Beam penetration and photoemission benchmark

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Benchmark progress

I. Constant profile test cases					Available codes
Calculation length: 2m					
1.	H(+) 100%		*only proton collisions*		RENATE, RENATE-OD, FIDASIM, CHERAB
	Beams:	Energies:	Densities (n_e):	Temperatures:	
	H	30, 100, 1000 keV	1E19, 1E20 m-3	0.1, 1 , 20 keV	
2.	H(+) 100%			*Te = Ti*	RENATE, RENATE-OD, FIDASIM, BBNBI (good stat.), CHERAB, CRM-stat
	Beams:	Energies:	Densities (n_e):	Temperatures:	
	H	30, 100, 1000 keV	1E19, 1E20 m-3	0.1, 1 , 20 keV	
3.	D(+) 100%			*Te = Ti*	RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB
	Beams:	Energies:	Densities (n_e):	Temperatures:	
	H	30, 100, 1000 keV	1E19, 1E20 m-3	0.1, 1 , 20 keV	
4.	He(2+) 100%			*Te = Ti*	RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB
	Beams:	Energies:	Densities (n_e):	Temperatures:	
	H	30, 100, 1000 keV	1E19, 1E20 m-3	0.1, 1 , 20 keV	

Benchmark progress

5.	D(+) 95% + Be(4+) 5% (n_i %)			*Te = Ti*	RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB
	Beams:	Energies:	Densities (n_e):	Temperatures:	
	H, D, T	30, 100, 1000 keV	1E19, 1E20 m-3	1 , 20 keV	
6.	D(+) 95% + C(6+) 5% (n_i %)			*Te = Ti*	RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB
	Beams:	Energies:	Densities (n_e):	Temperatures:	
	H	30, 100, 1000 keV	1E19, 1E20 m-3	1 , 20 keV	
7.	D(+) 99.9% + W(64+) 0.1% (n_i %)			*Te = Ti*	RENATE, RENATE-OD, new W cross-sections?
	Beams:	Energies:	Densities(n_e):	Temperatures:	
	H	30, 100, 1000 keV	1E19, 1E20 m-3	20 keV	
8.	D(+) 50% + T(+) 50% (n_i %)			*Te = Ti*	RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB
	Beams:	Energies:	Densities(n_e):	Temperatures:	
	H	30, 100, 1000 keV	1E19, 1E20 m-3	20 keV	
9.	D(+) 40% + T(+) 40% + He(2+)15% + Be(4+) 4.5% +C(6+) 0.2% + Ne(10+) 0.29% + W(64+) 0.01%			*Te = Ti*	RENATE, RENATE-OD, new W cross-sections?
	Beams:	Energies:	Densities(n_e):	Temperatures:	
	H	30, 100, 1000 keV	1E19, 1E20 m-3	20 keV	

Benchmark progress

II. Plasma profile test cases		
profiles along beam provided		
1.	ITER scenario	
	Beams:	Energies:
	H	30, 100, 1000 keV
	D, T	100 keV
2.	ITER scenario with blob	
	Beams:	Energies:
	H	30, 100, 1000 keV
	D, T	100 keV
3.	Island divertor	
	Beams:	Energies:
	H	30, 100, 1000 keV

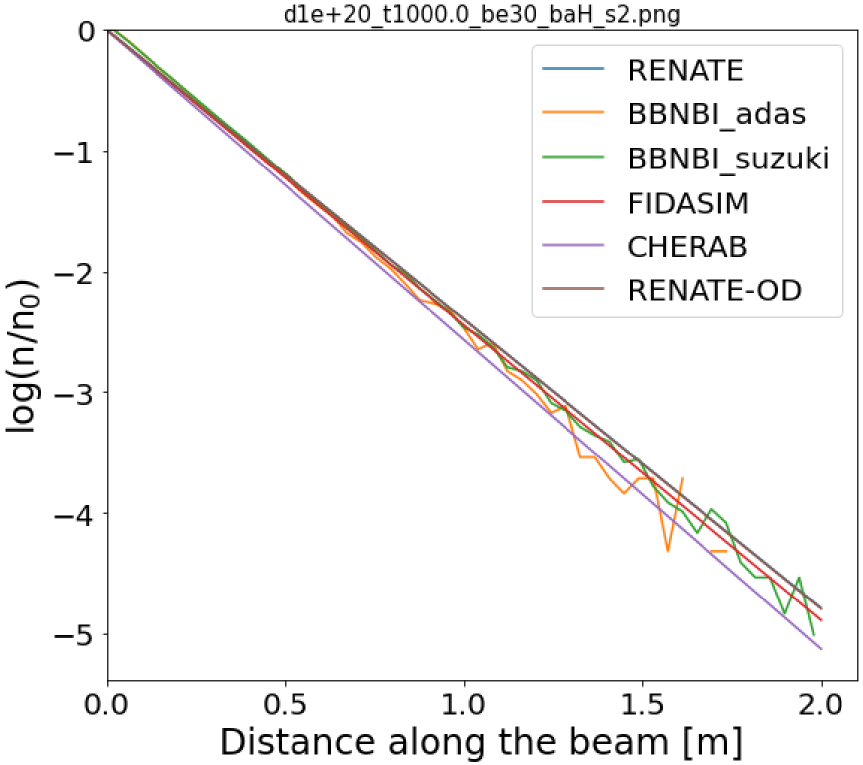
RENATE, RENATE-OD, FIDASIM, BBNBI, CHERAB

Li and Na beams: RENATE, RENATE-OD

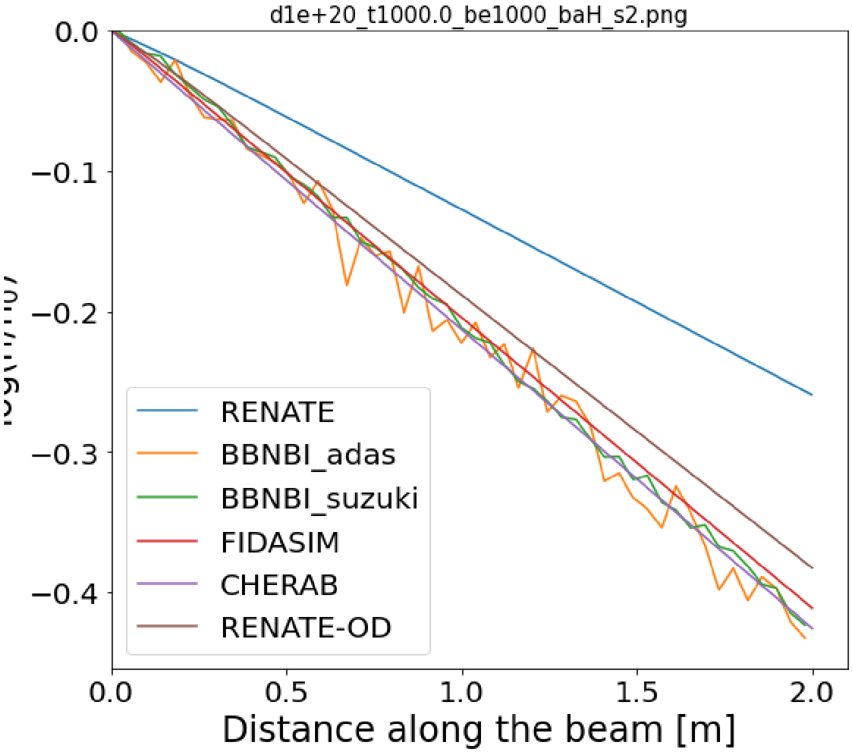
Most standard: pure H (case 2)

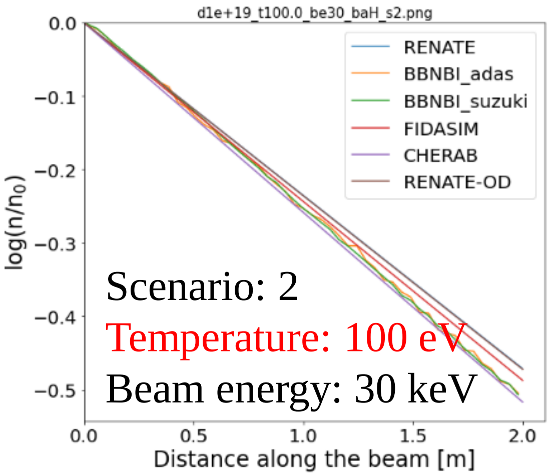
Scenario: 2
Density: 1E+20 1/m3
Temperature: 1 keV

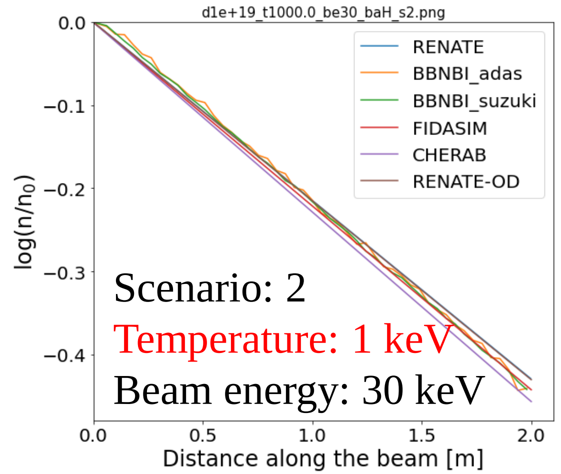
Beam energy: 30 keV

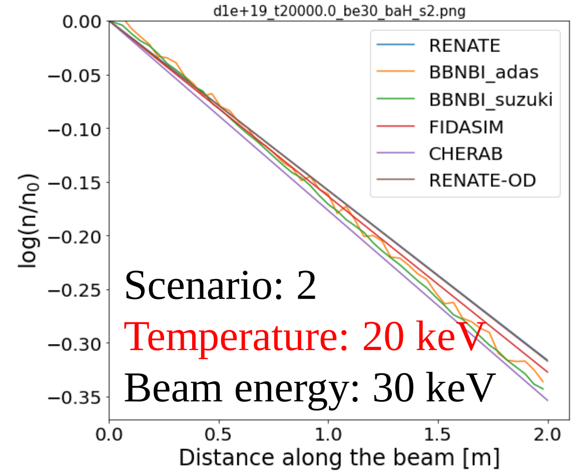


Beam energy: 1 MeV









					Attenuation coefficient (1/m)							
Density [1/m3]	Temp [eV]	Beam energy [keV]	Beam atom	Scenario	RENATE	BBNBI-ADAS	BBNBI-Suzuki	FIDASIM	CHERAB	RENATE-OD	CRM-stat	**average**
1E+19	100	30	H	2	0,543	0,588	0,589	0,562	0,595	0,544	0,562	**0,569**
1E+19	1000	30	H	2	0,494	0,499	0,504	0,510	0,526	0,495	0,510	**0,506**
1E+19	20000	30	H	2	0,364	0,382	0,399	0,377	0,407	0,365	0,376	**0,381**

					Attenuation coefficient deviation from average (%)						
Density [1/m3]	Temp [eV]	Beam energy [keV]	Beam atom	Scenario	RENATE	BBNBI-ADAS	BBNBI-Suzuki	FIDASIM	CHERAB	RENATE-OD	CRM-stat
1E+19	100	30	H	2	-4,6	3,3	3,5	-1,3	4,7	-4,4	-1,2
1E+19	1000	30	H	2	-2,2	-1,2	-0,2	0,8	4,0	-2,0	0,9
1E+19	20000	30	H	2	-4,6	0,2	4,5	-1,2	6,8	-4,3	-1,4

Case 2 (pure H plasma) general conclusions

Matching attenuation coefficients **within a few percent**. → quantify staistics?

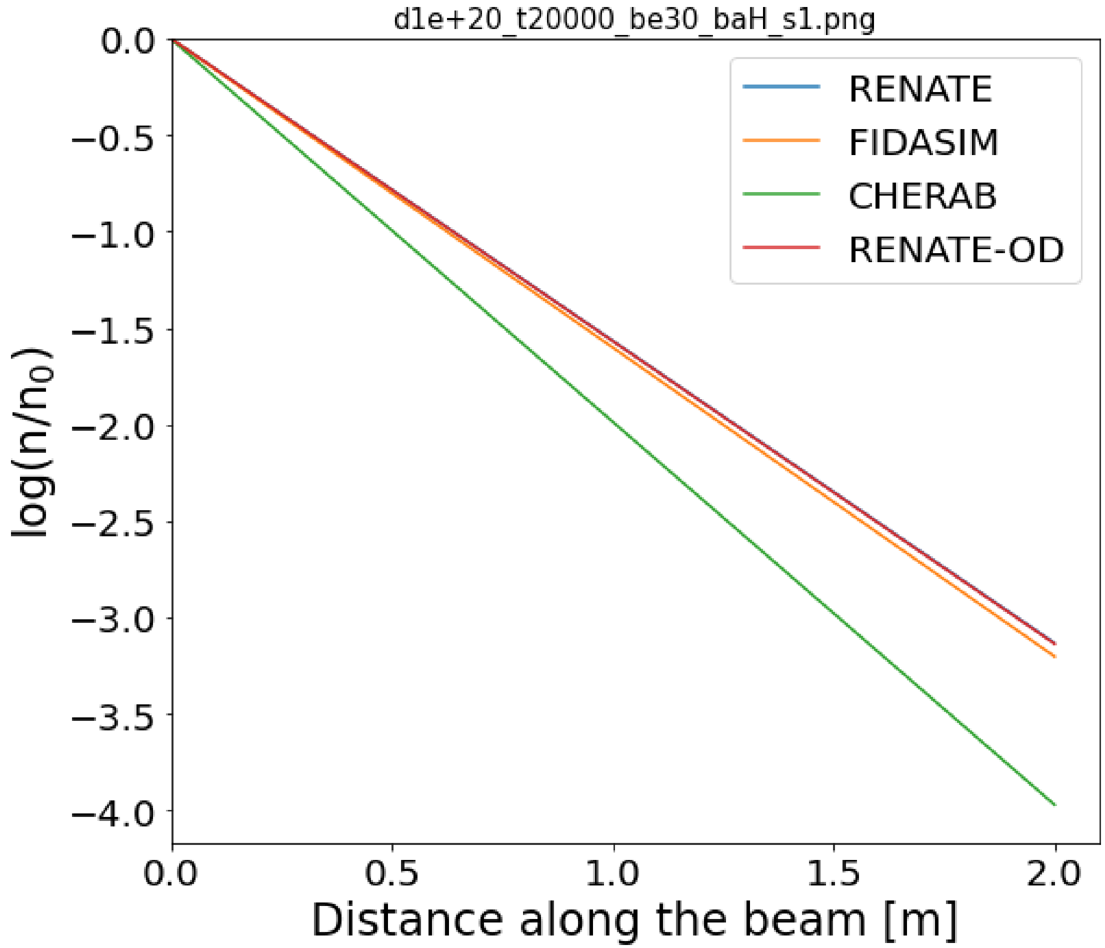
1. BBNBI and CHERAB use the effective attenuation coefficients calculated by ADAS. BBNBI data features stochasticity due to its Monte-Carlo nature. → fit exponential on BBNBI?
2. Both RENATE and RENATE-OD are based on the ALADDIN database and solve bundled-n CRM, so no significant difference is observed for pure plasmas. → RENATE-OD fixed for high energy!
3. FIDASIM and CRM-stat (by O. Marchuk) also solves bundled-n CRM but based on ADAS – their agreement is very good.
4. nl-model needed! nlm-model needed?
5. New bundled-n cross-sections?
6. … ?

All codes agree on a tendency of a **significant effect of plasma temperature** and appear to produce reliable results.

Pure ions – H plasma (case 1)

Scenario: 1
Density: 1E+20 1/m3
Temperature: 20 keV
Beam energy: 30 keV

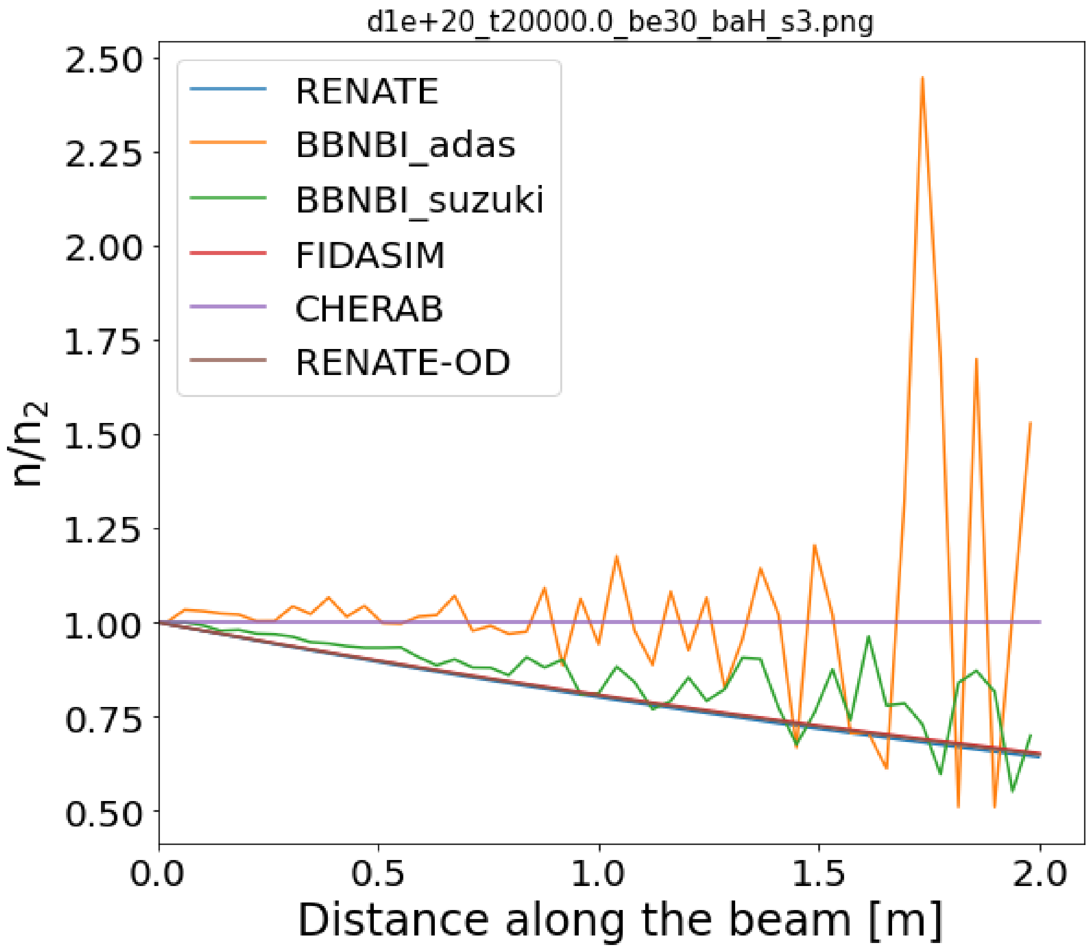
Beam energy ~ ion temperature extreme case.
RENATE and FIDASIM use similar methods to integrate rates.
(Input from ADAS and Marchuk CRM?)



Isotope effects – H vs D plasma (case 2-3)

Scenario: 2-3 relative
Density: 1E+20 1/m3
Temperature: 20 keV
Beam energy: 30 keV

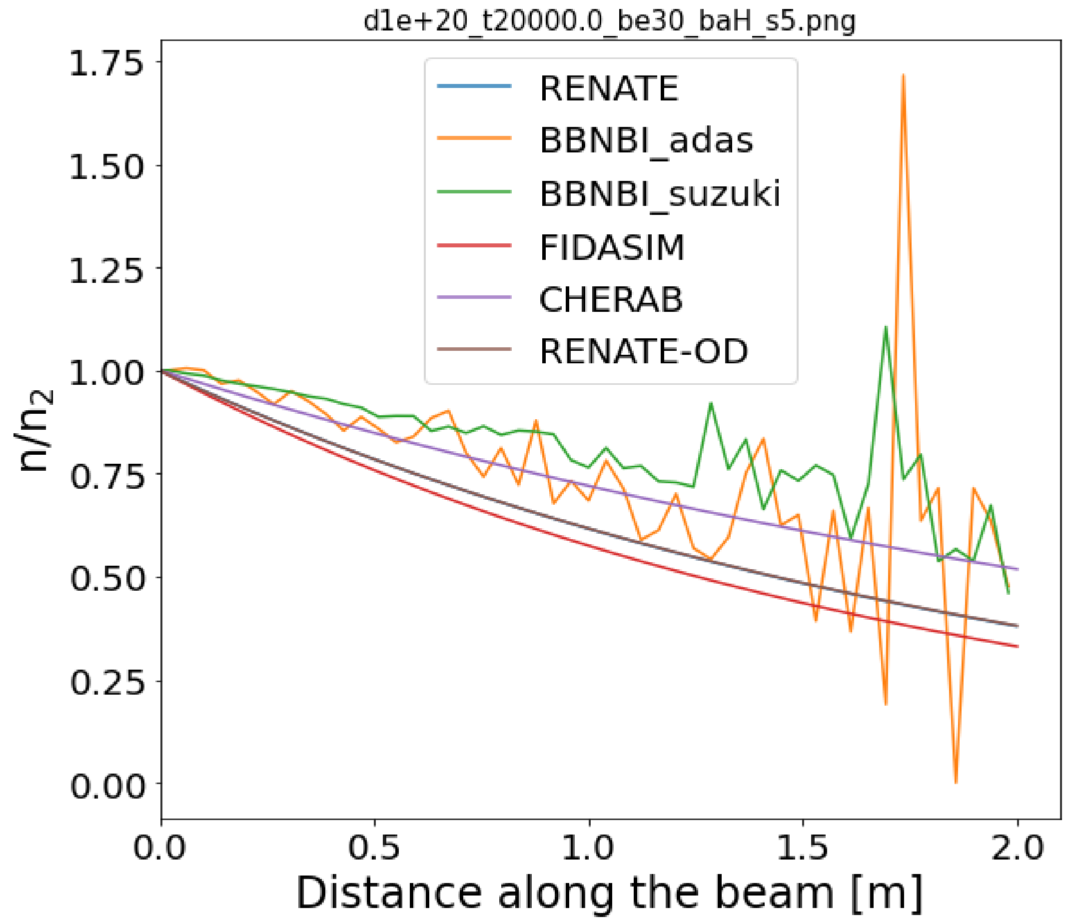
Comparison of H and D plasma showed a **small isotope effect**, at high temperature and low beam energy.
(Need to check CHERAB, BBNBI.)



Impurities – Be impurity (case 5)

Scenario: 2-5 relative
Density: 1E+20 1/m3
Temperature: 20 keV
Beam energy: 30 keV

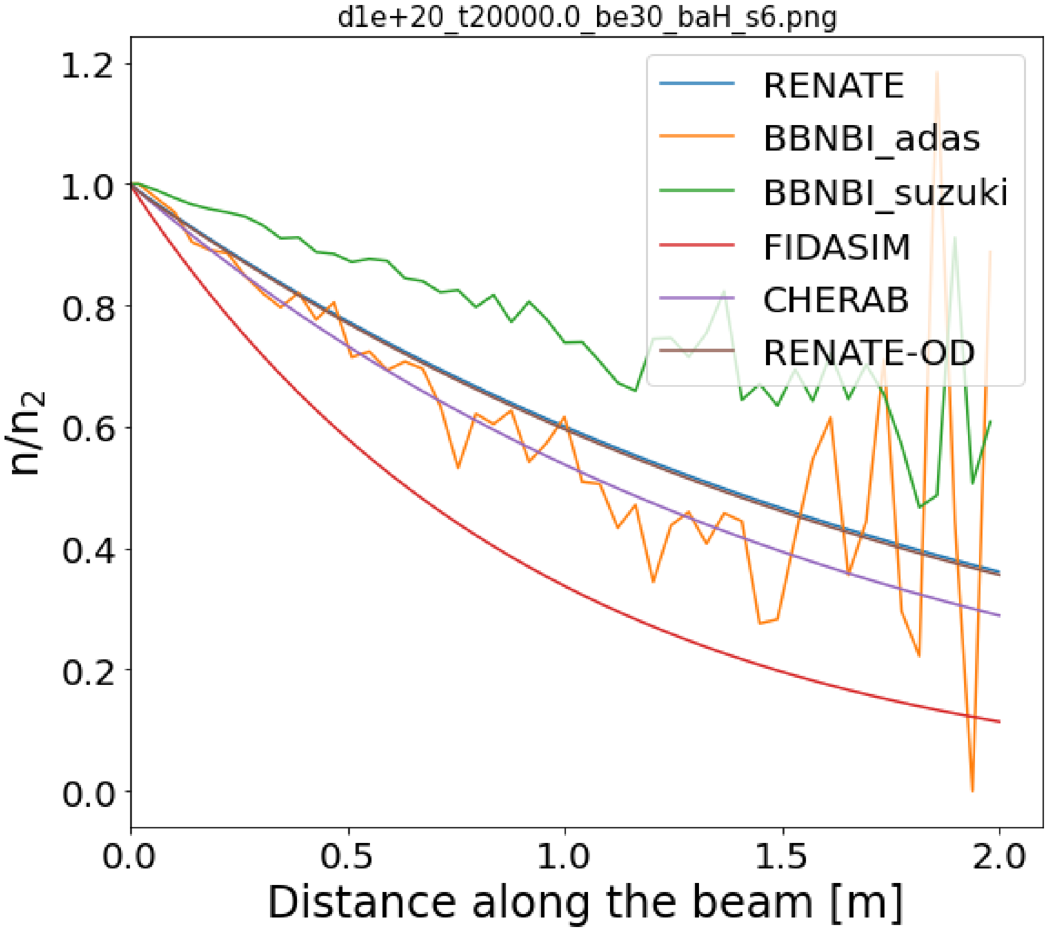
The **effect of impurities** – provided the same electron density and quasi-neutrality – is a **increase in the attenuation rate**.



Impurities –C impurity (case 6)

Scenario: 2-6 relative
Density: 1E+20 1/m3
Temperature: 20 keV
Beam energy: 30 keV

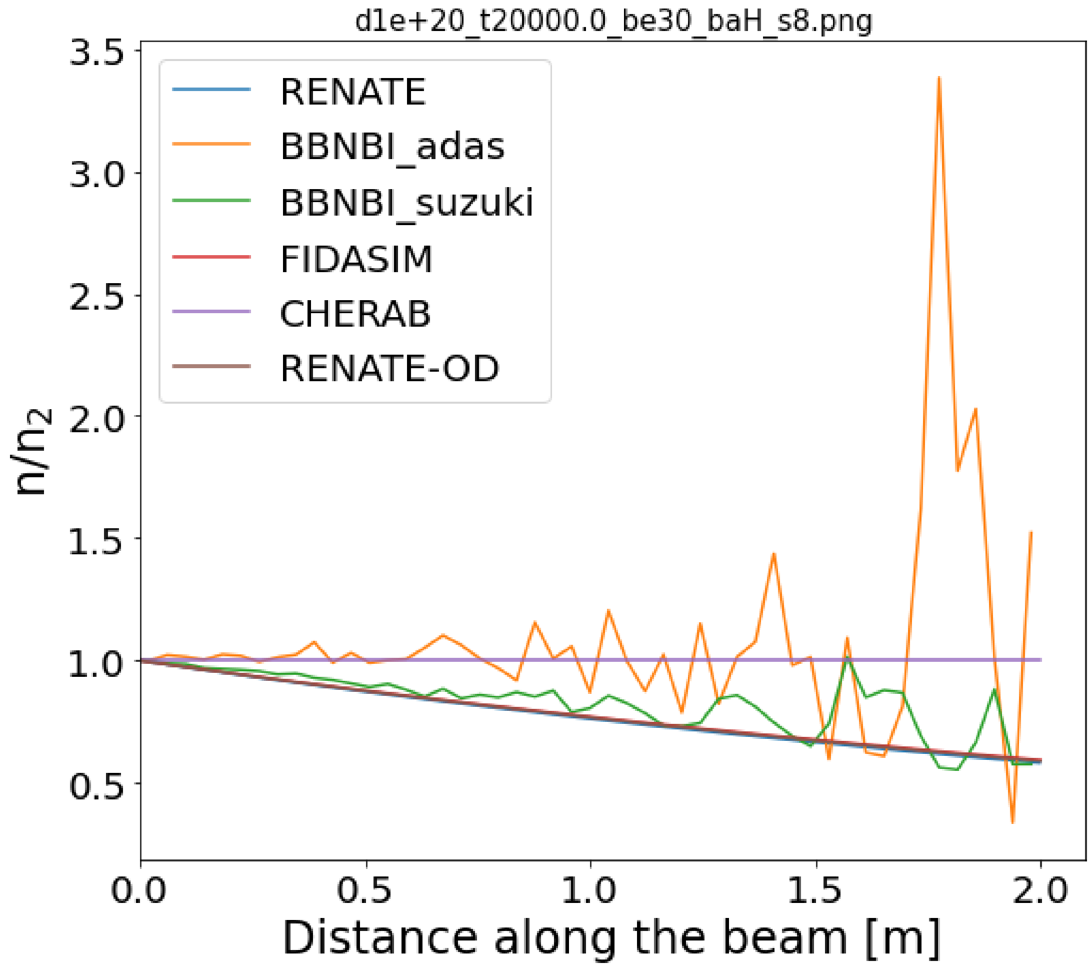
More scatter of results for C impurity – requires further investigation.



Mixed plasma D-T (case 8)

Scenario: 2-8 relative
Density: 1E+20 1/m3
Temperature: 20 keV
Beam energy: 30 keV

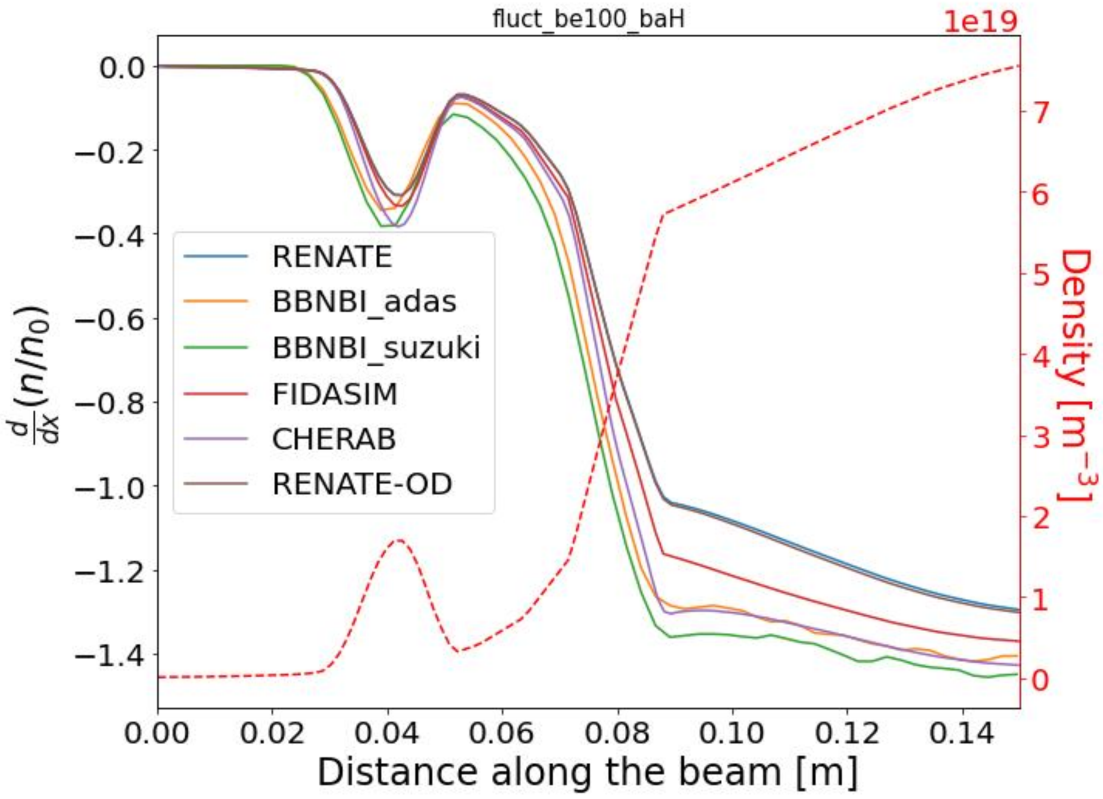
The **effect of is like the H-D isotope effect.**
(Need to check CHERAB, BBNBI.)



Plasma profile: ITER with SOL blob

Beam type: H
Beam energy: 100 keV
(ITER DNB)

Good agreement of all codes
With **the CRM-solvers** (FIDASIM and RENATE(-OD)) **featuring a slightly delayed response to the density changes**.

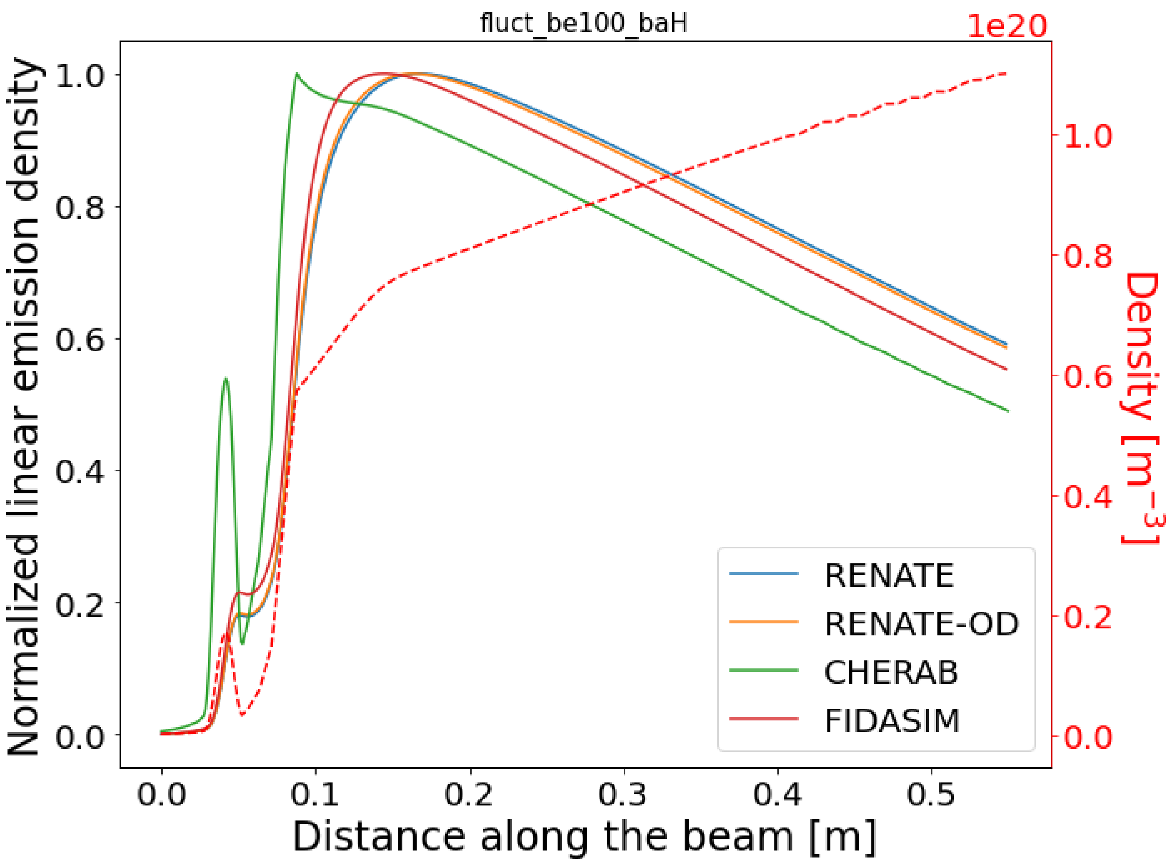


Plasma profile: ITER with SOL blob

Beam type: H
Beam energy: 100 keV
(ITER DNB)

Not all codes can calculate.
With **the CRM-solvers** (FIDASIM and RENATE(-OD)) **featuring a significantly delayed response to the density changes**.

Photoemission



Summary

1. **Benchmark was already very useful for code development** – preliminary results published at [EPS2021, Pokol et al.].

2. **RENATE Open Diagnostics** got a new rate calculation module – **corrected rates calculation at beam energy >> 100 keV**.

4. Some **constant profile test cases were challenging**: 7 (W impurity), 9 (with W impurity) – **new W data** could be added to RENATE-OD.

5. **Plasma profile test cases** show expected results, but small effects – **more pronounced effects in photoemission!**

6. Sufficient input data **only for beams of Hydrogenic species**.

7. Benchmark could be more complete with the missing codes and nl-resolved models.

8. Another direction would be to **test the effect of the new cross-sections → add Be data → rather in CRP summary paper?**

9. Journal publication in progress to Journal of Physics B, accepted SOFT2022 abstract.