Tailored Excitation Signals for RFKO

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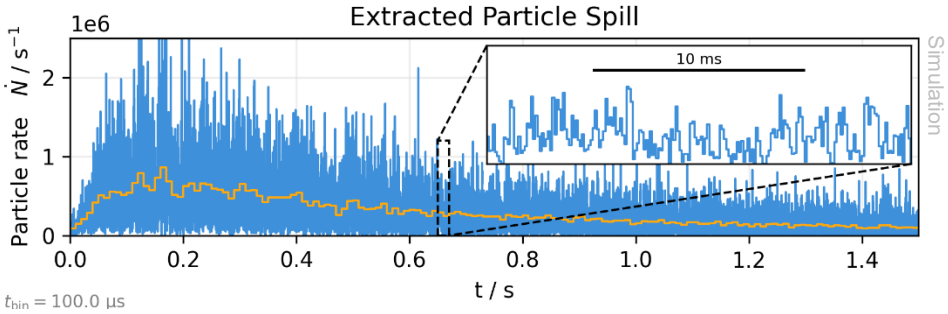
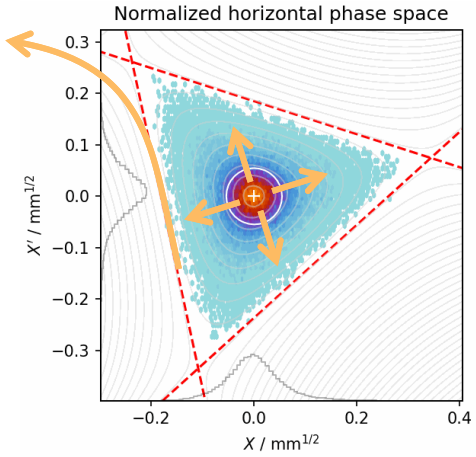
Bild: D. Fehrenz, GSI/FAIR 2023

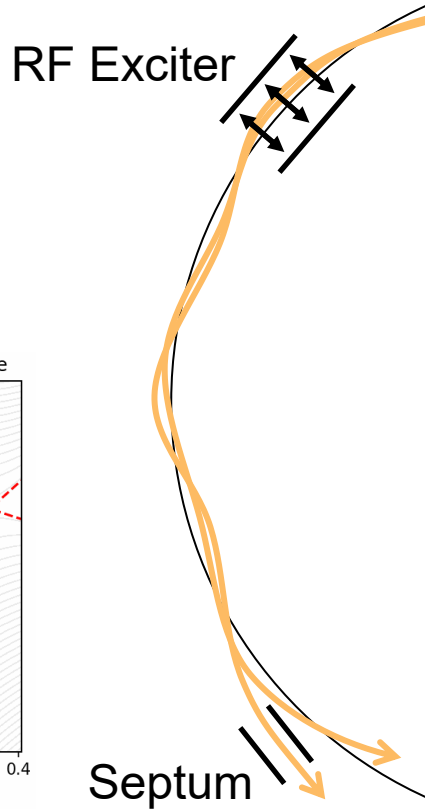
RFKO Slow Extraction

- Sextupole driven 3rd order resonance
- Transverse excitation to control particle amplitude
- Particles become unstable and are extracted → Spill

► **Excitation signal controls spill**

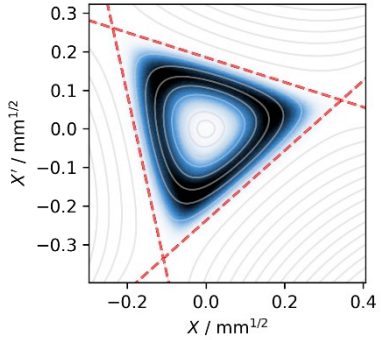






Outline

- What properties of the excitation signal make for a good spill?
  - Macro-spill (above ms) → **Control** amplitude with feedback → Talks by R. Singh & C. Schömers
  - Micro-spill (below ms) → **Optimize** excitation waveform



- Simulations
  - Particle dynamics for coherent excitation

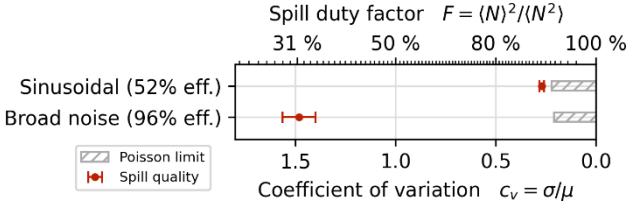
- Experimental Comparison
  - Software-Defined Radio

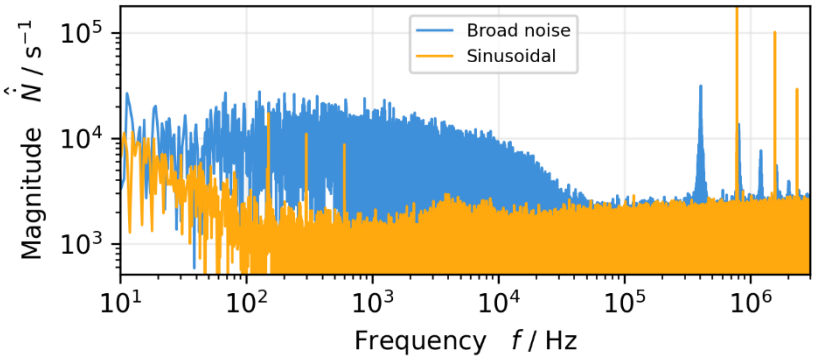
Particle Dynamics Simulations

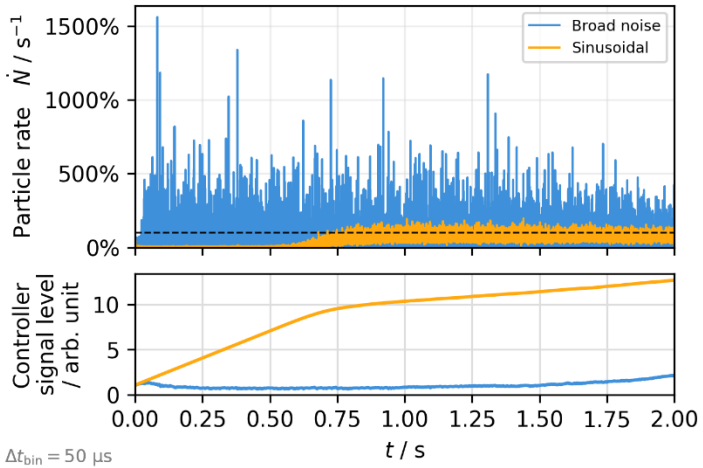
Xsuite

Tracking Simulations with Xsuite

- Sinusoidal excitation
  - Poisson spill quality even for coasting beam
  - Bad extraction efficiency and high power demand
    - → Broadband signals are used
    - → Drastically diminishes spill quality



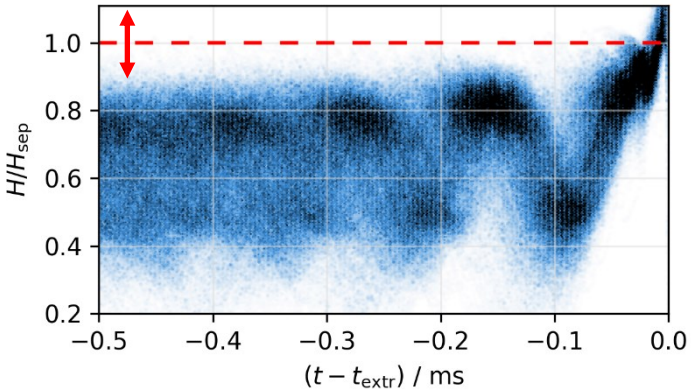


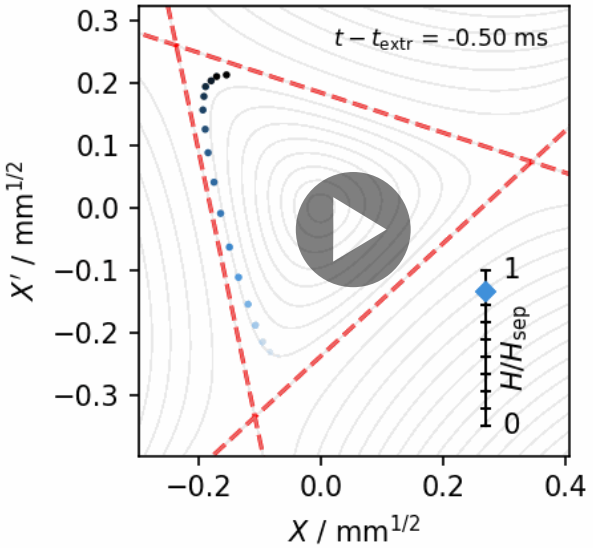


Tracking Simulations with Xsuite

- Dynamics under sinusoidal excitation
  - Strong coherent excitation
  - Periodic in- and decrease of Hamiltonian
  - Fast crossing of separatrix

➔ Reduces effect of ripples

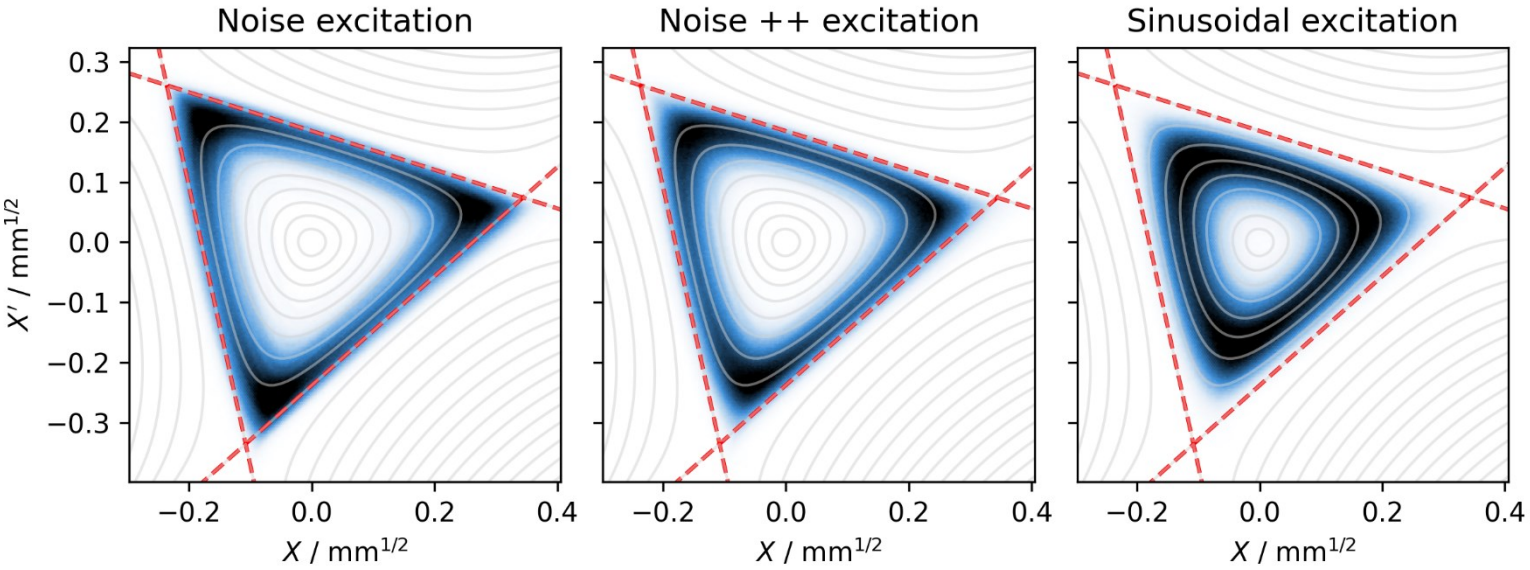




Tracking Simulations with Xsuite

- Noise and sinusoidal excitation

  → Combination “Noise ++”

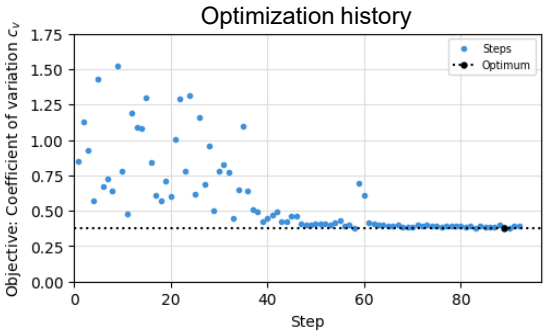


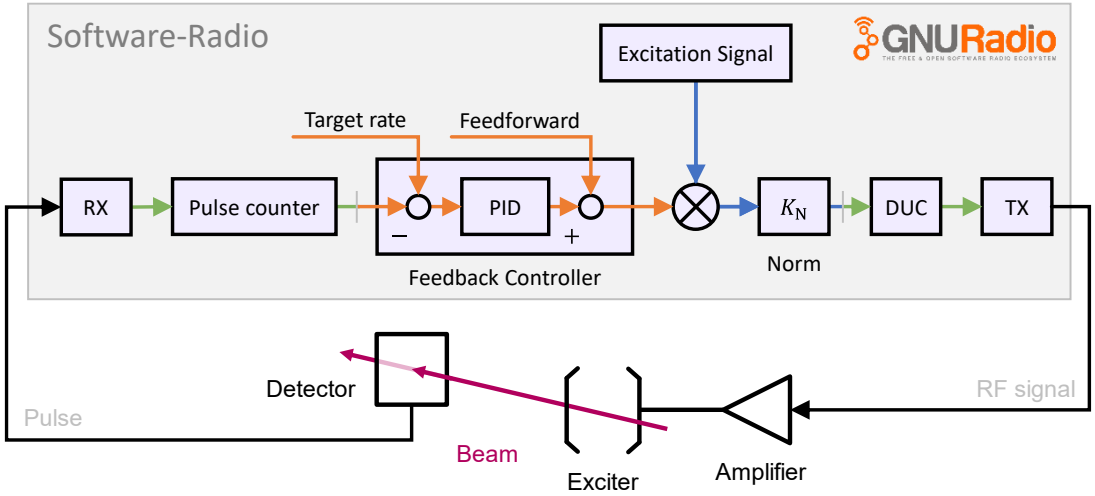
Normalized phase space distribution of 1900 particles in their respective last 10 ms before extraction

Experimental Comparison

Experimental Setup at COSY Jülich

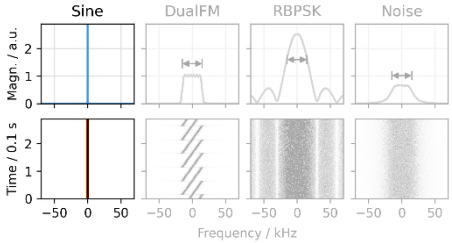
- Coasting p-beam at 1 GeV/c
- Software-defined radio
  - Generates excitation signal
  - Feedback on detector signal
  - Automatic optimisation of signal parameters with PyBOBYQA

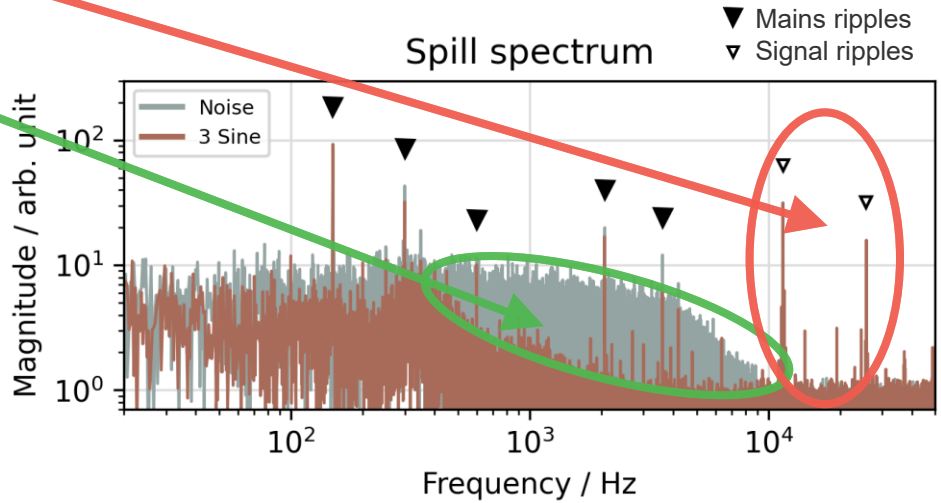




Experiment: Sinusoidal Excitation

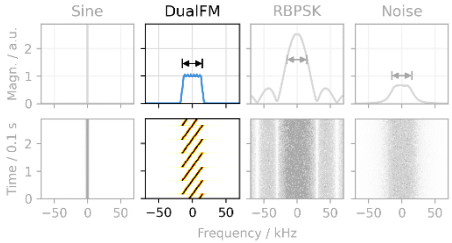
- Sinusoidal
  - 3 frequencies at different sidebands
  - High power requirements, signal level saturation
    - → Artificial ripples due to clipping
  - Strong coherent excitation
    - → Ripple noise floor supressed

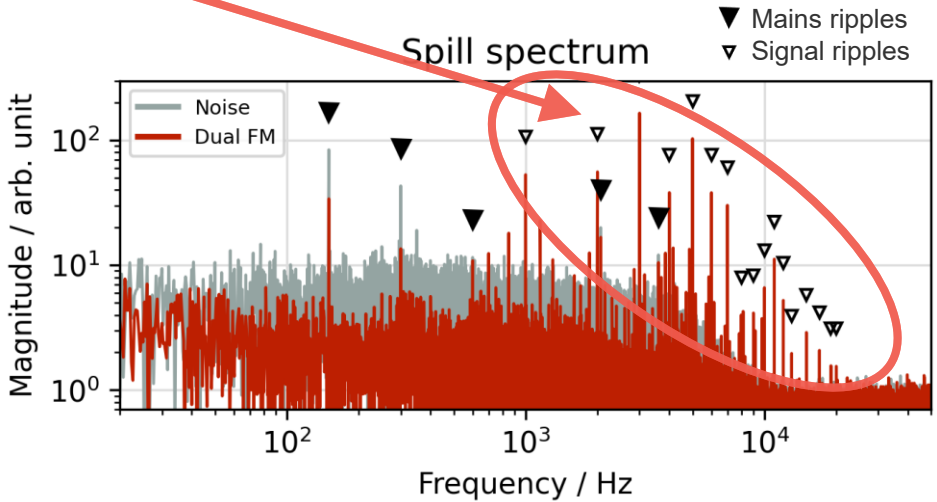




Experiment: Frequency Modulated Excitation

- Frequency modulation
  - Dual FM method at HIMAC [1]
  - Periodic crossing of tune
    - → Artificial ripples at modulation frequency

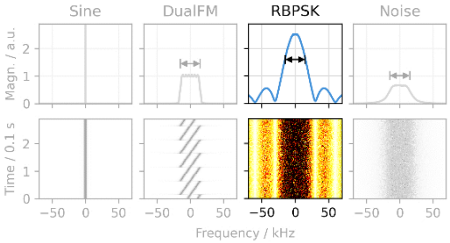


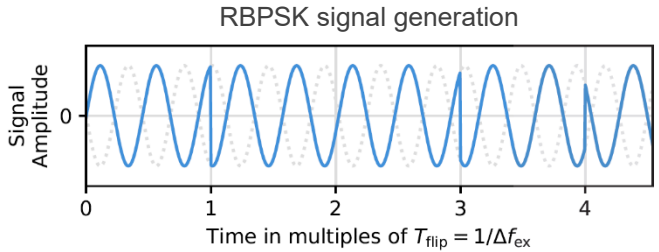


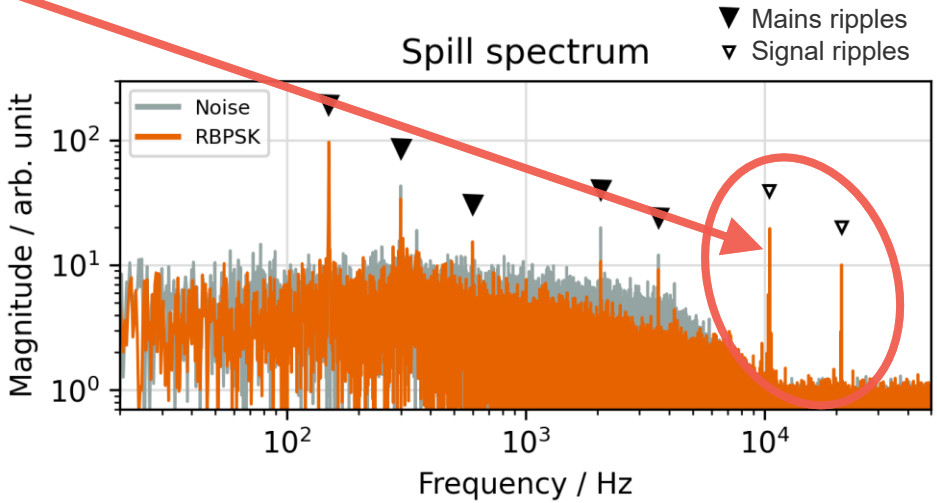
[1] K. Noda et. al.: Advanced RF-KO slow-extraction method for the reduction of spill ripple, Nucl. Instrum. Methods Phys. Res., Sect. A, 2002

Experiment: Phase Modulated Excitation

- Random Binary Phase Shift Keying (RBPSK)
  - Simple to implement, broad spectrum
  - Periodic phase flipping
    - → Artificial ripples at bandwidth







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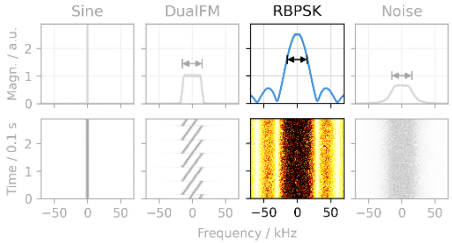
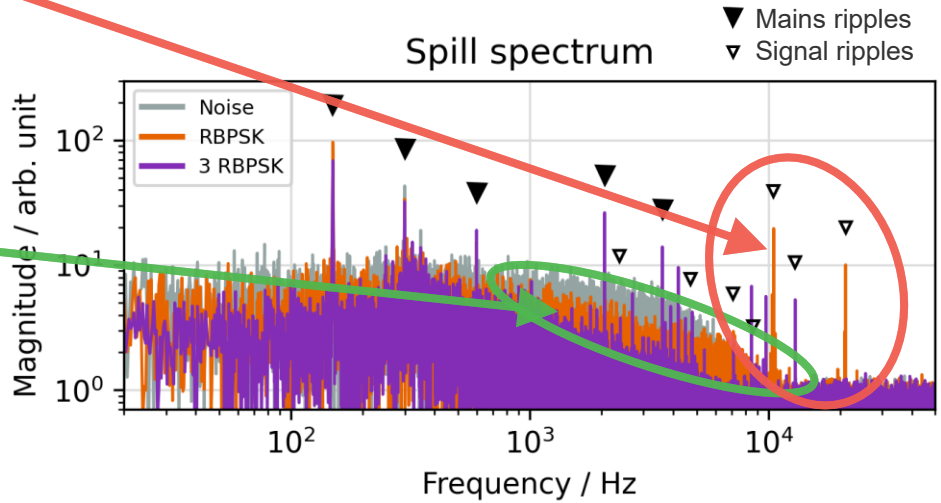


- 3 RBPSK → Talks by C. Cortés & E. Feldmeier
  - Narrow multi-band method at HIT [2]
  - Less frequent phase flipping
    - → Ripple noise floor suppression

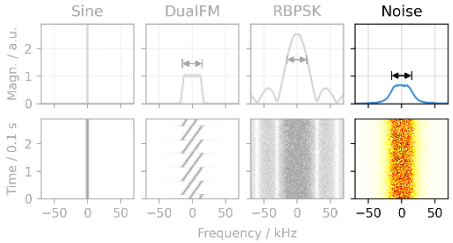


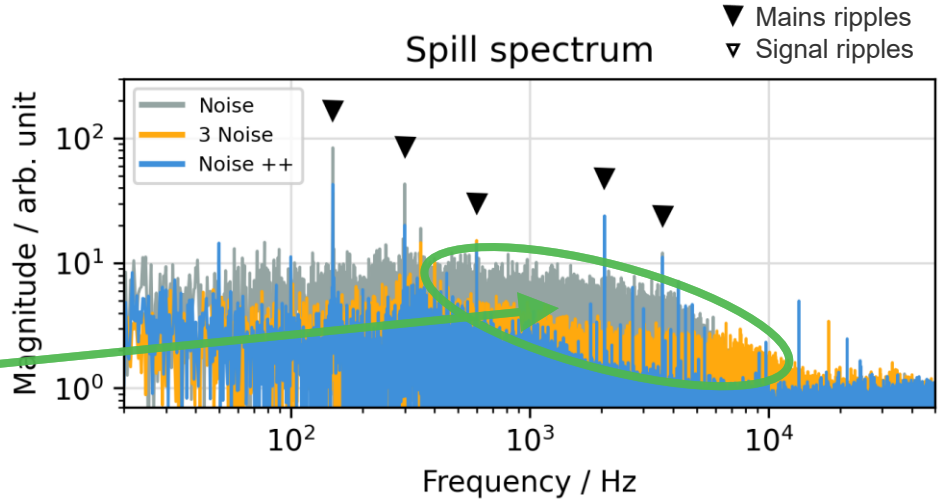
[2] C. Cortés et. al.: Optimization of the spill quality for the hadron therapy at the Heidelberg Ion-Beam Therapy Centre, Nucl. Instrum. Methods Phys. Res., Sect. A, 2022

Experiment: Noise excitation

- Band-filtered Noise
  - No artificial ripples induced

- Noise ++
  - Broadband noise signal
    - → Incoherent excitation & random walk
    - → Efficient power transfer to beam
    - → No artificial ripples induced
  - Mono-frequent sinusoidal
    - → Strong coherent excitation
    - → Fast separatrix crossing
    - → Reduce ripples & noise floor





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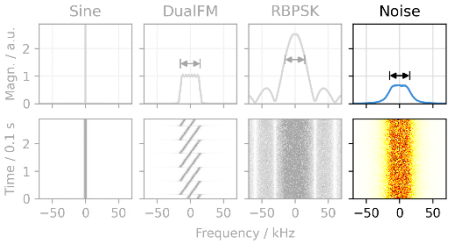
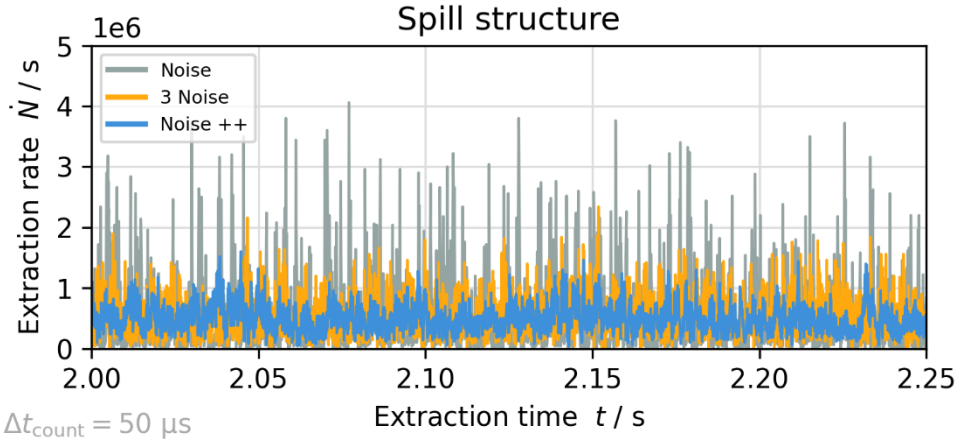
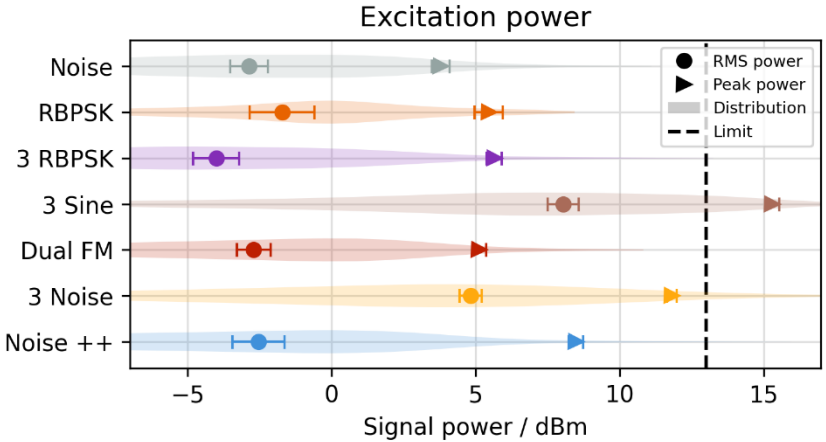
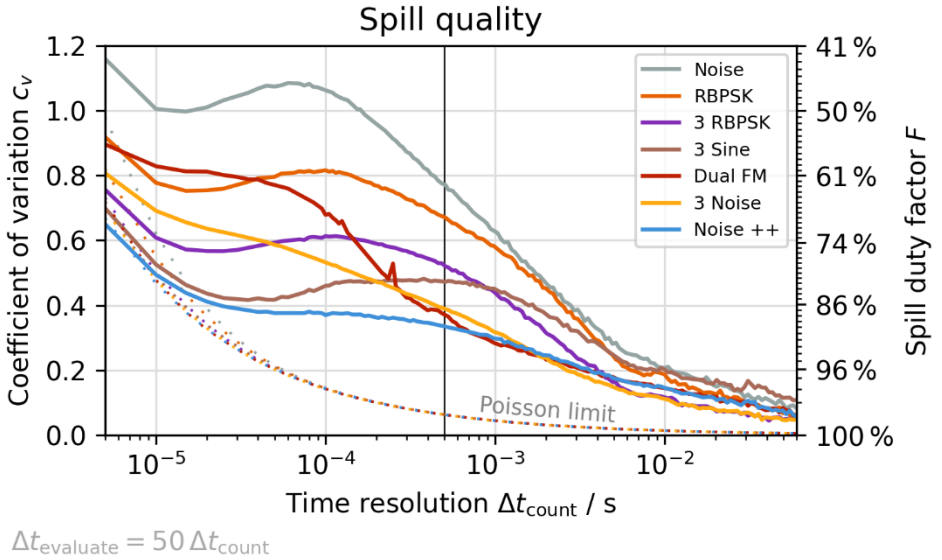




Experiment: Comparison

- Excitation signals
  - Components distributed across sidebands
    - → Mitigates beating
  - Parameters optimized at $\Delta t_{\mathrm{count}} = 500\ \mu\mathrm{s}$
    - → Comparing best cases each



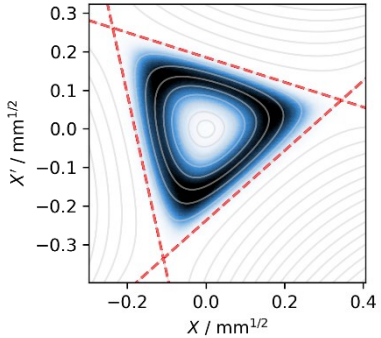


$\Delta t_{\mathrm{evaluate}} = 50\,\Delta t_{\mathrm{count}}$

Conclusions

Conclusions for Excitation Signal Design

- Excitation signal is crucial, it dictates the spill properties
- Avoid periodic signals, they introduce more ripples
  - → Use **noise excitation** instead of frequency/phase modulation
  - → Distribute signals across **multiple sidebands** to prevent beating
- Combine with coherent signals, e.g. Noise ++
  - → **Sine excitation** speeds up separatrix crossing and supresses ripples
- Optimize parameters
  - → Use **software radio with auto-optimizer**



git.gsi.de/p.niedermayer/exciter