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# Observation of an enhanced helicity injection mode in a rotating plasma annulus

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# Outline

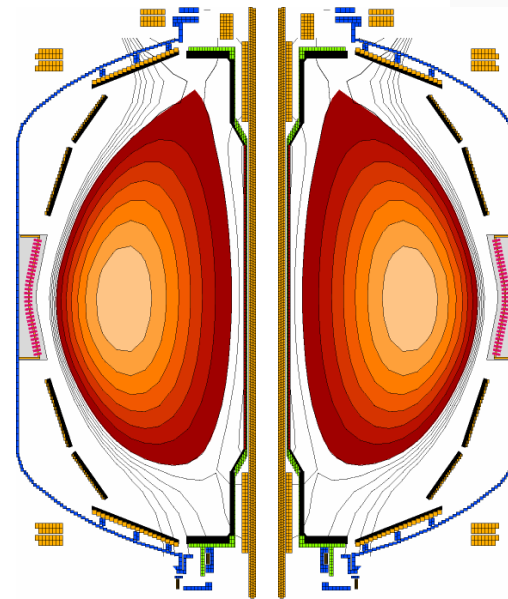
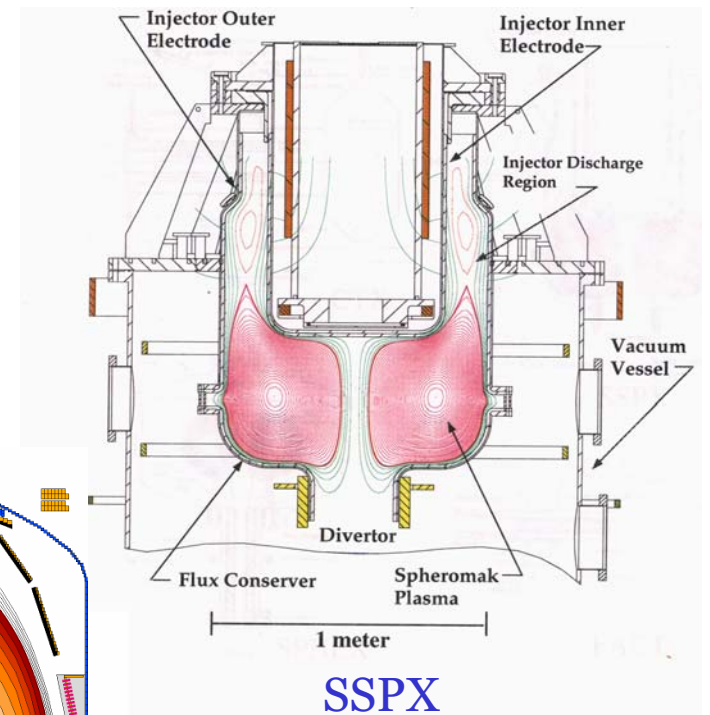
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- Motivations
  - Magnetic helicity injection is important to ICC's
  - Helicity injection beyond the Taylor's paradigm?
- Experimental configuration & approach
  - FMP (flowing magnetized plasma) experiment
  - Plasma annulus configuration & diagnostics
- Results and discussion
  - Observation of an enhanced helicity injection mode
  - Characteristics of the enhanced helicity mode
  - IV characteristic analysis (circuit model)
  - Gun voltage ( $V_g$ ) correlation with plasma rotations
- Conclusion: *Magnetic helicity injection is enhanced through rotating plasmas*

# Magnetic helicity injection is important to ICC's



- Current drive → tokamaks
- Magnetic helicity injection → ICC's
  - Spheromaks
  - FRC's (by merging spheromaks)
  - ST (e.g., HIT, NSTX)



# A key to helicity injection is to maximize and sustain gun voltage



- First-principles & empirical *helicity balance* arguments
  - To maximize  $2 \int V_g \Phi_g dt$  when  $\mu_0 I_g / \Phi_g \geq \lambda_{th}$
- Approaches
  - Magnetized coaxial plasma gun for simply-connected geometry
    - “Programming” the gun operation  
(SSPX, McLean *et al.* PRL’02, Woodruff *et al.* PRL ’03, ’04)
    - Planar (“zero”-length) coaxial gun (Caltech)
  - Coaxial helicity injection (CHI) to doubly connected geometry (HIT, NSTX, Raman *et al.*, PRL ’03)
  - Steady inductive helicity injection (HIT-SI, Jarboe *et al.*)

# Is there a more generic paradigm for magnetic helicity injection?

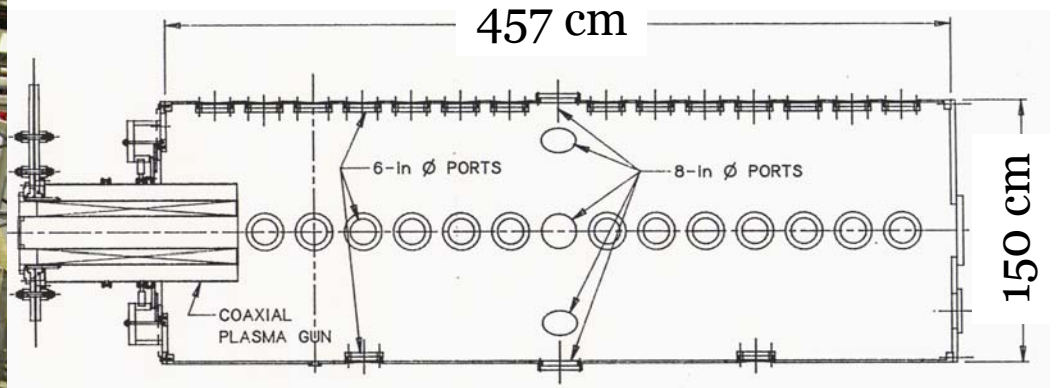
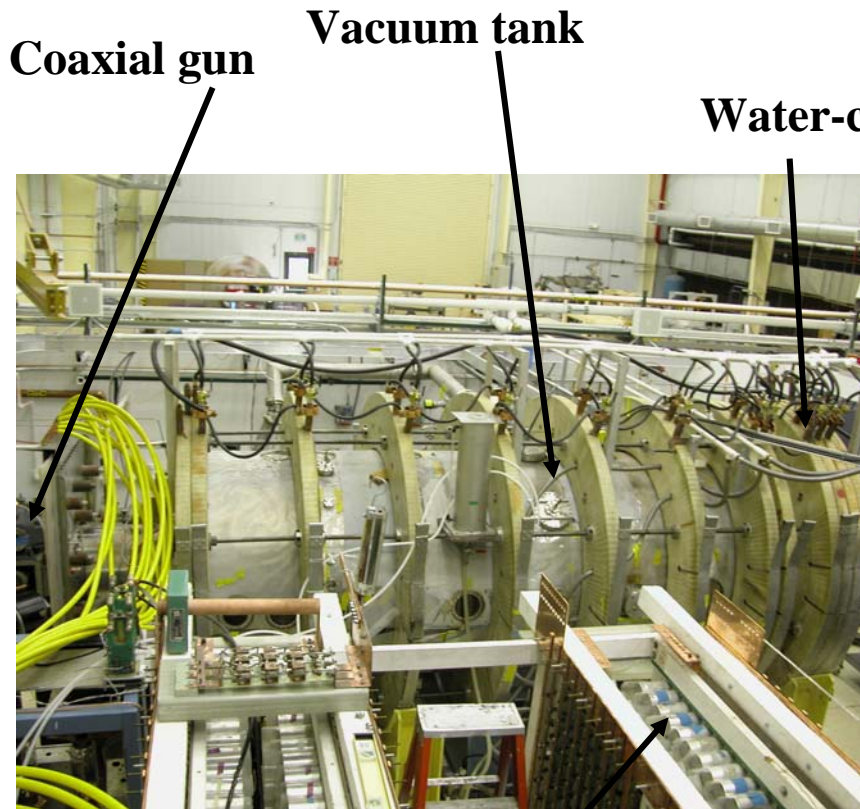


- “Taylor’s paradigm” for helicity injection using plasma guns:
  - $0.5 CV^2 \rightarrow \mathbf{J} // \mathbf{B}_0 \rightarrow$  (Taylor Relaxation)  $\rightarrow$  spheromak ( $=0.5 B^2/\mu_0$ )

Observation: The role of plasma rotation in magnetic helicity injection is usually not considered

- A possible more generic paradigm
  - $0.5 CV^2 \rightarrow \mathbf{J} // \mathbf{B}_0 + 0.5 \rho \mathbf{U}^2 \rightarrow$  (Plasma self-org.)  $\rightarrow 0.5 B^2/\mu_0$ .
- Our approach : modification of the coaxial gun geometry so that magnetic helicity is injected in conjunction with plasma rotation.

# FMP is a linear machine with a coaxial plasma gun/injector at one end

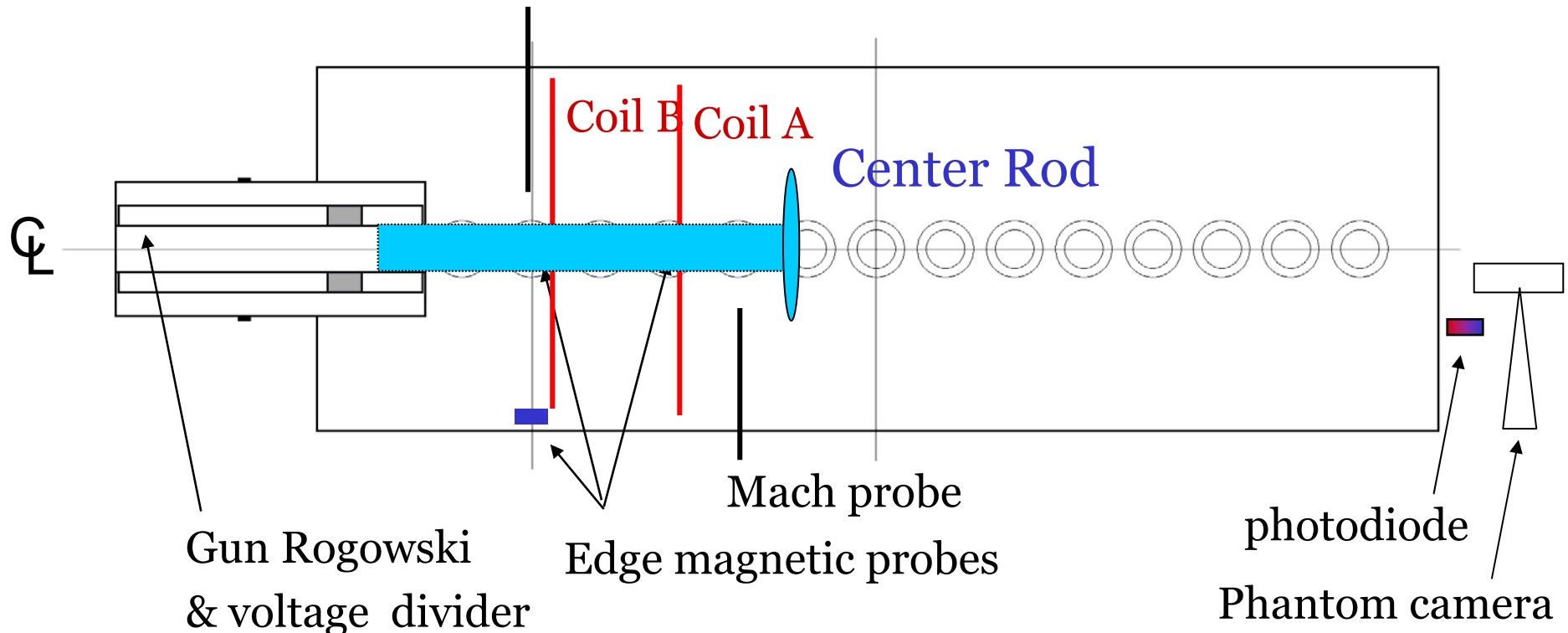


0.76 F, 900 V main bank

# Plasma annulus configuration is formed by “extending” the inner electrode



Radially scannable triple probe, magnetic probe



*In addition: Ion Doppler spectroscopy*

*Langmuir probe array, (x 20 channels)*

*Magnetic probe array (x 12 points), NEP (x 9 tips)*

*Plasma Physics*



# Further comparisons with CTX

	FMP	CTX
– Pulsed power	900V/300 kJ	10 kV/1MJ
– $\lambda_{th}$ (threshold)	$\leq 5 \text{ m}^{-1}$	$\sim 15 \text{ m}^{-1}$
– Bias flux config.	$\sim$ axial/volumetric	localized
– Characteristic B field:	0.1 kG	2 kG
– Cu Flux conserver	No	Yes

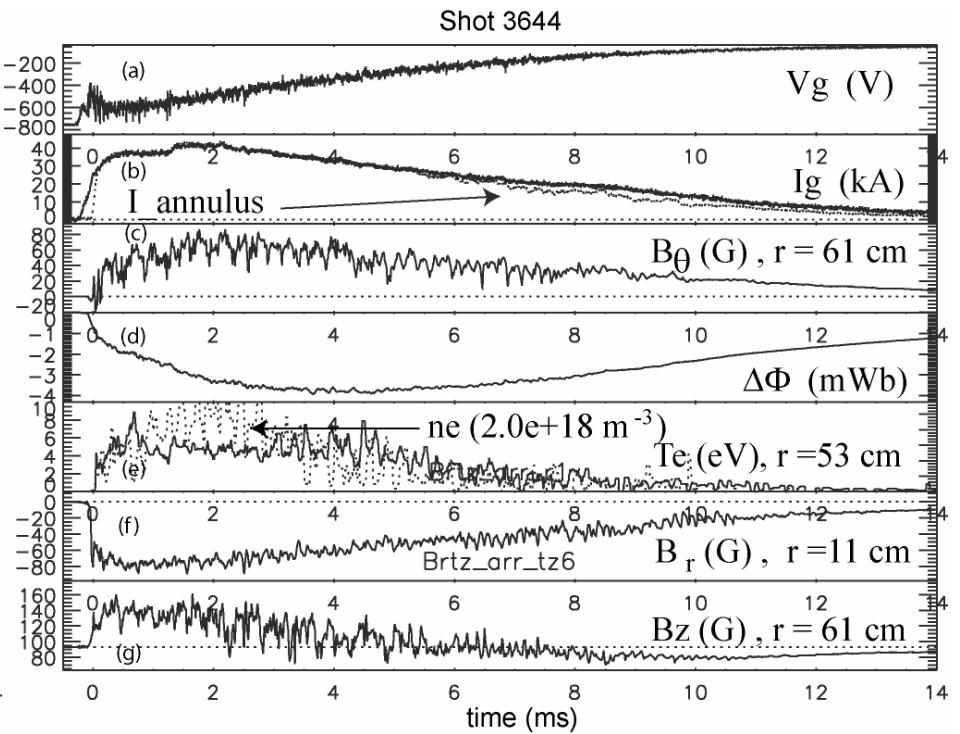
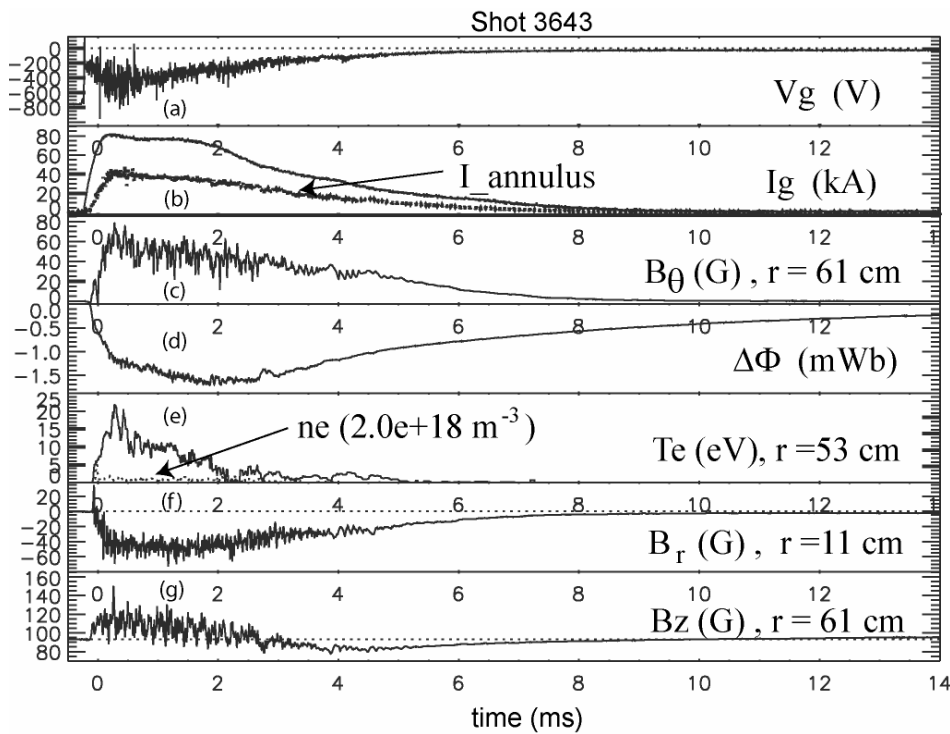


# Characteristics of two operating modes

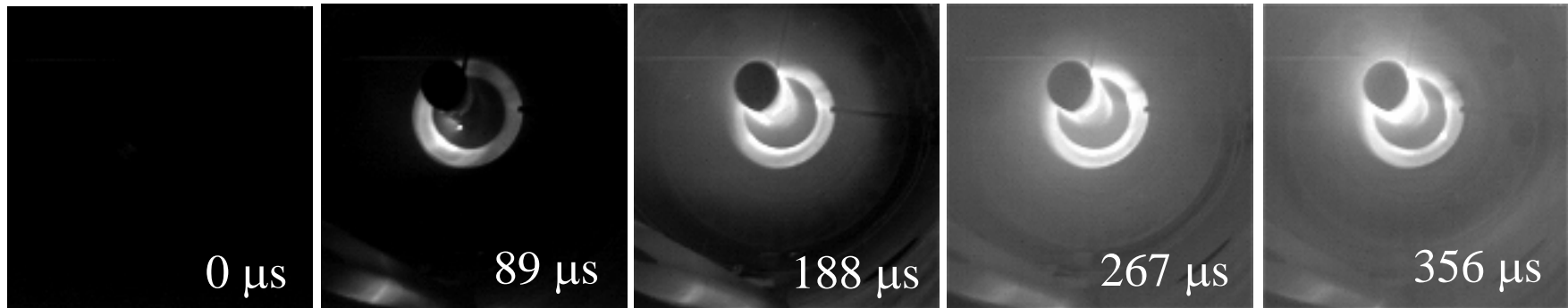


“normal” mode

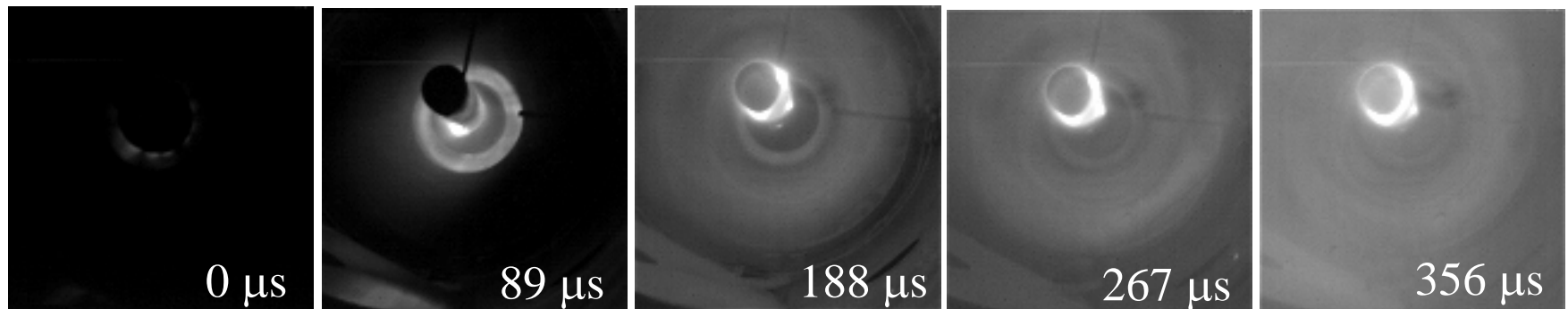
“enhanced” mode



# Fast camera images (views towards the coaxial gun)



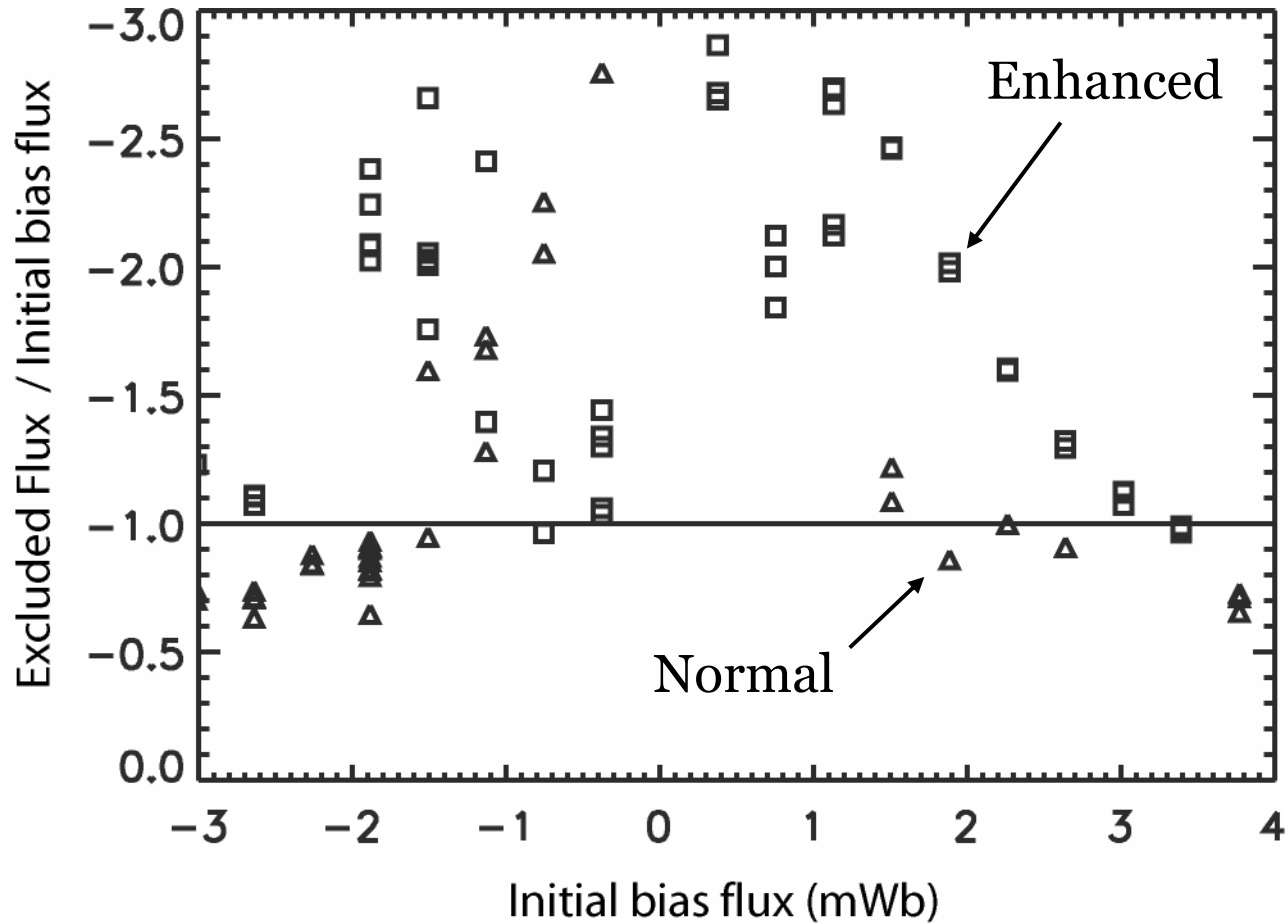
Shot 2680, normal mode



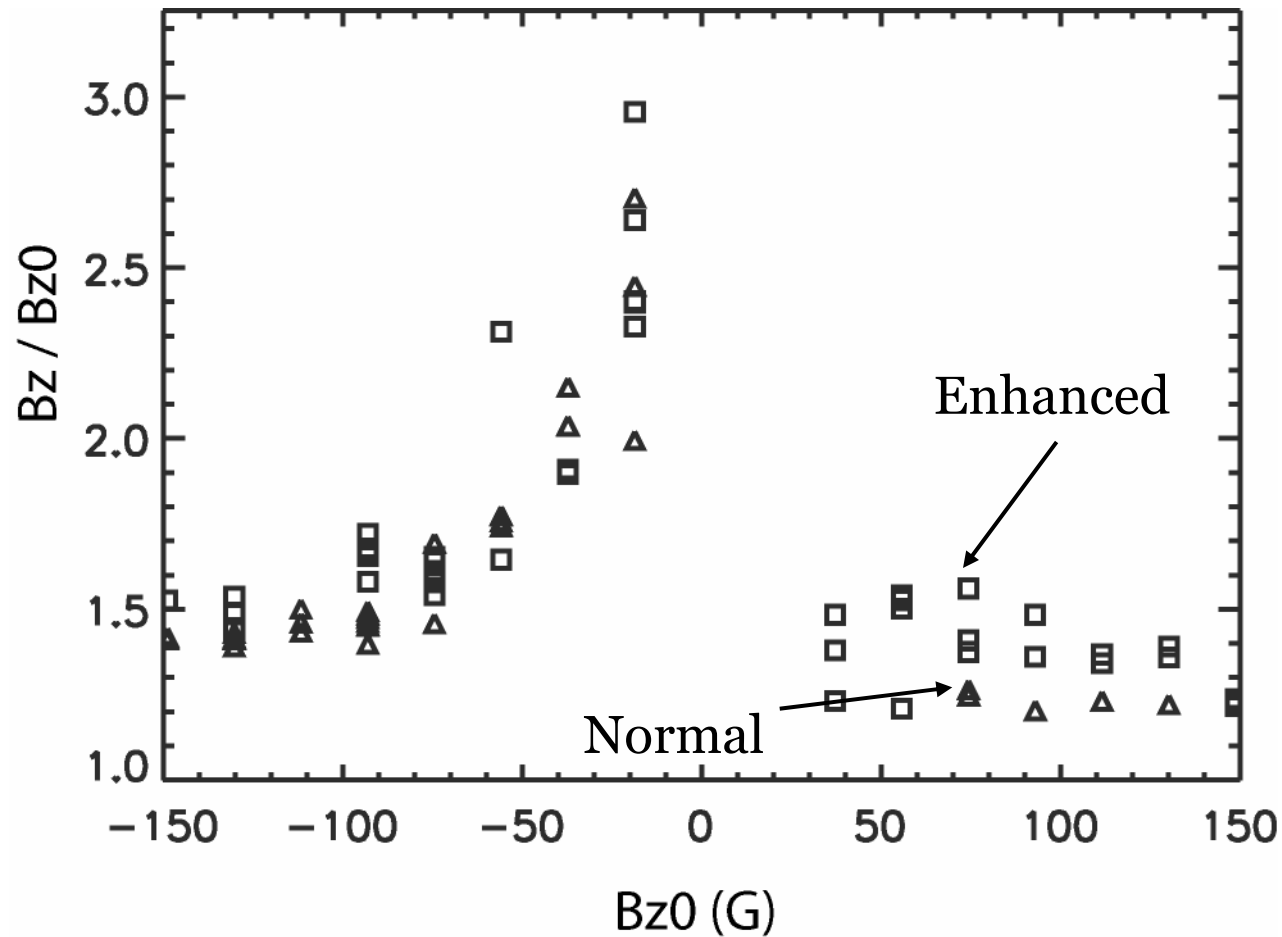
Shot 2681, enhanced mode

Exposure = 25  $\mu$ s,  $B_{z_0} \sim 100$  Gauss

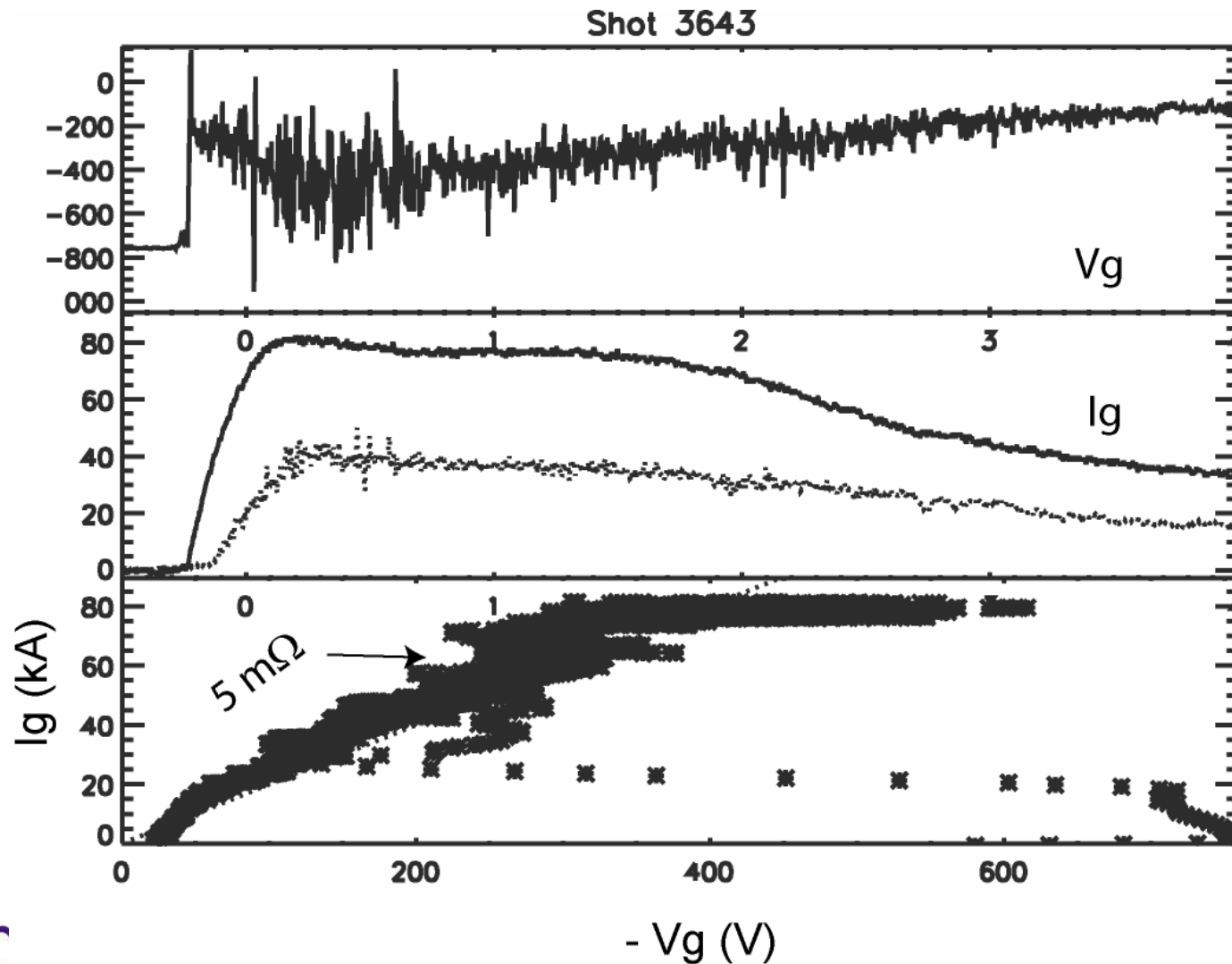
# The enhanced mode corresponds to larger excluded flux



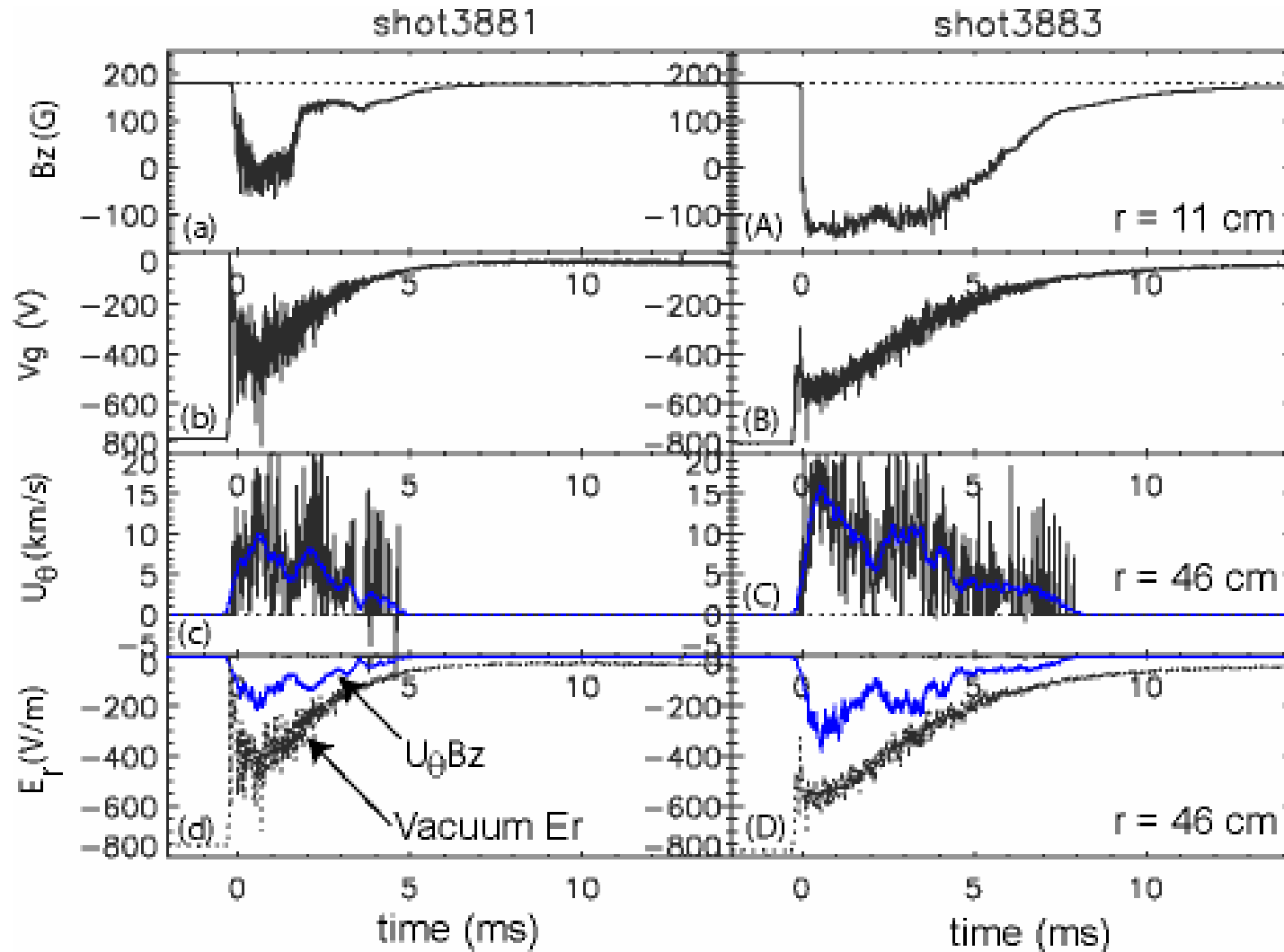
# The enhanced mode corresponds to larger edge magnetic field



# The “normal” mode is mostly resistive



# The enhanced mode correlates with larger rotation

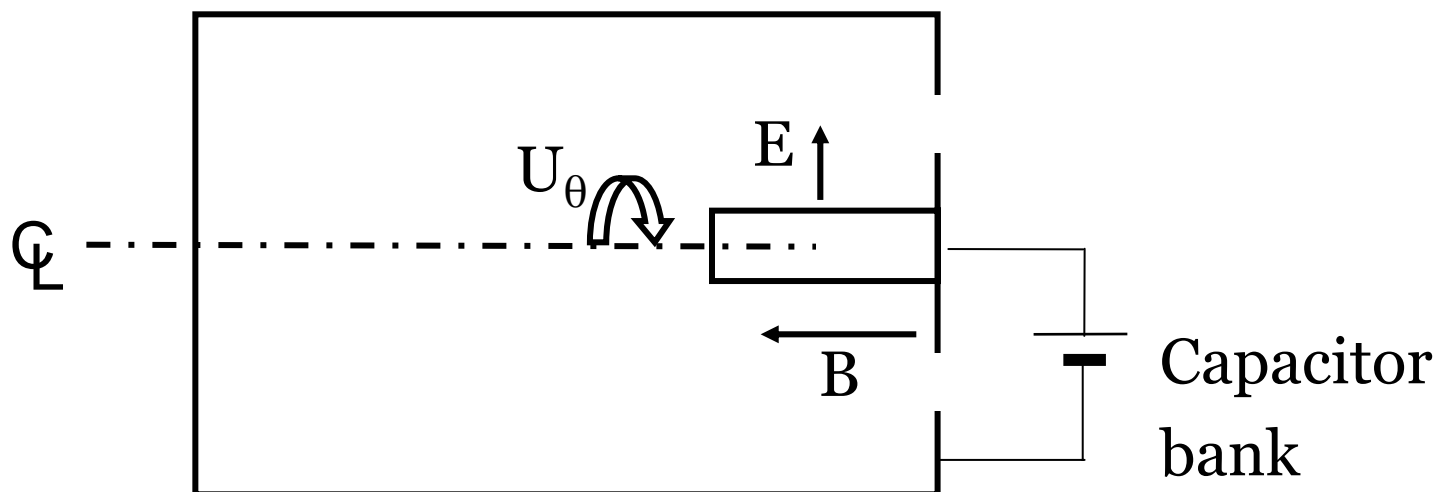


(Flow consistent with spectroscopy data)

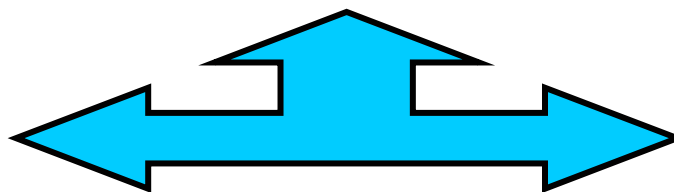
# A possible new ICC concept using the “Generalized helicity” injector



(magnetic helicity + angular momentum injection)



spheromaks using standard CHI



Centrifugally confined mirrors

(*pure* magnetic helicity injection)

(*Pure* angular momentum injection)

# Conclusions

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- An enhanced magnetic helicity injection mode has been observed in rotating plasmas
- $V_g$  increase correlates with plasma rotation

**→ More magnetic helicity can be injected through rotating plasmas**

- New ICC's are possible based on magnetic helicity injection using rotating plasmas