



HAL
open science

Advancing pellet trajectory modeling in injection pipe: Introduction of the CRISTAL simulation tool

E Geulin, B Pégourié

► To cite this version:

E Geulin, B Pégourié. Advancing pellet trajectory modeling in injection pipe: Introduction of the CRISTAL simulation tool. SOFT 2024 - 33rd Symposium on Fusion Technology, Sep 2024, Dublin, Ireland. . <cea-04974590>

HAL Id: cea-04974590

<https://cea.hal.science/cea-04974590v1>

Submitted on 3 Mar 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

E. Geulin¹, B. Pégourié¹

¹CEA, IRFM, 13108 St Paul lez Durance, France

eleonore.geulin@cea.fr

Topic I. Fuel Cycle and Breeding Blankets - ID - 806

I- Context & Objectives Modeling pellet trajectory into a guide tube

Currently, no tools exist to predict the maximum velocity, mass, and ice quality (degree of fragility) of a pellet exiting an injection pipe. However, these parameters critically influence the ablation process of the pellet. It is essential to develop a tool capable of :

1. modelling the complex 3D geometries of the injection pipe, as well as
2. simulating the pellet's trajectory and the resulting damage to the ice.

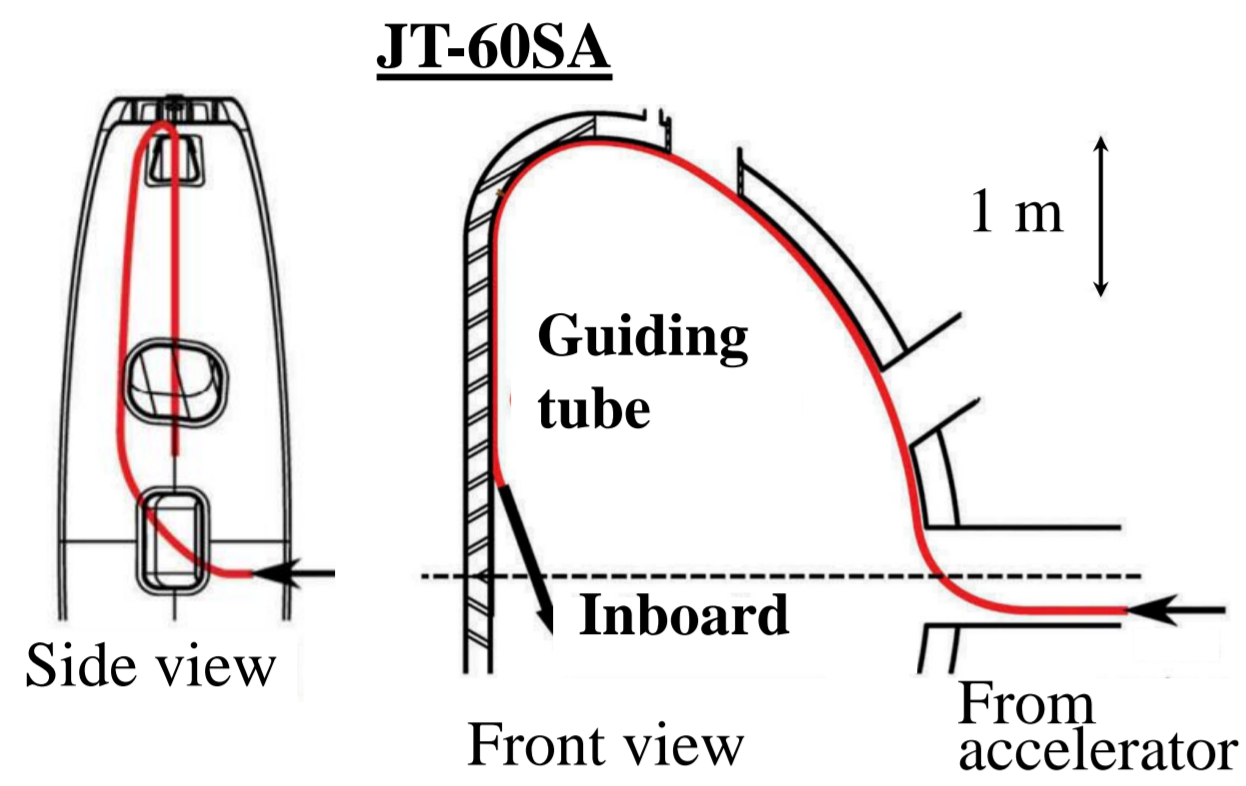


Fig1. JT-60SA guide tube as an example¹ [Lang et al. FED 2017]

II- Guide tube building

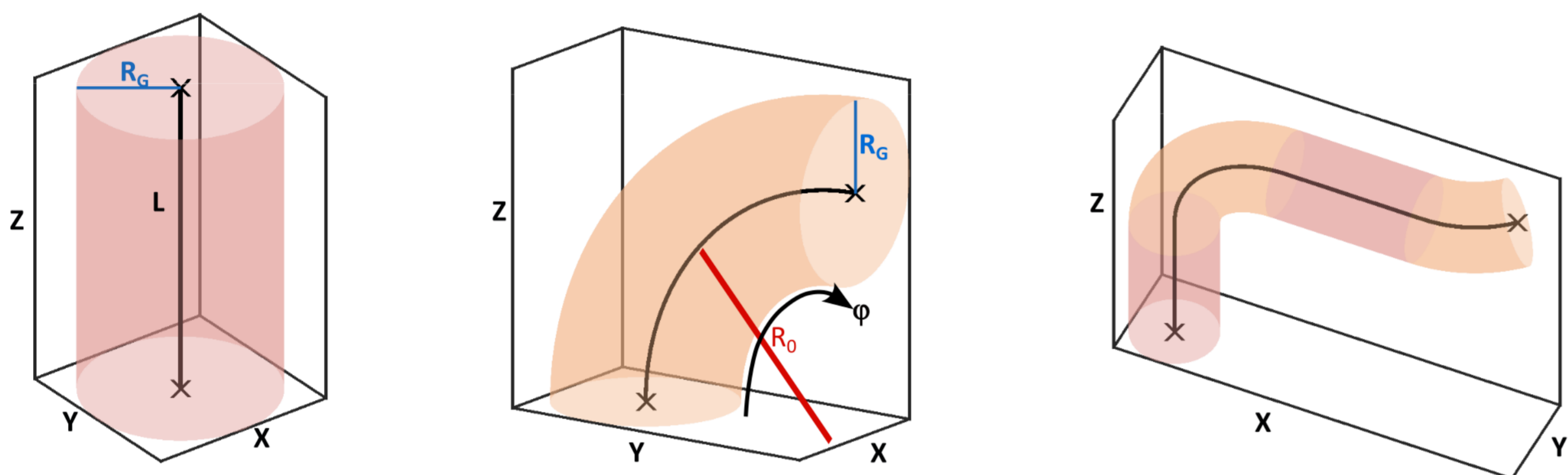


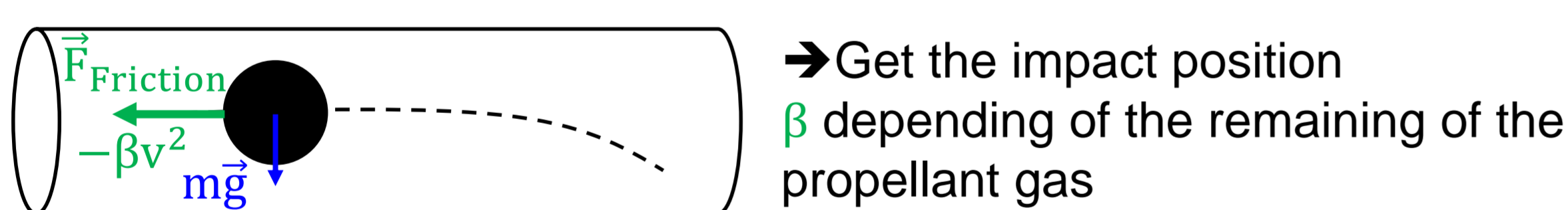
Fig2. Geometric representation of cylindrical and toroidal sections, and a simulated pipe²

The construction of a pipe involves the assembly of cylindrical sections and toroidal segments, with characteristics specified by the user. R_G represents the guide tube radius, L is the length of a cylindrical section, R_0 is the bending radius of the toroidal segment, and φ corresponds to its angular opening.

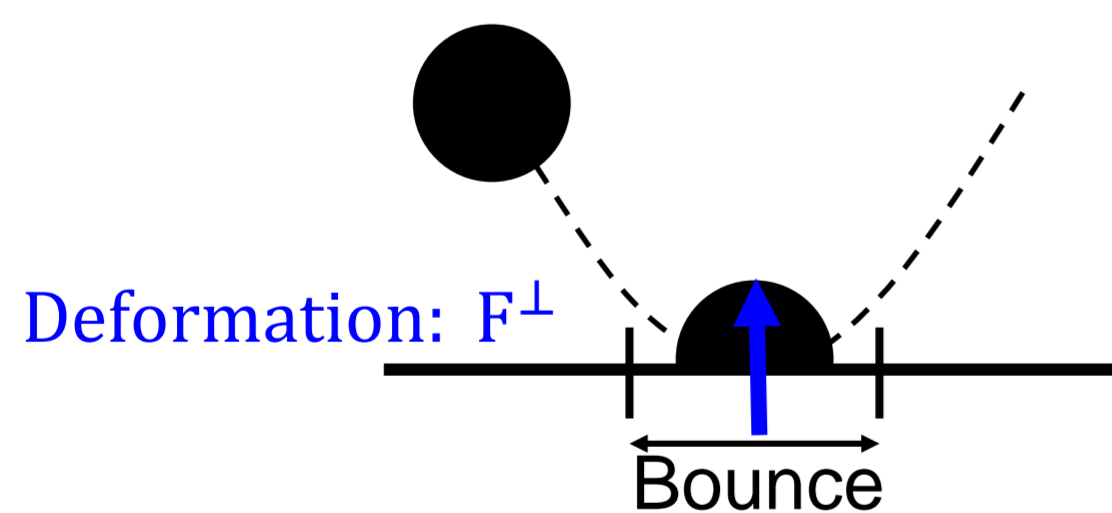
III- Modeling of pellet behavior and trajectories

The pellet is modeled as a sphere, simplifying the analysis by eliminating rotation issues and the need to manage leading edges. The pellet is restricted from rolling. It can only experience:

Free flight –gravity required



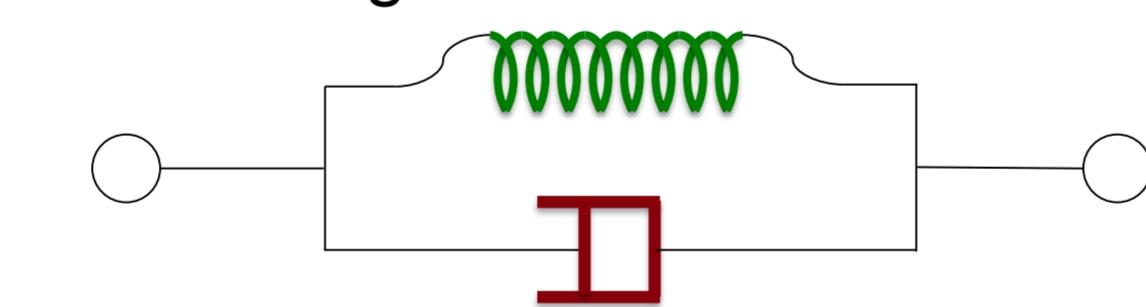
Bounce modeling – Loss of kinetic energy



Damped harmonic oscillator:

$$F^\perp = F_{\text{ext}} - \kappa r - \theta \dot{r}$$

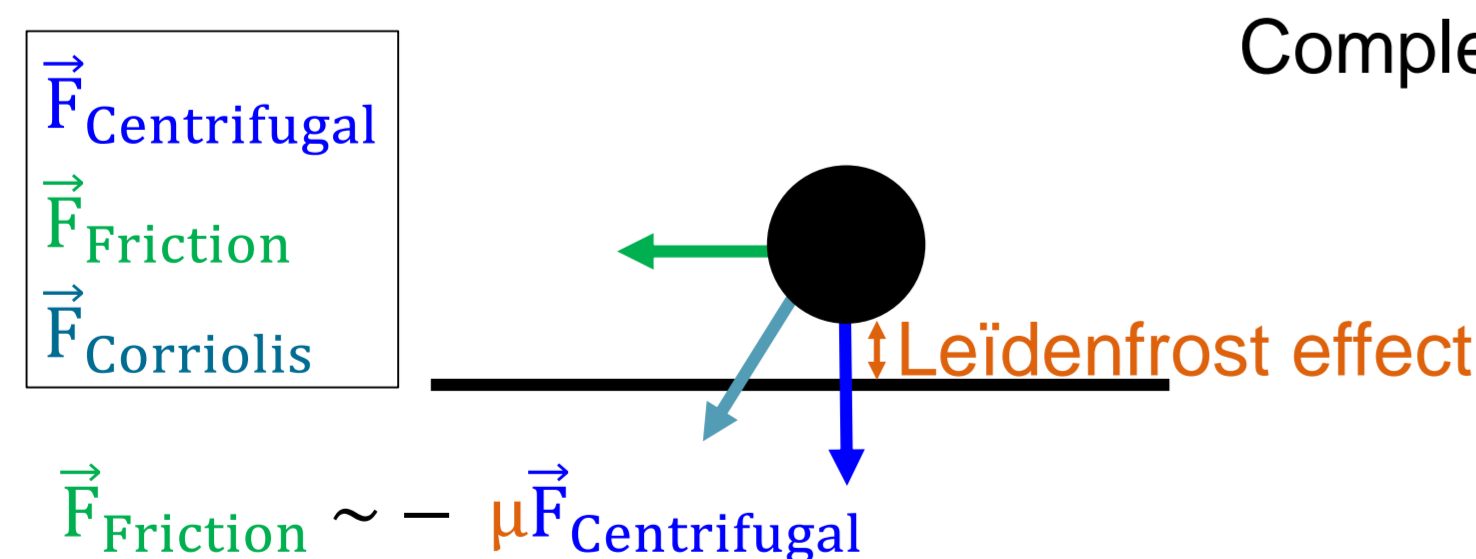
Kelvin-Voigt model:



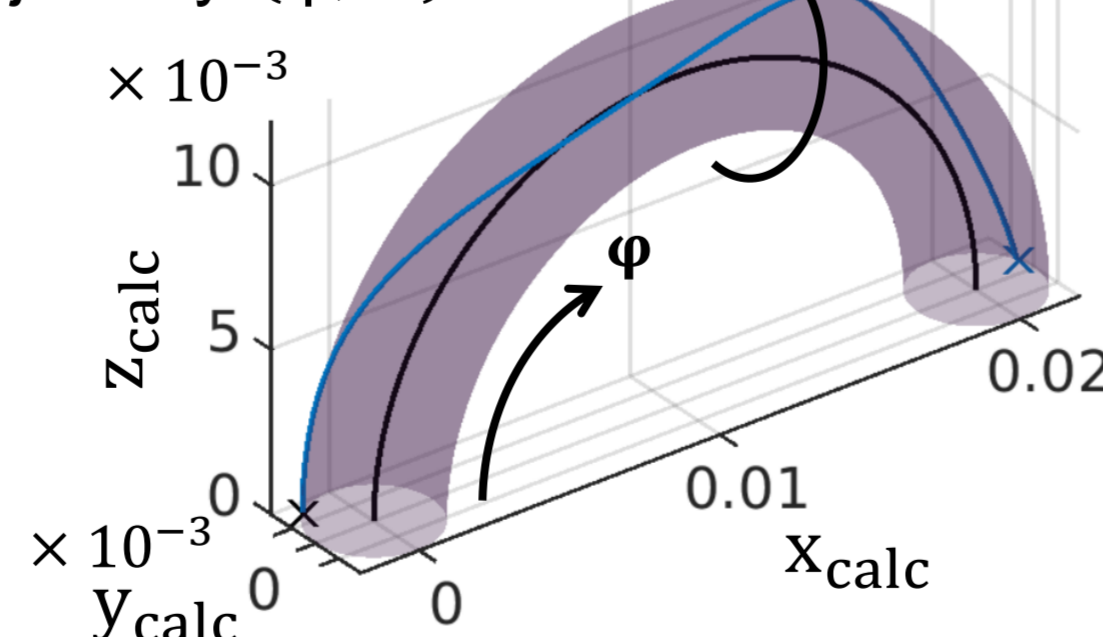
In our model:

- 1 spring (stiffness constant κ)
- 1 attenuator (attenuation factor θ)

Sliding modeling – Loss of kinetic energy

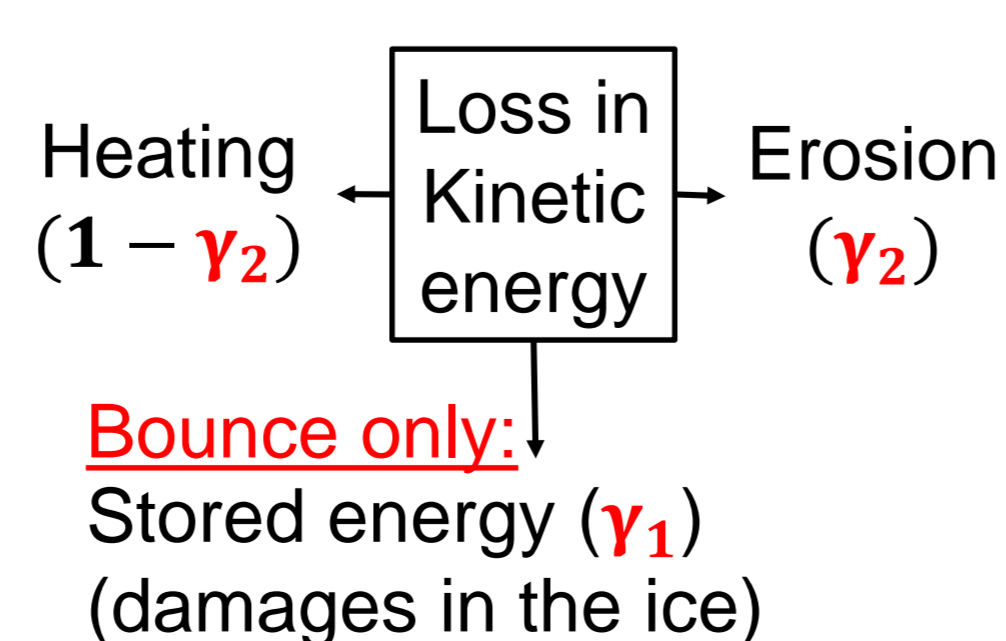


Complex trajectory (φ, ψ):



IV- Kinetic energy loss transformation

The proportion of kinetic energy lost to heating, erosion, or energy storage depends on the coefficients γ_1 and γ_2 , which are currently *ad hoc*. γ_1 represents the proportion of perpendicular kinetic energy lost, manifesting as defects recorded in the ice. γ_2 accounts for the remaining energy associated with pellet erosion. Thus, the coefficient $(1 - \gamma_2)$ corresponds to the heating of the ice. We also consider the heat transfer by conduction (f) as long as the ice remains in contact with the pipe wall.



V- Pellet breaking limit and bounce dynamics

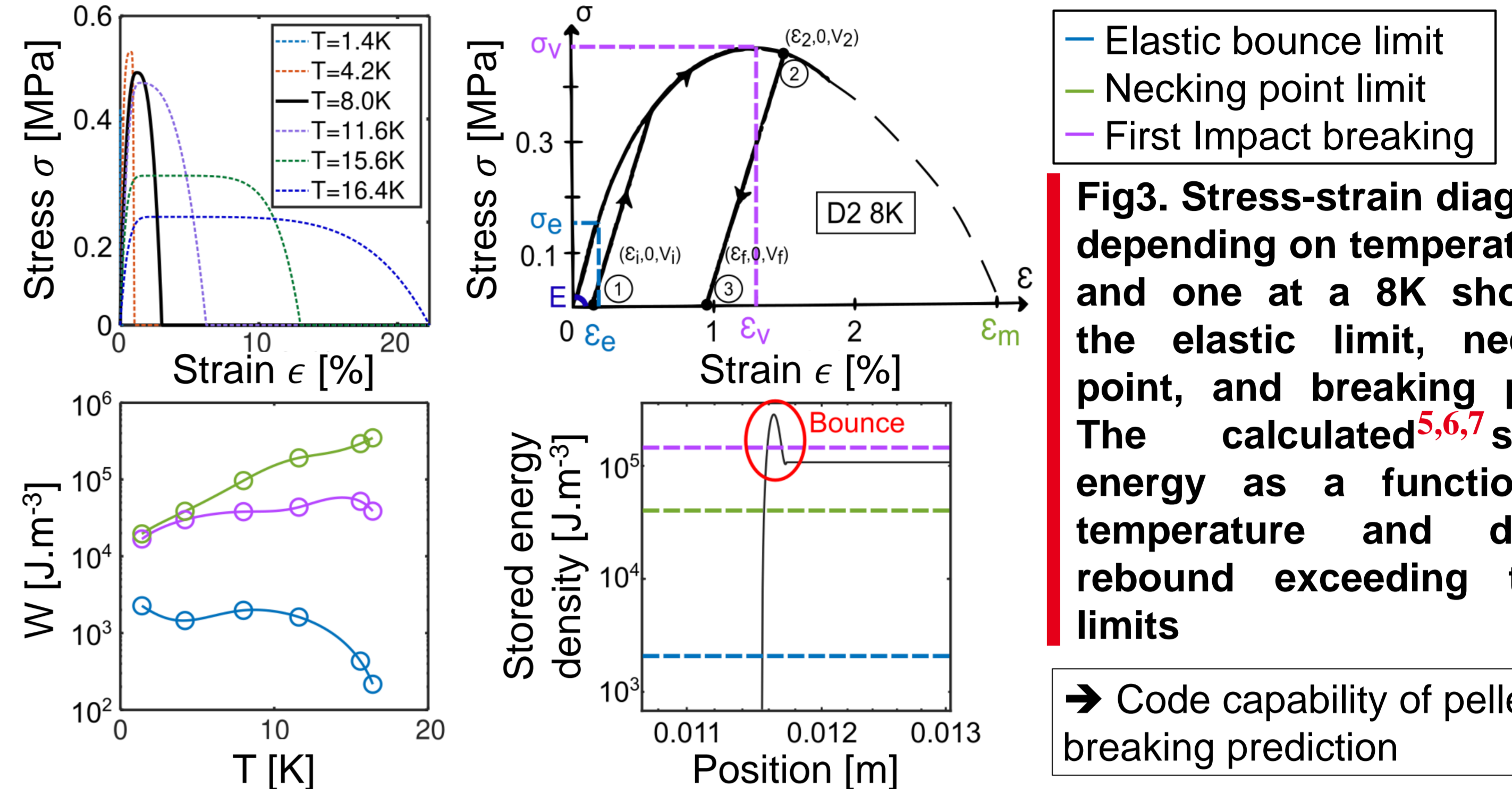


Fig3. Stress-strain diagrams depending on temperatures³, and one at a 8K showing the elastic limit, necking point, and breaking point⁴. The calculated^{5,6,7} stored energy as a function of temperature and during rebound exceeding these limits

→ Code capability of pellet breaking prediction

VI- Simulation results in the JT60-SA injection pipe

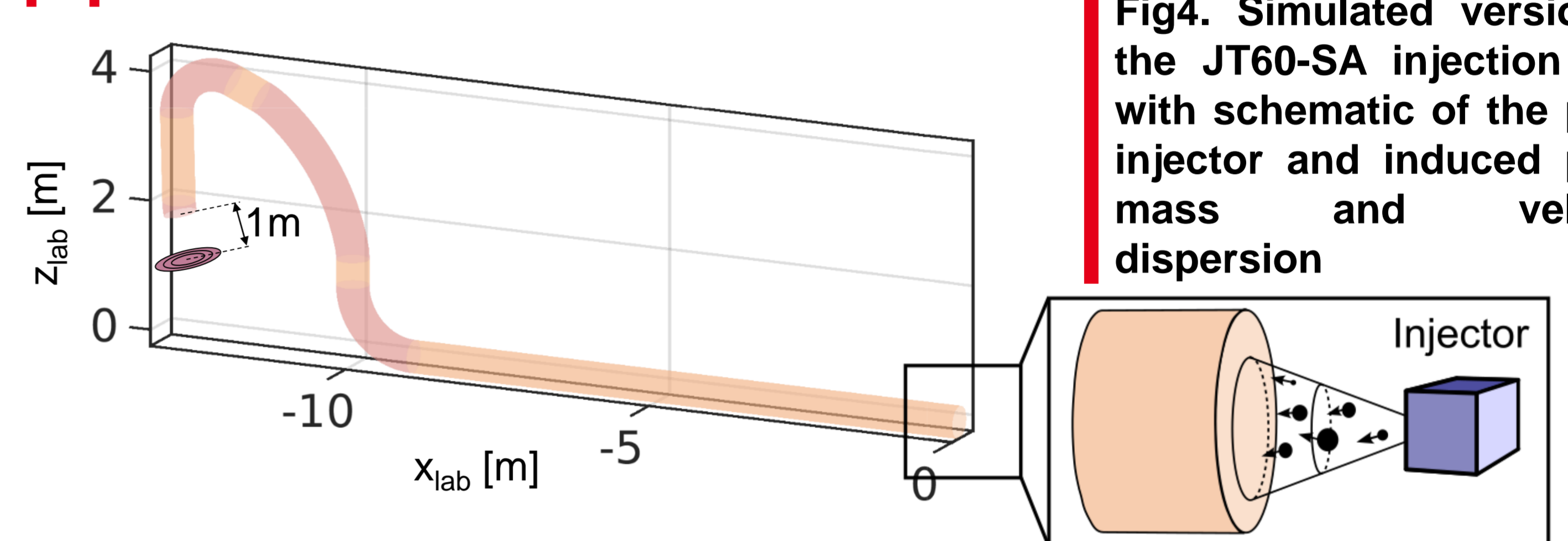


Fig4. Simulated version of the JT60-SA injection pipe with schematic of the pellet injector and induced pellet mass and velocity dispersion

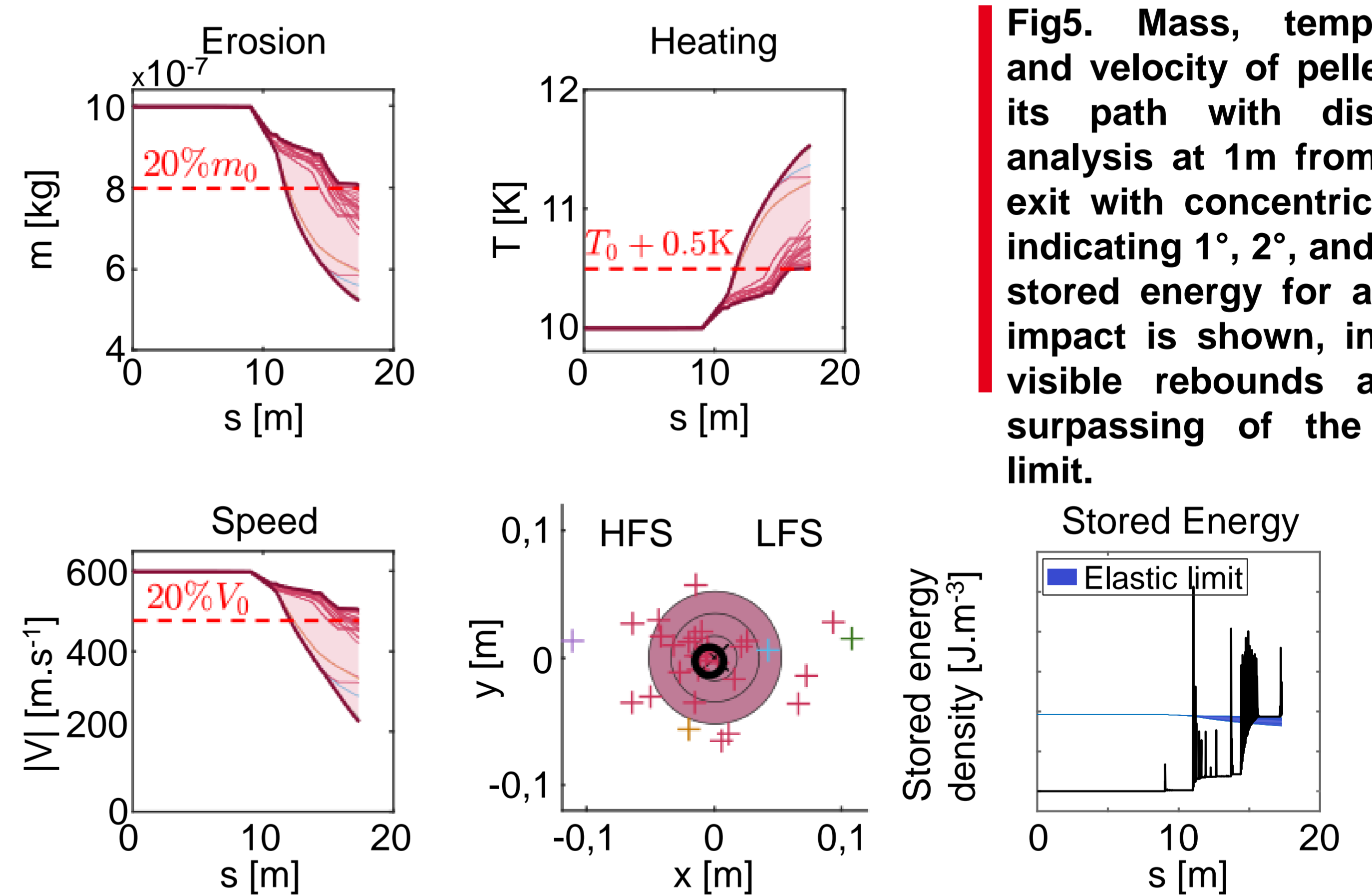


Fig5. Mass, temperature, and velocity of pellet along its path with dispersion analysis at 1m from nozzle exit with concentric circles indicating 1°, 2°, and 3°. The stored energy for a typical impact is shown, including visible rebounds and the surpassing of the elastic limit.

The simulation was conducted using the geometry of the JT60-SA pipe. Multiple pellets were launched with random variations in velocity and mass, within ranges achievable by the injector, to enable a statistical analysis. We analyze pellet behavior along the trajectory, with a focus on erosion, heating, and deceleration. We observe dispersion in these parameters at the exit, and see the first rebound. In this study, 30/32 pellets exceeded their elastic limit, 14/32 reached the necking point, and none fractured. A target positioned 1m from the pipe exit was used to measure the angular aperture. **It is important to note that these results only demonstrate the code's capabilities and do not represent realistic simulations due to numerous free parameters ($\beta, \kappa, \theta, \mu, \gamma_1, \gamma_2, f$).**

Achievements

Full prediction tool of guide tube performance:

- Pellet physical characteristics: (mass, temperature, position and speed) all along pellet path
- Pellet survival probability

Future work

Pellet Physical characteristic:

- Determining ice properties: Parameters need to be experimentally determined (SBT-Grenoble)
- AUG guide tube & Test bend DIPAK-PET in construction (Eurofusion)

References

- 1 P. T. Lang et al. Fus. Eng. Design 123 (2017)
- 2 E. Geulin, Contribution to the modeling of pellet injection : from the injector to ablation in the plasma (Aix Marseille University) (2023)
- 3 J.G. Daunt & R.J. Roberts, Low Temp. Phys. 6 (1972)
- 4 J-F. Artaud and A. Géraud. Poster session - 20th SOFT Marseille (France) (1998)
- 5 P. Clark Souers. Hydrogen Properties
- 6 D.N. Bold'shutkin et al. In: Solid State 12 (1970)
- 7 S. Laroze. Résistance des matériaux et structures. Vol. 1. Eyrolles, Paris, (1974). Chap. 4