Modeling of Particle and Power Control for Compact Stellarators Update

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UCSD

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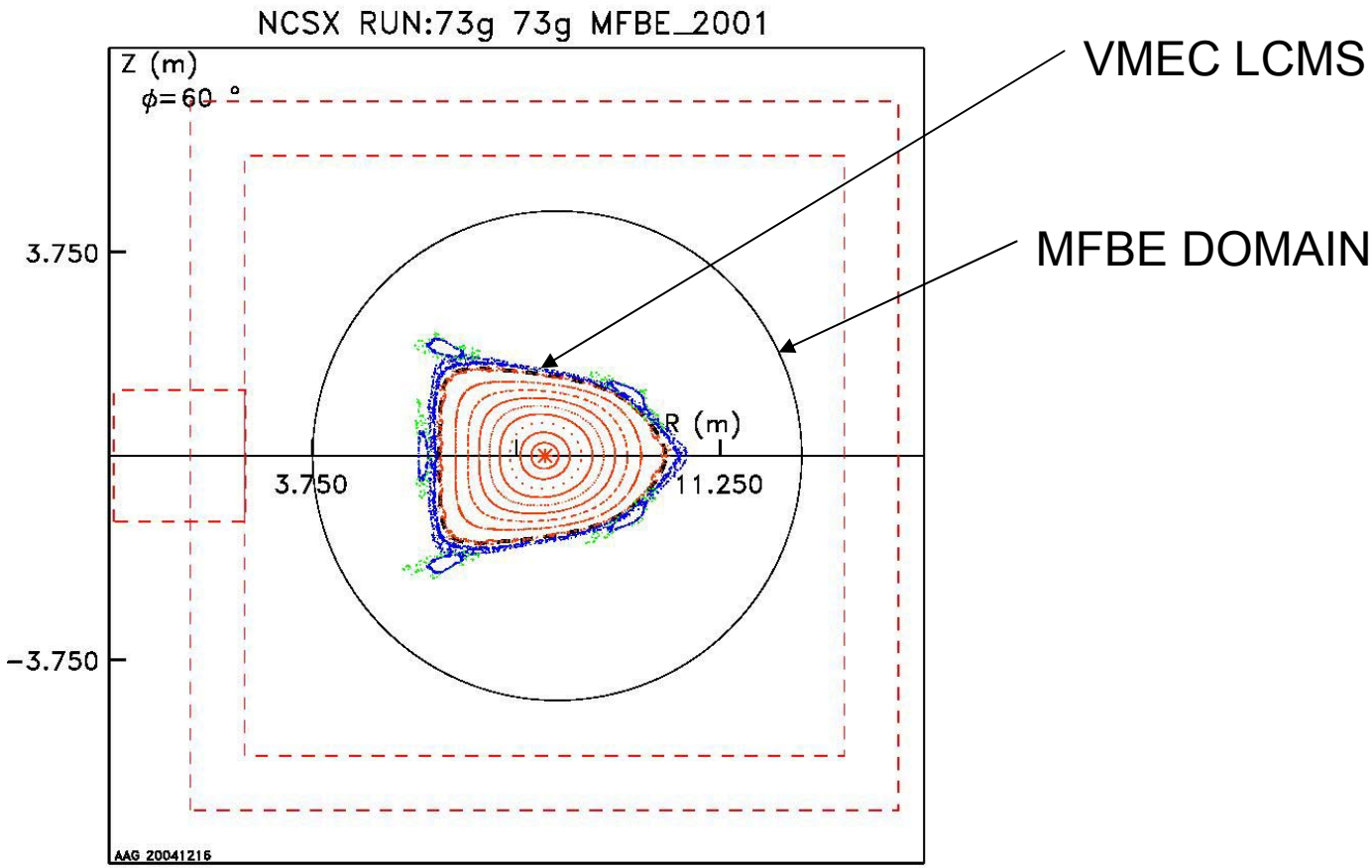
LCMS Agreement Achieved



VMEC Parameters Used

VACUUM FIELD PARAMETERS:

nr-grid	nz-grid	np-grid	rmin	rmax	zmin	zmax	input-file
101	101	30	2.500	13.534	-5.517	5.517	mgrid.m50kzd_r8.25b6.5

FREE BOUNDARY EQUILIBRIUM COMPUTATION PARAMETERS: (u = theta, v = zeta)

ns	nu	nv	mu	mv
49	28	30	11	6

Radial surfaces = 47 Poloidal grid points = 15 Toroidal grid points = 30
Poloidal modes = 11 Toroidal modes = 6

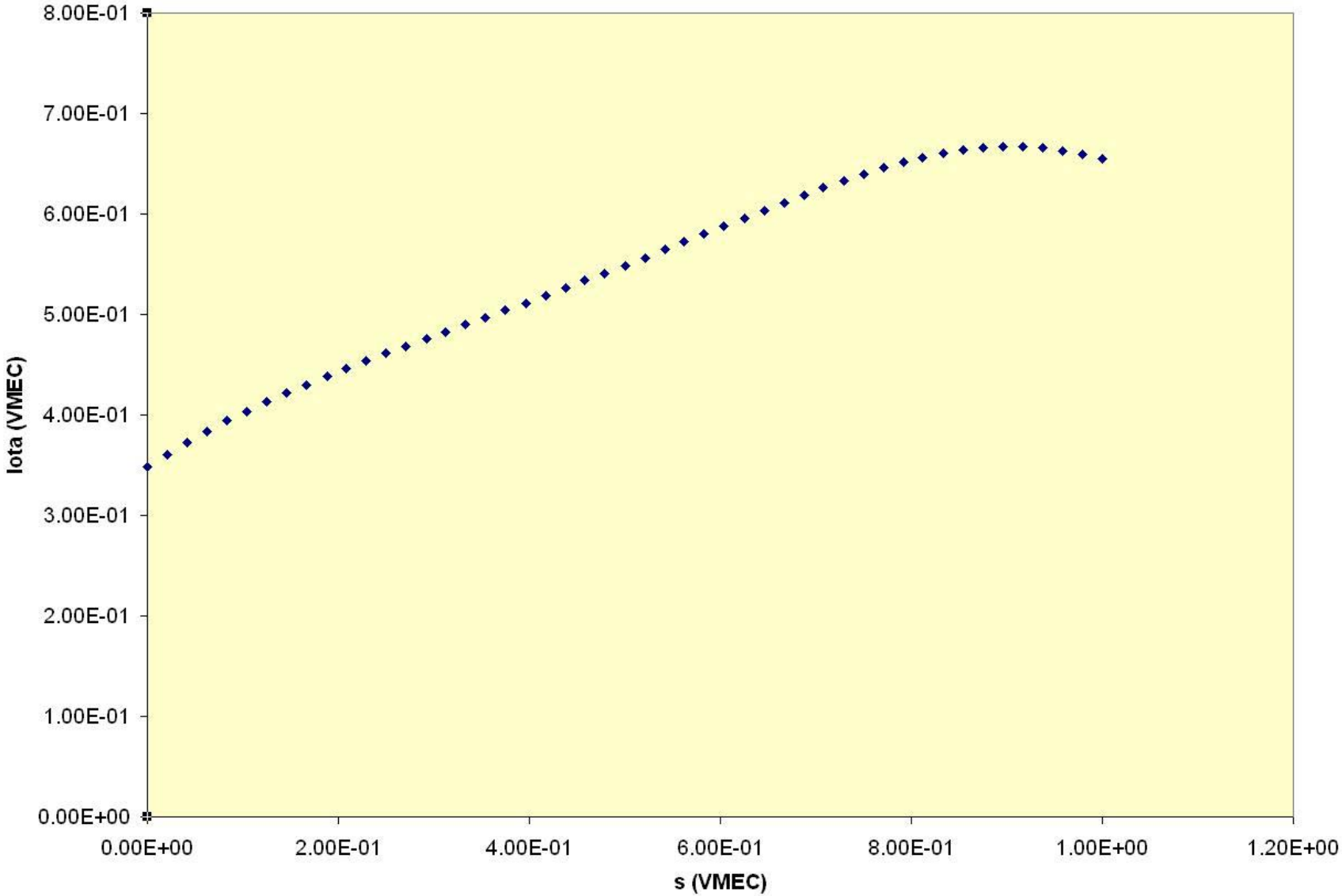
CONFIGURATION PARAMETERS:

nfp	gamma	spres_ped	phiedge(wb)	curtor(A)
3	0.000E+00	1.000E+00	6.931E+01	-4.347E+06

VMEC Output for iota from s=0 to 1

S	<RADIAL FORCE>	TOROIDAL FLUX	IOTA	<JPOL> (X mu0)	<JTOR> (X mu0)	d(VOL)/ d(PHI)	d(PRES)/ d(PHI)	<M>	PRESF	<BSUBV>	<J.B>	<B.B>
0.00E+00	-1.19E-01	0.000E+00	3.480E-01	7.439E-04	-4.796E-04	8.423E+00	-1.401E-03	1.000	1.238E+06	5.639E+01	-1.348E+05	4.222E+01
2.08E-02	-6.44E-02	1.444E+00	3.606E-01	1.660E-03	-1.153E-03	8.414E+00	-2.362E-03	1.036	1.235E+06	5.639E+01	-3.252E+05	4.211E+01
6.25E-02	-2.08E-03	4.332E+00	3.840E-01	3.547E-03	-2.385E-03	8.395E+00	-4.481E-03	1.119	1.227E+06	5.640E+01	-6.724E+05	4.222E+01
8.33E-02	-4.82E-04	5.776E+00	3.943E-01	4.627E-03	-2.860E-03	8.385E+00	-5.761E-03	1.161	1.221E+06	5.641E+01	-8.065E+05	4.227E+01
1.04E-01	-1.96E-04	7.220E+00	4.038E-01	5.769E-03	-3.296E-03	8.375E+00	-7.103E-03	1.203	1.214E+06	5.642E+01	-9.293E+05	4.233E+01
1.25E-01	2.02E-04	8.664E+00	4.129E-01	6.936E-03	-3.708E-03	8.365E+00	-8.464E-03	1.243	1.205E+06	5.643E+01	-1.045E+06	4.240E+01
1.88E-01	4.52E-04	1.300E+01	4.380E-01	1.027E-02	-4.898E-03	8.331E+00	-1.240E-02	1.360	1.169E+06	5.648E+01	-1.381E+06	4.262E+01
2.08E-01	5.26E-04	1.444E+01	4.458E-01	1.128E-02	-5.294E-03	8.318E+00	-1.363E-02	1.397	1.154E+06	5.650E+01	-1.492E+06	4.270E+01
2.71E-01	3.23E-04	1.877E+01	4.683E-01	1.402E-02	-6.514E-03	8.274E+00	-1.706E-02	1.502	1.101E+06	5.658E+01	-1.836E+06	4.300E+01
2.92E-01	3.45E-04	2.022E+01	4.756E-01	1.487E-02	-6.942E-03	8.258E+00	-1.816E-02	1.535	1.081E+06	5.660E+01	-1.957E+06	4.311E+01
3.12E-01	2.51E-04	2.166E+01	4.828E-01	1.569E-02	-7.386E-03	8.241E+00	-1.925E-02	1.567	1.059E+06	5.663E+01	-2.082E+06	4.323E+01
3.96E-01	1.63E-04	2.744E+01	5.115E-01	1.899E-02	-9.396E-03	8.165E+00	-2.379E-02	1.691	9.604E+05	5.676E+01	-2.649E+06	4.375E+01
4.17E-01	1.95E-04	2.888E+01	5.188E-01	1.984E-02	-9.965E-03	8.145E+00	-2.500E-02	1.721	9.324E+05	5.680E+01	-2.810E+06	4.390E+01
5.21E-01	9.77E-05	3.610E+01	5.565E-01	2.418E-02	-1.316E-02	8.037E+00	-3.150E-02	1.867	7.703E+05	5.701E+01	-3.714E+06	4.470E+01
5.42E-01	1.33E-04	3.755E+01	5.643E-01	2.499E-02	-1.384E-02	8.014E+00	-3.279E-02	1.895	7.333E+05	5.705E+01	-3.906E+06	4.488E+01
5.62E-01	9.07E-05	3.899E+01	5.722E-01	2.574E-02	-1.451E-02	7.991E+00	-3.403E-02	1.924	6.949E+05	5.710E+01	-4.096E+06	4.506E+01
5.83E-01	1.13E-04	4.043E+01	5.801E-01	2.641E-02	-1.517E-02	7.968E+00	-3.520E-02	1.952	6.552E+05	5.715E+01	-4.283E+06	4.524E+01
6.04E-01	7.23E-05	4.188E+01	5.880E-01	2.697E-02	-1.580E-02	7.944E+00	-3.626E-02	1.980	6.141E+05	5.719E+01	-4.461E+06	4.543E+01
6.25E-01	8.37E-05	4.332E+01	5.959E-01	2.741E-02	-1.639E-02	7.921E+00	-3.717E-02	2.007	5.719E+05	5.724E+01	-4.629E+06	4.562E+01
6.46E-01	5.14E-05	4.477E+01	6.037E-01	2.769E-02	-1.692E-02	7.897E+00	-3.790E-02	2.034	5.288E+05	5.729E+01	-4.781E+06	4.581E+01
6.67E-01	7.54E-05	4.621E+01	6.114E-01	2.780E-02	-1.738E-02	7.874E+00	-3.842E-02	2.061	4.849E+05	5.734E+01	-4.912E+06	4.601E+01
6.88E-01	2.83E-05	4.765E+01	6.188E-01	2.769E-02	-1.774E-02	7.851E+00	-3.867E-02	2.087	4.406E+05	5.739E+01	-5.017E+06	4.620E+01
7.08E-01	4.05E-05	4.910E+01	6.261E-01	2.738E-02	-1.799E-02	7.828E+00	-3.864E-02	2.112	3.962E+05	5.744E+01	-5.089E+06	4.640E+01
7.29E-01	-2.47E-05	5.054E+01	6.331E-01	2.682E-02	-1.809E-02	7.805E+00	-3.827E-02	2.137	3.520E+05	5.749E+01	-5.119E+06	4.659E+01
7.50E-01	-3.10E-05	5.199E+01	6.396E-01	2.601E-02	-1.802E-02	7.783E+00	-3.754E-02	2.161	3.085E+05	5.754E+01	-5.102E+06	4.678E+01
7.71E-01	-9.48E-05	5.343E+01	6.458E-01	2.496E-02	-1.775E-02	7.761E+00	-3.642E-02	2.184	2.660E+05	5.759E+01	-5.027E+06	4.697E+01
7.92E-01	-1.14E-04	5.487E+01	6.513E-01	2.365E-02	-1.724E-02	7.740E+00	-3.489E-02	2.205	2.250E+05	5.763E+01	-4.886E+06	4.715E+01
8.12E-01	-1.93E-04	5.632E+01	6.562E-01	2.211E-02	-1.648E-02	7.720E+00	-3.293E-02	2.226	1.860E+05	5.767E+01	-4.671E+06	4.733E+01
8.33E-01	-2.25E-04	5.776E+01	6.604E-01	2.034E-02	-1.543E-02	7.700E+00	-3.054E-02	2.245	1.496E+05	5.771E+01	-4.374E+06	4.750E+01
8.54E-01	-3.00E-04	5.921E+01	6.636E-01	1.835E-02	-1.407E-02	7.682E+00	-2.771E-02	2.264	1.161E+05	5.774E+01	-3.991E+06	4.765E+01
8.75E-01	-3.23E-04	6.065E+01	6.658E-01	1.618E-02	-1.242E-02	7.664E+00	-2.446E-02	2.282	8.611E+04	5.777E+01	-3.522E+06	4.780E+01
8.96E-01	-3.93E-04	6.209E+01	6.669E-01	1.383E-02	-1.047E-02	7.648E+00	-2.083E-02	2.299	6.008E+04	5.780E+01	-2.970E+06	4.794E+01
9.17E-01	-3.89E-04	6.354E+01	6.668E-01	1.132E-02	-8.295E-03	7.633E+00	-1.686E-02	2.317	3.843E+04	5.782E+01	-2.350E+06	4.806E+01
9.38E-01	-5.34E-04	6.498E+01	6.654E-01	8.636E-03	-5.969E-03	7.619E+00	-1.262E-02	2.335	2.149E+04	5.784E+01	-1.689E+06	4.817E+01
9.58E-01	-5.62E-04	6.643E+01	6.629E-01	5.767E-03	-3.645E-03	7.607E+00	-8.193E-03	2.355	9.527E+03	5.785E+01	-1.029E+06	4.826E+01
9.79E-01	-2.17E-03	6.787E+01	6.594E-01	2.654E-03	-1.545E-03	7.597E+00	-3.689E-03	2.377	2.700E+03	5.786E+01	-4.353E+05	4.833E+01
1.00E+00	-3.77E-03	6.931E+01	6.554E-01	-4.673E-04	5.614E-04	7.587E+00	8.156E-04	2.403	-1.539E+03	5.786E+01	1.587E+05	4.840E+01

Iota increases from 0.348 (at s=0) to 0.655 (s=1)


8.00E-01
7.00E-01
6.00E-01
5.00E-01
4.00E-01
3.00E-01
2.00E-01
1.00E-01
0.00E+00
Iota (VMEC)
0.00E+00
2.00E-01
4.00E-01
6.00E-01
8.00E-01
1.00E+00
1.20E+00
s (VMEC)

Iota results from field line tracing INSIDE the VMEC LCMS

- Startpunkte der Feldlinien:
- r0mi= 9.2220 m r0ma= 10.0400 m ir0= 10
- z0mi= 0.0000 m phi0g= 0.00
- hpasz= 0.0120
- npper= 120 ntour= 200
- nlin= 72001
- feldlinie nr. 1 lss= 72001 jota/periode= 0.113813 jota/umfang= 0.341438 sxmn= 0.840564E+01
- feldlinie nr. 2 lss= 72001 jota/periode= 0.120303 jota/umfang= 0.360908 sxmn= 0.840527E+01
- feldlinie nr. 3 lss= 72001 jota/periode= 0.127038 jota/umfang= 0.381114 sxmn= 0.838882E+01
- feldlinie nr. 4 lss= 72001 jota/periode= 0.136369 jota/umfang= 0.409107 sxmn= 0.836066E+01
- feldlinie nr. 5 lss= 72001 jota/periode= 0.146742 jota/umfang= 0.440226 sxmn= 0.831744E+01
- feldlinie nr. 6 lss= 72001 jota/periode= 0.158354 jota/umfang= 0.475063 sxmn= 0.824824E+01
- feldlinie nr. 7 lss= 72001 jota/periode= 0.172029 jota/umfang= 0.516088 sxmn= 0.814268E+01
- feldlinie nr. 8 lss= 72001 jota/periode= 0.189713 jota/umfang= 0.569138 sxmn= 0.799126E+01
- feldlinie nr. 9 lss= 72001 jota/periode= 0.210609 jota/umfang= 0.631826 sxmn= 0.779526E+01
- feldlinie nr. 10 lss= 72001 jota/periode= 0.216544 jota/umfang= 0.649631 sxmn= 0.760273E+01

Iota increases monotonically from 0.34 (magnetic axis) to 0.65 at LCMS

Iota results from field line tracing OUTSIDE the VMEC LCMS

- Startpunkte der Feldlinien:
- r0mi= 10.0500 m r0ma= 10.1500 m ir0= 10
- z0mi= 0.0000 m phi0g= 0.00
- hpasz= 0.0120
- npper= 120 ntour= 200
- nlin= 72001
- feldlinie nr. 1 lss= 72001 jota/periode= 0.210637 jota/umfang= 0.631910 sxmn= 0.754624E+01
- feldlinie nr. 2 lss= 72001 jota/periode= 0.210487 jota/umfang= 0.631460 sxmn= 0.754406E+01
- feldlinie nr. 3 lss= 72001 jota/periode= 0.206757 jota/umfang= 0.620272 sxmn= 0.751220E+01
- feldlinie nr. 4 lss= 23831 jota/periode= 0.201769 jota/umfang= 0.605306 sxmn= 0.747842E+01
- feldlinie nr. 5 lss= 8509 jota/periode= 0.201870 jota/umfang= 0.605611 sxmn= 0.749065E+01
- feldlinie nr. 6 lss= 19160 jota/periode= 0.201996 jota/umfang= 0.605987 sxmn= 0.748787E+01
- feldlinie nr. 7 lss= 72001 jota/periode= 0.199968 jota/umfang= 0.599905 sxmn= 0.746228E+01
- feldlinie nr. 8 lss= 3838 jota/periode= 0.197705 jota/umfang= 0.593115 sxmn= 0.747763E+01
- feldlinie nr. 9 lss= 2603 jota/periode= 0.196192 jota/umfang= 0.588575 sxmn= 0.750775E+01
- feldlinie nr. 10 lss= 2023 jota/periode= 0.195336 jota/umfang= 0.586007 sxmn= 0.750623E+01

Iota decreases from 0.63 when the LCMS is crossed, forming the 3/5 island chain at iota =0.60 and then decreases to 0.586 for starting point 10cm from LCMS

Relation of lss to Ergodicity

- npper = number of toroidal cross sections per period
- ntour = number of toroidal turns of the field line
- np = number of periods

- lss=npper*ntour*np+1

Example maximum lss for the specified 200 turns:
lss=120*200*3+1=72001

- Maximum of lss points per field line.
- If lss is smaller than the maximum number, the field line is ergodic and has left the box of the magnetic field.

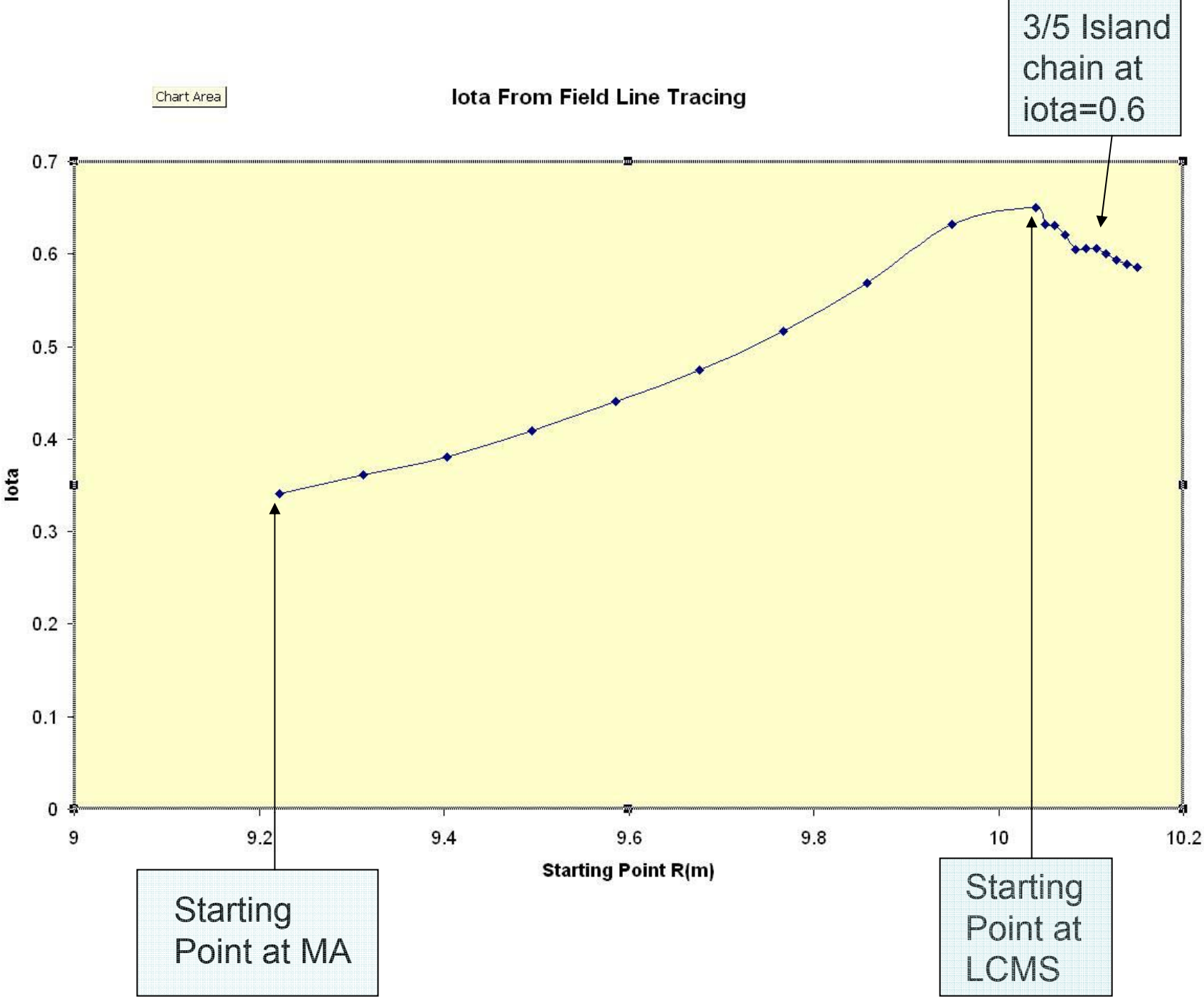


Chart Area
Iota From Field Line Tracing
3/5 Island chain at iota=0.6
Iota
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
9
9.2
9.4
9.6
9.8
10
10.2
Starting Point R(m)
Starting Point at MA
Starting Point at LCMS

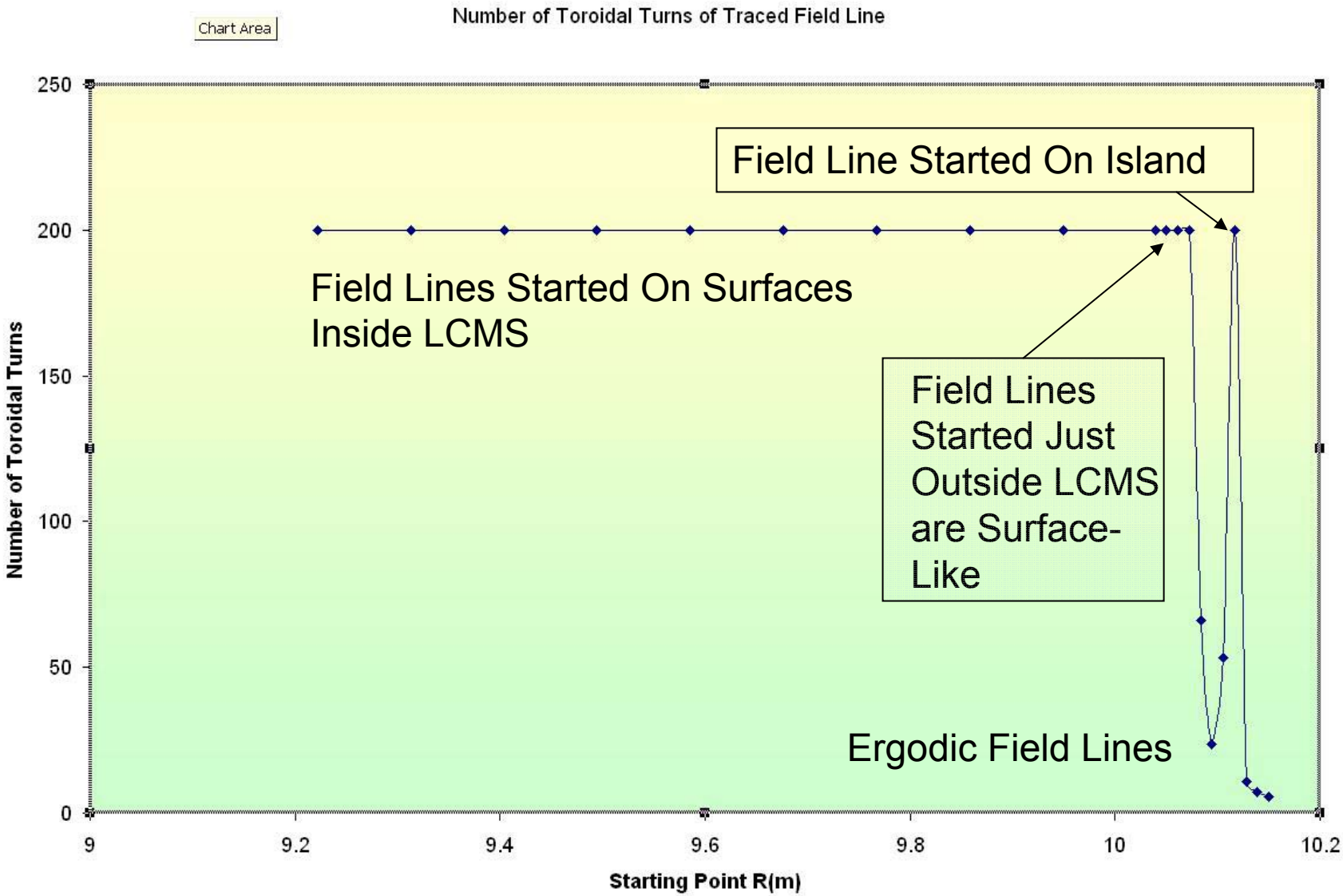
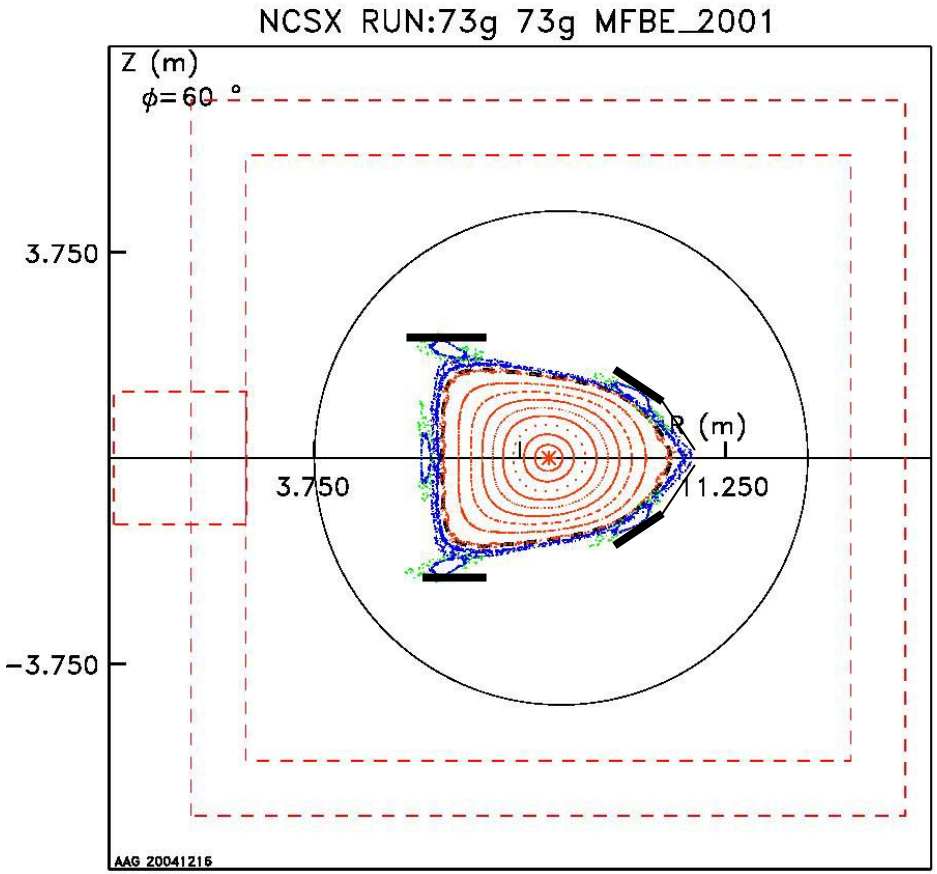


Chart Area
Number of Toroidal Turns of Traced Field Line
Number of Toroidal Turns
250
200
150
100
50
0
9
9.2
9.4
9.6
9.8
10
10.2
Starting Point R(m)
Field Line Started On Island
Field Lines Started On Surfaces Inside LCMS
Field Lines Started Just Outside LCMS are Surface-Like
Ergodic Field Lines

Island Divertor Concept

Particle and power flow around periphery of islands



Plates located at cross-sections where island width is maximized.

Conclusions

- Problems with the non-agreement between MFBE and VMEC LCMS's were resolved.
- A large increase in the number of processors and toroidal planes was found not to be necessary for good agreement in LCMS's.
- Iotas from MFBE field line traces and VMEC output are consistent.
- A 3/5 Island structure outside the LCMS consistent with iota=0.6 is clearly seen. The maximum width of these islands was obtained at the bullet shaped cross-section.