WP 4.7 XGC for Fusion Turbulence

Alex Prokopyszyn[12], Robert Hager[3], Aaron Scheinberg[4], Choong-Seock Chang[3]
and the rest of the XGC team

UKAEA,

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[1] UK Atomic Energy Authority

[2] Science and Technology Facilities Council

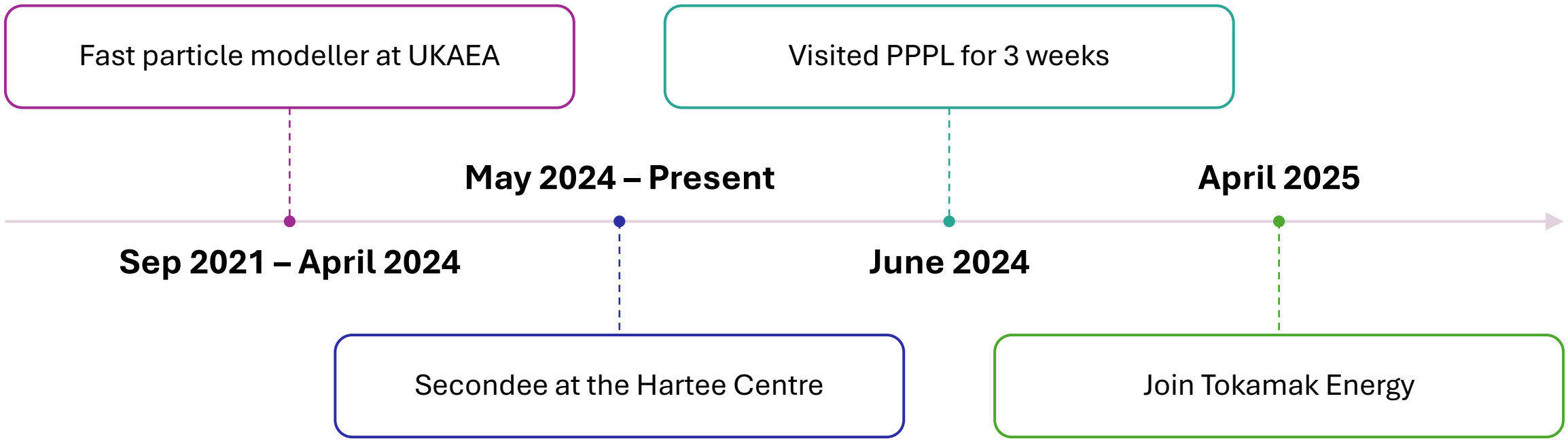
[3] Princeton Plasma Physics Laboratory

[4] Jubilee Development

Science and Technology Facilities Council
Hartree Centre

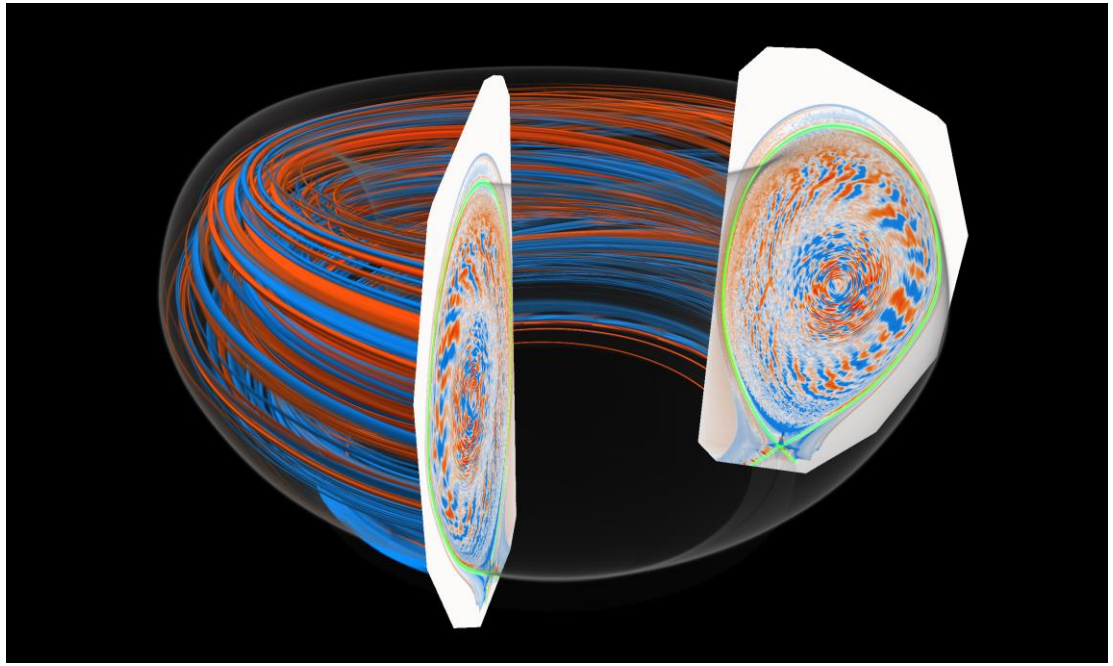
UK Atomic Energy Authority
COMPUTING DIVISION

About me/Project overview



What is XGC?

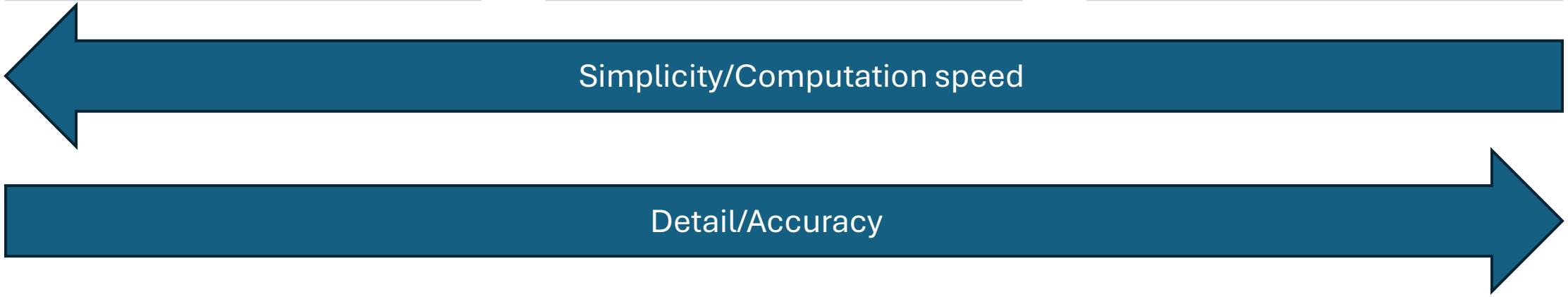
- XGC = X-point included Gyrokinetic Code
- Whole plasma volume code
- Particle-in-cell code
- Mostly written in Kokkos C++
- Scales to 1000s of nodes on GPU HPC hardware
- Alex Whittle installed it on CSD3



A time-slice view of plasma turbulence in XGC [Simulation by S. Ku (PPPL), and visualization by K. Ma (UC Davis)]

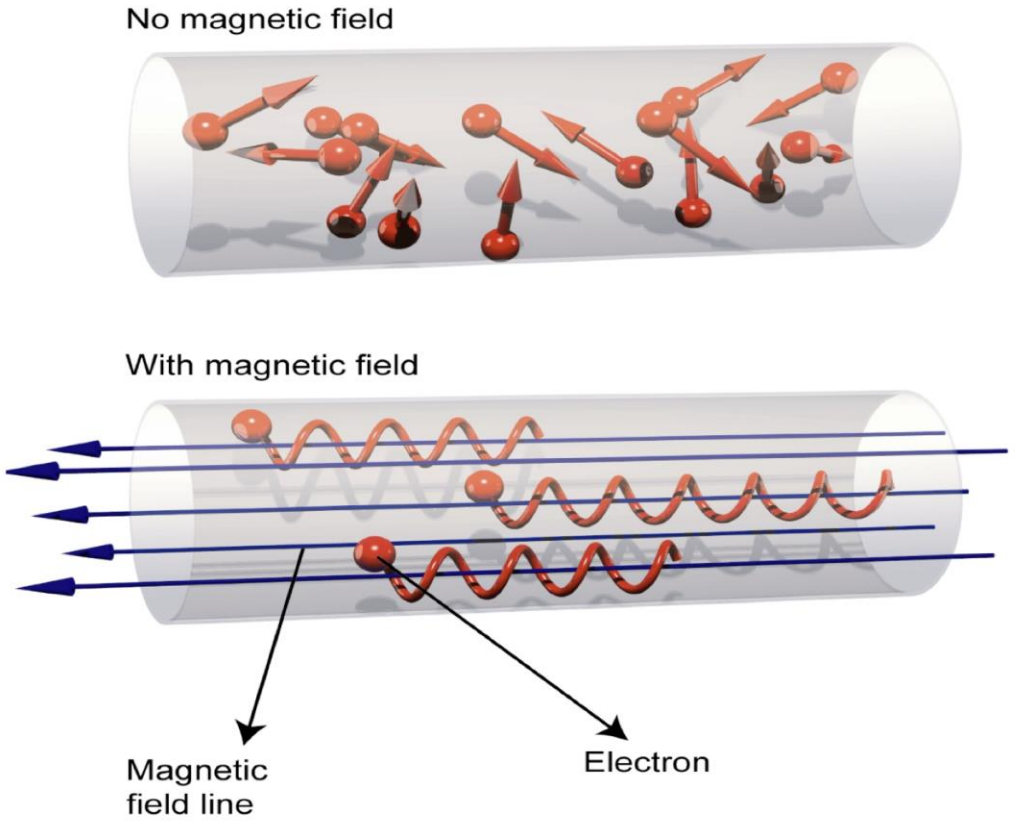
What is Kinetics/Gyrokinetics?

Fluid Models	Kinetics/Gyrokinetics	Everything
• 3D • e.g. MHD • Valid for highly collisional plasma	• 6D/5D • Solve for distribution function $f = f(\boldsymbol{x}, \boldsymbol{v}, t)$	• $> 10^{20}$ particles • Impractical



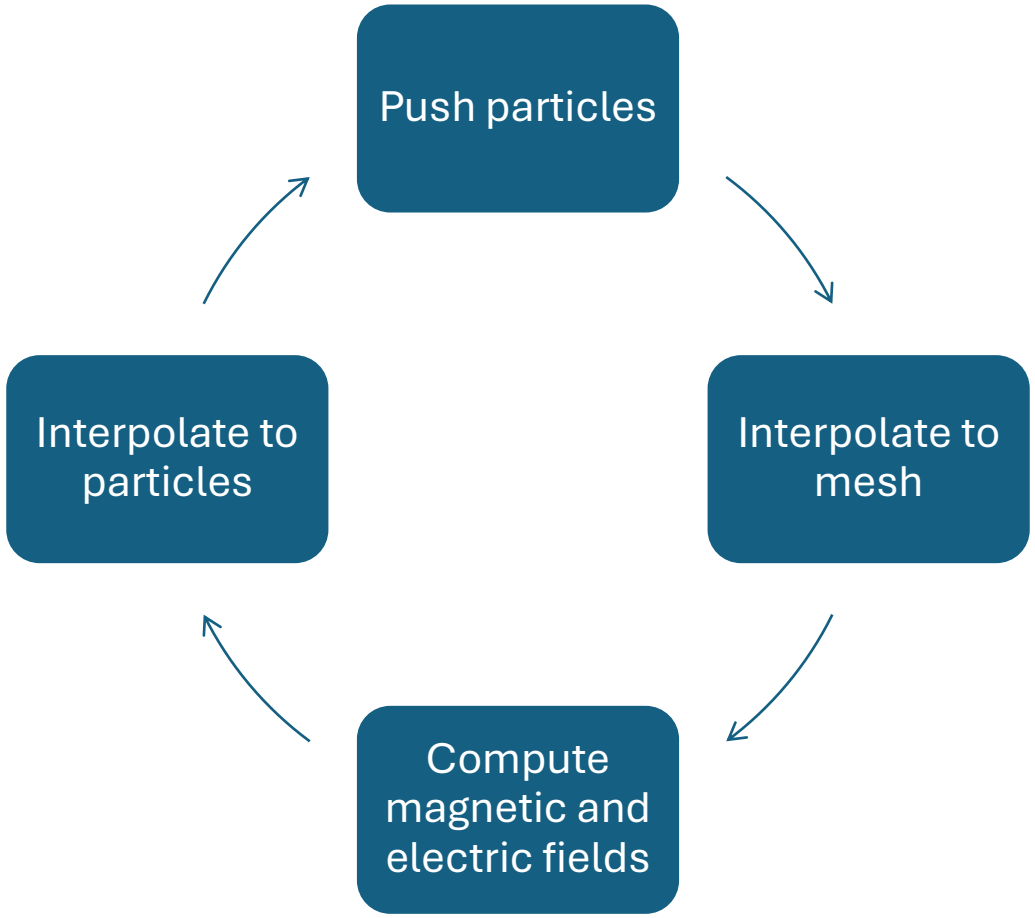
What is Gyrokinetics?

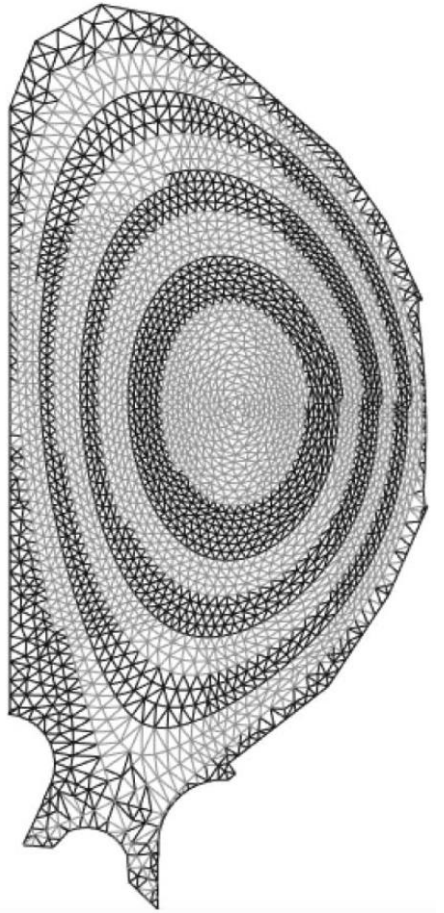
- Gyro-averages kinetic equations
- Reduces problem from 6D to 5D
- Assumes:
  - $t \gg$ Gyroperiod
  - $L_{||} \gg L_{\perp}$
- Does not assume:
  - $L \gg$ Gryoradius
  - $L \gg$ Mean free path



Gyro-motion of charged particles [Visualisation by ITER]

What are particle-in-cell codes?



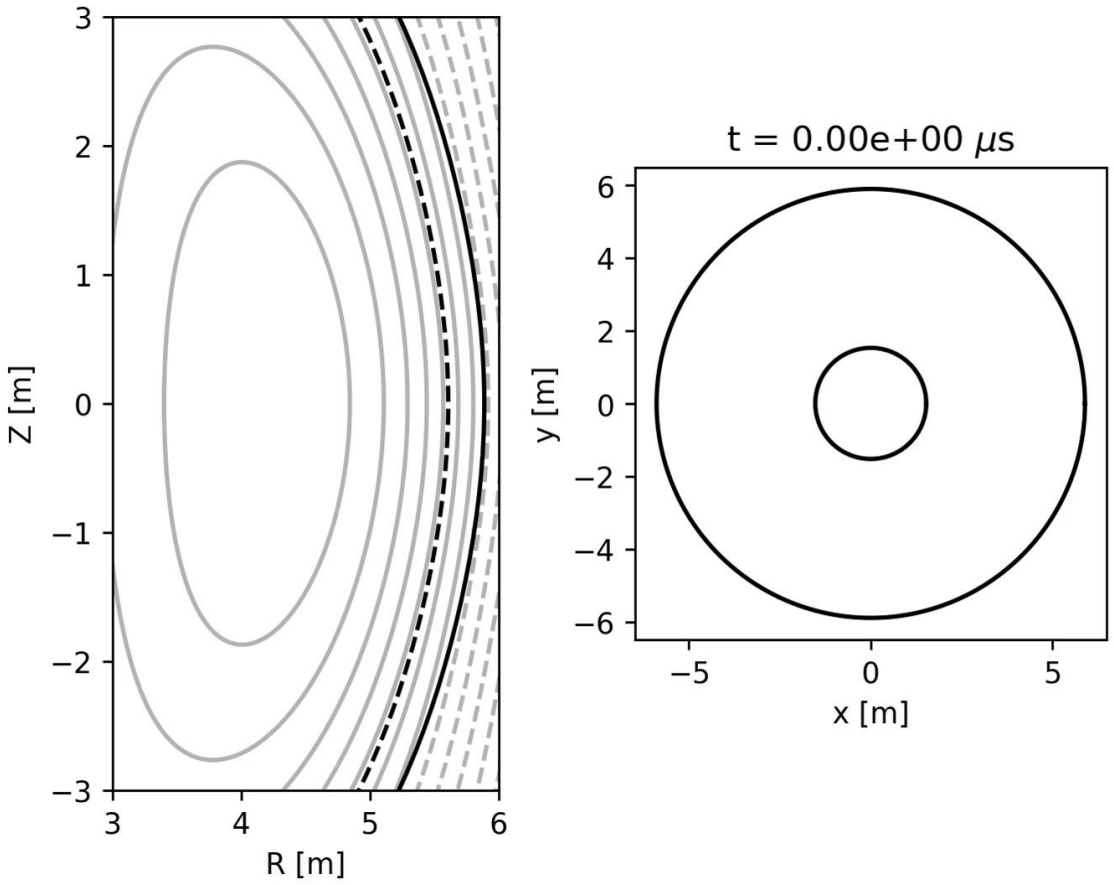


XGC Mesh [Visualisation by A. Scheinberg]

Why isn’t adding fast particles straightforward? Reason 1

Gyrodiameter for 1 T field

Particle	Energy	Gyrodiameter
Electron	10 keV	< 0.1 cm
Tritium	10 keV	< 9 cm
Alpha	3.5 MeV	< 54 cm



Thermonuclear α in STEP

Why isn't adding fast particles straightforward? Reason 2

- Fast particles are not Maxwellian
- XGC uses a "Delta-F" scheme where:

Distribution function ⟶ $f = f_0 + \delta f$ ⟵ Perturbation term:
- Sample particles from this
- Very noisy

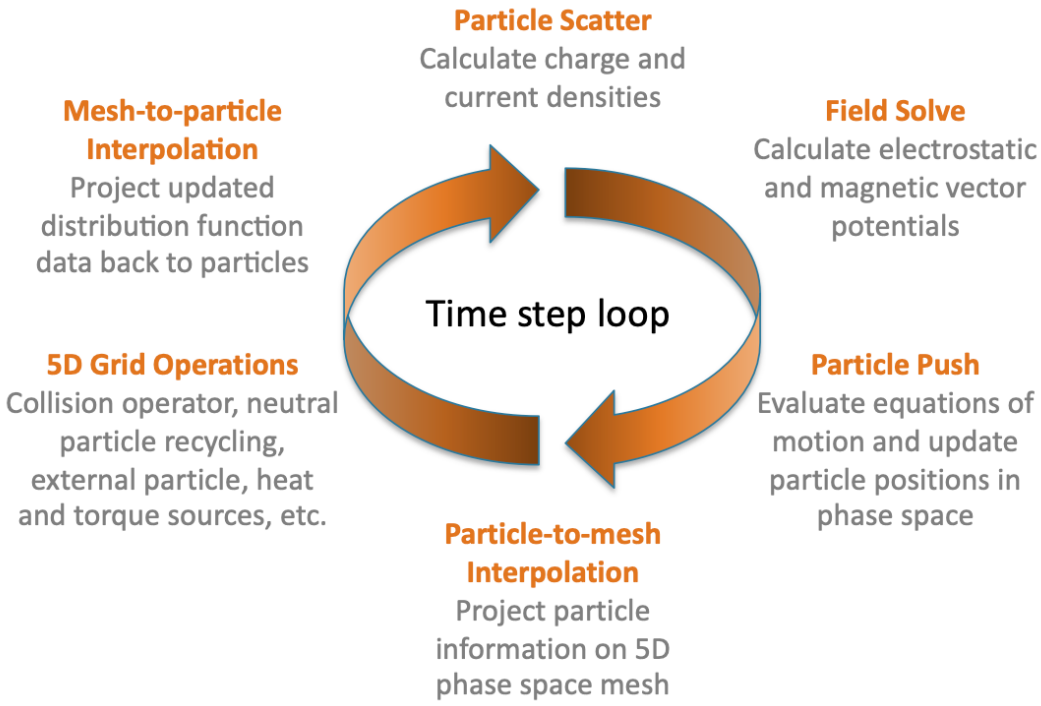
↑ Background term:
- Approximately Maxwellian
- Evolves slowly on the grid

- We brought back a "Full-F" scheme where:

$$f = f$$

Why isn’t adding fast particles straightforward? Reason 3

- Need “Full-F” and “Delta-F” species simultaneously
- Code not written in a way that easily allows for this



Project summary

Add fast particle physics to XGC

Brought back “Full-F”

Simultaneous support of “Delta-F” and “Full-F”

Realistic fast-particle simulation

“Delta-F” support with slowing down distribution

Summarise work and hand over to Yiyun Tan