Improving our models of nonlocal transport

C.P RIDGERS

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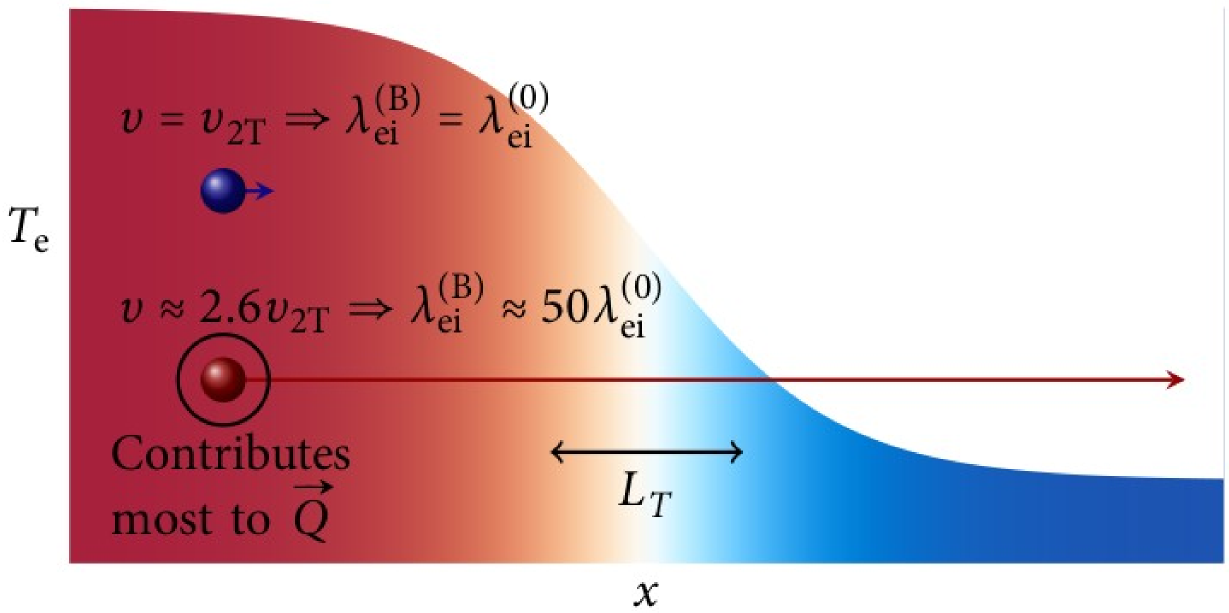
- Mean-free path of heat carrying electrons long



J. Brodrick PhD thesis (2018)

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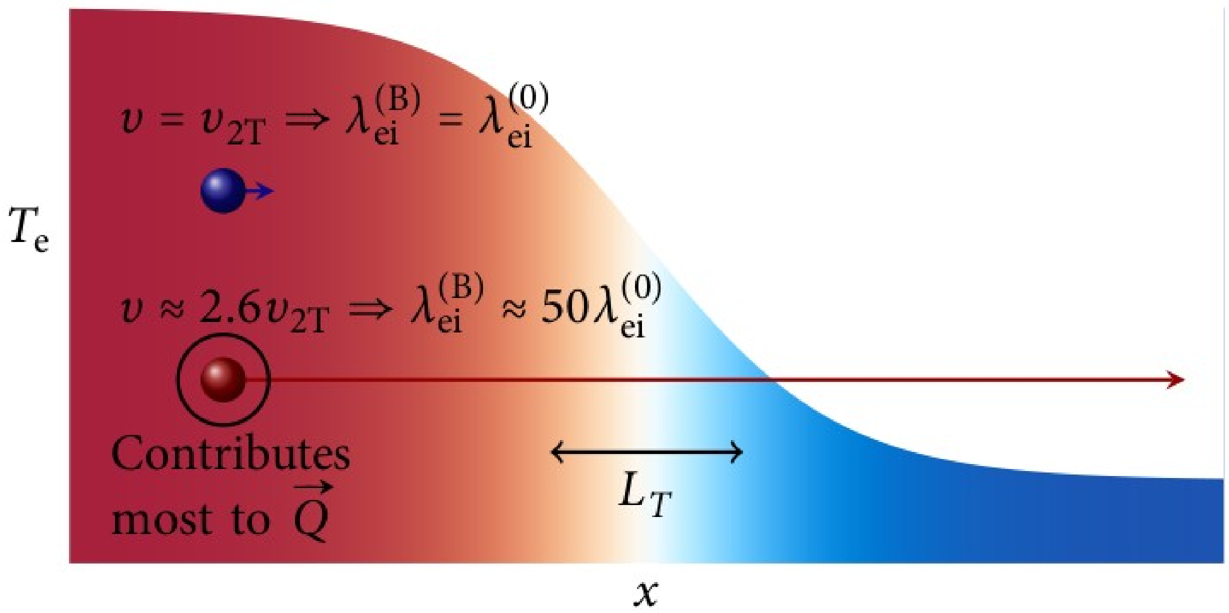

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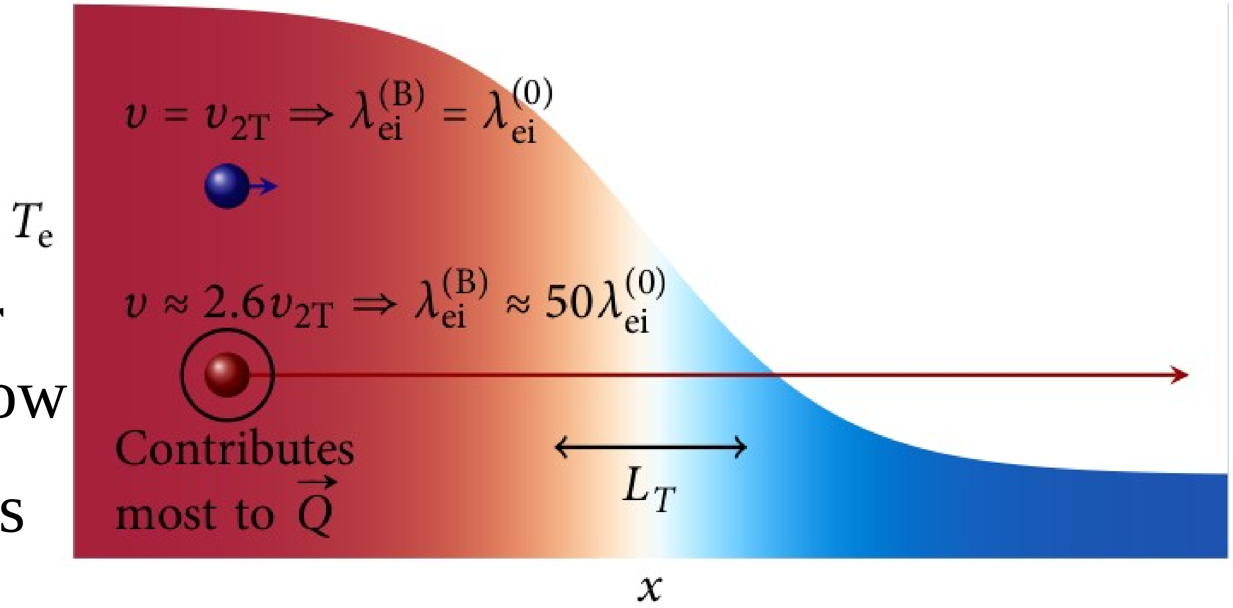
- Reduced non-local models must be used



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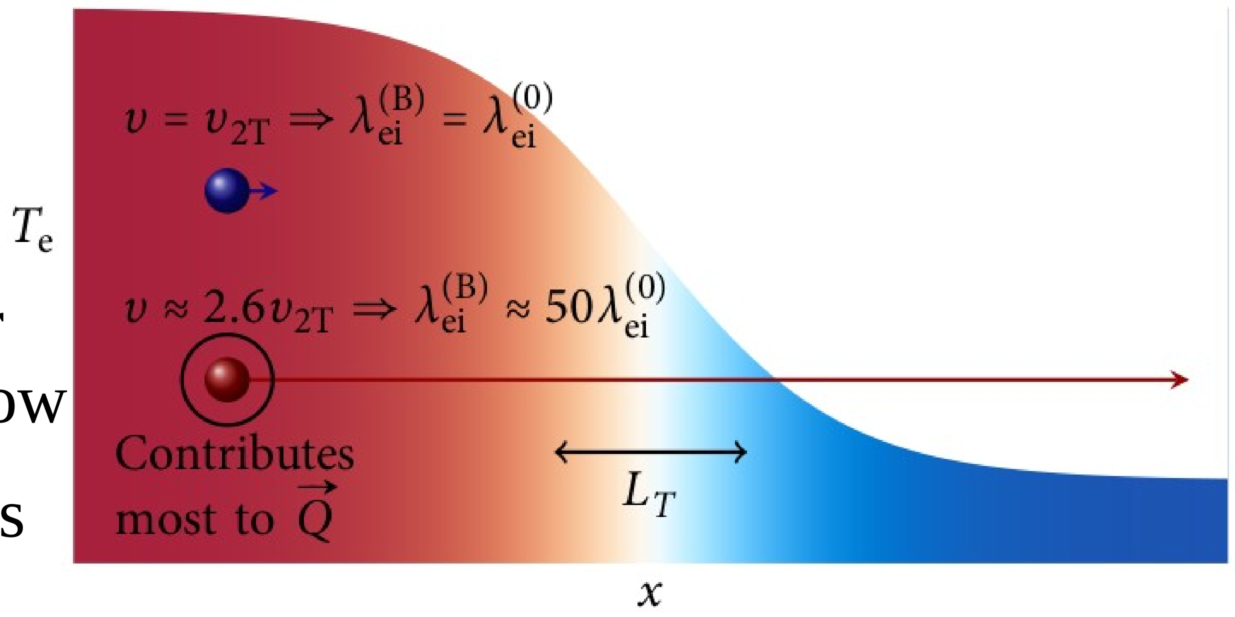

- Flux limiter – arbitrarily limit heat flux when unphysical
- Reduced kinetic models also available (e.g. SNB)

Example – Nonlocal Transport

- Ab-intio calculation – Vlasov-Fokker-Planck (VFP) equation

$$\frac{\partial f}{\partial t} + \boldsymbol{v} \cdot \frac{\partial f}{\partial \boldsymbol{r}} - \frac{e}{m_e}\left(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B}\right) \cdot \frac{\partial f}{\partial \boldsymbol{v}} = \left(\frac{\partial f}{\partial t}\right)_{coll}$$

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IMPACT VFP code
- f0+f1 code
- 3D (2 spatial, 1 velocity)
- B-fields

R.J. Kingham & A.R. Bell, J. Comp. Phys., 194, 1 (2004)

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Max heat flow = free streaming limit (q_{FS})

Arbitrary limiter = f

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Quickly reach steady state heat flow

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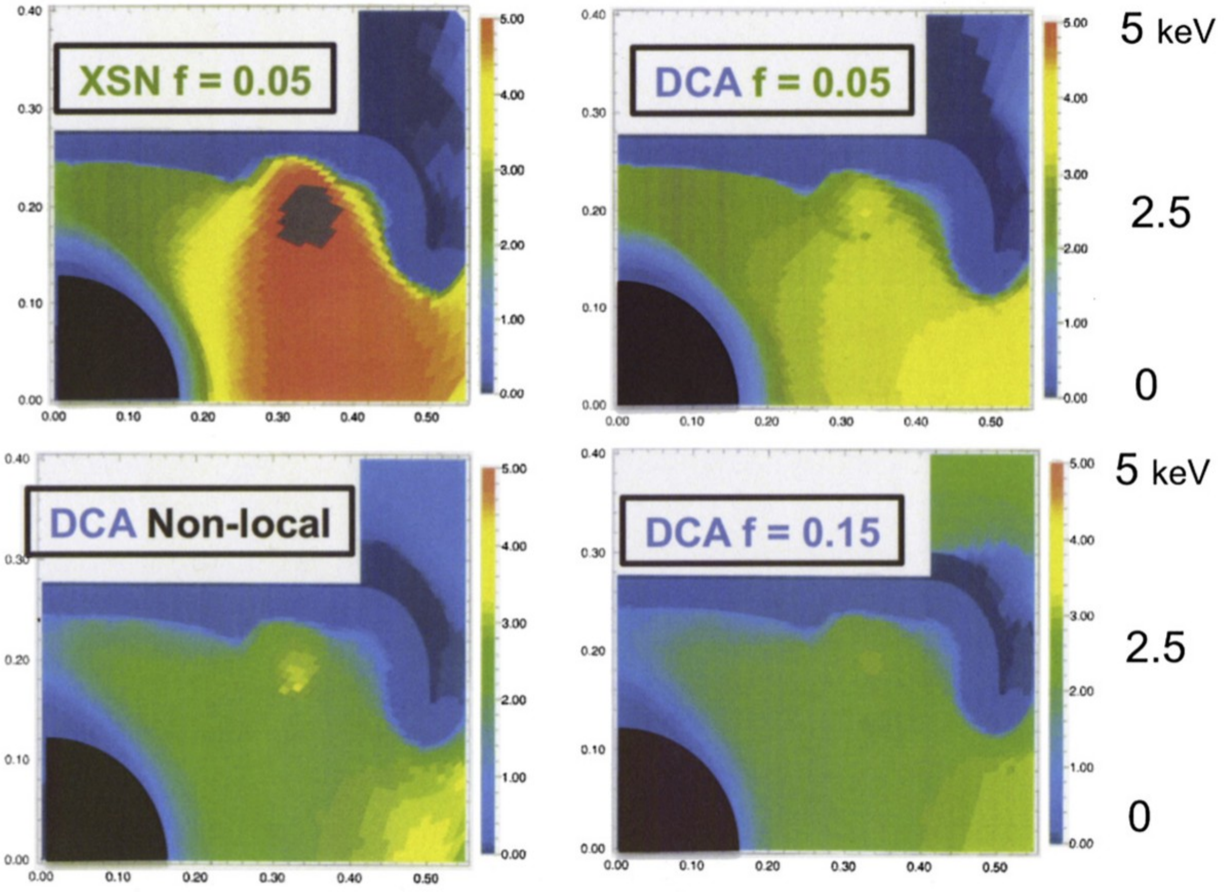
High flux model



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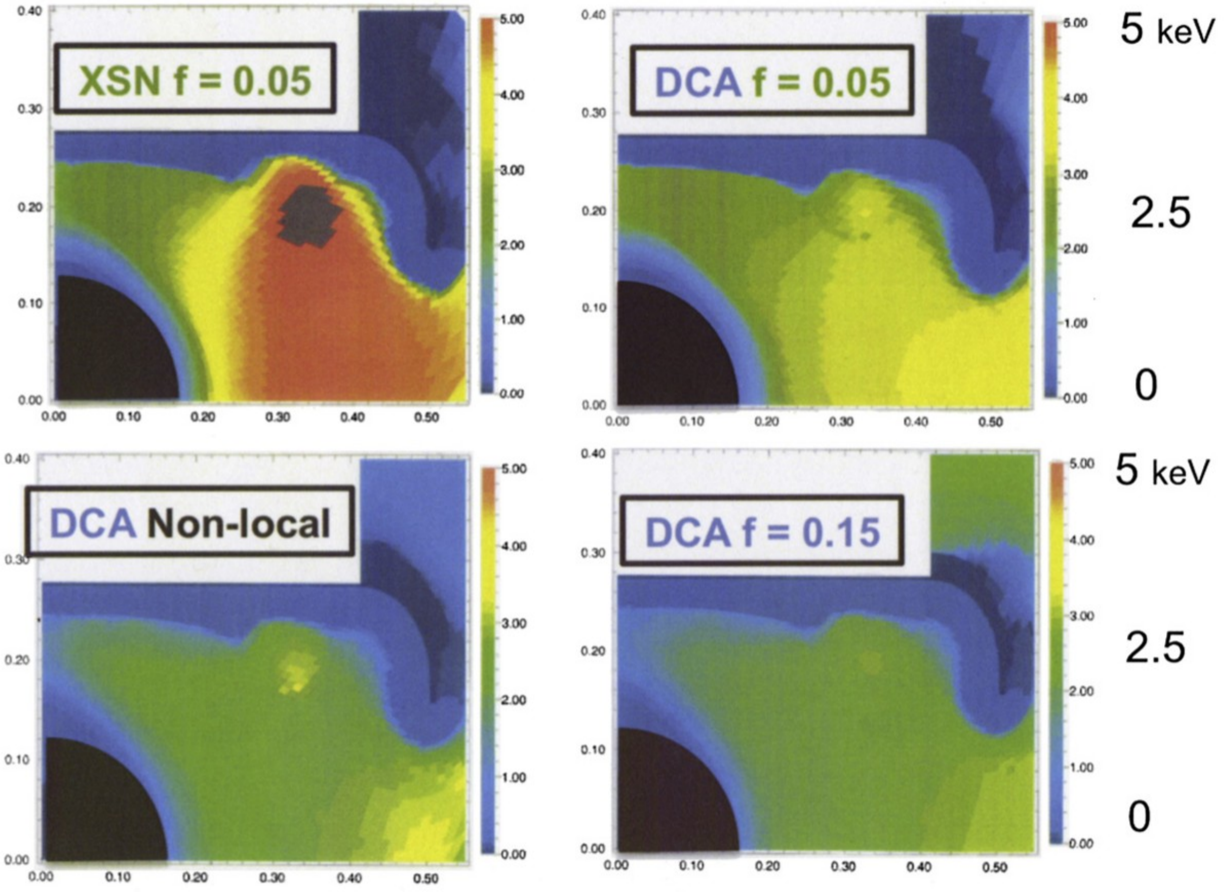
High flux model

- XSN + f=0.05

  first model for NIC



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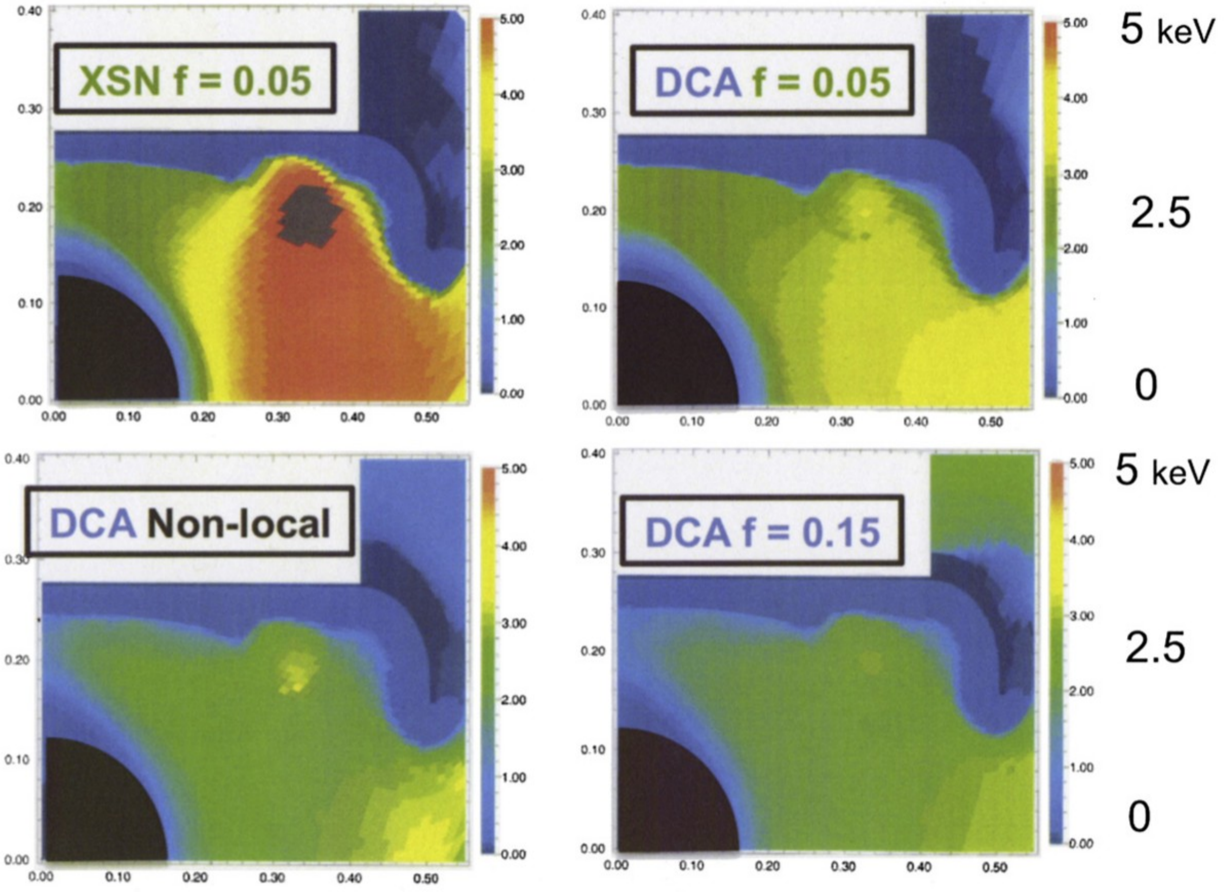
- DCA + Non-local

  Better NLTE physics but slow



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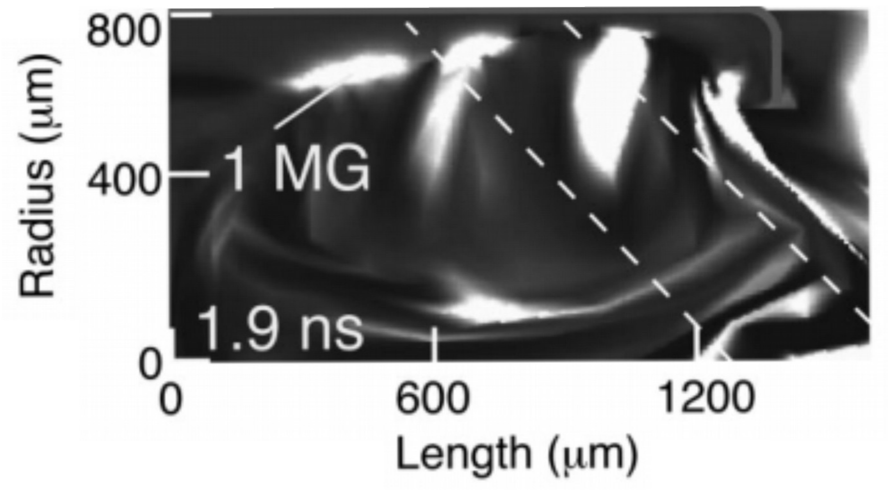
Magnetic fields & transport



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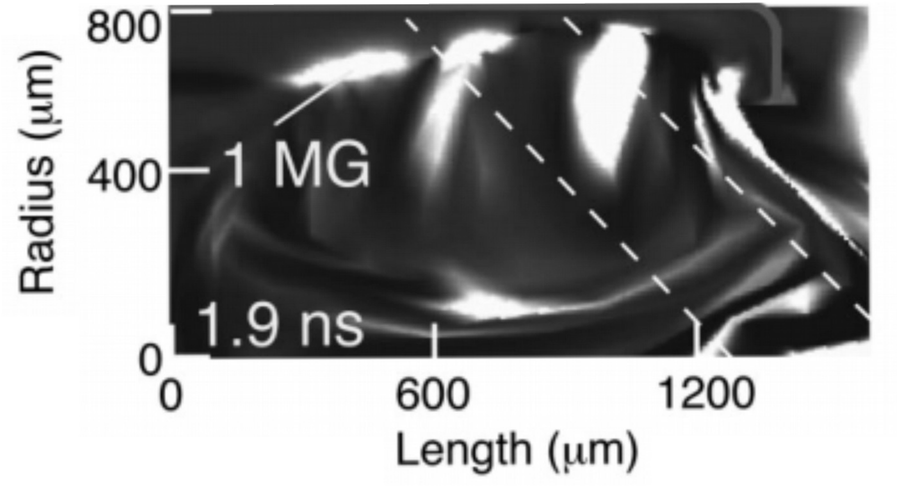

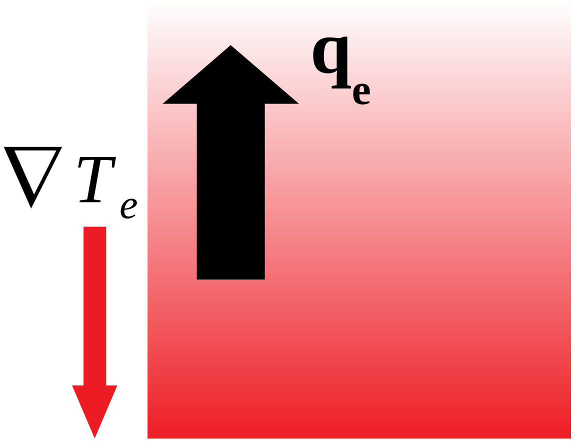

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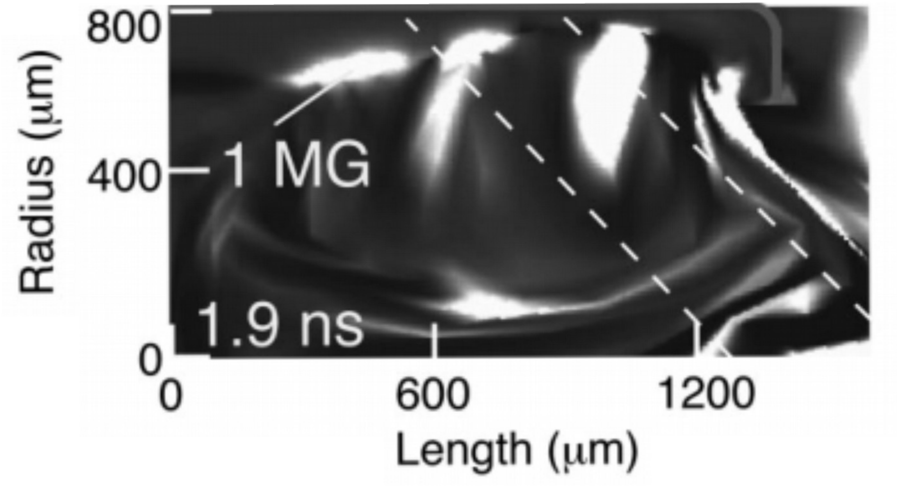

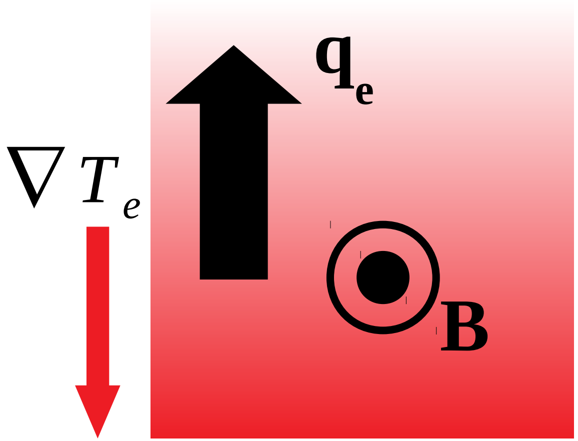

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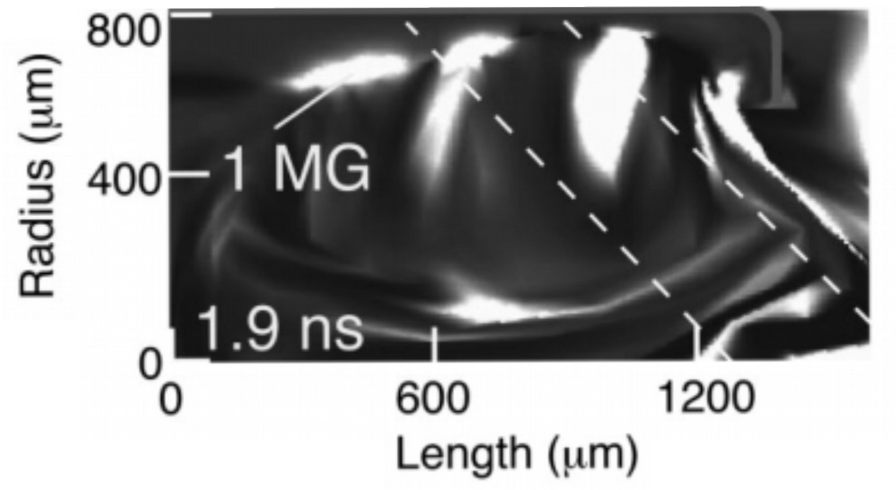

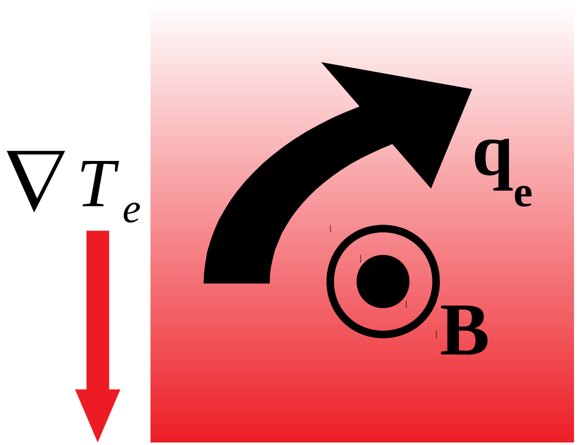

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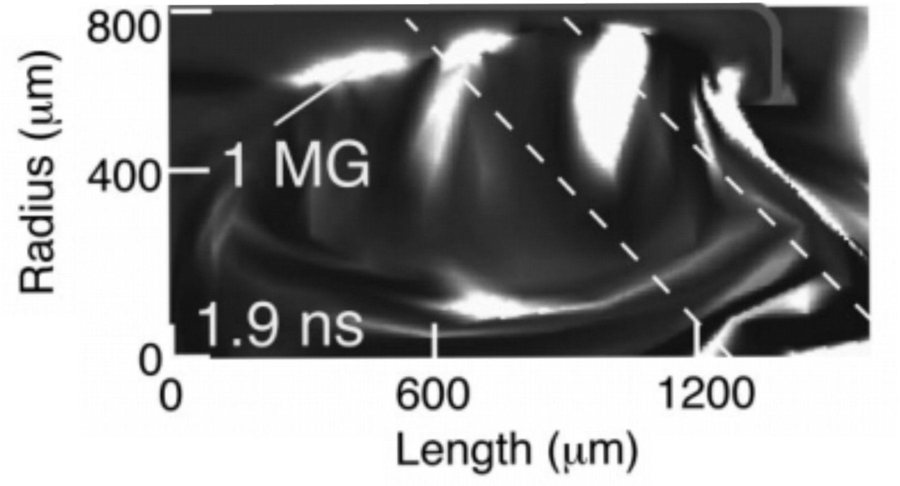

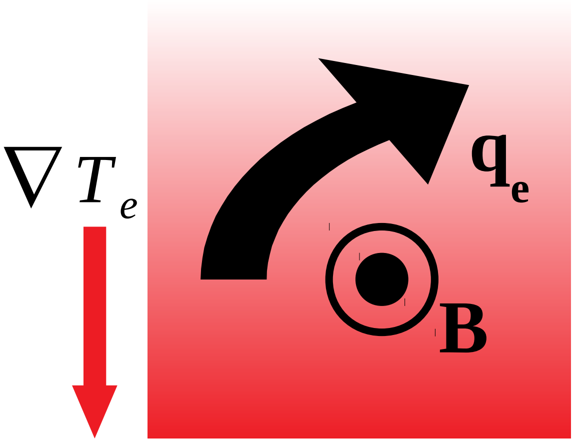

Magnetic field deflects heat flow

1. Restricts conduction

2. Righi-Leduc

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Magnetic fields & transport

- Heat transport determines B-field evolution

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$$e\,n_e\left(\boldsymbol{E}+\boldsymbol{C}_i\times\boldsymbol{B}\right)=-\nabla P_e+\frac{\underline{\underline{\alpha}}\cdot\boldsymbol{j}}{en_e}+n_e\underline{\underline{\beta}}\cdot\nabla T_e \qquad \frac{\partial\boldsymbol{B}}{\partial t}=-\nabla\times\boldsymbol{E}$$

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Frozen-in flow

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Frozen-in flow **Biermann**

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Frozen-in flow   Biermann   **Resistive diffusion**

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Frozen-in flow | Biermann | Resistive diffusion | **~Nernst**

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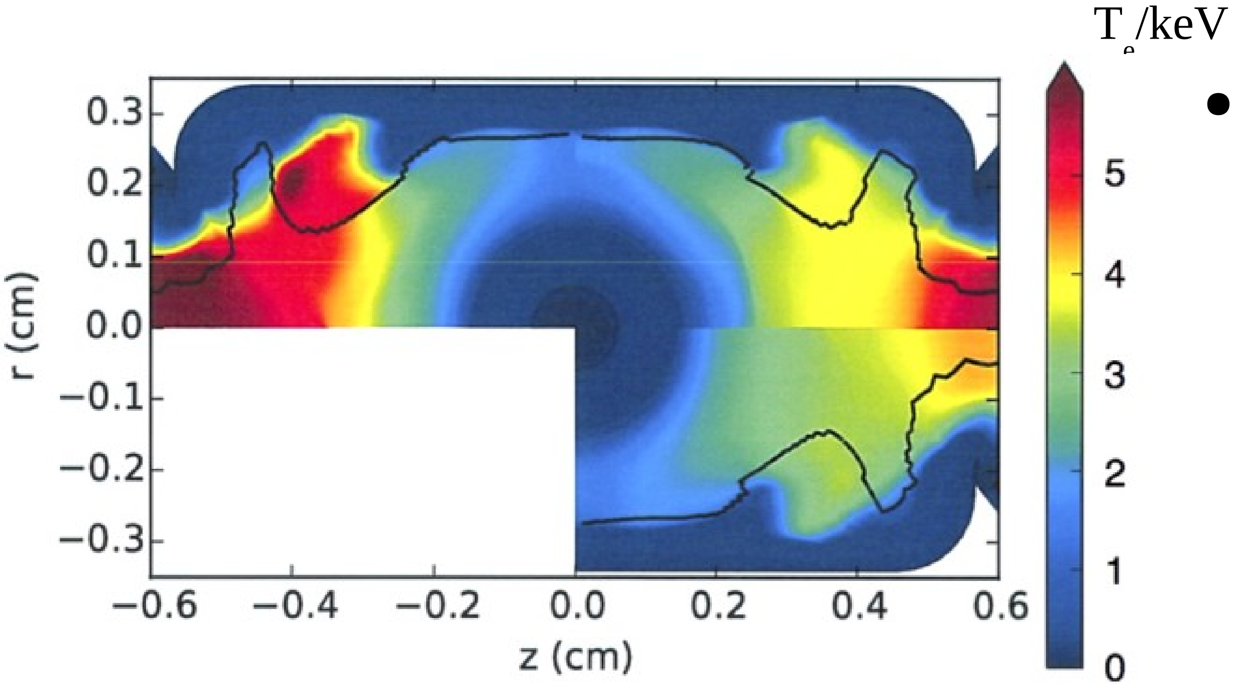

- HYDRA high-foot simulation (CH capsule 0.6mg/cc fill) t=13ns

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W.A. Farmer et al., Phys. Plasmas, 24, 052703 (2017)

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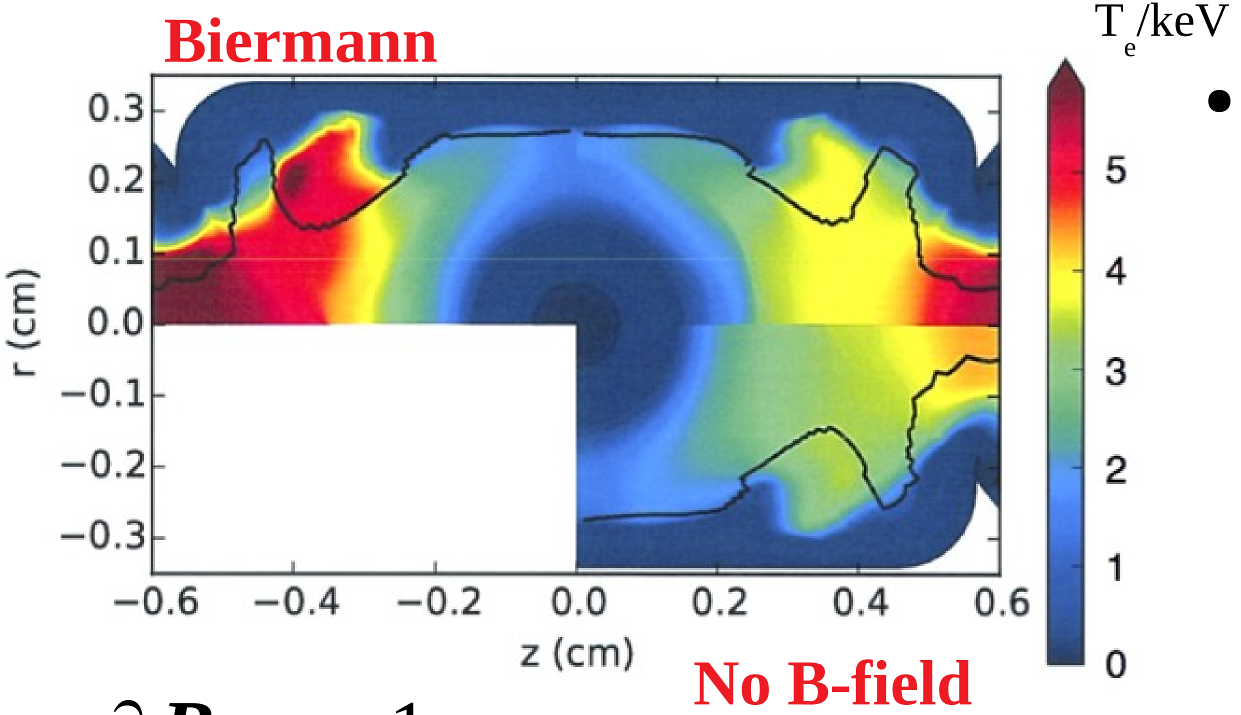

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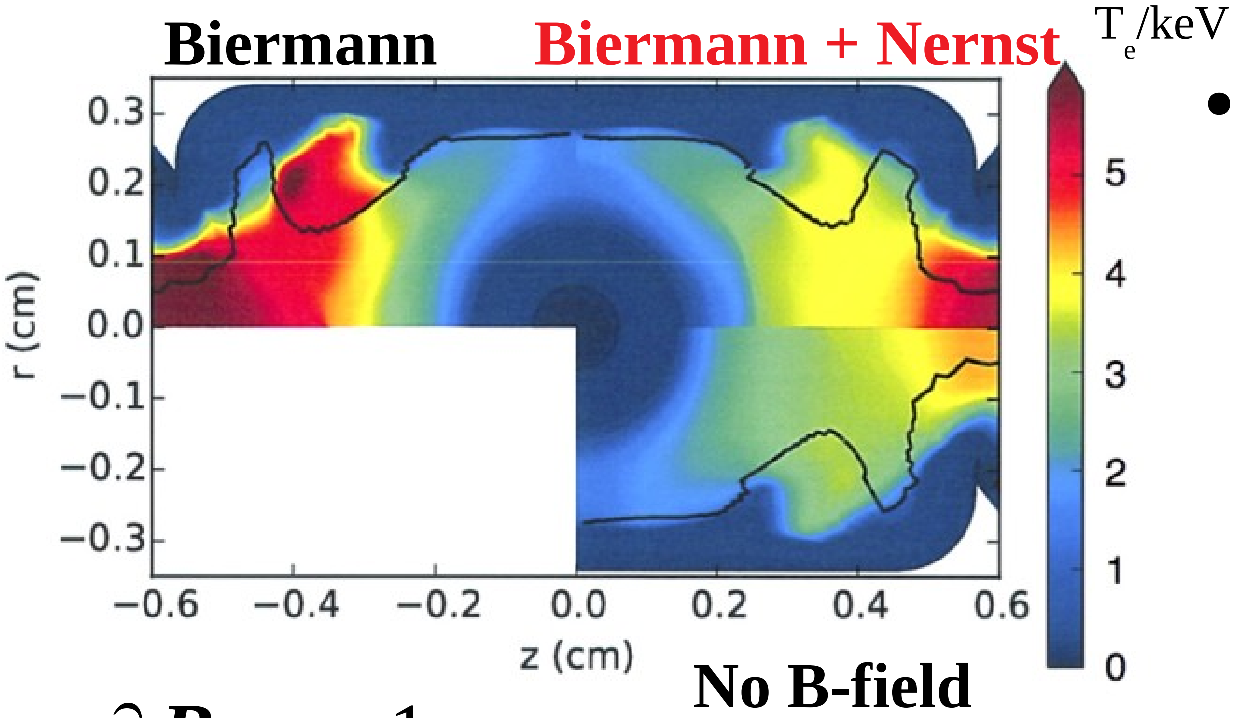

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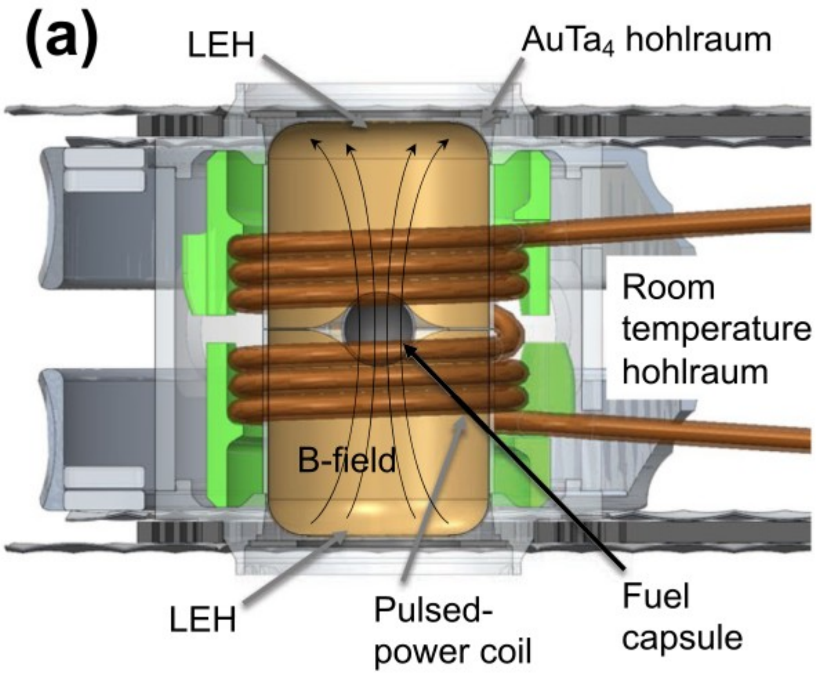
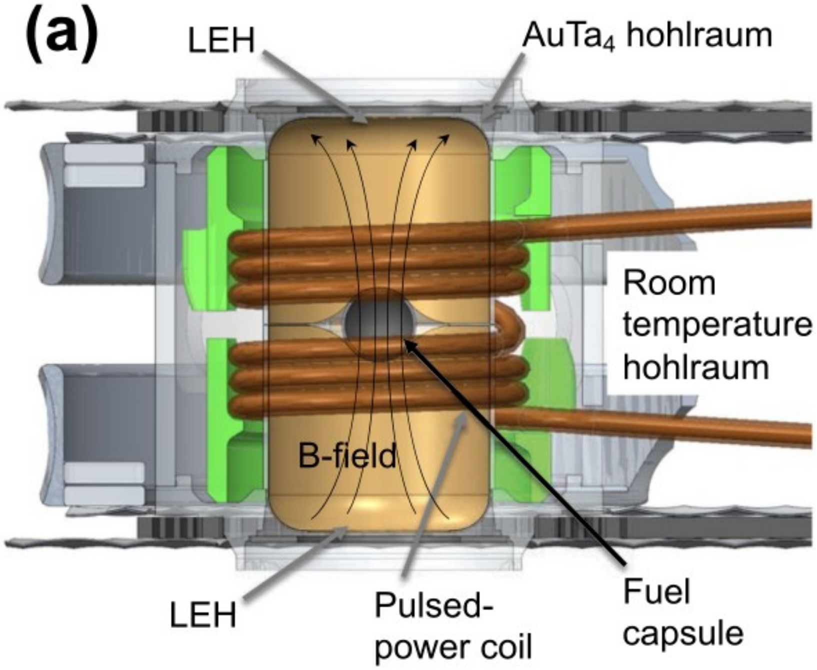
- Magnetize hohlraum to imporove capsule yield



J. Moody et al., J. Fusion Energy, 41, 7 (2022)

Magnetic fields & transport

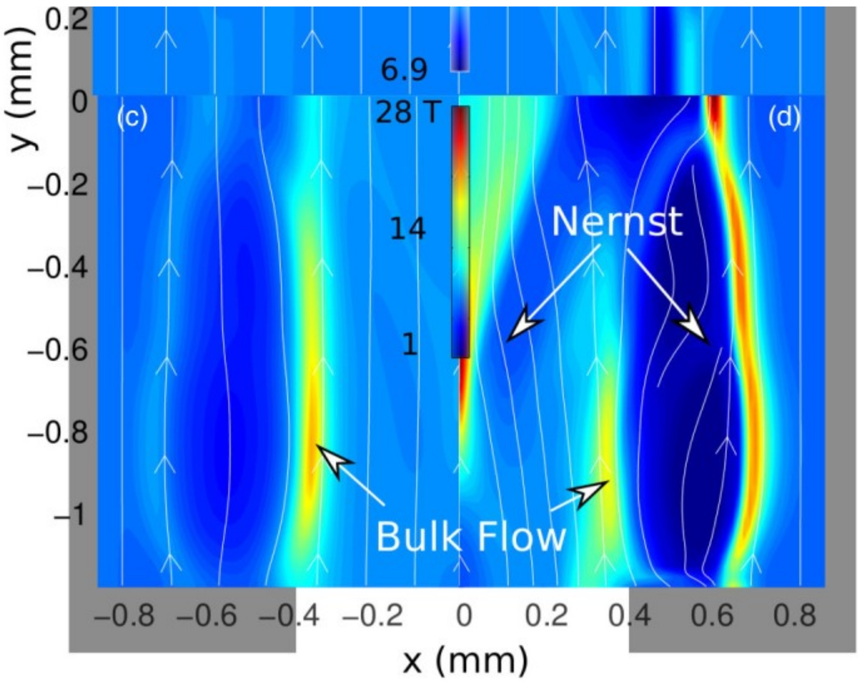
- Magnetize hohlraum to imporove capsule yield
- Simulations indicate Nernst effect crucial in magnetized hohlraums



J. Moody et al., J. Fusion Energy, 41, 7 (2022)

Magnetic fields & transport

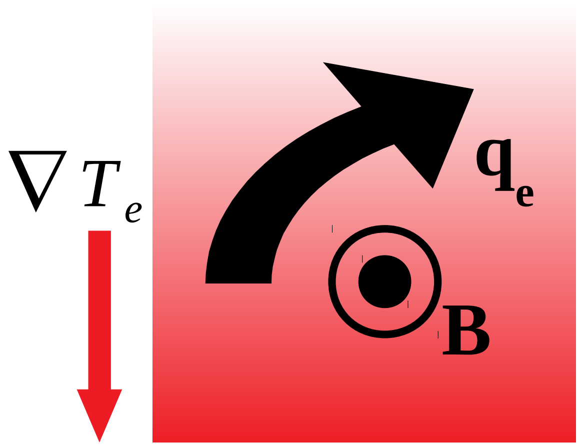
- Magnetize hohlraum to imporove capsule yield
- Simulations indicate Nernst effect crucial in magnetized hohlraums
- VFP simulations after 400ps with 7.5T applied field, density $5x10^{19}Wcm^{-2}$. Ray tracing, intensity $\sim 5x10^{14}Wcm^{-2}$



A. Joglekar et al., Phys. Rev. E, 93, 043206 (2016)

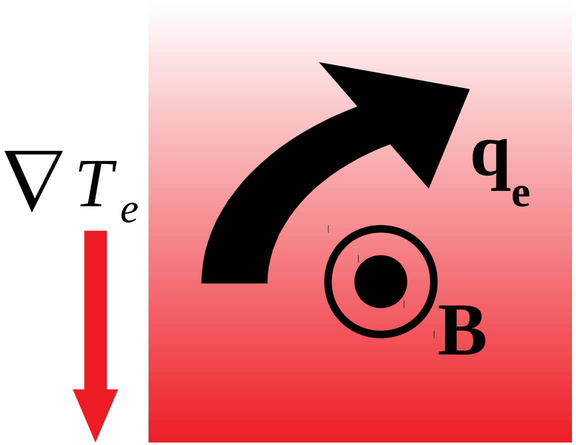
Magnetic fields & nonlocal Transport

- Magnetic fields modify degree of nonlocality



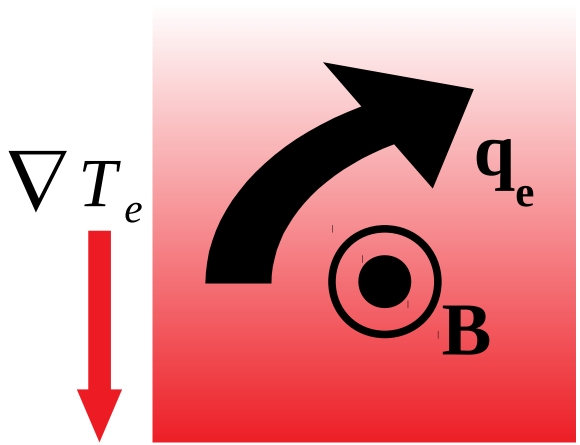
Magnetic fields & nonlocal Transport

- Magnetic fields modify degree of nonlocality
- Magnetic field evolution non-local



Magnetic fields & nonlocal Transport

- Magnetic fields modify degree of nonlocality
- Magnetic field evolution non-local
- Need non-local models which self-consistently include B-field



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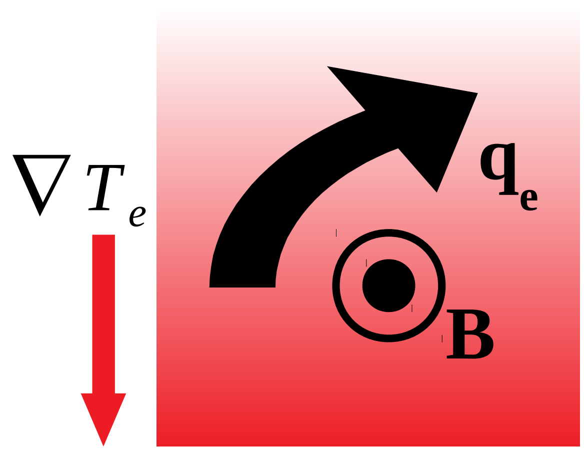

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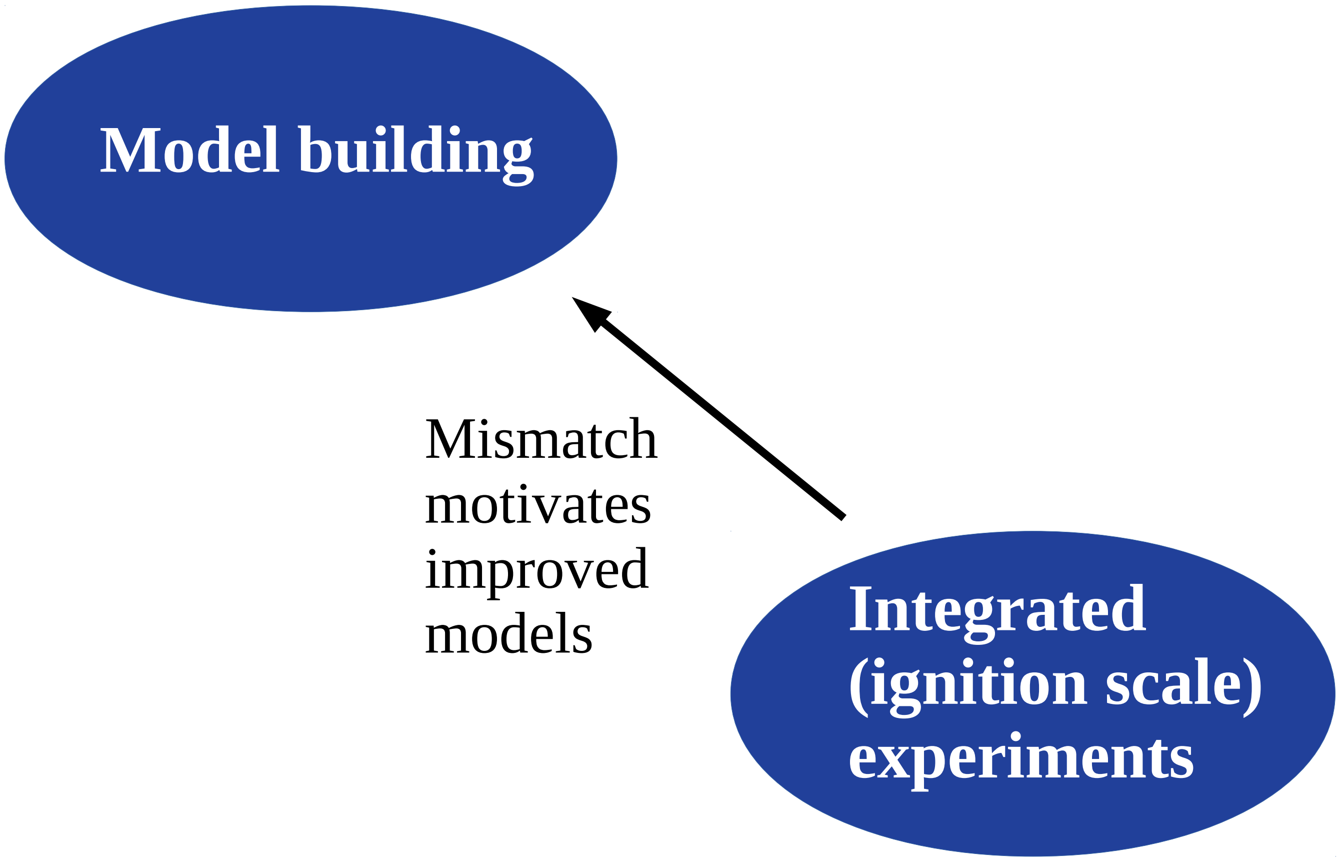
An idealised view….



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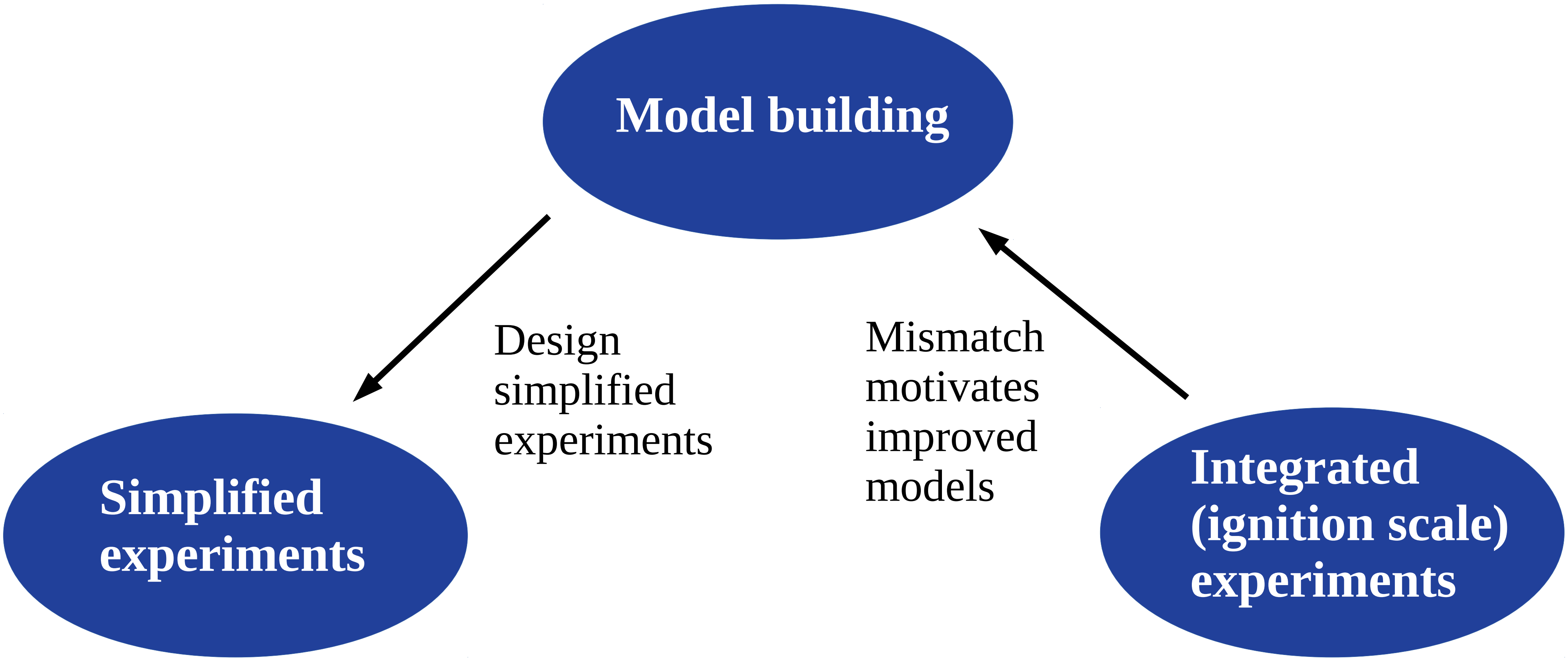

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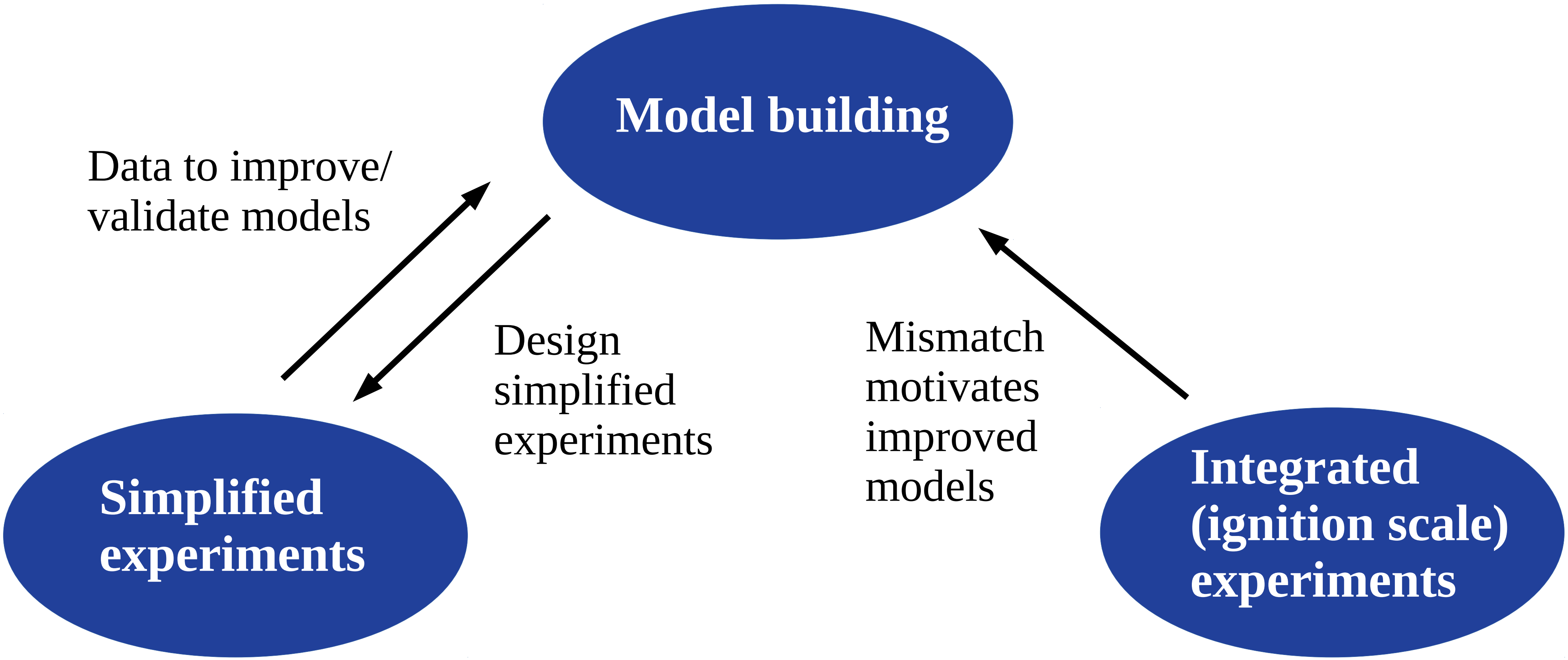

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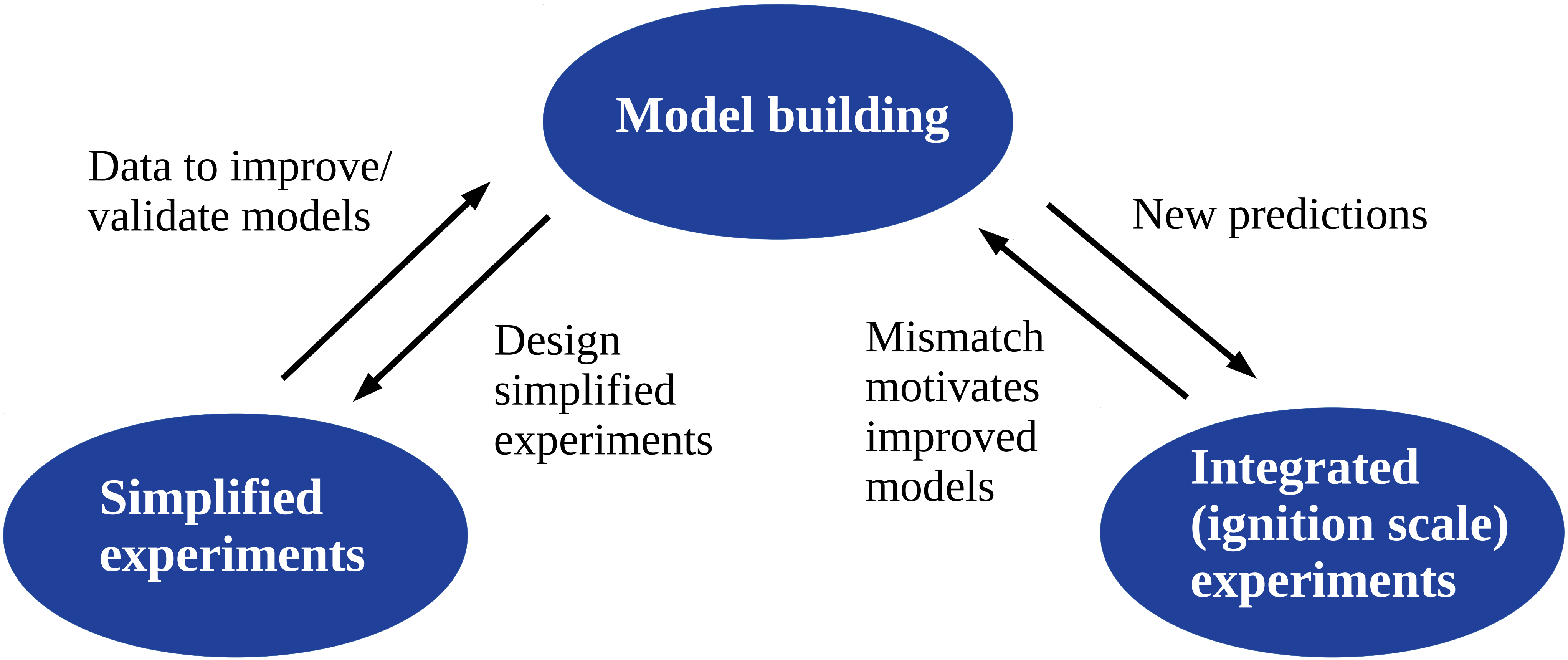

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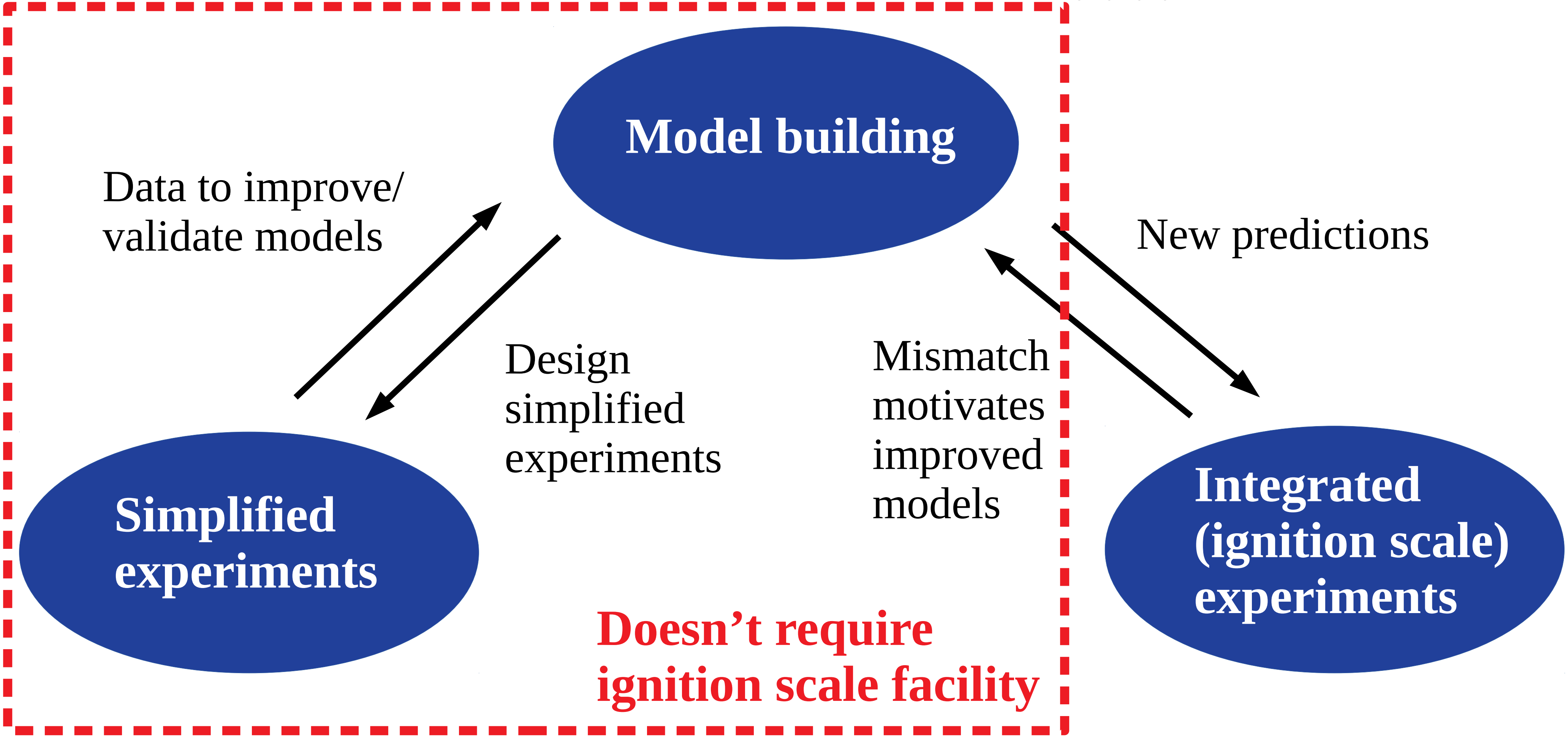
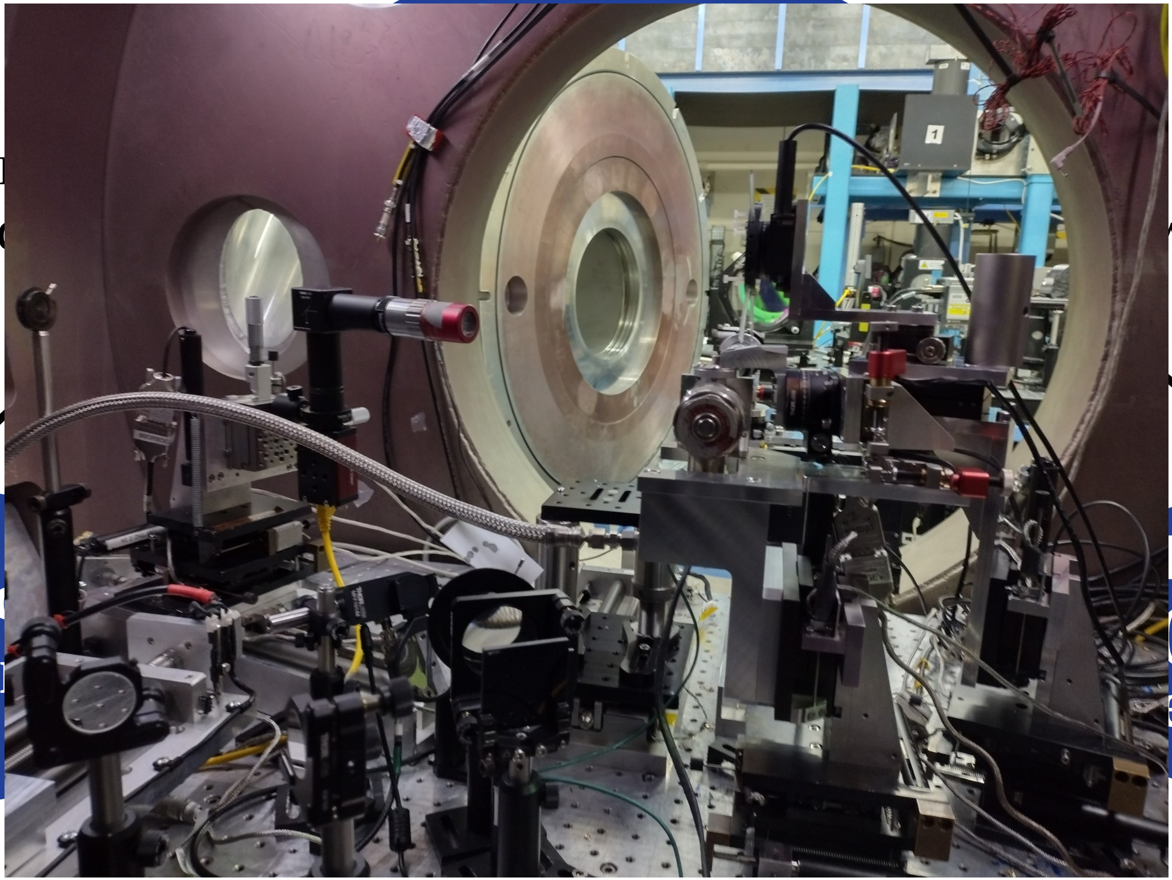


An idealised view….

Data to impr
validate moc

v predictions



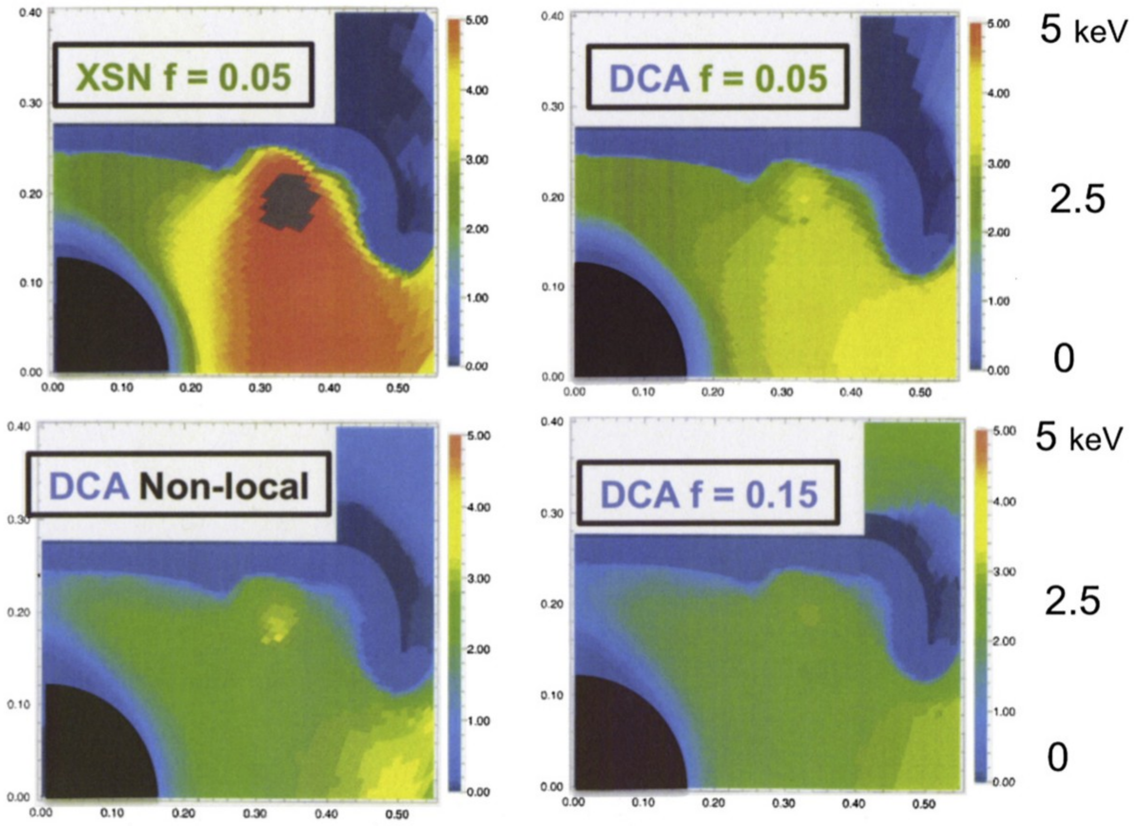
**Simplifie
experime**

**Integrated
(ignition scale)
experiments**

What can you do if you dont have an ignition-scale facility?

- Large-scale ICF experiments inherently multi-scale – necessitates simple models for kinetic processes
- Small-scale experiments can stress-test these models (e.g. atomic kinetics, plasma kinetics, LPI, **transport**, WDM……)

Nonlocal transport experiment



M.D. Rosen et al., HEDP, 7, 180 (2011)

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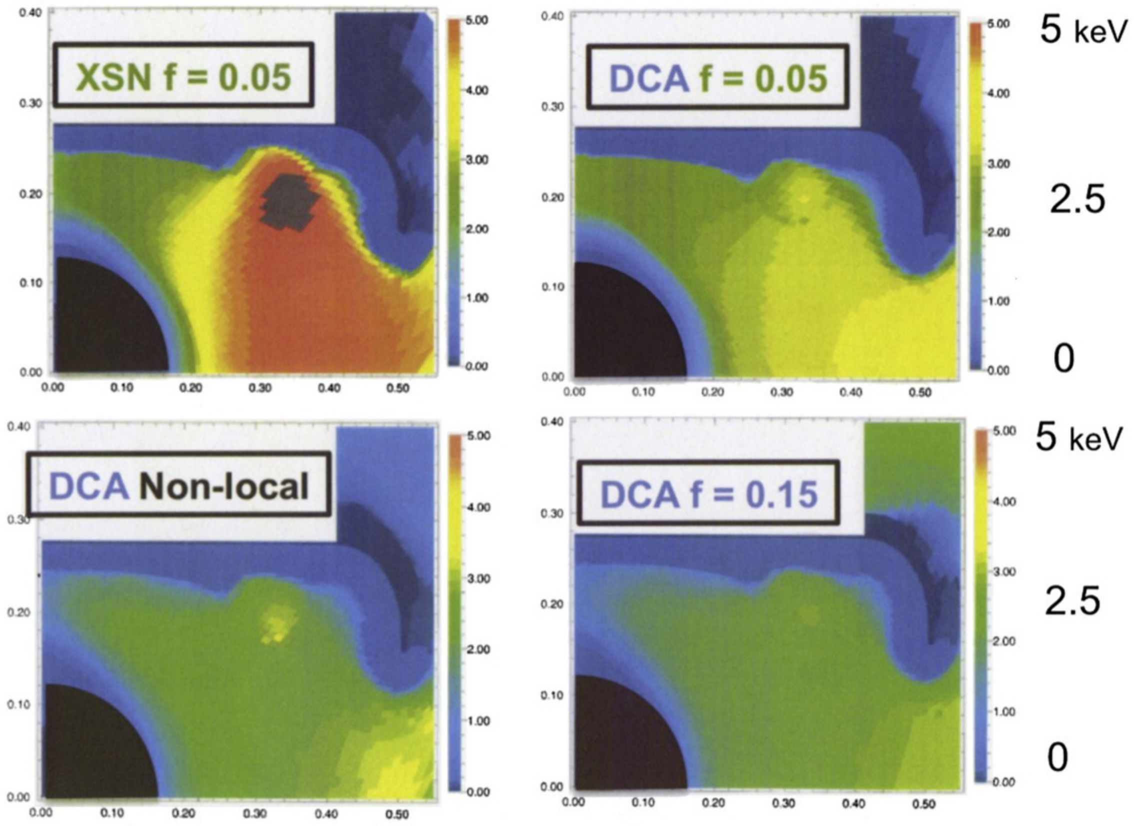

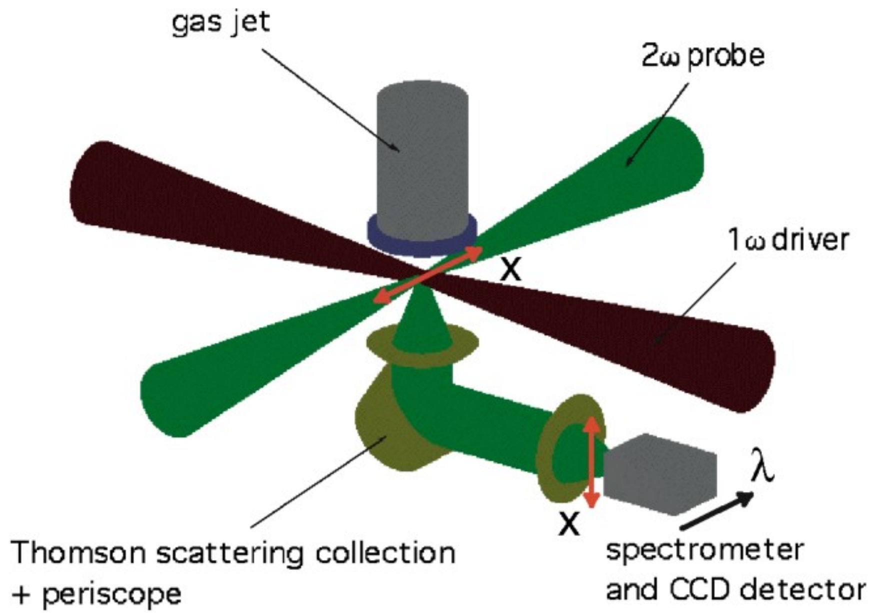

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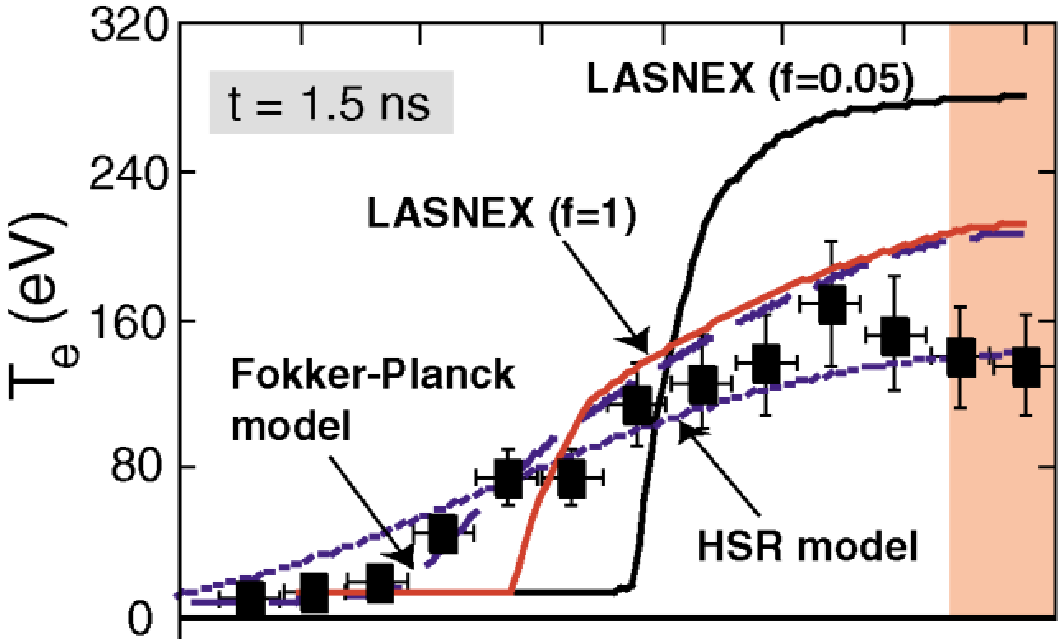

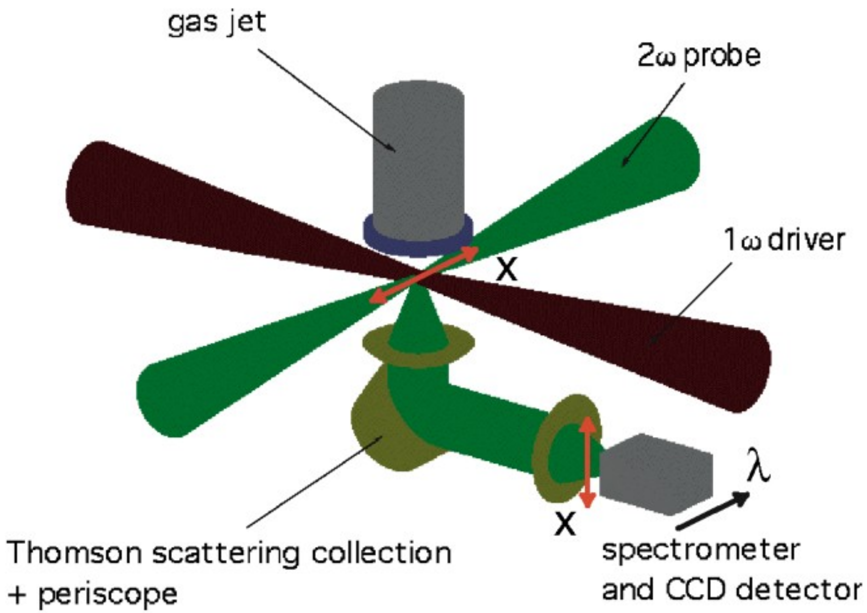

G. Gregori et al., PRL, 92, 205006 (2004)

Nonlocal transport model

'Classic' SNB

$$\left[\frac{1}{\lambda_g} - \nabla \cdot \left(\frac{\lambda_g}{3} \nabla\right)\right] H_g = \nabla \cdot \boldsymbol{U_g}$$

$$\boldsymbol{q} = \boldsymbol{q_{LTE}} - \frac{m_e}{2} \int \frac{\lambda_g}{3} \nabla H_g \, dv$$

J. Brodrick et al, Phys. Plas., 24, 092309 (2017)

Nonlocal transport model

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Modified SNB

$$\left[\frac{1}{\lambda_{ee}^*} - \nabla\cdot\left(\frac{\lambda_{ei}^*}{3}\nabla\right)\right]H_g = \nabla\cdot\boldsymbol{U_g}$$

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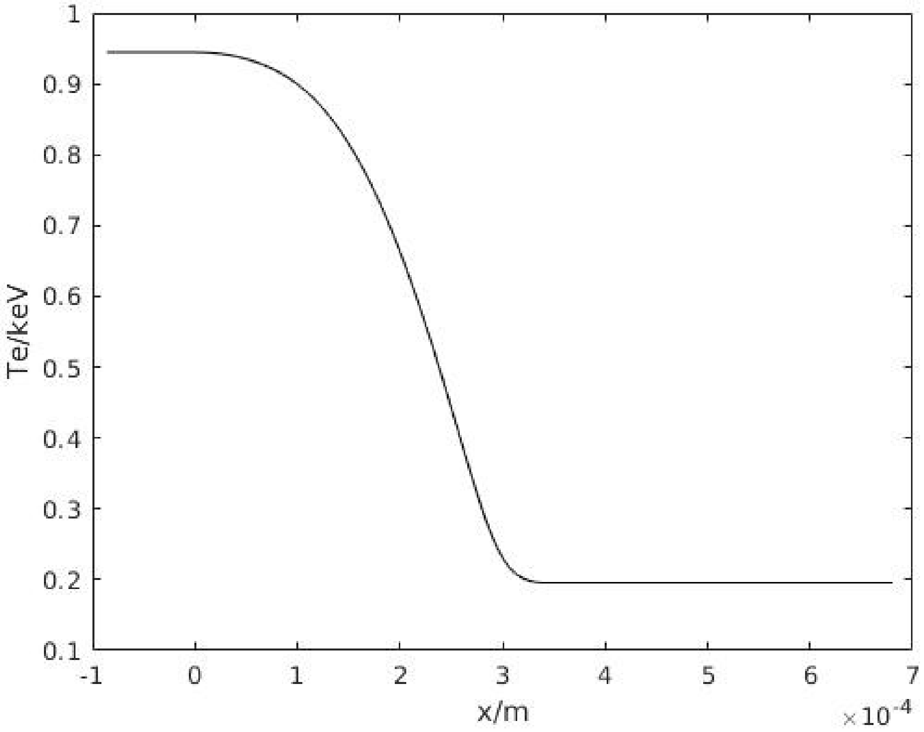

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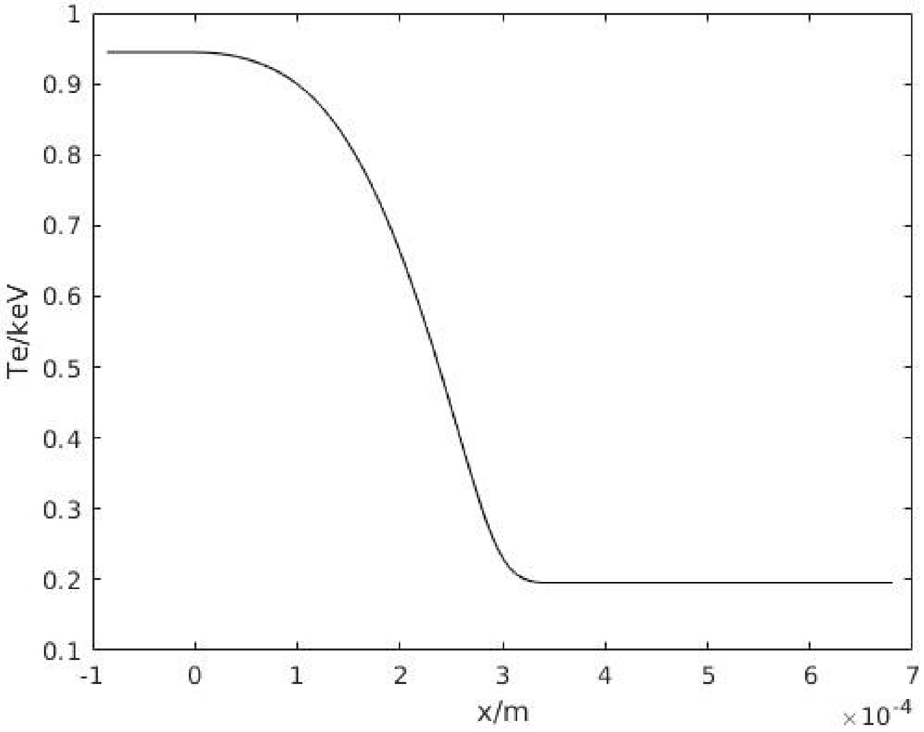

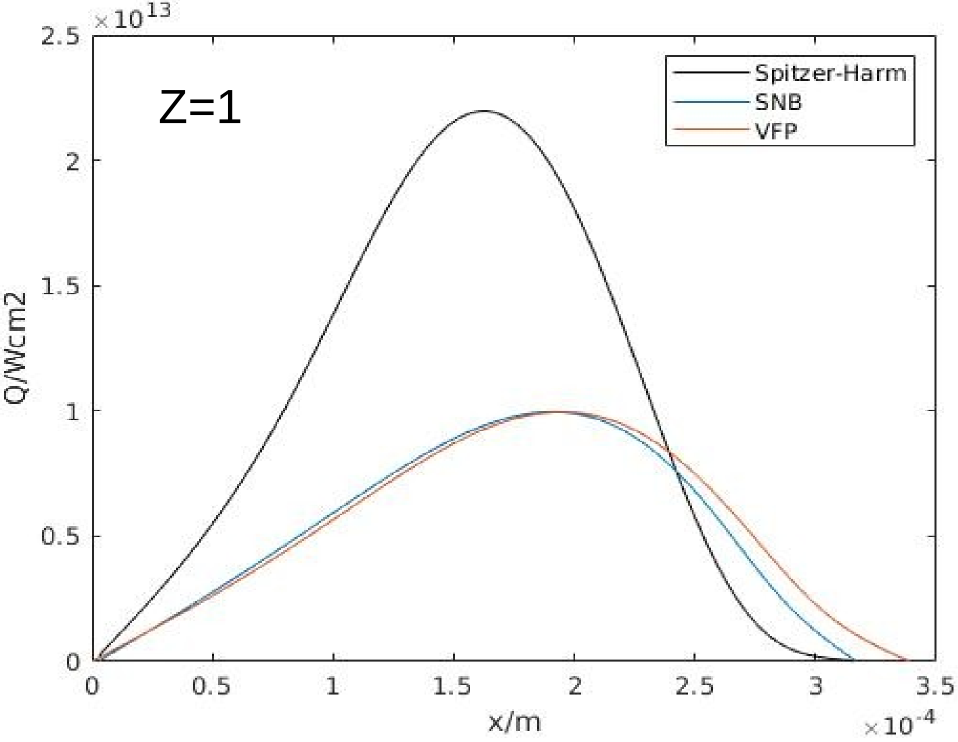

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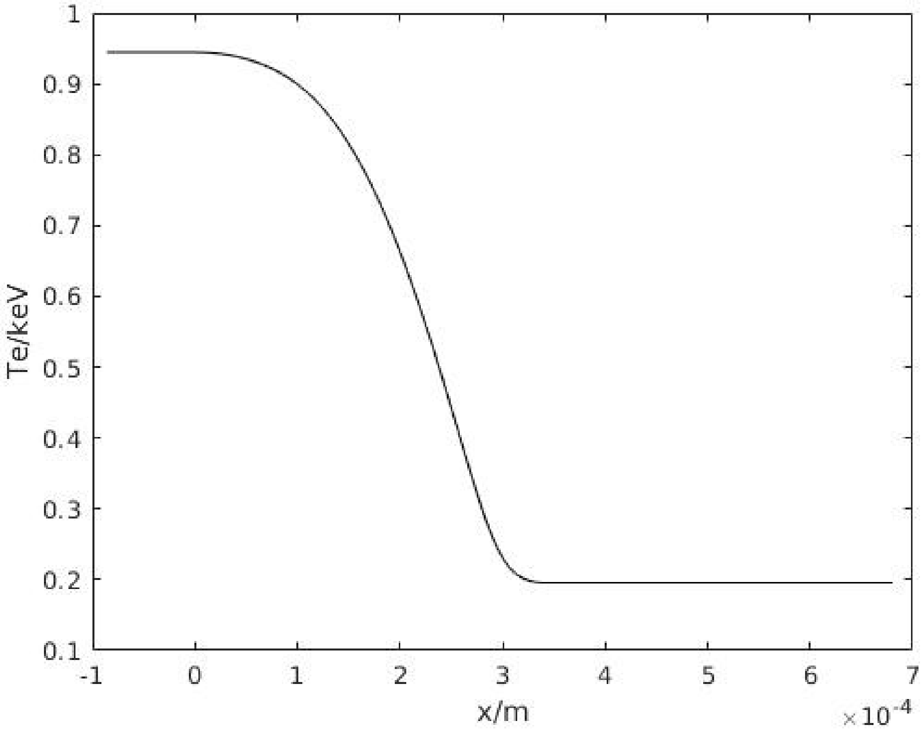

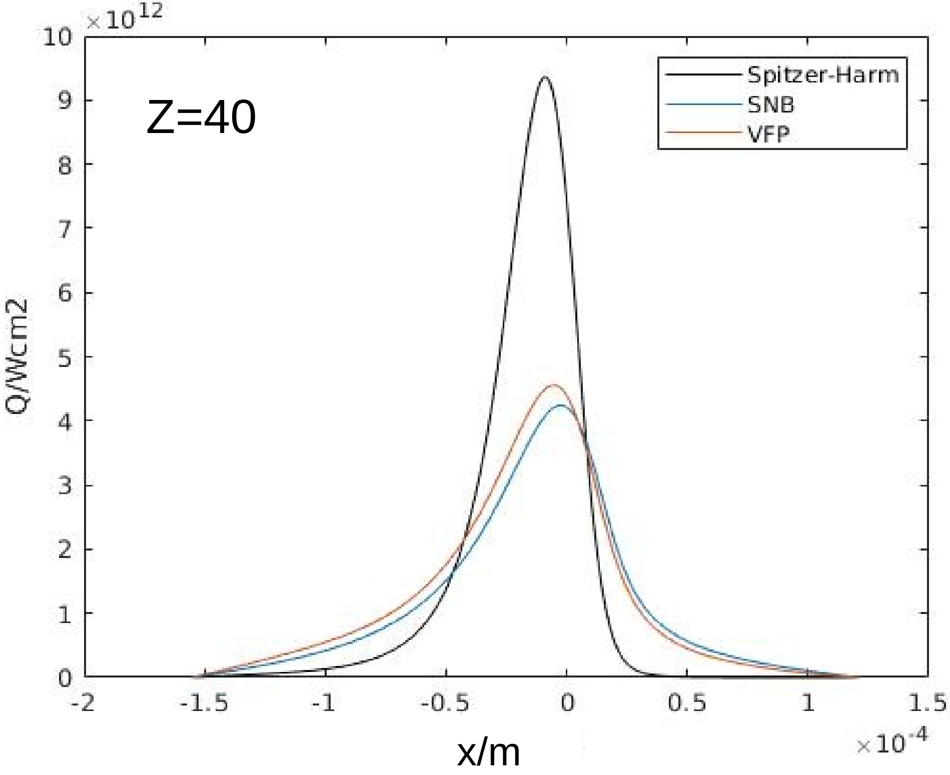

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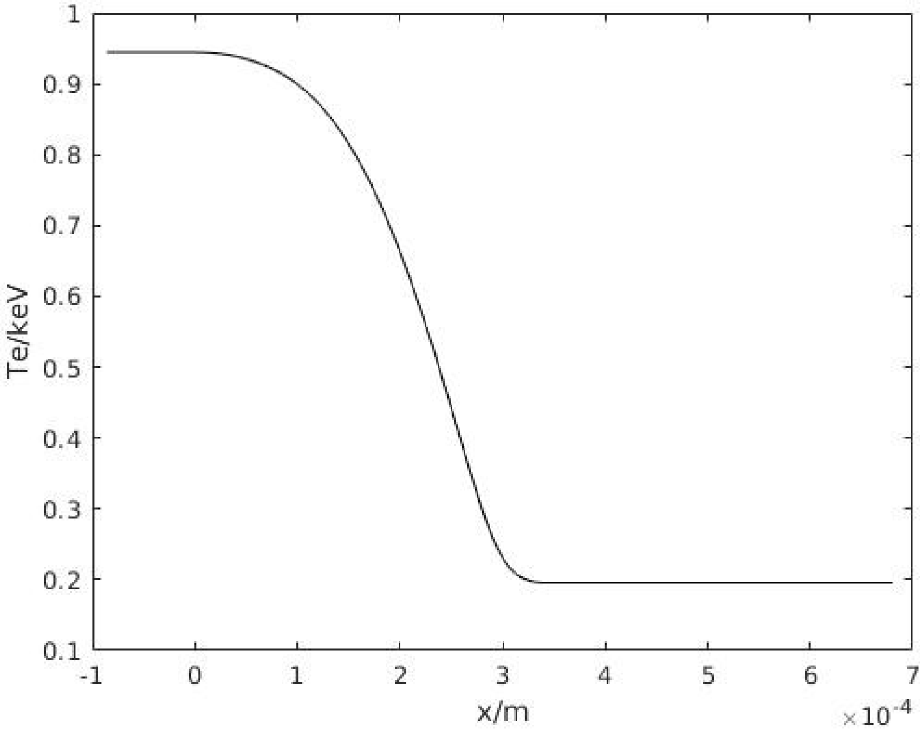

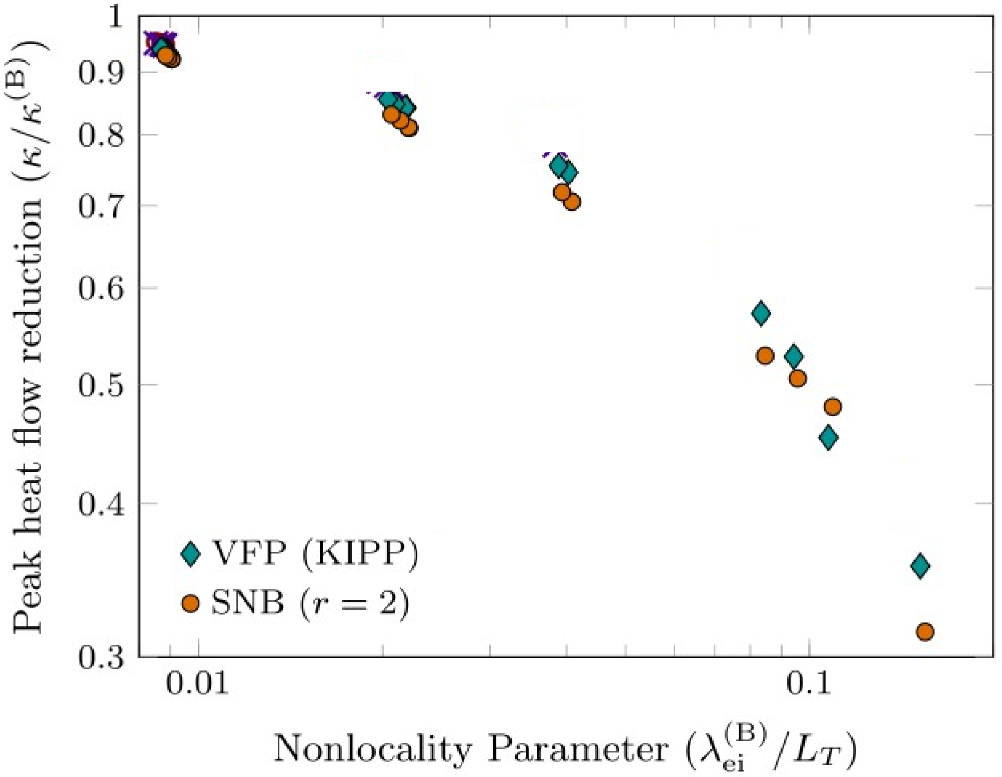

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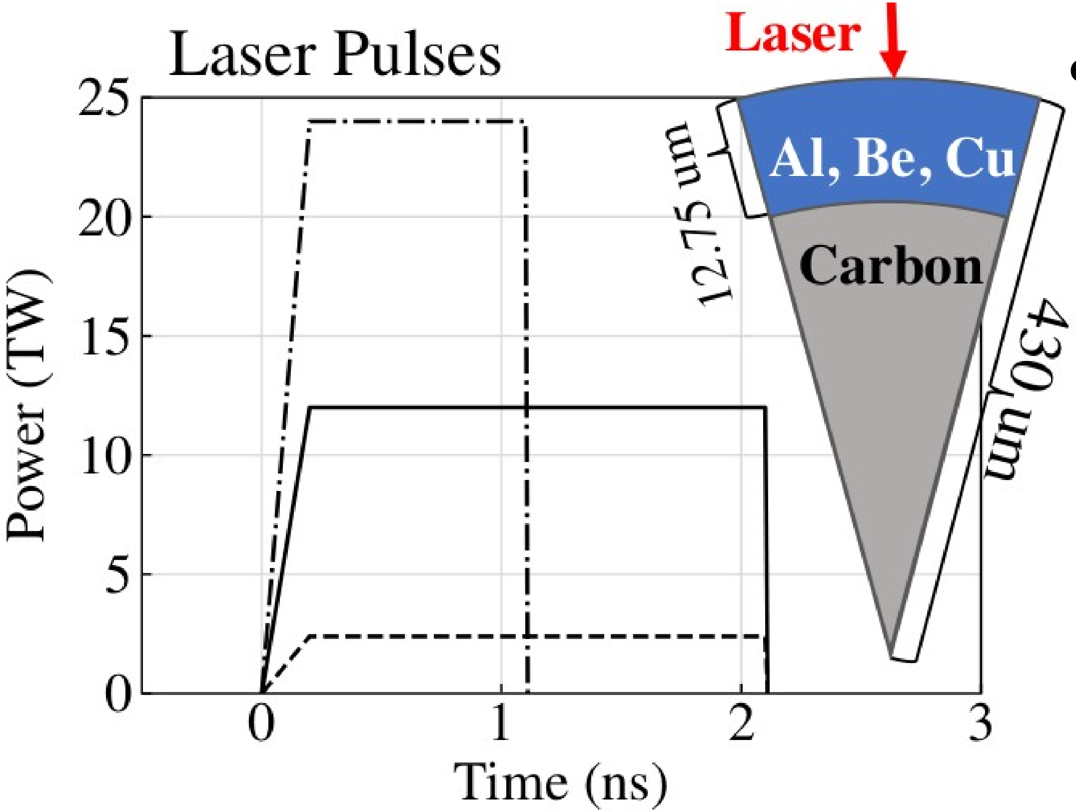
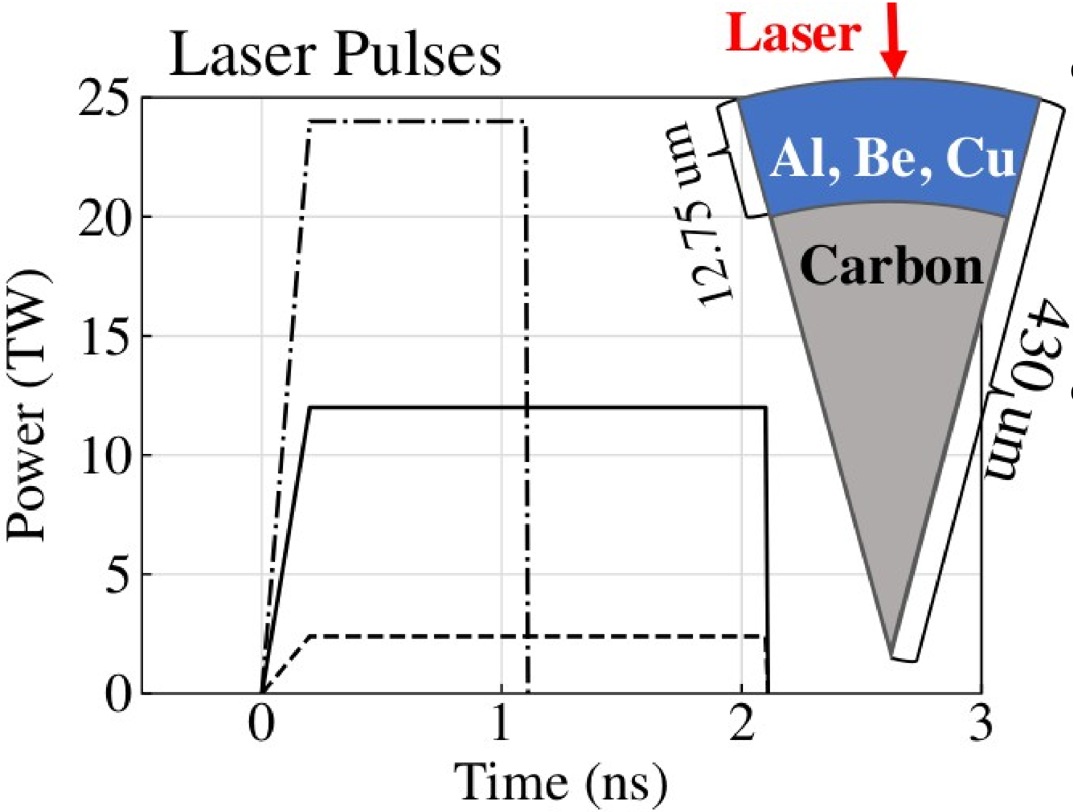


- 1D HYDRA mid-Z sphere Omega-like simulations

K. Ma et al, in press

Nonlocal transport model



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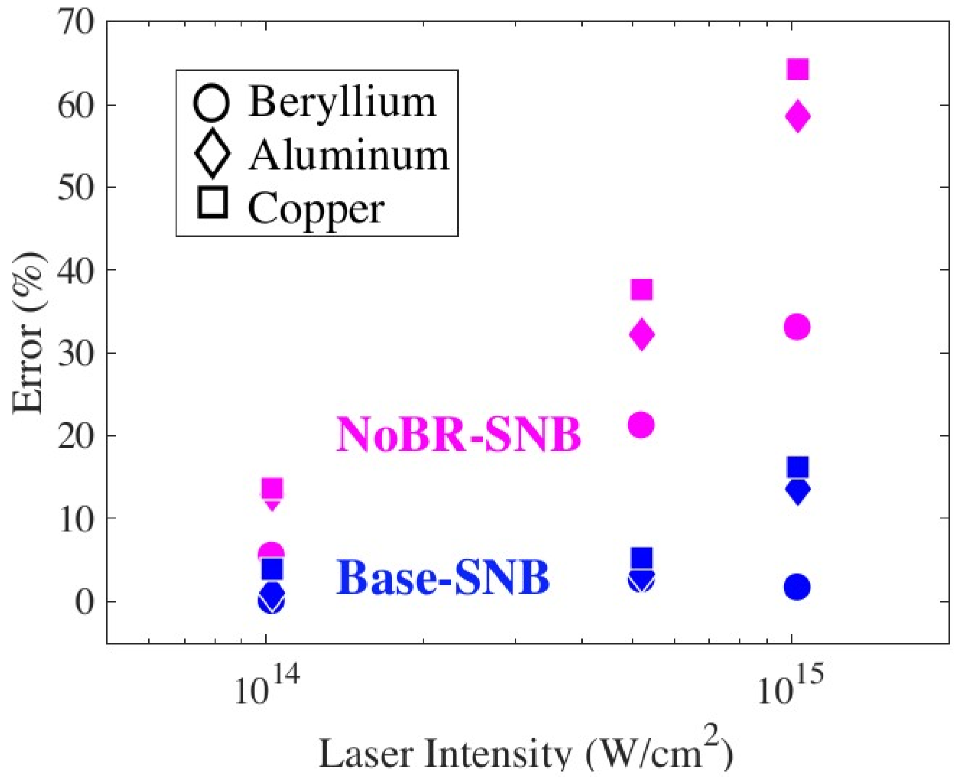
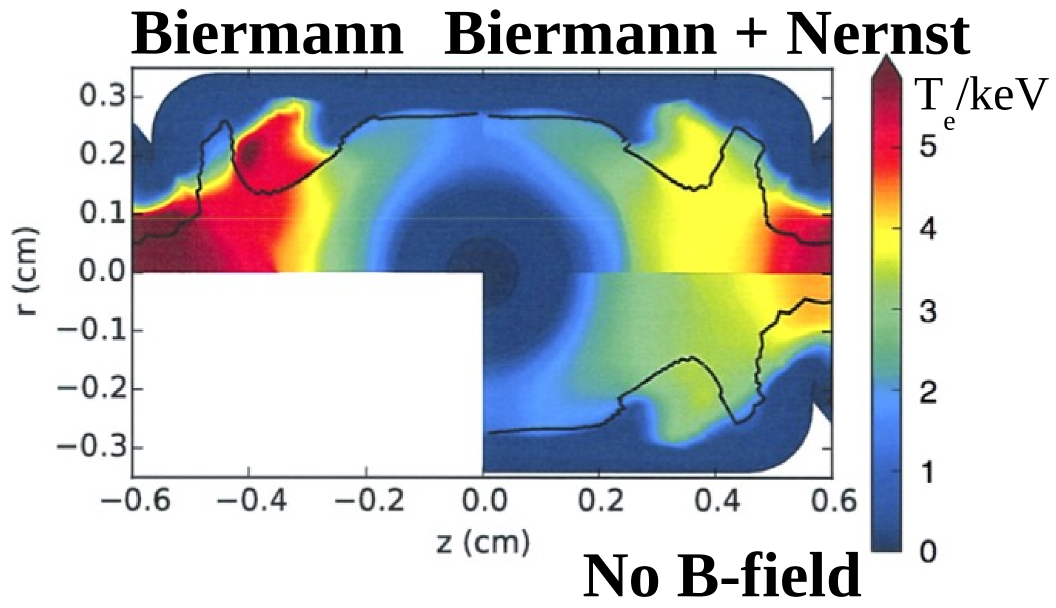


K. Ma et al, in press

- 1D HYDRA mid-Z sphere Omega-like simulations
- Modified SNB improvement on classic SNB
- Comparison to K2 – error in heat flux at 1ns

Magnetic fields & nonlocal transport



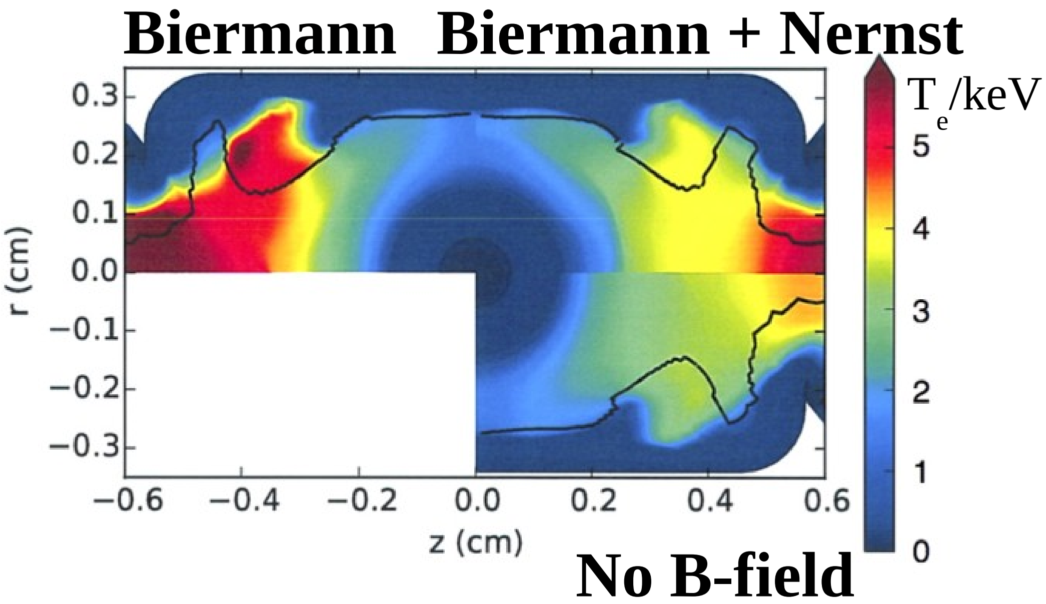
- HYDRA high-foot simulation (CH capsule 0.6mg/cc fill) t=13ns

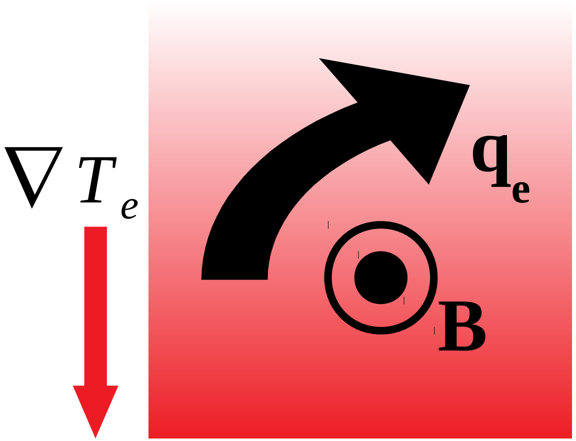
$$\frac{\partial \boldsymbol{B}}{\partial t} \approx -\frac{1}{en_e} \nabla n_e \times \nabla T_e - \nabla \cdot (\boldsymbol{v}_N B_z)$$

$$\boldsymbol{v}_N \propto \boldsymbol{q}_e$$

W.A. Farmer et al., Phys. Plasmas, 24, 052703 (2017)

Magnetic fields & nonlocal transport





- Magnetic field deflects heat flow
1. Restricts conduction
2. Righi-Leduc

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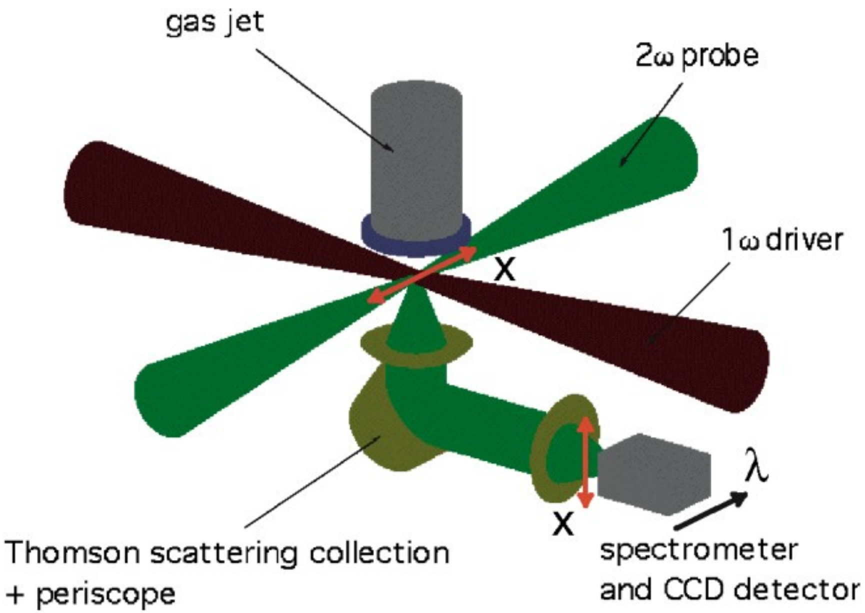
Nonlocal transport experiment



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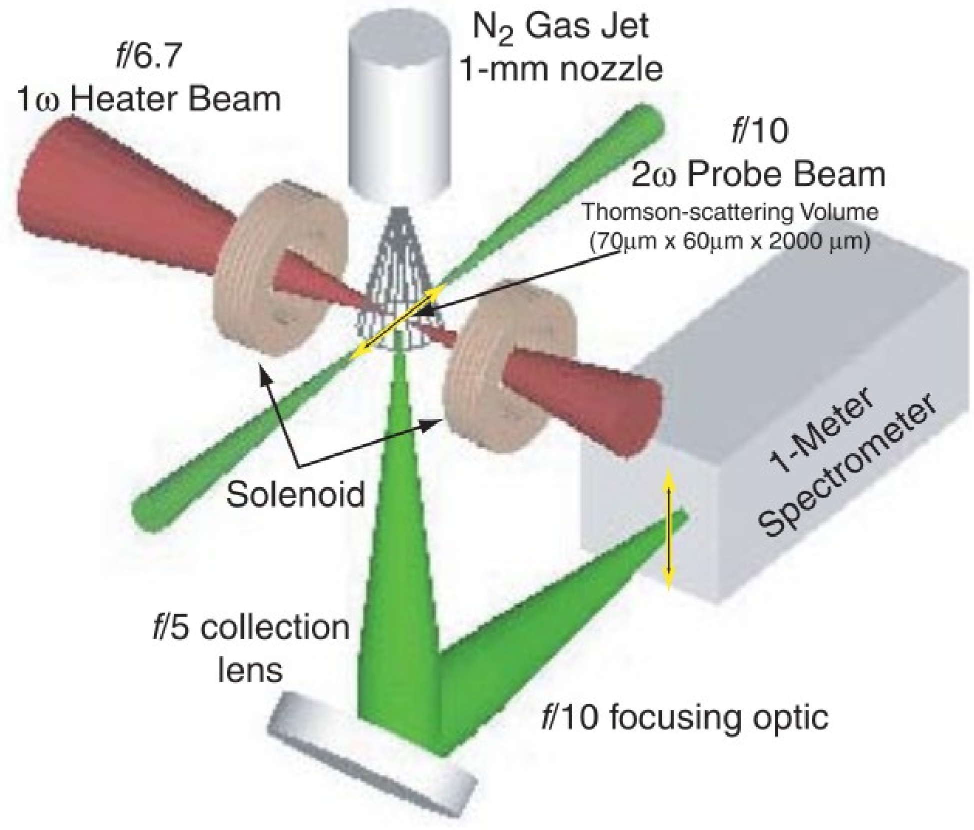

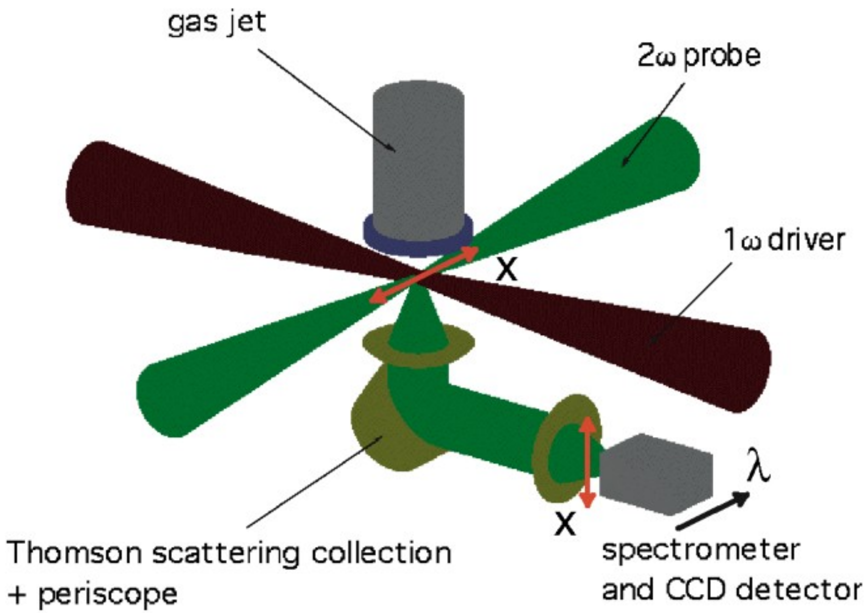

D.H. Froula et al., PRL, 98, 135001 (2007)

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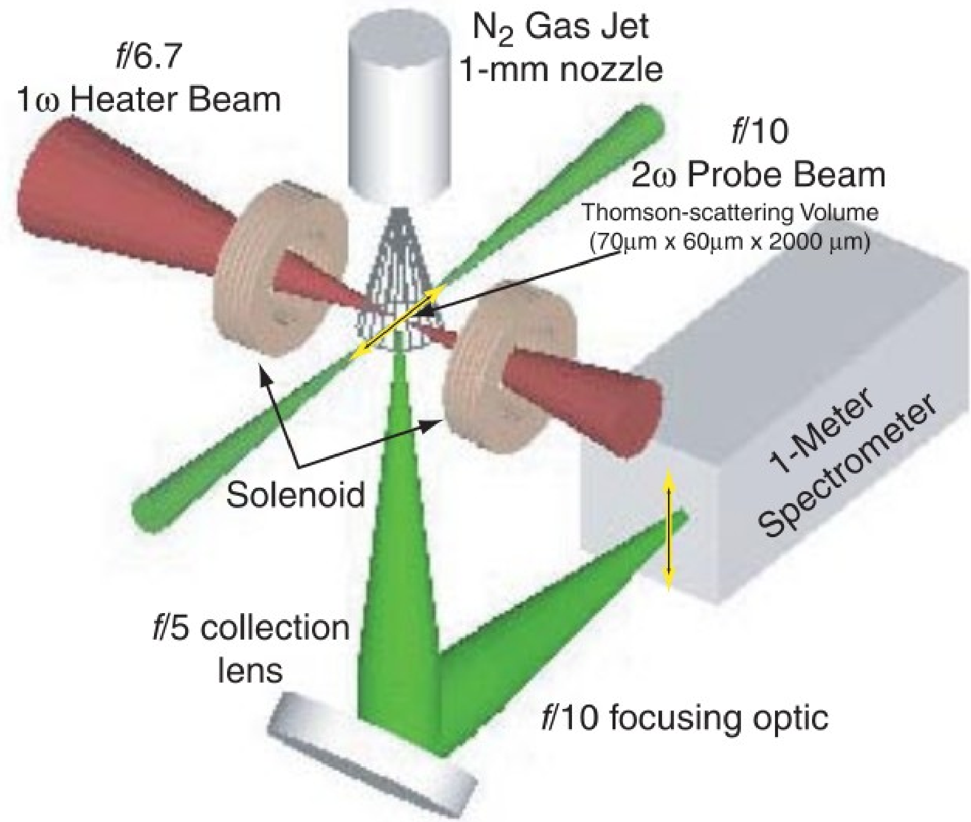

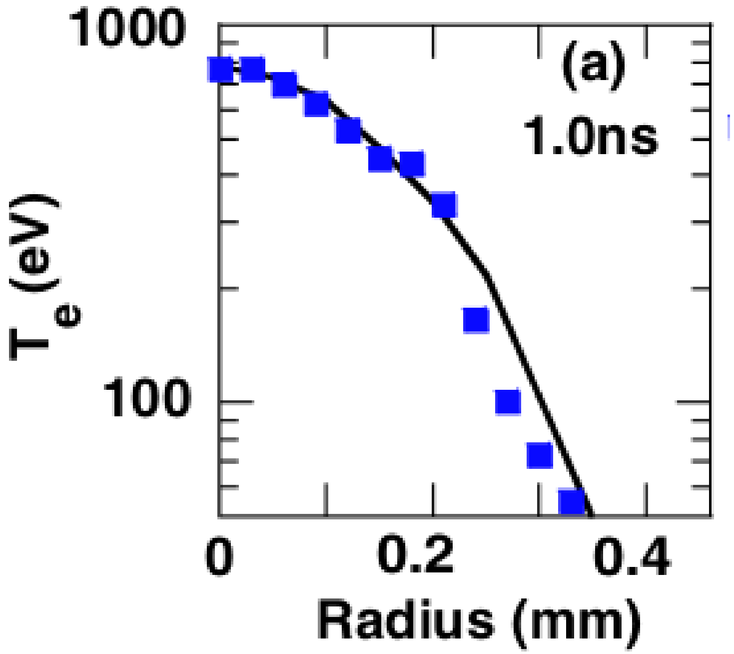

Blue – experimental data

- Black – LASNEX simulations

D.H. Froula et al., PRL, 98, 135001 (2007)

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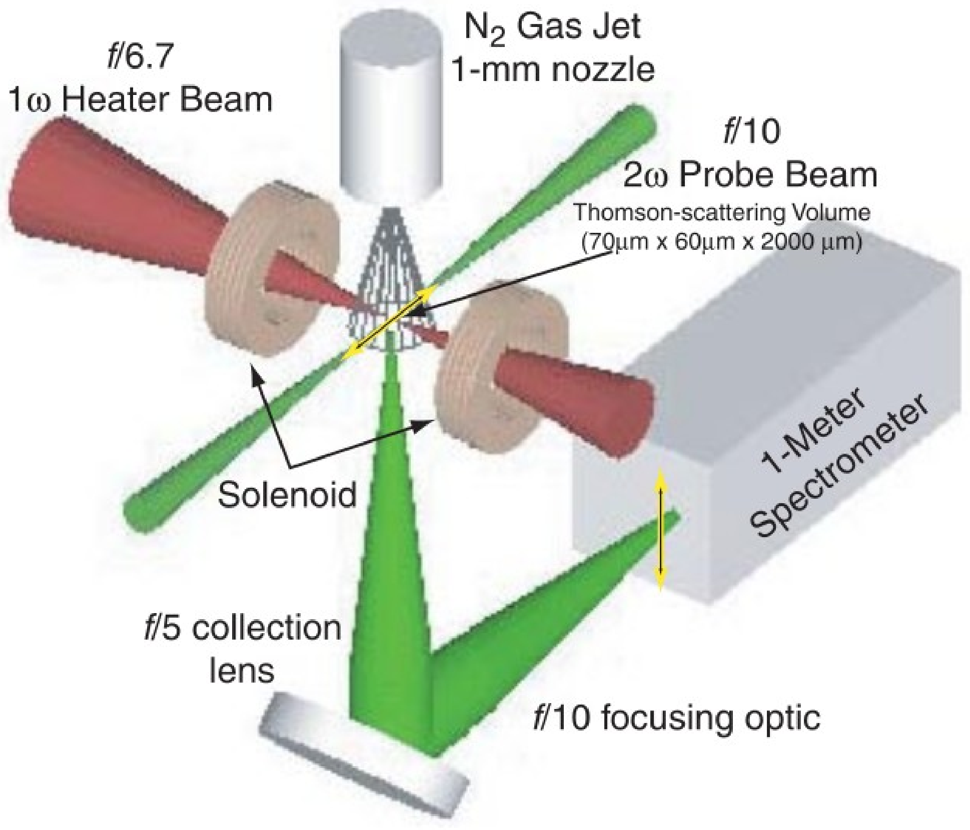
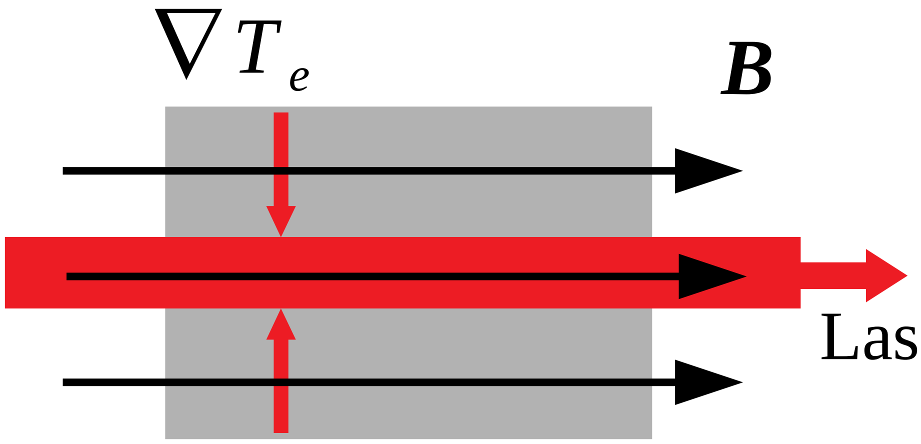


IMPACT VFP code
- f0+f1 code
- 3D (2 spatial, 1 velocity)
- B-fields



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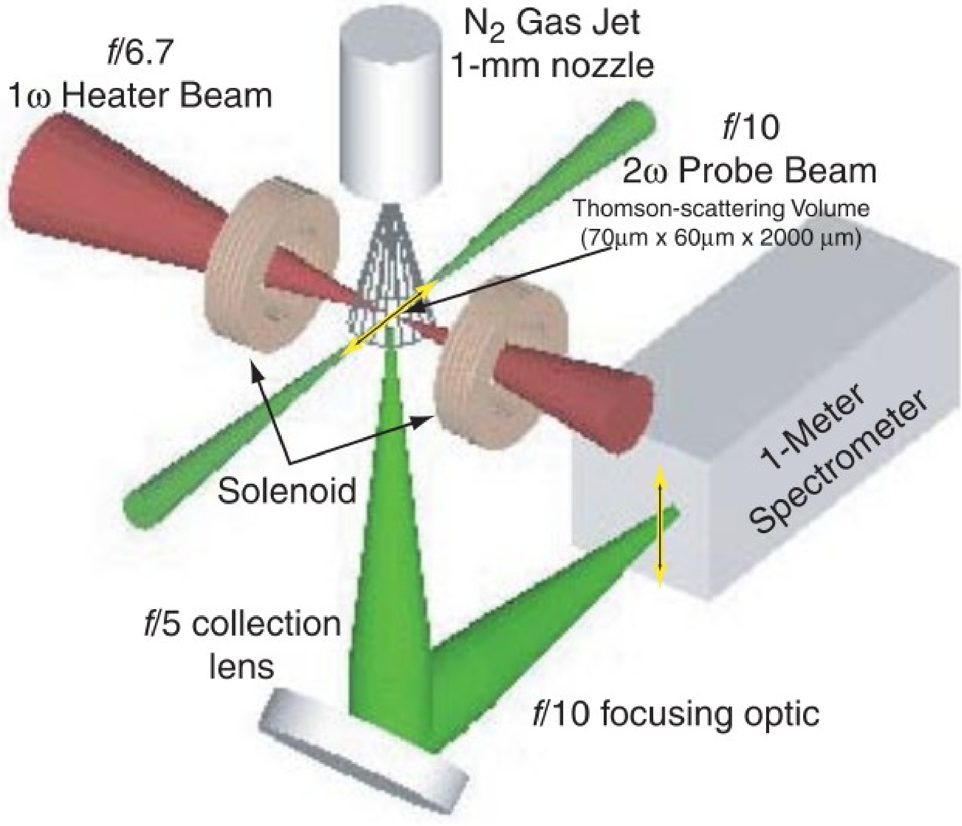

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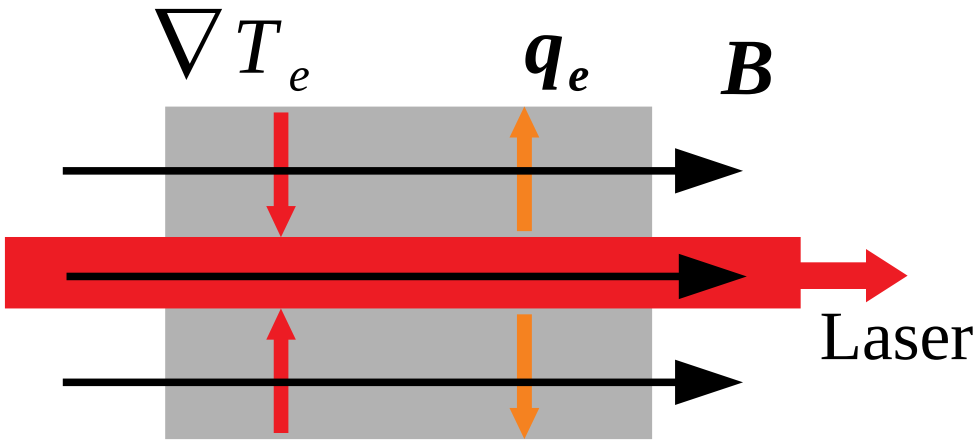

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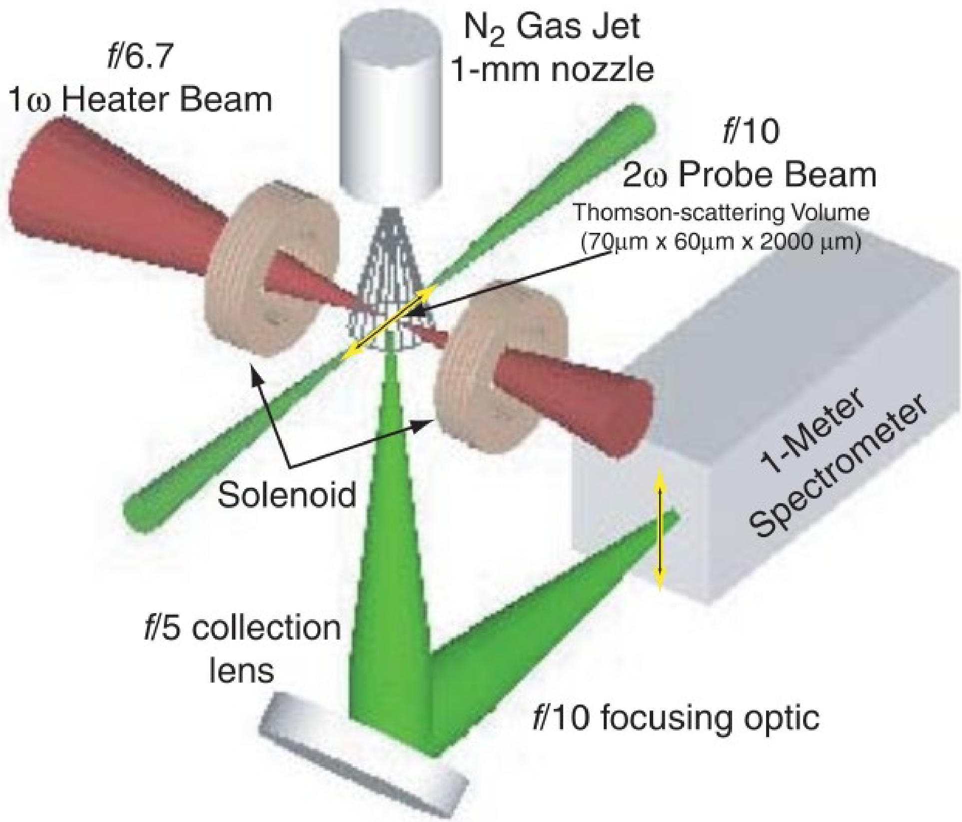

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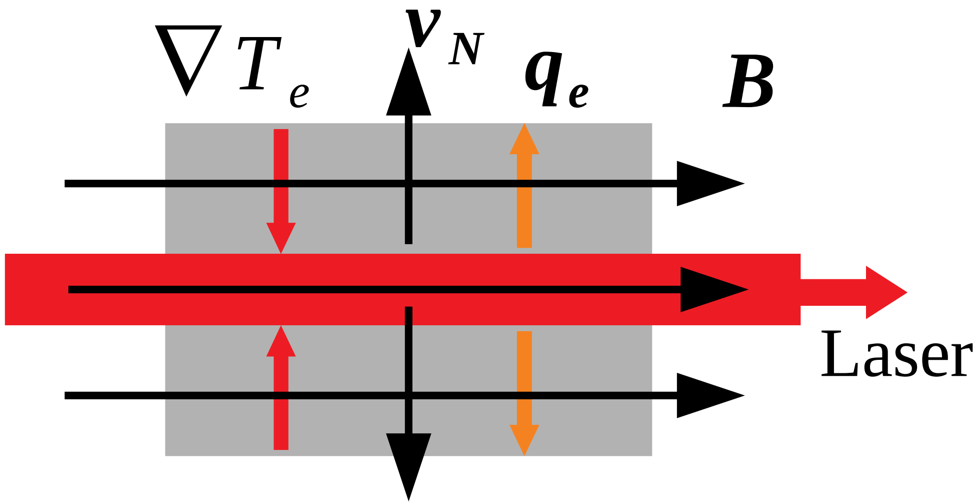

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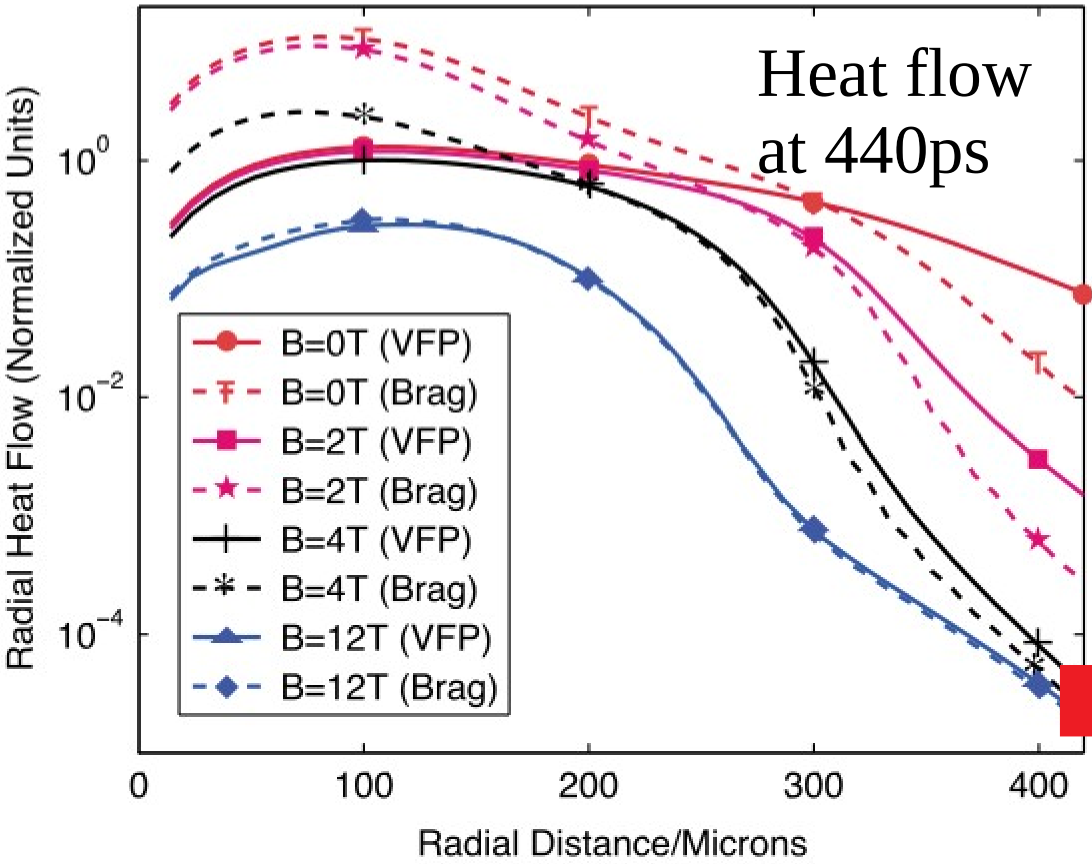

C.P. Ridgers et al., PRL, 100, 075003 (2008)

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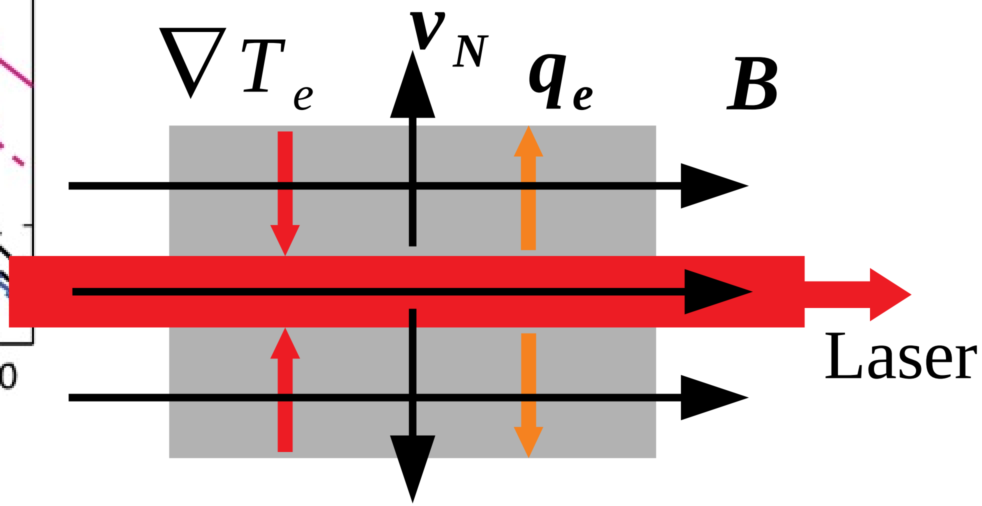

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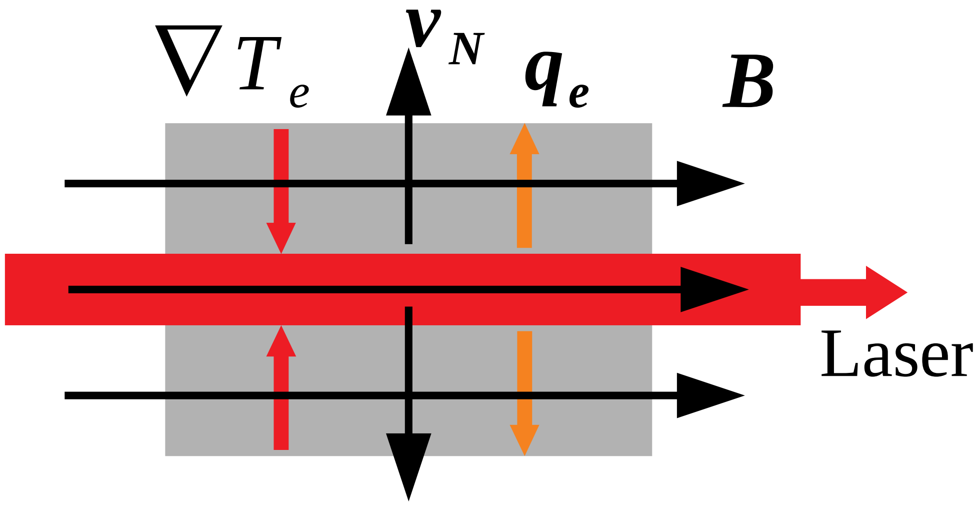

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- In simplified geometry with $\boldsymbol{B}=(0,0,B_z)$

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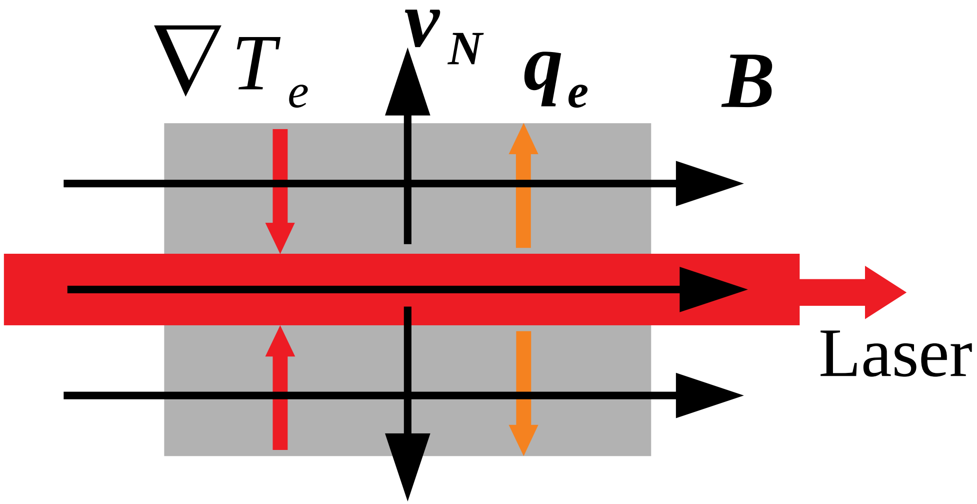

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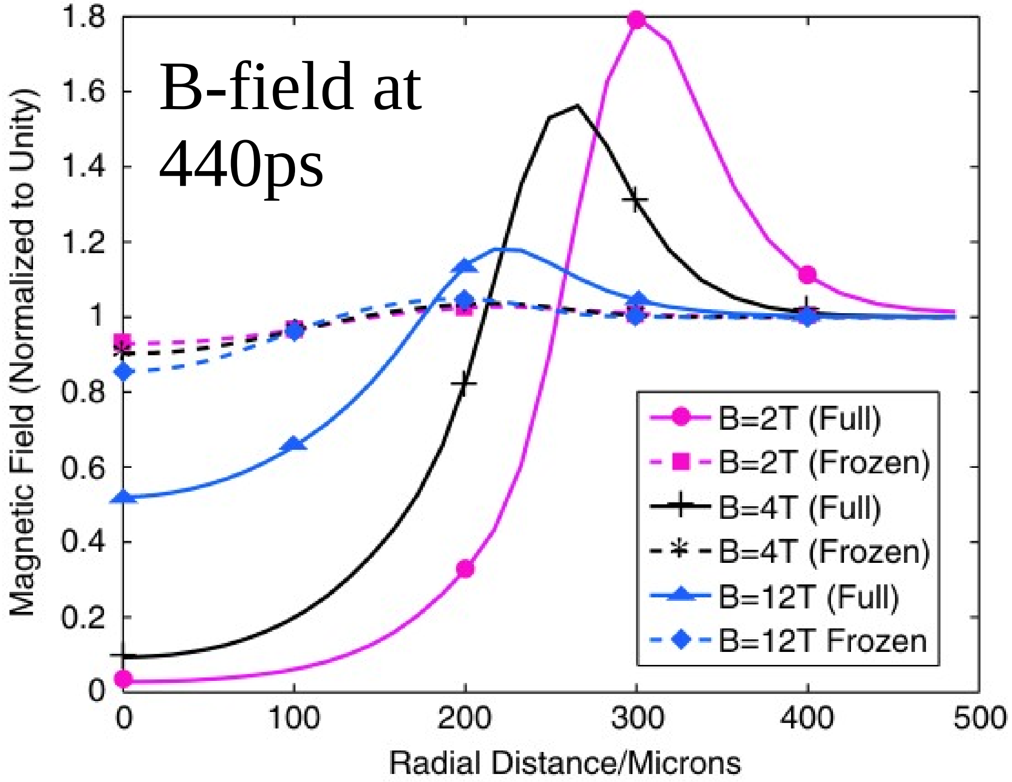

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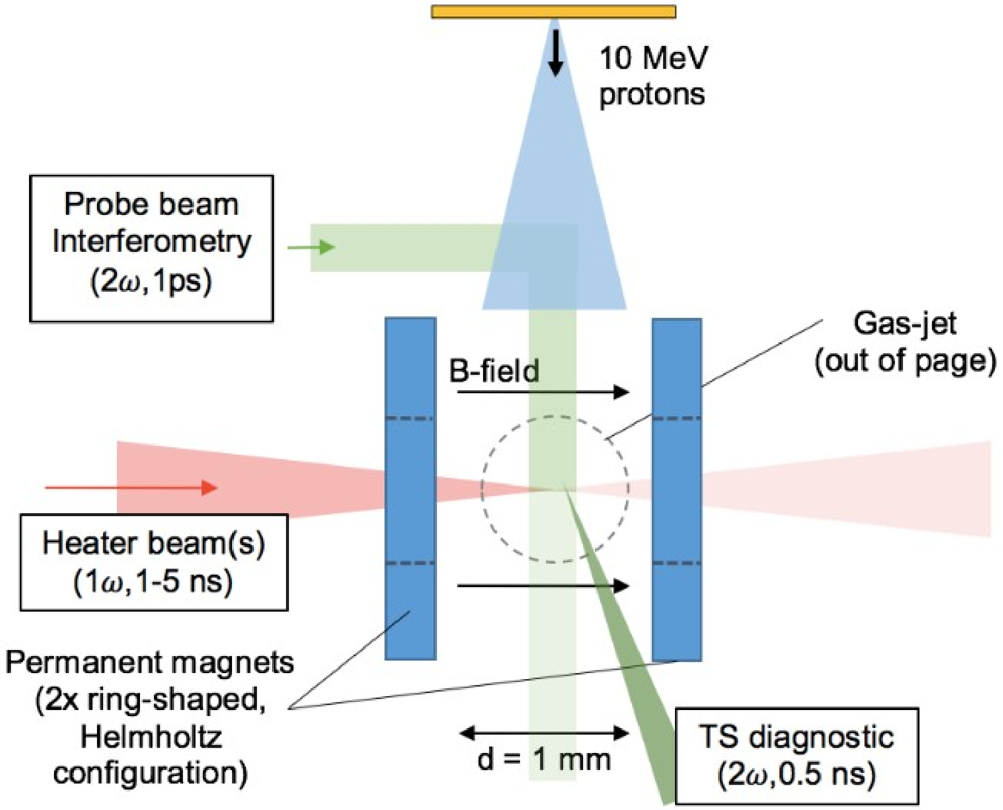
Observing Nernst effect

- Gas-jet target → easily change collisionality (n_e ~5×10^{18}-5×10^{19}cm^{-3})



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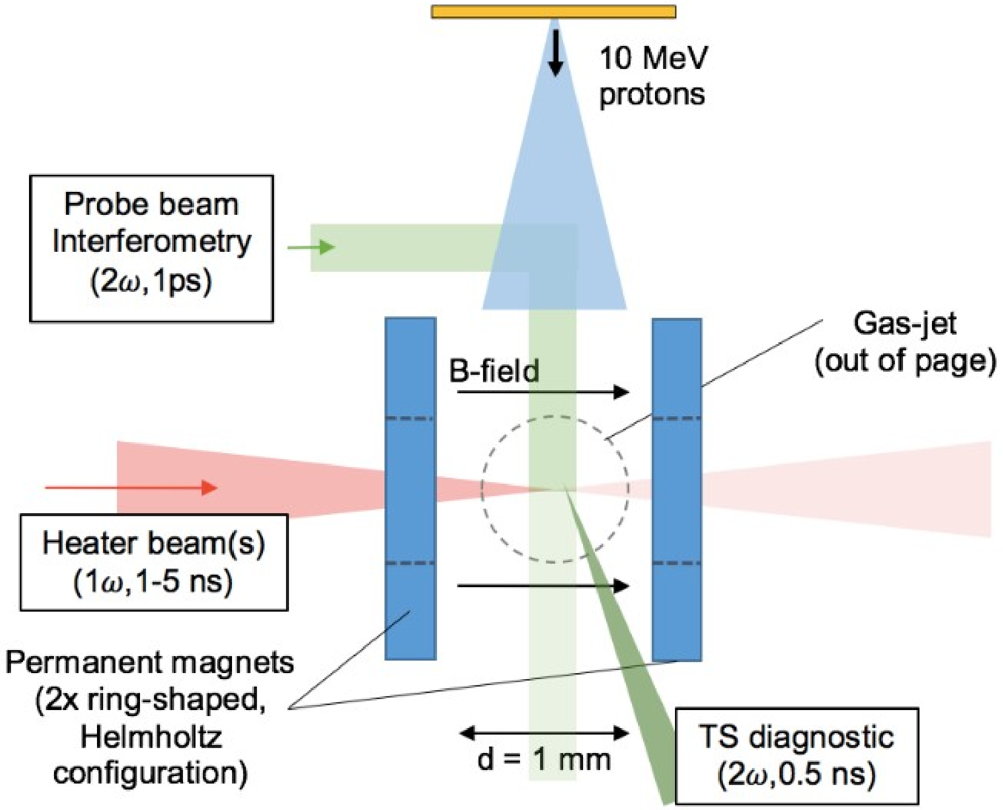

Observing Nernst effect

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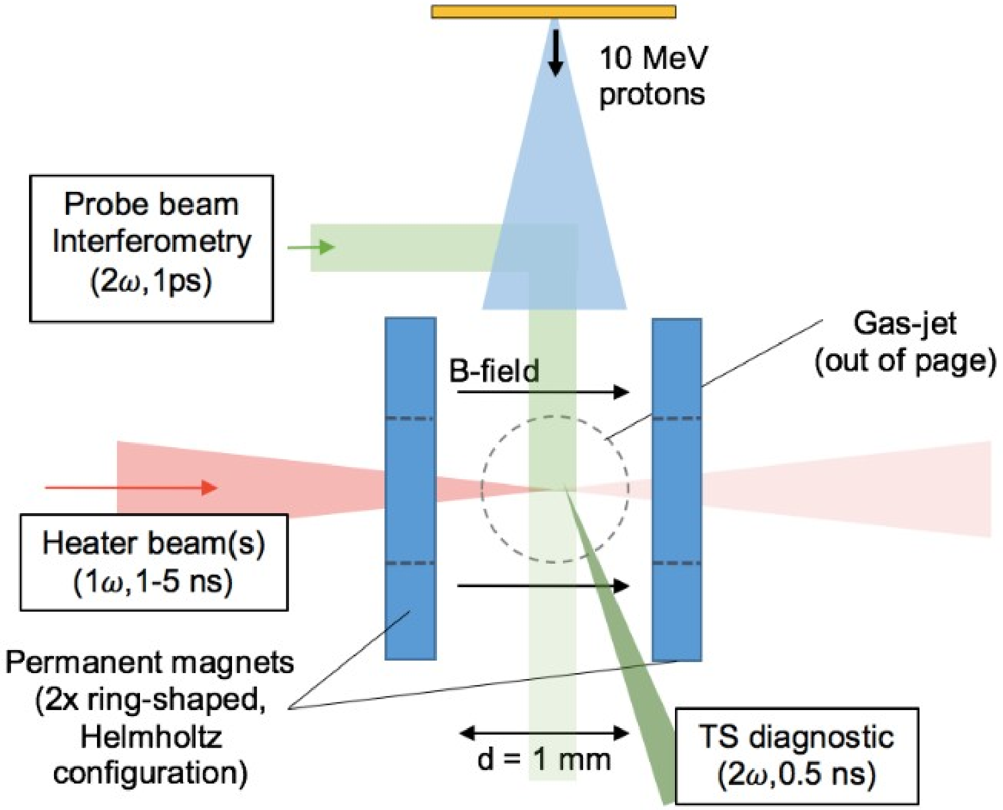
- Impose a magnetic field (~3T)
- Diagnose B-field using proton radiography



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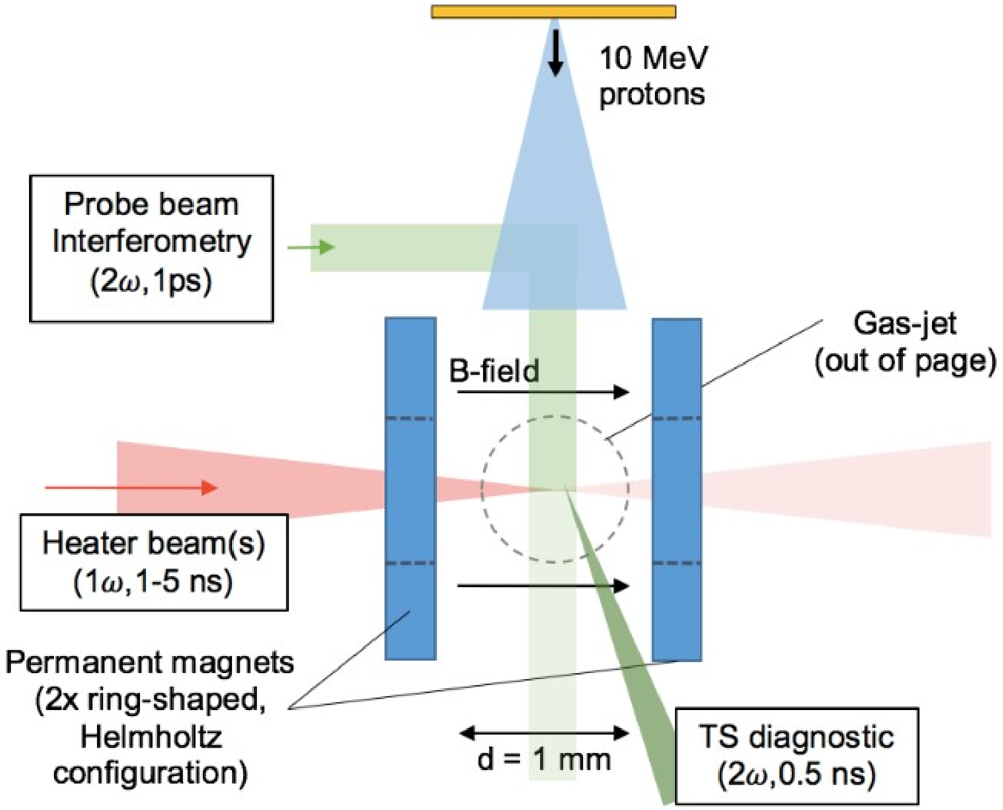
$$\frac{\partial B_z}{\partial t} \approx -\nabla \cdot (\boldsymbol{v}_N B_z) \qquad \boldsymbol{v}_N \propto \boldsymbol{q}_e$$



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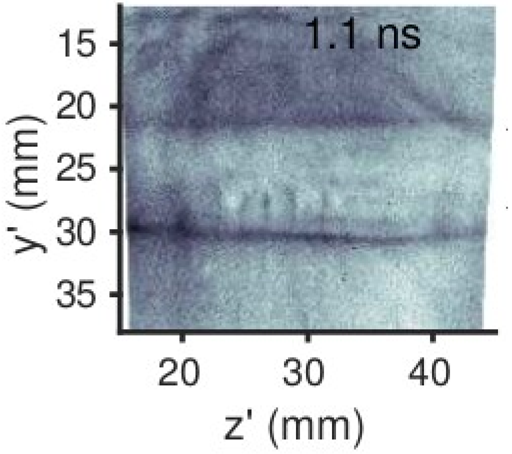

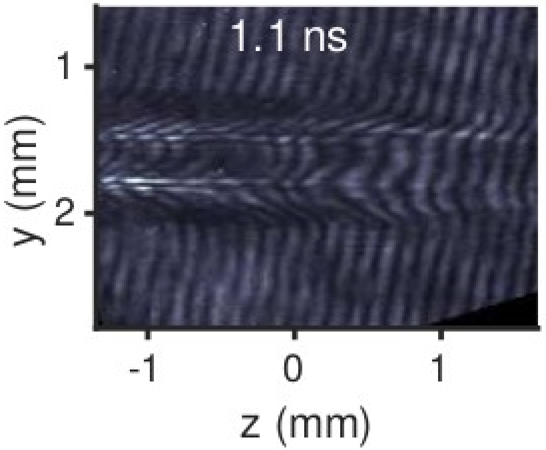

Proton radiograph and inteferogram at 1.1ns (10^{19}cm^{-3})

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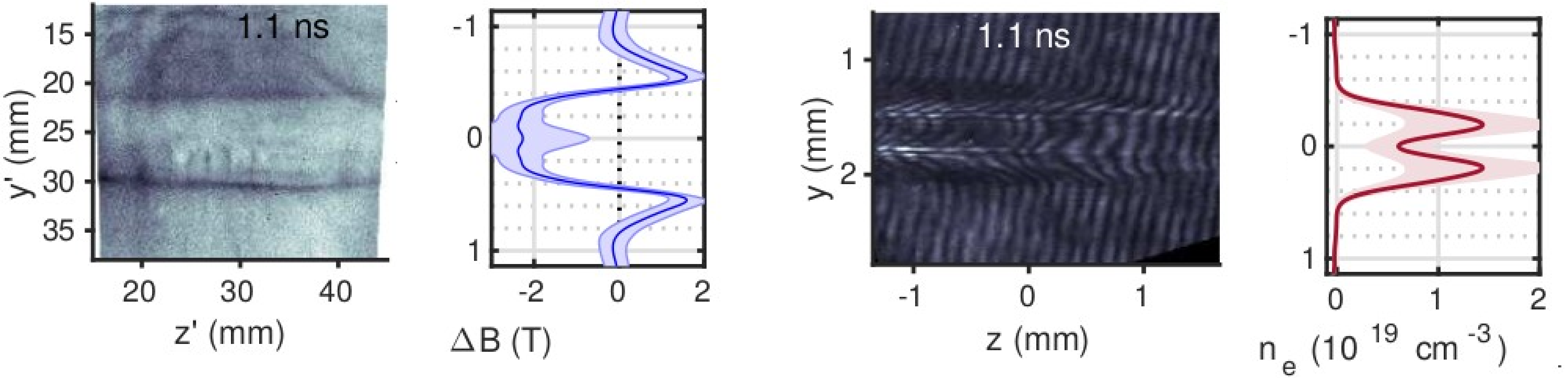

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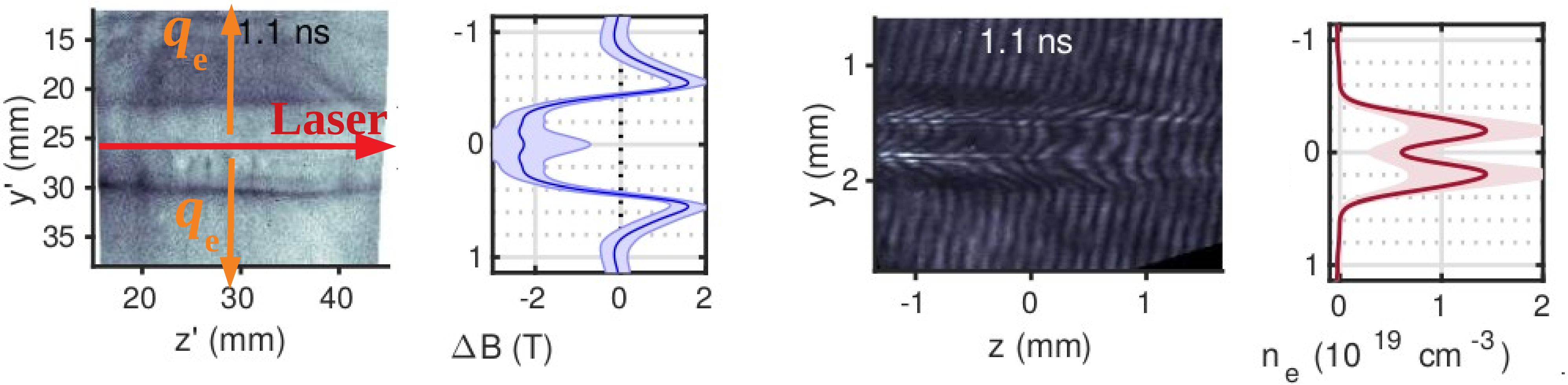

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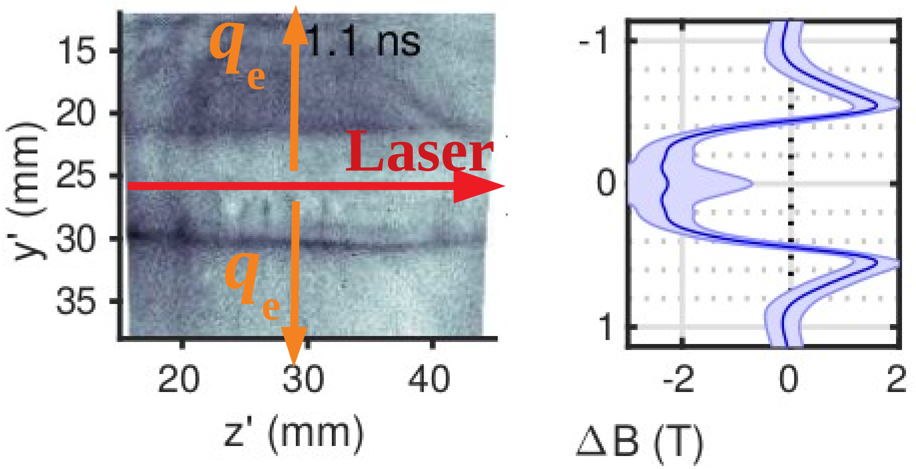

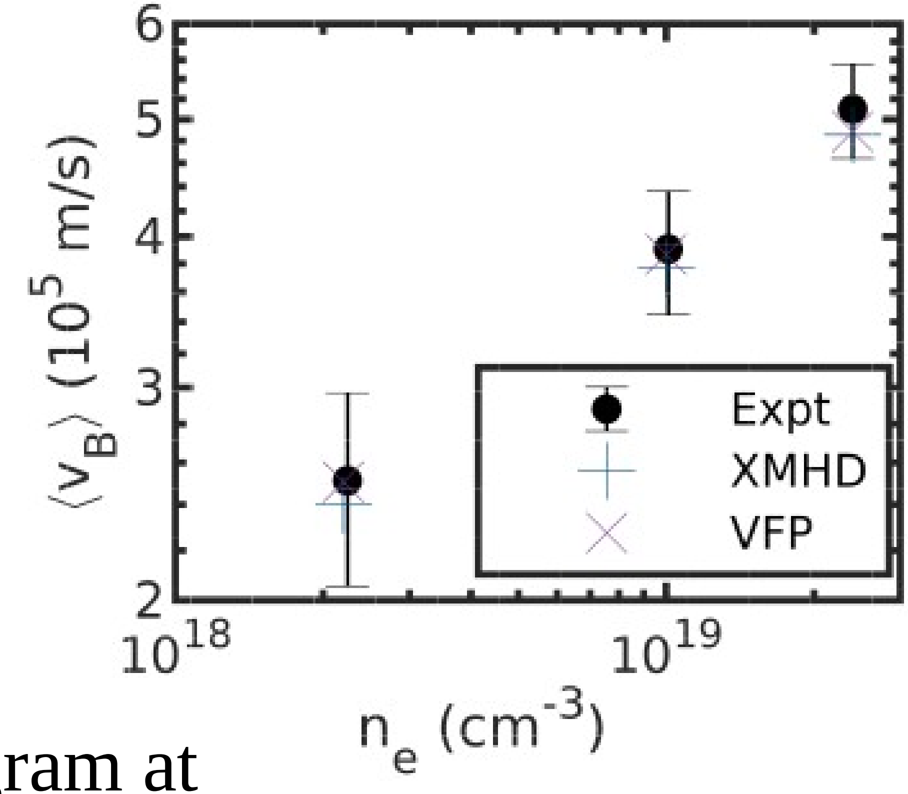

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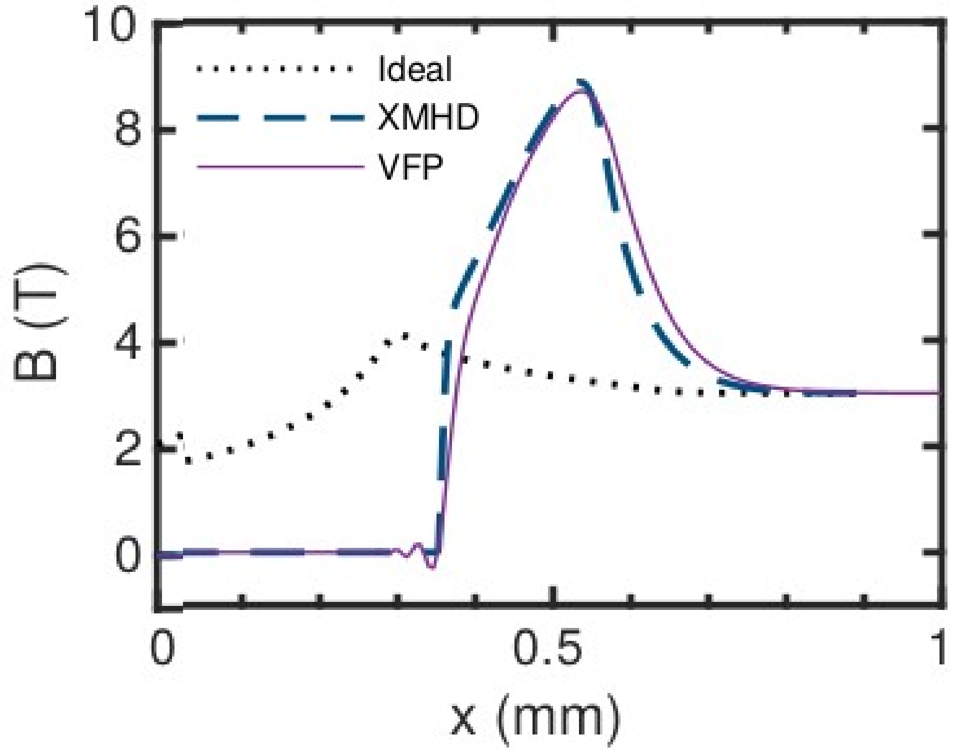
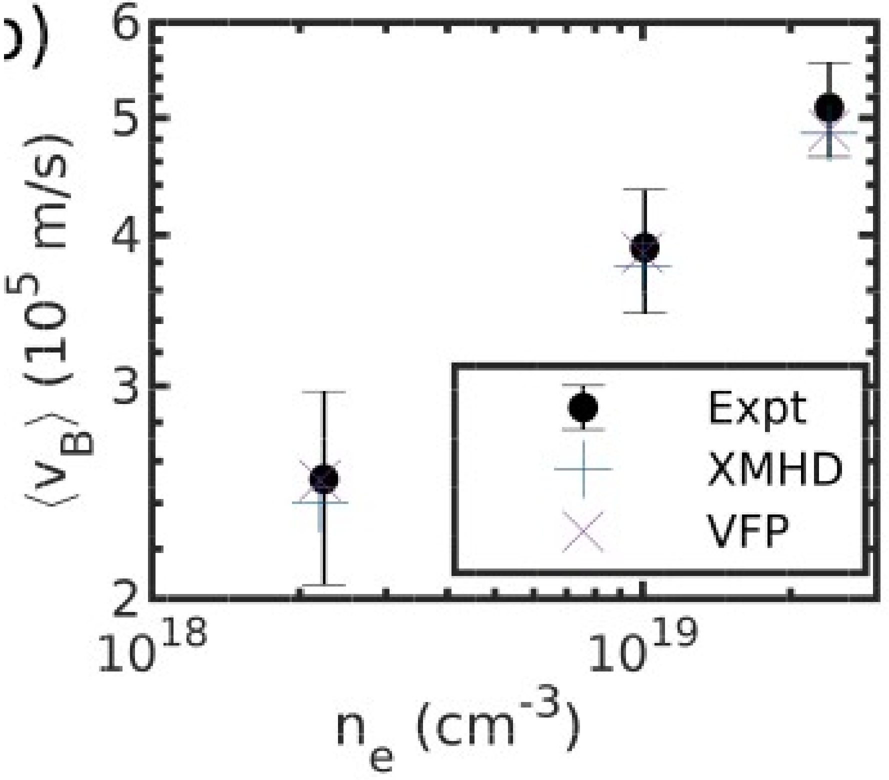
Nonlocality in magnetised plasmas





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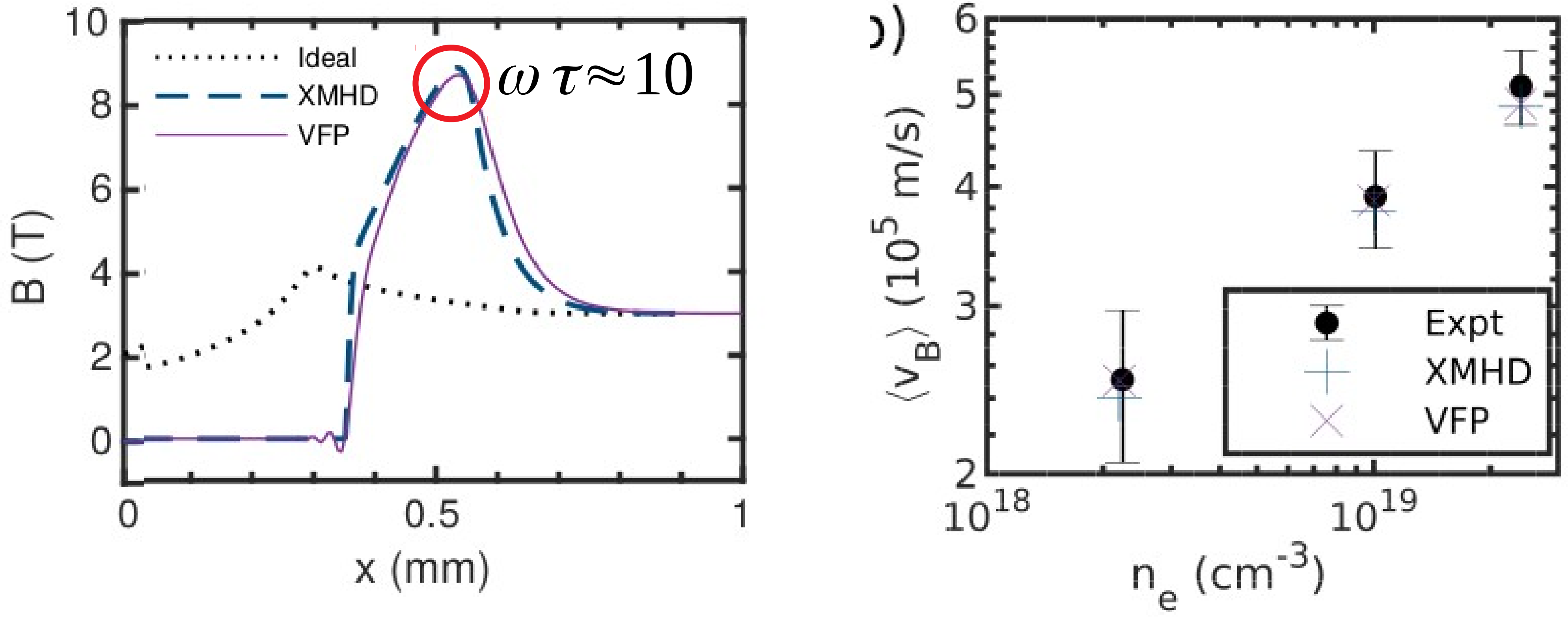

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Magnetic fields & transport

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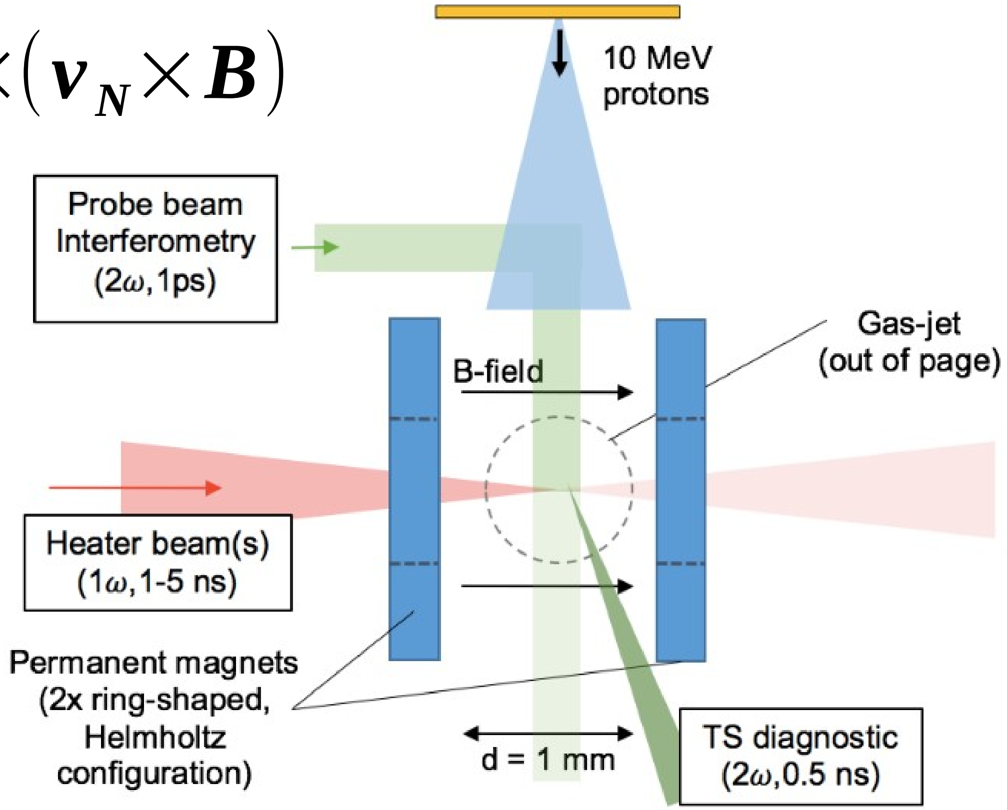

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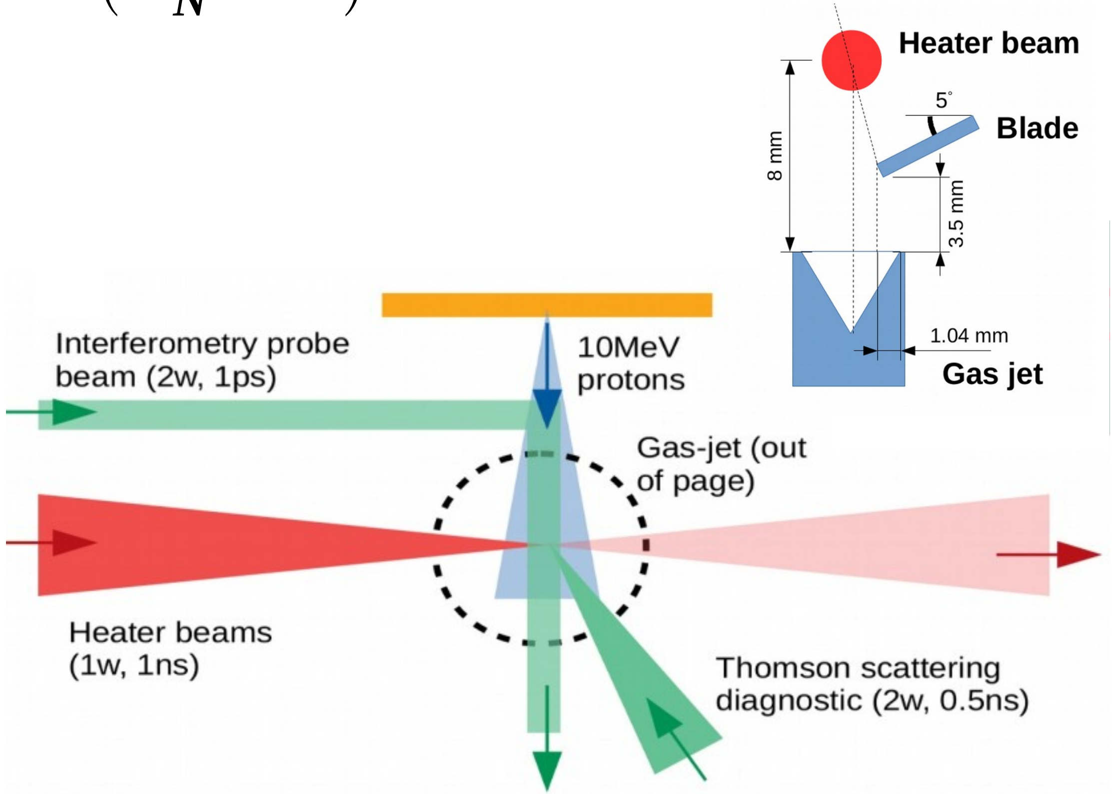

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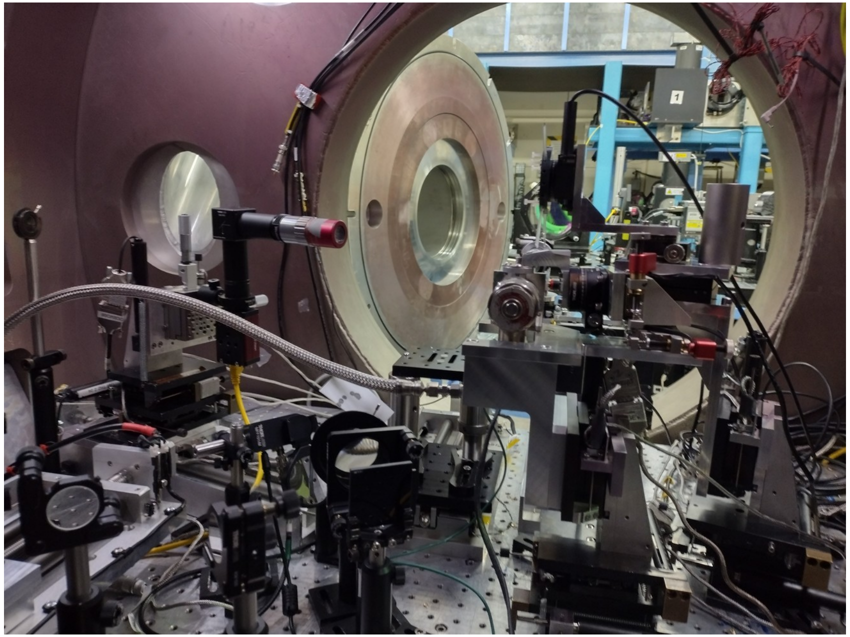

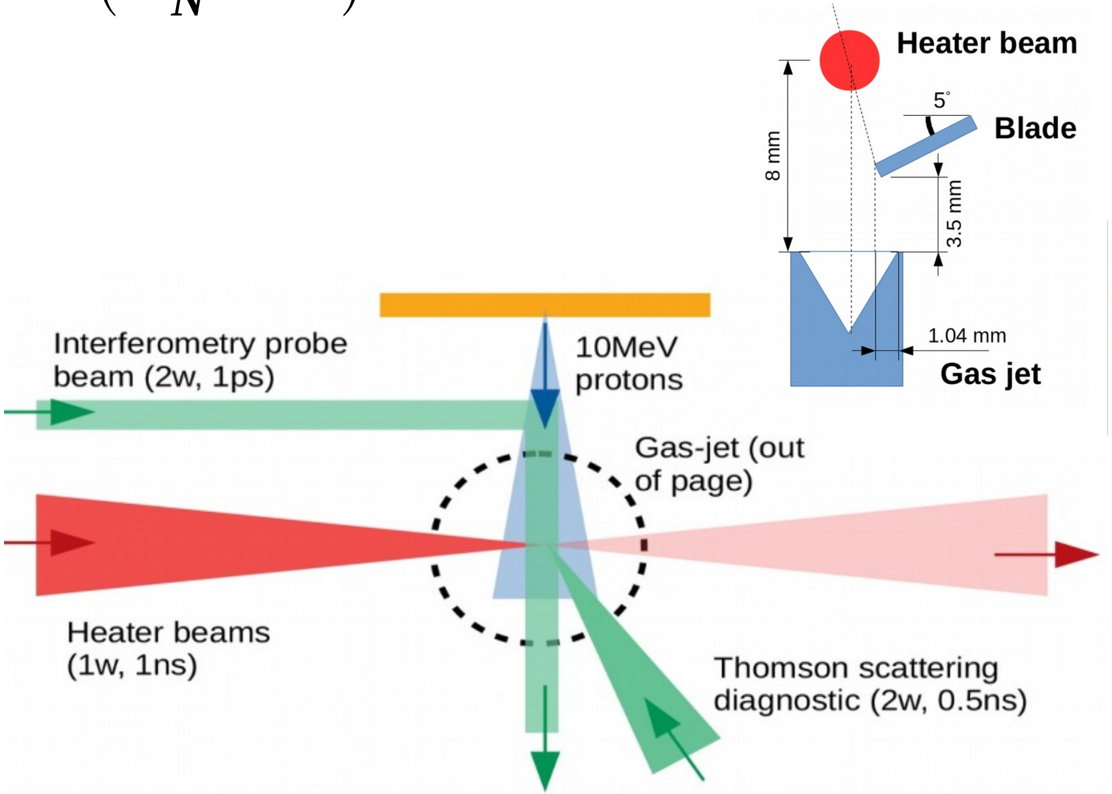

Kinetic Biermann

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R.J. Kingham & A.R. Bell, PRL, 88, 045004 (2002)

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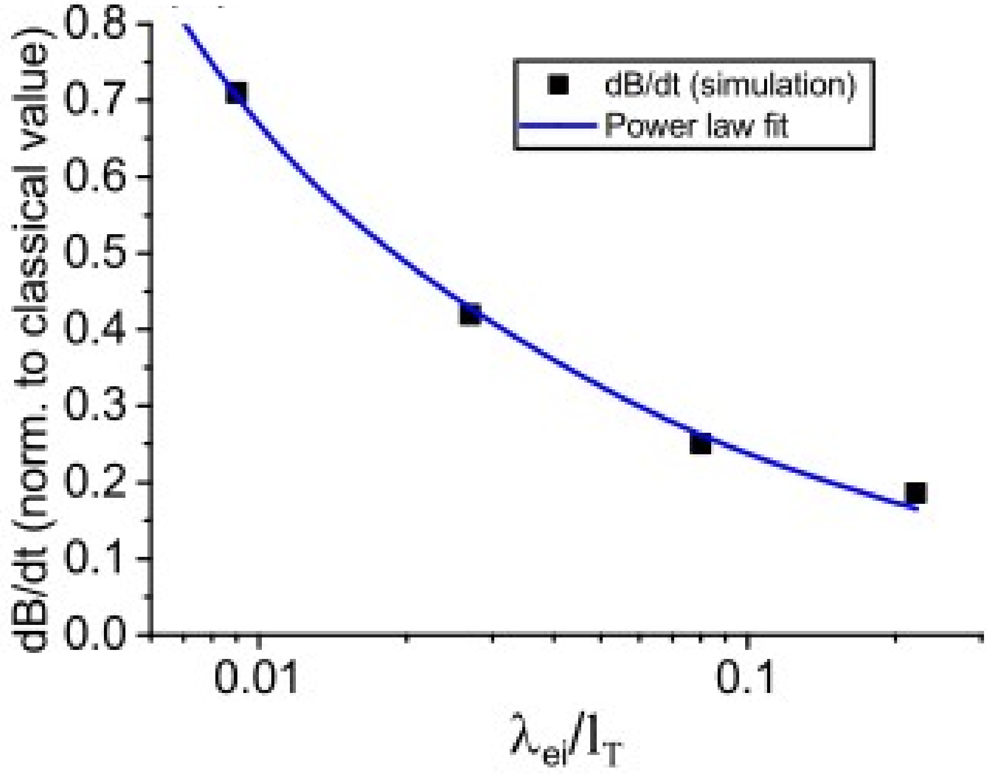

M. Sherlock & J.J Bissell, PRL, 124 055001 (2020)

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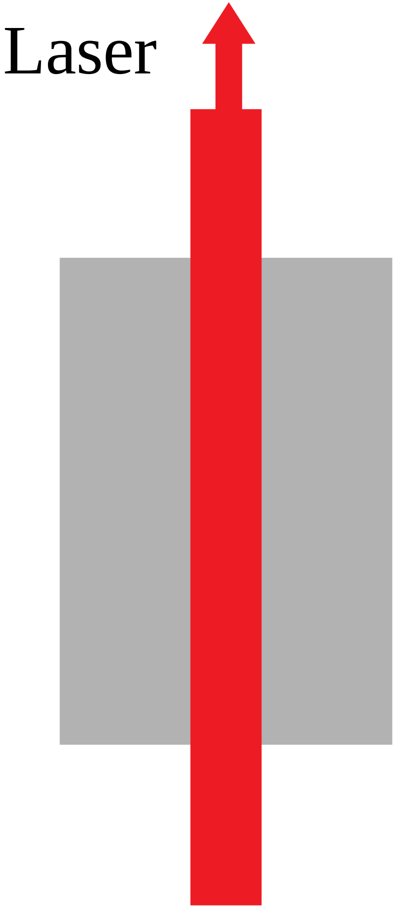

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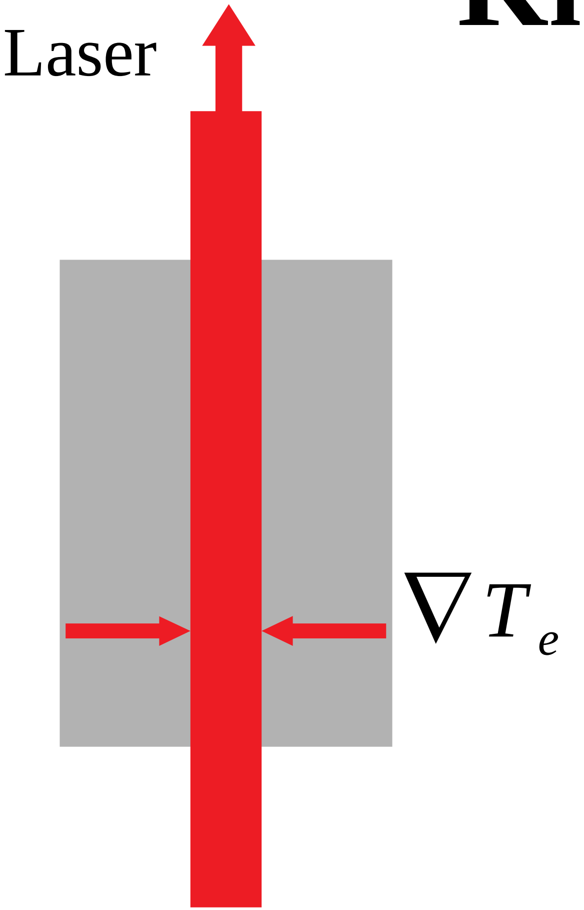

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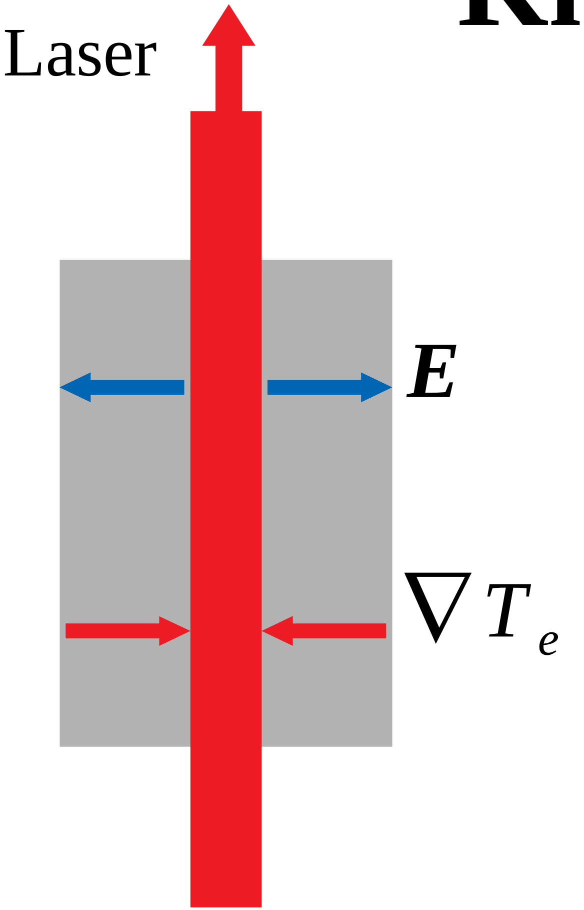

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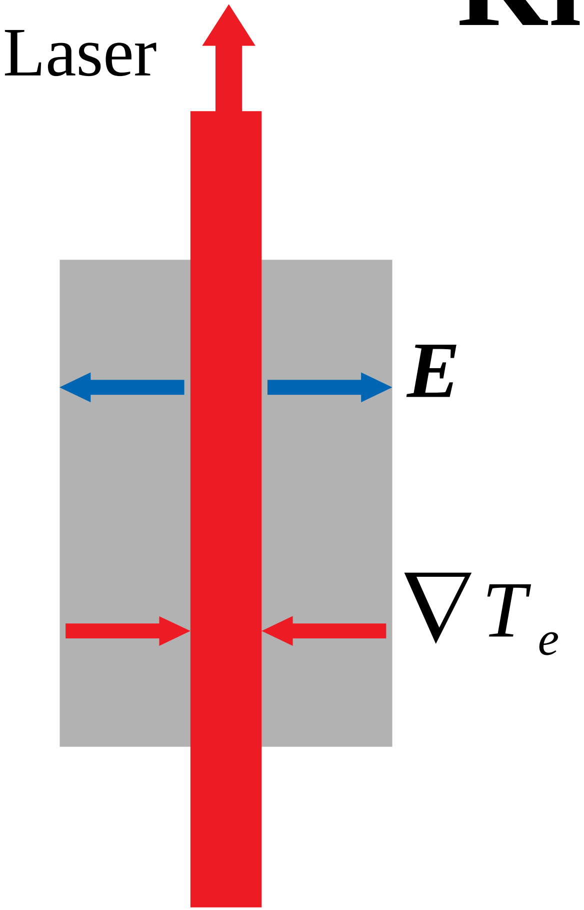

- Laser intensity 2×10^{14} Wcm^{-2}, spot size 33μm. Gas density 1.5×10^{19} cm^{-3}

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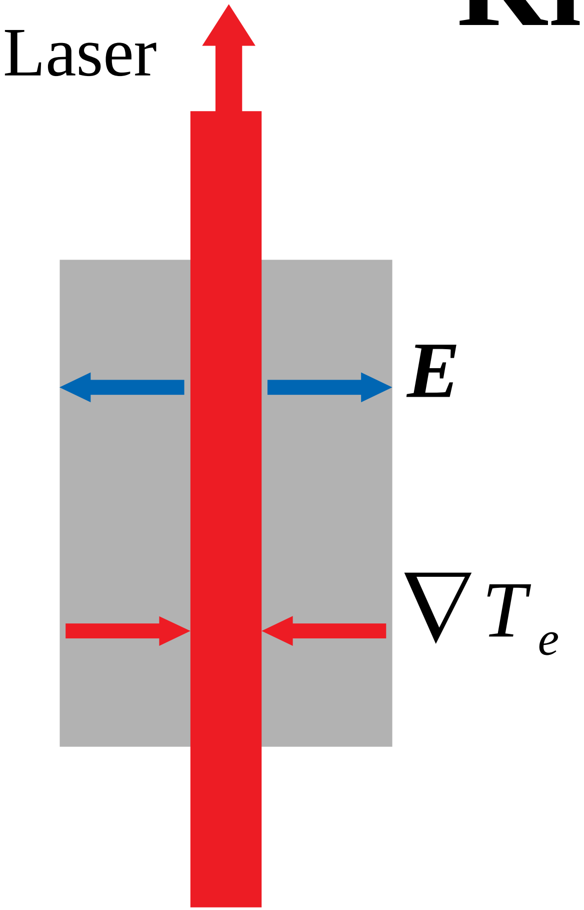

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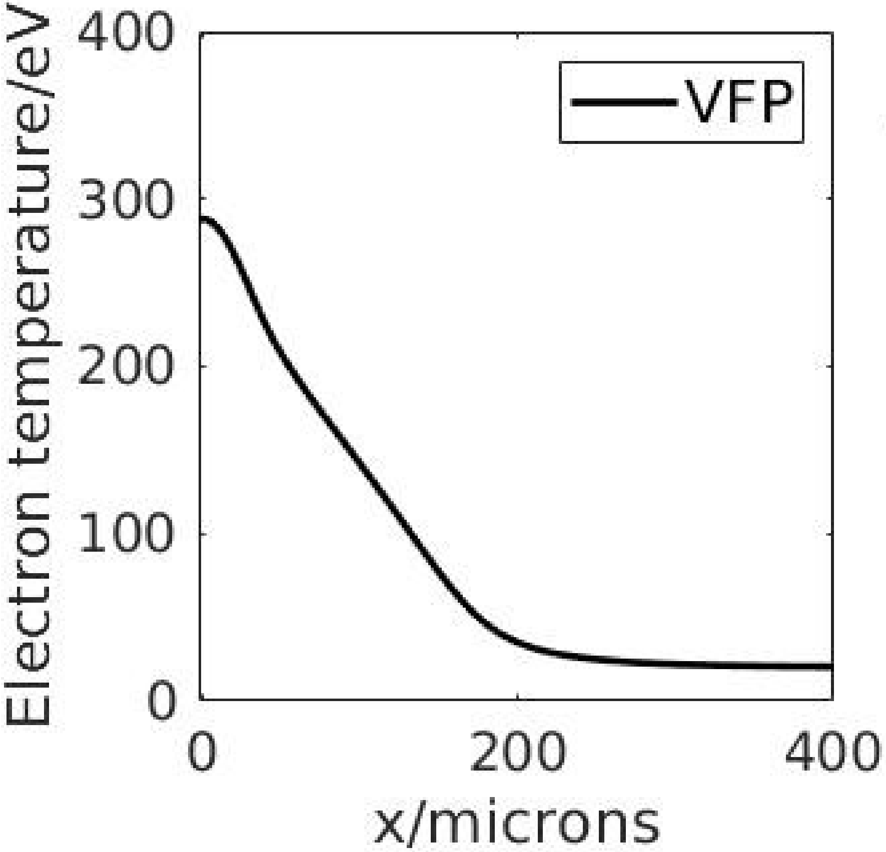

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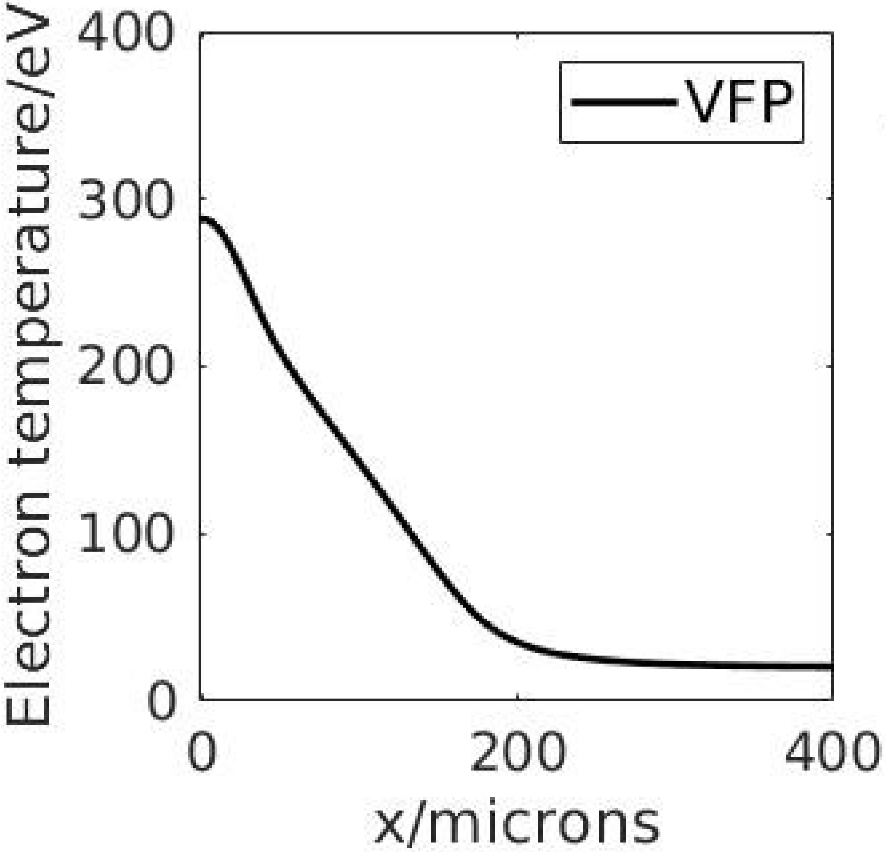

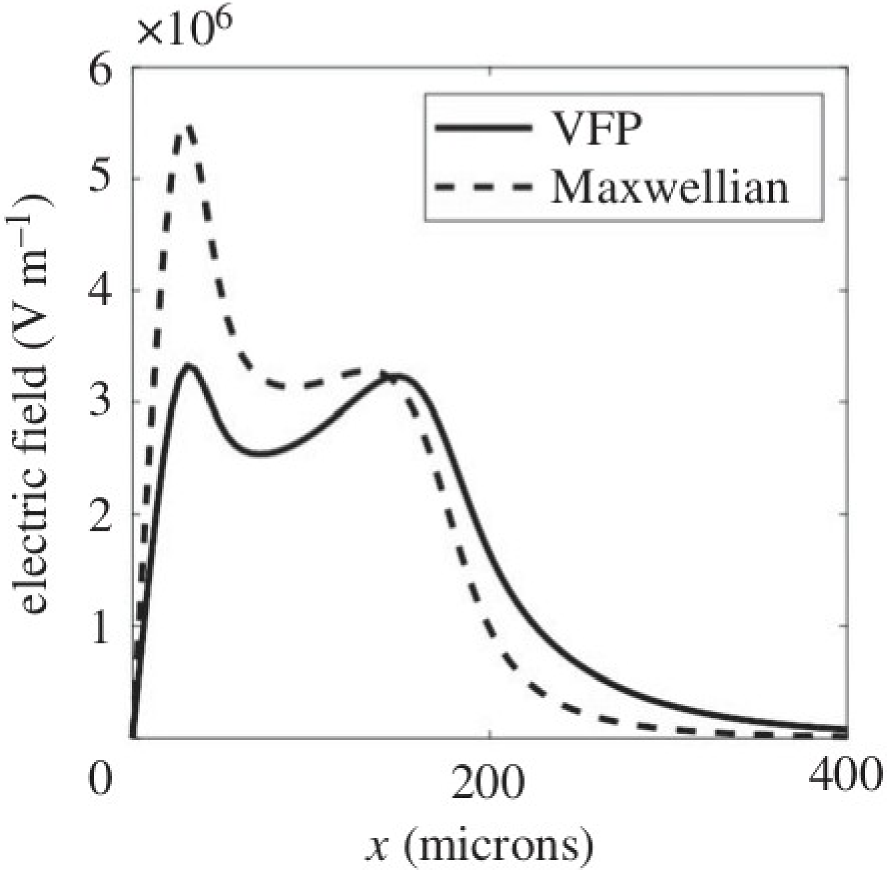

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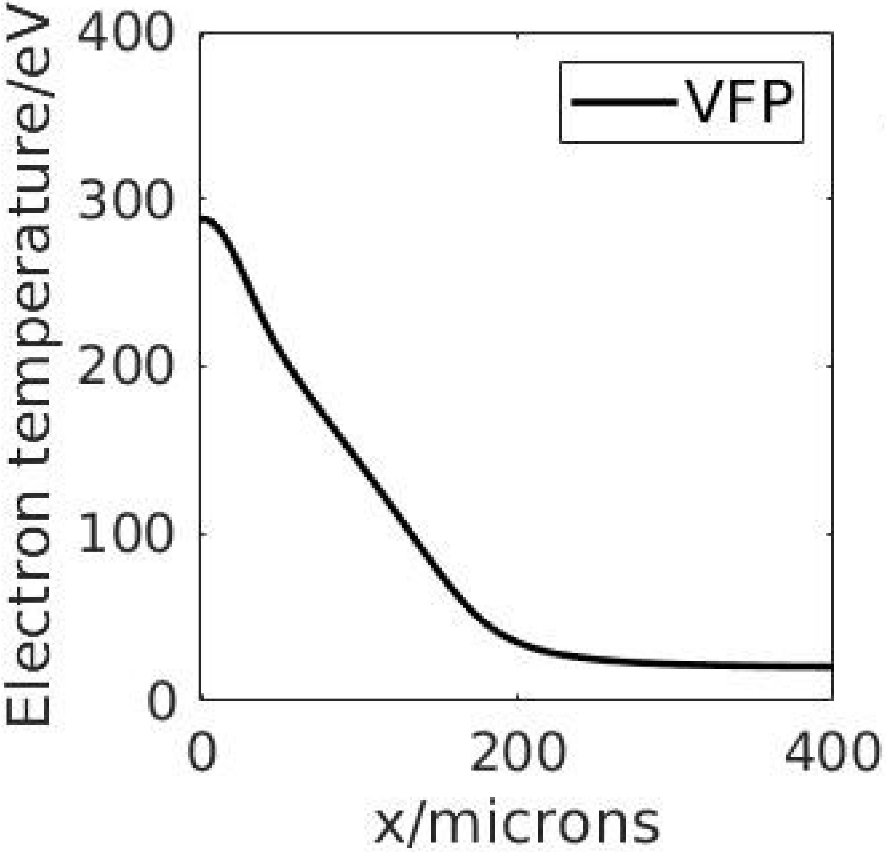

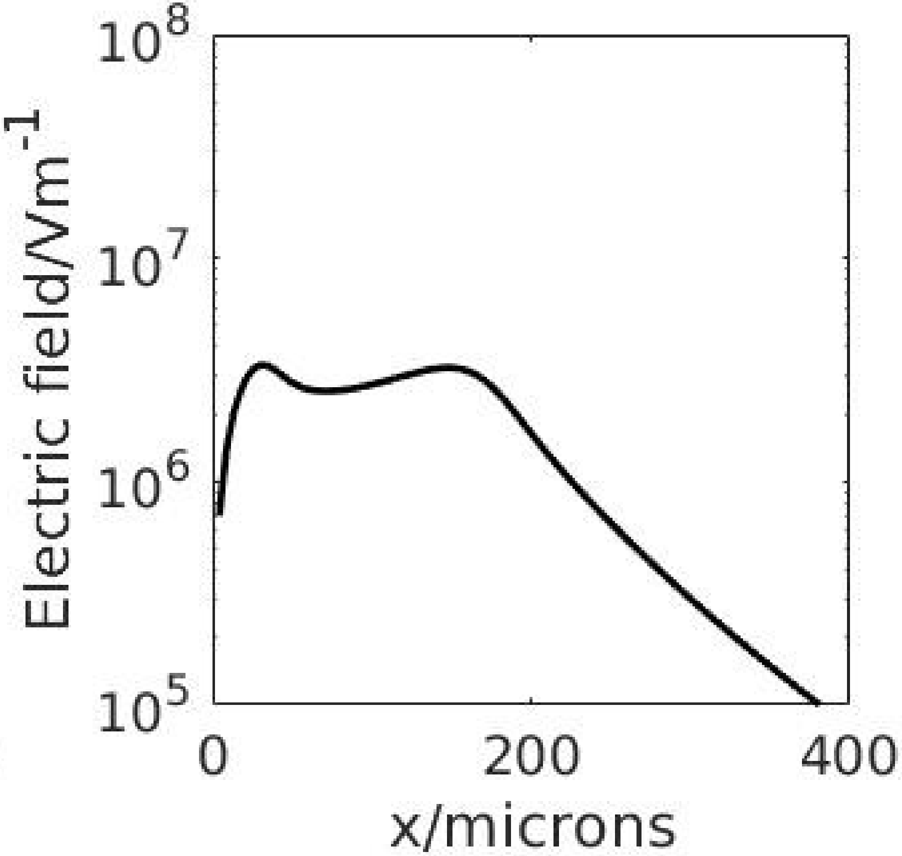

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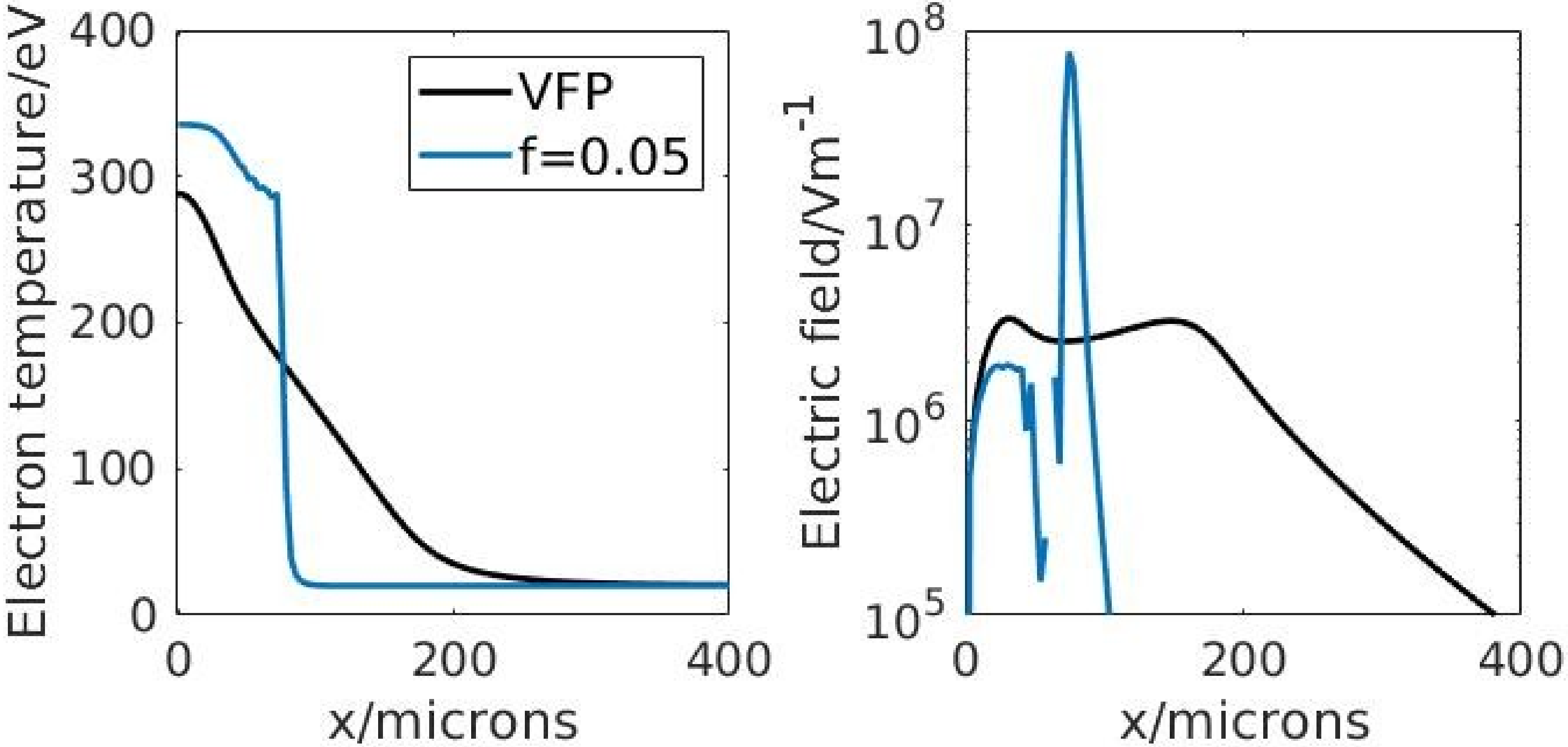

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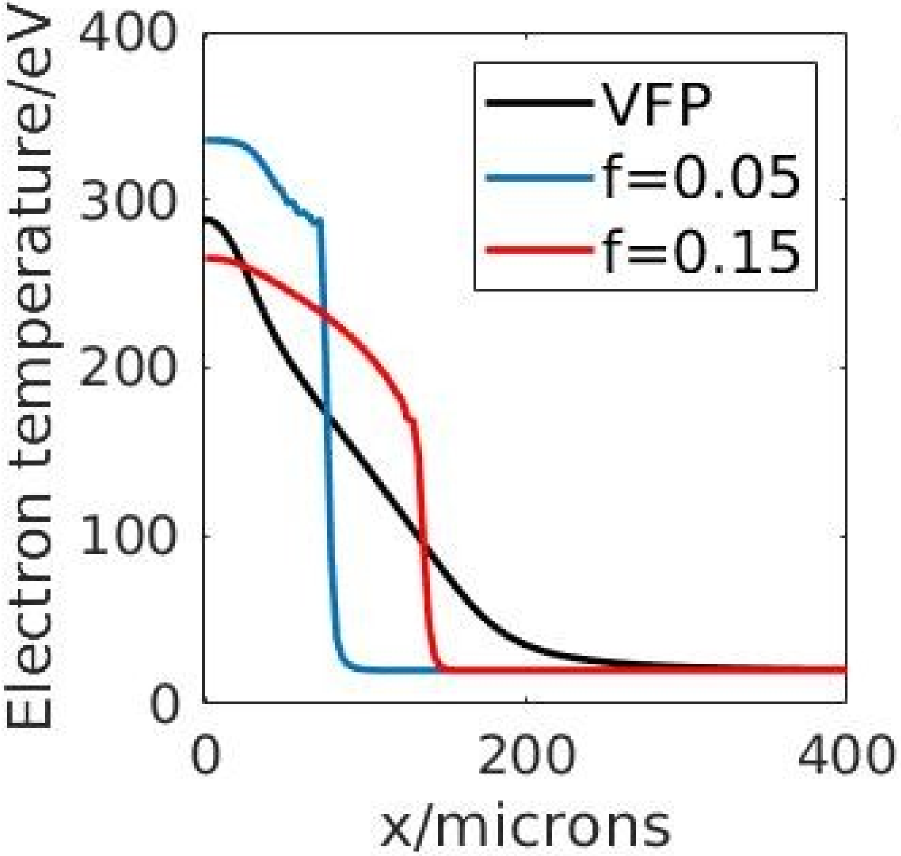

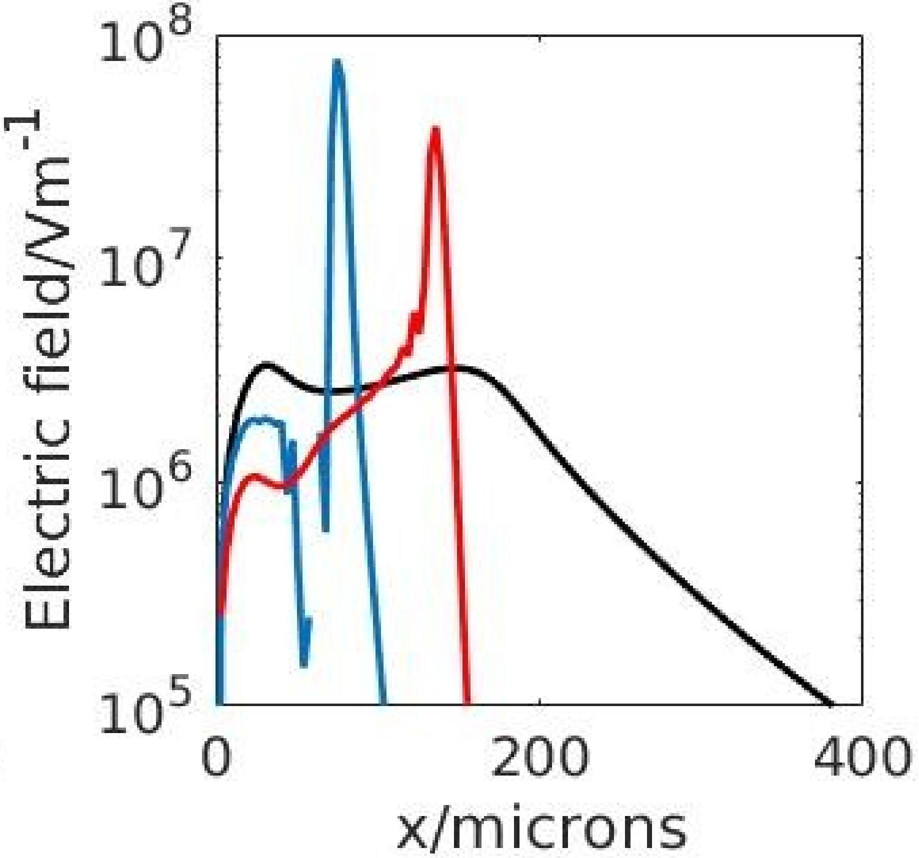

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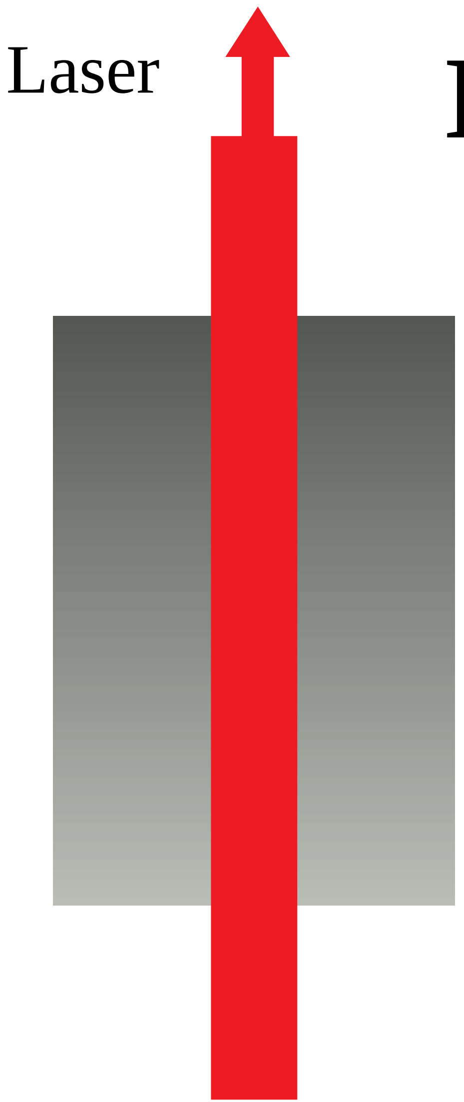

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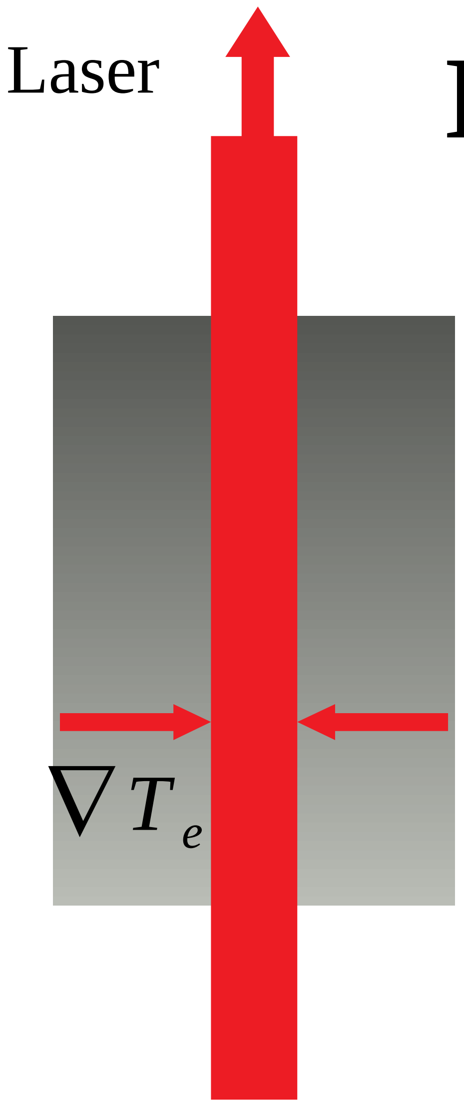

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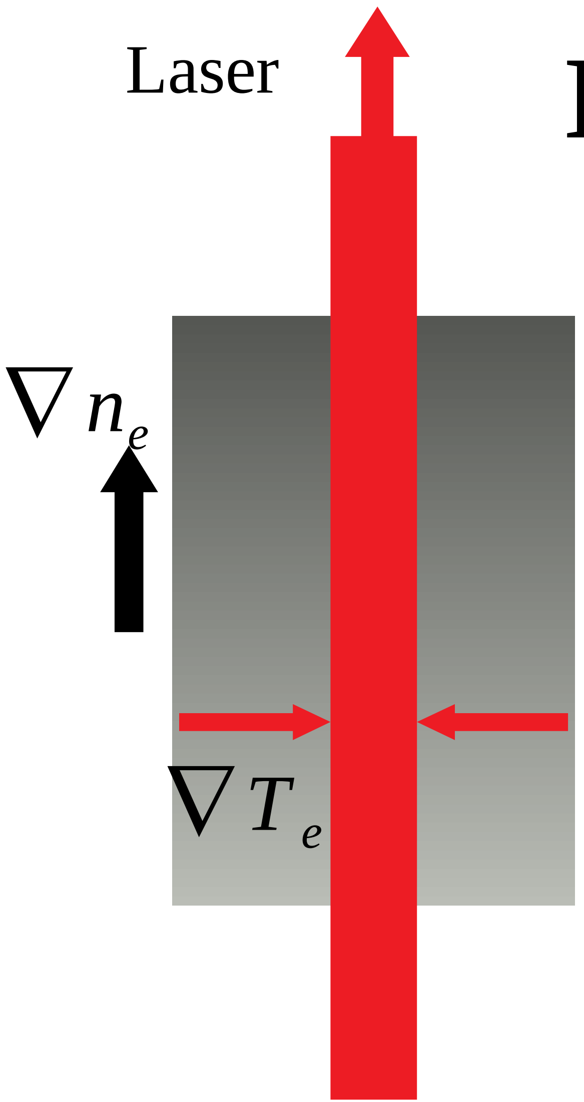

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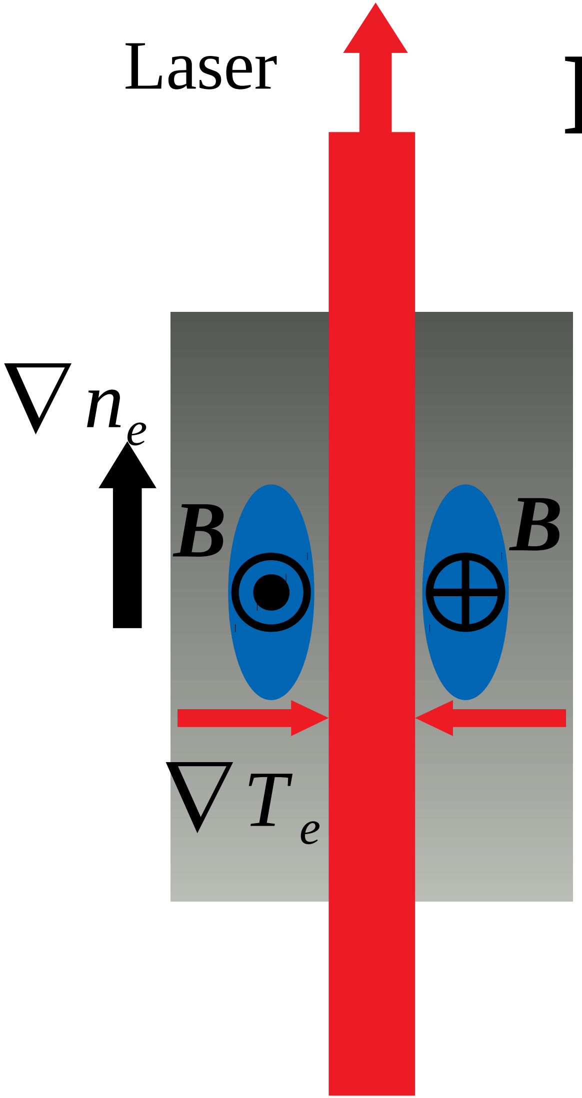

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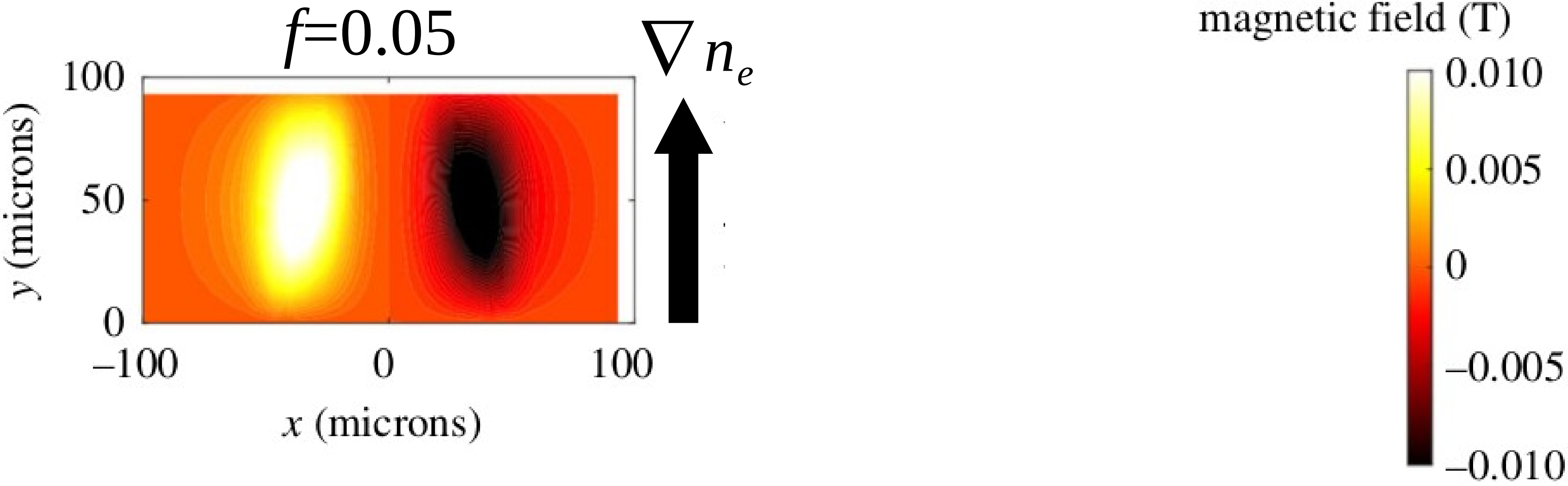

- 2D MHD simulations with density gradient
- B-field after 60ps

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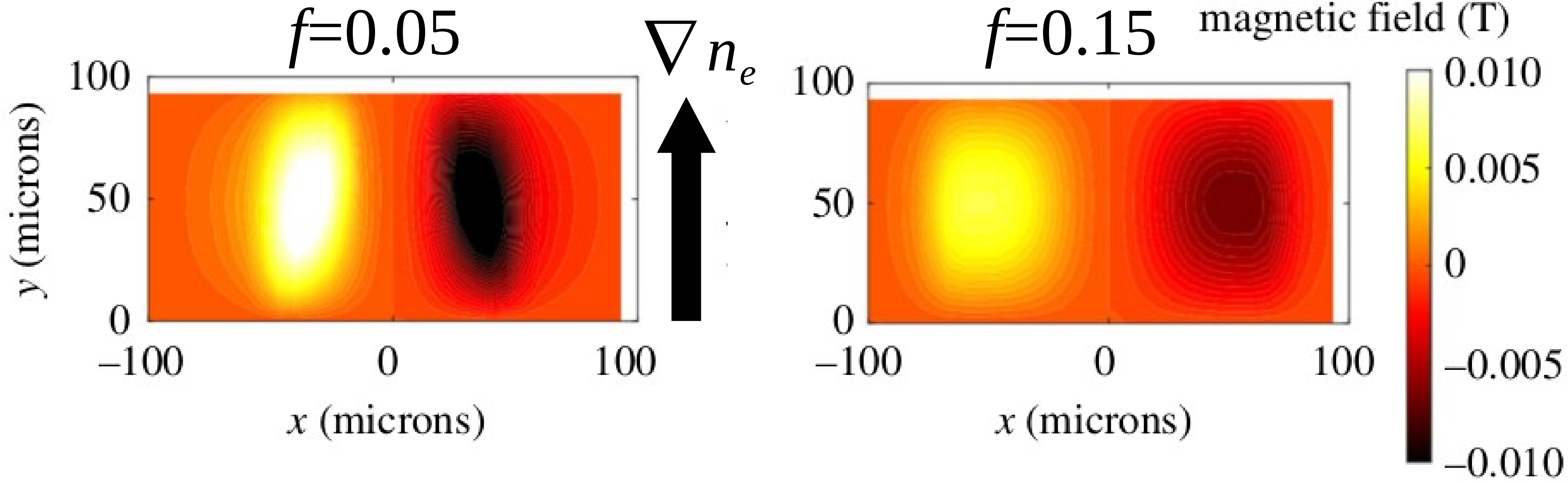

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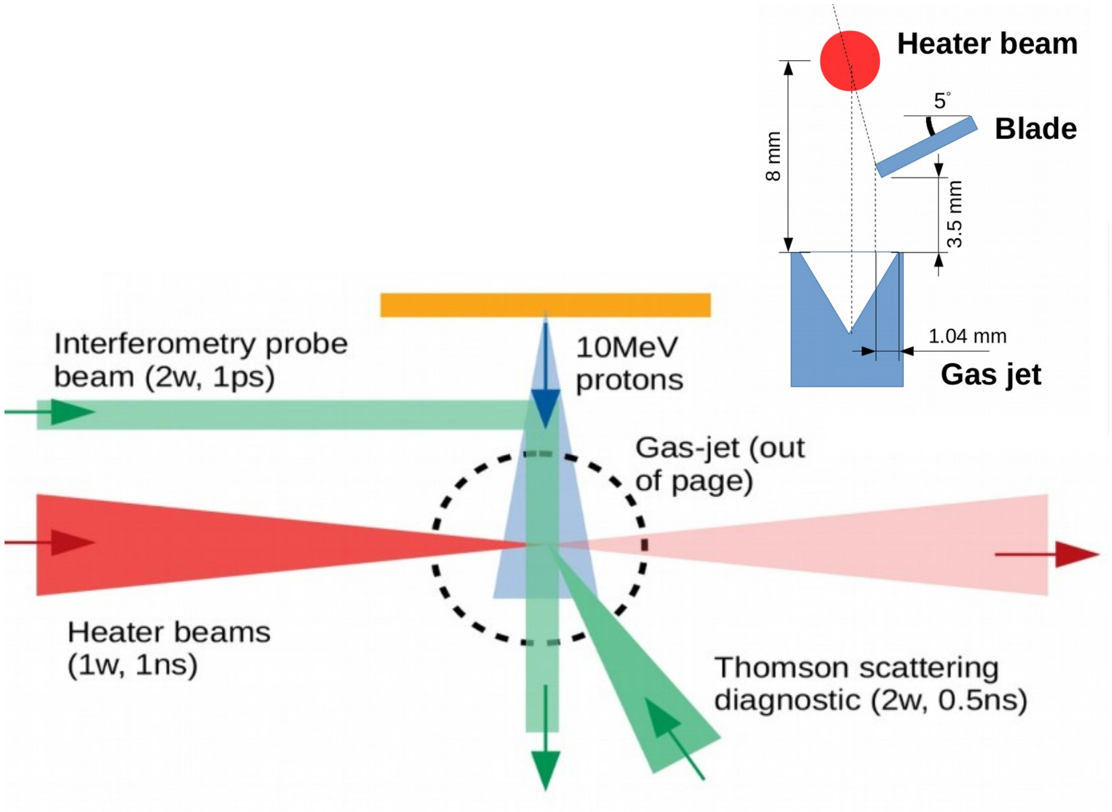

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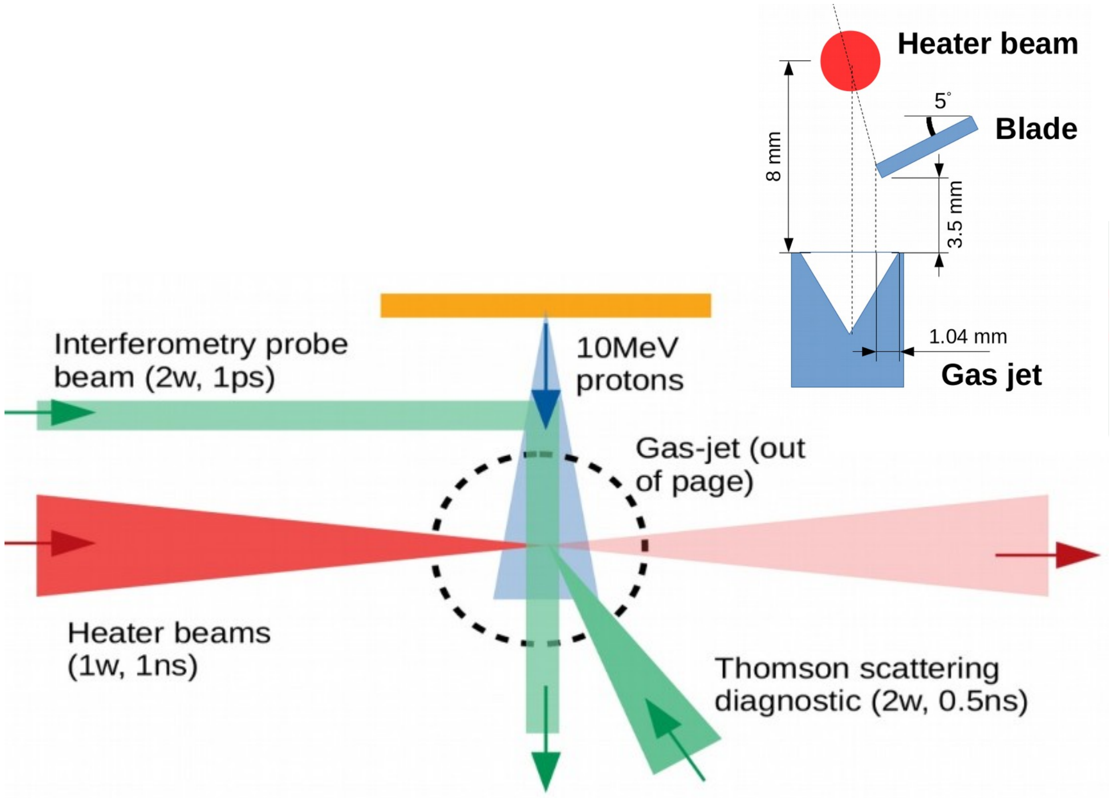

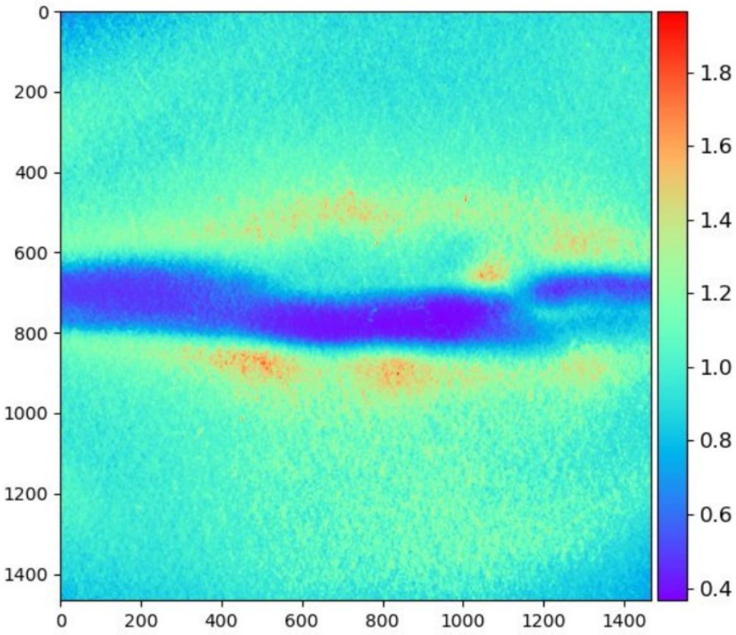

- Proton radiograph (normalised intensity map)

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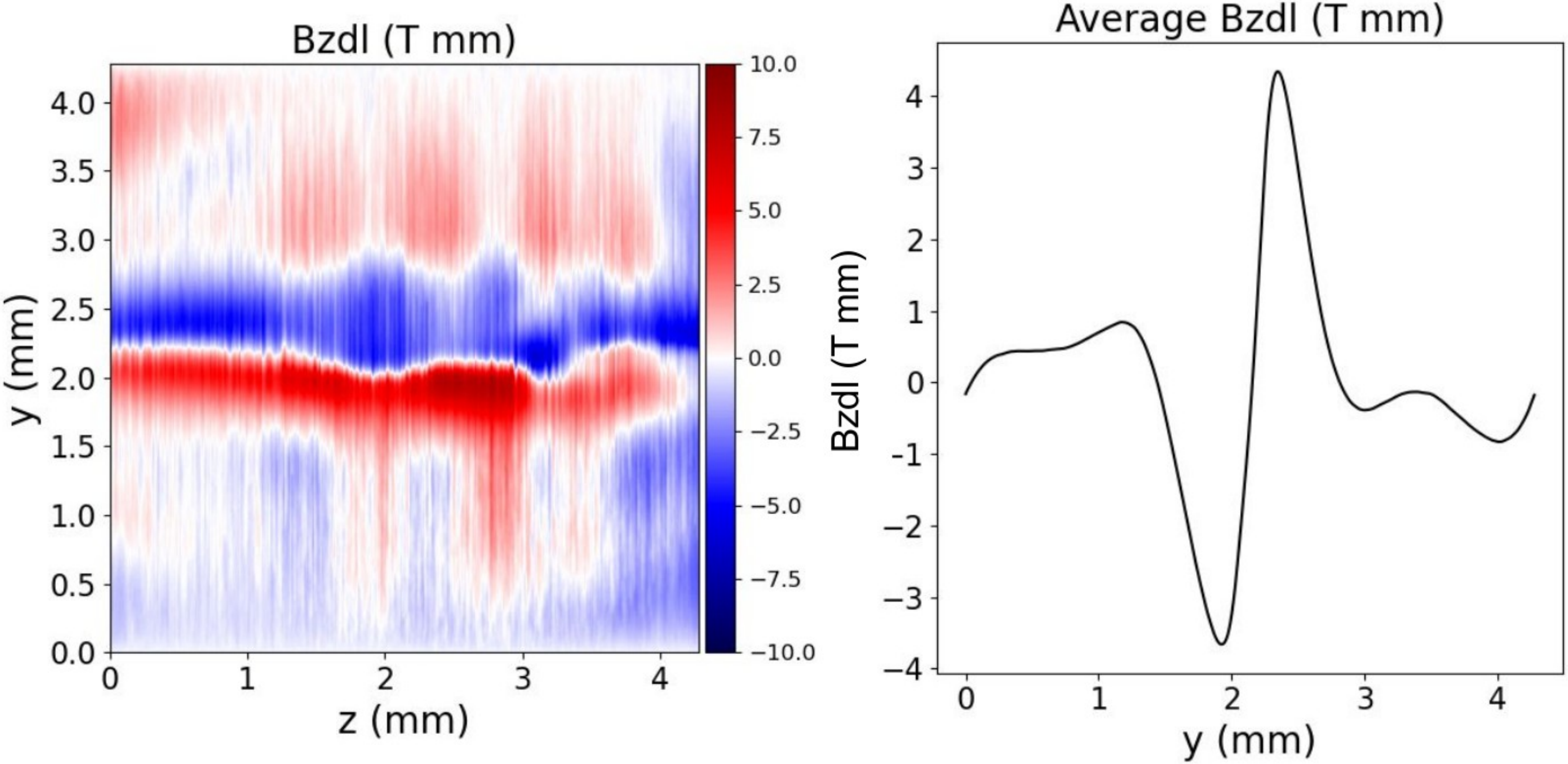

M1 model - work in progress

- M1 model – similar to SNB (more complicated)
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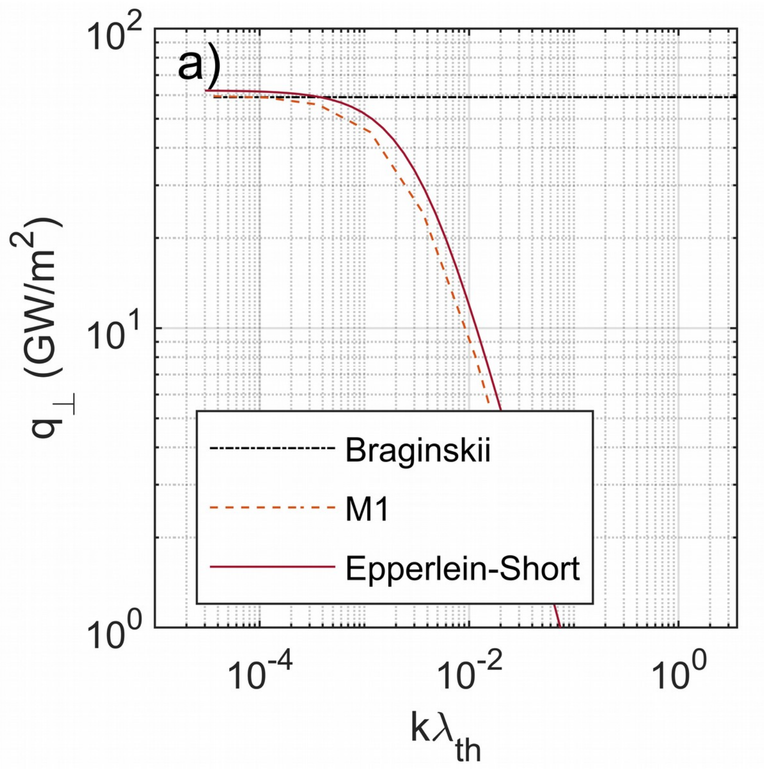

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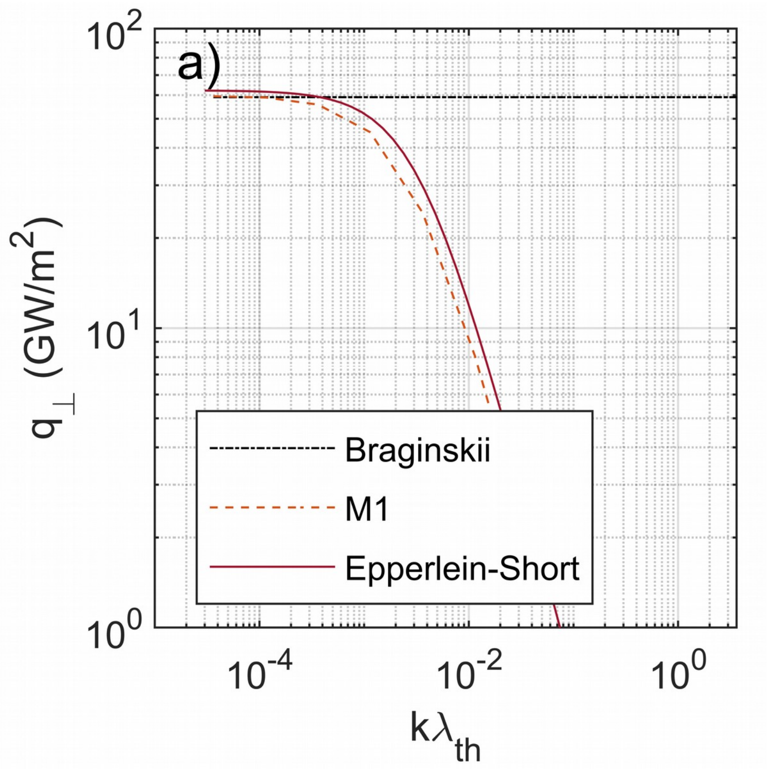
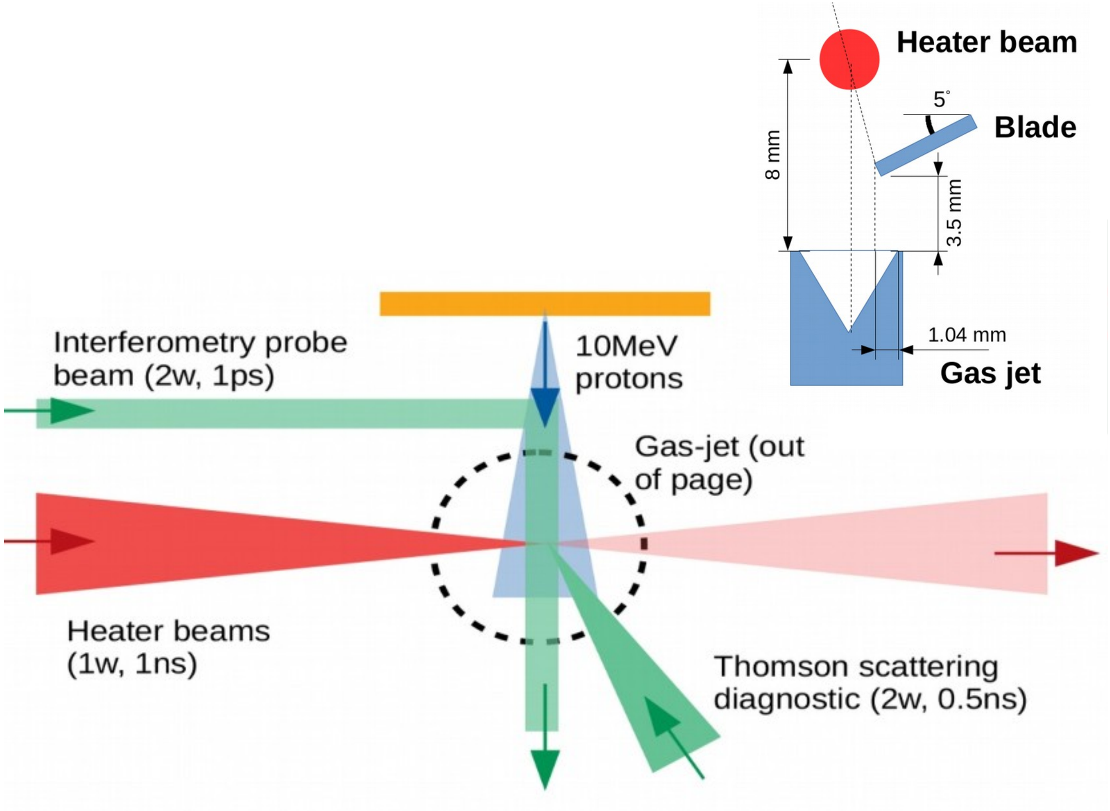


Future experiments



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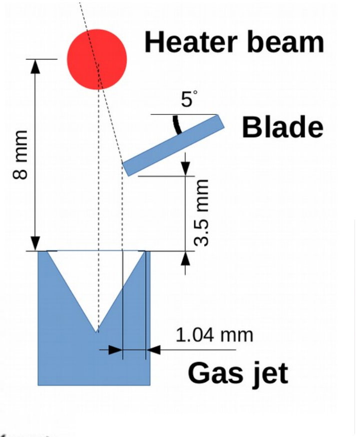
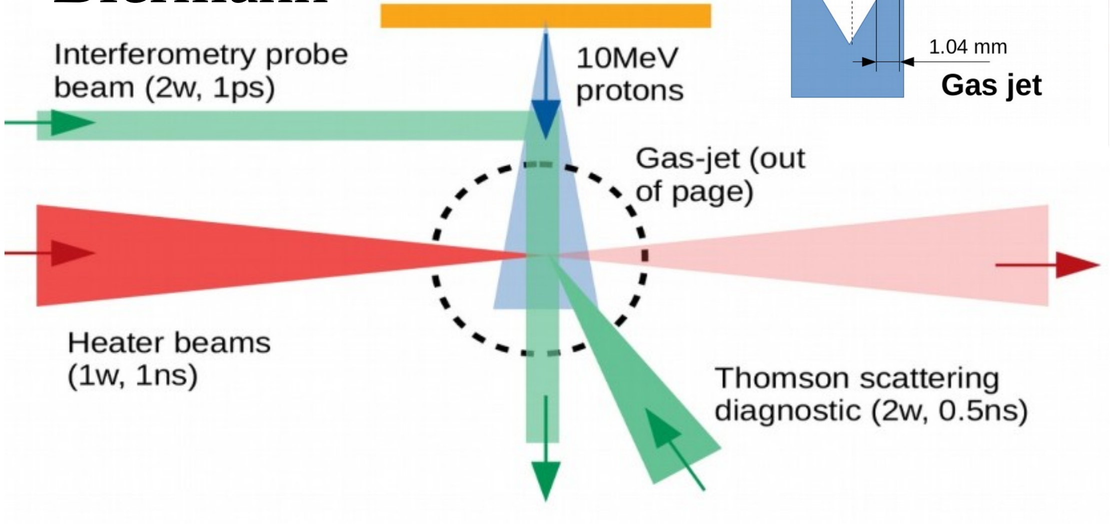
- Ongoing analysis of Vulcan expt. May see kinetic Biermann





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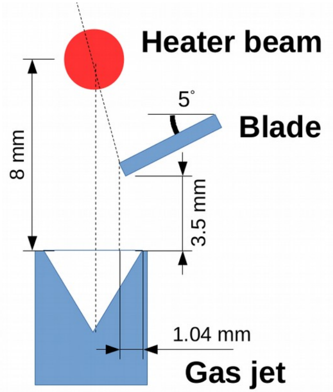

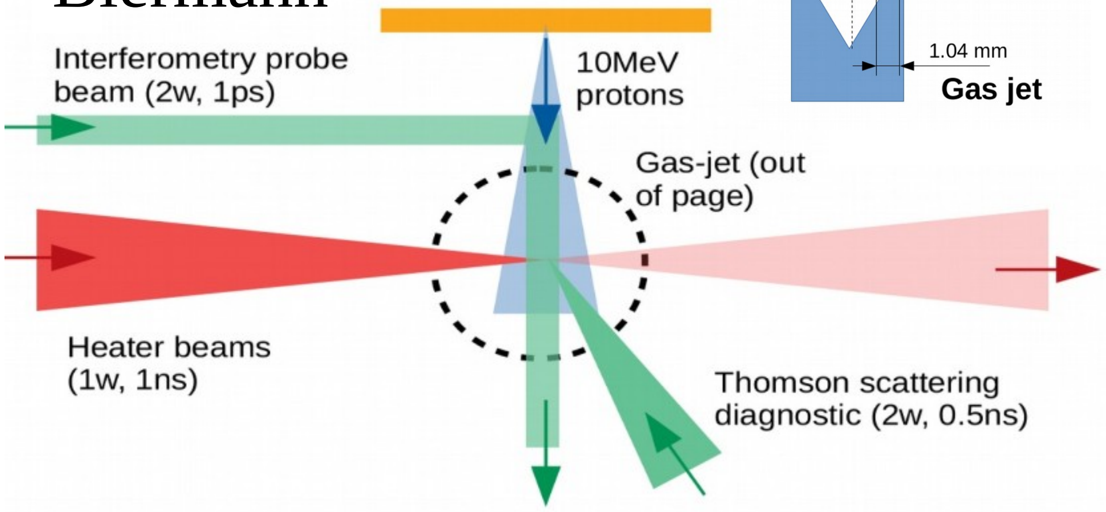

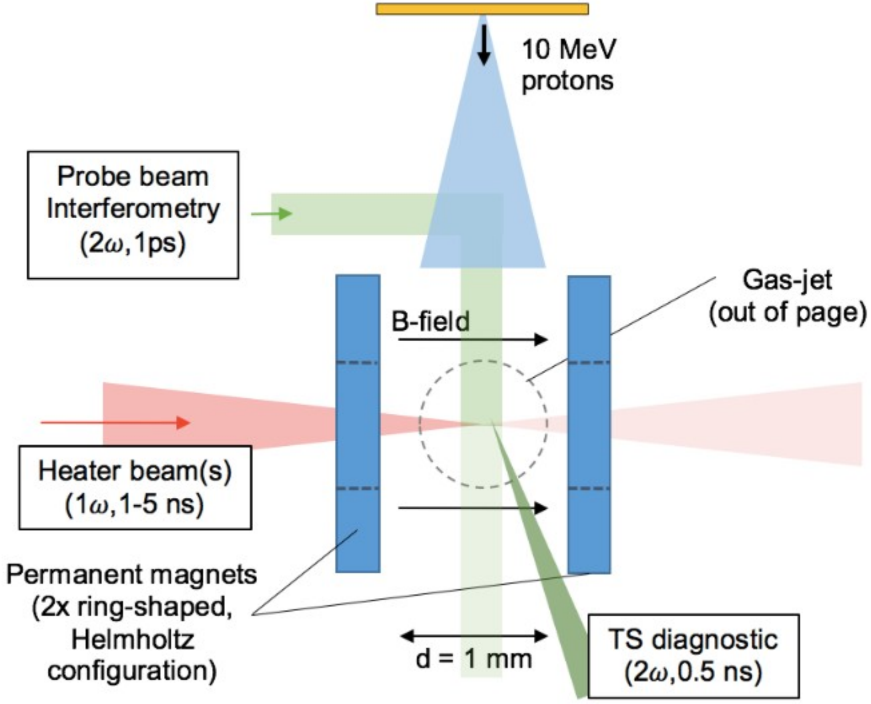

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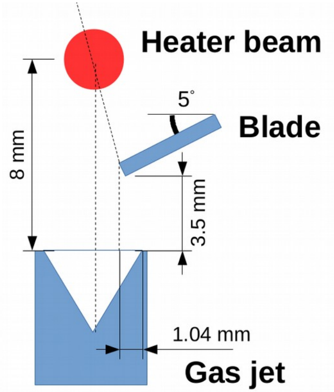
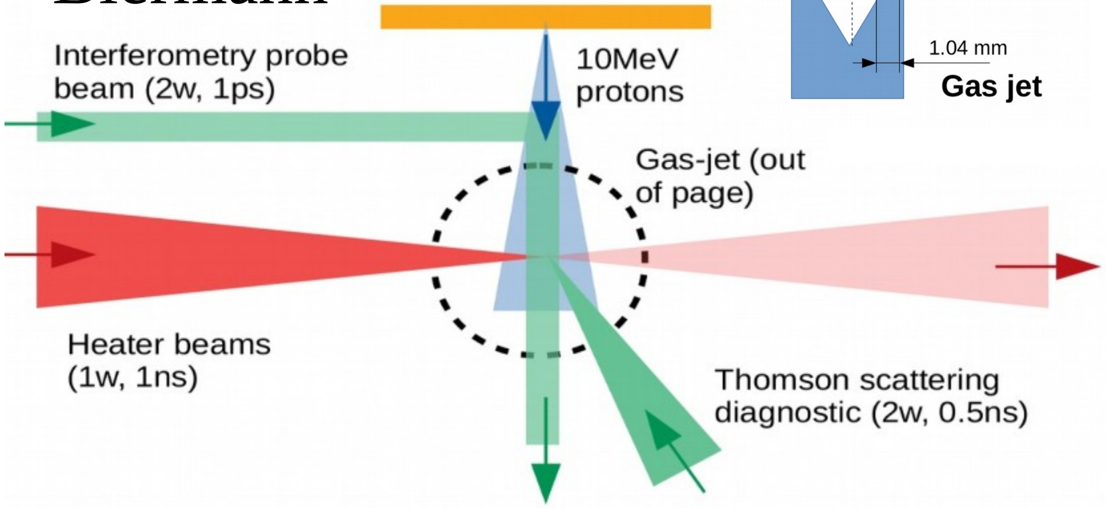
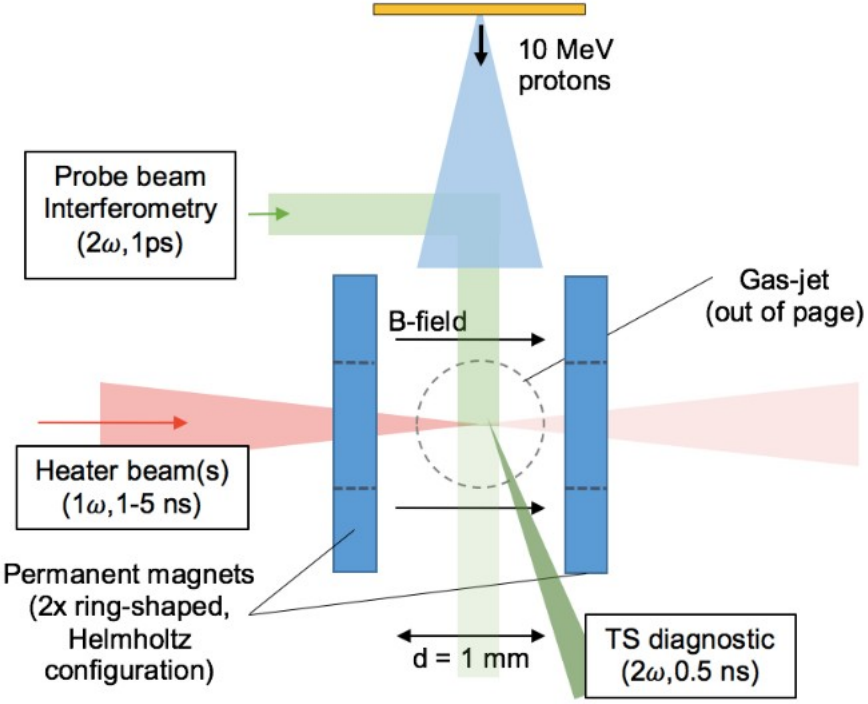




- Kinetic Nernst needs lower -field



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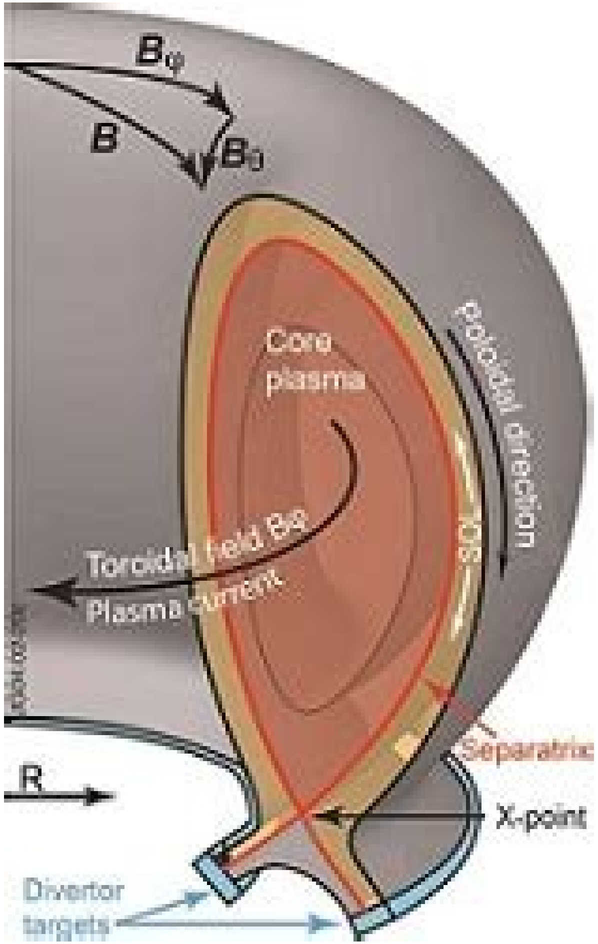
- No nonlocal model incuding B-fields has been benchmarked...

Non-local transport in MCF

- Scrape-Off Layer (SOL) - ‘open’ field lines outside core plasma onto divertor



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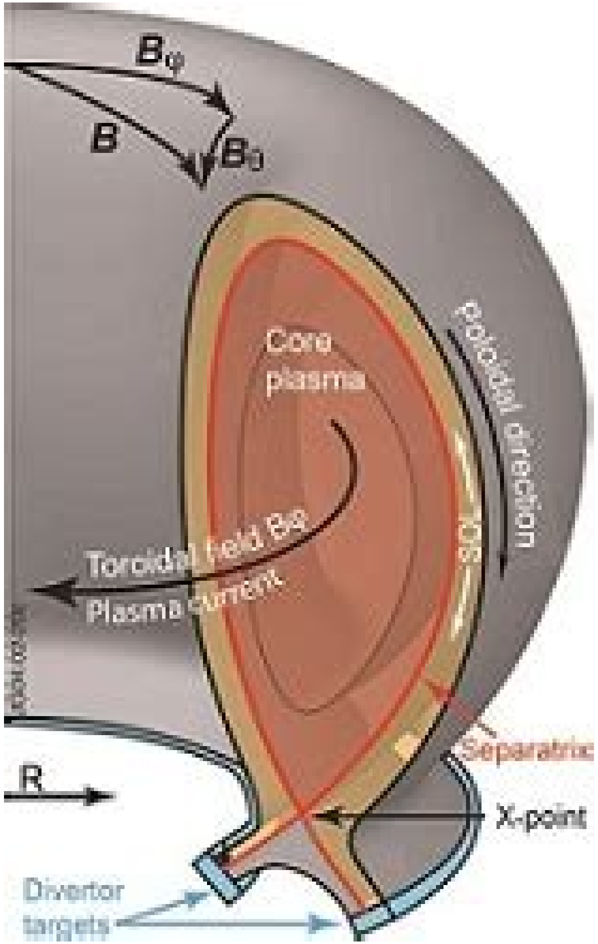

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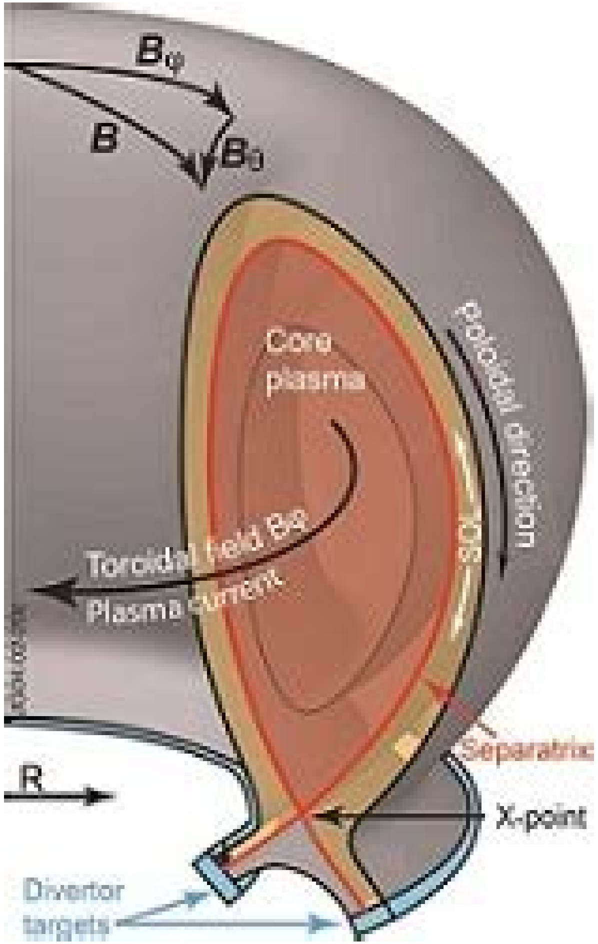

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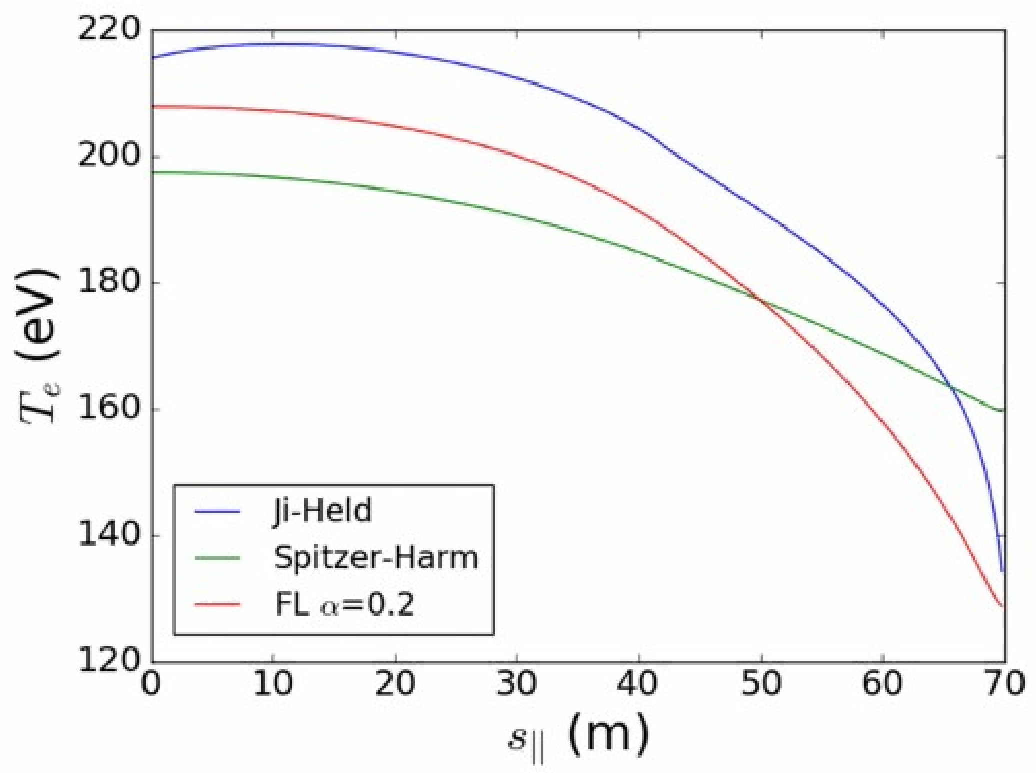

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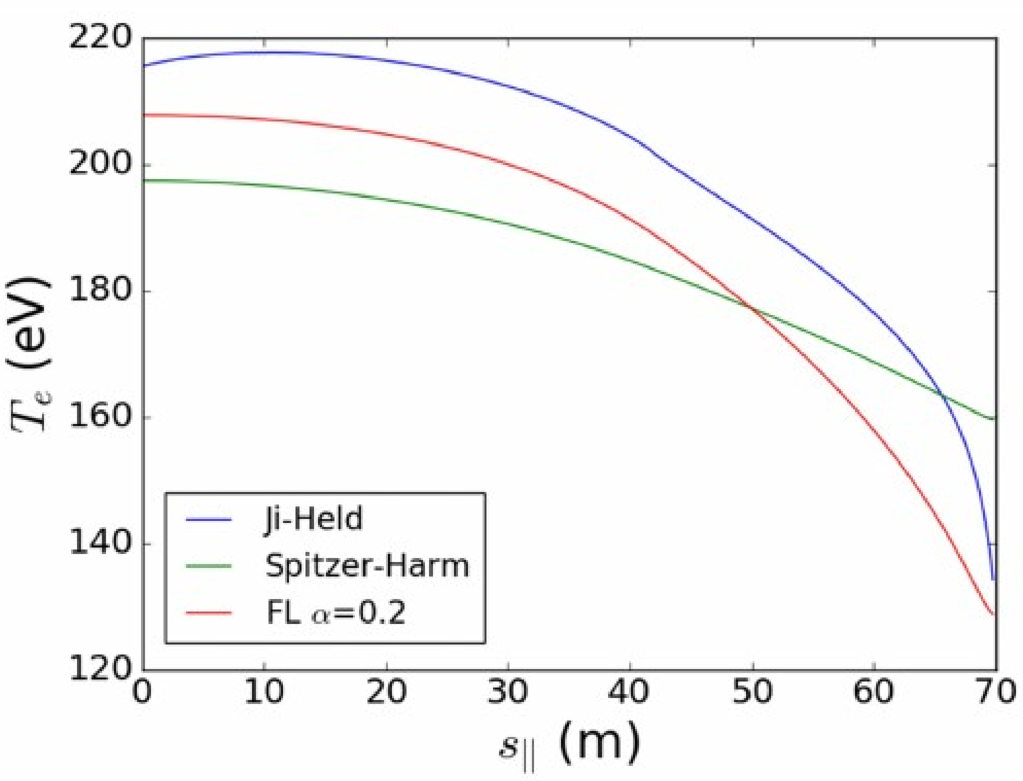

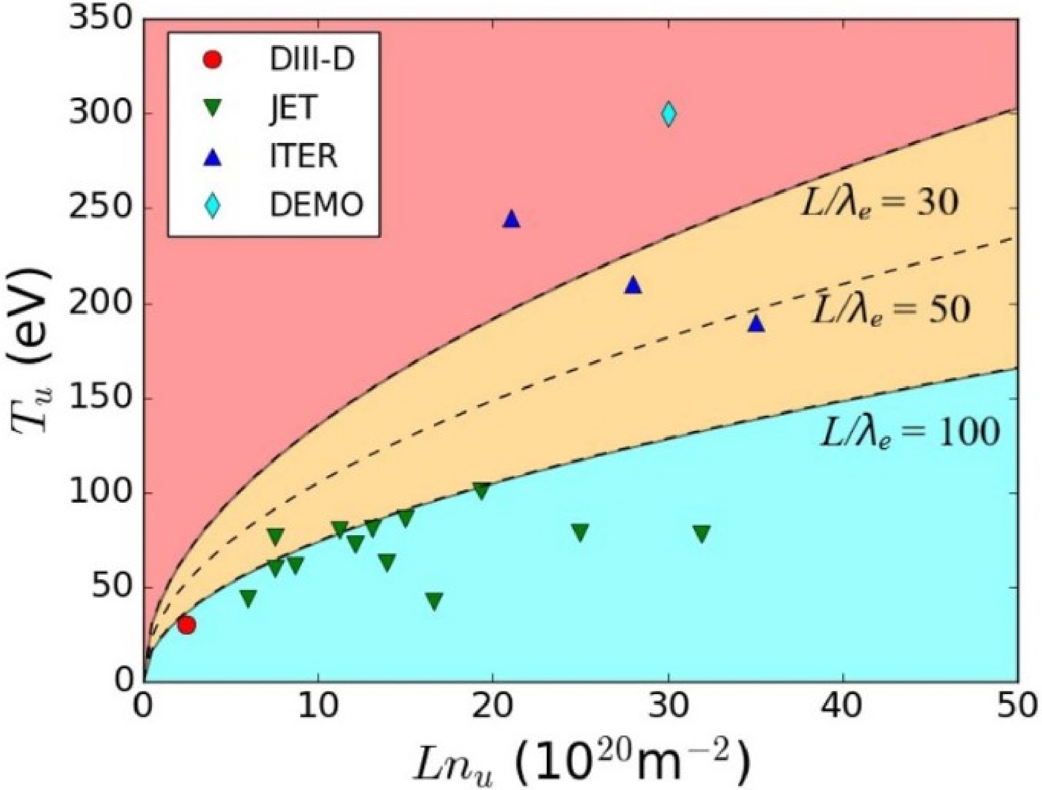

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