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Observations from XP-950: Dependence of metallic impurity accumulation on I_p and the outer gap in the presence of lithium deposition

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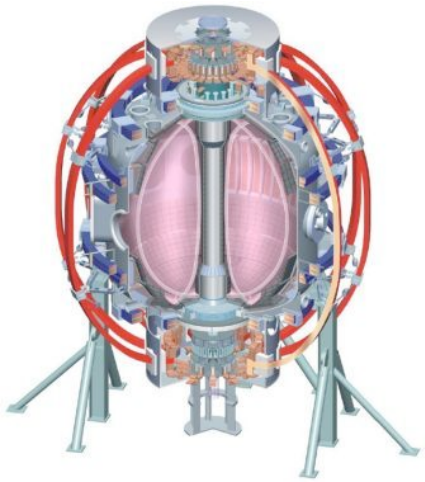
•Summary of results



Motivation and design of experiment

- Li-conditioned ELM-free scenarios are known to suffer from massive radiated power if they achieve long pulse.
- Unverified subjective opinions about whether fast ion loses contribute in a major way
- If so, hypothesize that a large outer gap (thin gas blanket) or high I_p (better fast ion confinement) or beam source geometry might limit the impurity accumulation.
  - Test this hypothesis with systematic scans.
  - Try, if possible, to diagnose the difference impurities, impurity sources, and provide operations/infrastructure guidance.
- Scanned I_p, outer gap, and source mix
  - Two shots for I_p scan 1) [I_p =700 kA, B_T = 0.45 T] and 2) [I_p =1200 kA, B_T = 0.5 T].
    - For I_P=700kA, did gap scan @[5,10,15,20] cm, for I_P=1.2MA , scanned [10,15, 20] cm.
    - For each case, varied source geometry, switching between sources A+B and A+C.
  - Left the early beams, early shape, current ramp rate alone.
  - Did 2 shots with all fixed except for LFS puffing during the flat top.
- Not always fully ELM-free
  - We thought that bay-K LITER was on the verge of running out, and so rationed the usage.
  - Ended the day with negative Li in Bay-K LITER.
- Follow-up 2 hour run to inject beam fast ions earlier in shot @ low I_p stage.

Metrics and Diagnostics Used So Far

- Particle inventories from CHERS, MPTS & EFIT02: N_D, N_e, and N_C
- Carbon dilution: $6N_C/N_D$
- Bolometry: P_{rad} and P_{rad}/N_e, profiles of power density.
- SPRED:
  - Spectrum vs λ at fixed time, normalized by the line density ($1/cm^2$)
    - Caveat that Fe XV (284 A), FeXVI (335, 361 A) have relatively low ionization potentials (100s of eV).
  - Metal "hump" vs time: median filter spectrum to remove discreet lines, sum all pixels with $200<\lambda<400$, normalize by the line density.
- Bremsstrahlung Z_{eff} estimation
- Z_{eff} profiles from CHERS, assuming C only.

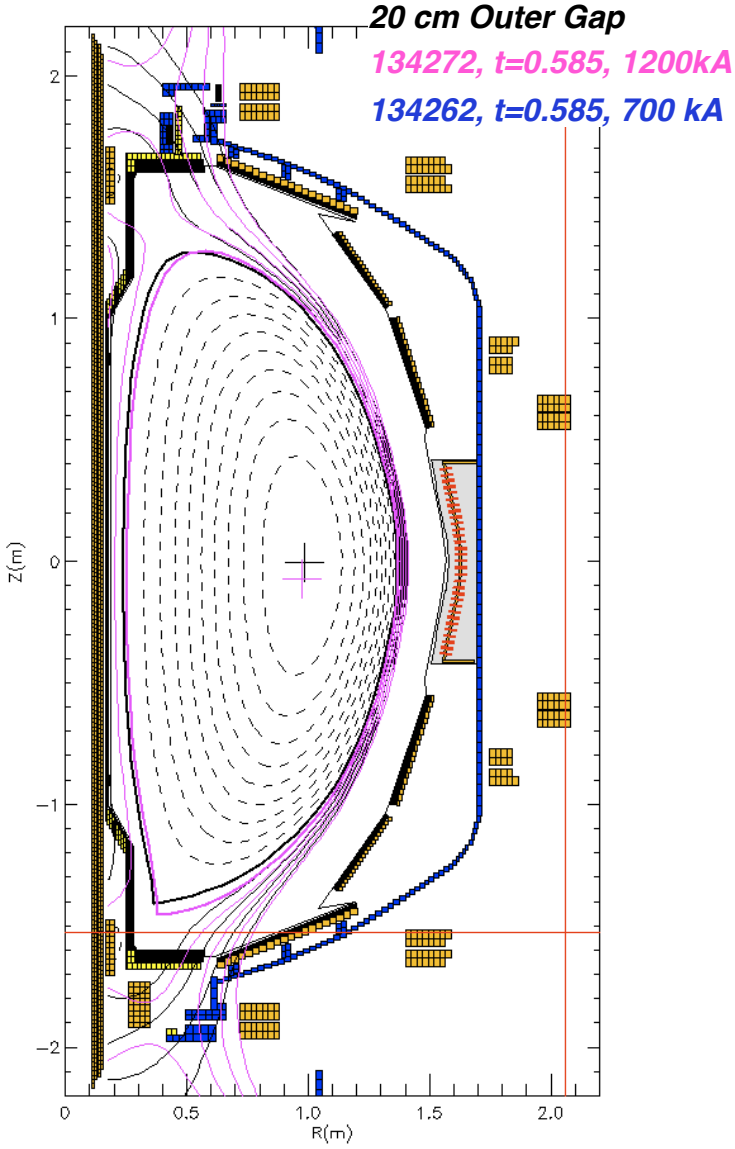
Need to try to recover some LowEUS, XEUS data if possible

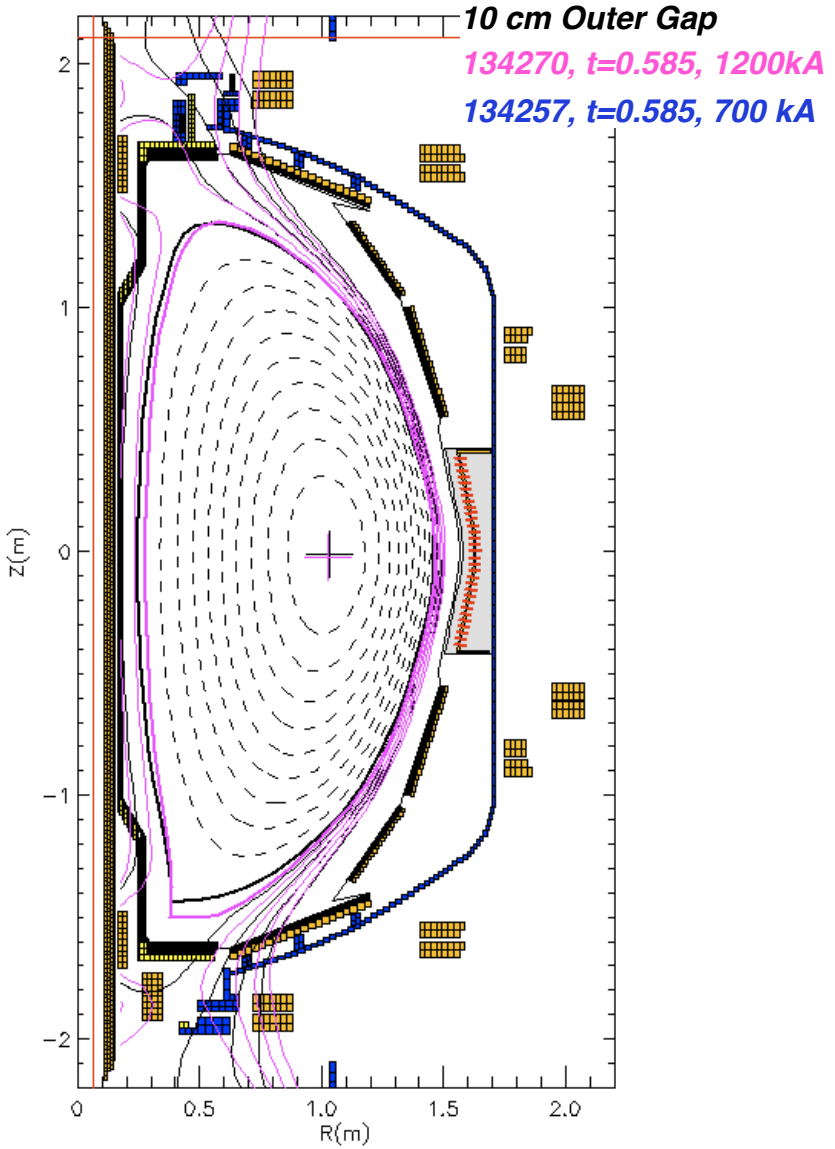
Shot List with comments

1200kA Cases have BT=0.5 T
700kA Cases have BT=0.45 T
FT Gas= LFS Fueling Rate During the Flat Top (TL/s)
= Shots with A+B
= Shots that are not useful

shot	Ip	Outer Gap	Sources	LI Evaporated	FT Gas	Comment
134256	700	10	A+B	247	0	
134257	700	10	A+B	251	0	
134258	700	10	A+C	206	0	
134259	700	15	A+C	195	0	
134260	700	15	A+B	208	0	No CHERS, so repeat
134261	700	15	A+B	186	0	No CHERS
134262	700	20	A+B	192	0	
134263	700	20	A+C	204	0	
134264	**700**	**5**	**C Only**	**203**	**0**	**Source C Only**
134265	700	4	A+C	202	0	
134266	700	5	A+B	202	0	
134267	1200	15	A+B	202	0	
134268	1200	15	A+C	202	0	
134269	1200	10	A+C	200	0	
134270	1200	10	A+B	202	0	
134271	**1200**	**20**	**A Only**	**202**	**0**	**Source A Only**
134272	1200	20	A+B	202	0	
134273	**1200**	**20**	**A+C**	**202**	**0**	**Disrupts During Ramp**
134274	1200	20	A+C	202	0	
134275				**202**	**0**	**No Fields**
134276	700	15	A+C	202	20	
134277	700	15	A+C	202	40	Reduced Prad, probably because ELMs come back
134278	700	15	A+C	202	0, then 20	

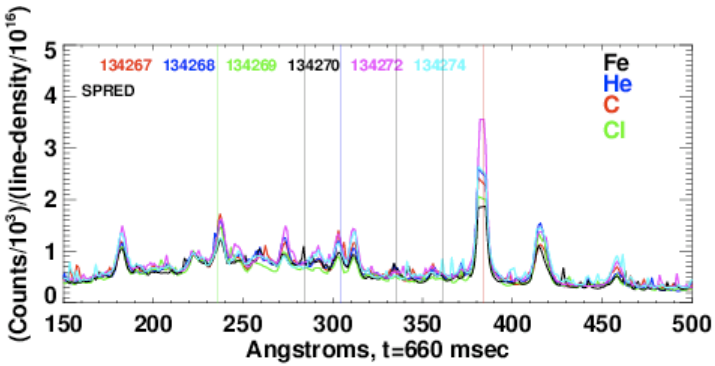
Plasma shapes used for scanning the outer gap

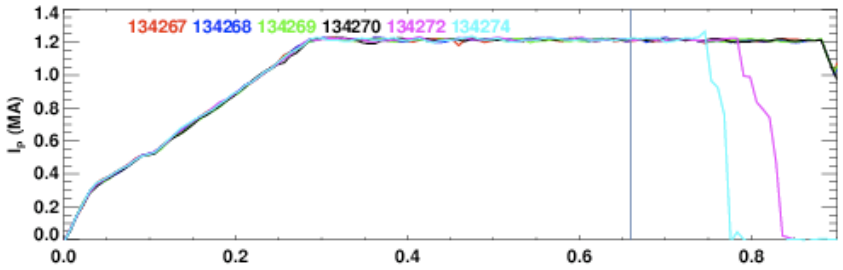


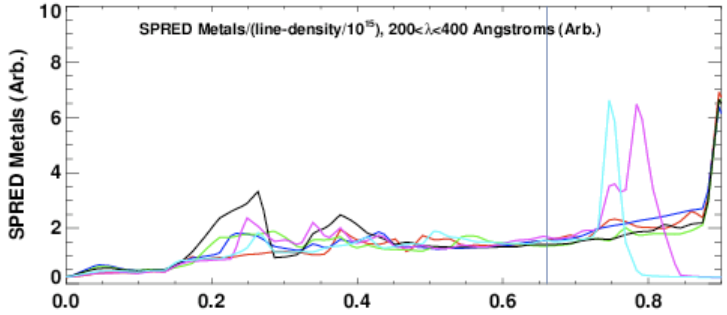


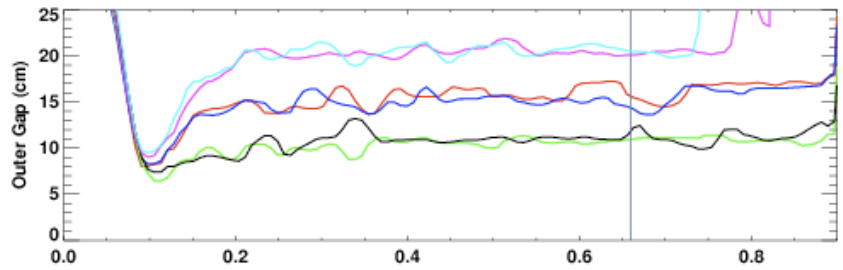
At I_P=1200 kA, B_T=0.5T, SPRED Shows that Accumulation of Metals is Arrested, Regardless of Outer Gap

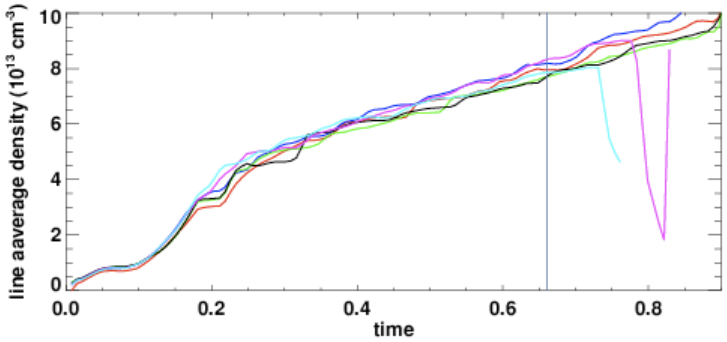
- SPRED spectra essentially overlap.
- Time evolution shows no ramp of metals accumulation.
  - Caveat: Fe XV and XVI lines observed by SPRED have ionization potentials of only about 500 eV; indicative of region with T_e around 100-200 eV.





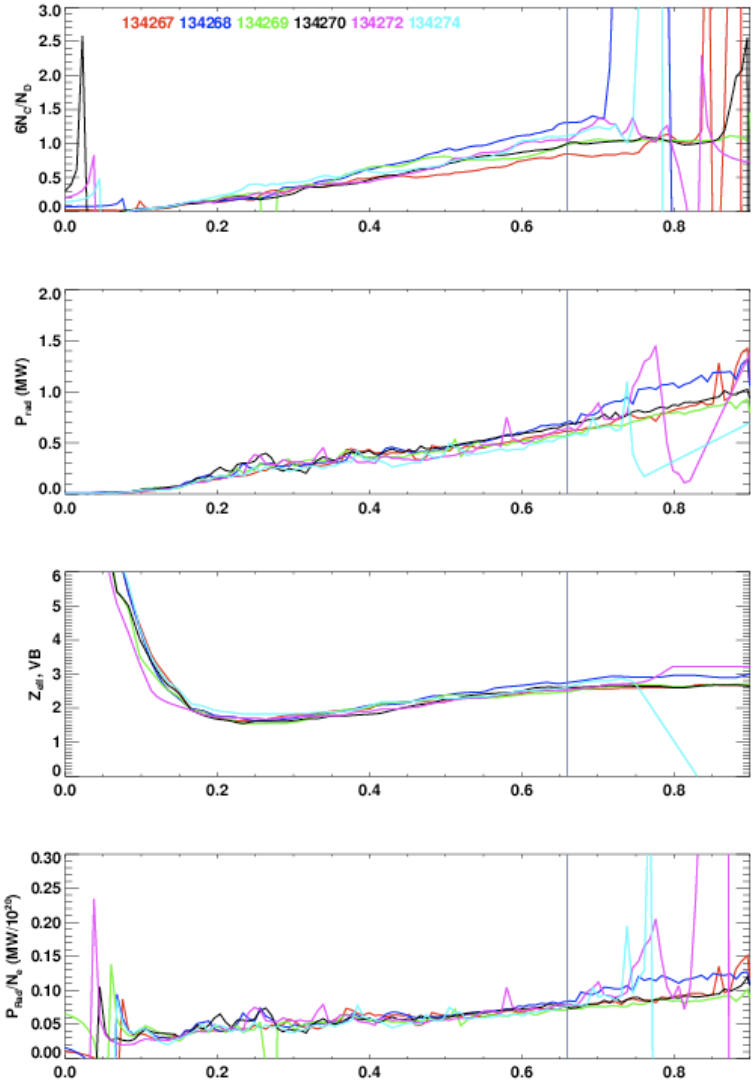


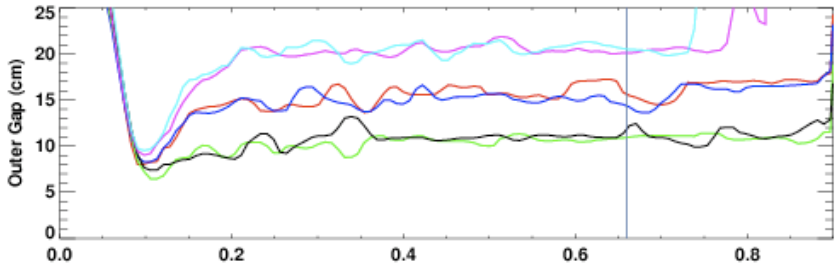




At I_P=1200 kA, B_T=0.5T, P_{rad}/electron Rises Slowly & is Independent of Outer Gap, Carbon Dilution Uncorrelated With Gap

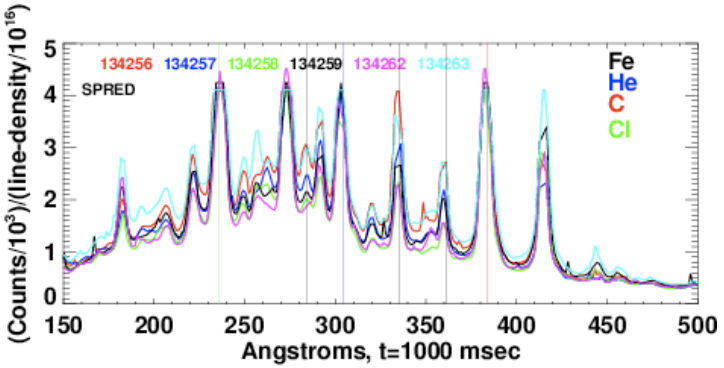
- Carbon dilution is present, though not well correlated with the outer gap.
  - Typically 50% of electrons from C at the end of these shots.
- P_{rad} ramps.
- $Z_{eff,VB}$ is independent of the outer gap.
- P_{rad}/N_e ramps very slowly

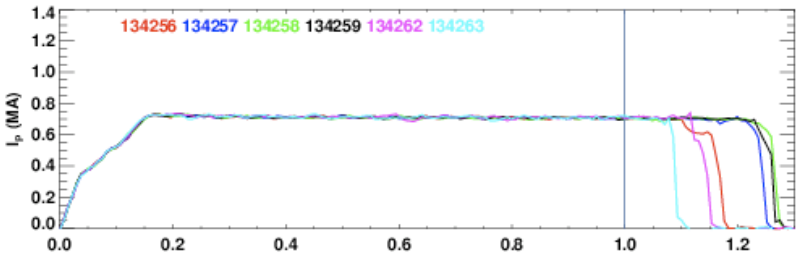


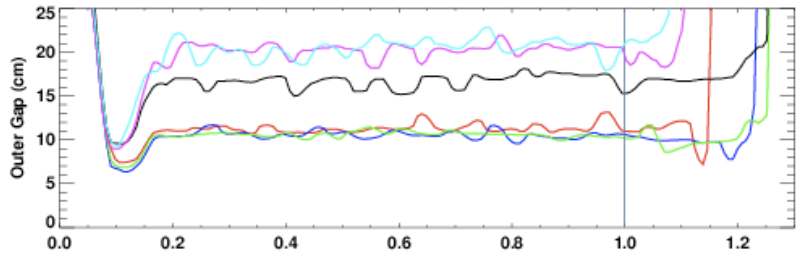


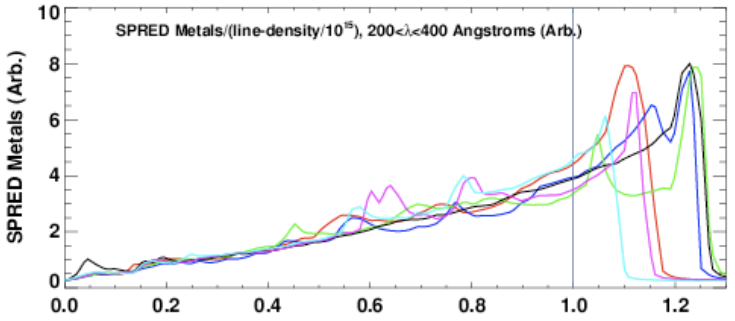
At I_P=700 kA, B_T=0.45T, SPRED Shows that the Accumulation of Metals Occurs, Regardless of Outer Gap

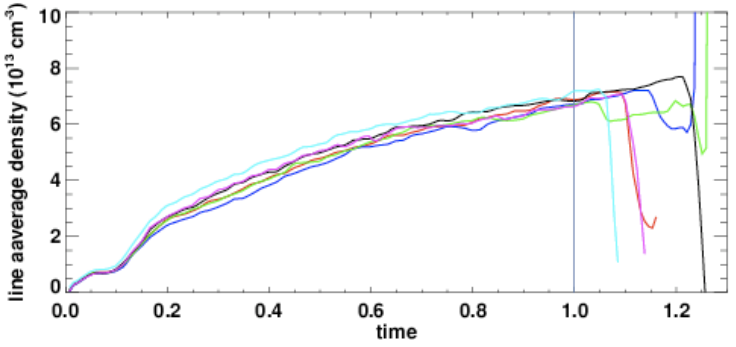
- Iron lines are prominent in the SPRED spectrum at I_P=700 kA.
- Normalized SPRED metals ramp strongly through the shot





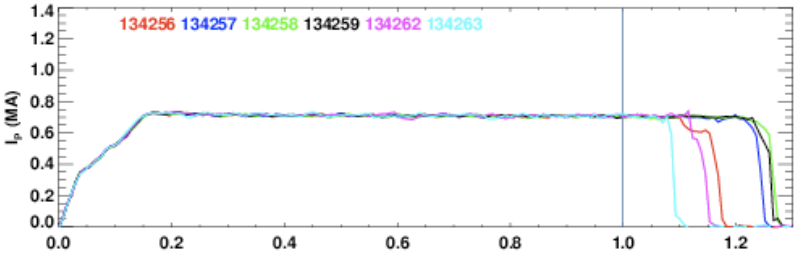


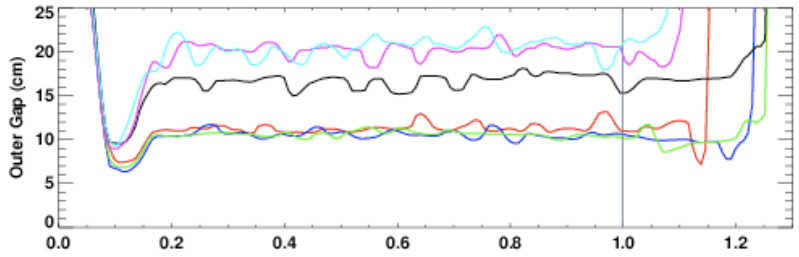


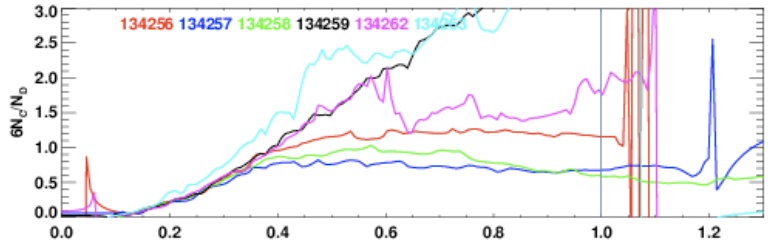


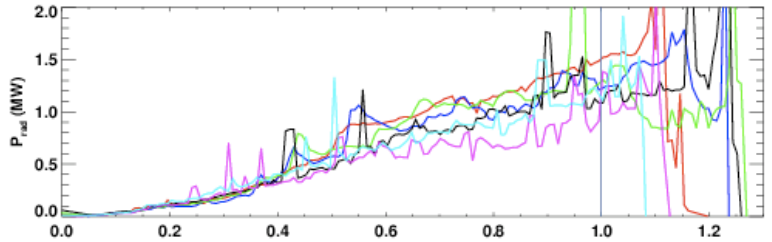
At I_P=700 kA, B_T=0.45T, P_{rad}/electron Rises More Rapidly, Carbon Dilution Becomes Severe at Large Outer Gap

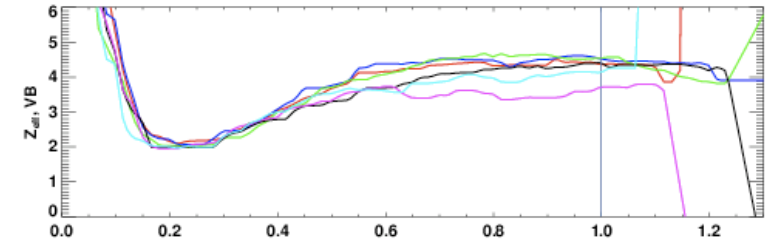
- Carbon dilution is severe when outer gap is 15 or 20 cm
- Radiated power per electron:
  - Is larger for small outer gap, though the trend is not strong
  - Ramps strongly throughout the shot

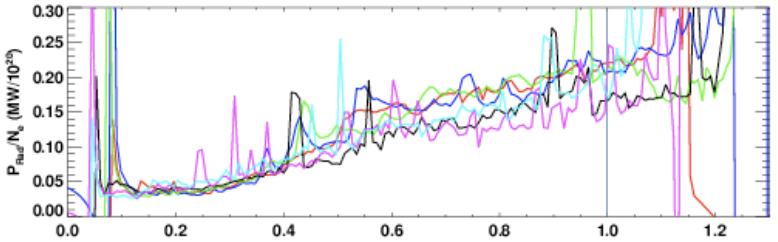




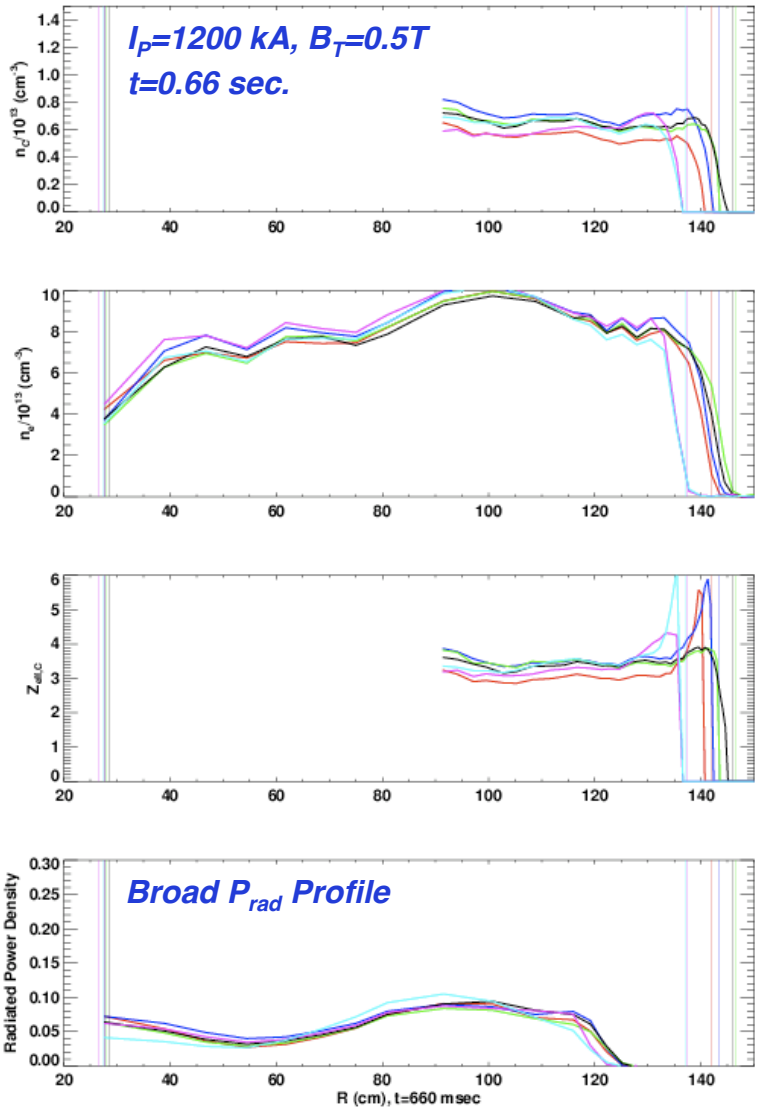


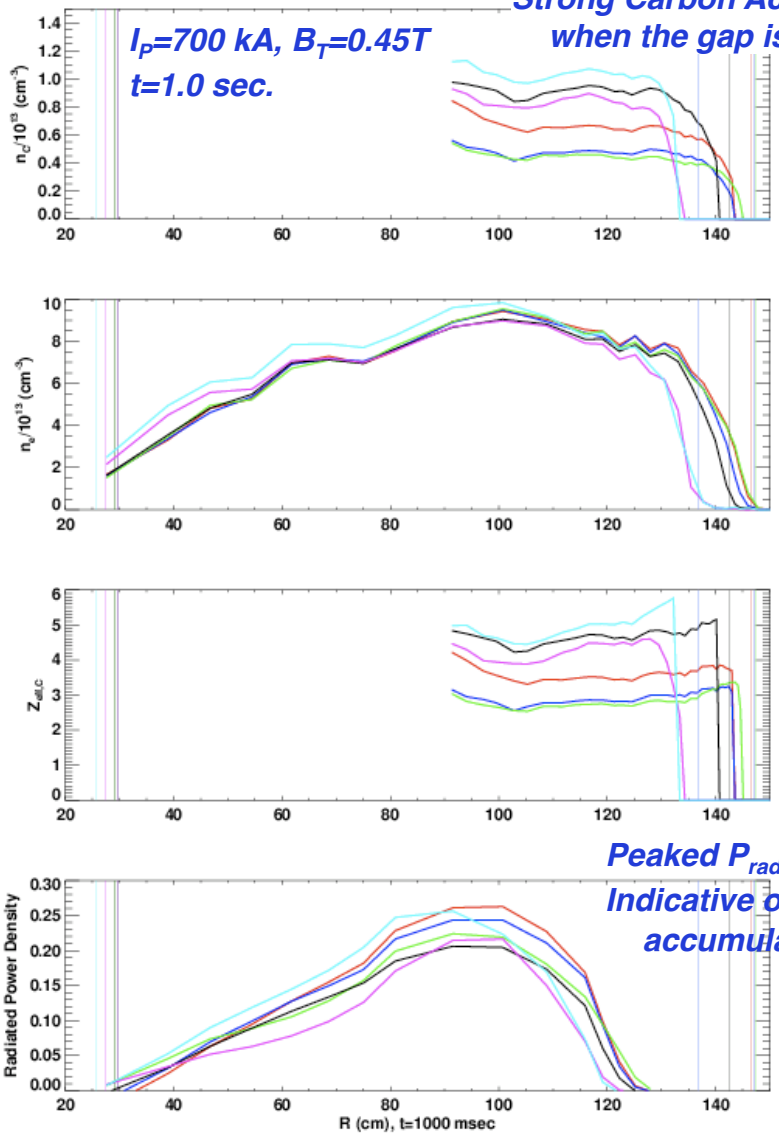






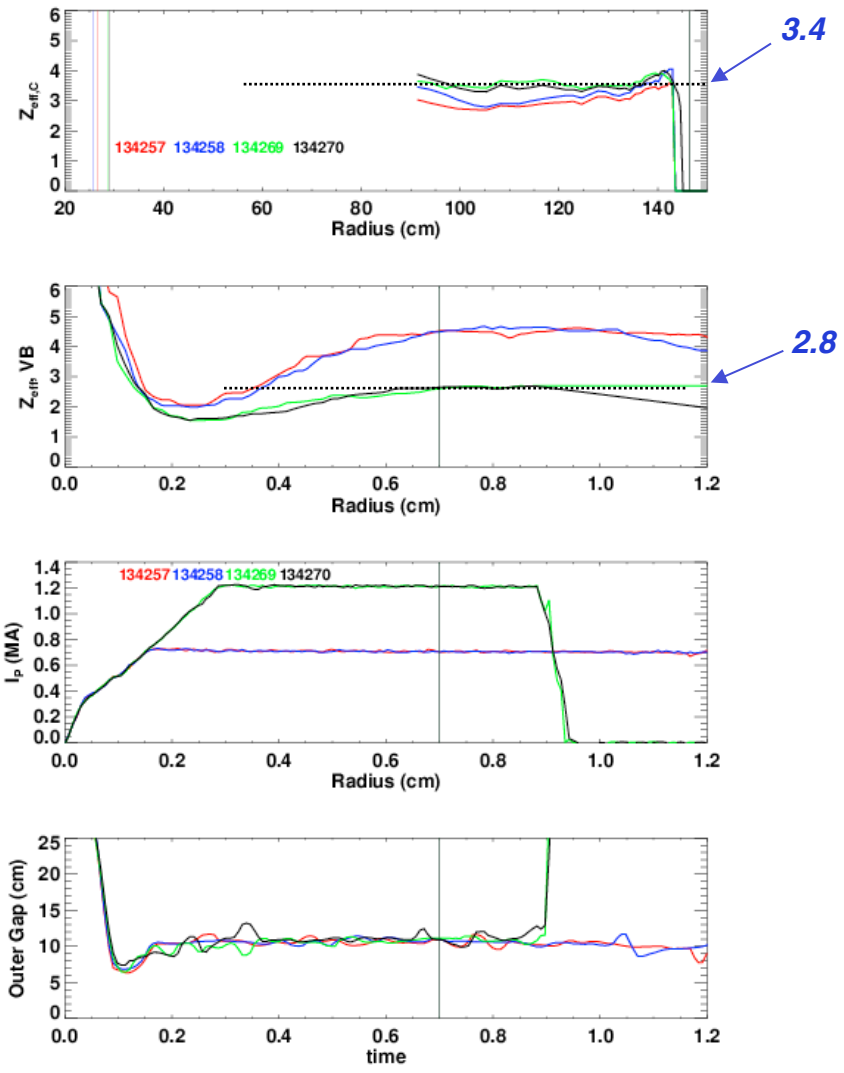
Radiated Power Profiles More Peaked at low Ip
1200 kA vs. 700kA



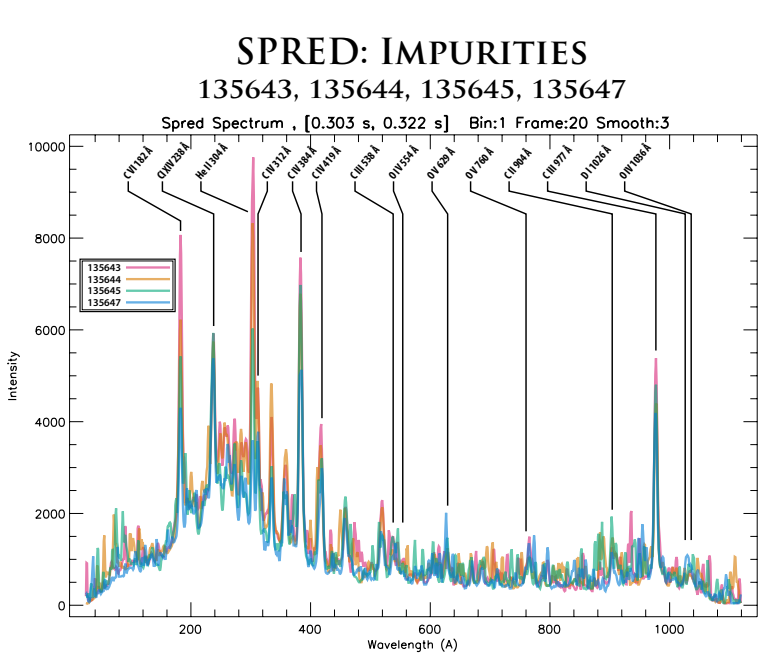


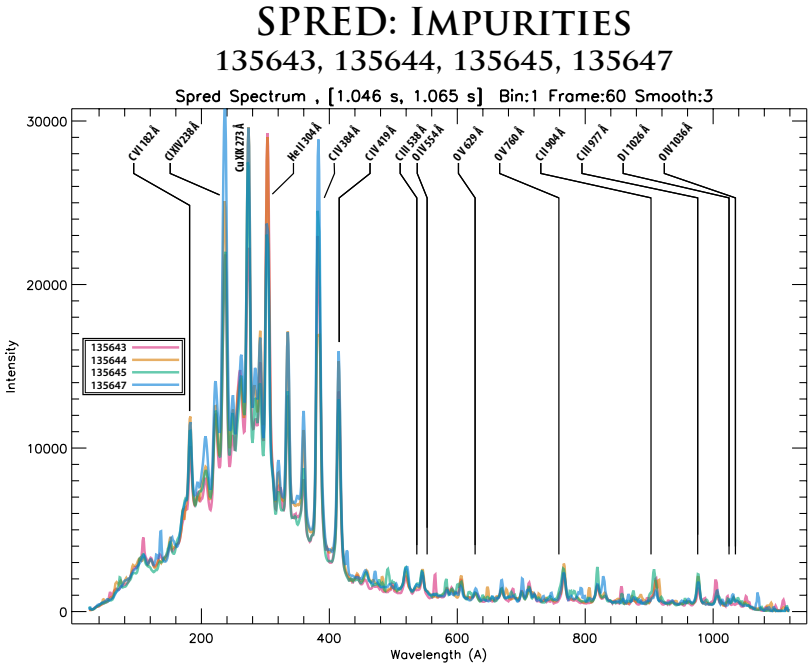
The CHERS and VB Z_{eff} May Have Some Inconsistencies

- Large I_P case has flat $Z_{eff,C}$ profiles, at about 3.5.
- The chord average effective charge is $Z_{eff,VB}$=2.8
- For a flat profile of $Z_{eff,C}$, how can the Z_{eff} measured by bremsstrahlung be less than that assuming carbon only?
  - If this is a profile effect, then it implies that $Z_{eff,VB}$ should not be used as a metric for comparison.



Follow-on run to examine effect of beam timing





- ***Both at the beginning of the discharge (.3 seconds through the end (1.05 sec) the SPRED spectra virtually overlay***
- ***Very little effect was seen when beam timing was varied***
- ***Conclusions: I_p makes the largest difference by far – but little evidence that operating the beams differently and different beam orbits are directly responsible***
- ***The main tools for limiting impurities (especially with Li operation) is high plasma current and masking steel surfaces with low-Z materials.***