IFAST-REX: An Initiative for the Mitigation of Beam Current Fluctuations in Slow Extraction

P. Forck, R. Singh on behalf of the IFAST-REX Consortium

TUPM096 **IPAC 2023**

Abstract

Within the EU-funded project IFAST, the task REX (Resonance Extraction Improvement) was launched in 2021 as a Prototype Activity. The IFAST-REX consortium comprises hadron synchrotron facilities CERN and GSI, the European hadron therapy centers, as well as the companies Barthel HF-Technik and Bergoz Instrumentation.
It deals with the crucial challenge of slow extraction concerning mitigating current fluctuations on the time scale of typically 0.01 to 10 ms, primarily caused by magnet power supplier ripples. Higher frequency ripples due to the properties of beam excitation methods are also considered.
IFAST-REX is organized into four modules: Two modules execute the realization of a high dynamic range low-frequency current transformer and tailored high power amplifiers for beam excitation. The other two modules focus on developing simulation tools for accurate long-term slow extraction and developing diagnostics related to extracted particle detection and analysis.
This contribution summarizes the status of the consortium by indicating to selected results.
More details can be found on the contribution to this conference and previous publications.

Consortium Partners

Barthel HF Technik: M. Bathel
Bergoz Instrumentation: L. Depuy, F. Stulle, E. Touzain
CERN: P. Arrutia Suta, T. Bass, M. Cerqueira Bastos, Y. Dutheil, M. Fraser, W. Höfle, V. Kain, S. Mazzoni, I. Ortega, M. Pari, F. Roncarolo, F. Velotti
CNAO: P. Meliga, A. Mereghetti, M. Pullia
GSI: C. Cortes, P. Forck, B. Galnander, P. Niedermayer, D. Ondreka, R. Singh, S. Sorge, A. Stafiniak, J. Yang
HIT: E. Feldmeier, A. Peters
MedAustron: F. Kühteubl, Ch. Kurfürst, D. Prokopovich, C. Schmitzer, A. Wastl
MIT: T. Blumenstein
SEEIIST: E. Benedetto, R. Taylor (also CERN)

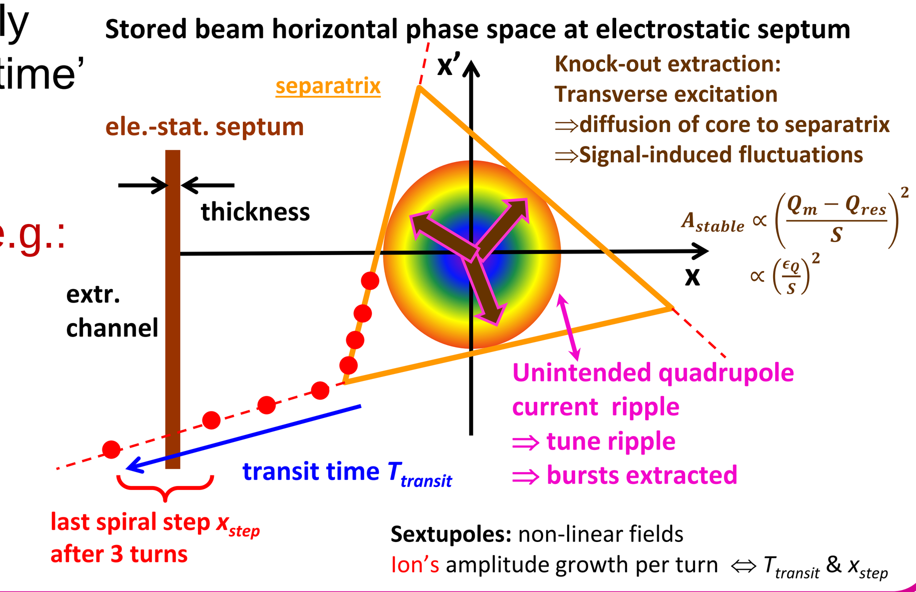
Challenge: Microstructure during Slow Extraction

Slow extraction: Gentle beam excitation at **third** order resonance within 1…10 s

- Particle crosses separatrix sequentially
- Exp. amplitude growth during 'transit time' ≈ 50…1000 turns to reach septum

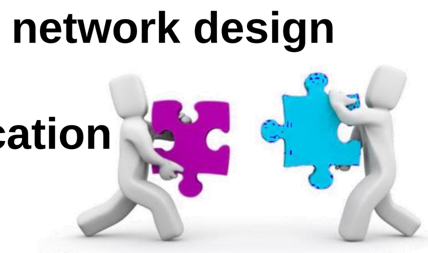
Problem:
Sensitivity to **unintended** resonances, e.g.:

- Tune variation by quadrupole ripple
- Stochastic amplitude excitation for for 'knock-out' extraction
- Varying beam conditions during spill, in particular for tune scan



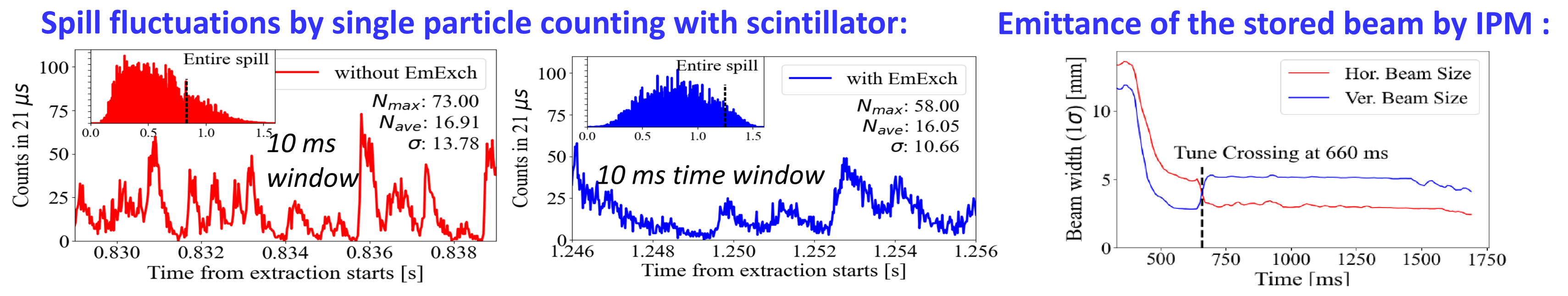
Organization: IFAST and REX Structure

IFAST = Innovation Fostering in Accelerator Science and Technology
Accelerator physics & technology project funded by European Union Horizon 2020
Duration: 4 years from May 2021 to April 2025
REX = Resonance EXtraction Improvement as Prototyping Activity
Working Group 1: chaired by F. Stulle (Bergoz)
Development of high dynamic range AC current measurement device
Working Group 2: chaired by E. Feldmeier (HIT)
Knockout extraction signal generation, amplifier & matching network design
Working Group 3: chaired by F. Velotti (CERN)
Advanced slow extraction simulations & experimental verification
Working Group 4: chaired by P. Forck (GSI)
Spill detector development and experiential analysis



Example: Improvement by Emittance Exchange

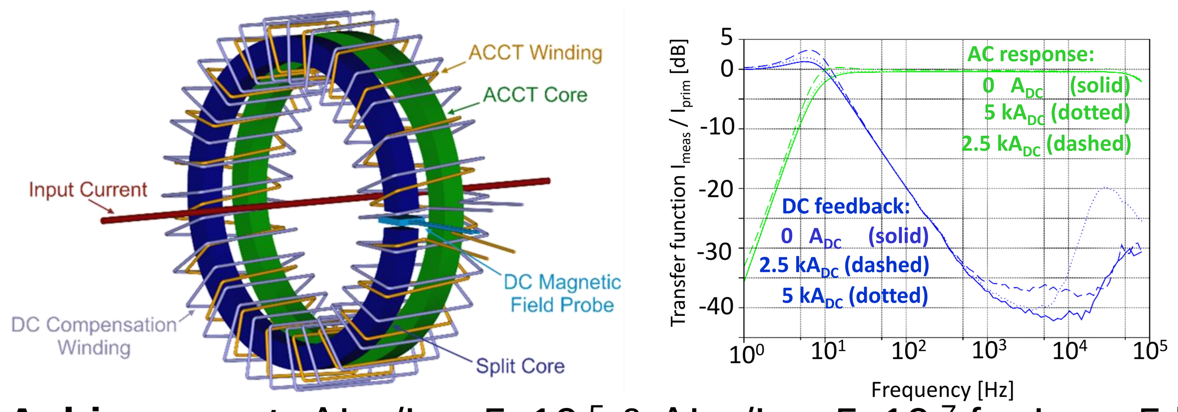
Possible mitigation of fluctuations performed at GSI for tune scan extraction:
Decrease of hor. emittance by crossing shortly a coupling resonance $Q_x = Q_y + 1$
⇒ **significant improvement**



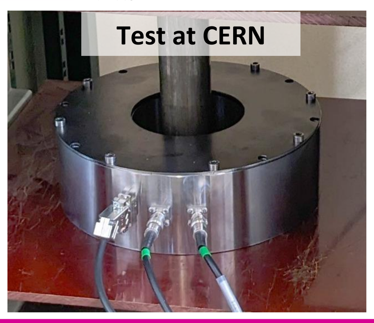
See J. Yang (GSI) et al., IPAC'23 & IPAC'22

Task WG1: AC Measurement in Presence of DC

Measure of power supplier fluctuations AC current by two transformers
Challenge: Saturation of core by high DC ⇒ **Compensation by DC winding**



Parameter	Abbreviation	Value
DC current	I_{DC}	5…10 kA
AC current	I_{AC}	≤1% I_{DC}
Bandwidth	$\Delta f = f_{max} - f_{min}$	10 Hz – 40 kHz
Resolution	$\Delta I_{AC}/I_{DC}$	~10^{-7} (!)
	$\Delta I_{AC}/I_{AC}$ for Δf	~10^{-5} (!)
Accuracy	u_i/I_{AC}	<1%

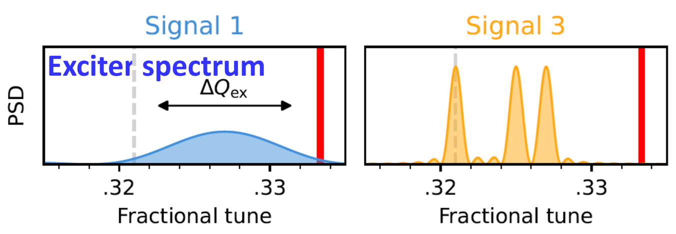


Achievement: $\Delta I_{AC}/I_{AC}$=5x10^{-5} & $\Delta I_{AC}/I_{DC}$=5x10^{-7} for I_{DC} = 5 kA

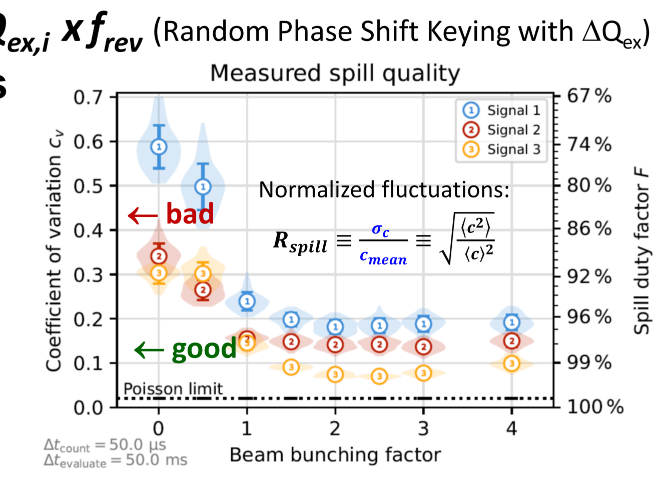
See F. Stulle (Bergoz) et al., to be published

Task WG2: Beam based Test for Exciter Spectrum

Exciter spectrum dependence at HIT for knockout extraction:
Extension of harmonics of betatron frequency $f_{ex,i} = Q_{ex,i} \times f_{rev}$ (Random Phase Shift Keying with ΔQ_{ex})
⇒ **Improvement for coasting and bunched beams**



Signal	1	2	3
$Q_{ex,1}$	--	0.321	0.321
$Q_{ex,2}$	0.327	0.327	0.327
$Q_{ex,3}$	--	1.327	1.327
ΔQ_{ex}	0.009	0.009	0.001



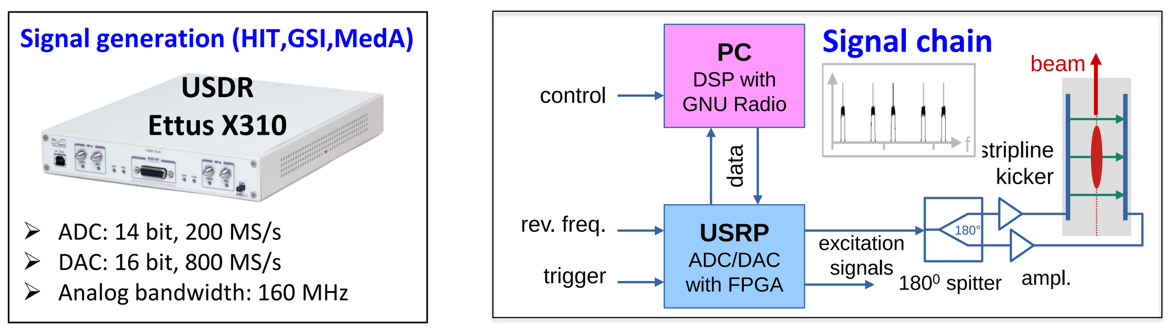
Further signals tested; confirmed by simulations

See P. Niedermayer (GSI) et al., IPAC'23, F. Kühteubl (MedA) et al., IPAC'23
E.C. Cortes Garcia et al, IPAC'22, NIM A, 167137 (2022)

Task WG2: Technical Design of Knockout Exciter Chain

Beam-based specification for optimized signal chain after experiments:

- Control by Universal Software Defined Radio USDR operated by GNURadio
- Power amplifier: broadband 0.5 … 15 MHz, 500 W, manufacturer Bathel HF Technik



Power amplifier specification

Parameter	Value
Frequency range	0.5 … 15 MHz
Output power	500 W cw
Gain	57 … 60 dB
Gai flatness	better 3 dB
Output VSWR	< 3:1
Electrode capacitance	50 pF
Matching network	1:5 for GSI
Mechanics, cooling	19" rack, air

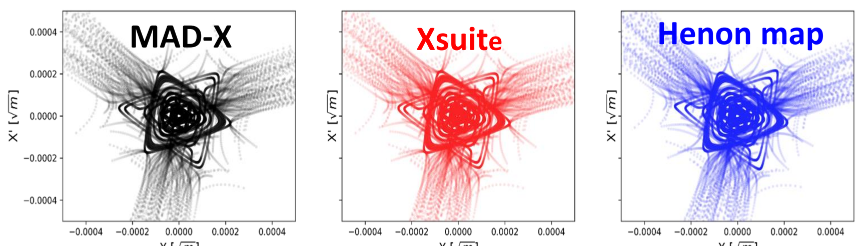
See P. Niedermayer (GSI) et al., IBIC'22, F. Kühteubl et al., IPAC'23
E. Feldmeier et al., IPAC'22, M. Barthel et al., to be published

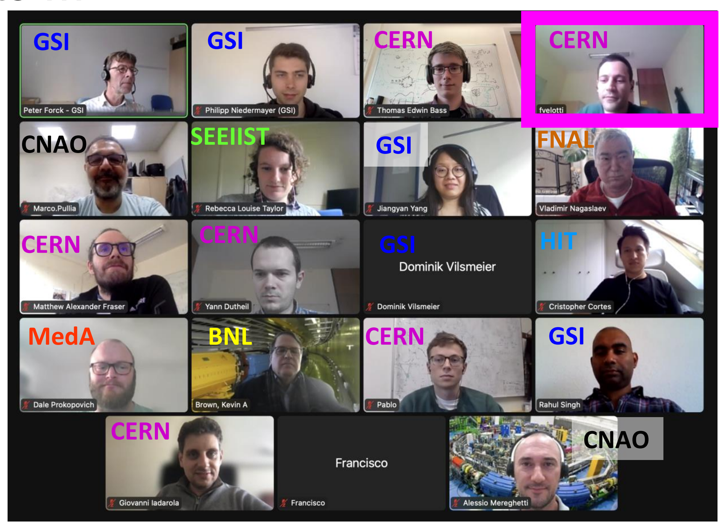
Task WG3: Simulation and Experiments

Simulations are key elements for understanding the complex dependencies

- Used codes: elegant, MAD-X, Maptrack, Xsuite …
- Particle tracking due for non-linear process
- Xsuite as novel & frequently used code
- Knowledge transfer between participants
  → Network via quarterly Zoom meeting

Example: Phase space comparison from codes:

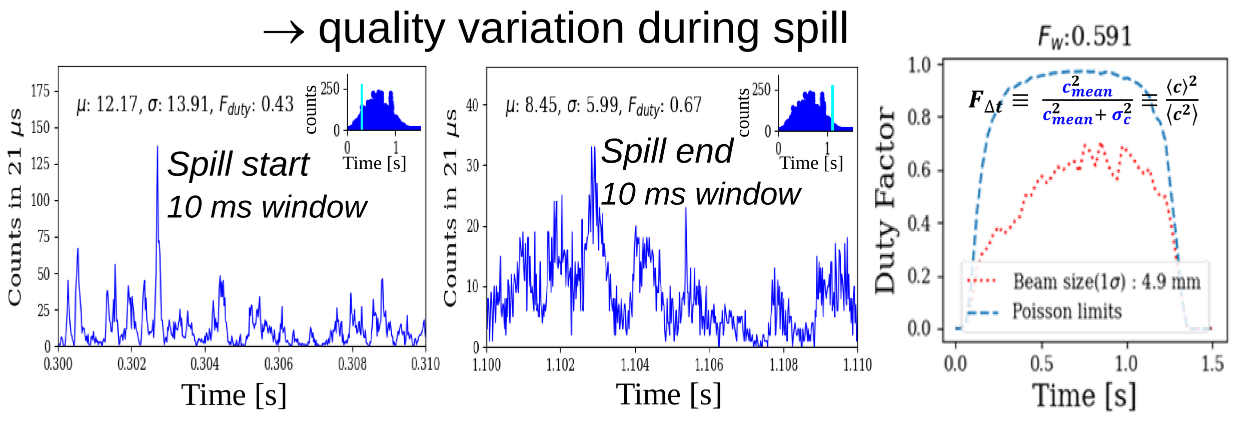




Example: Tune scan simulation for GSI (50Hz-harm.+ noise)
→ quality variation during spill

Advantage of Xsuite:

- Open source
- Usable from Python
- Input from other codes
- Operated on **G**PUs
- Adding modules possible



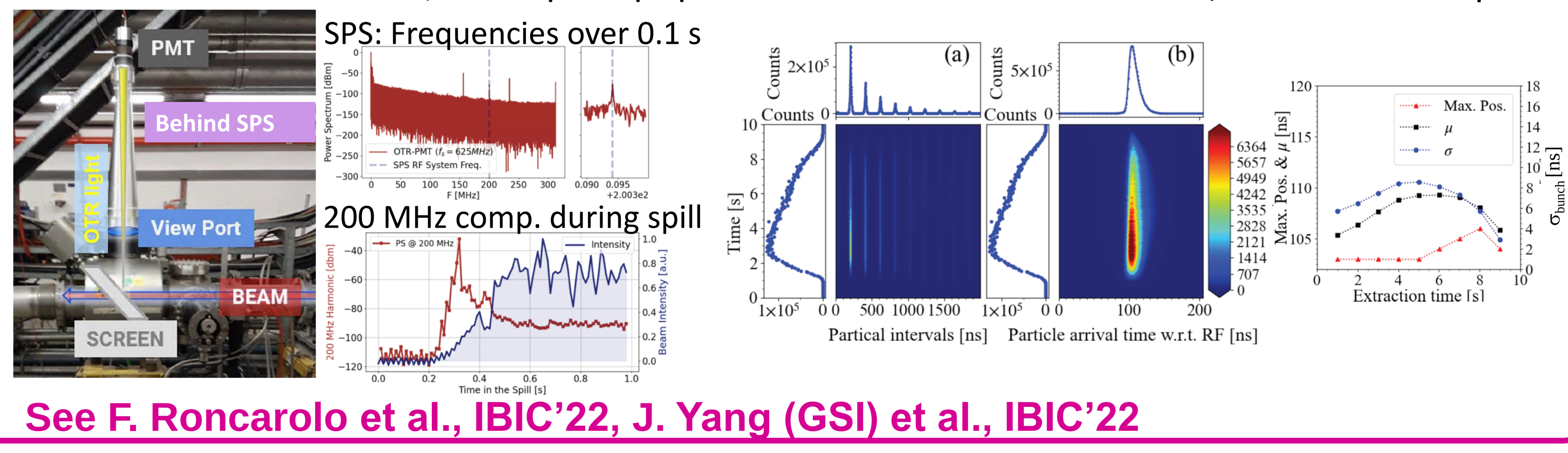
See posters at IPAC'23: P. Arrutia Sota (CERN) et al., F. Kühteubl (MedA) et al., P. Niedermayer (GSI) et al., R. Taylor (CERN & SEEIIST) et al., J. Yang (GSI) et al.

Task WG4: Detectors with high temporal Resolution

Example for particle counters for characterization of fluctuation mitigation:

Detector at CERN: OTR screen read by PMT bandwidth DC…300 MHz ;OTR is prompt process

DAQ at GSI: Single-particle arrival time by TDC for bunched beams, resolution 100 ps



See F. Roncarolo, IBIC'22, J. Yang (GSI) et al., IBIC'22

Summary & Acknowledgment

European Union funding increases knowledge transfer within this Prototyping Activity:

- Several mitigations strategies developed with the network of participants
- WG1: Technical design of power supplier AC current transformer uses novel methods
- WG2: Technical design of knockout amplifier and its control using SDR at several facilities
- WG3: Intensive collaboration for simulation work with contributions of all partners
- WG4: Development of detectors and data acquisition with high temporal resolution

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