Effect of rotation on confinement

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Summary

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- L-mode toroidal velocity and field scans
- Result: even modest flow shear can have a significant effect on transport
- Preliminary analysis shows ion energy confinement affected most strongly
- In highly rotating supershots:
  - τ_E better with slight co-injection
  - significant improvement of local χ_i with co-rotation

Motivation

- **Toroidal rotation shear is correlated with enhanced confinement**
  - **H-, VH-, supershot, and reverse shear confinement modes**
- **Conjecture: radial electric field shear stabilizes turbulence**
- **ITER global database and ρ* scaling**
  - **mostly with unidirectional beam injection**
  - **Do sheared flows affect the “usual” confinement?**

Radial electric field shear: Some definitions

- **Force balance:** $E_r = \nabla P / nZe + V_t B_p - V_p B_t$
- **Shearing rate:** $\gamma_{ExB} \equiv \frac{RB_p}{B_t} \frac{\partial (E_r / RB_p)}{\partial r}$
- **When pressure gradient is small:**

$$\frac{\gamma_{ExB}}{\gamma_{lin}^{max}} \propto M \frac{B_p}{B_t}$$

  - **where M is the toroidal Mach number**
  - **Does modest rotation reduce transport?**

L-mode experiment: Outline

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- **Measure effect of rotation and toroidal field on confinement**
  - **vary Mach number by changing direction of injected power (co- or counter- to I_p)**
  - **repeat at lower toroidal field at fixed q(a)**
  - **test at two different values of ρ^***
    - **not a ρ^* scan: did not match β or ν^***
- **Match edge density and temperature**
  - **confinement is sensitive to edge effects**

L-mode: Strong global τ_E scaling with rotation

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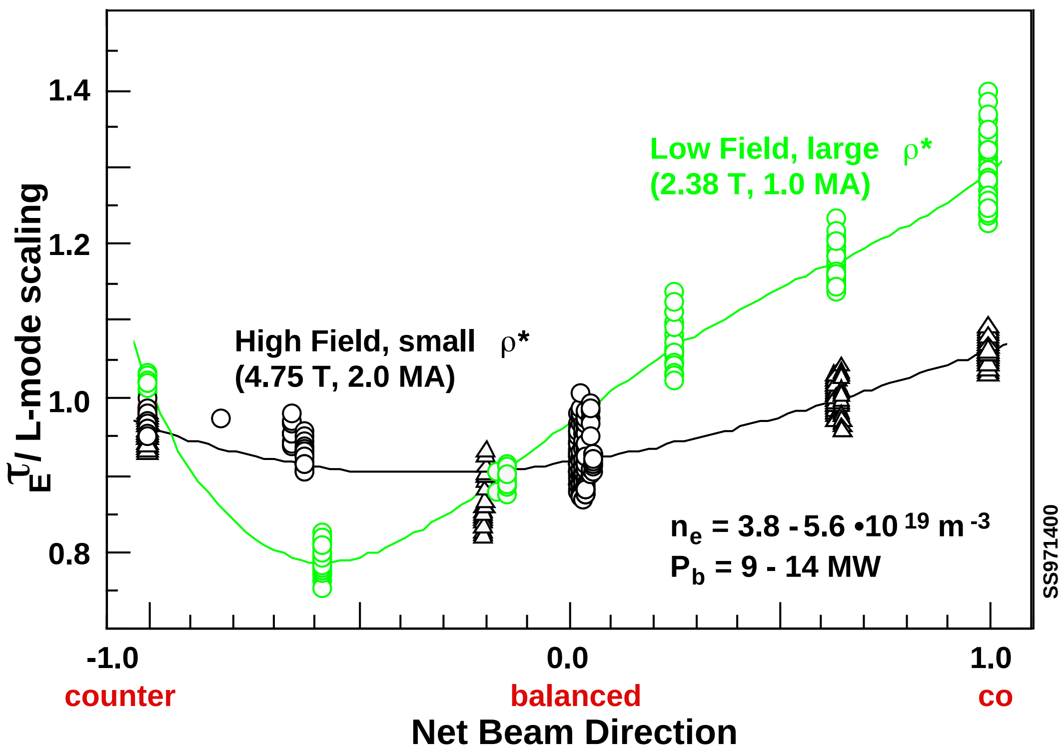
- *Both* co- and ctr- injection improved over balanced
- Effect is stronger at low magnetic field



L-mode: High-field confinement improved with co-injection

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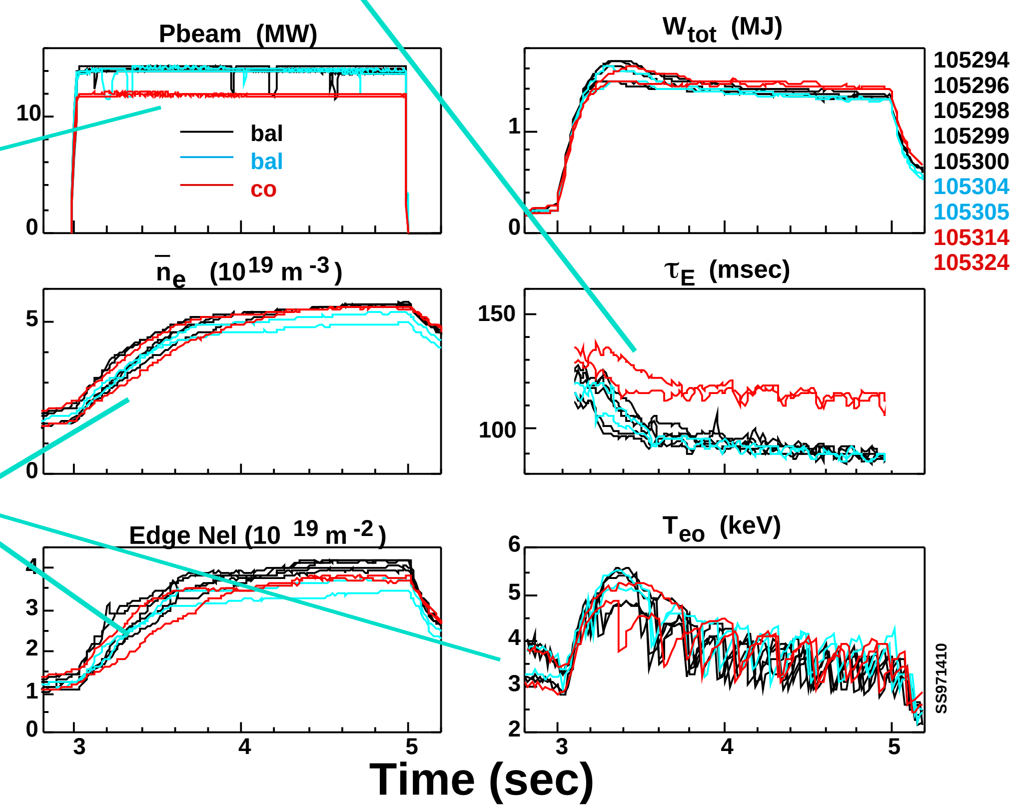
- τ_E better with co-injection than balanced
- reduced beam power needed for pure co-inj.
- good match of edge and central density & T_e



L-mode: Low-field confinement even better with co-injection

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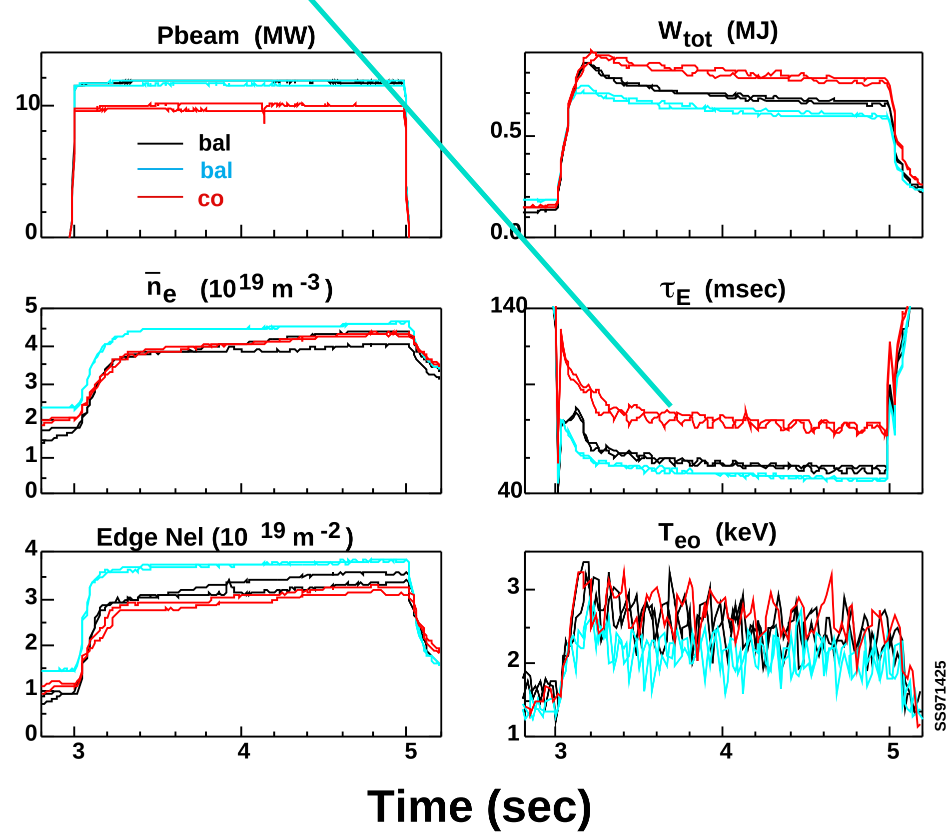
- τ_E better with co-injection than balanced
  - "balanced" here is slightly ctr-dominated
- less co-power is needed to match power deposition profiles due to beam-orbit effects



L-mode: Core ion heat confinement improves with rotation

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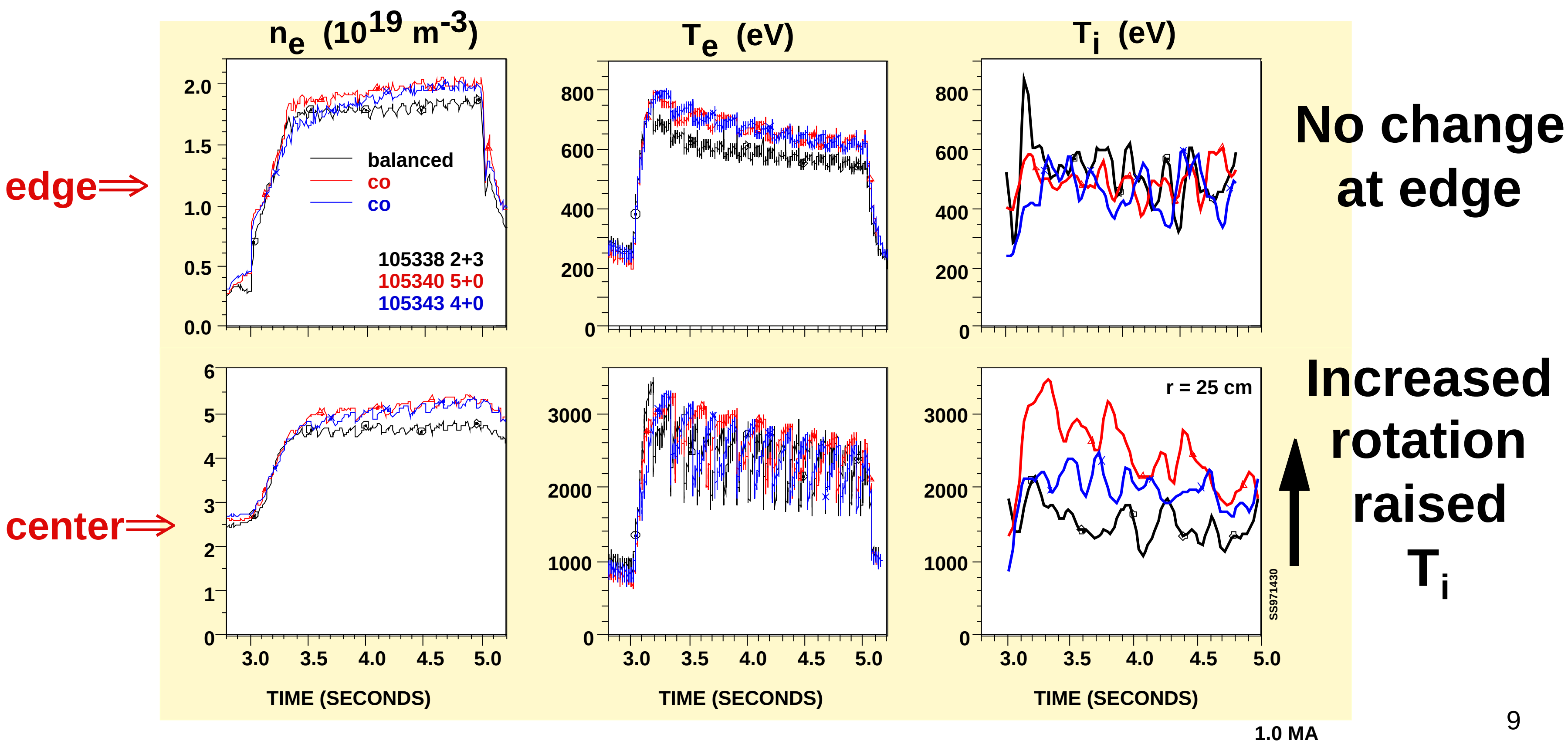
- good match of density and T_e profiles
- confinement improvement seen in T_i



L-mode: Kinetic analysis

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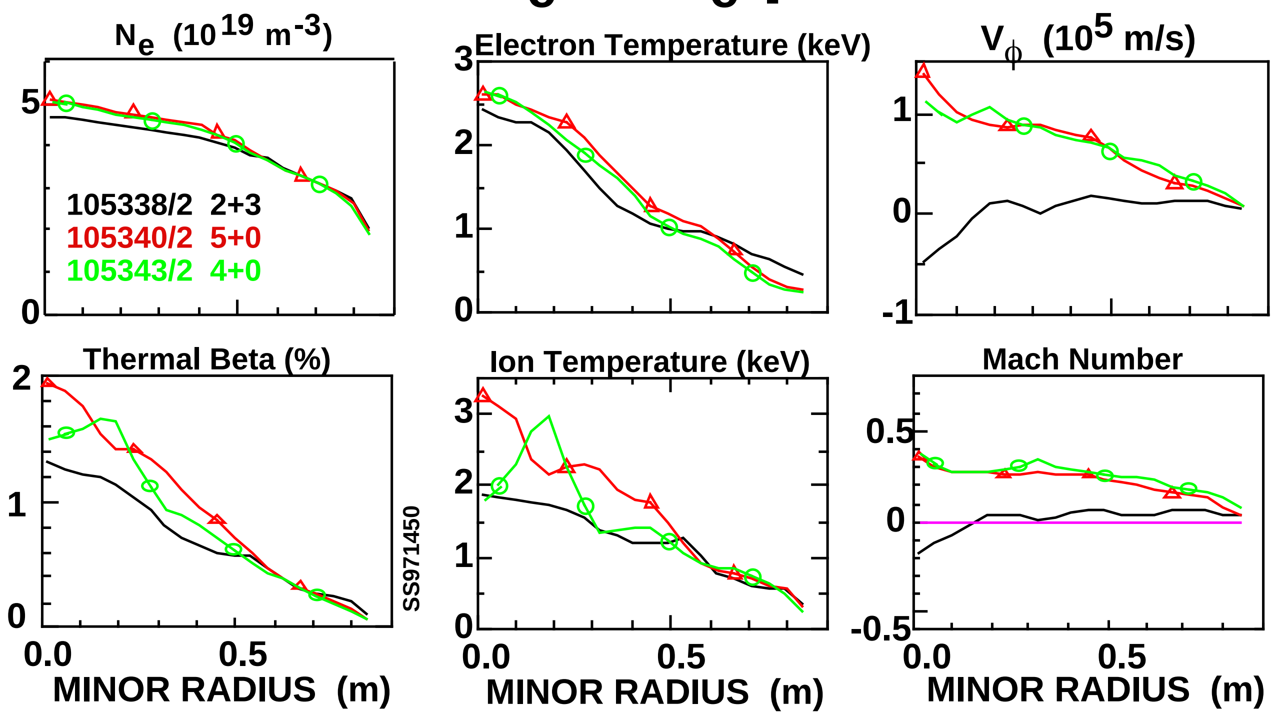
- **Rotation increases thermal β**
  - **especially in ions**
- **M ≈ 0.3 achieved, n_e & T_e profiles matched**

Low field

Increased rotation raised β



L-mode: Future plans

- Detailed kinetic analysis
- Determine correlation between flow shear, local χ_i, and global τ_E
  - include beam-orbit effects, etc.
- Comparison with theory
- Higher rotation can be obtained with "supershot" plasmas
  - extend Mach number to 0.8
  - strong local effect observed
  - global effect weakened

Supershots: Maximum global τ_E not at zero rotation

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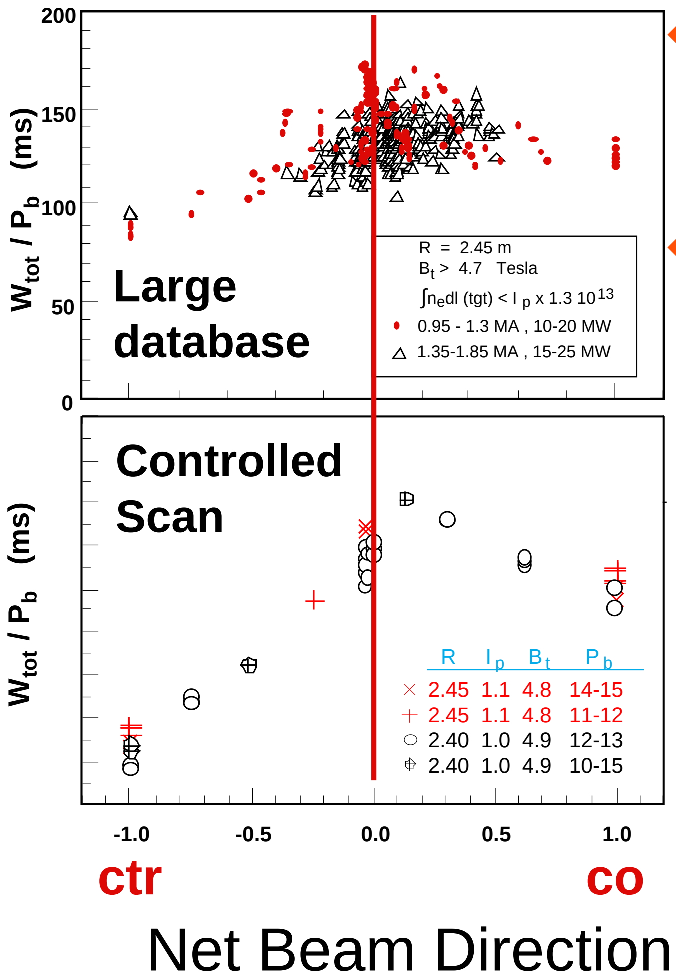

- Optimum τ_E is always found for slight co-rotation
- Classical beam effects lower τ_E in highly rotating plasmas
  - lower beam penetration
  - less beam stored energy
  - less heating because more pushing

Supershots: Local transport improved strongly with rotation

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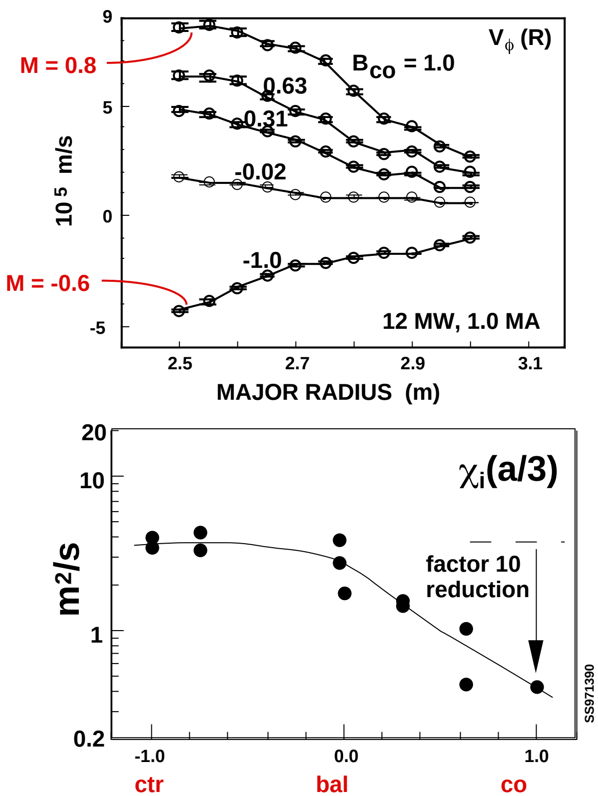

Net Beam Direction

- **Local χ_i *improved* by factor of 10 for all co-inj.**
- **Supershots have features not anticipated in ITER**
  - **low edge particle influx**
  - **high T_i/T_e**
  - **peaked density profiles**
  - **core ion heat flow dominated by convection**

Conclusions

- **L-mode: Rotation & field scaling tested**
- **Even modest rotation (M = 0.3) can have an effect on transport**
  - **full field: 20% increase of global τ_E**
  - **half field: 50% increase of global τ_E**
- **Global τ_E and ρ* scaling deduced from rotating plasmas could be misleading for ITER**
- **Supershots: Toroidal rotation has a pronounced effect on local χ_i**

Outline

- L-mode experiments to test scalings
  - pressure gradient small
  - vary toroidal rotation
    - co/ctr injection of neutral beams
  - vary toroidal field at constant q(a)
- Comparison with supershot experience

Supershot experience: Need better comparison for ITER scaling

- **Supershots have features not anticipated in ITER**
  - **high T_i/T_e, higher Mach number**
  - **peaked density profile**
  - **high Z_{eff} (≈ 3.8), low $n_{i,thermal}$ / n_e**
  - **ion heat flow dominated by convection in core**
- **Comparable L-mode experiment needed to assess possible effect in ITER**