45 GHz Microwave Power Transmission and Coupling Scheme Study With Superconducting ECR Ion Source at IMP

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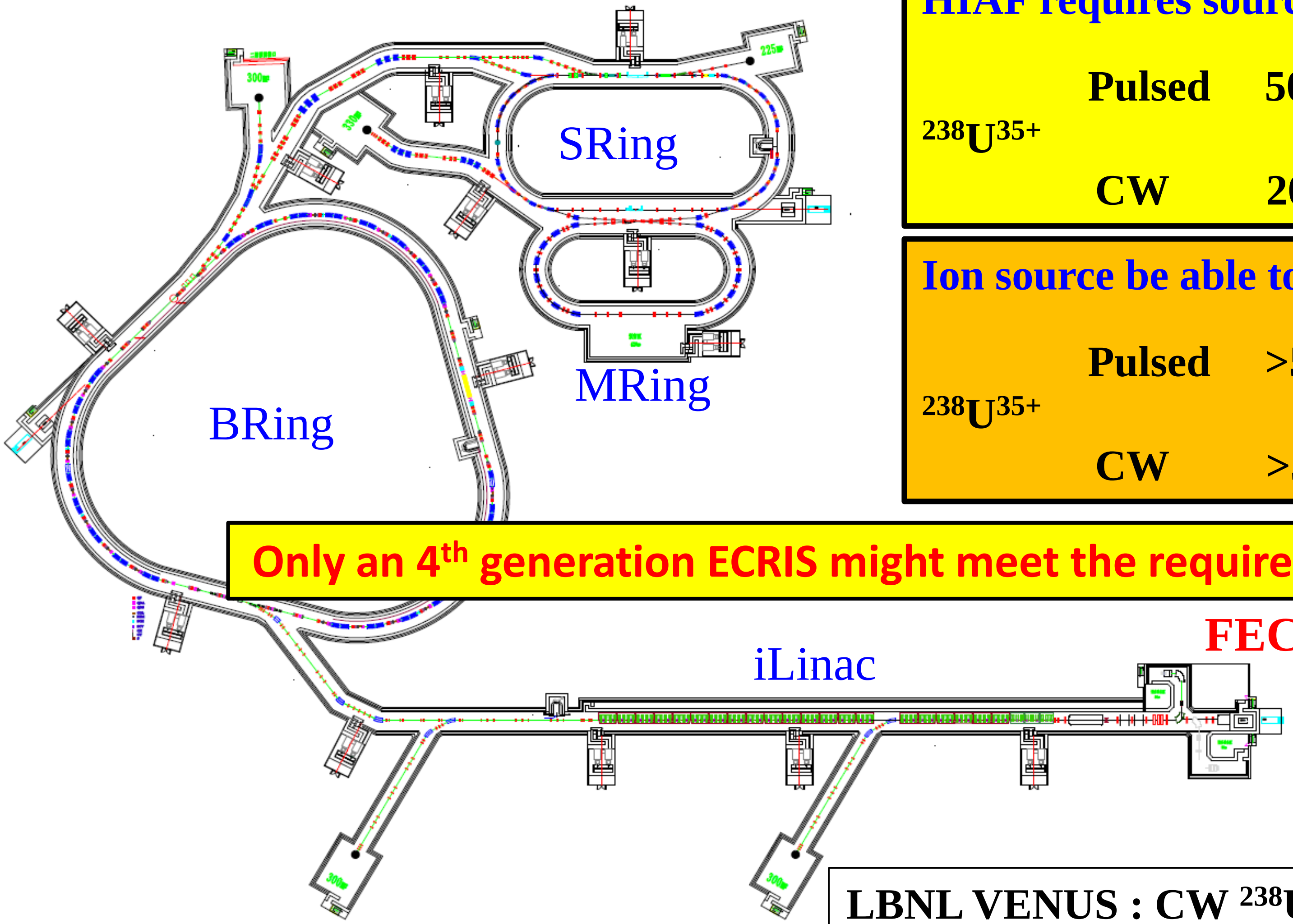
Outline

- Background
- Gyrotron system for 3rd Gen ECRIS
- 45 GHz microwave solutions
- Summary

Project HIAF

High Intensity heavy ion Accelerator Facility



HIAF requires source to deliver:

$^{238}U^{35+}$	Pulsed	50 pμA
	CW	20 pμA

Ion source be able to produce:

$^{238}U^{35+}$	Pulsed	>50 pμA
	CW	>30 pμA

Only an 4th generation ECRIS might meet the requirements

LBNL VENUS : CW $^{238}U^{35+}$: 10-12 pμA

45 GHz Fourth generation ECR ion source

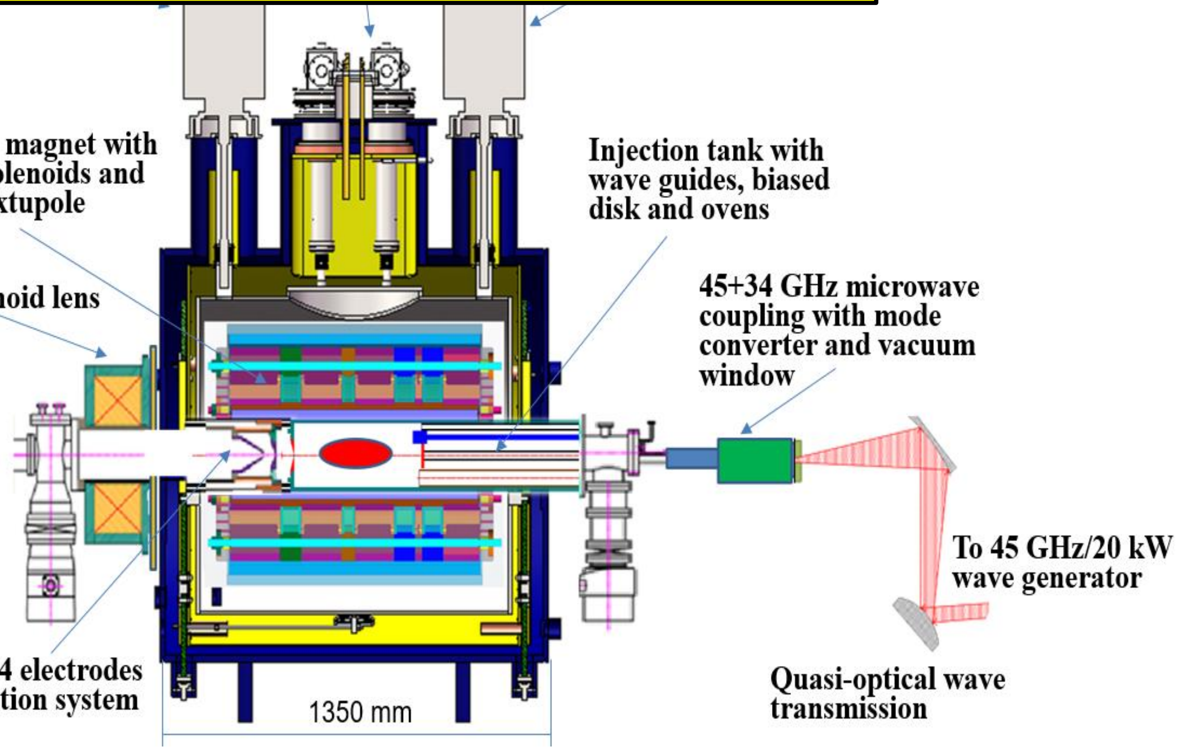
FECR key parameters

Parameters	Unit	FECR
Frequency	GHz	45
B_{ECR}	T	1.6
B_{inj}	T	>6.4
B_{extr}	T	3.2
B_r	T	>3.2
Mirror Length	mm	500
Chamber ID	mm	150
Warm bore ID	mm	170
Extra. voltage	kV	50

FECR expected beam intensities

$^{238}U^{35+}$	**>1000 μA**
$^{238}U^{41+}$	200-400 μA
$^{238}U^{56+}$	30-100 μA

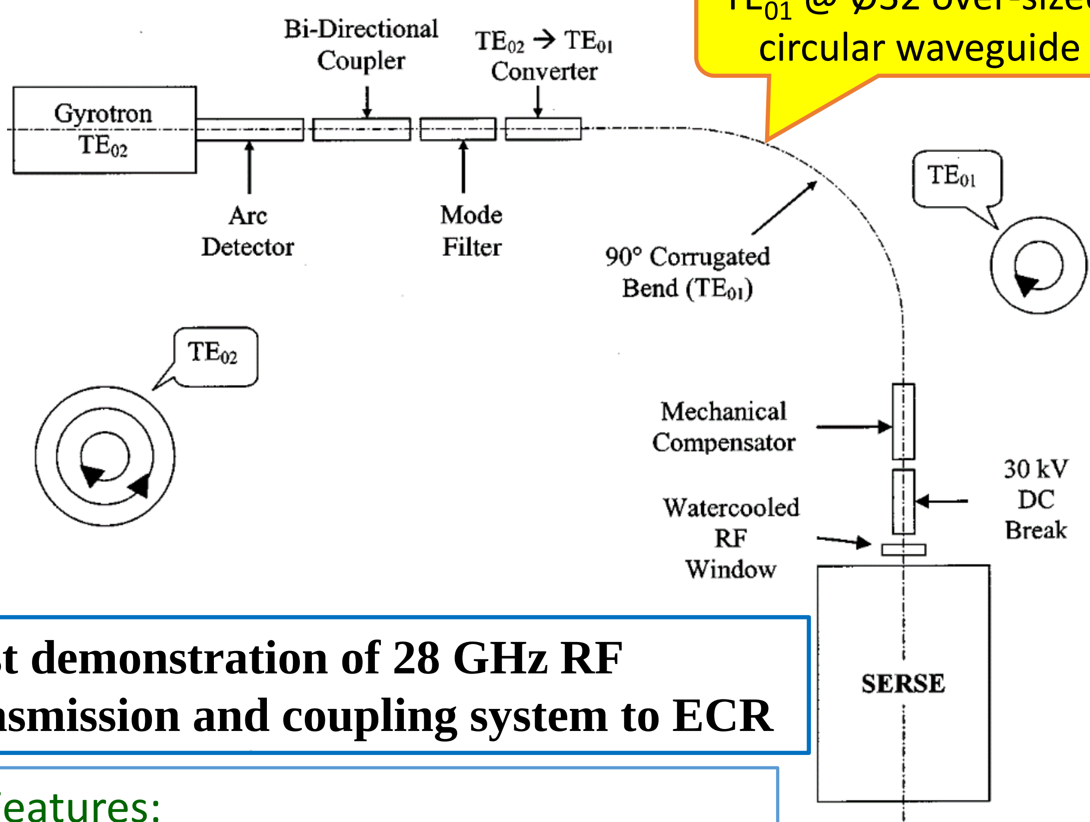
What kind of microwave coupling for the 4th generation ECR ?



See H. W. Zhao talk on Wednesday for details

3^{rd} Gen ECRIS microwave system

TE_{01} @ Ø32 over-sized circular waveguide



First demonstration of 28 GHz RF transmission and coupling system to ECR

Features:

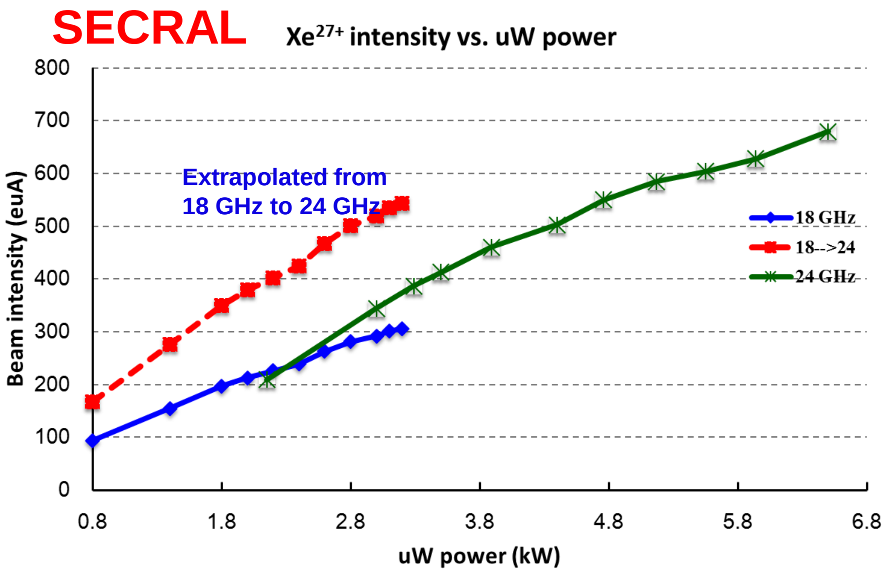
- Low ohmic loss over distances
- Good for 24/28 GHz µwave power

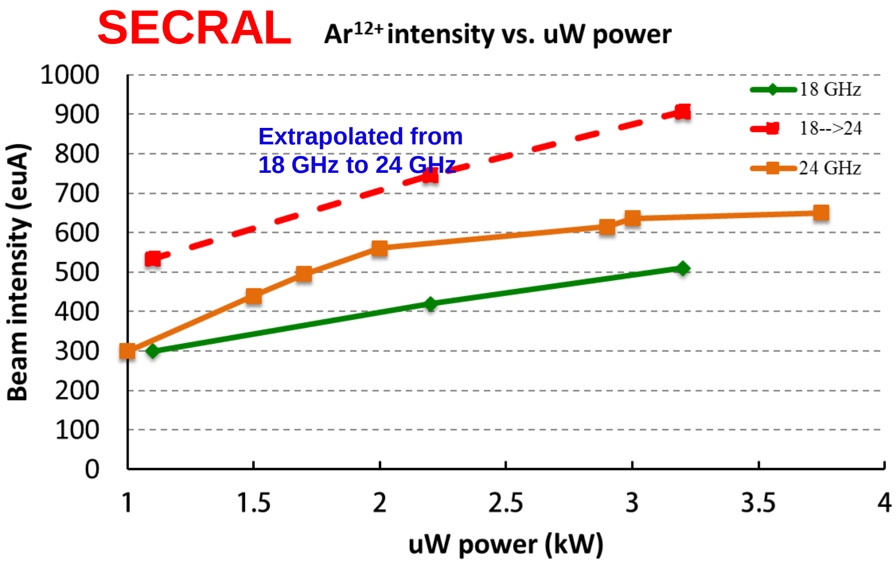
Problems:

- ECRH efficiency ??

S. Gammino, et al. Rev. Sci. Instrum., ***72*** *(2001)4090.*

3rd Gen ECRIS microwave coupling efficiency



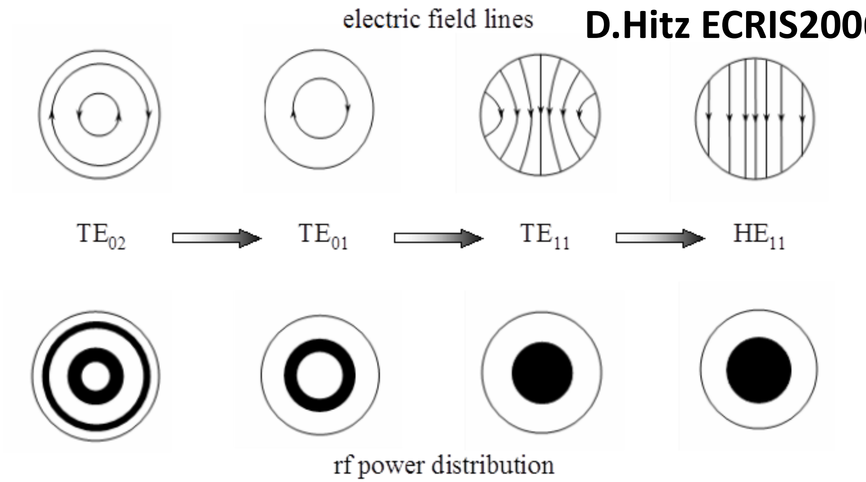


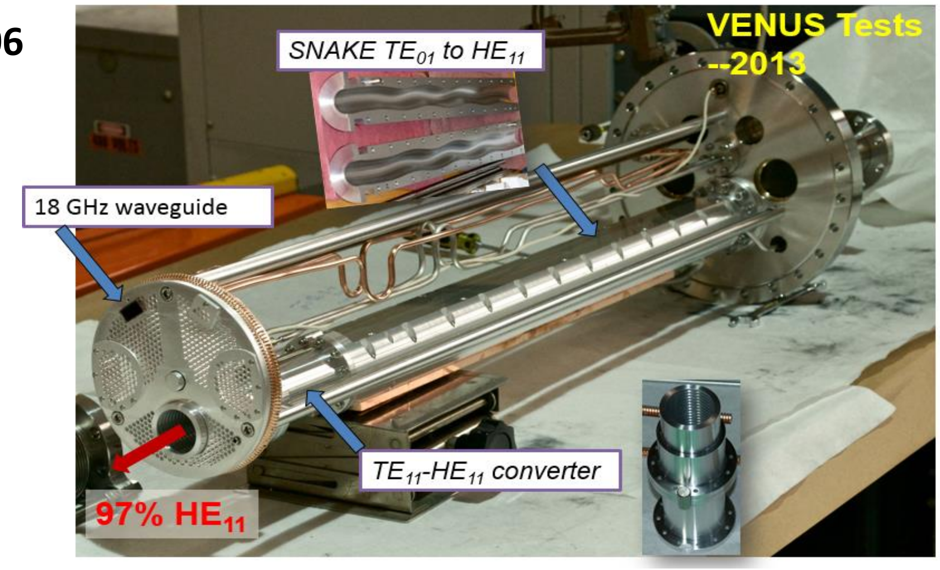
Similar results have also been observed with VENUS and SUSI

- Gyrotron frequency boosts beam intensities
- Beam intensity increase more like µW power scaling
- Frequency effect not obvious

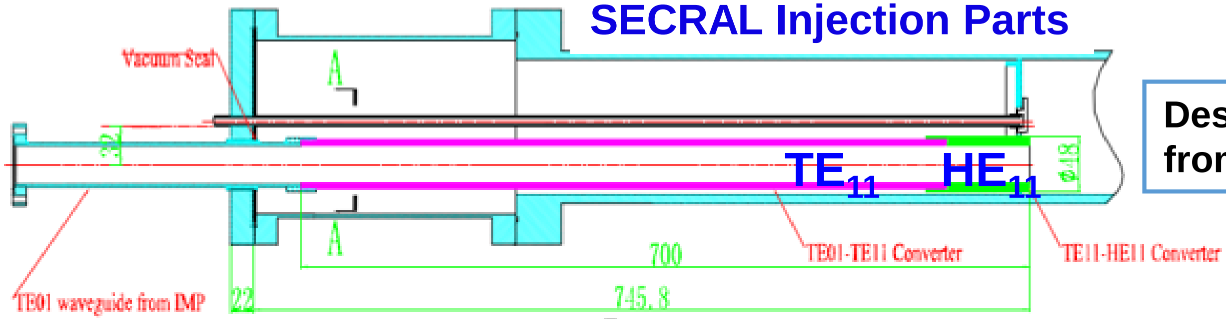
Exploration of μW coupling with SECRAL

D.Hitz ECRIS2006





SECRAL Injection Parts

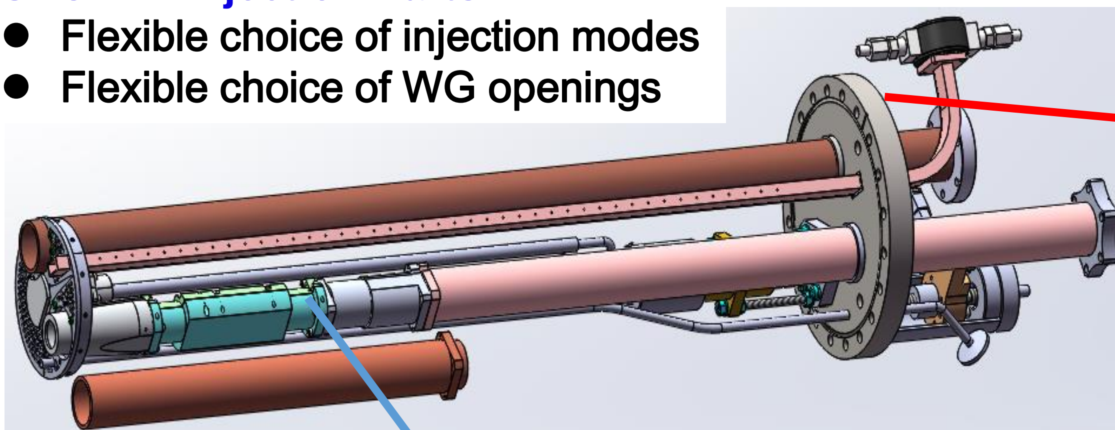


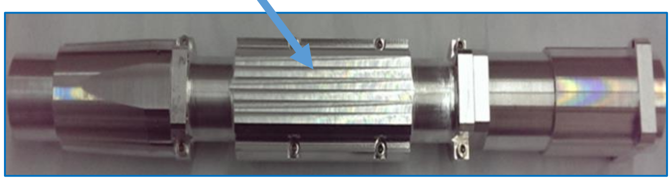
Designed by B. Plaum, W. Kasparek from Stuttgart University

Exploration of μW coupling with SECRAL

SECRAL Injection Parts

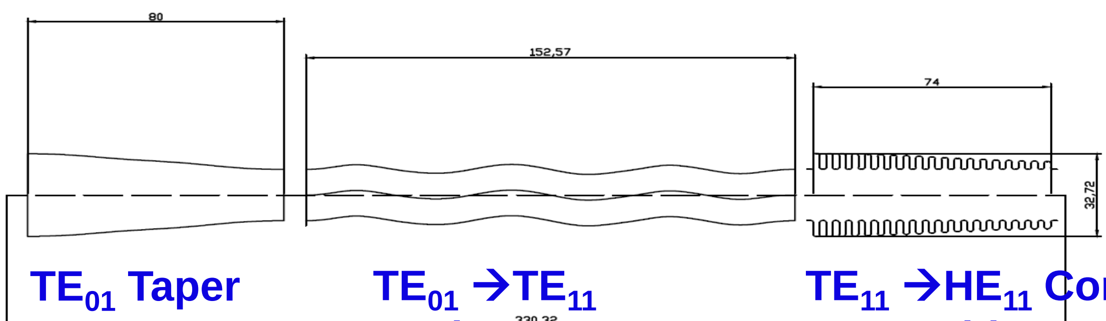
- Flexible choice of injection modes
- Flexible choice of WG openings





Compact Design:

- Waveguide ID: Ø32.6 mm→Ø20 mm
- Convector length: 745 mm→330 mm

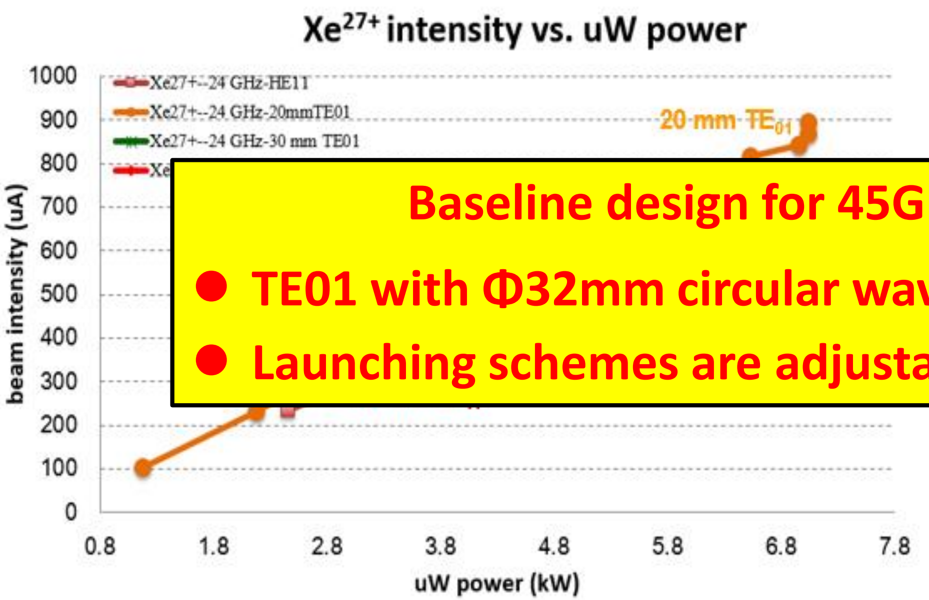


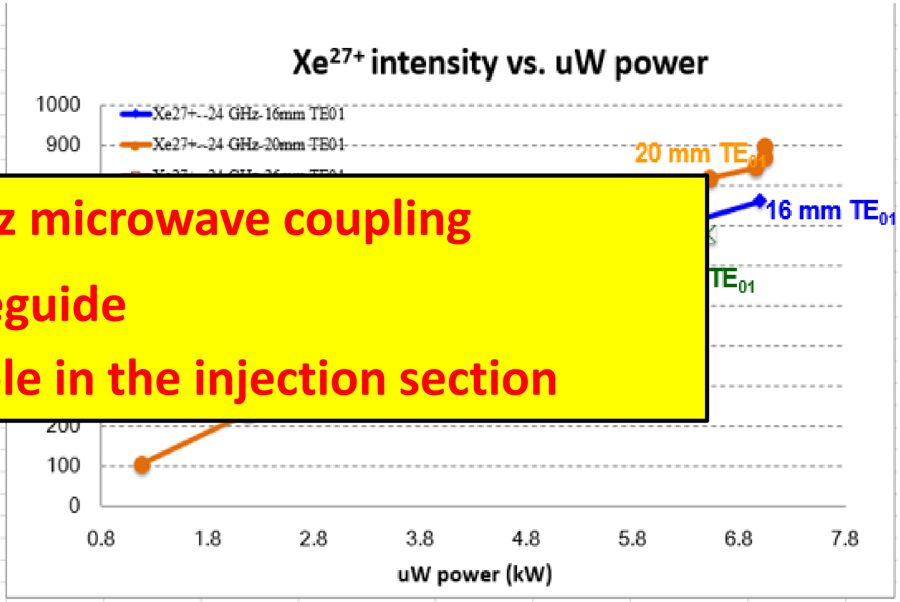
TE_{01} Taper convertor

$TE_{01} \rightarrow TE_{11}$ Snake convertor

$TE_{11} \rightarrow HE_{11}$ Corrugated waveguide

Exploration of μW coupling with SECRAL





Baseline design for 45GHz microwave coupling

- **TE01 with Φ32mm circular waveguide**
- **Launching schemes are adjustable in the injection section**

- TE_{11} @ Ø8 mm: Plasma is less stable at the power level over 5 kW
- **HE_{11} @ Ø20mm mode did not show any sign of advantage over TE_{01}**
- TE_{01} @ Ø16 mm: it is possible to couple high level of μW power, but not too much gain
- TE_{01} @ Ø26 mm: output tends to saturation at the power level over 5 kW

- **TE_{01} @ Ø20 mm shows obvious advantage in HCI production at high power level, No sign of saturation even at high power level**

45 GHz/20 kW microwave system

Parameters	SECRAL-II	FECR
Frequency	28 GHz	45 GHz
Operation Mode	CW	CW/Pulsed
Gyrotron output Mode	TE_{02}	Gaussian beam
Ion source input mode	TE_{01}	TE_{01}
Mode Purity	>95%	>95%
Max. Power	10.0 kW	20 kW
Transmission line	Circular waveguide	Combined mirror and waveguide
Waveguide Size	~Ø32.6 mm	~Ø32.6 mm
Pulse mode operation specifications		
Fall Time		<10 μs
Rise Time		<200 μs
Pulse Duration		5-200 ms
Repetition Rate		1~10 Hz

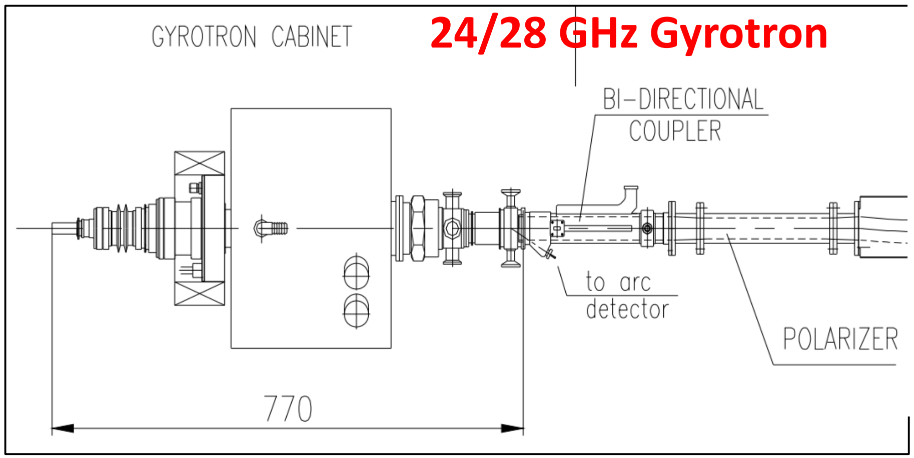
45 GHz/20 kW gyrotron

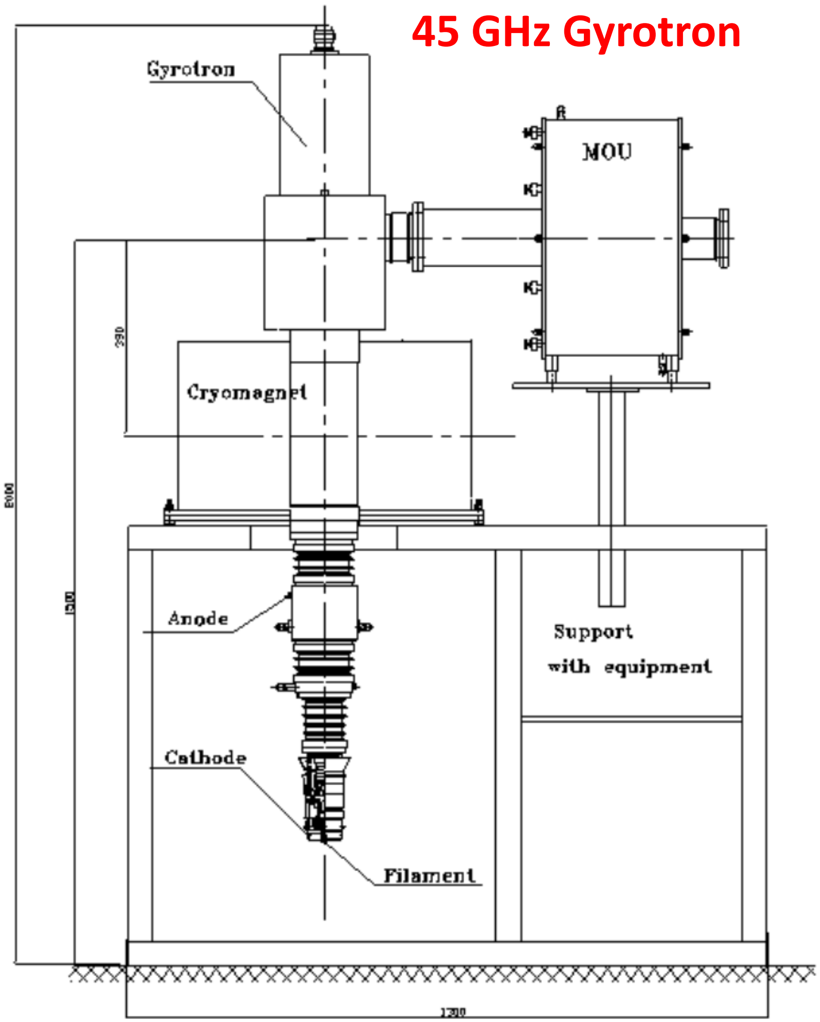
24/28 GHz (<35 GHz) Features:

- longitudinal output in TE_{mn} mode
- Normal electromagnet (on the second harmonic of electron cyclotron resonance)
- Transmission line: Smooth wall circular waveguide

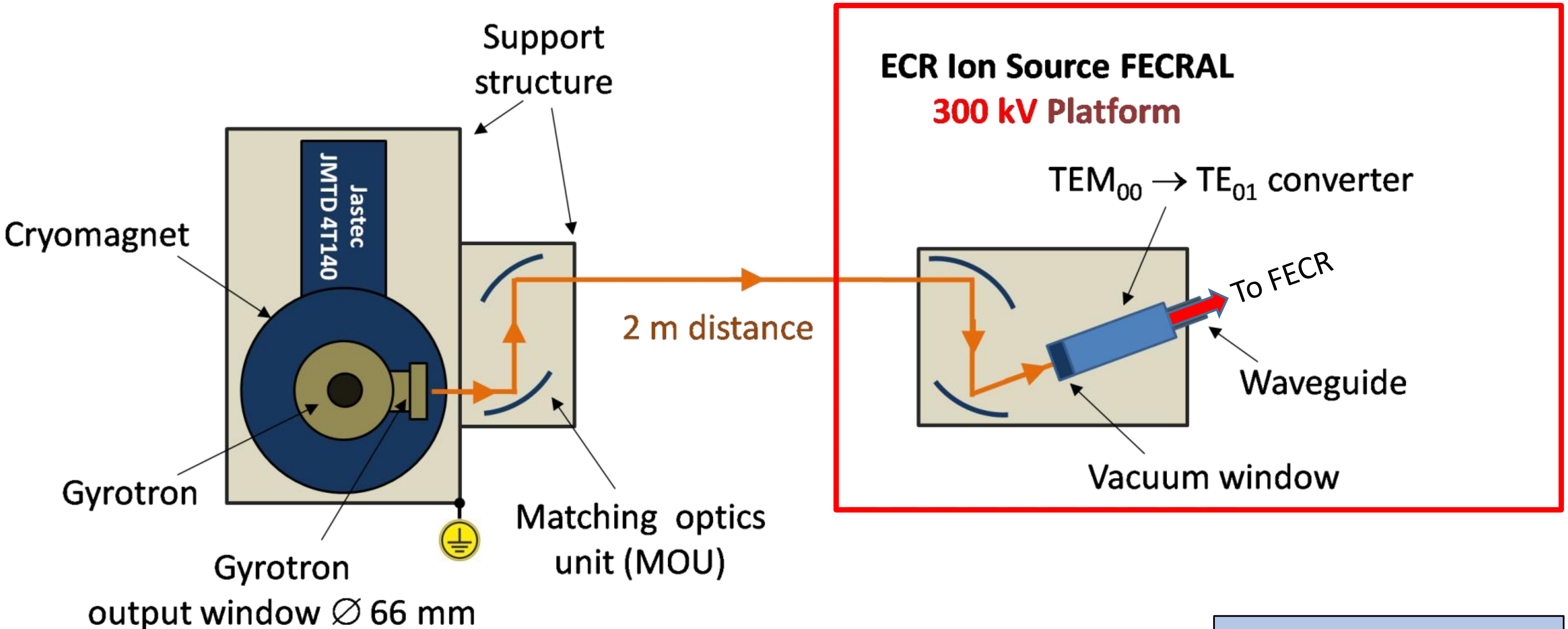
45 GHz (>35 GHz) Features:

- lateral output in Gaussian mode.
- Cryogenic superconducting magnet (liquid helium cooled or liquid helium free)
- Transmission line: Quasi-optical mirror, corrugated waveguide





FECR 45 GHz μW Power Schematic

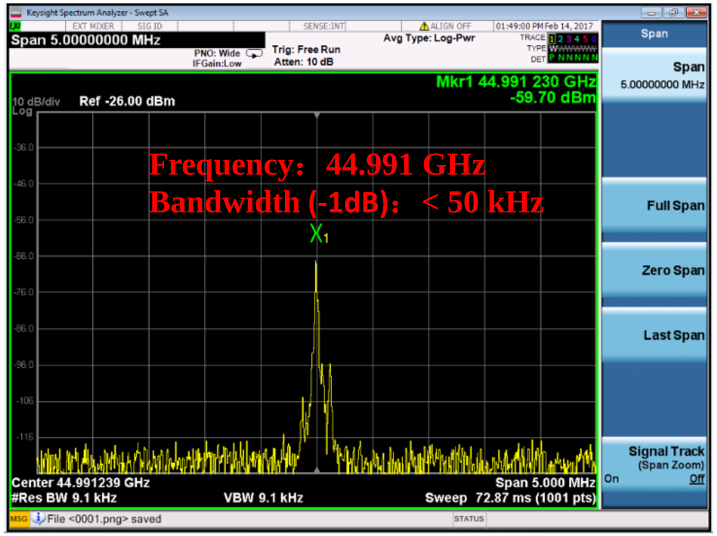


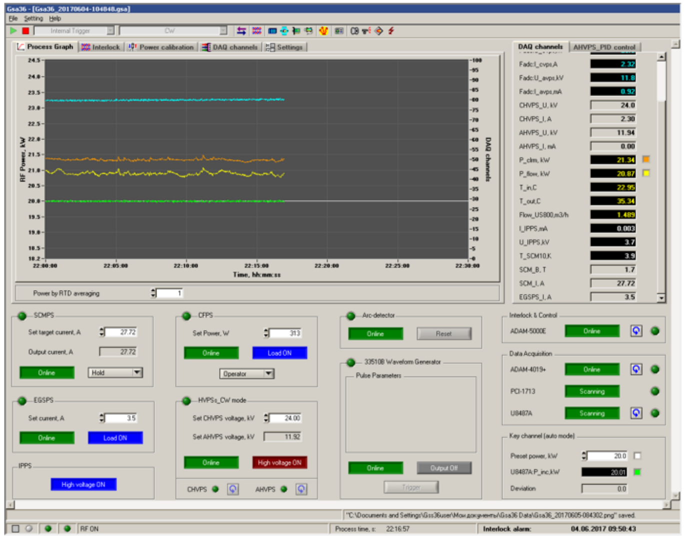
Courtesy of A.I.Tsvetkov

Gyrotron microwave source main components

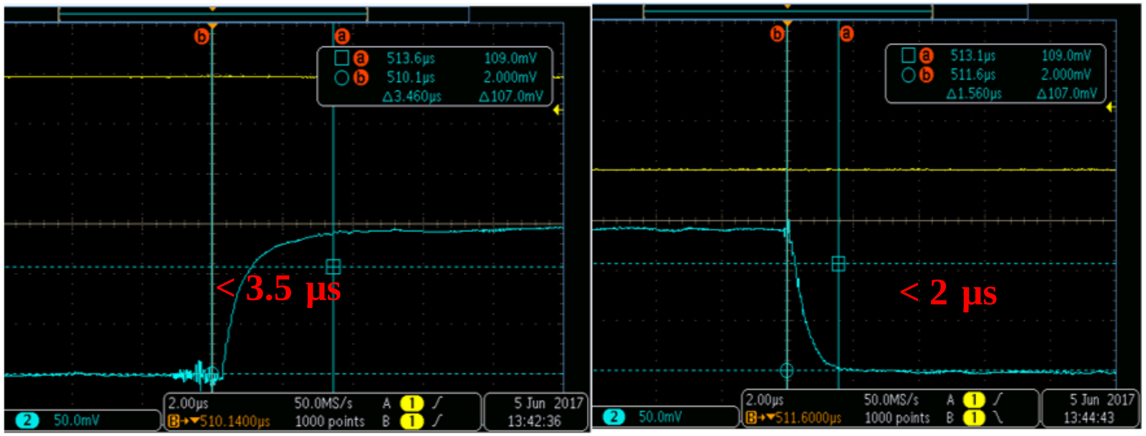
45 GHz/20 kW microwave generator is manufactured by GYCOM, Russia.

Commissioning test of 45 GHz system

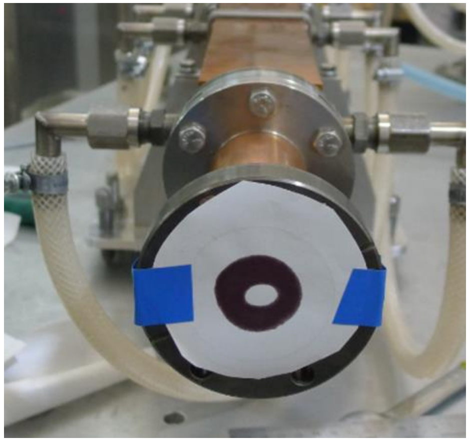




Long-term CW mode stability test at 20 kW



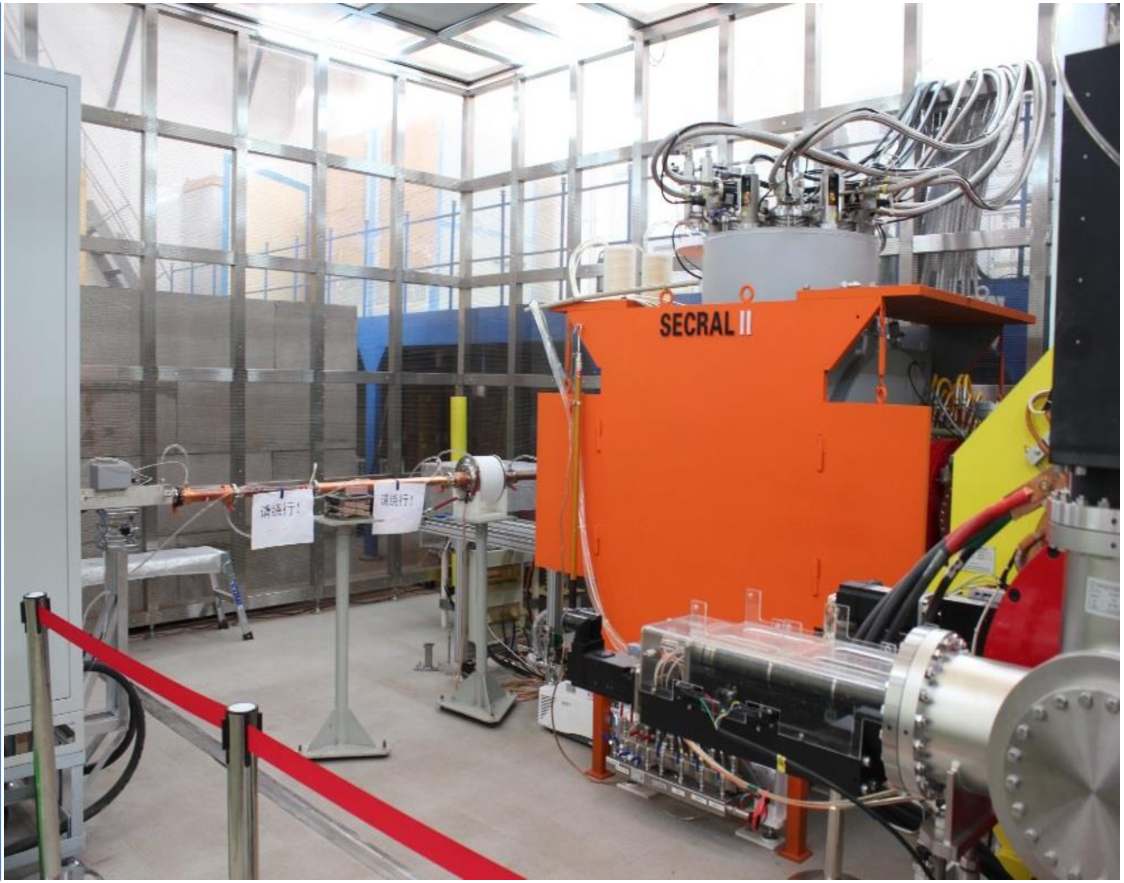
Pulse mode operation test



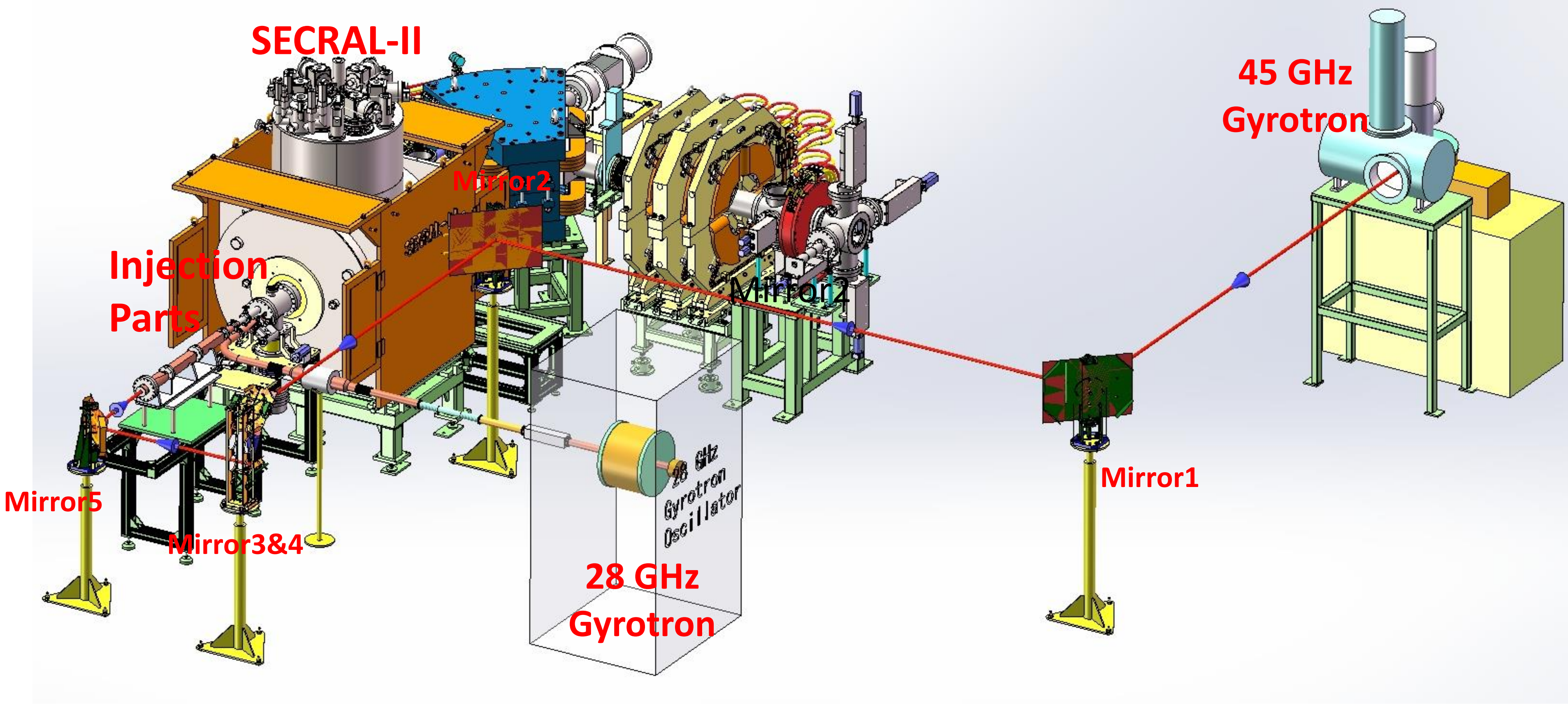
Microwave mode test

SECRAL-II: Test Bench Layout

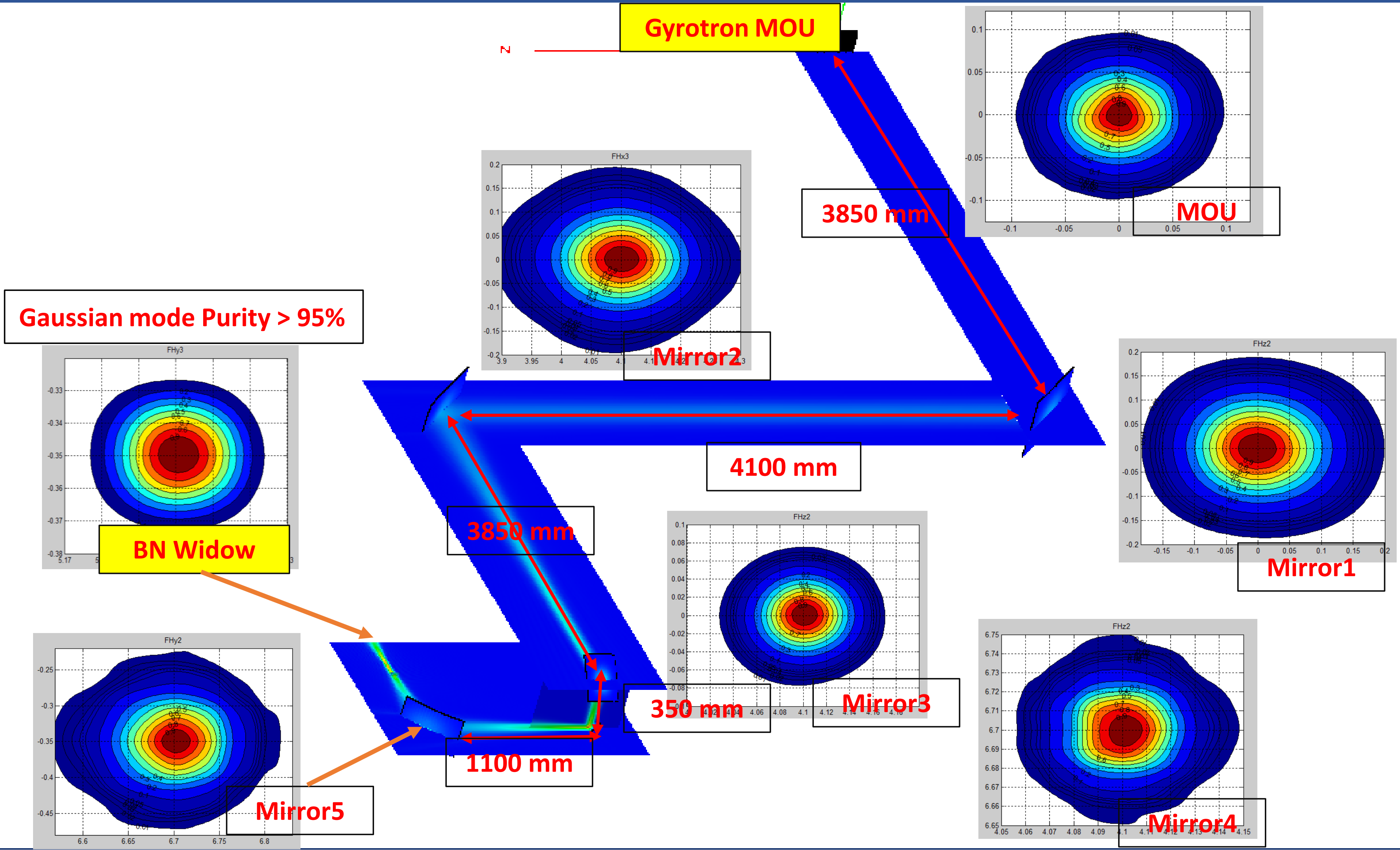
Parameters	SECRAL-II
ω_{rf} (GHz)	18-28
Axial Field Peaks (T)	3.7 (Inj.), 2.2 (Ext.)
Mirror Length (mm)	420
No. of Axial SNs	3
B_r at r=63 mm (T)	2.06
Coldmass Length (mm)	810
SC-material	NbTi
Magnet Cooling	LHe bathing
Warm bore ID (mm)	142 .0
Chamber ID (mm)	125.0



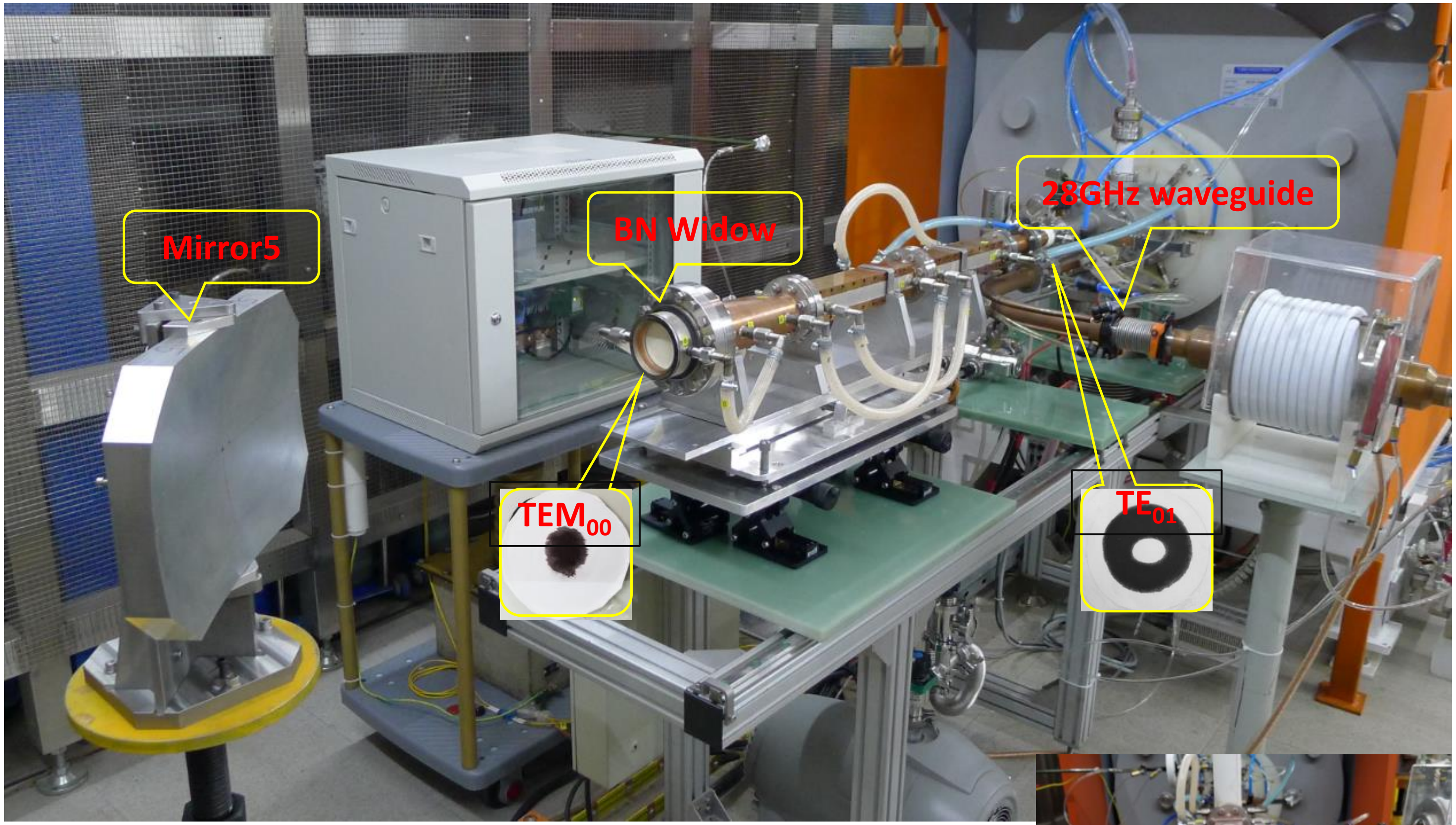
The Layout of the setup for 45 GHz test with SECRAL-II

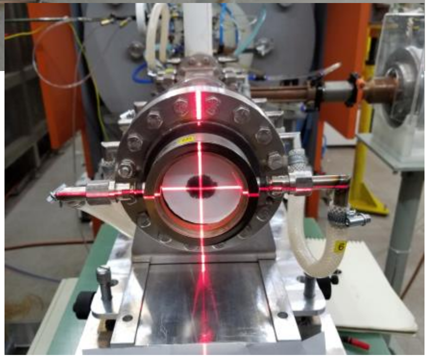


Design of the 45GHz transmission line for SECRAL-II



Transmission line installation and test

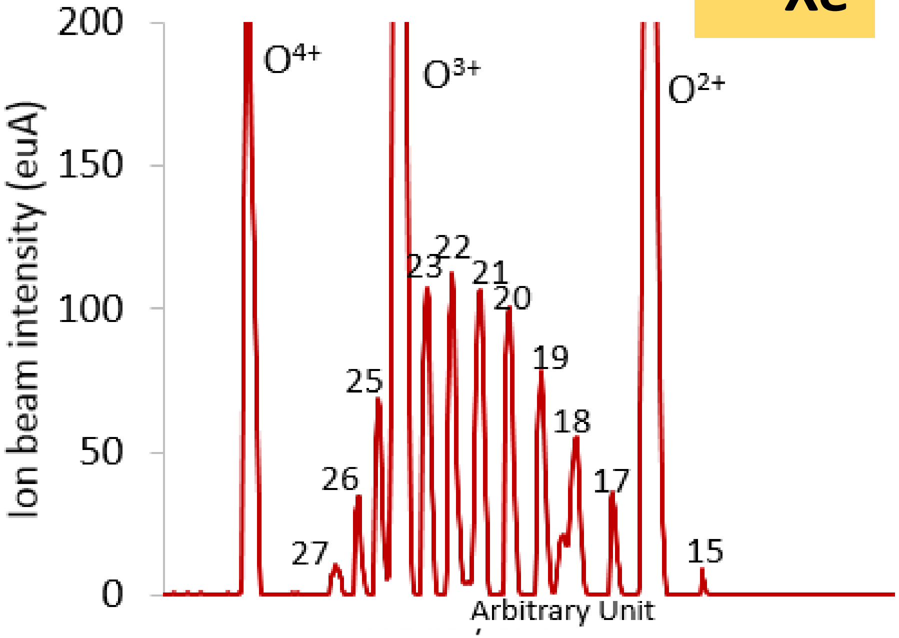




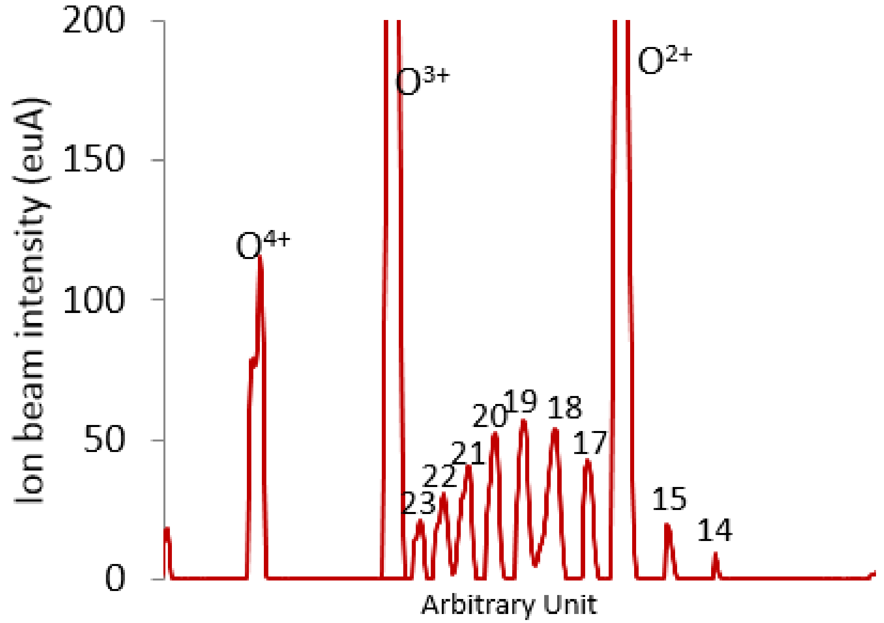
- Stringent alignment
- Total efficiency of quasi-optical transmission line and mode converter is about 97%.

First 45 GHz ECR plasma

^{129}Xe



ω_{rf}: 28 GHz, Pw= 4.0 kW, HV= 20 kV, Slit-x= 24 mm
Io= 4.0 emA, B: 3.4 T, 0.67 T, 1.8 T/1.87 T
2017/10/12



ω_{rf}: 45 GHz, Pw= 4.0 kW, HV= 20 kV, Slit-x= 24 mm
Io= 3.6 emA, B: 3.4 T, 0.6 T, 1.8 T, 1.87 T
2017/10/12

- Quasi-optical transmission lines work well in the early tests up to 4 kW of power

Summary

- TE_{01} with Φ32mm circular waveguide coupling scheme can work for 45 GHz
- Quasi-optical transmission lines work well in the early tests up to 4 kW of power
- First 45 GHz plasma was obtained with SECRAL-II

- ☐ What is the optimized microwave power injection scheme for 45GHz needs better understanding and more investigation
- ☐ Further detailed tests on SECAL-II with 45 GHz are planned, especially a systematic study of the magnetic field and measurements of the plasma bremsstrahlung at different conditioning parameters.

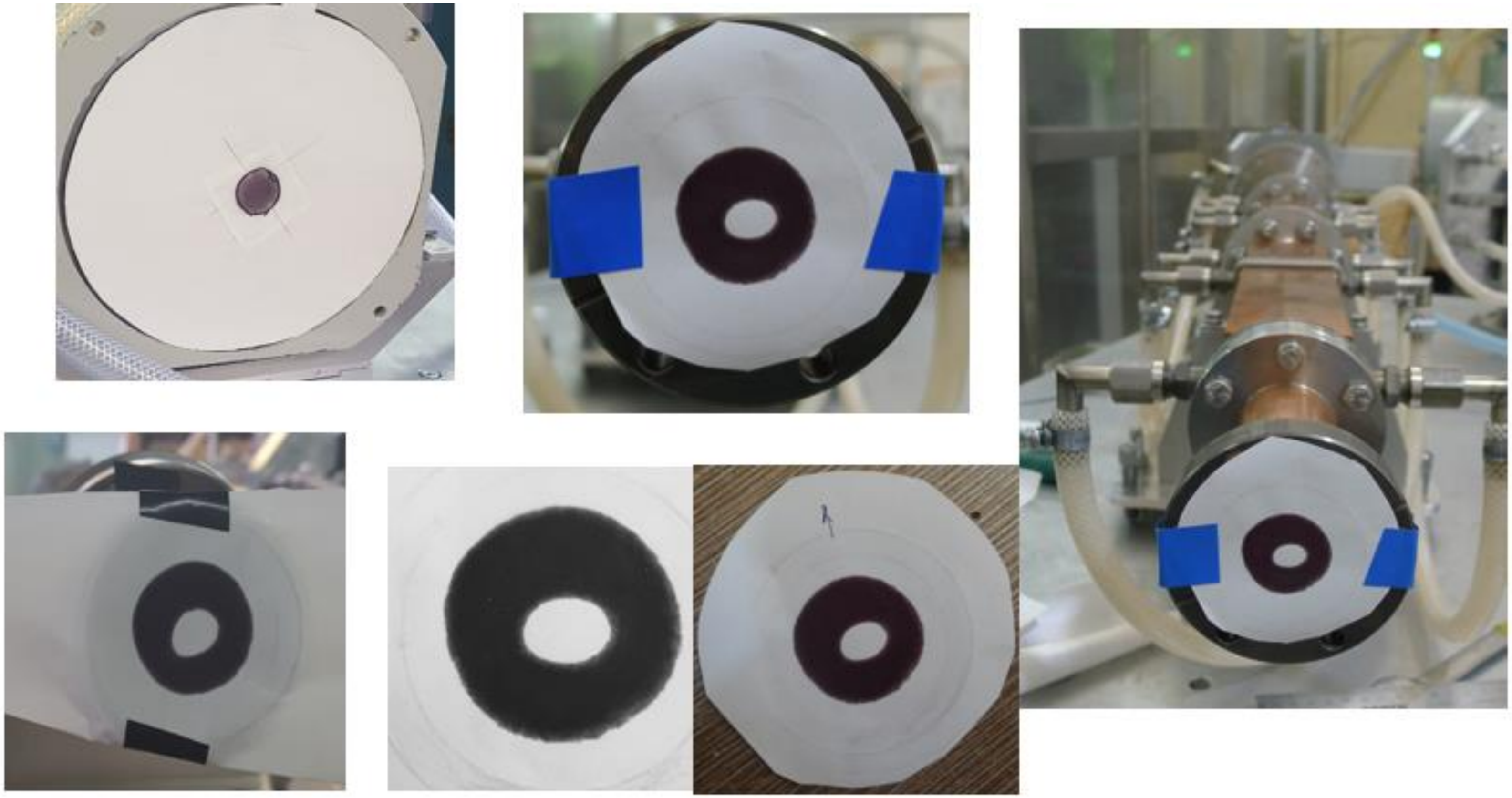
Thanks for your attention!

45 GHz Gyrotron at IMP

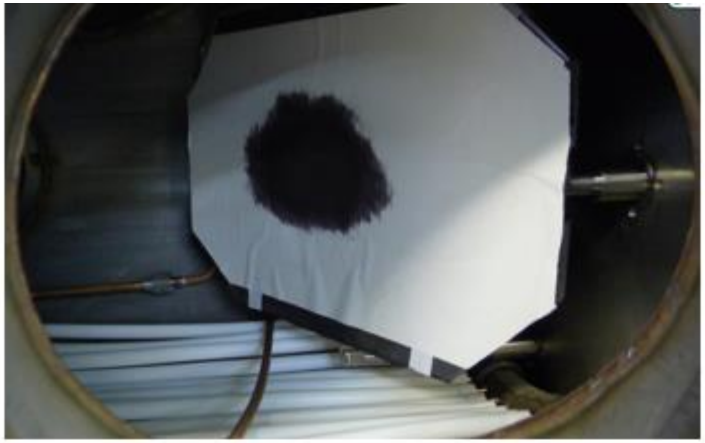
Gyrotron Magnetic System

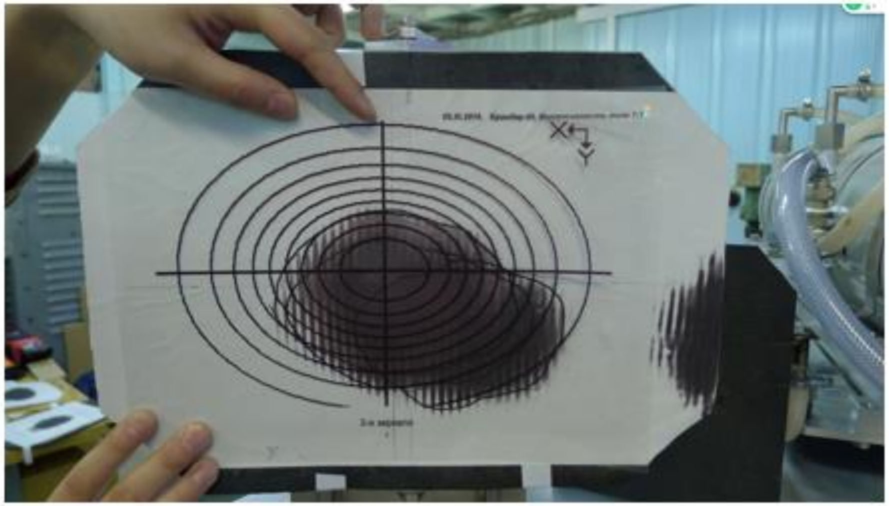
The system based on JMTD 4T140 liquid helium free magnet
(up to 4 T, warm bore ∅140 mm)
Operating magnetic field ~ 1.7 T

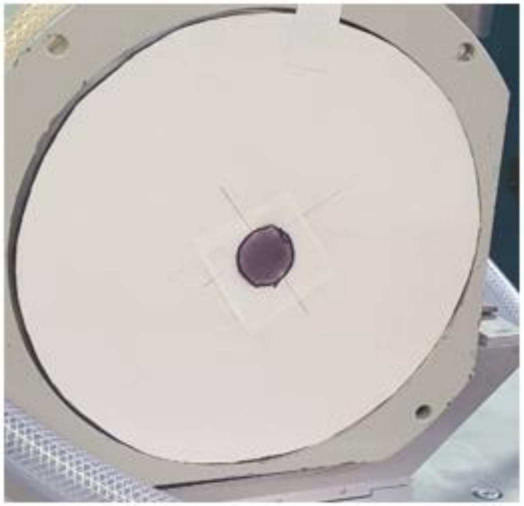
Microwave mode test



45GHz quasi-optical transmission line installation

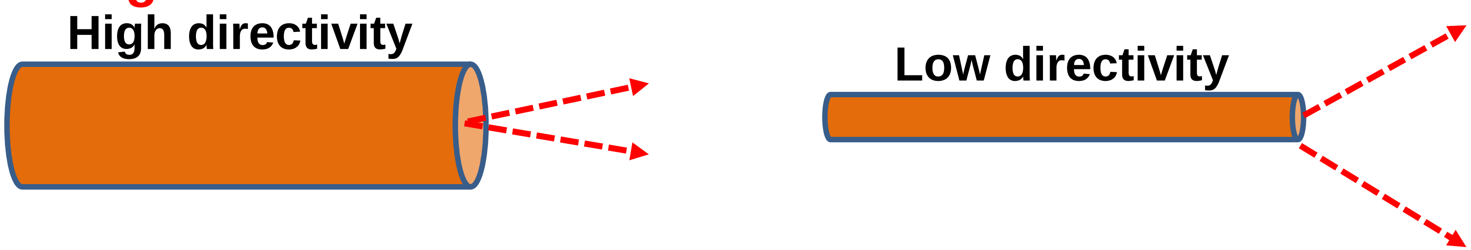




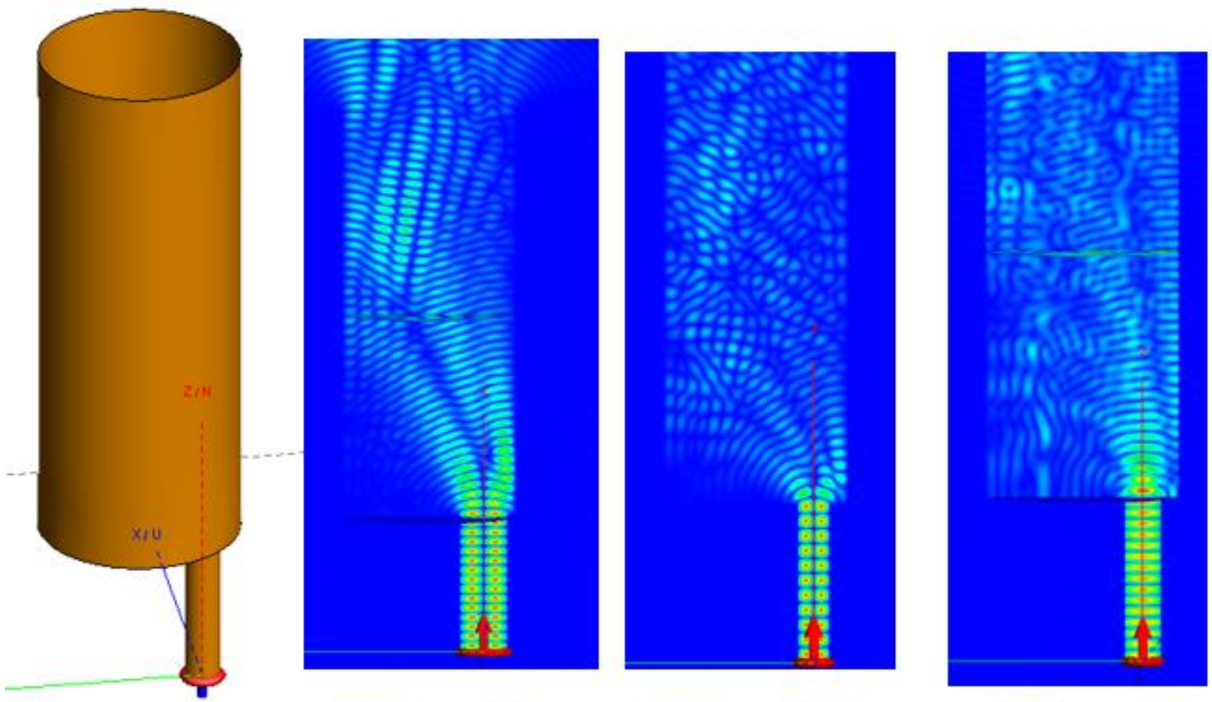


1st pass absorption is important

Waveguide: Antenna



Radiation with chamber wall



Ø32 mm TE_{01} Ø20 mm TE_{01} Ø20 mm HE_{11}