A proposed measurement of rf-antenna electric field through Stark broadening of D_α and D_β on JET

T.M. Biewer, R.H. Goulding, D.L. Hillis,
R.C. Isler, C.C. Klepper
Oak Ridge National Laboratory
S. Locke
Auburn University & ORNL
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.
  - See following slides from C.C. Klepper's presentation.
- Preliminary data from JET (gathered parasitically) could support the ORNL/Tore Supra proposal.
- If successful, a more systematic set of (targeted) experiments could be performed to understand *E* near rf antennas on JET.

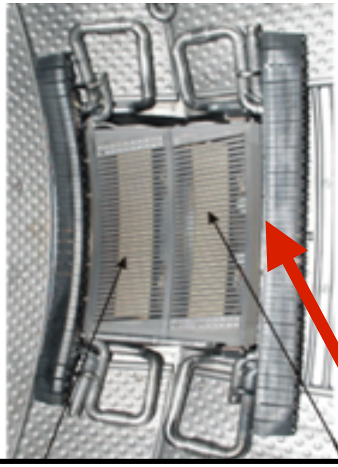
Tore Supra Collaboration Proposal

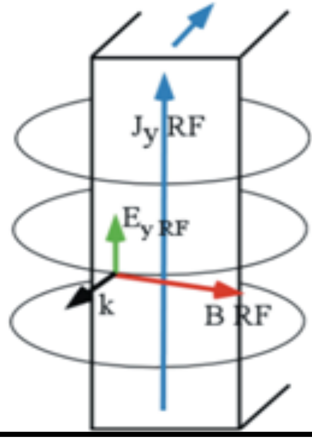
Goal of Collaboration

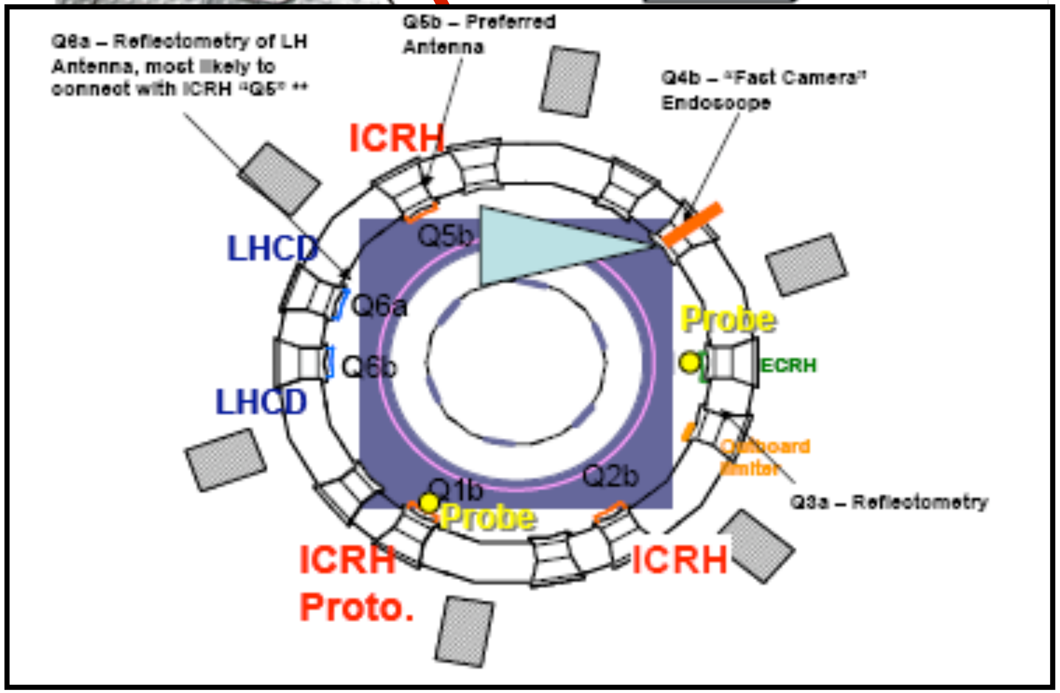
- Improve Understanding of coupling of RF antenna to core plasma through SOL
- Spectroscopic measurements can provide new understanding of region in front of ICRH antenna
  - **Provide impurity sources (C, B, Cu, etc) from RF antenna area (not currently available on Tore Supra)**
  - **Provide Electric Field via Stark Effect & from sputtering models**
- Measurements will be supported by additional ORNL modelling and theory efforts
  - **RF modelling (ITER related models)**
  - **Edge modelling (SOLPS, etc)**
- Better understanding of boundary plasma between antenna and core plasma will improve RF coupling in ELMing H-mode
  - **Important to ITER**

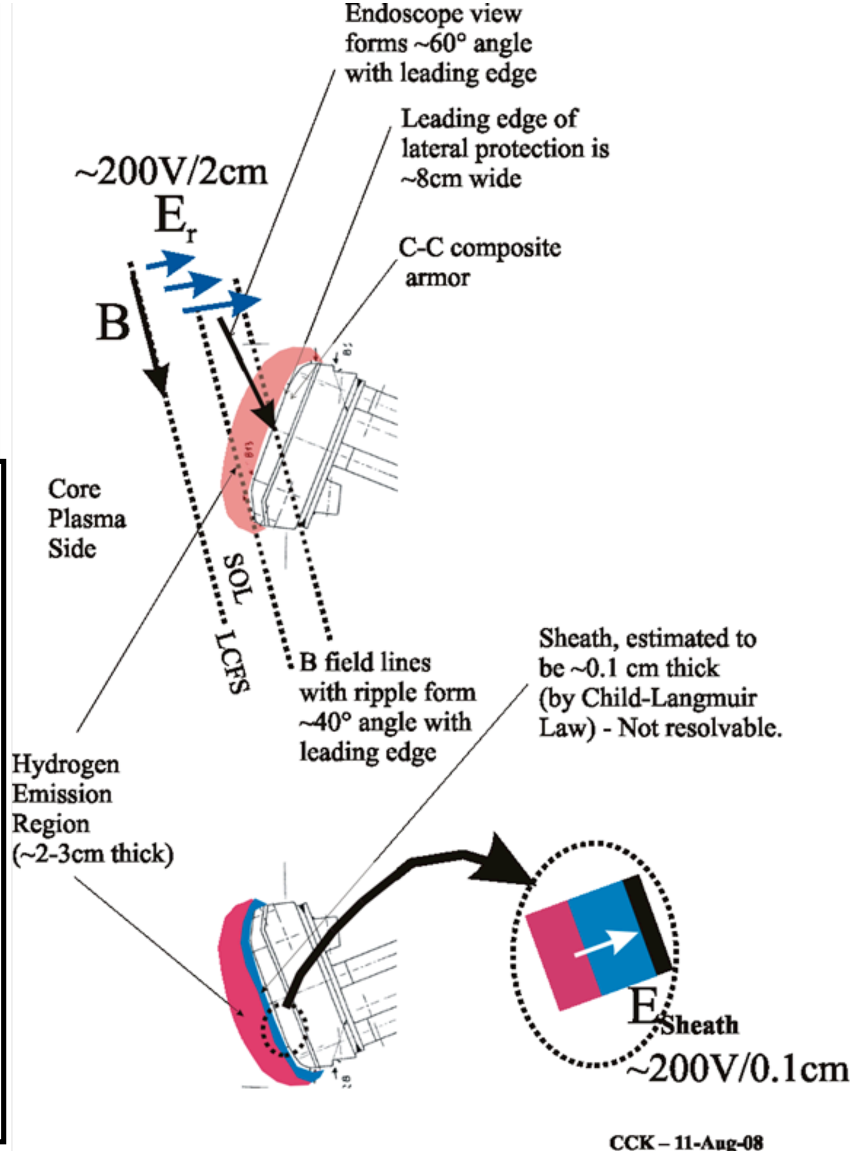
Slide from C.C. Klepper presentation at Tore Supra, 26-Sep-2008.

Geometry on Tore Supra







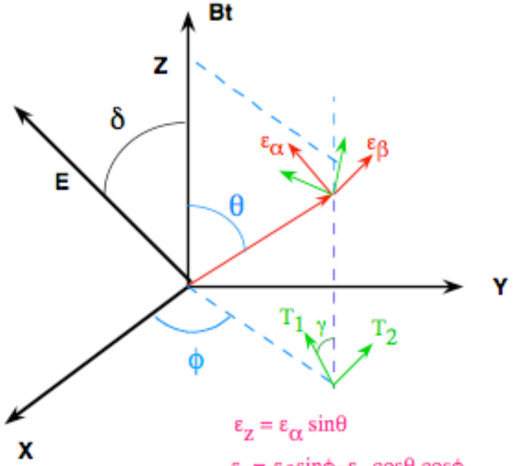


Taken from C.C. Klepper presentation at Tore Supra, 26-Sep-2008.

Spectral Profile Modeling

Isler spectral profile modeling supports E-field measurement

Viewing Geometry



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

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

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

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

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

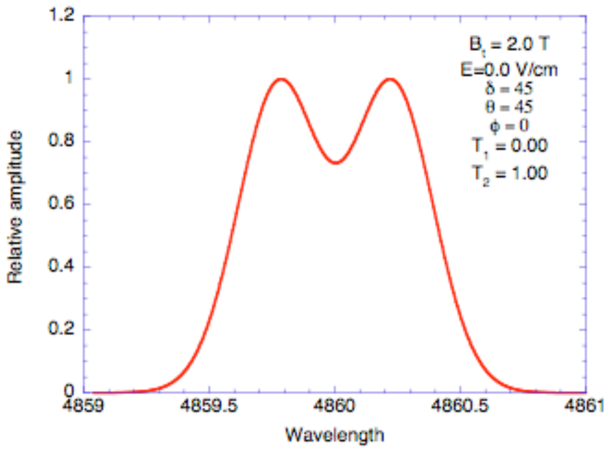
- Full quantum mechanics with both E, B perturbations treated together.
- Able to handle the 3-d geometry of E, B and optical view.
- Polarization of optical system is an input.
  - But note: σ and π components not well defines with combined E and B perturbation!
  - Also polarizations are not strictly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

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

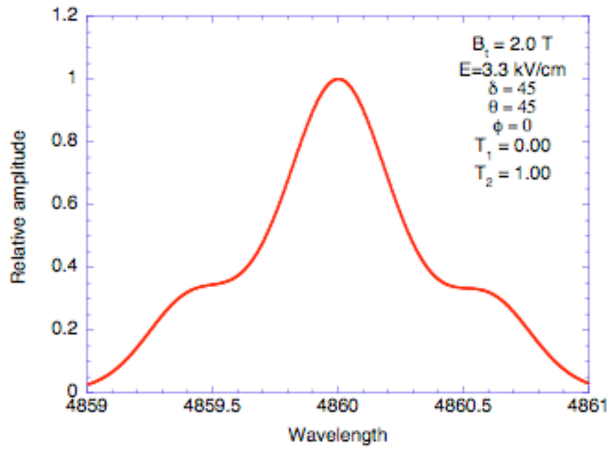
Simulated Zeeman and Stark Spectra

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)



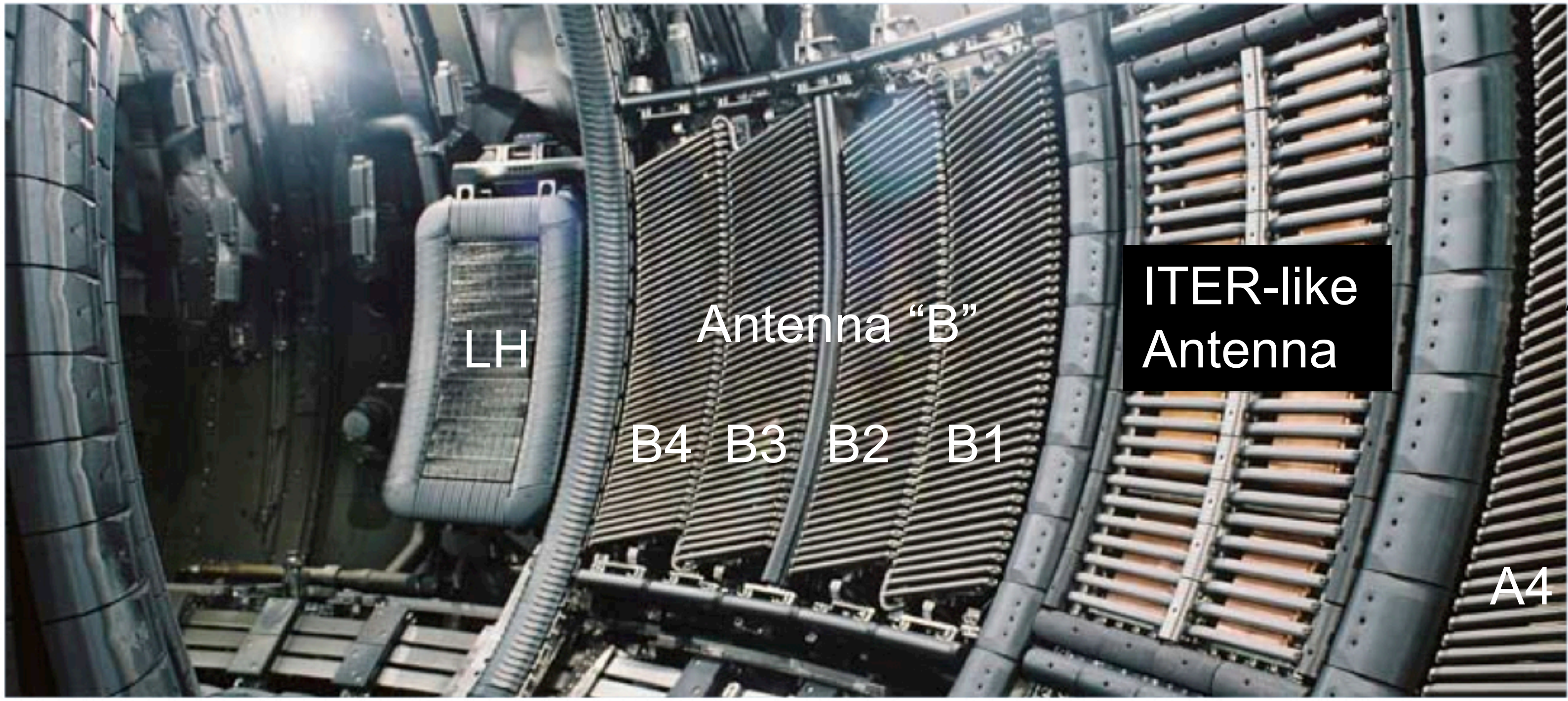
B only



Both B and E

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

RF antennas on JET

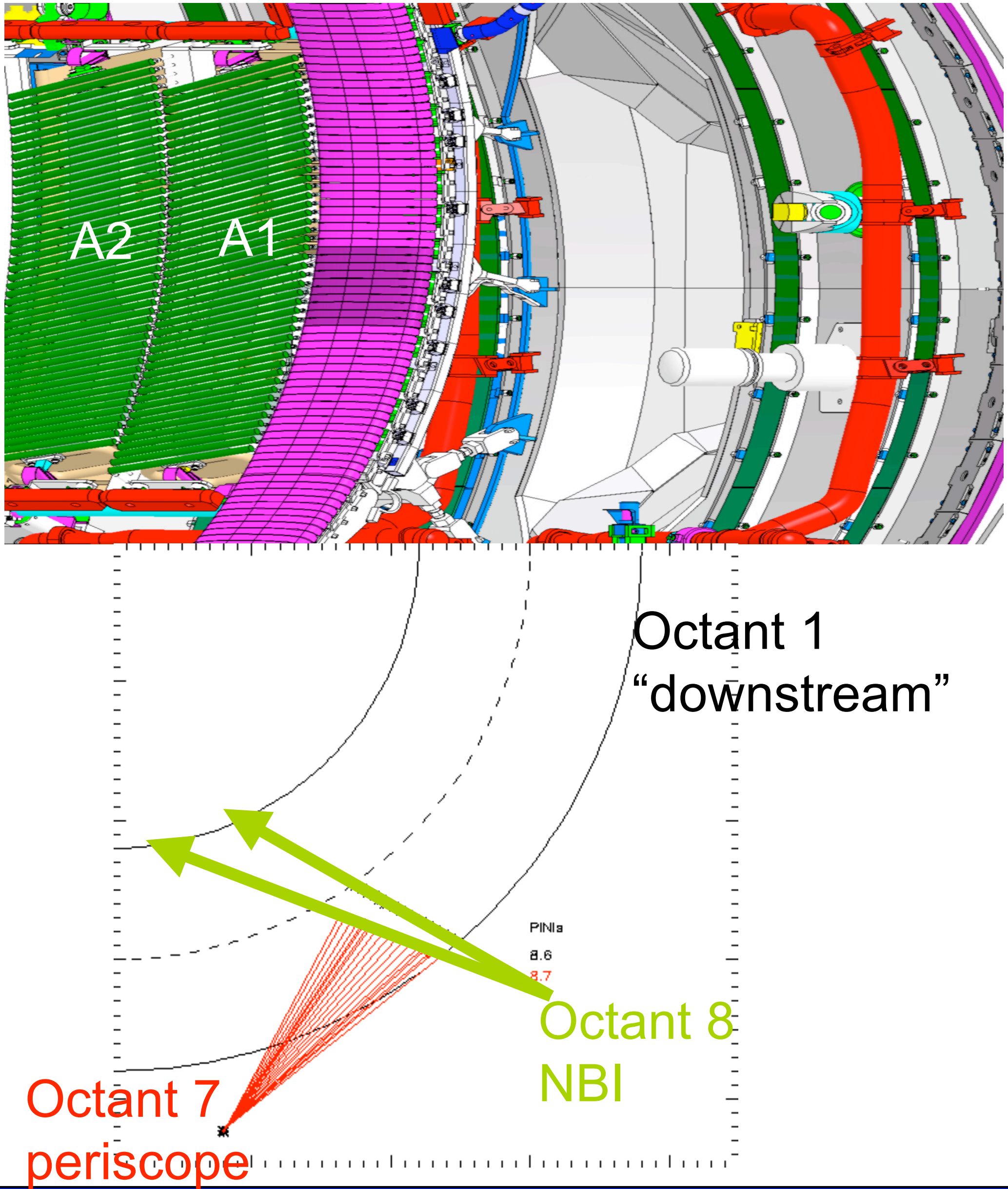


Antenna "A"
. . .

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.

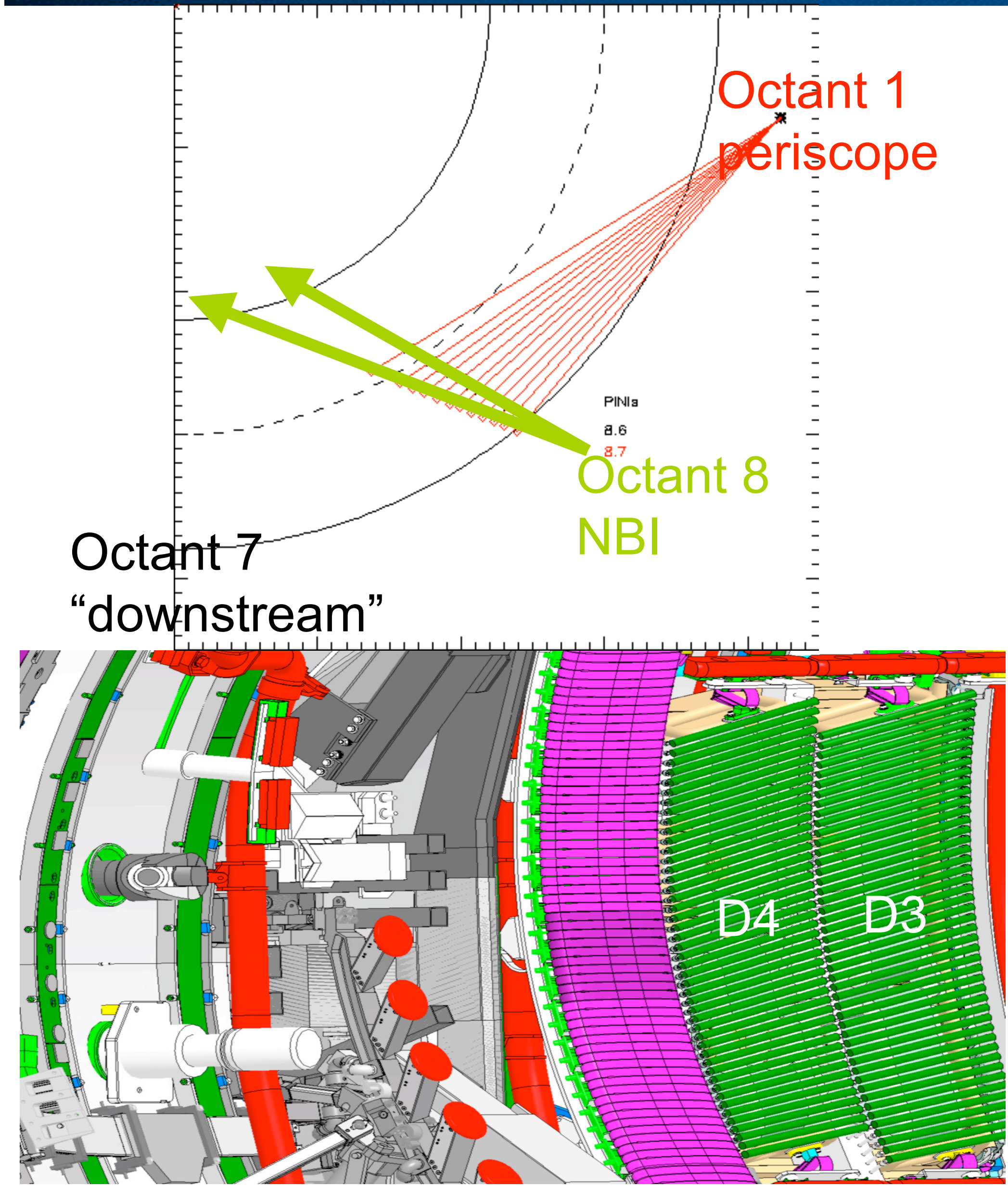
- Identify existing diagnostic sightlines on JET, which fall on/near the rf antennas.
- Provide some spectroscopic data to support simulations of D_α and D_β emission.

JET KS5 Sightlines (Part 1)

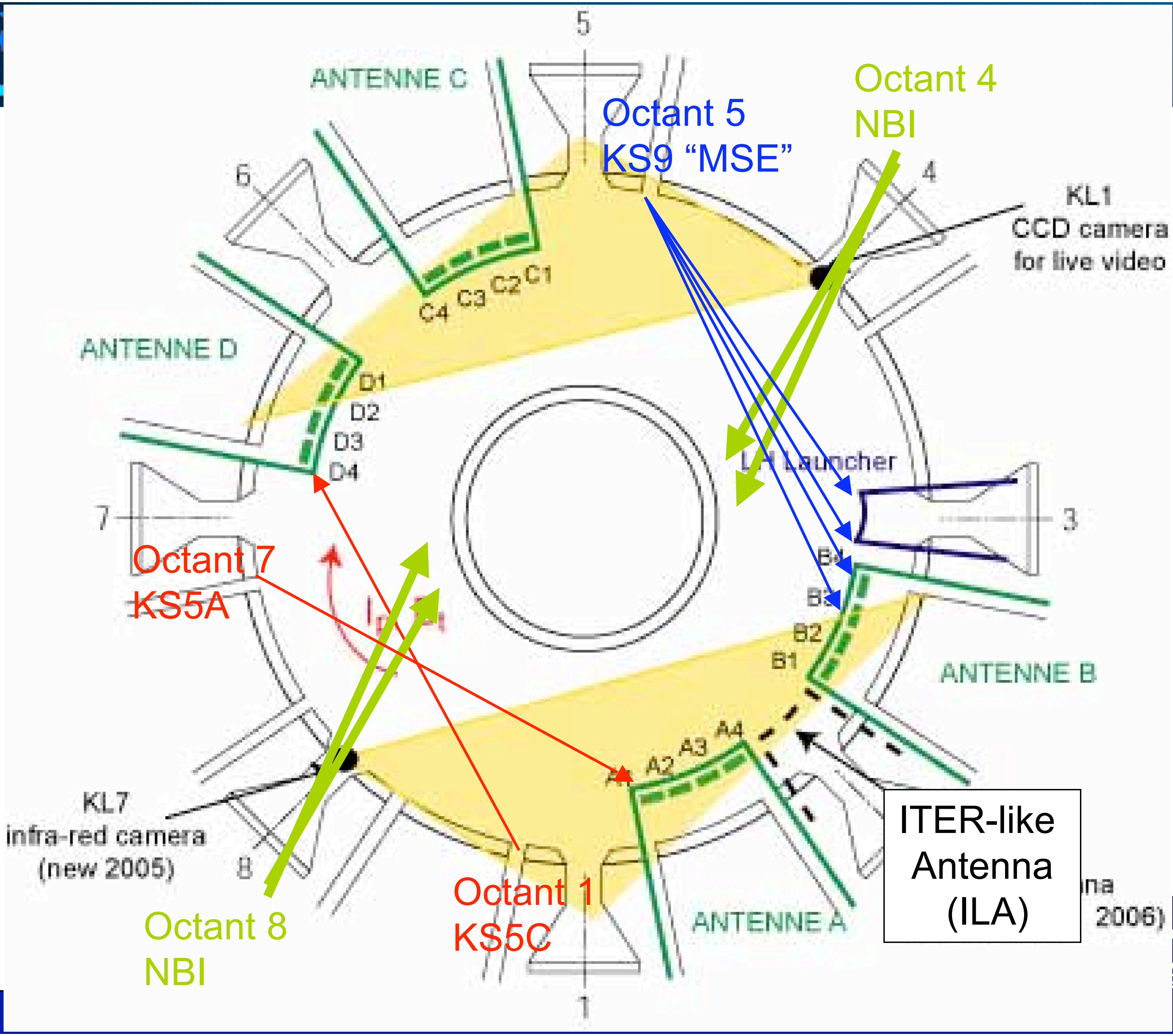


- KS5 (CXRS) consists of 5 instruments.
  - KS5D and E are fixed wavelength (not looking at D_α or D_β).
  - KS5A, B, and C are “tunable”; can look at D_α or D_β if not being used for CXRS.
- KS5A has 1 relevant sightline that falls on Antenna A (strap A1).

JET KS5 Sightlines (Part 2)

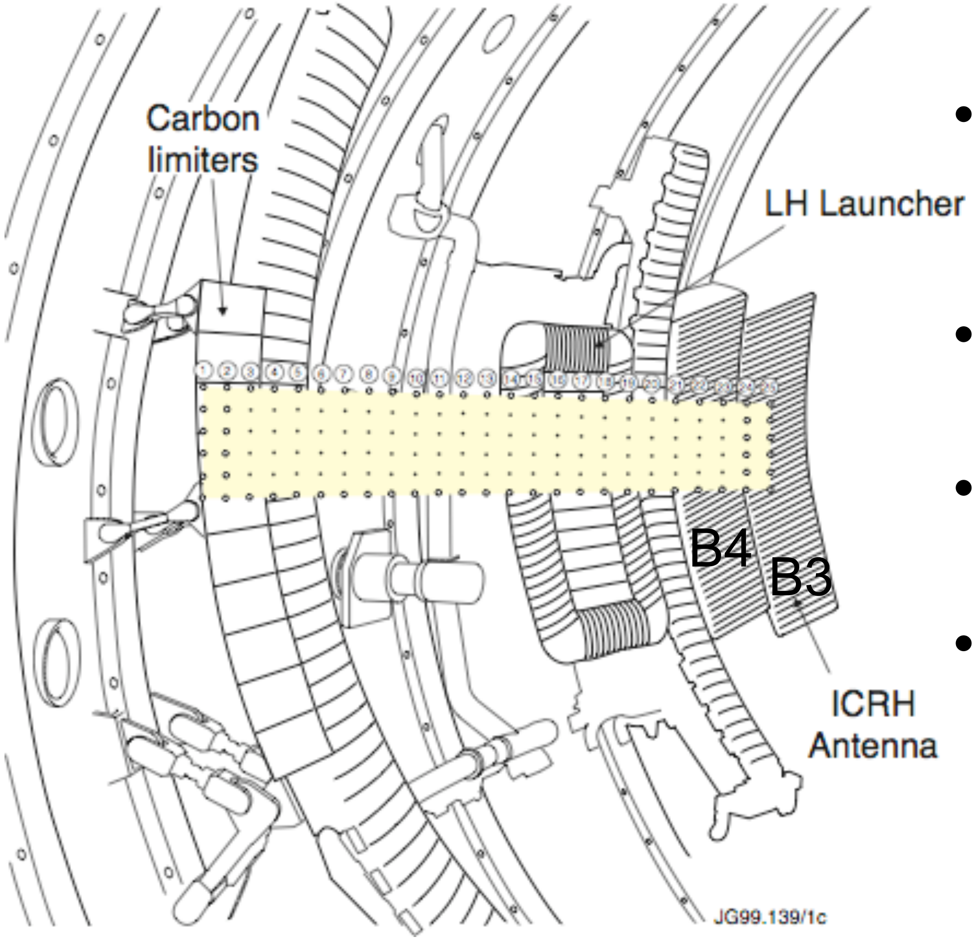


- KS5C has 1 relevant sightline that falls on Antenna D (strap D4).
- Again, these instruments can only be used if not being used for CXRS.
- KS5A and KS5C are fully calibrated and can quickly yield spectroscopic data with sufficient foresight.



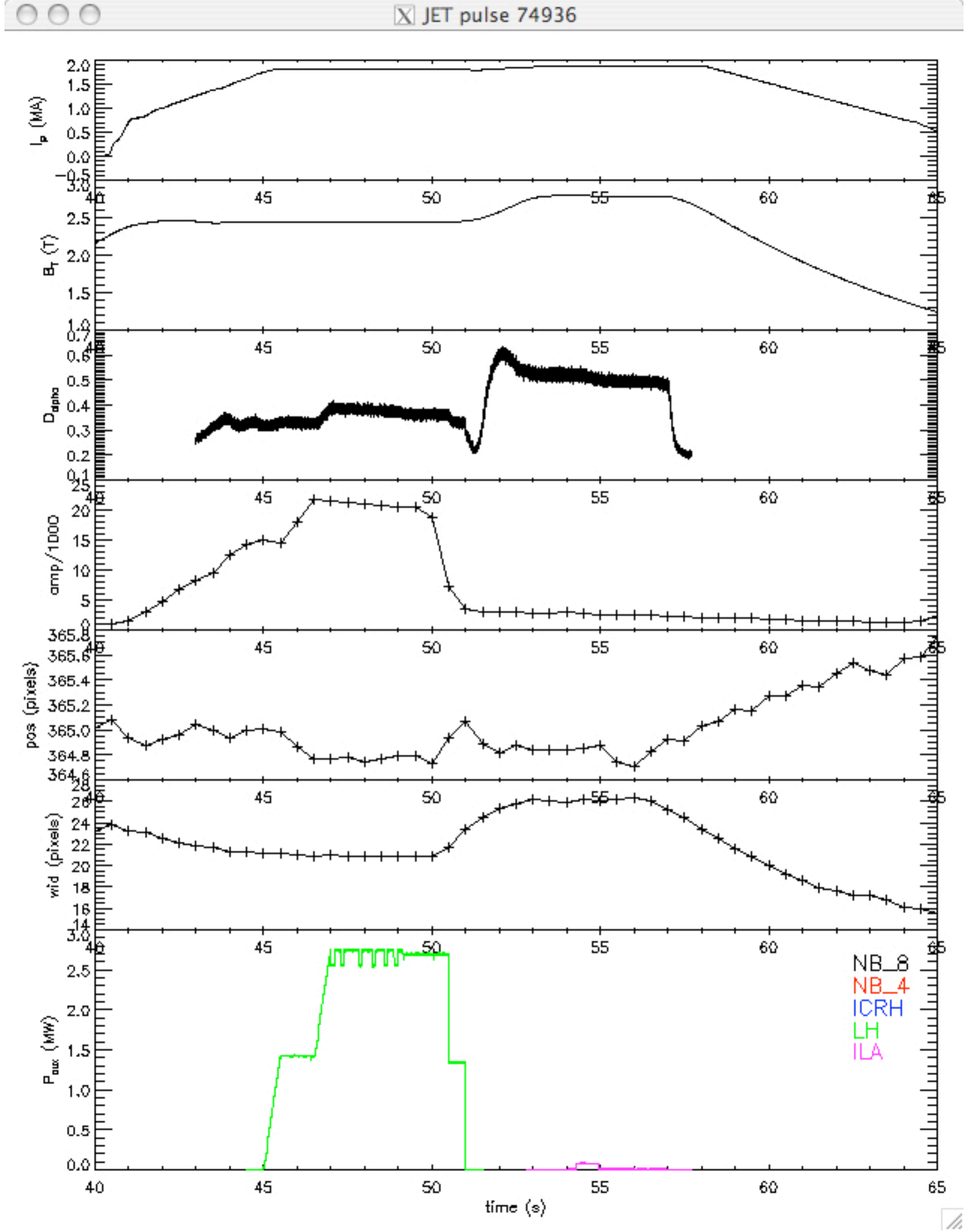
5
ANTENNE C
Octant 5
KS9 "MSE"
Octant 4
NBI
6
4
KL1
CCD camera
for live video
C4 C3 C2 C1
ANTENNE D
D1
D2
D3
D4
LH Launcher
7
3
Octant 7
KS5A
B4
B3
B2
B1
ANTENNE B
A1 A2 A3 A4
KL7
infra-red camera
(new 2005)
8
ITER-like
Antenna
(ILA)
2006)
Octant 8
NBI
Octant 1
KS5C
ANTENNE A
1

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.
- MSE PEMs could enable (σ, π) polarization differentiation.
- KS9A (spectrometer with "new" CCD camera) is being revived.
  - MSE spectrum during ELMs.
  - NBI ions slowing-down spectrum.
  - Stark broadening in rf antenna near-field.

Preliminary JET Data



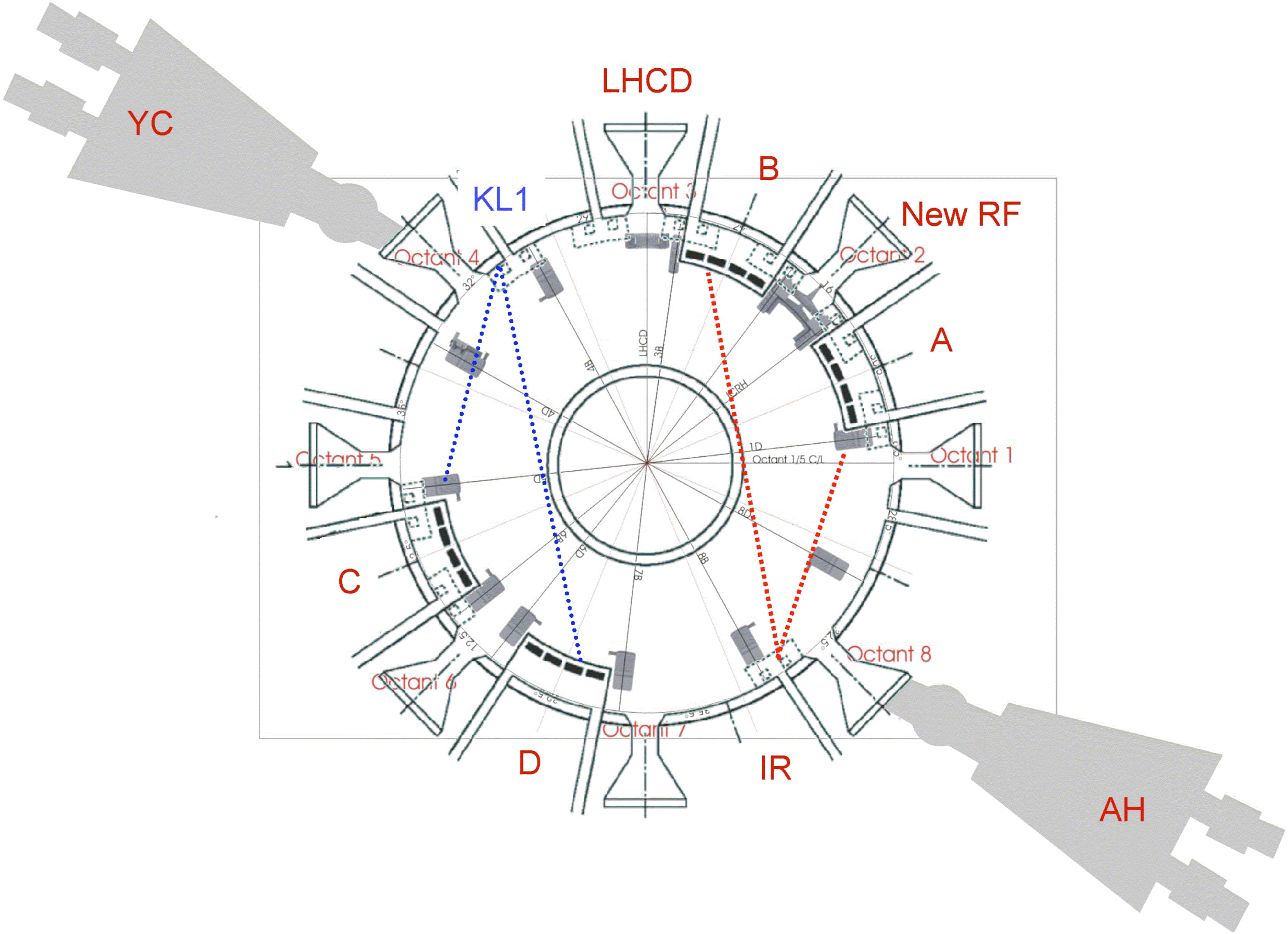
- Have observed MSE spectrum.
- Have observed NBI slowing-down spectrum.
- Have observed D_α from LH launcher (KS9A Ch 17).
- Data interpretation pending.

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 (gathered parasitically) could support the case for the ORNL/Tore Supra proposal.
  - 2 relevant sightlines (KS5A & KS5C) are currently available.
    - Barring any CXRS requirements.
    - Need to know when there will be power on straps A1 & D4 (respectively).
  - "New" KS9A will enable various measurements.
    - Poloidal variation along antenna straps B3 & B4 and LH launcher.
    - Polarization sensitivity possible with MSE PEMs.
    - Disturbs a single channel of MSE during a given pulse.
    - Still under development, but progressing rapidly.
- If successful, could explore further on JET, but bulk of work to take place on Tore Supra.

Supplemental Slides

JET Overview



A Spectroscopic ICRH Antenna Diagnostic for Tore Supra

-to measure Impurity Sources & Electric Fields-

A Proposal for ORNL-Tore Supra collaborative project

Presented by

C.C. Klepper, D.L. Hillis

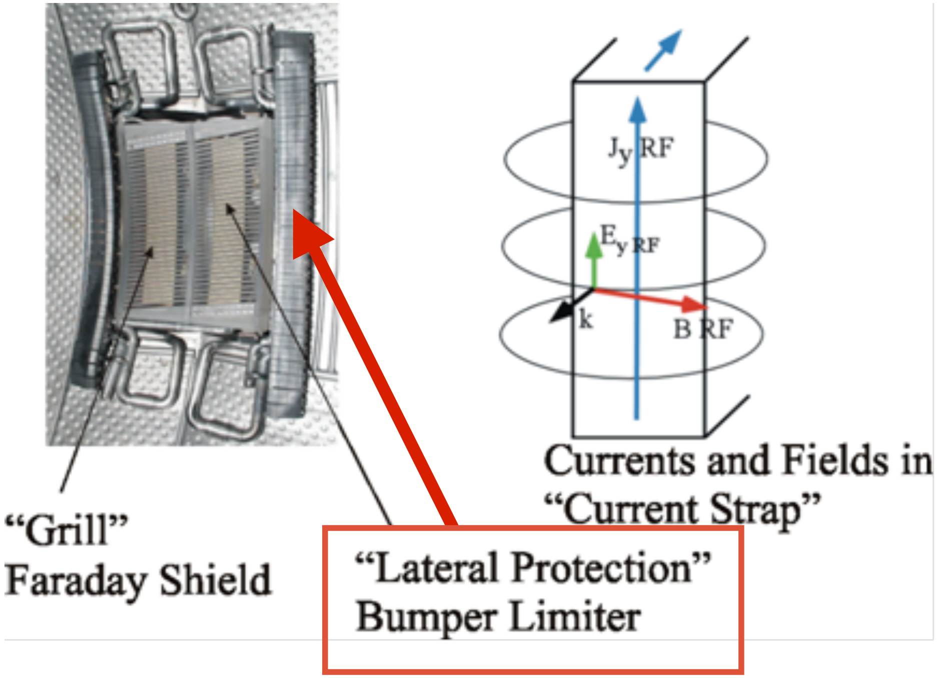
Oak Ridge National Laboratory
Fusion Energy Division

At Cadarache,
September 26, 2008

Goal of Collaboration

- Improve Understanding of coupling of RF antenna to core plasma through SOL
- Spectroscopic measurements can provide new understanding of region in front of ICRH antenna
  - **Provide impurity sources (C, B, Cu, etc) from RF antenna area (not currently available on Tore Supra)**
  - **Provide Electric Field via Stark Effect & from sputtering models**
- Measurements will be supported by additional ORNL modelling and theory efforts
  - **RF modelling (ITER related models)**
  - **Edge modelling (SOLPS, etc)**
- Better understanding of boundary plasma between antenna and core plasma will improve RF coupling in ELMing H-mode
  - **Important to ITER**

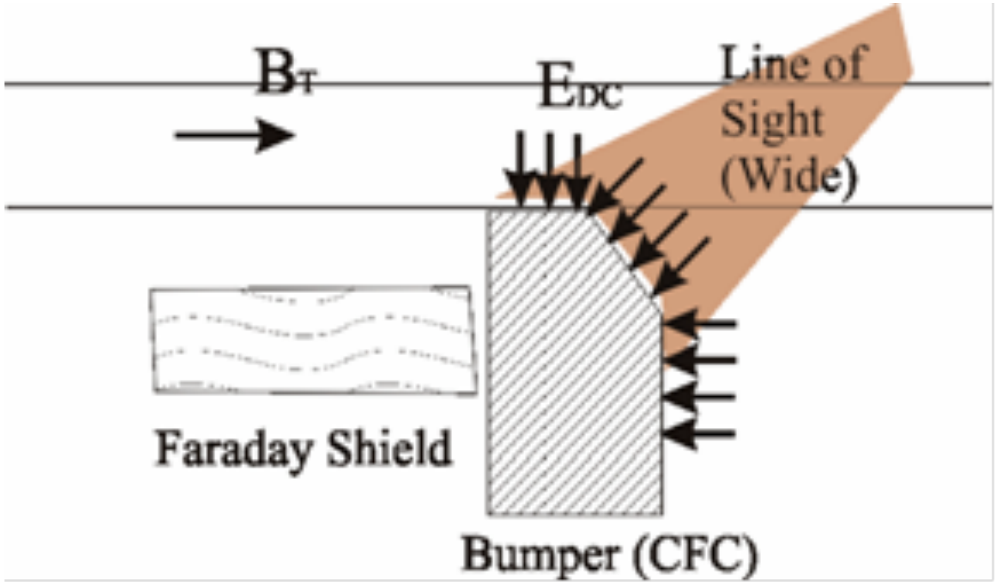
Vision: Direct measurement of both E_{dc} & impurity sources at ICRH antenna



- Possible only with optical spectroscopy
  - **Non-intrusive**
  - **Impurity Sources (C, B, Cu,etc) from line intensities and calibration**
  - **E-field from Stark effect**
- In both cases, poloidal dependence is of most interest
- **A single optical system for both is ideal and possible!**

Images are from presentation by L. Colas, Jul'08

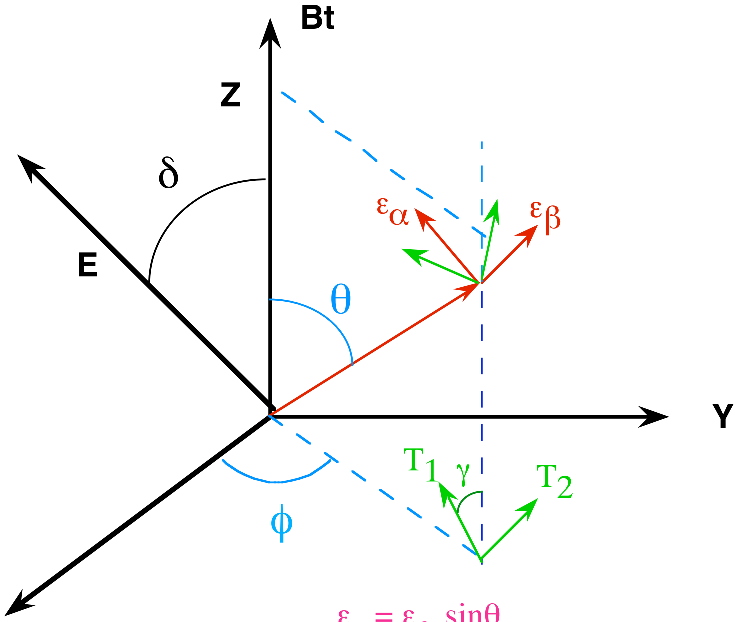
For E_{dc} best optical view measurement: toroidal, ~tangential



- Best for missing the Faraday shield
- Allows for access to large surface with high **D** light emission
- Provides for poloidal resolution

Isler spectral profile modeling supports E-field measurement

Viewing Geometry



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

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

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

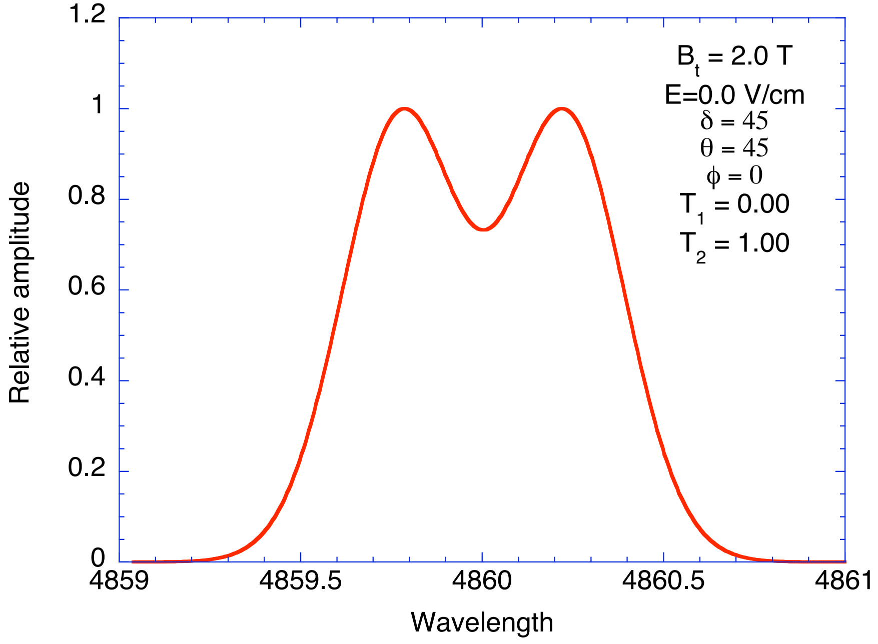
$\varepsilon_\alpha = T_1 \cos\gamma + T_2 \sin\gamma$

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

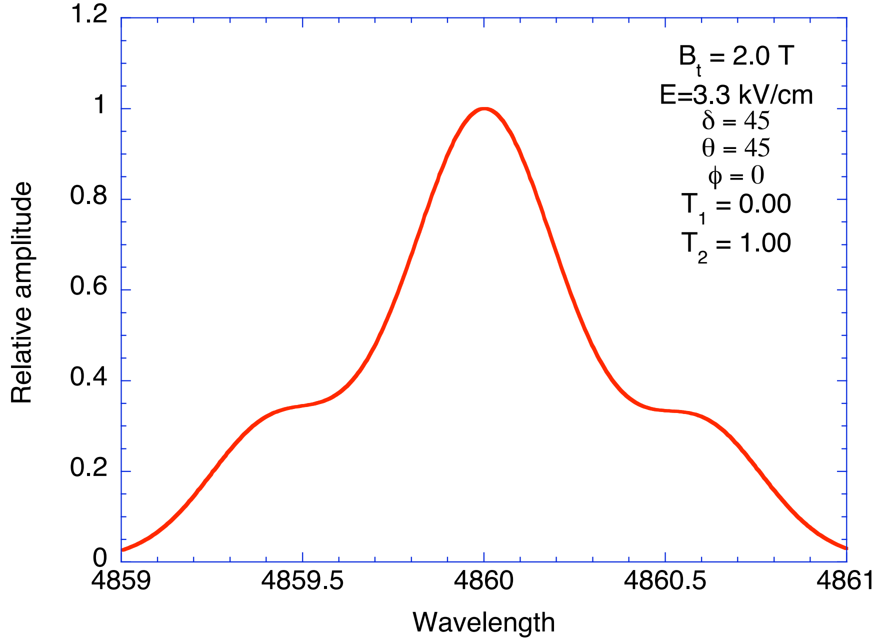
- Full quantum mechanics with both E, B perturbations treated together.
- Able to handle the 3-d geometry of E, B and optical view.
- Polarization of optical system is an input.
  - But note: σ and π components not well defines with combined E and B perturbation!
  - Also polarizations are not strictly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

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)



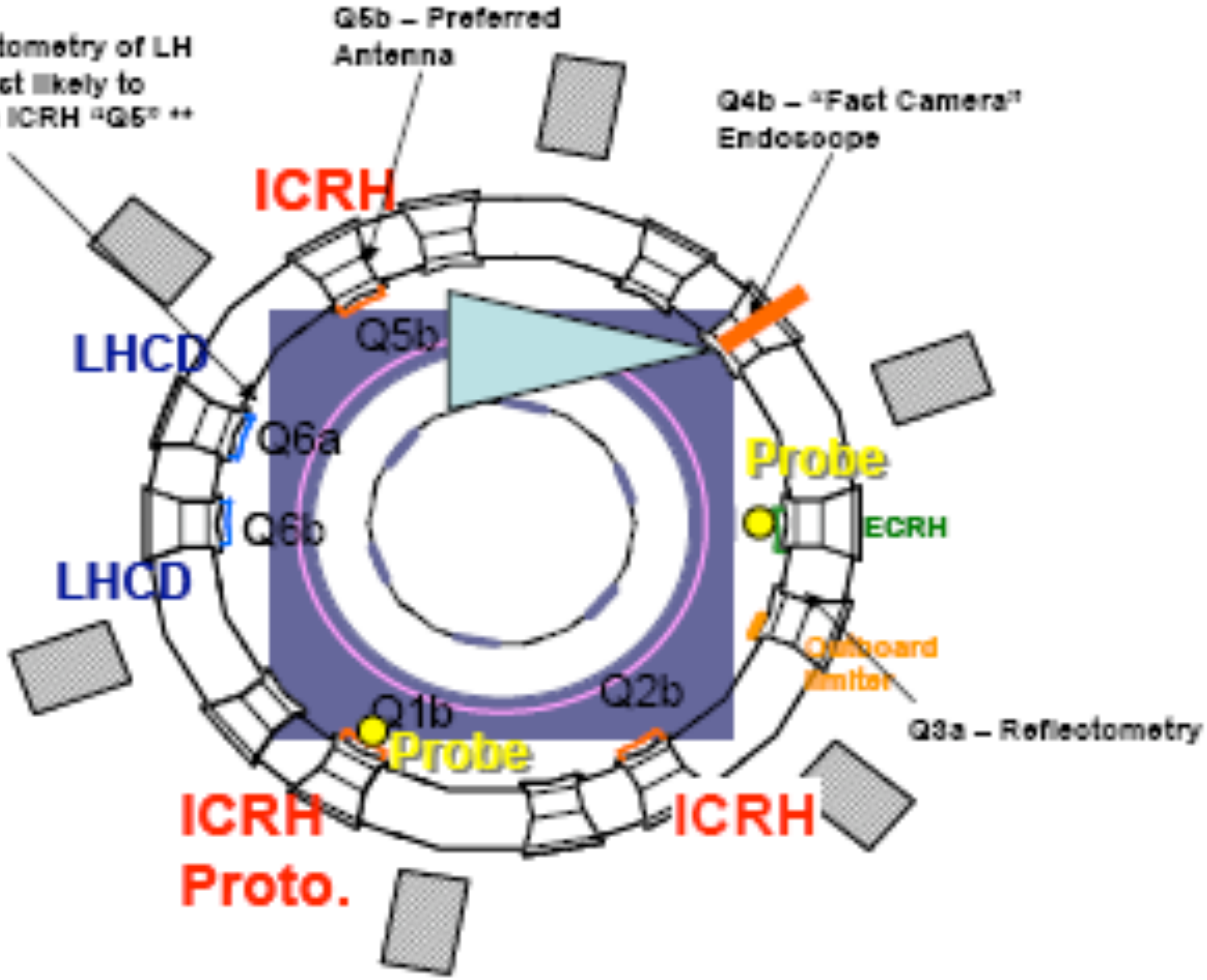
B only



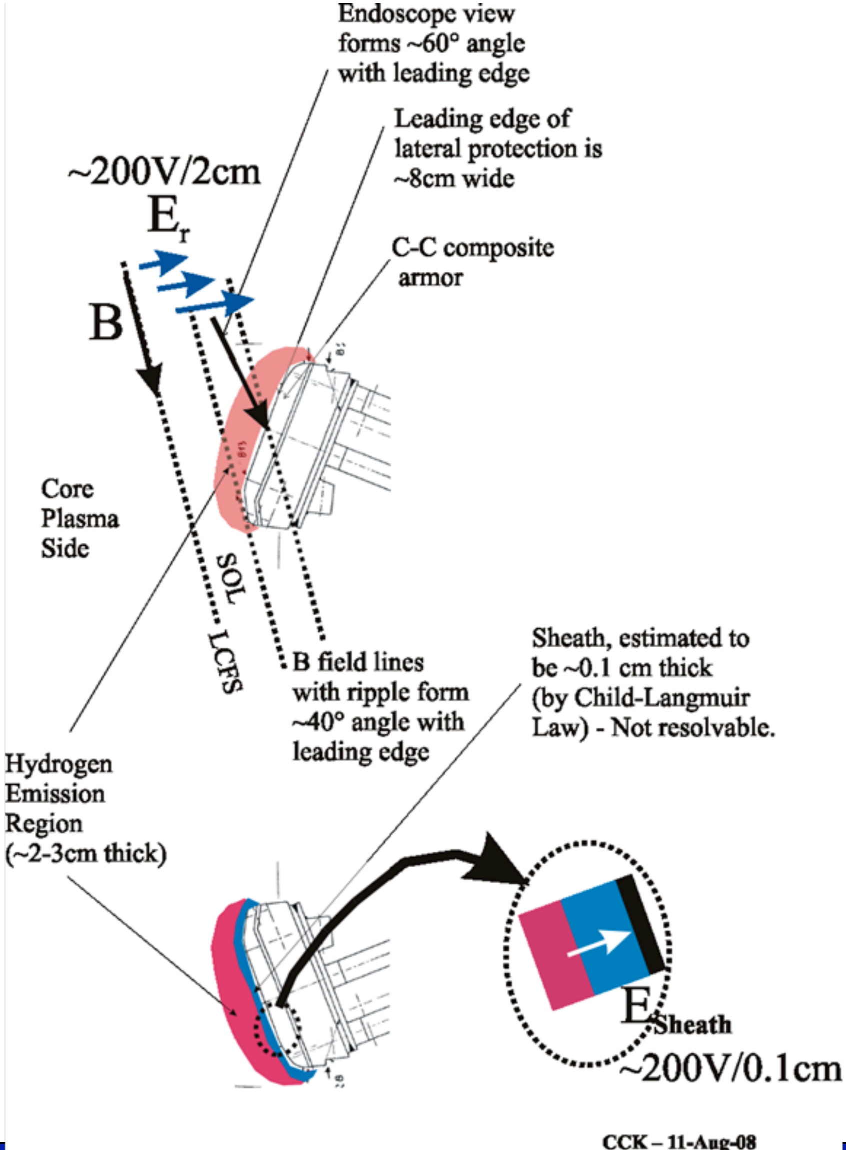
Both B and E

Existing “Camera Rapide” endoscope provides near-ideal access!

Ready view of antenna Q5, plus good connections to supportive diagnostics (i.e. for SOL parameters needed to model the profiles)



Actual Geometry
(with input from Bureau d'Etudes)



- Geometry details for "Camera Rapide" endoscope access obtain with help from M. Goniche and also Bureau d'Etudes.
- For Sheath Field, we determine (for Isler's coordinate system):

  θ= 20° (between view and B)

  δ=50° (between E and B)

And assume 200V/0.1cm

- For "Fringing" field, we find

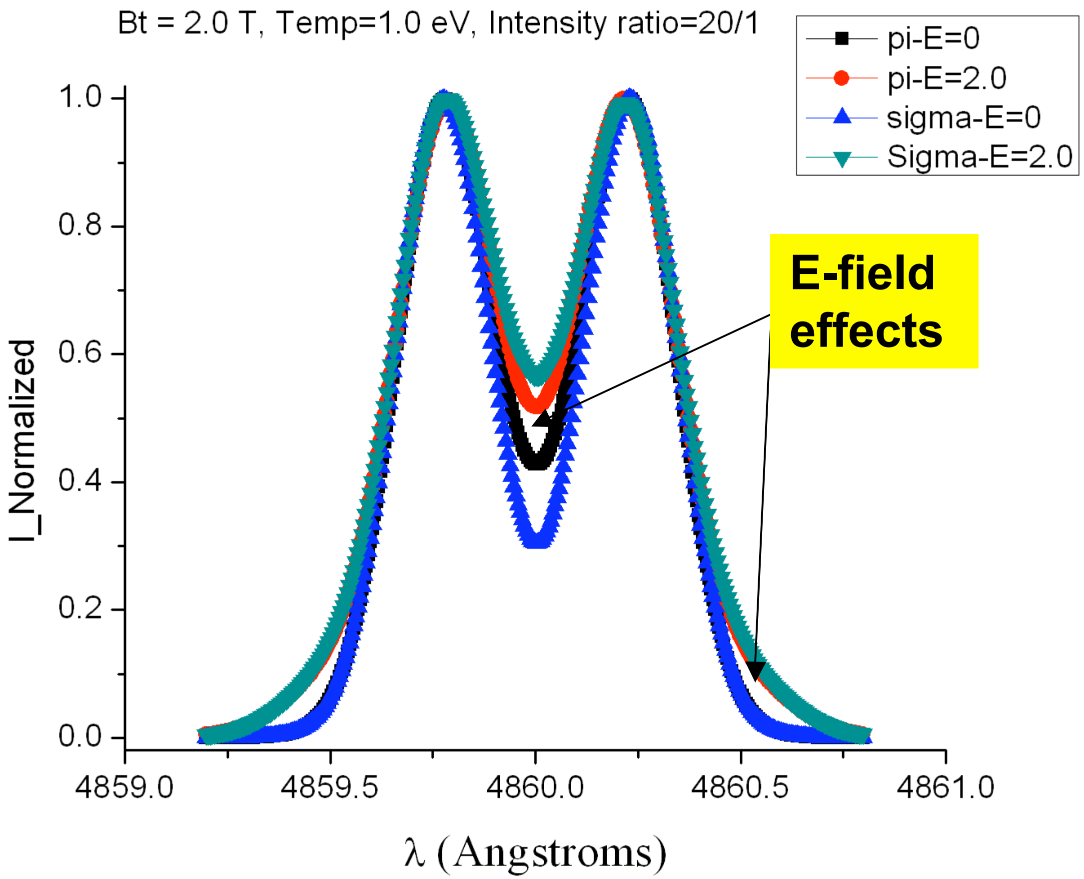
  θ= 20°

  d=90°

And assume 200V/2cm

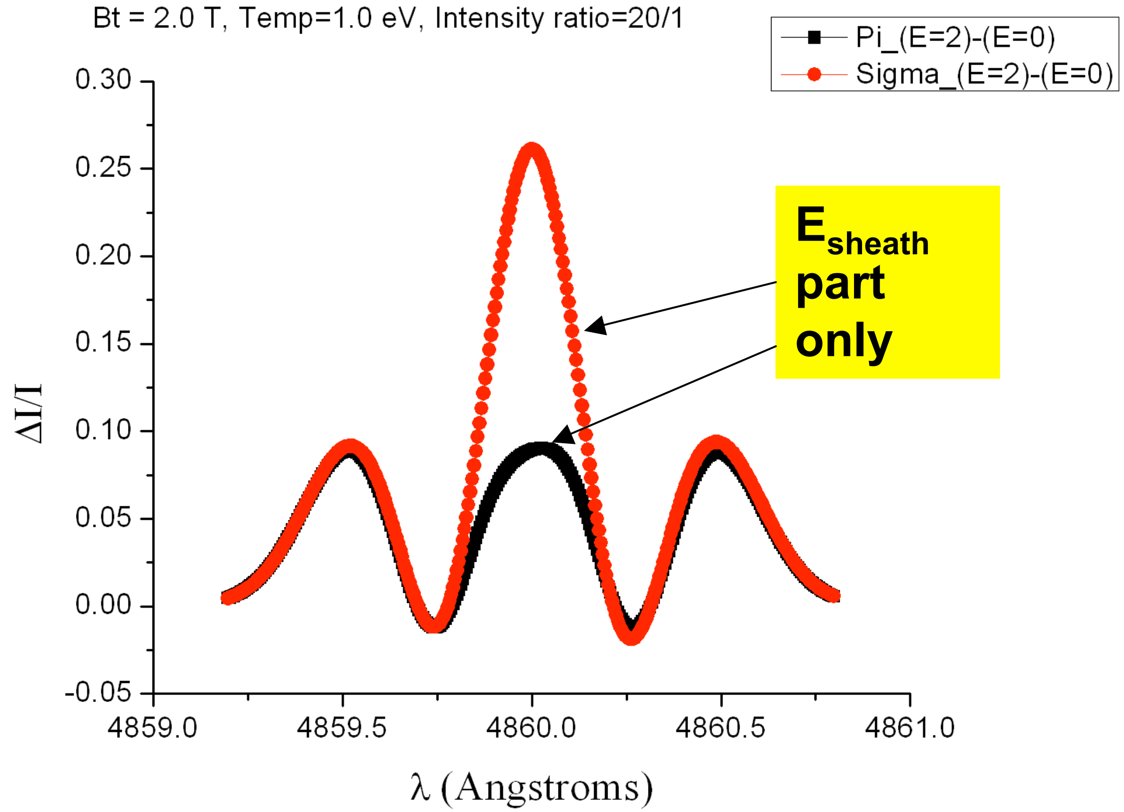
Simulated Profiles

for actual geometry + background emission



- Although the differences between the profiles are small, they are clearly visible
- The effect would become clearer by plotting "difference profiles"
  - See next four slides.
- This suggests the use of rf power modulation as an integral part of the experiment.
  - This is possible in TS
  - Could do 10ms or 100ms modulation
  - Statistics

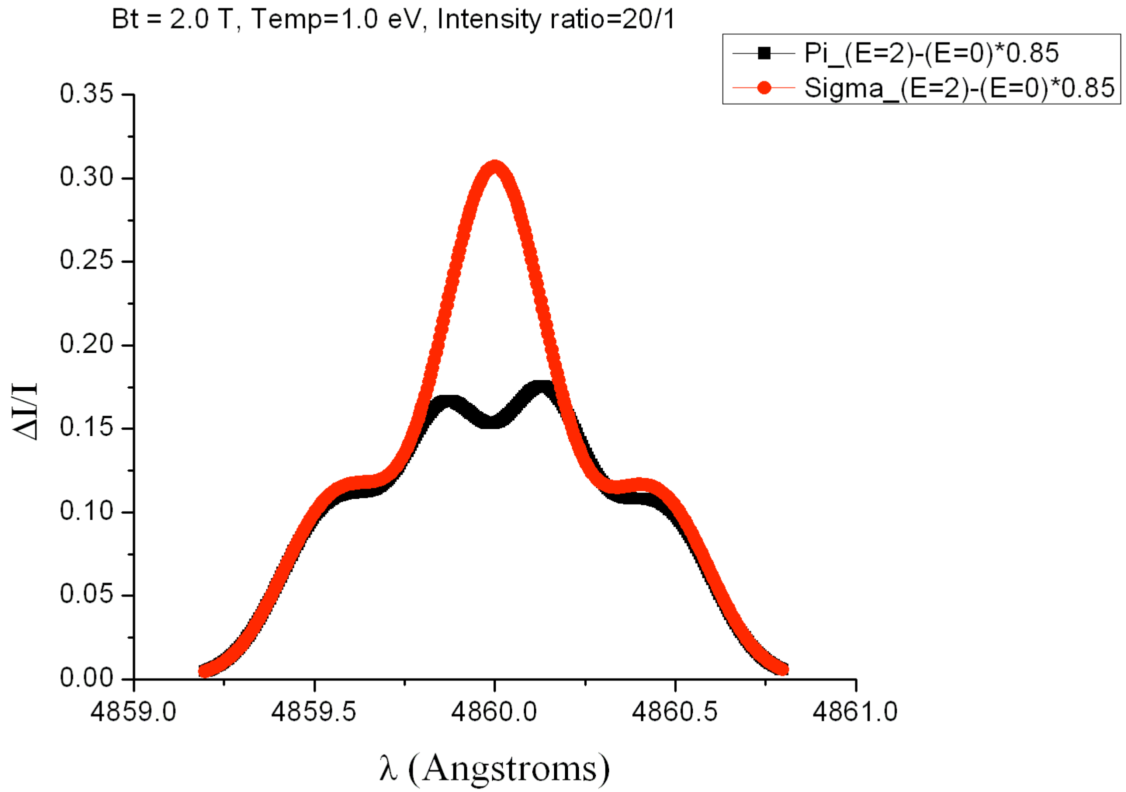
Modulation of RF to remove background H_α emission



- The characteristic side-lobes on the spectral profile have ~10% of the intensity of the total emission.
- In actual measurement, we will likely have contributions from both polarizations.
- **Still, even 10% effects may be measurable if sufficient statistics, e.g. modulate at 10ms and sample over 1s.**

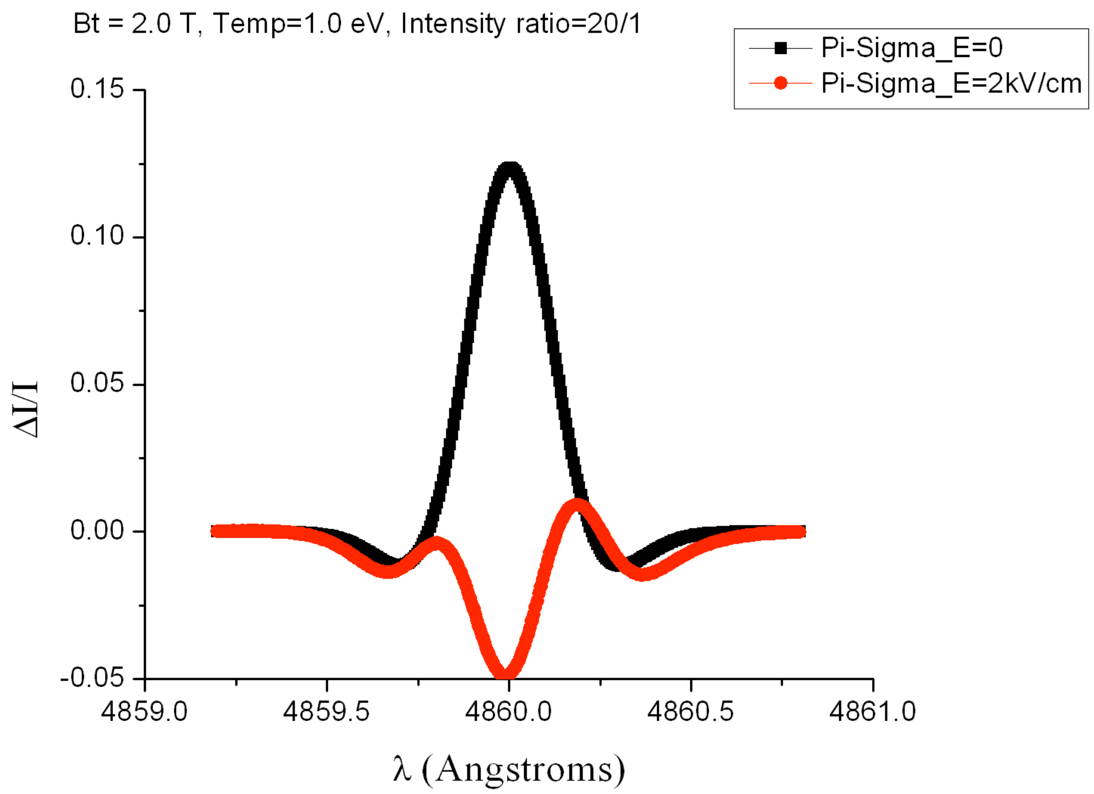
Difference Profiles

(<u>here</u>: effect of rf ON/OFF; same polarization; assume 15% drop in n_e SOL with rf OFF)



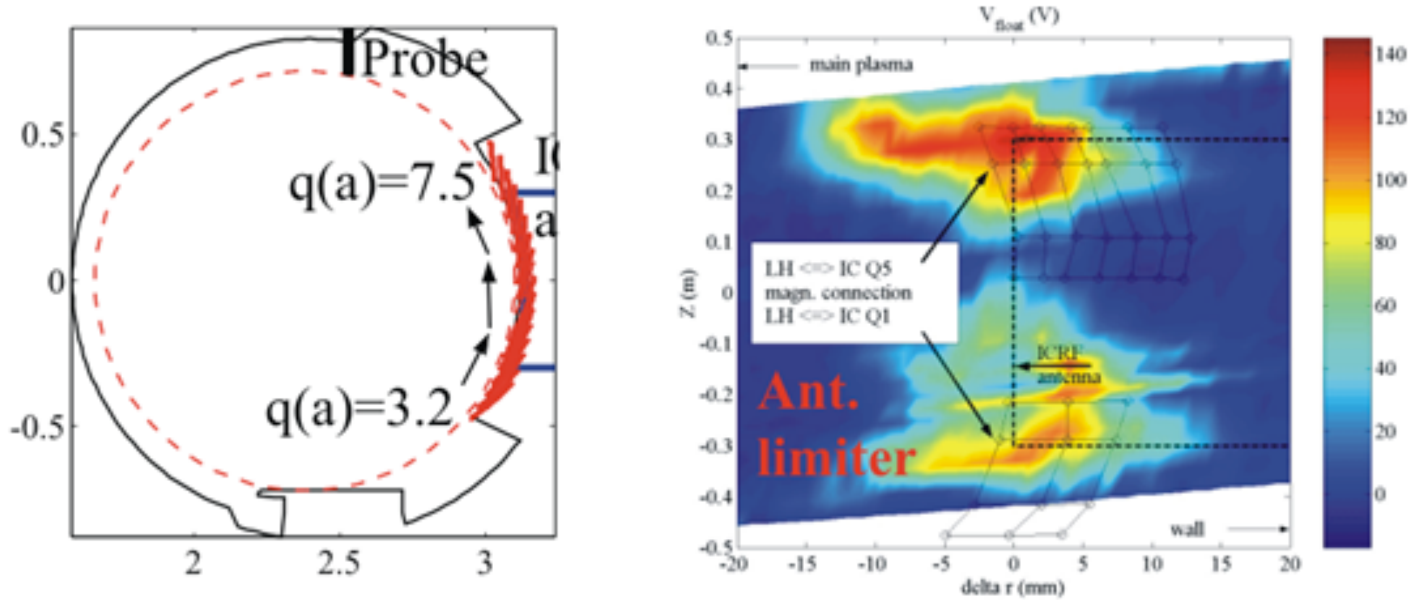
- **What if rf_OFF subtraction is imperfect?** Suppose the SOL n_e (or just the local n_e) drops by 15% with rf OFF.
- We still see a small but significant effect (bumps in the profiles).
- **If change in the SOL parameters is the issue, we could modulate a second antenna 180 degrees put of phase.**

Difference Profiles
(<u>here</u>: effect of collection optic polarization)



- If it were possible to alternate the polarization from shot-to-shot, while modulating the rf-power, we would get "difference profile" that change substantially at ~2kV/cm E_sheath, even with 20:1 background emission.
- This approach would likely require a dedicated optical system.

Large poloidal variations already seen in RLP studies of the antenna in TS



From R,Z scan of the floating potential with the RLP connected to one of the ICRH antennas in TS.

- We also wish address poloidal dependence and propose to start with, at least, three poloidal views.

Images are from presentation by L. Colas, Jul'08

Implementation

- Minimize impact on existing diagnostics and access to the enclosure (Hall Tore)
- Spectrometer and its camera will be outside the Hall; **Use PI camera, already known to TS.**
- Minimal interference with "Camera Rapide" system
  - **Simply replace the camera with an optical fiber bundle connector at the exposed end of the endoscope**
- Construct the specialized fiber bundle at ORNL.

Interface details

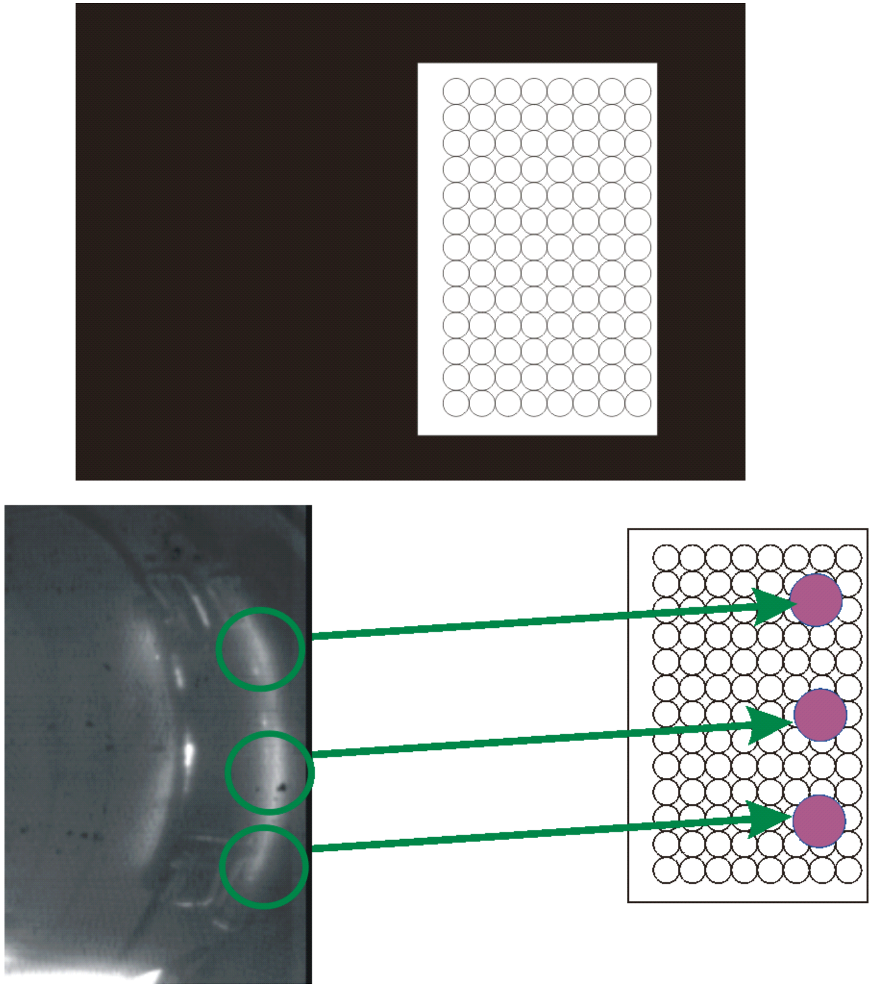
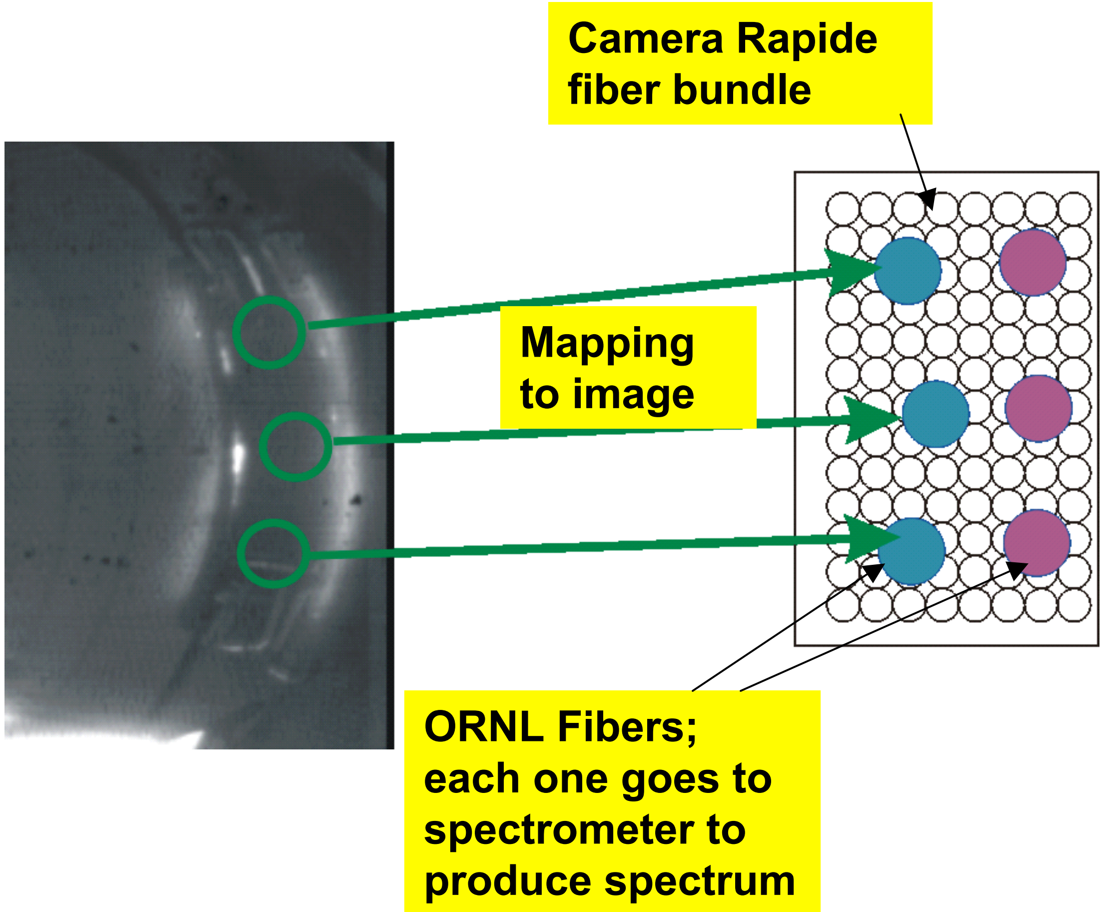


Figure 1. Illustration of the concept of mapping groups of mini-fibers to large fibers (or set of large fibers)

- Adapt existing large bundle of small fibers to small bundle of large fibers
- **Keep simple**: begin with 3 or 6 large poloidal regions on the bumper

Simple transition between impurity sources and E_{dc} measurement



- It is clear from the camera image that the grill is just as accessible as the bumper!
- The interface could either provide for additional large fibers, or
- Benefit from existing "moving stage" feature for the Fast Camera to simple shift the three fibers from bumper to grill access!
  - Stage is remote controlable

Proposed Schedule

- Physics Program Review: Week of September 22, 2008
- Conceptual Design Review: Week of October 6, 2008
- Engineering Design Review: Late January 2009
- Spectrometer/Filtercope installation: Feb/Mar 2009
- System fully operational by mid-May 2009

Connection to TS Priorities and Existing Programs

- SOL physics
  - RF coupling: antennas impurity sources; already measure effect inside plasma; connect to sources.
  - Antenna electric field measurement for verification of Laurent Colas models; comparisons to ASDEX-U.
  - Link between wall/antenna impurity sources and turbulence (EFDA Transport TF project)
  - Expertise in (n_e, T_e) measurements on TPL with He beam; already planned for next operation period.
- Carbon migration
  - Expertise in impurity sources measurements

Summary

- A dual use, spectroscopic diagnostic for studies of ICRH physics that are relevant to the ITER program.
  - direct measurement of the **rectified, dc electric field near the antenna** for the Stark-effect broadening of the spectral line of the Balmer series lines of H/D.
    - **The "great unknown" in the understanding of rf coupling with ICRH heating. Its direct measurement will constitute a substantial contribution to ICRH physics.**
  - real time monitoring of **impurity sources at the antenna** and, with the use of well-established calibration techniques, the determination of absolute source of the impurities generated at the antenna.
    - **contribute to the overall understanding of impurity content and radiative balance in Tore Supra,**
    - **also tie into the electric field study, since the dc electric field is believed to be the main cause of enhanced sputtering leading to localized erosion and impurity production (see, e.g. Bobkov et al., PSI'08).**
- Implement with minimal impact on Tore Supra operation.
  - Most of the instrumentation will be outside the main experimental area.
  - An existing, endoscopic optical system will be used to optically access the antenna with a nearly tangential, toroidal view.
  - rapid change-over between the two configurations..