Tokamak Collaborations

Understanding the physics of tokamaks and contributing to the experimental program and machine design

J. Manickam

- Experience - TFTR, DIII-D, JET, JT-60U .....
- Working with experimentalists
- Large suite of codes available
- Experience in machine design - Next Step Option

FESAC goals

Develop and assess high beta instability feedback control methods
Advance understanding of turbulent transport
Develop detailed predictive capability

The Theory Department at PPPL participates in many experimental collaborations

DIII-D - GA
CMOD - MIT
HBT-EP - Columbia
APEX - IFS, LLNL
ET - UCLA
HIT - U. Washington
FIRE - USA

ASDEX - Germany
IGNITOR - Italy
JET - Europe
JT60U - Japan
KSTAR - Korea
Tore Supra - France
TCV - Switzerland

The majority of the theory department is involved in collaborations

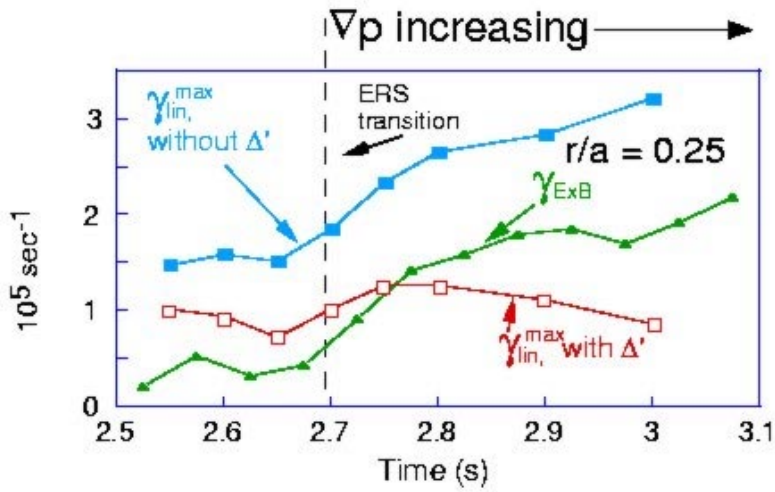
Collaborations address many Tokamak Physics Issues

- Transport barrier physics ⇐
- Resistive wall mode stabilization ⇐
- Profile effects on β-limits ⇐
- Energetic particle interaction with MHD
- Boundary physics
- Next Step Option design
- Collaborative code development and Code Sharing ⇐

Transport barrier physics

- Numerical studies analyzing data from
  - TFTR, DIII-D, JET, JT60-U
- $\Rightarrow$ analyze experimental data
- $\Rightarrow$ compare with theoretical models
- $\Rightarrow$ Plan and propose experiments

E×B shear, Shafranov shift stabilization are elements for sustainment of enhanced confinement in ERS plasmas



Synakowski, PoP 4 '97

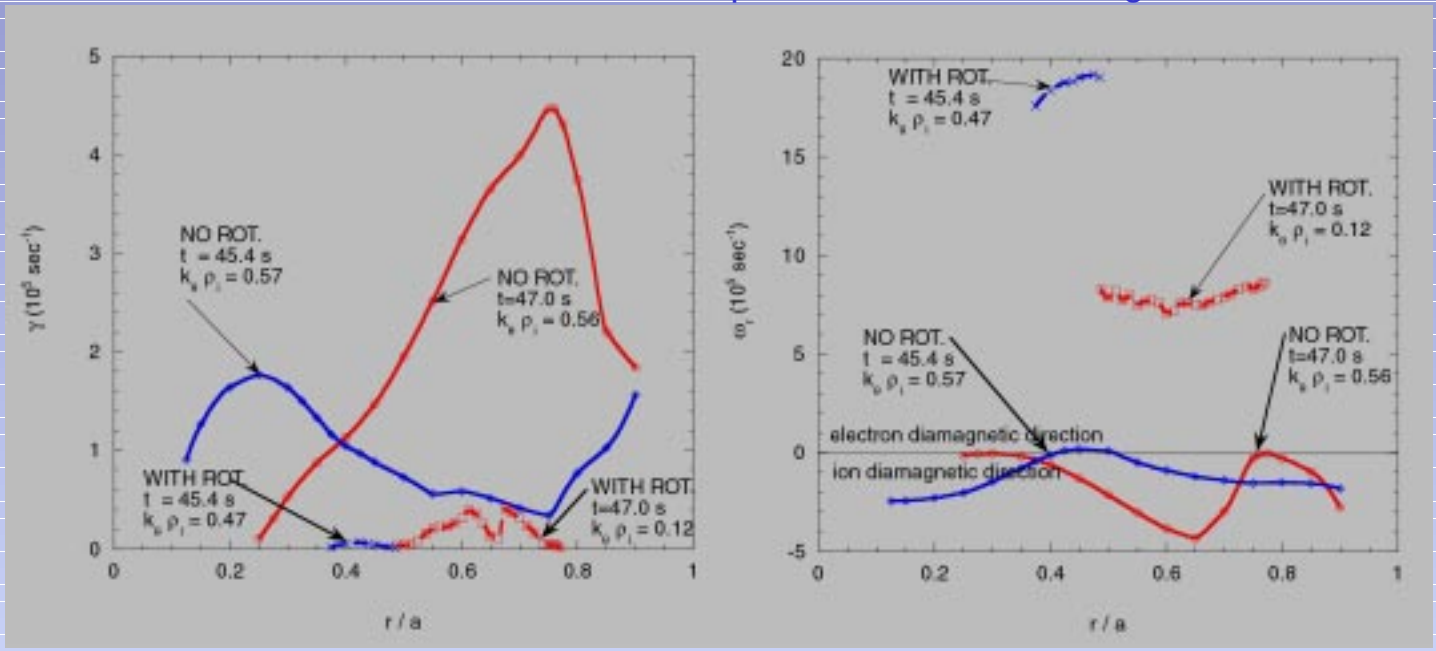
$\gamma_{E\times B} \equiv (RB_\theta)^2/B\ \partial/\partial\psi\ [E_r/RB_\theta]$
(Hahm and Burrell, PoP 2 '95)

γ_{lin}^{max} from Beer, PhD thesis, Princeton University 1995 and PoP 4 '97

- Increasing E×B shear with increasing ∇p
- Possibility of increasing stabilization with increasing ∇p improved with inclusion of Shafranov shift stabilization

ExB Rotation Causes Substantial Stabilization

Electrostatic drift mode in JET Optimized Shear Discharge:40542



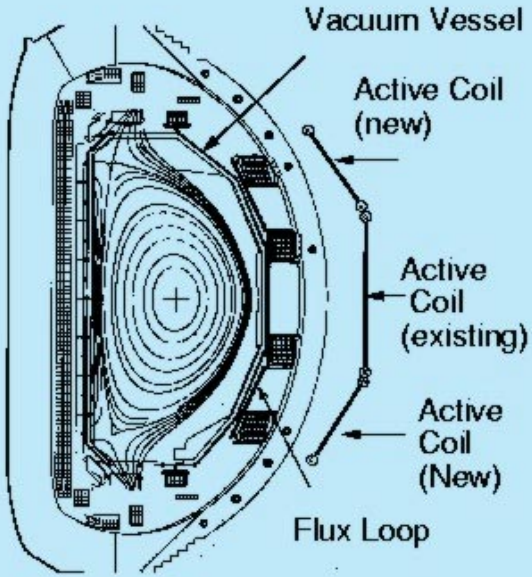
Motivates additional experiments - Planned for this summer

Resistive Wall Mode

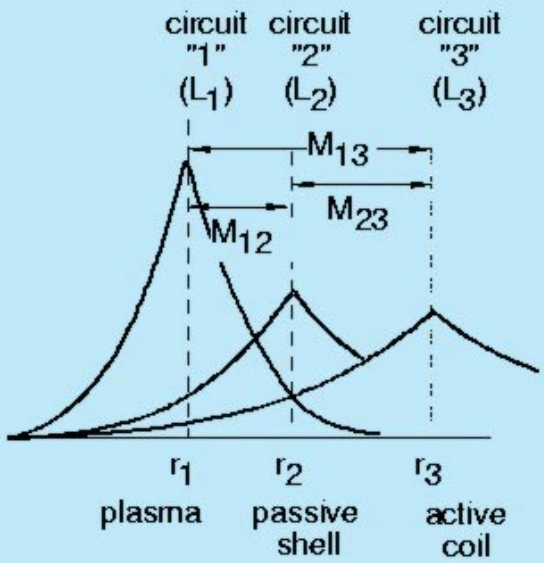
- External kink, modified by a resistive wall
- Hard β-limit i.e. Fast collapse
- Stabilization important for Advanced Tokamaks and STs with high-β,high I_bs
- Collaboration with Columbia and GA on DIII-D and HBT-EP
- Leads to application on NSTX

The PPPL theory group is helping to lead RWM feedback stabilization

The VACUUM code couples plasma perturbations determined by PEST with external feedback systems

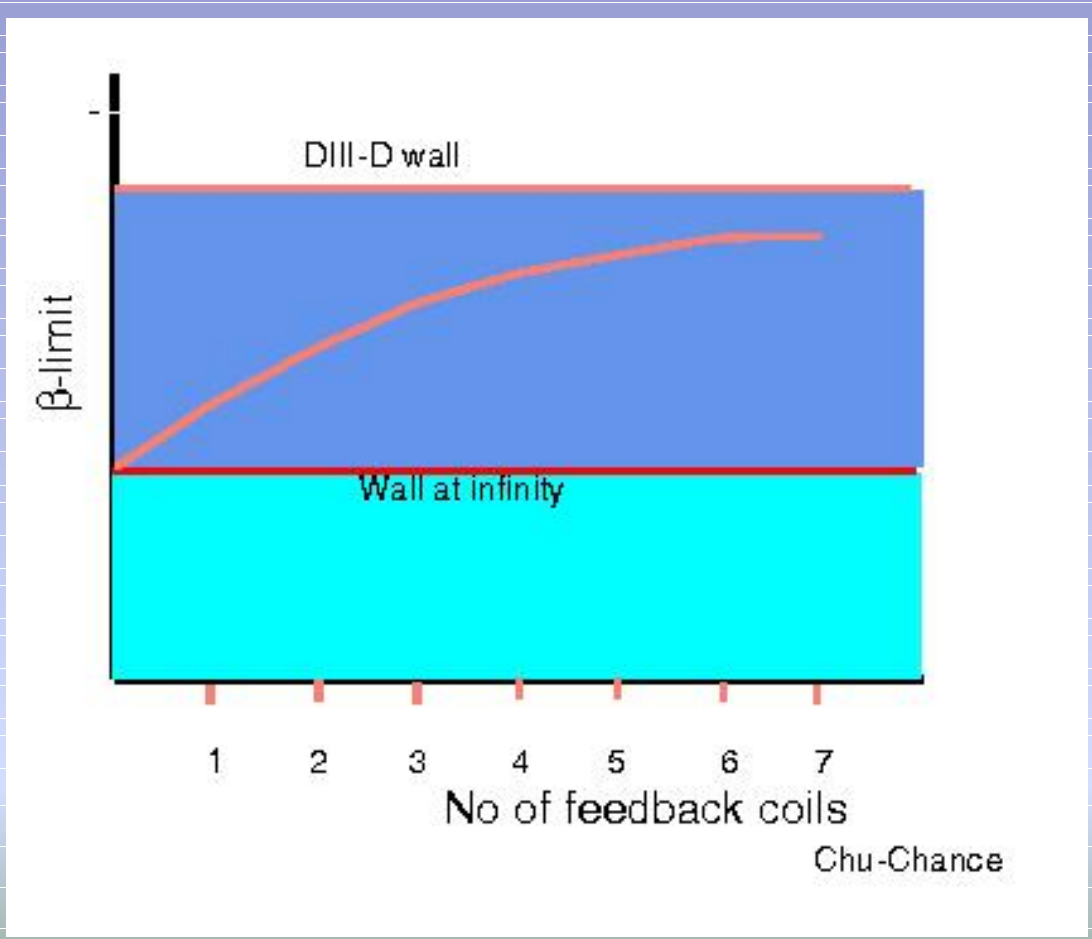


DIII-D RWM feedback system



RWM circuit geometry

Preliminary results from vacuum



Making our tools available to the community

- Mature Codes Online
- Universal accessibility
- Linkage with experimental data
- User friendly interface
- EZ-PEST

Online β-limit study: EZ-PEST

- Complete package of linear MHD stability
  - Interface to EFIT file or MDSplus data tree
  - PEST-1, low-n, growth-rate, eigenvector, perturbed field, diagnostic simulation
  - PEST-2, fast stability boundary analysis
  - BALLOON, high-n
  - PEST-3, resistive Δ' evaluation
- Profile effects in near real time, between shot analysis
- Interface for FULL, ORBIT, Gyro-fluid ....

Conclusion

Through collaborations the theory department continues to advance the physics of tokamaks and the goals of the magnetic fusion program

We work closely with experiments and are committed to sharing our codes and expertise with the world's fusion community

EZ-PEST examples

- Analysis of ALCATOR CMOD at MIT
- Data will be retrieved from MIT
- Medium β - single null - free boundary
- PEST-1 analysis

- NSTX β =28% model equilibrium
- PEST-2 analysis

RWM plans

- Complete feedback implementation in VACUUM
- Support VALEN development and benchmarking
- Help optimize feedback circuits
- Assist data analysis for DIII-D and HBT-EP
- Future applications
  - NSTX, JET, JT60U, KSTAR

Confinement experiment on JET with R. Budny

- Compare NBI heated and RF heated plasmas
- Role of energetic particles, rotation and impurities
- Transport calculation
- Micro-instability studies to explore underlying physics

Methane screening experiment on JET with J. Strachan

- Methane puff
- Examine transport into plasma
- DEGAS-2 modeling
- Extends work currently being done at GA

Next Step Option

- Defining and refining a burning plasma experiment
- Steady state - profile control and feedback
- Energetic particle physics
- Disruptions - avoidance and mitigation

Selected References Relating to Tokamak Research

- DIII-D
- JET
- JT-U60
  - Shirai, ..., Rewoldt, Tang, ... IAEA98
  - Manickam, Gorelenkov, Fujita, ... Nuc. Fusion 39 1819(1999)
  - Kusama, ..., Fu, Cheng, ... IAEA98
  - Kramer, Cheng, Fu, ... IAEA98