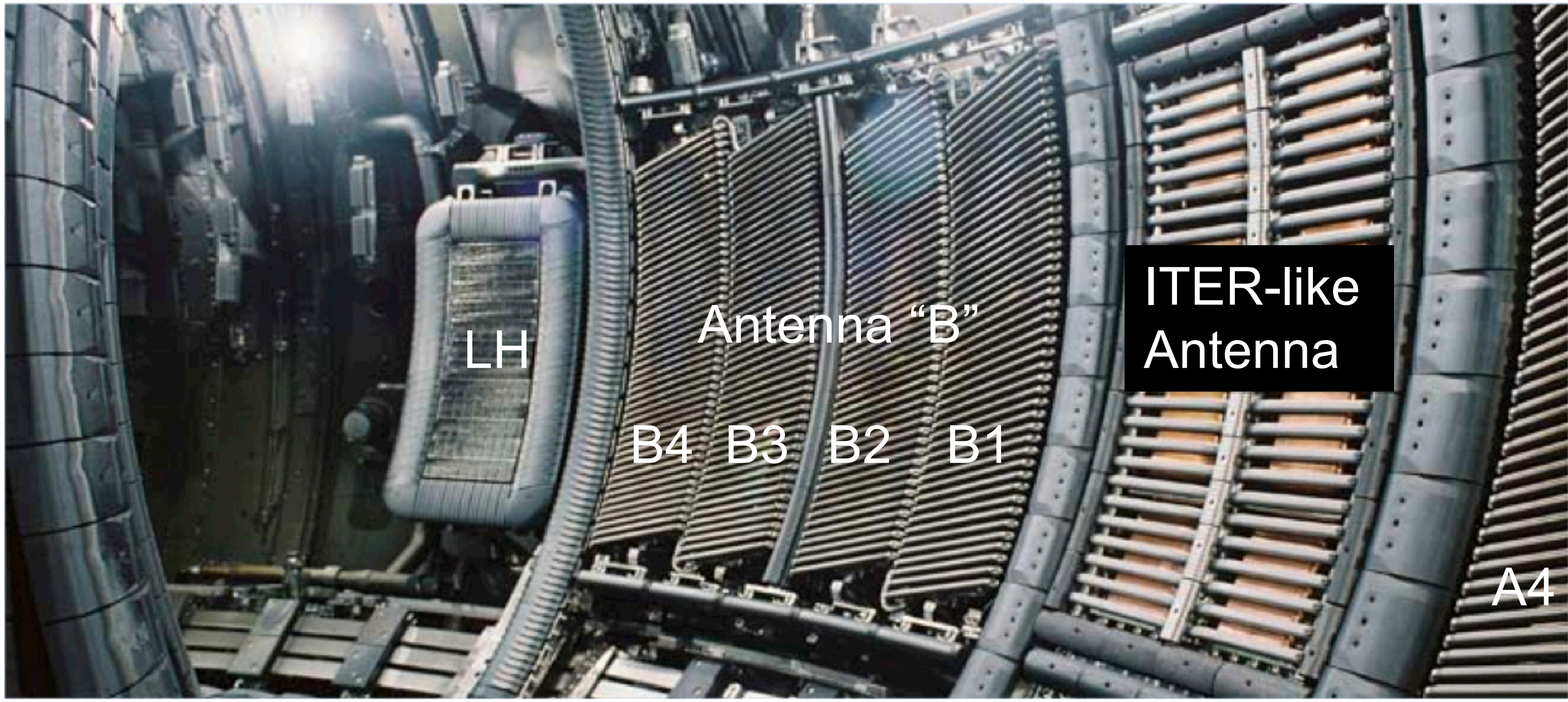
HLC-20: A proposed measurement of RF antenna electric field through Stark broadening of D_α on JET

T.M. Biewer, R.H. Goulding, D.L. Hillis,
R.C. Isler, C.C. Klepper
Oak Ridge National Laboratory
M. Brix, C. Giroud
Euratom/UKAEA

Motivation

- The electric field, *E*, in front of RF antennas on plasma devices (JET, Tore Supra) is "not known."
- A proposal is being developed between ORNL and Tore Supra to make spectroscopic measurements near the RF antennas.
- Preliminary data from JET could support the ORNL/Tore Supra proposal.
  - See TF-H presentation by T. Biewer on 30-Sep-2008.
  - Various (opportunistic) measurements of D_α near LH and ICRF antennas obtained in Sep-Dec 2008.
  - HLC-20 performed on 29-Oct-2008 and 11-Nov-2008 to get data on ICRF antennas (A, B, D).

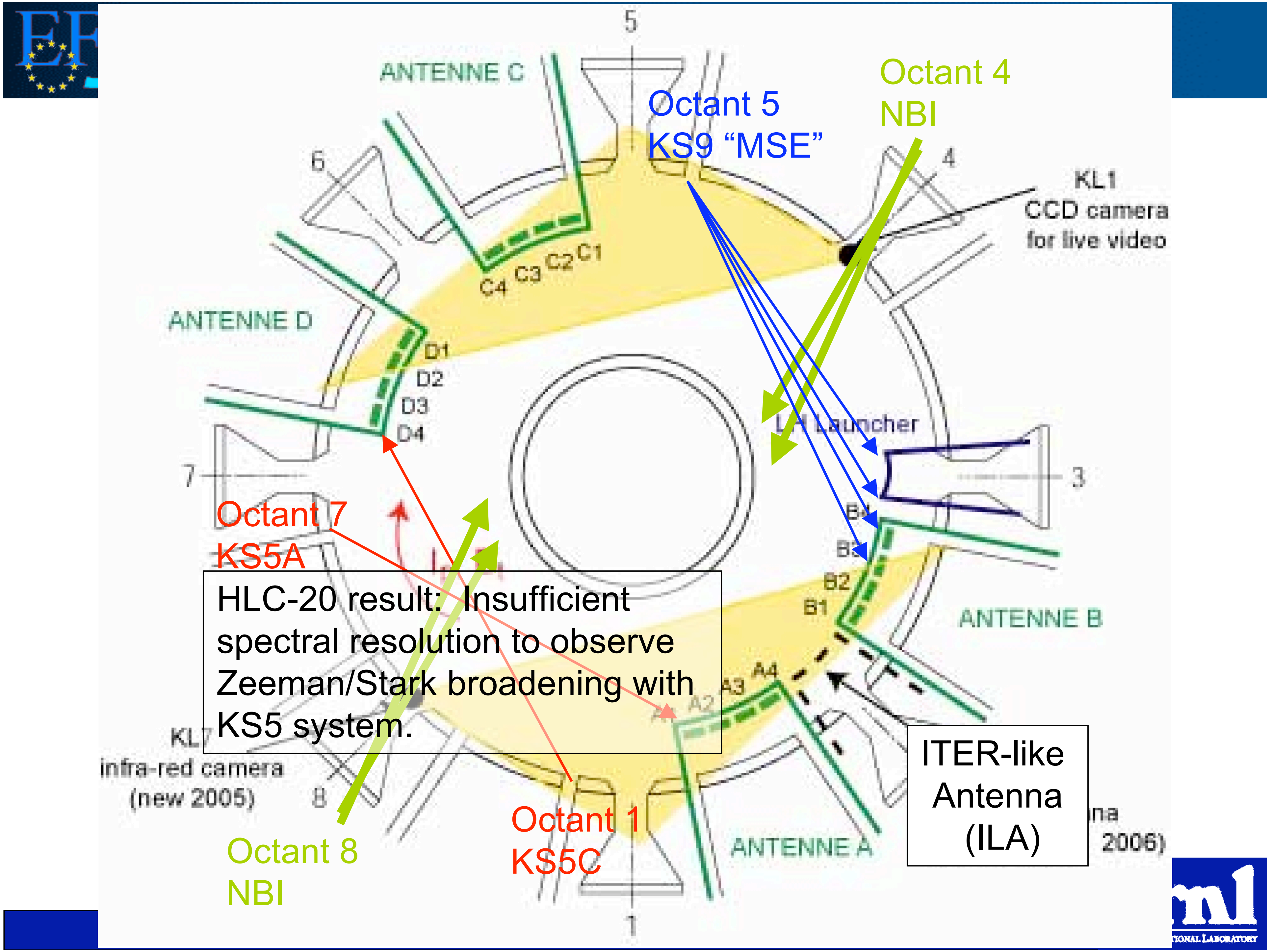
RF antennas on JET



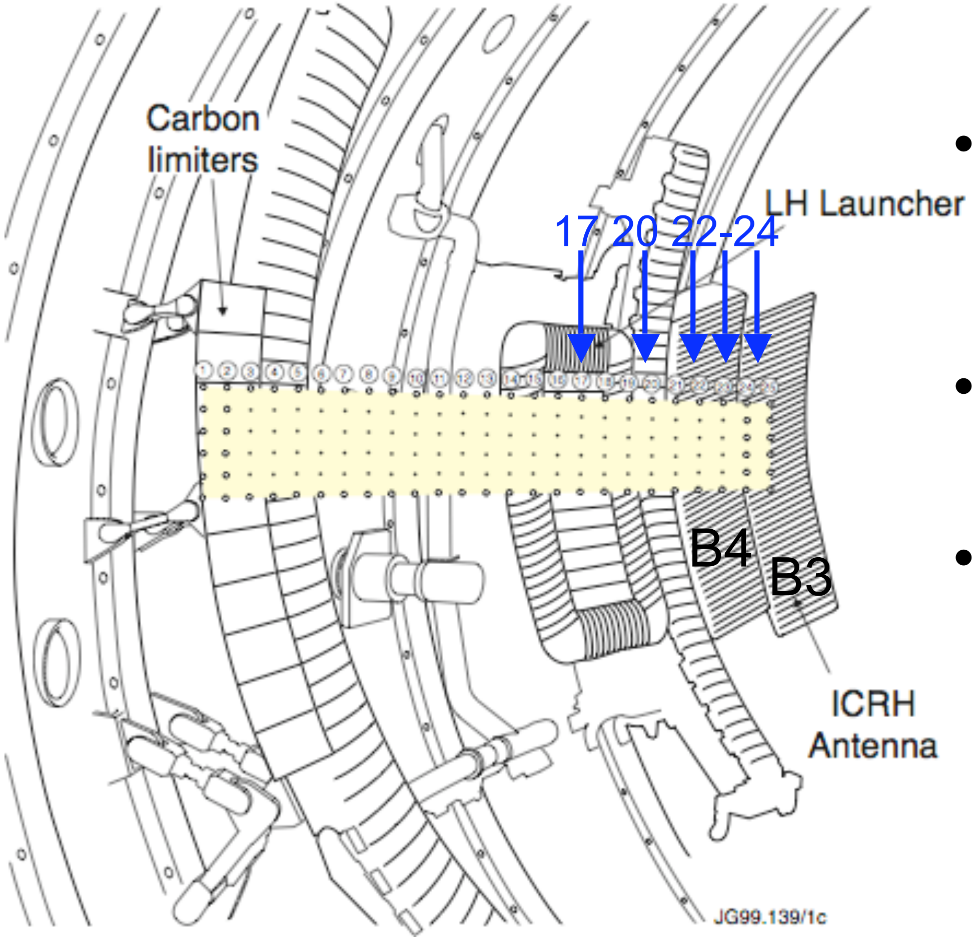
Antenna "A"
. . .

A look inside the vessel: The three rectangular elements are antennas for heating systems available at JET; (from left) the Lower Hybrid, the ICRH and the ITER-like ICRH.

- Diagnostic sightlines on JET, which fall on/near the rf antennas.
  - KS5A has sightline on A1; KS5C on D4.
  - KS9A has sightlines on LH, B4, and B3.


5
ANTENNE C
Octant 5
KS9 “MSE”
Octant 4
NBI
6
4
KL1
CCD camera
for live video
C4 C3 C2 C1
ANTENNE D
D1
D2
D3
D4
LH Launcher
7
3
Octant 7
KS5A
HLC-20 result: Insufficient spectral resolution to observe Zeeman/Stark broadening with KS5 system.
B2
B1
ANTENNE B
A4
A3
A2
KL7
infra-red camera
(new 2005)
8
ITER-like Antenna (ILA)
2006)
Octant 1
KS5C
Octant 8
NBI
ANTENNE A
1

JET KS9 Sightlines



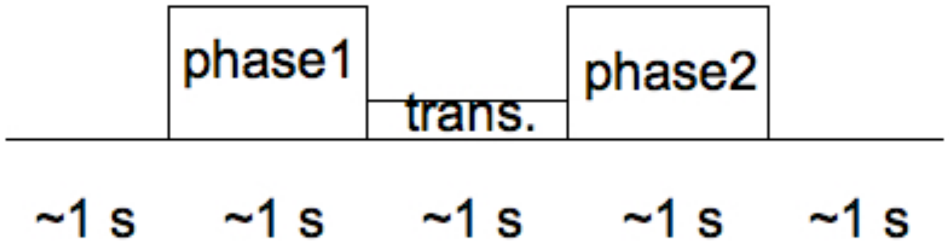
- KS9 (MSE) sightlines intersect the LH Antenna and ICRH Antenna B (straps B3 and B4).
- Each view consists of 6 poloidally separated sub-sightlines.
- Dielectric coatings limit λ range to D_α +/- 10 nm.
- KS9A (spectrometer with "new" CCD camera) has been revived.
  - MSE spectrum during ELMs.
  - NBI ions slowing-down spectrum.
  - Stark broadening in RF antenna near-field.

Goals of HLC-20

- 0^{th}-order: Measure (spectroscopically, due to E-field) a distinguishable difference between RF-on and RF-off.
  - D_α, D_β, "forbidden" He lines
- 1^{st}-order: Vary antenna parameters to vary the E-field, and distinguish that variation.
  - Phase scan: $0–0–\pi–\pi$ should be big, and $0–\pi–0–\pi$ should be small
  - ROG scan: The larger the ROG the bigger E is.
  - Power scan?

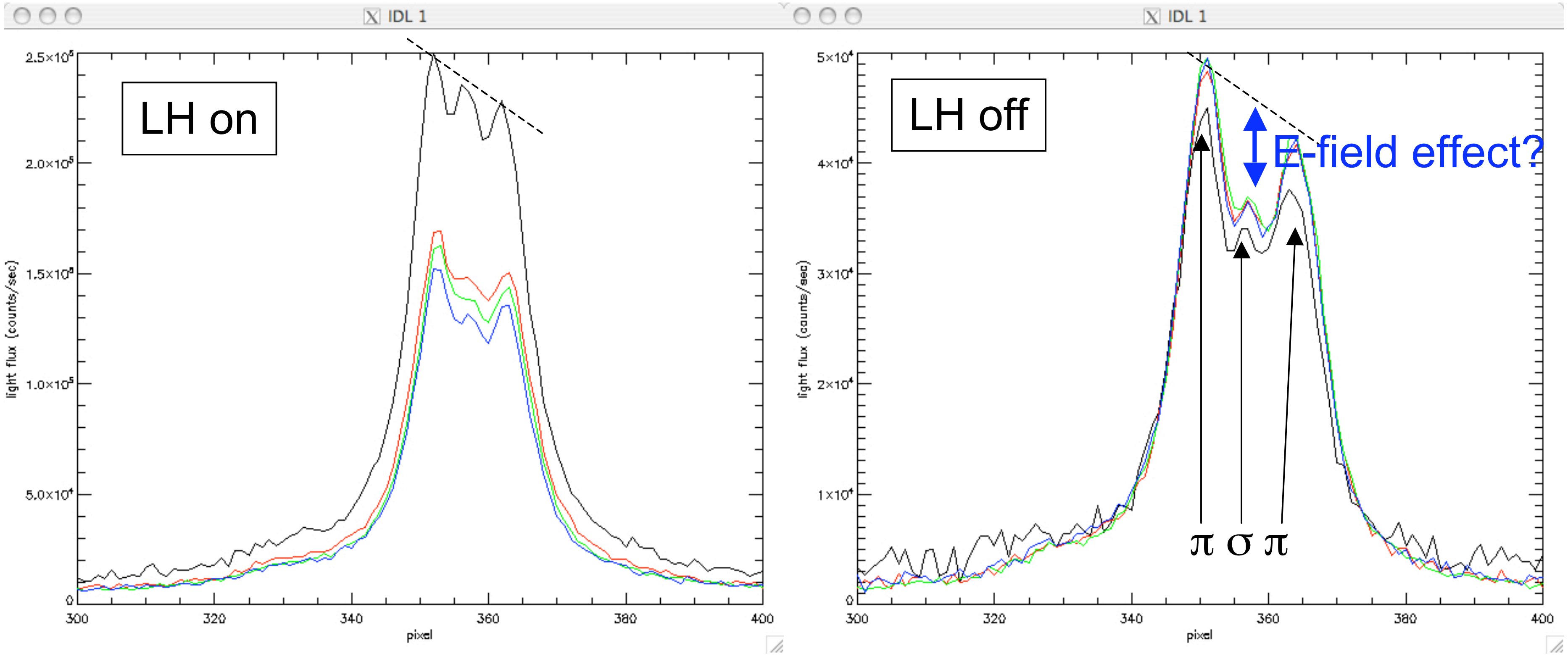
“Negative” HLC20 (Part 1) Results

- HLC-20 initially performed on 29-Oct-2008 at JET
  - Pulse range: 75425-75436
  - ICRH antennas at 42 MHz
  - Phase $0–\pi–0–\pi$ to $0–0–\pi–\pi$
  - ROG ~ 5cm
  - B_T ~ 2.5 T



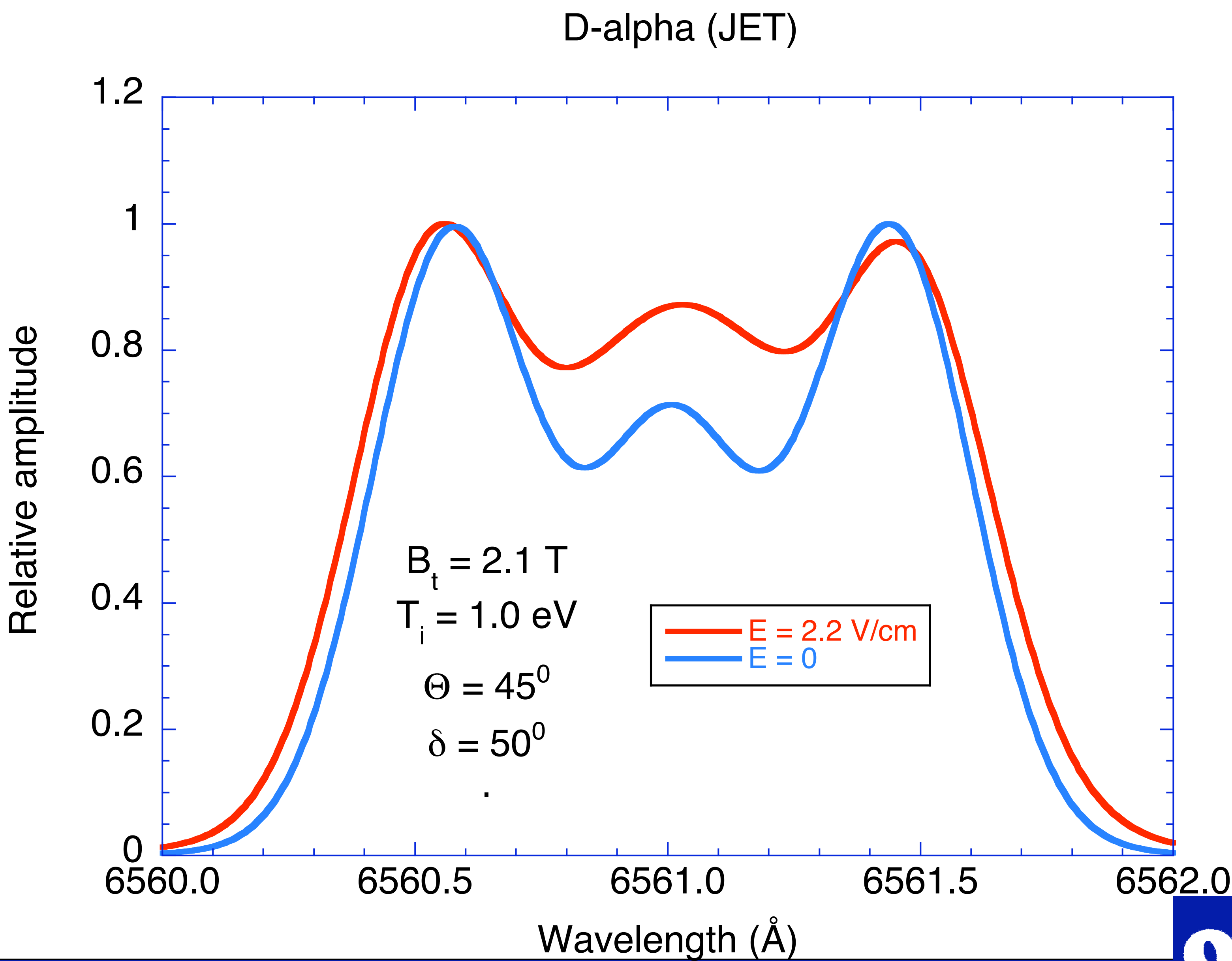
- KS5A/C sightlines (ICRH antenna A1/D4) not useable: Current configuration of (CXRS) instruments not suitable for Zeeman/Stark measurements.
  - Insufficient resolution for D_β and D_α measurements: need narrower instrument function.
  - Insufficient resolution and sensitivity for observation of “forbidden” He lines at ambient JET He concentrations.
- KS9A had observations (Channel 22, 23, 24) of ICRH antenna B3 and B4 at “low” power: ~200kW/strap
  - “E-field effect” was subtle and/or difficult to distinguish.

"E-field effect" from LH launcher?



- KS9A observed (parasitically) D_α spectra on pulse 75093 *et. al*.
  - Zeeman splitting ($B_{T,0}$=2.3 T) of π peaks.
  - Enhancement of σ peak when LH is on (~ 3MW).

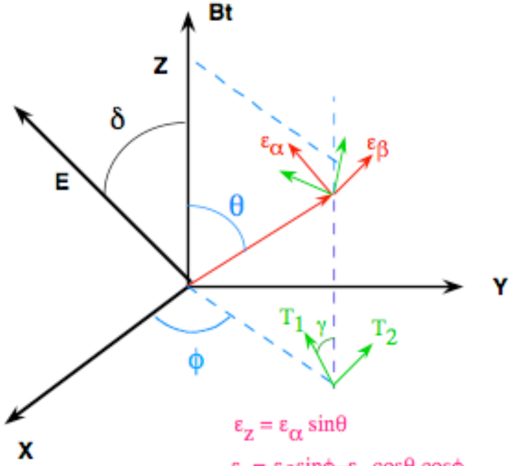
R. Isler simulation of JET D_α



Spectral Profile Modeling

Isler spectral profile modeling supports E-field measurement

Viewing Geometry



$\varepsilon_z = \varepsilon_\alpha \sin\theta$

$\varepsilon_x = -\varepsilon_\beta \sin\phi - \varepsilon_\alpha \cos\theta \cos\phi$

$\varepsilon_y = \varepsilon_\beta \cos\phi - \varepsilon_\alpha \cos\theta \sin\phi$

$\varepsilon_\alpha = T_1 \cos\gamma + T_2 \sin\gamma$

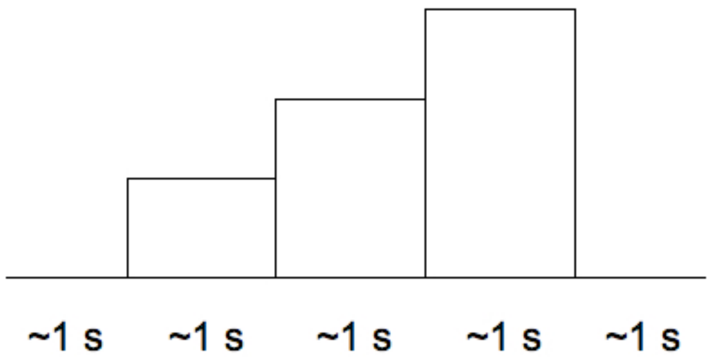
$\varepsilon_\beta = T_1 \sin\gamma + T_2 \cos\gamma$

- Full quantum mechanics with both E, B perturbations treated together.
- Able to handle the 3-d geometry of E, B and optical view.
- Polarization of optical system is an input.
  - <u>But note</u>: σ and π components not well defines with combined E and B perturbation!
  - Also polarizations are not strictly perpendicular or parallel either field.

Slide from C.C. Klepper presentation at Tore Supra, 26-Sep-2008.

HLC-20 (Part 2) Results

- HLC-20 again performed on 11-Nov-2008 at JET
  - Pulse range: 75634-75648
  - ICRH antennas at 42 MHz
  - Phase $0–\pi–0–\pi$
  - ROG ~ 5cm
  - B_T ~ 2.3 and 2.5 T
  - Power scan in three steps



- KS9A had observations (Channel 20, 22, 24) of ICRH antenna B3 and B4 at "higher" power: ~400kW/strap
  - "E-field effect" was still subtle and/or difficult to distinguish.
  - Is it a power issue?
  - Is E simply higher for LH?
  - Do we not understand what we're looking at?

Summary

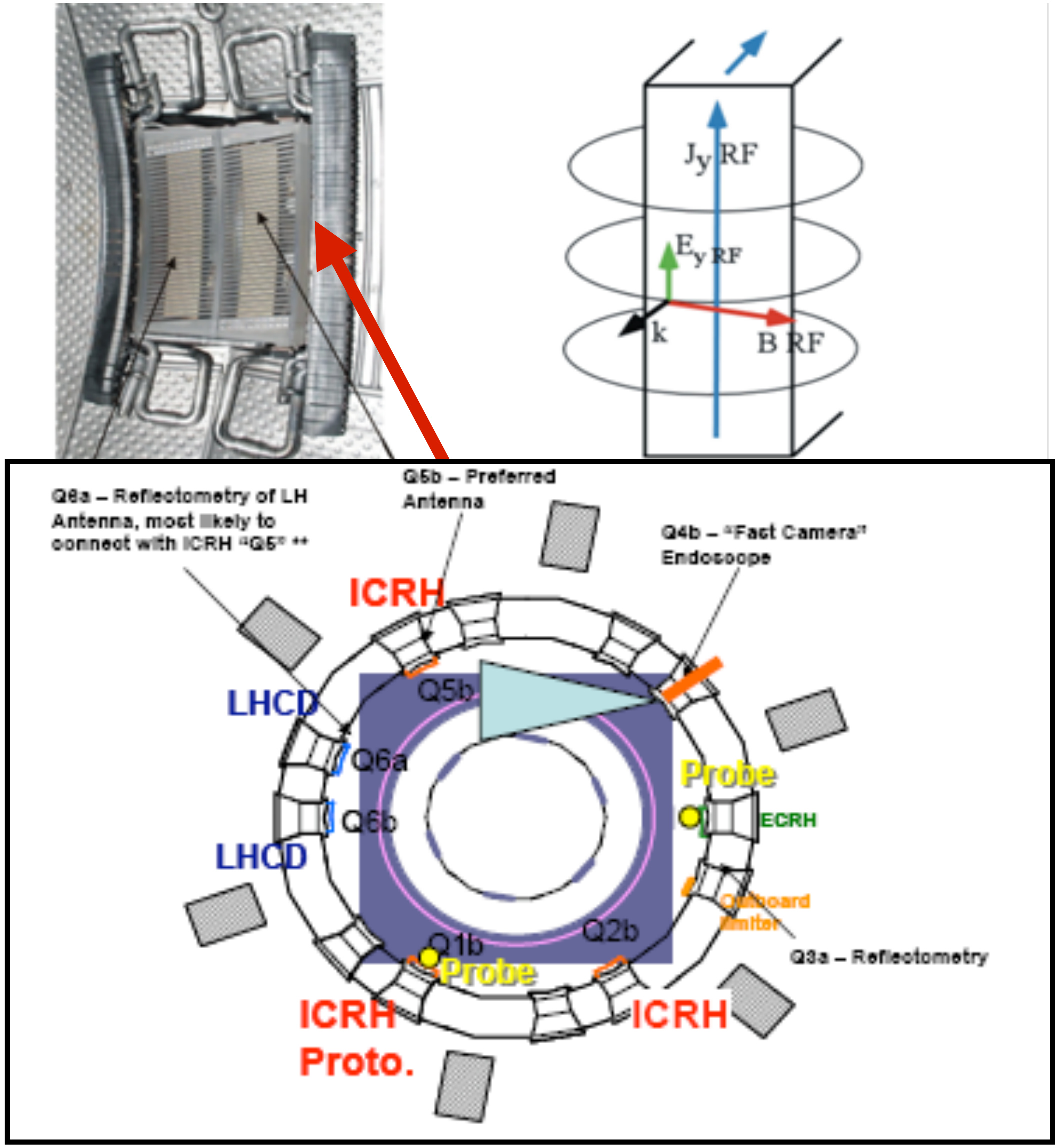
- ORNL proposal seeks to explore (with spectroscopy) the *E*-field in front of the rf antennas at Tore Supra.
  - Simulations show a promising approach.
- Measurements from JET (HLC-20 and gathered parasitically) could support the case for the ORNL/Tore Supra proposal.
  - 2 relevant sightlines (KS5A & KS5C) are currently available, but CXRS configured instruments are not suitable for Zeeman/Stark broadening spectroscopy.
  - “New” KS9A enables various measurements.
    - Poloidal variation along antenna straps B3 & B4 and LH launcher.
    - Disturbs a single channel of MSE during a given pulse.
    - Still under development, but progressing rapidly.
- Results are promising, but confusing.

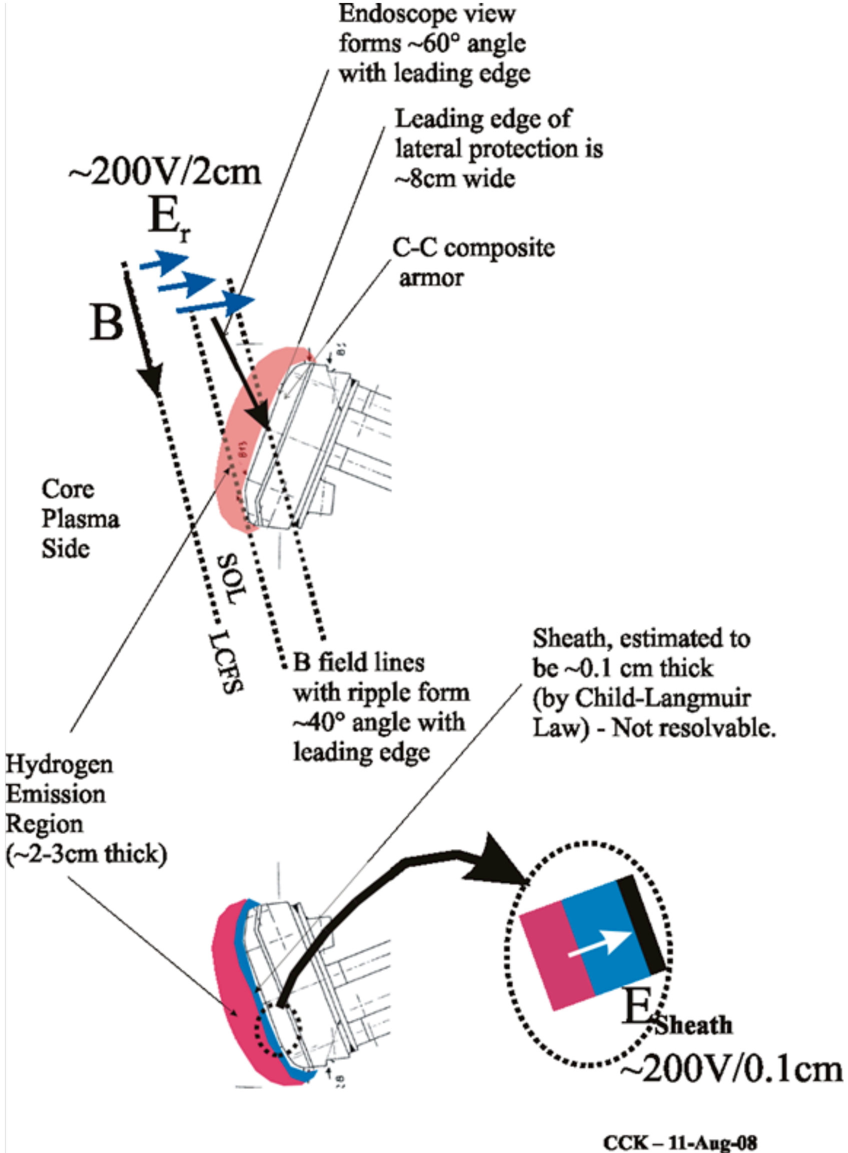
Future Work

- Further diagnostic improvements: better SNR, dynamic range, etc.
- Spectral fitting in development to remove "subjectivity" of the experimental results.
- R. Isler's Zeeman/Stark code adapted to JET, but needs to be generalized to "fit" spectra, deriving E-field.
- Education of principle researcher (T. Biewer) on the subtleties of the D_α spectrum.

Supplemental Slides

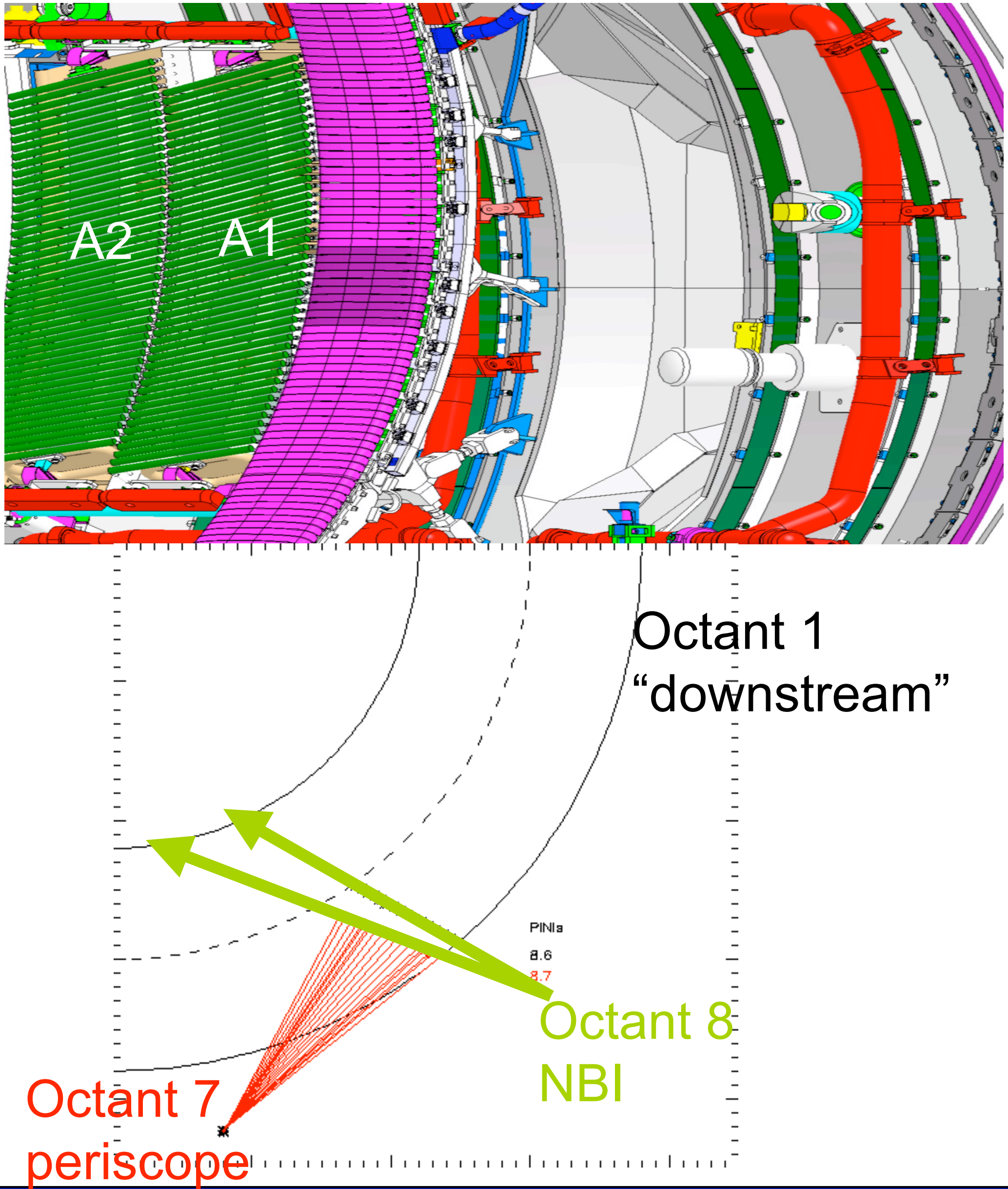
Geometry on Tore Supra





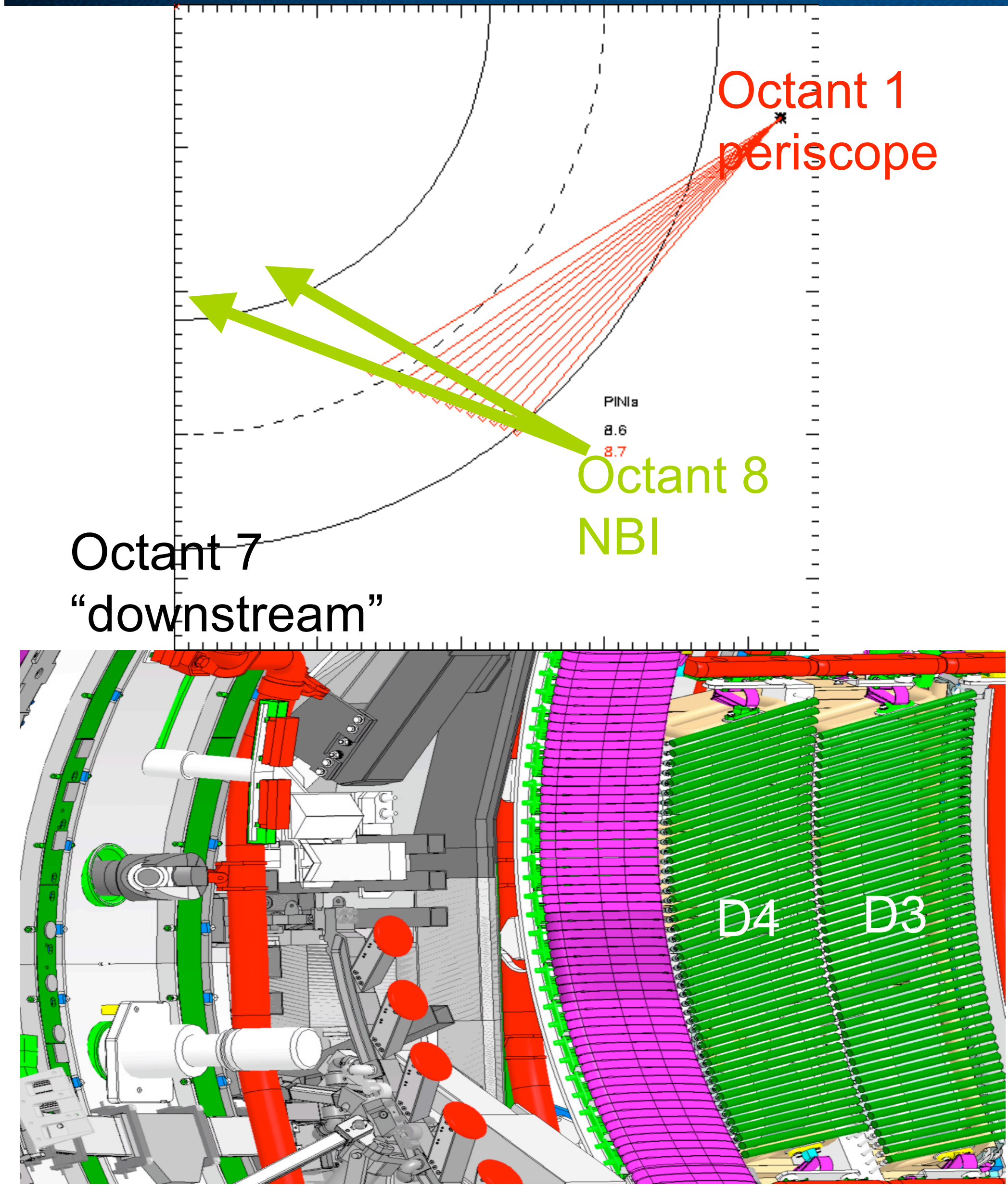
Taken from C.C. Klepper presentation at Tore Supra, 26-Sep-2008.

JET KS5 Sightlines (Part 1)



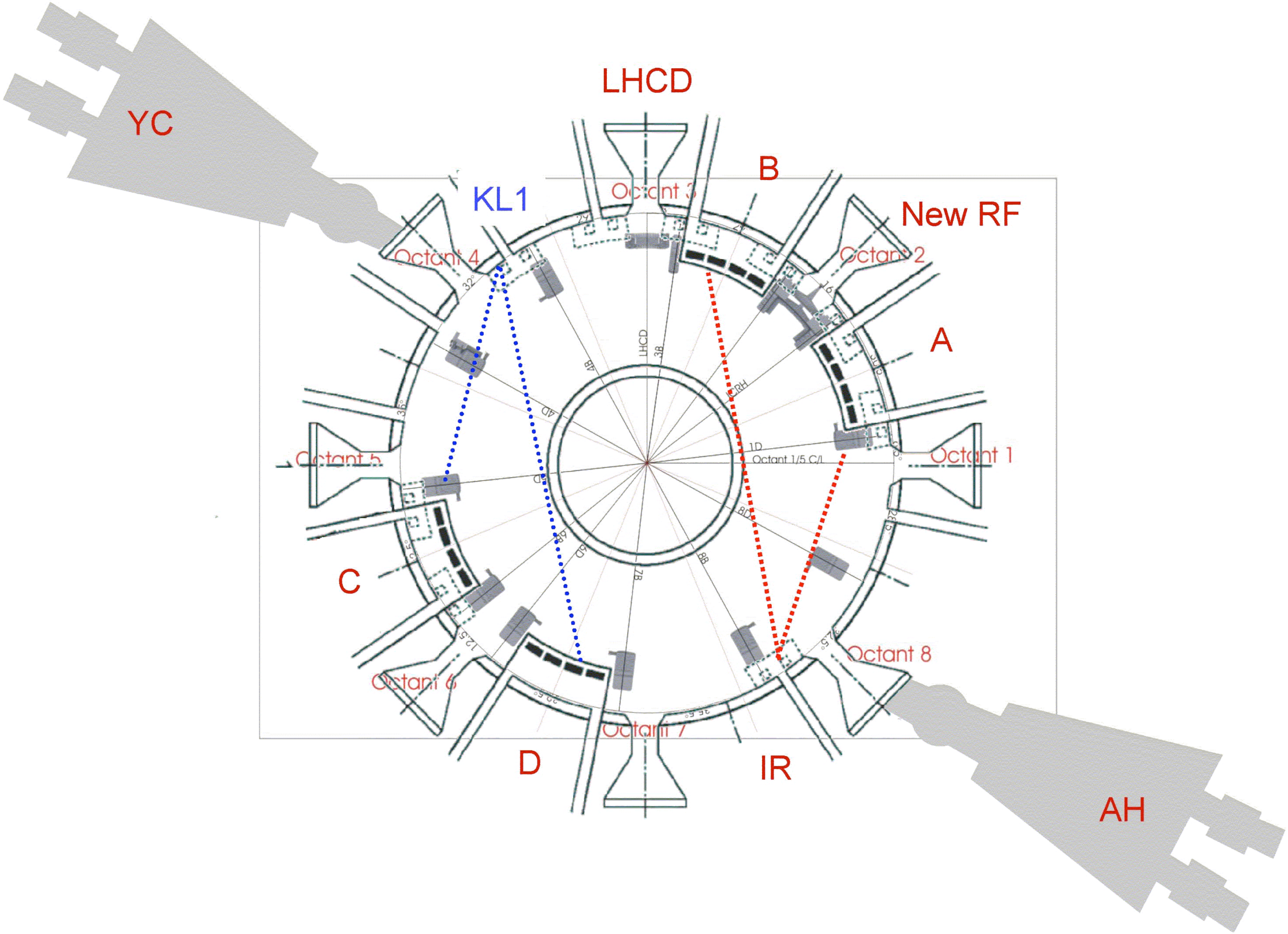
- KS5 (CXRS) consists of 5 instruments.
  - KS5D and E are fixed wavelength (not looking at D_α or D_β).
  - KS5A, B, and C are “tunable”; can look at D_α or D_β if not being used for CXRS.
- KS5A has 1 relevant sightline that falls on Antenna A (strap A1).

JET KS5 Sightlines (Part 2)



- KS5C has 1 relevant sightline that falls on Antenna D (strap D4).
- Again, these instruments can only be used if not being used for CXRS.
- KS5A and KS5C are fully calibrated and can quickly yield spectroscopic data with sufficient foresight.

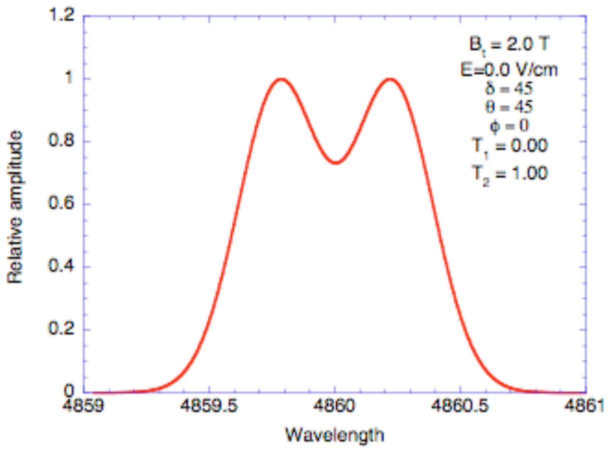
JET Overview



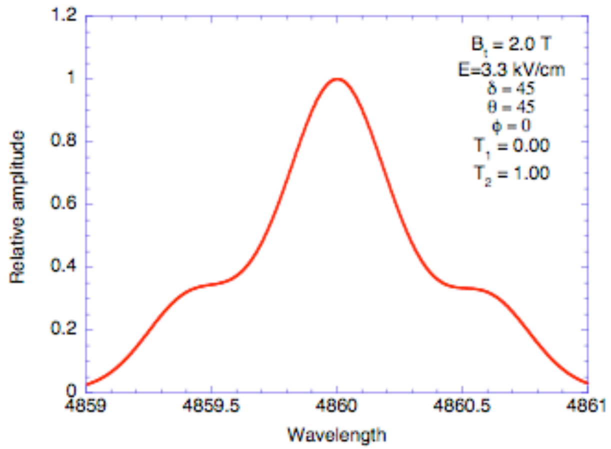
Simulated Zeeman and Stark Spectra

Due to the Zeeman and Stark effects, both B and E affect Spectral Line Profile

e.g. for D_β (Assuming only effect of sheath dc E-field)



B only



Both B and E

Slide from C.C. Klepper presentation at Tore Supra, 26-Sep-2008.