Bremsstrahlung and Ion Beam Current Measurements with SuSI ECR Ion Source

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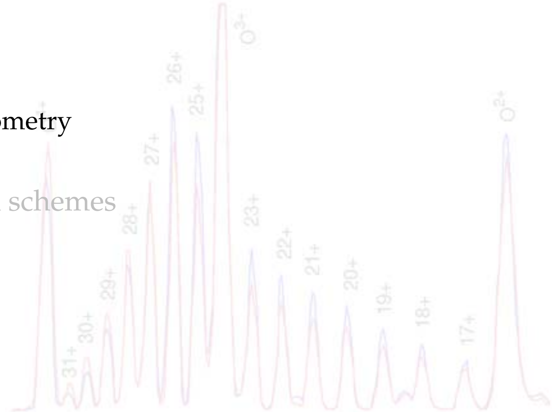
Overview

1. Measurement setup
    - SuSI
    - Measurement geometry
    - DAQ
2. Different collimation schemes



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OVERVIEW

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   - Measurement geometry
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4. The effect of ∇B
   - With fixed plasma length and B_{min}

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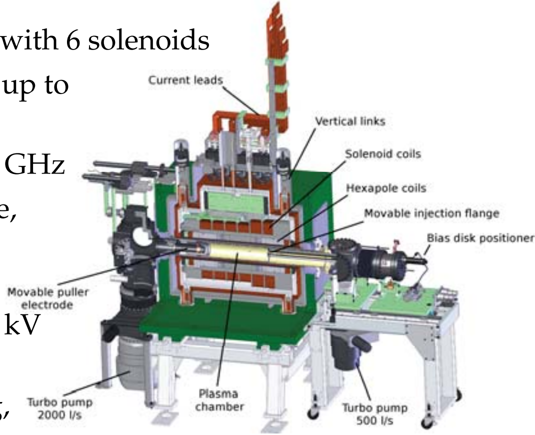
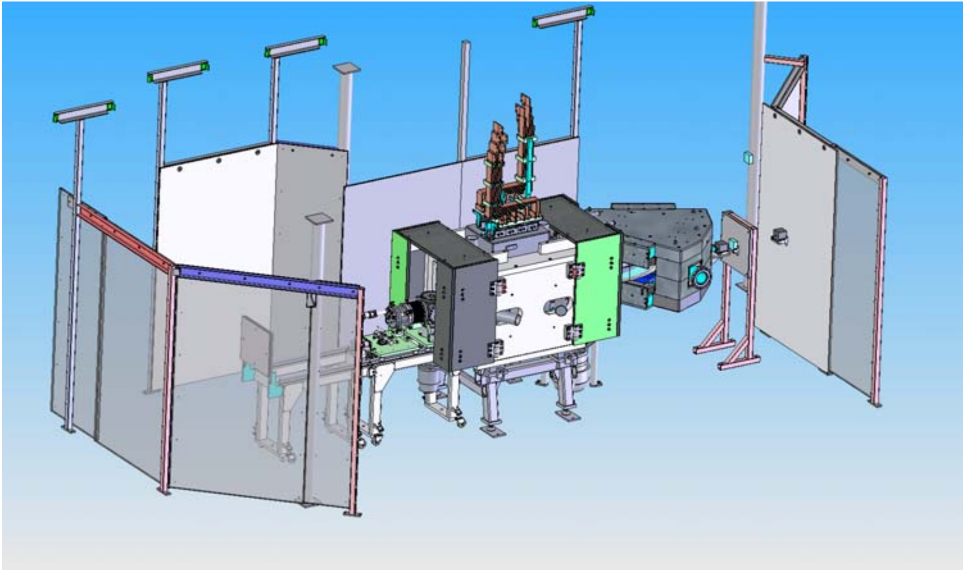
SuSI - Superconducting Source for Ions

- Fully superconducting with 6 solenoids
- Two 18 GHz klystrons, up to 3 kW
- Magnetic field up to 24 GHz
- Movable injection baffle, bias disk and puller electrode
- Extraction HV up to 27 kV
- Collimation channel, on-axis axial sputtering, on/off-axis axial oven



- More information: MOCOAK02 (L. T. Sun), MOCOBK01 (G. Machicoane), MOPOT16 (D. Cole)

X-RAY MEASUREMENT SETUP



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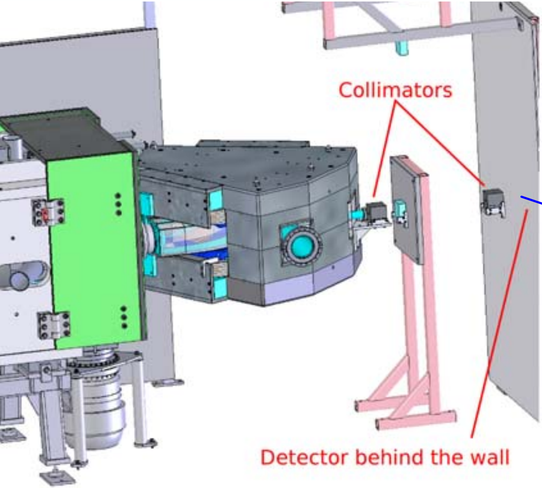

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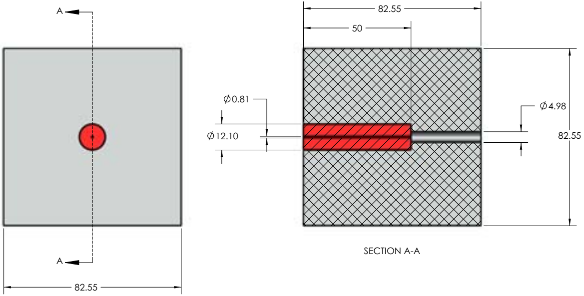

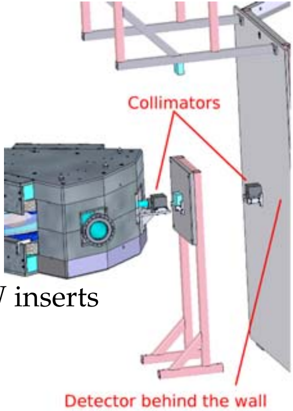

- 2 collimators: Pb (83x83x83 mm) with W inserts (50 mm, OD 12 mm, hole ⌀ 0.8 mm)
- Additional shielding:
  - Pb blocks inside the dipole
  - Stand-alone Pb shield between the collimators, hole ⌀ 5 mm
  - ECR room Pb wall, hole ⌀ 5 mm

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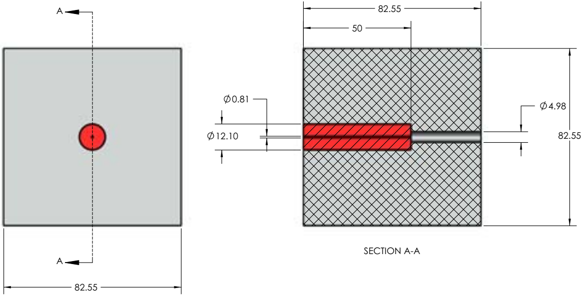
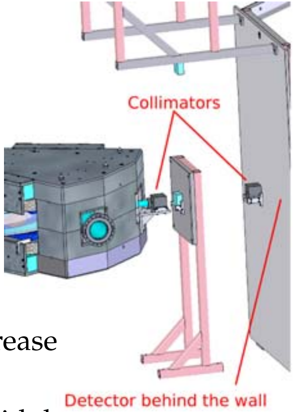
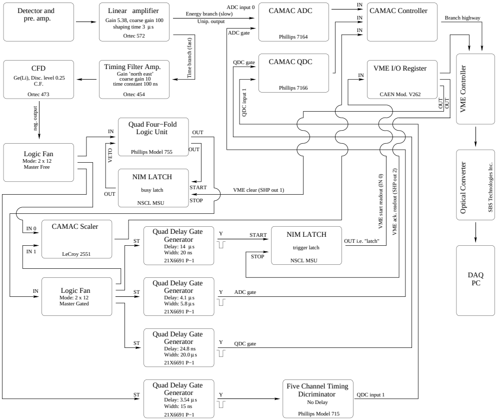


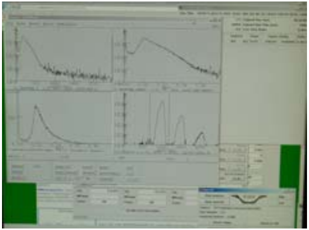


- Ge detector located behind the wall
- Pb shielding around the detector to decrease background
- Collimators aligned through injection with laser
- 30 min measurement time
- Distance between extraction and detector: ≈ 3.2 m

X-RAY MEASUREMENT SETUP

- NIM, CAMAC & VME electronics, NSCL DAQ & SpecTcl
- Time-stamped list mode data
- Pile-up rejection
- Efficiency and energy calibration: ^{133}Ba, ^{152}Eu
  - Resolution: 2.14 keV@81 keV, 6.15 keV@1085 keV





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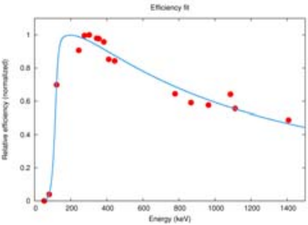
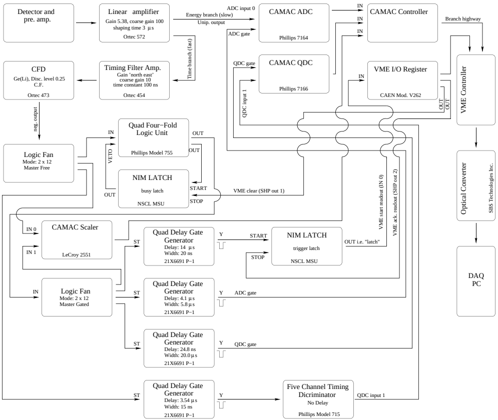
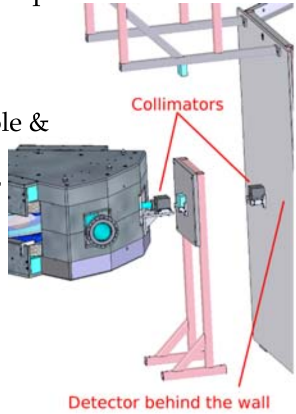
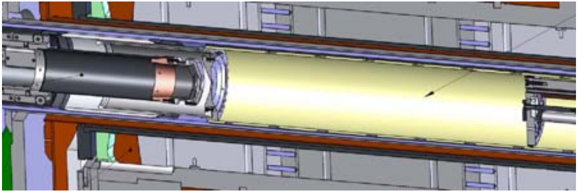




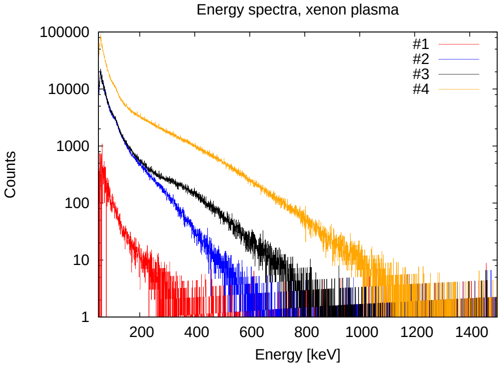
DIFFERENT COLLIMATION GEOMETRIES

- Area seen by the detector at the extraction aperture ($\varnothing$ 10 mm) of SuSI
  - #1 $\varnothing$ 7 mm: All collimators
  - #2 $\varnothing$ 62 mm: 1 st collimator removed
  - #3 $\varnothing$ 83 mm: #2 + Pb blocks inside the dipole & stand-alone Pb shield removed
  - #4 $\approx$ The whole ECRIS: #3 + 2 nd collimator removed





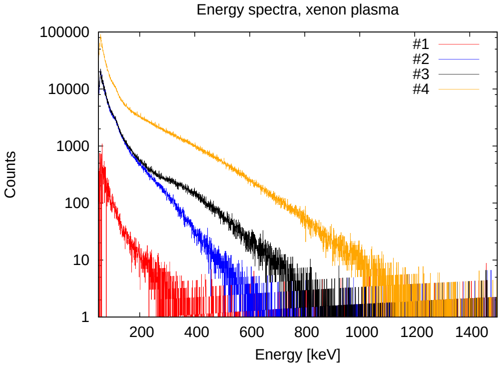
Different collimation geometries



- Xenon/oxygen plasma, 1200 W
- Endpoint energies:

  #1: ≈ 400 keV, **#2:** ≈ 650 keV, **#3:** ≈ 850 keV, **#4:** ≈ 1200 keV

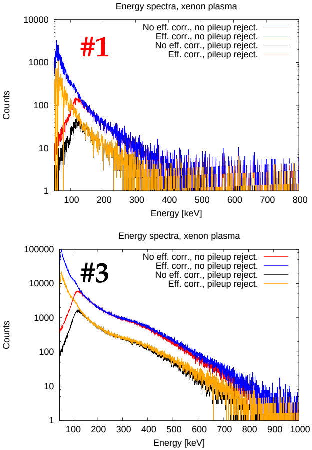
DIFFERENT COLLIMATION GEOMETRIES



Difference in the shape:

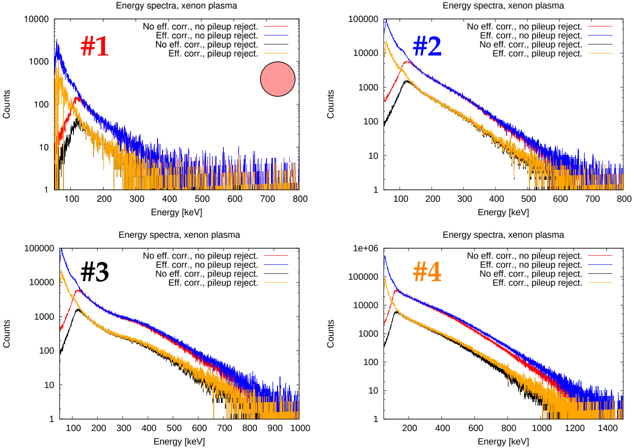
- Plasma (cyclotron/synchrotron radiation) & collisions
- High energy electron losses
- Scattered radiation

Efficiency correction and pile-up rejection



- Energy spectra with and without efficiency correction and pile-up rejection for **#1**, **#2**, **#3** and **#4**

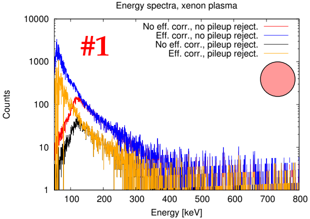
Efficiency correction and pile-up rejection

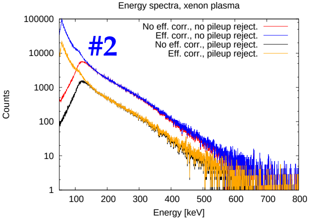


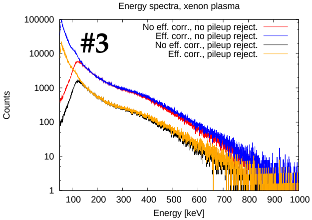
1 st figure: spectral temperature (fit range 130–175 keV)

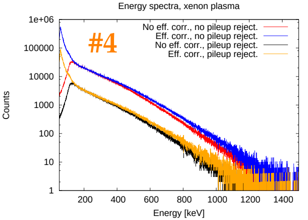
no eff. corr. no pile-up reject.	eff. corr. no pile-up reject.	no eff. corr. pile-up reject.	eff. corr. pile-up reject.
56.8±2.8 keV	49.4±2.2 keV	56.6±5.4 keV	49.2±4.1 keV

Efficiency correction and pile-up rejection





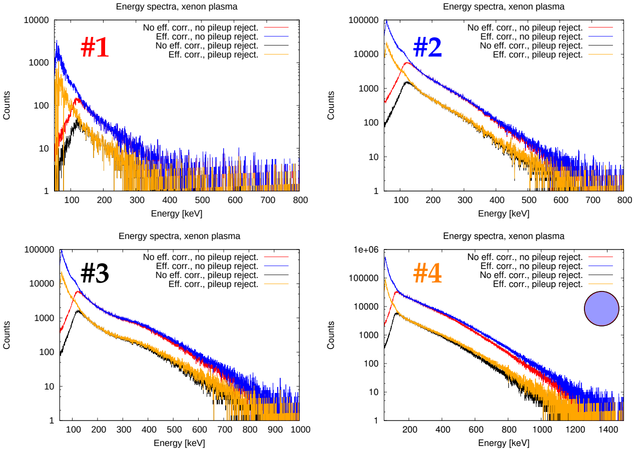




1 st figure: endpoint energies

no eff. corr. no pile-up reject.	eff. corr. no pile-up reject.	no eff. corr. pile-up reject.	eff. corr. pile-up reject.
425±20 keV	440±20 keV	385±20 keV	375±20 keV

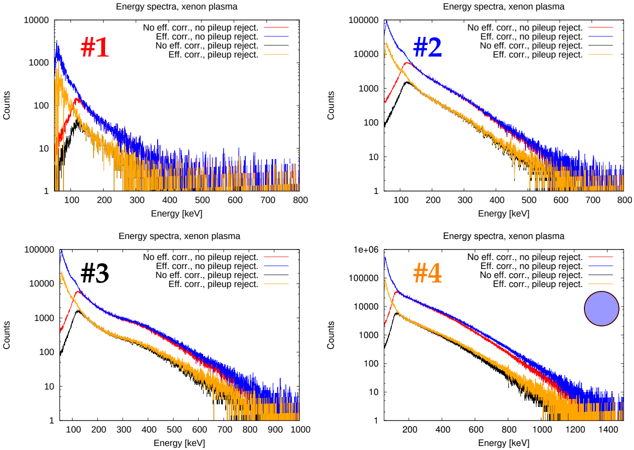
EFFICIENCY CORRECTION AND PILE-UP REJECTION



4 th figure: spectral temperature (fit range 600–800 keV)

no eff. corr. no pile-up reject.	eff. corr. no pile-up reject.	no eff. corr. pile-up reject.	eff. corr. pile-up reject.
118.9±0.6 keV	129.9±0.7 keV	117.7±1.3 keV	128.5±1.5 keV

Efficiency correction and pile-up rejection

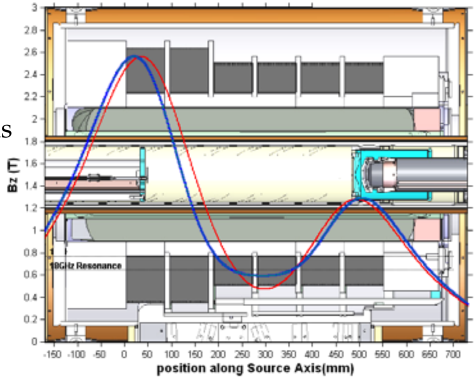


4 th figure: endpoint energies

no eff. corr. no pile-up reject.	eff. corr. no pile-up reject.	no eff. corr. pile-up reject.	eff. corr. pile-up reject.
1340±30 keV	1430±30 keV	1140±30 keV	1230±30 keV

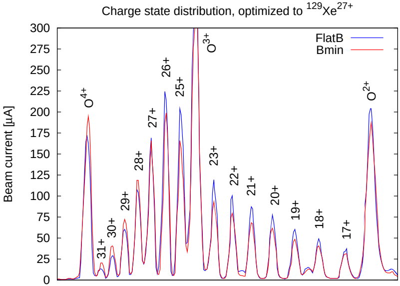
FlatB vs. Bmin operation

- FlatB operation
  - Unstable plasma
  - Very sensitive to tuning
  - Very high radiation levels at the extraction side (outside Pb shielding): 50 mR/h (FlatB) vs. 6 mR/h (Bmin)
- 0.1 T difference in Binj
- Tuned to $^{129}Xe^{27+}$, oxygen as a support gas
- 1500 W (18.0 GHz) + 350 W (17.8 GHz)



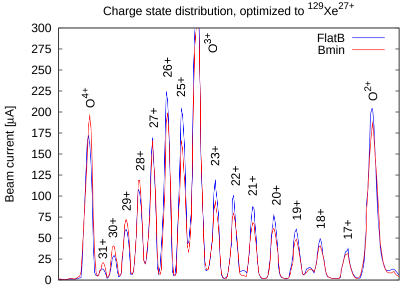
#profile	gradB (inj, ext)	plasma length	res. location (inj, ext)	B_{min}
Bmin	-5.73 T/m, 5.01 T/m	124.5 mm	237.3 mm, 361.8 mm	0.47 T
FlatB	-2.19 T/m, 2.25 T/m	127.1 mm	229.1 mm, 356.1 mm	0.59 T

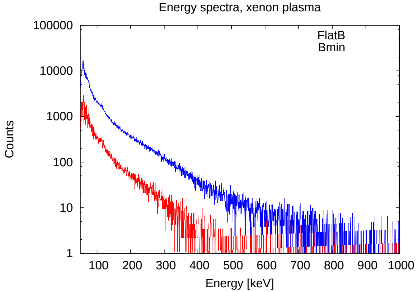
FLATB VS. BMIN OPERATION



- SuSI tuned in both cases keeping RF power constant
- 170 μA of Xe^{27+} with FlatB and Bmin
- CSD shifts towards lower charge states with FlatB
  - Reasons: injection field(?), B_{min}(?), ∇B/EEDF(?), plasma–wave coupling(?)
  - FlatB: 4.4 mA, ext. pressure 8.2e-8 torr
  - Bmin: 4.5 mA, ext. pressure 9.5e-8 torr

FlatB vs. Bmin operation



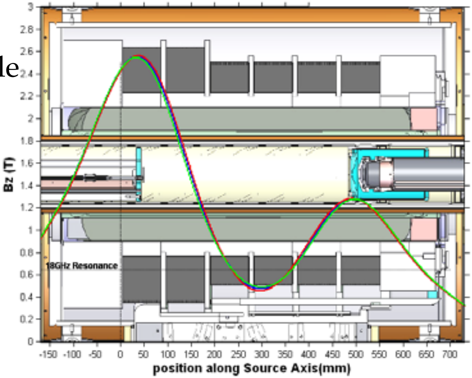


- Fit range for spectral temperature values: 130–200 keV

Spectral temperature		Endpoint energy	
FlatB	Bmin	FlatB	Bmin
68.1±1.1 keV	58.0±1.7 keV	850±30 keV	450±30 keV

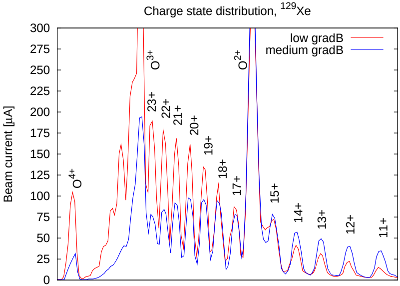
∇B WITH FIXED PLASMA LENGTH AND B_{min}

- 6 coils of SuSI allow tuning the ∇B while keeping profile almost unchanged
- Differences:
  - ∇B: 23 % (inj), 13 % (ext)
  - Plasma length: 1.1 mm
  - B_{min}: 6.5 %
- Source tuned with profile 'med gradB' and then only the field profile is changed



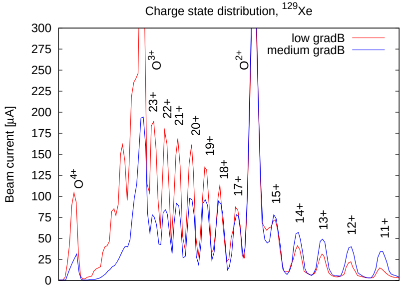
#profile	gradB (inj, ext)	plasma length	res. location (inj, ext)	B_{min}
med gradB	-5.73 T/m, 5.01 T/m	124.5 mm	237.3 mm, 361.8 mm	0.47 T
low gradB	-5.19 T/m, 4.75 T/m	125.4 mm	237.8 mm, 363.2 mm	0.49 T
high gradB	-6.38 T/m, 5.39 T/m	124.3 mm	236.1 mm, 360.4 mm	0.46 T

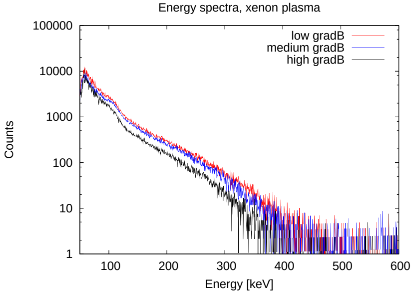
∇B WITH FIXED PLASMA LENGTH AND B_{min}



- SuSI tuned to Xe^{20+} with constant RF power (1500 W)
- CSD shifts to higher charge states while lowering ∇B
  - Reasons: ∇B/EEDF(?), plasma–wave coupling(?)
  - low ∇B: 5.0 mA, ext. pressure 1.4e-7 torr
  - med ∇B: 5.0 mA, ext. pressure 1.6e-7 torr

∇B WITH FIXED PLASMA LENGTH AND B_{min}





- Fit range for spectral temperature values: 130–200 keV

Spectral temperature

low ∇B	med ∇B	high ∇B
60.1±0.9 keV	57.8±0.8 keV	56.4±0.9 keV

Endpoint energy

low ∇B	med ∇B	high ∇B
470±20 keV	435±20 keV	405±20 keV

SUMMARY

When accurate spectroscopy information is needed:

- Efficiency correction...
- Pile-up rejection...
- Unfolding of the spectra (LBNL group)
  - Has impact on spectral temperature but not endpoint energy
- Energy resolution also affects the determination of endpoint energy (e.g. Ge vs. NaI)

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Different collimation geometries:

- By using different solid angles the shape and the endpoint energies of the X-ray spectra change significantly
- One can choose to study only the plasma or also higher energy electrons
- Shielding from the scattered radiation is very important

Summary

FlatB operation:

- Same amount of medium charge states of xenon than with Bmin operation, but
- Very high radiation levels
- Endpoint energies almost doubled
  $\rightarrow$ possible issues with LHe consumption and radiation damage to insulator materials
- *However:* FlatB needs to be studied further...

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Changing ∇B with fixed field profile

- A clear impact on the heavy ion beam intensities
  - Smaller difference with oxygen
- A well-known trend in the X-ray spectra
- The effect of just the gradB shown now for the first time experimentally

ACKNOWLEDGMENTS

G. Machicoane (ion sources)
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