Summary of Disruption Related Talks at 26th ITPA-MHD Meeting

Presented by
V.A. Izzo

CEMM Meeting

15 November 2015

Disruptions, session 1

Ch

10:00	Lehnen, M.	Report on joint experiment "MDC-01 Disruption mitigation by massive gas jets"	
10:30		*Break*	
11:10	Pautasso, G.	MGI and Runaway experimental results from AUG	
11:40	Yunbo, D.	Experimental results of disruption mitigation with MGI on HL-2A	
12:10		Discussion	
12:40		*Group picture*	
12:45		*Break*	

Three-dimensional MHD

Chair: Izzo, V.

14:10	Volpe, F.	Report on working group "WG-11 "Control of locked modes"	
14:40	Villone F.	3D effects on plasma breakdown in ITER	
15:10	Jardin, S.	3D Modeling of NSTX Vertical Displacement Events with M3D-C1	

Disruptions, session 2

C

14:00	Pustovitov, V.	Calculation of the integral disruption forces in tokamaks
14:30	Izzo, V.	Rotation effect in Massive Gas Injection Simulations of DIII-D
15:00	Pautasso, G.	Report on joint experiment "MDC-22 Disruption Prediction"
15:30		*Break*
16:00	Granetz, R.	Disruption Mitigation of Plasmas with Locked Modes
16:30	Eidietis, N.	Modeling and measurement of poloidal radiation asymmetries on DIII-D **(REMOTE)**
17:00	Eidietis, N	Report on joint experiment "MDC-15 Disruption database development" **(REMOTE)**
17:10	Myers, C.	Rotating halo currents **(REMOTE)**

Disruptions, session 3

09:00	Lehnen, M.	Report on working group "WG-08 Radiation asymmetry during MGI"
09:30	Nardon, E.	On the mechanisms governing gas penetration into a tokamak plasma during a massive gas injection **(REMOTE)**
10:00	Nardon, E..	Update on disruption simulations with JOREK **(REMOTE)**

Runaway electrons

Chair: Gribov, Y.

09:00	Chen, Z.Y.	Prevention/ Dissipation of runaway current in the J-TEXT tokamak **(REMOTE)**	0:30
09:30	Lukash, V.	Analysis of position control of runaway beam in 7.5 MA ITER disruptive plasma	0:30
10:00	Granetz, R.	Report on joint experiment "MDC-16 Runaway electron generation, confinement, and loss"	0:30
10:30		Discussion	0:15
11:45		*Break*	0:30

Halo current

Chair: Pautasso, G.

11:15	Bandyopadhyay, I.	Report on working group "WG-10 "Halo current modelling"	0:30
11:45	Rubinacci, G.	Modeling the electro-magneto-mechanical transient of a Tokamak component during a VDE with Halo currents	0:30

MODELING
EXPERIMENT
BOTH

ITER DMS: High priority issues

ITER (Lehnen)

The ITER mitigation system has maximum flexibility within the technical constraints.

Design relevant issues

- **Performance of Shattered Pellet Injection** – extrapolation to ITER
  - shard size, speed…
  - multiple/staggered injection
  - impact of plasma parameters
- **Runaway mitigation scenario** (compatible with EM load constraints)
  - pre-/post-TQ injection
  - minimum energy achievable before RE loss (instability)
- **Efficiency in sick plasmas**
  - timescales / efficiency
- **Thermal quench mitigation efficiency** high E_{rad}/E_{th}
  - optimum Z mixture / multiple injection / compatibility with t_{CQ}>50 ms
- **RE-free thermal load mitigation** avoidance of primary generation
  - optimum Z mixture / injection scheme

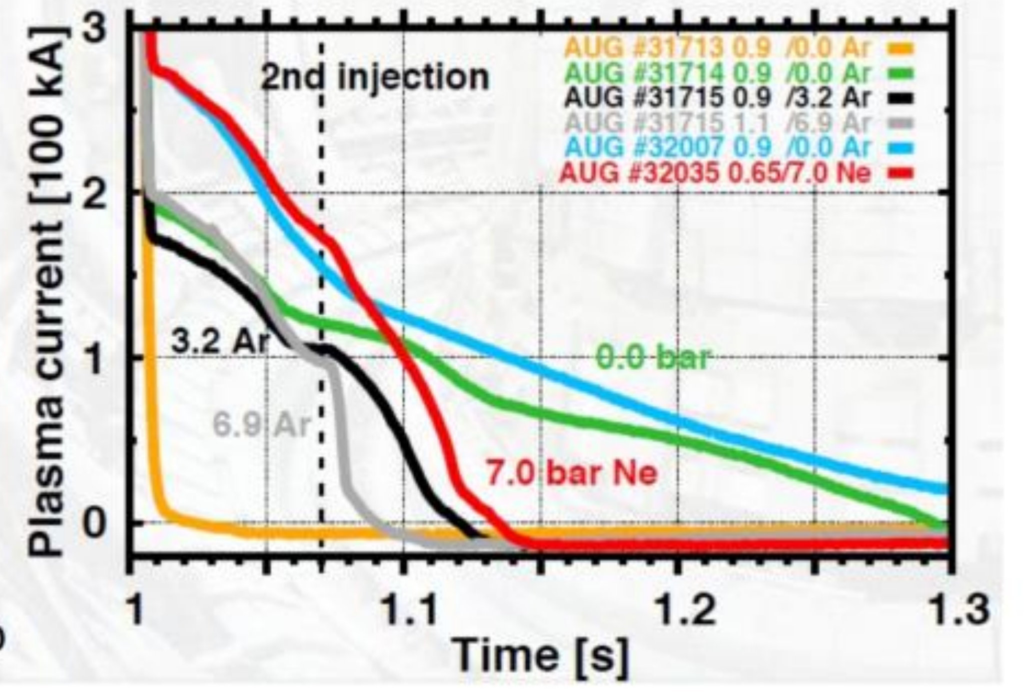
Operation related issues (performance optimisation)

Briefly: Some recent experimental results

ASDEX-U (Pautasso)

RE generation

- target plasma for RE generation: 0.8 MA, $B_t \sim 2.5$, $n_e \sim 2\ 10^{19}\ /m^3$, $P_{ECRH} \sim 2$ MW, circular plasma, injection of ≤ 1 bar Ar
- very-similar gas quantities and target plasmas
  → different initial RE current
  → unidentified variable

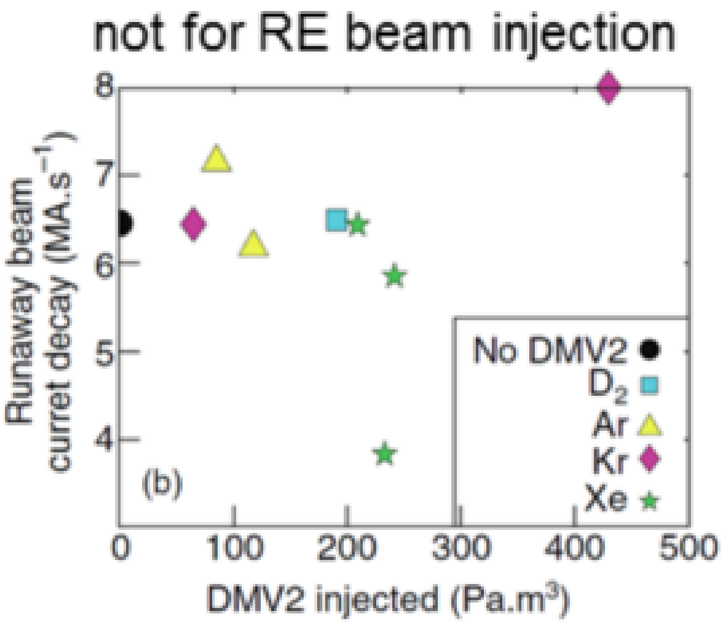


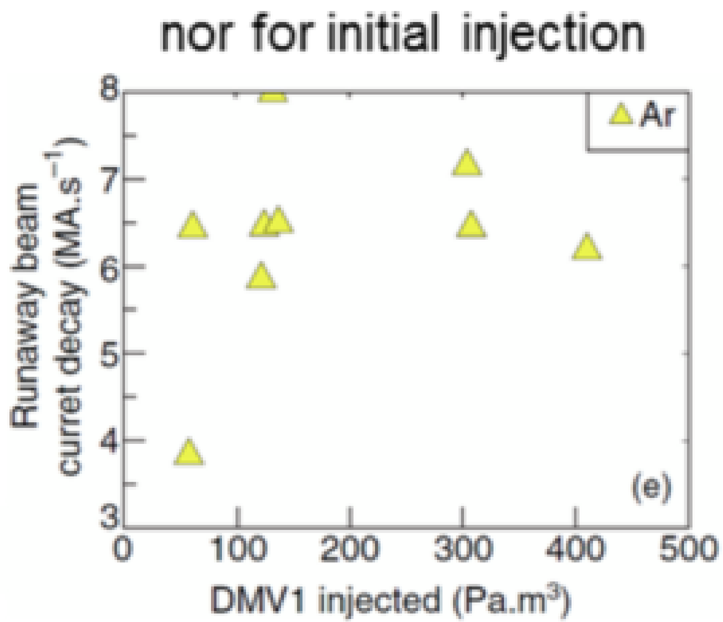
G. Papp

RE beam dissipation by high-Z injection also seen on DIII-D (previous), J-TEXT, and HL-2A (this meeting)

JET (Lehnen)

JET MGI: no impact of quantity on dI_{RE}/dt





C. Reux et al, NF 2015

Beam penetration can be affected by density and temperature:

T ~ 2eV (AUG & DIII-D) 20 eV (JET, ArV lines observed)

n ~ 8x10^{19} (AUG) 2x10^{20} (DIII-D) several 10^{20} (JET)

Power to background plasma: $P = -LI_{RE}\frac{dI_{RE}}{dt}$

Reux et al:
Impermeable regime
T_i > 5-10 eV

Power density: $\frac{P}{V} = 2\,\frac{\mathrm{MW}}{\mathrm{m}^3}$ (JET) $0.1\,\frac{\mathrm{MW}}{\mathrm{m}^3}$ (AUG) *with initial injection*

Comparison of NIMROD modeling with DIII-D poloidal peaking factors

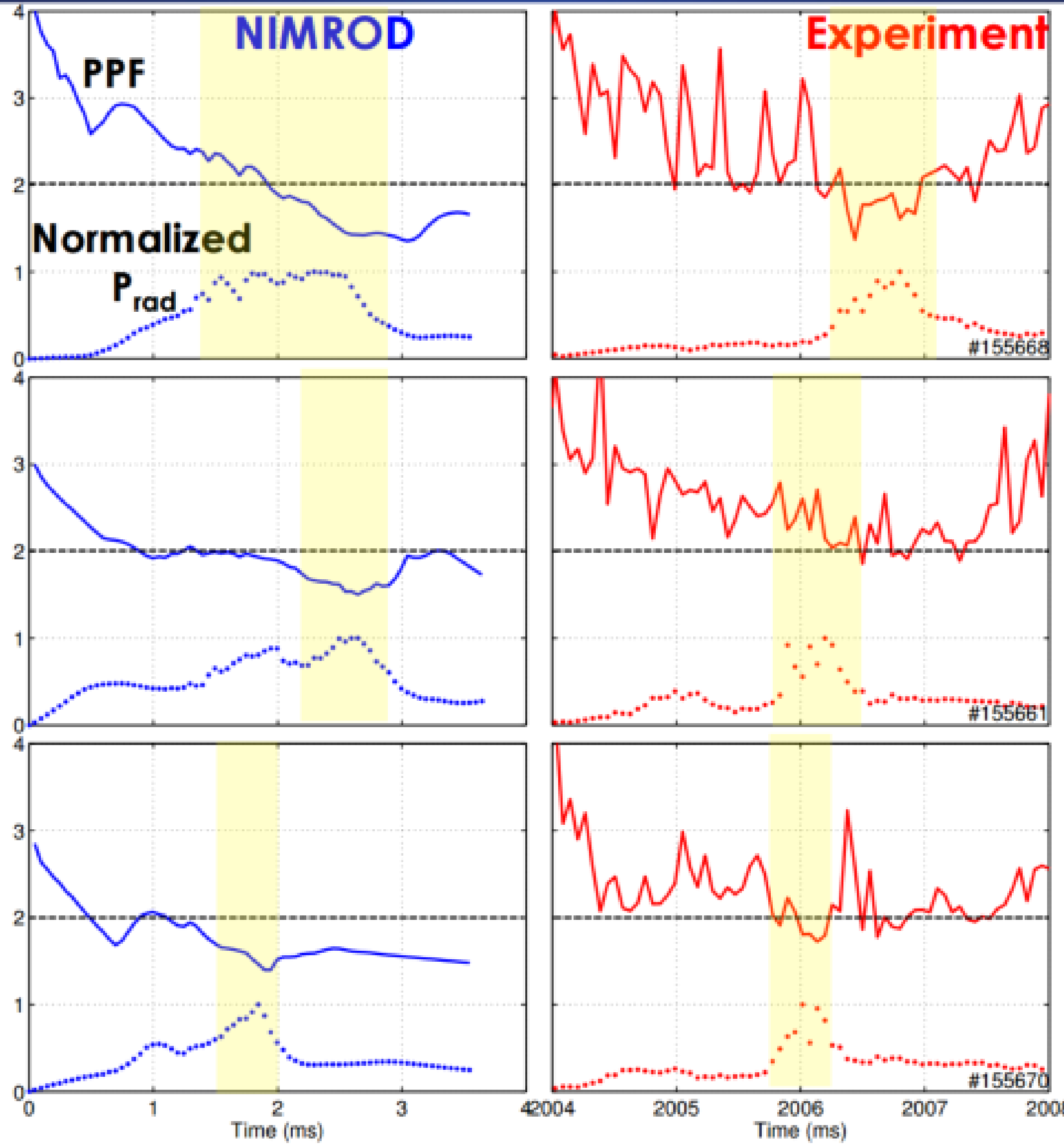
NIMROD generally predicting lower PPF than experiment

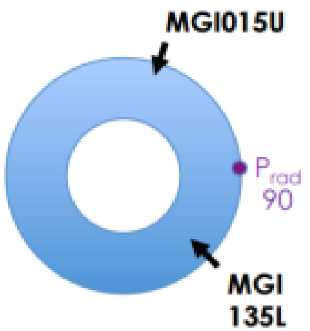
DIII-D (Eidietis)

MGI015U

MGI135L

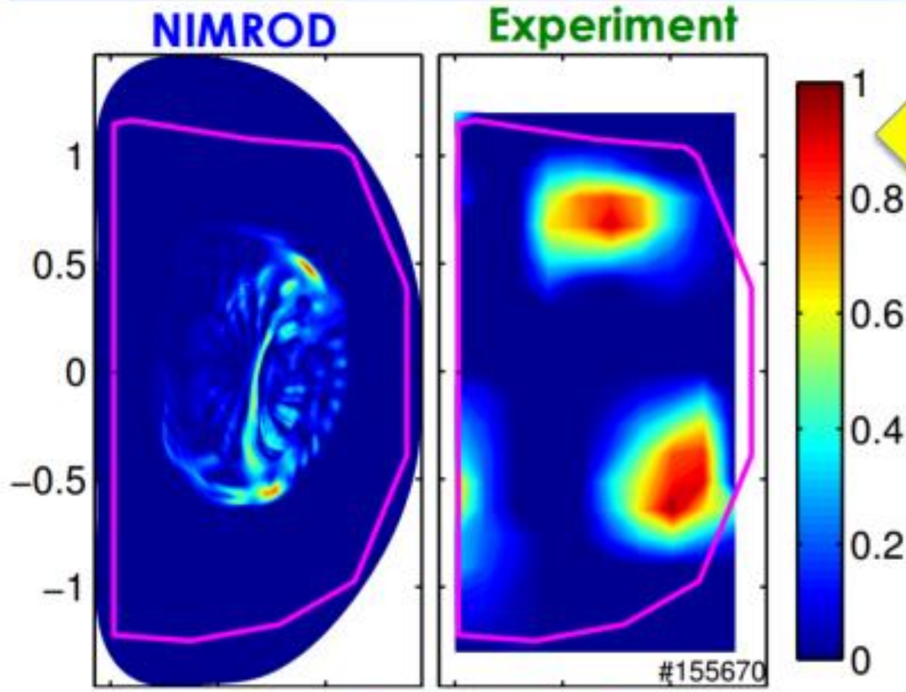
BOTH



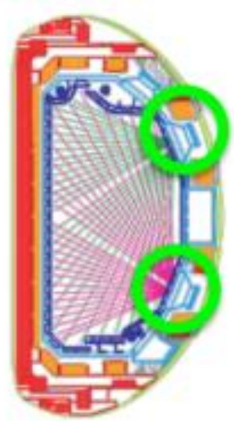


PPF sampled at 90° for all cases

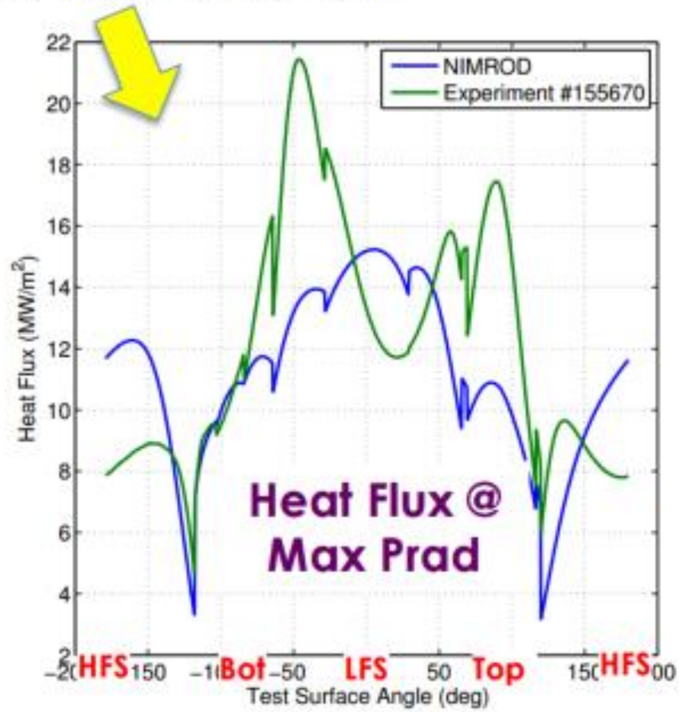
Details of NIMROD vs experimental emissivity contours may explain slightly greater experimental PPF



Normalized Emissivity Contours
90° @ Time of Max P_{rad}
Both MGI



- Bolometry inversion exhibits localized emissivity blobs near wall
- NIMROD also exhibits local emission, but farther from wall
- Proximity of emission to wall in experiment results in more peaked wall heat flux calculation

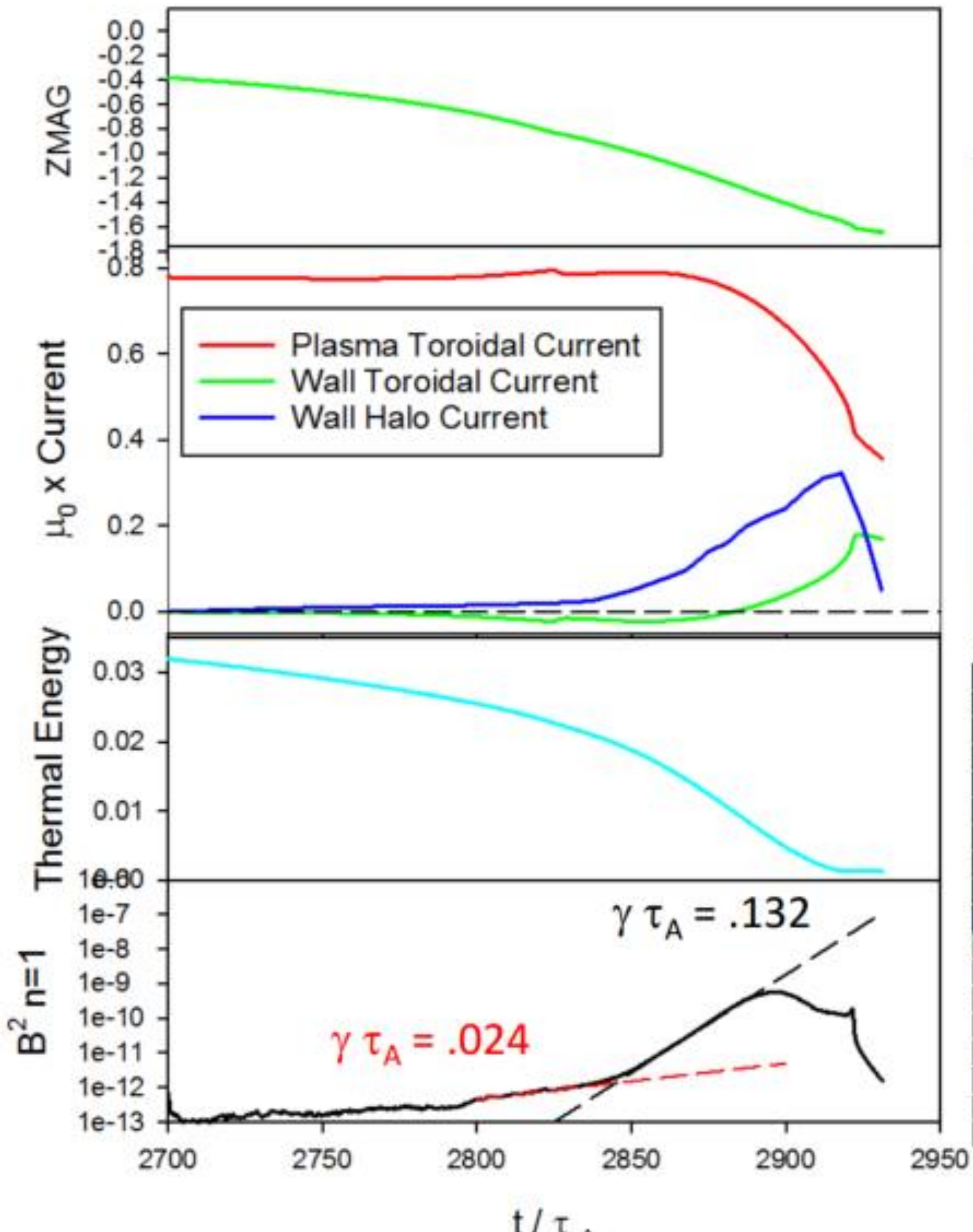


DIII-D NATIONAL FUSION FACILITY SAN DIEGO

Disruption modeling

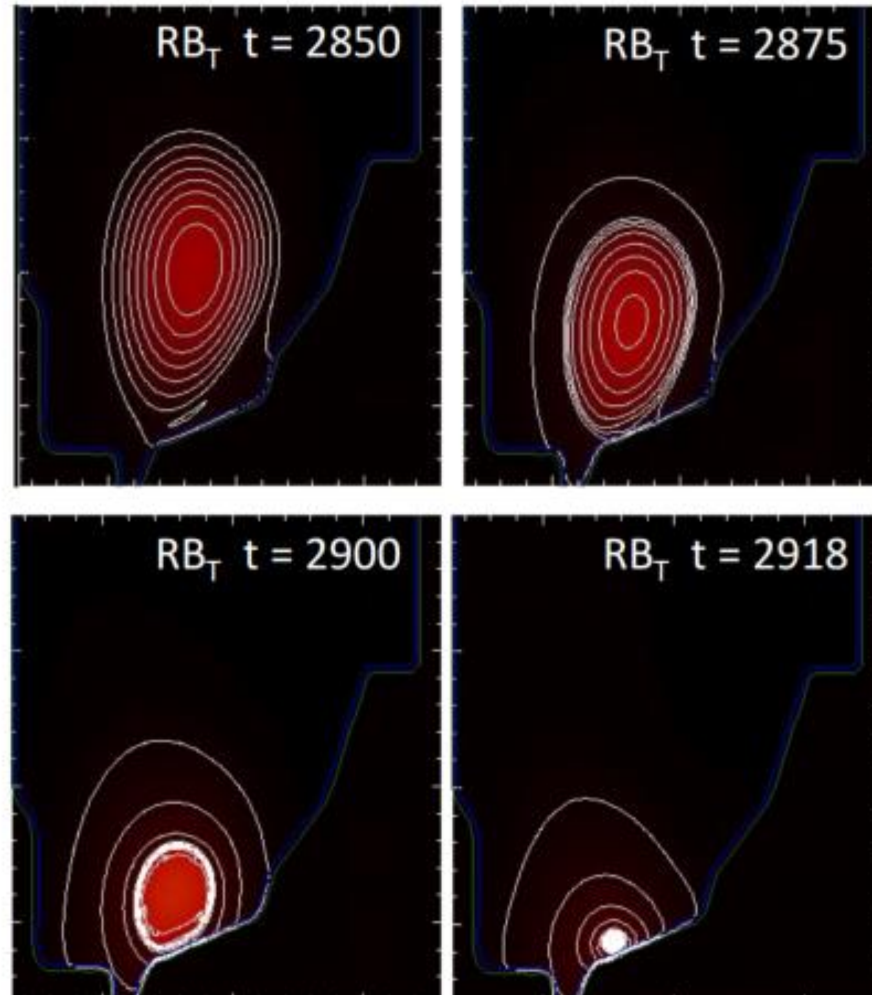
(Jardin)

NSTX Shot 132859 η_W=0.00025

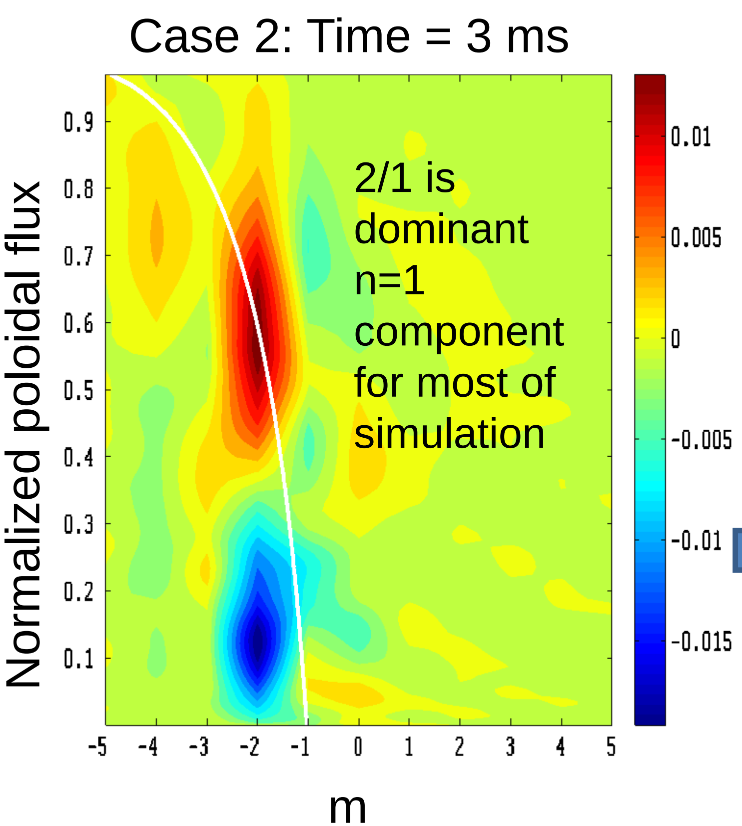


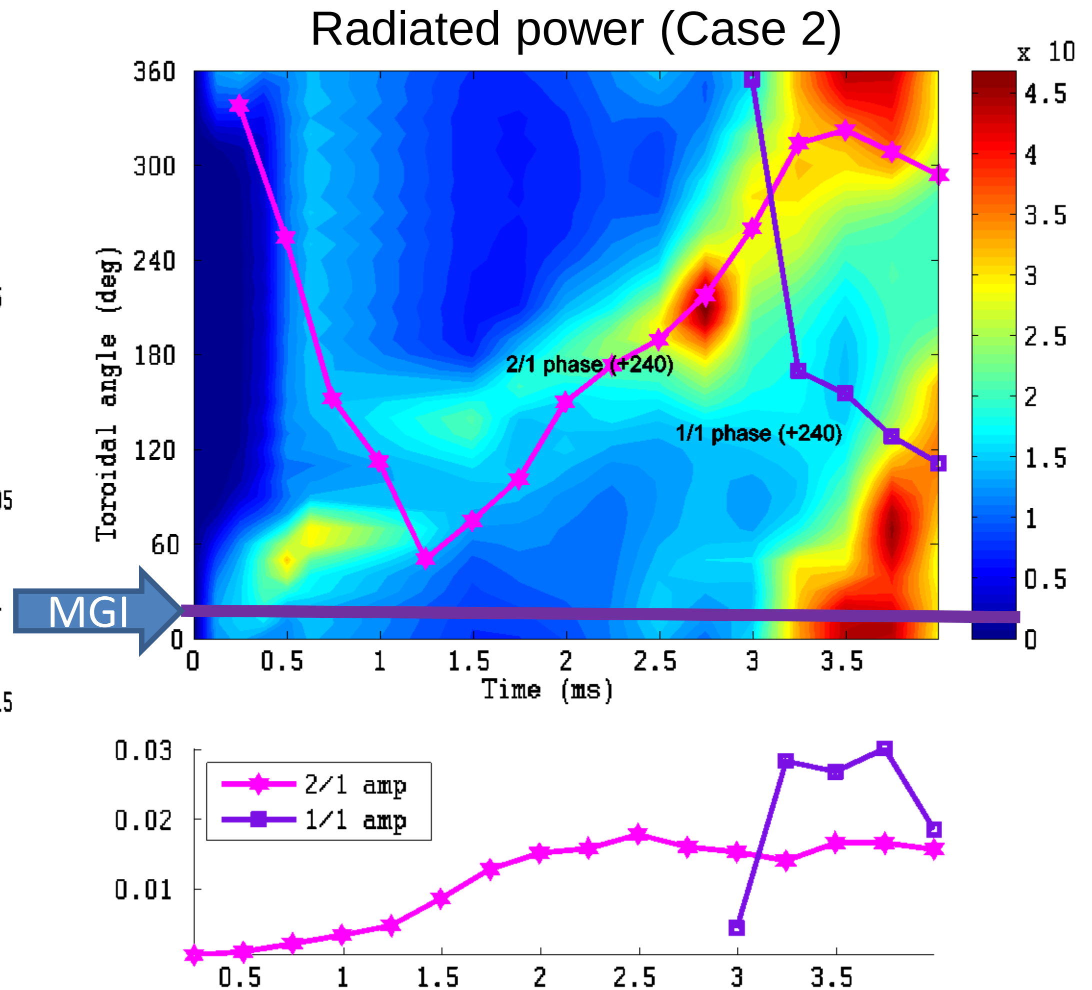
Disruption phase 2700 < t < 2950

Contours of RBT show halo currents



Rotation of m=2/n=1 mode tracks with rotation of peak radiated power



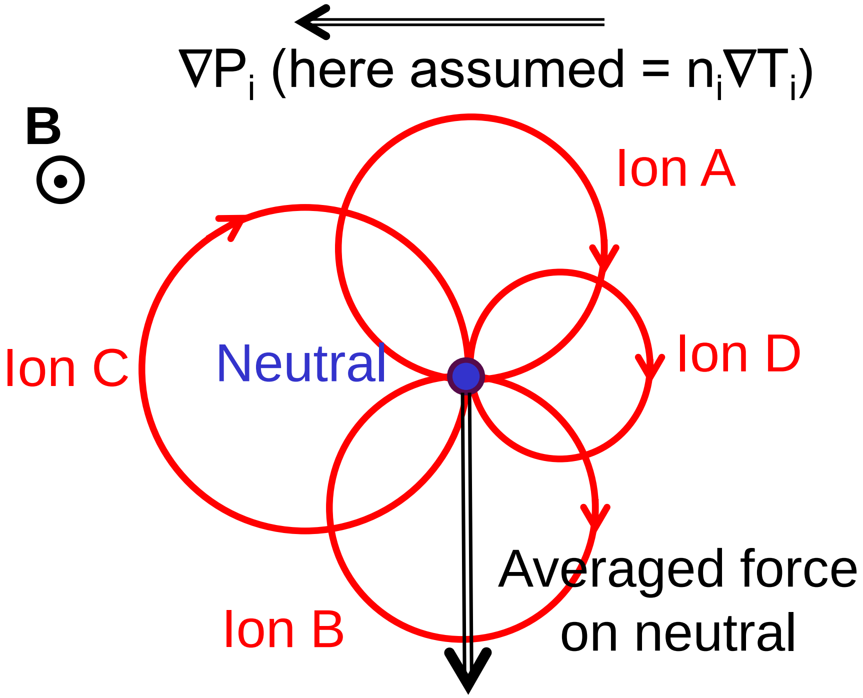


Is the gas flow stopped/braked by the plasma pressure?

- Perhaps, but not by a direct action of ∇P_{plasma} onto the gas:

Microscopic viewpoint

- Collisions with plasma ions/e^- result in a force perpendicular to ∇P_{plasma} (for $\mathbf{V}_0=\mathbf{V}_{i/e}$)



Macroscopic viewpoint

- In the plasma momentum equation, ∇P_{plasma} is « already » compensated by the $\mathbf{j}\mathrm{x}\mathbf{B}$ force, so there is a priori « no reason » that ∇P_{plasma} should apply on neutrals

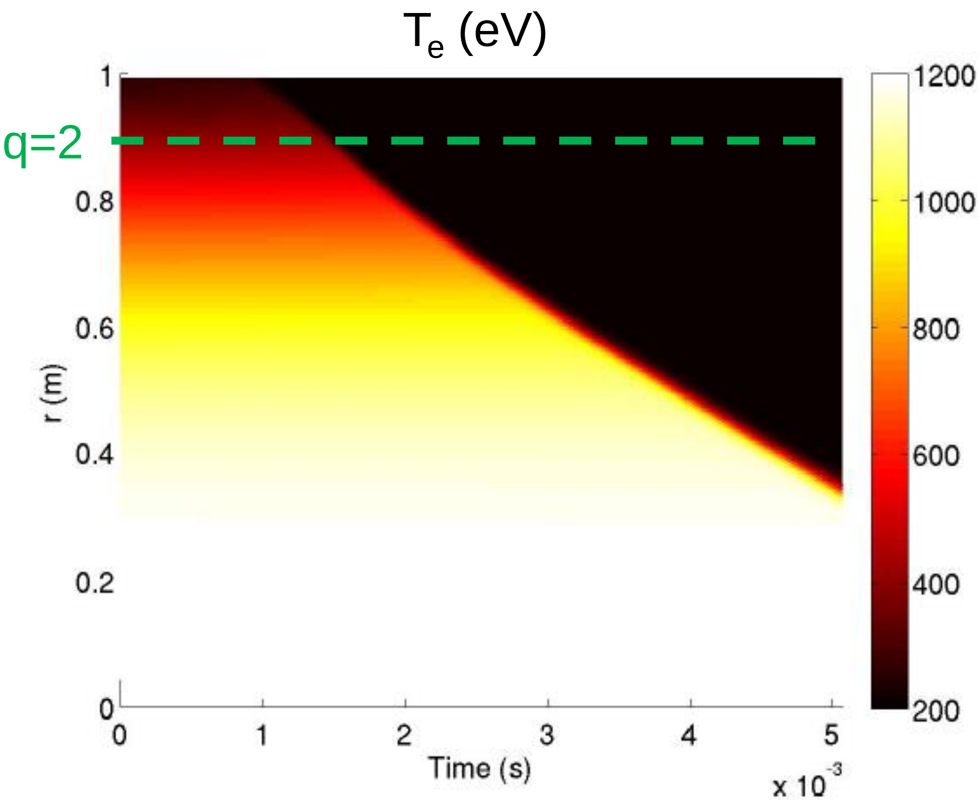
- Collisions (both scattering and reactions [CX, ion., rec.]) actually result in friction forces, $\propto (\mathbf{V}_0-\mathbf{V}_{i/e})$

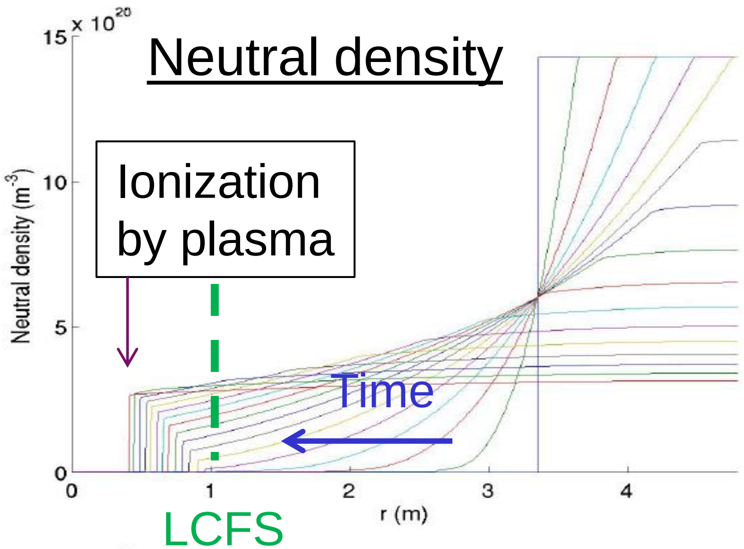
Meier and Shumlak, PoP 2012

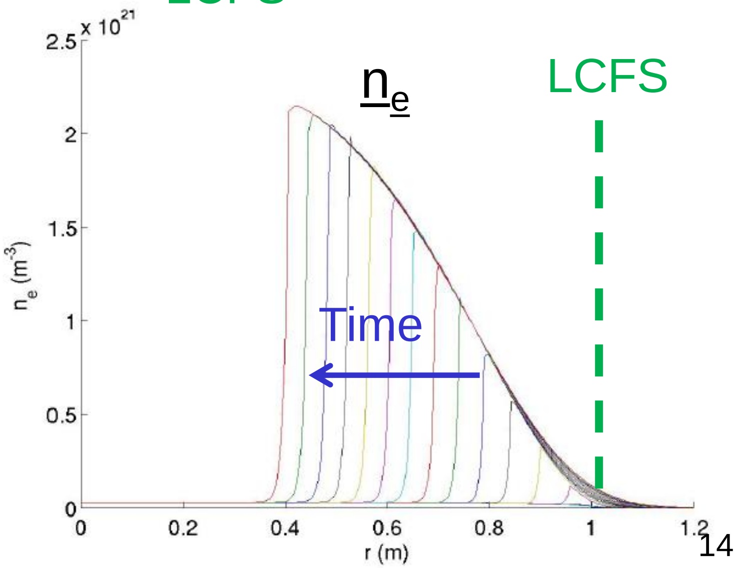
- We will see later how plasma pressure acts indirectly on the gas flow

Neglecting charge exchange and recombination, the gas penetrates unrealistically easily

- Very short penetration time (experimental TQ onset time ~12 ms):
  - ~1.5 ms up to q=2 (r~0.9 m)
  - ~5 ms up to plasma centre
- Very high n_e: > 10^{21} m^{-3}





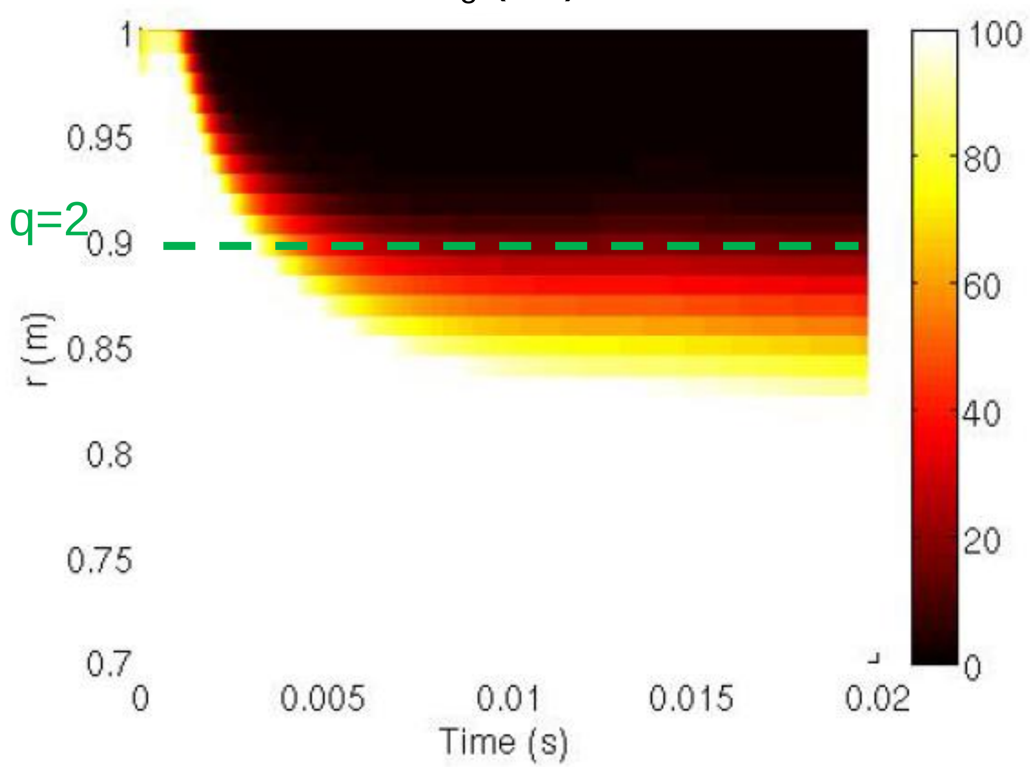


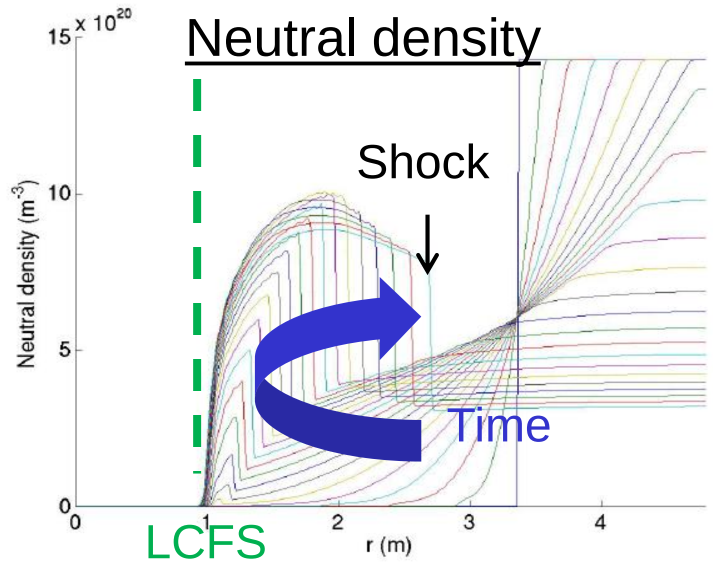
Including charge exchange and recombination, the gas penetration is significantly reduced

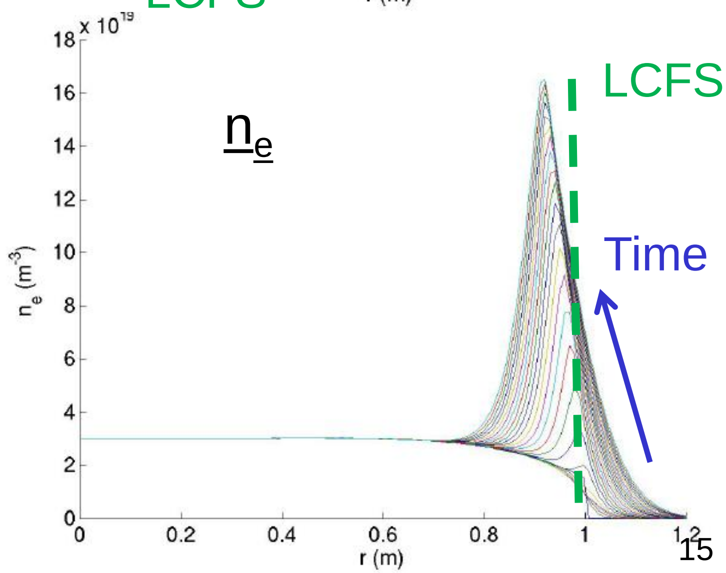
- Fast (10^{-5} s) heating of the neutrals creates a shock wave and strongly slows down the incoming gas

⇒ Much slower penetration (consistent with TQ onset time)

T_e (eV)







Interpretation: gas braking mechanism

- In IMAGINE, gas pressure is spread over plasma surface:

$$P_{res}^{IMAGINE} = \frac{A_{orifice}}{4\pi^2 R_0 a} P_{res}^{\exp} \approx 6 \cdot 10^{-6} P_{res}^{\exp}$$

  - 5 bar in DMV2 → 3 Pa in IMAGINE!
- Plasma pressure (JET Ohmic plasma) ~ several kPa

$P_{plasma} >> P_{gas}$

- The conversion (by, e.g., CX) of even a small fraction of P_{plasma} into P_{gas} strongly heats the gas

- Hot neutrals can go either toward the plasma center or back toward incoming gas
  - The former are ionized and their momentum is dissipated by the braking force acting on charged species
  - The latter brake the incoming gas flow by collisions

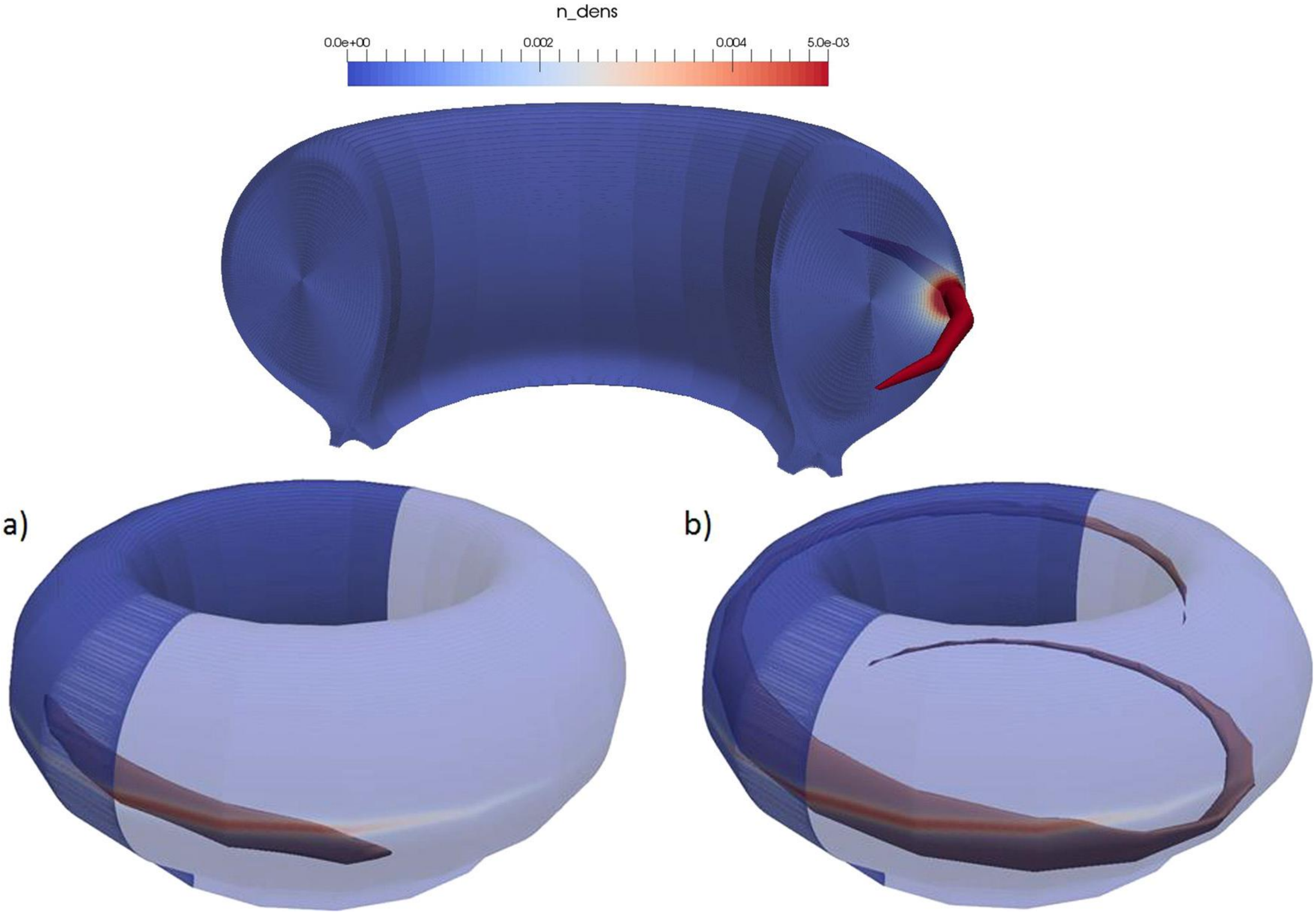
⇒ Overall, gas momentum is dissipated by the braking force

⇒ Plasma pressure does cause gas braking after all, but in an indirect way

Three-dimensional non-linear magnetohydrodynamic modeling of massive gas injection triggered disruptions in JET

A. Fil, E. Nardon, M. Hoelzl, G. T. A Huijsmans, F. Orain, M. Becoulet, P. Beyer, G. Dif-Pradalier, R. Guirlet, H. R. Koslowski, M. Lehnen, J. Morales, S. Pamela, C. Passeron, C. Reux, F. Saint-Laurent, and JET Contributors

Physics of Plasmas **22**, 062509 (2015); doi: 10.1063/1.4922846



D_2 MGI model in JOREK

- Equations:

Neutral density:

$$\frac{\partial \rho_n}{\partial t} = \nabla \cdot (\mathbf{D}_n : \nabla \rho_n) - \rho \rho_n R_{ion}(T) + \rho^2 R_{rec}(T) + S_n$$

Energy:

$$\frac{\partial(\rho T)}{\partial t} = -\mathbf{v} \cdot \nabla(\rho T) - \gamma \rho T (\nabla \cdot \mathbf{v}) + \nabla \cdot (\kappa_\perp \nabla_\perp T + \kappa_\parallel \nabla_\parallel T) + \frac{2}{3R^2} \eta_{Spitzer} j^2$$
$$- \xi_{ion} \rho \rho_n R_{ion}(T) - \rho \rho_n L_{rays}(T) - \rho^2 L_{brem}(T)$$

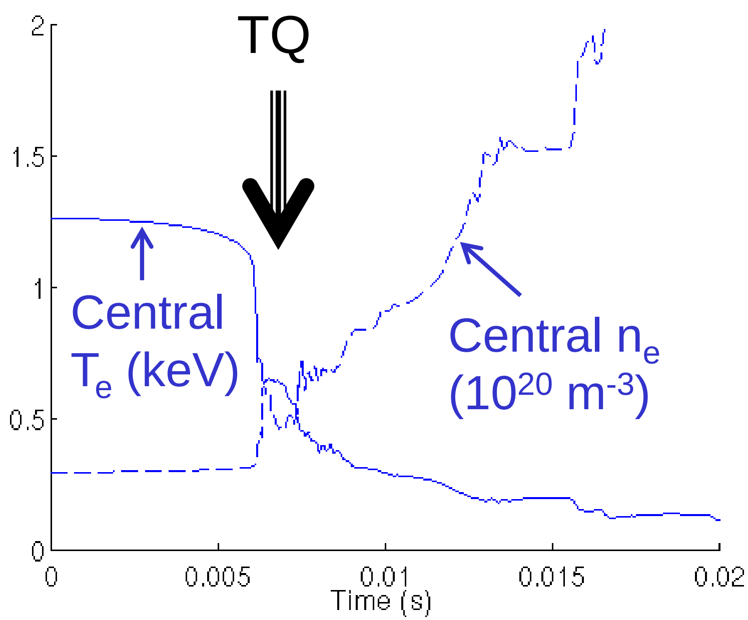
(+ 6 other equations: large aspect-ratio reduced non-linear MHD)

- Important features:

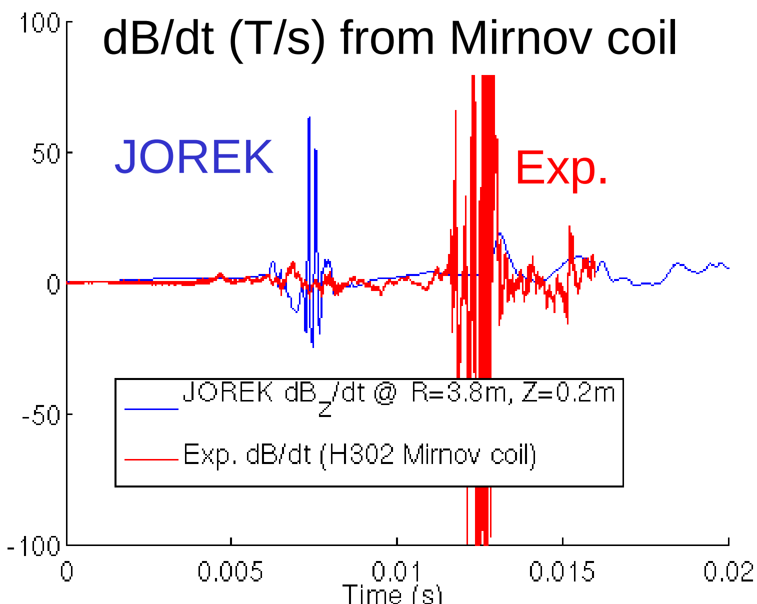
Ad hoc {
- Neutrals are deposited via a volumetric source term
- Neutral transport is diffusive

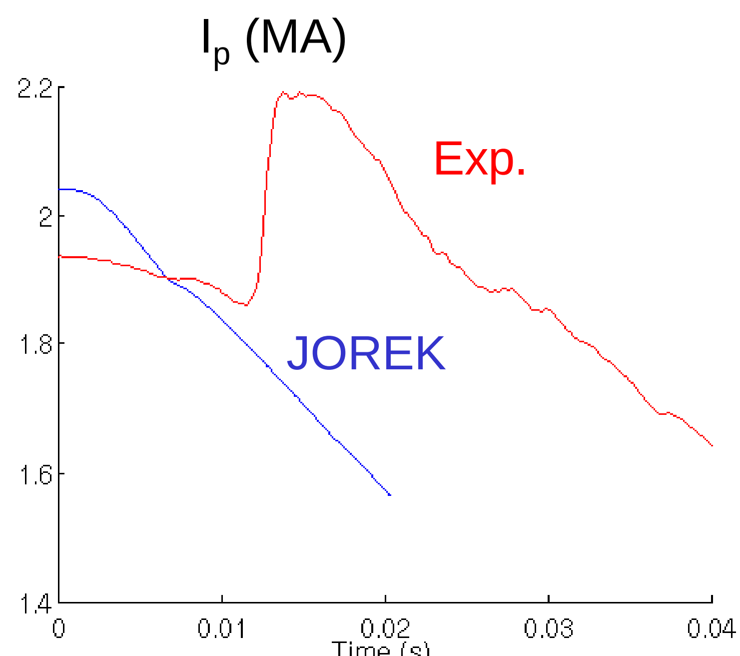
- Ionization, recombination and radiation (line and bremsstrahlung) with coefficients from the ADAS database
- Ohmic heating (with Spitzer resistivity)

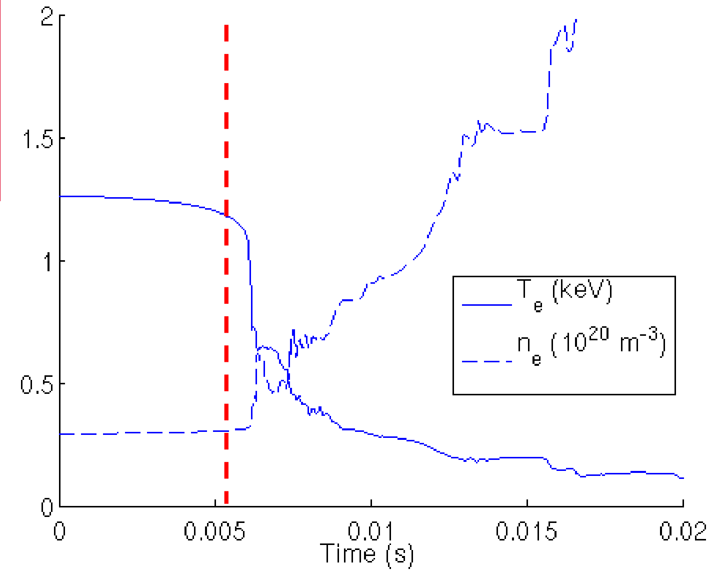
A thermal quench is obtained in the simulations



- Fast drop of central T_e + burst of dB/dt
- MHD activity (dB/dt and I_p spike) much weaker in simulation
  - Likely consequence of e.g. too high η_0 or hyper-resistivity
  - ⇒ Work is being pursued to improve the simulations



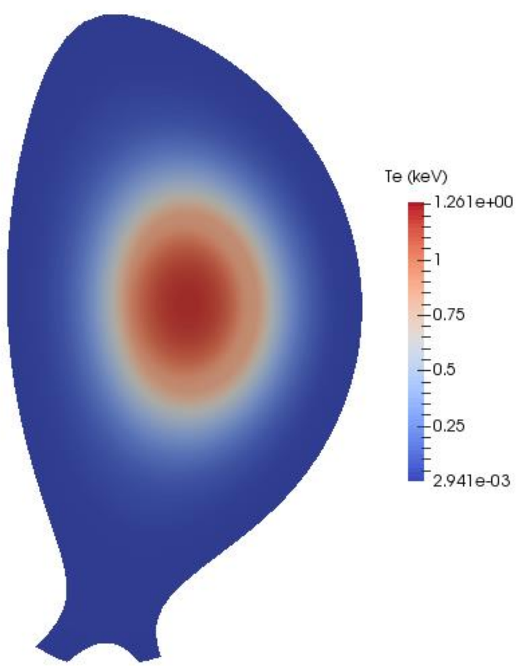




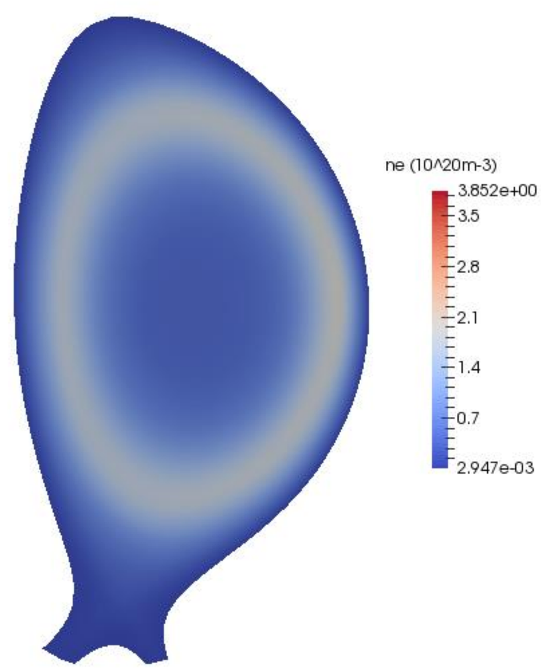
t=5.3 ms

- Then, m/n=1/1 and 2/1 islands grow
  - Note: 1/1 internal kink mode is intrinsically unstable since $q_0<1$; it is seeded by the perturbation from the MGI
- O-points of islands are spatially in phase with gas deposition region
  - Also observed with NIMROD

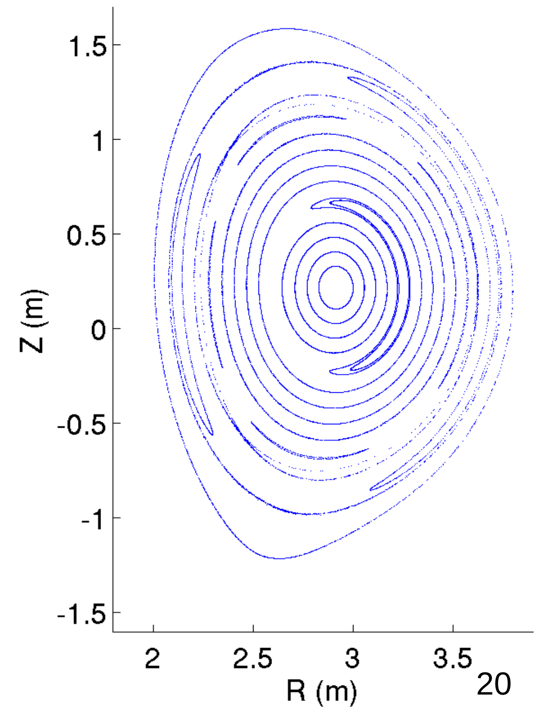
T_e



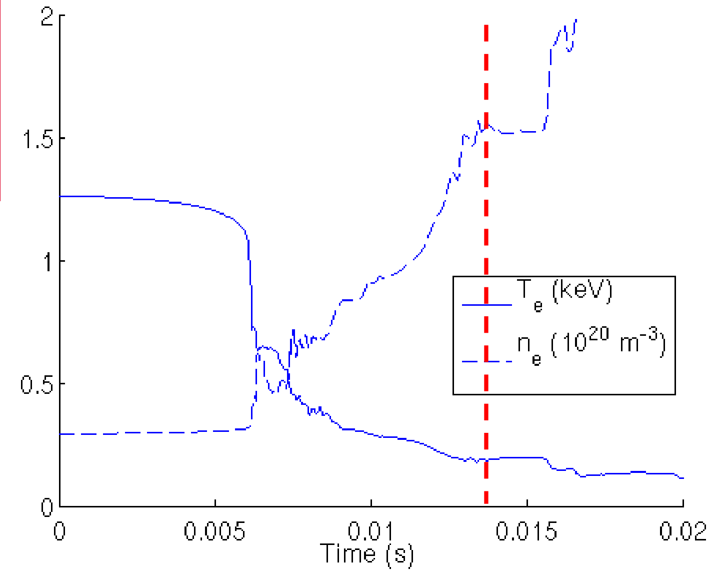
n_e

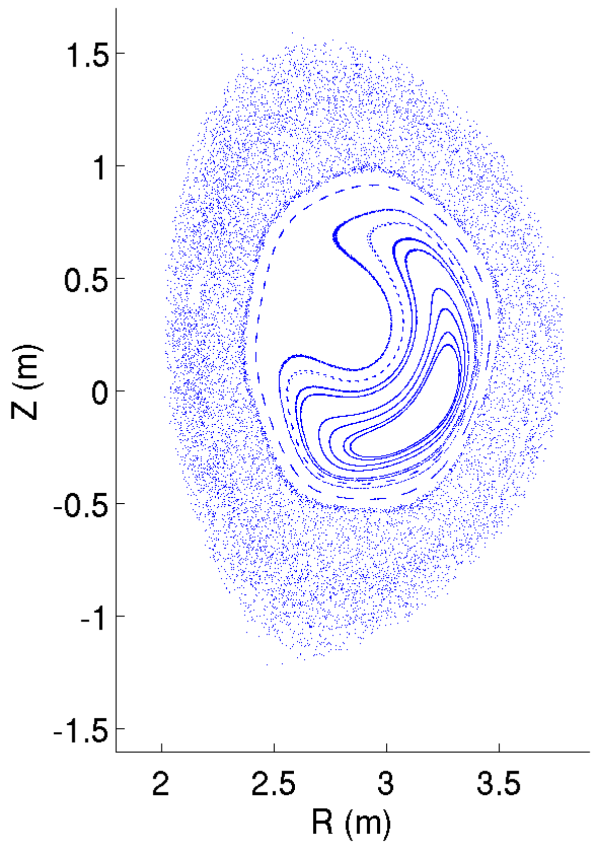


Poincaré



t=13.6 ms





- Edge ergodization pertains for a « long » time
- But core has good flux surfaces

⇒ Consequences for runaway electron formation processes?

  - Suggests RE can be created only in the core

Summary

Many outstanding disruption challenges that could be addressed in the context of 3D MHD modeling:
Runaway electrons- generation, loss, confinement, interaction with gas, pellet injection
Mitigation- MGI, SPI, Self-consistent RE-free solutions
Wall currents and forces
etc.,

Solutions that are successful on small to medium sized tokamaks may not work on JET let alone ITER; modeling is required to understand scaling and extrapolation

Efforts to model mitigation are ramping up (NIMROD, JOREK, …)

Efforts to model VDEs and wall forces are ramping up (M3D, DSC, M3D-C1, NIMROD…)