



Development of scenarios and diagnostics for fast ion studies in next generation tokamaks without beryllium

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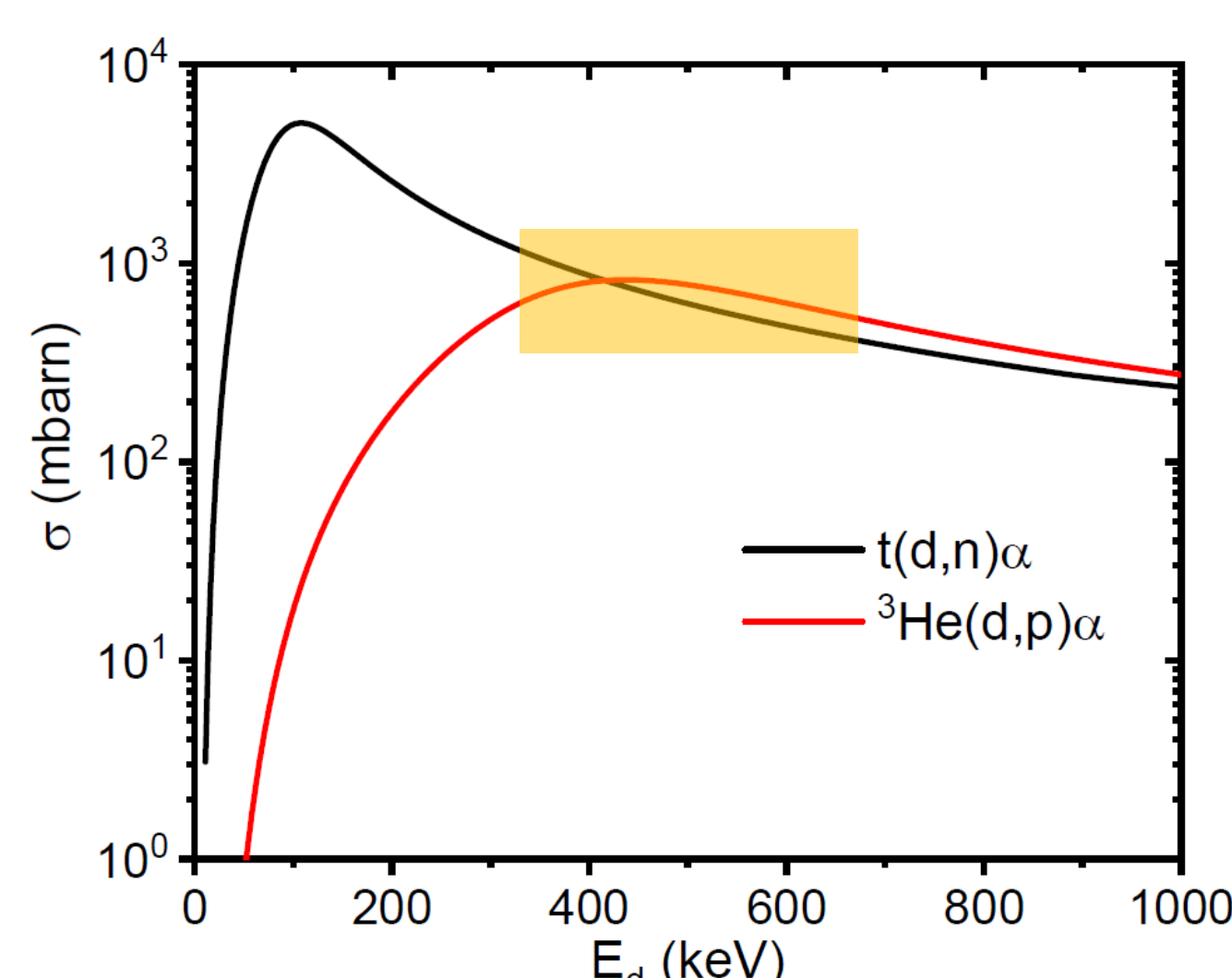
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MOTIVATION AND SCOPE

Following the latest ITER baseline, **no tokamak will use beryllium as the first wall material**, unlike the JET experience. In preparation of forthcoming DT capable devices without beryllium, we have started a **research program aimed at developing scenarios for MeV range and α particle generation and studies** in mid-size tokamaks, **related diagnostics** and **modelling**. In this contribution, we present the early results of this activity.

ALPHA PARTICLE GENERATION OPTIONS WITHOUT DT

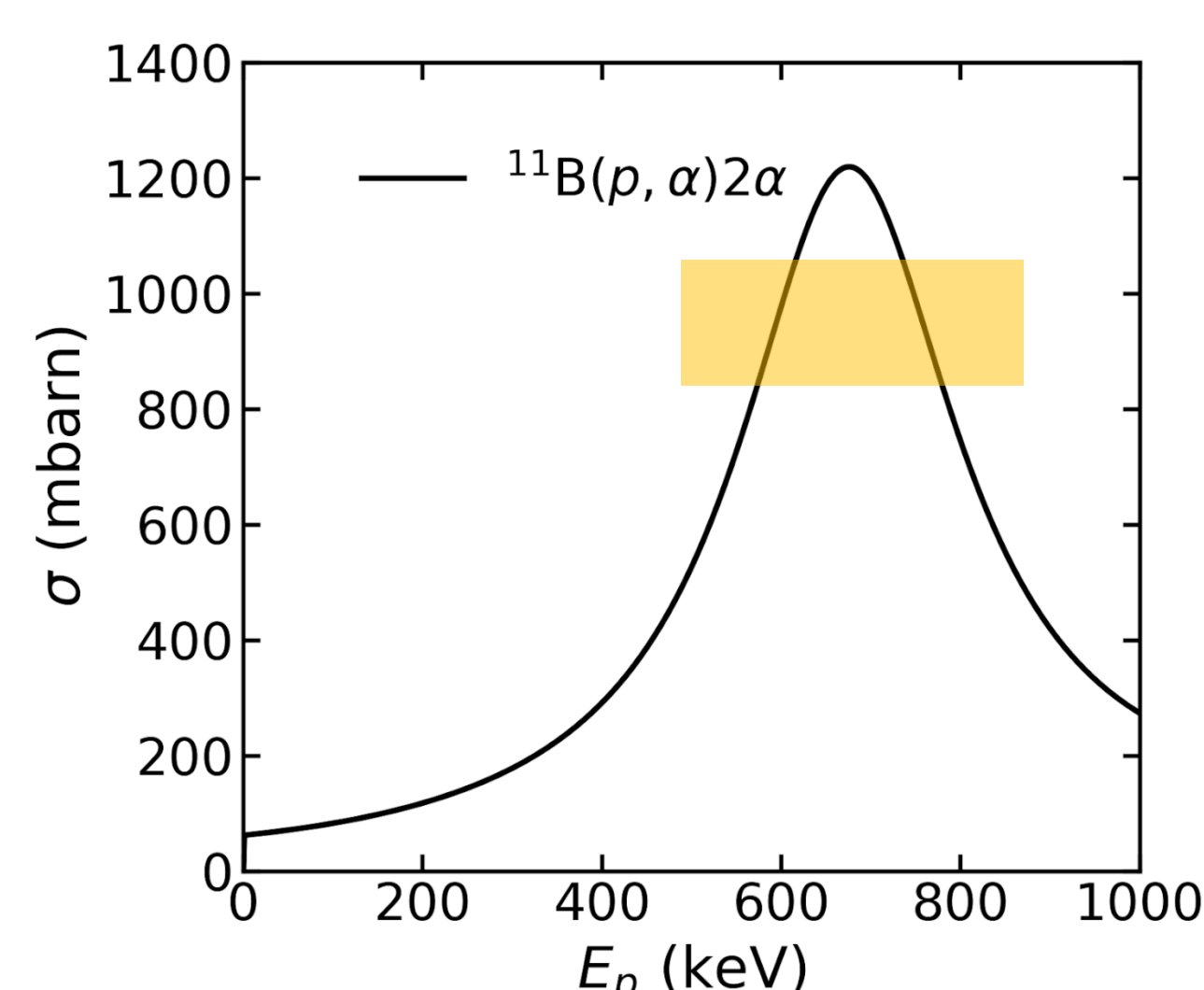


Plasmas with hydrogen + boron injection

Requires protons in the 500-800 keV energy range

D-³He plasmas

Requires deuterons in the 400-600 keV energy range



See also V. Kiptily, this conference and Nucl. Fusion 66 (2026) 066024
See also R. Coelho, this conference and Nucl. Fusion 66 (2026) 086029

In mid-size tokamaks, **ICRH** is the tool to generate 100s keV range ions.

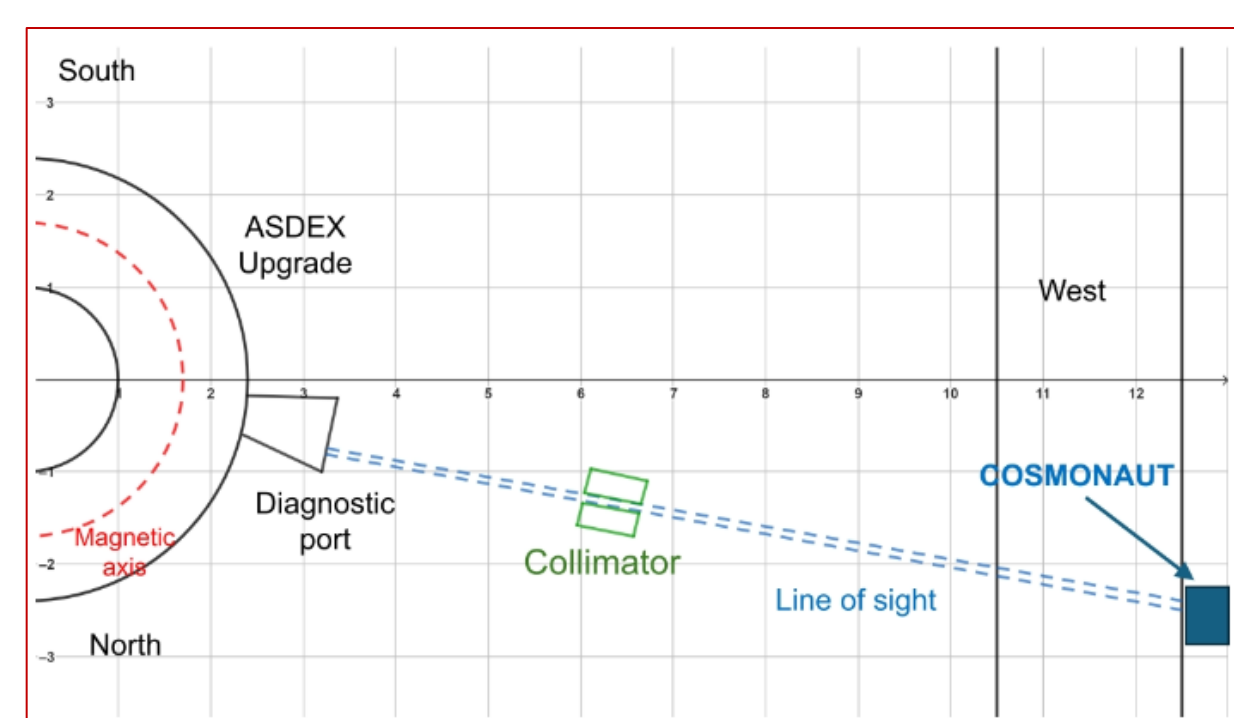
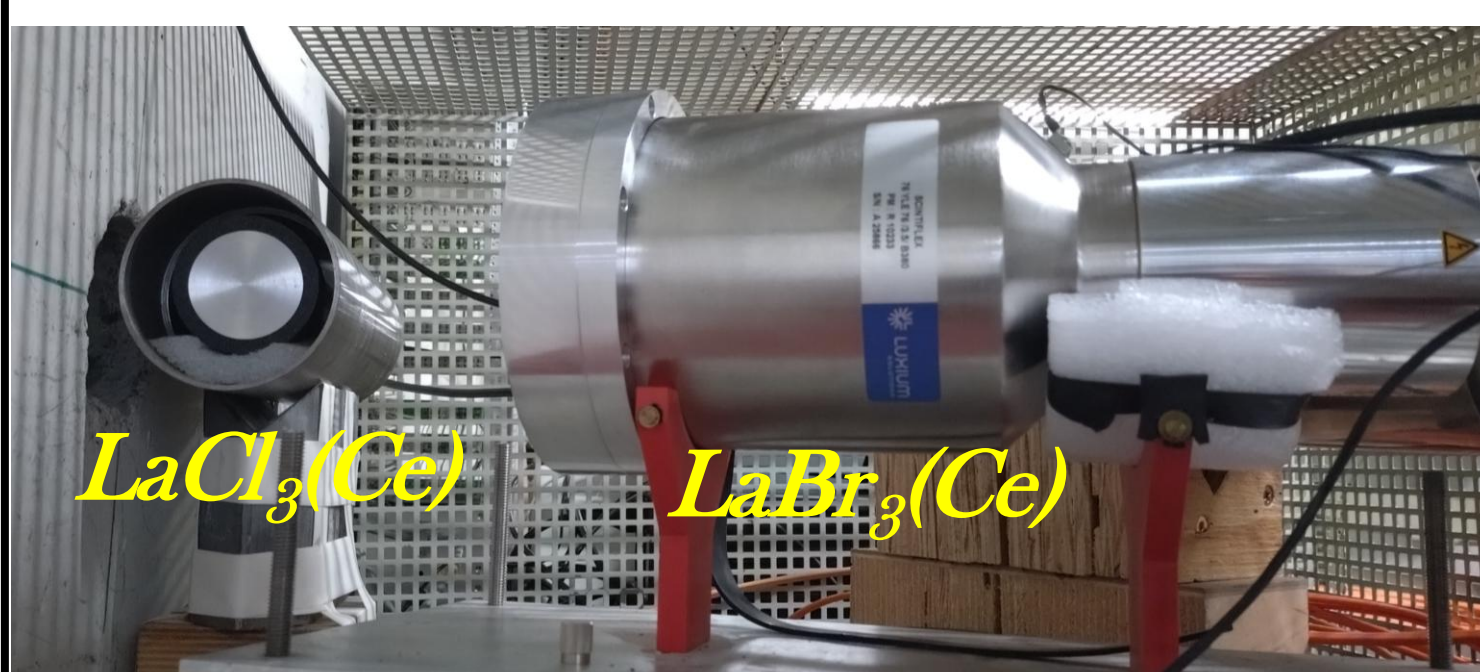
Gamma-ray spectroscopy diagnoses fast ions and alpha particles.

E_γ (MeV)	Reaction	Physical parameter
≈ 16.4 MeV	$^3\text{He}(d,\gamma)^5\text{Li}$	Alpha particle source
≈ 16 MeV	$^{11}\text{B}(p,\gamma)^{12}\text{C}$	Alpha particle source
3 – 4 MeV	$^{10}\text{B}(\alpha,p\gamma)^{13}\text{C}$	Alpha particle confinement

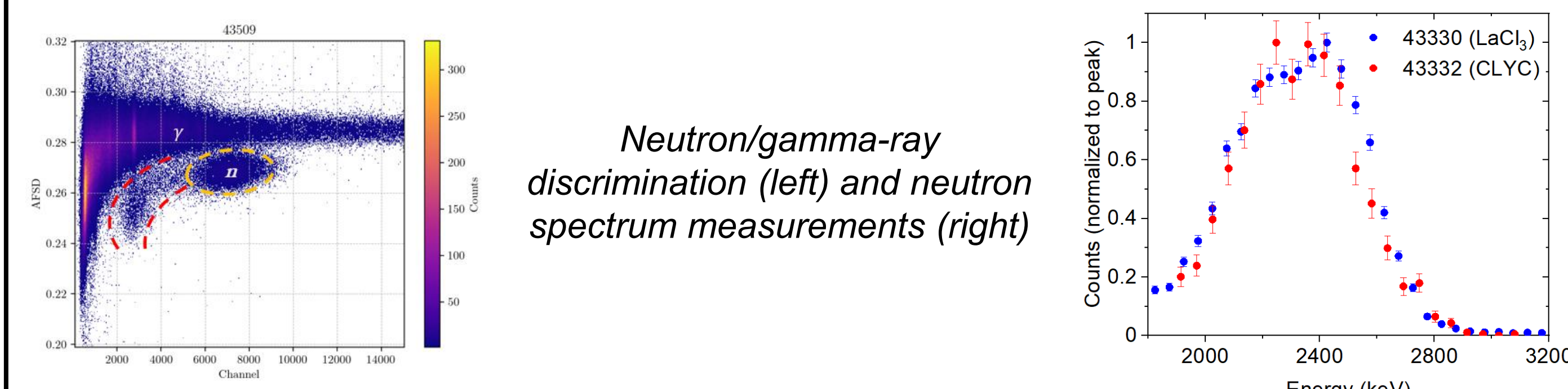
NEW FAST ION DIAGNOSTICS AT ASDEX UPGRADE

The FIRE&GO project has developed **new fast ion diagnostics for these scenarios at ASDEX Upgrade**. These are:

- **COSMONAUT+**, a 1'.5"x1.5" LaCl₃(Ce) based **compact neutron spectrometer** for **fast deuterium** studies.
- A 3"x3" LaBr₃(Ce) **gamma-ray spectrometer** for **proton and alpha particle studies**.



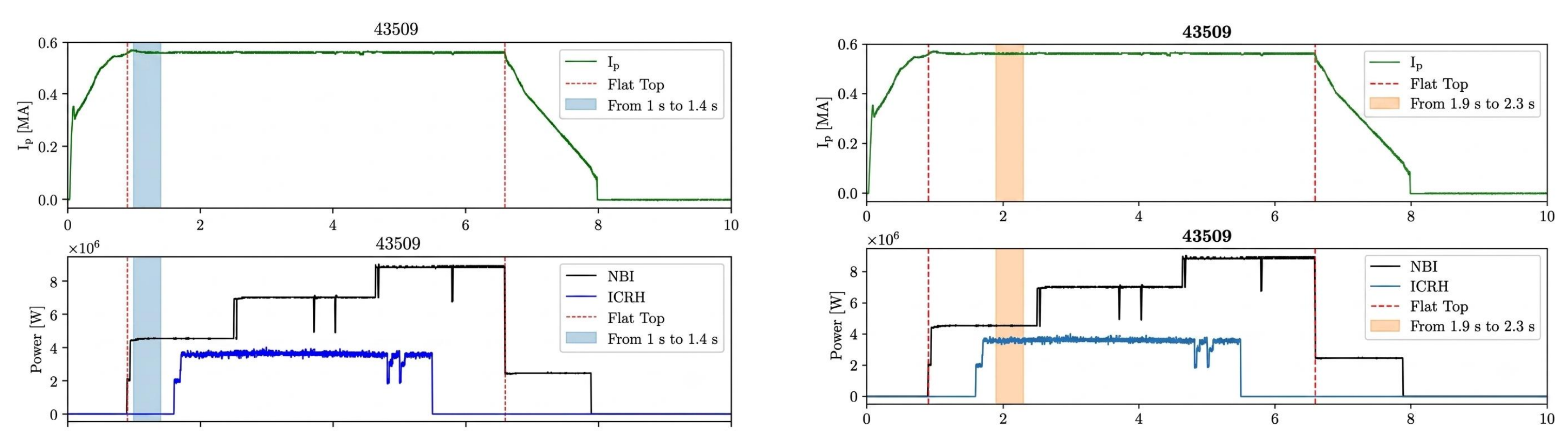
The LaCl₃(Ce) and LaBr₃(Ce) diagnostics at ASDEX Upgrade



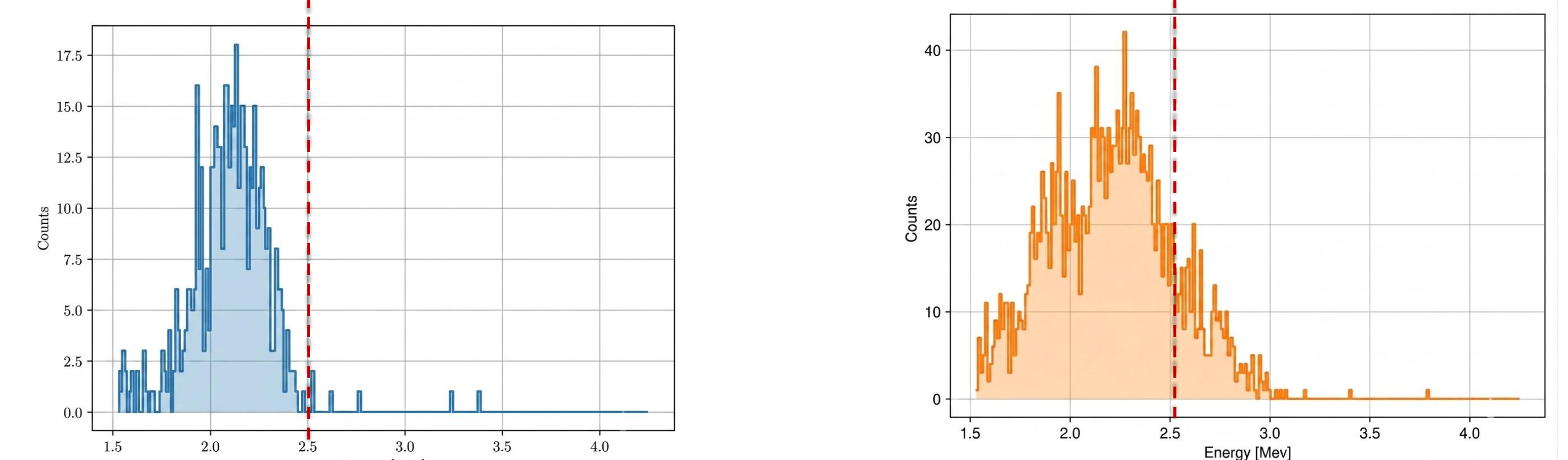
Neutron/gamma-ray discrimination (left) and neutron spectrum measurements (right)

3rd HARMONIC ICRH SCENARIO AT ASDEX UPGRADE ESTABLISHED

#43509 - waveforms



#43509 – Neutron spectra



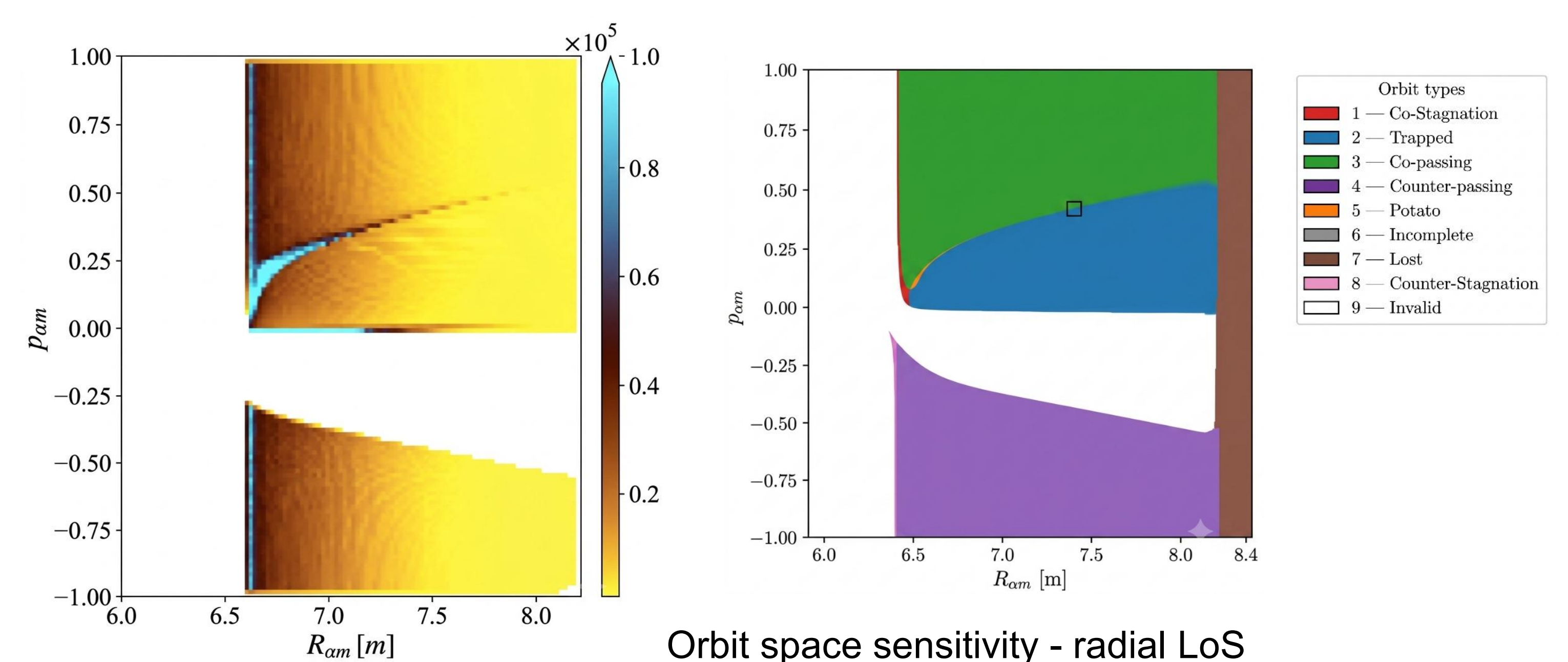
High energy tail observed in the neutron spectrum measured by COSMONAUT+
Analysis ongoing.

ALPHA PARTICLE VELOCITY AND ORBIT SPACE SENSITIVITY OF $^{10}\text{B}(\alpha,p\gamma)^{13}\text{C}$

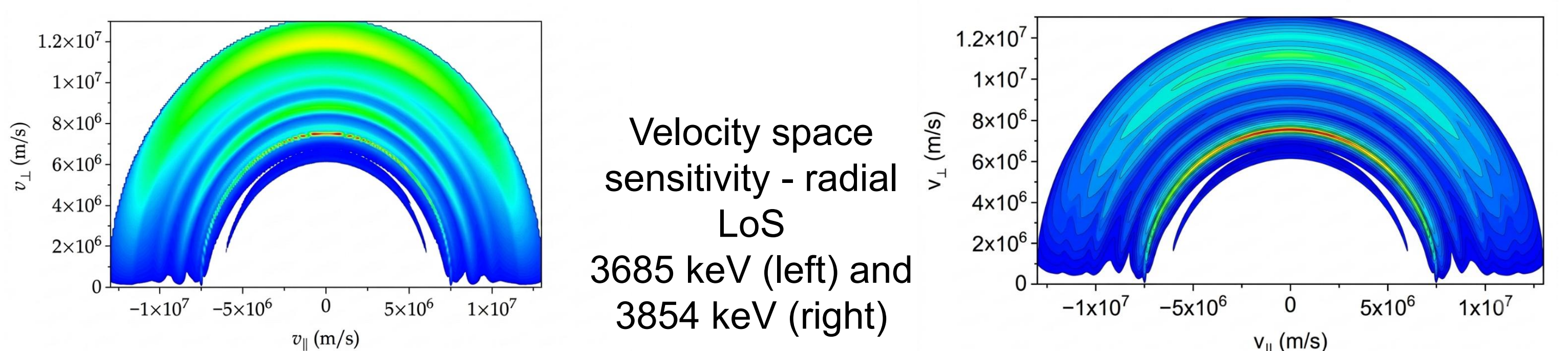
Alpha particle measurements based on the **$^{10}\text{B}(\alpha,p\gamma)^{13}\text{C}$ reaction**.

Simultaneous observation of the **3 γ -ray lines probes both super- and sub-alfvenic alpha particles** when $B_T=5-6$ T in the core (improvement over $^9\text{Be}(\alpha,n\gamma)^{12}\text{C}$ at JET).

Trapped and potato orbits dominate the signal for a radial diagnostic, such as RGRS at ITER.



Orbit space sensitivity - radial LoS



Velocity space sensitivity - radial LoS
3685 keV (left) and 3854 keV (right)

Details in M. Nocente et al. Nucl. Fusion 66 (2026) 096017

OUTLOOK

- Addition of **^3He** to the 3rd harm. D scenario and **alpha particle generation** at ASDEX Upgrade
- Development of the **proton scenario** at ASDEX Upgrade.
- Counterpart experiments at **EAST**.
- **Alpha particle generation at JT-60SA** with NBI and studies using the NES/GRS system.