Turbulent Saturation (or Lack thereof) in TCV Plasmas

DIFFER

M.J. Pueschel

TU/e
EINDHOVEN
UNIVERSITY OF
TECHNOLOGY

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TCV Discharges

Here, focus on **TCV shots 69515 (PT), 69340 (NT)**
Compare Justin's shot table:

Comp. Num.	Description	Constants of comparison	Discharge	Time (sec)	elong	delta	betaN	P_nbi (kW)	q95	Ip (kA)	<ne> (x10^19 m^-3)	Comments
1	Diverted, PT	q95, betaN	69515	1.02	1.43	+0.29	0.97	636	3.17	242	4.0	not great q95 match
1	Diverted, NT	q95, betaN	69340	0.58	1.42	-0.28	0.97	362	2.94	218	3.3	with Langmuir probes
2	Diverted, PT	q95, ne, Pheat	69515	1.02	1.43	+0.29	0.97	636	3.17	242	4.0	not great q95 match
2	Diverted, NT	q95, ne, Pheat	69271	1.60	1.42	-0.27	1.59	612	2.90	217	4.4	-
3	Diverted, PT	Ip, betaN, ne	69508	1.49	1.43	+0.28	1.12	735	3.31	217	4.0	-
3	Diverted, NT	Ip, betaN, ne	69340	0.58	1.42	-0.28	0.97	362	2.94	218	3.3	with Langmuir probes
4	Limited, PT	Ip, betaN, ne	69511	1.50	1.34	+0.35	1.25	1030	3.38	228	3.4	-
4	Limited, NT	Ip, betaN, ne	69273	0.85	1.29	-0.29	1.30	475	2.85	228	3.4	-
5	Limited, PT	Ip, Pheat	69511	1.50	1.34	+0.35	1.25	1030	3.38	228	3.4	-
5	Limited, NT	Ip, Pheat	69273	1.70	1.26	-0.26	2.02	1020	2.79	226	4.6	-
-	Diverted, PT	-	69515	1.58	1.43	+0.34	1.84	1020	3.29	239	7.1	in H-mode; no CXRS so Ti=Te
-	Diverted, NT	-	69340	1.60	1.40	-0.27			2.92	217	5.4	with Langmuir probes

At $r/a = 0.72$, normalized gradients are

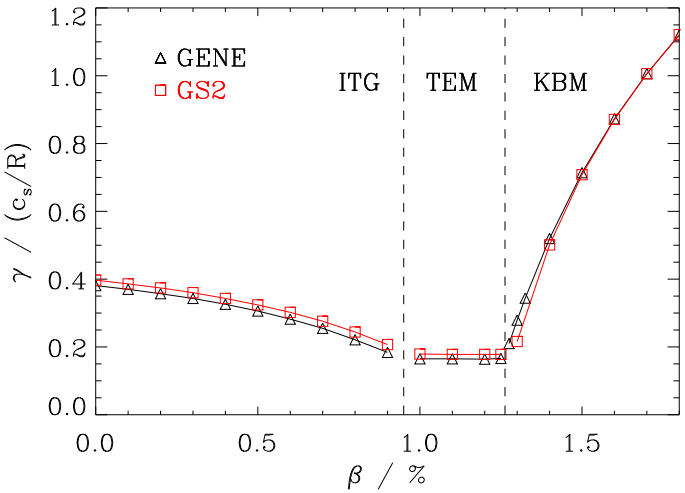
shot	$R_0/L_{T\mathrm{i}}$	$R_0/L_{T\mathrm{e}}$	R/L_n
69515	5.43	10.48	6.77
69340	9.40	9.85	6.97

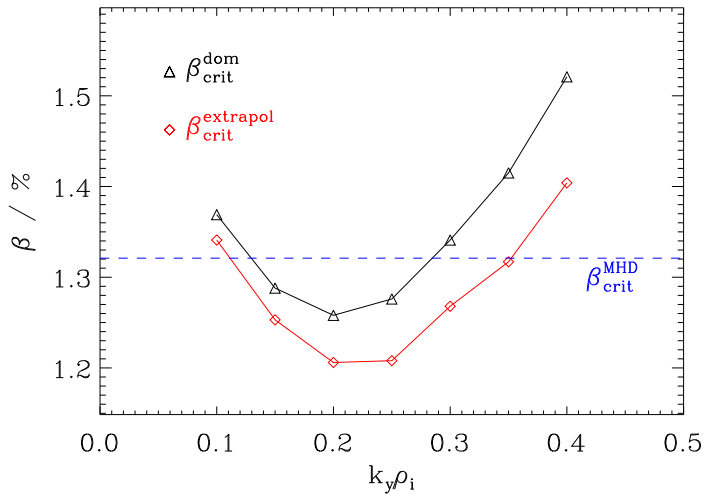
$\Rightarrow$ useful to look at *flipped gradients* scenario (PT geometry)

KBMs in Circular Tokamaks

Increasing normalized electron pressure β affects instabilities

Kinetic Ballooning Mode (KBM): kinetic sibling of IBM



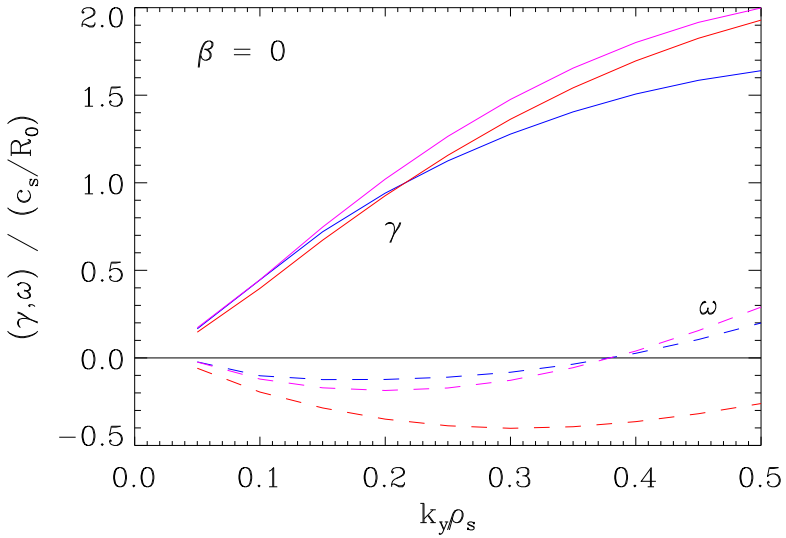


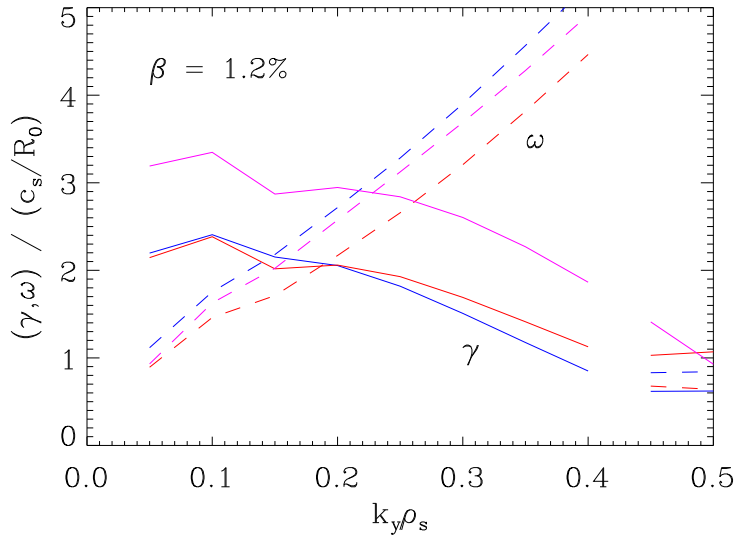
- ITG β-stabilized, TEM unaffected
- stiff KBM onset

- $\beta_{\mathrm{KBM}} \lesssim \beta_{\mathrm{MHD}}$
- Nonlinearly, low fluxes in KBM regime

KBMs in PT/NT (I)

Linear growth rates for PT, NT, and PT flipped:

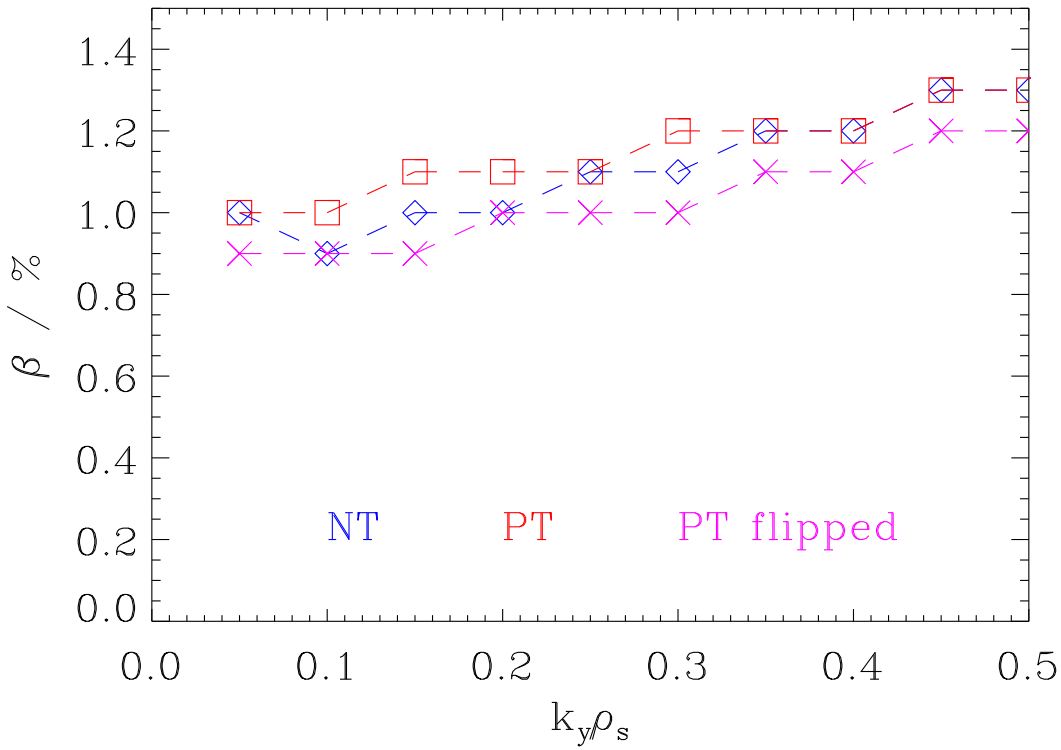




- do we need better mode identification?
  is the electrostatic mode ITG, UTEM, or iTEM?
- multiple KBM branches? *need to look at Φ structure*
- near-zero ω: possible impact on saturation efficiency!

KBMs in PT/NT (II)

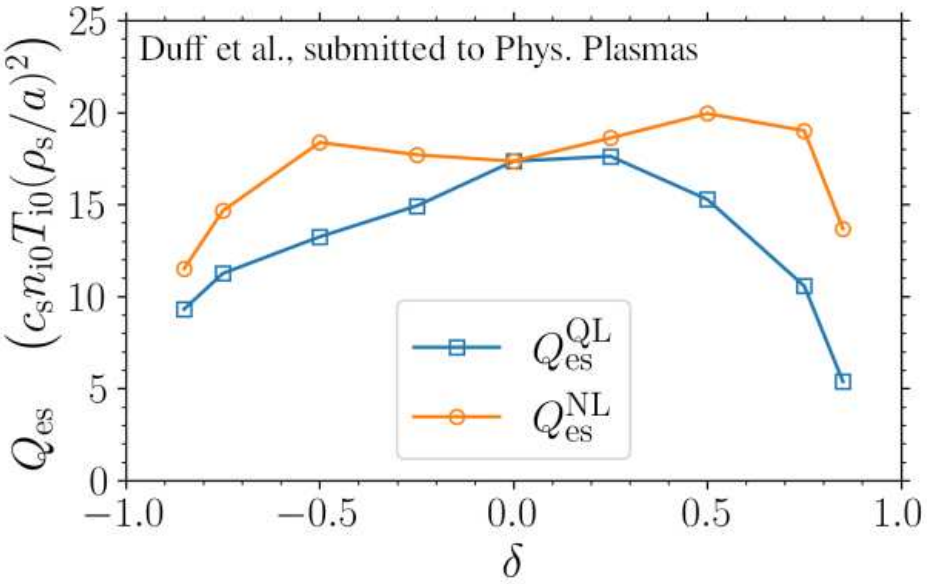
Extract $\beta_{\mathrm{crit}}^{\mathrm{KBM}}$ from linear data:



- PT has higher $\beta_{\mathrm{crit}}^{\mathrm{KBM}}$ than NT, **only due to lower gradients**
- **PT-flipped: lower threshold** than NT
- more substantial increase in β threshold for $\delta \lesssim 0.7$?

Extreme Triangularities

Initial ITGae survey of NT/PT performance at extreme $|\delta|$: Joey Duff



RT07: this year, no time for extreme δ, resubmitted for 2022
(Stefano Coda: will be included in campaign)

Should we look at other physics at extreme triangularity, e.g. MHD?

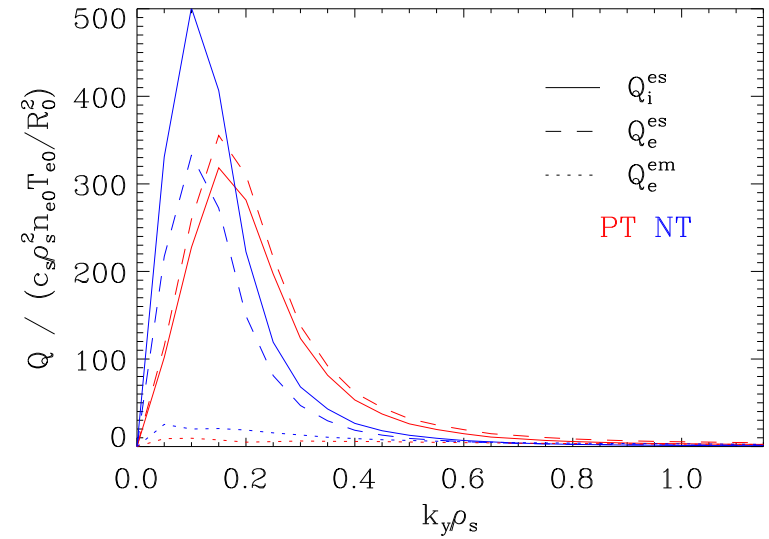
Nonlinear TCV Simulations

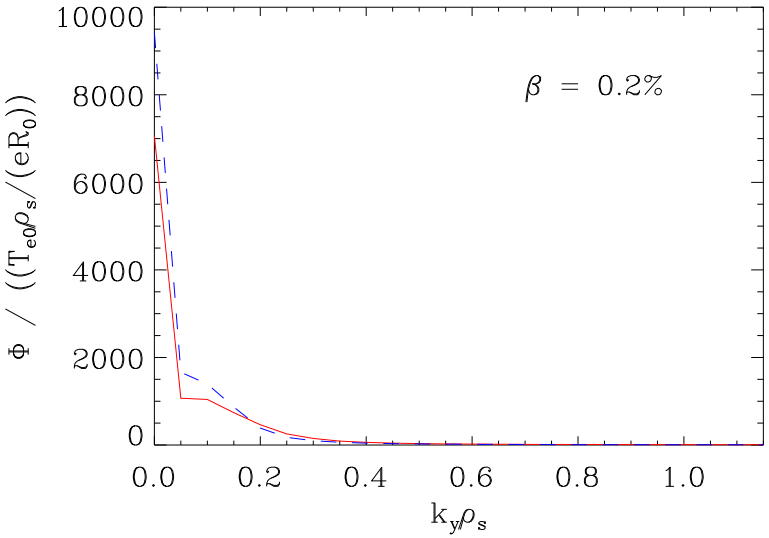
Justin TSVV presentation

- mixed ITG-TEM regime
- $Q_i \gtrsim Q_e$
- *swapped gradients*: NT has lower fluxes

Nonlinear GENE runs:

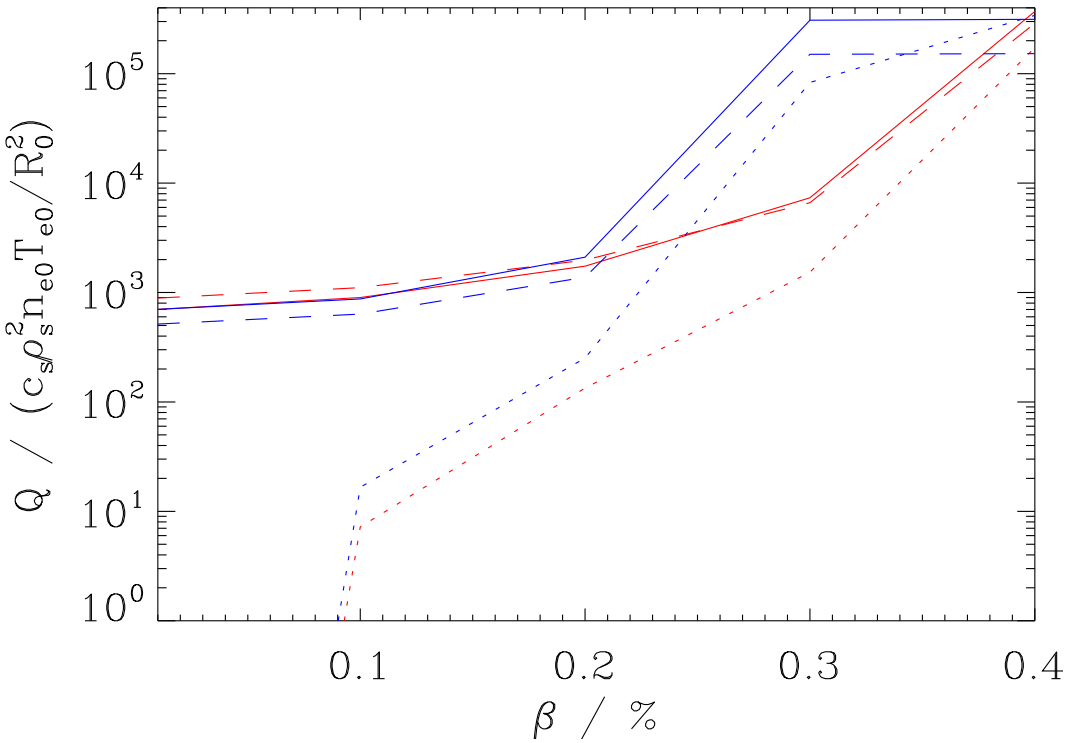
- generally well-behaved, moderate resolutions
- **very high fluxes, but not very stiff!**
- *substantial zonal flow*





Nonlinear β Scans

Nonlinear β scan: experimental β *just below some threshold*:



Still far below KBM treshold $\Rightarrow$ **we are in a runaway**

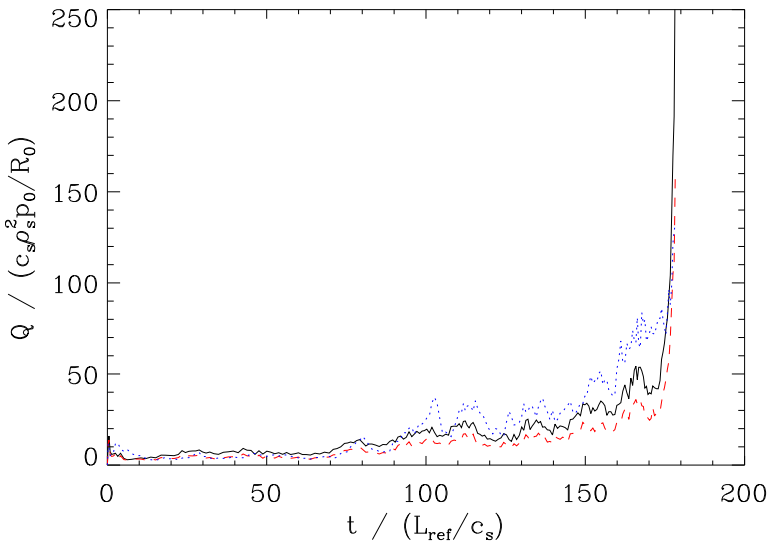
Most likely candidate: **Non-Zonal Transition** (NZT), which is particularly restrictive at steep gradients

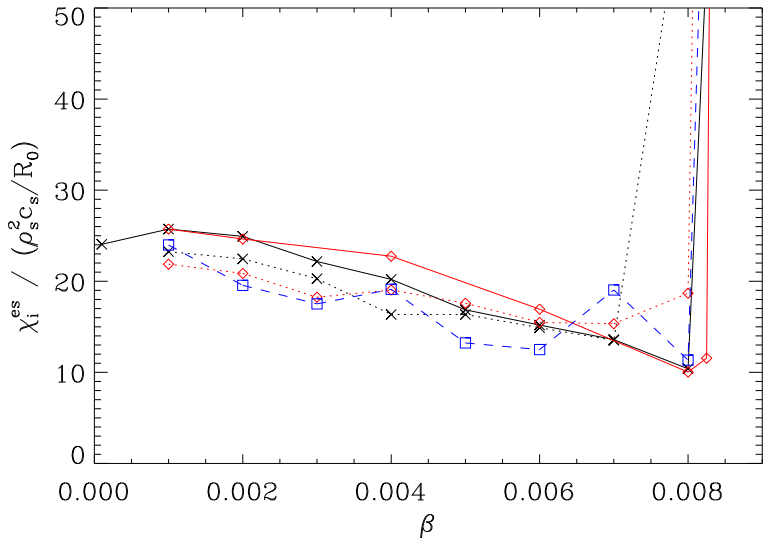
The High-β Runaway

For 10 years, strange, unexplained simulation behavior:

no saturation of turbulence above pressure $\beta_{\mathrm{crit}} < \beta_{\mathrm{KBM}}$

Seen in many codes: GENE, GYRO, GKW



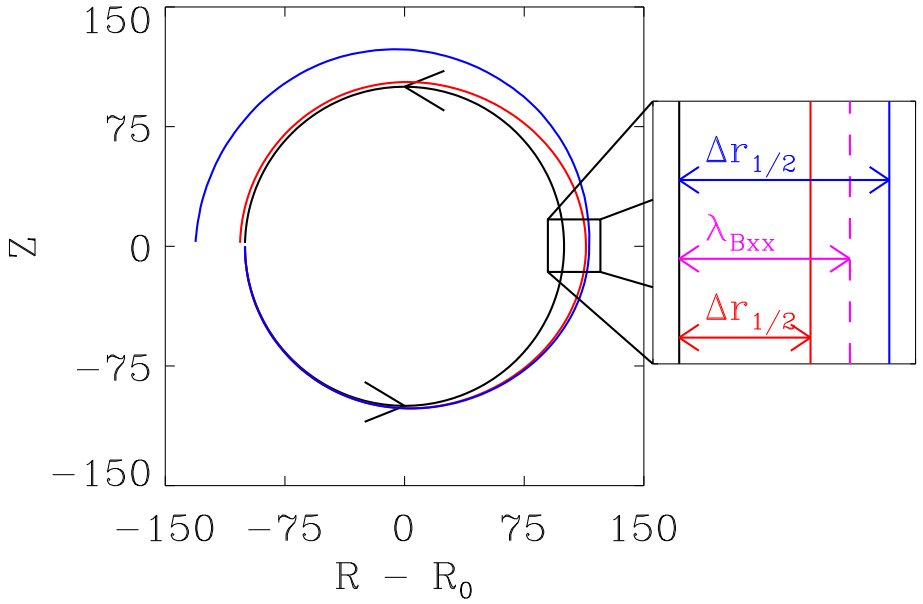


Key observation: **zonal flows absent** as fluxes take off

Preliminary simulation results by Aylwin Iantchenko (EPFL):
Predicted β values are right at threshold in JT60-SA

Field Line Decorrelation

Non-resonant B_x: field line leaves flux surface from inboard, maximum Δr at outboard, returns (almost) to B_0 surface



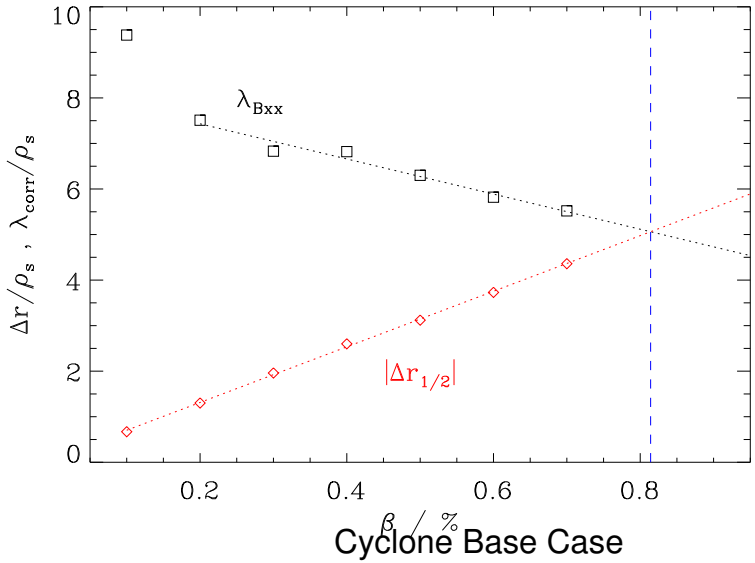
- $\Delta r_{1/2}$ is the radial displacement at $\theta = 0$
- λ_{Bxx} is the correlation length of B_x along x

However: if field line decorrelates, **second half turn** becomes **independent of first**, no return to original position

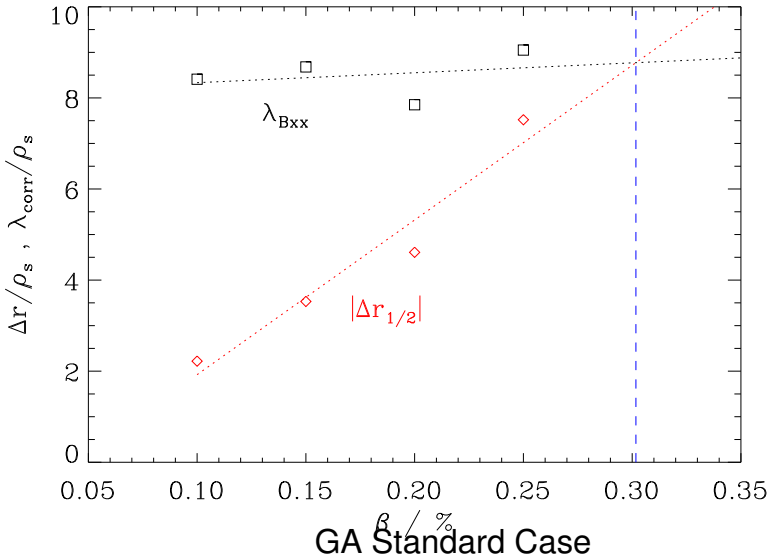
Zonal flows shorted out $\Rightarrow$ **Non-Zonal Transition** (NZT)

The Non-Zonal Transition

Can field line decorrelation really explain the runaway?



Cyclone Base Case



GA Standard Case

$\Rightarrow$ **excellent prediction** of runaway (blue) by decorrelation!

Consequences for realistic applications:
heat transport time scale in NZT-marginal state can be $\sim \gamma^{-1}$,
orders of magnitude faster than typical transport
$\Rightarrow$ stiff profiles, cannot increase plasma pressure anymore

Summary

- **KBM threshold increased** at negative triangularity (flipped gradients for comparison)
- very large fluxes, near runaway $\Rightarrow$ non-zonal transition?
- **extreme triangularity** $|\delta| \gtrsim 0.7$ seems to be rather **promising** from turbulence standpoint