EUROfusion

TSVV-H in-person meeting June 2026

Pedestal modelling:
Workflow for integrating Europed in ETS

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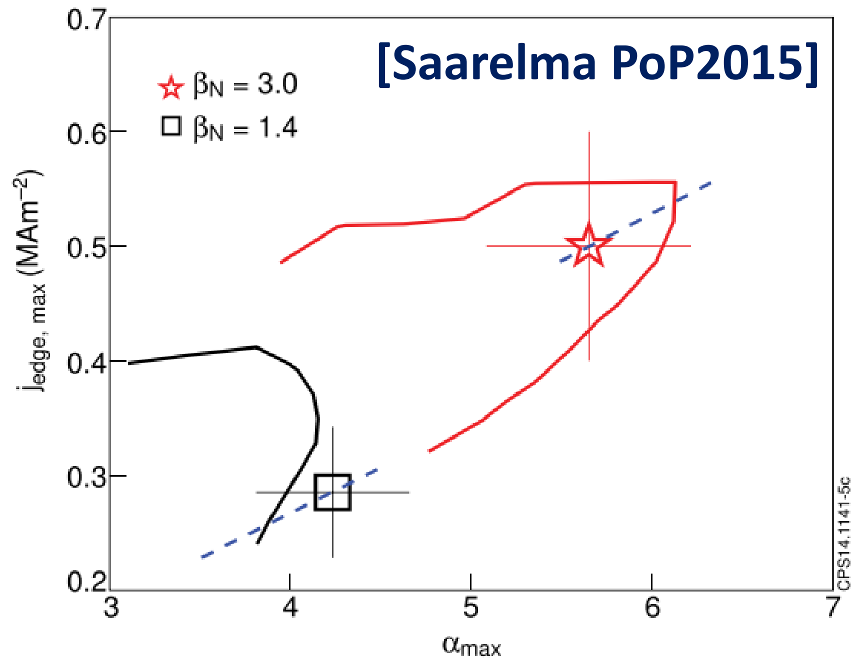
Outline

1. Motivation: why core–pedestal coupling?
2. Europed: a predictive pedestal code
3. Europed–ETS integration workflow
4. Current status and next steps
5. Discussion

Motivation: why core–pedestal coupling?

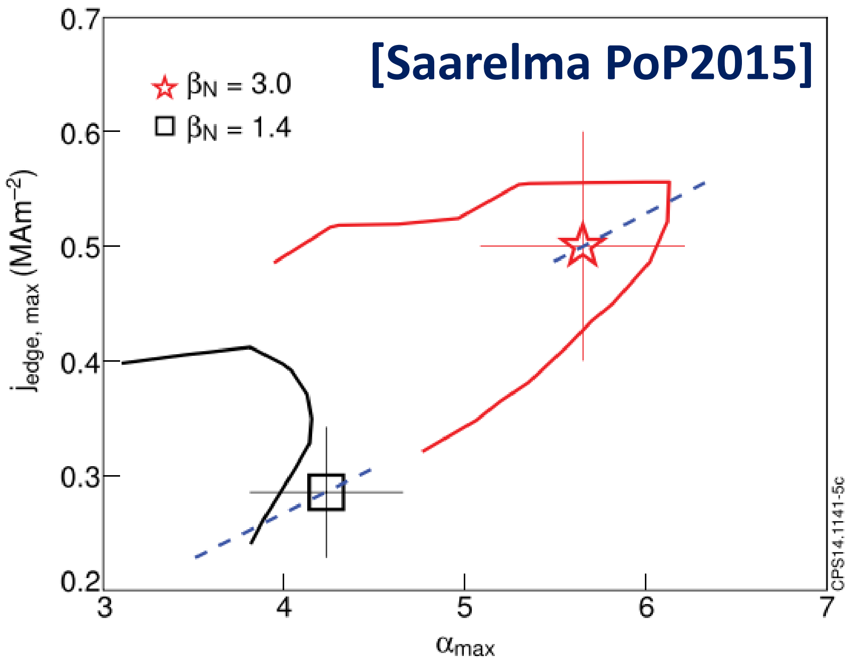


- ❑ Core profiles can strongly affect the pedestal prediction
- ❑ **Example:** higher β_N / Shafranov shift can stabilize ballooning modes and modify the pedestal stability [Saarelma Pop2015]

Core affects the pedestal

Plasma Core → **Pedestal**

Motivation: why core–pedestal coupling?



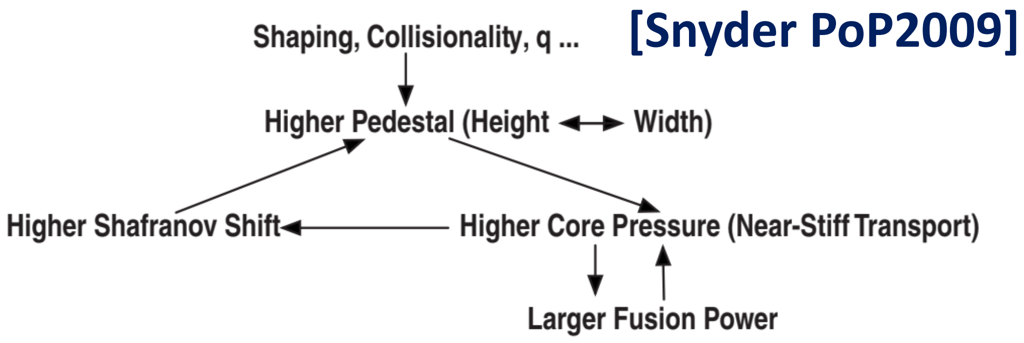
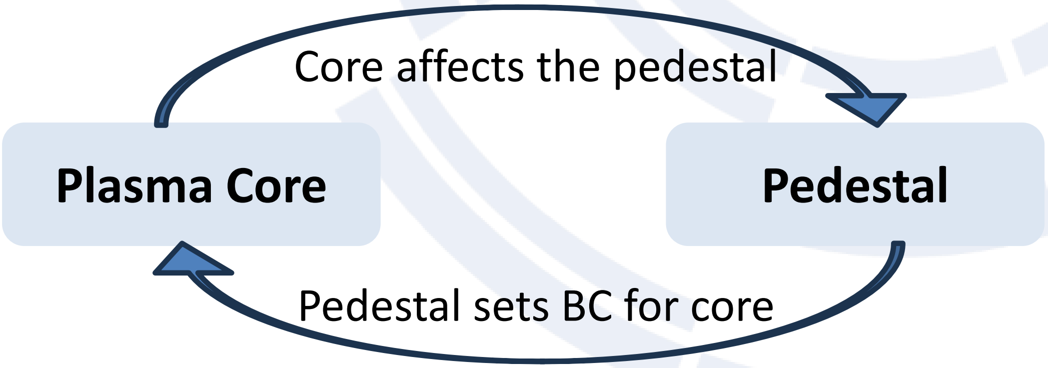


FIG. 8. Schematic illustrating the complex feedback cycles connecting the pedestal and the plasma core via the Shafranov shift.

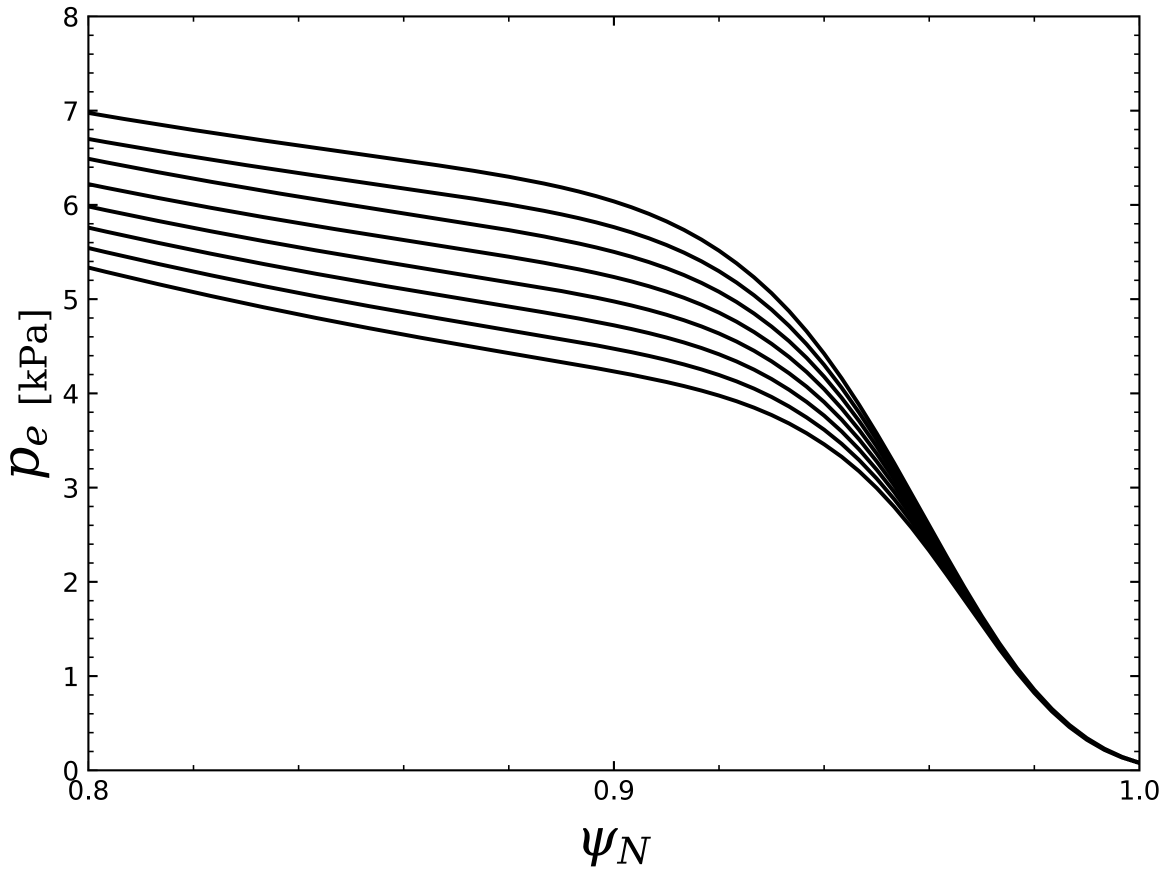
- ❑ Core profiles can strongly affect the pedestal prediction
- ❑ **Example:** higher β_N / Shafranov shift can stabilize ballooning modes and modify the pedestal stability [Saarelma Pop2015]
- ❑ This creates a complex feedback loop [Snyder Pop2009]:
  - ➢ core profiles affect pedestal stability, while the pedestal sets the boundary condition for the core transport



Europed: a predictive pedestal code

List of pedestal widths w → $w = k\sqrt{\beta_{\mathrm{pol}}^{\mathrm{ped}}}$ → List of pedestal profiles

[Saarelma PPCF2018, Snyder PoP2009]



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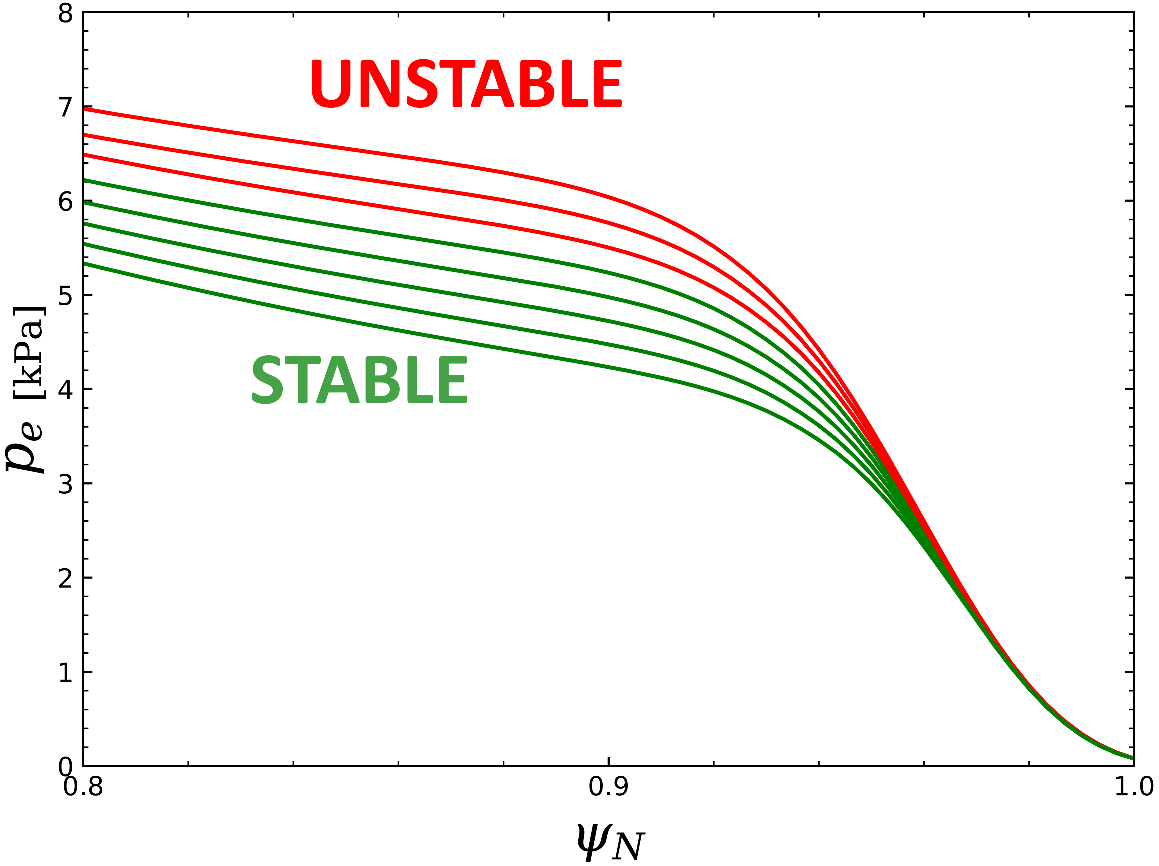
Stability code (MISHKA, CASTOR, ELITE, …)

↓

Stability of each pedestal



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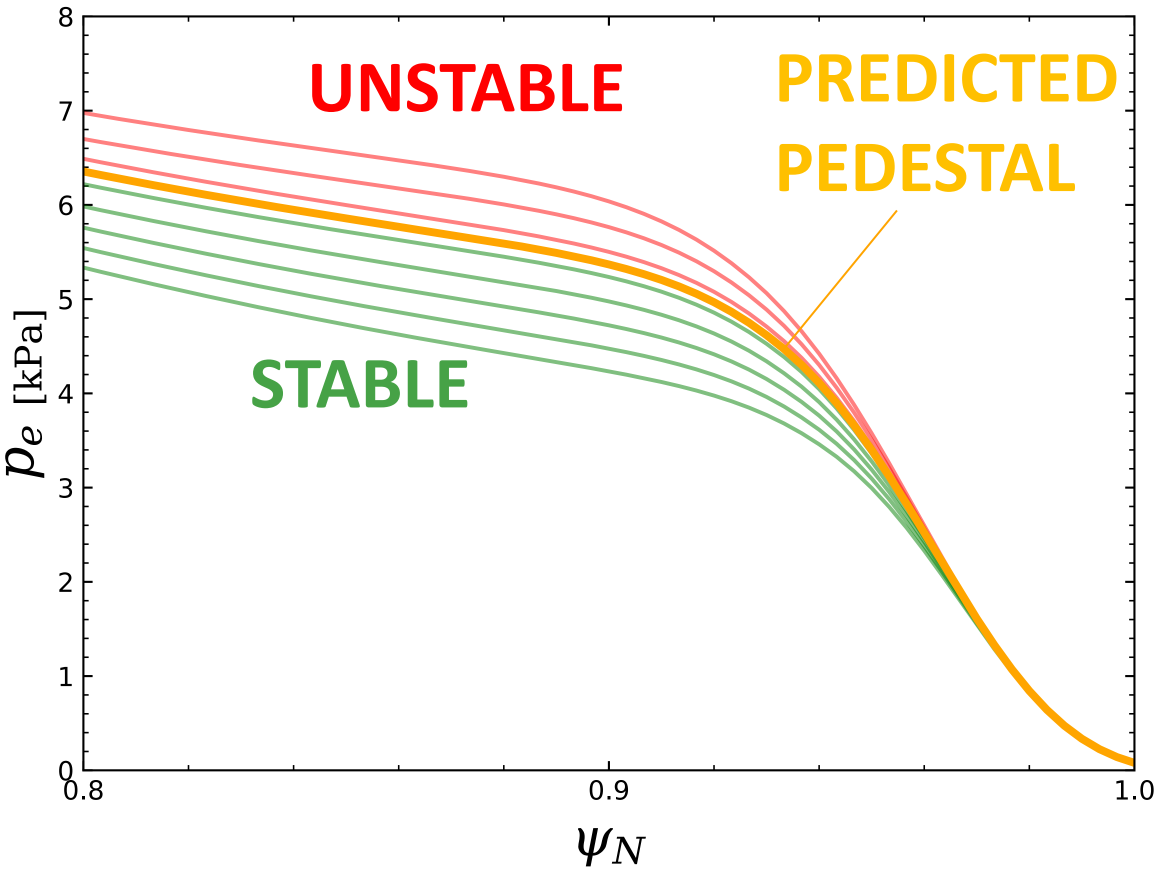
Prediction: marginally stable pedestal

[Saarelma PPCF2018, Snyder PoP2009]



Europed: a predictive pedestal code

- Inputs currently needed by Europed:
  - I_P, B_t, plasma shape
  - β_N, Z_{eff}, Z_{imp}, n_e^{ped}, $n_e^{\mathrm{sep}}/n_e^{\mathrm{ped}}$, T_i/T_e, core peaking, q_0

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  - I_P, B_t, plasma shape
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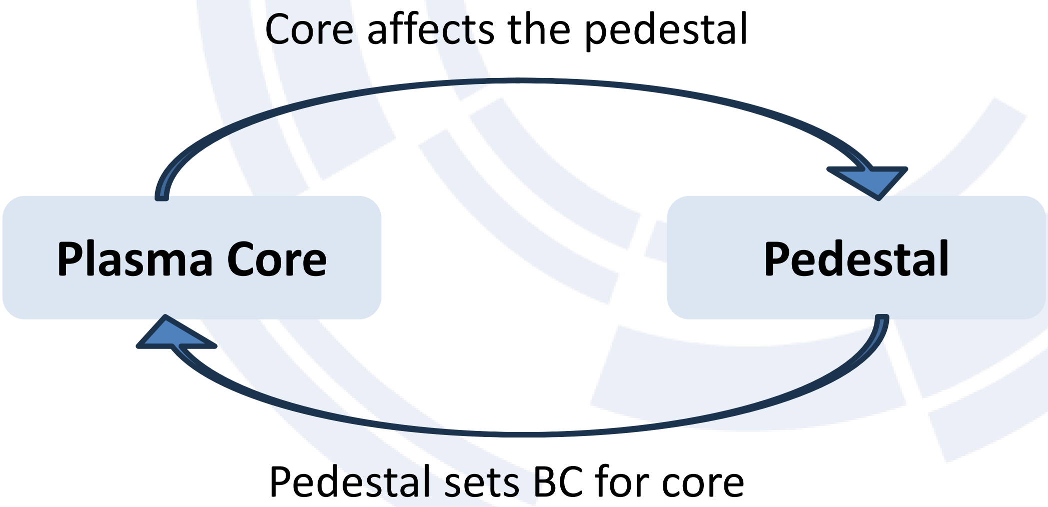
  - Integrate Europed in ETS to allow for core-edge coupling



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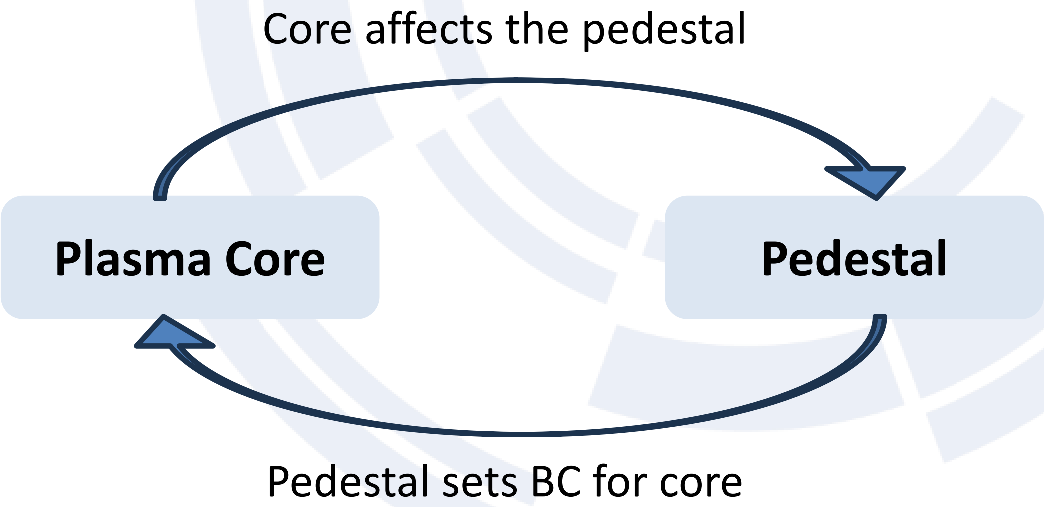

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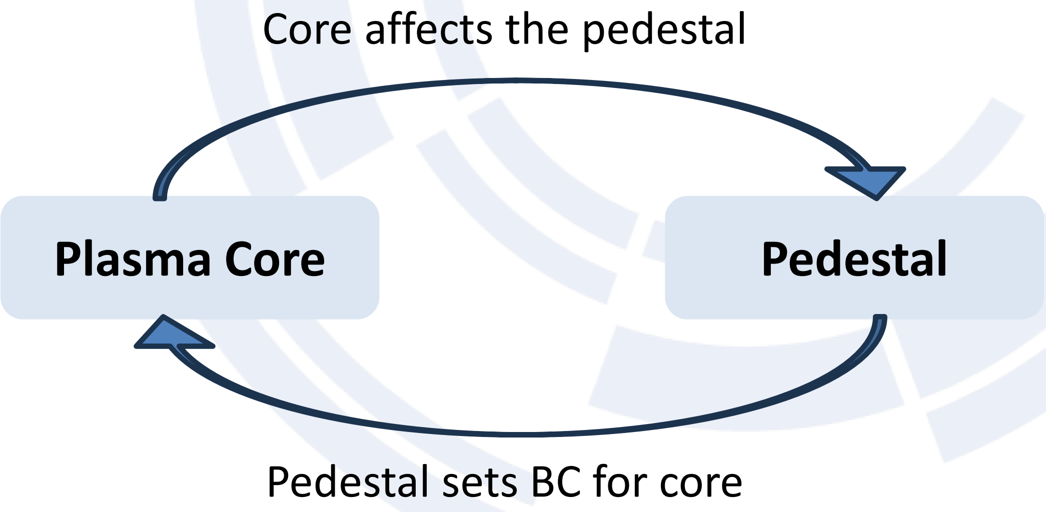
- **Especially important: $\boldsymbol{\beta_N}$, through its effect on the global Shafranov shift**
  [Saarelma PoP2015, Snyder PoP2009]



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  - $\cancel{\beta_N}$, Z_{eff}, Z_{imp}, $\cancel{n_e^{ped}}$, n_e^{sep}/n_e^{ped}, T_i/T_e, core peaking, q_0

In principle, n_e^{ped} could also be replaced by the density model developed by Samuli [NF2023] and implemented in Europed.

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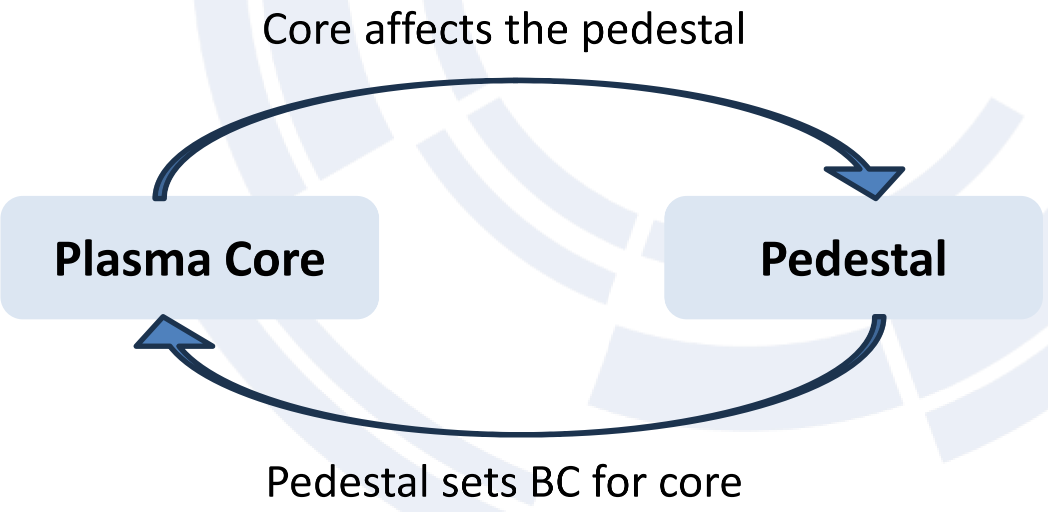


Europed–ETS integration workflow

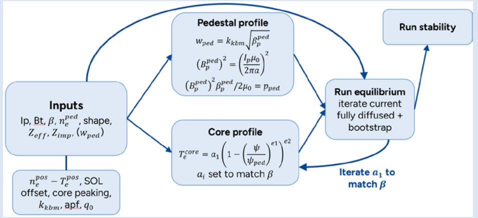
1

Key inputs

I_p, B_T, n_e^{ped}, shape , β_N

2

Europed



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$\beta_N \in \{\beta_N^1, .., \beta_N^i\}$

β_N^1 … β_N^i

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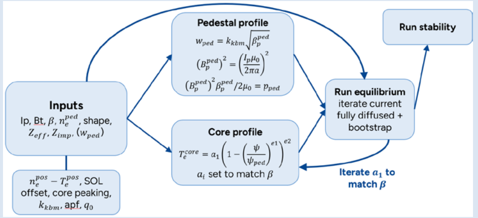
Europed



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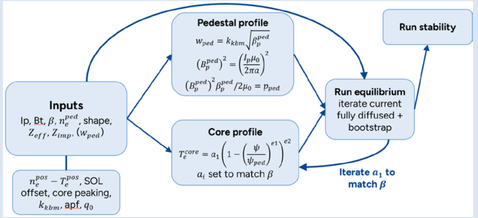

$p_{ped}(\beta_N^1)$

⋮

$p_{ped}(\beta_N^i)$

3

ETS

With the BC from Europed output (+ ETS parameters)

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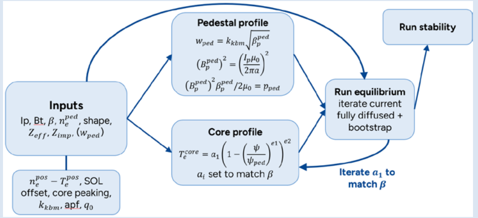

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$\beta_N^1(\text{ETS})$ ... $\beta_N^i(\text{ETS})$

4 Compare β_N from ETS with Europed input

5 Predicted β_N given by $\min\{|\beta_N^i(\text{in}) - \beta_N^i(\text{ETS})|\}$

Europed–ETS integration workflow

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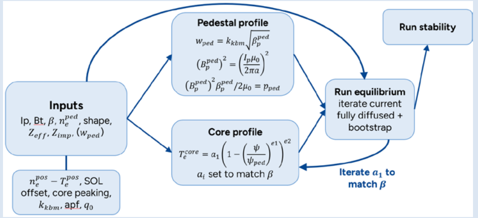
Europed



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Compare β_N from ETS with Europed input

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Predicted β_N given by $\min\{|\beta_N^i(\mathrm{in}) - \beta_N^i(\mathrm{ETS})|\}$

6

Rerun Europed with predicted β_N and core profile

7

Final predicted pedestal from Europed output

Europed–ETS integration workflow

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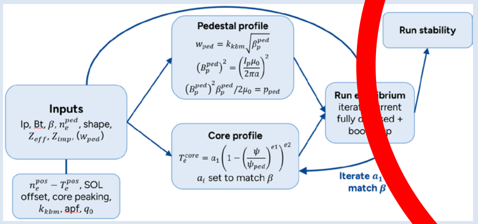
β_N^1 … β_N^i

2. Europed



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7. Final predicted pedestal from Europed output

Practical question: how do we pass data from Europed to ETS?

Europed–ETS integration workflow

- ETS uses the IMAS framework
  - Data are exchanged between codes through Interface Data Structures (IDSs)

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- **Implementation approach:**
  - Write the IDSs needed to initialize an ETS simulation from Europed output
  - Main IDSs:
    - **equilibrium:** from Europed/HELENA critical equilibrium
    - **core_profiles:** from Europed profile output

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Current bottleneck

- Writing consistent equilibrium and core_profiles IDSs from Europed/HELENA output
- Work ongoing with T. Jonsson, using IMAS-HELENA as reference

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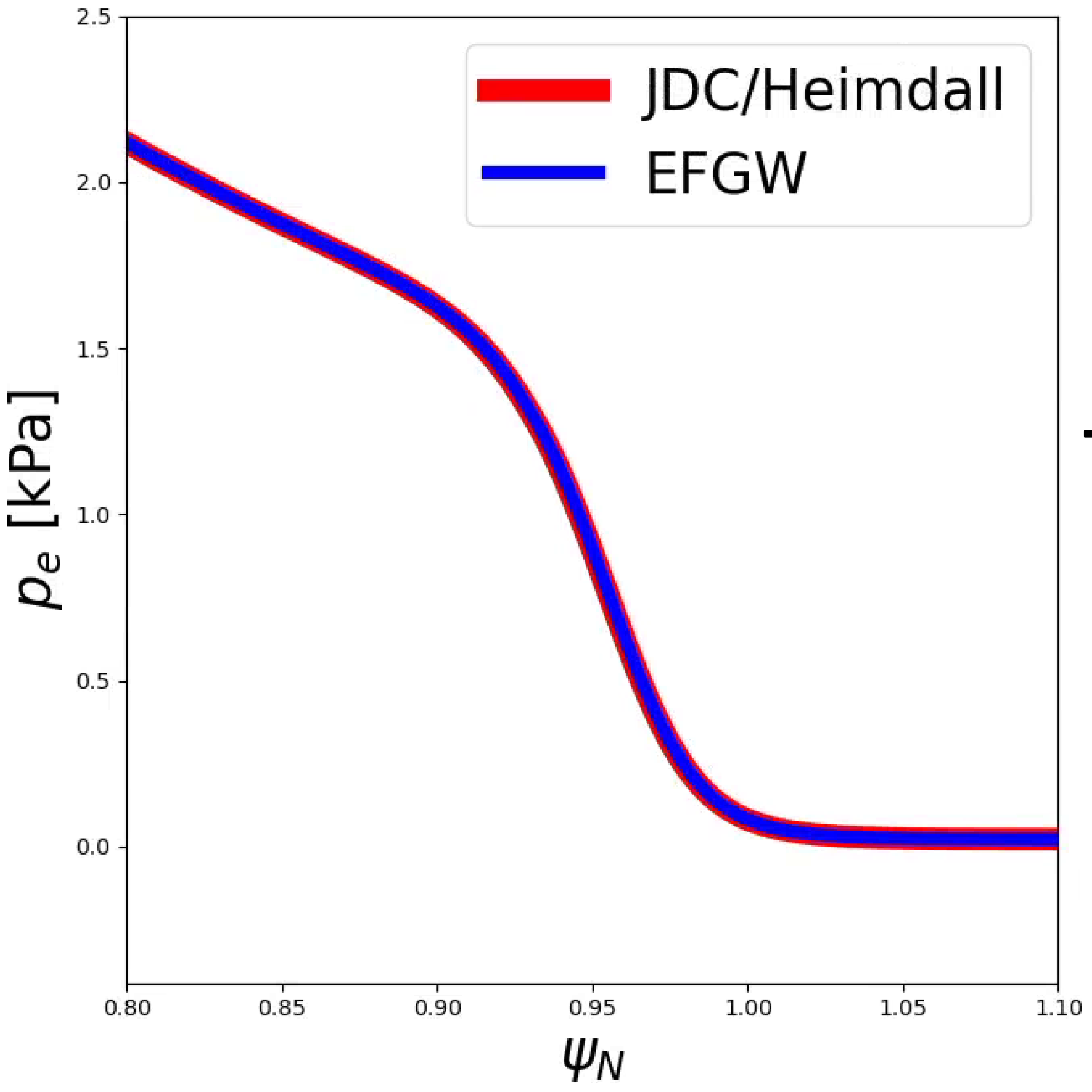
Design choice:

use Europed as a complete code, rather than reimplementing selected parts, to benefit directly from future Europed developments.

Europed reproducibility: JDC/Heimdall vs EFGW



Europed results are reproducible across JDC/Heimdall and EFGW ✓

Tested over a wide range of input parameters

Example case:

- $\mathbf{I_p = 176\ kA}$
- $\mathbf{B_T = 1.46\ T}$
- $\boldsymbol{\beta_N = 1.9}$
- $\mathbf{n_e^{ped} = 4.0 \times 10^{19} m^{-3}}$

Next steps

1. Complete the Europed → IMAS conversion
   - ➢ write consistent equilibrium and core_profiles IDSs from Europed/HELENA output

2. Validate the generated IDSs in ETS
   - ➢ choose a suitable ETS workflow together with the Chalmers team

3. Test the full Europed–ETS coupling
   - ➢ apply the workflow to selected JET pulses

4. Benchmark against JINTRAC
   - ➢ assess agreement between the ETS–Europed workflow and JINTRAC

Discussion

Coupling strategy:

- Does the proposed Europed–ETS coupling workflow make sense?
- Should the workflow be made more iterative, or is the current approach sufficient?

Implementation:

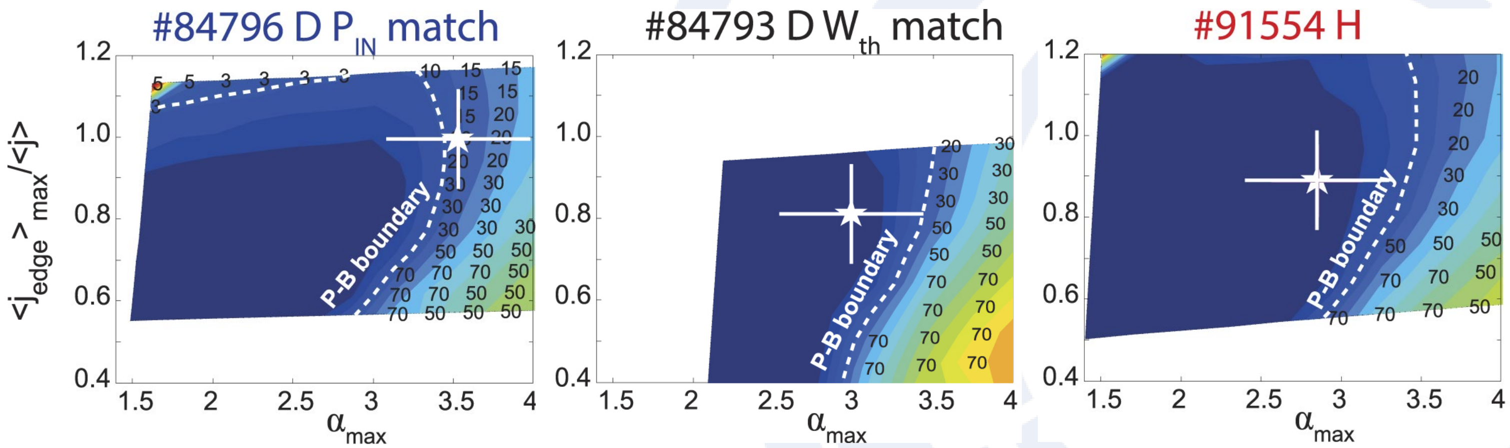
- Are there potential issues with writing the IDSs directly from Europed/HELENA output?
- Are there alternative coupling routes I should consider?

Other comments or suggestions?

Backup slides

Some proposed pulses for testing the integrated modelling

- Three pulses from [*L. Horvath et al., Nucl. Fusion 61 (2021) 046015*]
  1. Pedestal ideally limited in deuterium (#84796, 1.4MA/1.7T) → starting point
  2. Pedestal non-ideally limited in deuterium (#84793, 1.4MA/1.7T) → good to test resistive MHD
  3. Pedestal non-ideally limited in hydrogen (#91554, 1.4MA/1.7T) → good to test resistive MHD and the effect of the isotope mass



- Two pulses from [*Nyström NF2022*], [*Chapman NF2022*], [*Maggi NF2015*]
  1. Pedestal ideally limited in deuterium (#84794 , 1.4MA/1.7T low gas)
  2. Pedestal non-ideally limited in deuterium (#87342 , 1.4MA/1.7T high gas) → good to test resistive MHD

Detailed Europed workflow

Run stability

Pedestal profile

$$w_{ped} = k_{kbm}\sqrt{\beta_p^{ped}}$$

$$\left(B_p^{ped}\right)^2 = \left(\frac{I_p\mu_0}{2\pi a}\right)^2$$

$$\left(B_p^{ped}\right)^2 \beta_p^{ped}/2\mu_0 = p_{ped}$$

Inputs

Ip, Bt, β, n_e^{ped}, shape, $Z_{eff}, Z_{imp}, (w_{ped})$

$n_e^{pos} - T_e^{pos}$, SOL offset, core peaking, k_{kbm}, apf, q_0

Run equilibrium

iterate current fully diffused + bootstrap

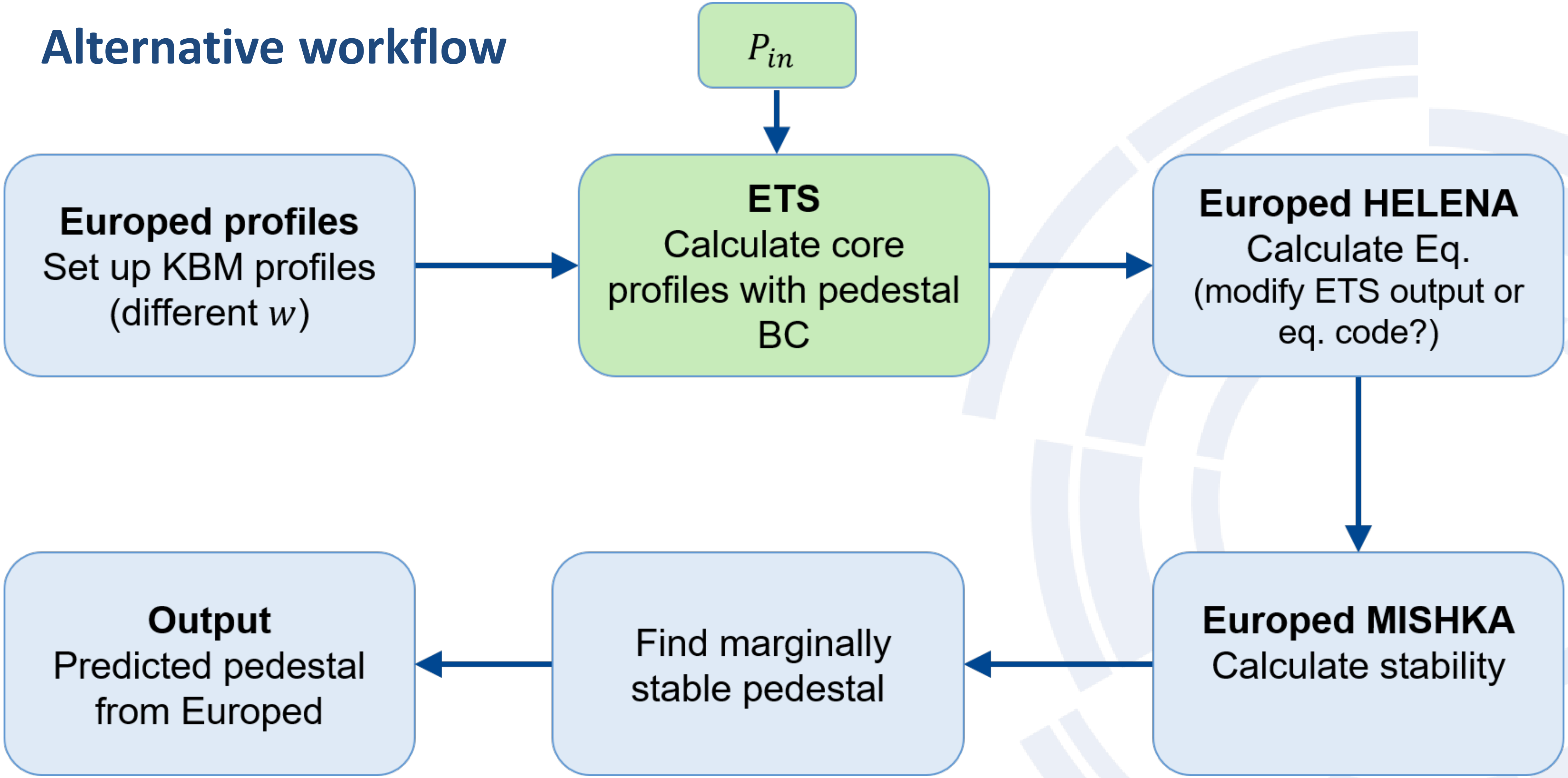
Core profile

$$T_e^{core} = a_1\left(1-\left(\frac{\psi}{\psi_{ped}}\right)^{e1}\right)^{e2}$$

a_i set to match β

Iterate a_1 to match β

Alternative workflow



- Europed-ETS integration (use many parts of Europed with ETS core transport)
  - Set up profiles with KBM width constraint → Run ETS with P_{in} to steady state (+ initial guess for core profiles) → Run Europed Equilibrium and Stability → Prediction

Overview

Deliverables:

- WP2.4-D1: *Test ideal MHD calculations within integrated modelling on JET discharge* Deadline: [12/2026]
- WP2.4-D2: *Test resistive MHD calculations within integrated modelling* Deadline: [12/2027]

People involved in the project:

- Olle Sundberg (PhD student), KTH
  - integration of Europed in ETS
  - benchmarking with HFPS
  - application of integrated Europed+ETS to JET pulses
- Arnaud Lafay (PhD student), KTH
  - pedestal stability and predictions with ideal and resistive MHD
- Lorenzo Frassinetti (supervisor), KTH
  - support for the pedestal part and the general work
- Thomas Jonsson (supervisor), KTH not covered by TSVV-H
  - support for the ETS part
- Samuli Saarelma (supervisor), UKAEA not covered by TSVV-H
  - support for Europed

WP2.4: Pedestal modelling – Planned work for 2026 (and 2027)

Prerequisites for TSVV-H work

- ➢ EUROPED-ETS integration
  - ▪ Define the integration approach (with Samuli Saarelma) [1/2026]
  - ▪ Install EUROPED on the new EFGW [2/2026]
  - ▪ Verify reproducibility across clusters (EFGW vs Heimdall/JDC) [3/2026]
  - ▪ Develop an ETS workflow with the necessary physics [6-7/2026]
  - ▪ Implement EUROPED-ETS coupling and perform initial tests [7-8/2026]

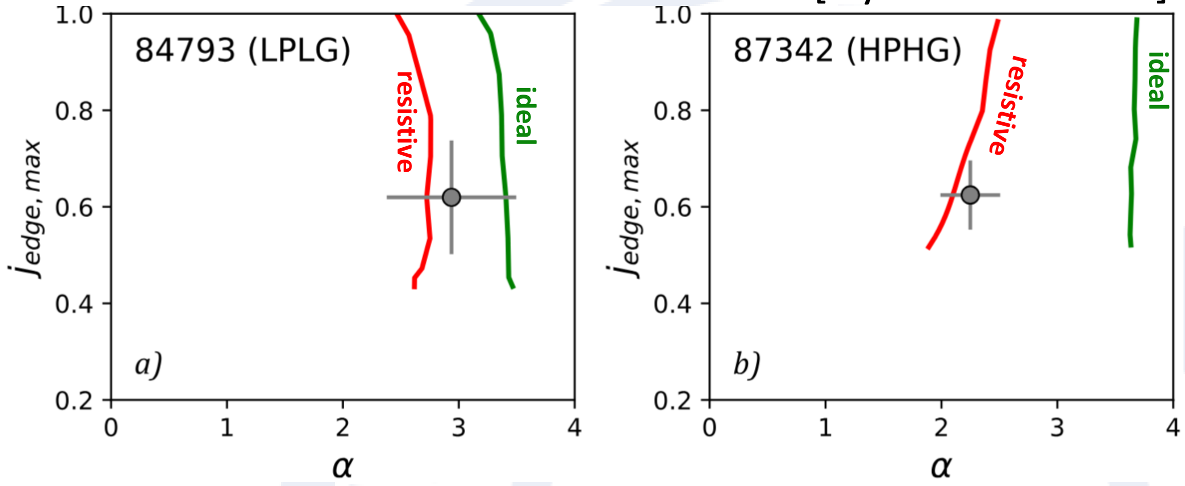
TSVV-H contribution

- ➢ Application to JET cases
  - ▪ Run the integrated workflow on selected JET discharges: [8-12/2026]
    - • 3 discharges from *L. Horvath et al., Nucl. Fusion 61 (2021) 046015* (isotope effect)
    - • Extend to additional datasets
  - ▪ Benchmark against HPFS [12/2026+]
- ➢ Extension to resistive MHD [1-12/2027]
  - ▪ Integrate CASTOR into the EUROPED-ETS workflow
  - ▪ Test on a resistive-relevant JET discharge

Why resistive MHD in the pedestal?

- In some conditions (high gas rate, high power [Maggi NF2015]) the pedestal is not limited by ideal MHD
- The pedestal is at the resistive MHD boundary [Nyström NF2022]

[Nyström NF2022]



- Resisitve MHD has been implemented in Europed with promising results [Lafay submitted to NF]

[Lafay submitted]