Machine learning methods for mass and lifetime measurements of unstable isotopic and isomeric states in storage rings

Shahab Sanjari
GSI Darmstadt

GSI/FAIR AI Workshop
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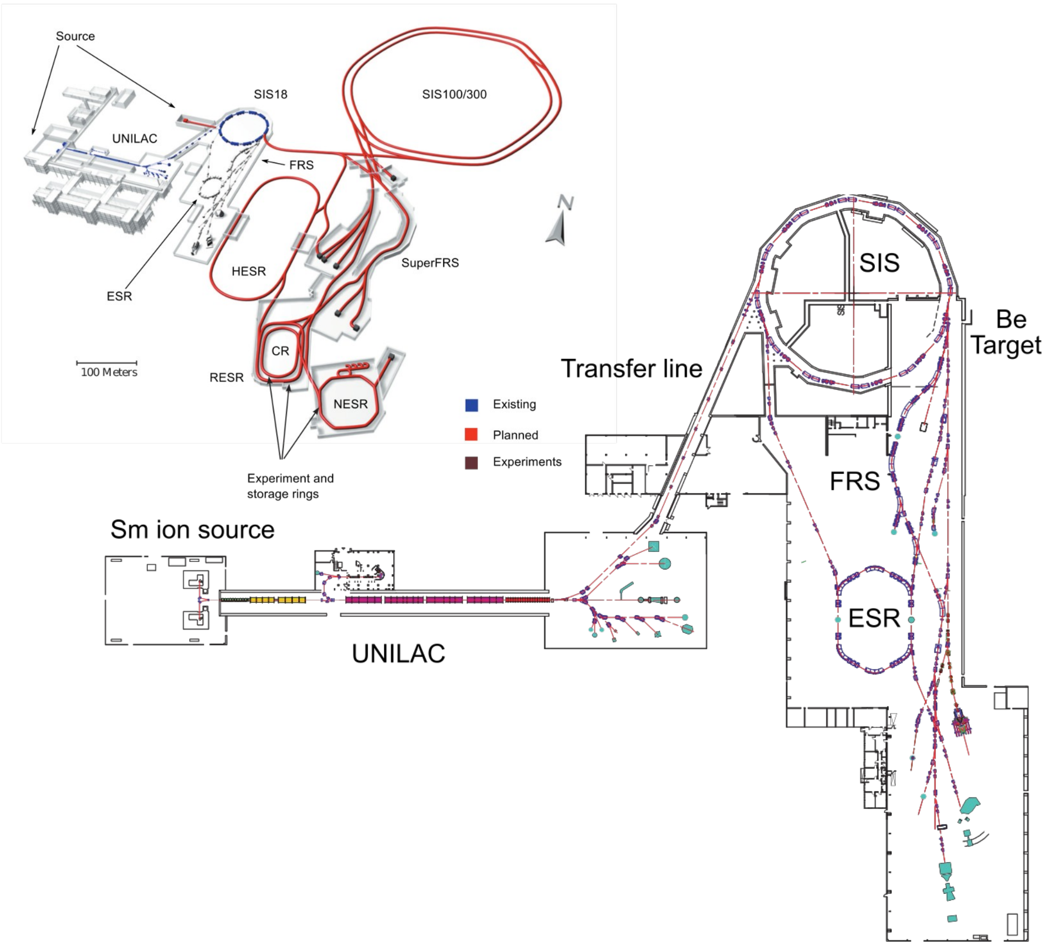
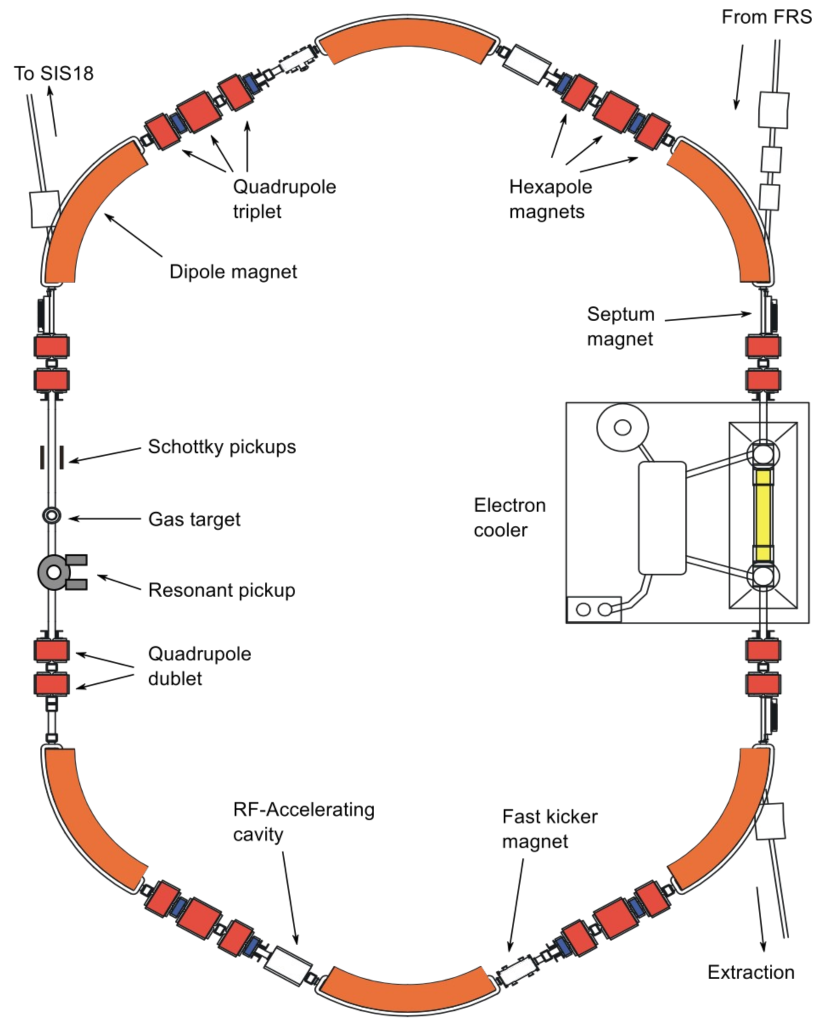
Schottky detectors @ GSI

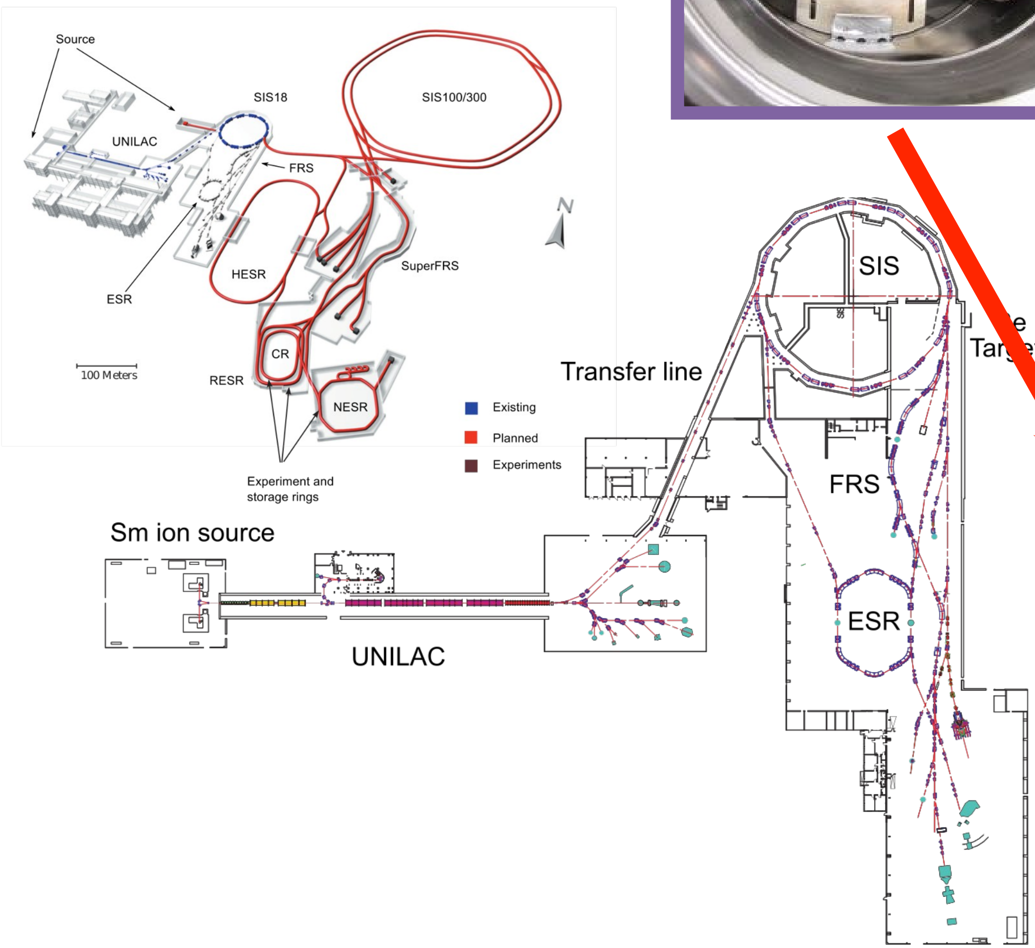


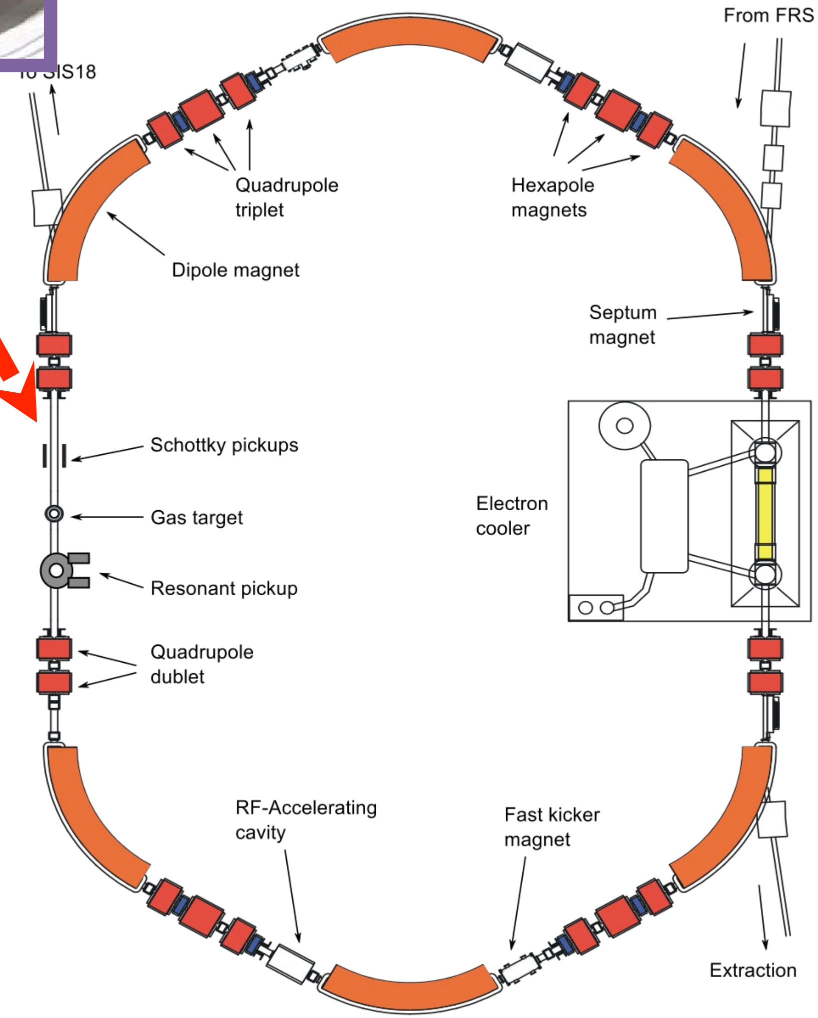


Schottky detectors

B. Schlitt, PhD Thesis 1997

60 MHz





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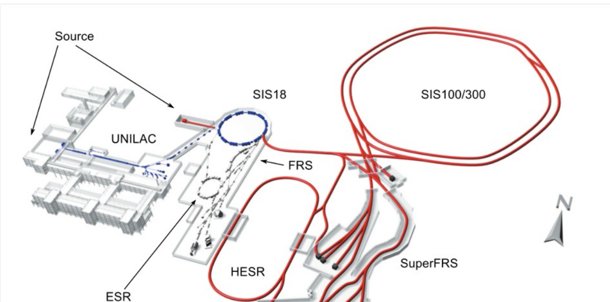
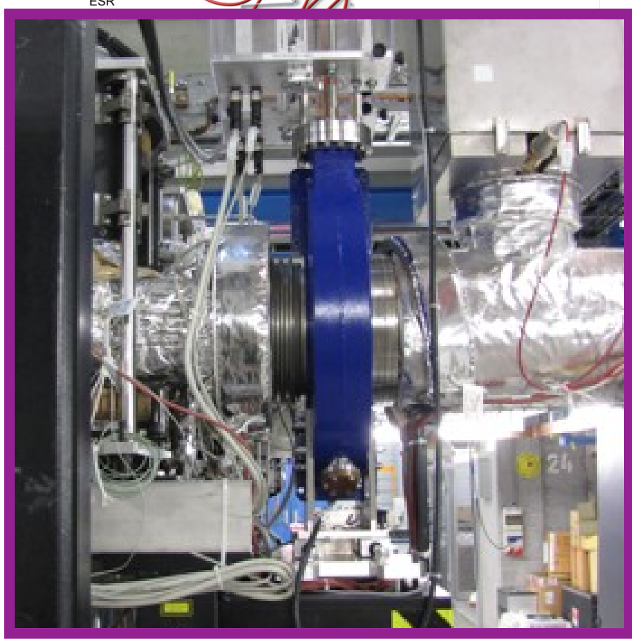
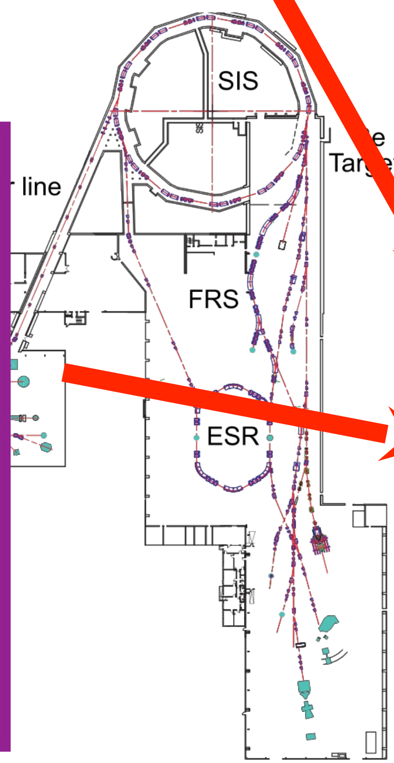
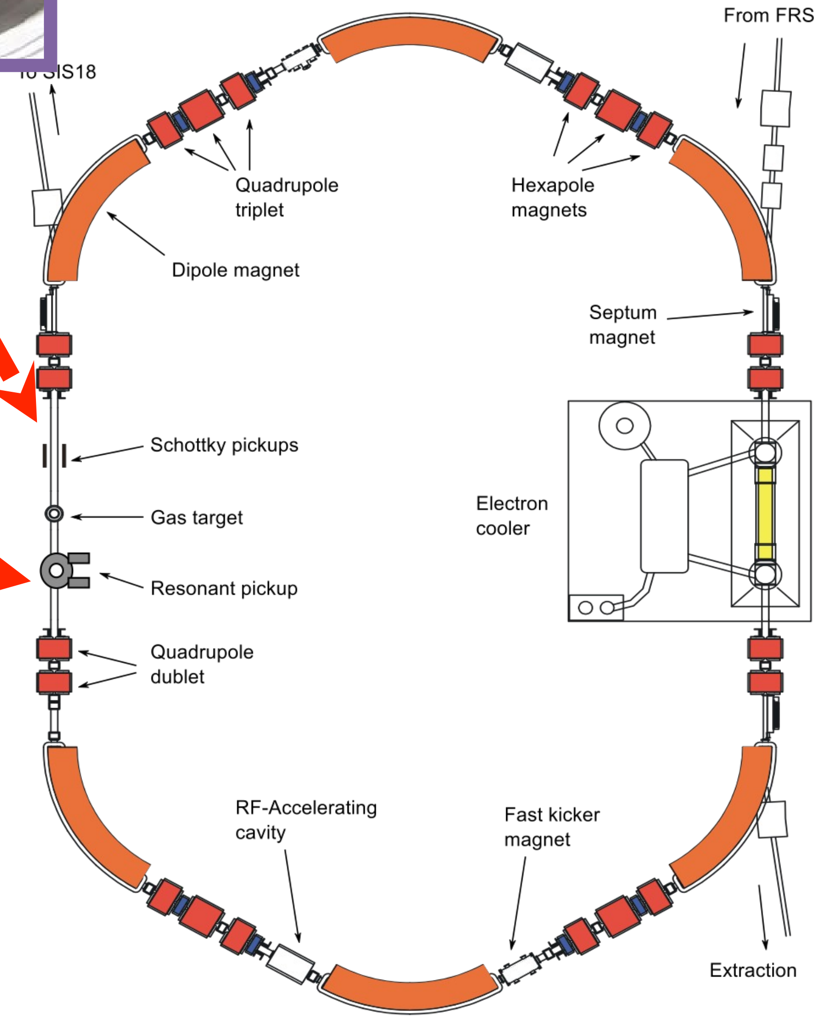




245 MHz





Sanjari et. al. Phys. Scr. 014088 (2013)

Nolden et. al. NIM-A 659-1 (2011)

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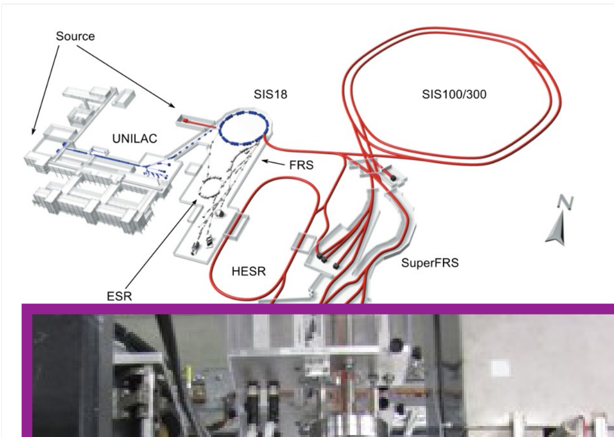

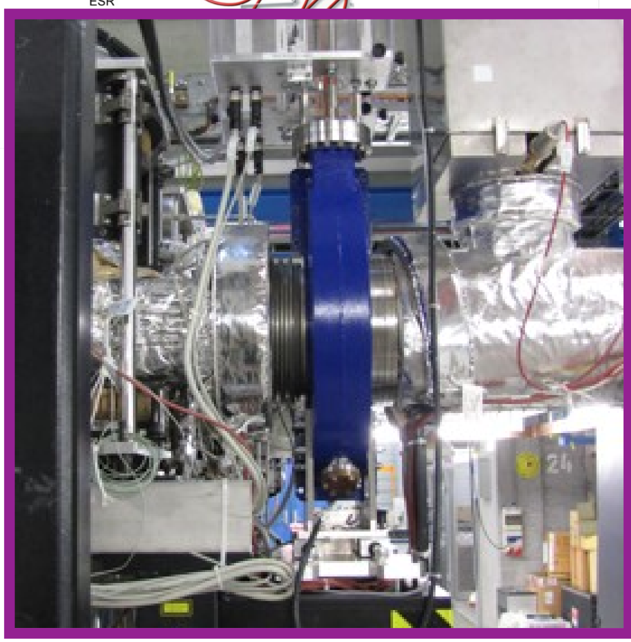

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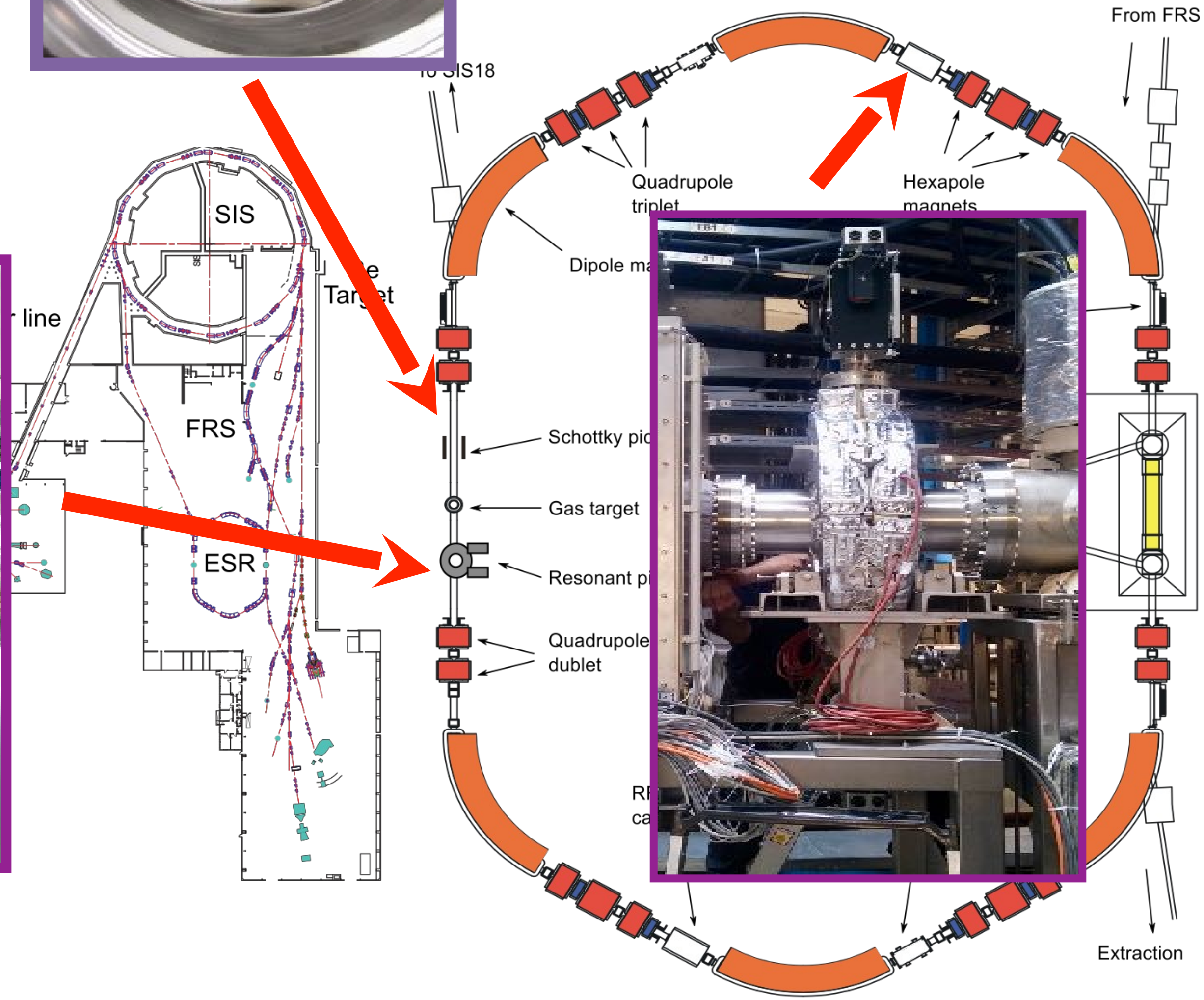


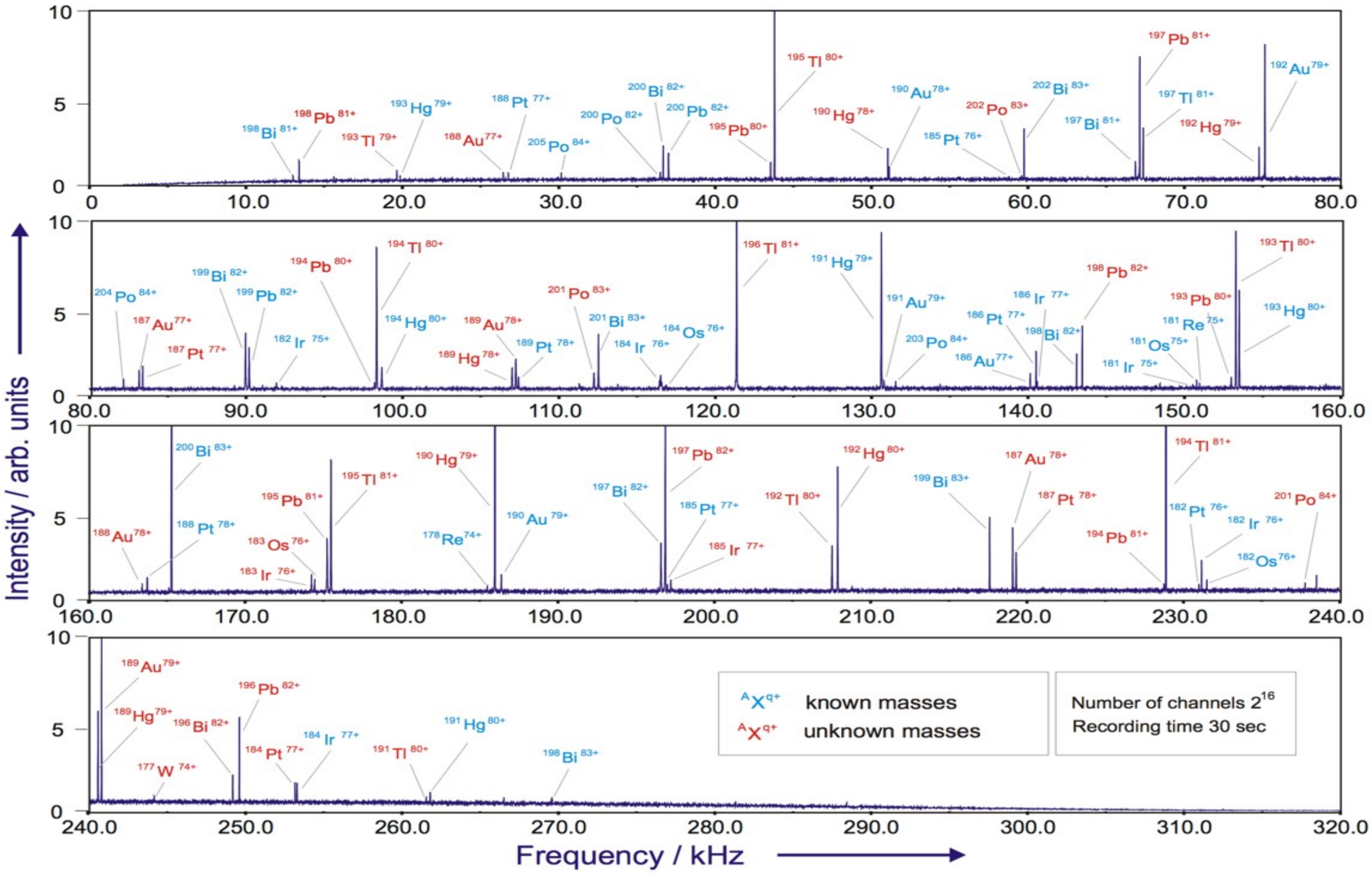
Sanjari et. al. Phys. Scr. 014088 (2013)

Nolden et. al. NIM-A 659-1 (2011)

Sanjari et. al. Rev. Sci. Inst. 91(8), pp. 083303 (2020)

410 MHz

SMS: broadband mass measurement example



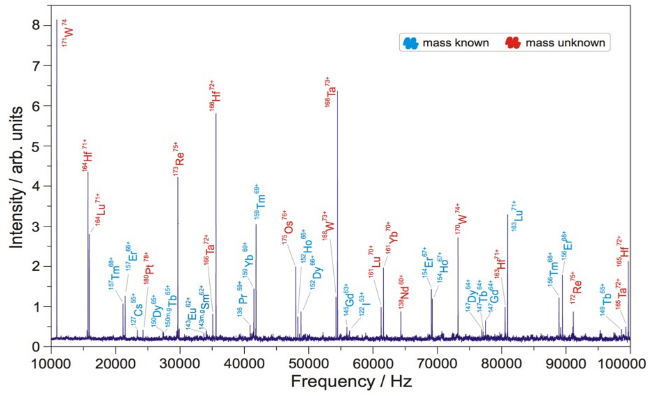
Bosch F., Litvinov Yu. A. Int. J. Mass Spec. V349-350, (2013)

ML for Particle Identification (PID)

- Methods up to now:
  - Manual
  - Semi-automatic (Simulation based, manual correction
    - Python Library **RionID**)
- Goal is to have ML based PID
- Challenges of particle identification PID
  - Different spectral resolution possible
  - Spectral overlap of different harmonics
  - Presence of artifacts
  - The presence of interesting stuff! (that is unknown or unstable peaks!)

ML for Particle Identification (PID)

- **NuClident** Code
  - Use of higher-level APIs for TensorFlow:
  - Simple multi-layered CNN and one-hot matrix
  - Trained on Atomic Mass Evaluation Data (AME)
    - m/q ratio in three different charge states
    - Calculation of simulated frequencies and Δf
    - Using CUDA on 4 GPUs (Tesla K80, Kepler architecture, no tensor cores)
    - Training several hours, use of HDF5

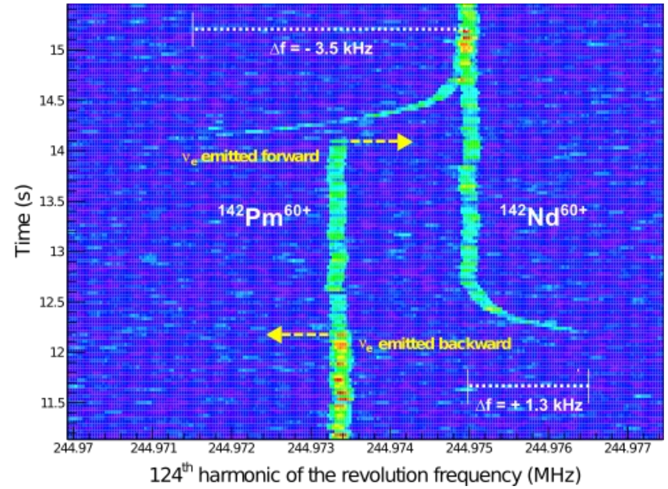


- Results:
  - Perfect match in narrow band regions!
  - Broadband results are bad → needs physics informed model for storage ring (correction for orbital path lengths)

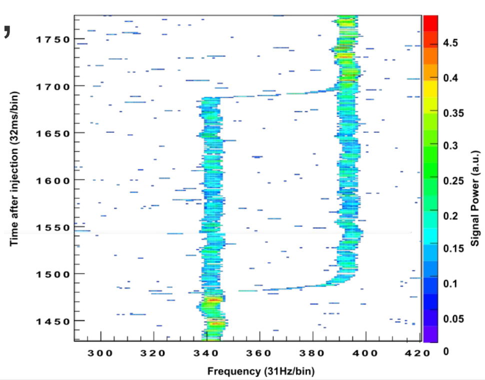
ML for lifetime measurements

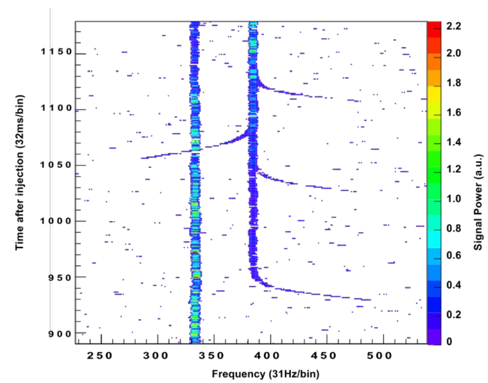
- Unlike mas measurement only possible using non-destructive detectors:
  - Time resolved Fourier analysis
- Challenges:
  - Noise, artifacts, combination of PID etc..
  - Different spectral settings (resolution, amplitude cuts, etc.)

$$^{142}_{61}\mathrm{Pm}^{60+} \longrightarrow {}^{142}_{60}\mathrm{Nd}^{60+} + \nu_e$$



Kienle, Bosch et. al., Phys. Lett. B 726 (2013) 4–5, p.638



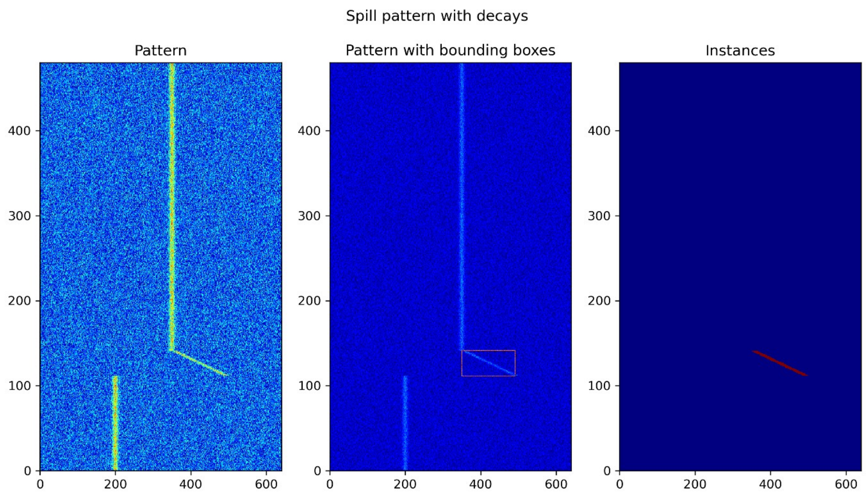


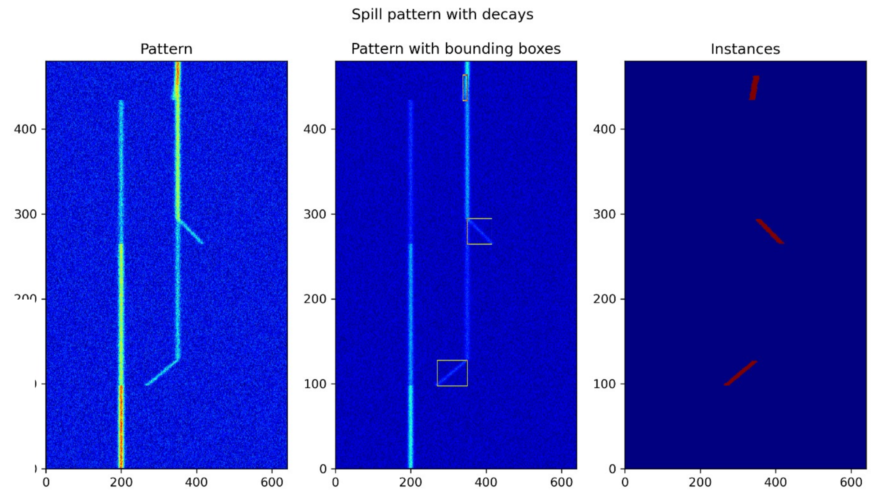
ML for Lifetime measurements

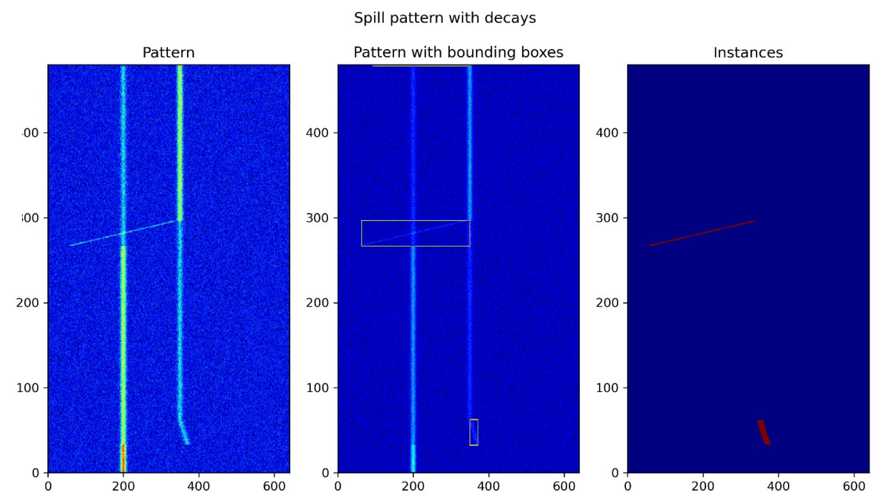
- **DecayDent** Code
  - Use of image detection frameworks
    - NnDetection (originally from medical applications)
    - MmDetection
  - Conversion of measurement data to NIFTII format
  - Creation of tagged training datasets
  - Use of HDF5 file format
- Challenges:
  - No electron cooler tails, (IMS method), amplitude variation, etc.
- Work in progress:
  - Physics informed (use of phase information)

ML for Lifetime measurements

- Tagged training data set

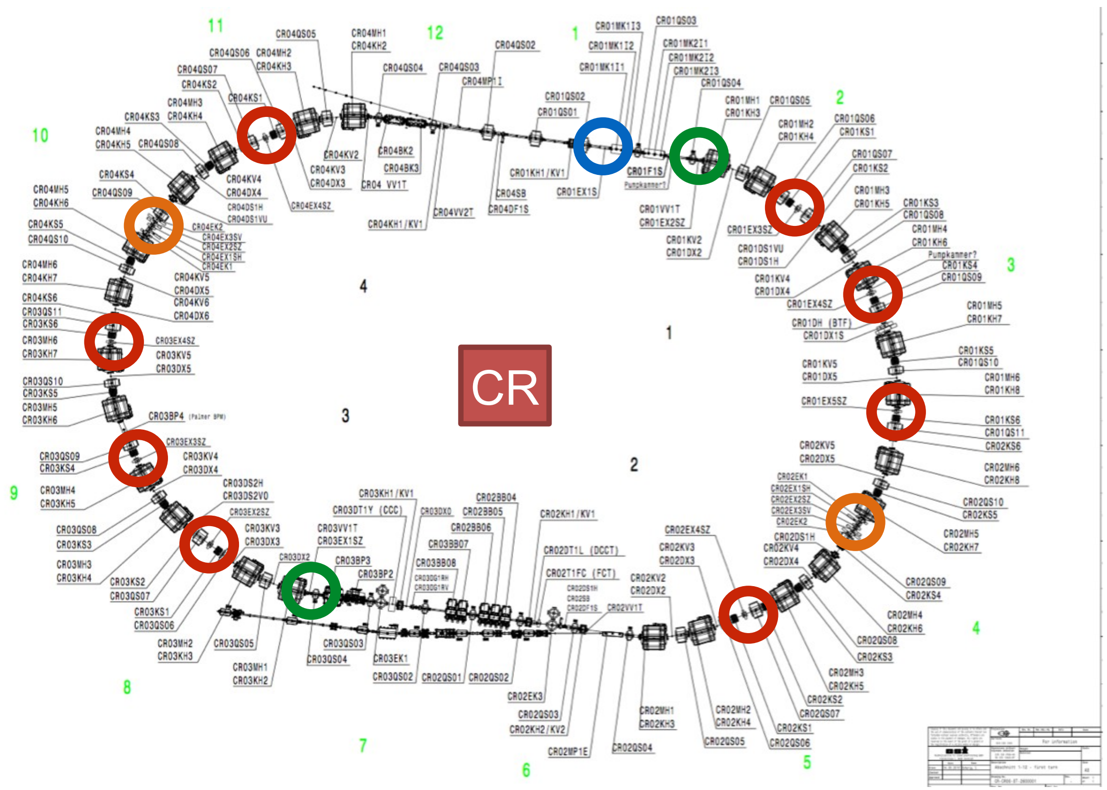






Future plans

- Future detection methods based on many detectors need use ML

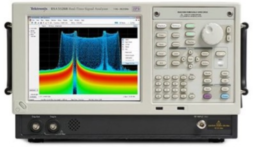


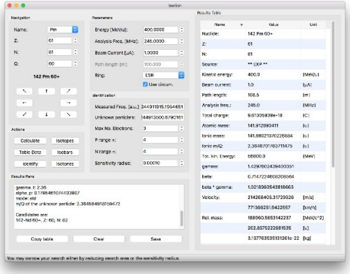
Possible Schottky detector locations in future Collector Ring (CR) @ FAIR

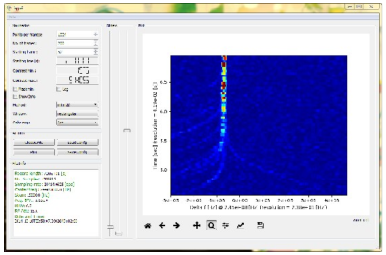
Data acquisition and analysis

Fork me on GitHub

- Moving away from commercial solutions:
  - Spectrum analyzers
  - Long term time capture device NTCAP (C. Trageser, PhD Thesis, 2018)
- Towards open hardware open source:
  - GNURadio based Software Defined Radios
  - Scalability, easy maintenance
- Analysis code published on GitHUB
  - Python (+ROOT) based framework
  - IQTools / IQGUI (for different DAQs)
  - Barion (Ion calculations)
  - RionID (D. Freire-Fernandez et. al.)
  - Other recent tools for identification / mass measurement
- Use of HPC and ML is inevitable for future







GSI Green IT Cube

R. Steinhagen, A. Krimm et. al. @ GSI

D. Dmytriiev et al 2020 J. Phys.: Conf. Ser. 1668 012014

Thank you!