FRS Ion-Optics Corrections, Degrader Scans

Helmut Weick

6th expert meeting on fragment separators
Grand Rapids, 30th Aug 2016

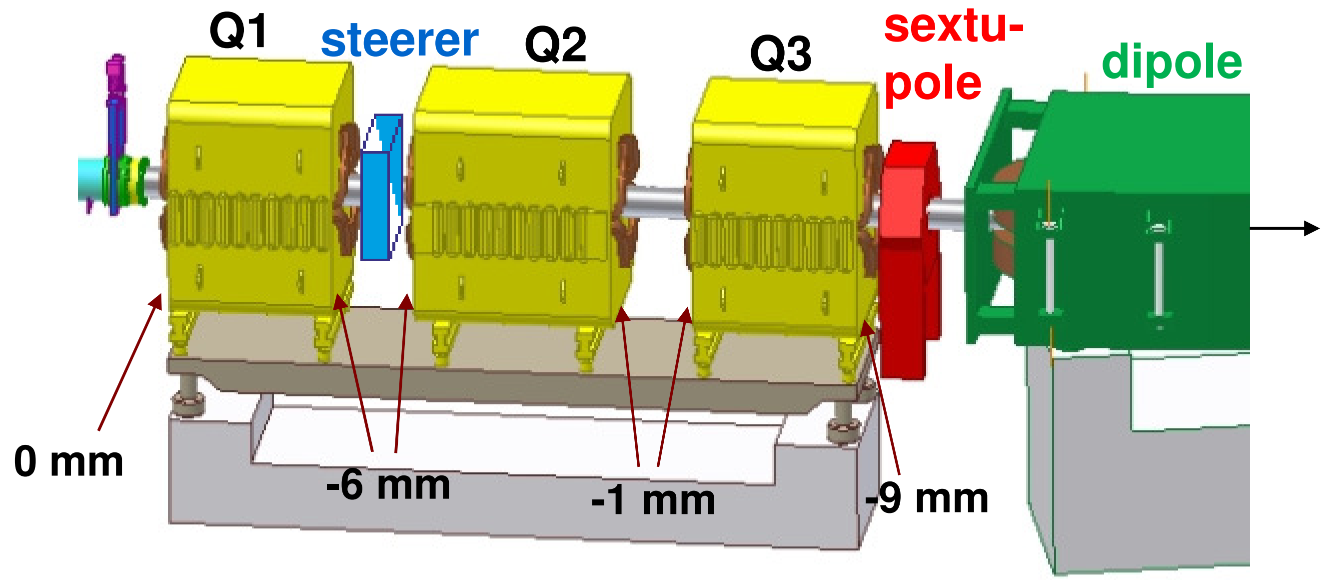
- Influence of Neighboring Magnets
- Sextupole Correction
- Correction in High-Dispersion Mode

- Scanner Setup
- Results for Degraders and Target Wheel
- Gas Degrader

GSI

FAIR

Influence of Neighboring Magnets
- shortening of effective lengths -



L_{eff} = 1.046 or 1.246m (at low B, shorter when close to 1T), shortening of L_{eff} was measured in combined triplet setup.

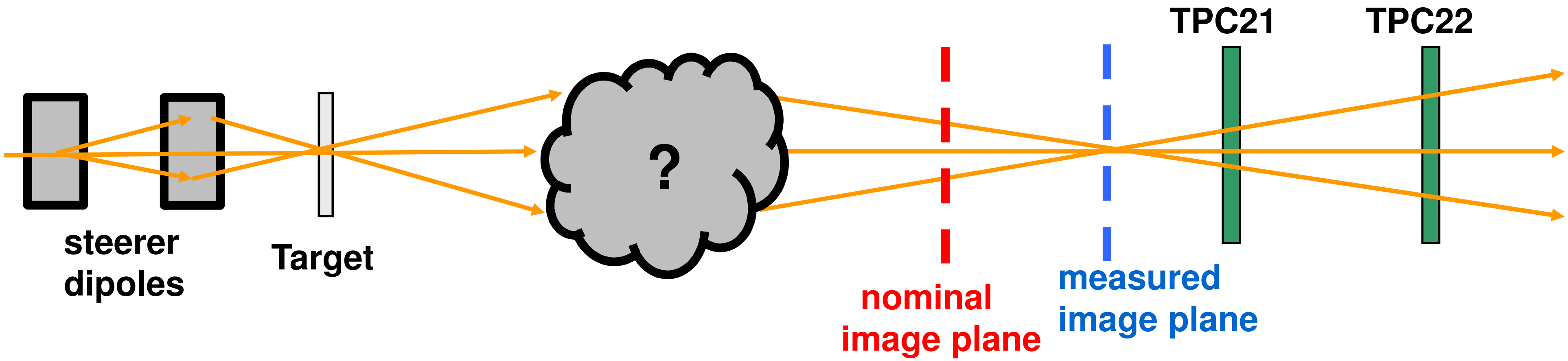
Set polynomials for I(B'L) are based on mapper data for magnets standing alone (I=current, B'L = integral of B/G_0 along axis).

We sent directly B'L values to GSI accelerator control system, but in the polynomials a longer quadrupole is assumed.

→ We must increase field strength to preserve the integral.

Test method:
Vary initial angle of beam on target

Calculate dipole or steerer setting to change the angle of the beam before target, but not the position.



X angles: A_0 =0, -5.0 , +5.0 mrad
Y angles: B_0 =0, -2.25, +2.5 mrad

Measure positions at S2 (midplane) and S4 (end) with two detectors --> position and angle

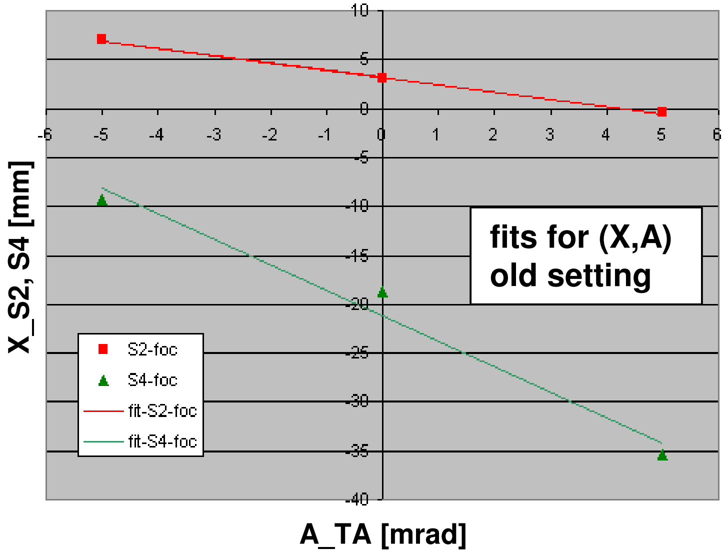
Determine matrix coefficients
--> shift of image plane

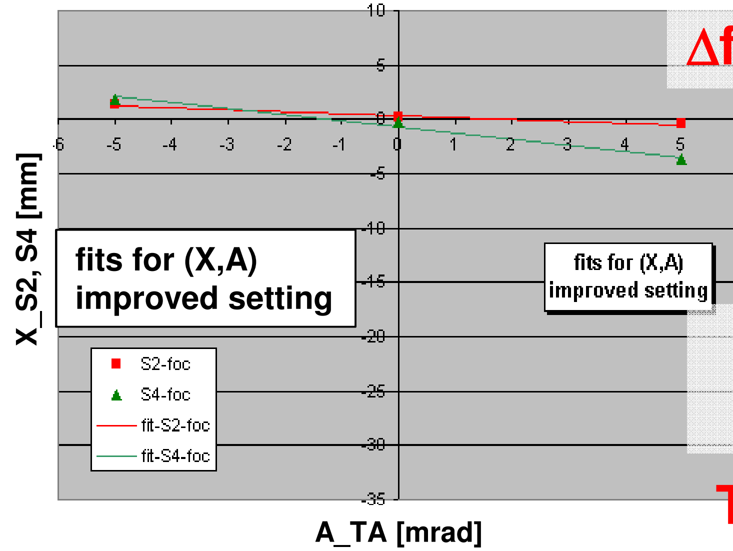
Standard mode RUN81-TA2B-220cm

$\Delta f_x = -(X,A) / (A,A)$

TA-S2:

$\Delta f_x = 0.55 \rightarrow 0.13\text{m}$



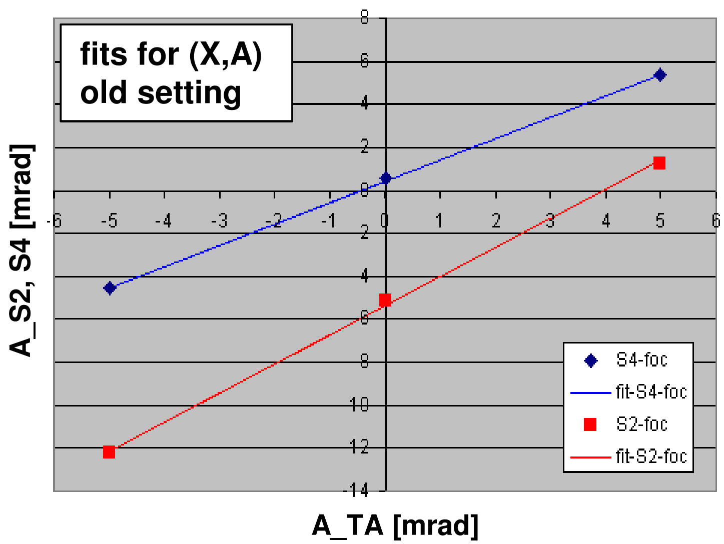


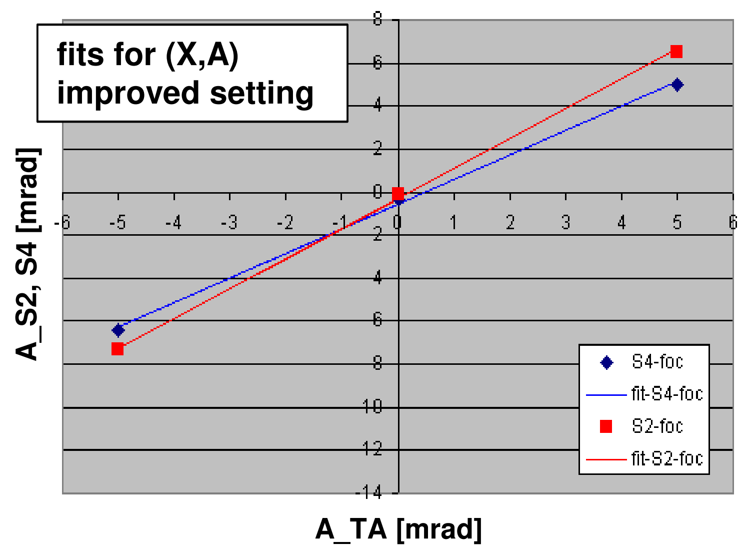
TA-S4:

$\Delta f_x = 2.6 \rightarrow 0.5\text{m}$

TA-S4 simulation

$\Delta f_x = 1.5 \rightarrow 0.0\text{m}$





Same in Y Direction

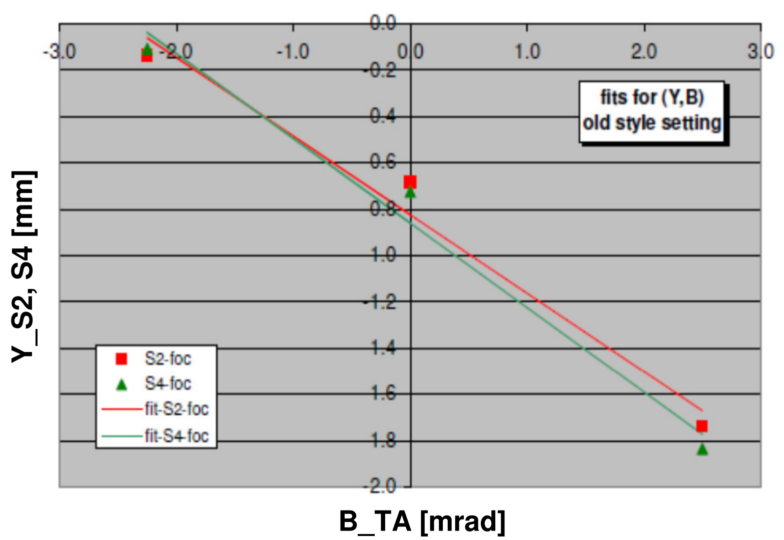
Standard mode RUN81-TA2B-220cm

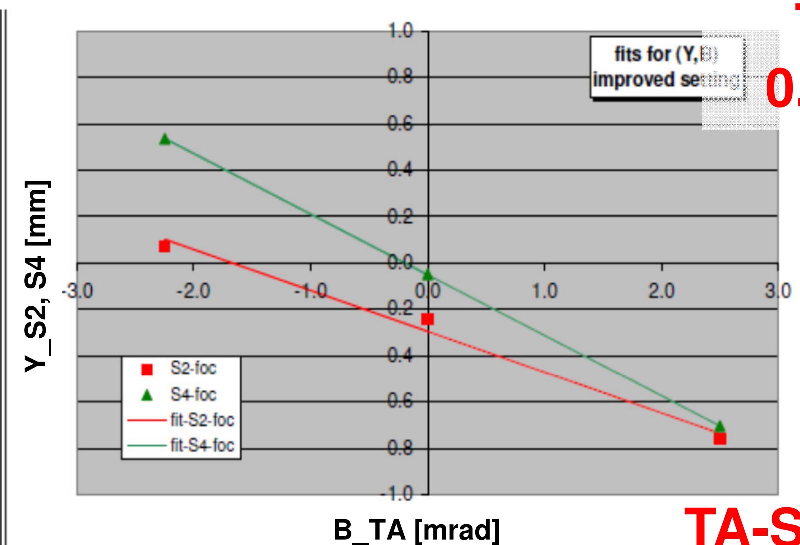
$\Delta f_y = -(Y,B) / (B,B)$

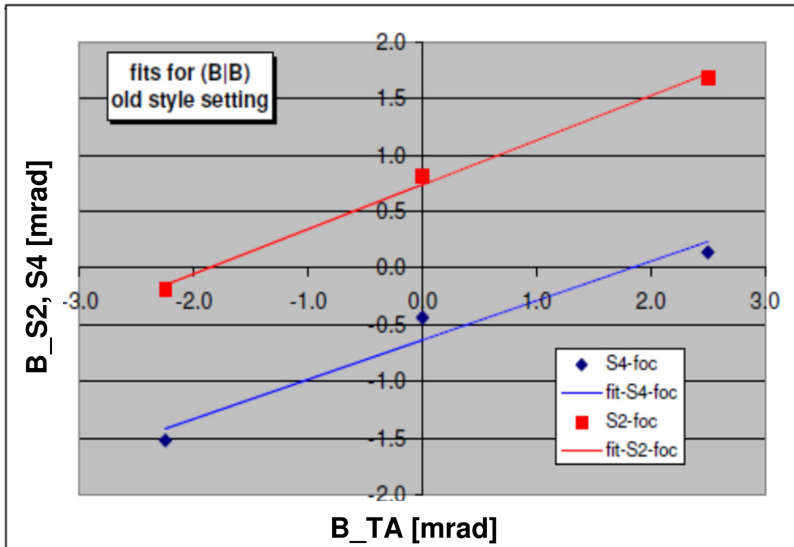
TA-S2: Δf_y = 0.85 -> 0.45m

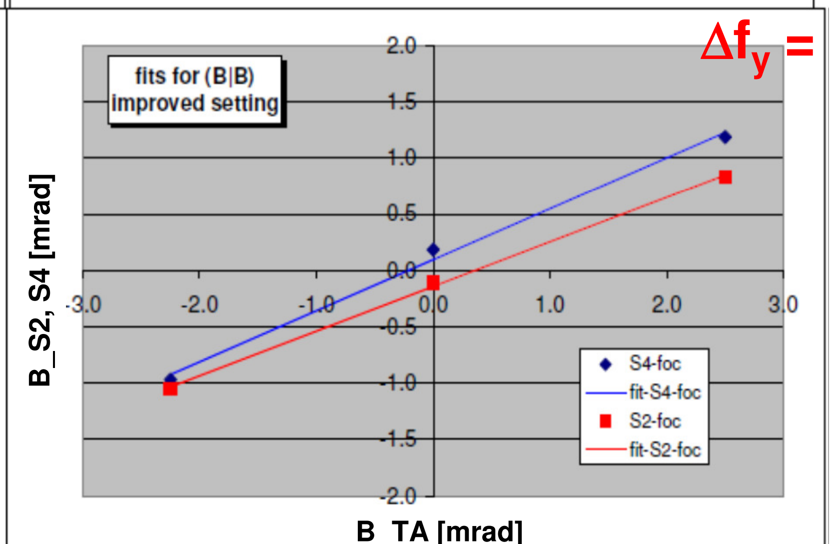
TA-S4: Δf_y = 1.1 -> 0.58m

TA-S4 simulation Δf_y = 0.2 -> 0.0 m









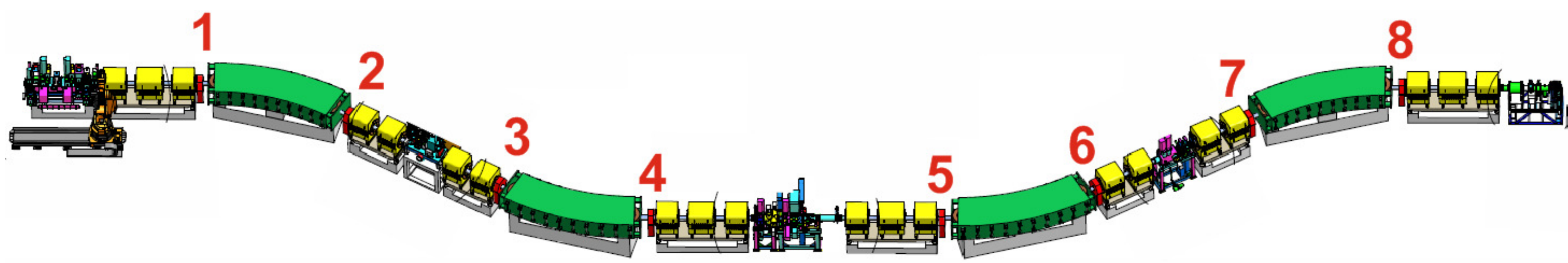
Sextupole Correction

Understand correct sextupole settings and find good setting for future experiments

1.) Apply value to all 8 single sextupoles and check effect -> calibration, sign, L_eff

2.) Use combination of sextupoles for correction of (X,AD) and (X,AA)
consider also intrinsic sextupole components and adjust correction

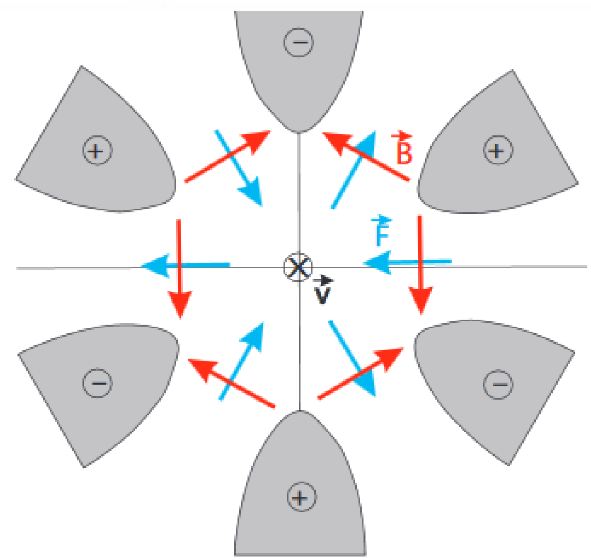
3.) Correction for high dispersion mode



In GSI control program
B''L > 0 for south pole on top

$$B''L = -\,2\,B_0/G_0^{\,2} * L_{eff}$$

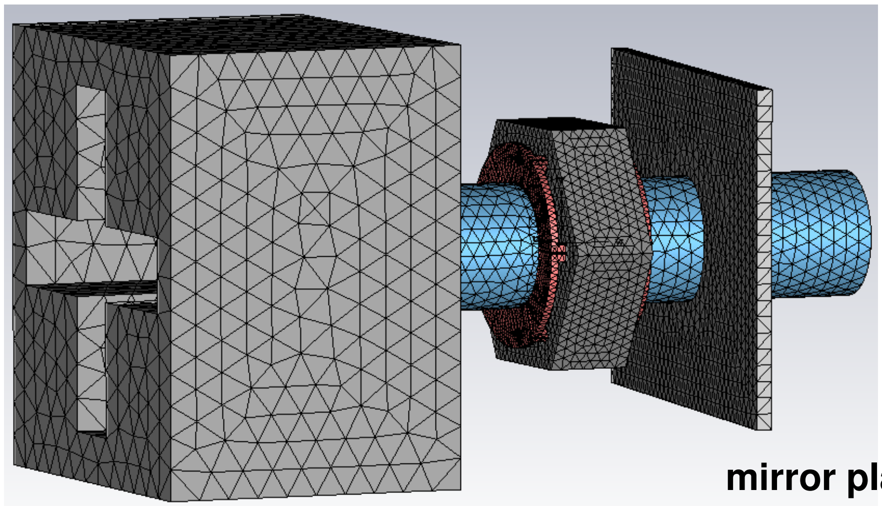
$$(A,XX)_{sext.} = -\,B''L \,/\, 2\,B\rho$$

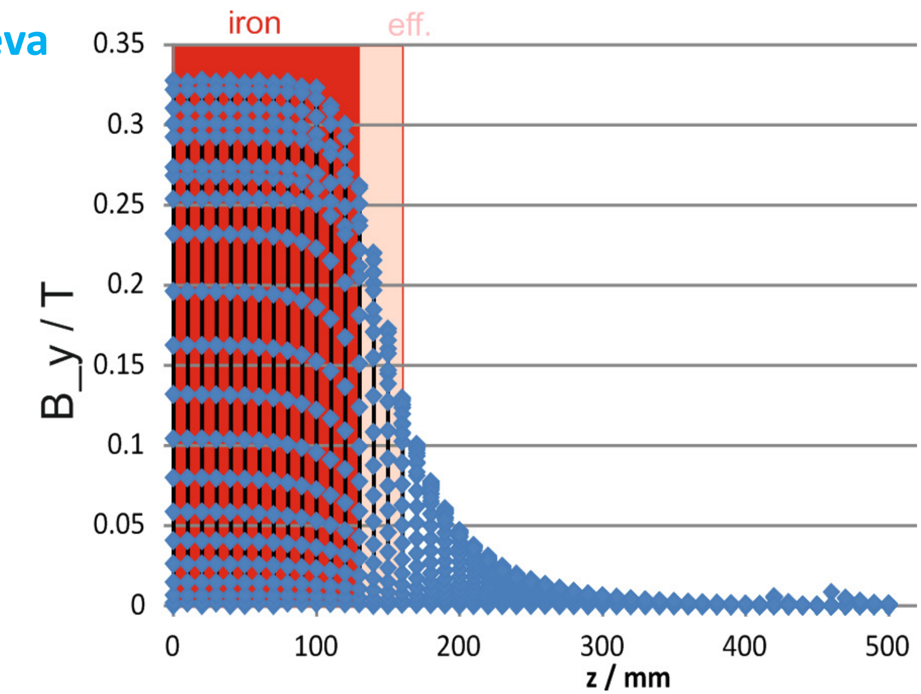


(A|XX)=R211 > 0 (for q>0 particles),
B is negative in GICOSY

FEM Simulation for Effective Length

Erika Kazantseva





L_geometric = 260 mm
L_eff (alone) = 330 mm (measured)
L_eff (comb.) = 319 mm (calculated)

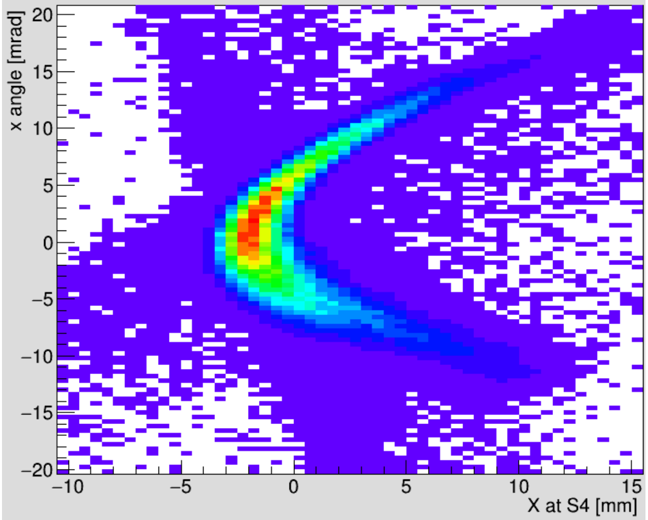
old combined measurement found again
➔ L_eff = 330mm – 11mm - ? (only one side tested).

Yoshiki Tanaka, Emma Haettner,
Hans Geissel, HW

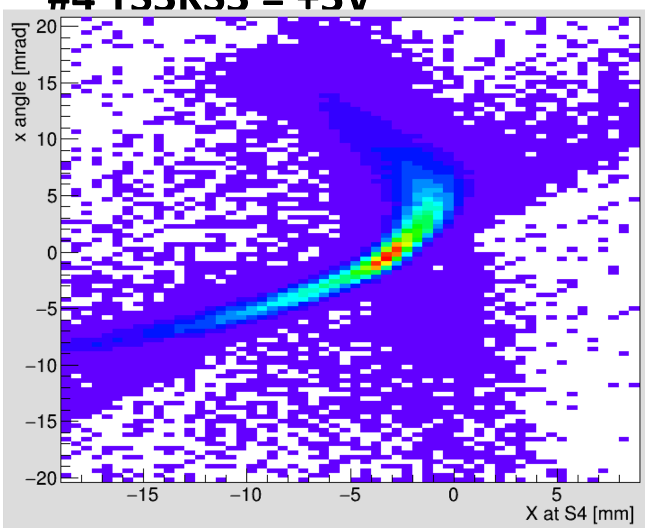
Effect of Single Sextupoles

Standard mode with Ta-6045 mg/cm² target in 600 MeV/u ^{12}C beam (Bρ=7.88 Tm)

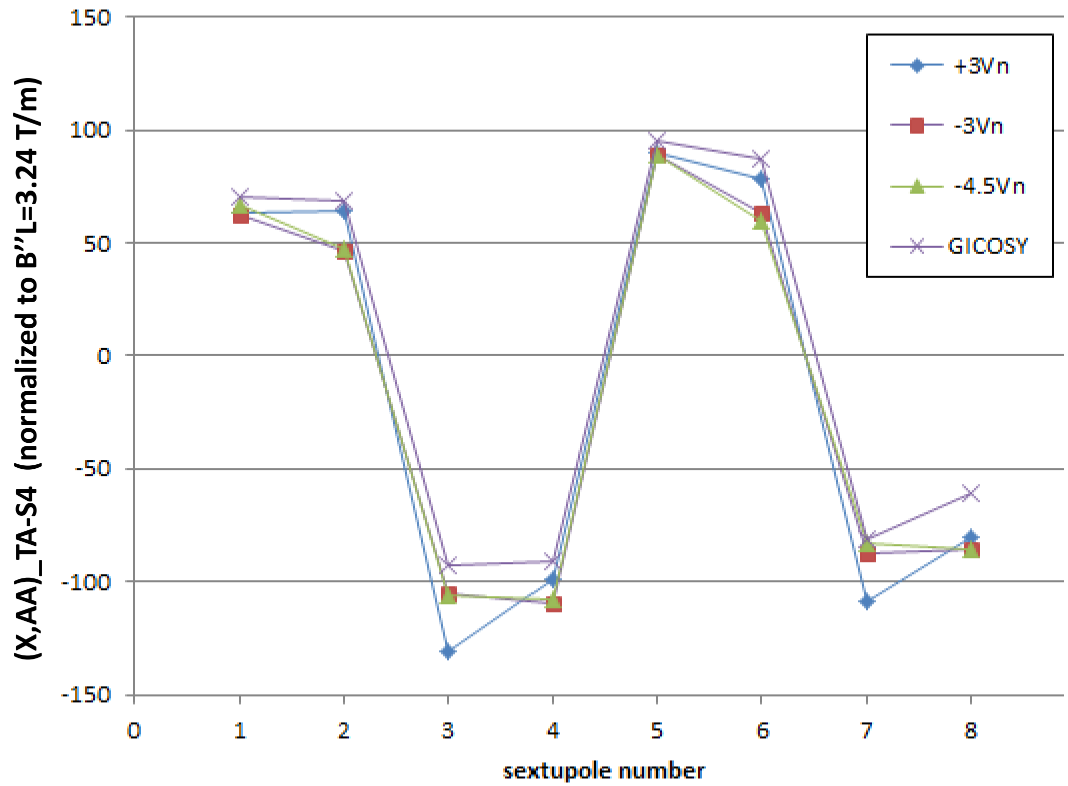
#3 TS3KS2 = +3V (B''L = 3.24 T/m)



#4 TS3KS3 = +3V



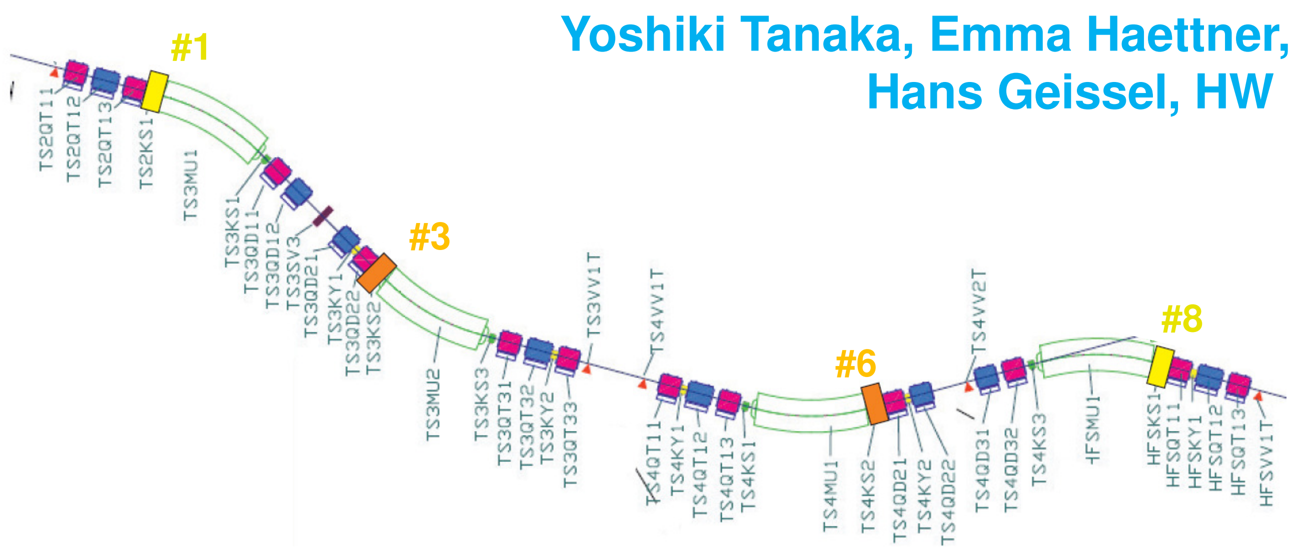
Fit parabola into phase space and compute (X,AA).
Comparison of effect of single sextupoles at different strength but normalized to B''L =3.24 T/m.



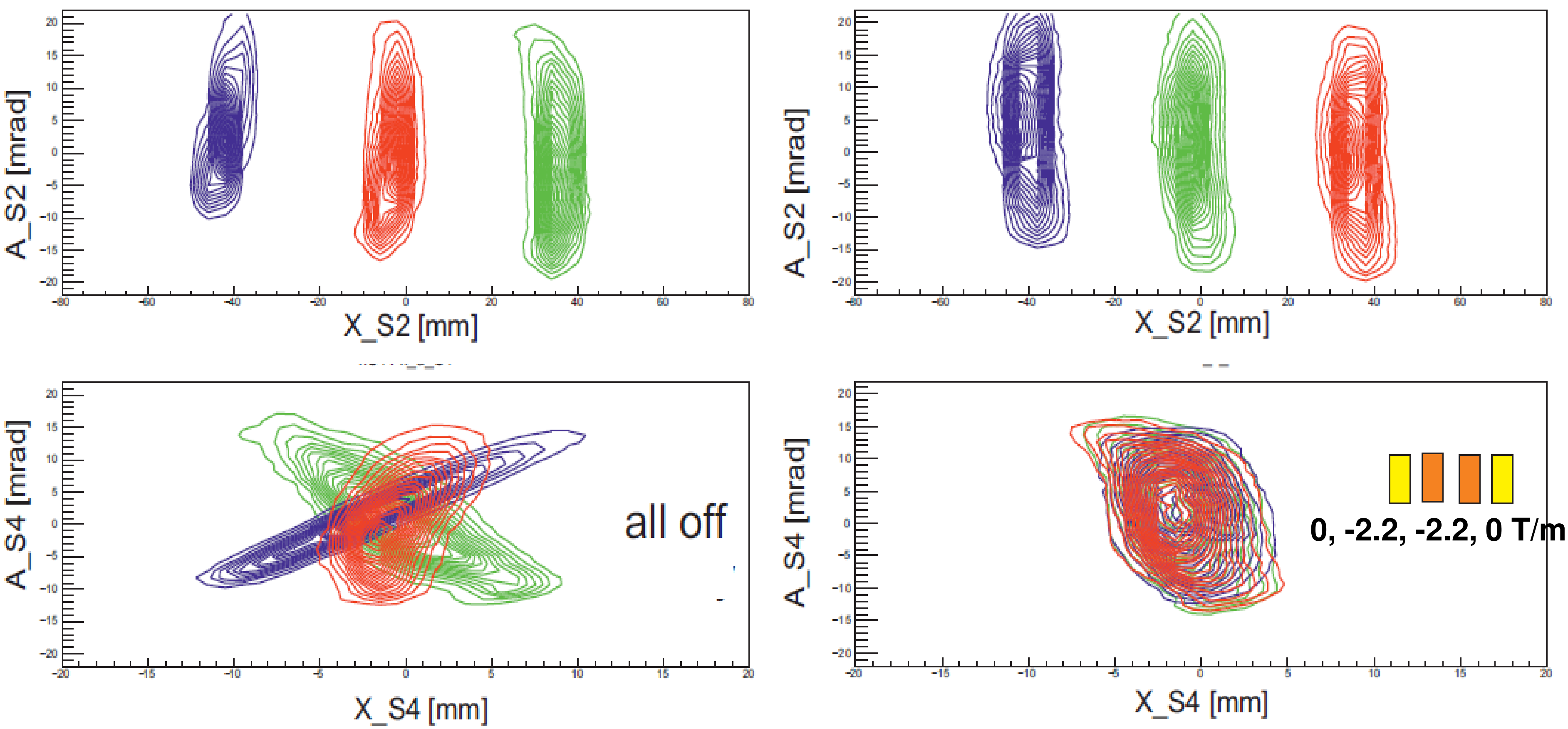
➔ **agreement with L_eff = 310 – 340 mm**

Standard Mode Correction

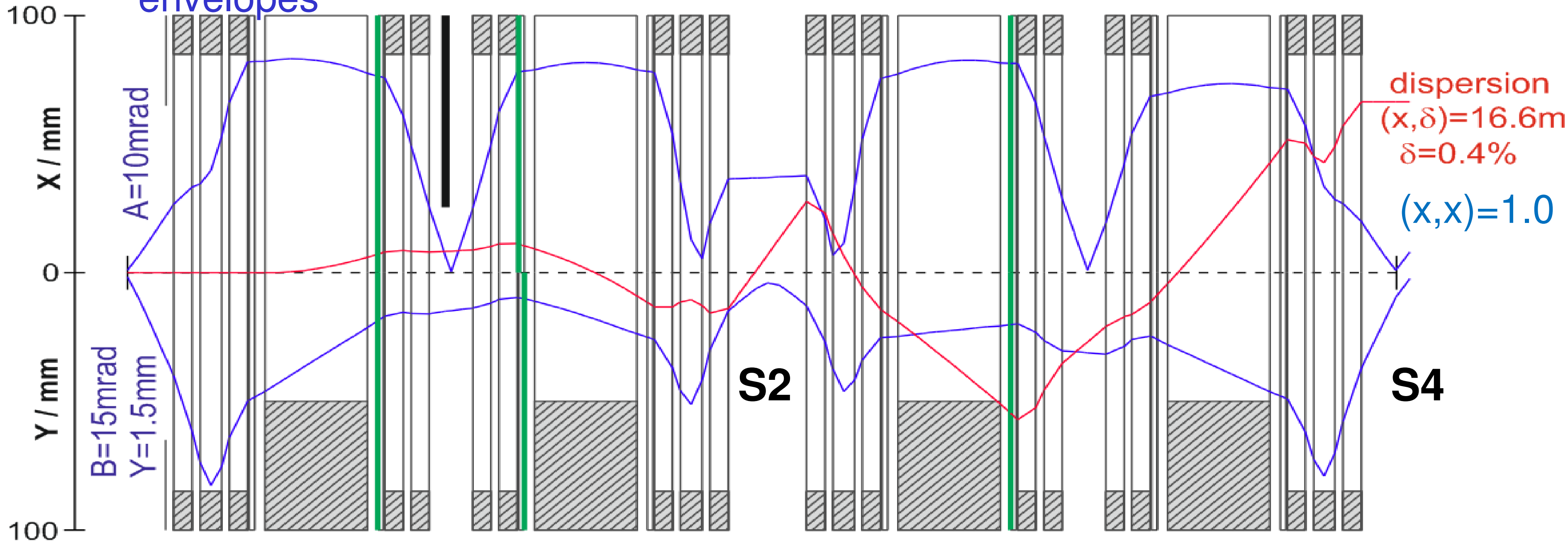
Yoshiki Tanaka, Emma Haettner, Hans Geissel, HW



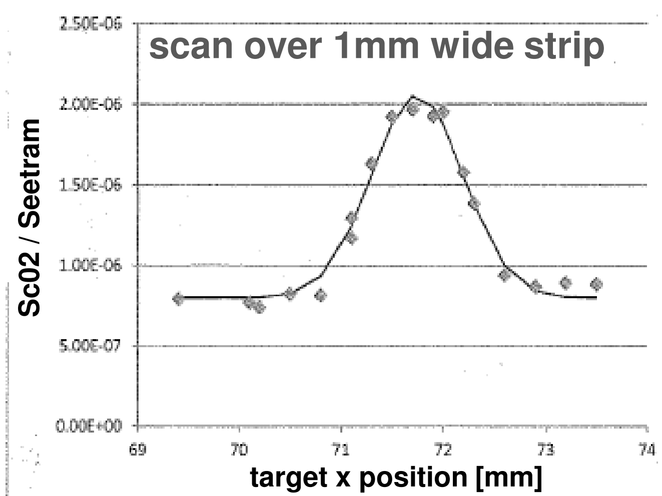
Ta-6045 mg/cm^2 target in 600 MeV/u ^{12}C beam, FRS scaled by ±0.6%

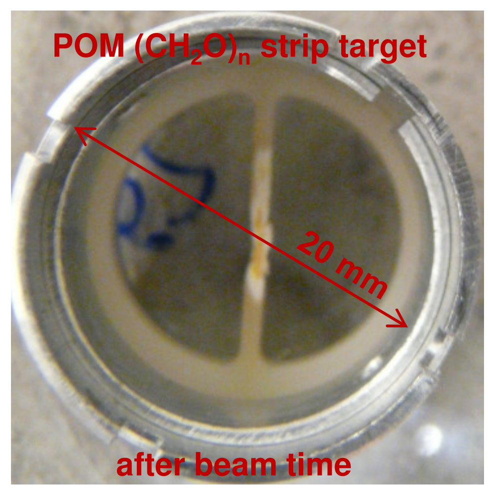


FRS - High Dispersion Mode

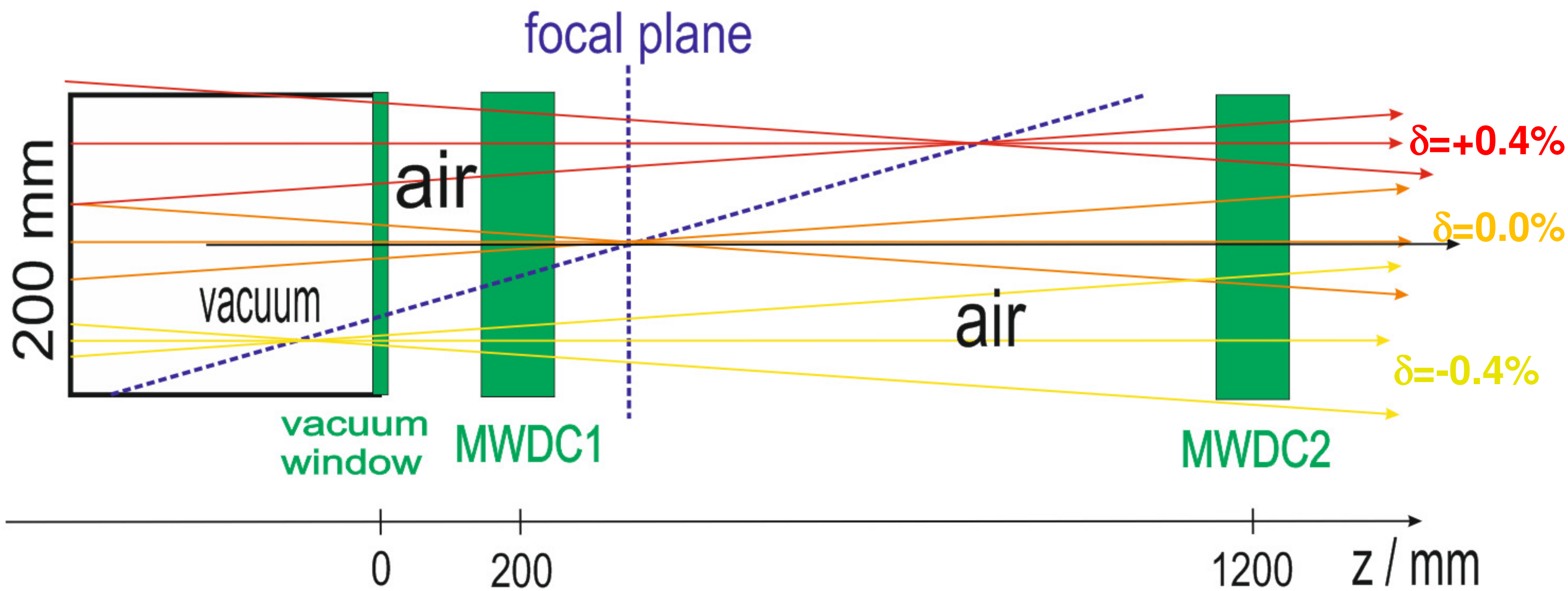


Two images near center to sum up dispersion of both halves.
Spot size achieved for proton beam: ΔX_{FWHM} = 0.80 mm => R = 20 000





Detector Setup at S4 in S436 Experiment



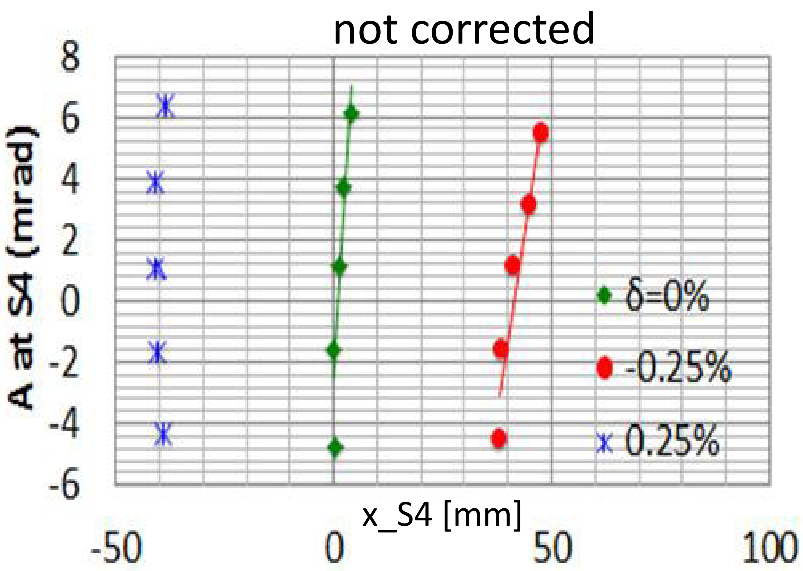
Influence of straggling in matter (window, air, thin tracking detectors), focal plane position for best resolution Δx_{FWHM} = 0.8 mm by detectors alone for δ=0%, but much worse for other momenta.

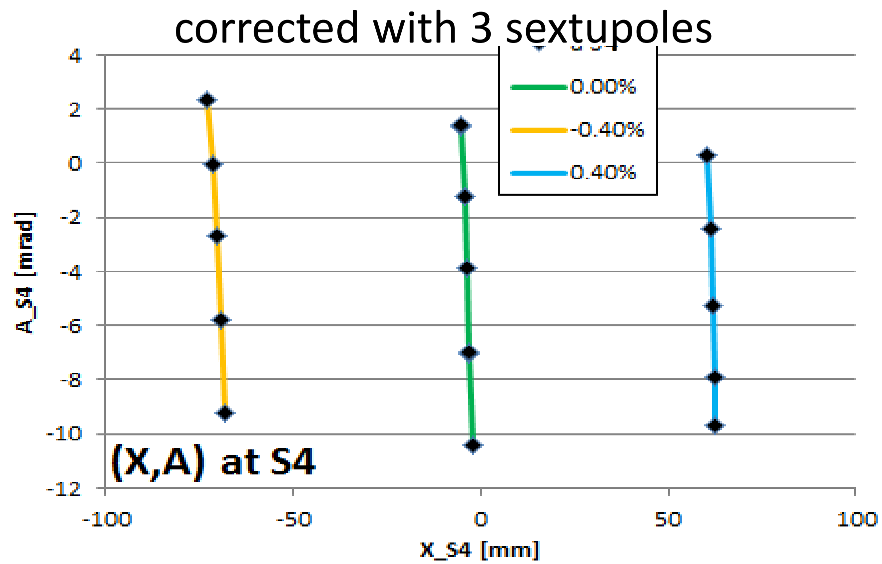
==> Optics correction can be helpful even with tracking detectors

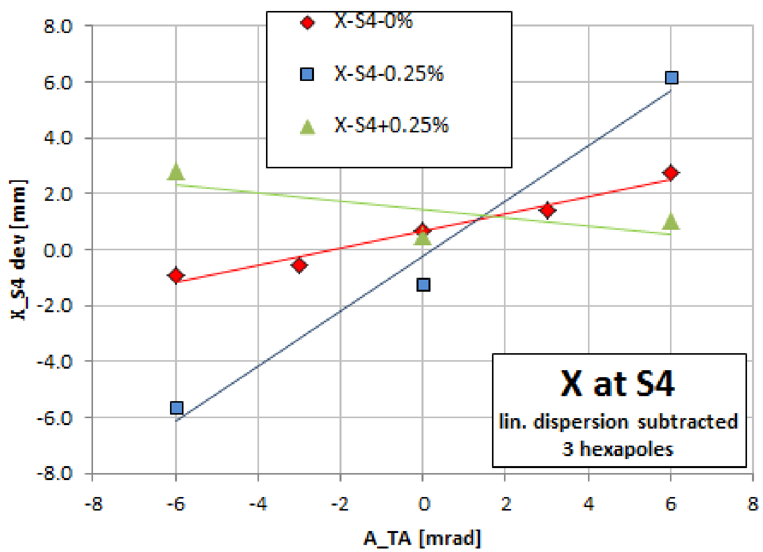
Test of Sextupole Correction

not achromatic -> wide beam at S4

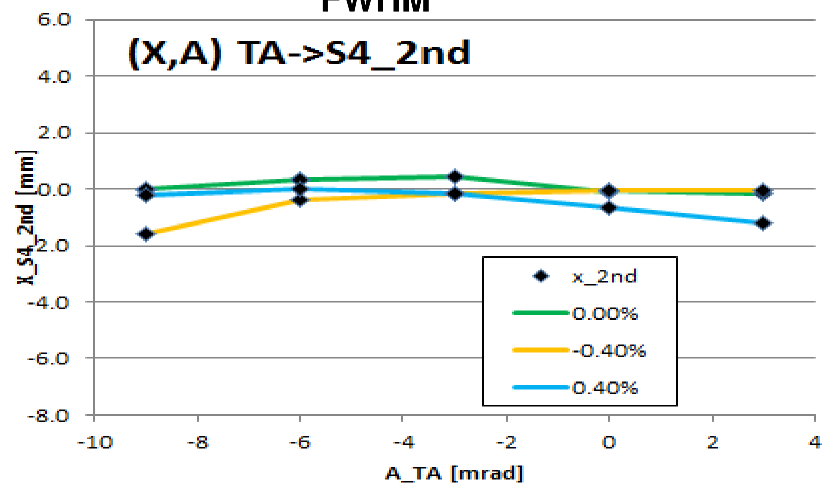
do not measure with thick target, scan initial angle on target with steerers (± 6 mrad)







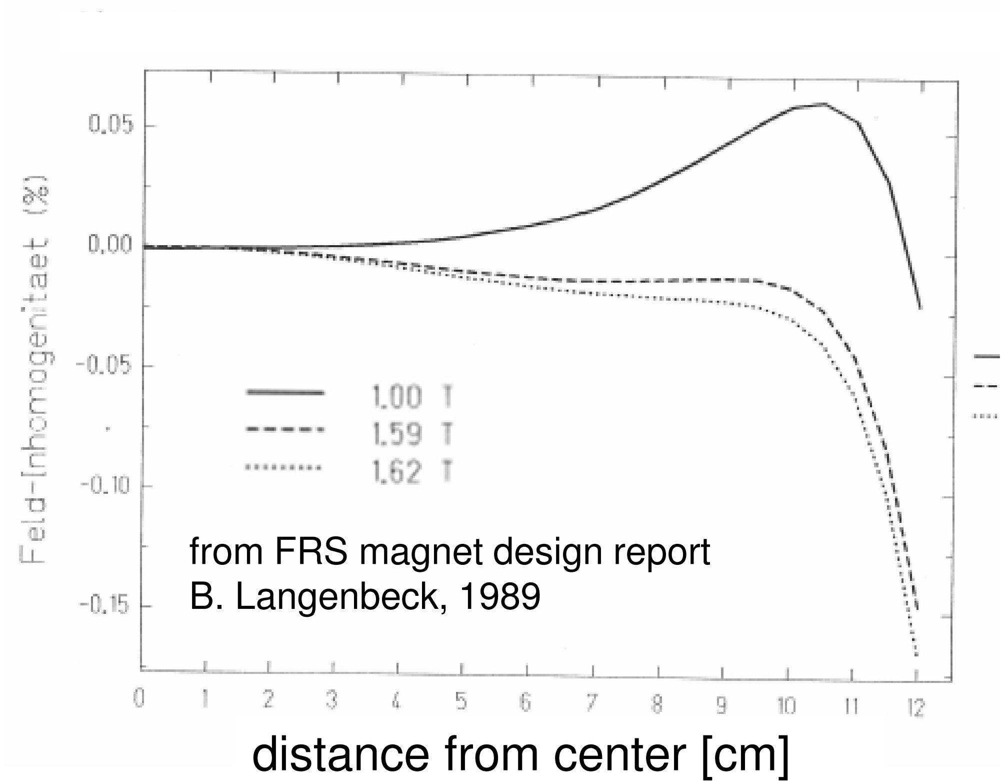
$\Rightarrow$ **Δx_{FWHM} = 1 mm**



Intrinsic Sextupoles

- **Phase space is already a bit curved without any explicit sextupoles**

- **Intrinsic sextupole components of other FRS magnets have to be considered in addition.**
  A fitted model (n_2=6.3 in all dipoles) roughly agrees with expected dipole inhomogeneity.

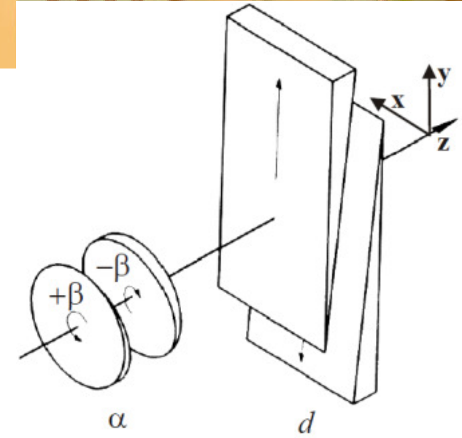


- **Calculation of coupling coefficients shows that dipoles are by far the most sensitive part.**

- **Due to accelerator restrictions we could test only up to Bρ = 7.88 Tm -> B_{Dipole} = 0.70 T.**

Degrader Scans

Al degraders: **plates, wedge-shaped plates, wedge shaped disks, overall shape is critical**



GSI target scanner

sensors from both sides

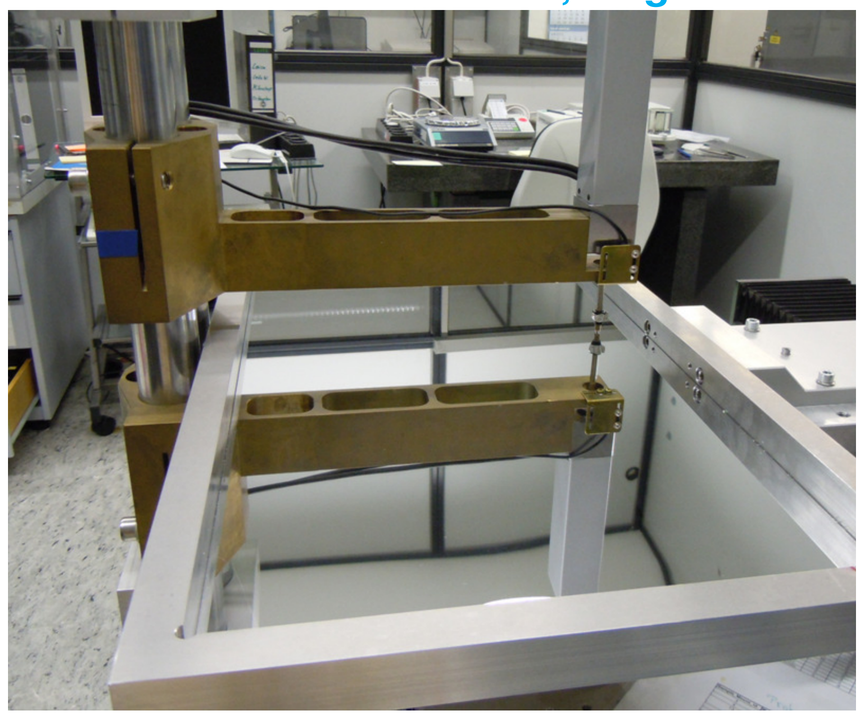
Δx_{abs} ~ 3 μm

Δx_{rel} ~ 1 μm

Heidenhain CERTO CT60 range 60mm δx = 0.1 μm

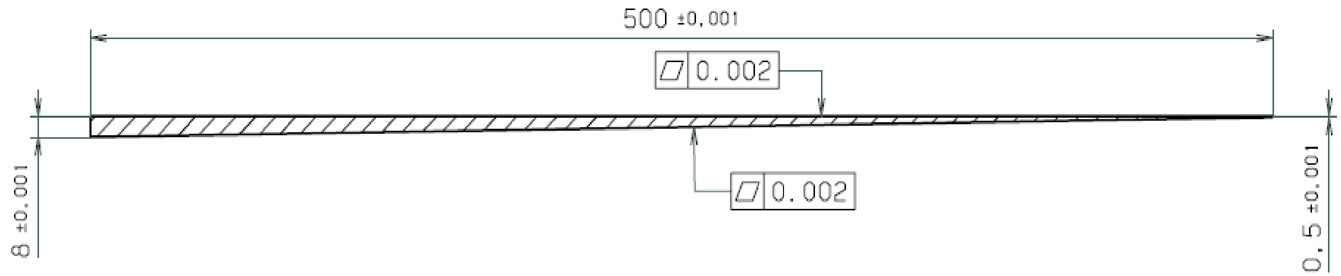
Schneeberger optical table for 1m x 0.6m

Bettina Lommel, Birgit Kindler



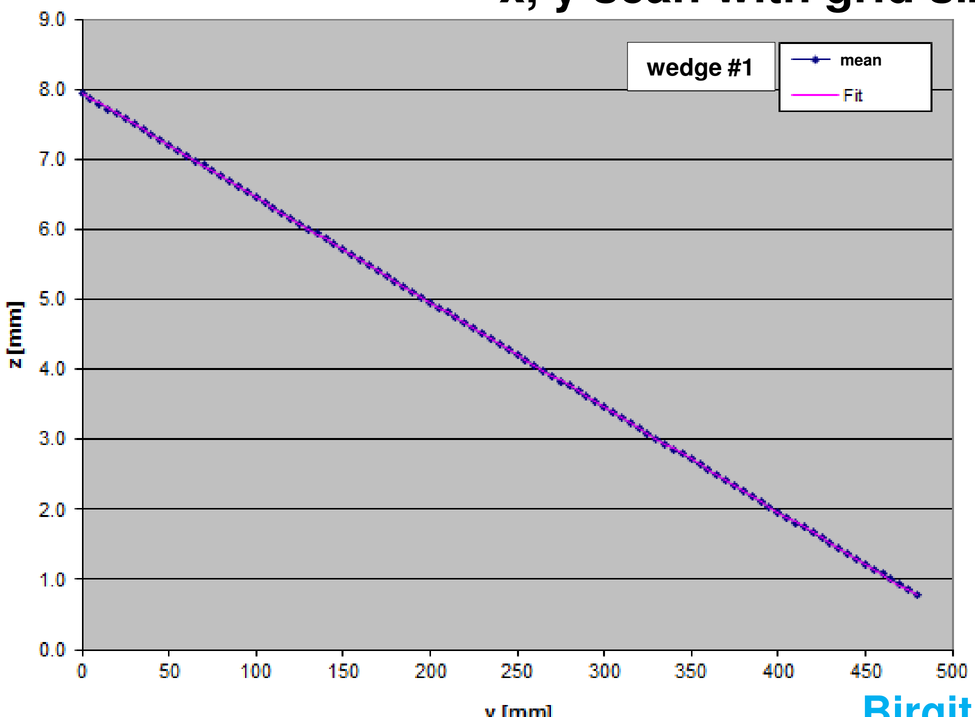
Degrader Wedge - Slope

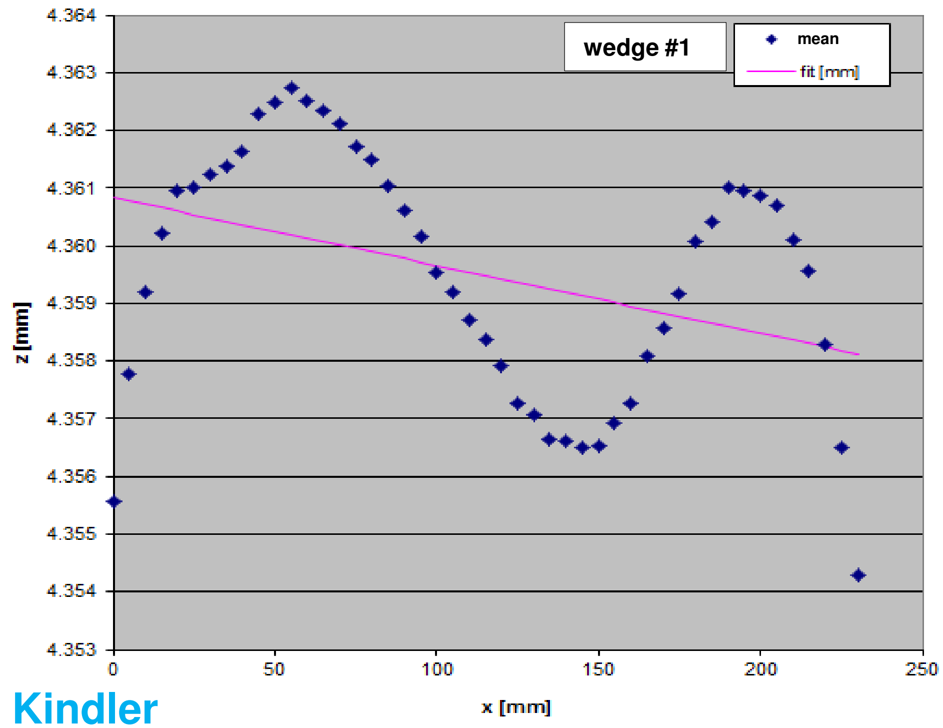
Plates 500 mm x 230 mm, slope = 0.015



$slope_1 = 0.01496$
$slope_2 = 0.01499$
→ matches specification

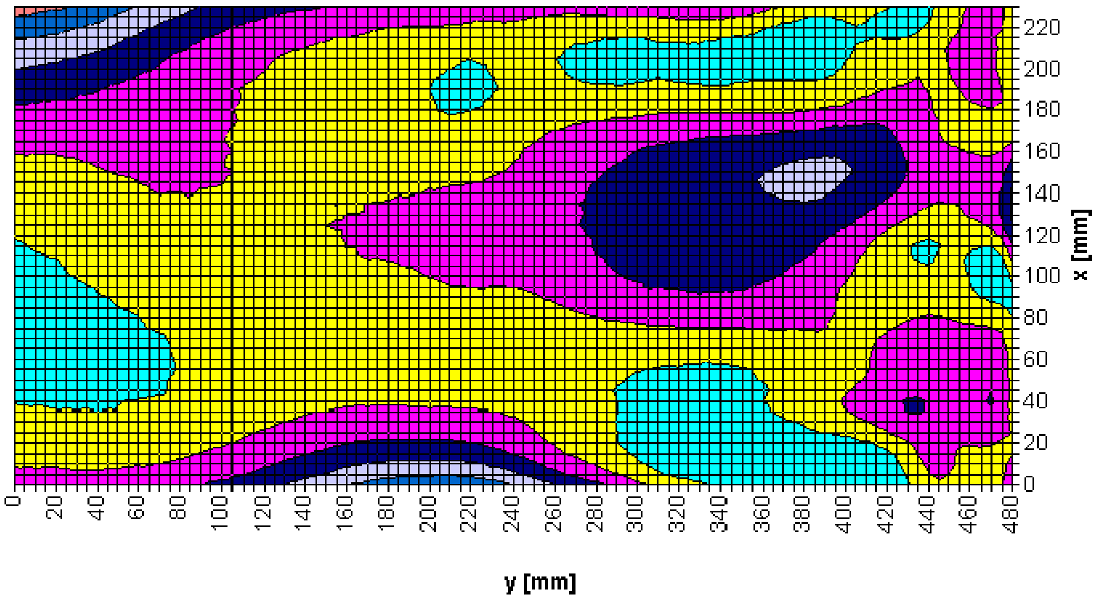
x, y scan with grid size 5 mm

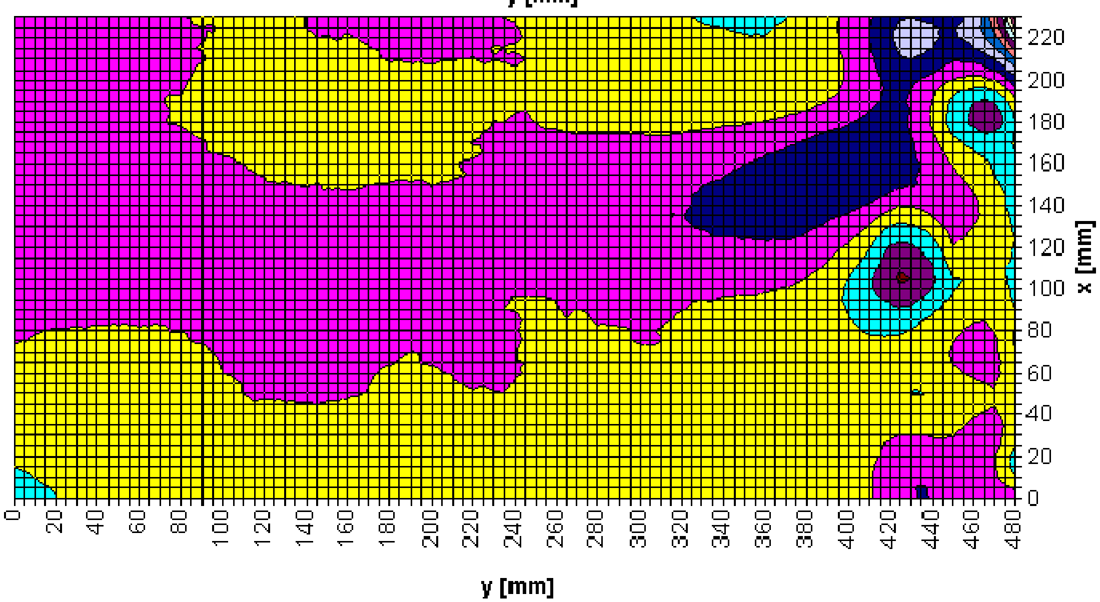




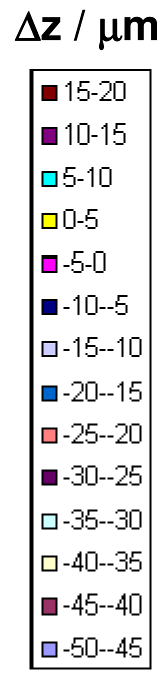
Birgit Kindler

Degrader Wedge Homogeneity



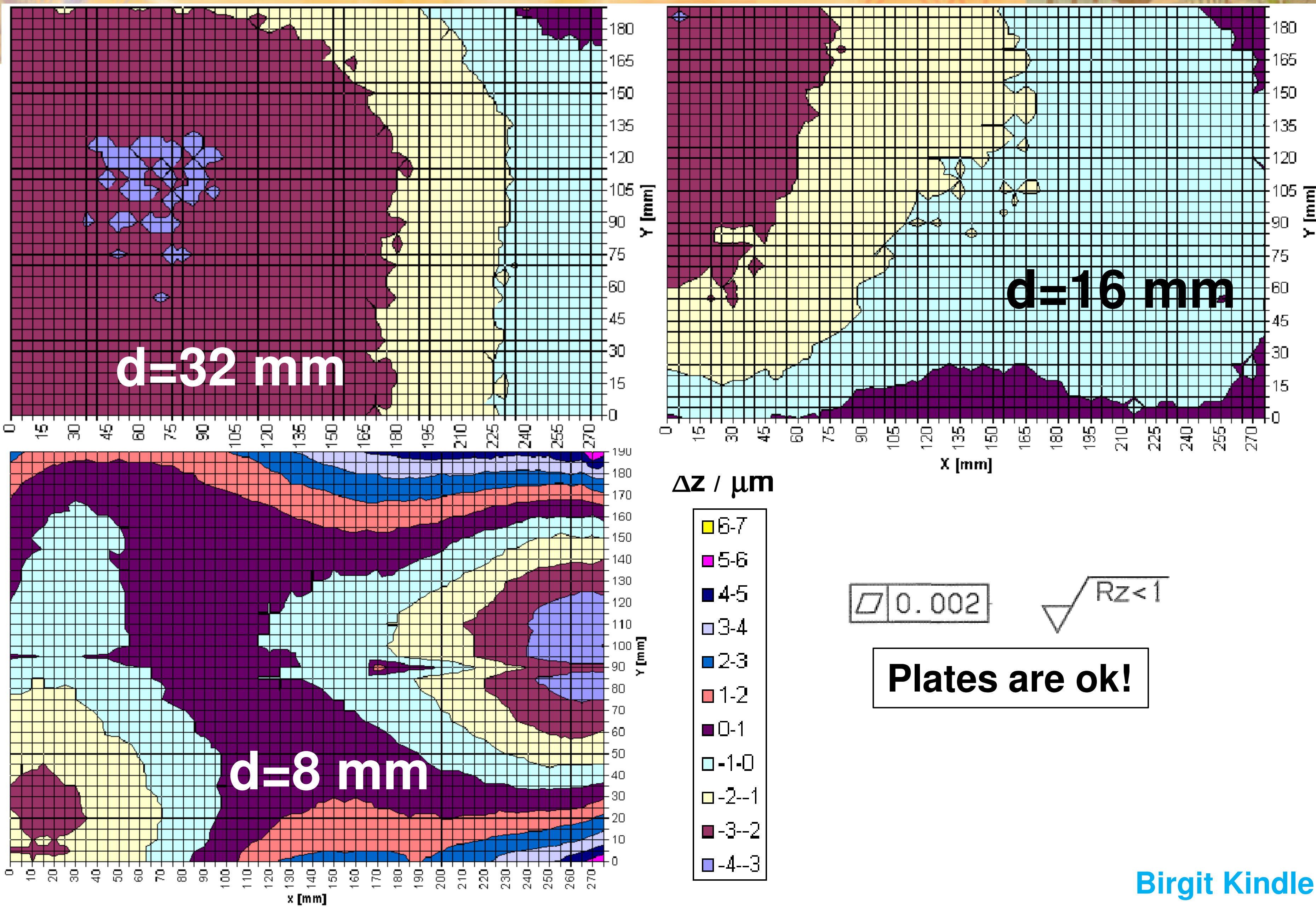


Deviation of thickness from average slope



Birgit Kindler, GSI target lab

Degrader Shape – Simple Plates



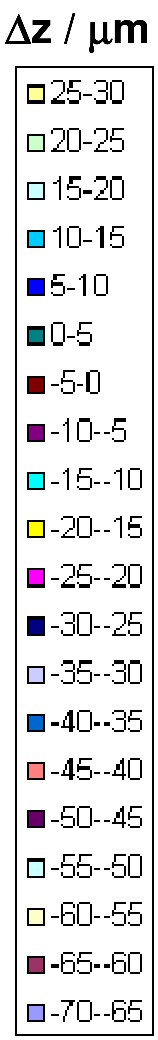
⏥ 0.002

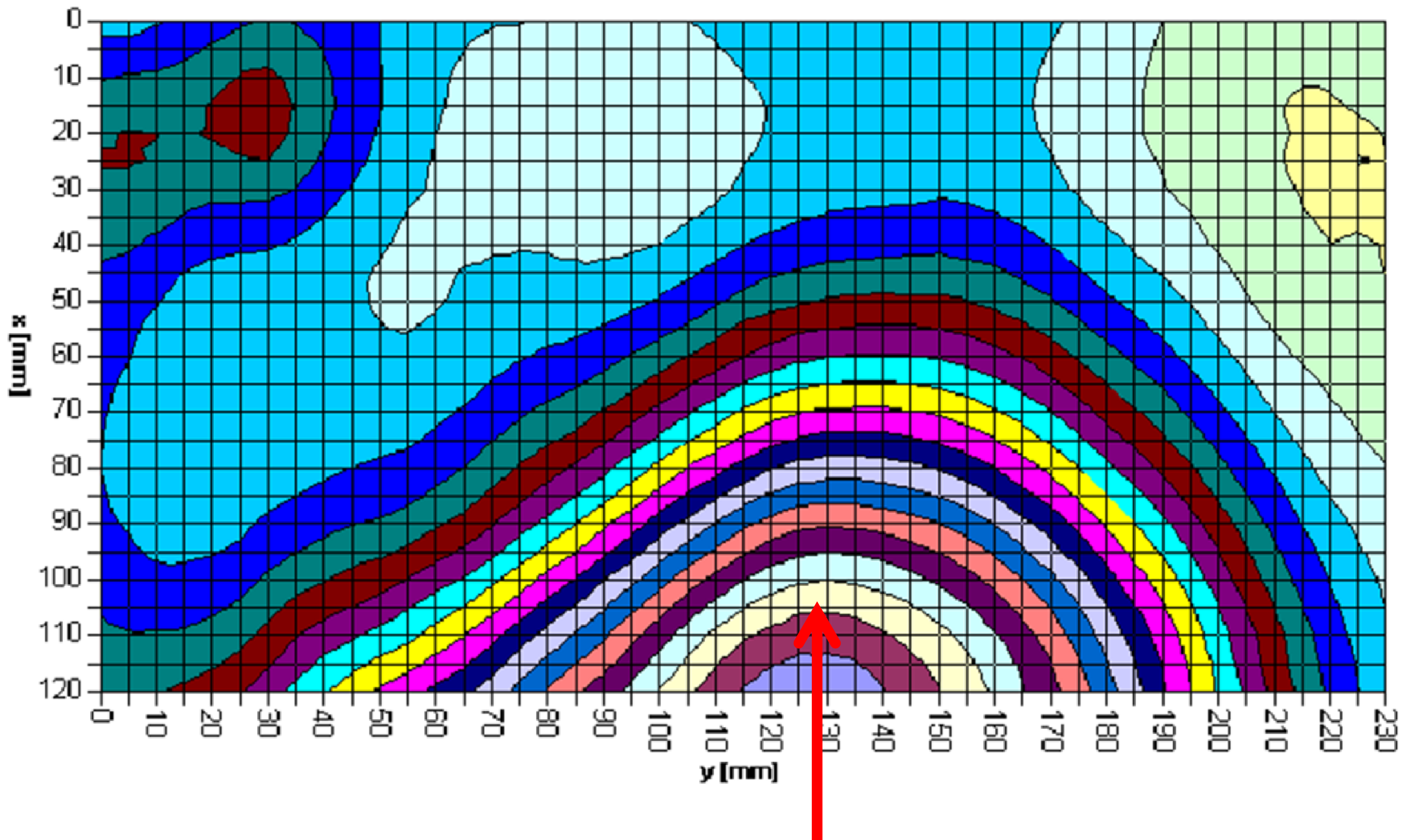
$\sqrt{Rz<1}$

Plates are ok!

Birgit Kindler

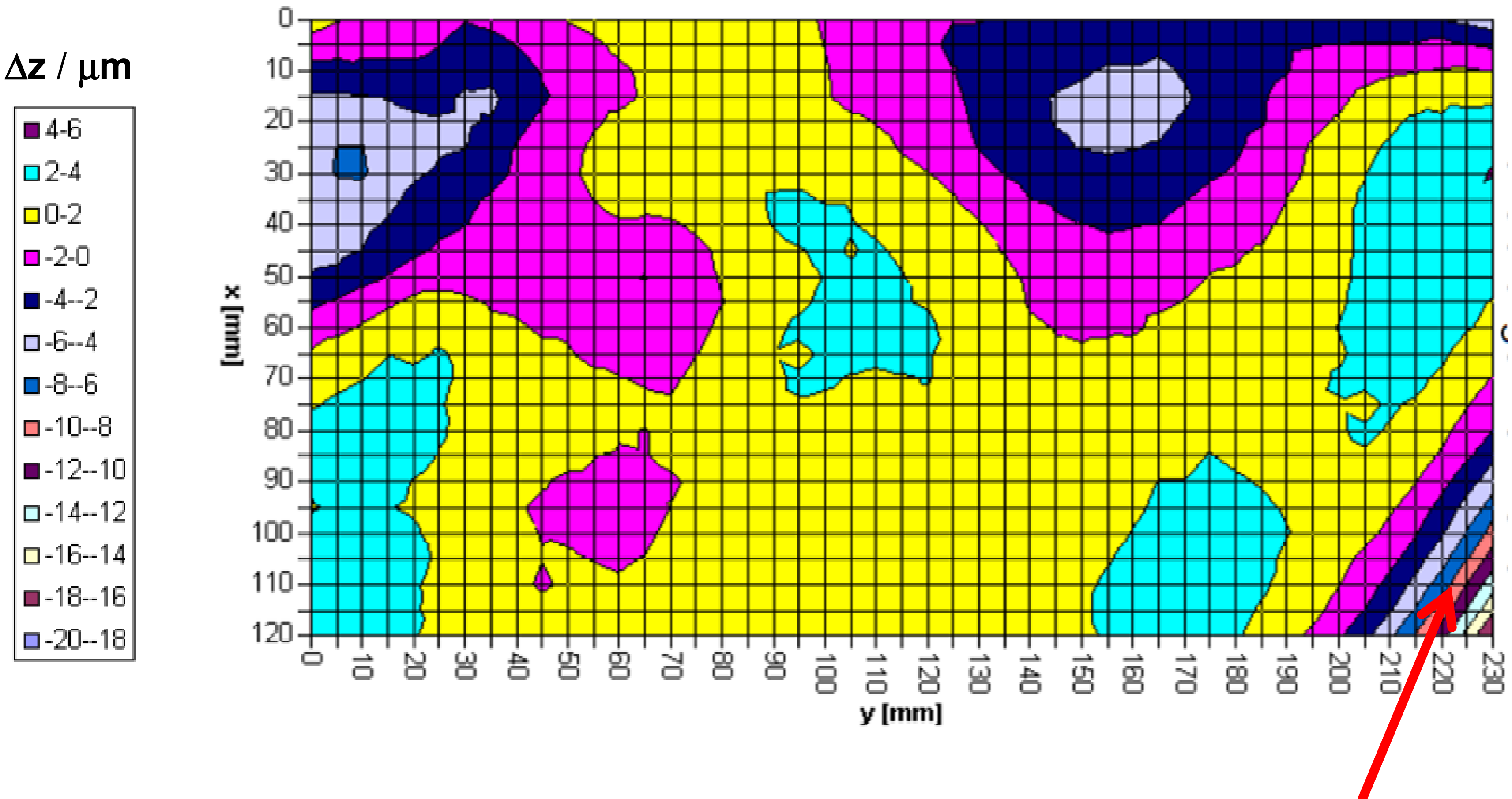
Wedge-Shaped Disk #1





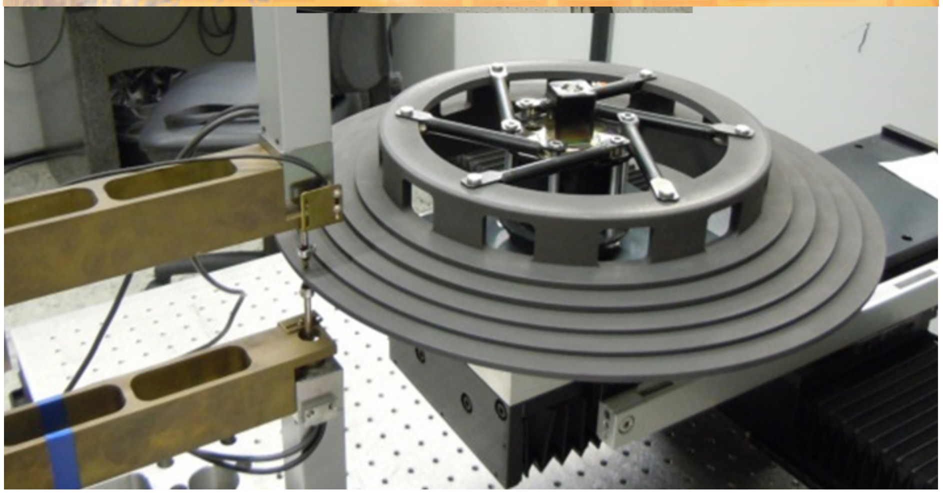
Not acceptable for FRS or Super-FRS

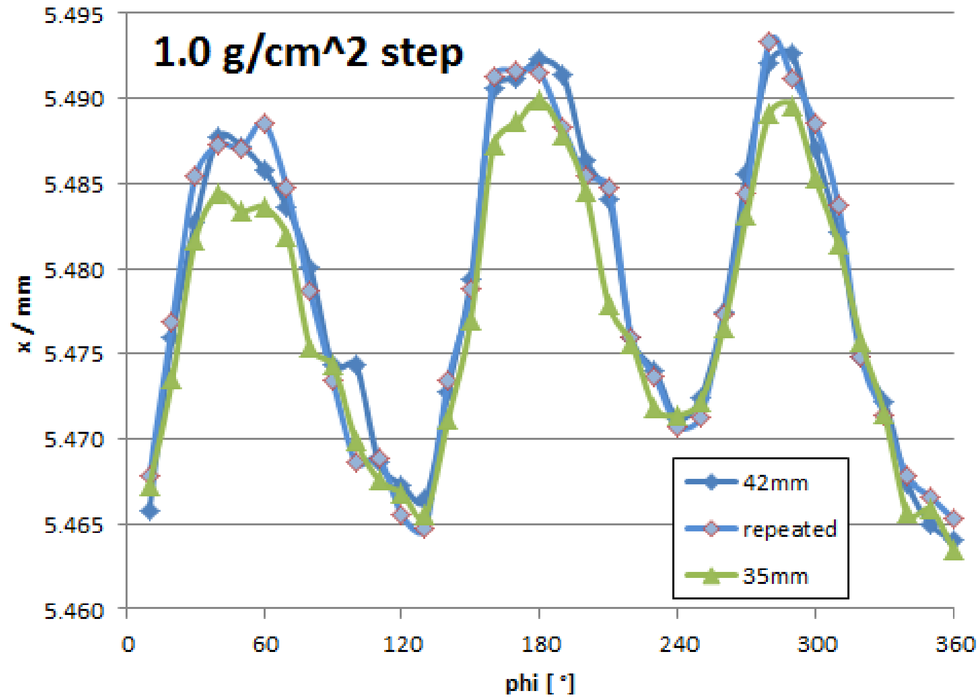
Wedge-Shaped Disk #2



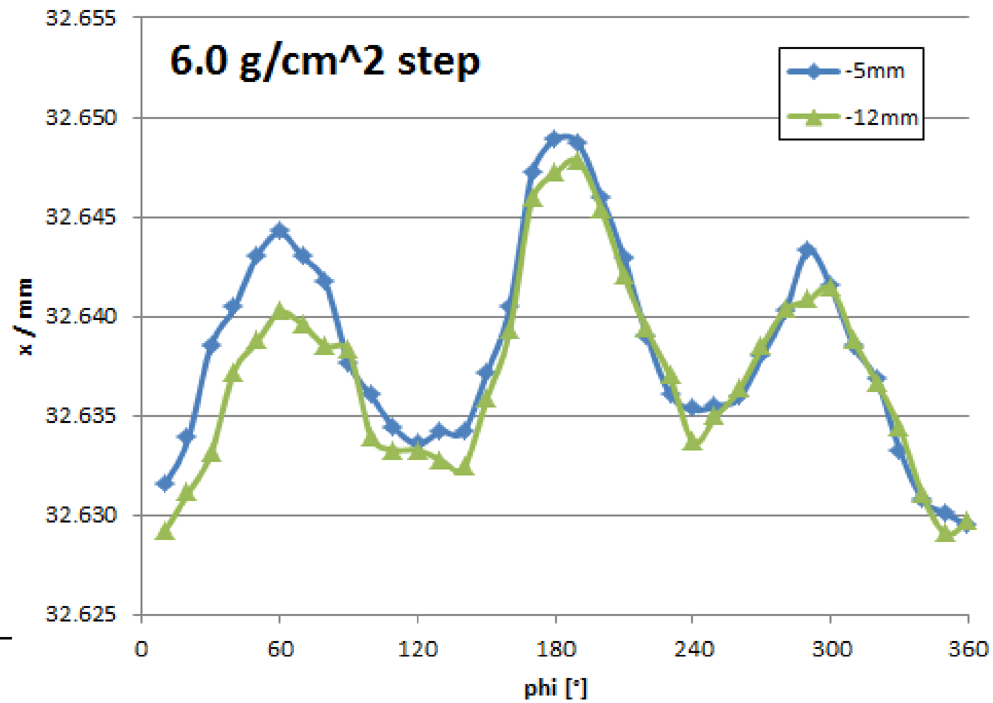
Bad corner, rest ok.

Target Wheel Thickness





Measure on two radii (ΔR=7mm)



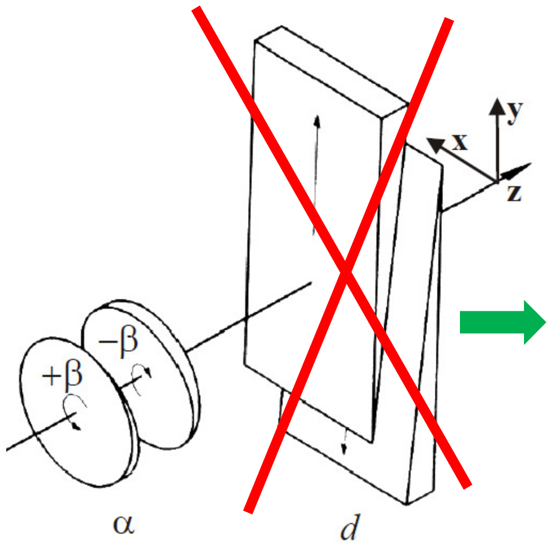
standard deviation for each step

1.0 g/cm^2 σ_x/x = 1.5E-3
2.5 g/cm^2 σ_x/x = 5.1E-4
4.0 g/cm^2 σ_x/x = 2.6E-4
6.0 g/cm^2 σ_x/x = 1.5E-4
8.0 g/cm^2 σ_x/x = 1.1E-4

Birgit Kindler, GSI target lab

Low-Energy-Branch Degrader

Problem: large aperture but for given wedge shape too large thickness in center → too high energy → absolute energy spread still too high



Example: (x,δ) = 4.0m, ^{230}Th at 300 MeV/u
monoenergetic wedge angle = 5.1 mrad
$\Delta x = \pm$ 190mm, $\Delta y \sim \pm$ 200 mm, Δz_{min} = 0.5mm
central thickness > 10 mm (ion gets stuck)
➔ E_{in} > 360 MeV/u ($B\rho$ > 7.6 Tm > $B\rho_{max}$)

➡ **gas volume**

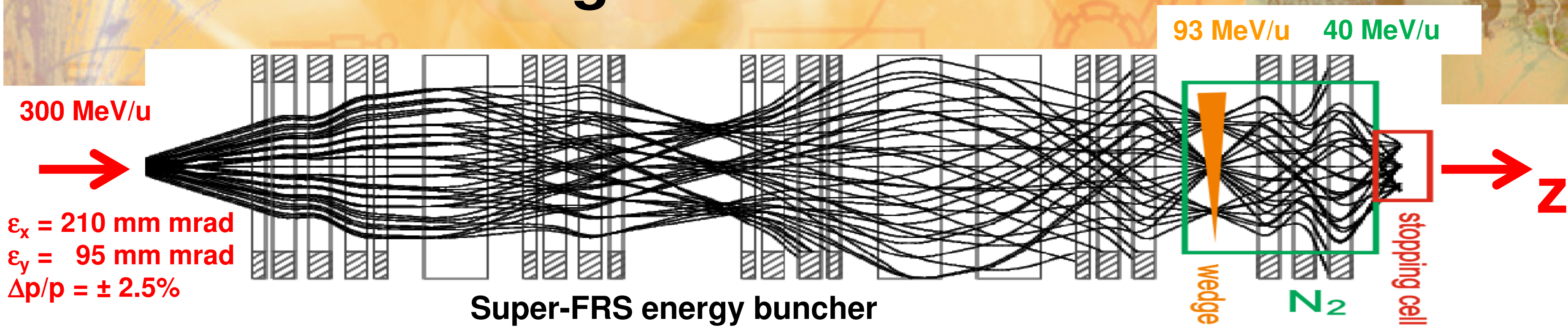
use long distance including quadrupoles to keep pressure low.

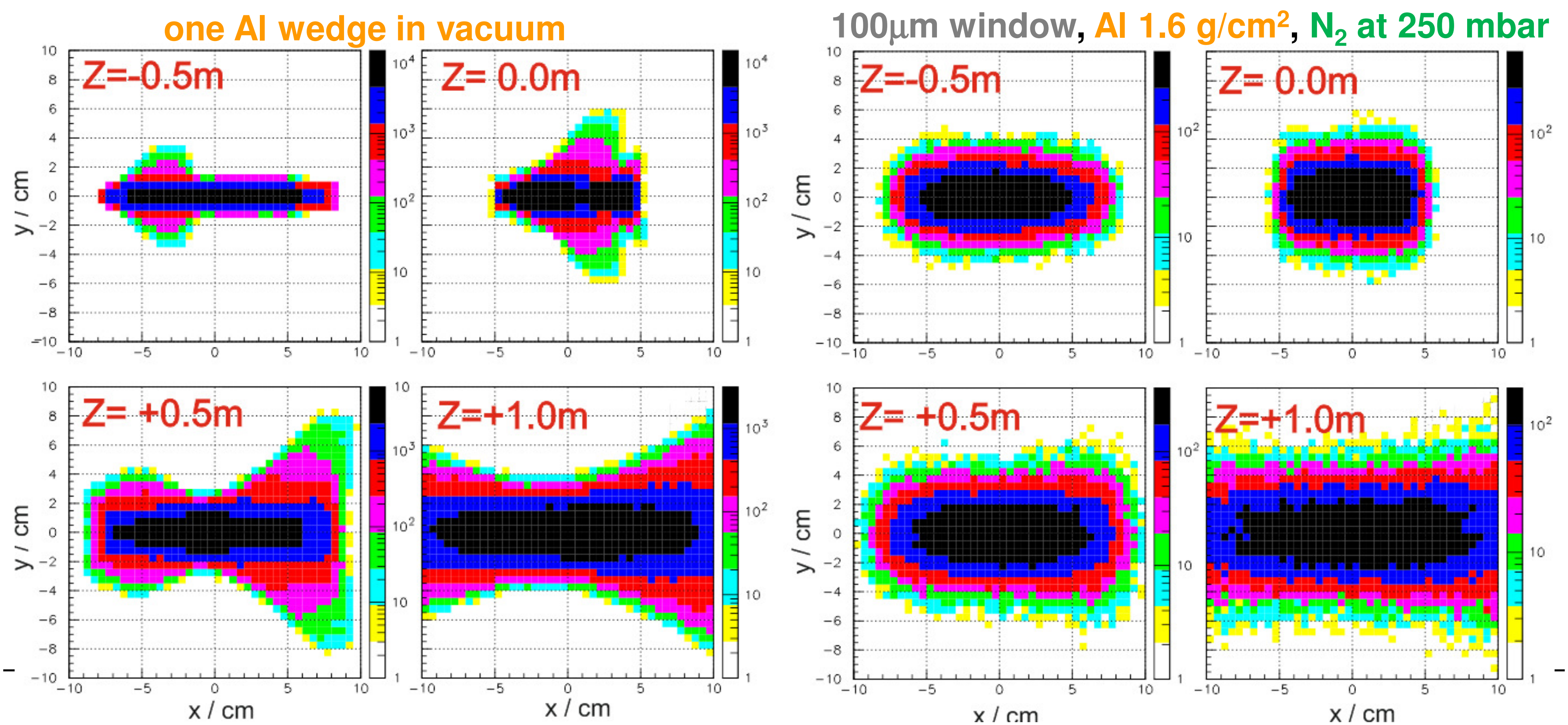
Slow down ^{230}Th from 300 → wedge disks 93 → gas 40 → 0 MeV/u.
N_2 over L=7.8m up to 1 g/cm^2, set quadrupoles in triplet to average $B\rho$.

Enlarged spot in stopping cell, transmission losses ?
but same good range bunching to σ_E/E = 1.31 / 40 = 3.3%
→ σ_R = 4.2 mg/cm^2 He (without matter in inhomogeneity)

=> MOCADI in many layers with angular straggling and charge exchange.

Gas degrader Simulation





Summary

- Knowledge was there but correct application was lost.

- Shortening by neighboring magnets is important.
  It does not depend much on strengths of other magnets.
  Important for setting of new modes without long adjustment.

- Sextupole correction, needed for FRS with narrow slits.
  Can also improve high resolution spectrometer with tracking.
  Simple symmetric corrections work best.

- High dispersion mode can go to R=10 000.

- Manufactured degraders must be scanned.