The impact of geometrical constraints on collisionless magnetic reconnection

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Purpose

- Determine the structure of the outflow current sheet depending on external constraints
- Determine current distribution between ions and electrons
- Determine acceleration mechanism to sustain current density

Basics: Momentum Input

$$\frac{\partial n_i \vec{v}_i}{\partial t} + \nabla \cdot (n_i \vec{v}_i \vec{v}_i) = \frac{e n_i}{m_i}\left(\vec{E} + \vec{v}_i \times \vec{B}\right) - \frac{1}{m_i} \nabla \cdot \overleftrightarrow{P}_i$$

$$\frac{\partial n \vec{v}_i}{\partial t} + \frac{m_e}{m_i}\frac{\partial n \vec{v}_e}{\partial t} = \frac{1}{m_i} \nabla \cdot \left[\frac{\vec{B}\vec{B}}{\mu_o} - m_i n \vec{v}_i \vec{v}_i - m_e n \vec{v}_e \vec{v}_e - \left(\overleftrightarrow{P}_i + \overleftrightarrow{P}_e + \frac{B^2}{2\mu_o} \overleftrightarrow{1} \right) \right]$$

$$\frac{d}{dt} \int_V dV \left(n \vec{v}_i + \frac{m_e}{m_i} n \vec{v}_e \right) =$$

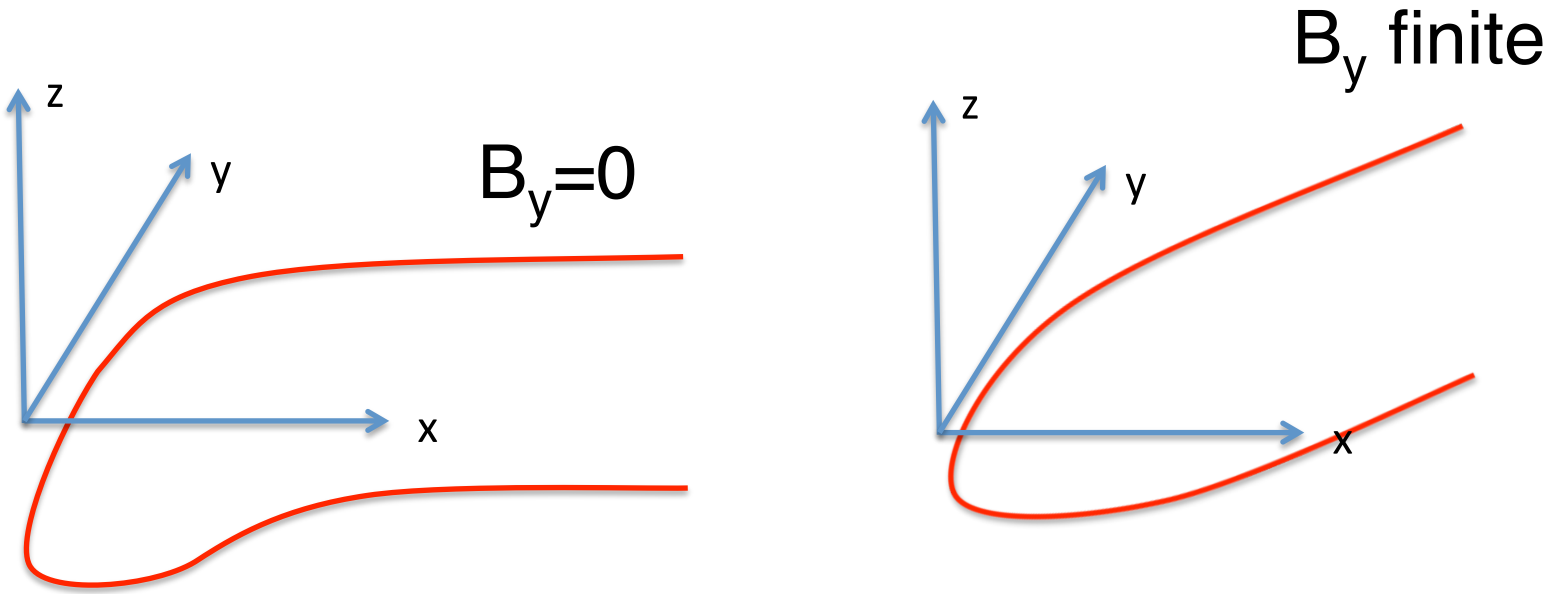
$$\vec{M} = \frac{1}{m_i} \oint_{\partial V} dS \left[\frac{\vec{B} B_n}{\mu_o} - m_i n \vec{v}_i v_{in} - m_e n \vec{v}_e v_{en} - \left(\overleftrightarrow{P}_i + \overleftrightarrow{P}_e + \frac{B^2}{2\mu_o} \overleftrightarrow{1} \right) \cdot \vec{e}_n \right]$$

Basics: Momentum Input

$$\frac{d}{dt}\int_V dVn\vec{v}_i = \frac{m_i}{m_i + m_e}\left(\vec{M} + \frac{m_e}{em_i}\frac{d\vec{I}}{dt}\right)$$

$$\frac{d}{dt}\int_V dVn\vec{v}_e = \frac{m_i}{m_i + m_e}\left(\vec{M} - \frac{1}{e}\frac{d\vec{I}}{dt}\right)$$

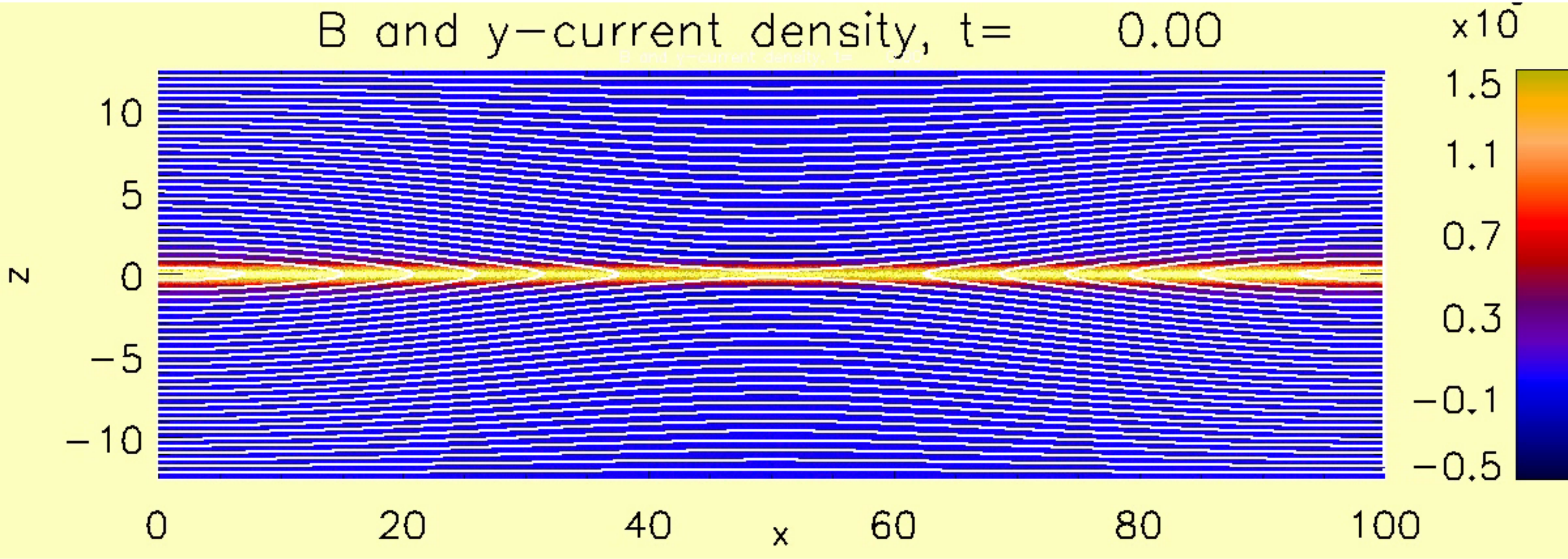
Geometry



Method

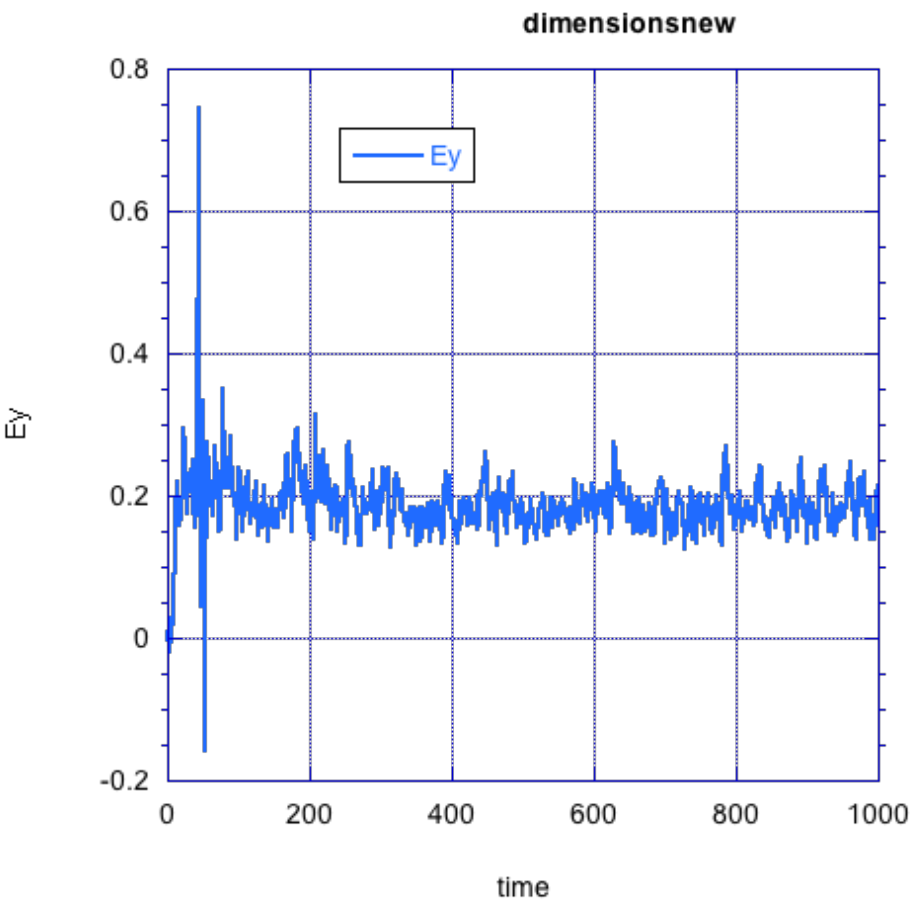
- Open BC PIC simulations
- One simulation with guide field set to zero at outflow boundaries
- 1600x800 cells, 2×10^8 particles
- Inflow density n=0.2, $T_e = T_i$, $T_e + T_i = 1/8$
- One simulations with free BC for guide field
- Constant driving with $E_y = 0.2$
- $m_i/m_e = 25$

B_y=0 Simulation

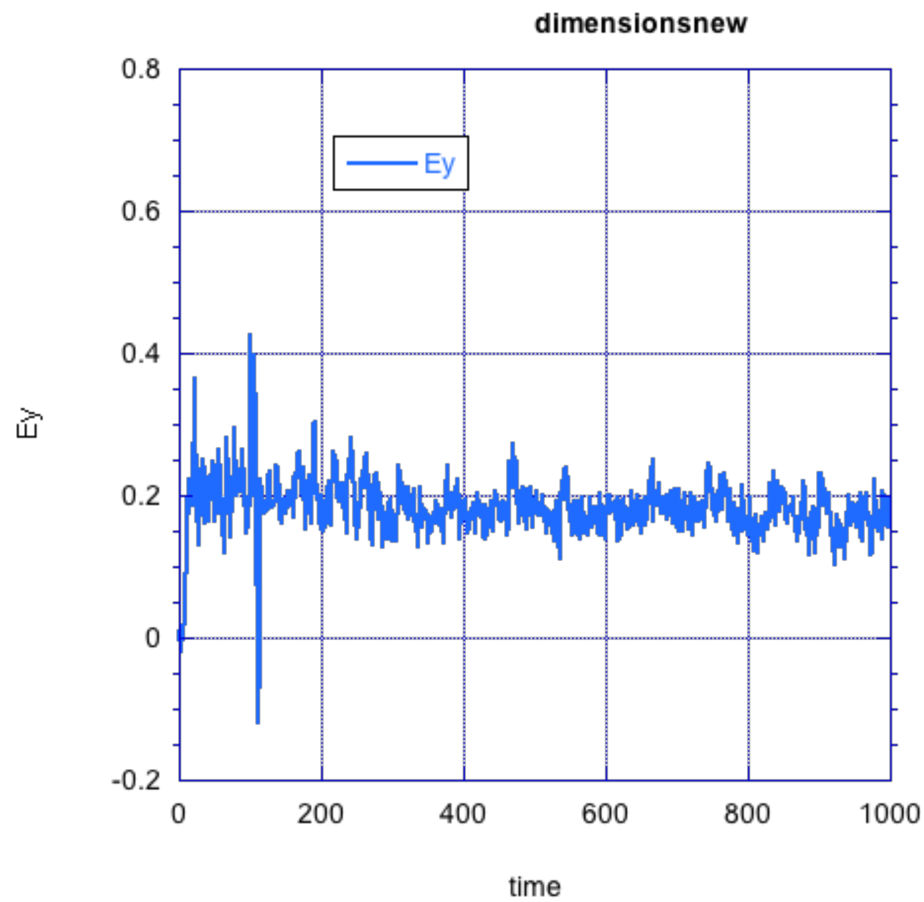


E_y Evolution

B_y=0

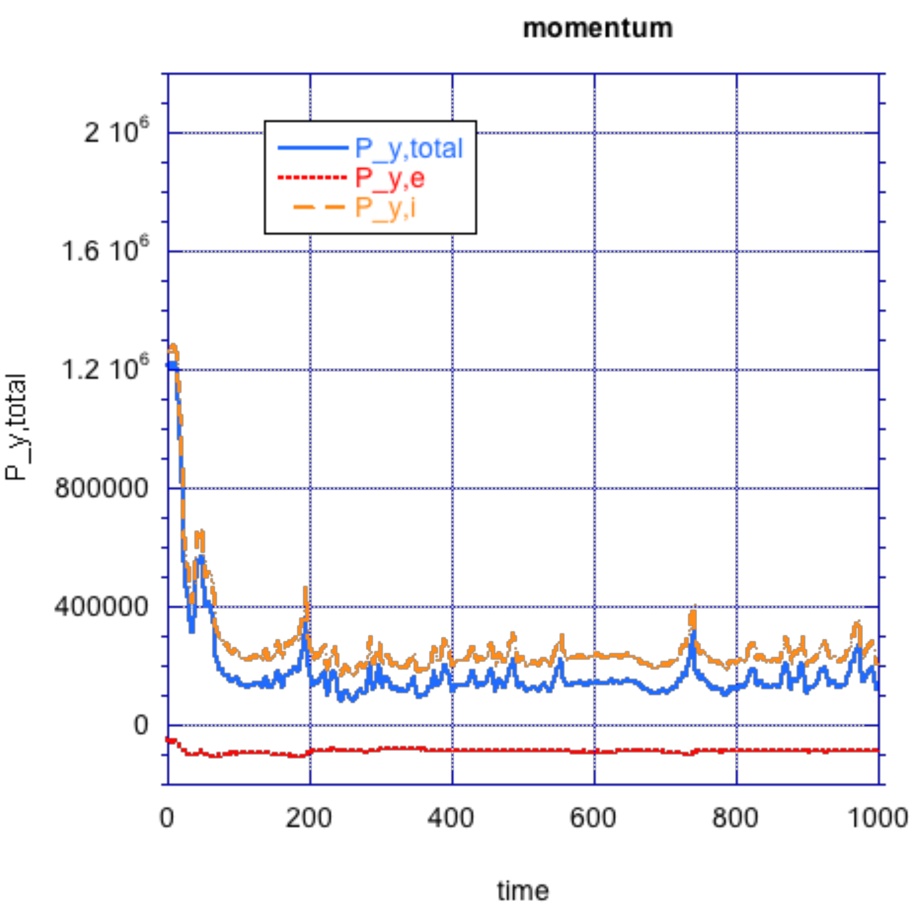


B_y finite

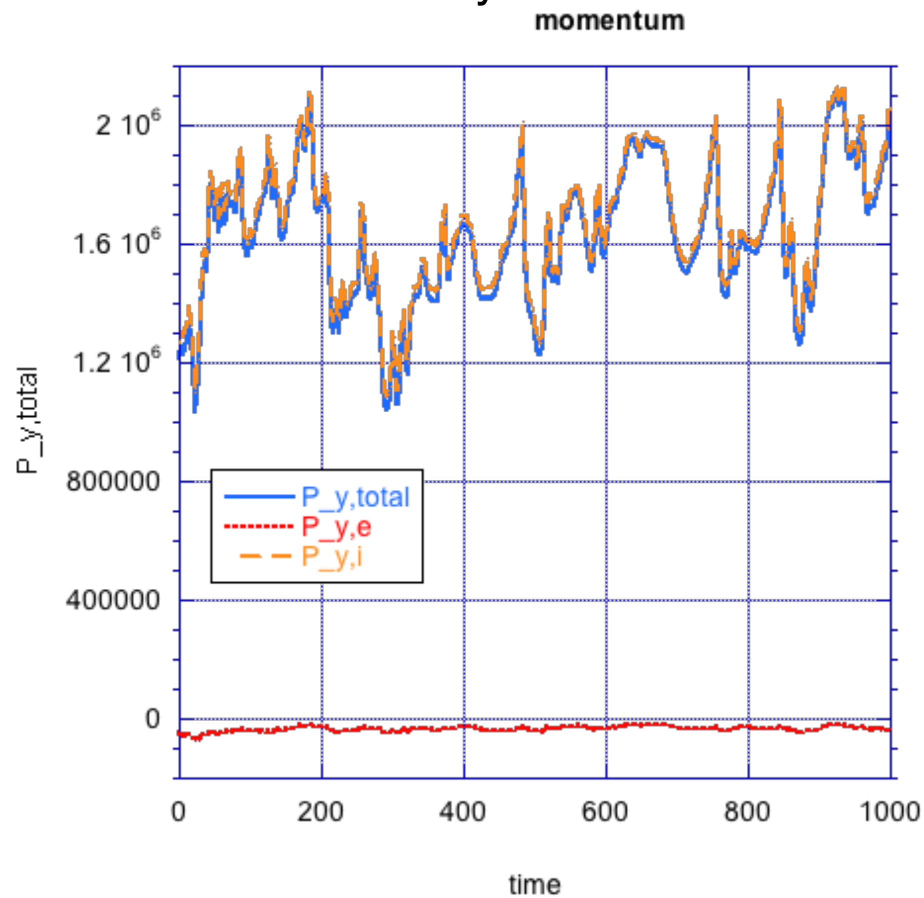


y-Momentum Evolution

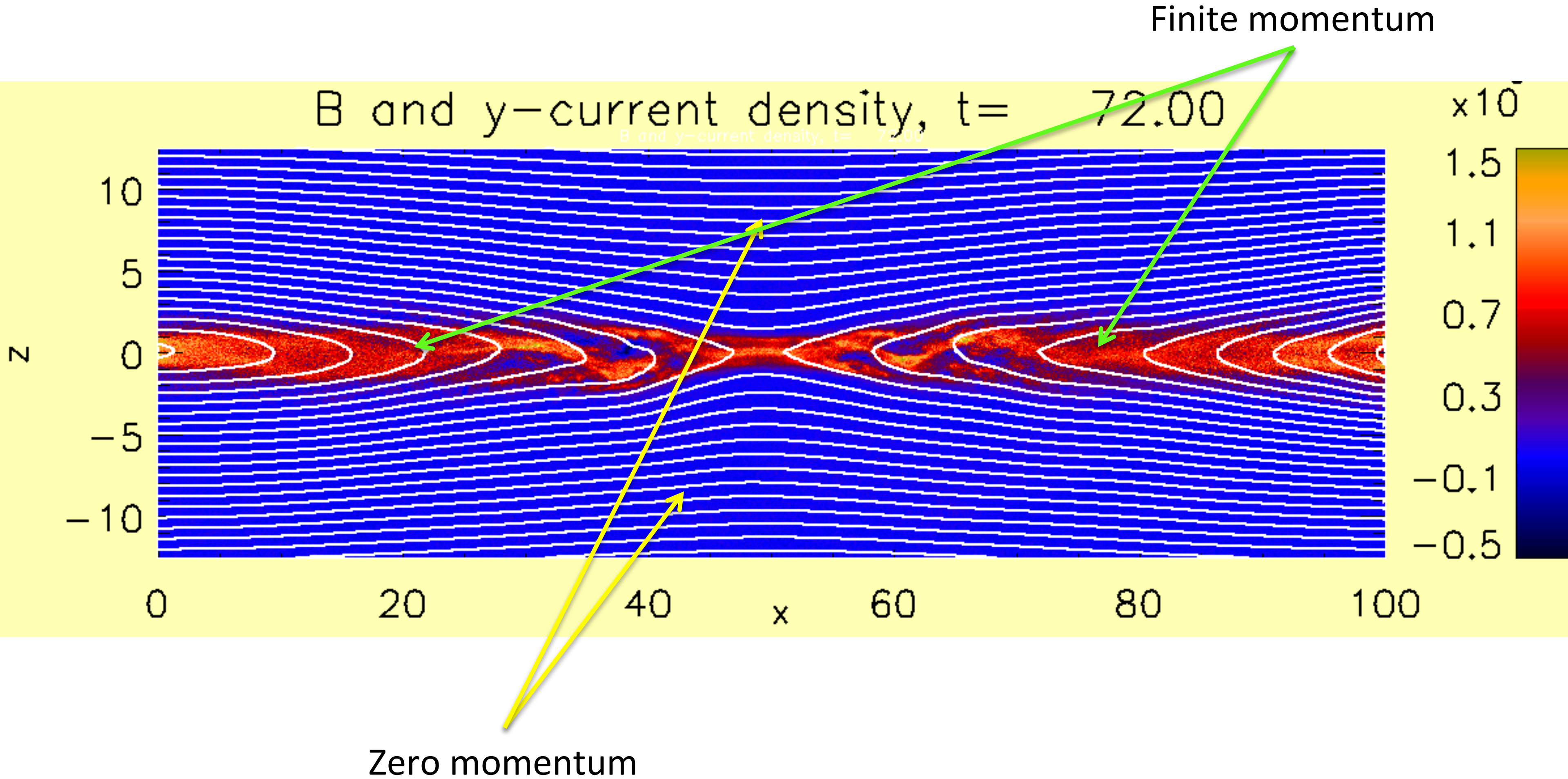
B_y=0



B_y finite



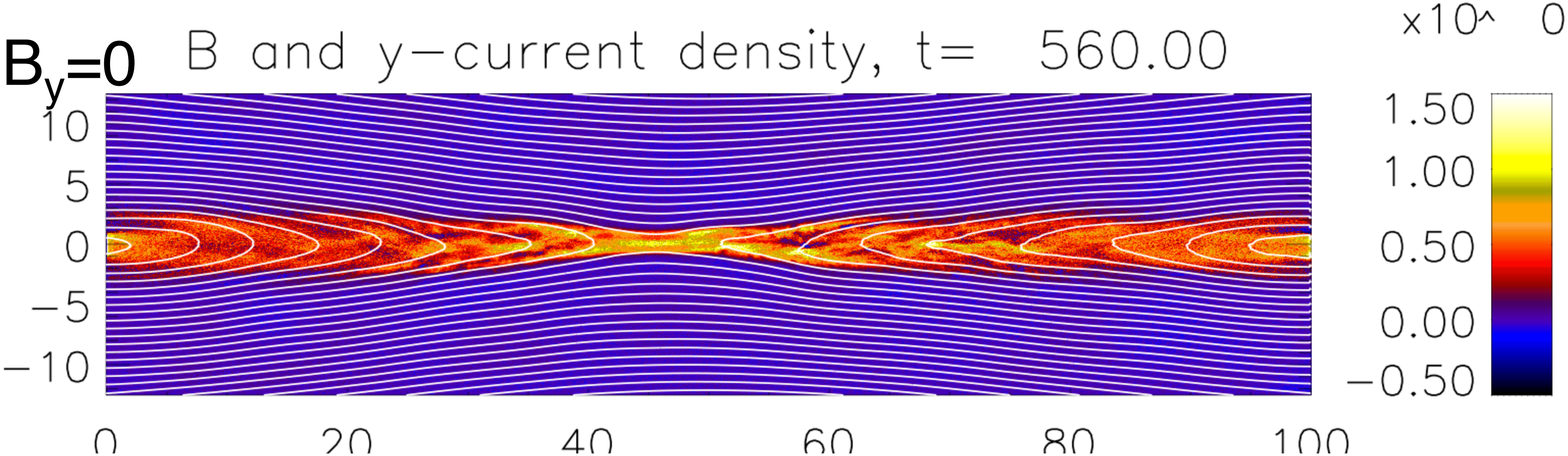
Basic Question



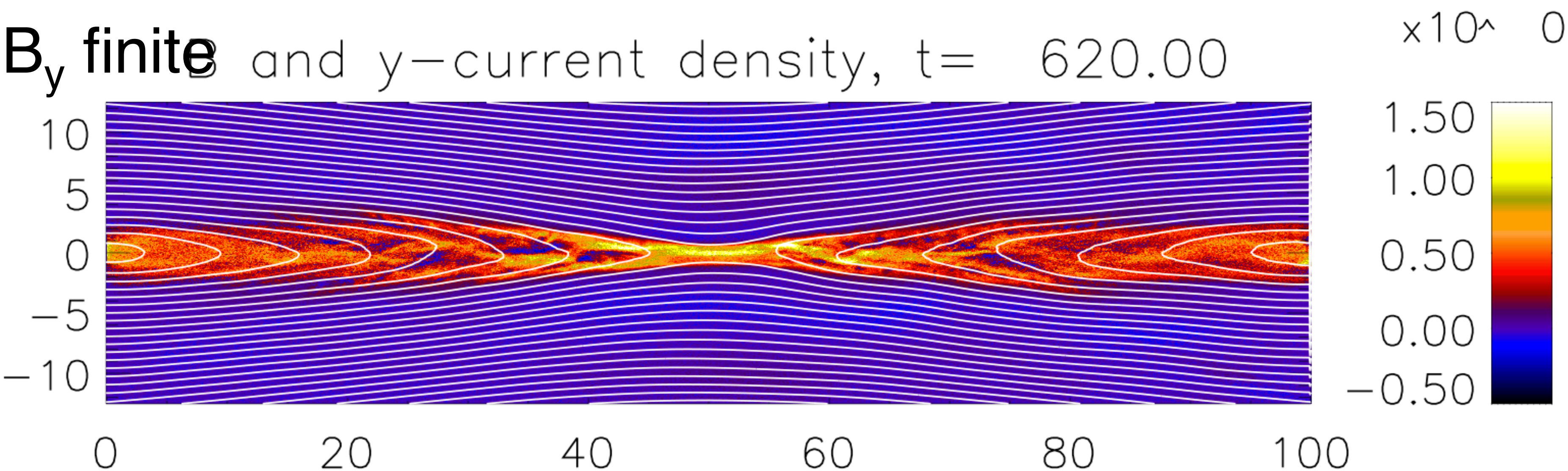
How?

Detailed Study: Time Selection

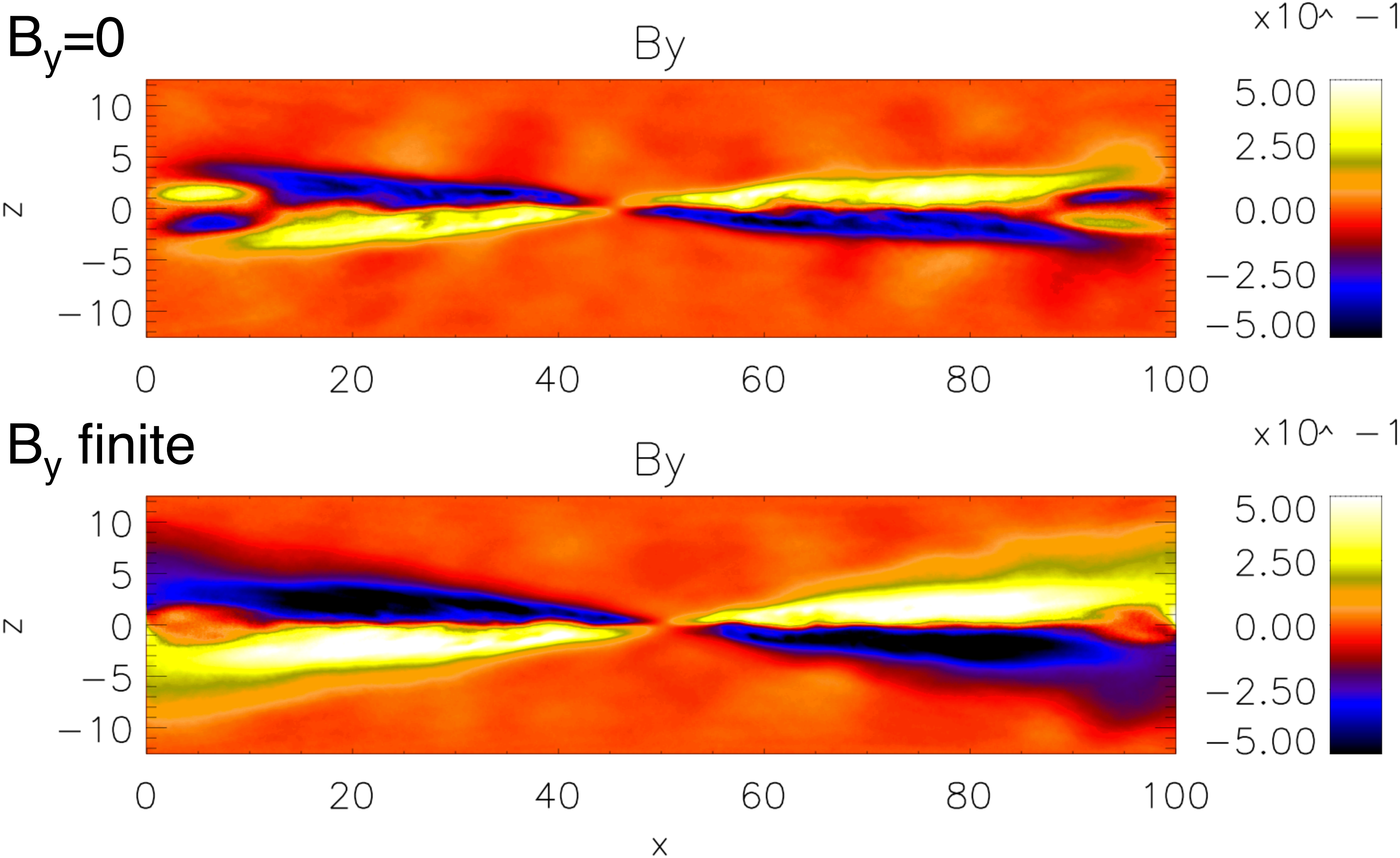
$B_y=0$



B_y finite

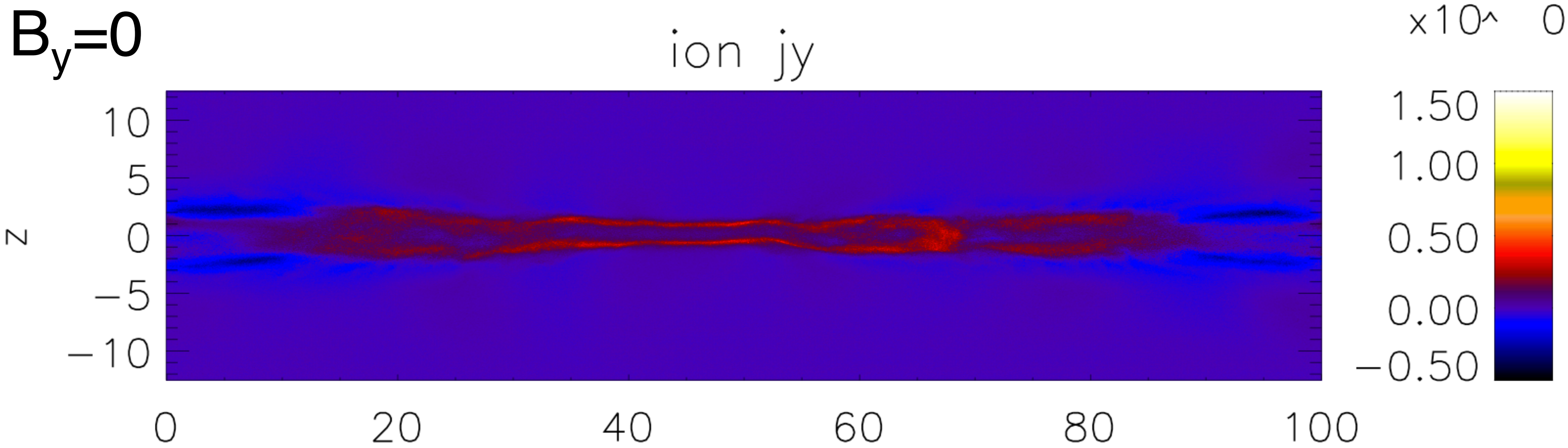


Guide Field

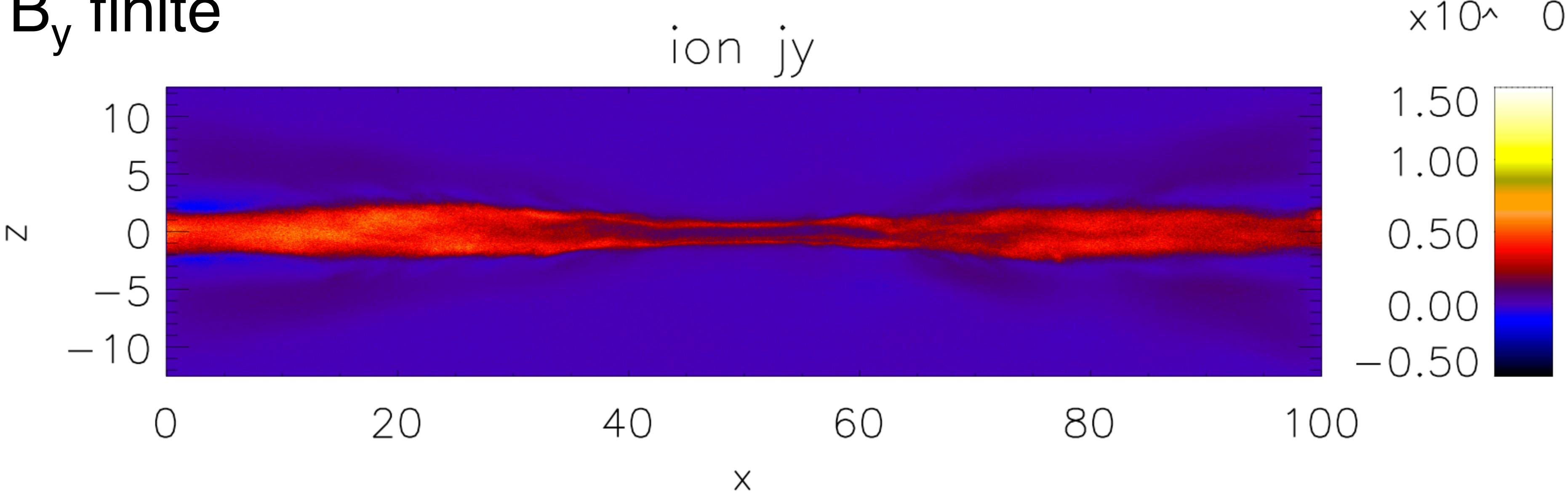

B_y=0
By
x10^ −1
10
5
0
−5
−10
z
0
20
40
60
80
100
5.00
2.50
0.00
−2.50
−5.00
B_y finite
By
x10^ −1
x

Ion Current Density

B_y=0

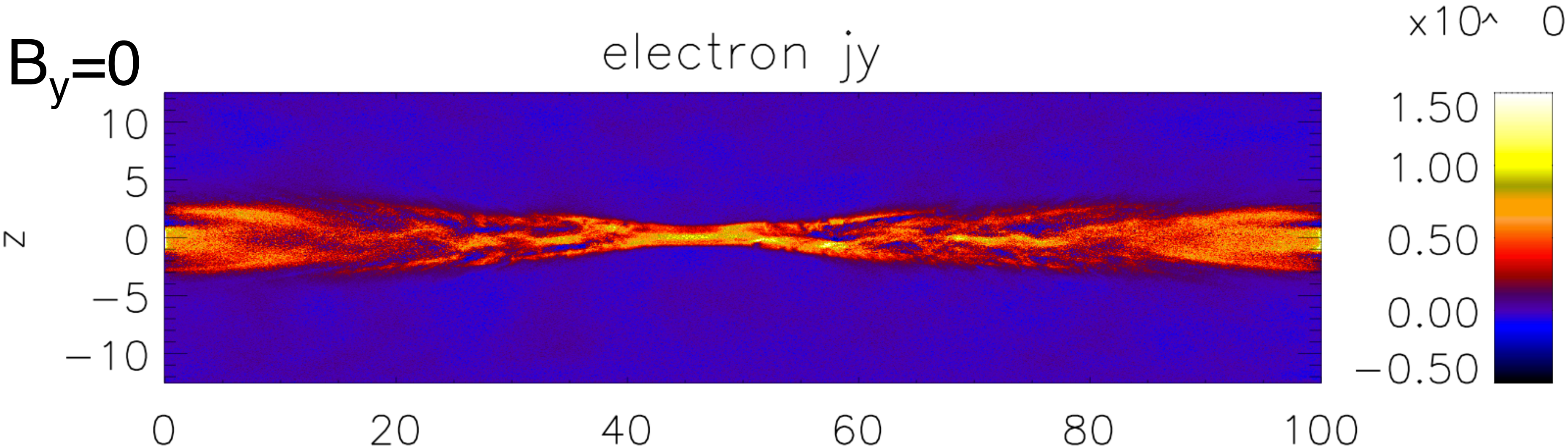


B_y finite

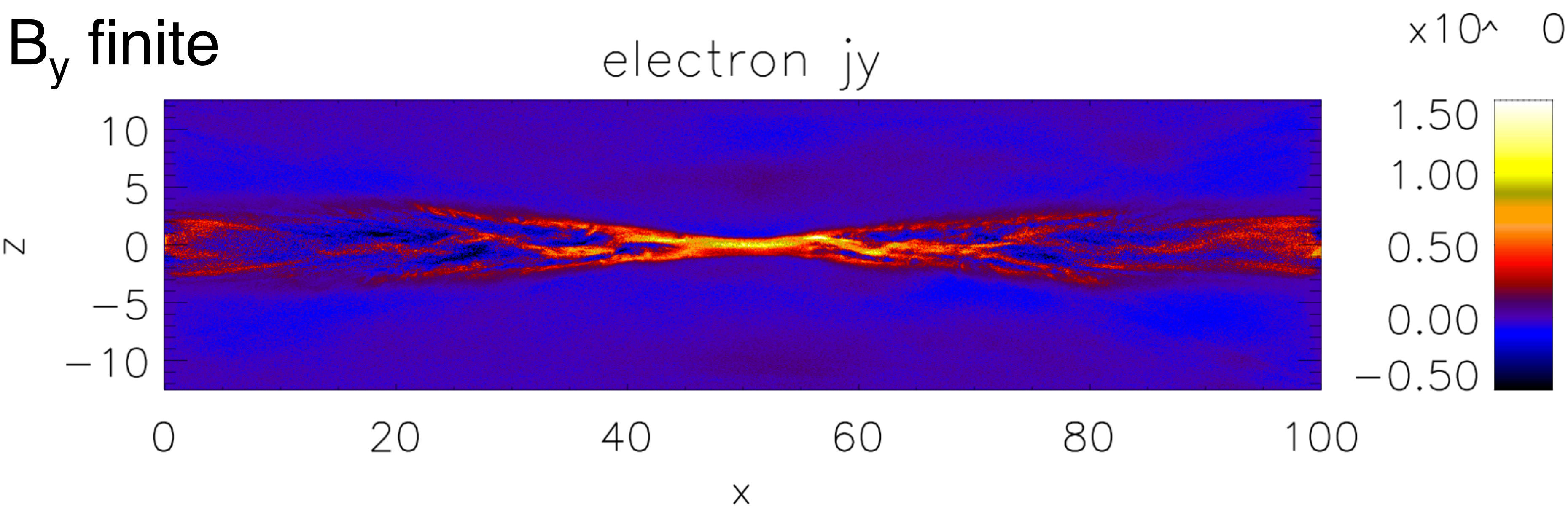


Electron Current Density

$B_y=0$

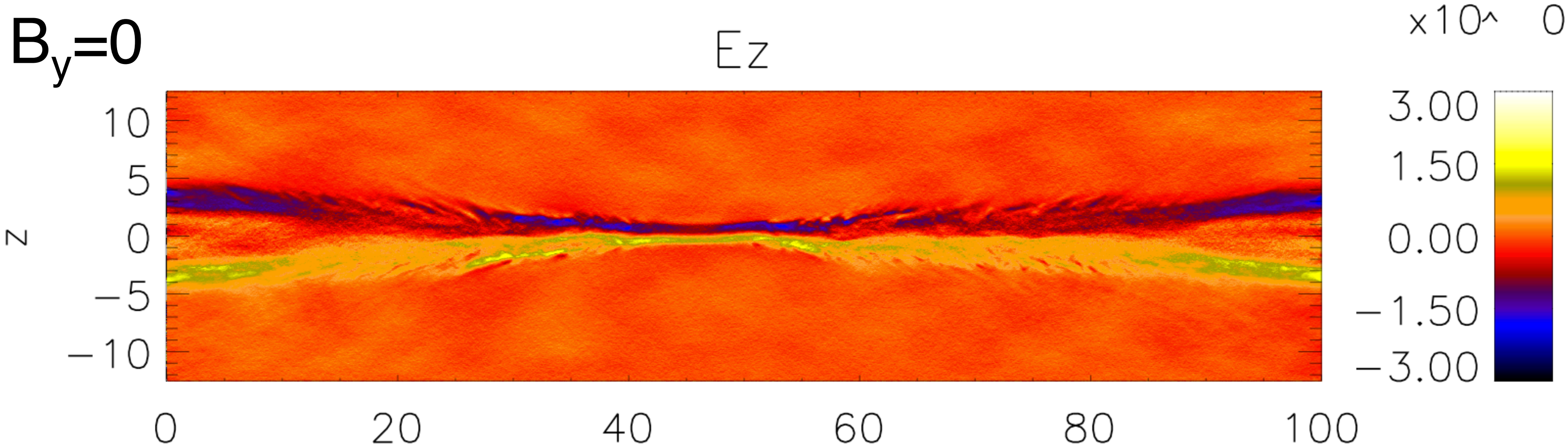


B_y finite

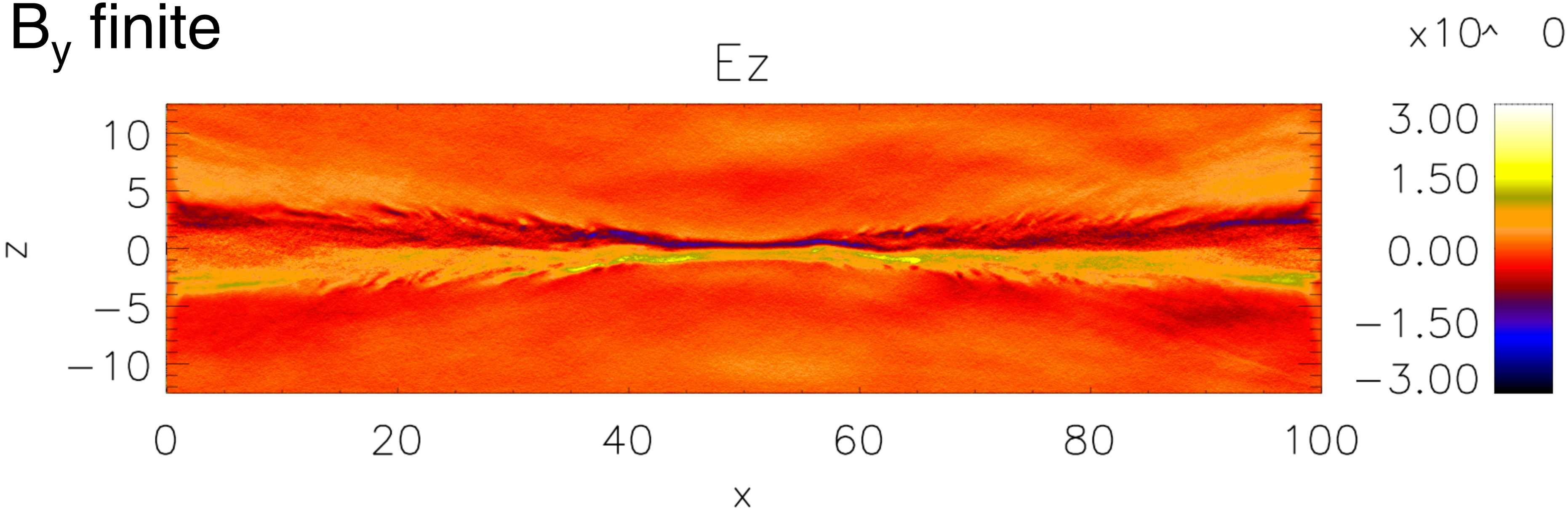


Normal Electric Field

$B_y=0$



B_y finite

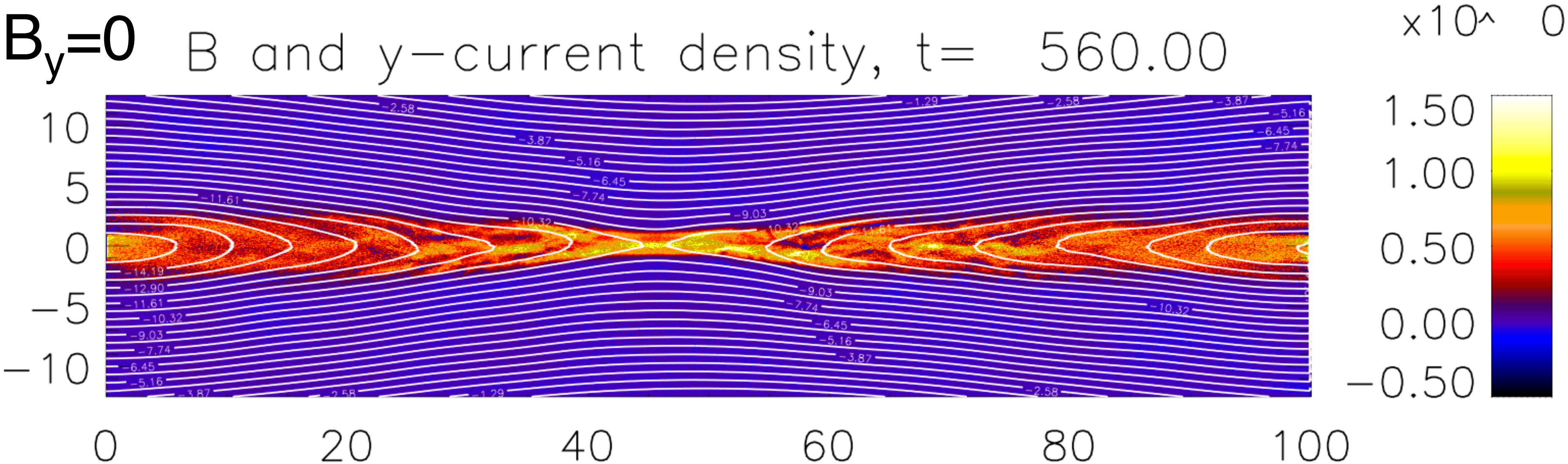


Ion Force Densities

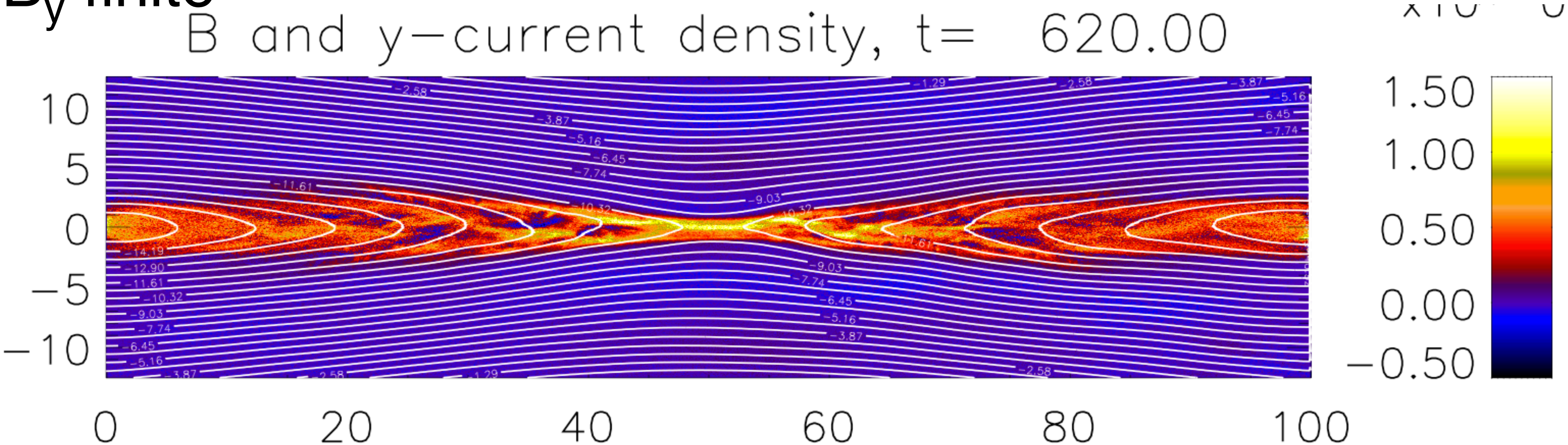
$$\frac{\partial m_i n_i \vec{v}_i}{\partial t} + \nabla \cdot (m_i n_i \vec{v}_i \vec{v}_i) = e n_i \vec{E} + e n_i \vec{v}_i \times \vec{B} - \nabla \cdot \overleftrightarrow{P}_i$$

Flux Tube Integration

$B_y=0$



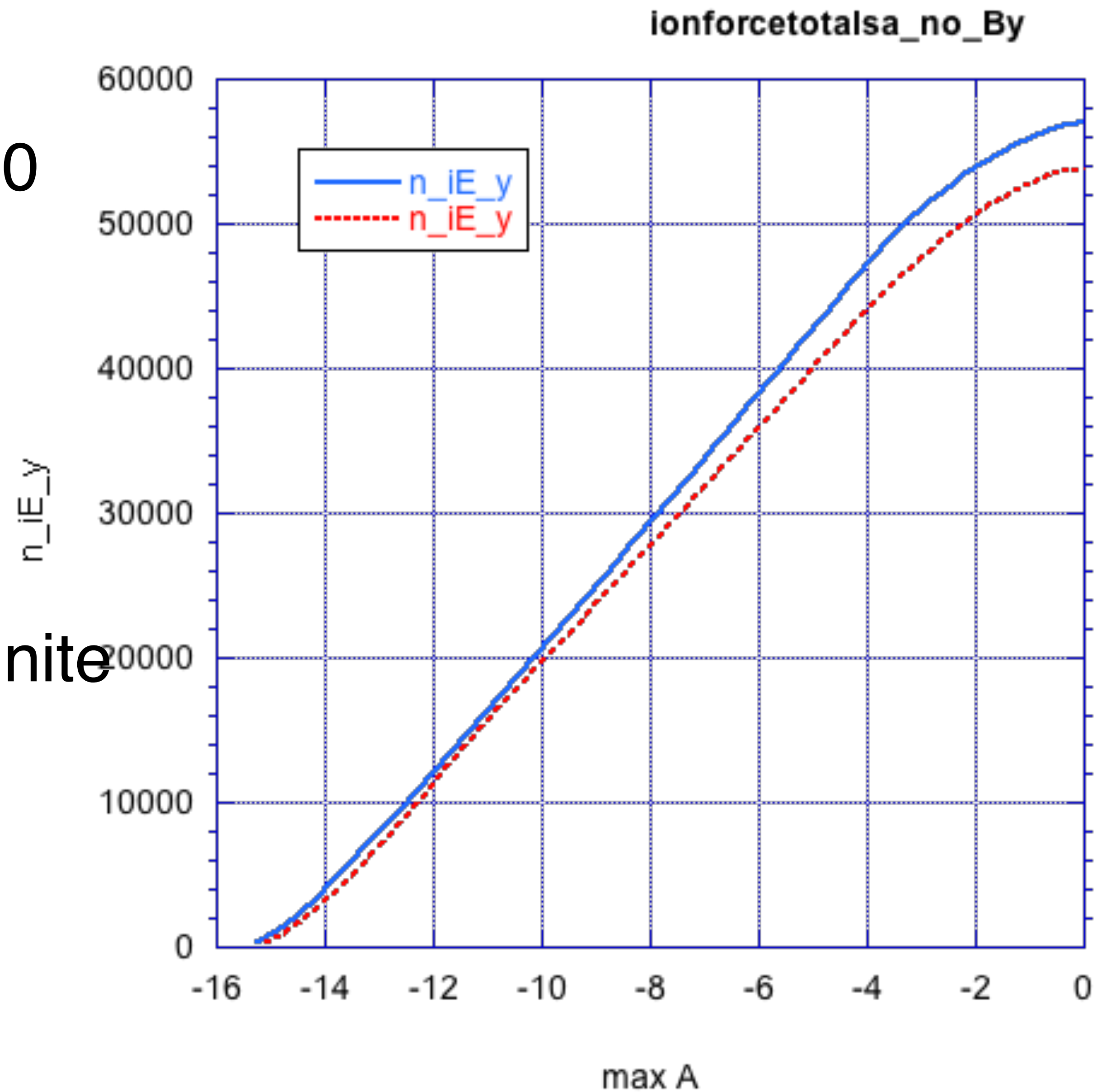
B_y finite



Electric Force Density

Blue: B_y=0

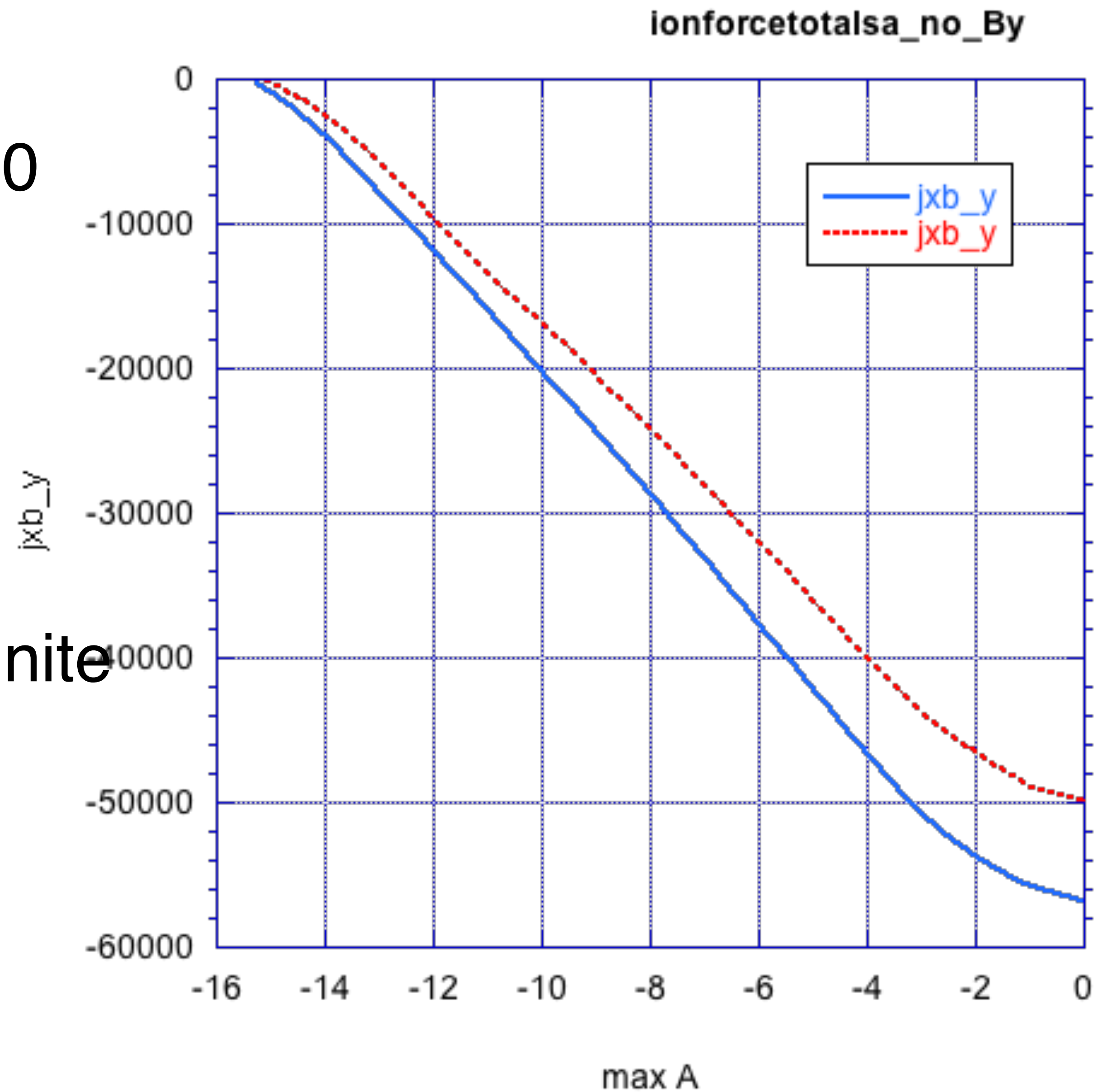
Red: B_y finite



Lorentz Force

Blue: B_y=0

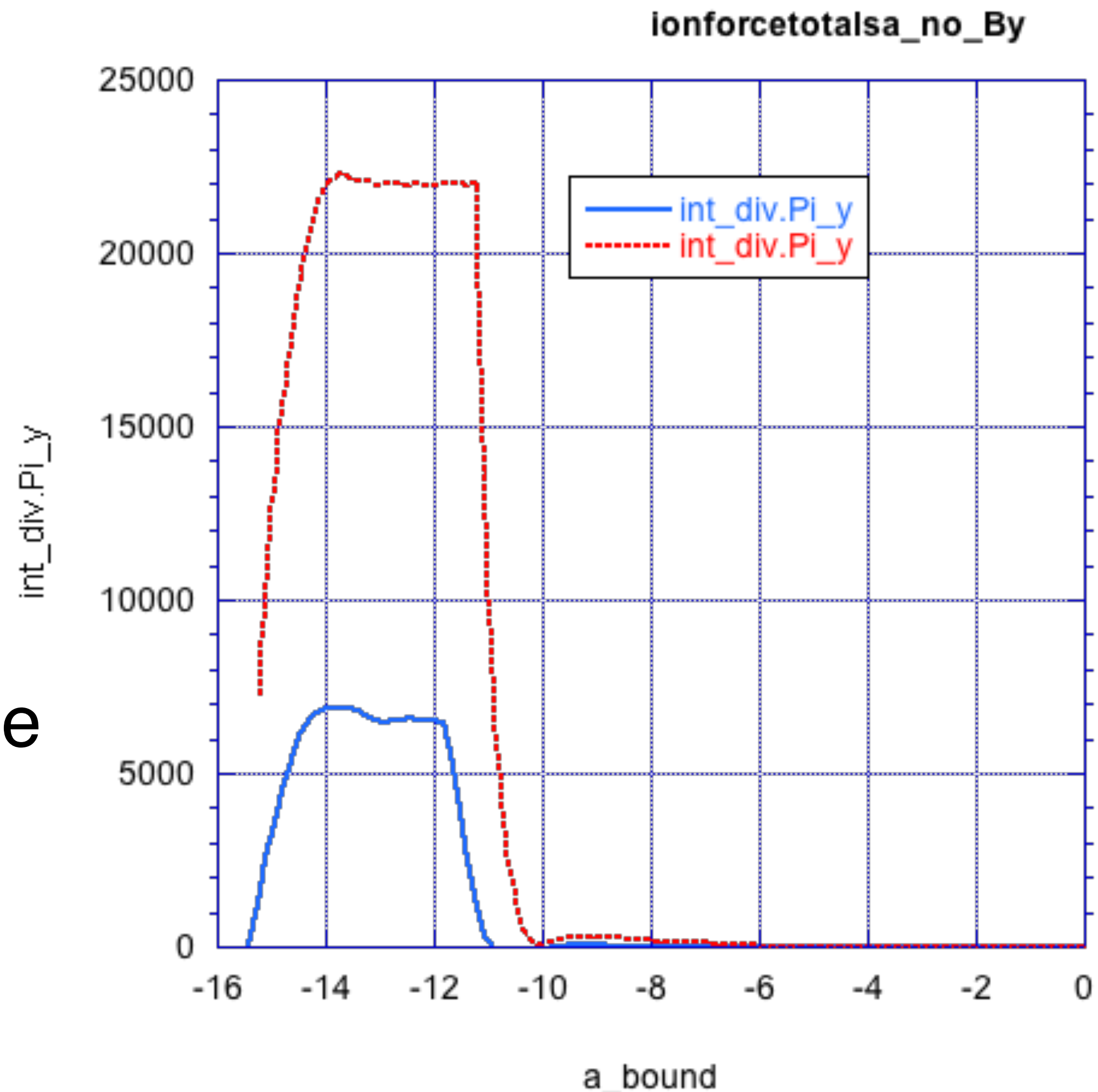
Red: B_y finite



Pressure Force Density

Blue: B_y=0

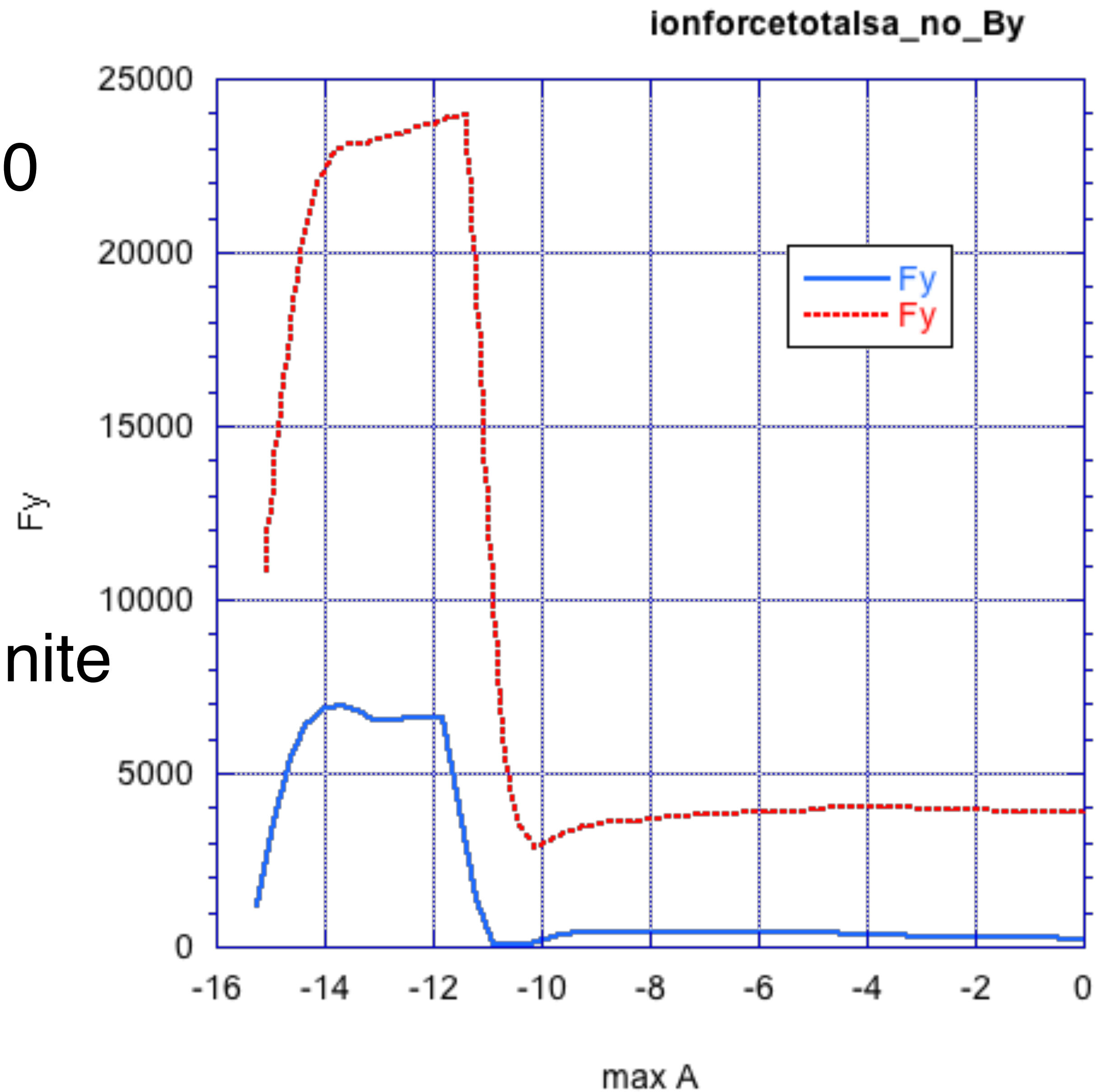
Red: B_y finite



Total Force Density

Blue: B_y=0

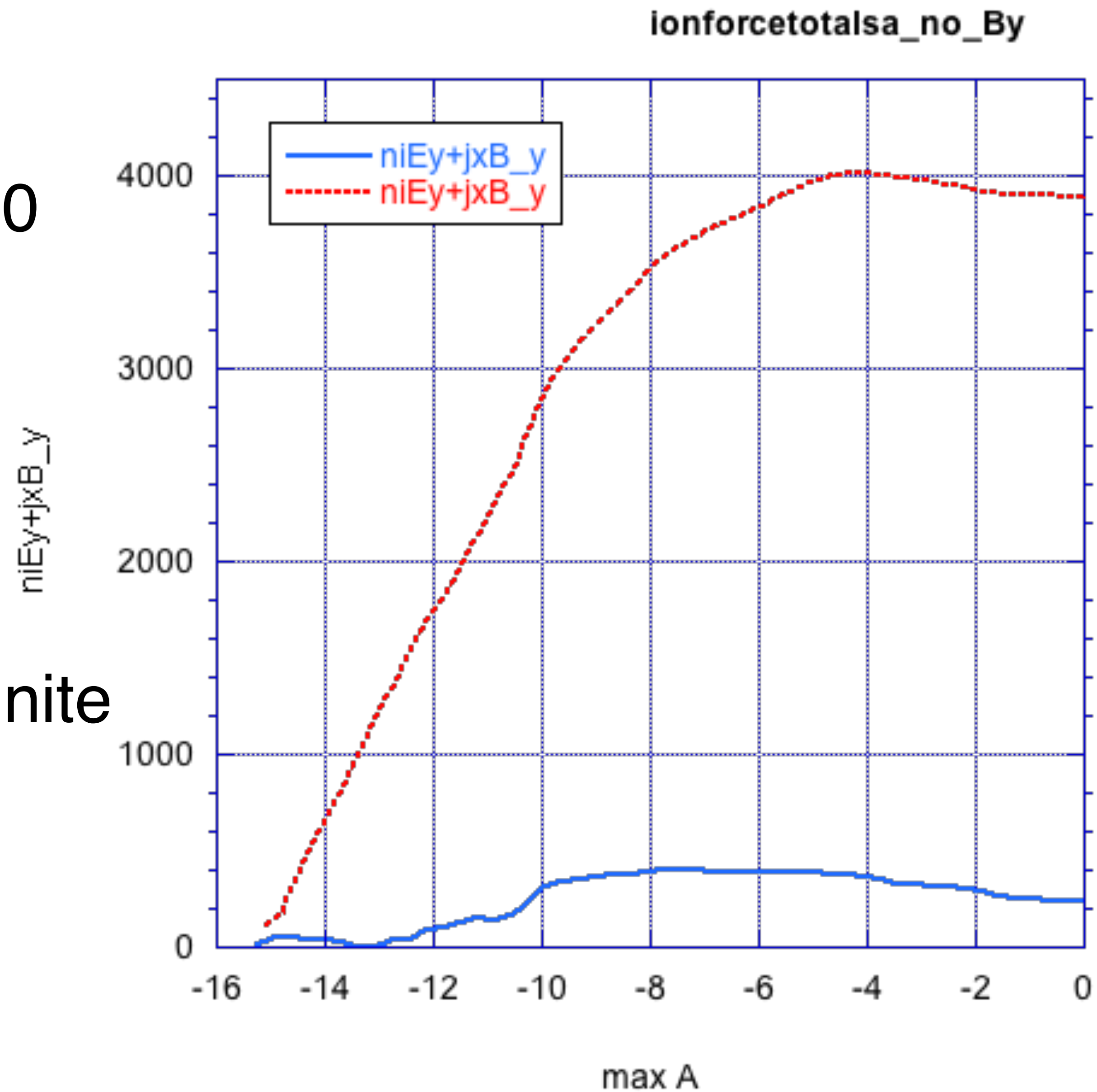
Red: B_y finite



Total Relevant Force Density

Blue: $B_y=0$

Red: B_y finite



Acceleration accomplished by reduction in average Lorentz force

Can this be understood?

Ion Current Contributions

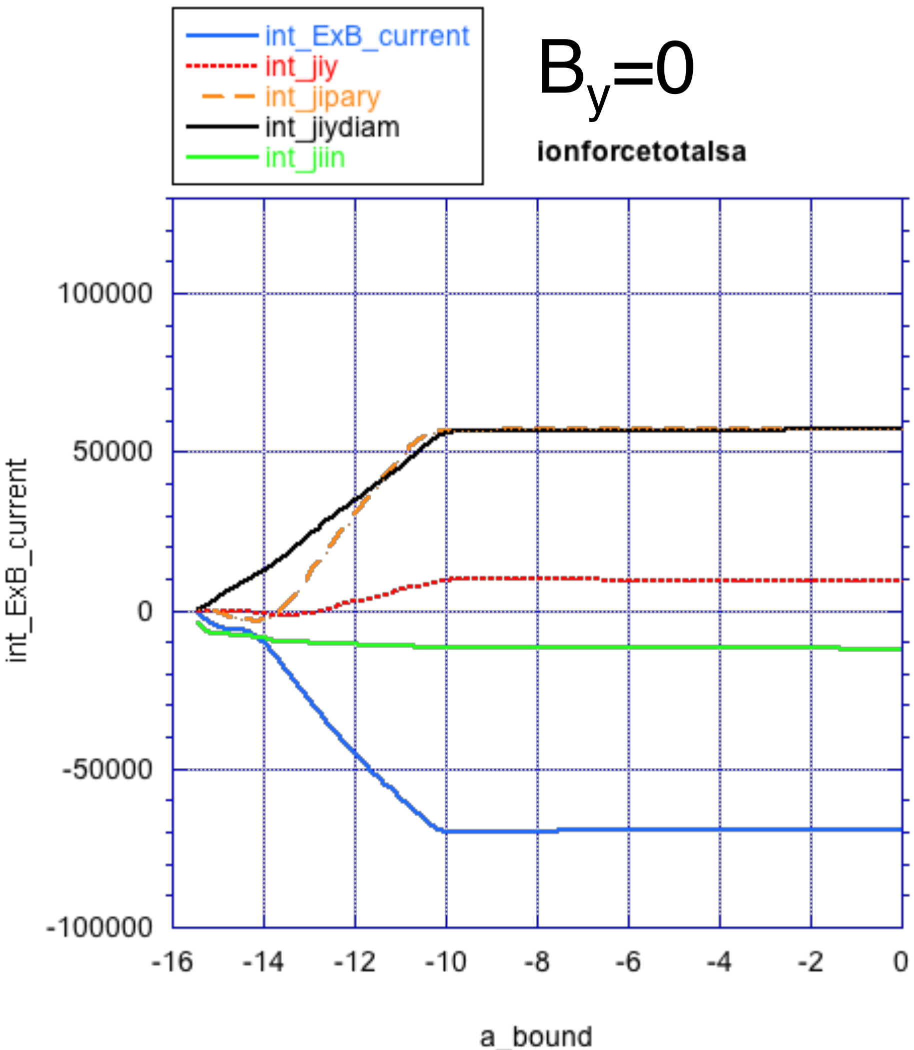
$$\vec{j}_{i,diam} = -\frac{\nabla \cdot \overleftrightarrow{P}_i \times \vec{B}}{B^2}$$ diamagnetic

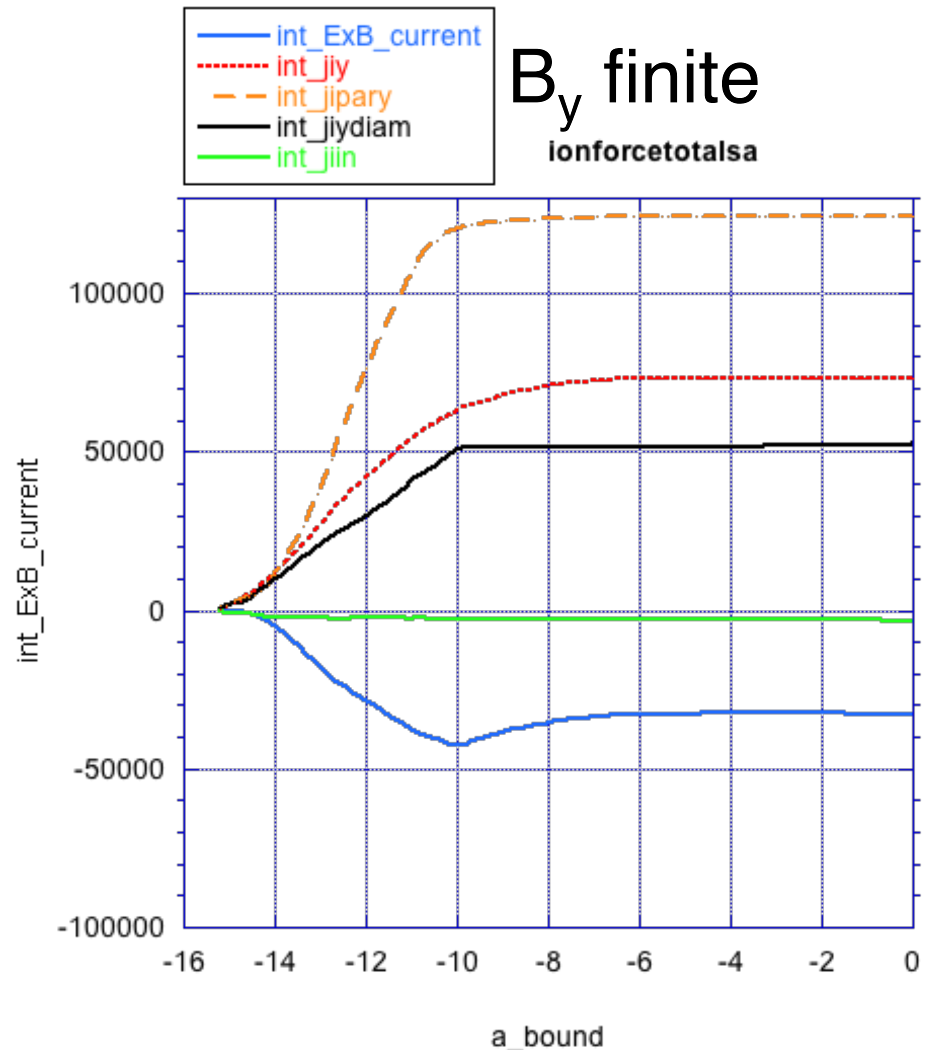
$$\vec{j}_{i,inertial} = \frac{m_i n_i \vec{v}_i \cdot \nabla \vec{v}_i \times \vec{B}}{B^2}$$ inertial, νο δ/δτ

$$\vec{j}_{i,ExB} = \frac{e n_i \vec{E} \times \vec{B}}{B^2}$$ ExB

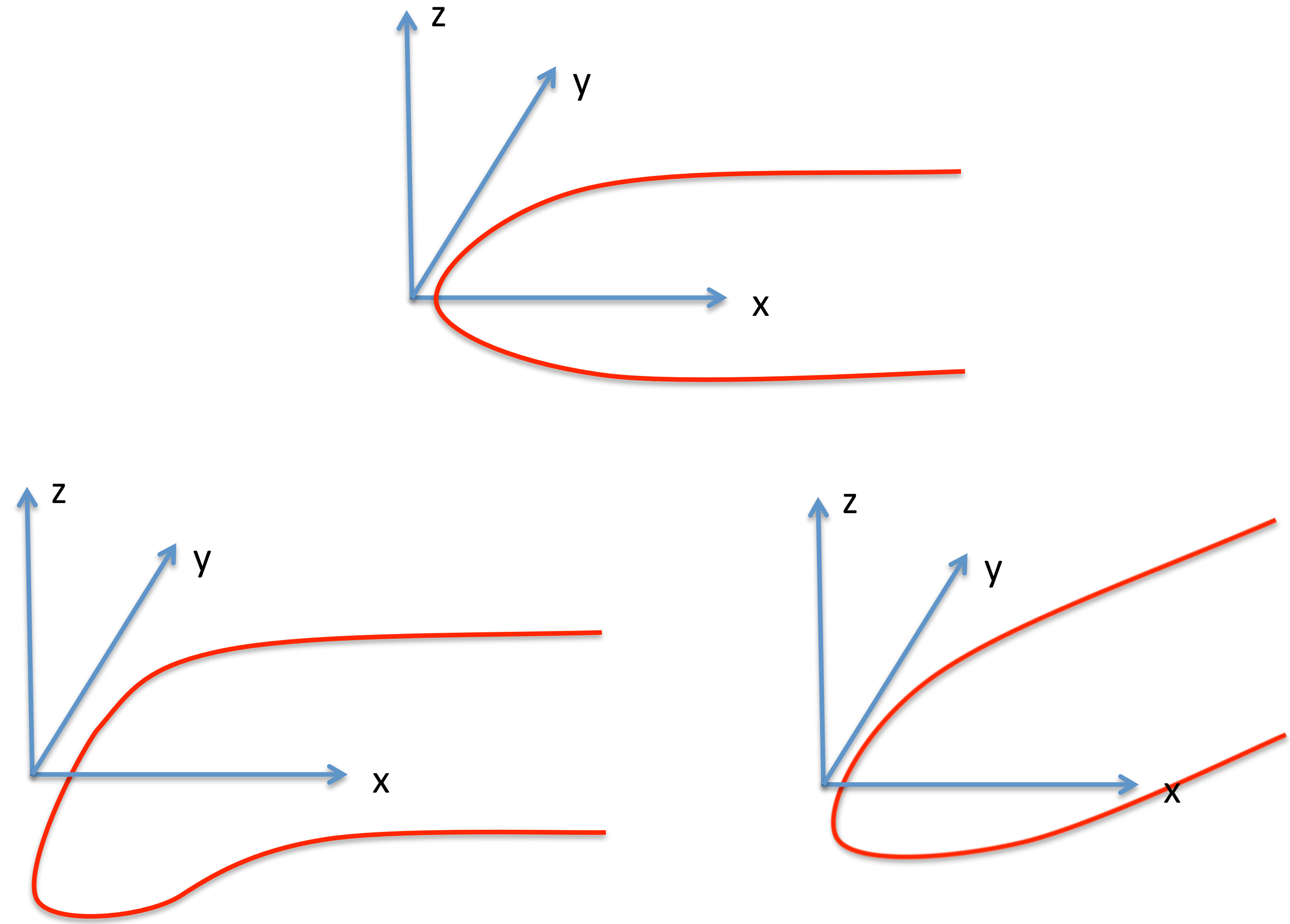
$$\vec{j}_{i,\parallel}$$ parallel

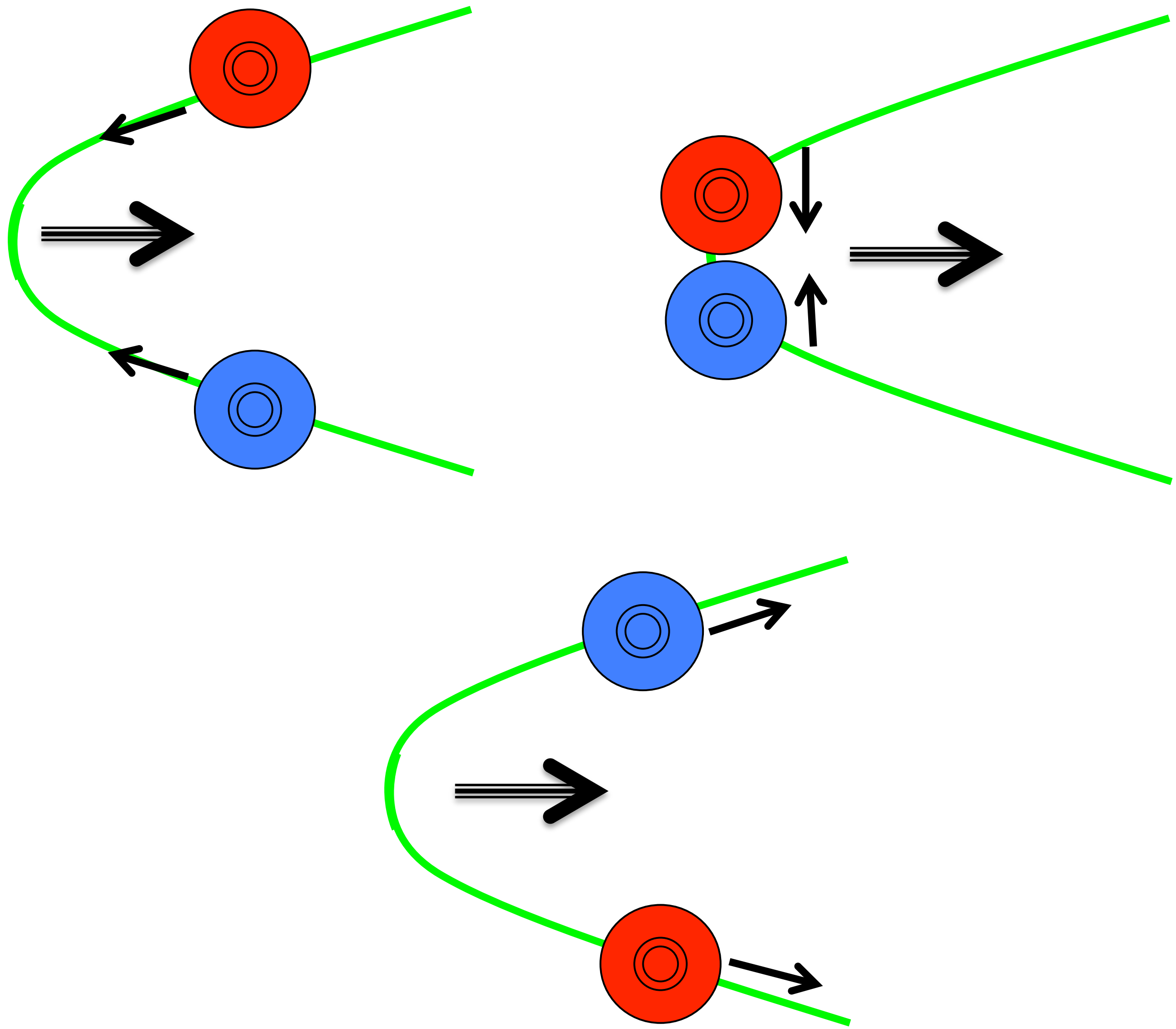
Total Current Contributions



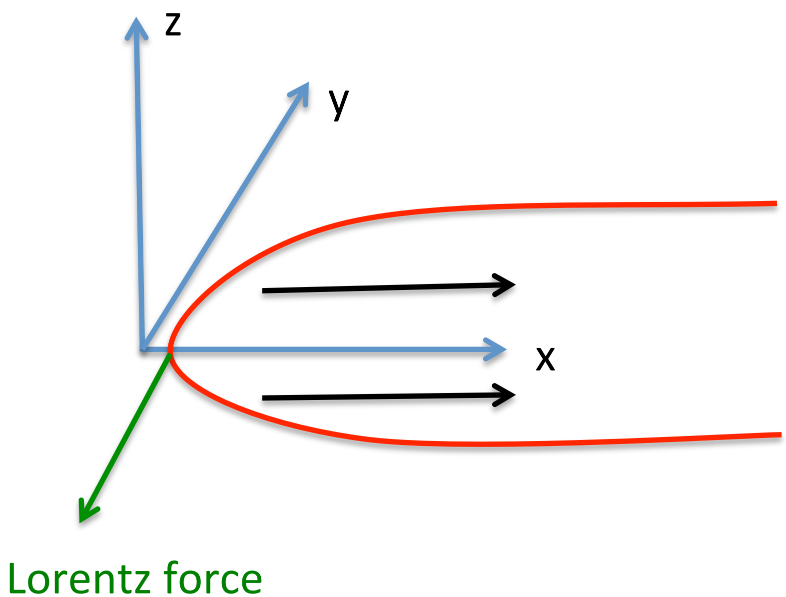


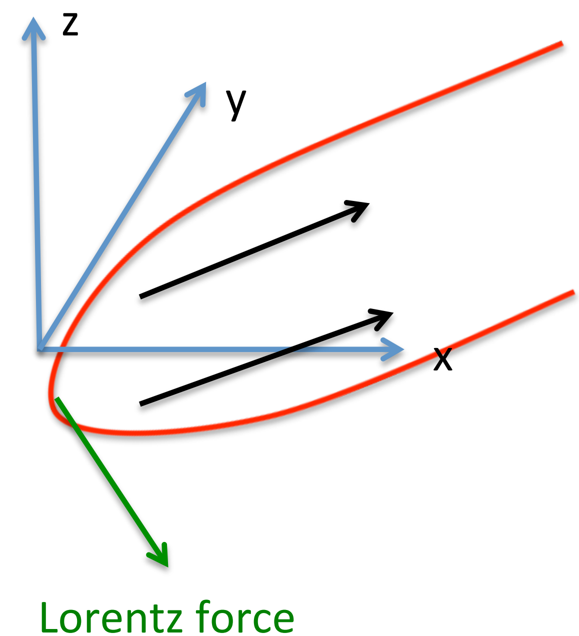
Geometry Effect on Outflow





Geometry Effect on Outflow





Summary

- Geometric constraints on the outflow jet have
  - no effect on the reconnection rate
  - a substantial effect on the momentum distribution within the jet
- Ion momentum is determined primarily by
  - the strength of the normal electric field
  - the magnetic geometry
- Momentum distribution in an outflow jet remote sensing effect of the overall geometry

Final Words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