Bremsstrahlung Measurements with SECRAL-II Ion Source

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Outline

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III. Analysis of Bremsstrahlung Spectra

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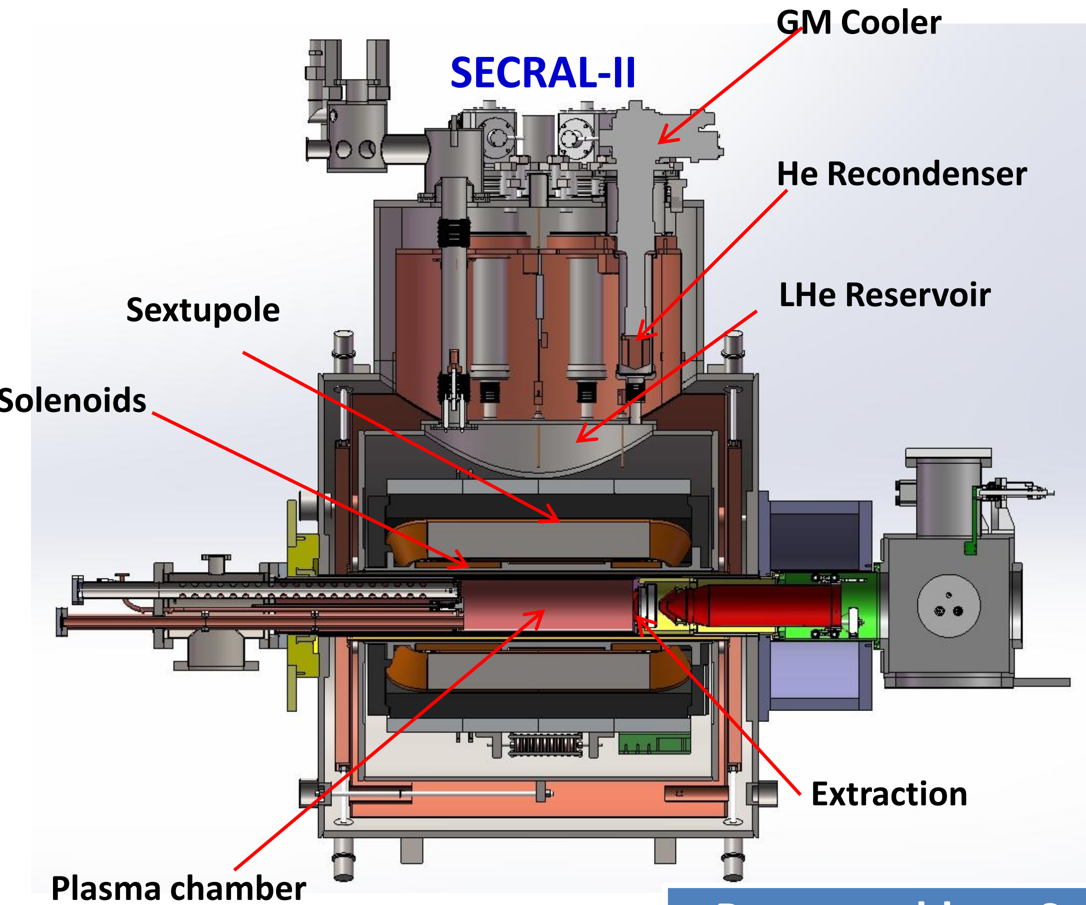
Quick Overview



Key Parameters

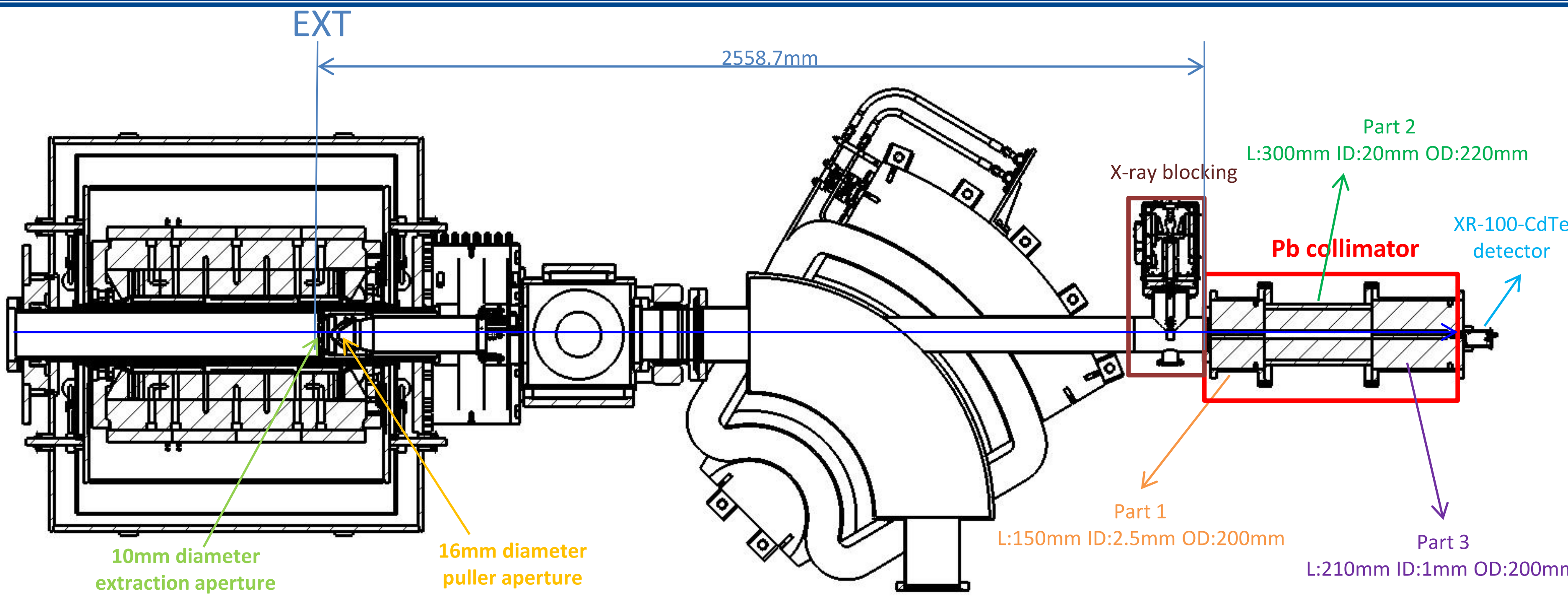
ω_{rf} (GHz)	18-28
Axial Field Peaks (T)	3.7 (Inj.), 2.2 (Ext.)
Mirror Length (mm)	420
No. of Axial SNs	3
B_r at Chamber Inner Wall (T)	2.0
Magnet Cooling	LHe bathing
Chamber ID (mm)	125.0
Dynamic cooling power (W)	~6

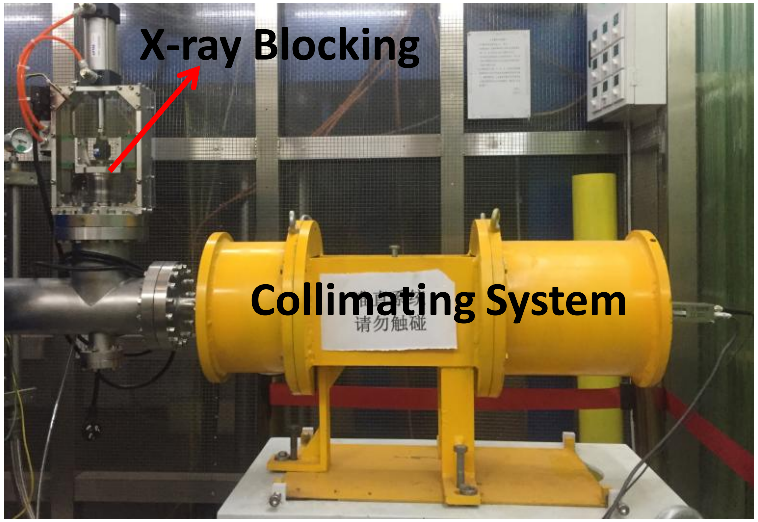
Bremsstrahlung Spectra & Spectral Temperature T_s

Aim of Research

- Magnetic Field Configuration
- RF Power
- Gas Pressure
- Bias Voltage
- HV

X-ray Measurement Setup with SECRAL-II

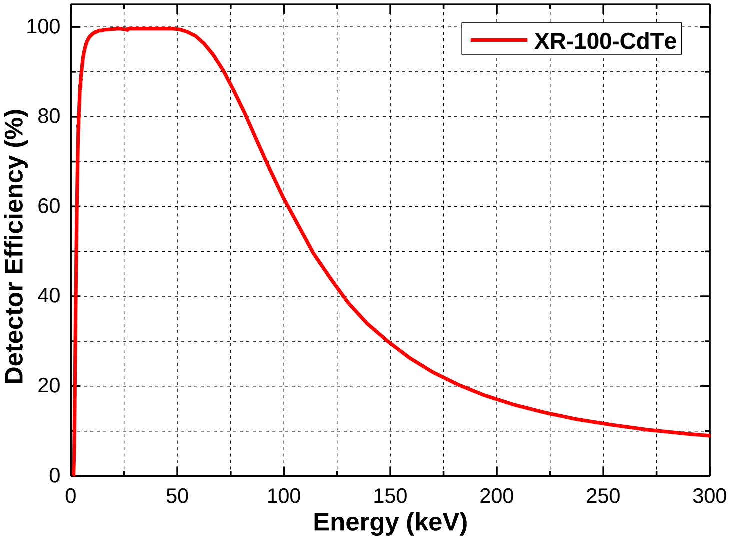




- ☐ Designed using **MCNP** code to avoid
    - I. Thick target bremsstrahlung
    - II. Secondary radiation

X-ray Measurement Setup with SECRAL-II

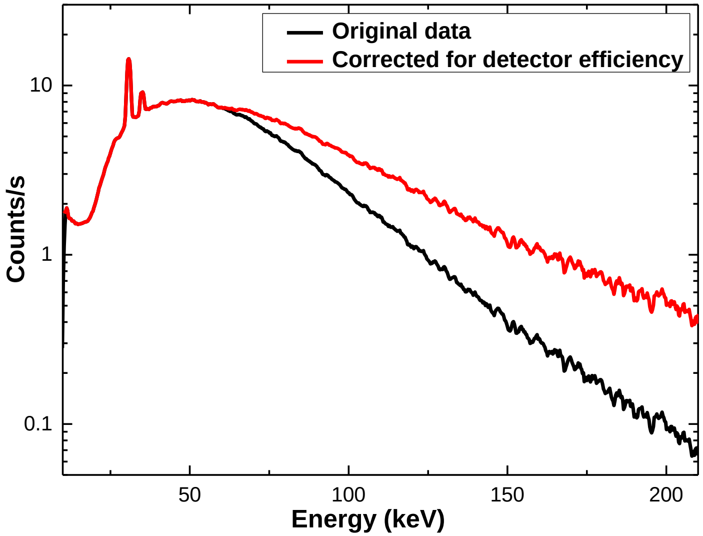
XR-100-CdTe Detector	
Detector type	Cadmium Telluride (CdTe) Diode
Detector areas	3 x 3 mm (9 mm^2)
Detector thickness	1 mm
Energy resolution @ 122 keV, ^{57}Co	<1.5 keV FWHM, typical
Detector window	Be: 4 mil thick (100 μm)
Energy range	10 – 300 keV
Detector efficiency	See below

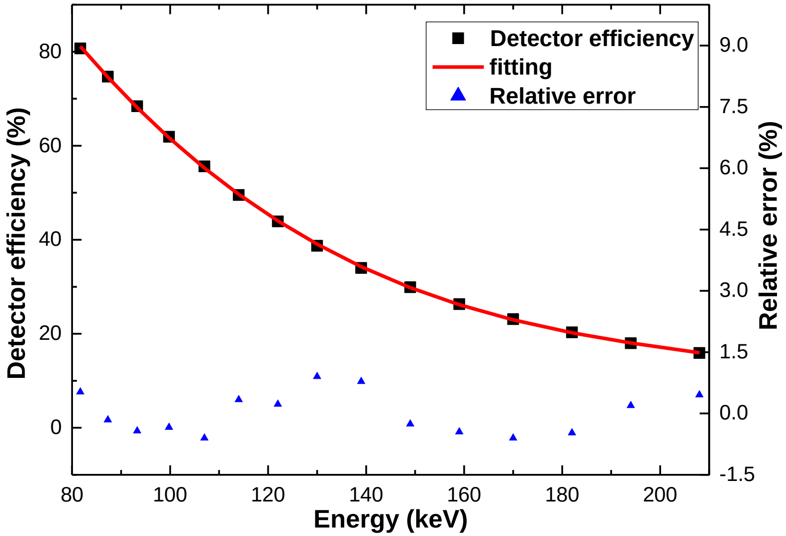


Analysis of Bremsstrahlung Spectra

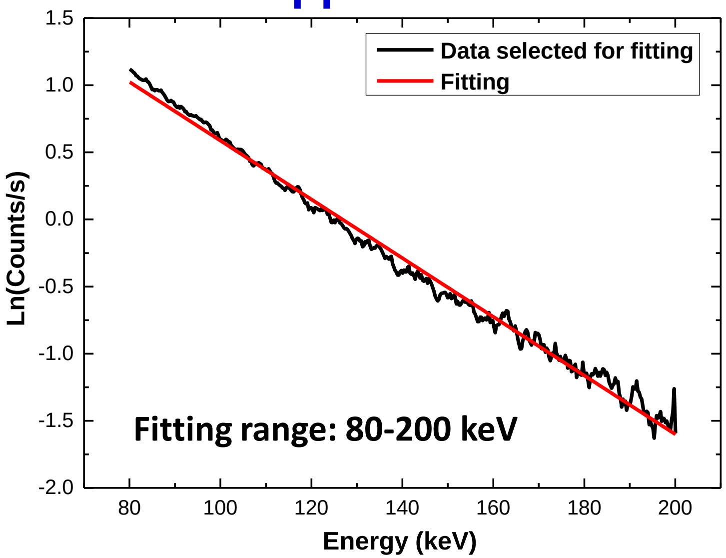
I. Calibration applied

II. Spectra corrected for detector efficiency





III. Linear fit applied

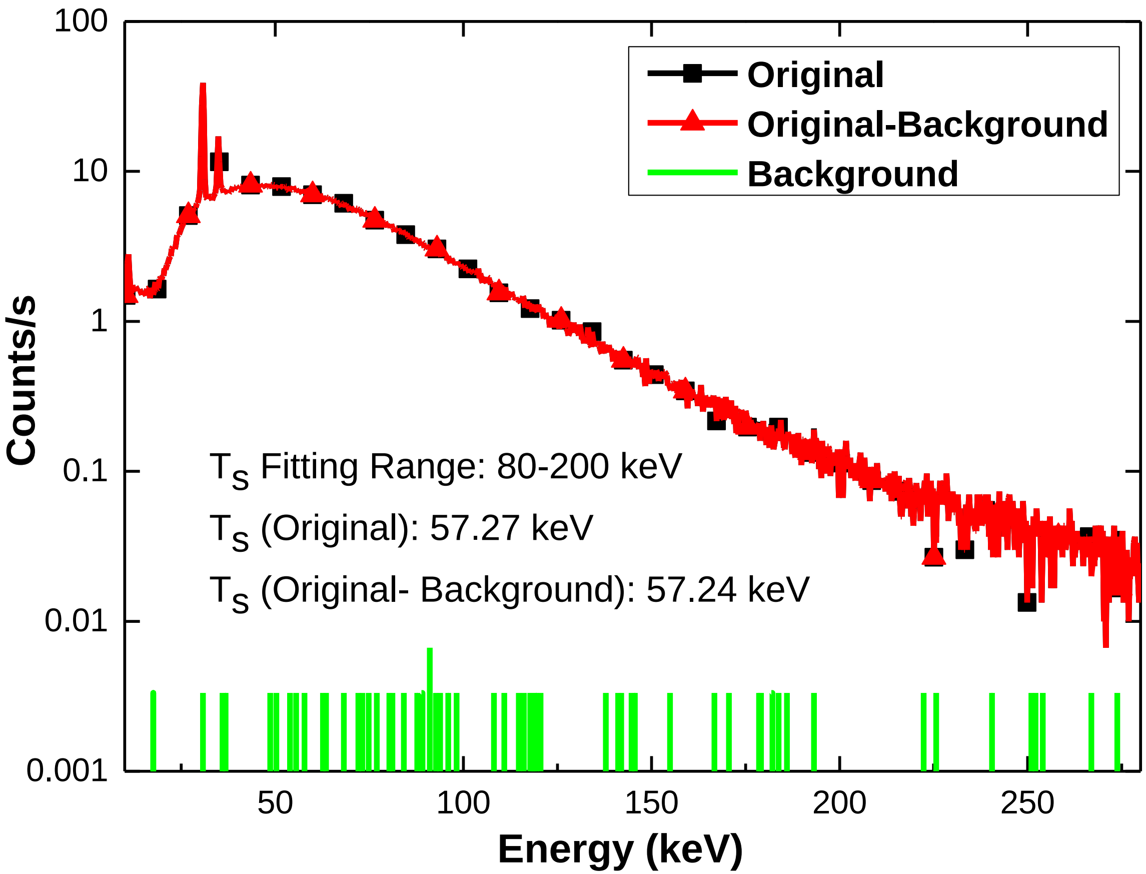


$$Spectral\ Power\ \ j(\hbar\omega) \propto \exp(-\hbar\omega / T_s)$$

In semi-log plot

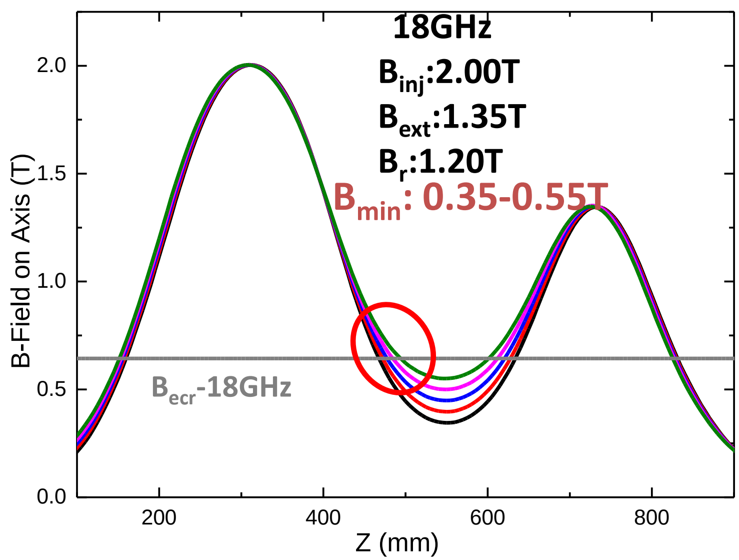
T_s=-1/slope

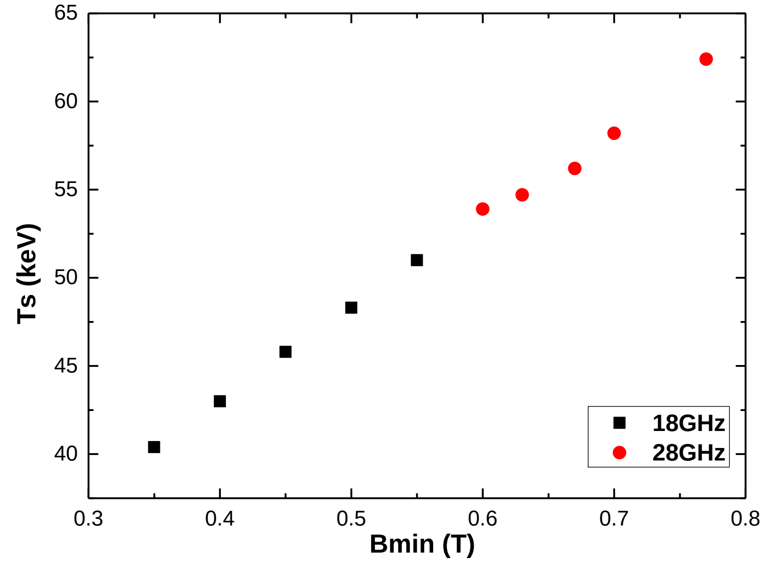
Efficiency of Collimating System



- **Difference (with or without background) of T_S is less than 0.06%**
- **All data presented in the following sections are spectra without background subtraction**

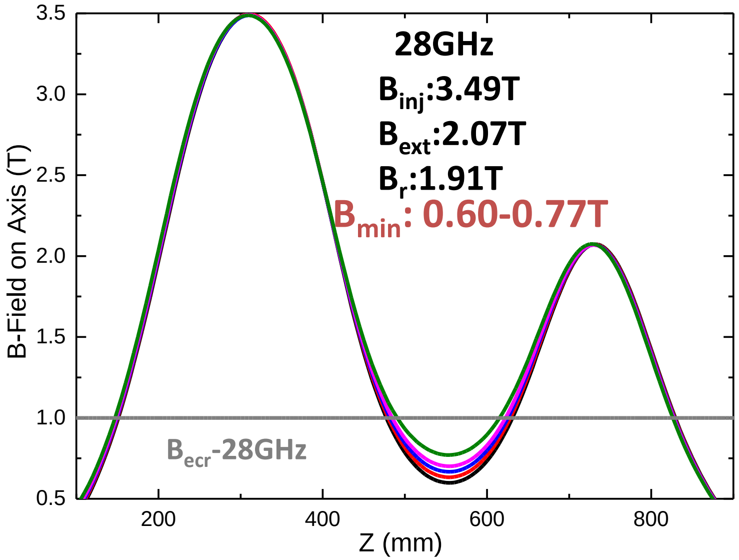
Constant B_{inj}, B_{ext} and B_r while Varying B_{min}

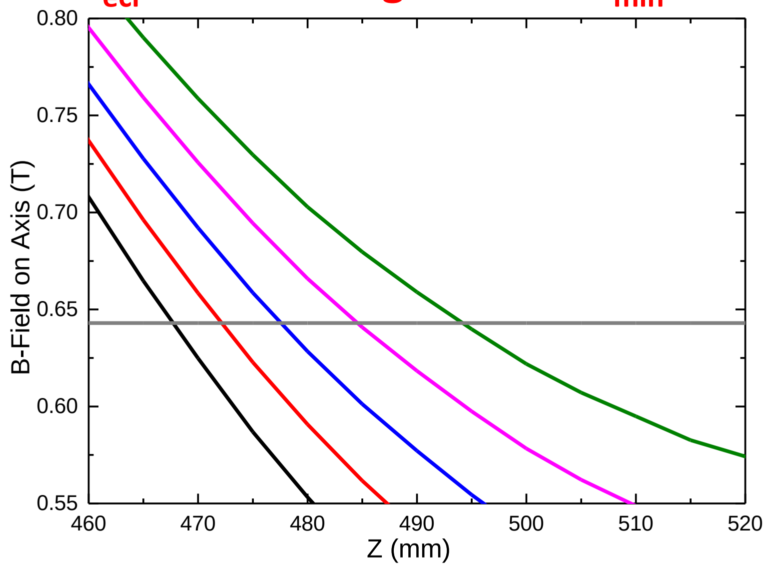




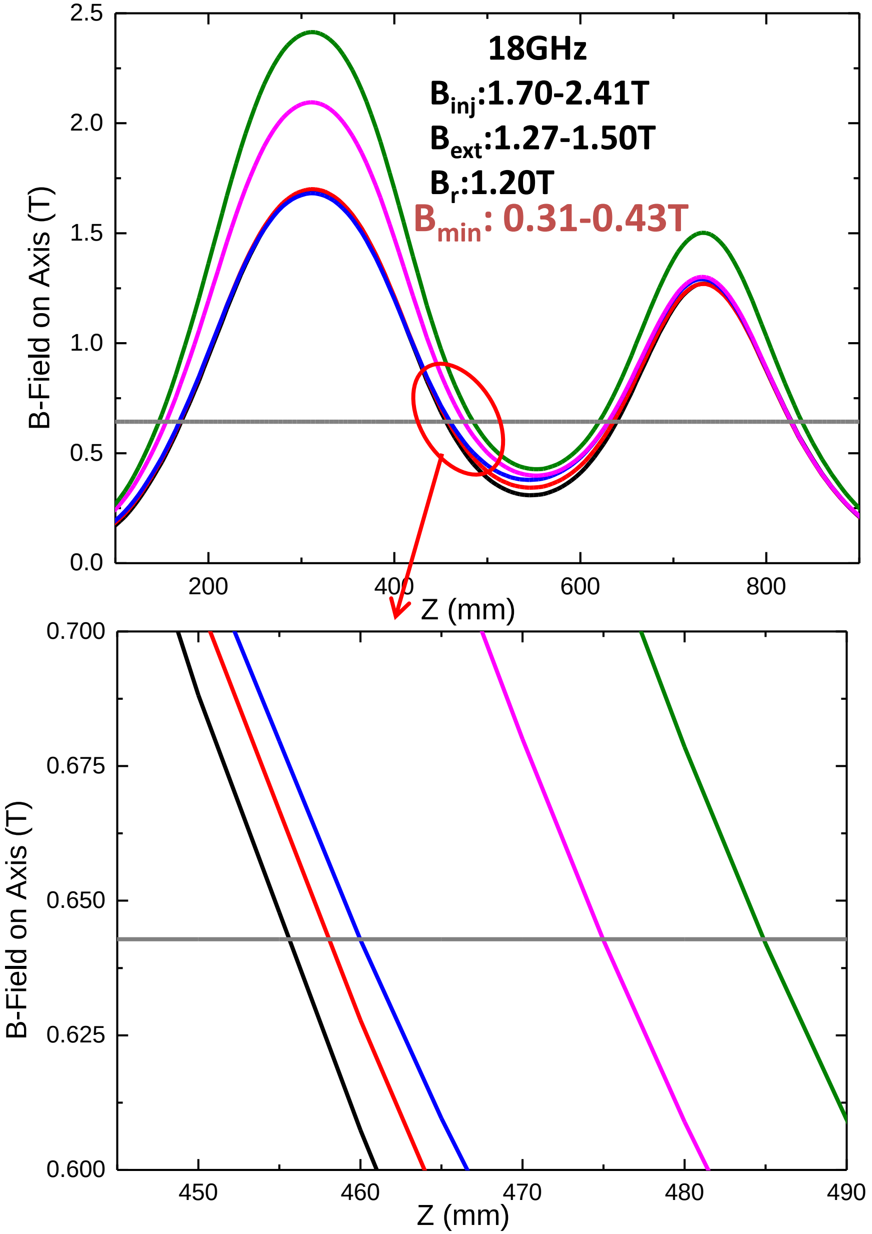
➢ T_s appears to be a function of B_{min}

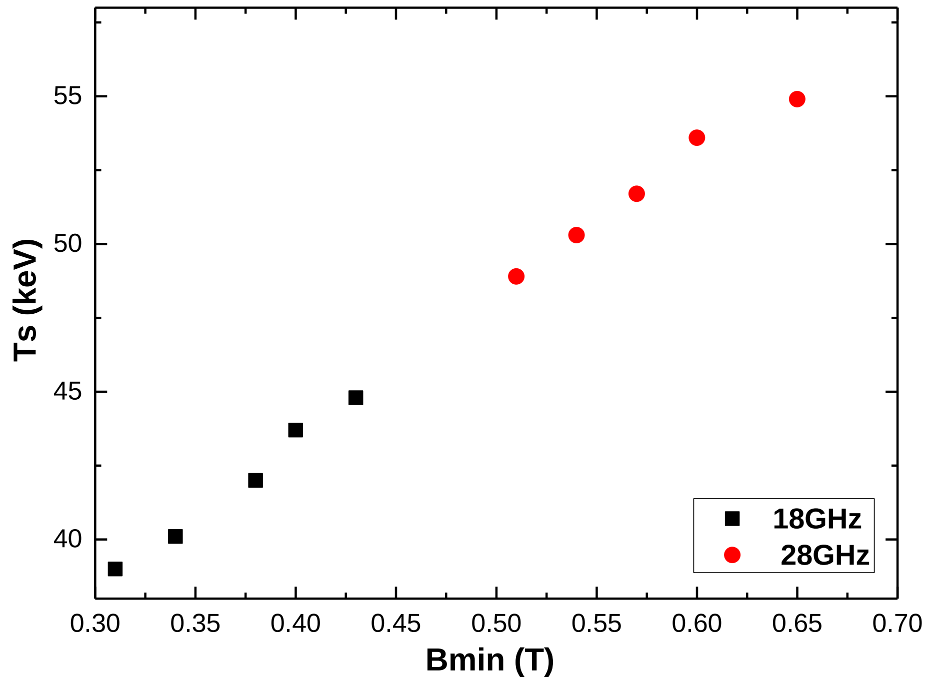
Note: ∇B_{ecr} is also changed when B_{min} is changed





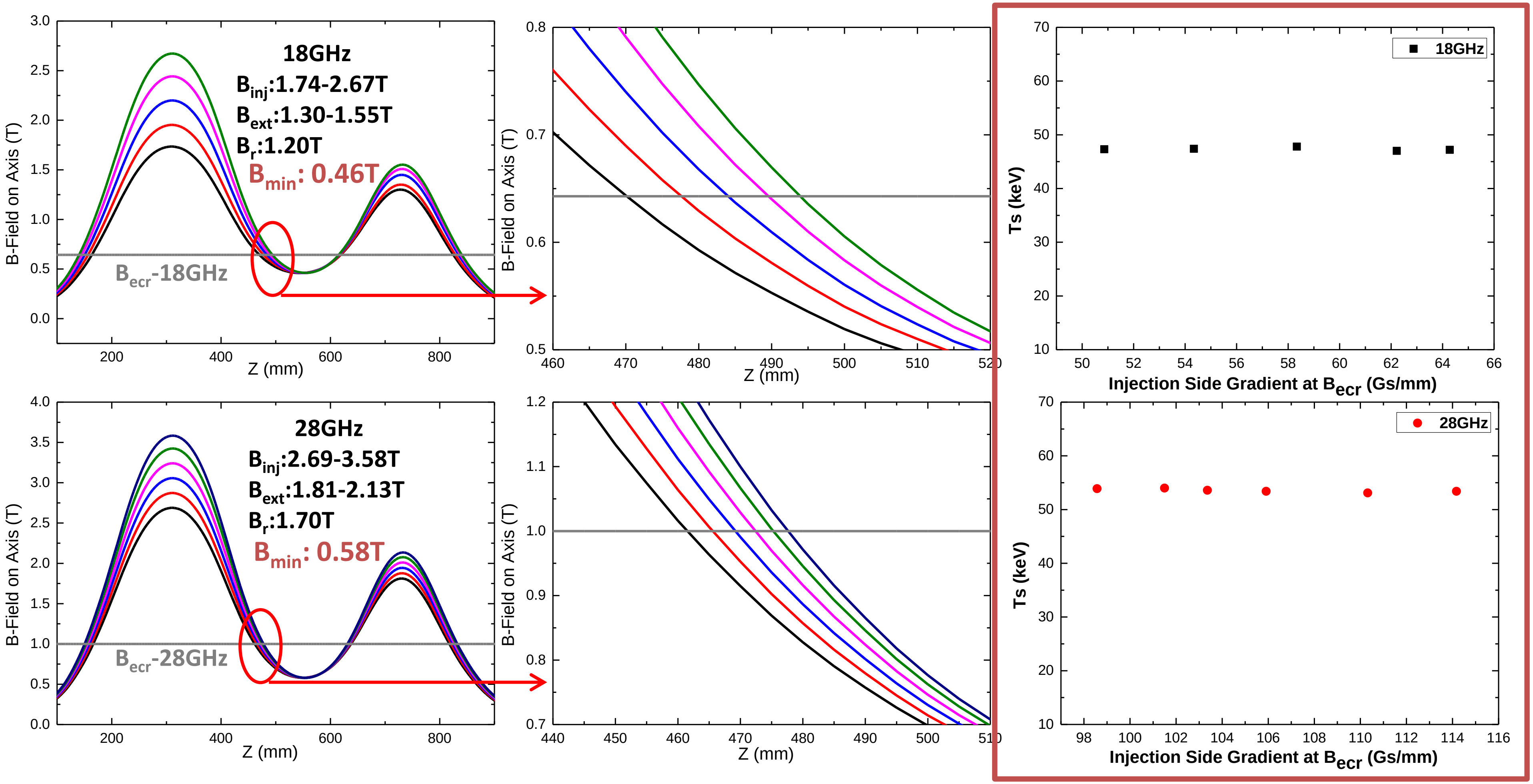
Constant ∇B_{ecr} while Varying B_{min}





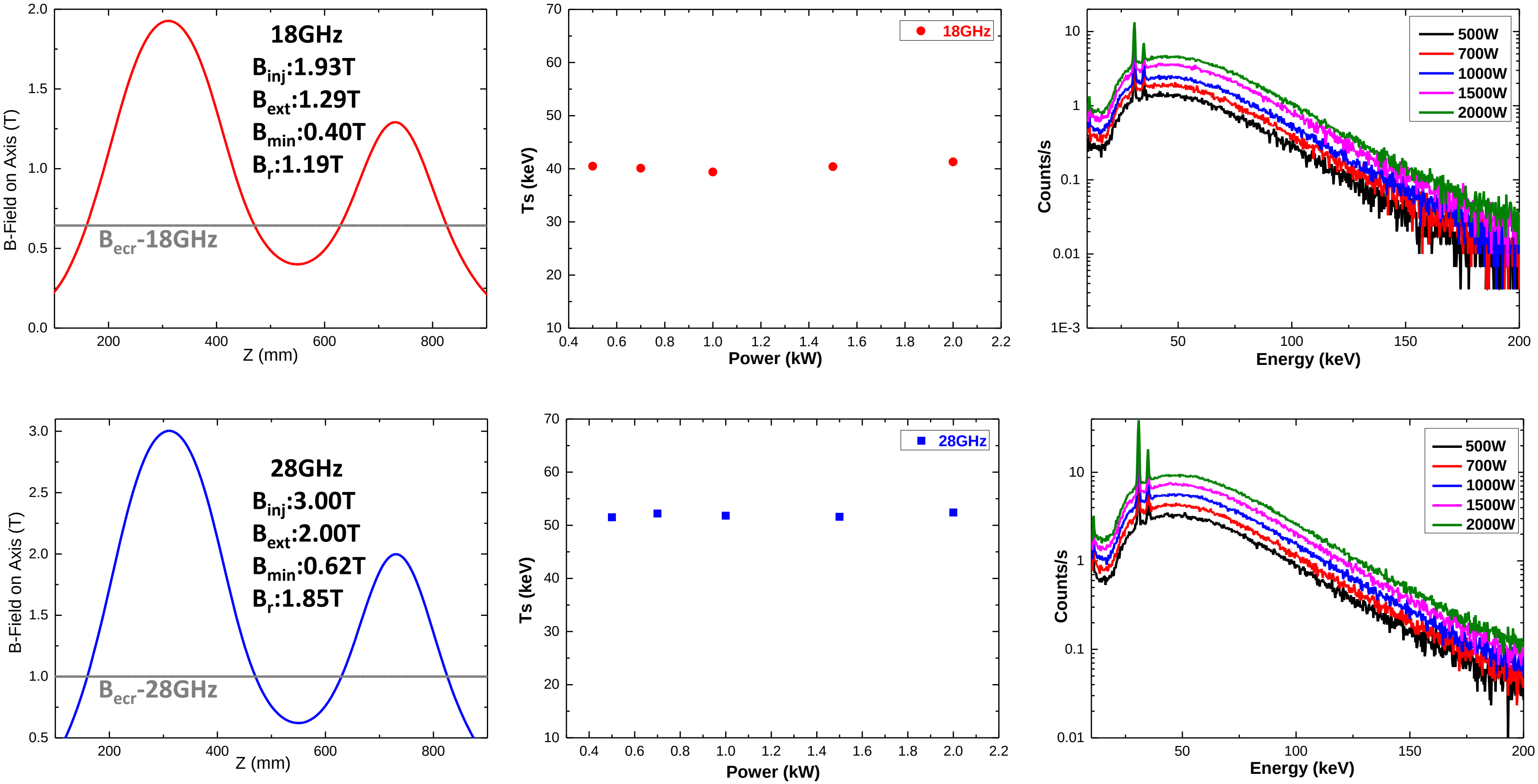
- For 18GHz, B_{min} was varied by 38% while ∇B_{ecr} was varied by 9%
- For 28GHz, B_{min} was varied by 27% while ∇B_{ecr} was varied by 9%
- It seems that T_s depends linearly on B_{min}

Constant B_{min} while Varying ∇B_{ecr}



- For 18GHz, ∇B_{ecr} was varied by **26%** while T_s was varied by **1%**
- For 28GHz, ∇B_{ecr} was varied by **16%** while T_s was varied by **1%**
- T_s does not depend on ∇B_{ecr}

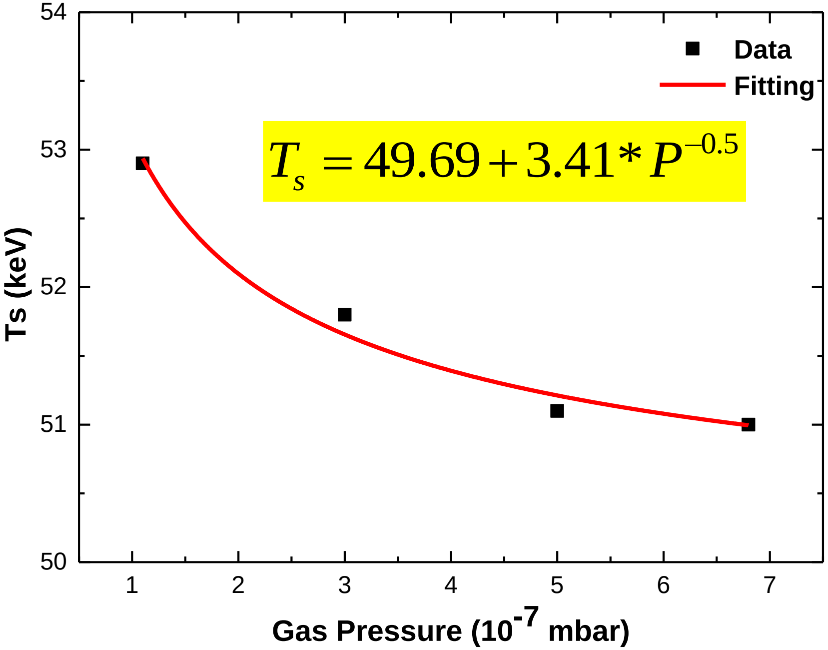
T_s VS RF Power



- ➢ **T_s is at saturation even at 500W, which is consistent with the experimental study from VENUS** *(Review of Scientific Instruments 79, 033302 (2008))* **and Mini-mafios** *(Journal of Applied Physics 76, 2662 (1994))*
- ➢ **T_s rapidly saturates with microwave power (above 500W, whatever the frequency)**

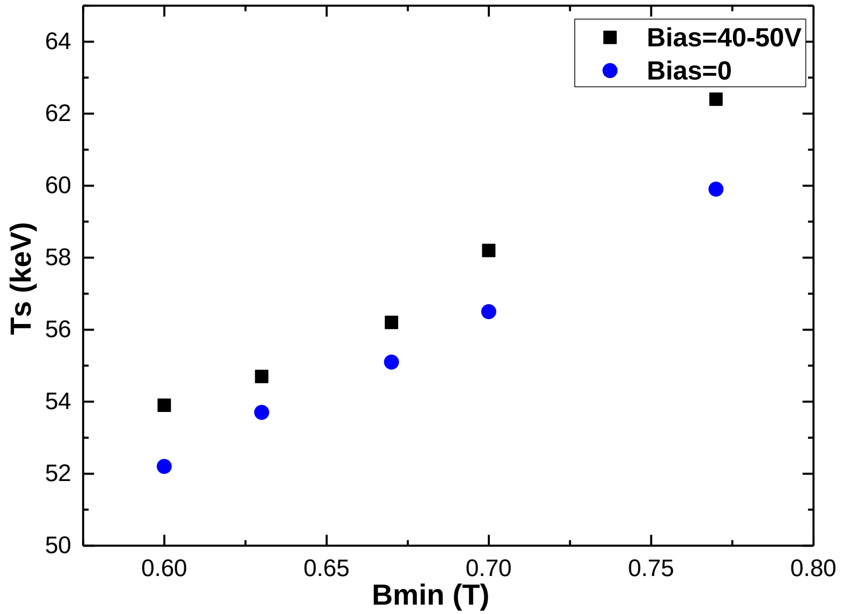
T_s VS Gas Pressure

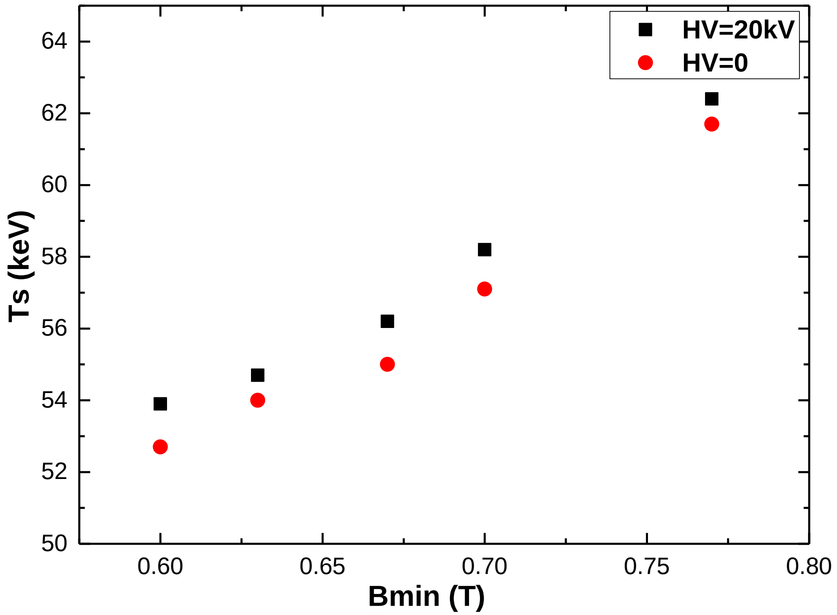
Frequency (GHz)	Injection Pressure (10^{-7} mbar)	T_s (keV)
28	1	52.9
	2	51.8
	5	51.1
	7	51.0



➢ T_s is inversely proportional to the square root of the gas pressure
(Journal of Applied Physics 76, 2662 (1994))

Effect of Bias Voltage and HV



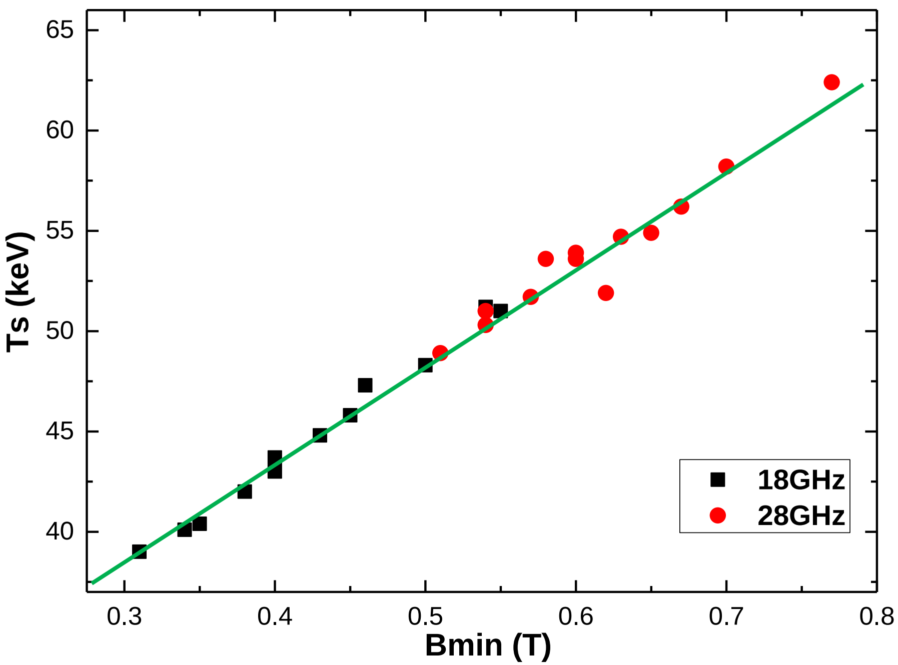


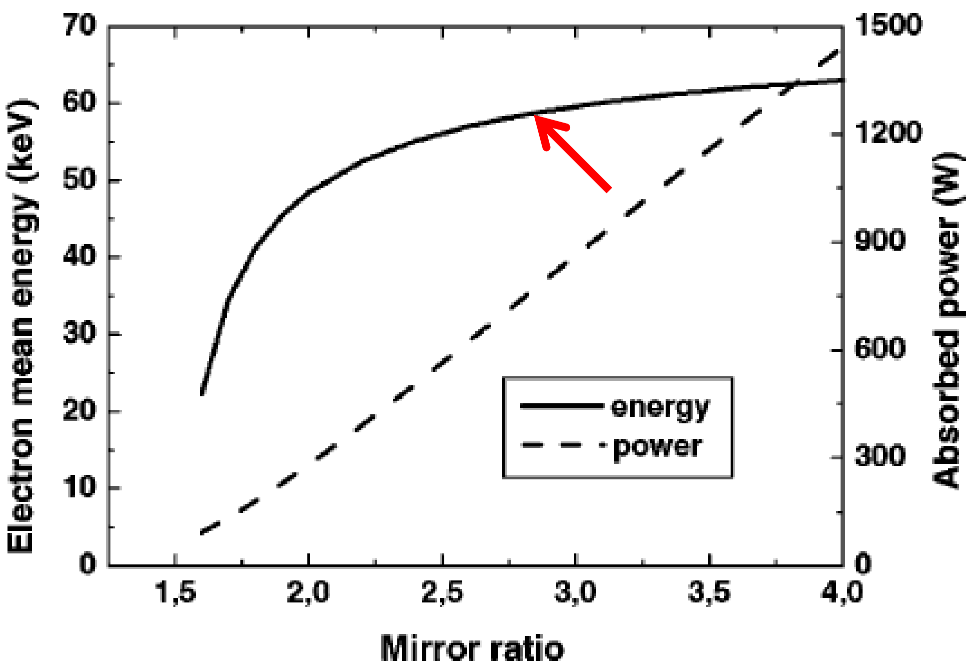
- ➢T_s decreases with the decreasing of Bias and HV at each point
- ➢T_s is slightly affected by biased disk and extraction voltage (difference less than 4%)

1^{st} Conclusion

- T_s appears to be linearly dependent on B_{min}
- T_s seems to be independent on ∇B_{ecr} and heating power
- T_s is inversely proportional to the square root of gas pressure
- T_s is slightly affected by biased disk and extraction voltage

Discussion



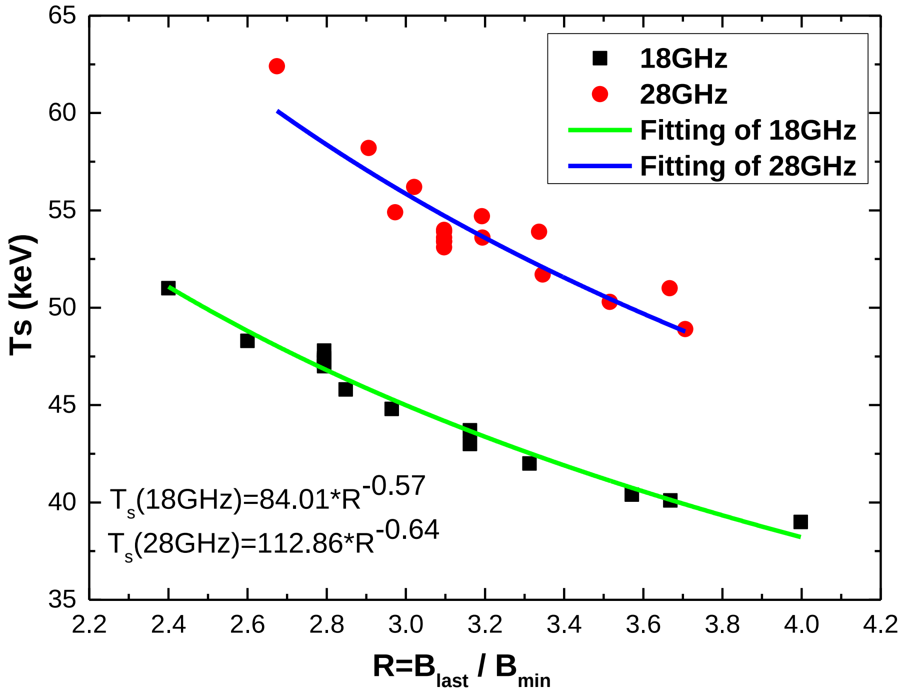


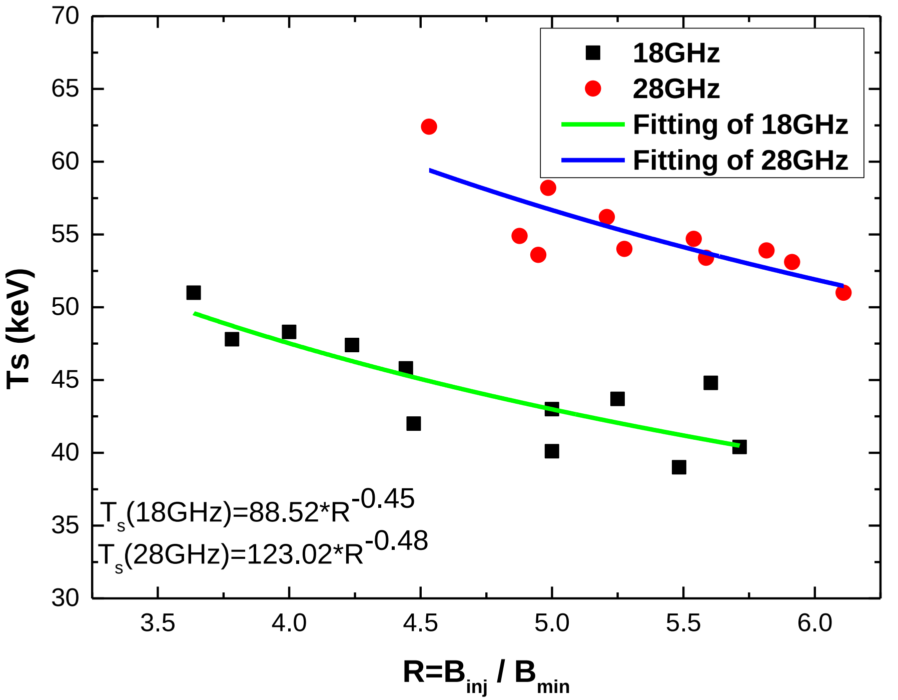
It is hard to understand why T_s appears to be dependent solely on the minimum magnetic field B_{min} since electrons move back and forth in a minimum-B structure

Electron energy saturates with mirror ratio

(Girard et al. Journal of Computational Physics 191 (2003))

T_s VS Mirror Ratio





T_s decreases with increasing mirror ratio $R=B_{last}/B_{min}$ or B_{inj}/B_{min}

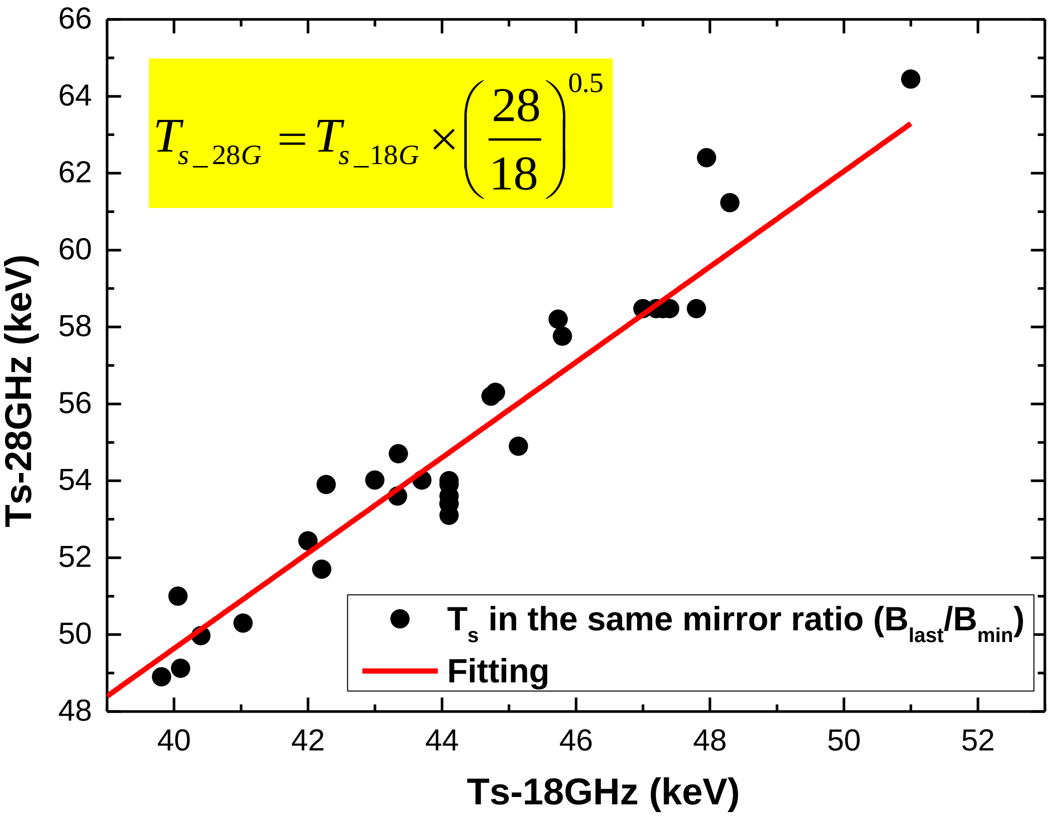
At high mirror ratios, electrons are more and more trapped in the min-B structure

↓

They no longer cross the resonance after several travels back and forth

(Barue et al. Journal of Applied Physics 76, 2662 (1994))

Another Factor



T_s depends on the heating frequency *f*

2nd Conclusion

- All experiments were done at conventional mirror ratios where electrons are well trapped and high ion currents are extracted

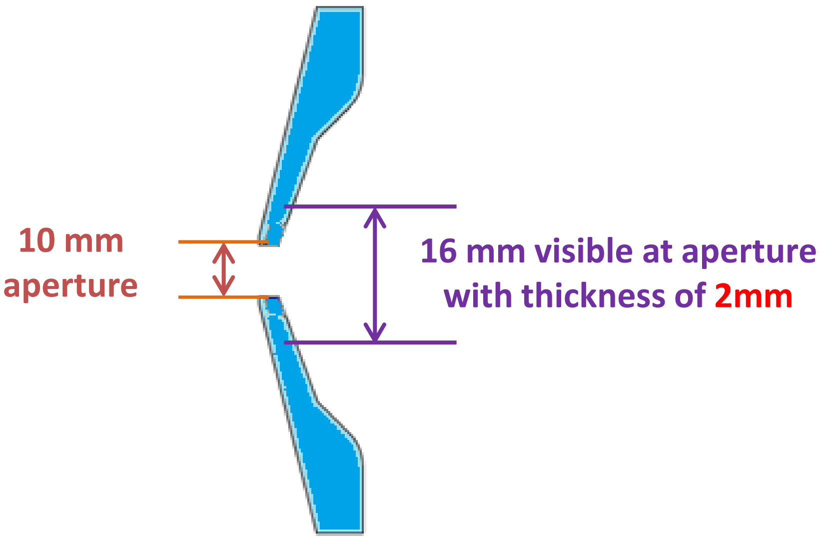
- Next experiments will be done at lower mirror ratios

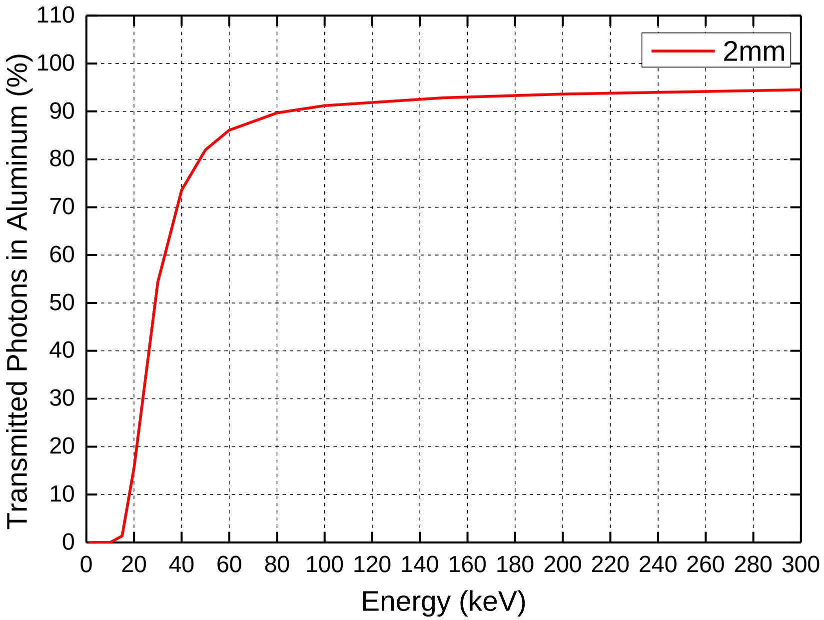
Acknowledgement

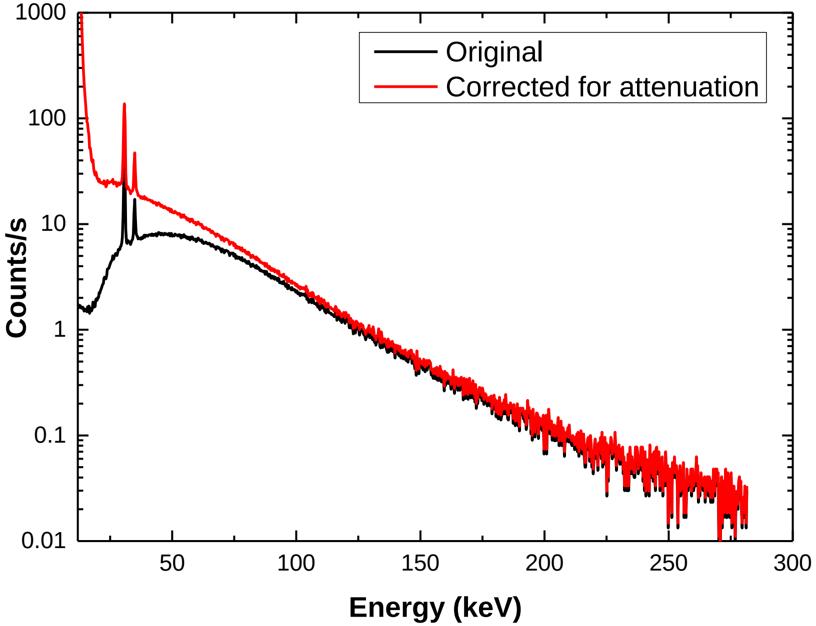
- Janilee Benitez, LBNL
- Daniel Z. Xie, LBNL

Thanks for your attention !

Appendix


10 mm
aperture
16 mm visible at aperture
with thickness of 2mm


Transmitted Photons in Aluminum (%)
Energy (keV)
2mm
0
10
20
30
40
50
60
70
80
90
100
110
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300


Counts/s
Energy (keV)
Original
Corrected for attenuation
1000
100
10
1
0.1
0.01
50
100
150
200
250
300

Source Parameters

Beam	Xe27+
Frequency (GHz)	18、28、45
Power (w)	2000
Extraction Voltage (kV)	20
Biased Disk Voltage (-V)	~40-50
Injection Pressure (mbar)	$1\sim2\times10^{-7}$