MEASUREMENT AND SIMULATION OF THE SPILL STRUCTURE

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FAIR Experiments and Accelerators, Darmstadt, December 15, 2017

Introduction

Strong focus on slow extraction, in particular spill structure, since beginning of last year.

$\rightarrow$ Several events, e.g.

- HIC4FAIR Follow-Up Workshops in February and June 2016.
- Slow Extraction Workshop in Darmstadt in June 2016.

Start of new activities:

- Measurement campaign at SIS-18 (GSI) in 2016, leading role of GSI Beam Diagnostics. Start of simulation work in order to reproduce and explain experimental results in 2017.
- Slow extraction experiment at COSY (FZ Jülich) in December 2017.
- Proposal funded by BMBF with title "Optimierung und Messung der Spillstruktur langsam extrahierter Strahlen"
  Major aim: investigation and comparison of different slow extraction techniques to find ways for improving spill quality.

SIS-18 Measurement campaign in 2016

Contributors: R. Singh, P. Forck, P. Kowina, P. Schmid, A. Stafiniak, H. Welker et al.

→ spill measurements for several techniques, variation of many parameters:

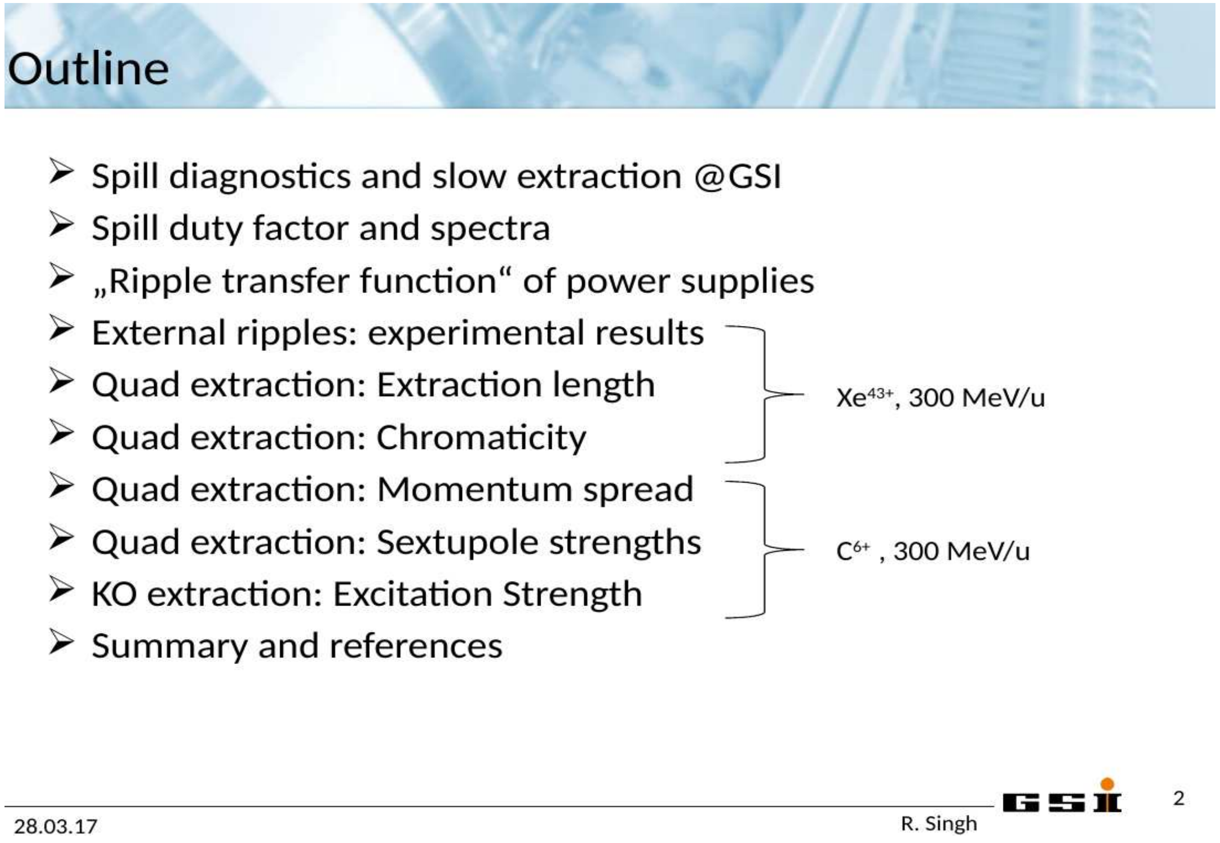
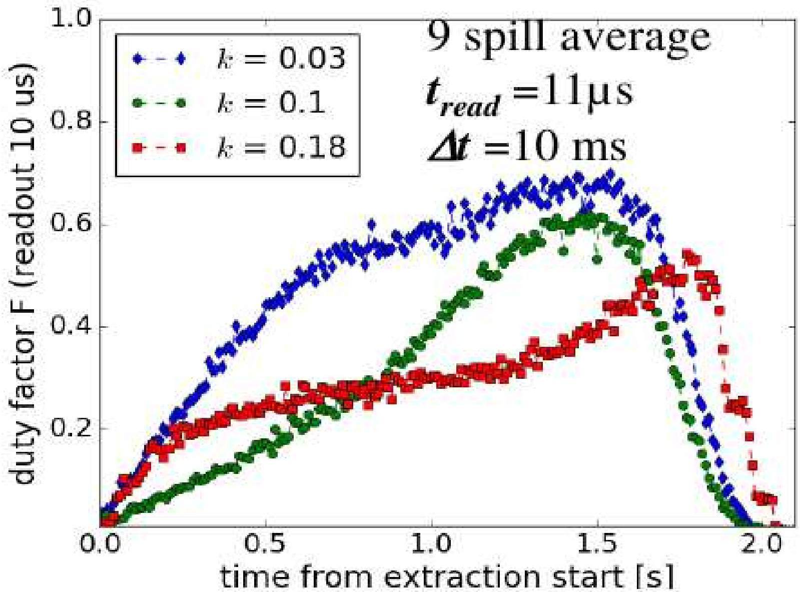


Figure:
R. Singh *et al.*

SIS-18 Measurement campaign in 2016

- Example: Spill structure of quadrupole driven extraction, dependence on sextupole strength.
- Spill characterization by time dependent duty factor:



Duty factor:

$$F = \frac{\langle N \rangle^2}{\langle N^2 \rangle}$$

Data acquisition in bins of $t_{bin} = 10\ \mu\mathrm{s}$.

Average $\langle ... \rangle$ in time intervals of $t_{av} = 10\ \mathrm{ms}$.

Figure: P. Forck *et al.*, Slow Extraction Workshop, CERN, 2017.

- Observations: duty factor
  - is larger for weaker sextupoles.
  - increases with time.

SIS-18 Measurement campaign in 2016

- Example: Spill structure of quadrupole driven extraction, dependence on sextupole strength.
- Spill characterization by frequency spectrum:

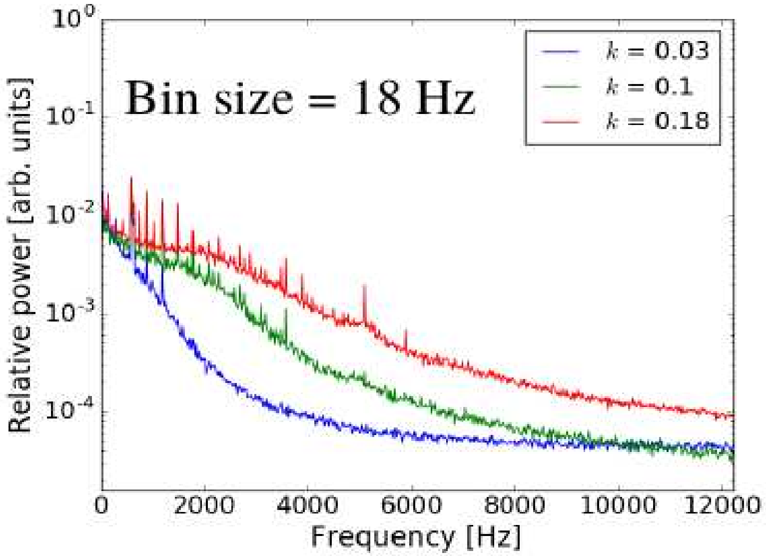


Figure: P. Forck *et al.*, Slow Extraction Workshop, CERN, 2017.

- Observations: Spectra
  - drop at higher frequencies, i.e. higher frequencies are suppressed.
  - corresponding limiting frequency lower for weaker sextupoles.

Simulation

Example is starting point for simulation work to verify experimental results in early 2017.

- Clear effects which can be tried to be reproduced.
- Measurements with plastic scintillation counter → nice conditions for simulations:
  Particle number: $N_p \approx 2 \cdot 10^6$ extracted in $T_{ext} = 2$ s.
  Resulting extraction rate $N_p/T_{ext} \approx 10^6/\mathrm{s}$.
  → can be approached in simulations.

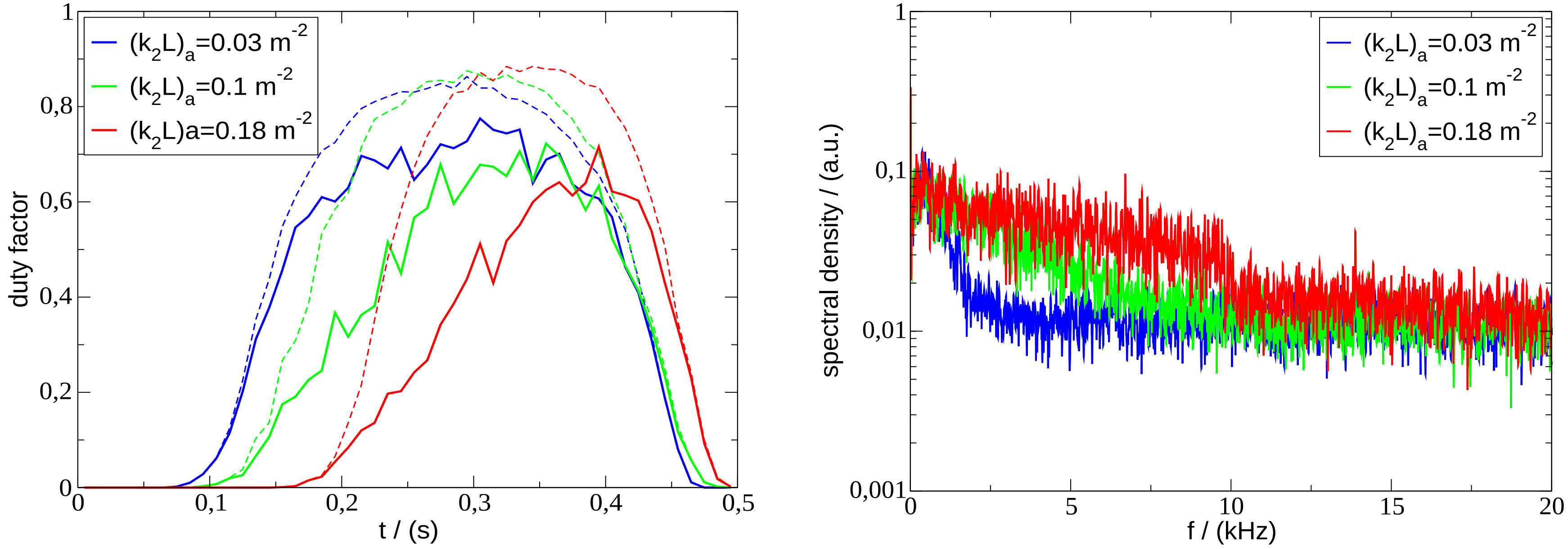
Simulation conditions:

- Particle number: $N_p = 10^5$, extracted in $T_{ext} = 0.5$ s.
  Resulting extraction rate $N_p/T_{ext} = 2 \cdot 10^5/\mathrm{s}$.
- Field ripple signal in defocusing quadrupoles, two signals applied:
  - Sum of five sinusoidal signals and white noise signal with bandwidth limited to 10 kHz.
  - Amplitudes correspond to spectral power of sinusoidal signal generated by current ripple

$$I_{ripple} = 10^{-5} \cdot I_{magnet}$$

Comparison: Measurement vs. Simulation

Time dependent duty factors and frequency spectra for white noise ripple with bandwidth 10 kHz



Poisson limit for duty factor: $F_{Poisson} = \dfrac{\langle N \rangle}{\langle N \rangle + 1}$

- Time bins and average intervals like in measurements, $t_{bin} = 10\ \mu$s and $t_{av} = 10$ ms.
- Qualitative reproduction of experimental results.

Comparison: Measurement vs. Simulation

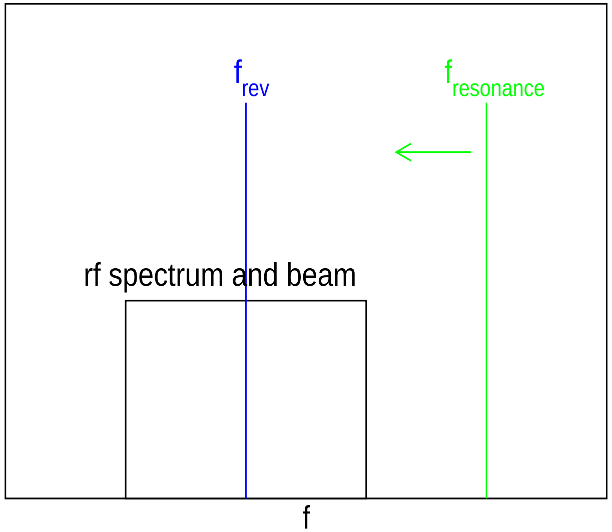
Discussion

- Results suggest better spill quality for weaker sextupoles.
- Possible explanation: weak sextupoles and according small difference between machine and resonance tunes result in increased transit times and spread in transit times of particles arising from momentum spread.
  - Quadrupole extraction: tune approaches resonance $\rightarrow$ duty factor increases with time.
  - High frequency components of spill structures are washed out by spread in transit times:
    $\rightarrow$ Spectral density decreased for high frequencies and is time dependent.
    $\rightarrow$ High frequency decrease starts at lower frequency for weak sextupoles.
- Weak sextupoles result in small spiral step.
  $\rightarrow$ Contradiction to requirement of low particle loss.

Example denotes beginning of studies with measurements and simulations.
Further measurement results are waiting: e. g. rf-ko extraction.

COSY spill measurements

- Agreement on experiment collaborations with IKP4 at FZ Jülich during workshop in November 2016.
- One week of beam time, December 4 – 8, 2017. Data not processed yet.
- Aim was to use possibility of longitudinal stochastic rf beam excitation at COSY. Applied:
  - Stochastic and quadrupole driven extraction separately. Stochastic extraction most proper for ultra-slow extraction with extraction times of minutes.
  - Combine quadrupole driven extraction with additional longitudinal rf noise to smoothen spill structure by diffusion, similar method developed at CERN around 1980 (See W. Hardt, 1978 and D. Boussard *et al.*, 1980). Goal: allow for extraction in a few seconds with low noise power according to GSI requirements.



Work possibly to be continued if results look promising.

BMBF Proposal

- Project is part of Verbundforschungsvorhaben "FuE für höchste Strahlintensitäten in Ringbeschleunigern".
- Major goal: Understanding how spill ripples are generated and propagated in beam and finding ways for spill ripple reduction.
- Frame for activities introduced above and new activities.
- Official applicant: O. Boine-Frankenheim (TUD).
- Application prepared in collaboration with F. Faber (TUD), P. Forck (GSI), A. Peters (HIT), and S. Sorge (GSI).
- Collaboration partner: B. Goddard (CERN).
- Application by November 1, 2017.
- Project with beginning in 2018 and duration of three years.

BMBF Proposal

- Proposal consists of two parts:
  1. Experimental part:
     - Measurements at SIS-18 and in other facilities: HIT, CERN, FZ Jülich.
     - Development and construction of particle detector based on diamond counter and data acquisition system. System portable for measurements in other facilities.
  2. Simulation part:
     - Numerical modelling of several slow extraction techniques:
       quadrupole driven, rf-ko, stochastic, ...
     - Verification of experimental results.
     - Identification of proper procedures and parameter settings to minimize spill structures: e.g. sextupole settings, noise spectra for rf-ko extraction, ...
     - Check for robustness of settings against deviations.
- Two positions for PhD students.

Summary

- Experimental campaign at SIS-18 last year and beginning collaboration with simulation studies this year to understand and with aim to improve slow extraction.
  - First simulation results promising: major effects could be reproduced.
  - Next steps: rf-ko extraction, bunches.
- Slow extraction experiment at COSY in FZ Jülich, December 4-8, 2017.
  - Aim: investigation of longitudinal stochastic beam excitation.
  - So far only measurements, data evaluation not done yet.
- Proposal for BMBF project on investigation and improvement of slow extraction.
  - Three years. Start next year.
  - Consists of experiment and simulation parts $\rightarrow$ also frame for activities above.
  - Agreements on beam time in other facilities.
  - Two positions for PhD students.

Thank you for your attention