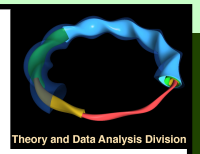
US-Japan Workshop on Stellarator/Helical System Concept Improvement
Oak Ridge, September 23-24, 1999

NIFS



Study of Energetic Particle Confinement in the CHS-qa configuration

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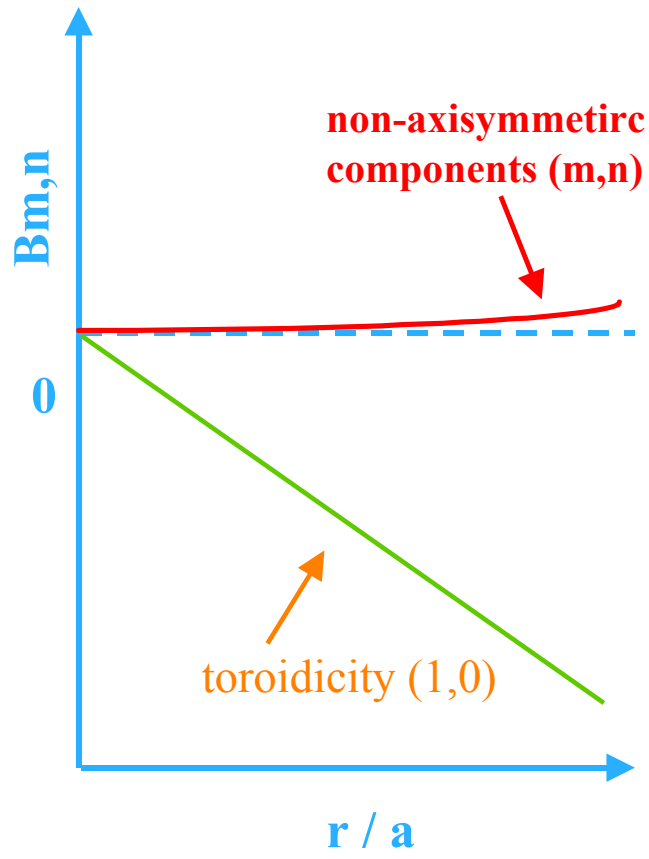
1. Intruduction
2. CHS-qa configurations
3. Collisionless α-particle confinement
4. Energetic beam ion confinement
5. Conclusions

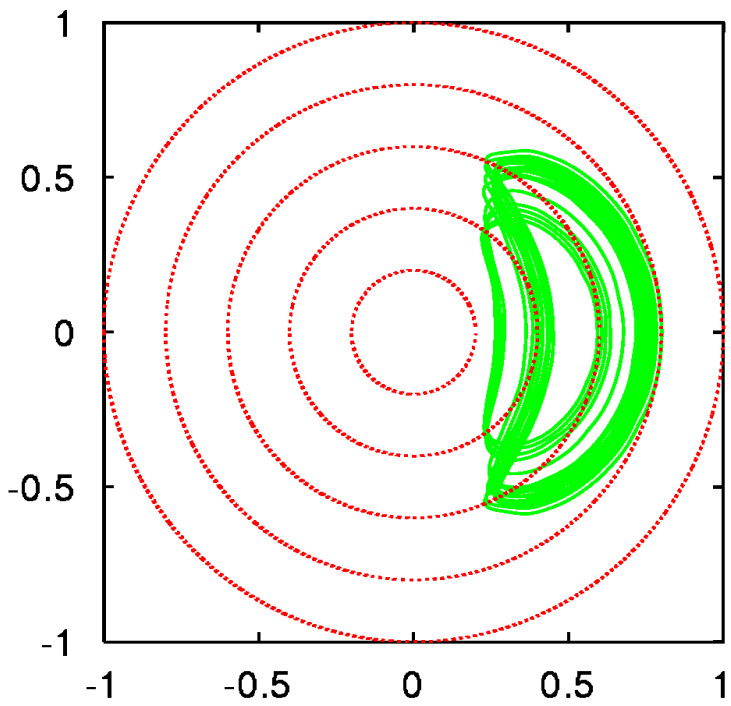
Confinement of Energetic Particle in QA

- In QA configurations particle confinement would be improved considerably without assuming strong radial electric field.
  (no radial drift due to helical ripple trapping)
- However the existence of small non-axisymmetric components is inevitable in actual QA device.
  - QA configuration
  - Coil ripple
- Effect of non-axisymmetric components on energetic particle confinements is important?

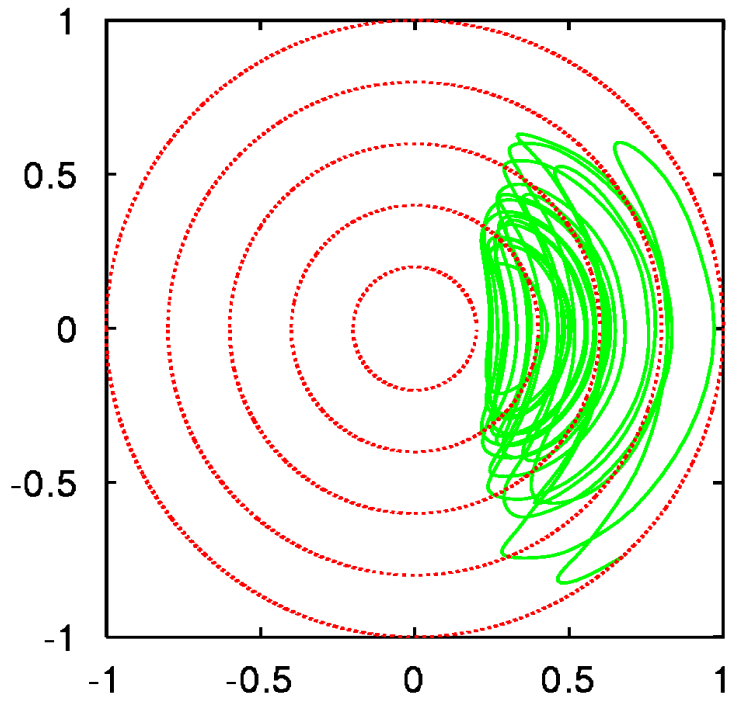


Banana-Drift Diffusion in QA

E_0=20keV (ρ/a=1/64)



low iota config.



high iota config.

Normalization

- We study the collisionless α-particle confinement using following normalization.

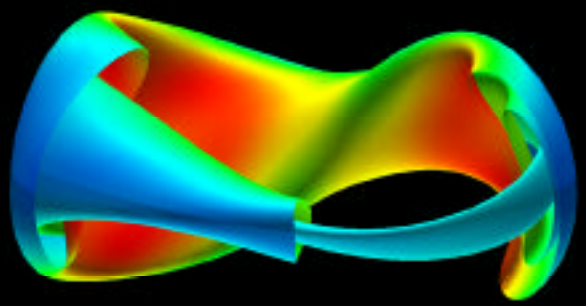
α-particle	:	3.4MeV
Plasma volume	:	1000 m^3
Magnetic field	:	5 T
beta value at center	:	6%

- 3 types of QA configuration
  1) A=2.8
  2) A=3.9
  3) A=4.6

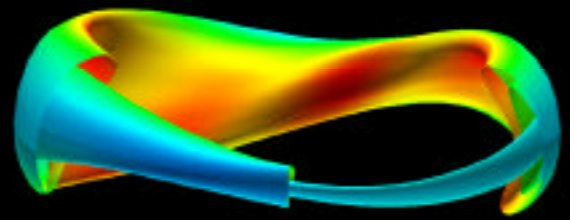
QA configurations (3D plots of modB)

Side view

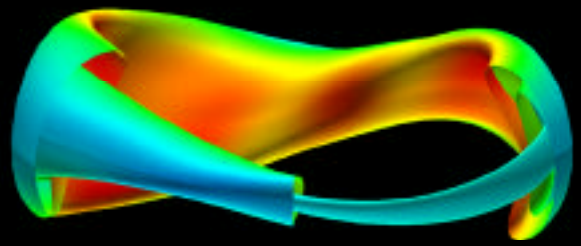
A=2.8



A=4.6

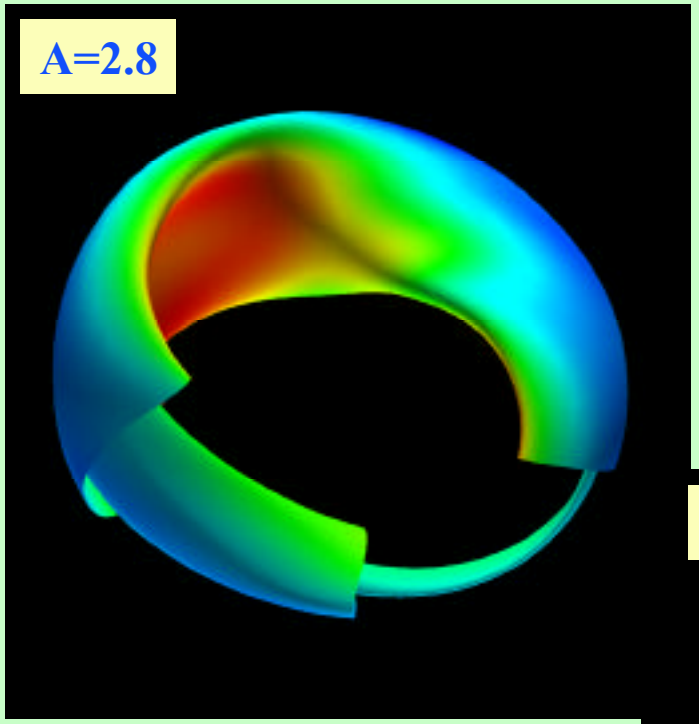


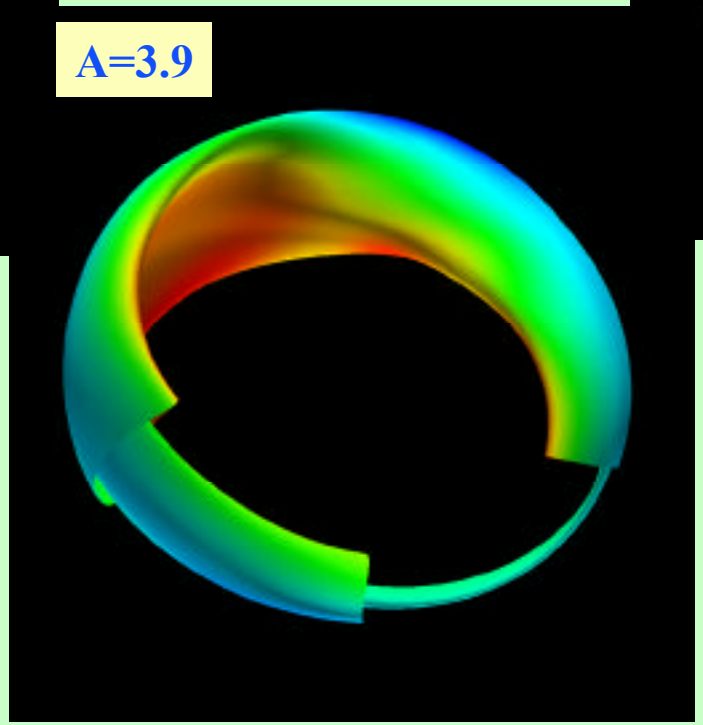
A=3.9

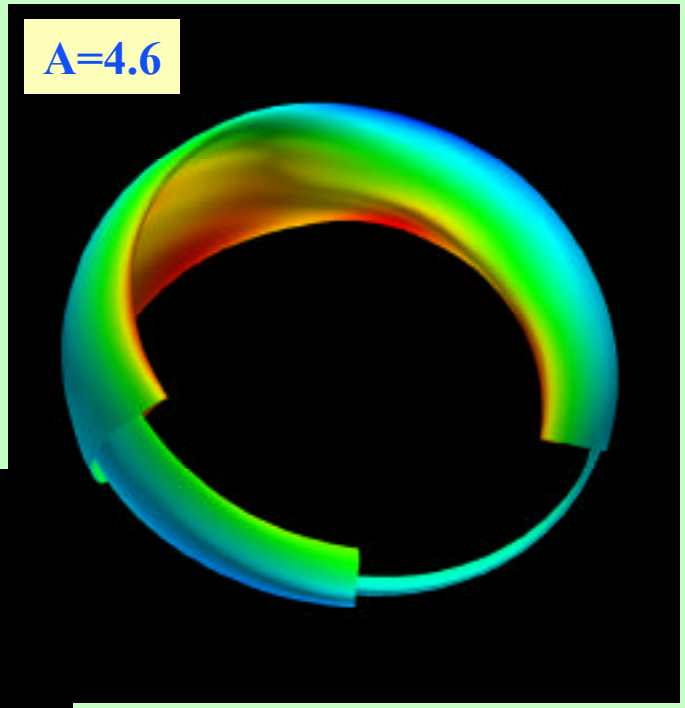


QA configuration (3D plots of modB)

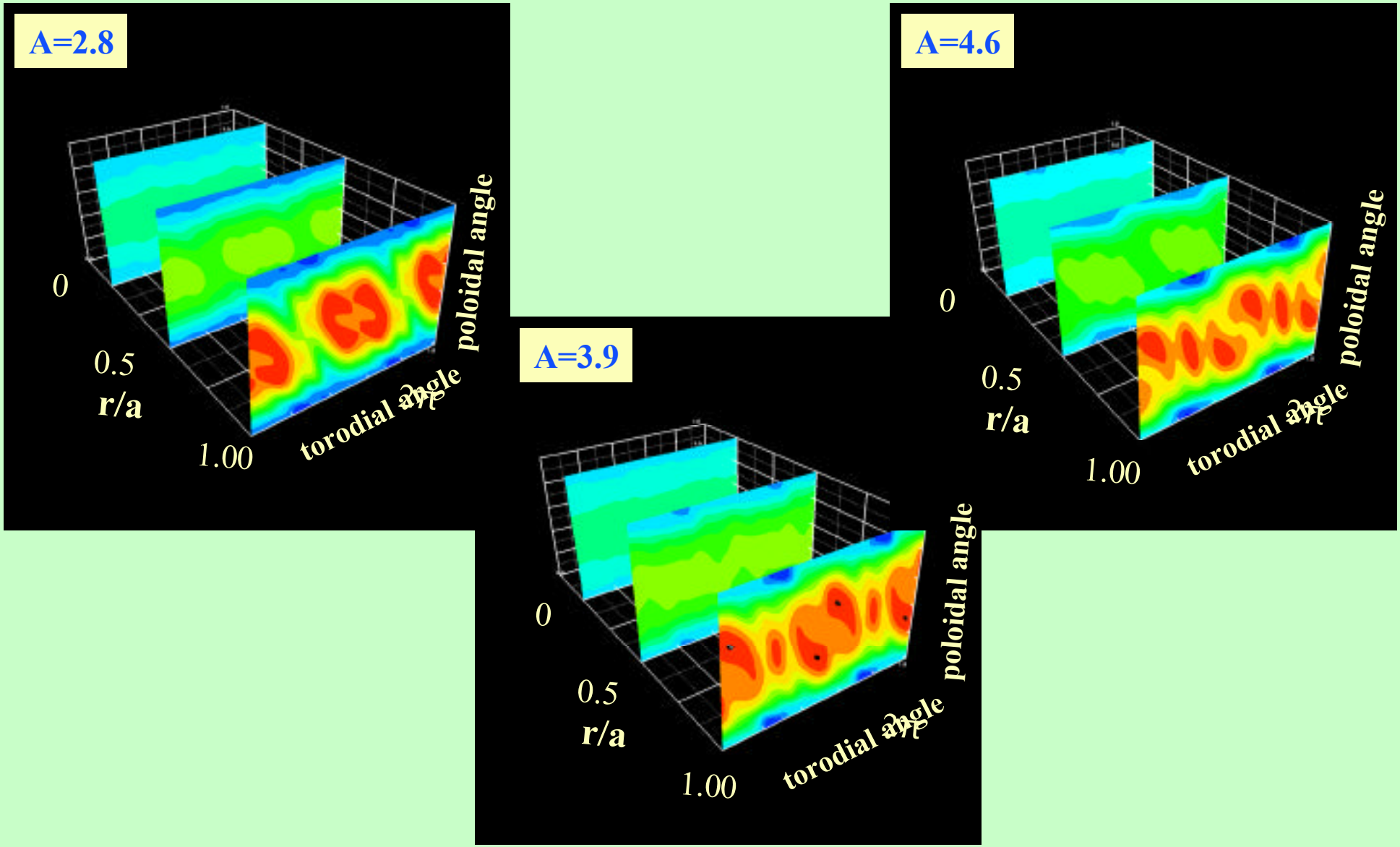
Top view





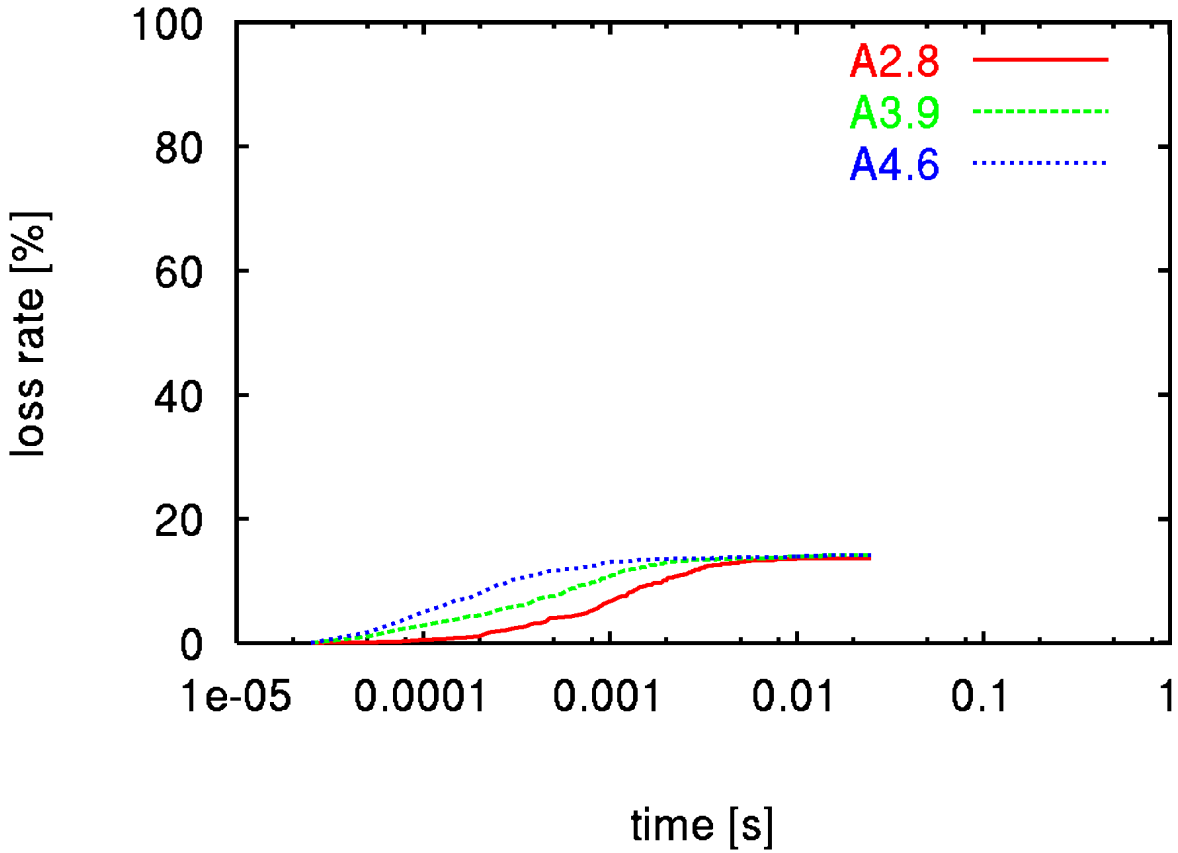


QA configurations (modB plots)



MC Simulation Results in QA

α-particle confinements



- **Simulation**
  - 1000 particles
  - $r_0/a=0.25$
  - θ, φ, pitch angle => randomly distributed
- **We obtain better confinement in the low A case.**
- **Trapped α-particle lost 1 -10 msec.**

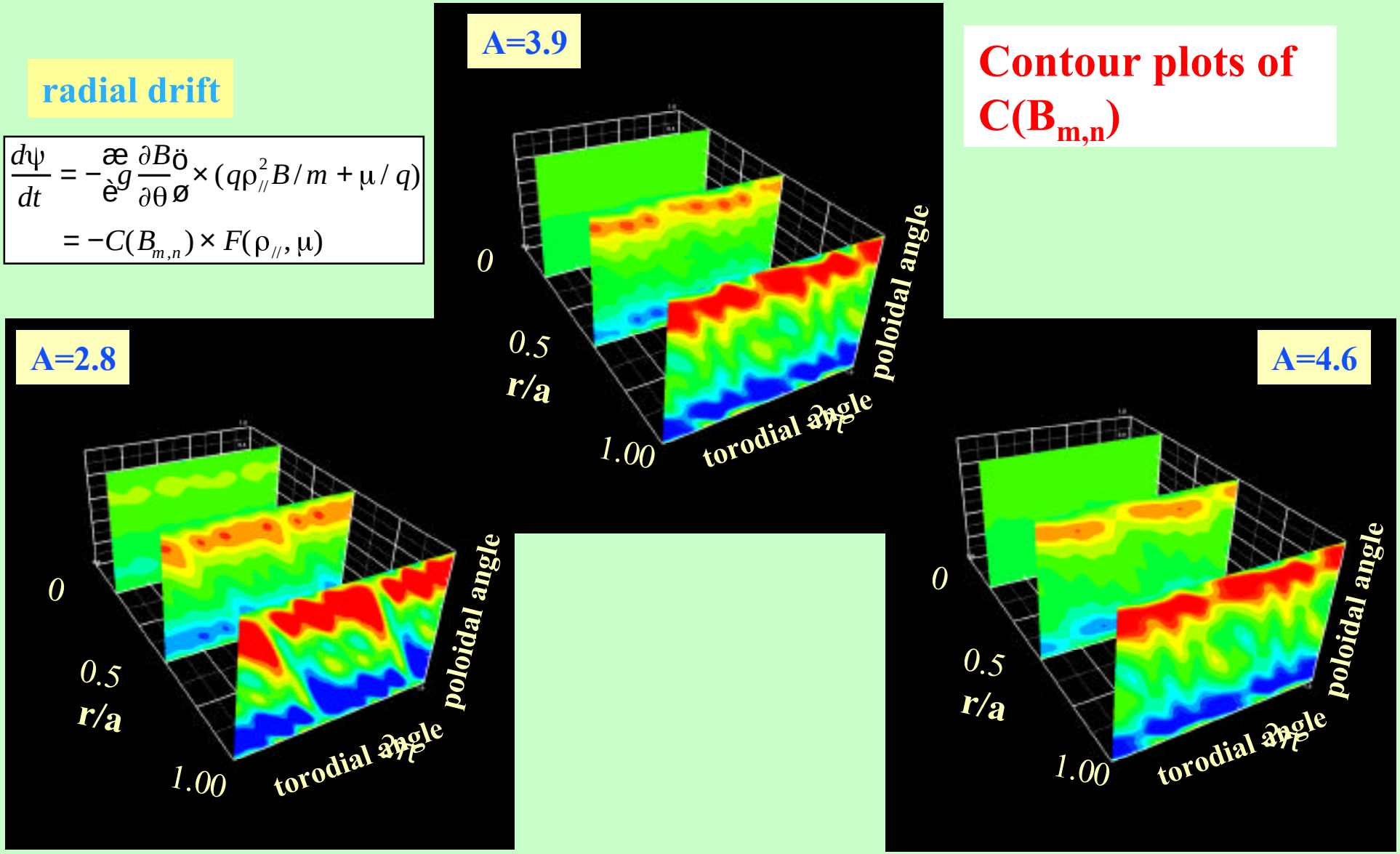
Normalization
$V=1000m^{-3}$
B=5T
$\beta_0=6\%$
α-particle 3.4MeV

Radial Drift Coefficient in QA

radial drift

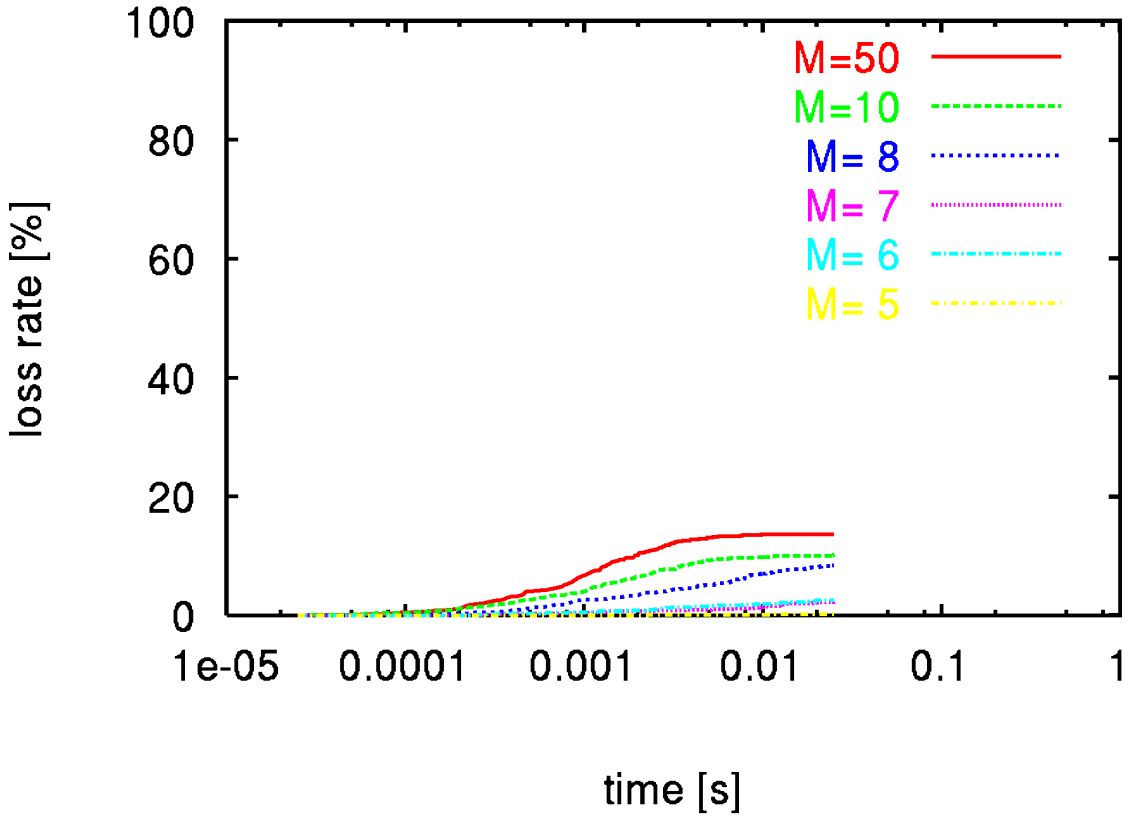
$$\frac{d\psi}{dt} = -\left(g\frac{\partial B}{\partial \theta}\right) \times (q\rho_{//}^2 B/m + \mu/q)$$
$$= -C(B_{m,n}) \times F(\rho_{//}, \mu)$$

Contour plots of $C(B_{m,n})$



Mode numbers Dependency

α-particle confinements



- **Simulation**
  - 1000 particles
  - $r_0/a=0.25$
  - θ, ϕ, pitch angle => randomly distributed
- **Mode number of $B_{m,n}$**
  - 5 to 50
- **50 modes are necessary for good evaluation.**
- **The Difference between M=8 and M=7 is (2,4).**

Normalization

$V=1000m^{-3}$

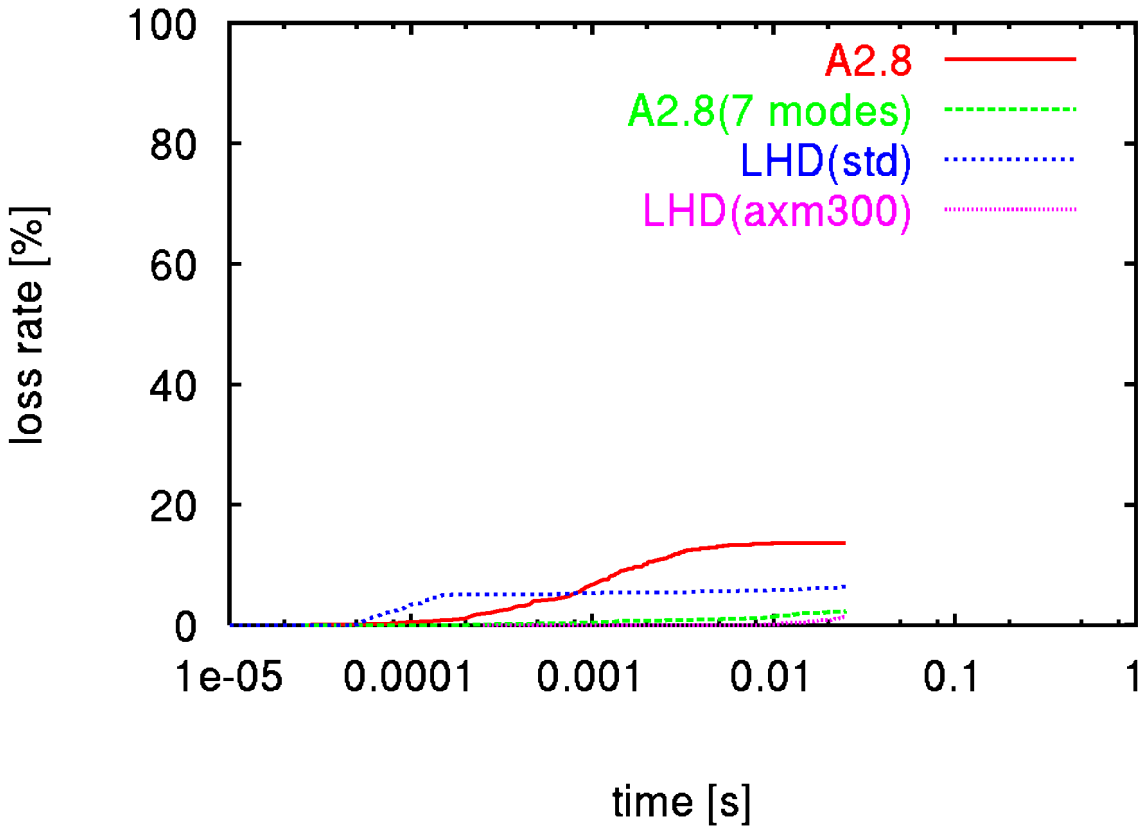
$B=5T$

$\beta_0=6\%$

α-particle 3.4MeV

Comparison with Conventional Helicals (LHD)

α-particle confinements

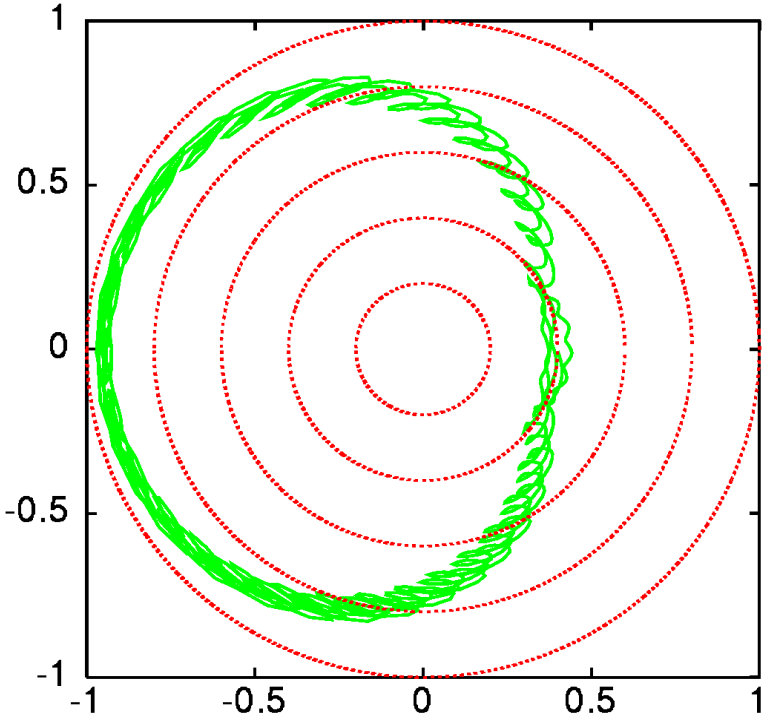


Better confinement for short time period Compared with LHD(std)

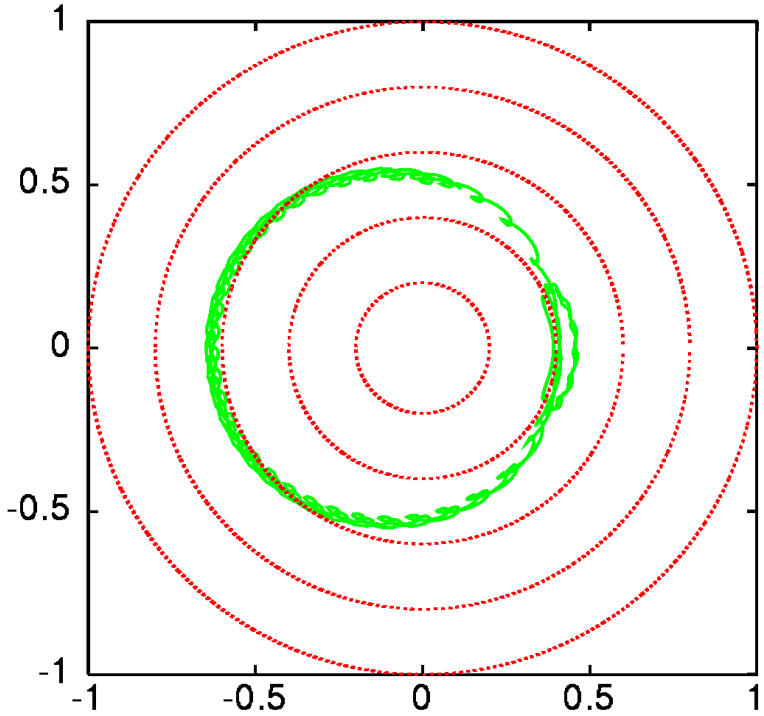
Normalization
V=1000m^{-3}
B=5T
β_0=6%
α-particle 3.4MeV

Energetic Particle Orbits in LHD

E_0=69keV (ρ/a=1/64)



standard config.
R_{ax}=3.75m (Δ_{ax}=-15cm)



inward shifted config.
R_{ax}=3.6m (Δ_{ax}=-30cm)

Simulation of Energetic Particle Transport

- Since the energetic particle drifts with high velocity and has an large orbit size, the neoclassical (collisional) transport would play dominant role in the radial transport process of energetic ions.
- Many efforts have been made to analyze the neoclassical transport of thermal plasma, analytically and numerically, in heliotrons.
- However, because of the large orbit size of energetic ions, the conventional approach based on the local approximation can not be utilized to this problem and a new non-local approach is required to study the neoclassical transport of the energetic ions in heliotrons.
- In this paper we study the neoclasical transport of energetic ions in heliotrons using a newly developed global neoclassical transport simulation code, GNET.

GNET (Global Neoclassical Transport simulation)

- The steady state of energetic particle distribution is calculated in 5D phase space based on the Monte-Carlo technique.

$$\frac{\partial f}{\partial t} + (\mathbf{v}_{//} + \mathbf{v}_D) \quad f + \mathbf{a} \quad {}_{\mathbf{v}} f = C(f) + S_{NBI} + L_{particle}$$

C(f) : linear Clulomb Collision Operator
(engery and pitch angle scattering)

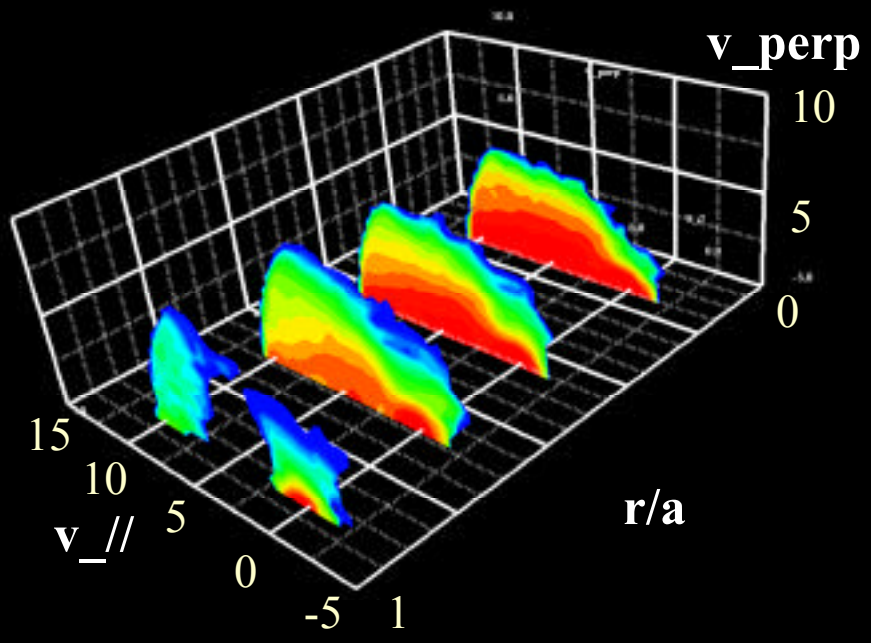
S_{NBI} : heating source term
=> NBI beam birth profile (HFREYA)

$L_{particle}$: particle loss
=> CX and Orbit loss

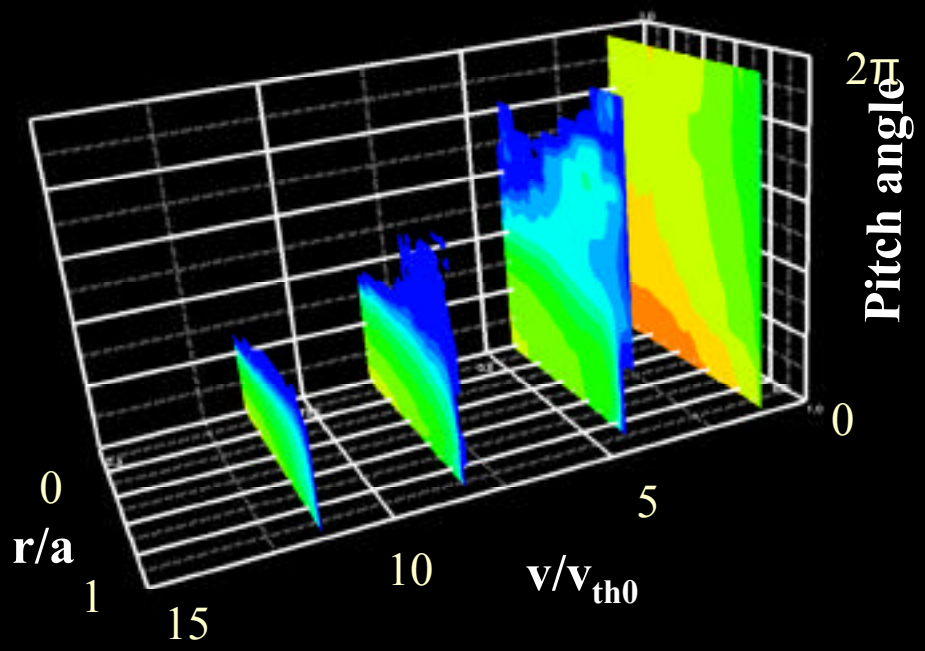
- The complex magnetic field configuration and finte-β effects on the particle motion are included using the Boozer coordinates based on 3D MHD equilibrium (VMEC+NEWBOZ code).

Energetic Beam Distribution in CHS

Contour plot of $f(v_{//}, v_{perp}, r)$



Contour plot of $f(v, \theta_p, r)$

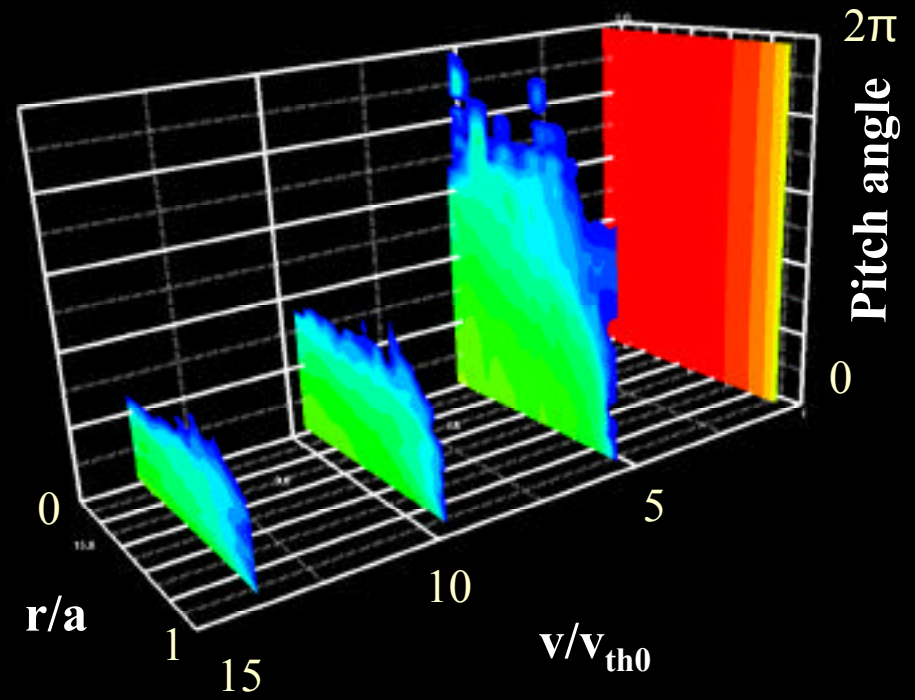


$T_{eo}=T_{io}=0.4$keV, $n_{e0}=2\times10^{19}$m^{-3}
$B_0=1.8$T, $P_{NBI}=1$MW, $E_b=40$keV

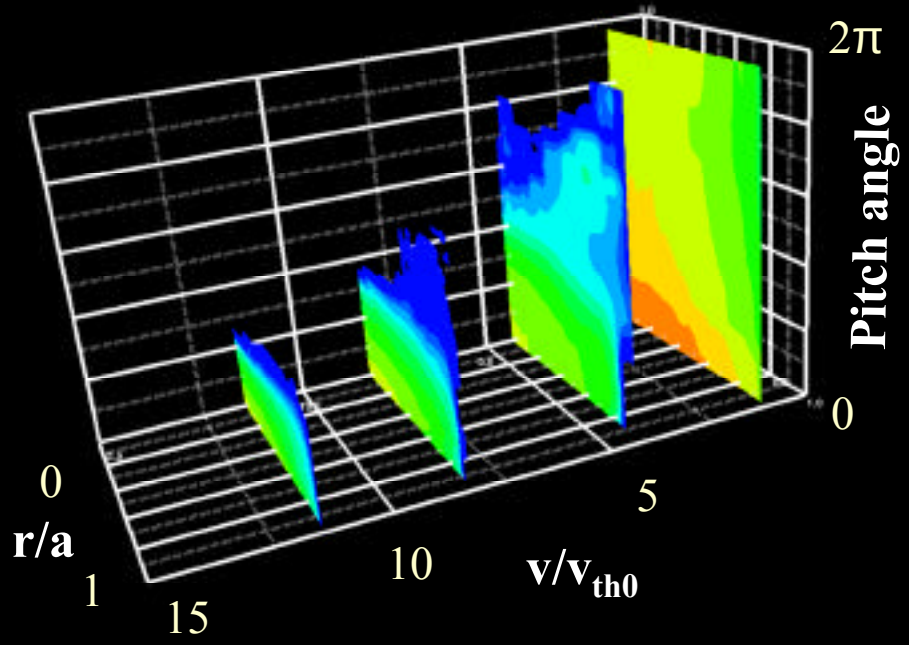
Energetic Beam Distribution in CHS-qa

Contour plot of $f(v, \theta_p, r)$

CHS-qa(A=2.8) R_{ax}=1.5m, B_0=1.5T



CHS R_{ax}=0.921m, B_0=1.8T



$T_{eo}=T_{io}=0.4$keV, $n_{e0}=2\times10^{19}$m^{-3}
P_{NBI}=1MW, E_b=40keV

Conclusions

- We have investigated the confinements of energetic particles in three types of QA configuration using MC simulation code.
- The better confinement is obtained in the low A case.
- Important role of (2,4) mode was found in the case of A=2.8.
- Comparisons with the LHD results show that the better confinement of energetic particle in the LHD(R_{ax}=3.6$_m$).
- The more optimization is necessary for the QA design in a point of view of energetic particle confinement.
- We have started the study of energetic ion transport in QA using GNET(Global Neoclassical Transport code).
- The good property of energetic beam ion transport is obtained compared with CHS case in the case of relatively low temperature (Te0=0.4keV).