Particle-in-cell modeling of recent HED reconnection experiments

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with collaboration from

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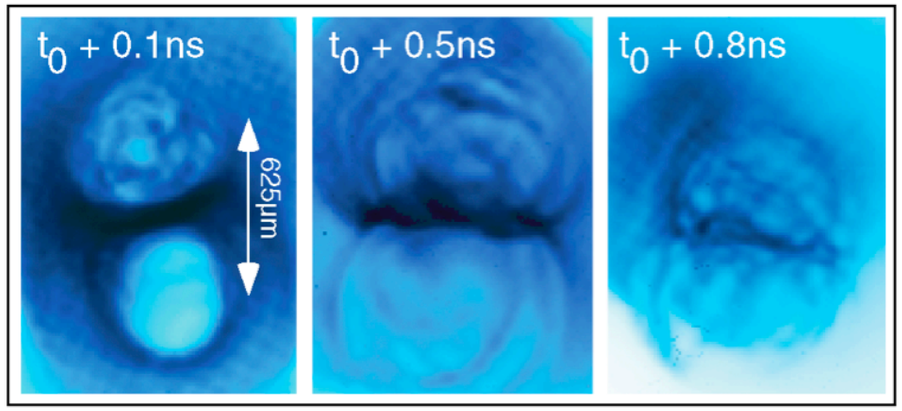
G. Fiksel, P. Nilson, U Rochester LL

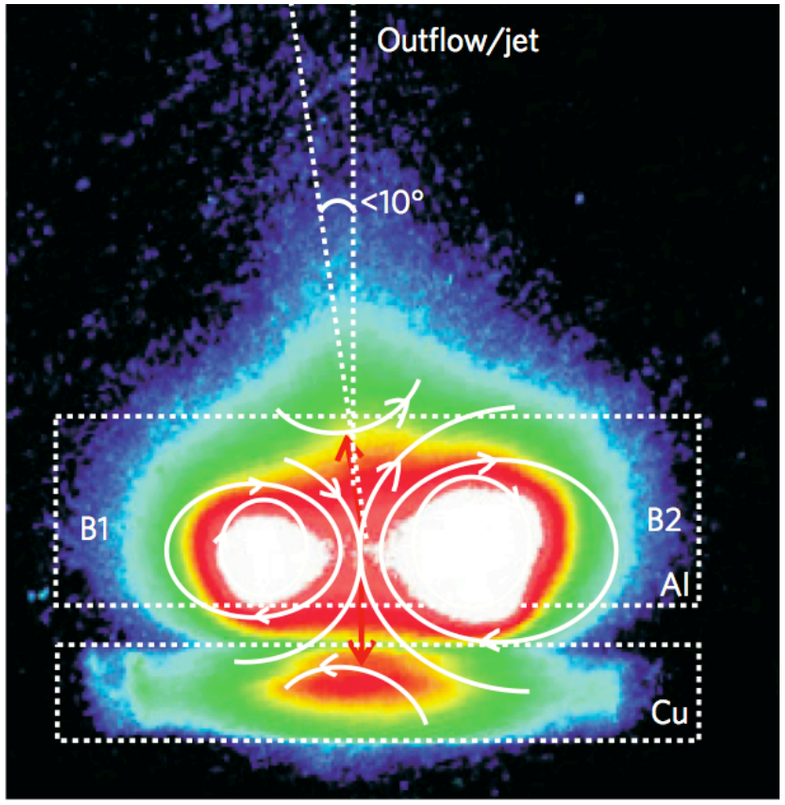
2012 Rochester HED Workshop

Reconnection observed in laser-driven plasma bubble experiments

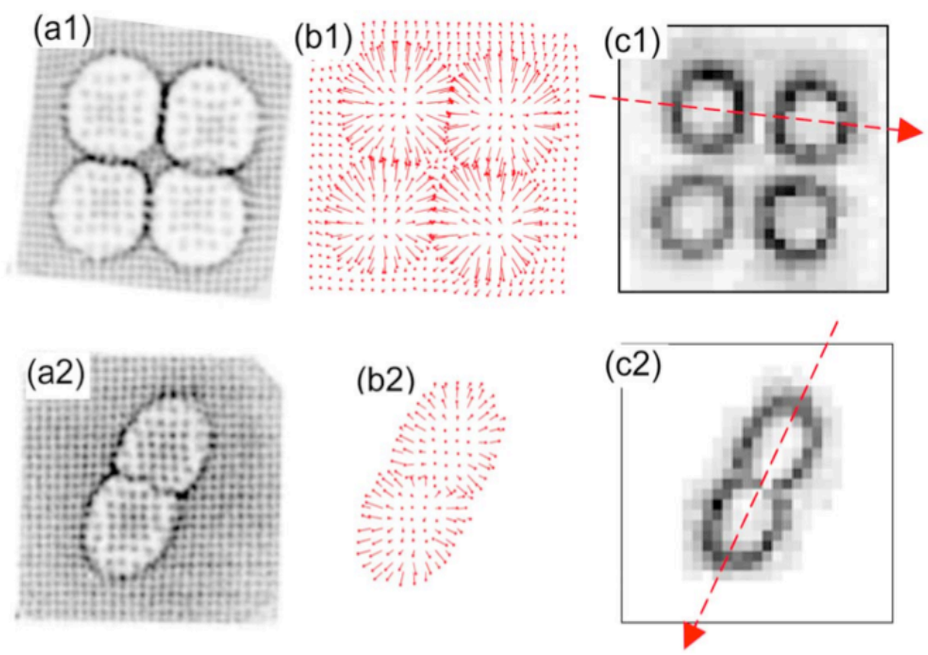
Rutherford [Nilson, *et al* PRL 2006, PoP 2008, Willingale *et al* PoP 2010]



Shenguang [Zhong *et al* Nature Phys 2010]



Omega: [C.K. Li, et al PRL 2007]



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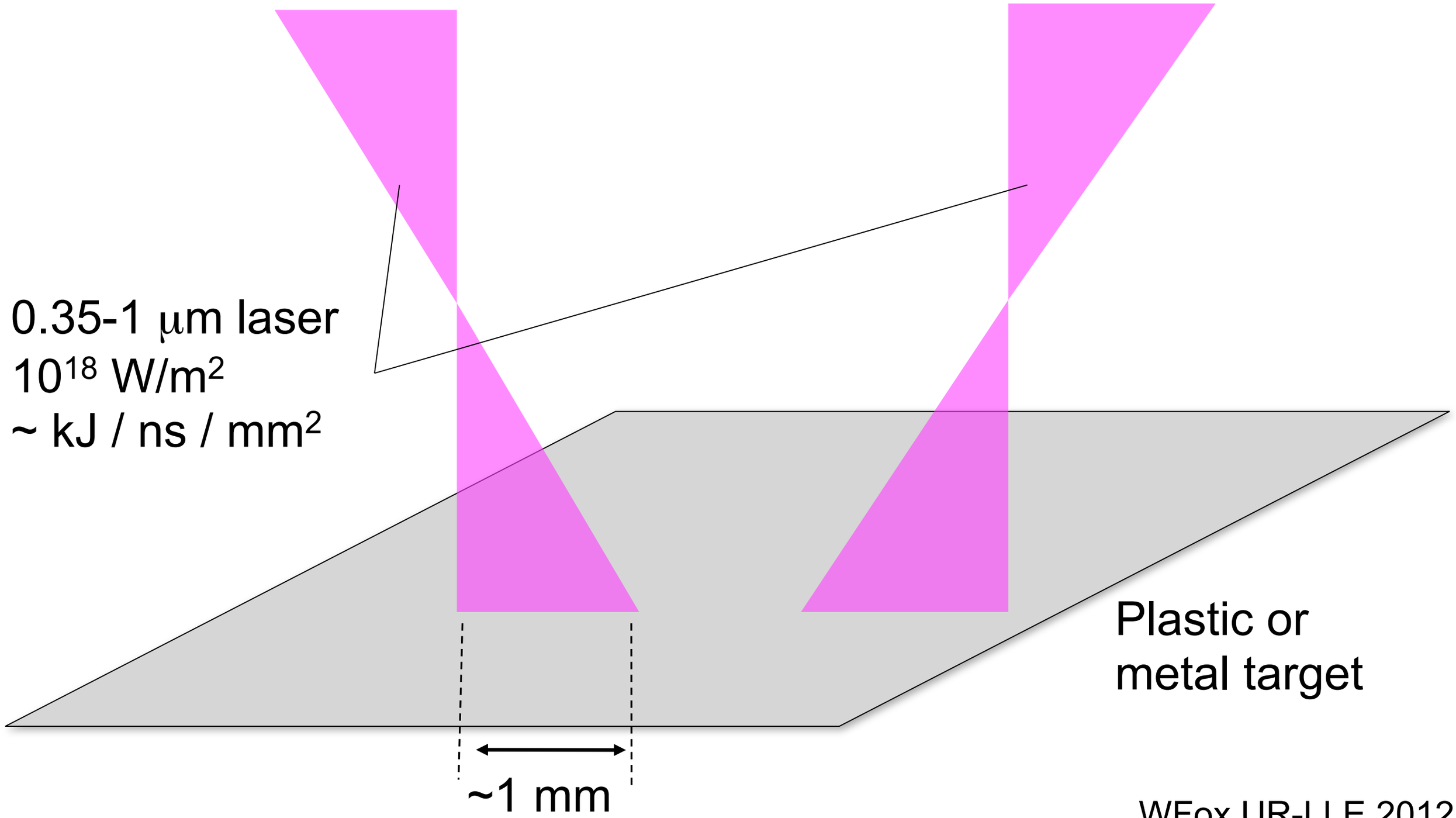
How to make a plasma bubble



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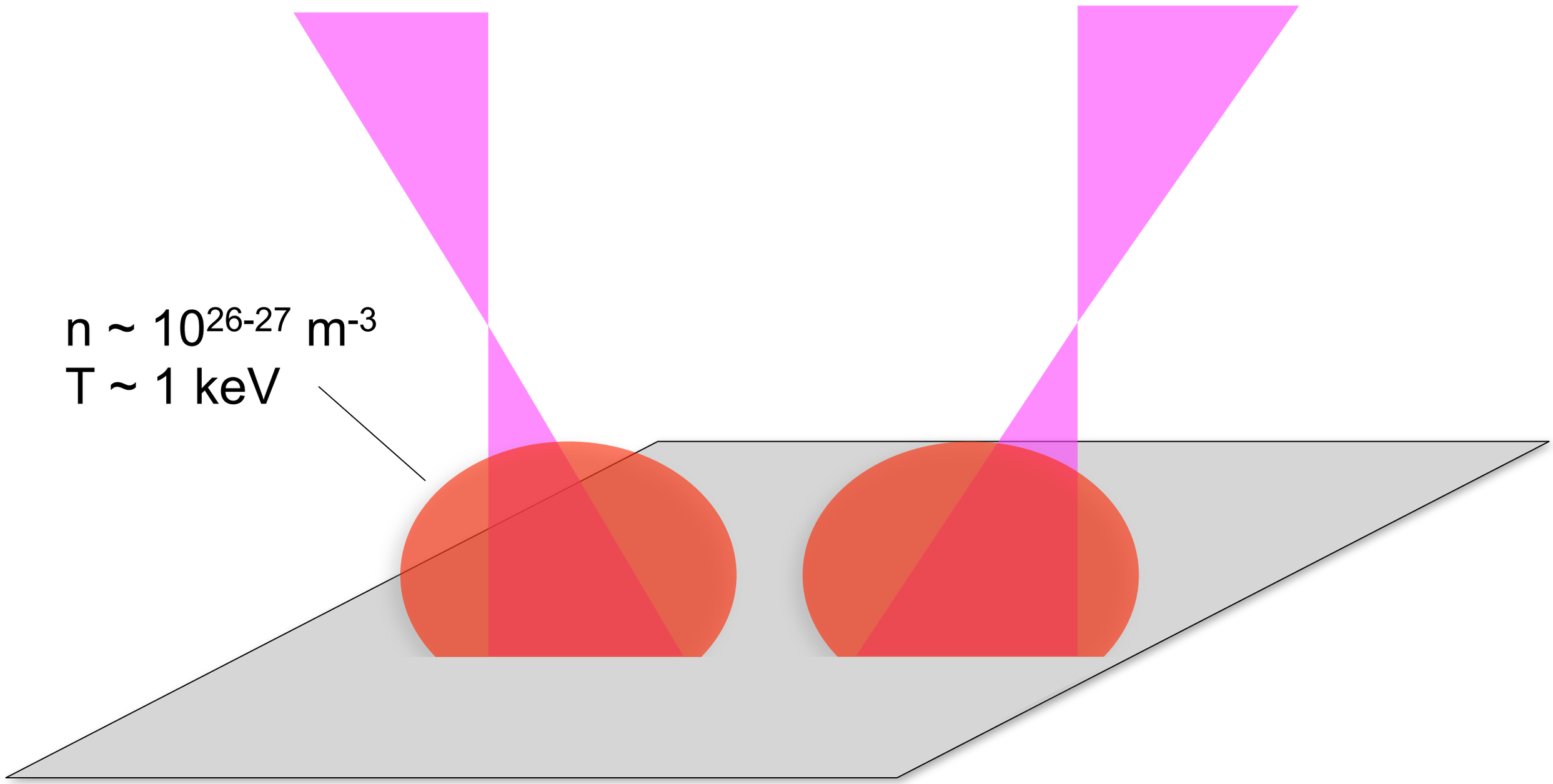

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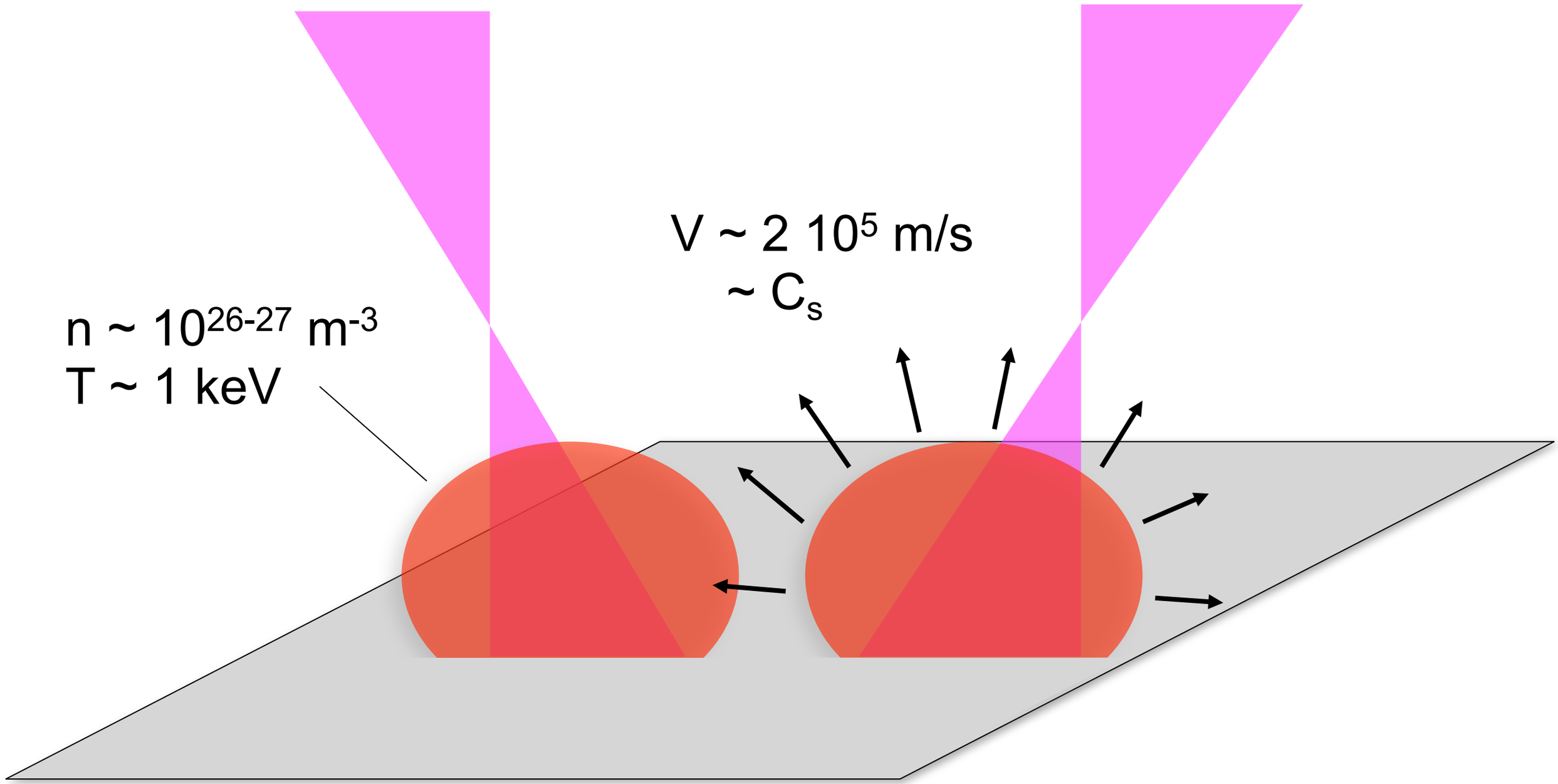
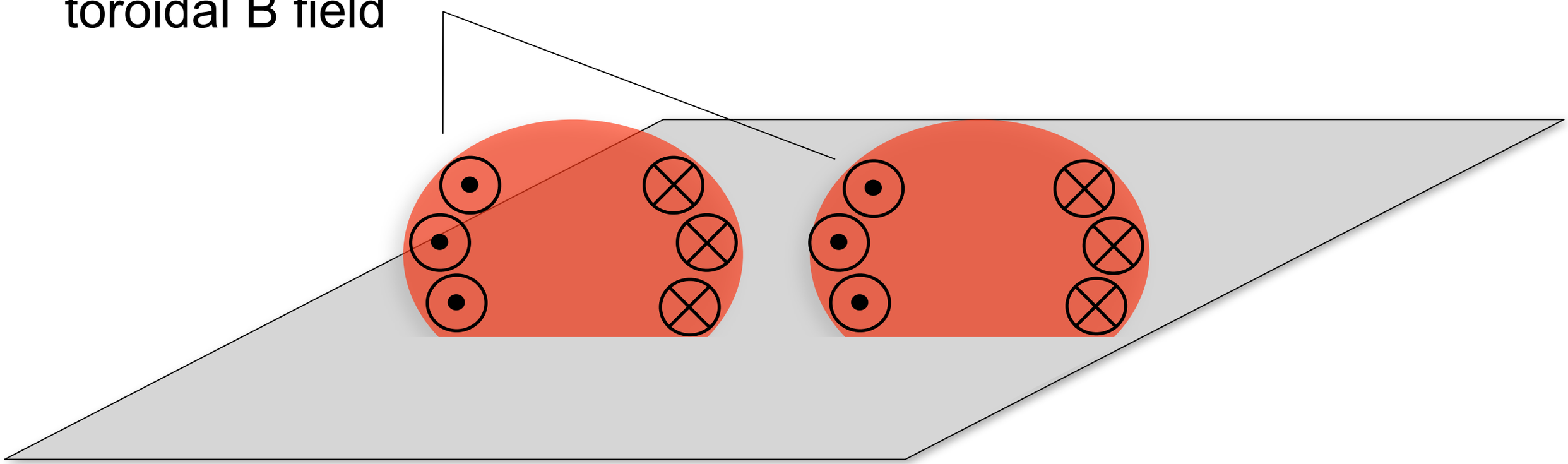


How to make a plasma bubble

~50-100 T ("MG")
toroidal B field



B field generated through a Biermann battery two-fluid effect

$$\frac{\partial B}{\partial t} = \nabla \times (v \times B) - \frac{1}{ne}(\nabla n \times \nabla T)$$

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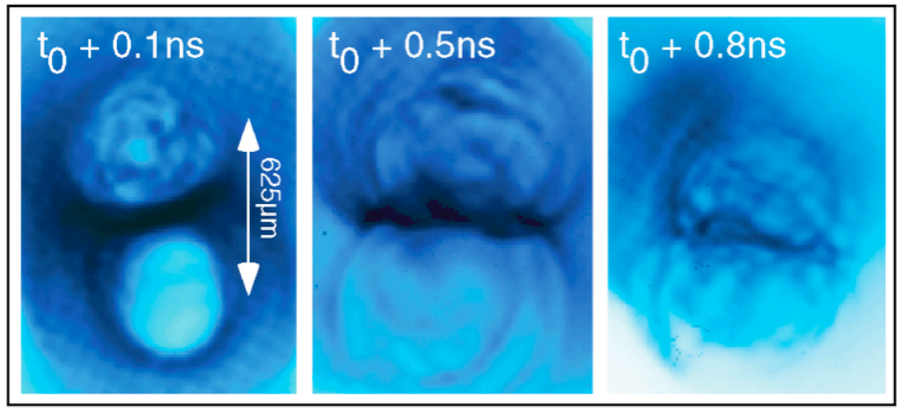
Reconnection observed in driven plasma bubble experiments

Rutherford [Nilson, *et al* PRL 2006, PoP 2008, Willingale *et al* PoP 2010]



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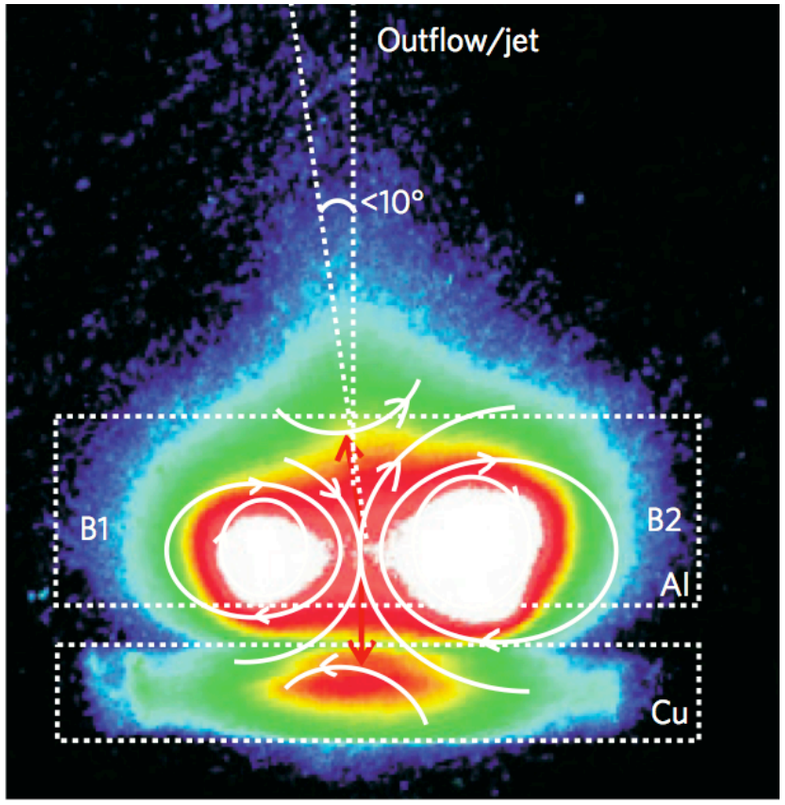

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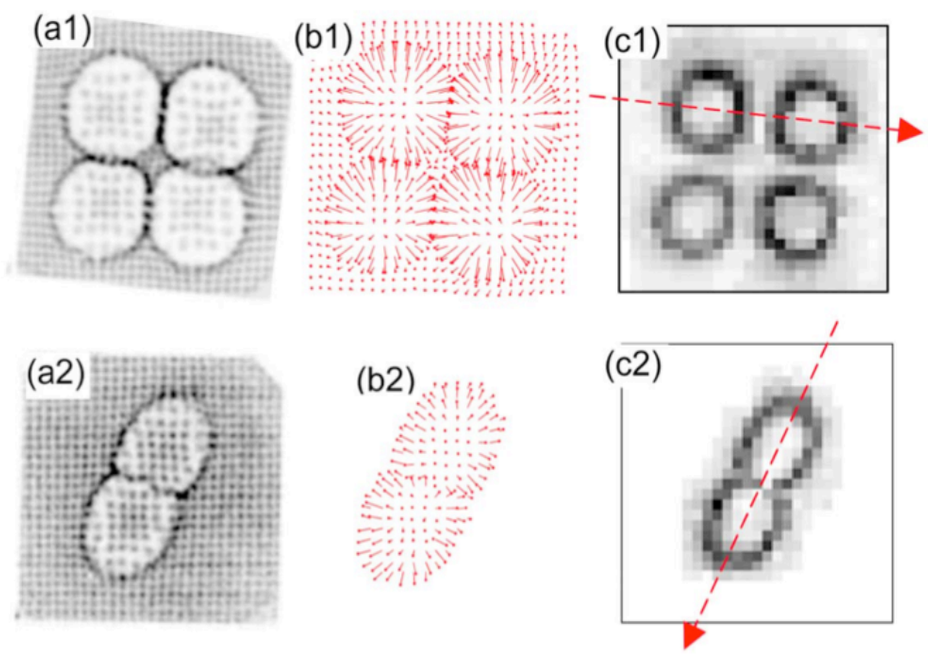

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Outline

- Thoughts on “HED” reconnection regime
- Particle-in-cell modeling of experiments
- Essential ingredients for rate of observed reconnection:
  - magnetic flux pile-up due to very strong reconnection drive.
  - reconnection is mediated by collisionless two-fluid effects (Hall and pressure tensor)
  - at large system size also see the development of islands and breakup of the current sheet
- Proposed reconnection experiments for OMEGA EP
- Ongoing studies.... 3-D reconnection, particle energization, couple better to laser-plasma code, radiation effects

HED reconnection regime

- β ~ 10-100 for laser experiments. β ~ 1 in magnetosphere, << 1 in tokamaks, solar corona

- L/d_i :10-100. Very interesting at high end among lab experiments.

- $V_{in} \sim C_s > V_A$. Very strongly driven, impulsive reconnection
- Experiments find $t_{rec} \sim L/V$
  - Alfvenic - super-Alfvenic reconnection rates

HED reconnection regime

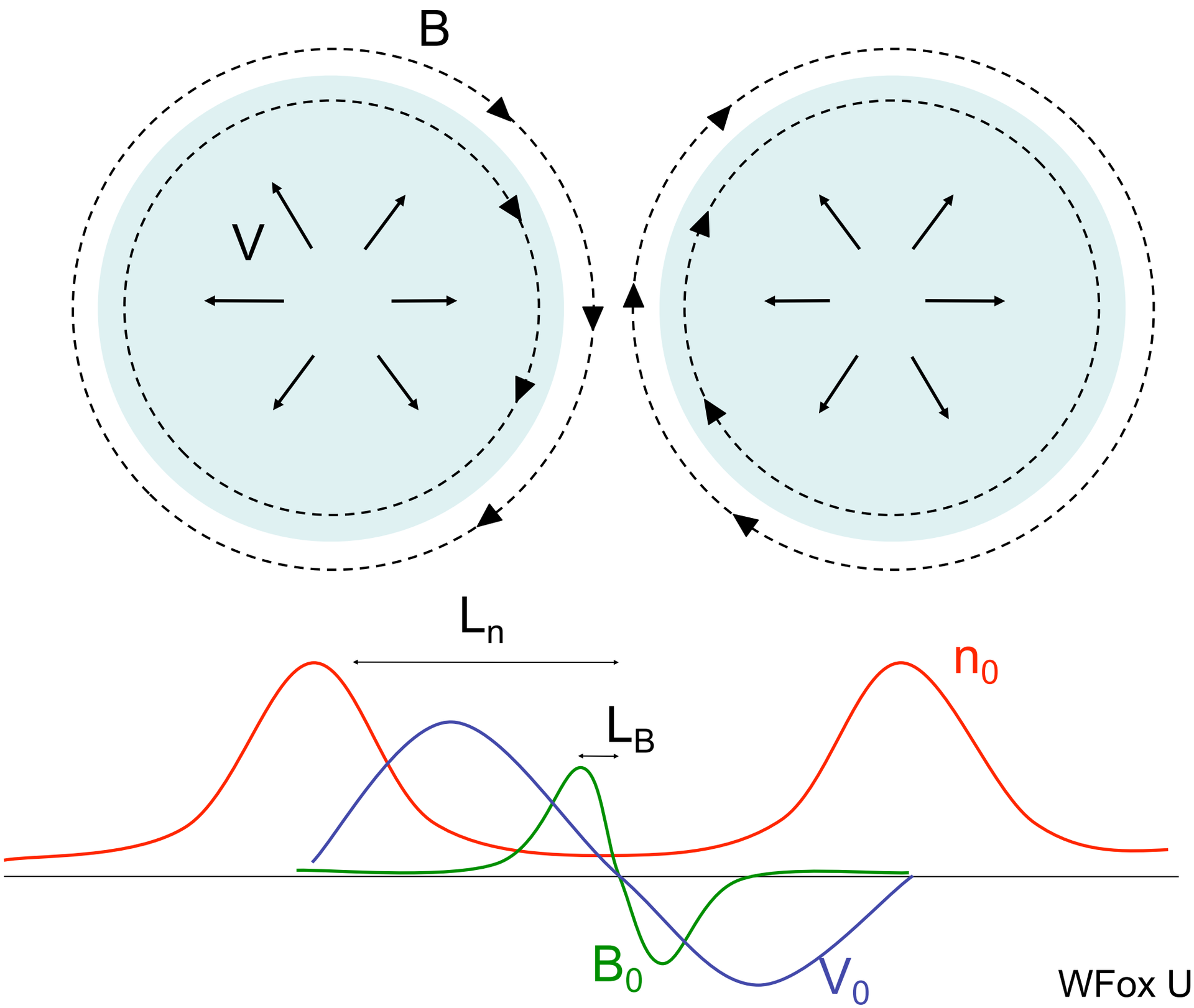
- $L_B / d_i \sim few$. Suggests that two-fluid effects will play a role in reconnection layer.
  - good for improving reconnection rate (via two-fluid effects)

- But reported $V_{in} \sim Cs > 0.1\text{-}0.2\ V_A$ of two-fluid theory!

- (Resolution: consider in more detail time dynamics of current sheet - *flux pileup*)

Reconnection modeling

2D PIC simulations for bubble collisions



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Experiment parameters

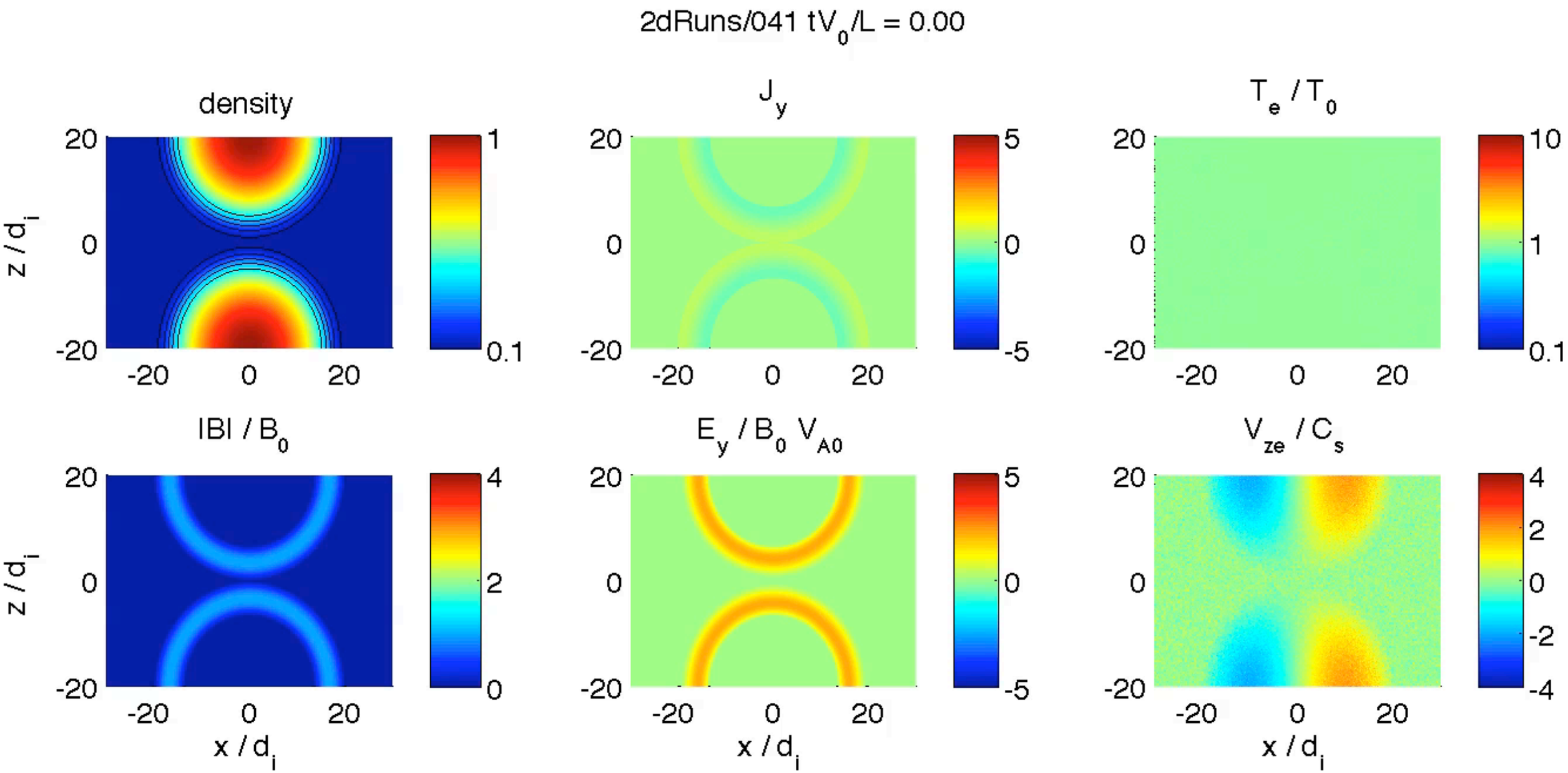
	Rutherford	**Omega**
L_n / d_{i0}	10-20	80
$\beta_0 = 2\, n_0 T / B_0^2$	5	200
L_B / di	~3	~8
V_0 / C_s	2	2
S_0	150	250
n_b / n_0	0.1	0.01

Regime 1:
Rutherford experiments

Experiment parameters

	Rutherford	Omega
L_n/d_{i0}	10-20	80
$\beta_0 = 2\, n_0 T / B_0^2$	5	200
L_B / di	~3	~8
V_0 / C_s	2	2-3
S_0	150	250
n_b / n_0	0.1	0.01

Bubble reconnection simulation



<u>Parameters</u> (Rutherford-like)

- $L_n/d_i = 20$, $L_B/d_i = 3.3$, $V_0 = 2\ C_s$, $\beta_e = 8$

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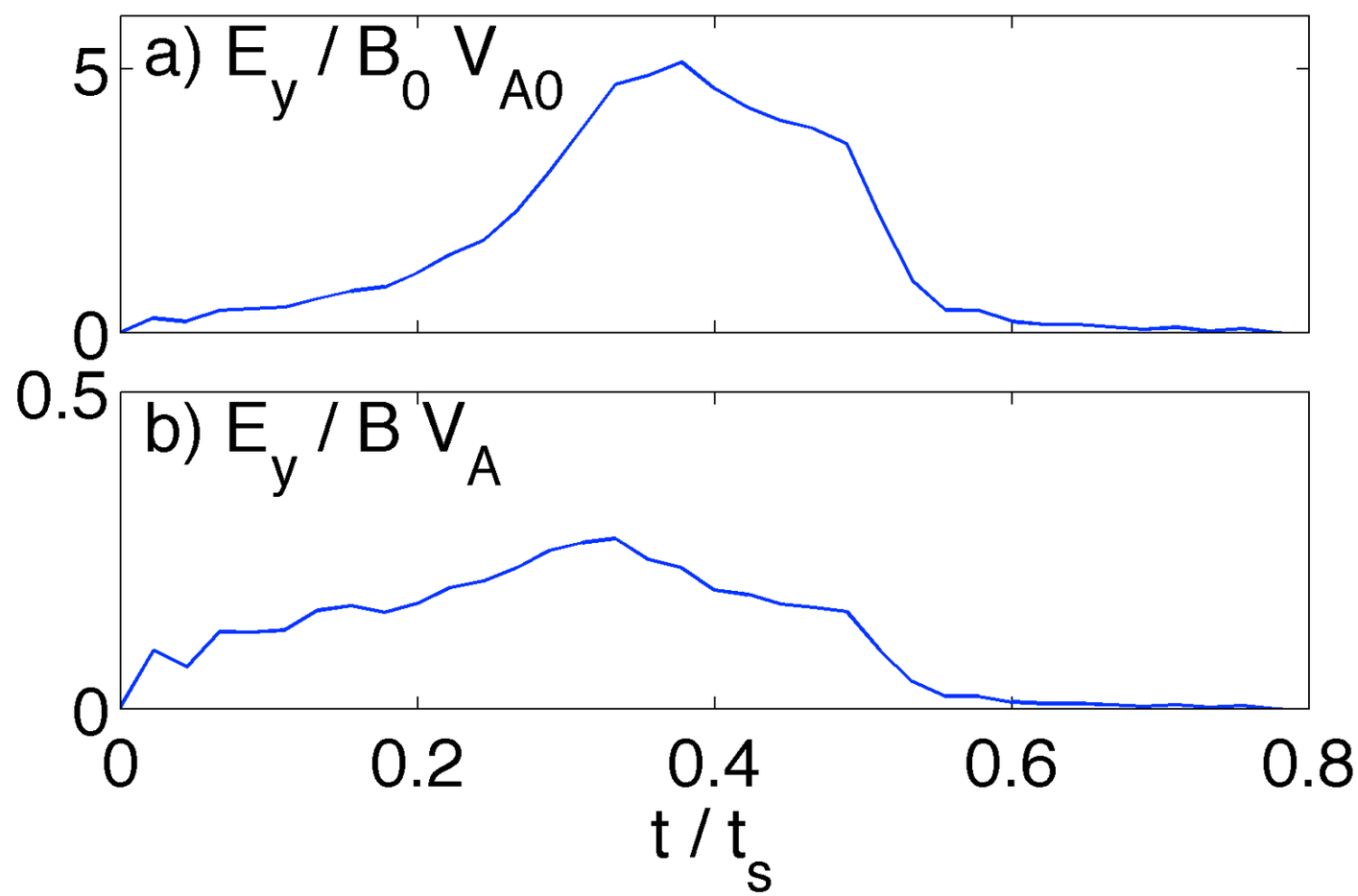
Reconnection super-Alfvenic compared to nominal B_0, V_{A0}

Compare to nominal B_0V_{A0}:

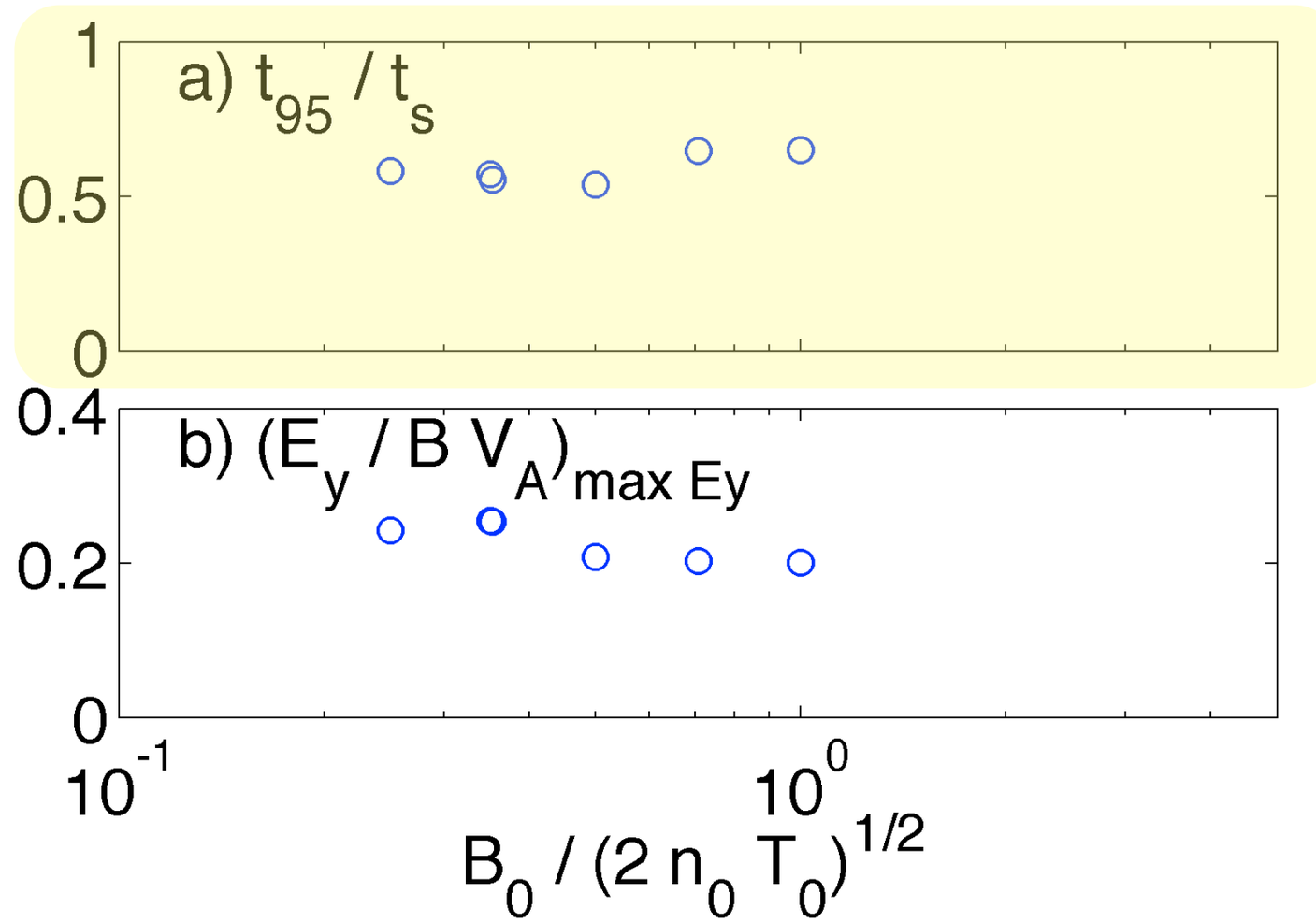
Compare to instantaneous BV_A:



Consequences of flux pileup

Vary initial B_0, but find total reconnection time does not change.

Reconnection independent of nominal V_{A0}



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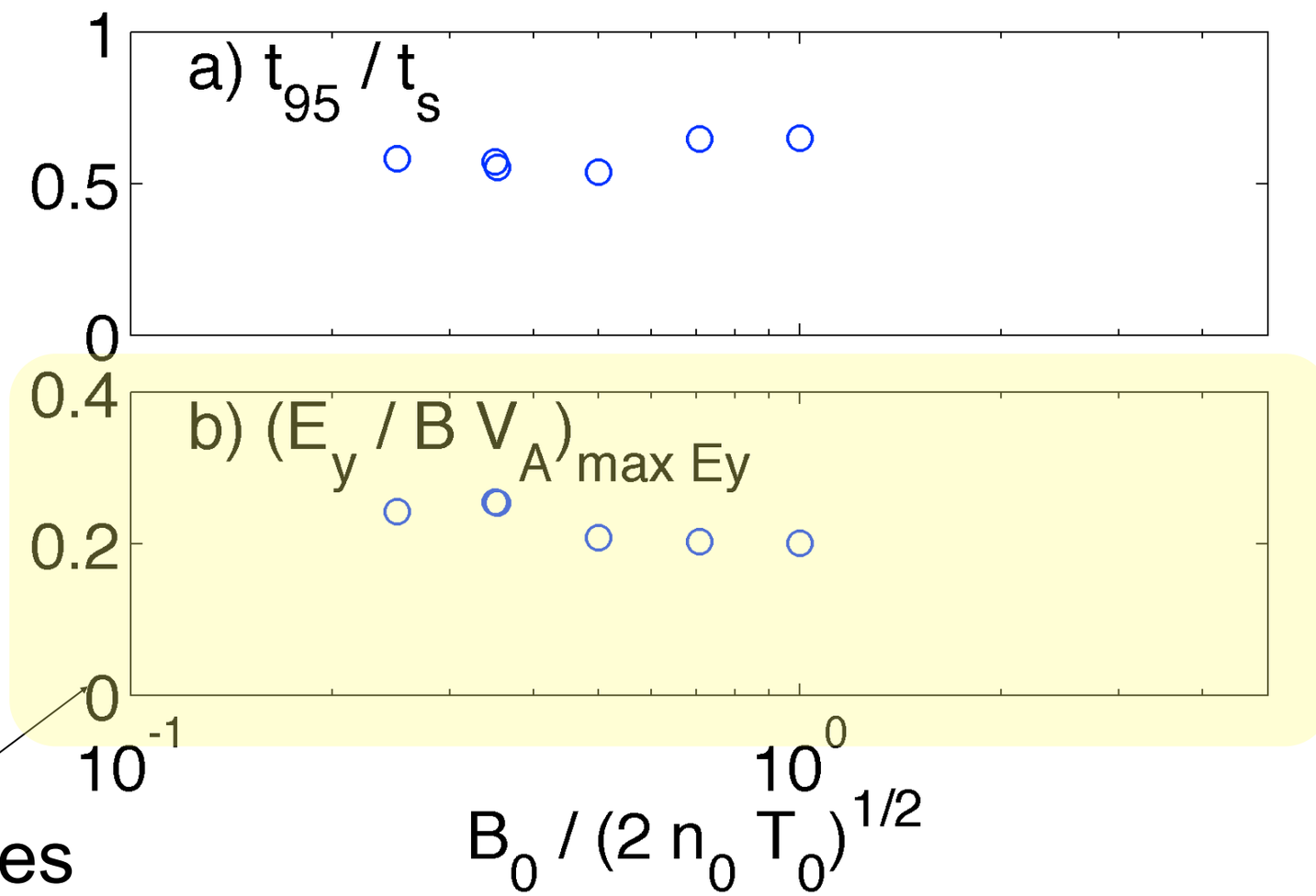
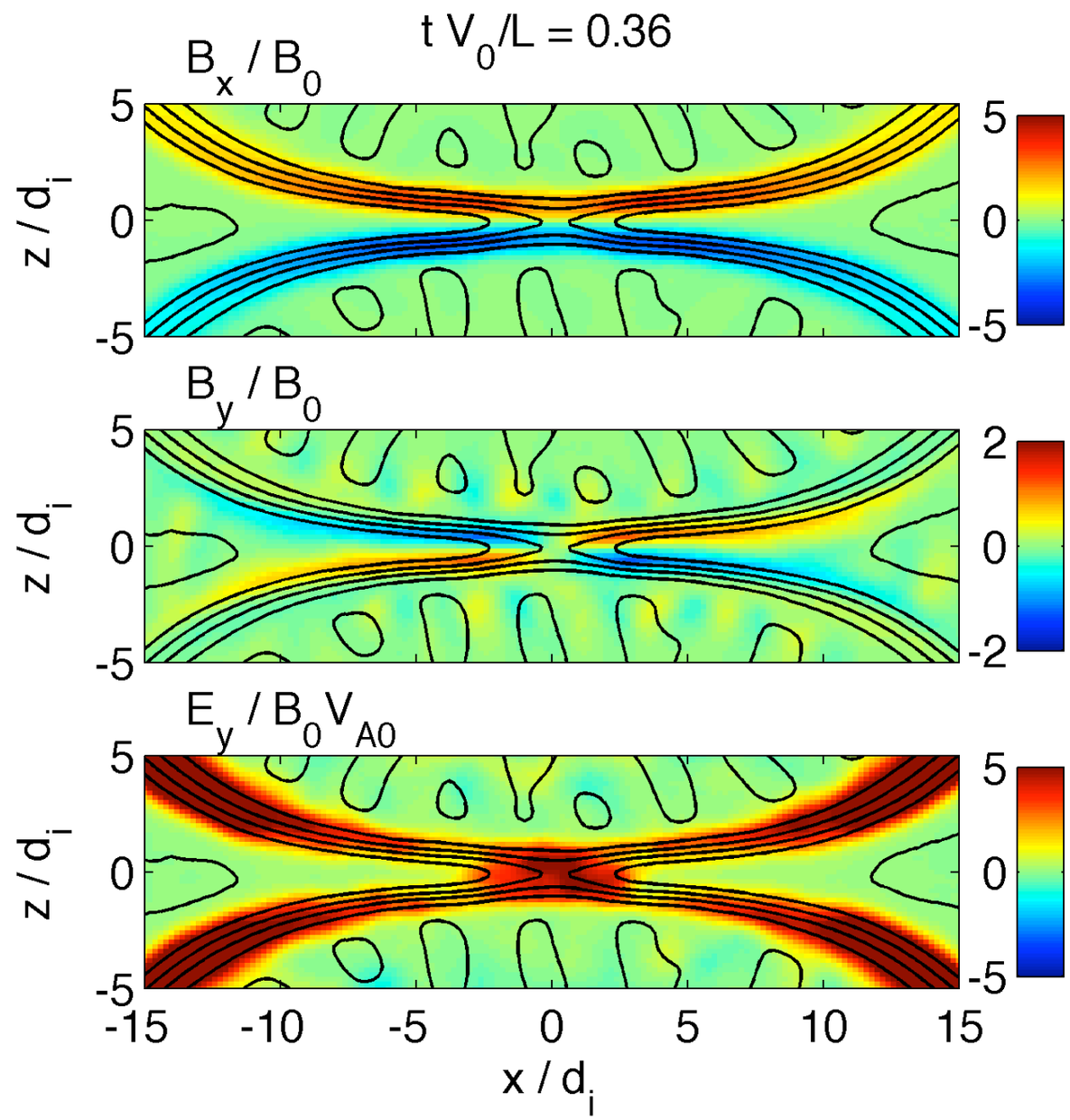


Peak reconnection rate scales with *instantaneous* V_A

[Fox, Bhattacharjee, Germaschewski, PRL (2011)]

Quadrupole “Hall” magnetic field signature observed

$B_{Hall} / B_{up} \sim 40\%$



$V_0 = 3\ C_S,\ L_n = 20\ d_i,\ \beta_{e0} = 8$

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Rutherford results summary

- Recent HED plasma bubble experiments appear to be in a previously inaccessible, strongly-driven reconnection regime with two-fluid effects.

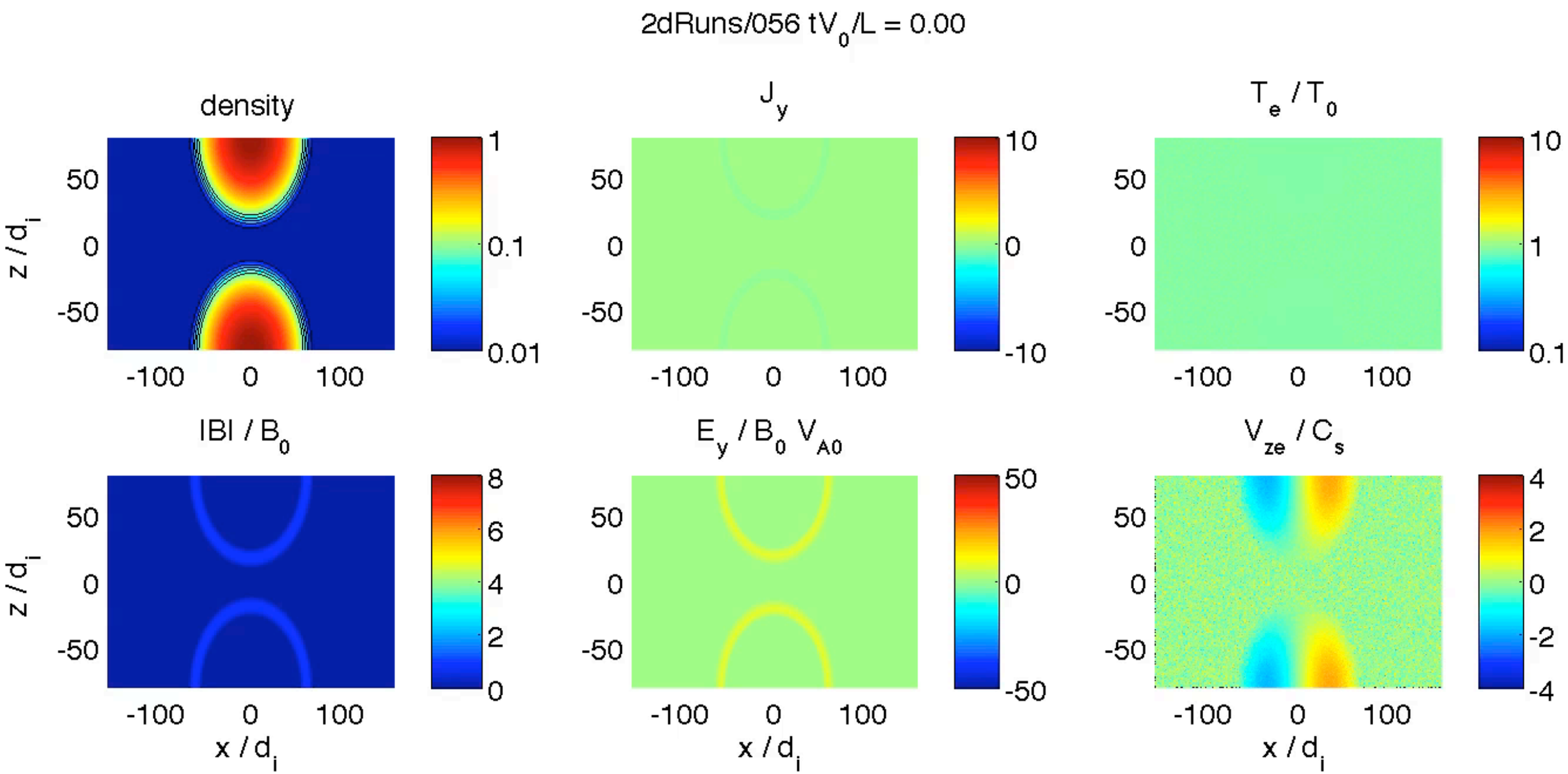
- PIC simulations find reconnection with a combination of pile-up and two-fluid effects, and reconnection times in qualitative agreement with experiments

Regime 2:
OMEGA experiments

Experiment parameters

	Rutherford	**Omega**
L_n/d_{i0}	10-20	80
$\beta_0 = 2\, n_0 T / B_0^2$	5	200
L_B / di	3	8
V_0 / C_s	2	2
S_0	150	250
n_b / n_0	0.1	0.01

OMEGA scale bubbles: reconnection with multiple island formation



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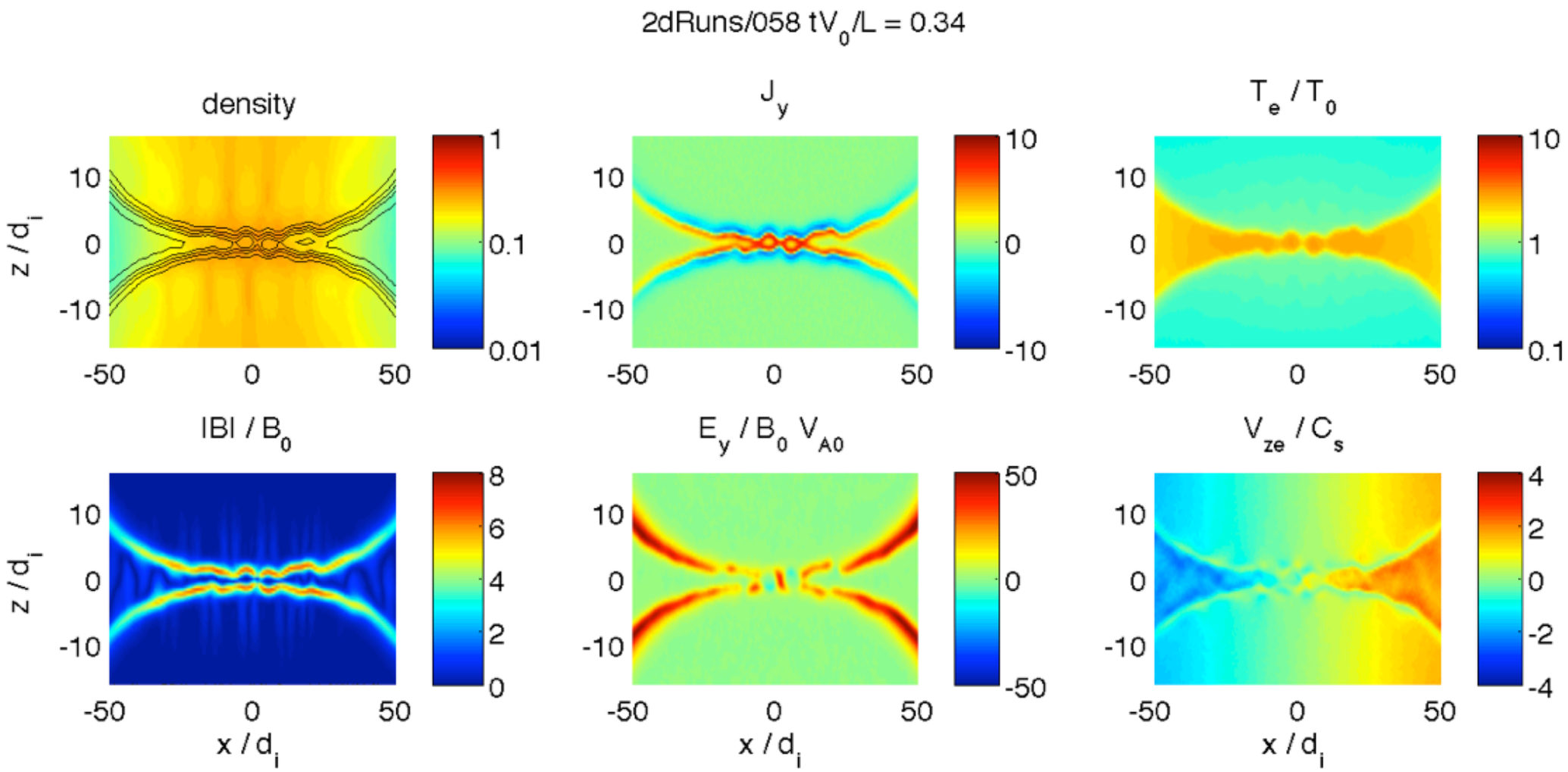
Current sheet properties



n/n_0	~0.25
B/B_0	~6
L/d_{i*}	~40
S^*	~6000
β^*	~6

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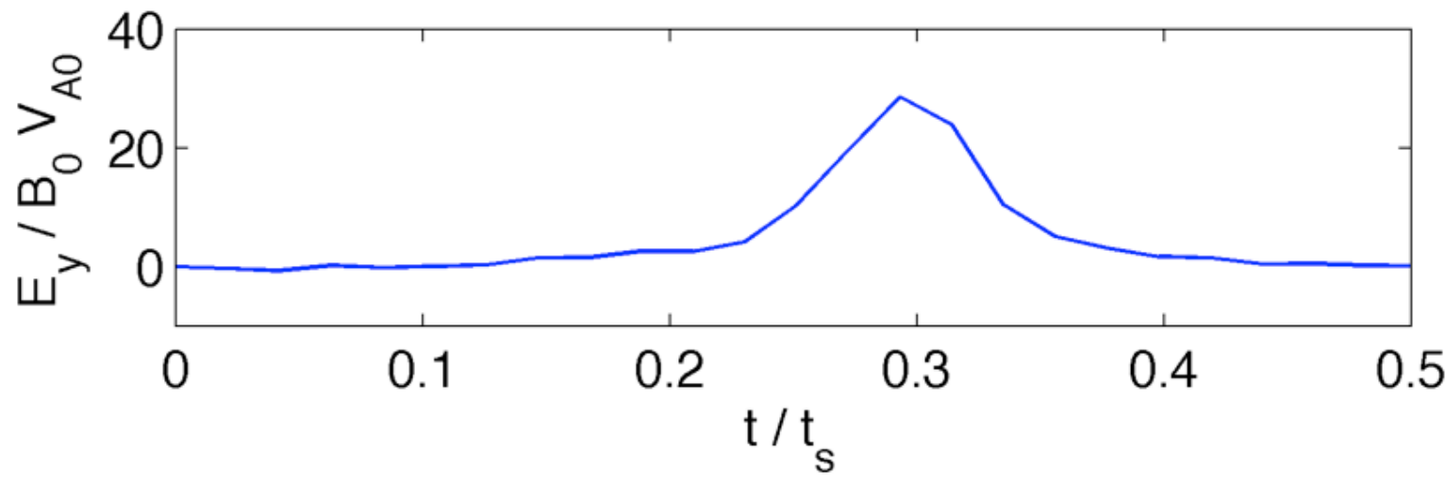
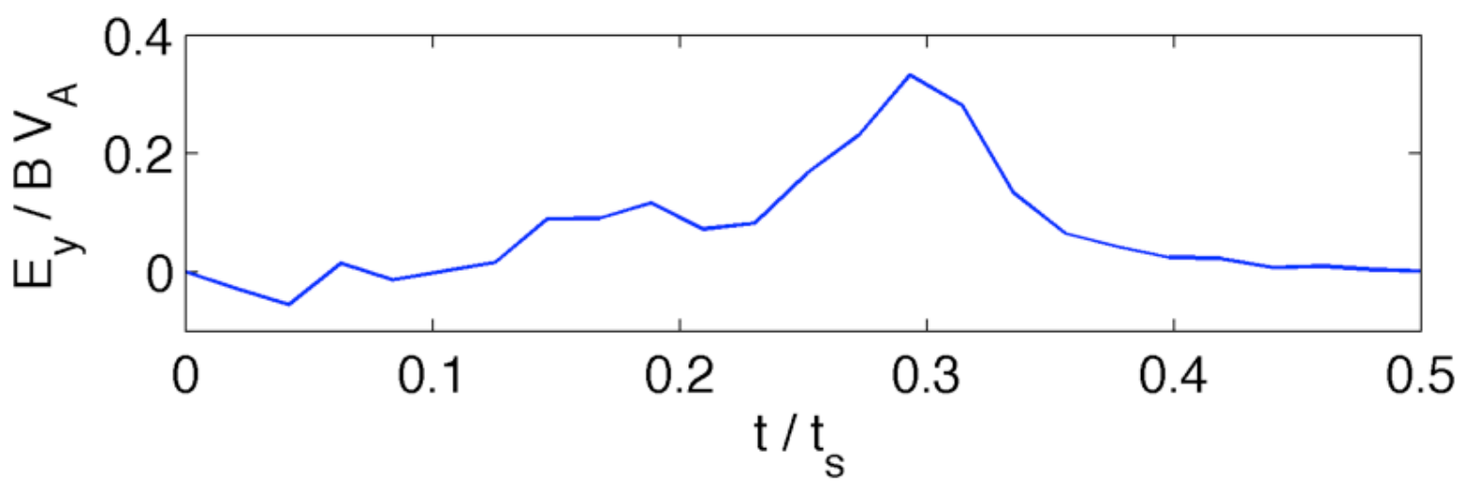
Extremely fast reconnection rates in OMEGA regime

Nominal



Normalized



Summary

- Recent HED plasma bubble experiments appear to be in a previously inaccessible, strongly-driven reconnection regime with two-fluid effects.

- PIC simulations find reconnection with a combination of pile-up and two-fluid effects, and reconnection times in qualitative agreement with experiments

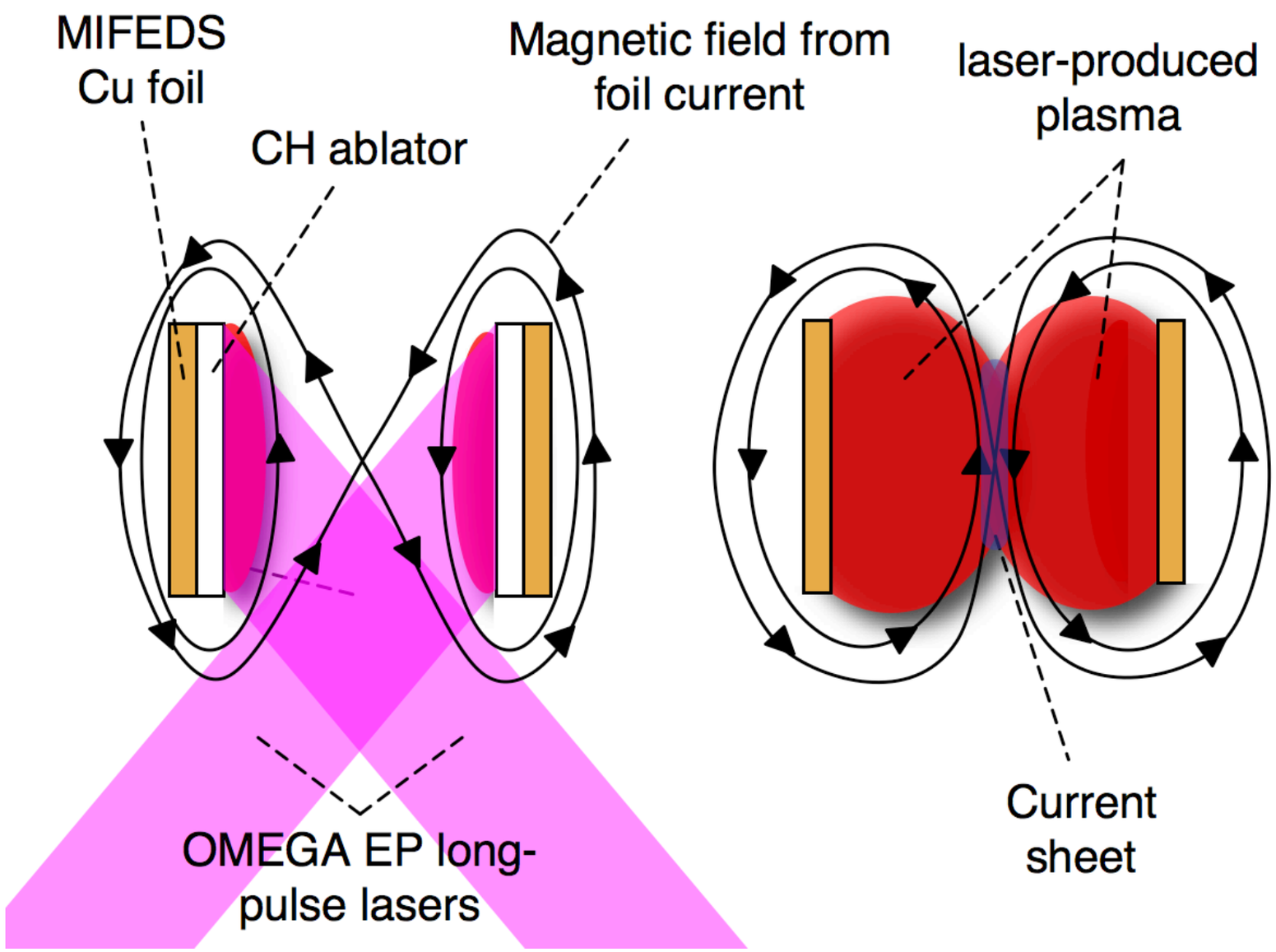
- At large system size (OMEGA), the current sheets are found to break up, and form multiple islands.

[Fox et al PRL 2011, PoP 2012 (submitted)]

Prospects for laser-driven reconnection experiments

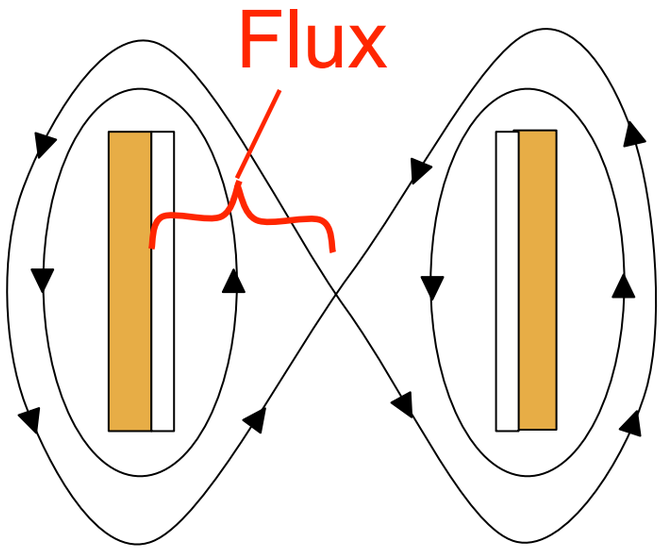
- Possibility to reach and study reconnection in a wide range of L/di (maybe 100-200?) and high S regimes
- Test predictions of flux pile-up, island formation (will require further experimental and diagnostic creativity)

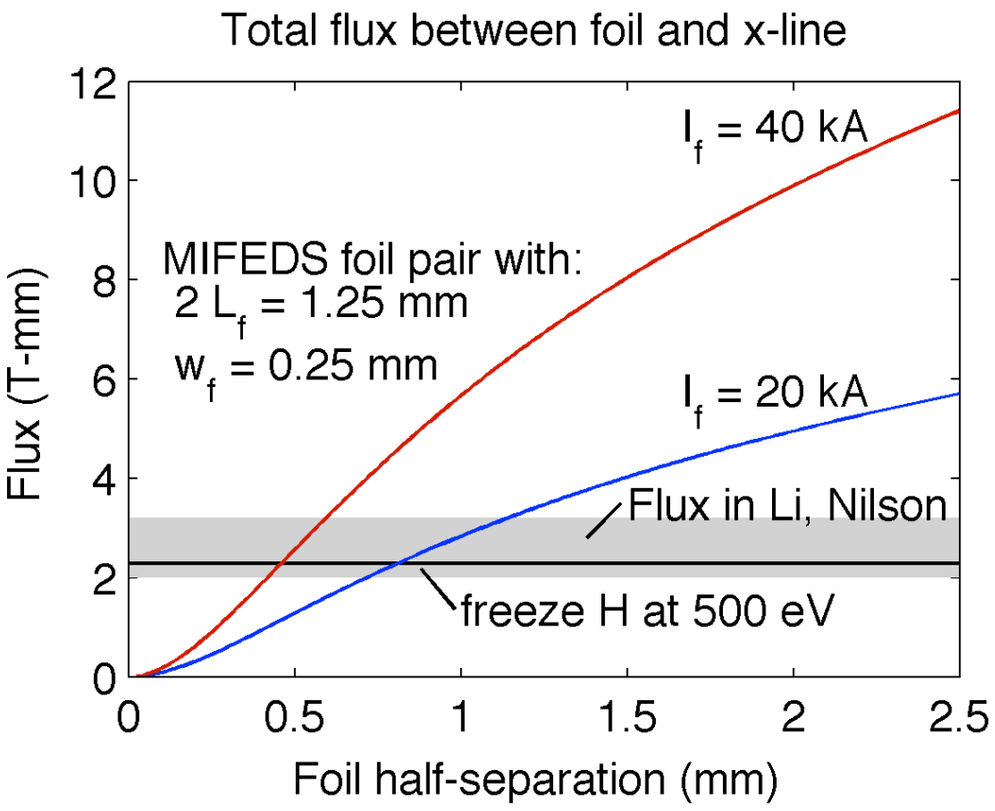
Newly proposed experiments (in collaboration with G. Fiksel, P. Nilson, Rochester LLE)



Comparison with previous bubble reconnection experiments

- Quasi-2d geometry
- MIFEDS: control, vary magnetic flux available for reconnection
- Null experiment: B = 0
- Eventually study **guide field** reconnection.





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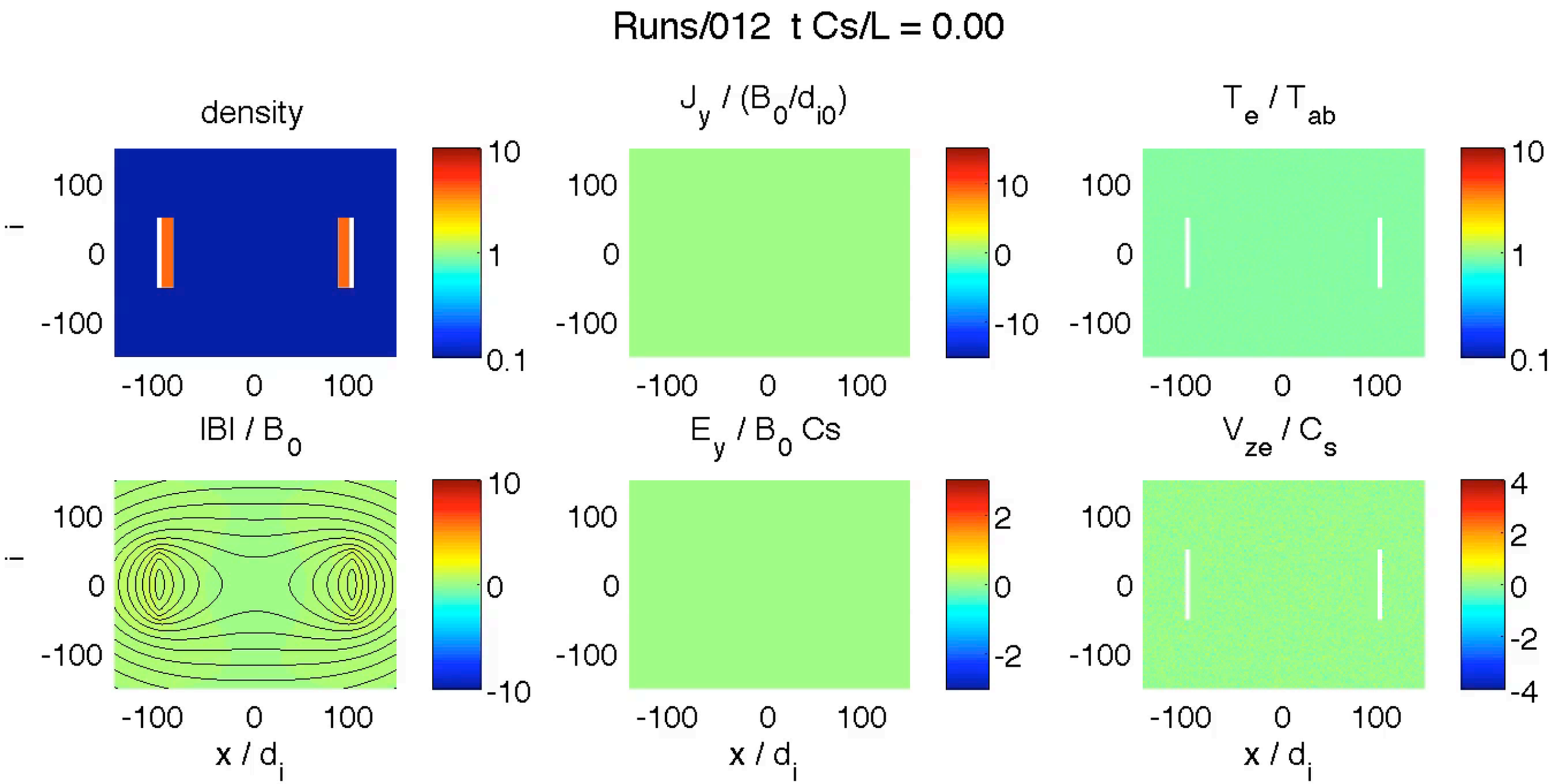
Prospects for laser-driven reconnection experiments

- Possibility to reach and study reconnection in a wide range of L/di (maybe 100-200?) and high S regimes
- Test predictions of flux pile-up, island formation (will require further experimental and diagnostic creativity)

- MIFEDS-based experiment:
  - control magnetic flux available for reconnection (from 0 to more than available from Biermann fields)

- Further knobs (e.g. collisionality, separation) are being explored through further detailed computation

MIFEDS reconnection simulation



Parameters: $\beta_0 = 200$, $L_f / d_i = 50$, $L_{sep} / L_f = 2$, $S = \infty$

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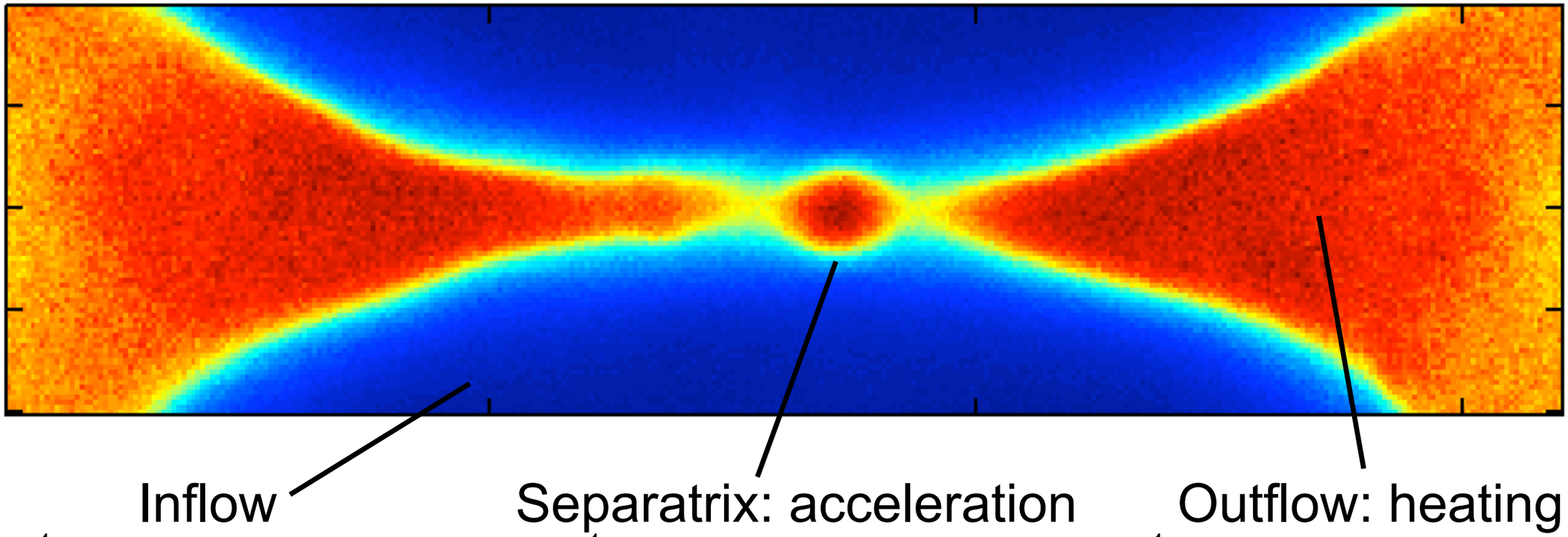
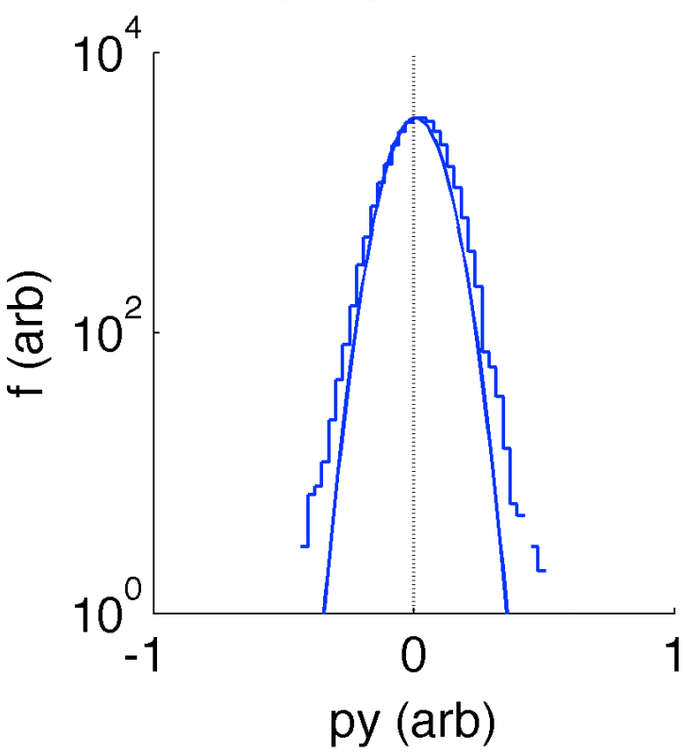
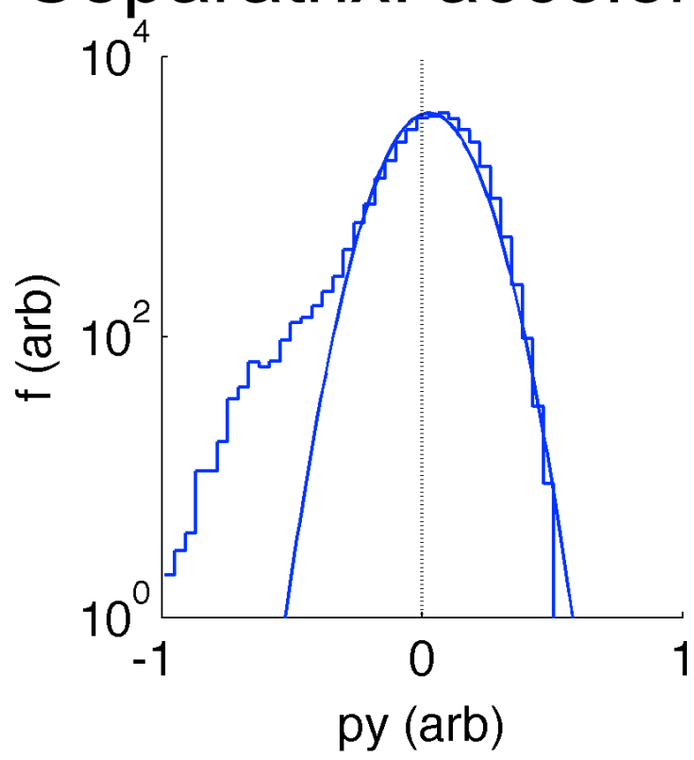
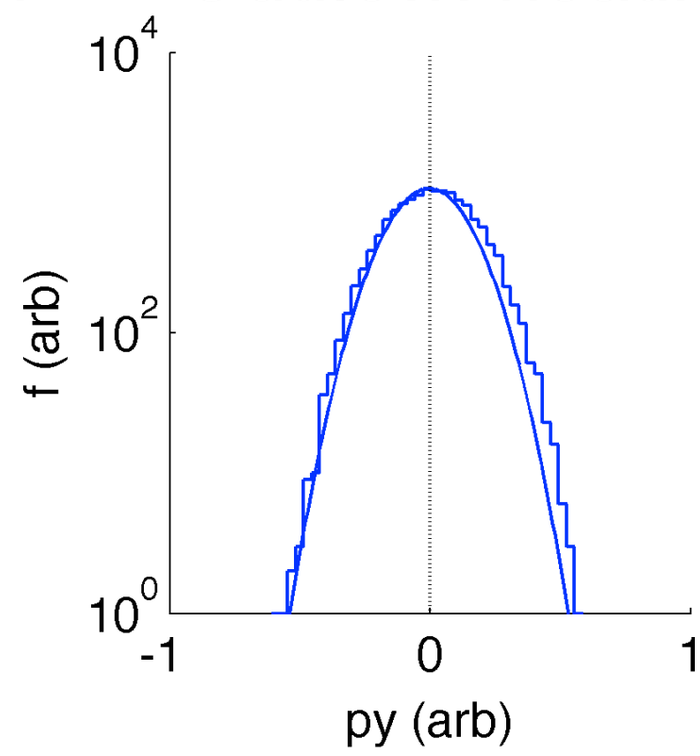
(PRELIMINARY) particle energization









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