Research at IAP
&
Current Topics of the **F**igure-**8** **S**torage **R**ing
F8SR

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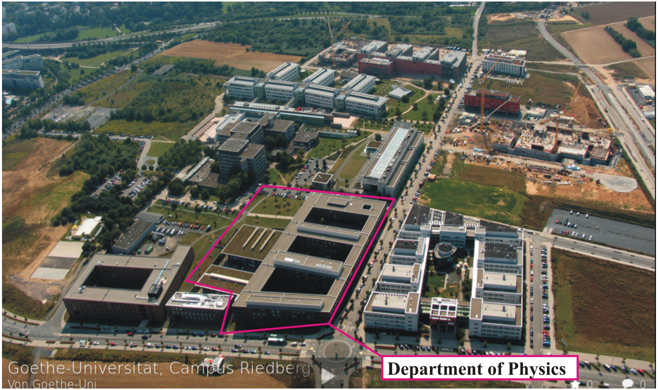
Outline

Natural Sciences Campus

GOETHE UNIVERSITÄT FRANKFURT AM MAIN



Institute of Applied Physics - **IAP**

executive director: Prof.Dr.Podlech

Prof.Dr. Holger Podlech
LINACS, NC & SC, RFQs

Prof.Dr. Ulrich Ratzinger
LINACS, RFQs, IonSources & NNP

Prof.Dr. Oliver Kester
FAIR@GSI, Director

Prof.Dr. Rene Reifarth
Experimental Nuclear Astrophysics

Prof.Dr. Joachim Jacoby
Plasma Physics

Prof.em.Dr.Alwin Schempp
RFQs

IAP is one of the leading laboratories for low and medium energy hadron accelerators with in total **140 members** including Postdocs, PhD, Ma & Ba Students & Technical Employees

Collaborations in Accelerator Technology

- TECHNISCHE UNIVERSITÄT DARMSTADT
- BROOKHAVEN NATIONAL LABORATORY
- Fermilab
- CERN
- HIT Heidelberger Ionenstrahl-Therapiezentrum
- SIEMENS
- LANZHOU UNIVERSITY 1909

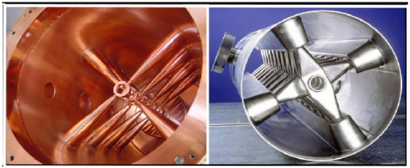
LINAC Research & Development

IH-Structure 100 MHz for BNL, 13 MV

Interdigital **H**-Mode-Structure
H111-Mode
Efficient DTL-structures for the low and medium energy range

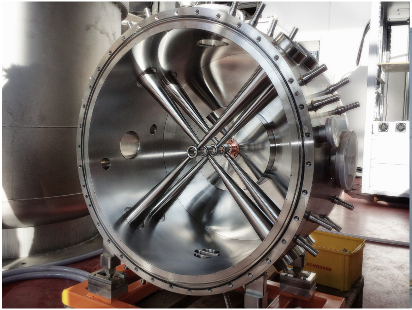
LINAC Research & Development

Crossbar **H**-Mode-Structure



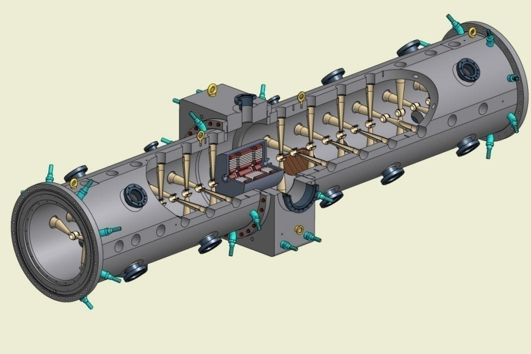
H211-Mode

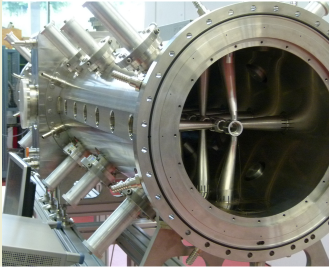
175 MHz CH-Rebuncher



LINAC Research & Development

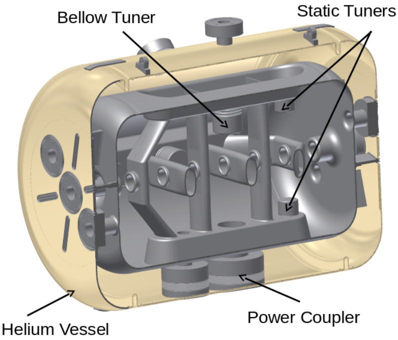
FAIR Proton-Injector
325 MHz 70 MeV 70 mA



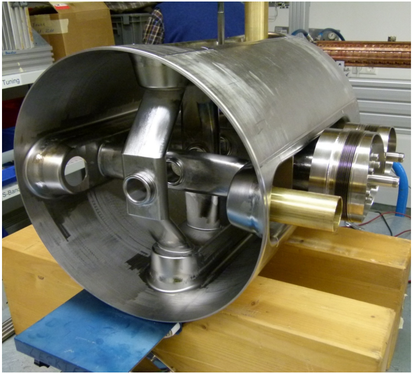


LINAC Research & Development

Superconducting
325 MHz CH-Cavity

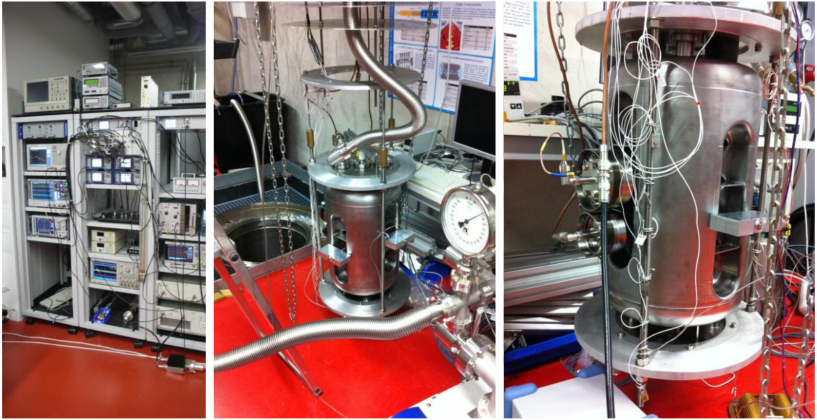


Prototype



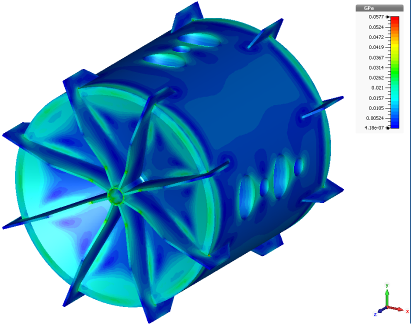
LINAC Research & Development

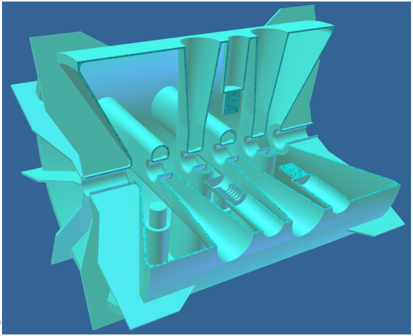
Cryogenic Prototype Testing



LINAC Research & Development

SC 176 MHz Cavity $\beta = 0.096$ for the **MYRRHA** Injector



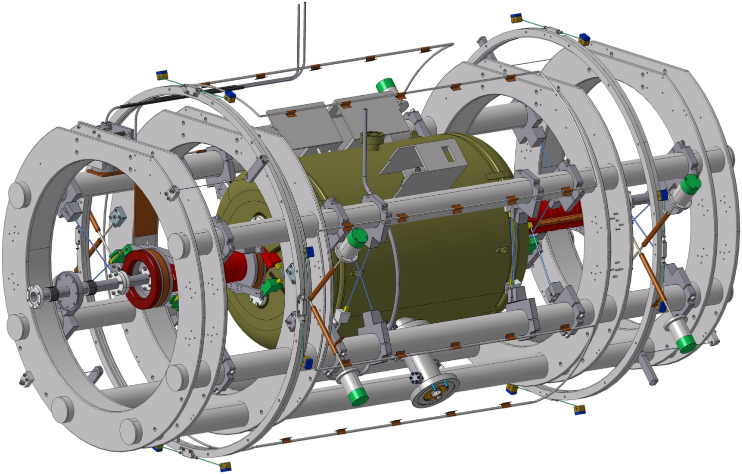


special design due to mechanical stress

LINAC Research & Development

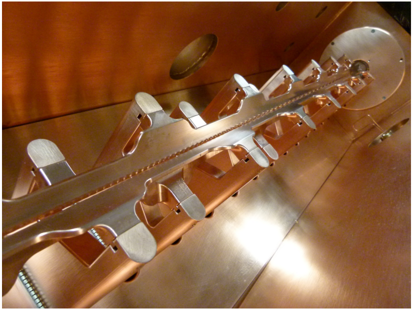
Cold mass of SHE cw-LINAC at GSI

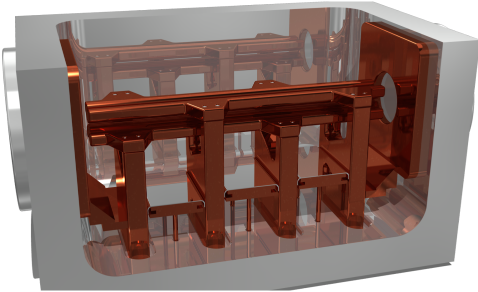
$216\,\mathrm{MHz}\ \beta = 0.059$



RFQ Research & Development

4-rod type RFQs
Fermilab 200 MHz RFQ

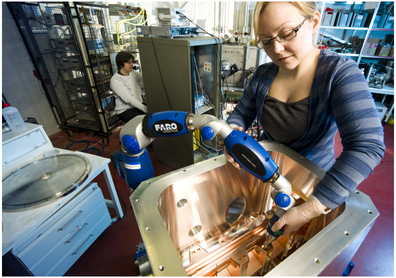


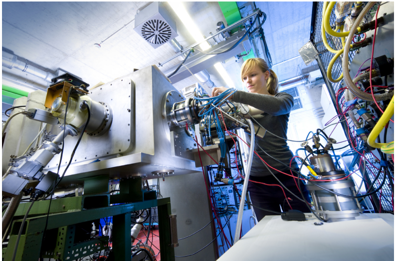


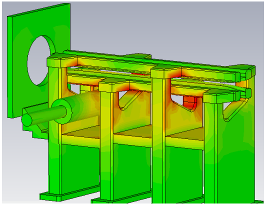
High Power RFQ
for FRANZ & MYRRHA
176 MHz Goal: $P > 50\,\mathrm{kW/m}$

RFQ Research & Development

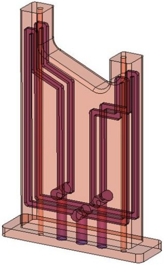
Adjustment, Testing and Commissioning







High Power Cooling



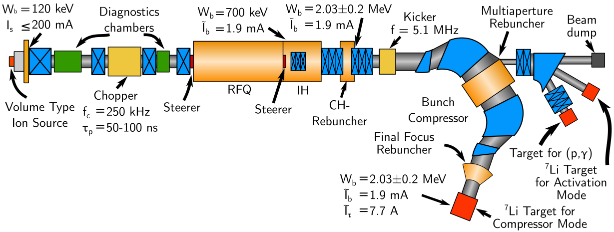
Present Projects

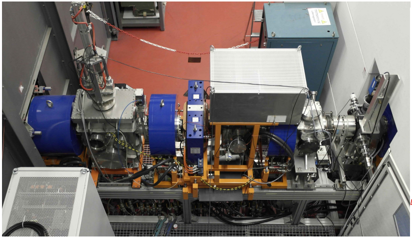
- **MYRRHA** 17 MeV Injector (responsible), protons, cw operation, NC and SC, 176 MHz
- **FAIR** proton Linac, 70 MeV, 70 mA, 325 MHz
- superconducting cw heavy ion linac at **GSI**, 5-6 AMeV, 217 MHz
- High Charge Injector **GSI**, cw operation, 108 MHz
- High Current Injector **GSI** 36 MHz
- HTL (H-Mode Test Linac), 108/217 MHz, focussing with plasma lenses, 1 AMeV ^{4}He
- Beam Funneling at IAP Frankfurt
- **FRANZ**, 2 MeV protons, cw operation, 2-200 mA, 175 MHz
- High Current Low Energy Figure-8 Storage Ring, **F8SR**

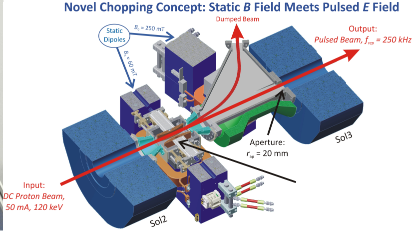
Achievements

- 50-60 RFQs have been built and put into operation all over the world:
  GSI, BNL, Fermilab, Japan, HZB Berlin, Lyon, HIT, MedAustron, SARAF, MSU, Dubna, DESY, ...
- more than 30 IH-DTL-Linacs:
  GSI, CERN Linac-3, BNL, Munich, REX-ISOLDE, HIT, FRANZ, Dubna,...

FRANZ Project
Frankfurt Neutron Source at the Stern-Gerlach-Zentrum

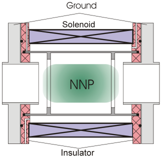


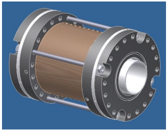




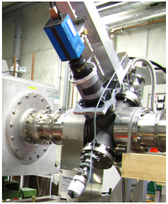
Non Neutral Plasma Group - **NNP**

- Beam focussing with Garborlenses via electron clouds





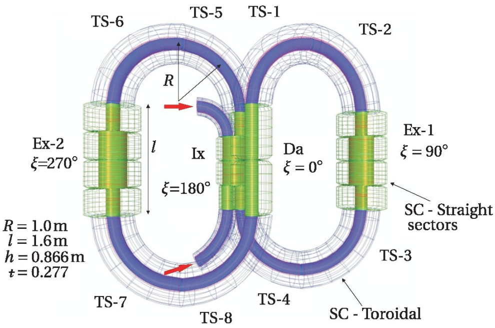
- Beam diagnostics, such as non destructive 180°CCD scan of residual gas

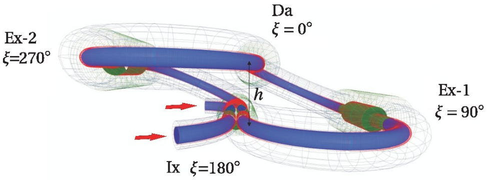


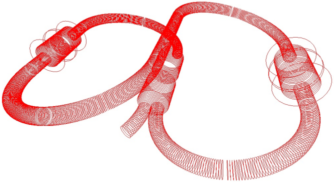
- High current beam physics and space charge effects
- Code development such as *BENDER* and *tralitrala*

Superconducting High Current Ion Storage Ring **F8SR**

- Magnetostatic $|\vec{B}| \approx 6\,\mathrm{T}$
- Beam Energy: $W = 150\,\mathrm{keV}$-$1\,\mathrm{MeV}$
- Beam Current: $I =$ 1-10 A
- Orbital revolution period: $T = 2\,\mu\mathrm{s}$
- Stored Beam Energy & Power:
  $E = 3\,\mathrm{J}$
  $P_{\max} = 1.5\,\mathrm{MW}$







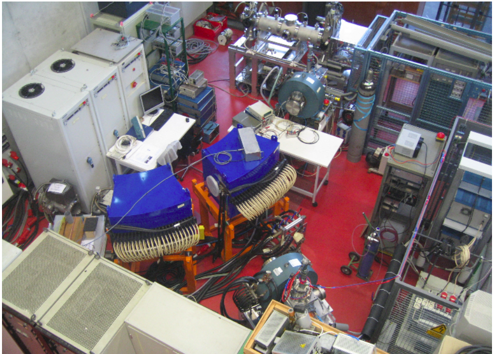
Why to build a new and such crooked Storage Ring - Motivation:

- Fusion reactivity studies in a *High Current Mode* such as p $+ {}^{11}$B $\rightarrow$ 3 ^{4}He $+$ 8.7 MeV
- multiple beam & particlespecies experiments in *Collider Mode* down to center of mass collision energies of 100 eV
- space charge compensation by magnetic surface bounded secondary electrons
- multi ionisation of light atoms by an intense proton beam
- beam plasma interaction
- coulomb screening effects

F8SR Experiments - Setup

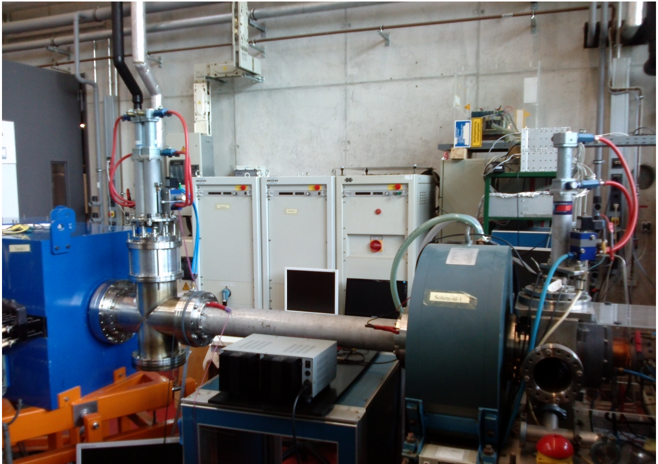
Two 30° Toroids, $B_{max} = 0.6\,\mathrm{T}$
Two refurbished injectors, each with:

- terminal, $U_{max} = 20\,\mathrm{kV}$
- volume source, $I \approx 3.4\,\mathrm{mA}$ hydrogen mix, max 50% protons
- faraday-cup + solenoid, $B_{max} = 0.72\,\mathrm{T}$



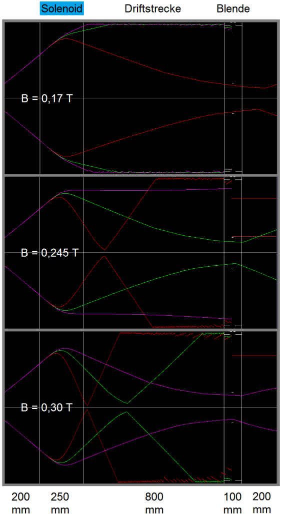
F8SR Experiments - Momentum-Filter

- Design and construction of a magnetic **Momentum-Filter** for different hydrogen species (H^+,H_2^+,H_3^+)

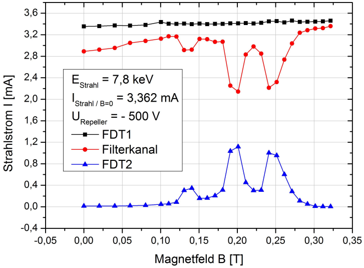


F8SR Experiments - Momentum Filter

Simulations of hydrogen species H^+, H_2^+, H_3^+ with *LINTRA*

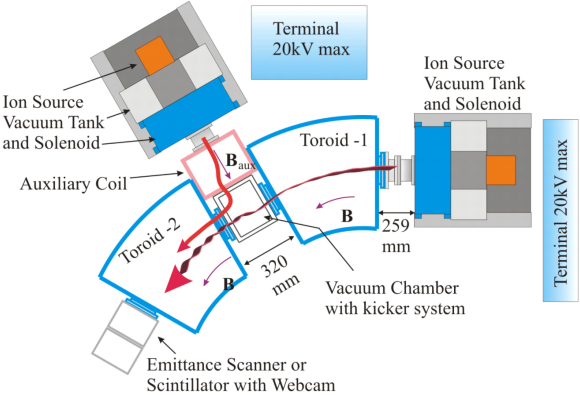


Measurements:
beam current in Faraday-Cups
FDT1: in front of solenoid
FDT2: behind filter-aperture
filterchannel: grounded via ampèremeter, $I \sim$ losses



F8SR Experiments - Injection

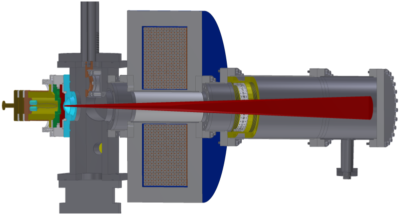
Injection simulations to determine air-core-coil parameters done (sim.-code *segments*). $B = 0.2 - 0.3\,\mathrm{T}$
Coil-design and construction is upcoming.

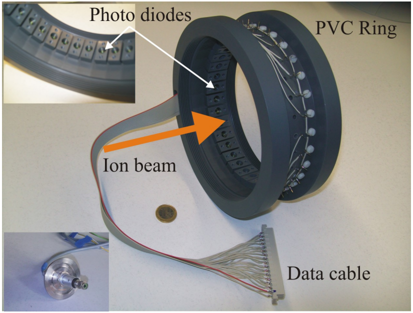


F8SR Experiments - Diagnosis

Non invasive beam diagnosis via residual gas monitor in high magnetic fields

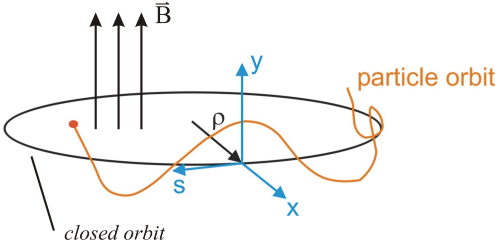
- movable ring of azimutal photodiodes for visible light



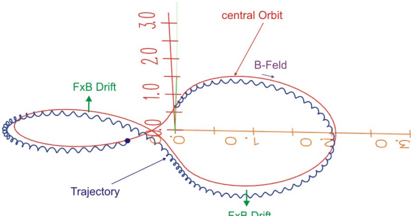


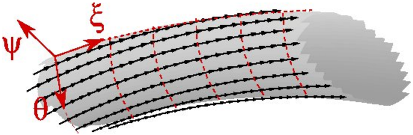
Theory & Simulations - Closed Orbit Studies

Traditional Rings, focussing & corrections → Dipole, Quadrupoles



F8SR → Guiding-Fields



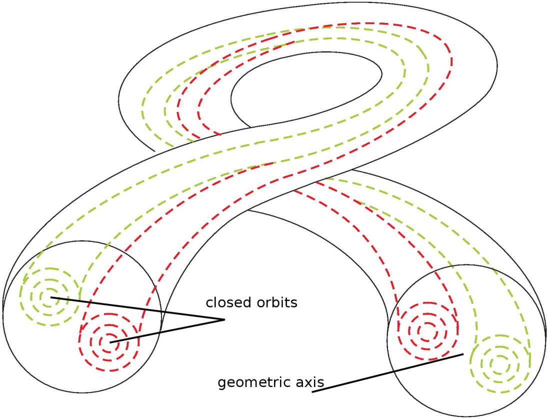


Complex magnetic field geometry inhibits traditional transport description via matrices & fixpoints

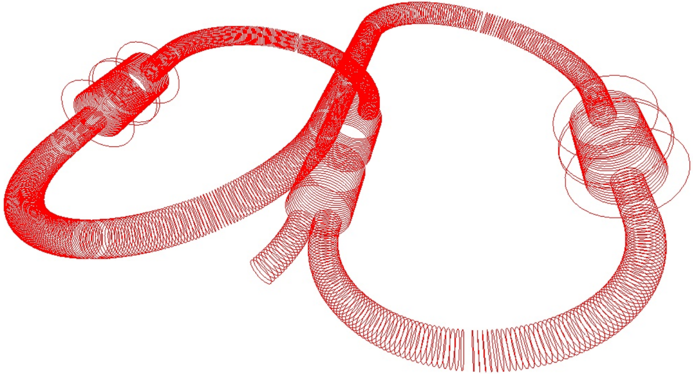
→ find analogous description to interlink
In magnetic coordinates (Boozercoordinates) ψ,θ,ξ
→ canonical variables for Drift-Hamiltonian:

- fixpoint studies with multipole expansion within the fieldmap are ongoing
- conventional 2d multipole expansion investigations do not satisfy the complex field geometry

Trajectories (drift surfaces) of two reverse beams



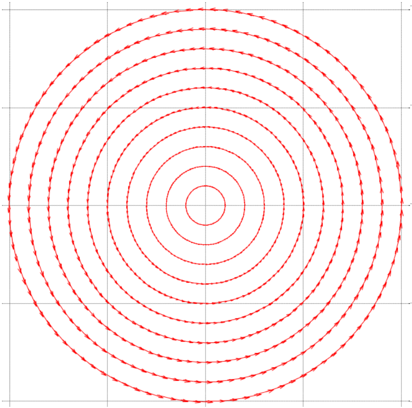
Field Imperfections & Error Studies

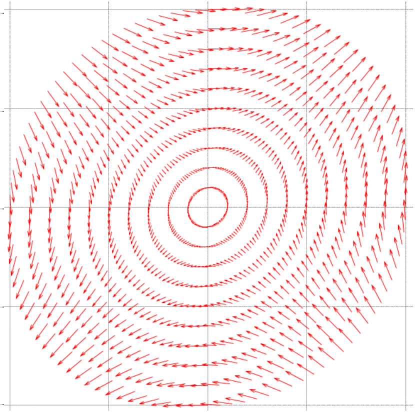


Construction always has coil missalignment $\rightarrow$ interfering multipole fields

Since $\vec{B}$ has components: $B_\psi = 0$, B_ξ, B_θ

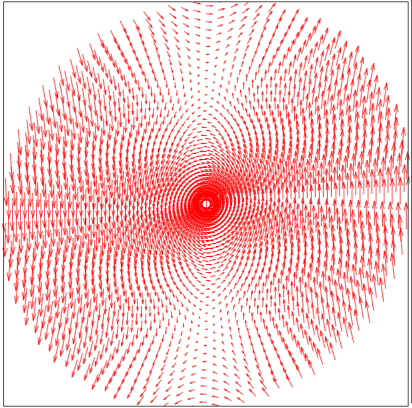
Superposing a **poloidal** (B_θ) and **multipole** field. What do we get?



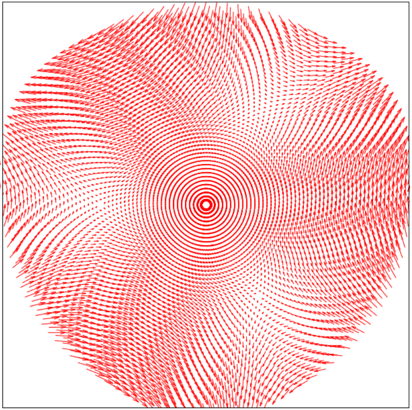


One obtains points with $|B| = 0 \rightarrow$ analytically solvable

poloidal + quadrupole
$\rightarrow$ Quadrupoles around $|B| = 0$
Poloidal around center area

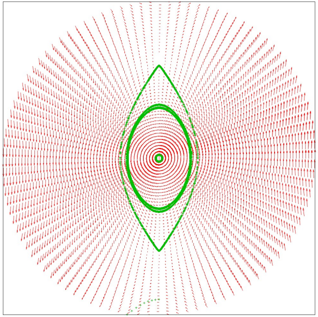


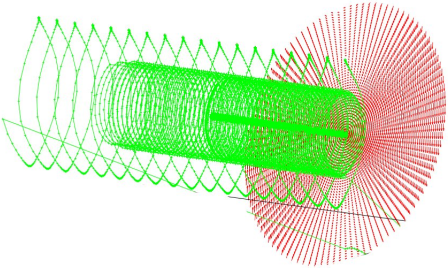
poloidal + sextupole



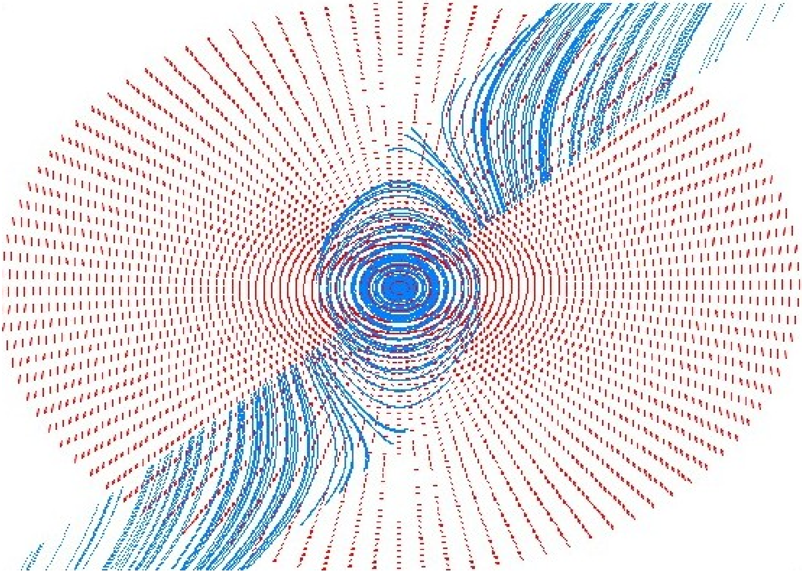
Influence on particle transport?

Simulations with $\hat{B}_\theta = \hat{B}_\mathsf{q} = 0.1\%\hat{B}_\xi$

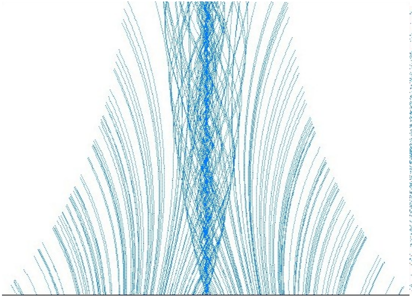




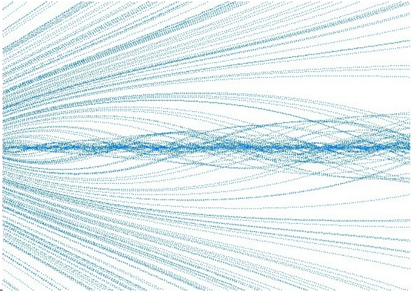
front view



top view



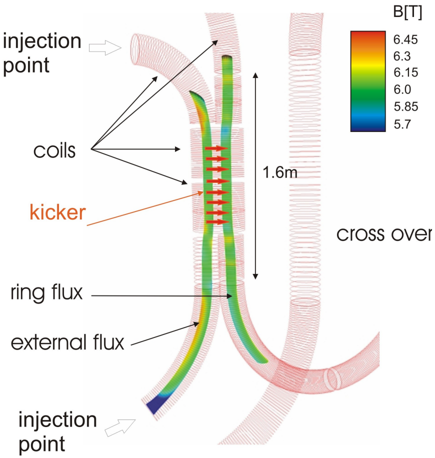
side view



$\rightarrow$ certain aperture at a specific slice
$\rightarrow$ dynamic aperture along the ring axis
Acceptance of the confinement area is reduced
$\rightarrow$ areas of particle loss

Injection via Adiabatic Compression

Concerning the canonical momentum
$\vec{p} = m\vec{v} + q\vec{A}$
even if $\vec{v} \| \vec{B}$ at injection point one obtain
$\Delta\vec{A} \rightarrow \Delta\vec{v}$ during entering
$\rightarrow$ radius of acceptance
$r = \frac{2mv_{\|}}{qB}$
$r\big|_{B\,=\,6\,\mathrm{T}} = 8\,\mathrm{mm}$

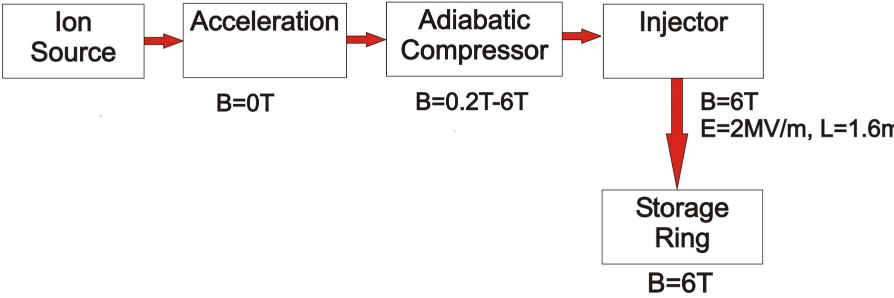


Injection via Adiabatic Compression

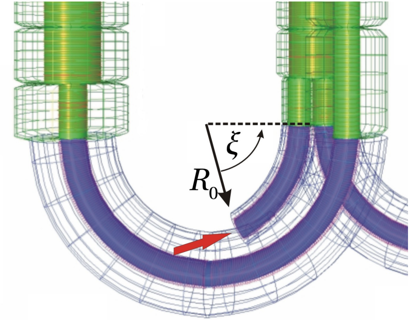
- the facing problem is a smooth field transition

magnetic moment $\mu = \frac{mv_\perp^2}{2B}$ must be constant
$\rightarrow$ adiabatic invariant

$$\frac{\mathrm{d}B}{\mathrm{d}t} = \underbrace{\frac{\partial B}{\partial t}}_{=0} + v_z \frac{\partial B}{\partial z} < B\frac{\omega_c}{2\pi} = \frac{qB^2}{2\pi m} \rightarrow v_z \frac{\Delta B}{\Delta z} < q\frac{B^2}{2\pi m}$$

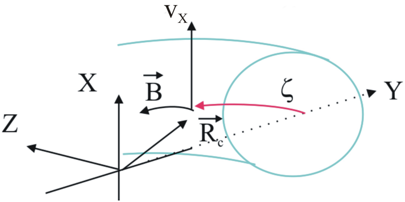


Injection via Adiabatic Compression



due to the gradient $\frac{\Delta B}{\Delta s} \rightarrow B(x, y, z) \rightarrow B(\xi)$

Injection via Adiabatic Compression



$$\vec{v}_{\mathrm{d}} = \frac{1}{q}\frac{\vec{F}\times\vec{B}}{B^2} \qquad \vec{F}_{\mathrm{c}} = \frac{mv_{\parallel}^2}{R_{\mathrm{c}}} \rightarrow \vec{v}_{\mathrm{d}} = \frac{mv_{\parallel}^2}{qB^2}\frac{\vec{R}_{\mathrm{c}}\times\vec{B}}{R_{\mathrm{c}}^2}$$

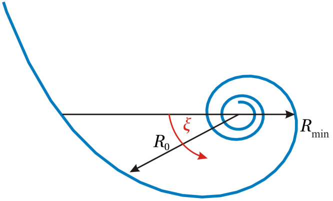
drift velocity coming from $R \times B$ drift

$$v_x = \frac{mv_{\parallel}^2}{qB(\xi)R}$$

$v_x \overset{!}{=} \text{const.}$

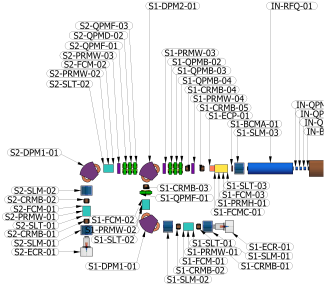
$\rightarrow B(\xi)\cdot R(\xi) \overset{!}{=} \text{const.}$

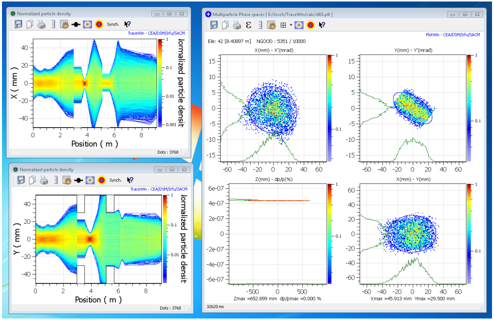
$B(\xi) = a_1 \cdot \xi \qquad R(\xi) = a_2 \cdot \frac{1}{\xi}$



hyperbolic spiral transport channel

Participation in KHIMA Project - Simulations for Errorstudies in the LEBT with TraceWin





[TraceWin - CEA/DSM/Irfu/SACM]

여러분의 관심에 감사드립니다

Thank you for your attention!

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