M3D-C1 ZOOM Meeting

01/25/2021

General

1. Recent and Upcoming Meetings

CS Issues

1. GPU solve status (J. Chen)
2. Mesh Adaptation status RPI/Brendan
3. Local and other systems
4. NERSC Time
5. Changes to github master since last meeting

Physics Studies

1. Initial Stellarator results from M3D-C1-S (Yao)
2. Add knock-on term to Runaway source
3. Progress in 3D M3D-C1/NIMROD benchmark
4. Helical band to remove runaway electrons (Brendan)
5. Resistive Kink with RE current in DIII-D shot 177040 (Chang)
6. Carbon Mitigation in NSTX-U (shell pellet)
7. Other?

MPPC Meeting 1/19 – 1/26

- K. Aleynikova … Modeling of Current Crashes in W7-X
  - This would be a good target for M3D-C1-S
- W.Fox .. Progress in sawtooth magnetic reconnection experiments in DIII-D
  - Plan to use M3D-C1 to compare with experimental data
- Y. Zhou .. Extending M3D-C1 to stellarator geometry
  - Initial calculation of W7-X equilibrium with heating
- Holzl .. Nonlinear Simulations of Transient Events in tokamaks
  - Mentioned JOREK/M3D-C1 benchmark
- C. Liu .. NL simulation of Energetic-Particle-Driven Alfven modes using M3D-C1
  - Excellent description of M3D-C1-K
- A. Wright .. Predicting Non-Resonant Pressure-Driven Modes in Low Shear Equ.

Sessions were all recorded and (presumably) can be accessed. Let me know of interest

NERSC Users Group Meeting

- squeue –start –u (user name)
  - Gives projected start time (updated every 5 min)

- Perlmutter phase I nodes will each have 4 GPUs and1 CPU w 64 cores
  - This will be available soon, and there will be no charge in 2021

- Perlmutter Phase II will have 3000 nodes, each with 2 x 64 cores, 512 GB mem
  - This probably won't be available until 2022. … usage will be charged

- GPU and CPU time will be allocated separately.

Upcoming meeting

1. Disruption Meeting to go over 2nd Q Joint Research Target Feb 4, 2021
    1. “Begin comparison of existing SPI simulations and experimental data”

2. ITPA 37th meeting on MHD, Disruptions, and Control: 22-25 March 2021
    1. SPI Physics Validation…Nick Eidietis coordinator
    2. Runaway Electron Avoidance & Mitigation … Carlos Paz-Soldan coordinator
    3. Disruption Avoidance and Prediction…Gabriella Pautasso coordinator
    4. Disruption Consequences…Fabio Villone coordinator

3. 28th IAEA Fusion Energy Conference: 10-15 May 2021 (virtual)

4. SCIDAC PI Meeting 27-29 July 2021

5. 2021 Sherwood Meeting ??? Anyone heard?

GPU Solve status

KPRAD_2d

GPU: Tot 1.4477E+01 compute 8.2121E+00 solve 6.2647E+00
CPU: Tot 1.4852E+01 compute 8.2631E+00 solve 6.5893E+00

KPRAD_restart

GPU: Tot 1.2338E+01 compute 6.2637E+00 solve 6.0741E+00
CPU: Tot 1.4377E+01 compute 8.2655E+00 solve 6.1117E+00

RMP_nonlin

GPU: Tot 2.0339E+03 compute 1.6791E+02 solve 1.8660E+03
CPU: Tot 1.9707E+03 compute 1.5433E+02 solve 1.8164E+03

pellet

GPU: Tot 1.4386E+03 compute 6.7181E+02 solve 7.6681E+02
CPU: Tot 2.1187E+02 compute 1.7426E+02 solve 3.7615E+0

Jin Chen

Mesh Adaptation Status

01/17/21: RPI Email to Brendan

“The capability to adapt 2D meshes is ready and everything is updated in the git. Please find attached the document describing the procedure to use the capability along with a few examples of meshes.”

Brendan now testing.

Local Systems

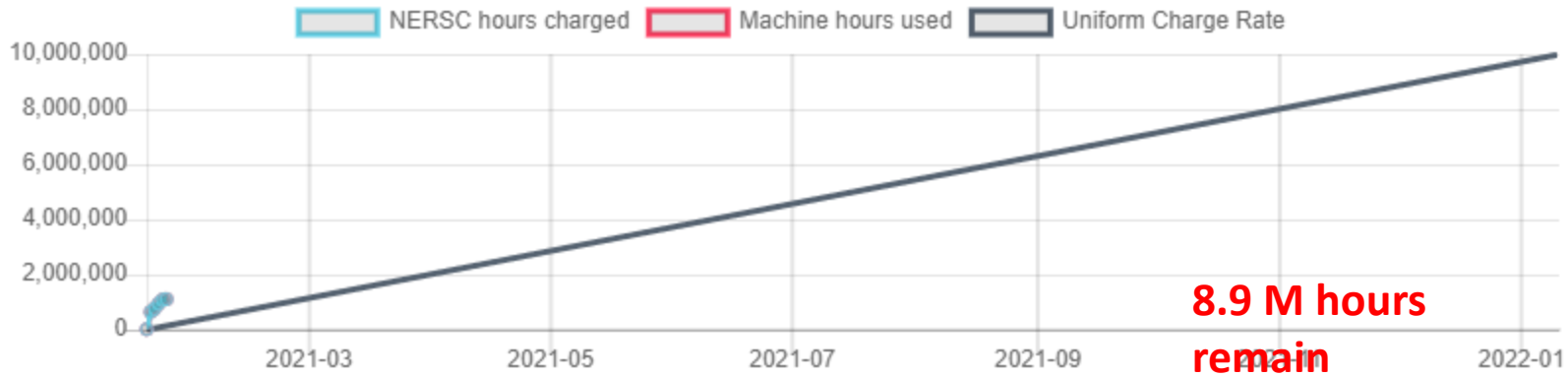
- PPPL centos7(1/25/21)
  - All 6 regression tests PASSED on centos7:
- PPPL greene (1/25/21)
  - 5 regression tests PASSED
  - KPRAD_2D originally failed…error in partitioning the mesh, but passed on resubmission
  - No batch file found for pellet
- EDDY (1/25/21)
  - 5 regression tests PASSED
  - RMP_nonlin **failed** .. Differences growing in time
- TRAVERSE(1/4/21)
  - Code compiles
  - Regression test failed: split_smb not found in PATH
  - Have not yet tried shipping .smb files from another machine

Other Systems

- Cori-KNL (1/25/2021)
  - 6 regression tests passed on KNL
  - RMP_nonlin **failed …** differences growth in time, agrees with eddy
- Cori-Haswell (1/25/2021)
  - 4 regression tests passed
  - KPRAD_RESTART did not pass, but differences are very small in velocity variables. All magnetic and thermal good. Similar difference as Cori-KNL
  - RMP_nonlin **failed** …however, agrees with Cori-KNL and eddy
- PERSEUS
  - All 6 regression tests PASSED on perseus (J. Chen, 9/04/20)
- MARCONI
  - All regression tests PASSED on MARCONI (J. Chen, 9/04/20)
- CORI GPU (10/26)
  - ??

NERSC Time

mp288



8.9 M hours remain

m3163

Closed for general use

- New NERSC allocations started 10:00 AM ET Jan 20, 2021:
- mp288 received 10M Hrs for CY 2021
- We will certainly exhaust this in 2-3 months. Transition to stellar (PU/PPPL)

Changes to github master since last meeting

- S. Seol
  - 01/23/21: fixing error with adaptation unit test with pumi model/mesh
- B. Lyons
  - 01/19/21: Correct helical wall resistivity for itor=0
  - 01/19/21: Include wall and vacuum resistivities in resistivity_func
- S. Jardin
  - 01/21/21: Helical wall resistivity can be used in 2D if ntor_rekc=0
  - 01/25/21 : Another correction to toroidal current diagnostic for itor=0

Stellarator Capability update

Yao Zhou

Add knock-on term to Runaway Source

$$\frac{\partial n_{RA}}{\partial t} = \frac{n_{RA}}{\tau \ln\Lambda}\sqrt{\frac{\pi\gamma}{3(Z+5)}}\left(\frac{E_{\|}}{E_C}-1\right)\left(1-\frac{E_C}{E_{\|}}+\frac{4\pi(Z+1)^2}{3\gamma(Z+5)\left(\frac{E_{\|}^2}{E_C^2}+\frac{4}{\gamma^2}-1\right)}\right)+S_D$$

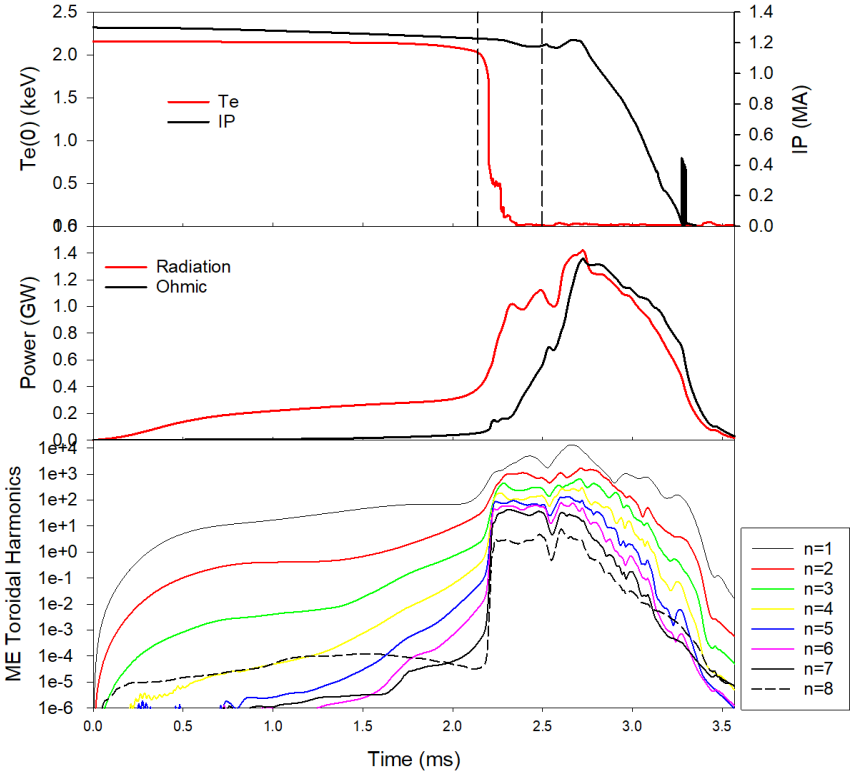
$E_C = \left(2\pi e^3 (n_e + n_T)/m_e c^2\right)\ln\Lambda$ is critical electric field strength, n_T is total electron density including free and bound: $\gamma = \left(1+1.46\sqrt{r/R}+1.72r/R\right)^{-1}$ $\tau = m_e c/eE_C$

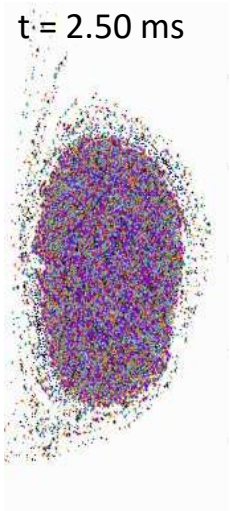
See Rosenbluth and Putvinski, Nucl. Fusion **37** (1997) 1355

Q: Is there a good, published, benchmark case for this?

B. Lyons 3D Benchmark case with NIMROD

case “f” with denm= 4.05 e-6



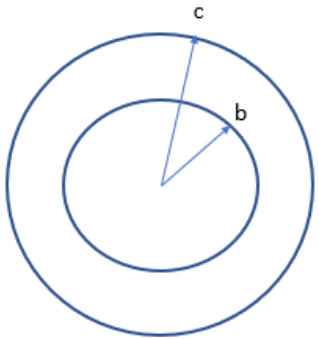


Now doing convergence test in # of planes: nplanes

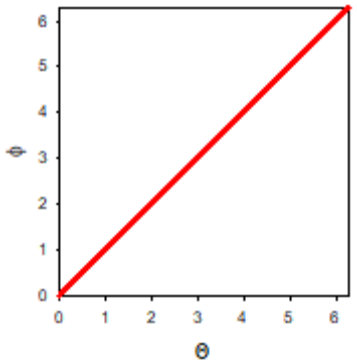
/global/cscratch1/sd/u431/BLH8f

Helical Band to remove runaway electrons

- Brendan Lyons performed a calculation last year with a conducting helical band that did not show large helical currents
- Want to try and reproduce, first in circular cylindrical geometry.



Circular cylindrical geometry.
Conductor in region
b < r < c



3D helical band of good conductivity at $|\Theta-\phi| < \delta$

#1. Will a purely toroidal voltage from the plasma current decaying drive a helical current in this geometry?

$$\nabla \times \mathbf{E} = 0 \quad \Rightarrow \quad \mathbf{E} = -\nabla\Phi + \frac{V_L}{2\pi}\nabla\phi$$

$$\mathbf{J} = \sigma\mathbf{E}$$

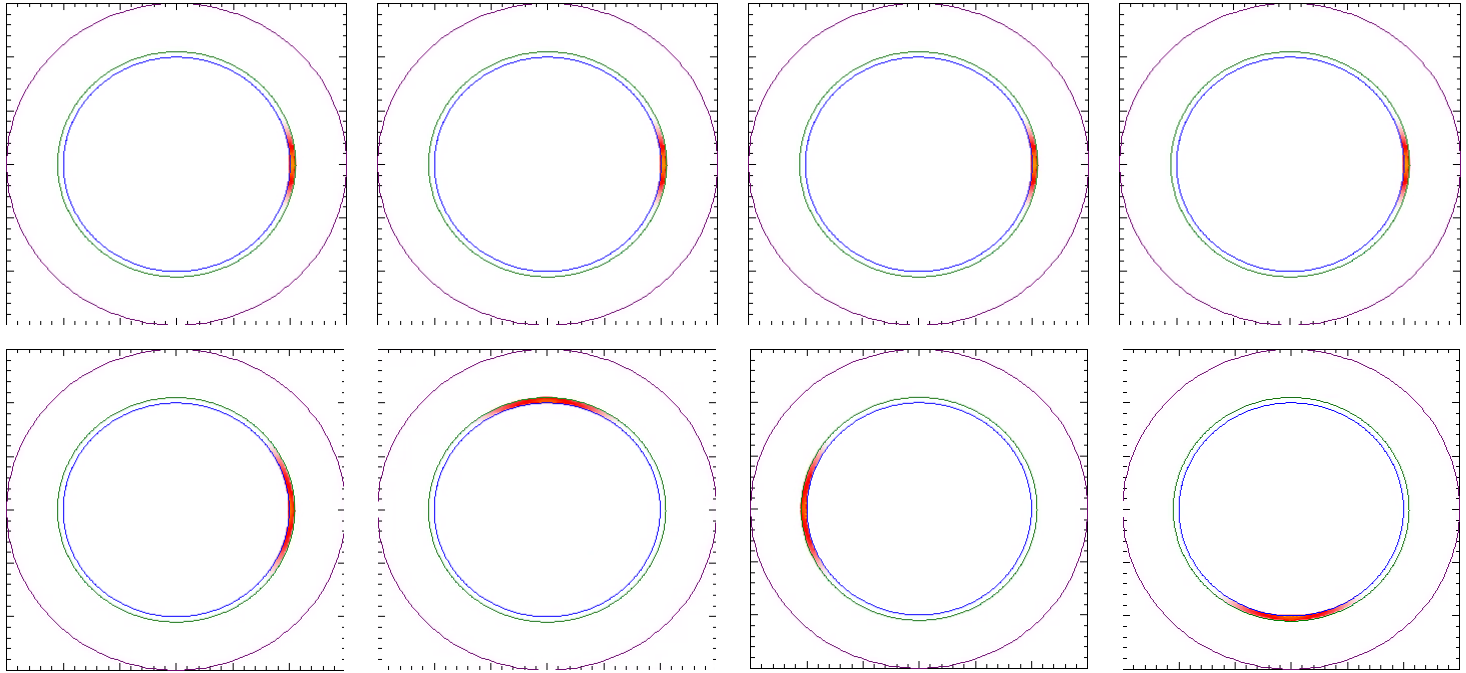
What is driving the current in the θ direction? It can't be Φ unless

$$\int_0^{2\pi} \sigma^{-1} J_\theta d\theta = \int_0^{2\pi} \frac{d\Phi}{d\theta} d\theta = 0$$

Comparison between Straight and helical band

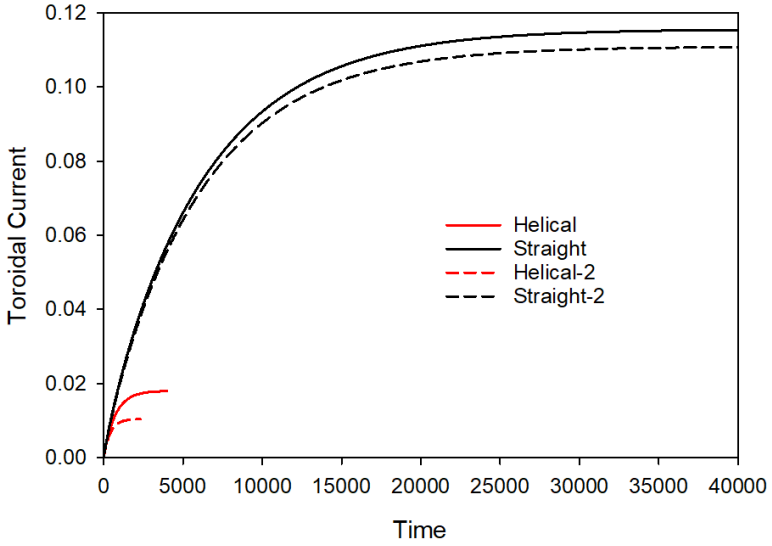
Straight ➔

Helical ➔



$\varphi = 0$ $\varphi = \pi / 2$ $\varphi = \pi$ $\varphi = 3\pi / 2$

Toroidal current vs time for same applied voltage V_L

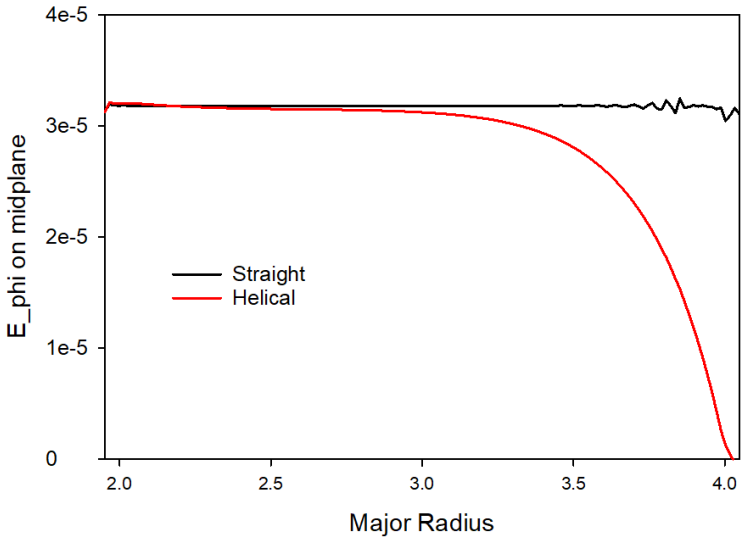


Helical and Straight
1.e-2 > η > 1.e-6

Helical-2 and Straight-2
2.e-2 > η > 1.e-6

Same applied voltage V_L drives about 6 times less current in helical band than in straight band. Even less when "insulator" conductivity is increased.

Compare E_phi on midplane at ϕ=0



For straight case: $E_\varphi = V_l / 2\pi R_0$

For helical case: $E_\varphi = V_l / 2\pi R_0 - R_0^{-1} \partial\Phi / \partial\varphi$

The electrical potential arises, opposing the loop voltage, as it is needed to drive the poloidal current

$$\Phi \cong (V_L / 2\pi)\left(\frac{r}{a}\right)^2 \sin(\theta - \varphi)$$

This electrical potential drives the current in the theta direction:

$$J_\theta = \sigma \frac{1}{r}\frac{\partial\Phi}{\partial\theta} = \frac{\sigma V_L}{2\pi a}\left(\frac{r}{a}\right)\cos(\theta - \varphi)$$

$$J_\varphi = \frac{\sigma V_L}{2\pi R_0}\left(1 - \left(\frac{r}{a}\right)^2 \cos(\theta - \varphi)\right)$$

Seek Analytic Solution

Presented on the previous slides was an approximate solution based on code results. We should be able to calculate an analytic, or semi-analytic solution for the steady state.

$$\begin{bmatrix} \Phi \\ F \\ f \\ \psi \end{bmatrix} = \mathrm{Re} \begin{bmatrix} \Phi(r) \\ F(r) \\ f(r) \\ \psi(r) \end{bmatrix} e^{i(\theta-\varphi)}$$

$$\nabla_\perp \bullet \nabla \Phi = \nabla_\perp \cdot \eta \left[-\nabla F \times \nabla \varphi - \nabla f'' \times \nabla \varphi - \frac{1}{R_0^2} \nabla_\perp \psi' \right]$$

$$\eta \left[\nabla F \times \nabla \varphi + \nabla f'' \times \nabla \varphi + \frac{1}{R_0^2} \nabla_\perp \psi' \right] = -\nabla_\perp \Phi$$

$$-\eta \nabla_\perp^2 \psi = -\frac{\partial \Phi}{\partial \varphi} + \frac{V_L}{2\pi}$$

$$F \equiv F_0 + R^2 \nabla \bullet \nabla_\perp f$$

Resistive Kink with RE current in DIII-D shot 177040

Chang Liu and Chen Zhao made presentation to GA Disruption group last Thursday

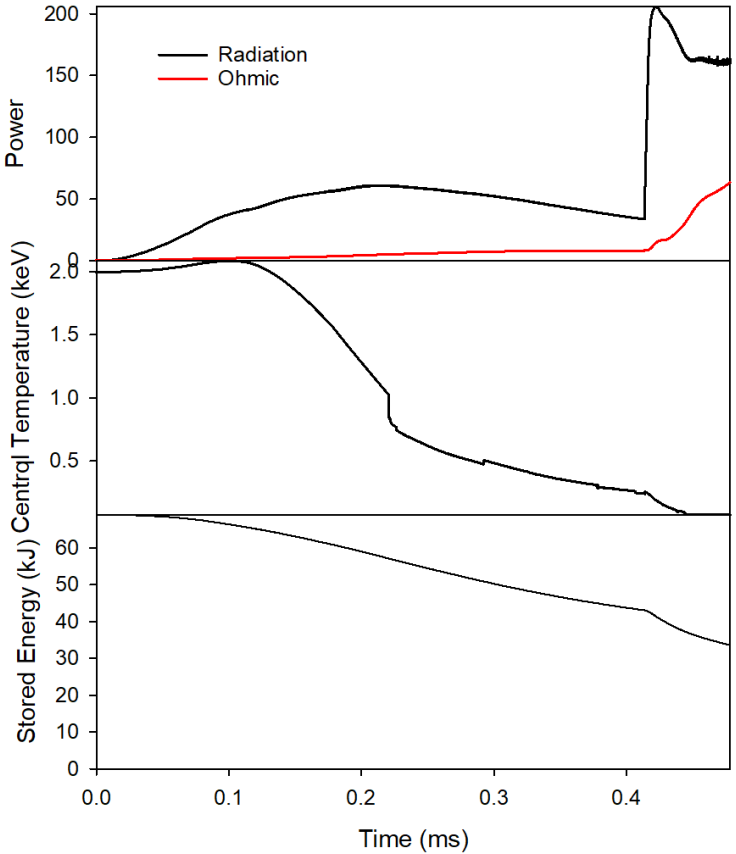
- Mode saturates at δB ~ 1000 G causing loss of 95% of runaways
- Characteristic method for runaway convection using GPUs.

- **Considerable interest by Nick Eidietis and others**
  - **Asked if we could model JET SPI mitigation including runaway sources with knock-ons**

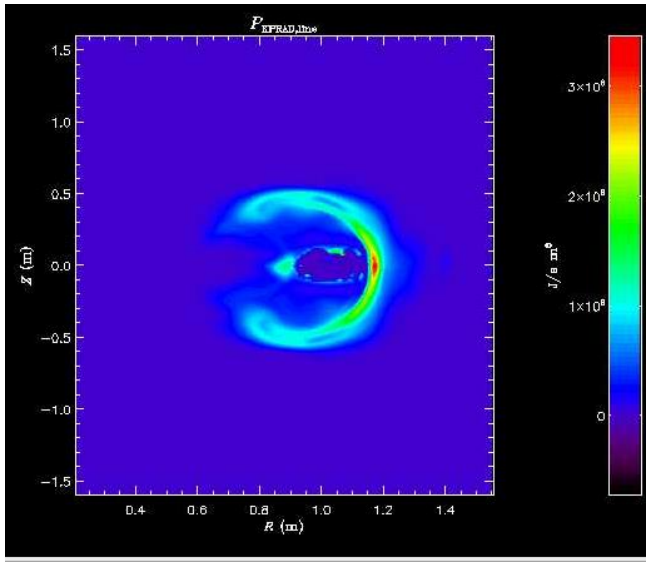
- **What is status of RE benchmark with JOREK? (Chang)**

NL data at: /scratch/gpfs/liuchang/177040_3d_re1_new_40

Carbon Mitigation in NSTX-U (shell pellet)



Shell carbon pellet in NSTX (now running)

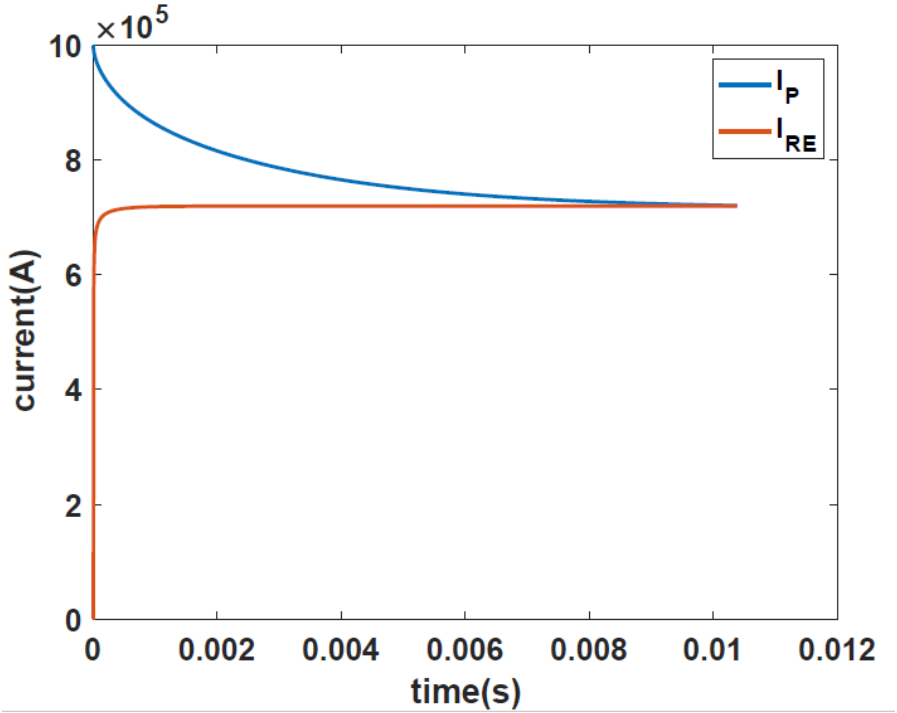


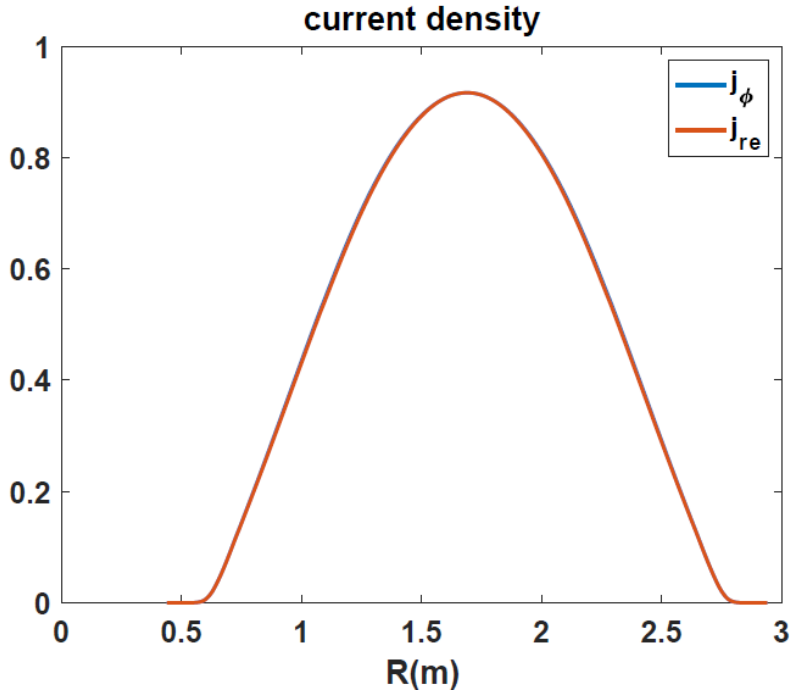
Trying to keep radiation “hot spots” from forming and causing crash. To date, by decreasing dt. But, may need to increase denm.

That’s All I have

Anything Else ?

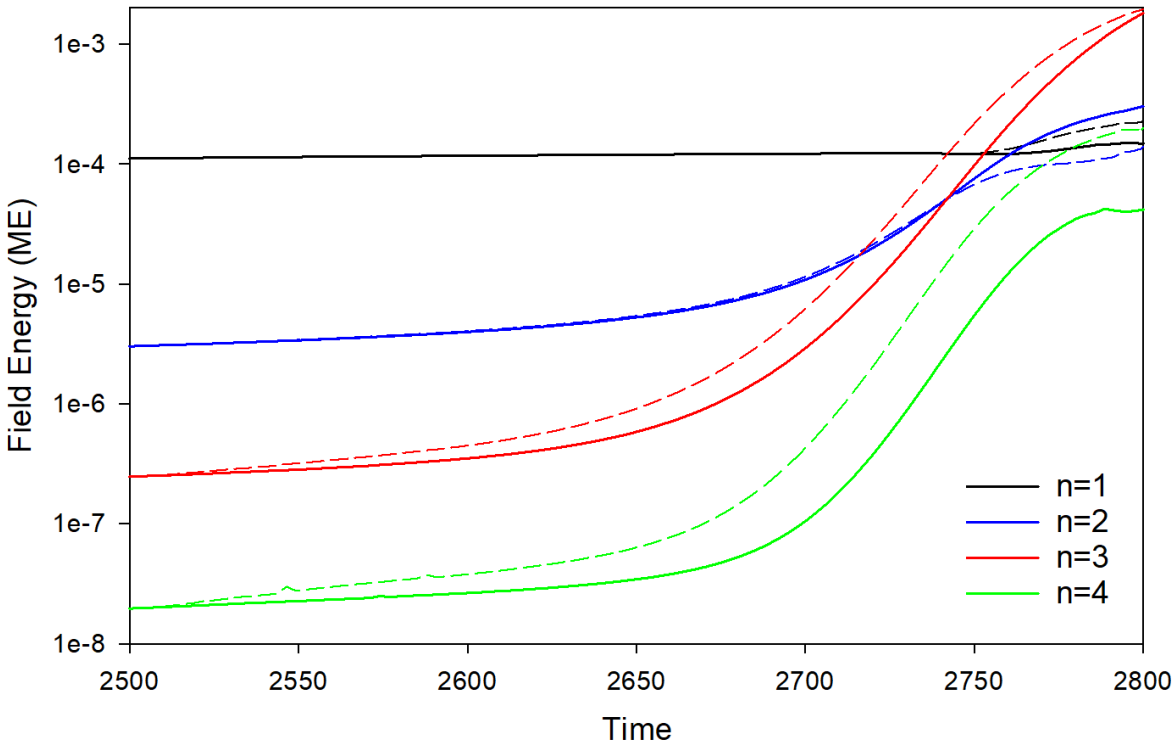
2D (cylindrical) RE with sources (12/19/2020)



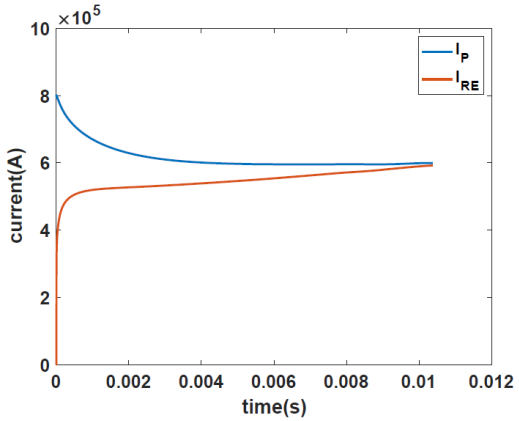


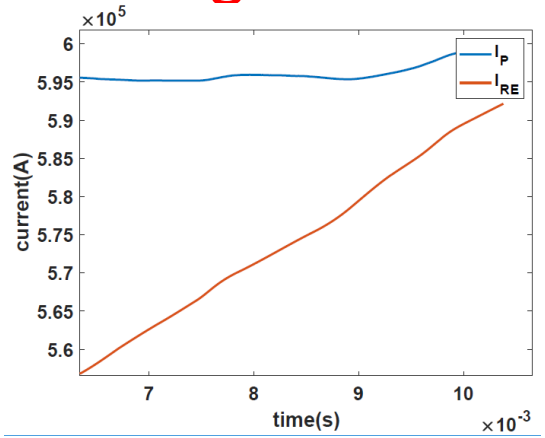
Chen Zhao

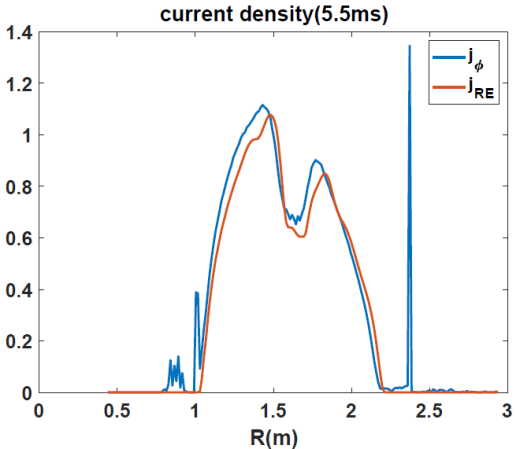
Energy in base case 36742317 (solid) and 16 plane case 37248033 (dashed)

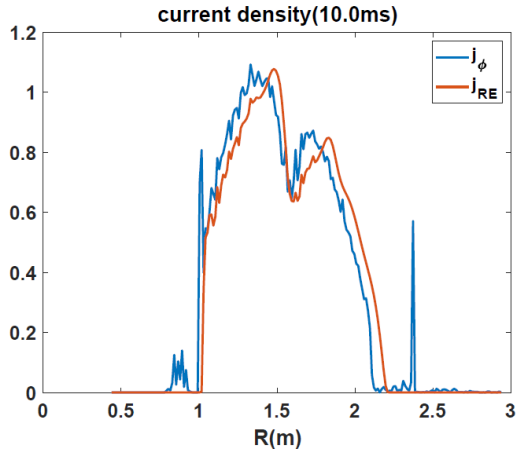


DIII-D 177053 with Argon





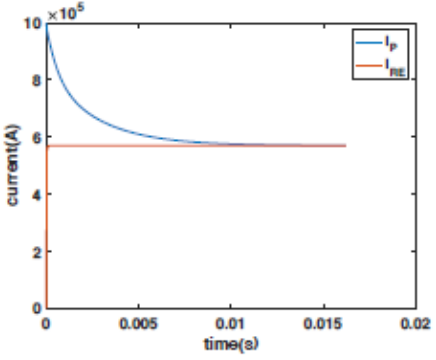


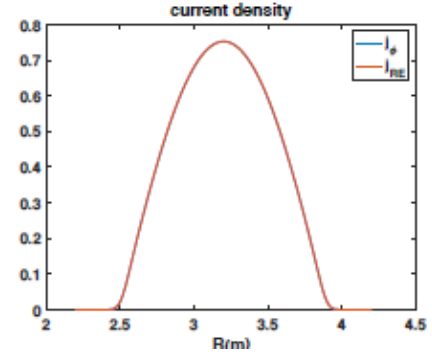


Chen Zhao

Same calculation in a Cylinder

M3D-C1 runaway generation with cylinder geometry





- Parameters: $\beta_0 = 0.15$

$$a = 0.65m$$
$$\mathrm{R} = 1.7m$$
$$B_0 = 1.9T$$
$$\eta = 1.0\times10^{-4}$$
$$n_0 = 1.0\times10^{20}m^{-3}$$
$$c = 150v_A$$
$$N_{elements} = 12261$$
$$\Delta t = 1.0\tau_A$$

- The plasma current was equal with plasma current by the runaway current at about 12ms.
- The radial profile of runaway current profile are exactly same when the plasma current equal to runaway current.

Progress on other shots?

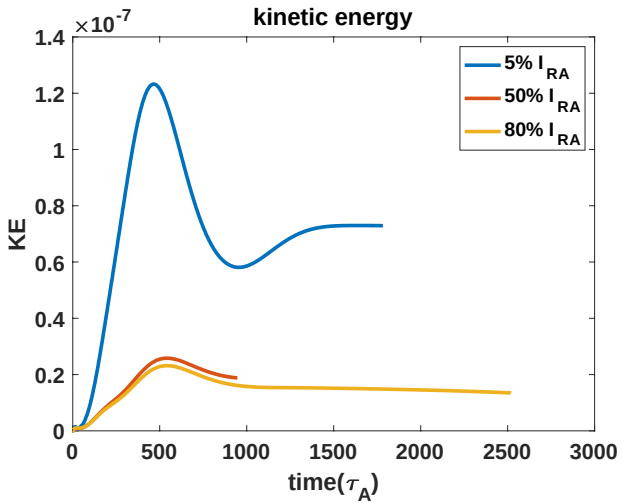
- M3D-C1/NIMROD 3D Benchmark

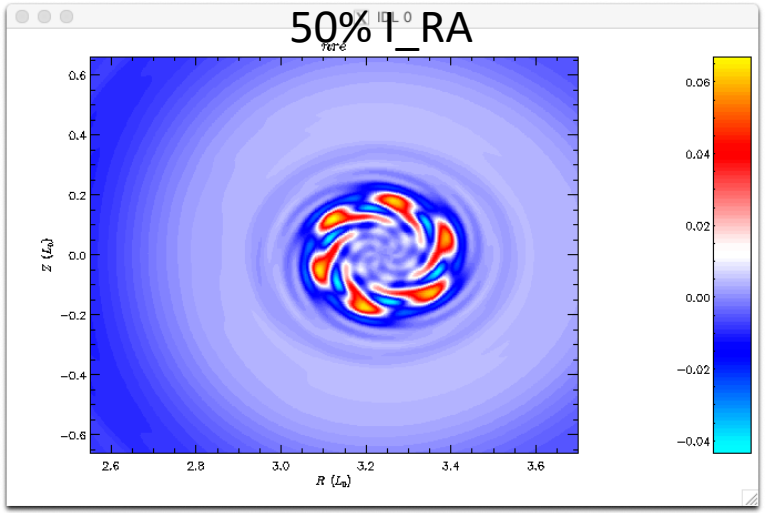
NSTX shot 1224020 – Fast ion transport with coupled kink and tearing modes
Chang Liu

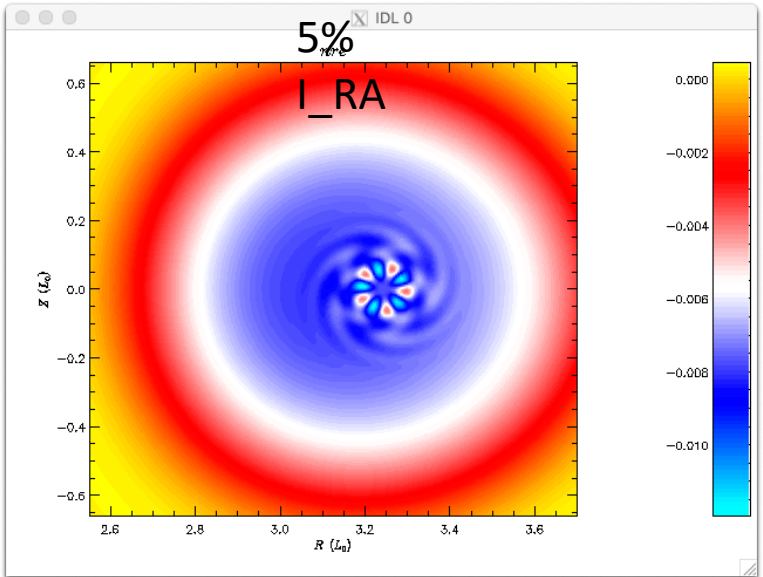
DIII-D Neon pellet mitigation simulation for KORC

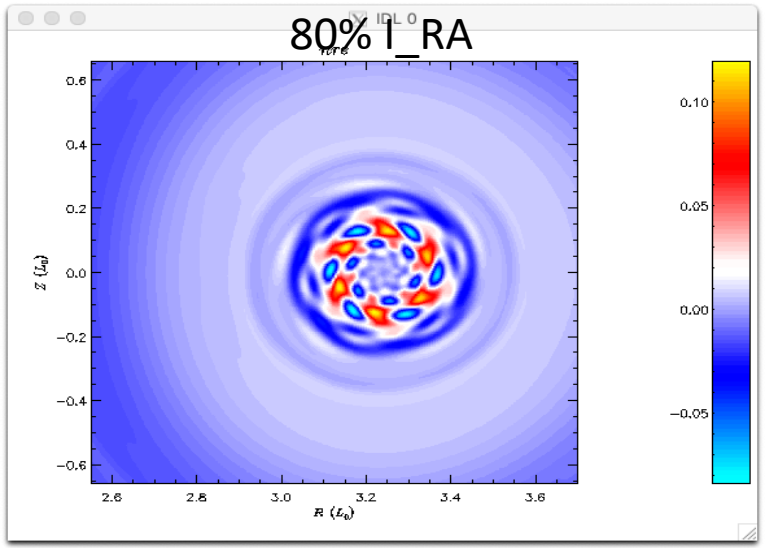
- Brendan Lyons trying to extend 8 plane case to 32 planes

SPARK ? Do we need to do anything?


kinetic energy
×10^-7
KE
time(τ_A)
5% I_RA
50% I_RA
80% I_RA

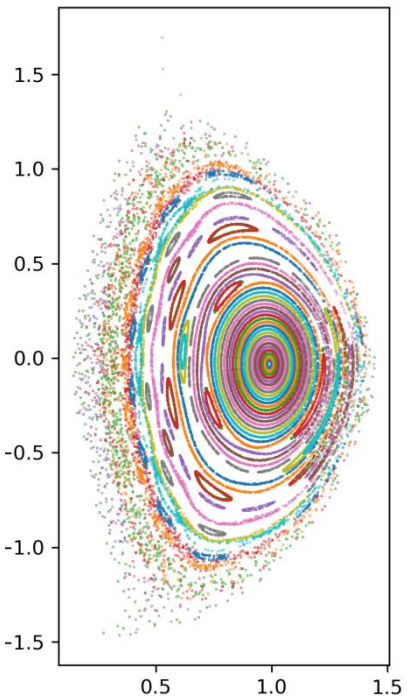

50% I_RA
IDL 0
Z (L_0)
R (L_0)


5% I_RA
IDL 0
Z (L_0)
R (L_0)


80% I_RA
IDL 0
Z (L_0)
R (L_0)

NSTX shot 1224020 – Fast ion transport with coupled kink and tearing modes

Chang Liu



- In the original geqdsk file, the equilibrium was poorly converged. New one is much better. Has q(0) = 1.3
- Chang has analyzed new equilibrium (left)
- No ideal (1,1) mode, several tearing modes

- If goal is to get unstable (1,1) mode, likely need to lower q(0)
- Adding sheared toroidal rotation should help stabilize resistive modes.

Grad-B drift in M3D-C1—HF side

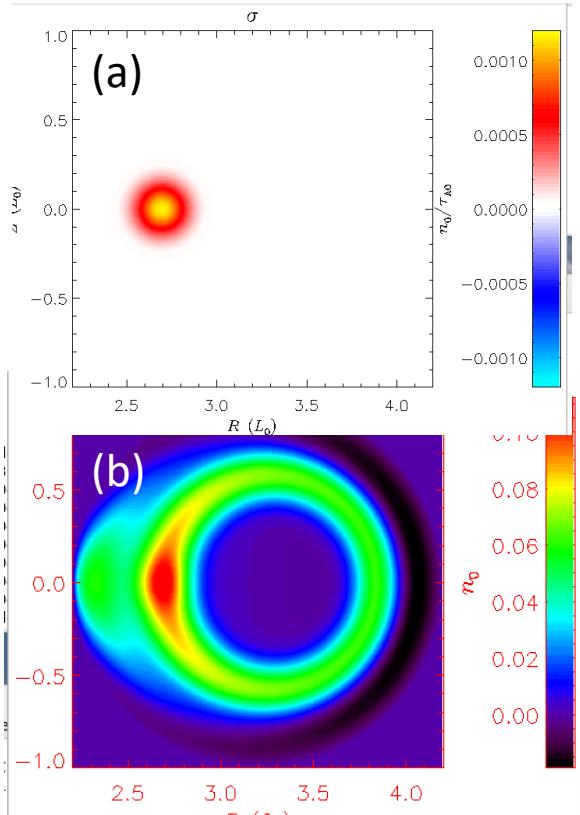
Request to calculate grad-B drift in M3D-C1 and to compare with that being put into the LP Code

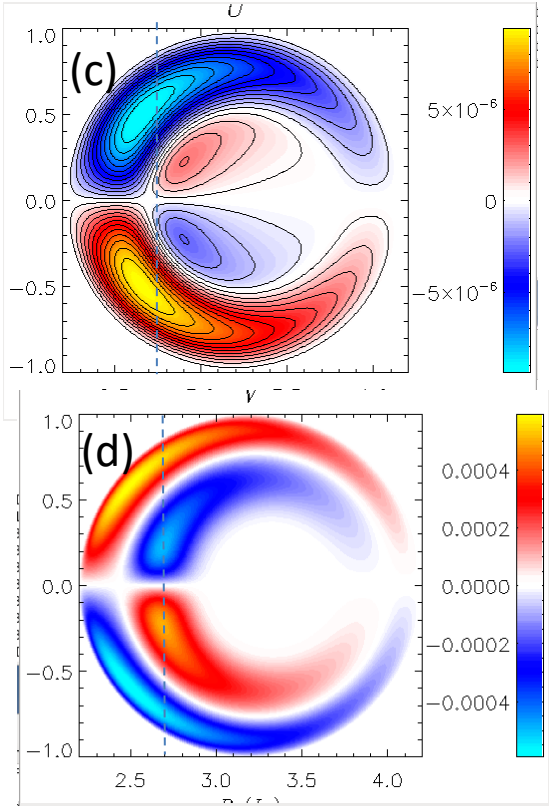
(a) Density source in 1F toroidal equilibrium

(b) Change in density after 10^3 τ_A

(c) Poloidal velocity stream function

(d) Toroidal velocity contours





Grad-B drift in M3D-C1– LF source

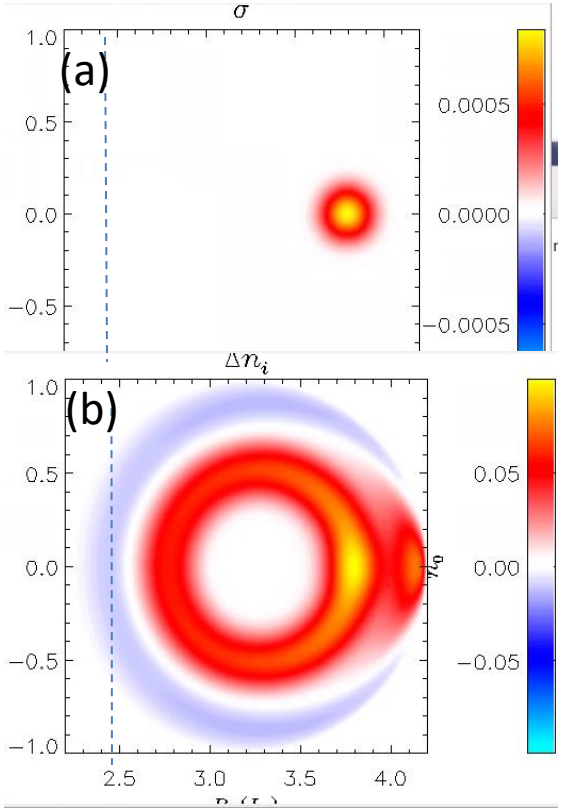
Request to calculate grad-B drift in M3D-C1 and to compare with that being put into the LP Code

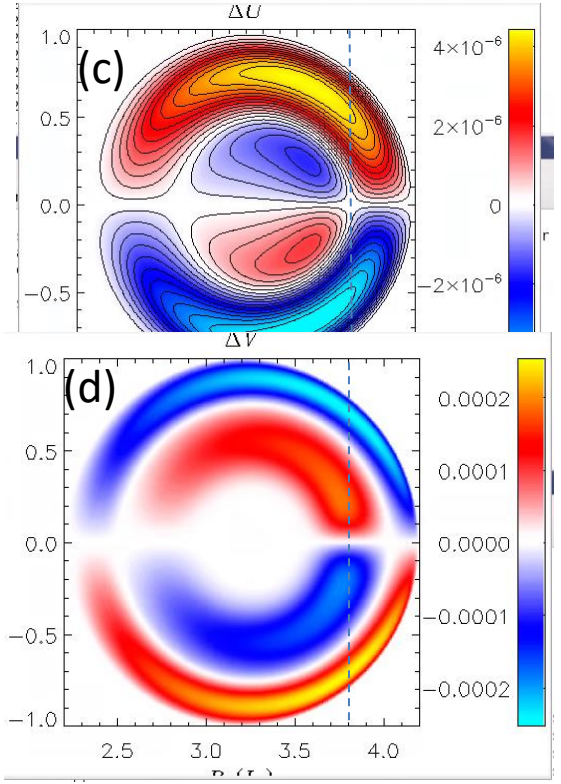
(a) Density source in 1F toroidal equilibrium

(b) Change in density after 10^3 τ_A

(c) Poloidal velocity stream function

(d) Toroidal velocity contours





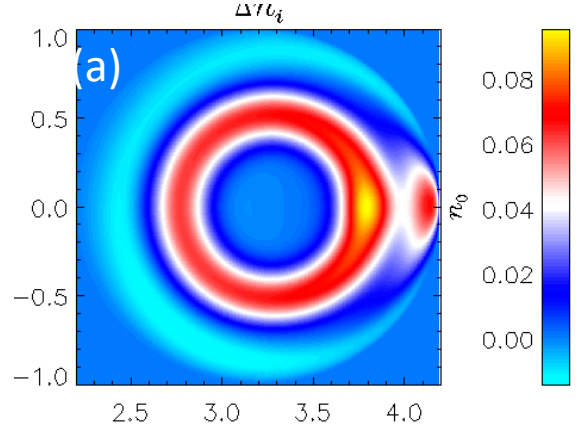
Grad-B drift in M3D-C1—2F effects

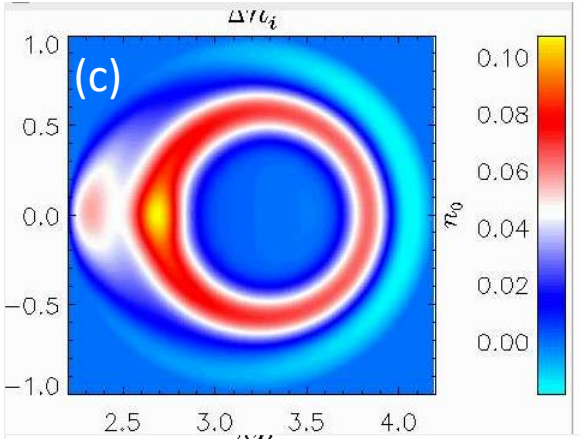
(a) 2F density change after 10^3 τ_A for LF side source

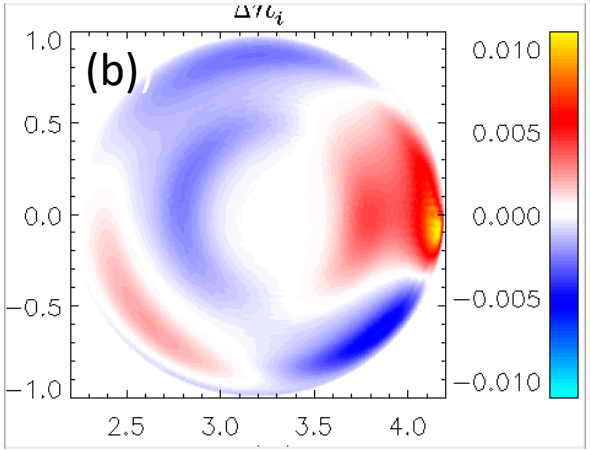
(b) Difference in 1F and 2F density (LF)

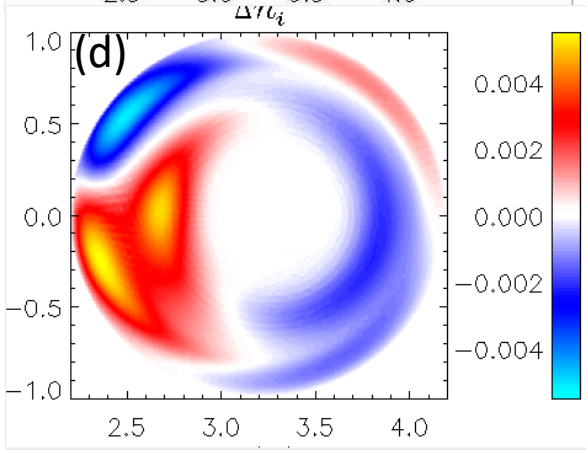
(c) 2Fdensity change after 10^3 τ_A for HF side source

(d) Differencein 1F and 2F density (HF)

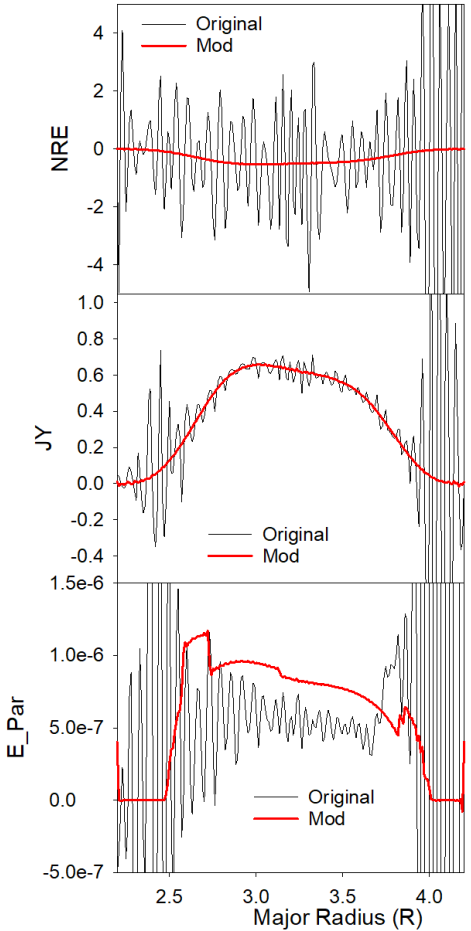








Sawtoothing discharge with runaway electrons

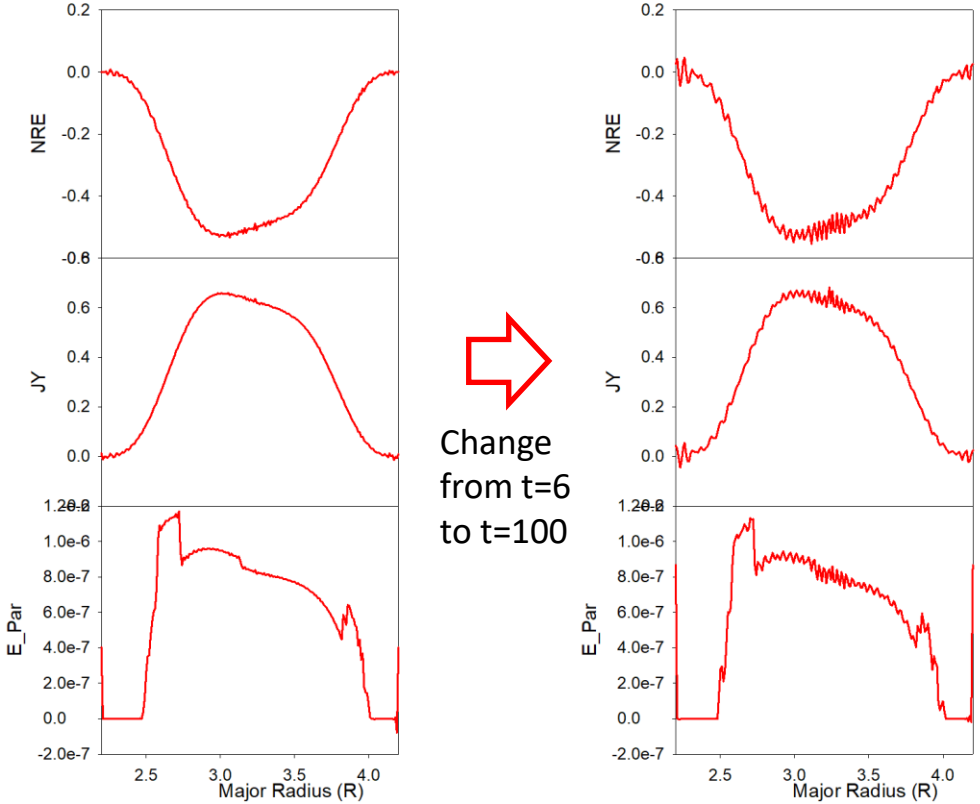


Profiles of nre, jy, and E_par after 30 timesteps

Original: /p/tsc/m3dnl/Isabel/Chen2D
Mod: /p/tsc/m3dnl/Isabel/Chen2D-mod1

Changed:
mesh size
"regular"
"integration points"
ipres=1
cre
pedge
viscosity
denm
equilibrium density

Longer times develops oscillations



- Short wavelength oscillations occur first in nre and then in other quantities (jy, e_par)
- Could we add some smoothing?