# The Role of MHD in 3D Aspects of Massive Gas Injection

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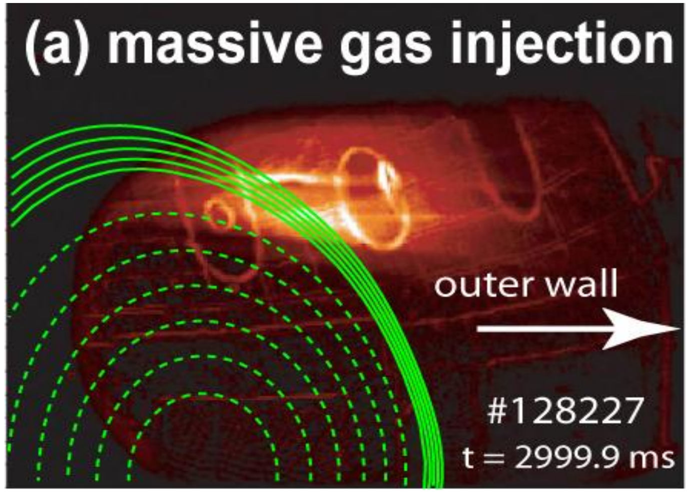
# Massive Gas Injection is a leading candidate for disruption mitigation on ITER

**In the event that a disruption is unavoidable, the goal of massive gas injection (MGI) shutdown is to radiate plasma stored energy in order to:**




1) **Avoid conduction of large heat loads to the divertor during the thermal quench (TQ), and …**

2) **Appropriately tailor the current quench (CQ) time to avoid large vessel forces**

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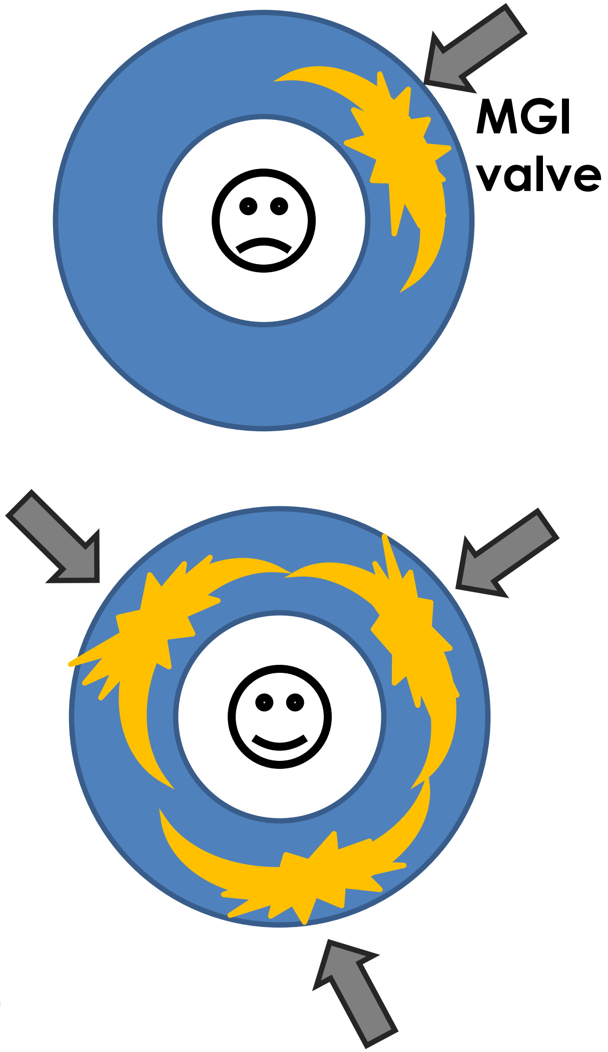
# Goal of massive gas injection is to isotropically radiate plasma stored energy




# of valves & location(s)

↓

Radiation toroidal peaking factor (TPF)

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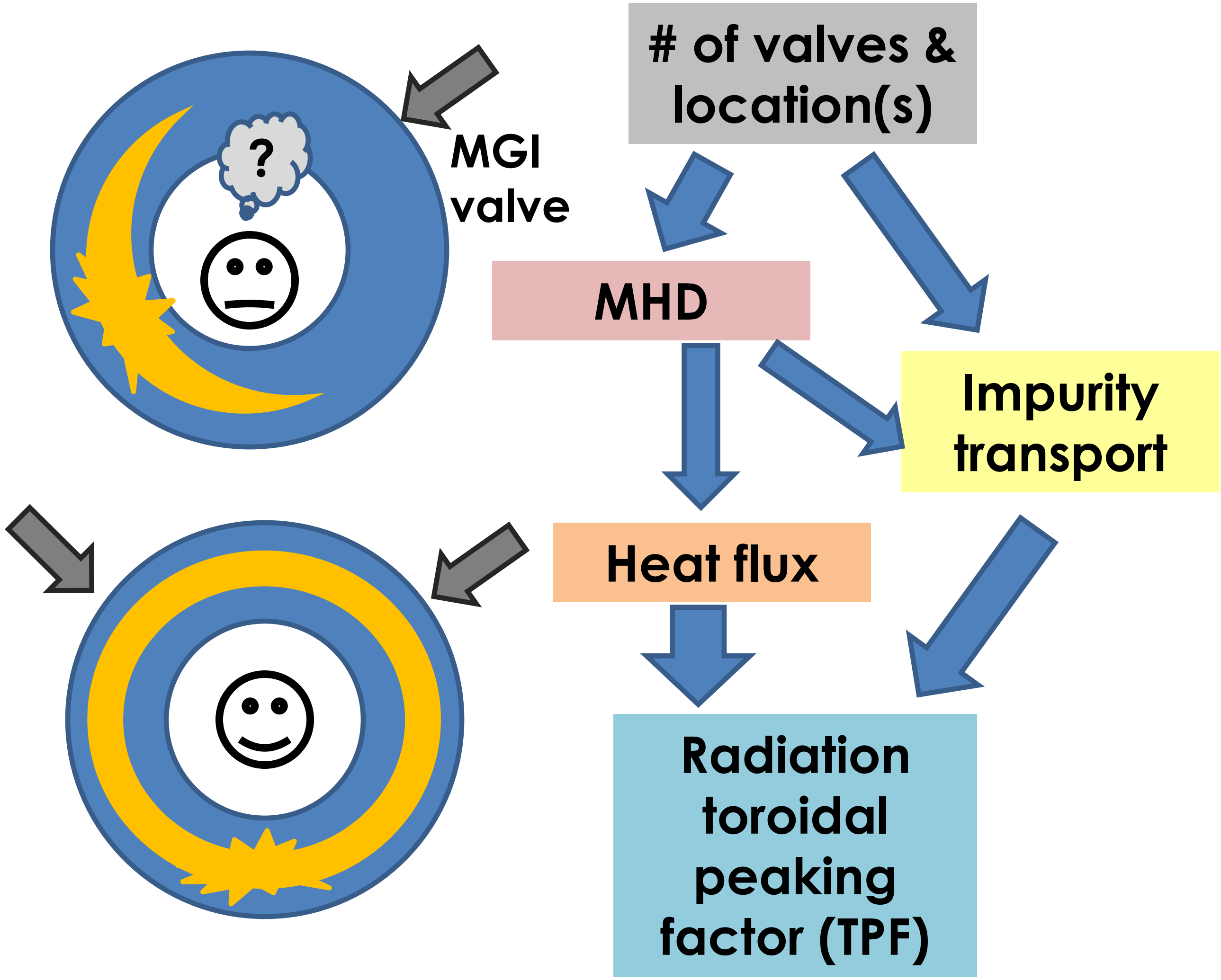
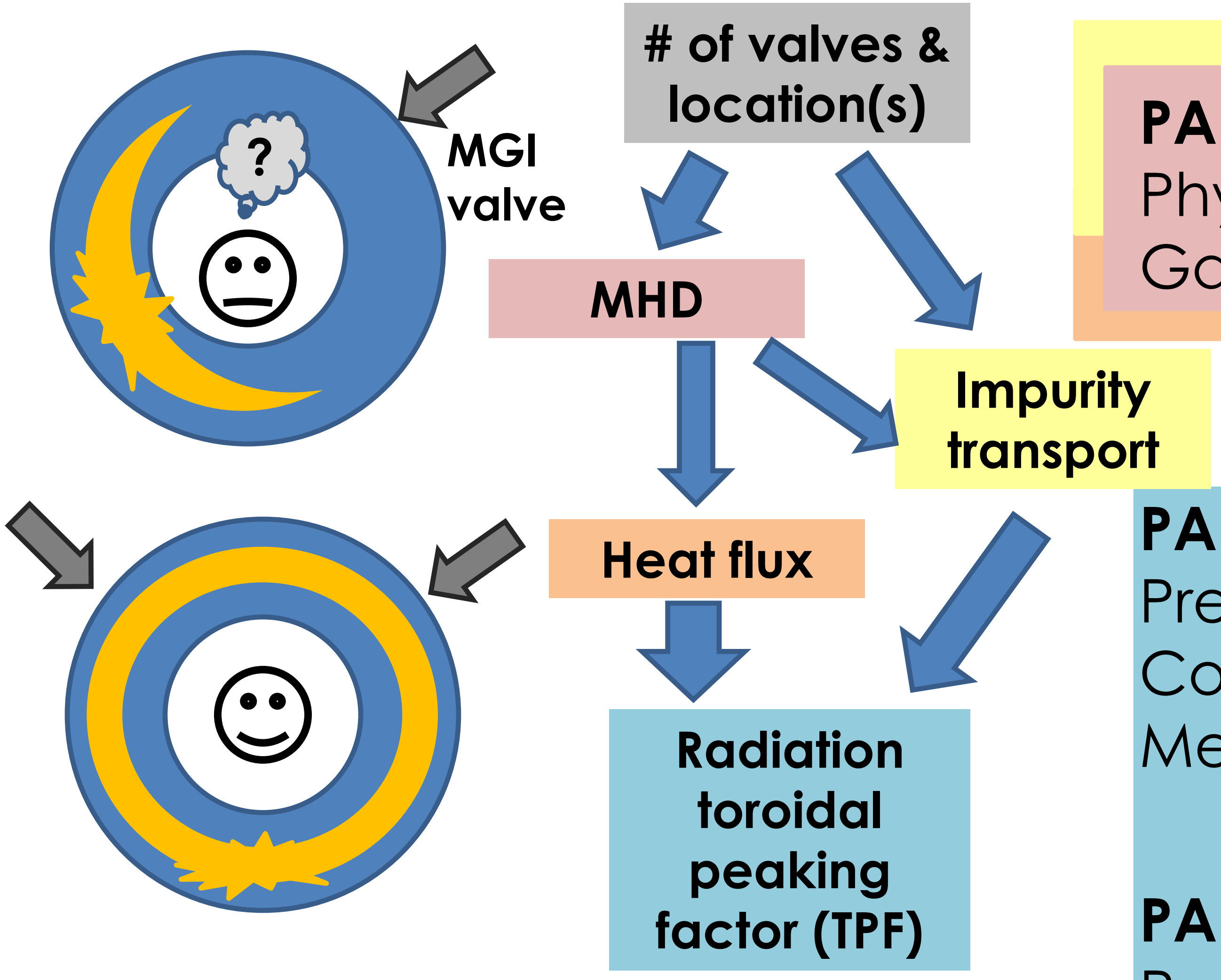
# NIMROD modeling finds a more complicated relationship



# Outline



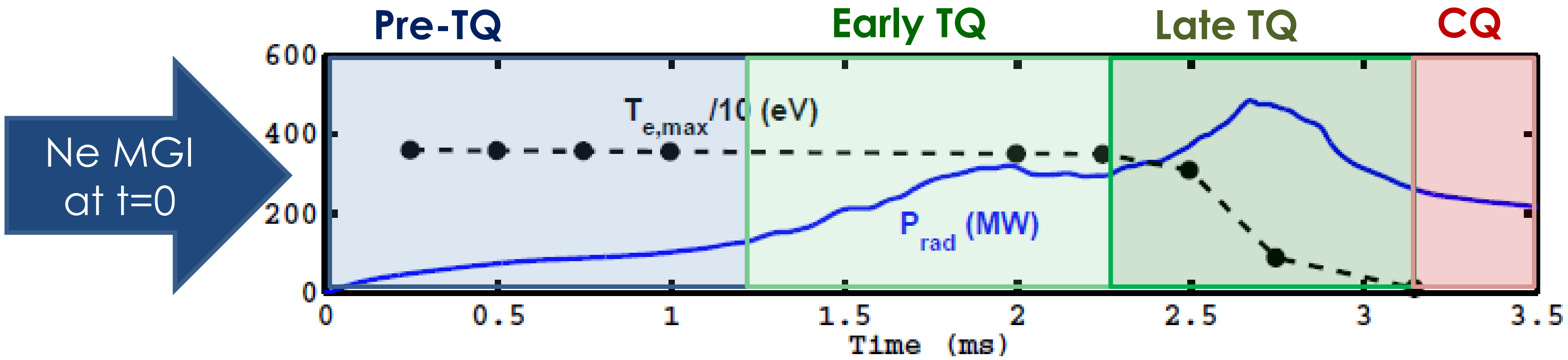

**PART I.** Key 3D Physics of Massive Gas Injection

**PART II.** DIII-D TPF Predictions & Comparison with Measurements

**PART III.** ITER TPF Predictions

# PART I. Key 3D Physics of Massive Gas Injection

## NIMROD 4-stage MGI shutdown

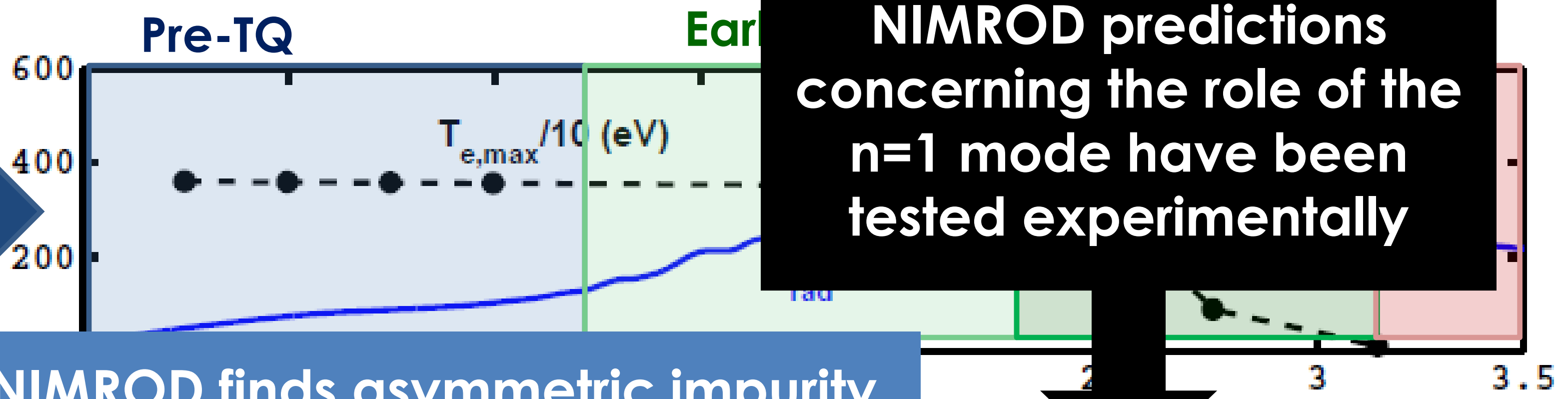



| | | | |
|---|---|---|---|
| **MHD** | None | m/n >1 | m=1/n=1 |
| **Particle Transport** | Ne plume expansion \|\| to B | | Radial mixing |
| **Heat Transport** | Slow ⊥ conduction | Fast \|\| $\delta B_r$ conduction | $V\cdot\nabla T$ convection |

# PART I. Key 3D Physics of Massive Gas Injection

## NIMROD 4-stage MGI shutdown

Ne MGI at t=0




NIMROD predictions concerning the role of the n=1 mode have been tested experimentally

NIMROD finds asymmetric impurity spreading for off-midplane injection

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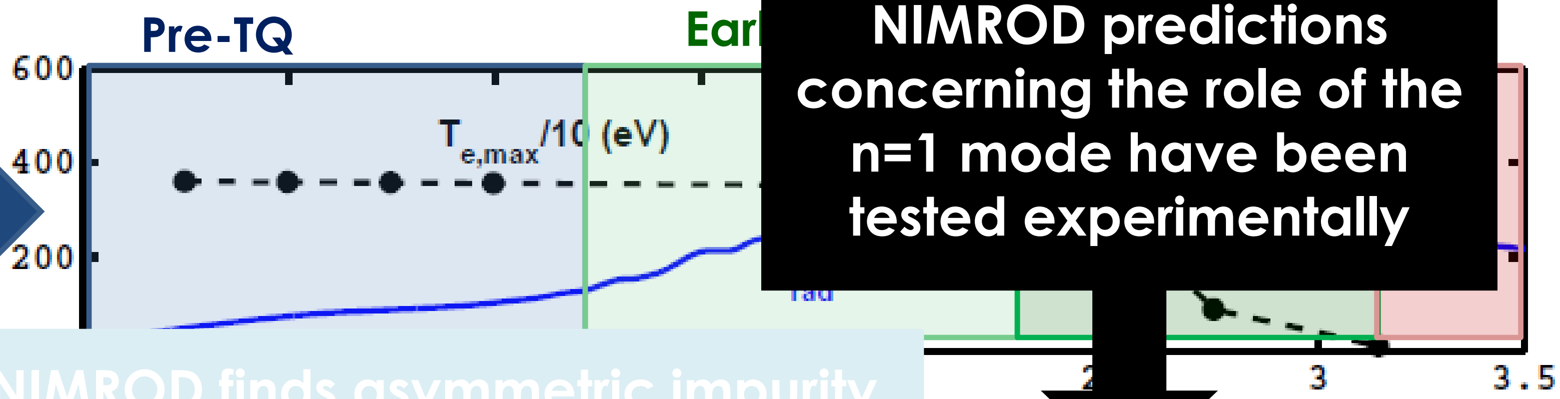
NIMROD multi-valve MGI simulations reveal implications of both effects for optimum valve positioning

# PART I. Key 3D Physics of Massive Gas Injection

## NIMROD 4-stag

Ne MGI at t=0

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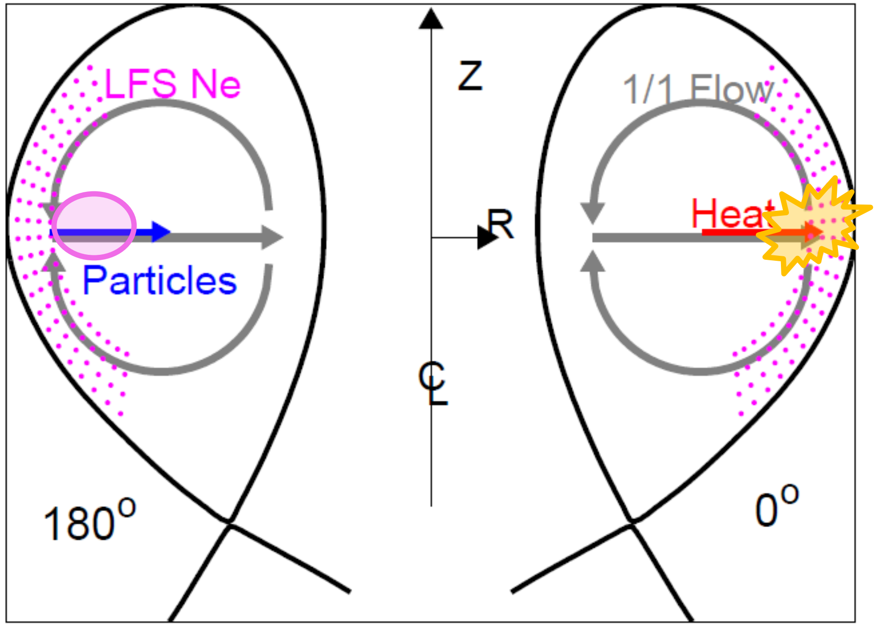
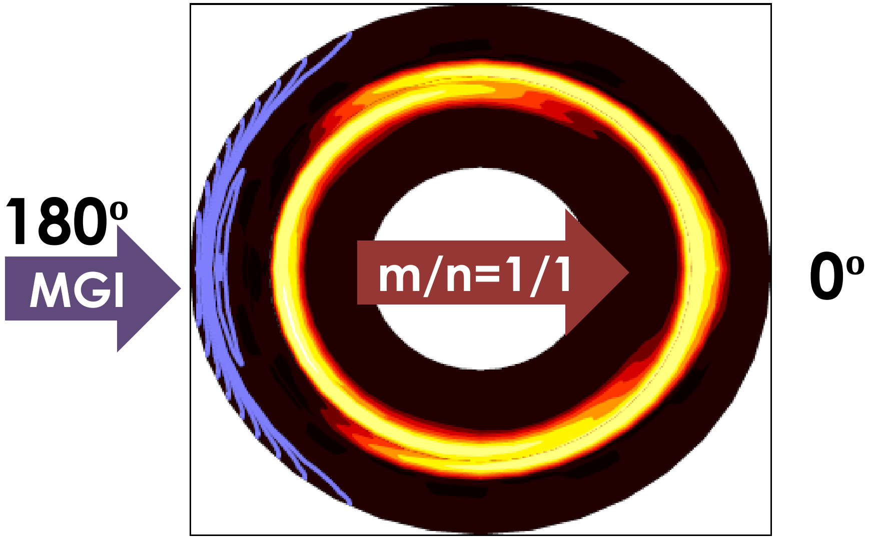
# NIMROD simulations produced two predictions regarding the role of the 1/1 in an MGI TQ*



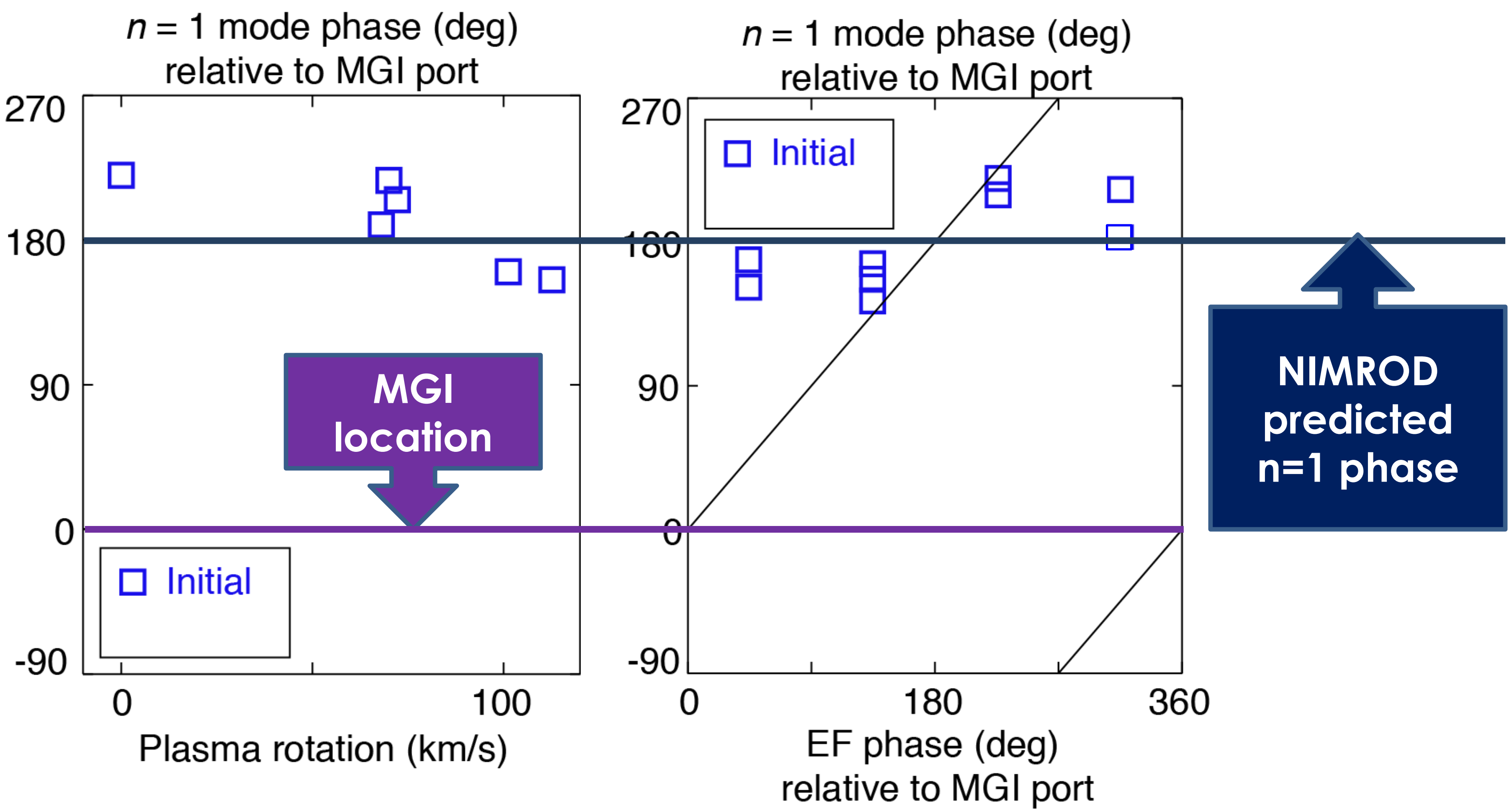

1) 1/1 phase determines location of toroidal radiation peaking due to asymmetric convected heat flux

2) Absent other asymmetries, 1/1 phase is anti-aligned with gas jet

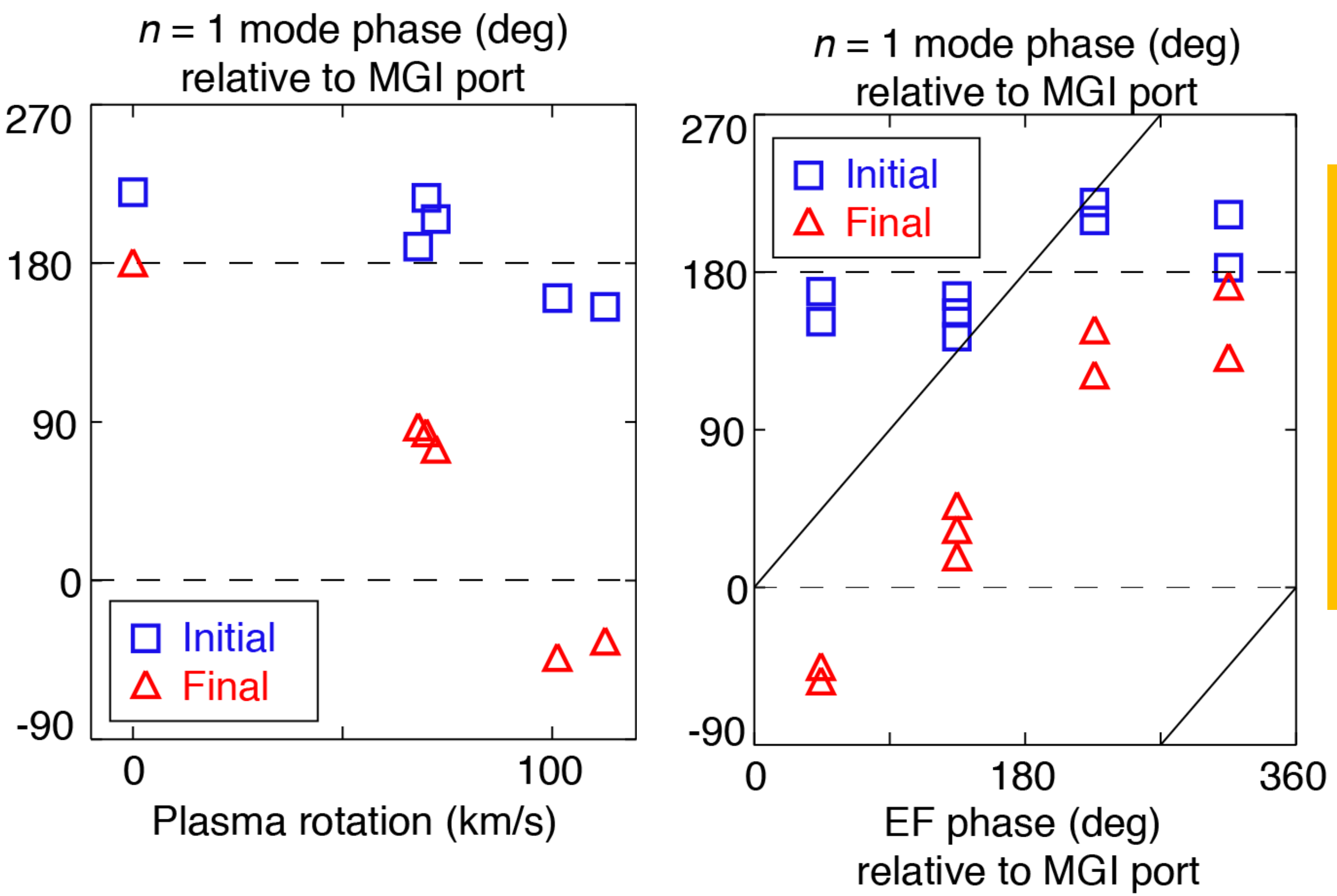



*IZZO, V.A., Phys. Plasmas **20** (2013) 056107.

# DIII-D experiments: Initial n=1 phase corresponds to NIMROD prediction



# DIII-D experiments: n=1 phase at TQ influenced by rotation, error fields




**Rotation and error field effects (not in simulations) also determine final mode phase at TQ**

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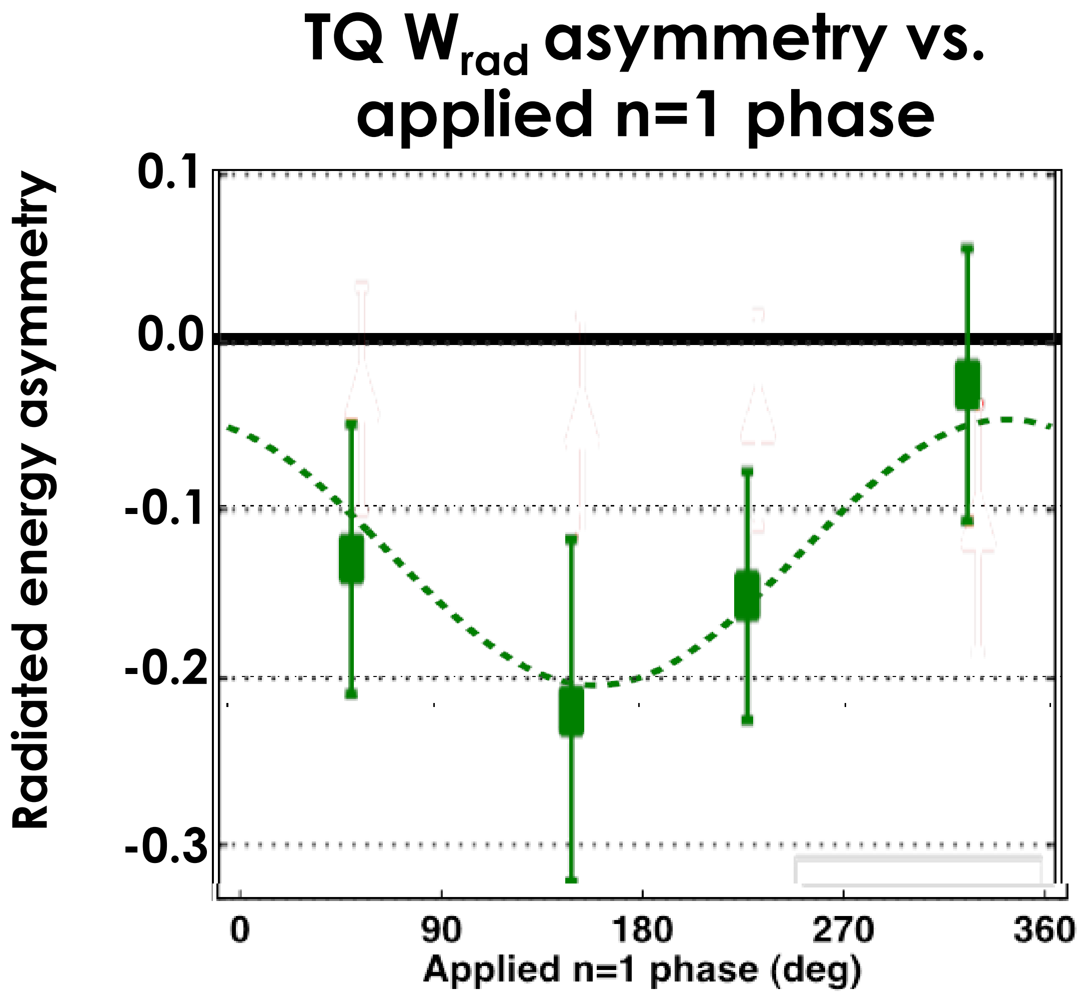
# Experiments verify: the phase of the n=1 mode (relative to the gas jet) affects asymmetry

→ DIII-D experiments: Changing phase of applied n=1 fields changes measured radiation asymmetry during TQ

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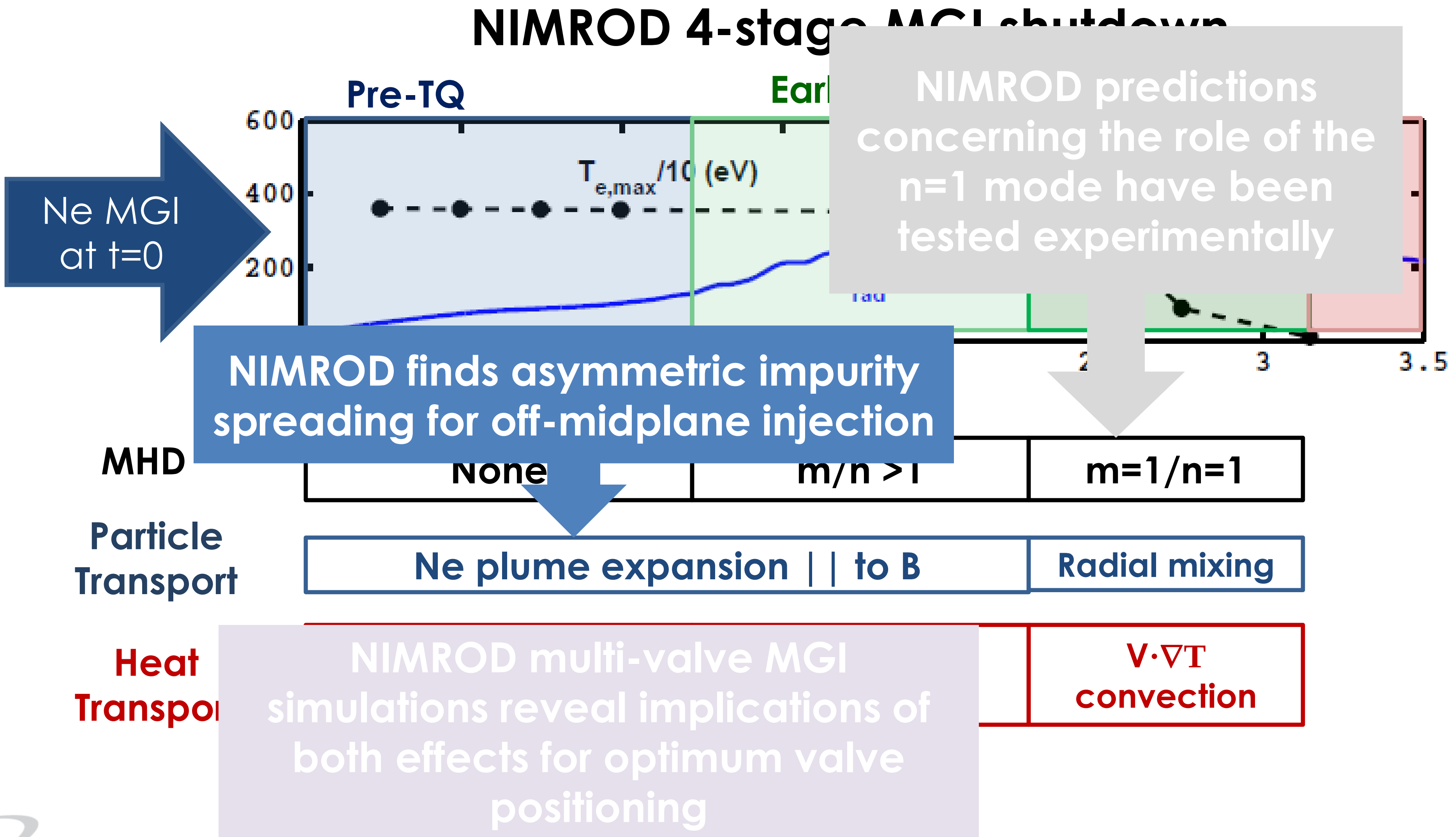
# PART I. Key 3D Physics of Massive Gas Injection

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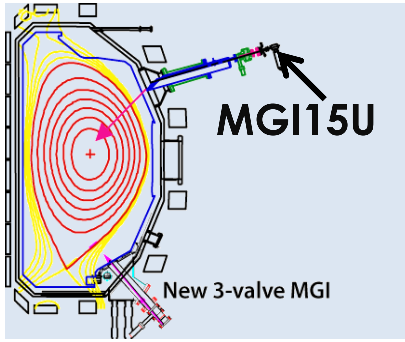
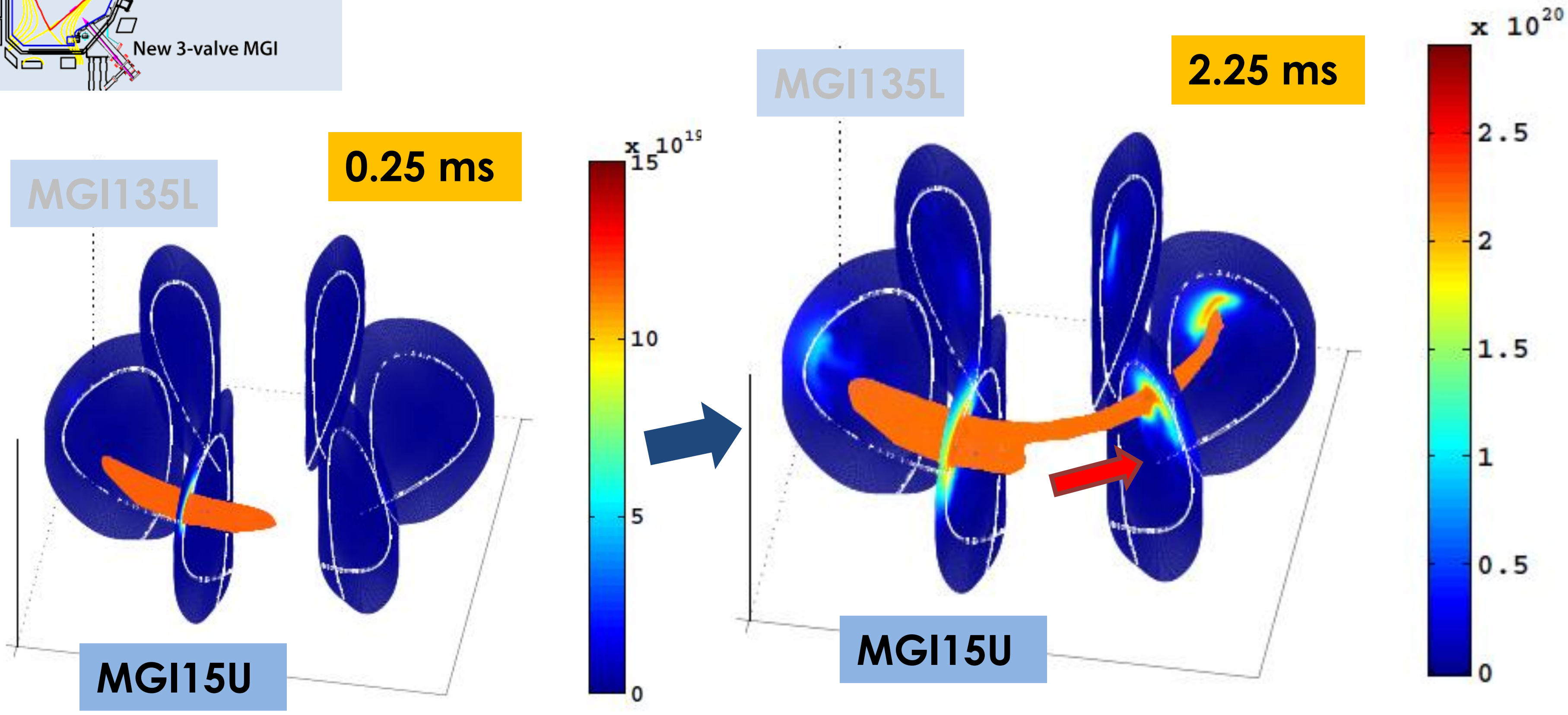
# Injected Ne plume spreads along B-field in one direction toroidally → toward HFS poloidally




Contours/isosurface of ionized Ne density

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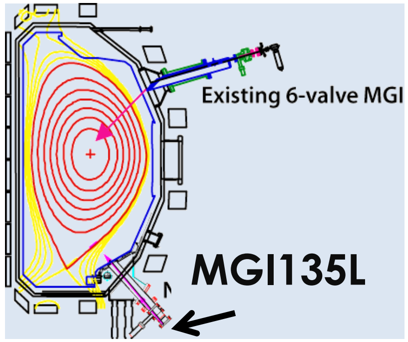
# Below midplane jet spreads in the opposite toroidal direction, also toward HFS

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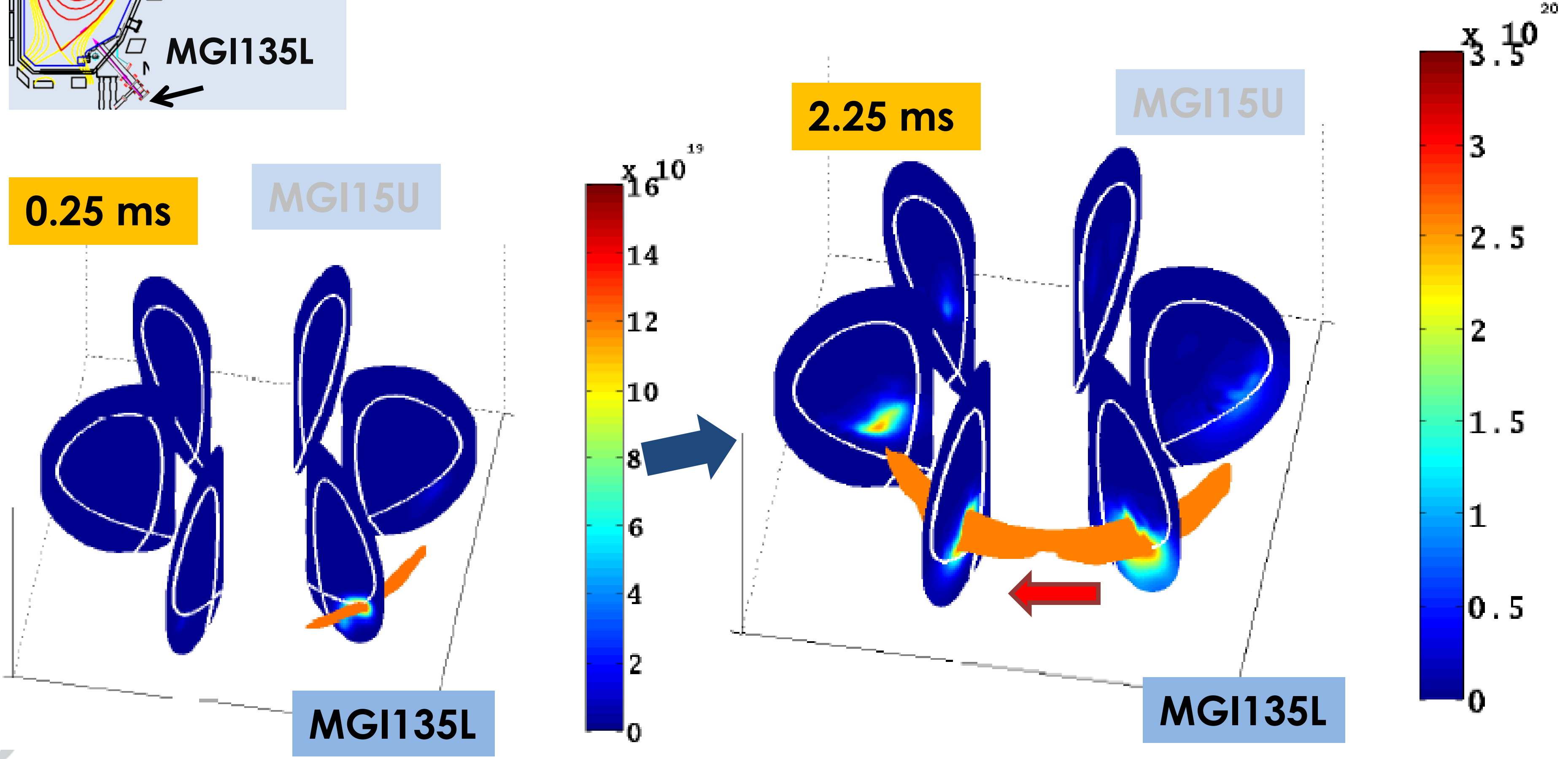


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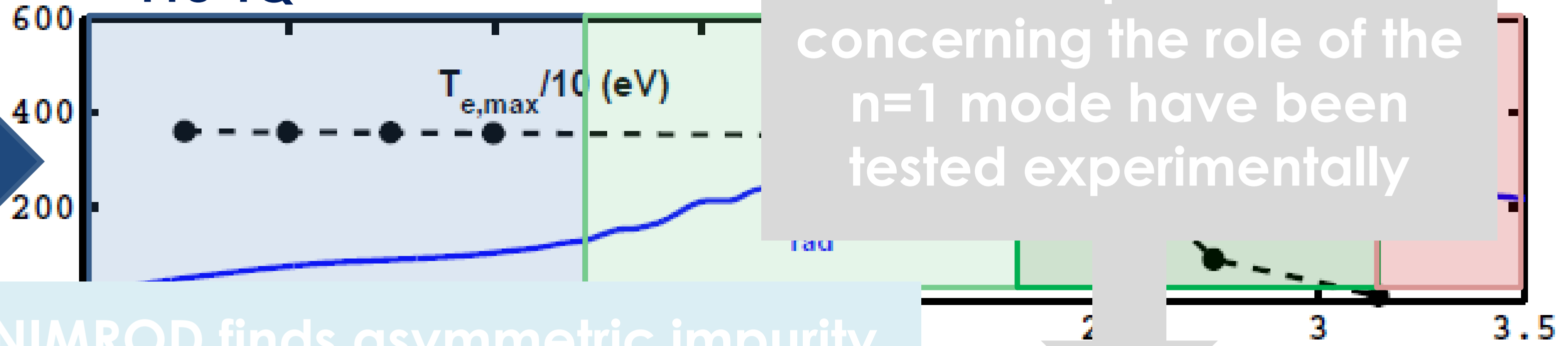
# PART I. Key 3D Physics of Massive Gas Injection

## NIMROD 4-stage MGI shutdown

Ne MGI at t=0

Pre-TQ

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NIMROD finds asymmetric impurity spreading for off-midplane injection

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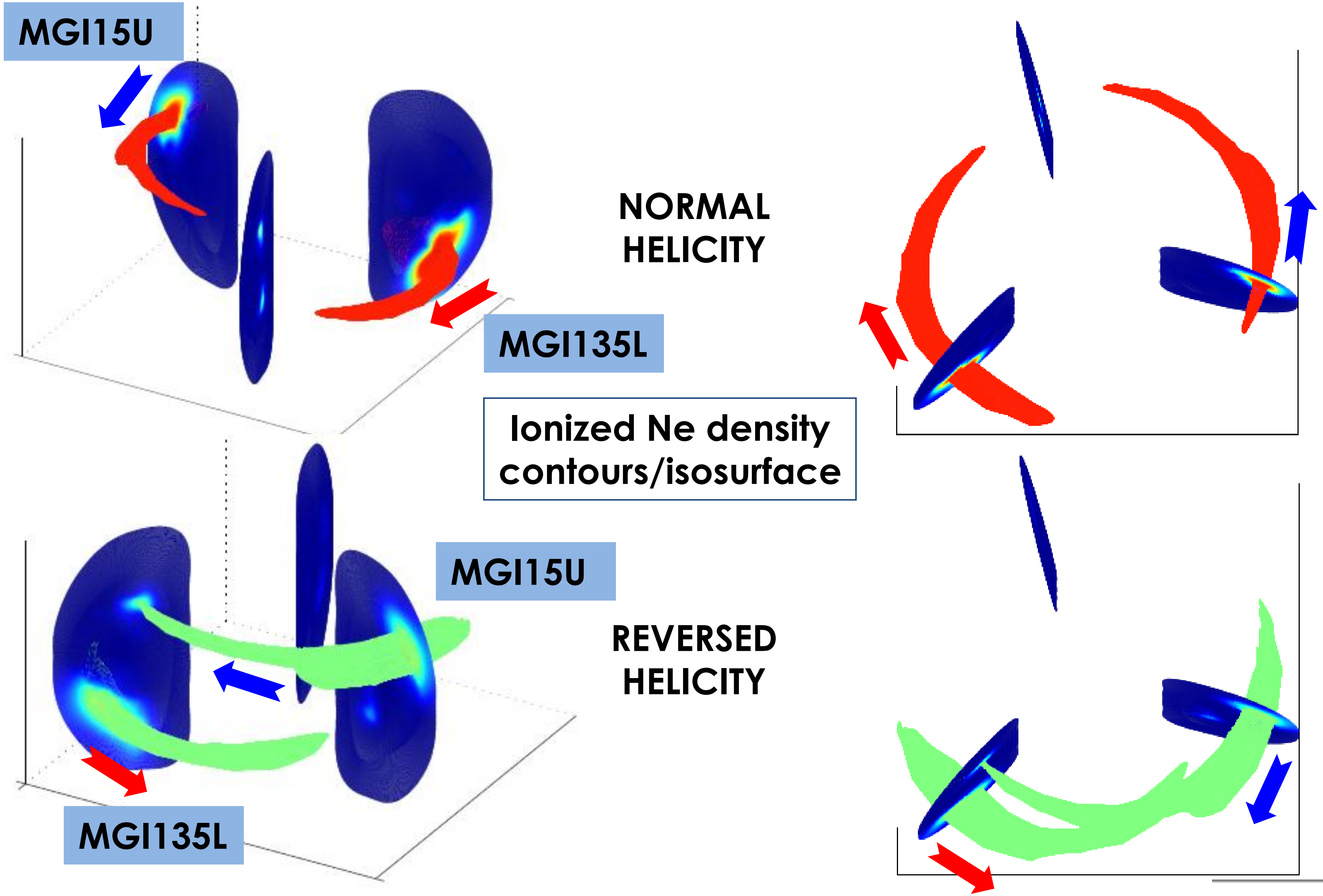
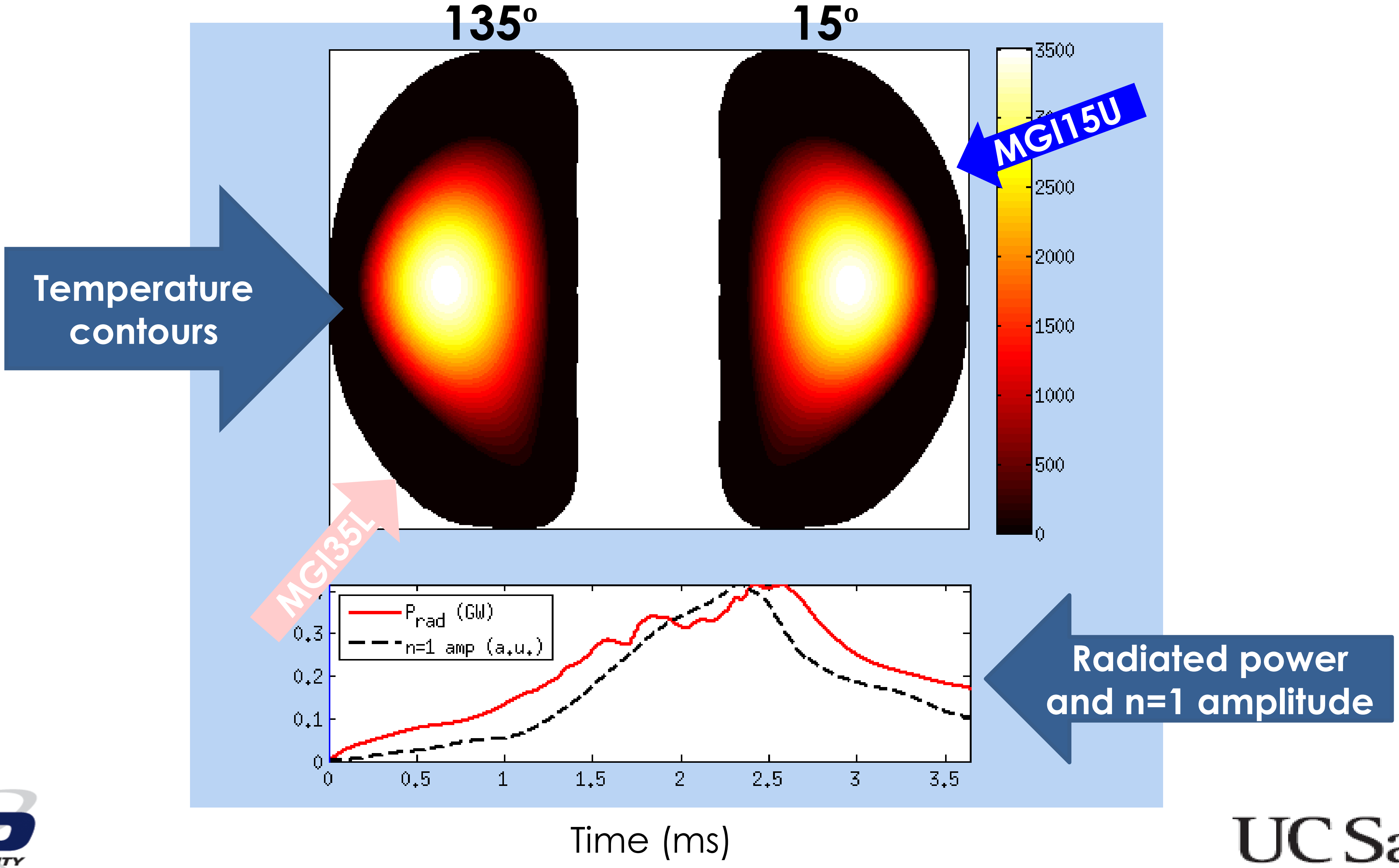
| Heat Transport | | | $V \cdot \nabla T$ convection |

NIMROD multi-valve MGI simulations reveal implications of both effects for optimum valve positioning

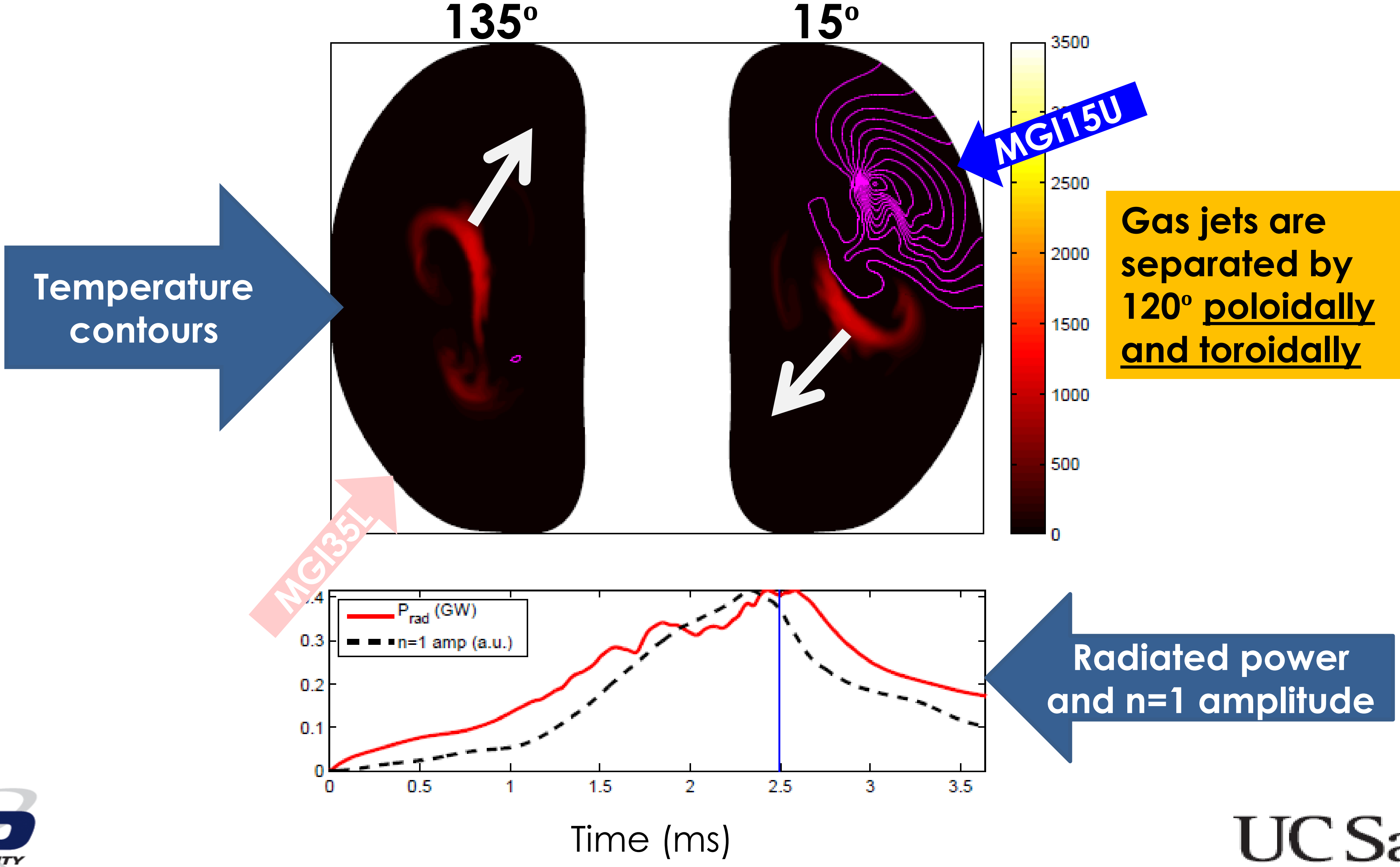
# NIMROD: $I_p$ direction affects direction of impurity spreading



# Relative spacing of gas valves affects interaction with 1/1 mode



# MGI15U and MGI135L will tend to drive the same 1/1 mode phase




Gas jets are separated by 120° poloidally and toroidally

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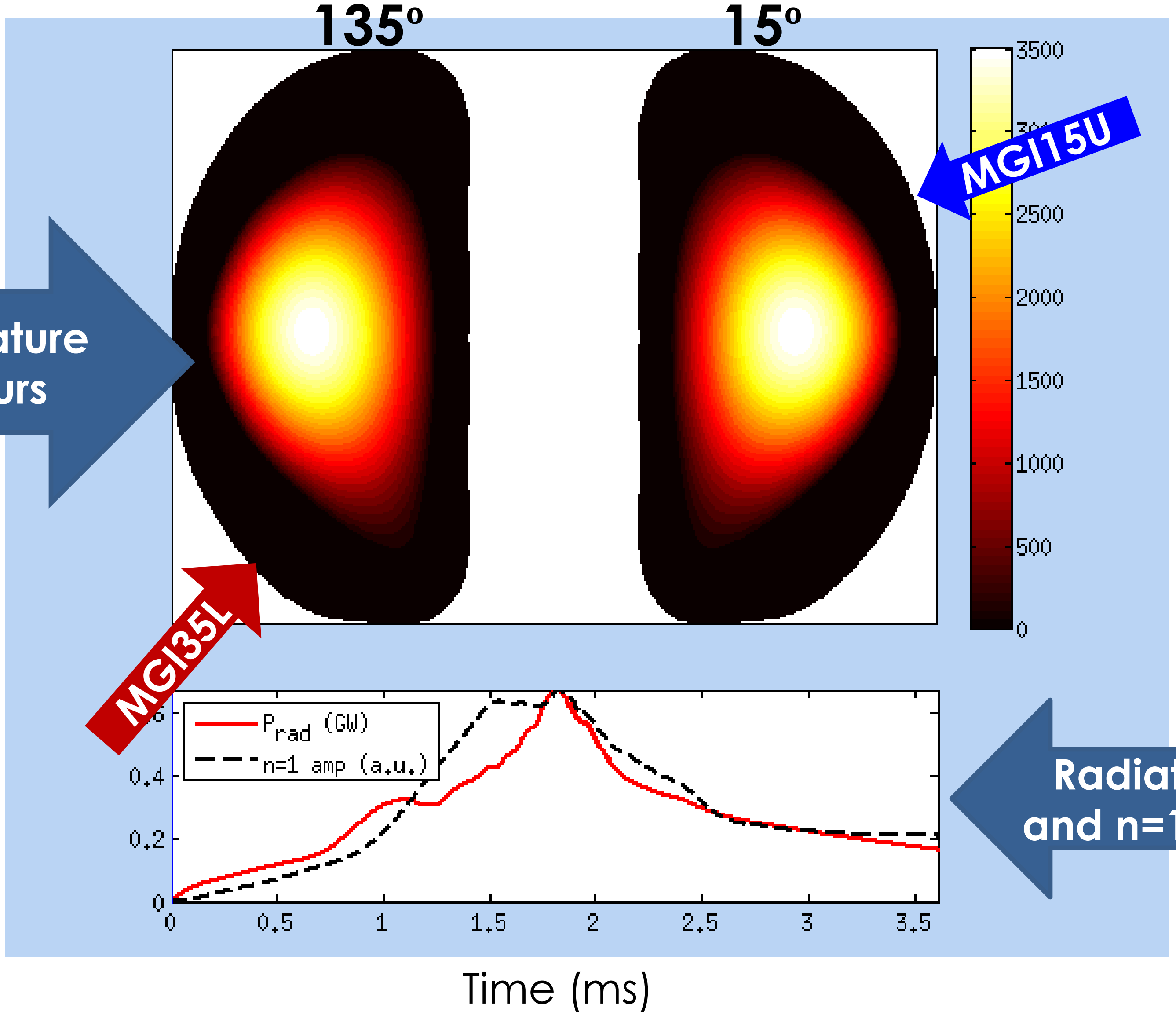
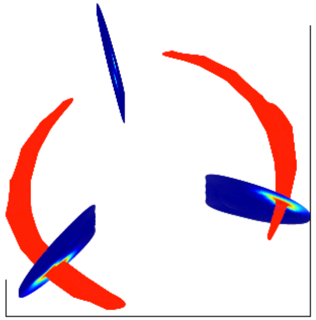
# Simulation with both gas jets drives same mode phase as single jet

Temperature contours

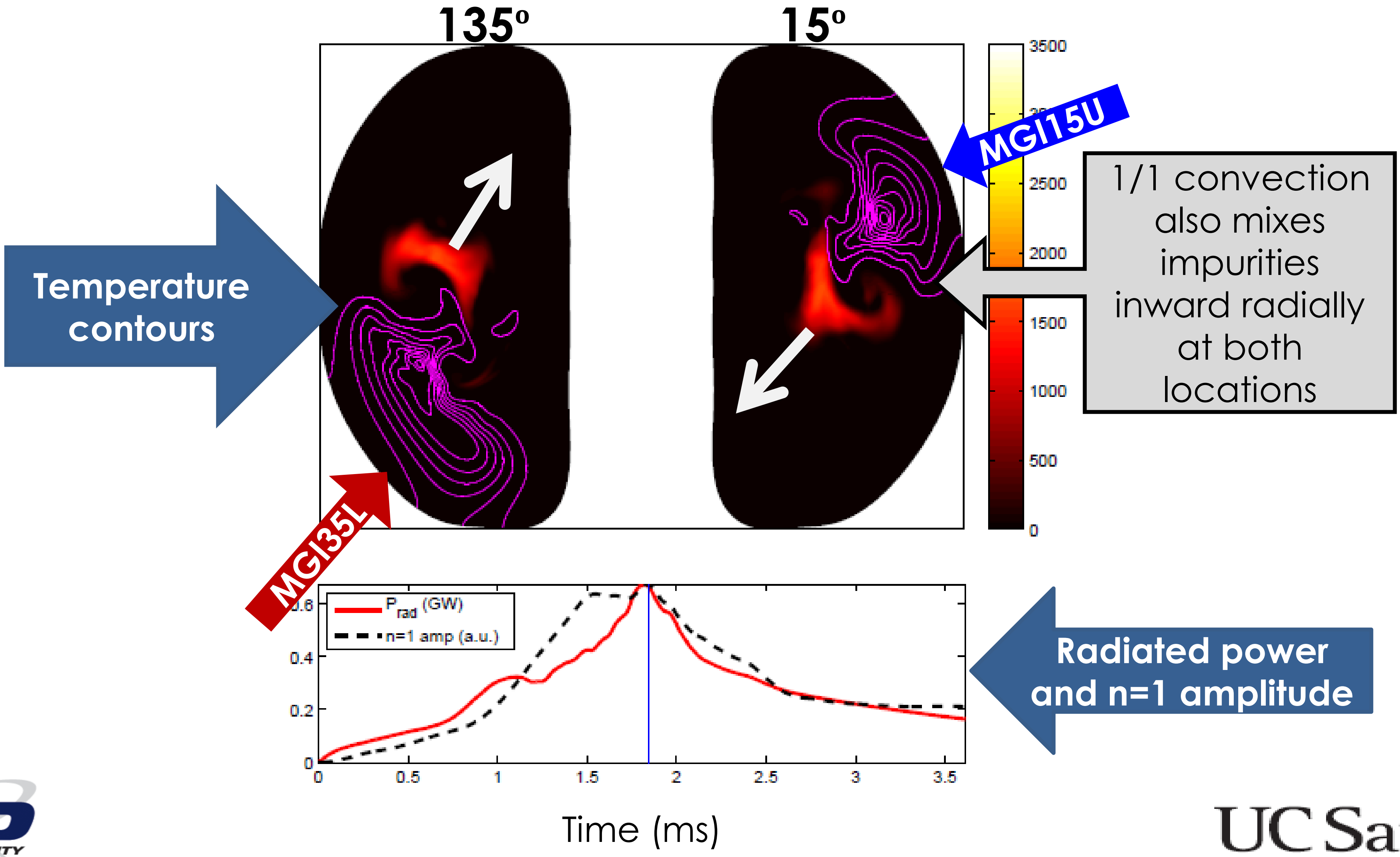



Normal Helicity

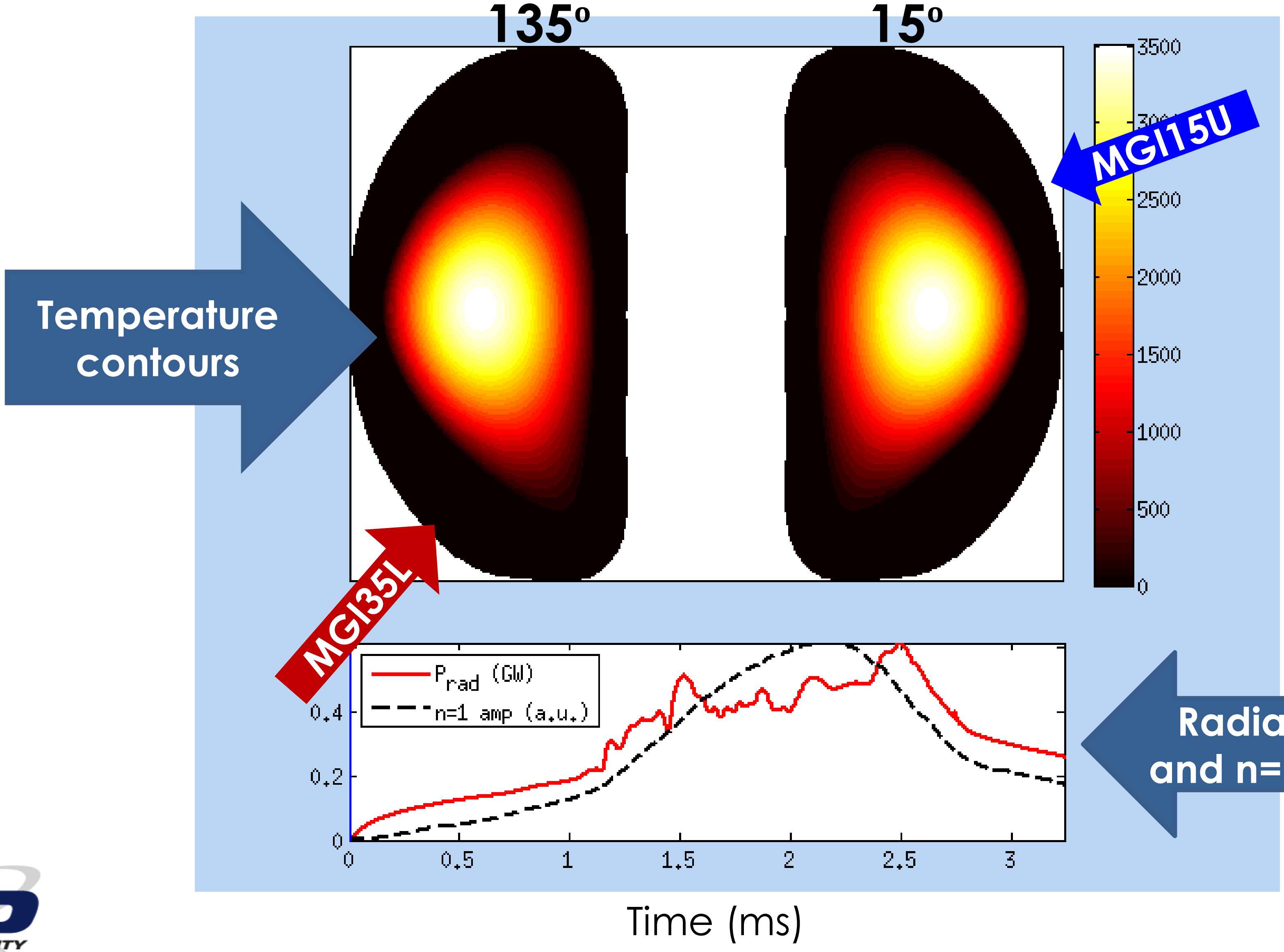


Radiated power and n=1 amplitude

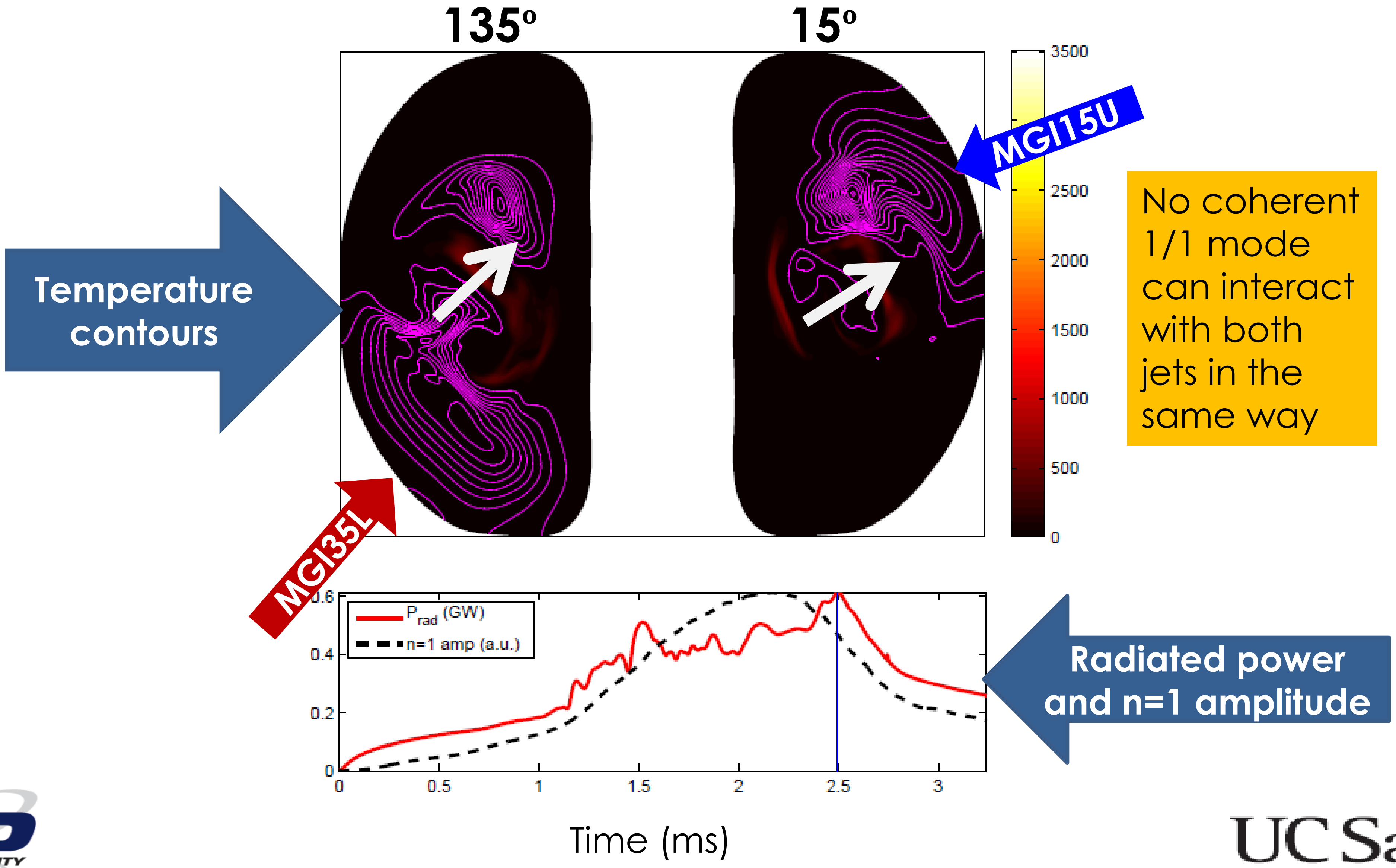
# Heat flux due to 1/1 convection is simultaneously away from both jets



# In reversed helicity, spacing of two jets no longer coheres with 1/1 symmetry




# Interaction of 1/1 mode with each of the two impurity plumes is very different

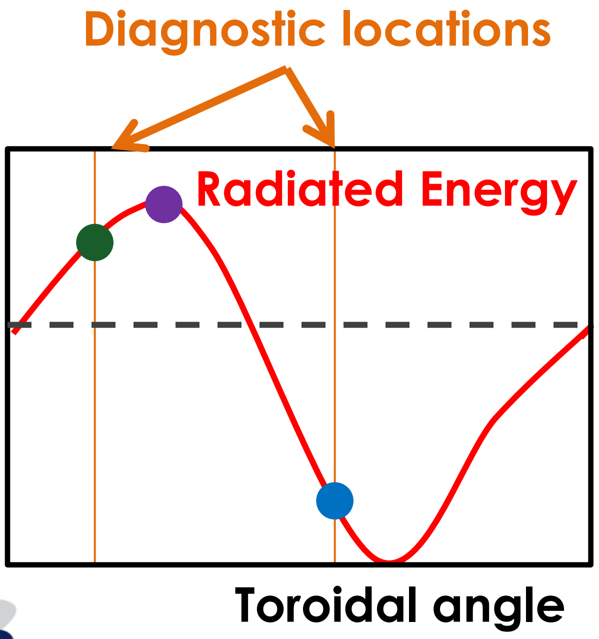


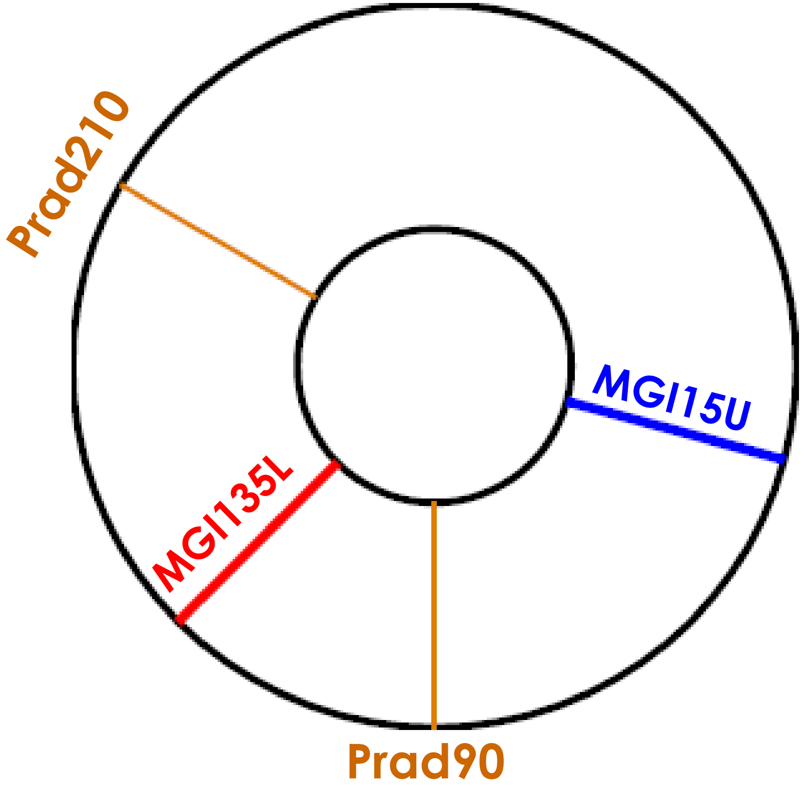

No coherent 1/1 mode can interact with both jets in the same way

# PART II. NIMROD asymmetry predictions and comparison with DIII-D measurements

→ DIII-D has two fast radiated power measurements

→ Both jets are closer to Prad90

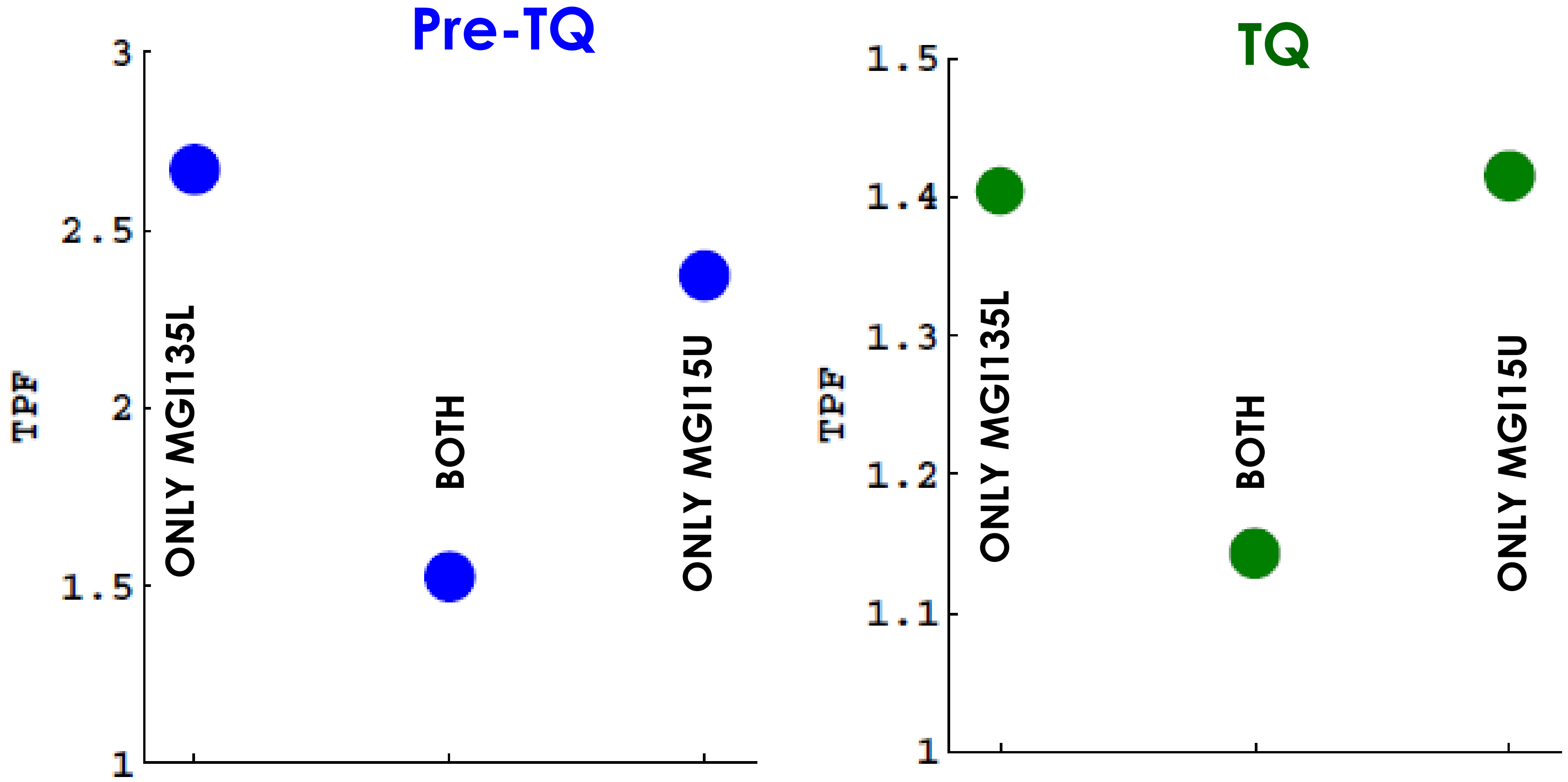



TPF = Max(Wrad)/Mean(Wrad)

Clearly, asymmetry calculated from 2 measurement locations is an approximation…

# NIMROD predicts improved symmetry when both DIII-D jets are used




**All cases in normal helicity**

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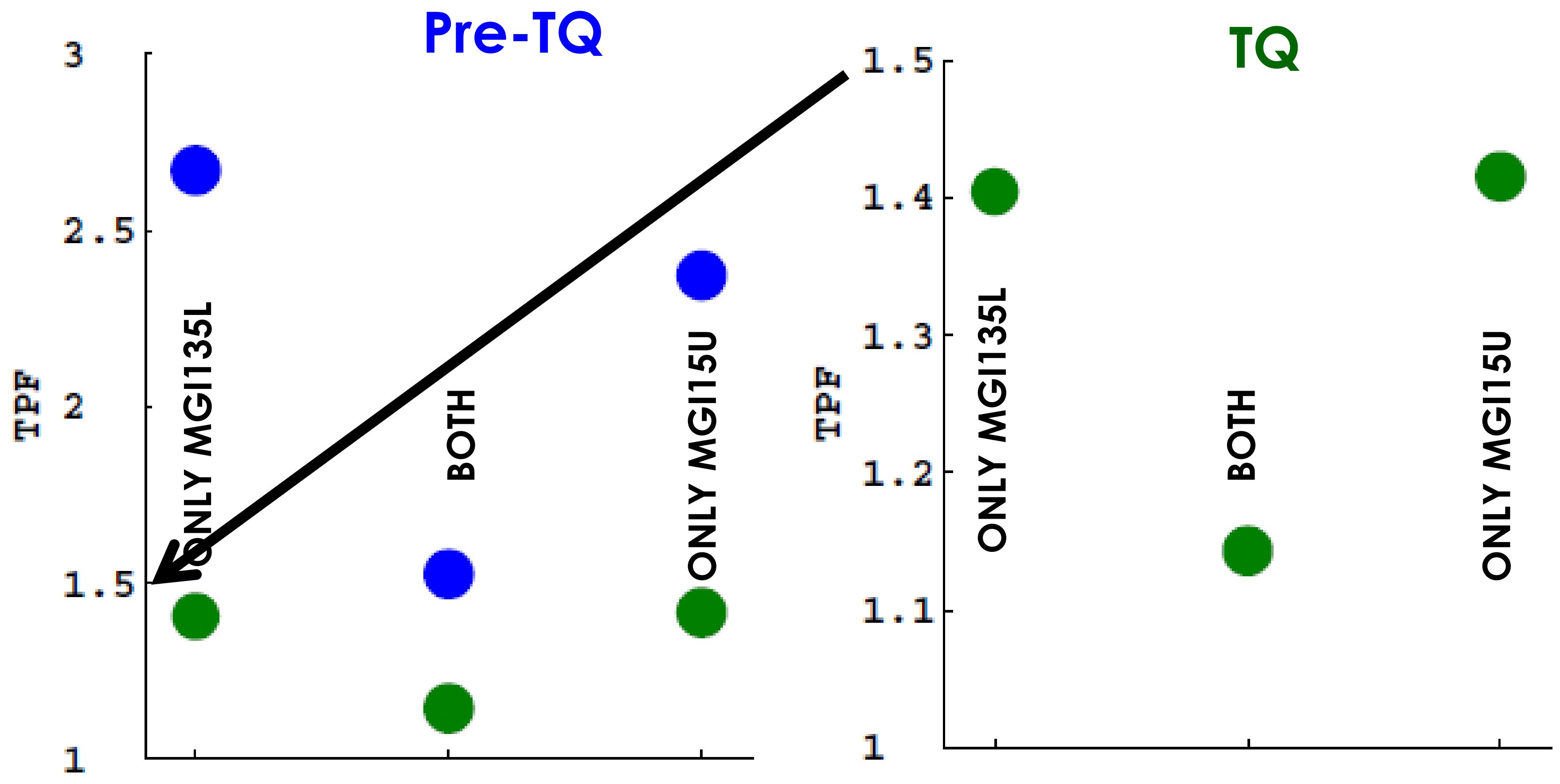
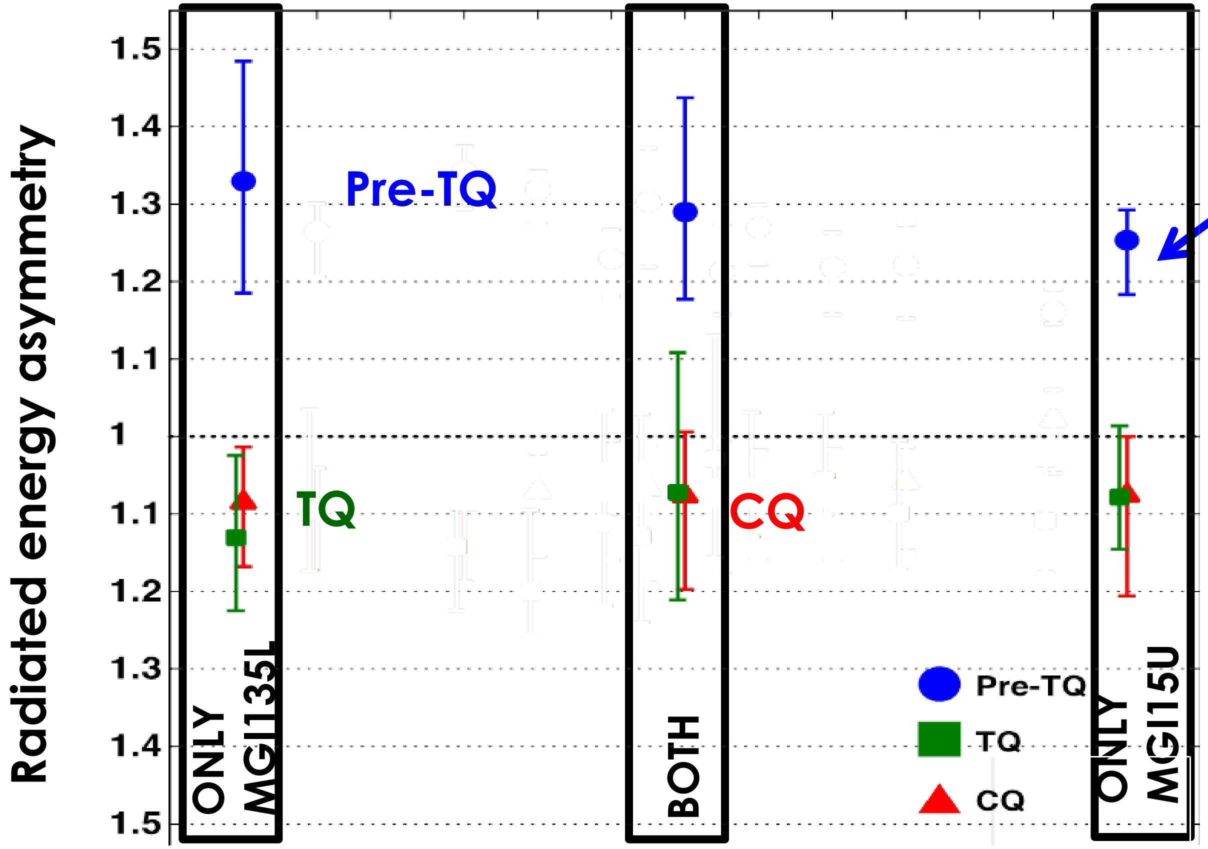



All cases in normal helicity

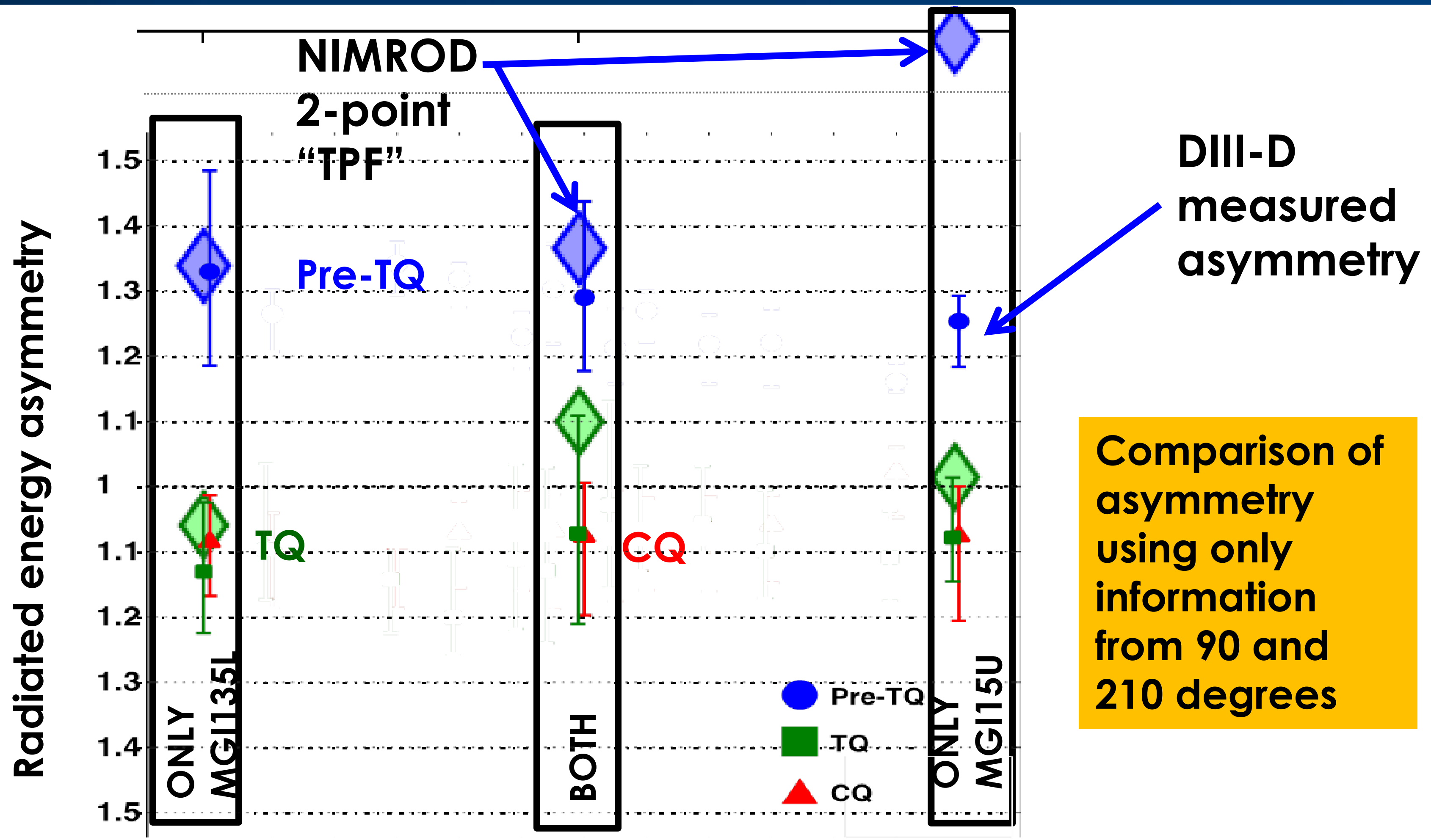
# DIII-D finds little or no variation in the asymmetry for one vs two gas jets




DIII-D measured asymmetry

Asymmetry calculated from 90 and 210 degree detectors

# NIMROD synthetic asymmetry diagnostic largely reproduces missing trend in DIII-D data




Comparison of asymmetry using only information from 90 and 210 degrees

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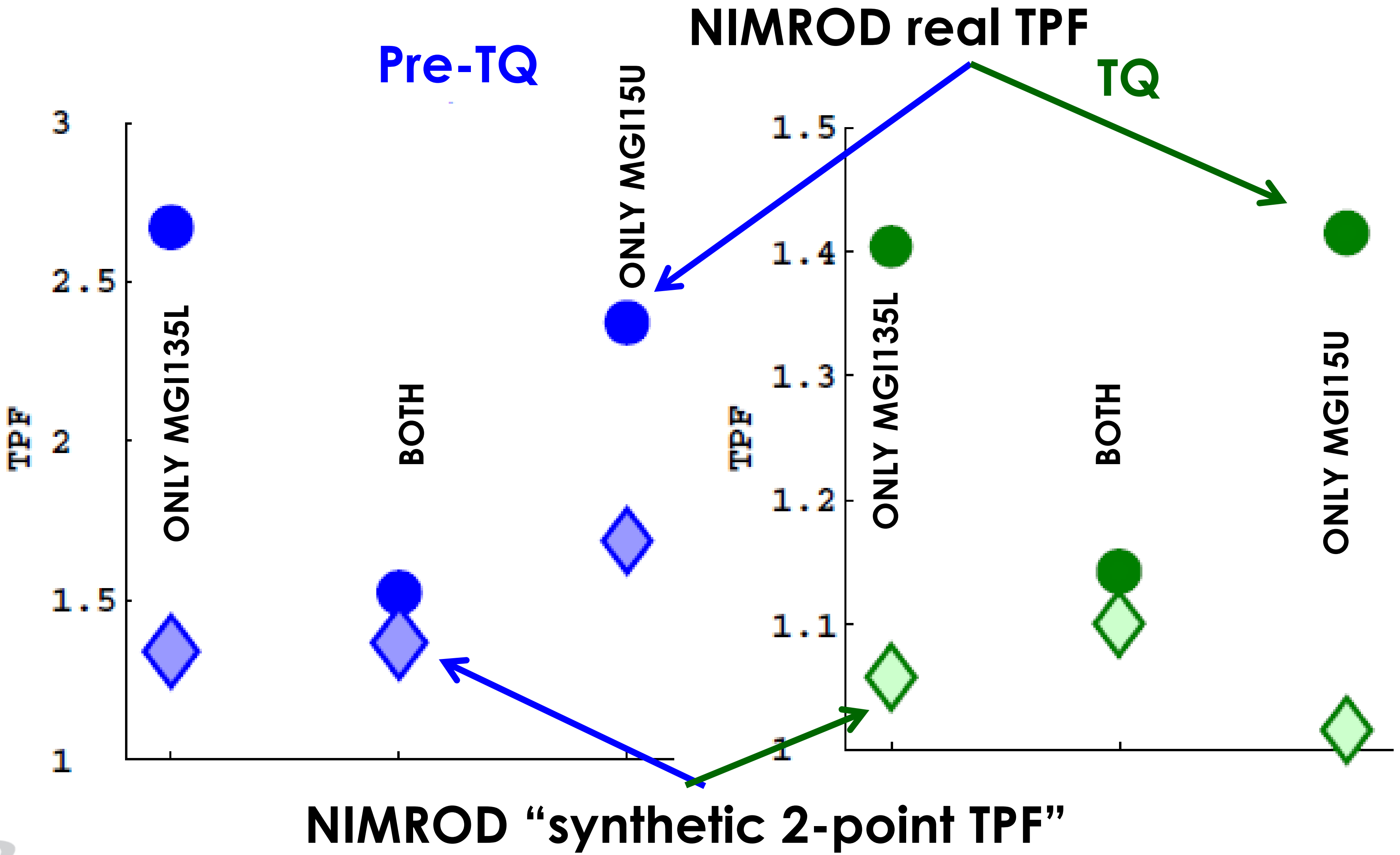
# NIMROD: 2-point "TPF" does not capture real trend in TPF

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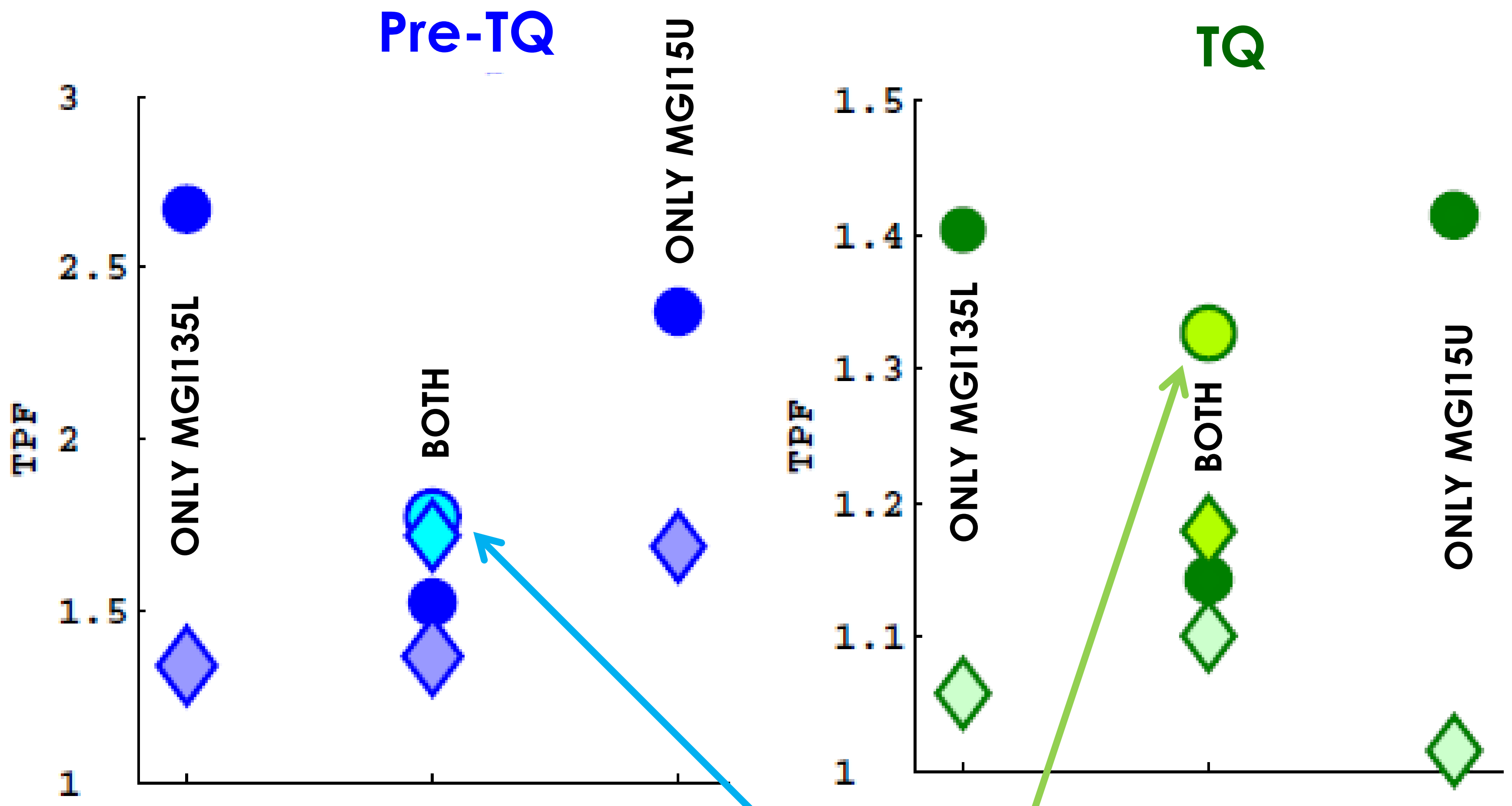
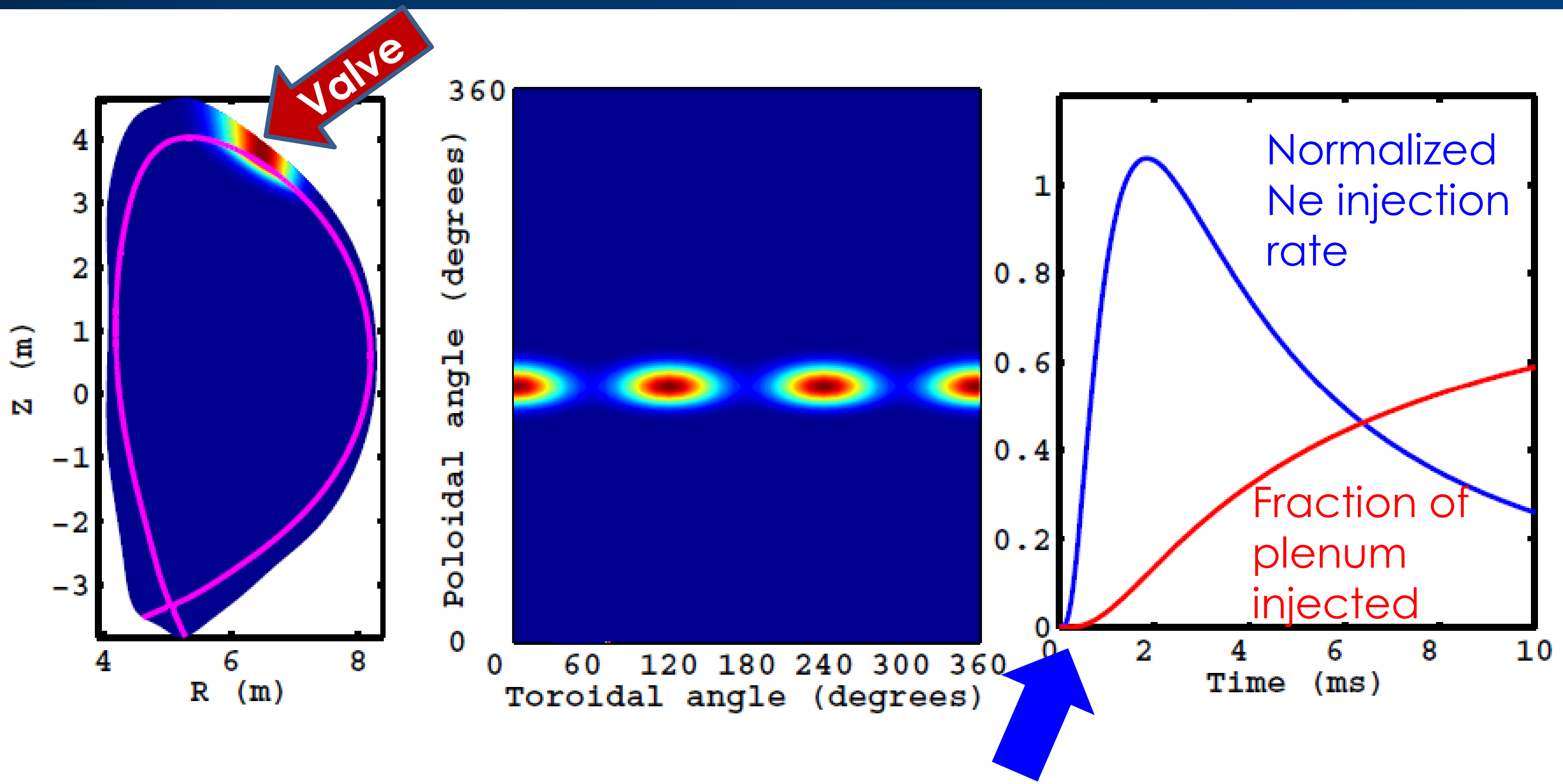
# NIMROD: reversing helicity increases TQ TPF with 2 jets




Reversed Helicity Case

# Part III. ITER simulations use three upper ports allocated for TQ mitigation part of DMS




**Total particle injection rate vs. time based on FLUENT calculations**

**→ Assumes 1 m delivery tube: unrealistically short!**

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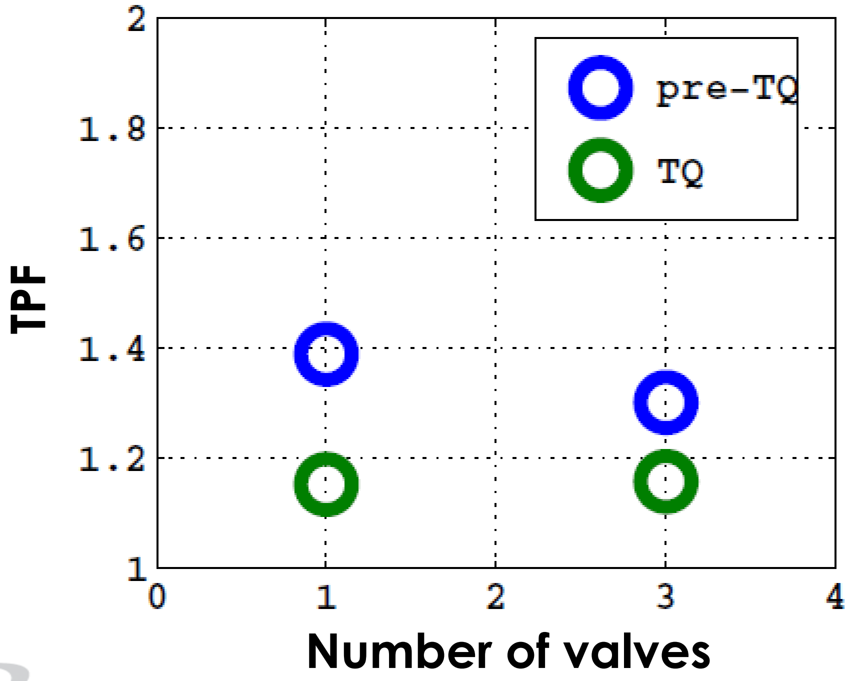
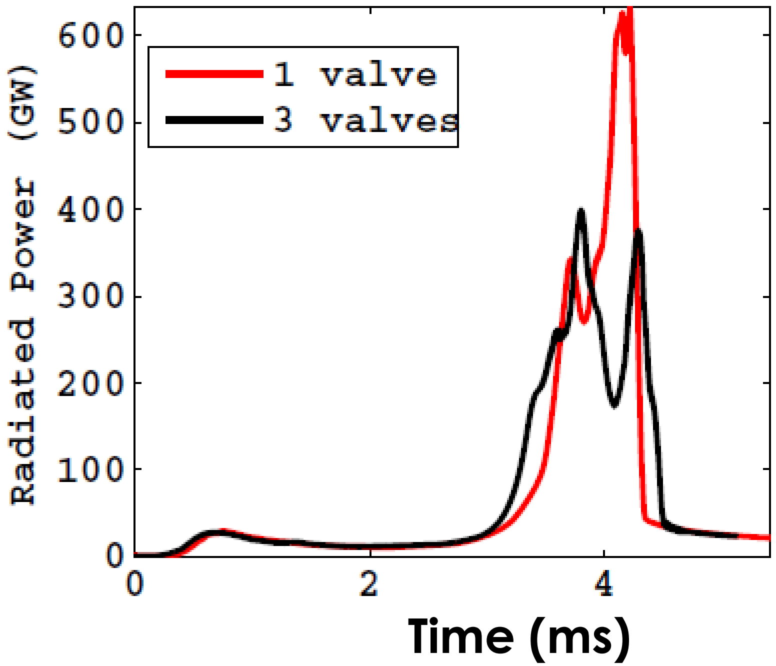
# 3-valves and 1-valve have same TPF, different TQ durations

- Slight decrease in TPF during pre-TQ with 3 valves
- Virtually no change in TPF during TQ

- Single valve has higher maximum Prad
- Three valve has longer TQ duration

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# NIMROD modeling provides new physics insights into MGI with single or multiple gas valves

NIMROD predicts that DIII-D 2-valve configuration reduces TPF, but increased diagnostic resolution is needed to capture trend, validate model

On ITER, 3 upper valve configuration is not found to reduce TPF compared to single upper valve during TQ

→ Single jet TPF during the thermal quench is not very severe in DIII-D or ITER

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THANK YOU!

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# # of valves → MHD Mode # → TQ duration?

1 valve → n=1 dominant

3 valves→ n=3 dominant