ASDEX Upgrade

Max-Planck-Institut
für Plasmaphysik

IPP

I) Neoclassical Tearing Modes and Fast Ions Confinement
II) Sawtooth control by ECCD

in ASDEX Upgrade

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the AUG team

Present AUG work on mode control

Sawtooth active stabilization/destabilization

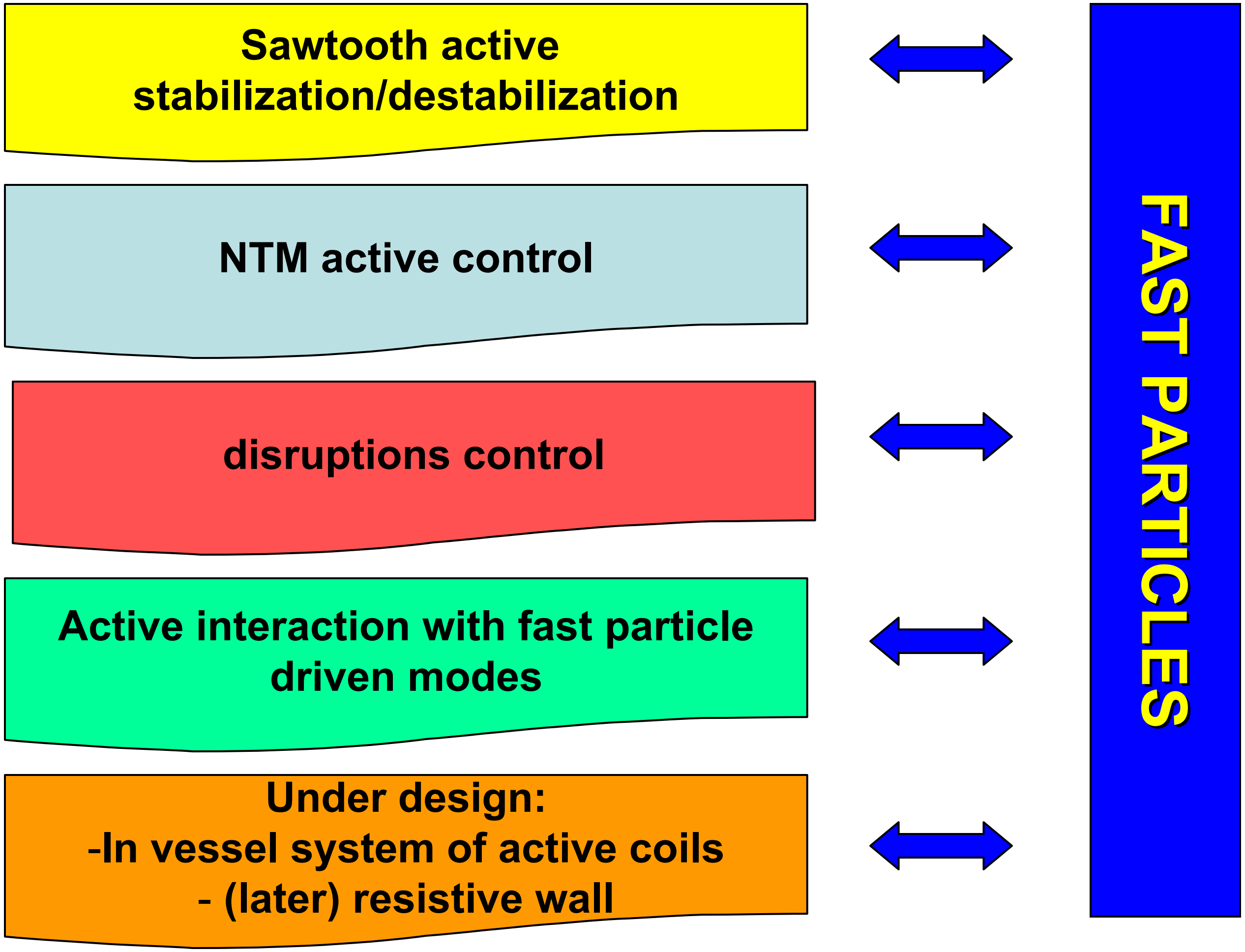
NTM active control

disruptions control

Active interaction with fast particle driven modes

Under design:
- In vessel system of active coils
- (later) resistive wall

Present AUG work on MHD control



Sawtooth active stabilization/destabilization

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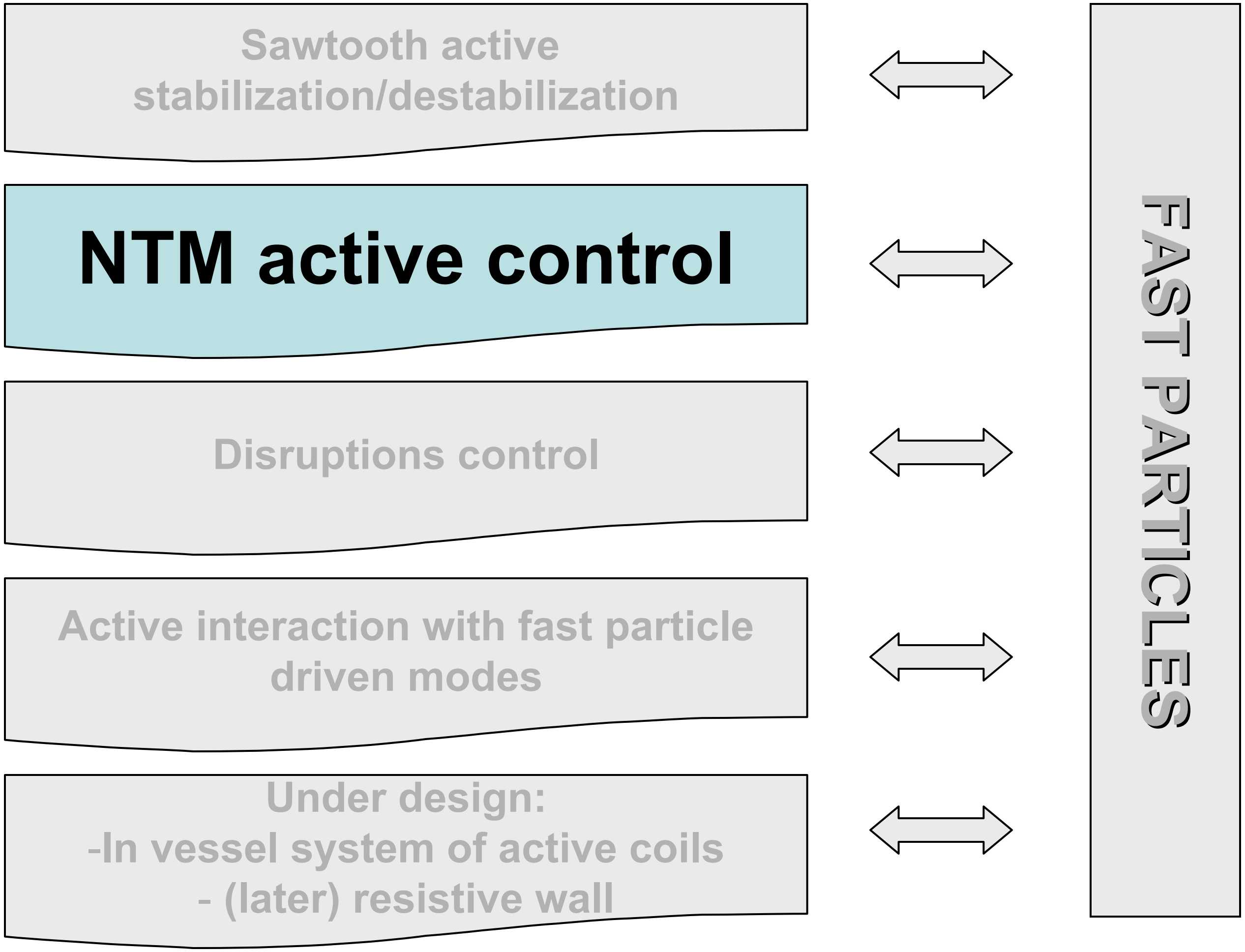
FAST PARTICLES

NTM ←→ Maraschek's talks wednesday



Sawtooth active stabilization/destabilization

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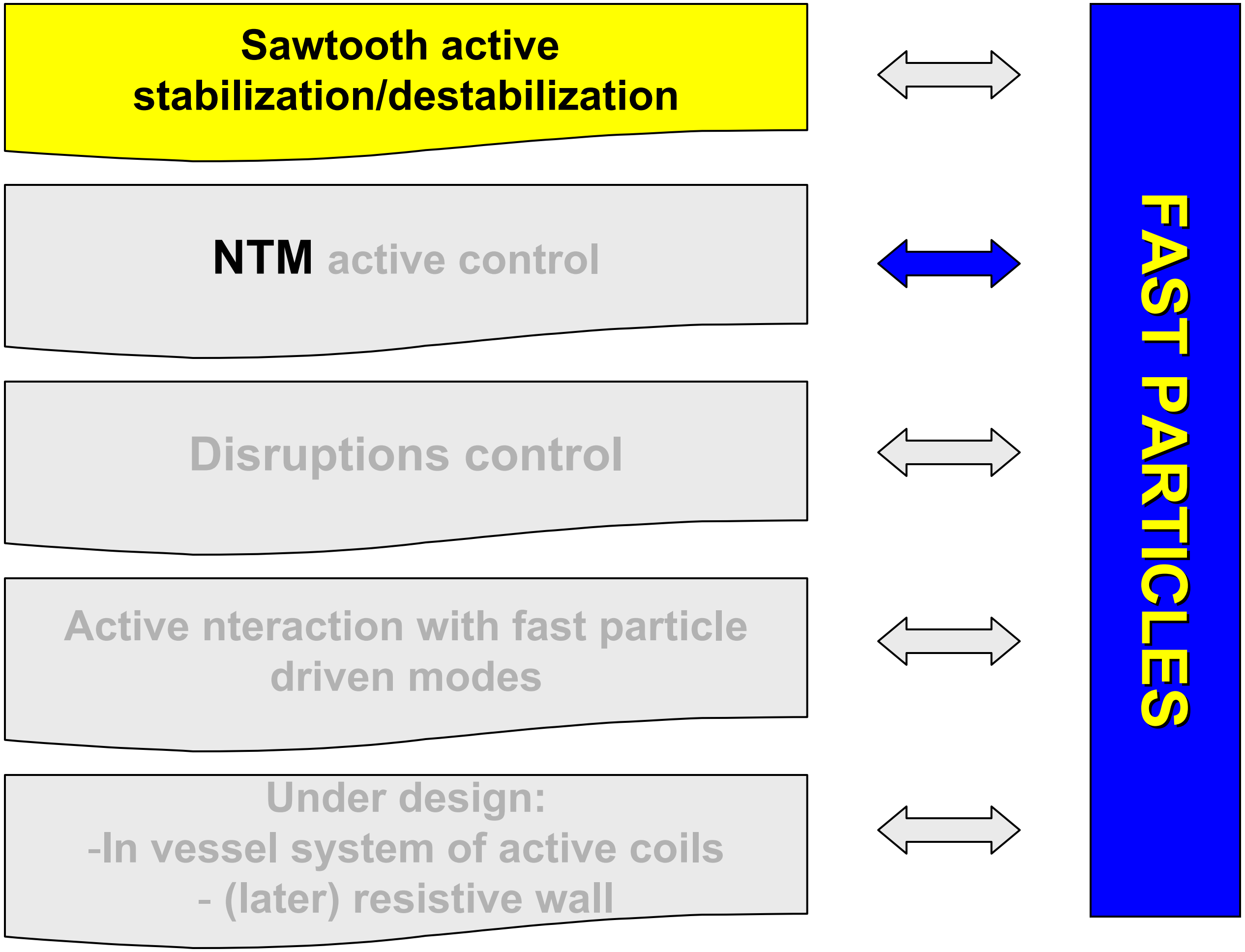
FAST PARTICLES

Topics for this talk



Sawtooth active stabilization/destabilization

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Active nteraction with fast particle driven modes

Under design:
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FAST PARTICLES

Outline

- *PART 1:*
  - Fast ions transport due to neoclassical tearing modes

- *PART 2:*
  - Sawtooth control

Headlines for part 1

- We have measured NBI ***fast ion losses*** due to a Neoclassical Tearing Mode (NTM) in ASDEX Upgrade with:
  - Energy and pitch angle resolution
  - 0.5 μs time resolution

- These losses have been explained as the result of ***orbit stochasticity***, due to overlapping of multiple islands chain in the fast particles orbit space.
  Numerical simulations done with the code ORBIT:
  - predict losses in presence of magnetic islands and
  - agree with experimental results

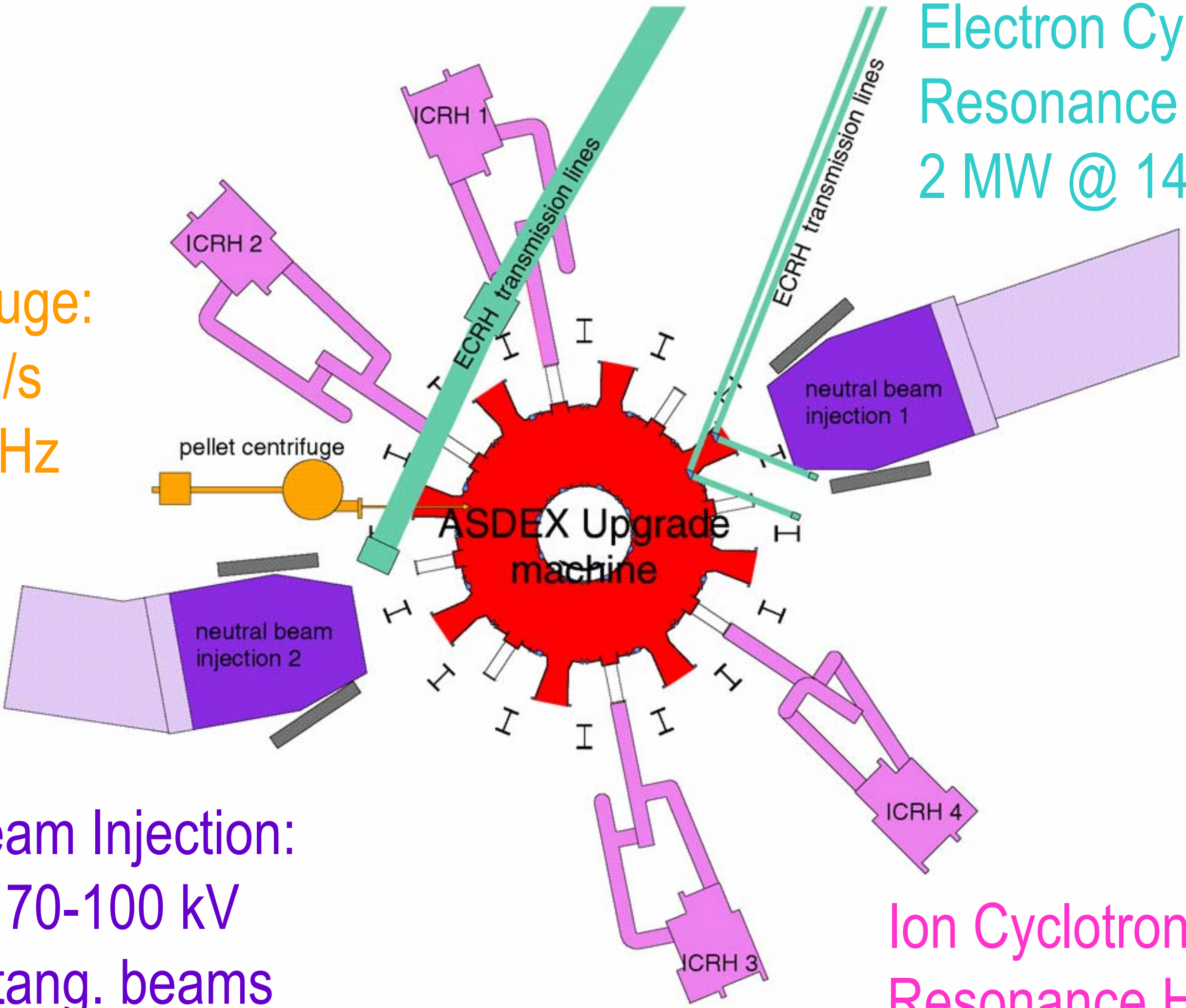
Headlines for part 2

- Stabilization / destabilization of sawtooth by ECCD-ECRH successfully obtained in AUG
- Higher efficiency with narrower ECCD deposition (i.e. larger J_{CD}) demonstrated
- Project for monster sawtooth destabilization launched

ASDEX Upgrade heating and fuelling systems

Electron Cyclotron Resonance Heating:
2 MW @ 140 GHz

Pellet Centrifuge:
240 - 1200 m/s
rep. Rate 80 Hz



Neutral Beam Injection:
20 MW @ 70-100 kV
NBCD by tang. beams

Ion Cyclotron Resonance Heating:
8 MW @ 30-60 MHz

NTM induced fast ion losses

NTM induced fast ion losses: why we study them

- The effect of **NTM** on **confinement of thermal particle** is well known, but…

- Less information is available on the **effect of NTM on fast particle confinement**.

- This might be an issue **relevant for ITER and a reactor:**
  - *A small level of NTM might be an ingredient of improved H-mode*
  - *NBI heating and current drive efficiency might be affected by NTM or other slow MHD modes*
  - *Interaction with plasma facing components*
  - α *particles confinement and thermalization*

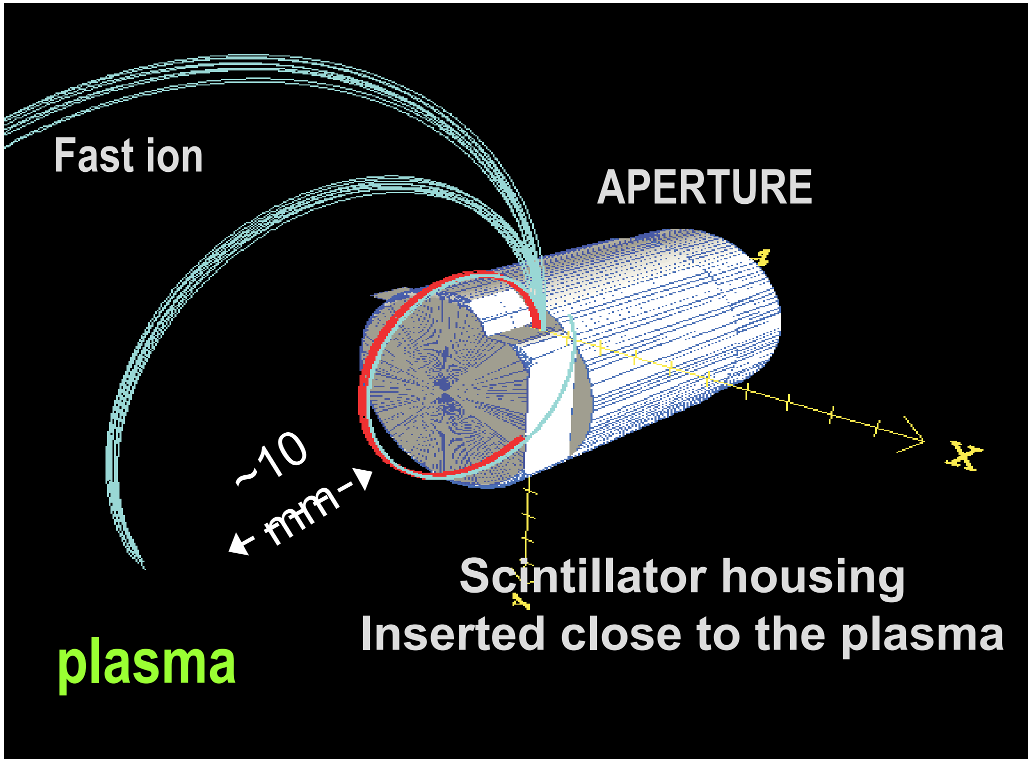
The new AUG Fast Ion Losses Detector (FILD)

PLASMA IONS
thermal + fast (NBI, ICRH)

FAST IONS SELECTOR:
aperture

DETECTOR:
scintillator plate

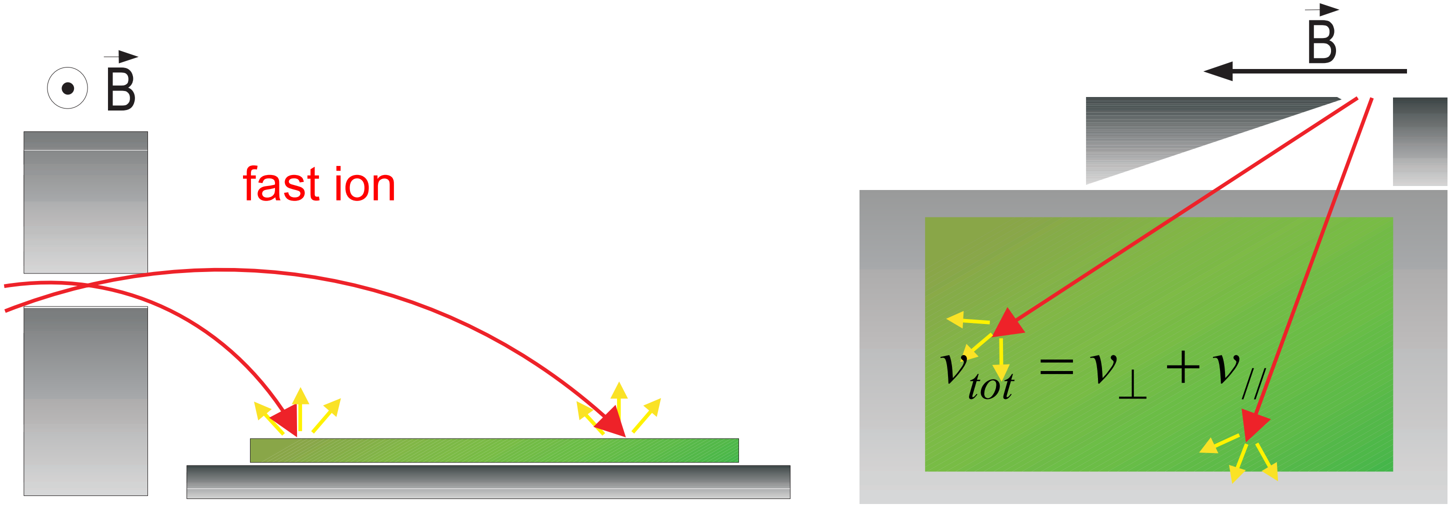
M.Garcia Muñoz, Ph.D. thesis, LMU , München (2006)
M.Garcia Muñoz, U. Fahrbach et al., 2005 EPS paper P5.085



2-d detector for energy and pitch angle resolution

- The strike points of the ions on the scintillator plate depend on their:
  - **gyroradius (energy)** and
  - **pitch angle**

➔ Magnetic spectrometer



- Simultaneous imaging of the scintillator with:
  - **CCD camera** (slow, but high spatial resolution)
  - Array of **20 photmultiplier** tubes (very fast – **1 MHz** overall bandwidth)

FIELD setup overview

- Simultaneous imaging of the scintillator with:
  - **CCD camera** (slow, but high spatial resolution)
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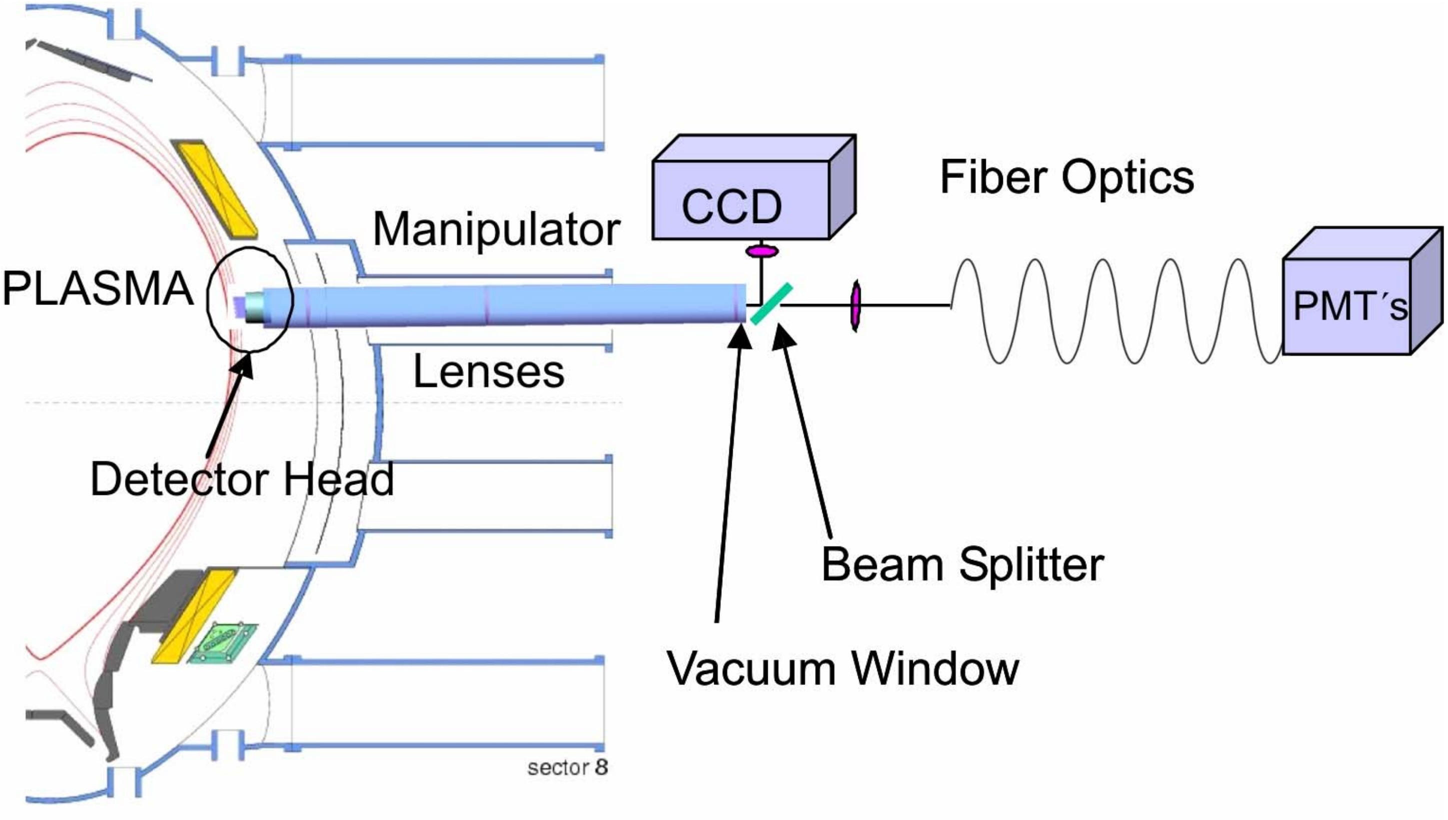
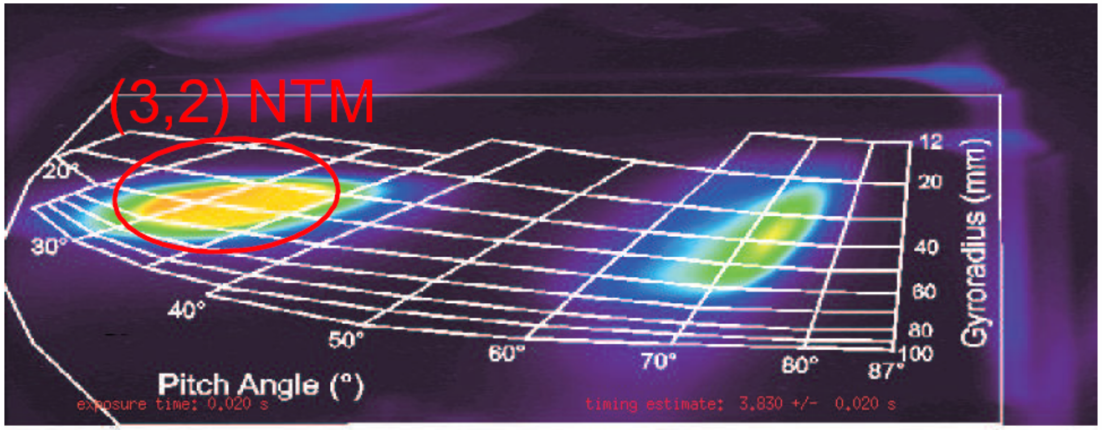
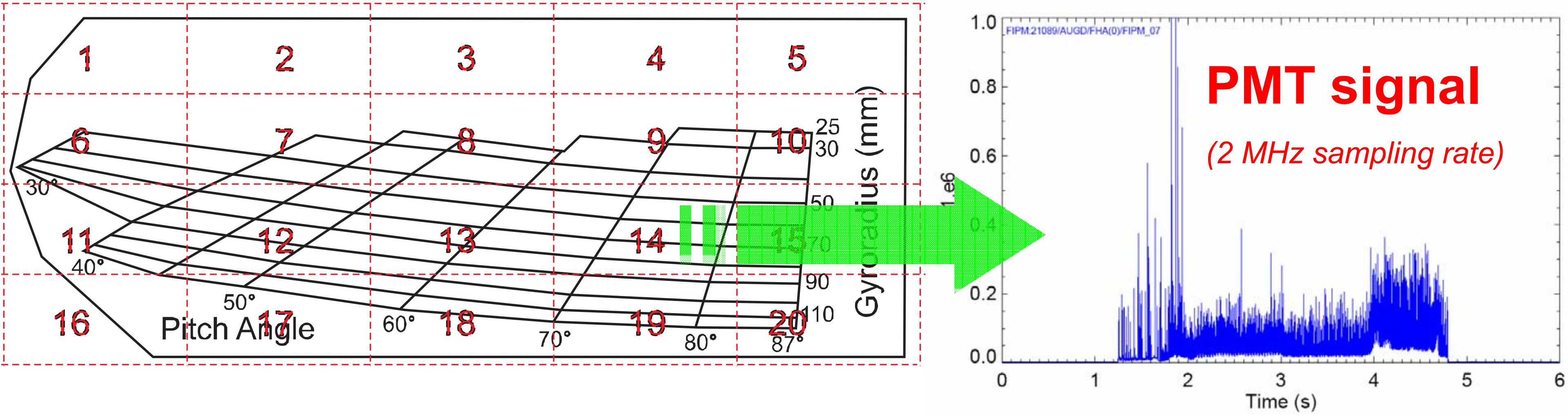


Energy and pitch angle resolution



CCD image



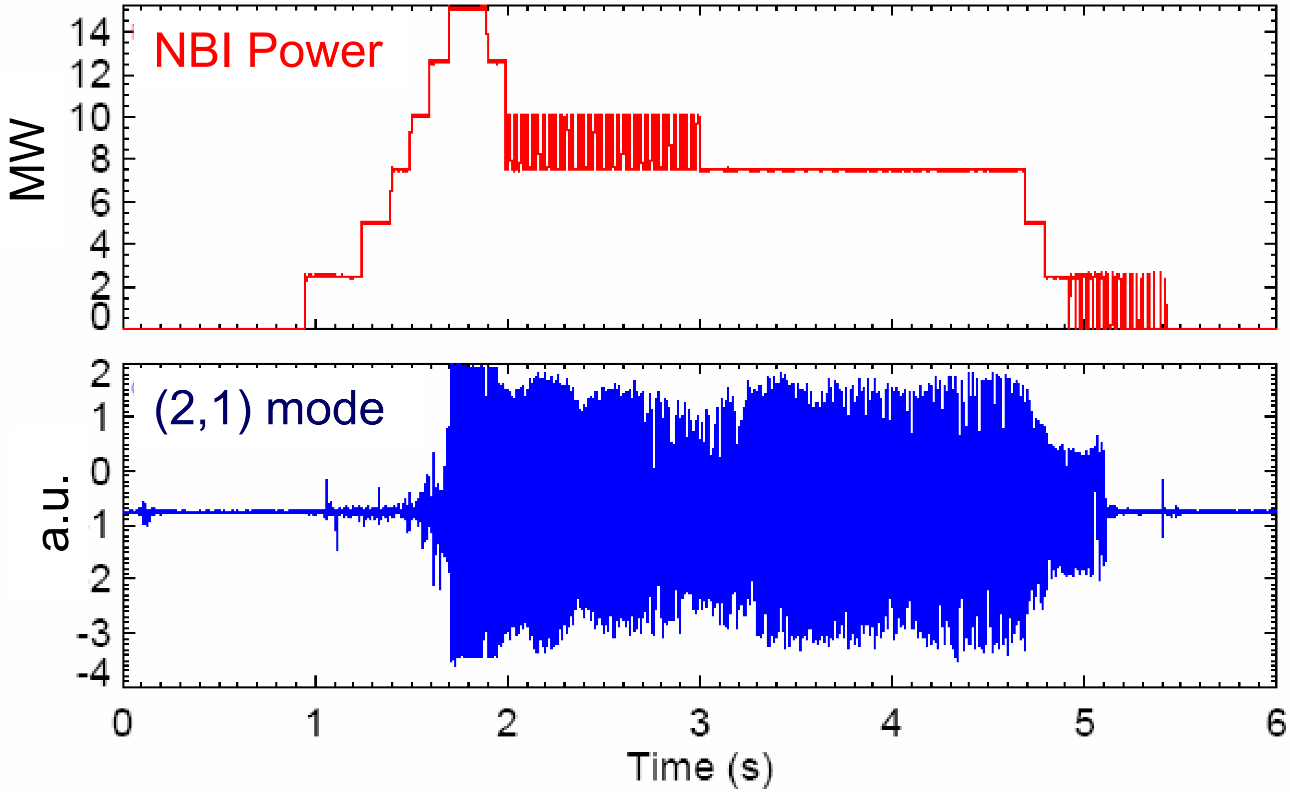
PMT signal

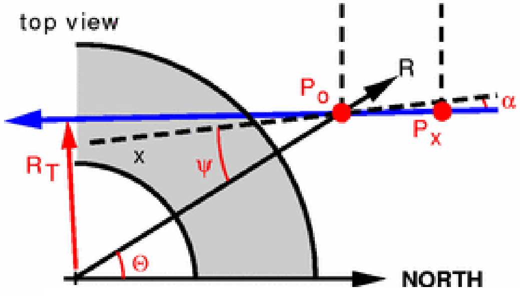
(2 MHz sampling rate)

NBI: drive and source

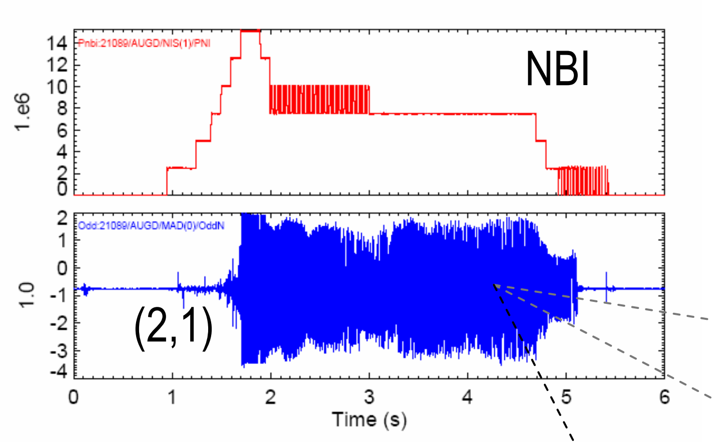
- **The NBI:**
  - ***drives the NTM***
  - ***provides a source of fast particles***, which can be modulated to study time scales of the loss mechanism

$I_p = 0.8$ MA, $B_t = 2$ T, $q_{95} = 4.5$

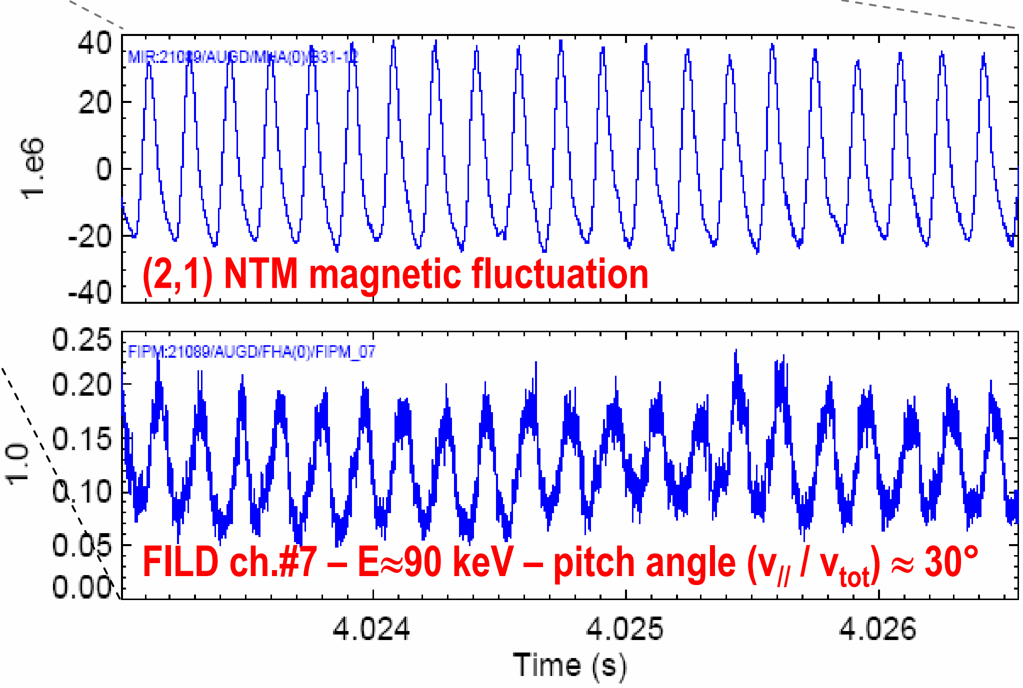




(2,1) and (3,2) NTMs induce fast particle losses

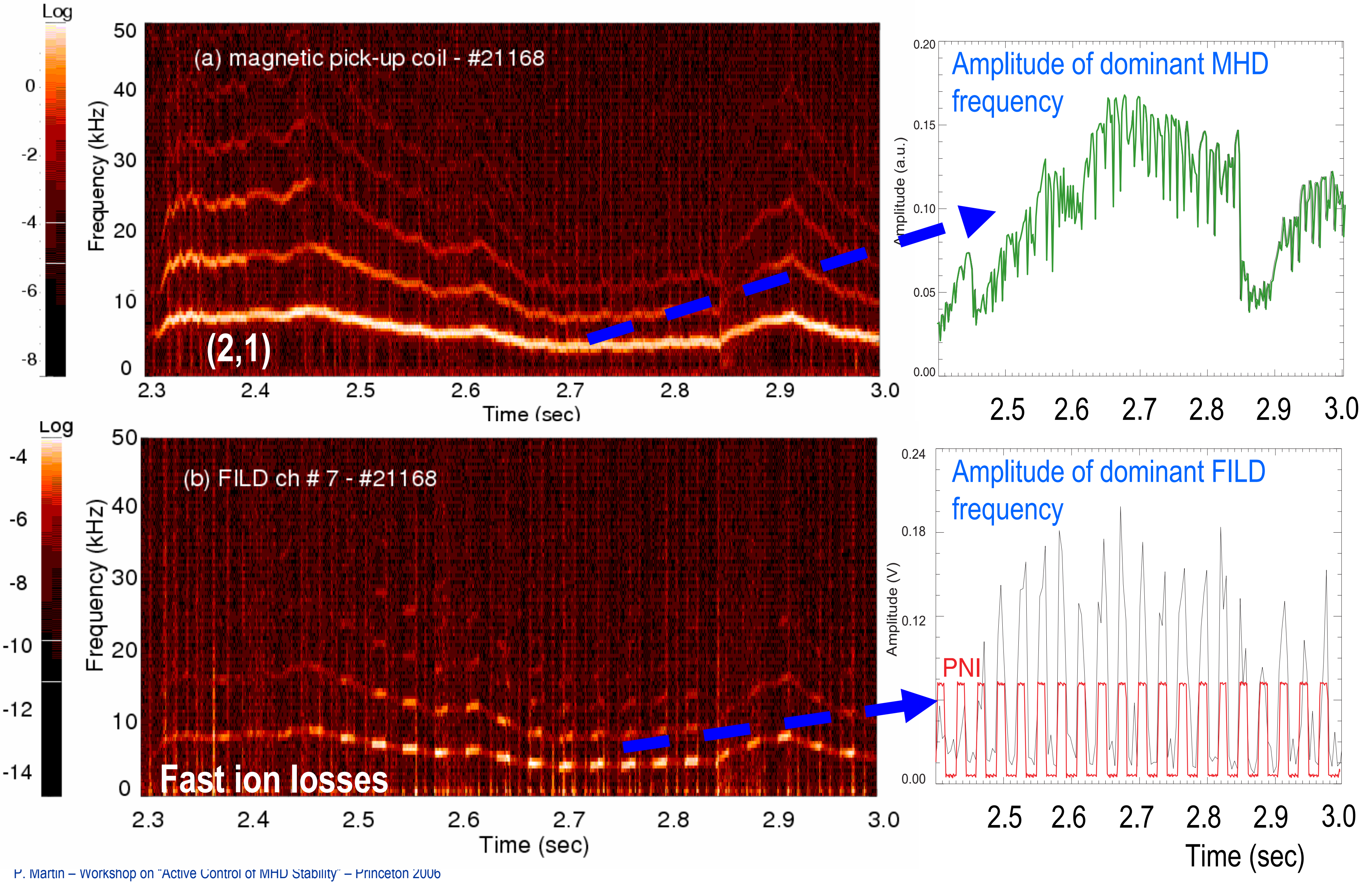


- Losses are well correlated in ***amplitude***, ***phase*** and ***frequency*** with the mode
- Lost particles have ***transit frequency*** (~ 200 kHz) >> mode frequency (< 20 kHz).



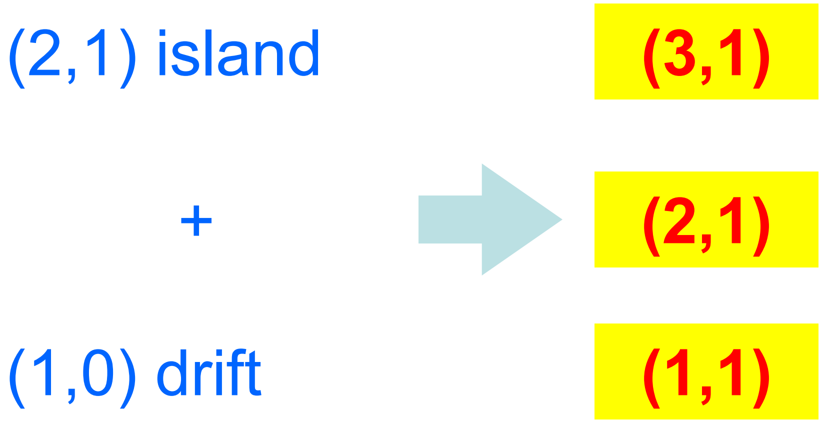
- Lost particles:
  - are mostly **passing**
  - have their birth energy i.e. the **NBI energy (93 keV)**.
- **Total amount of losses ≈ first orbit losses w/o NTM**

Fast ion losses track the mode and the source



Explanation of the losses

- In the **fast particles orbit space**, the **Guiding Center motion** along the perturbed magnetic field – due to the mode – combines with the **drift**
- The helical field perturbation introduces **new resonances** **between the orbital motion of the fast ions and the structure of the field**



(2,1) island

\+

(1,0) drift

(3,1)

(2,1)

(1,1)

*even if **only one island** is present in the **magnetic field**,*

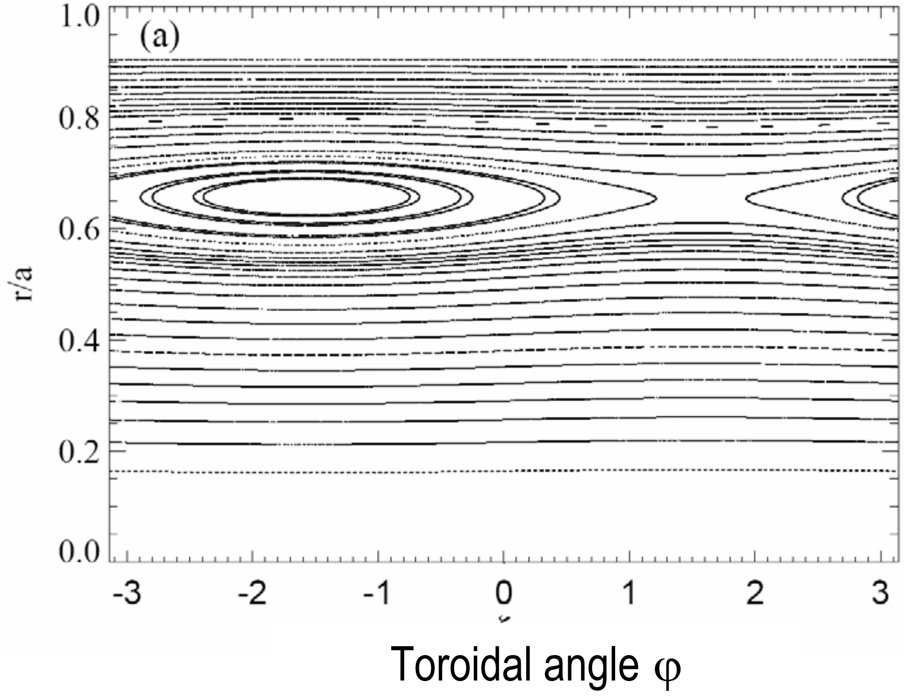
several drift islands** are present in the **fast particles orbit space

A stochastic region in fast particles orbit space

- Multiple island chains in **the orbit space** may overlap and cause **stochastic motion of the fast particles**

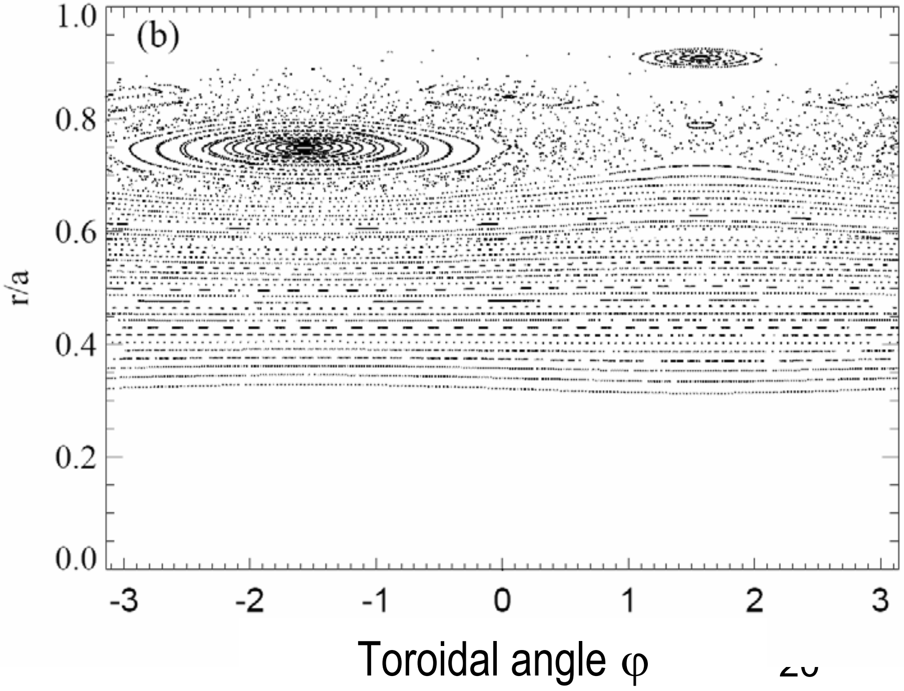
[Carolipio et al., Nucl. Fusion 42 (2002), Mynick PoF B5 (1993)]

Magnetic field (with a 2/1 mode)



100 keV deuterons orbits

(in the magnetic field of the left frame)



Simulation of fast ions behaviour

(in collaboration with Consorzio RFX)

- Montecarlo code **ORBIT** (*R. White, PPPL*) allows to follow the guiding center motion of fast ions

- A population of ~30000 test deuterons with E > **90 keV** is deposited **in a 2 T** plasma with circular cross section, AUG size and **a (2,1) mode**

- The particles **birth location, energy and pitch** are calculated with FAFNER code using AUG plasmas and NBI parameters

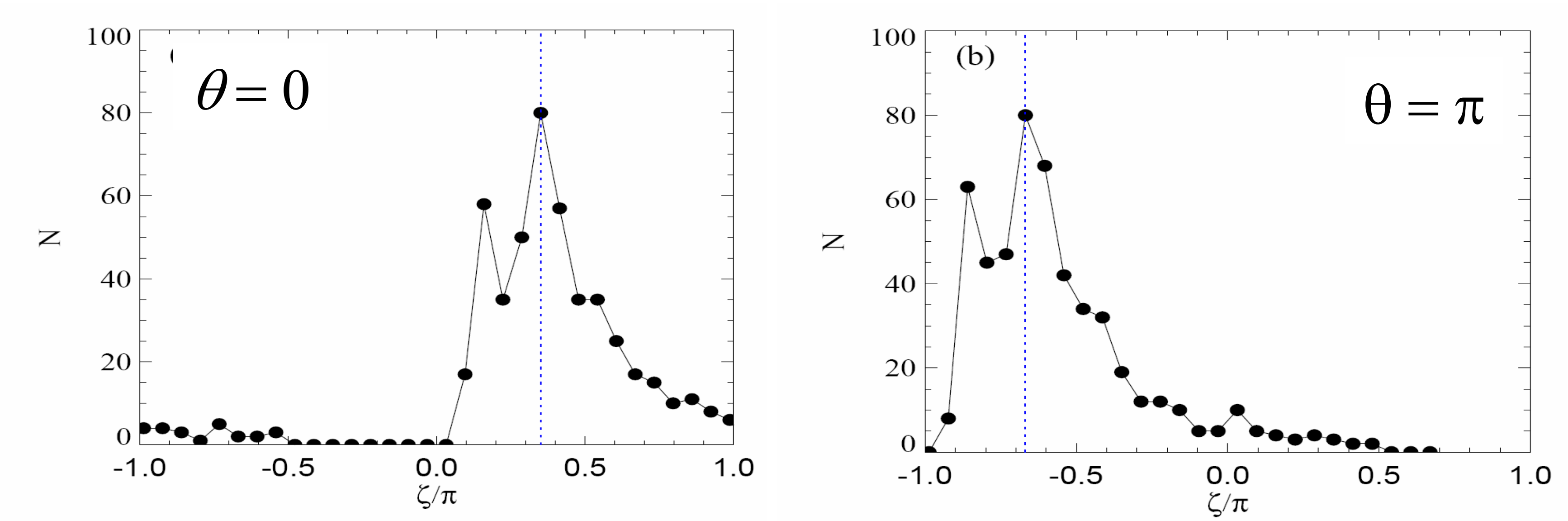
- **Pitch angle scattering** and **slowing-down** included

Fast ion losses are recorded at the plasma edge

Loss times and positions of lost particles are monitored

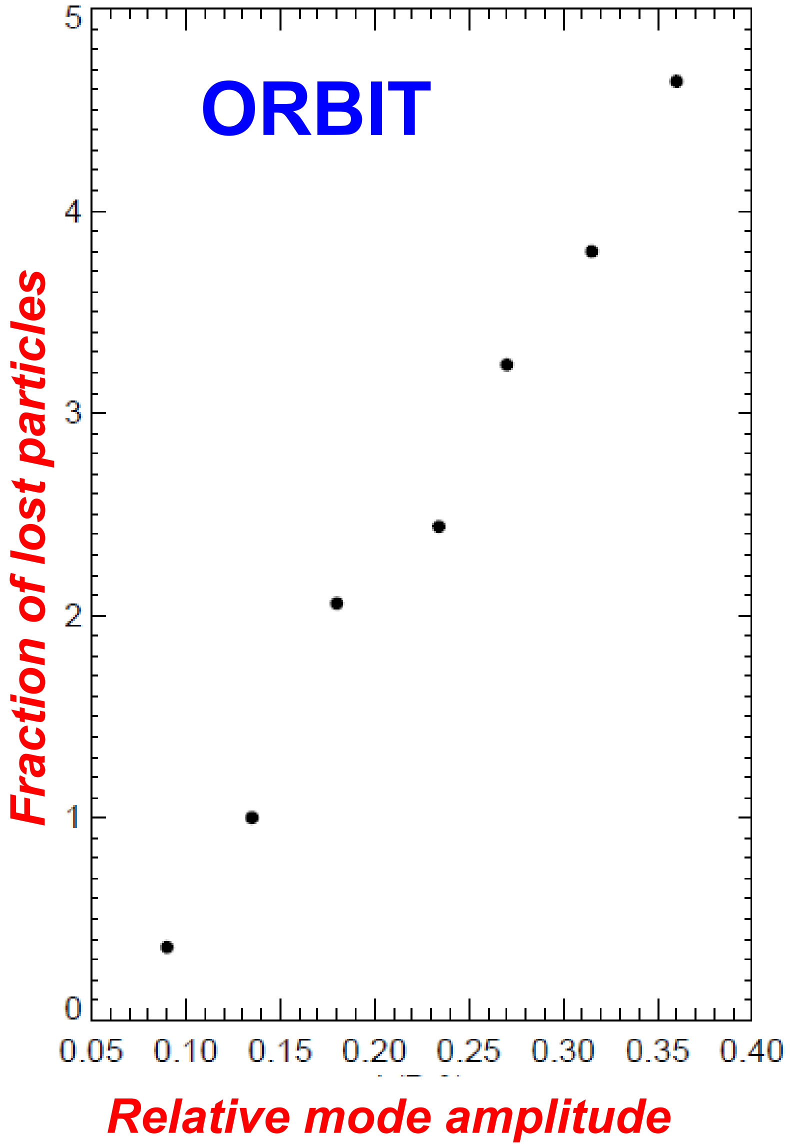
Toroidal localization of the losses

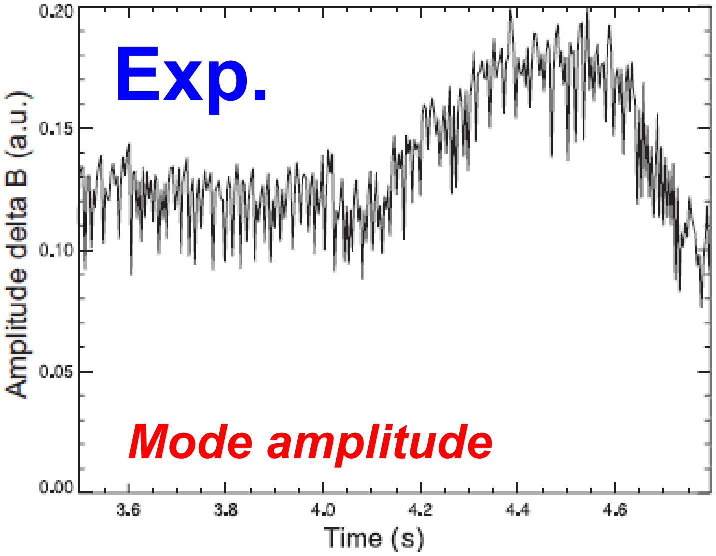
- A clear **maximum** as a function of the toroidal angle φ is evident, which changes its location according to the mode poloidal phase
- This is a signature of a **dominant *n*=1 pattern** *(we have a (2,1) mode!)*

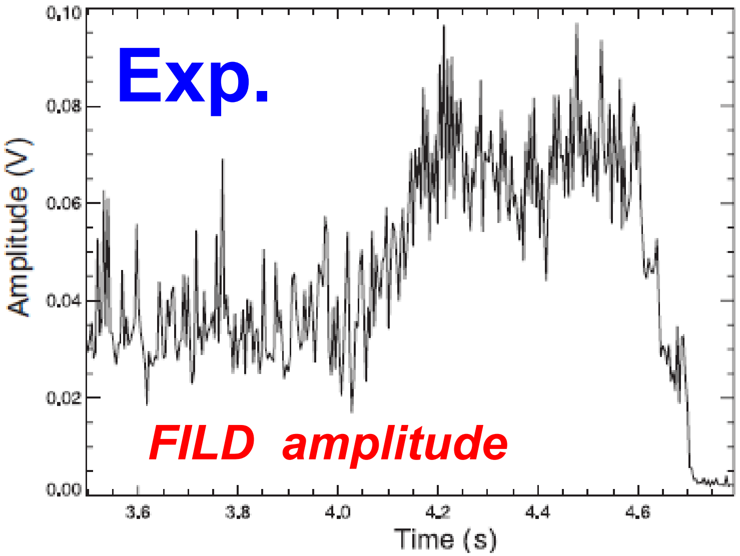


This is consistent with the experimental observation of the constant phase locking between the NTM and the losses signal.

Scaling with mode amplitude





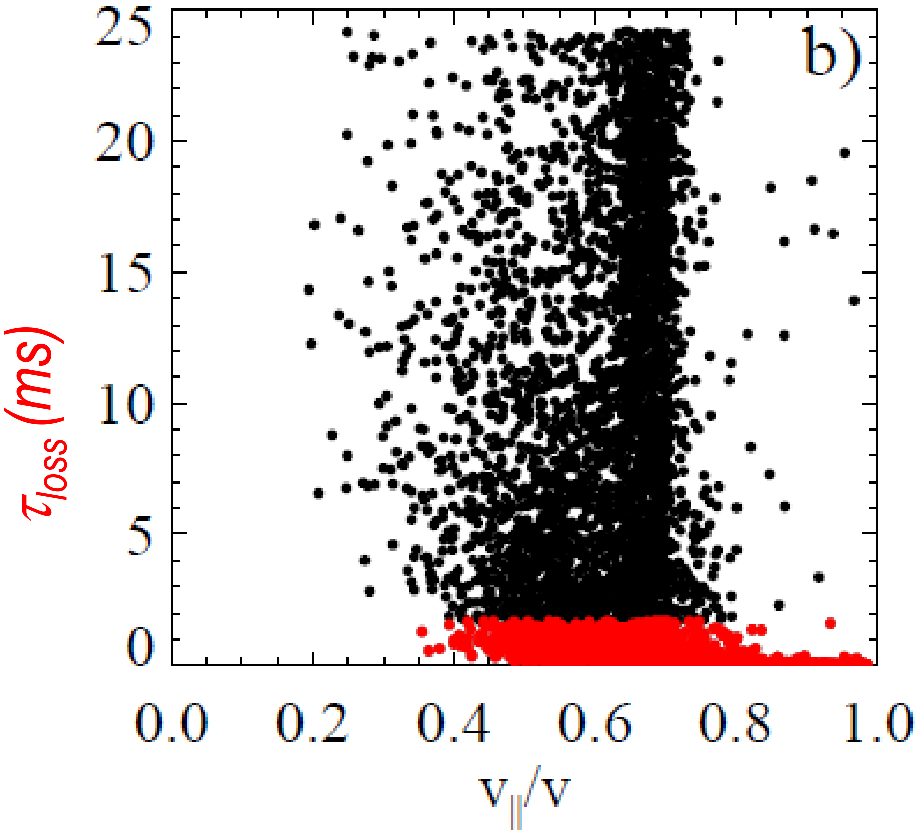


Properties of the lost particles

Run time of the order of slowing down time

Particle lost with a broad distribution of pitch angles

High energy particles lost on the shortest time scales

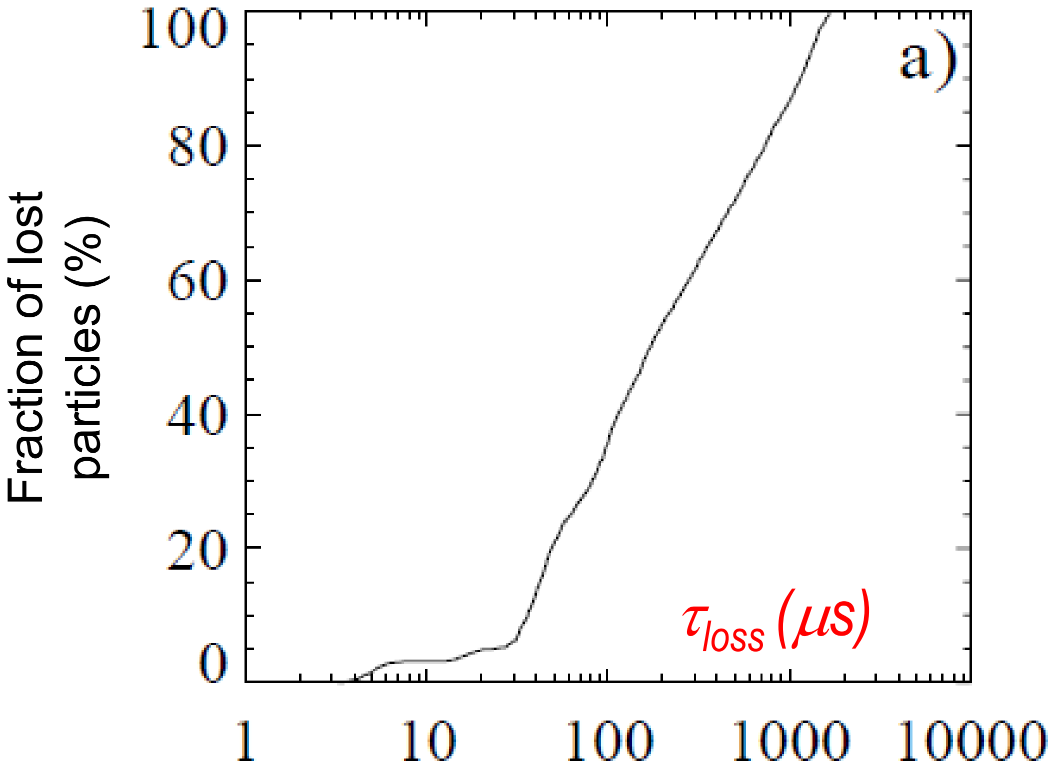


Red points ➔ *E* > 90 keV

Particles are lost in a broad range of time scales

Cumulative probability distribution of particle lost with E> 90 keV

as a function of loss time τ_{loss}



Consistent with experimental observations

Various time scales for the losses in the experiment, too

- **Prompt losses and 'slower' escapes**

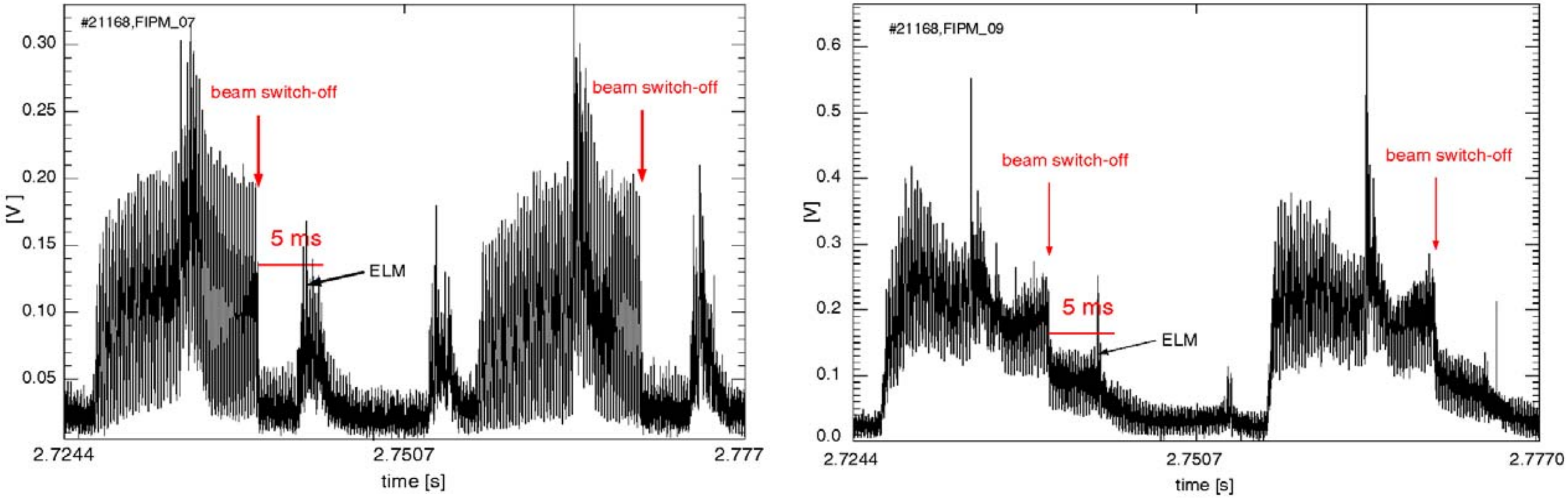


Fig. 8: Response of the fast ion losses to switch-on and –off of the NBI source #8. Left for particles deposited on the high field side, right for particles deposited on the low field side.

Conclusions on part I

- **Fast particle losses due to tearing modes have been measured in AUG with pitch angle and energy resolution**
- **NBI passing ions are lost with their birth energy, on time scales ≤ 2-3 ms**
- **Experimental results described by the orbit stochasticity mechanism**
- **Qualitative and quantitative agreement between experimental and numerical results**

- **Next steps:**
  - New measurements with additional detectors, for better space resolution
  - Optimization of numerical simulations
  - Particles redistributions studies

M.Garcia Muñoz, Ph.D. thesis, LMU , München (2006) & POSTER NP1 40

M.Garcia Muñoz, U. Fahrbach et al., 2005 EPS paper P5.085

M.Garcia Muñoz et al. Submitted to PRL

P. Martin et al., EPS 2006 postdeadline

Sawtooth control

A. *Manini et al.*

14th Joint Workshop on ECE and ECRH , Santorini, 2006

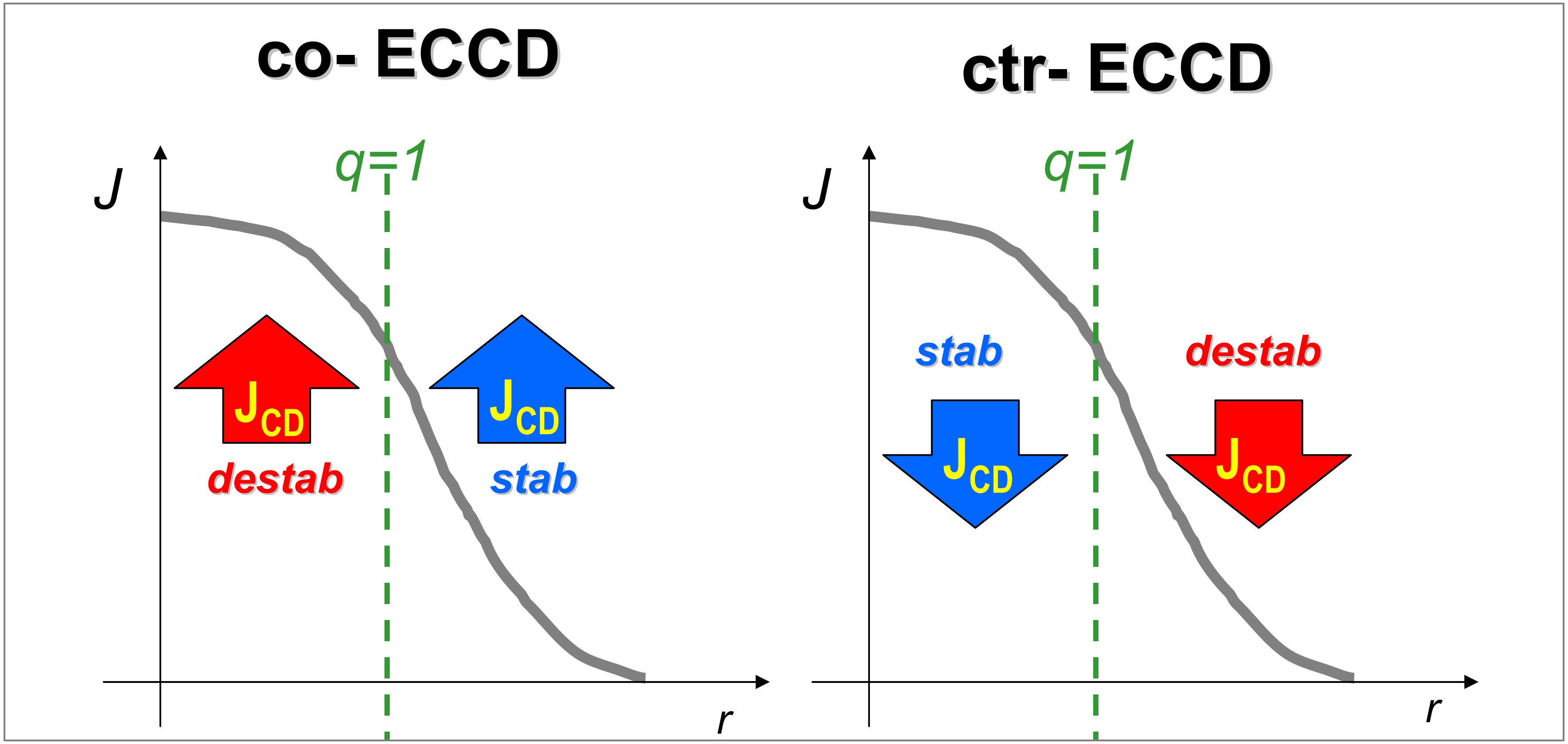
Motivations

- Optimisation of sawtooth control: can we achieve the same goals with less power ? i.e., do we gain if we deposit the same ECCD power in a smaller spatial region (as happens for the NTM case) ?

- Can we use ECCD to destabilize monster sawtooth, to avoid the drawbacks related with their crash ?

The principle of ECCD sawtooth control

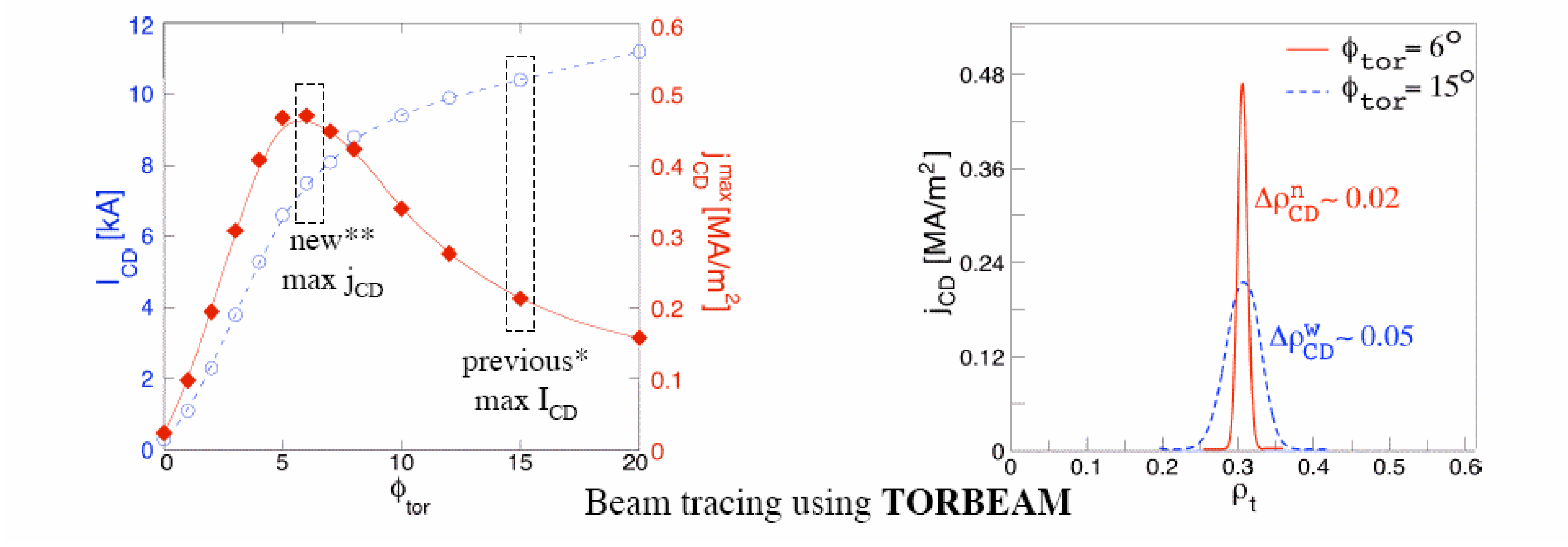
- Interact with the current density *J* profile to tailor its shape around the *q*=1 surface and affect magnetic shear (stability).
  - *Direct interaction: ECCD current drive*
  - *Indirect interaction: ECRH heating, via change of the resistivity profile*



- *Heating has the similar effect as co-ECCD*

Optimization of sawtooth control

- As for NTM stabilization, it is the current density which matters



Beam tracing using **TORBEAM**

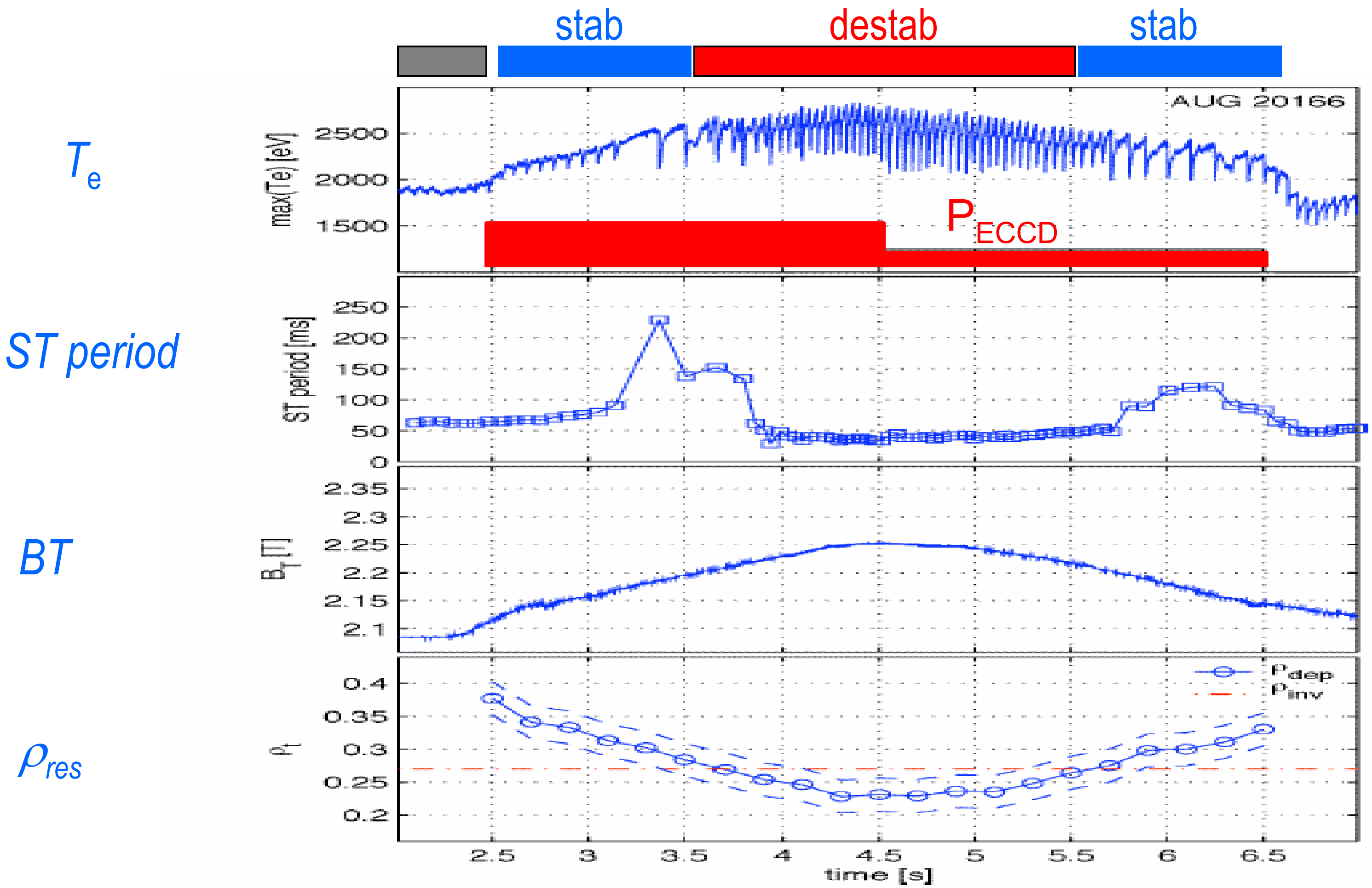
- Practical impact: less power needed with narrow deposition for ITER application?

The sawtooth stabilization experiment

1. B_t ramp to move radially ECCD resonance and scan the minor radius with:
    - *CO-injection*
    - *CTR-injection*
    - *Pure heating*
2. Measure for each case the sawtooth period (the gauge of the experiment)

The principle works !

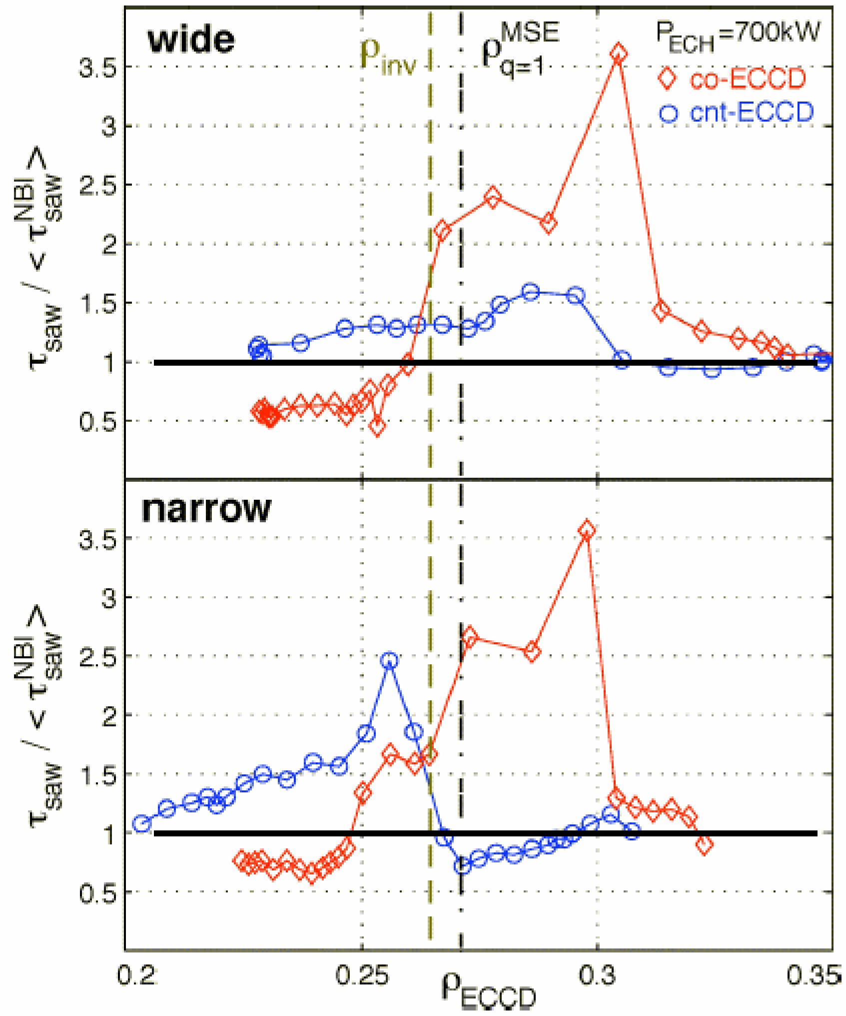
- Gauge ➔ sawtooth period
- B_t ramp to move radially ECCD resonance and scan the minor radius



Narrow vs. wide deposition

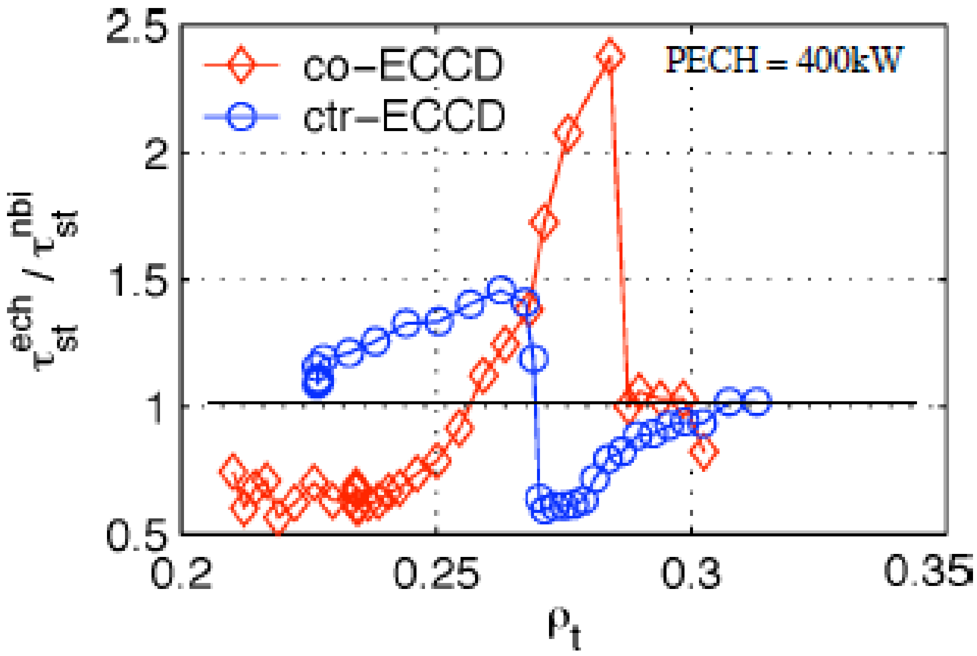
- With **wide** deposition heating effects dominate with ctr-CD

- With **narrow** deposition stronger effects are observed, in particular for ctr-CD



Advantages of narrow deposition

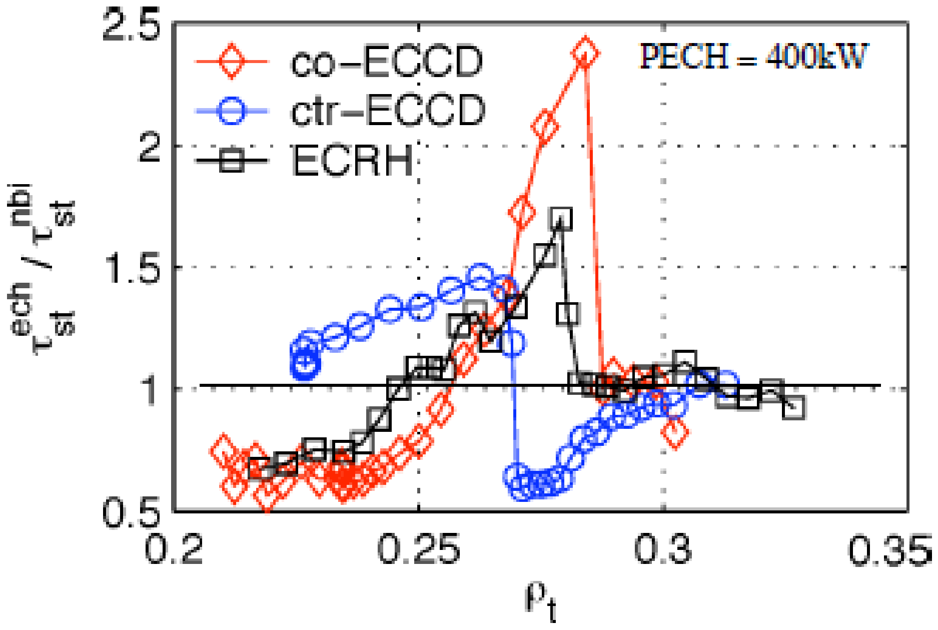
- **co-ECCD:**
  - more efficient for stabilization (less power needed)
  - Destabilization over larger ρ in comparison with CTR-



Pure heating with narrow deposition

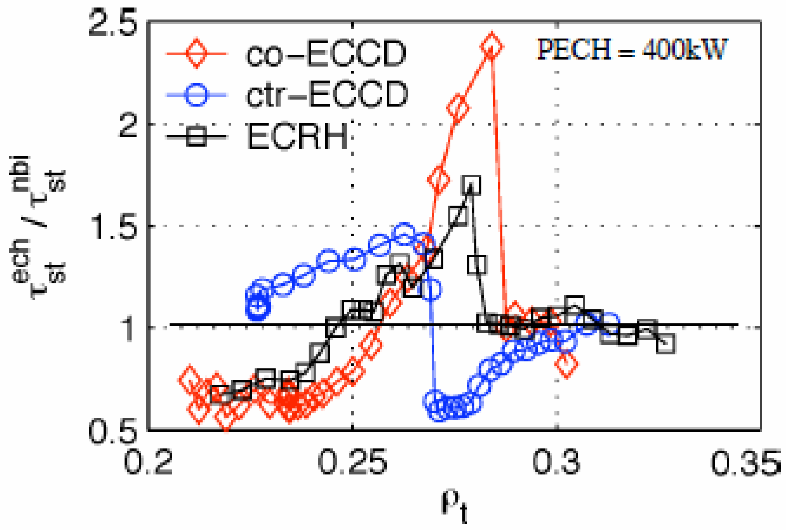
- **co-ECCD:**
  - more efficient for stabilization (less power needed)
  - Destabilization over larger ρ in comparison with CTR-

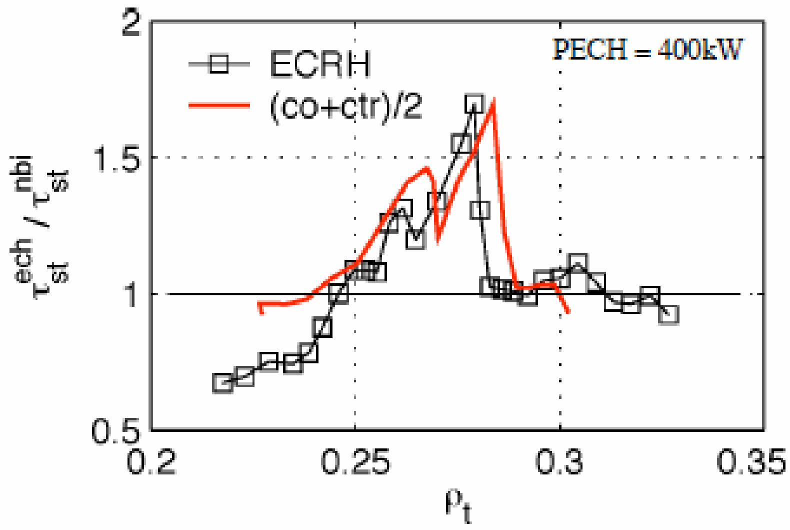
- **PURE HEATING** (co- & ctr-CD at half PECH)**:**
  - As co-ECCD



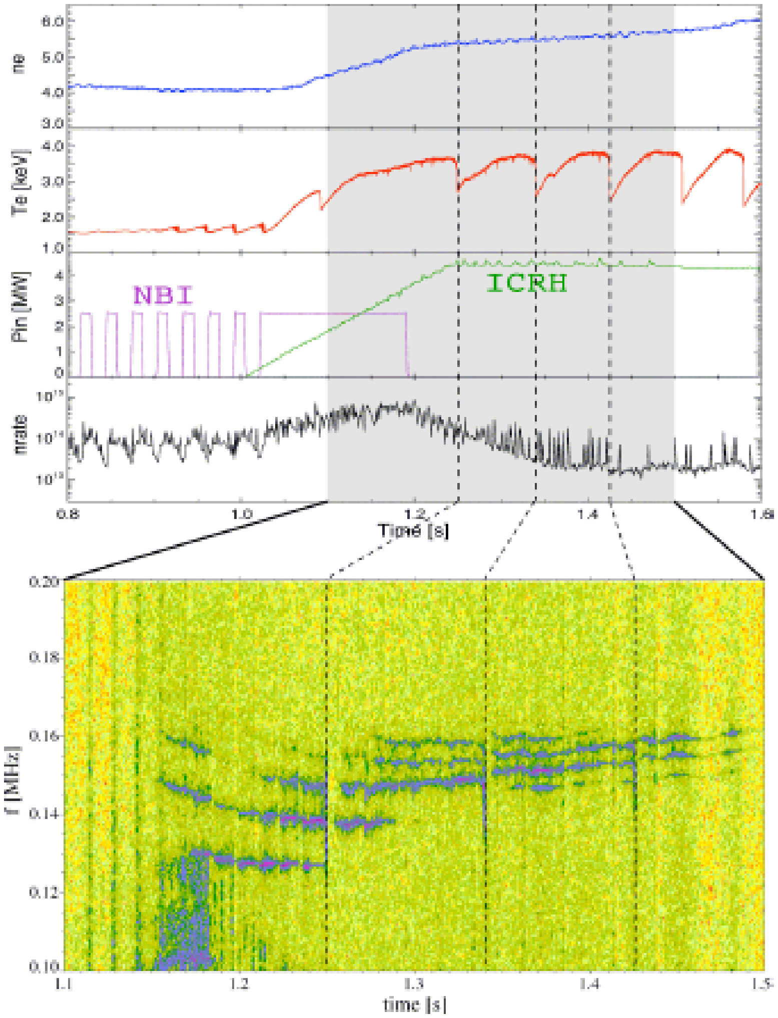
ECCD vs. ECRH

- Removing (linearly) the CD contributions results in heating contribution
- More modeling on-going





Destabilization of monster sawtooth



- First experiments to generate sawteeth stabilised by fast ions
- $I_P = 1.0\text{-}1.2\text{MA}$, $B_T = 2.0\text{T}$, natural n_e
- $P_{NBI} = 2.5\text{MW}$, $P_{ICH} > 4.0\text{MW}$

- First 2-3 show characteristics of "monster" sawteeth
- FILD [M. Garcia-Muñoz, 32nd EPS, Tarragona (2005)] shows TAE modes which expel fast ions
- First 2-3 sawteeth interrupt the TAE
- Signature seen also on Mirnov and SXR (central?)
- NBI deuterium accelerated by ICRH

Conclusions

- ECCD narrow deposition allows for higher J_{CD} and is more efficient in stabilizing / destabilizing sawtooth ➔ experiments successful
- Positive implications for ITER
- More accurate modelling on-going, to test theoretical predictions

- Experiments for destabilization of monster sawtooth started, but not conclusive, yet. (may be delayed because of the power limitation and of the priorities set by the tungsten program)

- New gyrotron system will provide great flexibility and improved performance for these experiments

The end