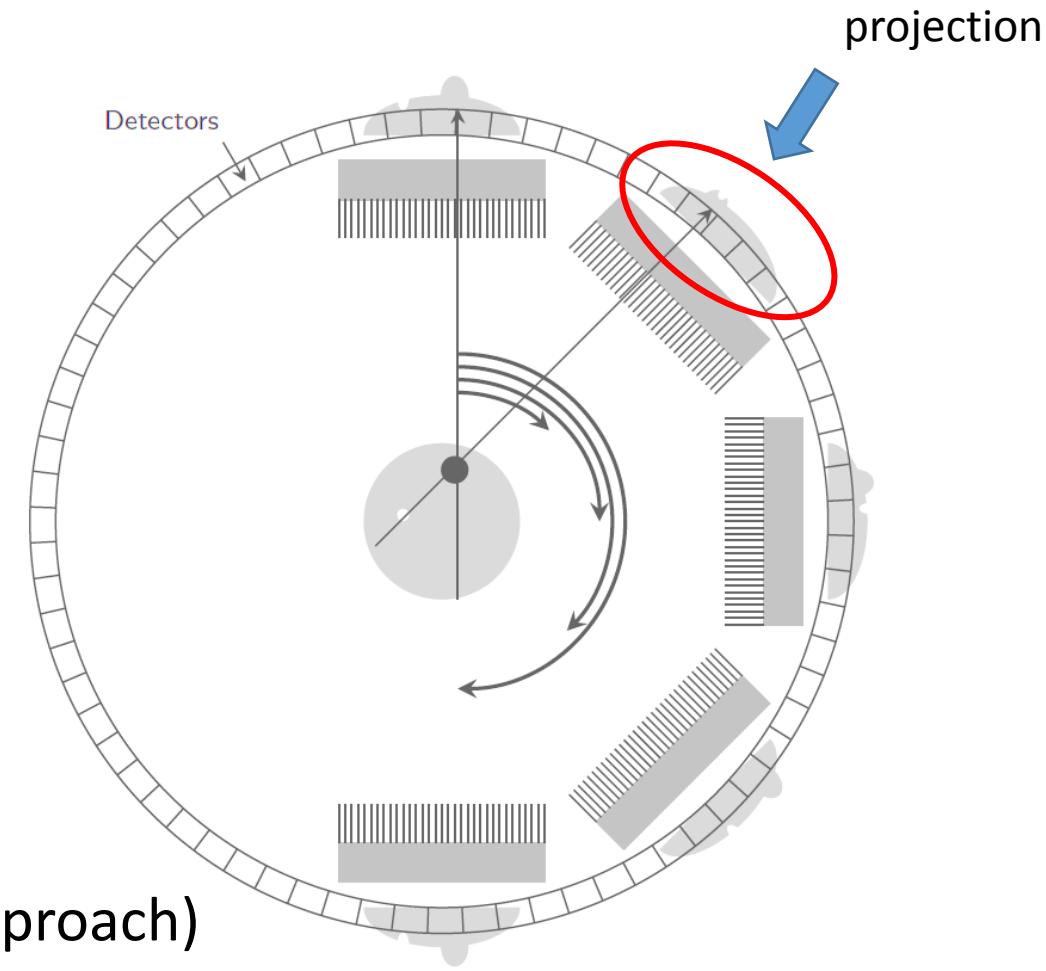
Synchrotron 77 m delivers proton (60-252MeV) and Carbon ion beams (120-400MeV/u) to:

- **IR 1: non clinical research room: horizontal beam outlet, protons** and carbon ions
- **IR 2: medical use: horizontal** & vertical beam outlet, **protons** and C6+
- **IR 3: medical use: horizontal** beam outlet, **protons** and C6+
- IR 4: medical use: proton-gantry

Status: operational shown in **green**

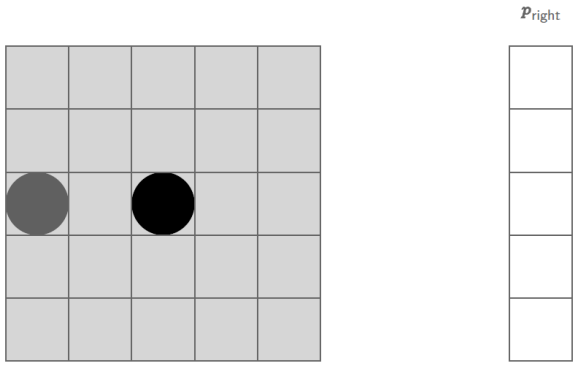
Tomographical reconstruction

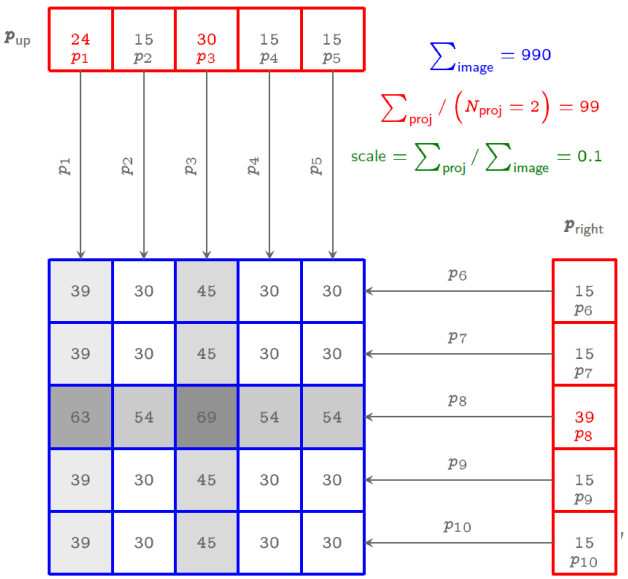
- example: CT or PET
- goal: inner structure of a 2D object
- measure 1D density projections from various perspectives (angles)
- reconstruct 2D density by solving inverse Radon transformation
- Two common techniques:
  - Filtered back projection (FBP; next slide)
  - Algebraic reconstruction (ART; iterative approach)



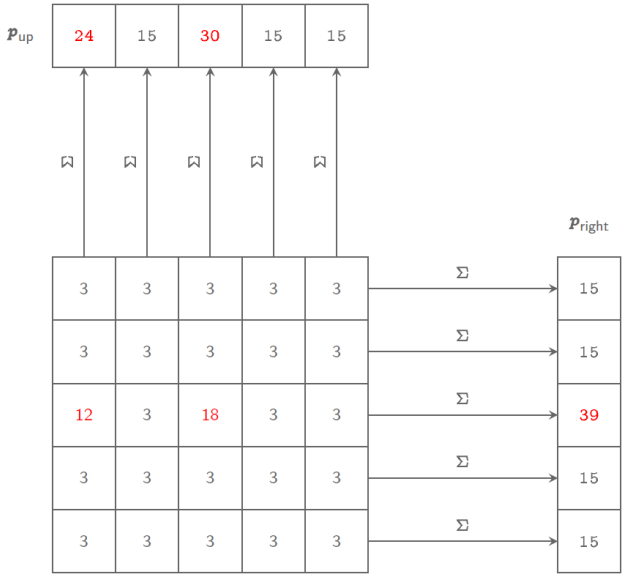
A.Hirtl

Principle of reconstruction

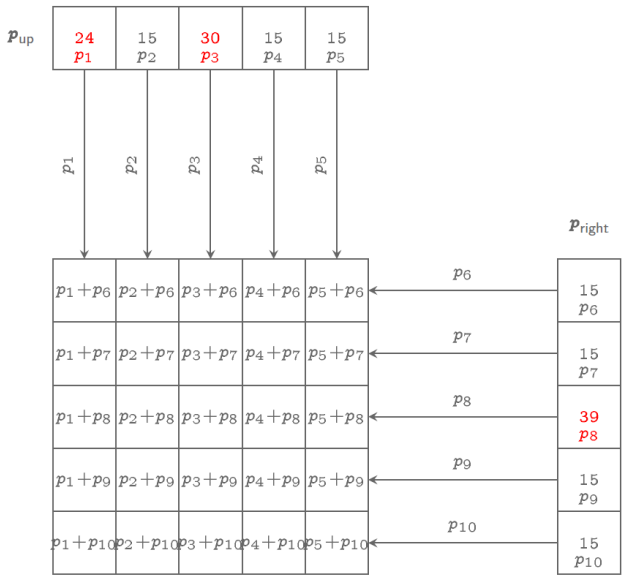




1D projection
“measurement”



back projection



2D projection
“reconstruction”

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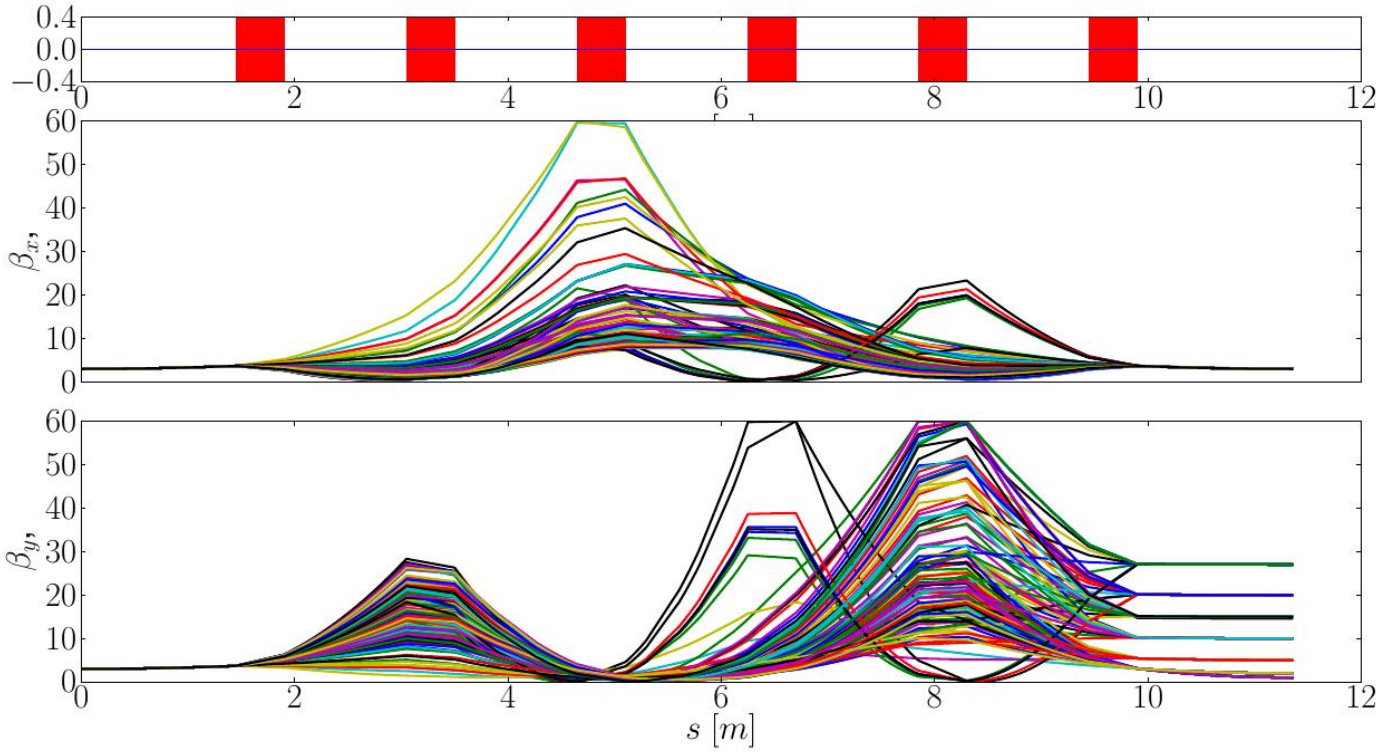
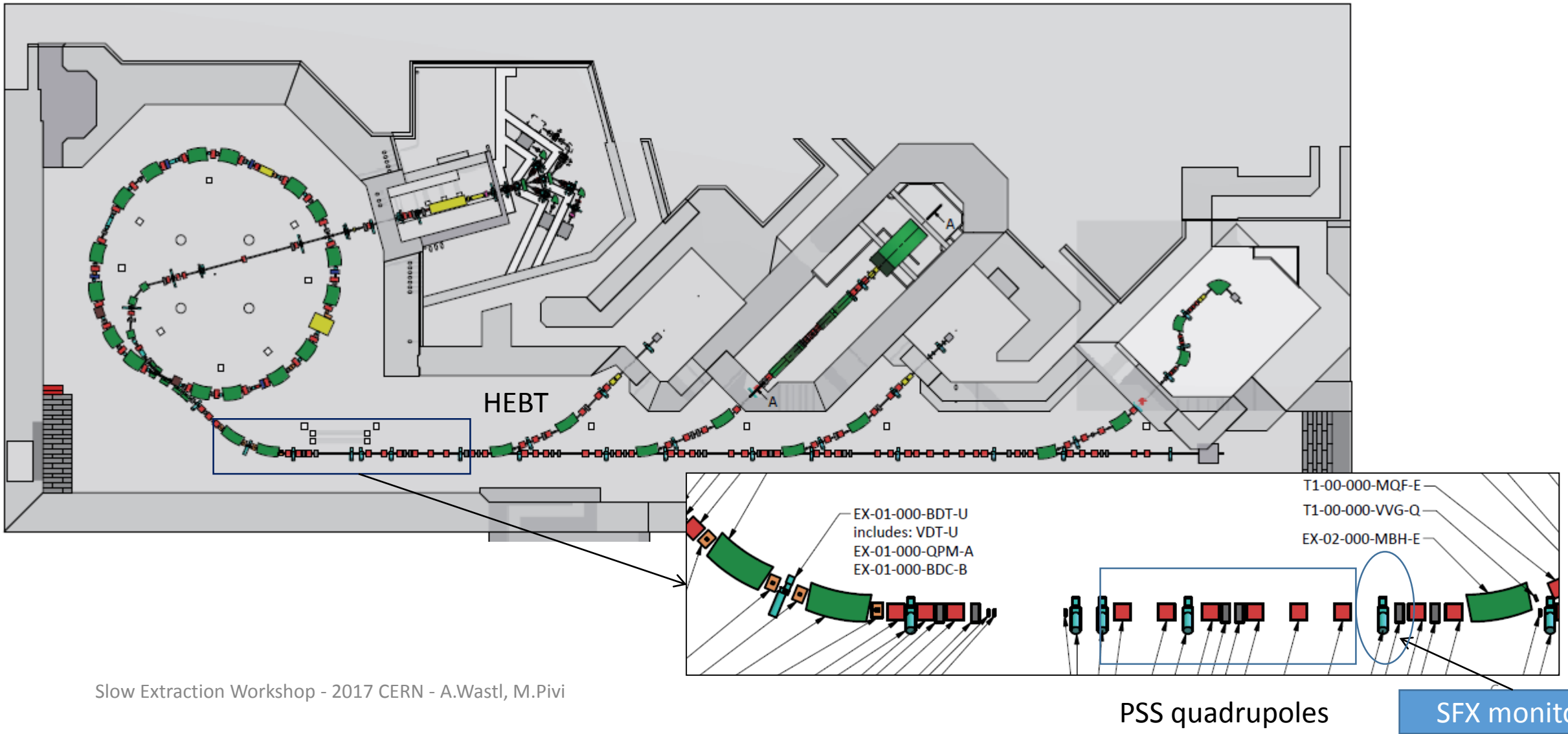
Particle Accelerator

- Instead of rotating the monitor (beam profile monitor)
- rotate the beam (in normalized phase space)
- MedAustron Phase-Shifter-Stepper (6 quadrupole magnets)

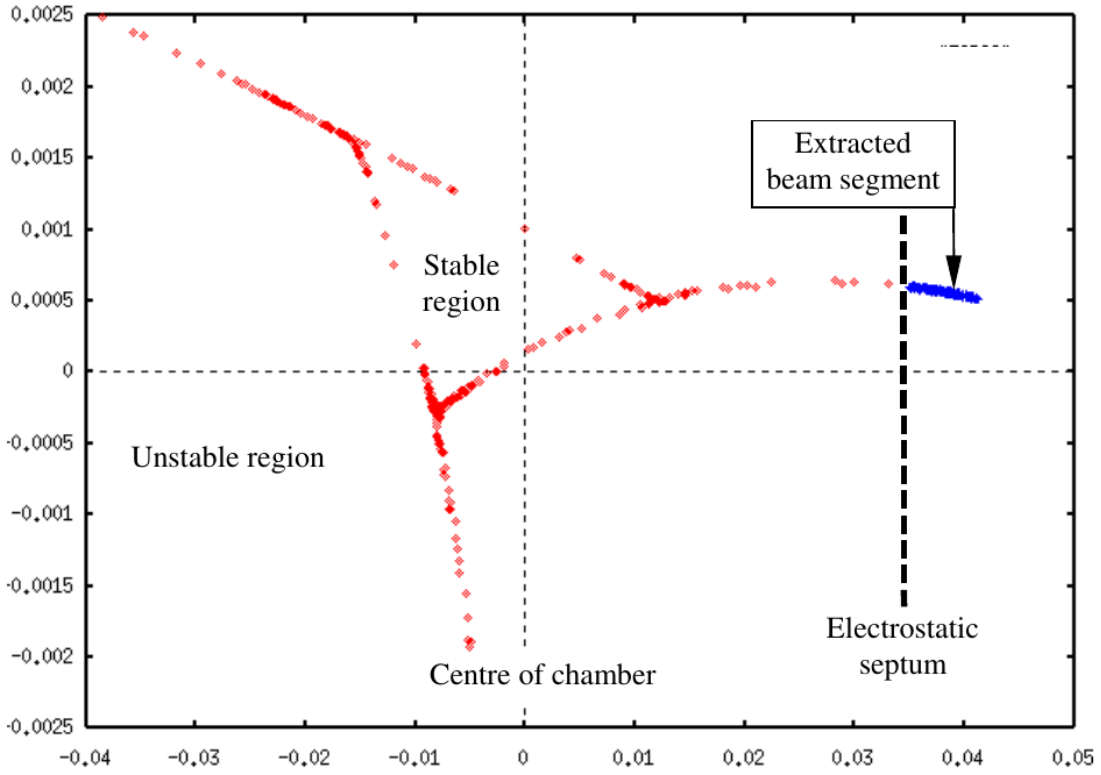


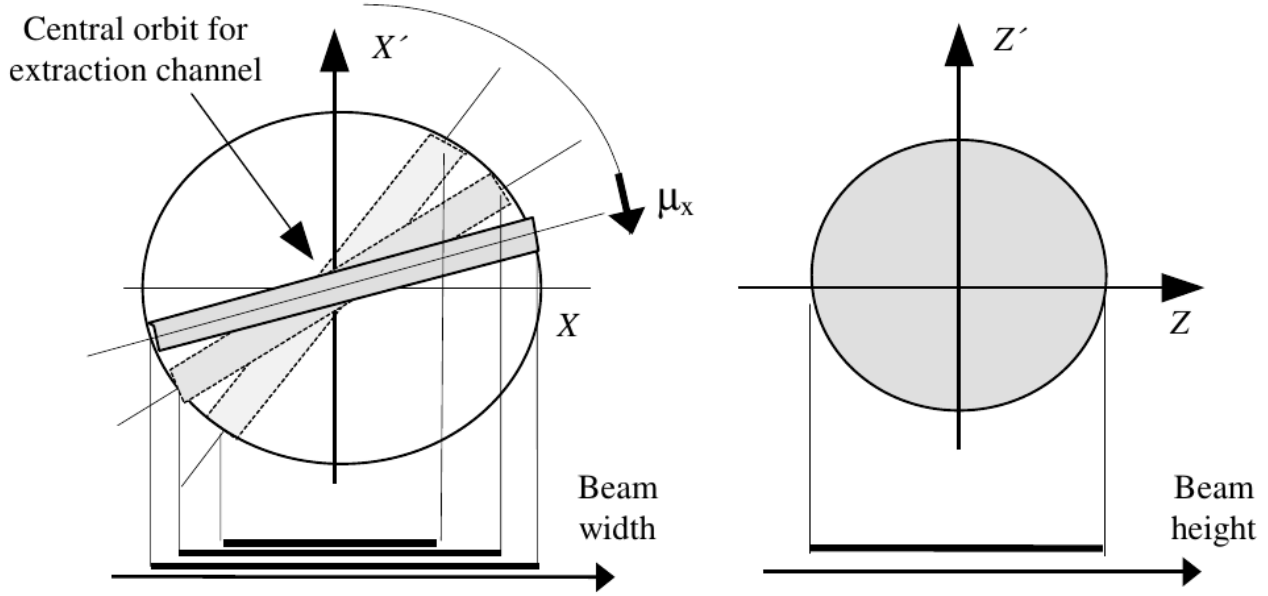
- HEBT
- control beam size downstream:
  horizontal: via phase advance
  vertical: via BETAy
- BETAx in = BETAx out
- 180 degree rotation sufficient

MedAustron Phase-Shifter-Stepper (PSS) quadrupoles in the HEBT



Object of interest: Bar-of-Charge



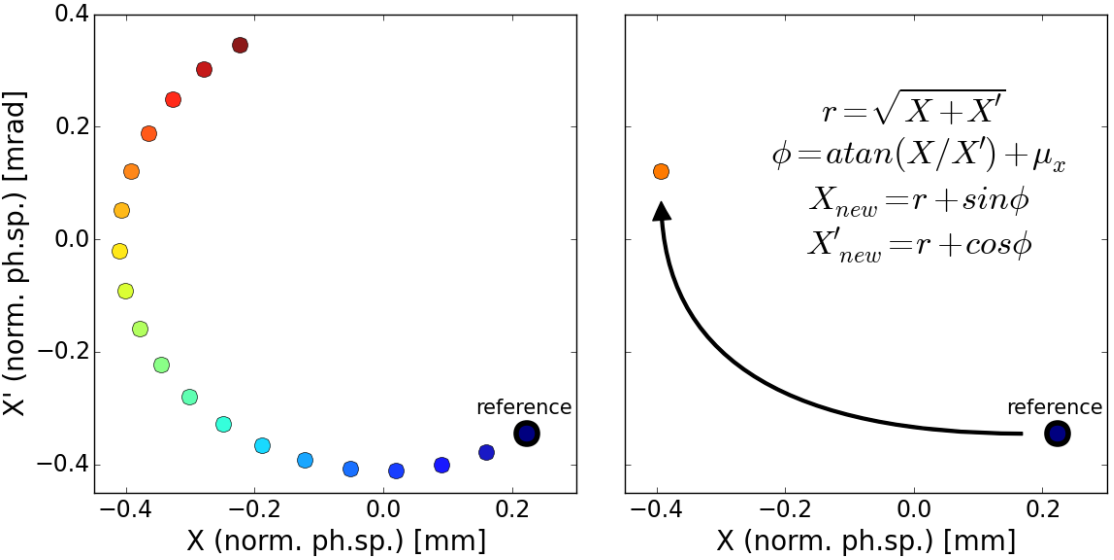


Proton-Ion Medical Machine Study, CERN

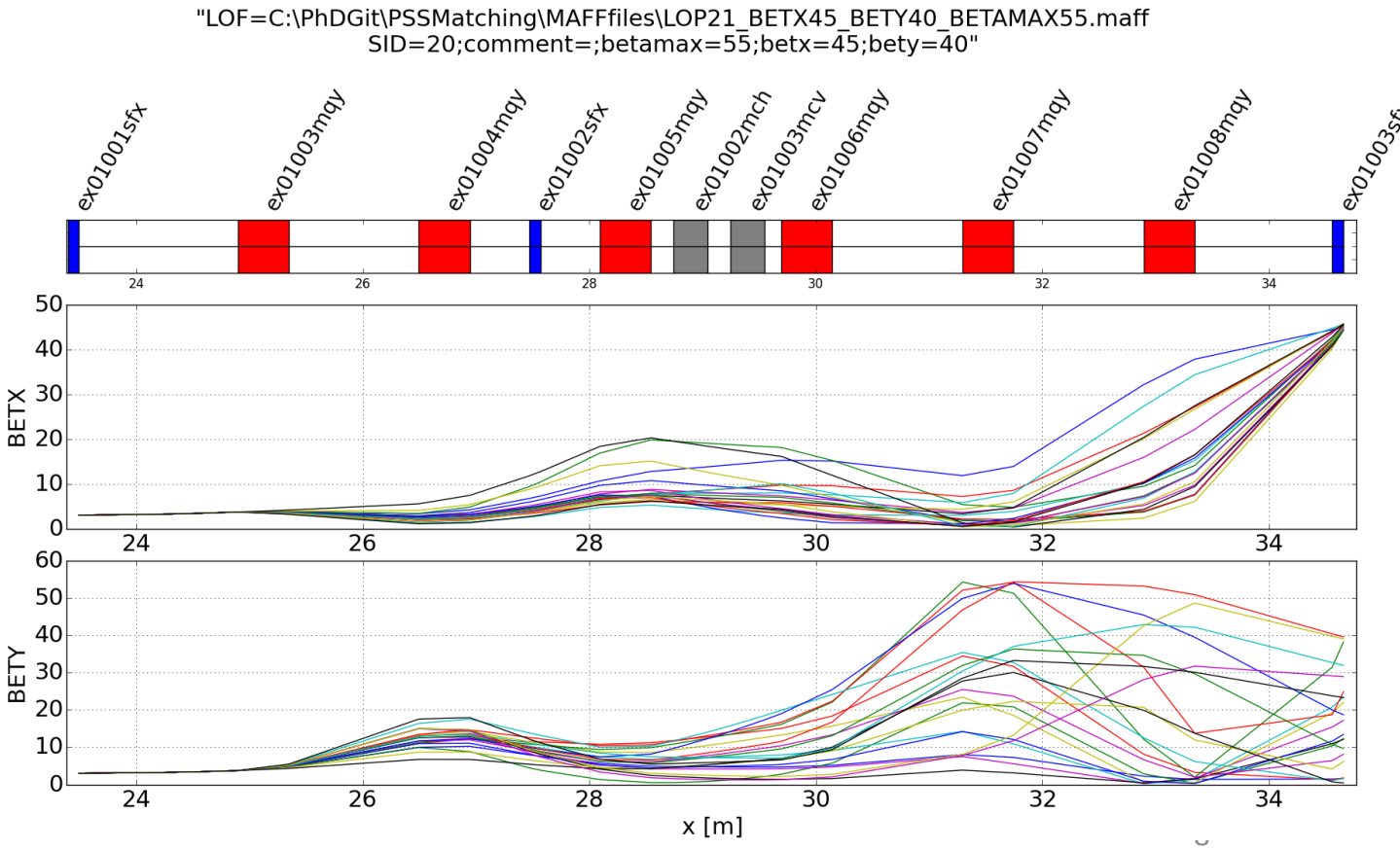
- non-Gaussian phase space distribution

Bar-of-Charge rotation

1) Mathematically operation in normalized phase space (Rotorgram)

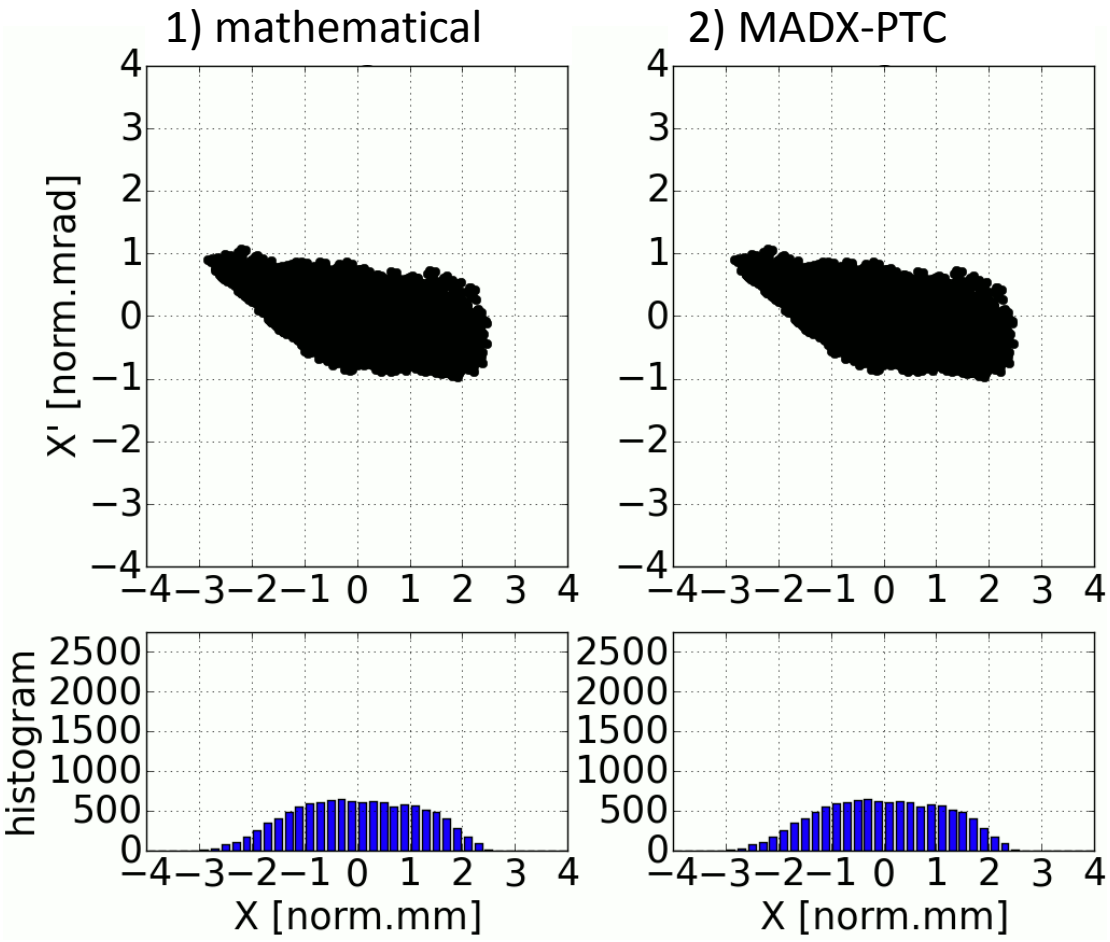


2) "Physically" via MADX-PTC tracking for various matched quadrupole settings

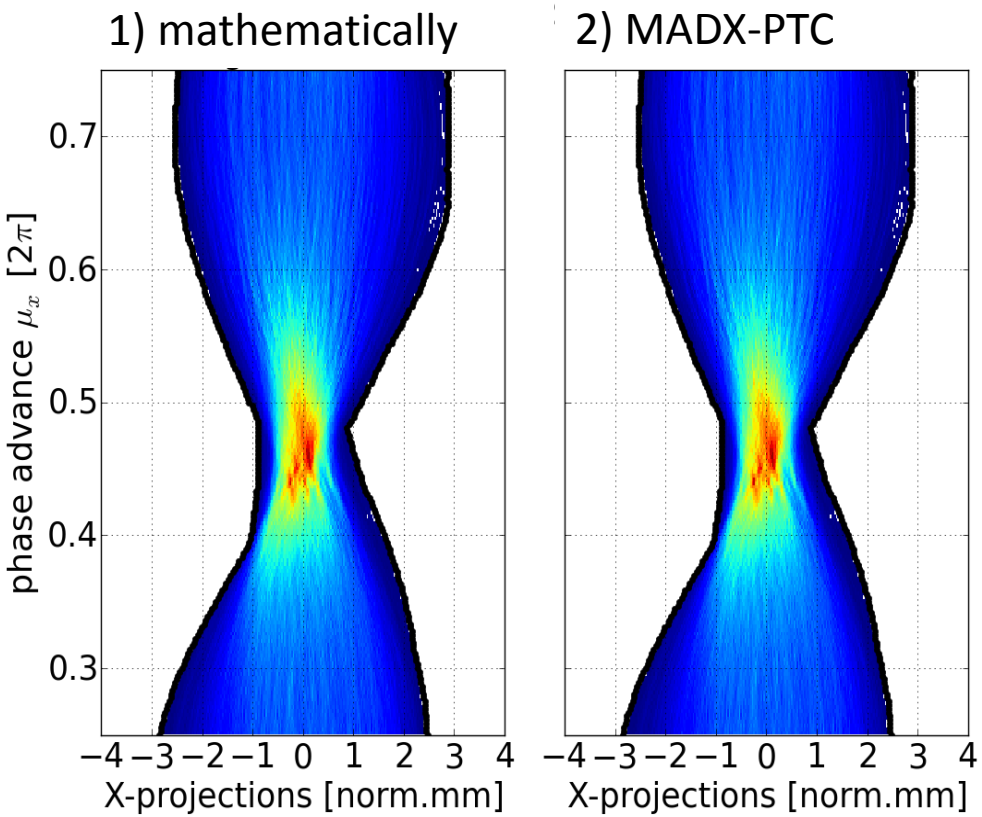


SIMULATION

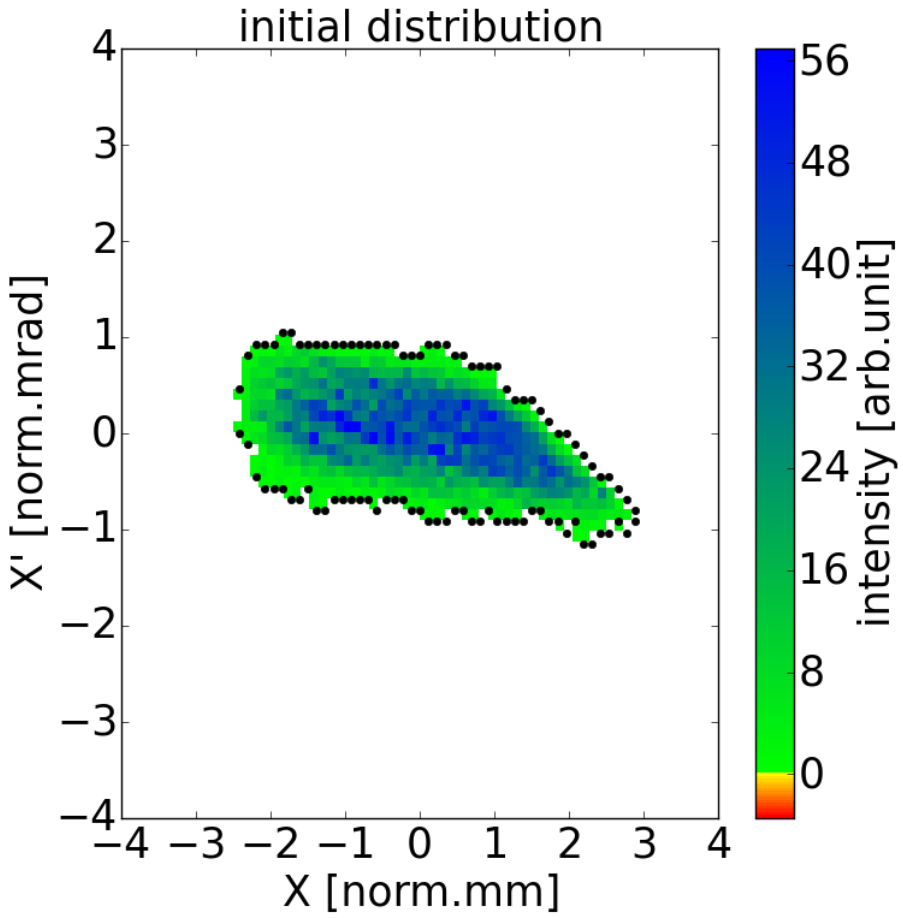
Sinogram



SINOGRAMS (profile vs. angle/phase advance) are identical



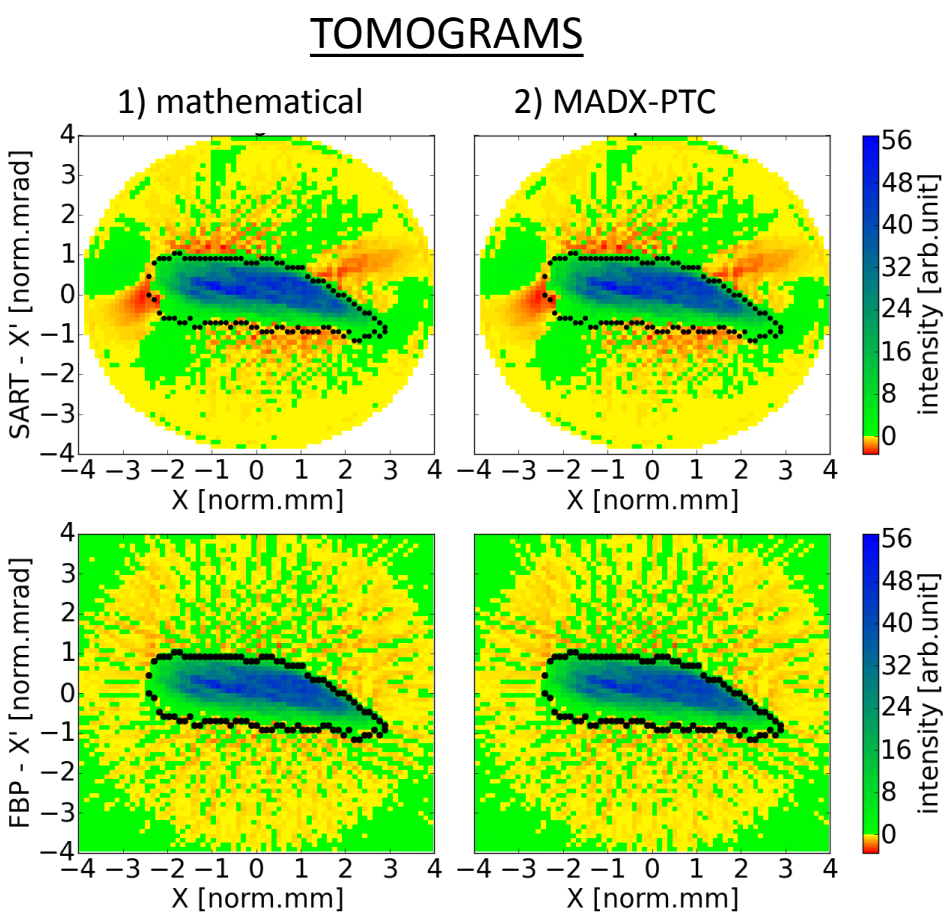
Reconstruction quantification parameters

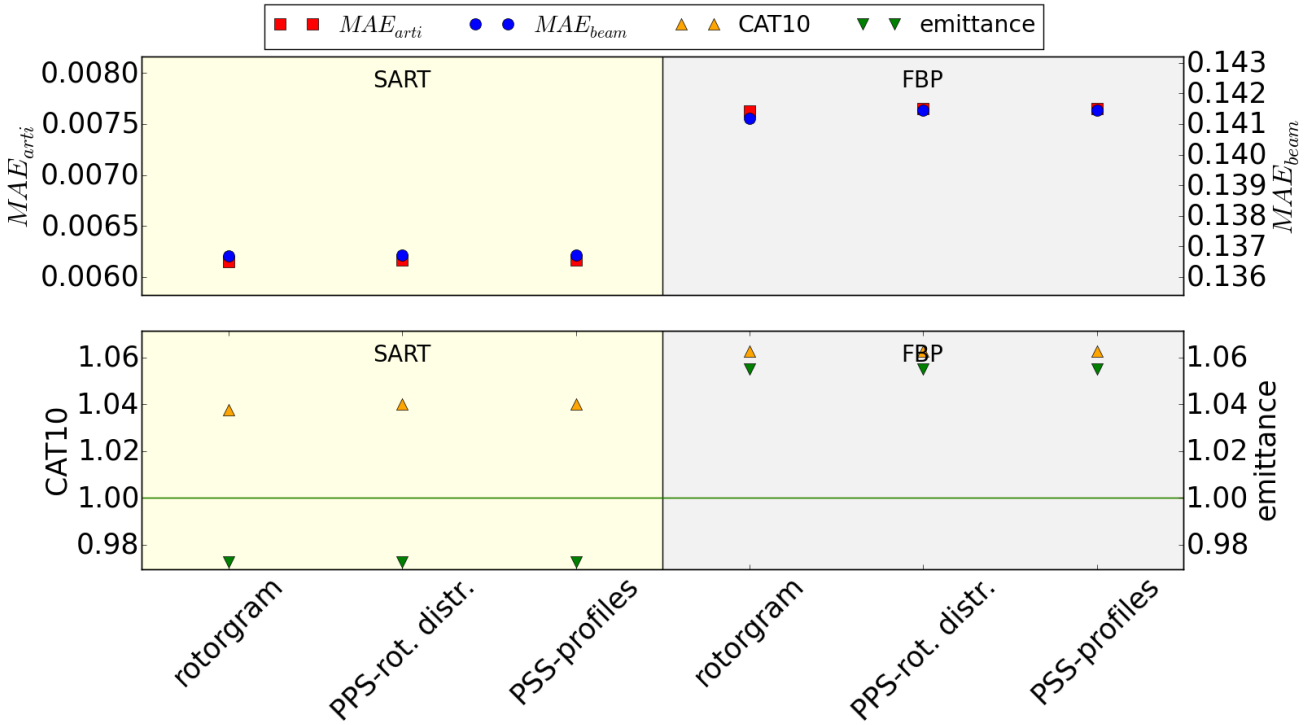


- cell-wise comparison with reference
- **MAEarti**: Mean Absolute Error outside black enclosed area
- **MAEbeam**: Mean Absolute Error inside black enclosed area
- Emittance:
  - **EM** (threshold): area covering 90% of beam intensity (cell-wise)
  - **εrms** (SCUBEEx): exclusion ellipse method
- **CATx**: number of cells above a threshold (x)

SIMULATION

Reconstruction algorithms



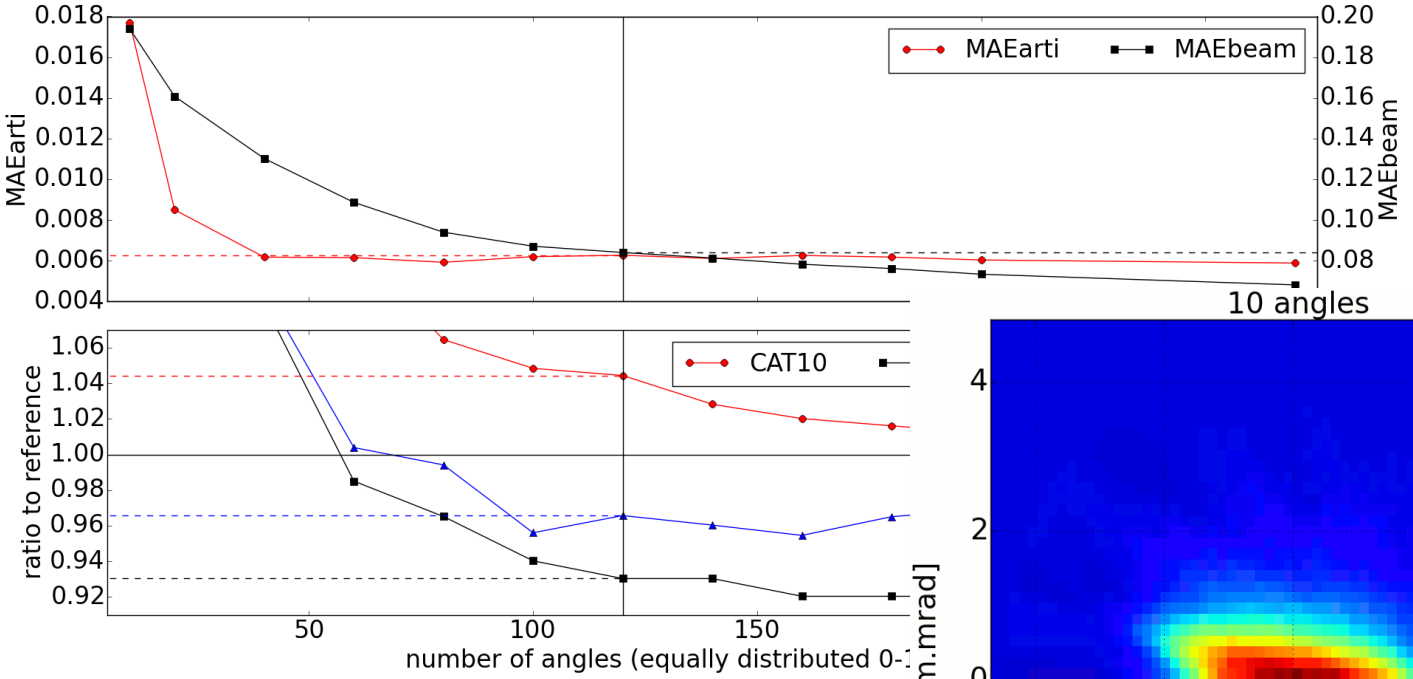


- Mean Average Errors are lower for Simultaneous Algebraic Reconstruction Technique
- Emittance and CAT error lower (w.r.t reference)

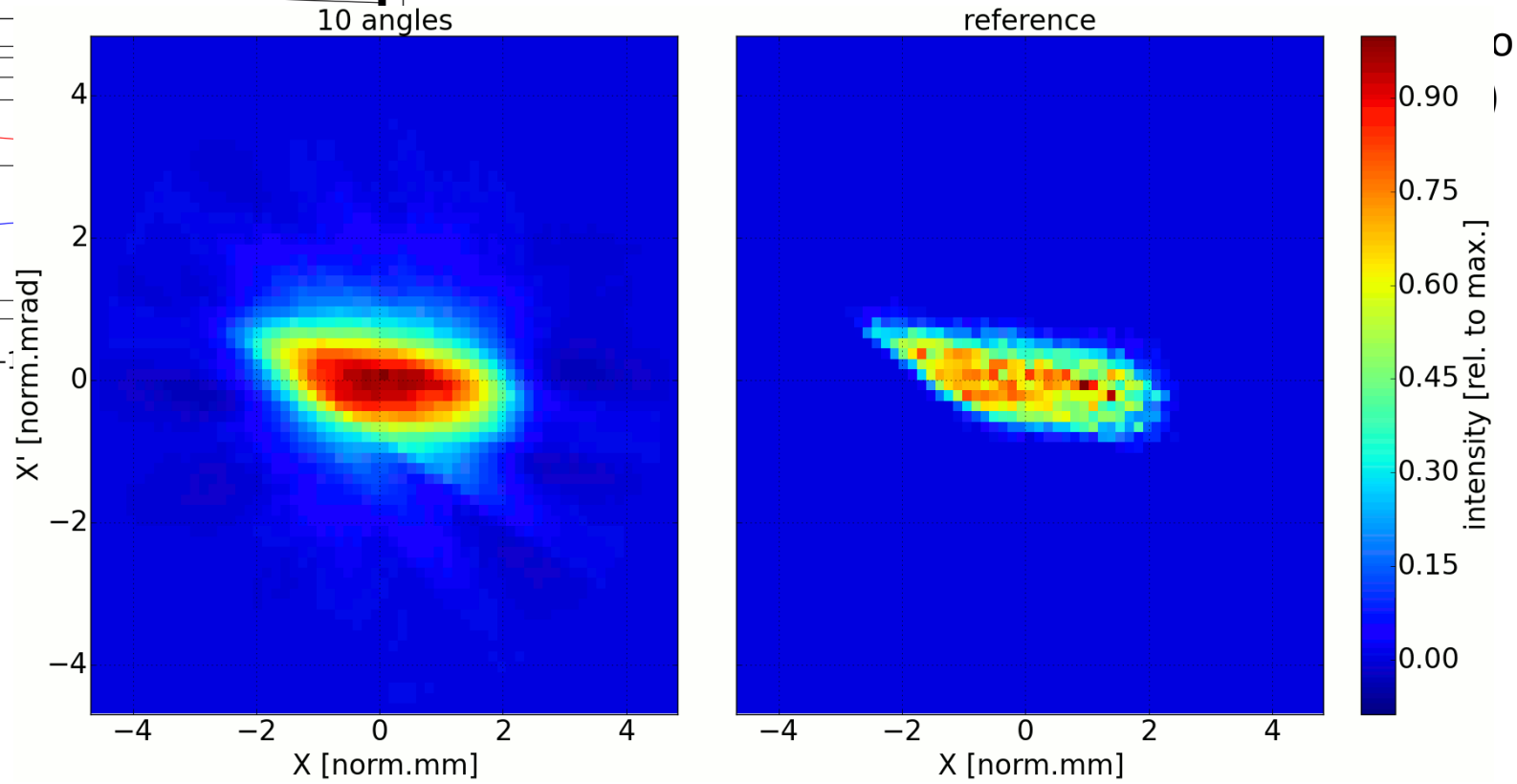
➔ SART

SIMULATION

Number of perspectives (projection angles)

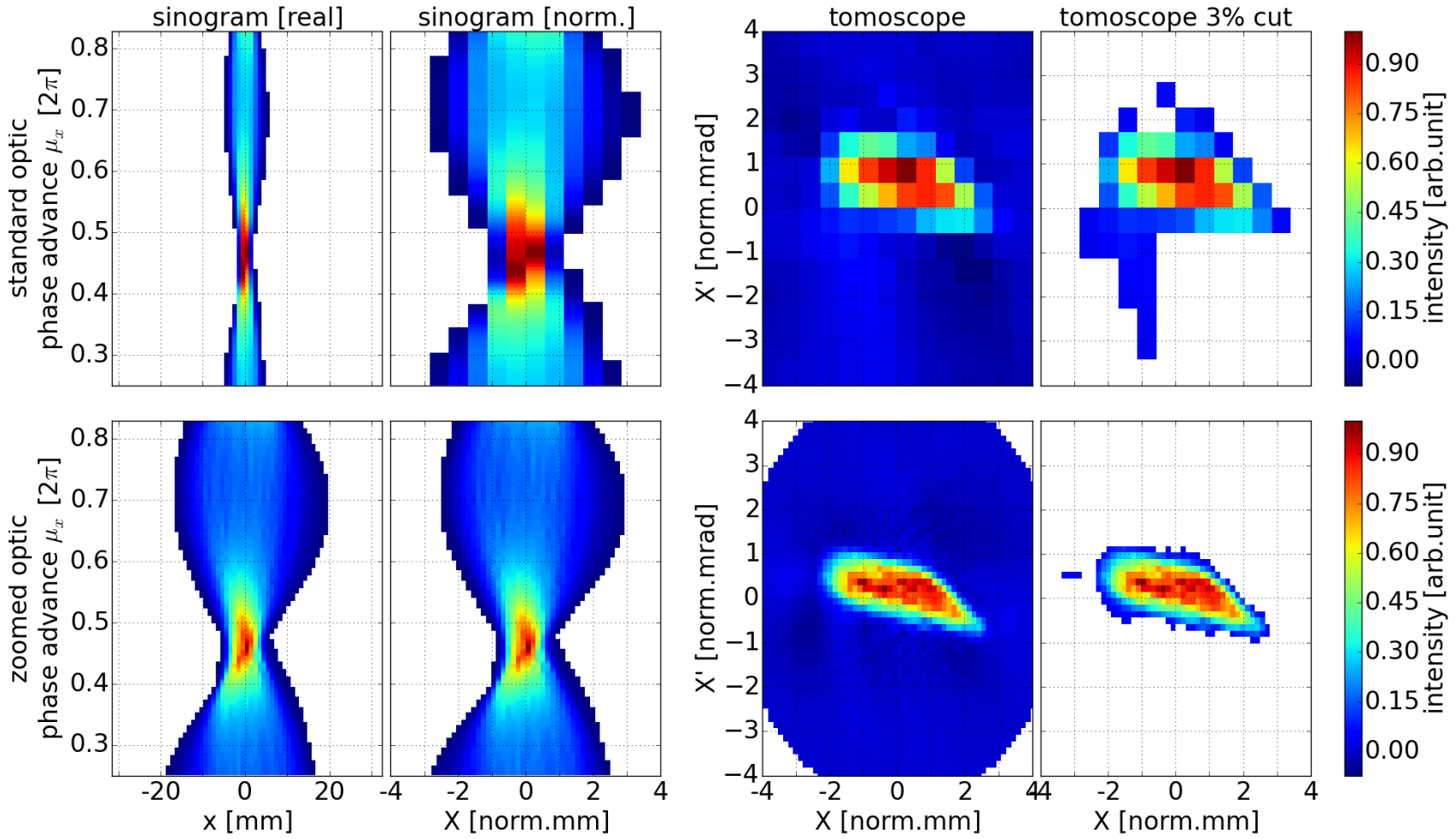


- Define the required measurement duration
- More perspectives require more quadrupole settings (which might even change polarity)



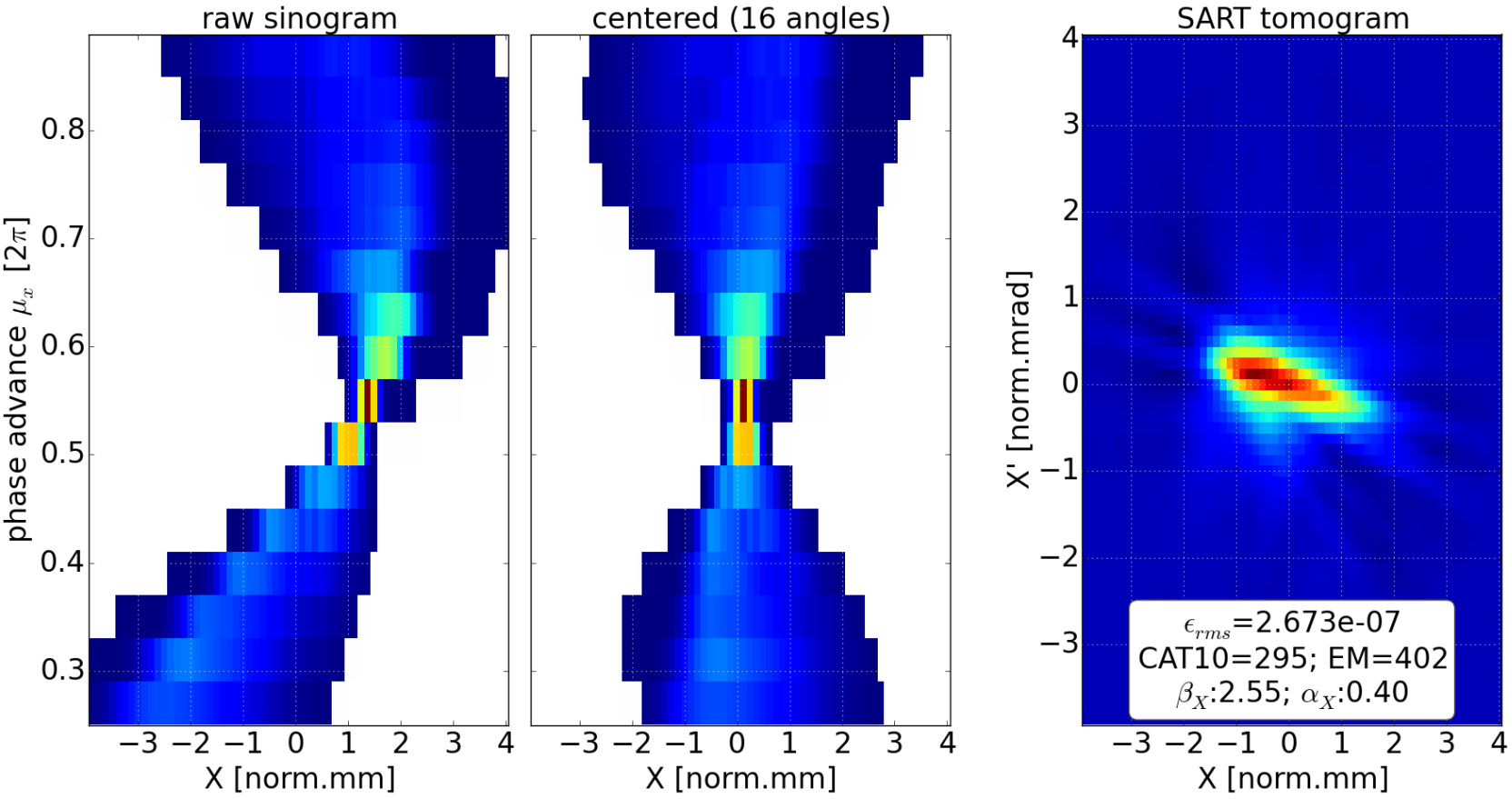
SIMULATION

Beam Profile Monitor resolution



- Standard optic:
  - BETAx in: 3m
  - BETAx out: 3m
- Zoomed optic:
  - BETAx in: 3m
  - BETAx out: 45m
- MedAustron BPM res: 1mm

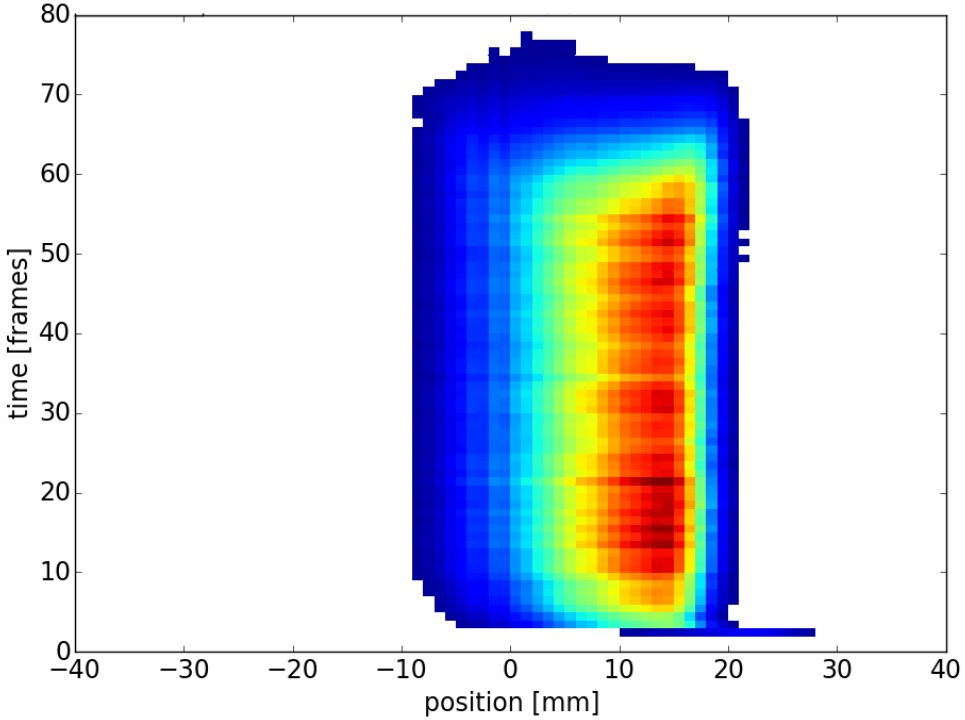
First measurements

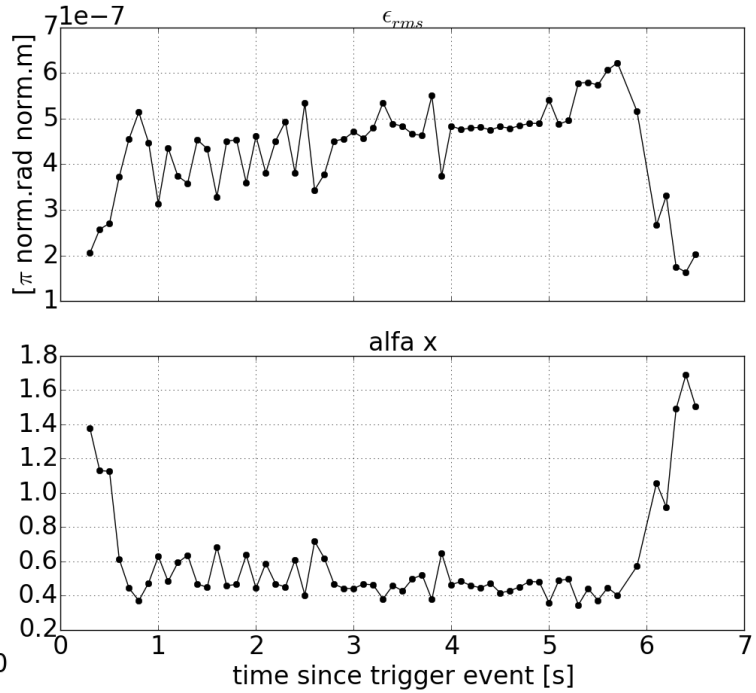


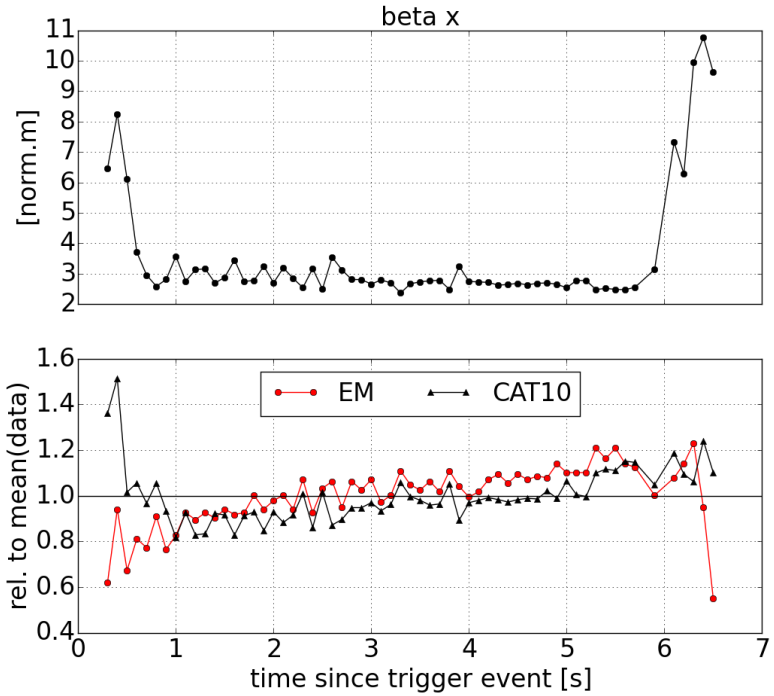
- incoming beam (x/x')
- misalignments

➔ profile centering required (via Center of Gravity)

Time resolved analysis







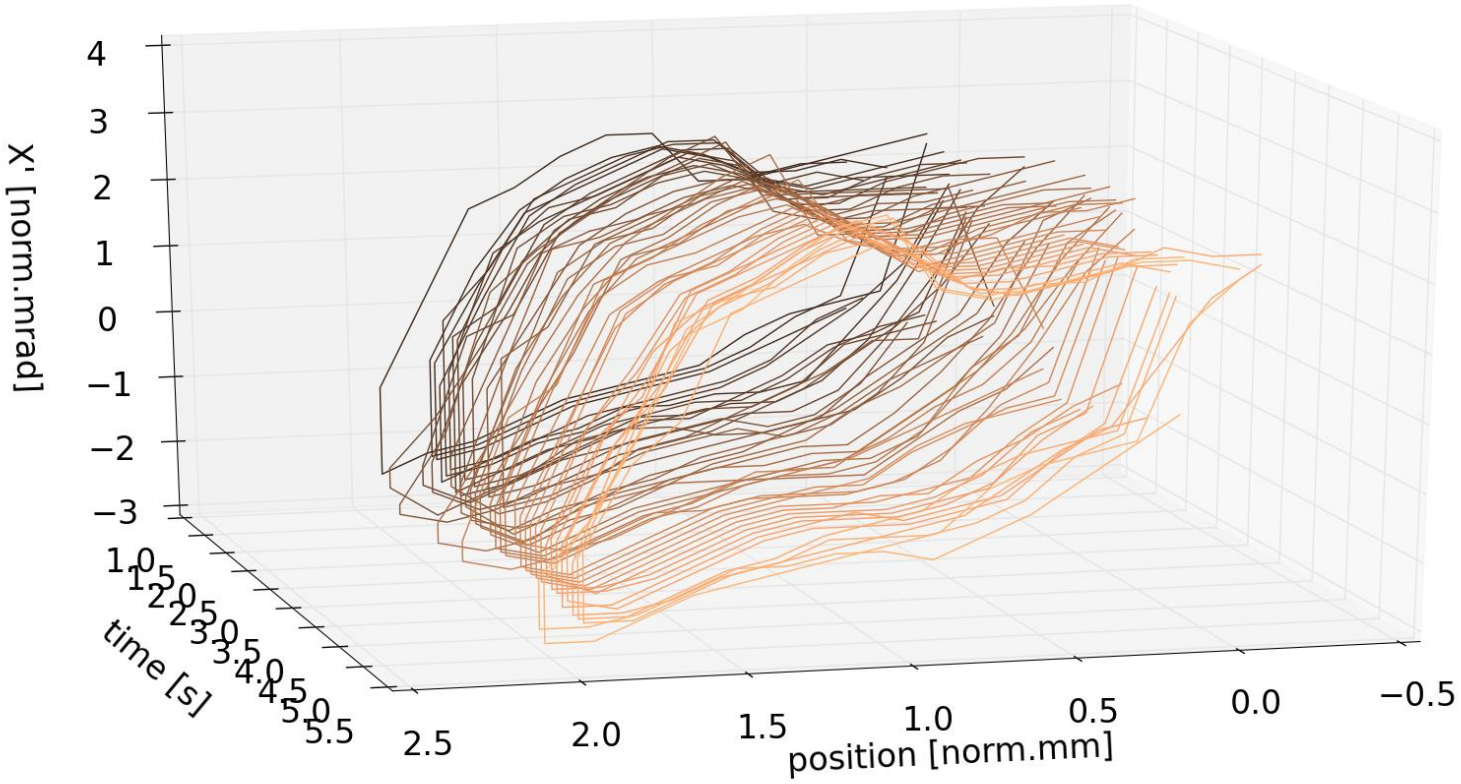
- Scintillating fibers
- 80ms exposure time
- 1 frame / 100ms

- for treatment beginning and end of beam are chopped

Conclusion and Outlook

- First results indicate that :
  - the method is suitable to study the slow extracted proton beam
  - the method can be used to verify result of tuned accelerator settings
  - a reasonable set of data can be acquired in 120 spills
  - intraspill phase space analysis is possible

- use a quadrupole setting dependent corrector setting to keep the beam on the beam profile monitor without scraping
- compare the result of different driving mechanisms and particle types



Thank you for your attention.

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