Beam modelling by RENATE Open Diagnostics and proposed test cases for beam model benchmark

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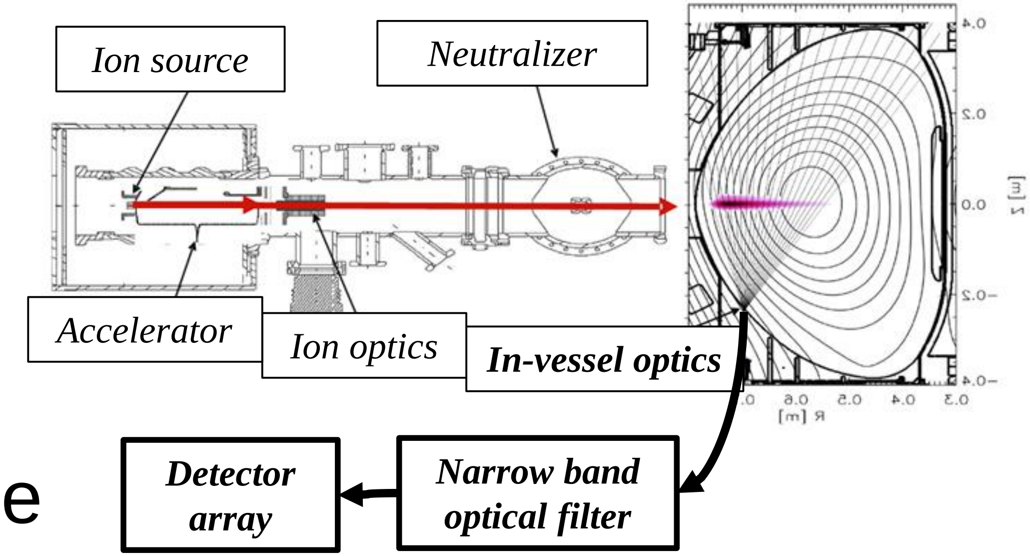
BES diagnostics

- **Active** plasma diagnostics procedure
- Use of H-like atoms such as D,Li,Na. (which posses **one valence electron**)
  - Heating beams (H, D)
  - Diagnostic beams (Li, Na)
- **Purpose:** density profile and
  fluctuation measurement

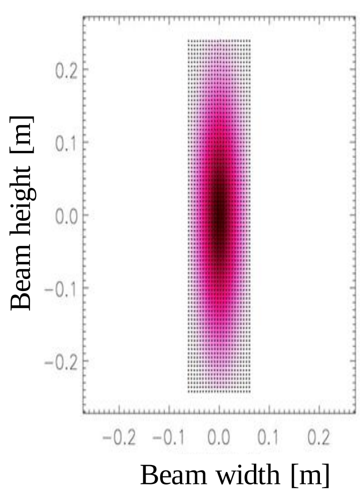


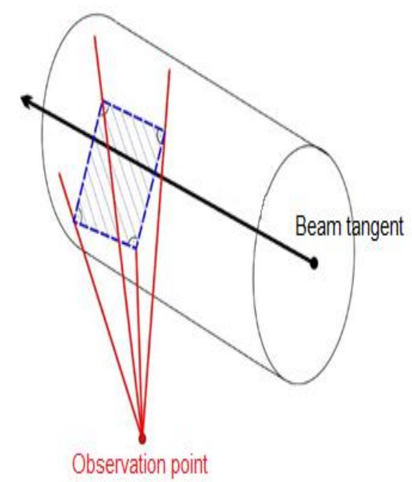
RENATE Simulation code

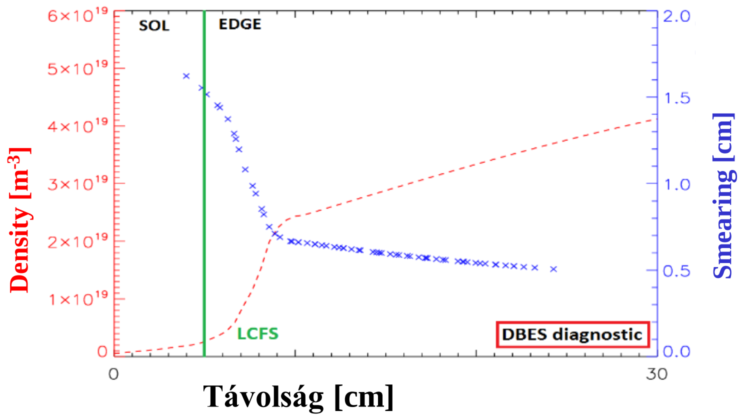
- Full 3D, based on CR model:
  1. Quasi-static for H from Open ADAS (2010)
  2. Bundled-n for H from ALADDIN (2010) with corrections from E. Delabie, et al. PPCF 2010 → benchmarked with O. Marchuk's CRM (2011)
  3. l-resolved for Li from J. Schweinzer, et al. Atomic Data and Nuclear Data Tables 1999 → benchmarked with J. Schweinzer's simula (2007)
  4. l-resolved for Na from K. Igenbergs, et al. Atomic Data and Nuclear Data Tables 2008

→ Revise cross-section data!

Elliptical beam

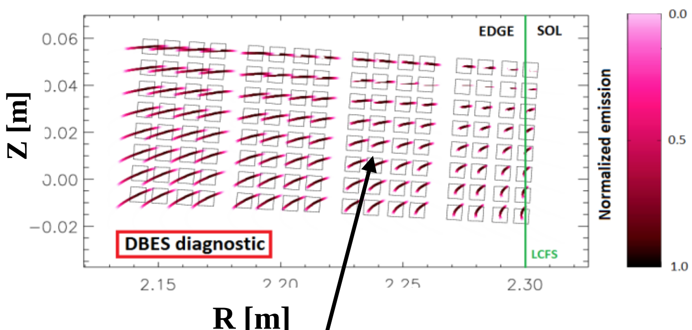






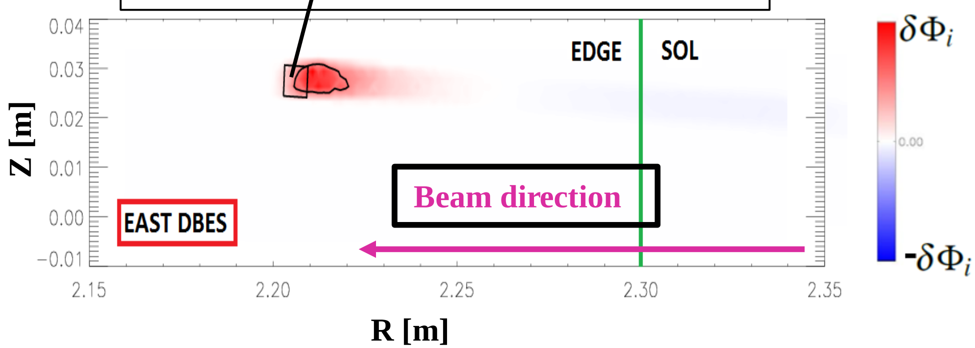
- **Factors of spatial resolution**:
  - **Detector size * magnification**
  - **Atomic physics**
  - **Beam and magnetic geometry**
- **Fluctuation response**:
  - Reconstruction of density fluctuations
  - Determination of effective spatial resolution

Favourable magnetic geometry

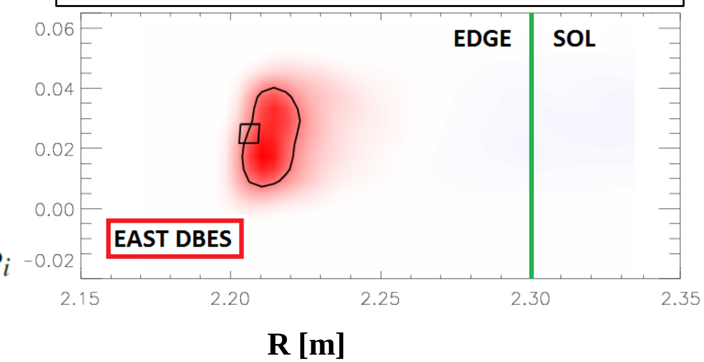


O. Asztalos *et.al*. EPS 2017

Favourable magnetic configuration

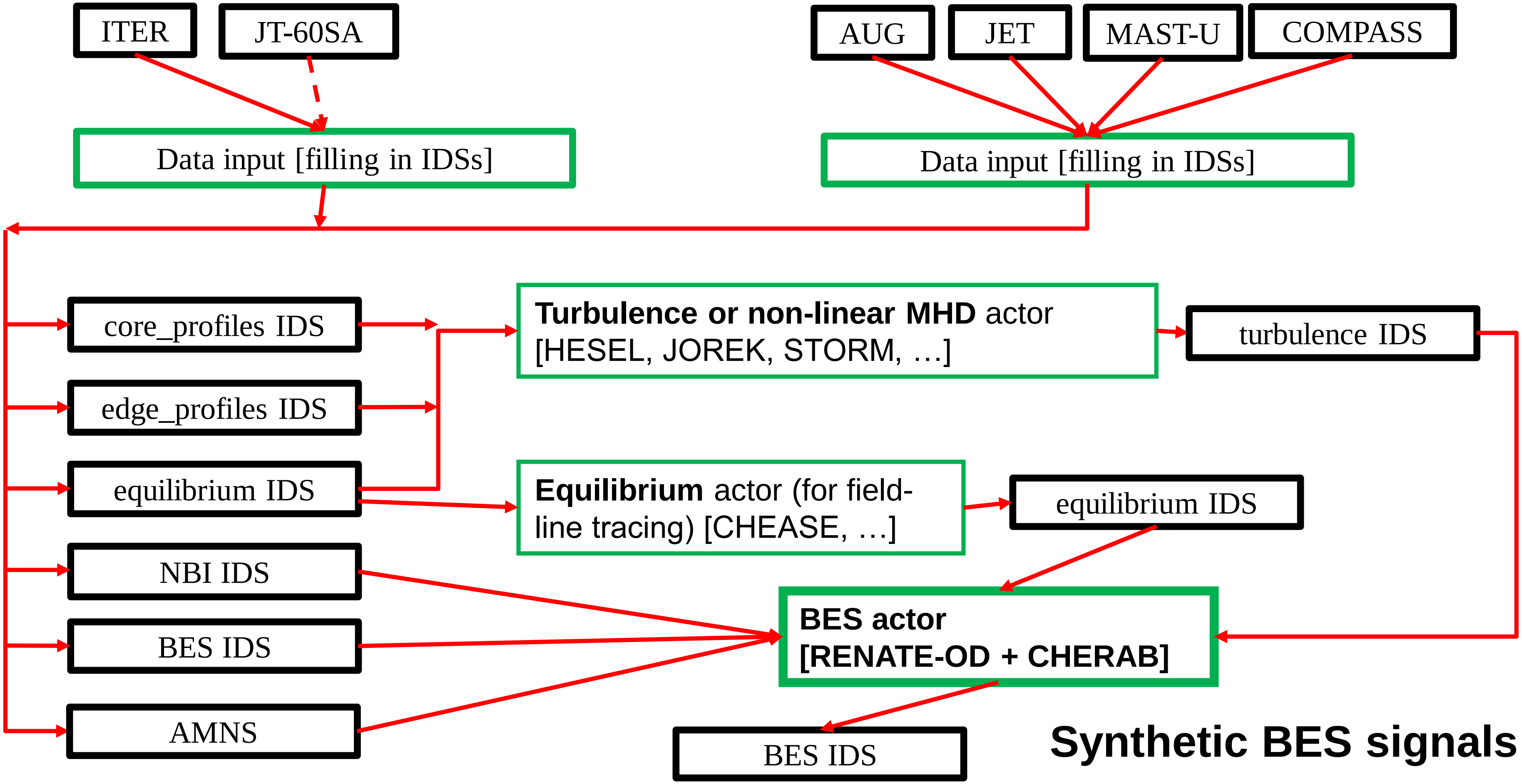


Unfavourable magnetic configuration



BES synthetic diagnostic in EU-IM

The aim is to have a turbulence with synthetic diagnostics workflow with interchangeable turbulence (and non-linear MHD) codes for comparison with fluctuation measurements.

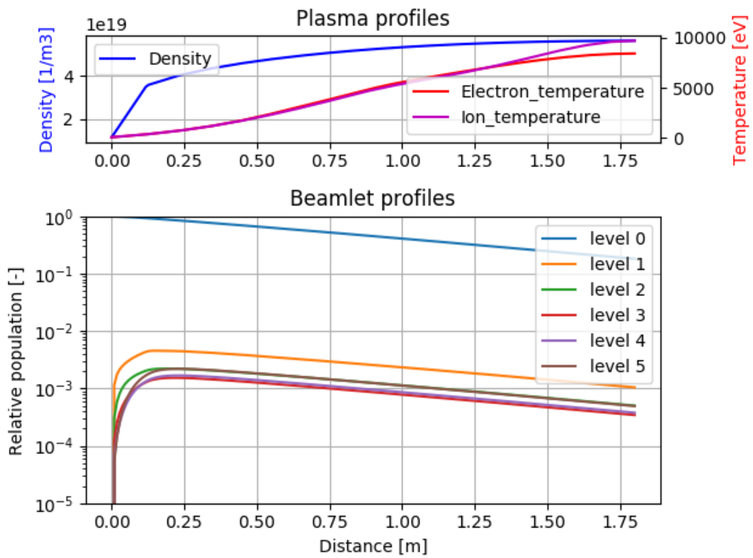


BES actor: RENATE – Open Diagnostics

- Open development in Python: https://github.com/gergopokol/renate-od
- 1D rate equation solver is ready.
- More general input than RENATE: independent (n,T) profiles for each (Z, A) ion population.
- Possibility to generate Zeff és <q> profiles for rates.
- **Benchmarked to RENATE.** (It just failed with impurities...)

$$
\begin{aligned}
\frac{dn_i(x)}{dx} = n_e(x)\Bigg[&- n_i(x)\left(\sum_{j=i+1}^{m} \frac{R^{e-ex}_{i\to j}(T_e(x))}{v_B} + \sum_{j=0}^{i-1} \frac{R^{e-dex}_{i\to j}(T_e(x))}{v_B} + \frac{R^{e-ion}_{i\to +}(T_e(x))}{v_B} \right) + \\
&+ \left(\sum_{j=0}^{i-1} n_j(x) \frac{R^{e-ex}_{j\to i}(T_e(x))}{v_B} + \sum_{j=i+1}^{m} n_j(x) \frac{R^{e-dex}_{j\to i}(T_e(x))}{v_B} \right) \Bigg] + \\
&+ \sum_I n_I(x) \Bigg[- n_i(x)\left(\sum_{j=i+1}^{m} \frac{R^{I-ex}_{i\to j}(T_I(x))}{v_B} + \sum_{j=0}^{i-1} \frac{R^{I-dex}_{i\to j}(T_I(x))}{v_B} + \frac{R^{I-ion}_{i\to +}(T_I(x))}{v_B} + \right. \\
&+ \left. \frac{R^{I-CX}_{i\to +}(T_I(x))}{v_B} \right) + \left(\sum_{j=0}^{i-1} n_j(x) \frac{R^{I-ex}_{j\to i}(T_I(x))}{v_B} + \sum_{j=i+1}^{m} n_j(x) \frac{R^{I-dex}_{j\to i}(T_I(x))}{v_B} \right) \Bigg] - \\
&- n_i(x) \sum_{j=0}^{i-1} \frac{A_{i\to j}}{v_B} + \sum_{j=i+1}^{m} n_j(x) \frac{A_{j\to i}}{v_B} \\
&(i = 0, 1, \ldots, m)
\end{aligned}
$$

Beam evolution for ITER DNB



Proposed test cases for benchmark

- **Aim**: benchmark of beam codes and models in order to verify correct implementation and explore applicability of different physics models.
- All participating codes should do the test cases they are capable of with all possible beam models and provide detailed output, but primarily information on beam attenuation and beam emission.
- Small variation of proposed test cases at

  https://www-amdis.org/CRP/neutral-beam-penetration-and-photoemission
- 1D beam in semi-infinite (0.le.x) plasma.

1. Constant profiles

- **Aim**: study the dependence of beam dynamics on different parameters and plasma compositions.

2. Constant profiles

- **Aim**: compare the precision and explore the applicability of different beam models for realistic cases.

Constant profile test cases

- **Aim**: study the dependence of beam dynamics on different parameters and plasma compositions.
- **Beam materials**: H, D, T, (Li, Na)
- **Beam energies**: 40 keV, 100 keV, 1 Mev (H isotopes)
- **Calculation length**: 1m
- **Electron densities**: 1e18 m^{-3} (for pure D plasma), 1e19 m^{-3}, 1e20 m^{-3} (for pure D plasma)

- **Plasma composition and temperatures**:
  - H^+(100%), T_e=10 keV, T_i=1keV
  - H^+(100%), T_e=T_i=100 eV, 1 keV, 20 keV
  - D^+(100%), T_e=T_i=100 eV, 1 keV, 20 keV
  - T^+(100%), T_e=T_i=100 eV, 1 keV, 20 keV
  - He^{2+}(100%), T_e=T_i=100 eV, 1 keV, 20 keV
  - He^+(100%), T_e=T_i=30 eV
  - D^+(95%) + Be^{4+}(5%), T_e=T_i=1 keV, 20 keV
  - D^+(95%) + C^6+(5%), T_e=T_i=1 keV, 20 keV
  - D^+(99%) + W^{70+}(1%), T_e=T_i=20 keV
  - D^+(50%) + T^+(50%), T_e=T_i=100 eV, 1 keV, 20 keV
  - D^+(40%) + T^+(40%) + He^{2+}(20%), T_e=T_i=100 eV, 1 keV, 20 keV
  - D^+(40%) + T^+(40%) + He^{2+}(15%) + Be^{4+}(4%) + W^{70+}(1%), T_e=T_i=20 keV

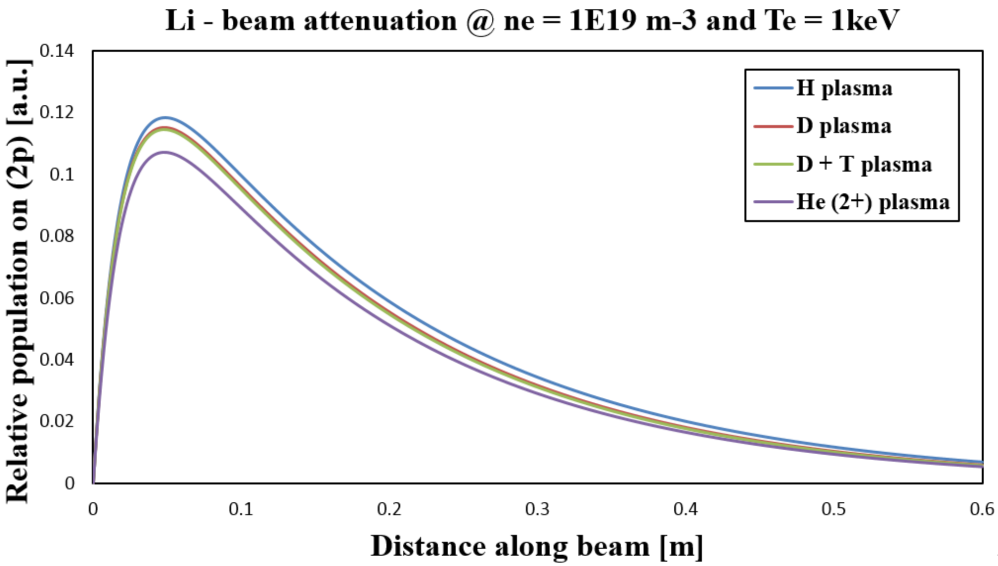
Temperature effects

Isotope effects, scaling of rates

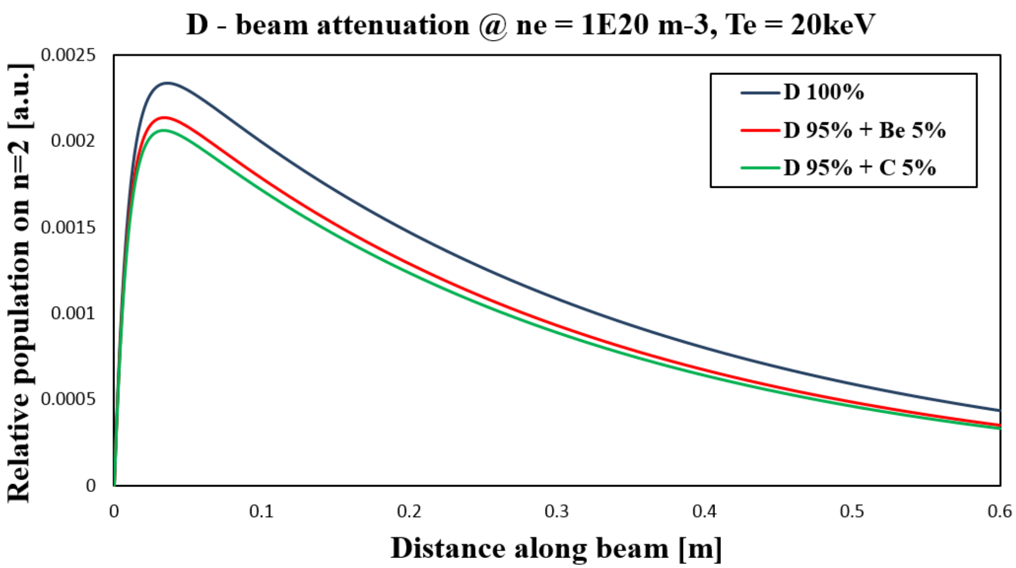
Trace impurities

Multi-component plasmas

Should discuss: reduction of test cases?



Only small changes expected for isotope effects



Small changes for impurities ?

Determine impurity concentration to have relevant impact on beam evolution?

Plasma profile test cases

- **Aim**: compare the precision and explore the applicability of different beam models for realistic cases.
- **Beam materials**: H, D, T, (Li, Na)
- **Beam energies**: 40 keV, 100 keV, 1 Mev (H isotopes)
- **Calculation length**: 1m
- **Plasma composition**: pure D

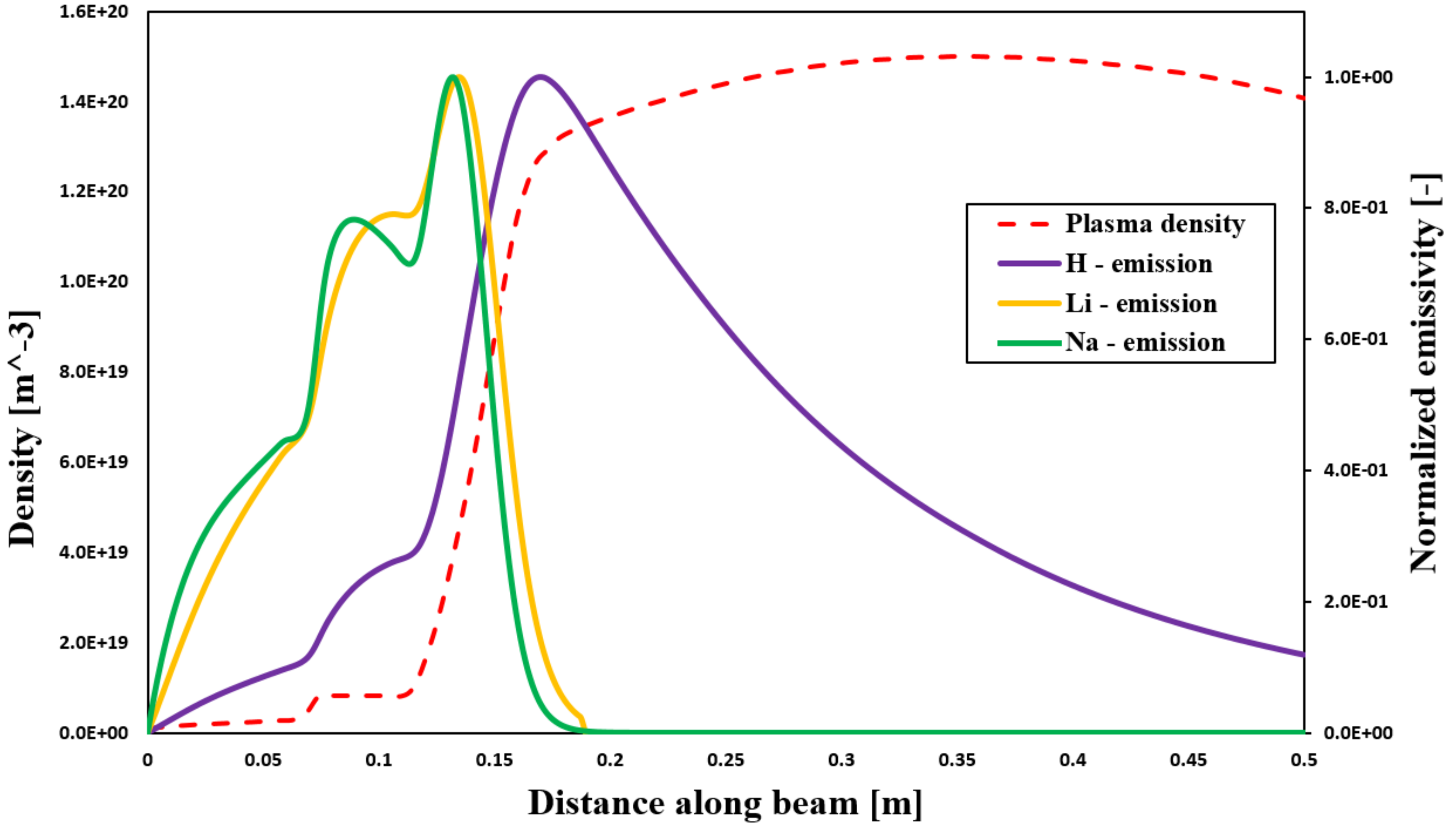
- **Density and temperature profiles**:
  - ITER scenario2 (Q=10)
  - ITER scenario5 (non-inductive Q=5)
  - COMPASS-like L-mode
  - COMPASS-like H-mode
  - W7-X island divertor – flat plateau
  - Density blob in SOL (on ITER scenario5), relative amplitude: 5%, 50%
  - Density blob in edge (on ITER scenario5), relative amplitude: 5%, 50%

Profiles at extremes of fusion step-ladder

Localized features on profiles

W7-X island divertor – flat plateau

Non-monotonic emissivity profiles for perturbed radial profiles – could be exciting?



Benchmark schedule

20. February: Discussion and finalization of test cases

21. February: Officially advertising the benchmark

March-April: Continuous comparison and iteration

24-26. April: Workshop in Debrecen

May: Refinement of results

Summer: Summary paper?

Summary

1. Old **3D RENATE** is being utilized as **synthetic diagnostic for turbulence code validation**.

2. **RENATE Open Diagnostics** will be used as **atomic physics kernel in CHERAB optics simulator**, and integrated into IMAS.

3. **Test cases** for the benchmark have been proposed (minor changes to earlier version). **To be discussed and finalized!**

4. **Constant profile test cases** are to study the dependence of beam dynamics on different parameters and plasma compositions.

5. **Plasma profile test cases** are to compare the precision and explore the applicability of different beam models for realistic cases.

6. **Benchmark schedule** and Workshop in Debrecen (24-26. April) proposed.

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