Validation and verification of the LOCUST-GPU fast ion code

FUSION CDT
EPSRC Centre for Doctoral Training in the Science and Technology of Fusion Energy

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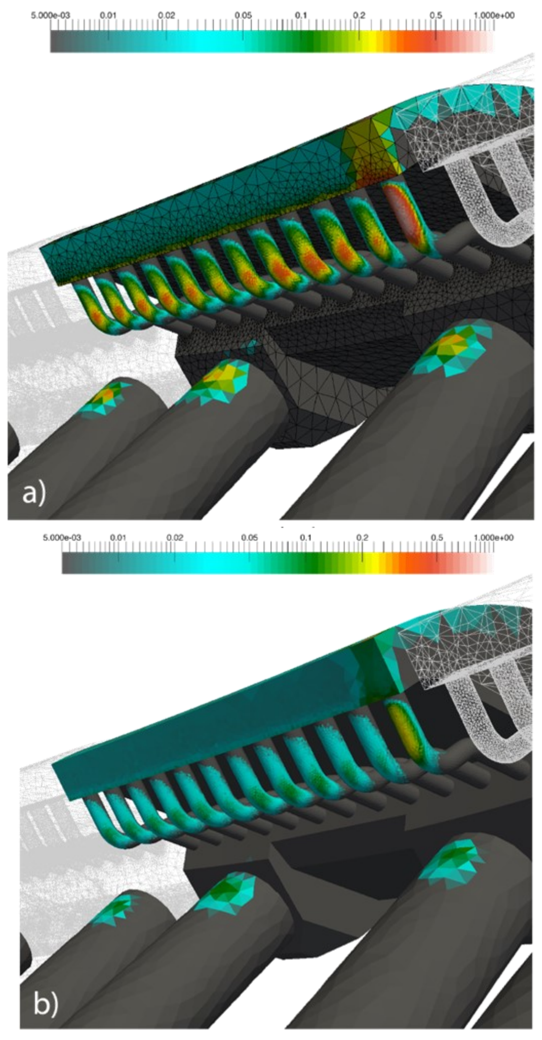
SUMMARY

- RMPs → phase-space-dependent fast ion (FI) redistribution + power loads
- LOCUST quickly generates high-stats FI distributions for long spatio-temporal scales
- Verification/validation for 2-3D cases with ASCOT, TRANSP and SPIRAL codes
- Deployable as modular rapid fast ion solver in ITER IMAS → more comprehensive investigations newly available e.g. detailed RMP loss mechanism studies

BACKGROUND - How do 3D RMP fields redistribute fast ions?

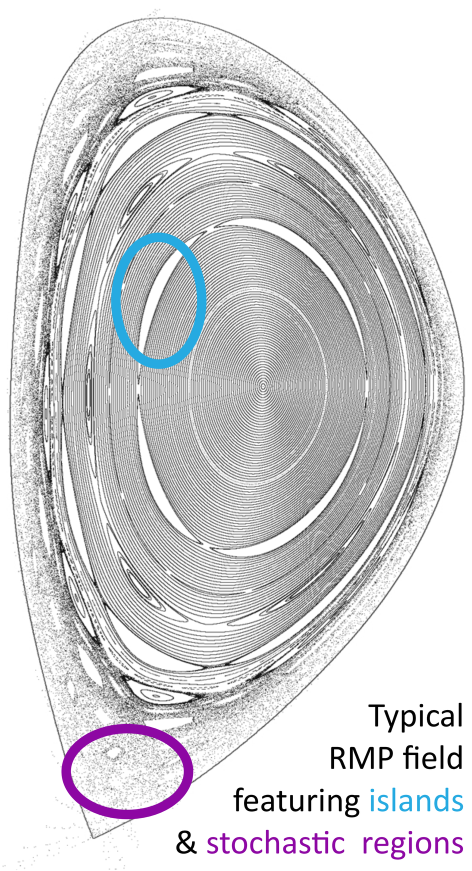
- RMPs are enforced 3D field perturbations - used to prevent ELMs
- RMPs interfere with fast ion confinement - especially NBI due to edge injection
- ITER fast ion heating power = 150MW (~33MW NBI >> 2MWm^{-2} PFC tolerance)



Above: ITER under-dome divertor pipes - R. Akers et al 2016 IAEA Fusion Energy Conference TH/4-1

QUESTIONS

- What are loss mechanisms? Islands or stochastic regions? (right)
- Can we quantify RMP structure-dependent FI losses?
- Can we optimise RMP operation (FI confinement + ELM) mitigation?



Typical RMP field featuring islands & stochastic regions

CHALLENGES

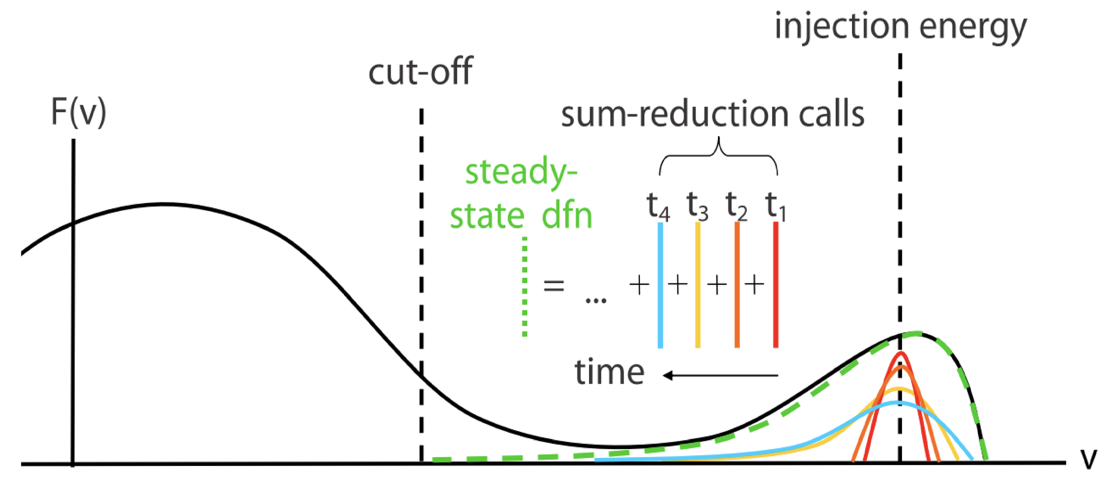
- Computed losses are RMP model dependent (left top/bottom: PFC power loads calculated without/with plasma response to RMP field)
- ITER has huge spatio-temporal domain → need high stats for resolving localised power loads

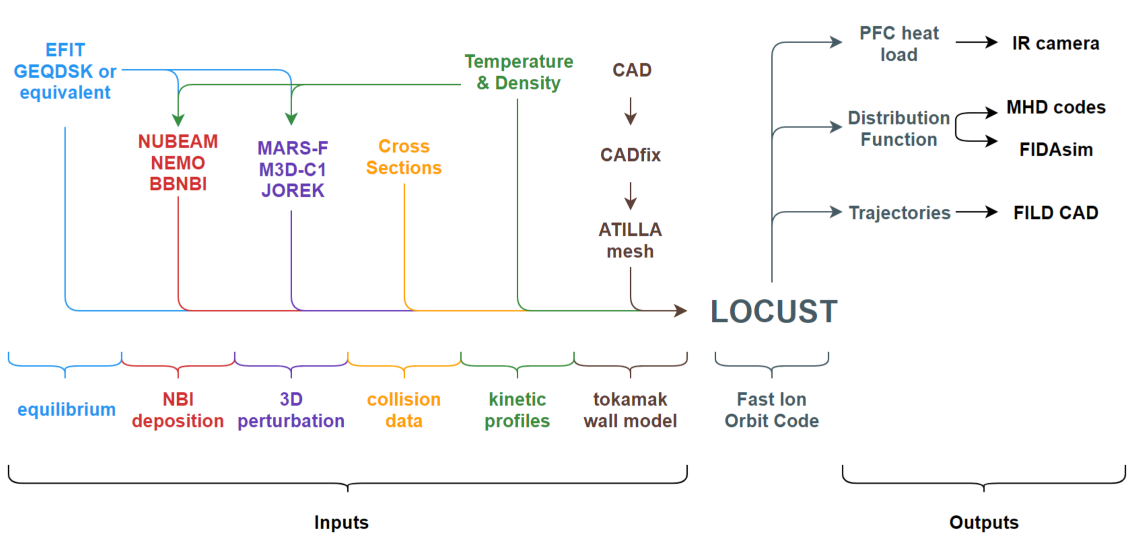
METHOD - LOCUST-GPU = Desktop HPC Kinetic Solver

- Assume independent FIs
  → track Monte Carlo FI markers with parallel threads
  → off-shelf GPGPUs (£3000/¥400,000 per 2k logical threads, low-power, compact) openMP → launch multiple (8-16) GPUs (K80/P100)
- Static topology (temperature, density, magnetic field, CAD wall + rotating RMP)
  → non-blocking sum markers in time (below)
  → 2M markers (10^{13} equivalent particles) to thermalisation in 10 hours (full-orbit)

FEATURES

- Full-orbit (FO) or guiding-centre (GC) trackers
- Generate heat loads, orbits and distribution function in real or constants-of-motion space
- Efficient Poincaré map generator
- Adapted to IMAS integrated modelling platform
  → couple community codes via data schema
- LOCUST_IO Python wrapper
  → plotting, automation and data conversion

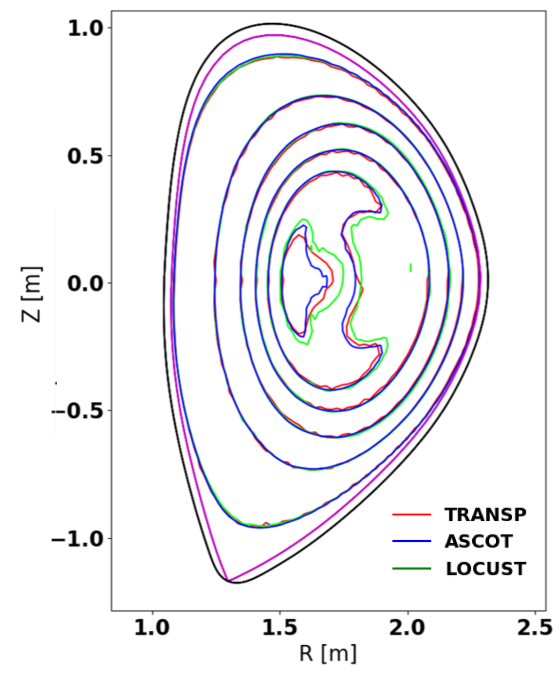




LOCUST example workflow

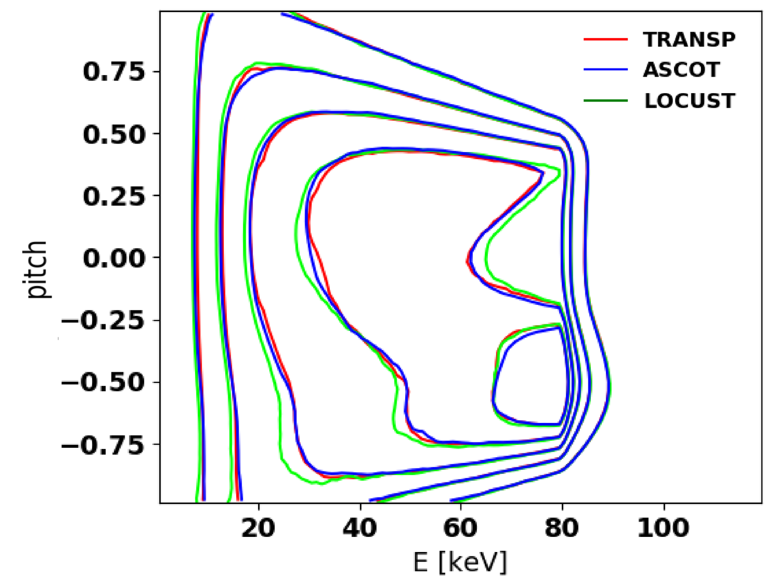
BENCHMARK RESULTS

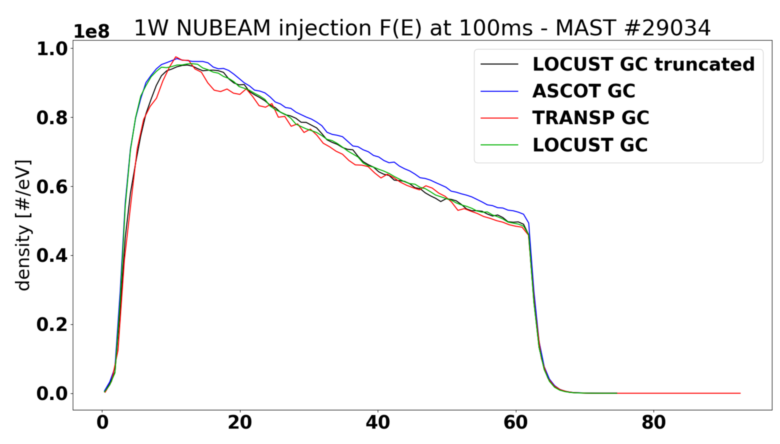
- Predictive capacity → must verify and validate
- Cover spherical/conventional devices, 2D & 3D fields, multiple plasma states against many similar codes (summarised in table at bottom)
- $E_r = \omega = 0$, $Z_{eff} = 1$, no beam-beam interactions

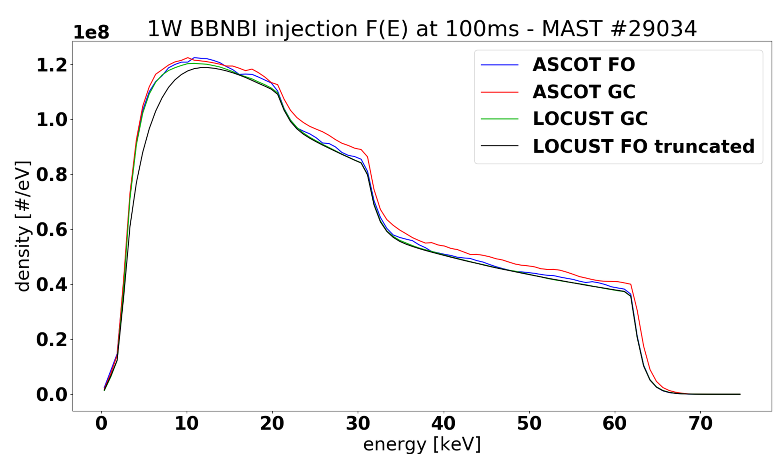


DIII-D

- Right - FI density in R-Z (top) & energy-pitch space (bottom)
- Single full-energy 80keV counter-current NBI
- NUBEAM deposition (GC)
- Artificial wall (black) imposed close to LCFS (pink) and 2D magnetic field
- Moving wall away from plasma → only TRANSP diverges







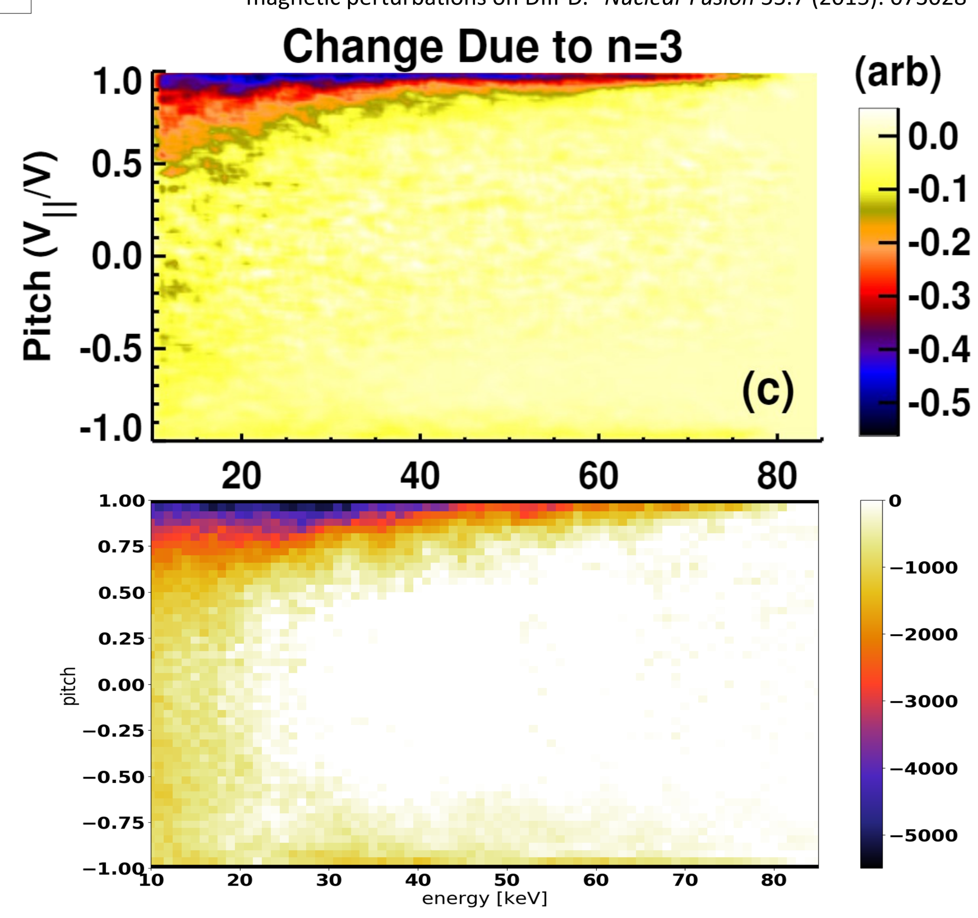
MAST guiding centre & full orbit

- Left - FI density for NUBEAM (top) & BBNBI (bottom) co-current depositions
- Small difference between GC & FO
- 62keV full-energy NBI
- 2D magnetic field

DIII-D n=3 RMP

- Right - SPIRAL (top) LOCUST (bottom) FI density loss in energy-pitch space
- Field calculated by M3D-C1 non-linear MHD code
- 3D wall, co and counter-current NBI injection with all 3 beam energy components

Below: Van Zeeland, Michael A., et al. "Fast ion transport during applied 3D magnetic perturbations on DIII-D." *Nuclear Fusion* 55.7 (2015): 073028



Case	core T_i, core T_e [keV]	core N_e	Codes
DIII-D #157418 - 2D	9.4, 4.1	5.9 x 10^{19}	ASCOT, TRANSP
MAST #29034 - 2D	1.5, 1.1	3.7 x 10^{19}	ASCOT, TRANSP
DIII-D #157418 - 3D	9.4, 4.1	5.9 x 10^{19}	SPIRAL

CONCLUSION & FUTURE

- Now LOCUST-GPU tested and available with Python wrapper in IMAS
- Next → leverage linear RMP codes to generate expansive high fidelity RMP dataset
- Optimise ITER RMP operation - rotation, toroidal harmonic, coil current
- Parametrise phase-space dependent losses according to 3D field structure
  → infer losses and footprint from input data only - no simulations required

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