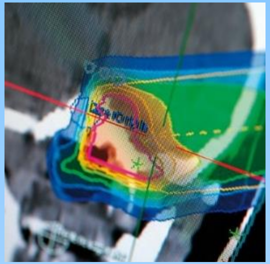

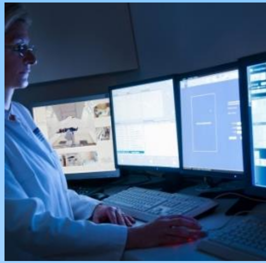

UNIVERSITÄTS
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HIT
Heidelberger Ionenstrahl-Therapiezentrum

Analysis of Low and Medium Energy Beams at HIT

Rainer Cee, HIT GmbH

Experiences During Hadron LINAC Commissioning
25-29 January 2021

Co-Authors:
Ch. Dorn, A. Peters, J. Schreiner, T. Winkelmann, HIT GmbH
O. Chubarov, A. Robin, SHC (Siemens Healthcare GmbH)

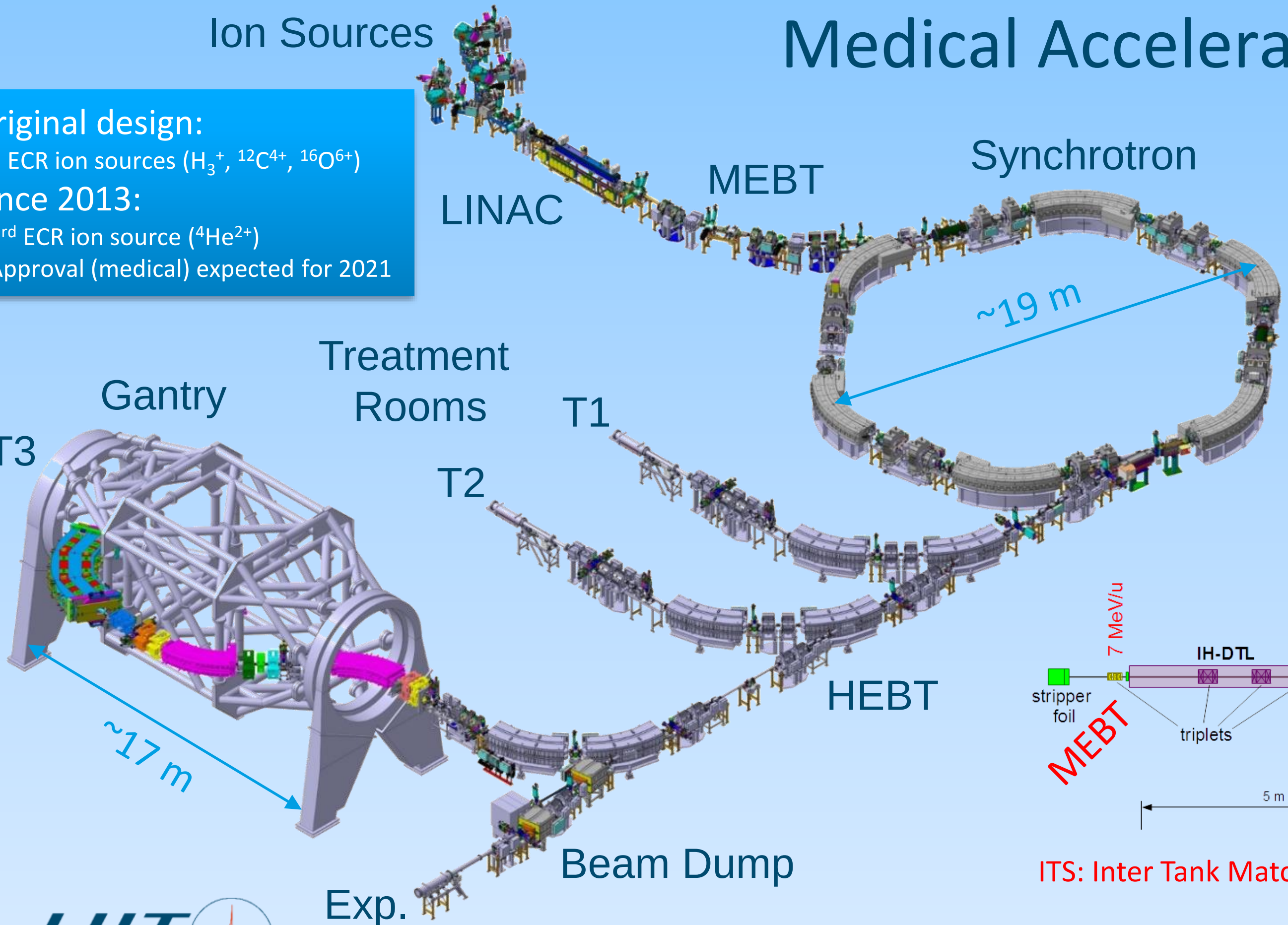
Outline

- Introduction
  - Medical Accelerator Overview
  - LINAC Beam Diagnostics
    - Profile Grid Measurement
    - Phase Probe Measurement Time-of-Flight
- Test Bench Common Test Bench of HIT and Siemens Healthcare
  - Overview
  - Recommissioning of the Siemens-Spare-RFQ
  - Pepper Pot Measurements

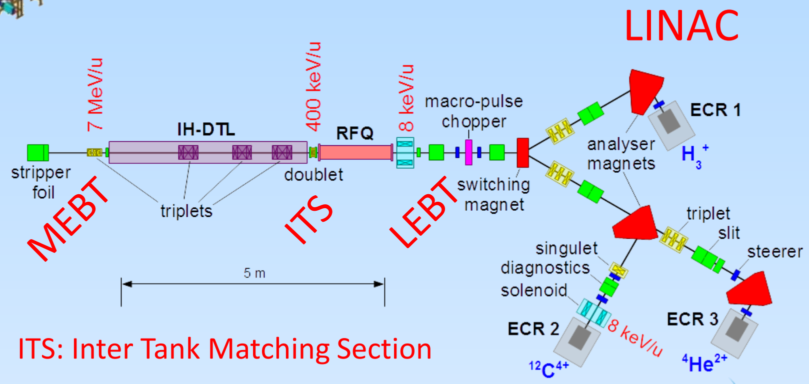
Medical Accelerator Overview

Original design:
- 2 ECR ion sources (H_3^+, $^{12}C^{4+}$, $^{16}O^{6+}$)

Since 2013:
- 3rd ECR ion source ($^4He^{2+}$)
- Approval (medical) expected for 2021

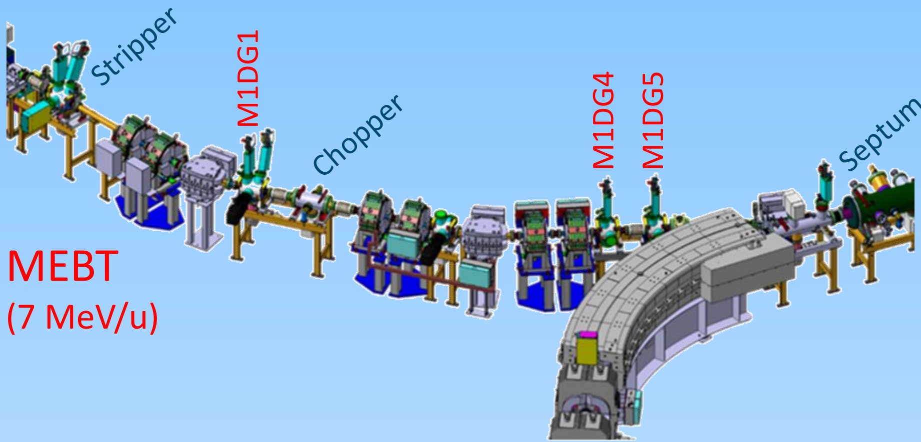


Main Features		
Ions	treatment	^{12}C, p
	experiment	^4He, ^{16}O
Max. beam energy	treatment	430 (220) MeV/u
	experiment	p: 480 MeV/u He: 430 MeV/u
Footprint		5.027 m²
First Patient		Nov. 2009
Patients treated		>6500

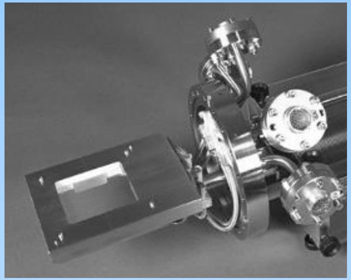


ITS: Inter Tank Matching Section

Profile Grid Measurement MEBT



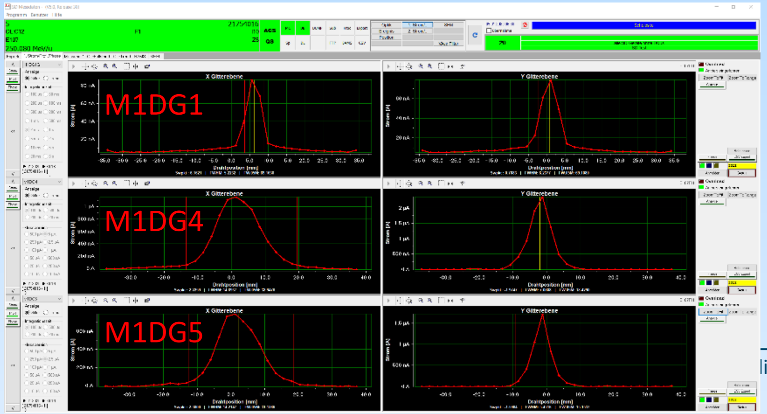
HIT profile grid (LEBT+MEBT):

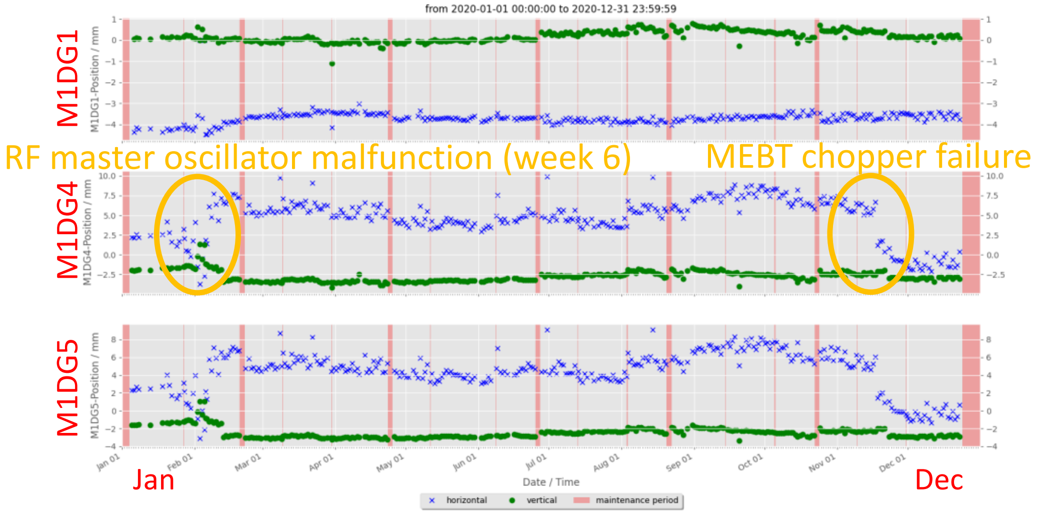


Specification	
Supplier	GSI
Type	SEM-grid
Wires (channels) per plane	64 (32)
Channel spacing	2.4 mm
Active area	80×80 mm²

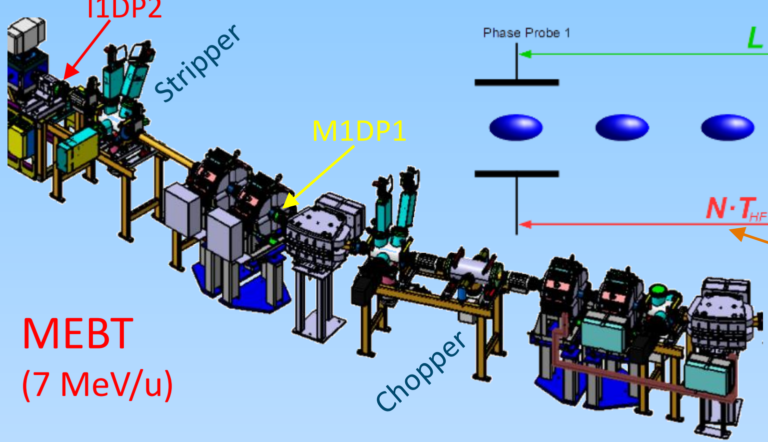
- Beam width and position is taken daily in the frame of a protocol
- Profile references are stored before maintenance periods

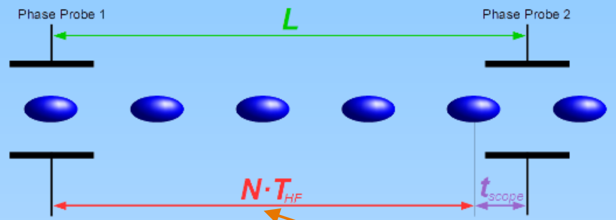
Control System Integration:





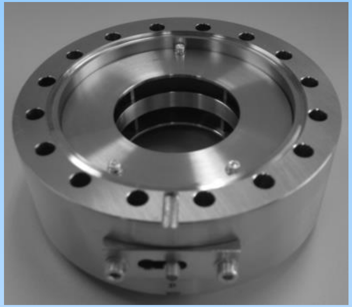
Phase Probe Measurement Time-of-Flight





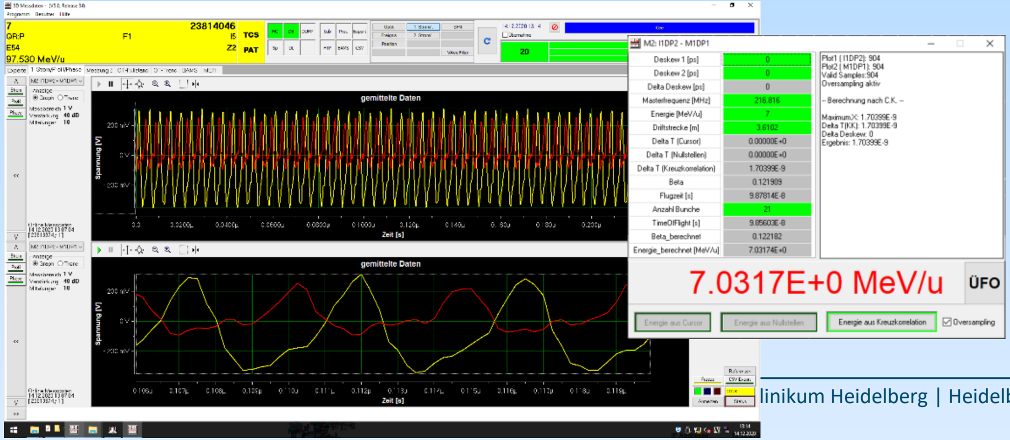
- Number of bunches *N = 21 from design energy 7 MeV/u*

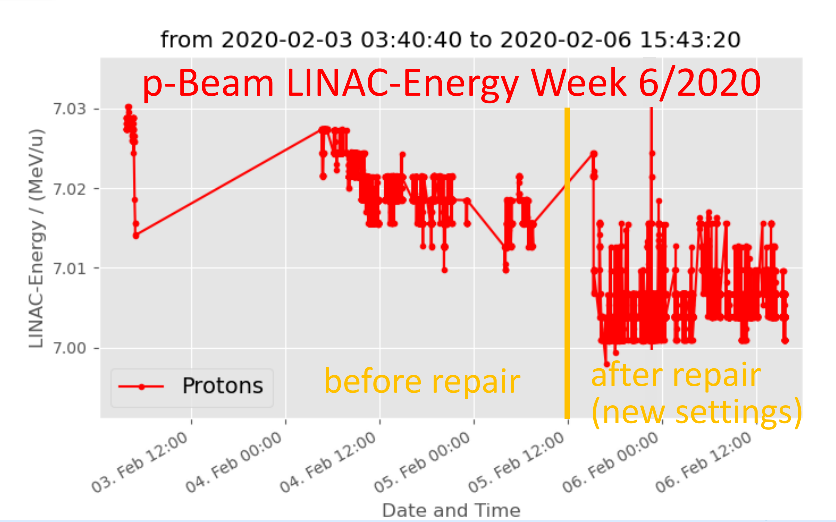
HIT phase probe:



Specification	
Supplier	GSI
Total length	50 mm
Ring length	10 mm
Ring diameter	62 mm
Aperture diameter	60 mm

Control System Integration:





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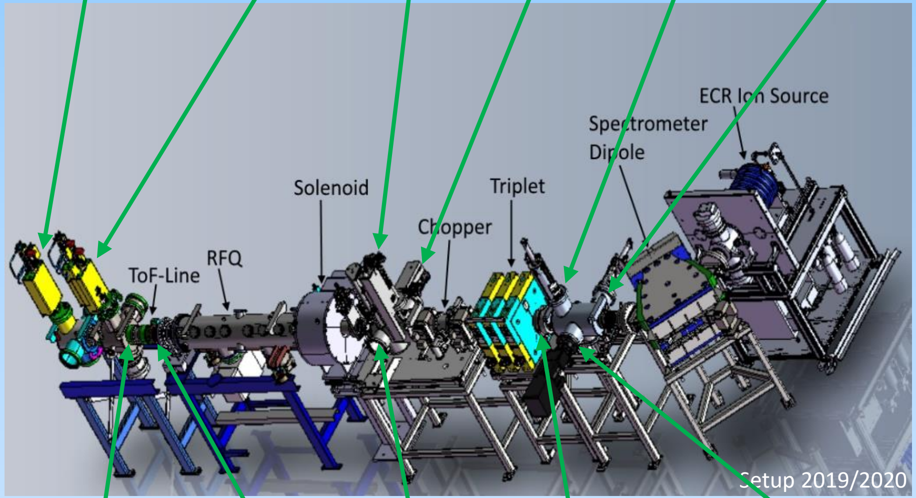
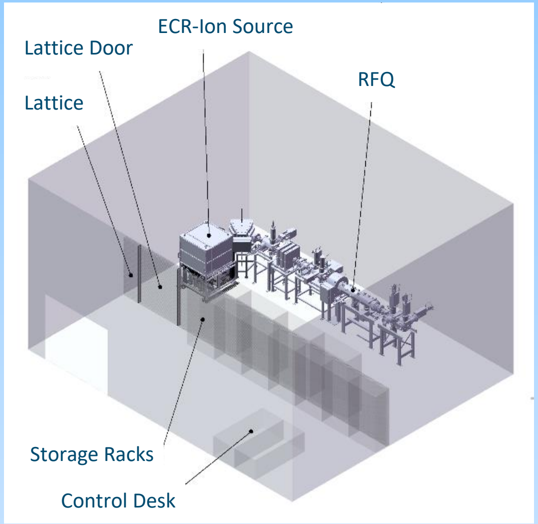
The Test Bench at HIT Common Test Bench of HIT and Siemens Healthcare



Mechanics workshop in accelerator level:



Main purpose:

- Ion source R&D
- RFQ R&D

Projects	Partners	Year
He ion source	HIT	2011
HIT spare RFQ	HIT	2012
EBIS-SC	HIT, DREEBIT	2014
ECR extraction	HIT, Siemens	2015
Pepper pot	HIT	2018
ROSE	HIT, GSI	2019
SHC spare RFQ	HIT, Siemens	2020

- Test bench is controlled by an associated control system which is, itself, subject of development by Siemens (esp. ion source control)

Papers (others than HIT):

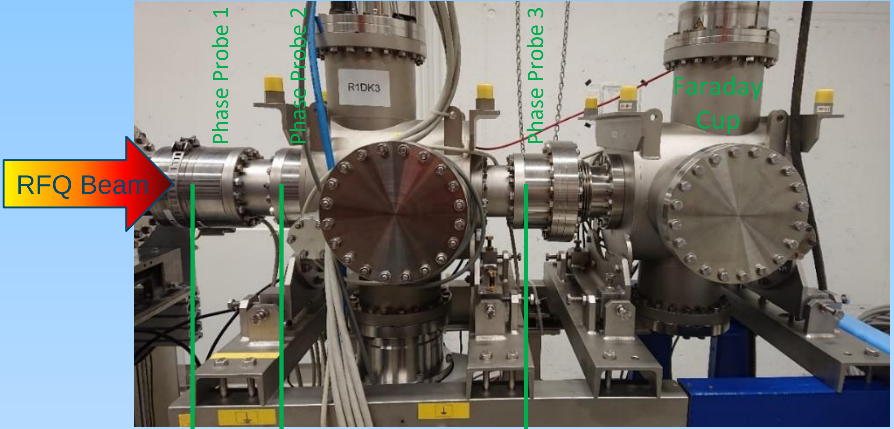
- IMPLEMENTATION OF A SUPERCONDUCTING ELECTRON BEAM ION SOURCE INTO THE HIT ION SOURCE TESTBENCH, *E. Ritter* , *A. Silze*, DREEBIT GmbH, Großröhrsdorf, *R. Cee*, *T. Haberer*, *A. Peters*, *T. Winkelmann*, HIT, Heidelberg, IPAC 2014, Dresden.
- ROSE - A ROTATING 4D EMITTANCE SCANNER, *M.T. Maier*, *L. Groening*, *C. Xiao* GSI Helmholzzentrum für Schwerionenforschung GmbH 64291 Darmstadt, Germany *A. Bechtold*, *J. Maus*, NTG Neue Technologien GmbH & Co. KG, 63571 Gelnhausen, Germany, IBIC 2019, Malmö.

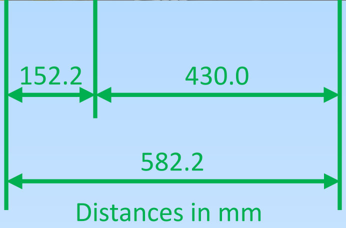
HIT Heidelberger Ionenstrahl-Therapiezentrum

Time-of-Flight Measurement

400 keV/u

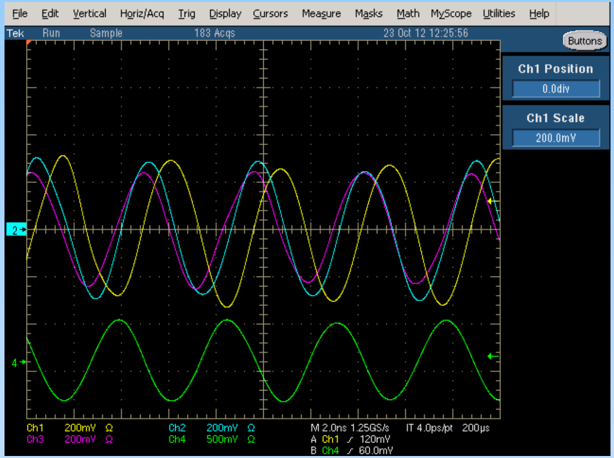
Time-of-Flight Line:





HIT owned laser tracker.

- Phase probe distances were measured with laser tracker
- Difficulty:
  - no survey station for the reflector probe on phase probe



Phase probe signals (top) and RF signal (bottom).

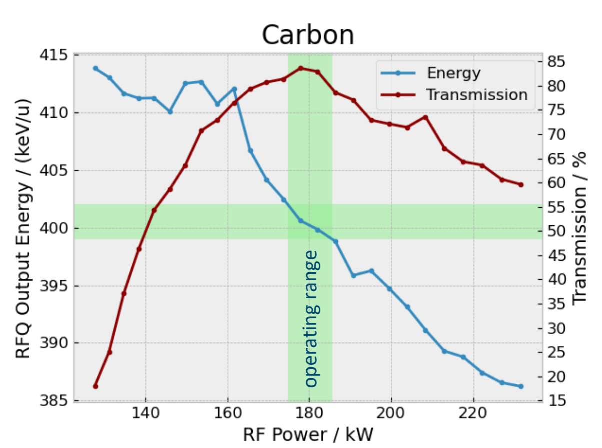
Oscilloscope	
Model	Tektronix TDS 5104B
Bandwidth	1 GHz
Sampling rate	5 GS/s
Channels	4

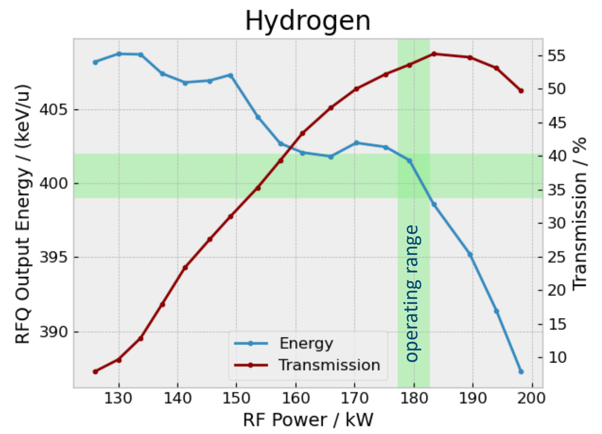
Data processing:

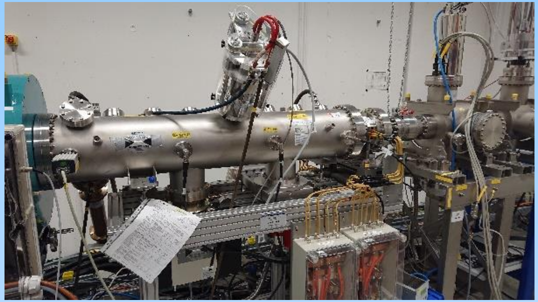
- Phase probes are not integrated in the test bench control system
- Oscilloscope raw data (*.wfm) are exported and converted to *.csv
- Time-of-flight and energy is determined by means of a python script[1] calculating the cross correlation between the signals on basis of the FFT

[1]: script in its original version written by C. Kleffner, GSI

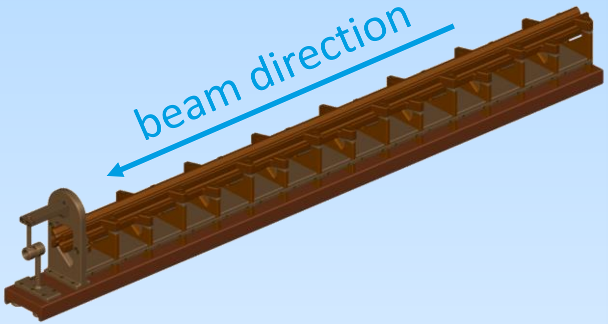
Energy and Transmission Measurement SHC Spare RFQ







SHC spare RFQ during recommissioning.



Resonant structure with rebuncher of medical RFQ.

Comparison of Spare RFQs:

including matching section

Ion	HIT (2012)		SHC (2019)	
	Output Current	Trans-mission	Output Current	Trans-mission
H_3^+	364 µA	45%	375 µA	57%
$^{12}C^{4+}$	69 µA	50%	117 µA	84%

Conclusion:

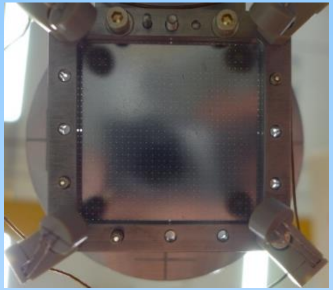
- The SHC spare RFQ shows better performance with respect to transmission and output currents having the same electrode design as the HIT spare RFQ
- The improvement can be attributed to optimised manufacturing techniques
- Further improvements can be expected with a new electrode design based on realistic (ECRIS) particle distributions

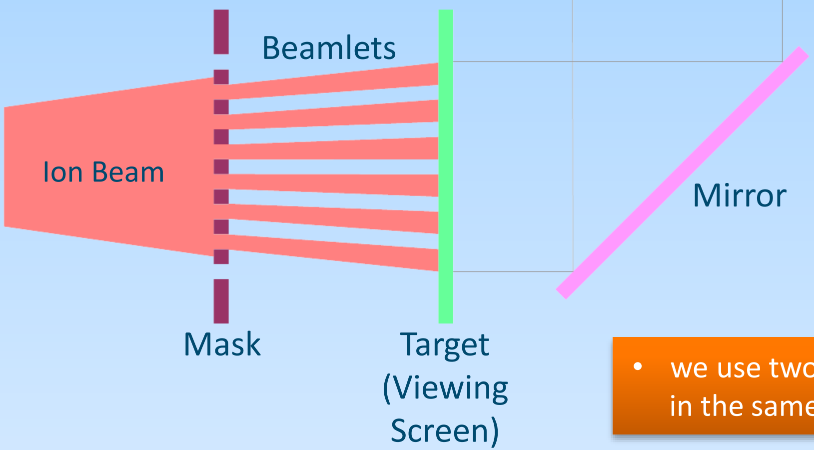
Pepper-Pot Emittance Measurement

Mask Properties	
Material	tungsten
Thickness	100 µm
Whole spacing	1,5 mm
Whole diameter	100 µm
Active area	45×45 mm²

Target Properties	
Material	quartz glass
Supplier	Aachener Quarzglas-Technologie Heinrich
Product	Herasil 3
Thickness	200 µm
Diameter	60 mm

HIT mask:





Pros:

✓ fast, single pulse measurement
✓ both plains at once
✓ 4D-information (important for ECR-beams)

Cons:

! limited spatial resolution (beamlets must not overlap)
! sensitive to high power beams
! evaluation non-trivial

- we use two flanges (mask+target / mirror+camera) in the same vacuum chamber

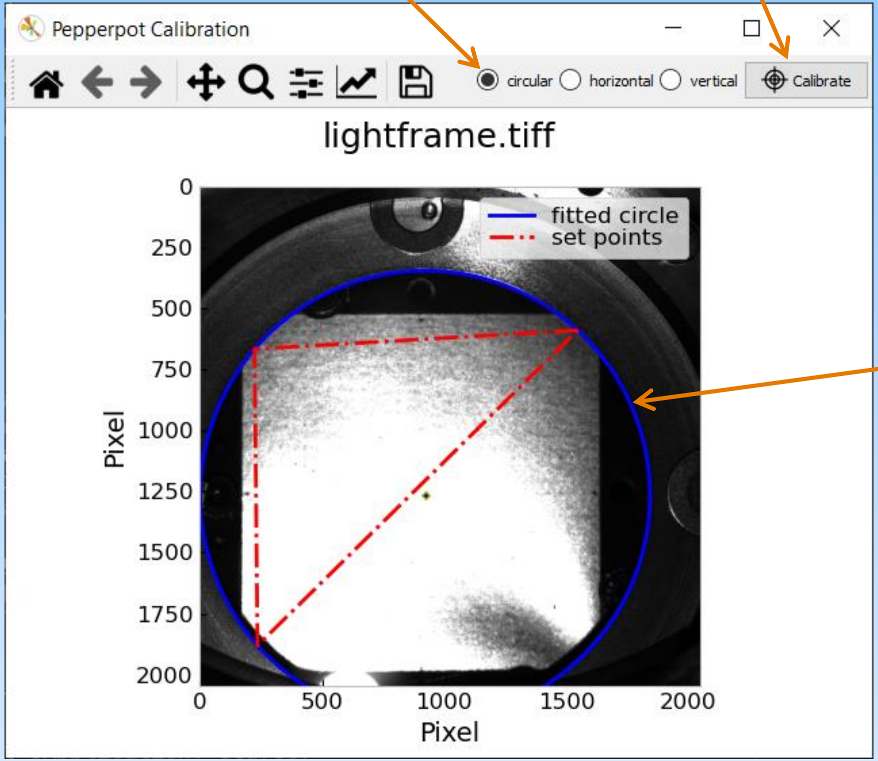
For the HIT pepper pot see e.g.:

- **A LOW ENERGY ION BEAM PEPPER POT EMITTANCE DEVICE,** *M. Ripert, A.Büchel, A. Peters, J.Schreiner, T.Winkelmann,* HIT, Heidelberg, Proceedings of BIW10, Santa Fe, New Mexico, US.

Pixel Calibration

Choose type of calibration mark

Start calibration



Calibration in this example:

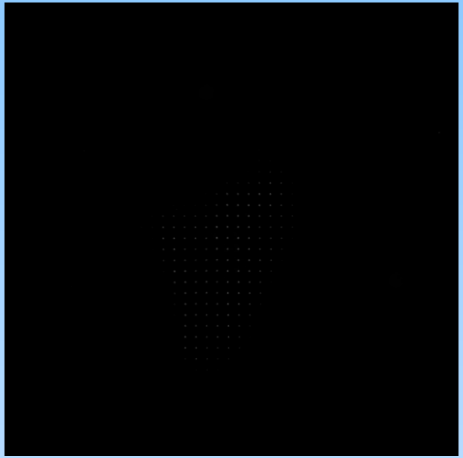
32.9 pixel per mm

aperture: **56 mm!**

- Pixel calibration should be done with care as angle calculation is very sensitive to it
- Calibration must be done in the plane of the target, not in the plane of the mask
- It is good to have an alternative method (e.g. laser light) for cross-check

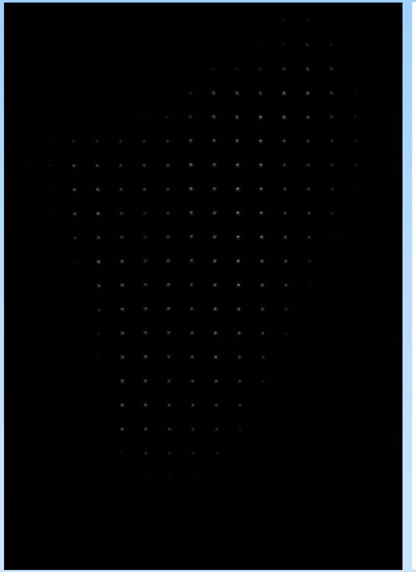
Raw Data Example (300 µA H_3^+-Beam)

Image:



Image, inverted:

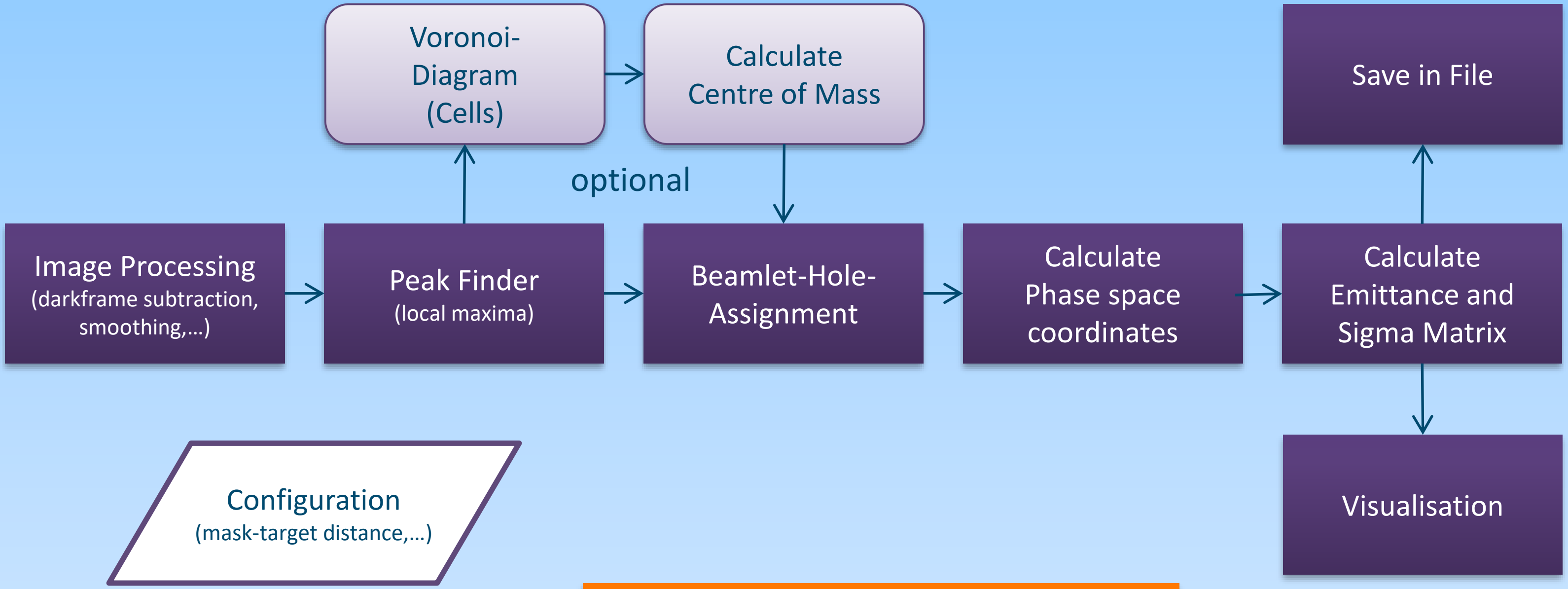
Zoom:



Zoom, inverted:

Image Properties	
Camera	Allied Vision Prosilica GT
File format	tiff greyscale
Bit depth	16
Size	8,2 MB (4,2 MPixel)
Width	2048 Pixel
Height	2048 Pixel

Evaluation Steps



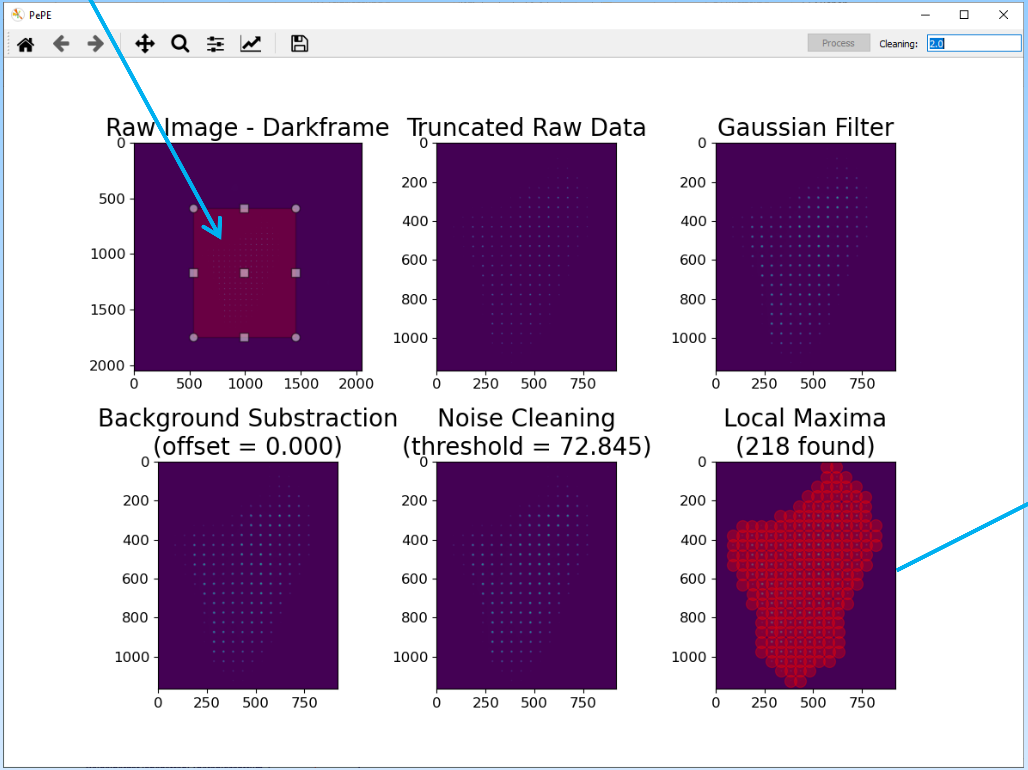
- The evaluation process was implemented in python:

PePE

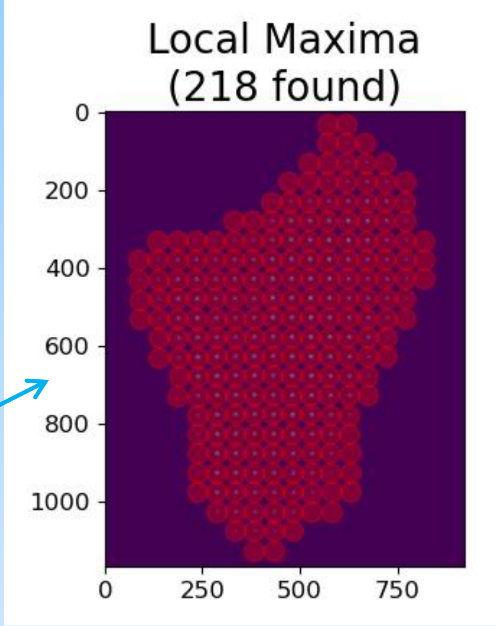
(**Pe**pper **P**ot **E**valuation Programme)

Image Processing

Zoom window:



Result peak finder:

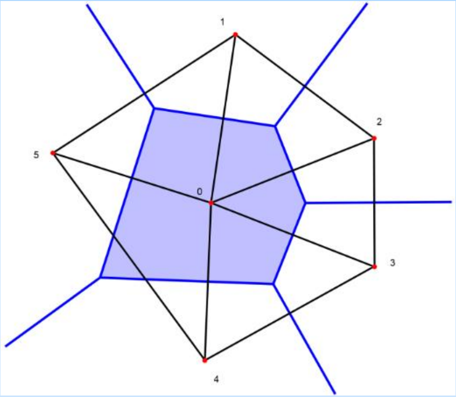


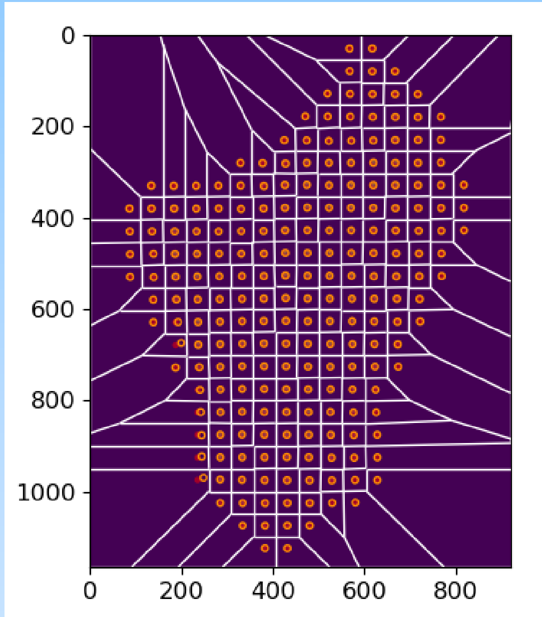
- The local maxima are weighted with the pixel intensity

Voronoi-Diagram

- Local maxima can be used as seeds for Voronoi cells

Voronoi-Cell:
2-dimensional equivalent to 3D Wigner-Seitz-cell.





Weighting:
sum of pixel intensity in cell

● : Maxima
○ : Centres of Mass

Code base:
scipy.spatial.Voronoi from SciPy.org:

open boundary cells are not treated correctly!

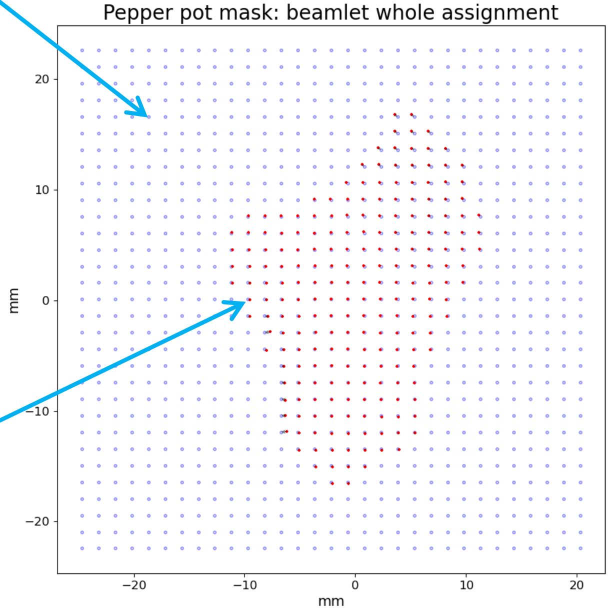
- A special treatment of the boundary cells was implemented

Idea:
APPLICATION OF VORONOI DIAGRAM TO MASK-BASED INTERCEPTING PHASE-SPACE MEASUREMENTS, A. Halavanau, IPAC 2017

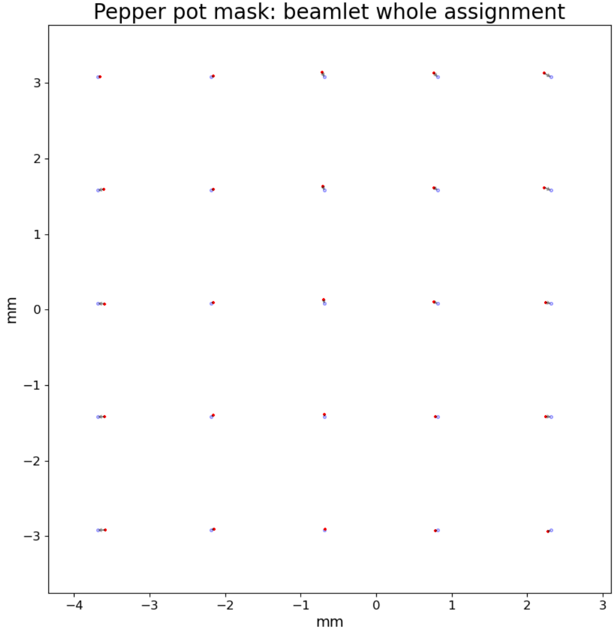
Beamlet-Hole-Assignment

Mask holes (blue):

Beamlets (red):

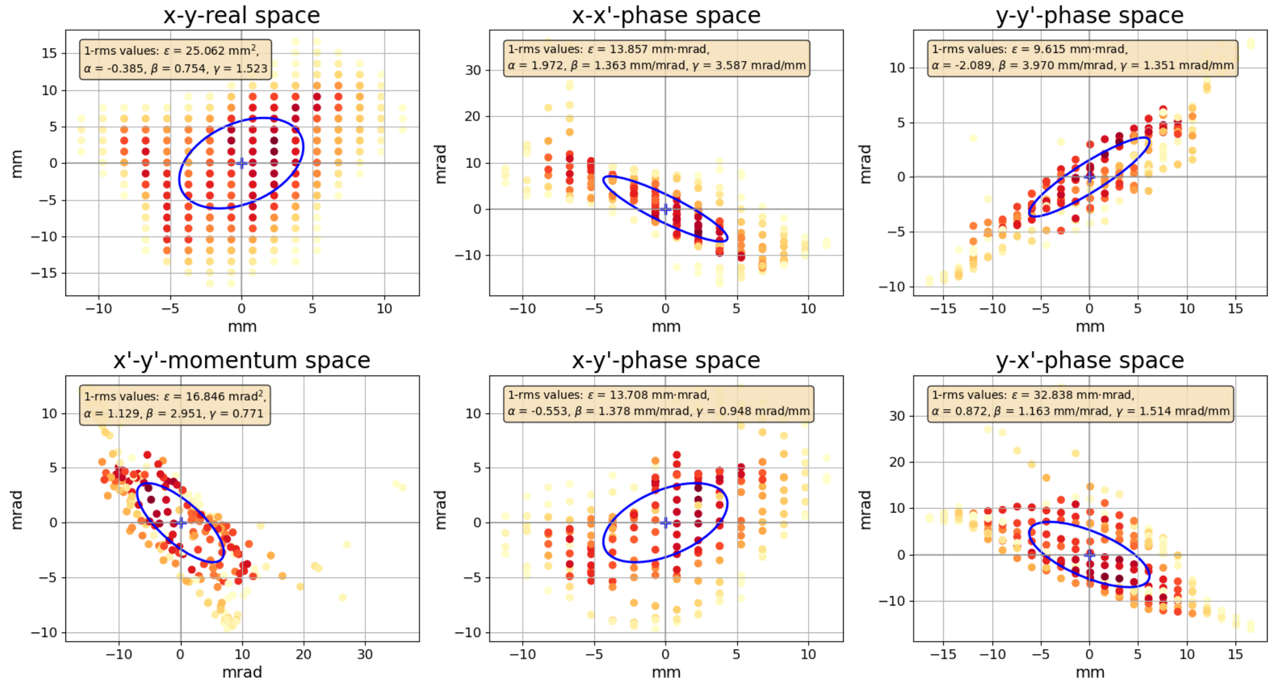


Zoom:



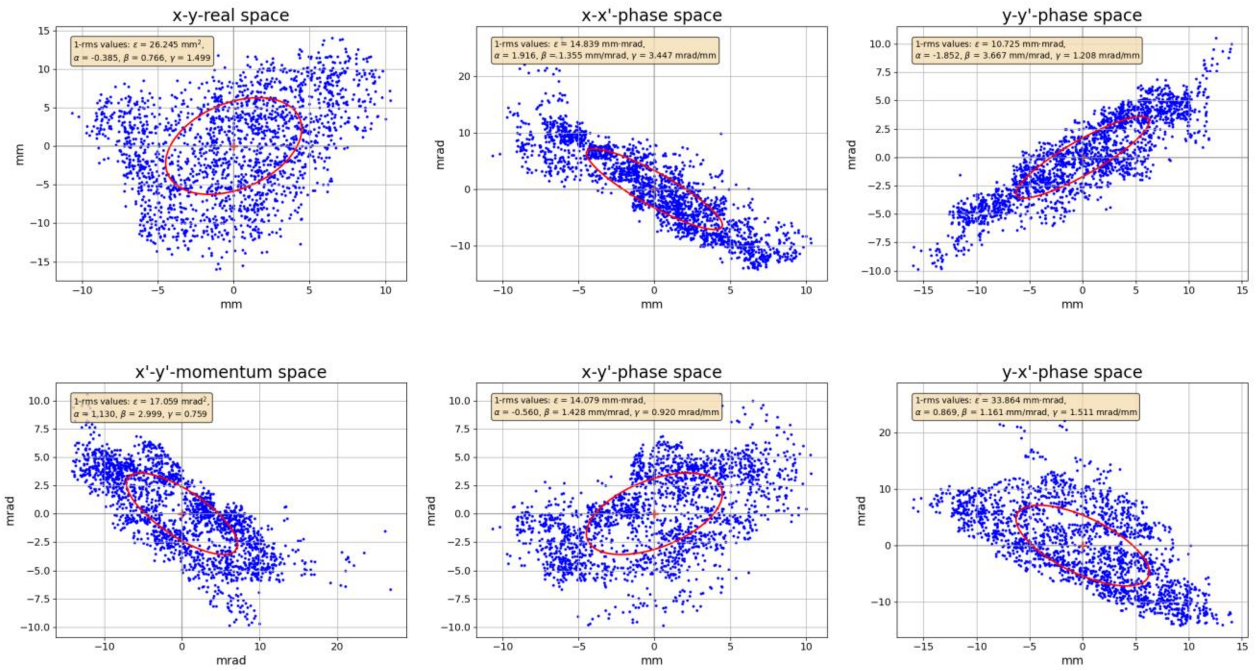
Hole diameter not scaled!

Visualisation of Final Result (300 µA H_3^+-Beam)



Particle Distribution (2000 particles)

- Particle distribution can be used for RFQ simulation and design

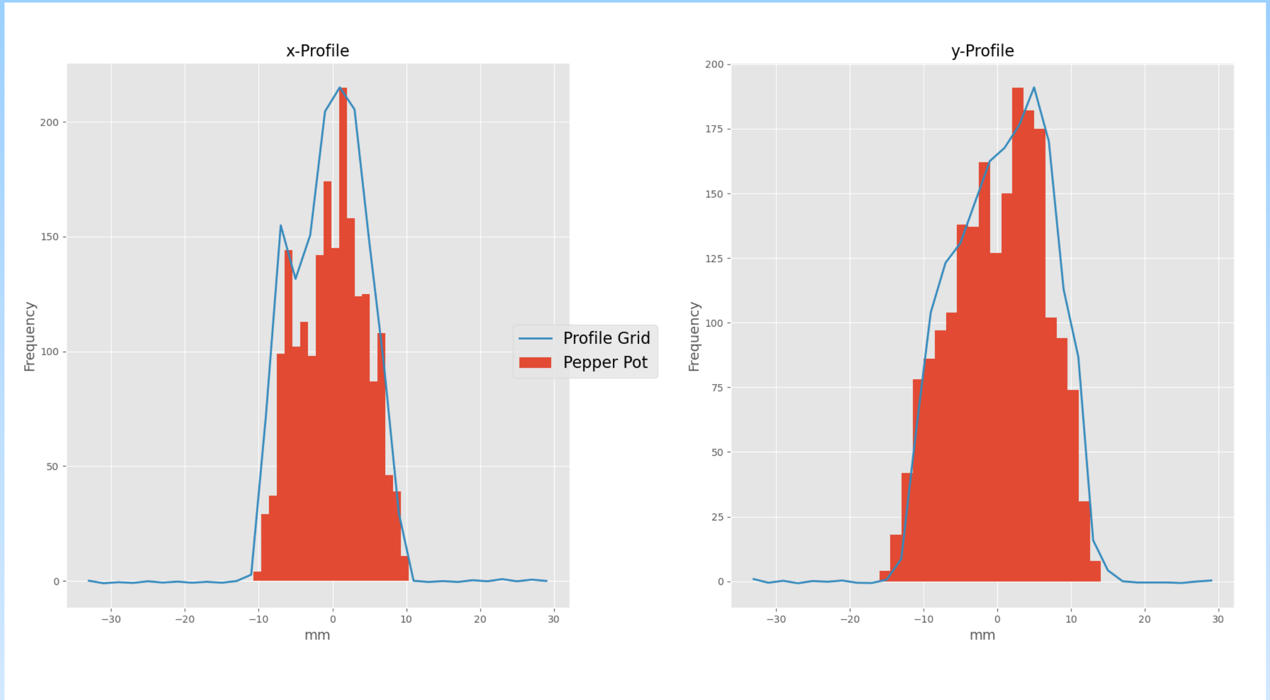


4D-particle generator written by Th. Gläßle (formerly HIT)

Comparison Pepper Pot vs. Profile Grid

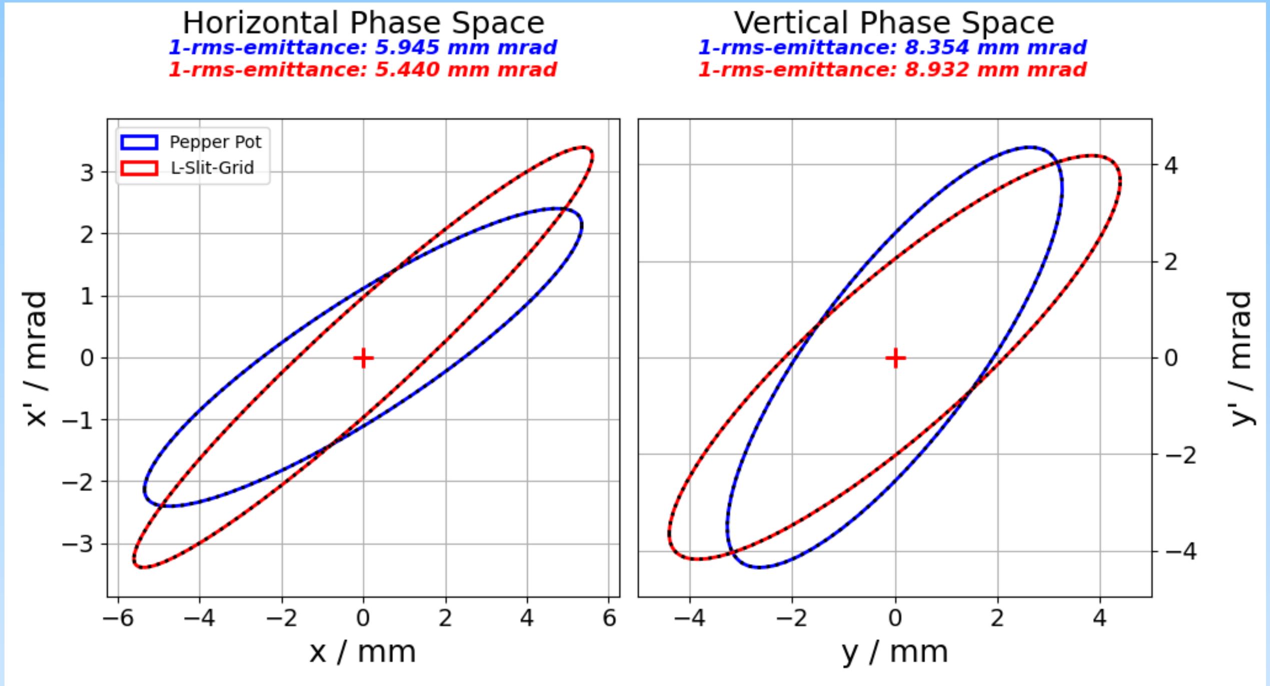
(300 µA H_3^+-Beam)

- Pepper pot and profile grid in same chamber (no particle transformation)
- Histogram refers to generated particles (2000)
- Maxima are scaled
- Centre of mass is shifted to zero
- One broken wire is ignored



- Good agreement confirms linearity between light intensity and beam intensity and correctness of our particle generator.

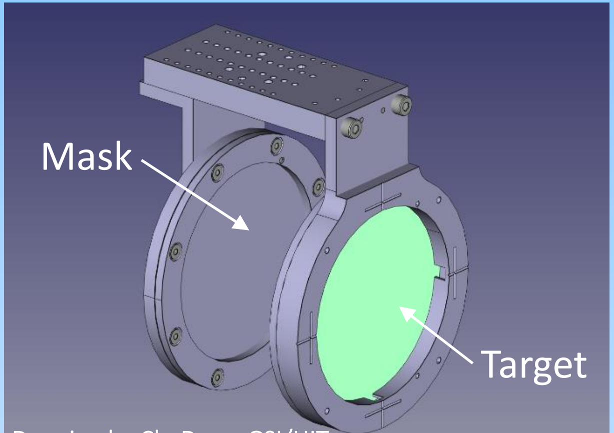
Comparison Pepper Pot vs. Slit-Grid



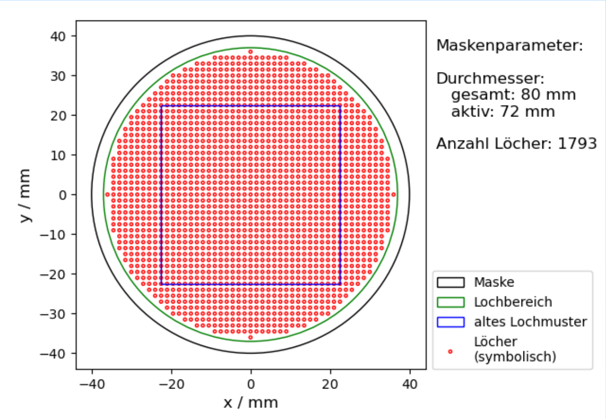
- Discrepancies are supposed to be caused by inaccuracies of the angle coordinate

Pepper Pot Next Steps

Reconstruction:



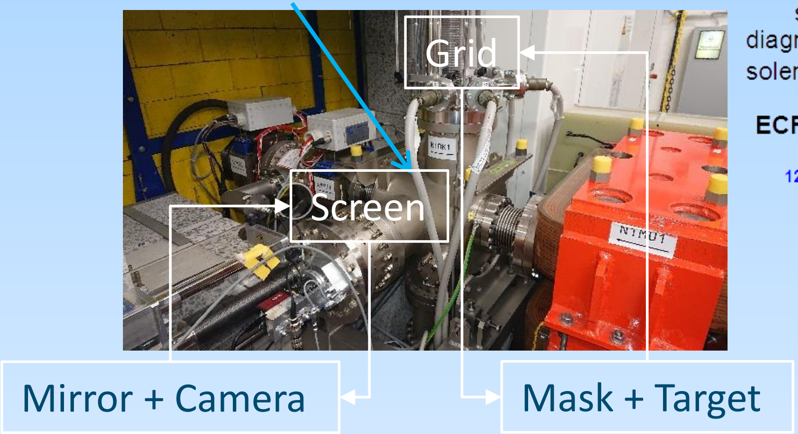
Drawing by Ch. Dorn, GSI/HIT

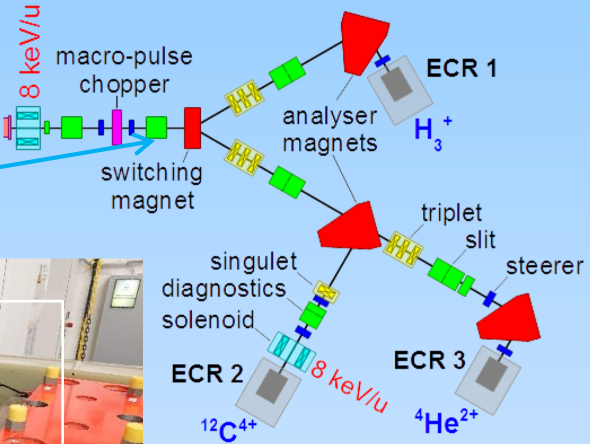


Main motivation for reconstruction:

- increase active area

Designated place of installation





Summary and Outlook

- Medical Accelerator:
  - Profile grids and phase probes are routinely used for monitoring the LINAC-beam properties
  - The obtained data serve as reference and permit us to investigate the beam behaviour prior failures (i.e. aging effects)

The goal is to have an early-warning system by comparison of beam patterns with previous occurrences.

- Test Bench:
  - Common test facility with Siemens Healthcare for ion sources, RFQs and beam diagnostics
  - Siemens-spare-RFQ has been requalified
  - 4D emittance data, taken with a pepper pot device, have been evaluated with the tool PePE

A pepper pot device with new layout is under development.

We plan to install the pepper pot into the LEBT and use the measured beam distributions for the design of a new RFQ with high transmission.