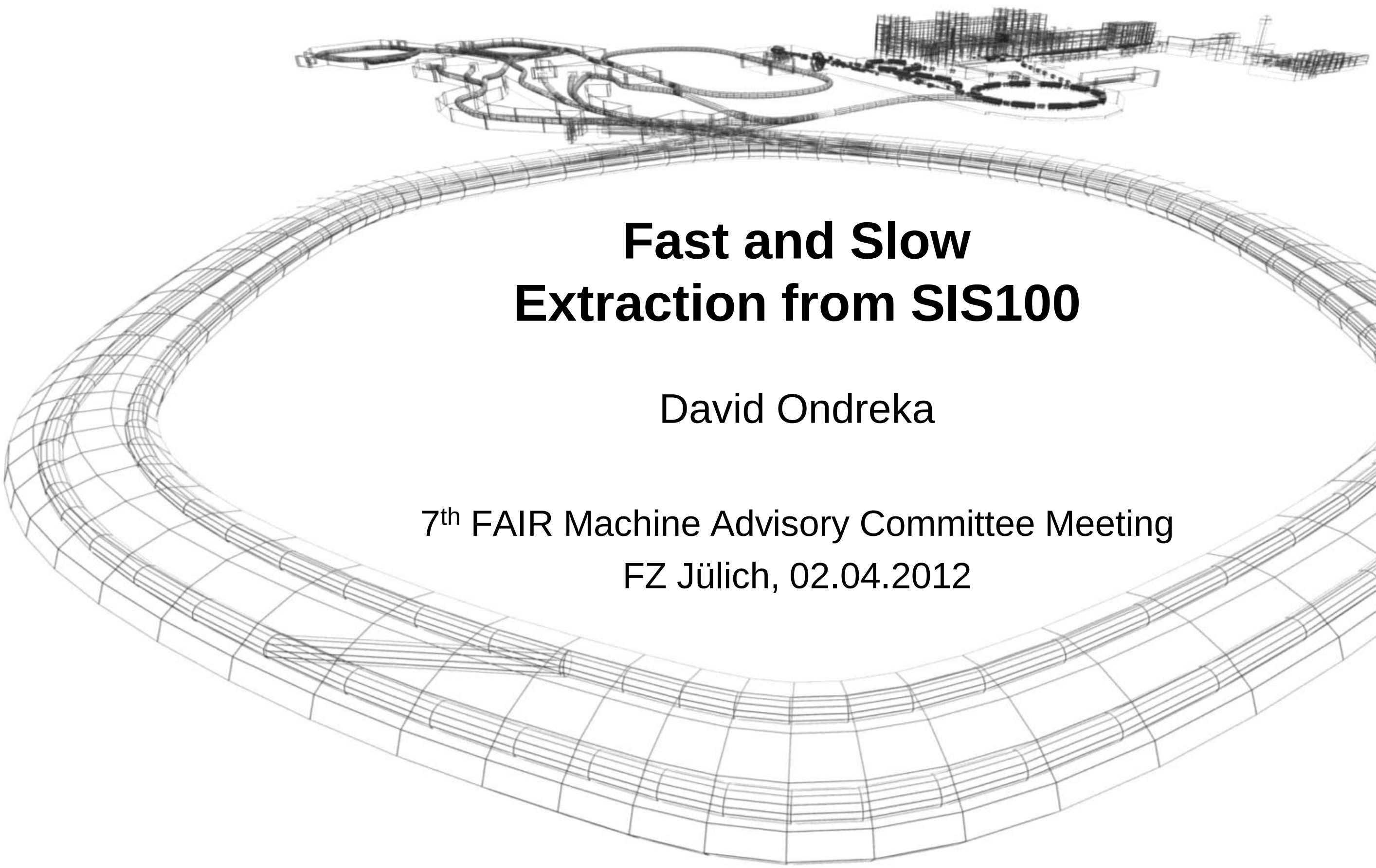
Fast and Slow
Extraction from SIS100



David Ondreka

7th FAIR Machine Advisory Committee Meeting

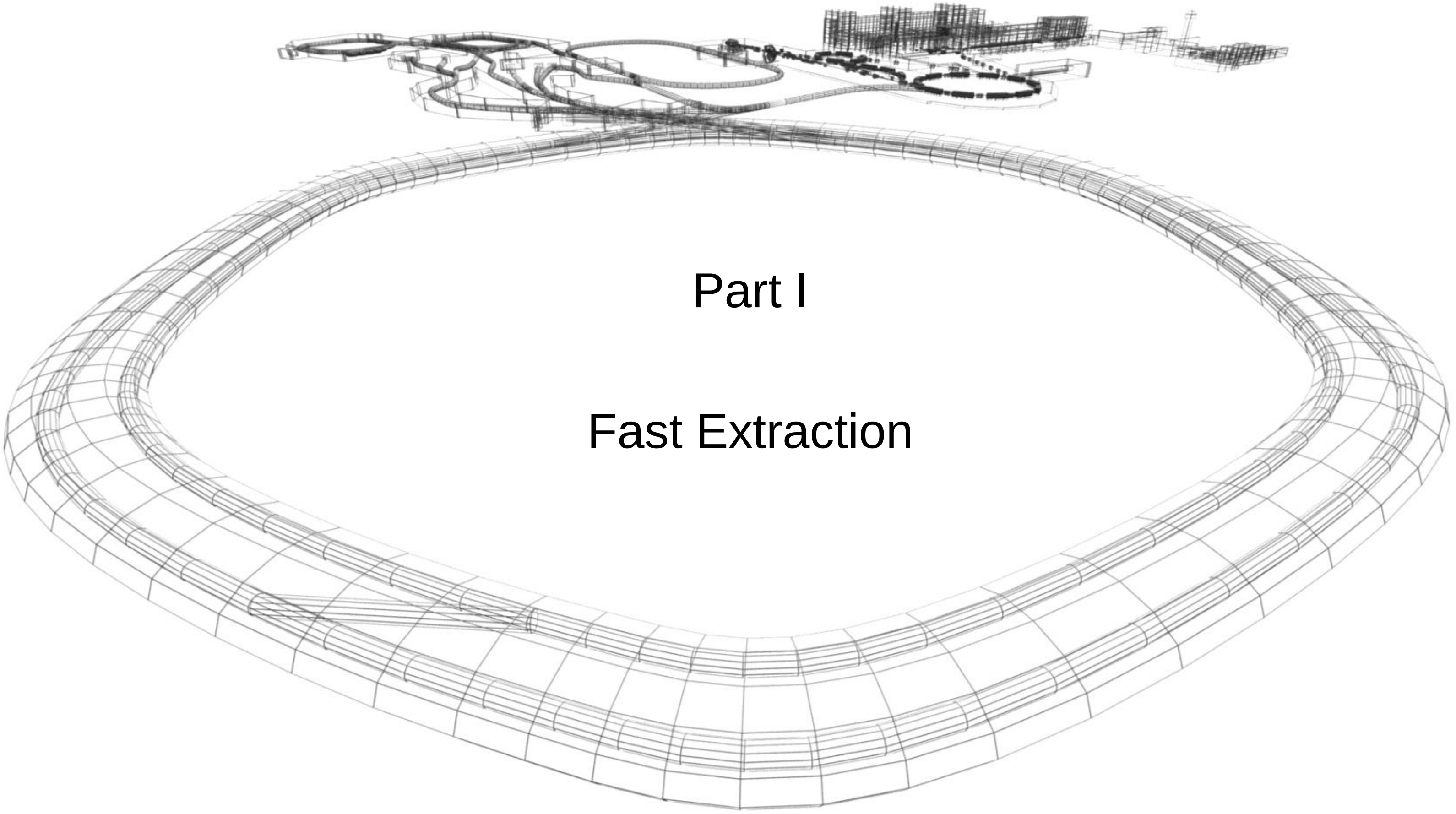
FZ Jülich, 02.04.2012

Outline

- Fast Extraction
  - Ions
  - Protons

- Slow Extraction
  - Summary of status
  - Design review
  - Proposed changes
  - Simulation results

- Summary/Outlook



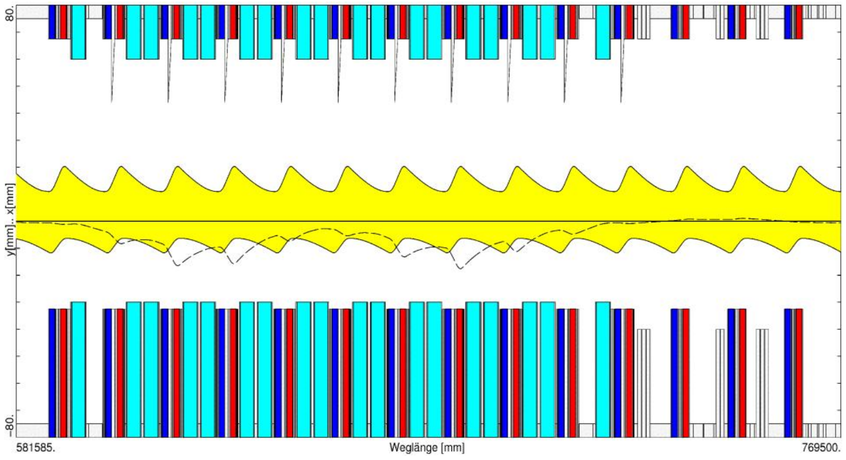
Part I

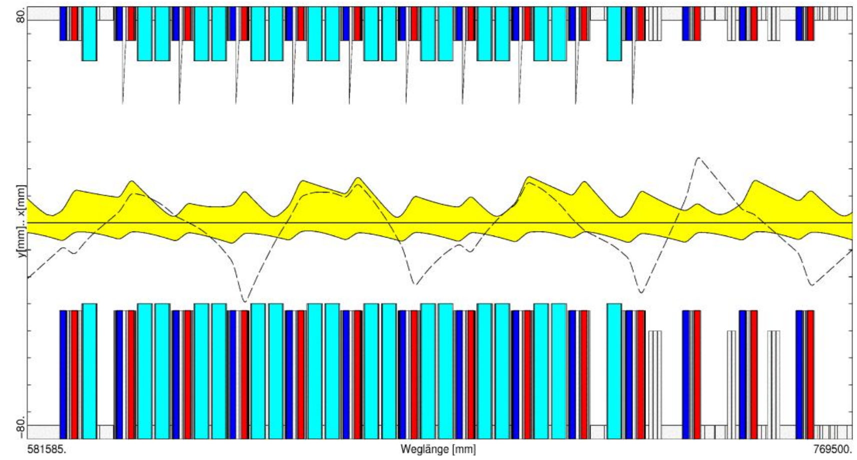
Fast Extraction

Lattice Comparison

Ion Lattice	
Q_h/Q_v	18.88 / 18.80
γ_t	15.4
D_{max} [m]	1.8
$\varepsilon_h/\varepsilon_v$ [mm mrad]	25 / 10
Energy [GeV/u]	0.4 – 2.7

Proton Lattice	
Q_h/Q_v	21.78 / 17.40
γ_t	**45.5**
D_{max} [m]	3.0
$\varepsilon_h/\varepsilon_v$ [mm mrad]	4 / 2
Energy [GeV/u]	29.0

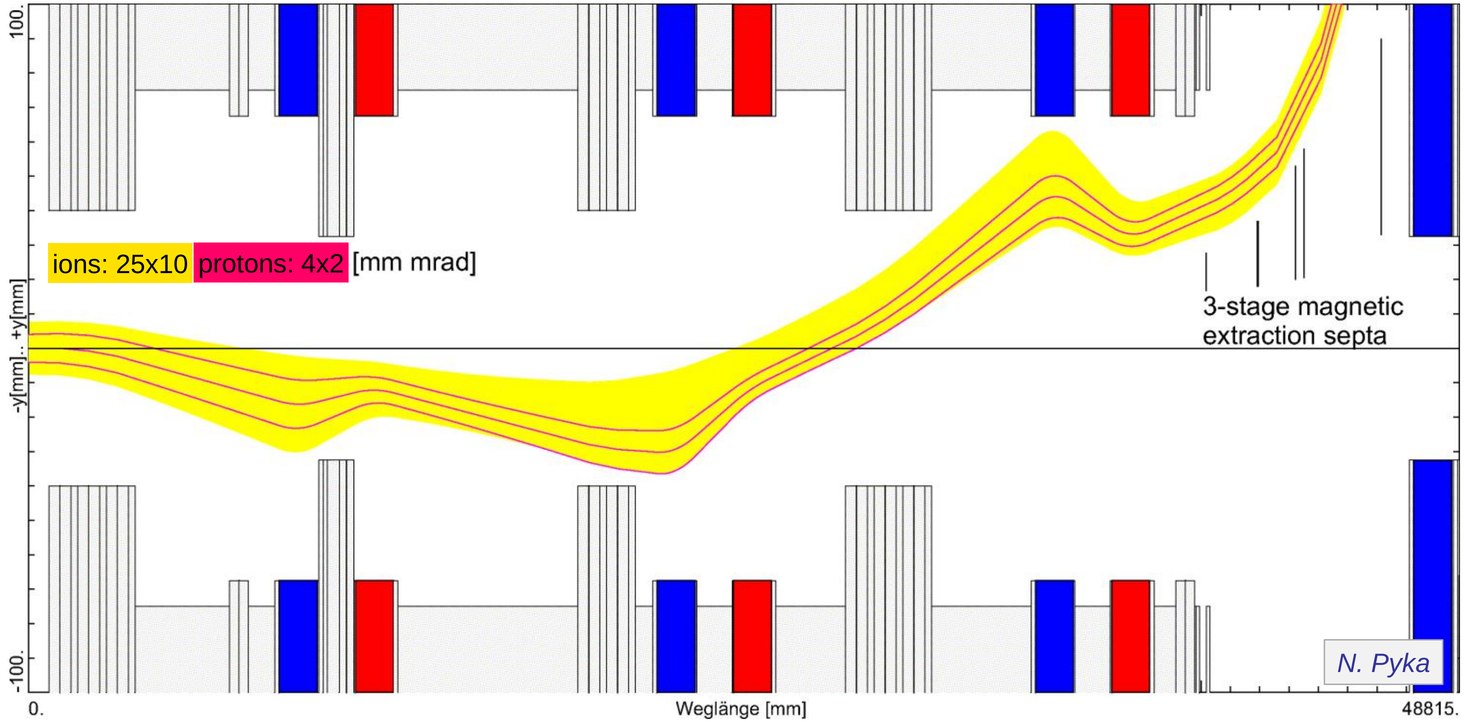




- Symmetric doublet lattice (14 x DF)

- Symmetry broken to shift γ_t (6 x DF_1, 8 x DF_2)
- Vertical plane only weakly affected

Fast Extraction of Ions and Protons



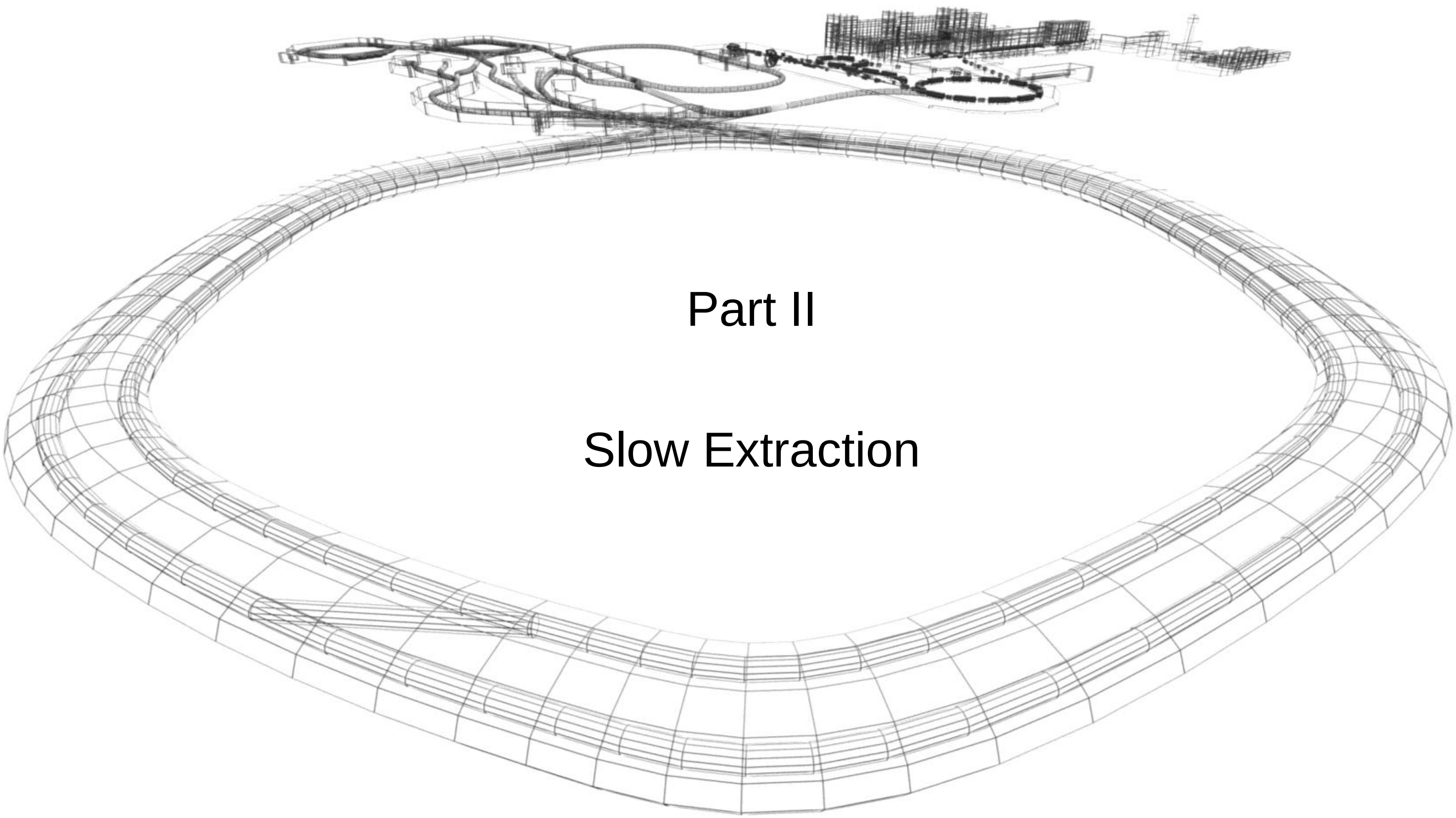
Fast extraction works for both ion and proton lattice

- Beam of twice design emittance can be extracted
- Identical settings for kicker magnets
- No further changes to fast extraction layout

For technical details of the extraction system, see talk U. Blell

Part II

Slow Extraction



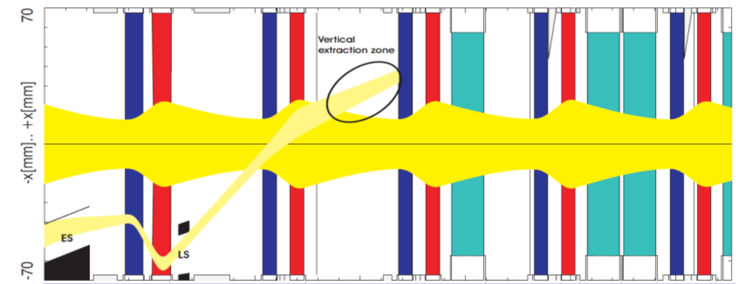
HELMHOLTZ GEMEINSCHAFT

GSI

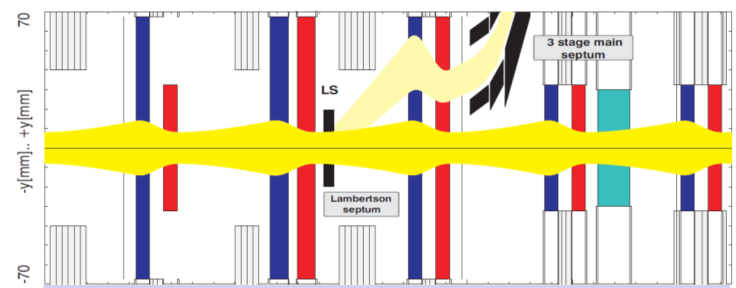
Summary of Status

Status presented to MAC (Pyka, 11.02.2010):

- Creation of 3rd order resonance $3Q_h=52$ by 11 resonance sextupoles
- Correction of horizontal chromaticity by 48 chromaticity sextupoles
- RF Knockout Extraction
- Extraction devices
  - 2-stage electrostatic septum (hor.)
  - Lambertson magn. septum (vert.)
  - 3-stage magnetic septum (vert.)
- Systematic field errors can be compensated

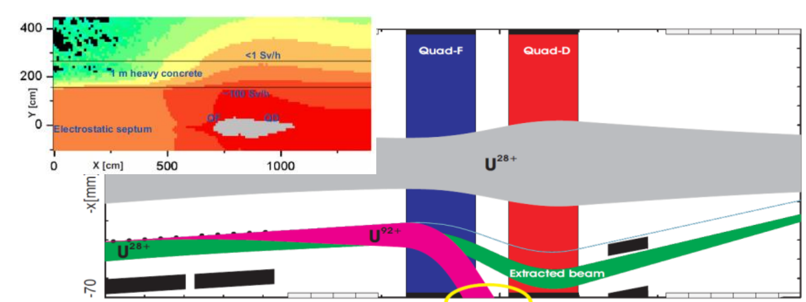


Extraction section (horizontal plane)



Extraction section (vertical plane)

- Machine protection issues due to beam loss
  - Protection of septum wires from heat load requires control of extraction rate and spiral step (> 8mm)
  - Installation of radiation hard warm quadrupoles behind the septum due to stripped ion losses
  - Additional shielding to protect equipment from radiation levels up to 100 Sv/h



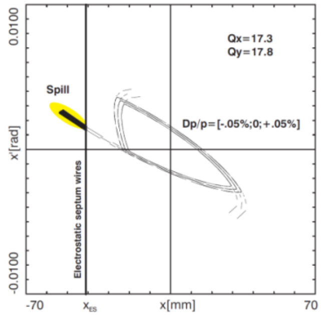
Loss distribution and dose

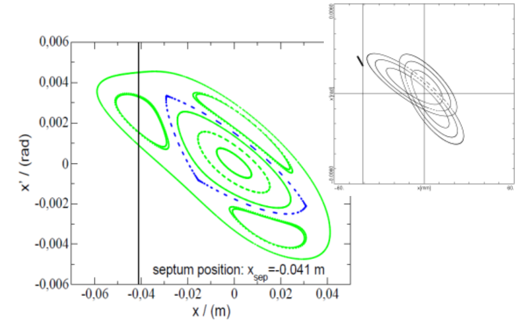
Design Review of Slow Extraction

- Design review performed with the aim of **optimizing the robustness** of slow extraction
  - Geometry of extraction system well established
  - Non-linear dynamics in the strong sextupole fields challenging for controlling slow extraction

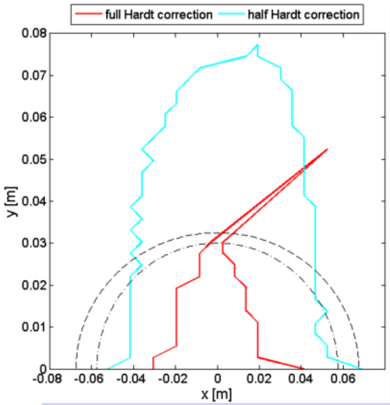
- Optimization goals
  - Decoupling of planes for hor. chromaticity sextupoles
  - Relaxation of constraints on chromaticity correction by dynamic aperture
  - Linearization of separatrices to gain freedom in adjusting size and angle
  - Increase of tolerance against closed orbit distortions

- Goals can be achieved
  - Changes to lattice required
  - Changes to settings required

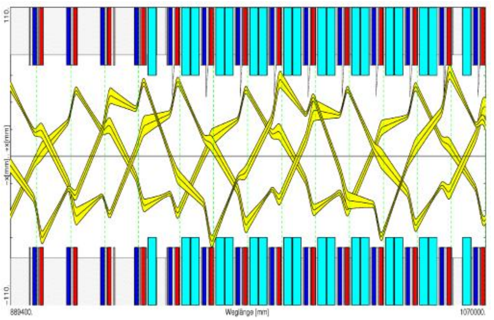




Curved separatrices and island structure



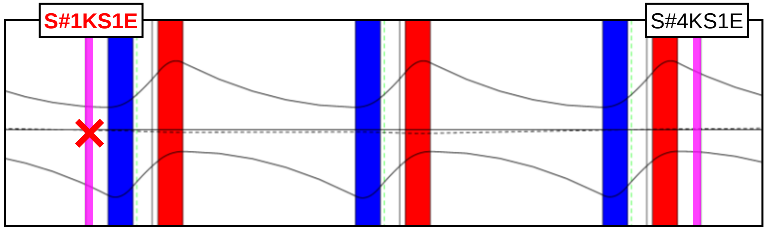
Dynamic aperture limiting Ch correction



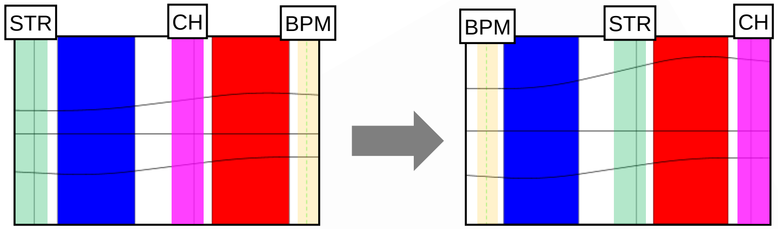
Small margin for orbit distortions

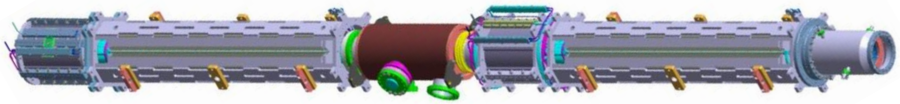
Proposed Lattice Changes

- Elimination of 5 resonance sextupoles
  - Goal: Space and cost saving
  - Reasoning:
    - Located at position with small ratio β_x/β_y
    - Not necessary even for TDR
  - Implications: None

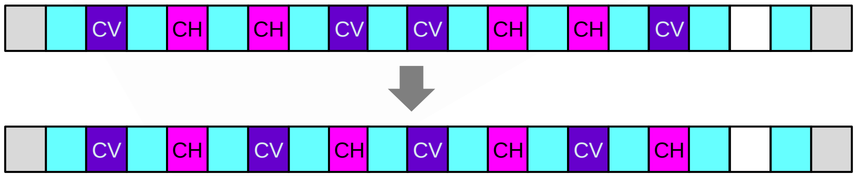


- Relocation of CH sextupoles
  - Goal: Better separation of planes
  - Reasoning:
    - Place at position with maximum possible β_x/β_y
  - Implications: Change of element order in cryo module
    - Move steerer between D and F quad
    - Move BPM in front of D quad
    - Slightly higher beam loss on BPM (ok)





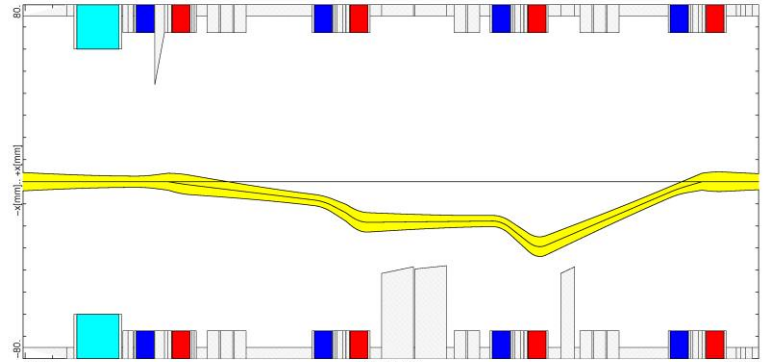
- Rearrangement of chromaticity sextupoles
  - Goal: More favorable phase advances
  - Reasoning:
    - Minimize higher order driving terms
  - Implications: None



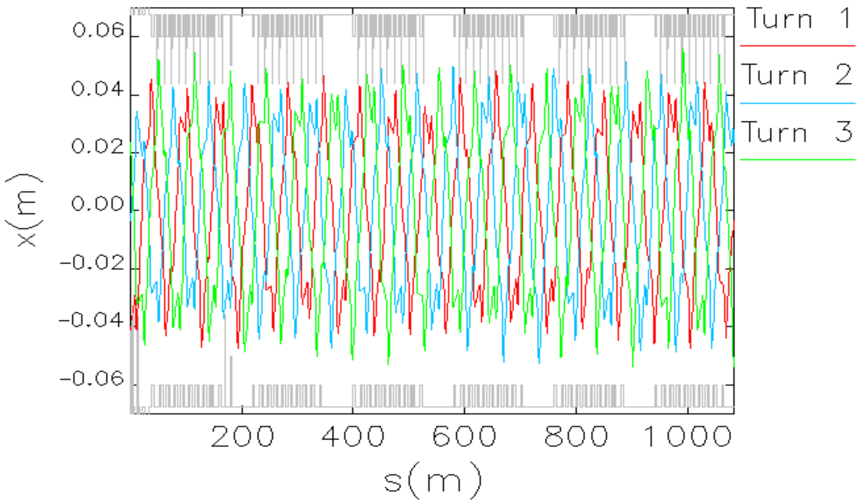
Proposed Changes to Settings

- Introduction of bump at septa
  - Reduction of amplitude of resonant particles
  - Increase of margin for closed orbit distortions
- Correction of chromaticity using horizontal chromaticity sextupoles only
  - Shift of vertical chromaticity remains small
- Introduction of octupole component
  - Compensation of higher order terms from strong chromaticity sextupoles

	Mod	TDR
Q_h/Q_v	17.31 / 17.80	
C_h/C_v (corr.)	-1.0 / -27.2	-5.2 / -39.4
$K2L_{ch}$ [1/m²]	-0.48 (28%)	-0.4 (23%)
$K2L_{cv}$ [1/m²]	0.0	-0.4 (23%)
$K2L_{sr}$ [1/m²]	0.8 (72%)	0.15 (14%)
K3L [1/m³]	4.9 (30%)	0.0
Bump [mm]	-6.0 (40%)	0.0



Bump at septa (magnified)



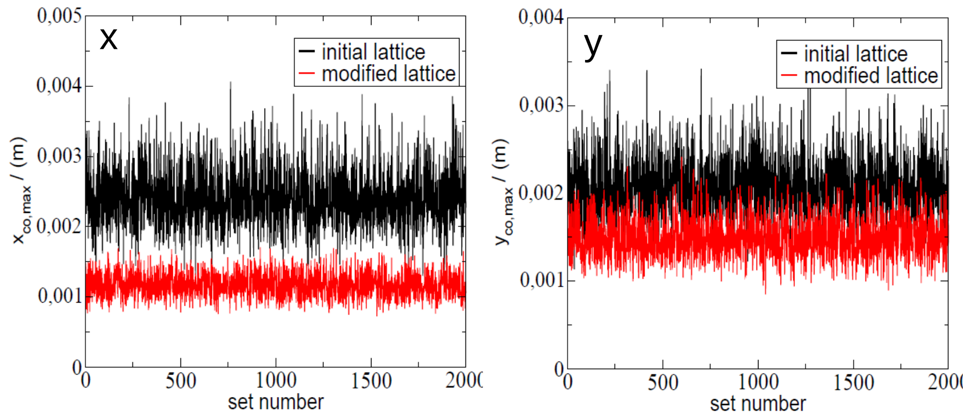
Amplitude of resonant particle during last three turns

Improved Control of Closed Orbit

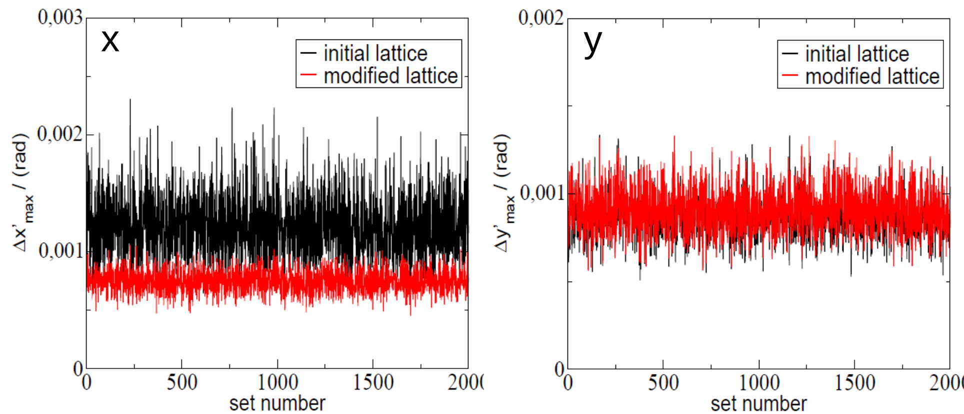
Comparison of closed orbit correction for TDR lattice and modified lattice

- Misalignments considered
  - Transverse shifts of quadrupoles
    - $\Delta x_{rms} = \Delta y_{rms} = 1$ mm
  - Dipole tilt around longitudinal axis
    - $\Delta \psi_{rms} = 1.4$ mrad
  - Gaussian distributions, truncated at 2σ
- Residual orbit distortions significantly smaller for modified lattice
  - More favorable β functions in new position
- Corrector strengths comparable

Residual CO	TDR	Mod
x_{rms}/x_{max} [mm]	3.1 / 6.3	**1.3 / 2.7**
y_{rms}/y_{max} [mm]	2.6 / 5.5	**1.5 / 3.2**



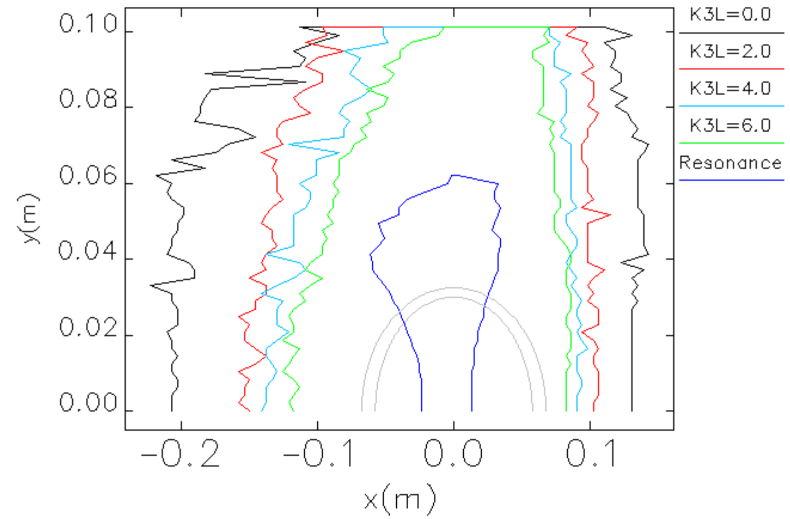
Maximum residual orbit distortion vs. seed



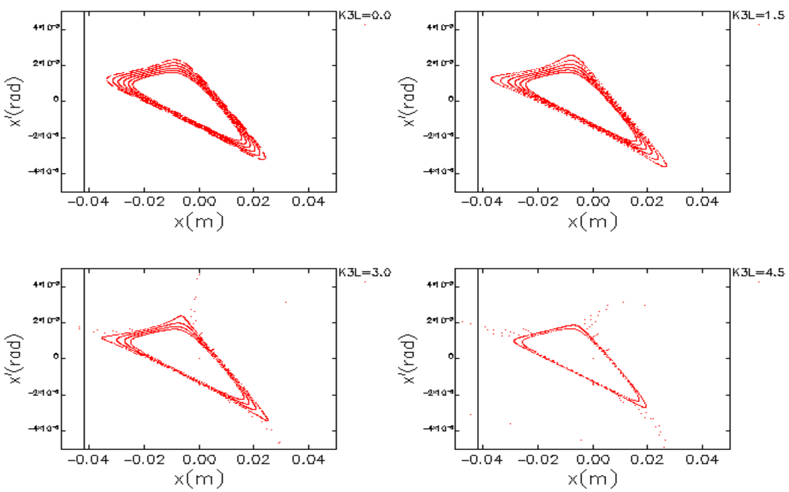
Distribution of corrector settings vs. seed

Higher Order Effects and Dynamic Aperture

- SIS100 lattice with chromaticity correction exhibits **large amplitude dependent tune shifts**
  - Dispersion small, hence large sextupole strength
  - Second order effects give large contribution
  - Without compensation dynamics is far from perturbative theory of slow extraction (Kobayashi)
- Amplitude dependent tune shifts can be **compensated by using octupole correctors**



Dynamic aperture for Ch=-1
(with and without resonance sextupoles)

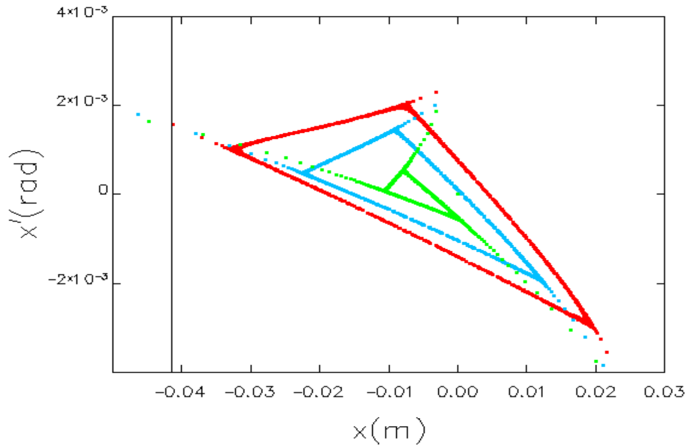


Trajectories in horizontal phase space
vs. octupole strength (resonance conditions)

- **Dynamic aperture** improved compared to TDR
  - DA larger than for TDR
  - No restriction on hor. chromaticity correction by DA

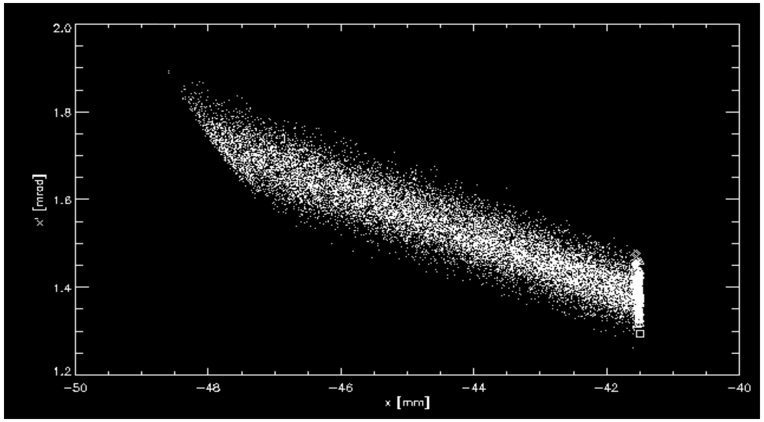
Improved Performance

- Compensation of amplitude dependent tune shift permits variation of separatrix
  - Separatrices of different size are possible
  - Bump allows limitation of oscillation amplitude
  - Spiral step can be controlled in all cases
  - Fallback extraction scheme using quadrupole to shift tune seems feasible



Separatrices with different sizes

- Tracking calculations indicate high extraction efficiency
  - No losses on apertures
  - Small beam divergence at septum (±0.1mrad for extraction within 5000 turns)
  - Losses on septum ≈ 1%



Horizontal phase space of extracted particles

Summary/Outlook

- Fast extraction from SIS100 works both for ion and proton lattice
- SIS100 lattice optimized for better robustness of slow extraction
  - Improved control of closed orbit
  - Higher margin for closed orbit distortions
  - Larger dynamic aperture
  - Separatrices linearized
  - Higher extraction efficiency
  - Additional benefit: only six resonance sextupoles required
- Further studies
  - Influence of closed orbit distortions
  - Compensation of β distortion due to warm quadrupoles
  - Extraction performance with bunched beam
  - Stabilization of coasting beam during extraction

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Thank you for your attention!