Nano-second time scale measurements of the particle arrival times

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

HGS-HIRe for FAIR – Helmholtz Graduate School for Hadron and Ion Research
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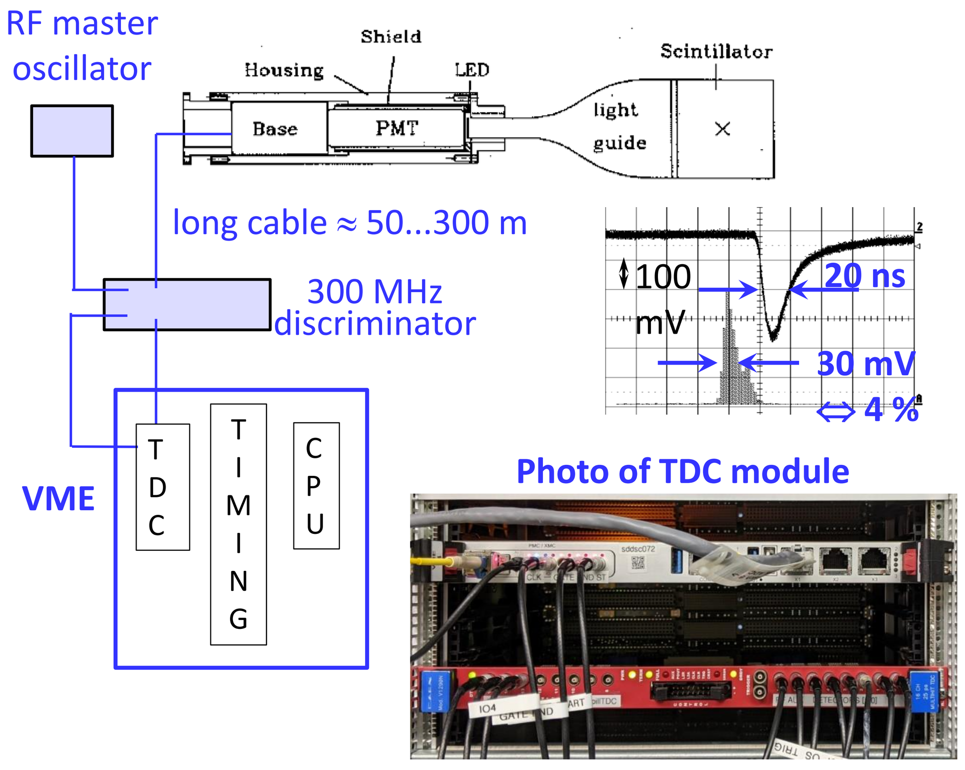
GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Introduction

At SIS18, spill smoothing was commissioned by bunching the circulating beam with RF cavities using two different frequencies: at roughly 4.85 MHz (4 circulating bunches) or at roughly 81.44 MHz (with 90 circulating bunches). Tune scan slow extraction was performed. The arrival times of the individual particles at plastic scintillators were recorded using Time-to-Digital-Converters (TDC) with a resolution of about 50 ps. Time structures of the particle arrival times were analyzed and compared for different RF.

Measurement technique

- Particle counter:
  BC400 plastic scintillator, 75 x 75 mm^2 area, 1 mm thickness
- Photomultiplier:
  gain: 10^6; rising time: 1.9 ns
- Discrimilator: 300 MHz frequency
- Time-Digital-Converter (TDC):
  CAEN V1290N, resolution σ_{rms} ~ 35 ps



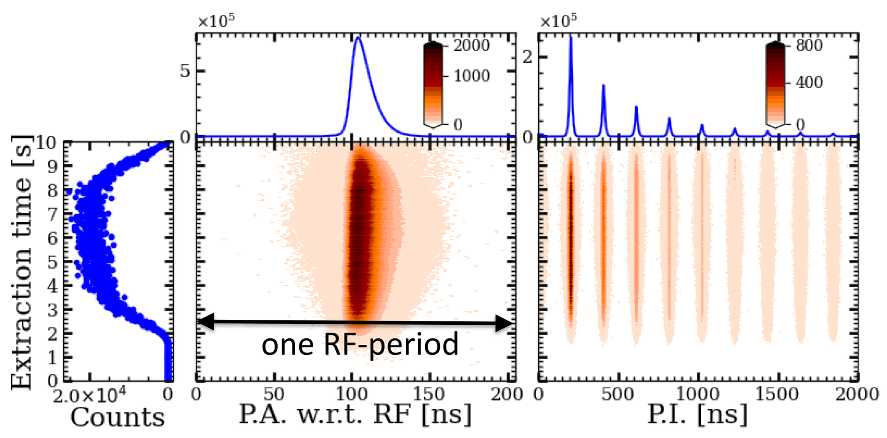
Lower frequency

Beam: Ar^{18+}, 500 MeV/u; RF: ~4.85 MHz, h = 4

Characterization of the spill time structure

- Distribution of particle arrival times with respect to the RF cavity (P.A.)
- Distribution of particle intervals with respect to each other (P.I.)

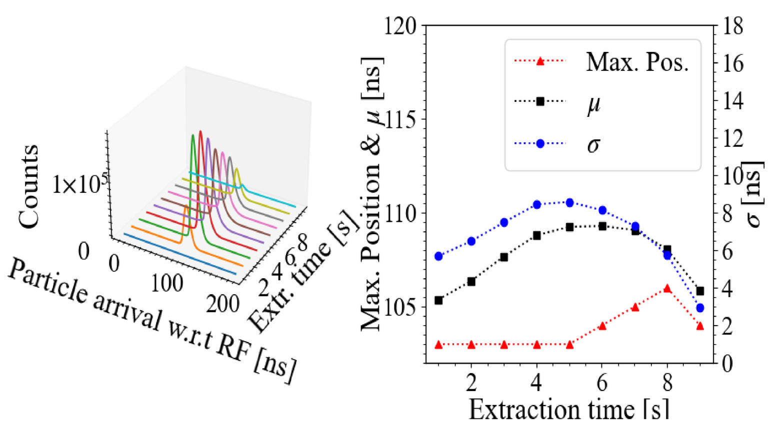
Example of displays of spill time structure (505 V)



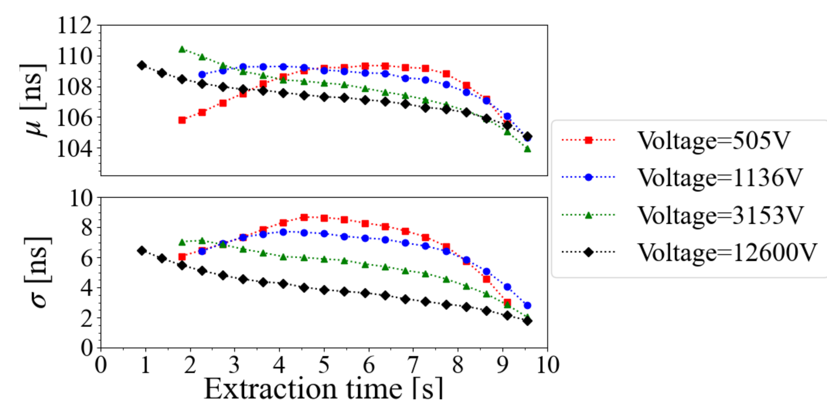
Statistics moments of spill slices extracted with different RF voltages

V = 505 V for bunching in SIS18

- Standard deviation σ of distribution of P.A. is ~8 ns, which is significantly shorter than for circulating bunches
- Variation of σ and a drift of the center of approximately 5 ns



V = 0.505, 1.136, 3.153, and 12.6 kV



- Evolution of the mean value (μ) and standard deviation (σ) of the spill slices with different RF voltages. A decrease toward the end of spill is clearly visible and understandable.

Higher frequency

Beam: $^{14}N^{7+}$, 300 MeV/u; RF: ~81.44 MHz, h=90

Spill quality evaluations

Duty factor

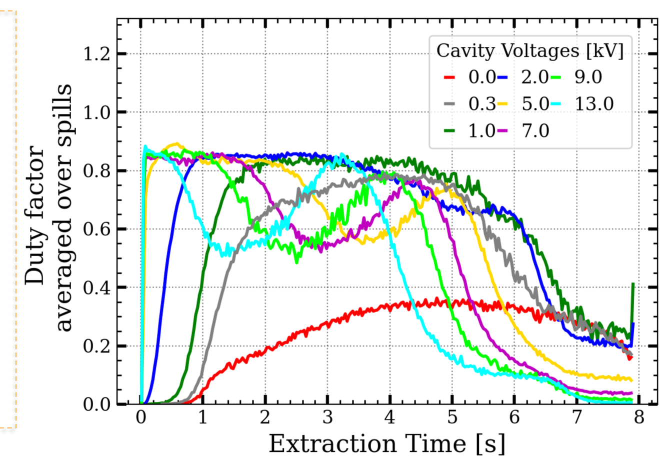
Time-dependent duty factor:

$$F(t_i) = \frac{N^2_{ave(t_i)}}{N^2_{ave(t_i)} + N^2_{std(t_i)}}$$

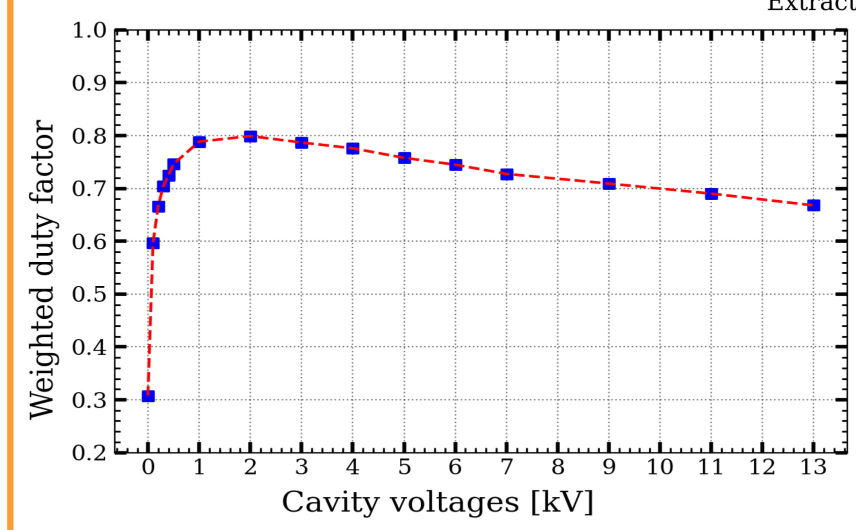
Weighted Duty Factor:

$$F_w = \frac{\sum N_{ave(t_i)} F(t_i)}{\sum N_{ave(t_i)}}$$

$N_{ave(t_i)}$ & $N^2_{std(t_i)}$: mean & variance during window t_i



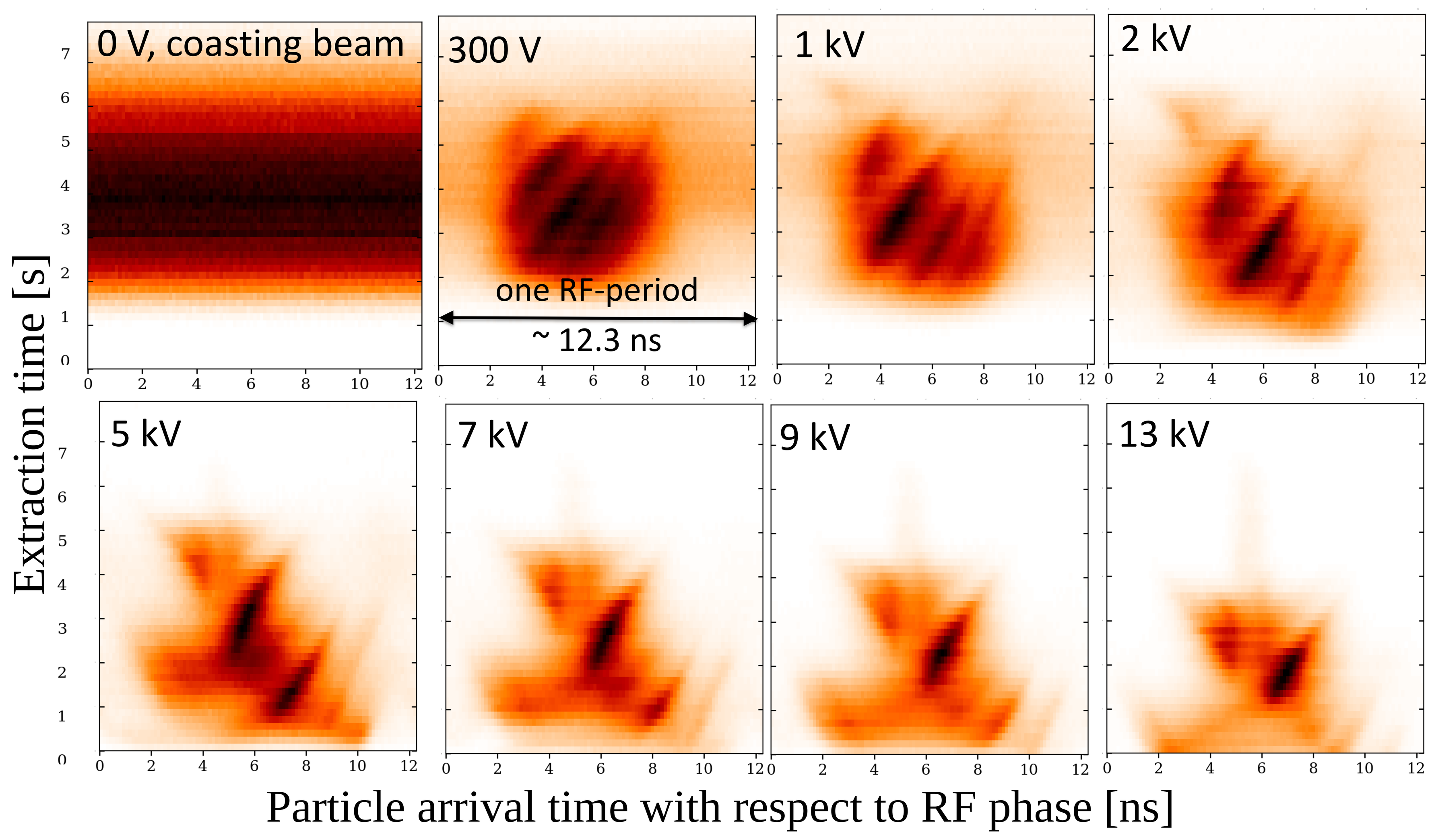
- Spill quality is improved by bunching circulating beam;
- the occurrence of 'dips' in time-dependent duty factors indicates lower spill quality at a specific time, T_{dip};
- 'dips' moves to the front of extraction while increasing cavity voltages;



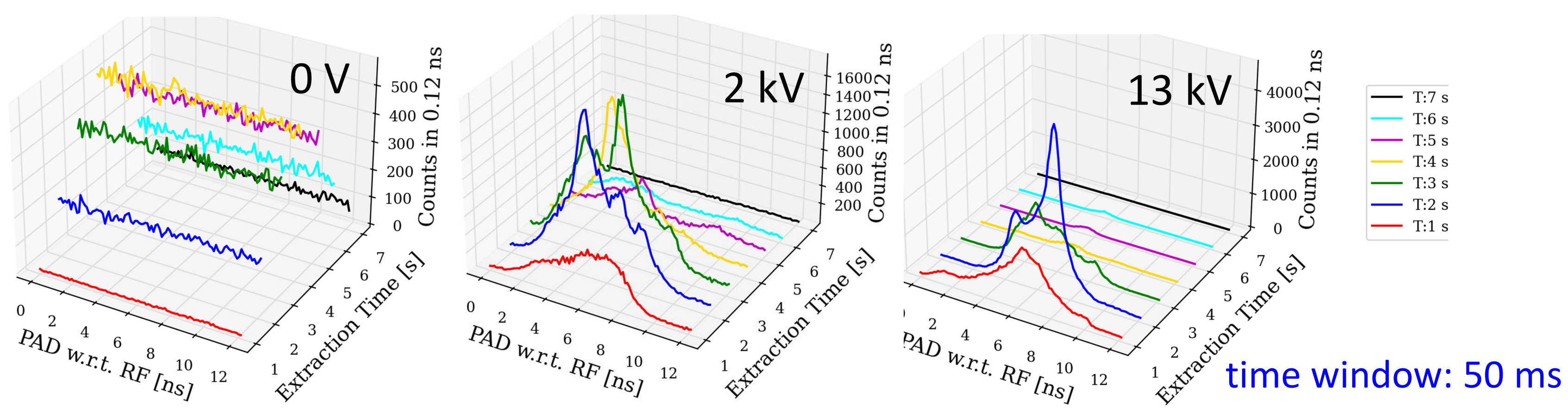
- the optimal RF voltage for spill quality, as defined by the weighted duty factor, is suggested to be 2 kV;
- agreement with the tendency of the weighted duty factors while varing the RF voltages, as reported in [3] for bunched beam slow extraction at lower frequencies.

Distribution of particle arrival times with respect to RF phase

2-dimensional distribution of P.A. with varying voltages



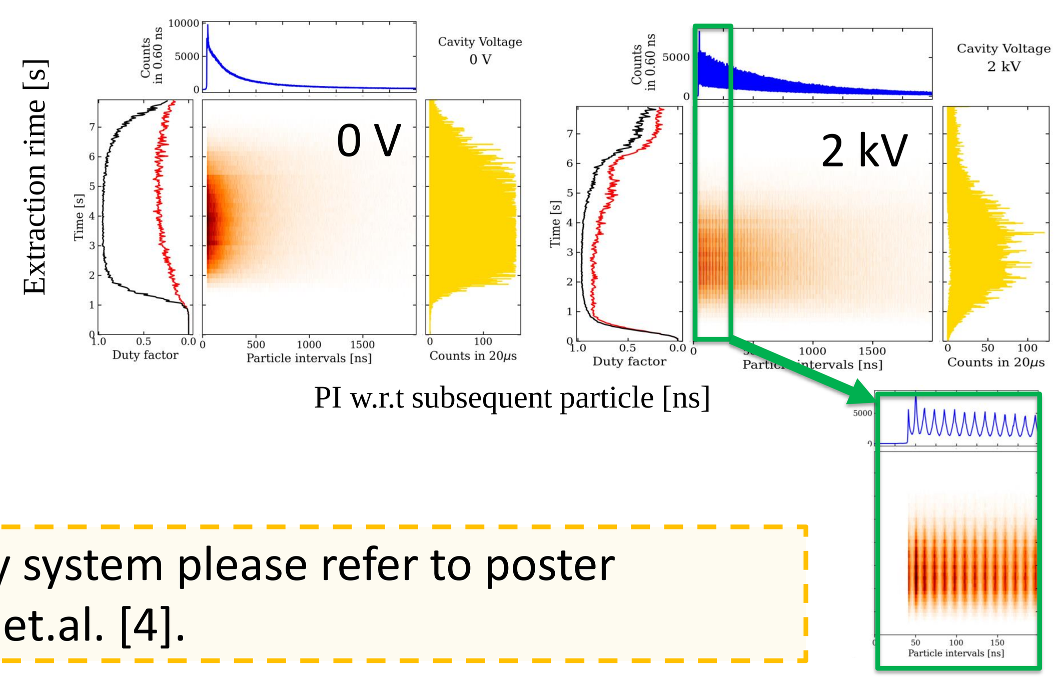
Distribution of P.A. of spill slices for measurements with typical voltages



- The standard deviation (σ) for spills extracted from bunching beam is around 2 ns;
- the shape of the distribution of P.A. changes significantly during the extraction;
- the variation of the distribution of P.A. along extraction shows different behaviours with different RF voltages;
- a possible reason for this change could be the excitation of the synchrotron-betatron resonance.

Distribution of P.I. for measurements with typical voltages

- The distribution of P.I. can be evaluated and demostrated with the TDC set up;
- sub-ns scale time scale measurement of the particles arrival time can be realized at GSI SIS18.



Commissioning of the RF cavity system please refer to poster presentation given by K. Groß et.al. [4].

Conclusion

- Two different frequencies were used for the RF cavities during the bunched beam tune scan slow extraction: about 4.85 MHz for 4 circulating bunches and about 81.44 MHz for 90 circulating bunches.
- Particle arrival times at SIS18 were measured on a sub-ns time scale and time structures were characterized. Further investigations into beam dynamics will be continued.

References

[1]. P. Forck, "Lecture Notes on Beam Instrumentation and Diagnostics", in *Joint University Accelerator School*, 2021.
[2]. T. Milosic et al., "Sub-ns Single-Particle Spill Characterization for Slow Extraction", *in Proc. IBIC'21*, 2021
[3]. S. Sorge, et. al., "Spill ripple mitigation by bunched beam extraction with high frequency synchrotron motion." Physical Review Accelerators and Beams, 2023
[4]. K. Groß et.al., "A New 80 MHz Cavity in the Heavy Ion Synchrotron SIS18", poster presentation, 5th slow extraction workshop, 2024

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