



Suggestions for Hybrid and AT Operating Modes in DIII-D

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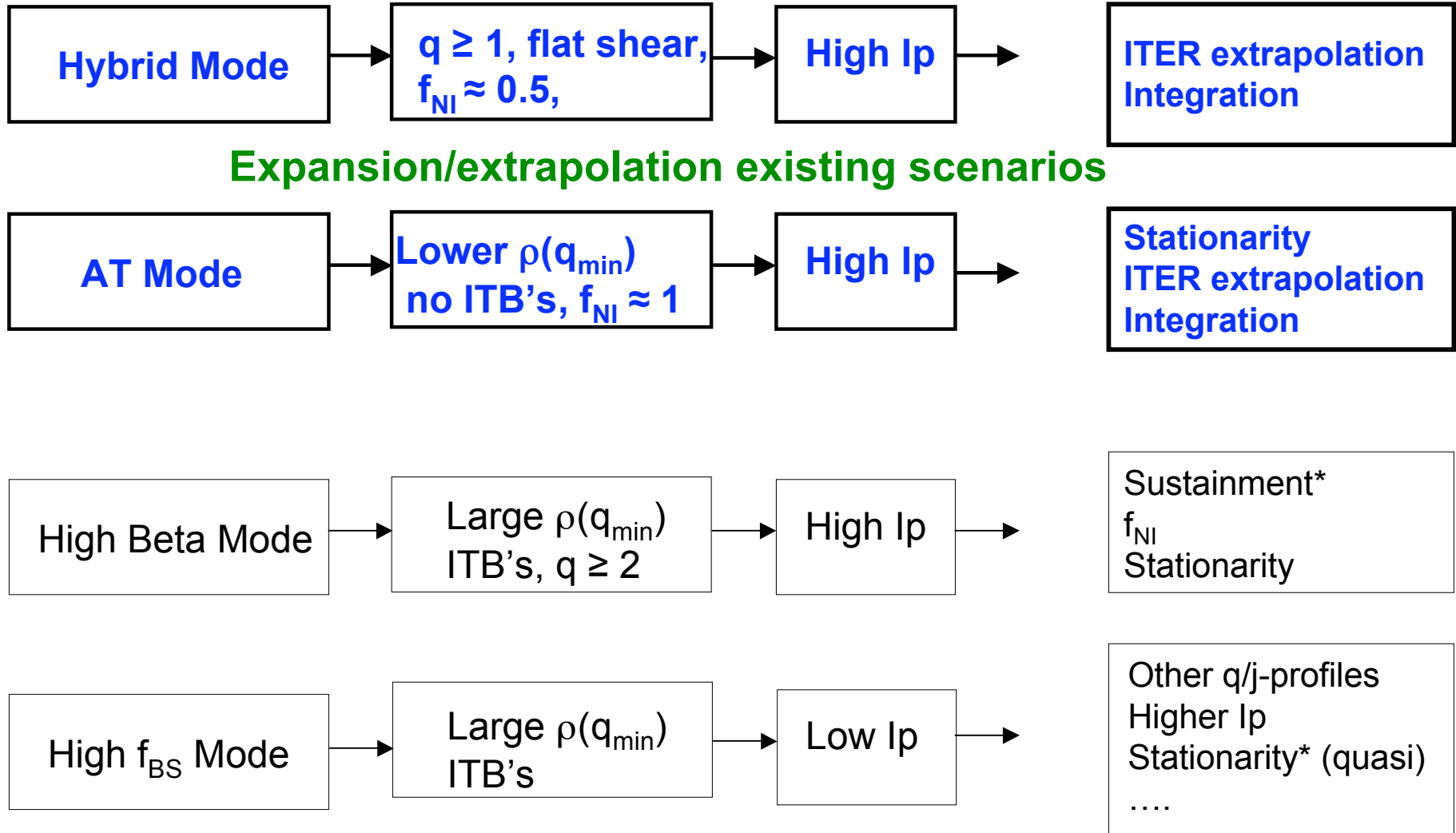
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Major Advanced Operating Modes

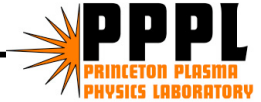
mode

characterization

issues

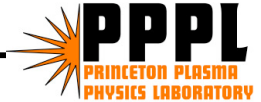


The Hybrid Operating Mode is a Mode That Any Tokamak Should Be Able to Make



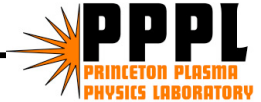
- Characterization (attractive features): (if I dare)
 - 40-60% non-inductive current
 - $q(0) \text{ \& } q_{\min} \geq 1$
 - Access to $\beta_N \approx 0.8-0.95 \times \beta_N^{\text{no wall}}(n=1)$
 - Long pulse stationary
 - $H_H \geq H_{98(y,2)}$ (ELMy H-mode)
 - What are the truly generic features?
- However, each tokamak has
 - Different basic device parameters, B_T , R/a , I_p , etc.
 - Different sources (and their corresponding deposition)
 - Different plasma physics parameter regime (v_* , β , ρ_* , T_i/T_e , Ω_{tor} , etc.)
 - These differences will lead to different devices having a better or worse figure of merit ($H \times \beta_N / q_{95}^2$), **but they can still make a hybrid**

The ITER Hybrid May Be Different From the DIII-D Hybrid



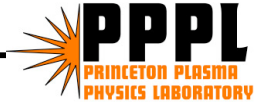
- Projections using GLF23, $T_{ped} = 5$ keV, broad density, low rotation indicate $\beta_N \approx 2.1-2.3$
- What gives rise to the improved confinement/performance dependence of the hybrid
 - Rotation
 - T_i/T_e
 - Density profile obtained
- What is the β_N dependence of the hybrid operating regime
 - β_N too low, do you get 3/2 that degrades confinement significantly?
 - β_N just high enough to get weak 3/2, is the resulting current profile playing a role (FIR-NTM's)
 - β_N limit determined by n=1 no wall boundary (although it induces a 2/1 NTM) is easier to understand
 - Is there any hysteresis in the β_N , that is enter weak 3/2 regime and then reduce β_N

ITER Hybrid, cont'd



- Is $q(0) > 1$ all that is necessary?
 - It is not clear that ITER will have the same non-ideal MHD as DIII-D
 - Use methods to increase sawtooth frequency/reduce amplitude so that $q(0) \approx 1$, like ECCD?
 - Use enough off-axis non-inductive CD to raise $q(0) > 1$
 - How important is flat shear over $\rho < 0.5$
- There may actually be a very wide range of hybrid configurations that can be produced on present tokamaks and future tokamaks
 - Exploring “other” hybrids would be a good place to develop more understanding, and allow better projections to ITER
 - Pursue a better basis for extrapolating to ITER from DIII-D experiments, experimental/theoretical (theoretical models are used because they incorporate physics differentiating ITER from existing tokamaks, BUT they are incomplete)

AT Operating Mode



- This operating mode has reached several features simultaneously
 - $\beta_N \approx 3.2$
 - $f_{NI} \approx 1.0$, $f_{BS} \approx 0.5-0.6$
 - $H_{89} > 2$
- This operating mode is the most like the ARIES-I steady state power plant
- However, it has not demonstrated the level of stationarity that the hybrid operating mode has
 - Significant fraction of the discharge is spent setting up the plasma q-profile
 - Can the sources be used shorten the time spent waiting for the q-profile to set up?
 - Or can the back end of the discharge be extended?

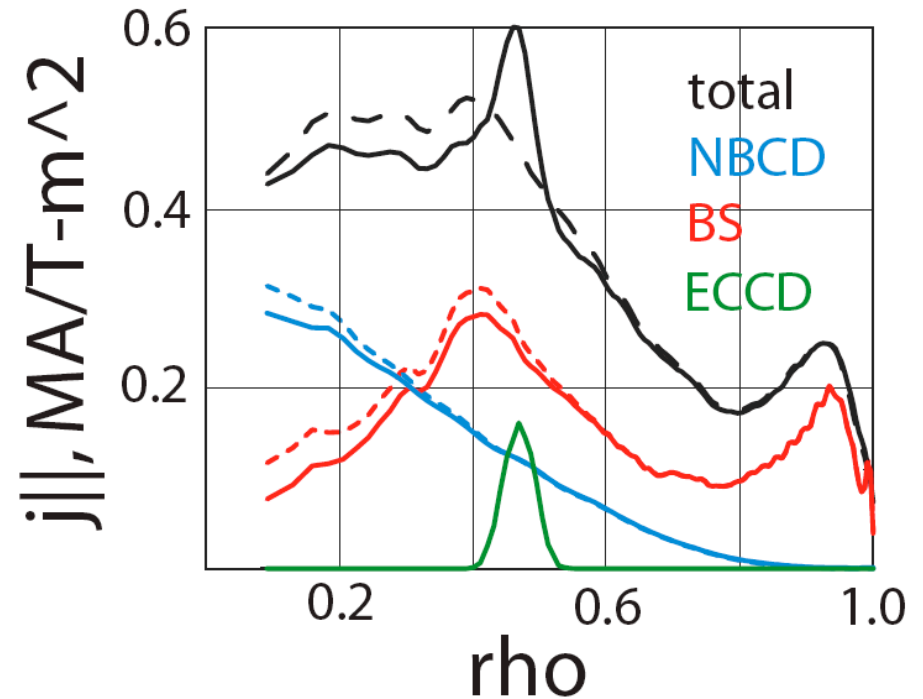
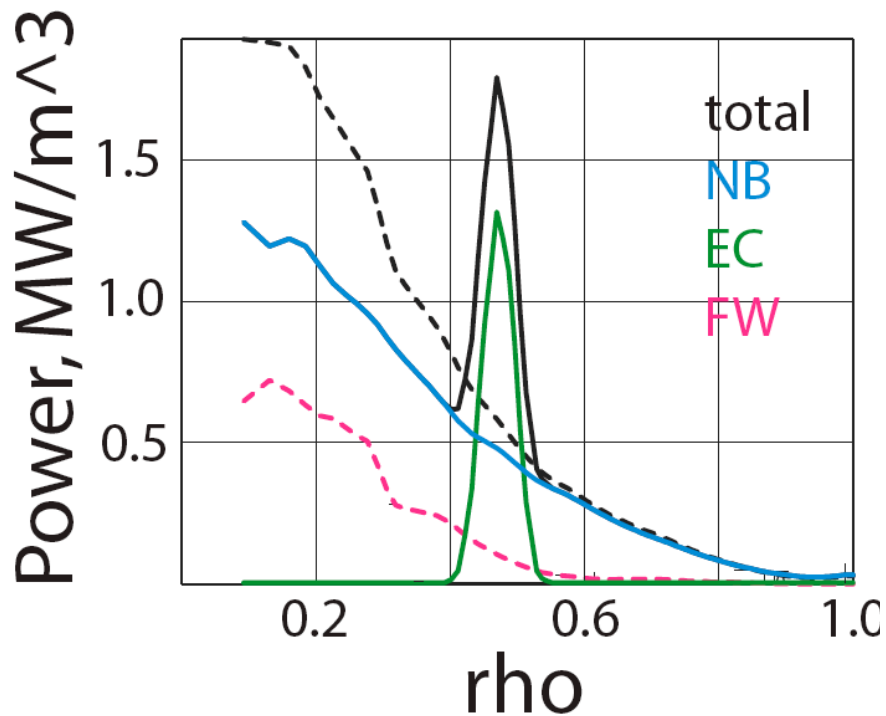
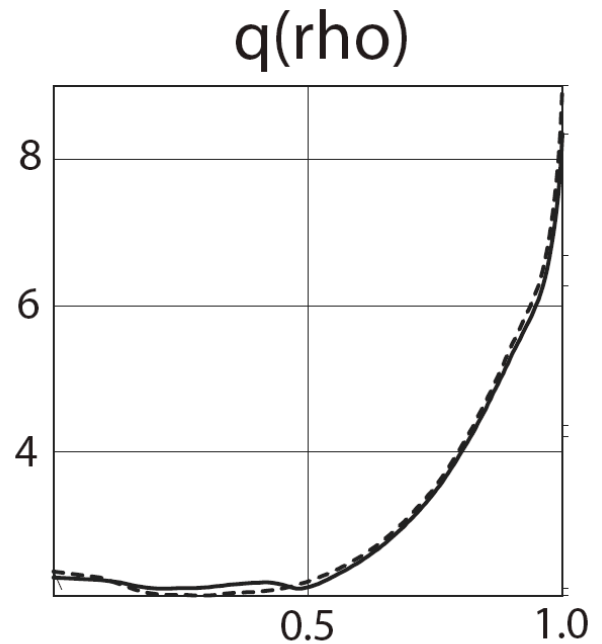
ARIES-I and ARIES-RS/AT Parameters

	ARIES-I	ARIES-I*	ARIES-RS	ARIES-AT
I_p , MA	10.2	10.9-12.6	11.3	12.8
B_T , T	11.3	8.4-9.0	8.0	5.9
R, m	6.75	7.4-8.0	5.5	5.2
a, m	1.5	1.85-1.99	1.38	1.3
κ	1.8	1.8	1.9	2.2
δ	0.7	0.7	0.7	0.85
β_N	3.2	2.9	4.84	5.4
f_{BS}	0.68	0.65-0.57	0.88	0.89
li(3)	0.74		0.42	0.30
q_{cyl}	4.4	4.06-3.77	2.37	1.85
$q(0)$	1.3	1.3	2.8	3.5
$\langle n_{20} \rangle_v$, /m ³	1.5		2.1	2.3
P_{CD} , MW	100	200	80	40
f_{recirc}	0.2	0.3	0.13	0.14
H_{89P}	2.59	1.7-1.8	2.40	2.55
$\langle N_W \rangle$, MW/m ²	2.5	2.1	4.0	3.3
b/a low-n	∞	∞	0.25	0.33
b/a n=0	0.6	0.6	0.45	0.33

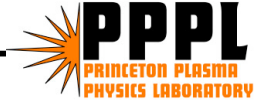
Can the ECCD be Used to Set q_{\min} and $\rho(q_{\min})$?

TSC simulation of 122976, **where EC is on top of NB+BS current profile, which leads to fixed q_{\min} location and value**

NB + EC (ref) & NB + FW
Profiles at $t = 1.5s$

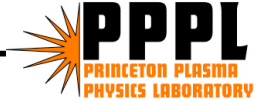


Possible Approach to Shortening the AT Setup and Getting Longer Duration



- Use **ECCD** with **narrow deposition**, inject 1-2 MW for as long a pulse as possible (122976 injected EC for over 3 s)
- ECCD **localized to stand on top of BS and NB j profile**, so it can create a spike in j , and correspondingly a minimum in q
- This does not require a lot of current, can phase EC sources
- This q minimum value and location can be sustained
- On-axis safety factor evolution????
 - On-axis CD could balance NBCD and FWEH, that is use FW (phased to heat, not CD) to replace NB if too much current near the axis ---> of course this could also be done with cntr-NB, but is less long term relevant
- Hopefully, the q profile can be established sooner and sustained for multiple current relaxation times, using the sources, with less reliance on waiting for the “set up”

The AT Mode May Be in a Position to Begin “Integrating” New Features



- Integration:
 - Core/mantle radiation
 - Radiated/conducted power in divertor
 - Impurity control
 - ELM optimization
 - Error field correction/RWM feedback (you may already be integrating features but have not quantified their influence)
 -
- Projecting to ITER
 - Establishing a better basis on which to predict/project an AT plasma in ITER, similar to the hybrid