PROGRESS ON
DIVERTOR HEAT LOAD ASSESSMENT

T.K. Mau

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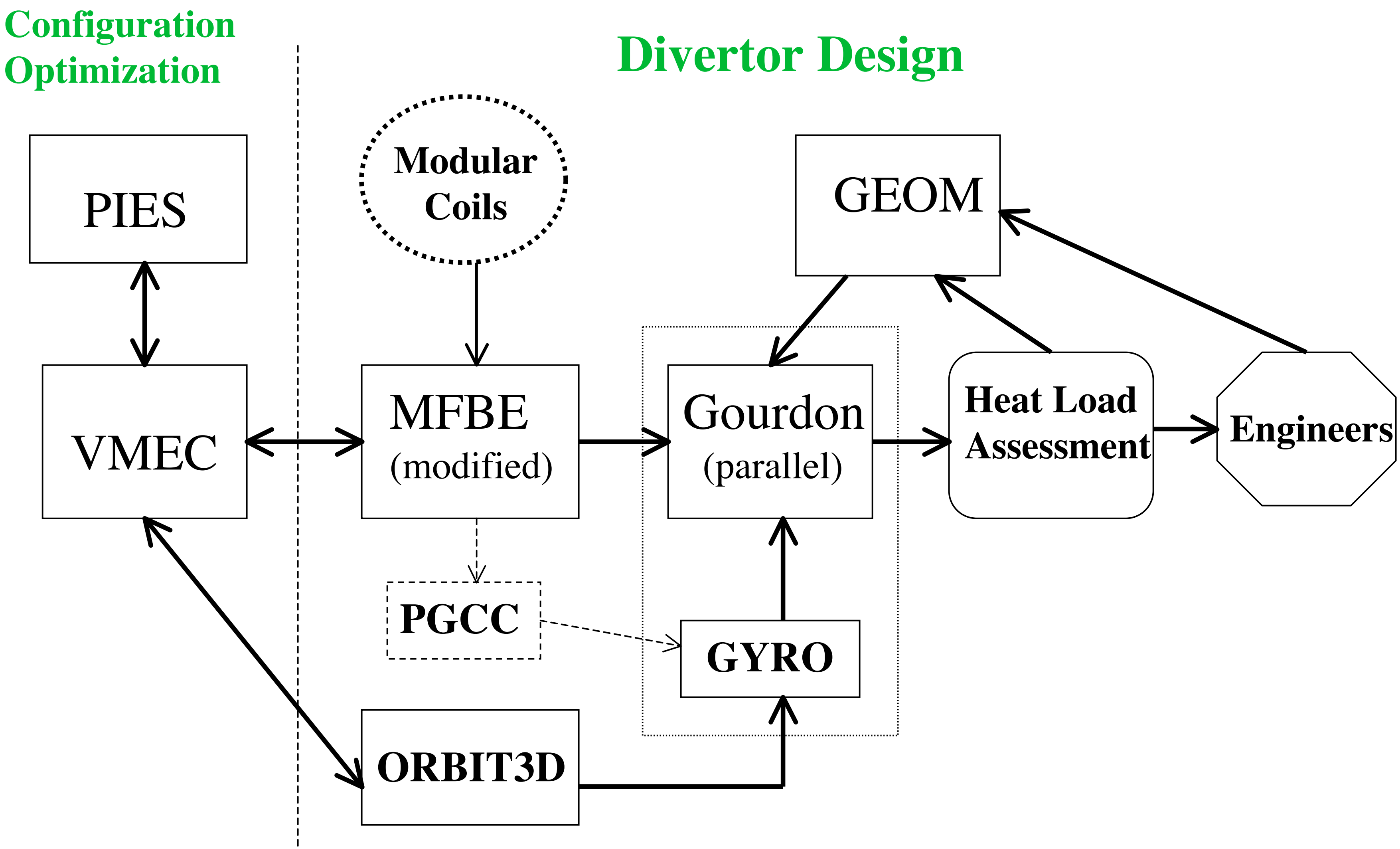
Divertor Assessment Objectives

- Develop divertor concept
- Locate divertor plates and other PFCs
- Evaluate heat load distribution (thermal & alphas)
- Optimize design to within physics and engineering limits

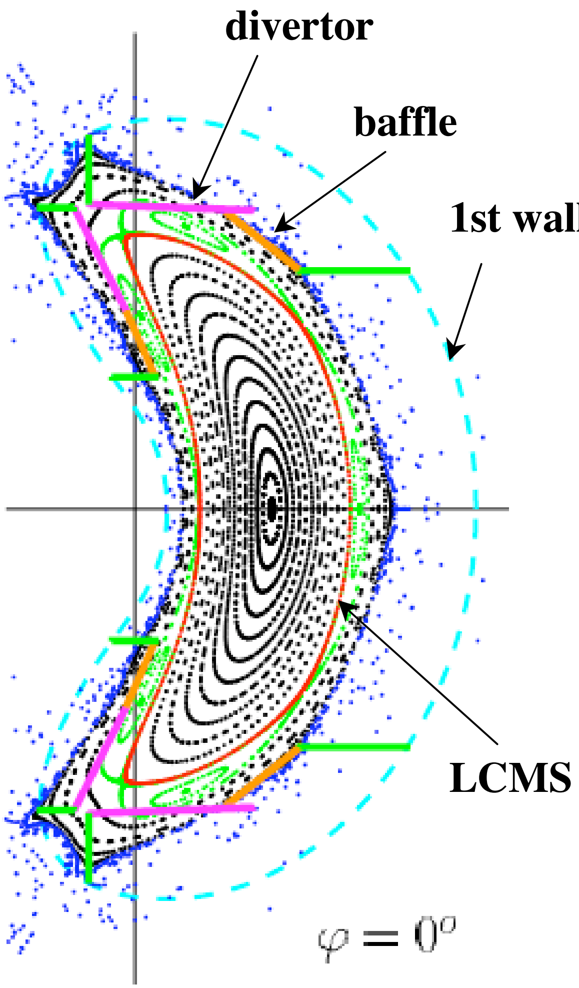
Divertor Assessment Strategy Flowchart



Status of Tasks for Divertor Design

- **Prerequisite**: Develop an acceptable CS equilibrium (devoid of resonant island structures inside the LCMS) and create free-boundary VMEC equilibrium. [**Ku**, **Garabedian**, Mau] √√ (achieved)

- Create 3D magnetic field table for inside and outside LCMS with MFBE; re-determine LCMS with Gourdon, and adjust toroidal flux until LCMS agrees with VMEC. [Grossman] √√
- Initiate divertor plate locations with GEOM. [McGuinness] √ (making progress)
- Use GOURDON to trace field lines outside LCMS until they strike divertor plates. [McG]√
- Calculate alpha particle exit points with ORBIT3D. [Mau] √
- Follow alpha gyro-orbits outside LCMS with GYRO-CS until reaching divertor. [Mau] √
- Evaluate thermal and alpha heat load distribution on plates. ⟶ Algorithm/Post Processor
- Adjust plate locations and geometry until heat load limit is satisfied.



Divertor Heat Load due to Alphas

- To model the alpha heat load, the gyro-orbits of the energetic alphas should be taken into account, since $\rho_{c\alpha} \sim \Delta_{sol}$; also of concern are local hot spots, and blistering of surface materials which depends on angle of incidence.

- Propose to add to Gourdon a direct solution to equation of motion for α's

$$m_\alpha \frac{d\vec{v}_\alpha}{dt} = q_\alpha \left[\vec{v}_\alpha \times \vec{B}(\vec{r}) \right]$$

in a 3D spatially varying magnetic field.

- We have created a stand-alone code, GYRO-CS, that solves the equation in cylindrical coordinates:

$$\frac{d\dot{r}}{dt} = \frac{q}{m}\left(r\dot{\theta} B_z - \dot{z} B_\theta \right) + \frac{(r\dot{\theta})^2}{r}$$

$$\frac{d(r\dot{\theta})}{dt} = \frac{q}{m}\left(\dot{z} B_r - \dot{r} B_z \right) - (r\dot{\theta})\frac{\dot{r}}{r}$$

$$\frac{d\dot{z}}{dt} = \frac{q}{m}(\dot{r} B_\theta - r\dot{\theta} B_r)$$

where B = B(r, θ, z). A standard Runga-Kutta method of order h^4 is used.

Testing GYRO-CS on a Tokamak-like Magnetic Geometry

- GYRO-CS is first tested on an axisymmetric magnetic geometry to make sure it is correct results.
- Assume a tokamak with concentric, circular flux surfaces:

  $R_o = 5.0$ m, $a = 2.25$ m, $B_o = 3$ T, $I_p = 2$ MA.

  $B_{\square} = B_o \, R_o \, / \, R$

  $j_{\square} = j_o \, [1 - (r/a)^2 \,]$; $r^2 = Z^2 + (R-R_o)^2$

  $B_{\square} \, (r) = 0.4 \, I_p(MA) \, (r/a^2) \, [\, 1 - 0.5 \, (r/a)^2 \,]$

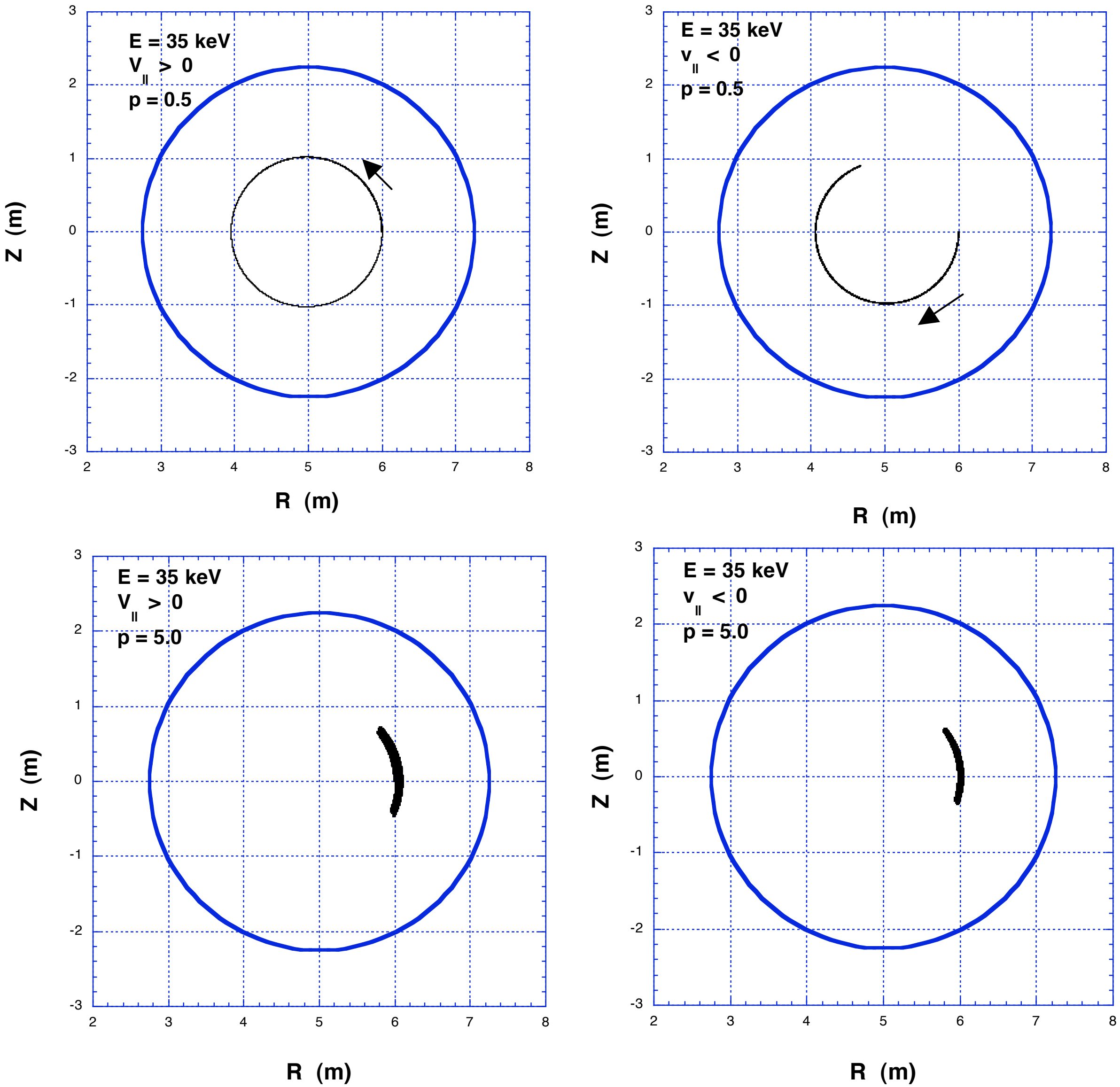
- Initial conditions:

  particle energy E_o

  velocity pitch $p = v_{\square}/v_{||}$

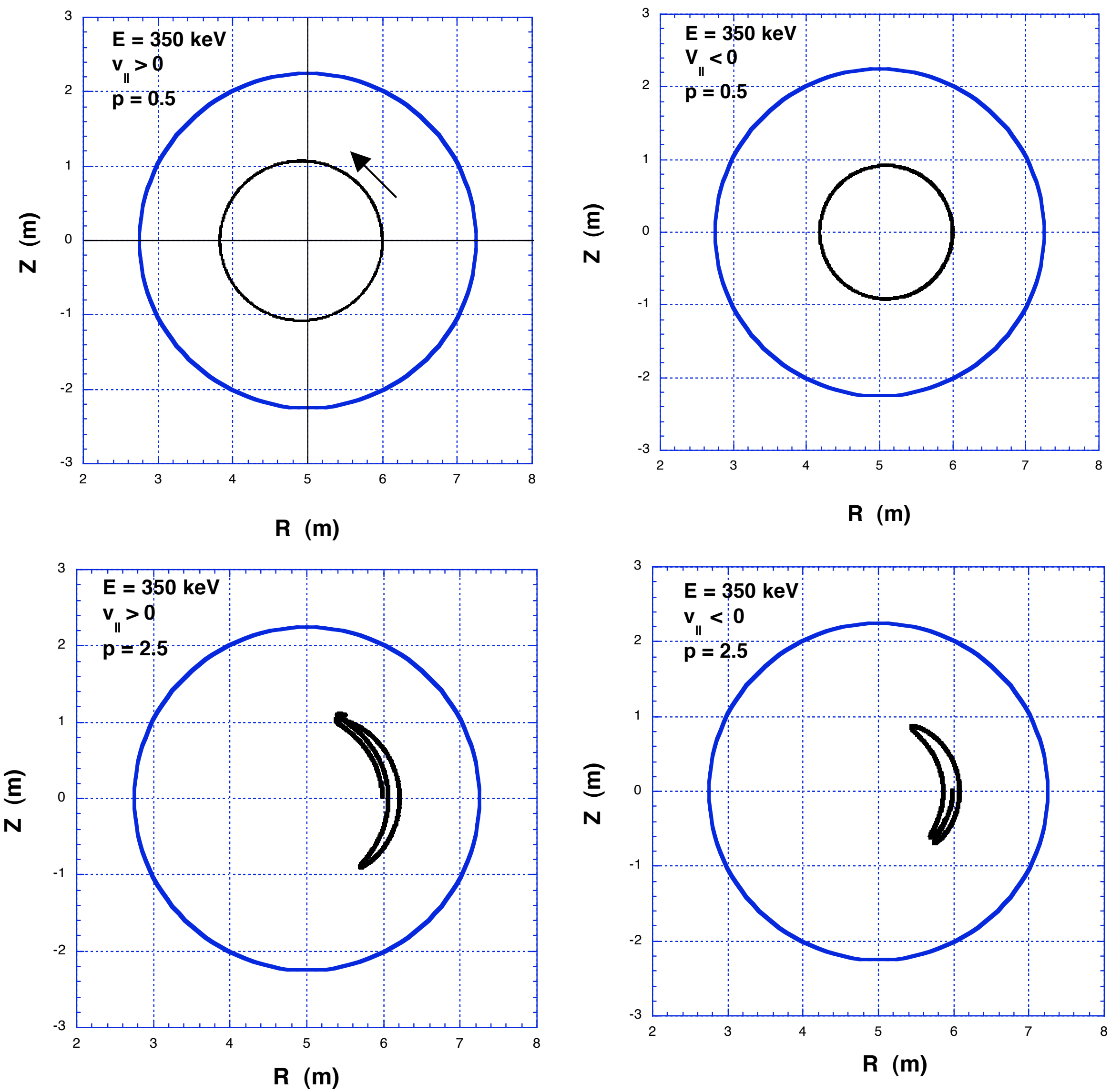
  starting location $R = 6.0$ m, $\square = 0.$, $Z = 0$ m.   : OB midplane

Results for □ Particles with E = 0.035 MeV



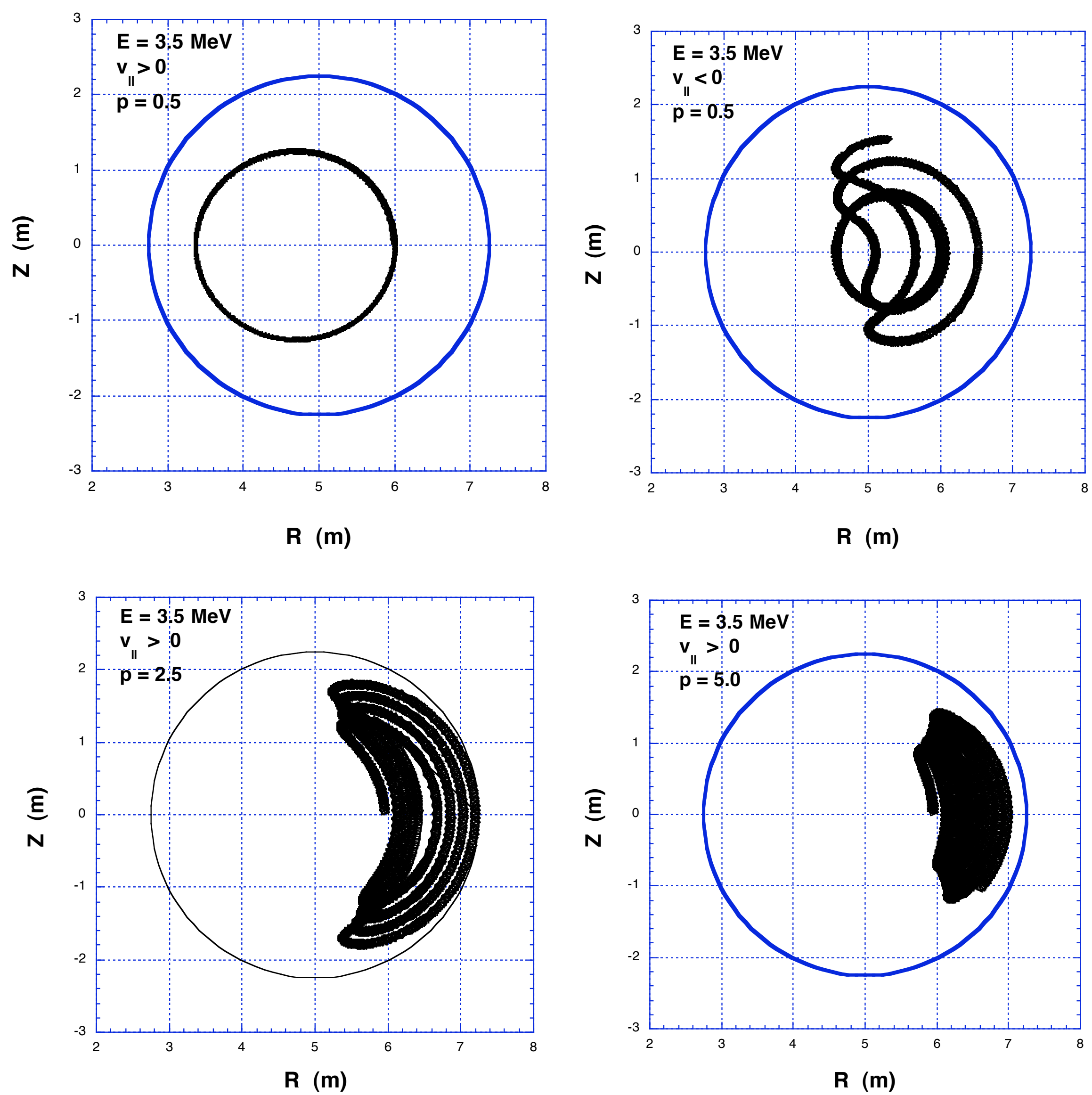
- passing particles with circular drift orbits coincident with flux surfaces
- trapped particle orbits observed at p = 5.0 with small banana width

Results for □ Particles with E = 0.35 MeV



- Circulating orbits are displaced inwards for $v_{||} > 0$ and outward for $v_{||} < 0$.
- Trapped orbits have finite banana width.
- Gyro-orbits are visible from pictures.

Results for □ Particles with E = 3.5 MeV

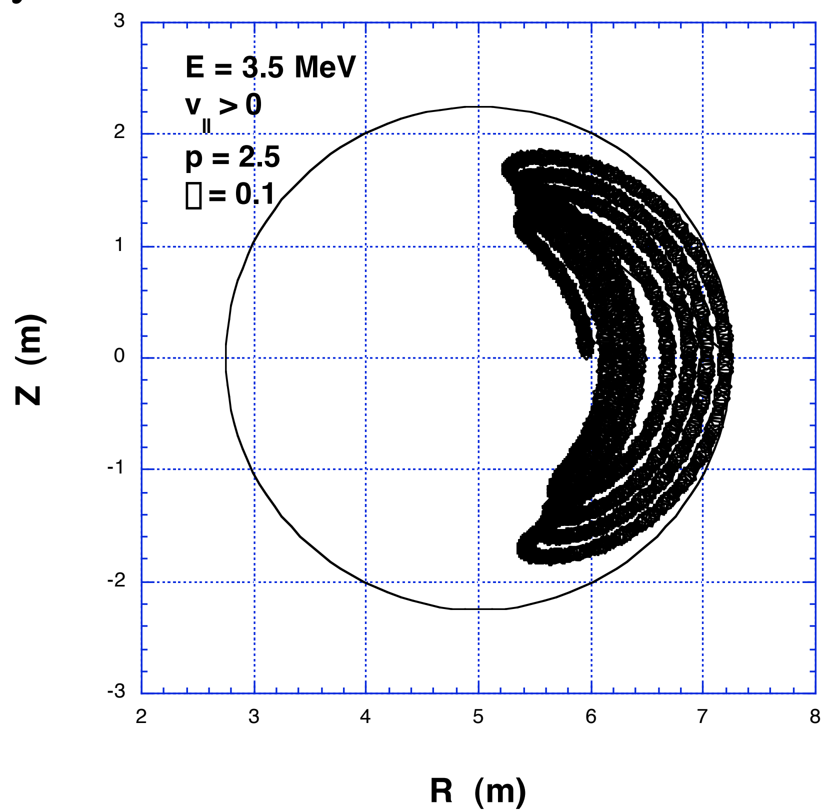


- Severe displacement of circulating orbits
- Large gyro-orbits are displayed. ($\square_{\square} \sim 10$ cm)
- Very fat banana orbits for $v_{||} < 0$ and $p = 0.5$
- Trapped orbits drift radially outward.

Addition of a Moderate Non-Axisymmetry

- We add a small ripple field to the toroidal field component: B_o□cos(N□) where □ is ripple size and N is the number TF coils.

- This results in the gyro-orbit radius clearly being modulated along the particle trajectory.



Future Plans for GYRO-CS

- In a simple tokamak configuration, GYRO-CS reproduces particle orbits that are well known, indicating that GYRO-CS is working well.

- The code is now ready to be incorporated into the Gourdon code.

  - An algorithm will be developed to transition from drift orbits calculated either by ORBIT3D or PGCC, to full gyro-orbits using GYRO-CS at or near the LCMS.

  - The fast ion Monte-Carlo code, LOCUST, from Culham Laboratory has a similar feature.

Recent Progress and Future Tasks for Divertor Heat Load Assessment

- A 3D magnetic field table has been generated for the ARIES-CS 3-FP configuration using MFBE.

  The corresponding table for a 2-FP case will be calculated.
- A gyro-orbit code in cylindrical coordinates, GYRO-CS, has been written and tested successfully with a tokamak magnetic topology.

  This needs to be incorporated into GOURDON.
- The parallelized GOURDON code has been successfully compiled on SEABORG/NERSC, and closed flux surfaces and LMCS have been traced for the 3-FP case.

  Field line tracing should be done from LCMS to divertor plates set up by GEOM.
- A post-processor code should be set up to compile the data from GOURDON to calculate the heat flux distribution on all intercepting plates. This can be a subroutine in GOURDON.
- A cross-field diffusion model should be incorporated into the parallelized GOURDON code.
- A fixed boundary VMEC capability has been added to UCSD with the help of Lang Lao, and a 2-FP VMEC equilibrium with imposed iota profile was generated. Interfacing to ORBIT3D code is on-going.