ACT1 Physics Results

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Outline

Plasma configurations from 1.5D TSC simulations

Ideal MHD stability and identification of alternate operating points from systems results

PF coil solution

Heating and current drive simulation (LH, IC, EC)

Systems analysis of n/nGr

Systems analysis of heat flux in divertor

Fast particle MHD, new case to be done

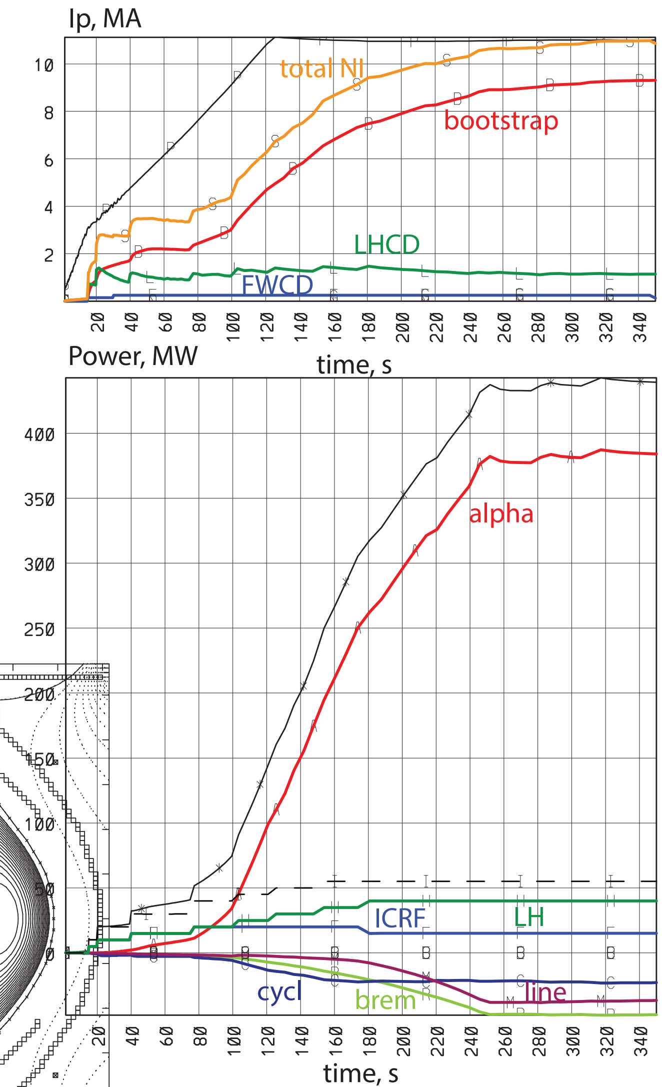
Heat flux assessment – TOFE paper

Simple assessment of erosion

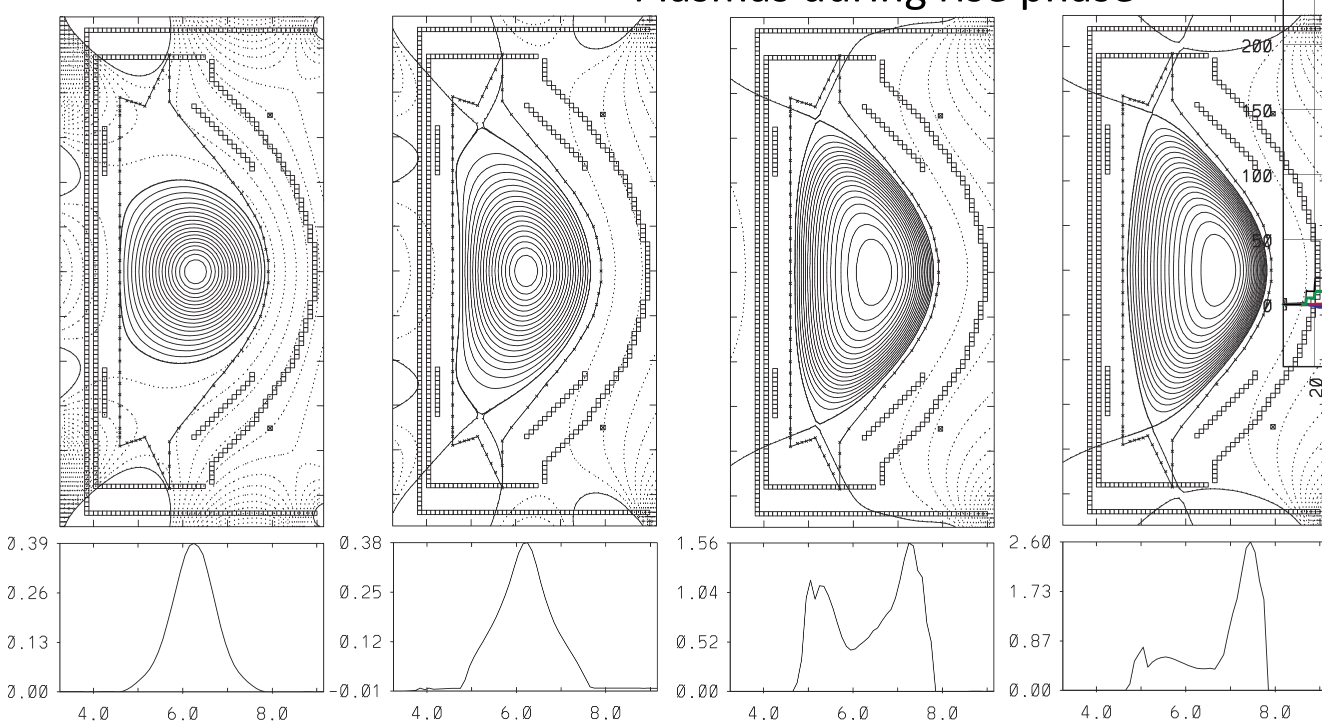
Fueling and pumping

1.5D Time-dependent free-boundary plasma configurations

1) Broad p, ref density
2) Broad p 2, ref density
3) Broad p, spread out density
4) Medium p, ref density
5) Peaked p, ref density

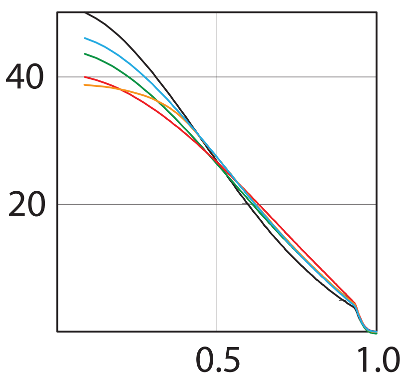


Plasmas during rise phase



5 cases relaxed at $\beta_N^{total} \sim 5.72$

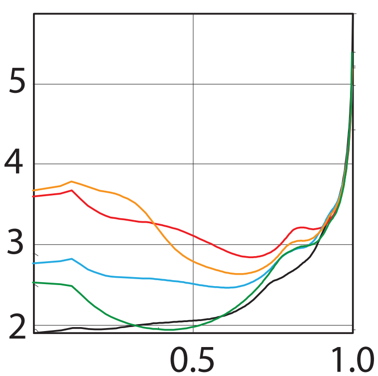
Te(rho), keV at 2750 s



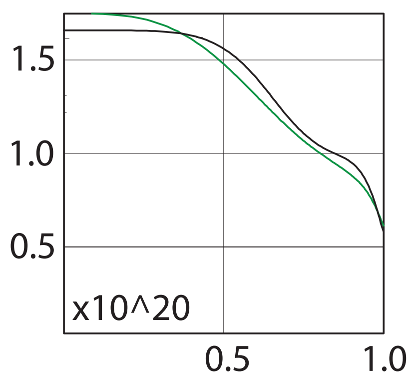
Peaked p case
Medium p case
Broad p case
Broad p 2 case
Density/med p case

Same density profile used for all cases except the density/med p

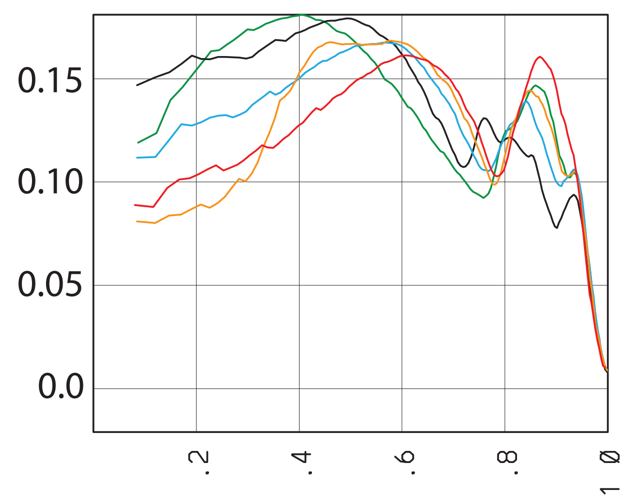
q(rho) at 2750 s



ne(rho), /m3 at 2750 s



j-parallel, MA/m2-T at 2750 s



1.5D Plasma configurations

All 5 cases were simulated to provide β_N^{total} ~ 5.75, from the systems code target

	Sys Op Point	TSC/peaked p	TSC/med p	TSC/broad p	TSC/broad p 2	TSC/med p, dens
Ip, MA	10.9	11.0	11.1	11.1	11.1	11.1
I_{BS}, MA	9.89	9.25	9.50	9.75	9.20	9.36
I_{LH}, MA	1.04	1.20	1.12	1.12	1.08	1.23
I_{IC}, MA		0.125	0.125	0.125	0.35	0.125
q_{min}, q(0)		2.0, 2.0	2.43, 2.75	2.83, 3.60	2.63, 3.80	1.92, 2.50
li	0.5 (input)	0.59	0.53	0.47	0.51	0.58
n/n_{Gr}	1.0	1.0	1.0	1.0	1.0	1.0
W_{th}, MJ		665	677	673	669	634
n(0), $/m^3$ x10^{20}		1.67	1.67	1.67	1.67	1.75
$\langle n \rangle_v$, $/m^3$ x10^{20}	1.3	1.28	1.33	1.33	1.33	1.23
$n(0)/\langle n \rangle$	1.27	1.31	1.27	1.27	1.27	1.42
β_N^{th}, β_N^{fast}	4.75, 0.89	4.85	4.9	4.9	4.8	4.6
τ_E, s	2.26	2.10	2.05	1.94	1.95	2.0
$H_{98(y,2)}$	1.65	1.53	1.50	1.50	1.50	1.44
$T_{e,i}(0)$, keV	40.4	50.5, 44.0	46, 41	40, 35.6	38.5,34.4	43, 38.3
$Te,i(0)/\langle T \rangle$	2.15	2.68, 2.56	2.42, 2.33	2.09,2.05	2.05, 2.0	2.35,2.27
P_{alpha}, MW	363	364	385	389	389	347
P_{LH}, MW	39	40	40	40	40	40
P_{IC}, MW	3.0	15	15	15	15	15
P_{cycl}, MW	35.0	20.3	27	23	23	23.3
P_{line}, MW	24.2	24.3	35	32.7	34.6	29.2
P_{brem}, MW	56.3	45.6	48	48.4	48.3	43.3
$P_{L-H,thr}$, MW	109	119	119	119	119	116
$P_{net}/P_{L-H,thr}$		2.67	2.8	2.86	2.8	2.66
Z_{eff}	2.11	2.0	2.0	2.0	2.0	2.0
n_{He}/n_e	0.097	0.078	0.077	0.076	0.066	0.0675
n_{DT}/n_e	0.752	1.025	0.79	0.802	0.82	0.81
n_{Ar}/n_e	0.003	0.003	0.003	0.003	0.003	0.003

Broad p case stable at β_N^{total} ~ 5.72, b/a = 0.3-0.35

Broad p 2 case stable at β_N^{total} ~ 5.65, b/a = 0.3-0.35

Med p case stable at β_N^{total} ~ 5.25….pursuing in TSC at Bt = 6.75 T

Peaked p case stable at β_N^{total} ~ 4.6….pursuing in TSC at Bt = 7 T

Density with broad p found stable at β_N^{total} ~ 5.65…..pursuing in TSC

Systems code output for COE $\leq$ 1.05 x COE_{min} and ordered by $q_{peak,div}^{OB}$

There are lower β_N^{th} solutions nearby our reference operating point, which we can pursue for the lower stability profiles

6.75	68.9508	142652	10.2527	9.11E+06	40	5.75	11.31	0.0475	4.5
6.5	68.3831	219109	11.3042	9.26E+06	45	6.25	11.21	0.045	4.75
6.5	68.6602	219090	11.3042	9.36E+06	42.5	6.25	11.21	0.045	4.75
6.5	68.8693	253784	11.7566	9.76E+06	42.5	6.5	11.08	0.0425	5
6.5	68.807	218994	11.3076	1.02E+07	35	6.25	11.21	0.045	4.75
6.5	68.3583	142642	10.4001	1.02E+07	40	5.75	10.89	0.0475	4.5
6.5	68.7168	142610	10.4001	1.03E+07	37.5	5.75	10.89	0.0475	4.5
6.25	67.9891	219103	11.4788	1.05E+07	45	6.25	10.78	0.045	4.75
6.25	67.9962	292748	12.4019	1.05E+07	40	6.75	11.06	0.0425	5
6.5	69.0533	253703	11.76	1.06E+07	35	6.5	11.08	0.0425	5
6.25	67.2419	182786	11.0227	1.06E+07	42.5	6	10.93	0.0475	4.5
6.25	68.3549	292721	12.4019	1.07E+07	37.5	6.75	11.06	0.0425	5
6.25	67.5527	182757	11.0227	1.07E+07	40	6	10.93	0.0475	4.5
6.25	68.7697	292687	12.4019	1.08E+07	35	6.75	11.06	0.0425	5
6.25	67.9083	182724	11.0227	1.09E+07	37.5	6	10.93	0.0475	4.5
6.25	68.8808	324144	12.86	1.10E+07	37.5	7	10.93	0.04	5.25
6	66.7571	259637	12.1473	1.13E+07	45	6.5	10.77	0.045	4.75
6.25	68.071	219017	11.4823	1.13E+07	37.5	6.25	10.78	0.045	4.75

Ideal MHD stability

Taking plasma configurations from TSC, into JSOLVER, PEST1 (low-n kink) and BALMSC (high-n ballooning)

Determine that plasma is high-n ballooning stable….

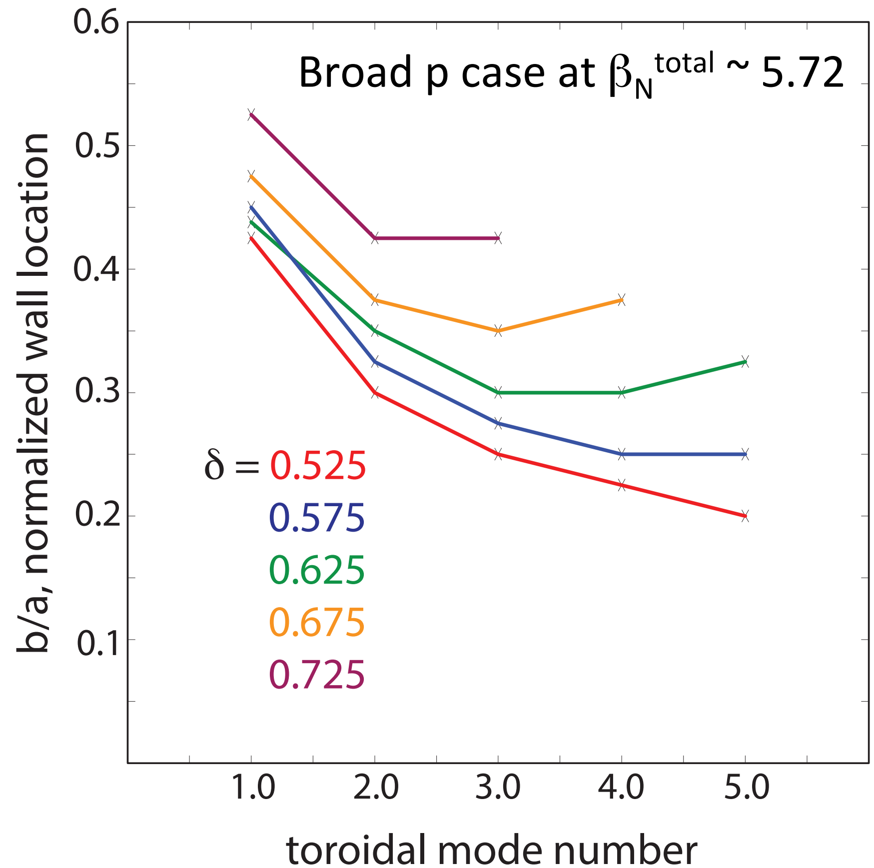
Then examine the low-n stability (n=1-5) and determine the location of a perfectly conducting wall (b/a) for stability

Since we recently reduced the triangularity to accommodate engineering in the divertor area, scanning shows the impact on the required wall location

Broad p 2 case has similar wall location behavior at δ = 0.625

Density profile with broad p appears similar also, waiting for TSC simulation

Checking other cases as well



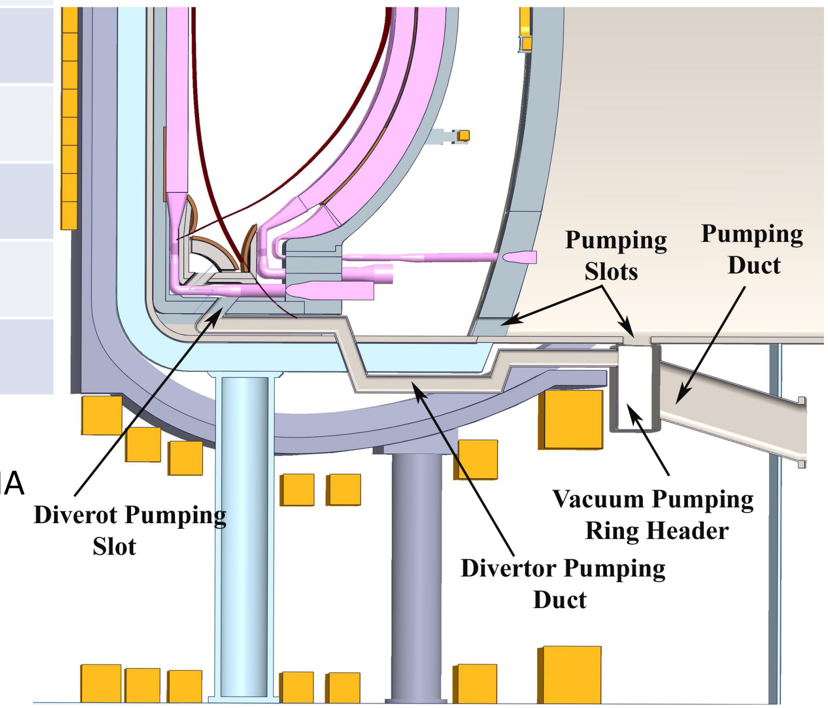
PF Coil Solution

Kessel→Wang→Kessel

	R, m	Z, m	I_{max},MA
CS1	2.75	0.9	4.5
CS2	2.75	2.7	6.8
PF1	3.10→ 3.23	6.10→6.57	5.65→8.05
PF2	3.65→3.91	6.50→7.03	4.60→5.54
PF3	4.20→4.58	7.00→7.26	4.14→5.46
PF4	6.00→6.39	7.50→7.75→7.45	3.80→6.62
PF5	6.75→7.13	7.50→7.75→7.45	3.57→4.84
PF6	9.25	7.25→7.15	5.95→8.45
PF7	11.25→10.78	6.00→6.61	12.9→14.4

Coils need to be resized and positioned

Wang's coil layout



Fiducial plasma states at Ip = 0.5, 2,25, 3.00, 4.25, 6.5, 8.5 and 11 MA

These have li, betaN, flux states, shape that correspond to those in TSC rampup simulation

LH Heating and Current Drive

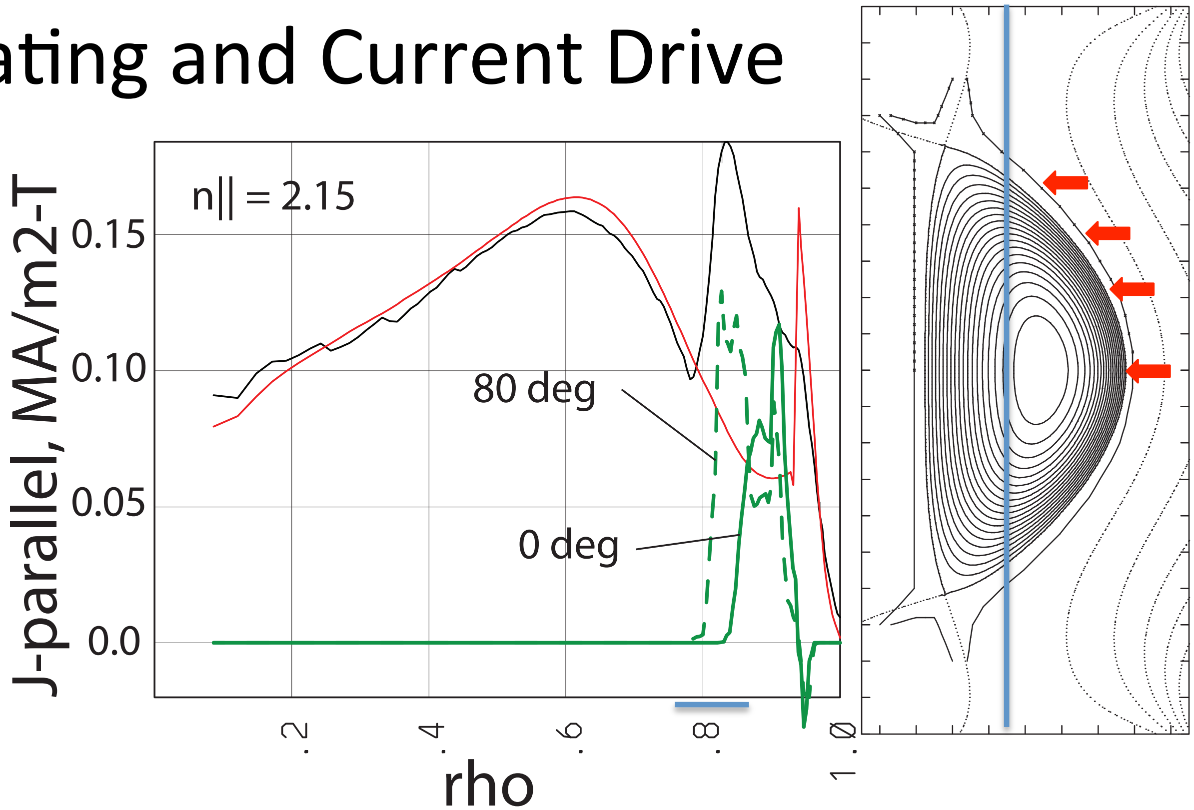
Using 5 GHz

Scan $n_{||}$ = 1.85-2.25

Scan launching location on OB

- 0 deg (midplane)
- 40 deg
- 60 deg
- 80 deg
- -60 deg

40, 60 and 80 deg: Above the midplane



Launching above the midplane provides higher CD and deeper deposition

Time-dependent simulations using 60 deg

I_{LH}, MA	$n_{\|\|}$=1.85	$n_{\|\|}$=1.9	$n_{\|\|}$=2.05	$n_{\|\|}$=2.15	$n_{\|\|}$=2.25
Θ=0	0.87	0.90	0.98	0.91	0.90
Θ=40	0.85	0.92	1.03	1.04	0.95
Θ=60	0.98	0.98	1.12	1.10	1.0
Θ=80	1.22	1.35	1.30	1.32	1.25

Fast Particle MHD

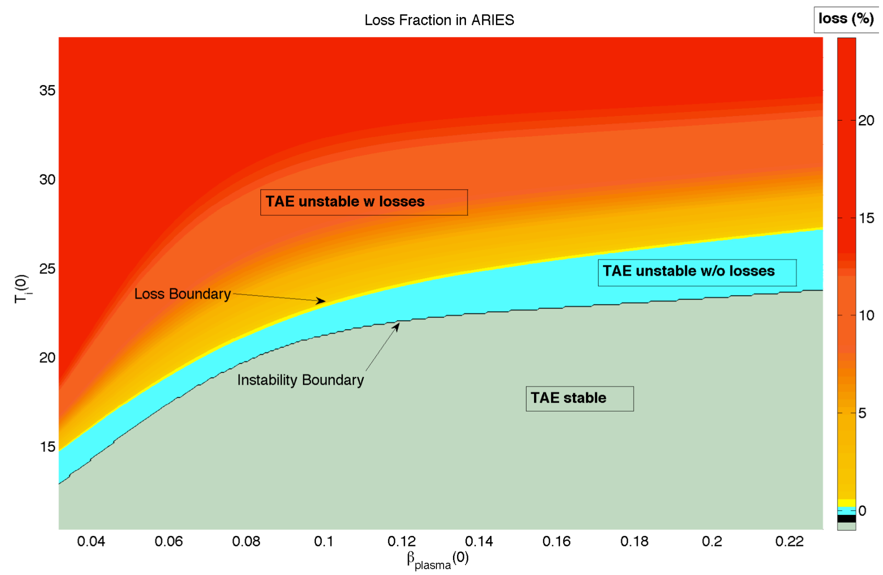
Previous analysis done at R = 5.5 m, a = 1.375 m, B = 5.5 T, Ti(0) = 35 keV, $\beta_\alpha(0) = 0.035$

Parameter space diagram agrees with NOVA-K normalized 1.5D if radiative damping is not considered.
Accounting for radiative damping might shift the loss diagram significantly allowing for a large operational space without any significant α particle losses.

Using NOVA and 1.5D model, there can be up to 9% loss of α particles. (Since 1.5D is a conservative model, this is great news for ARIES ACT-1.)
More detailed study of the radiative damping is required to access whether the TAE modes in ARIES ACT-1 will result in losses or not.
As a preliminary study, α particles in ARIES ACT-1 are well confined upon interacting with TAE modes.

Pursuing another analysis of R = 6.25 m case, with intermediate q profile, correct beta.

Simple model without radiative damping, predicts >15% losses



n/nGr and its impact, using systems code

Fast particle MHD instabilities are aggravated by high q and high Ti(0)….see Ghantous and Gorelenkov presentation (9/2012)

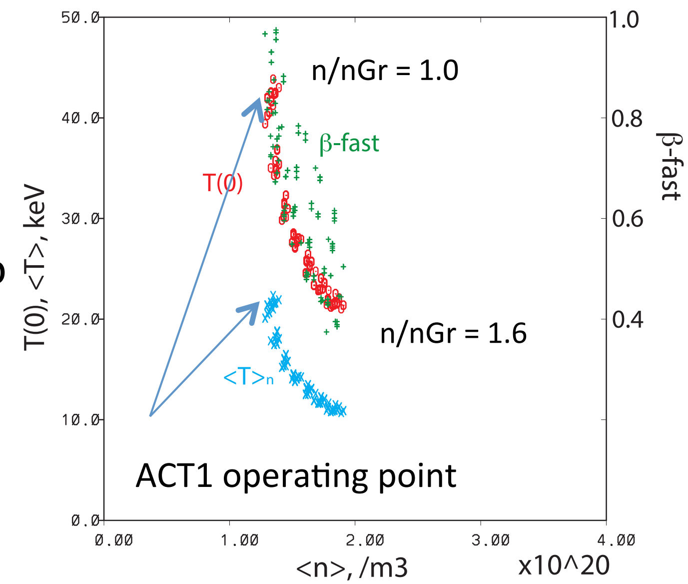
Our operating point has been pushed to higher R in order to accommodate the heat load in the divertor…..new physics results since ARIES-AT

We have limited our plasma density to be $\leq$ 1.0 x nGr (nGr = Ip/(πa^2))

In routine tokamak operation, reaching or exceeding nGr is difficult and leads to problems…..however, discharges have been made that exceed nGr by controlling the way the plasma is fueled, and SOL properties

We find in power plant studies that we need n $\geq$ nGr, since we need high density to make high fusion power

We can lower Ti(0) by operating above the nGr….and what else does it provide



We can recover R = 5.5 m operating points with:

- $q_{div}^{peak,OB} \leq$ 15 MW/m2
- n/nGr = 1.5-1.6
- β_N^{th}, β_N^{fast} = 4.0-4.25, 0.38-0.46
- q_{95} = 5.2-5.5
- <Nw> = 3.5 MW/m2
- H_{98} = 1.2-1.3

Assessment of Heat Loading for Steady State, ELM transient, and Disruption Off-Normal in TOFE paper

We want to re-organize/accumulate results into a Table of loading formulations and resulting heat load ranges

We want to compare the heat loading formula for steady state with the heat loading from UEDGE/LLNL…..particularly when slot length goes from very long to more realistic lengths, and the ability to achieve high radiated power fractions

Similar to TOFE paper we want to go through what is different about power plants and ITER

Make only one type of plasma
Operate for very high duty cycles (1 year before routine maintenance)
…..

Integrate the loading results with ELM regimes, controlled-ELM regimes, no-ELM regimes, etc.

Integrate loading results with any engineering analysis

Physics paper and topics

Systems identification of operating point, target parameters

1.5D time-dependent transport evolution

- various TSC cases with modified L-mode thermal diffusivity
- MMM model

Ideal MHD

- High-n ballooning
- Low-n kink
- Peeling-ballooning / pedestal height
- Vertical instability/control

PF coil design

Heating and Current Drive

- TSC/LSC for LH
- TSC/TRANSP/GENRAY for EC
- TSC/TRANSP/TORIC for IC
- ???? For HHFW

Physics Paper and Topics, cont'd

Fast particle MHD

n/nGr scan in systems code

Heat flux assessment for power plant….TOFE paper…connection to edge plasma analysis

Power scrape-off width scan in systems code

Erosion discussion in conjunction with edge plasma analysis

Fueling and pumping and connection to edge plasma analysis

Parks analysis for HFS pellet

Discussion of burnup

Simple pumping analysis