Accelerator Innovation Pilot Project Proposal Form

Short title of proposed action: Improvement of slow extraction spill quality

Type of action (Strategy / Development / Prototype): Prototype

Name and Affiliation of main proposer: Peter Forck, GSI

E-mail of main proposer: p.forck@gsi.de

Requested EC contribution (in k€): 500

Adjusted version as of December 13, 2019

Please send your proposal to Accelerator.Innovation@cern.ch before August 31, 2019

A. General Information

Type of action proposed *(Strategy/Development/Prototype) Prototype*

Duration *(must be between 12 and 48 months) 48 months*

Short title / Acronym **Improvement of slow extraction spill quality**

Title *Slow extraction spill quality improvements by mitigation of inherent current fluctuations and knock-out excitation optimization*

Abstract

(max. 600 characters including spaces)

There is a consistent increase in requests for reduction of slowly extracted beam current fluctuations from several accelerator facilities which arises from magnet power supply ripples. These demands are driven by improvements in detector response times at user facilities and the spill quality requirements associated with ion therapy synchrotron centres. This proposal intends to assimilate and prototype the ongoing efforts at the partner facilities for countering the power supply ripples by either cancelling the ripples with feedback systems, introducing transit time dependent tune modulation or developing improved knock-out hardware and waveforms.

Main proposer (contact person for the action)

(Peter Forck, GSI, p.forck@gsi.de, present deputy Rahul Singh, GSI, r.singh@gsi.de)

Participating institutions and contact persons *(complete the Table below)*

	Name	Short name	Country	Contact Person	Institution Type*
1	GSI Helmholtz Centre for Heavy Ion Research	GSI	DE	P. Forck, R. Singh	Laboratory
2	Conseil Européen pour la Recherche Nucléaire	CERN	-	B. Goddard	Laboratory
3	Marburg Ion Therapy Centre	MIT	DE	U. Scheeler, C. Krantz	Industry
4	Heidelberg Ion Therapy Centre	HIT	DE	A. Peters, E. Feldmeier	University
5	Centro Nazionale di Adroterapia Oncologica	CNAO	IT	M. Pullia	Laboratory
6	Med-Austron	MedA	AT	P. Urschuetz	Laboratory
7	South-east Europe International Institute for sustainable Technology	SEEIIST	MN	S. Damjanovic	Laboratory
8	Barthel HF-Technik GmbH	BT	DE	M. Barthel	Industry
9	Bergoz Instrumentation	BI	FR	F. Stulle	Industry

Theme

Indicate to which of the following R&D themes your action belongs:

___ Accelerator designs and new concepts
___ New techniques for high-gradient acceleration
___ Societal applications of accelerators
___ Advanced magnet technologies
___ Radio-frequency technologies (acceleration and sources)
___ Particle Sources
_Y_ Diagnostics, instrumentation and control
___ Sustainability of accelerator and technology infrastructure
___ Other (specify:________________________________)

B. Scientific and technological excellence

Describe your proposed action, indicating in particular the problem or limitation that your action will address, how it will allow going beyond the present state of art, and (for developments/prototypes) the Technology Readiness Level resulting from your action. (max. 3500 characters including spaces, corresponding to about 1 page)

The control of fluctuations in slowly extracted spill mainly arising from minuscule current fluctuations (typical value $\Delta I/I = 10^{-5}$) in the magnet power supplies has found increased attention at several facilities as relevant for various beam properties. This task is in R&D stage and has been widely discussed in specialized workshops in the past 3 years [indico.fnal.gov/event/20260/, indico.cern.ch/event/639766/, indico.gsi.de/event/4496/] covering technical requirements in connection with beam physics issues. The time scale of interest in the operational ion therapy patient treatment centres is 100 µs - 1 ms and the demand on the smoothness of the spill is stringent (maximum-to-mean ratio smaller than 1.5). For experimental beam users, the tolerance of spill fluctuations is higher in comparison to therapy machines. Still, the useful event rates, and thus the beam time requirements, have been found to be correlated to the spill quality [R. Singh et al., arxiv.org/abs/1904.09195v2]. For some user facilities like CERN and GSI, the improvements of experimental electronics have extended the detector response times into ~ ns scales, making some experiments sensitive to spill fluctuations up to 100 MHz. For these experiments many of the earlier “rf cavity” based spill smoothing methods had become obsolete as they imprint unwanted MHz-scale structure.

We propose a four-pronged approach towards a significant improvement:

1. The first approach is to build a measurement device, which can reliably measure magnet current ripples in the $\Delta I / I < 10^{-6}$ regime. This prototyping activity will be performed in association with the industrial partner Bergoz Instrumentation, which is the industry leader in high sensitive beam current transformers. The measured

current fluctuations will be countered using a feedback or feedforward system and the efficacy on the spill structure will be demonstrated.

2. The second approach is, to identify spill-smoothing mechanisms based on slow extraction mechanism itself, with the help of comprehensive particle tracking simulations along with accurate modelling of all the extraction section components. As an example, recently simulation based optimization of machine settings led to significant improvement of the spill structure at GSI's SIS-18 [S. Sorge et al., IPAC2018]. Additionally, feedforward systems are used at CERN to reduce spill ripple [F.M. Velotti et al., IPAC 2018]. These lines of investigations along with simulations will be intensified.
3. The third approach involves the knock-out extraction scheme. It is the workhorse extraction mechanism at most ion therapy centres and the future GSI's SIS-100, but there are limited studies on the effect of excitation waveform on spill structure. This part of the project will study the knock-out spill quality in simulations and the appropriate waveforms will be proposed [C. Krantz et al., IPAC2018]. The hardware of generator for the optimal waveforms, along with amplifiers will be realized in association with the industrial partner Barthel HF-Technik GmbH (specialized on high performance rf-amplifiers).
4. The final item is the development of appropriate particle detectors and the online data analysis, which can operate in a large dynamic range and provide online spill characterization in order to quickly assess the spill quality for variety of beams at the involved facilities.

At least the Technology Readiness Level 6 will be reached, but 7 might be possible in terms of a fully operational system at one facility.

C. Impact

Describe what will be the impact of your action on present or future accelerator-based Research Infrastructures and/or on society. Wherever possible, use measureable criteria. (max. 1500 characters including spaces, ½ page)

The outcome of this work will have a significant impact on the operational output of the present and future accelerator facilities, which utilize slow extraction. For the example at GSI there is an expectation of a factor 3 increase in the detector event rates if the spill structure approaches Poisson limit in the currently operational facilities for physics experiments. This inversely correlates with the amount of beam-time requested for a certain experiment and therefore constitutes a large impact of all user experiments. For the ion therapy machines, the average extracted beam current from the synchrotron can be increased, more smoothed on a long time scale while the reduced short-term fluctuations lead to less interlocks, reducing significantly the treatment times for patients. For the

planned facility SEEIIST the application at a small super-conducting synchrotron will be incorporated in the investigations as well.
The investigated methods and achievements will be documented in detail in terms of simulation results, experimental verification and technical design documents. There will be a worldwide impact from these studies e.g. for facilities like Fermilab or J-PARC where some related efforts are ongoing [see e.g. D. Naito et al., Phys Rev. Accel. Beams 22, 072802 (2019)].

D. Methodology

Describe how your action is going to be organised and implemented. Indicate what will be the role of the different partners, in particular for industry.
(max. 1000 characters including spaces)

The action is organized into six items each led by one of the partners:

1. Development of sensitive power supply AC current measurement device: Bergoz Instrumentation in collaboration with MedA
2. Development of feedback/feedforward system, which can cancel the effect of power supply ripples on beam: CERN
3. New methods for better spill structure and extraction efficiency with accurate slow extraction simulation models for quadrupole driven and knock-out extraction: GSI in collaboration with CERN
4. Development of efficient waveforms for knock-out extraction and related hardware: Barthel HF-Technik in collaboration with the MIT, HIT, CNAO and MedA
5. Demonstration of ripple cancellation in effect of action items (1-3): GSI, CERN, HIT, MIT, CNAO and MedA (i.e. experimental demonstration are possible at all facilities)
6. Development of detectors and relevant software to quantify the improvement of spill for a large dynamic range of beam intensities: GSI

E. Schedule and Deliverables

List in the Table below the main deliverable(s) of your action and the time required to achieve them from the start of the project. Suggested: one Deliverable for Developments, two or more for Prototypes and Strategies.

	Deliverable description	Month
1	**Technical developments:**	
	1. Current measurement for $\Delta I / I < 10^{-6}$	
	a) Feasibility study with Mock-up / model	12
	b) Device prototype	24
	2. Matched rf amplifier prototype incl. versatile control	24
	3. Detectors software for online spill characterization	24
2	**Beam physics:**	
	Slow extraction simulation for quad-driven and knock-out with	36

	coasting and bunched beams incl. experimental validation	
3	**System commissioning:** Demonstration of operational usage and demonstration of ripple cancelation with beam	48

F. Potential risks and mitigations

Indicate the main potential risks related with the implementation of your action and the mitigations that you foresee (suggested between 1 and 4 risks) – please note that we understand that this is a high-risk R&D programme and that some risks may have no mitigation within the project.

	Potential Risk	Mitigation
1	Unavailability of experimental beam-time in the planned facility	Possibility to conduct experiments in other partner facility with re-installation of the equipment and modified simulations
2	No possibility to feed signals to existing magnet power supplies	Installation of extra air-quadrupoles in the synchrotron
3	Bergoz Instrumentation: no technical solution to measure current ripples at $\Delta I / I < 10^{-6}$	"Go on/stop" Review at month 8, with definition of new objective for BI in case of a "stop" decision

G. Continuity with previous EC-funded activities

In case your action is related to activities previously funded in the frame of European Scientific Programmes (Horizon2020, FP7, etc.), indicate the programme, the name of the project and the relation.

The topic was not funded before by those programmes.

H. Tentative Budget

Indicate in the Table below an estimate of the budget required to execute the action (one column per participant), and calculate the corresponding funding rate (last line):

In this project Beneficiaries and Associated Partner are foreseen. Both groups have the same rights within the consortium (e.g. the Consortium Agreement is signed by all partners and they are represented within the Governing Board). For the Associated partners the budget transferred from the EC is organized via GSI. The two tables contain the budgets for the Beneficiaries and the Associated Partners, respectively.

Beneficiaries:

			GSI	*CERN*	*HIT*	*BT*	*BI*	**Totals**
A	Personnel and travel costs	k€	310	100	100	200	200	910
B	Material and other costs	k€	70	20	20	40	40	190
C	**Requested EC contribution Incl. budget for Ass. Partners**	k€	**190**	**60**	**60**	**95**	**95**	**500**
	Funding rate F=C/(1.25*(A+B))		40%	40%	40%	31.6%	31.6%	36.4%

Associated Partners:

			MIT	*CNAO*	*MedA*	*SEEIIST*
A	Personnel and travel costs	k€	30	30	30	20
B	Material and other costs	k€	10	10	10	0
C	**Requested EC contribution including overhead costs**	k€	**20**	**20**	**20**	**10**
	Funding rate F=C/(1.25*(A+B))		40%	40%	40%	40%
	Available budget from requested EC contribution Without overhead costs	k€	15	15	15	7.5

Remarks:

- The requested EC contribution for the Associated Partners is organized via a contract between the individual Associated Partners and GSI.
- The requested EC contribution for GSI includes the requested EC contribution from the Associated Partners. It consists of 120 k€ directly for GSI plus 3 times 20 k€ for MIT, CNAO and MedA plus 10 k€ for SEEIIST; the sum is 190 k€.
- The costs A and B are added correspondingly to the requested EC contributions. It amounts for the Personnel and travel costs to 200k€ + 3x30k€ + 20k€ = 310k€ and for material and other costs to 40k€ + 3x10k€ + 0k€ = 70k€.
- GSI will retain the overhead cost of the Associated Partners; the overhead costs are 25 % of the requested EC contributions. It consists of 3 times 5 k€ for MIT, CNAO and MedA plus 2.5 k€ for SEEIIST; the sum is 17.5 k€. The budget for the four medical facilities is correspondingly lower. The last line ‘Available budget from requested EC contribution without overhead costs’ corresponds to the budget available of each Associated Partner.

Notes to the budget Table:

1. *The numbers in the Table have to be intended as **preliminary.** If the proposal is accepted, the proposers will be able in the final preparation phase to modify costs, budget share and number of participants <u>within a reasonable range</u> (i.e. without affecting the main features of the proposal). Modifications to the total EC contribution will not be allowed.*

2. *The **funding rate** F = EC_contribution / (1.25*(sum of columns A + B)) is the ratio between EC contribution and total cost of the action. The latter is calculated as sum of all costs with the flat 25% overhead of Horizon 2020. We expect the funding rate F to be of the order of 50% as in previous EU accelerator projects, although different ratios can be accepted, in particular for industrial partners. In the evaluation, some priority will be given to projects raising a high amount of matching funds from the partners.*

I. Final remarks

Provide any additional information that might be useful in the evaluation of your action.