Investigations of transit times for tune scan slow extraction at SIS18 GSI

J. Yang[1], P. Forck, R. Singh, S. Sorge
GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
[1] also at Goethe Universität, Frankfurt am Main, Germany

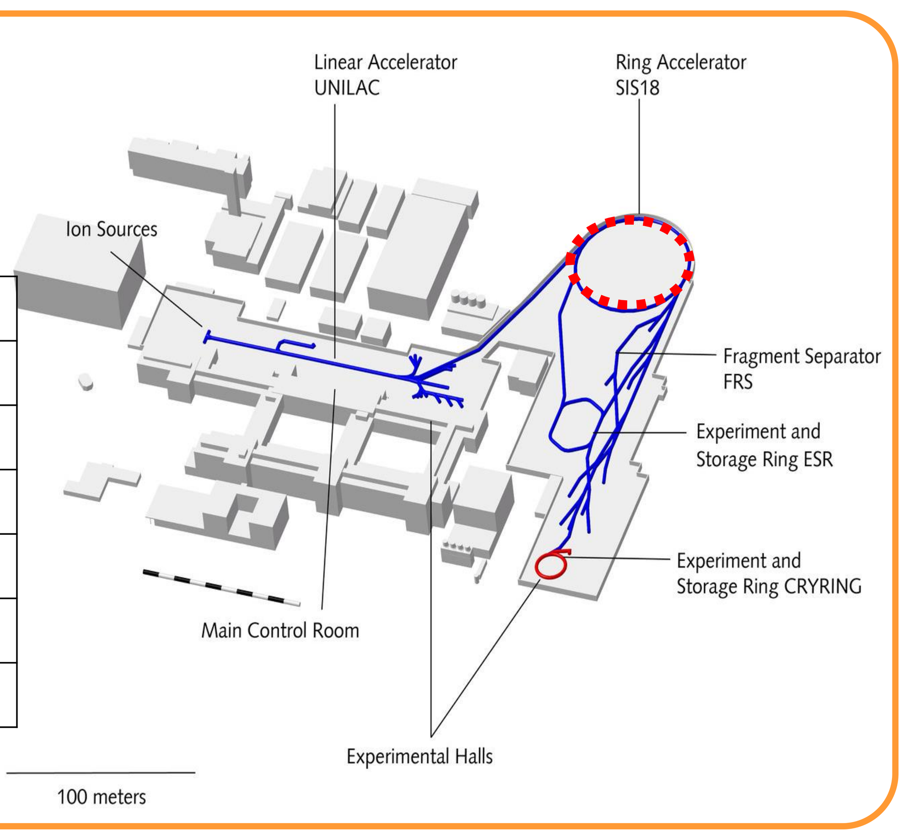
Introduction

The temporal structures of the slowly extracted beams from a synchrotron on the 100 microseconds time scale is crucial for fixed-target experiments and hadron therapy. The transit time is a crucial physics quantity which relates the beam dynamics inside the synchrotron with the temporal structure of the extracted beam. In simulation, different approaches for the transit time determination were proposed and executed with the particle tracking tool Xsuite. Experimentally, spills with sinusoidal tune excitations were evaluated, a test of quasi-step-type excitations of a fast quadrupole field was performed.

SIS18 synchrotron facilities

❖ 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
Extraction method	Tune scan (KO possible)



Simulation

4 approaches were used under varying conditions to determine the start of transit time T_{start}

$$T_{tr} = T_{end} - T_{start}$$

where T_{end} is the particle arrival time T_{PA}.

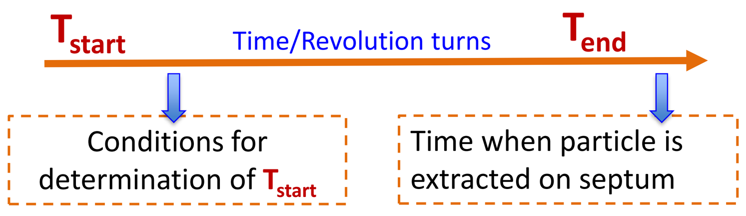
❖ Discription of approaches

- **Methods Category I :**
  - ➢ **Tune crossing (1):**

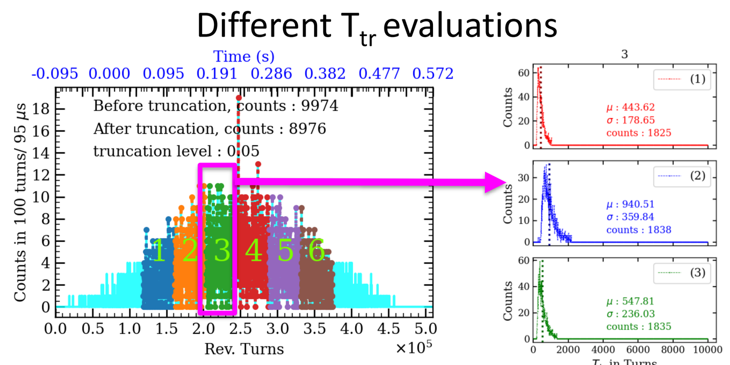
    T_{start}: the moment when a particle crosses third order resonance.
  - ➢ **Amplitude increase I (2):**

    T_{start}: the moment when a particles' amplitude begins a continuous increase
  - ➢ **Amplitude increase II (3):**

    T_{start}: the moment when the amplitude of the particle is continuously increasing and larger than it has ever reached

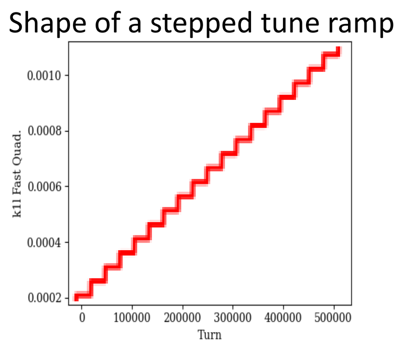


Different T_{tr} evaluations

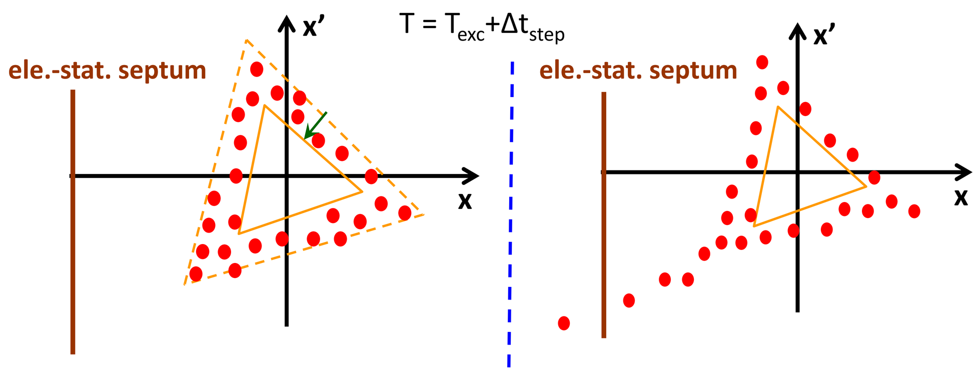


- **Limitations:**
  - Simulations involve calculating and recording amplitude and tune for each single particle at every revolution turn
  - Heavy computation loads limit achievable statistics
  - Challenging T_{start} determination with power supply ripples

Shape of a stepped tune ramp



- **Methods Category II :**
  - ➢ Spill simulation with **a dedicated stepped tune ramp, $T_{start} = T_{exc}$**
  - Stepped excitations cause the instantaneous shrinkage of the separatrices in phase space, leading to particles' instability, and transitting to the septum.
  - The evaluation of the transit time distribution relies on analyzing the arrival time during each step.
  - A suitable step length is required



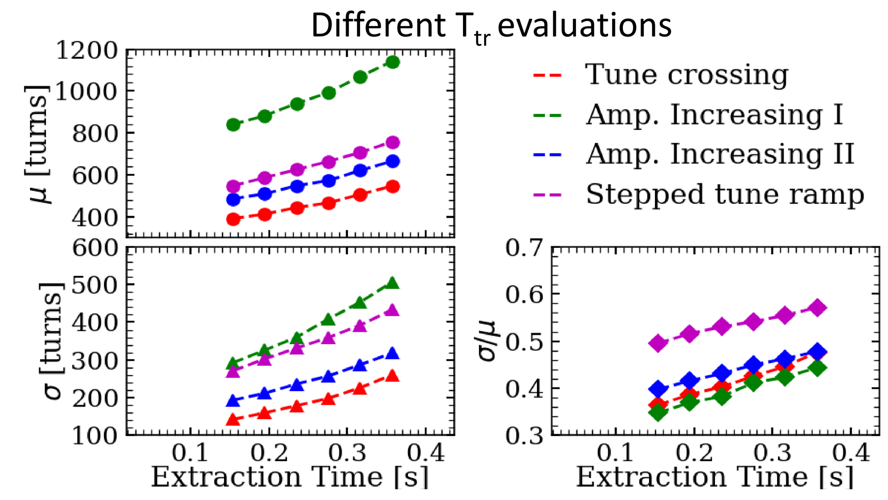
❖ Results

- **Data Refinement**

  low-statistics regions were eliminated and the outliers were excluded.
- **Consistency in results**

  The average transit time (μ) and transit time spread (σ) both increase towards the end of the extraction, indicating that the spill is becoming smoother towards the end.

Different T_{tr} evaluations

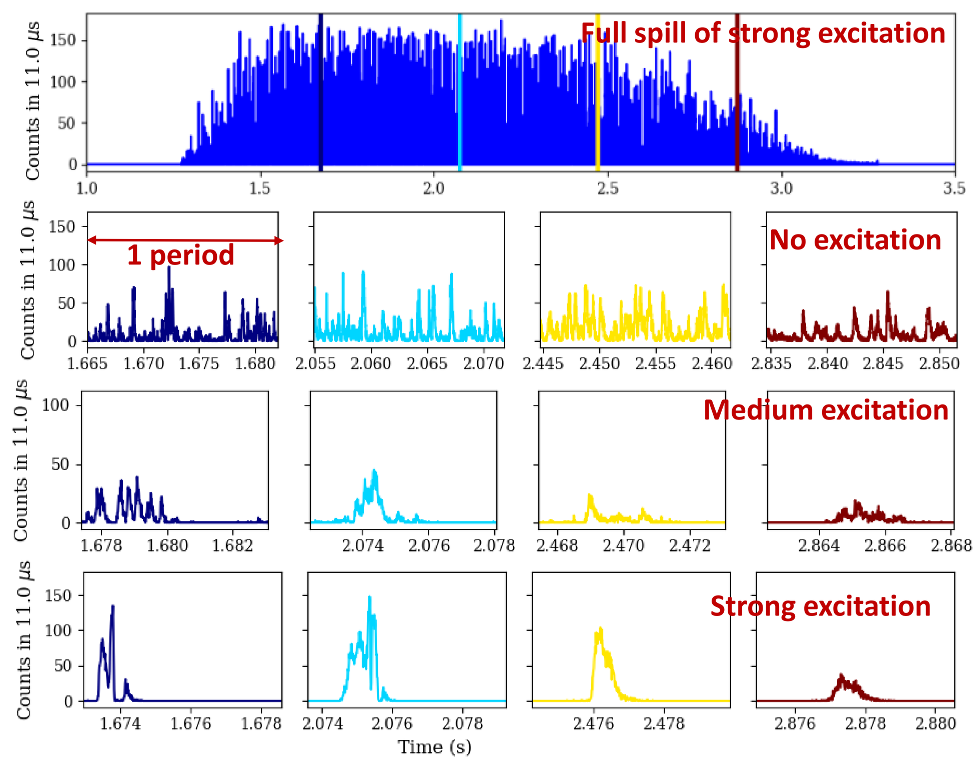


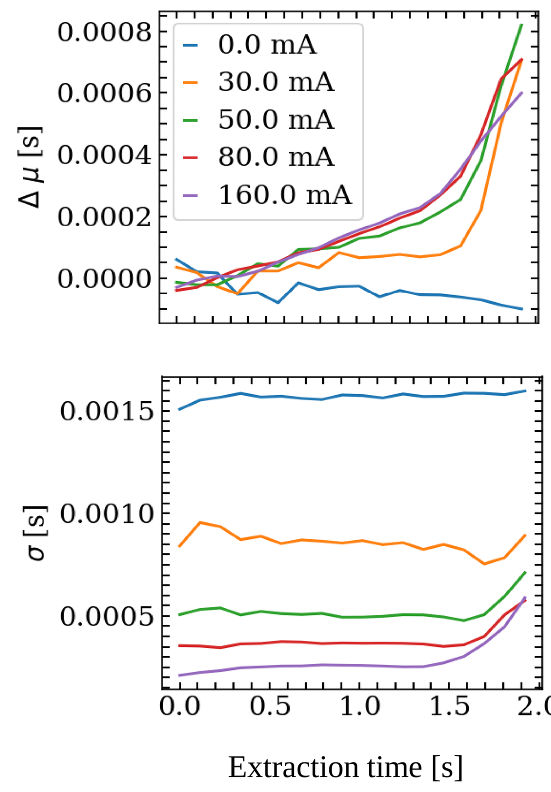
❖ Conclusion

- Particle tracking using a stepped tune ramp is a valid approximation, and can be used for fast calculations, and suggests the possibility of measurements
- Power supply ripples were not applied in simulations
- All simulations were performed using Xsuite
- For more simulations please see S. Sorge's talk: "Spill structure simulations for GSI and FAIR"

Measurements

❖ Measurements using tune ramp with sinusoidal excitation: f= 177 Hz



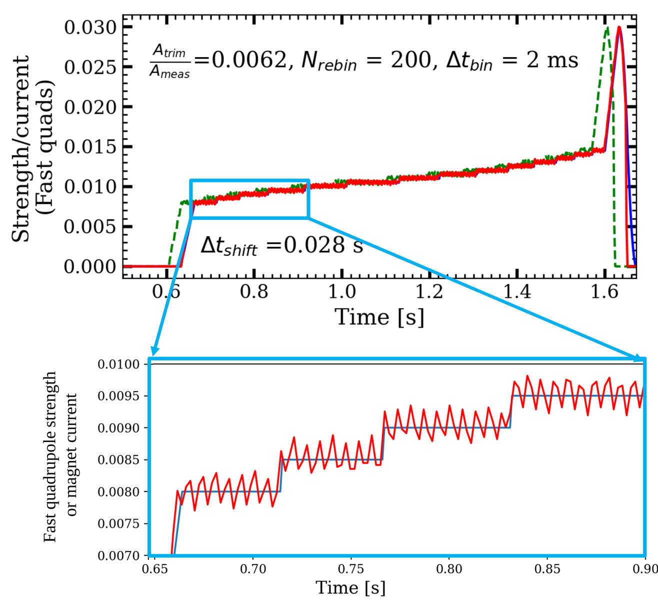


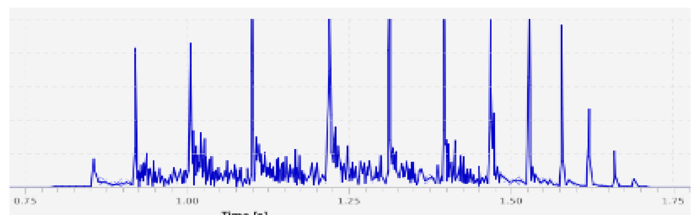
- The center of the particle distribution (μ) in a period symmetrically shifts along the extraction time;
- The increase of the transit time and its spread is clearly demonstrated experimentally.

❖ Measurements with stepwise tune ramps

- **Parameters**
  - Beam: $^{238}U^{73+}$, 300 MeV/u
  - Measurement technique:
    - particle counting: BC400 scintillator
    - data acquistion: ABLAX scaler
    - readout time: 10 μs
  - Parameters of the tune ramp:
    - polynomial tune ramp + quasi-step excitation
    - realized by varying the strengths of 'fast quadrupoles'
    - hor. tune change for one spill: $\Delta Q_{x,spill}$: 0.007
    - time of extraction: 1 s
    - different heights of the stepped tune ramp $Q_{x,step}$:

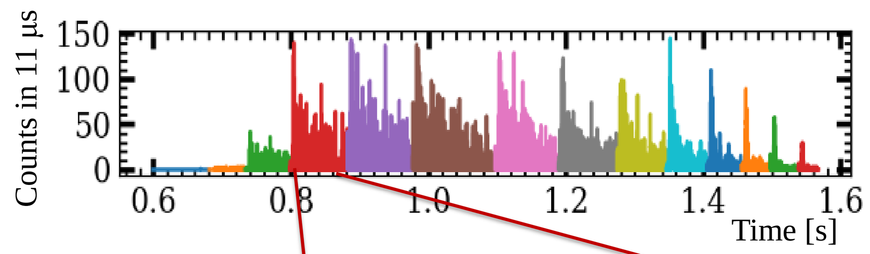
      1×10^{-3}, 5×10^{-4}, 1×10^{-4}, 5×10^{-5}



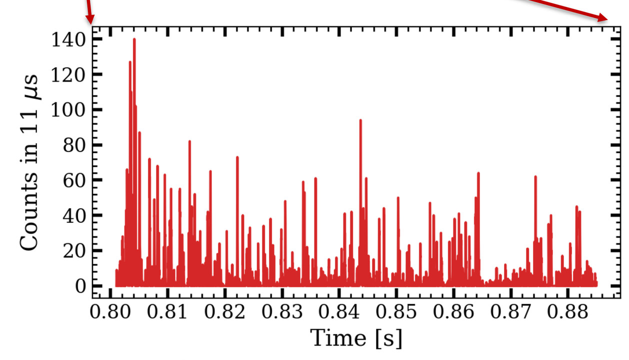


Online observation of spill shape measured by ionization chamber $\Delta Q_{x,step} = 5 \times 10^{-4}$

- **Results within one extraction cycle**
  - Variation of the quadrupole strength was measured, and the stepwise excitations are responded in spills
  - Particle arrival time distributions from different excitation steps are visually distinguished with various colors



- **Time structure of particle arrival times within an excitation step**
  - Challenges in transit time determination arise due to unwanted fluctuations in the spill distribution



- **Various evaluation methods have been tested to mitigate the impact**
  - Method 1: averaging distributions over entire spills or within the same excitation steps for all spills
  - Method 2: analyzing the first peaks of the distributions of steps within indivadual steps of a spill
  - Ongoing analysis
  - **However, a variation of transit time during extraction is detected**

Conclusion

Investigations of transit time and spread in slow extraction are presented. Measurements were carried out at GSI SIS18. Dedicated stepped tune ramps were used in tune scan slow extraction and were reflected in the shapes of the spills. The challenges in determining the transit time were described. However, a variation of transit time during extraction is detected.

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Contact: Jiangyan Yang, E-mail: Jia.Yang@gsi.de

Poster for 5th slow extraction workshop at MedAustron in collaboration with GSI