# RECENT PROGRESS AND 2011 PLANS FOR IOS-5.3: ASSESSMENT OF LOWER HYBRID CURRENT DRIVE AT HIGH DENSITY FOR EXTRAPOLATION TO ITER ADVANCED SCENARIOS

G. Wallace for:

M. Goniche *et al*: Tore Supra,

R. Cesario, *et al:* FTU,

B. Ding, et al: HT-7/EAST,

S. Shiraiwa, A. Hubbard, O. Meneghini, S.G. Baek, *et al:* C-Mod

# Background and overview

- IOS 5.3 is a fairly new JE started in 2010.
- Prompted by 2009 results from several devices (C-Mod, FTU, Tore-Supra, JET) indicating that LH efficiency drops at a density lower than would be expected simply from accessibility considerations.
- We need a better, common, understanding of the physical mechanism(s) and validated simulation model(s) in order to extrapolate to the conditions of ITER!
- Since previous meeting, C-Mod has been working on improving analysis techniques and modeling. No new experiments due to machine shutdown for installation of rotated ICRF antenna.
- Tore Supra has some new data and worked on interpretation of past experiments.
- New data from HT-7.

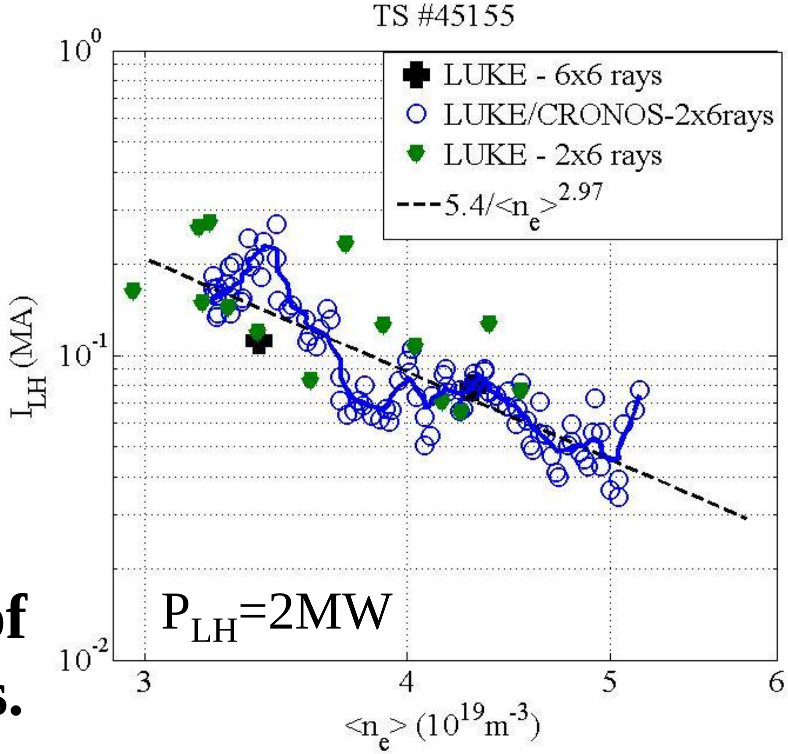
# LHCD modelling

Strongly inductive discharges -> C3PO/LUKE simulations are rather sensitive to E-field and current profile reconstruction by CRONOS

- **Wave is still absorbed at <$n_e$> ~$5\times10^{19}$m$^{-3}$ ($n_l$= $5.5\times10^{19}$m$^{-3}$)**

- **Large scattering for $I_{LH}$ but degradation of η ($n_eRI_{LH}/P_{LH}$) with density close to $n_e^{-2}$**

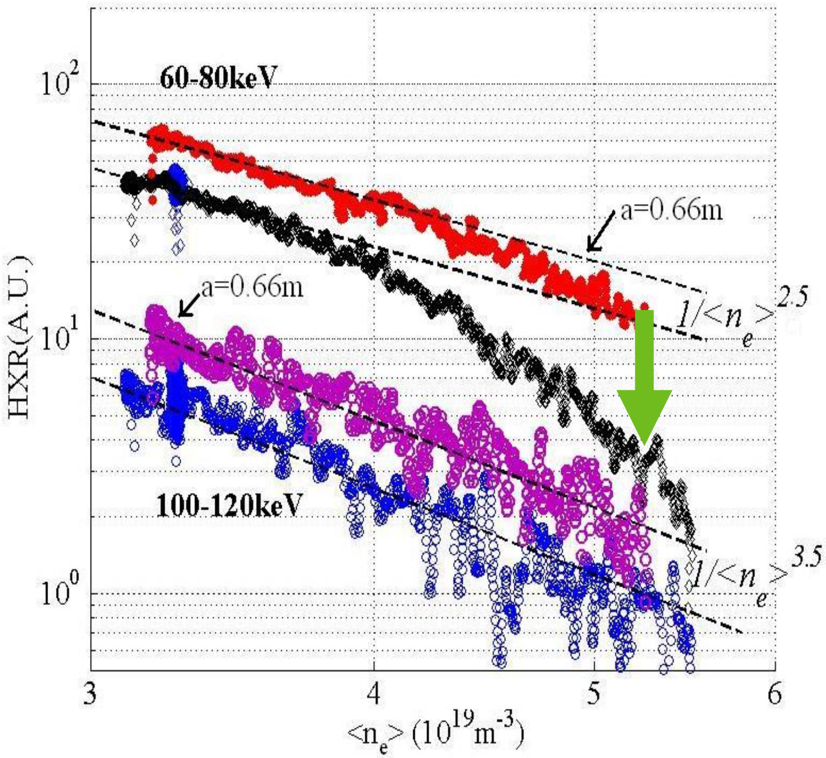
- **Sensitivity studies show lack of robustness in LHCD simulations. However $n_e^{-3}$ scaling is resilient**



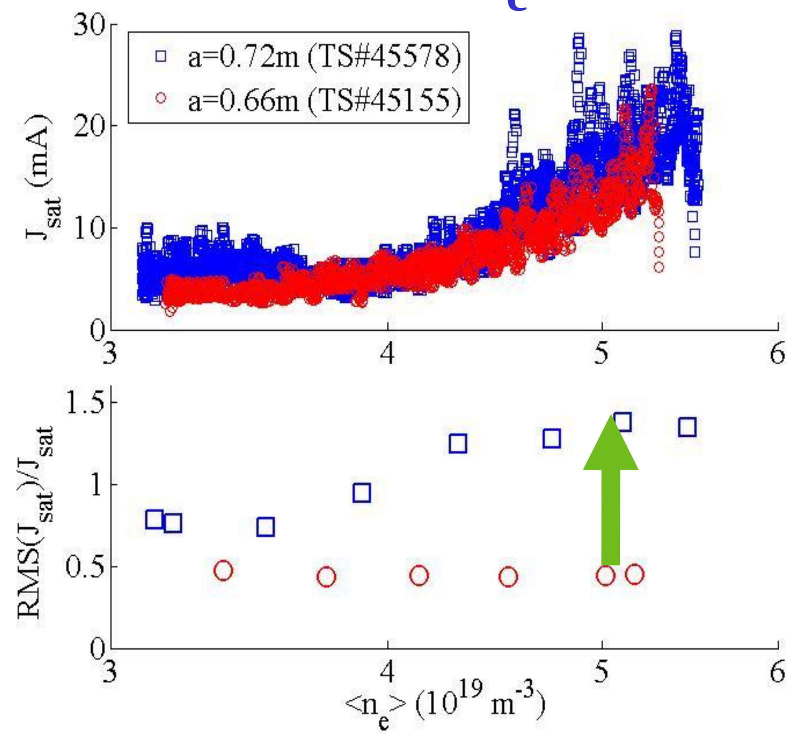

*M.Goniche et al., EPS2011*

*Further modelling in progress*

## HXR vs. $n_e$




## $J_{sat}$ & $RMS(J_{sat})/J_{sat}$ vs. $n_e$

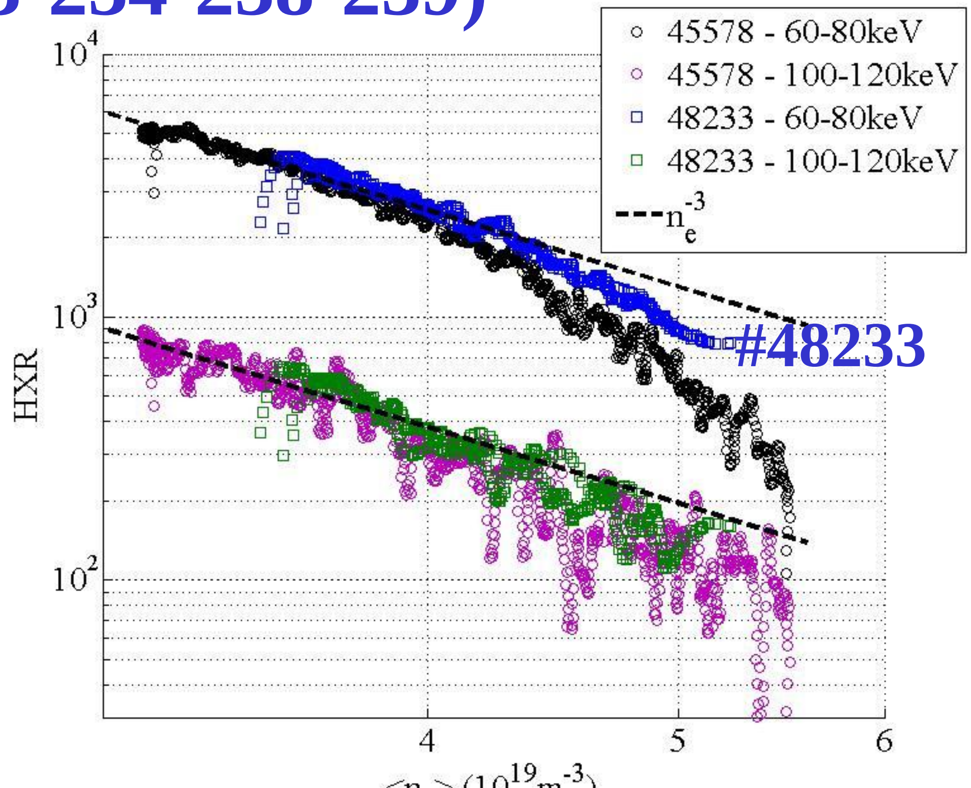



*M.Goniche et al., EPS2011*

- **Faster decay of HXR for $<n_e> > 4\times10^{19}m^{-3}$ is correlated to strong increase of $j_{sat}$ fluctuation rate (a=0.72m)**
- **Same result obtained for gas vs. pellet fuelling (⇨PPCF10)**

# New high density experiments (TS#48233-234-238-239)

- Change gas valves (233, 234 & 238)
- Change $I_p$ (1.0=> 1.2MA)
- **More edge diagnostics**:
  - ▪Reflectometer in LH launcher
  - ▪RF meas. for spectrum around 3.7GHz
  - ▪Very fast acquisition (200MHz) for probes



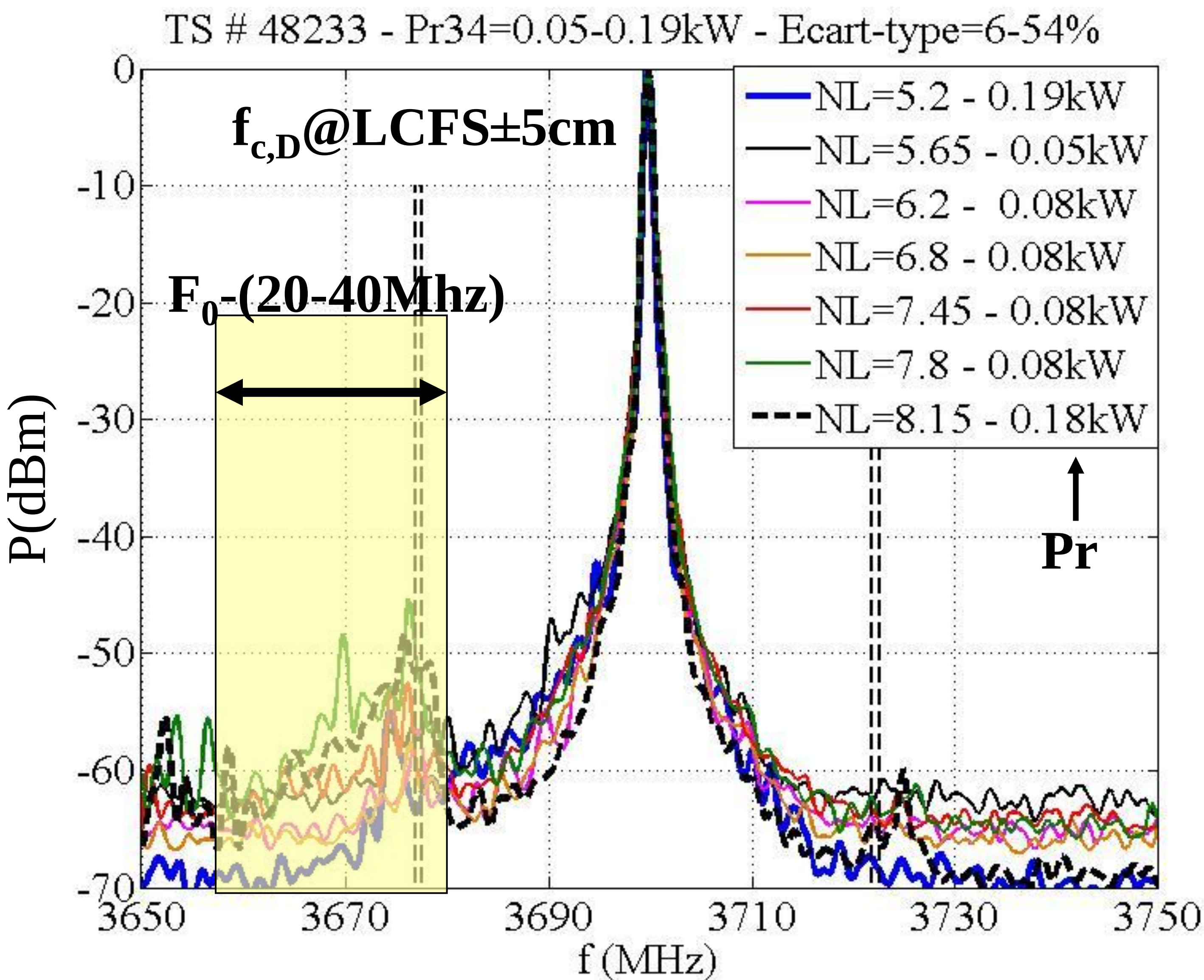

**⇨ Reference pulse with fast decay of HXR ( $<n_e> > 4\times10^{19}m^{-3}$) not really reproduced (change of gas injection valves ?)**

**⇨ Lower fluctuation rate compared to pulse #45578**

**⇨ Power in sidebands ($f_0$-(20-40)Mhz) increases with $n_e$ up to -50 dB (-60 dB on average in the 20-40MHz band)**

**⇨ No significant spectral broadening with $n_e$ (ΔF@-10dB ~ 1.2MHz)**

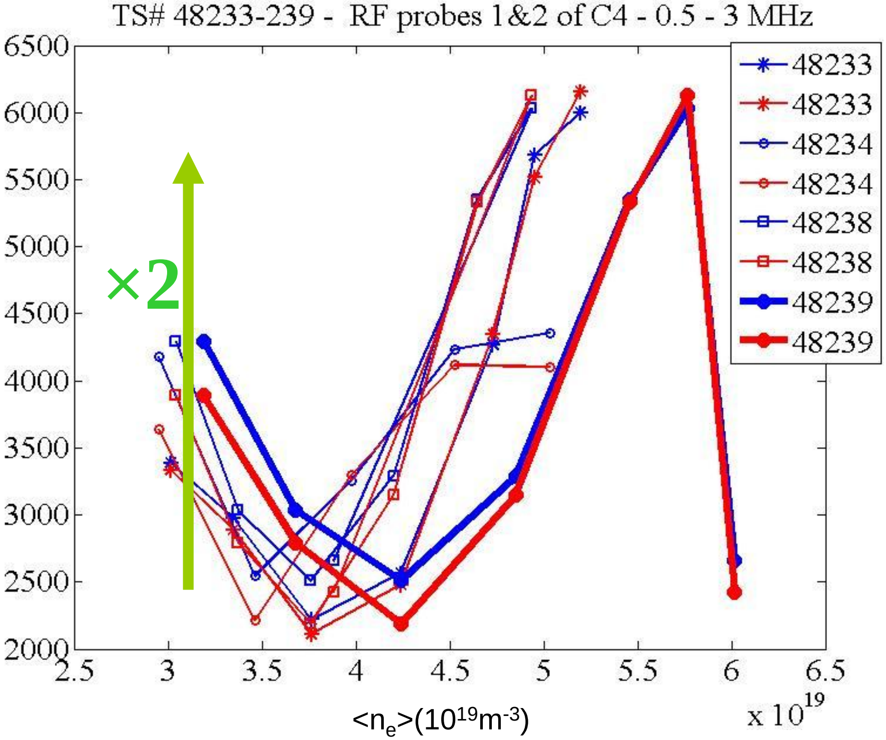
# Power Spectrum in TL




**RF power in Transmission Line**

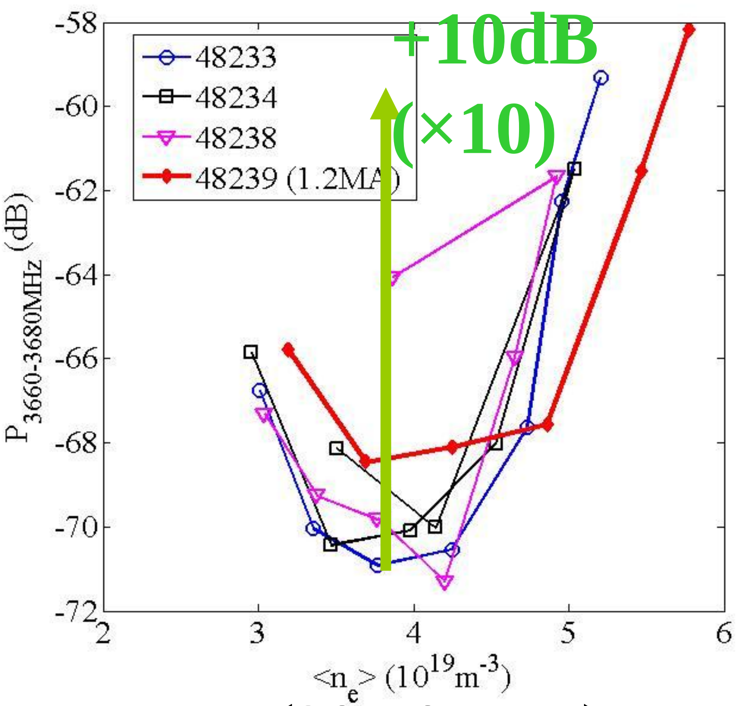
# Turbulence & Sidebands

**Langmuir probe @launcher mouth**




**0.5-3MHz**

**RF power in Transmisson Line**



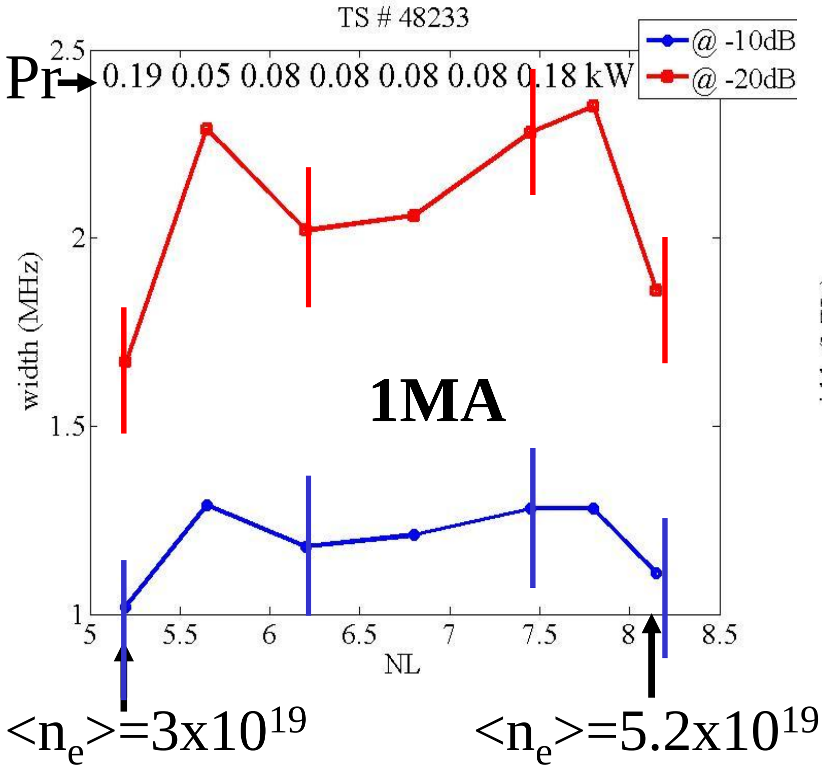

**$F_0$ – (20-40MHz)**

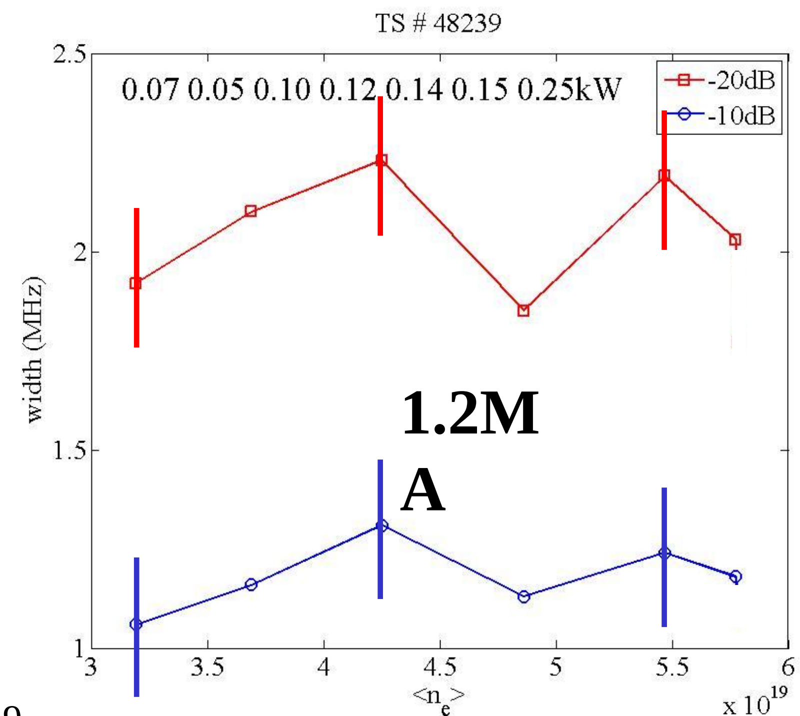
- **Level of turbulence & RF power in sidebands very well correlated**
- ***Is -60dB (-50dB peak) power level in sidebands (PDI) effective for reducing CD efficiency ?***

# Pump width

## RF reflected power in Transmisson Line

(width of $P_{forward}$ ≤0.2MHz)




- *Rather poor resolution (ΔF=0.2MHz), can be improved in next expt.*

➢ **Width @-10dB is ~ 1.2MHz (C-Mod:~2.5MHz, FTU:1=>2.5MHz)**

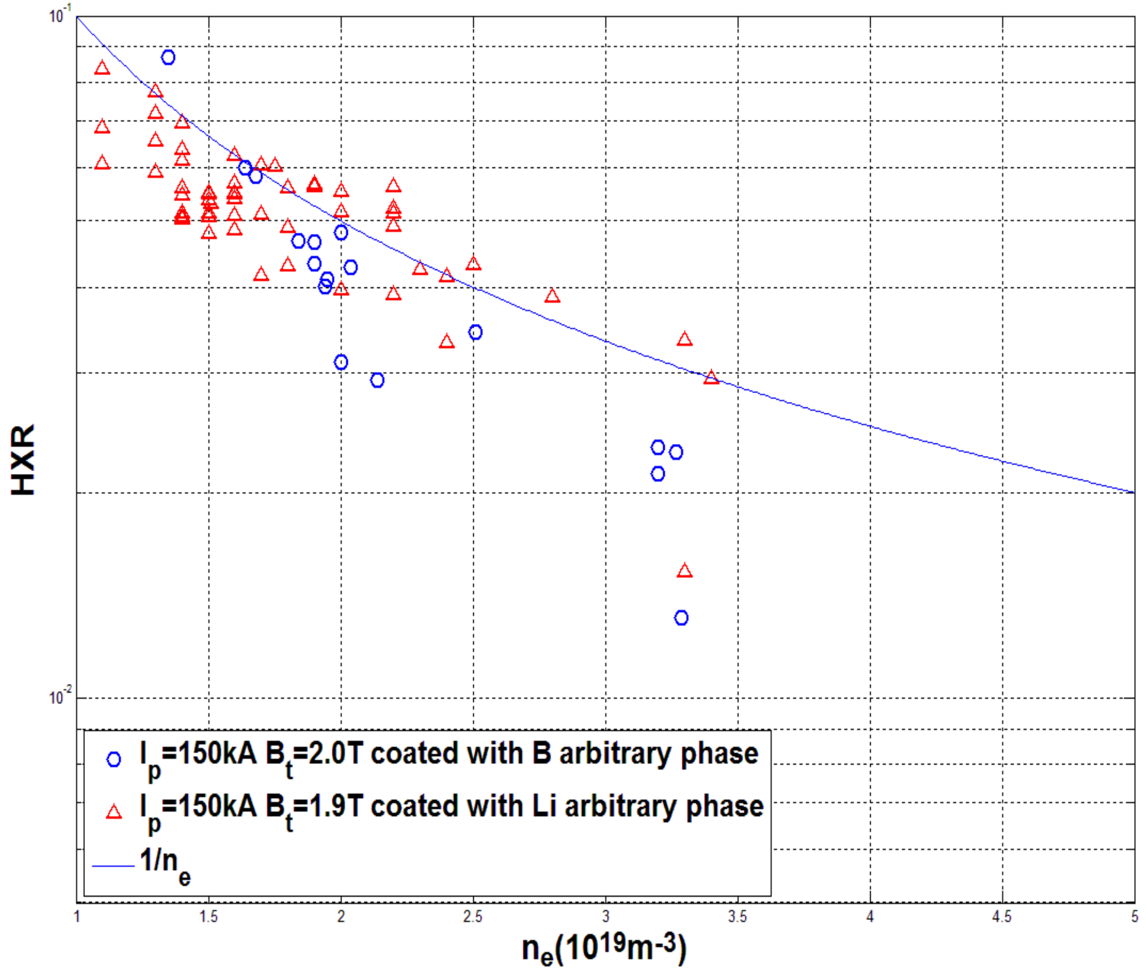
➢ **No significant broadening between $n_l$=3.6 & 5.7×$10^{19}m^{-3}$ (1MA), $n_l$=3.75 & 6.2×$10^{19}m^{-3}$ (1.2MA)**

ASIPP

# Results and analyses

HT-7

- **No obvious difference of HXR between lithium and boron coating wall**



ASIPP

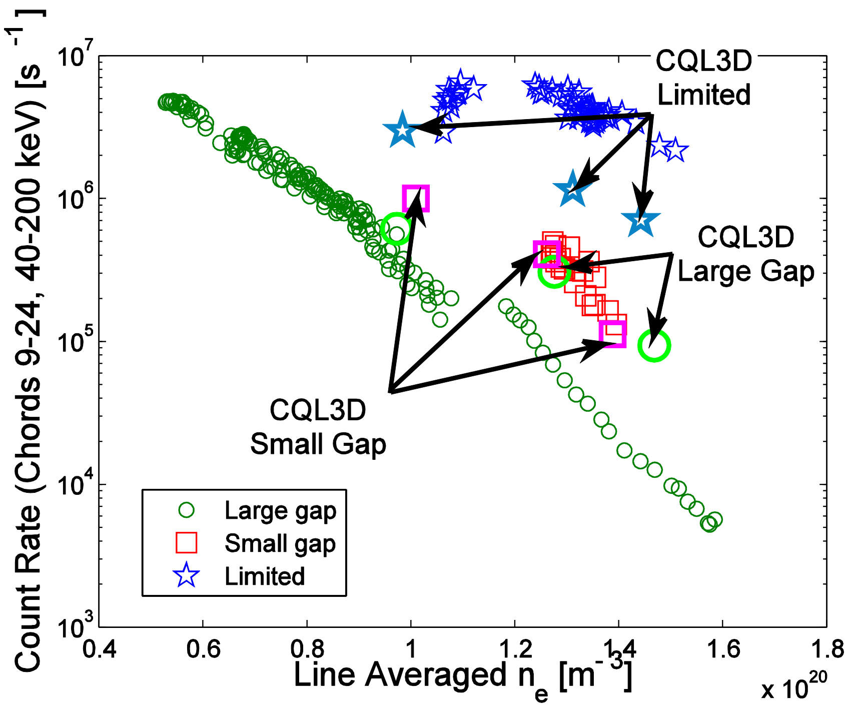
# Conclusions

HT-7

- In the limited configuration with wall maintenance, CD efficiency satisfies the $1/n_e$ trend as the density is less than $3.5\times10^{19}\ m^{-3}$
- There is no obvious difference in CD between lithium and boron coating wall
- More discharges are needed in EAST at different configurations, plasma currents and magnetic to investigate the current drive efficiency at a large density range

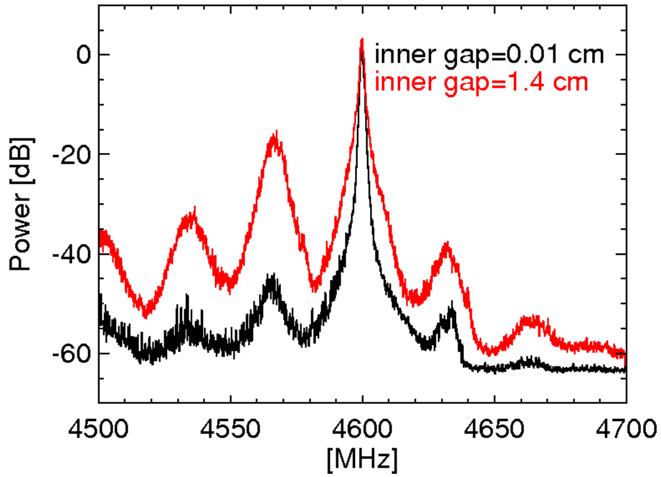
# Ray tracing w/ collisional SOL shows qualitative agreement w/ experiment

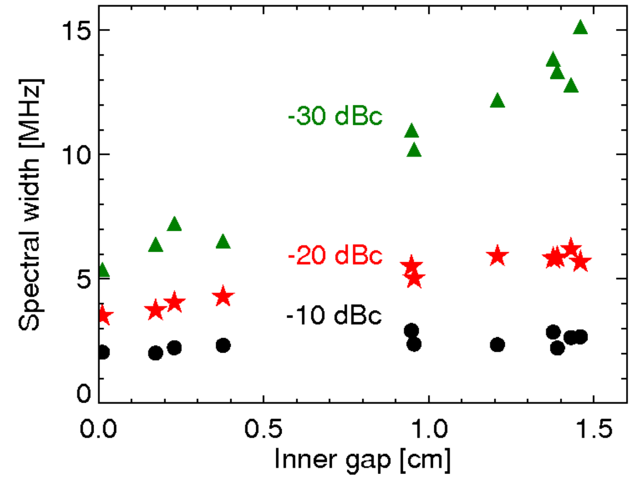
- GENRAY/CQL3D code predicts significant drop in fast electron population with density
- Model shows higher non-thermal emission for limited discharges
- Plan to limit plasma on different surfaces in upcoming campaign



# Limited discharges show narrower spectrum and more fast electrons

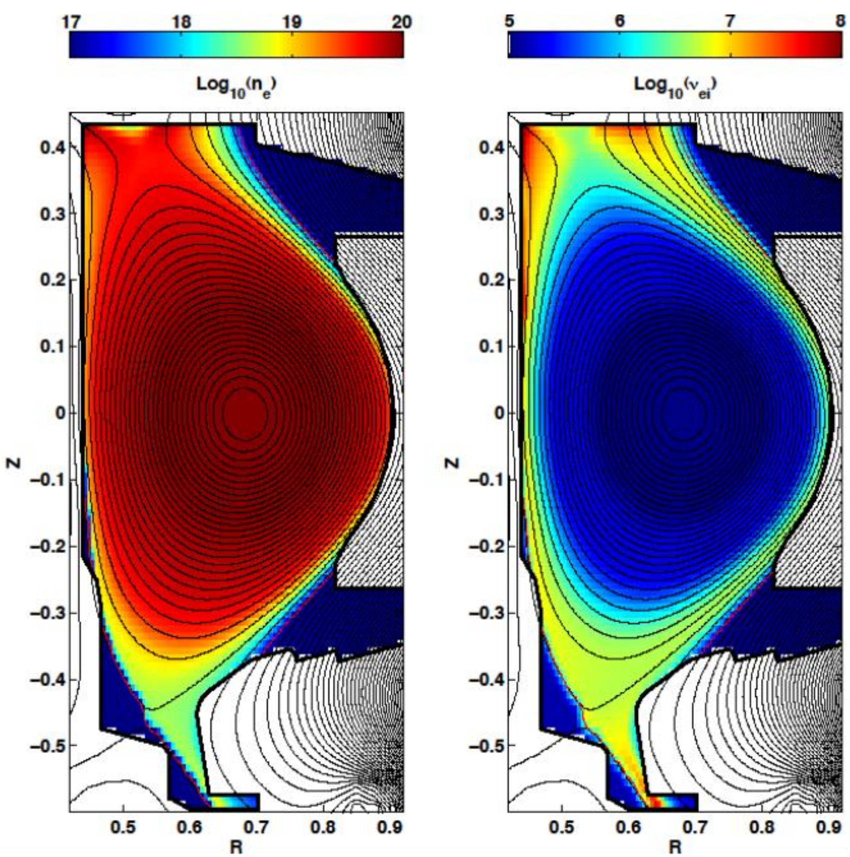
- Inner wall limited discharges exhibit less spectral broadening at high density (line averaged $n_e \sim 1.4\times10^{20}\ m^{-3}$)
- Downshifted harmonics due to PDIs are seen, but at -20dB or lower
- Analyzing data to determine if broadening of main peak is due to fluctuation scattering or PDI



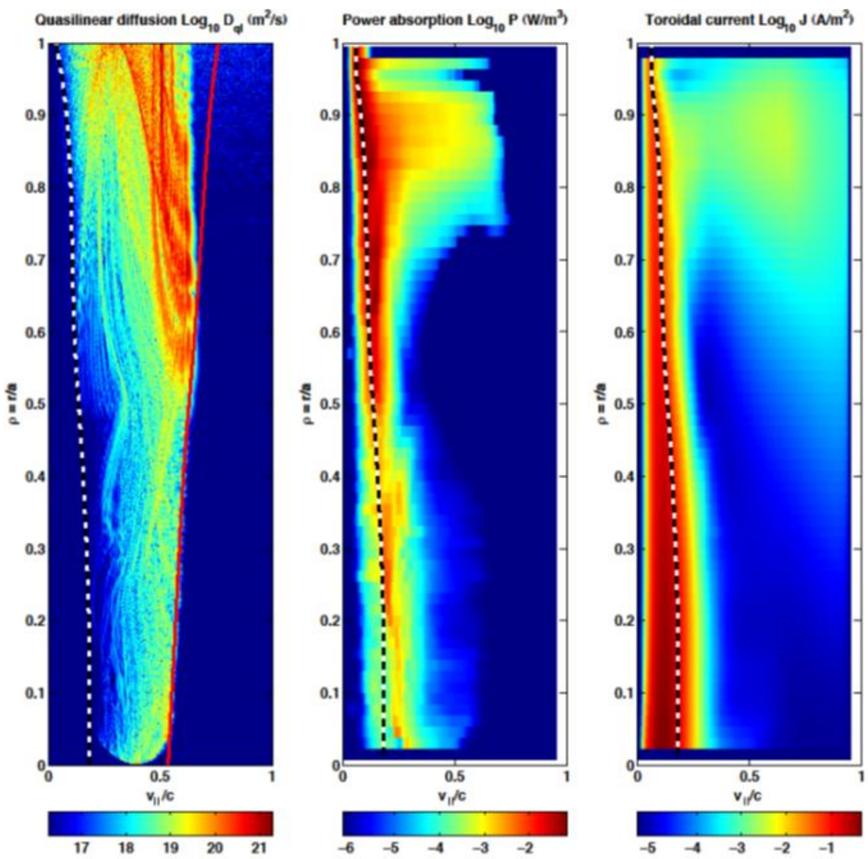
# Full wave model with 2-D SOL shows little collisional absorption on C-Mod

- 2-D SOL model based on conservation of pressure along field lines
- Full wave solution using LHEAF shows minimal power absorbed in SOL ( < 10 kW at $1.5 \times 10^{20}$ $m^{-3}$)



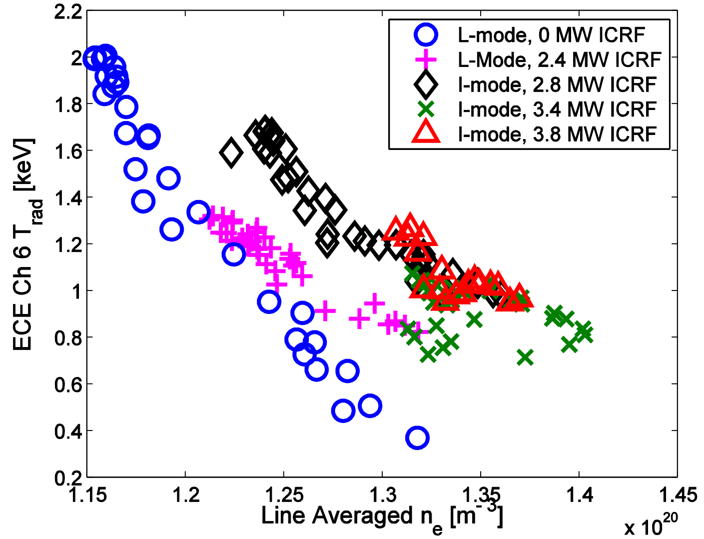
# Full wave simulations show very far off axis absorption → fast electrons not confined

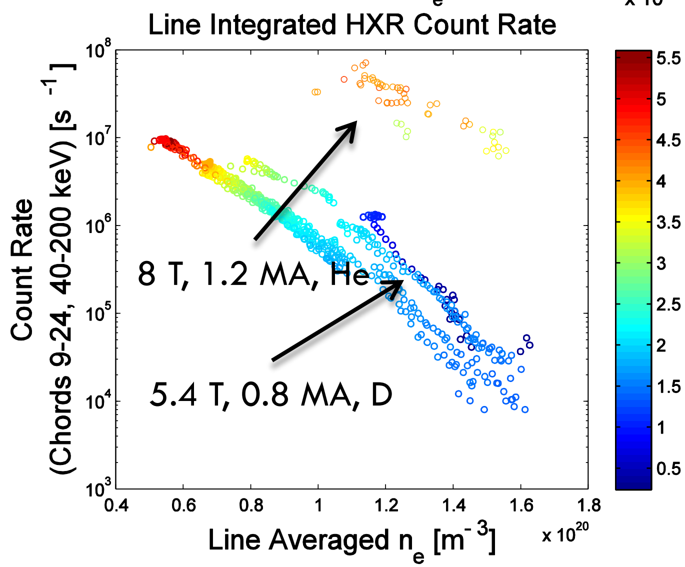
- Strong upshift of $n_{||}$ as waves reflect from edge
  - Effect not produced by ray tracing
- Waves absorbed near *r/a*=0.9
- Fast electrons diffuse across LCFS before slowing down
- Stronger absorption of waves at smaller *r/a* improves current drive



# Increasing plasma temperature leads to more non-thermal emission at high $n_e$

- Models predict stronger single-pass absorption should mitigate impact of edge/SOL losses
- Hotter I-mode discharges show enhanced non-thermal ECE as compared to L-mode
- Hot He discharges show improved HXR emission as compared to cold D discharges



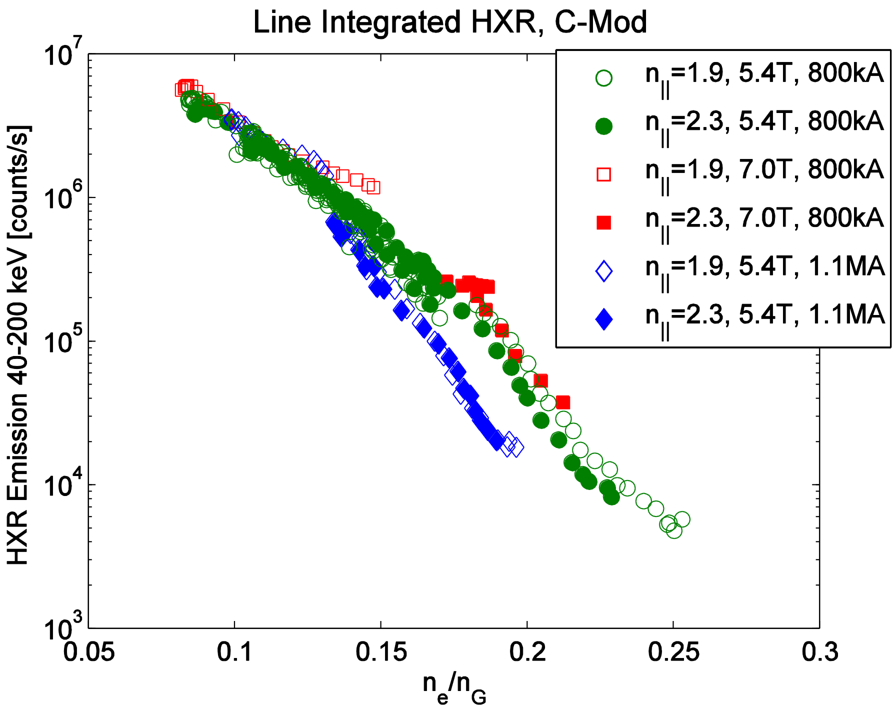



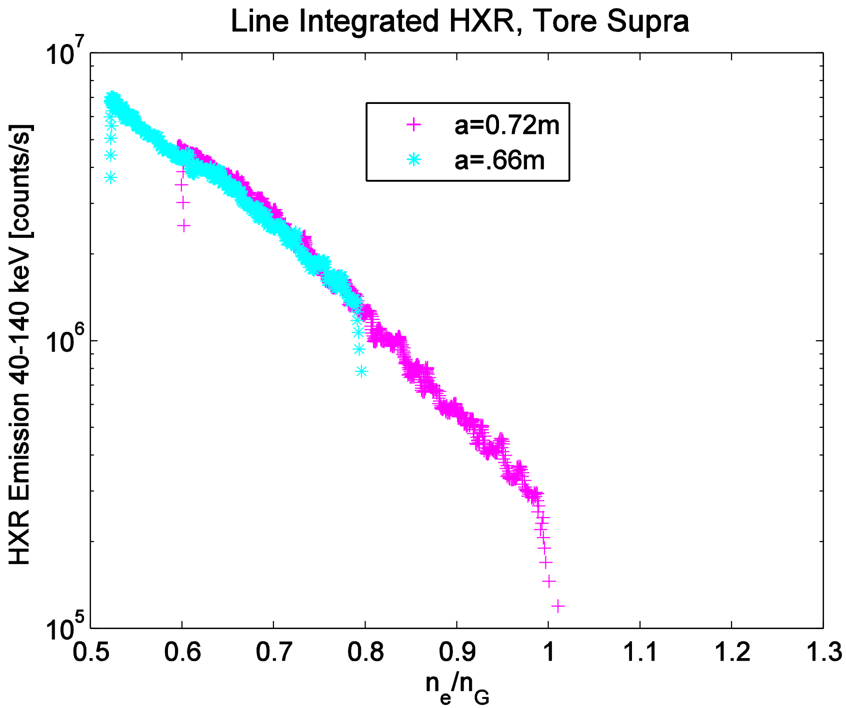
# More cross-machine comparisons needed

- Need to determine proper normalized parameters to compare data from C-Mod, Tore Supra, FTU…
- Density limit does not scale with traditional parameters of $\omega/\omega_{LH}$ and $n_{||}-n_{||crit}$
- Reducing magnetic field on C-Mod to TS values (~3 T) should make comparisons easier with $f_{LHCD}$ as main difference for wave propagation

# Density limit does not scale with $n_e/n_G$ across machines

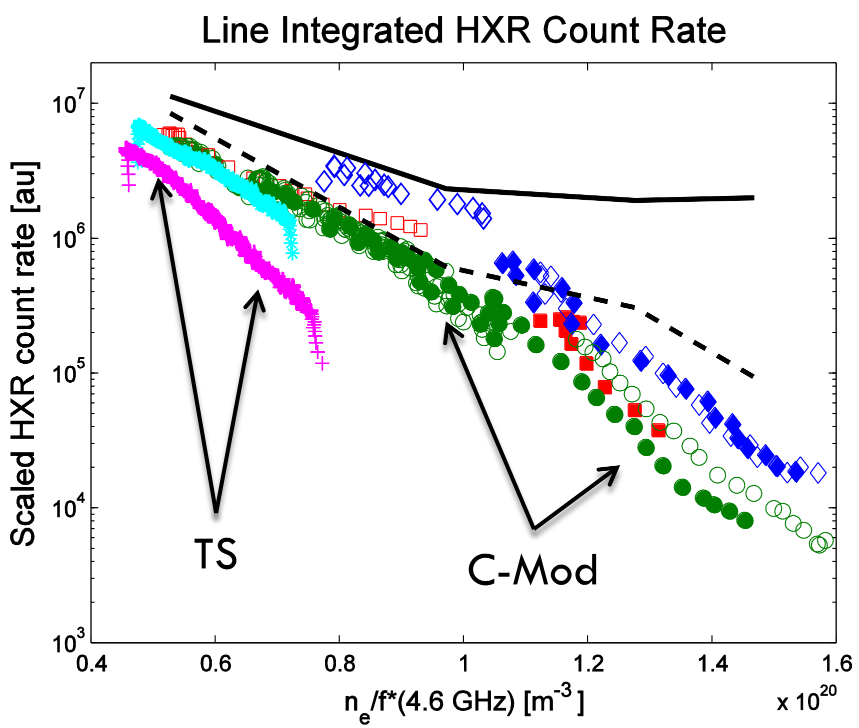
- HXR on TS drops at high $n_e/n_G$, but C-Mod density limit is at very low $n_e/n_G$

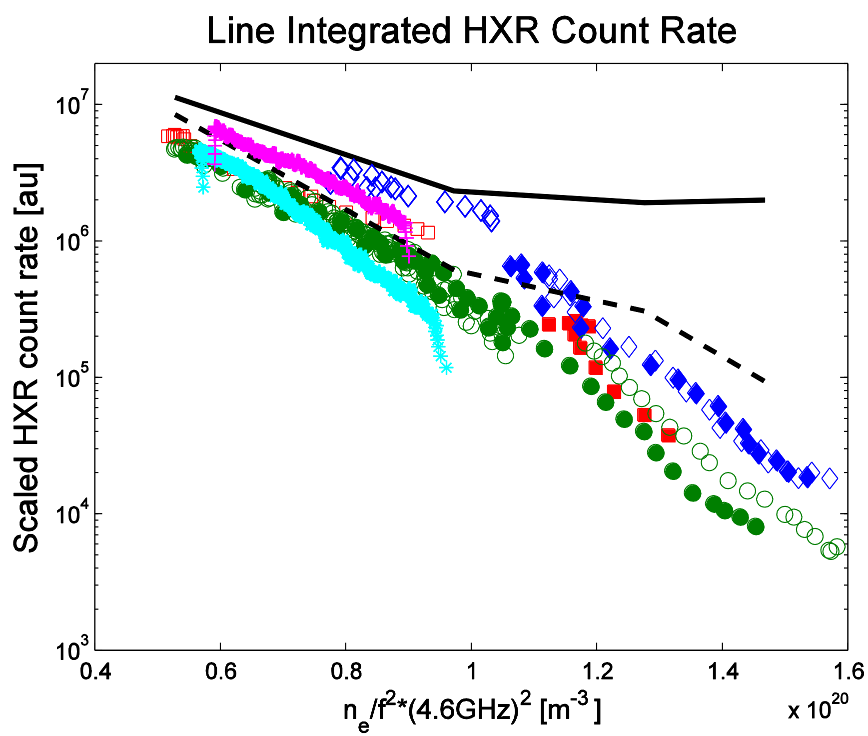


# Line averaged density normalized to $f^2$ seems to be reasonable for comparisons between TS, C-mod

- Need to account for difference in magnetic field?
  - B impacts $n_{||crit}$, $\omega_{LH}$, although density limit does not scale with these parameters on C-Mod
  - Low field experiments on C-Mod will help comparison



# Overview of status for IOS-5.3

- The variety of new dependences found in independent high density LHCD experiments makes clear that the physics is complex. Effects in the SOL and/or plasma periphery (r/a~0.8) appear critical. Likely mechanisms in include wave refraction in combination with:
  - Collisional absorption.
  - Diffusion of fast electrons across LCFS
  - Parametric decay, and/or
  - Scattering from density fluctuations.
- Dependence on magnetic configuration (limiter vs divertor, plasma size) again point to SOL and ray trajectory effects. Would be very helpful to compare configurations in other divertor devices (eg JET, EAST) to see if the difference is consistent.
- No models currently include all potential effects. Applying all available models to each machine would be very helpful – can the dependences be understood? Some experimental profiles have been shared but modeling work is not complete.
  Equally important in extrapolating to ITER is a reliable prediction of its SOL profiles! For this we need collaboration with ITPA DIV/SOL group. Error bars on ITER SOL profiles are large!

# Plans for IOS 5.3 in 2011-2012

All devices: Assemble and/or obtain with improved diagnostics, SOL n, T profiles, and density fluctuations, and parametric instabilities, for cases with and without anomalously low $n_e$ density 'limit'. (ie at $n < n_{acc}$)
Do comparisons reveal common trends, point to causes?
Use in comparisons with (extended, shared) models.

Tore Supra: Continue analyzing existing data.

FTU: Increase/control off-axis $T_e$ using ECRH + LHCD. LH power scan at high $n_e$.

C-Mod: Extend configuration studies (limit plasma on upper divertor tiles).

- Higher ICRF power experiments to obtain high single pass absorption.
- Diverted/limited experiments at lower B (~3 T) to get LHCD frequency scaling at TS field. Also useful for comparing with EAST and JET.

JET: Increase B ($N_{//,acc.}$) Dedicated density scans in divertor vs limiter could be critical for ITER! But run time unlikely until 2012.

EAST: LHCD is operating at 2.45 GHz, not yet at 4.6 GHz. In 2011, plan higher density experiments in different configurations, also effect of density fluctuation and parametric instability? Spokesperson will be Bojiang Ding