Status of DIAS**

-- and related ORNL activities on Tore Supra --

Presented by

Chris Klepper @ORNL for
FEST Seminar, 08-OCT-2009

Original DIAS Proposal was in Sep'08

**New Tore Supra Diagnostic:
DIAS
(Diagnostic: ICRH Antenna Spectroscopy)

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Content

- Summary of main goal and specific aims of the DIAS diagnostic
- Quick account of the adventures in optical alignment to get the desired optical views
- Present capability after best alignment
- Predicted spectral profiles and projections for extracting the desired ICRH antenna physics
- Experimental plan for DIAS
- Parallel proposals for “Limiter H-Mode” Studies on TS

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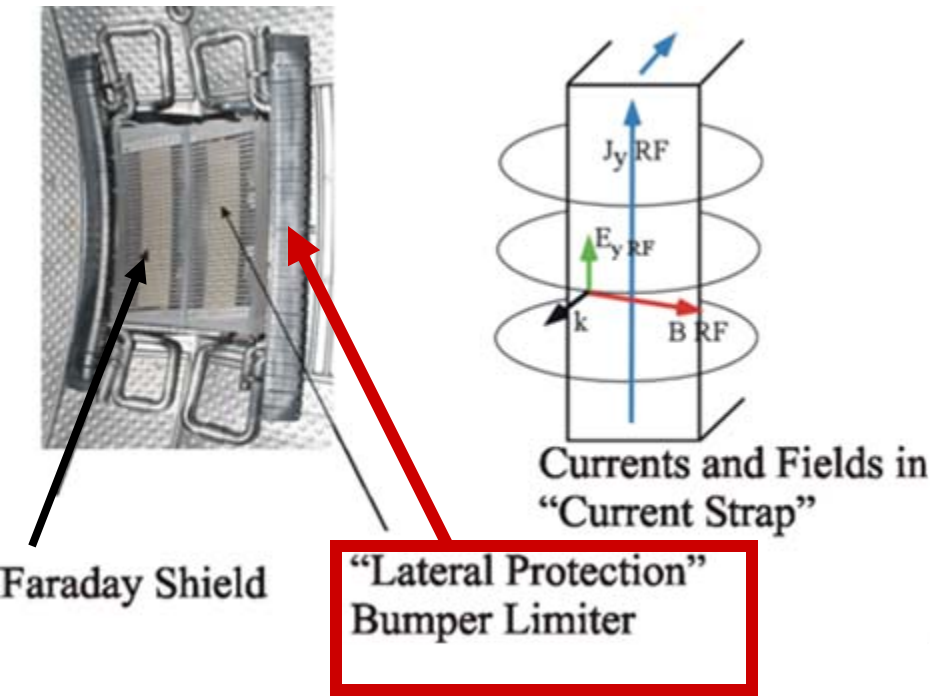
Goal: Diagnostic intended to provide direct, optical views on ICRH antenna



- Dedicated (Visible-range) Spectroscopy
  - Impurities
  - Particle sources
  - **Electric Field** (Stark Effect)
- We needed at least 1 view on the lateral protection bumper.
- We hoped for 3- 5 distinct views on the bumper to get poloidal variation.
- Also of interest: 1-2 views of Faraday Shield

Original DIAS Proposal was in Sep'08

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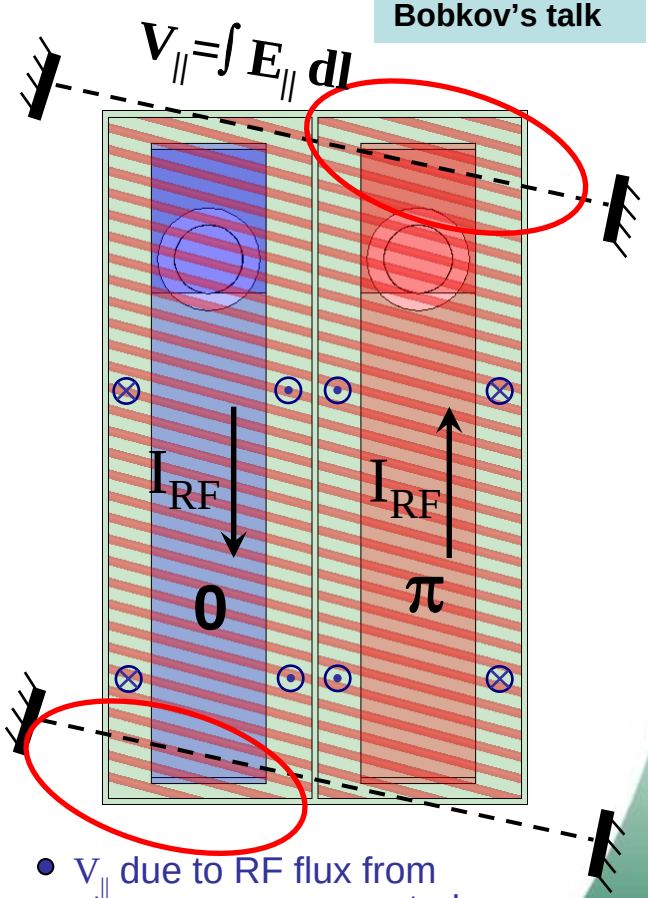
E-Field Measurement: High Risk, High Impact!

- Main Interest is in E_{DC}(SOL)
- Most relevant models from L. Colas
- Renewed interest resulting from:
  - "Operation of ICRF antennas in a full tungsten environment in ASDEX Upgrade," by V. Bobkov et al. PSI 2008, Toledo, Spain
  - "ICRF Specific Impurity Sources and Plasma Sheaths in Alcator C-Mod", S.J. Wukitch, B. LaBombard, et al., PSI 2008-Toledo.
- Both studies confirm the ~200V level POTENTIALS predicted by Colas
- But neither is measuring ELECTRIC FIELD directly!

Figure from Bobkov's talk



- $V_{||}$ due to RF flux from straps, uncompensated contributions in the corners

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HOT SPOTS from RF Sheaths
CRITICAL ISSUE FOR ITER!!!

IR image of Tore Supra ICRF antenna after 60s pulse with P_{ICRF} = 4.2 MW (2 ant.) and P_{LH} =3 MW

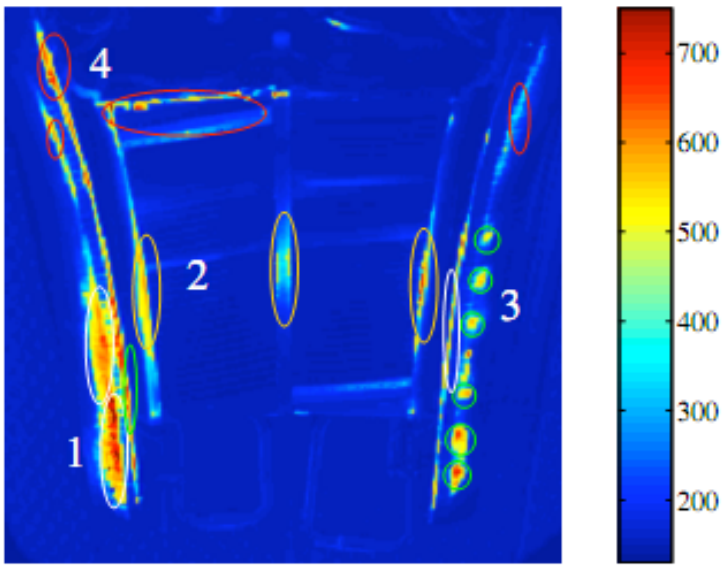
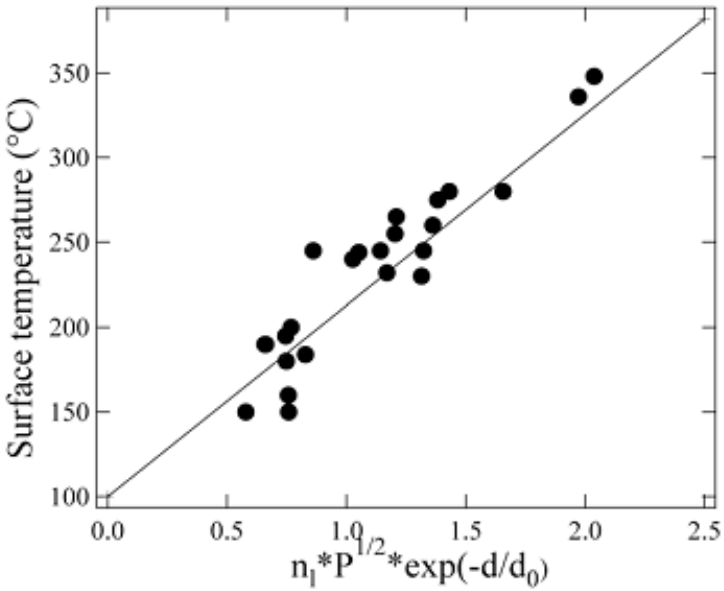


Figure 10. IR image of antenna Q1 on shot TS33748 at t = 63.7 s. Unit is °C. Superimposed on the image, a selection of zones on the front faces, classified according to their sensitivity to different sources of additional power are: zone 1 (white): mainly sensitive to the total power, zone 2 (orange): mixed total ICRF power and private ICRF power, zone 3 (green): sentitive to LH power only and zone 4 (red): predominantly private ICRF power.

Hot spot temperature scaling with local antenna power (range up to ~ 2 MW)



- Similar issues with LH launchers
- Neutrons will make things worse.
- Failures of thin-walled, actively cooled antenna components => water leaks,
- Remedies: optimize RF potentials
  materials, shaping

Slide from recent JH Harris talk

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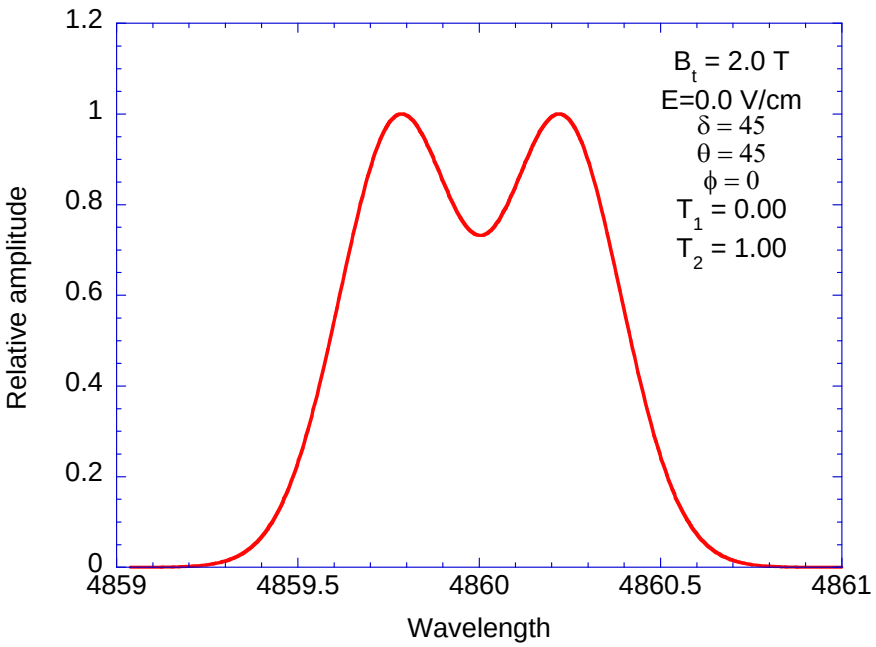
The principle of the E-field measurement:

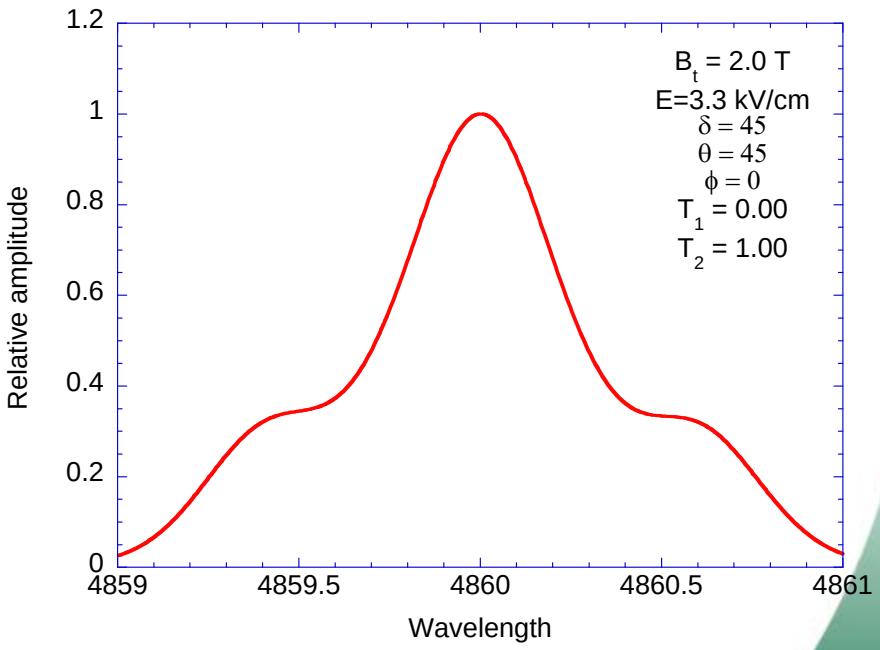
Due to the Zeeman and Stark effects, both B and E affect Spectral Line Profile

e.g. for D_β

Spectral profiles predicted using R.C. Isler codes (quantum mechanics)



B only



Both B and E

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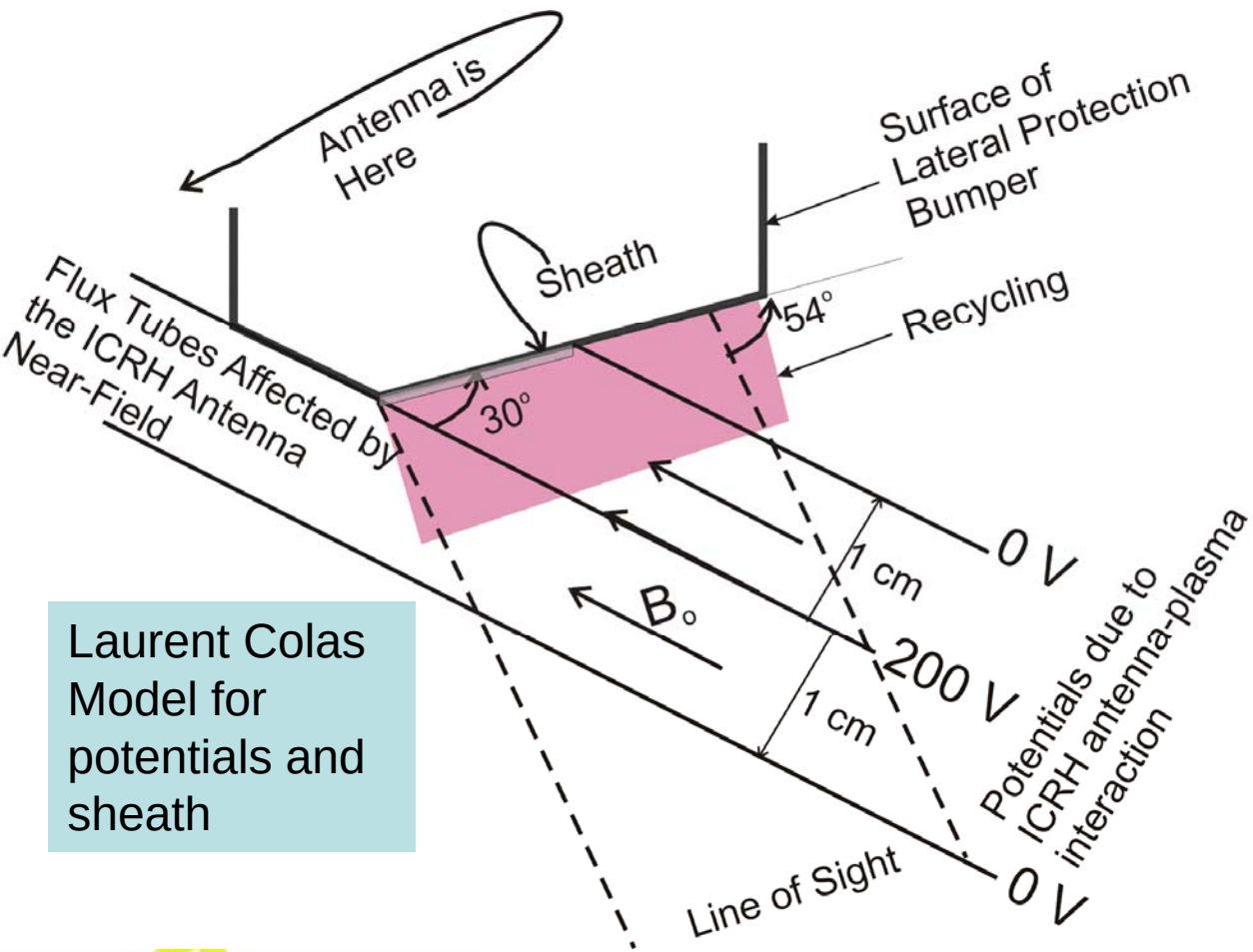
Full Model Should Account for Actual Geometry and "Background" Emission

e.g. for Optical View Intercepting only the Nearest Lateral Protection Bumper:



Laurent Colas Model for potentials and sheath

Note:

1. Only the "Recycling" region contributes to the spectral profile.
2. There are three parts to this contribution: >>Two of these have low E-fields (~200V/cm) and with opposing directions; >>The other region ("Sheath") has high E, perpendicular to Surface. The Sheath region is very thin (~0.5 – 1mm), leading to E~2 – 3kV/cm.

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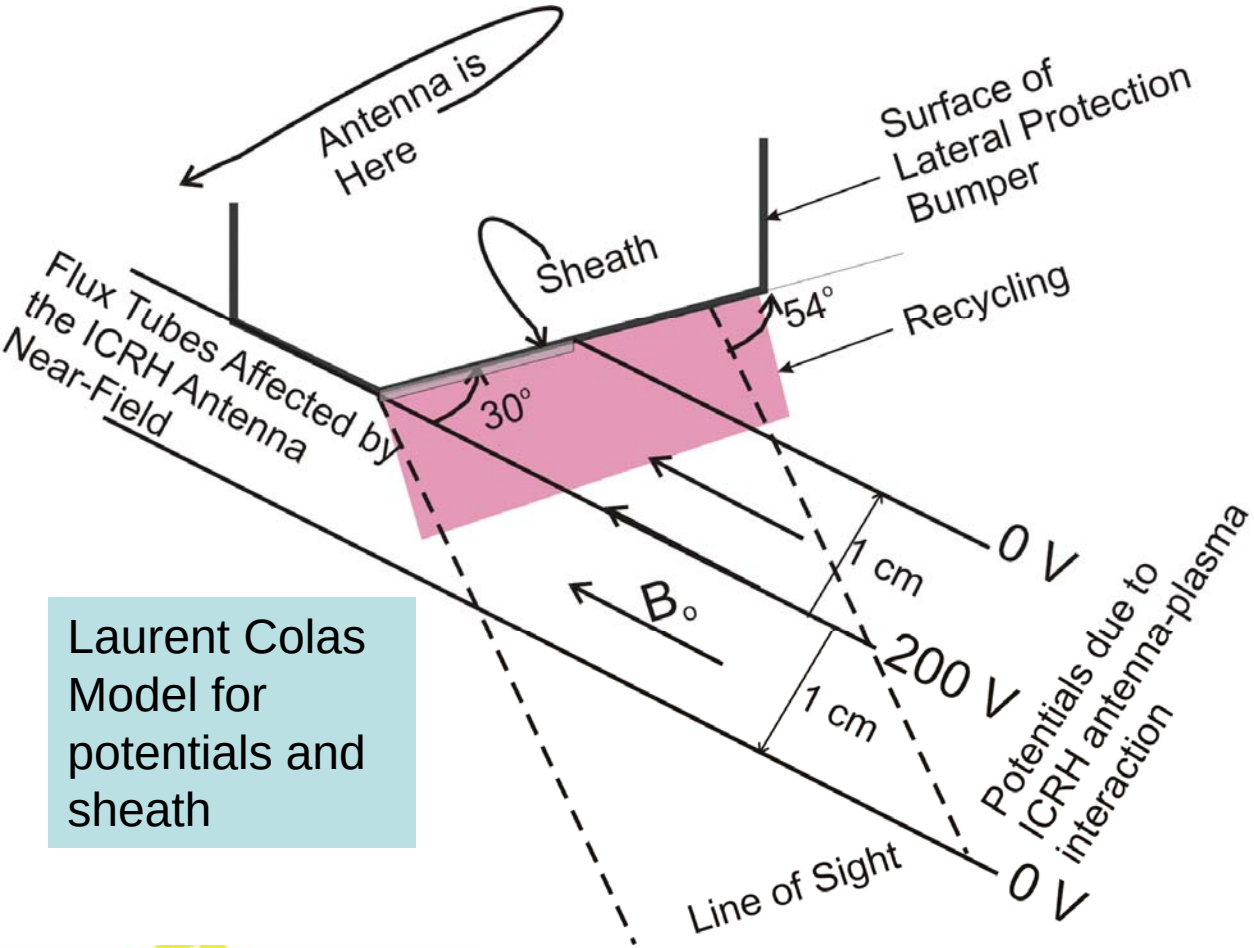
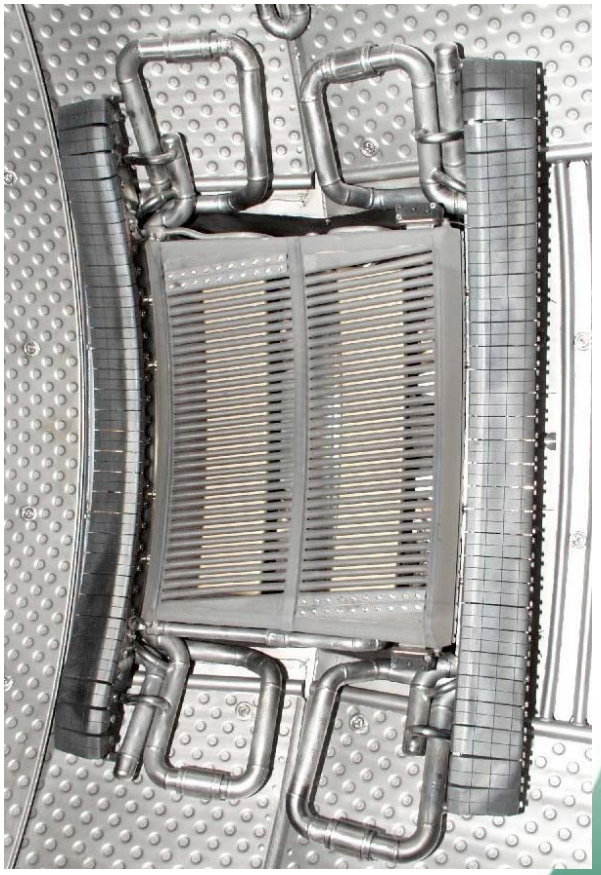
Geometry for Optical View Intercepting only the Nearest Lateral Protection Bumper





Laurent Colas Model for potentials and sheath

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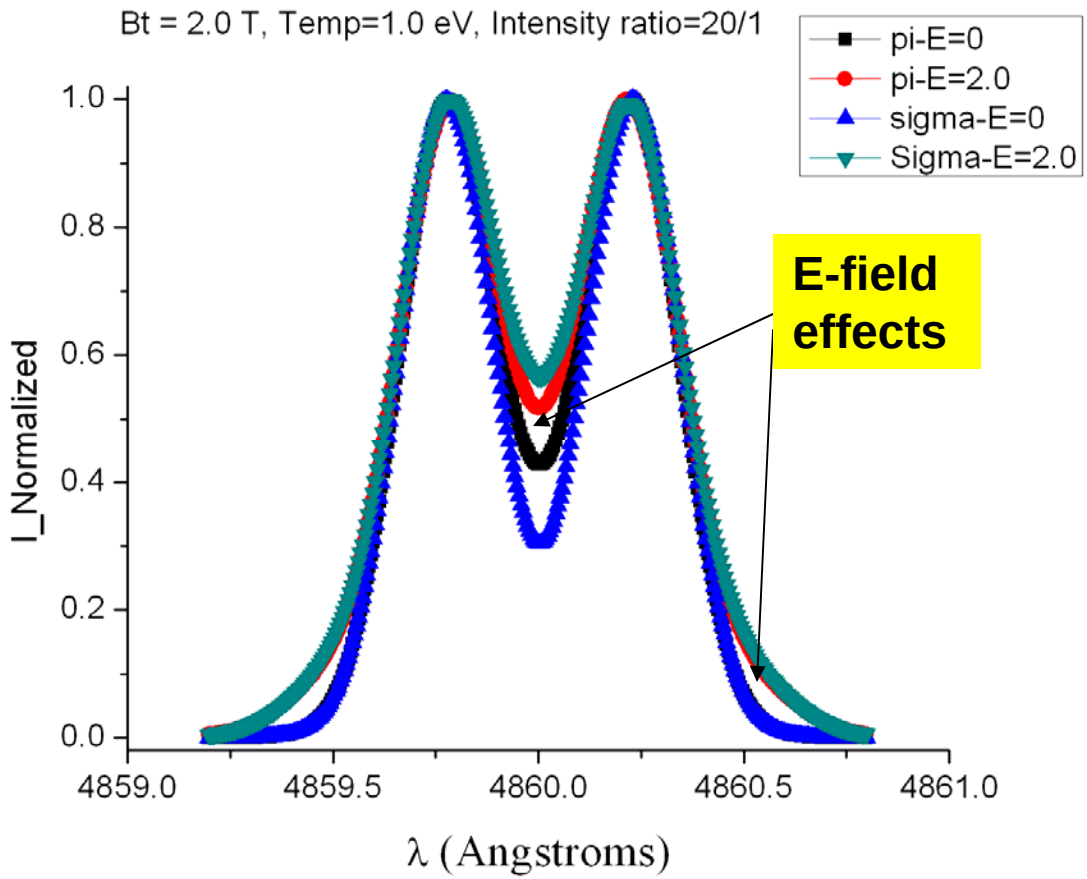
Simulated Profiles

for actual geometry + background emission

Here assuming 20:1 background emission (pessimistic scenario)



- Although the differences between the profiles are small, they are clearly visible
- The effect would become clearer by plotting "difference profiles"
  - See next slide.
- 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

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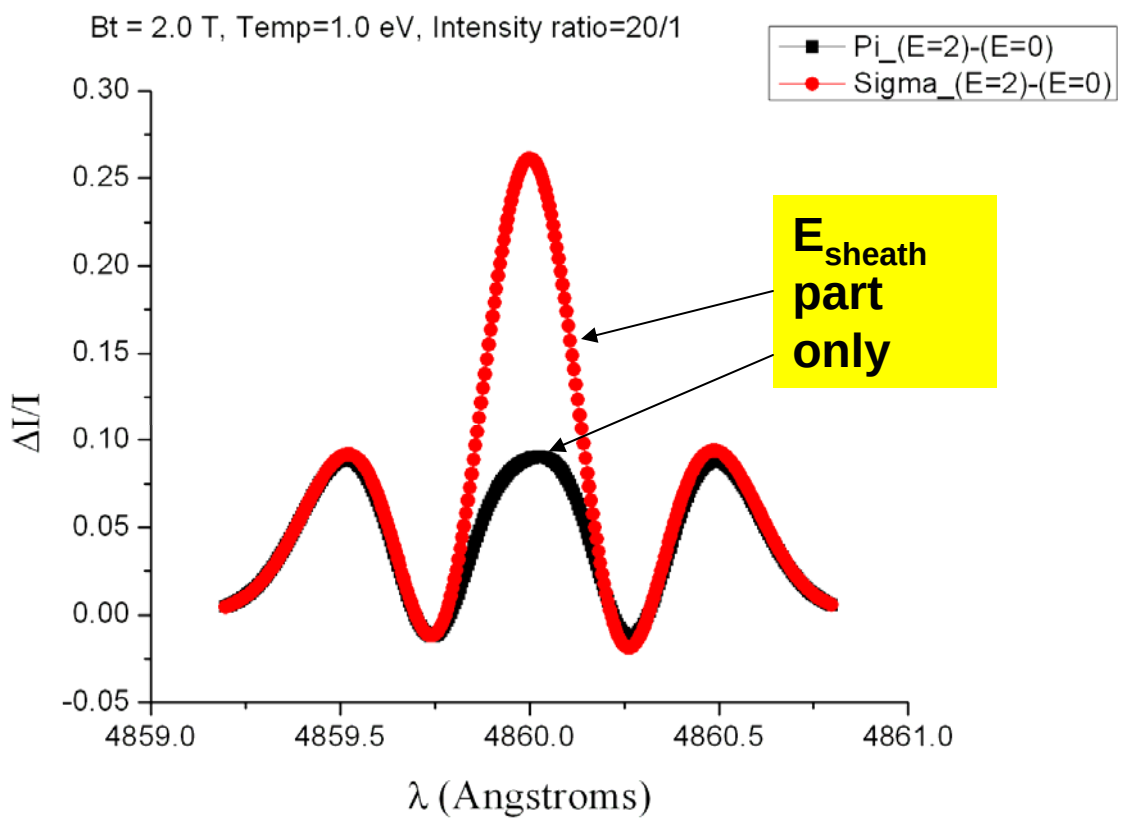
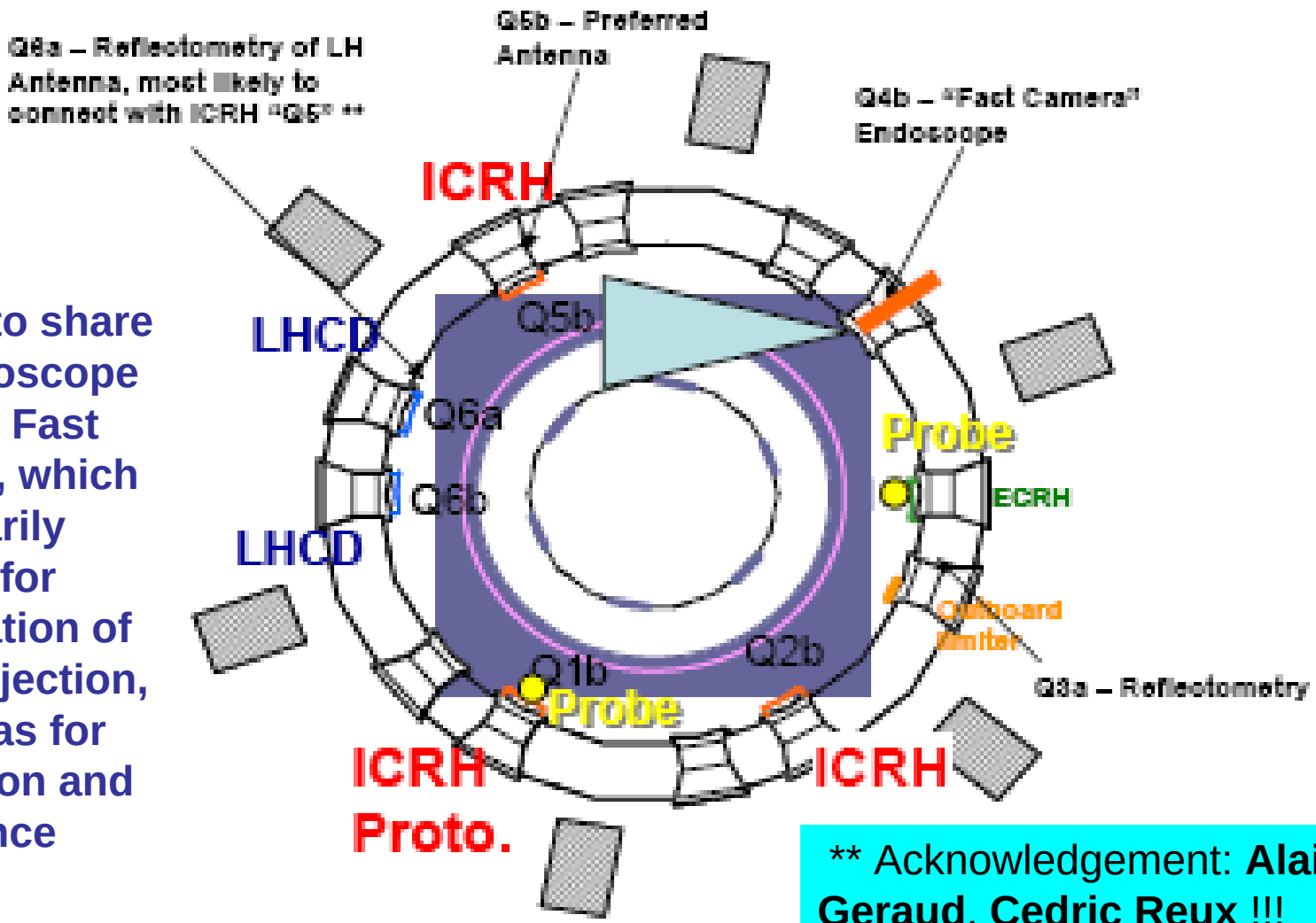
Modulation of RF to remove background H_α emission



- 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.**

“Camera Rapide”** (Fast Camera) endoscope: toroidal view of the ICRH antenna at Q5b

Plan is to share the endoscope with the Fast Camera, which is primarily needed for observation of pellet injection, as well as for disruption and turbulence studies.



** Acknowledgement: **Alain Geraud**, **Cedric Reux** !!!

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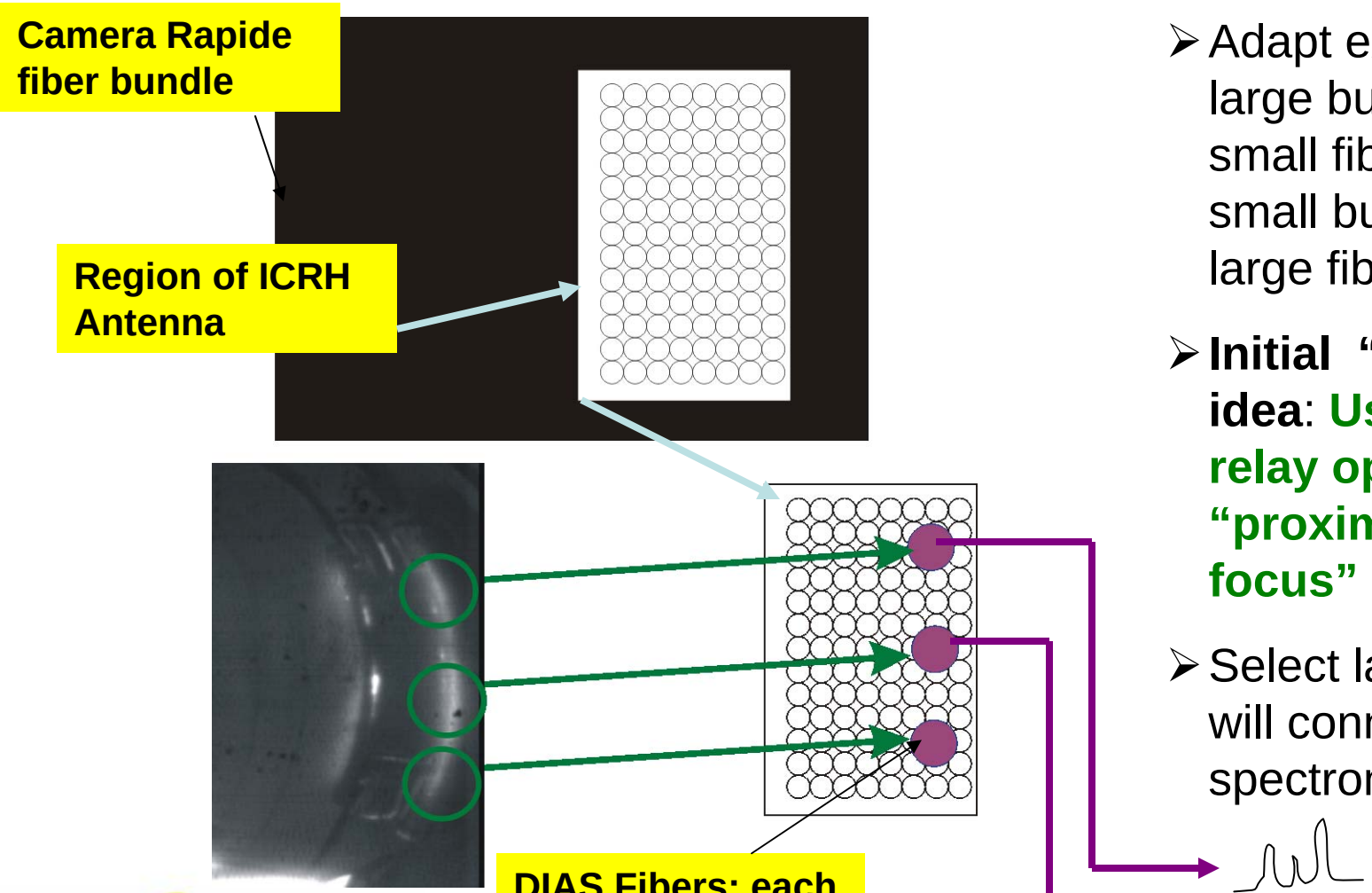
Optical Interface Concept



- Adapt existing large bundle of small fibers to small bundle of large fibers
- **Initial "simple idea**: **Use no relay optics; just "proximity focus"**
- Select large fibers will connect to the spectrometer

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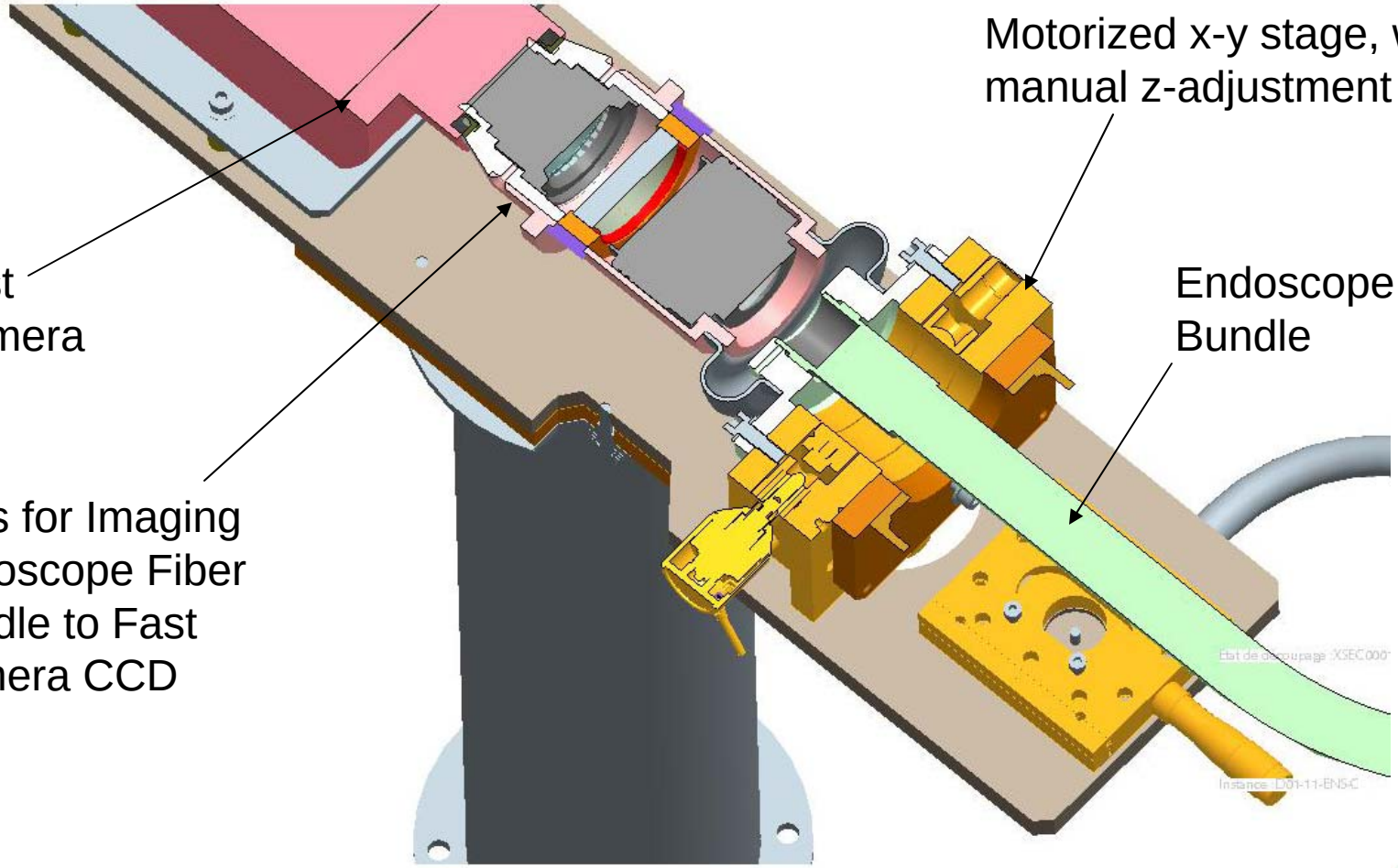
Camera-Fiber Bundle Interface

Existing Hardware



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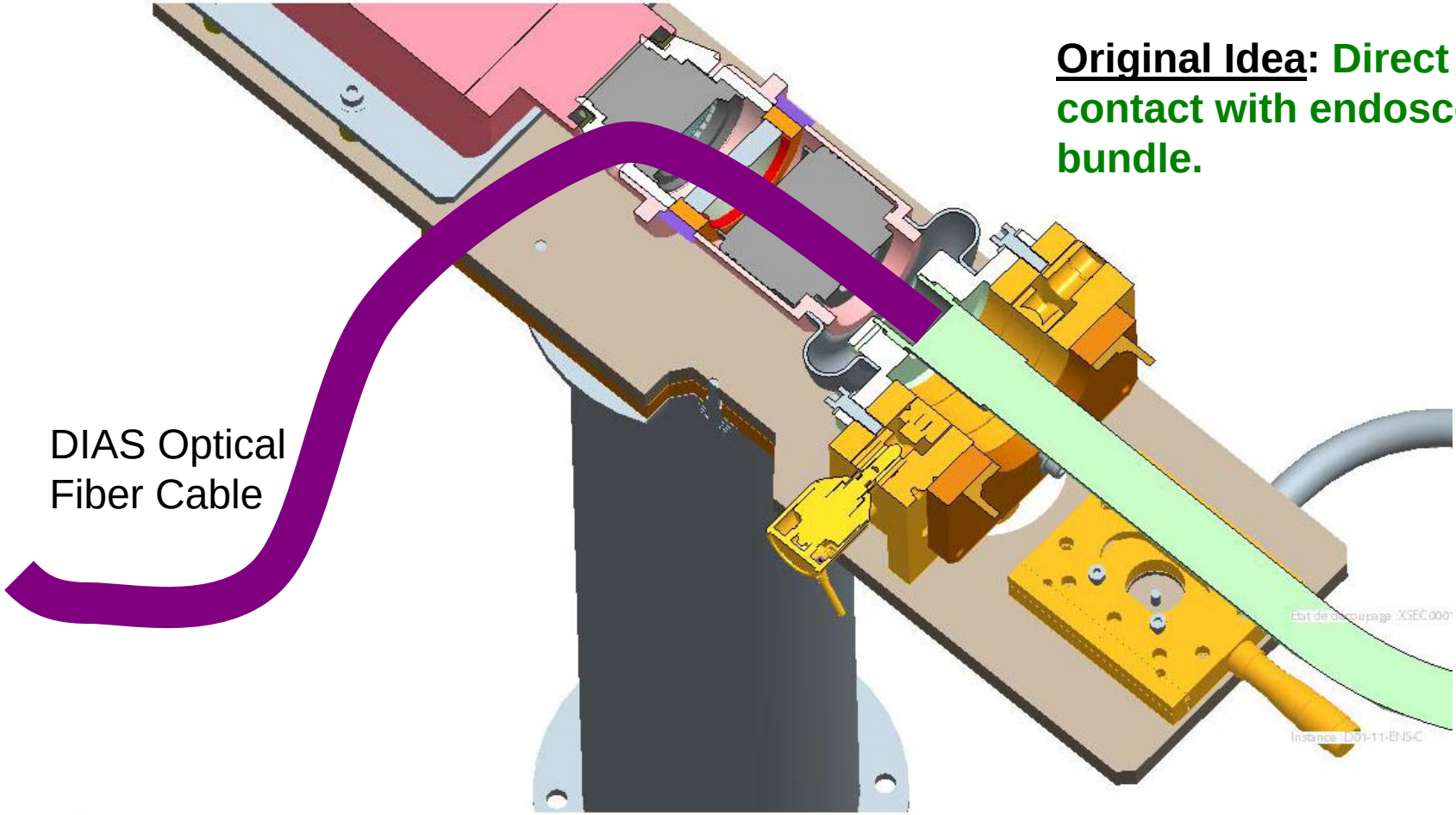
Camera-Fiber Bundle Interface

Add ORNL Bundle (DIAS)



<u>Original Idea</u>: Direct contact with endoscope bundle.

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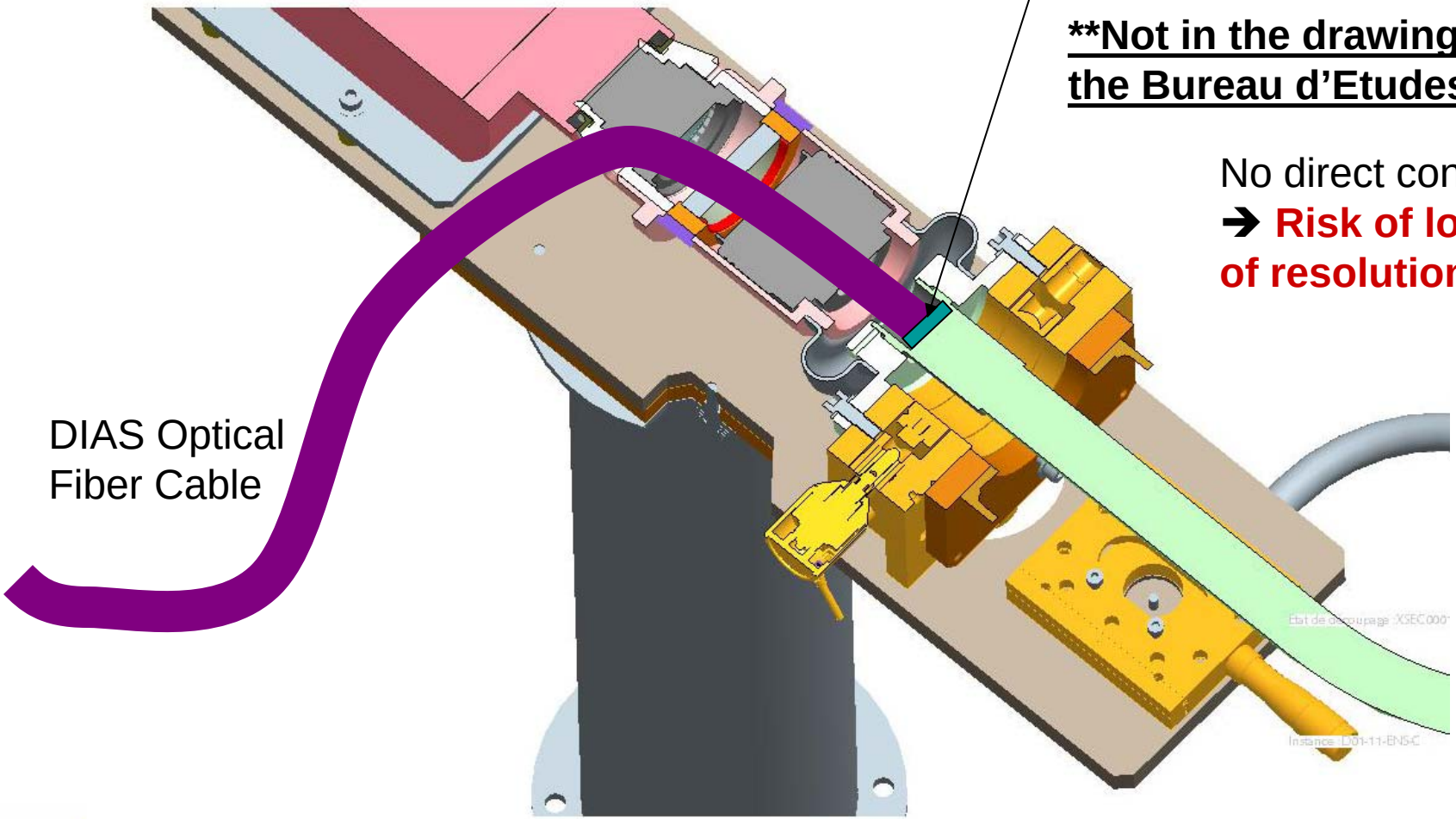
Problem with Direct Contact Idea:

Endoscope bundle includes protective plate**



<u>Not in the drawings of the Bureau d'Etudes</u>.**

No direct contact
➔ **Risk of loss of resolution!**

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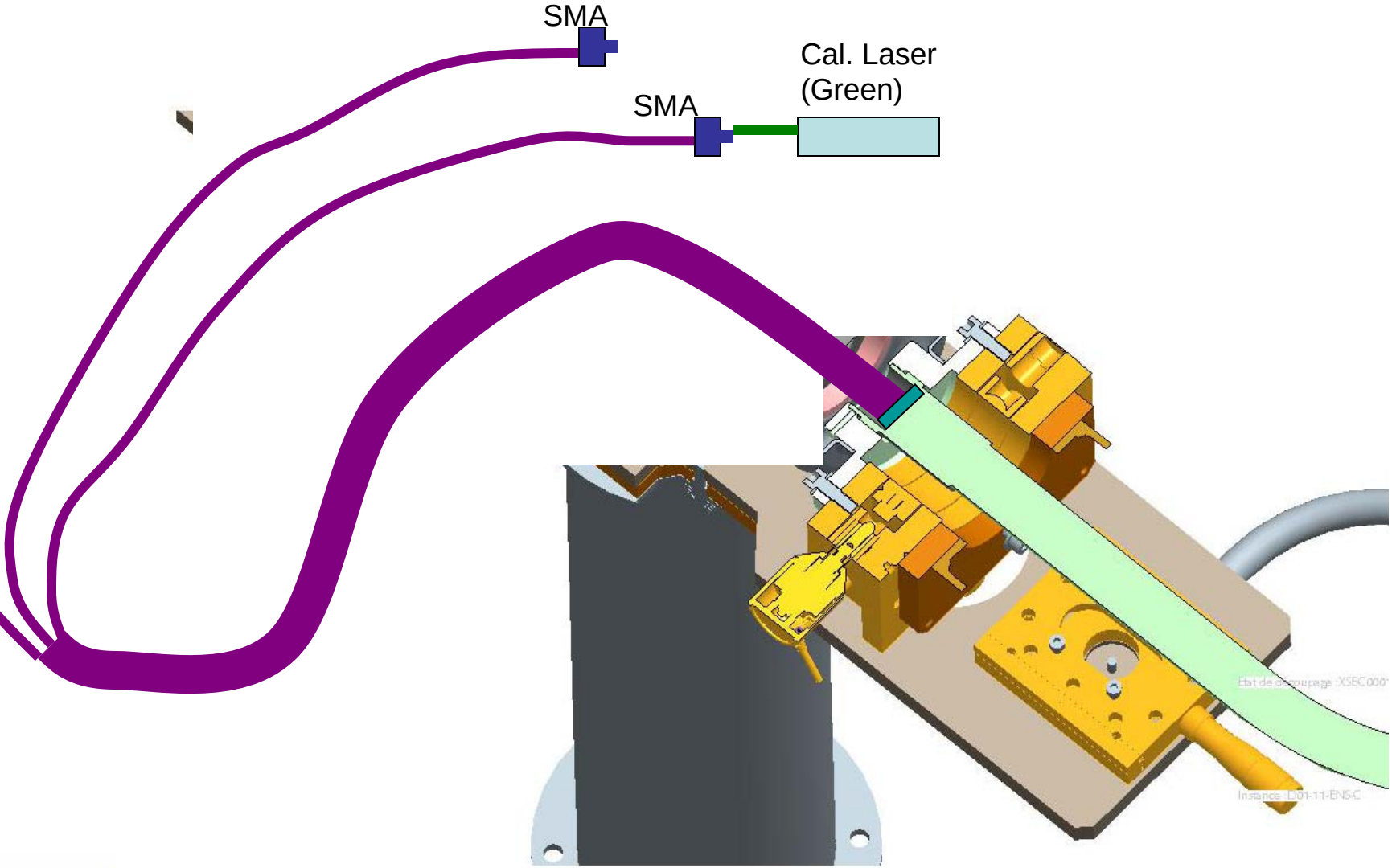
Spatial Calibration Approach: Backlight Each Fiber of Bundle DIAS



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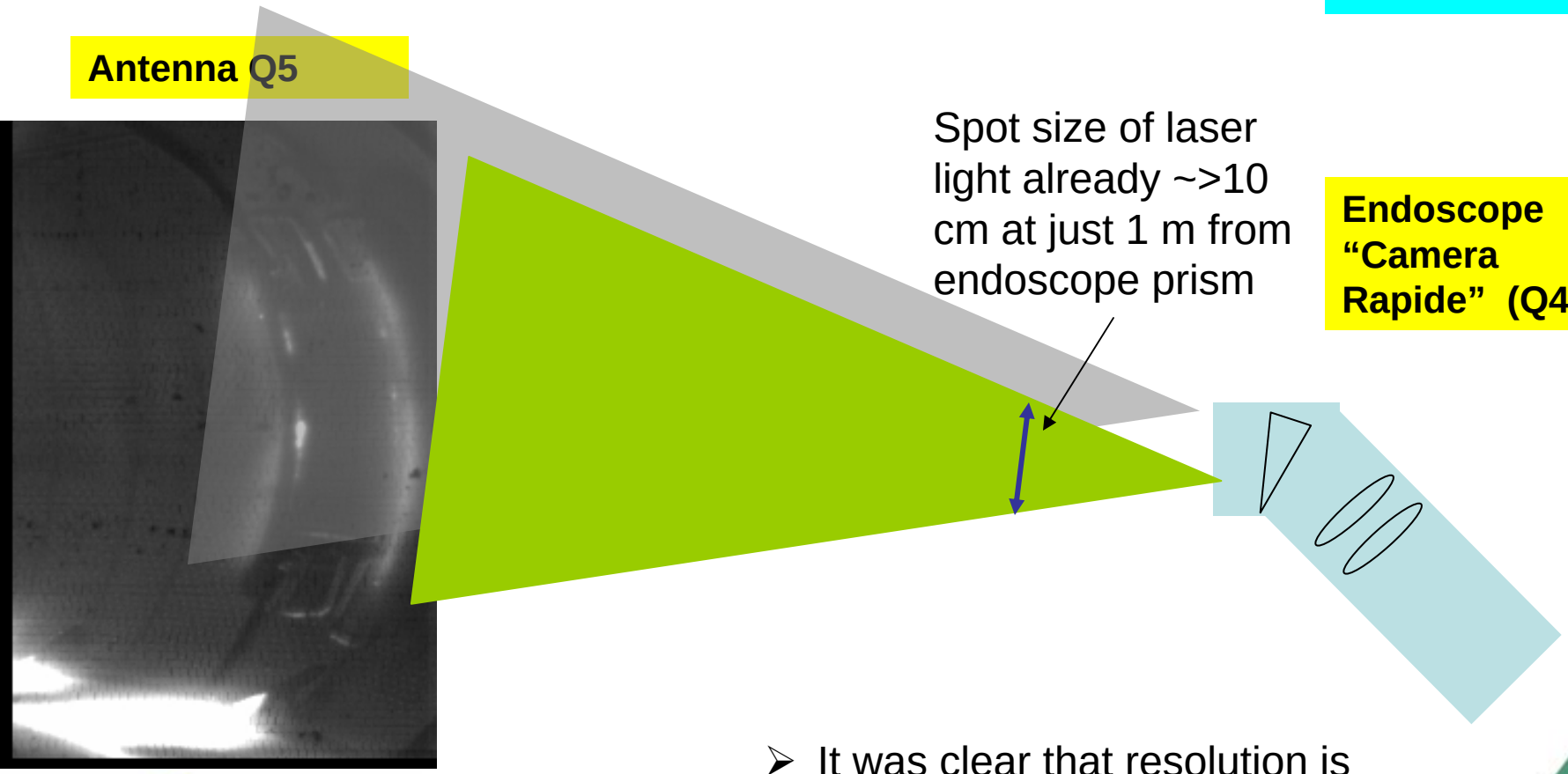
Views with original design: Direct contact of DIAS fiber array with FastCam bundle

Spot size for each fiber way too large!

Calibr. of Mar'09



- It was clear that resolution is lost due to unexpected gap between fiber bundles!

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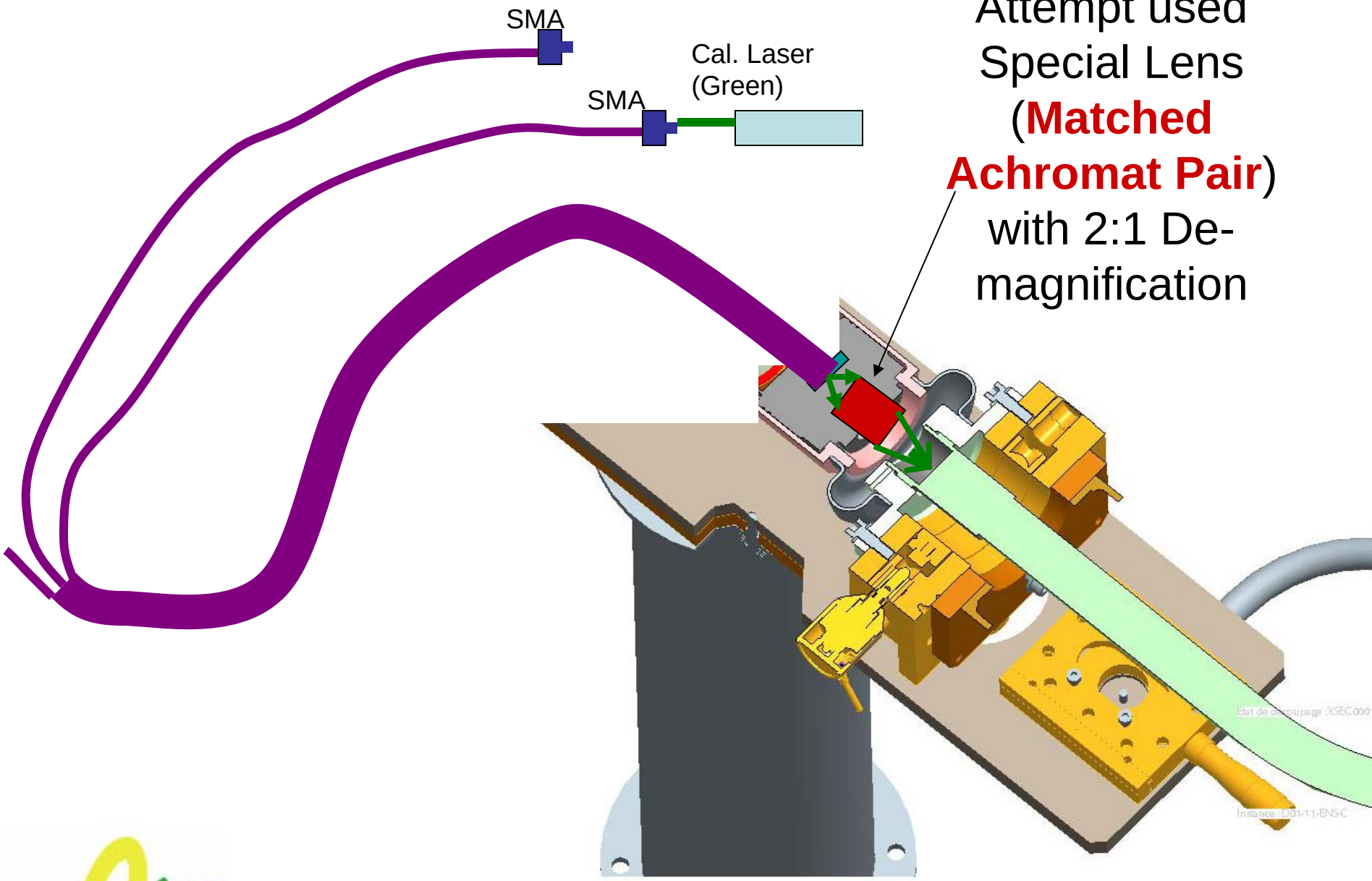
1st Corrective Optic Attempt used Special Lens (**Matched Achromat Pair**) with 2:1 De-magnification



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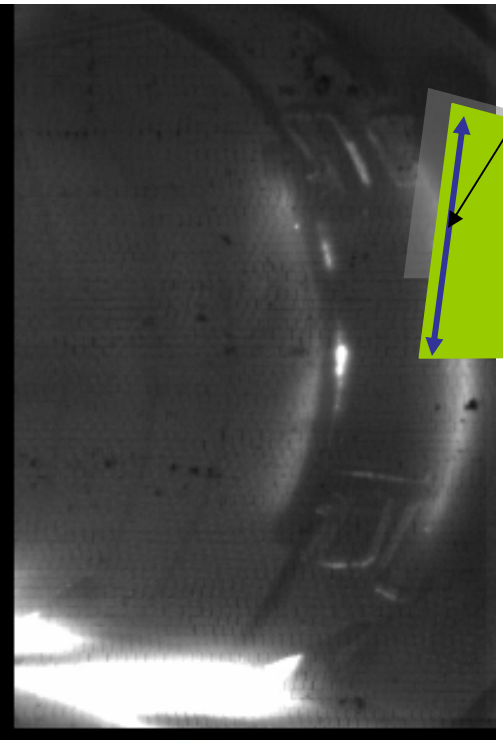
Result of 1st corrective optic

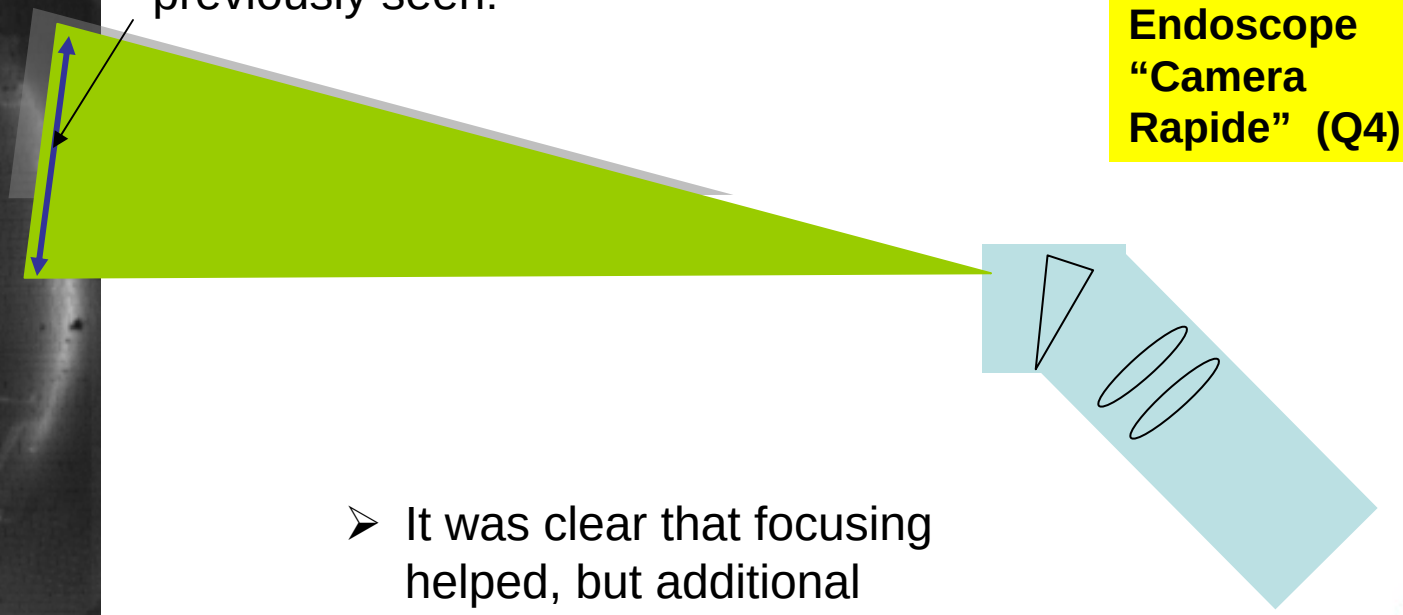
More than one spot on the antenna but Spot size for each fiber still too large!

Calibr. of Jul'09

Antenna Q5

Spot size of laser light still >30cm at the antenna, but now can see multi-fiber texture, not previously seen!





Endoscope "Camera Rapide" (Q4)

- It was clear that focusing helped, but additional demagnification was also needed!

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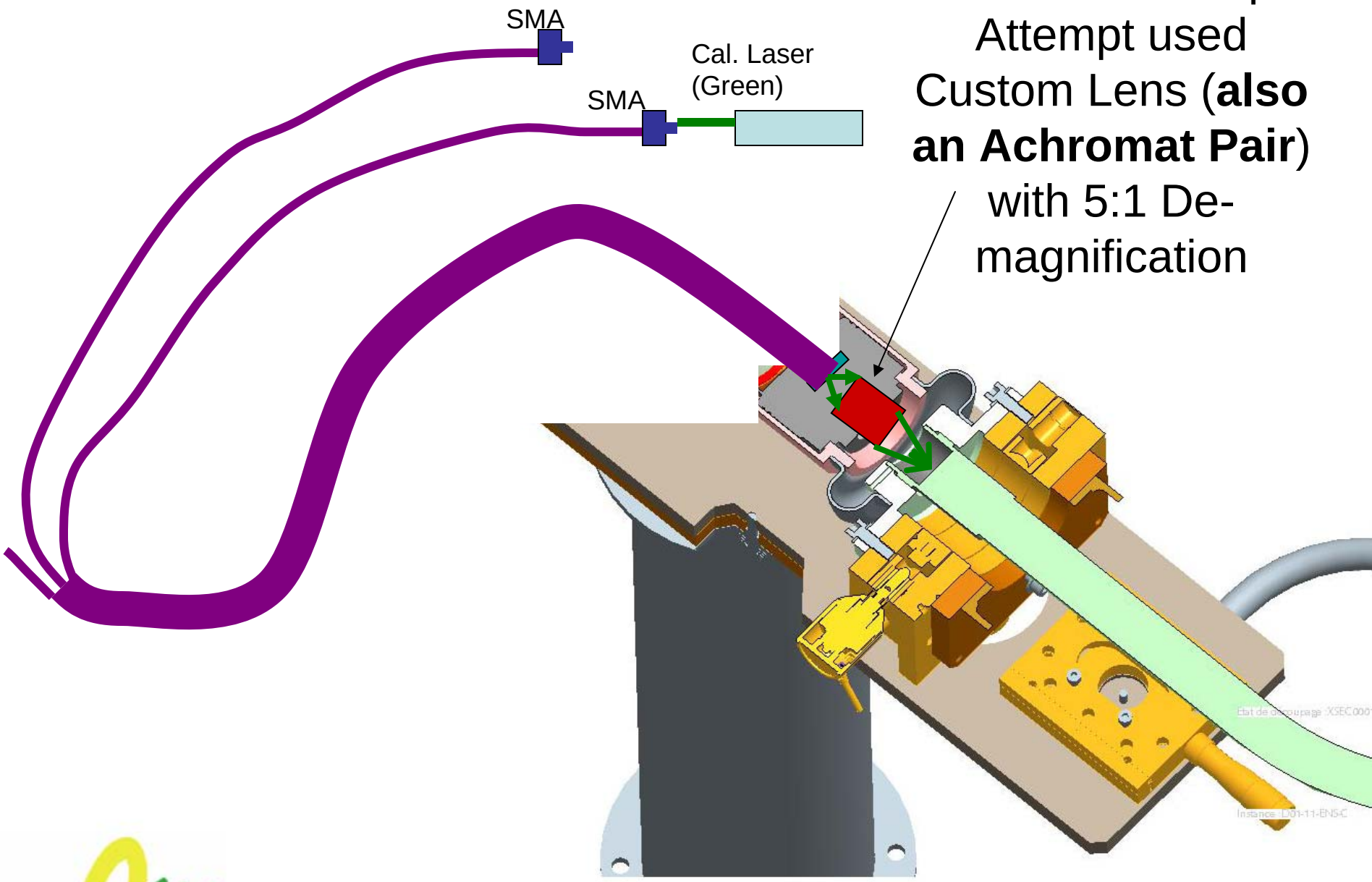
2nd Corrective Optic Attempt used Custom Lens (**also an Achromat Pair**) with 5:1 De-magnification



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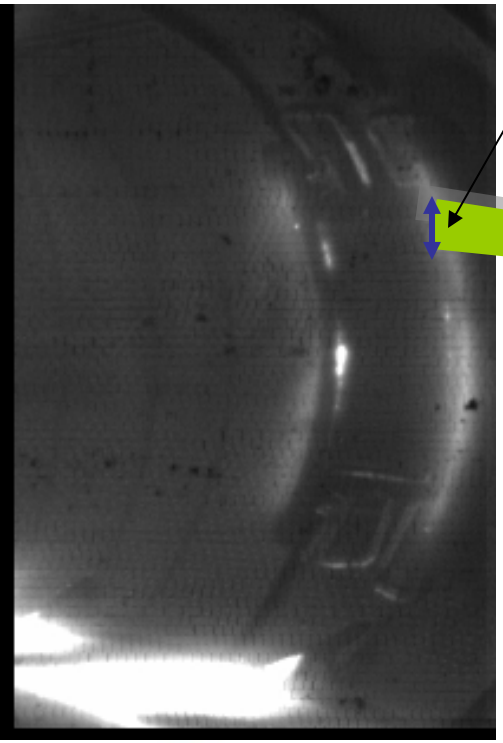
Result of 2nd corrective lens

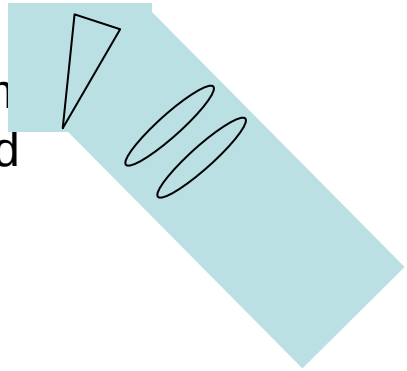
Spot size nearly perfect at the antenna

Antenna Q5



Spot size of laser light ~<5 cm at the antenna ➔ ~ Ideal!

Endoscope "Camera Rapide" (Q4)



- Note this correction images the 400μm DIAS fibers to spots <~ 100 μm on end of the endoscope bundle!
  - ➔ Some concern about light collection.
  - Better match to the large numerical aperture of the Fast-Cam fibers may correct for this!

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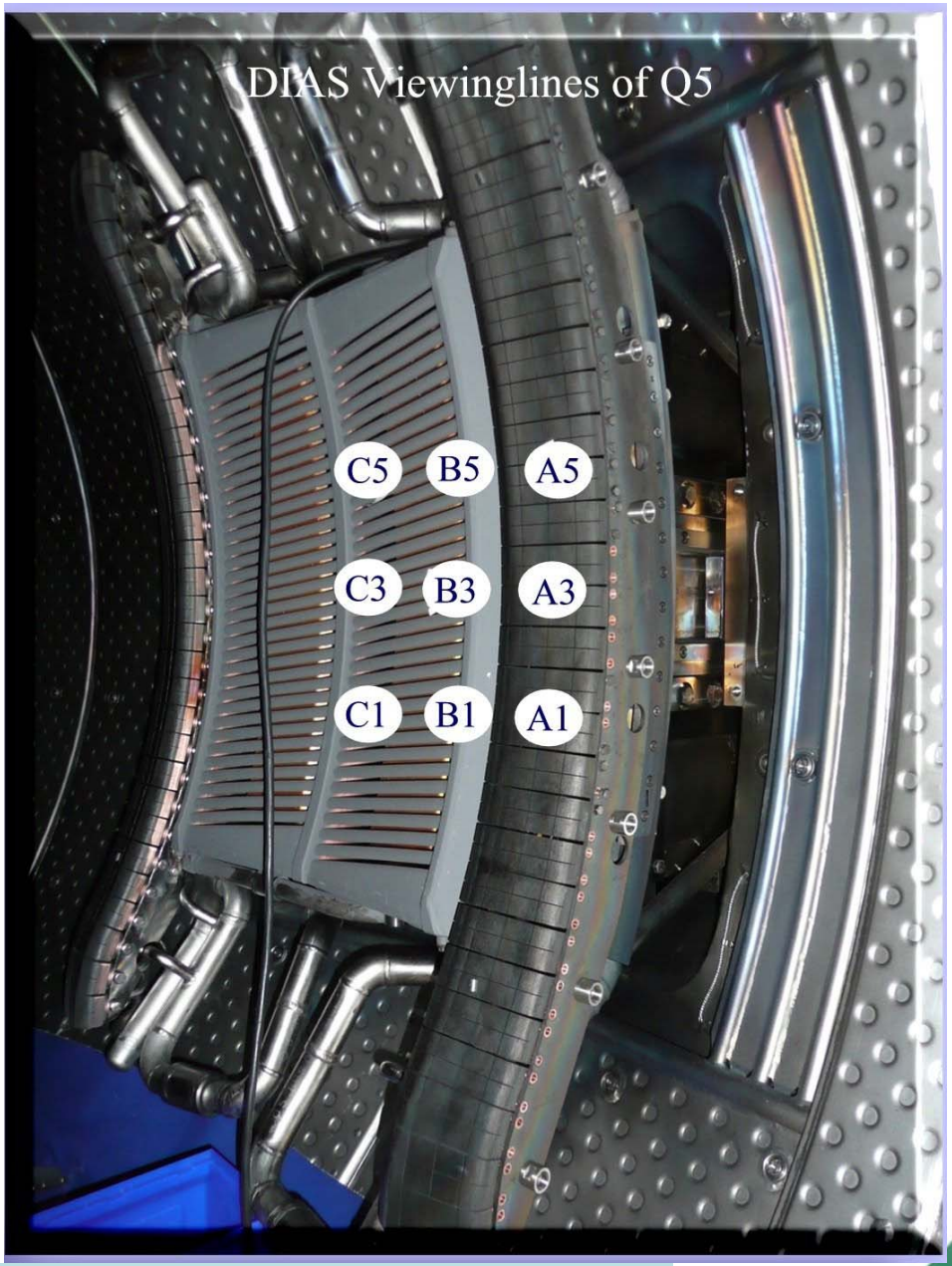
- Location of DIAS optical views on the Q5 antenna ➔

Now possible to move these with the FastCam stepper motor!



Acceptable viewing line pattern on the antenna achieved in the last week of the vent!

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Old Schedule DIAS

As presented mid-Mar'09

- Design Corrective Optics: March - April 2009
- Procure New Optics: May 2009
- New Calibration: Late June/early July 2009 (with Klepper visit)**.
- Spectrometer/Filtercope installation: June/July 2009
- System fully operational by mid-Sept'09

** Need also to coordinate with re-installation of antenna in Q5)

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Revised Schedule DIAS

As presented mid-Sep'09

- Design Corrective Optics: Jun - Jul 2009
- Procure New Optics: July-Aug. 2009
- New Calibration: Late Aug/early Sept 2009 (with Klepper visit)**
- Princeton Instruments Camera – Data Acqu. (L. Ducobu) – Jul/Aug'09
- Spectrometer/Filtercope installation: Sep/Oct 2009 (includes grating motor-drive upgrade)
- Long fibers to Hall Tore: Sept'09
- System fully operational by mid-Oct'09

** Coordinated with re-installation of antenna in Q5)

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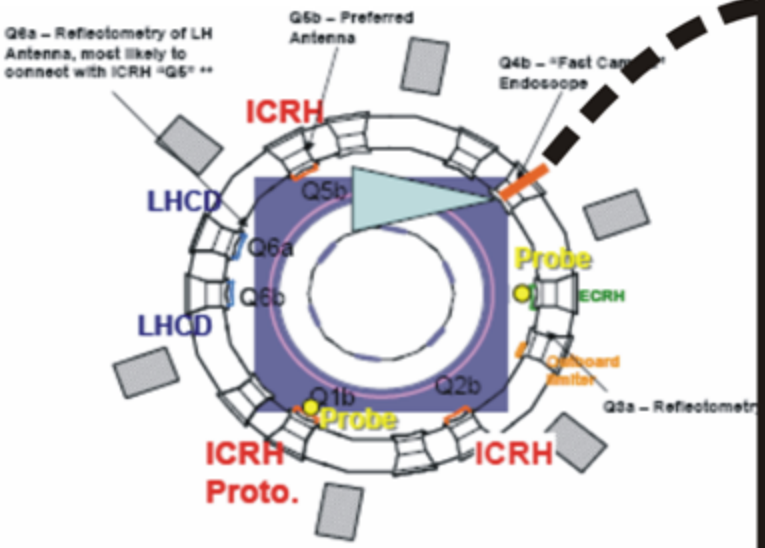
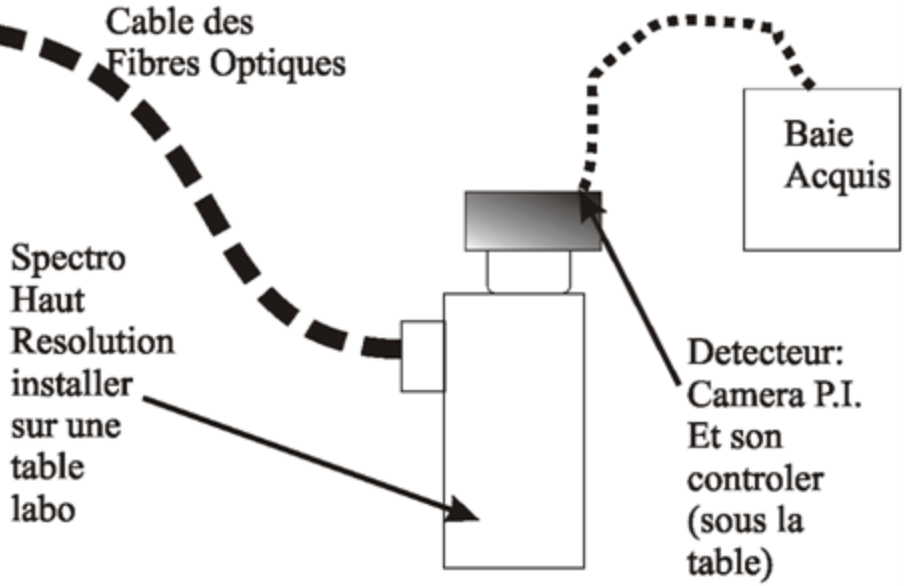
Hall Tore

Gallerie Electroniques





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Summary (DIAS Status)

As presented mid-Sep'09

- Optical Alignment now OK
- Spectrometer/2-d Detector Installed
  - Data acquisition already developed
  - Plan to test acquisition with spectral lamp on 15-Sep-09 (Tuesday)
- Optical Fibers from TS to Diagnostic Corridor already in place
  - Presently only one fiber connects to spectrometer
  - Multiple fibers to slit assembly under development
- Basic system essentially ready for Nov'09 experiments

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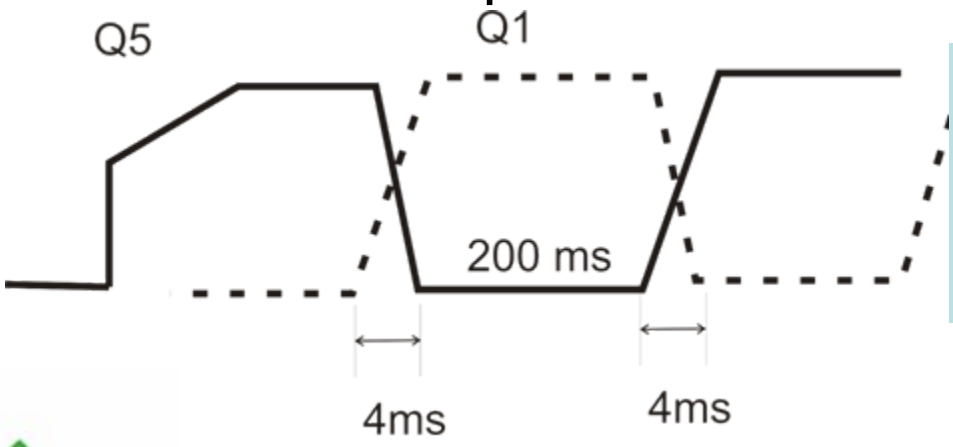
Proposed Experiments for Commissioning Phase

- **Piggy-back Runs**:
- Anything we can get, as long as Q5 antenna is in front of C4 LH launcher and can be powered on for ~2s
- **Dedicated Runs**:
- ICRH D(H) 57MHz, [0,π] phasing w/ BT = 3.8T and q_{edge} such that RLP connects with Q5 antenna at midplane.
- In both cases, we requested ANTENNA MODULATION:



🡐Antenna modulation waveforms

🡐Spectra acquisition will be synched to these

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DIAS Acknowledgements

- Installation & calibration of the diagnostic in collaboration with Gilles Colledani and Philippe Lotte, CEA/IRFM
- **Spectral profile modelling by Ralph Isler.**
- Original Proposal in collaboration with Don Hillis, input from Jeff Harris, Phil Ryan and Rick Goulding and championing by Alain Becoule and Pascale Monier-Garbet.

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Proposed H-Mode Studies:

2 collaborative proposals for Fall'09 operation

- "Exploration of L-H transition with FWEH in Tore Supra," by Jérôme Bucalossi
- "H mode transition – ICRH at the 2nd harmonic of He3 – Plasma rotation without momentum," by Roland Sabot

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Bucalossi Proposal

- FWEH scheme to be used to allow for plasma heating at low magnetic field
  - Large impact in the L-H power threshold**
  - Does not produce fast ions (difficult to confine at low B and low I_P).
- ICRH in FWEH mode @ 63 MHz (at 1.3T) and 48 MHz (at 2T). 3 antennas w/ min ~ 5-6 MW.
- D_2 working gas. Gas puffing from all the poloidal locations including HFS; possibly also pellets.
- Some "squeezing" of the plasma against the inner wall to get shaping and more pumping.

** $P_{LH} = 0.042\ n_{20}^{0.73}\ B_t^{0.74}\ S^{0.98}$ (MW)[1])
[1] Progress in ITER Physics basis, Nuclear Fusion 47 (2007)

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Sabot proposal

- Two objectives:
  1. Development of ICRH @ 2nd harmonic of ^{3}He
  2. Search for H-mode
- Advantage: Slower ions ➔ lower ripple losses (for TS δripple=6% with edge at R=3.16, δripple=3% with edge at R=3)
- Start with lower ripple case: expect plasma rotation less negative and hope to induce positive (co-current) rotation

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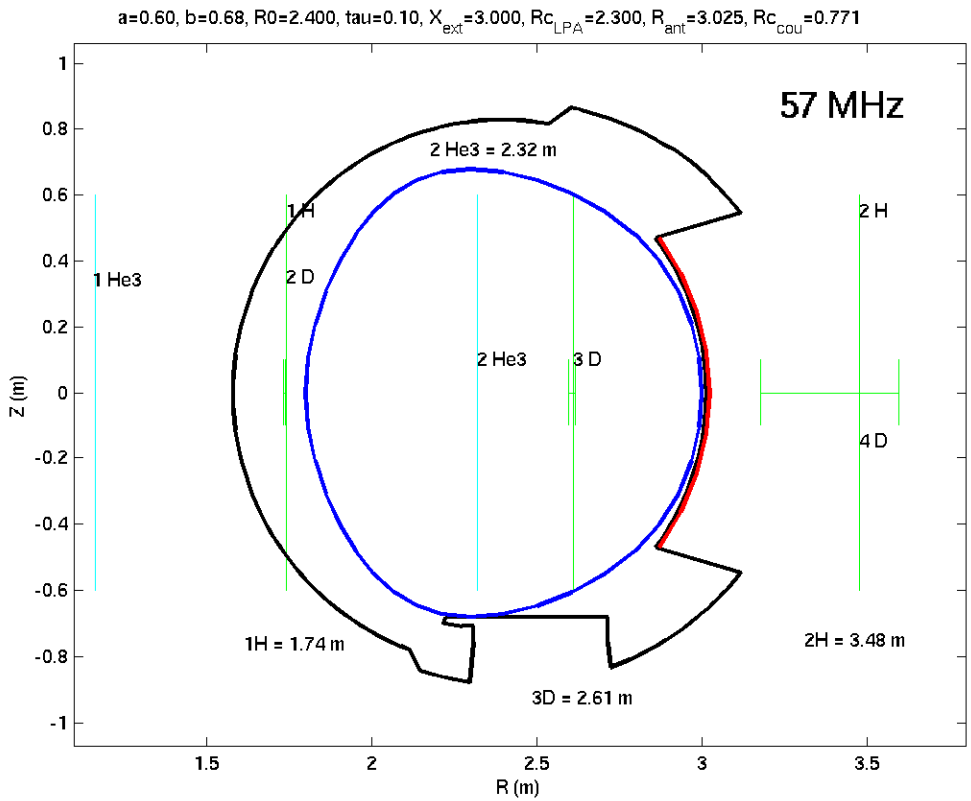
Both proposals use of elongation and triangularity, mostly to get more pumping through he toroidal PL



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Benefits to ORNL

- The proposed H-mode campaigns on TS will provide synergy with the collaborative "Ohmic H-Mode" proposal for KSTAR (J-W Ahn, DL Hillis) planned for the same period of time (late Fall'09).
- The strong dependence of these experiments on inject of large amounts of ICRH power is synergistic with the needs of the early DIAS experiments.

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