

# M3D-C1 ZOOM Meeting

08/02/2021

## Announcements

### CS Issues

1. LBL: Solvers update
2. SuperLU\_dist and mumps on stellar
3. Mesh adaptation update
4. Stellar QOS
5. NERSC Time
6. Changes to github master since last meeting
7. Regression tests

### Physics Studies

1. More on TF boundary conditions
2. Small pellet ablation simulations with LP code
3. Tearing Mode with resistive wall

**Note:** [meeting minutes posted on m3dc1.pppl.gov](https://m3dc1.pppl.gov)

## In attendance

Steve Jardin

Hank Strauss

Chen Zhao

Andreas Kleiner

Adelle Wright

Brendan Lyons

Mark Shephard

Usman

Seegyong Seol

Chang Liu

Jin Chen

Patrick Kim

Sam Williams

Nan Ding

Yang Liu

Sherry Li

# Announcements

- Virtual Sherwood Meeting August 16-18
  - Registration until August 9
  - No m3dc1 meeting August 16
- APS Nov 8-12
  - Meeting will be IN PERSON with virtual option
  - M3D-C1 Invited talks by C. Liu, A. Wingen

# Solvers Update

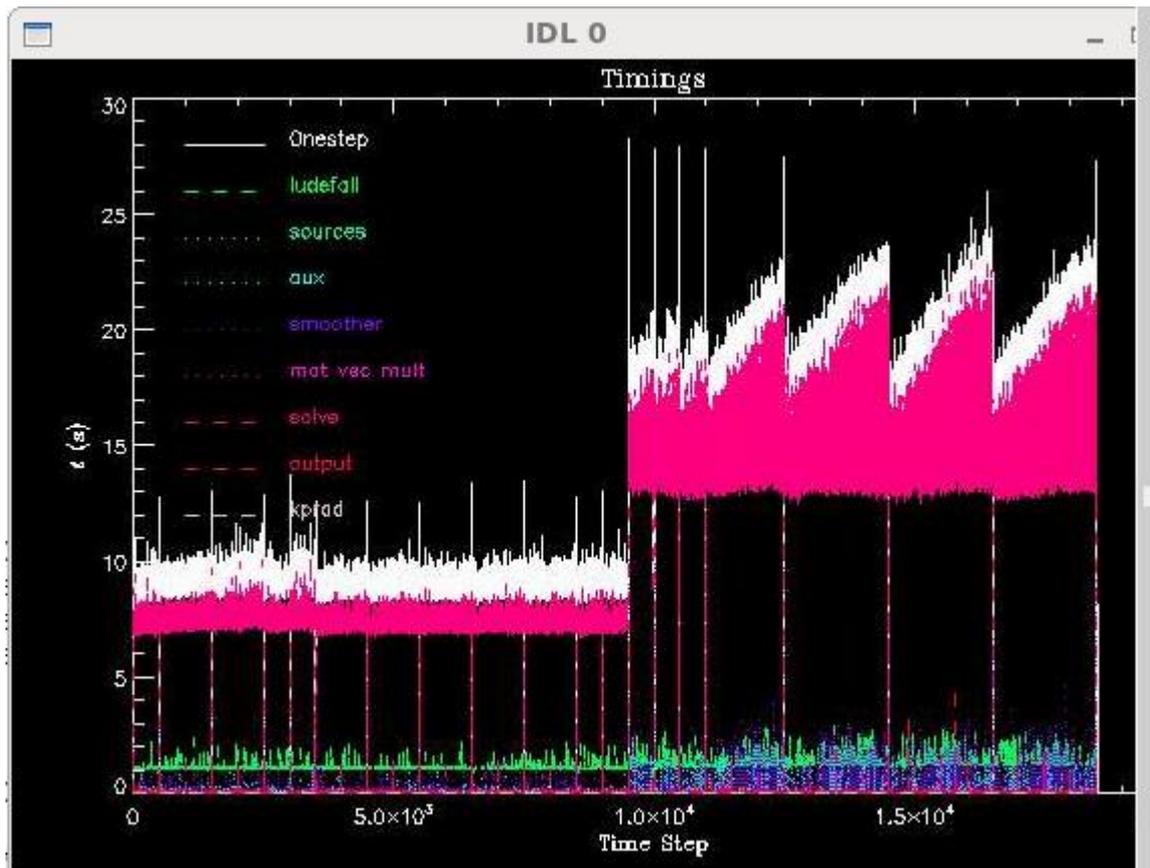
Here is some status summary regarding the upper-triangular (U) solve:

1. We implemented the U solve on a single GPU and did quite some code optimization. But with the current superlu meta data structure, the GPU solve is not as good as the CPU solve.
2. We are improving the data structure of U.
3. We are moving to multi-gpu U solve with the current data structure.

The following are some more detailed numbers on Cori GPU if you are interested.

[https://docs.google.com/spreadsheets/d/1srQ89qDSf3Q9VUtaApfGzhqsHCur6uC5thC4\\_lPyelU/edit#gid=139809464](https://docs.google.com/spreadsheets/d/1srQ89qDSf3Q9VUtaApfGzhqsHCur6uC5thC4_lPyelU/edit#gid=139809464)

rows 19-28 are L-solve, rows 32-39 are U-solve. s1\_mat\_\* means one jacobi block from m3dc1. You can see for L-solve, both threaded CPU and single-GPU implementations get reasonable speedups. But for U-solve, neither is faster than a single CPU core.



Switch from mumps to SuperLU\_dist

2D (real) runs with 96p

**Beginning of restart.**

Solve time varies between 12-16 s

**End of plot range**

Solve time varies between 13-21s

**NOT SHOWN:**

Just before mpi crash, solve time increases to 86 s

mumps runs often end in NaN, although it may be possible to eliminate these with more frequent output cycles (every 100 instead of every 500)

# stellar.princeton.edu

Jin Chen began experimenting with intel-mpi and requested Seegyong to rebuild SCOREC libraries and PETSc

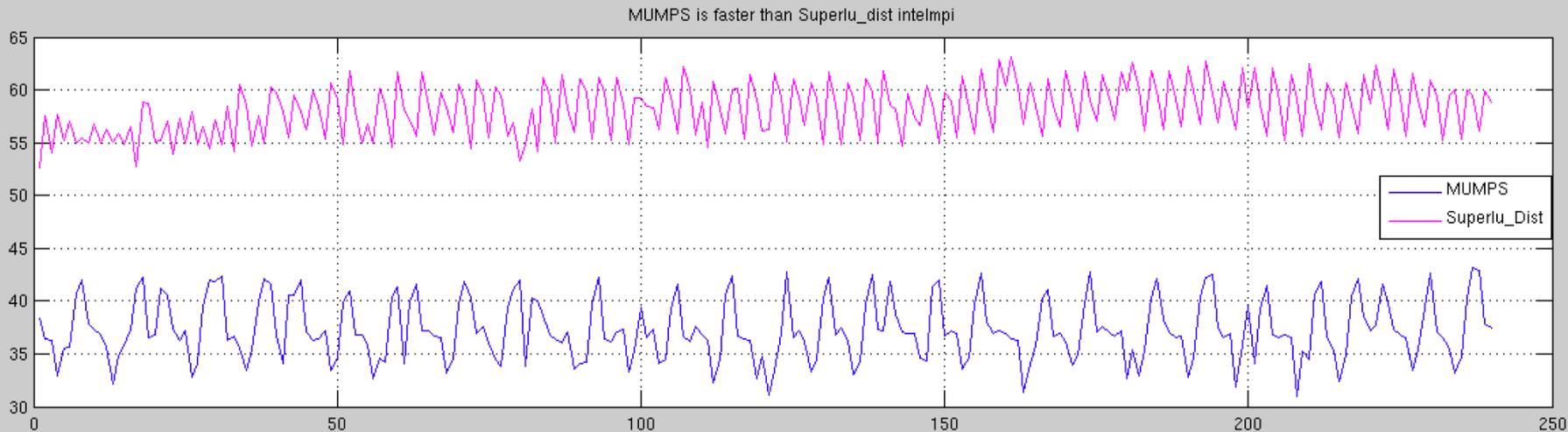
## **From Seegyong 7/30/2021:**

The libraries and executables with intel-mpi are available in `/projects/M3DC1/scorec/intel2021.1.2-intelmpi/petsc3.13.5`

Please get `stellar.mk` and `README/readme.stellar` from `/projects/M3DC1/scorec/src/M3DC1` and let me know if it passes all the regression tests.

Seegyong

stellar.princeton.edu

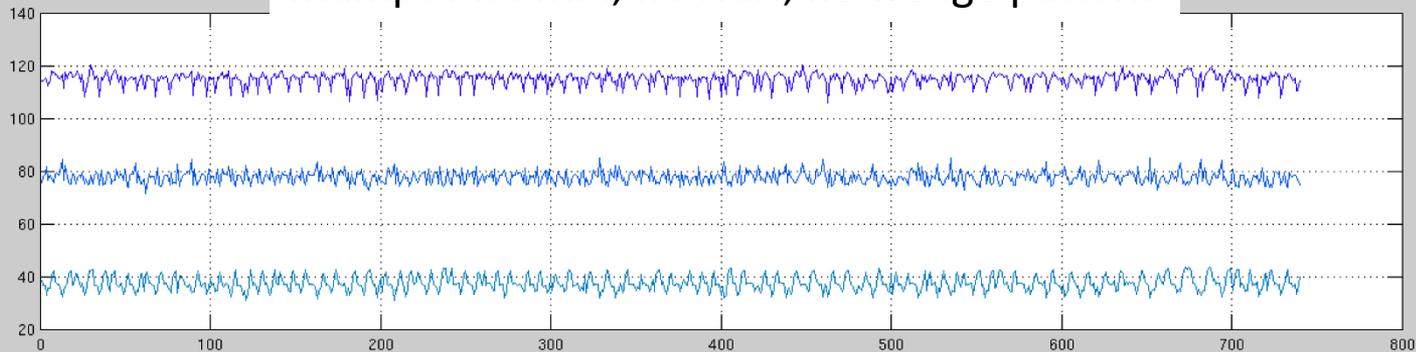


Mumps is faster than superLU\_dist using intel-mpi

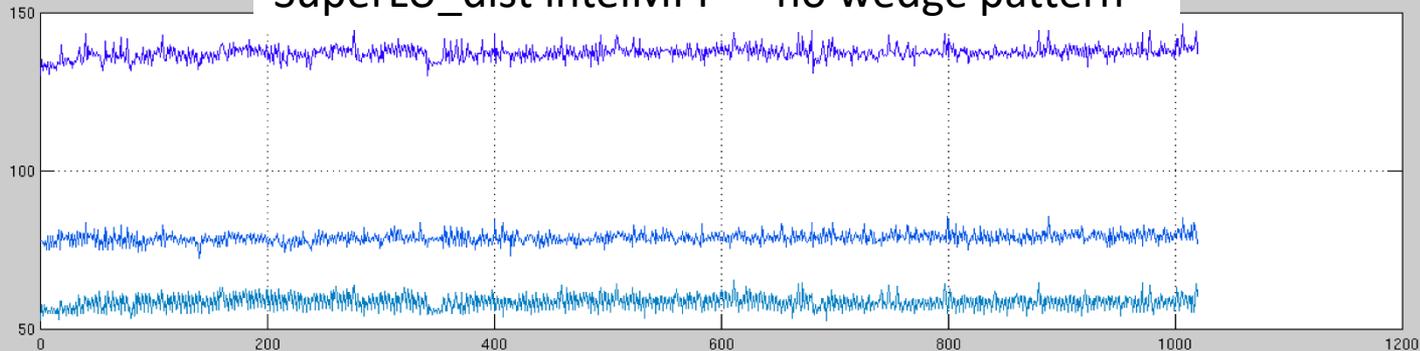
Mumps NaN no longer occurs with `-sub_mat_mumps_icntl_14 100`

# stellar.princeton.edu

mumps intelMPI, no NaN, no wedge pattern



SuperLU\_dist intelMPI --- no wedge pattern



# stellar.princeton.edu

Should we switch from openmpi to intel-mpi on stellar?

- Stellarator branch ?
- M3D-C1-K branch ?
- Other?

# J. Chen 08\_02\_21 - 1

The intelmpi option is available now. Please pull the changes from the git repository. The changes involves the following 11 files:

README/readme.stellar

regtest/KPRAD\_2D/base/batchjob.stellar

regtest/KPRAD\_2D/base/batchjob.stellar-intelmpi-sg

regtest/KPRAD\_restart/base/batchjob.stellar

regtest/KPRAD\_restart/base/batchjob.stellar-intelmpi-sg

regtest/RMP/base/batchjob.stellar

regtest/RMP/base/batchjob.stellar-intelmpi-sg

regtest/RMP\_nonlin/base/batchjob.stellar-intelmpi-sg

regtest/adapt/base/batchjob.stellar-intelmpi-sg

regtest/pellet/base/batchjob.stellar-intelmpi-sg

stellar-intelmpi-sg.mk

You would load the following modules

module load intel/2021.1 ; module load intel-mpi/intel/2021.1.1 ; module load fftw/intel-2021.1/intel-mpi/3.3.9 ;

module load hdf5/intel-2021.1/intel-mpi/1.10.6 ; module load gsl/2.6

**continued on next page**

## J. Chen 08\_02\_21 - 2

before compiling. Please note that the make file is named as stellar-intelmpi-sg.mk

So you need to set

ARCH=stellar-intelmpi-sg

when compiling your code. At runtime, please be sure to add

-sub\_mat\_superlu\_dist\_rowperm norowperm (when using superlu\_dist for 3D run)

-sub\_mat\_mumps\_icntl\_14 100 (when using mumps for 3D run)

at your "srun ...." line or in your file "options\_bjacobi" to speed up your code and reduce memory costs.

# Mesh Adaptation

Usman had a question regarding current density in M3D-C1

$$\mathbf{A} = R^2 \nabla \varphi \times \nabla f + \psi \nabla \varphi - F_0 \ln R \hat{Z}$$

$$\mathbf{B} = \nabla \times \mathbf{A} = \nabla \psi \times \nabla \varphi - \nabla_{\perp} f' + F \nabla \varphi$$

$$= \nabla \psi \times \nabla \varphi - \nabla f' + F^* \nabla \varphi$$

$$F \equiv F_0 + R^2 \nabla \cdot \nabla_{\perp} f$$

$$F^* \equiv F_0 + R^2 \nabla^2 f = F + f''$$

$$\mathbf{J} \equiv \nabla \times \mathbf{B} = \nabla F^* \times \nabla \varphi + \frac{1}{R^2} \nabla_{\perp} \psi' - \Delta^* \psi \nabla \varphi$$

$$\Delta^* \psi \equiv R^2 \nabla \cdot \frac{1}{R^2} \nabla_{\perp} \psi = \frac{\partial^2 \psi}{\partial R^2} - \frac{1}{R} \frac{\partial \psi}{\partial R} + \frac{\partial^2 \psi}{\partial Z^2}$$

$$f' \equiv \partial f / \partial \varphi \quad |\nabla \varphi| = 1/R$$

In code:

pst79(j, OP\_GS) is the  $\Delta^*$  operator acting on  $\psi$  at the  $j^{\text{th}}$  integration point in a given zone ITRI

We can get  $\Delta^* \psi$  at an arbitrary (R,  $\varphi$ , Z) location but it will require a deep dive into the low-level routines in the code.

Needed? Volunteer?

# Stellar QOS

Type the command 'qos' to see which running jobs are in which groups

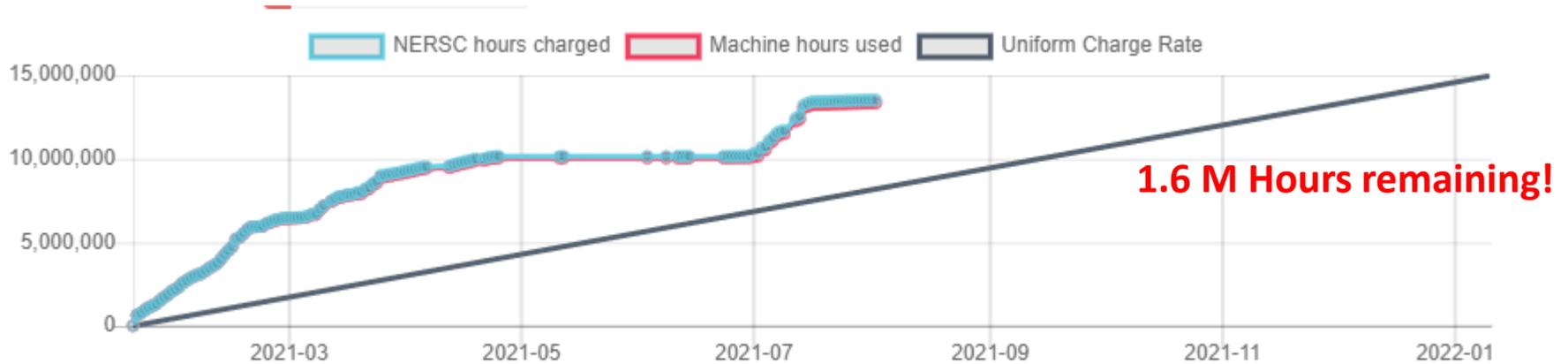
<u>Name</u>	<u>Priority</u>	<u>GrpTRES</u>	<u>MaxCPUsPU</u>	<u>MaxJobsPU</u>
pppl-long-stellar	0	cpu=4096	2048	3
pppl-medium-stellar	1000	cpu=4096	2048	4
pppl-short-stellar	3000		4096	20

GrpTRES Group Trackable RESource

QOSGrpCpuLimit if total cpu's in that group are reached

# NERSC Time

mp288



- mp288 received 10M Hrs for CY 2021
- Initial allocation exhausted by May 1
- John Mandrekas (DOE) added 5M Hrs additional
- More time may be possible if this is exhausted
- Pearlmuter time will not be charged for this FY

# Changes to github master since 07/14/21

- **B. Lyons**
  - **07/26/21:** Add option to keep pellet deposition fixed with ablating pellet
  - **07/26/21:** Don't compute density and temperature for inactive pellets

## Local Systems

- PPPL centos7(08/02/21)
  - 6 regression tests **PASSED** on centos7:
- PPPL greene (08/02/21)
  - 5 regression tests **PASSED on greene (m3dc1)**
- STELLAR (08/02/21)
  - 6 regression tests **PASSED** on stellar
- TRAVERSE(03/29/21)
  - Code compiles
  - Regression test failed: split\_smb not found in PATH

## Other Systems

- Cori-KNL (2/08/2021)
  - 6 regression tests passed on KNL
- Cori-Haswell (6/29/2021)
  - 6 regression tests passed
- 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)
  - ??

# TF boundary condition test

DIII-D mitigation Run-f (Lyons)

Denm= 32 planes

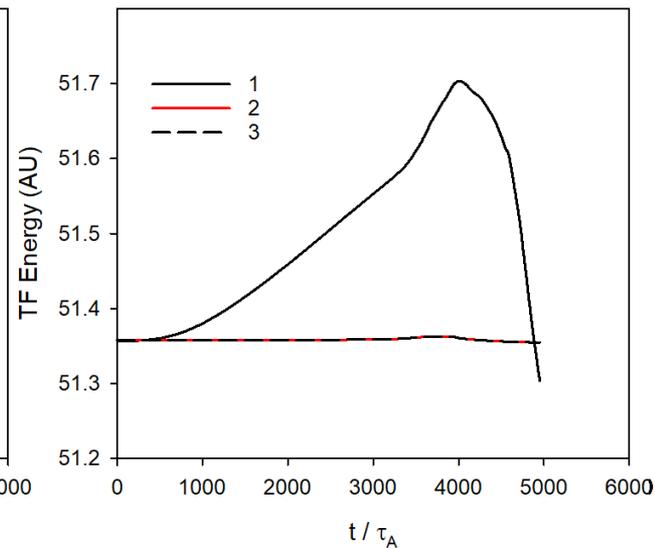
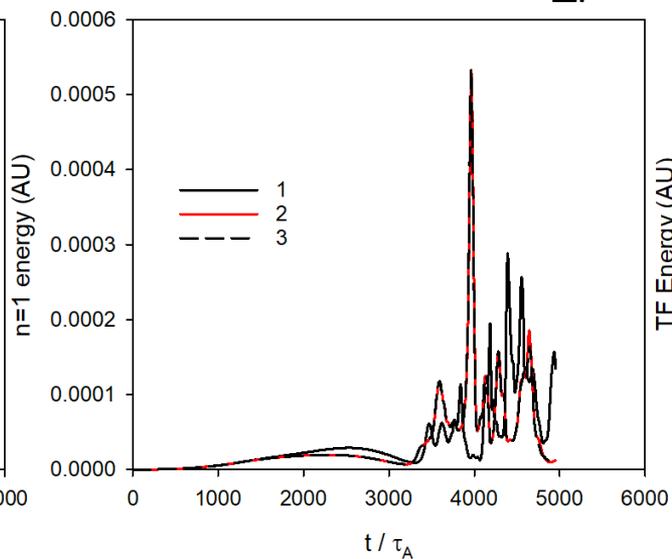
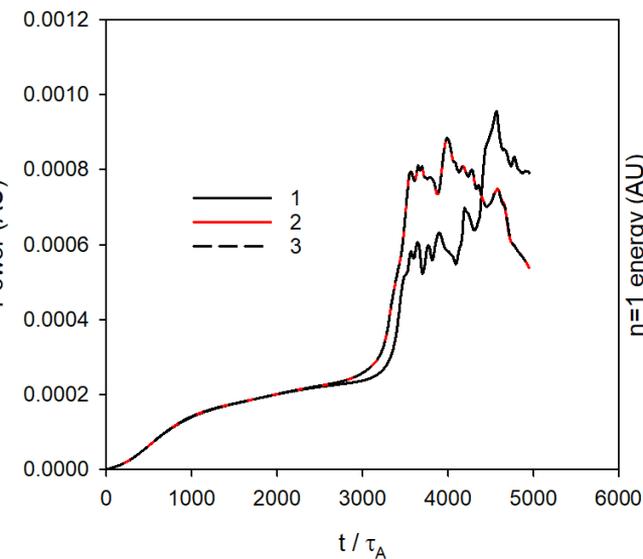
iconst\_bz

inocurrent\_pol

Run01 Run02 Run03

1 0 0

0 0 1



Runs 2,3 with iconst\_bz=0 almost identical, conserve TF energy

# Small pellet ablation experiment in DIII-D

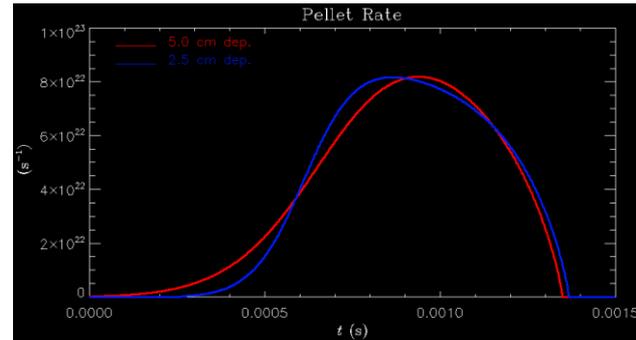
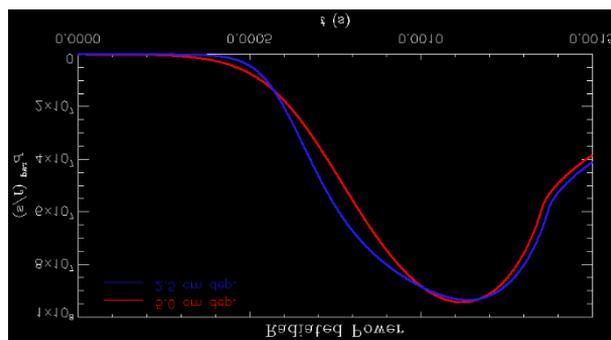
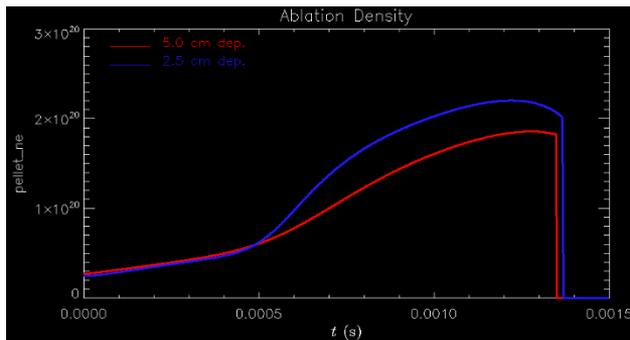
Roman,

From Brendan 7/28/21

I finally got a decent equilibrium reconstruction for the plasma used in the small-pellet-ablation experiment on DIII-D (shot 185282). I carried out two 2D simulations with M3D-C1, one with a 5-cm poloidal deposition half-width, and one with 2 cm. Both have a 0.66 mm radius pellet traveling at 179.5 m/s. These were the parameters given to me by Daisuke Shiraki on 5/1/21.

You can find both simulations on cori at [/global/cscratch1/sd/blyons/abl\\_185282/](/global/cscratch1/sd/blyons/abl_185282/) and I've attached a few screenshots of traces. You should be able to use the previous script to analyze the plasma conditions.

I'll carry out some 3D runs in the near future as well.



# Tearing Mode with resistive wall

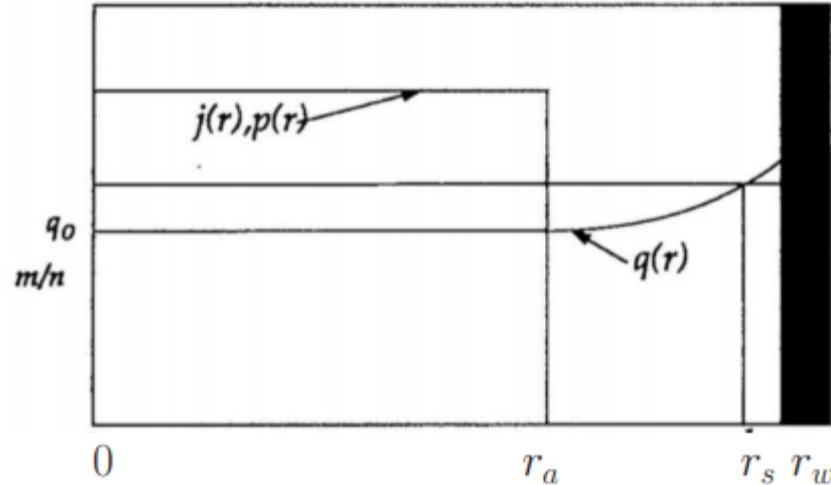


Figure 1: *Finn model equilibrium.*

Resistive Wall Tearing Mode in a periodic cylinder

H. Strauss

## From Nate 08/02/21

The cases for the wall thickness scan in that paper are in

`/p/tsc/nferraro/data/RWM/resistive/adapt0.02_ew1e-4_eta-2_dt2_etamod`  
`/p/tsc/nferraro/data/RWM/resistive/adapt0.05_ew1e-4_eta-2_dt2_etamod`  
`/p/tsc/nferraro/data/RWM/resistive/adapt0.10a_ew1e-4_eta-2_dt2_etamod`  
`/p/tsc/nferraro/data/RWM/resistive/adapt0.20a_ew1e-4_eta-2_dt2_etamod`  
`/p/tsc/nferraro/data/RWM/resistive/adapt0.50a_ew1e-4_eta-2_dt2_etamod`

Corresponding to wall thicknesses of 2, 5, 10, 20, and 50 cm, respectively.

An example of the mesh adaptation can be found here:

`/p/tsc/nferraro/data/RWM/resistive/mesh_adapt_d0.20a`

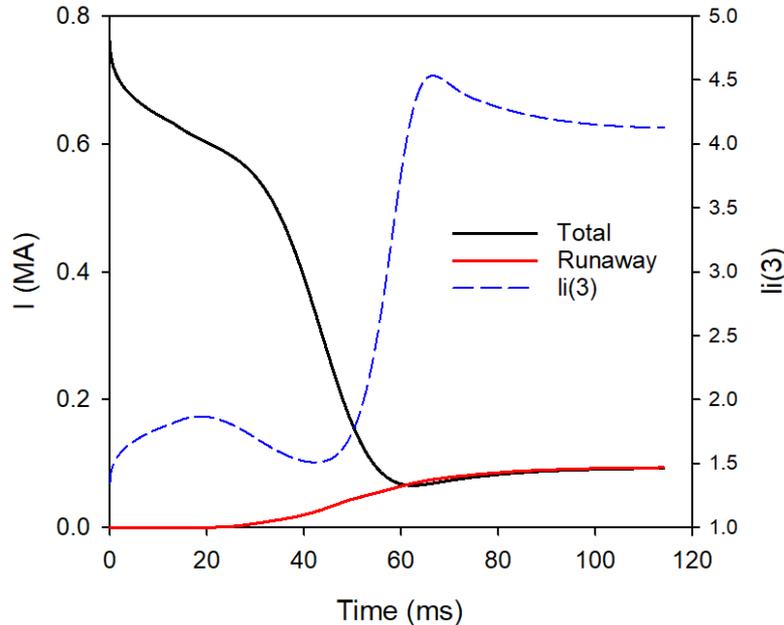
However, the mesh creation and adaptation routines have changed significantly since then so it's likely these won't work anymore without some tweaking.

That's All I have

Anything Else ?

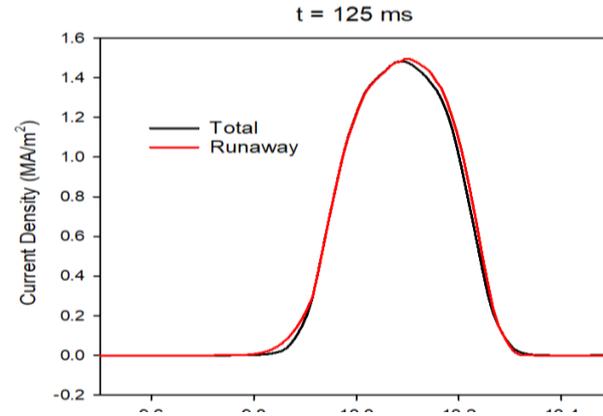
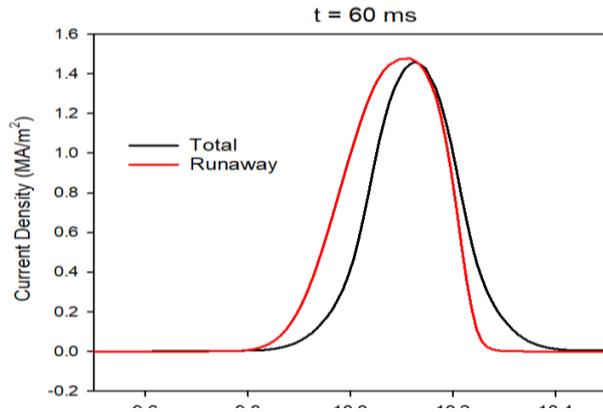
# RE current plateau

From: C. Zhao, et al “Simulation of the runaway electron plateau formation during current quench” , *in preparation*



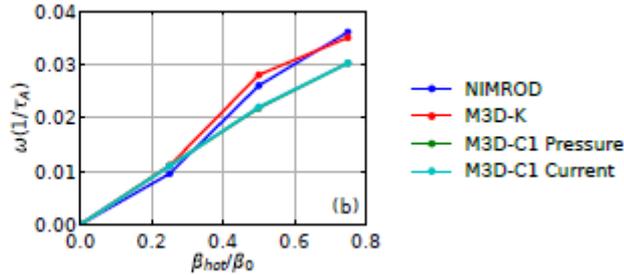
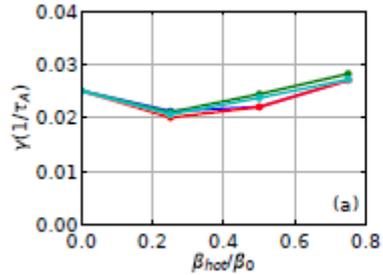
Note: runaway current increases from 60-120 ms due to  $li(3)$  decreasing

# RE current plateau - 2

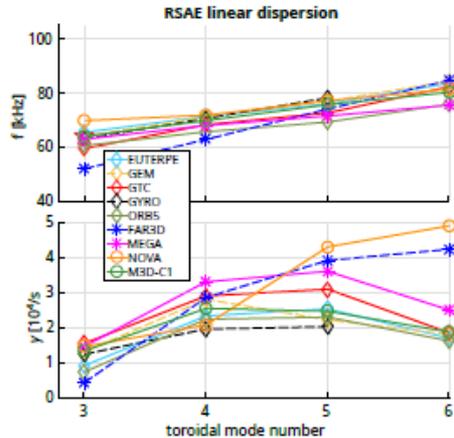


# M3D-C1-K

Chang Liu, et al. “Hybrid simulation of energetic particles interacting with magnetohydrodynamics using a slow manifold algorithm and GPU acceleration”, *in preparation*



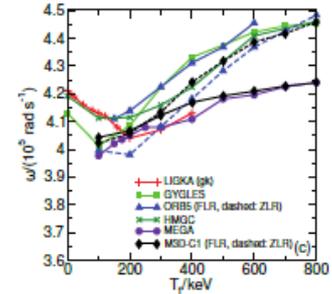
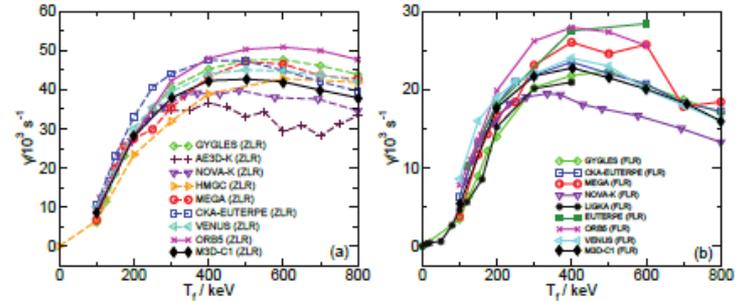
- NIMROD
- M3D-K
- M3D-C1 Pressure
- M3D-C1 Current



Top: n=1 internal kink/Fishbone benchmark with NIMROD

Left: n=3-6 RSAE benchmark vs 8 codes

Right: n=6 TAE benchmark w & wo FLR effects w 8 codes



# Gaps - 1

- Effect of wall asymmetries in wall forces for ITER
- Mitigation of already disrupting plasmas (especially for the staggered H injection scheme that can be very sensitive to existing instabilities)
- Model that captures large vs small dB/B at the stability boundary for RE final loss
- Simulations of the final impact of runaways on the wall, including runaway regeneration, beam movement dynamics and MHD. Associated measurements on existing experiments (fast diagnostics needed) → need for experimental data has been communicated to ITPA MHD/DivSOL, joint effort could be formed

## Gaps-2

- Experimental test of RF current condensation
- Study of ECCD stabilization of islands produced by off-normal events, using reconstructed experimental equilibria.
- Simulations of off-normal events (other than NTMs) that produce magnetic islands, and of ECCD stabilization of those islands

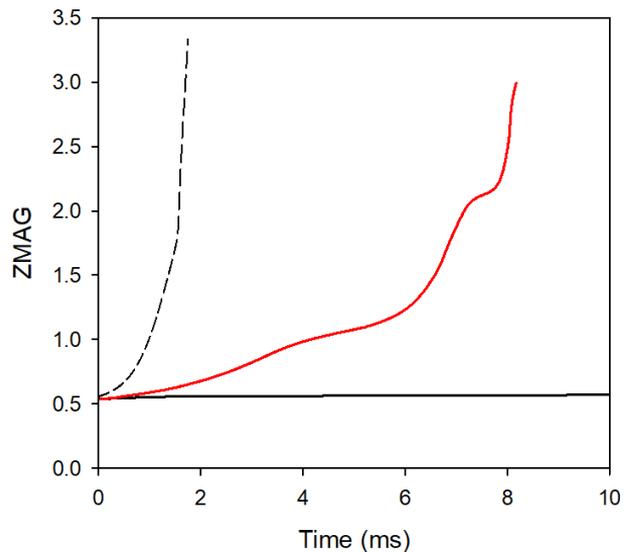
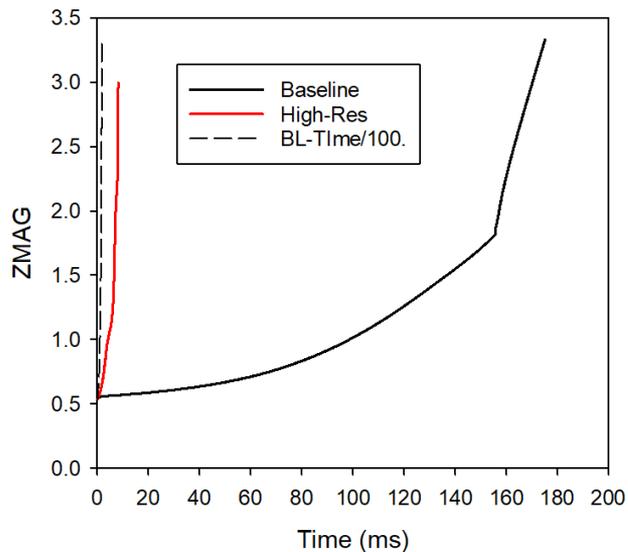
## Gaps-3

- Simulations of off-normal events (other than NTMs) that produce magnetic islands, and of ECCD stabilization of those islands.
- Extended MHD modeling of mitigation experiments with D2 injection (more generally, species dynamics)
- Improved SOL models in extended MHD
- Study of resistive wall stabilization of disruptions, much more important in ITER than in present experiments like JET
- Robust predictive capability of tearing onset (neoclassical or classical)

## Gaps-4

- gradB, rocket effect, etc. to be considered for SPI modelling; experiments would need to quantify the observed effects (e.g. description of fragment trajectories / velocities; density profile measurements); especially relevant for the staggered H injection scheme for ITER
- Performance of disruption predictors to be assessed as function of different root cause paths and with respect to severity of the disruption (higher performance is needed for high disruption loads)
- Ability to predict/avoid disruptions in experimentally inaccessible and/or disruption-intolerable regimes (e.g., burning plasmas)
- Improved understanding of physics mechanism for rotation of post-disruptive plasma asymmetries and the implications for next step devices (i.e. development of predictive capability for likelihood of resonant amplification of forces on in-vessel structures)

# ITER Sideways Force



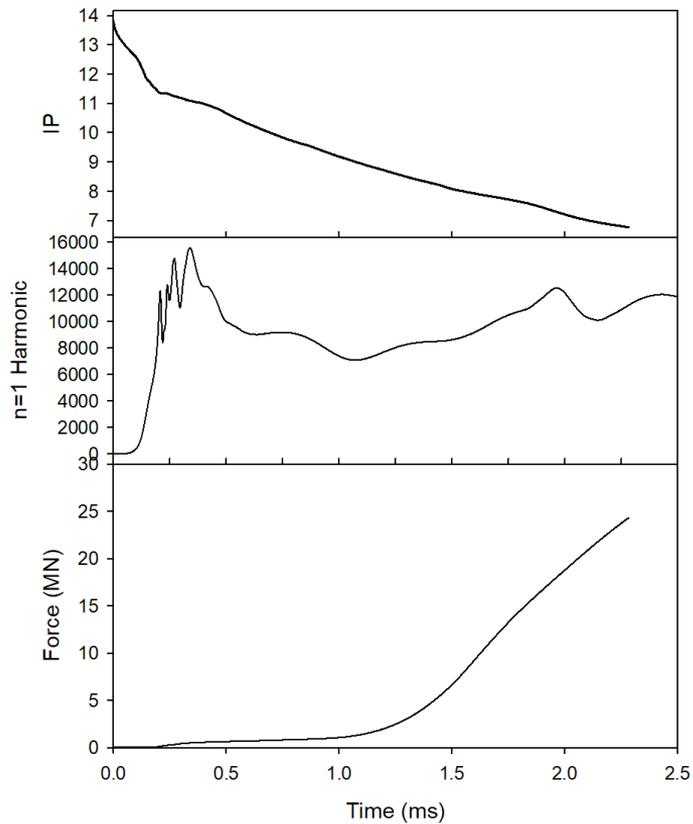
	High-Res	Baseline
eta_wall	.4e-4	.4e-6
eta_wallRZ	.4e-4	.4e-6
wall_region_eta	1.0	1.e-2
wall_region_etaRZ	.5e-6	.5e-8

eta_te_offset	1.009943e-3	1.00668e-3
eta_max	1.29242	1.29242e-2
amu	4.e-5	1.e-4

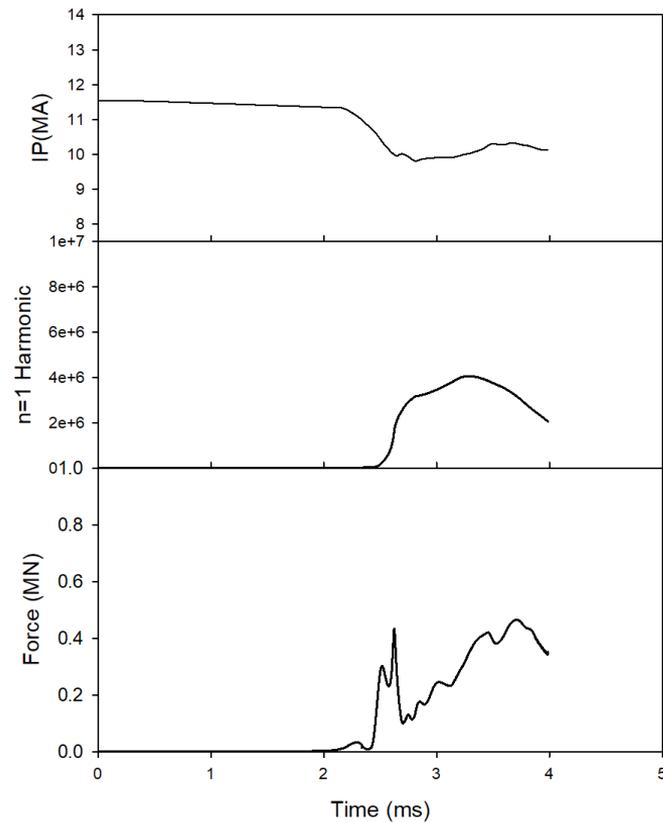
tedge = 1.01010e-3

# ITER Sideways Force

## 100 x vessel resistivity



## Realistic vessel resistivity



# Porcelli Theory

A new preprint claims that an ideal MHD diverted plasma will be stable to the vertical instability: Opportunity to demonstrate this numerically (or not)

## Impact of magnetic X-points on the vertical stability of tokamak plasmas

A. Yolbarsop<sup>1,2</sup>, F. Porcelli<sup>1</sup>, and R. Fitzpatrick<sup>3</sup>

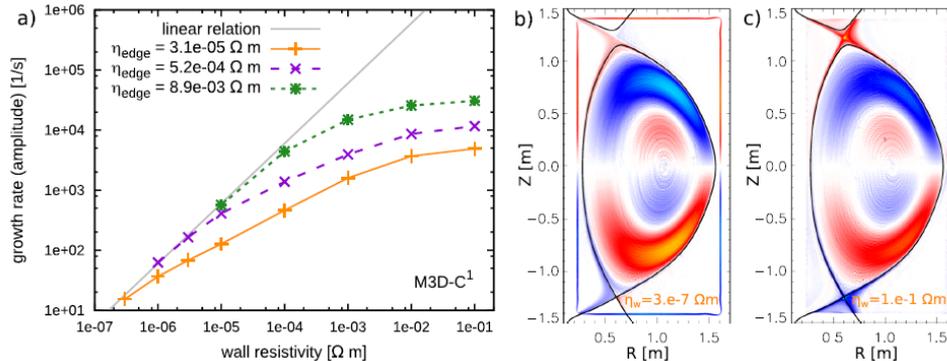
<sup>1</sup>*DISAT, Polytechnic University of Turin, Torino 10129, Italy*

<sup>2</sup>*KTX Laboratory, School of Nuclear Science and Technology, University of Science and Technology of China, Hefei, 230022, China*

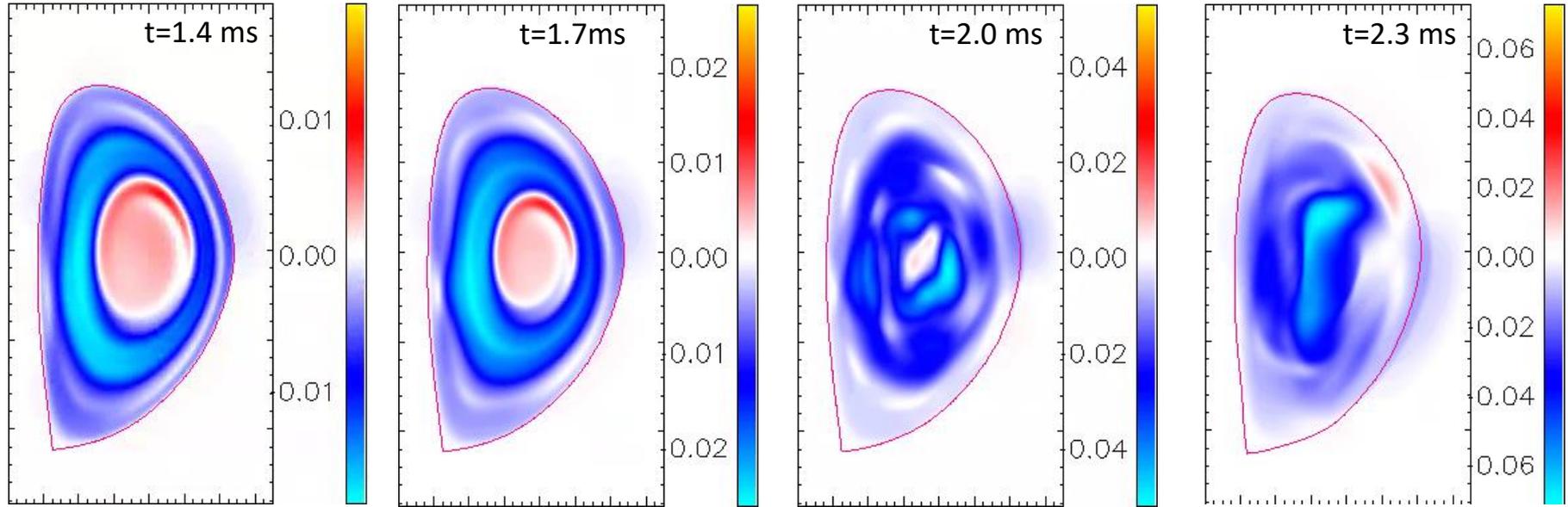
<sup>3</sup>*Institute for Fusion Studies, University of Texas at Austin, USA*

(Dated: March 7, 2021)

The ideal-MHD theory of axisymmetric modes with toroidal mode number  $n = 0$  in tokamak plasmas is developed. These modes are resonant at the magnetic X-points of the tokamak divertor separatrix. As a consequence, current sheets form along the separatrix, which profoundly affect the stability of vertical plasma displacements. In particular, current sheets at the magnetic separatrix lead to stabilization of  $n = 0$  modes, at least on the ideal-MHD time scale, adding an important ingredient to the mechanism of passive feedback stabilization.



## Why is toroidal magnetic energy increasing for $\text{iconst\_bz}=1$ ?



Plotted is the difference between initial  $RB_T$  and the  $RB_T$  at that time. Note initial  $RB_T$  is negative everywhere.  $RB_T$  is being held fixed at plasma boundary.

`/scratch/gpfs/bclyons/C1_8511`

# Energy is coming from voltage required to maintain TF constant at boundary

$$\frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E} \Rightarrow \frac{\partial}{\partial t} \int \mathbf{B} \cdot d\mathbf{A} = -\oint \mathbf{E} \cdot d\boldsymbol{\ell}$$

As pressure decreases, plasma becomes more para-magnetic to maintain equilibrium. → toroidal flux in plasma increases

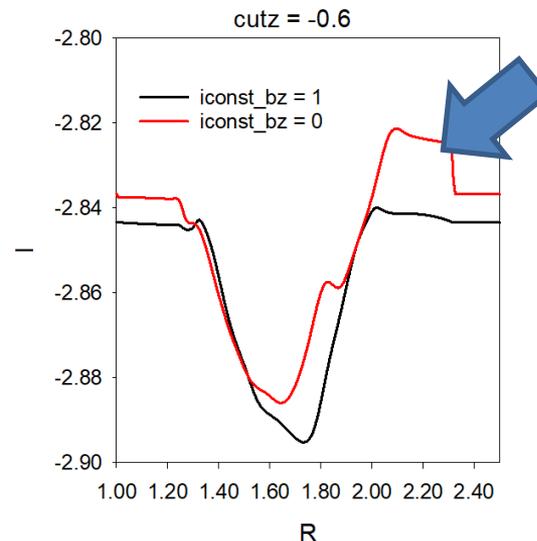
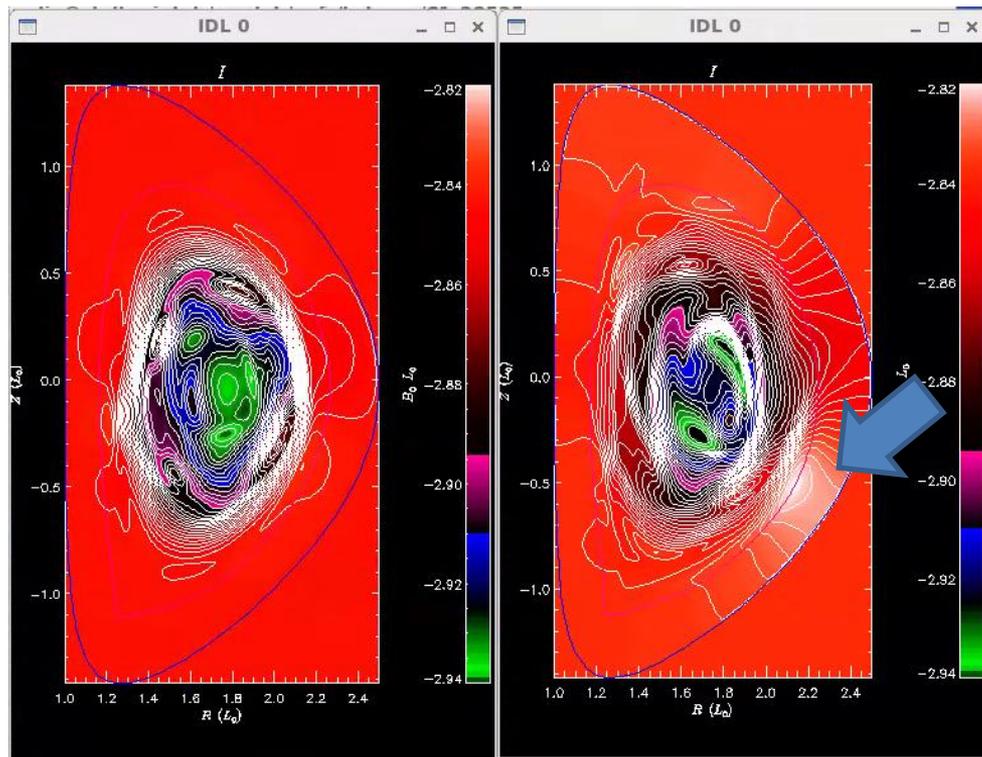
The increase in toroidal flux inside the plasma produces a poloidal electric field. That poloidal electric field would tend to reduce the poloidal current in the TF coils and lower the toroidal field, thus conserving the toroidal flux in the plasma.

We are keeping the toroidal field at the boundary constant. To do this in reality, one would need to increase the voltage in the TF coils to counter the poloidal field coming from the flux change.

# Compare `iconst_bz=0` and `iconst_bz=1`

`iconst_bz = 1`

`iconst_bz = 0`



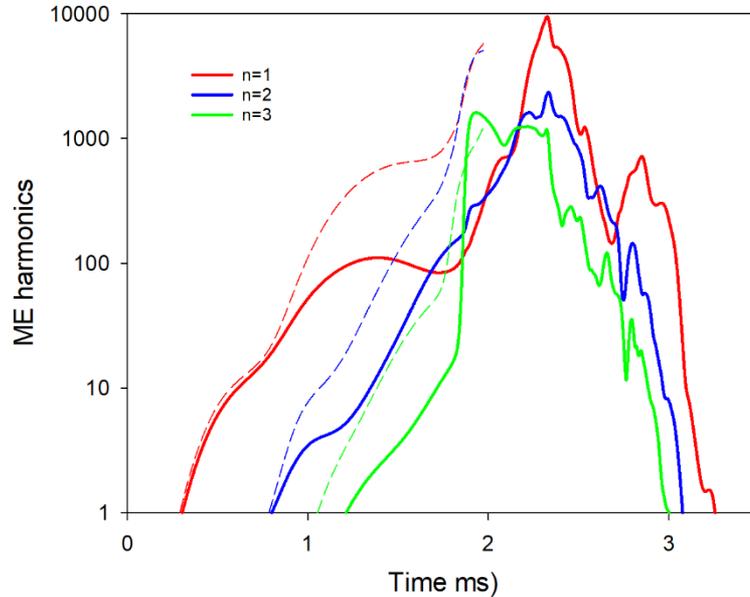
`iconst_bz = 0` develops RBz glitches on open field lines. Unphysical?

`plot_field,'i',19,/lines,/lcfs,/bound`

`/scratch/gpfs/bclyons/C1_8511`  
`/scratch/gpfs/bclyons/C1_28525`

`iconst_bz=1`  
`iconst_bz=0`

# Compare $iconst\_bz=0$ and $iconst\_bz=1$



Magnetic energy in first 3 toroidal harmonics

Solid  $iconst\_bz = 1$

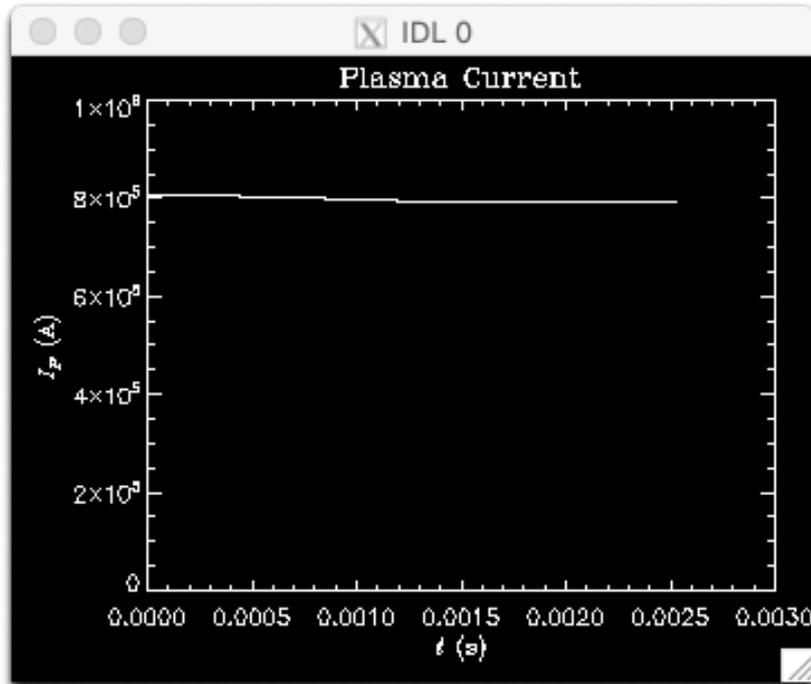
Dashed  $iconst\_bz = 0$

Note:  $iconst\_bz=0$  always goes unstable

# Pellet with RA

06/28/21

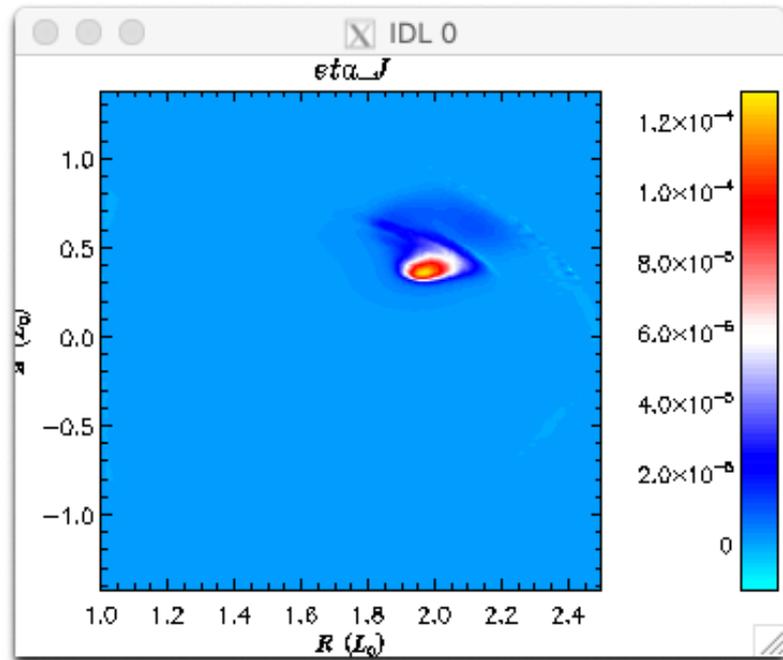
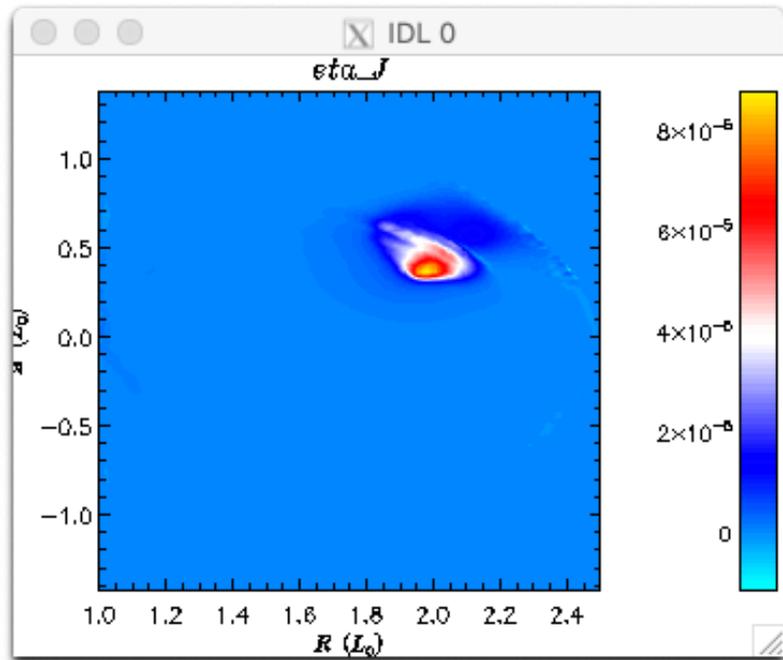
DIII-D shot 177053  
Chen Zhao



The plasma current stop dropping down at about 1.3ms.

I think that is not match the experiment, how could we change the parameters to fit the experimental current decreasing rate?

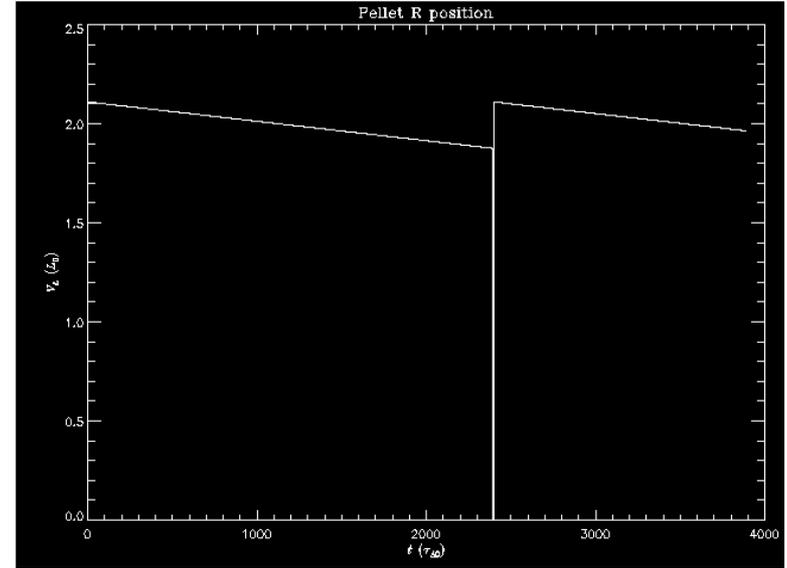
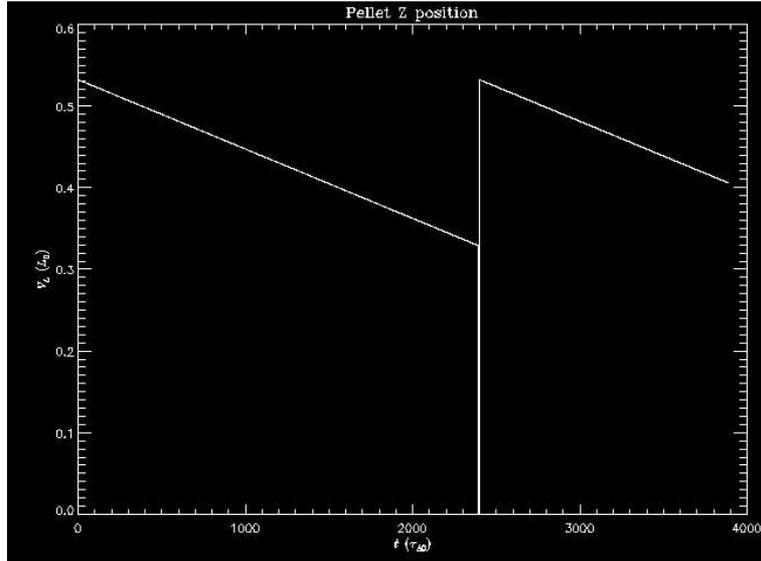
SJ: The pellet has to cool the plasma to increase the resistivity, and then the current will drop.



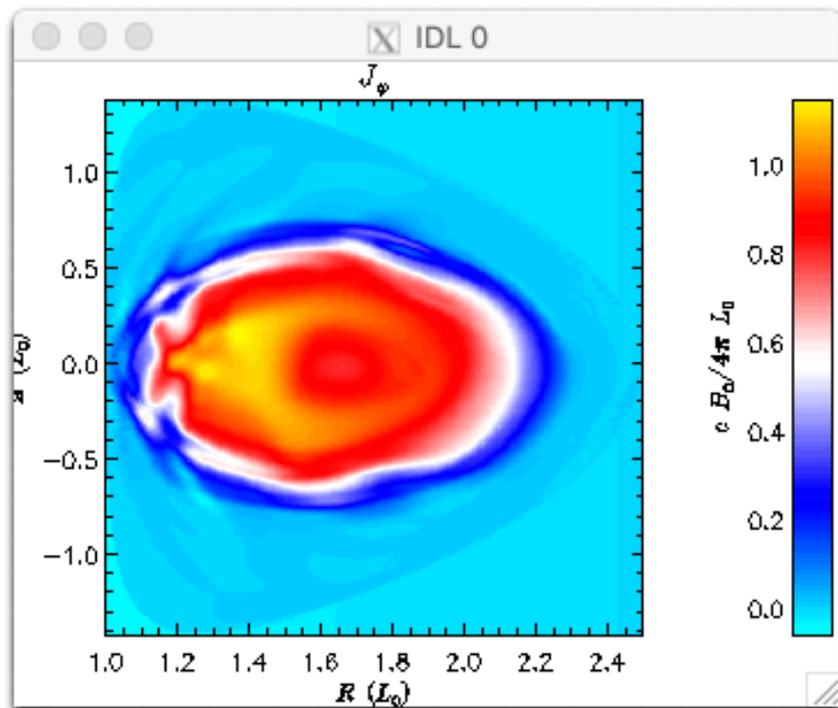
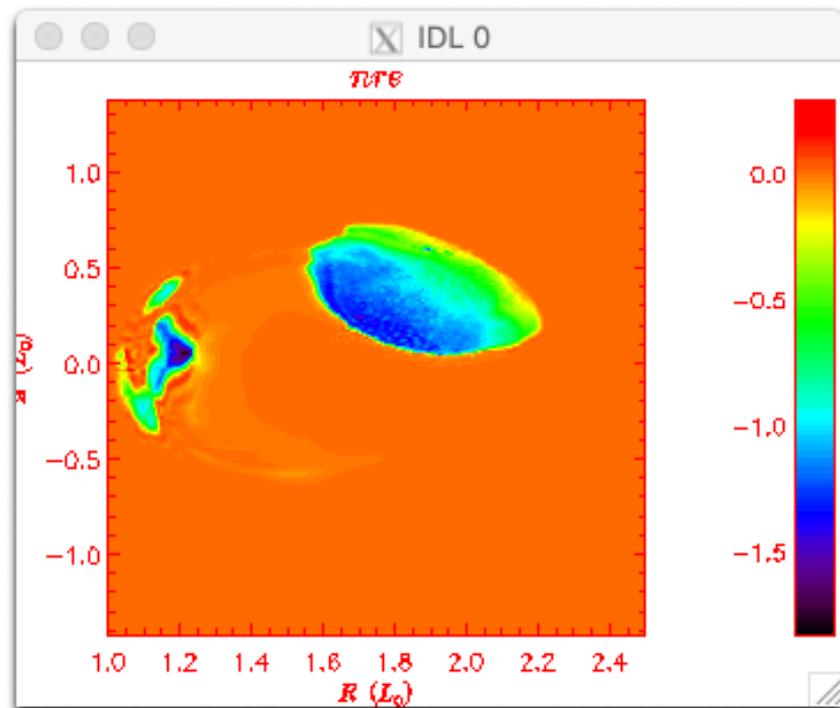
The pellet seems stop moving to the center but start moving along the field line at about 1.5ms.

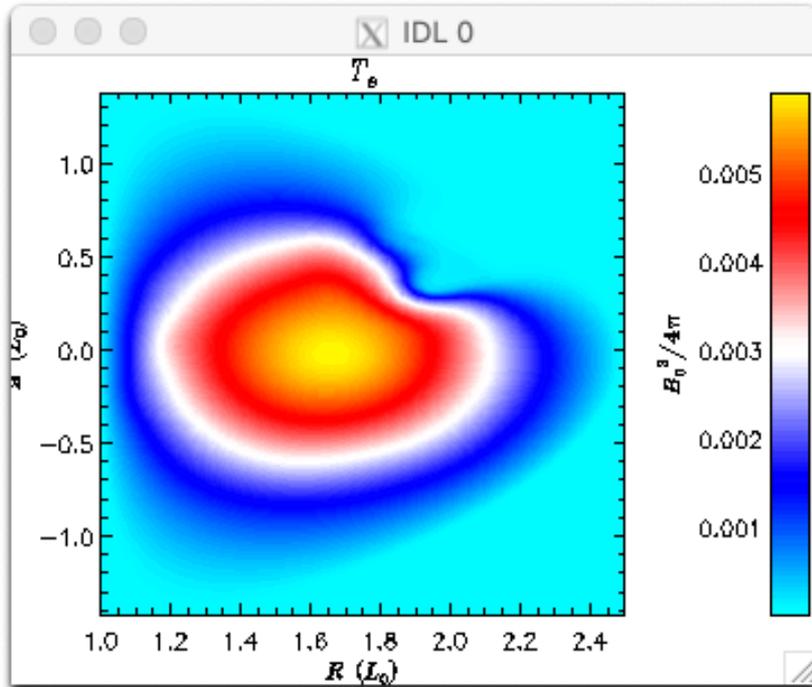
SJ: see the next vg

# Pellet position being reset at restart time!



# Runaway current density and plasma current density at 2.5ms

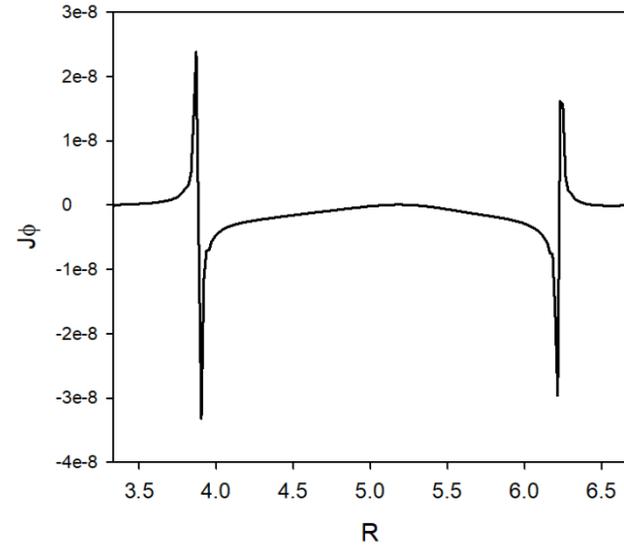
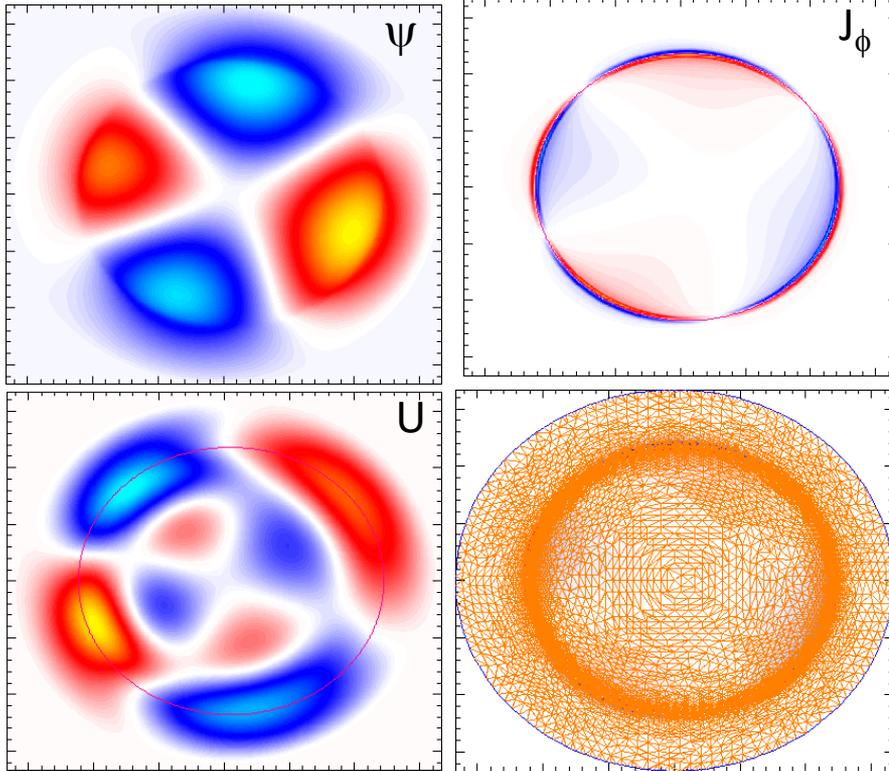




Electron temperature at 2.5ms

SJ: you should include /mks in the IDL plot\_field,'te' command in order to get the temperature in eV. This is about 300 eV.

# Typical Tearing Mode



$$\begin{aligned}\eta &= 2.e-6 \\ 1.1 &< q < 2.9 \\ \gamma\tau_A &= 10^{-4}\end{aligned}$$

## DIII-D Resistive Wall Mode

Email from Hank Strauss on 5/27/21

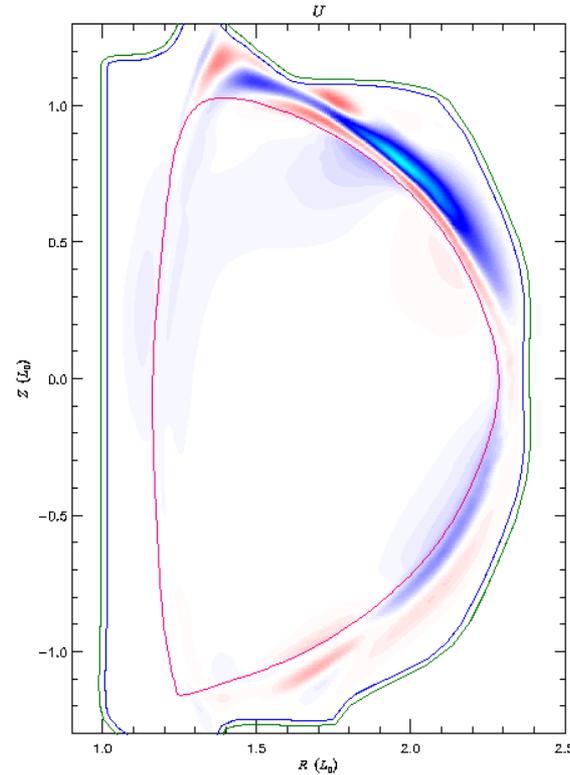
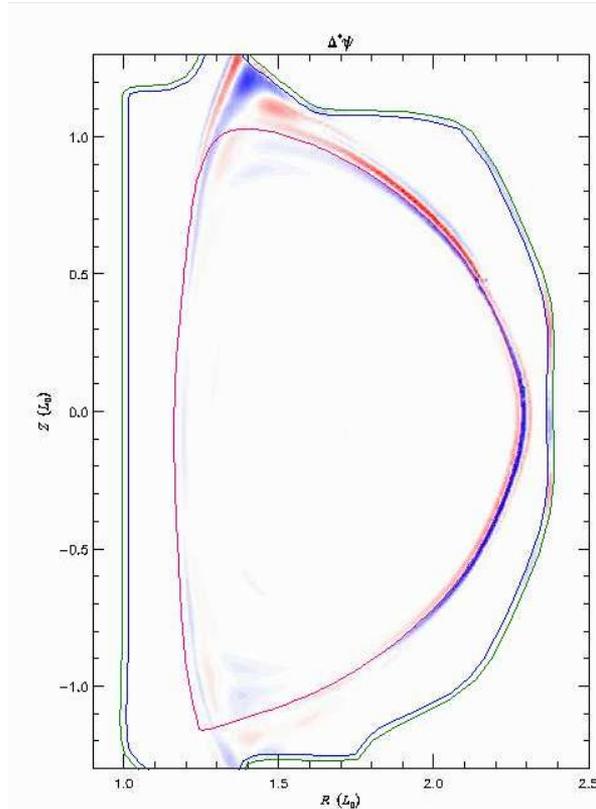
I tried to find D3D RWMs (RWTM)s with Brendan's mesh and C1input files, but it seems that the wall is behaving like an ideal wall. It needs much more adaptive refinement. I also tried a nonlinear run, but even though  $\epsilon > 0$ , it didn't have a 3D perturbation.

A linear run is in /scratch/gpfs/hs9956/d3d\_eb1\_1f\_eq\_l11 and nonlinear in rw1\_nl\_54576.03354\_945b2.

I think lack of resolution at the wall is also causing AVDE simulations to fail at small  $\eta_{\text{wall}}$ . The mesh needs adaptive refinement at the wall.

An ADVE simulation is in JETm3dc1\_0.12h9b4.

# Linear Eigenfunction



Physical mode? Not tearing.

# Chen Zhao paper on RE with sources

Simulation of the runaway electron plateau formation during current quench

C. Zhao<sup>1</sup>, C. Liu<sup>1</sup>, S. C. Jardin<sup>1</sup>, N. M. Ferraro<sup>1</sup>, B. C. Lyons<sup>2</sup>  
V. Bandaru<sup>3</sup>, M. Hoelzl<sup>3</sup>

<sup>1</sup> Princeton Plasma Physics Laboratory, Princeton, NJ, United States of America

<sup>2</sup> General Atomics, San Diego, CA, United States of America  
General Atomics, San Diego, CA, United States of America

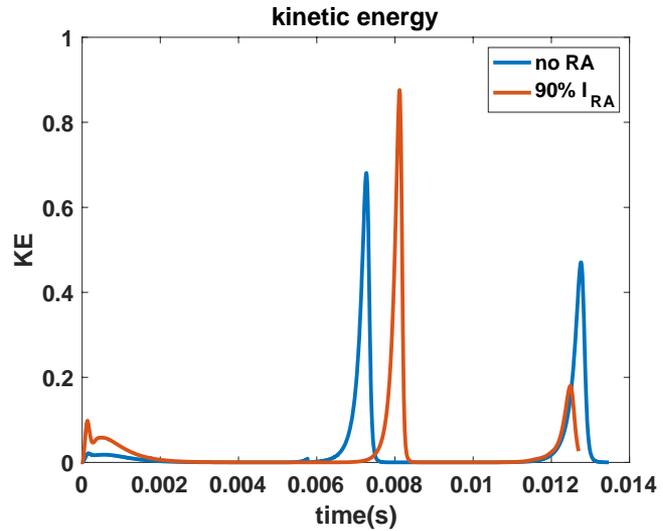
<sup>3</sup> Max Planck Institute for Plasma Physics, Boltzmannstraße, Garching, Germany

- Source terms and coupling to MHD
- Runaway source test case and benchmark with JOREK
- Current quench result with DIII-D parameters

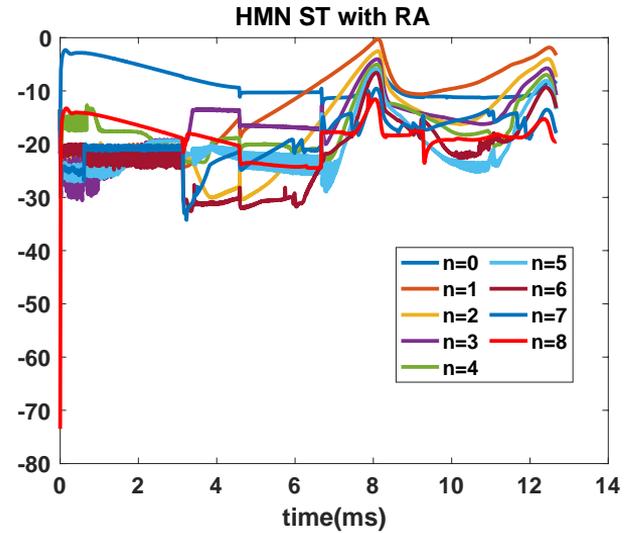
Isabel ST with RA

06/1/21

- Both cases are use Isabel eq with mesh 0.01m



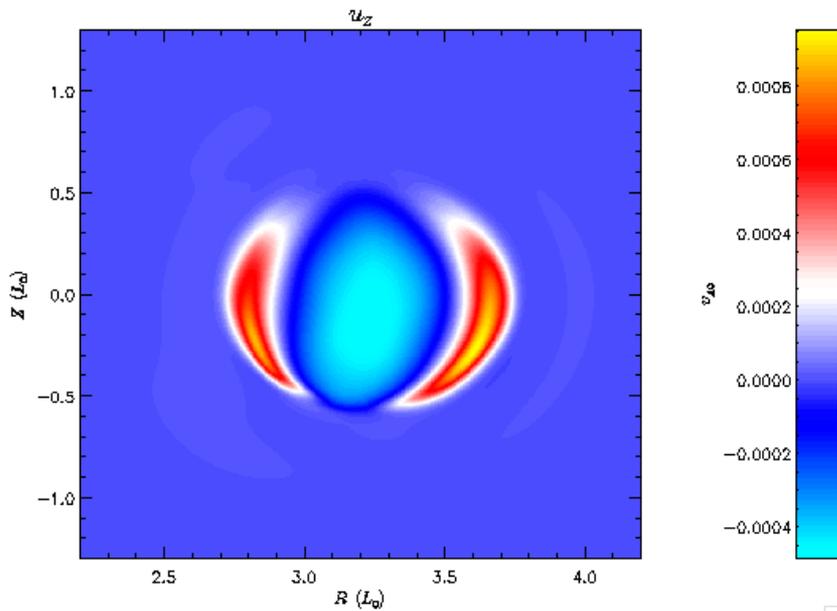
- It needs more time to see if there is only on ST phase with RA



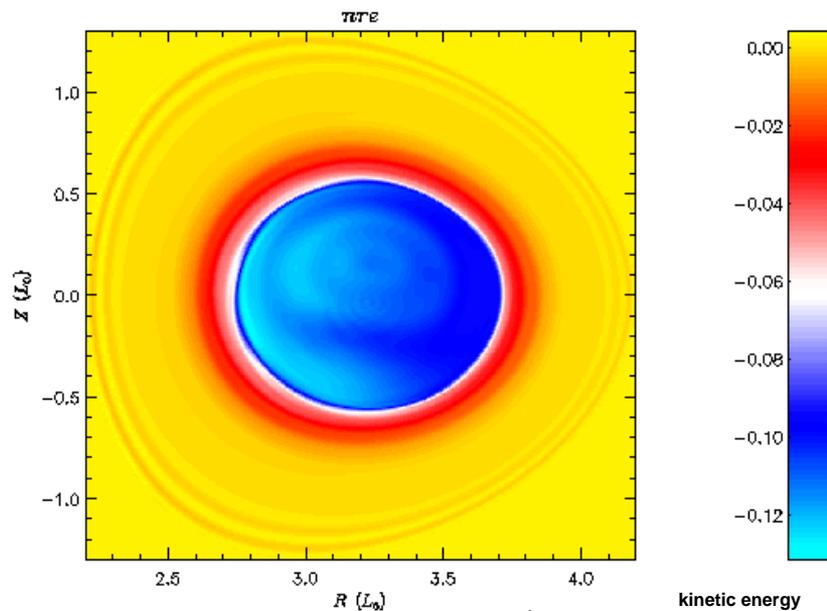
- Most unstable mode is n = 1 with RA

# Profiles at 8ms with RA (1<sup>st</sup> ST phase)

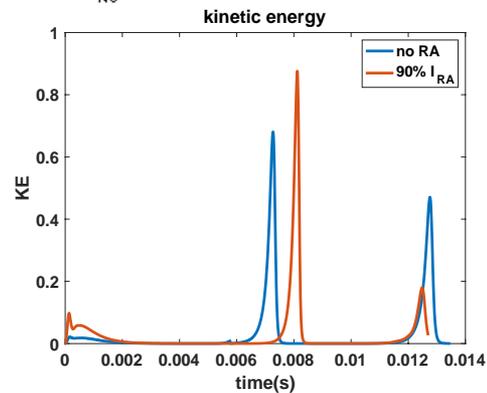
V<sub>z</sub>



J\_RA

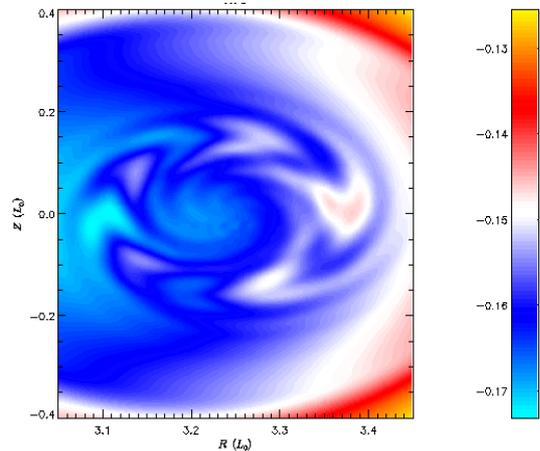


- No clear mode in runaway current

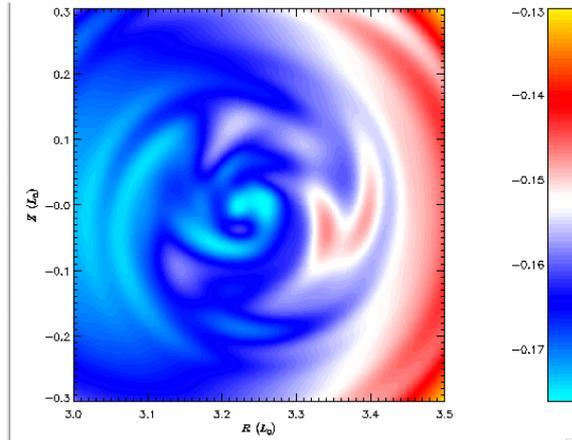


## Runaway current during 2<sup>nd</sup> ST phase

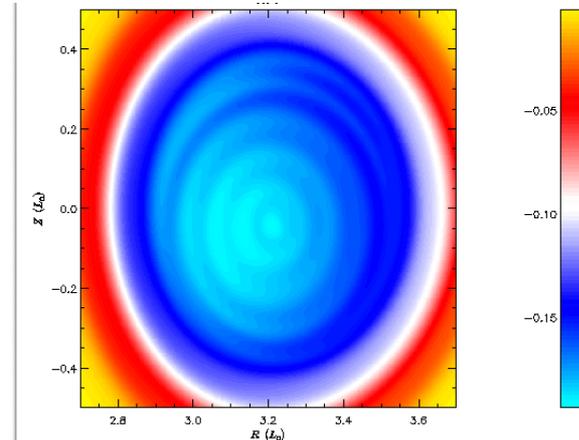
J\_RA 10.6ms



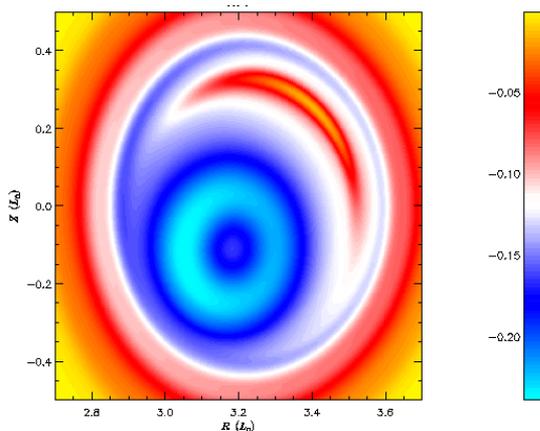
J\_RA 10.8ms



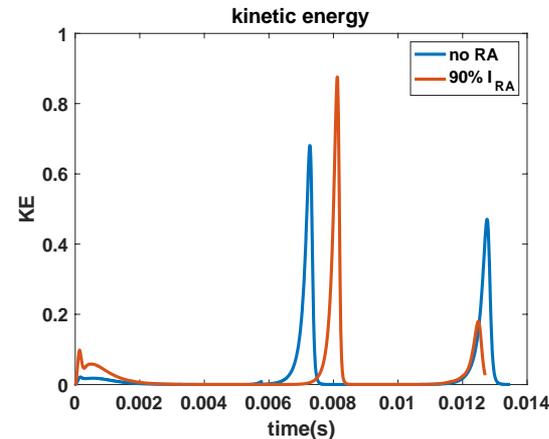
J\_RA 11.4ms



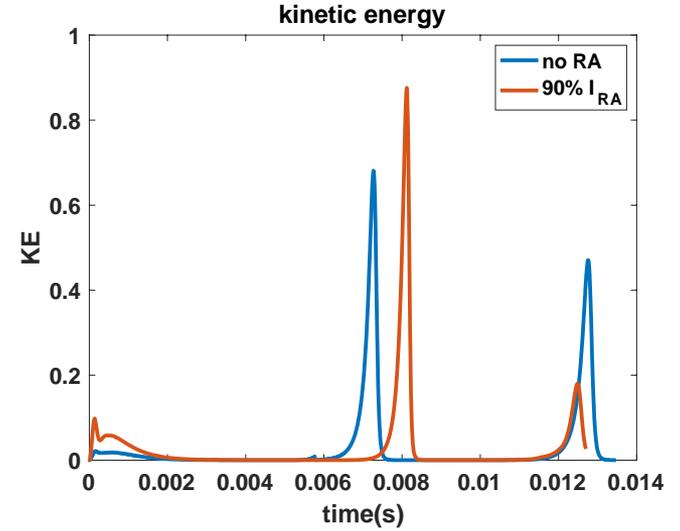
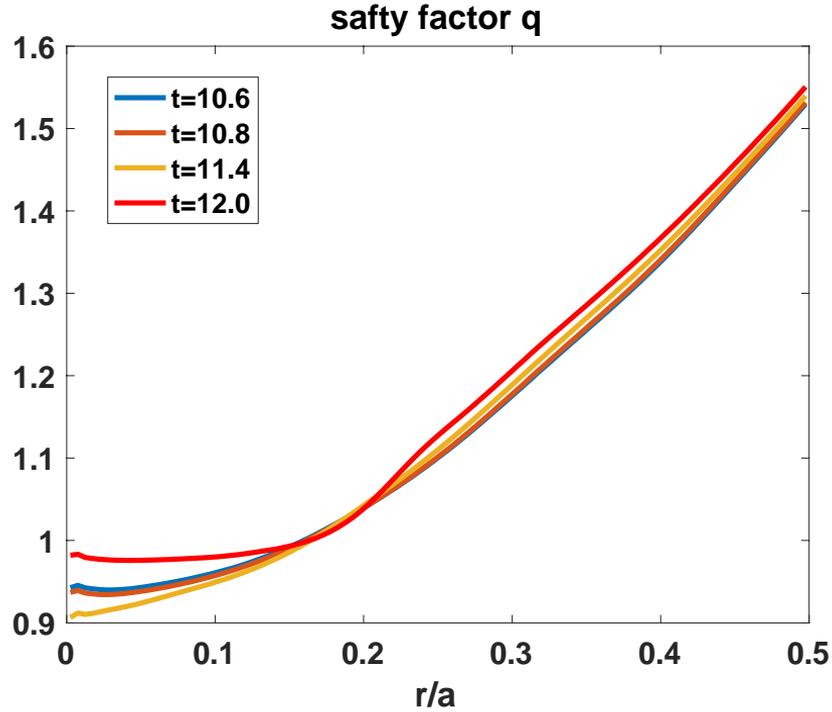
J\_RA 12.0ms



- At 2<sup>nd</sup> ST phase there is a  $n \sim 5$  mode reduced to  $n \sim 1$  mode in runaway current
- The instabilities in runaway current may cause the much lower kinetic energy at 2<sup>nd</sup> ST phase.



# q profile during 2<sup>nd</sup> phase



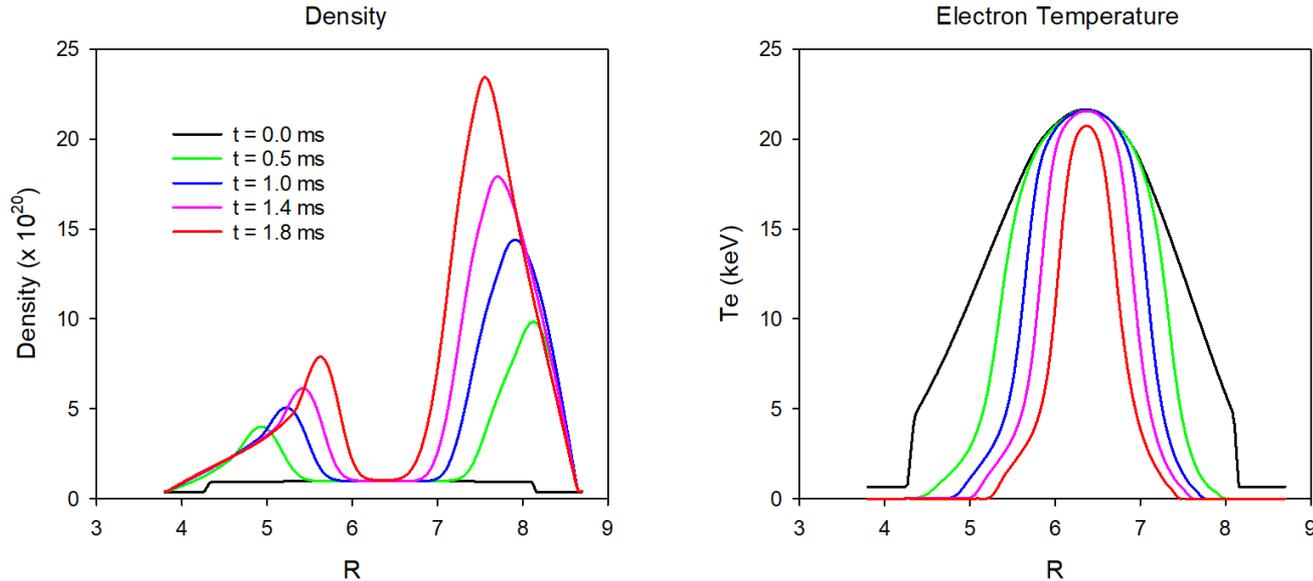
Directory : /projects/M3DC1/chenzhao/Chen2D-mod3/

## 2D ITER modeling of SPI -- Brendan Lyons 5/6/21

- I've recently started some 2D ITER modeling of SPI and I'm getting a weird result.
- The attached video show the density, every time step, from `/scratch/gpfs/bclyons/C1_11735` on stellar.
  
- Good NEWS
  - I got this to run to 2 ms by setting `pedge=.01`, `idenmfunc=1`
  
- Bad NEWS
  - After that time, code crashes with segmentation fault in velocity solve
  - Doesn't always crash at same time step, and numbers can be different for different runs restarting from same time!!

`/scratch/gpfs/sjardin/Brendan`

## 2D ITER SPI Modeling (cont)



- Density and temperature at Z= 1m at different times
- However, calculation stops with “segmentation fault” at seemingly random time steps...also, differing results!

# Inconsistencies in 2D nonlinear restarting at N=1000

## -1 slurm18347 died 1018 SEGV (SuperLU)

1000	2.7500E+03	3.0076E-01	3.6364E-01	2.8914E-02	2.7081E-01	1.0371E-03	6.3888E+02	2.1293E+04	3.2050E+02	2.22524E+04
1001	2.7528E+03	<b>3.0125E-01</b>	<b>2.9180E-04</b>	2.9007E-02	<b>2.7121E-01</b>	1.0298E-03	6.3882E+02	2.1293E+04	3.2028E+02	2.22521E+04
1002	2.7555E+03	<b>3.0170E-01</b>	<b>2.7516E-04</b>	<b>2.9101E-02</b>	2.7157E-01	<b>1.0278E-03</b>	6.3875E+02	2.1293E+04	3.2005E+02	2.22518E+04
1003	2.7582E+03	3.0214E-01	<b>2.6496E-04</b>	<b>2.9189E-02</b>	<b>2.7193E-01</b>	<b>1.0246E-03</b>	6.3869E+02	2.1293E+04	3.1982E+02	2.22515E+04

## -2 slurm18516 died 1088 SEGV (SuperLU)

1000	2.7500E+03	3.0076E-01	3.6364E-01	2.8914E-02	2.7081E-01	1.0371E-03	6.3888E+02	2.1293E+04	3.2050E+02	2.22524E+04
1001	2.7528E+03	<b>3.0124E-01</b>	<b>2.8901E-04</b>	2.9007E-02	<b>2.7120E-01</b>	1.0298E-03	6.3882E+02	2.1293E+04	3.2028E+02	2.22521E+04
1002	2.7555E+03	<b>3.0169E-01</b>	<b>2.7320E-04</b>	<b>2.9100E-02</b>	2.7157E-01	<b>1.0279E-03</b>	6.3875E+02	2.1293E+04	3.2005E+02	2.22518E+04
1003	2.7582E+03	3.0214E-01	<b>2.6685E-04</b>	<b>2.9188E-02</b>	<b>2.7192E-01</b>	<b>1.0250E-03</b>	6.3869E+02	2.1293E+04	3.1982E+02	2.22515E+04

## -3 slurm18607 died 1049 SEGV (SuperLU)

1000	2.7500E+03	3.0076E-01	3.6364E-01	2.8914E-02	2.7081E-01	1.0371E-03	6.3888E+02	2.1293E+04	3.2050E+02	2.22524E+04
1001	2.7528E+03	<b>3.0124E-01</b>	<b>2.9042E-04</b>	2.9007E-02	<b>2.7121E-01</b>	1.0298E-03	6.3882E+02	2.1293E+04	3.2028E+02	2.22521E+04
1002	2.7555E+03	<b>3.0170E-01</b>	<b>2.7414E-04</b>	<b>2.9101E-02</b>	2.7157E-01	<b>1.0278E-03</b>	6.3875E+02	2.1293E+04	3.2005E+02	2.22518E+04
1003	2.7582E+03	3.0214E-01	<b>2.6593E-04</b>	<b>2.9189E-02</b>	<b>2.7193E-01</b>	<b>1.0248E-03</b>	6.3869E+02	2.1293E+04	3.1982E+02	2.22515E+04

Each of these died in the velocity solve with a segmentation fault at different time steps!

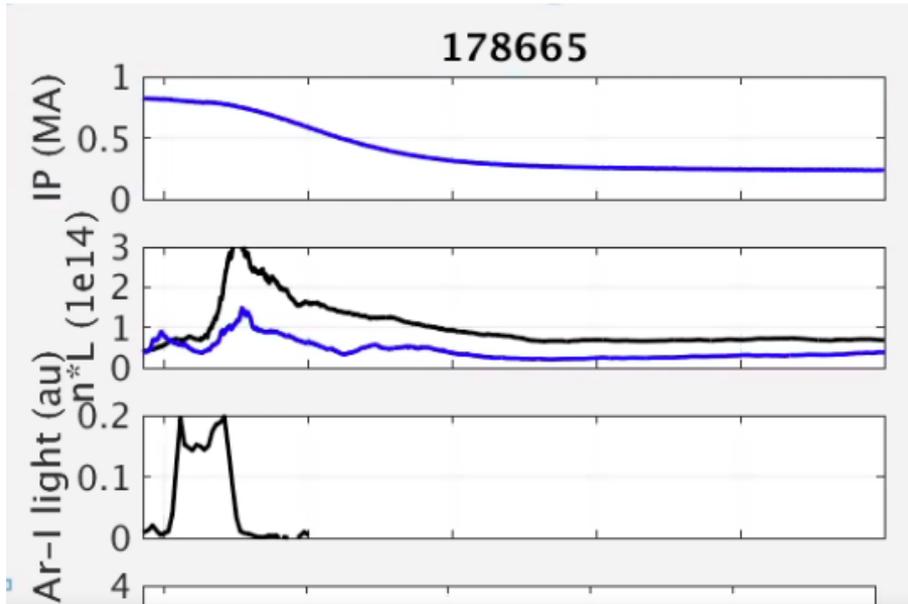
## 5/31/21 meeting w JOREK regarding RE benchmark

\* A recent paper has appeared using the 1 ½ D code ASTRA-STRAHL to examine in detail a ASDEX-U mitigation shot that produced Runaway Electrons. Linder, et al. “Self-consistent modeling of runaway electron generation in massive gas injection scenarios in AUG”, NF 60 (2020) 096031

- 1) Vinodh and Matthias will look further into defining the setup for the AUG based benchmark case that was looked at with ASTRA-STRAHL and contact the M3D-C1 team as soon as they have something ready.
- 2) Chen will look into modeling the DIII-D discharge 178665 and will let JOREK team know when there are any interesting observations.
- 3) The two teams will meet again in a few weeks as soon as there is something new to look at for 1) or 2).

In attendance: Matthias Hoelzl, Vinodh Bandaru, Chen Zhao, Stephen Jardin

# DIII-D RE generation with Ar shot 178665



Carlos suggested this shot:

$\langle n_e \rangle$ ,  $Te(r,t)$ ,  $IP(t)$ , AR-1 (R,Z,t)

Eric Hollman studied this shot in detail in an upcoming paper so we may want to write to him

Use equilibria from 177053. You might want to look at matching the pre-TQ density integral to 665

That's All I have

Anything Else ?

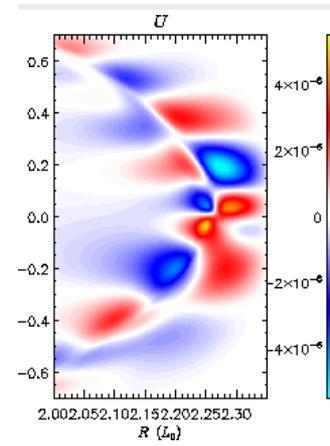
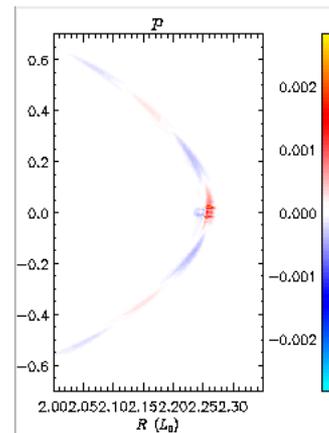
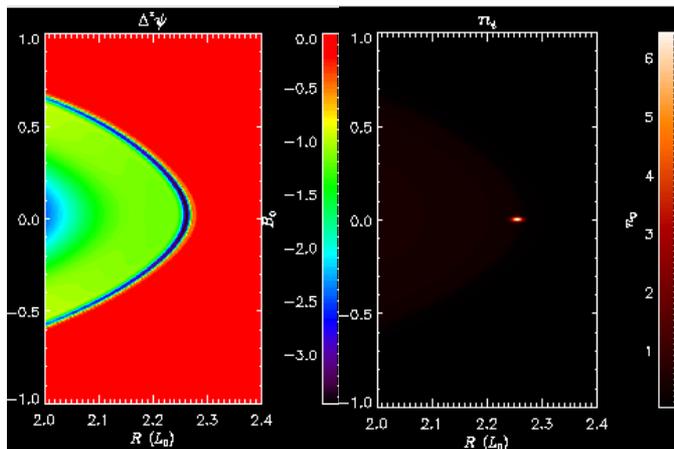
That's All I have

Anything Else ?

# M3D-C1 modeling of pellet ELM triggering in low-collisionality discharges

- Preprint by A. Wingen (ORNL), Linear and non-linear simulations
- Linear simulation with  $ipellet=1$  perturbs only the density profile. Large enough perturbation excites an unstable mode

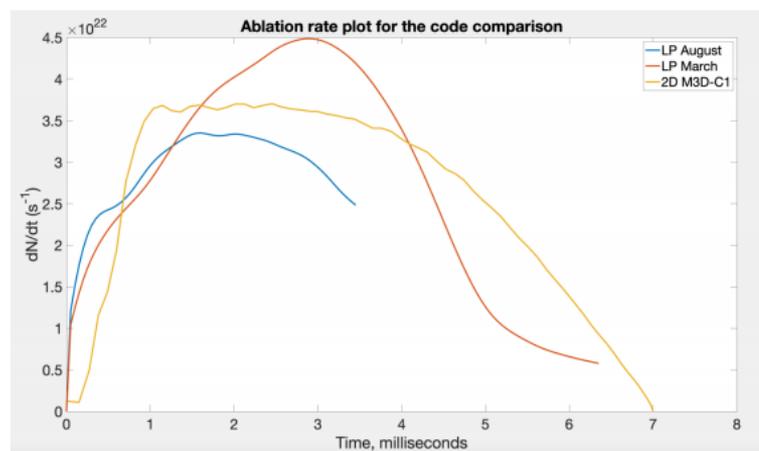
**Q: How does a density perturbation excite a MHD mode?**



Density perturbation causes decreased  $T_e$  at one location on flux surface. Thermal conduction during linear phase causes pressure to increase there. Gives an unstable mode for  $n_{tor}=9$  only if  $k_{\perp} \neq 0$

# Interfacing M3D-C1 and LPC

- Zoom meeting was held 04/08/21 with Roman Samulyak and students
- Presentation posted on m3dc1.pppl.gov
- Small differences between m3dc1 pellet model and LPC local model
- Brendan to see what data is available for single neon pellet ablation test
- **Daisuke Shiraki will address this in a special call set for Tuesday at 2:00 ET. Lyons, Samulyak, Jardin, ..... (assuming Samulyak availability)**



## Approach to nonlinear MHD simulations in stellarator geometry

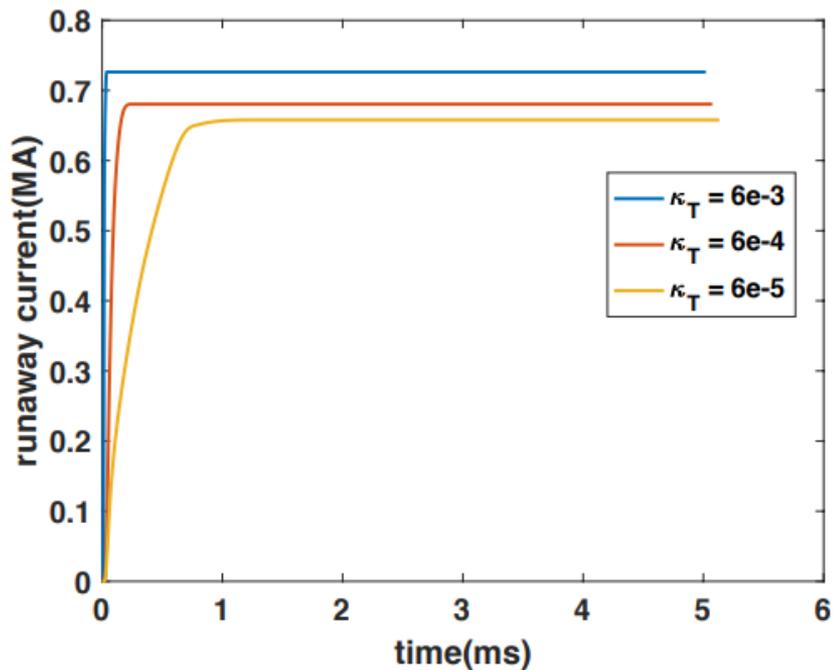
- Yao Zhou has an excellent preprint he plans to submit to Nuclear Fusion

# Self-consistent simulation of resistive kink instabilities with runaway electrons

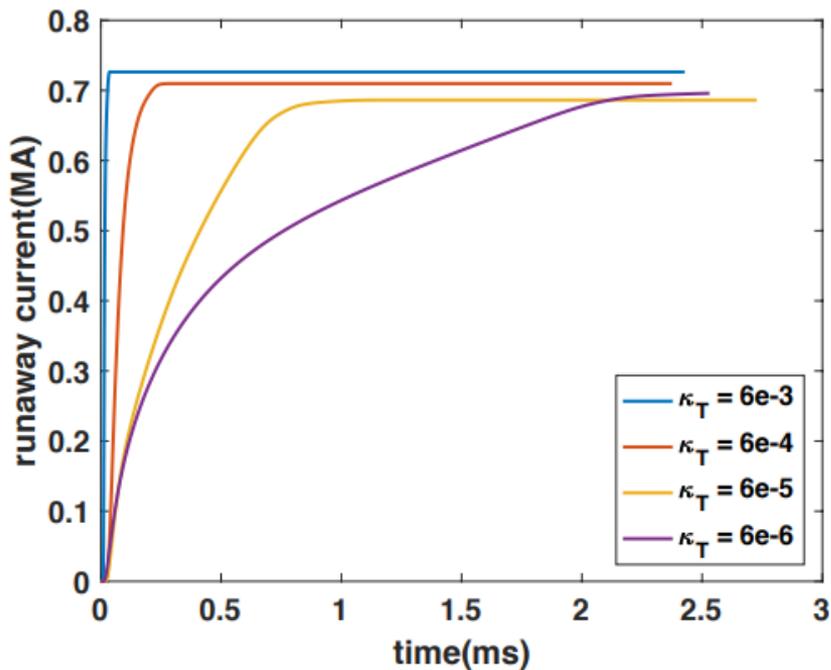
- Chang Liu, et al manuscript submitted to Plasma Physics and Controlled Fusion 04/21/2021

# Effect of Avalanche term on DIII-D 177053

Only Drecier



Drecier and Avalanche



## Next Steps

- Chen Zhao should consider writing a paper on the incorporation of the runaway source term in M3D-C1 and include the DIII-D result
- NIMROD is interested in doing a benchmark of the runaway source calculations. I gave them Chen's equilibrium and results. This could be included in paper if done sufficiently fast.
- I asked Carlos Paz-Soldan to help us identify a series of DIII-D shots where runaways are generated and there are good diagnostics. Still waiting to hear. (he did indicate that he's working on it)
- We had a zoom call with the JOREK group this morning. They will also check with ASDEX-U to see if there is a series of experiments that we could model

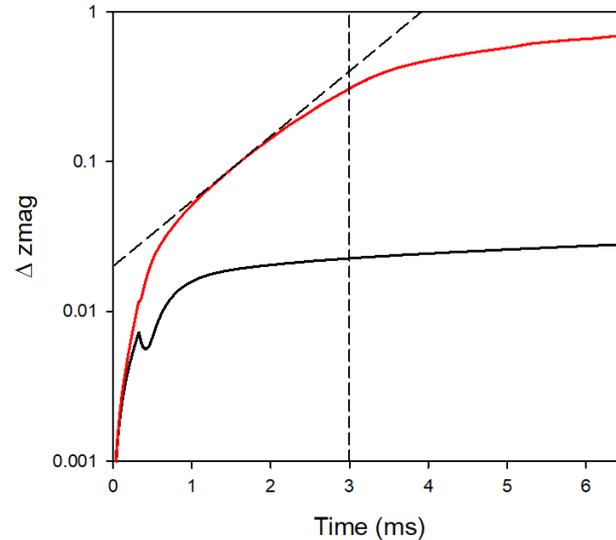
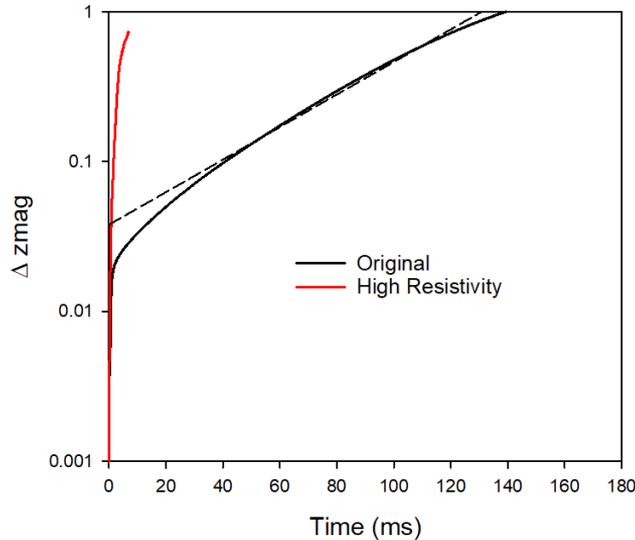
# Effect of resistive wall on the thermal quench

- Hank Strauss requested an EFIT equilibrium for shot 154576 at 3312ms, just before it disrupts
- This was studied in the paper: R. Sweeney, et al, "Relationship between locked modes and thermal quenches in DIII-D"
- Focus of paper is that sometimes overlapping locked modes just flatten the temperature around the  $q=2$  surface ( $q=3/2$  to edge) whereas sometimes they also cause a collapse of the core temperature
- NIMROD simulations were initialized with islands of the size and phase of the experiment:  $3/2$ ,  $2/1$ ,  $3/1$ , and  $4/1$
- In the simulation, the  $2/1$  island decays in time, unlike in the experiment. Also, the experiment shows a wider region of  $T_e$  collapse. Can M3DC1 improve on this?

# Current coupling scheme of fishbone simulation in M3D-C1

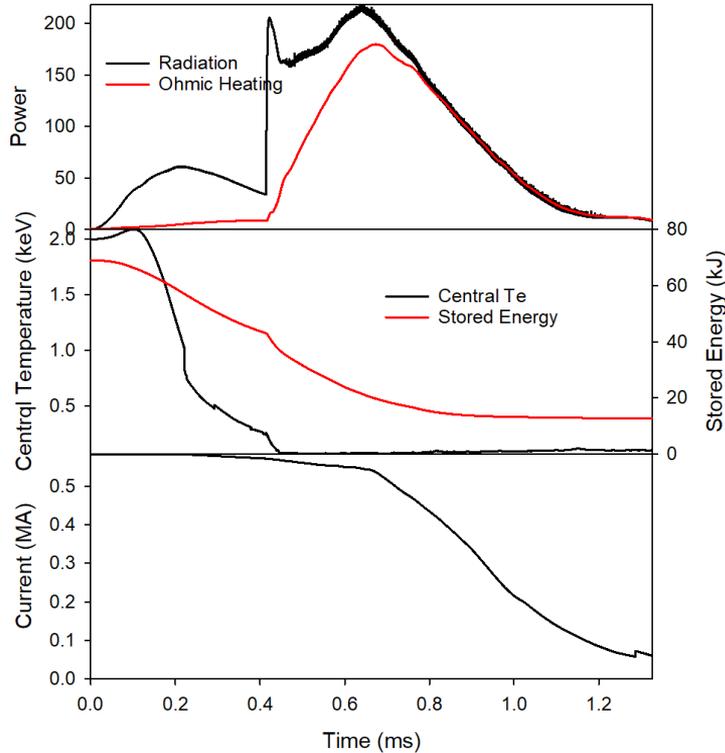
- Chang Liu to present

# ITER disruption with more resistive vessel



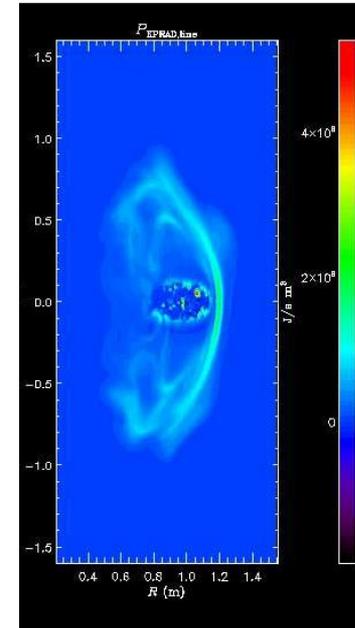
- Increased all vessel resistivities by 100
- Growth rate went from  $.025 \text{ ms}^{-1}$  to  $2.0 \text{ ms}^{-1}$
- New case greatly slows down after contact with wall is made

# Carbon Mitigation in NSTX-U (shell pellet)



Shell carbon pellet in NSTX (now running)

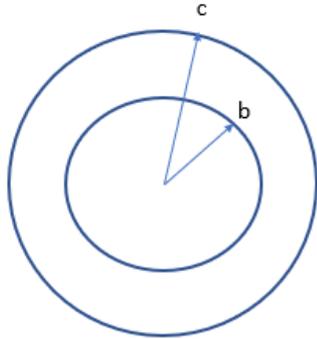
Radiation  
 $t = 0.73$  ms



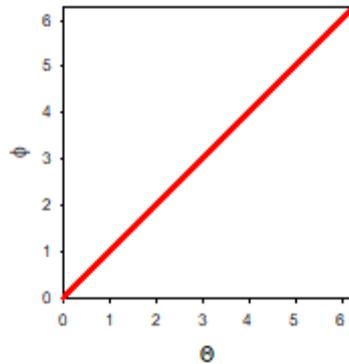
This run is essentially done and can be incorporated into Cesar's paper

# 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?

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

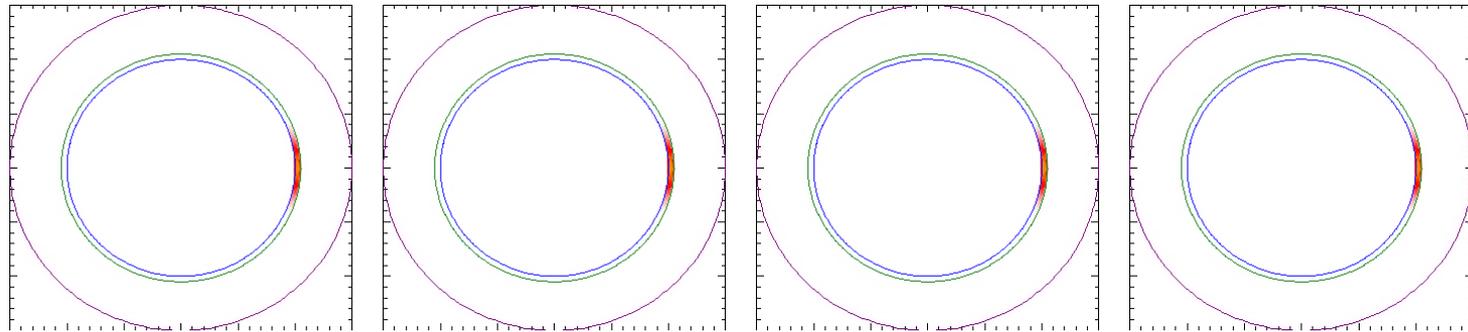
$$\mathbf{J} = \sigma \mathbf{E}$$

What is driving the current in the  $\theta$  direction? It can't be  $\Phi$  unless

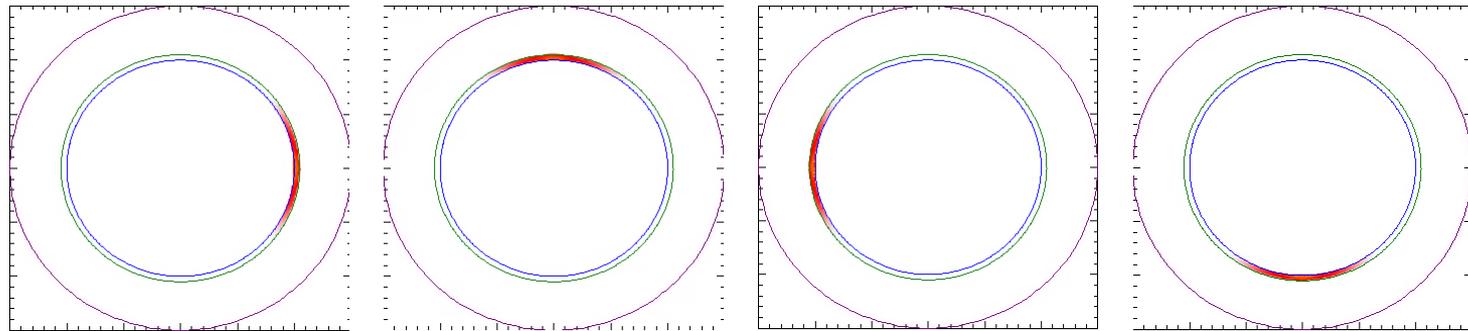
$$\int_0^{2\pi} \sigma^{-1} J_\theta d\theta = \int_0^{2\pi} \frac{d\Phi}{d\theta} d\theta = 0$$

# Comparison between Straight and helical band

Straight →



Helical →

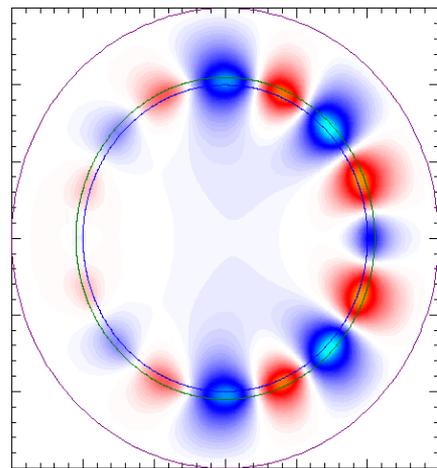
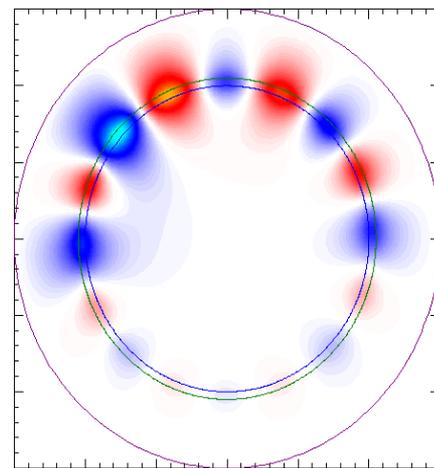
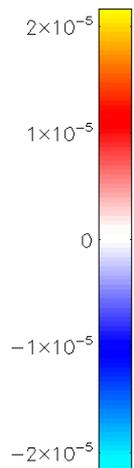
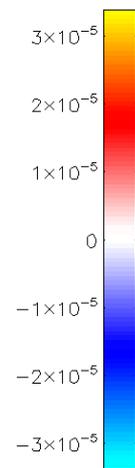
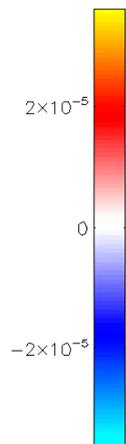
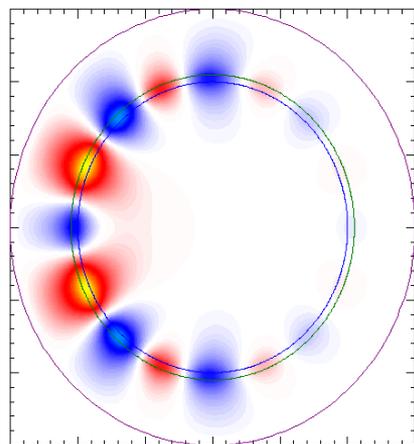
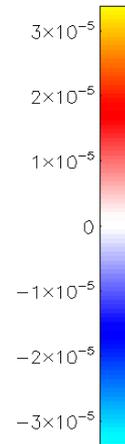
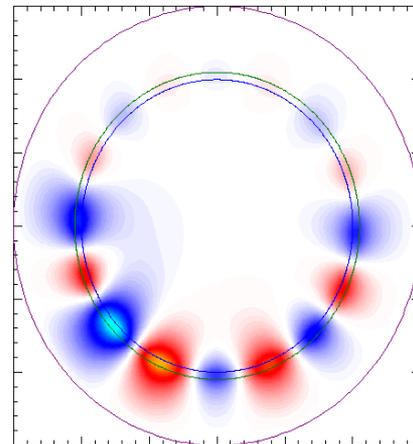


$$\varphi = 0$$

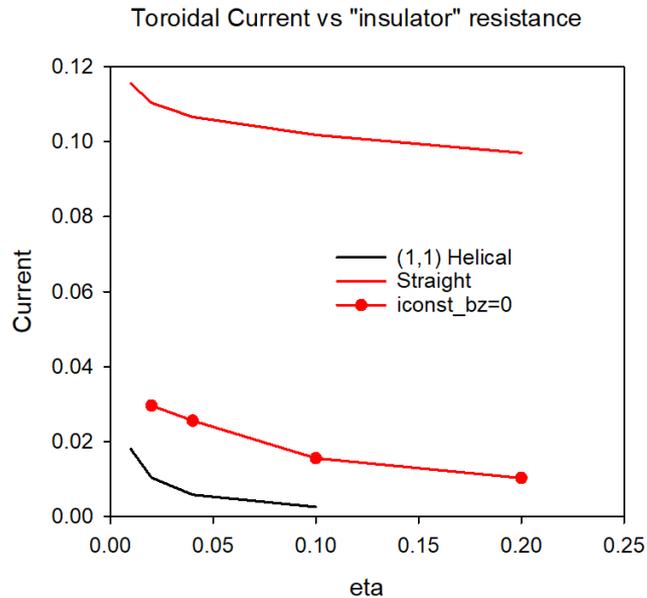
$$\varphi = \pi / 2$$

$$\varphi = \pi$$

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

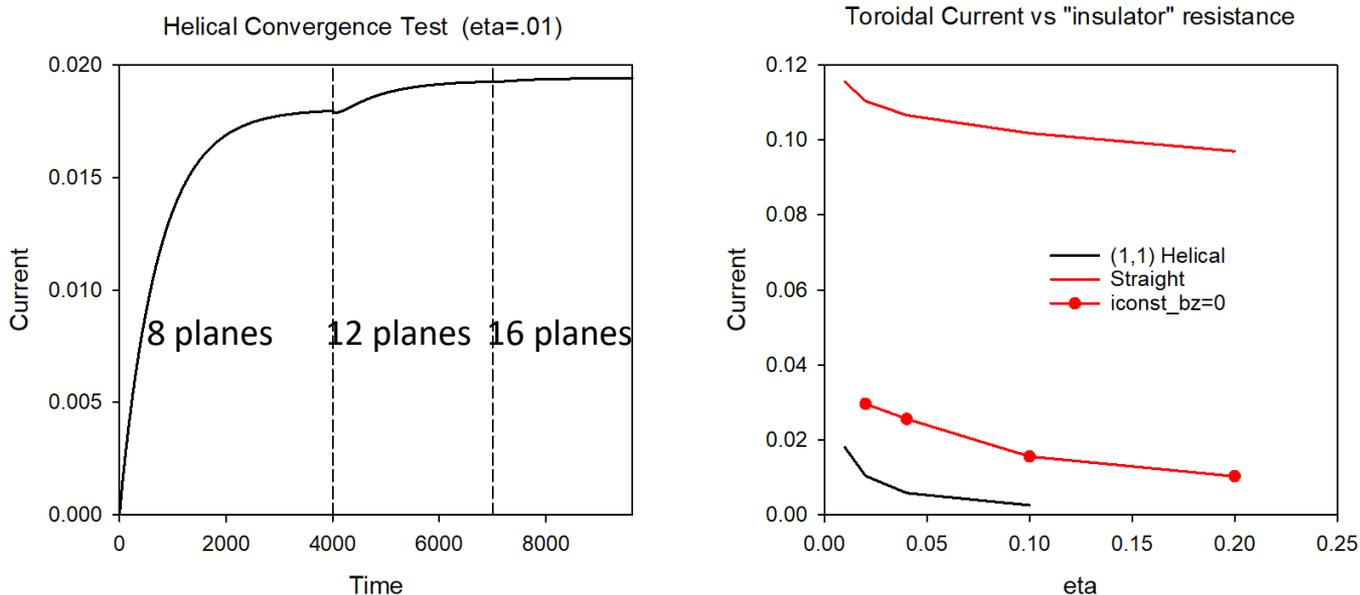
$\Phi_\varphi$  $\varphi = 000^\circ$  $\varphi = 090^\circ$  $\varphi = 180^\circ$  $\varphi = 270^\circ$ 

# Helical resistive band to suppress runaways



- I have asked Matthias Hoelzl if he could try and reproduce this with the STARWALL code. He seems interested

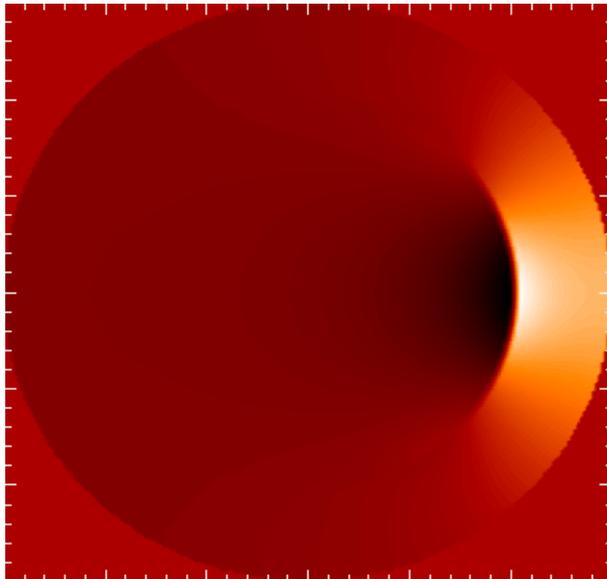
# Some Convergence Tests



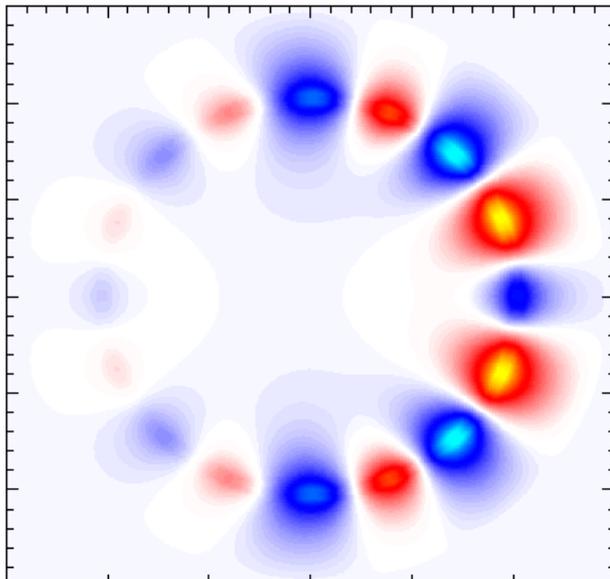
- Wall current appears to be converged in # of planes
- Helical wall current tending towards zero for large values of insulator resistance
- Now testing dependence on boundary conditions (location of ideal wall)
- Helical (1,2) case gives less than half the current of helical (1,1) case
- Iconst\_bz=0 increases current, but still far below straight case

## Plots for iconst\_bz=0

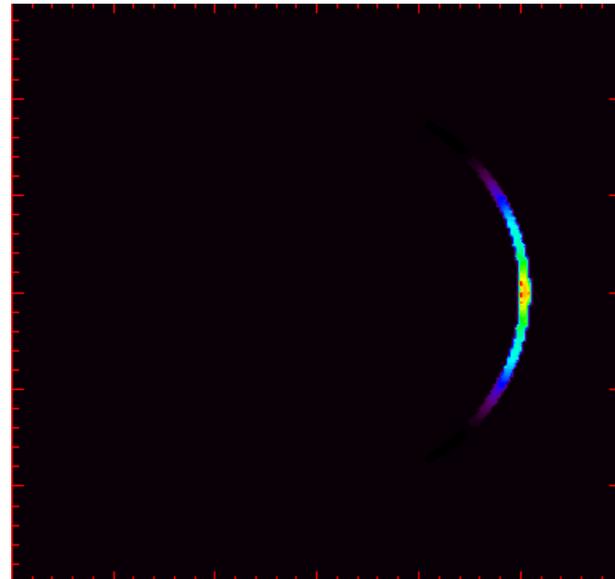
$I$



$\frac{\partial \Phi}{\partial \varphi}$



$J_\varphi$

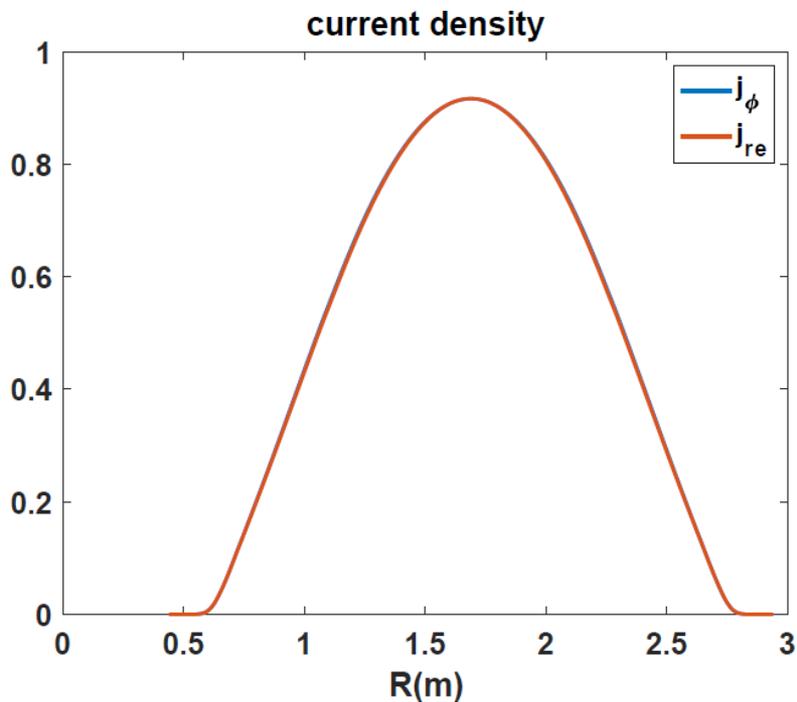
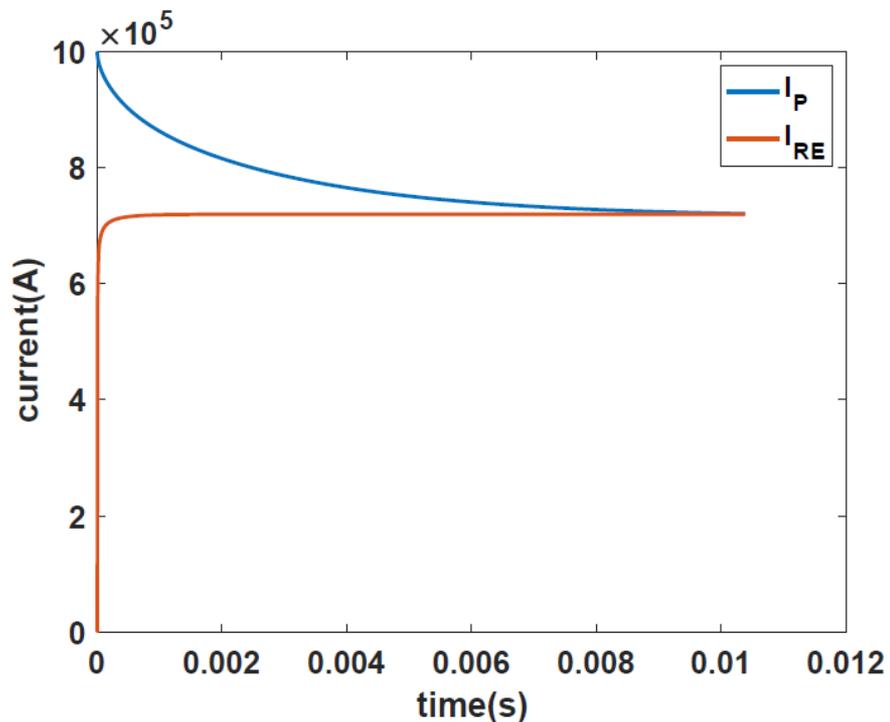


$$\nabla_\perp \cdot \frac{1}{R^2} \nabla \Phi = \nabla_\perp \cdot \eta \left[ -\frac{1}{R^2} \nabla F \times \nabla \varphi - \frac{1}{R^2} \nabla f'' \times \nabla \varphi - \frac{1}{R^4} \nabla_\perp \psi' \right]$$

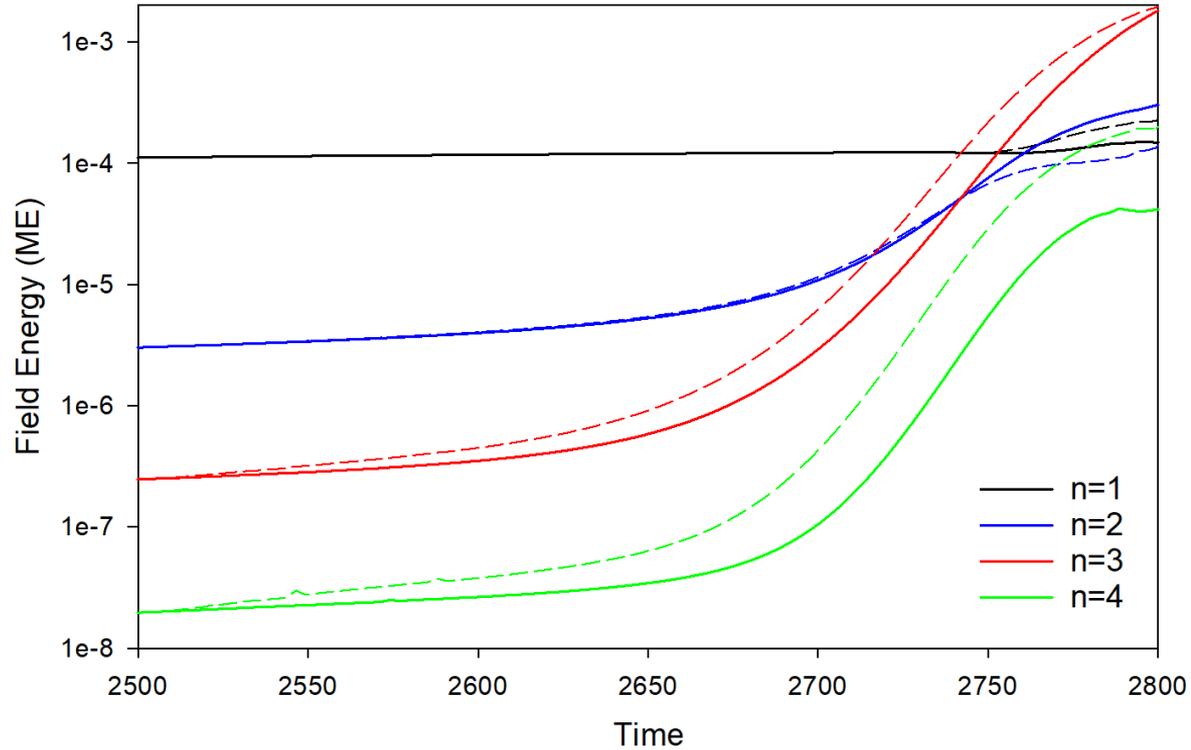
## Local Systems

- PPPL centos7(02/22/21)
  - 6 regression tests PASSED on centos7:
- PPPL greene (02/15/21)
  - 4 regression tests PASSED
  - RMP\_nonlin timed out (but gave correct results)
  - No batch file found for pellet
- EDDY (2/15/21)
  - 6 regression tests PASSED
- 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

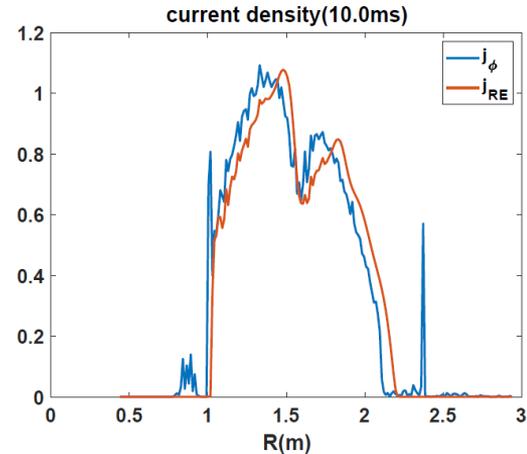
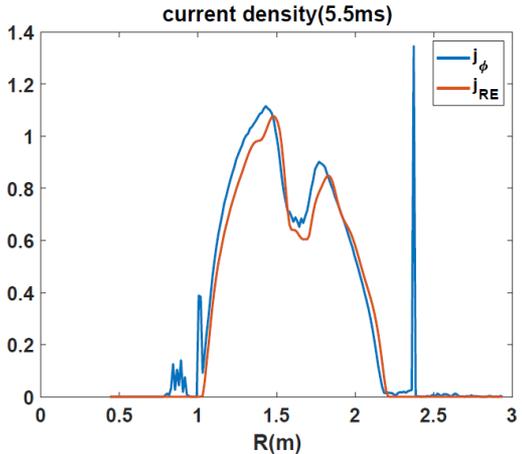
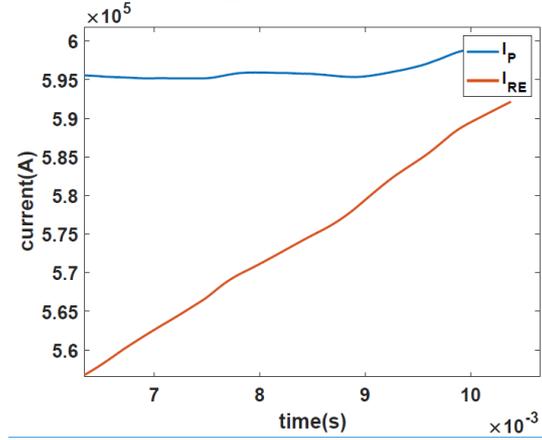
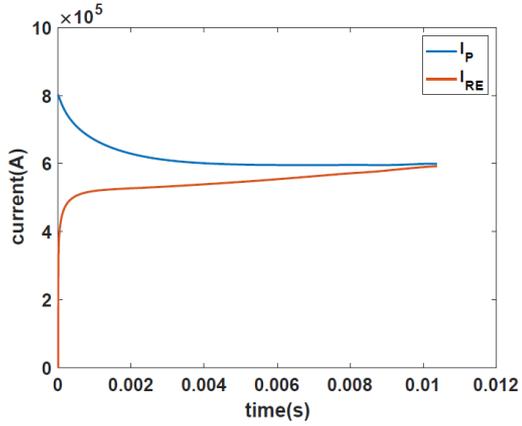
# 2D (cylindrical) RE with sources (12/19/2020)



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

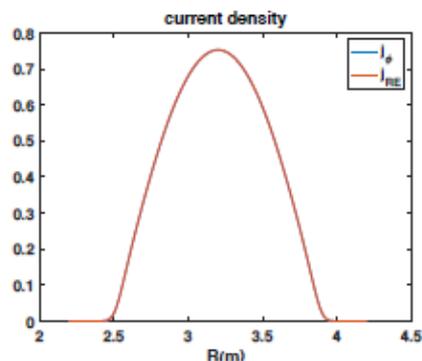
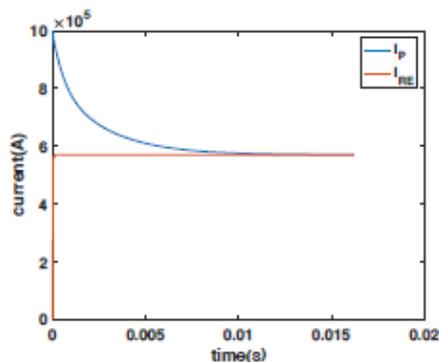


# DIII-D 177053 with Argon



## Same calculation in a Cylinder

### M3D-C1 runaway generation with cylinder geometry



- Parameters:
  - $\beta_0 = 0.15$
  - $a = 0.65m$
  - $R = 1.7m$
  - $B_0 = 1.9T$
  - $\eta = 1.0 \times 10^{-4}$
  - $n_0 = 1.0 \times 10^{20} m^{-3}$
  - $c = 150v_A$
  - $N_{elements} = 12261$
  - $\Delta t = 1.0\tau_A$

- 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?

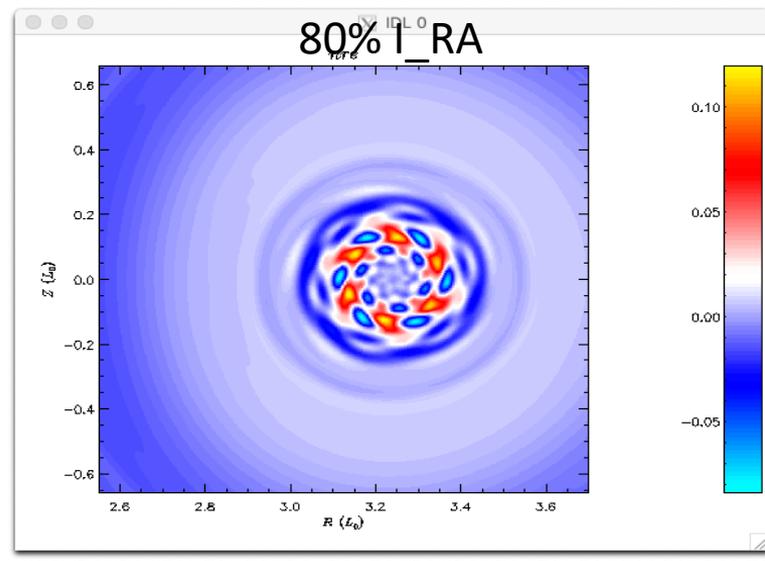
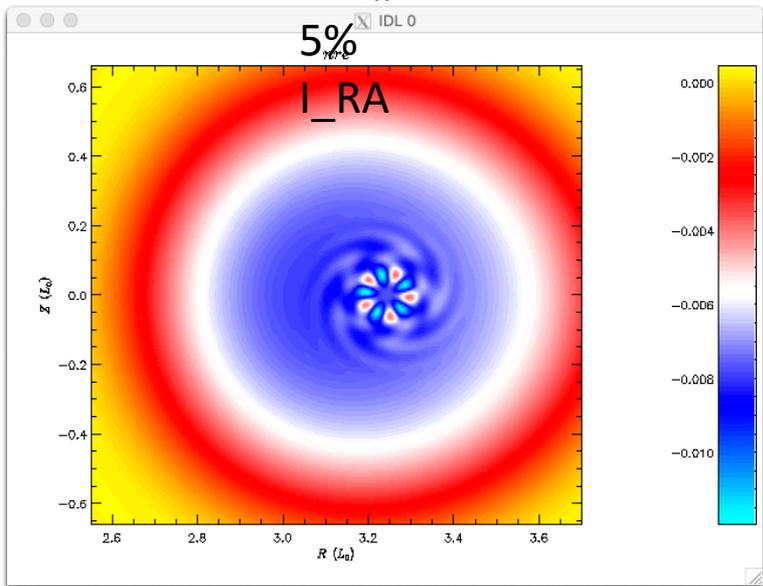
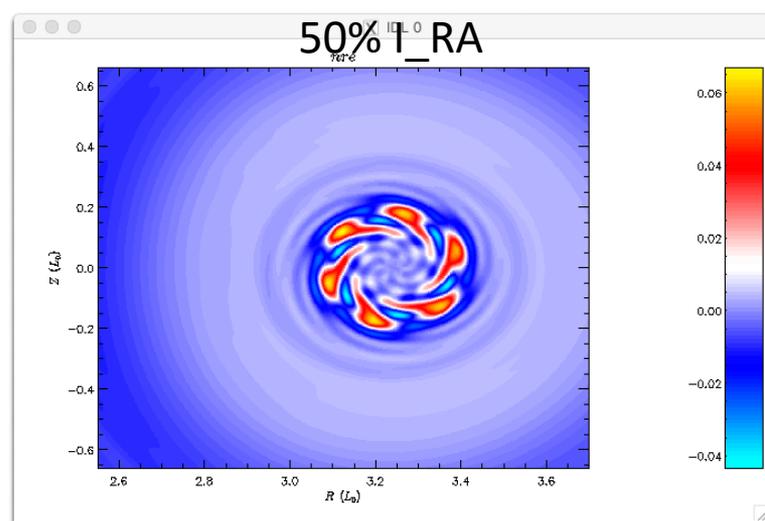
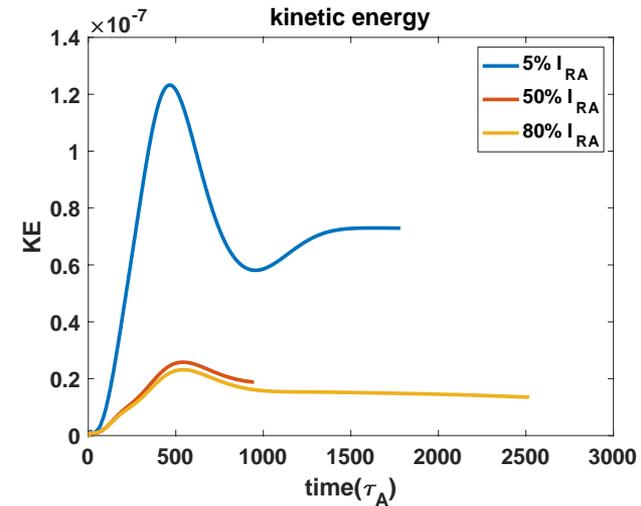
- M3D-C1/NIMROD 3D Benchmark

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

DIII-D Neon pellet mitigation simulation for KORC

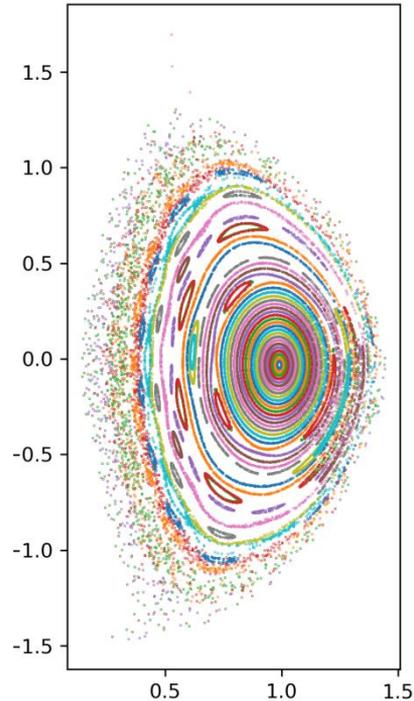
- Brendan Lyons trying to extend 8 plane case to 32 planes

SPARK ? Do we need to do anything?



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

## Chang Liu

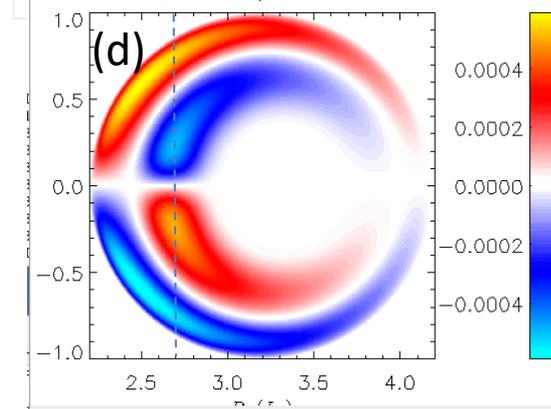
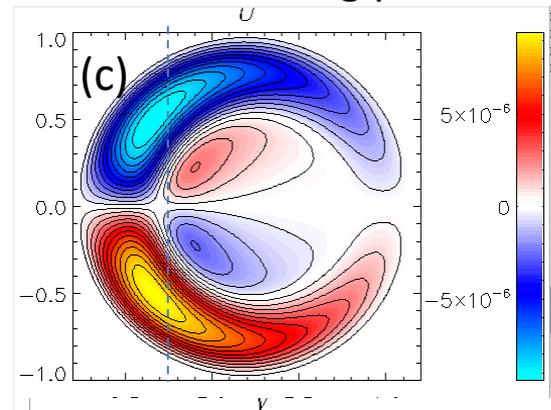
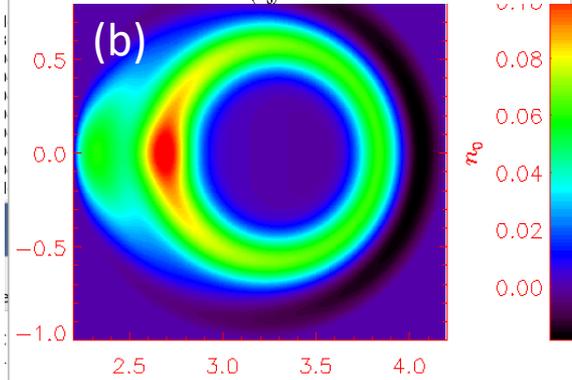
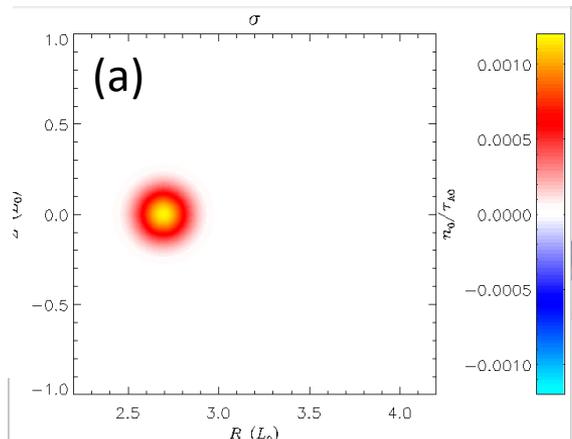


- In the original geqdsk file, the equilibrium was poorly converged. New one is much better. Has  $q(0) = 1.3$
  - Chang has analyzed new equilibrium (left)
  - No ideal (1,1) mode, several tearing modes
- 
- If goal is to get unstable (1,1) mode, likely need to lower  $q(0)$
  - Adding sheared toroidal 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

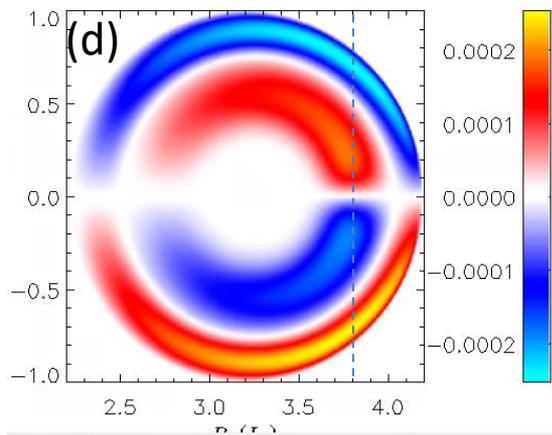
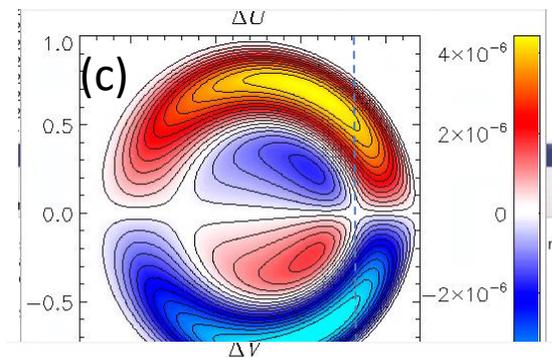
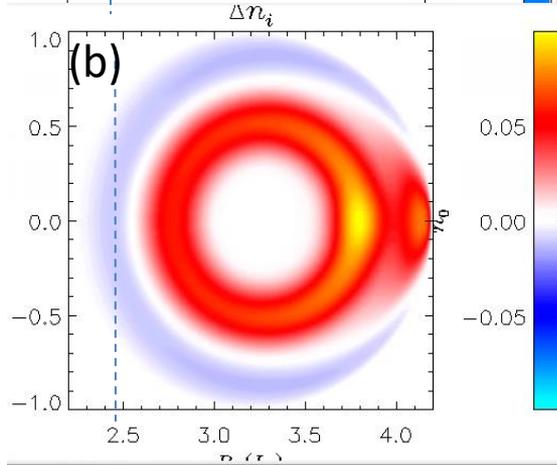
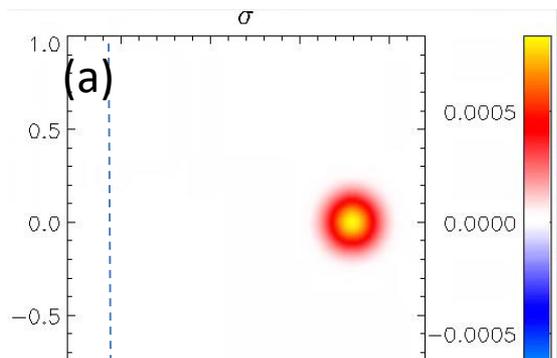
- (a) Density source in 1F toroidal equilibrium
- (b) Change in density after  $10^3 \tau_A$
- (c) Poloidal velocity stream function
- (d) Toroidal velocity contours



# Grad-B drift in M3D-C1– LF source

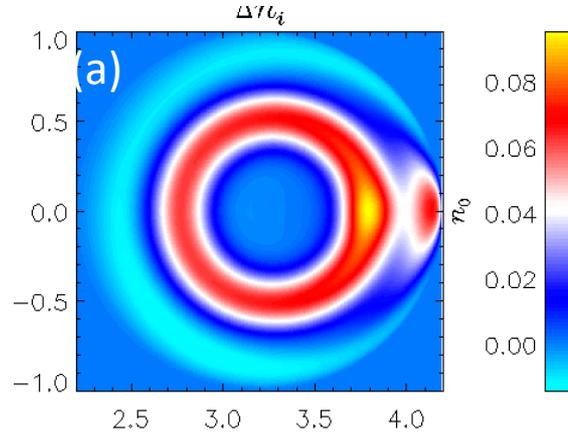
Request to calculate grad-B drift in M3D-C1 and to compare with that being put into the LP Code

- (a) Density source in 1F toroidal equilibrium
- (b) Change in density after  $10^3 \tau_A$
- (c) Poloidal velocity stream function
- (d) Toroidal velocity contours

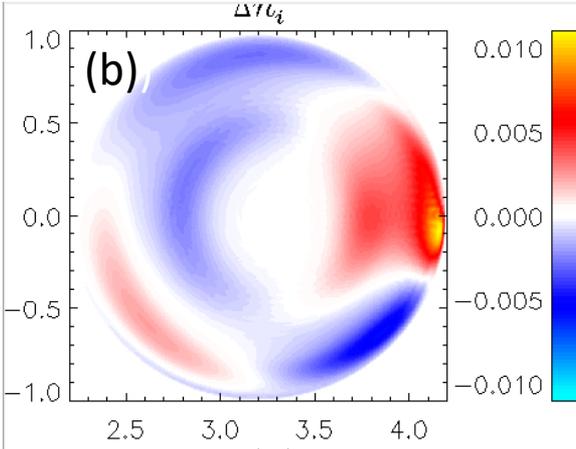


# Grad-B drift in M3D-C1—2F effects

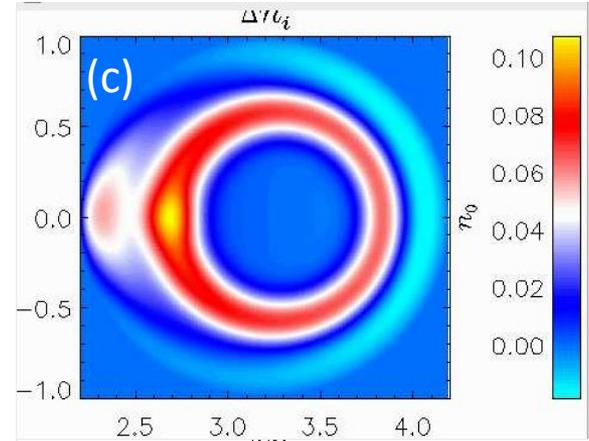
(a) 2F density change after  $10^3 \tau_A$  for LF side source



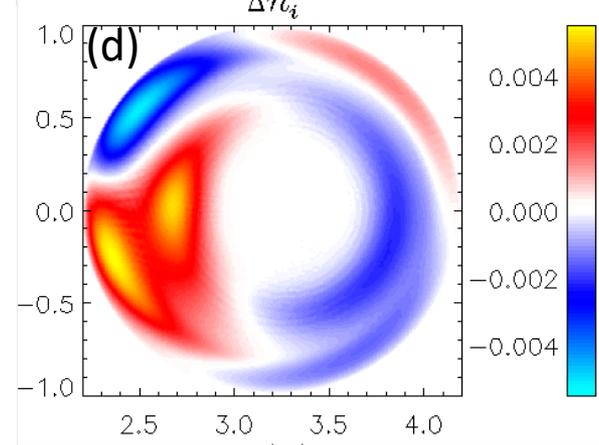
(b) Difference in 1F and 2F density (LF)



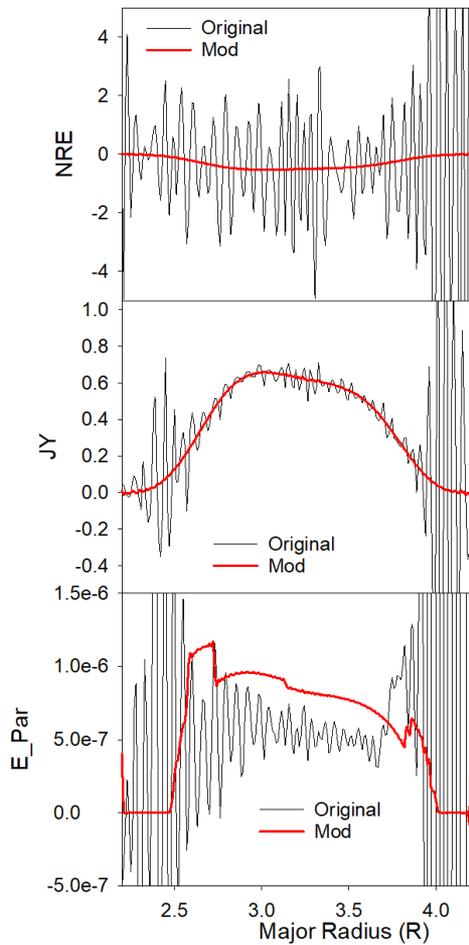
(c) 2F density change after  $10^3 \tau_A$  for HF side source



(d) Difference in 1F and 2F density (HF)



# Sawtooth 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

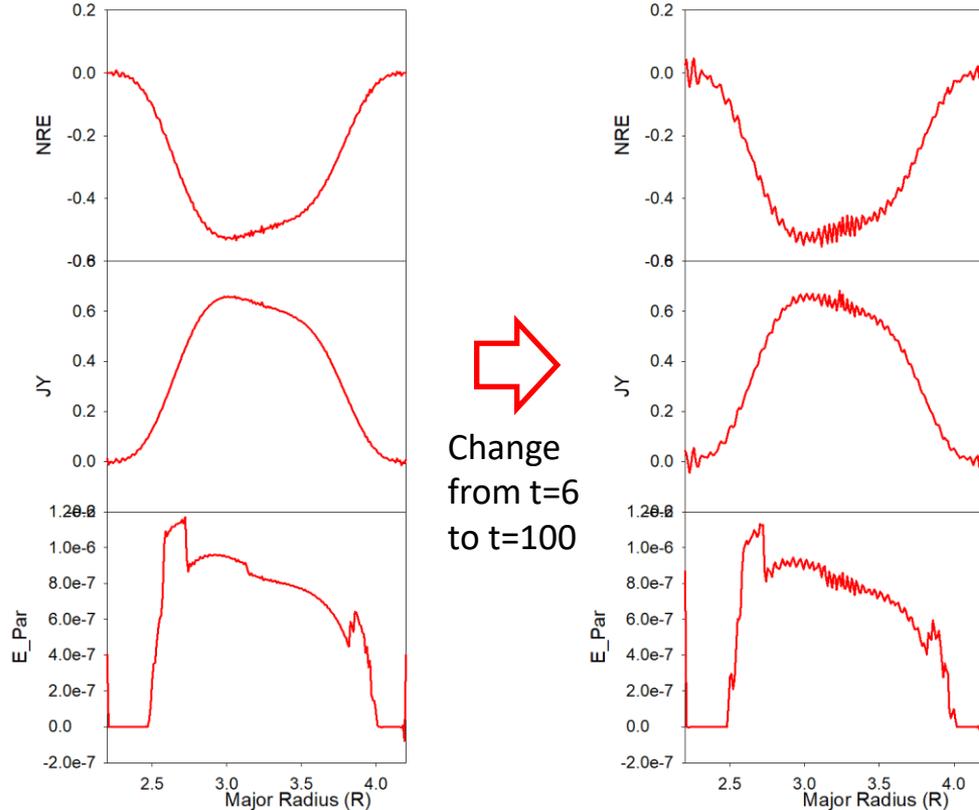
pedge

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?