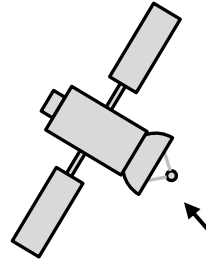
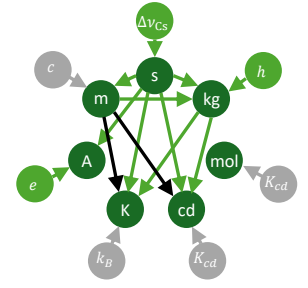


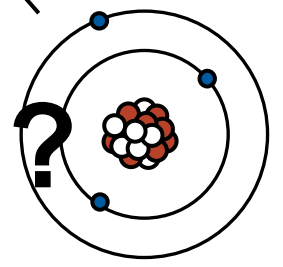
Astrophysics



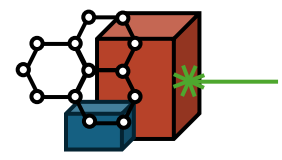
SI-Units



Structure of Ions and Atoms

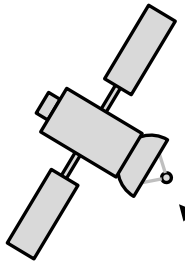


Material science
Plasma diagnostics

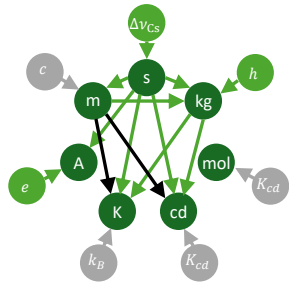


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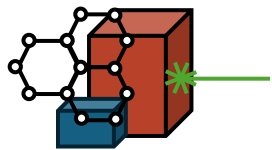
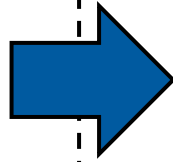
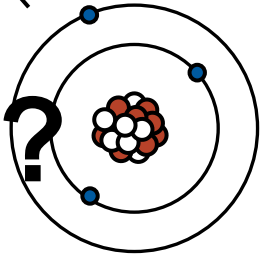
Astrophysics



SI-Units



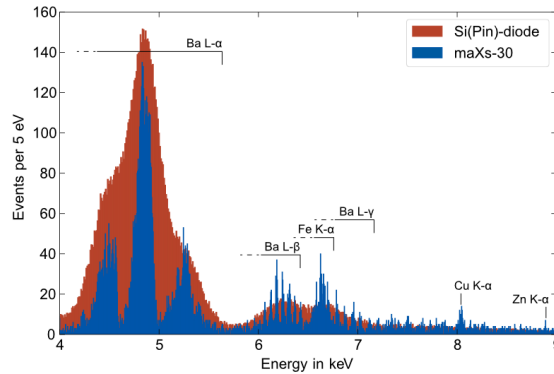
Structure of Ions and Atoms



Material science
Plasma diagnostics

Bound-state
Quantum Electro Dynamics

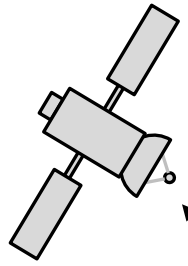
$$\propto Z^4$$



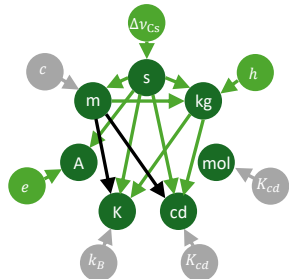
Close to Schwinger-limit
Transition ≈ 100 keV
2nd order QED ≈ 1 eV

\Rightarrow Precision

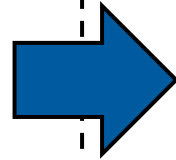
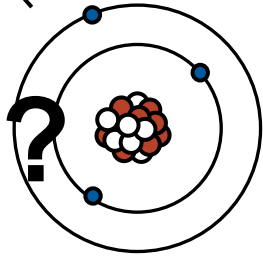
Astrophysics



SI-Units

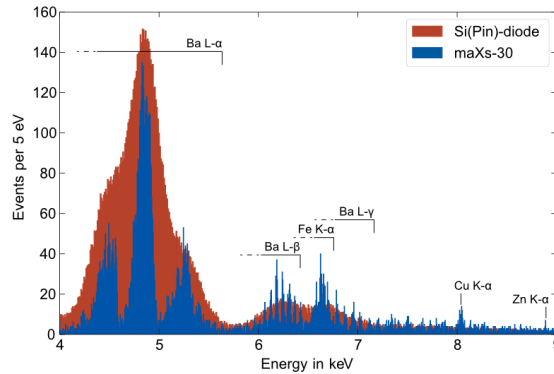


Structure of Ions and Atoms



Bound-state Quantum Electro Dynamics

$$\propto Z^4$$



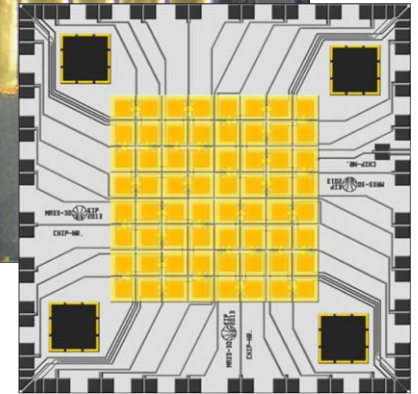
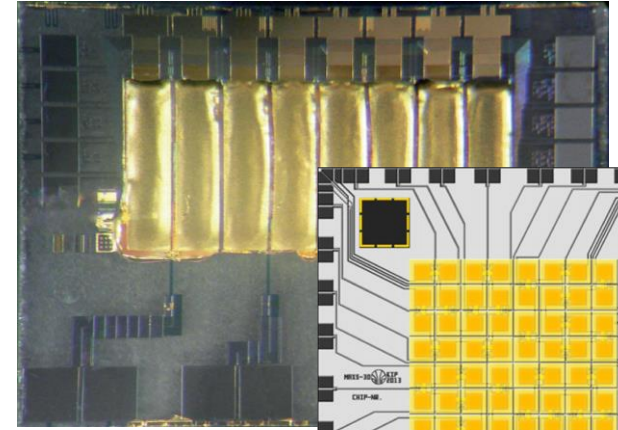
Close to Schwinger-limit
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\Rightarrow Precision

Micro-Calorimeters

» Small thermometers for measuring single particle energies «

maXs-200 (8 pixels)



maXs-30 (64 px)

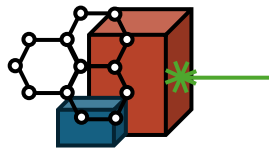
High energy resolution



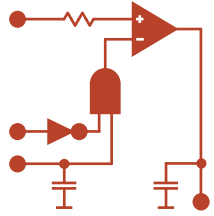
High quantum efficiency



Material science
Plasma diagnostics



High sensitivity...
... also to **noise**



Signal processing:

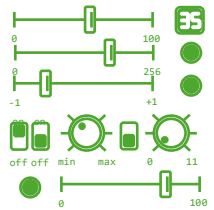
Analog



```
01 float get_e
02 {
03     uint32_t
04     for ( uin
05     {
06         float v
07         mwd_maf
```

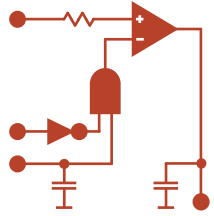
Digital

Compensate
artifacts



Optimization of many
parameters / pixel
⇒ **Future: More Pixels**
> 1000 px

High sensitivity...
... also to **noise**



Signal processing:

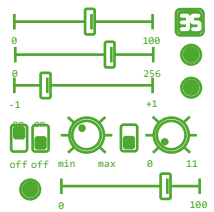
Analog



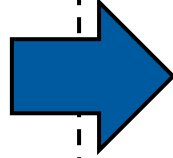
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Digital

Compensate
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parameters / pixel
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> 1000 px



Solution:
Artificial Intelligence?



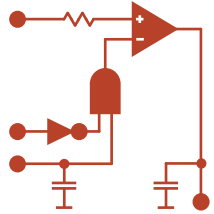
Parameter optimization
Signal characterization
1D temporal analysis

...



⇒ **Lots of potential!**

High sensitivity...
... also to noise



Signal processing:

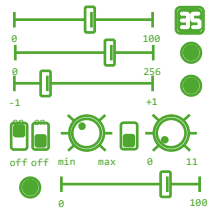
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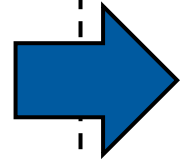


Parameter optimization
Signal characterization
1D temporal analysis

...



⇒ Lots of potential!



Utilizing Artificial Intelligence Technologies for the Enhancement of X-ray Spectroscopy with Metallic-Magnetic Calorimeters (MMC) 110

M. O. Herdrich^{1,2,3,4}, Ph. Pfäffli^{1,2,3,4}, G. Weber^{1,2,3,4}, D. Hengstler^{1,2,3,4}, A. Fleischmann^{1,2,3,4}, C. Ernst^{1,2,3,4}, and Th. Söhler^{1,2,3,4}

¹Helmholtz-Institute Jena, Jena, Germany
²Faculty for Physics and Quantum Electronics, Friedrich-Schiller-Universität Jena, Germany
³DFG Collaborative Center for Matter at Research, Jena, Germany
⁴DFG Collaborative Center for Matter at Research, Jena, Germany

What are MMCs?

Small thermometer for measuring single particle energies

Developed within SPARC collaboration: **maxS**

Why use MMCs?

Outstanding properties associated with MMCs [1,2,3]:

- Fast signal rise time up to $\tau_{90} \approx 100$ ns
- High energy resolution $\Delta E_{FWHM} = 1.6$ eV @ 6 keV
- Excellent linearity $\Delta E / E < 5.9\%$ @ 60 keV

Several successful benchmark campaigns on ion accelerators and an ion trap [4,5,6]

Measurement of K α line-splitting in U⁹² at CRYRING of FAIR [7]

Challenges of using MMCs?

However: Best performance is only achievable ... with a transition Analog ⇒ Digital signal processing

MMC is susceptible to environmental changes... vibrations, magnetic flux, etc. ⇒ corrections needed

Development of a complex signal analysis framework

- Test and improvement through experiments [8]
- Requires multitude of numerical values and hardware settings to be optimized
- Partial automation but several manual steps involved for individual pixels
- Future: From few to many pixels. ⇒ Setup 'by hand' is no longer feasible

How could AI be involved?

Hardware

- Auto-tuning of read-out SQUID electronics
- Goal: Use Feedback between operation parameters and signal quality to improve the performance ⇒ Reinforcement Learning (RL)

Software

- Simple signal characterization
- Goal: Automate the rejection of false-positives and improvement of trigger timing capabilities ⇒ Classification
- Numerical parameter optimization
- Goal: Automate and improve the optimization of the finite response filter (FIR) used for signal analysis ⇒ Reinforcement Learning
- Full signal analysis
- Train a neural network on the specific MMC detector pulse characteristics
- Goal: Extract relevant measurements directly
- Bonus: Use NN to synthesis MMC pulses for testing ⇒ 1D temporal analysis

First steps: Full signal analysis ⇒ Extraction of pulse amplitude

Setup: Synthesize MMC detector pulses with known parameters Perform RL on 1D temporal signal processing network [9]:

Use n layers of a convolutional neural network (CNN) followed by m layers of a simple perceptron ⇒ Amplitude

Under optimal conditions: FIR-filter outperforms AI in reading energy from pulses However: AI is less effected by jitter of pulse timings Next: Optimize the model

[1] S. Koenig et al., Supercond. Sci. Technol. **28** (2015)
 [2] C. Ernst et al., J. Low Temp. Phys. **187**, 203 (2015)
 [3] A. Fleischmann et al., Thin. Appl. Phys. **99** (2005)
 [4] M. O. Herdrich et al., Phys. Rev. Lett. **112** (2014)
 [5] M. O. Herdrich et al., Eur. Phys. J. D **17**, 225 (2014)
 [6] M. O. Herdrich et al., Phys. Rev. B **89**, 080401 (2014)
 [7] Ph. Pfäffli et al., Phys. Rev. Lett. **110**, 014801 (2013)
 [8] M. O. Herdrich et al., Thin. Appl. Phys. **99** (2005)
 [9] S. Koenig et al., ICAASP 2013, 8360 (2013)

SPARC GSI Thuringen ESF HI JENA
 European AI for Fundamental Physics Conference (EuAIFP) 2024

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