Energetic Particle Physics in Fusion Research: Snowmass and the ICC community

Useful perspectives:

(i) The “axi-symmetric large aspect ratio device” P.I.

(ii) The ICC device P.I.

(iii) The physicists interested in energetic particle phenomena

Why is there a separate field of Energetic Particle Physics in Tokamak Research?

- **Alfvén frequency much higher than thermal diamagnetic frequency**
  - **separation of scales**

- **Fast ions are usually perturbative**
  - **Ideal MHD spectrum excited by particles**

- **Thermal particles weakly damping**
  - **perturbative damping due to small number of resonant particles**

- **Small number of weakly interacting modes:**
  - **weak non-linear MHD (strong particle) interactions**

Why Study Energetic Particle Physics in Tokamaks?

- **Programmatic manager perspective:**
  - Determine the effect of energetic particles on performance limiting MHD phenomena
  - Determine the effect of energetic particle phenomena on heating and current drive efficiency

- **Basic plasma physics perspective:**
  - Understand the dielectric response of a plasma to the addition of a minority distribution of non-thermal particles
  - Understand the non-linear dielectric response of the medium and effect on the minority population of resonant particles

Conventional tokamaks provide an ideal test bed for advancing understanding of the basic physics of linear and non-linear resonant wave-particle interactions in the Alfvén range of frequency

Greatest Scientific Challenges in Tokamak Energetic Particle Physics

- **Understand the non-perturbative response of the plasma to energetic ions**

- **Understand the non-linear mechanisms leading to saturation and particle redistributions**

- **Develop quantitative simulation of non-linear and non-perturbative modes**

Question:

Is energetic particle physics a meaningful speciality within the ICCs?

Relevance of Basic Tokamak Research to the ICC Community

- **Perturbative kinetic- MHD is the starting point for all other developments**
    - conceptual framework devised on tokamaks extends to ICCs
    - verification of perturbative theory is the essential first step towards a more general non-perturbative theory
    - confirmation/understanding of non-linear dynamics of a few modes is of fundamental importance to all of plasma physics
        - relevant to turbulence and transport

- **Deviations from perturbative models can be systematically studied by varying the magnetic shear in a Tokamak**
    - Non-perturbative effects can be controlled in the transition from positive to weak to reverse shear

- **Deviation from axi-symmetry can also be studied:**
    - e.g. effect of large NTM on Alfven spectrum

Question: What is the Relevance of a Burning Plasma Experiment to the Advancement of Energetic Particle Physics

- **Investigate the non-linear dynamics of multi-mode resonance overlap**
  - **- criteria for avalanche loss**

- **Investigate the role of isotropy (weak motivation)**

- **Understand the operational consequences of alpha heating on transport and MHD stability**
  - **- sawtooth, ITB formation**
  - **- some of the most interesting alpha physics questions are not purely energetic particle physics issues**

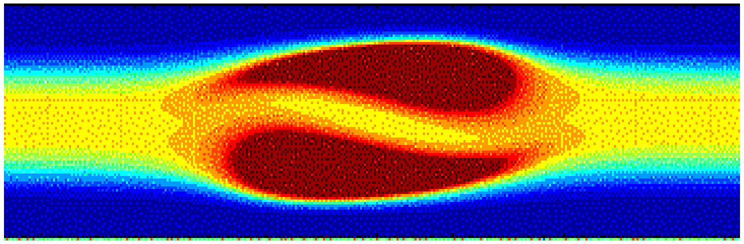
Note: Requirements for a successful *experiment* need to be met in a burning plasma experiment

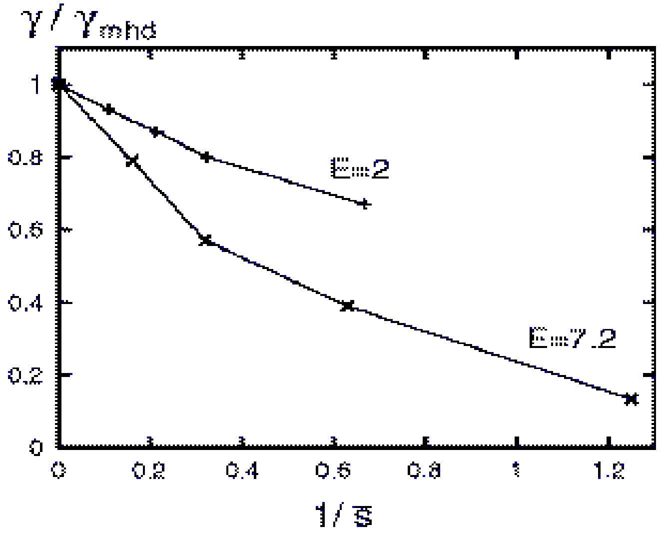
- **- device flexibility !!**
- **- diagnostic capability !!**

Similarity at the level of Specific Phenomena I: Universality of FLR Stabilization

- FLR stabilization of m=1 mode
  - Tokamak sawtooth instability
  - FRC m=1 mode
  - relevance to STs…

FRC: E. Belova





- Topics for comparison
  - linear stability analysis
  - non-linear simulation
  - experiment

Qn: Is there the equivalent to the FB instability for a beam driven FRC?

Compressional Alfven Eigenmodes II: A Case Study

- ICE emission in Tokamaks
  - $\omega = |k|\, V_A$, $k \approx |k|$
  - wave excitation by supra Alfvénic particles
  - proposed for channeling energetic ion energy to thermal ions by coupling to TAEs

- Strong connection to CAEs in Spherical Tokamaks
  - no modification in tokamak theory
  - broad spectrum of modes predicted and observed
  - possible ion heating due to multi-mode resonance overlap

- Relevance to Burning Plasma
  - potential for ion heating in conventional torus and spherical torus

Relevance of Alfven Eigenmodes in 3-D torus to Axi-symmetric Torus III:

- Gap modes, TAEs, EAEs, etc common to axi-symmetric and 3-D torii

- Toroidal coupling due to 3-D geometry is not necessarily unique to stellarators
  - 3-D error fields in tokamaks are very important
  - large amplitude modes MAY lead to toroidal coupling of Alfven modes in axi-symmetric systems

- Stability of AEs in a B.P. is highly relevant to 3-D systems
  - same drive and damping physics
  - addition of toroidal coupling needs controlled experiments
  , could be possible in tokamak plasma!

Lets Get to Work: A White Paper for Snowmass on ICCs and Energetic Particle Physics in the Tokamak is Needed

Ideas, Connections, Volunteers !!