Progress on global tearing/resistive interchange mode simulations in GEM

Jugal Chowdhury, Yang Chen, Scott E Parker, Weigang Wan, Scott Kruger

About the Simulation Model

The simulation model is composed of

1. **Drift-fluid model for electrons, and**
2. **Gyrokinetic ions**

- Drift-fluid model for electrons uses the following continuity equation,

$$\frac{\partial \delta n_e}{\partial t} + n_0(B\nabla_{\|} + \delta B_{\perp} \cdot \nabla)\frac{u_{\|}}{B} + v_E \cdot (n_0 + \delta n_e) + \frac{1}{m_e \Omega_e B^2} B \times \nabla B \cdot \nabla(\delta P_{\perp} + \delta P_{\|}) + \frac{2n_0}{B^3} B \times \nabla B \cdot \nabla \phi = 0$$

- Along with parallel Ohm's law,

$$E_{\|} = -\tilde{b} \cdot \nabla \delta P_{\|} - \frac{\delta B_{\perp}}{B} . \nabla P_{\|0} + \eta_e j_{\|}$$

- Perturbed distribution function δf_i for gyrokinetic ions evolves according to the equation:

$$\frac{d\delta f_i}{dt} = -\left(v_{\|} \frac{\delta B_{\perp}}{B} + v_E\right) \cdot \nabla f_{0i} - \dot{\varepsilon}_i \frac{\partial f_{0i}}{\partial \dot{\varepsilon}_i}$$

The particle motion is governed by the guiding center equations:

We consider three cases:

- Case I. Furth, Rutherford and Selberg (Phys. Fluids **16** (7), 1973) parameters;
- Case II. Holmes *et al.*, Phys. Fluids **26** (9), 1983;
- Case III. Artificial profile for safety factor.

Equilibrium Profiles:

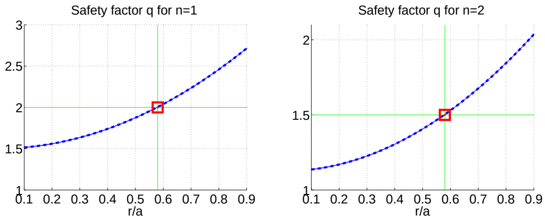


Figure: Safety factor profiles for $n = 1$ and $n = 2$ cases; differ by q_0; $q_0 = 1.5$ and 1.1, respectively, for $n = 1$ and $n = 2$, to capture $m/n = 2/1$ and $3/2$ modes.

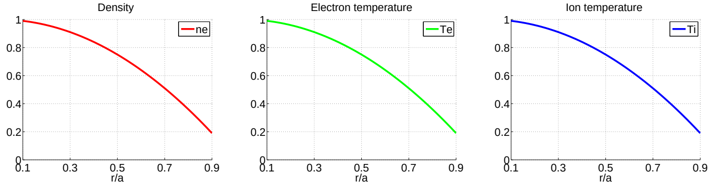


Figure: Density and temperature profiles

Growth rate and real frequency vs S_A, the Lundquist number

$\left(S_A = \frac{\tau_R}{\tau_A}\right.$, where $\tau_R = \frac{a^2 \mu}{\eta_j}$ is resistive skin time and $\tau_A = L/v_A$, $\;v_A = B/\sqrt{(\mu_0 \rho)}$ is Alfven time)

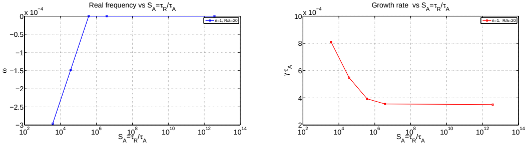


Figure: Real frequency ω_r (left panel) and growth rate γ (right panel) for $n = 1$.

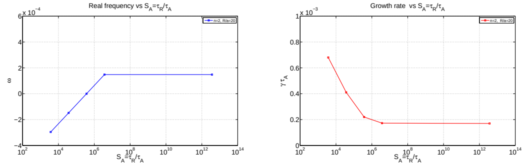


Figure: Real frequency ω_r (left panel) and growth rate γ (right panel) for $n = 2$.

- The mode growth rate decreases with increasing S_A on the lower side of S_A; however at higher S_A mode growth remains constant.
- The dependence of mode growth rate on S_A on the lower side of S_A is not strong??

A β scan for $n = 2$

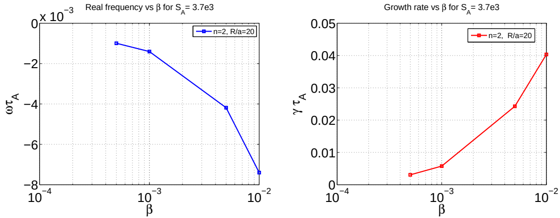


Figure: Real frequency ω_r (left) and growth rate γ (right) versus β for $n = 2$ case.

✓ The mode growth rate increases with increasing β

Mode structures for $n = 1$, $S_A = 3.7 \times 10^6$, $\beta = .0001$, $R/a = 20$, $dP/dr \neq 0$

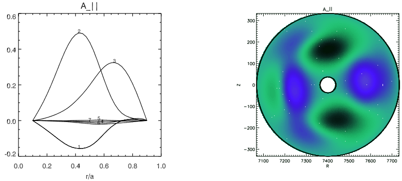


Figure: Mode structures for $A_{\|}$

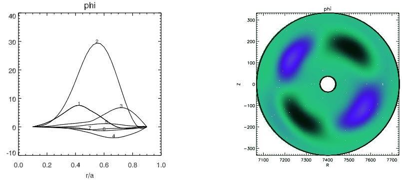


Figure: Mode structures for ϕ

- The mode structures do not exhibit tearing parity.
- Same is the case for $n = 2$.

Case III. Artificial profile for safety factor

Other parameters:

- Aspect ratio, $R/a = 2.83,\ 10,\ \text{and } 20,$
- $\beta = 0.0015,$
- $n = 1,\ 2,\ 3,\ 4,\ 5$

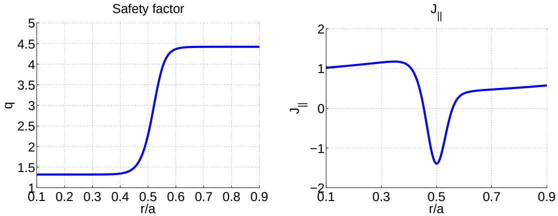


Figure: Safety factor profile and resulting current profile

- The pressure profile is kept flat, so that $\nabla P = 0$, no pressure gradient drive.

Growth rate and real frequency vs S_A for $n = 1$ and $n = 2$; $R/a = 2.83$, $\beta = 0.0015$

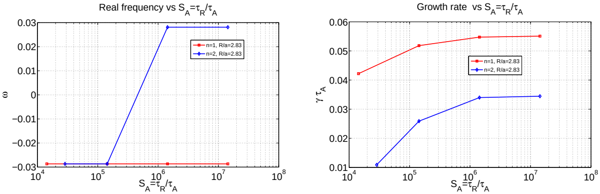


Figure: Real frequency ω_r (left) and growth rate γ (right) versus S_A; $R/a = 2.83$, $\beta = 0.0015$

- The growth rate is observed to be insensitive to higher S_A; increases with S_A on the lower side??
- The growth rate for $n = 1$ is greater than that of $n = 2$.

Mode structures for $n = 2$

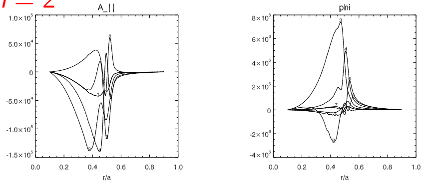


Figure: Poloidal harmonics for $A_{||}$ (left) and ϕ (right); $n = 2$, $R/a = 2.83$, $\beta = 0.0015$, and $S_A = 1.4 \times 10^5$

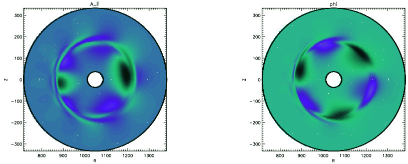


Figure: Mode structure on the poloidal plan for $A_{||}$ (left) and ϕ (right); $n = 2$, $R/a = 2.83$, $\beta = 0.0015$, and $S_A = 1.4 \times 10^5$

- The mode structures seem to exhibit a tearing parity. A current layer is noticed in the poloidal mode structure (lower panel).

Growth rate and real frequency vs S_A for $n = 1$ for different aspect ratio

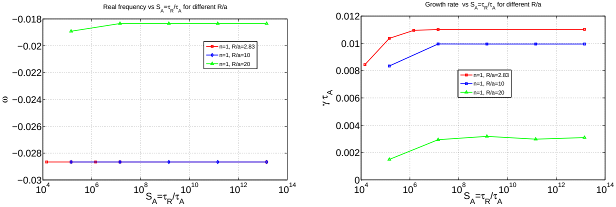


Figure: Real frequency ω_r (left) and growth rate γ (right) versus S_A for $R/a = 2.83$, $R/a = 10$, and $R/a = 20$; $n = 1$, $\beta = 0.0015$

- The growth decreases with increasing R/a.

Gyrokinetic Simulations of the Tokamak Edge Pedestal

Scott Parker, Weigang Wan, Yang Chen, Jugal Chowdury

University of Colorado, Boulder

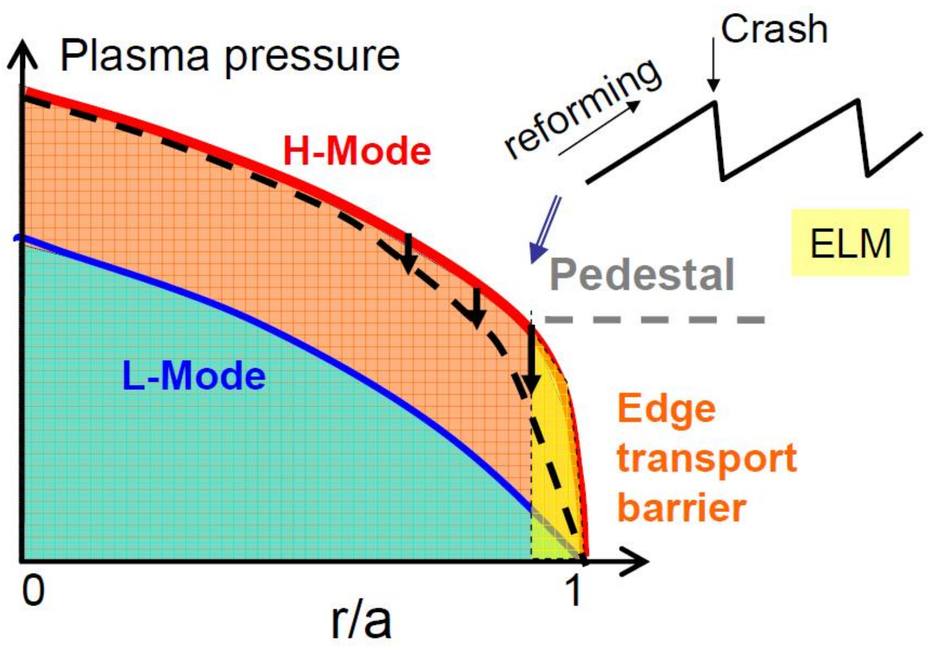
Collaborators: R. Groebner, General Atomics; D. Smith, Univ. of Wisconsin;
C.S. Chang, S. Ku, J. Lang, R. Hager, PPPL

Work funded by DOE SciDAC Edge Physics Simulation (EPSI) Project

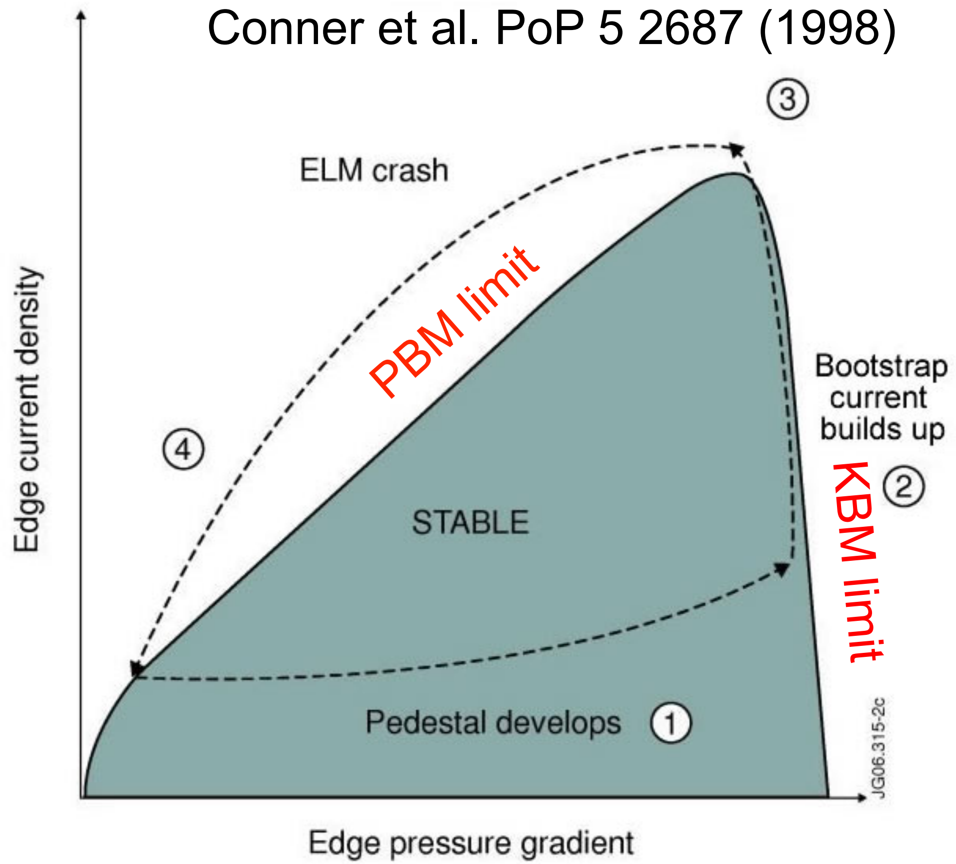
International Sherwood Fusion Theory Conference, March 25, 2014

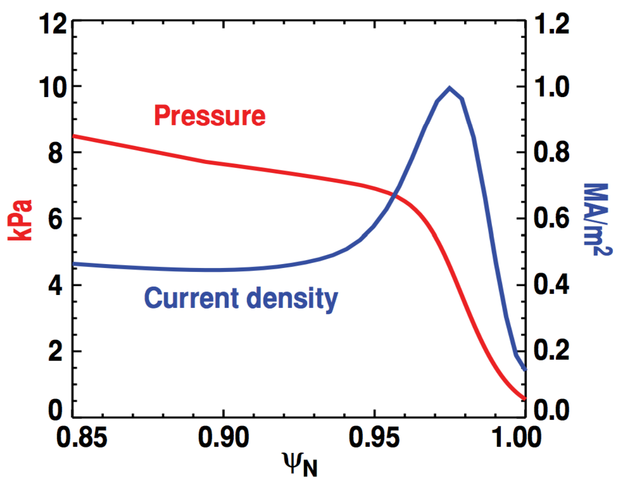
ELM Cycle (Large "Type-I" ELMs)

Liang et al. IAEA EFDA-JET-PR(10) 19 (2008)



Conner et al. PoP 5 2687 (1998)





Groebner *et al.*
Nucl. Fusion 53 093024 (2013)

Flux-tube Simulations of Edge Pedestal

Pedestal top:

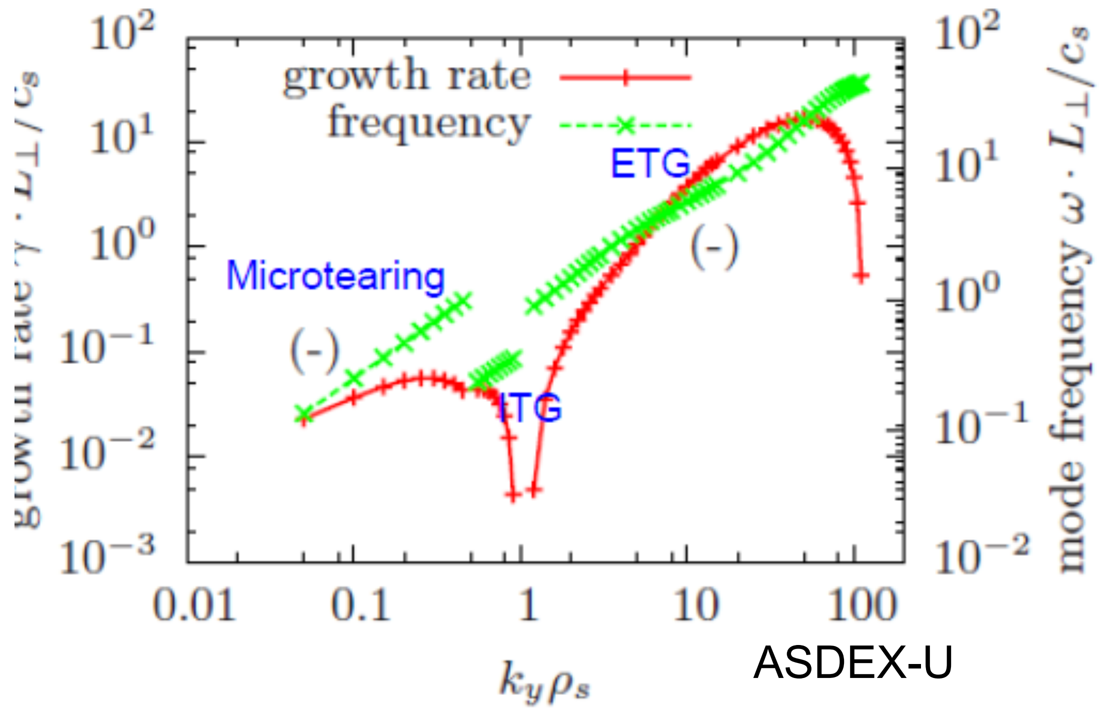
ITG and ETG

Steep gradient region:

Micro-tearing, ITG, ETG

KBM is elusive!

KBM is not the most unstable mode



ASDEX-U

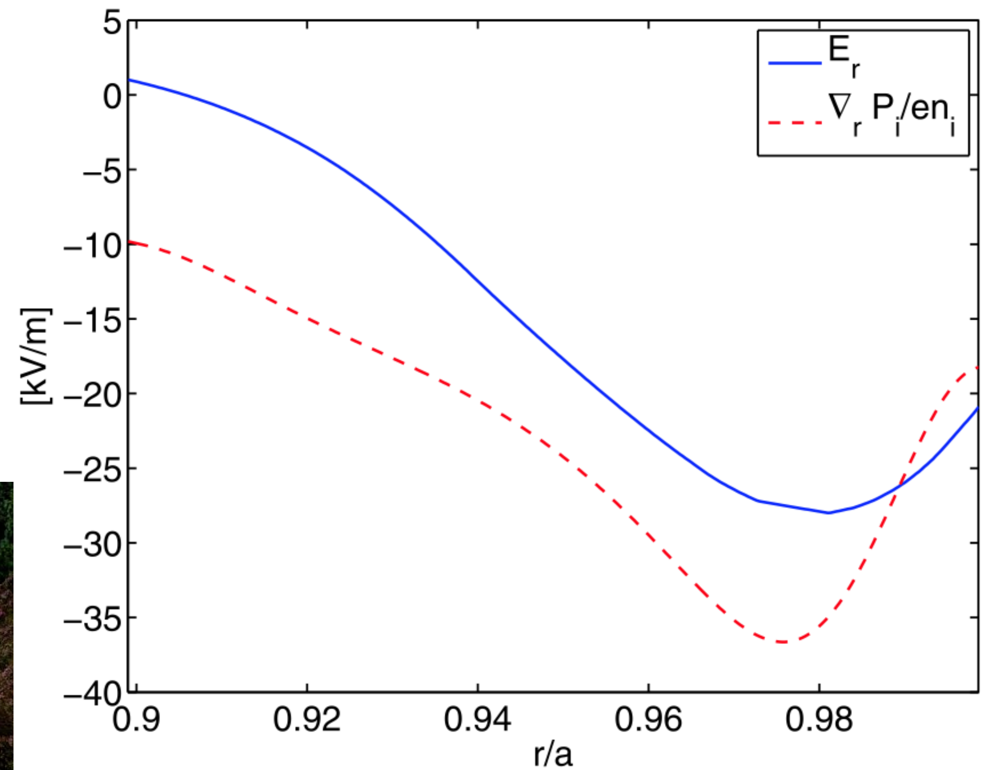
D. Told et al. PoP 15 102306 (2008)

Wang et al. Nuc. Fusion (2012)
Groebner et al. Nuc. Fusion (2013)
Bravenec et al. PoP (2013)

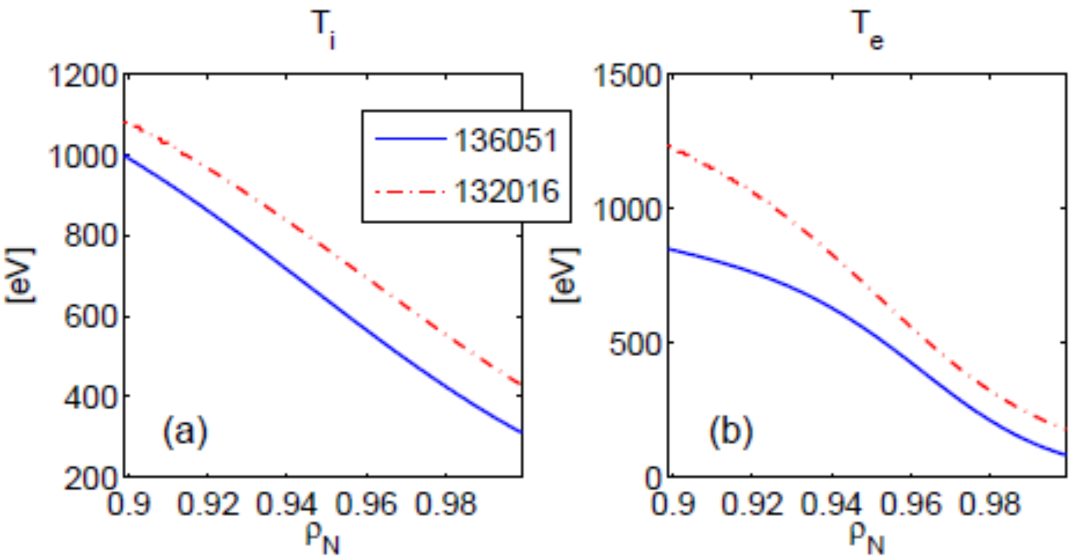
GEM Simulations of Edge

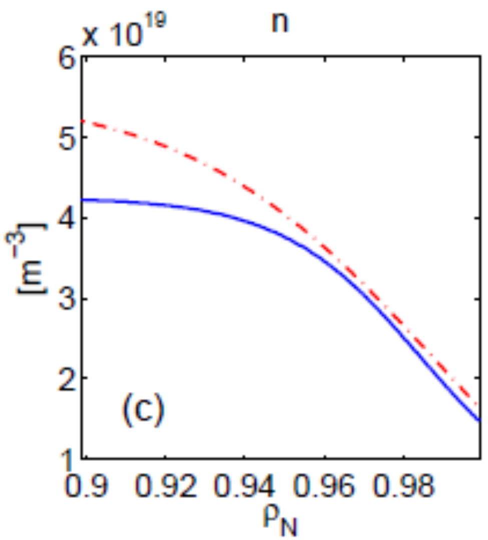
Specified Equilibrium Er

Closed flux surface edge:
r/a=[0.899, 0.999]



Experimental Profiles before ELM onset



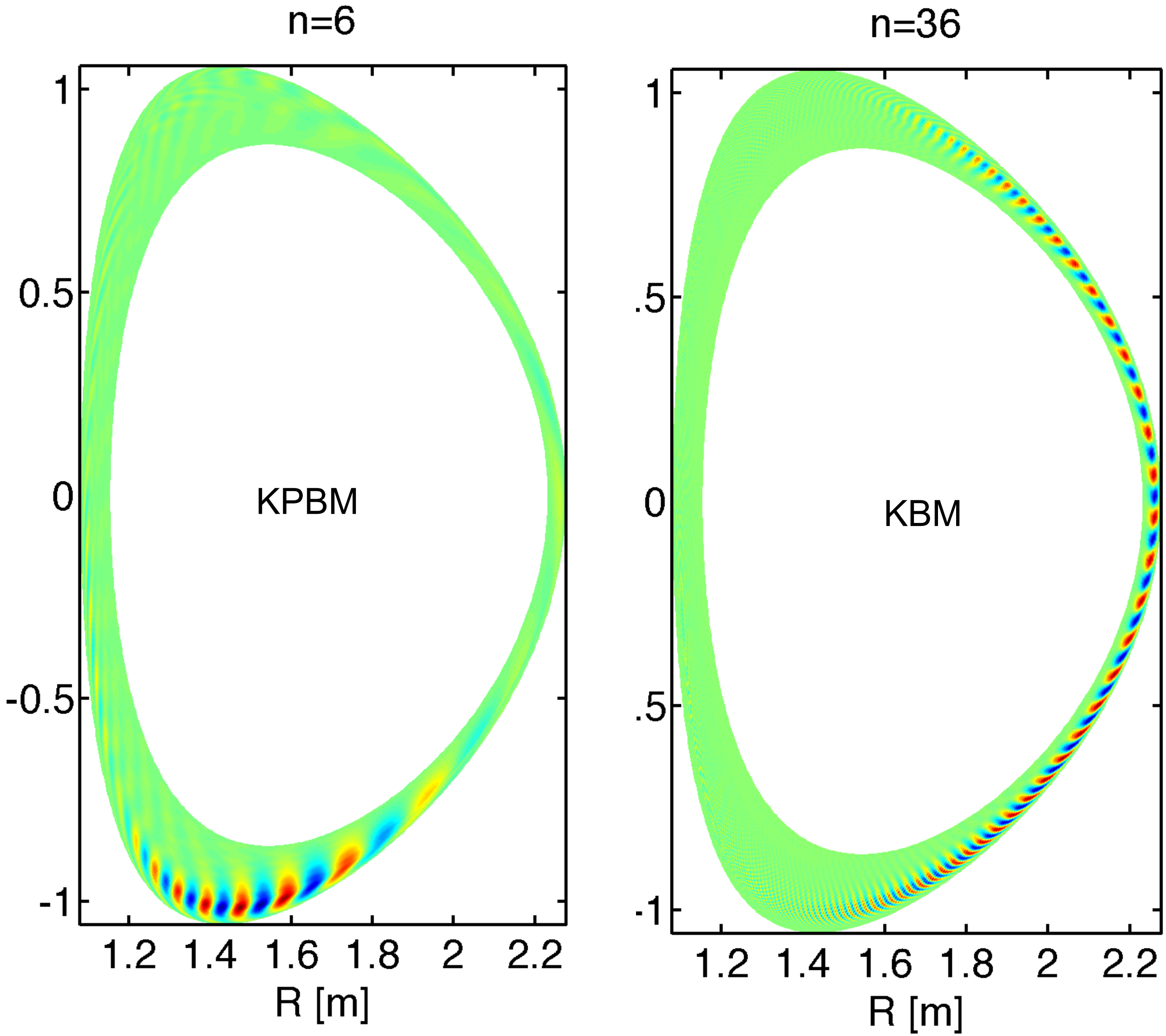


DIII-D

Shot 132016: kinetic EFIT from Groebner

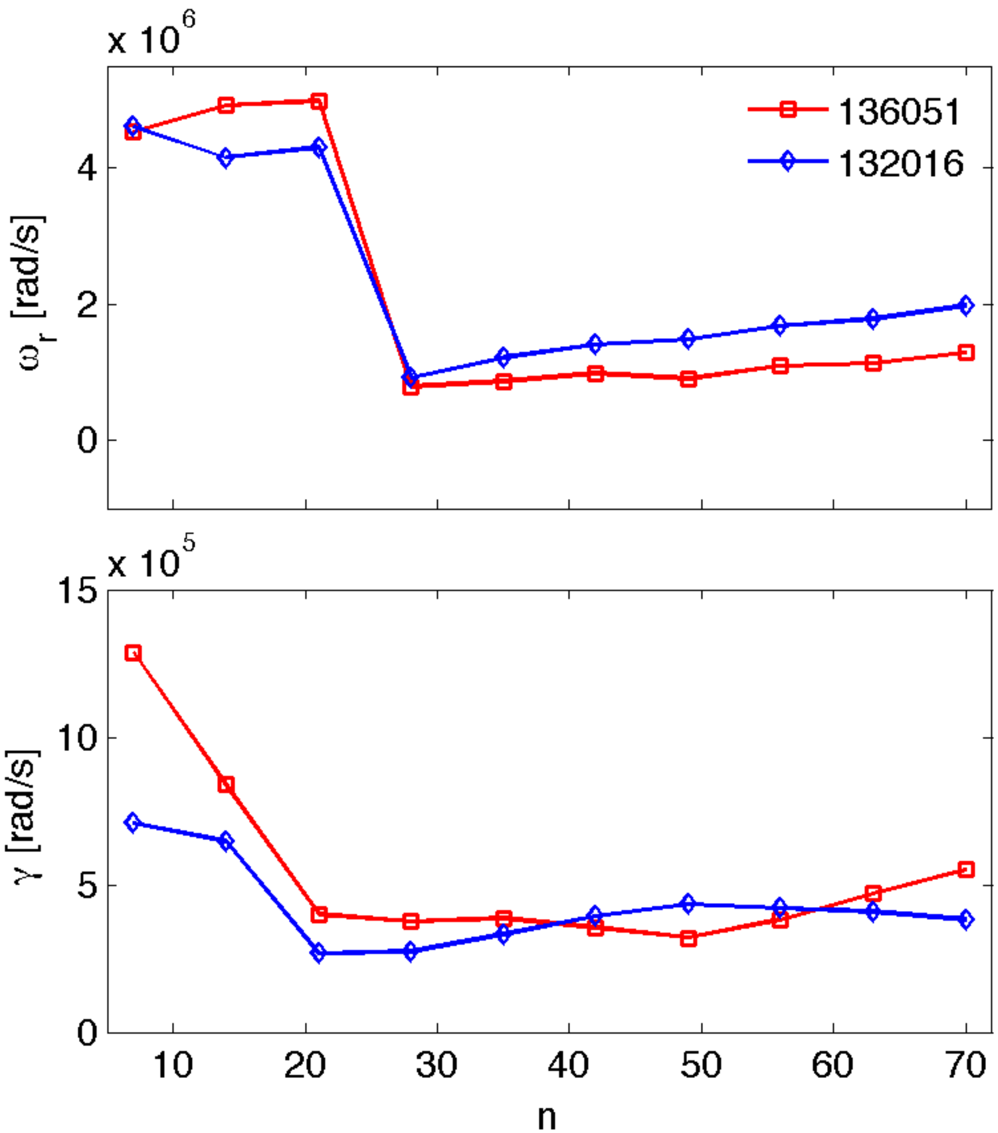
Shot 136051: from Yan et al., PoP 18, 056117 (2011)

Two unstable modes



Two types of instabilities are found

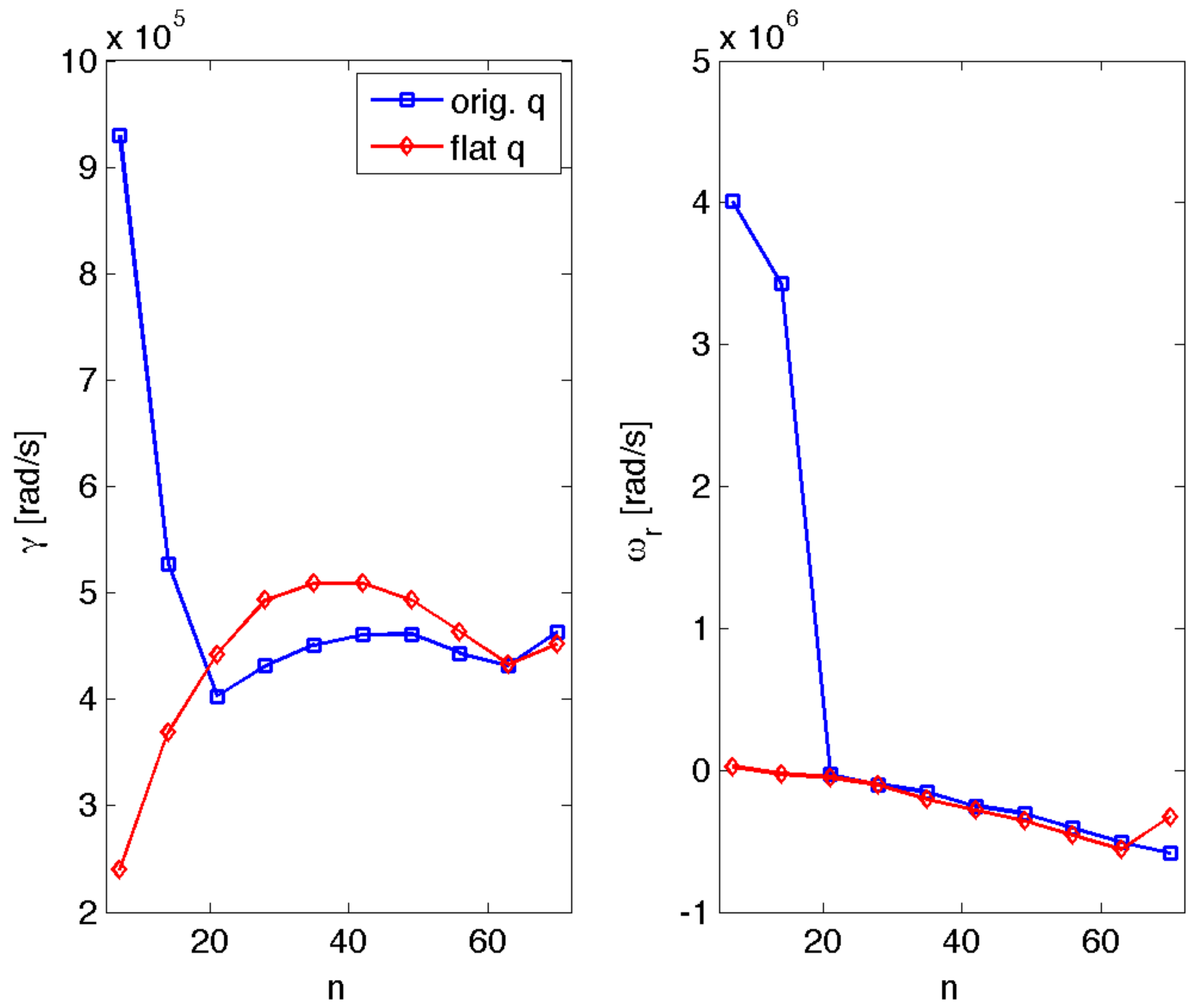
The "Kinetic Peeling-Ballooning Mode" (KPBM):
- Intermediate-n
- Drift-Alfven frequency range
- Large growth rate
- Electromagnetic



"KBM":
- High-n
- Low frequency
- Propagates in the ion direction
- Smaller growth rate

Wan et al. PRL (2012)

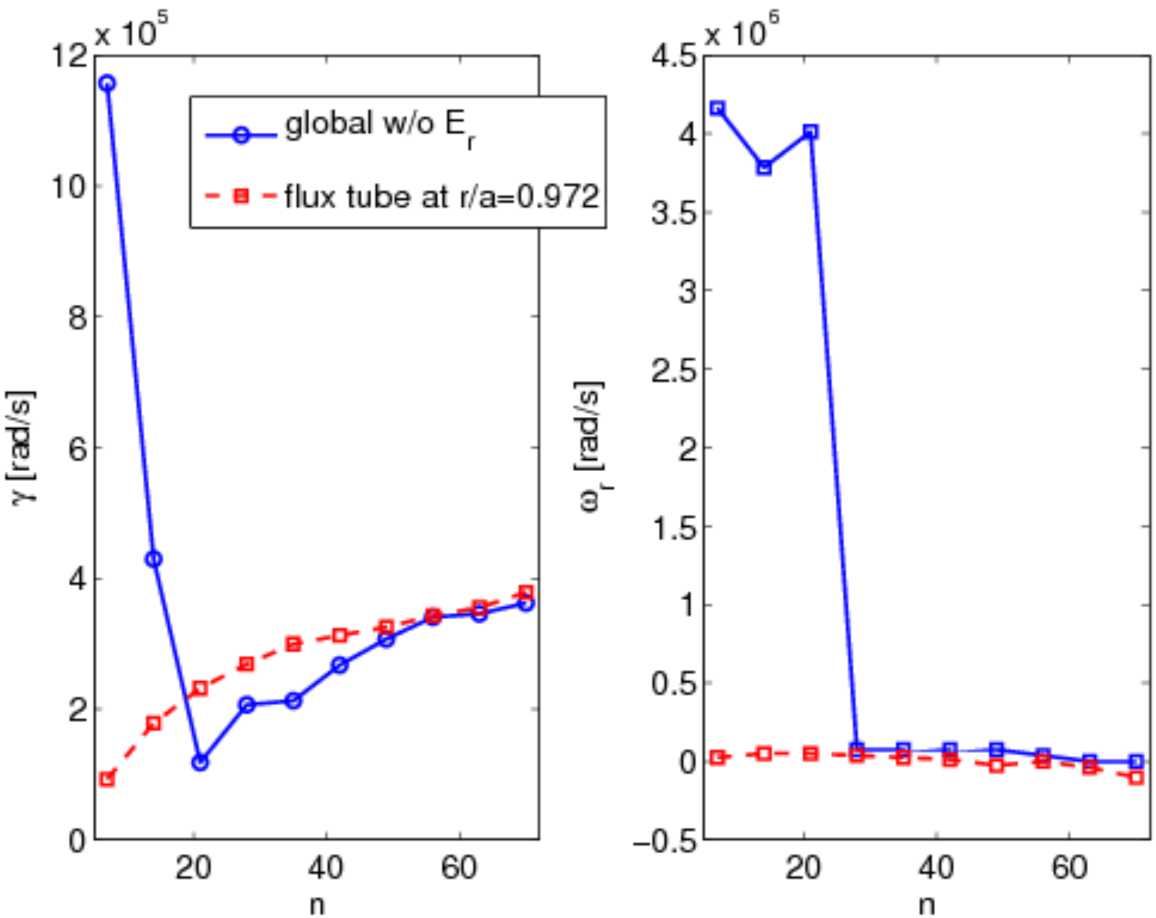
The effect of flattening the q-profile



- KPBM stabilized
- KBM becomes dominant

DIII-D Shot 136051, 2x experimental β, no equilibrium E_r

No KPBM in flux tube simulations

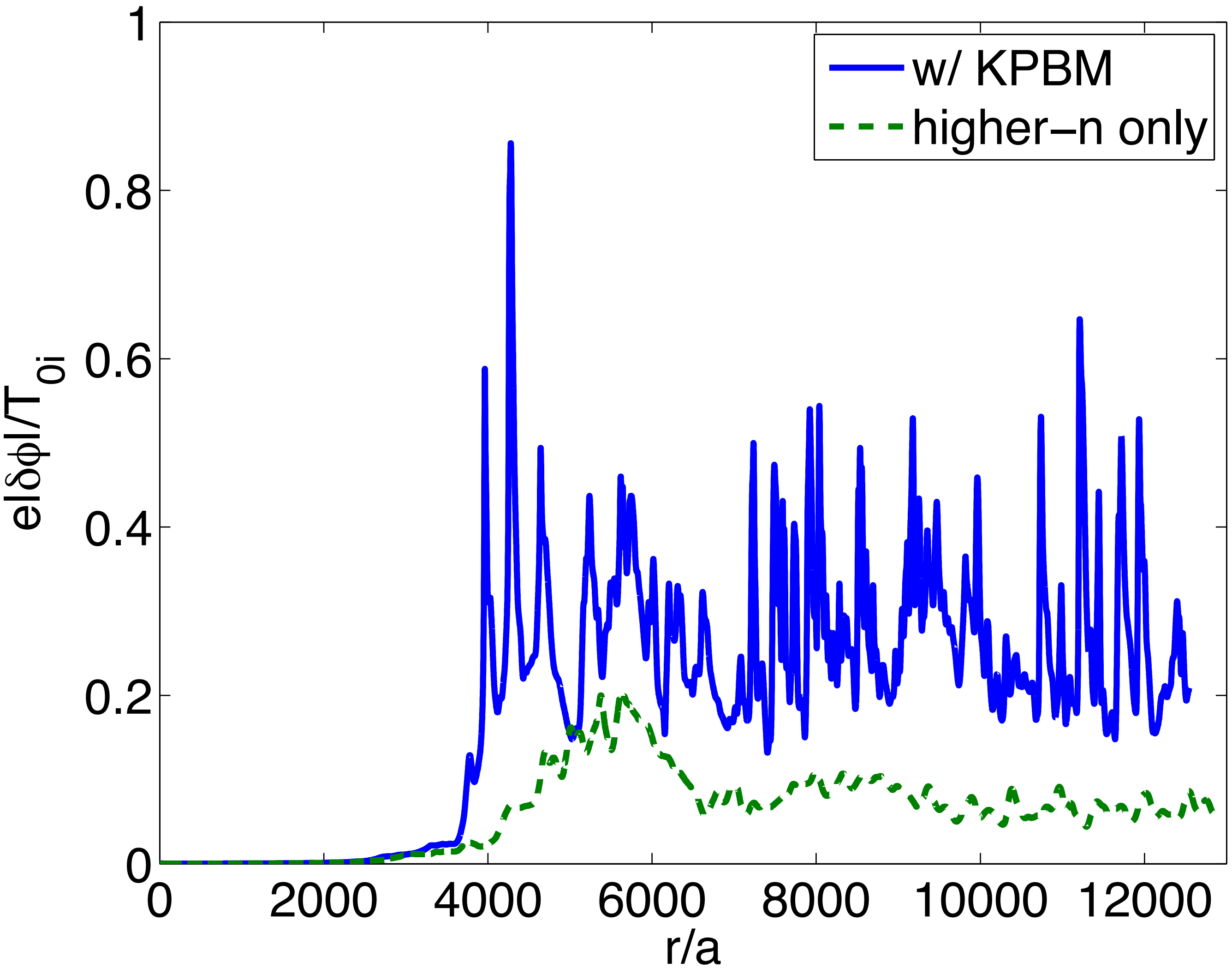


Global agrees well with flux tube for the high-n mode

- And flux tube results agree with GYRO, GS2

The low-n mode is only found in global simulations

Nonlinear results with GAMs

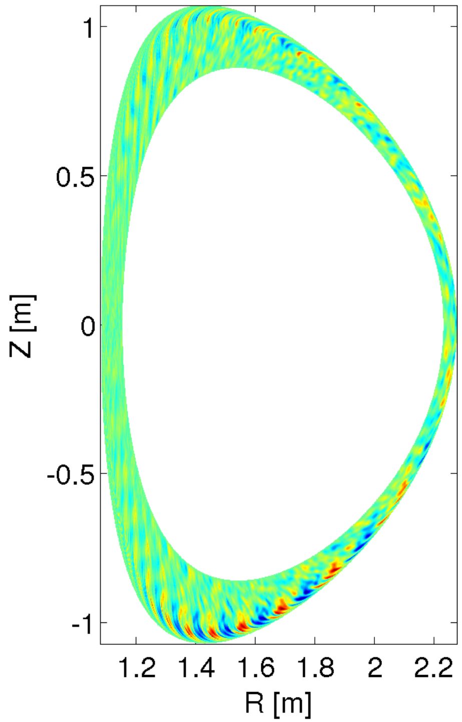


n>=6

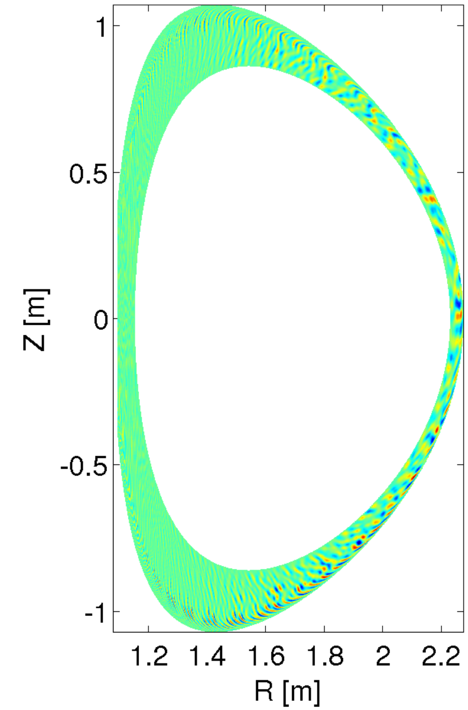
n>=18

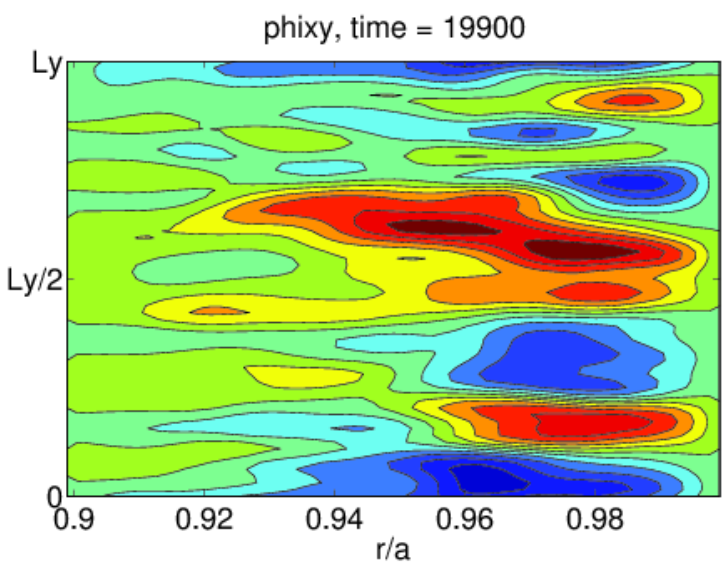
Turbulence still peaks in the steep gradient region

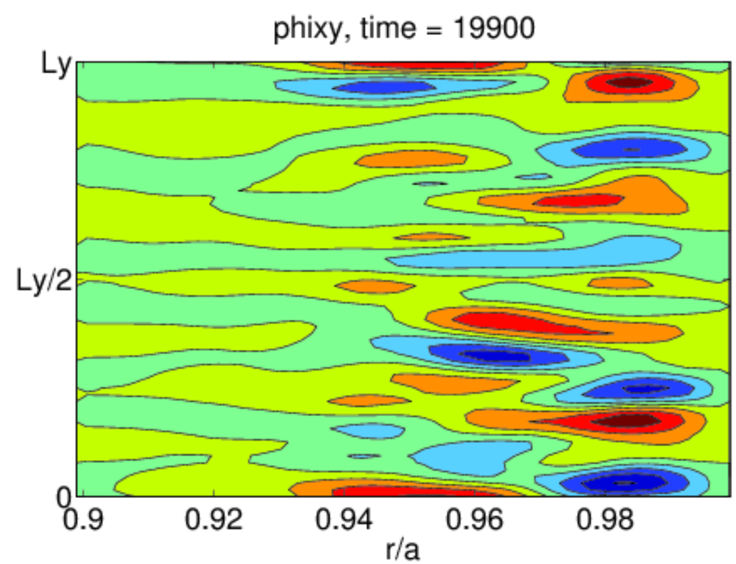
With KPBM



High n only

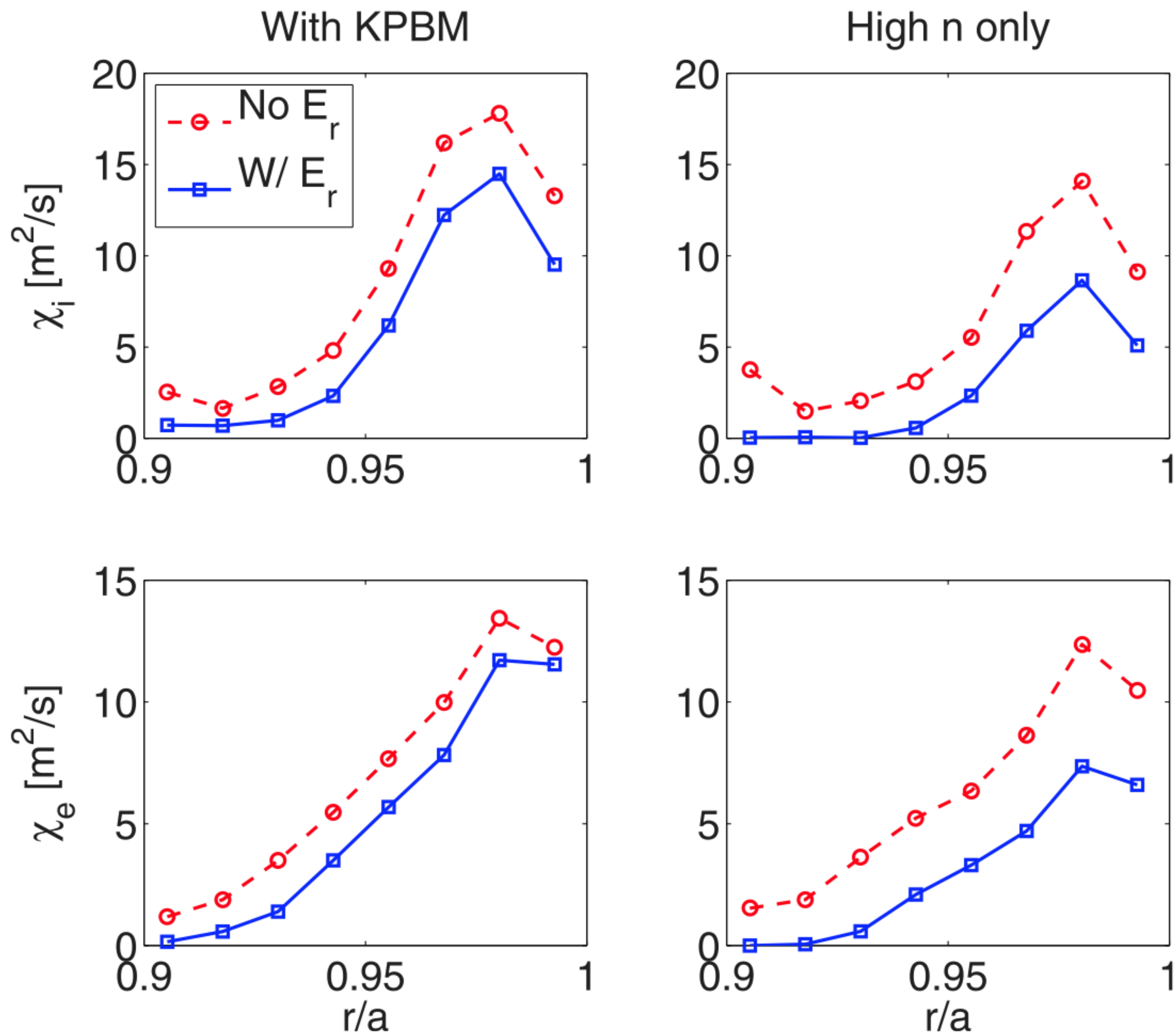






Field line following geometry radial and “y”-toroidal direction

Fluxes at high levels



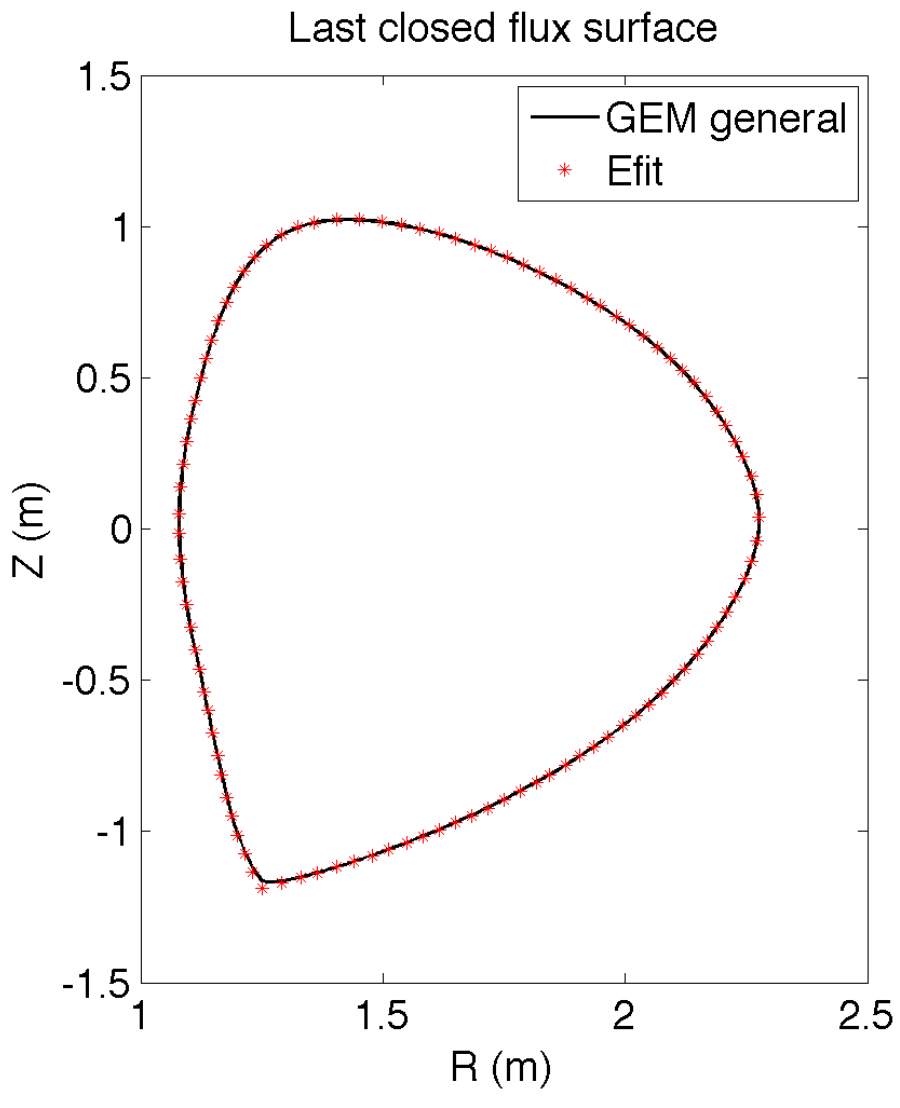
Summary

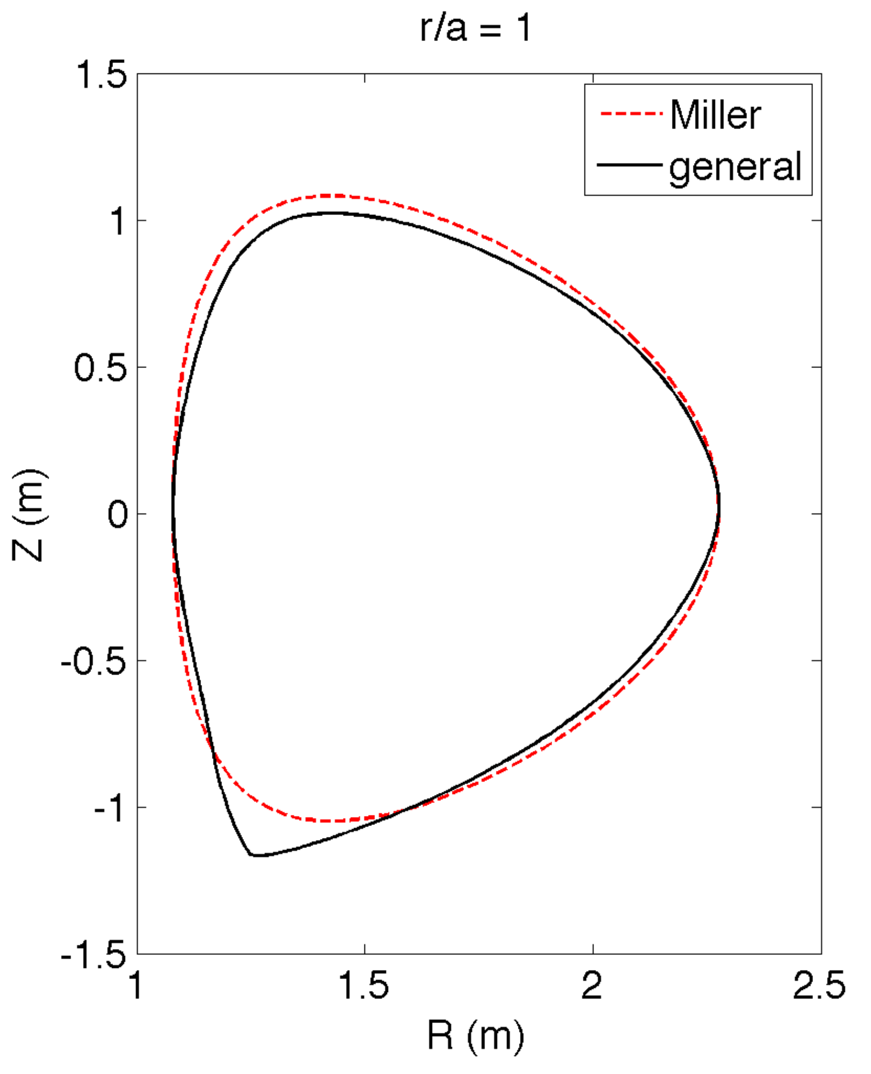
- Global GK simulations show near threshold conditions for two instabilities: KPBM and KBM
- KPBM “Kinetic Peeling-Ballooning Mode”:
  - Mostly destabilized by density gradient
  - Electromagnetic
  - Only seen in global simulations
  - Stabilized by reducing magnetic shear
- Nonlinear simulations show both KPBM saturates at high levels and fluxes (ELM). Likewise, for KBM turbulence

For further details see:

Wan et al. PoP (2013), Wan et al. PRL (2012)

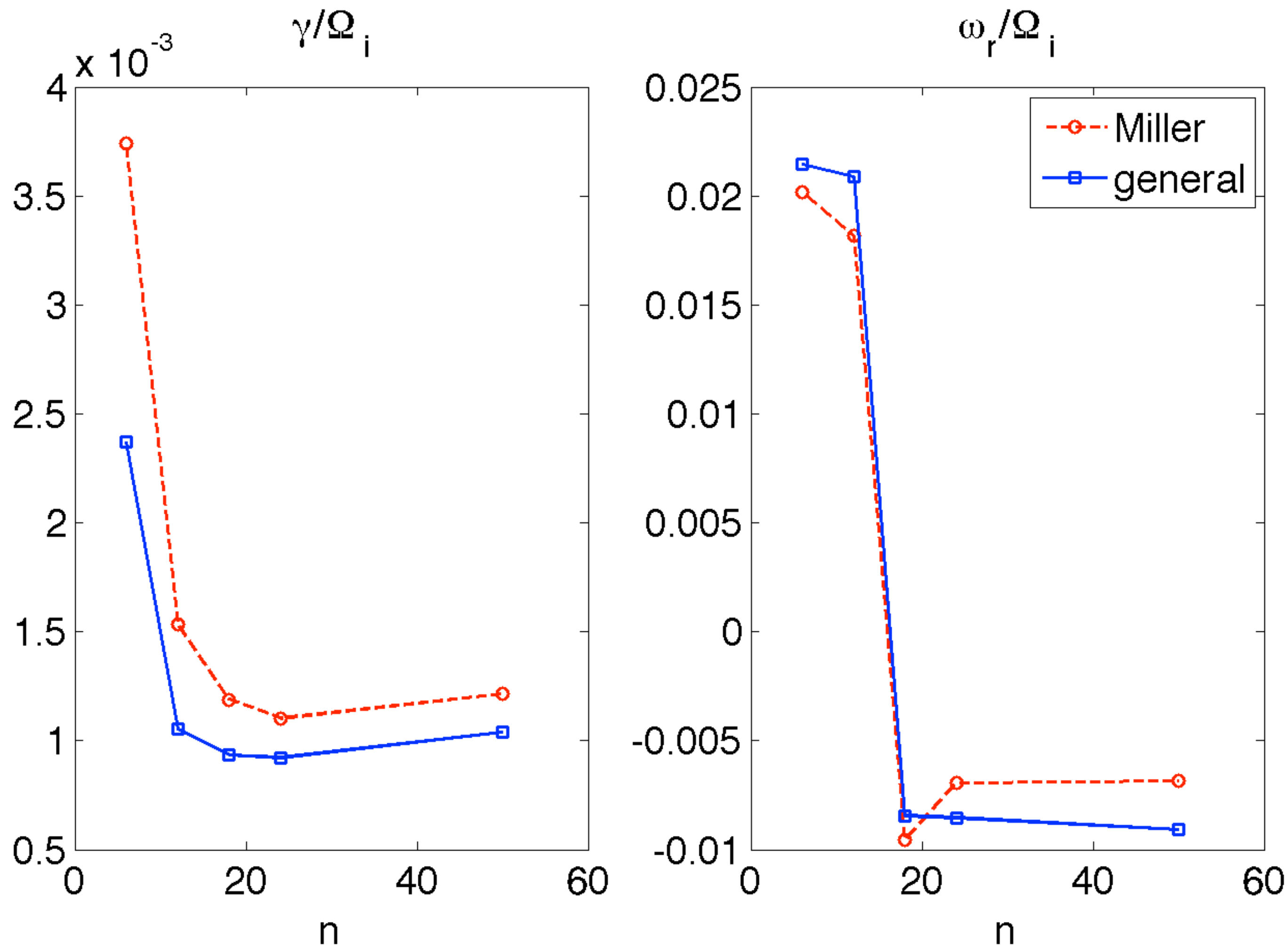
Edge: general geometry vs. Miller Geometry





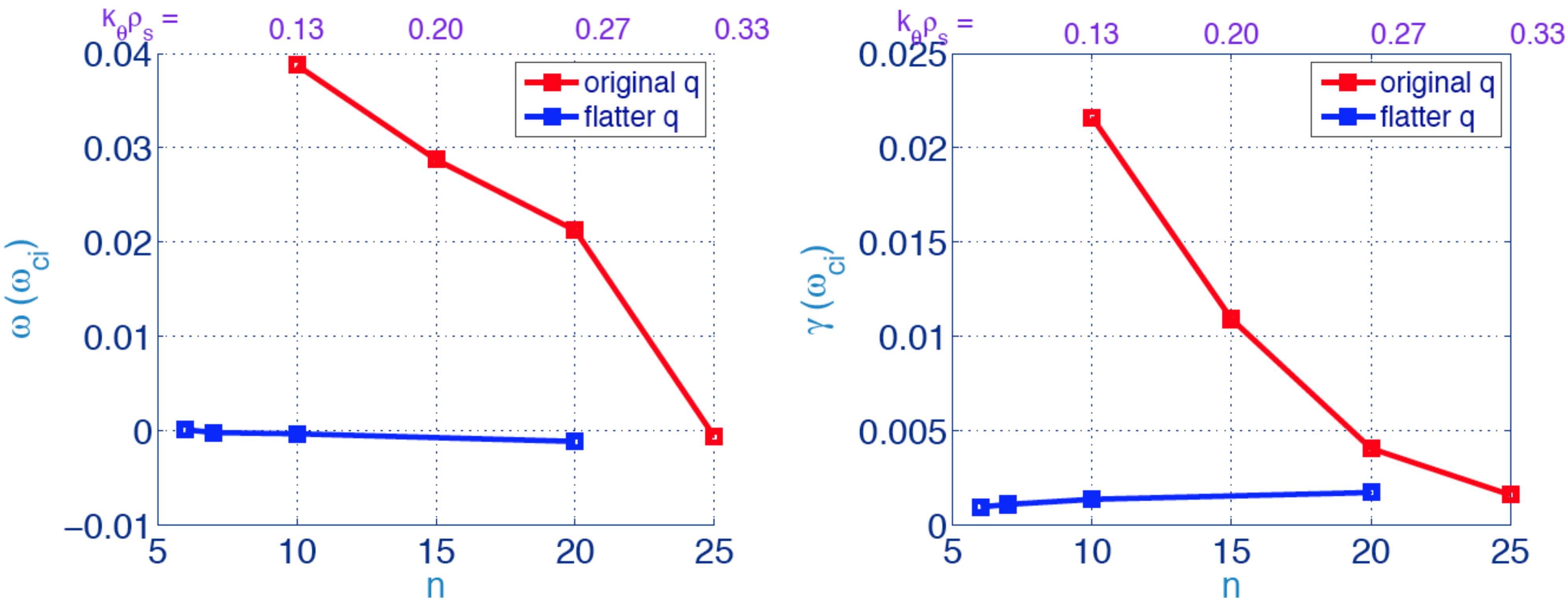
GEM general geometry uses the EFIT magnetic equilibrium
Miller parameterization not valid at edge

Edge instabilities are quantitatively sensitive to magnetic parameters…



…but the story does not change from Wan et al. PRL (2013)

Similar trends seen for C-Mod edge



Flattening q-profile at steep gradient location stabilizes KPBM and exposed KBM