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SPICE2 PROGRESS WITHIN TSVV-7

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EMISSIVE SHEATH (MK)
SPICE2 BASELINE SHEATH (AP)

OUTLINE

PROGRESS IN EMISSIVE SHEATH SIMULATIONS

- Angular scan
- Scaling validity

BENCHMARK SIMULATION OF THE SHEATH

- Motivation
- Setup and relevance
- Results

EMISSIVE SHEATH IN ITER INTER-ELM PLASMA

ANGULAR SCAN

Objective: Assess the validity of the scaling for the escaping current [Komm NF 2020] for the case of TE+SEE+EBS (using models described in [Tolias NME 2020])

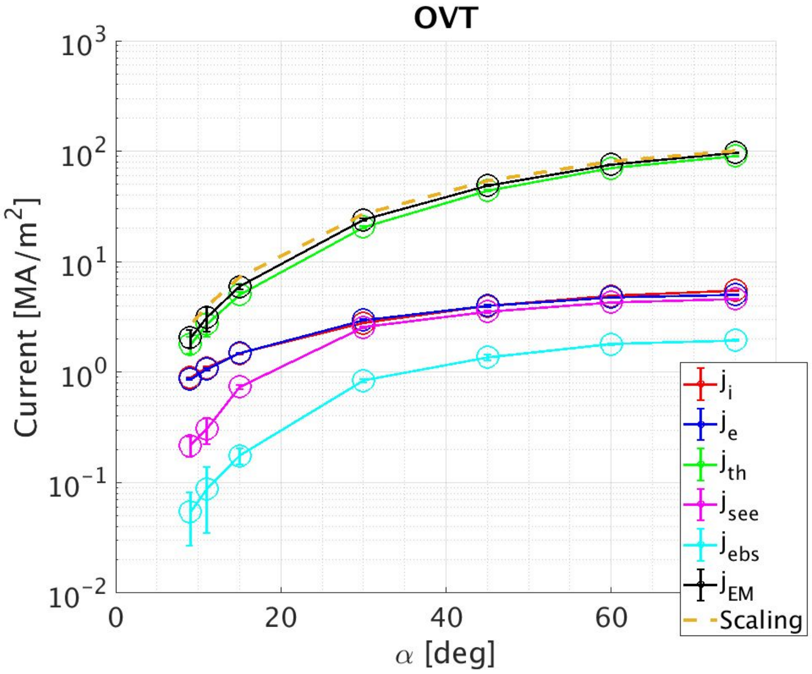
$$J_{\mathrm{th}}^{\mathrm{lim}} \simeq 0.43 e n_{\mathrm{e}} \nu_{\mathrm{Te}} \sin^2 \alpha$$

Plasma conditions: ITER intra-ELM plasmas (T_e = 500 eV) for…

- OVT (B_T = 6 T, n_e = 1.67e20 m^{-3}) and
- IVT (B_T = 8 T, n_e = 2.9e20 m^{-3})

Model settings

- Schottky correction has been turned off
- Angular scan: **75**, **60**, **45**, **30**, **15**, **11**, **9**, 7, 5 degrees



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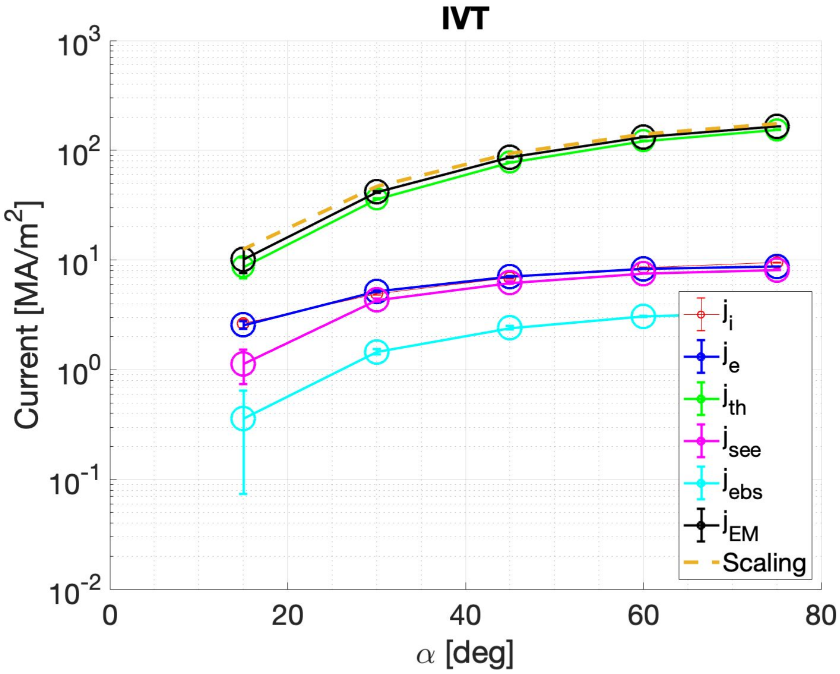
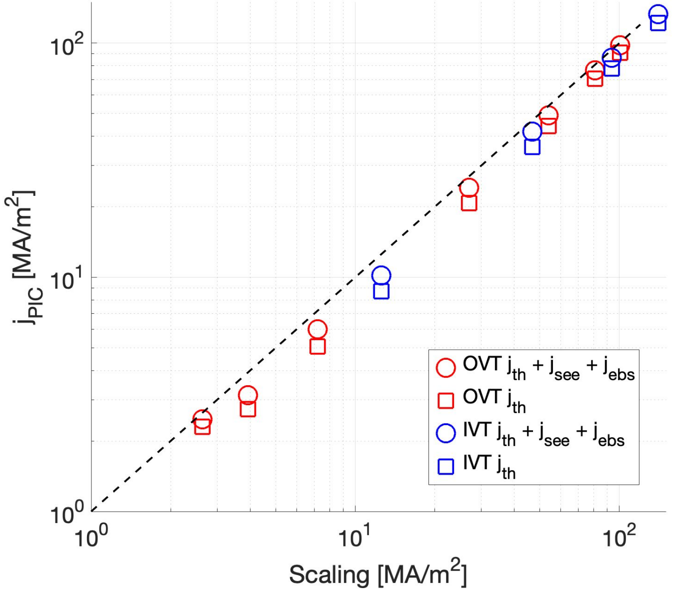


EMISSIVE SHEATH IN ITER INTER-ELM PLASMA

SCALING VALIDATION

- So far the total escaping current follows the scaling law and the contribution of SEE and EBS is not significant
- Let's see what happens at 5 degrees

Simulations for low angle of incidence are expected to be done by the end of this year.



SPICE2 BASELINE SHEATH

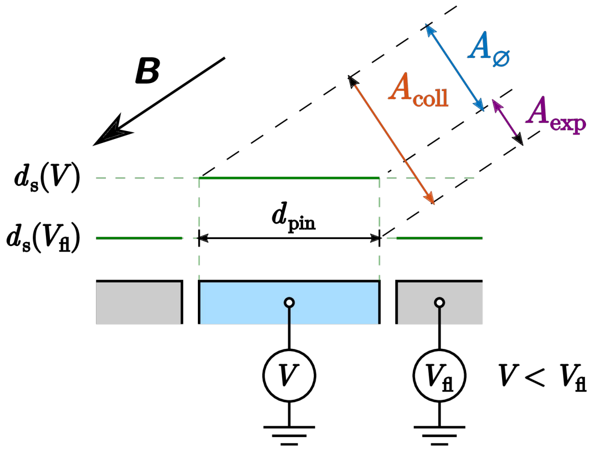
DOUBLE MOTIVATION – (A) SHEATH EXPANSION

Sheath thickness in front of charged surface appears to change with the voltage. Simple formula w/o ***B*** gives approx. ¾ power:

$$z_{\mathrm{DS}} = \frac{2\sqrt[4]{2}}{3}\left|\frac{V}{T_{\mathrm{e}}}\right|^{\frac{3}{4}}\lambda_{\mathrm{D}}$$

Simple conclusion: **More negative voltage, more extra current collected.** Some corrections on angular dependence – not good.

Main application: Correction of probe measurements that depend on low-biased probes.



Sheath in front of the flush-mounted probe biased below floating potential.

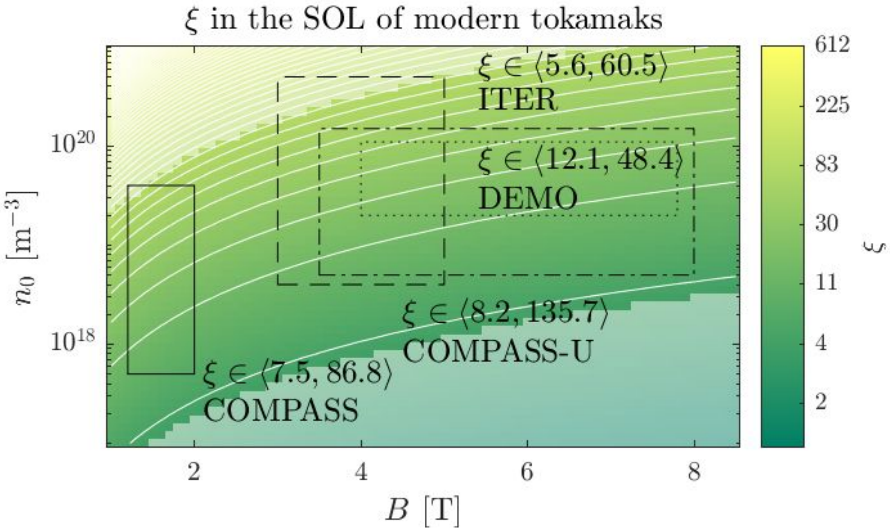
SPICE2 BASELINE SHEATH

DOUBLE MOTIVATION – (B) SHEATH

SPICE task within TSVV-7 aims to provide tools for simulation of **novel processes** within the Debye sheath and magnetic presheath.

However, no baseline sheath properties table/database has been provided with **current capabilities**.

Both (A) and (B) are in synergy – setup of the **database** of sheath parameters and profiles and infer either comparison or direct results.



Magnetization parameter ξ in upcoming tokamaks.

THE SETUP

Using SPICE2 as 1D simulation tool – fast, allows a lot of…

PARAMETRIC SCANS

TEMPERATURE RATIO

τ $= T_i/T_e = 0.2, 0.5, 1, 2, 4$

MAGNETIZATION

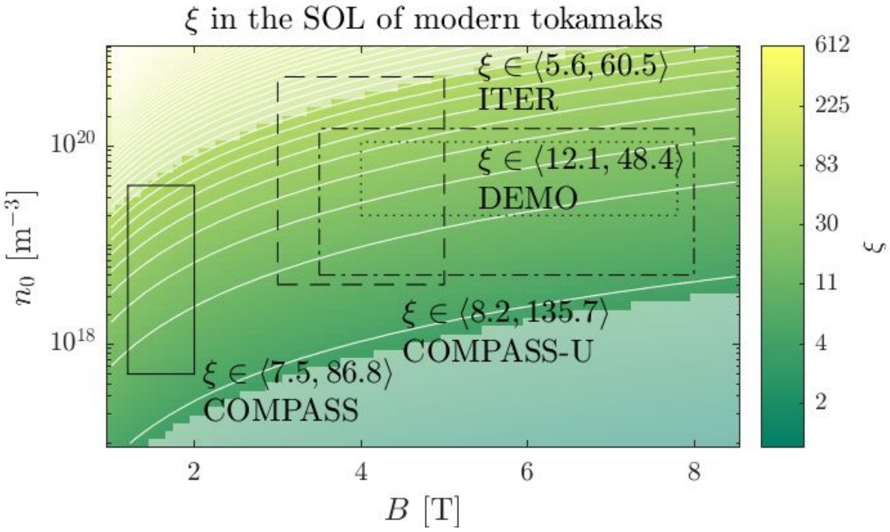
ξ $= r_L/\lambda_D = 4, 6, 12, 19, 38, 87$

MAGNETIC FIELD ANGLE

$\ln \sin \alpha_B$ $= -5\ (0.4°), -4.5, \ldots, -1, -0.5, -0.25, 0\ (90°)$

TOTAL SHEATH POTENTIAL DROP

V/T_e $= -10, -8, -6, -5, -4.5, \ldots, 0$



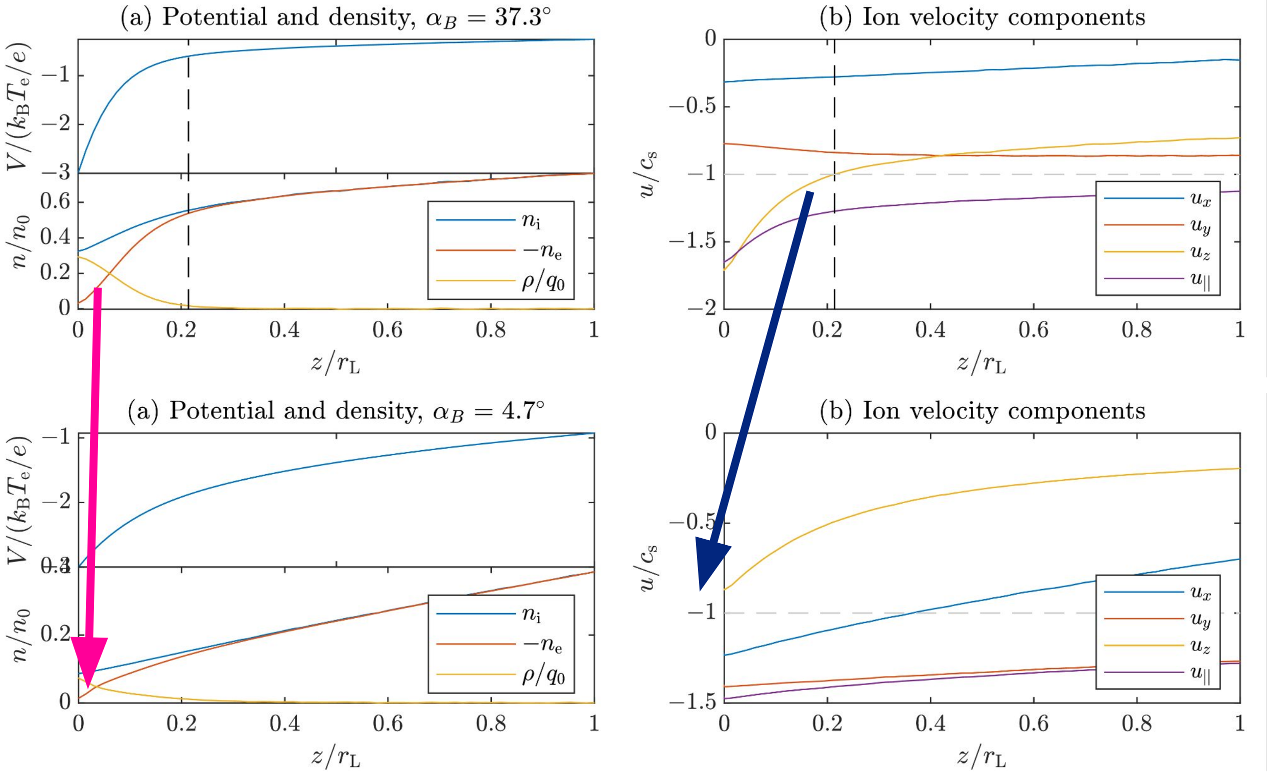
Magnetization parameter ξ in upcoming tokamaks.

Sheath w/*B*

Region where quasineutrality is broken and plasma particles interface with surface via electric forces.

Bohm-Chodura condition gives values of u_z at sheath entry, however, angular dependency and a critical angle exist [Stangeby 2012].

- One of investigated tasks was to identify the sonic-subsonic transition wrt magnetic field angle.



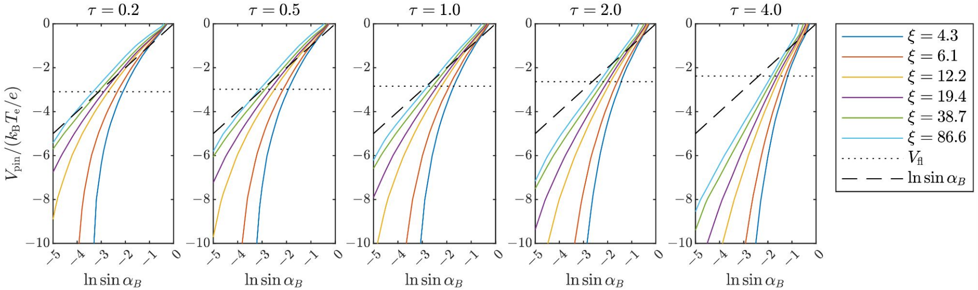
SONIC FLOW LIMIT

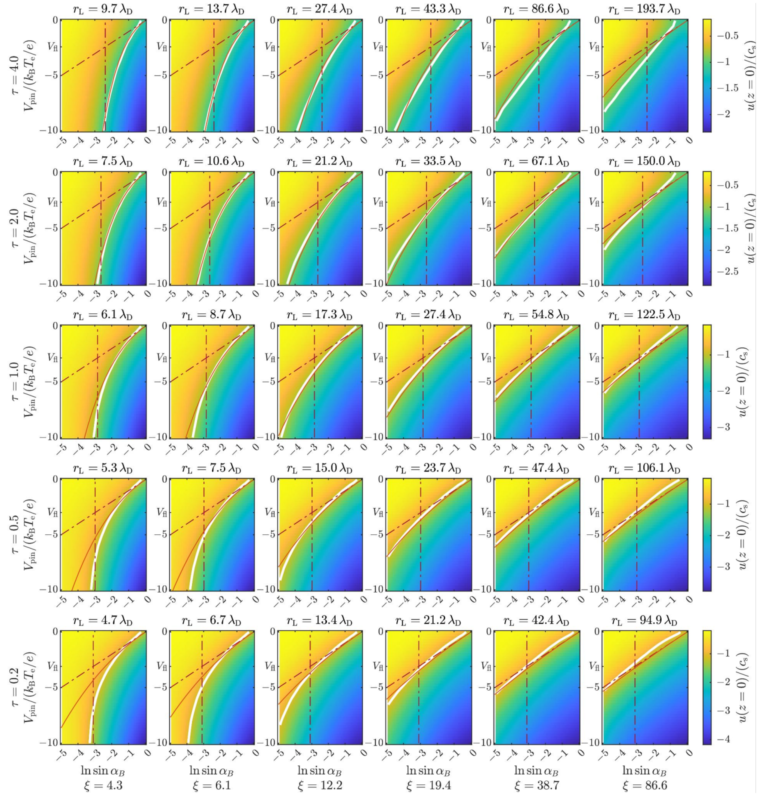
Color – perpendicular velocity (u_z) at surface = **limit of a sonic flow**

White line – $\boldsymbol{u_z = c_s}$

Red dashed – equivalent magnetic **pre-sheath potential drop**

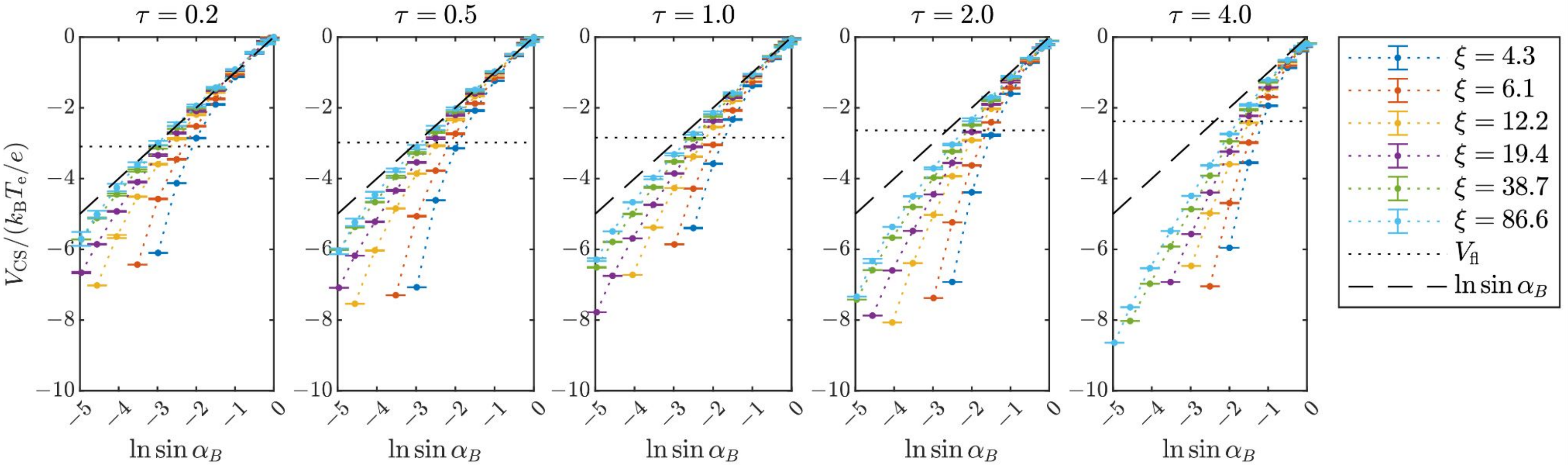
Probing surface transitions from sub-sonic to supersonic.





CS POTENTIAL V_{CS}

1. Find a place (in z), where $u_z = c_s$,
2. Get plasma potential → V_{CS}



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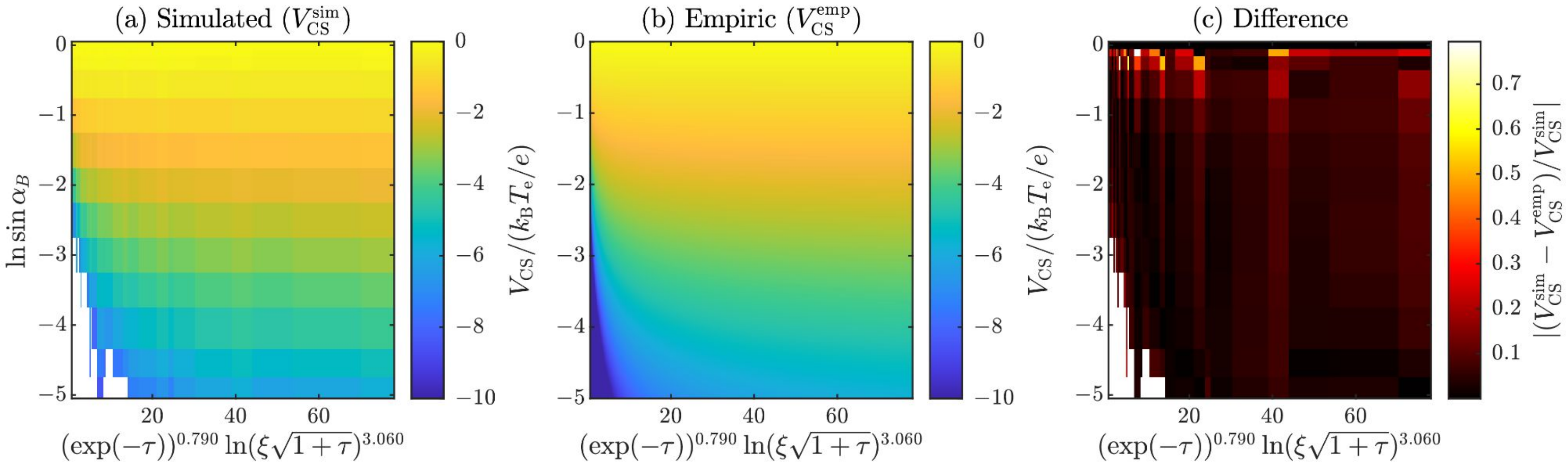

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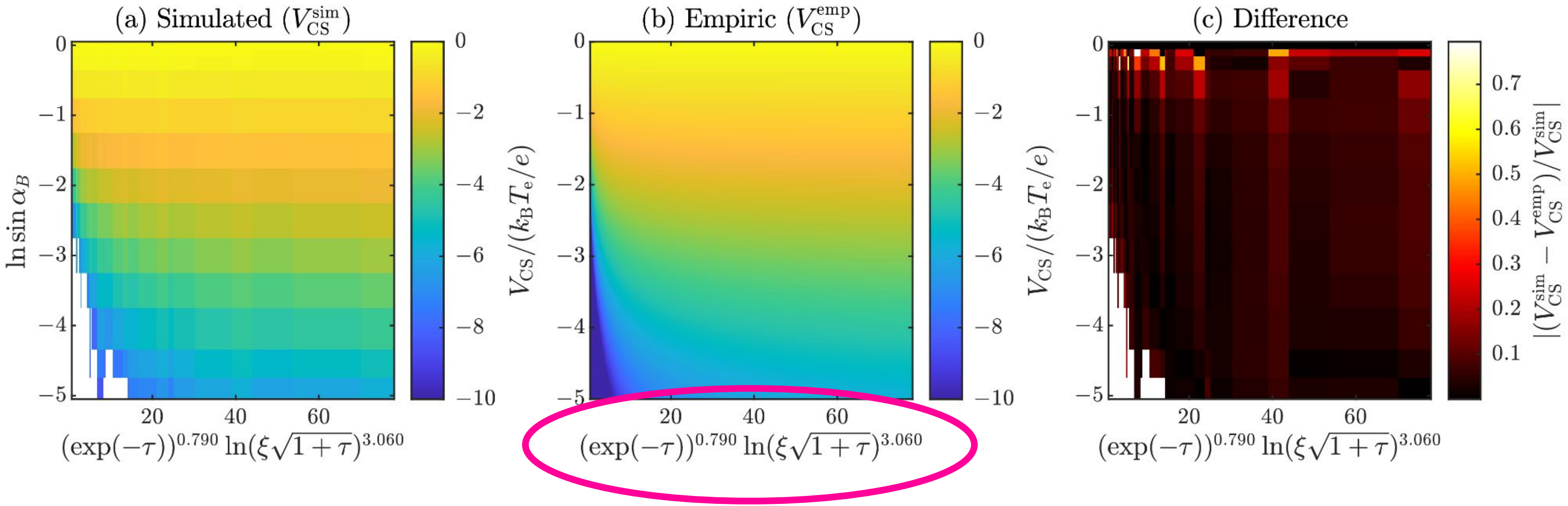

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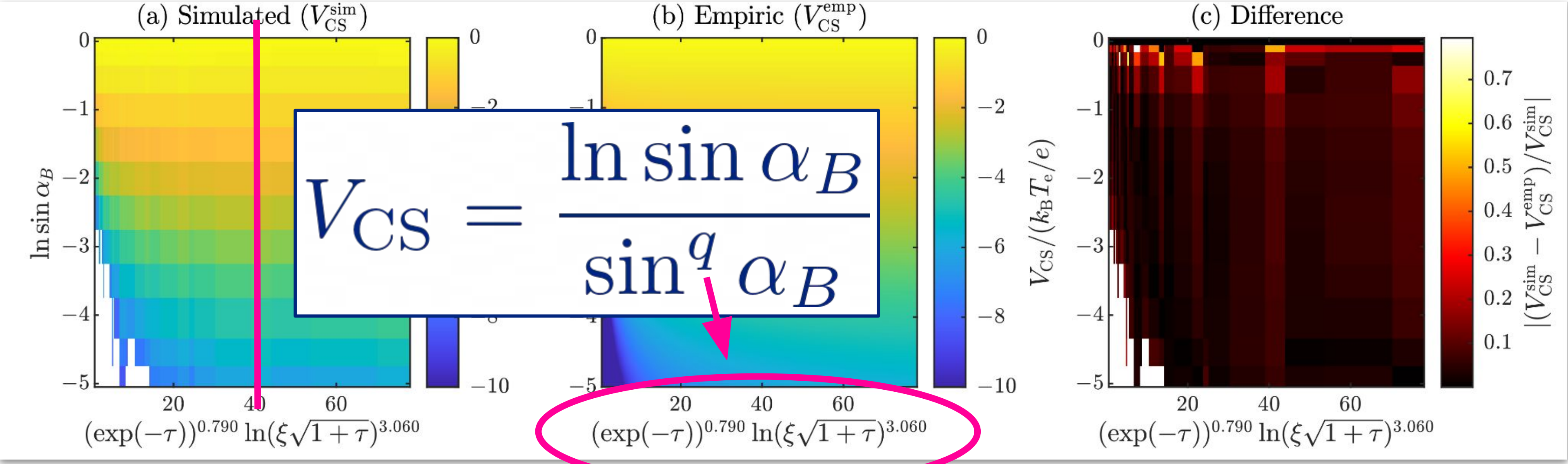


$$V_{\mathrm{CS}} = \frac{\ln\sin\alpha_B}{\sin^q\alpha_B}$$

POTENTIAL IN z-axis

Usually, some codes use following expression for *V*(z) in CS:

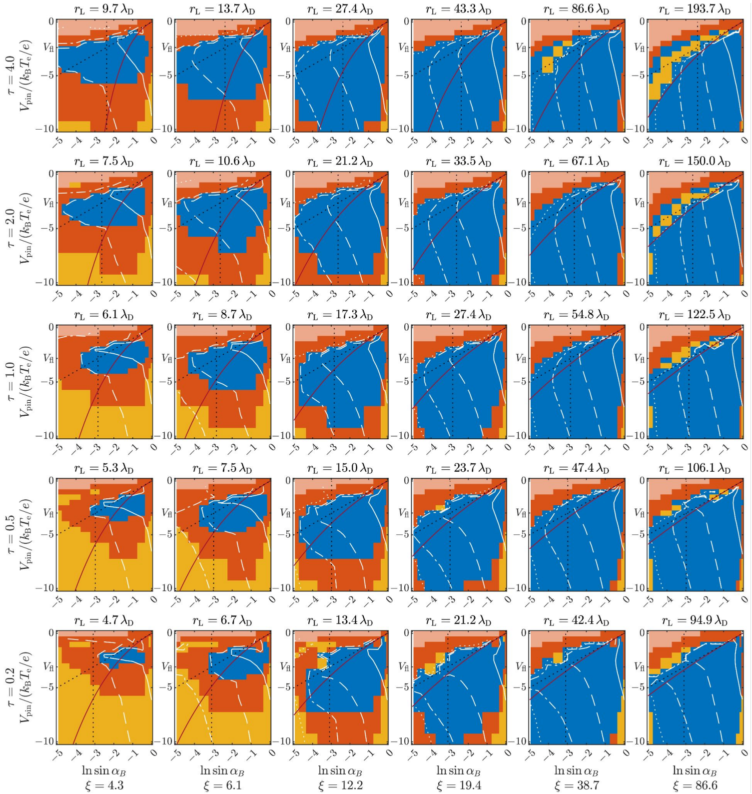
$$V(z) = V_{\mathrm{DS}} \exp\left(\frac{-z}{L_{\mathrm{DS}}}\right) + V_{\mathrm{CS}} \exp\left(\frac{-z}{L_{\mathrm{CS}}}\right)$$

However, other descriptions can be used…

$$V(z) = V_{\mathrm{sh}} \exp\left(\frac{-z}{L_{\mathrm{sh}}}\right) + kz$$

$$V(z) = V_{\mathrm{sh}} \exp\left[\left(\frac{-z}{L_{\mathrm{sh}}}\right)^{q}\right]$$

Which fits the *V*(z) the best? Use **LSQ comparison**!



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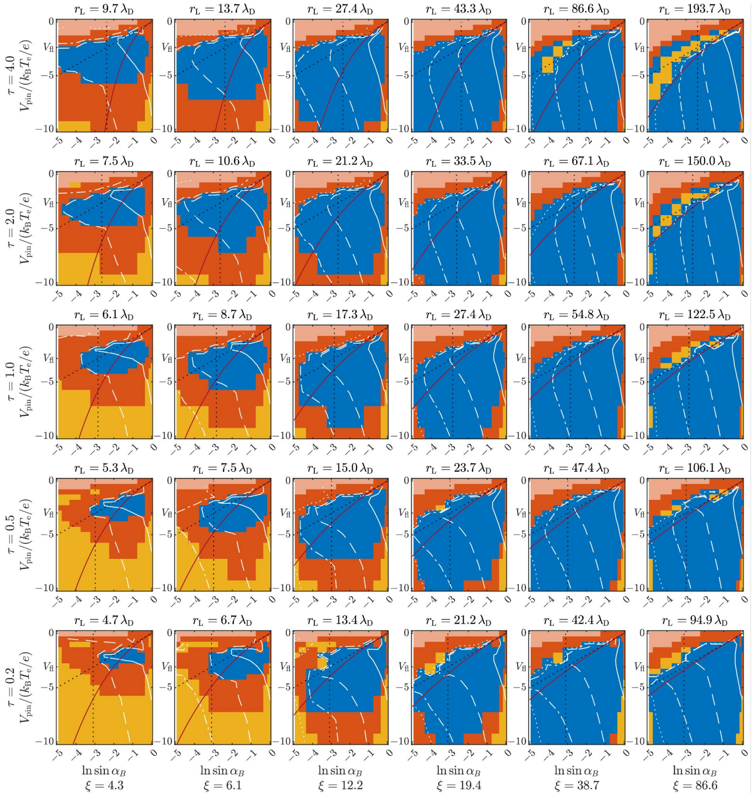
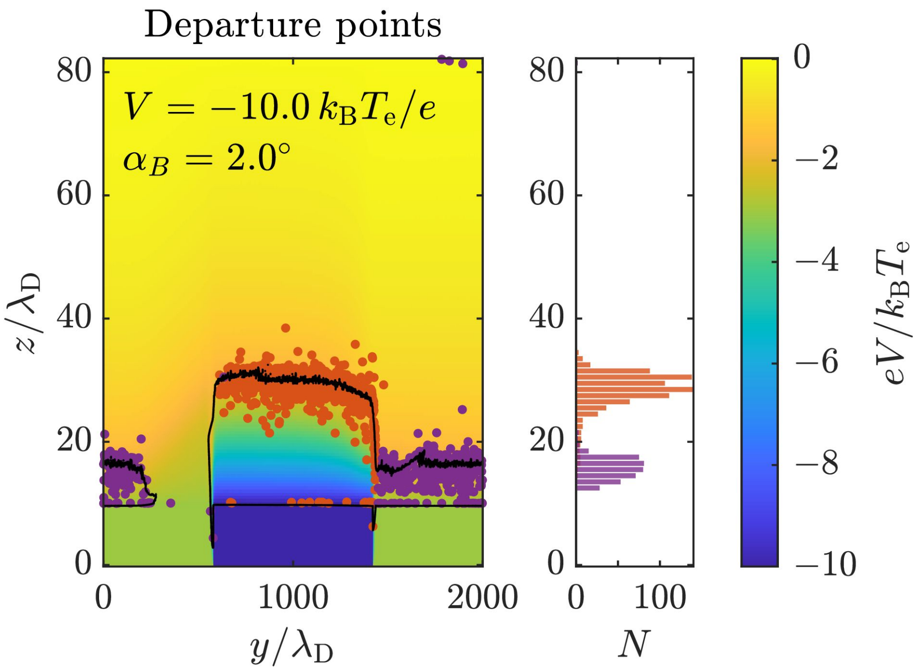


OTHER TASKS

- Particle collection location identification using particle tracing (right figure).
- Identification of scalings related to the location point.
- Extrapolation of results to sheath expansion effect prediction.



Sheath edge identification using different methods.

SUMMARY pt. 1

- Emmisive sheath simulations under way.
  Preliminary results indicate **validity of** previously discovered **scalings**.
- General sheath simulations for comparison were performed.
  Sheath properties were tracked.
  Publication under way for **sheath expansion** estimation.

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UPGRADES OF INJECTION SCHEMA IN SPICE2

Outline

- SPICE injection
    - Updates of injection schema
    - Double-bounded system
    - Benchmarking simulations
- Coupling with BIT1

SPICE PARTICLE INJECTION SCHEMA

How does SPICE inject particles?
Several options are available, however, most commonly used is the “injection plane” scenario.

The algorithm

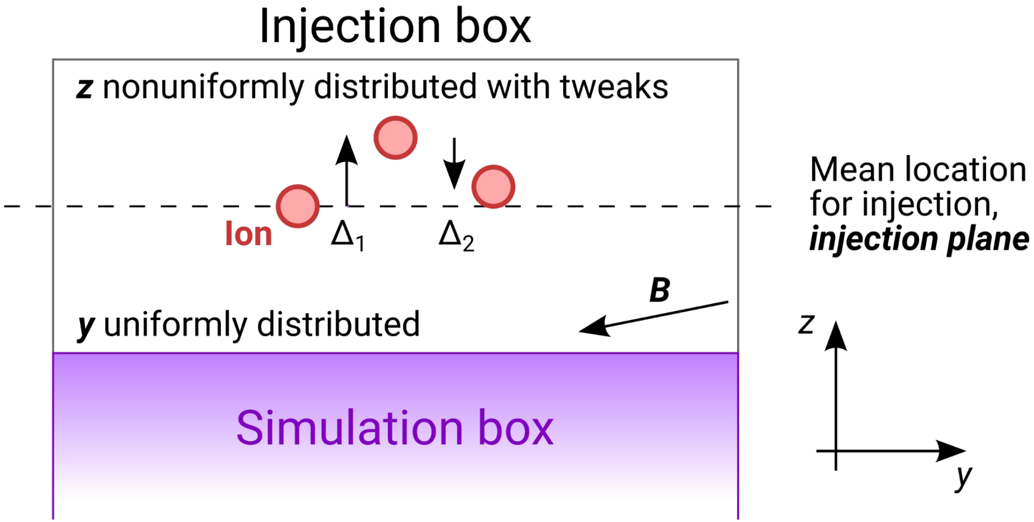
- Generate velocity – $v_{\perp,1}$, $v_{\perp,2}$, $v_{//}$ W/RT the magnetic field orientation.
  - Perpendicular components **Gaussian**, parallel component from a **prescribed SOL1D** distribution.
  - Transform to xyz coordinates.
- Generate location
  - 2D geometry – no x component
  - y – uniformly distributed
  - z – injection box strategy

Injection box strategy

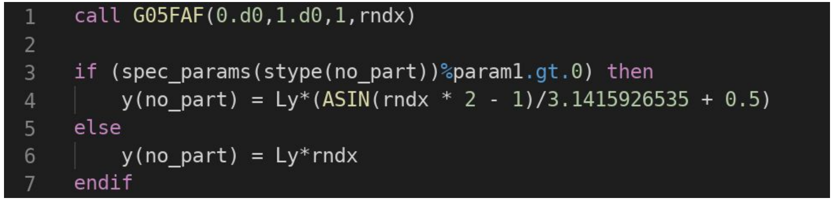
SINGLE BOUNDED SYSTEM

Place generated particles around the injection plane. Shake slightly.

1. Δ_1 – randomize within a time step
2. Δ_2 – equalize within Larmor rotation
3. Wind back for leapfrog motion



FIRST STEPS



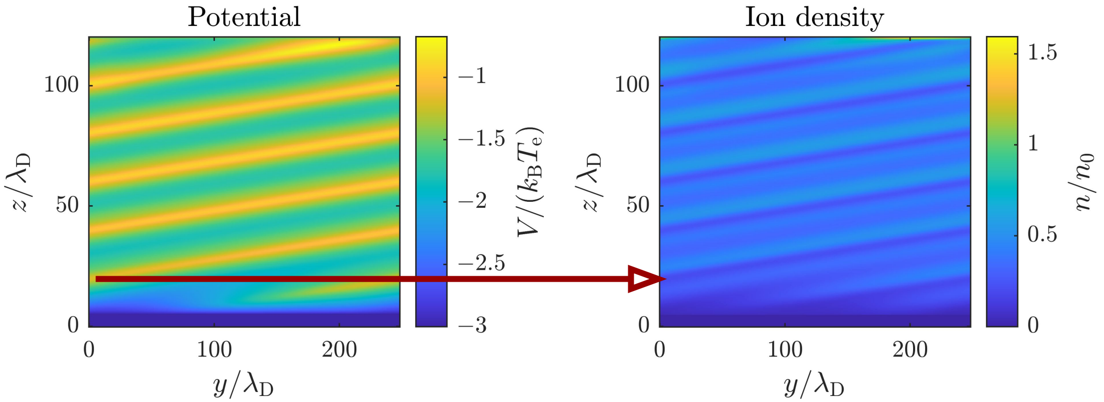
```
1   call G05FAF(0.d0,1.d0,1,rndx)
2
3   if (spec_params(stype(no_part))%param1.gt.0) then
4       y(no_part) = Ly*(ASIN(rndx * 2 - 1)/3.1415926535 + 0.5)
5   else
6       y(no_part) = Ly*rndx
7   endif
```

Simple sinusoidal injection location modulation.

Fig. in the left, line 4.

First test results

- Formation of **potential wells** near injection plane - propagating downwards.
    - Minima on ion density close to zero!
- Possible **influence of parallel streamlines**



NONUNIFORM DENSITY

Tweak 1: Inject from arbitrary probability distribution function (PDF). Will be useful later.

1. Prescribe PDF using SPICE input.
2. Generate the PDF
   Implemented: sinusoidal wave-like "bump" distribution with prescribed width and position.
3. Calculate and invert the cumulative distribution function (CDF).
4. Draw a number from 0 to 1 and convert it to location using inverted CDF.

New Fortran module for generating PDF created.

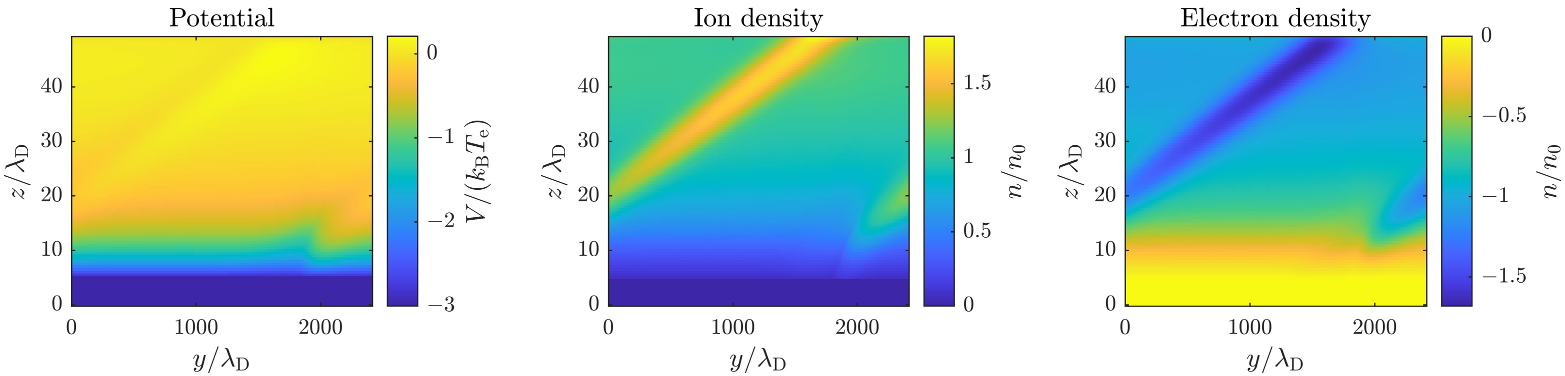
Tweak 2: Inject extra electrons to compensate for extra ions.

Extra ions form positive cloud thus blocking more extra ions from entering the simulation box.

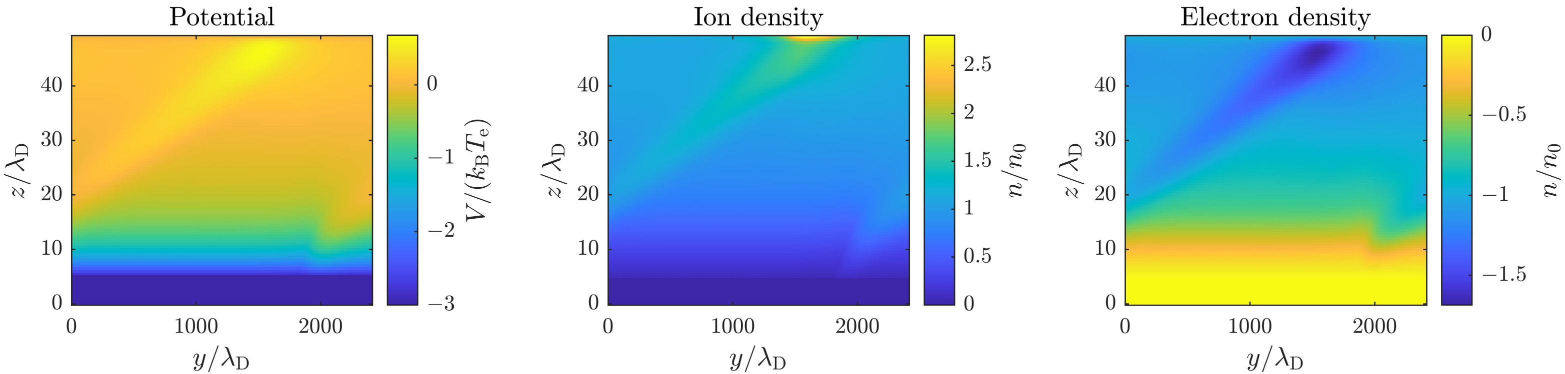
Tweak 3: Feedback the extra electron density on density of extra ions at the simulation box entrance.

Now the usefulness of arbitrary PDF generator comes into play.

All tweaks on



No extra electrons



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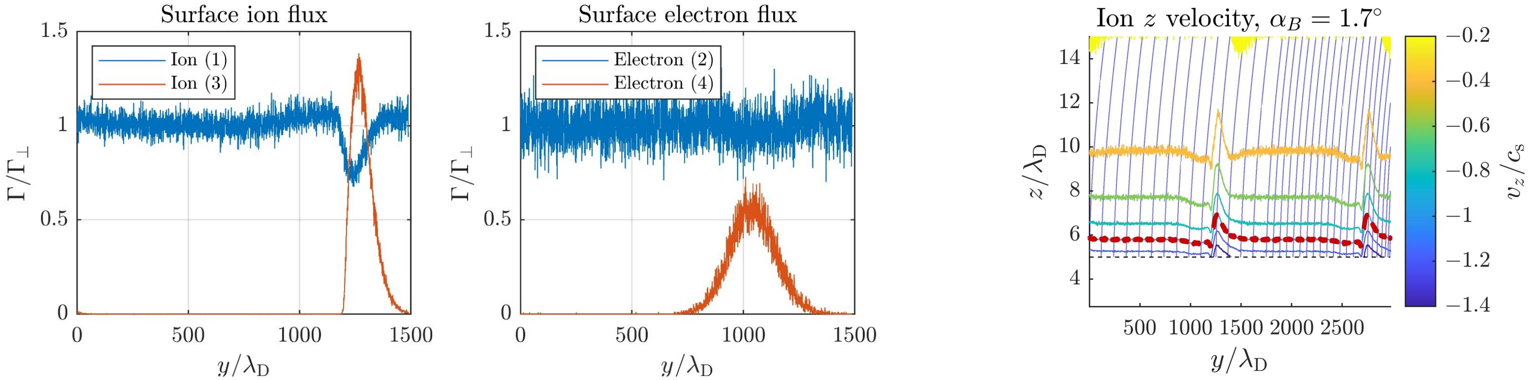

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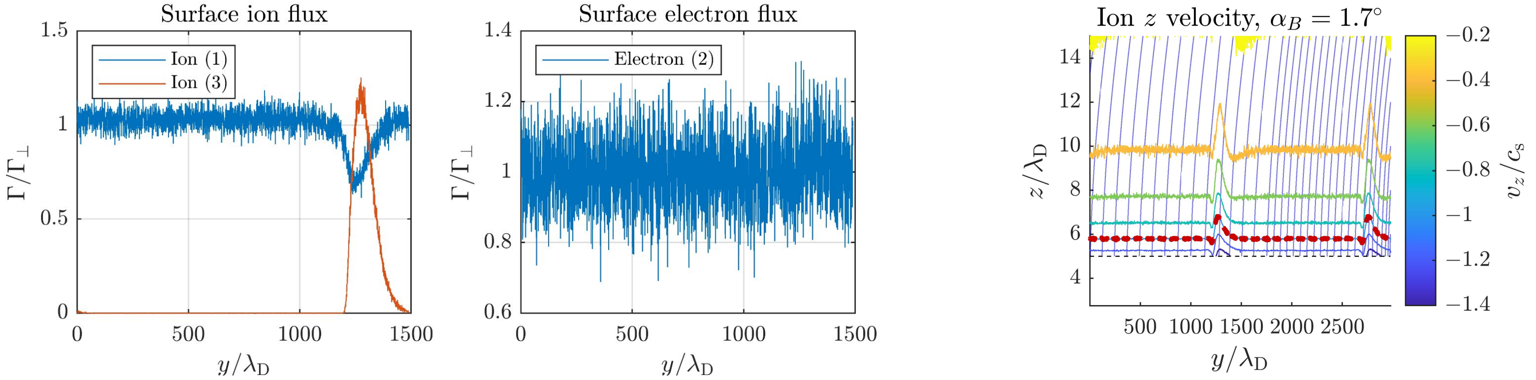

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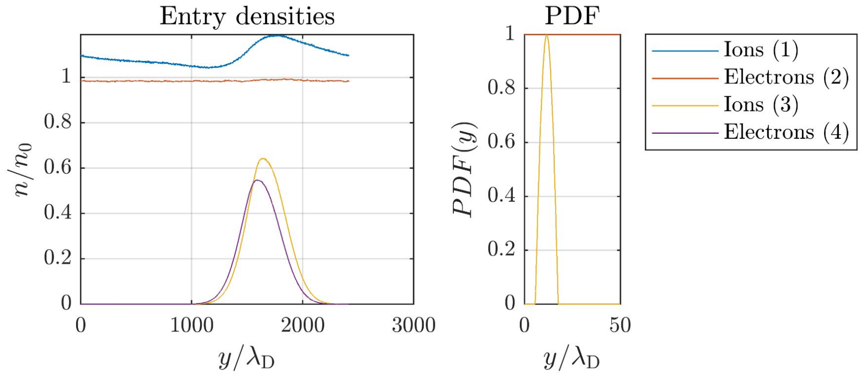

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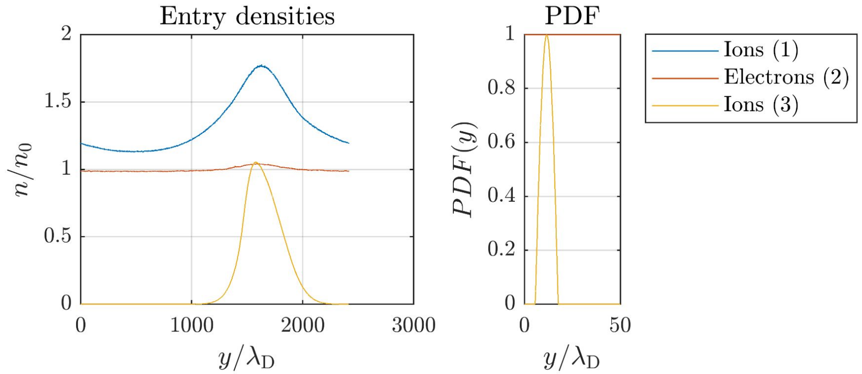


Effects summary

Arbitrary PDF injection enables us to

- inject nonuniform ion density,
- compensate using feedback.

Extra electron injection compensates the potential maximum formed by ions.

Extra electron injection stabilizes the cross-species influence between injected ions.

Both variants show similar ion flux, substantial difference in electron fluxes.

Extension of the simulation box length minimizes cross-streamline influence.

NONUNIFORM TEMPERATURE

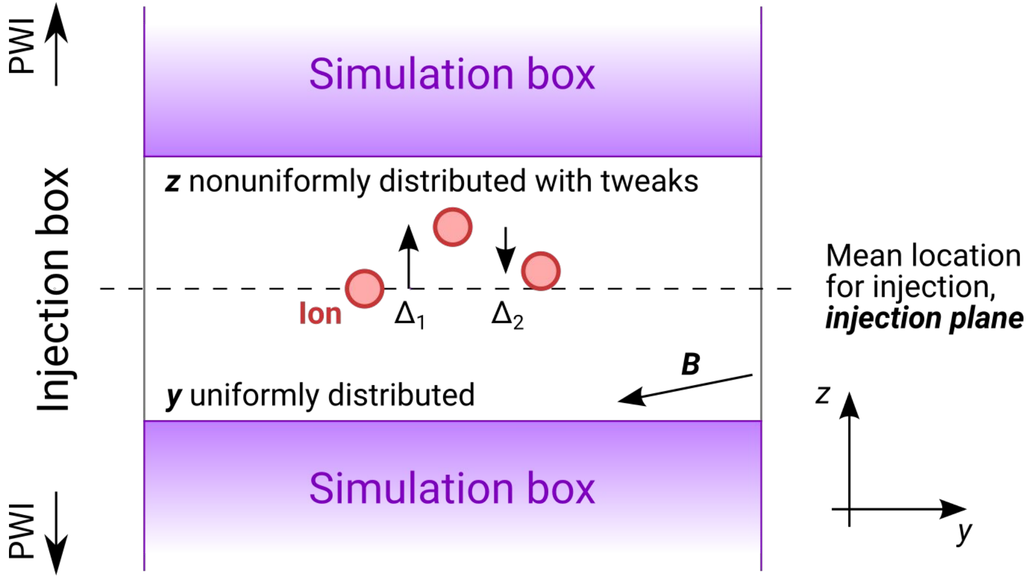
DOUBLE BOUNDED SYSTEM

Nonuniform T_e injection implies nonuniform boundary conditions on potential. Possible solution = **double bounded system**.

Previous work done by M. Komm and J. P. Gunn already introduced first attempt.

A novel injection schema was introduced to SPICE2.

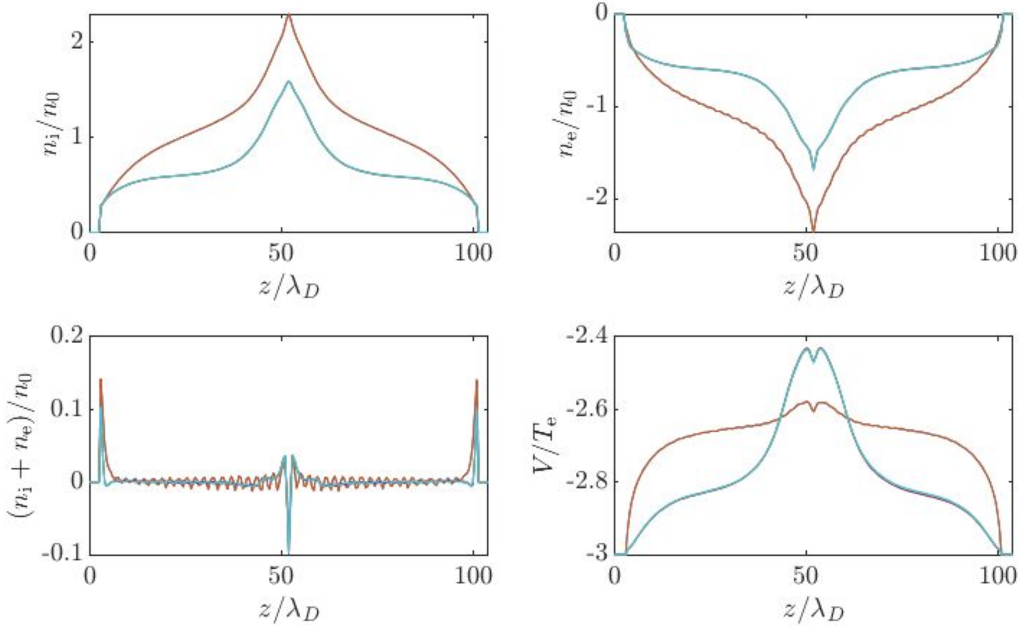
- Maxwellian source in the middle.
- Simple collision operator (re-maxwellization)-
- **Pre-sheath acceleration maybe necessary**!



DOUBLE BOUNDED SYSTEM

IMPLEMENTATION RESULTS

- Sheath-like structures are produced.
- Potential oscillation in space is visible
    - Mitigation using dz < 1.
- Oscillations in time initially visible, proper collision operator did help.



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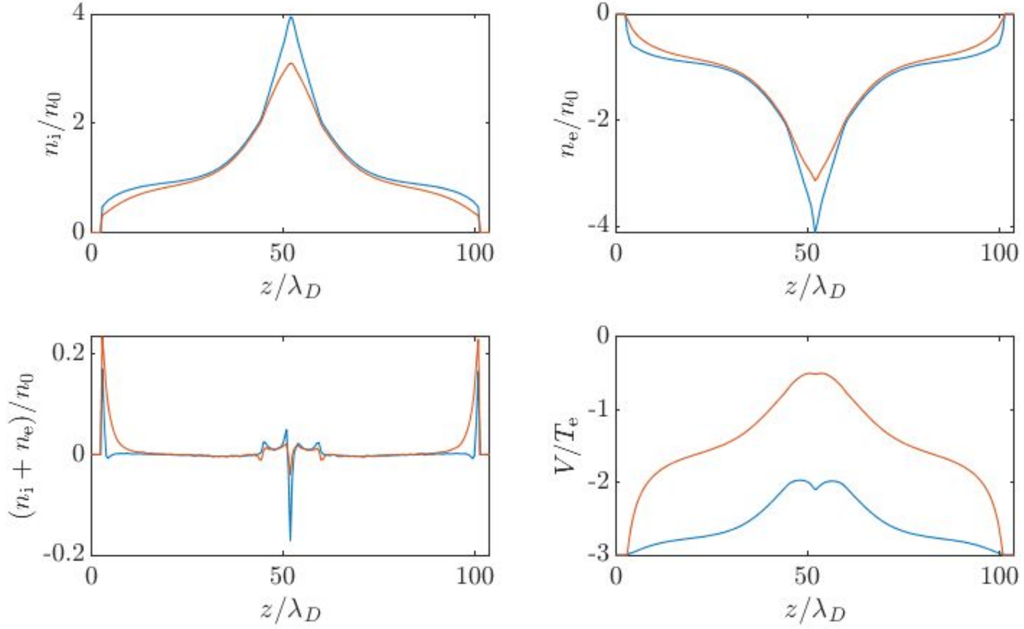
Best solution so far (fig. left, red line) still shows that proper pre-sheath acceleration region should be introduced – TBD.



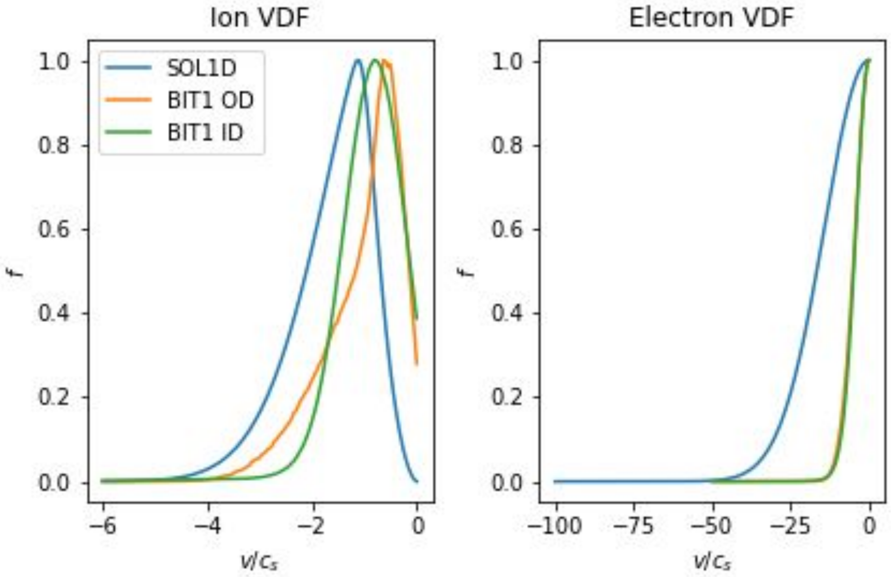
COUPLING TO BIT1

DISTRIBUTION FUNCTION TRANSFER

BIT1 (D. Tskhakaya) produces distribution functions for velocity/energy.
SPICE2 so far used DFs from SOL1D, new results with BIT1 are simulated = need of coupling.

Simple **conversion tool** was introduced for format conversion.

Fig. right: Comparison of SOL1D injection VDF to BIT1 solution. BIT1 results – courtesy of D. Tskhakaya.

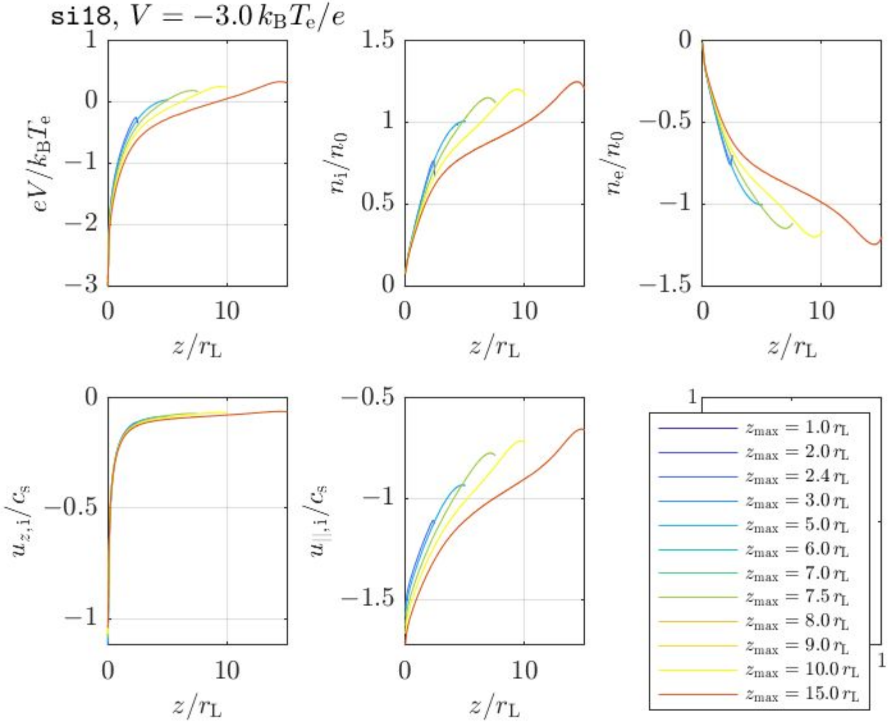


COUPLING TO BIT1

DISTRIBUTION FUNCTION TRANSFER

Comparison with SOL1D DF for identical Ti/Te ratio was performed.
Standard exercise “find proper injection location” to suppress artificial injection sheath.

Fig. right (stage 1): Results using SOL1D injection VDF.
Fig. right (stage 2): Results using BIT1 OD injection VDF.



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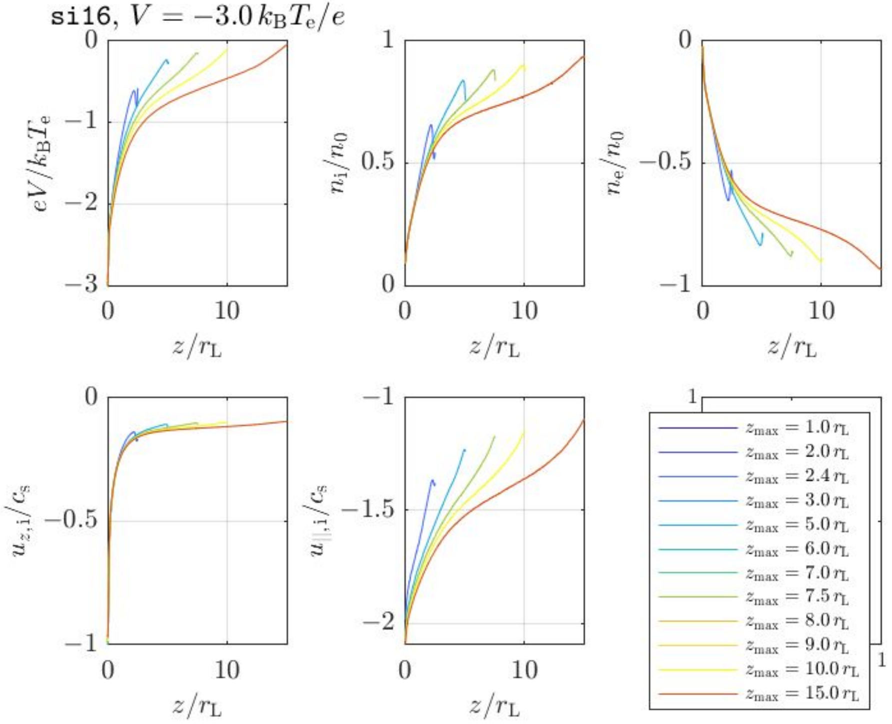

SUMMARY pt. 2

- SPICE2 contains nonuniform density injection schema
  Applicable especially for toroidal injection
- Double-bounded injection was also introduced
  For proper functionality, pre-sheath acceleration region should be introduced.
- BIT1/SPICE injection coupling was introduced and first comparison was provided.
- **Handling of neutrals?**