Study on spill quality and transit times for slow extraction from SIS18

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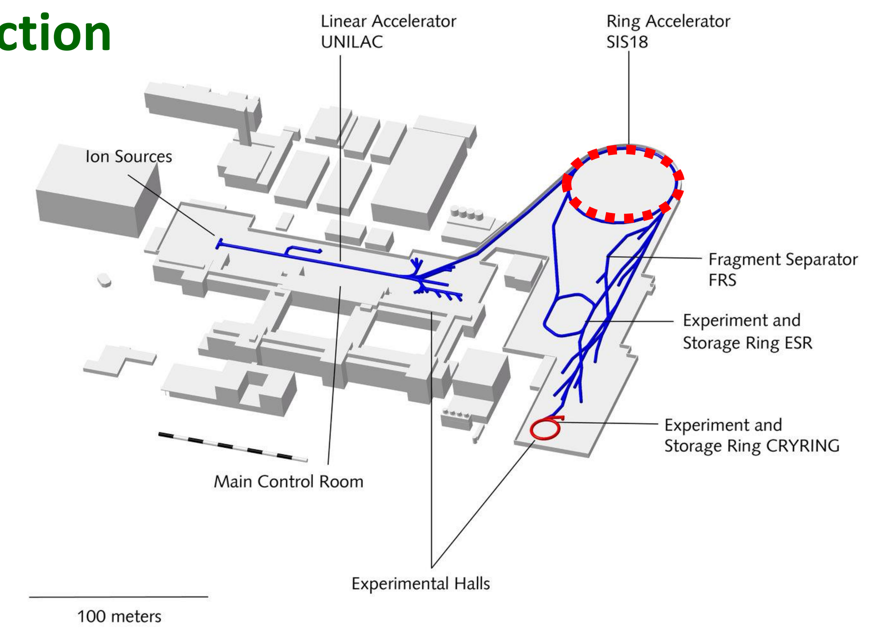
Abstract

- Slowly extracted beams from a synchrotron have temporal fluctuations, the so-called spill micro structure. The reason is related to power supply ripples that act on the quadrupole magnets, leading to unintended tune fluctuations during extraction.
- Related simulations regarding the dependency of spill quality on the power supply ripples were executed with varying excitation levels of the sinusoidal ripples and bandwidth-limited white noise. In addition, transit time spread was simulated and a few simulation approaches were proposed and related data analysis procedures and simulation results were described.

Introduction

SIS18 synchrotron facilities

Circumference	216 m
Beam Rigidity	18 Tm
Ion Range	p to U
Injection Energy	11 MeV/u
Extraction Energy	100 MeV/u – 2 GeV/u
Tune h/v	4.29/3.27
Slow extraction method	Tune scan (KO possible)



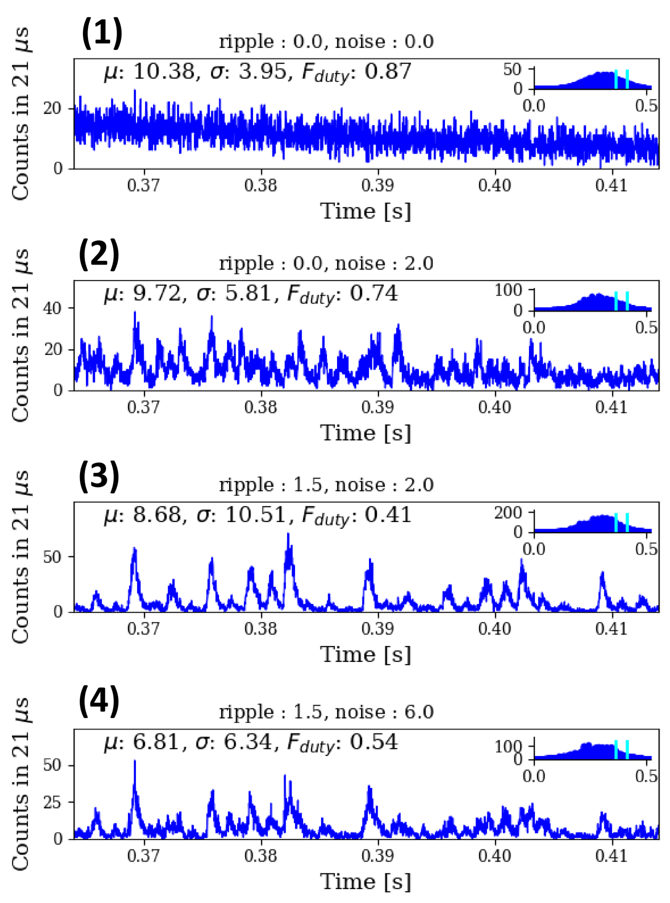
Simulation about Power Supply Ripples

Spill quality depency on power supply ripples

- Sinusoidal frequency components with corresponding weights (shown in right figure)
- Bandwidth limited white noise (0-20 kHz)
- Particle tracking tool: Xtrack of Xsuite packages collection

Frequencies (Hz)	50	100	150	300	600
weights	0.25	0.3	0.1	0.25	0.35

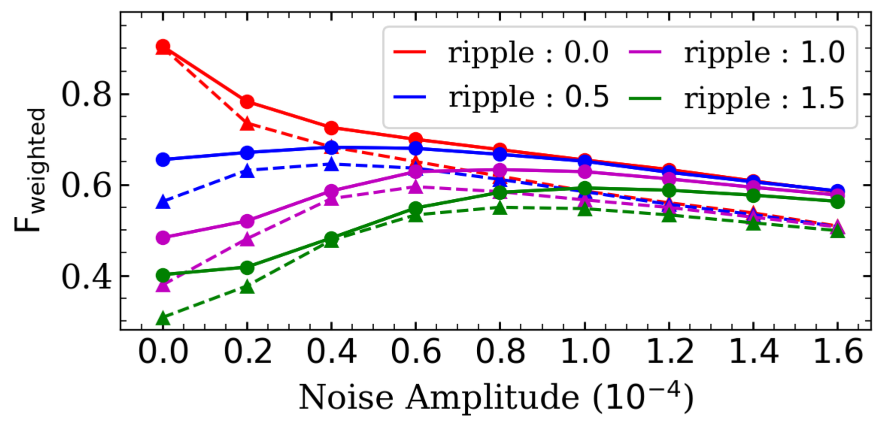
- Micro structures with different ripple settings (time window = 50 ms)



The unit of ripple and noise amplitude is 10^{-5} of the main quadrupole family strength.

Signal	Ripple	Noise	F_{duty}
(1)	0	0	0.87
(2)	0	2	0.74
(3)	1.5	2	0.41
(4)	1.5	6	0.54

- Spill quality reduces after introducing a noise excitation: (1, 2);
- When introducing sinusoidal frequency components to the main quadrupoles, spill micro structures appear (3);
- The micro structure was mitigated with larger noise excitation (4).



Simulated weighted duty factor as a function of sinusoidal ripple and bandwidth-limited white noise amplitudes.

- Duty factor Evaluation

Duty factor:

$$F(t_i) = \frac{\mu^2(t_i)}{\mu^2(t_i)+\sigma^2(t_i)}$$

Weighted Duty Factor:

$$F_w = \frac{\sum \mu(t_i)\cdot F(t_i)}{\sum \mu(t_i)}$$

$\mu(t_i)$ & $\sigma^2(t_i)$: mean & variance during window t_i

Observations

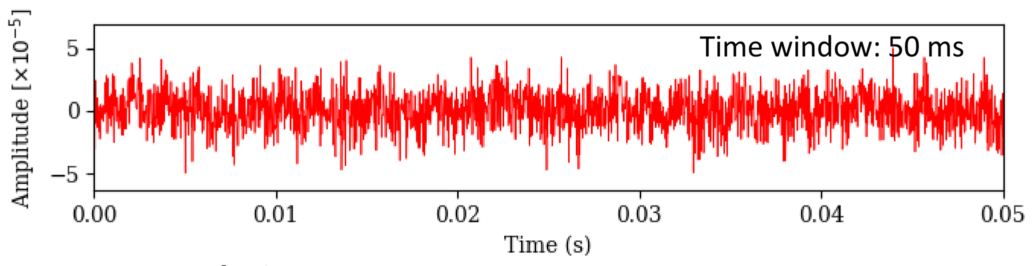
- Spills extracted from narrower circulating beam have better spill quality;
- Spills extracted when ripples with higher sinusoidal frequency components have worse spill quality;
- An increase of the noise amplitude leads to a maximum of the duty factor at intermediate noise amplitudes. When exceeding this noise amplitude, the spill quality is reduced.

The observation suggests that introducing noise into the power supply feedback system can have a spill-smoothing effect, especially for machines with large sinusoidal ripples, as the noise can help to reduce their impact.

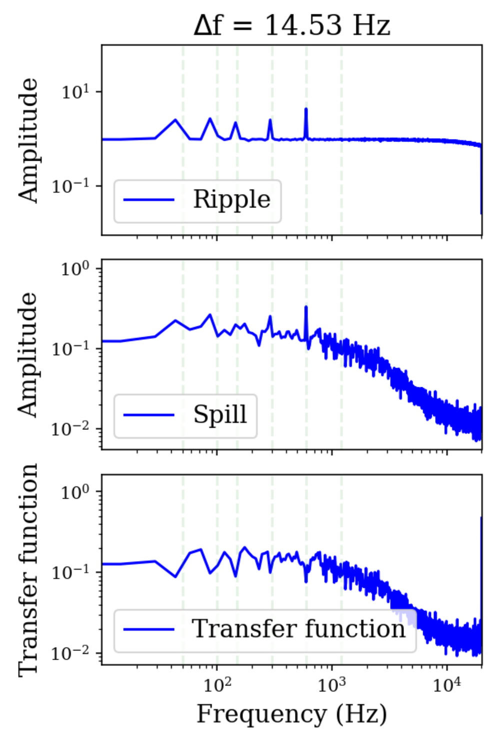
Suitable Ripple and Noise Parameters

Particle tracking with a suitable ripple and noise paramters

- Ripple amplitude = 1.0
- Noise amplitude = 6
- Spill duration: 1.5 s
- Particle number: 10^6



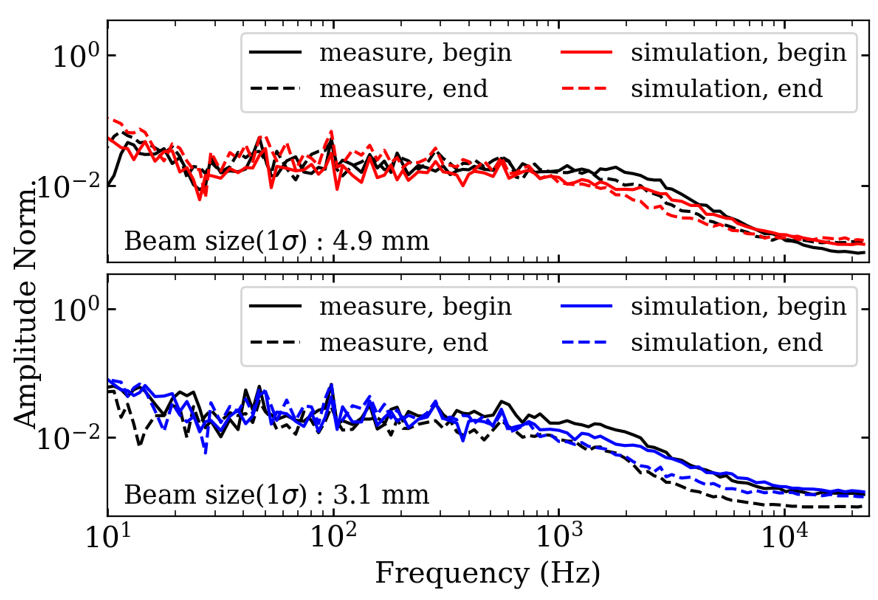
- Transfer function



- Sinusoidal ripple frequencies components (50 Hz + harmonics) were reflected on the spill FFT spectrum;
- High frequencies contributions from bandwidth limited white noise were diminished.

- FFT analysis

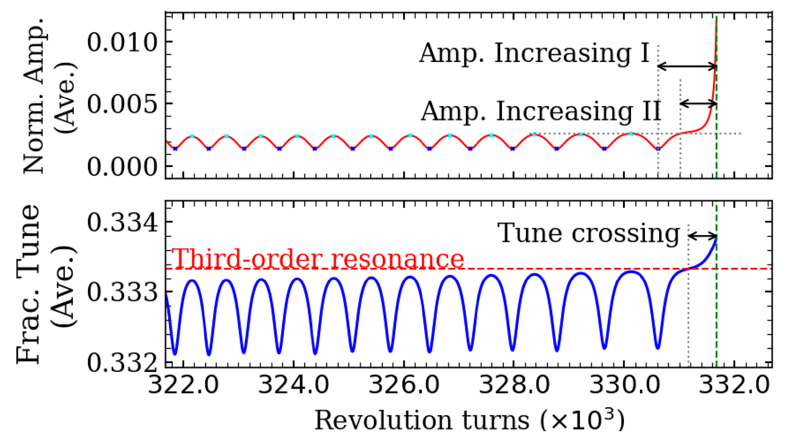
Comparison of simulated Fourier transformation spectrum for beam with different beam sizes to the measured results.



- Better spill quality shows in the second half of each spill;
- Spill extracted from a lower emittance circulating beam have better spill quality.

Transit Time Simulation

Transit time determination approaches

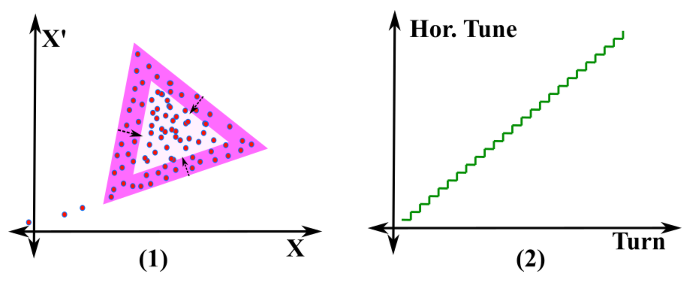


Category I: Transit time determination using amplitude and tune information for a single on-momentum particle.

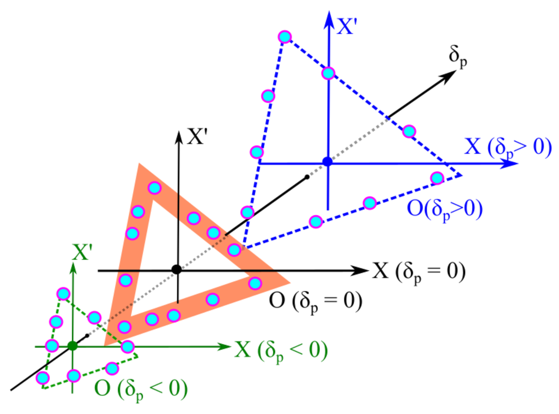
- **Category I**: Recording particles amplitude and tune information turn by turn:
  - Amplitude increasing:
    - Amplitude Increasing I
    - Amplitude Increasing II
  - Tune crossing

  Heavy computation loads limit achievable simulation statistics
- **Category II**: Approximation for fast calculations
  - Spill simulation using a stepped tune ramp

  Suitable step length is demanded



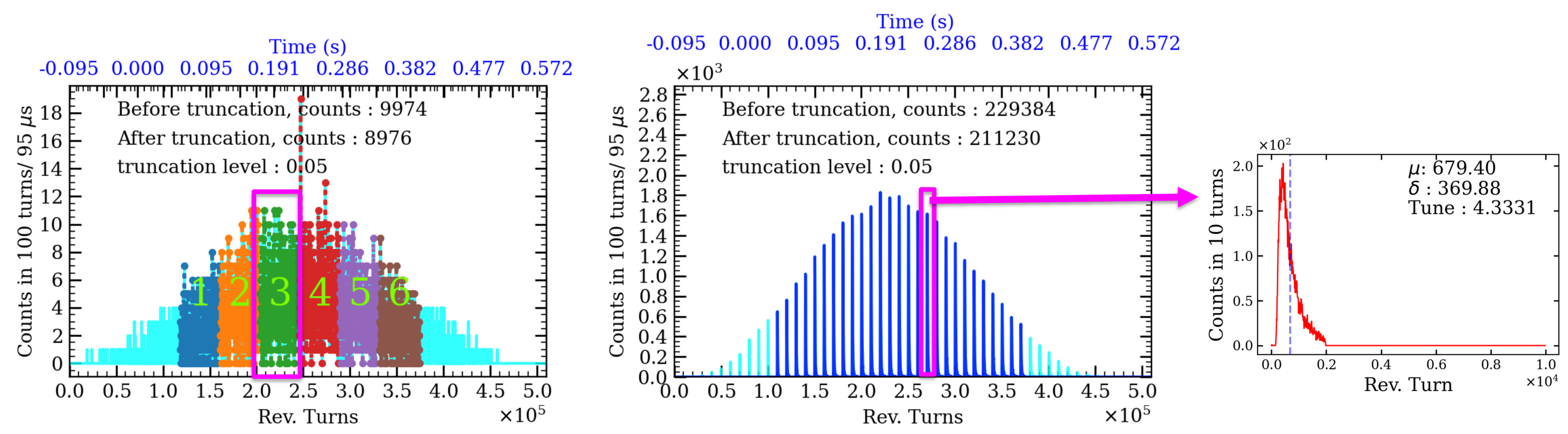
Category II: Schematic show of tune sweep slow extraction withApproximation for fast calculations a stepped tune ramp.



Resonant particles at same tune step

Data Analysis Procedure

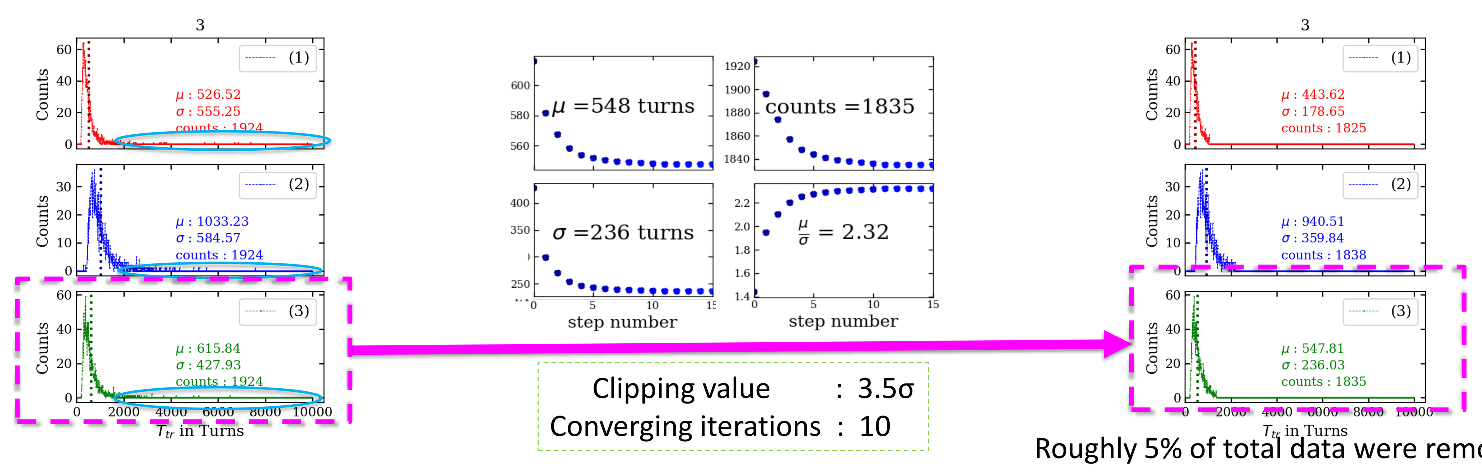
Spill chopping: Removal of the low statistics area



Spill from Category I — Spill from Category II

Data Converging: Removal of the outliers

Origin data — (Using sigma-clipping algorithm) — Refined data



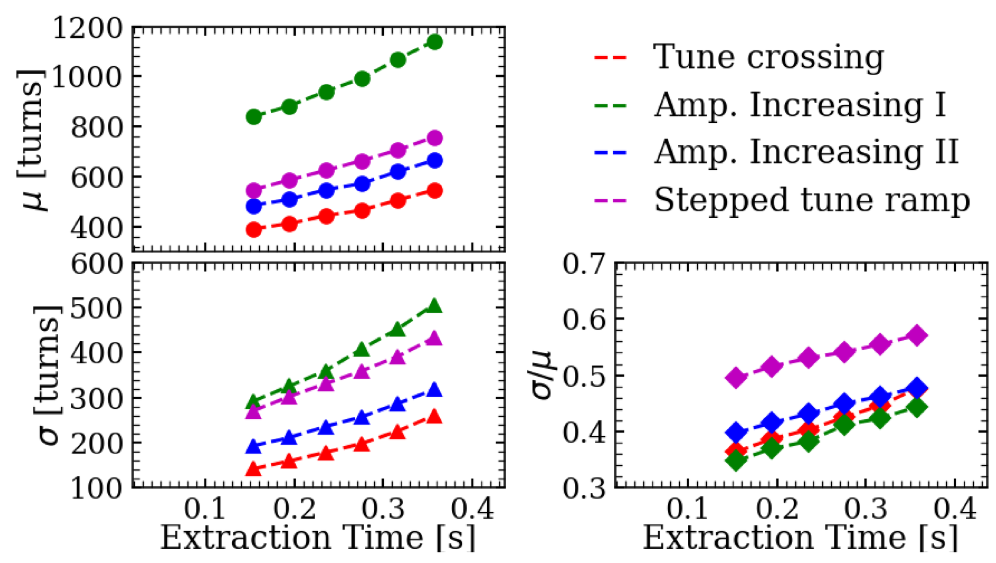
Clipping value : 3.5σ
Converging iterations : 10

Roughly 5% of total data were removed

Simulation Results

Comparison of simulation results from all approaches

After data refining, the remaining spill was divided into 6 parts by extraction time.



- The average transit time (μ) increases for all simulation methods;
- The average transit time (μ) from method 'Amp. Increasing I' line is expected to be larger by the half-period;
- The transit time spread (σ) and relative spread (σ/μ ratio) increase, indicating that the spill gets smoother towards the end;
- The same tendency from all methods suggests that transit time simulation adopting a stepped tune ramp with a step length of 10 ms is a valid approximation and can be used for fast calculations;
- Power supply ripples were not applied.

Conclusion

The simulations using different power supply ripple settings show that introducing white noise positively affects the spill quality for machines with large sinusoidal ripples. Besides, different transit time simulation methods were proposed and discussed, suggesting that the spill gets smoother towards the end of the extraction. Transit time simulations with introducing power supply ripples are ongoing.

References

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