first light

Investigating the role of transport in uniaxially-driven conical fusion targets

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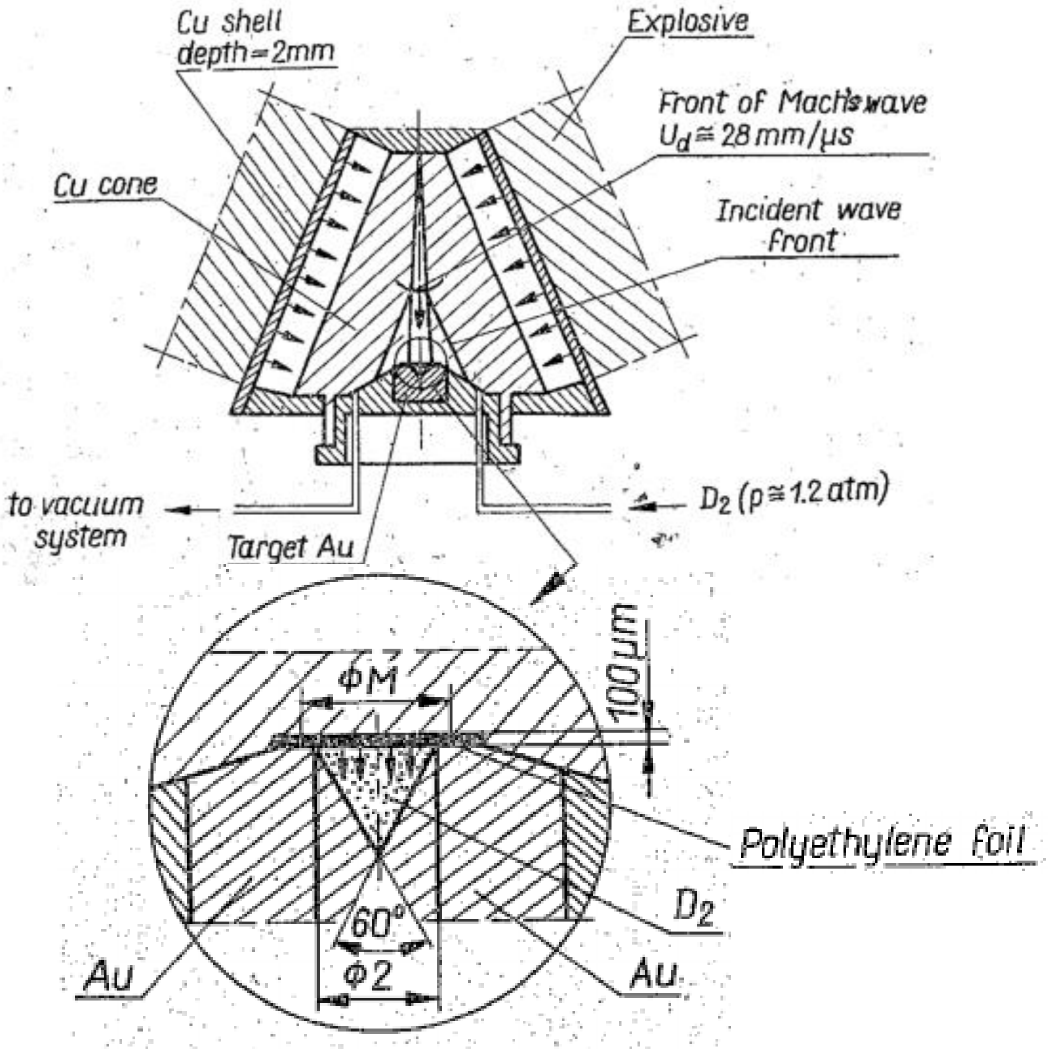
Outline of talk

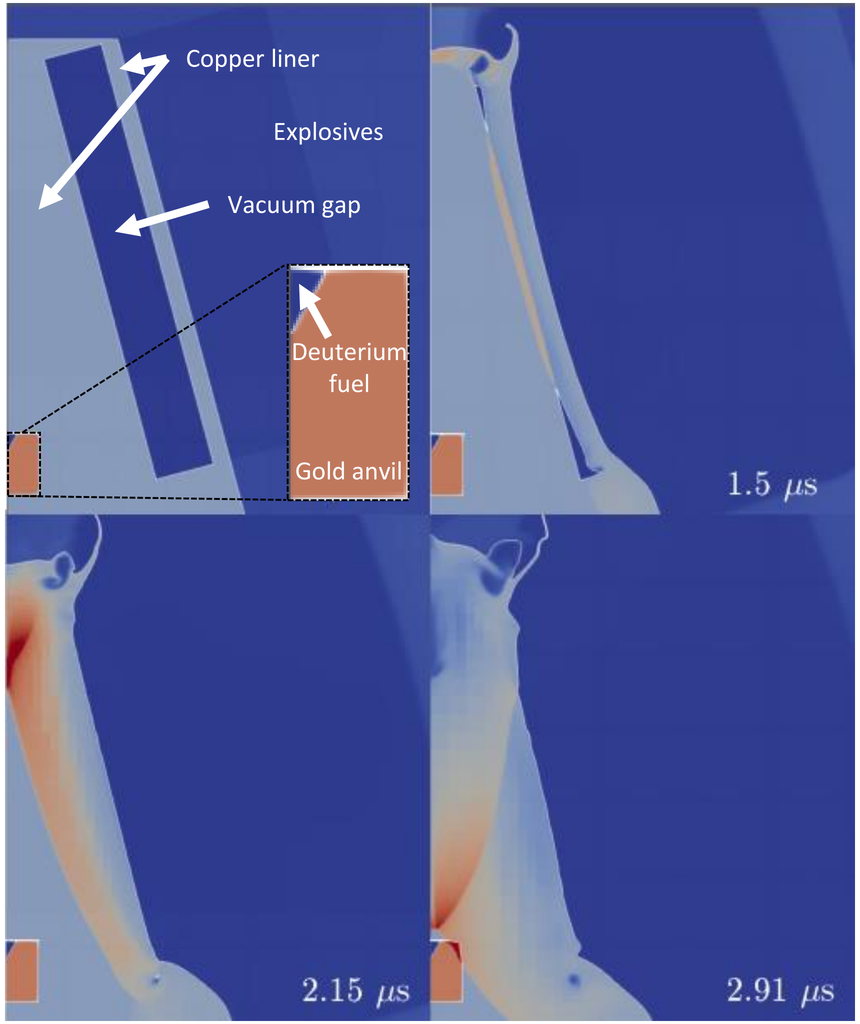
- Experiments of Derentowicz et al.
- Transport model sensitivity
- SpK and TRansport and MicroPhysics (TRaMP) models
- Ongoing work - towards a predictive capability
- Summary and conclusions

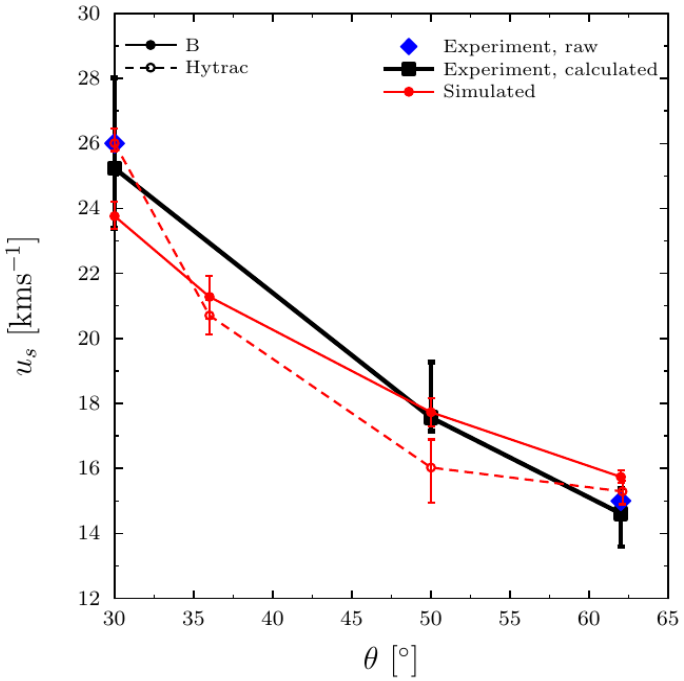
Derentowicz et al. (1977) experiment aligns to FLF's core vision for reactor technology - uniaxially-driven system

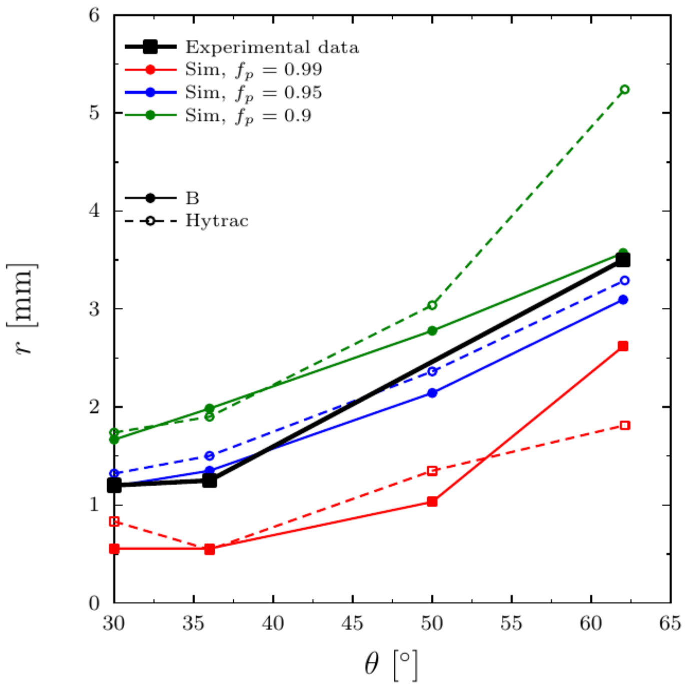


- Drive pressure of 46 Mbar in copper gives 13 Mbar in plastic coverslip - **believed to be reproduceable using FLF's existing facilities**
- Diagnostics fielded:
  - Shock velocity – Cu-NI-Cu bimetallic gauge
  - Mach wave radius – optical framing camera
  - Fusion neutrons – multiple shielded scintillators arranged in an arc around the explosive assembly
  - Null shots – repeats of fusion shots w/o D_2 gas fill
- Fusion neutron output - **claimed to be ~10^4 with highest yield of $3.5\text{x}10^7$**
- **Considered a high-value piece of experimental validation for our in-house modelling codes and as a means of interacting with external collaborators**

Integrated simulations have closely reproduced original experimental data but **do not** substantiate reported yields





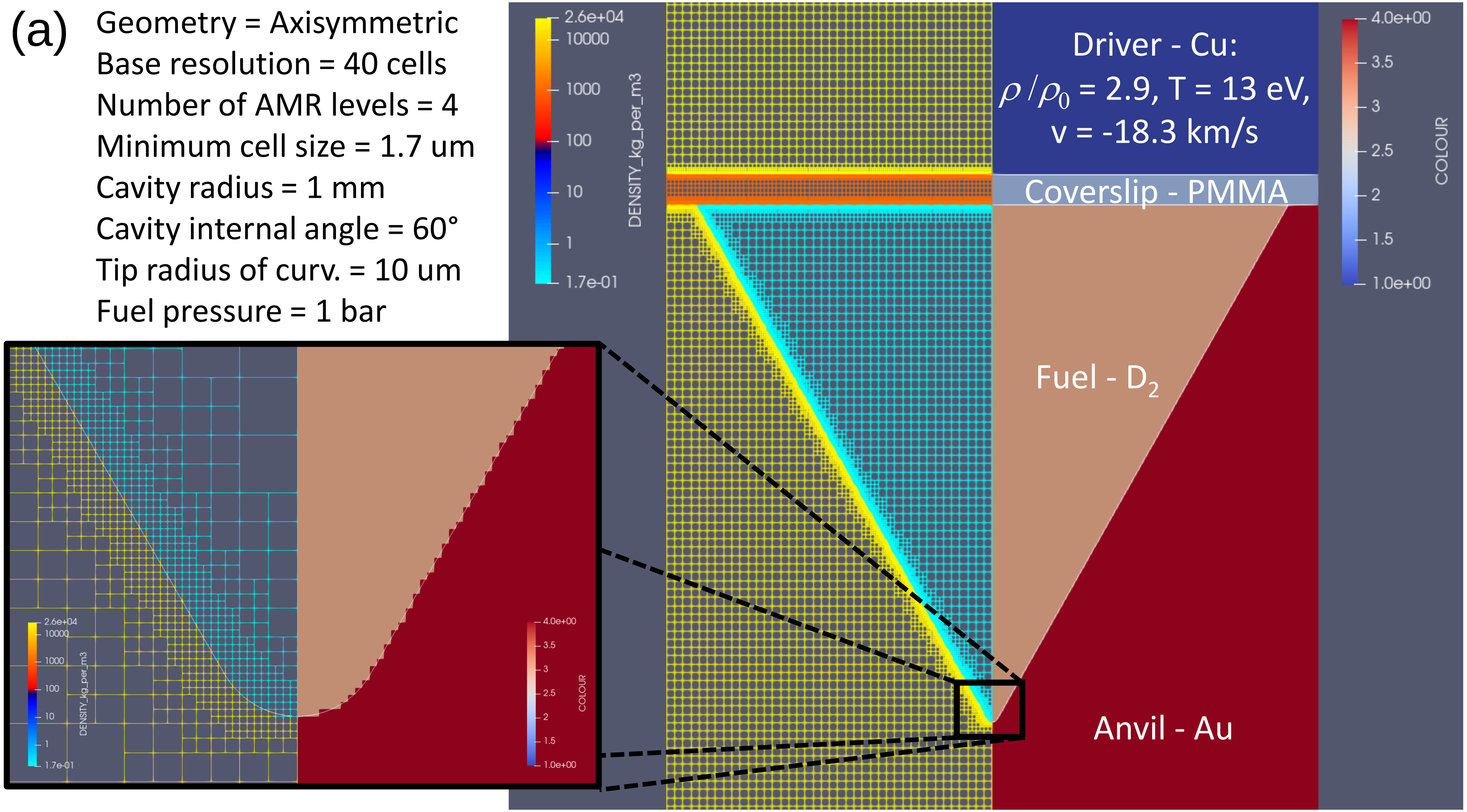


- Modelled predictions agree well with experimental data
- **Drive planarity is very high over initial implosion phase, enabling target operation phase to be decoupled**

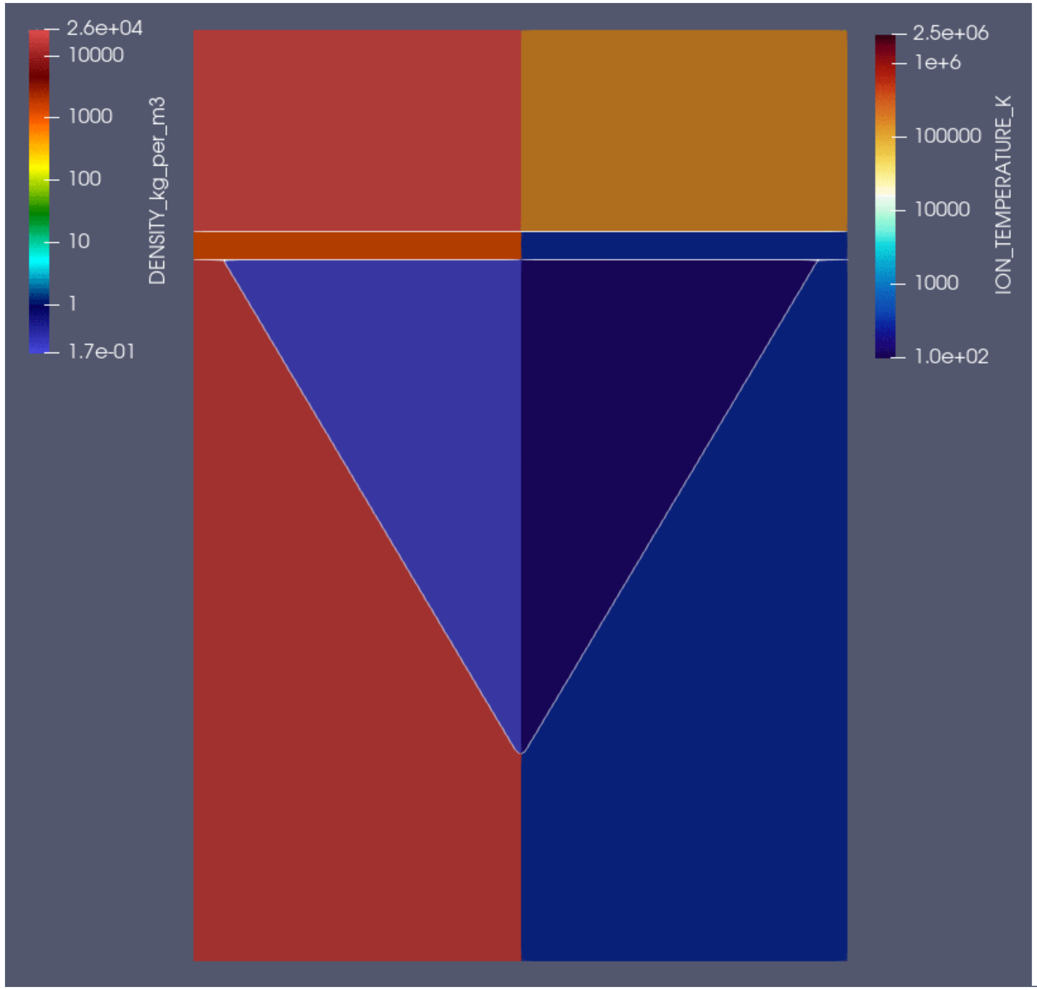
Idealised target model for sensitivity studies - basic setup

(a)

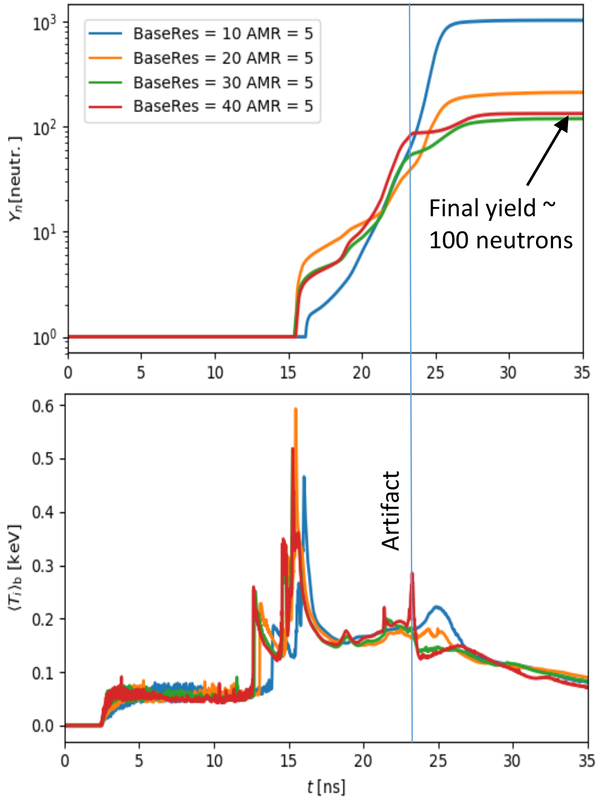
Geometry = Axisymmetric
Base resolution = 40 cells
Number of AMR levels = 4
Minimum cell size = 1.7 um
Cavity radius = 1 mm
Cavity internal angle = 60°
Tip radius of curv. = 10 um
Fuel pressure = 1 bar



Idealised simulations with standard multiphysics model produce neutron yields **~100x smaller** than experimental claim!



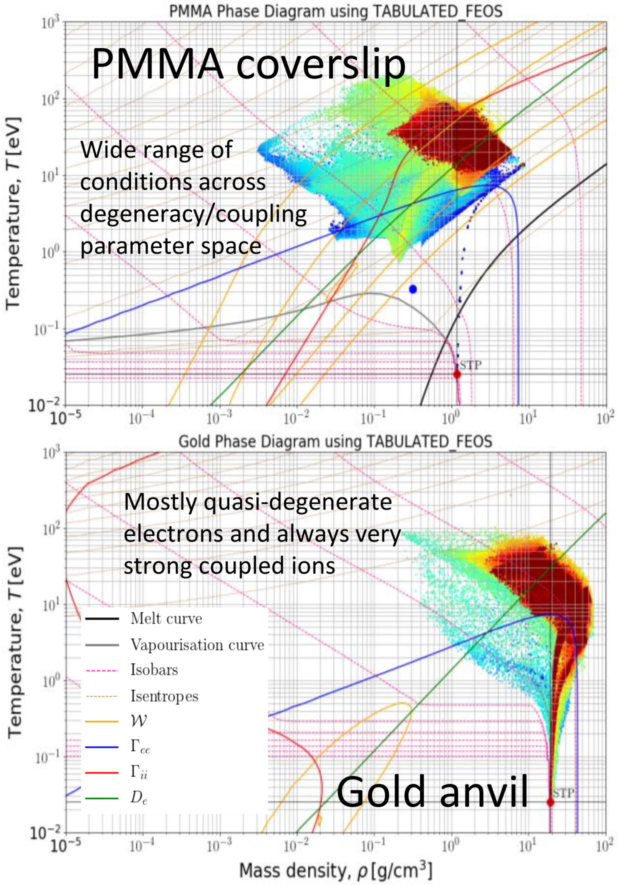
- **PMMA coverslip and gold anvil are driven into states characterised by WDM-like conditions**



Final yield ~ 100 neutrons

Artifact

Cumulative yield and burn-weighted average ion temperature histories



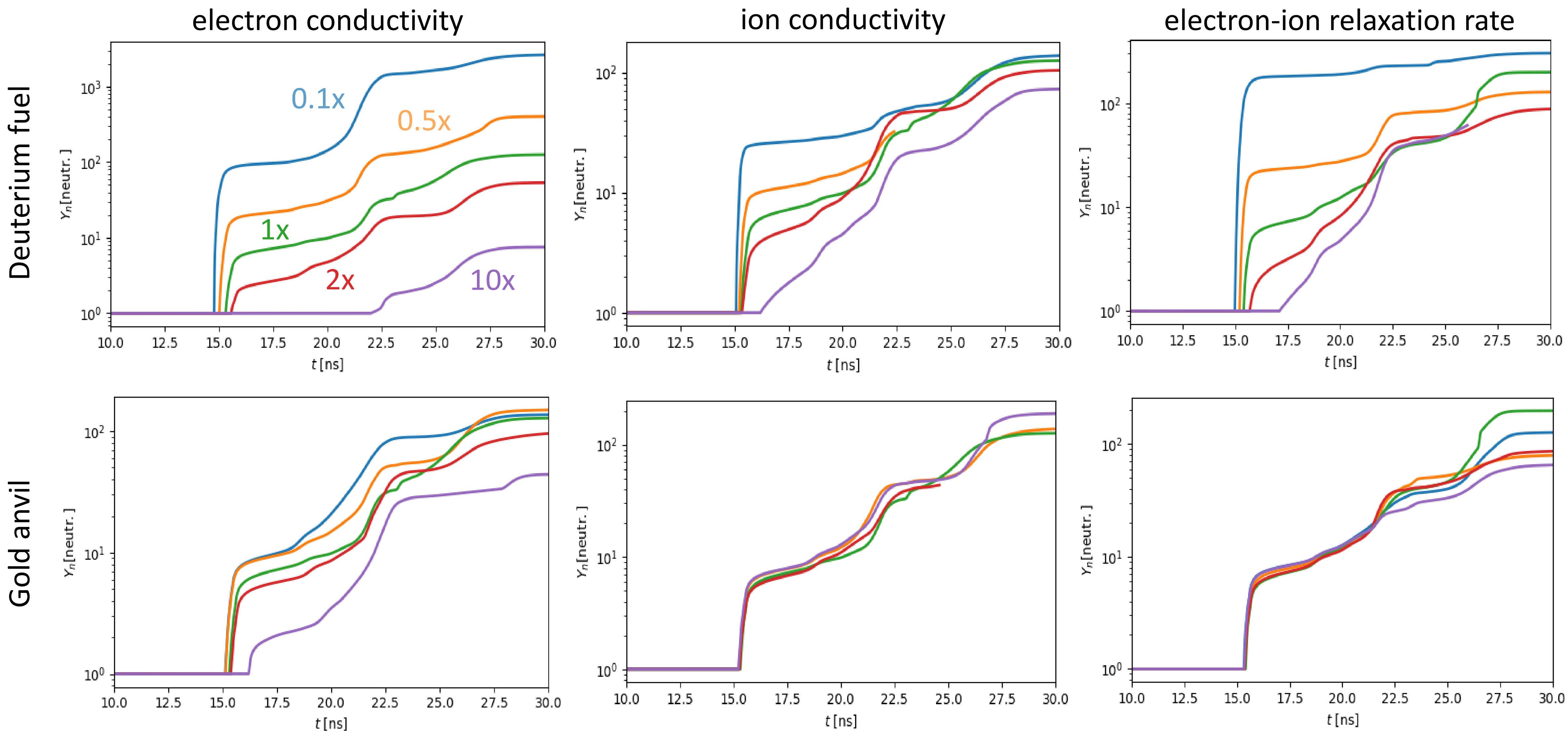
PMMA coverslip

Wide range of conditions across degeneracy/coupling parameter space

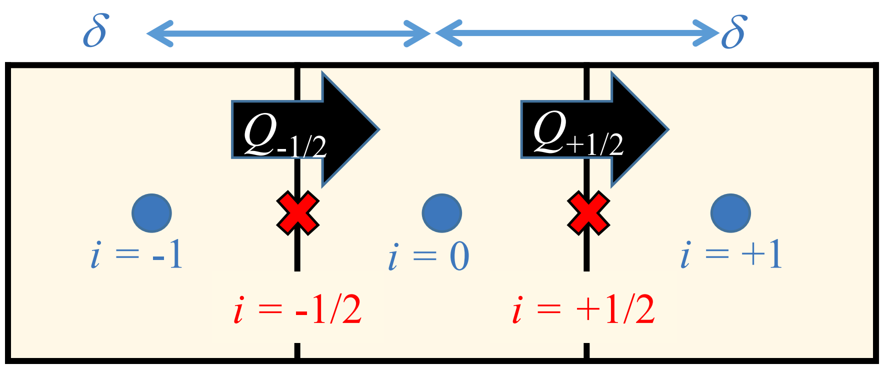
Mostly quasi-degenerate electrons and always very strong coupled ions

Gold anvil

Scaling factor studies show uncertainties in electron and ion conductivities and equilibration can give larger sensitivities



The implementation and configuration of the conduction operator itself also contains many free parameters

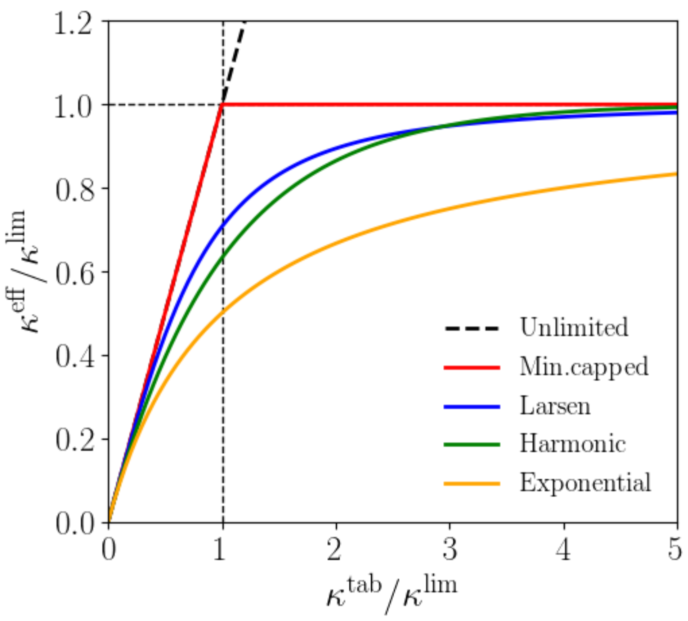


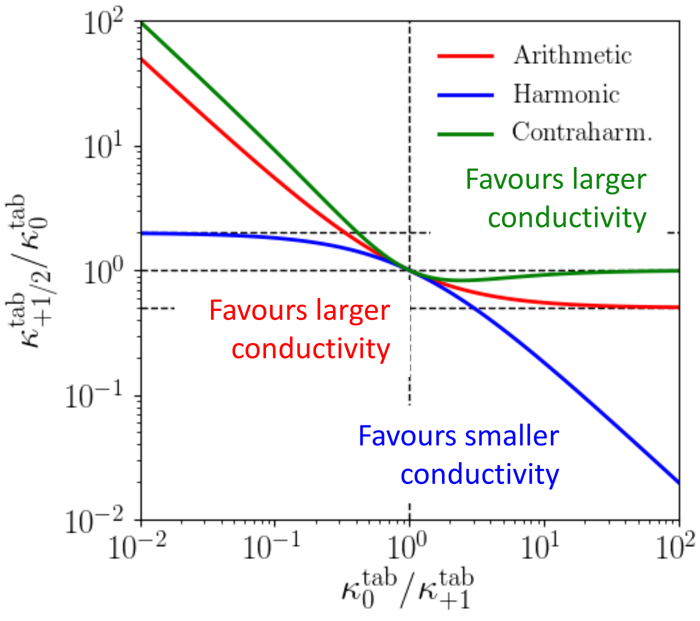
$$
\begin{aligned}
Q_{+1/2} &= (-\kappa^{\mathrm{eff}}\,\nabla T)_{+1/2} \\
&= -\kappa^{\mathrm{eff}}|_{+1/2}\,(T_{+1}-T_0)\,/\,\delta
\end{aligned}
$$

$$\kappa^{\mathrm{eff}}|_{+1/2} = f_{\mathrm{interp}}^{\;1}(\kappa^{\mathrm{tab}}|_{+1/2},\ \kappa^{\mathrm{lim}}|_{+1/2})$$

$$\kappa^{\mathrm{tab}}|_{+1/2} = f_{\mathrm{interp}}^{\;2}(\kappa^{\mathrm{tab}}(\rho_0,T_0),\ \kappa^{\mathrm{tab}}(\rho_{+1},T_{+1}))$$

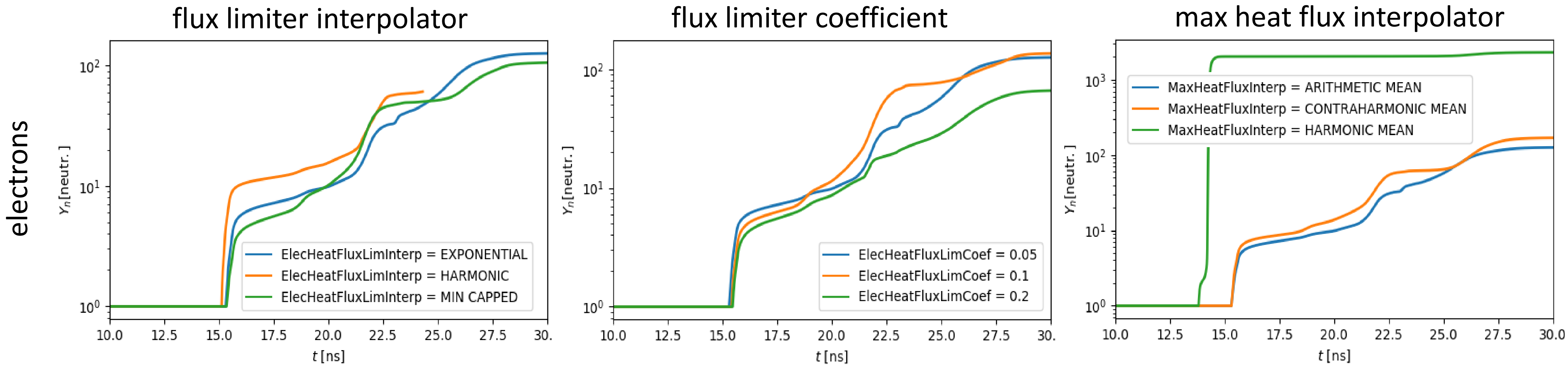
$$\kappa^{\mathrm{lim}}|_{+1/2} = \alpha\ \frac{f_{\mathrm{interp}}^{\;3}(Q^{\mathrm{fs}}(\rho_0,T_0),\ Q^{\mathrm{fs}}(\rho_{+1},T_{+1}))}{(T_{+1}-T_0)\,/\,\delta}$$

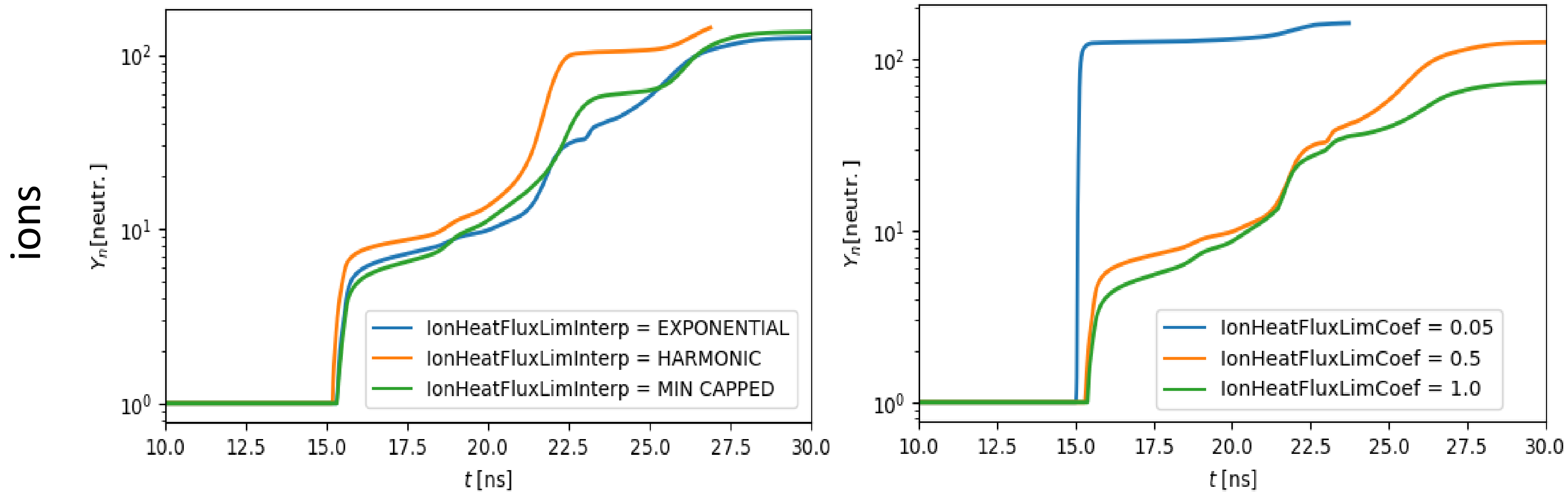




- Interpolation functions - all converge ‘in medium’
- Flux limiter coefficients (separate values for electrons/ions)
- **Significant uncertainties exist for whether any of these models work at material interfaces**

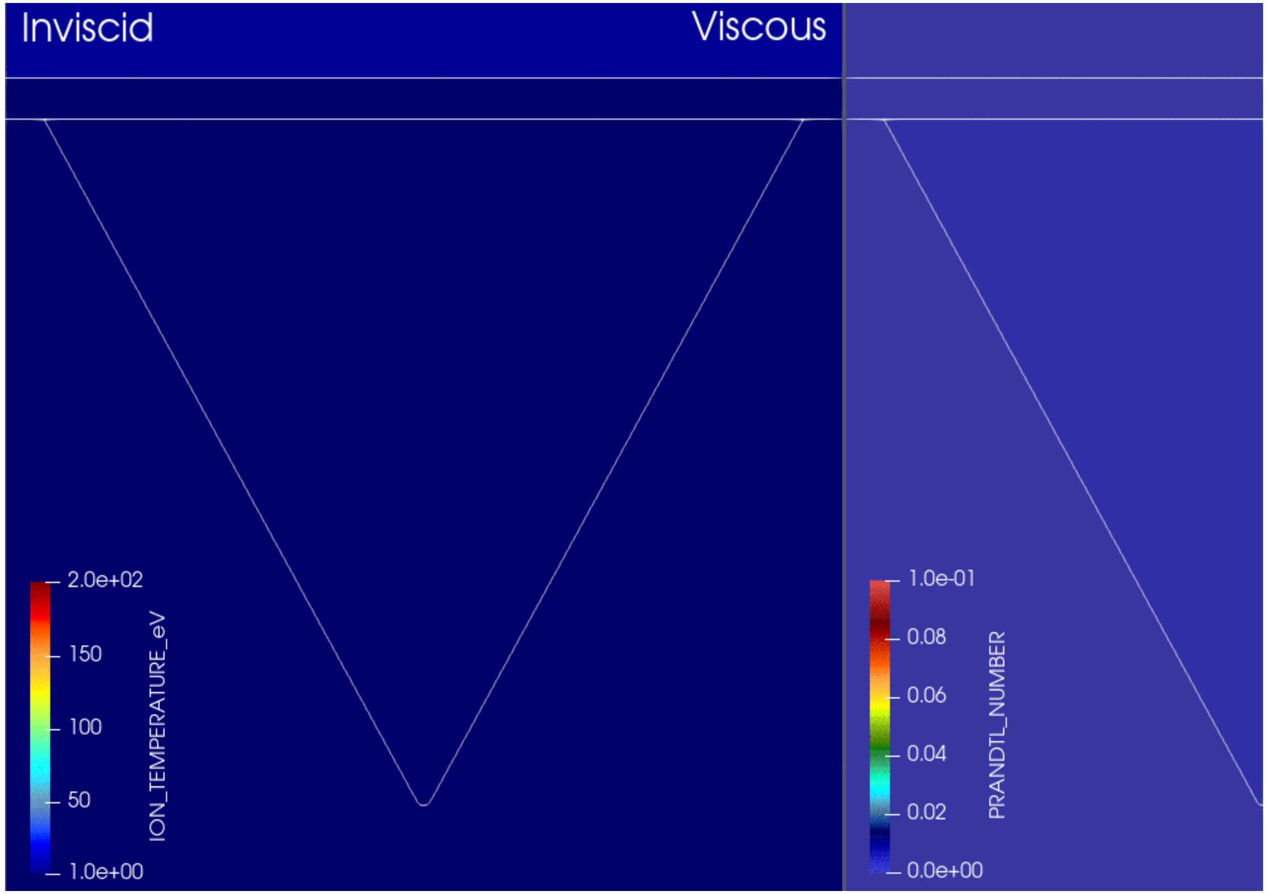
Generally small sensitivities for different conduction options with larger effects due to unreasonable/unphysical choices

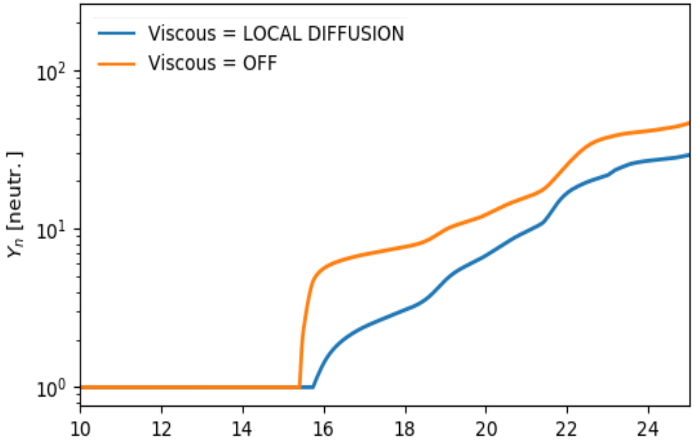


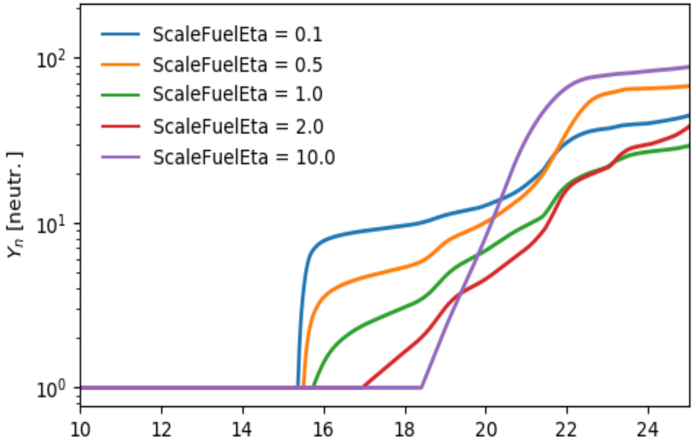


- **Largest yield comes from using harmonic mean for obtaining cell-face max heat flux - unphysical fuel insulation**
- **Such sensitivities suggest a non-local conduction model is needed**

Viscous effects are important in the initial shock dynamics and has some handle on the fuel energetics and yield





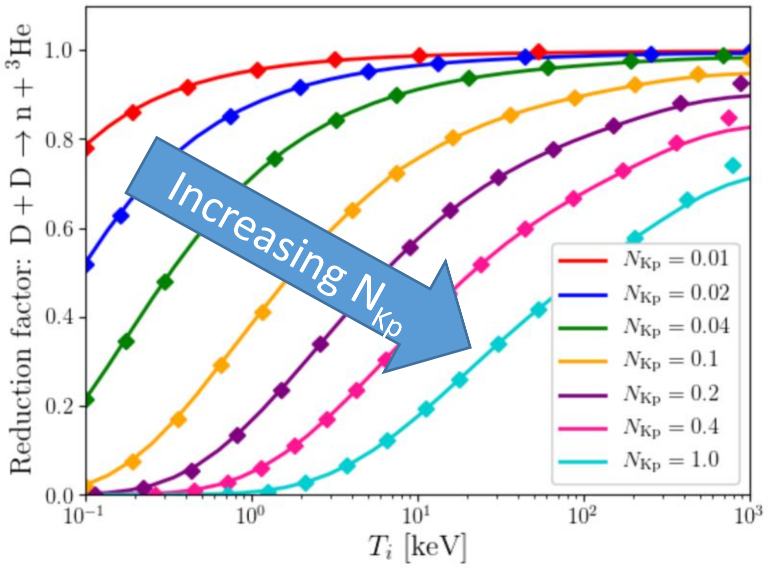


- **Ion viscosity model from Stanton-Murillo model (PRE 2016)**

Reactivity reduction due to Albright-Molvig model [Hoffman et al. 2015] only reduces neutron yield further (up to ~10x)

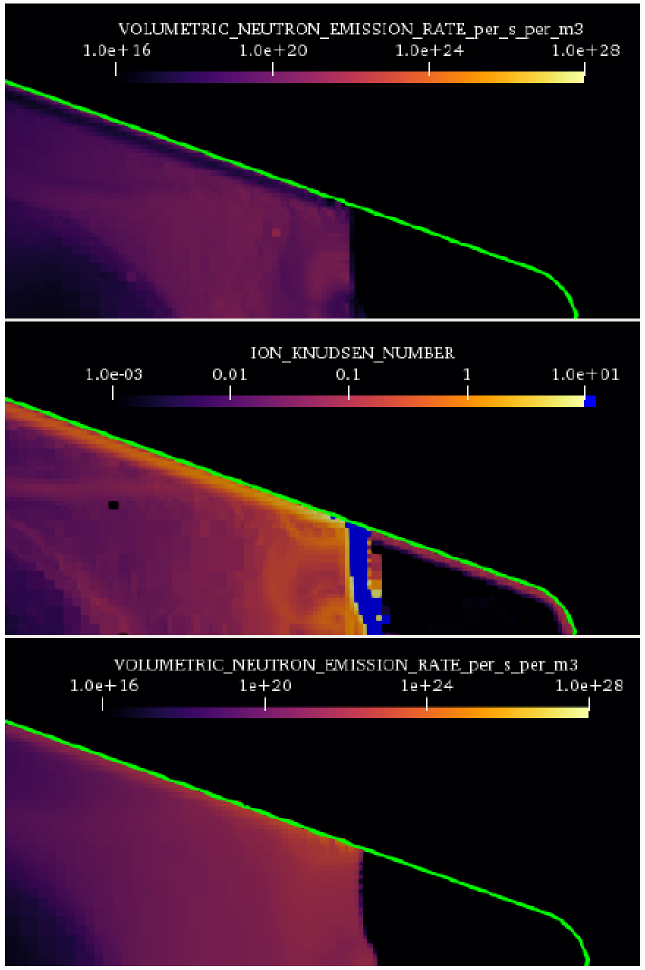
$$f_i^{\text{Padé}}(\epsilon; N_{\mathrm{K}}) = \frac{2\pi^{-1/2}}{(1+N_{\mathrm{K}}\epsilon^{3/2})^{1/2}} \exp\left[-\epsilon\left(\frac{1+\frac{4}{5}N_{\mathrm{K}}\epsilon^{3/2}(1+\frac{2}{5}N_{\mathrm{K}}\epsilon^{3/2})}{1+\frac{4}{5}N_{\mathrm{K}}\epsilon^{3/2}}\right)\right]$$

$$\langle\sigma v\rangle_{12} = \frac{16\sqrt{2}\pi^2}{(m_1 m_2)^2}\int_0^\infty \mathrm{d}E_1\sqrt{E_1}f_1(E_1)\int_0^\infty \mathrm{d}E_2\sqrt{E_2}f_2(E_2)$$
$$\times\int_{-1}^{+1}\mathrm{d}\zeta\,\sigma_{12}(E_{\mathrm{CM}})\sqrt{m_2E_1+m_1E_2+2\zeta\sqrt{m_1m_2E_1E_1}}$$

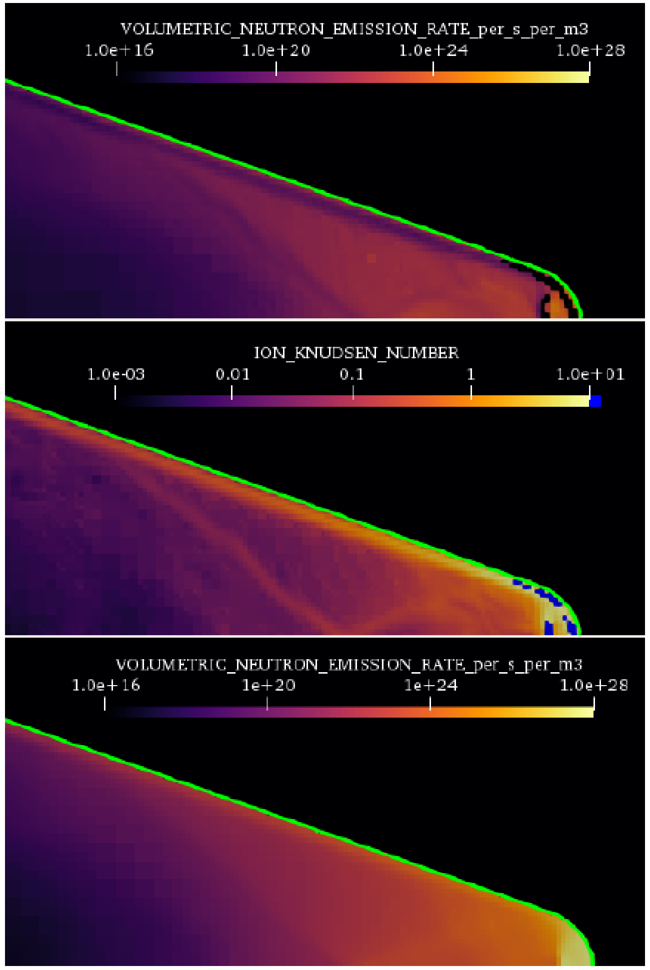


- **Correlations between strong gradients in plasma with reduced neutron yield**

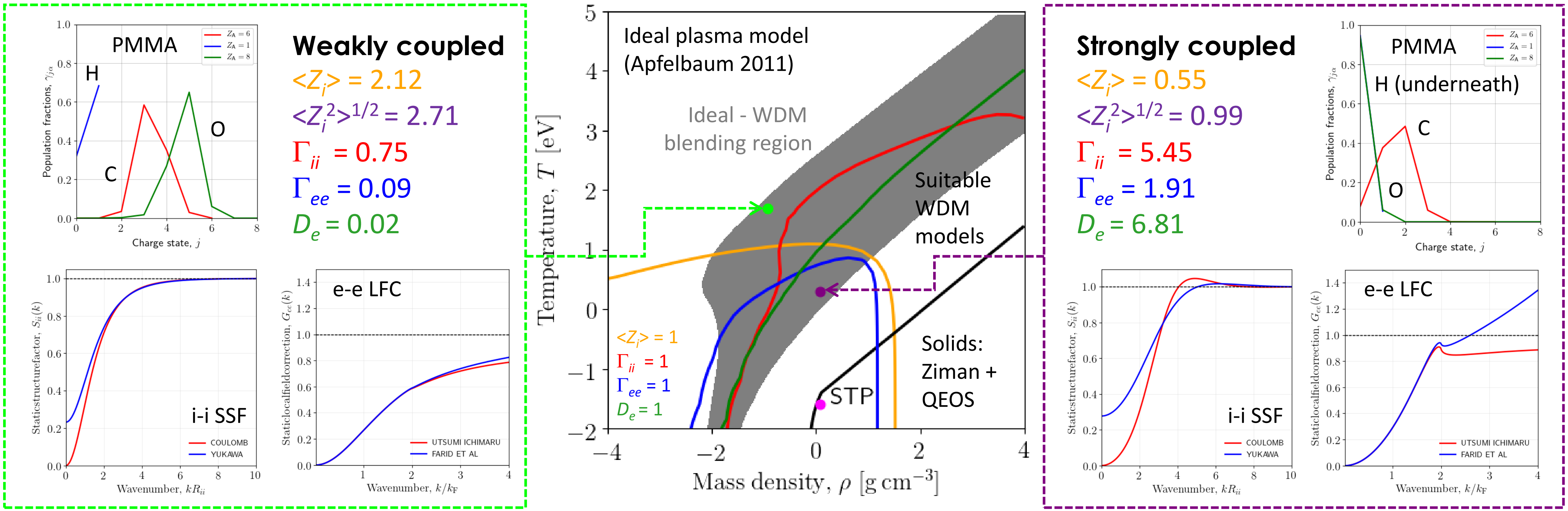
Prior to shock into cone tip



After shock reflects from cone tip



We are building an improved Transport and Microphysics (TRaMP) model to reduce uncertainties - driven by SpK



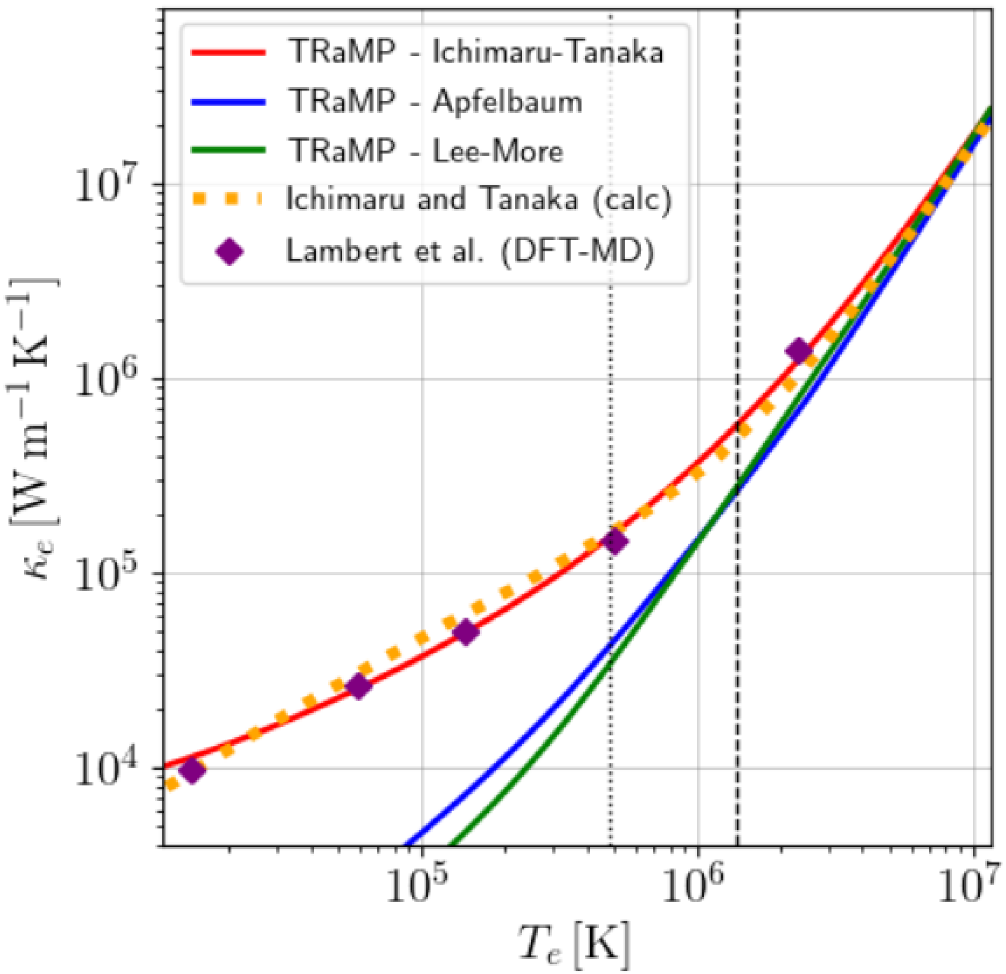
Weakly coupled
$\langle Z_i \rangle = 2.12$
$\langle Z_i^2 \rangle^{1/2} = 2.71$
$\Gamma_{ii} = 0.75$
$\Gamma_{ee} = 0.09$
$D_e = 0.02$

Strongly coupled
$\langle Z_i \rangle = 0.55$
$\langle Z_i^2 \rangle^{1/2} = 0.99$
$\Gamma_{ii} = 5.45$
$\Gamma_{ee} = 1.91$
$D_e = 6.81$

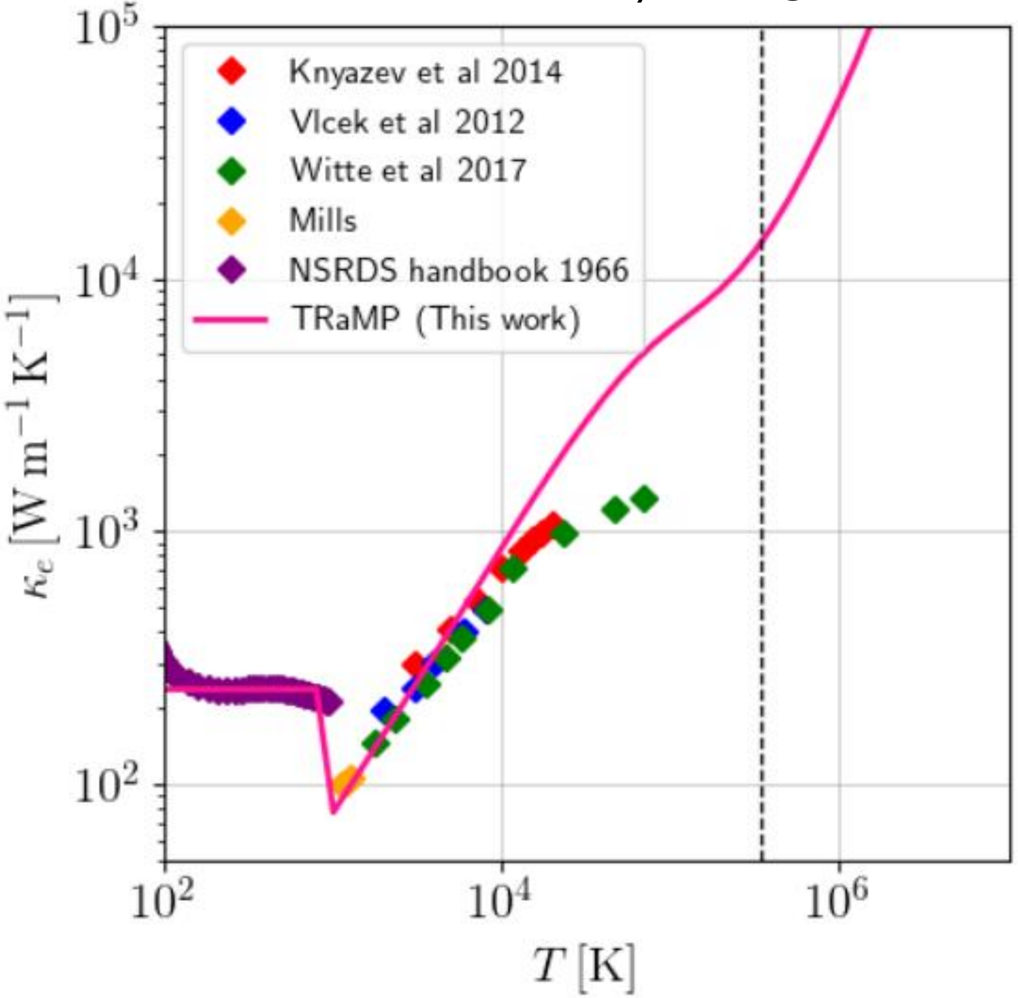
- SpK produces ionisation equilibrium -> TRaMP uses different models over ρ-T space
- **Electron transport in WDM driven by Ichimaru-Tanaka model with HNC ion structure factors and various interaction potentials and local field correction models**

TRaMP model results - much improved over current tables (Lee-More and Helios-style) with only one free parameter

Compressed hydrogen - ρ = 10 g/cc



Solid aluminium - ρ = 2.7 g/cc



Ongoing work

Possible Multi-physics improvements required for a predictive capability:

- **From this work...**
  - Non-local heat transport - local flux-limited diffusion appears to be inadequate
  - Improvements to physics and robustness of TRaMP model
  - Make EoS model consistent with SpK-TRaMP **- See A. Fraser's talk (Tuesday GO07.00010)**
- **Next on the list...**
  - Multi-group radiation transport - radiatively-driven wall ablation/high-Z admixtures
  - Mass diffusion/enthalpy transport model - important for jet breakup in cavity collapse
  - Improvements to existing AMR and HPC scalability - non-ideal, fully-integrated sims
  - MHD/xMHD - self-generated fields and magnetised transport physics

Summary and conclusions

- Detailed sensitivity study of Derentowicz 'fusion cone' experiments has been undertaken
- Experiments report neutron yields mostly around10^4
- **So far simulations cannot substantiate these claims - yields around 100x smaller!**
- Thermal conduction can make a large difference
  - Principally through uncertainty in electron thermal conductivity
  - Evidence for non-local effects - presently not implemented in Hytrac
- Real plasma viscosity affects internal shock dynamics and final fuel energetics
- Reactivity reduction in high Knudsen number flows tend to reduce yields by around 10x
- We have developed a new TRansport and MicroPhysics (TRaMP) model to reduce the uncertainties that lead to the largest sensitivities on yield (ongoing work)
- Several new components of the multiphysics model are being developed to further Hytrac's capabilities (ongoing work)
- **We welcome collaboration in understanding this and other ICF-related problems**

THANK YOU FOR YOUR ATTENTION, AND PLEASE GET IN TOUCH!