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

IFAST Prototyping Activity **REX**

Resonant **EX**traction Improvement

Work Package 5 Task 3

Kick-off meeting / 4th of May 2021

Peter Forck and Rahul Singh, GSI

Consortium:

barthel HF-Technik, bergoz INSTRUMENTATION, CERN, CNAO Centro Nazionale di Adroterapia Oncologica, GSI, HIT Heidelberger Ionenstrahl-Therapiezentrum, MedAustron, MIT Marburger Ionenstrahl-Therapiezentrum, SEE IST

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Challenges for slow Extraction form Synchrotrons

Slow extraction: Gentle excitation of a beam **third** order resonance

Beam physics: Extraction as 'slow losses' for 1 … 10 s

- Particle crosses stability boarder sequentially
- Exponential amplitude growth during 'transit time'
  ≈ 50 … 1000 turns reaching septum and is extracted

Problem: Sensitivity to any **unintended** resonance condition, e.g.:

- Change of tune: unintended quadrupole current ripple
- Change of excitation strength: sextupole current ripple
- Stochastic amplitude excitation of 'knock-out' extraction

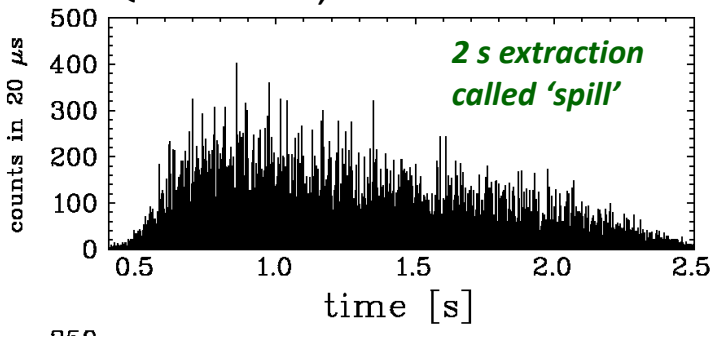
Mitigation research within IFAST-REX:

Beam physics: Methods for beam sensitivity reduction
Proposal of non-standard excitation methods
⇒ Extensive simulation of extraction process

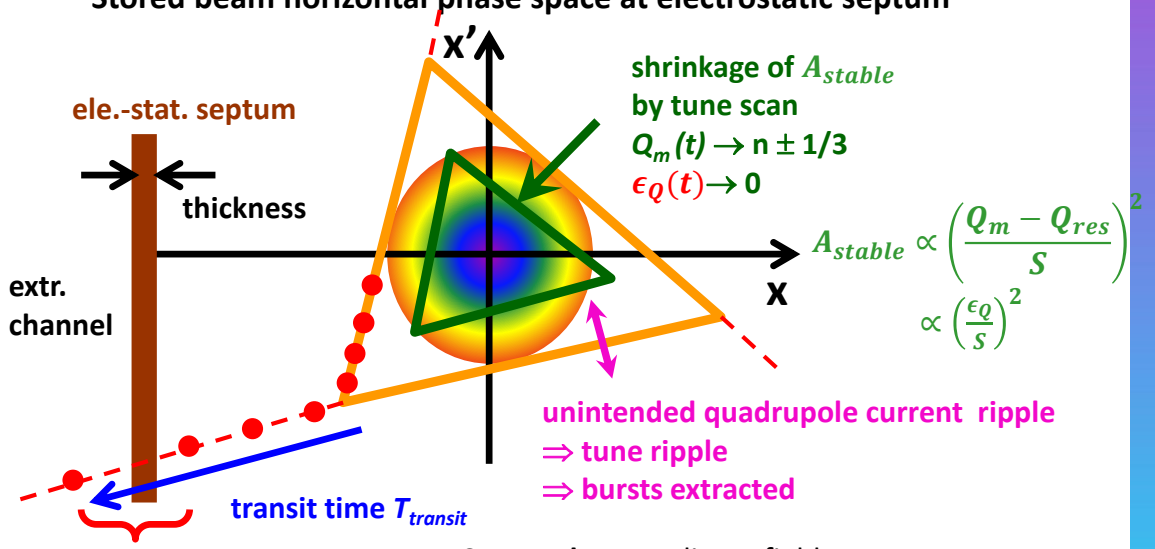
Technical installations: Improved power supplier for magnets
Improved transverse particle excitation for knock-out extraction
⇒ Non-standard power converter and rf-amplifier control

Validation: Experimental validation at all facilities
Tailored improvements for IFAST-REX participants

***Example*:** C^{6+} at 300 MeV/u
Quad. scan, un-bunched beam



Stored beam horizontal phase space at electrostatic septum



Sextupoles: non-linear fields
Ion's amplitude growth per turn
⇔ $T_{transit}$ & x_{step}

Example for 'Spill Micro-Structure' for a coasting Beam

Slow extraction: Gentle Excitation of a beam **third** order resonance

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  ≈ 50 … 1000 turns reaching septum and is extracted

Problem: Sensitivity to any disturbance of resonance condition

***Example*:** C^{6+} at 300 MeV/u
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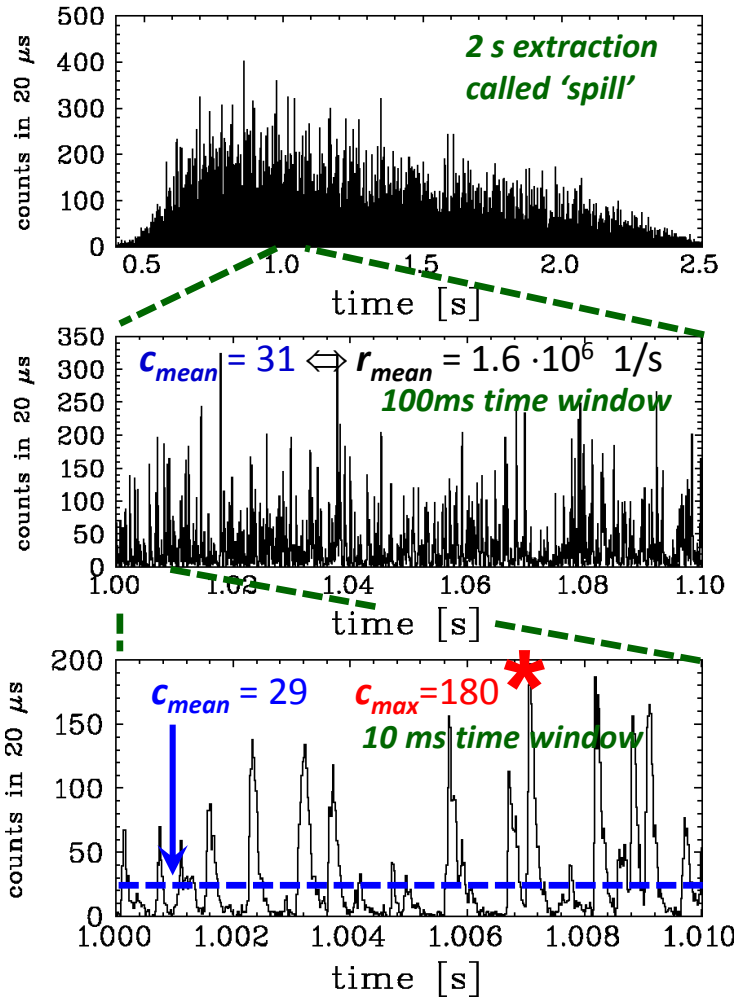


Time domain characterization:

Spill characterization readout time $t_{read} = 20\ \mu s$

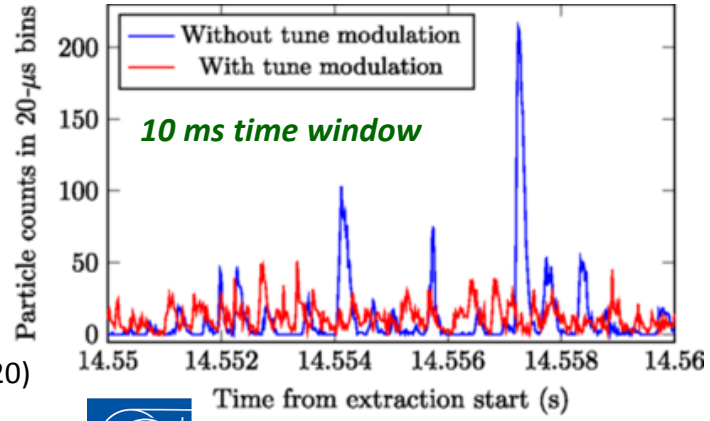
→ Time intervals of e.g. Δt = 10 ms

- ***Max.-to-aver.*** $r_{\Delta t}$ = c_{max} / c_{mean}
- ***Duty factor, i.e. normalized fluctuations*** $F_{\Delta t} \equiv \frac{c_{mean}^2}{c_{mean}^2 + \sigma_c^2} \equiv \frac{\langle c \rangle^2}{\langle c^2 \rangle}$

Improvement possible:

- Low sextupole strength
- Controlled tune variation

⇒ experimental & theoretical demonstration



R. Singh et al., Phys. Rev. Applied **13,044076 (**2020)

Requirements at different Synchrotrons focusing on 'Spill Micro-Structure'

Slow extraction is used for fixed target users:

CERN & GSI: Uniformity of spill required for high count rate matched to detectors

- **CERN PS & SPS:** Tune scan including optics correction via COSE (Constant Optics Slow Extraction)
- **GSI SIS18 & planned for SIS100**: Tune scan & stochastic horizontal amplitude excitation, so-called 'rf-knockout'

Hadron therapy facilities: Safety requirements of intensity monitoring

- **HIT & MIT:** rf-knockout with bunched beams, air-core quadrupole for 50 Hz compensation, slow spill control
- **CNAO & MedAustron:** Longi. acceleration by 'betatron-core', bucket channeling & rf-knockout, air-core quadrupole

⇒ Improvement of spill micro-structure for <u>all</u> facilities required and envisaged

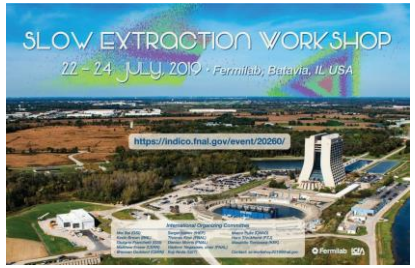
Methodology:

- **Beam dynamics simulation:** Detailed modeling of extraction process for all facilities
- **Technical improvements:** Magnet power supplier and rf exciter control
- **Validation:** Experimental validation at all facilities

Further topics for slow extraction from user perspective:

- Transverse beam stability at target
- Handling of different horizontal and vertical emittance
- High transmission for loss reduction at septum (within synchr.)
- Varying beam parameter during extraction, 'macro-spill control'

Workshops 2016 to 2019 about 50 participants each, EuCARD² & ARIES frame. Follow-up planed in Japan



IFAST-REX Participants and Goals

Industrial beneficiaries:

Barthel:

Special rf-amplifier and control

→ matched rf-generation & amplification

Bergoz:

Sensitive & high dynamic range transformer

→ power supplier control

providing $\Delta I / I < 10^{-6}$

All facilities:

- **Contribution to development**
- **Experimental verification**

⇒ Beneficiaries of improvement

⇒ Proposals for facilities (USA, Japan, China)

Facility beneficiaries:

CERN:

- Detailed simulations
- Feedforward and feedback systems
- Accelerator physics description

GSI:

- Detailed simulations
- Accelerator physics description
- Versatile fast detector system

HIT:

- rf-control development
- Power supplier development

Associated partners:

CNAO:

- Methodology for extraction
- Test of different extraction types

MedAustron:

- Test of different extraction types
- Power supplier development

MIT:

- 'air-coil' quadrupole

SEEIIST:

- Presently observer

IFAST-REX Kick-off Meeting 8th and 9th Feb. 2021

Remote kick-off meeting at 8th & 9th February, 1.5 days:

INDICO: https://indico.gsi.de/event/11868/

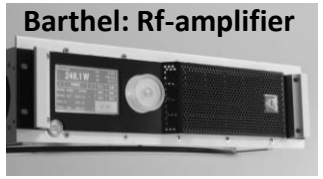
40 participants from all consortium members,

Participants per institution: Barthel:1, Bergoz: 2, CERN: 6, CNAO: 4, GSI: 12, HIT: 5, MedAustron: 6, MIT: 2, SEEIIST: 2

Discussed topic:

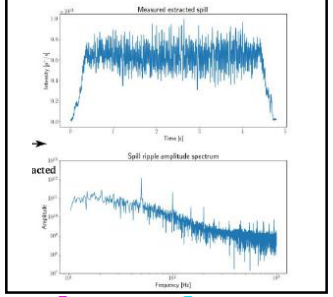
- Introduction of involved people and institutions
- Overview on each facility requirements → understanding of different realizations
- Achievements and ideas for spill quality → condensed information on present status
- Used beam dynamics simulation tools → overview on methodology for improvements
- Status of technical developments & plans → first plans for innovative technical realizations
- Technical status form companies → roadmap for technical realization

Barthel: Rf-amplifier

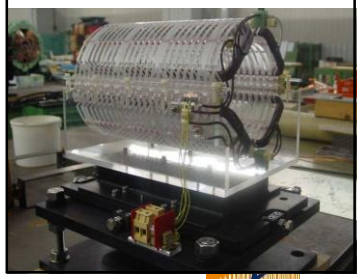


Bergoz: transformer

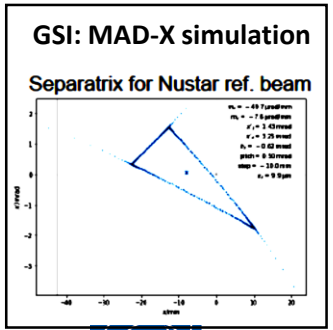
CERN SPS: Measure



CNAO: air-coil quad.

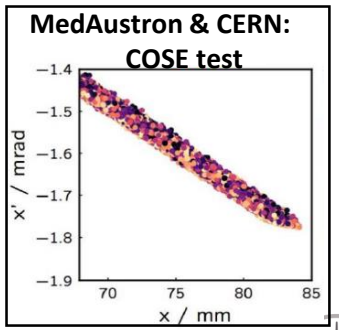


GSI: MAD-X simulation

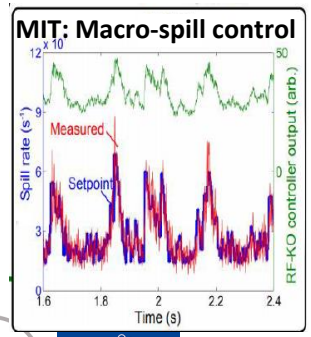


HIT: Signal generation of knock-out

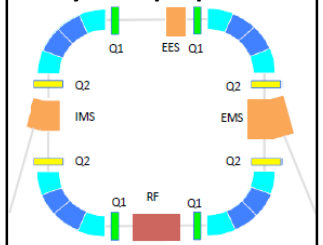
MedAustron & CERN: COSE test



MIT: Macro-spill control



SEEIIST: SC-synchr. proposal



Working Groups and first Steps

Working groups formation:

1. Specifications for development and integration of high dynamic range current measurement device
2. Specification and contribution for knock-out signal generation, exciter and amplifier design
3. Slow extraction simulations
4. Fast particle detector development and measurement analysis

Most working groups have members from all facilities; industry partners in 1 and 2, respectively.

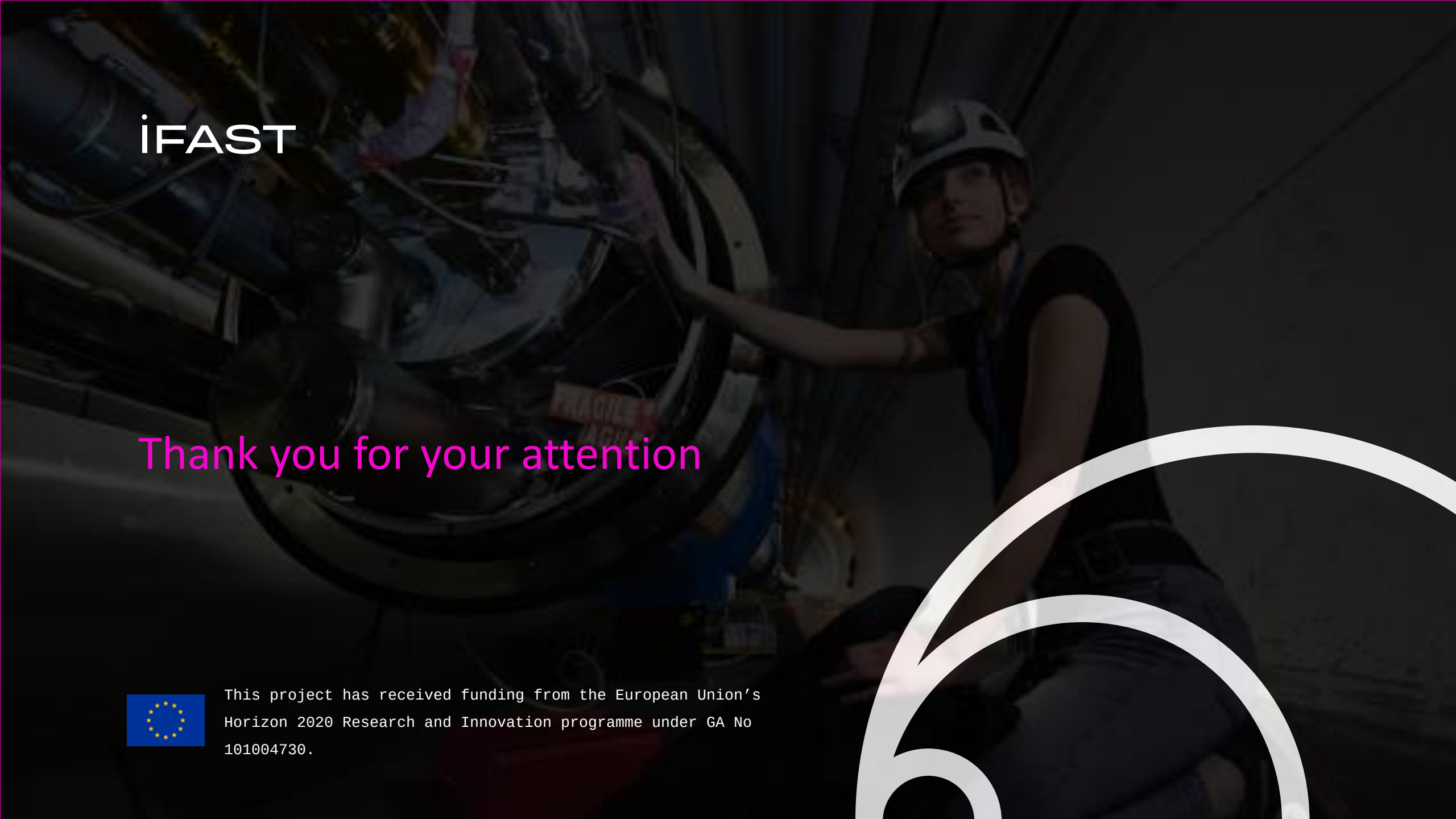
Frist Steps:

- Compilation of important slow extraction parameters by Florian Kühteubl, MedAustron
  - ⇒ Comparison of parameters at facilities
  - ⇒ Possible 'scaling' of parameter for comprehensive comparison of different beam parameter (e.g. beam energy)
- Roadmap for theoretical investigations, e.g. simplified model synchrotron
- First ideas for performant detector development
- Design specifications for technical developments

⇒ **Start-up of working groups to form a lively consortium**

Milestone and deliverable:

- MS20 report (M24): *Engineering design of improved power supply current meas. and rf-amplifier layout*, April 2023
- D5.3 demonstrator & report (M46): *Ripple mitigation for slow extraction beam quality improvement*, February 2025



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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.

IFAST-REX Participants and Tasks

Consortium:

Financial support by EU of Beneficiaries and Associated Partners:

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:

			CNAO	*MIT*	*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

Associated Partners' budget:
Request: 70 k€
Overhead: -17.5 k€
included in GSI budget:
Ass. Part: 70 k€
GSI direct: +120 k€

Administrative documents: Grand agreement, consortium agreement & contract GSI ↔ Associated Partners **will** be produced & signed

IFAST-REX Working Group members

1) Development and integration of high dynamic range current measurement device:

CERN: Diogo Alves, Marek Gasior
CNAO: ---
GSI: Rahul Singh, Andrzej Stafiniak
HIT: Eike Feldmeier
MedAustron: Claus Schmitzer
MIT: ?
SEEIIST: Mariusz Sapinski
Bergoz: Frank Stulle

2) Specification and contribution for KO signal generation, exciter and amplifier design:

CERN: Paolo Sota
CNAO: Marco Pullia, Luciano Falbo, Paolo Meliga, Al.Mereghetti
GSI: Rahul Singh
HIT: Eike Feldmeier
MedAustron: Claus Schmitzer, Florian Kühteubl, Dale Prokopovich
MIT: ?
SEEIIST: Elena Benedetto
Barthel: Matthias Barthel

3) Slow extraction simulations:

CERN: Verena Kain, Matthew Fraser, Francesca Velotti
CNAO: Marco Pullia, Luciano Falbo, Paolo Meliga, Al Mereghetti
GSI: Peter Forck, Stefan Sorge
HIT: ---
MedAustron: Florian Kühteubl, Alexander Wastl, Dale Prokopovich
MIT: ?
SEEIIST: Rebecca Tayor

4) Spill detector development and analysis:

CERN: Federico Roncarolo (maybe Matthew Fraser)
CNAO: Marco Pullia, Luciano Falbo, Paolo Meliga, A. Mereghetti
GSI: Peter Forck, Plamen Boutachkov
HIT: Andreas Peters
MedAustron: Dale Prokopovich
MIT: ?
SEEIIST: Mariusz Sapinski