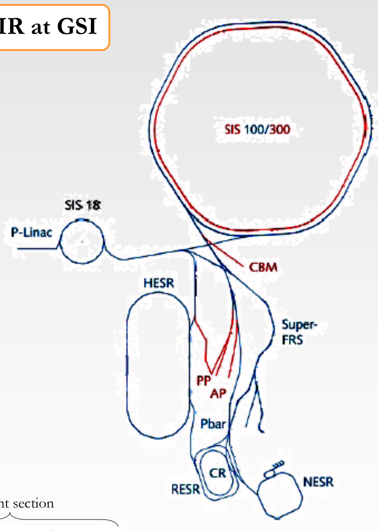
Beam dynamic simulations for the superconducting synchrotron SIS300 at FAIR

A. Saa Hernandez for the FAIR Synchrotrons group
GSI Darmstadt (Germany)

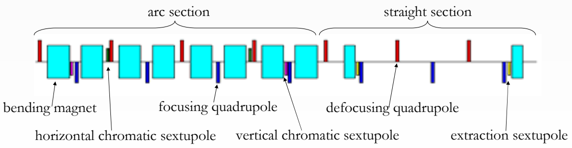
Motivation: new facility FAIR at GSI

Synchrotron and storage rings complex
maximum energy achievable:
300Tm or 32GeV/u from SIS300

SIS300 basic requirements:
- in SIS100 tunnel
  - ⟶ fixed radius
  - ⟶ B up to 4.5T
  - ⟶ superconducting magnets
- parallel operation to serve different experiments (CBM, RIB)
  - ⟶ fast cycling

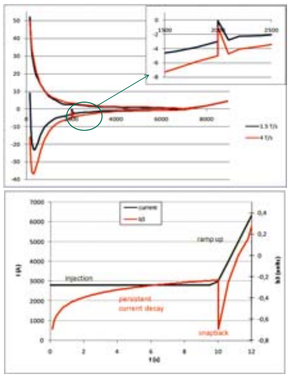


SIS300 ring has a 6-fold periodicity
One period of the machine:



Current effects in Superconducting Magnets

Magnetic field quality in SC magnets is determined by cable positioning and current effects (static and time-dependent)



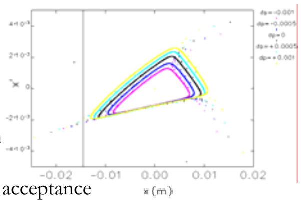
- Persistent currents, its decay at constant current and reinduction (snapback)
- Field periodic pattern
- Coupling currents (between strands and between filaments) during ramps

Superconducting cable made of hard superconductor
⟶ hysteresis-like behavior (ramp rate dependent amplitude)
⟶ memory effects = dependence on previous cycles (powering history).

Beam dynamics at slow extraction

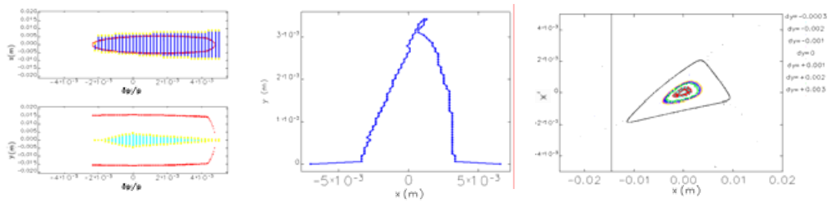
Slow extraction from SIS300 to the fragment separator and the experimental caves is achieved by controlled excitation of a third integer-resonance in the horizontal plane

1 - ideal linear lattice:
natural chromaticity, unlimited DA
2 - adding chromatic sextupoles:
matched to fulfill Hardt condition (momentum independent of extraction trajectory) to avoid beam losses
→still linear chrom and DA 1 order > acceptance



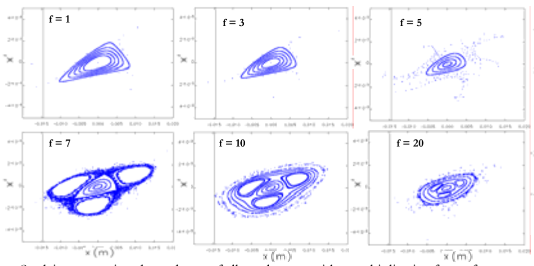
- Phase space restricted by triangular separatrix
- Particles on separatrix are unstable, drift along it from turn to turn direction the septum aperture

3 - adding resonant sextupoles → still Hardt condition fulfilled (sext. compensate each other)

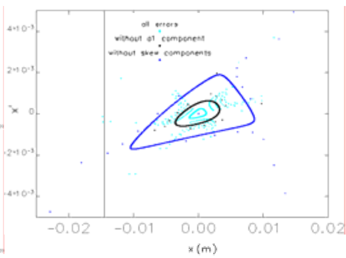


Only particles with y=0 are actually reaching the separatrix, others have DA so small that are lost (unstable) before reaching separatrix !!!

4 – adding field errors → b3 → chromatic sextupoles have to be matched again to Hardt's condition



Studying extraction dependency of allowed errors with a multiplicative factor f



Studying extraction dependency with skew errors

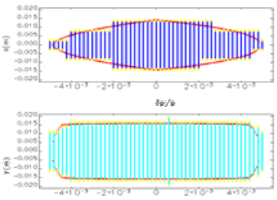
Field Quality vs. Beam Dynamics

Magnetic field expanded in Taylor series

$$B_y + iB_x = B_N^{(r)} \sum_{n=1}^{\infty} (b_n + i a_n) \left(\frac{z}{R_r}\right)^{n-1} \qquad n=1 \ \text{dipolar comp}, \quad n=2 \ \text{quadrupolar comp}$$

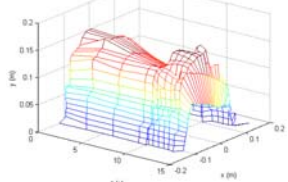
components allowed depending on magnet symmetries

1st step: static field errors
Field errors corresponding to the cycle flat top (4.5T) simulated with ROXIE [3]



Acceptance vs. dynamic aperture for different momentum spreads when adding field errors to the dipoles

2nd step: time dependent field errors
Estimated variation of dynamic DA along a standard ramped cycle



At other facilities with SC magnets and lighter operation requirements (Tevatron, Hera, Rhic) the presence of:
- Non-allowed components (along whole cycle)
- Time dependent components (injection, flat top)
- Ramp rate dependent components (ramps)

⟶ **limit machine operation!**

Different control methods used:
- static field description models
- off-line and on-line reference magnet systems

References
[1] M. Borland, "Elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation". Advanced Photon Source LS-287, September 2000.
[2] Frank Schmidt et al, "MADX: Methodical Accelerator Design". CERN, June 2002.
[3] M. Sorbi et al. *Field quality and losses for the 4.5T Superconducting Pulsed Dipole of SIS300.* Proceedings Magnet Technology MT-20.
[4] A. Jain et al. *Measurements of Field Quality in GSI001 at High Ramp Rates. Internal Note.*

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