X-ray spectroscopy on slow highly charged ions

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Project

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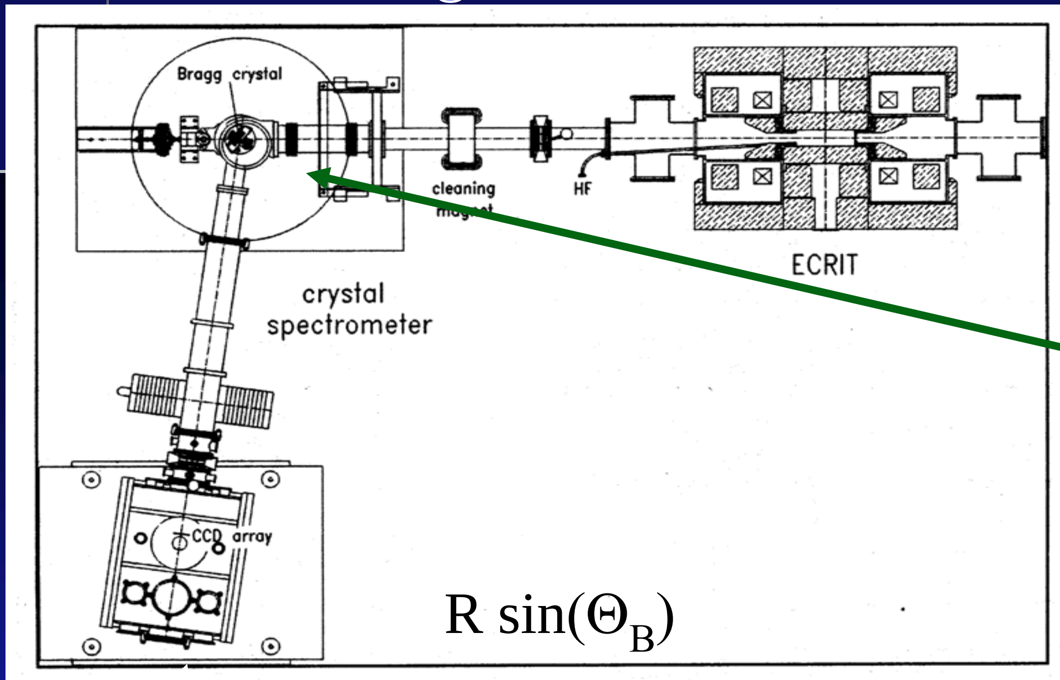
- D. Gotta, KFA Jülich
- D. Parente, J. Marques, J.-P. Santos, M.C. Martins, A.M Costa, University of Lisbon
- D. Vernhet, J.P. Rozet, E. Lamour, C. Prigent, Institut des Nanoscience de Paris, CNRS, UPMC, Univ. Paris VII.

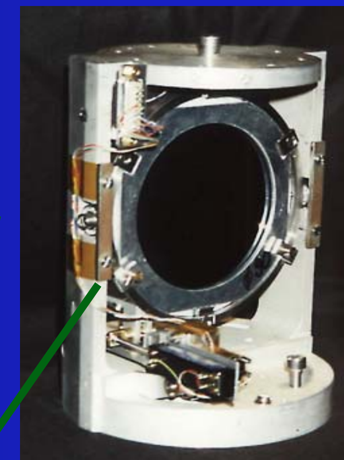
Outline

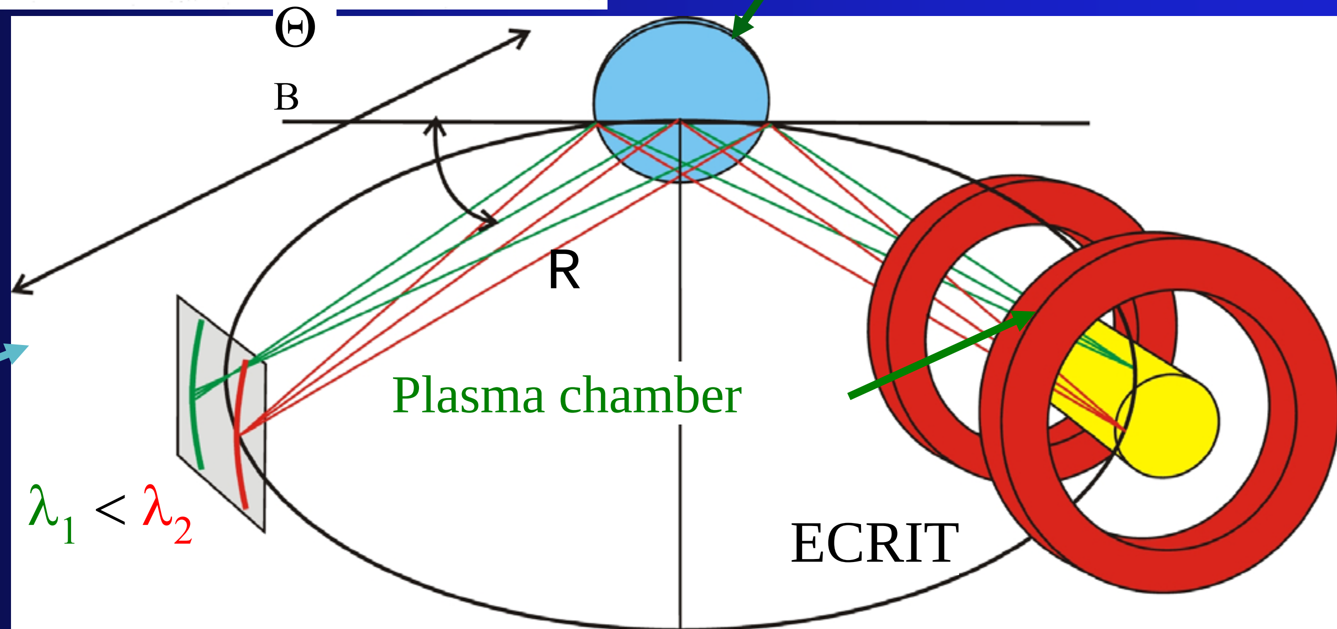
- A spectrometer to measure low energy X-rays from weak sources
- Experimental set-up
- Calibration from light highly charged ions
- Conclusion and perspectives

Using ions at rest



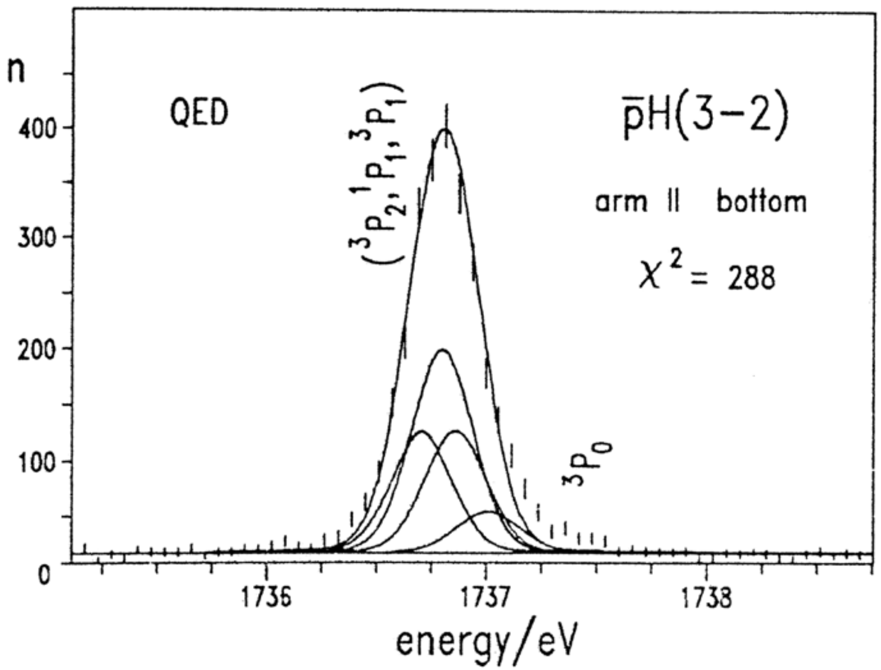
Spherically bent crystal

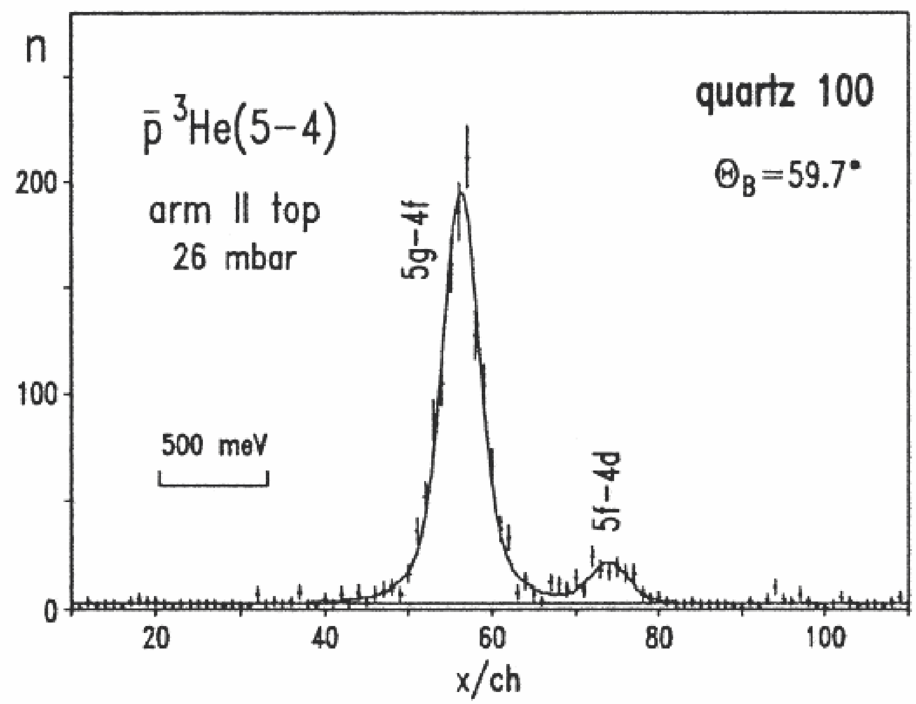




Position detector

Example of weak beam spectroscopy: (antiprotonic H)

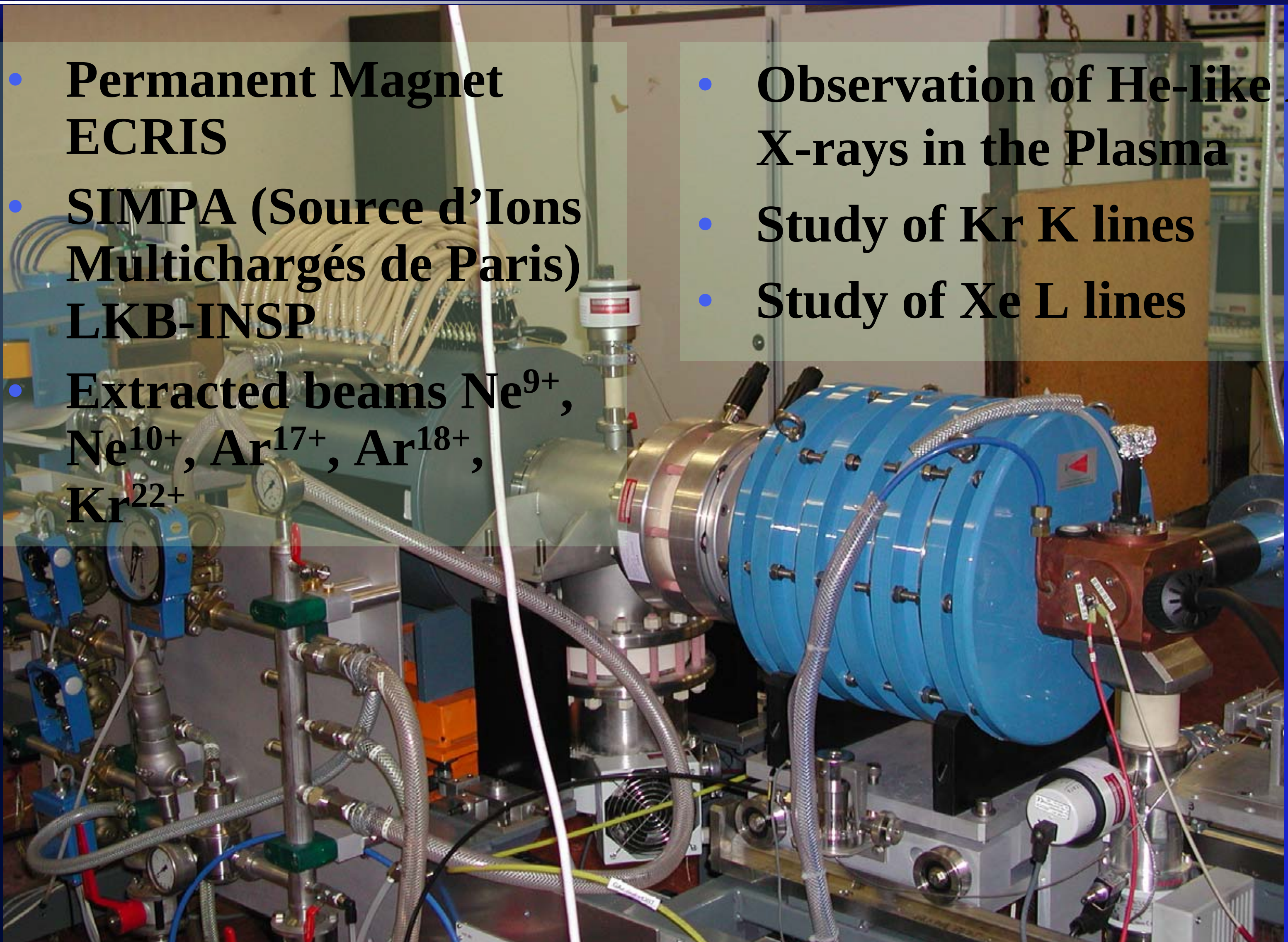




Stopped beam average to 3×10^5 antiprotons/s → 250 counts/hour (including excited state population yield)

We would have needed higher resolution → asymmetric cut crystals, but could not test them (no strong X-ray source with narrow lines at the time)

Can we use simpler, less expensive systems: SIMPA (commercial ECRIS)?

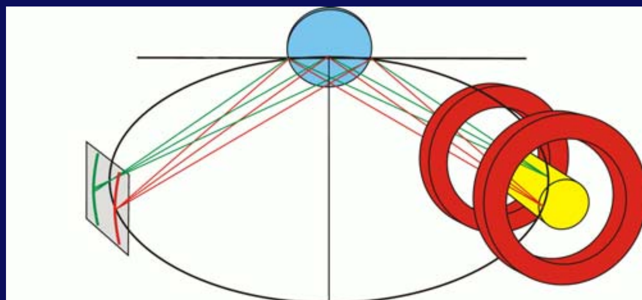


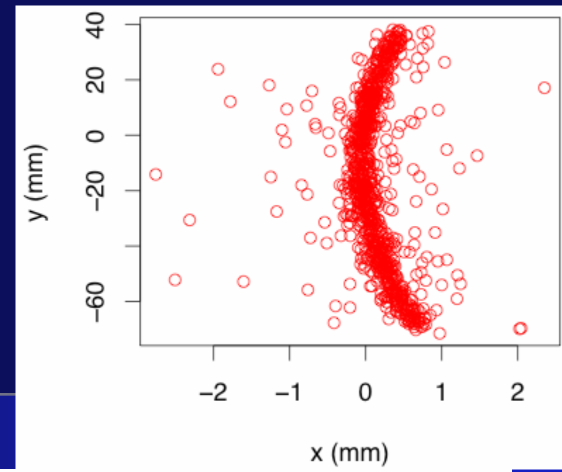
- **Permanent Magnet ECRIS**
- **SIMPA (Source d'Ions Multichargés de Paris) LKB-INSP**
- **Extracted beams Ne^{9+}, Ne^{10+}, Ar^{17+}, Ar^{18+}, Kr^{22+}**

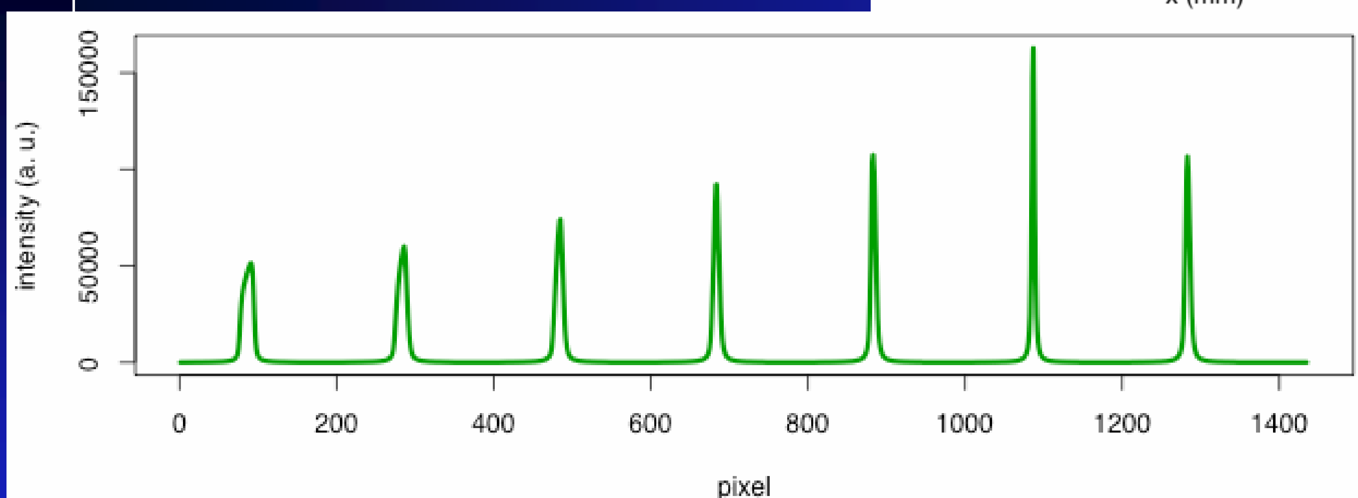
- **Observation of He-like Ar X-rays in the Plasma**
- **Study of Kr K lines**
- **Study of Xe L lines**

Line energies measurements

Precise line energies are obtained through simulations:





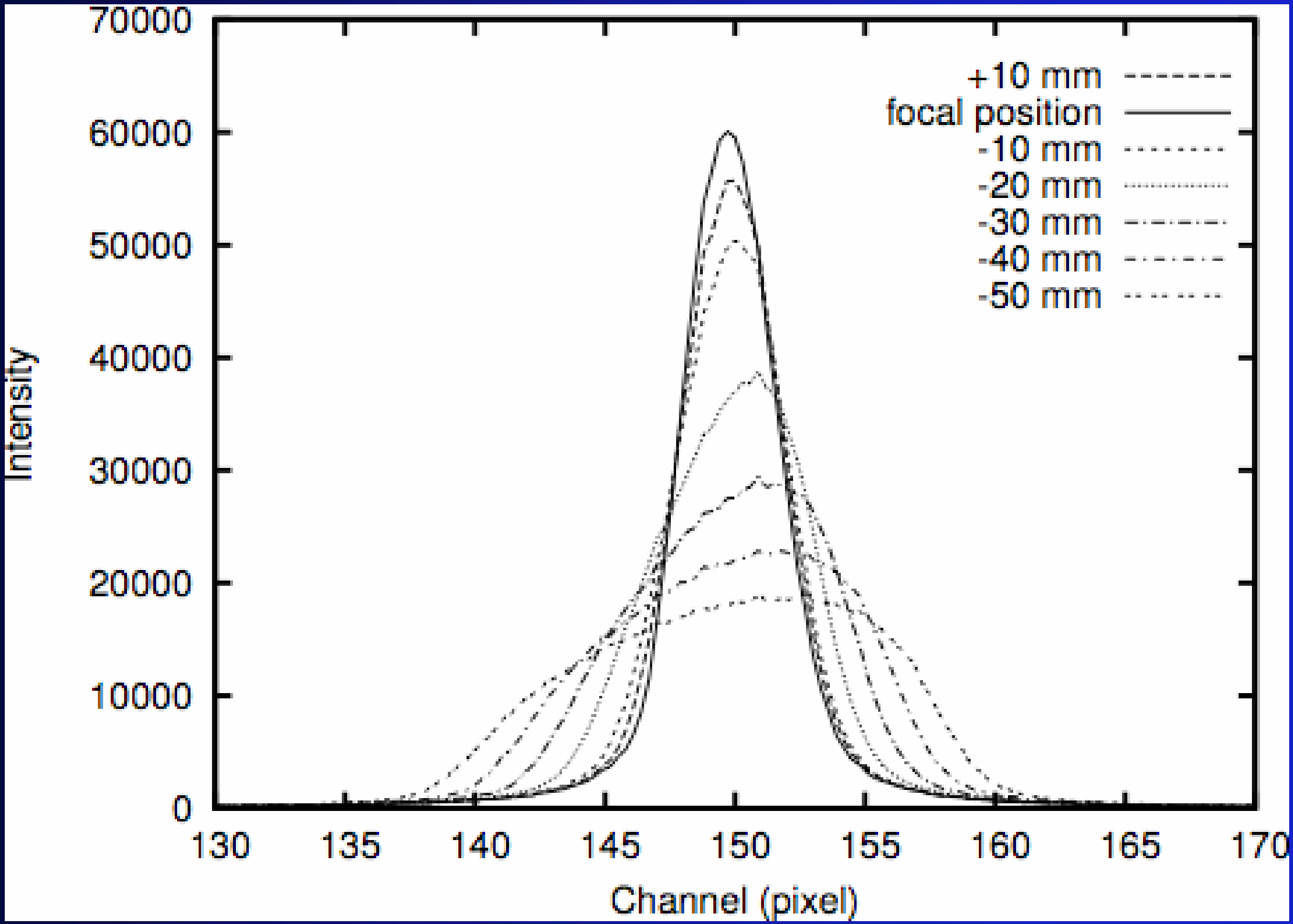


CCD

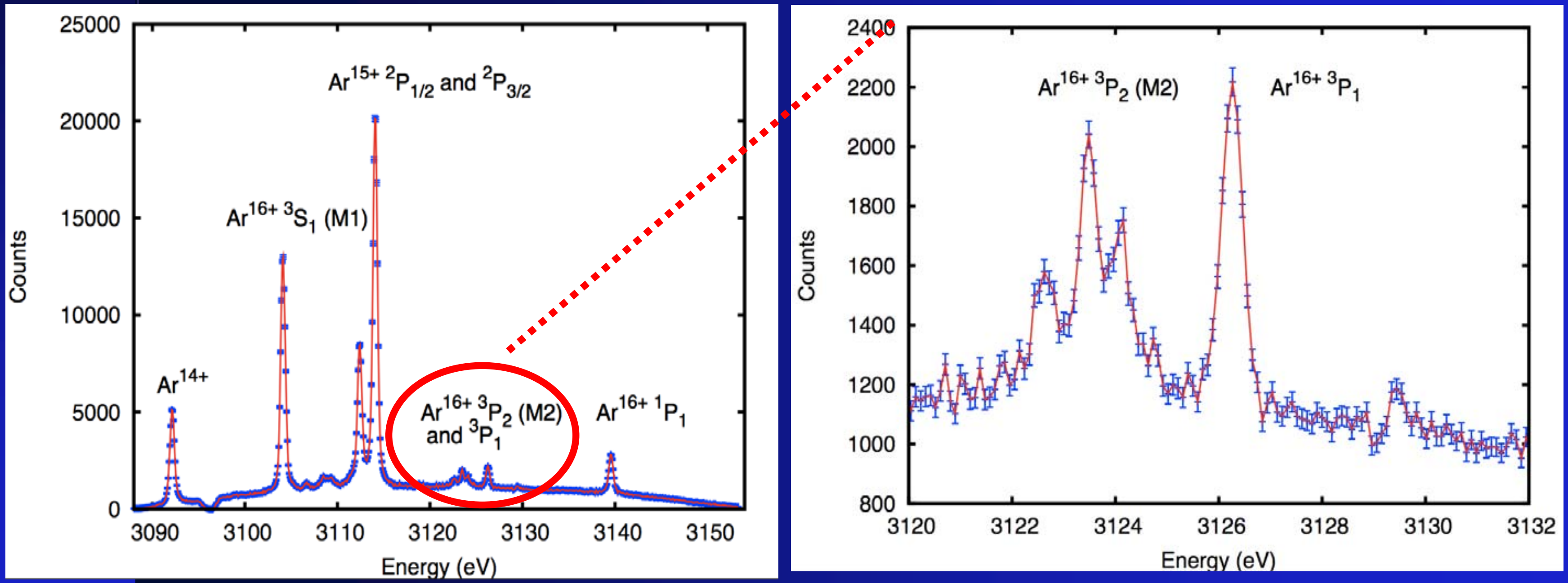
→ calibration: known **energy** versus simulated **line shape**.

Many effects are precisely accounted for: defocusing, mirror tilt,…

Variation of line shape with distance from focal position



Example of spectra



n=2-n=1 transition in He-like argon

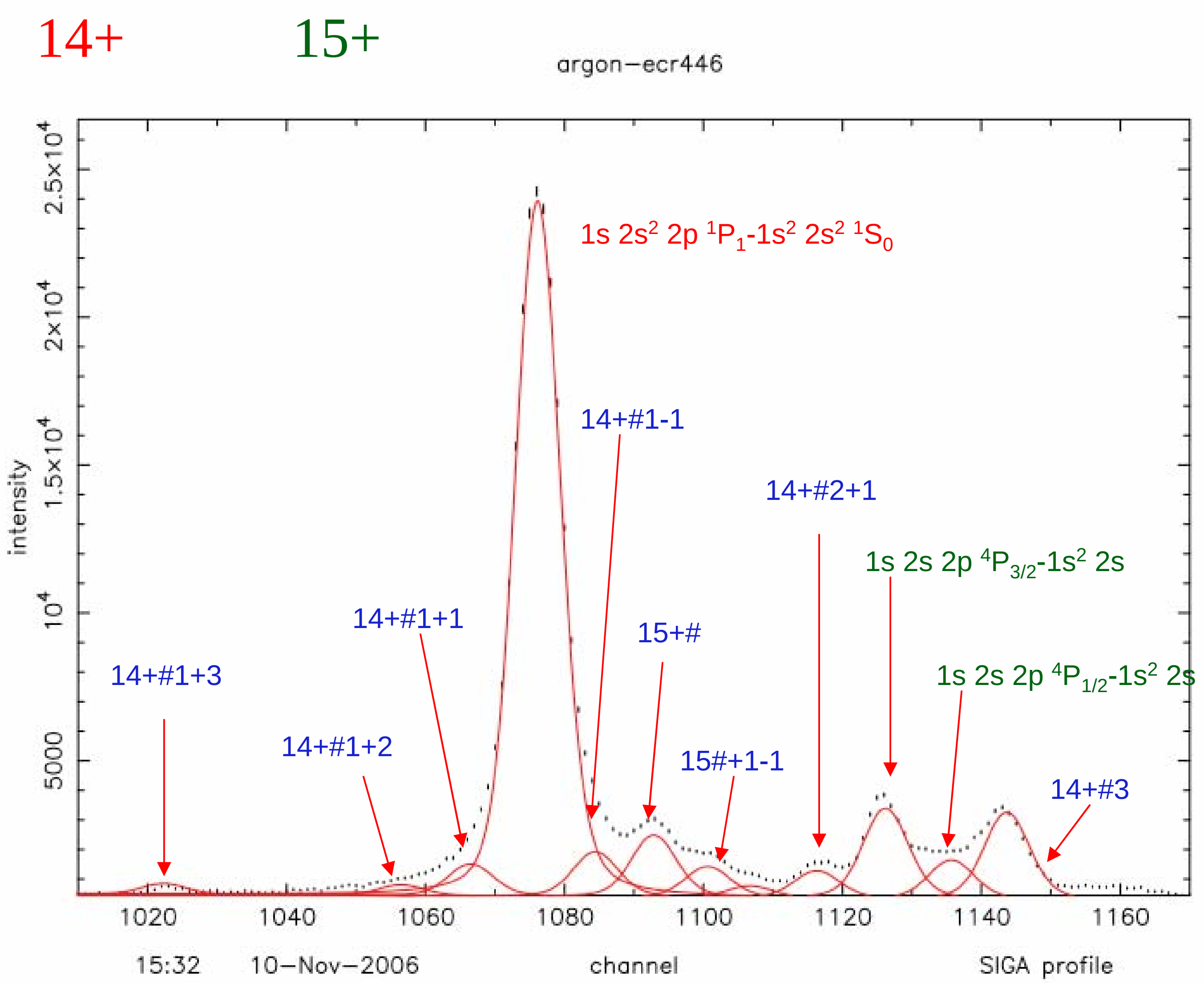
Integration time: 60 min

Injected power: 400 w

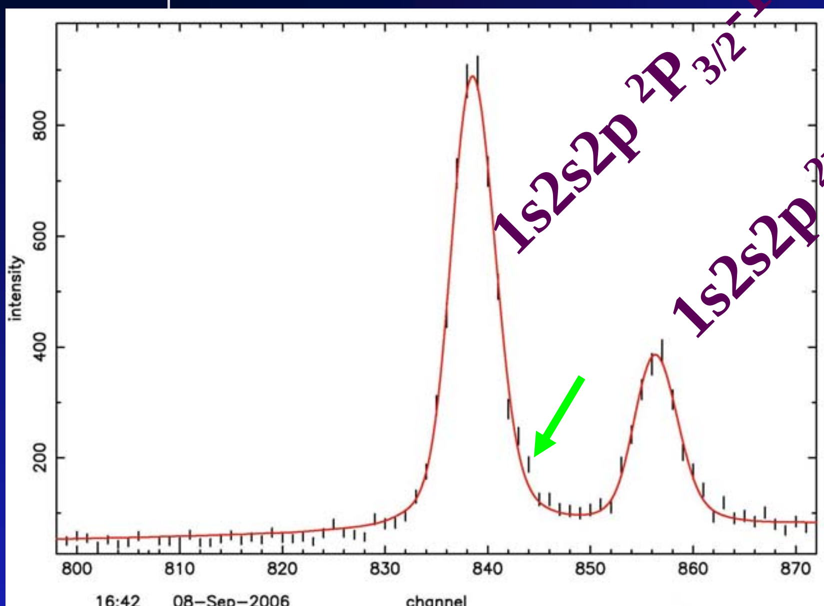
Gas pressure: 10^{-9} mbar (argon) (10.-1)

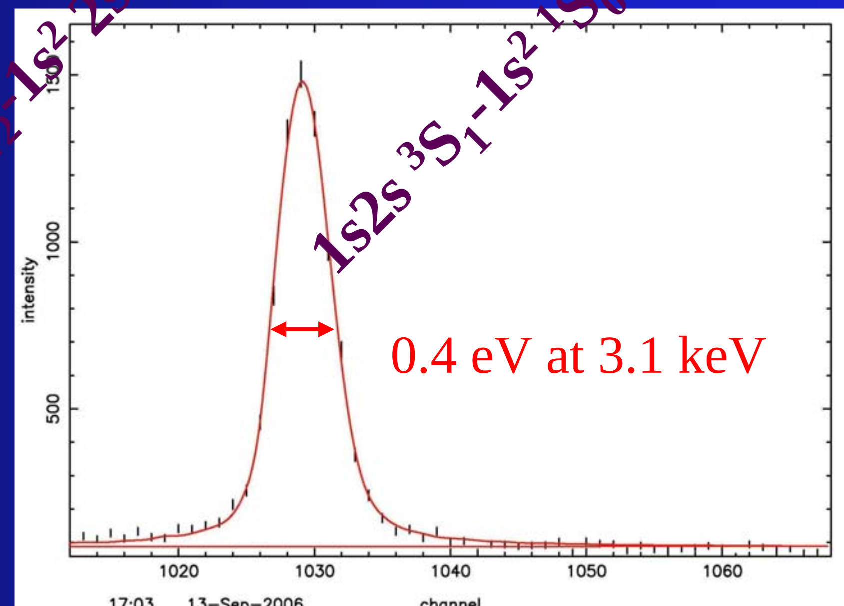
Crystal: Qz

Examples : Ar^{14+} and Ar^{15+}



Analysis with profile generated from first principles



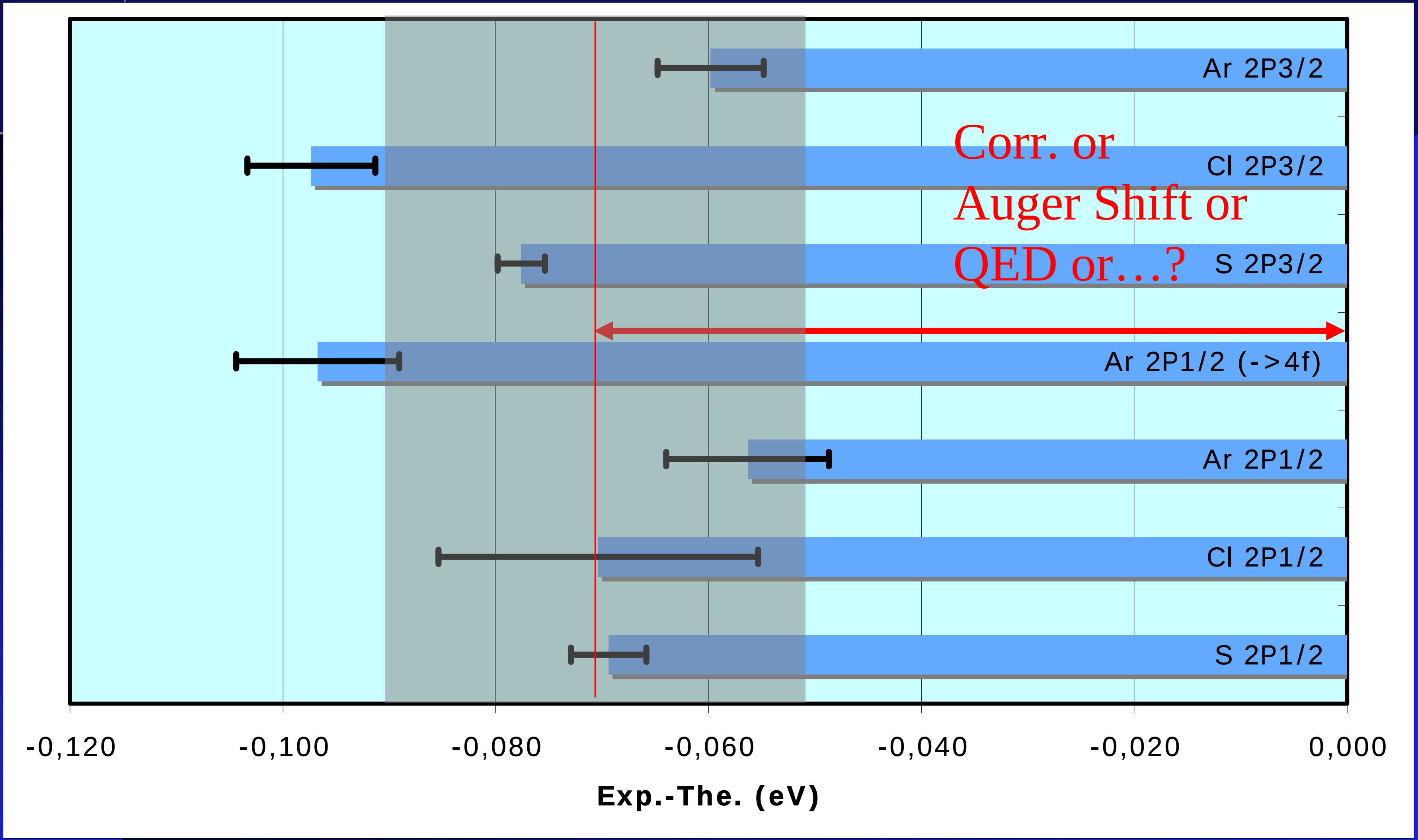


Li-like Ar
Natural width:
$^2P_{3/2}$-Radiative 66 meV Auger: 6 meV
$^2P_{1/2}$-Radiative 57 meV Auger: 65 meV

He-like Ar
Natural width 3 neV
Doppler width 40meV

We use the M1 He-like line as a reference

Comparison Theory-experiment (Li-like)



Experiment: statistical err. only

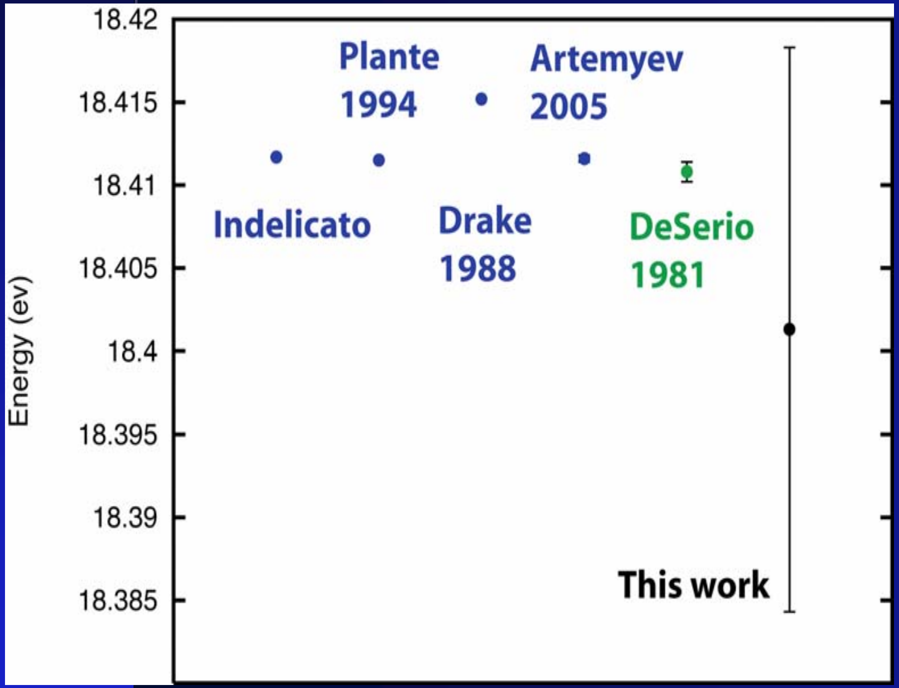
Theory correlation within (n=1 to n=2) active state except Ar $^2P_{1/2}$ (4f) (n=1 to n=4)

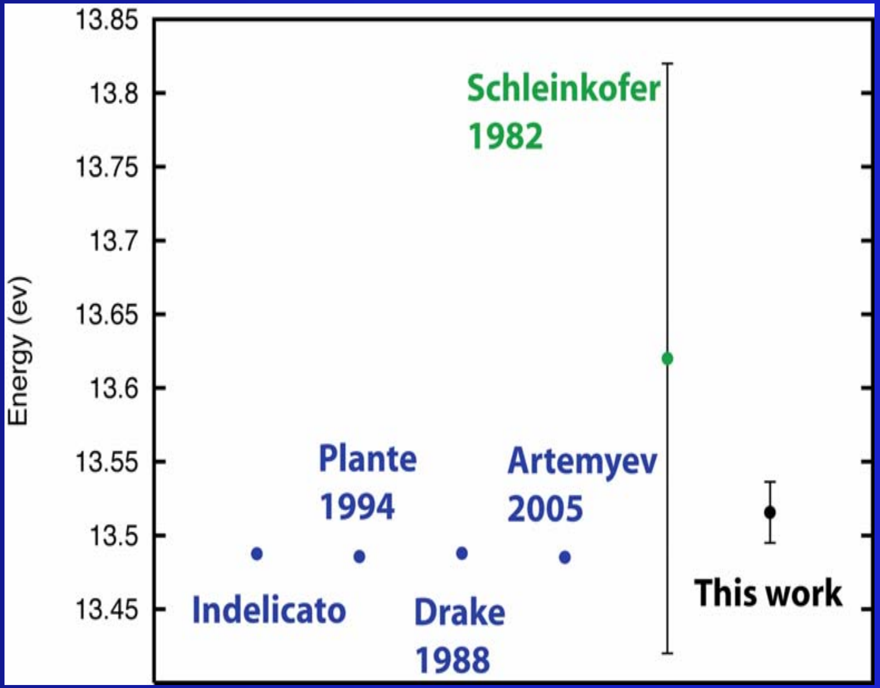
Preliminary Results for He-like Sulphur

Comparison against theory and previous experiments

1s2p $^3P_2$- 1s2s $^3S_1$ transition (preliminary)

1s2p $^1P_1$- 1s2p $^3P_1$ transition
This work: 13.483(16) eV



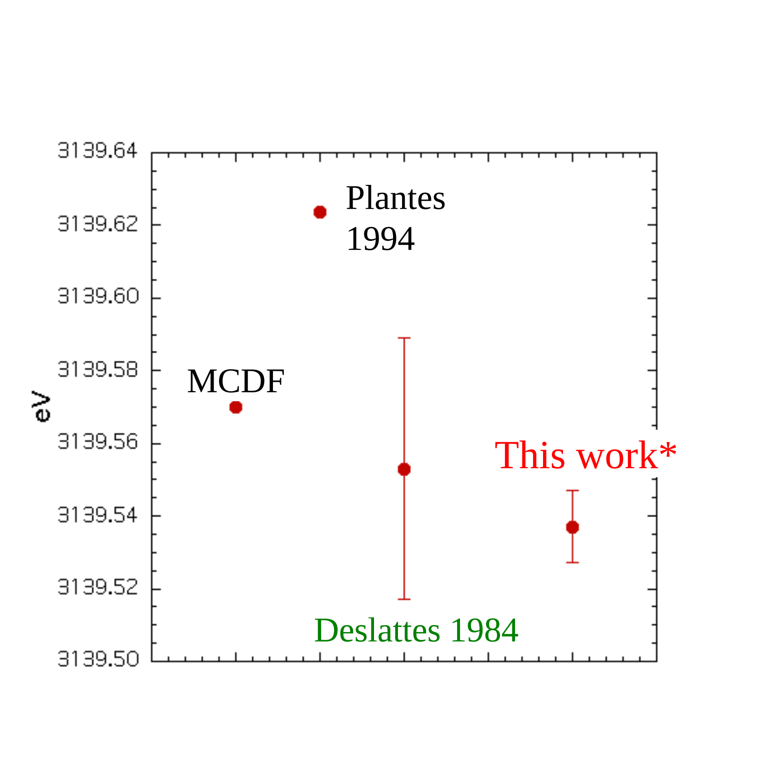


*using the MCDF theoretical value for the M1

Preliminary results for He-like Ar

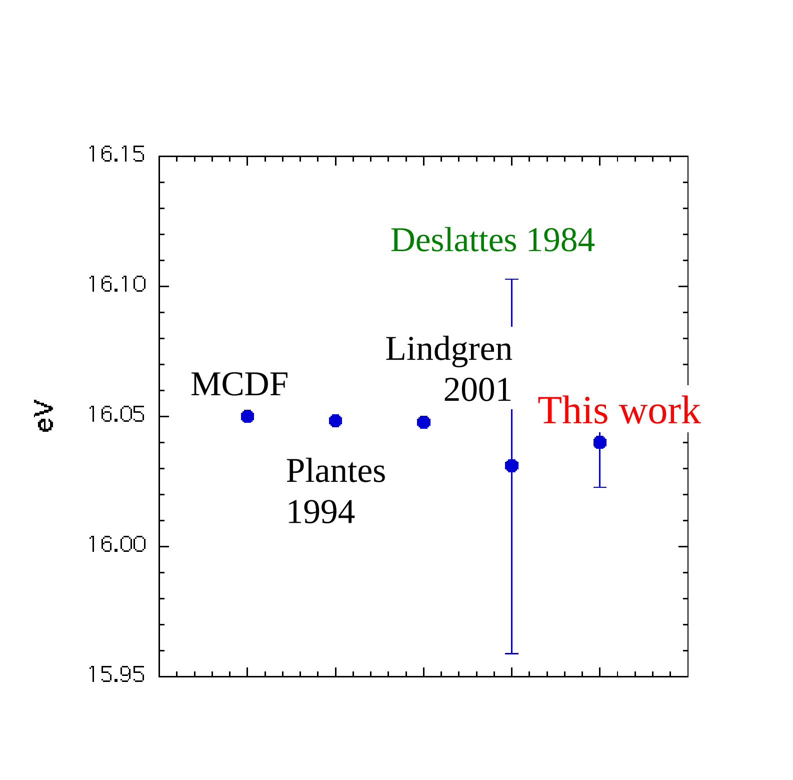
Comparison against theory and previous experiments

1s2p $^1P_1$- 1s^2 $^1S_0$ transition
This work: 3139.536(10) eV



*using the MCDF theoretical value for the M1

1s2p $^1P_1$- 1s2p $^3P_1$ transition
This work: 16.040(17) eV



X-ray energy absolute measurement

- We are building a new absolute X-ray spectrometer i.e., with no need for reference line (contract BNM-National Bureau of Metrology)

$$2d\sin(\theta_{\mathrm{Bragg}}) = k\lambda$$

Non-dispersive (Ref. Angle)

If *d* is known there is only an index of refraction correction (n~a few 10^{-5}) to the Bragg law

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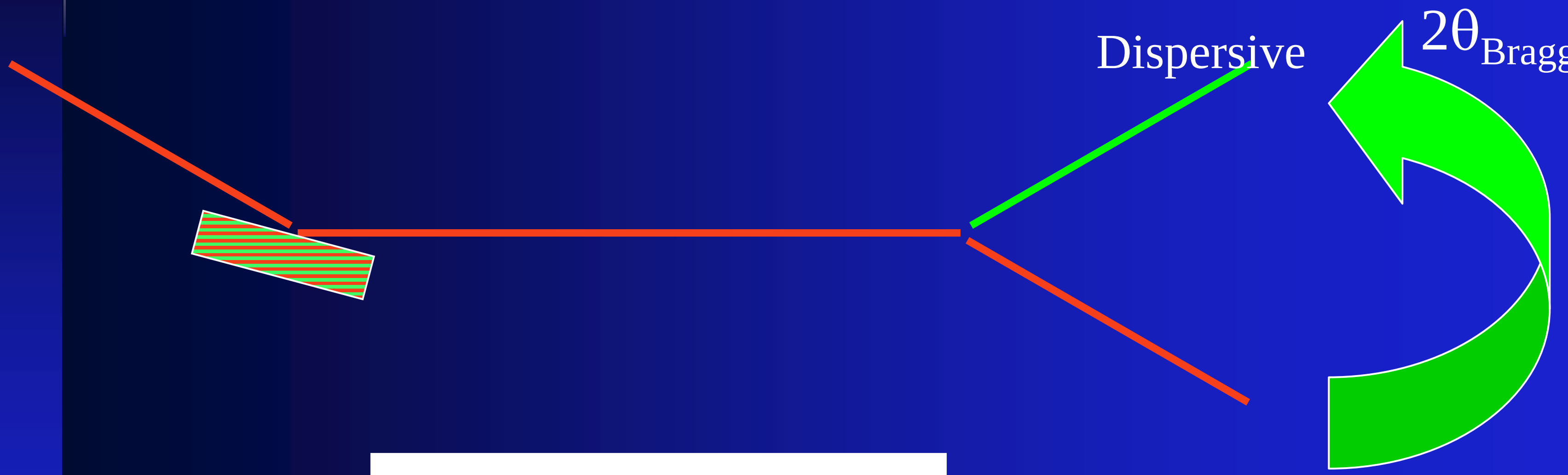

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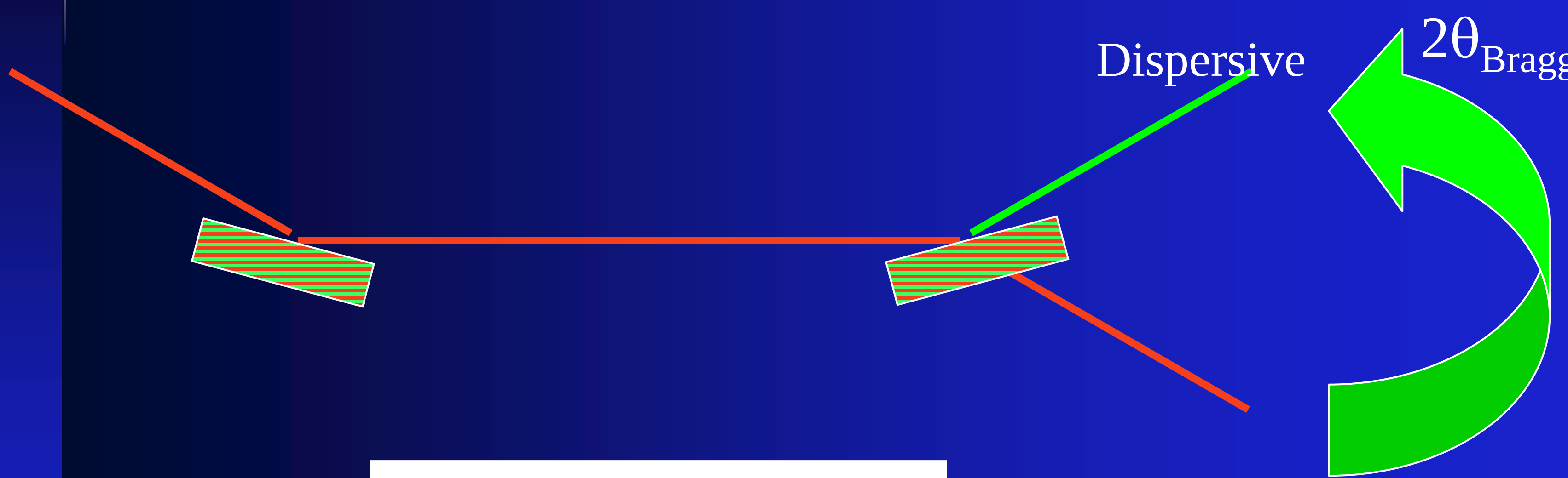

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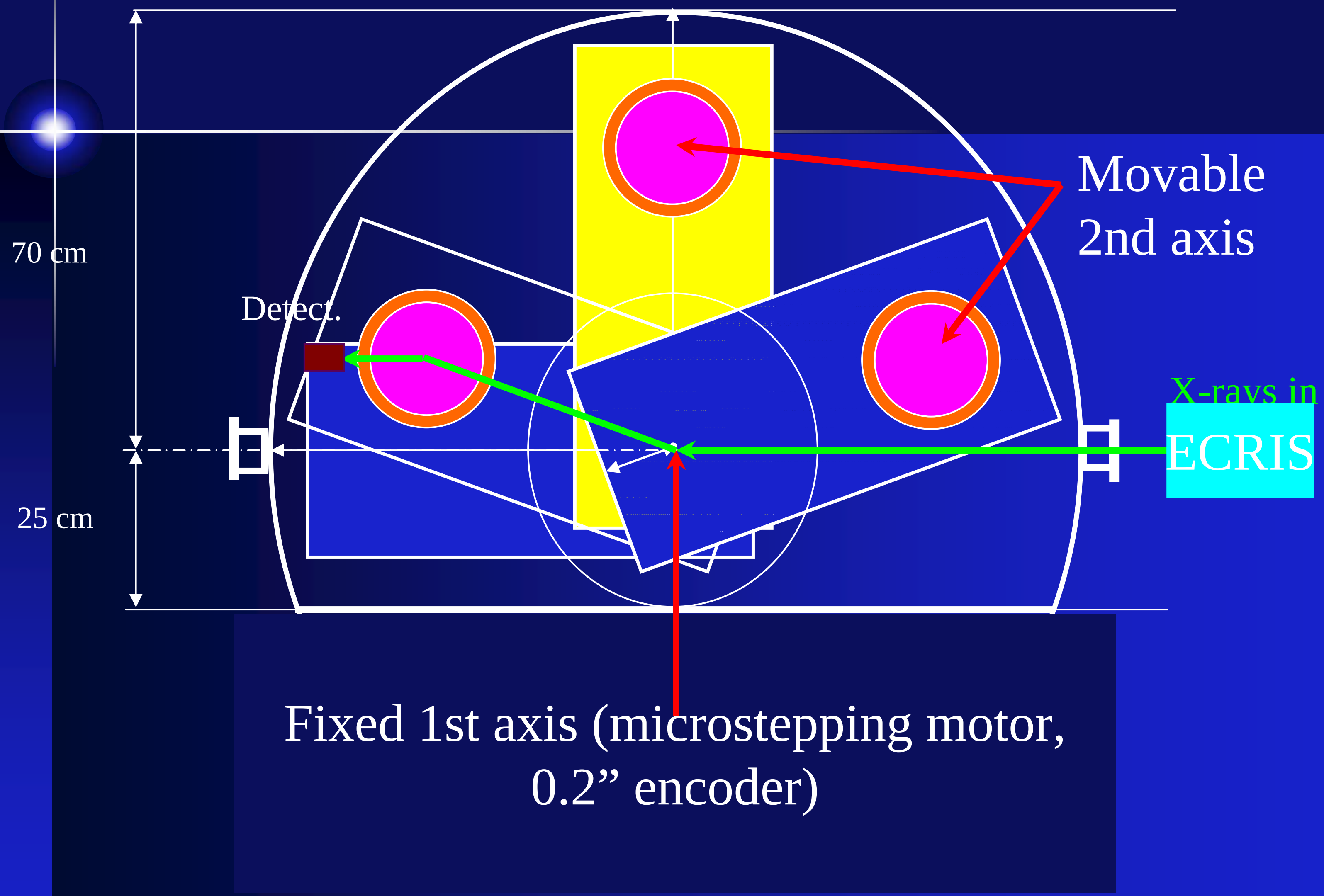
Two crystal spectrometer for a fixed source



Vacuum chamber, 900 kg+ spectrometer 300 kg

Status of the new double-flat crystal instrument

- Angular encoder accuracy 0.2”
- Angle range 15° to 65°
- Vacuum instrument
- Si 220 and Si 111 crystal pairs made and measured at NIST (< 0.1 ppm)
- Si 220: 3.6 (0.45 ppm) to 12 (3.6 ppm) keV
- Si 111: 2.2 (0.45 ppm) to 7.5 (3.6 ppm) keV

Experimental technique

- Use a portable, permanent magnet ECRIS to provide X-ray reference lines as close as possible to the line under study
- Send slow ions to a target (size can be large)
- With 10^4 ions/s one should observe ~40 counts/hour in the line (small but doable-we do not need very cold ions, a few eV total energy dispersion OK)
- Compare X-rays energies with reference (e.g., high-Z $2p_{3/2}$-2s to medium-Z 2p-1s)
- Accuracy will be mostly limited by statistic
- Ground state HFS splitting of some Li-like ions can be twice as large as the present resolution of the instrument

Conclusion and perspectives

- One can establish with high accuracy X-ray standards based on M1 transitions in He-like ions (and Li-like transitions too!)
- Even weak sources can lead to accurate measurements
- The absolute measurements are under way (SIMPA)
- Future facility SUPER-SIMPA will allow higher intensity, heavier elements…
- We can study, slow, highly charged ions starting from a few 10^4/s (not to mention antiprotonic atoms)
- We could study hollow atoms spectra with unprecedented details
- SIMPA will be used for developing and testing new asymmetric cut spherically curved crystals for even better resolution