Recent Bremsstrahlung Measurements from the Superconducting ECR Ion Source VENUS

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Outline

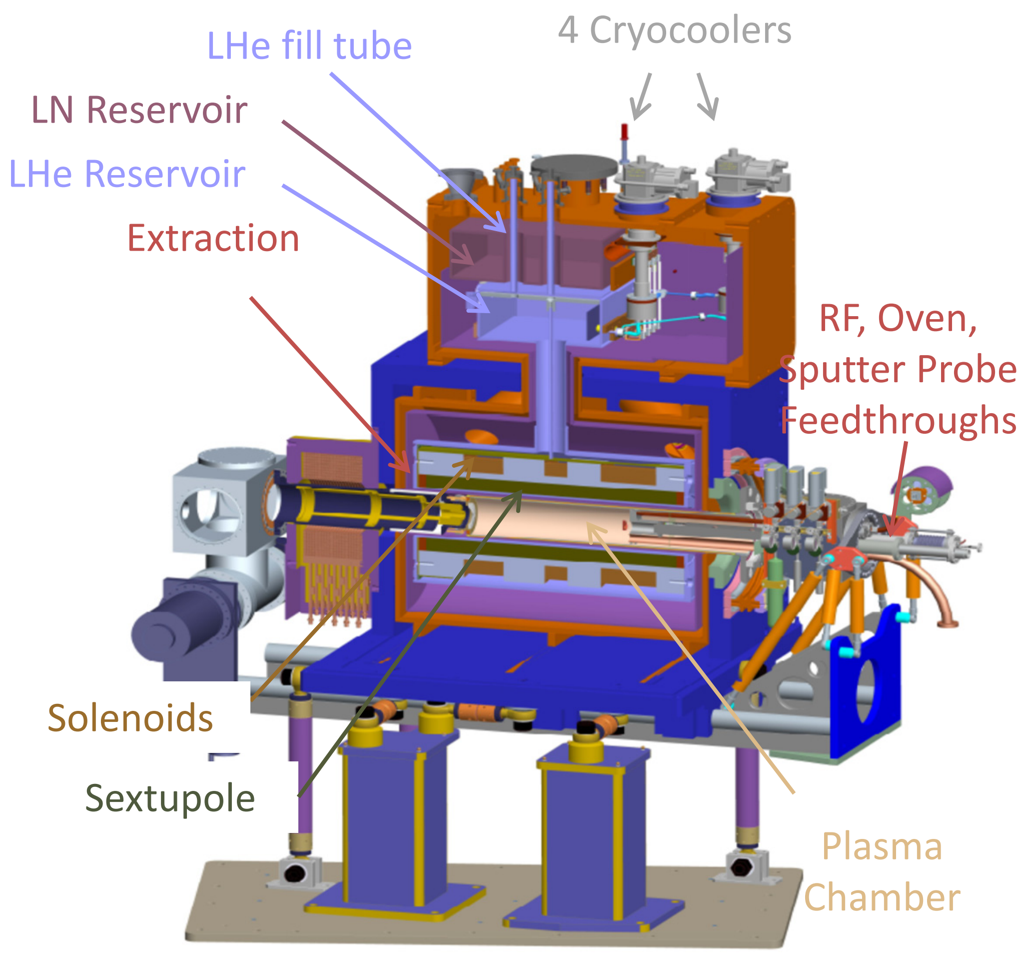
I. Quick Overview of VENUS
II. X-ray detector setup at VENUS
III. Analysis of Bremsstrahlung spectra
IV. Summary of Data
V. Investigation
VI. Conclusion

Quick Overview of VENUS

•**Fully Superconducting** Niobium-Titanium sextupole & 3 solenoids enclosed in LHe
•**LN Reservoir:** 70K, cools normal conducting leads
•**LHe Reservoir**: 4.2K
•Uses **4 cryocoolers** to condense evaporated LHe, provide 6W of cooling power at 4.2K

•can be run 1.5-2 yrs without transferring LHe

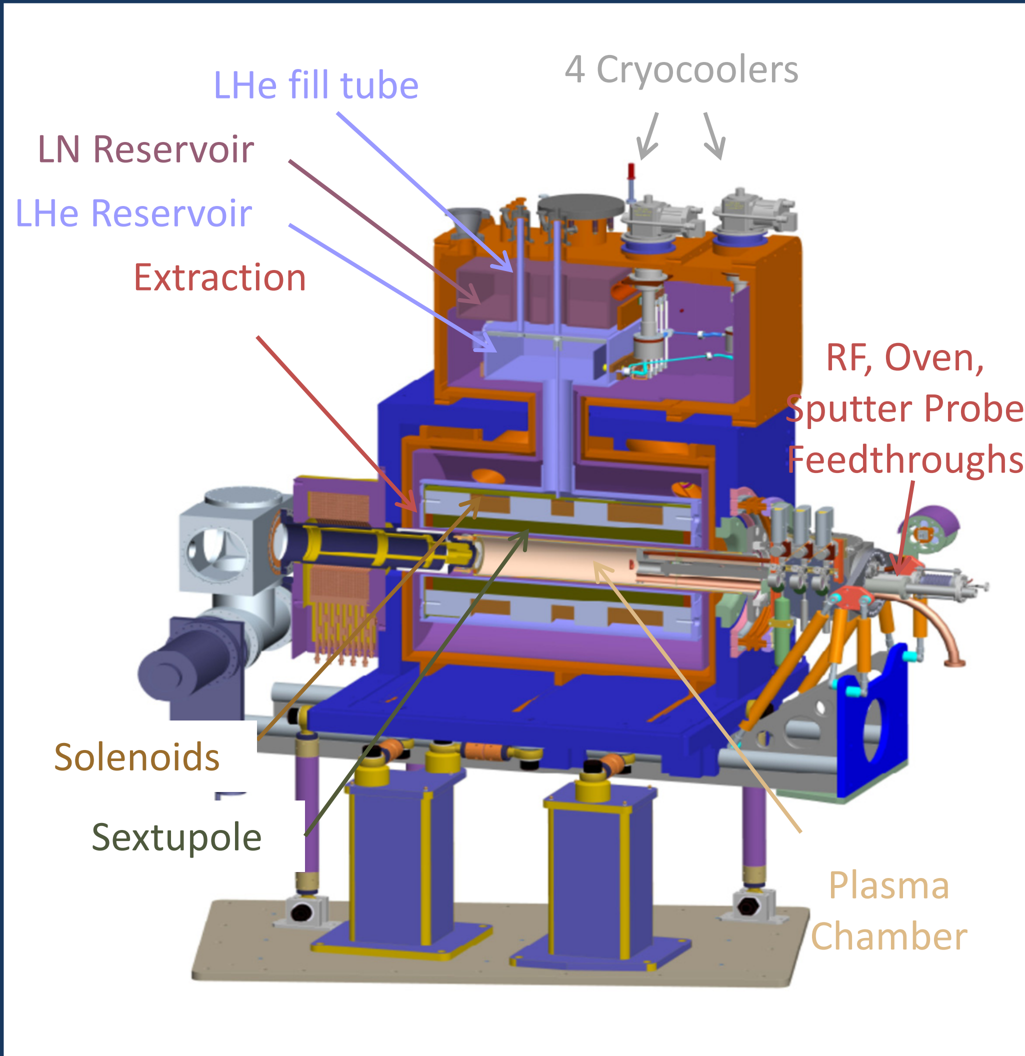
Maximum Injection Field, on axis	4.0T
Maximum Extraction Field, on axis	3.0T
Maximum Radial Field, at wall	2.2T
LHe reservoir Temperature	4.3K
28 GHz Maximum Power Injected	8.0kW
18+28 GHz Maximum Power Injected	10kW



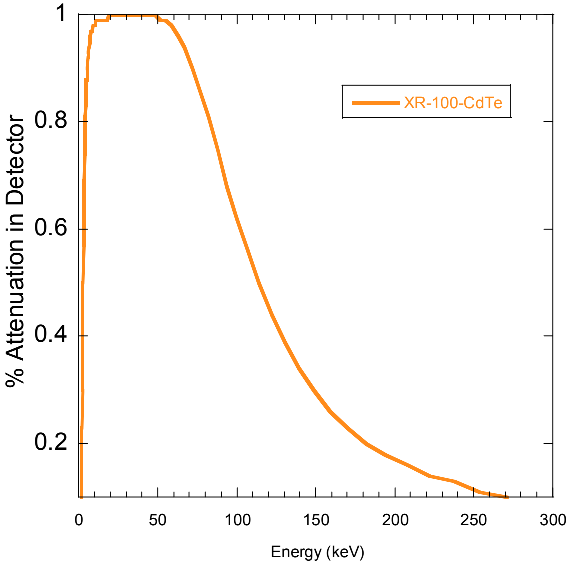
Quick Overview of VENUS

- Working towards 4^{th} Generation higher frequency ECR sources
- 4^{th} Gen ECRs expected to produce more intense and energetic bremsstrahlung that add thermal load to cryostat

We investigated how the magnetic field geometry and frequency affect the bremsstrahlung spectra and spectral temperature T_s

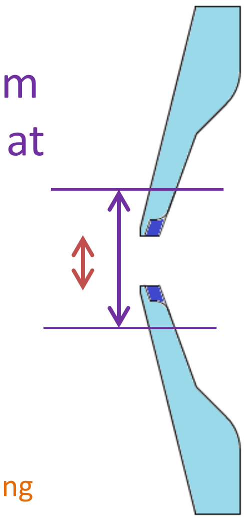


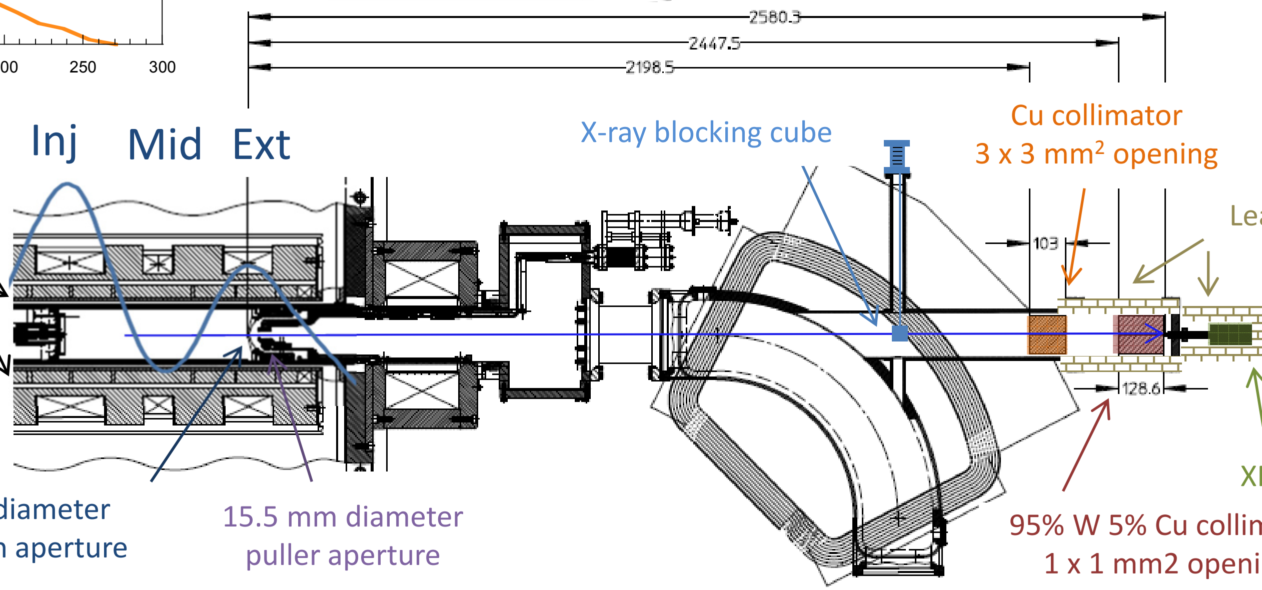
Detector & Setup



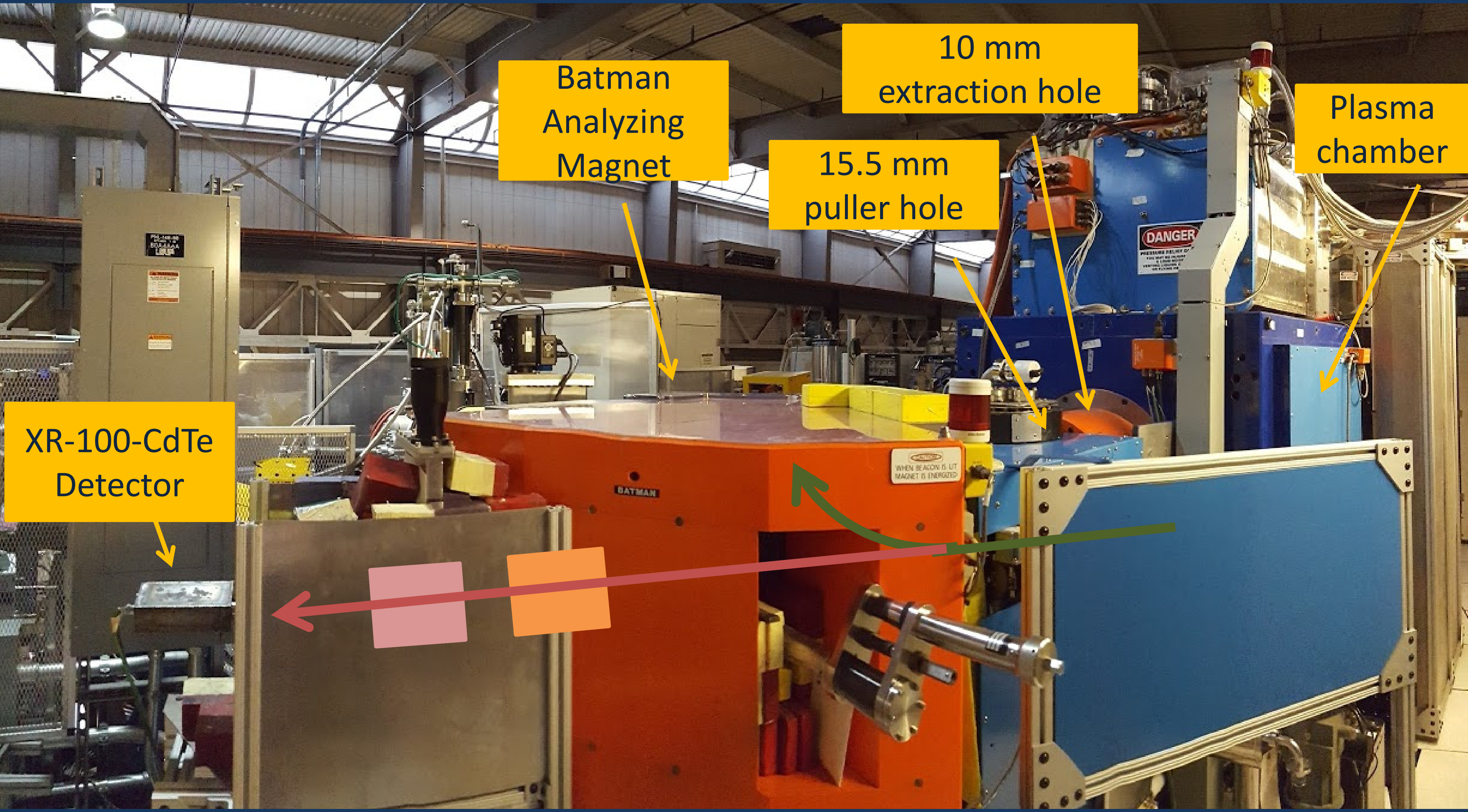
- XR-100-CdTe detector at VENUS
  - length: 1mm, size: 25 mm^2, window: 4 mil Beryllium

20 mm x 20mm square visible at aperture



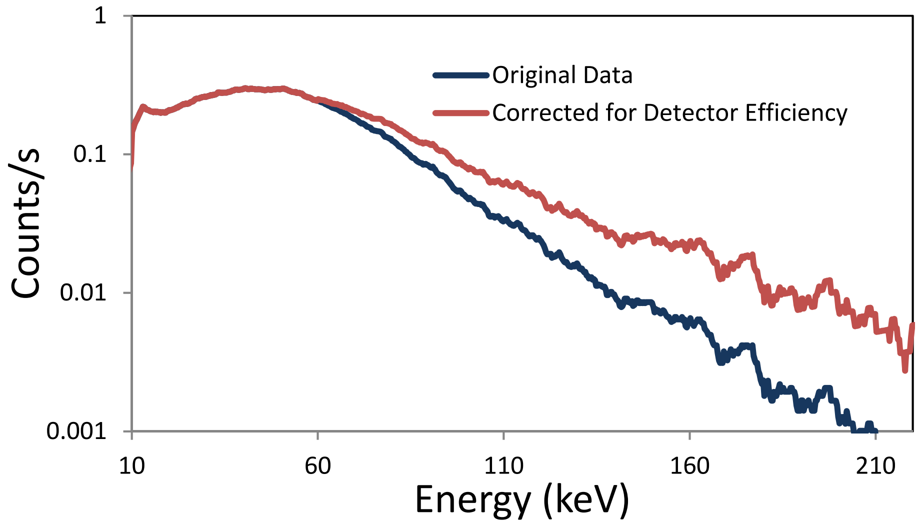


Setup


Batman Analyzing Magnet
10 mm extraction hole
15.5 mm puller hole
Plasma chamber
XR-100-CdTe Detector
DANGER
BATMAN

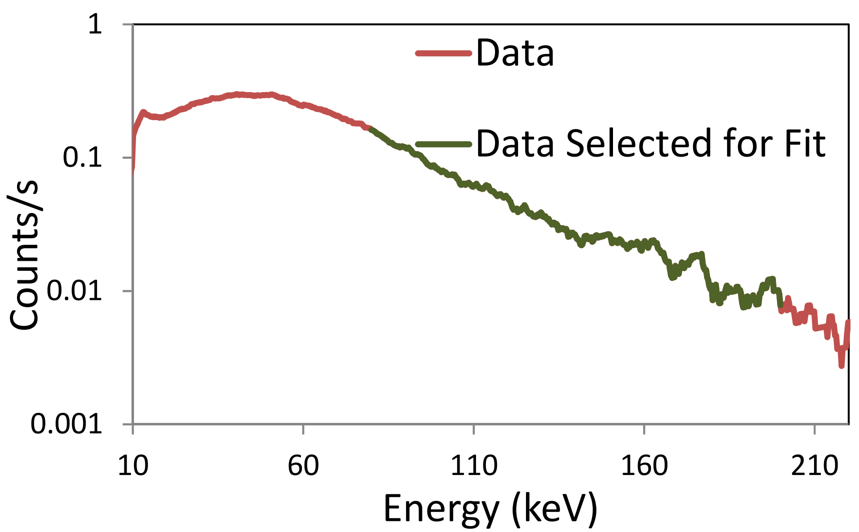
Analysis

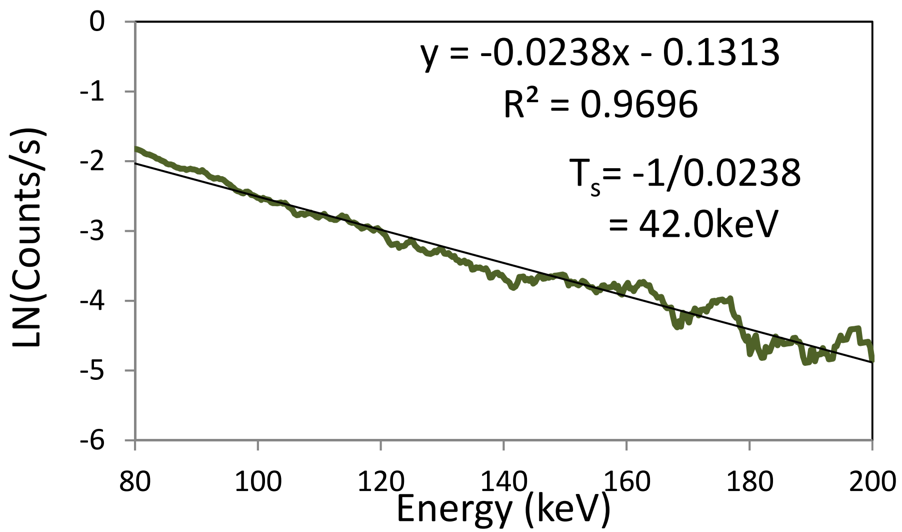
1. Calibration Applied
2. Spectra corrected for detector efficiency



Analysis

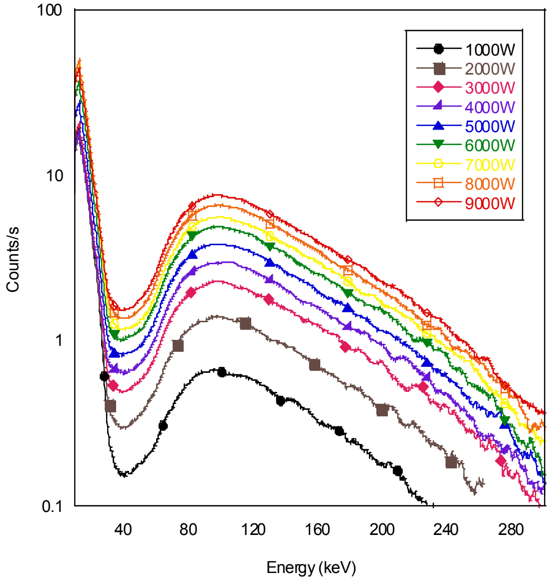
1. Calibration Applied
2. Spectra corrected for detector efficiency
3. Natural log of data taken in energy range of interest.
4. Linear fit applied. T_s=-1/slope

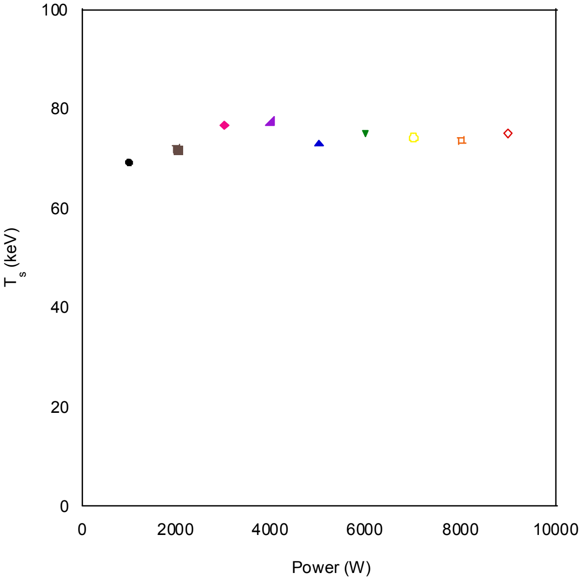




Source Parameters

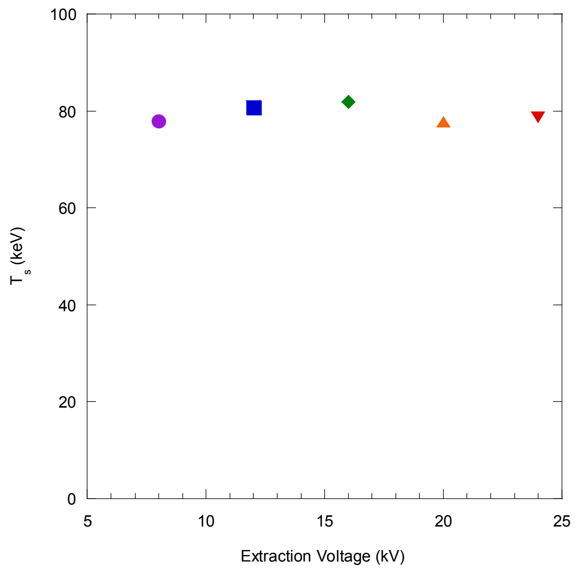
Power 14, 18, or 28GHz (W)	1000W





Source Parameters

Power 14, 18, or 28GHz (W)	1000W
Injection Pressure (Torr)	1-2x10^{-7}
Extraction Voltage (kV)	22



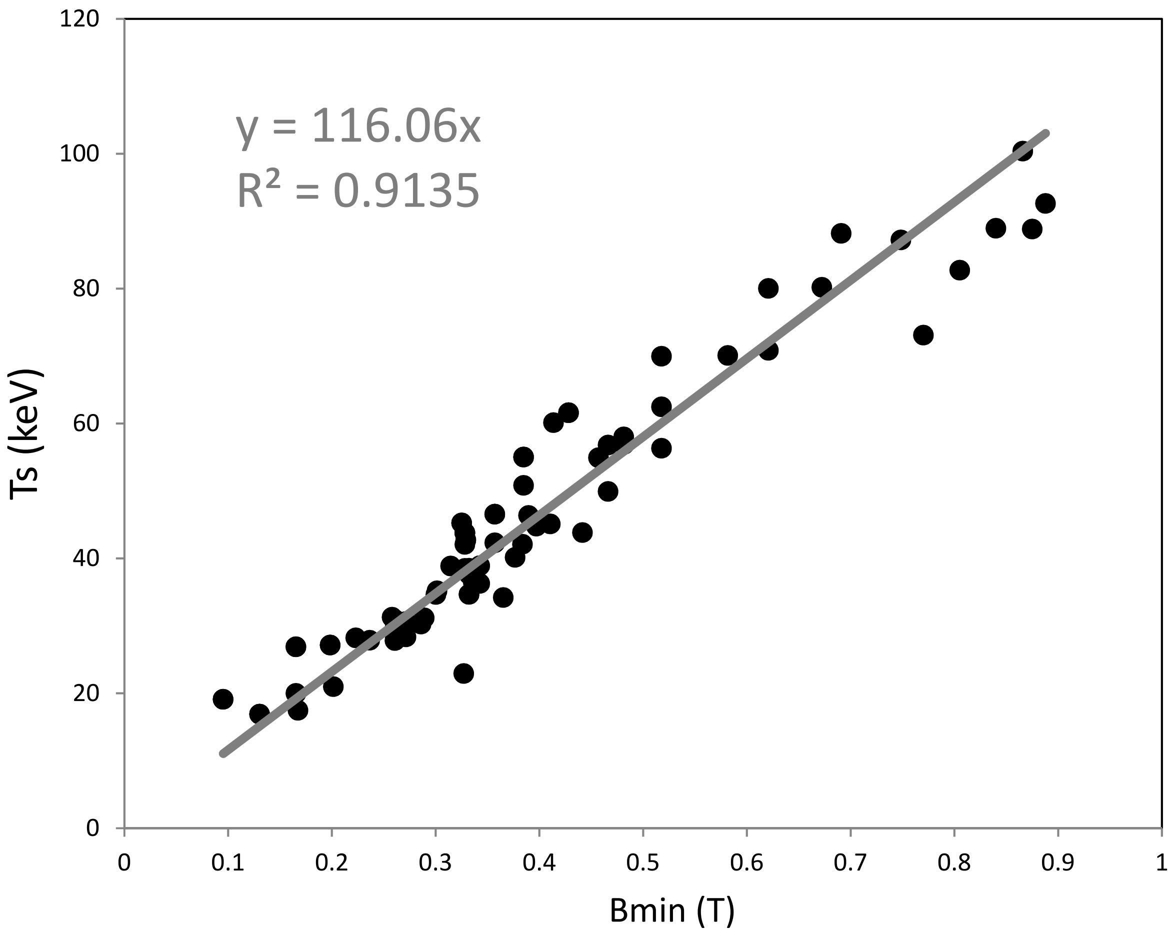
Source Parameters

Power 14, 18, or 28GHz (W)	1000W
Injection Pressure (Torr)	$1\text{-}2 \times 10^{-7}$
Extraction Voltage (kV)	22
Biased Disk Voltage (-V)	~40-50V
Gas	Oxygen

Summary of Data

VENUS Only

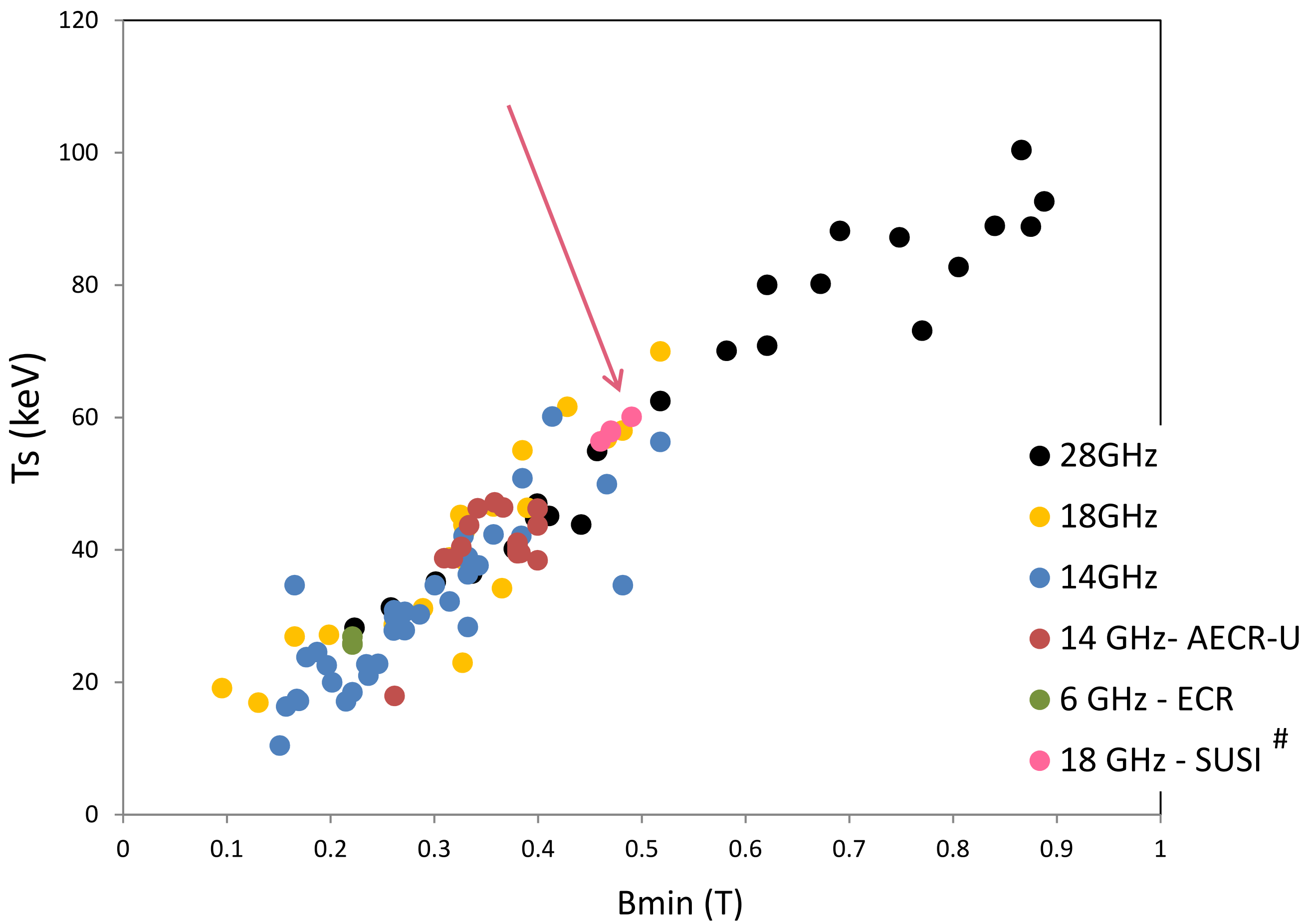
We investigated how the magnetic field geometry and frequency affect the bremsstrahlung spectra and spectral temperature T_s



Summary of Data

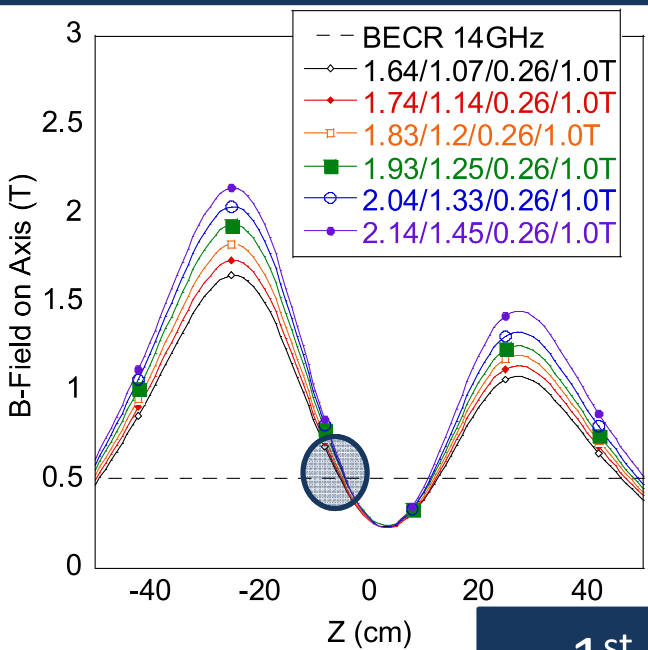
VENUS
& AECR-U
& ECR
& SUSI

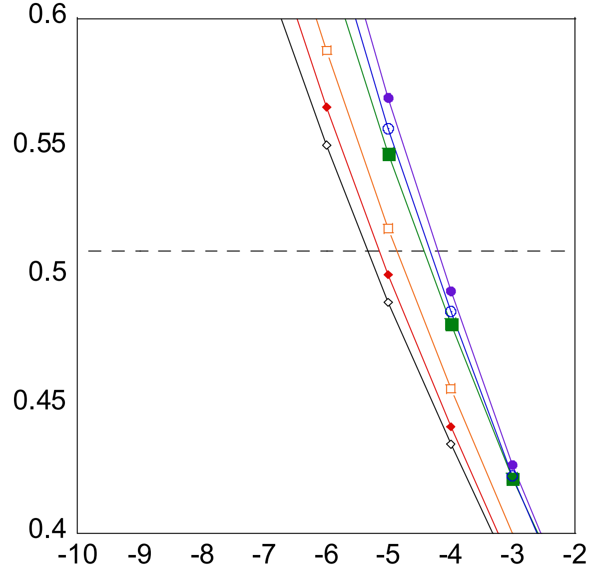
T_s^* is linearly dependent on B_{min} not ∇B_{ECR}

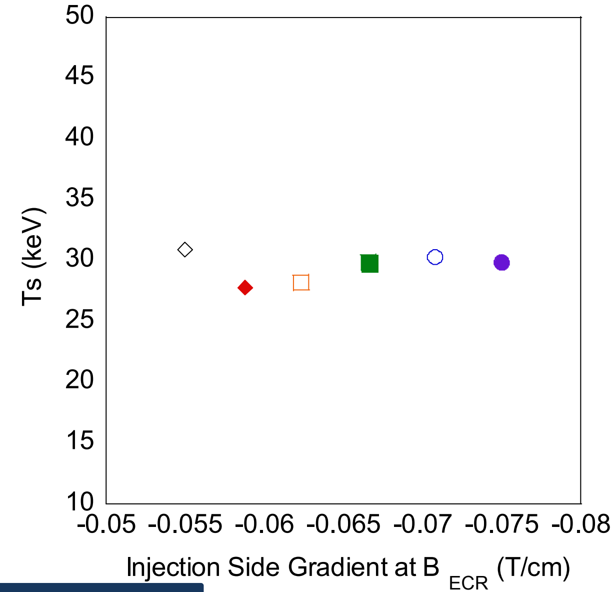


[#] T. Ropponen, Presented at ECRIS '10, Grenoble, France

Investigation Pt 1:
Constant B_{min} while Varying ∇B_{ECR}





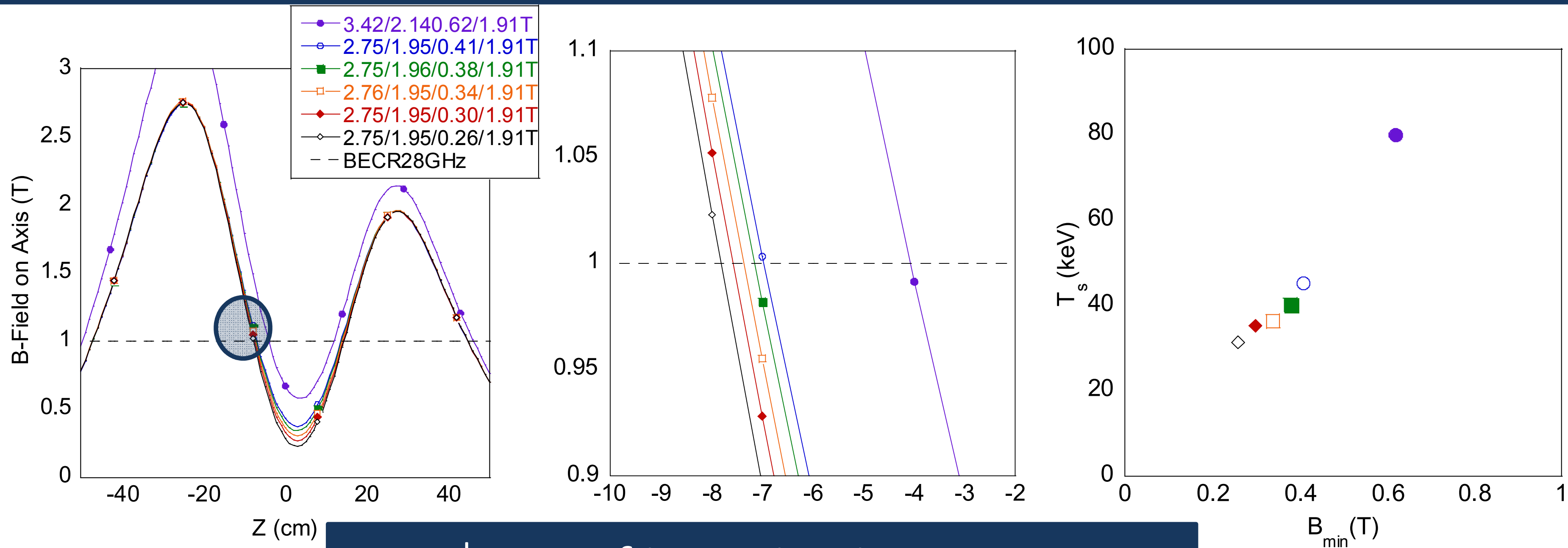


1st part of investigation:

- Hold B_{min} constant, vary ∇B_{ECR}

T_s did not increase with $\uparrow \nabla B_{ECR}$, constant B_{min}

Investigation Pt 2:
Constant ∇B_{ECR} while Varying B_{min}

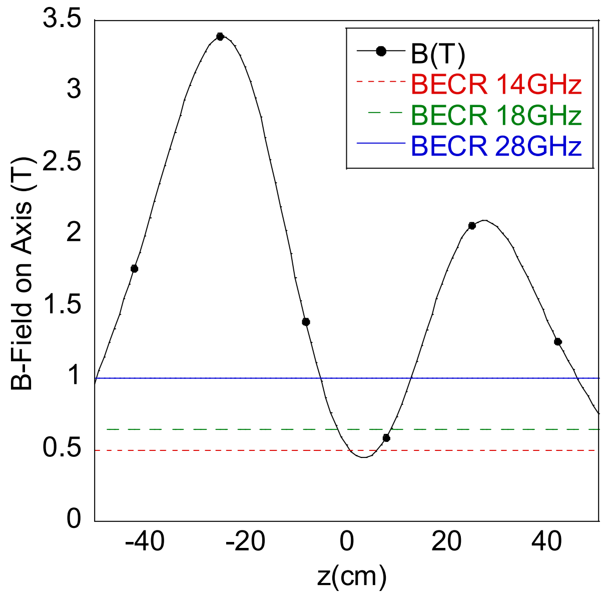


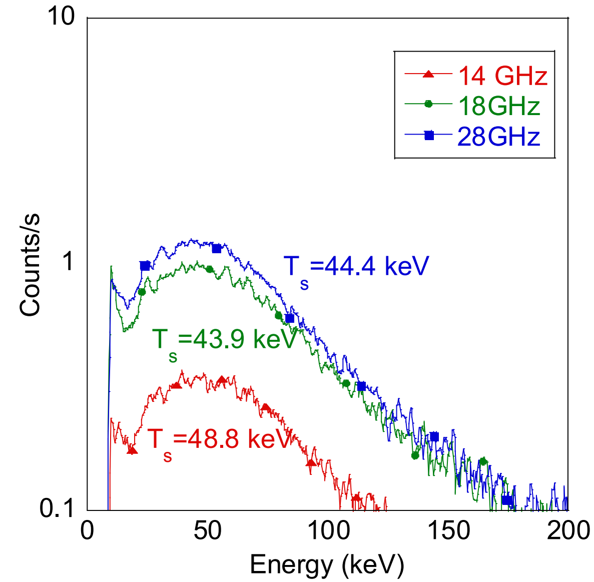
2nd part of investigation

Hol

$\uparrow T_s$ with $\uparrow B_{min}$, constant ∇B_{ECR}

Investigation Pt 3:
Different Frequencies at Same Magnetic Field Values





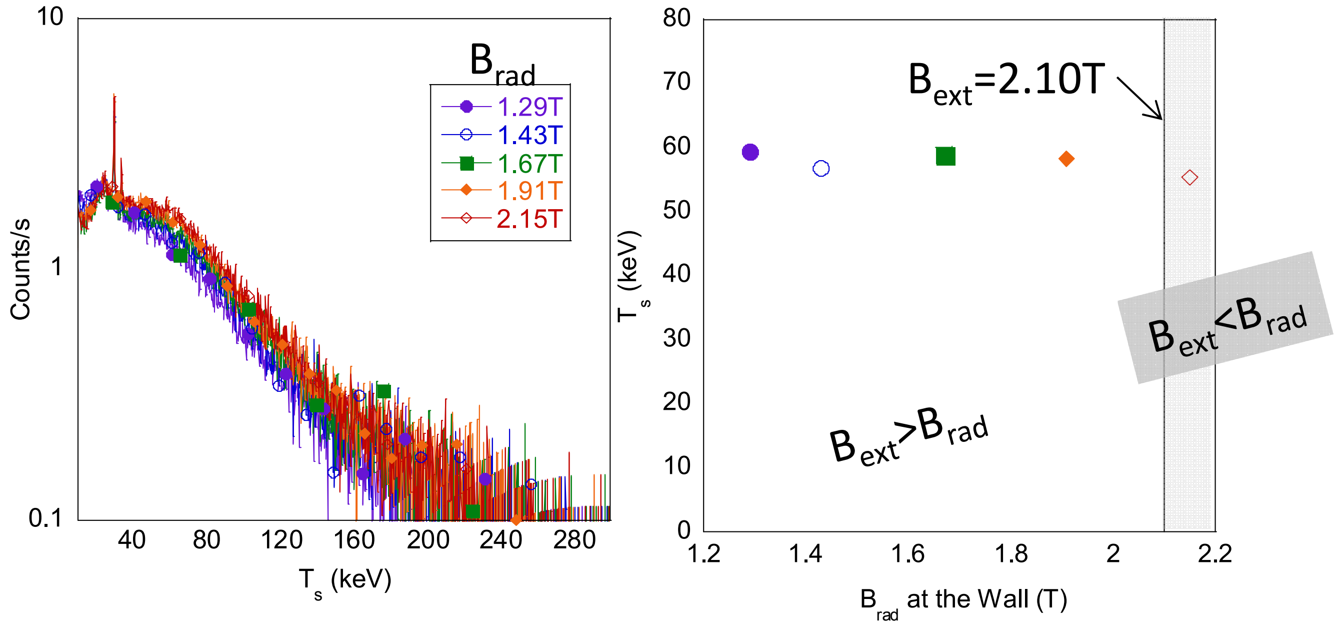
3rd part of investigation

- Hold B-field constant, Vary frequency 14, 18, 28GHz
- At same B-field, different gradients for each frequency

Frequency (GHz)	Injection Gradient at B_{ECR} (T/m)	Extraction Gradient at B_{ECR} (T/m)	Ts (keV)
14	-4.67	4.22	48.8
18	-7.71	6.54	43.8
28	-12.75	10.00	44.4

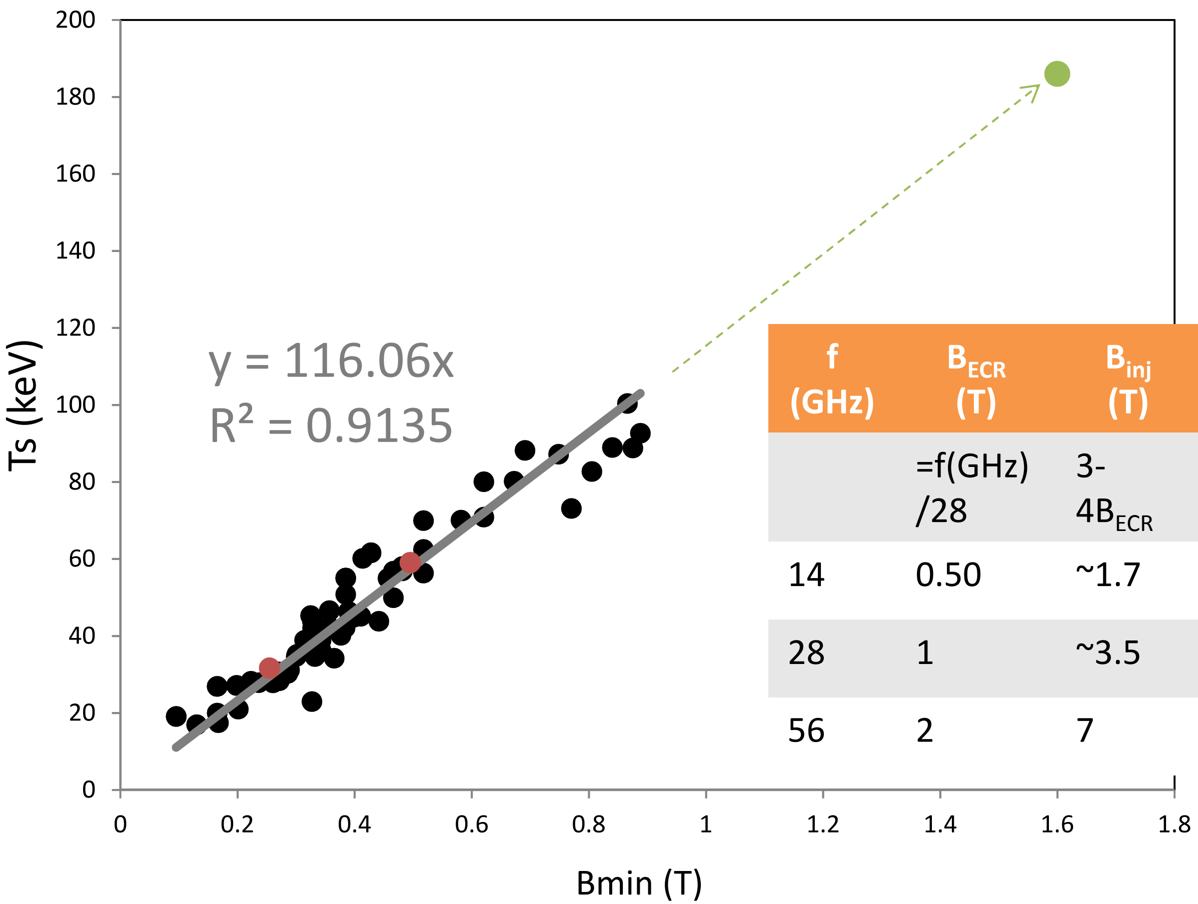
Varying the Radial Magnetic Field $B_{ext} > B_{rad}$

- Usually operate with $B_{ext} > B_{rad}$
- Varied B_{rad} from 1.29T to 2.15T
  with constant $B_{inj}/B_{ext}/B_{mid}$=3.39T/2.1T/0.48T



Summary of Data

4th generation ECRs: Hot electrons can be avoided if B_{min} is not scaled with frequency



f (GHz)	B_{ECR} (T)	B_{inj} (T)	B_{mid} (T)	B_{ext} (T)	B_{rad} (T)	T_s (keV) $\propto B_{min}$
	=f(GHz) /28	3-4B_{ECR}	0.5-0.8B_{ECR}	~B_{rad}	2B_{ECR}	
14	0.50	~1.7	0.25	1	1	30 keV
28	1	~3.5	~0.5	2	2	58 keV
56	2	7	~1-1.6	4	4	186keV!

Conclusions

1.

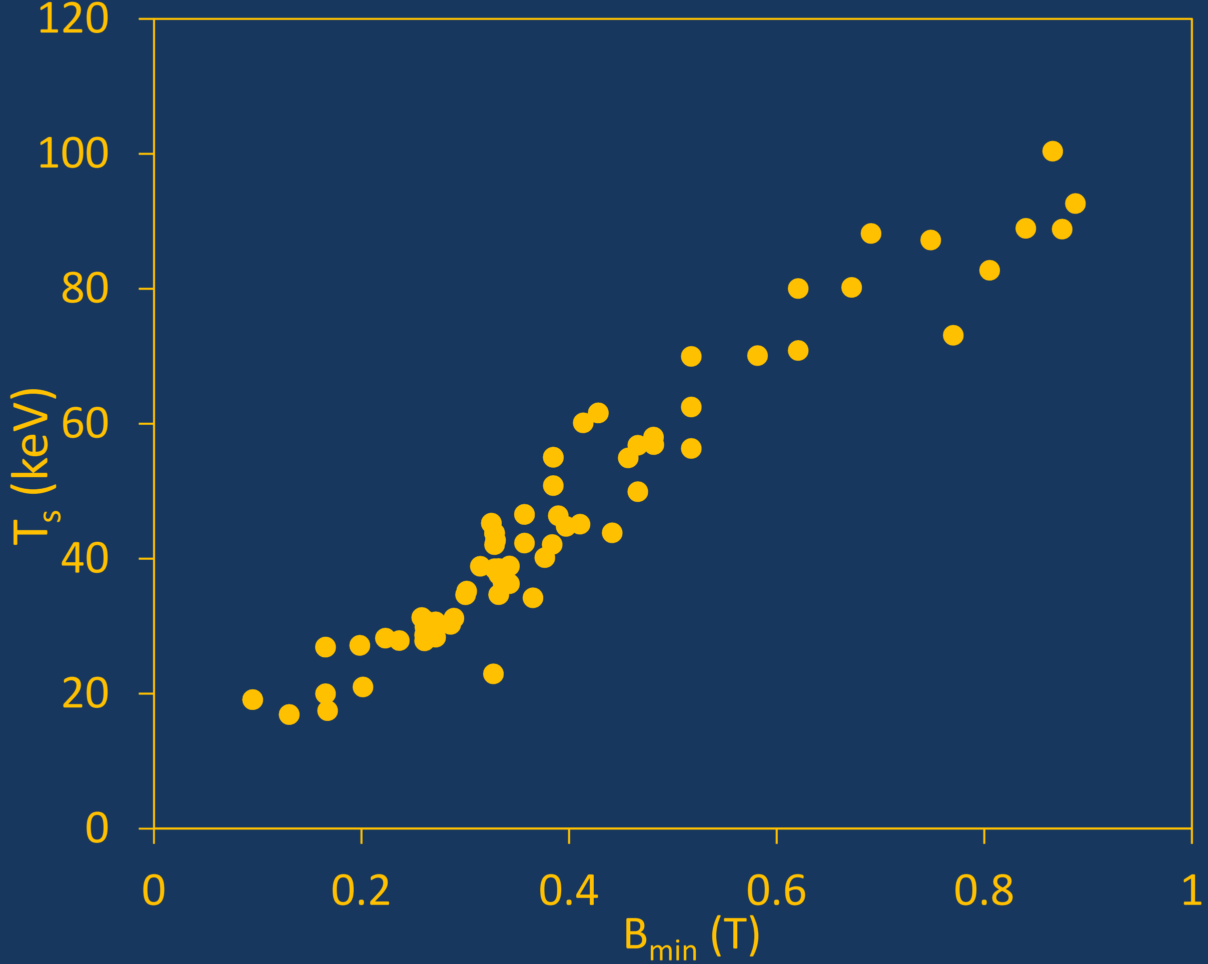
T_s depends on B_{min}, not ∇B_{ECR}

2.

T_s is independent of frequency

3.

In 4[th] generation ECRs, T_s is expected to be very high



Conclusions

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T_s depends on B_{min}, not ∇B_{ECR}

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T_s is independent of frequency

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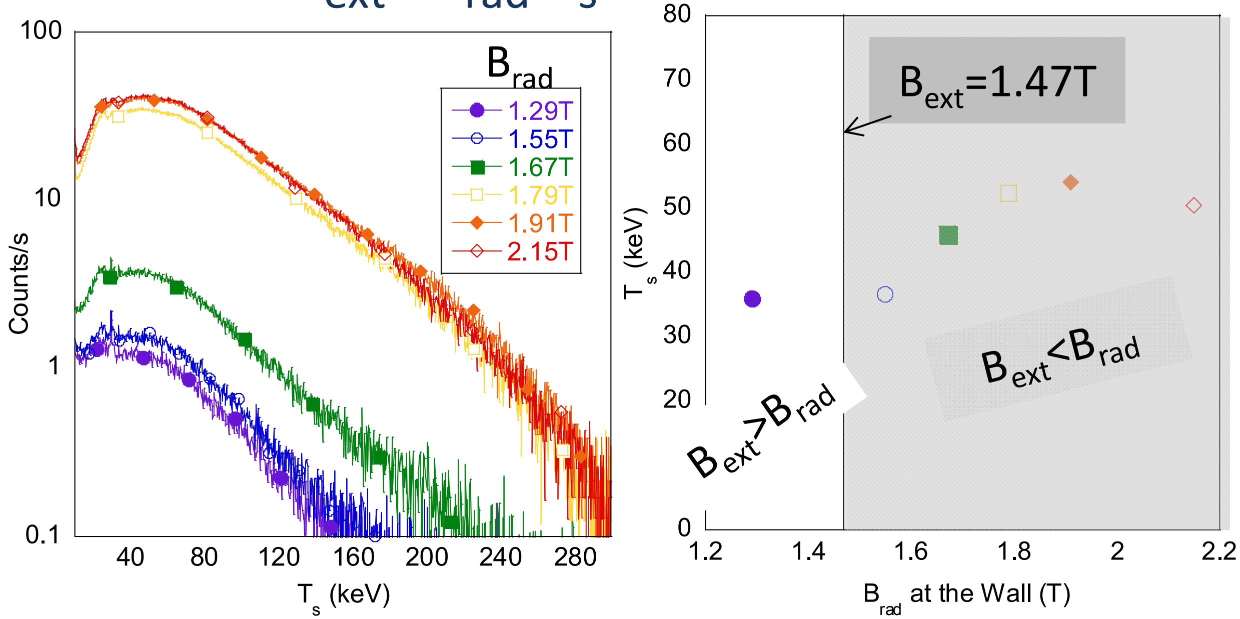
감사합니다

(gam-sa-ham-ni-da)

"Thank You"

Varying the Radial Magnetic Field $B_{ext}<B_{rad}$

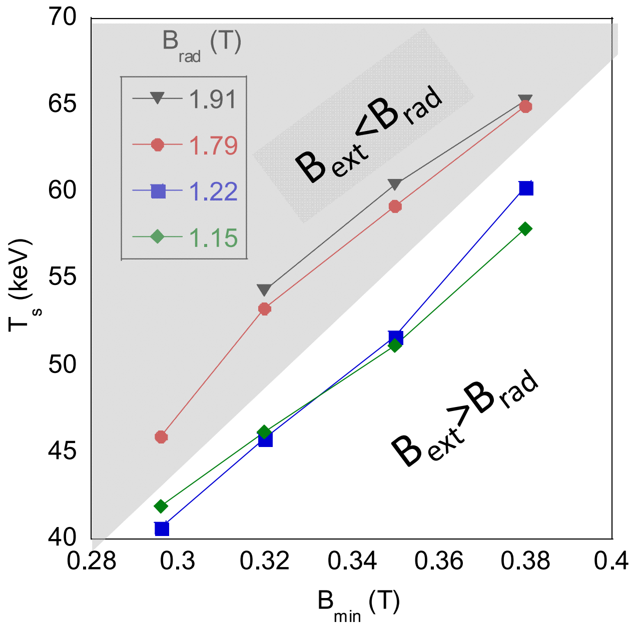
- Lowered B_{ext} to 1.47T
- Varied B_{rad} from 1.29T to 2.15T
  with constant $B_{inj}/B_{ext}/B_{mid}$=2.23T/1.47T/0.33T
- Found that with $B_{ext}<B_{rad}$ T_s increases



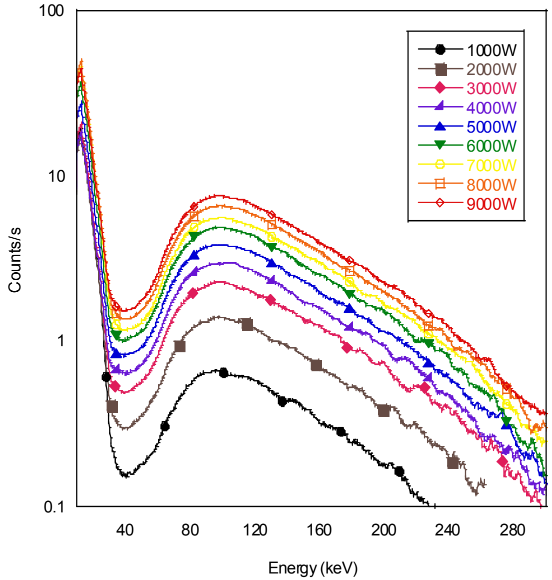
Varying the Radial Magnetic Field

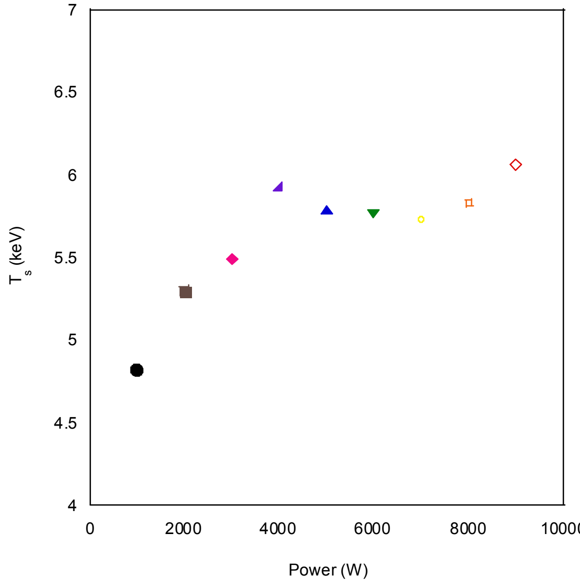
- When $B_{ext}<B_{rad}$ is T_s still dependent on B_{min}?
- Varied B_{min} at different values of B_{rad}

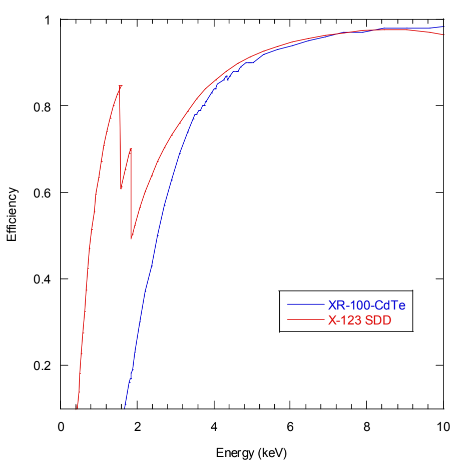
Found that T_s still depends on B_{min} when weak point in confinement is shifted towards extraction

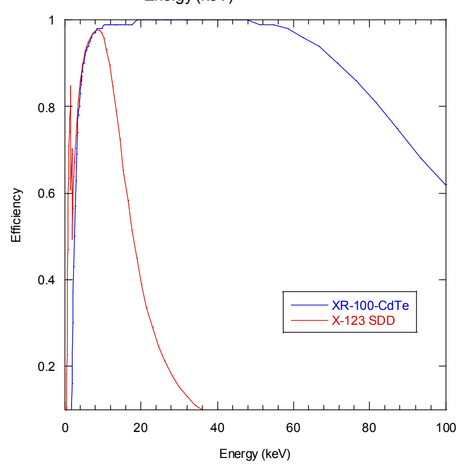


Future Work


Counts/s
Energy (keV)
1000W
2000W
3000W
4000W
5000W
6000W
7000W
8000W
9000W


T_s (keV)
Power (W)

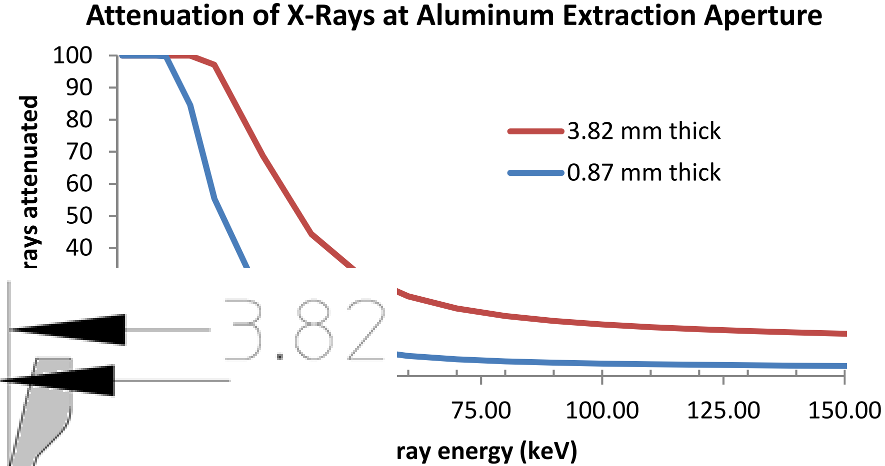

Efficiency
Energy (keV)
XR-100-CdTe
X-123 SDD

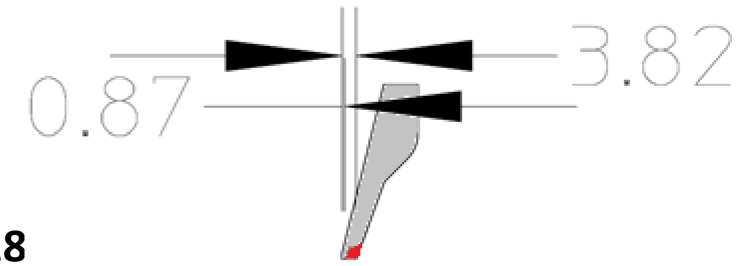

Efficiency
Energy (keV)
XR-100-CdTe
X-123 SDD

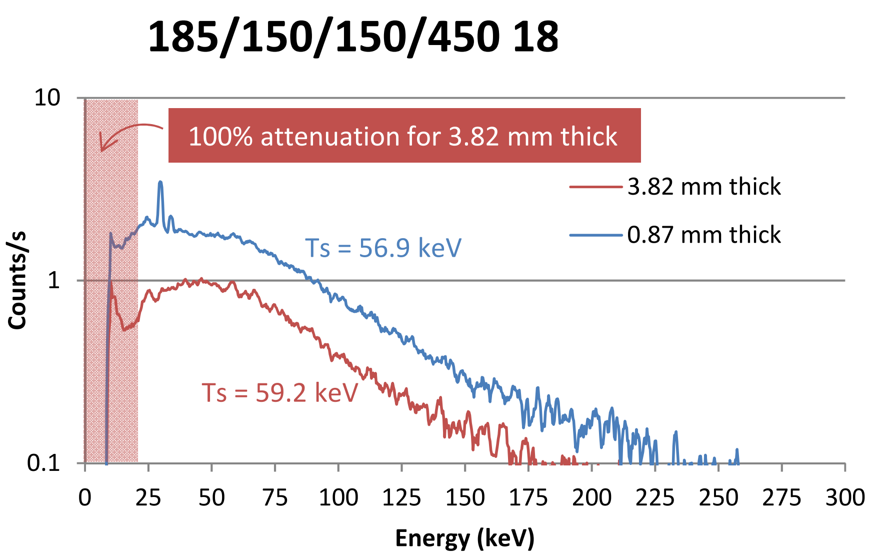

FAST SDD
1-2-3
SDD
X-Ray Spectrometer

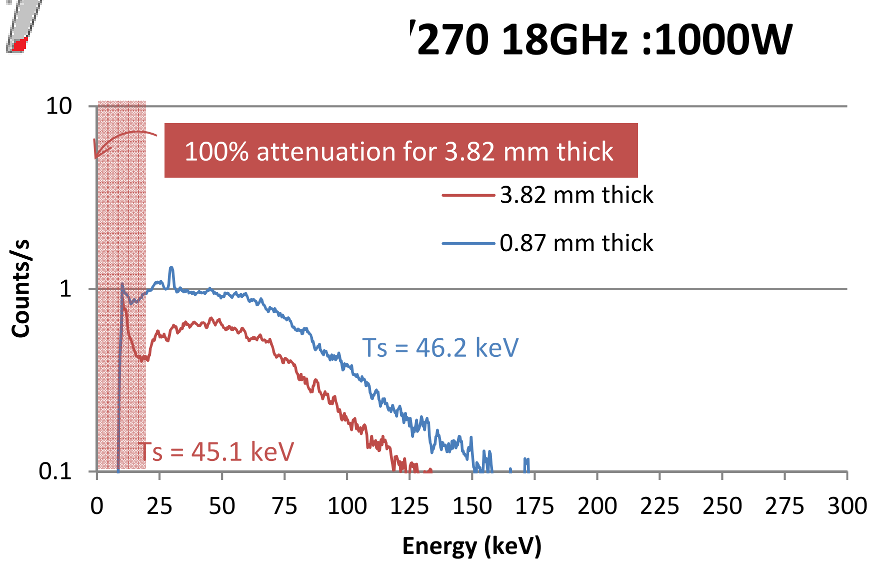
Extraction Electrode

Replaced Al extraction electrode with slightly thicker one in 10/2015





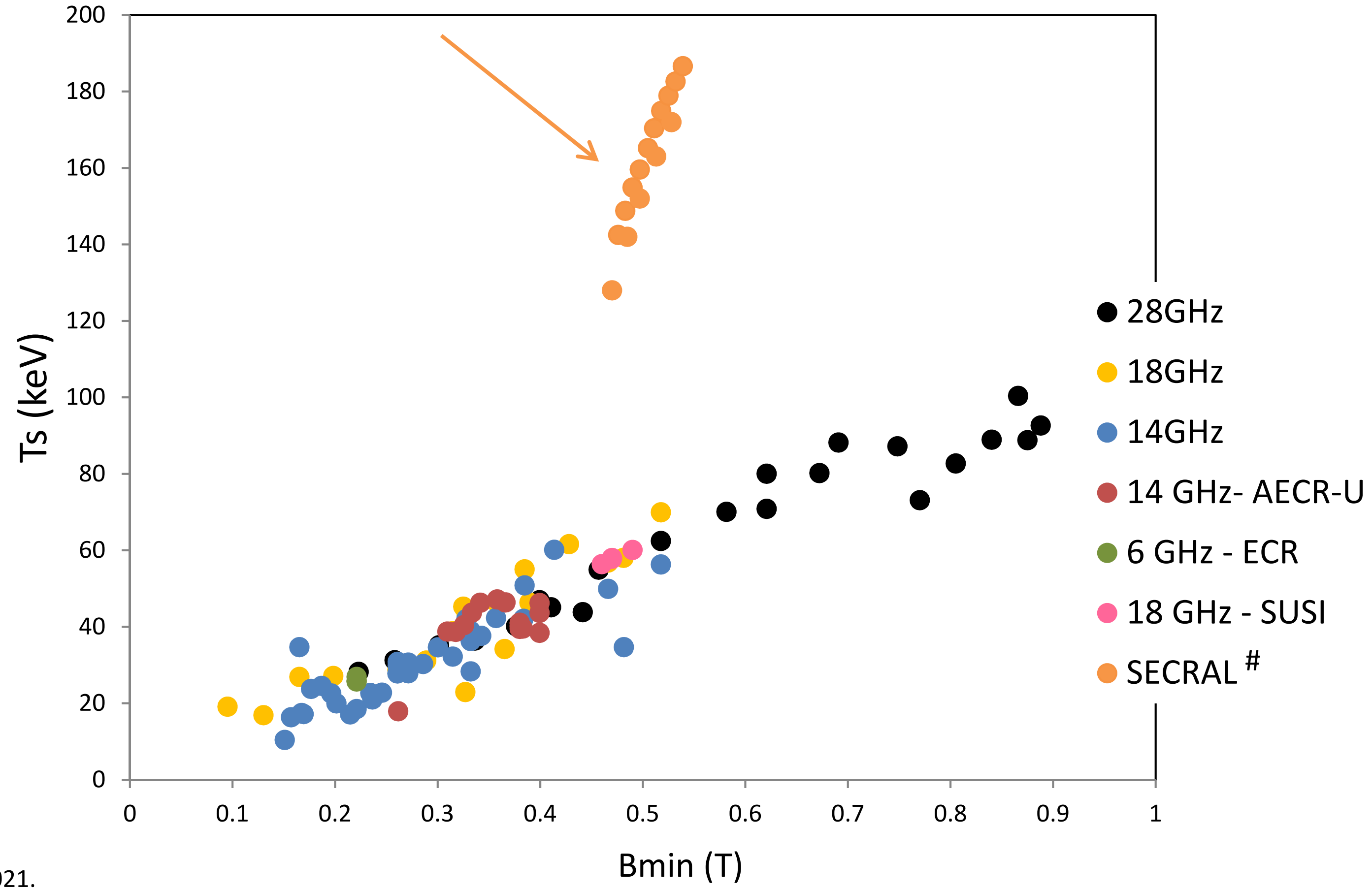




Conclusion

VENUS
& AECR-U
& ECR
& SUSI
& SECRAL

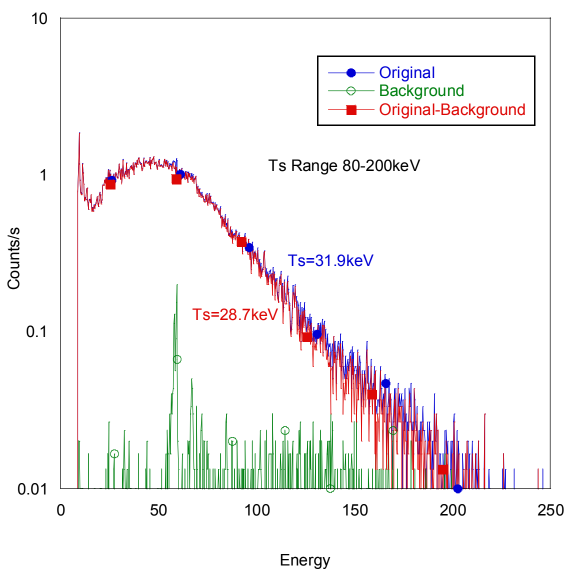
T_s^* is linearly dependent on B_{min} not ∇B_{ECR}

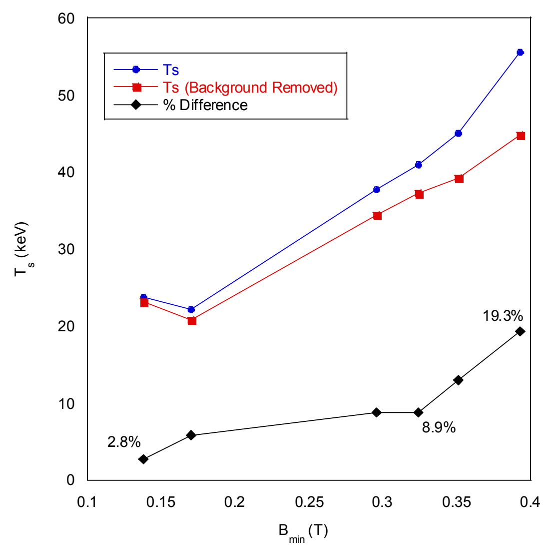


*in energy range we have studied

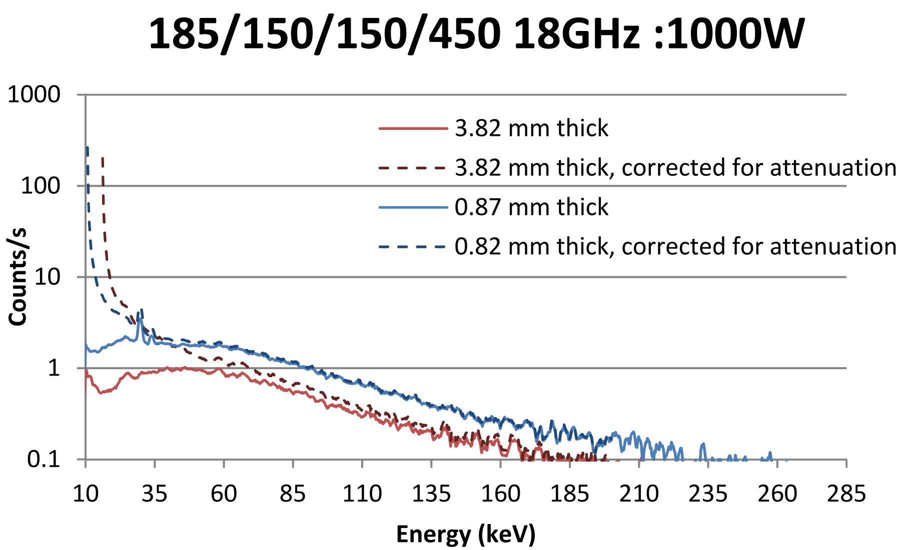
#Plasma Sources Sci. Technol. 18 (2009) 025021.

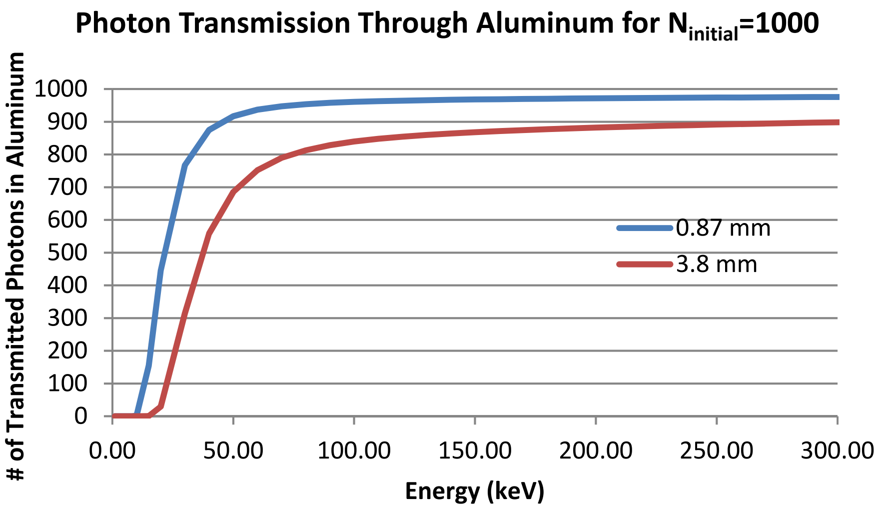
Background Subtraction





Extra


185/150/150/450 18GHz :1000W
1000
100
10
1
0.1
Counts/s
3.82 mm thick
3.82 mm thick, corrected for attenuation
0.87 mm thick
0.82 mm thick, corrected for attenuation
10
35
60
85
110
135
160
185
210
235
260
285
Energy (keV)


Photon Transmission Through Aluminum for N_initial=1000
# of Transmitted Photons in Aluminum
1000
900
800
700
600
500
400
300
200
100
0
0.87 mm
3.8 mm
0.00
50.00
100.00
150.00
200.00
250.00
300.00
Energy (keV)

Summary of Data