

# Magnetostatischer Speicherring mit Stellarator-Feldkonfiguration

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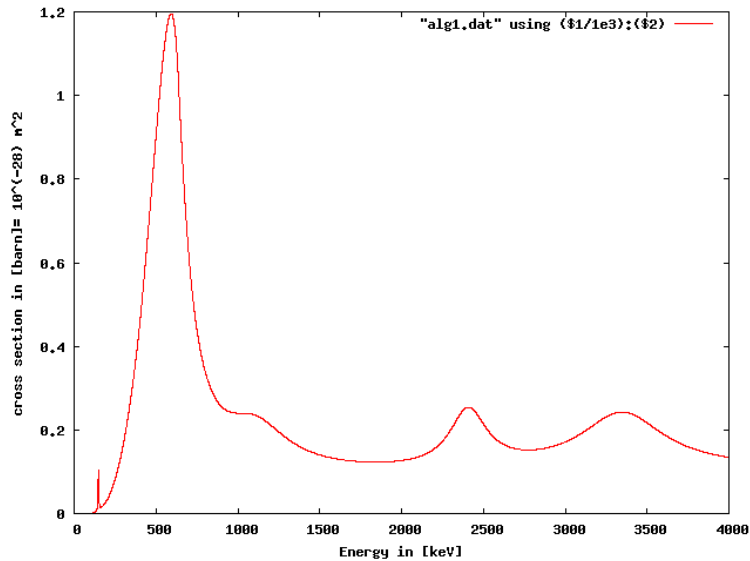
Unter Mitarbeit von: N.Joshi, P. Nonn, O. Meusel, K. Schulte, U.Ratzinger

# Hochstromspeicherring (MSR)

- Speicherringe mit longitudinalem Magnetfeld  
( $W \sim 100 \text{ AkeV} - 1 \text{ AMeV}$ )
- Fusionsquerschnitte
- Mehrteilchenreaktionen – Multispezies
- Sekundärteilchenspeicherung
- Multi-Ionisationsprozesse von leichten Atomen bei Wechselwirkung mit intensiven niederenergetischen Protonenstrahlen
- Raumladungskompensation – Restgaselektronen  
Elektronenstrahl
- Strahlkühlung, Kristalline-Strahlen



# $^{11}\text{B} + \text{p}$ Reaction

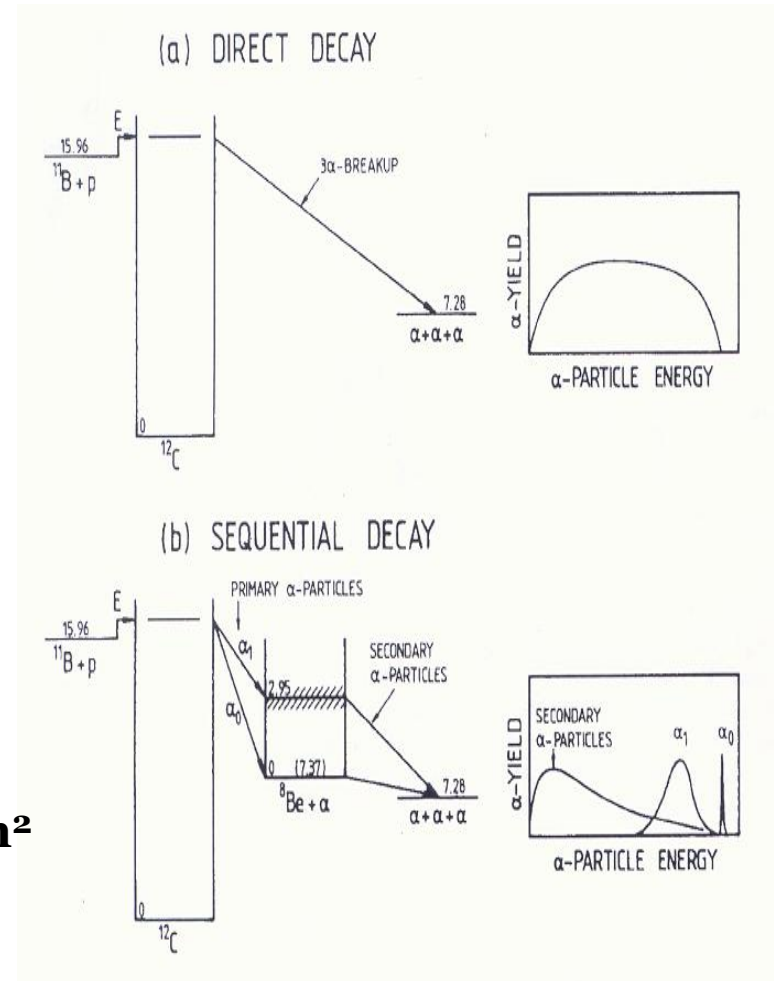


## Fusionsreaktion



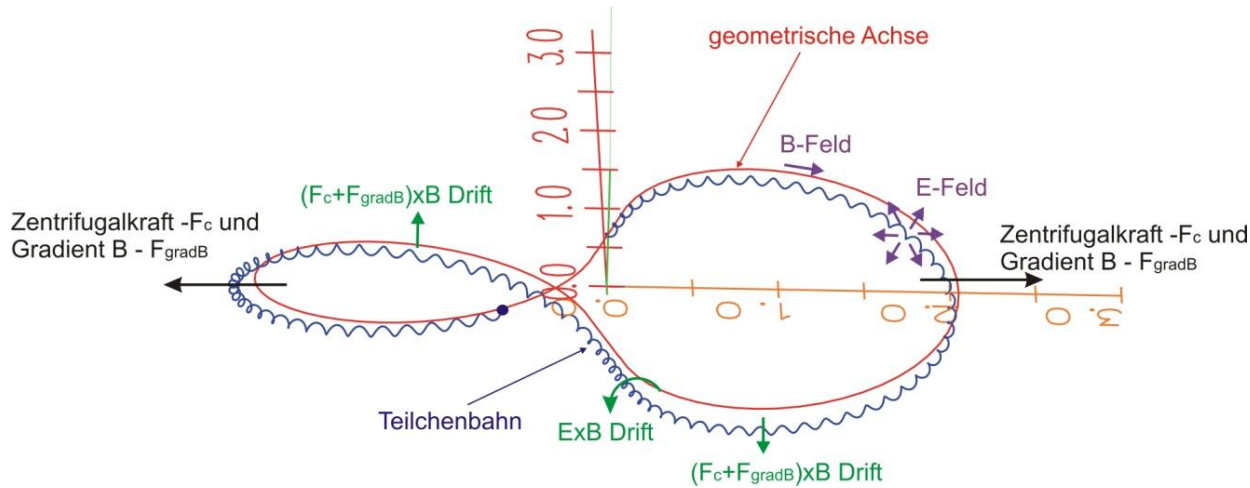
$$\text{Reaktionsquerschnitt } \sigma_{\text{max}} \sim 10^{-28} \text{ m}^2$$

Relaxationsprozesse – Strahl zur NNP

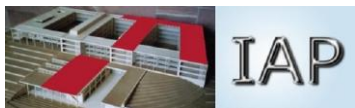
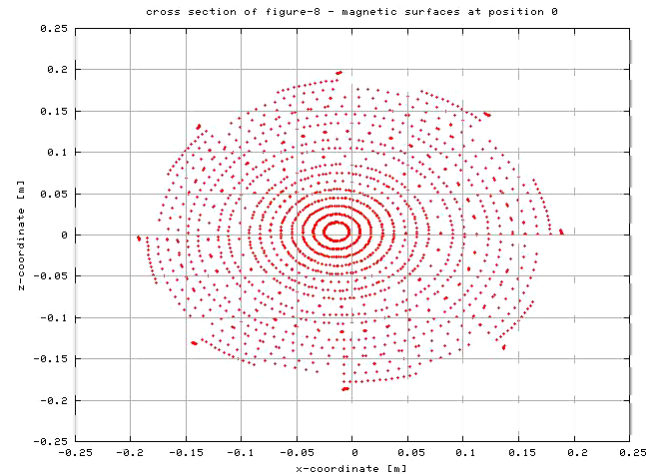
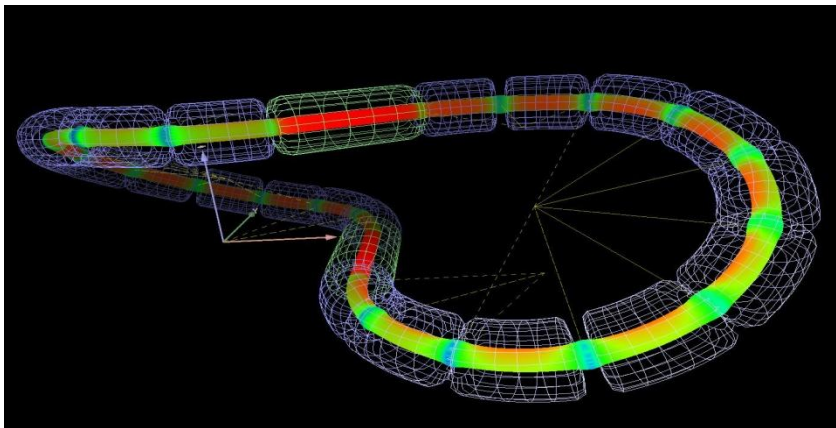


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# Figure-8 Hochstromspeicherring

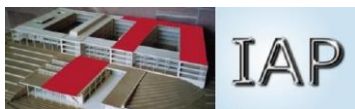


- **$R \sim 1\text{m}$**
- **$r \sim 0.15\text{m}$**
- **$L \sim 10\text{m}$**
- **22 Segmente**
- **$h \sim 1\text{m}$**
- **$B \sim 5\text{T}$**
- **$I \sim 10\text{A}$**



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Zyklotronfrequenz $\omega_c$ [ $s^{-1}$ ] @5T	$4.8 \cdot 10^8$
Brillouin-Limit $n_B$ [ $m^{-3}$ ]	$6.6 \cdot 10^{16}$
Strahlradius $a$ [m]	$>0.02$
Debye-Länge [m]	$3 \cdot 10^{-4}$
ExB Rotationsfrequenz [s]	$5.2 \cdot 10^{-10}$
UHV ( $n \sim 10^{12} m^{-3} \sim 4 \cdot 10^{-11} hPa$ ) Stoßfrequenz $\tau_c$ [s]	12.5
NNP Einschusszeit in toroidalen Magnetfeldern (Crooks 1994)	$\tau \approx \tau_c \cdot (R/\lambda_D)^2$
NNP Einschusszeiten auf magnetischen Flächen (Pedersen 2003)	$\tau \approx \tau_c \cdot (a/\lambda_D)^4$

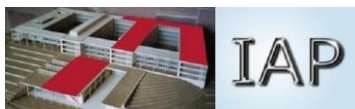


# Simulationsprogramme

- **Magnetfeld – Biot-Savart solver**  
(Predictor-Corrector method, Field-line integration –1D information)
- **Frequenzdekomposition – FFT (1D => 2D)**
- **Generierung von numerischen Gitter – in Clebsch-Koordinaten**  
 $\psi \in [0, 1], \theta \in [0, 2\pi], \xi \in [0, 2\pi]$
- **Poissongleichung (PIC – Particle in cell)**
- **Bewegungsgleichungen in Guiding-center-Koordinaten**

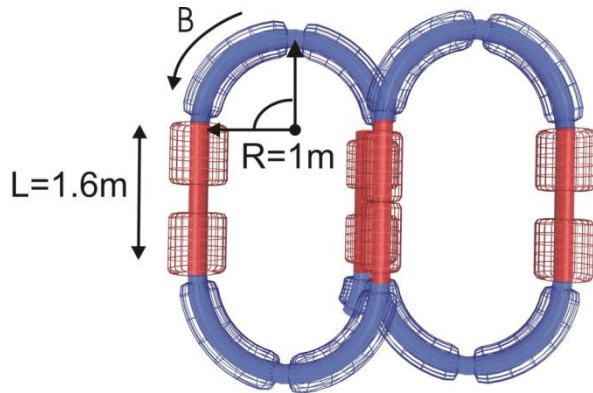
**Parallele Rechnercluster CSC (Centre for Scientific Computing)** <http://www.csc.uni-frankfurt.de>

**Bis zu 60 Prozessoren, 10Mio Makroteilchen**



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# F8SR – Strahldynamik in starken gekoppelten Magnetfeldern



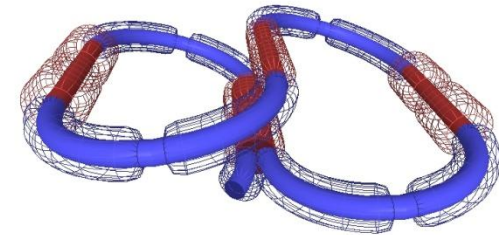
Strahlenergie:  $W_b = 150\text{keV}$

Strahlstrom:  $I = 10\text{A}$

Umlaufzeit:  $t = 2\mu\text{s}$

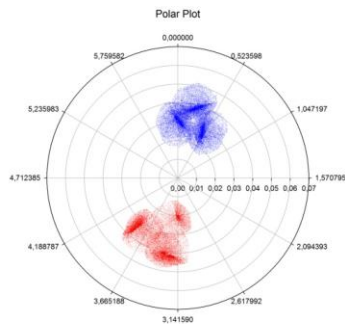
Gespeicherte Energie und Peakleistung

$$E = 3\text{J} \quad \Rightarrow \quad P_{\text{peak}} = 1,5\text{MW}$$



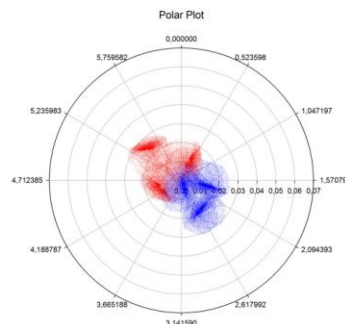
- Rot – Strahl parallel zum B-Feld
- Blau – Strahl antiparallel zum B-Feld

Injektion



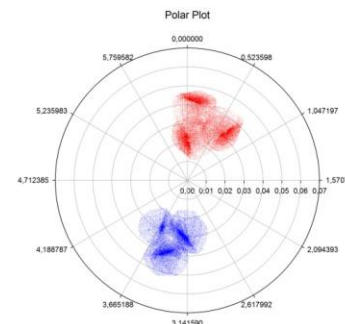
Col 11 vs Col 2  
Col 23 vs Col 14

$\pi / 2$  - Experiment



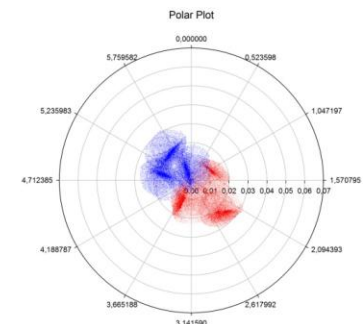
Col 11 vs Col 2  
Col 23 vs Col 14

$\pi$  - Brücke

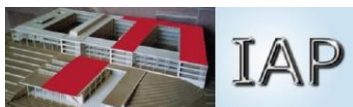


Col 11 vs Col 2  
Col 23 vs Col 14

$3\pi / 2$

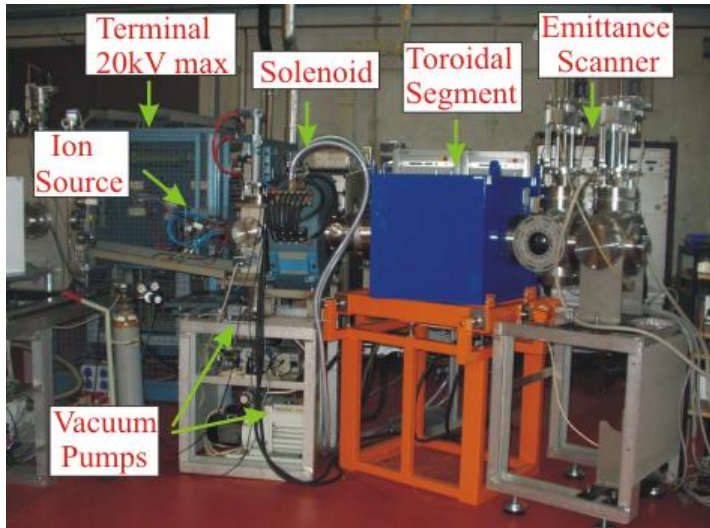


Col 11 vs Col 2  
Col 23 vs Col 14

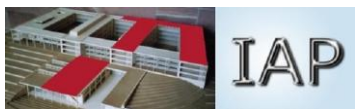
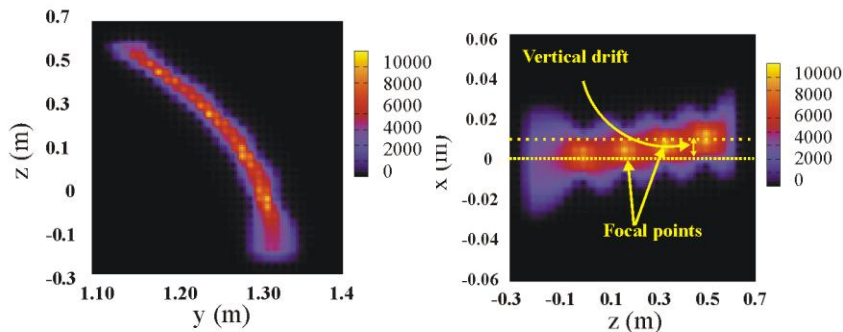
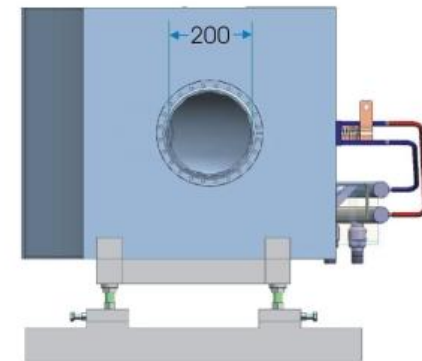
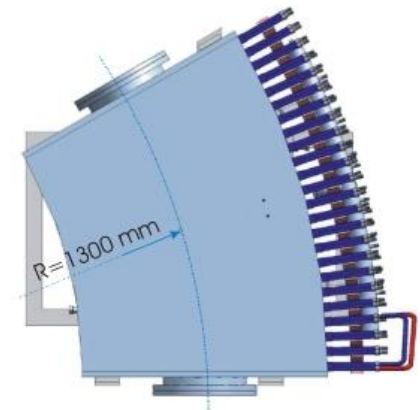


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# Toroidaler Strahltransport - skaliertes Experiment



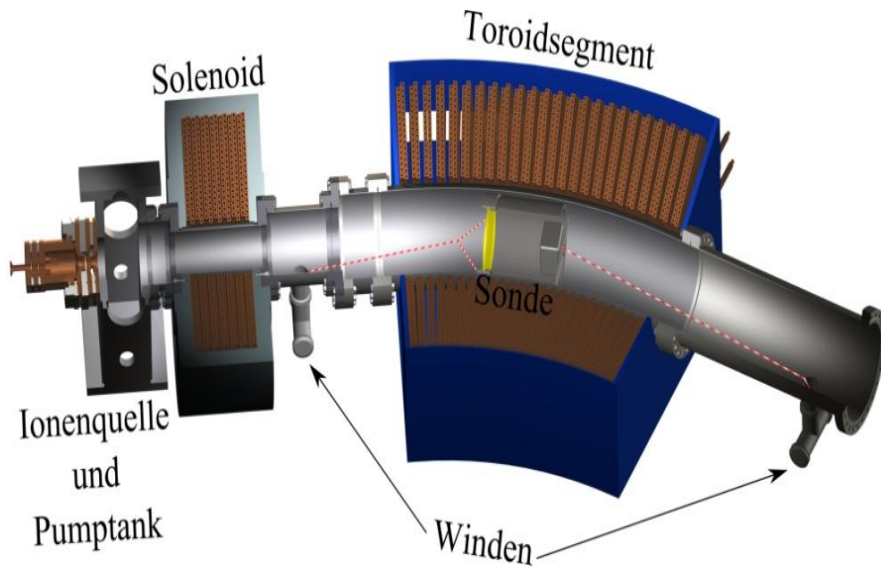
Strahlenergie	2 – 15 keV
Strahlstrom	0 – 5 mA
Ionen	$He^+$ , $p$ , $H_2^+$ , $H_3^+$
$ B _{\max}$	0,6 T
Krümmungswinkel	$30^\circ$
Krümmungsradius	1,3 m



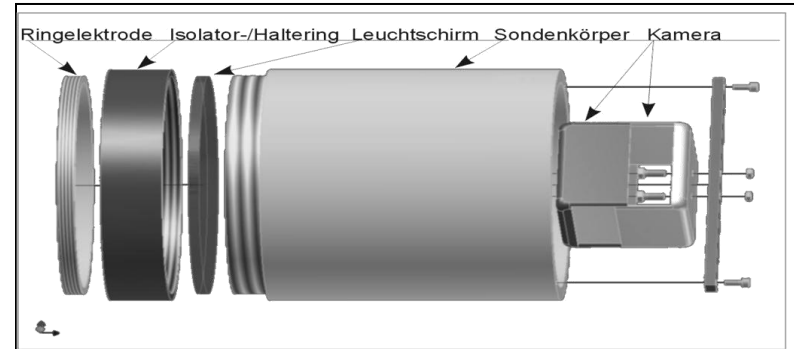
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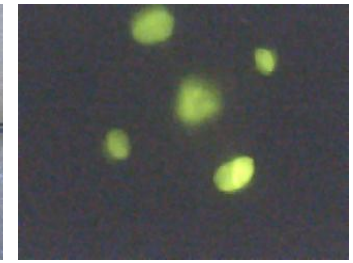
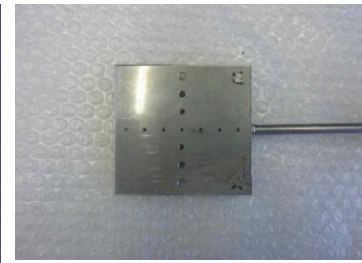
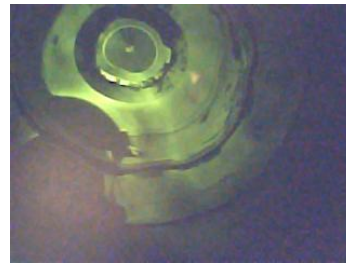
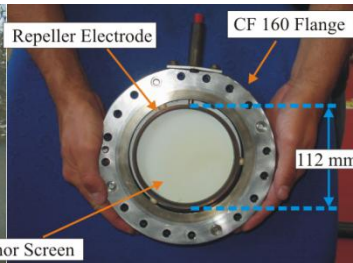
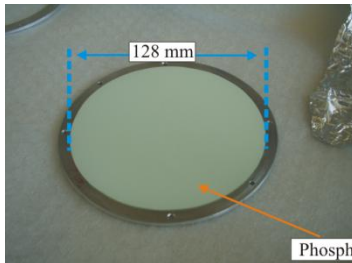
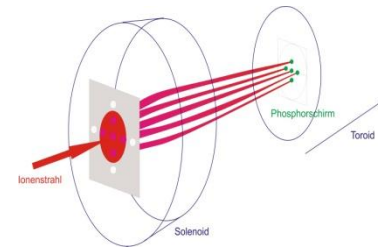
# Optische Strahldiagnose



## Aufbau der Sonde

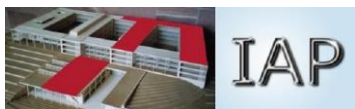
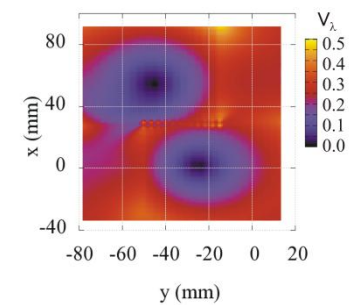
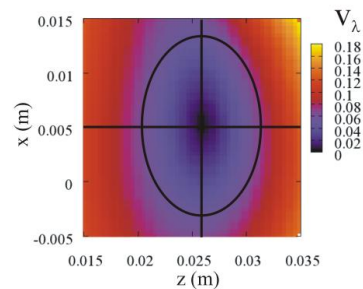
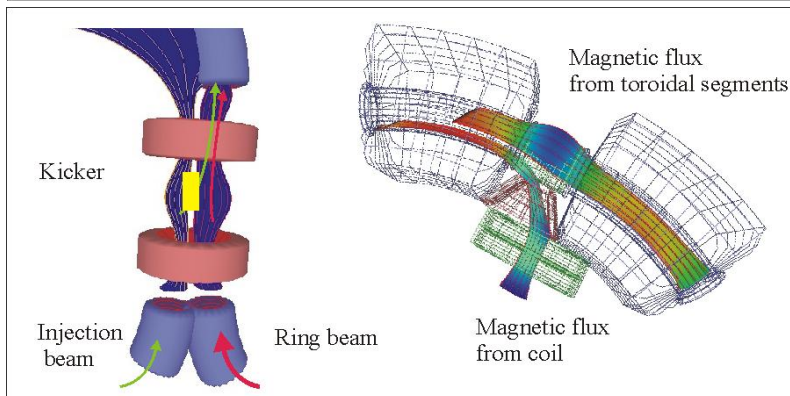
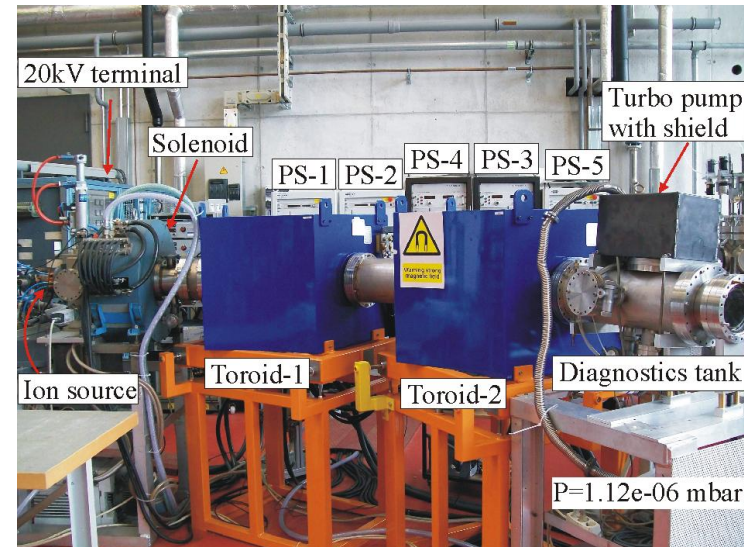
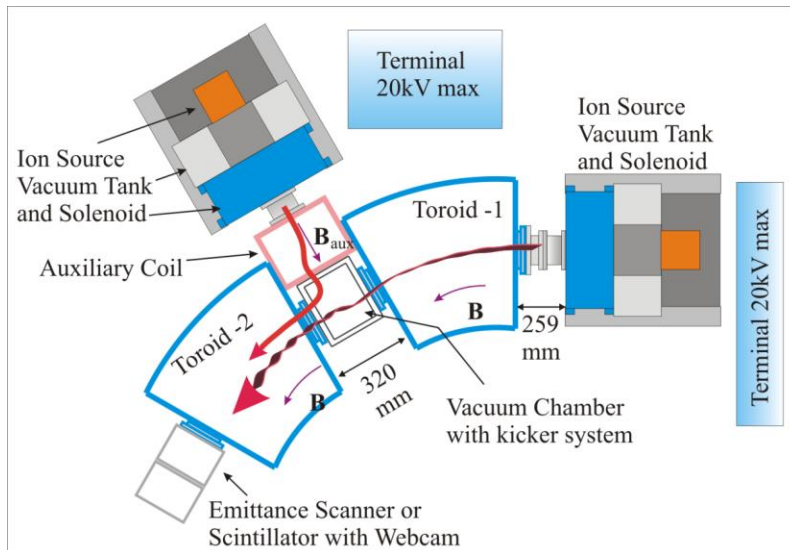


Länge: ca. 220 mm  
 Durchmesser: 180 mm  
 Gewicht: ca. 3 kg  
 Material: Aluminium, PVC



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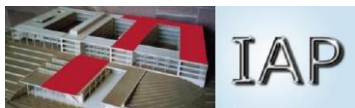
# Injektionsexperiment



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# Ausblick

- Untersuchung von Raumladungskompensation im toroidalen Strahltransport
- Untersuchung von Strahlinstabilitäten
- Aufbau von Injektionsexperiment
- Weiterentwicklung der optischen Strahldiagnose



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