



INSTYTUT FIZYKI JĄDROWEJ  
IM. HENRYKA NIEWODNICZAŃSKIEGO  
POLSKIEJ AKADEMII NAUK

# High Resolution Proton Induced X-Ray Emission (HR-PIXE) for Biological and Chemical Studies

Joanna Czapla-Masztafiak, Wojciech Błachucki, Rafał Fanselow  
Dept. Of Applied Spectroscopy

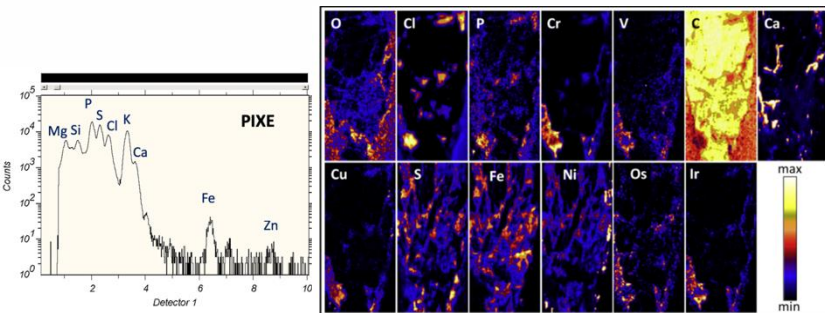


2nd Workshop on Research & Innovation in Poland  
IFJ PAN, Krakow, 26-27 May, 2026

## From elemental analysis to chemical speciation

### Conventional PIXE

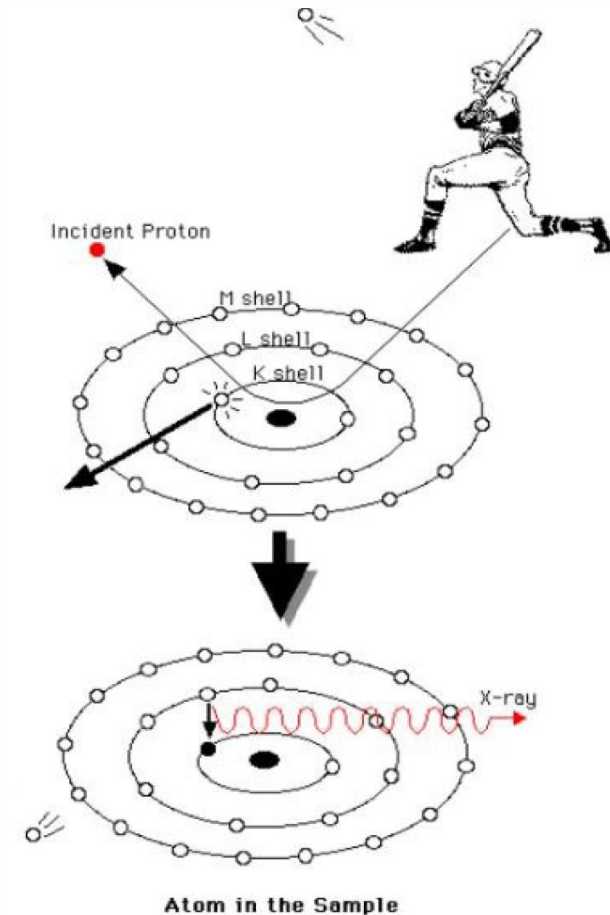
- *quantitative elemental analysis*
- *multi-element detection*
- *trace sensitivity*



PIXE is a well-established analytical technique.

**Excitation** – incident proton ejects an inner-shell electron

**X-ray emission** – an electron from an outer shell fills the vacancy, emitting a characteristic X-ray



## From elemental analysis to chemical speciation

### Conventional PIXE

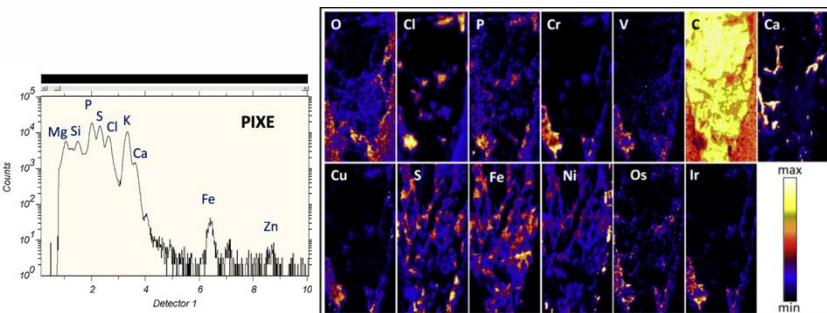
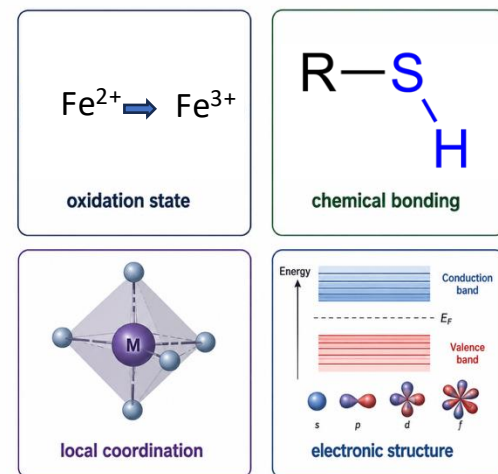
- quantitative elemental analysis
- multi-element detection
- trace sensitivity



### But concentration alone is not enough

#### Examples:

- $Fe^{2+}$  vs  $Fe^{3+}$
- sulfates vs thiols
- catalytic active sites
- metal speciation in tissues



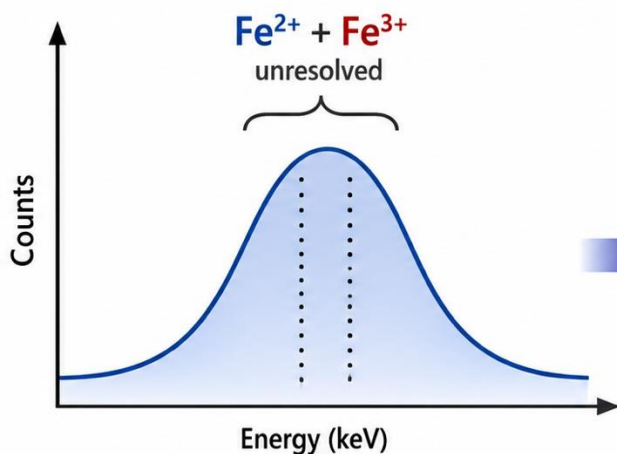
PIXE is a well-established analytical technique.

*This requires high-resolution spectroscopic methods.*

## From elemental analysis to chemical speciation

### Conventional PIXE / EDS

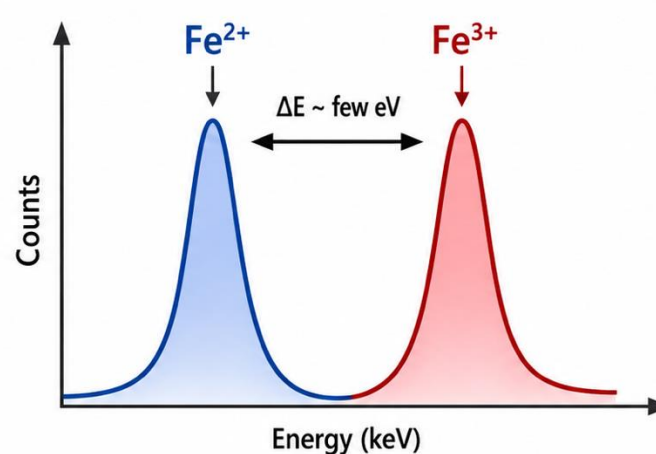
Low energy resolution



Only elemental concentration

### High-Resolution PIXE / XES

High energy resolution



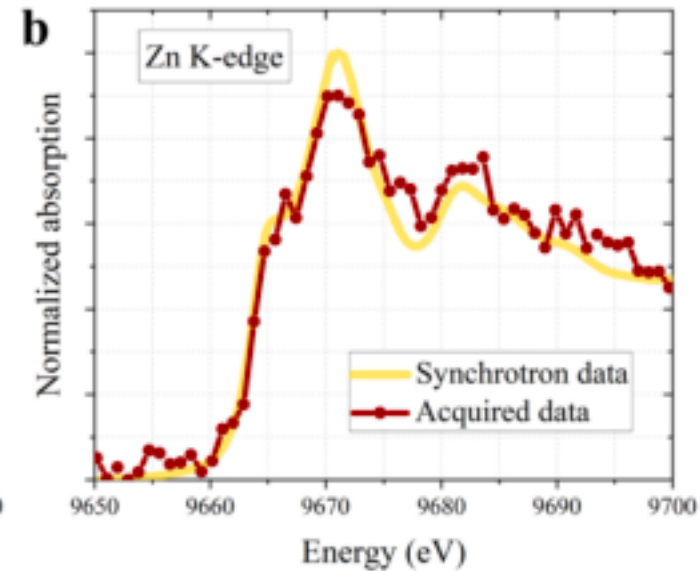
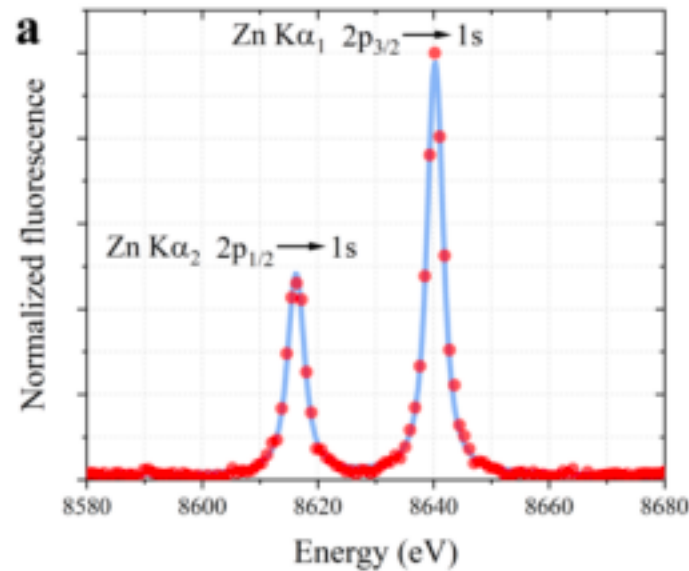
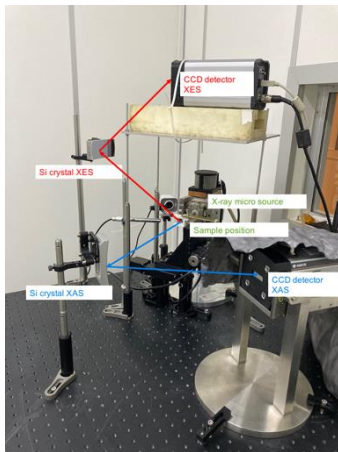
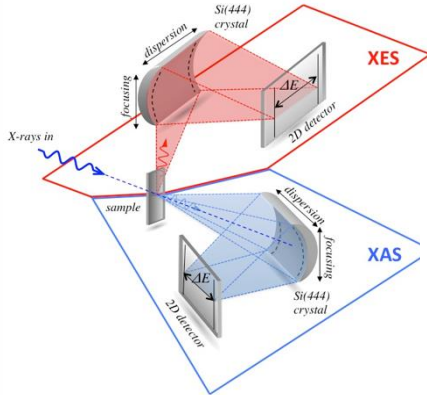
Chemical states resolved  
Oxidation state • Bonding • Local coordination

PIXE is a well-established analytical technique.

*This requires high-resolution spectroscopic methods.*

## Existing expertise at IFJ PAN

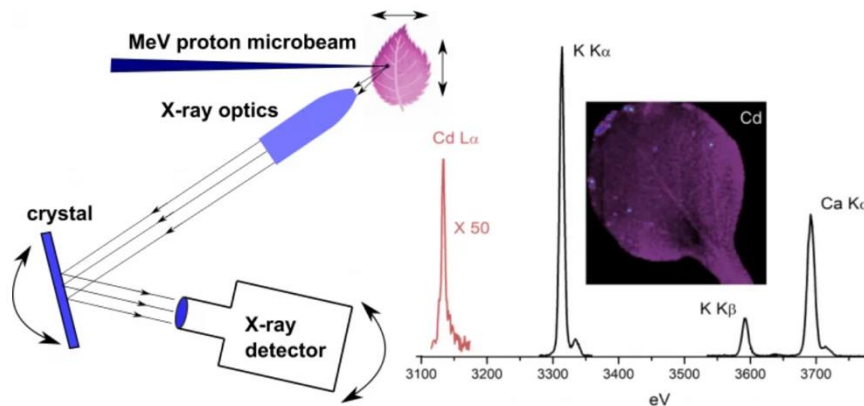
Laboratory X-ray spectrometer in Von Hamos geometry



Zn  $K\alpha$  XES (a) and Zn K-edge XAS (b) spectra of ZnO NPs.

## Proposed setup

- The proposed infrastructure would allow extension toward proton-excited tender X-ray HR-PIXE measurements
- The tender X-ray range (2–5 keV) is especially important for biologically relevant elements such as P, S and Cl.
- Potential applications include biological tissues, sulfur/iron speciation, catalysis, nanoparticles and functional materials.



Parallel-beam wavelength dispersive (PB-WDS) X-ray emission spectrometer at the Microanalytical Centre of the Jožef Stefan Institute in Ljubljana, Slovenia.

*K. Isaković et al., J. Anal. At. Spectrom., 2023,38, 1164-1172*

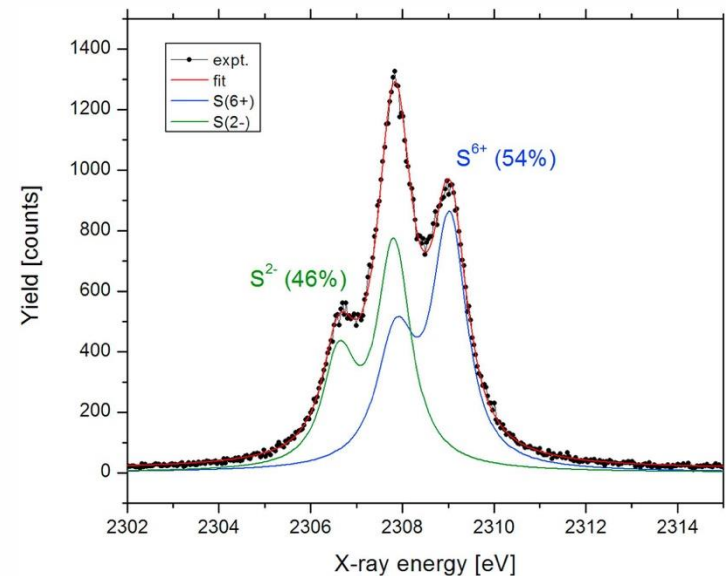
## Proposed setup

- The proposed accelerator infrastructure would allow extension toward proton-excited tender X-ray HR-PIXE measurements
- The tender X-ray range (2–5 keV) is especially important for biologically relevant elements such as P, S and Cl.
- Potential applications include biological tissues, sulfur/iron speciation, catalysis, nanoparticles and functional materials.

### Application example:

#### Sulfur speciation in mushrooms

High energy resolution proton induced  $K\alpha$  spectrum of *Boletus edulis* sample. The measured spectrum is decomposed into two components. HR-PIXE enables distinction between oxidized and reduced sulfur species. *Kavčič et al. NIMB 417 (2018)*





## Requirements

### Section 1

**Protons** with energy within **2 – 3 MeV** range

Beam current **from tens to hundreds of nA** depending on sample type

Possibility of **focused microbeam** operation



## Other requirements (detection system, infrastructure)

- High-resolution wavelength-dispersive X-ray spectrometer
- Tender X-ray optimized detector system
- Vacuum or He atmosphere operation to reduce absorption
- Possibility of coupling with microbeam setup



## SWOT analysis for the project

- **S (Strengths)**
  - Existing expertise in XES and spectroscopy
  - Combination of PIXE sensitivity with chemical-state analysis
- **W (Weaknesses)**
  - Long acquisition times for weak  $K\beta$  signals
  - Technically demanding vacuum spectrometer setup
- **O (Opportunities)**
  - Development of unique HR-PIXE capabilities in Poland
  - Complementarity to synchrotron XES/XAS techniques
- **T (Threats)**
  - Rapid development of competing synchrotron-based methods
  - Complexity of detector and optics optimization



## Conclusions

- HR-PIXE extends conventional PIXE toward chemical-state-sensitive spectroscopy.
- Tender X-ray spectroscopy enables studies of biologically relevant low-Z elements.
- Existing IFJ PAN XES experience provides a strong foundation for development.
- Proton excitation combined with high-resolution XES could become a unique research capability in Poland.
- The proposed accelerator infrastructure would open new opportunities in biological, chemical and materials research.



**Thank you for your attention!**