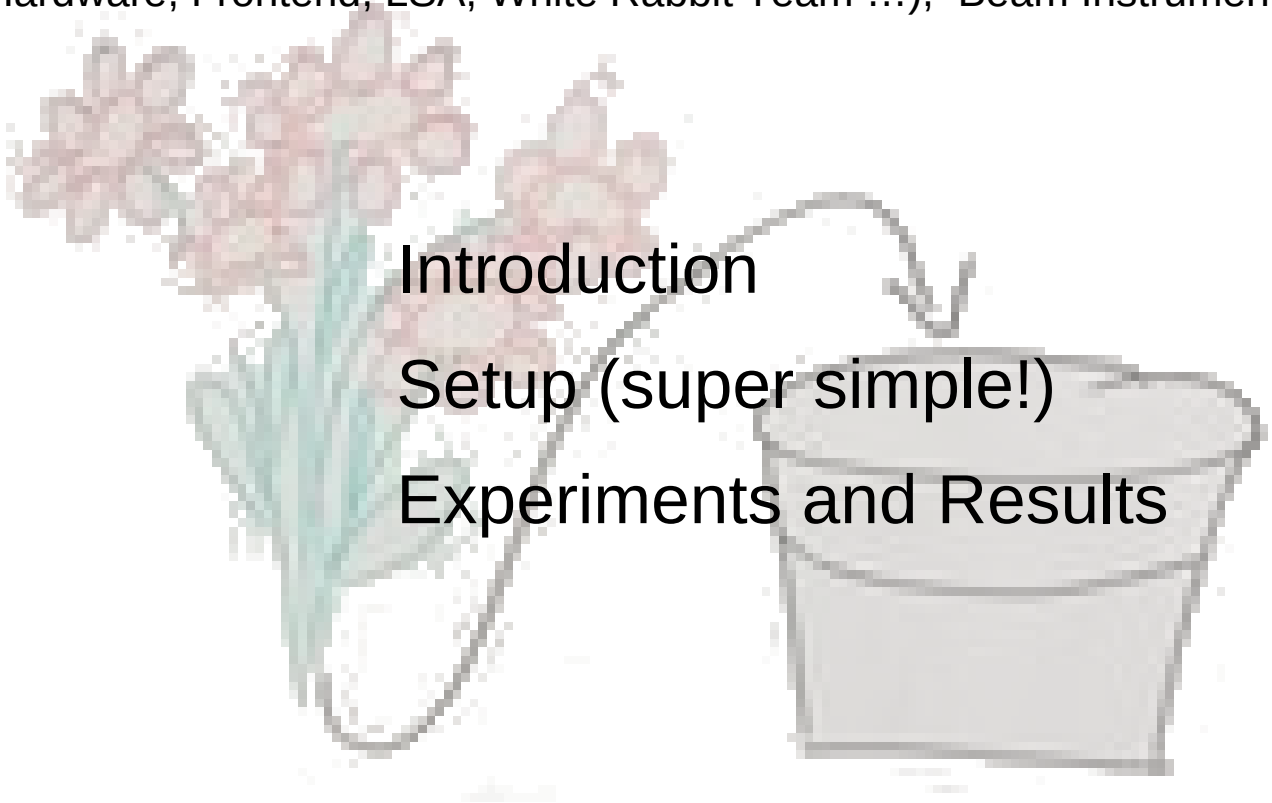
Bunch-to-Bucket (Lite)
Report Machine Experiment 2022

Dietrich Beck, Dieter Lens and many others

Acknowledgements: SIS18, ESR, CRYRING, Ring HV, Ring HF, Experiment Electronics, ACO (Hardware, Frontend, LSA, White Rabbit Team …), Beam Instrumentation, ...



Introduction

Setup (super simple!)

Experiments and Results

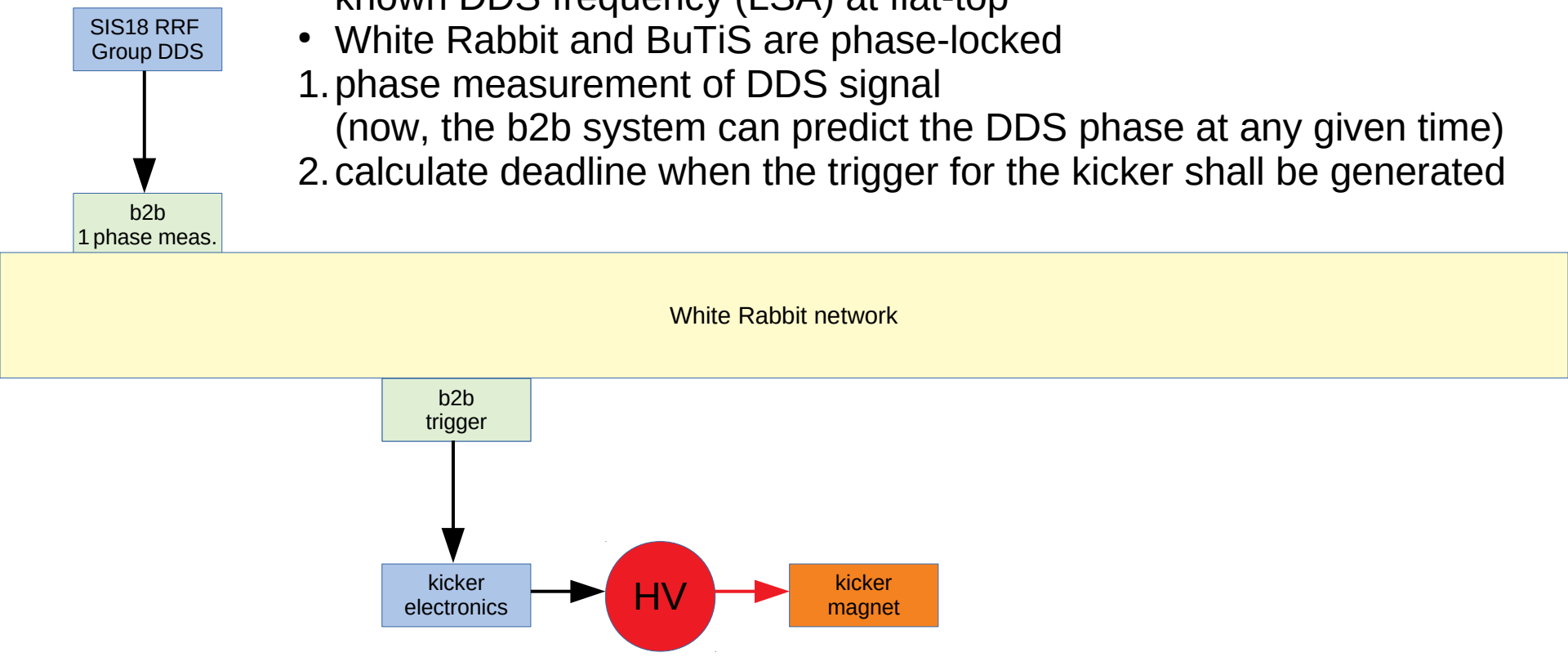
https://www-acc.gsi.de/wiki/BunchBucket

B2B Distributed Signals

Example: Fast Extraction

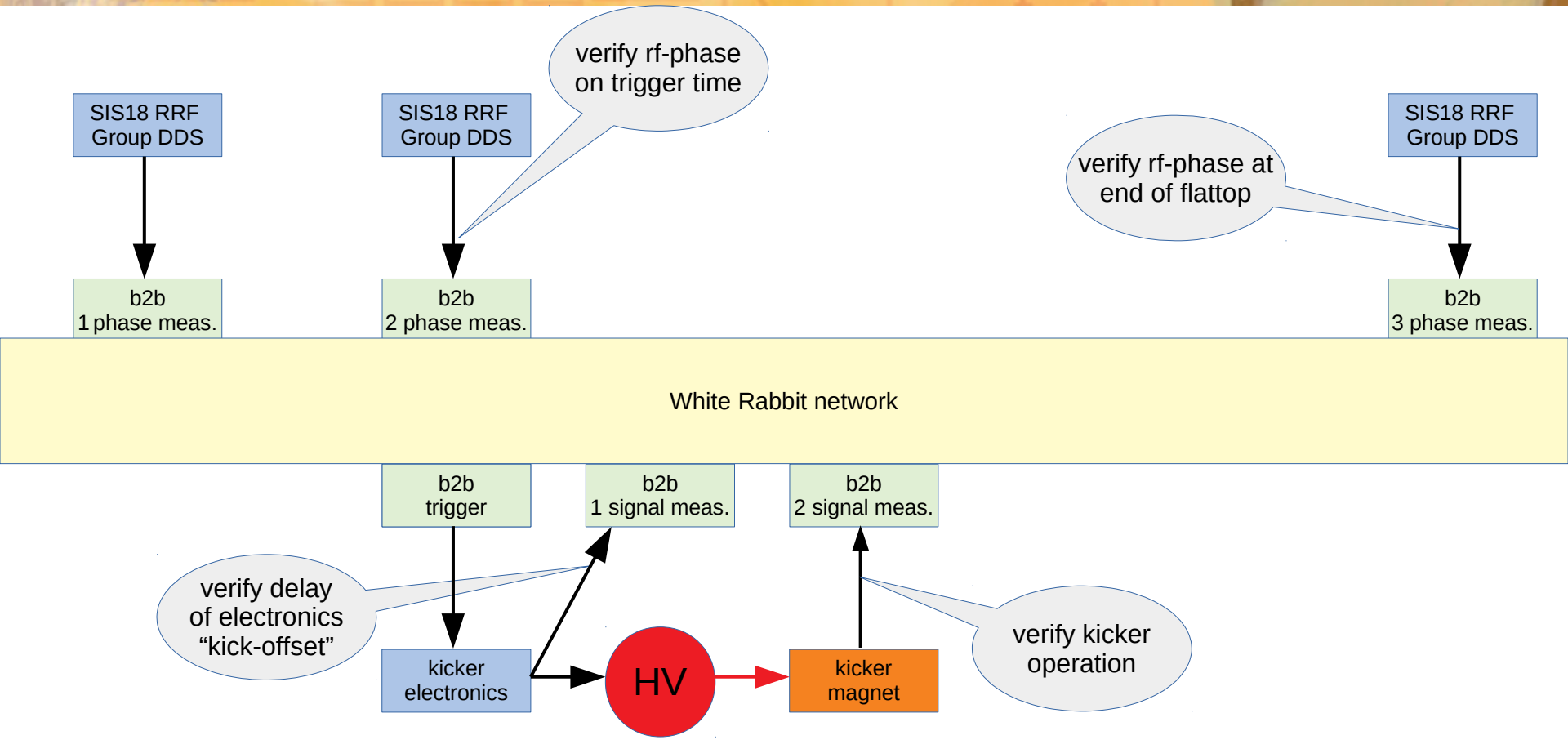
- known DDS frequency (LSA) at flat-top
- White Rabbit and BuTiS are phase-locked

1. phase measurement of DDS signal
   (now, the b2b system can predict the DDS phase at any given time)
2. calculate deadline when the trigger for the kicker shall be generated



B2B Distributed Signals

Example: Fast Extraction



time

New in 2022: Routine Operation!

- triggering of **all** kickers for extraction and injection over the full beam-time
- deployed at SIS18, ESR and CRYRING during last shutdown
  → kicker trigger for all transfers between rings
  → kicker trigger for all fast extractions to whatever cave or target
- just one failure of one minute, https://olog.acc.gsi.de/olog/event/showEvent/428049
- no questions from HKR even at first use

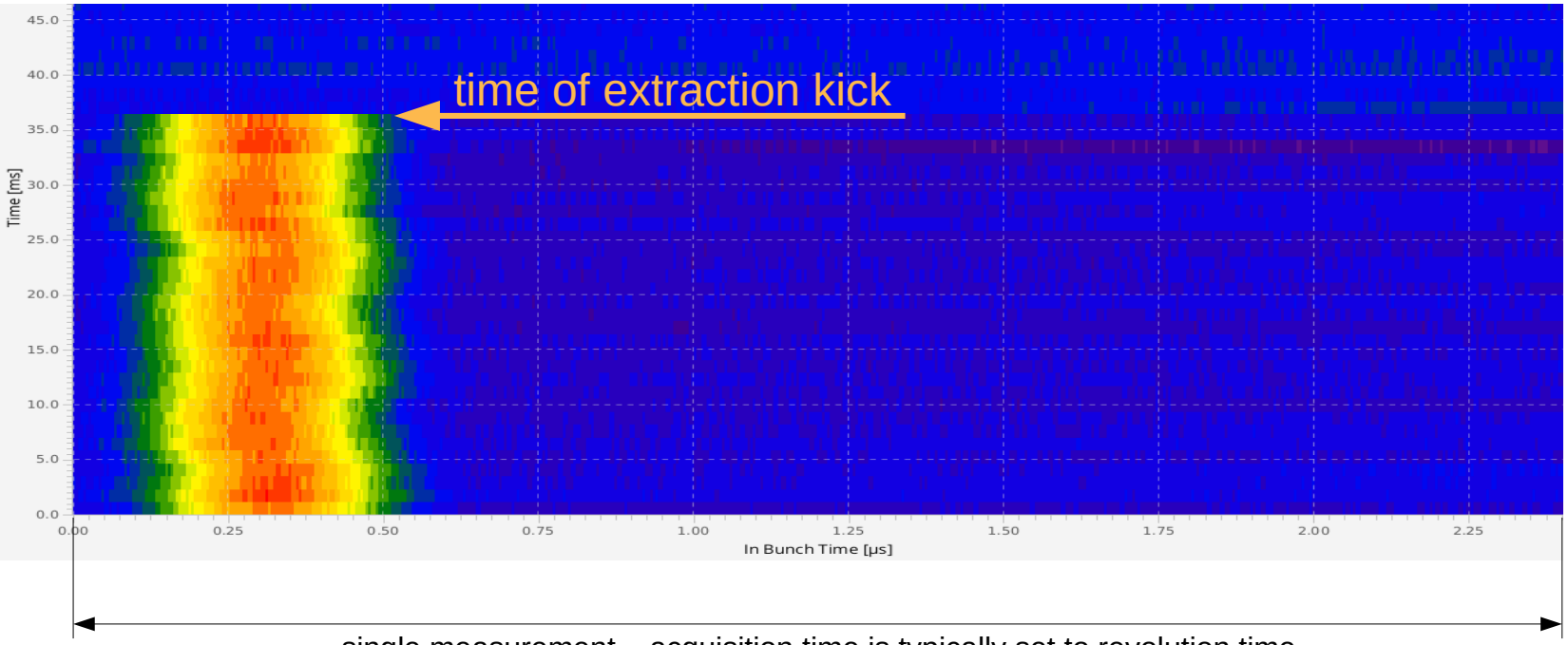
→ seems to work

Machine Experiments planned along the full chain

- SIS18 → ESR
- ESR → CRYRING
- CRYRING extraction

Beam Instrumention: ‘FCT-Ring’ System

(works also with BPM for low intensity beams)



single measurement – acquisition time is typically set to revolution time
start trigger: signal from DDS

FCT_Ring

- allows to observe bunch(es) in the ring
- usually used with FCTs, but can also be used with BPMs in case of low intensity
- implemented at all three rings (thanks to A. Reiter, O. Chorniy, H. Bräuning)
- example: beam in ESR ~35 ms prior extraction

SIS18 → ESR (part 1)

- 2 June 2022 $^{198}Au^{78+}$ @ ~145 Mev/u
- 119 µs frequency beat period (energy loss in stripper foil)
- SIS18 (h=1) → ESR (h=3)
- setting not very well suited
- just a quick test of one hour
- b2b system has just one parameter: phase difference between h=1 group DDS signals of the two rings involved

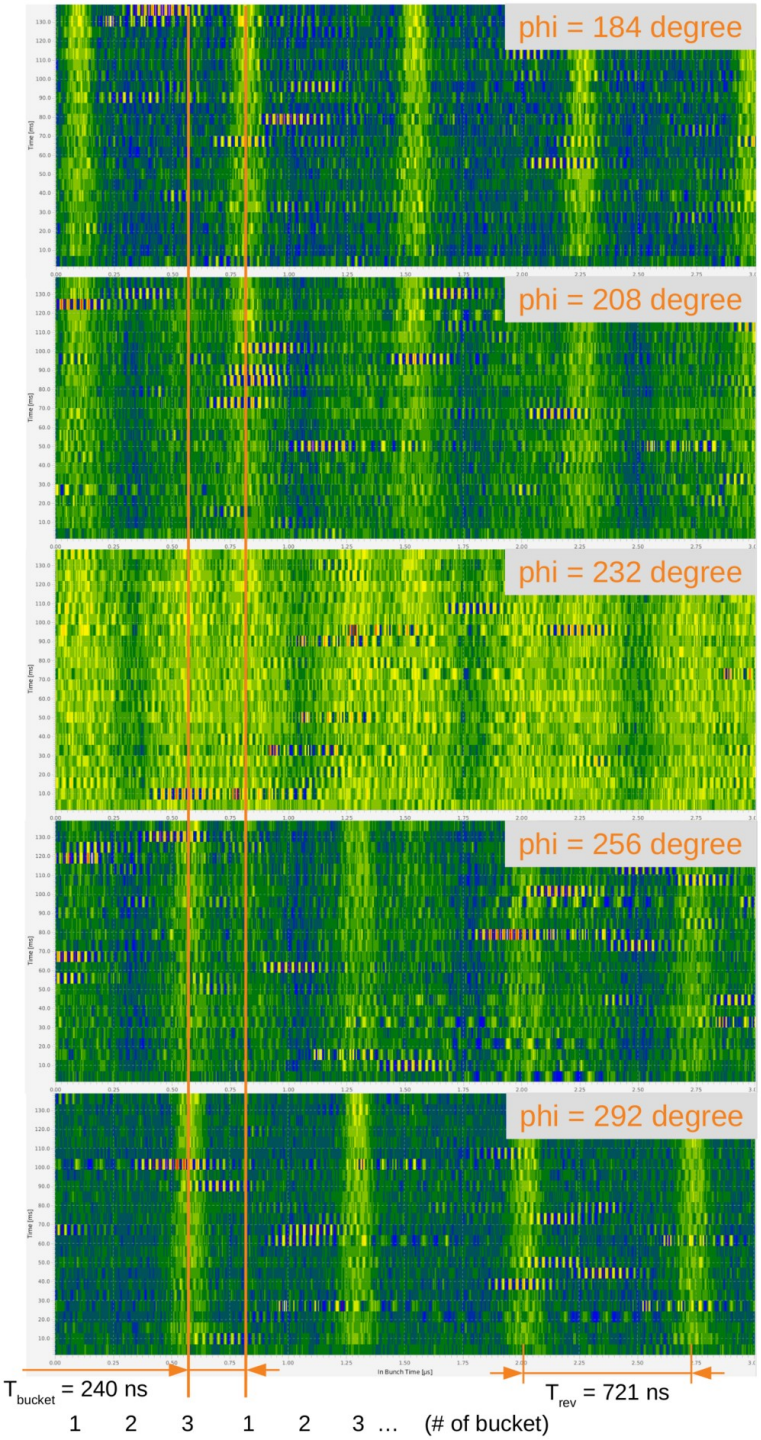
- ‘scan’ over ~120° (ESR) – from one bucket to the next
- figure on the right
  ~ 140 ms observation time (start of cooling visible)
  - bunch is moved from bucket #3 → #1

- b2b system allows to

→ select individual rf-buckets at the destination ring

→ new 2022: all combination of harmonic numbers possible

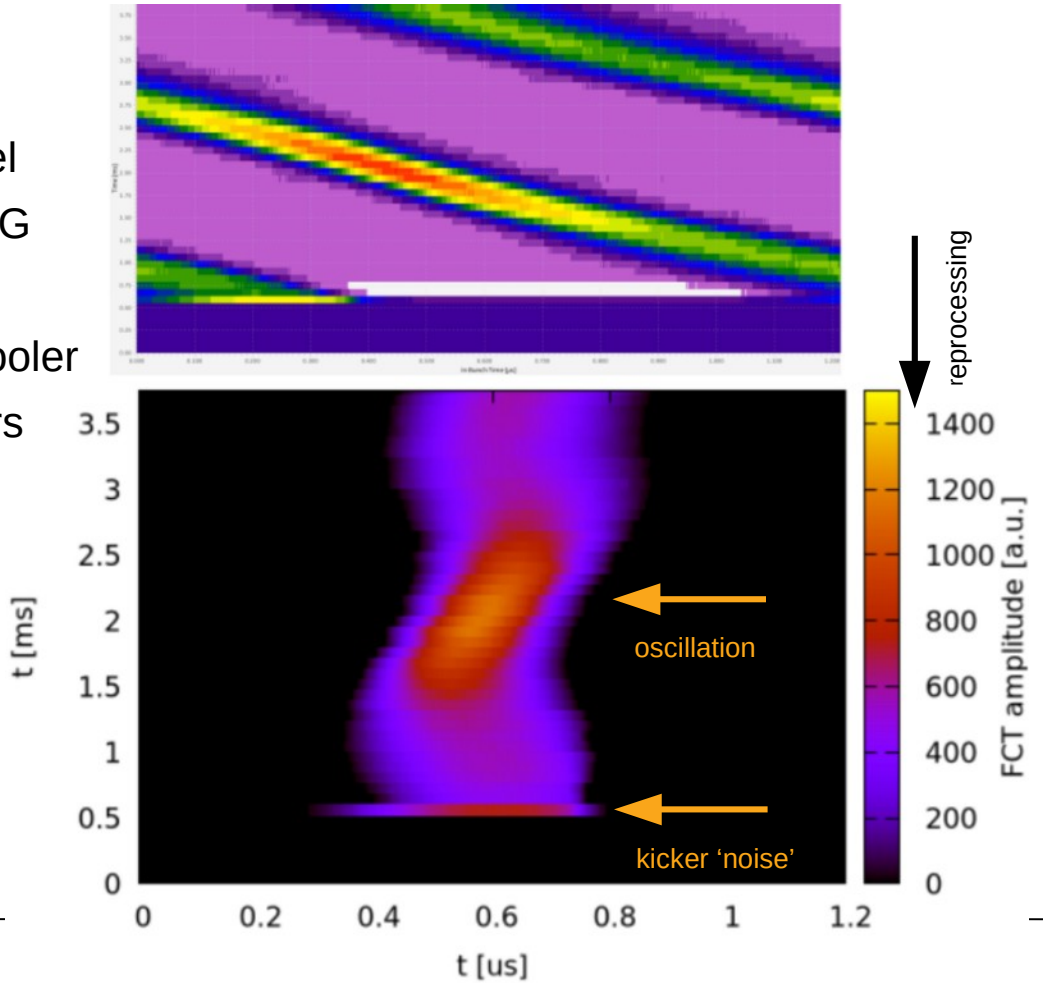
Result: true to bunch-2-bucket transfer still works in 2022



ESR → CRYRING 1

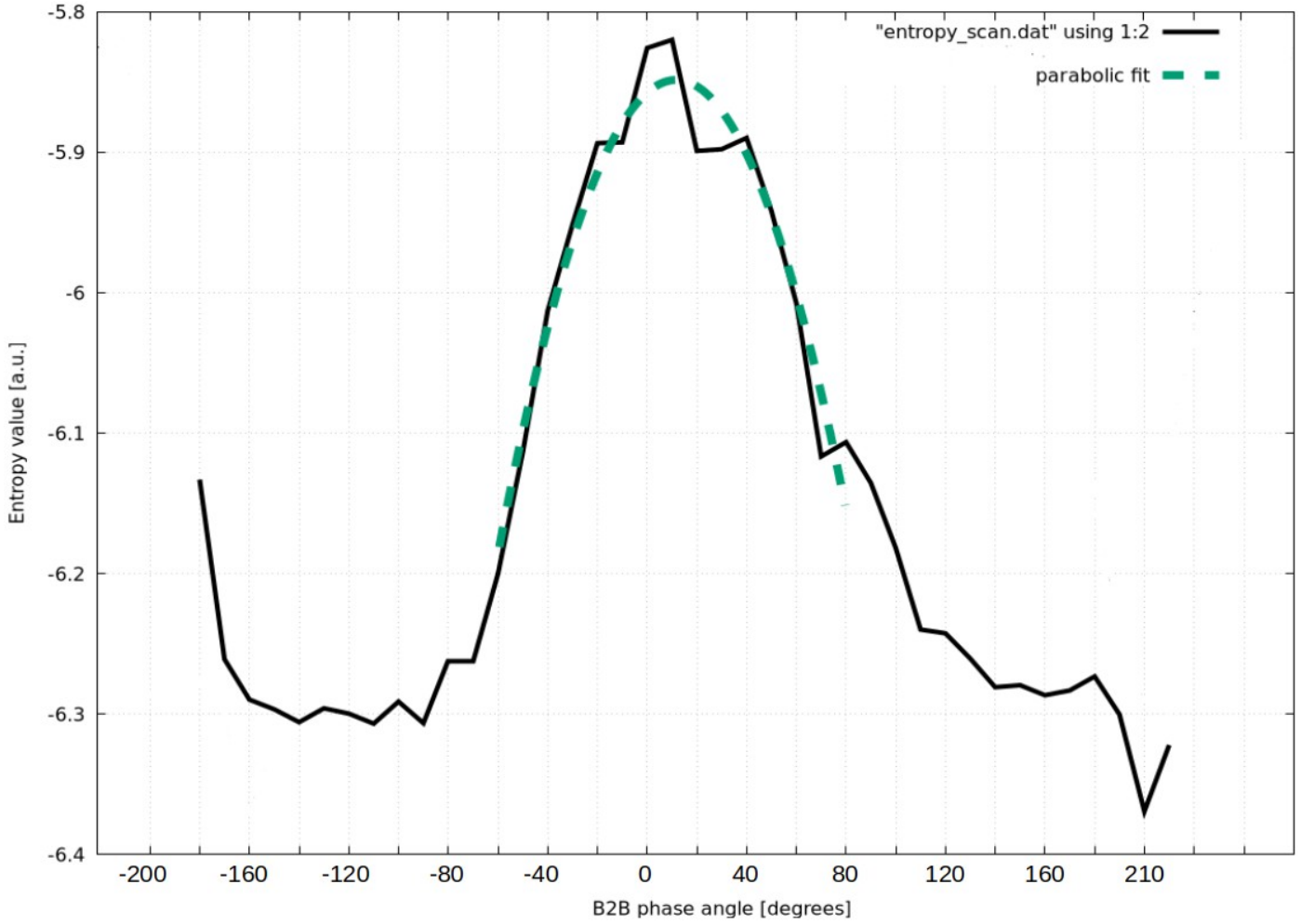
- 7 June 2022, $^{198}Au^{78+}$ @ ~10 Mev/u
- ~1 ms frequency beat period
- ESR (h=1) → CRYRING (h=1)
- well suited conditions, but …
  … schedule was quite delayed
- decision: do machine experiment in parallel to the physics experiment behind CRYRING
  - large acceptance of storage ring
  - ions cooled and bunched with electron cooler
  - parasitic machine experiment of two hours

- drawback: h=1 DDS frequency does not match revolution frequency of ion bunch
  - quick debunching
  - hard to analyze → reprocess image (Michael Reese)



ESR → CRYRING 2

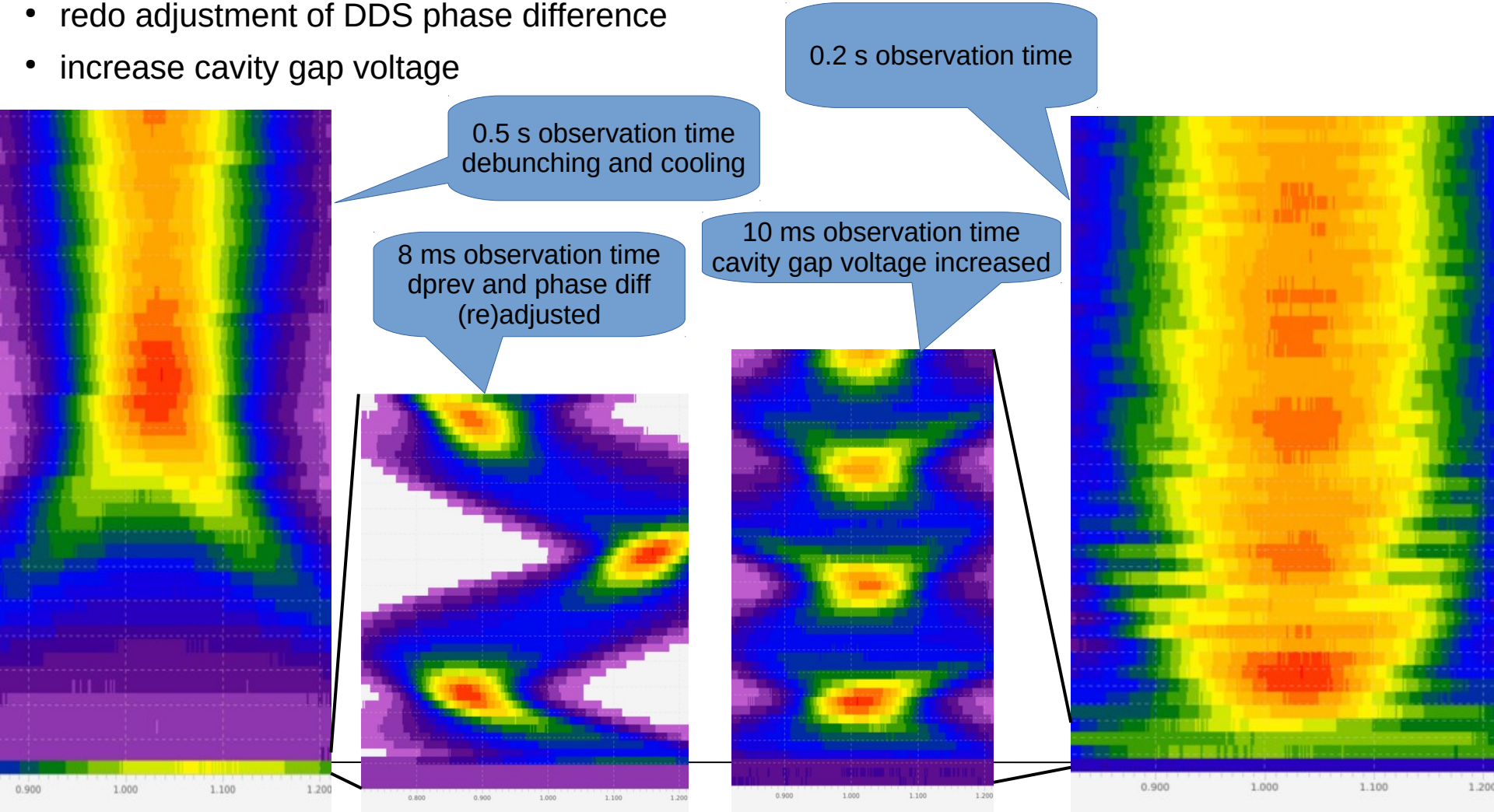
- measurements by changing the phase difference between the two DDSs from shot to shot
- 1st approach: plot ‘entropy’ as a function of phase difference, then fit a parabola



ESR → CRYRING 3

all this does not solve the problem of debunching

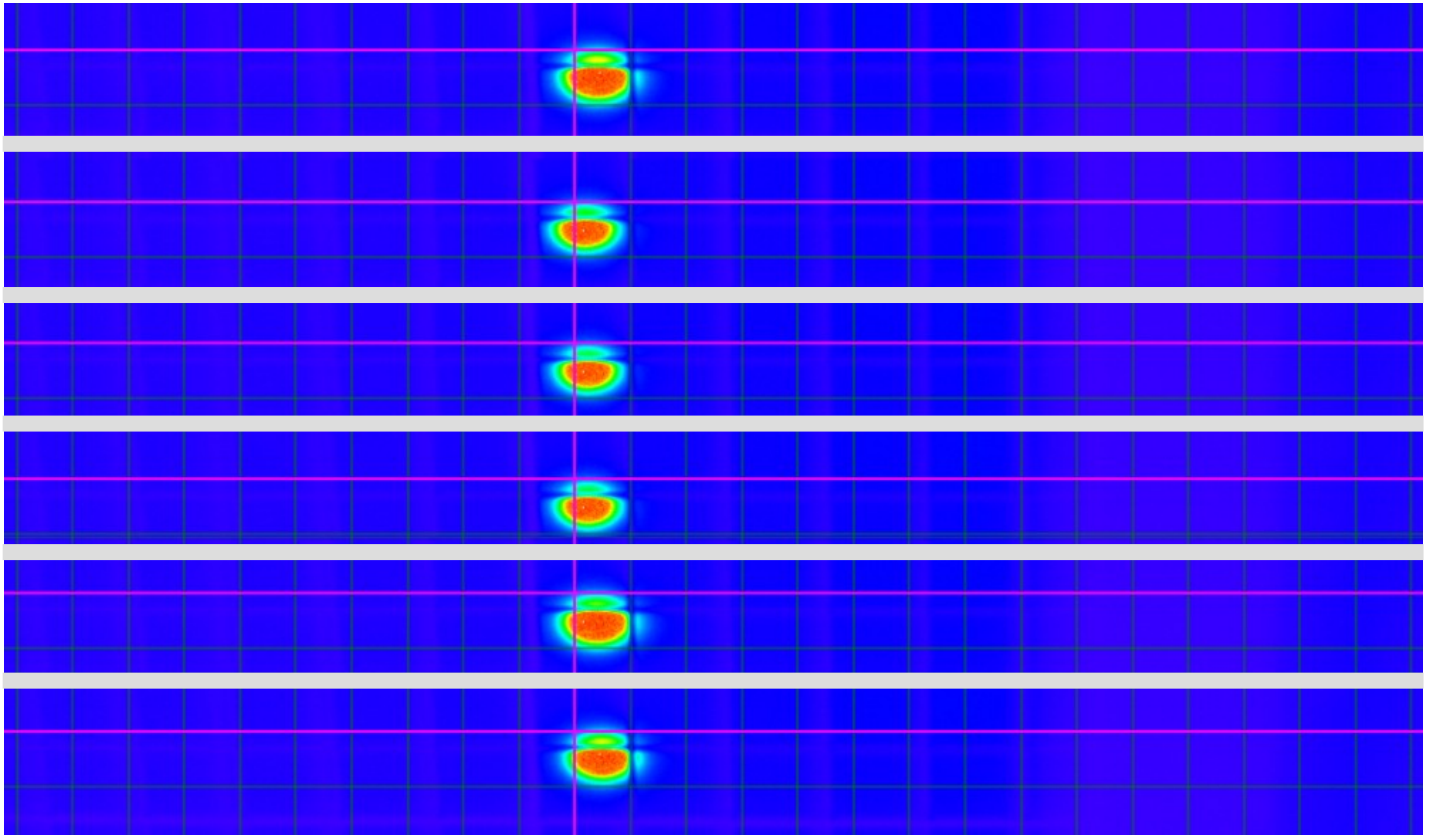
- adjust ParamModi parameter dprev → match revolution and DDS frequencies
- redo adjustment of DDS phase difference
- increase cavity gap voltage



ESR → CRYRING 4

CRYRING extraction: the CRYRING team managed this without any help

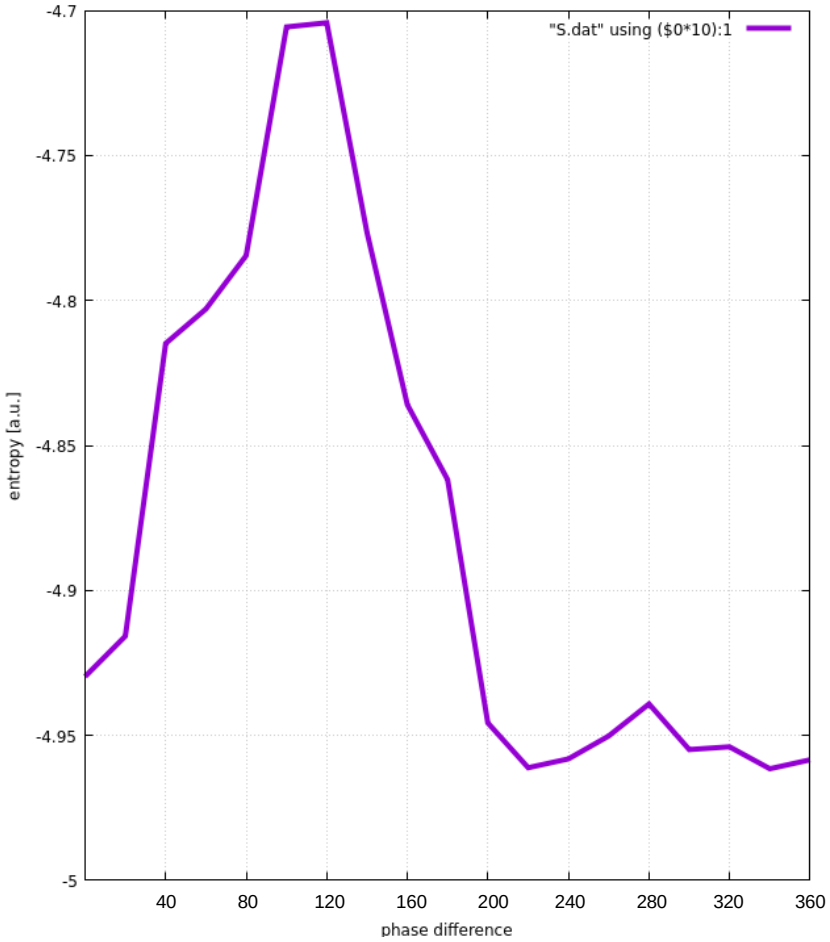
below: images of six consecutive extractions – the beam is always well centered



N.B.: This is the full chain of the GSI accelerator complex – all transfers use the b2b system, including the final extraction from CRYRING!

SIS18 → ESR (part 2)

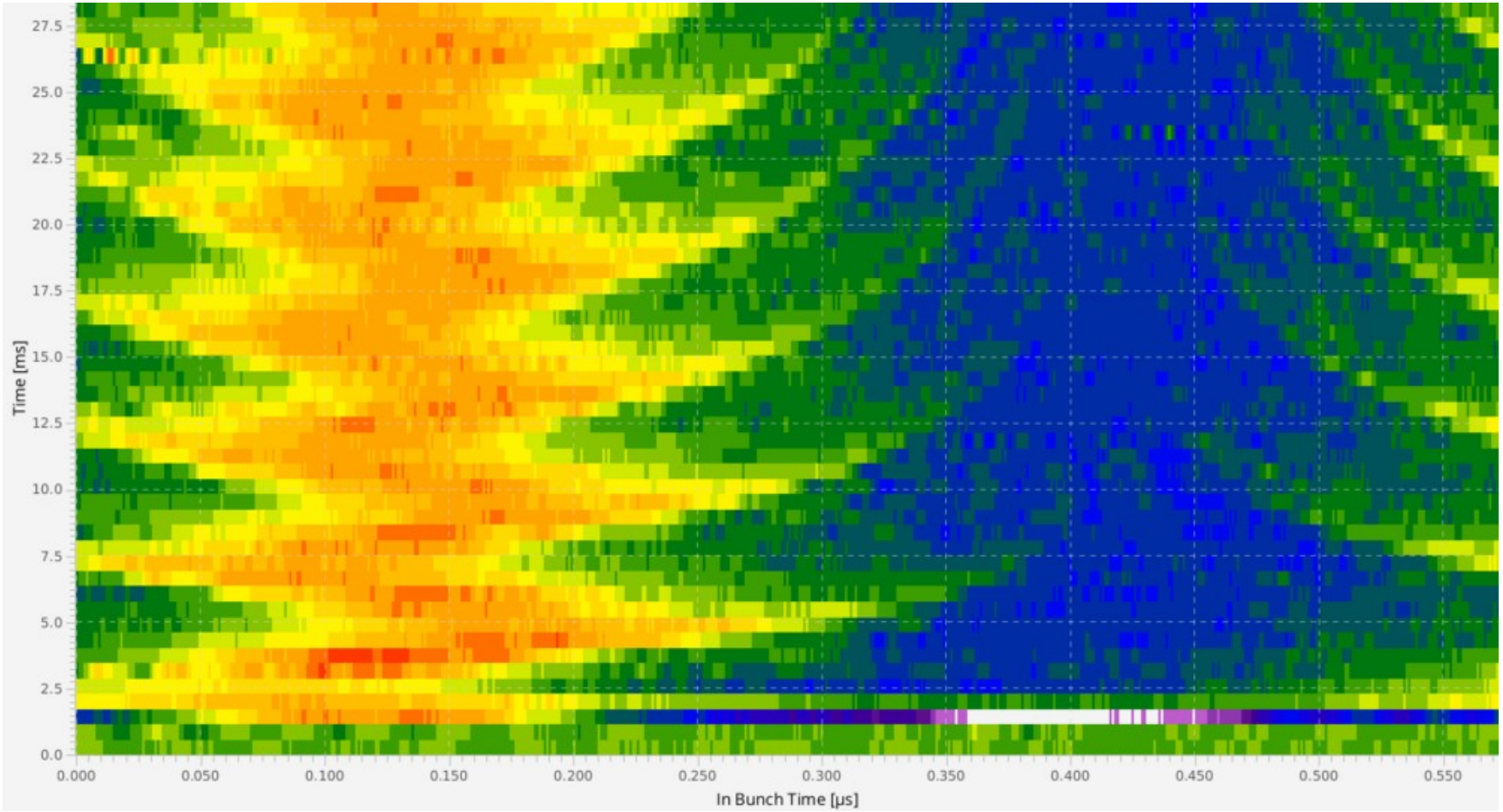
- 29 June 2022 $^{208}Pb^{82+}$ @ ~275 Mev/u
- 116 µs frequency beat period (energy loss in stripper foil)
- SIS18 (h=1) → ESR (h=1)
- setting well suited
- figure: ‘entropy scan’



- but ...

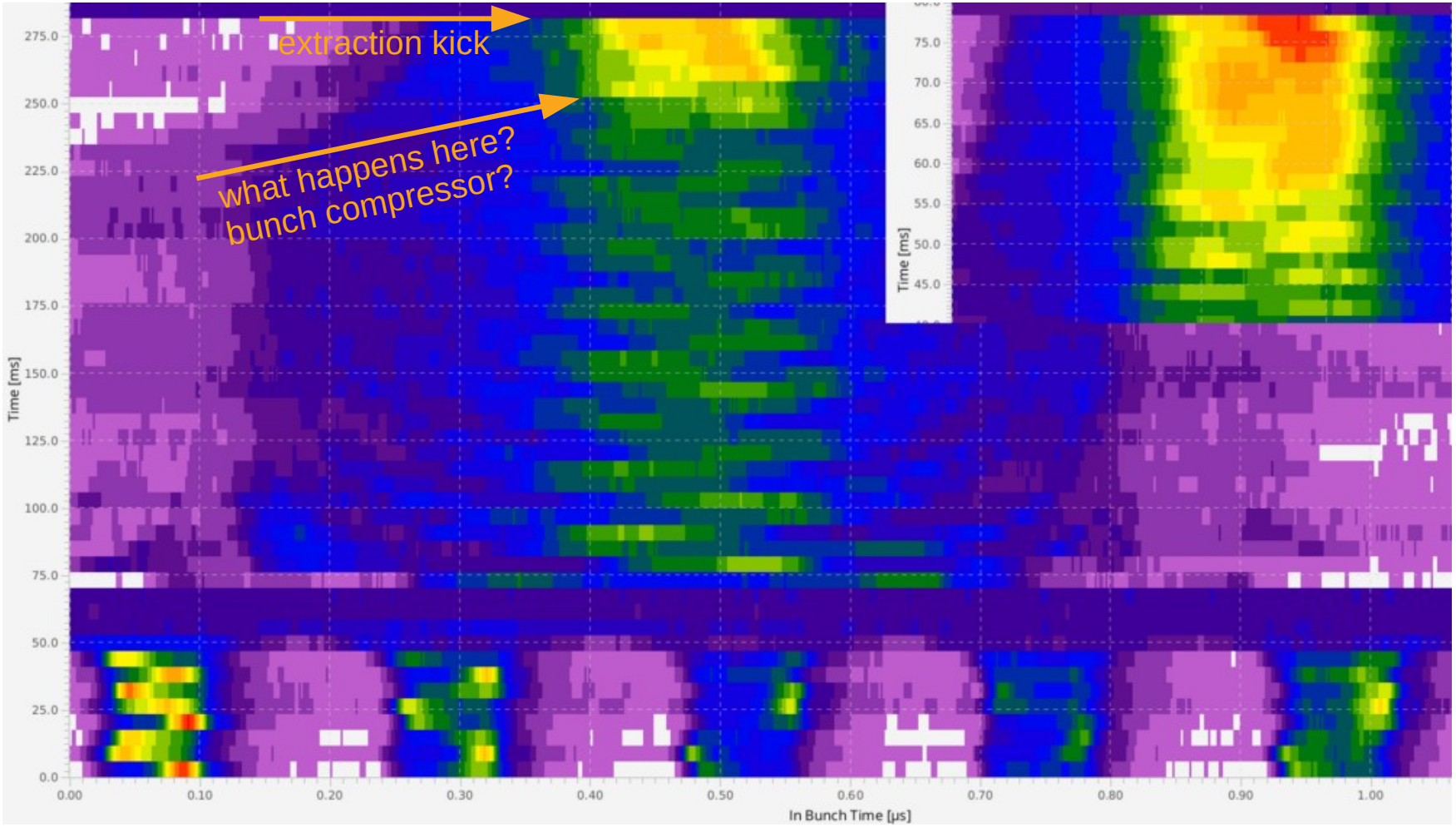
SIS18 → ESR (part 2)

‘best’ bunch-to-bucket transfer …



FCT_RING: ESR

SIS18 → ESR (part 2)



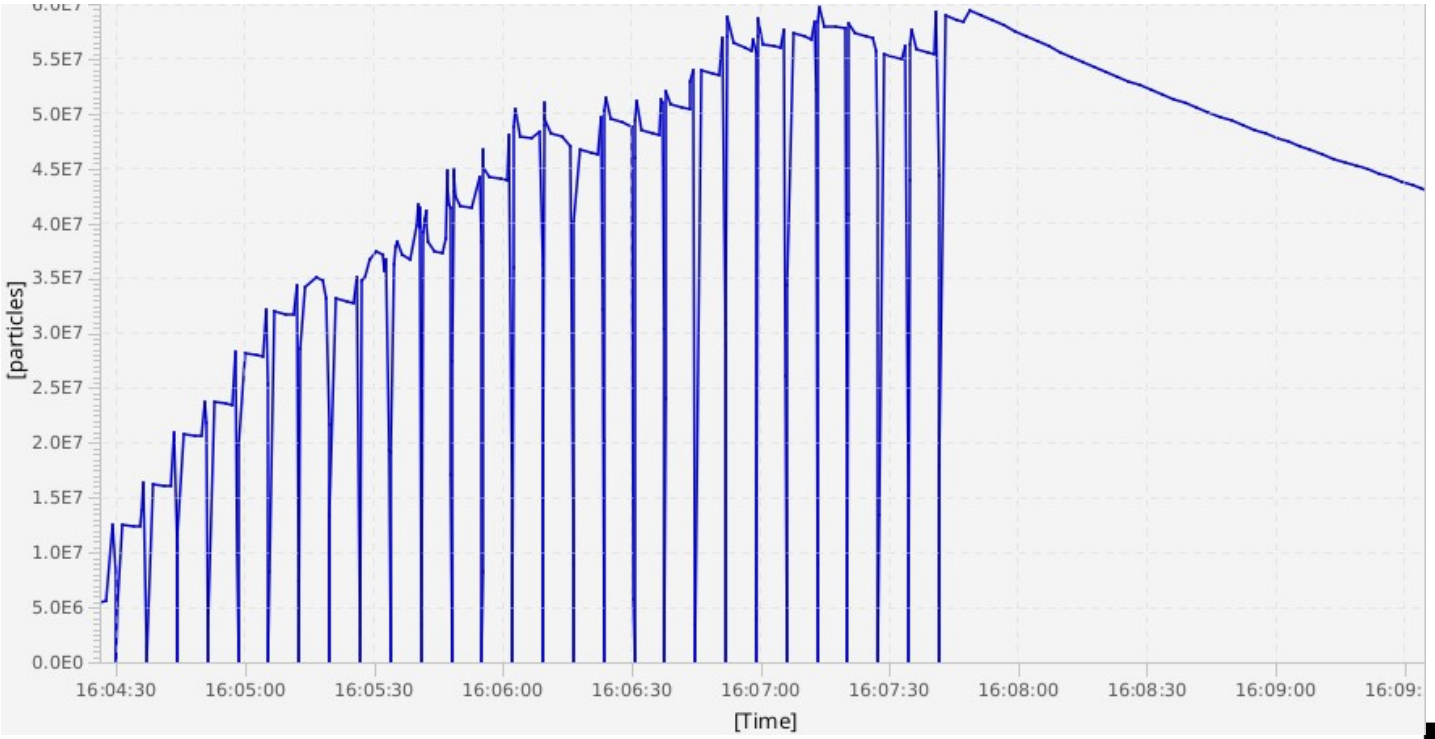
FCT_RING: SIS18

SIS18 → ESR (part 2)

‘Stacking’ of SIS18 beam in ESR

- ‘injection at the unstable fixpoint’, old-technique

  a. determine optimum phase difference between SIS18 and ESR DDSs
  b. inject bunch with addition phase shift of 180° - bunch-2-~~bucket~~ or bunch-2-gap
  c. cool bunch into the rf-bucket using the electron cooler
  d. inject another bunch into the gap and cool it into the rf-bucket
  e. ...



Conclusion

- B2B Transfer System
  - just one free parameter – phase difference of the two involved group DDSs
  - other parameters:
    - dprev
    - cavity gap voltage
    - preparation of bunch in extraction ring
    - ...
- SIS18 → ESR
  - routine operation: transfer as coasting beam (+ fast extraction to caves)
  - 2 June, b2b, ~1 hr, ~70 extractions from SIS18
  - 29 June, b2b, ~ 3 ½ hrs, ~800 extractions from SIS18
  - bonus: ‘Stacking’
- ESR → CRYRING
  - routine operation: transfer as coasting beam (+ fast extraction to HITRAP)
  - 7 June, b2b, ~ 2 hrs, ~ 170 extractions from ESR
- CRYRING Extraction
  - routine operation: fast extraction to experiment

Bunch-to-Bucket Transfer ESR → CRYRING@ESR

2022-jun-07

Bunch-to-bucket transfer of hydrogen-like $^{198}Au^{78+}$ @10 MeV/u between the two rings using frequency beating (T_{beat}= 915µs).

Shown is the position (relative to the relevant ring-RF signal) of a single bunch of 1E6 ions observed by beam profile monitors for about 35ms prior extraction (ESR, bottom) and 300ms after injection (CRYRING, right).

CRYRING: h=1, T_{rev}= 1.2µs, circumference 54m

ESR: h=1, T_{rev}= 2.4µs, circumference 108m