Spill Optimization System (SOS)

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Operator School, 2. – 4.12.2024

Image: D. Fehrenz, GSI/FAIR, April 2024

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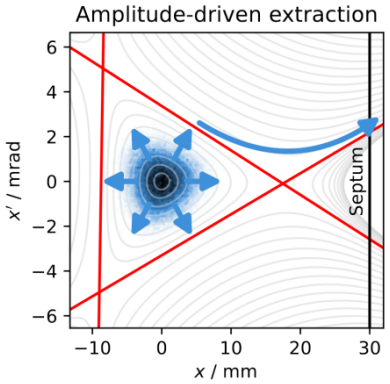
Slow Extraction from SIS18

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

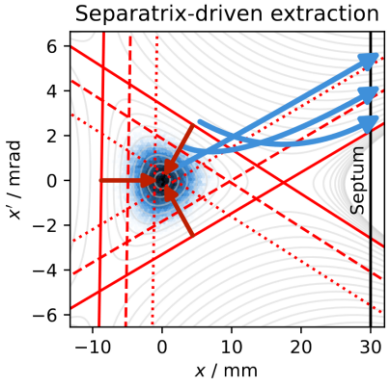
RF Knock Out (KO) extraction



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

“SIS18_KO”

Quadrupole-driven extraction



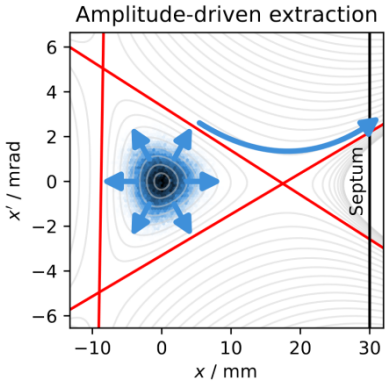
- Driven by tune ramp with fast quadrupole
- Dynamic optics, beam-on-target drifts
- Works also with large chromaticity, but then momentum drifts

“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

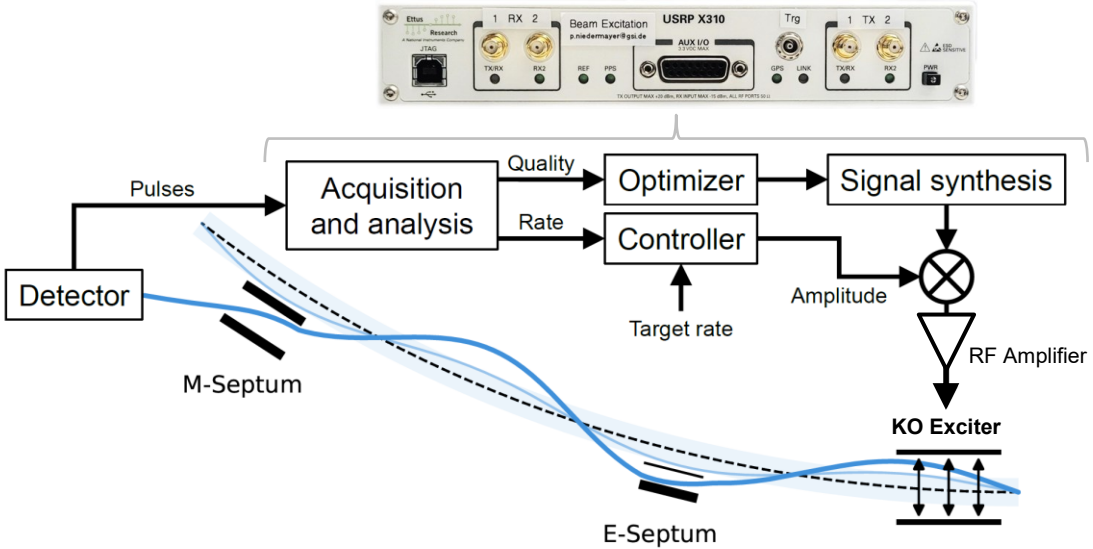
"SIS18_KO"

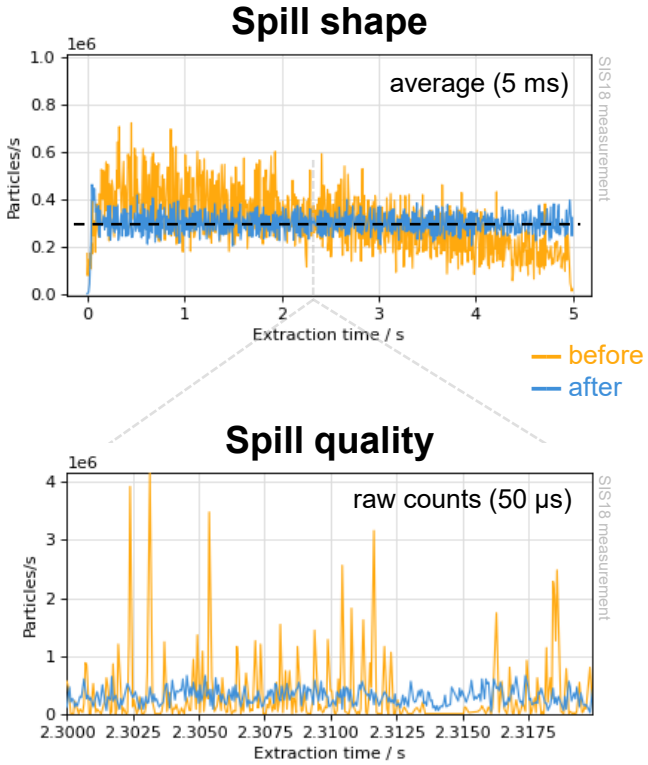
SOS replaces KO excitation signal

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	✔	

Spill Optimization System for KO Extraction

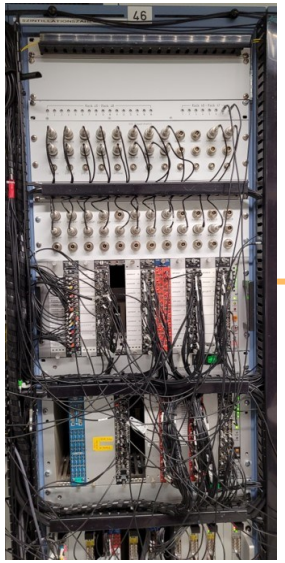
- Based on Software-defined radio technology
- Feedback controlled macro-spill shape (ms to s)
- Signals optimized for micro-spill quality (µs to ms)





Spill Optimization System for KO Extraction

Detector



BEA Electronics
in BG.2.009b

Genesys
Trigger

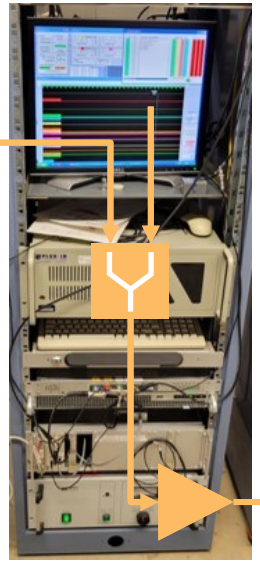
GHHDDI2P	Scintillator
GHHDDI2I	Ion-Chamber
GHHDDI2S	SEM-Grid
GS09DT	DCCT
GS04DL2I	Sept. BLM
GHADDIAE	Experiment

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
GS01BO1EH
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)

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

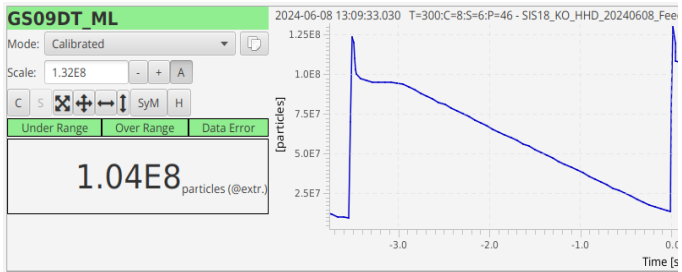
- System operation in 2025
  - Setup: Philipp & Rahul
  - Responsible: Dedicated person from user group
  - Gradual transition to operators intended
  - Documentation at git.gsi.de/p.niedermayer/exciter/-/wikis
  - Requests (as of 21.11.2024)
    - HADES Pion run (April/May 2025)
    - R3B beamtime (June 2025)
    - …

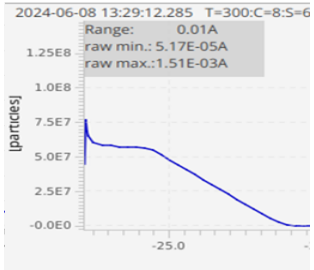
SOS as a “Toolbox”

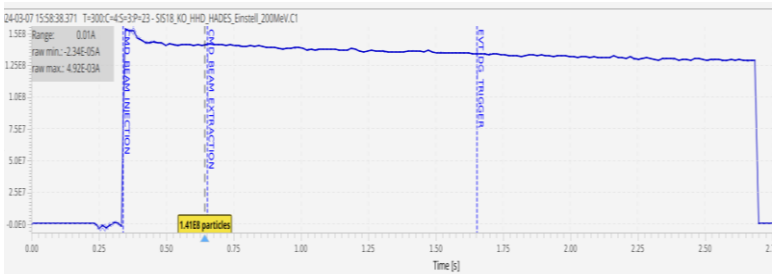
- Different operation modes (depending on user needs & beam energy/intensity)
  - E.g. “Full extraction and improved quality” at high energy/intensity
  - E.g. “Partial extraction and ultimate quality” at low energy and low intensity

DCCT

SEM







GNU Radio GUI

Spill detector settings

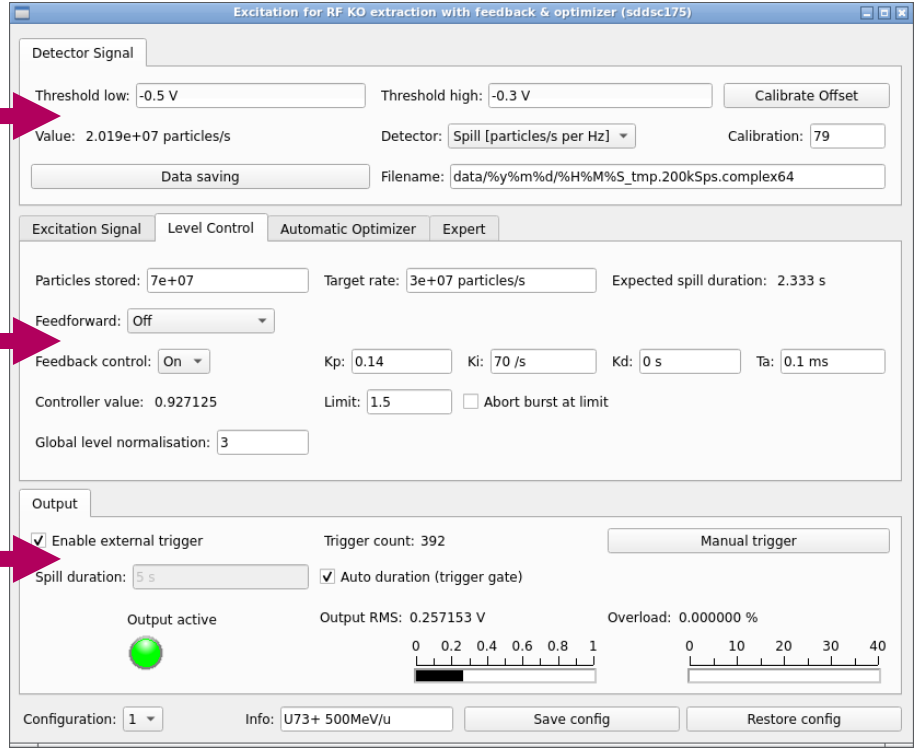
Plan: sync with LASSIE

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

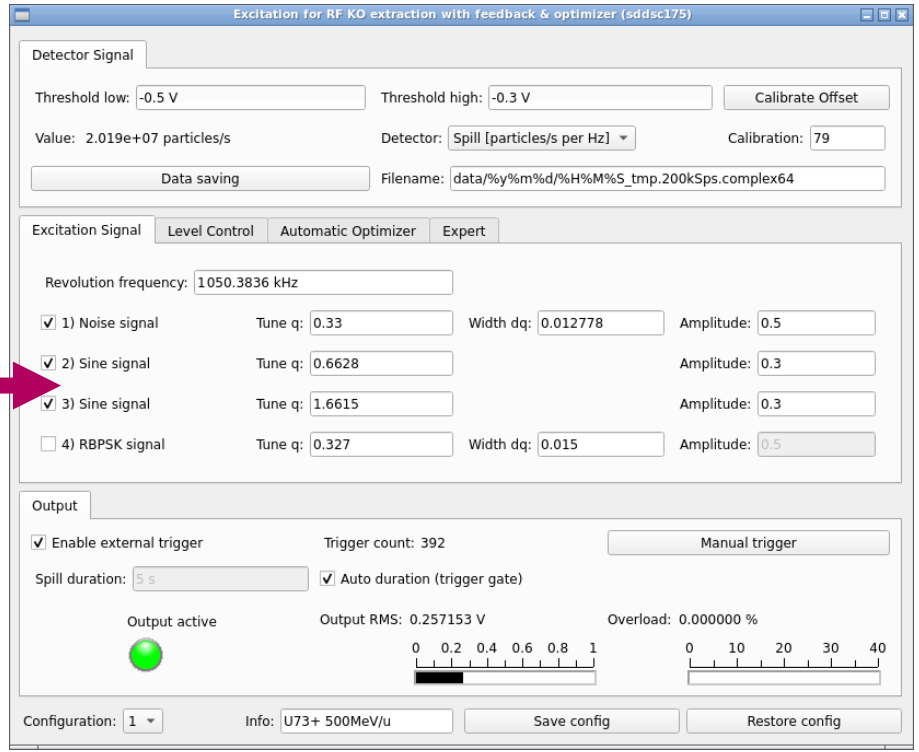
GNU Radio GUI

KO Rauschbandbreite (DQH) 0.01
KO Zentralfrequenz (frakt. QH) 0.327

More options for excitation signal

Use automatic optimizer

Plan: intelligent pre-sets



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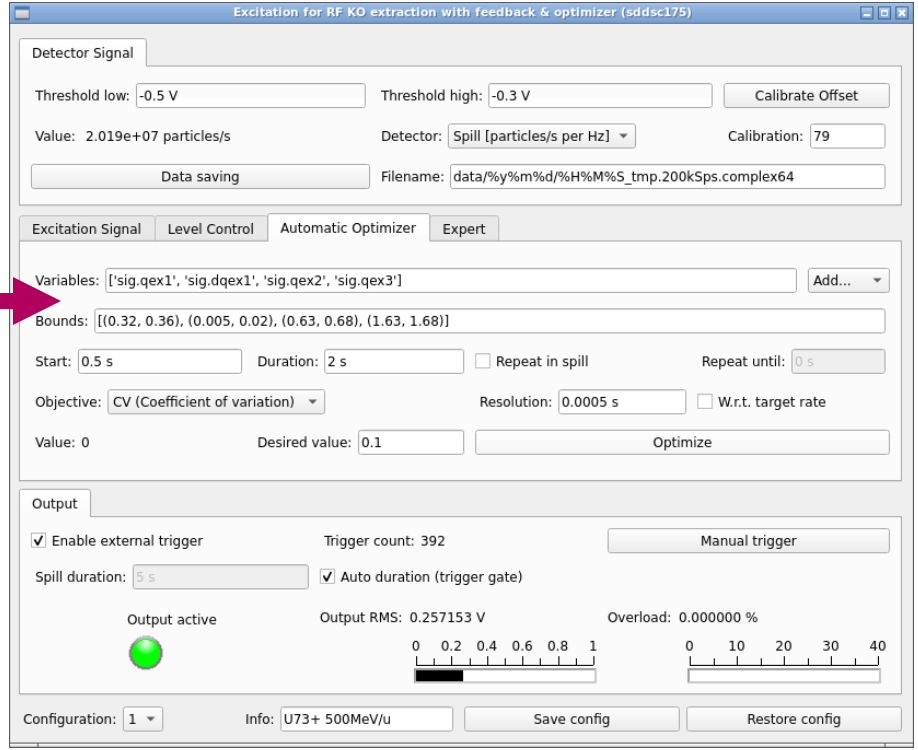
GNU Radio GUI

Automatic parameter optimization

Plan: pre-sets for common cases



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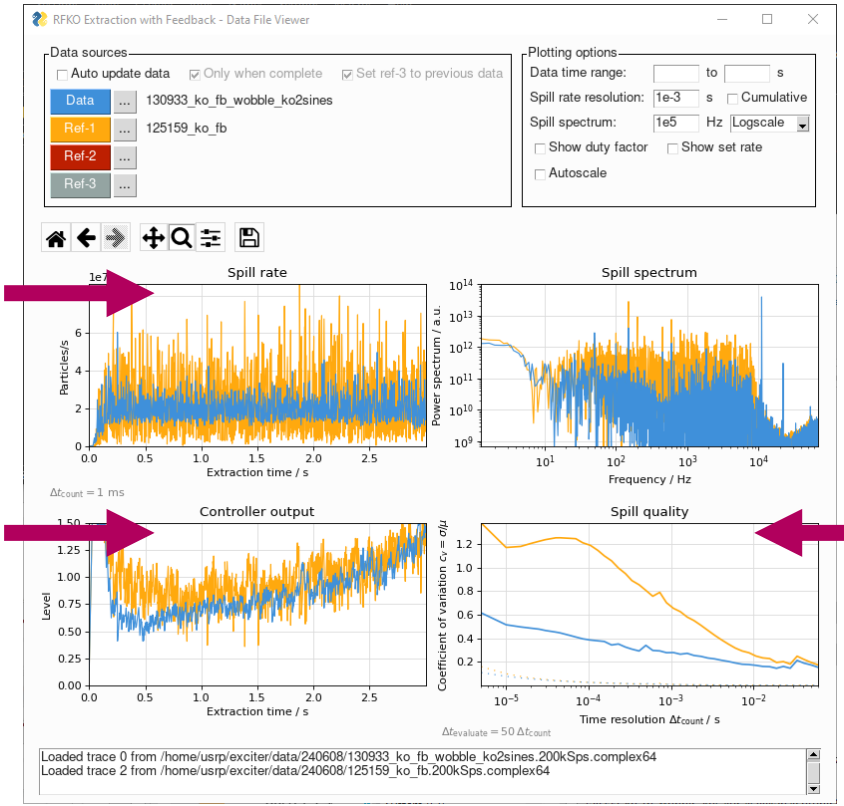
Python Qt GUI

- Online monitoring with dedicated app

Measured spill rate

KO amplitude

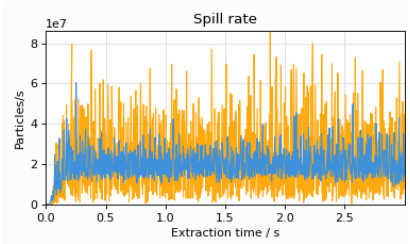
Spill quality

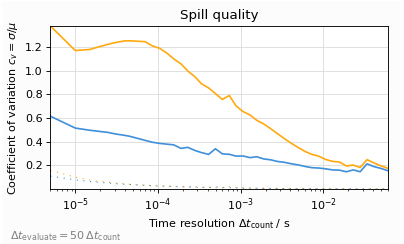


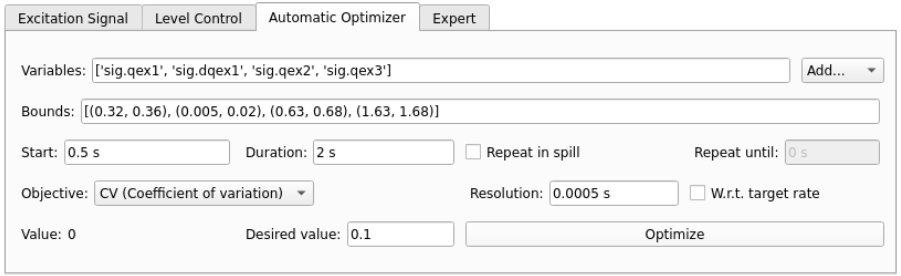
KO Amplitude (Anfang)	0
KO Amplitude (Ende)	0.0
KO Zeitkonstante (Anfang)	0.5
KO Zeitkonstante (Ende)	0

Optimizer

- Goal: reduce spill fluctuations
  - Minimize $c_v = \mathrm{std}/\mathrm{mean}$
  - On time scale $\Delta t_{\mathrm{count}} \approx 50\ \mu\mathrm{s}\ \ldots\ 500\ \mu\mathrm{s}$
- Method
  - Steps
    - Measure spill quality
    - Adjust frequencies & bandwidths
  - BOBYQA Optimization Algorithm
    - Intra-cycle → find good settings quick
    - Cycle-by-cycle → find optimal settings



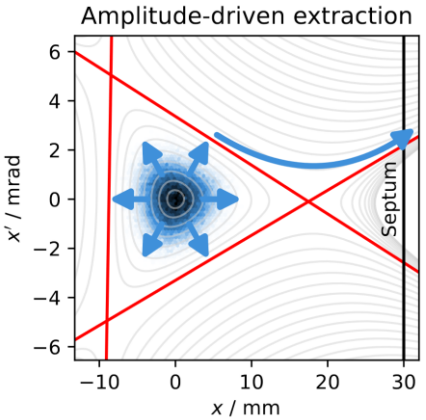


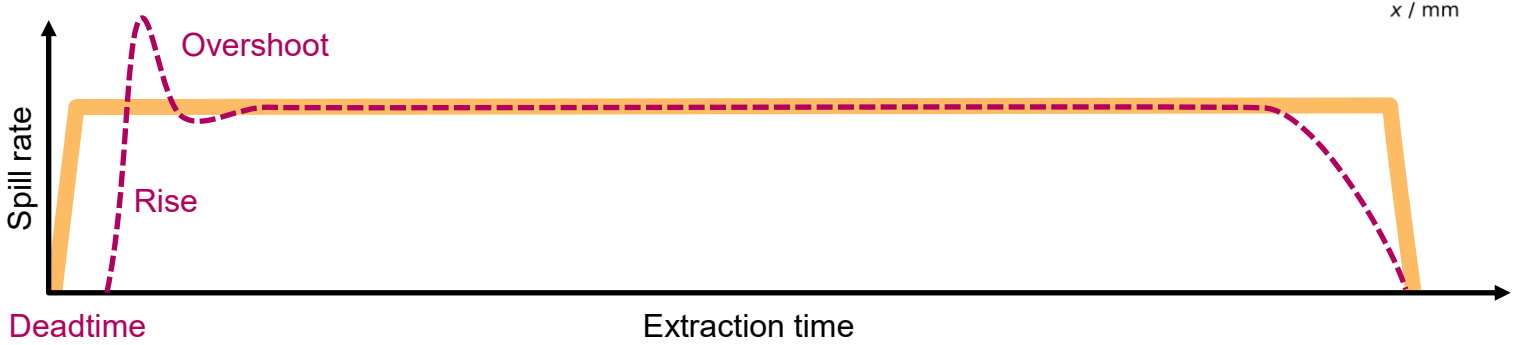


- Generic tool → can also optimize feedback or amplitude for macro-spill shape

Feedback System

- 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 Kamerdzhiev)
  - 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

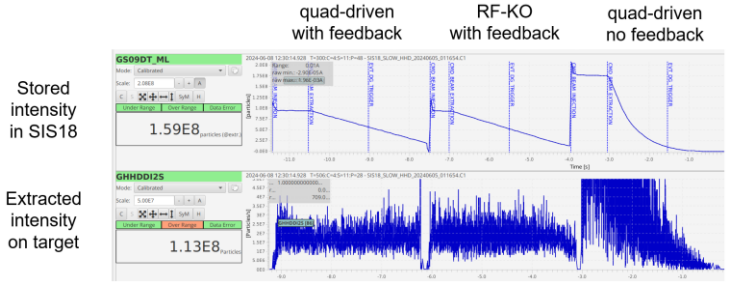
Summary & Outlook

- 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!

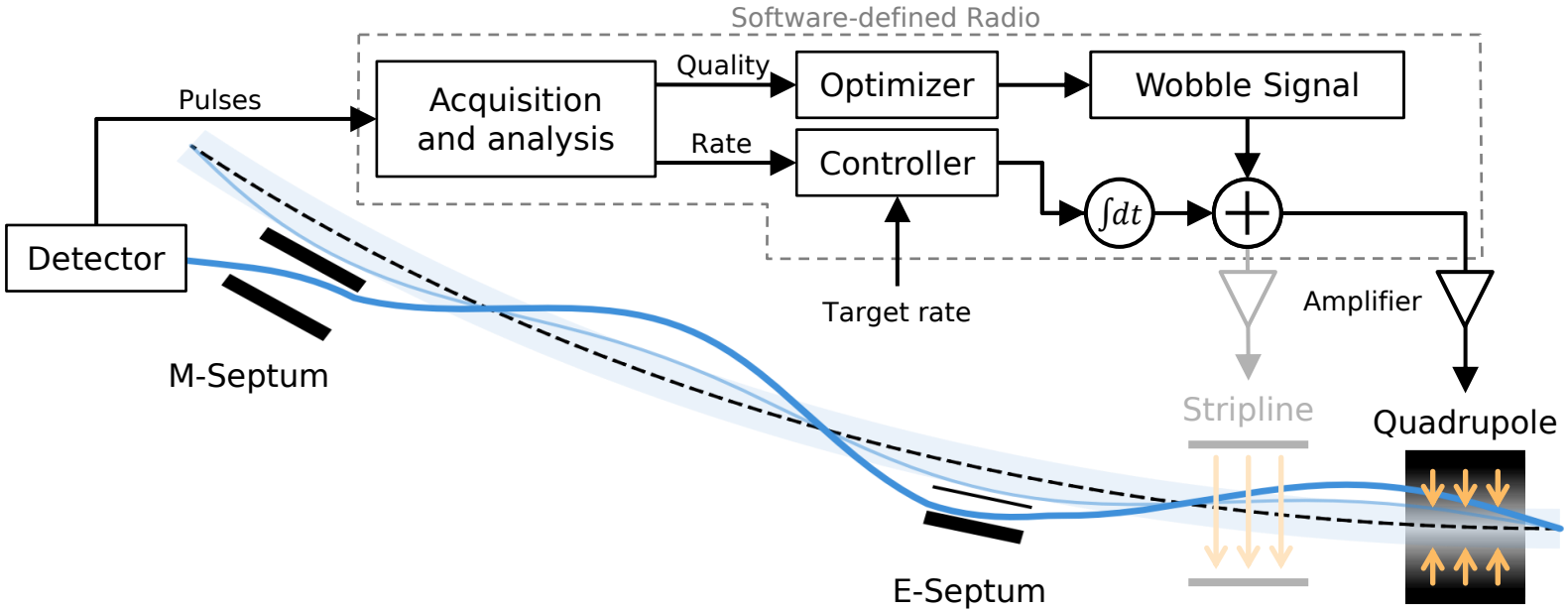
ACC, APH, BEA, EEL, EPS, FCO, OPE, RRF, SIS, SYS



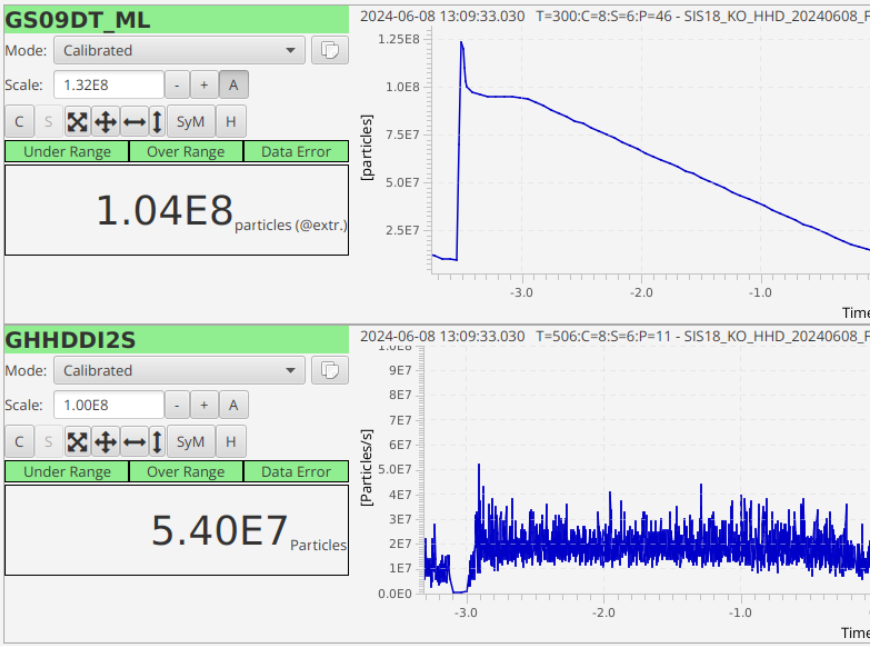
Backup Slides

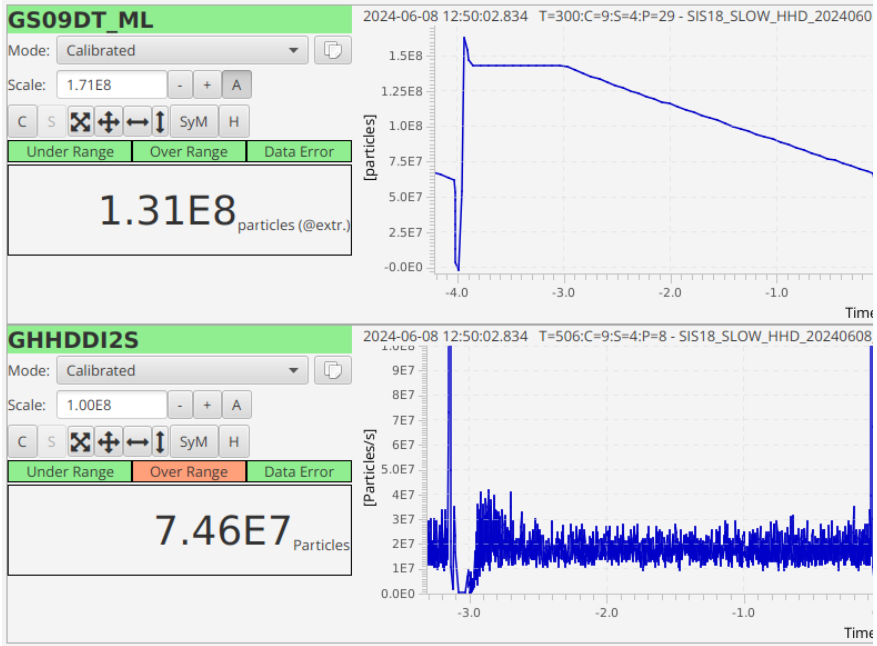
Spill Optimisation System (SOS)

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

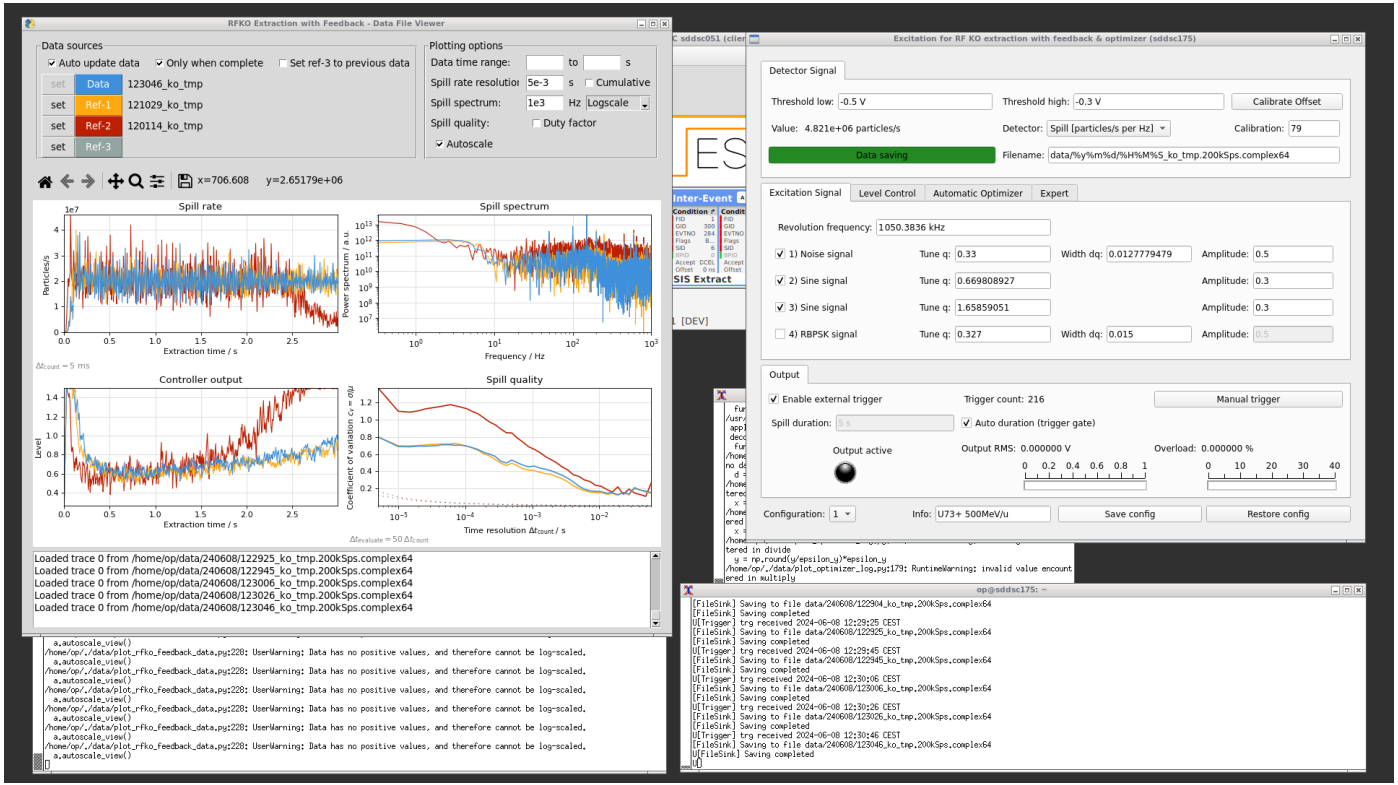


KO vs Quad-driven Extraction



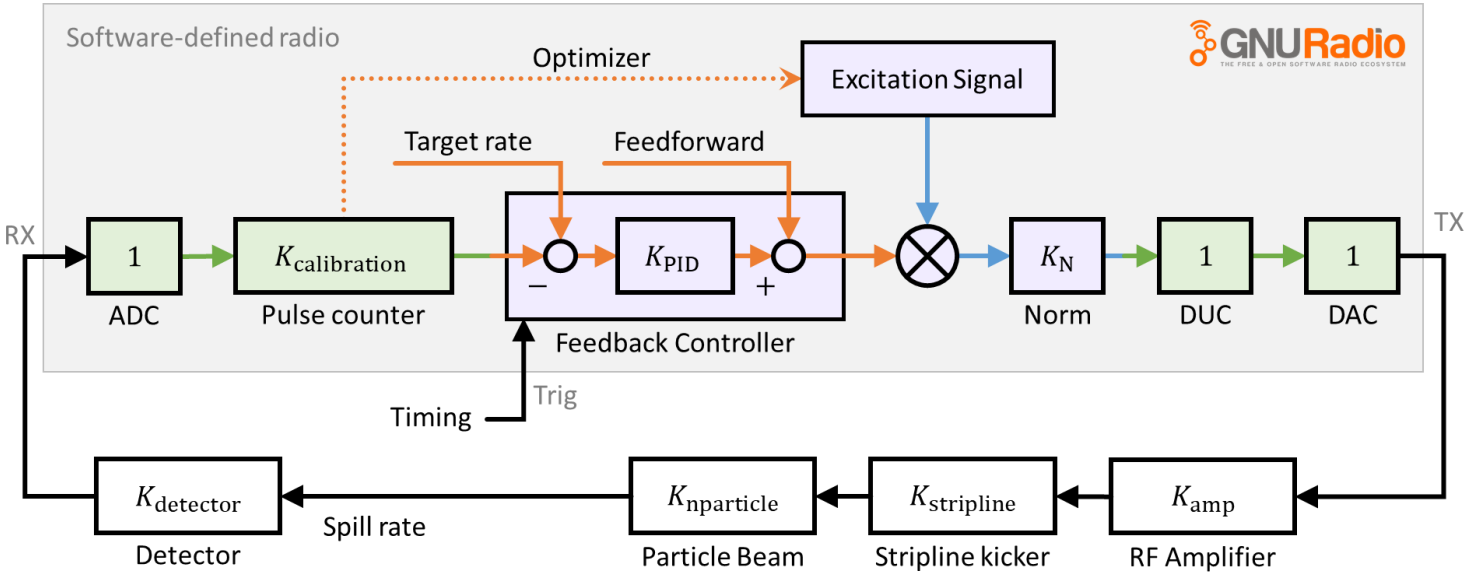


Operating example



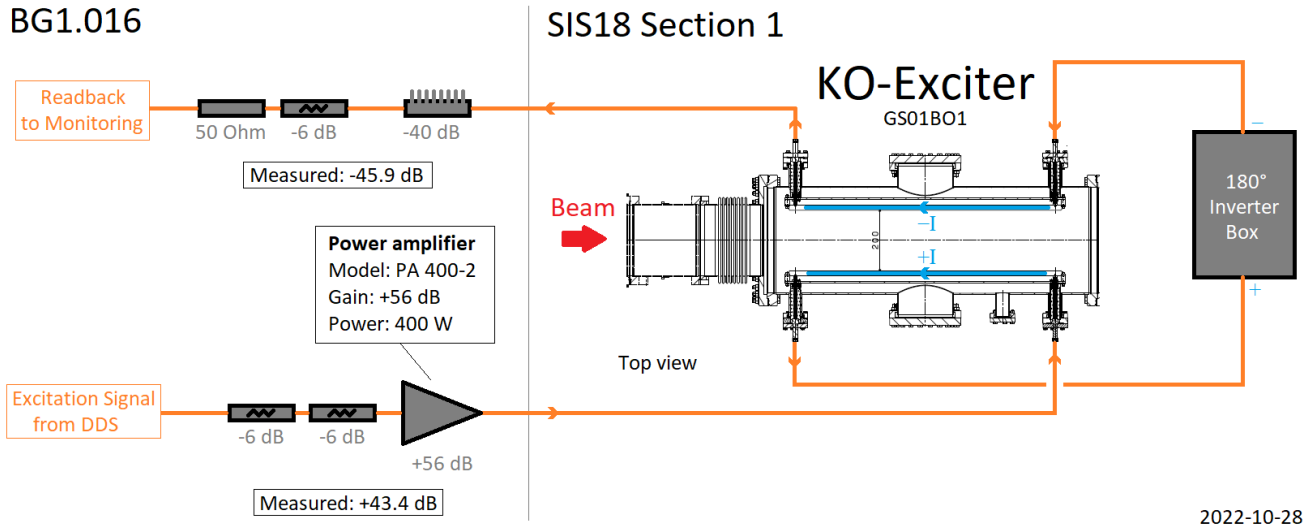
GNU Radio

- Flowgraph (strongly simplified) with PID controller



SIS18 KO Exciter

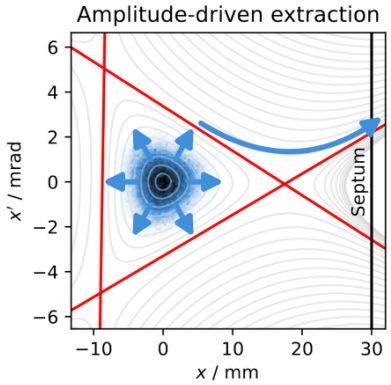
- RRF Group (Bernhard Zipfel)
- Monitoring: https://www-windows.gsi.de/hf-monitoring/ACQmain/system3.htm



Spill Abort

- SOS System
  - Currently: switch off when excitation power exceeds treshhold
  - 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

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.

Subprojects / Tasks

- 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

1. Replace the DDS based RBPSK KO signal generator with the feedback capable SDR signal generator
2. Remote controllable multiplexer for cycle-to cycle switching between beamline detectors and detector overload/failure checks
3. Add real-time (2-5 ms response time) dynamic spill rate control function and automatic optimizer in multiplexed operation
4. Full FESA / control system integration with dedicated GUI
5. Enable operations team to operate and maintain the system in the long term

Resource Profile

Year	Estimated costs	Person months
2024	20k	8
2025	15k	12
2026	5k	4
Total	**40k**	**24**

Major Milestones

Q4/2024	Finish specification and hardware procurement for multiplexed operation
Q1/2025	GNU Radio and FPGA Implementation of legacy KO and realtime rate control functionality
Q2/2025	Multiplexed operation with automatic optimizer
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

Risks, Boundary Conditions and Comments

Major Risks:
- Detection of detector failures/overload
- Availability of FPGA resource

Concerned departments:
- **BEA, ACC, ACO, EEL**
- **OPE, RRF, SYS**

Boundary Condition:

Comments:
Detailed comments in shared GSI Seafile folder:
https://seafile.gsi.de/group/982/

New GUI (layout draft in progress)