MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Recycling in the FCI approach ?

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EUROfusion

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Plasma-neutrals model in GRILLIX

Plasma model:

$$\partial_t\, n + \nabla \cdot \left(n\mathbf{v}_{ExB} + n\mathbf{v}_{e,dia} + nv_{e,\parallel}\,\mathbf{b} \right) = S$$

$$\vdots$$

Neutral model model:

$$\partial_t\, N - \nabla \cdot \left(\frac{1}{nk_{cx}} \nabla N T_i \right) = -S$$

$$S = k_{iz}\, nN - k_{rec}\, n^2$$

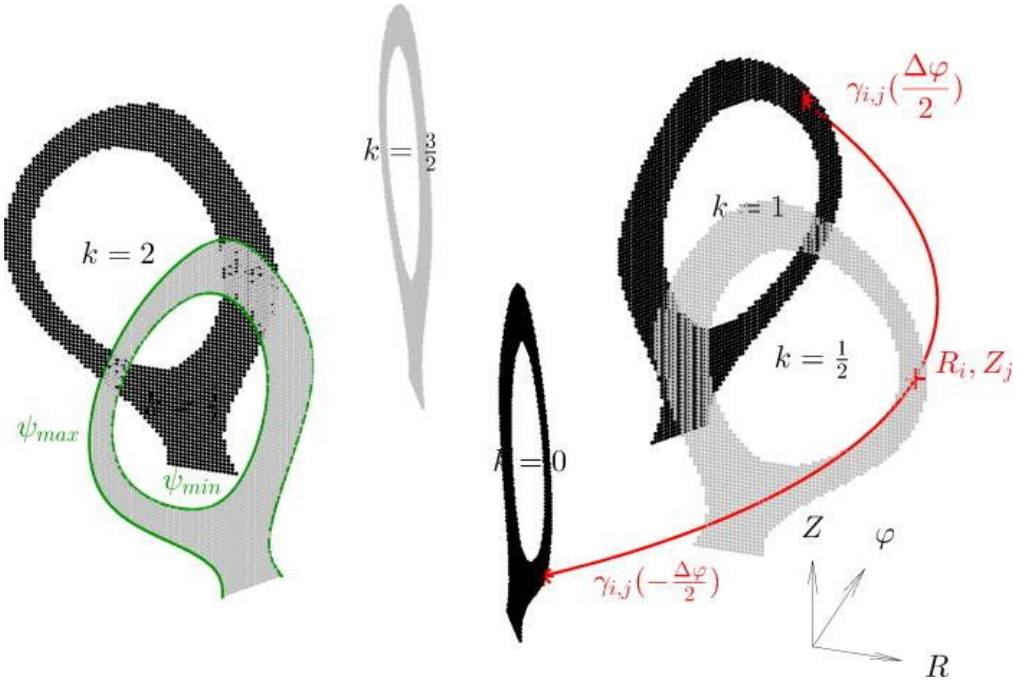
Total particle conservation:

$$\frac{d}{dt} \int_V (n+N)\, dV = \int_{\partial V} \left(\underbrace{\frac{1}{nk_{cx}} \nabla N T_i}_{\Gamma_N} \quad \underbrace{-n\mathbf{v}_{ExB} - n\mathbf{v}_{e,dia}}_{-\Gamma_{n,\perp}} \quad \underbrace{-nv_{e,\parallel}\,\mathbf{b}}_{-\Gamma_{n,\parallel}} \right) d\mathbf{S} \stackrel{!}{=} 0$$

$$\Gamma_N \big|_{\partial_V} = \left(\Gamma_{n,\perp} + \Gamma_{n,\parallel} \right) \big|_{\partial_V}$$

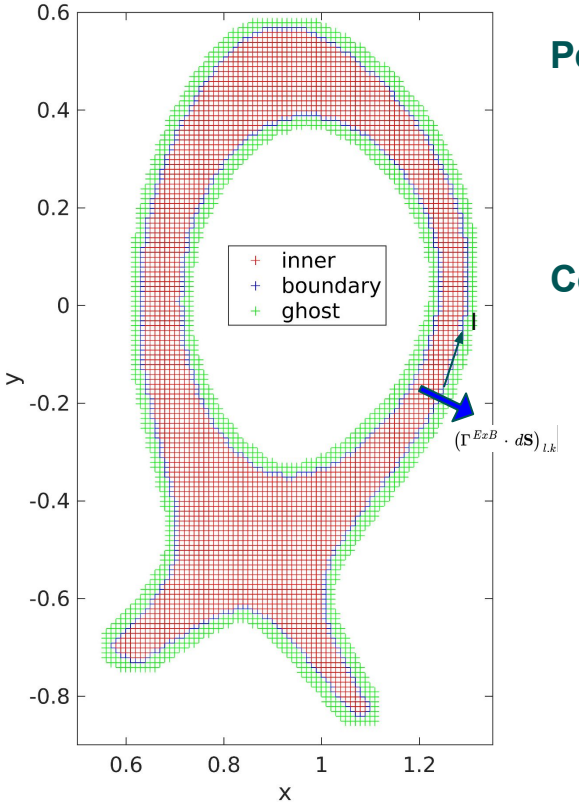
Here: Ideas how to compute **perpendicular** and **parallel** fluxes within the FCI approach

Reminder: FCI



- Set of locally Cartesian poloidal planes ~ ⊥
- Parallel operators via field line map
- Penalisation

Perpendicular fluxes



Perpendicular boundary polygons

- Set of closed polygons (ordered)
- Just a list of mesh indices l going along boundary polygon

Computation of ExB flux through boundary point (l,k)

$$\partial_t\, n + \nabla \cdot \left(\underbrace{n \mathbf{v}_{ExB}}_{=\Gamma^{ExB}} \right) = 0$$

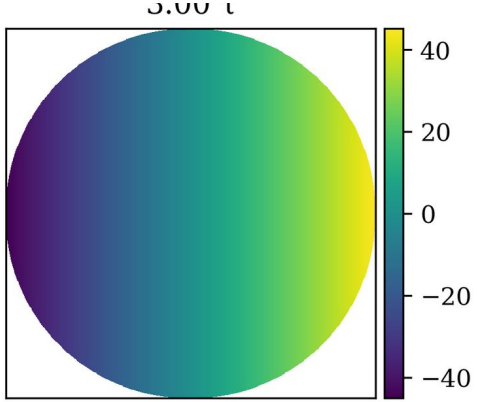
$$\Gamma^{ExB} = n \frac{B \times \nabla \phi}{B^2}$$

$$\left(\Gamma^{ExB} \cdot d\mathbf{S}\right)_{l,k} = \frac{R_l\, n_{l,k}}{B_l} \left(\phi_{l+1,k} - \phi_{l-1,k}\right)$$

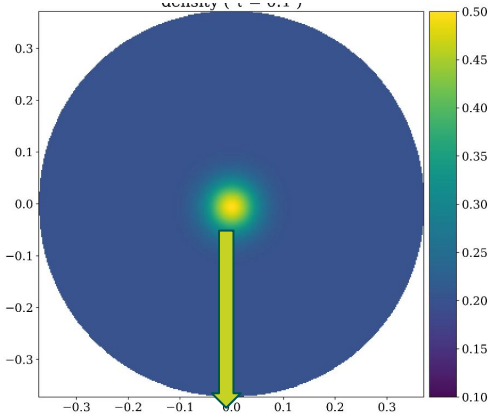
Test of perpendicular flux computation

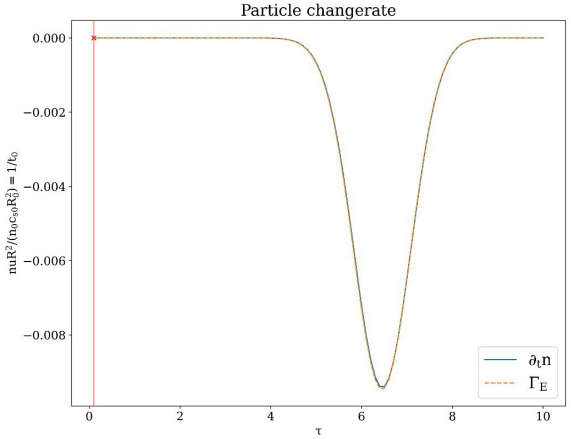
$$\partial_t\, n + \nabla \cdot \left(\underbrace{n \mathbf{v}_{ExB}}_{=\Gamma^{ExB}} \right) = 0$$

imposed potential

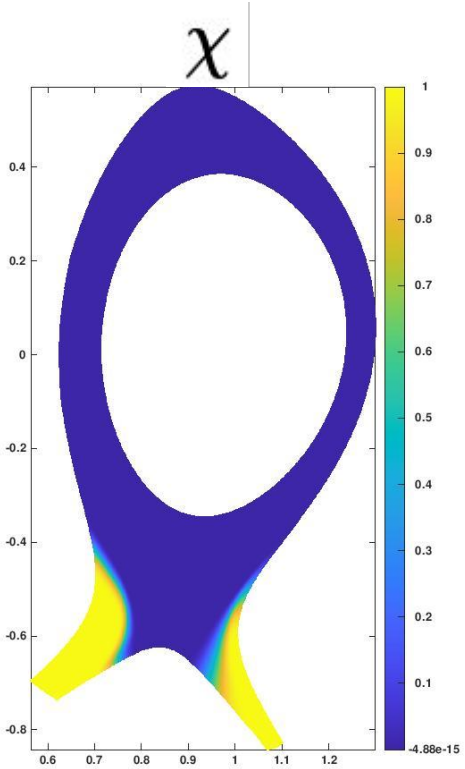


Plasma density blob propagating downwards





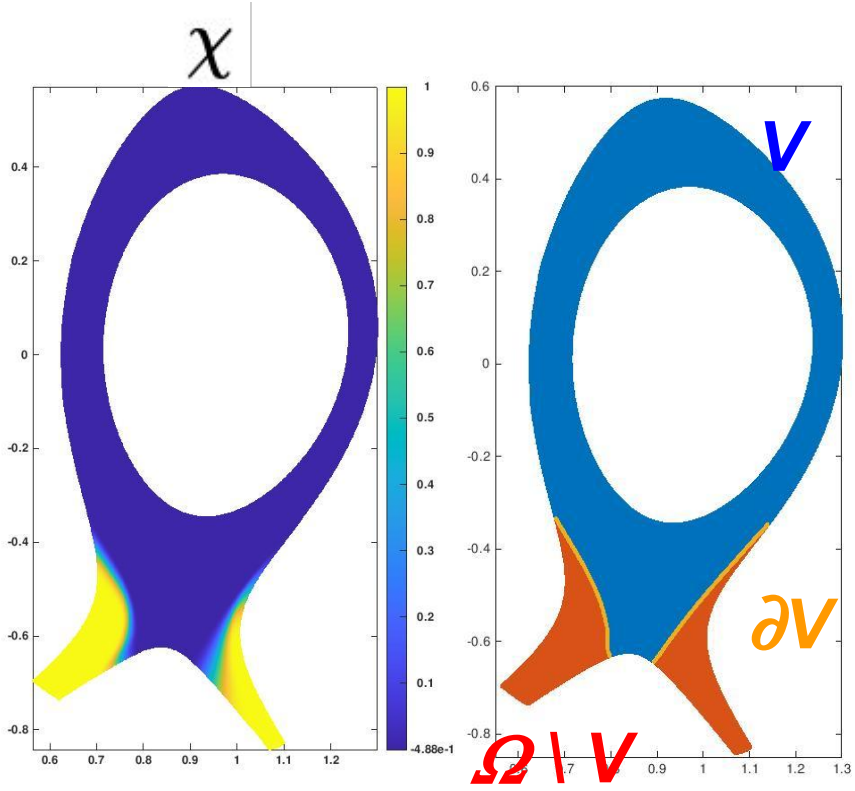
Penalisation



Penalisation

$$\partial_t\, n + (1-\chi)\left[\nabla\cdot(n\mathbf{v}_e) - S\right] + \frac{\chi}{\epsilon}\,(n_{pen} - n) = 0 \quad \text{in } \Omega$$

Penalisation



Penalisation

$$\partial_t n + (1-\chi)\left[\nabla \cdot (n\mathbf{v}_e) - S\right] + \frac{\chi}{\epsilon}(n_{pen} - n) = 0 \quad \text{in } \Omega$$

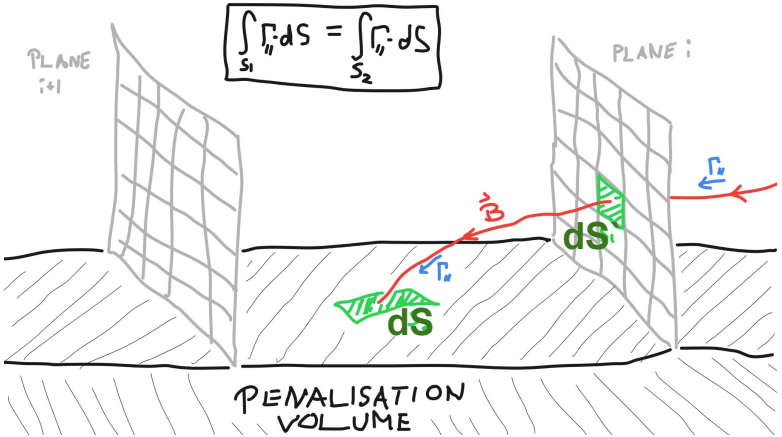
Physical boundary

- Physical domain is $V = \{(R,\varphi,Z) | \chi(R,\varphi,Z) = 0\}$ Here the conservation laws are fulfilled
- Penalisation region is $\Omega \setminus \partial V$, where conservation laws are violated
- The physical boundary is ∂V, where computation of boundary flux takes place

Perpendicular flux computation

- as described before

Parallel fluxes

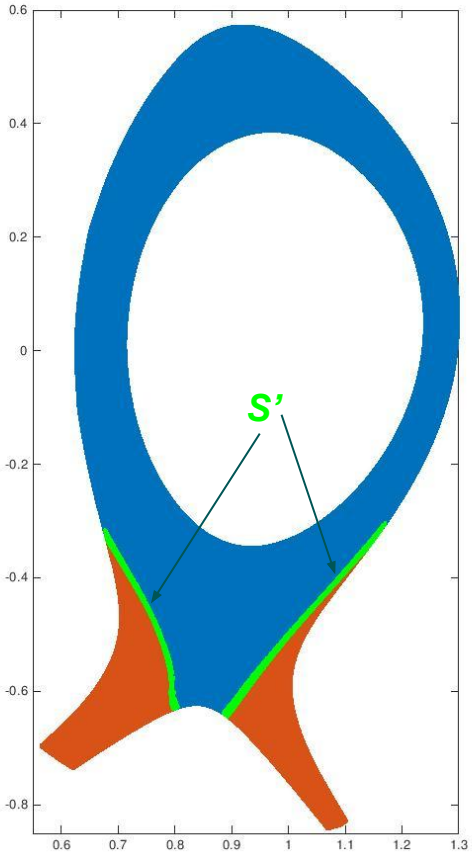


$$\partial_t\, n + \nabla \cdot \left(\underbrace{n v_{e,\parallel}\, \mathbf{b}}_{\Gamma_\parallel} \right) = 0$$

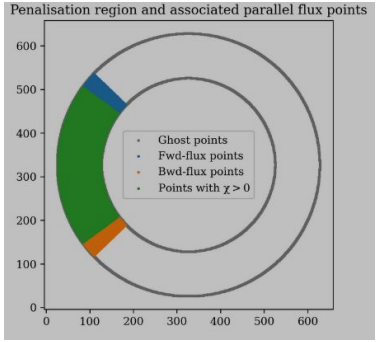
Computation of parallel flux through mapped surface S

$$\Gamma_\parallel \cdot d\mathbf{S} = n v_{e,\parallel}\, dS' = n_{s'}\, v_{e,\parallel,s'}\, \Delta R \Delta Z$$

→ Find points that are parallely (along B) connected to penalisation volume

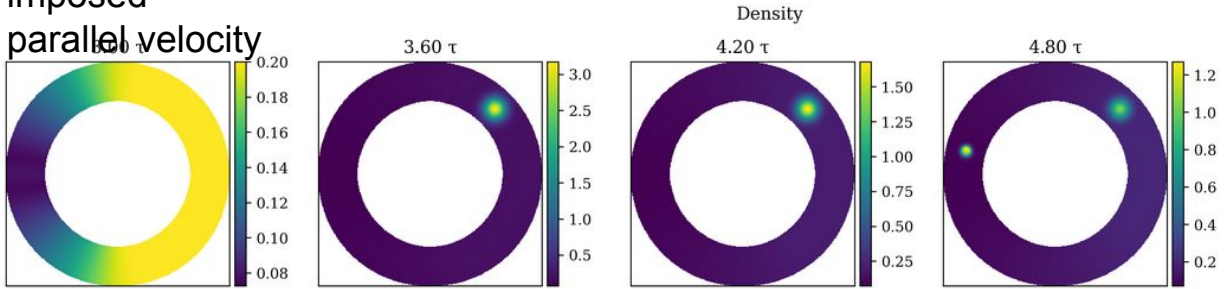


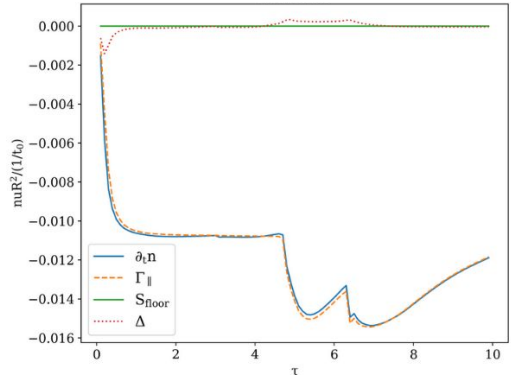
Test of parallel flux computation



Blob propagating along field line into limiter

imposed
parallel velocity





- Good agreement
- Quantitative behaviour currently under investigation

Conclusions

- Modelling of recycling requires accurate computation of plasma fluxes through boundaries
- This is challenging in FCI as mesh and field lines are not conformal with boundaries
- Perpendicular fluxes: Finite difference along boundary polygons
- Parallel fluxes: Integration over area mapped back from penalisation onto poloidal planes

Next steps

- More quantitative investigation in turbulent state
- Coupling with fluid neutral model
- Test case: TCV-X23