ARIES ACT1 progress & ACT2

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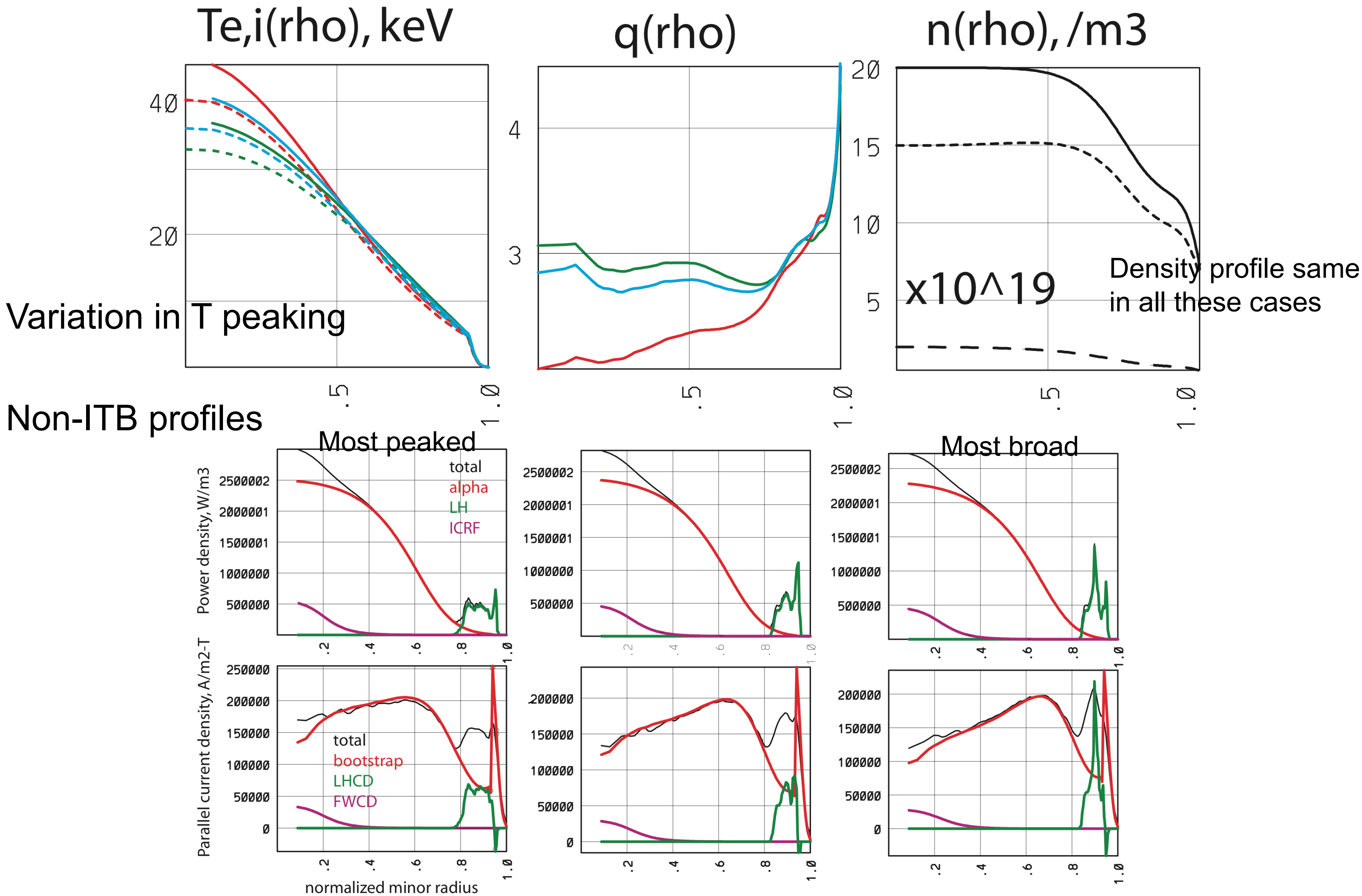
Outline

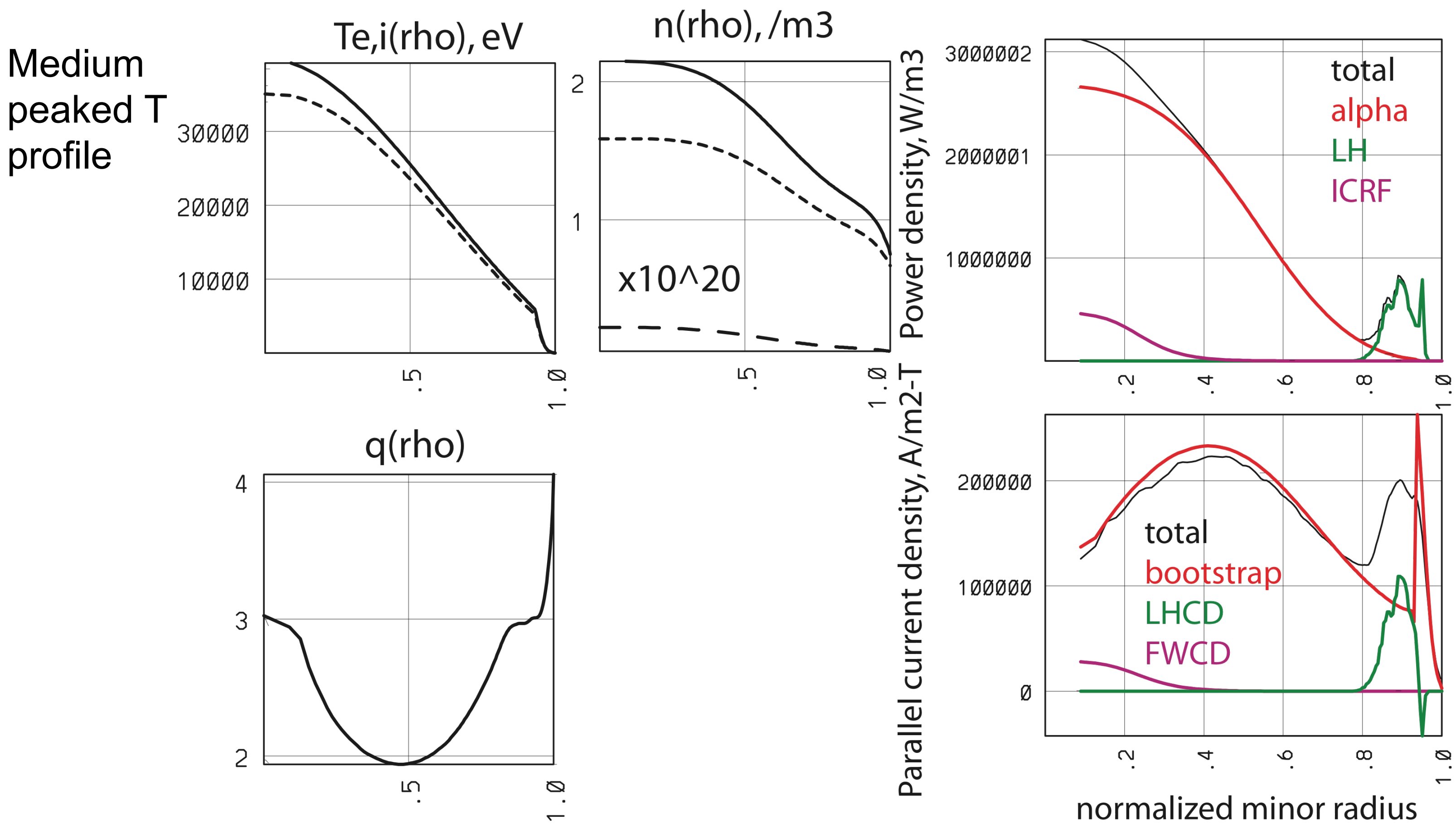
- Temperature and density profile variations at R = 5.5 m in order to see impact on q profile and MHD stability
  - T profile, non-ITB
  - n profile
  - T profile ITB
- H/CD analysis for R = 5.5 m
  - LH
  - ICRF
  - EC
- NEW ACT1 equilibrium at R = 6.25 m
- Systems analysis of ACT2, conservative physics/DCLL

Temperature and density profile variations



T and n profile variations, density modification

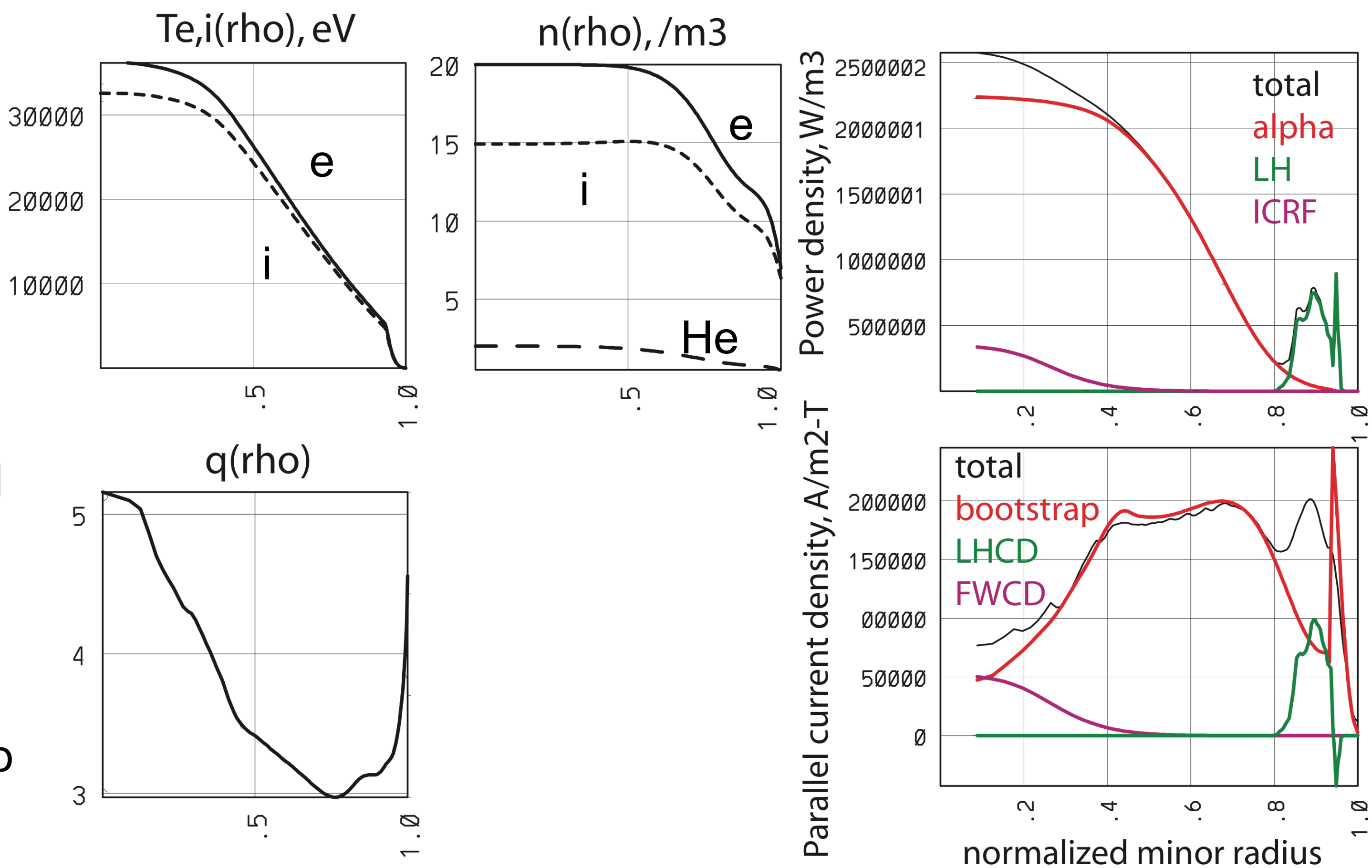
Density gradient spread out over the profile, using medium peakedness T



T and n profile variations, ITB profiles

Work in progress

An attempt at an ITB configuration, same density profile as shown with temperature peaking scan



Very strong reversed shear

Use more FWCD to control q(0)

Lower Hybrid Heating and Current Drive

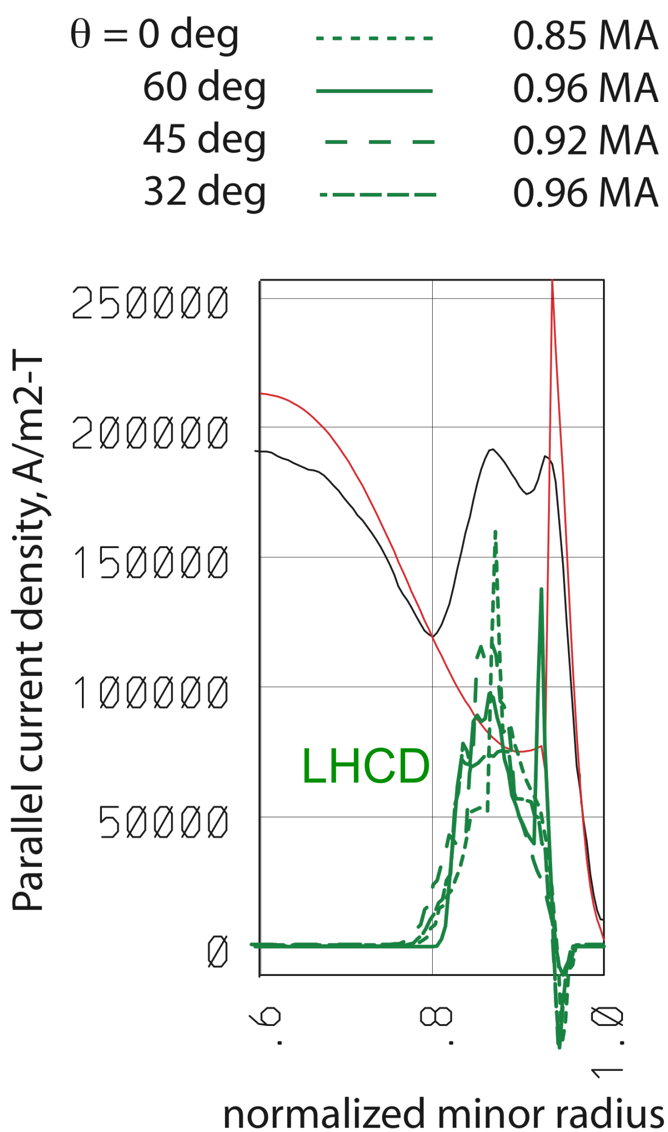
Using 5 GHz for Lower Hybrid, and LSC code

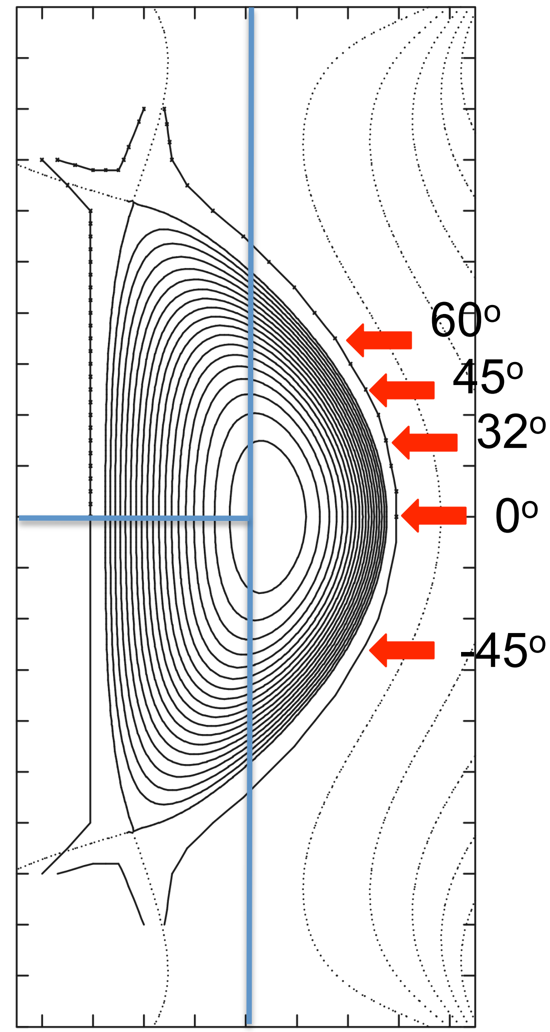
$n_{||}^{+}$ = 1.85-2.35, $n_{||}^{-}$ = 4.0
P^{+} = 87%, P^{-} = 13%
(provides 1.6x I_{CD} found between LSC and GENRAY/CQL3D)

Typical launching location is ~ midplane

Launching above midplane can provide slightly better A/W over broader $n_{||}$

Allows for improved T breeding by getting launcher off the midplane





Below midplane gives lower A/W and narrower $n_{||}$ range

Ion Cyclotron Heating and Current Drive

F. Poli, PPPL

Use TORIC full wave analysis

Examine 85, 90 and 95 MHz (chosen to avoid ion resonance at plasma center, to provide for FWCD)

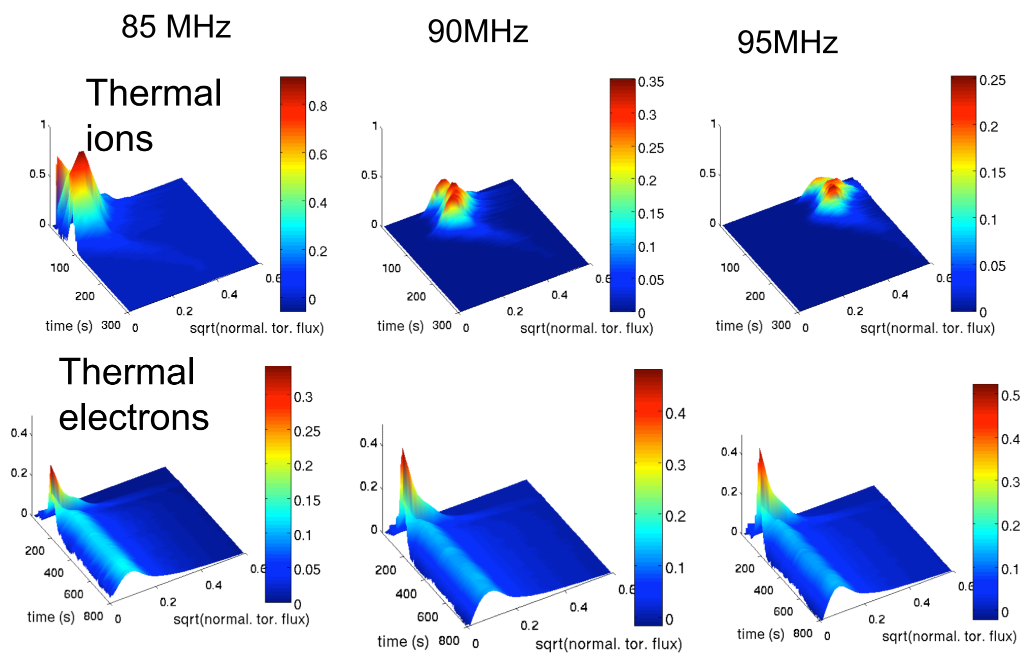
Deuterium 2nd harmonic closest ion resonance

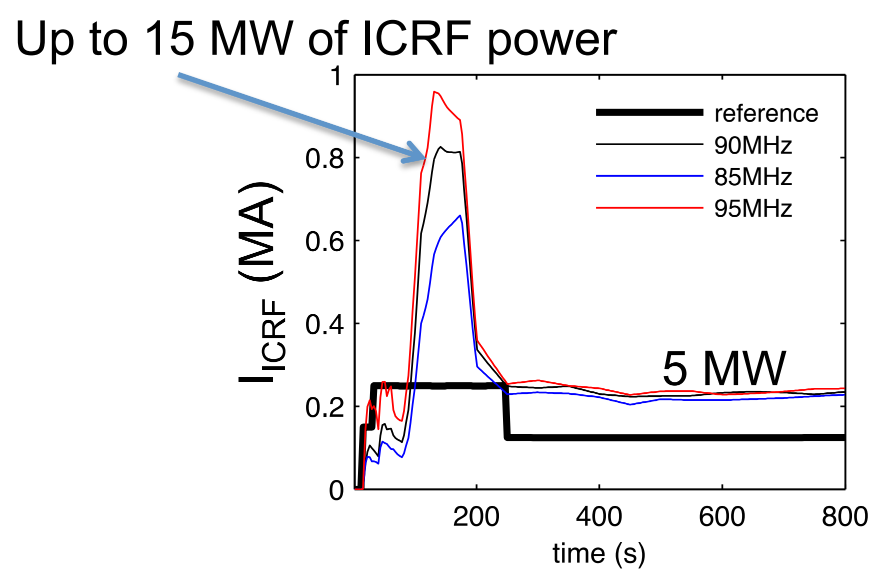
Find 5 MW drives ~ 200-250 kA

*more than we had assumed, so we can drop ICRF power in flattop to 5-10 MW from 15 MW

Early the ion resonance absorbs some energy, but later the R_{mag} shifts out and Te rises, then electrons absorb all the energy

→ A good startup



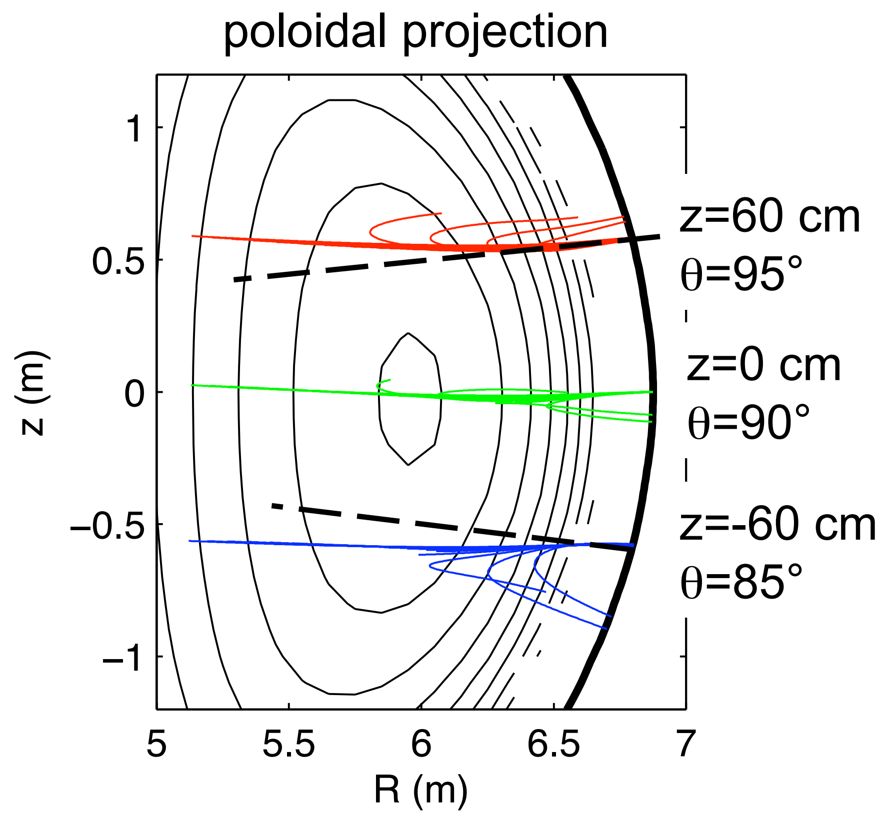


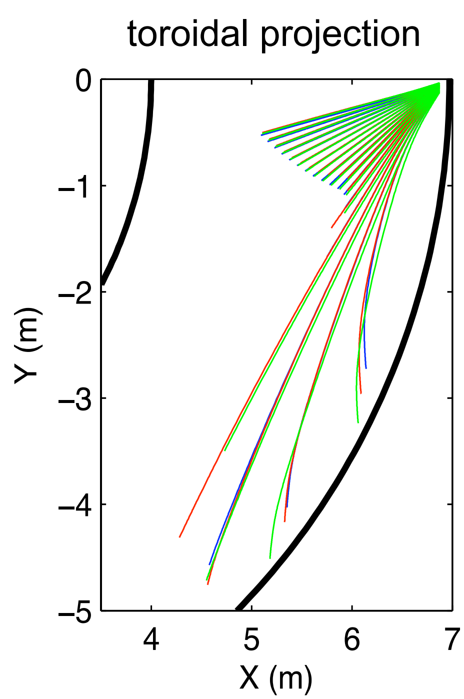
Electron Cyclotron Heating and Current Drive

Using GENRAY ray-tracing

An EC frequency of 170 GHz (same as ITER)

Outboard midplane launchers at Z = +0.6, 0.0, and -0.6 m





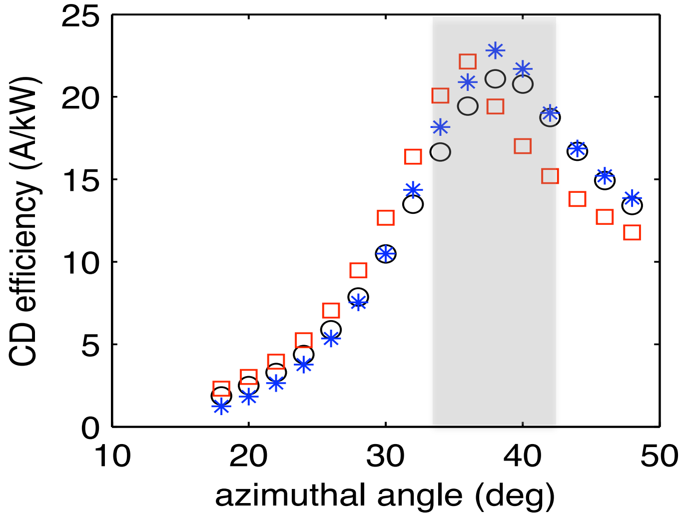
Trajectories are refracted out of plasma for ϕ>48-50^o

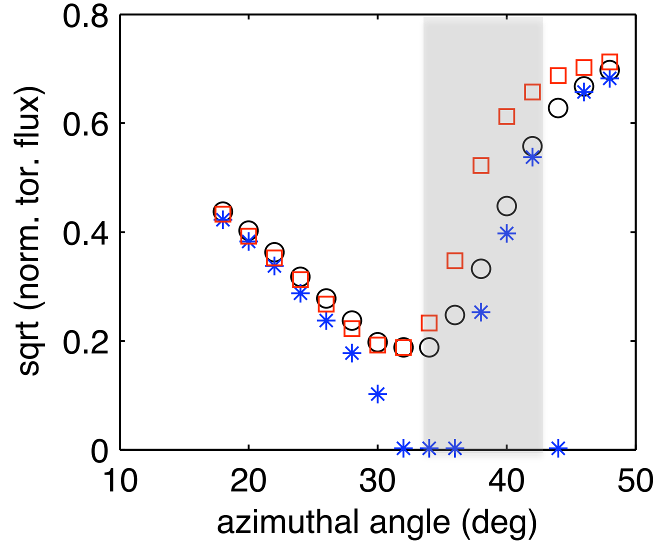
Set poloidal angles of 3 launchers, scan toroidal angles from 20^o to 50^o…… determine current drive efficiency

F. Poli, PPPL

EC, cont'd

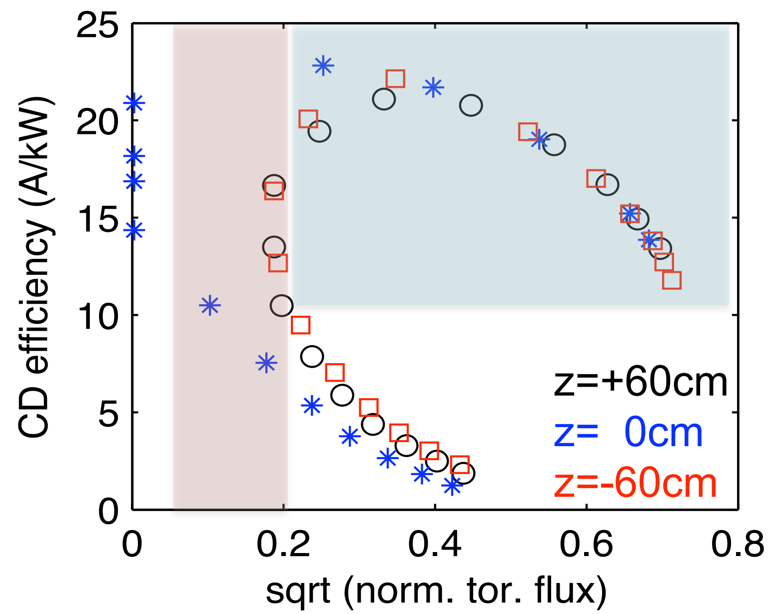
F. Poli, PPPL





All launchers have largest CD efficiency for ϕ~34-42 deg

broad range of radii, ρ=0.2-0.7

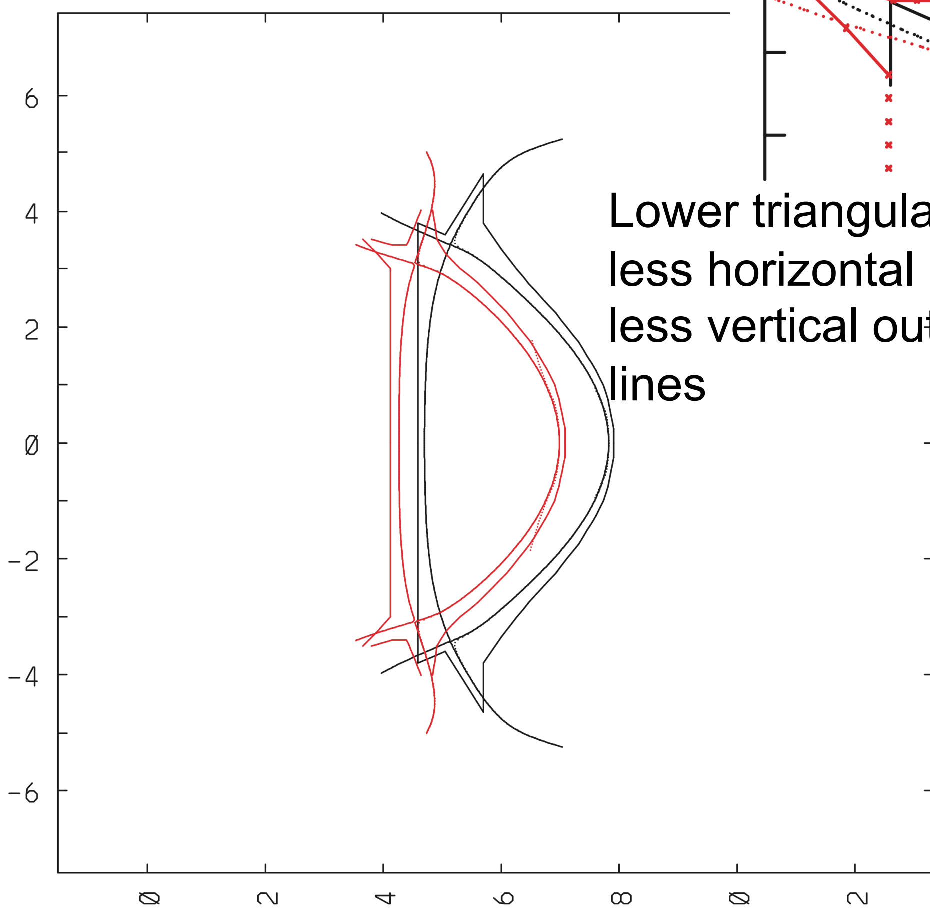


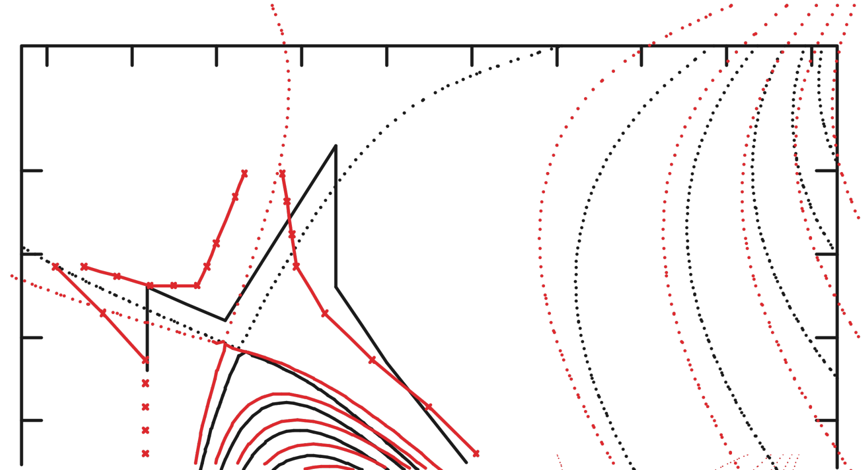
Can EC replace on-axis CD of ICRF?
FW gives ~ 50 A/kW

Can we use EC to manipulate q profile?
ρ_{EC} looks promising

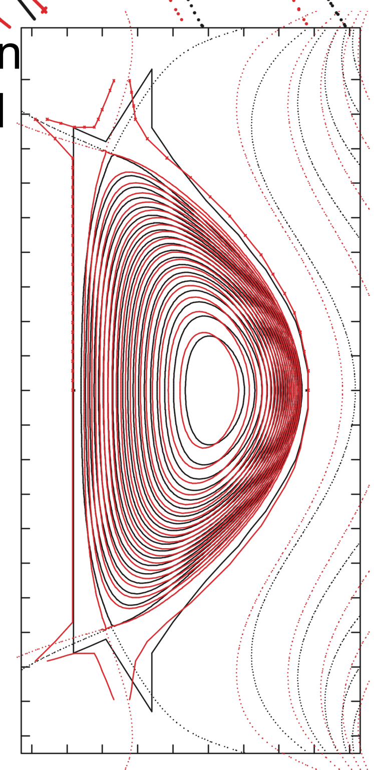
New ACT1 Plasma Equilibrium

ACT1-old, R = 5.5 m
ACT1, R = 6.25 m





Lower triangularity to obtain less horizontal inboard and less vertical outboard flux lines



Systems Analysis of ACT2

ACT2 is conservative physics

$\beta_N^{total} \leq 3.25$

$H_{98} \leq 1.3$

$n/n_{Gr} \leq 1.0$

$\kappa = 2.0$ or 2.2?

Inboard DCLL blanket (Laila)

$\Delta_{SOL} = 0.10$ m

$\Delta_{FW/Blkt} = 0.75$ m

$\Delta_{Skel} = 0.25$ m

$\Delta_{gap} = 0.02$ m

$\Delta_{VV} = 0.33$ m

$\Delta_{gap} = 0.06$ m

$q_{div,peak}^{OB} <$??

$B_{T,max} <$??

$\eta_{th} = 0.44 - 0.0065(1.5\langle N_w \rangle \times 1.25 q_{FW,ave} - 0.3)$

$P_{pump} = 0.04 \times P_{fusion}$, $\eta_{pump} = 0.9$

$P_{subs} = 0.04 \times P_{elec,gross}$

$\eta_{aux} = 0.4$

Used different j_{SC} vs $B_{T,max}$ since I was exceeding 18 T at the coil in some cases

Scanned $B_T = 5.5\text{-}10.5$ T

$\beta_N = 0.02\text{-}0.04$

$q_{95} = 3.5\text{-}8.0$

$n/n_{Gr} = 0.9\text{-}1.3$

$Q = 12.5\text{-}40.0$

$\kappa = 1.9\text{-}2.1$

$R = 5.0\text{-}11.5$ m

$f_{Ar} = 0.002\text{-}0.003$

This operating point is a bugger!

$975 < P_{elec}$ (MW) < 1025

Filter set #1

β_N^{total} $(\beta_N^{th} + \beta_N^{fast}) \leq 3.25$

$q_{div,peak}^{OB} < 15.0$ MW/m^2

Note large radius
Note large toroidal field
Note low β_N^{th}
Too high n/n_{Gr}
Too high H_{98}

R	B_T	I_p	β_N^{th}	q_{95}	n_G	Q	H_{98}	P_{aux}	f_{BS}	B_{Tc}	q_{div}	Nw	Z_{eff}
11.0	8.0	15.4	2.75	7.5	1.3	20	1.41	162	0.74	13.1	13.0	1.42	1.86
10.0	9.0	15.7	2.75	7.5	1.3	17.5	1.46	198	0.74	15.0	13.7	1.83	2.05
11.5	9.5	17.9	2.25	8.0	1.3	12.5	1.28	328	0.64	15.4	14.7	1.63	2.17
10.5	9.5	16.4	2.50	8.0	1.3	15.0	1.41	252	0.71	15.7	13.4	1.81	2.17
9.5	9.5	15.6	2.50	8.0	1.3	17.5	1.46	200	0.71	16.9	13.9	2.04	1.87
9.0	10.0	14.8	2.75	8.0	1.3	17.5	1.52	199	0.78	17.2	14.1	2.27	2.18

This operating point is a bugger!, cont'd

Filter set #2

$975 < P_{elec}$ (MW) < 1025

β_N^{total} $(\beta_N^{th} + \beta_N^{fast})$ ≤ 3.25

$H_{98} \leq 1.3$ ← does not do any filtering

$n/n_{Gr} \leq 1.1$

R	B_T	I_p	β_N^{th}	q_{95}	n_G	Q	H_{98}	P_{aux}	f_{BS}	B_{Tc}	q_{div}	Nw	Z_{eff}
9.0	9.5	17.2	2.50	6.5	1.1	12.5	1.10	335	0.58	16.3	41.4	2.73	1.82
8.5	10.0	17.1	2.50	6.5	1.1	12.5	1.08	349	0.58	17.5	48.5	3.19	1.82
7.5	10.5	15.9	2.50	6.5	1.1	12.5	1.00	345	0.58	19.1	66.0	4.05	1.78

$q_{div,peak}^{OB} < 20$ MW/m^2 and $n/n_{Gr} \leq 1.2$, turn H_{98} filter off

11.0	9.0	18.5	2.50	7.0	1.17	12.5	1.33	333	0.62	14.7	17.9	1.81	1.87

This operating point is a bugger!, cont'd

Filter set #3   continue to "box in" a solution set, relax desired n/n_{Gr} value

β_N^{total} $(\beta_N^{th} + \beta_N^{fast})$ ≤ 3.25

$H_{98} \leq 1.3$

$q_{div,peak}^{OB} < 17.5$ MW/m^2

$975 < P_{elec}$ (MW) < 1025

$n/n_{Gr} \leq 1.3$

R	B_T	I_p	β_N^{th}	q_{95}	n_G	Q	H_{98}	P_{aux}	f_{BS}	B_{Tc}	q_{div}	Nw	Z_{eff}
11.5	9.5	17.9	2.25	8.0	1.3	12.5	1.27	325	0.64	15.4	16.2	1.62	1.88

Scanned aspect ratio to 3.0 and 5.0, and found same results

Lower P_{elec}, in order to get viable solution range

We are stuck between needing high P_{fus} to cover recirculating power and thermal conversion, so we need high density

But we are trying to keep the Ip low (or q_{95} high) in order to reduce the CD part of recirculating power

750 MWe

R	B_T	I_p	β_N^{th}	q_{95}	n_G	Q	H_{98}	P_{aux}	f_{BS}	B_{Tc}	q_{div}	Nw	Z_{eff}
11.5	7.5	16.2	2.50	7.0	1.2	12.5	1.21	248	0.62	12.1	17.1	1.24	1.96
11.0	8.0	16.5	2.50	7.0	1.2	12.5	1.26	251	0.62	13.1	15.8	1.37	2.14
9.5	8.5	14.1	2.50	7.5	1.2	15.0	1.27	179	0.67	14.4	16.4	1.57	1.96
10.0	9.5	15.6	2.25	8.0	1.2	12.5	1.28	244	0.64	15.9	16.0	1.61	1.84

Lower P_{elec}, in order to get viable solution range

Try 500 MWe

R	B_T	I_p	β_N^{th}	q_{95}	n_G	Q	H_{98}	P_{aux}	f_{BS}	B_{Tc}	q_{div}	Nw	Z_{eff}
11.0	6.5	13.4	2.50	7.0	1.1	12.5	1.23	157	0.62	10.6	11.0	0.86	1.96
10.5	7.0	13.8	2.50	7.0	1.1	12.5	1.26	166	0.62	11.5	11.4	0.99	2.08
9.5	7.5	13.3	2.50	7.0	1.03	12.5	1.29	160	0.62	12.7	12.9	1.17	1.93
9.0	8.0	12.6	2.50	7.5	1.1	12.5	1.27	165	0.67	13.7	14.6	1.34	1.92
9.5	8.5	13.2	2.25	8.0	1.1	12.5	1.27	167	0.64	14.4	12.3	1.22	1.94
8.5	9.0	12.5	2.25	8.0	1.1	12.5	1.24	162	0.64	15.7	14.3	1.48	2.07

Physics

- Have generated EQDSK for ACT1 at 6.25 m
- All physics analysis has still been done at 5.5 m case
  - Need to update TSC simulations to 6.25 m
  - Need to update H/CD analysis to 6.25 m
  - Ideal MHD for 6.25 m cases
- Complete disruption simulation, at 5.5 m or change to 6.25 m?
- PF Coil solution for 6.25 m
- Begin to pursue ACT2 physics, expect the ACT1 physics/systems comparison to be valid here

Systems for ACT2

- This operating point is at LARGE radius

- It is difficult to get within desired physics parameters and divertor heat flux simultaneously, at 1000 MWe
  - Lowering P_{elec} helped, but the COE may suffer

- Battle between large P_{fus} and low recirculating CD power, requiring high n, but low Ip

- Plasma elongation ALWAYS was at higher value, so may not be able to adopt 2.0 for conservative case…W shells in outboard blanket

- Low β_N drives us to higher B_T, high CD power, …..

Changes to systems code that degrade solutions

- Power scrape-off width correction…good systems trade-off study
- Lower recirculating efficiency for H/CD sources
- Other recirculating powers
- Lower CD efficiency in plasma

- Lower thermal conversion efficiency for DCLL compared to SiC
- Inboard radial build increase for DCLL compared to SiC

- $\beta_N^{total} = \beta_N^{th} + \beta_N^{fast}$