An Update on Divertor Heat Load Analysis and Derived Geometry

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ARIES-CS Project Meeting

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OUTLINE

- Update on CS Configurations for divertor study.
- Considerations on divertor design
- Setting up divertor configuration with GEOM
- Magnetic topology study near LCMS with GOURDON
- Status of divertor heat load study
- Quick review of divertor designs for W7-X and HSR
- Summary and future work

Status of CS Configurations for Divertor Study

- NCSX-ARE (R = 7 m):
  - Effort to generate closed flux surfaces inside LCMS with field line tracing has not been successful, perhaps caused by the non-convergence of the MFBE field mapping.

- NCSX-KZD (R = 8.25 m):
  - Was able to generate closed flux surfaces inside LCMS with field line tracing, and produce ergodic region near LCMS.
  - Divertor study will be based on this configuration from now on.

Main Considerations for Divertor Design

- Achieve **low peaking factor** for heat load distribution on the target (<10)
  - Locate target plate in flux expansion zone far from the LCMS
  - Plate surface inclined or shaped to allow near-grazing incidence of heat flux
- **Minimize the surface area** of the divertor plate so coverage of first wall area is limited to below 10%.
  - Place target close to LCMS with dense field line crossing

Finding the Right Divertor Plate Configuration

- Divertor configuration is characterized by a large number of parameters:
  - Distance of plate from LCMS
  - Location target plate (toroidal and poloidal angles)
  - Size of plate surface (toroidal and poloidal extent)
  - Number of plates per field period and their locations
  - Shape (topology) of plate surface

$\Rightarrow$ Use an analytic model to describe divertor configuration.

- Use existing divertor design studies for hints and guidance.
  - W7-X
  - HSR

An Analytic Model for Divertor Plate Geometry

- Assume the divertor plate is located between conformal to the LCMS with offset distances of d_1 and d_2, between toroidal angles $\square_1 < \square < \square_2$ and between poloidal angles $\square_1 < \square < \square_2$. The area of the plate is given by the poloidal extent $\square\square$ and toroidal extent $\square\square$, and the divertor plate center is at $(\square_o, \square_o)$.

- The coordinates of the plate surface are then given by

  $R_{pl}(\square,\square) = R_{d2}(\square,\square) + [R_{dl}(\square,\square) - R_{d2}(\square,\square)]\ \square(\square,\square)$

  $Z_{pl}(\square,\square) = Z_{d2}(\square,\square) + [Z_{dl}(\square,\square) - Z_{d2}(\square,\square)]\ \square(\square,\square)$

  where

$$\square(\square,\square) = \square 1.\square \frac{|\square\square\square_o|}{\square\square} \square \frac{|\square\square\square_o|}{\square\square} \square^{\square_1} \square 1 \square 2 \frac{|\square\square\square_o|}{\square\square} \square^{\square_2} \square 1 \square 2 \frac{|\square\square\square_o|}{\square\square} \square^{\square_3}$$

  with $\square\square = \square_2 - \square_1$, and $\square\square = \square_2 \square\square_1$.

  The parameters $\square_1$, $\square_2$ and $\square_3$ control the shape of the plate surface.

- The two surfaces with offset distances of d_1 and d_2 are given by their respective Fourier series representations:

$$R_d(\square,\square) = \sum_{n_d, m_d} R_c(d)\cos(m_d\square + n_d\square)$$

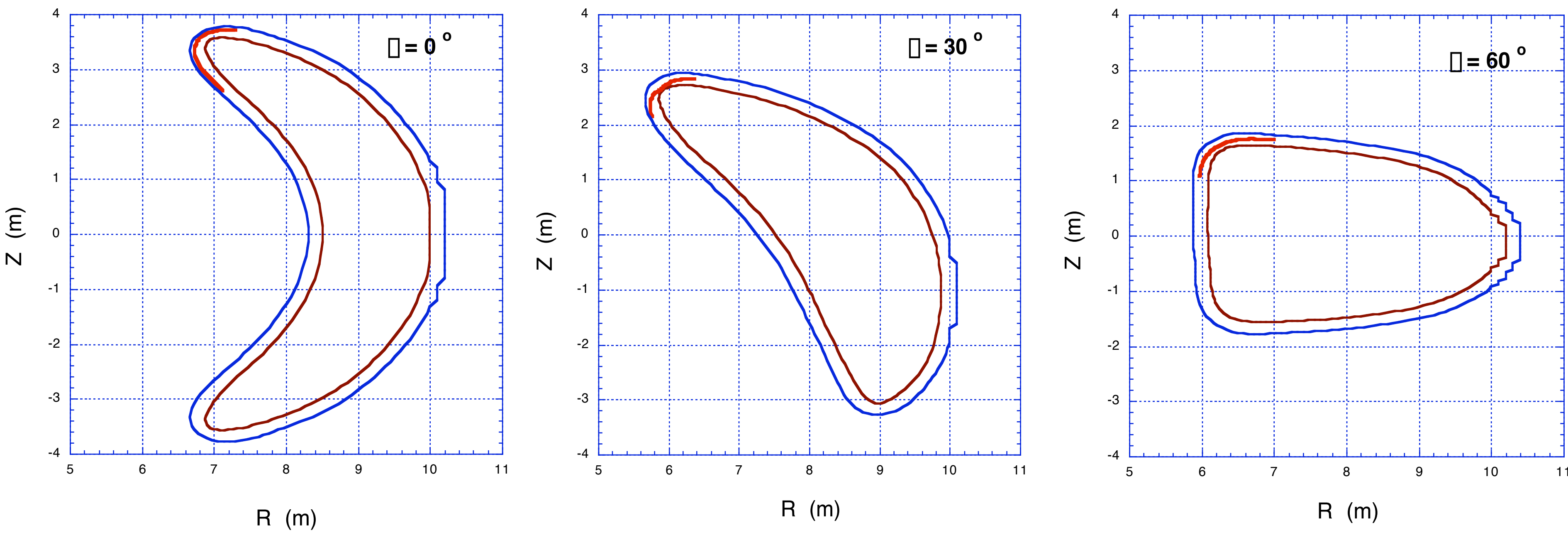
$$Z_d(\square,\square) = \sum_{n_d, m_d} Z_c(d)\sin(m_d\square + n_d\square)$$

An Example "Conformal" Divertor Plate Geometry

(based on NCSX case with R = 8.25 m)

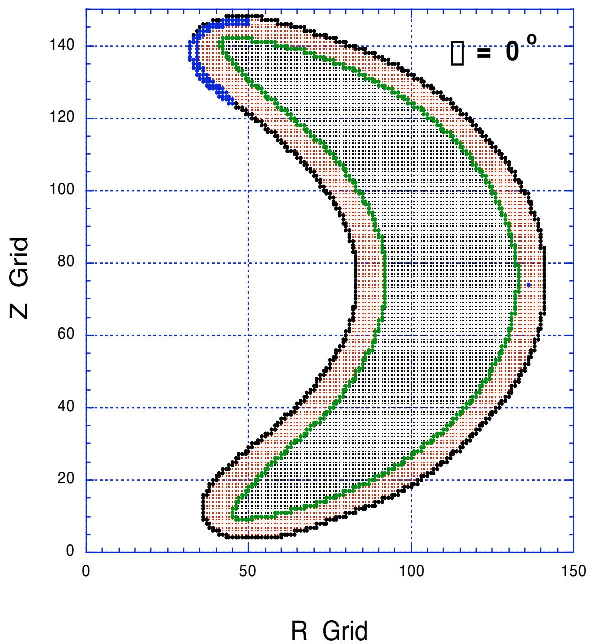
- This plate is located at $□_o$ = 30 ^{o}, $□_o$ ≈ 105^o -- 130 ^{o}, with □□ = 60^o, □□ = 40^o, between the d = 2 cm and d = 15 cm surfaces. It covers half of each field period.

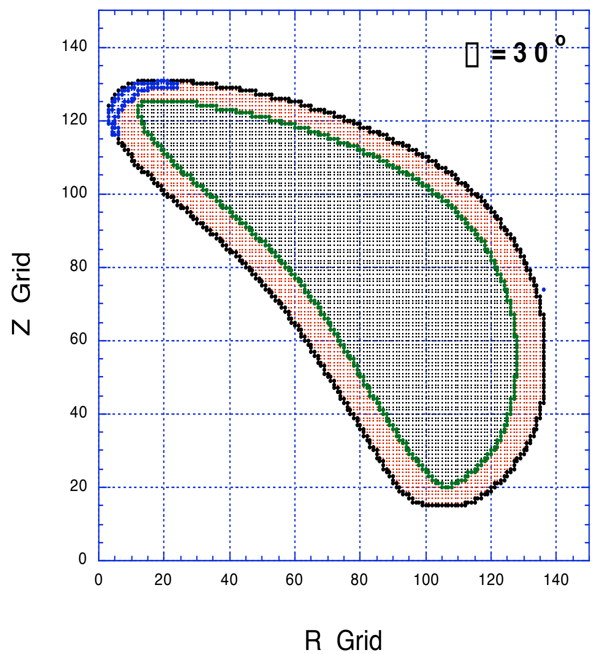
- The surface is inwardly convex from the d = 15 cm surface and peaks at ($□_o$,$□_o$) with an offset distance of 2 cm. Shape factors: $□_1$ = $□_2$ = $□_3$ =1.

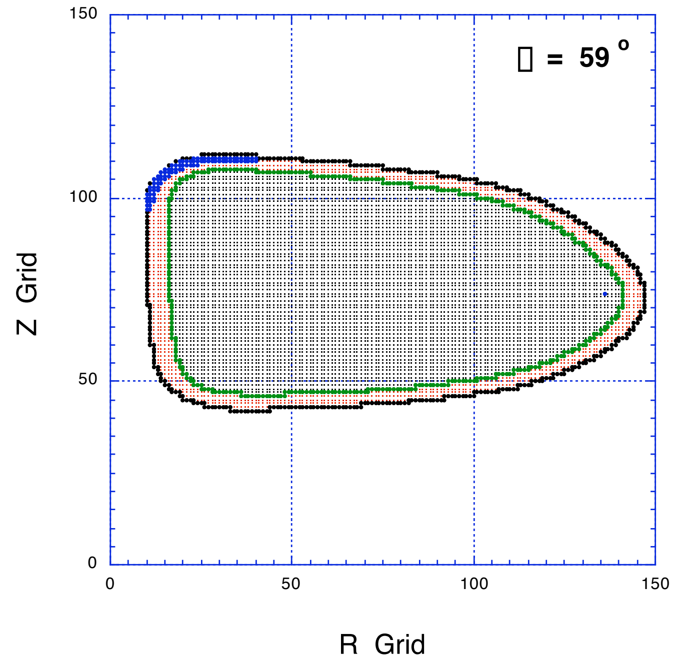


Various Regions and Surfaces are Successfully Tagged with GEOM in Preparation for Field Line Tracing

- Regions include (1) plasma, (2) SOL and (3) divertor.
- Surfaces include (1) LCMS, (2) first-wall and (3) target plate.



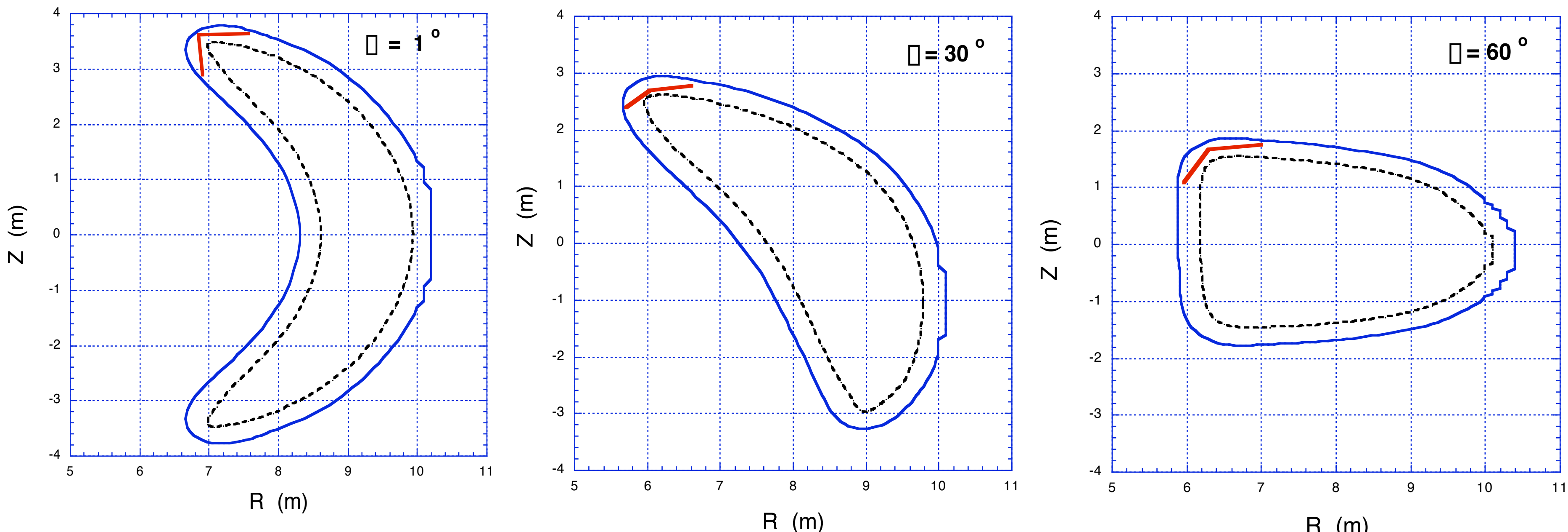




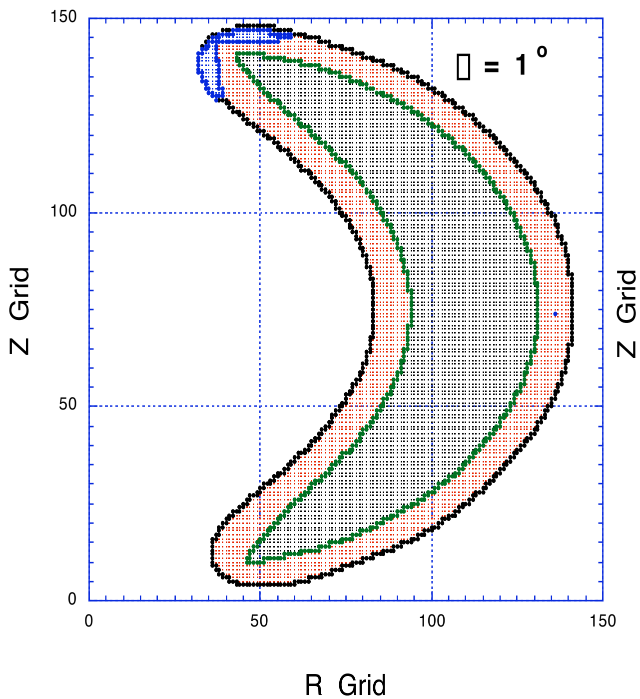
An Example Flat Target Plate Geometry

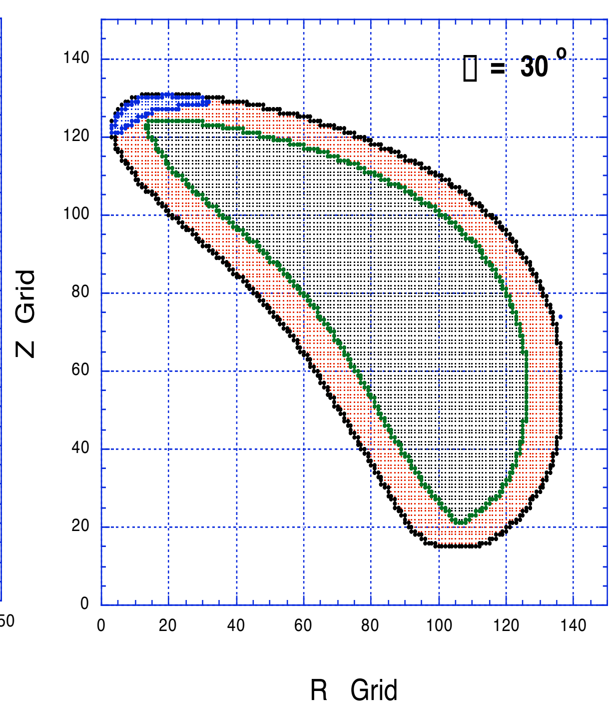
NCSX-like; R = 8.25 m

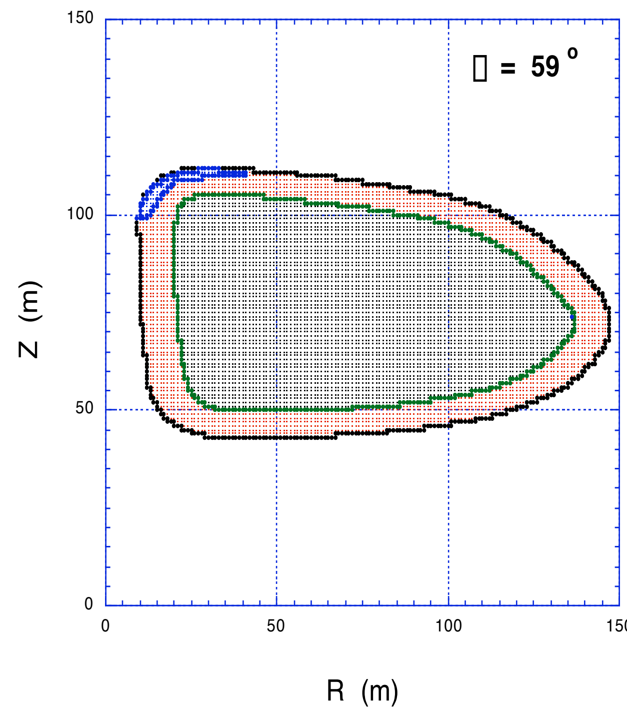
- A flat target plate geometry (similar to W-7X) can be modeled by specifying three points along the surface, using the analytic model.



Tagged Regions & Surfaces for Flat Target Plates

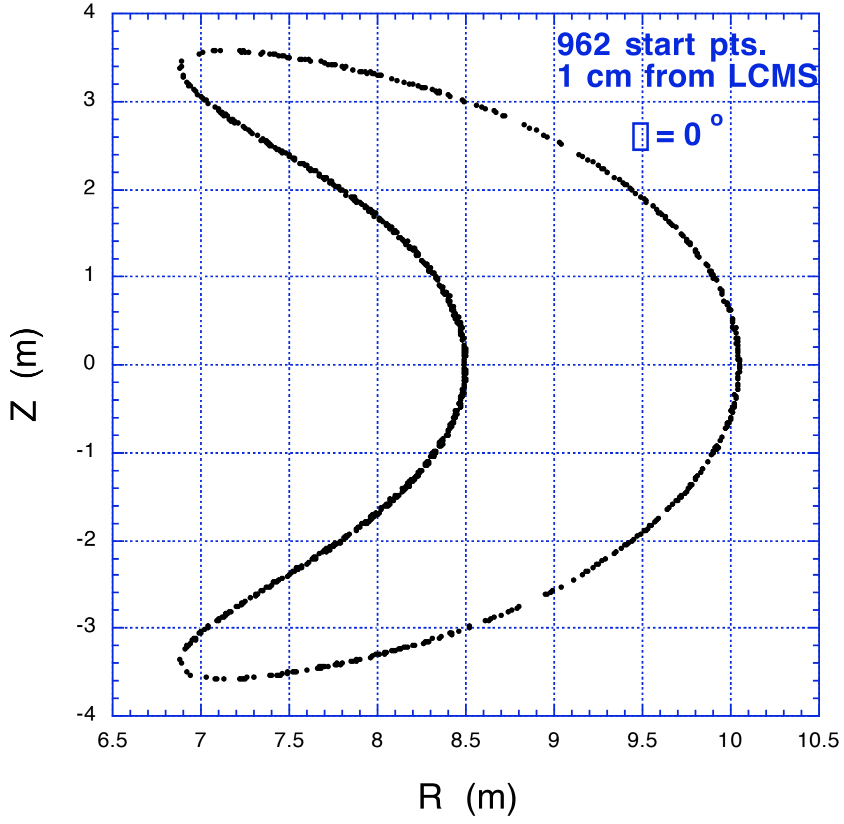


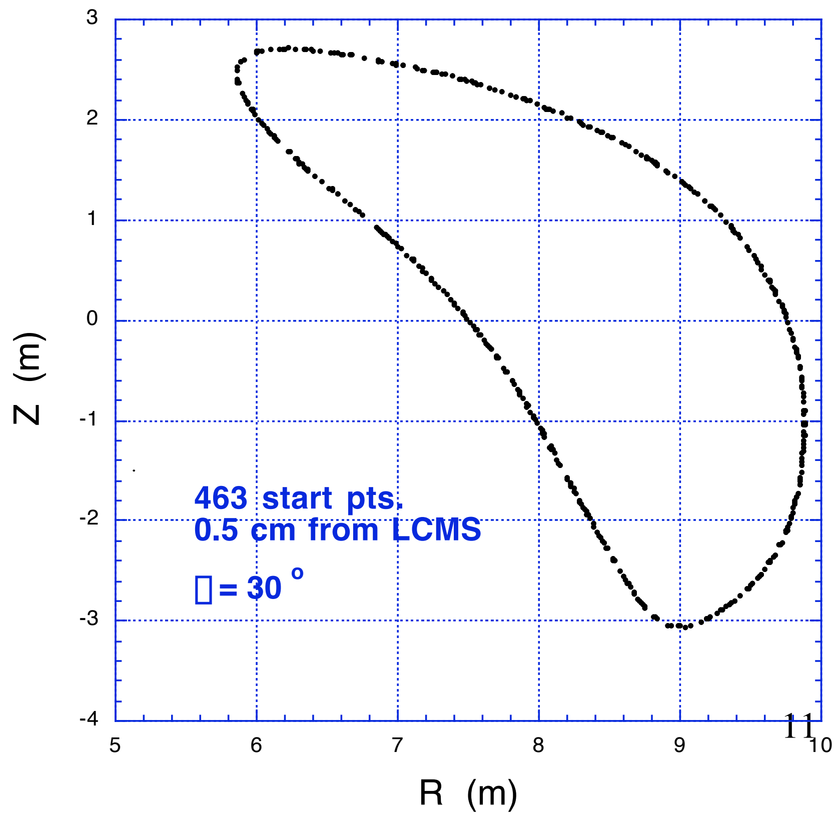




Field Line Starting Points at Two Toroidal Planes

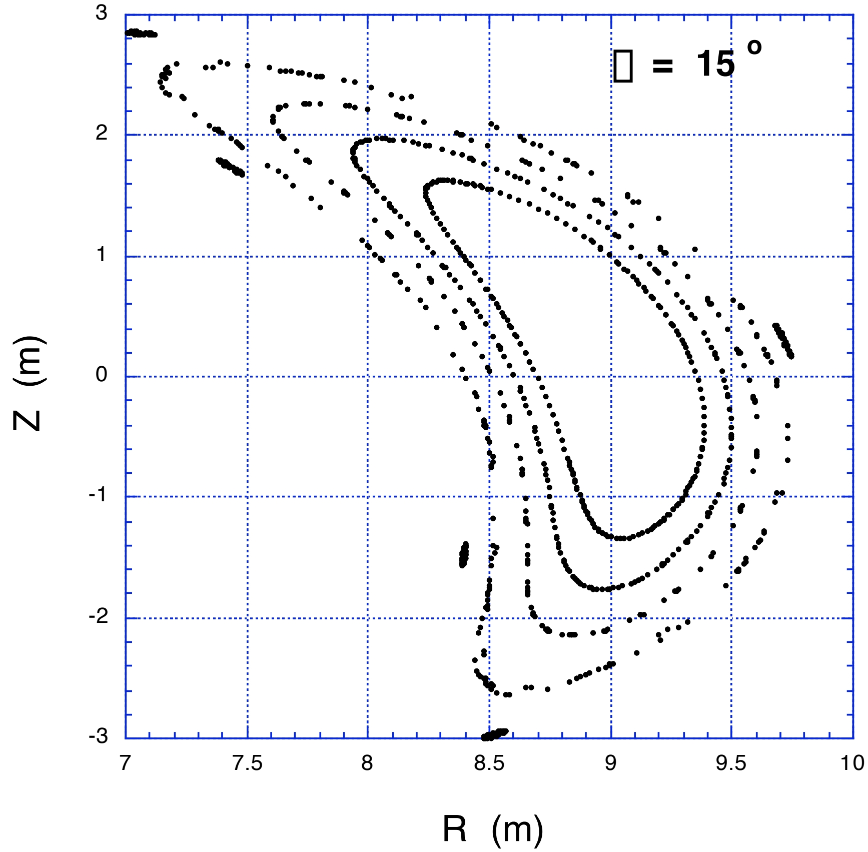
- Points are within 1 cm and 0.5 cm outside the LCMS.
- A total of 962 (464) starting points have been generated on the = 0º (30º) plane.





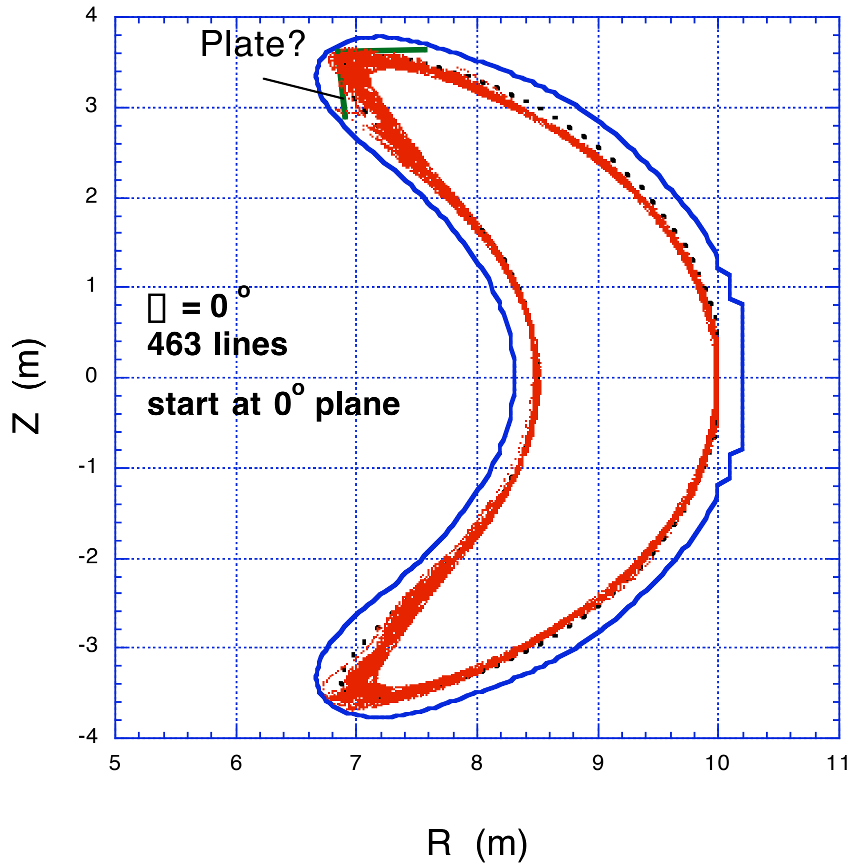
Field Line Tracing Closed Flux Surfaces Inside LCMS Verifies GOURDON Working Properly

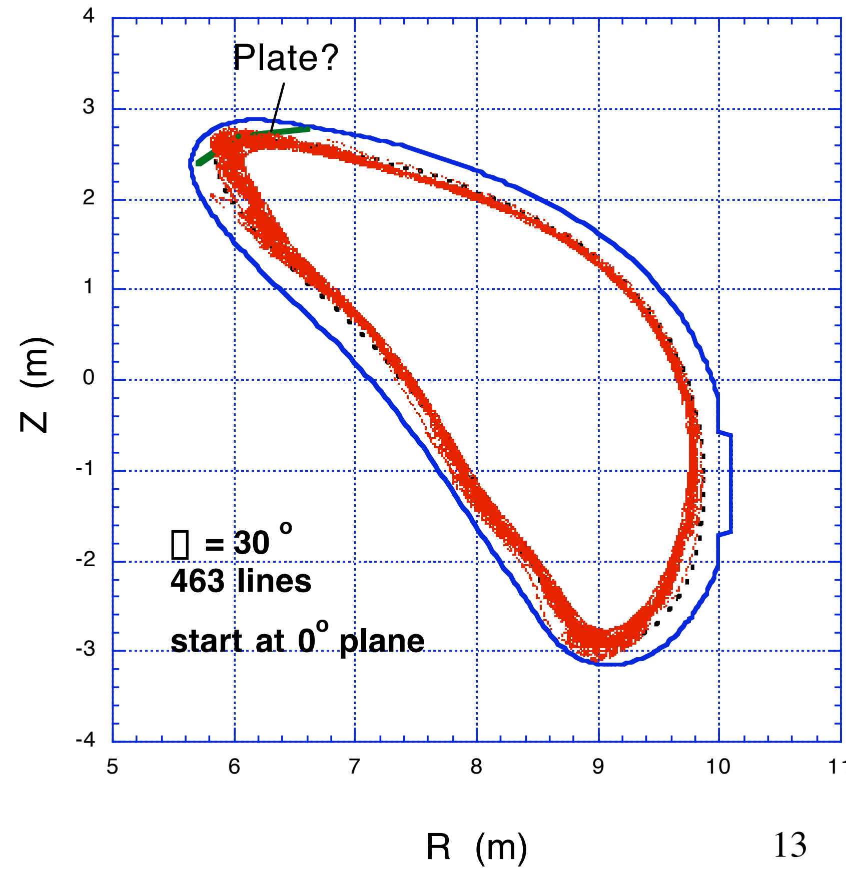
- A single field line started at = 0º inside LCMS traces out a closed magnetic flux surface.
- A remnant m=5 island structure is traced in the outer region, also inside LCMS.



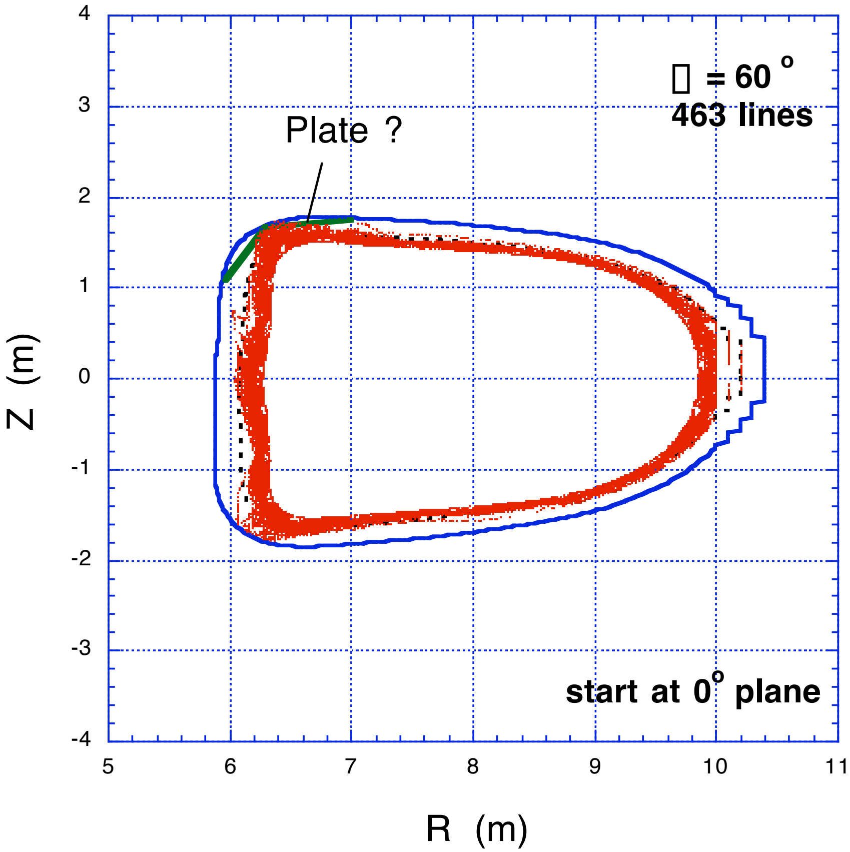
Magnetic Topology Turns Ergodic in LCMS Region

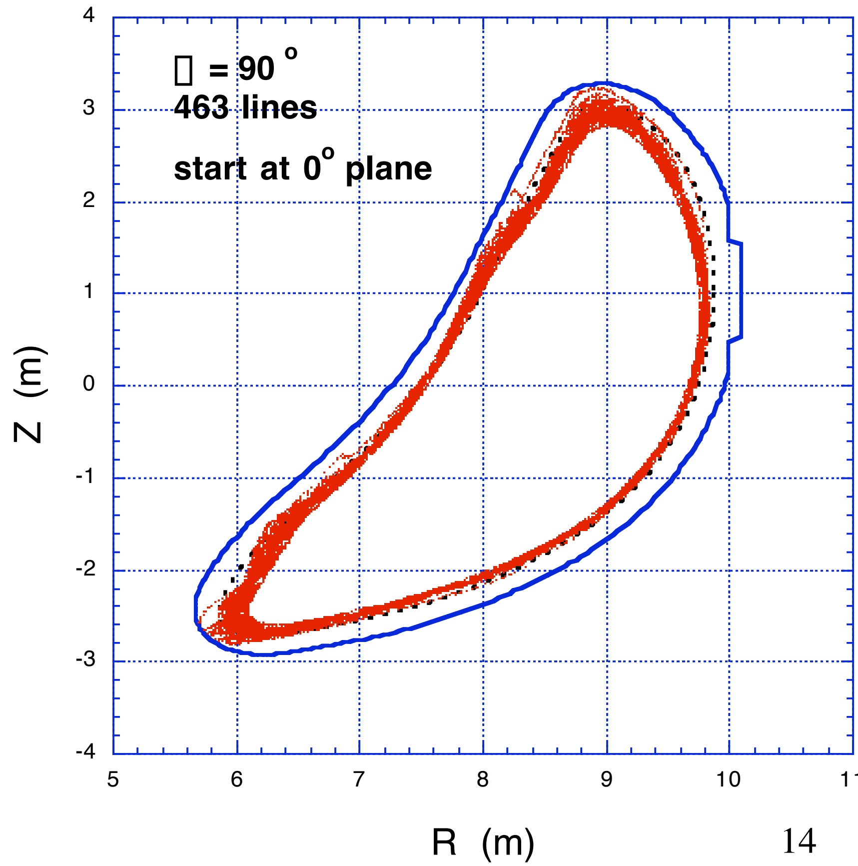
- Flux expansion is observed in regions of sharp curvature.
- There appears to be a remnant m=5 island structure present.





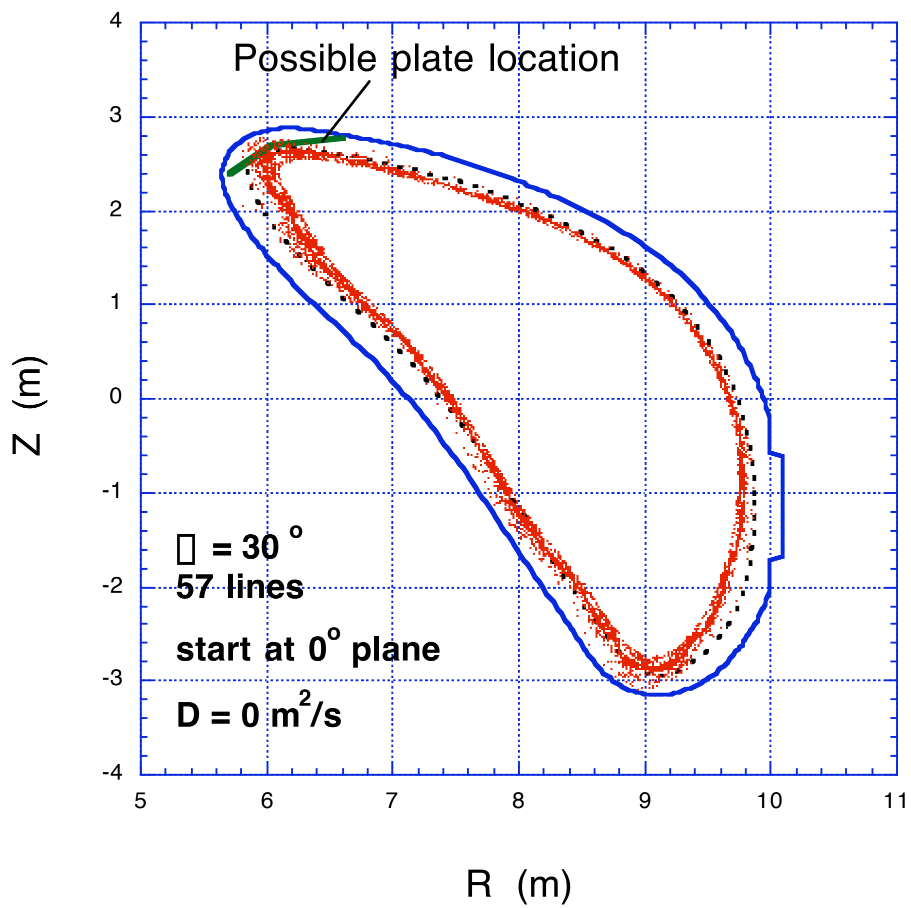
Magnetic Topology in LCMS Region (Cont'd)

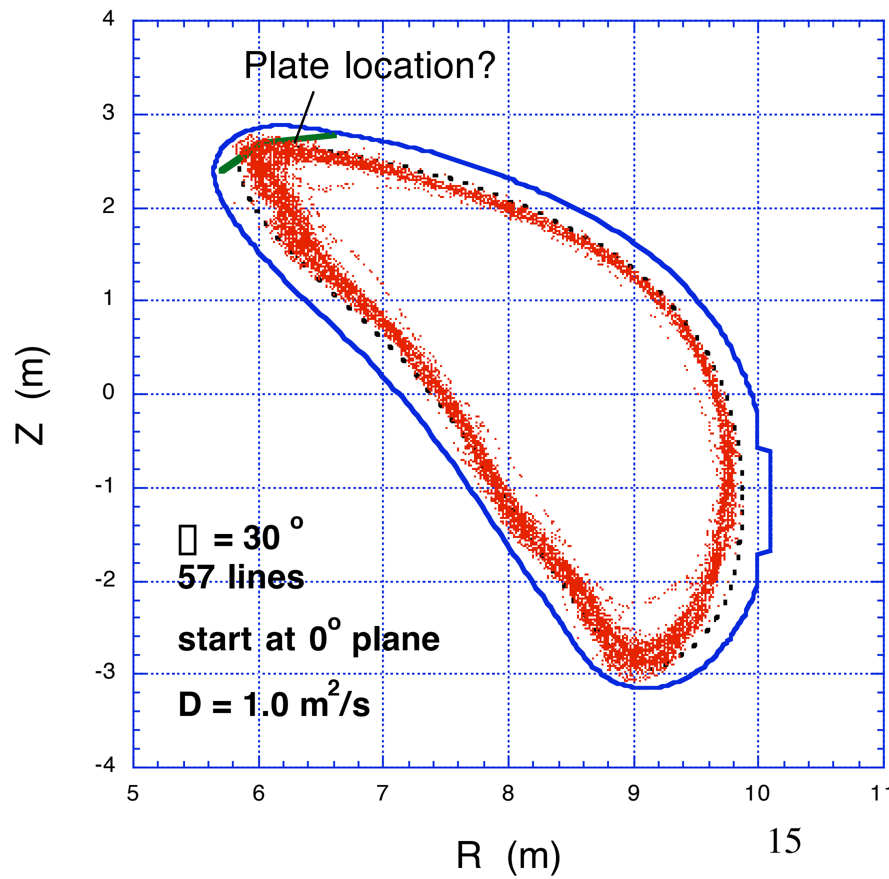




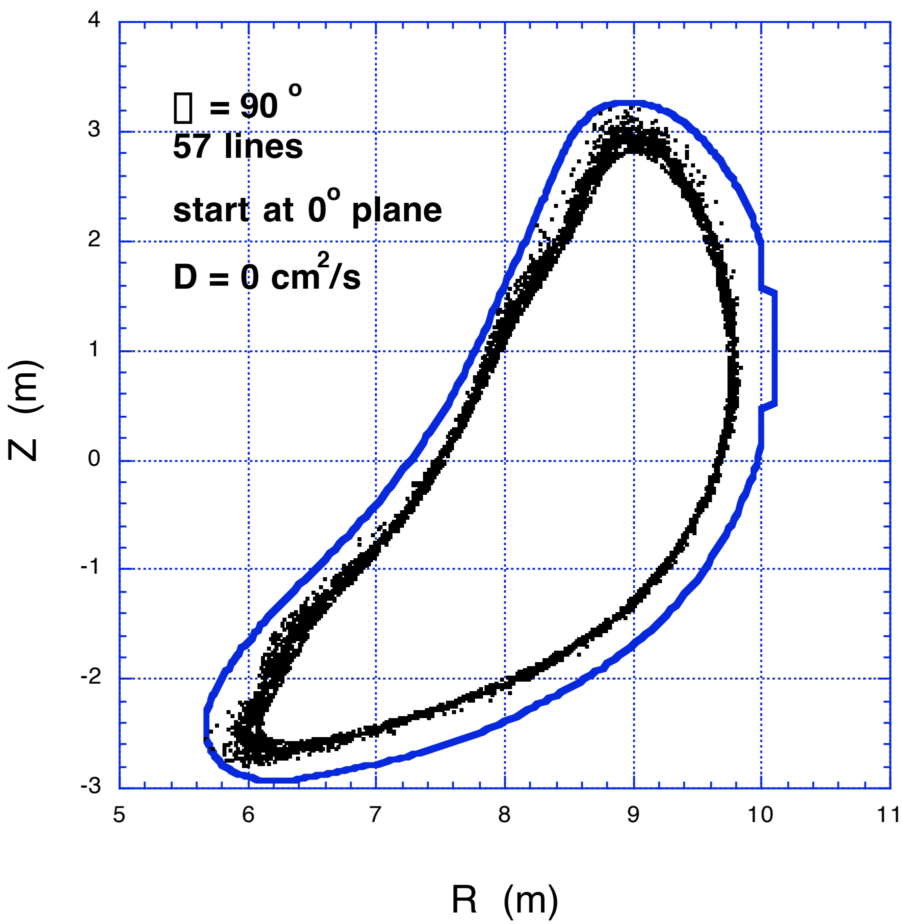
Effect of a non-zero diffusion coefficient

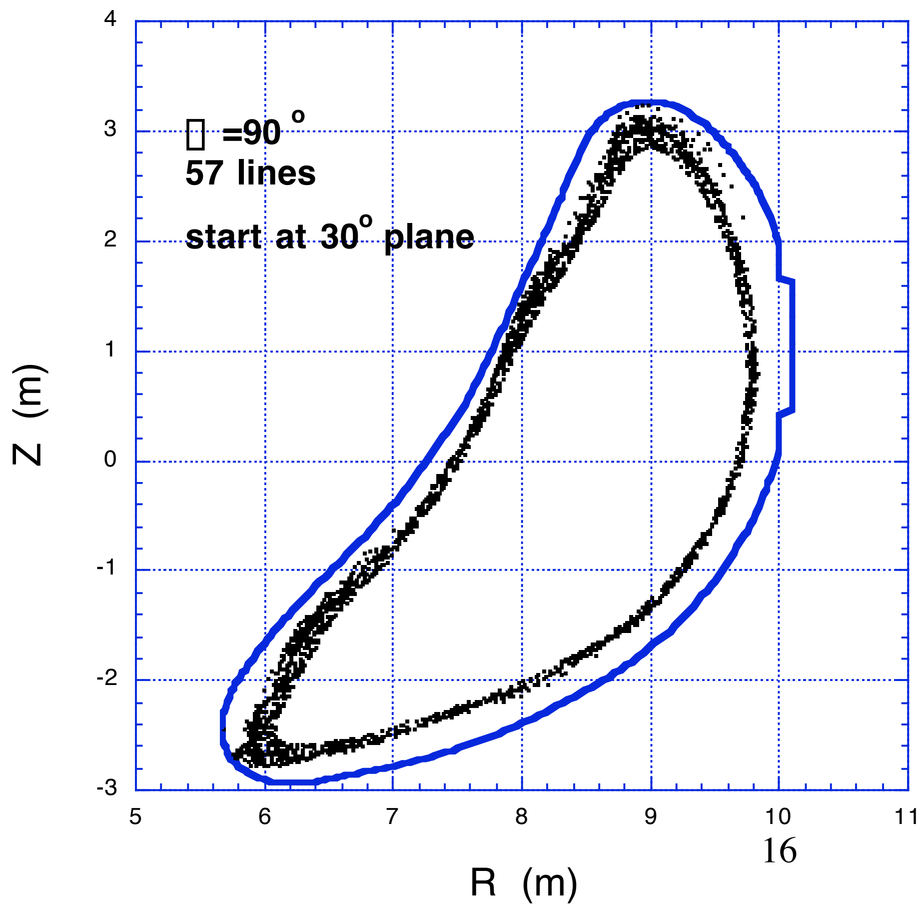
- The radial diffusion appears to thicken the ergodic zone (towards the inside?).
- The diffusion model assumes both the direction and magnetic of the step size to be random.





Traced Magnetic Topology appears Independent of Toroidal Launch Location



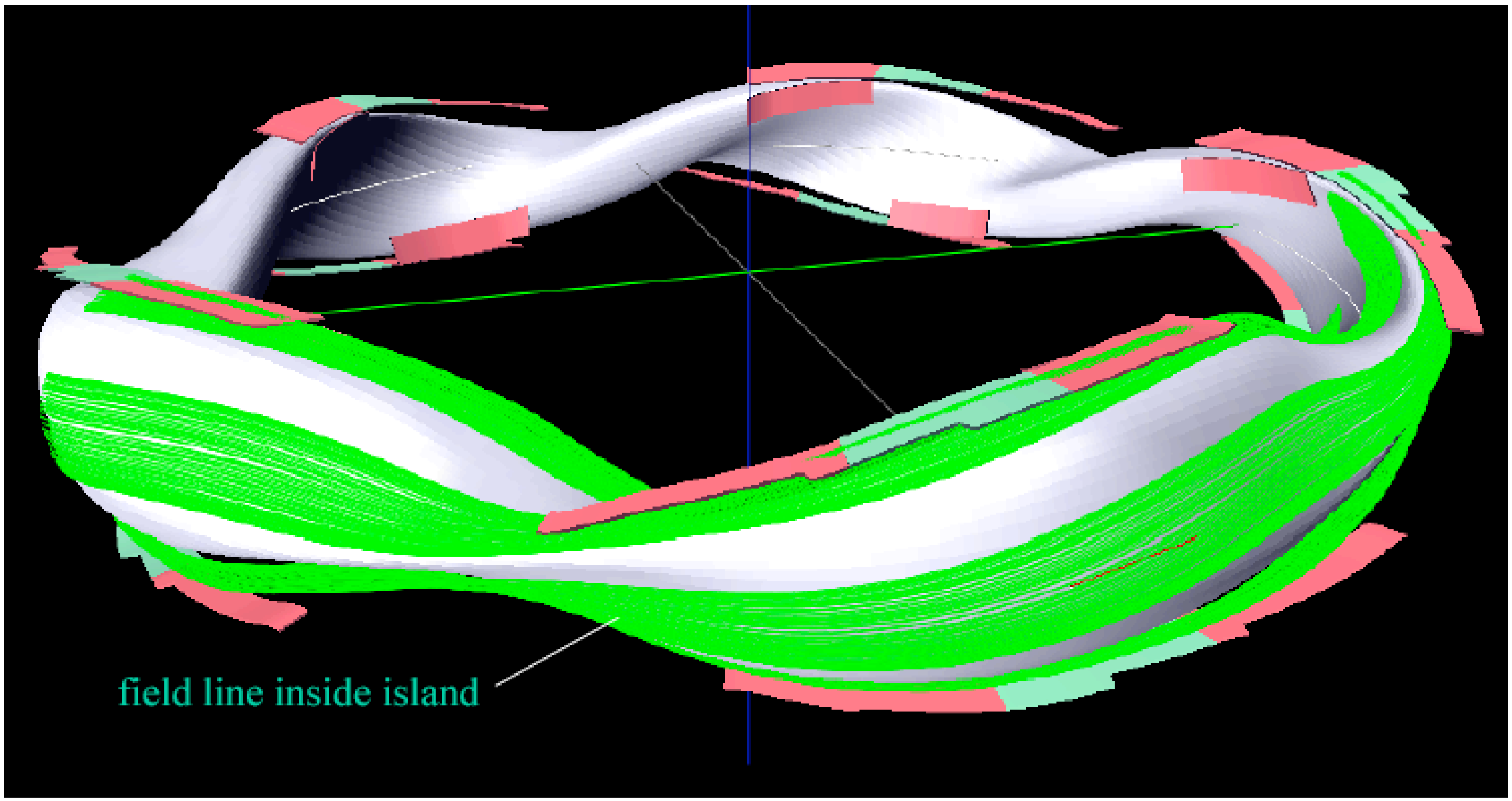


Status of GOURDON/GEOM Run with Plate

- A few test runs with ~100 field lines for a "conformal" plate geometry in the R=8.25 case resulting in field lines intercepting either the wall or the divertor plate, or still circulating after ~200 toroidal transits.
- Each of these runs uses up to 6 hours of clock time on SEABORG and was stopped before the heat load relevant output files are generated. This may be caused by excessive time used by the process of identifying strike point locations and is being investigated.
- The latest run with 57 field lines also takes 6 hours of clock time which seems excessive. Less than 10 of these lines strike the plates implying the initial plate geometry needs to be improved.
- Because of the above problems, the time allocated in the repository in SEABORG has all been used up.
- More time allocation is required to continue the divertor study.

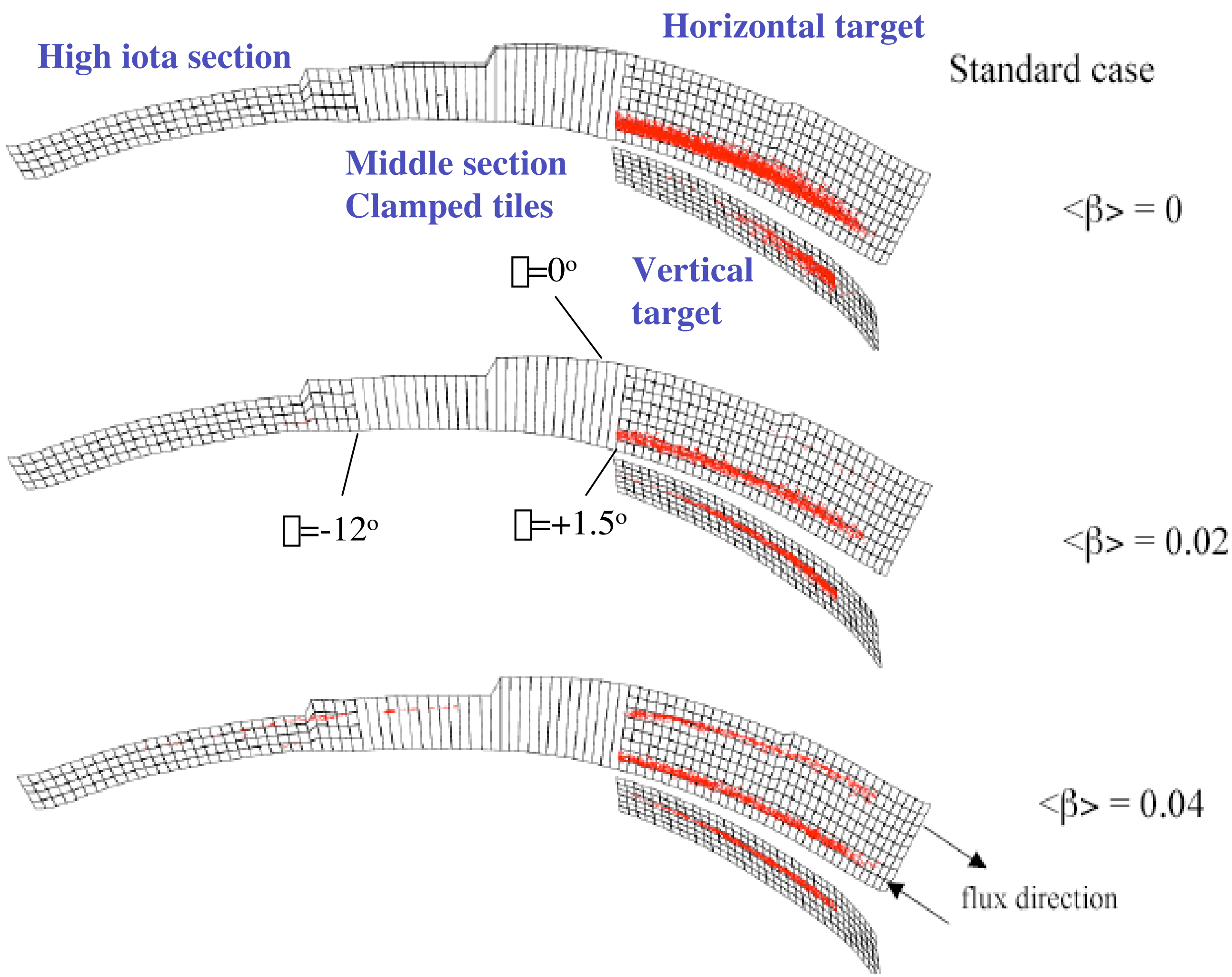
Geometry of target plates

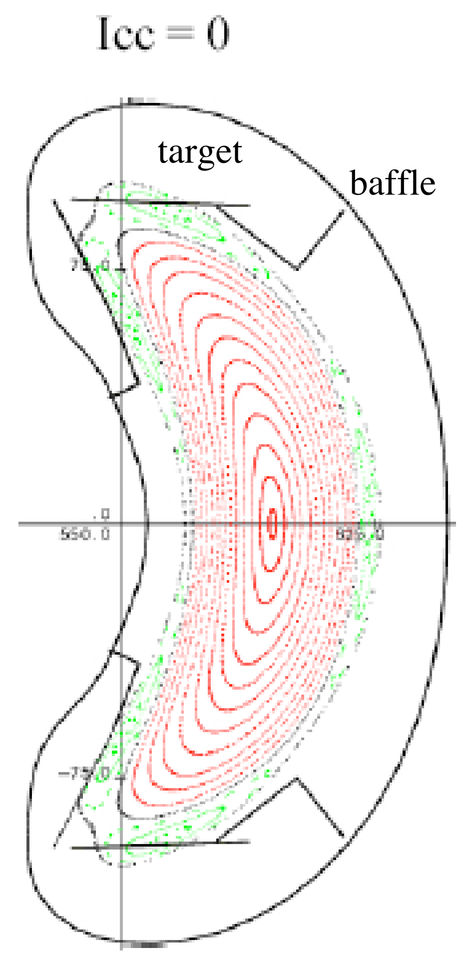
(Based on Island Divertor concept)



Target/baffle coverage ≈ 20%

Target/Baffle Configuration and Footprints for W7-X Divertor



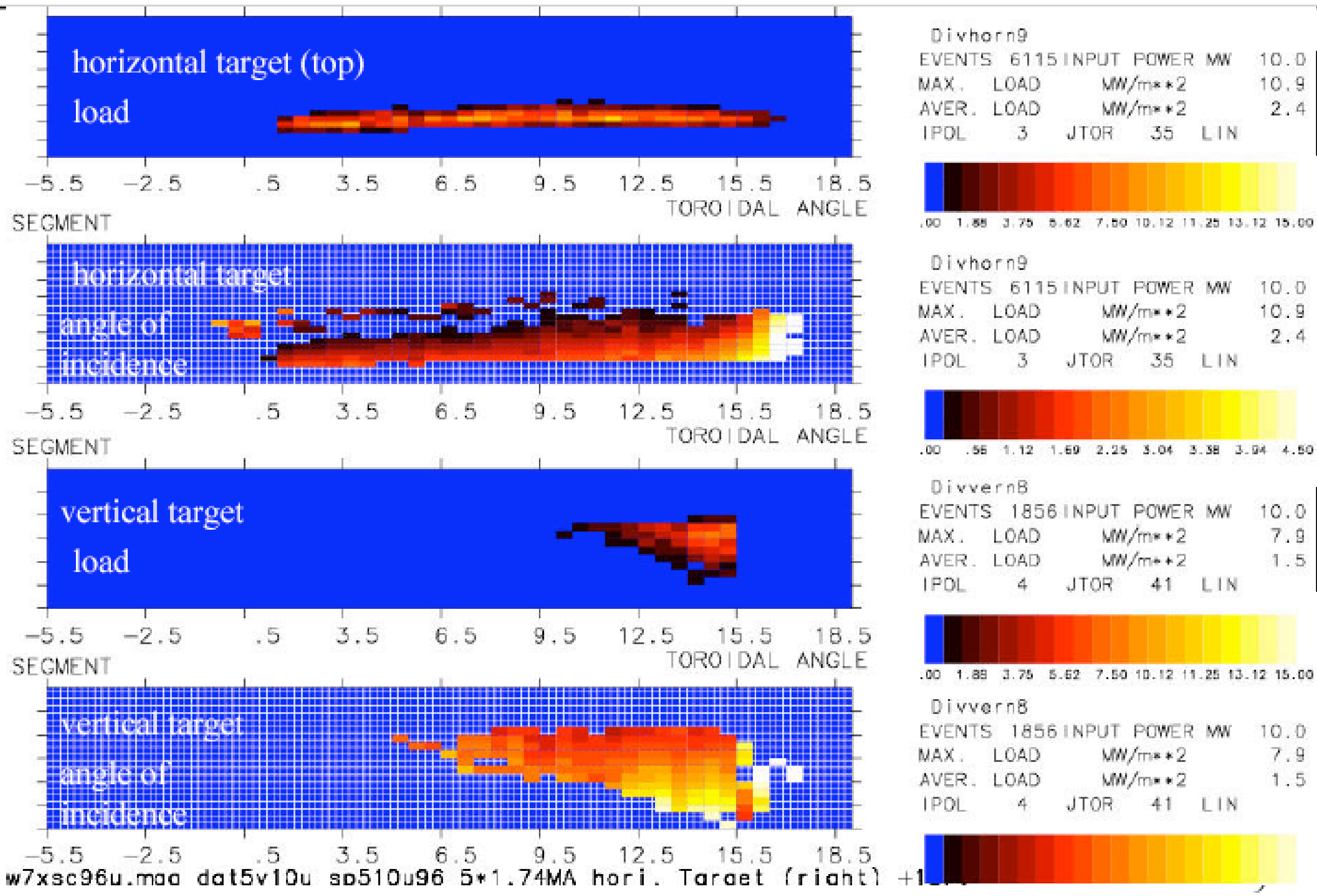


From Kiblinger via Lyon

WENDELSTEIN 7-X

Impact of magnetic configuration: Standard case, <β>=0; load and angle of incidence

IPP



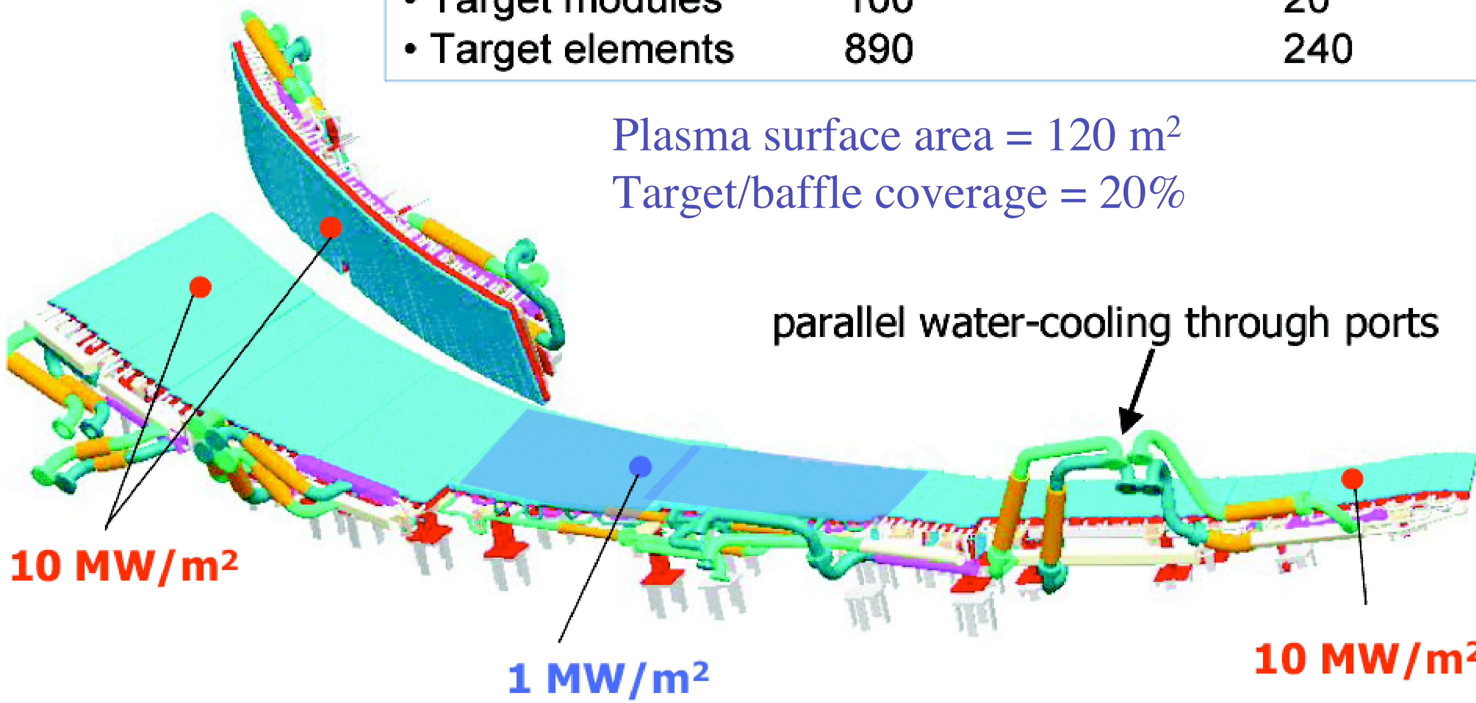
Peaking Factor=4.5

Peaking Factor=5.3

WENDELSTEIN 7-X
divertor module

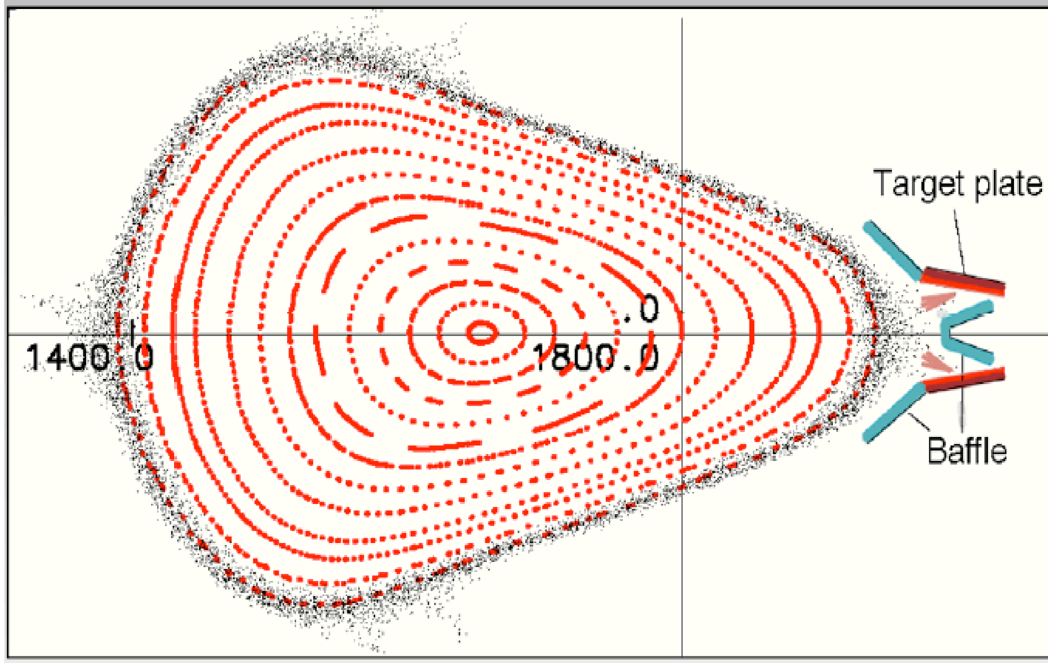
	Target	Baffle
• Max. P/A	10 MW/m²	1 MW/m²
• Total area	19 m²	5.6 m²
• Target modules	100	20
• Target elements	890	240

Plasma surface area = 120 m^2
Target/baffle coverage = 20%



Bosch via Jim Lyon

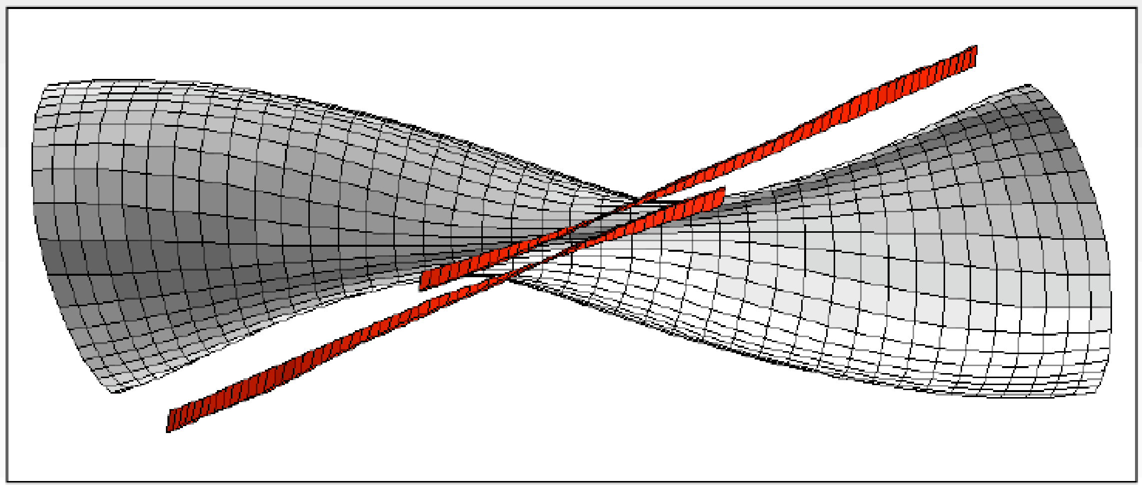
HSR4/18 Divertor



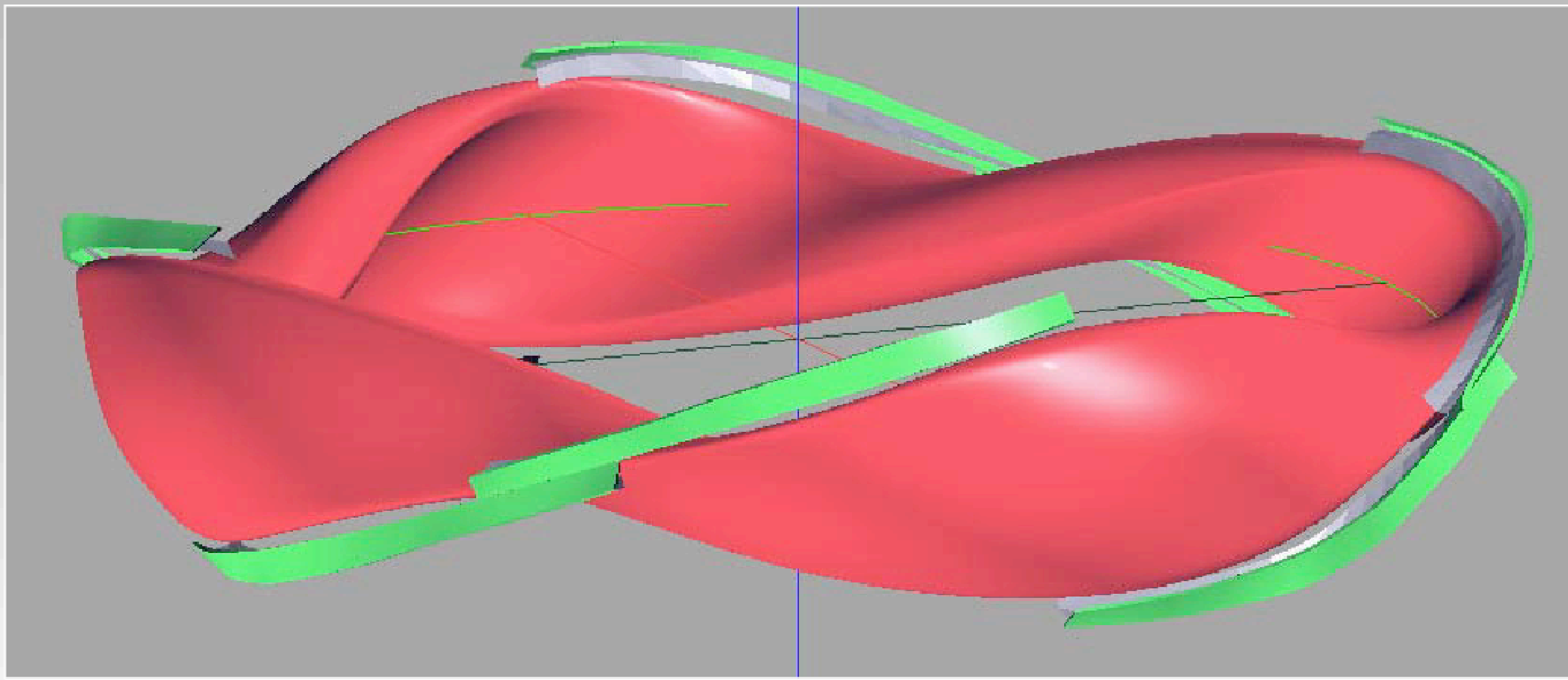
The last magnetic surface is enclosed by a stochastic region.

Remnants of 4/4 islands are utilized for divertor action

8 Target plates
Length 15 m
Width 1m
Segment length 2 m
Wetted area 40 m^2



HSR4/18 Divertor



8 Target plates
Length 15 m
Width 1m
Segment length 2 m
Wetted area 40 m^2

Plasma surface area = 2700 m^2
Target area = 148 m^2
Baffle area = 128 m^2
Target/Baffle coverage ≈ 10%

Summary

- Divertor plate geometry is being studied with R=8.25m NCSX-based case.
- Two initial divertor plate geometries, "conformal" and flat, have been set up and tagged successfully with GEOM.
- GOURDON has been run to do field line tracing near the LCMS. An ergodic magnetic topology has been obtained with what appears to be a weak island structure and with localized flux expansion zones where targets plates may be located.
- GOURDON/GEOM runs with target included encounter excessive run-time issues that generate little heat load information. Because of this, time allocation is used up in SEABORG repository.
- From divertor study results for W7-X and HSR, the divertor design goals can be reached for ARIES-CS. Our limited capabilities will allow to address only the target heat load issue.

Future Work

- Our ultimate objective is to optimize the divertor configuration to achieve low peaking factor and minimize diveror plate surface area, by following the strategy outlined. Work will be focused on the NCSX R=8.25 m configuration.

- Specifically, very near term, we need to resolve the numerical problems when running GOURDON/GEOM with plate included.

- Finish the incorporation of GYRO into GOURDON/GEOM, and determine the total heat load distribution on divertor plates and the first wall.

- Hopefully, Michael Canavan (RPI) will be able to contribute to running GOURDON/GEOM for divertor optimzation..