NSTX

Supported by

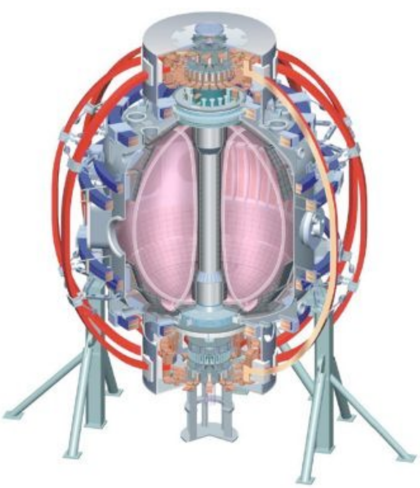
U.S. DEPARTMENT OF ENERGY | Office of Science

XP-948: Confinement and NI Current Fraction Trends on the Path to High Toroidal-β

S.P. Gerhardt, D. Gates

Advanced Scenarios and Control Group Review

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin



Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

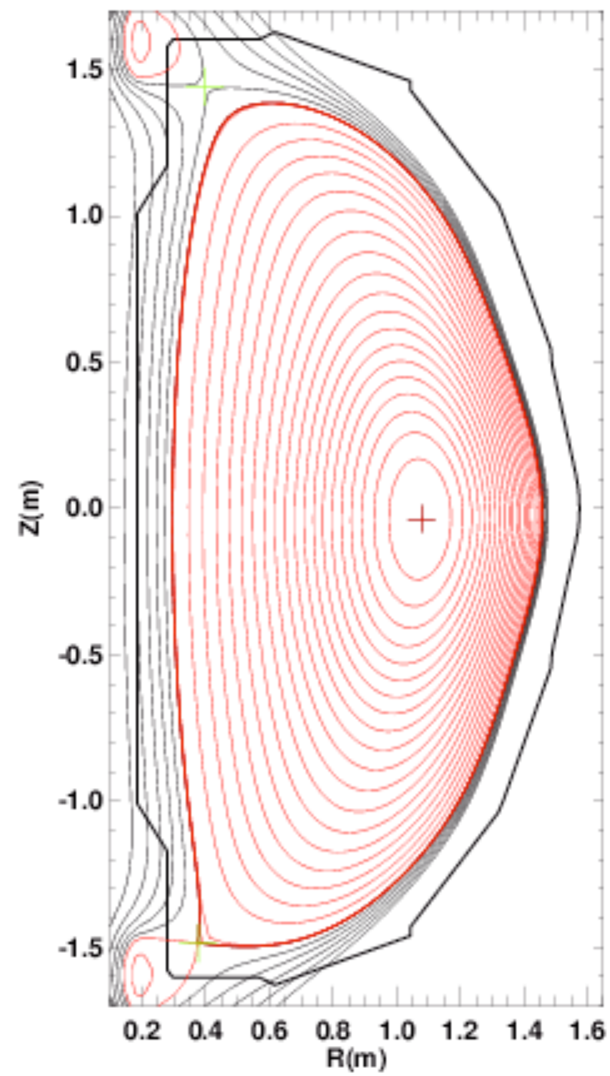
XP-Goal: Extend High-κ Scenario to High β_T, in the Process Studying the I_P and B_T Scaling of NI Fraction & τ_E In This Shape

- Scheme
  - Reload and touch base with high-κ, high-β_P shot 133964, I_P=0.7, B_T=0.47, $\tau_{flat\text{-}top}$=1.0 sec, $\langle\beta_N\rangle$=4.3, $\langle\beta_T\rangle$=11, $\langle\kappa\rangle$=2.55, $\langle q^*\rangle$=4.6, $\langle\tau_E\rangle$=36 msec, outer gap =15 cm.
  - Lower B_T, raise I_P to operate at high I_N and β_T.
    - Do this is controlled steps, so that confinement trends can be revealed.
  - Optimize RWM control, fuelling, in order to achieve long pulse.
  - Ultimate goal is to run at I_P=1.1 MA, B_T=0.35 T, $\beta_T \approx 28\%$
- Deliverables
  - Explore the I_P and B_T dependence of confinement and NI fraction in this unique high-κ, low-l_i regime.
  - Establish the low-q*, high-β_N operating boundary in NSTX with Li deposition and RWM feedback.
  - Bonus: Impurity behavior as a function of I_P and B_T to complement XP-950
- Milestone R09-3: Characterize non-inductive current drive fraction versus elongation, proximity to beta limit, and plasma density
  - Provide I_P, B_T, β-limit, scaling of NI fraction

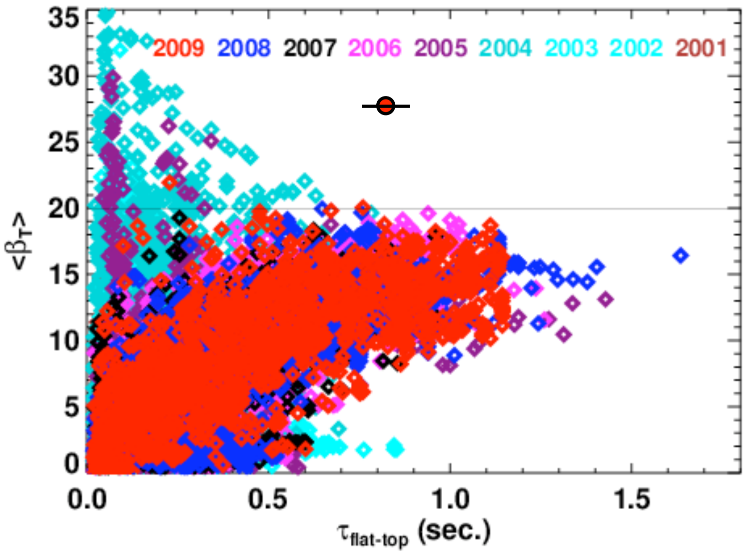
Target Shot is 133964, With I_P and B_T Scanning To High β_T

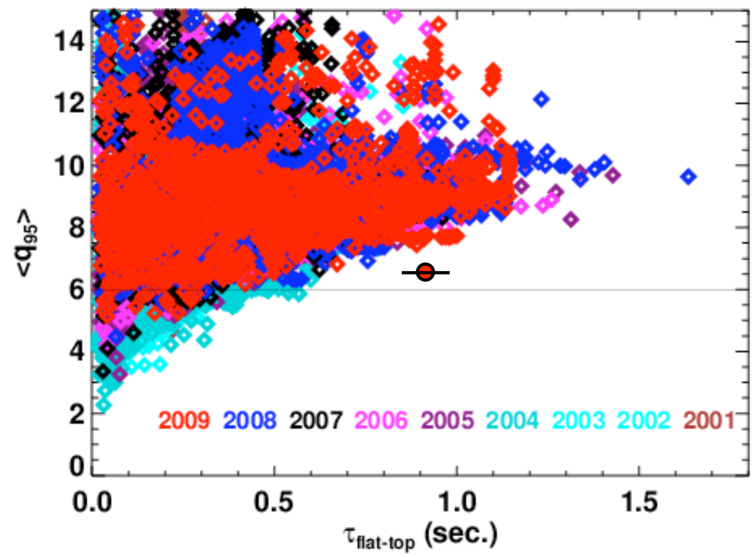
- 133964: κ~2.5, I_P=0.7, B_T=0.47, high triangularity, high β_P for high NI current fraction.
- Drop B_T, raise I_P, in order increase β_T at constant β_N.
  - Table shows sequence of equilibria fixed at β_N=5.5.
  - Try to stay above q* of 2.5
- Goal is to sustain I_P=1100kA, B_T=0.35 T, β_T=28% for the duration of the OH capability.
  - 0.35 T chosen as the lower limit of MSE calibration

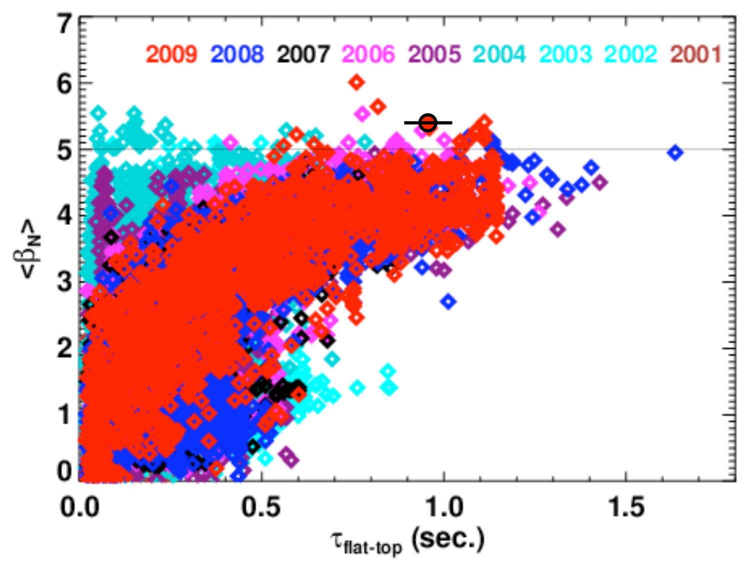
Case	Ip (MA)	BT (T)	betaN	betaT (%)	q*	q95	WMHD (kJ)
1	0.7	0.5	5.5	13.6	4.78	14	260
2	0.7	0.45	5.5	14.8	4.4	12.5	234
3	0.7	0.4	5.5	16.4	4	11.1	208
4	0.7	0.35	5.5	18.5	3.57	9.7	183
5	0.9	0.5	5.5	17	3.9	10.7	330
6	0.9	0.45	5.5	18.5	3.57	9.7	300
7	0.9	0.4	5.5	20.5	3.23	8.6	270
8	0.9	0.35	5.5	23	2.87	7.5	235
9	0.9	0.3	5.5	27	2.5	6.5	202
10	0.9	0.25	5.5	32	2.1	5.4	170
10	1.1	0.5	5.5	20	3.29	8.8	411
11	1.1	0.45	5.5	22	3	7.9	371
12	1.1	0.4	5.5	24.6	2.7	7.1	330
13	***1.1***	***0.35***	***5.5***	***28***	***2.4***	***6.2***	***289***
14	1.1	0.3	5.5	32	2.1	5.3	249
15	1.2	0.5	5.5	21	3.1	8.1	449
16	1.2	0.45	5.5	24	2.8	7.3	405
17	1.2	0.4	5.5	26.7	2.5	6.5	361
18	***1.2***	***0.35***	***5.5***	***30***	***2.2***	***5.7***	***317***
19	1.3	0.5	5.5	23.4	2.8	7.5	487
20	1.3	0.45	5.5	25.8	2.6	6.7	439
21	***1.3***	***0.4***	***5.5***	***28.8***	***2.3***	***6***	***391***
22	1.3	0.35	5.5	32	2.05	5.2	343

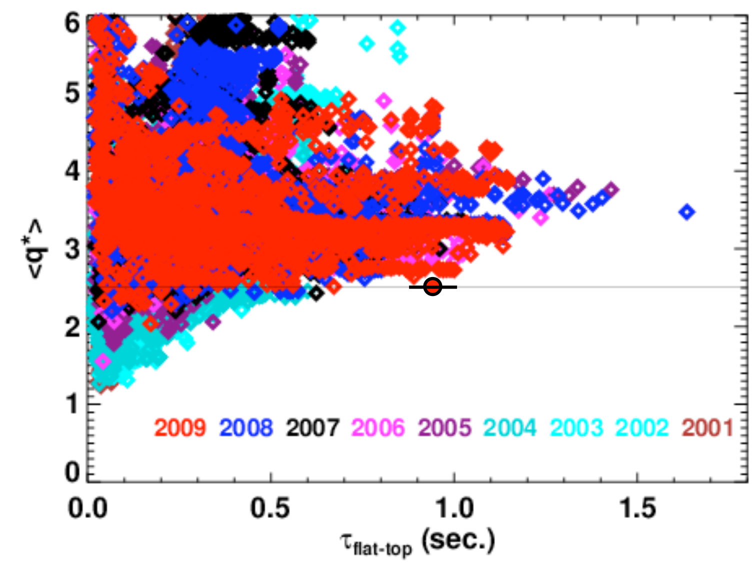


Target Equilibria Sits At Boundaries of NSTX Operating Space









Key Question : How will Confinement Scale with I_P and B_T in the high-κ, low-l_i configuration

Reference shot 133964 has $<\beta_N>$~4, while ultimate target has $<\beta_N>$~5.5

NSTX Scaling

$$\tau_E = B_T^{1.0} I_P^{0.6} P^{-0.6}$$

$$\beta_N = \frac{50\mu_0 P\tau a}{2 I_P B_T}$$

$$\beta_N = \frac{50\mu_0 P^{0.4} a}{I_P^{0.4}}$$

$ITER_{98PB(y,2)}$ Scaling

$$\tau_E = B_T^{0.15} I_P^{0.9} P^{-0.7}$$

$$\beta_N = \frac{50\mu_0 P\tau a}{2 I_P B_T}$$

$$\beta_N = \frac{50\mu_0 P^{0.3} a}{B_T^{0.85} I_P^{0.1}}$$

$$\frac{\tau_E}{B_T^{1.0} I_P^{0.6} P^{-0.6}}$$

$$\frac{\tau_E}{B_T^{0.15} I_P^{0.9} P^{-0.7}}$$

Case	Ip (MA)	BT (T)	betaN	betaT (%)	q*	q95	WMHD (kJ)	tauE (msec), 6MW input	tauE, NSTX Normalization	tauE, ITER98 Normalization
1	0.7	0.5	5.5	13.6	4.78	14	260	43.33	315	232
2	0.7	0.45	5.5	14.8	4.4	12.5	234	39.00	315	212
3	0.7	0.4	5.5	16.4	4	11.1	208	34.67	315	192
4	0.7	0.35	5.5	18.5	3.57	9.7	183	30.50	316	173
5	0.9	0.5	5.5	17	3.9	10.7	330	55.00	343	235
6	0.9	0.45	5.5	18.5	3.57	9.7	300	50.00	347	217
7	0.9	0.4	5.5	20.5	3.23	8.6	270	45.00	351	199
8	0.9	0.35	5.5	23	2.87	7.5	235	39.17	349	177
9	0.9	0.3	5.5	27	2.5	6.5	202	33.67	350	155
10	0.9	0.25	5.5	32	2.1	5.4	170	28.33	354	134
10	1.1	0.5	5.5	20	3.29	8.8	411	68.50	379	245
11	1.1	0.45	5.5	22	3	7.9	371	61.83	380	224
12	1.1	0.4	5.5	24.6	2.7	7.1	330	55.00	381	203
13	***1.1***	***0.35***	***5.5***	***28***	***2.4***	***6.2***	***289***	***48.17***	***381***	***181***
14	1.1	0.3	5.5	32	2.1	5.3	249	41.50	383	160
15	1.2	0.5	5.5	21	3.1	8.1	449	74.83	393	247
16	1.2	0.45	5.5	24	2.8	7.3	405	67.50	394	226
17	1.2	0.4	5.5	26.7	2.5	6.5	361	60.17	395	205
18	***1.2***	***0.35***	***5.5***	***30***	***2.2***	***5.7***	***317***	***52.83***	***396***	***184***
19	1.3	0.5	5.5	23.4	2.8	7.5	487	81.17	406	249
20	1.3	0.45	5.5	25.8	2.6	6.7	439	73.17	407	228
21	***1.3***	***0.4***	***5.5***	***28.8***	***2.3***	***6***	***391***	***65.17***	***408***	***207***
22	1.3	0.35	5.5	32	2.05	5.2	343	57.17	409	185

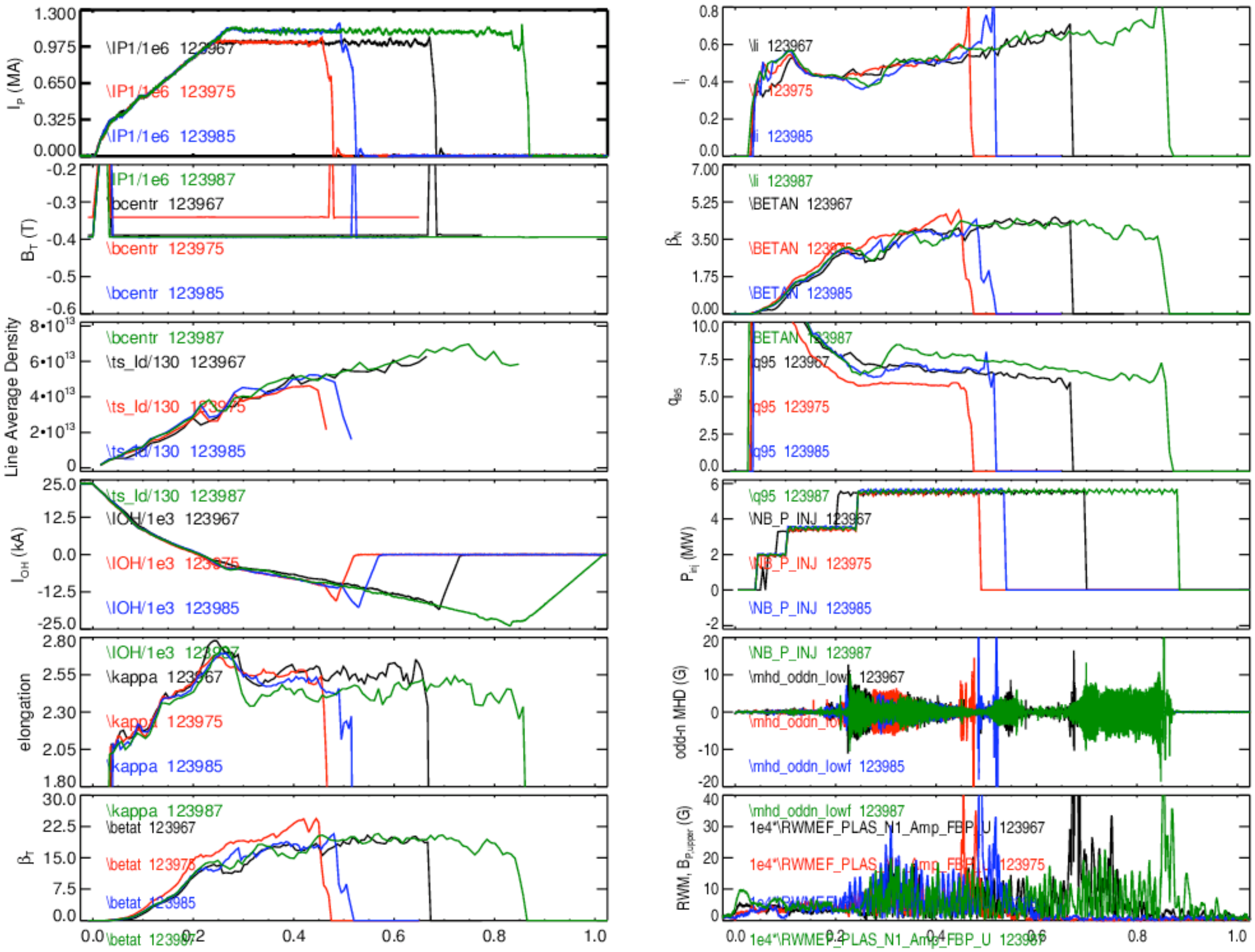
shot	Ip (MA)	BT (T)	Comment	Power (MW)	Measured tauE (msec)	tauE, NSTX Normalization	tauE, ITER98 Normalization
129125	0.8	0.41	Longest Pulse Ever in NSTX	5	36	264	155
133964	0.75	0.47	Basis shot for this experiment, high betaP	6	35	259	178
133078	0.9	0.45	Excellent Fiducial in 2009	6	45	312	195
132724	1.1	0.53	From n=3 EF experiment	5	52	243	162
132912	1.35	0.5	Shot proceeding record Wmhd discharge	6	55	269	163
123987	1.1	0.4		6	40	277	148
127985	1.2	0.45	q*=2.4 at 1.2 MA	6	44	257	148

123987, with I_P=1100, B_T=0.4, only managed β_N=4.4 in 2007

Different Goals, RWM Control, Dual LITER, Distinguish this XP from XP-727: Stability Limits with Strong Shaping at High-I_N (I)

- Focused on very high-I_N at high-κ.
  - κ=2.6, A=1.5 similar to equilibria in this XP.
  - I_P scanned from 1-1.2 MA, B_T scanned from 0.3-0.4 T
- Lots of current-ramp disruptions for B_T=0.30 & 0.35 T
- For discharges entering flat-top (B_T=0.4 T), large external modes (RWMs?) typically caused disruptions.
  - Modes grow rapidly in RWM sensors without rapidly rotating precursor.
    - Not a rotating TM that locks.
  - Edge USXR emission collapses after magnetic signature, but before core emission.
  - These modes are often suppressed with RWM feedback, which was not used if XP-727.

Different Goals, RWM Control, Dual LITER, Distinguish this XP from XP-727: Stability Limits with Strong Shaping at High-I_N (II)



Shot Sequence

List is structured so that important information is found on the way to the target equilibria.

- Step 1: Reload shot 133964, I_P=700 kA, lower to B_T=0.45 (5 shots)
  - Touch base with high β_P shot, for connection to D. Gates NI current drive studies and milestone.
  - Repeat a few times while lithiumization is established.
- Step 2: Raise I_P to 900kA, Lower B_T to 0.45. (2 shots)
  - I_P and B_T waveforms from fiducial, but with high-κ shape and lithiumization.
- Step 3: Lower B_T in steps to 0.4, (0.375?), 0.35 (8 shots)
  - Extend I_P in each condition in order to utilize full B_T waveform.
- Step 4: For optimal B_T in Step 2, raise I_P in steps to 1 MA, and 1.1 MA. (8 shots)
  - Choose B_T where plasma gets through step 3 without failure.
  - May be necessary to increase B_T for some steps of this sequence.
- Step 5: Fill in intermediate I_P, B_T combinations. (10 shots)
- Step 6: Time permitting, vary input power. (remainder)
  - Pick stable I_P,B_T combination and try 3,4,5,6 MW cases

Total: 33

Could use an extended day for contingency.

Questions:

Should we do a few cases with higher B_T (0.5, 0.55 T) in step 3, for study of τ_E, NI fraction scalings?

Should we do a shot in the fiducial shape, but full lithiumization, in step 2 (two points of kappa scaling)?

Should we consider using higher B_T for the current ramp (0.4 T), then ramping down (0.35T) ?

Notes on Machine Conditions and Diagnostics

- D_2 in both injectors 1 & 2.
- Li evaporation from 2 LITER Units
  - 200-300 mg/shot, on a 12.5 min. cycle
- β_N control could be useful.
  - Confinement likely dictates use of all 6 MW, but harmful transients could be avoided with β_N control.
- RWM Control.
  - Key system for controlling the stability
  - Start with gain P=1, τ_{FB}=1 msec, and increase gain if necessary.
- Spectroscopy
  - Provides controlled scan of I_P and B_T for studying metal accumulation.
  - Should have LoWEUS, SPRED, Bolometry to continue studies from XP-950