



Spill Optimization System (SOS)

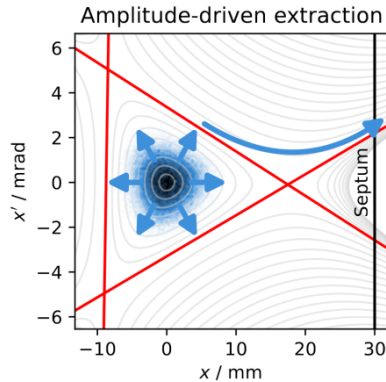
Philipp Niedermayer (ACC) and Rahul Singh (BEA)
Operator School, 2. – 4.12.2024



- Idea and overview
 - Slow extraction from SIS18
 - Spill Optimization System
- Current status and operation
 - Operation in 2025
 - GUI overview
- Project plan for system integration
 - Goals & plan
 - Feedback & wishes

- Working point near sextupole driven third-integer resonance
- Separatrix beyond which particles are unbound & extracted

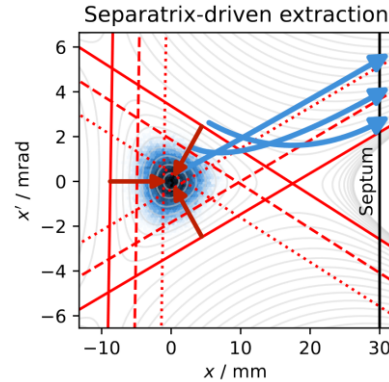
RF Knock Out (KO) extraction



- Driven by **RF excitation** with stripline kicker
- Static optics, beam-on-target fixed
- Small chromaticity** required & momentum distribution preserved

"SIS18_KO"

Quadrupole-driven extraction



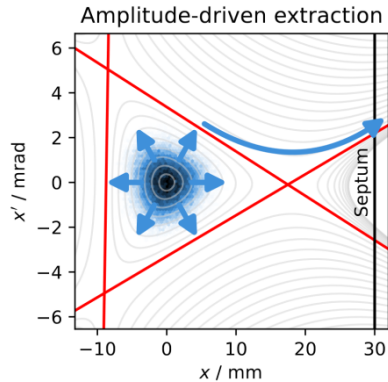
- Driven by **tune ramp** with fast quadrupole
- Dynamic optics, beam-on-target drifts
- Works also with large chromaticity, but then momentum drifts

"SIS18_SLOW"

Slow Extraction from SIS18

- Working point near sextupole driven third-integer resonance
- Separatrix beyond which particles are unbound & extracted

RF Knock Out (KO) extraction



- Driven by **RF excitation** with stripline kicker
- Static optics, beam-on-target fixed
- Small chromaticity** required & momentum distribution preserved

“SIS18_KO”

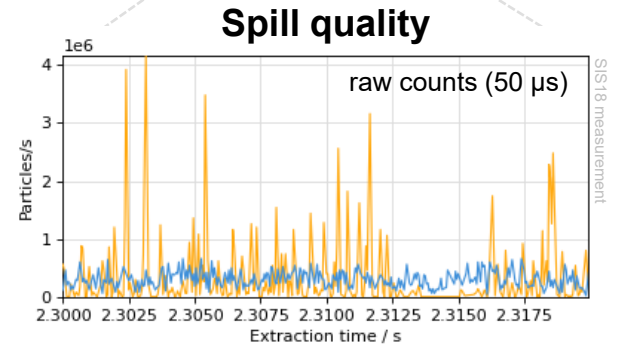
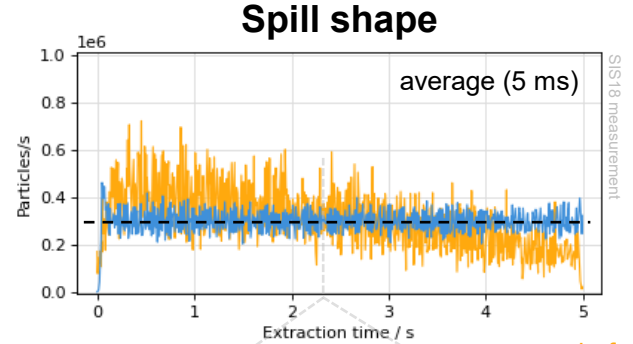
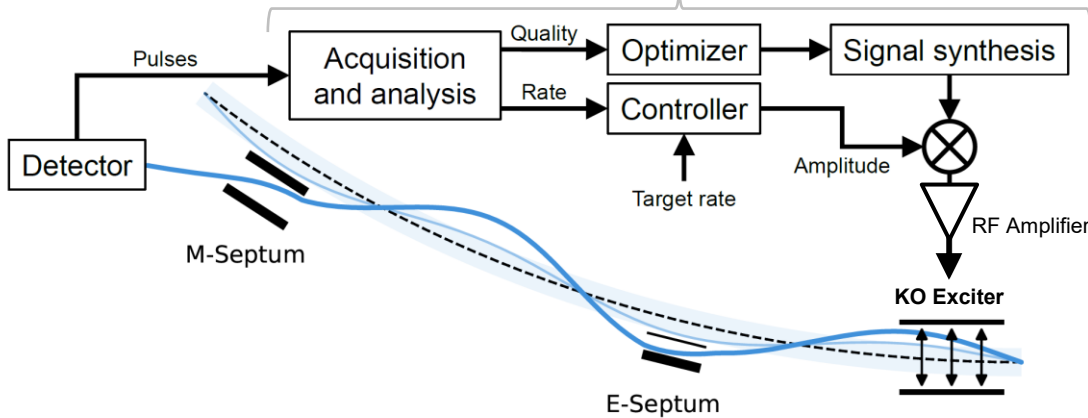
SOS replaces KO excitation signal

KO Extraktion

E-Septum Korrekturwinkel	-2.8	mrad
Extraktionszeit	3000.0	ms
DG Trigger Verschiebung (relativ)	0.5	
DQH pre (KO)	0.004	
Sextupol Amplitude	0.06	
Sextupol Phase	50.0	deg
KO Rauschbandbreite (DQH)	0.015	
KO Zentralfrequenz (frakt. QH)	0.329	
KO Amplitude (Anfang)	0.0	
KO Amplitude (Ende)	0.0	
KO Zeitkonstante (Anfang)	0.5	
KO Zeitkonstante (Ende)	0.6	
Spill Abbruch erlaubt	<input checked="" type="checkbox"/>	

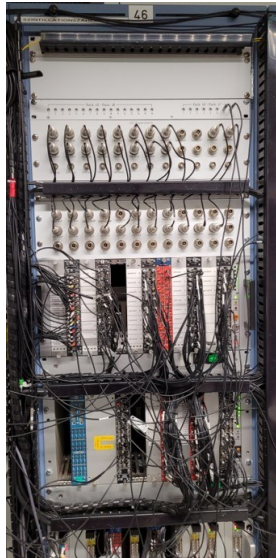
Spill Optimization System for KO Extraction

- Based on Software-defined radio technology
- Feedback controlled macro-spill shape (ms to s)
- Signals optimized for micro-spill quality (μ s to ms)



Spill Optimization System for KO Extraction

Detector



BEA Electronics
in BG.2.009b

GHHDDI2P Scintillator
GHHDDI2I Ion-Chamber
GHHDDI2S SEM-Grid
GS09DT DCCT
GS04DL2I Sept. BLM
GHADDIAE Experiment

Genesys
Trigger

Software Radio

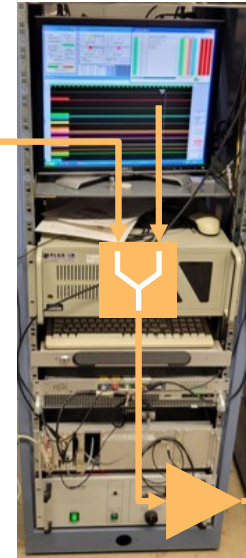


Digital Signal
Processing with
GNU Radio
CPU: 0.2 - 10 MHz
+ FPGA: 200 MHz



Radio & PC
in BG.2.009b

KO Exciter



KO Amplifier
in BG.1.016

Stripline Kicker
GS01B01EH
in SIS18 Tunnel



Current Status and Operation in 2025

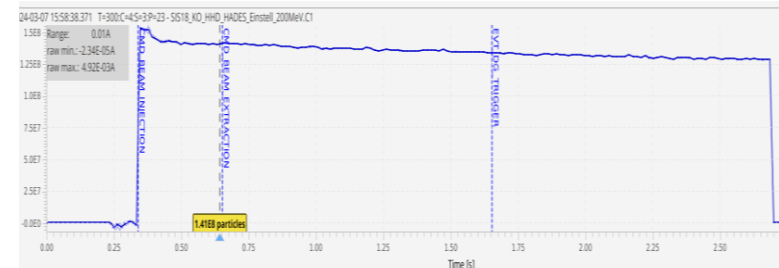
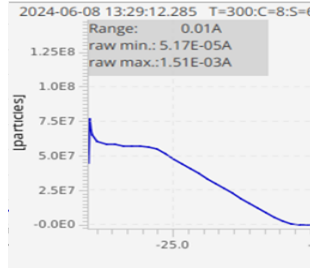
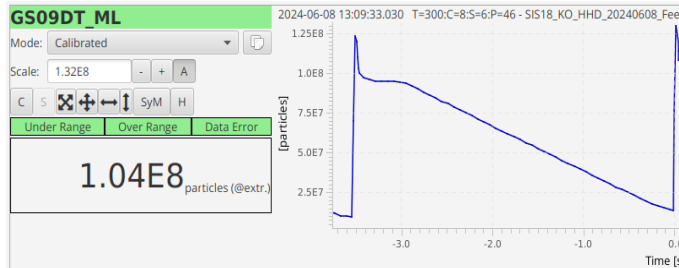
- Standalone system for single pattern
 - Pattern with SOS: “KO Amplitude = 0” in ParamModi
 - Other patterns: usual KO Extraction with ParamModi
(manual cable swapping in SIS18 RRF room no longer needed)
- System operation in 2025
 - Setup: Philipp & Rahul
 - Responsible: Dedicated person from user group
 - Gradual transition to operators intended
 - Documentation at git.gsi.de/p.niedermayer/exciter/-/wikis
 - Requests (as of 21.11.2024)
 - HADES Pion run (April/May 2025)
 - R3B beamtime (June 2025)
 - ...

KO Rauschbandbreite (DQH)	0.01
KO Zentralfrequenz (frakt. QH)	0.327
KO Amplitude (Anfang)	0
KO Amplitude (Ende)	0
KO Zeitkonstante (Anfang)	0.4
KO Zeitkonstante (Ende)	0.8

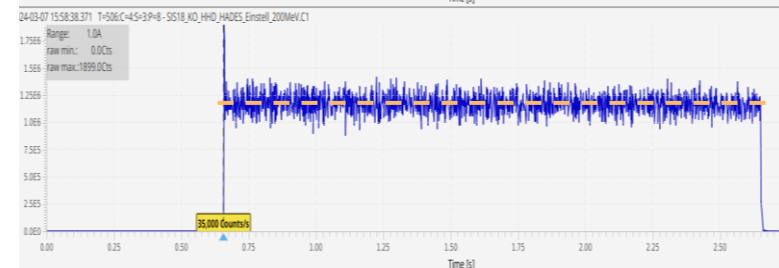
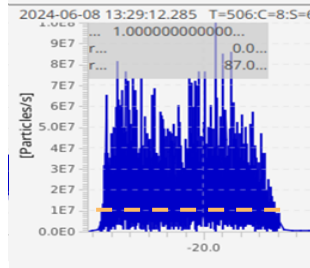
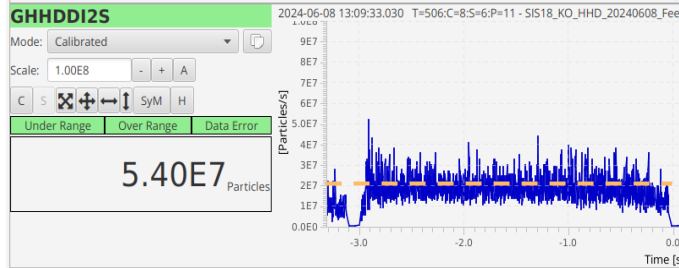
SOS as a “Toolbox”

- Different operation modes (depending on user needs & beam energy/intensity)
 - E.g. “Full extraction and improved quality” at high energy/intensity
 - E.g. “Partial extraction and ultimate quality” at low energy and low intensity

DCCT



SEM



Spill detector settings

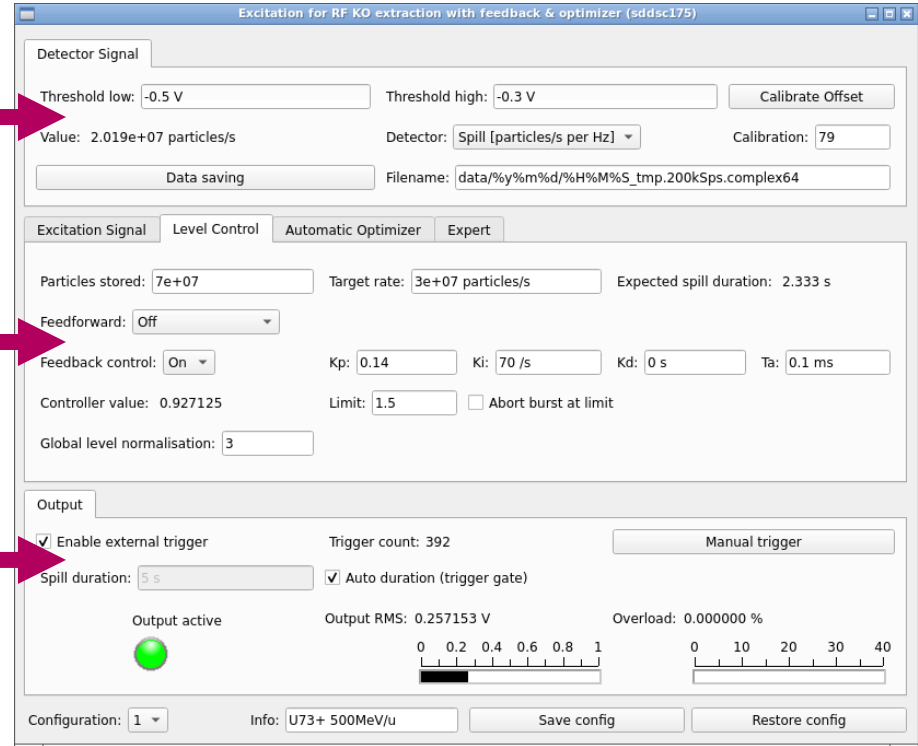
Plan: sync with LASSIE

Feedback and/or amplitude curve

Plan: curve from feedback (playback or fit)

Output settings and monitoring

Plan: sync with LSA

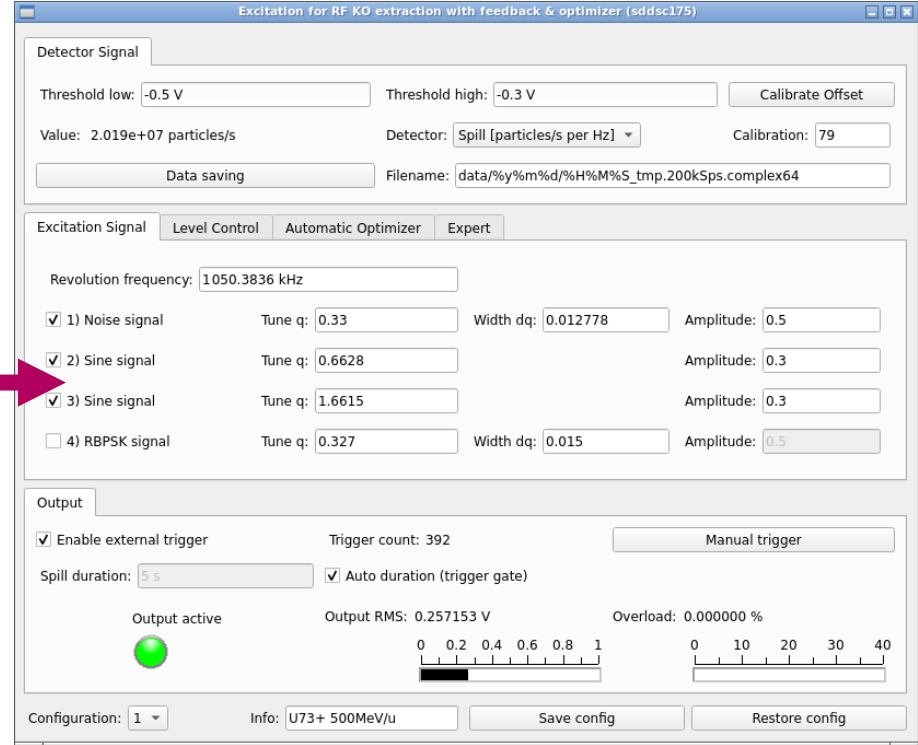


Documentation at
git.gsi.de/p.niedermayer/exciter/-/wikis

KO Rauschbandbreite (DQH)
KO Zentralfrequenz (frakt. QH)

0.01
0.227

More options for excitation signal
*Use automatic optimizer
Plan: intelligent pre-sets*



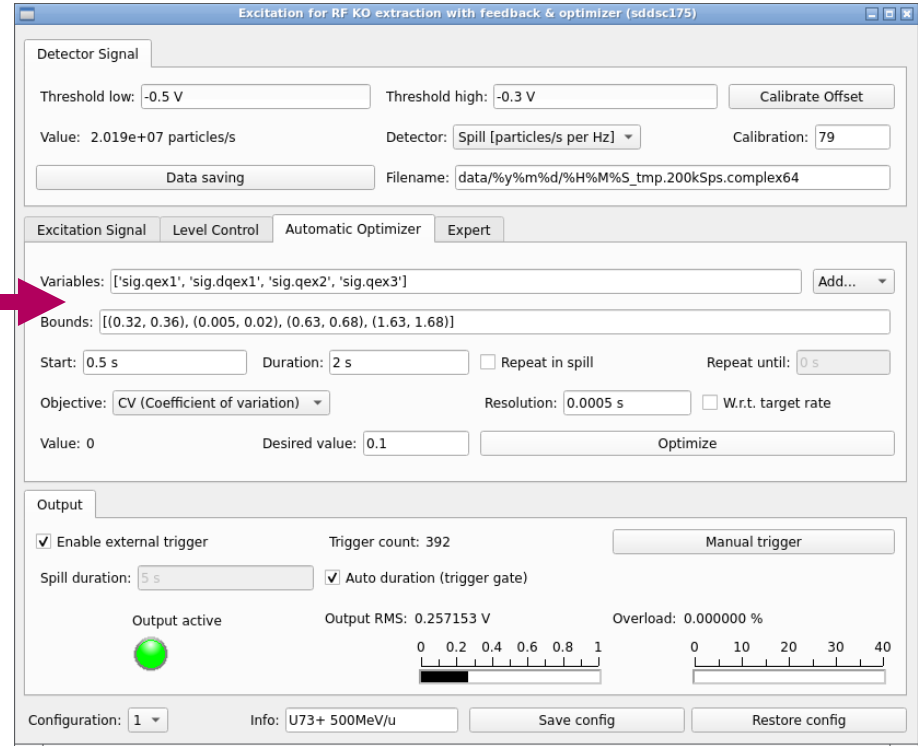
The screenshot shows the 'Excitation for RF KO extraction with feedback & optimizer (sddsc175)' window. It is divided into several sections:

- Detector Signal:** Includes fields for 'Threshold low' (-0.5 V) and 'Threshold high' (-0.3 V), a 'Calibrate Offset' button, a 'Value' of 2.019e+07 particles/s, a 'Detector' dropdown set to 'Spill [particles/s per Hz]', and a 'Calibration' field set to 79. There is also a 'Data saving' button and a 'Filename' field.
- Excitation Signal:** Features tabs for 'Level Control', 'Automatic Optimizer', and 'Expert'. The 'Revolution frequency' is set to 1050.3836 kHz. Under 'Level Control', there are four signal options:
 - 1) Noise signal: Tune q: 0.33, Width dq: 0.012778, Amplitude: 0.5
 - 2) Sine signal: Tune q: 0.6628, Amplitude: 0.3
 - 3) Sine signal: Tune q: 1.6615, Amplitude: 0.3
 - 4) RBPSK signal: Tune q: 0.327, Width dq: 0.015, Amplitude: 0.5
- Output:** Includes 'Enable external trigger' (checked), 'Trigger count: 392', and a 'Manual trigger' button. 'Spill duration' is set to 5 s, and 'Auto duration (trigger gate)' is checked. A green indicator light shows 'Output active'. Below are two scales: 'Output RMS: 0.257153 V' (0 to 1) and 'Overload: 0.000000 %' (0 to 40).
- Footer:** 'Configuration: 1', 'Info: U73+ 500MeV/u', and buttons for 'Save config' and 'Restore config'.

Documentation at
git.gsi.de/p.niedermayer/exciter/-/wikis

Automatic parameter optimization

Plan: pre-sets for common cases



Excitation for RF KO extraction with feedback & optimizer (sddsc175)

Detector Signal

Threshold low: -0.5 V Threshold high: -0.3 V Calibrate Offset

Value: 2.019e+07 particles/s Detector: Spill [particles/s per Hz] Calibration: 79

Data saving Filename: data/%y%m%d/%H%M%S_tmp.200kSps.complex64

Excitation Signal Level Control Automatic Optimizer Expert

Variables: ['sig.qex1', 'sig.dqex1', 'sig.qex2', 'sig.qex3'] Add...

Bounds: [(0.32, 0.36), (0.005, 0.02), (0.63, 0.68), (1.63, 1.68)]

Start: 0.5 s Duration: 2 s Repeat in spill Repeat until: 0 s

Objective: CV (Coefficient of variation) Resolution: 0.0005 s W.r.t. target rate

Value: 0 Desired value: 0.1 Optimize

Output

Enable external trigger Trigger count: 392 Manual trigger

Spill duration: 5 s Auto duration (trigger gate)

Output active Output RMS: 0.257153 V Overload: 0.000000 %

Configuration: 1 Info: U73+ 500MeV/u Save config Restore config

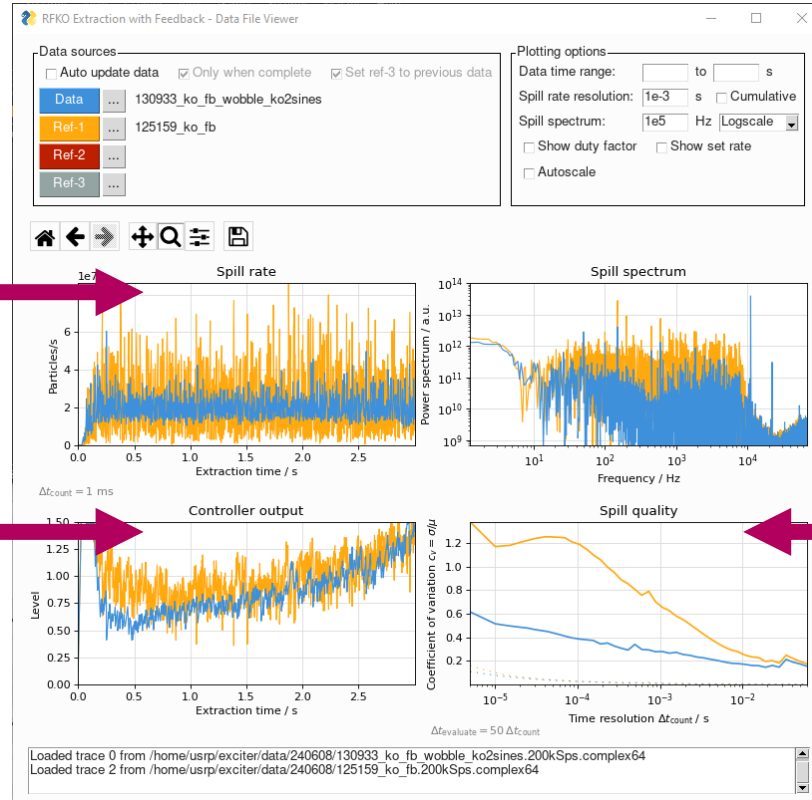
Documentation at
git.gsi.de/p.niedermayer/exciter/-/wikis

- Online monitoring with dedicated app

Measured spill rate

KO amplitude

KO Amplitude (Anfang)
KO Amplitude (Ende)
KO Zeitkonstante (Anfang)
KO Zeitkonstante (Ende)

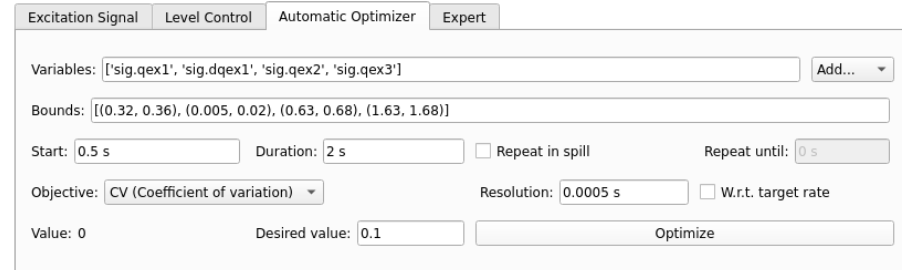
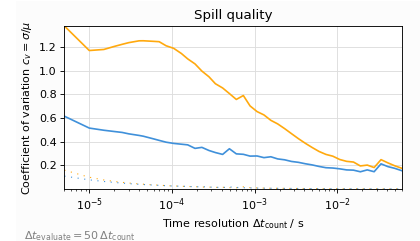
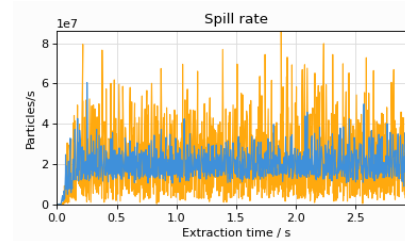


Spill quality

- Goal: reduce spill fluctuations
 - Minimize $c_v = \text{std}/\text{mean}$
 - On time scale $\Delta t_{\text{count}} \approx 50 \mu\text{s} \dots 500 \mu\text{s}$

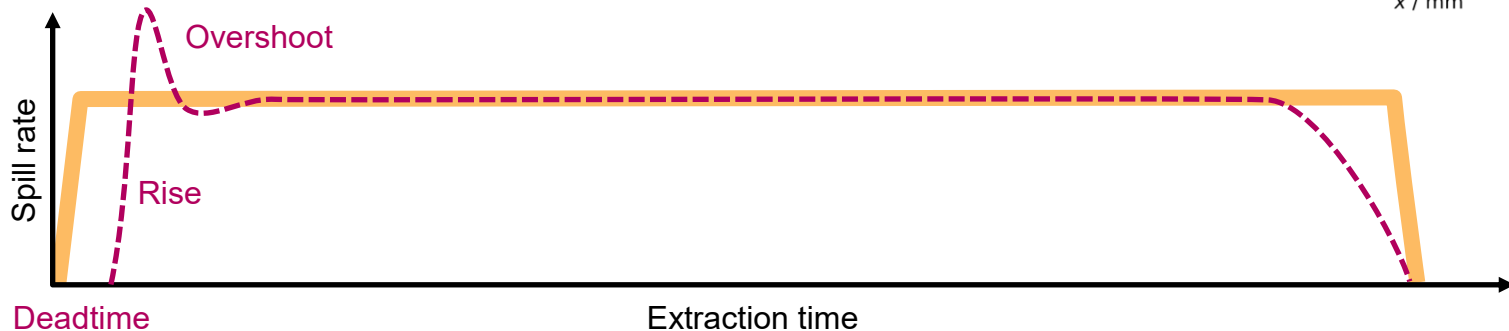
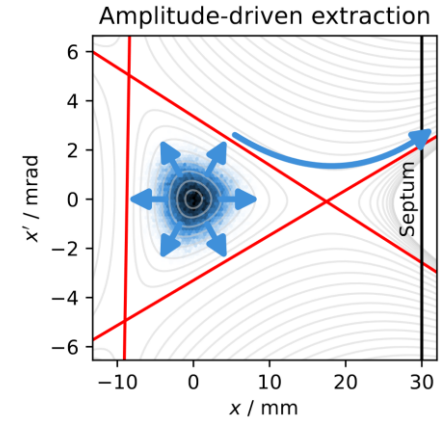
Method

- Steps
 - Measure spill quality
 - Adjust frequencies & bandwidths
- BOBYQA Optimization Algorithm
 - Intra-cycle → find good settings quick
 - Cycle-by-cycle → find optimal settings



- Generic tool → can also optimize feedback or amplitude for macro-spill shape

- Wanted: no deadtime, steep rise & no overshoot
 - Optimal **SIS KO optics setup** very important
 - Correct chromaticity, smallest separatrix, etc.
 - Fine-tuning of feedback parameters
 - Rise-time and PID controller gains



Plan for System Integration



- Implement missing & legacy features
 - E.g. dynamic spill rate, spill pause, amplitude curve without feedback
- Integration into control system
 - Serve more than one user in multiplexed operation
 - Subset of *highly available* spill detectors for feedback (DCCT, TE1 & HHD PDCs, ...)
 - Connected and selectable via multiplexer
 - Sync data from LASSI & LSA
 - Dedicated unified Java GUI
 - Simplifications (defaults, pre-sets, optimizer) and separate expert functionality

Plan for System Integration



- Wish: Gradual transition from “expert system” to standard operating toolbox
 - Feedback from operating during the process (direct or via Seva Kamerdzhev)
 - Knowledge transfer and hands-on during user operation in 2025
 - For you: How the system works → Documentation at git.gsi.de/p.niedermayer/exciter/-/wikis
 - From you: Best practice for daily usage

Your feedback is appreciated and essential for a successful transition

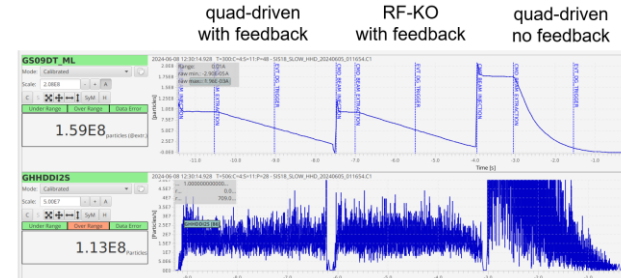
- Spill Optimization System for KO extraction
 - Spill rate feedback & spill quality improvement
 - System integration & transition to operating in the course of 2025 foreseen
- Later also for quad-driven SLOW extraction
 - Spill rate feedback on fast quad & spill quality improvement with built-in tune wobbling
 - Very similar setup & operation
 - Tested successfully at SIS18, requires involvement of EPS group

Thanks to everybody supporting this work!

ACC, APH, BEA, EEL, EPS, FCO, OPE, RRF, SIS, SYS

Stored
intensity
in SIS18

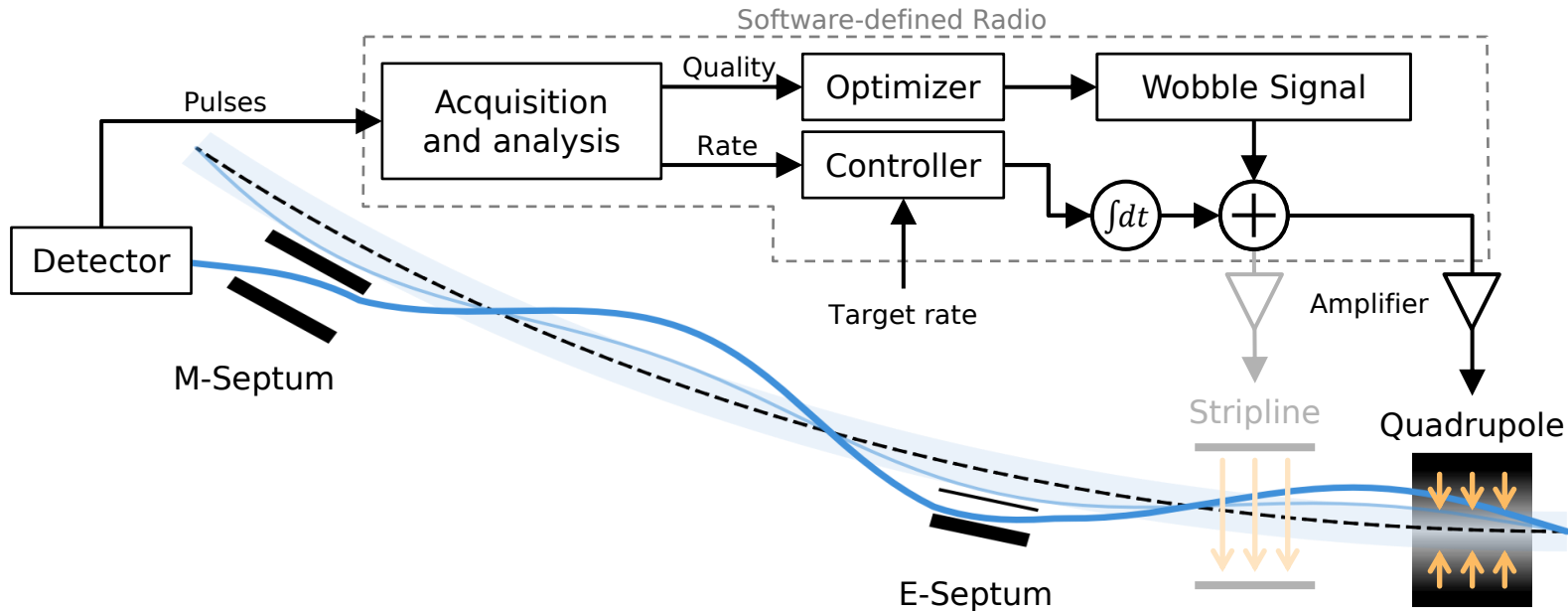
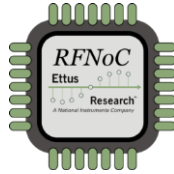
Extracted
intensity
on target



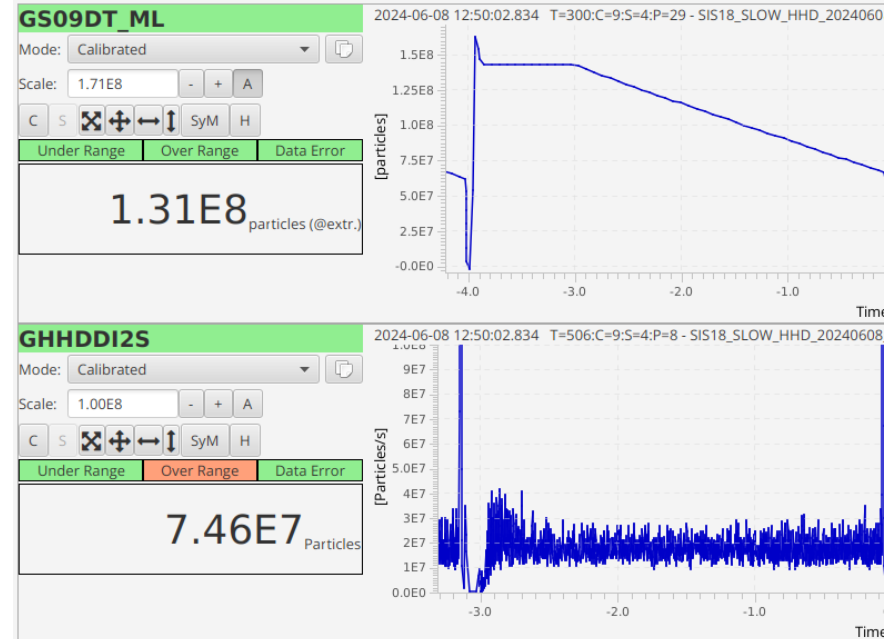
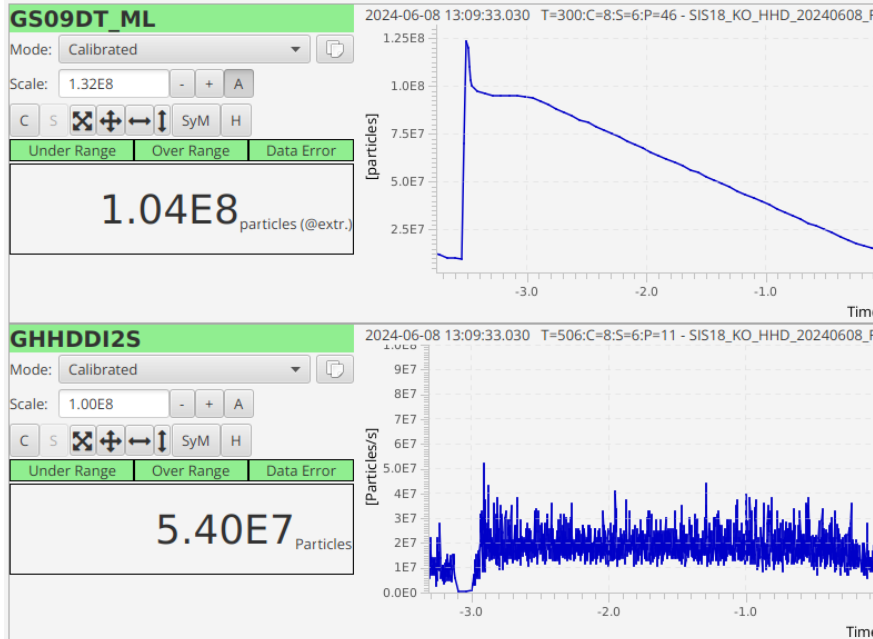
Backup Slides

Spill Optimisation System (SOS)

- Similar System for both extraction methods
- Using fast quadrupole as actuator (GS02KQ1E)



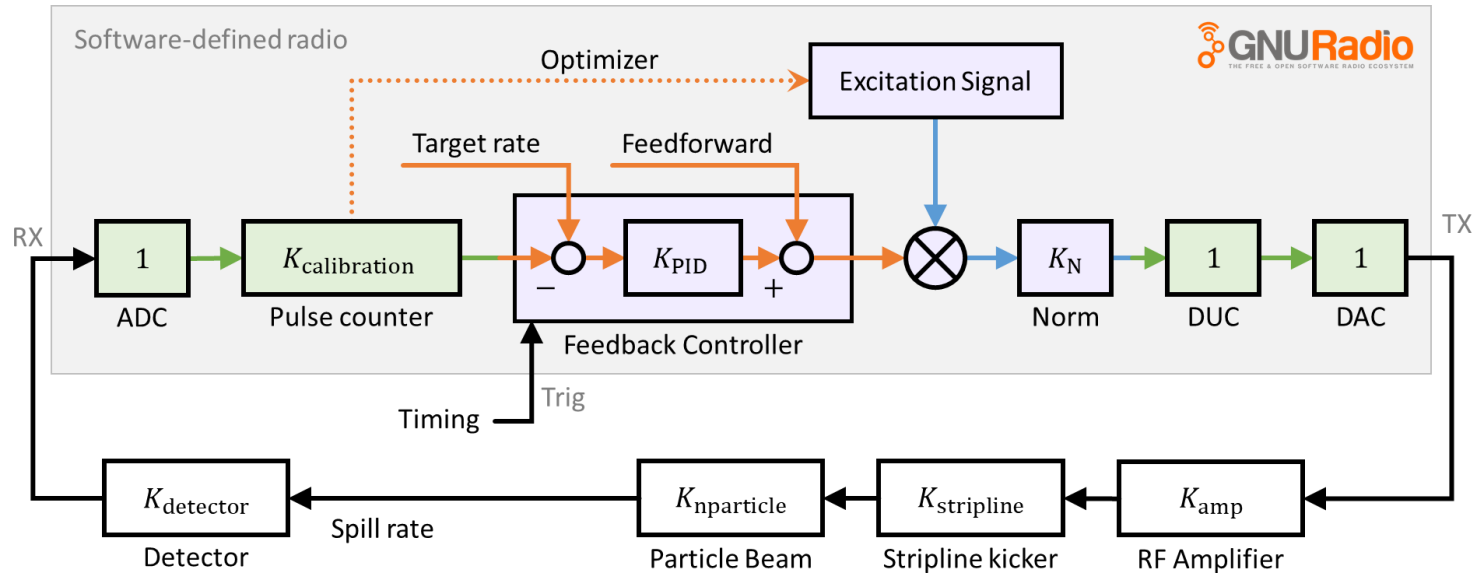
KO vs Quad-driven Extraction



Operating example

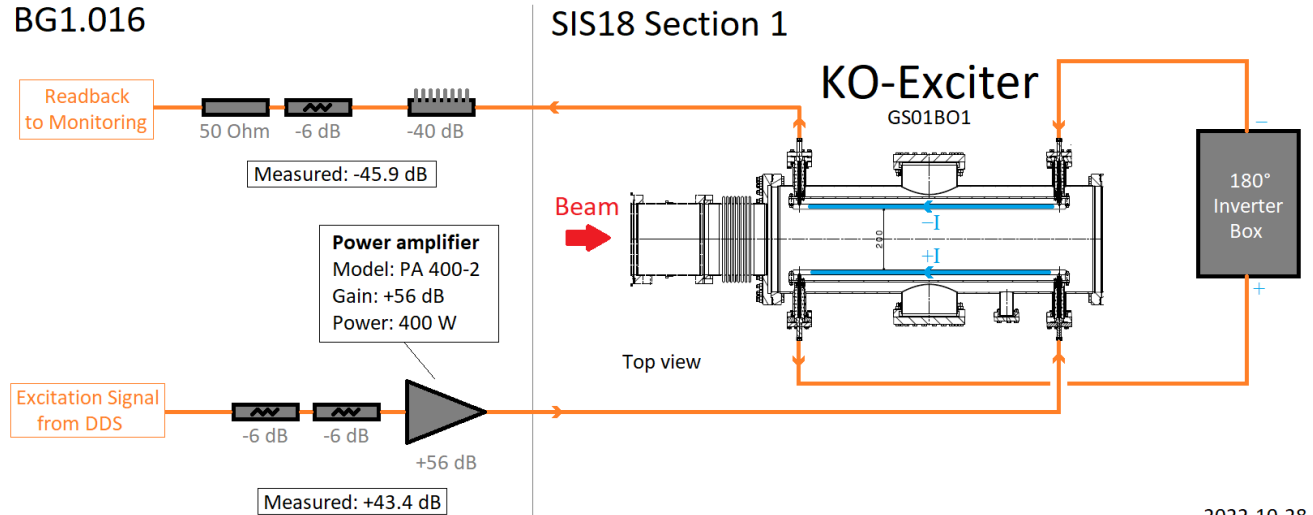
The image shows two software windows from the FAIR GSI system. The left window, titled "RFKO Extraction with Feedback - Data File Viewer", displays four plots: "Spill rate" (Particles/s vs Extraction time/s), "Spill spectrum" (Power spectrum / a.u. vs Frequency / Hz), "Controller output" (Level vs Extraction time/s), and "Spill quality" (Coefficient of variation $\sigma = \sigma_{sp}$ vs Time resolution Δt_{count} / s). The right window, titled "Excitation for RF KO extraction with feedback & optimizer (sdds051)", shows detector signal settings (Threshold low: -0.5 V, Threshold high: -0.3 V) and excitation signal parameters (Revolution frequency: 1050.3836 kHz, 3 sine signals with various tune q and amplitude values). A terminal window at the bottom right shows log output from the sdds051 process.

- Flowgraph (strongly simplified) with PID controller

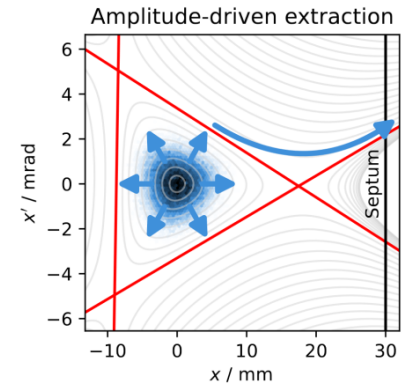


SIS18 KO Exciter

- RRF Group (Bernhard Zipfel)
- Monitoring: <https://www-windows.gsi.de/hf-monitoring/ACQmain/system3.htm>



- SOS System
 - Currently: switch off when excitation power exceeds threshold
 - Future: switch off via spill rate set-point signal (dynamic intensity control)
- SIS 18
 - Tune moved away from resonance (dqh-pre)



Project Plan: SOS System Integration

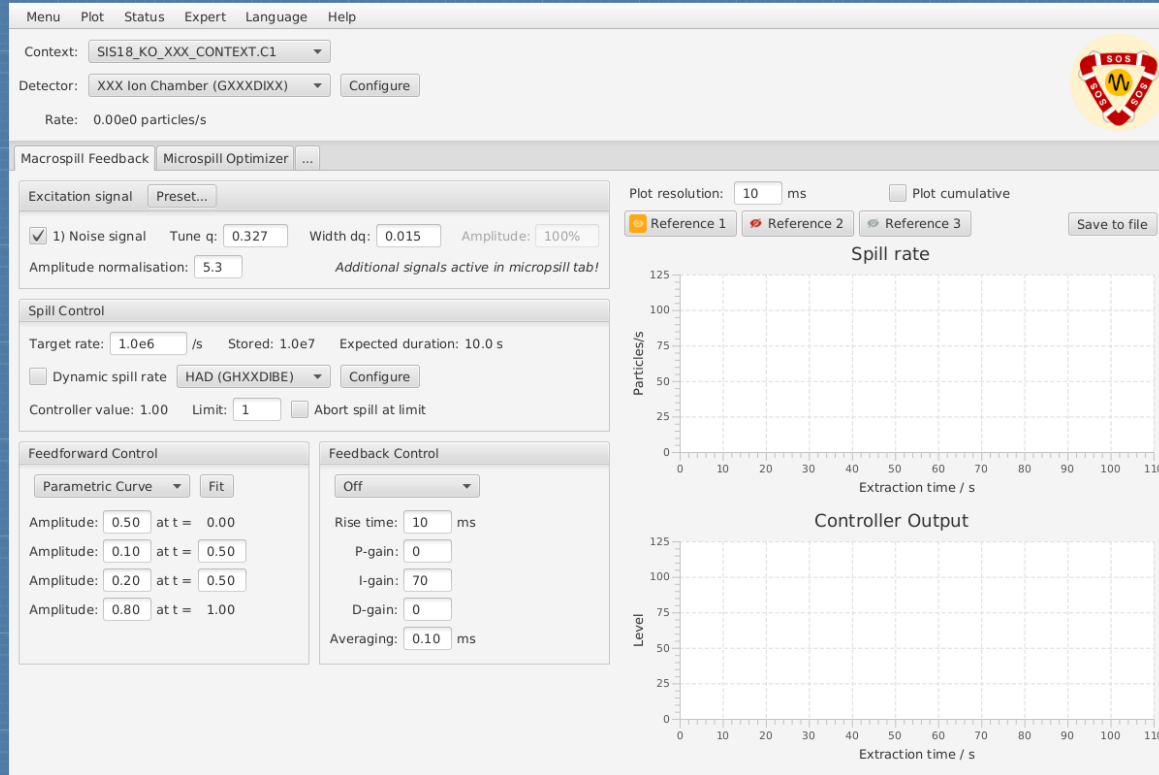
Project Lead: P. Niedermayer & R. Singh

Status: 11.10.2024



Project Description		Subprojects / Tasks																	
<p>This project will upgrade the software-defined radio (SDR) based spill optimization system (SOS) to provide essential user functionalities, and fully integrate it into SIS18 regular operation with multiplexed operation, and to commission the full system with beam. The spill pause and spill abort functionalities will be combined into a general functionality of user defined real-time spill rate control. A dedicated FESA class and GUI for operators is required. The multiplexed operation requires obtaining context based beam and machine parameters by interacting with the LSA database and LASSIE FESA class for detector calibration. The feedback system necessitates real-time communication of FESA software with GNU Radio frame-work as well as a reliable communication with a programmable switch between beam-line detectors and the feedback system.</p>		<ul style="list-style-type: none"> Specify the system Purchase and prepare hardware (GNU Radio with Yocto OS, multiplexer/switch, timing cards etc.) Add legacy KO functionalities to SDR Add real-time rate control functionality in SDR Add automatic optimizer functionality with multiplexing possibility Write FESA software communication with GNU Radio and LASSIE + GUI Commissioning of the full system with failure scenarios concerning machine protection Documentation and training for the long term system usage and maintenance 																	
Project Goals		Resource Profile																	
<ol style="list-style-type: none"> Replace the DDS based RBPSK KO signal generator with the feedback capable SDR signal generator Remote controllable multiplexer for cycle-to cycle switching between beamline detectors and detector overload/failure checks Add real-time (2-5 ms response time) dynamic spill rate control function and automatic optimizer in multiplexed operation Full FESA / control system integration with dedicated GUI Enable operations team to operate and maintain the system in the long term 		<table border="1"> <thead> <tr> <th>Year</th> <th>Estimated costs</th> <th>Person months</th> </tr> </thead> <tbody> <tr> <td>2024</td> <td>20k</td> <td>8</td> </tr> <tr> <td>2025</td> <td>15k</td> <td>12</td> </tr> <tr> <td>2026</td> <td>5k</td> <td>4</td> </tr> <tr> <td>Total</td> <td>40k</td> <td>24</td> </tr> </tbody> </table>			Year	Estimated costs	Person months	2024	20k	8	2025	15k	12	2026	5k	4	Total	40k	24
Year	Estimated costs	Person months																	
2024	20k	8																	
2025	15k	12																	
2026	5k	4																	
Total	40k	24																	
Major Milestones		Risks, Boundary Conditions and Comments																	
Q4/2024	Finish specification and hardware procurement for multiplexed operation	Major Risks: - Detection of detector failures/overload - Availability of FPGA resource		Concerned departments: - BEA, ACC, ACO, EEL - OPE, RRF, SYS															
Q1/2025	GNU Radio and FPGA Implementation of legacy KO and realtime rate control functionality																		
Q2/2025	Multiplexed operation with automatic optimizer	Boundary Condition:		Comments: Detailed comments in shared GSI Seafile folder: https://seafile.gsi.de/group/982/															
Q3/2025	Realtime FESA class and communication with GNU Radio, LSA, LASSIE, Timing, Multiplexer																		
Q4/2025	Commissioning of the full system with beam																		
Q1/2026	Documentation and training for regular usage in operation																		

New GUI (layout draft in progress)



Menu Plot Status Expert Language Help

Context: SIS18_KO_XXX_CONTEXT.C1

Detector: XXX Ion Chamber (GXXXDXX)

Rate: 0.00e0 particles/s

Macrospill Feedback | Microspill Optimizer | ...

Excitation signal

1) Noise signal Tune q: 0.327 Width dq: 0.015 Amplitude: 100%

Amplitude normalisation: 5.3 *Additional signals active in microspill tab!*

Spill Control

Target rate: 1.0e6 /s Stored: 1.0e7 Expected duration: 10.0 s

Dynamic spill rate HAD (GHXXDIBE)

Controller value: 1.00 Limit: 1 Abort spill at limit

Feedforward Control

Amplitude: 0.50 at t = 0.00

Amplitude: 0.10 at t = 0.50

Amplitude: 0.20 at t = 0.50

Amplitude: 0.80 at t = 1.00

Feedback Control

Rise time: 10 ms

P-gain: 0

I-gain: 70

D-gain: 0

Averaging: 0.10 ms

Plot resolution: 10 ms Plot cumulative

Reference 1 Reference 2 Reference 3

Spill rate

Particles/s

Extraction time / s

Controller Output

Level

Extraction time / s