



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

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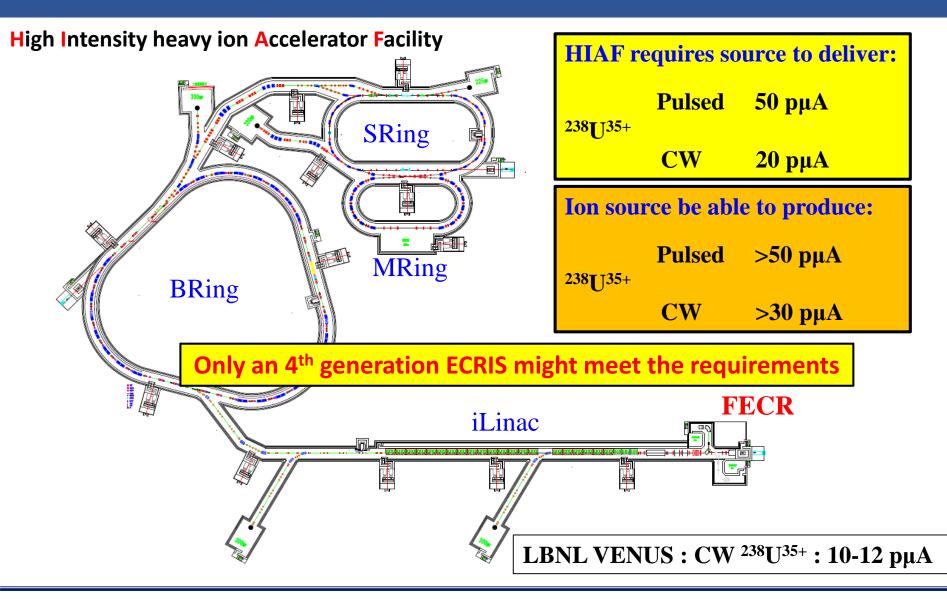


## • Gyrotron system for 3<sup>rd</sup> Gen ECRIS

## 45 GHz microwave solutions

## ♦ Summary

# **Project HIAF**



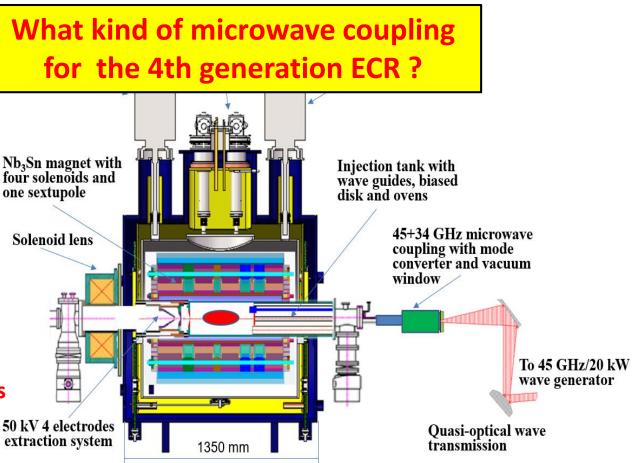
## 45 GHz Fourth generation ECR ion source

## **FECR key parameters**

Parameters	Unit	FECR	What kin
Frequency	GHz	45	for the
B <sub>ECR</sub>	Т	1.6	5. 10
B <sub>inj</sub>	Т	>6.4	
B <sub>extr</sub>	Т	3.2	Nb <sub>3</sub> Sn magnet with four solenoids and
B <sub>r</sub>	Т	>3.2	one sextupole
Mirror Length	mm	500	Solenoid lens
Chamber ID	mm	150	
Warm bore ID	mm	170	
Extra. voltage	kV	50	

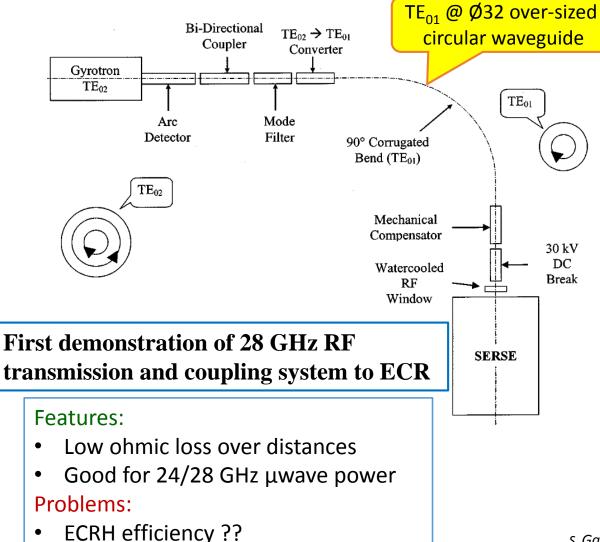
## FECR expected beam intensities

<sup>238</sup> U <sup>35+</sup>	>1000 µA
<sup>238</sup> U <sup>41+</sup>	200-400 μA
<sup>238</sup> U <sup>56+</sup>	30-100 μA



See H. W. Zhao talk on Wednesday for details

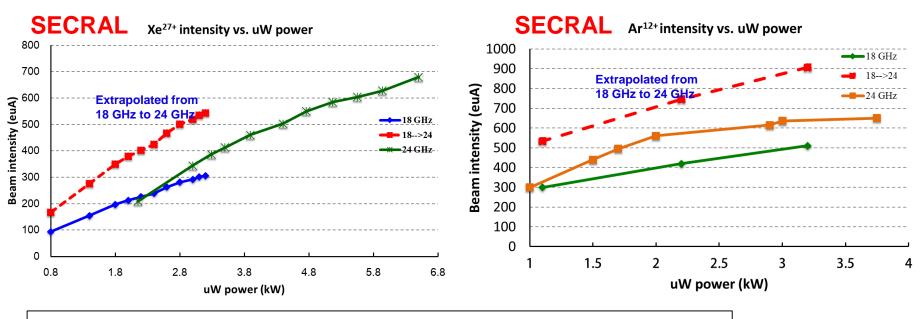
# 3<sup>rd</sup> Gen ECRIS microwave system





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

# 3<sup>rd</sup> Gen ECRIS microwave coupling efficiency



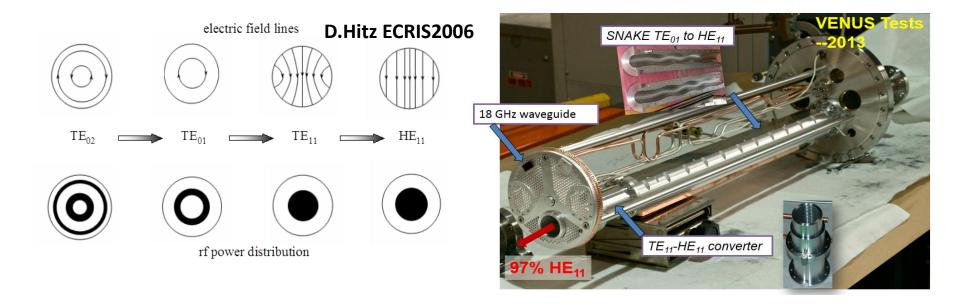
Similar results have also been observed with VENUS and SUSI

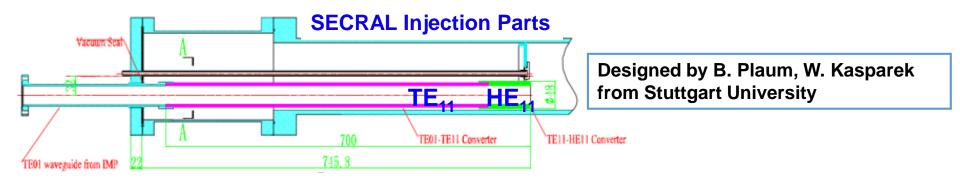
□ Gyrotron frequency boosts beam intensities

□ Beam intensity increase more like µW power scaling

Frequency effect not obvious

# Exploration of µW coupling with SECRAL





# Exploration of µW coupling with SECRAL

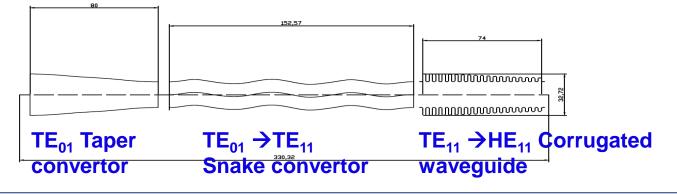
### **SECRAL Injection Parts**

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

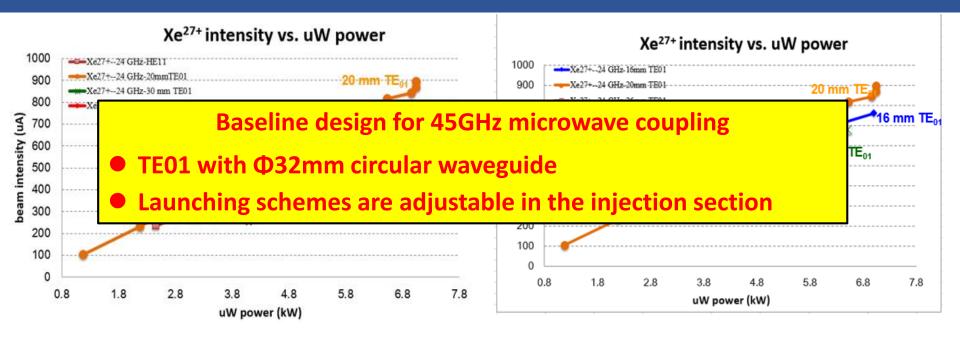


#### **Compact Design:**

- Waveguide ID:  $Ø32.6 \text{ mm} \rightarrow Ø20 \text{ mm}$
- Convector length: 745 mm→330 mm



# Exploration of µW coupling with SECRAL



- $TE_{11} @ Ø8 mm$ : Plasma is less stable at the power level over 5 kW
- HE<sub>11</sub> @ Ø20mm mode did not show any sign of advantage over TE<sub>01</sub>
- $TE_{01} @ Ø16$  mm: it is possible to couple high level of  $\mu W$  power, but not too much gain
- $TE_{01} @ Ø26$  mm: output tends to saturation at the power level over 5 kW
- TE<sub>01</sub> @ 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

SECRAL-II	FECR				
28 GHz	45 GHz				
CW	CW/Pulsed				
TE <sub>02</sub>	Gaussian beam				
TE <sub>01</sub>	TE <sub>01</sub>				
>95%	>95%				
10.0 kW	20 kW				
Circular waveguide	Combined mirror and waveguide				
~Ø32.6 mm	~Ø32.6 mm				
Pulse mode operation specifications					
	<10 µs				
	<200 μs				
	5-200 ms				
	1~10 Hz				
	28 GHz CW TE <sub>02</sub> TE <sub>01</sub> >95% 10.0 kW Circular waveguide ~Ø32.6 mm				

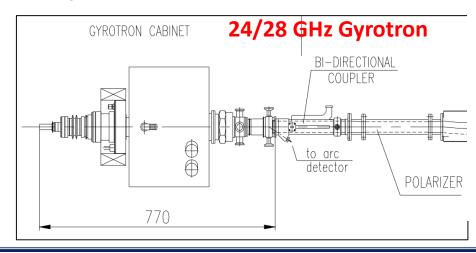
# 45 GHz/20 kW gyrotron

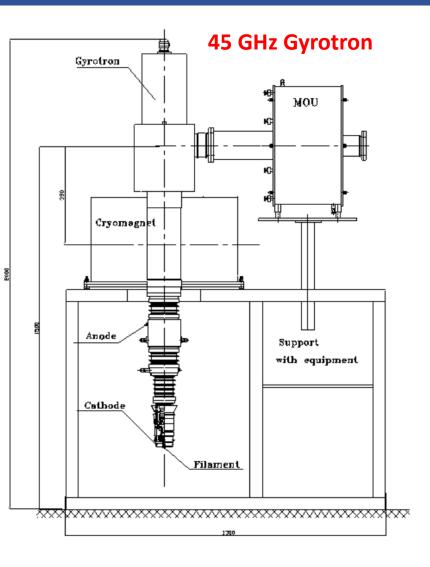
## 24/28 GHz (<35 GHz) Features:

- longitudinal output in TE<sub>mn</sub> mode
- Normal electromagnet (on the second harmonic of electron cyclotron resonance)
- Transmission line: Smooth wall circular waveguide

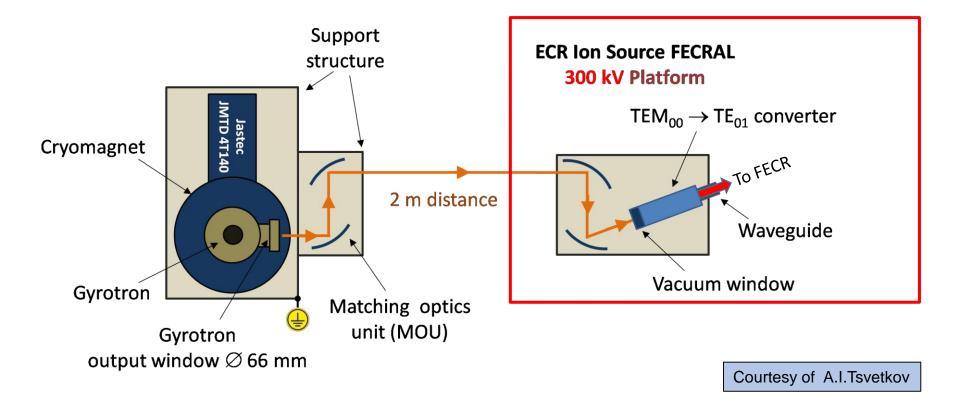
## 45 GHz (>35 GHz) Features:

- 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



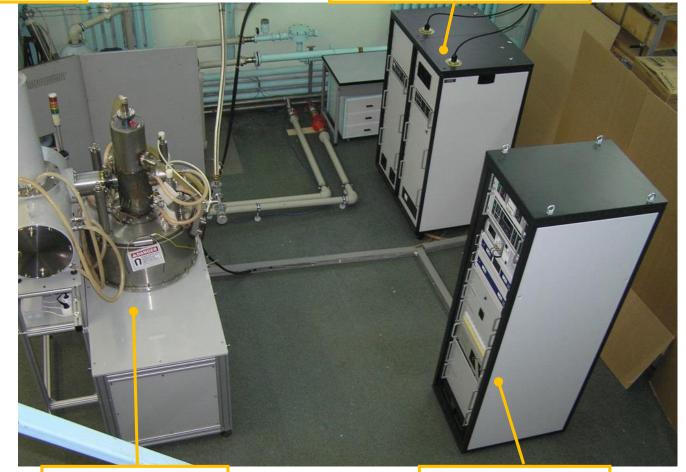
## Gyrotron microwave source main components

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

#### **Transmission Lines & Mode Converter**

High Voltage Power Supply



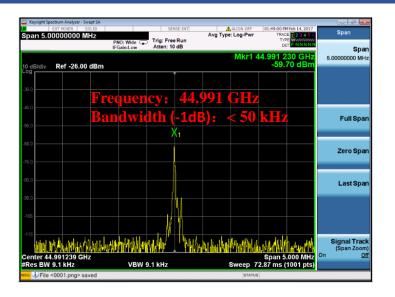


### **Gyrotron Module**

**Instrumental Rack** 

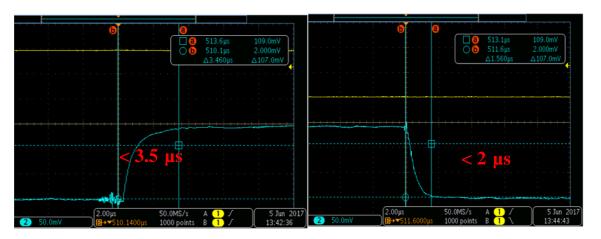
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# **Commissioning test of 45 GHz system**

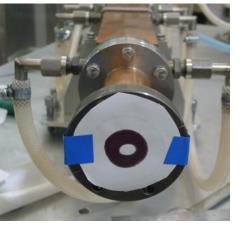


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24.5 -		-109	Fadc1_cvptA	2.32
24.8-		-95	Fadc:U_avpt,kV	11.8
22.5-		-90	Fadc1_avps.mA	0.92
2.4-		-60	CHVPS_U_KV	24.0
		-75	CHVPS_J.A	2.30
22.5-		-65	AHVPS_U, kV	11.94
22.8-		-00	AHVPS_J, mA	0.00
21.5 - mar and a stranger and the second stranger and		-50	P_clm, kW	21.34
21.8-		-6	P_Bow, kW	20.87
20.5 -		-15	T_in.C	22.95
29.9-		-30	T_out.C	35.34
19.5 -		-29	Flow_US800,m3/h	1.489
19.0-		-15	L_IPPS,mA	0.003
10.5 -			U_IPPS.kV	3.7
18.2-	22:19:59 22:15:09 22:2	9:09 22:25:99 22:20:09	T_SCM10,K	3.9
	Time, hh:mm:ss		SCM_B.T	1.7
Power by RTD averaging	1		SONULA EGSPS LA	27.72
			EGSPS_J.A	27.72
- SDMPS	OFPS	Arc detector	EGSPS_I, A	3.5
		Arc-detector Online Denset	EGSPS_J.A	
SCMPS	OFPS	Orline Reset	EGSPS_I, A	3.5
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#### Long-term CW mode stability test at 20 kW



Pulse mode operation test



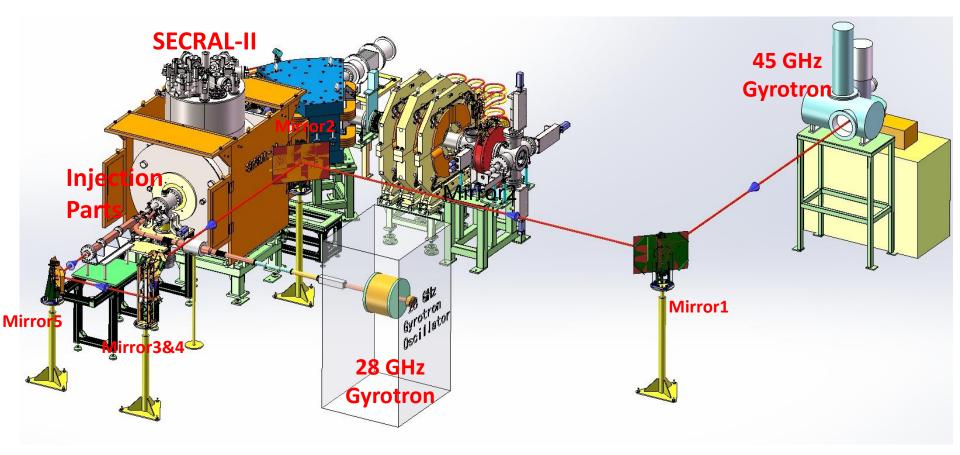
#### Microwave mode test

# **SECRAL-II: Test Bench Layout**

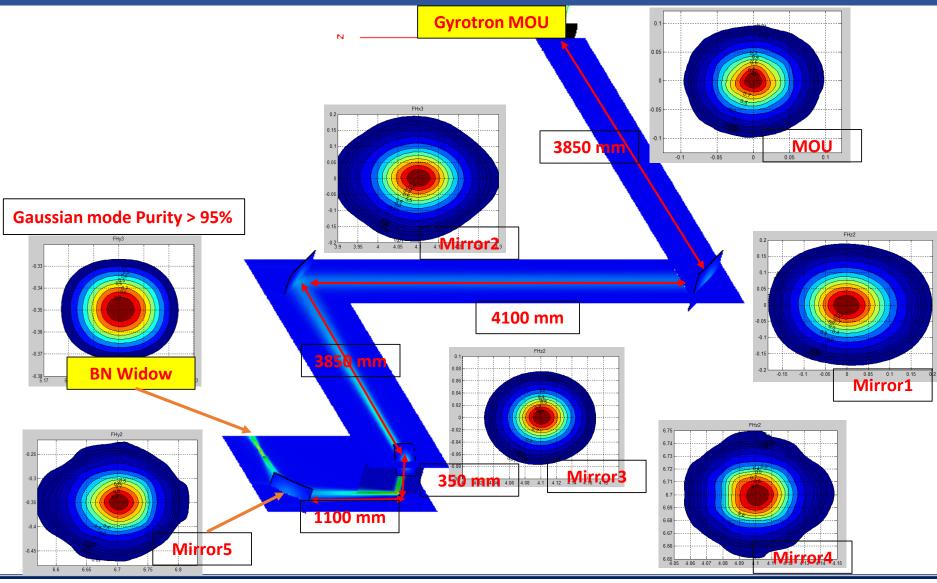
Parameters	SECRAL-II	St.
ω <sub>rf</sub> (GHz)	18-28	
Axial Field Peaks (T)	3.7 (Inj.), 2.2 (Ext.)	
Mirror Length (mm)	420	
No. of Axial SNs	3	
B <sub>r</sub> at r=63 mm (T)	2.06	
Coldmass Length (mm)	810	
SC-material	NbTi	1
Magnet Cooling	LHe bathing	1
Warm bore ID (mm)	142 .0	
Chamber ID (mm)	125.0	



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



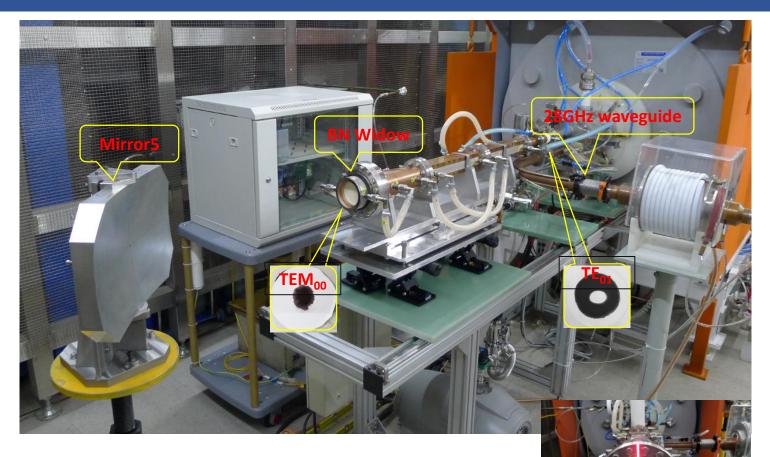
## Design of the 45GHz transmission line for SECRAL-II



October 17, 2017

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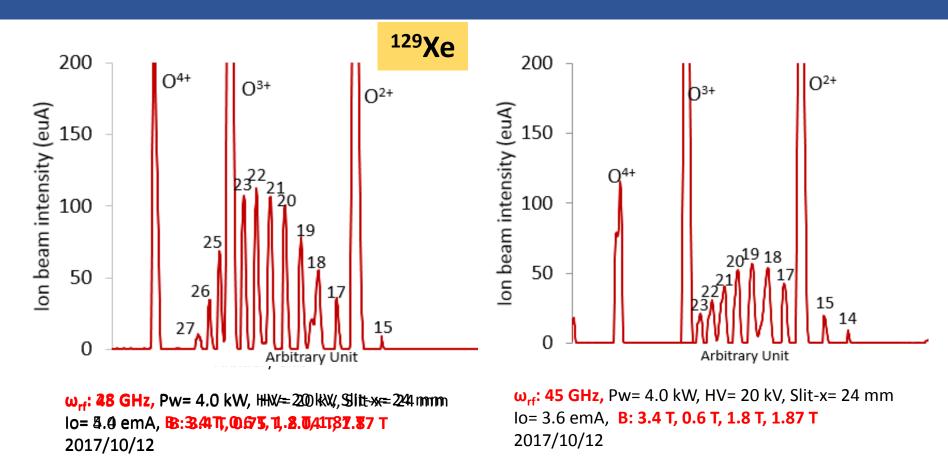
# **Transmission line installation and test**



Stringent alignment

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

# First 45 GHz ECR plasma



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



- TE<sub>01</sub> with  $\Phi$ 32mm 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**

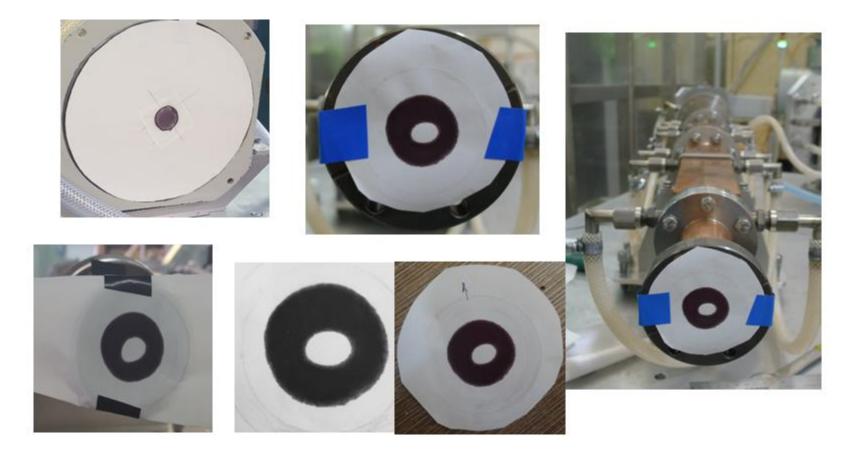


# **Gyrotron Magnetic System**

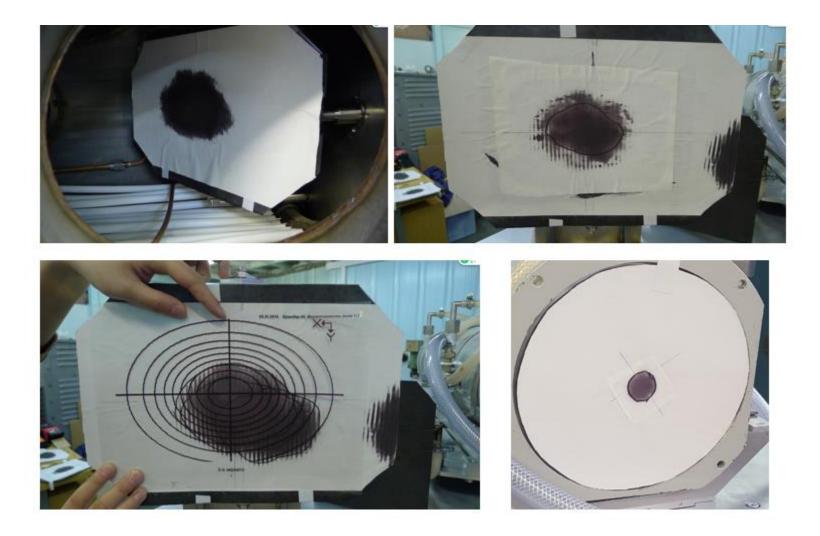


The system based on JMTD 4T140 liquid helium free magnet (up to 4 T, warm bore  $\emptyset$ 140 mm) Operating magnetic field ~ 1.7 T

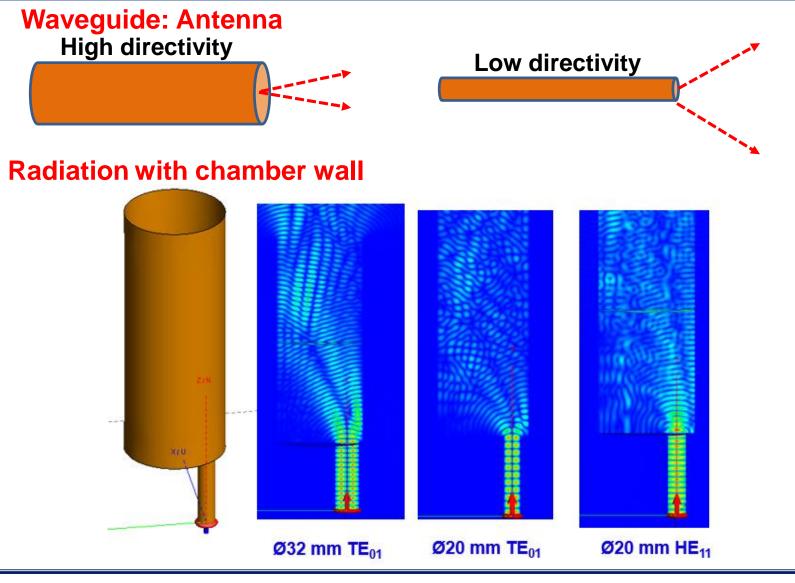
# **Microwave mode test**



# 45GHz quasi-optical transmission line installation



# 1st pass absorption is important



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