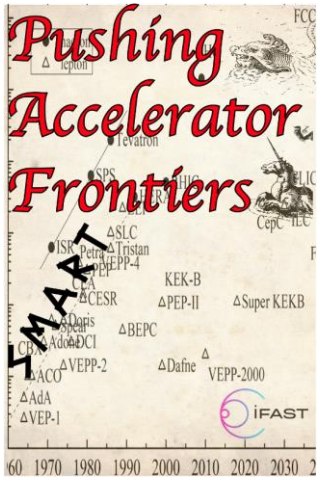


Frank Zimmermann, CERN

Peter Forck, GSI; Giuliano Franchetti, GSI

I.FAST Period 2 Review, 15.07.2024

WP5.2 & 5.3 structure and objectives

Task 5.2 Pushing Accelerator Frontiers (PAF)	**Task 5.3 Improvement of Resonant slow EXtraction spill quality (REX)**
Coordinators: Frank Zimmermann (CERN), Giuliano Franchetti (GSI)	Coordinator: Peter Forck (GSI)
CERN, GSI, CNRS, PSI + JGU Mainz	*GSI, Bergoz Inst., Barthel, CERN, HIT Heidelberg*
Significantly **improve the performance** of lepton and hadron accelerators	**Mitigate intensity fluctuations of slowly extracted beam** from synchrotrons by means of detailed parameter simulations, related experimental verifications, and **active beam control**
Identify **novel accelerator opportunities** and possible implementations	Produce a **prototype of improved hardware** for power supply control to achieve a **current stability in the range of $\Delta I / I < 10^{-6}$.**
Define a **roadmap for long-term accelerator R&D**	Design and produce a **high-performance RF-amplifier with versatile control for knock-out extraction.**

Progress of WP5.2 (PAF) activities in P2

- *Co-sponsored FCC-ee* ***Pre-Injector meeting***, *INFN-LNF, 20-21 April 2023,* https://agenda.infn.it/event/34369/
- *Topical iFAST workshop on* ***Gigahertz Rate and Rapid Muon Acceleration*** *(GR2M), Bern, 10-13 Dec 2023,* https://indico.psi.ch/event/14790 *;* 22 registered participants:: CERN (3), EPFL (3), PSI (3), ETHZ (1), Bern (1), TU Darmstadt (1), HU Duesseldorf (1), FAU Erlangen (1), LST Lisboa (1), Sorbonne (1), FNAL (1),...

Themes: (1) Dielectric laser acceleration (DLA) for single electrons – & muons too; (2) plasma wakefield acceleration for muons and pions

Upcoming WP5.2 (PAF) activities

- **“iFAST Brainstorm in Frankfurt (iBiF)” – Developing the Roadmap for Future Accelerators** – Goethe University Frankfurt, 2-3 September 2024
  https://indico.gsi.de/event/19422 *Themes: (1) review of Task5.2, (2) discussing present challenges, and discussing mid-long term concepts for accelerators. Cover quantum computers on storage rings and innovative concepts*
- “**Channeling 2024” (co-sponsored) –** Riccione, Italy, 8-13 September 2024
  https://www.lnf.infn.it/conference/channeling2024 *Themes: The use of crystals channeling in the development of a septumless slow extraction system, is essential for the SHIP experiment, but also for all slow extraction schemes.*
- **“SC2024” (co-sponsored) –** Dong Guan, China, 11-13 September 2024 https://indico.ihep.ac.cn/event/21466/
  Themes: (1) space charge effect on beams and resonant effects; (2) status of Chinese high-intensity facilities; (3) status of the studies and machine experiments, and codes; (4) state of the art of brightness beam: cooling review and perspectives
- **“AHIPS” – Advances in High-Intensity Positron Source Physics and Technologies,** Paris, France, 23- 25 October 2024, https://indico.ijclab.in2p3.fr/event/10644 Themes: High-Energy Positron Sources, Low-Energy Positron Sources and Physics Applications, High-Power Target Technologies, Polarized Positron Sources and Applications, Novel Approaches, Positrons in a Plasma Wakefield Accelerator, PWA-based Applications, Advanced optimization and Machine Learning Applications for Accelerators
- **SRGWmb2024 – Storage Rings & Gravitational Waves – mini brainstorm**, CERN, Switzerland, end ’24 or start ’25
  Themes: (1) catalyzing expert synergy to brainstorm on the potential use of storage rings in detecting GW. (2) disentangling the basis for the beam dynamics in the presence of GW.

6th Workshop on Space Charge

第六届空間電荷效應國際研討會

Chairs:
Sheng Wang (Workshop Chair)
Giuliano Franchetti (Program Committee Chair)

Richard Abram Baartman, TRIUMF
Hannes Bartosik, CERN
Oliver Boine-Frankenheim, GSI
Alexey Burov, FNAL
Yuan He, IMP
Dong-O Jeon, IBS
Shinji Machida, ISIS
Kazuhito Ohmi, KEK
Ji Qiang, LBNL
Jiancheng Yang, IMP
Yaoshuo Yuan, IHEP
Frank Zimmermann, CERN

Dong Guan, China, 10–13 Sep.2024
Coordinator: Yaoshuo Yuan ysyuan@ihep.ac.cn
https://indico.ihep.ac.cn/event/21466/

Hosted by IHEP and IMP, CAS

iFAST

HFHF
Helmholtz Forschungsakademie Hessen für FAIR

BrainStorm@GoetheUniversity
Roadmap for Future Accelerators
2nd-3rd September 2024
Campus Riedberg, Frankfurt a.M.
https://indico.gsi.de/event/19422/

Ralph Aßmann	**GSI**
Christian Carli	**CERN**
Iryna Chaikovska	**IJCLab**
Bernd Lorentz	**GSI**
Giuliano Franchetti	**GSI/IAP/HFHF**
Florian Hug	**J. Gutenberg Uni**
Rasmus Ischebeck	**PSI**
Anke-Susanne Müller	**KIT**
Holger Podlech	**Goethe Uni/HFHF**
Frank Zimmermann	**CERN**

Deliverables and Milestones in P2

Task 5.2

Milestone MS18:

Present and future AI accelerator applications

due in M24, 30/04/2023

Report *delivered & approved*

latest & future milestones & deliverables

Month 24/25 – milestone MS18

Task 5.2 Milestone MS18:
Present and future AI accelerator applications
Delivered 31/05/2023

I.FAST
Innovation Fostering in Accel
Horizon 2020 Res

accelerator
ications

MILESTONE: MS18

Document identifier:	IFAST-MS18
Due date of deliverable:	End of Month 24 (30 April 2023)
Report release date:	31/05/2023
Work package:	WP5: R&D Strategies
Lead beneficiary:	PSI
Document status:	Final

ABSTRACT

Based on presentations and discussions at two iFAST workshops, we review and classify present-day applications of artificial intelligence and machine learning in the field of particle accelerators, illustrating the various types of deployment and their demonstrated merits by way of example. Extrapolating ongoing trends and sketching possible future developments, we formulate a few open questions, and issue R&D recommendations. In particular, we suggest the construction of a testbed for self-controlling complex accelerators.

Upcoming

Month 42 (Oct '24) – deliverable 5.2

D5.2: Roadmap for future accelerators

Strategy for intense positron sources; R&D plan towards ultimate beams; State of the art and possible directions for crystalline beams; Strategy and requirements for EDM ring or other precision experiments; Roadmap for accelerator AI; State of the art and future roadmap for green accelerators

addressed by iBiF, Channeling2024, AHIPS

Upcoming

Month 48 (Apr '25) – milestone MS19

Ultimate hadron-beam brightness

addressed by SC2024

Relevance of WP5.2 (PAF) objectives & impact

- *Machine learning, dark sector searches, and sustainable accelerators (ERLs, GF, …) are attracting ever larger interest in the community; SMART-PAF is developing roadmaps and guidance*
- *Efficient e+ production is important for future e+e- Higgs factory of any flavor*
- *We further explore intriguing far-future possibilities, such as quantum computing, gravitational wave detection, and energy production using storage rings*

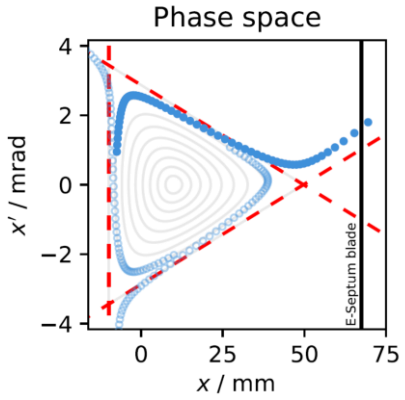
Progress of WP5.2 (REX) activities in P2

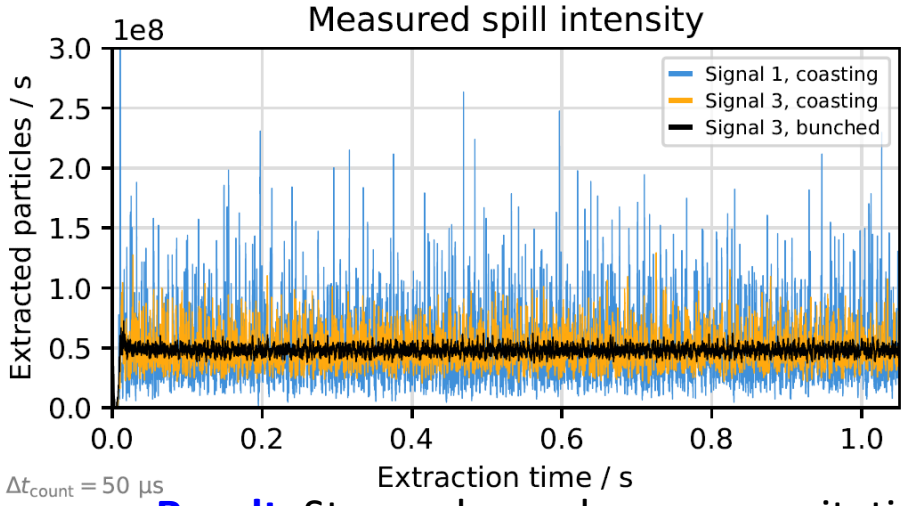
Experiment: Knock-out Extraction Signal Spectrum Dependence

Topic: Spill micro-structure dependence for knock-out extraction by HIT & GSI with contributions by CERN and MedAustron

Excitation spectrum influences:

- Separatrix crossing
- Diffusion from the beam towards core

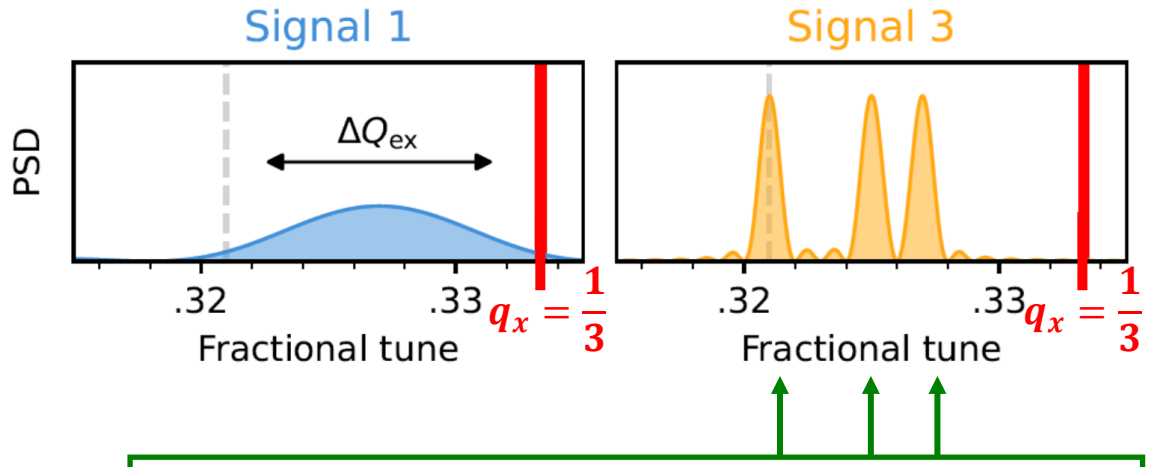




Horizontal tune at HIT Q_x= 1.6789 at end of acceleration

Excitation close to tune & harmonics $f_{ex,i} = Q_{ex,i} \times f_{rev}$

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



Result: Strong dependence on excitation spectra

⇒ **Optimization performed in 2023 (HIT, GSI, MedA)**

- Versatile signal generation
- Large power and bandwidth from amplifier

Improvement by multi-band excitation !

E.C. Cortes Garcia et al. IPAC'22 &
E.C. Cortes Garcia et al. NIM A 167137, 2022
P. Niedermayer el. al. IPAC'23

Experiment: Extension for Control of Knock-out Excitation

Topic: Feedback for macro-spill improvement

by GSI with contributions by HIT

Technology can be further used for feedback on 1 ms range

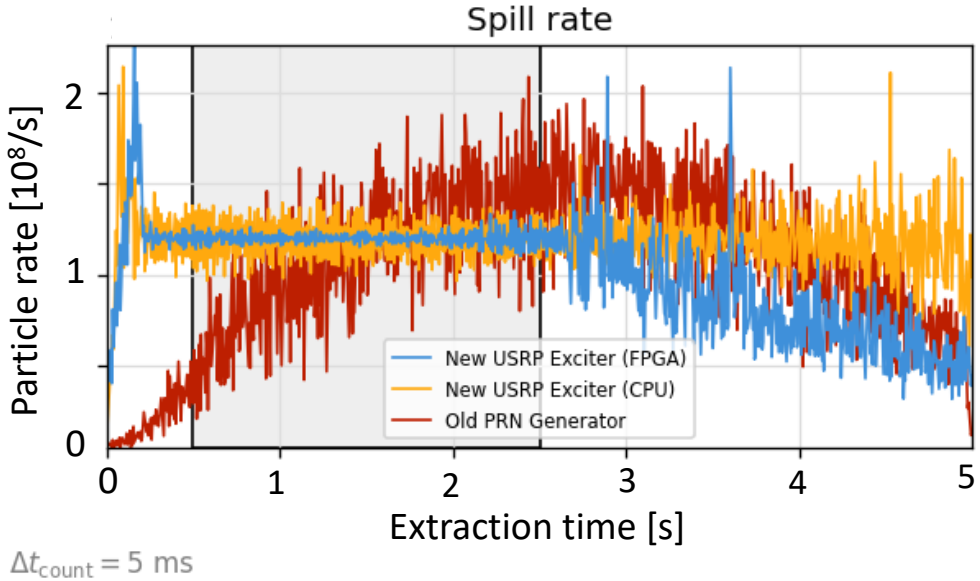
Control hardware & software: Feedback loop on USRP:

- ➢ Shift of several application to FPGA

⇒ Latency significantly improved to 30 µs

⇒ 300 Hz overall bandwidth **achieved**

⇒ Contribution to GNU-based software by GSI



$\Delta t_{count} = 5$ ms

GSI: Feedback plus improved Noise++:

⇒ Significant improvement for micro- & macro spill **achieved**

⇒ Automated parameter optimization successfully **tested**

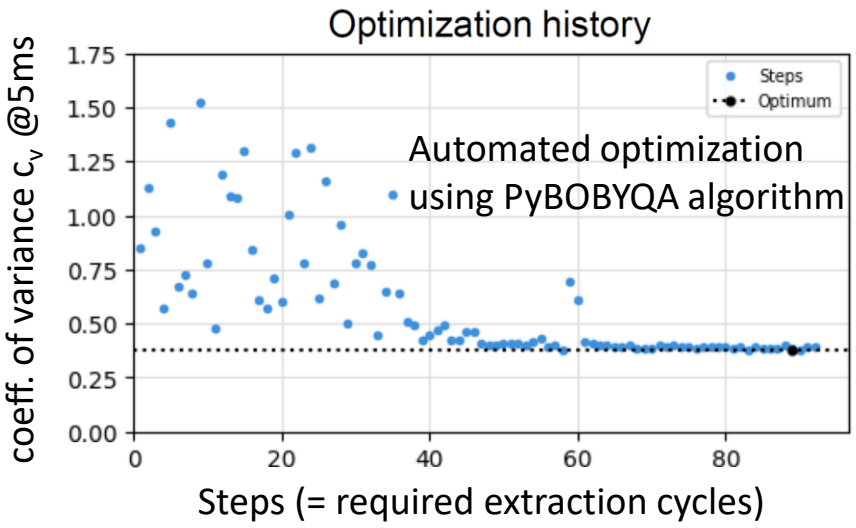
⇒ In **first operational stage** at GSI now

HIT: Feedback plus improved Phase Shift Keying BPSK:

⇒ Comparable system at HIT in **operation**

However, less performant due medical device requirements

⇒ **Milestone & deliverable for rf-control exceed**



Transformer for Power Supplier: Solutions and Achievements

Technical development by company Bergoz Instrumentation plus GSI & CERN

Accelerator physics: Spill fluctuation caused by quadrupole current ripple, i.e. **AC ripples** I_{AC} , bandwidth 10 Hz…40 kHz

Topic: **High dynamic range** current measurement device providing $\frac{\Delta I_{AC}}{I_{DC}} \approx 10^{-7}$ (!) in the presence of $I_{DC} \approx 1$ kA

Methodology: Production of large dynamic range AC current measurement device by company Bergoz

Novelty: **Additional** AC transformer for 10 Hz…40 kHz

Sensitivity for AC part: $\frac{\Delta I_{AC}}{I_{AC}} \approx 10^{-5}$

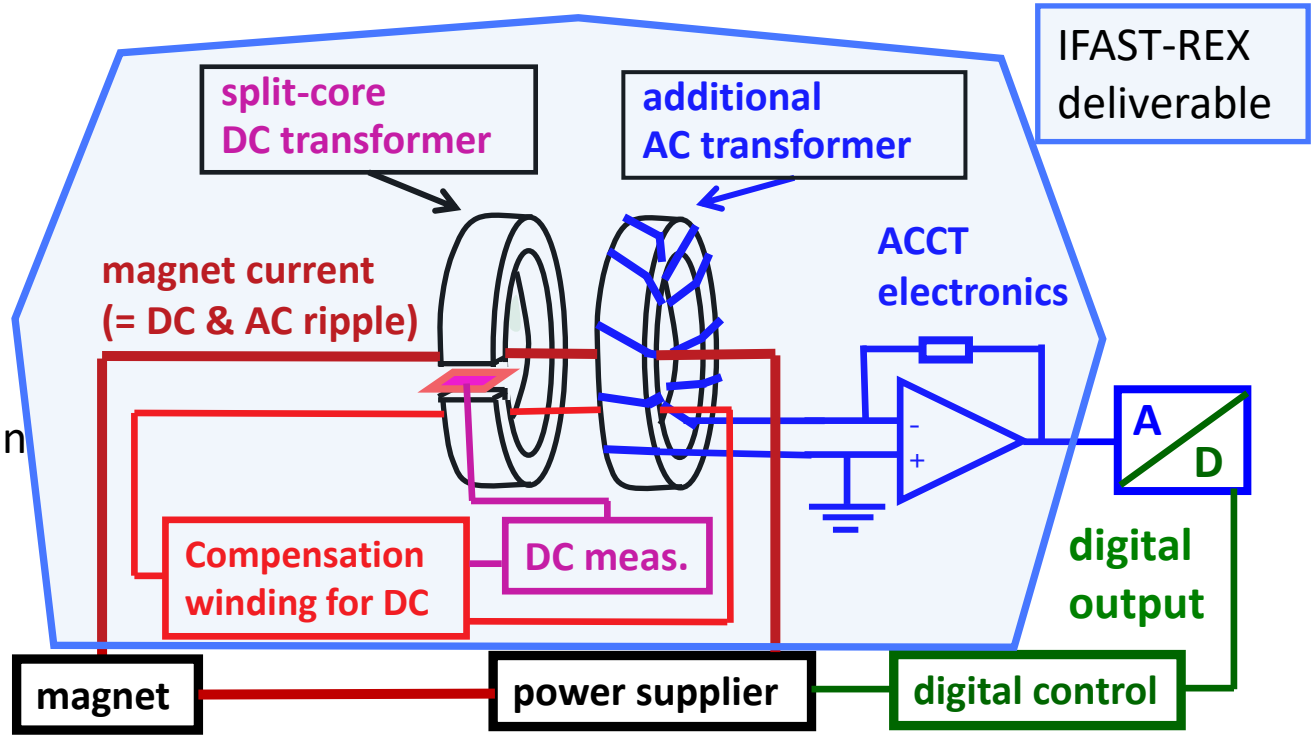
Challenges: AC-component on strong DC offset

$\Rightarrow$ magnetic core saturation for $I_{DC} \gtrsim 10$ A

Solution: Two transformers

- **DC** transformer measures I_{DC} & used for compensation

  compensation accuracy $\Delta I_{\mathrm{DC}} \approx 1\mathrm{A} \Leftrightarrow \frac{\Delta I_{\mathrm{DC}}}{I_{\mathrm{DC,max}}} \lesssim 10^{-4}$
- **AC** transformer for ripple measure I_{AC}
- **Milestone MS20 (May 2023) reached**



Status and Summary for IFAST-REX

Novel transformer:

- Successful proof-of-principle, specification almost reached, optimization almost finished

Knock-out extraction control and amplifier:

- Rf-amplifier manufactured; speciality: broadband gain-flatness & immunity against reflections suited for capacitive load
- Control by versatile capability of SDR implemented, contributions to GNU-based software

Experiments, simulation, and interpretation:

- **Ground-breaking experiments performed with dedicated excitation and feedback & broad to operational usage**
- Further experiments performed at several facilities, significant improvements demonstrated and operational
  e.g. CERN & MedAustron: Empty bucket channelling, COSE, rf-knock-out; CERN & GSI: Diagnostics improvements
- Usage of Xsuite by most members ⇒ advantage for networking
- Network with intensive discussion between participants

⇒ Milestone MS20 reached and reported in May 2023 (month24)

⇒ On very good track for Deliverable D5.3 in Feb. 2025 (month46)

IFAST-REX contributes significant to technical developments and networking !

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Relevance of WP5.3 (REX) objectives & impact

- **Modelling of slow extraction significantly improved:**
  - Performed by traditional tools like MAD-X and modern frame Xsuite
  - Intensive discussion on beam physics close to a 3rd-order resonance
  - Intensive exchange of knowledge between participants
- **Common experiments at various facilities and verification of improvements:**
  - Significant mitigations of beam current fluctuations achieved and interpreted
  - Good collaboration & cooperation between participants
- **General technical developments:**
  - Extreme high dynamic range ac-current measurement
  - Versatile, user-friendly rf-signal generation with GNU-Radio
  - Detector development for high count rate and related data management

⇒ Significant mitigations concerning beam current fluctuation achieved

⇒ General progress concerning technologies for measurements and accelerator control i.e. better beams for experiments and cancer treatment patients

⇒ Project in good swing thanks to motivated participants, further key results expected …

iFAST

Thank you for your attention!

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.