Specialists Working Group on Reflectometry report to ITPA-12 (Princeton)

G.D.Conway, G.Vayakis

Group activity summary

- Various progress meetings:
  - RWG meeting at IAEA, Chengdu (Oct. '06) – 1st report from E.Doyle on UCLA studies
  - Discussions with US group members at APS (Nov. '06) on UCLA proposals
  - IT team met with RF party (Nov. '06) to discuss HFS progress & next steps
- RF: HFS first bend simulations and mock-up results
  - In-line waveguide window simulations
- JP: Technological developments & MIR
- EU: Plasma position refl. antenna asymmetry study
  - ITER plasma pos. task: cluster of Associations formed = IST + CIEMAT + CEA + ENEA/CNR
- US: Preliminary re-assessment of LFS main refl. requirements
  - Initial UCLA report + proposals (T.Peebles) to BPO workshop (Feb. '07)
  - Report circulated to RWG for comment. Initial feedback provided
  - Updated report (T.Peebles) in US progress meeting on Monday

Actions

- Action 09a223: Reflectometry WG to coordinate the benchmarking of the various reflectometry simulation codes
- Action 10a235: Petrov/Petrov to report on the access conditions for refractometry on ITER (optimal launch frequency plus effects of beam refraction)
- Action 10a236: RWG to assess the deleterious effects of antenna misalignment on profile measurements by reflectometry (unwanted Doppler effects)

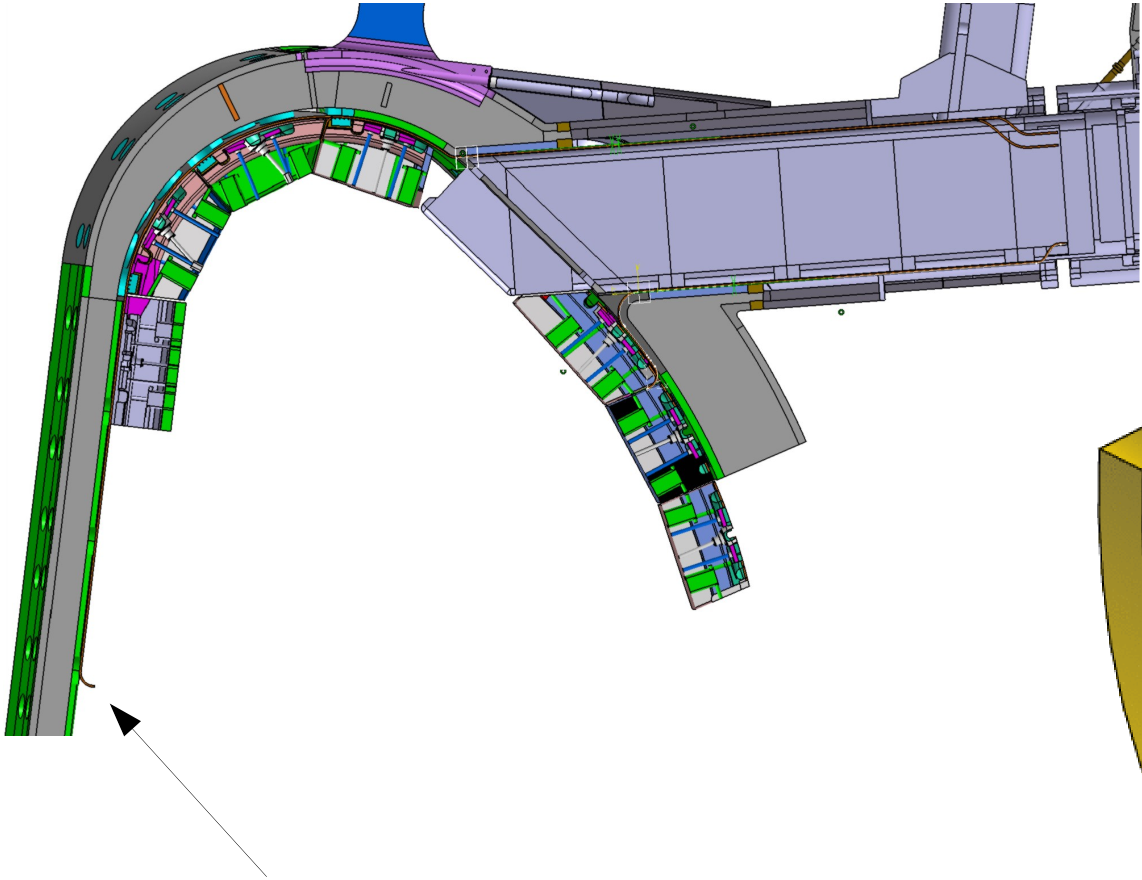
- Groups in U.Stuttgart & CIEMAT performing full-wave simulations to match Doppler simulations of V.Bulanin

- Detailed ray-tracing starting
- Progress on 2nd channel on FTU

- See US party report
- Beam tracing studies (Conway)
- GAP 5 plasma shape sensitivity (S.Heuraux)
- Results from AUG → $k_\perp \rho_s$ < 2 okay for ITER O-mode edge Doppler measurements

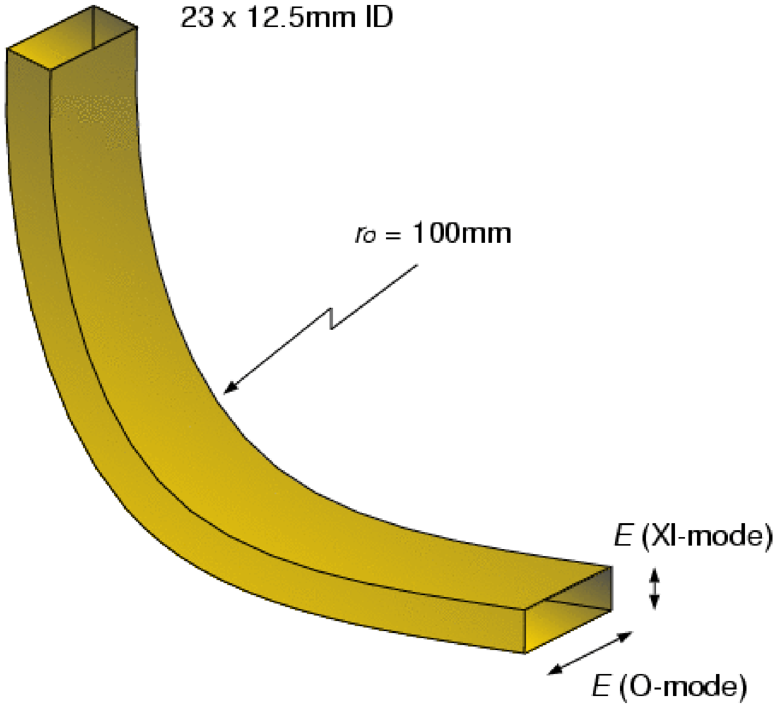
HFS first bend optimization

V.Vershkov



First bend has the tightest radius and hence most problematic

- 90° hyperbolic secant bend optimized for minimum mode conversion & loss
- $r = r_o / \cosh\{\alpha/r_o \times (z-L/2)\}$
- α = 1.948..   L = 399.5mm

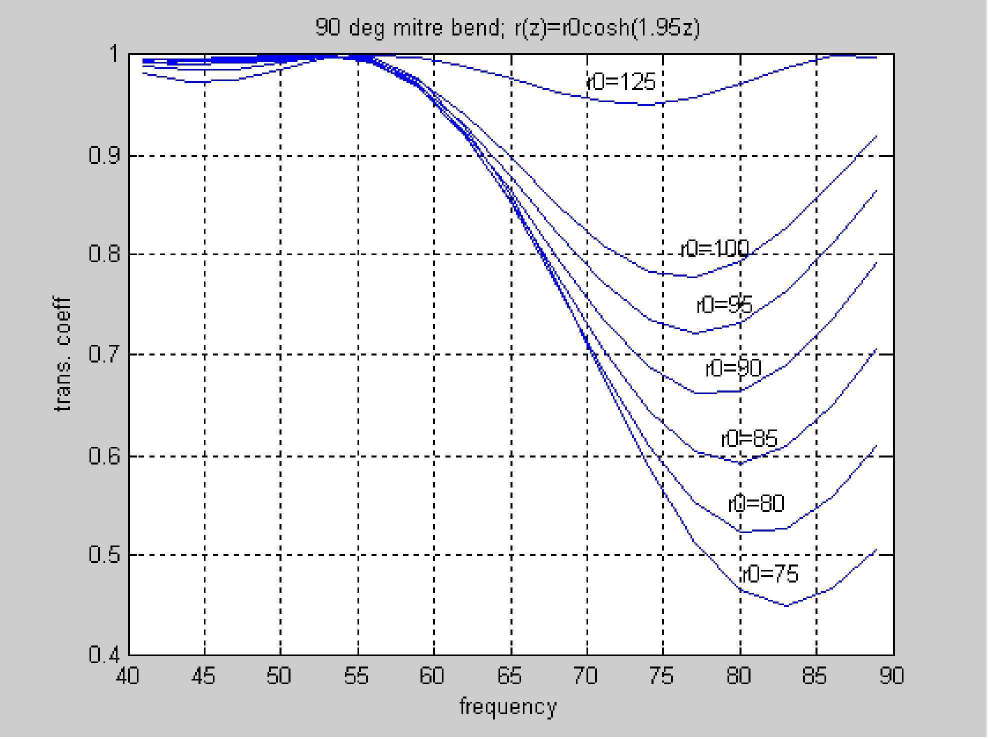


HFS first bend optimization - simulation

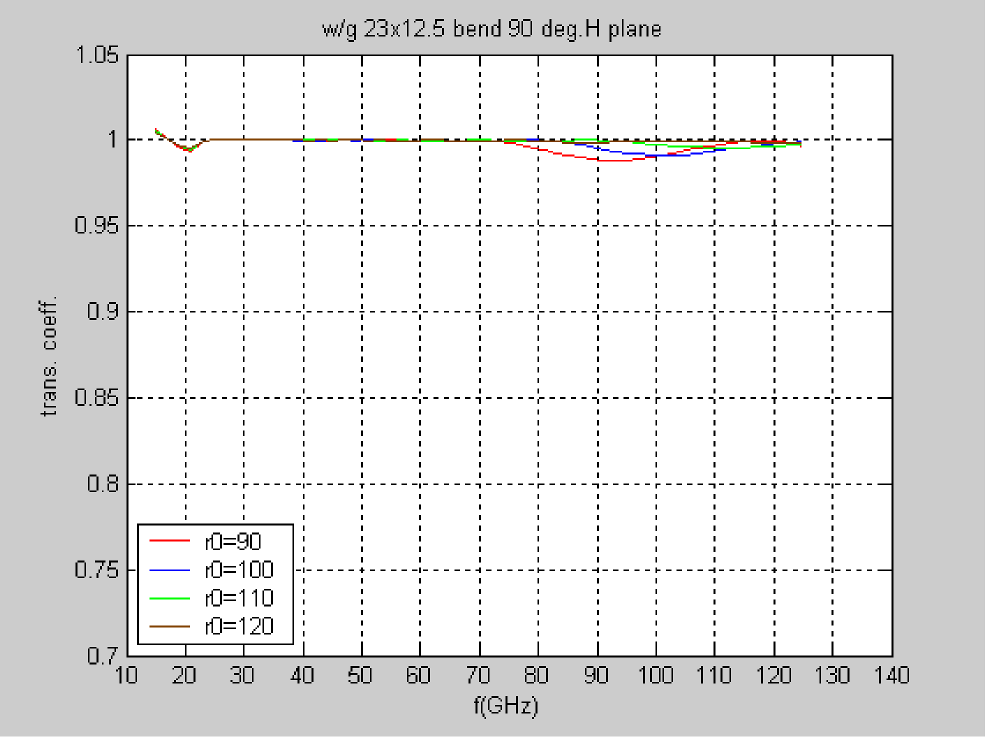
V.Vershkov

- Calculated transmission with various r_0 and for both polarizations
- X-mode (E-plane bend) most difficult case (note transmission 0.8 = 0.97dB)

E parallel to bend = Xl-mode



E perpendicular to bend = O-mode



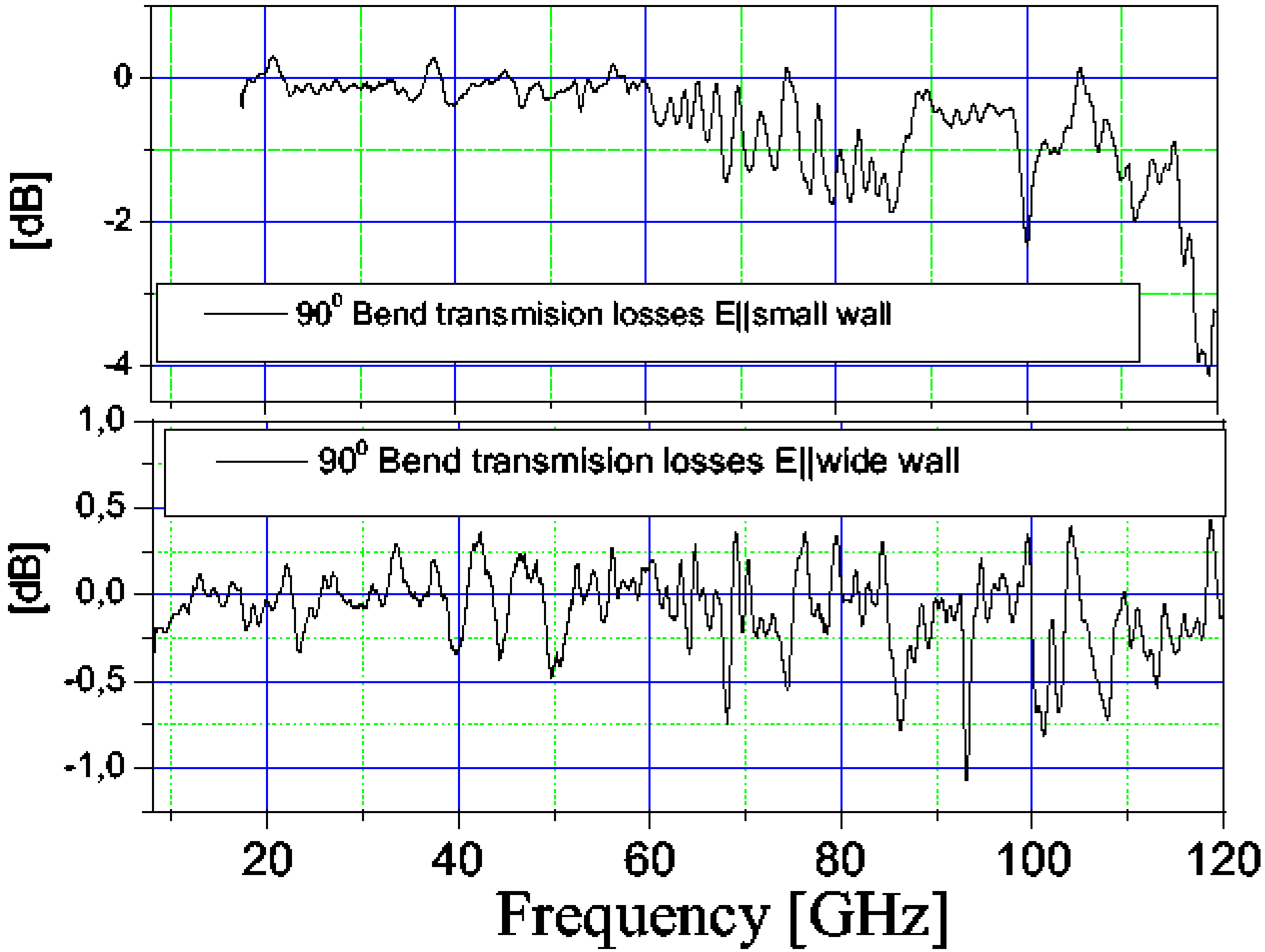
HFS first bend optimization - experimental

V.Vershkov

- Experimental measured transmission loss for E para. & perp. polarizations
- r_o = 100mm & L = 399.5mm
- attn. = (tapers + bend) – tapers
  → resonances + offset ~1dB
- Simulation & measured show good agreement
- Good performance with bend radius fitting in available space

  8 – 80GHz in X-mode

  15 – 120GHz in O-mode

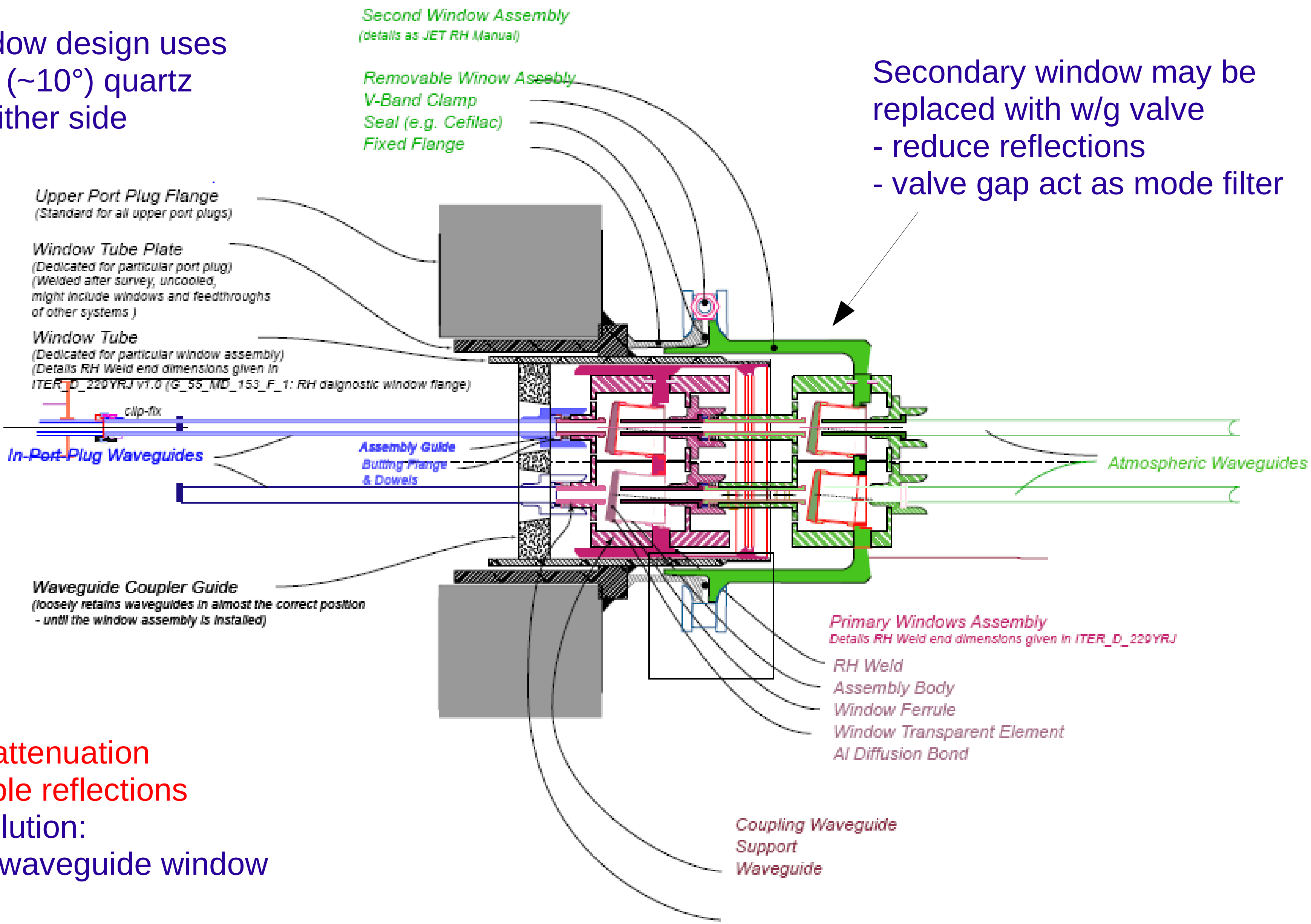


Contract with Rosatom

HFS + PP waveguide vacuum boundary

Current window design uses double tilted (~10°) quartz with horns either side

Secondary window may be replaced with w/g valve
- reduce reflections
- valve gap act as mode filter



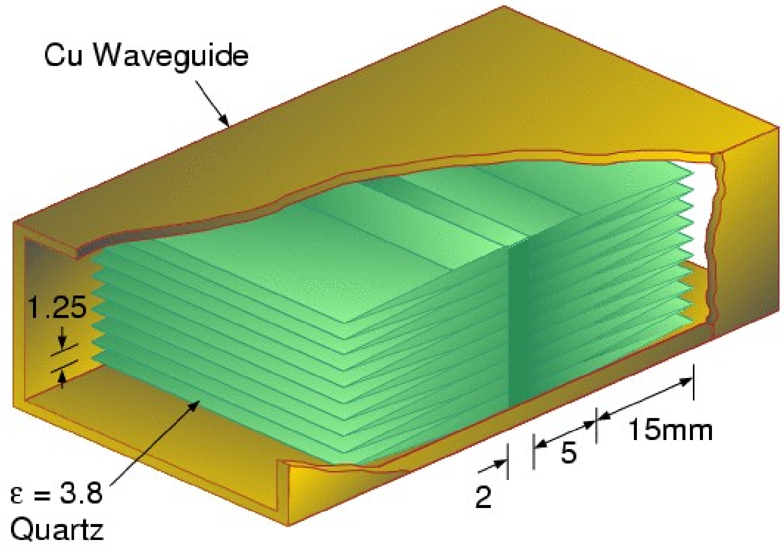
Drawbacks:
- high attenuation
- multiple reflections

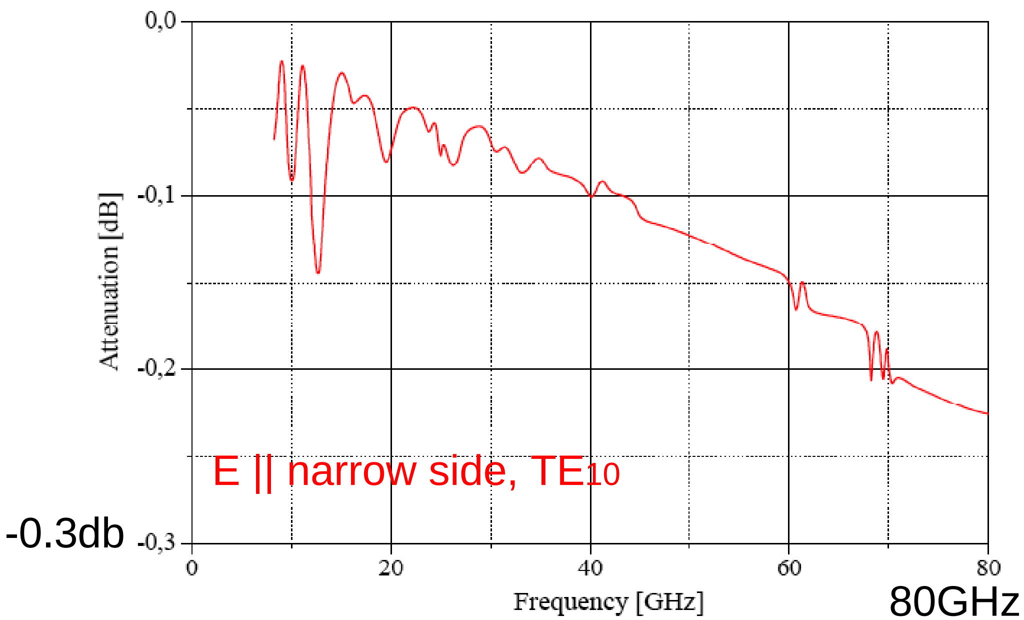
Alternate solution:
In-line waveguide window

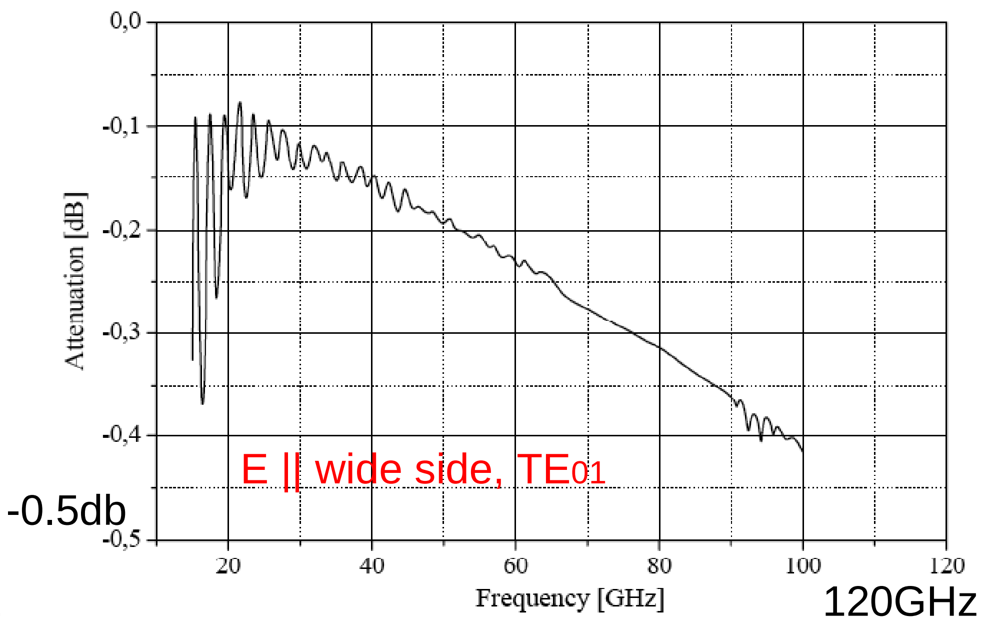
HFS waveguide window

V.Vershkov (Kuchatov + Nizhnij N.)

- Concept in-line waveguide window (Petelin & Kasparek 1991 Int.J.Elec.). Quartz fingers give refractive index transition → very low reflection
- Computed insertion loss 5% (TE_{10}) & 7% (TE_{01}) @ 80GHz. Double window → -0.82dB ripple loss
- Electro. mag. prototype under construction/test
- Edge bonding to Cu. still to be resolved

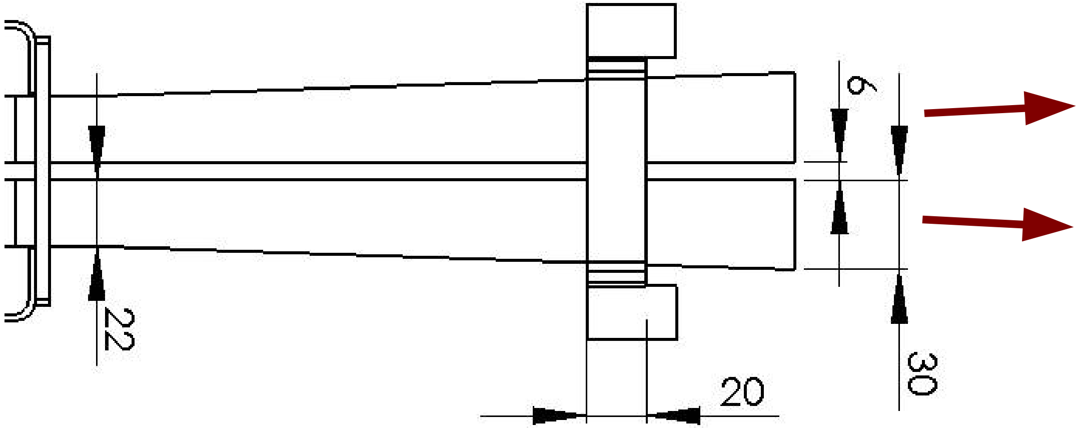


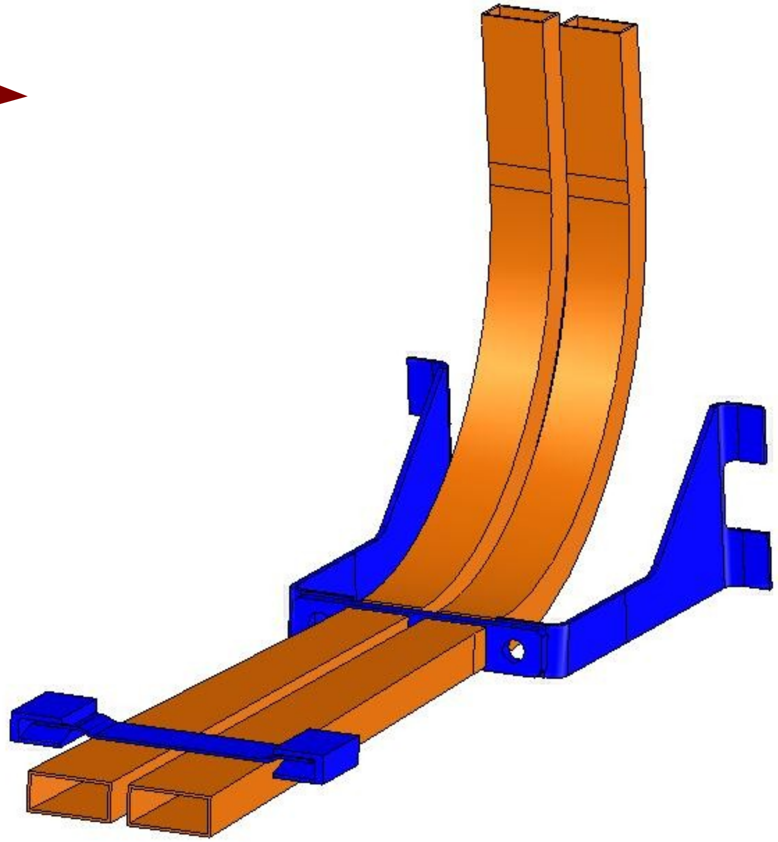




Position reflectometry antenna design

P.Varela



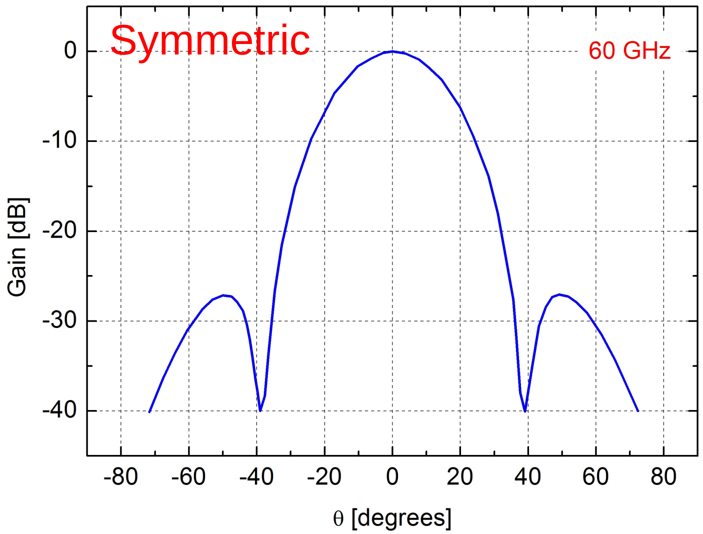


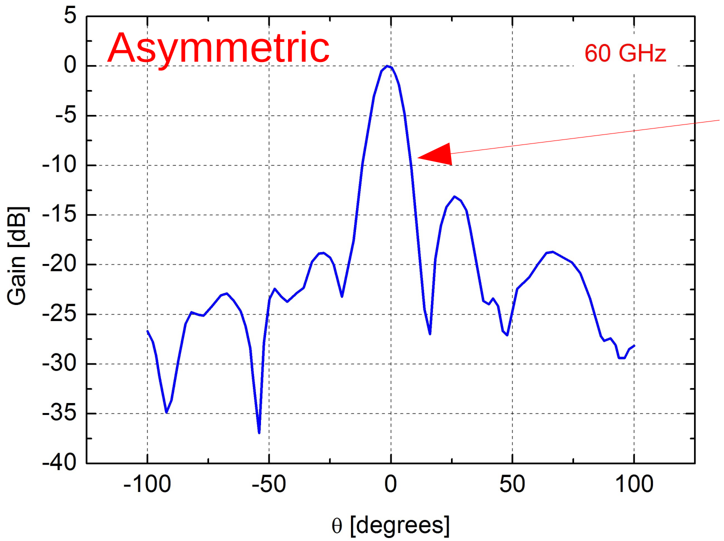
- Waveguide 22 x 14mm (outside dimension) flaring out to 30mm at antenna mouth with 6mm w/g spacing
- Spacing means antenna flare is asymmetric in toroidal direction → asymmetric radiation pattern, significant at highest launch frequencies

Position reflectometer antenna symmetry

P.Varela

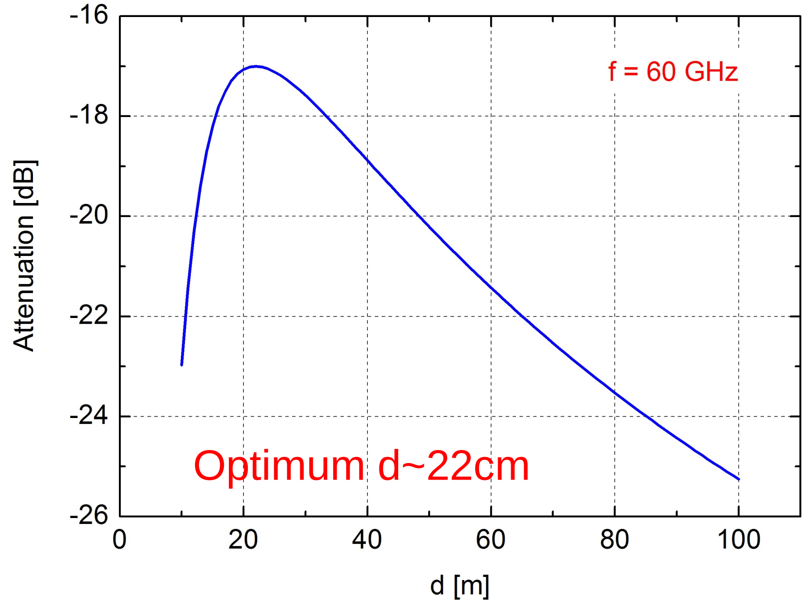
- Simulated (HFSS) E-plane radiation patterns for symmetric & asymmetric flares
- Asymmetric: ~2° tilt @ 60GHz; negligible @ 15GHz
- Emit / Receive pattern overlap varies with distance
- Symmetric flare would need w/g spacing >11mm, feasible in blanket but difficult elsewhere
- Shape toroidal wavefront? / Effect of blanket?





Note pattern very narrow!

E || wide wall
→ TE_{01} mode



Recent developments in Japan

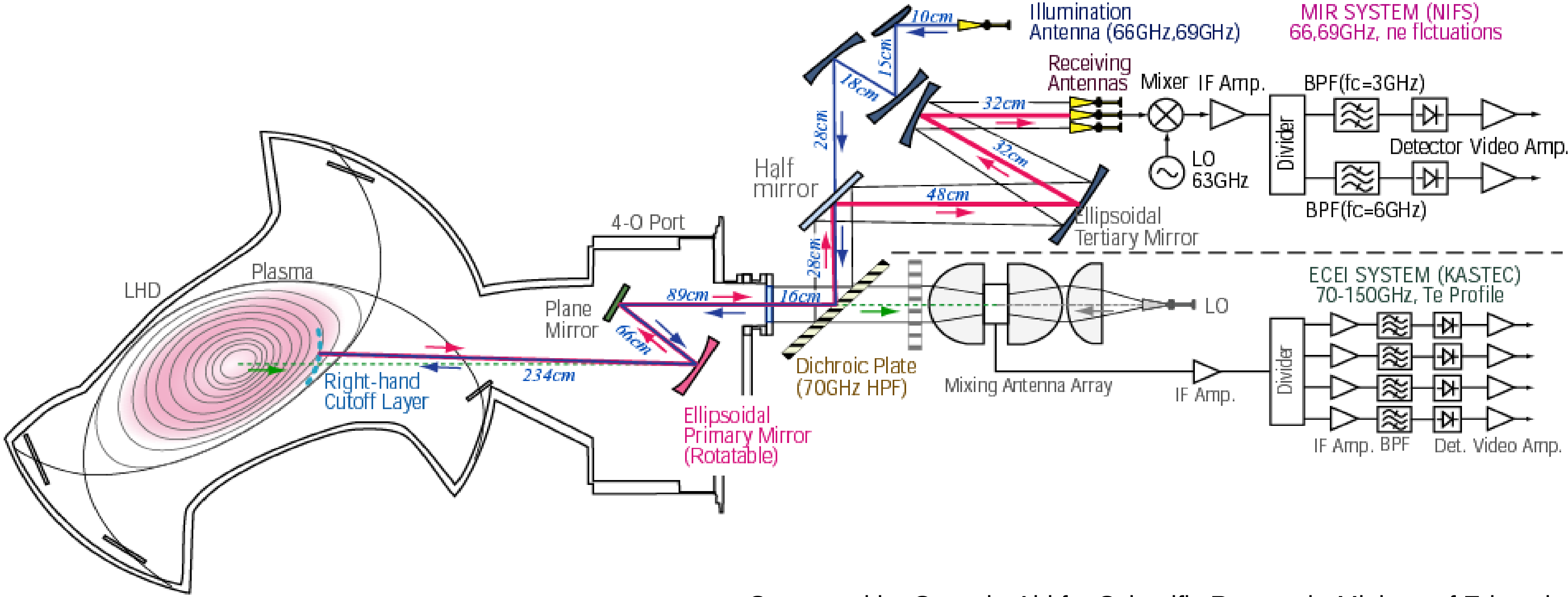
A.Mase

- Large effort devoted to technology development. Two major recent conferences:
  - 16th Intl. Toki Conf. (ITC-16) on Advanced Imaging & Plasma Diagnostics (Dec. 2006)
  - US-Japan-Korea Workshop on Microwave Devices (Dec. 2006)
- Development of 2D-3D full-wave simulation codes (Hojo) – applications to:
  - Relativistic effects
  - Ultra-short pulse reflectometery / radar (Tokuzawa)
  - Microwave imaging (Ignatenko)
  - Fundamental applications – Wire waveguides (Hojo)
- Development of MIR / ECEI system on LHD (Nagayama / Koji)
- Development of 20GHz MIR system on TPE-RX RFP device (Nagayama)
- Fabrication of notch filters, planar antennas & beam steering devices for MIR/ECEI using electro-fine forming (EF2) technology (UCD / KASTEC)
- Investigating application of THz-TDS (time domain spectroscopy) for ITER divertor reflectometer measurement of density (Tokuzawa) – See presentation by A.Donne on UCD proposals

Microwave Imaging Reflectometry on LHD

Y.Nagayama

- MIR system (NIFS) combined with ECEI (KASTEC) for turbulence studies
- In-vessel remote controlled mirrors for alignment
- Separate illumination & detection optics (dichroic plate) – reduces noise

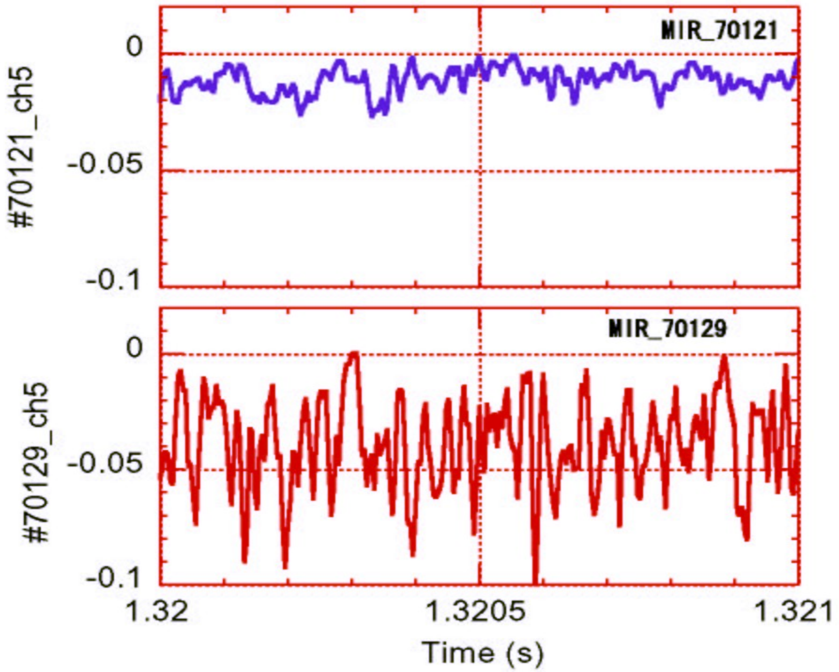


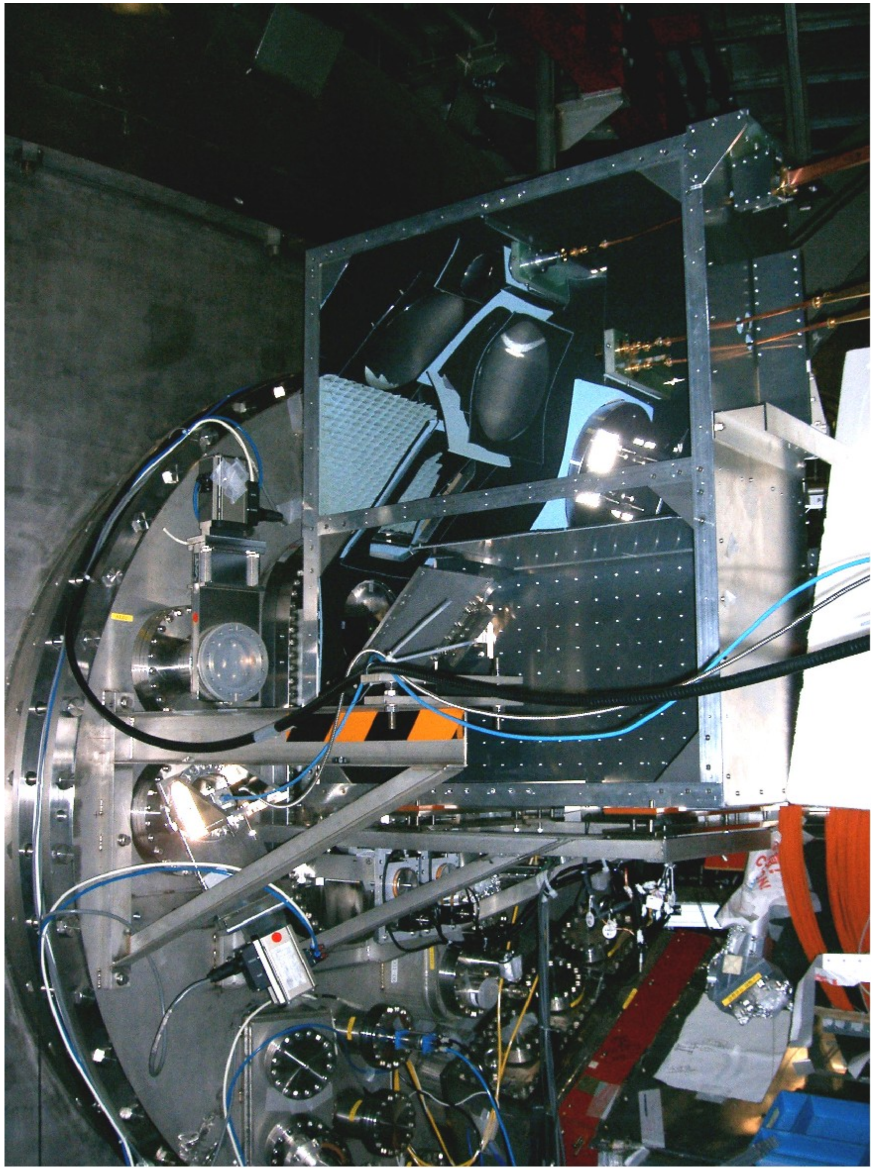
Supported by Grant-in-Aid for Scientific Research, Ministry of Education, Science, Sports & Culture ("Advanced Diagnostics for Burning Plasma")

MIR system on LHD

Y.Nagayama

- Optics and hardware installed (all mirror system)
- Test results – 25cm diameter illumination, 3.3cm resolution
- Initial results from LHD obtained – development ongoing

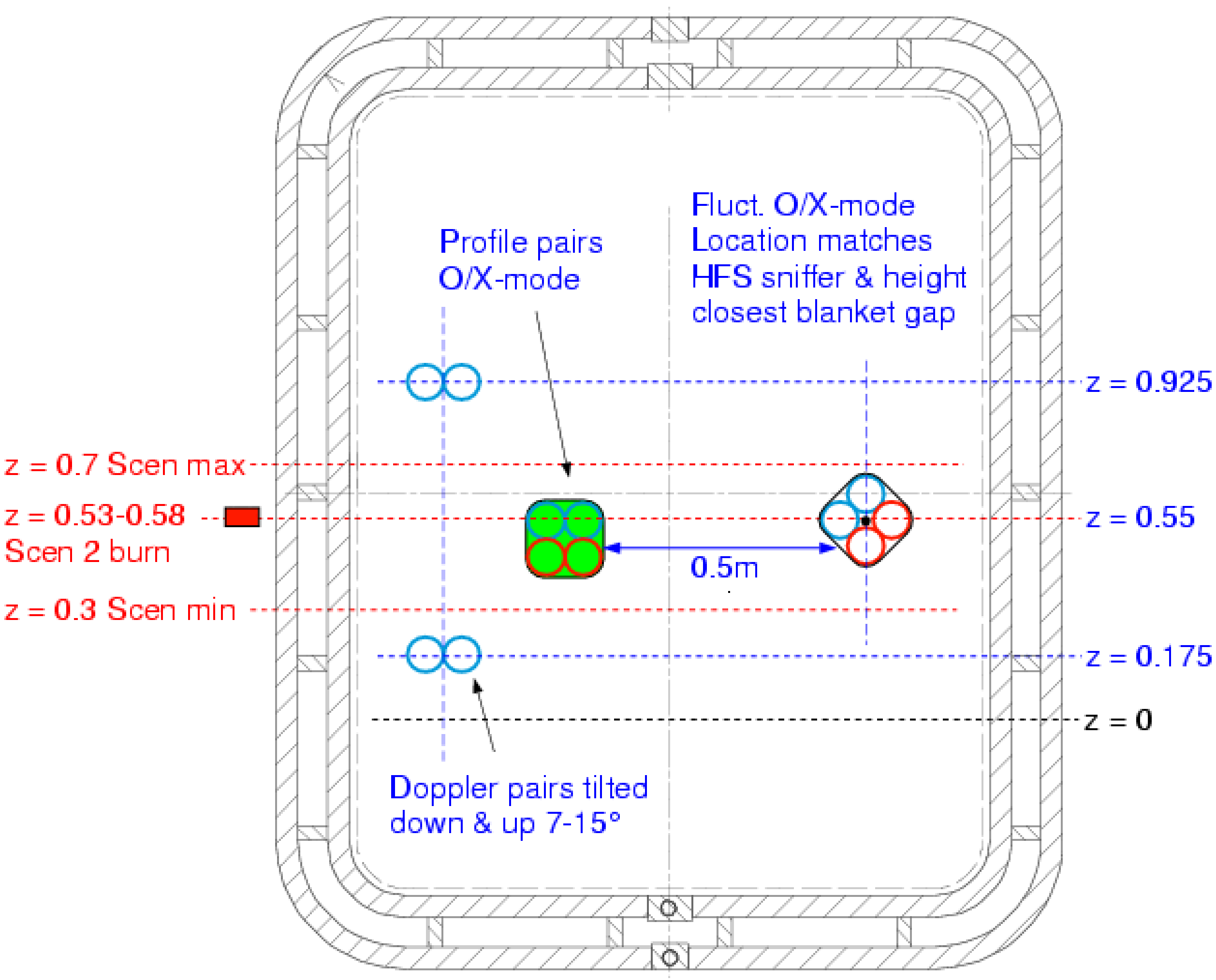




LFS reflectometer antennas

Original LFS outline design

- Allocation for 12 broad-band multi-mode (O/X) waveguides → 6 bistatic systems
- Antennas not optimized, place holders: 89.5mm∅ horns.
- Two sets of mid-plane clusters with different optimization & use
  - Profile: aligned with central z of Scenario 2. Anticipate $\Delta z \approx 30$cm coverage
  - MHD / fluctuation / turb. single chord, correlation
  - Plus 2 Doppler locations
- Edge gradient region primary aim, core when possible



Vayakis 2003: N 55 RI 29 03-05-02 W 0.1

Original layout – ITER_D_226HY6 Nov. 2002

LFS antennas – Summary of UCLA assessment

- Preliminary status report of LFS main plasma presented to US BPO diagnostic workshop, Feb.'06
  $\rightarrow$ Copy circulated to RWG with request to comment
- UCLA assessment provides first detailed investigation of LFS reflectometer requirements
  Very valuable exercise, much detailed information, but only a beginning!
- Main points:

  1. For technical reasons reduce frequency ranges, plus split O-mode into 2 bands:

Xu-mode:	76 – 220GHz	$\rightarrow$	76 – 180GHz	(single corrugated waveguide)
O-mode:	15 – 155GHz	$\rightarrow$	15 – 60GHz 40 – 160GHz	(two w/g sizes required)

     n.b. main constraint on O-mode is mitre-bend design at low frequency end

  2. Anticipate density peaking ($\times$1.2 – 1.4) $\rightarrow$ Improves radial access for all modes: Opens up core access from LFS

  3. Ray-tracing analysis $\rightarrow$ Need more antennas for z-tolerance (plasma column height variation)

- Proposed vertical array of 10 monostatic high-gain antennas
- Proposed combining (uncal.) O-mode ECE fluctuation and X-mode Refl.
- Alternate bistatic edge array presented in US Progress meeting (Monday)

LFS antennas – Initial RWG thoughts on UCLA proposals

- Monostatic LFS array driven by UCLA desire for core Xu-mode probing with z-tolerance
  - RWG has major concern with monostatic antennas
  - Can expect significant w/g resonances → Any measurement involving phase (profiles & fluctuations) needs bistatic configuration.

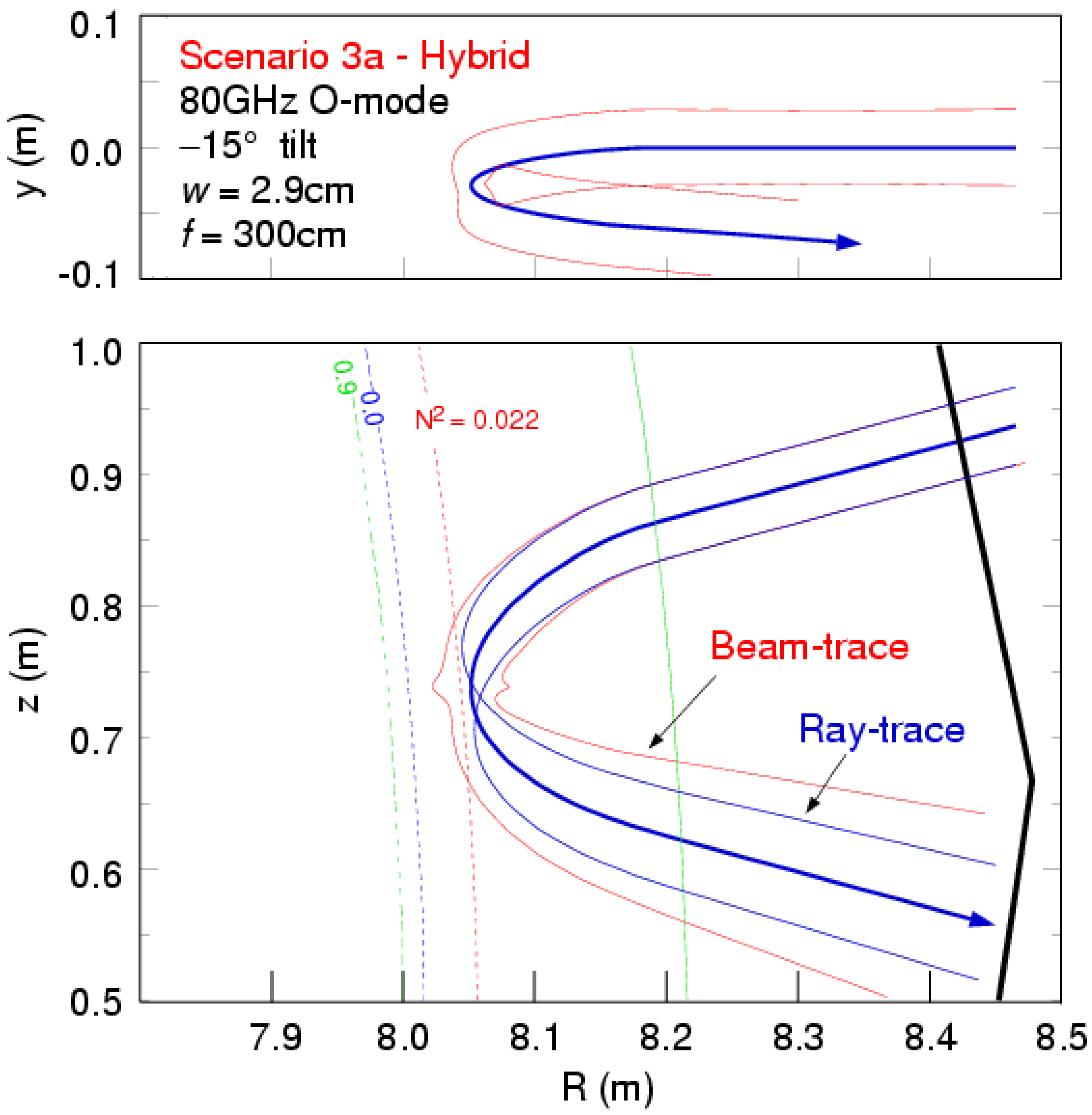
    "A bistatic launch & receive arrangement should be used to minimize waveguide modes and spurious reflections." Doyle etal. (Varenna 1995) p117
  - A monostatic concept must be demonstrated to work (e.g. on DIII-D or JET) before adoption
- Splitting O-mode band has 2 effects:
  - Need dedicated 15 – 60GHz antenna / waveguide pair → Rectangular w/g / PP ?
  - But upper O & X-mode bands have significant frequency overlap

    → allows polarization multiplexing of transmission lines

    → bistatic systems with same number of antennas as separate monostatic
- Need antenna gain optimization study
  - Profile antennas should be optimized for edge → increased z-tolerance. 2 or 3 pairs maybe sufficient. Path length possibly problematic
  - Try to maintain at least one high gain antenna pair optimized for fluctuations and core probing
- Combining Refl. & ECE in same w/g is likely to be problematic

LFS antennas – Diffraction effects

- Ray-tracing = asymptotic solution (Geometic optics) of Maxwell eqn.s
- GO / WKB breaks down at cutoff, but still a good approximation of beam propagation
- Ray-tracing does not account for diffraction and interference effects: can severely underestimate beam spreading
- Use beam-tracing or quasi-optical techniques
- Receiver spot size is much broader → relaxes constraint on array
- Also expect high level of turbulence in edge → broadens beam further

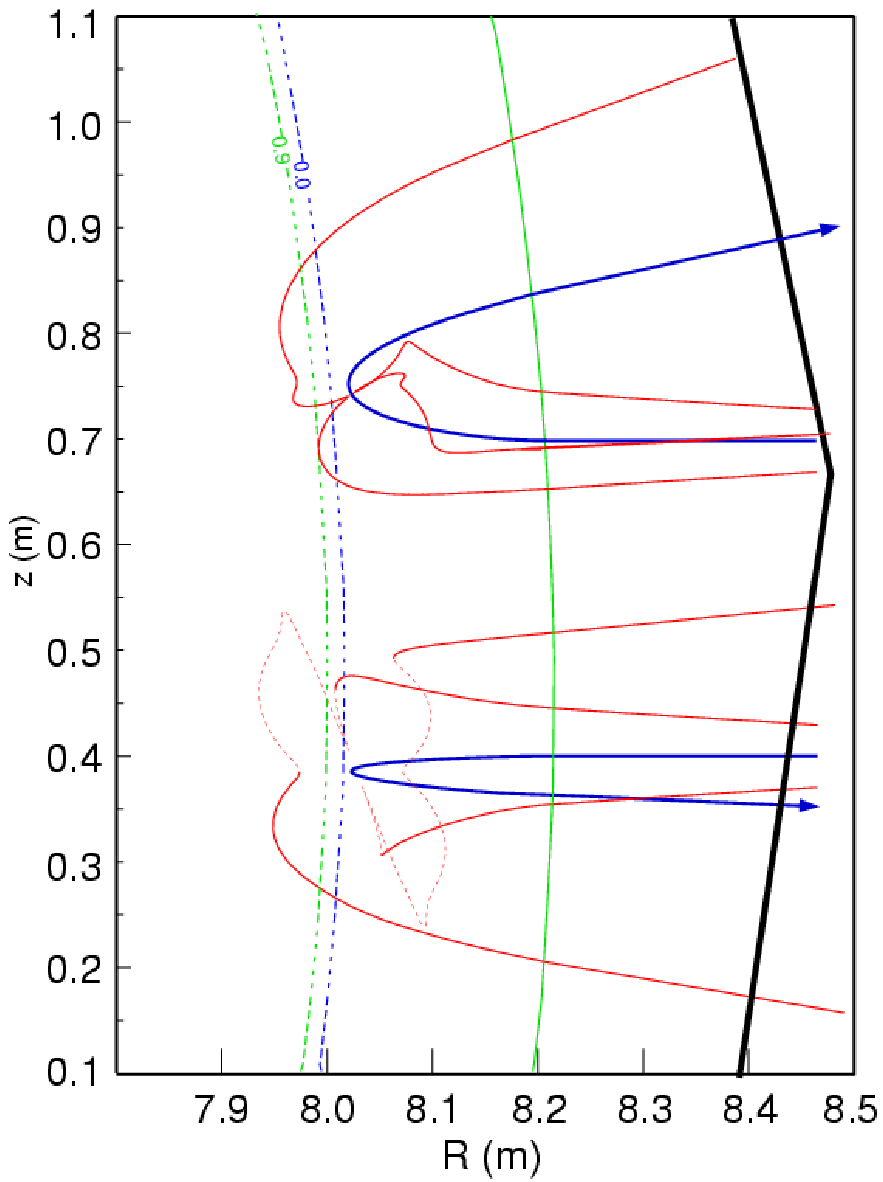


TORBEAM (Poli/Pereverzev) paraxial WKB Gaussian beam & 3D ray-trace – Doppler ant.

LFS antennas – Edge profile antenna optimization

G.D.Conway

- Increase tolerance to plasma column vertical movement & triangularity change (cutoff layer curvature) by decreasing antenna gain (fnct. of ant. dia. & freq.)
- Beam-tracing with divergent Gaussian beam at max. & min. scenario height → few degrees extra divergence maybe sufficient for scenario z-tolerance (edge O-mode) with 2 or 3 positions
- Higher z-tolerance comes at expense of returned signal strength
- Plasma start-up not covered
- Core probing (profiles X-mode or edge fluctuations) requires different antenna optimization → higher gain

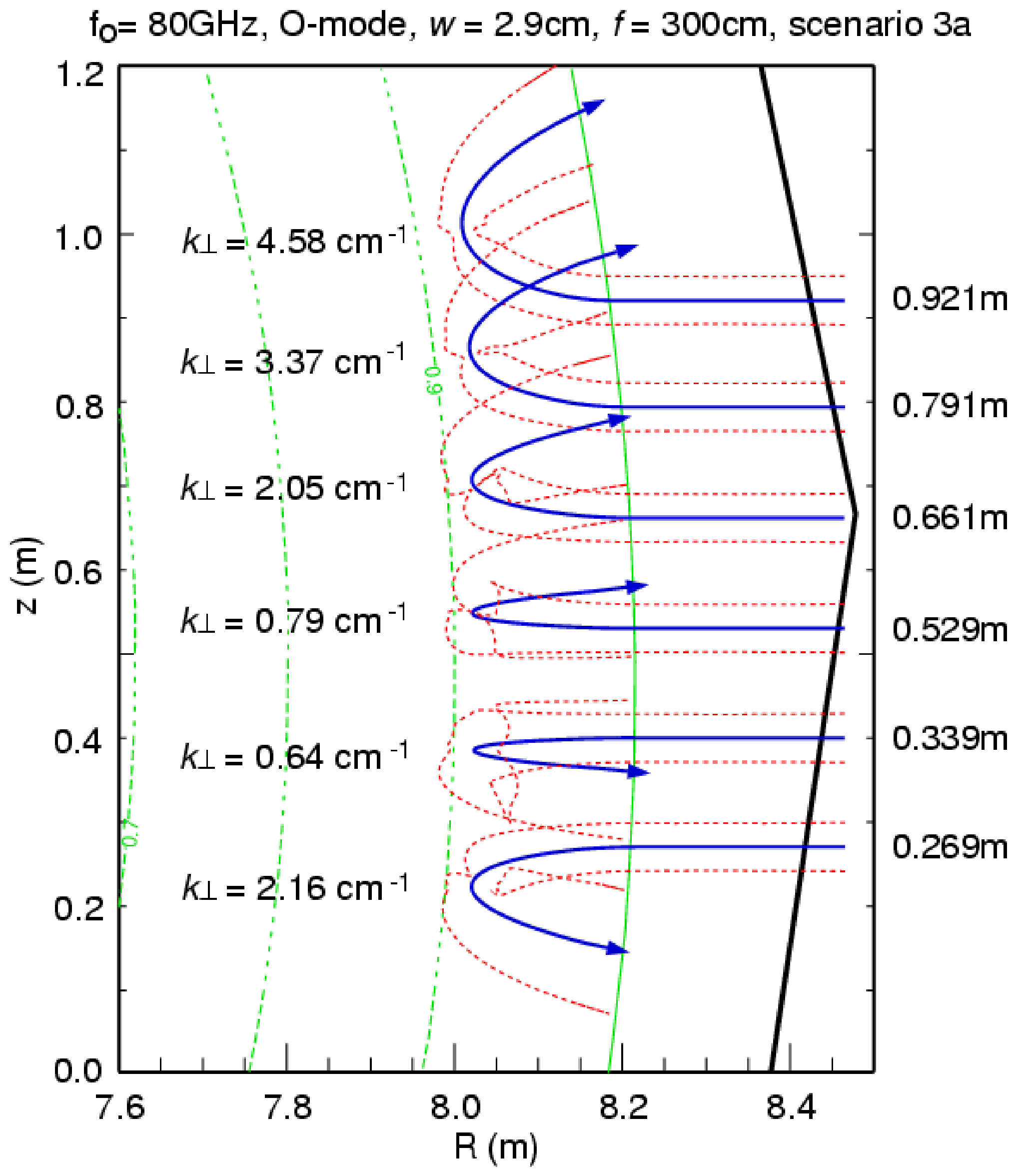


TORBEAM Gaussian beam: w = 2.9cm f = –50cm
Scenario 3a – Hybrid, 80GHz, O-mode

LFS antennas – Doppler reflectometry

G.D.Conway

- Doppler rotation measurement considered highly desirable by RWG. Rotation meas. in DDD via poloidal correlation refl.
- Maybe obtained as a by-product of "non-aligned" horizontal antennas, but parallel beam desirable
- Doppler could use monostatic ant.
- Beam tracing for proposed UCLA monostatic vertical array → all poloidal locations experience misalignment
- Array gives good spread in $k_\perp$ values for DR measurements!
- Horizontal core optimized antennas (high gain) maybe suitable for edge DR
- 2 dedicated tilt antennas minimum – question over bistatic versus 2 line-of-sight (differential meas. for tracking fast events)



LFS antennas – Alternatives for Port 9

G.D.Conway

- 12 w/g = 6 bistatic systems
- 1 pair O-mode
  15 – 60GHz
  edge profile optimized
  GAP 3 backup ?
- 2 pair O/X-mode
  40 – 180GHz
  edge profile optimized
- 2 pair O/X-mode
  40 – 180GHz
  fluct. / core optimized
- 2 pair O/X-mode tilted
  Doppler optimized – install all 4 antennas but only 2 w/g initially
- Possible integration of GAP 3 O-mode antennas
- Refractometry?