Disruption Mitigation Modeling Status and Plan

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CTTS APS Meeting
Portland, Oregon

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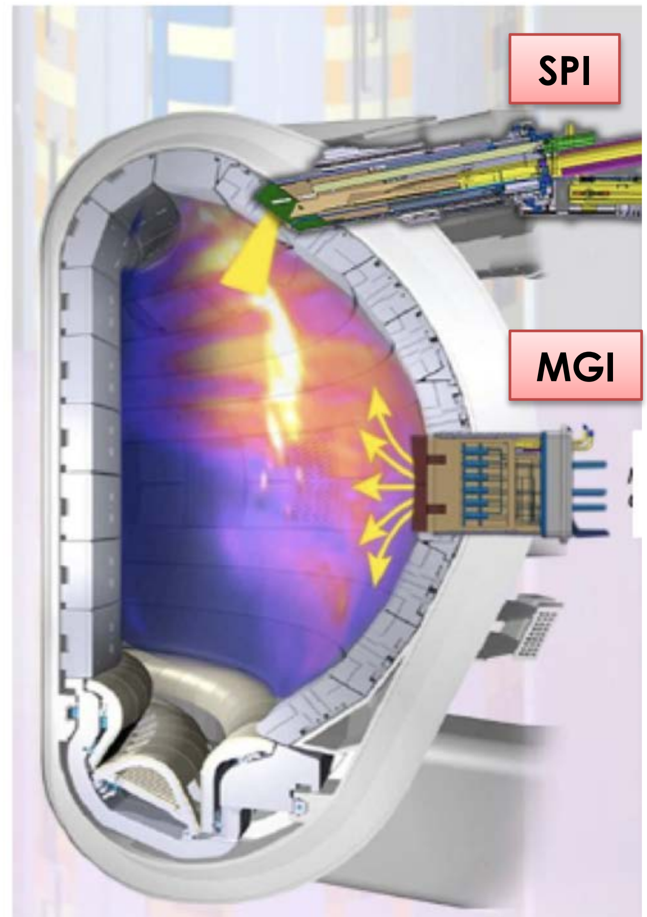
ITER SPI DMS



CTTS DM Objective: Develop, verify, and validate 3D models for disruption mitigation by SPI for future tokamak design and optimization

- **Original 2017-2019 proposed activities**

Disruption Mitigation by Shattered Pellets

Year 1	Construct SPI plume model and develop tracking algorithms
	Develop 3D local pellet ablation model for FronTier-MHD and perform single-pellet tests
	Perform SPI scoping and sensitivity studies using NIMROD with an existing analytic SPI model
	Implement full ionization/recombination/radiation model in M3D-C1
Year 2	Implement pellet debris plumes into FronTier-MHD and test tracking algorithms.
	Perform SPI simulations and validation tests using FronTier-MHD and DIII-D experimental data
	Develop analytic kinetic heat flow models for use with NIMROD and M3D-C1
	Complete SPI scoping studies using NIMROD and M3D-C1 with an existing analytic SPI model.

- **Revised plan**
  - **Focus on PiC based and Lagrangian Particle (LP) SPI models**
  - **FronTier-MHD used mostly as a stand alone test for benchmarking analytic ablation formulas for use with NIMROD and M3D-C1 SPI simulations**

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Significant Progress Made toward CTTS Disruption Mitigation Goals Since the Last APS Meeting

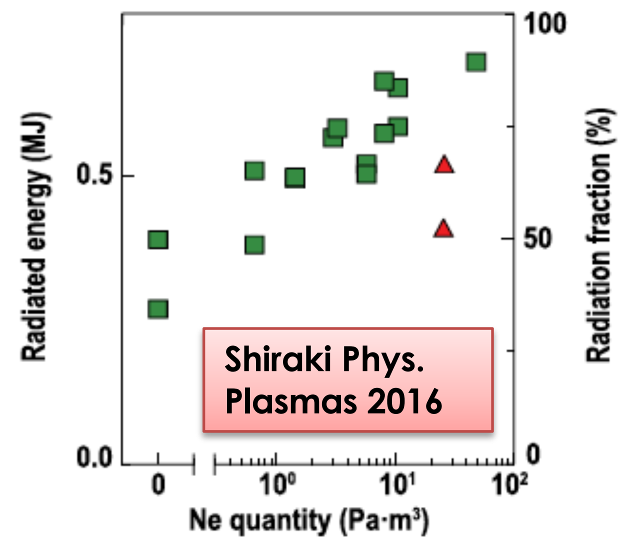
- **Resolved a number of NIMROD coding issues to allow accurate accounting of radiation power and energy balance.**
- **Implemented analytical SPI ablation model into M3D-C1 and successfully completed an axisymmetric verification benchmark between NIMROD and M3D-C1 for simulations of impurity-induced disruption mitigation.**
- **Completed first test of NIMROD PiC-based SPI model against DIII-D SPI experiments**
  - **Variation of SPI radiated energy and TQ time with Ne quantity**
- **Started testing of NIMROD PiC-based SPI model against ITER operation scenarios**
  - **ITER simulations share similar features with DIII-D but much more challenging**
- **Started exploring NIMROD/LP and M3D-C1/LP code couplings**
- **Developing a kinetic pellet plasma cooling model for use with NIMROD and M3D-C1**

CTTS Disruption Mitigation Modeling

DIII-D SPI Experiments Modeling Needs — *2017/10/22*

Eidietis

- **Variation in SPI radiated energy with Ne quantity**
  - **Ne/D_2 mixture, total pellet size constant**
- **Variation in SPI assimilation with injection angle**
  - **Relative strength of ballistic versus MHD mixing**
- **Interpretation of dual SPI experiments**
  - **Multiple pellets appear to not sum directly**



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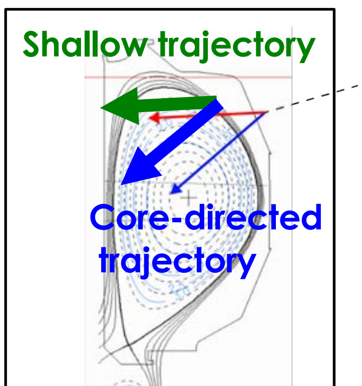

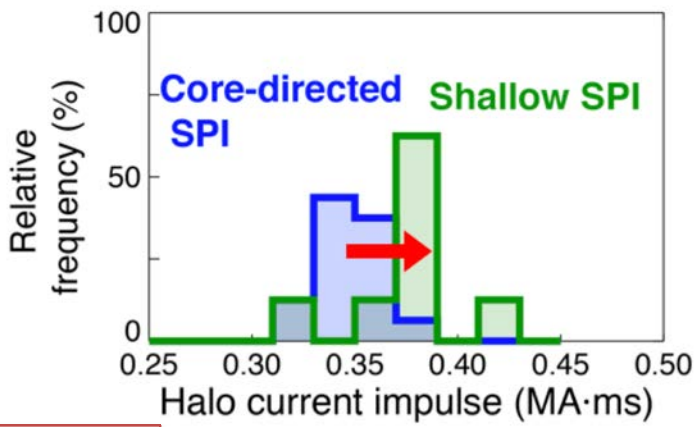

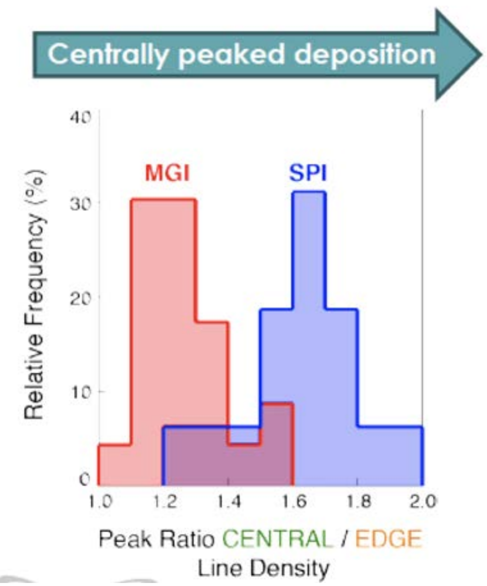

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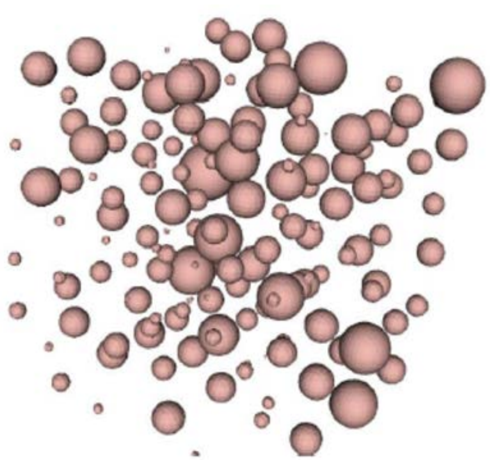
A NIMROD PiC-Based SPI Model Has Been Developed and Tested against DIII-D Data

- **Modeled as spherical point particle source with 2 poloidal and toroidal Gaussians moving at constant velocity**
- **Spherical SPI fragments ablate independently with analytical ablation formula from Parks**
- **After deposition, ionization and radiation are based on KPRAD**
- **Flexible and easy to modify for other applications such as shell pellet, and pellet fueling**

SPI Plume



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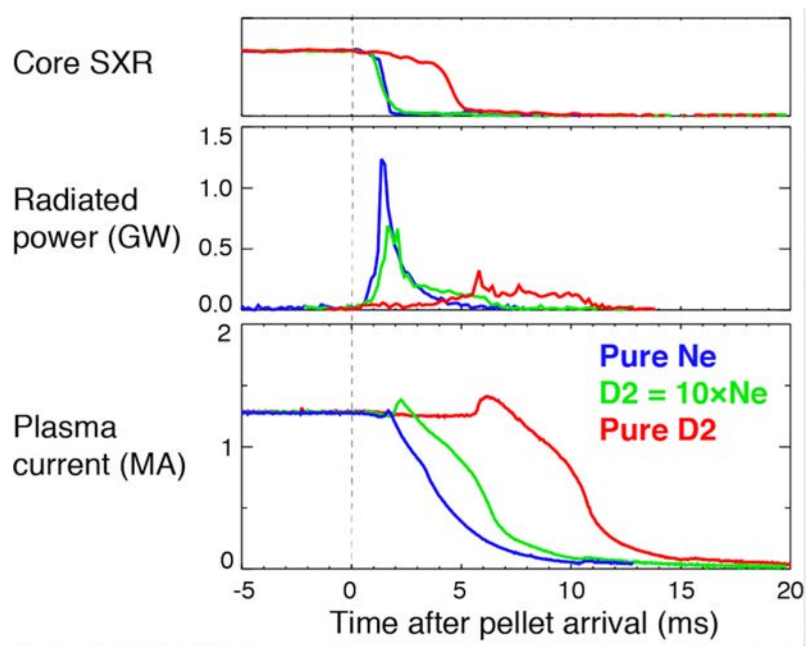

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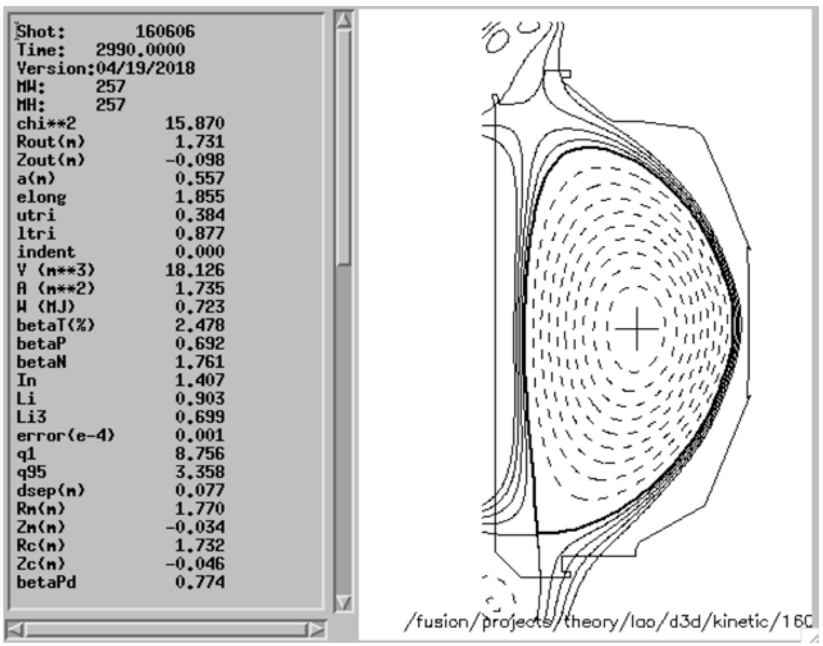
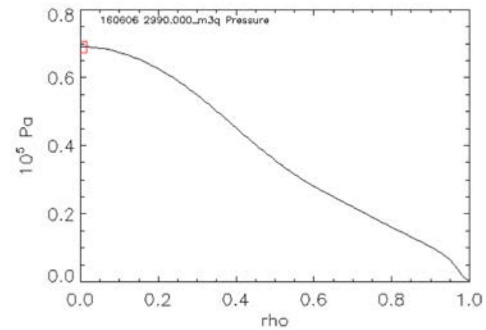
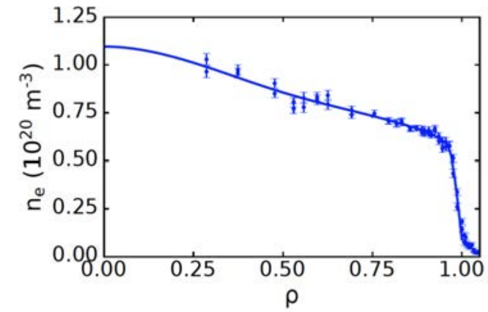
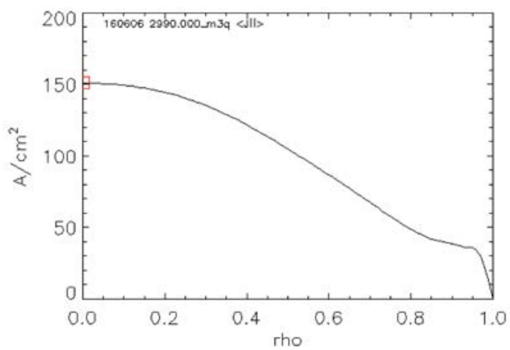
NIMROD Simulations Are Based on a Kinetic EFIT Reconstruction of a DIII-D SPI Discharge

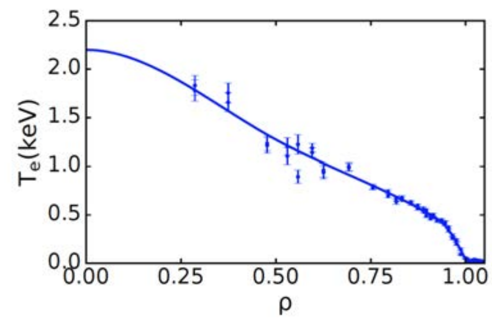
- **Tightly converged 257x257 kinetic EFIT reconstruction**

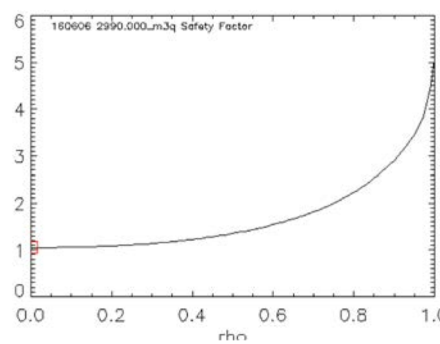


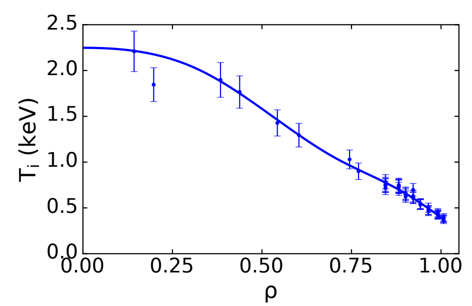








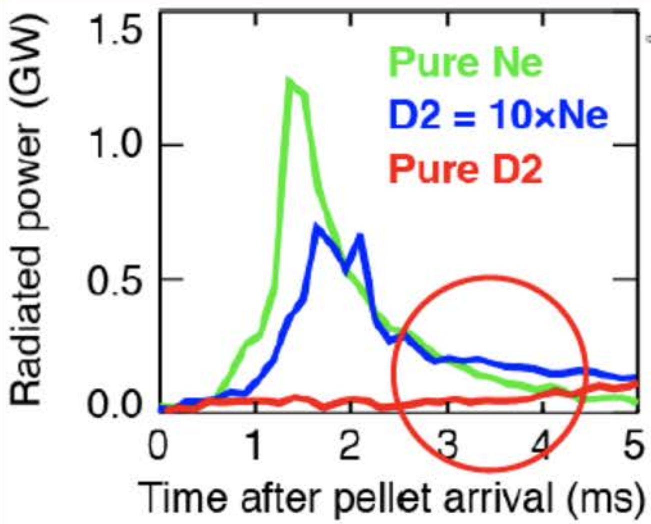




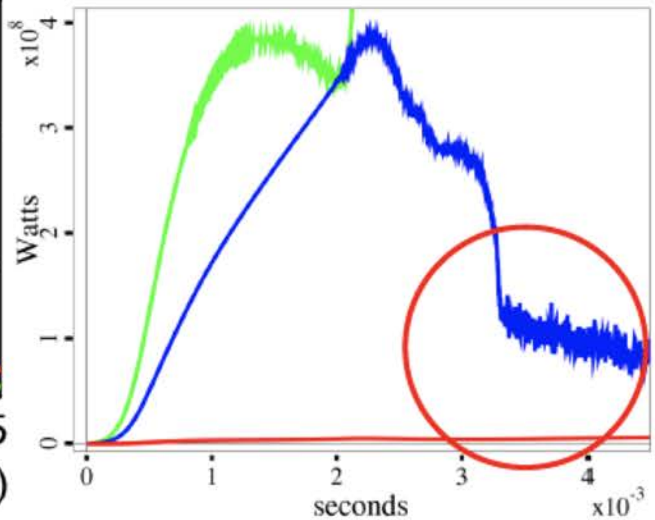
GENERAL ATOMICS

Impurity Validation Scan Shows Good Agreement with DIII-D Experiments

NIMROD



DIII-D



- radiated power shows common features
  - gap in early rise
  - slope changes
  - peak power
  - peak timings (v_f)
  - late radiation

	τ_{TQ}^{E}	τ_{TQ}^{S}	radfrac^{E}	radfrac^{S}	% ablated
pure Ne	1.7ms	2.2ms†	89%	83%†	4%†
D2=10xNe	2.3ms	2.8ms	75%	86%	34%
pure D2	6.2ms	5.6ms	50%	4%	58%

E = Experiment, S = Simulation †*@time of termination*

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GENERAL ATOMICS

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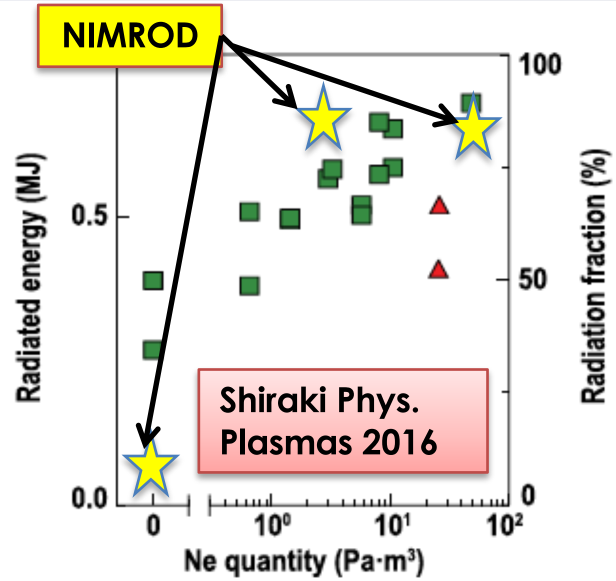

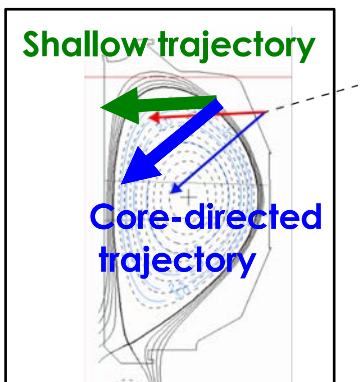

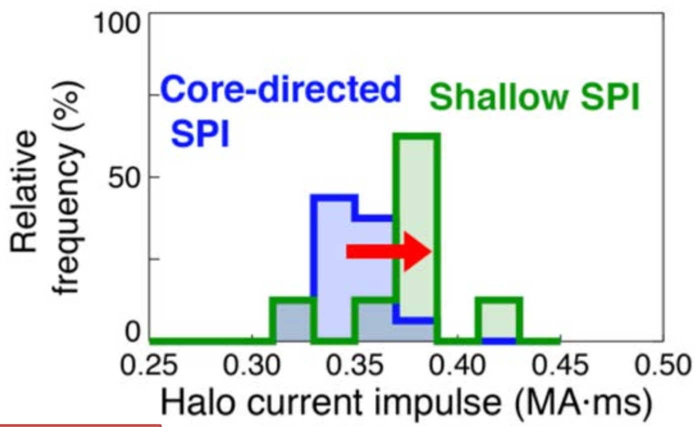

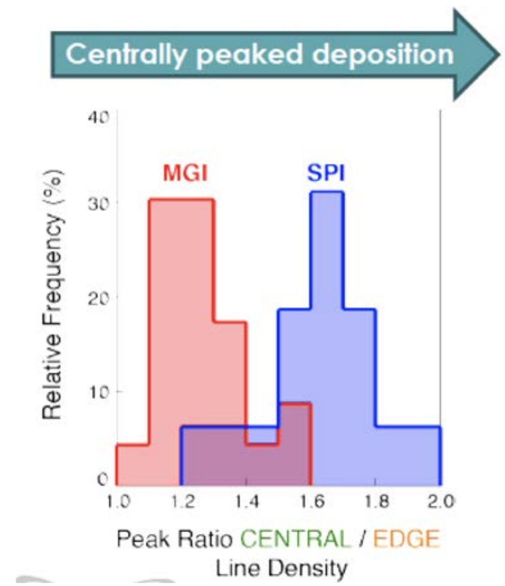

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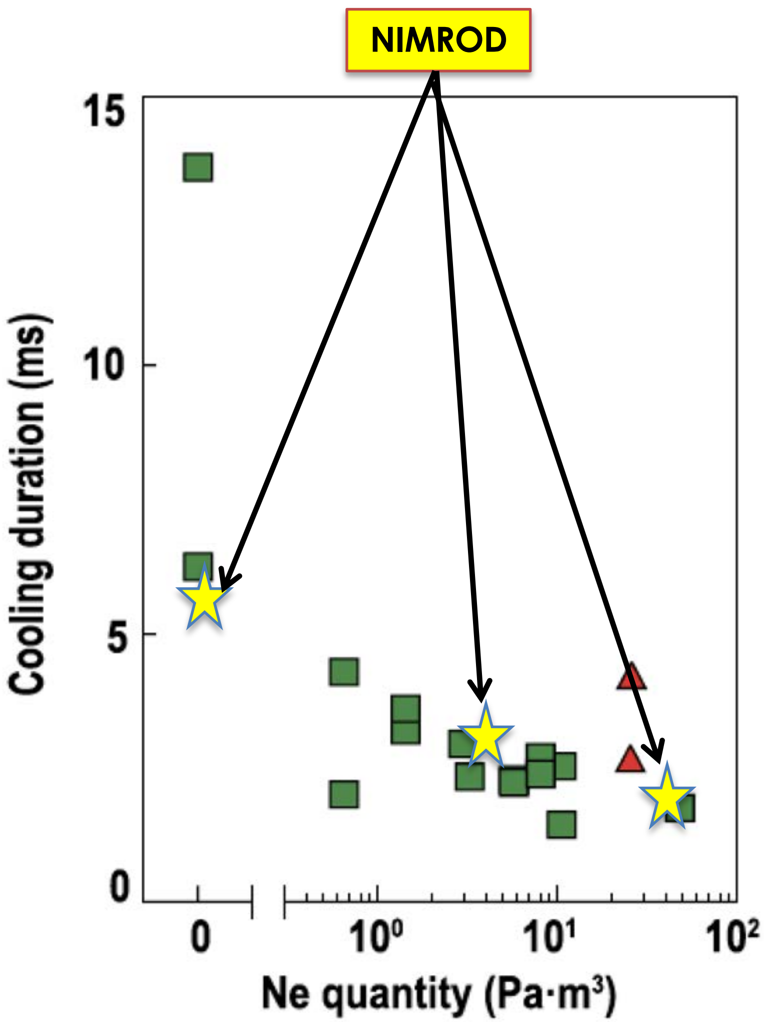
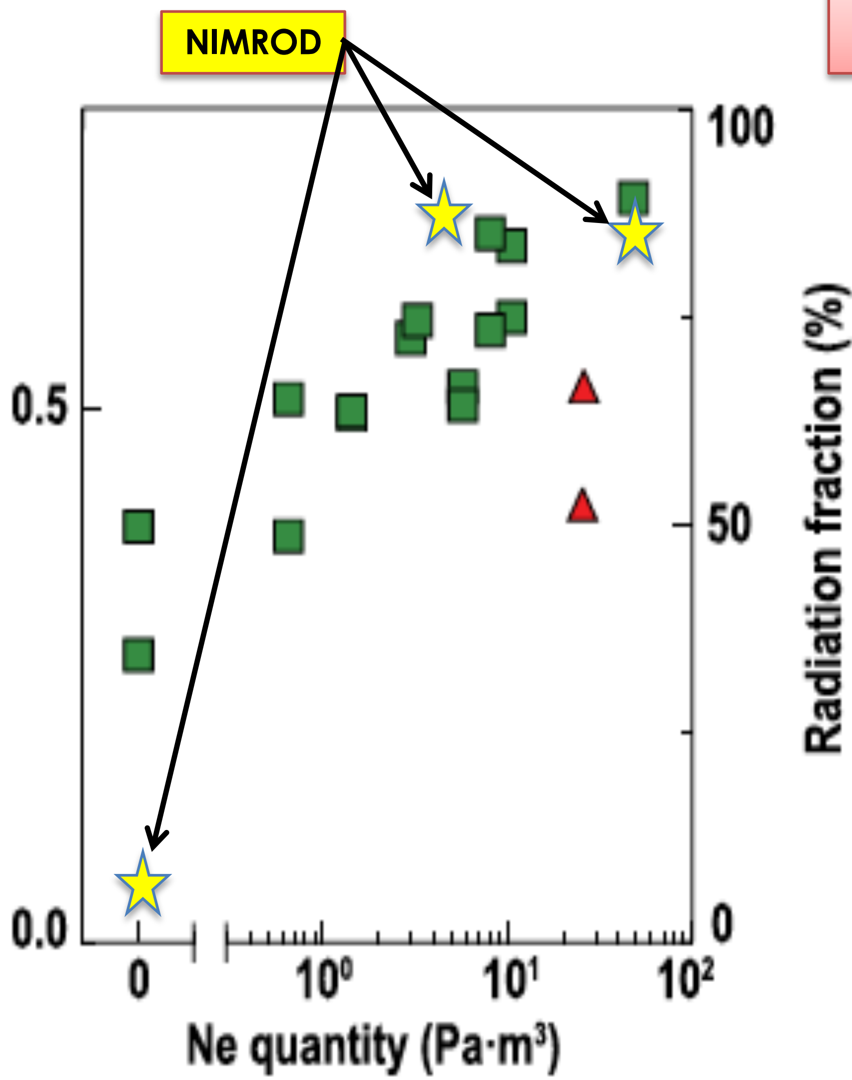
NIMROD Simulated Thermal –Quench Times Also Consistent with DIII-D Measurements





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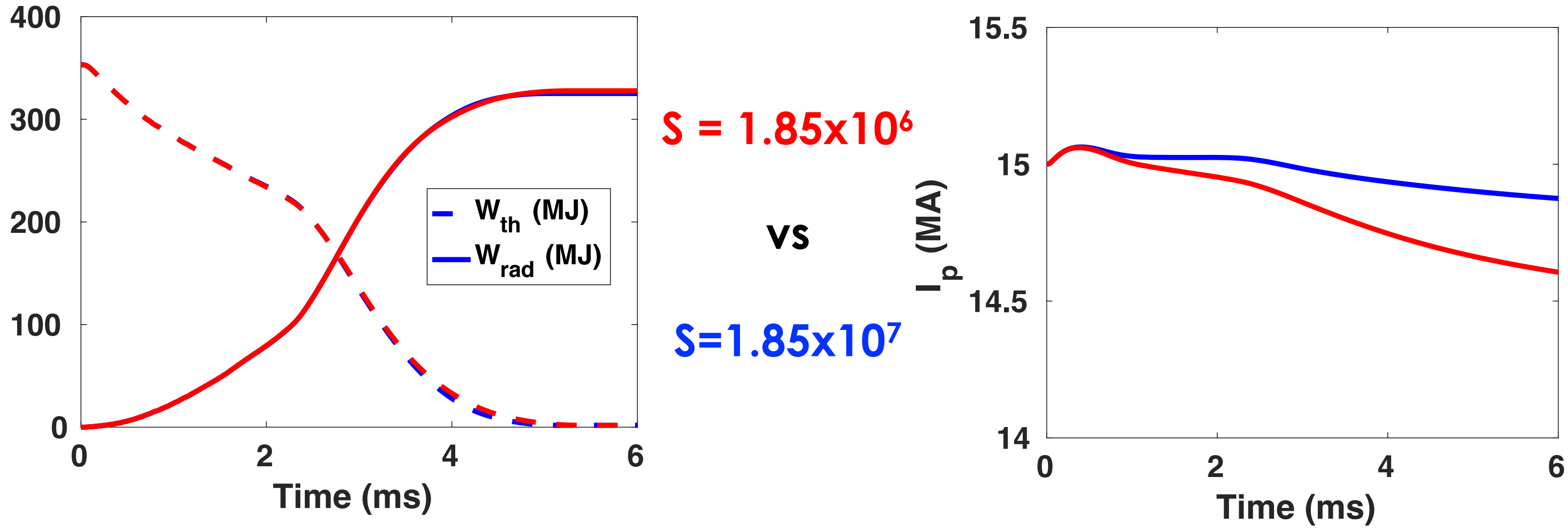
NIMROD used to simulated SPI induced TQ for ITER baseline and hybrid scenarios with varying impurity contents

Ne[kPa.m^3]	Ne:D2	Ip [MA]	r_frag [mm]	S (x10^6)	Kperp [m^2/s]	Kpara [m^2/s]	kin_vis [m^2/s]	mesh	Δt [μs]	τ_{TQ} [ms]	Burnt/total
0.5	0:1	15	1.71	1.85	10	10^{10}	2x10^4	96x96	0.2	8	125/125
1	0:1	15	2.15	1.85	10^2	10^7	5x10^3	96x96	0.5	5	75/125
0.5	10:1	15	4.42	1.85	10	10^{10}	2x10^4	64x72	0.2	4.5	65/125
0.5	10:1	15	4.42	18.5	10	10^{10}	2x10^4	64x72	0.2	4.5	65/125
0.5	10:1	15	4.42	1.85	10	10^{10}	2x10^2	64x72	0.2	4.5	75/125
0.5	10:1	15	3.51	1.85	10	10^{10}	2x10^4	64x72	0.2	4.5	150/250
0.5	1.5:1	15	2.51	1.85	10^2	10^7	5x10^3	96x96	0.5	>6	125/125
0.5	0:1	12.5	1.71	1.62	10^2	10^7	5x10^3	96x96	0.5	>5	125/125

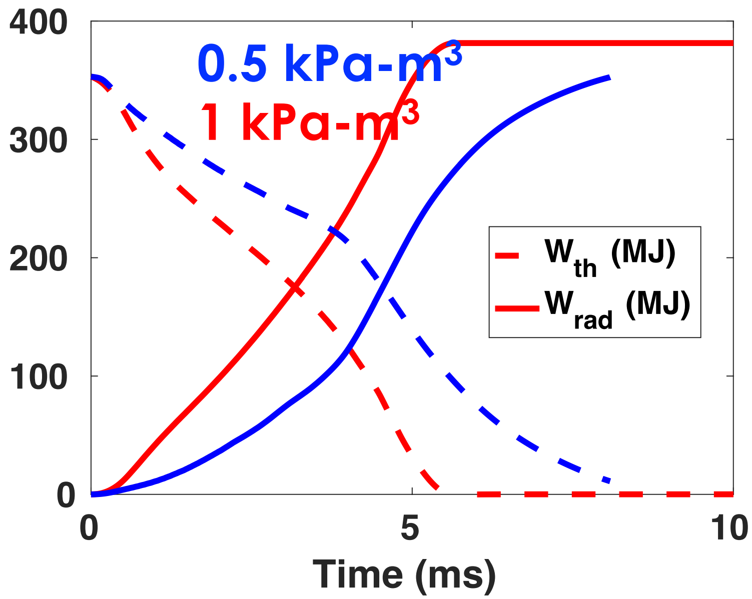
- Fixed plasma resistivity and thermal conductivity coefficients
- 25 PiC markers at V=500 m/s
- n=0-5 toroidal modes

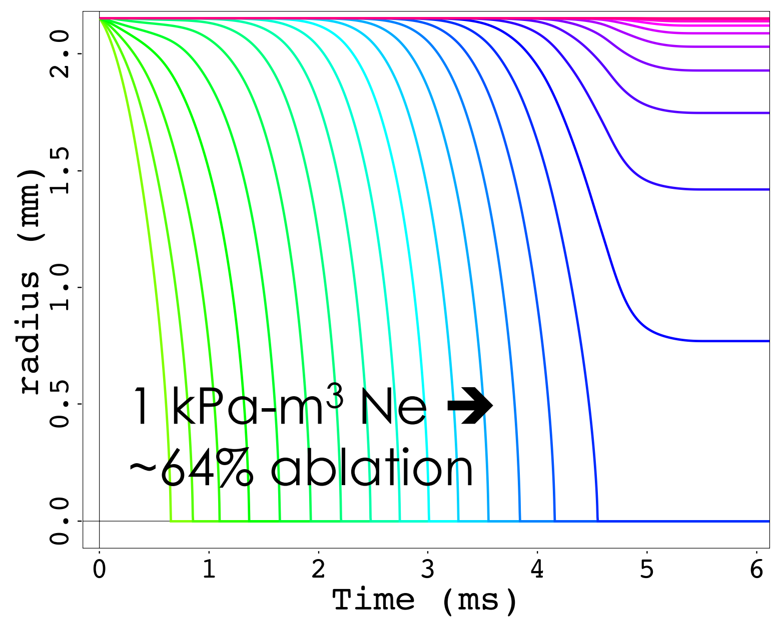
Numerical tests show that variation of assumed plasma resistivity weakly affects TQ phase

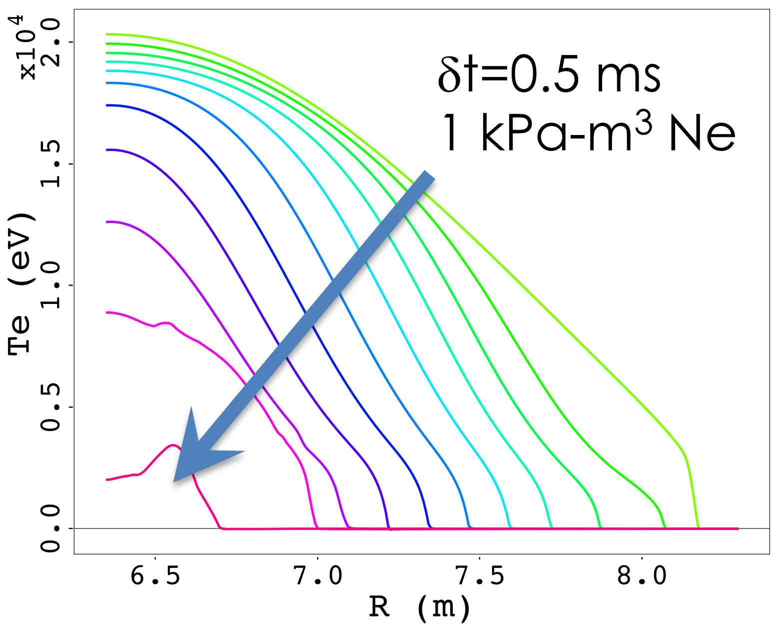


- **Mixture of 0.5 kPa-m³ neon + 5 kPa-m³ D_2**
- **15 MA ITER baseline scenario**
- **Vary plasma resistivity by factor of 10 ➔**
  - Nearly no effect on evolution of plasma thermal energy
  - Nearly no effect on evolution of radiated thermal energy
  - Some (albeit small) effect on plasma current decay during TQ

Twice larger amount of pure neon SPI reduces TQ time by ~35% for ITER 15 MA baseline scenario







- **0.5 kPa-m³ neon ➔**
  - 8 ms TQ
  - 100% ablation of injected pellet during TQ
- **1 kPa-m³ neon ➔**
  - 5 ms TQ
  - ~64% ablation
- **TQ time traces not very sensitive to assumed plasma resistivity & viscosity**

Y.Q. Liu | CTTS | Oct 2018

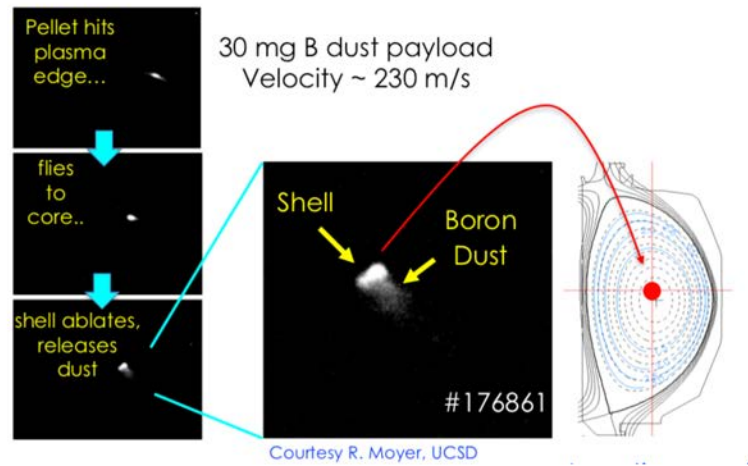
CTTS Disruption Mitigation 2018-2019 Plan

- Continue development of NIMROD PiC-based SPI model and validation against DIII-D data and higher fidelity simulations
  - Multiple injectors, deposition shape dependence, plume representation, dissipation parameters, parallel thermal conduction, disrupting target plasma
- Benchmark Frontier-MHD, LP, NIMROD, M3D-C1, and PAM pellet ablation models
- Start NIMROD and M3D-C1 3D benchmark
- Perform M3D-C1 production runs/scoping studies for pellet mitigation
- Explore coupling algorithms to integrate NIMROD/LP and M3D-C1/LP
- Continue development of kinetic pellet plasma cooling model and start testing against DIII-D data
- Test more realistic shell pellet ablation model into NIMROD and test model against DIII-D data

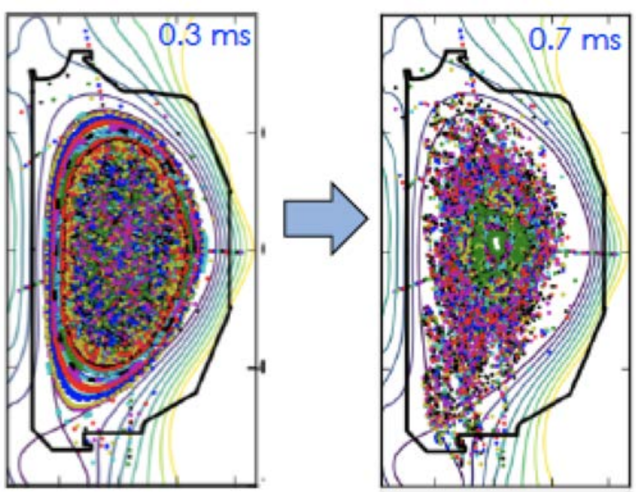
Core Impurity Deposition with Inverted Temperature Profile Demonstrated in DIII-D Recent Shell-Pellet Experiment

Thin Diamond-Shell Carries Payload of Boron Dust

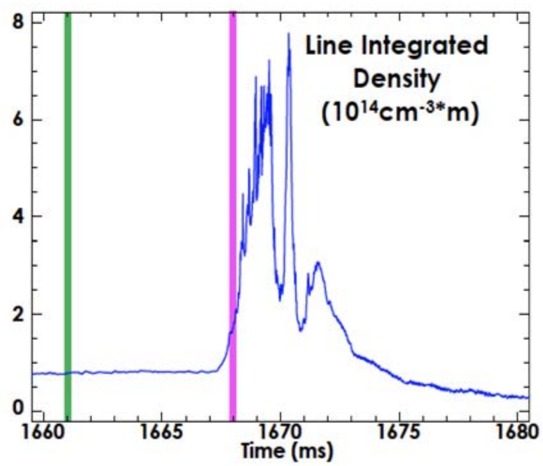
- **Inverted T_e indicative of desired inside-out mitigation to increase radiative energy fraction, prevent RE seed formation, plus a slower current quench to reduce stress in the surrounding vacuum vessel**

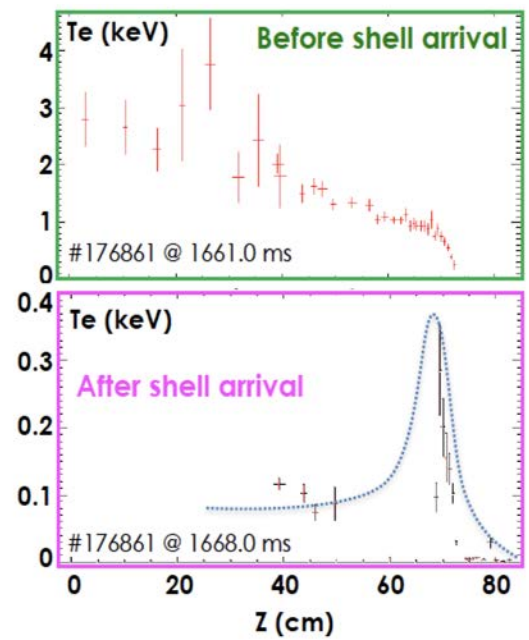


Field Line Stochastization Reduces RE Formation



Izzo, Parks Phys Plasmas 2017





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