Transport in Toroidal Magnetic field and Injection System

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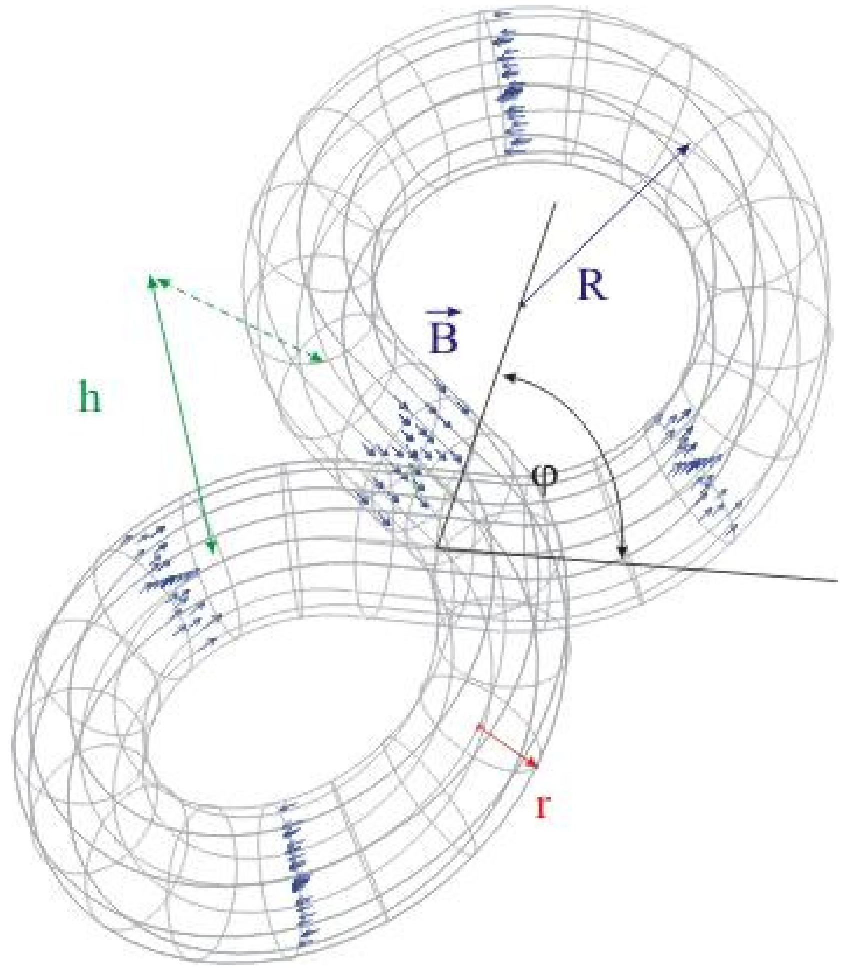
Outline

- Motivation
- Background and Numerical Codes
- Simulations
- Experiments
- Injection System

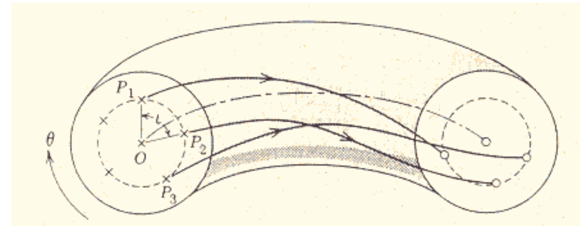
Motivation

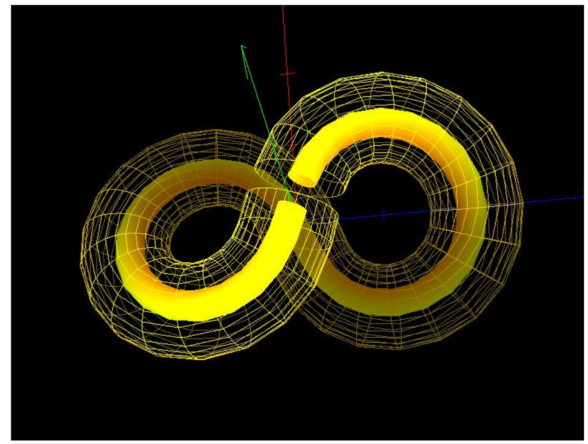
- Storage ring with toroidal magnetic field configuration.
- Transport in toroidal segment.
- Dynamics in Magnetic field with real configuration.
- Injection System

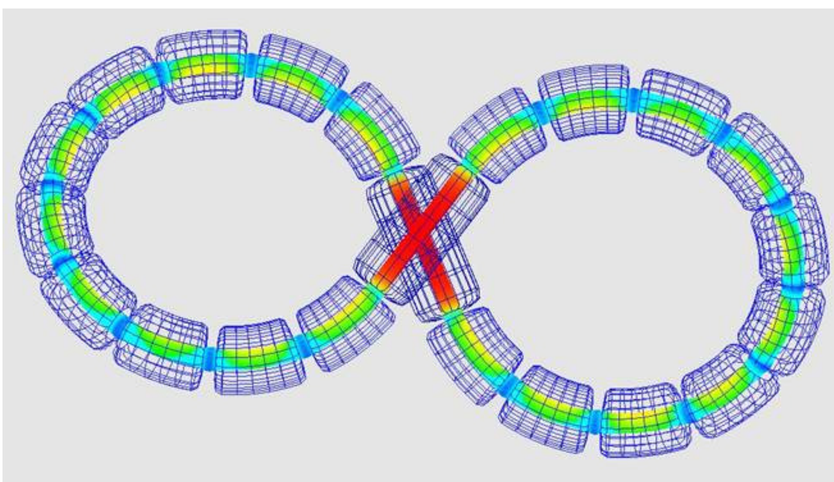


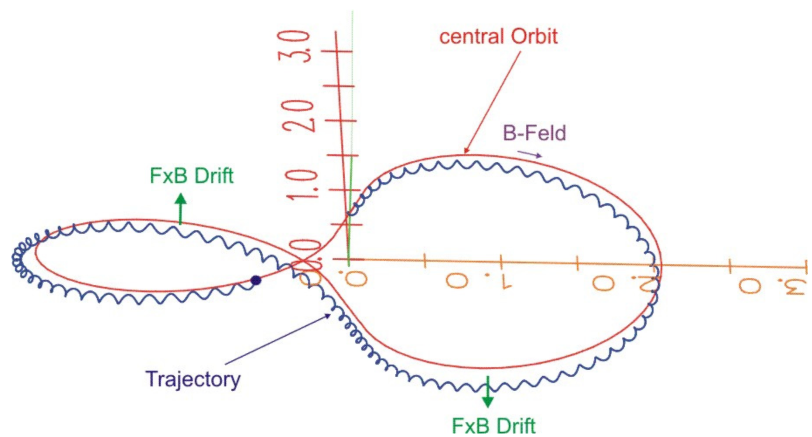
Magnetic Surface

- Figure 8 => first stellarator
- Field line tracing => magnetic surface
- Ring with segments



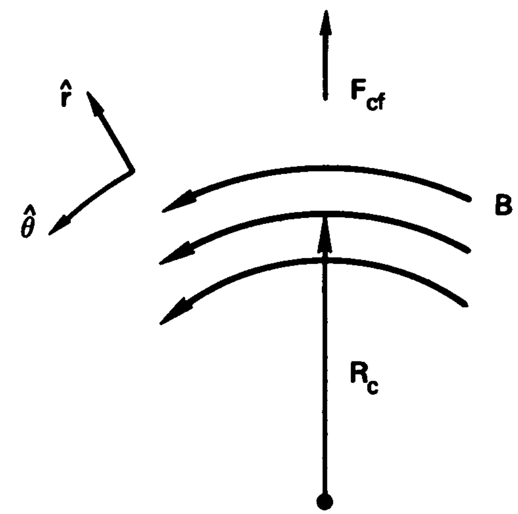






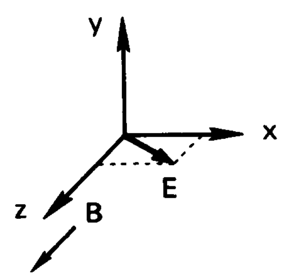
Motion in Magnetic fields

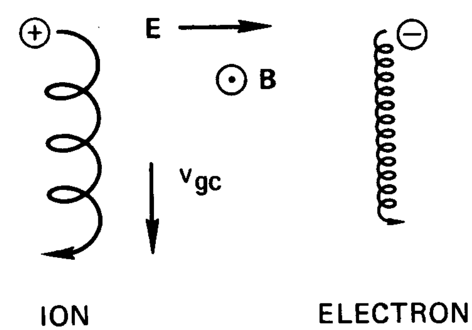
- Charged particles in magnetic field => Gyrating motion.
- When fields are varying the time step is important factor while simulations
- Curvature drift leads losses in vertical direction
- Crossed Electric-Magnetic drift independent of species
- Redistribution of momentum



A curved magnetic field.

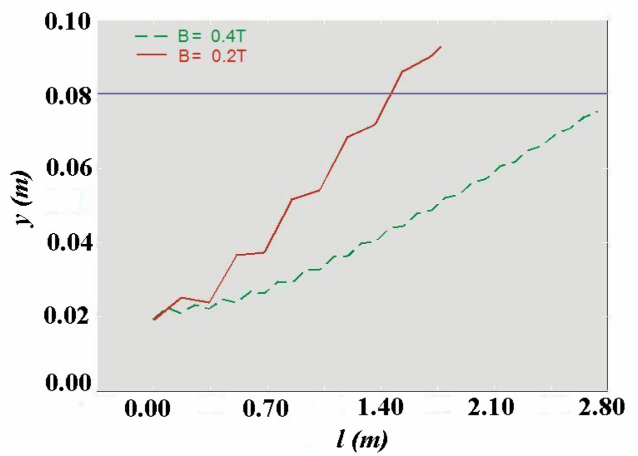
$$r_L \equiv \frac{v_\perp}{\omega_c} = \frac{m v_\perp}{|q| B} \qquad \omega_c \equiv \frac{|q| B}{m}$$





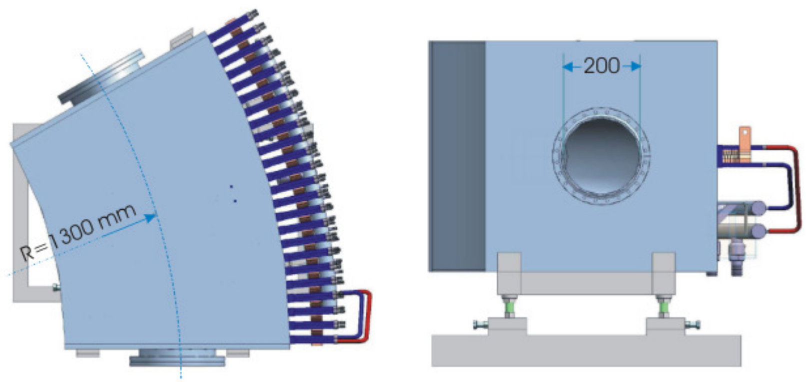
Leads to experiments

- Early simulations showed curvature drift is dominant.
- 20kV Terminal
- Experiments with curved sector magnetic field 0.6T on axis.



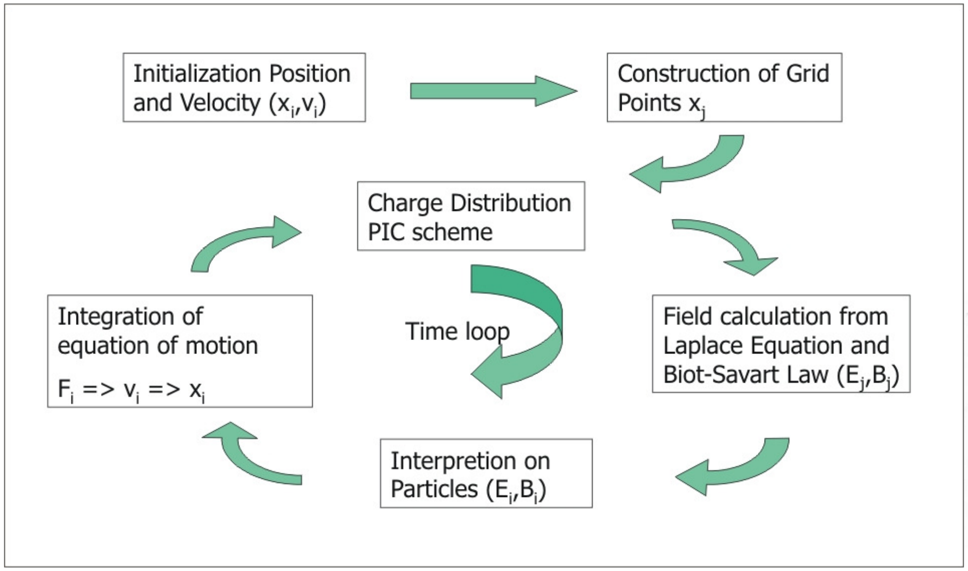
Parameter	Value for pre-experiments @ 20keV	Value for ring @ 150 keV
Longitudinal Velocity (v)	$1.96*10^6$ m/s	$5.36*10^6$ m/s
Major Radius (R)	1.3 m	1.5 m
Magnetic field on axis	0.6 T	1.0 T
Brillouin limit (n_B)	$9.54*10^{14}$ m^{-3}	$2.65*10^{15}$ m^{-3}
Beam current dencity (j)	30 mA/cm^2	225 mA/cm^2
Drift velocity (v_d)	$5.1*10^4$ m/s	$2.3*10^4$ m/s

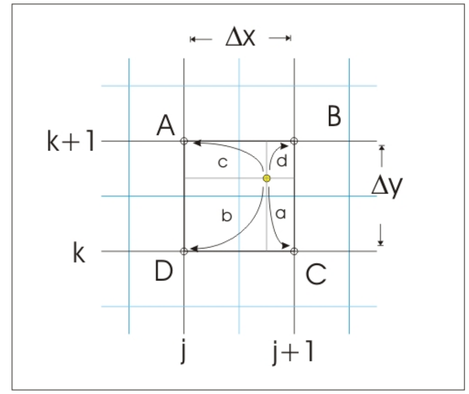
Toroidal Segments



- R=1300mm, r=100mm => CF200
- 24 double layer pancake coils, 33 windings
- 30 degree curved segments (2)
- ~680mm axial length
- 0.6T max at current 480A
- The segments are not shielded with material

PIC method





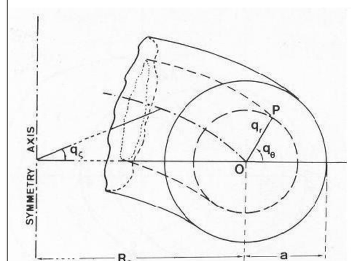


fig.1(a):Toroidal Coordinate System

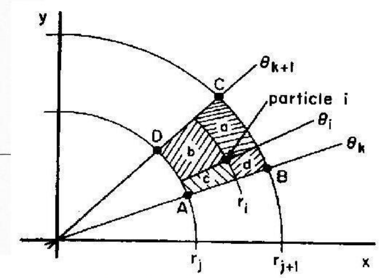
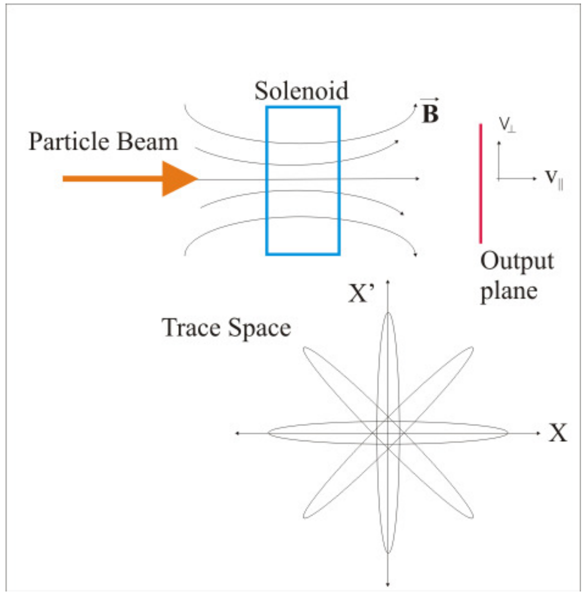
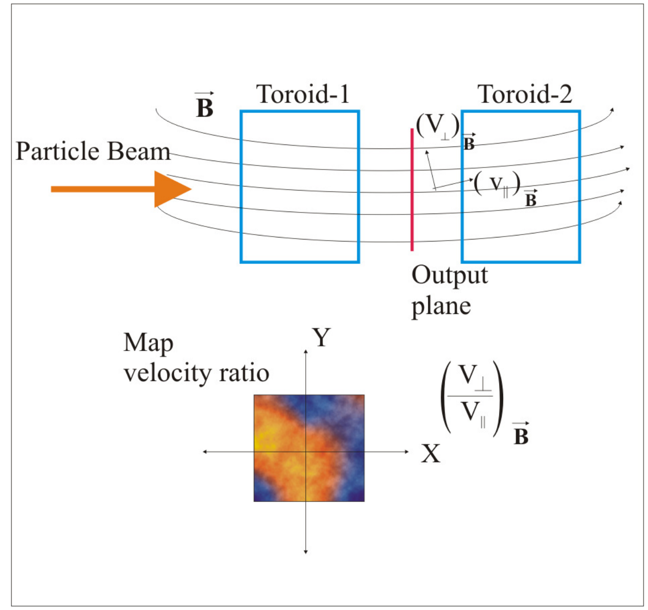


fig.1(b):charge distribution

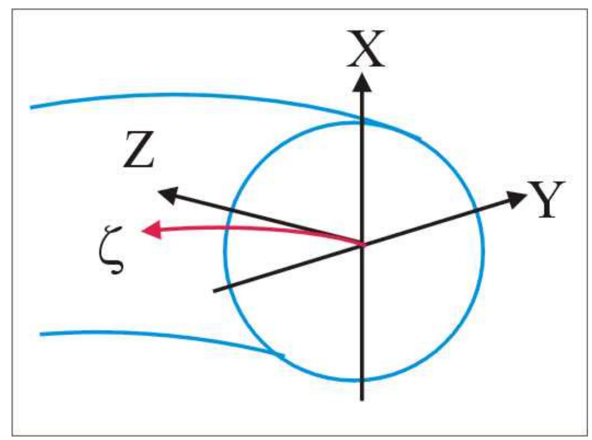
- Toroidal Geometry => r,θ,ξ right handed system
- Poisson Equation with toroidal boundary
- FDTD for equation of motion
- 10,00,000 particles can be simulated on CSC cluster
- Grid Points 50*50*180

Definitions

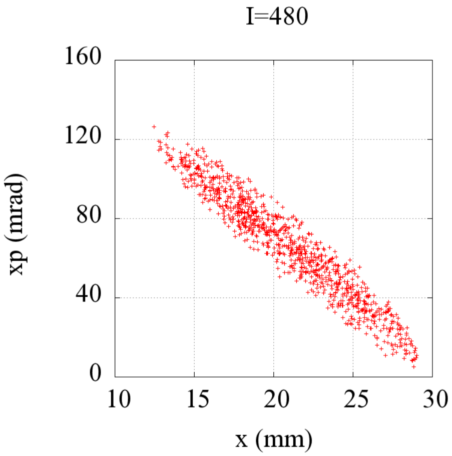


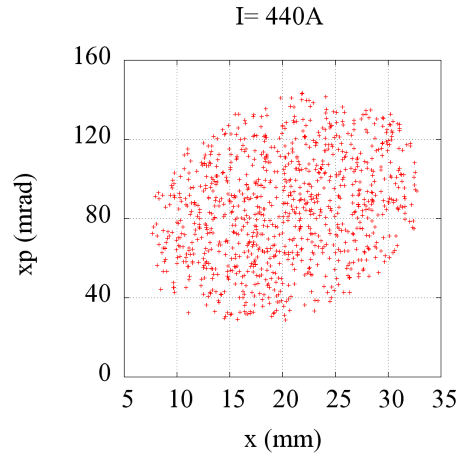


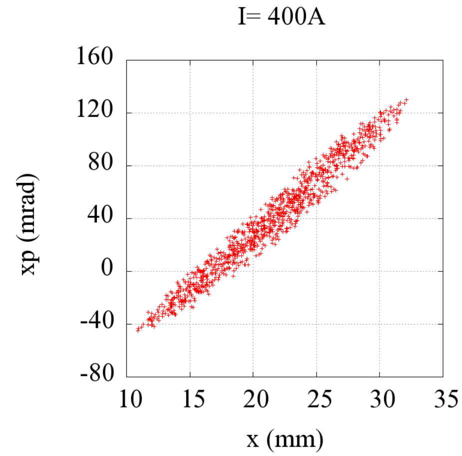
- Velocity ratio = $v_\perp/v_\parallel$
- Right handed co-ordinate system
- $v_\parallel$ taken parallel to **B**
- Low velocity ratio => smaller Larmour radius

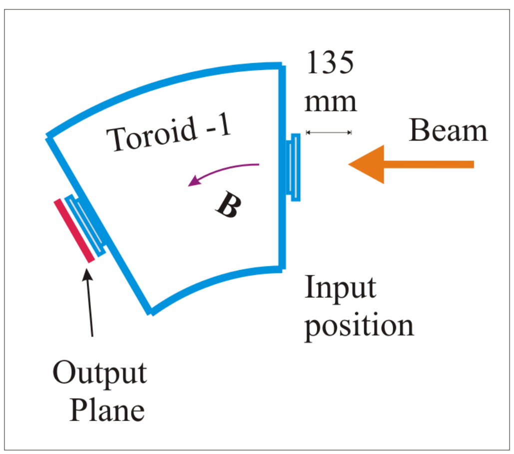


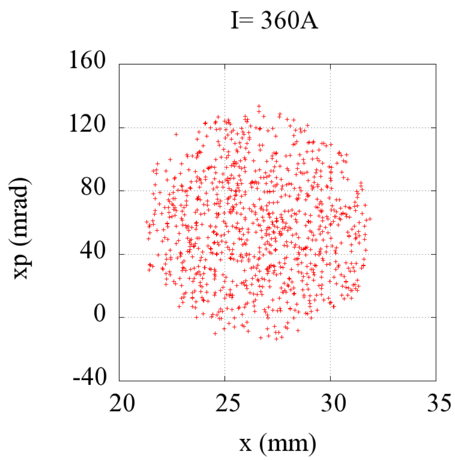
Variation in B-field

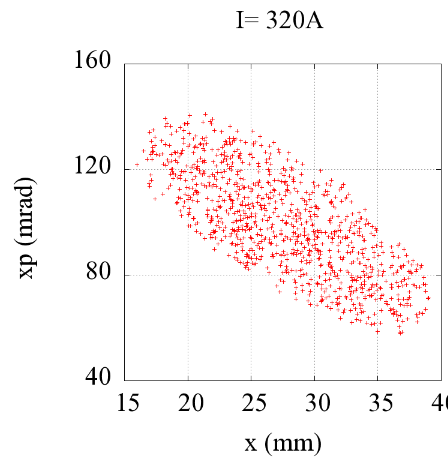






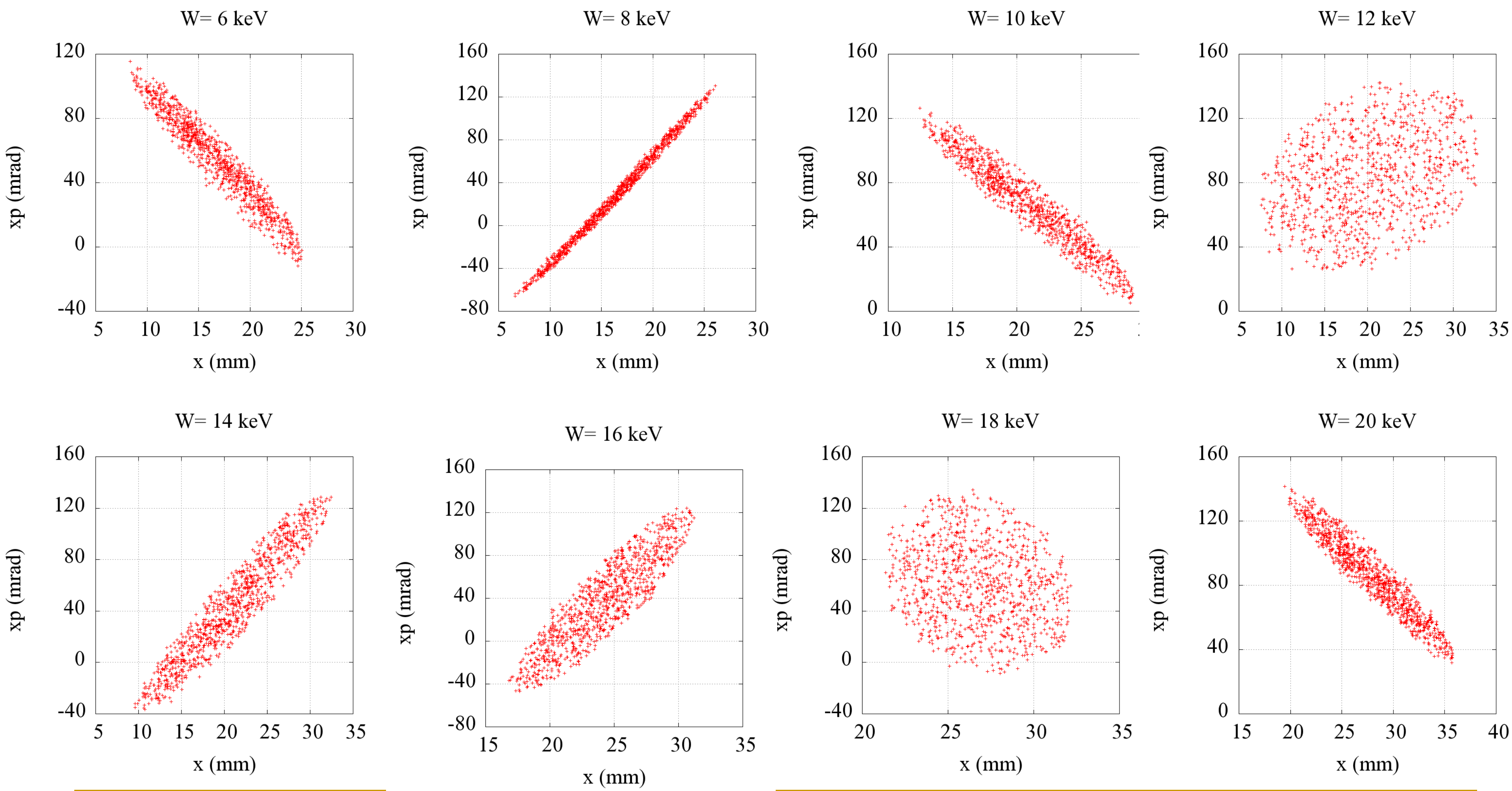




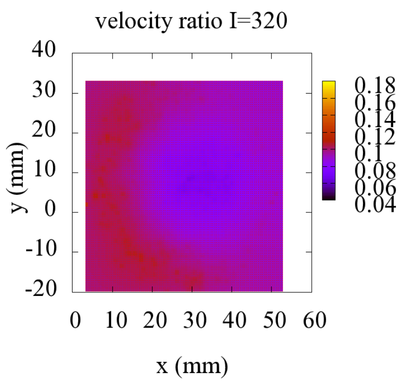


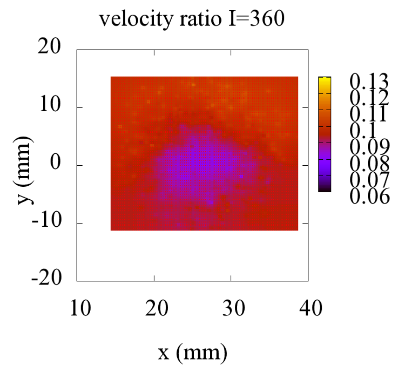
I=480 => B=0.6T

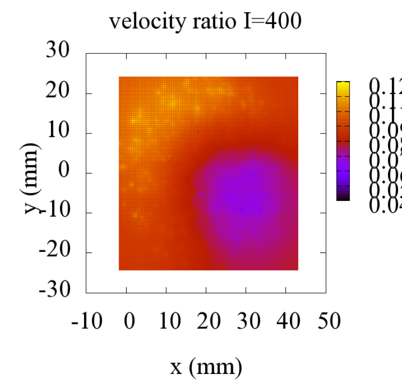
Variation with Energy

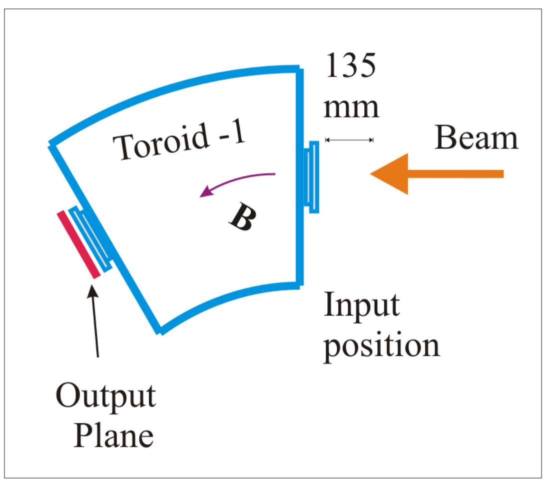


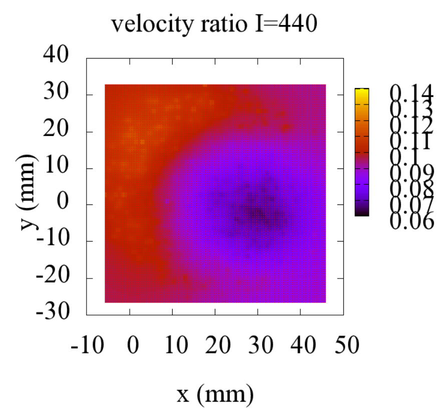
3d map at output plane

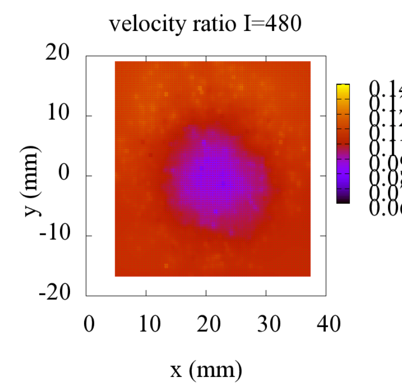




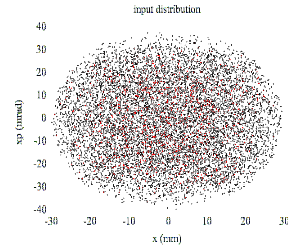


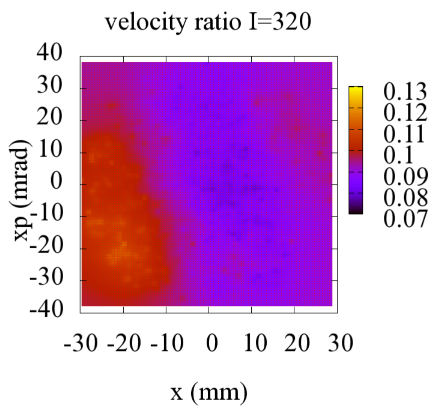


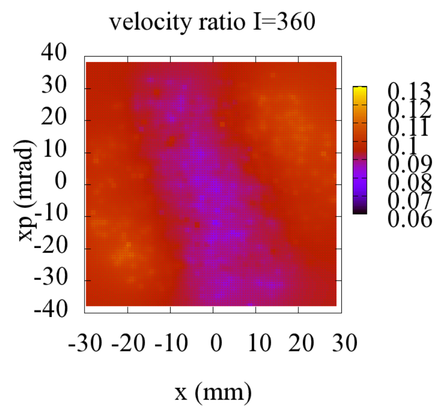


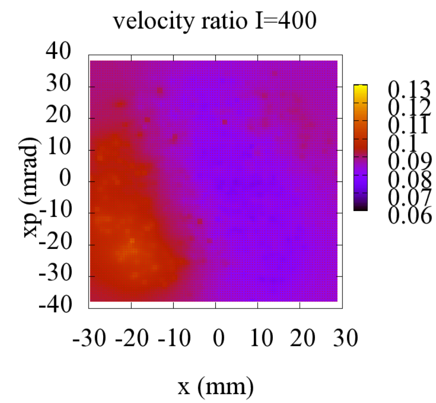


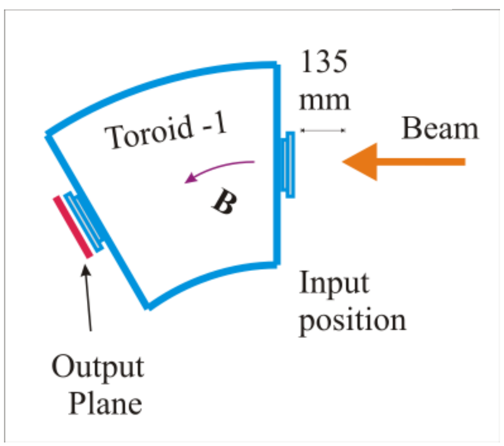
Mapping at input plane

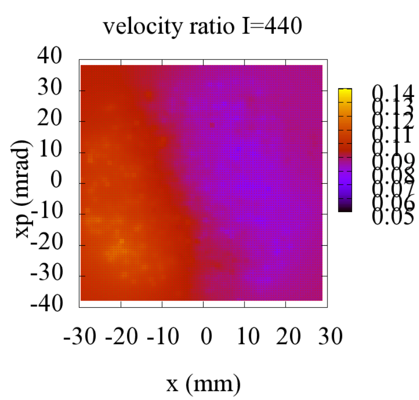


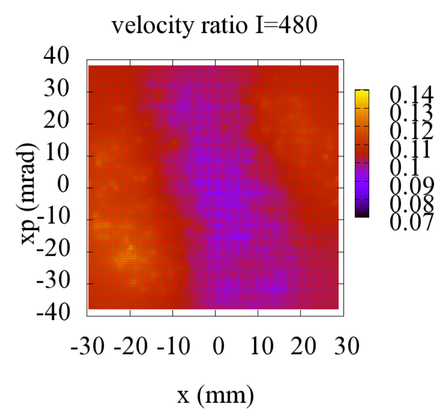






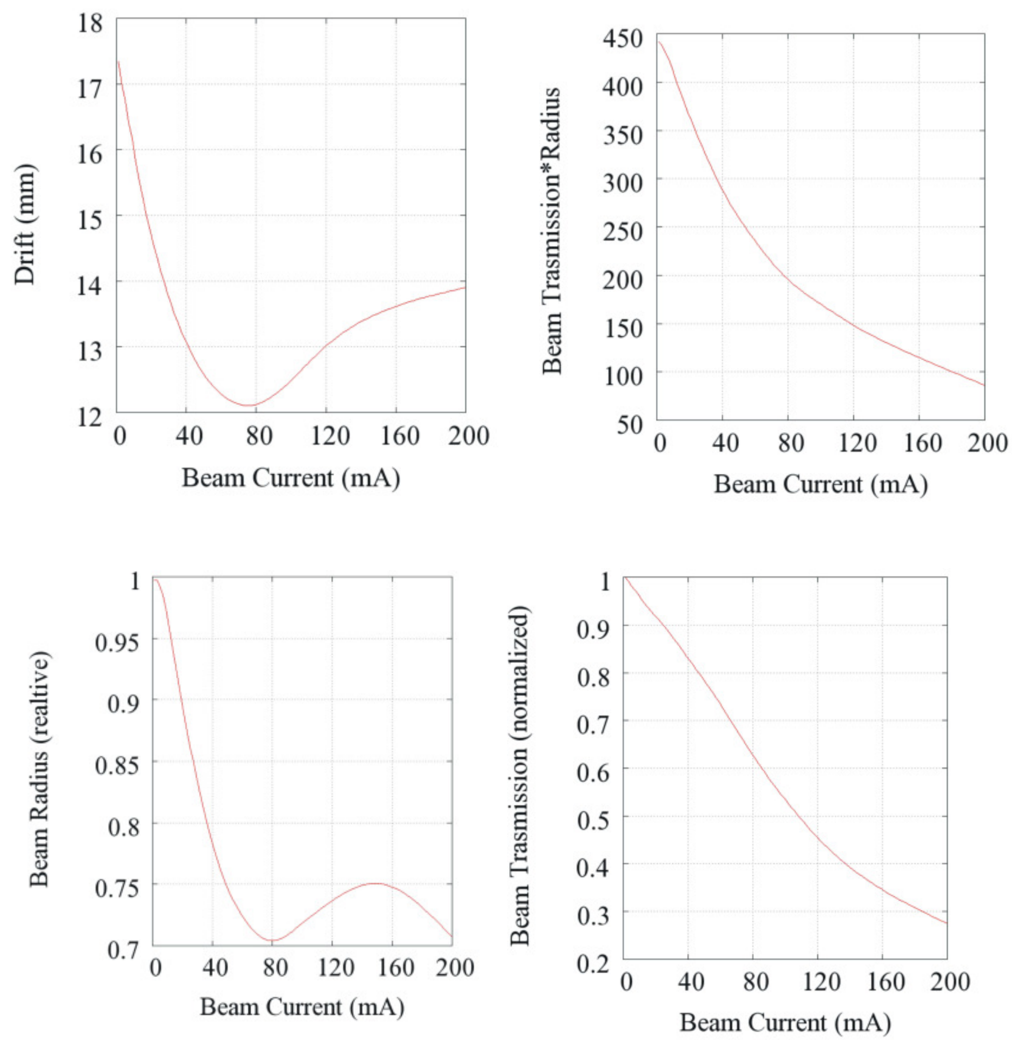






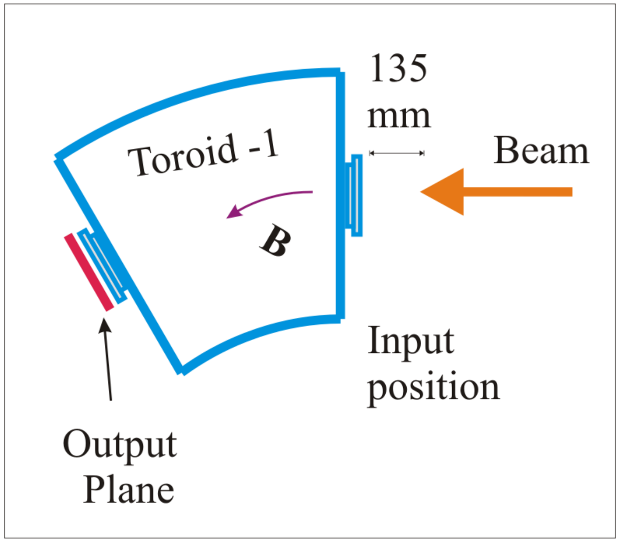
Space Charge

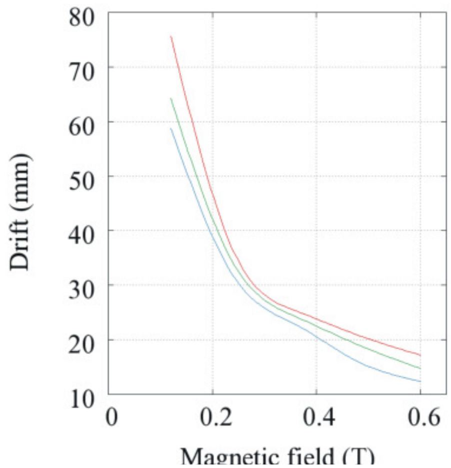
- Parallel beam 30mm into single toroid
- Due to space charge the vertical drift is lowered
- But also the „good beam“ is smaller
- The drift increases at ~80mA which is the brilluoin flow limit

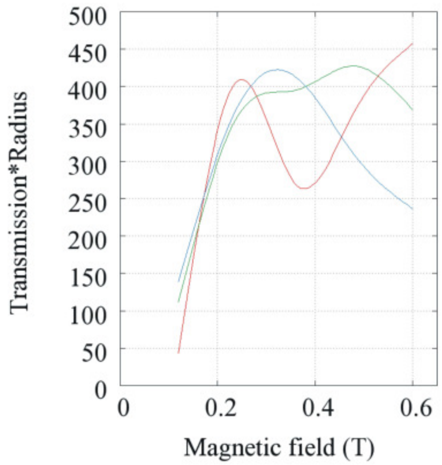


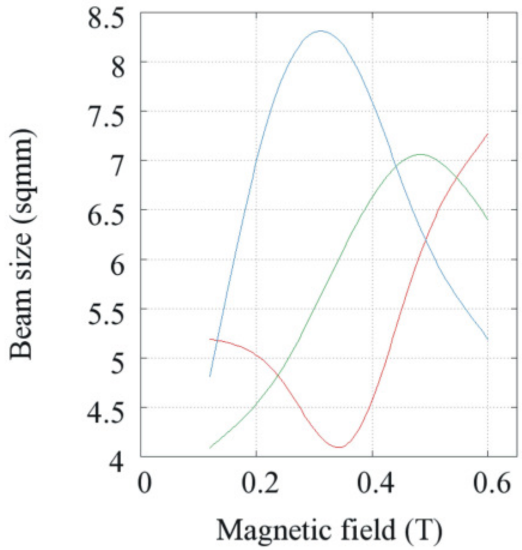
Magnetic field variation

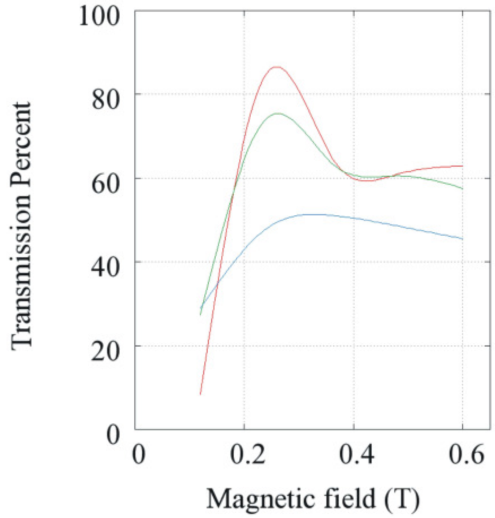
- Red =2mA, Blue=20mA, Green=60mA
- There is distinct difference in behaviour at lower and highe beam current









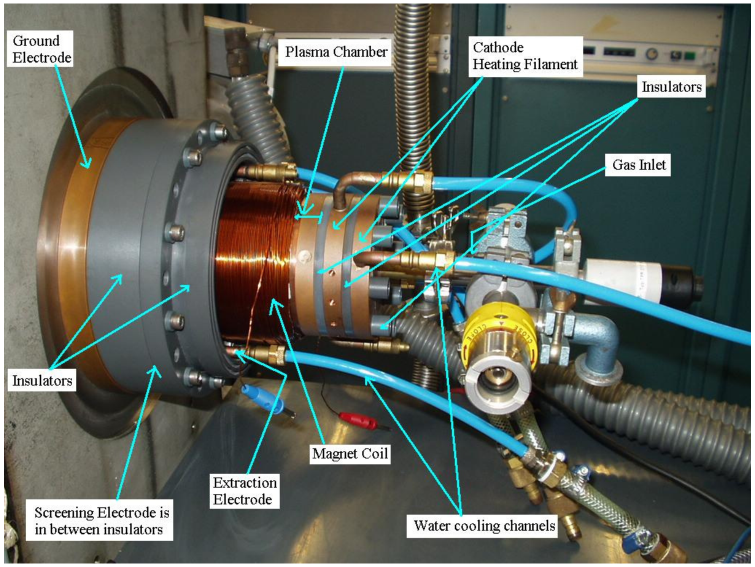


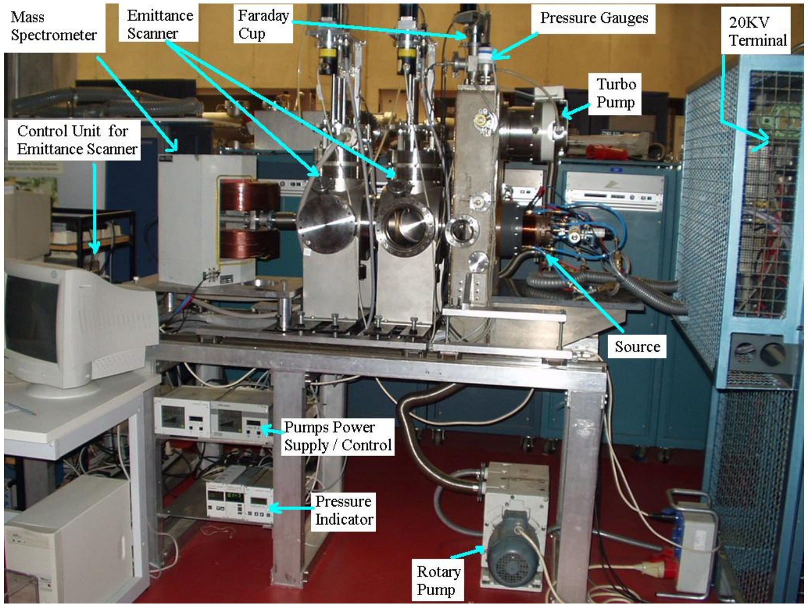
Experiments

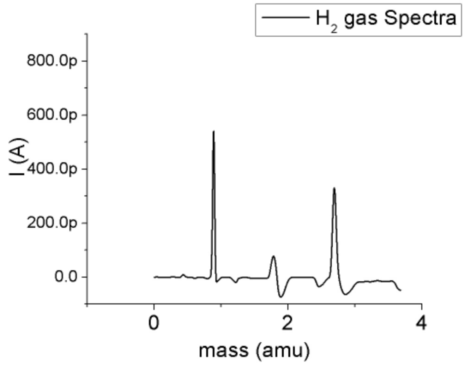
- Beam extraction from ion source
- Transport through Solenoid
- Transport through Toroidal Segment

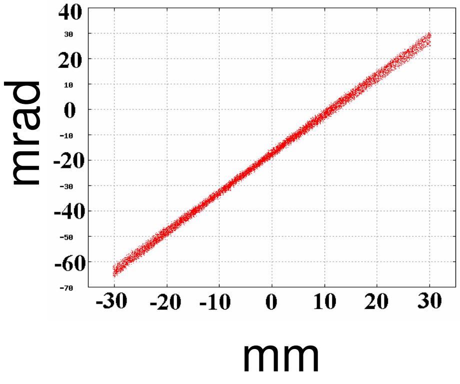
Proton beam

- Volume type Ion sorce , Triode extraction
- At 10 keV Energy, Current 5.2mA
- ~45% proton ~ 2.3mA
- ε_{rms} = 0.131 mm-mrad

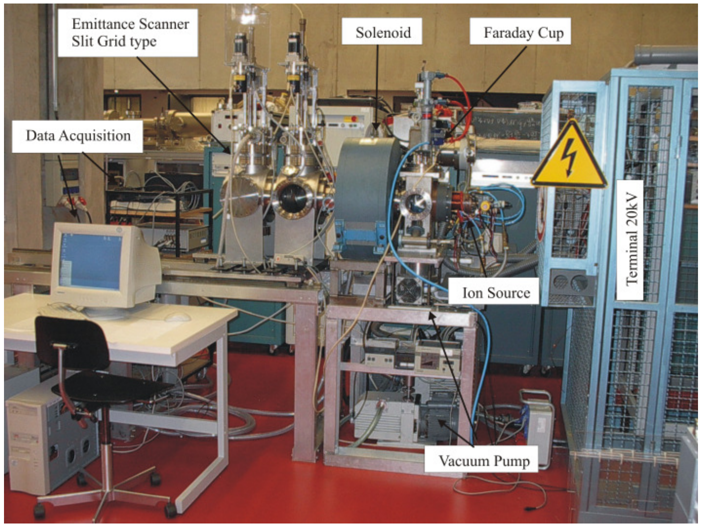


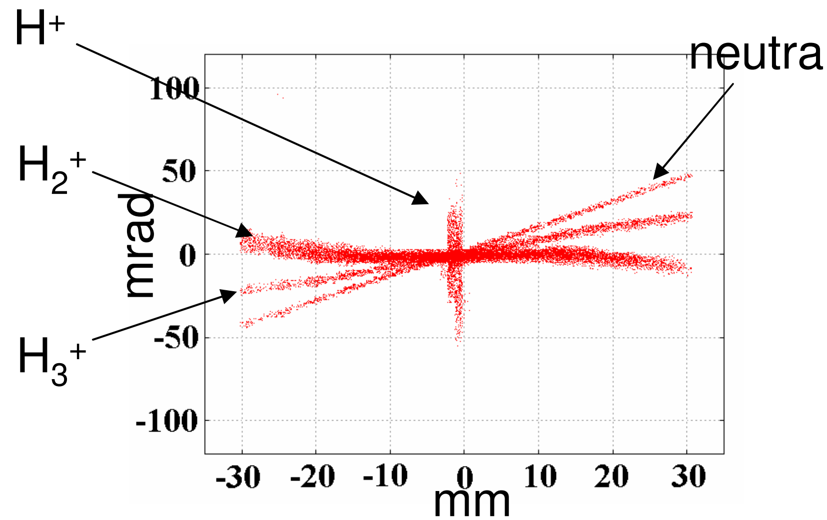






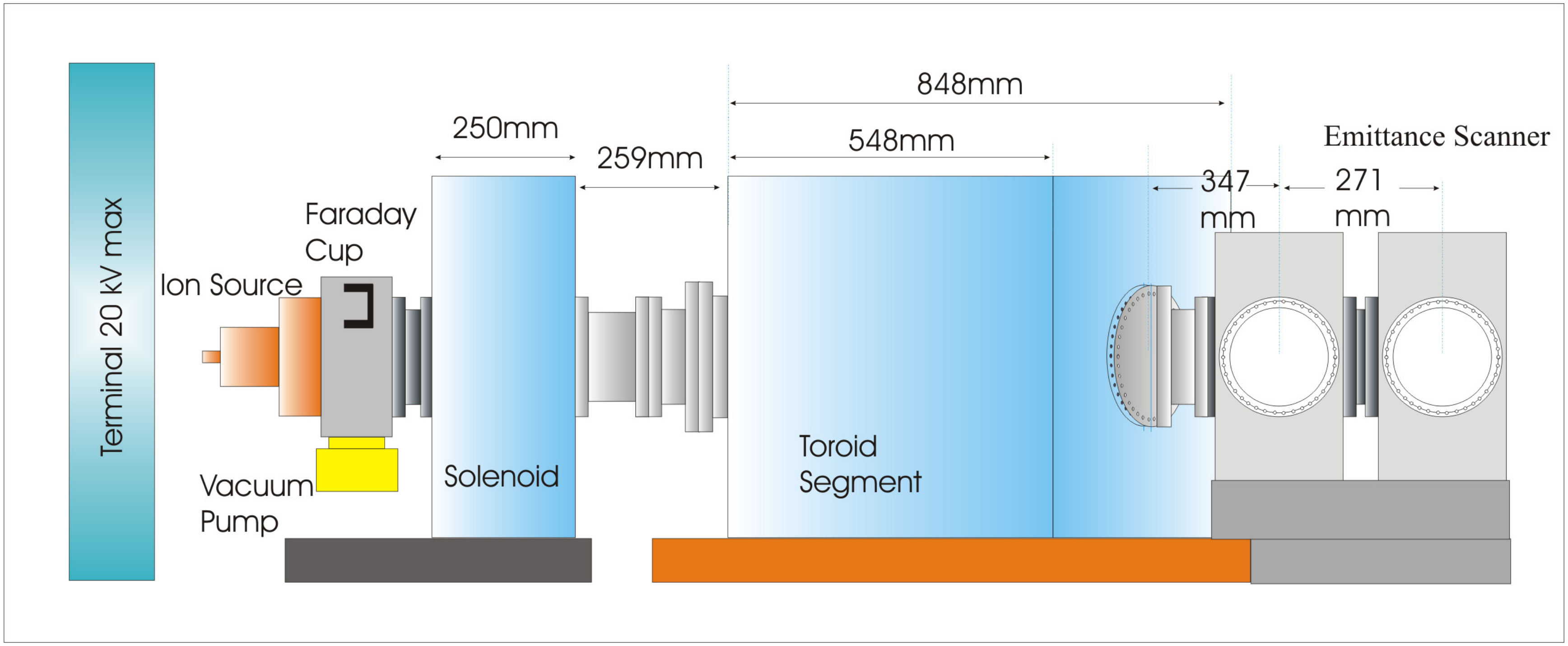
Transport through Solenoid



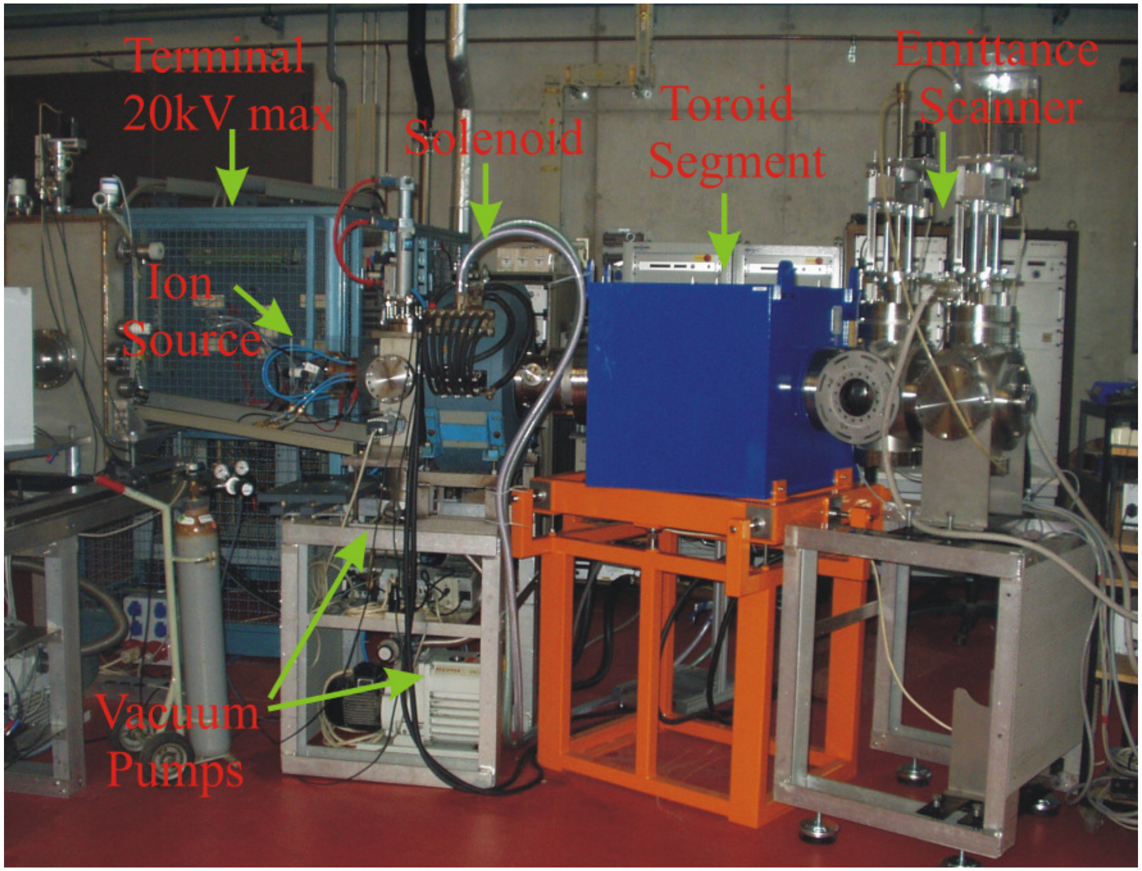


- Focusing strength $k = (B/(2p/e))^{2}$. Beam distribution downstream of the solenoid was measured and compared with simulations.
- Further simulations were done takeing into account the fringing field of toroid segment to get input distribution for beam transport into toroidal segments and injection system

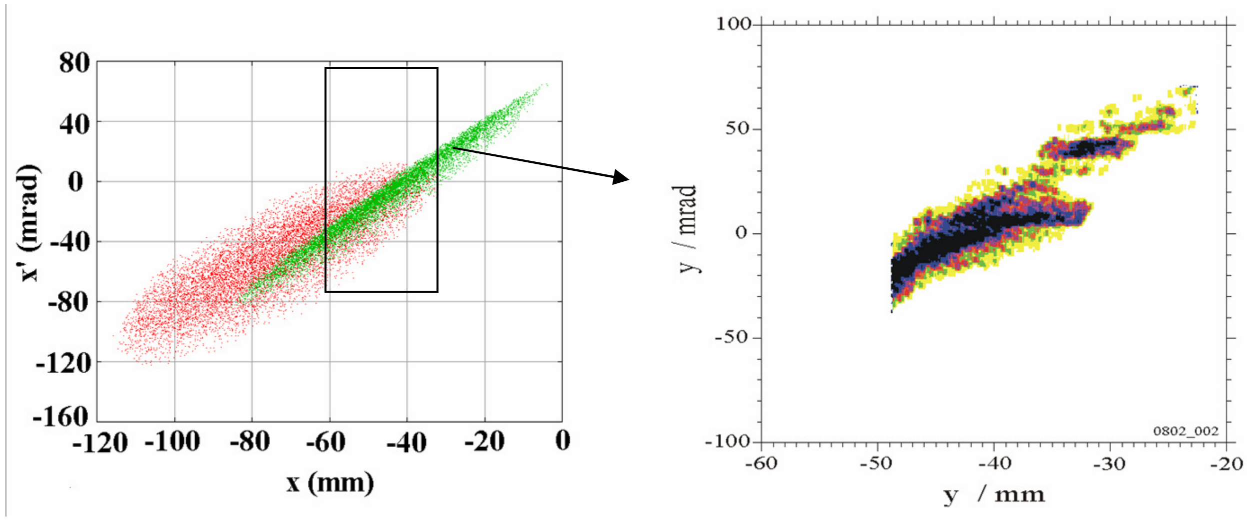
Transport through Toroidal Segments



Experimental Setup



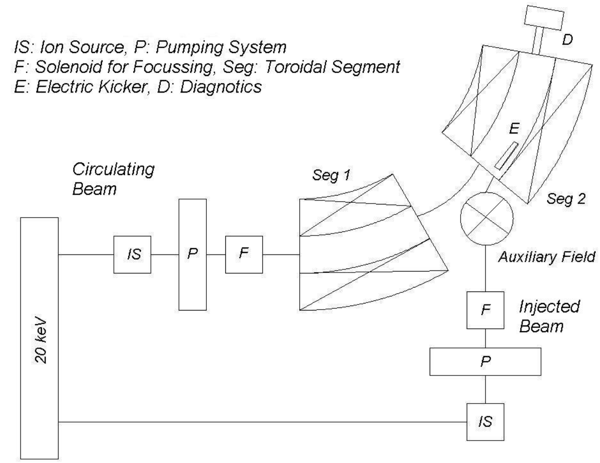
First Experimental Results

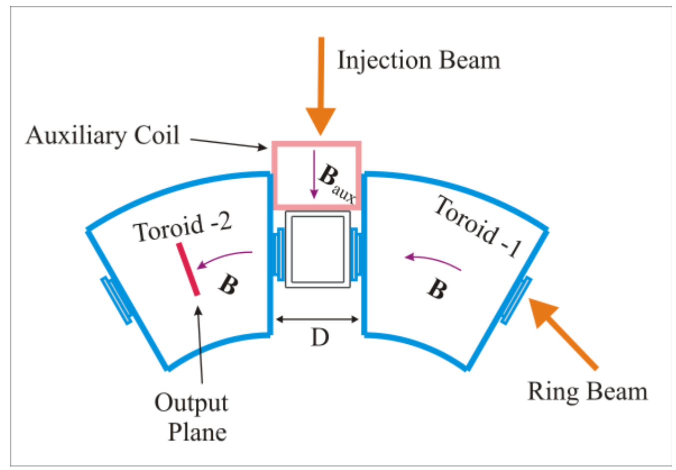


- On left => simulated Beam ; Green is H^+, Red is H_3^+
- Acceptance of Emittance scanner is not fulfilled due to which beam is chopped off
- Simulation Result is visually comparable => „ Proof of Simulations“

Injection System

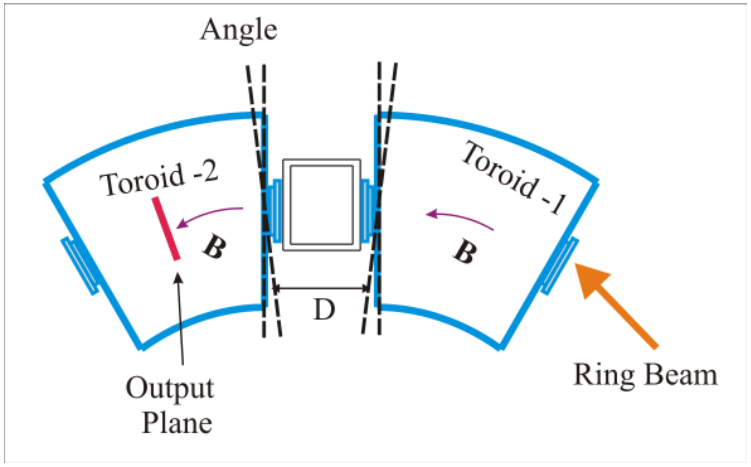
- Experiments with two toroidal segments
- Auxiliary coil for special magnetic field configuration
- Input parameters : Beam parameters magnetic field parameters, geometry
- Using measured transport parameters back calculation
- Transmission

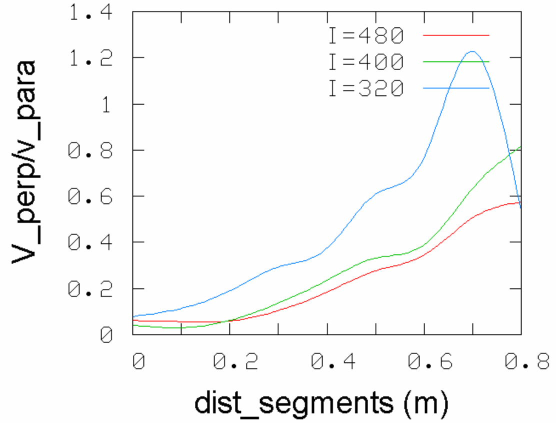




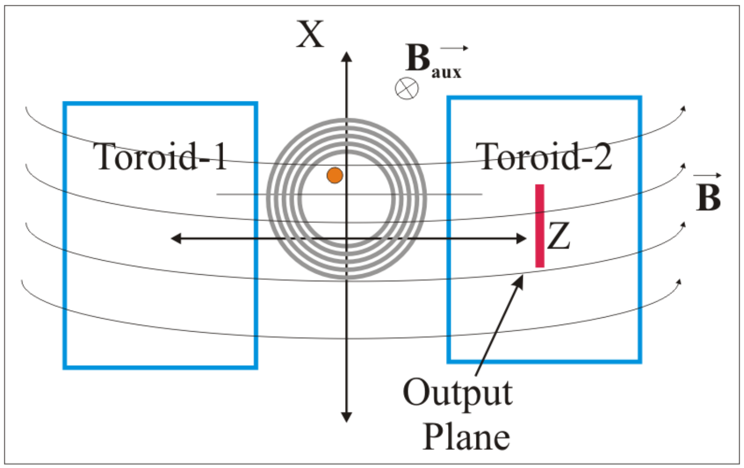
Segment Geometry

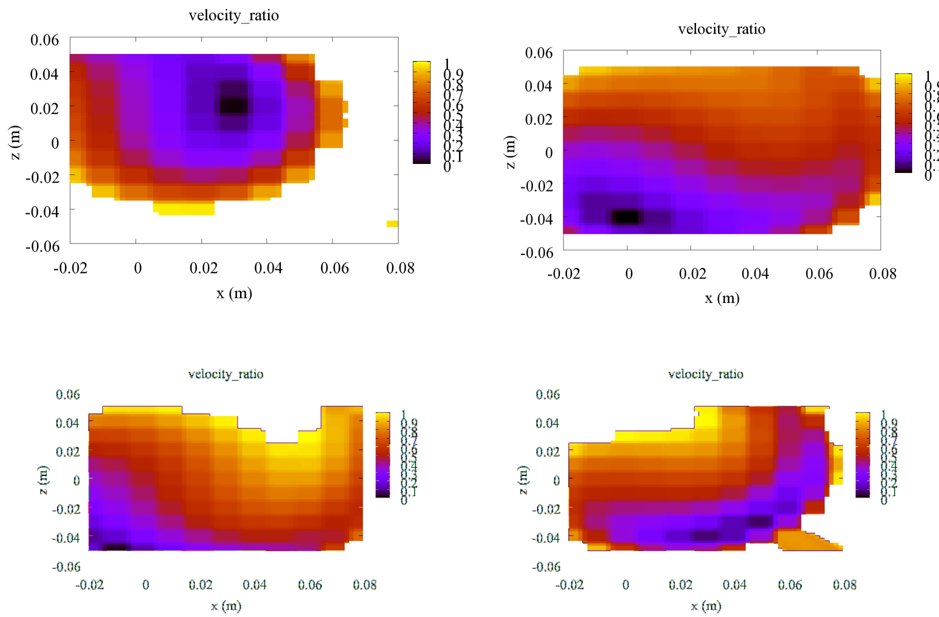
- Input parameters : Beam parametes fixed. 10keV proton with measured trace space distribution after solenoid.
- Velocity ratio for ring beam was simulated at middle plane of second segment.
- Segment distance chosen to 300~340mm.
- Angle between two segments => space for injection coil as well better in dynamics point of view. Angle between two segments can be 6 degree max. But technical point of view 0 degree since not two much effective





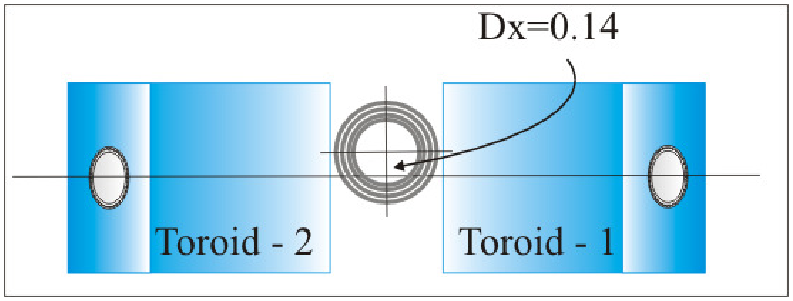
Configurations for injection coil

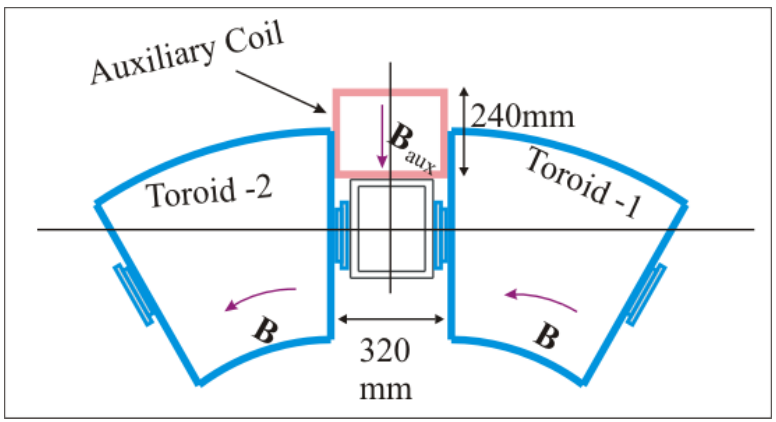




- 10keV proton beam injected parallel to find best position with respect to coil
- Coil itself can be moved up or down
- Aperture, length and number of winding parameters to play

Final Setup

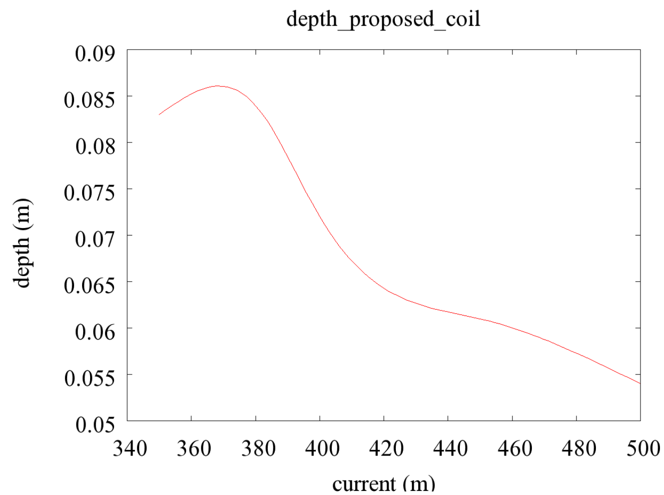


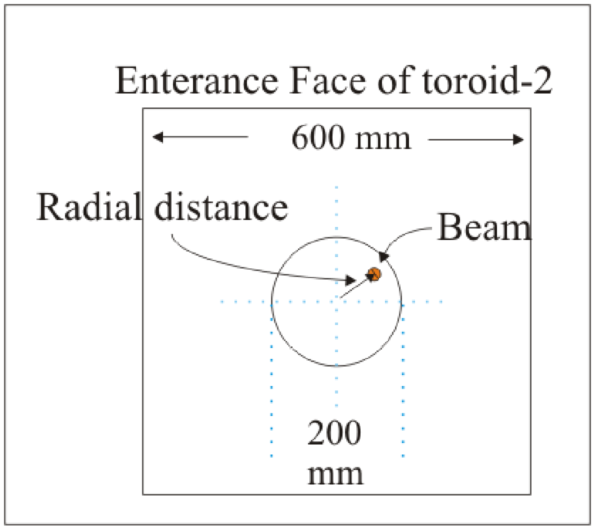


- Inner radius 120mm
- Outer 316mm
- Length 240mm
- 40 coils, 6 layers
- B-field 0.33T at 400A
- Distance between two toroidal segments 320mm
- Coil position 14cm above middle plane 12cm away from axis

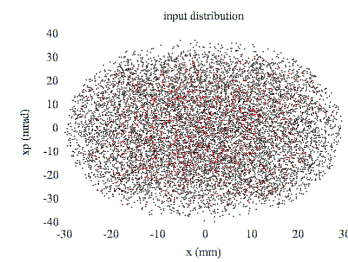
Penetration depth for given coil

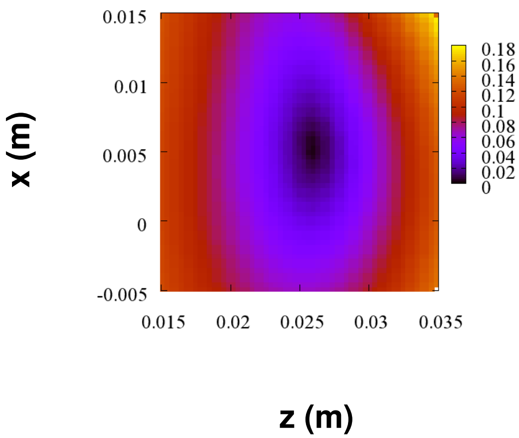
- The position at which beam enters injection toroid depends on current in injection coil at constant toroidal field
- On avarage r=0.075 was chosen so that no scraching on wall
- compromise ring beam space and influence on it.

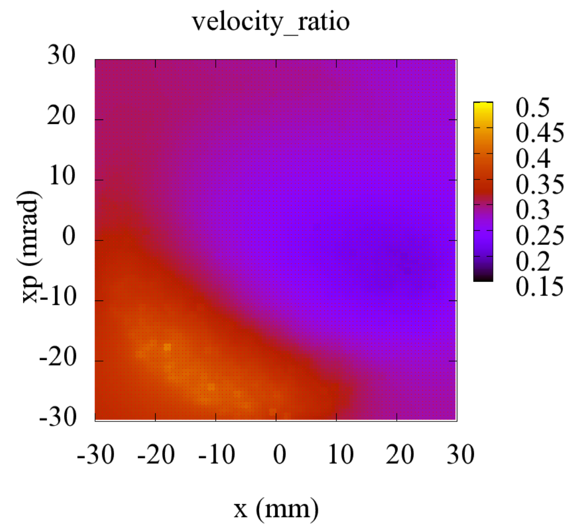




Beam acceptance

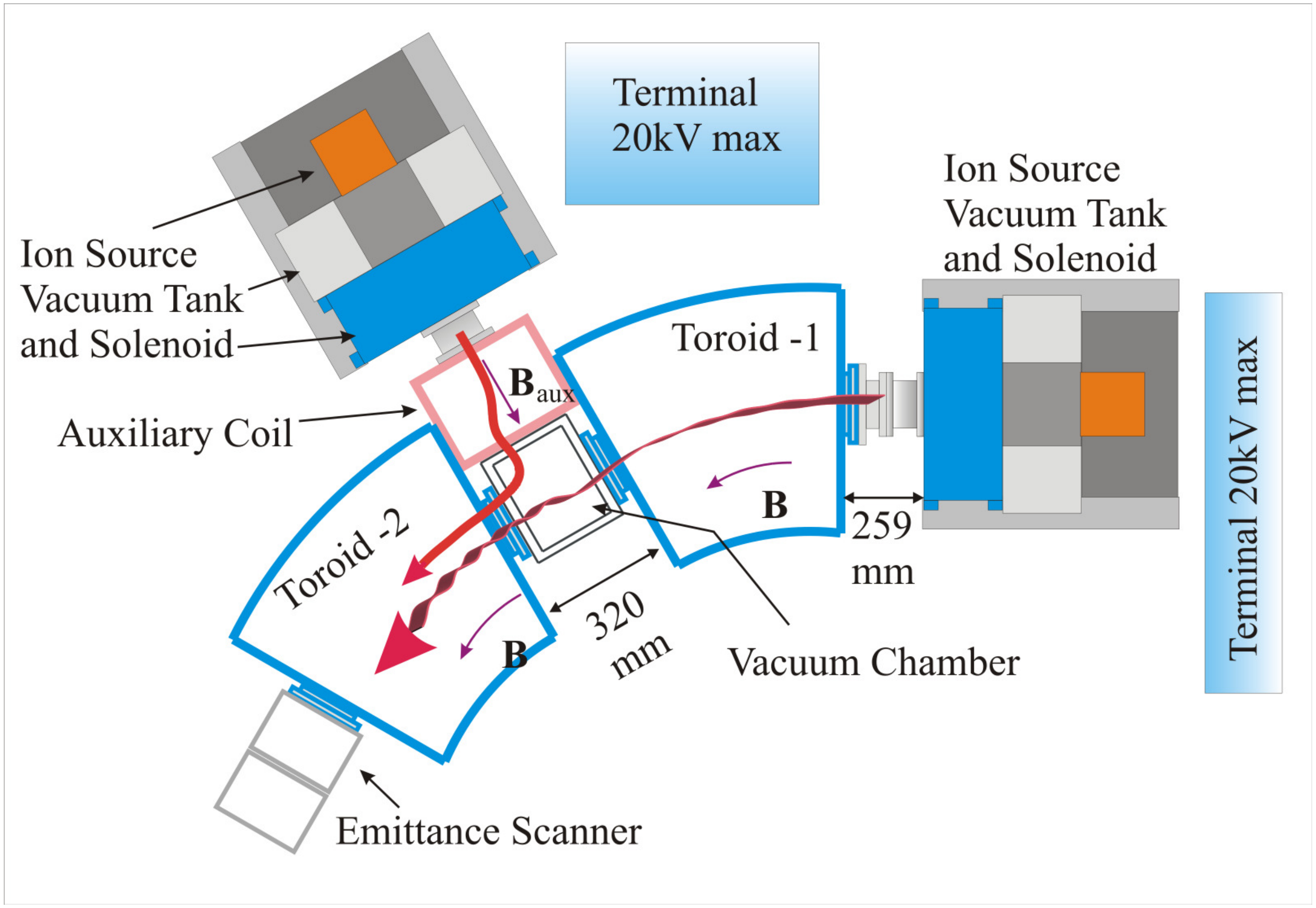




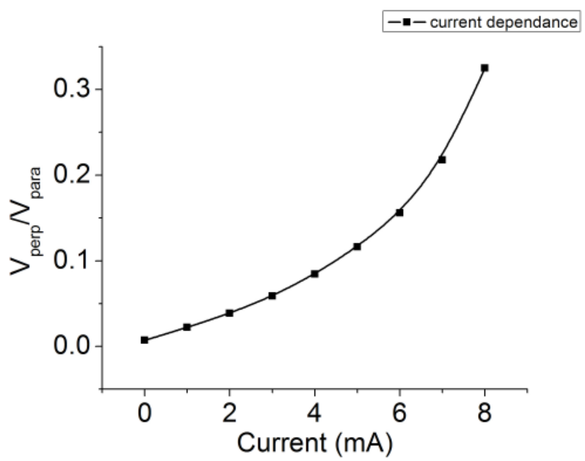


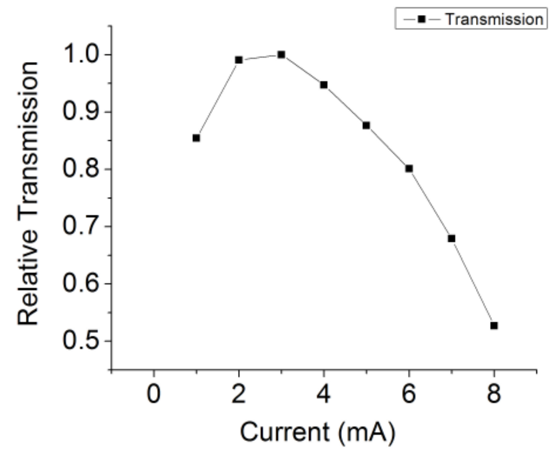
- Output distribution at the middle plane of toroid-2 is mapped on input
- 10keV proton beam with 30mm 30mrad injected
- Blue region depicts the “good beam” parameters

Two Beam paths

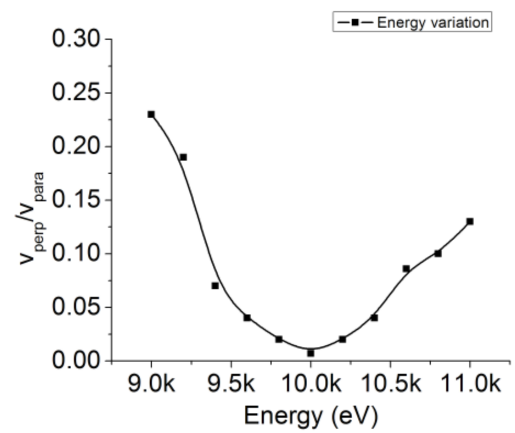


Space charge and energy variation





- Limited parameters
- These space charge results are glimpse
- Absolute trasmission simulated 72.6% for parallel beam



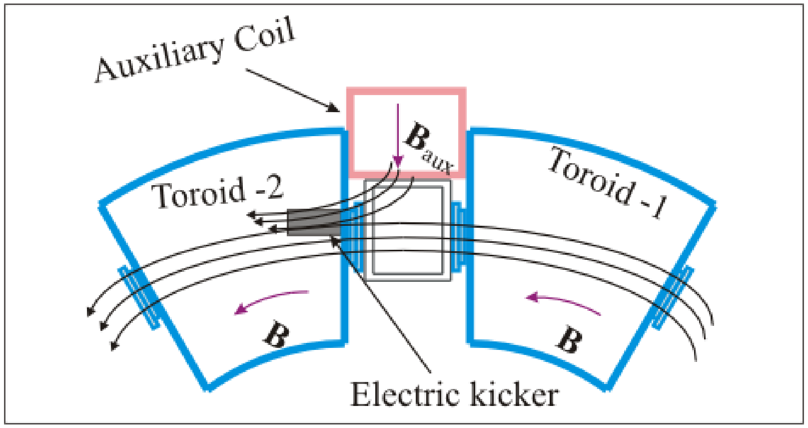
Concluding Remarks

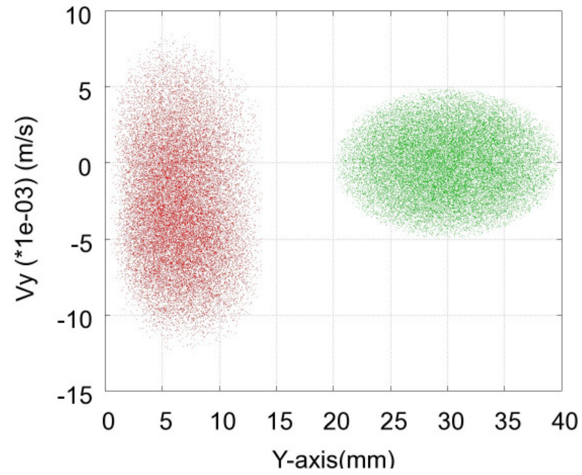
- Platform for investigation of beam transport in complete storage ring
- It give opportunity to compare the numerical simulation and predict for large scale machine
- On experimental stage many activities are still to come
- Beam profile with inside segments using scintillators moving in longitudinal direction

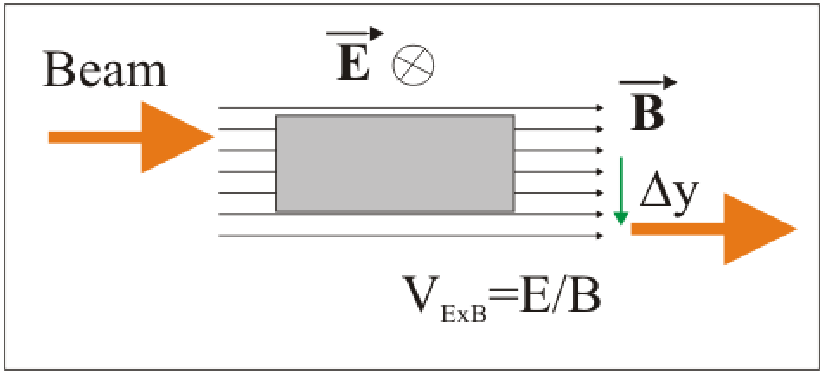
Thank You ..!!

- THE END

Kicker System

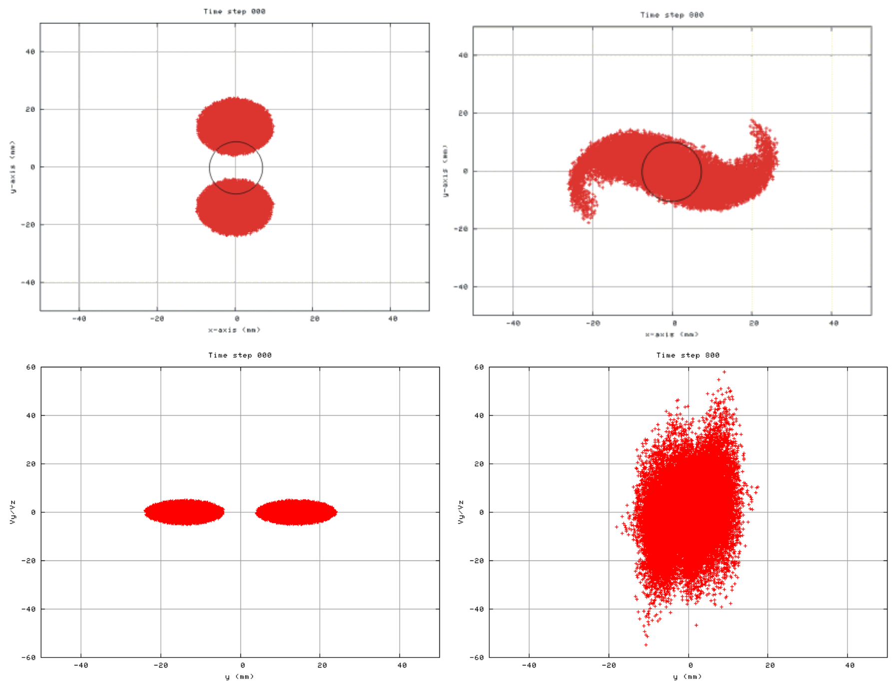


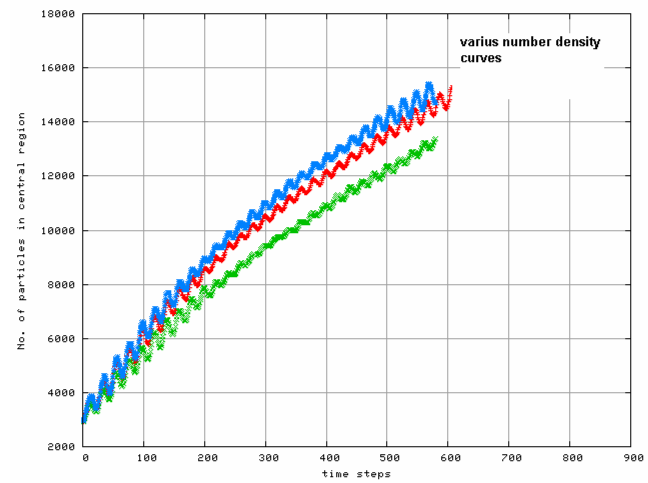




- At a beam energy of 20keV and in a magnetic field of 0.6T a deflection of 30mm with an electric field of E=10kV/cm can be achieved within a plate length of 14cm

Two Beams in magnetic field





Blue : $0.93*n_b$

Red : $0.85*n_b$

Green : $0.71*n_b$

- Energy 100 keV proton
- 1000 time steps represents single turn in 8-figure with R=1.3m, r=0.1m
- Magnetic field B=1.0 T, $N=0.81*n_b$