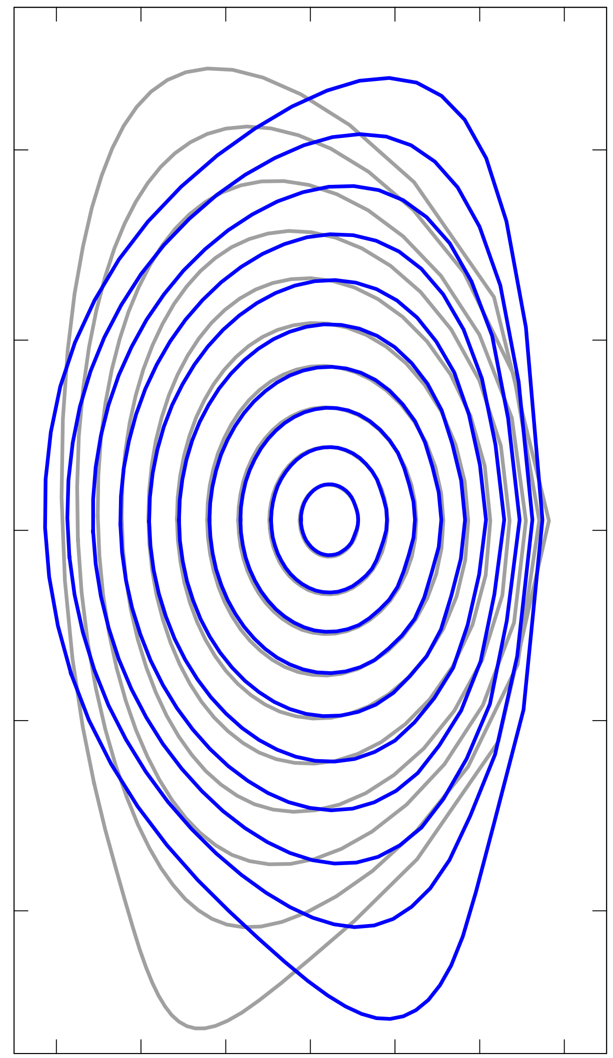
Gyrokinetic calculations for a negative triangularity DEMO



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Swiss Plasma Center, EPFL

KDII#8 Progress Meeting
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Introduction

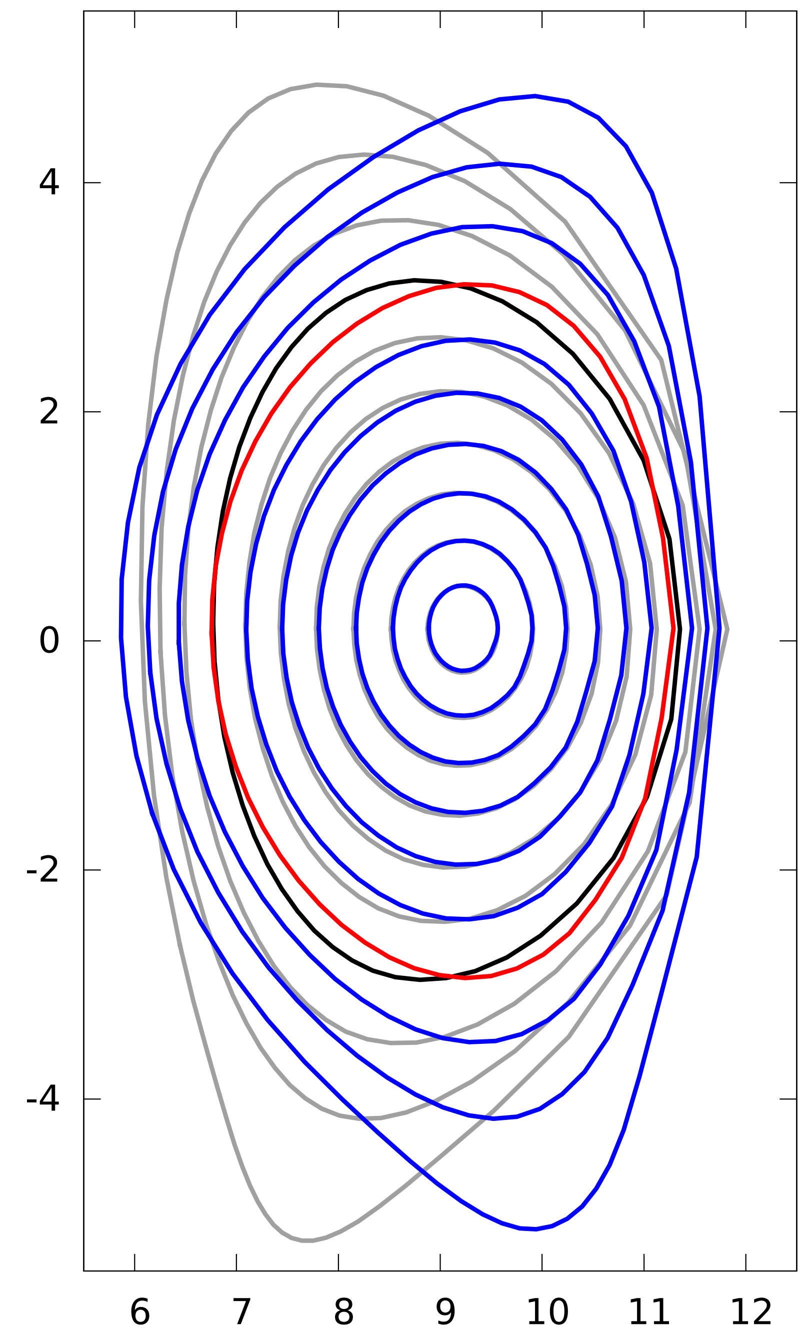
- Negative δ has been experimentally observed to:
    - Improve confinement
    - Increase the L->H power threshold, thereby keeping the plasma in L-mode and avoiding ELMs
    - Move the divertor to a larger major radius
- Use local gyrokinetic GENE simulations to compare **negative** δ and **positive** δ DEMO equilibria

Future plans

- Will soon receive computational resources enabling more simulations

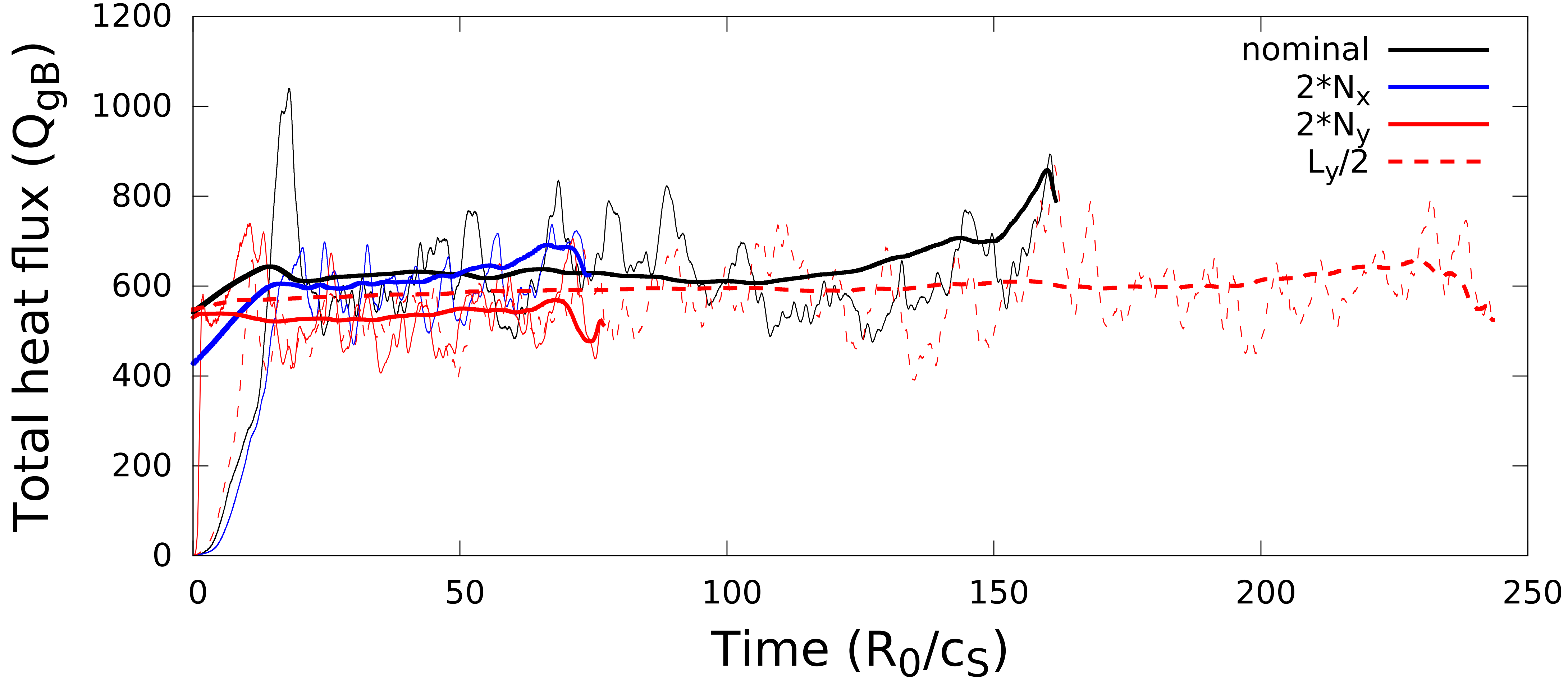
Past work: Selecting minor radius of $\rho = 0.72$

- Simulations near the <u>edge</u> are difficult due to:
  - Large values of magnetic shear
  - Large logarithmic gradients
- Simulations in the <u>core</u> are problematic because:
  - Sawtooth inversion radius at $\rho \approx 0.6$
  - Impact of triangularity is weaker



Past work: Nonlinear resolution study

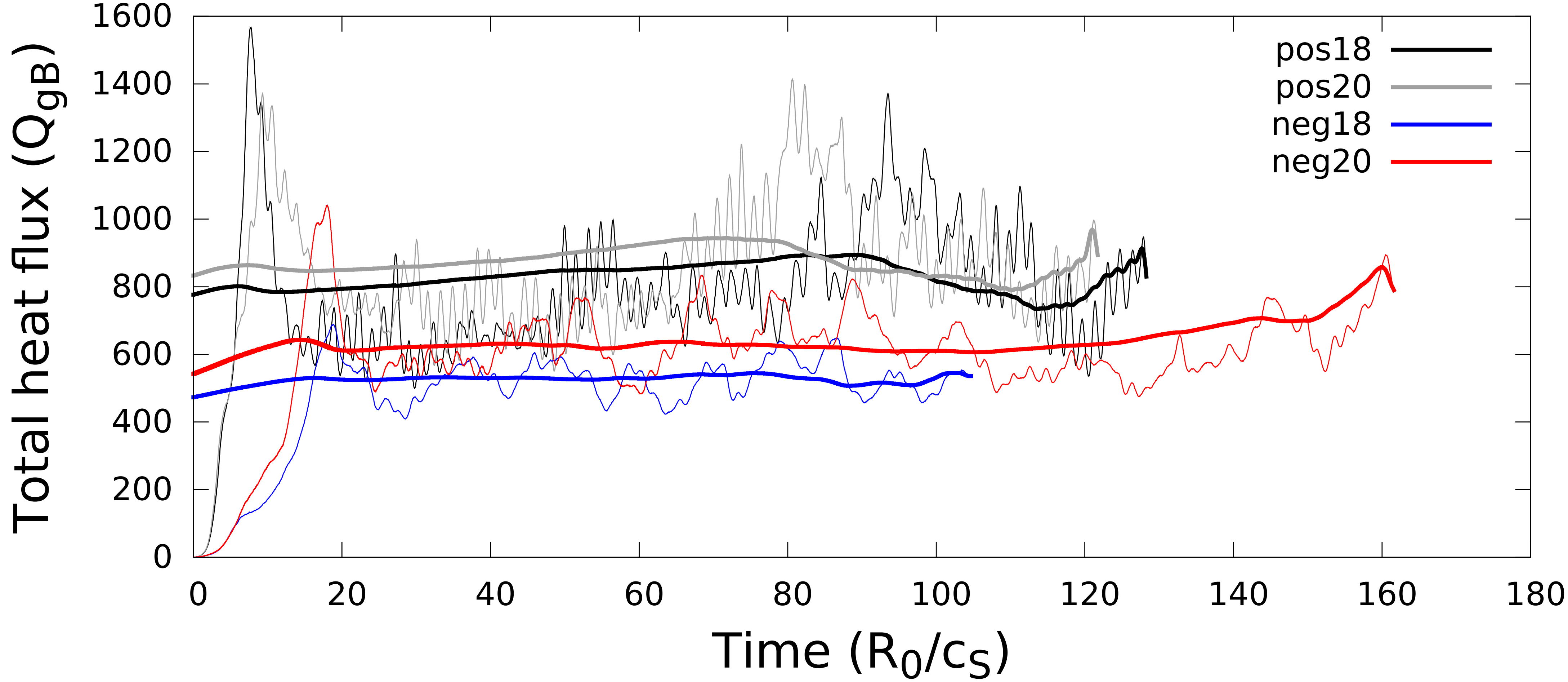
- Resolution study of a **negative** δ case for the most concerning parameters seems satisfactory



Past work: Nonlinear results

- Negative δ cases have lower total heat flux for nominal DEMO

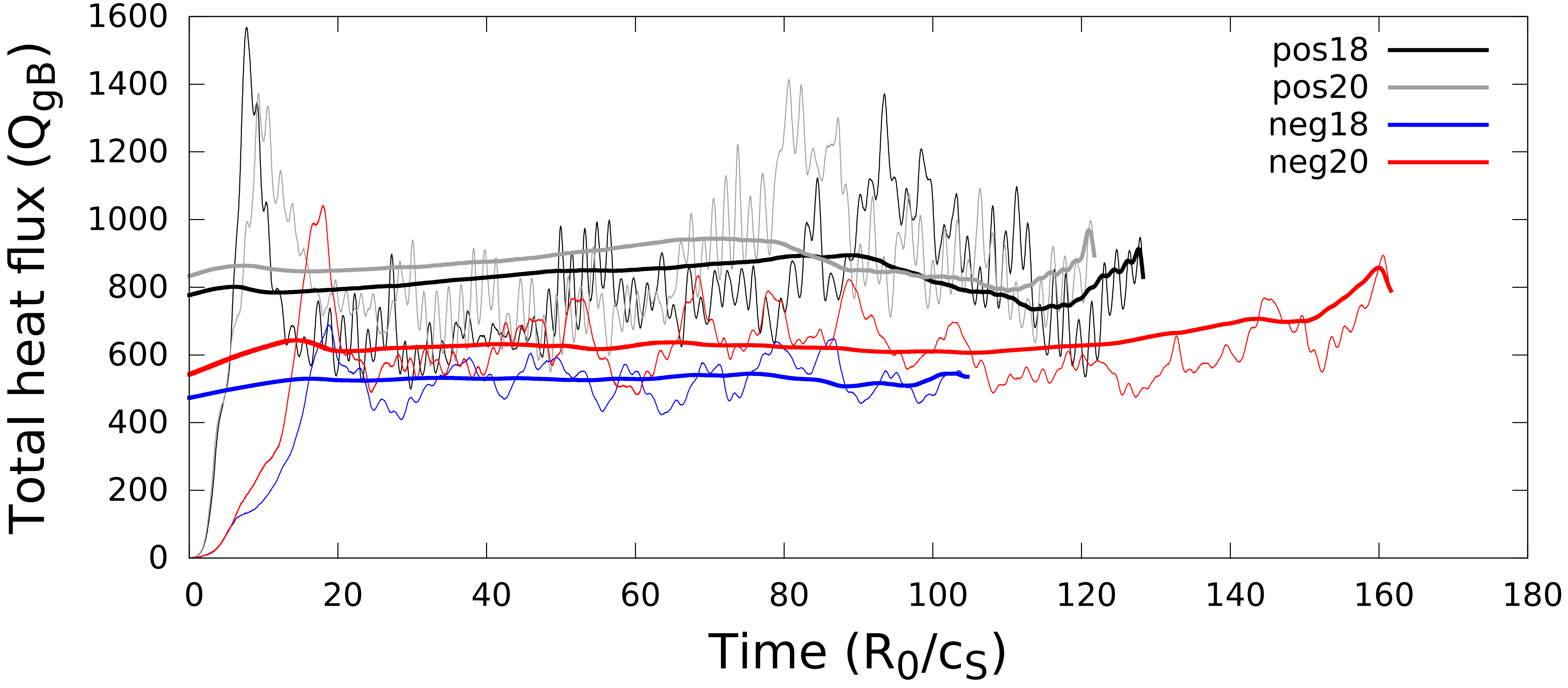
- Positive δ cases exhibit an unusual oscillation from the zonal flows



Future plans

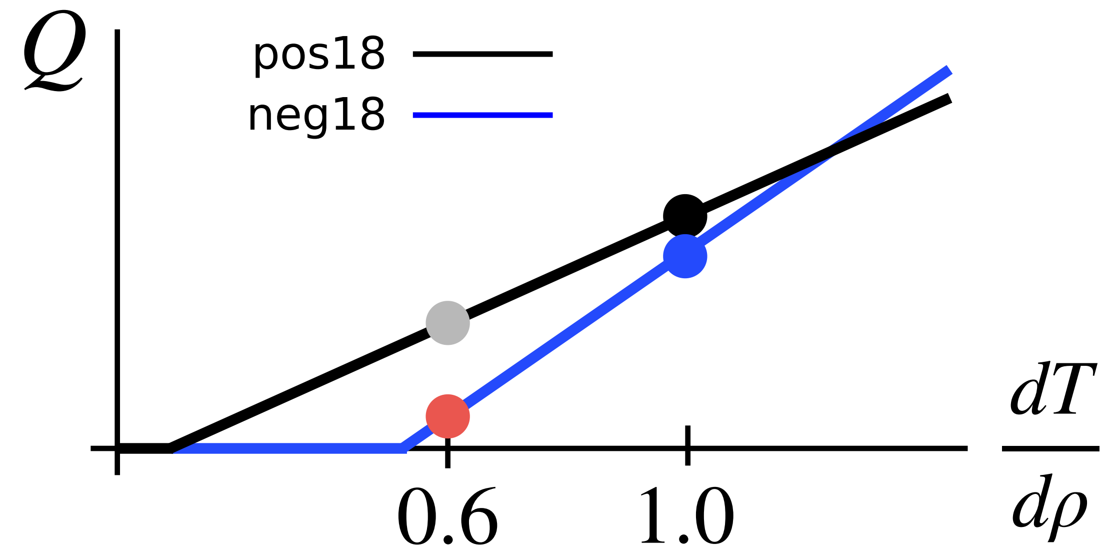
- Will soon receive computational resources enabling more simulations

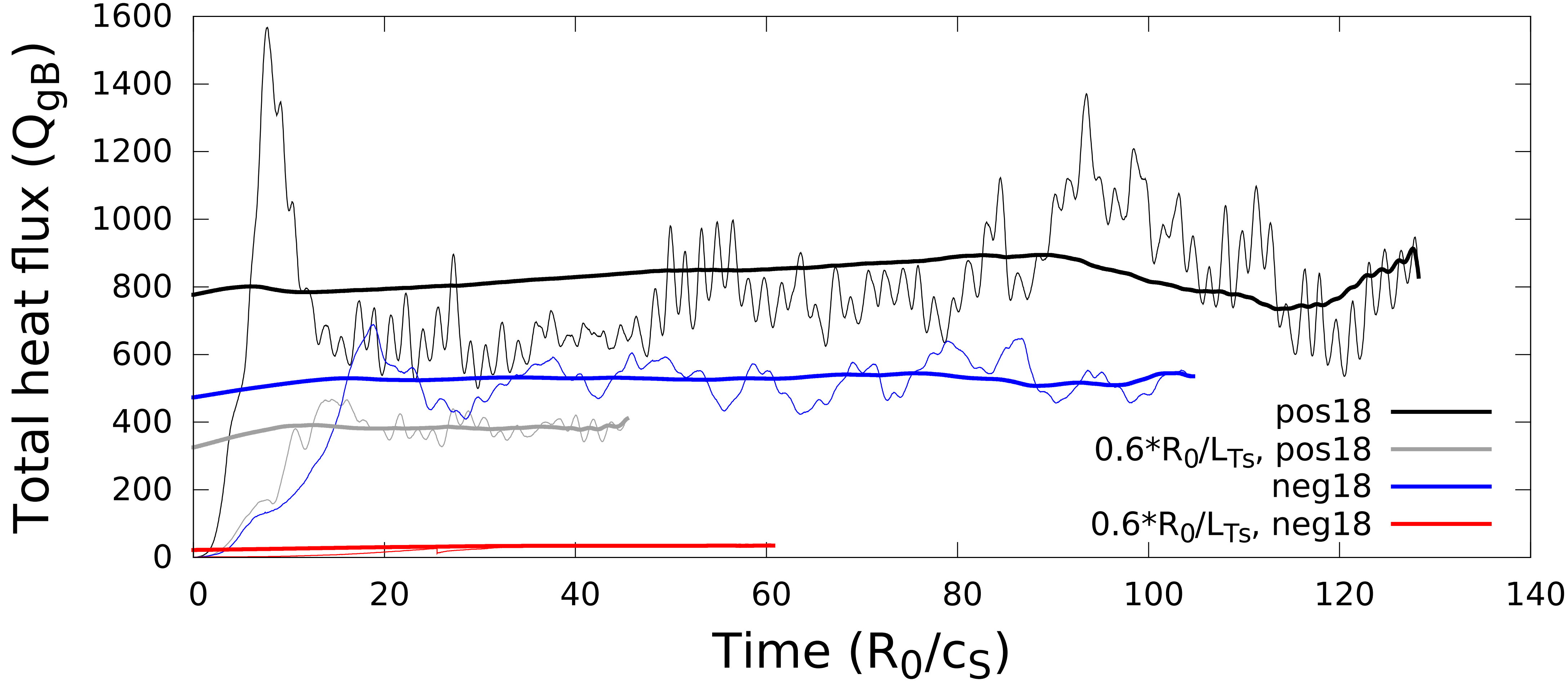
1. Perform resolution study for a **positive** δ case to resolve oscillation



Correction: Nonlinear stiffness study

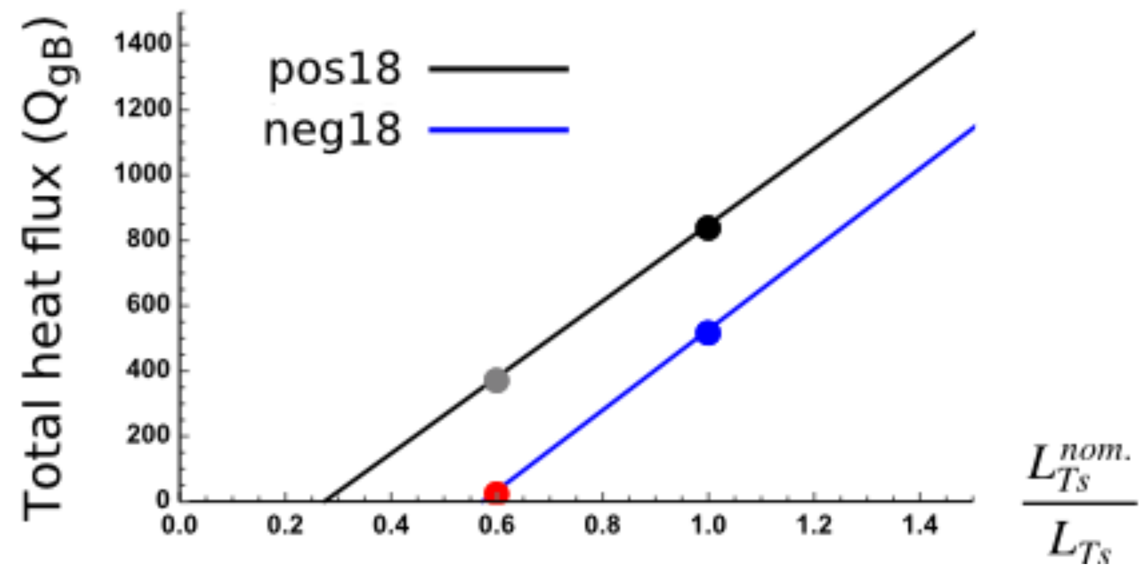
- Negative δ has a higher critical gradient

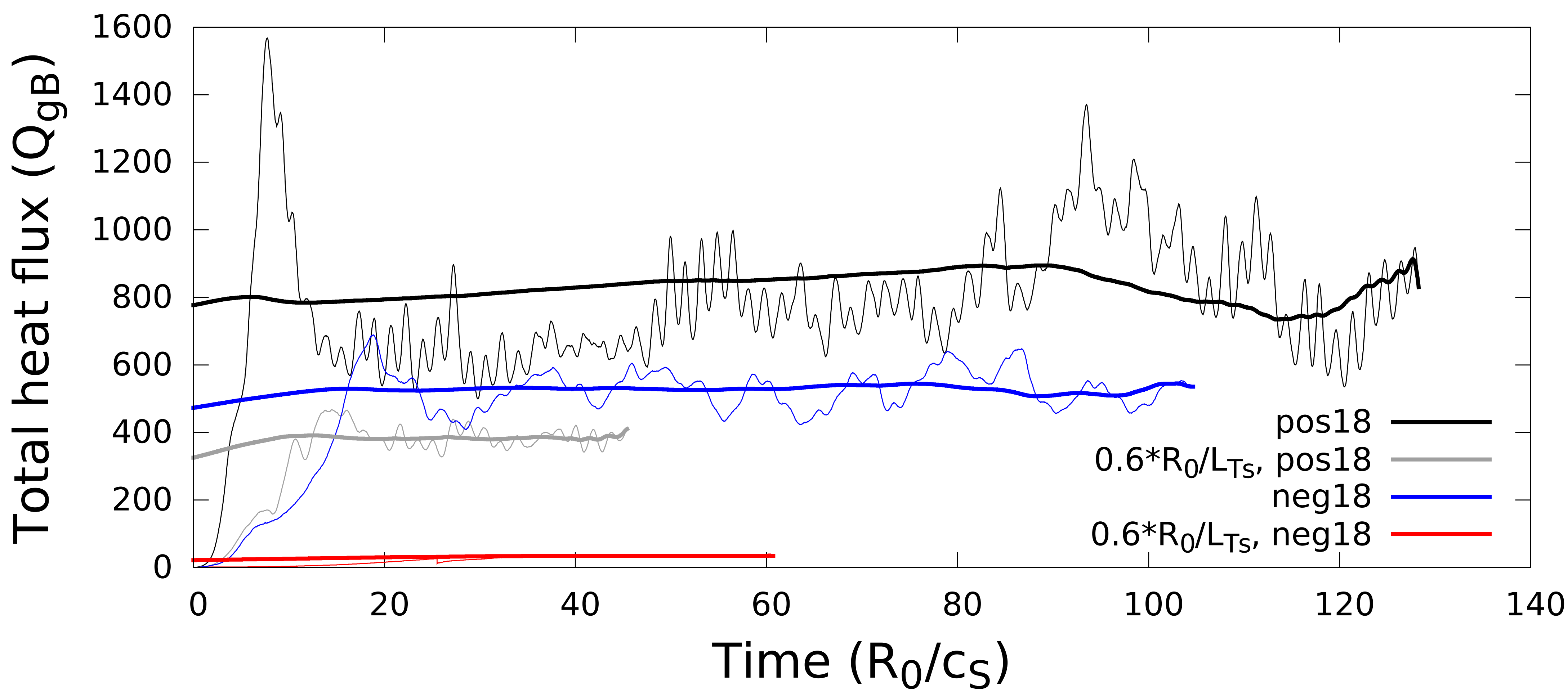




Correction: Nonlinear stiffness study

- Negative δ has a higher critical gradient
- **Stiffness is similar**



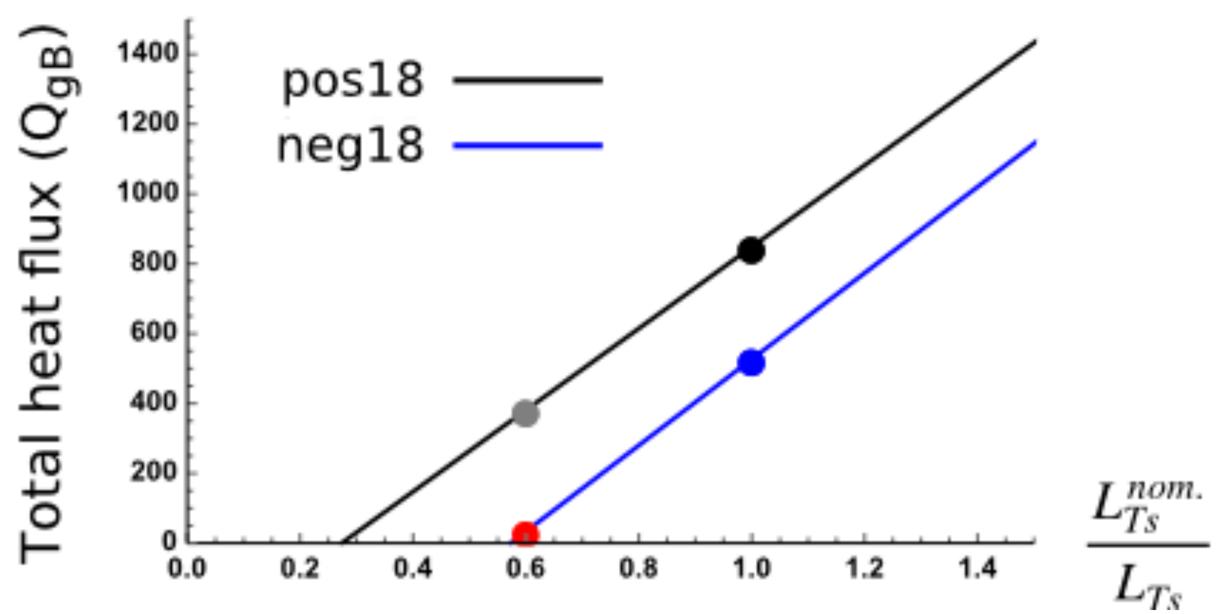


Future plans

- Will soon receive computational resources enabling more simulations

1. Perform resolution study for a **positive** δ case to resolve oscillation

2. Add points to critical gradient study at $\rho = 0.72$ and repeat for higher $I_p = 20MA$ case



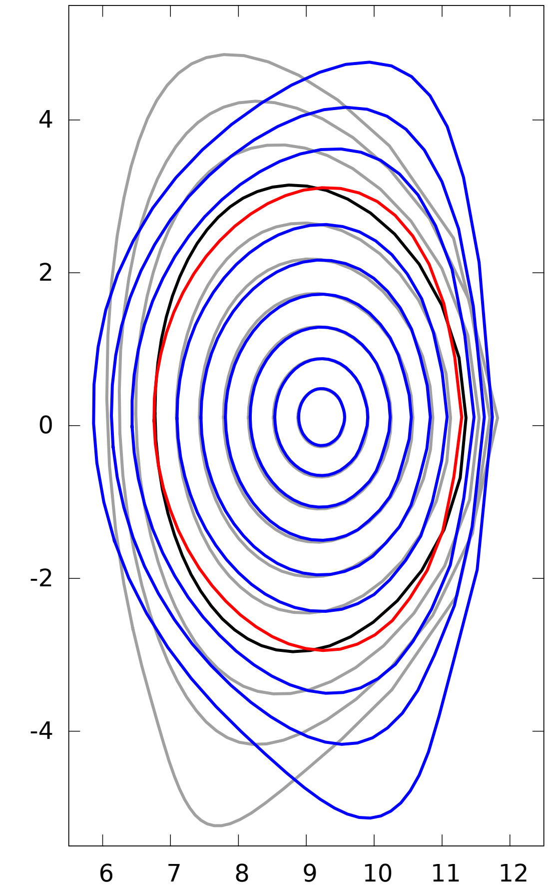
Future plans

- Will soon receive computational resources enabling more simulations

1. Perform resolution study for a **positive** δ case to resolve oscillation

2. Add points to critical gradient study at $\rho = 0.72$ and repeat for higher $I_p = 20MA$ case

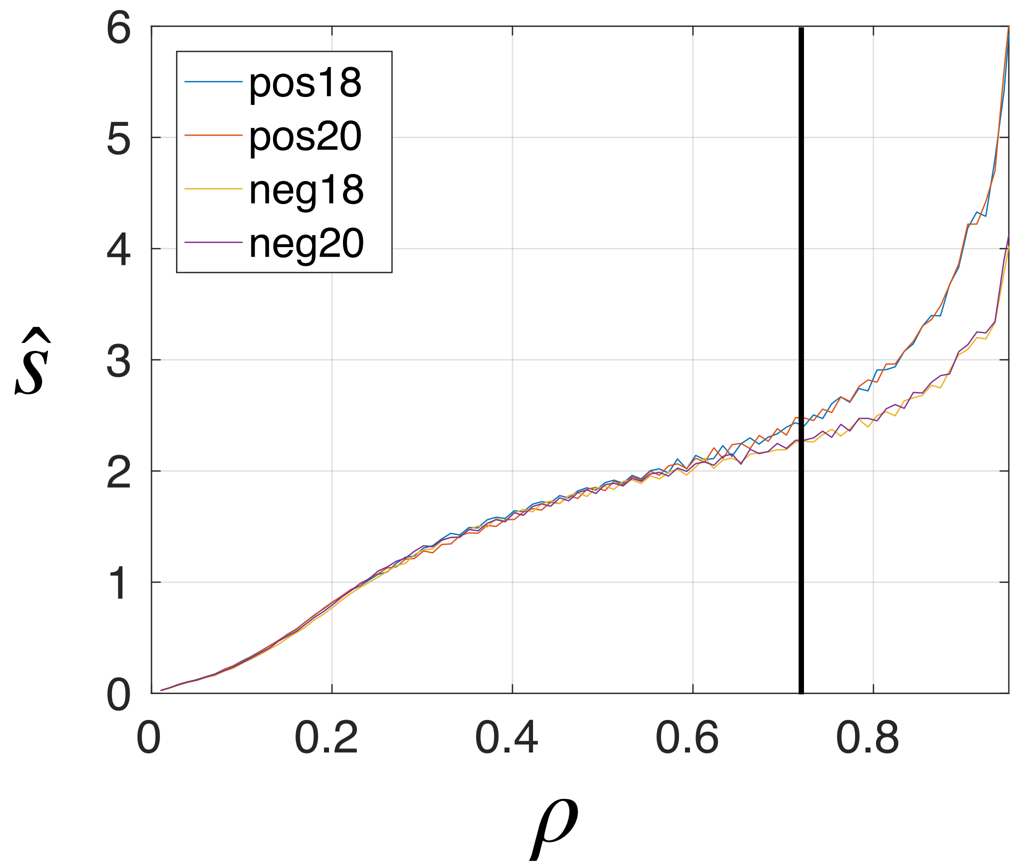
3. Repeat resolution study and simulations at $\rho = \{0.62, 0.82\}$, watching for multi-scale effects and possibly using the non-twisting flux tube simulation domain



Thank you!

Selecting minor radius of $\rho = 0.72$

- Simulations near the edge are difficult due to:
  - Large values of magnetic shear



Selecting minor radius of $\rho = 0.72$

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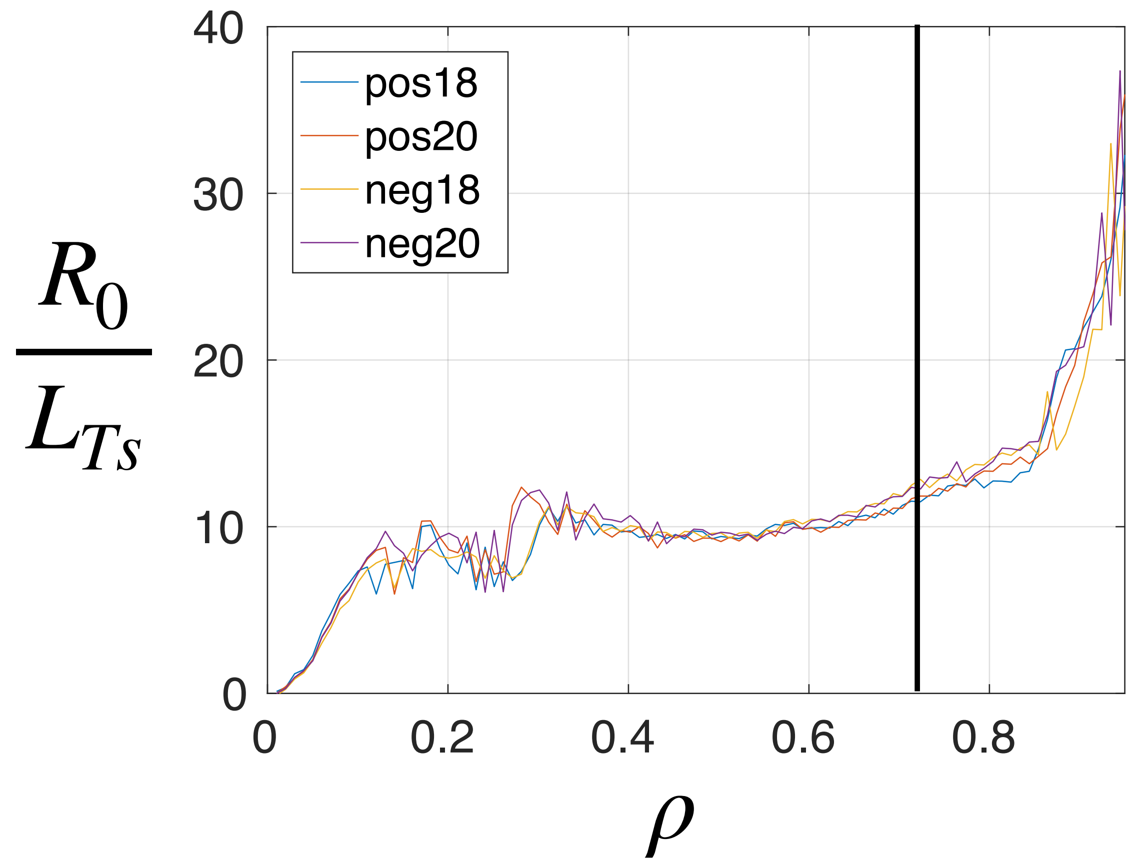
  - Large logarithmic gradients



Selecting minor radius of $\rho = 0.72$

- Simulations near the edge are difficult due to:
    - Large values of magnetic shear
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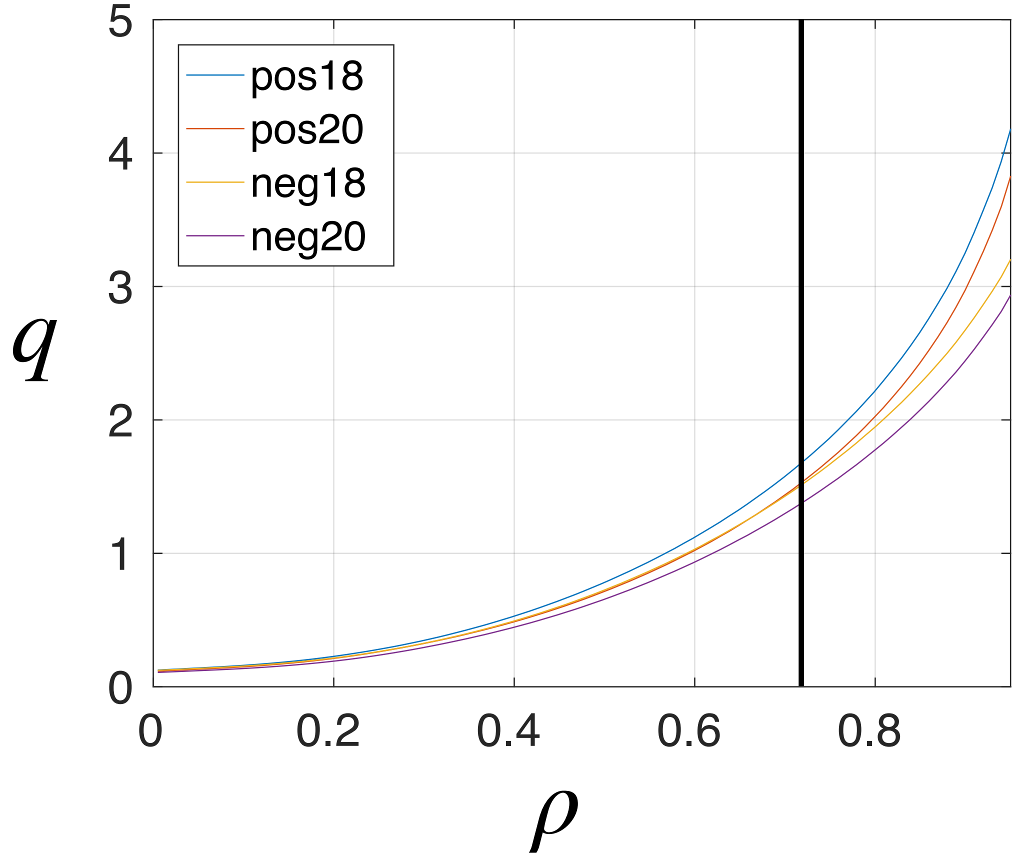
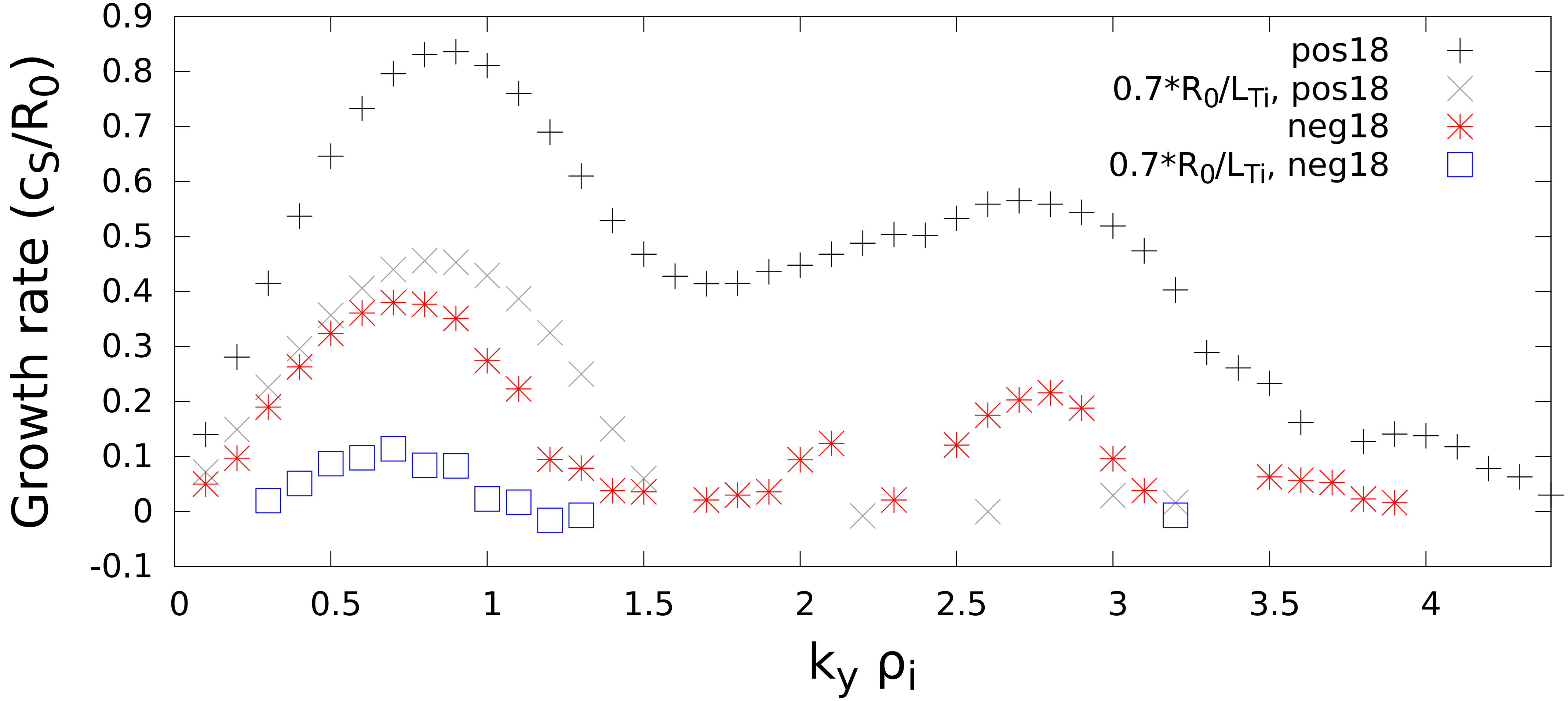
- Simulations in the core are problematic because:
    - Sawtooth inversion radius at $\rho \approx 0.6$



Linear results with adiabatic electrons

- Found a fairly broad spectrum of unstable modes

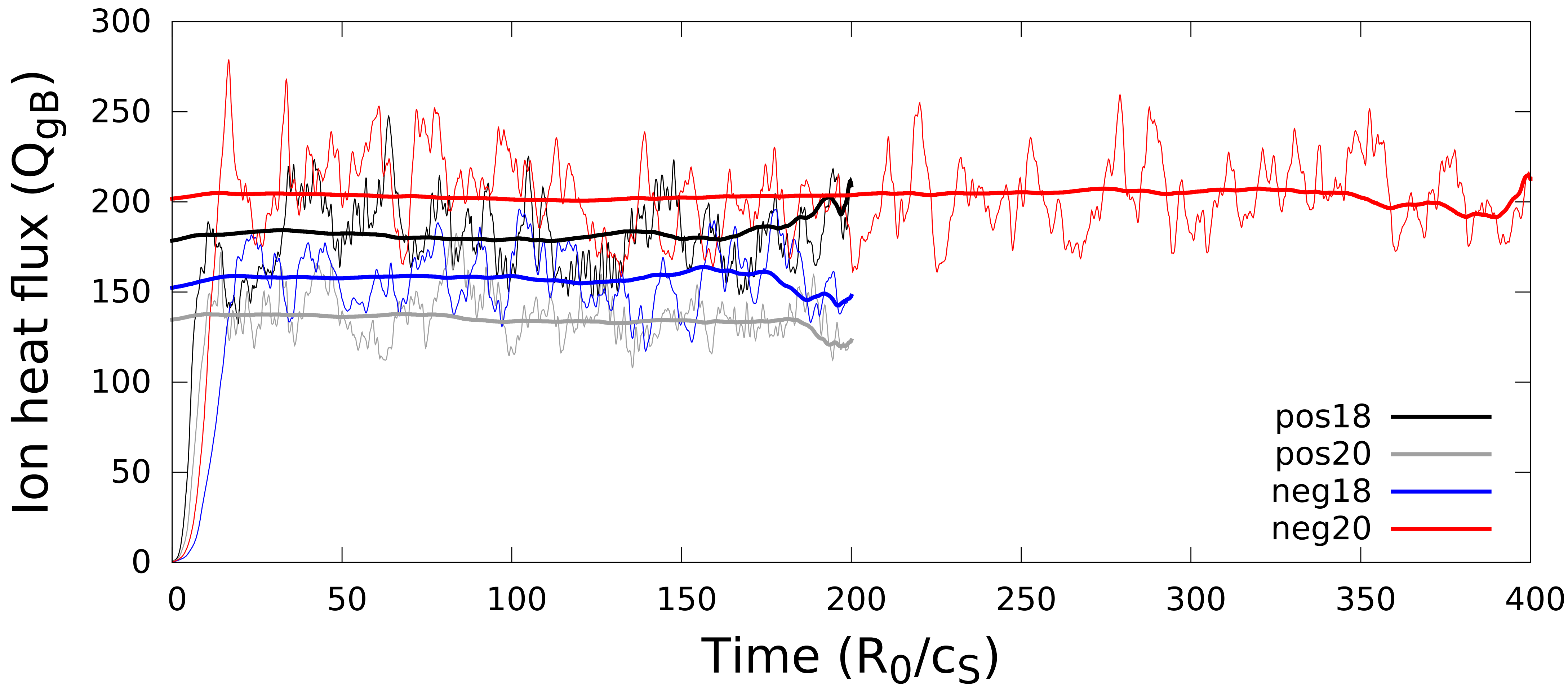
- Critical gradient for negative δ is maybe a bit larger



Nonlinear results with adiabatic electrons

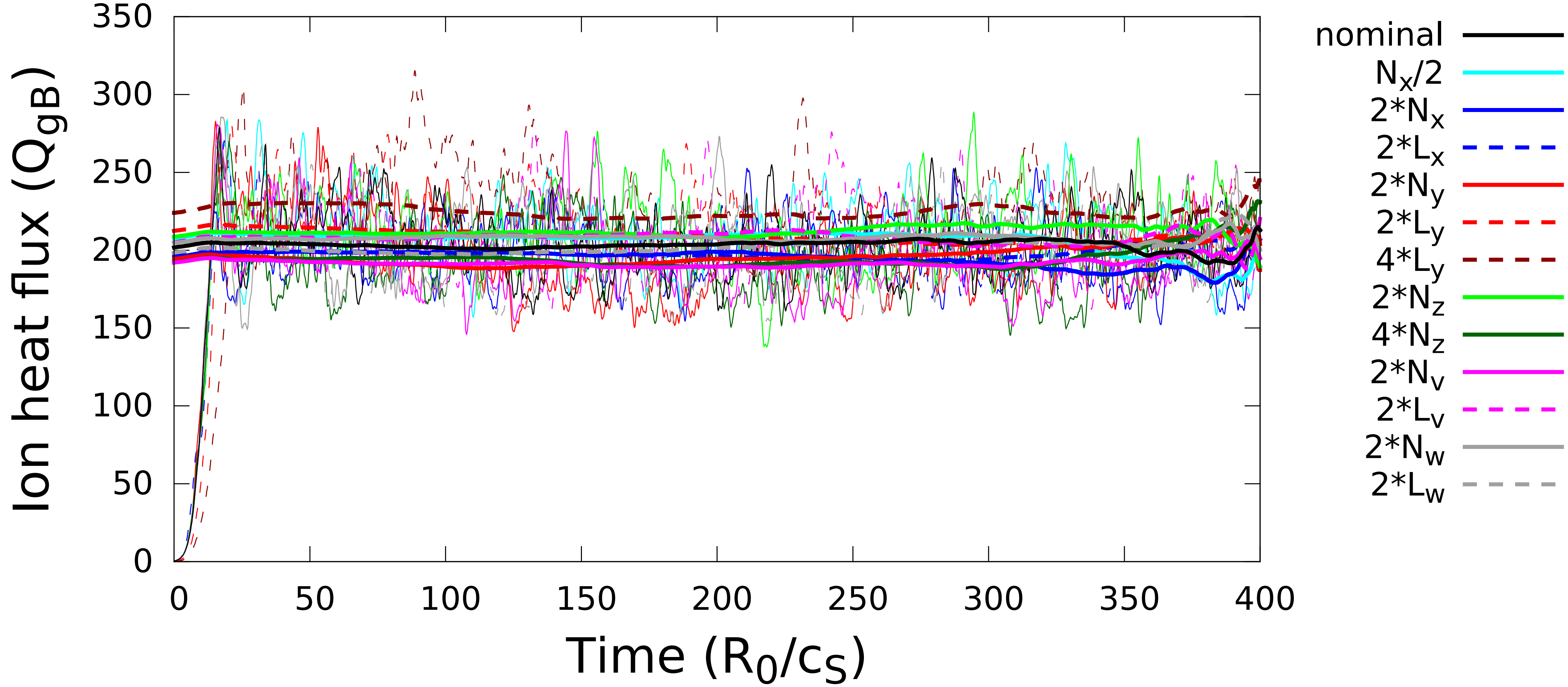
- Results are mixed, but indicates that negative δ **increases** energy transport

- Main purpose is to find most strongly driven case for resolution study



Nonlinear resolution study with adiabatic electrons

- Resolution study of the **neg20** case indicates that L_y should be doubled and N_x can be halved



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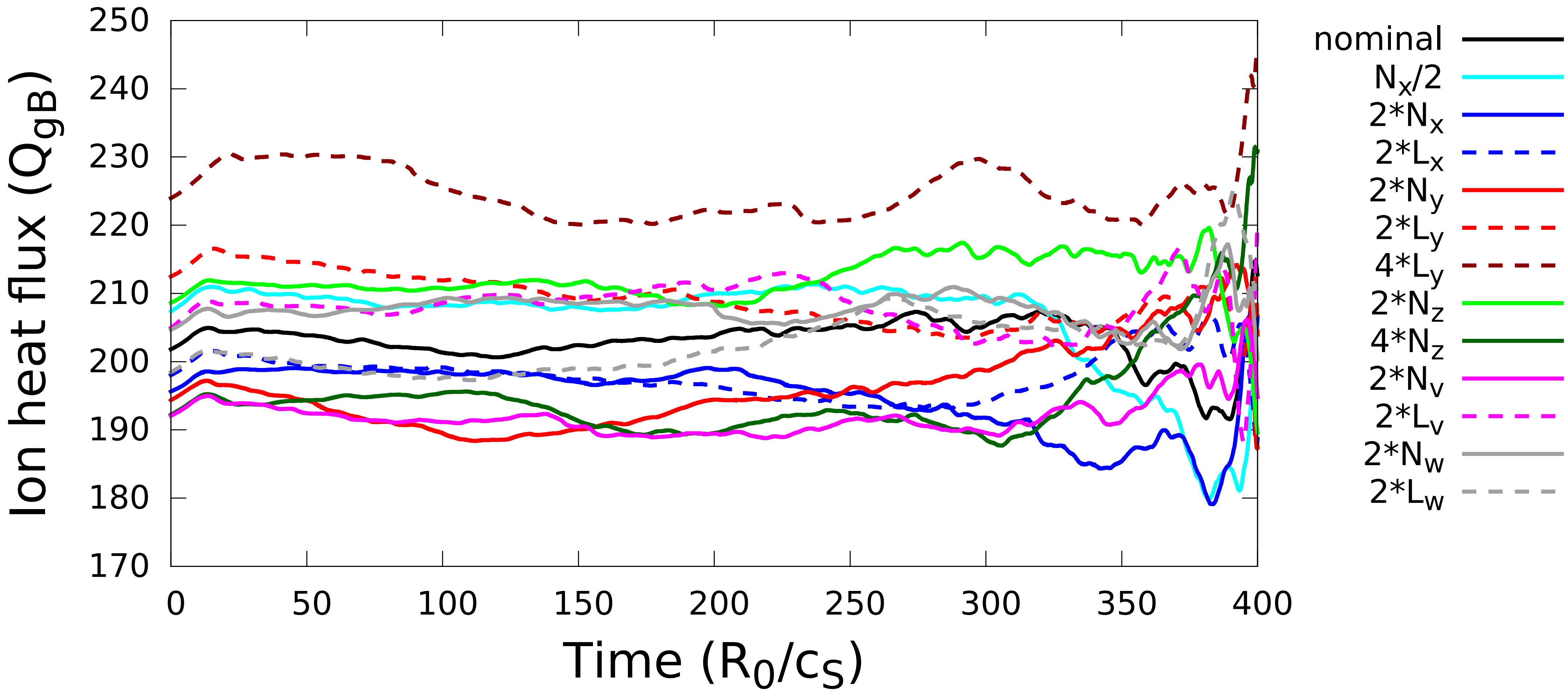
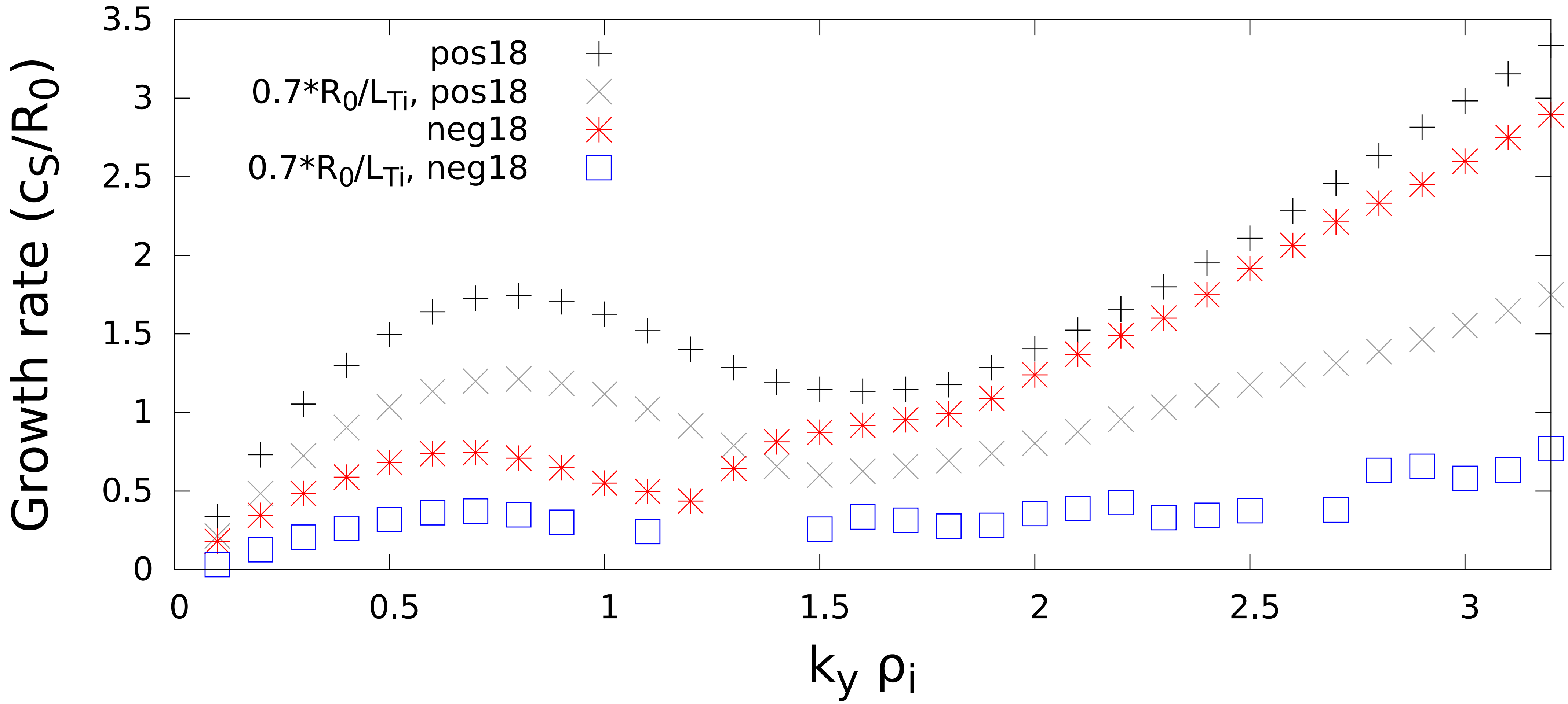


Linear results with kinetic electrons

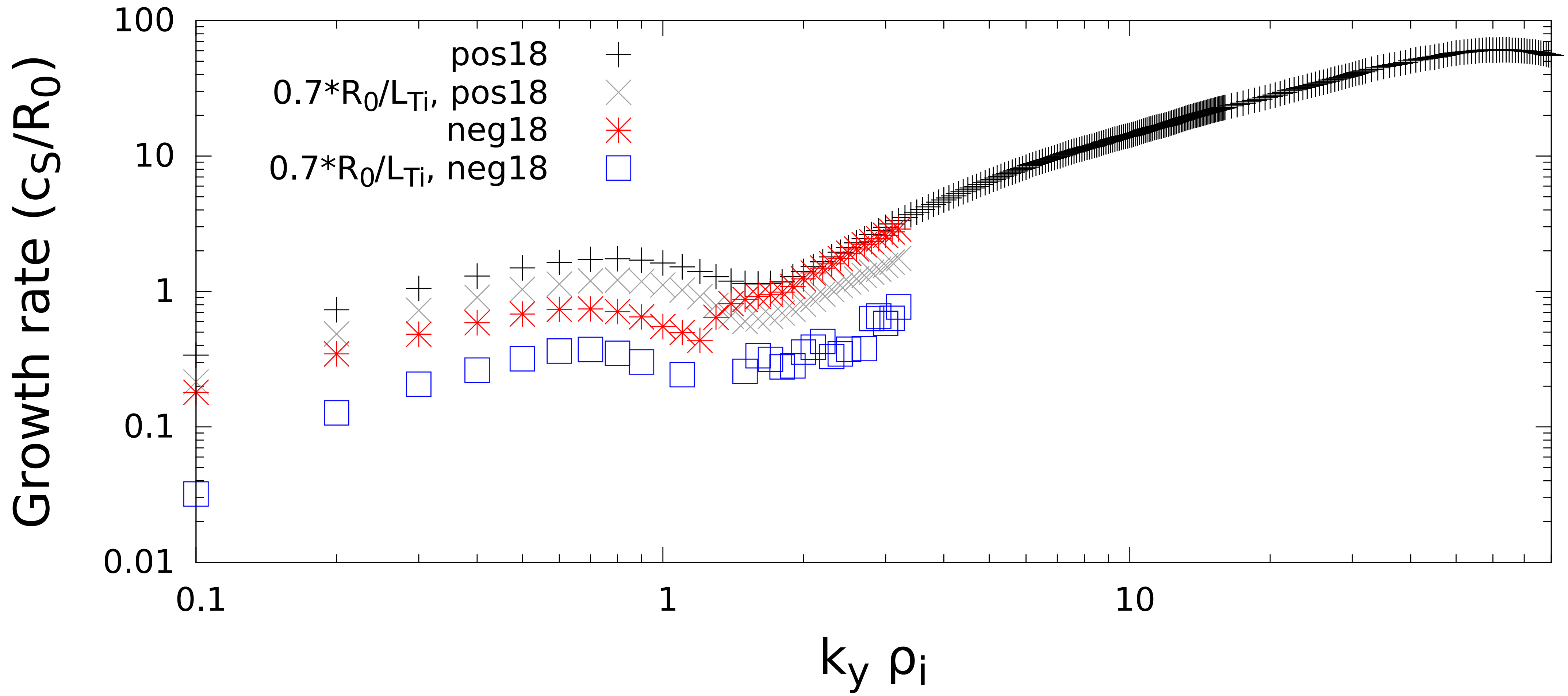
- See surprising divergence with small scale turbulence (concerning!)
- Again, critical gradient for negative δ is maybe a bit larger



Linear results with kinetic electrons

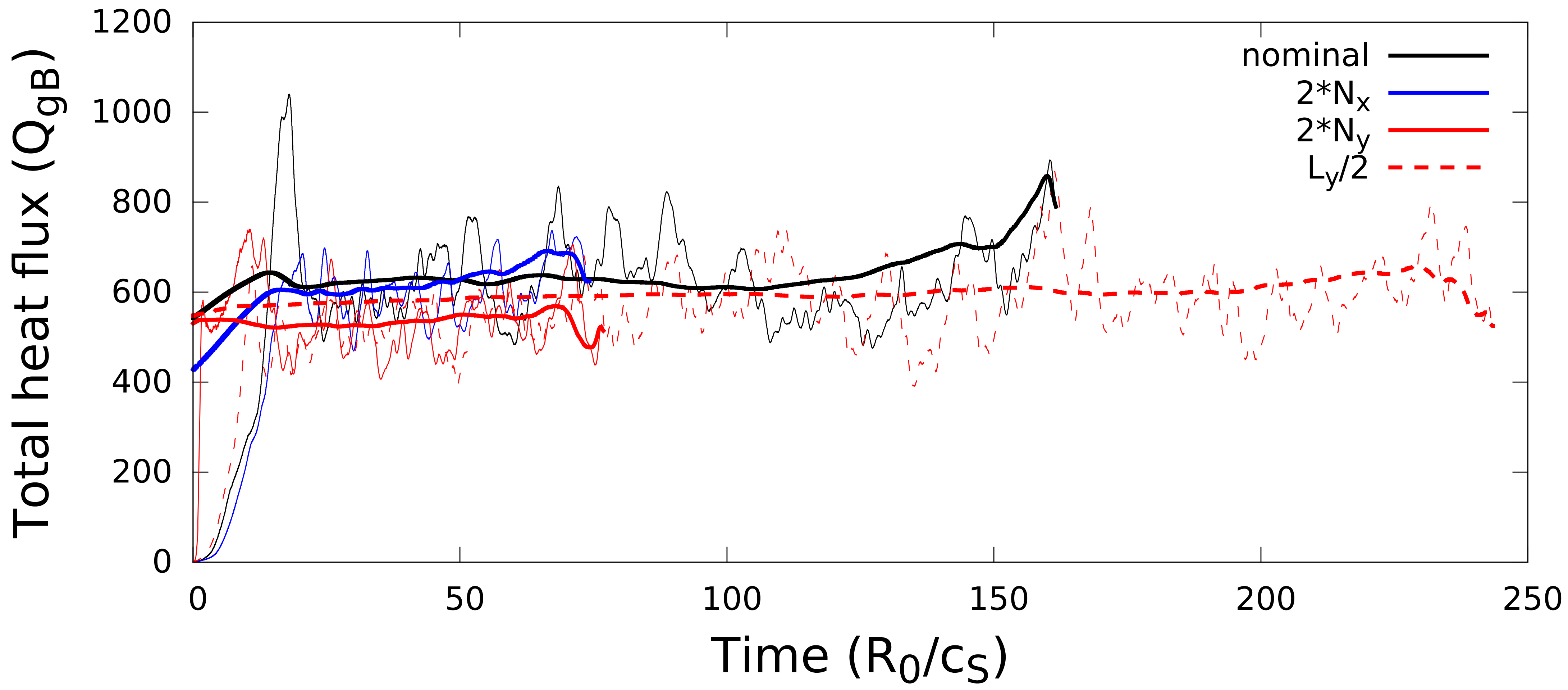
Staebler et al. *Nucl. Fusion* **57** (2017).

- A common rule of thumb, comparing $\gamma/k_y\big|_{ITG} \approx 2.2$ with $\gamma/k_y\big|_{ETG} \approx 1.0$, suggests that multi-scale interactions remain weak



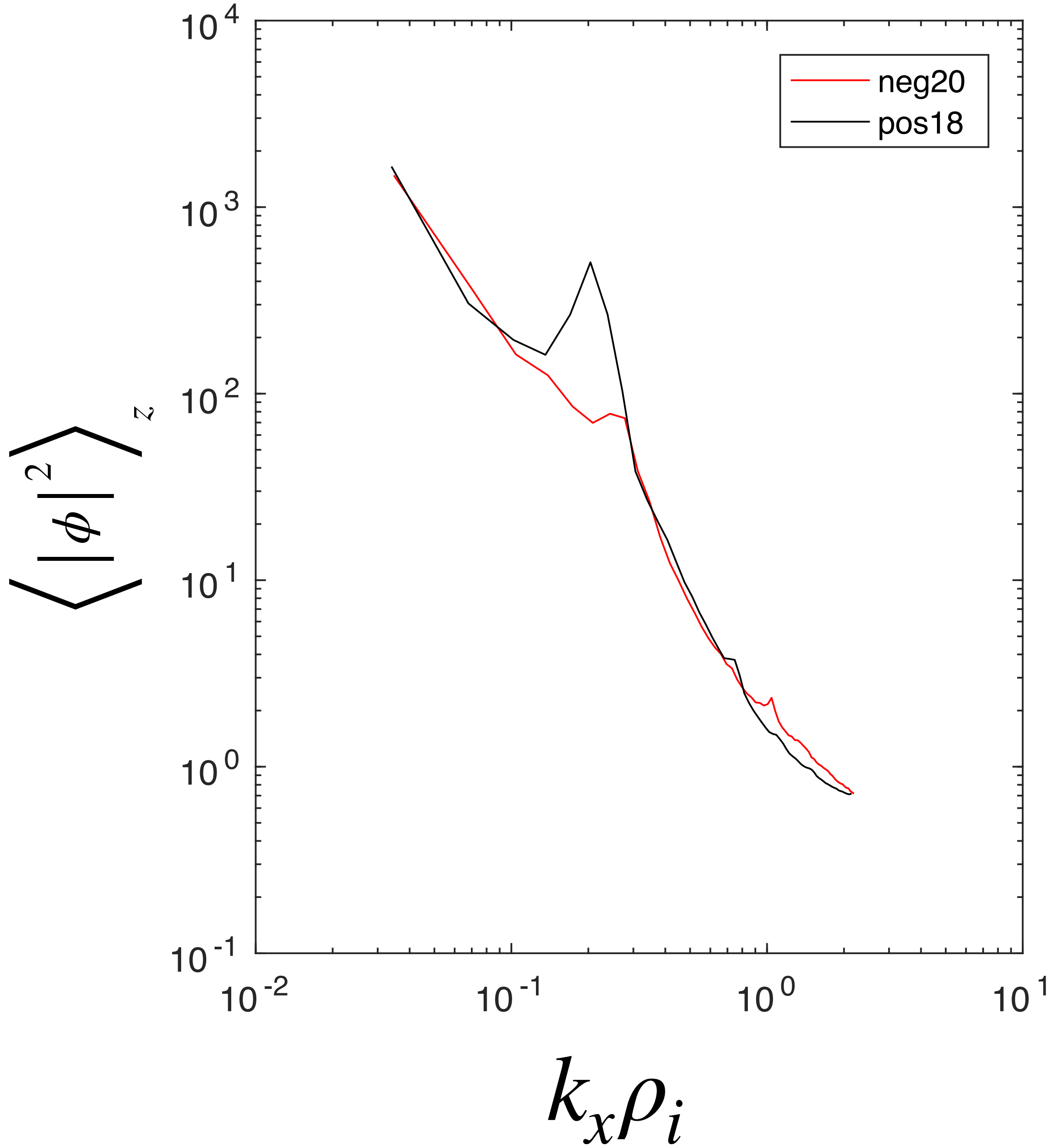
Nonlinear resolution study with kinetic electrons

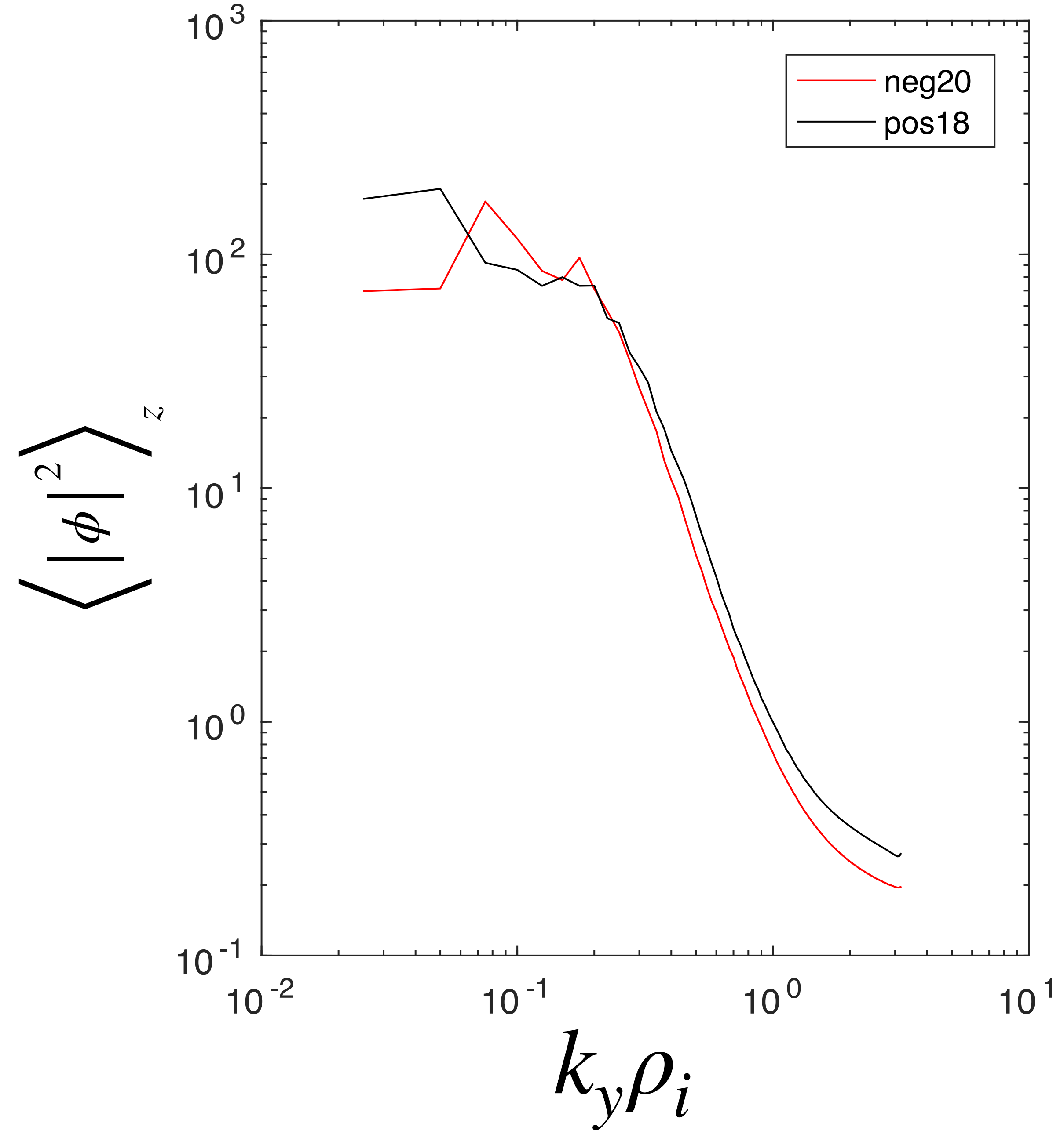
- Resolution study of the **neg20** case for the most concerning parameters seems satisfactory



Nonlinear resolution study with kinetic electrons

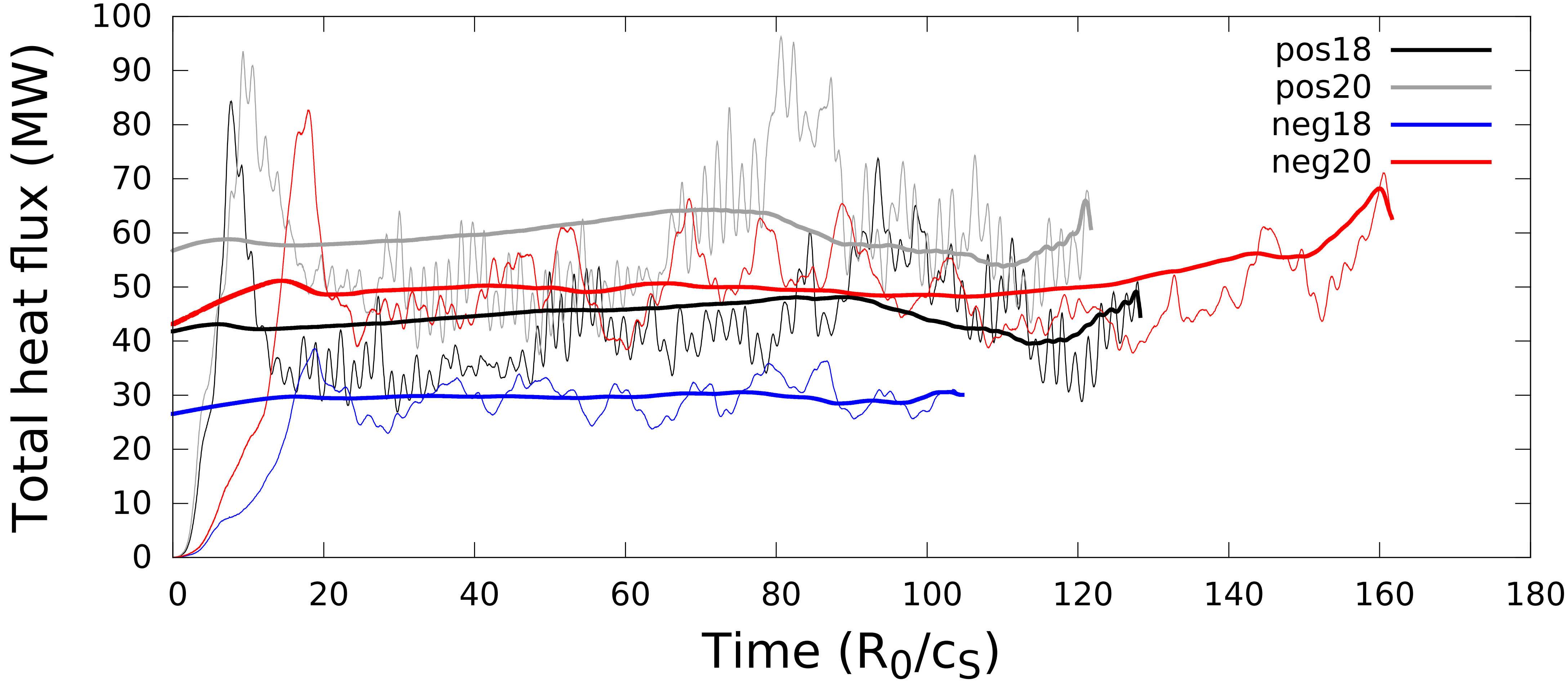
- Time-averaged spectra look normal (i.e. no pile-up at high k)





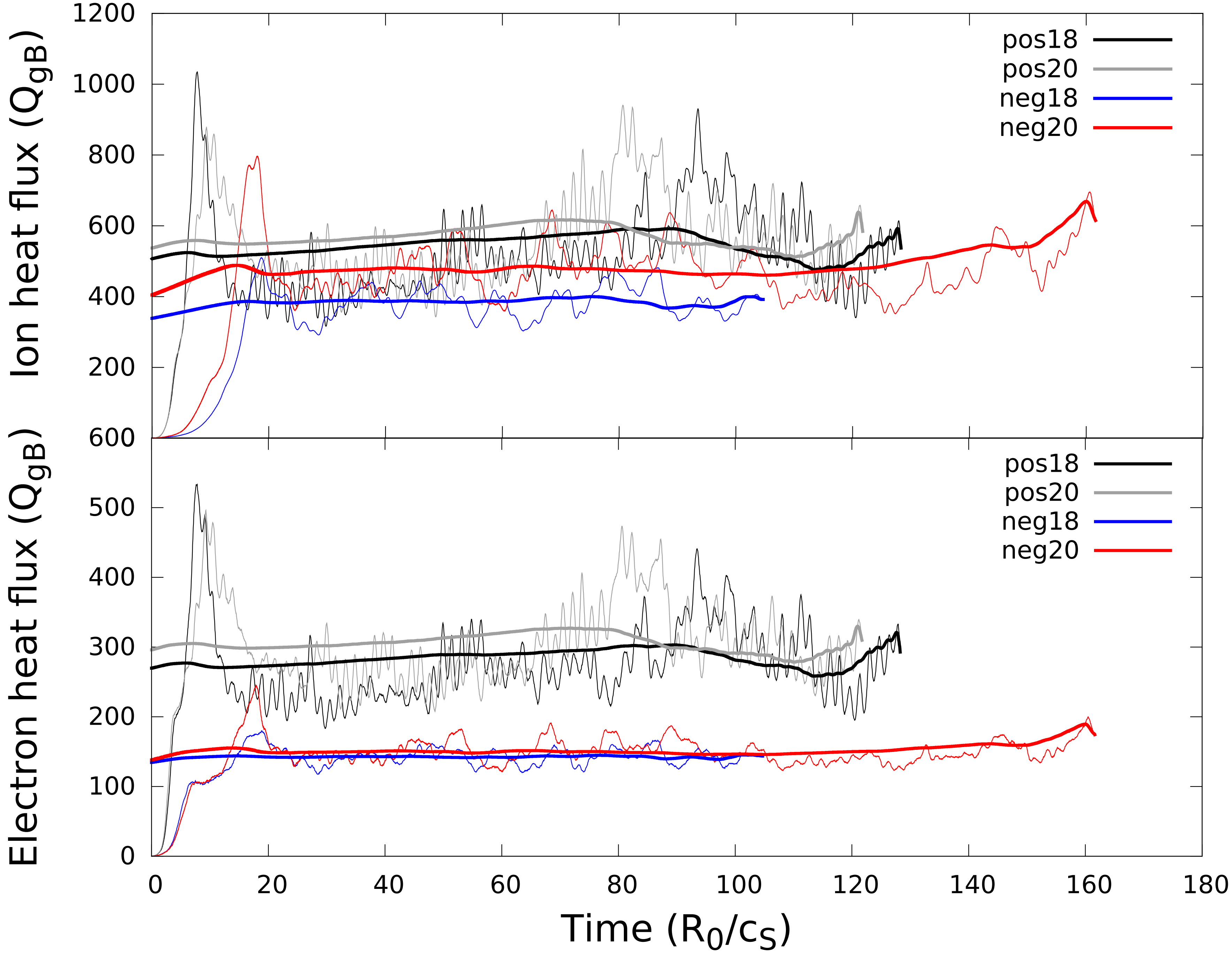
Nonlinear results with kinetic electrons

- Same trends hold true for required heating power (i.e. adjusting for differences in surface area, temperature, and density)

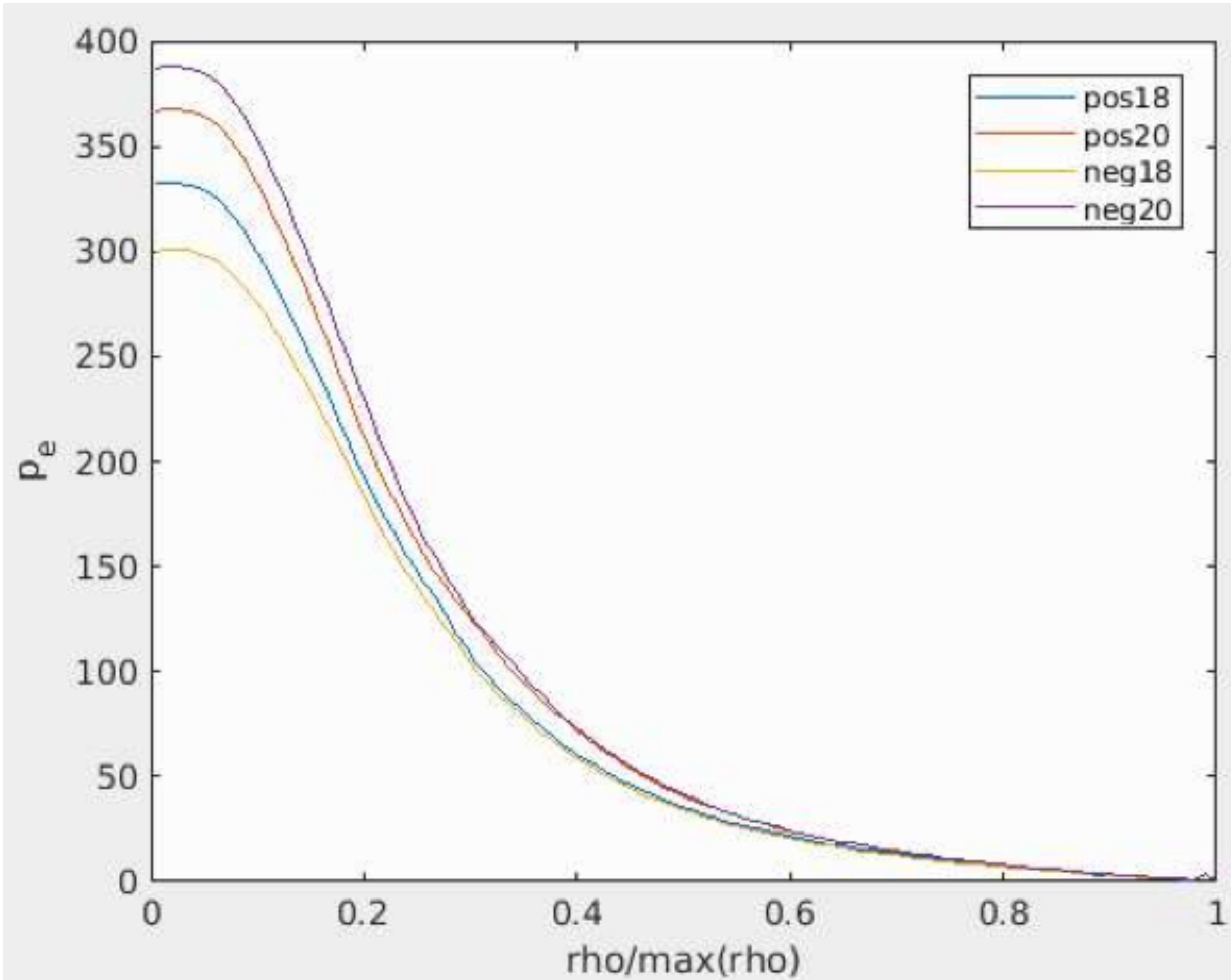


Nonlinear results with kinetic electrons

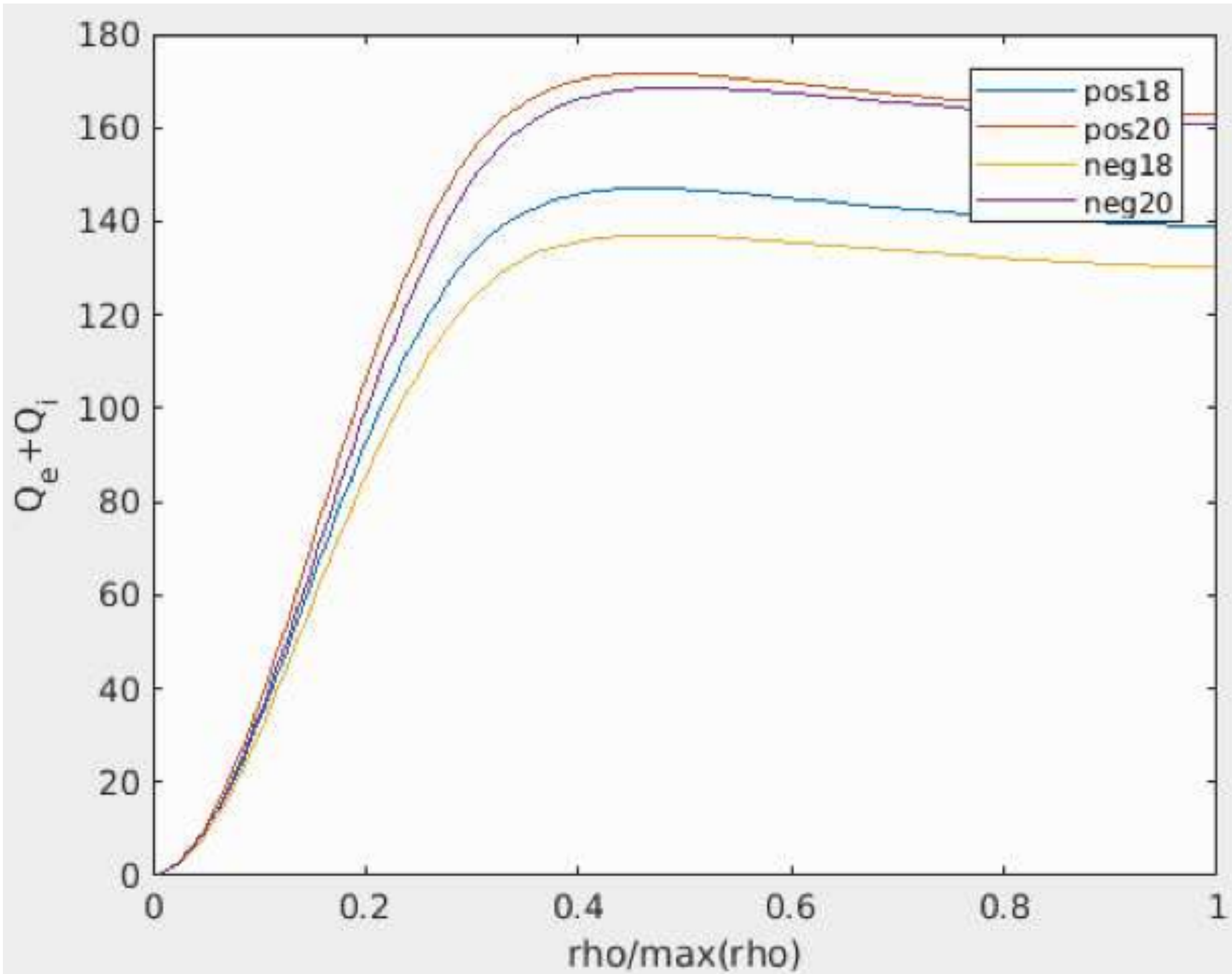
- Electron heat flux is more strongly affected by reversing δ



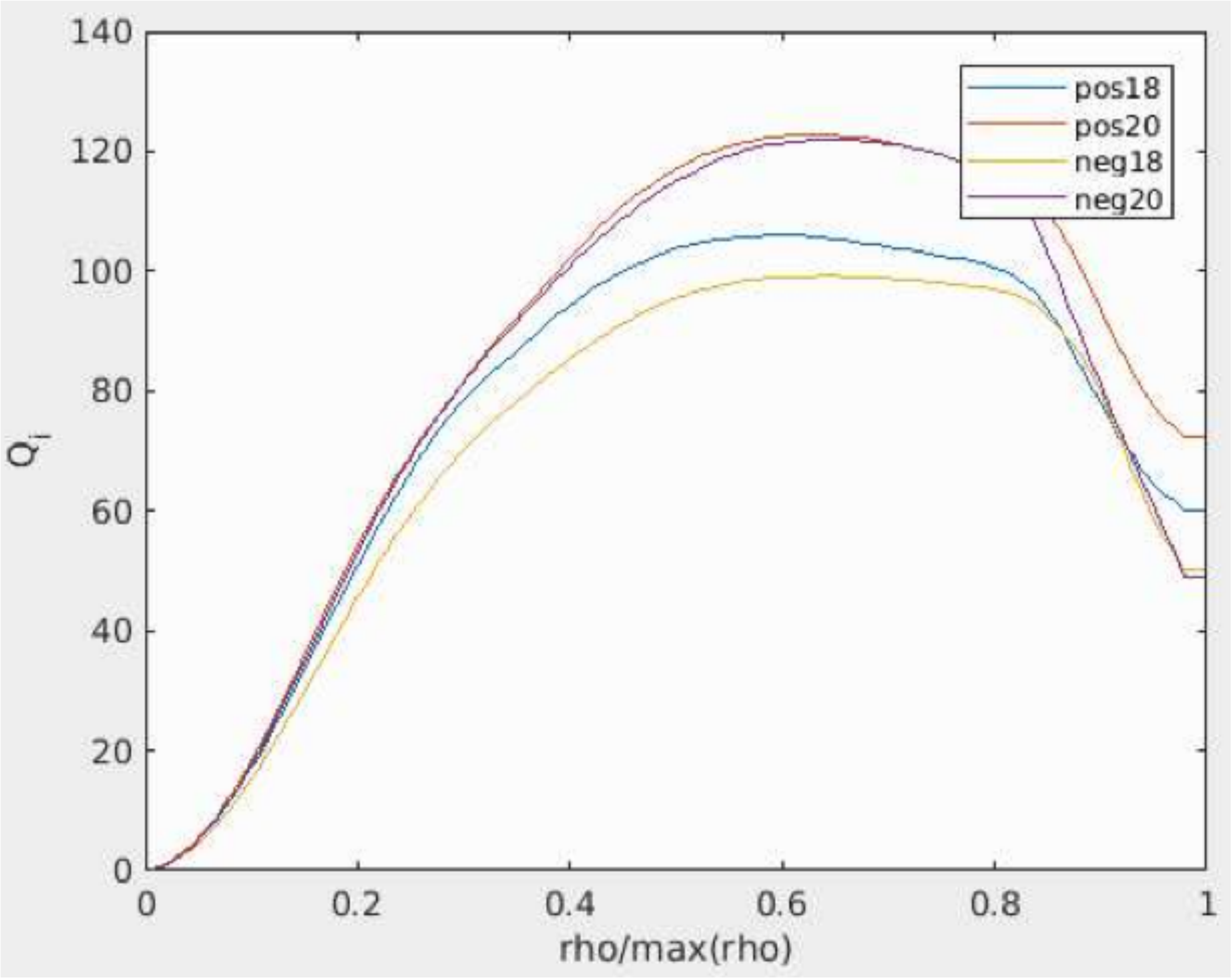
Electron pressure profile from TGLF



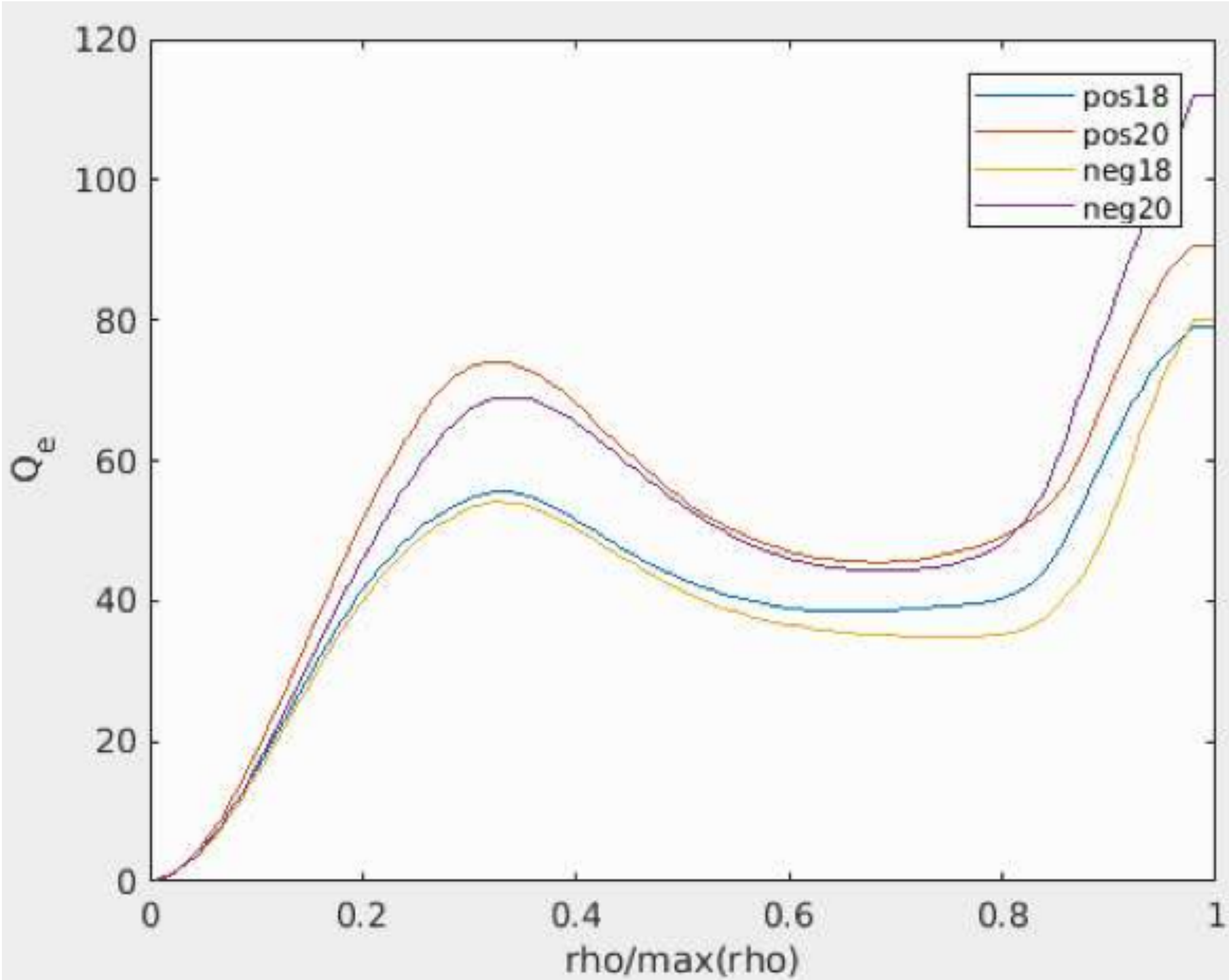
Total heat flux from TGLF



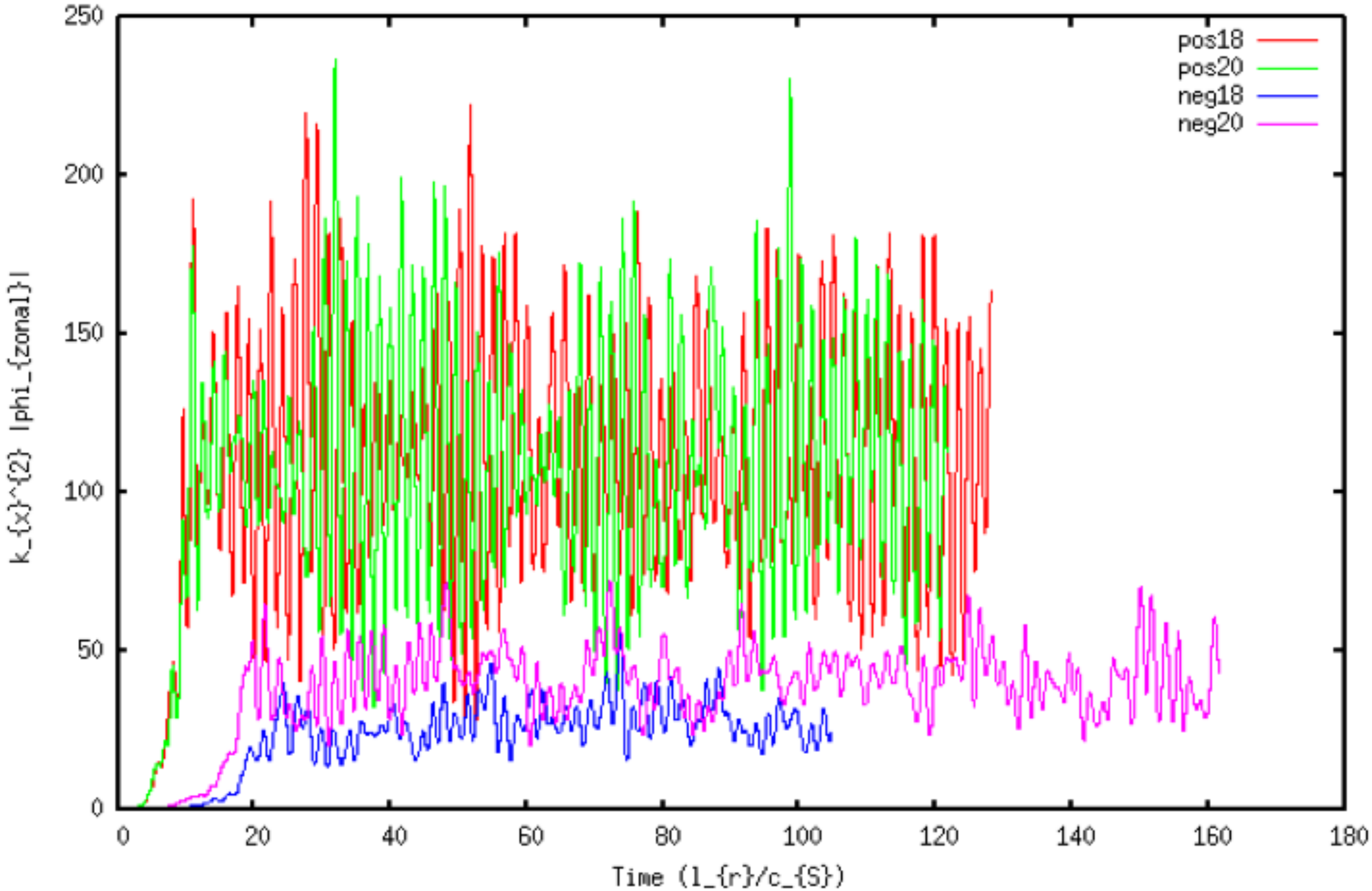
Ion heat flux from TGLF



Electron heat flux from TGLF



Zonal oscillations from nonlinear kinetic simulations



Input parameters for nonlinear kinetic simulations

```
! pos18
&geometry
magn_geometry = 'chease'
q0       =    1.7049163
shat     =    2.3791041
geomdir  = '.'
geomfile = 'ogyropsi.h5'
x_def = 'arho_t'
flux_pos =   0.72000000
minor_r  =   0.42802953
major_R  =    1.0000000
dpdx_term= 'gradB_eq_curv'
dpdx_pm  =   0.31365353E-01
norm_flux_projection  = F
/

&species
name    = 'ions'
omn     =    3.7726245
omt     =    10.384133

mass    =    1.0000000
temp    =    1.1012114
dens    =    1.0000000
charge =  1
/

&species
name    = 'electrons'
omn     =    3.7726245
omt     =    10.046073

mass    =   0.21785000E-03
temp    =    1.0000000
dens    =    1.0000000
charge = -1
```

omt/omn = 2.75

```
! pos20
&geometry
magn_geometry = 'chease'
q0       =    1.5550048
shat     =    2.3914969
geomdir  = '.'
geomfile = 'ogyropsi.h5'
x_def = 'arho_t'
flux_pos =   0.72000000
minor_r  =   0.42847416
major_R  =    1.0000000
dpdx_term= 'gradB_eq_curv'
dpdx_pm  =   0.33737323E-01
norm_flux_projection  = F
/

&species
name    = 'ions'
omn     =    3.9569369
omt     =    10.734664

mass    =    1.0000000
temp    =    1.1218137
dens    =    1.0000000
charge =  1
/

&species
name    = 'electrons'
omn     =    3.9569369
omt     =    10.514612

mass    =   0.21785000E-03
temp    =    1.0000000
dens    =    1.0000000
charge = -1
```

omt/omn = 2.71

```
! neg18
&geometry
magn_geometry = 'chease'
q0       =    1.5343302
shat     =    2.2000282
geomdir  = '.'
geomfile = 'ogyropsi.h5'
x_def = 'arho_t'
flux_pos =   0.72000000
minor_r  =   0.41714032
major_R  =    1.0000000
dpdx_term= 'gradB_eq_curv'
dpdx_pm  =   0.36014773E-01
norm_flux_projection  = F
/

&species
name    = 'ions'
omn     =    2.7080109
omt     =    8.5717145

mass    =    1.0000000
temp    =    1.1058137
dens    =    1.0000000
charge =  1
/

&species
name    = 'electrons'
omn     =    2.7080109
omt     =    9.9598991

mass    =   0.21785000E-03
temp    =    1.0000000
dens    =    1.0000000
charge = -1
```

omt/omn = 3.16

```
! neg20
&geometry
magn_geometry = 'chease'
q0       =    1.3988000
shat     =    2.2103327
geomdir  = '.'
geomfile = 'ogyropsi.h5'
x_def = 'arho_t'
flux_pos =   0.72000000
minor_r  =   0.41760834
major_R  =    1.0000000
dpdx_term= 'gradB_eq_curv'
dpdx_pm  =   0.39377451E-01
norm_flux_projection  = F
/

&species
name    = 'ions'
omn     =    2.9316145
omt     =    9.9035116

mass    =    1.0000000
temp    =    1.1116355
dens    =    1.0000000
charge =  1
/

&species
name    = 'electrons'
omn     =    2.9316145
omt     =    9.9796884

mass    =   0.21785000E-03
temp    =    1.0000000
dens    =    1.0000000
charge = -1
```

omt/omn = 3.38

Input parameters for nonlinear adiabatic sims.

```
pos18
&geometry
magn_geometry = 'chease'
q0        =    1.7049163
shat      =    2.3791041
geomdir   = '.'
geomfile = 'ogyropsi.h5'
x_def = 'arho_t'
flux_pos =    0.72000000
minor_r  =    0.42802953
major_R  =    1.0000000
dpdx_term= 'gradB_eq_curv'
dpdx_pm  =    0.31365353E-01
norm_flux_projection  = F
/

&species
name    = 'ions'
omn     =    5.5182257
omt     =    14.977186

mass    =    1.0000000
temp    =    1.0000000
dens    =    1.0000000
charge =  1
```

omt/omn = 2.71

```
pos20
&geometry
magn_geometry = 'chease'
q0        =    1.5550048
shat      =    2.3914969
geomdir   = '.'
geomfile = 'ogyropsi.h5'
x_def = 'arho_t'
flux_pos =    0.72000000
minor_r  =    0.42847416
major_R  =    1.0000000
dpdx_term= 'gradB_eq_curv'
dpdx_pm  =    0.33737323E-01
norm_flux_projection  = F
/

&species
name    = 'ions'
omn     =    5.0452291
omt     =    13.214426

mass    =    1.0000000
temp    =    1.0000000
dens    =    1.0000000
charge =  1
```

omt/omn = 2.62

```
neg18
&geometry
magn_geometry = 'chease'
q0        =    1.5343302
shat      =    2.2000282
geomdir   = '.'
geomfile = 'ogyropsi.h5'
x_def = 'arho_t'
flux_pos =    0.72000000
minor_r  =    0.41714032
major_R  =    1.0000000
dpdx_term= 'gradB_eq_curv'
dpdx_pm  =    0.36014773E-01
norm_flux_projection  = F
/

&species
name    = 'ions'
omn     =    3.4580024
omt     =    11.342345

mass    =    1.0000000
temp    =    1.0000000
dens    =    1.0000000
charge =  1
```

omt/omn = 3.28

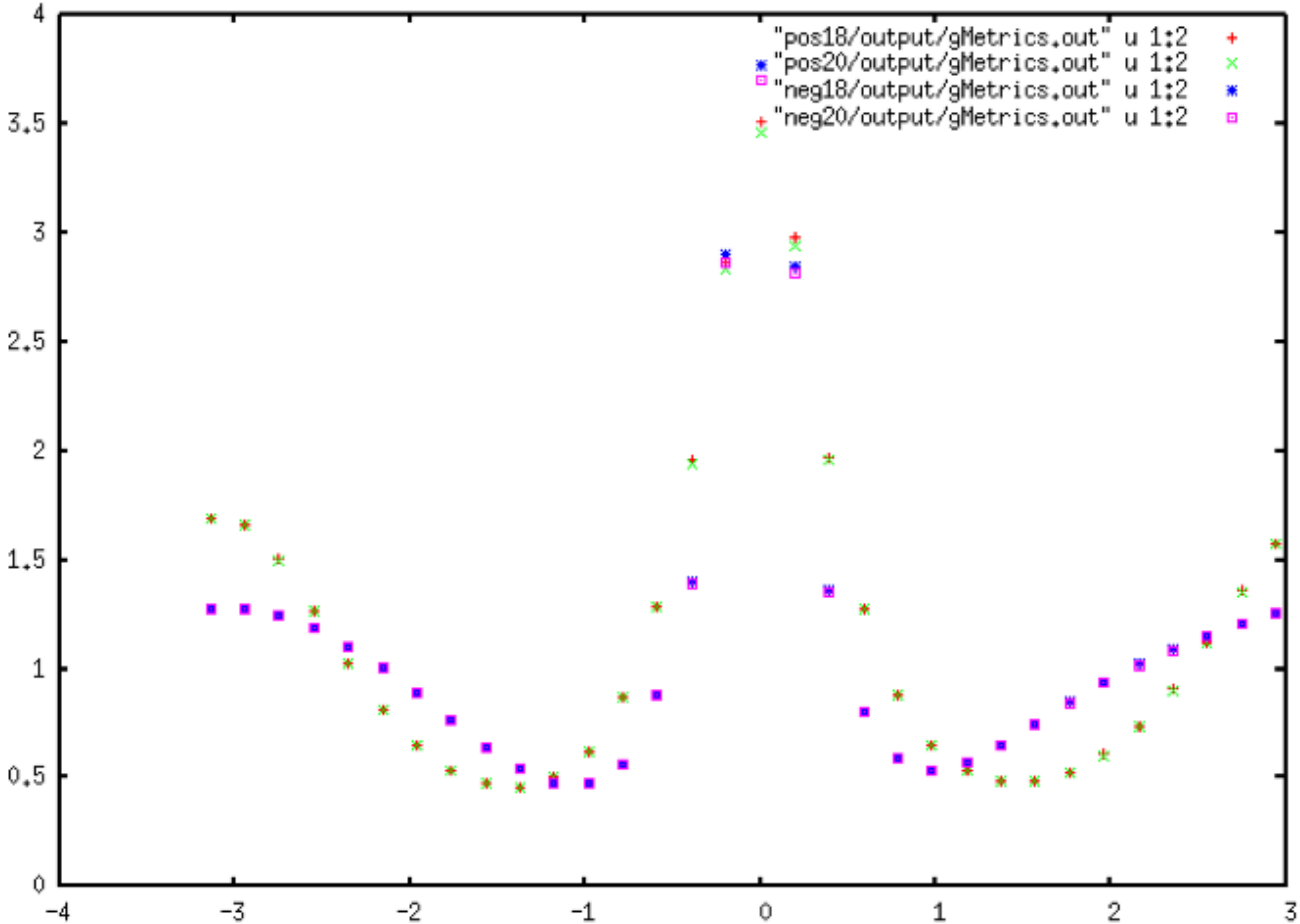
```
neg20
&geometry
magn_geometry = 'chease'
q0        =    1.3988000
shat      =    2.2103327
geomdir   = '.'
geomfile = 'ogyropsi.h5'
x_def = 'arho_t'
flux_pos =    0.72000000
minor_r  =    0.41760834
major_R  =    1.0000000
dpdx_term= 'gradB_eq_curv'
dpdx_pm  =    0.39377451E-01
norm_flux_projection  = F
/

&species
name    = 'ions'
omn     =    3.7474076
omt     =    13.374003

mass    =    1.0000000
temp    =    1.0000000
dens    =    1.0000000
charge =  1
```

omt/omn = 3.57

$\left| \vec{\nabla} \rho \right|^2$ as a function of poloidal angle



Flux surface shape in the poloidal plane