# Alpha confinement on ATEN with collisional ANTS

A. Bader

Wistell Meeting, Jan 10, 2020

# Outline

- Description of the collisional model in ANTS
- Particle profiles and sourcing
- Collisional results

# ANTS collisional model

- ANTS collisional model uses a Maxwwell-Rosenbluth formulation for the collisions
- The Monte-Carlo algorithm is given in a writeup by Maassberg
- Includes slowing down, pitch angle scattering, parallel scattering evaluated on a guiding center orbit

# Collision times for various processes

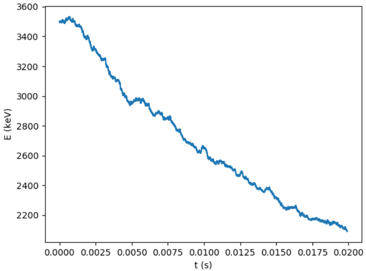
- $n_e = 5.0{\times}10^{20}$, $n_D = n_T = n_e/2$ ($Z_{\rm eff} = 0$)
- $T_e = T_i = 12$ keV; $E_\alpha = 3.5$ MeV
- $\nu_{0j} = \frac{4\pi n_j q_j^2 q_\alpha^2 * \ln(\Lambda)}{(4\pi\epsilon_0)^2 m_\alpha^2 v_\alpha^{3/2}}$; $x_j = \frac{v_\alpha^2}{v_j^2}$
- $\nu_{sj} = (1 + m_\alpha/m_j)\,\Psi(x_j)\nu_{0j}$; $\nu_{\|j} = (\Psi(x_j)/x_j)\,\nu_{0j}$
  $\nu_{\perp j} = (2\Psi(x_j) + 2\Psi'(x_j) - \Psi(x_j)/x_j)\,\nu_{0j}$;
- $\nu_x = \sum_j \nu_{xj}$; $\tau_x = 1/\nu_x$

| | **elec.** | **D** | **T** | **tot** |
|---|---|---|---|---|
| $\tau_s(s)$ | 0.086 | 2.46 | 3.15 | 0.081 |
| $\tau_\perp$ (s) | 12.3 | 3.69 | 3.68 | 1.602 |
| $\tau_\|$ (s) | 25.0 | 1080 | 1620 | 24.1 |

$\tau_s/\tau_\perp \approx 1/20$; $\tau_s/\tau_\| \approx 1/300$

All equations from Callen's 725 notes

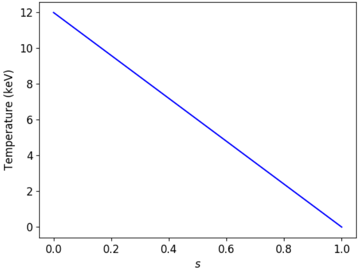
# Factor of 2 difference between ANTS decay and calculated value

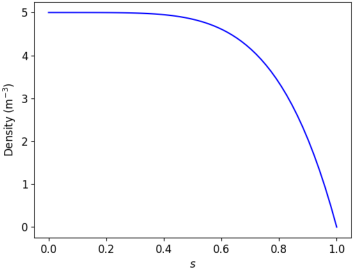



- Input flat temperature and density profiles
- Track a single particle
- Extract slowing down time of 0.040 s
- Since $\tau_E = \tau_s/2$ this agrees closely with Callen's values on the previous slide

# “Realistic” inputs for temperature and density profiles

- Temperature is linear in $s$: $T = T_0(1 - s)$; $T_0 = 12$ keV
- Density is mostly flat: $n = n_0(1 - s^5)$; $n_e = 5 \times 10^{20} \mathrm{m}^{-3}$
- $n_D = n_T$ and $Z_{\mathrm{eff}} = 1.1$



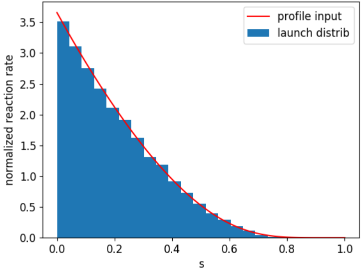




Note that since $\tau_s \propto T_e^{3/2}$, particle decay is much faster when given these profiles compared to the flat profile

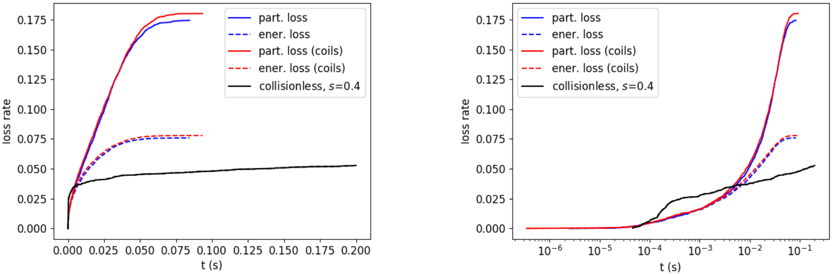
# Reaction rate sets particle source function

- $\langle \sigma v \rangle \propto T^{2/3} \exp\left(-19.94\, T^{-1/3}\right)$: from NRL
- $R \frac{dV}{ds} = \left(n_D^2/4\right) \langle \sigma v \rangle \frac{dV}{ds}$: $\frac{dV}{ds}$ from VMEC equilibrium

- Reaction rate calculated as a function of $s$
- This is passed into ANTS as the expected input function
- Histogram of particles launched by ANTS verify correct distribution

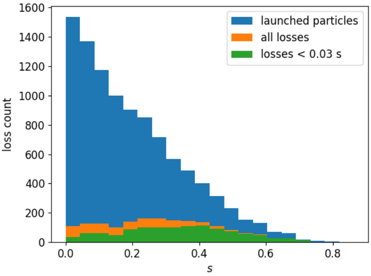


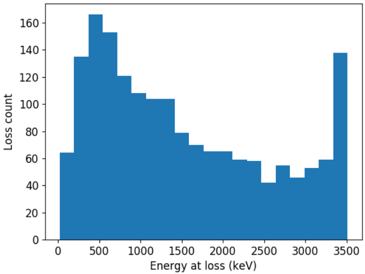
# Energy losses approx 7.5%




Energy losses much higher in collisional case compared to particle losses in collisionless case, even though particles are started inwards of $s = 0.4$

# Particle losses broad in $s$

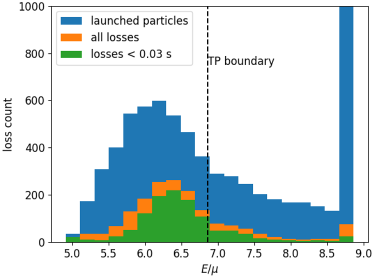


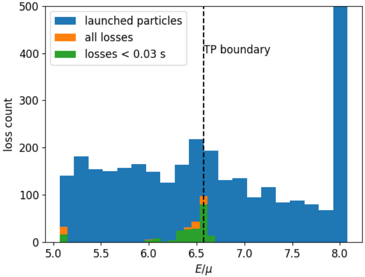

- Even some core ($s < 0.1$) particles are lost
- Significant prompt losses exist (these appear mostly at $s > 0.4$)

# Losses are broader in $E/\mu$ than in collisionless case

Collisional

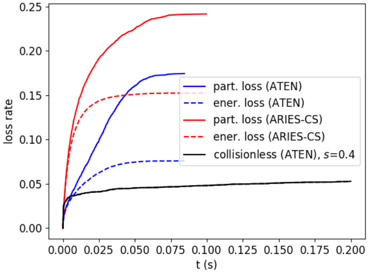


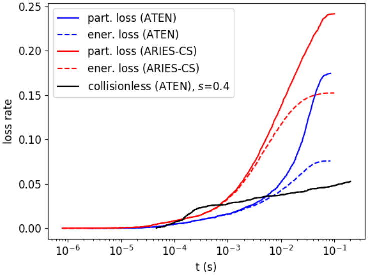

Collisionless $s = 0.4$




- Losses of particles born near the trapped passing boundary can be up to 50% when collisions are included
- Even some passing particles with very high $E/\mu$ are lost

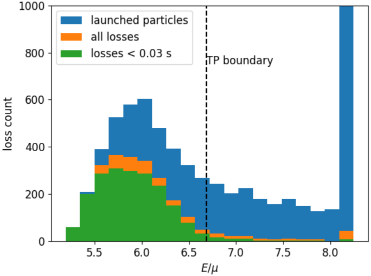
# ATEN outperforms ARIES by factor of 2 in energy loss

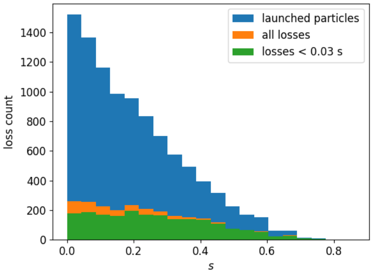


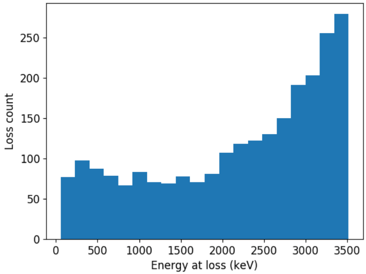

ARIES publication says 5% energy losses but this is not reproduced here. (No information on collisional model, or particle source distribution was given in ARIES-CS papers)

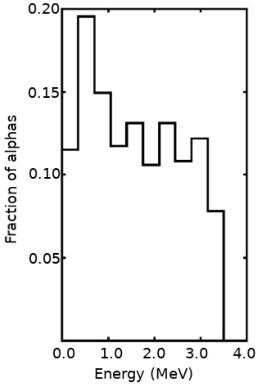
# ARIES loses nearly all deeply trapped particles promptly



# Cannot reproduce published result of ARIES energy loss distribution




- Possibility 1: I have the wrong ARIES-CS equilibrium (rot. transform and pressure match published values though)
- Possibility 2: Our particle following algorithm is incorrect
- Possibility 3: ARIES-CS published results are incorrect

# 7.5% Energy loss is too high so what next?

- Fix reactor by: larger size, larger minor radius (European approach)
- Fix reactor by: higher field values (MIT approach)
- Fix reactor by: Better optimization.
  - We have configurations (such as BILA) that outperform ATEN with ideal configuration
  - But BILA is worse than ATEN once coils are factored in
  - How far should we push EP optimization?