DIII-D research in support of the ITER disruption mitigation system

by

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DIII-D program aims to produce critical knowledge for the design & operation of the ITER Disruption Mitigation System

- **Establish physics & limitations of shattered pellet injection (SPI)**
- **Probe the mechanisms governing runaway electron (RE) evolution**
- **Develop new "inside-out" mitigation by core impurity deposition**

DIII-D program aims to produce critical knowledge for the design & operation of the ITER DMS

- Establish physics and limitations of shattered pellet injection (SPI)
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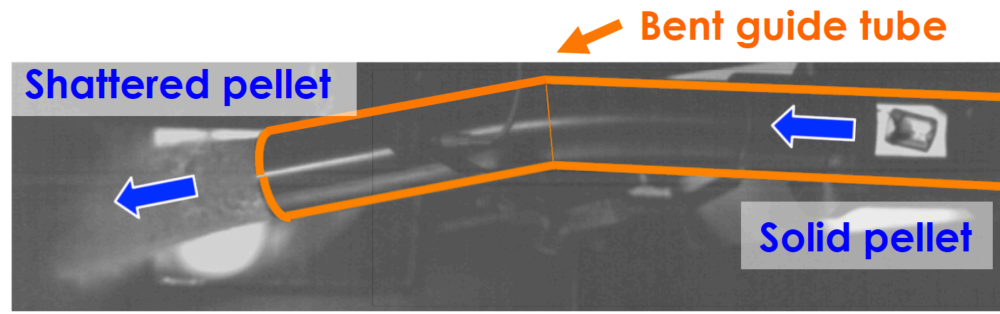
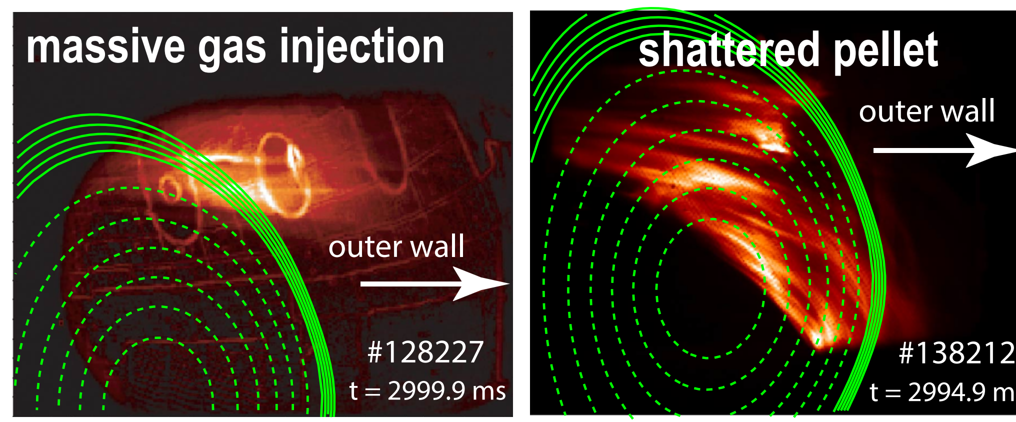
- Develop new "inside-out" mitigation by core impurity deposition

For several years, DIII-D has been only device able to test SPI, the baseline ITER DMS technology

- **Solid cryogenic impurity pellet shattered prior to entering plasma**
  1. Protects in-vessel components from a large solid pellet
  2. Improves assimilation due to increased surface area
  3. Provides faster response over long distances than massive gas injection (MGI)
- **DIII-D operates two SPI systems**
  – Toroidally separated by 120°
- ***New SPI online 2018 (J-TEXT, JET)***



Composite image from ORNL laboratory tests



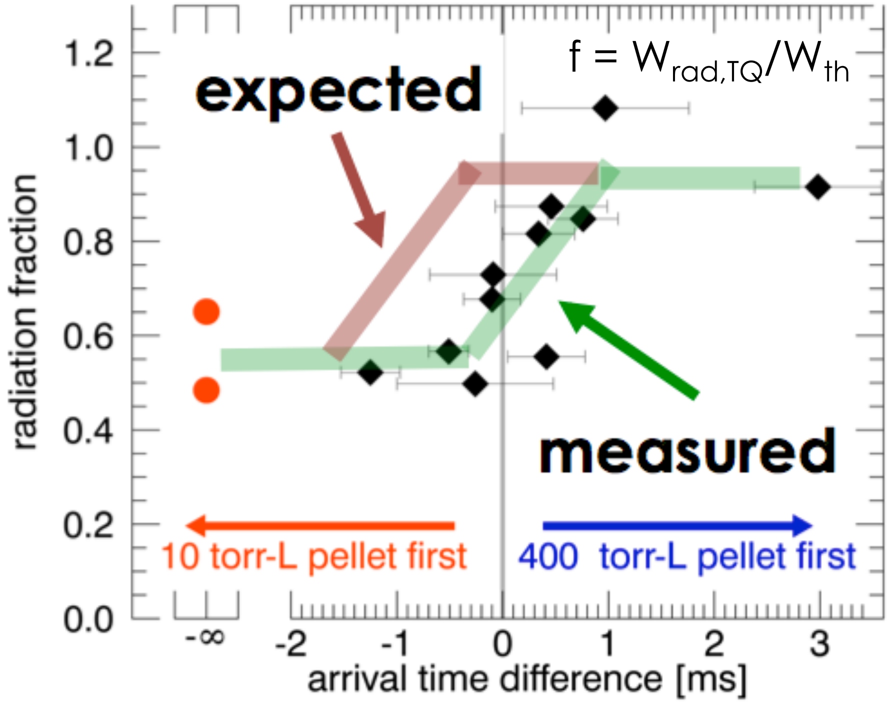
E.M. Hollmann et al., PoP 2015

Simultaneous injection of multiple SPI exhibits unexpected degradation in mitigation performance

- **ITER: Multiple simultaneous SPI needed to reduce radiation asymmetries & provide massive D_2 input for RE suppression**

- **DIII-D: Simultaneous injection of two pellets (10 torr-L & 400 torr-L Ne) exhibits worse 0-D mitigation metrics than single 400 torr-L pellet**

J.L. Herfindal et al, APS 2017



Arrival = Reaching plasma edge

[1]J.R. Martín-Solís et al, NF 2017

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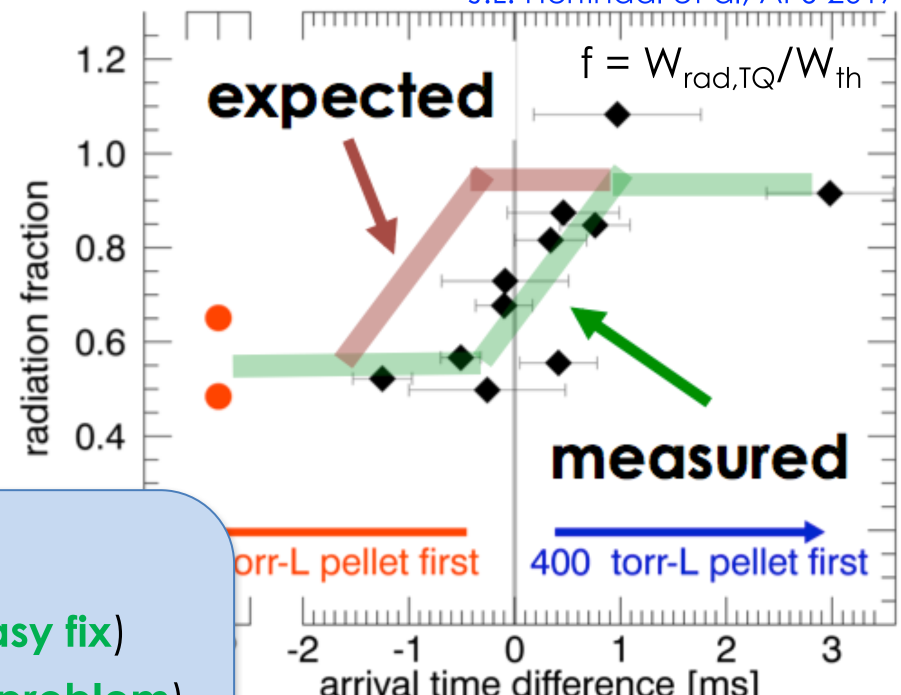

al = Reaching plasma edge

Hypotheses

1. Lighter/faster SPI hits q=2 first, initiates TQ (**easy fix**)
2. Dilution cooling reducing ablation (**not ITER problem**)
3. Impurities in multiple flux tubes initiate TQ faster than single flux tube (**basic physics problem**)

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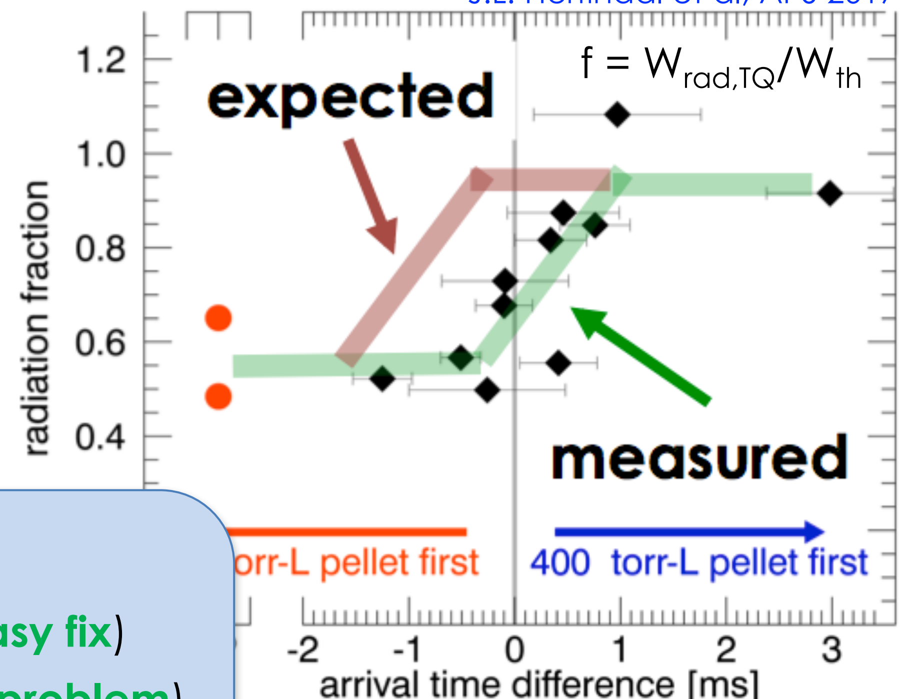

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DIII-D experiments planned in 2019 to test hypotheses

NF 2017

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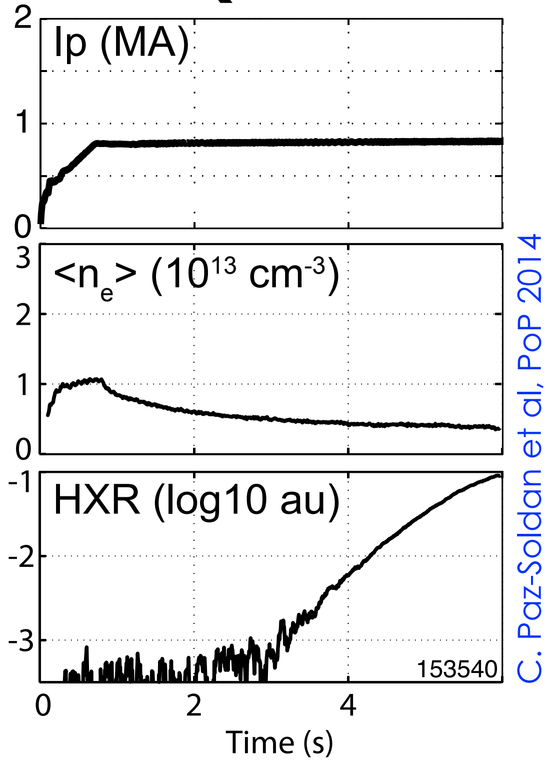
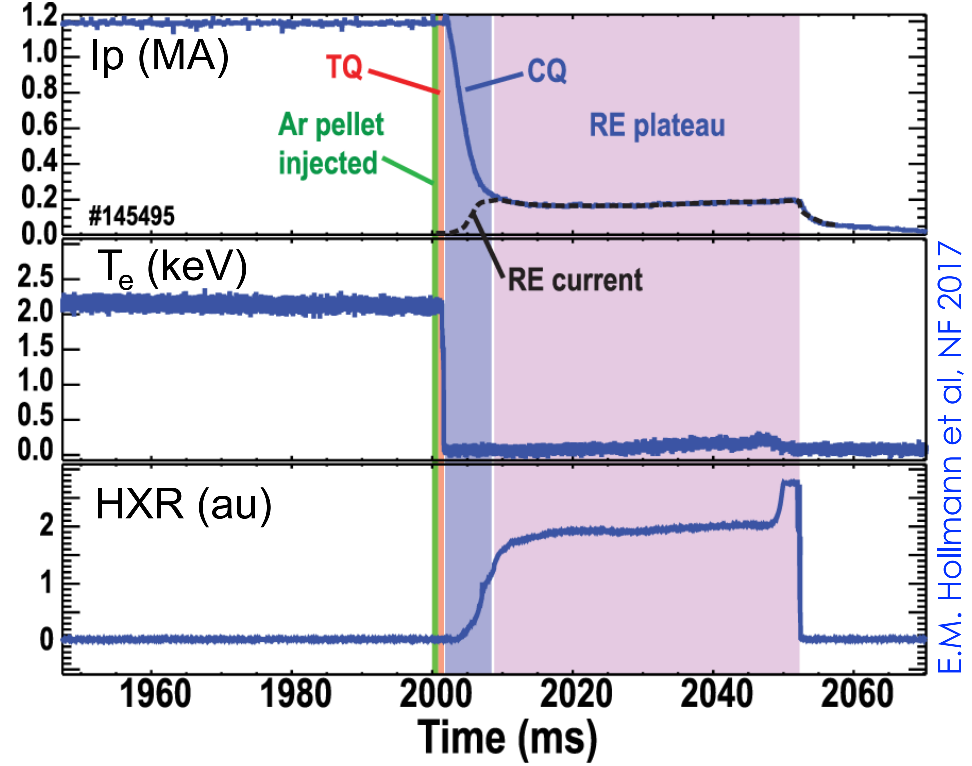
Two regimes used to study RE:
Flattop "quiescent" runaway (QRE) & post-disruption RE plateau

QRE



RE Plateau



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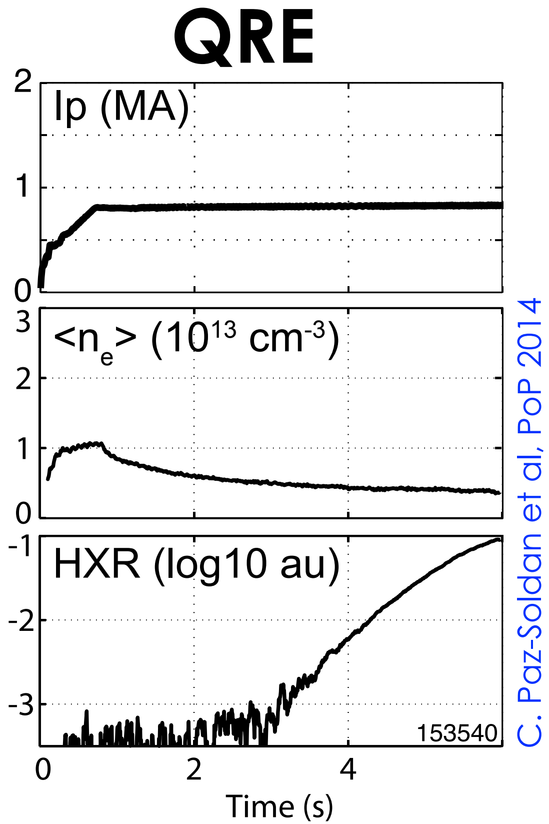


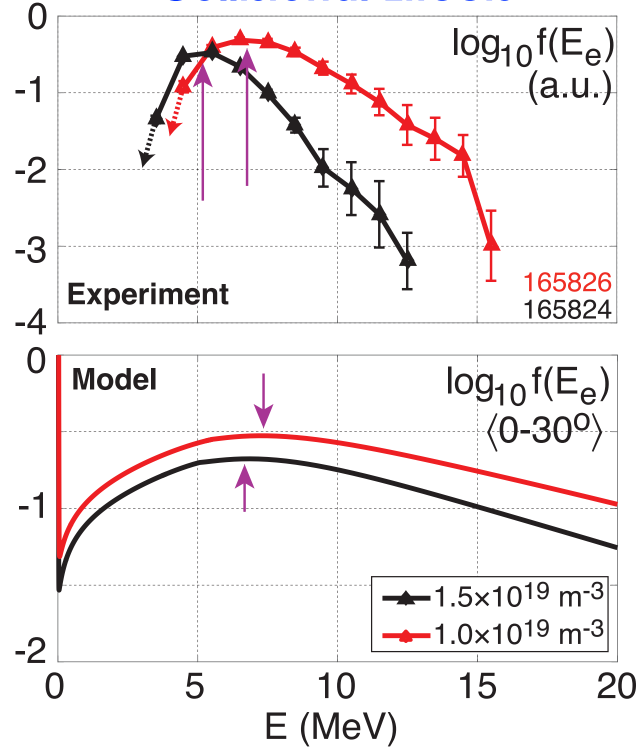
Strengths of using QRE to study RE physics:

1. **All DIII-D profile diagnostics available**
2. **Slow evolution**
3. **Trace RE avoid signal saturation**

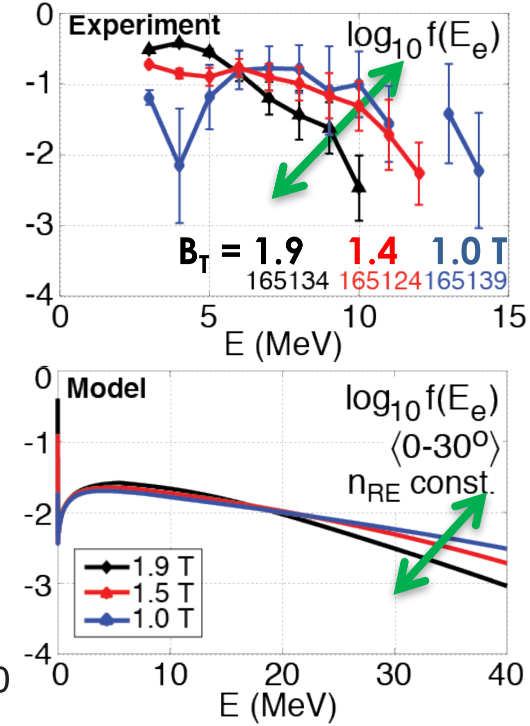
Observed RE f(E) exhibit qualitative agreement on collisional & synchrotron effects with theoretical model

- Non-monotonic peak observed at predicted energy
- Peak moves to lower energy with increased density (collisionality)
- Increasing B_T (synchrotron) suppresses high-energy RE

Collisional Effects



Synchrotron Effects



Model = 0-D Fokker-Planck + collisions & radiation

NO FREE PARAMETERS

C. Paz-Soldan et al, PoP 2018
C. Paz-Soldan et al, PRL 2017

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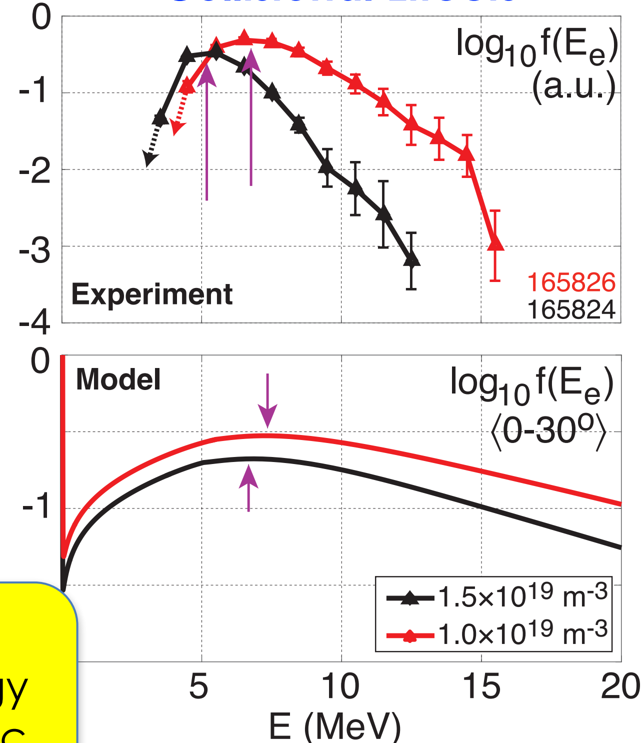
Significant quantitative discrepancy in high energy tail – possibly due to kinetic instabilities (later)

Collisional Effects



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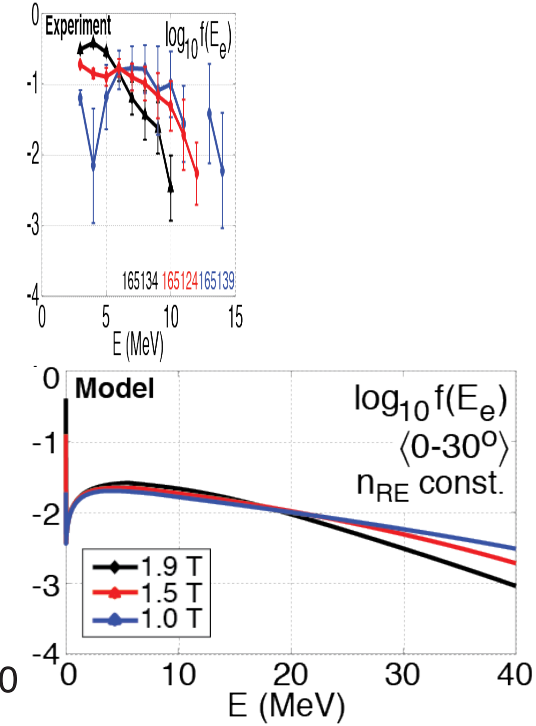

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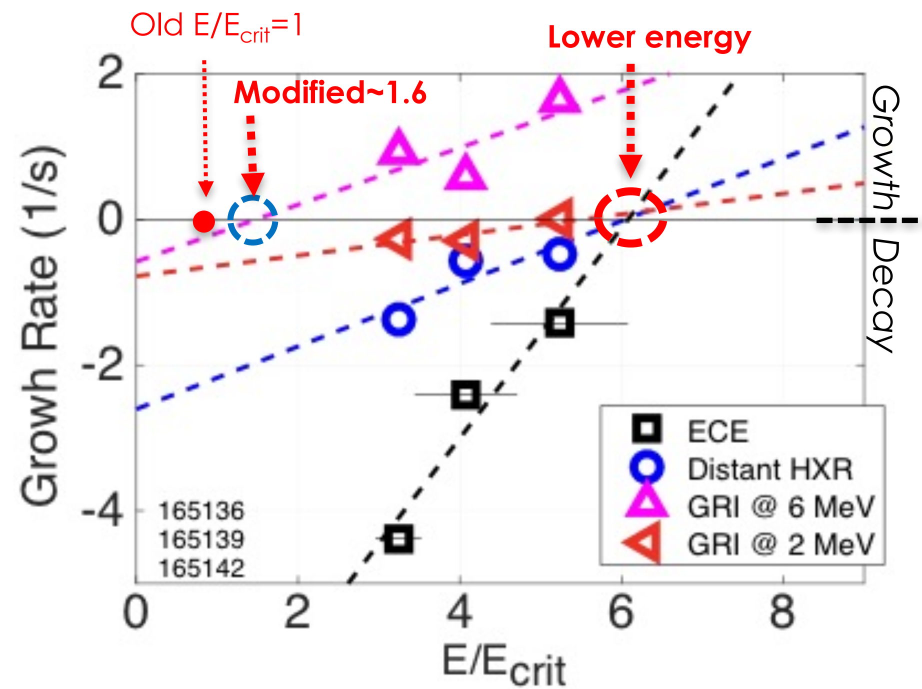
Anomaly between predicted & observed critical electric field (E_{crit}) for RE growth shows strong energy dependence

- Previous results (without energy resolution) found[1-2] HXR decay at anomalously high E/E_{crit}
- Energy–resolved measurements reveal E/E_{crit} threshold decreasing with increasing RE energy
- Extrapolated E/E_{crit} threshold for 6MeV RE in good agreement with theory incorporating pitch angle scattering & synchrotron effects[3]



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[1] Paz-Soldan et al, Phys Plasmas 2014
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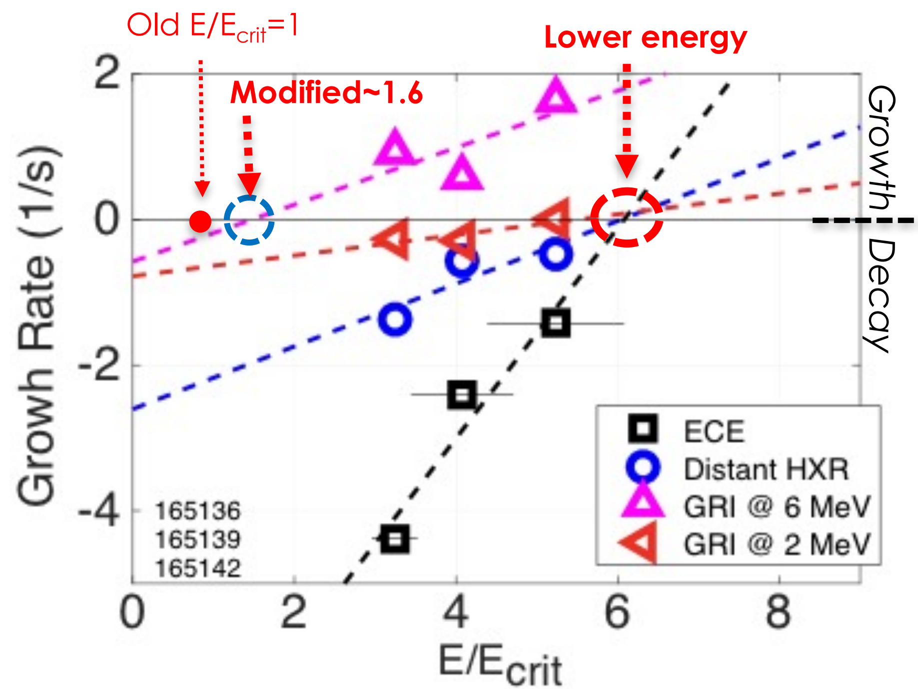

C. Paz-Soldan et al, PoP 2018

Anomalous dissipation remains large at low energy … what is going on ??

[1] Paz-Soldan et al, Phys Plasmas 2014
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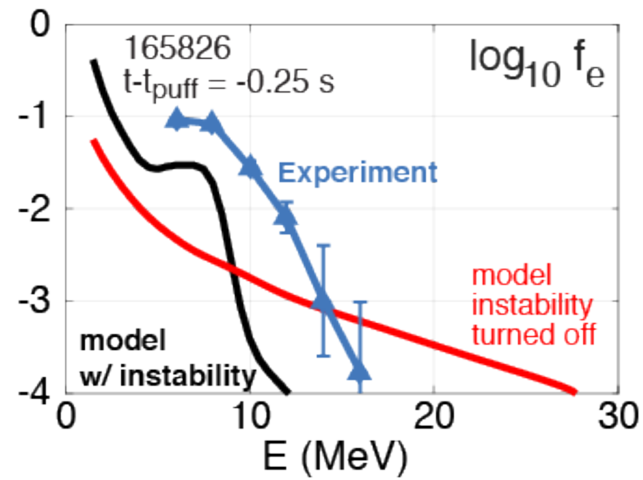
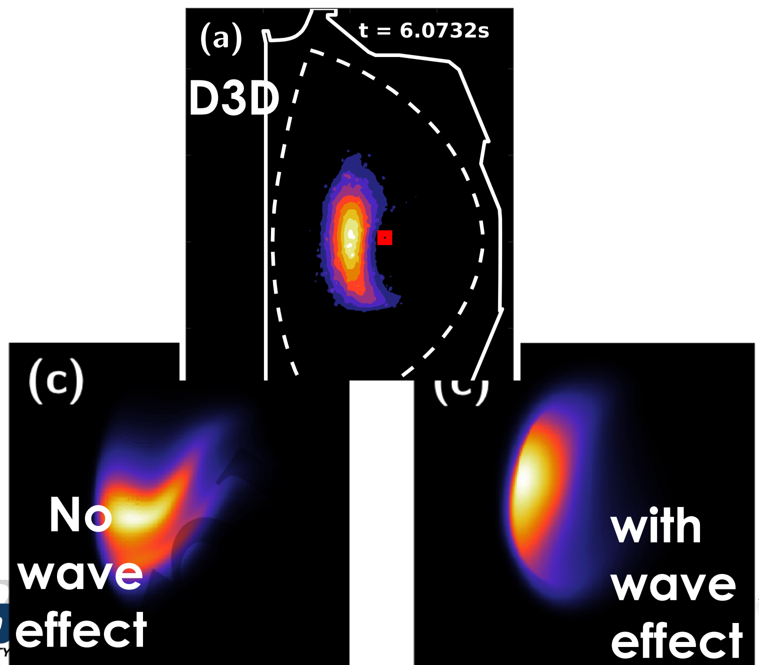
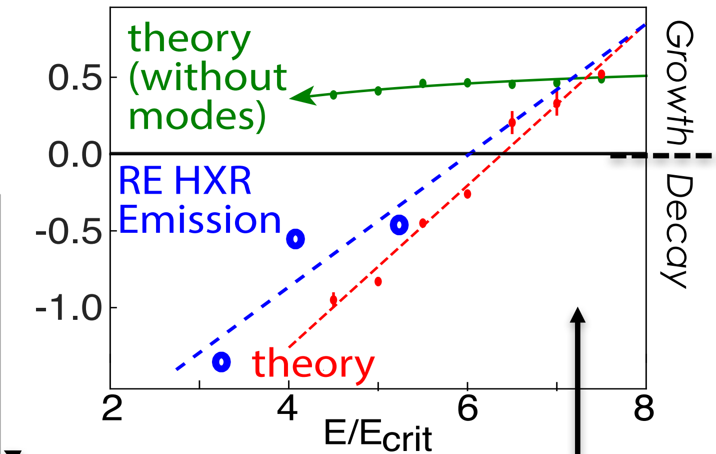
[3] Aleynikov & Breizman, PRL 2015

Inclusion of kinetic instability improves agreement of bremsstrahlung observations with modeling

- **Slope of distribution better matched when kinetic instability included**
- **Calculation w/ waves reproduces experimental E/E_{crit} threshold**
- **Better match to synchrotron image**







C. Liu et al, PRL 2018 (in review)
M. Hoppe et al, NF 2018

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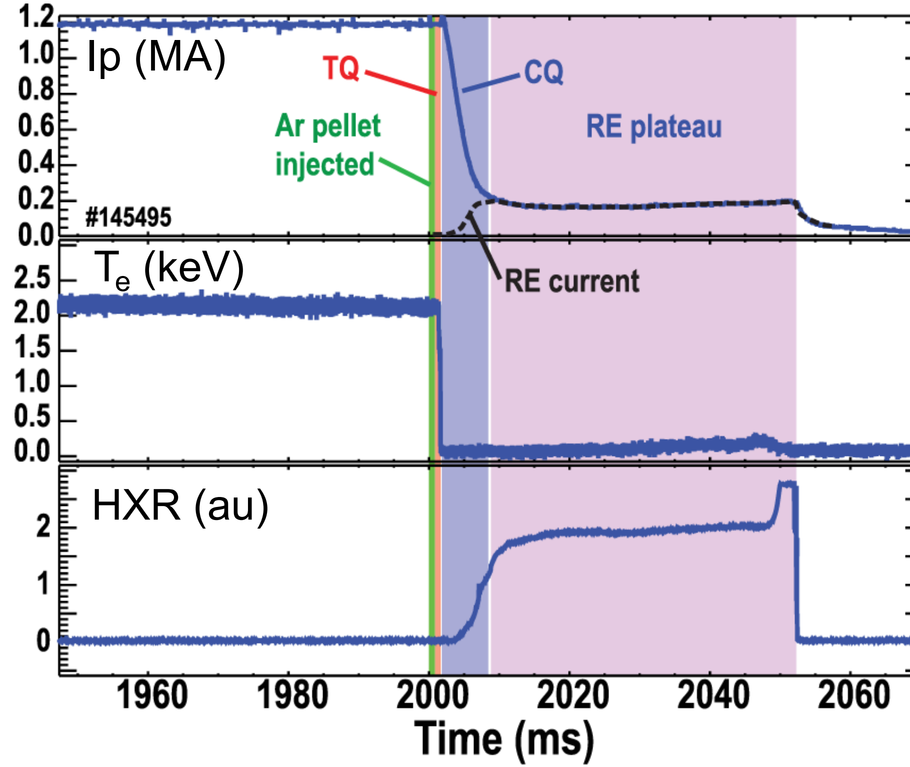
Flattop "quiescent" runaway (QRE) & post-disruption RE plateau

RE Plateau



E.M. Hollmann et al, NF 2017

RE plateau formation: High energy RE instabilities correlated with suppression of RE plateau formation after Ar MGI

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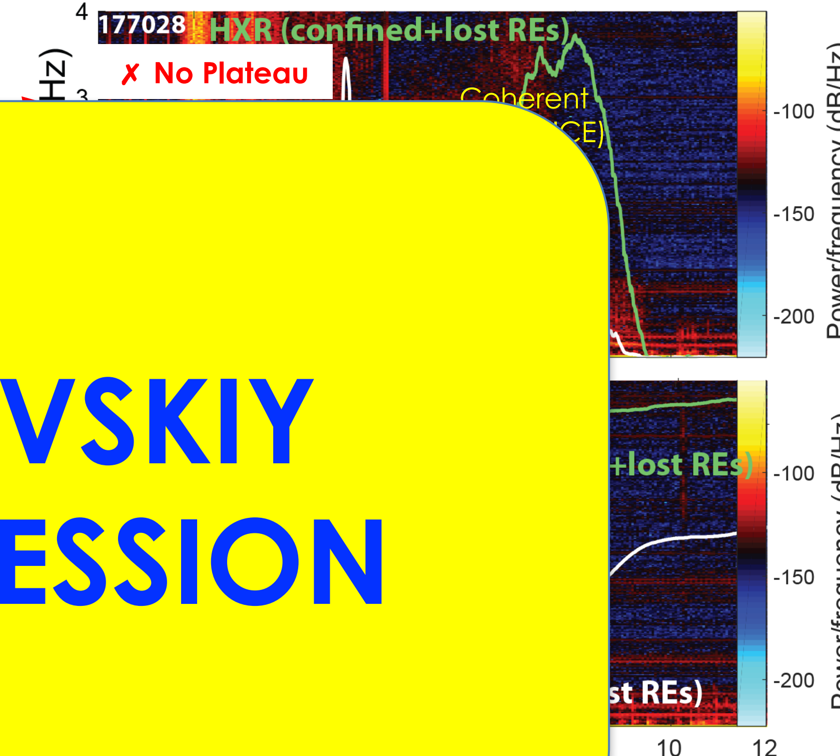
Ar quantity scan



- Sma… kine…
- Incr… s) suppr… aration)

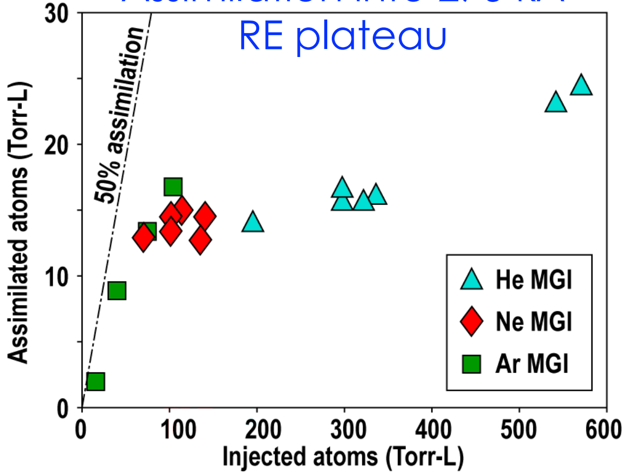
SEE A. LVOVSKIY LATER THIS SESSION

Collaboration Università di Milano-Bicocca

RE plateau dissipation: Assimilation of impurities into RE plateau exhibits strong saturation

- **At constant RE current, the # assimilated particles saturates as injected quantity increases…**

Assimilation into 275 kA RE plateau

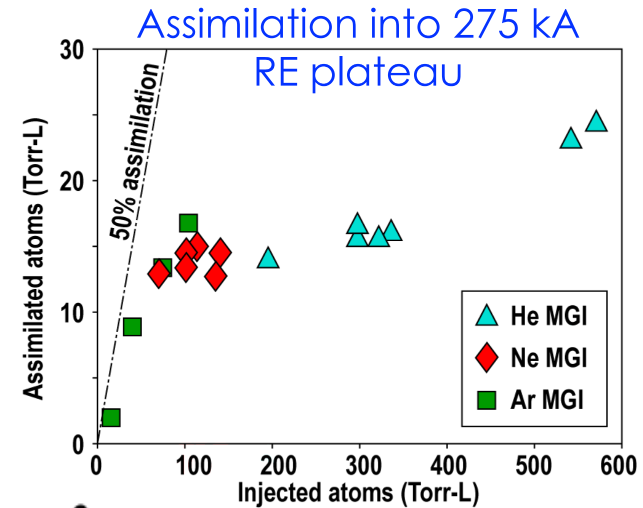


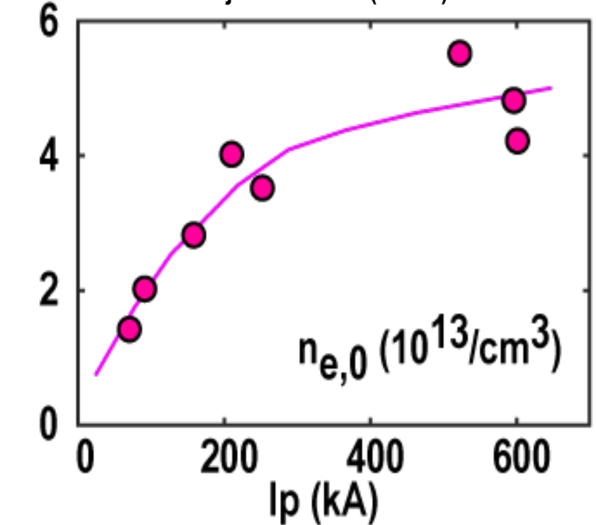
E. Hollmann et al 2018, in preparation

RE plateau dissipation: Assimilation of impurities into RE plateau exhibits strong saturation

- **At constant RE current, the # assimilated particles saturates as injected quantity increases…**

- **… but the # of particles that can be assimilated increases with Ip**
  - **Further analysis needed to determine if linear**





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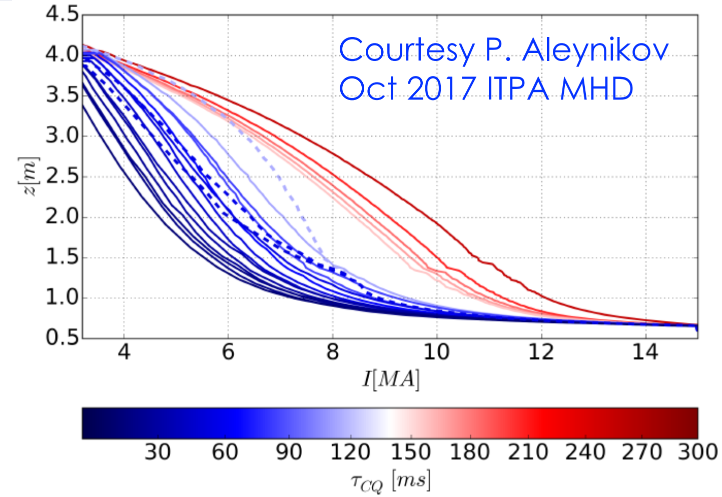
RE plateau dissipation: Assimilation of impurities into RE plateau exhibits strong saturation

- **DINA: Fixed relationship between Ip & Zp makes dissipation VERY difficult[1,2]**
  - ↑ Ar density → ↑ VDE velocity → ↑ $E_{||}$
  - $E_{||}$ tends to "run away" from $E_0 \sim N_{ar}$



1. Konovalov 2016 IAEA
2. Kiramov & Breizman PoP 2017

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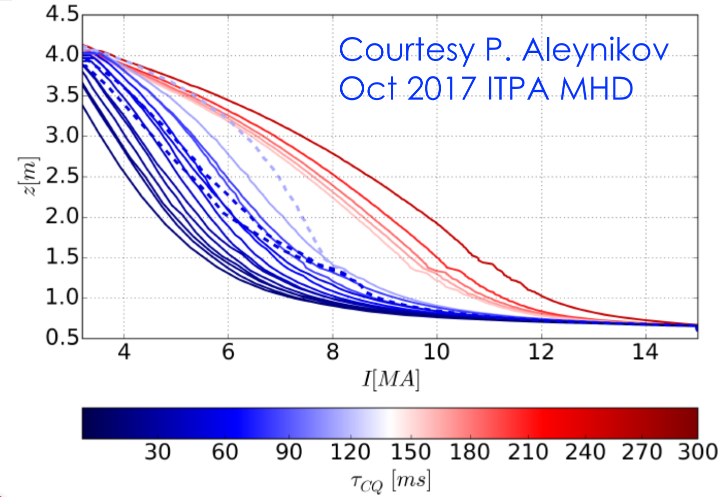
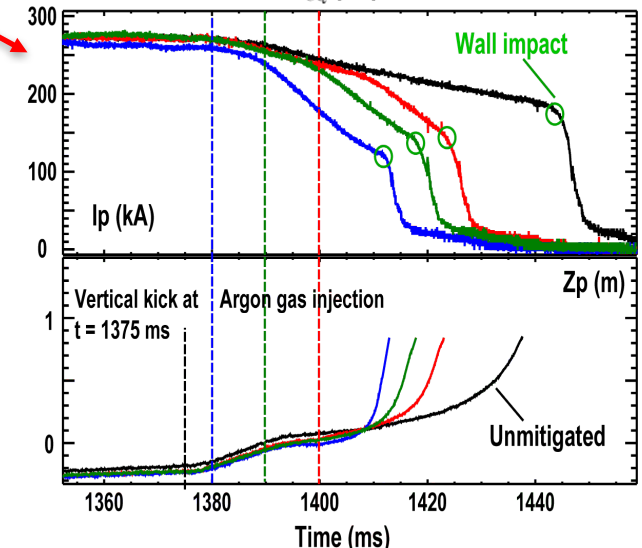


- **DIII-D: Faster RE plateau dissipation rate → Lower final loss current**



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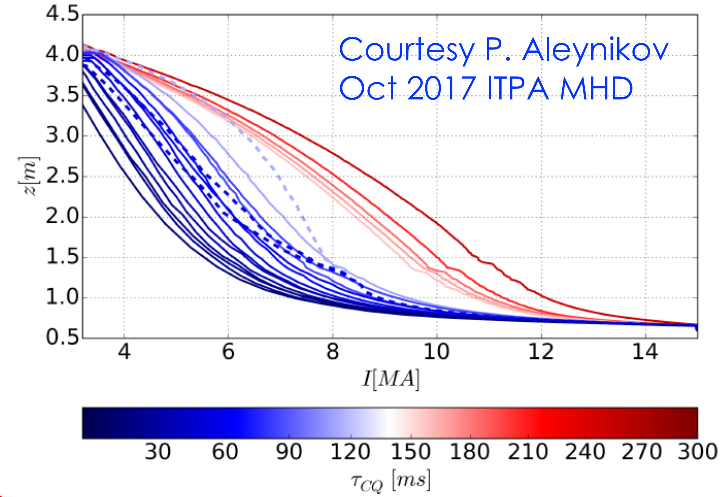
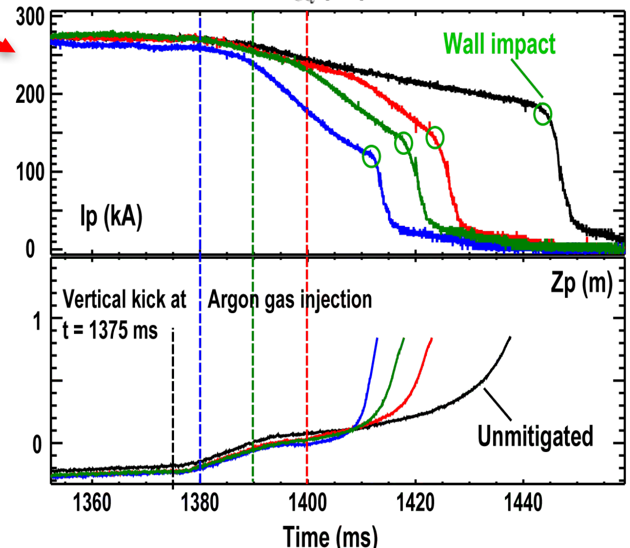


- **DIII-D: Faster RE plateau dissipation rate → Lower final loss current**

- **Modeling effort underway to understand discrepancy**



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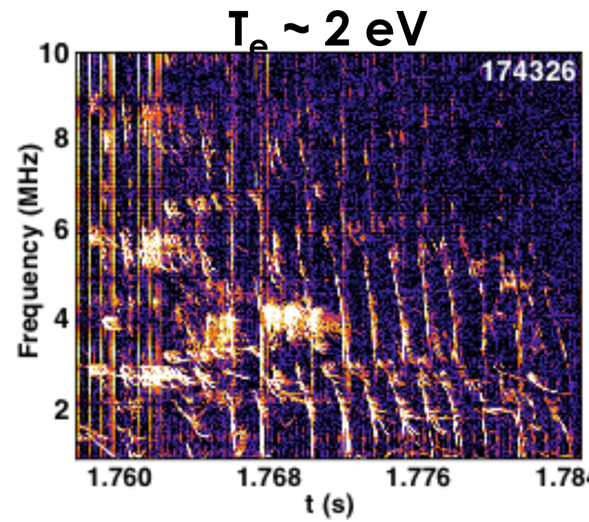
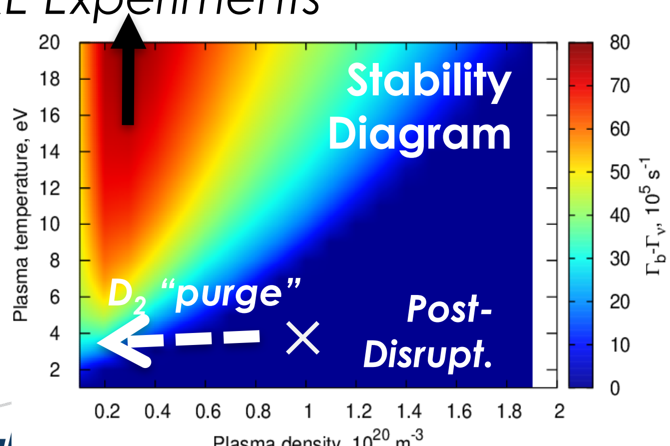
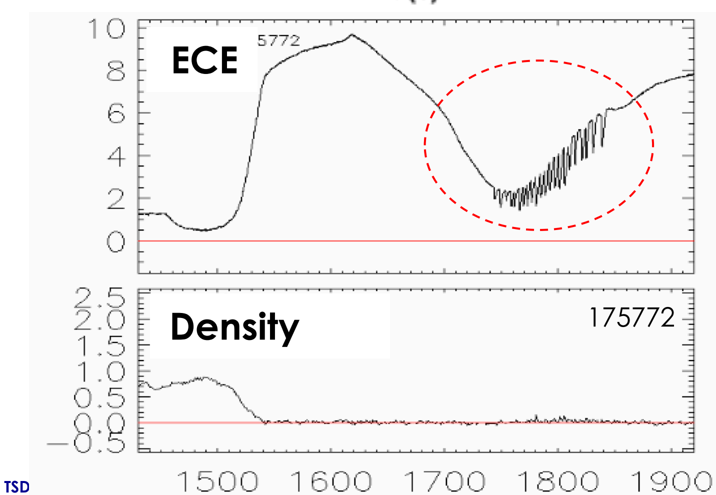
Recently excited kinetic instabilities in few eV RE RE plateau plasmas by reducing ne and changing f(e)

- **Instability Needs Collisionless Plasma**
  - Low Density or High T_e
- **QRE experiments met this condition**
  - Thermal T_e is several keV
- **Post-disruption ne can be reduced**
  - Essential to see instabilities
  - Loop voltage modification important



QRE Experiments





NW Eidietis/2018 TSD

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- Establish physics and limitations of shattered pellet injection (SPI)
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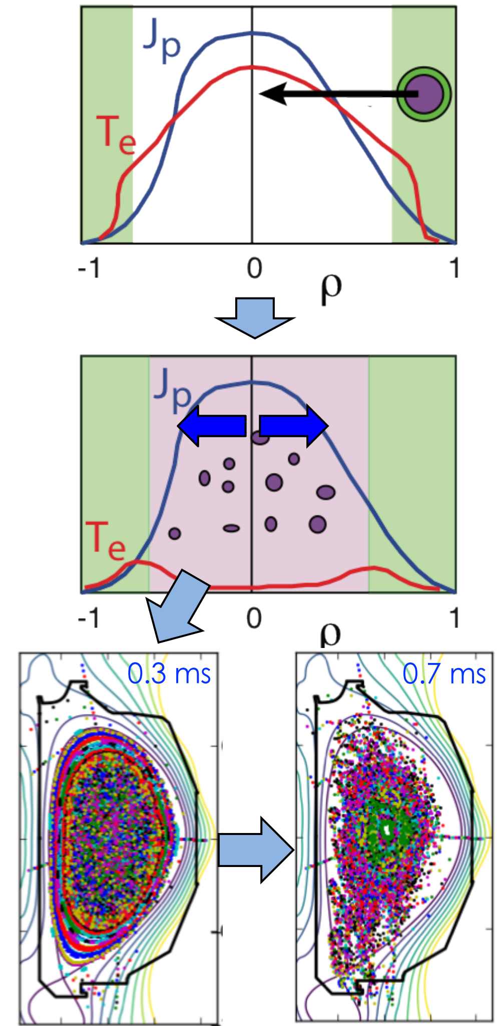
DIII-D developing new shell pellet technology to provide mitigation by core impurity deposition

Concept: Minimally perturbative shell transports radiating payload to core before ablating, releasing payload, & inducing TQ



Izzo & Parks, PoP 2017

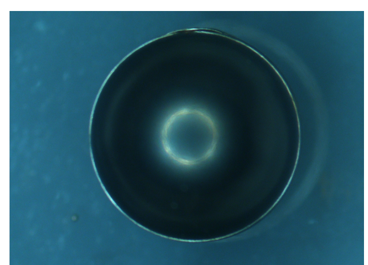
Potential Benefits:

TQ: "Inside-out" TQ mitigation → high radiated fraction

CQ: Low-Z dust produces moderate CQ rate

RE: Field stochastization & high n_e suppress RE seed

X-ray image of
3.6mm diameter
40μm thick
B filled diamond shell



Imaging indicates deep penetration of pellet before dust payload released

30 mg B dust payload
Velocity ~ 230 m/s

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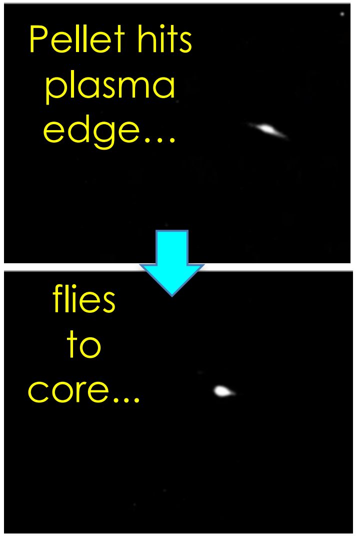

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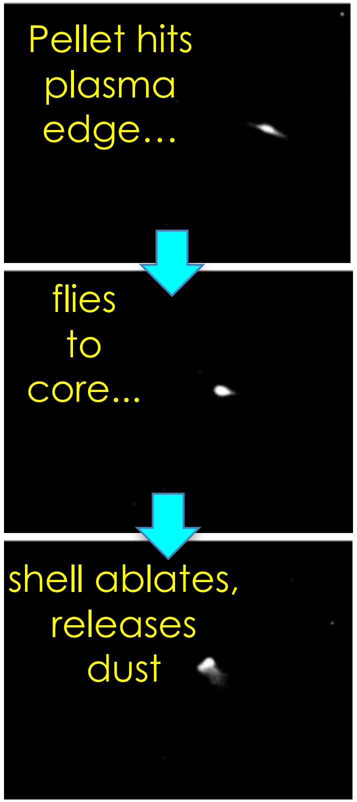

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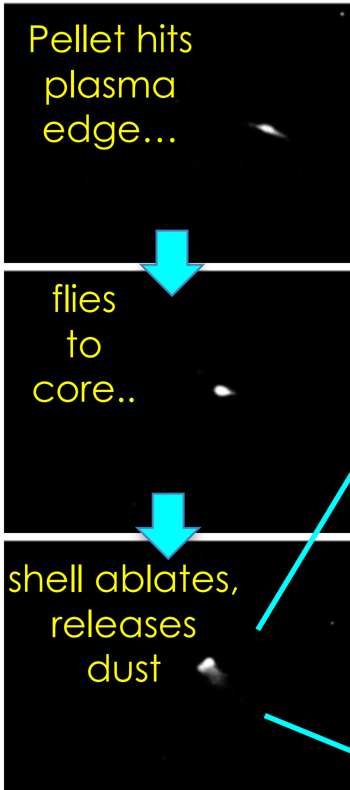
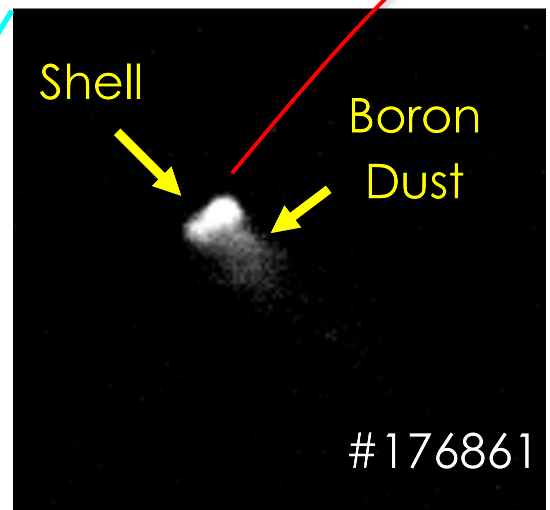
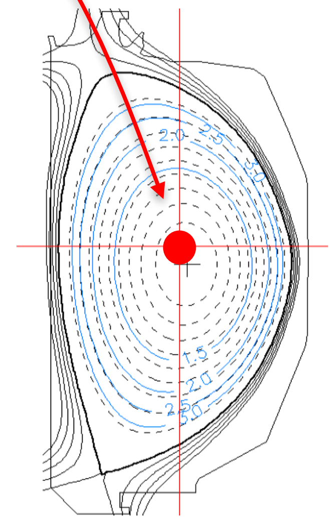




Courtesy R. Moyer, UCSD



Location consistent with prediction of 1-D shell penetration model

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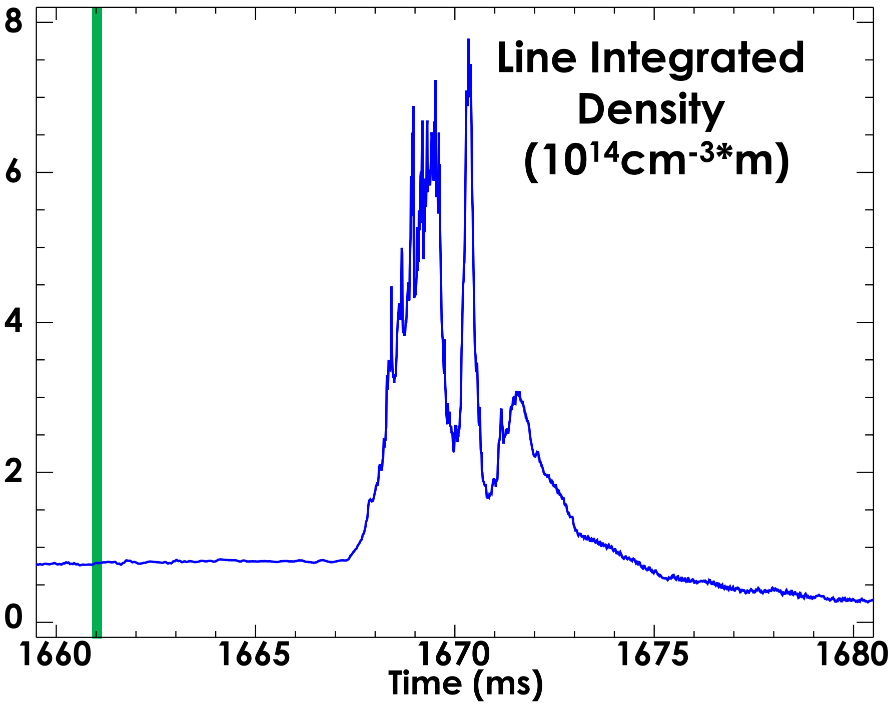
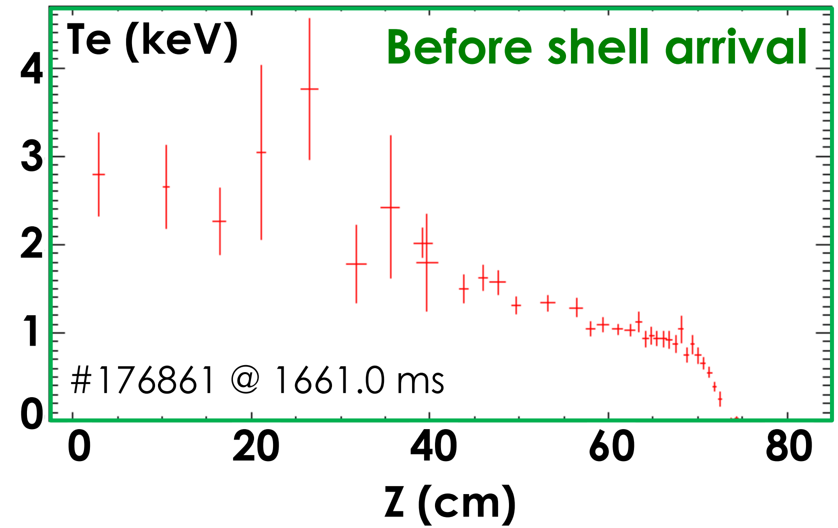
Limited evidence of shell producing inverted temperature profile ("inside-out mitigation")





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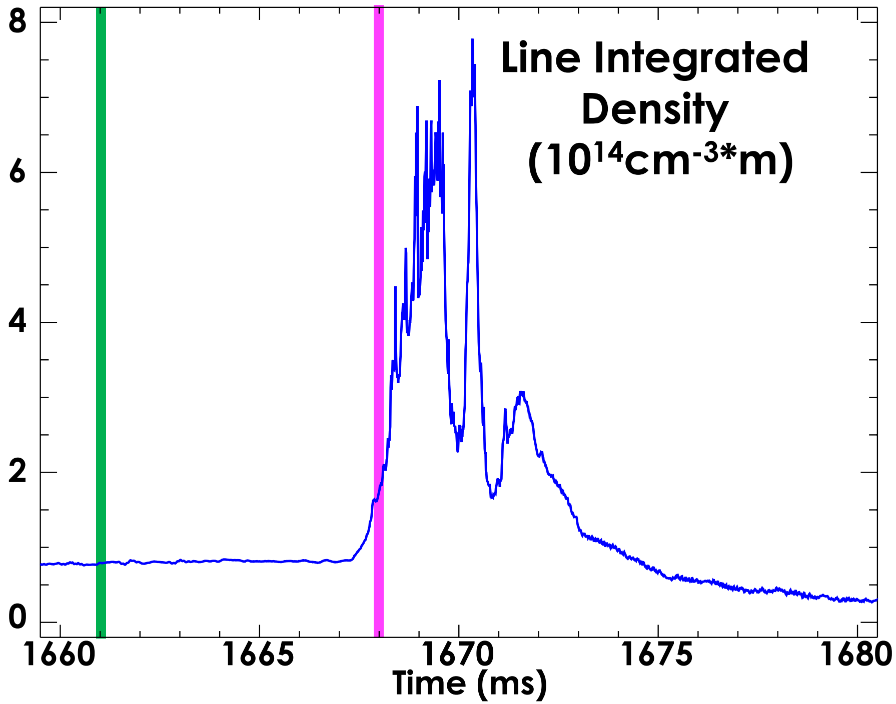

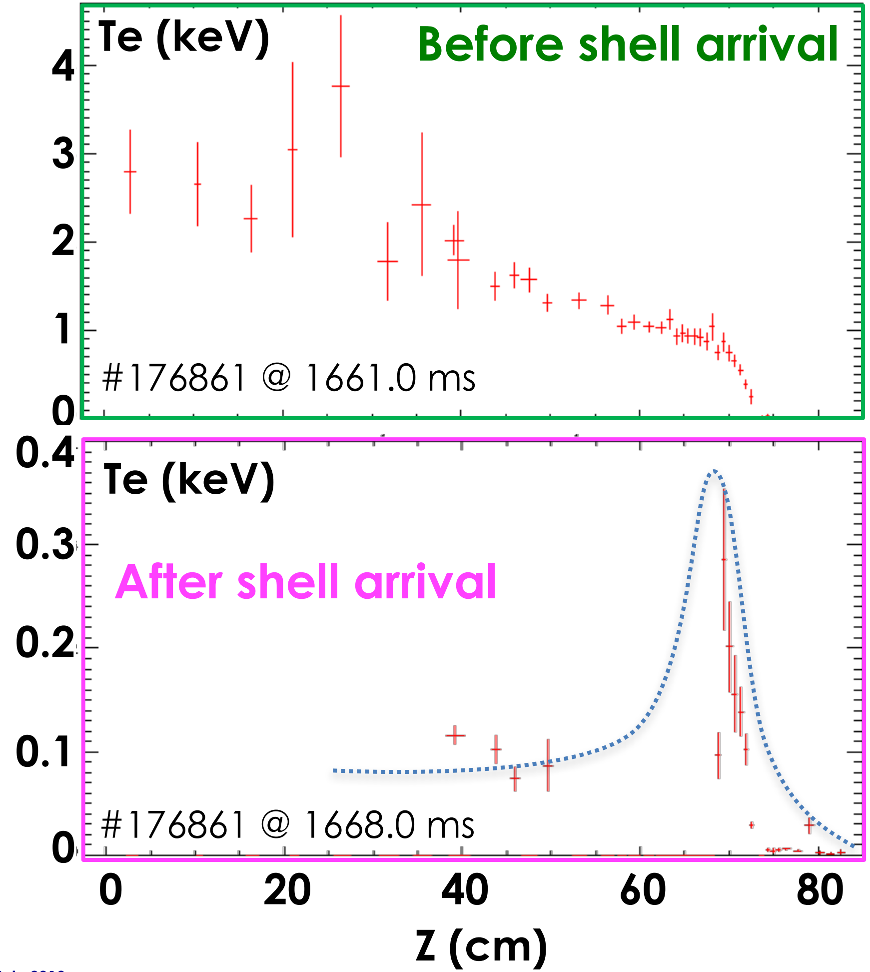

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DIII-D maintains a broad-based disruption mitigation program providing critical knowledge for the ITER DMS

- **Qualifying SPI for use as the baseline ITER DMS technology**
- **Understanding the physics of RE formation and dissipation**
- **Exploring innovative paths for improving DMS technology**

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