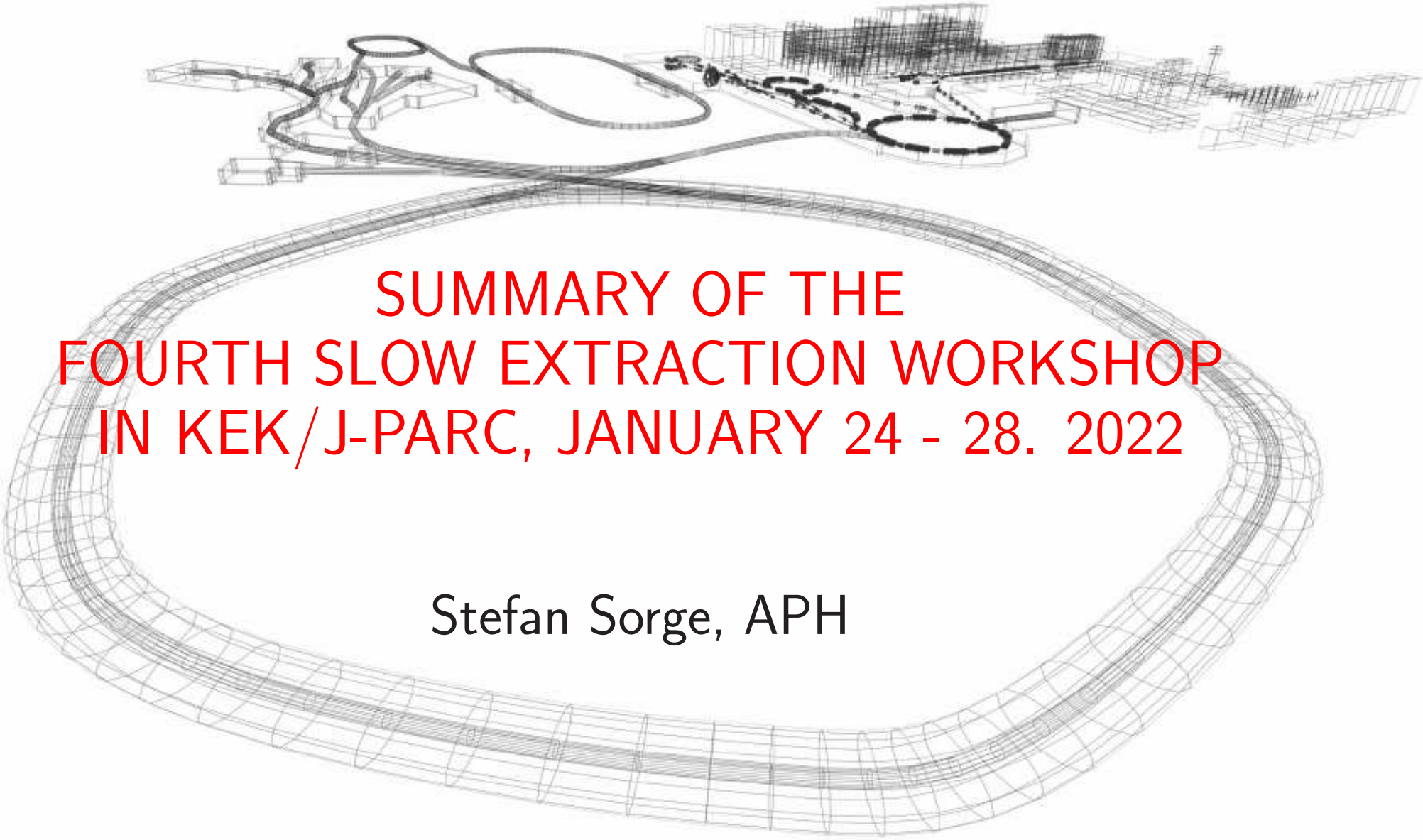

SUMMARY OF THE FOURTH SLOW EXTRACTION WORKSHOP IN KEK/J-PARC, JANUARY 24 - 28. 2022

Stefan Sorge, APH

- Fourth Slow Extraction Workshop in January 24 - 28, 2022, organised by KEK/J-PARC, Japan.
- One session per day starting at 6 AM and ending between 8:30 and 9 AM according to Japanese time.
- 30 presentations + opening talk + closing/discussion:
  - Monday: Overview talks
  - Tuesday: Medical facilities and related topics
  - Wednesday: Spill quality
  - Thursday: Septa and other instrumentation
  - Friday: Particle loss minimisation
- 89 participants.
- Program: see `https://conference-indico.kek.jp/event/163/`

Monday: Overview talks

M. Tomizawa: Status and plans for SX at J-PARC → Main Ring

- J-PARC Main Ring:
  - Proton ring with circumference: $C = 1567.5$ m.
  - Resonance tune: $Q_{x,r} = 67/3 = 22.3333$.
  - Slow extraction by tune sweep with quadrupoles (like SIS18).
- Interesting points:
  - Encounter instability at debunching time. Cure by injection with longitudinal phase offset and two step voltage debunching, where second voltage decrease non-adiabatic. → momentum increase.
  - Spill quality improvement by spill feedback with fast quadrupoles and transverse rf field (rf knockout), where rf amplitude low and without extracting influence → duty factor increased to $F = 0.55$, ideal: $F_{\text{ideal}} = 1$.
  - Beam loss reduction at electro-static septum with diffuser and bent crystals.

Monday: Overview talks

Verena Kain *et al.*: Status and plans for SX at CERN SPS

- CERN SPS: Circumference: $C \approx 7\ \mathrm{km}$, extraction of protons up to $p = 400\ \mathrm{GeV}/c$ and heavy ions with $p \in (30,\ \ldots\ ,\ \approx 380)\ \mathrm{GeV}/c$ proton equivalent. SX with tune sweep.
- Loss reduction:
  - Alignment of electro-static septum with algorithms: POWELL and Open Ai Gym. Time reduction form $\approx 8\ \mathrm{h}$ to $< 45\ \mathrm{min}$.
  - Reduce effective width of electro-static septum by thinner wires at entrance and thicker at exit: first 3: $60\ \mu\mathrm{m}$ INVAR, last 2: $100\ \mu\mathrm{m}$ stainless steel.
    $\rightarrow$ perhaps particle loss distributed over longer septum range?
  - Loss reduction with crystals. Goal: use crystals in routine operation.
- Spill quality:
  - Application of ripples for direct counteracting $n \times 50\ \mathrm{Hz}$ ripples.
  - Drift of $50\ \mathrm{Hz}$ ripple: not understood but optimisation works.
    $100\ \mathrm{Hz}$ with phase jumps and erratic noise, not understood and still open.

Monday: Overview talks

Matthew Fraser: Status and plans for SX at CERN PS.

- CERN PS:
  - Circumference: $C = 628$ m, proton operation. Extraction by tune sweep.
  - Many slow extraction system removed or decommissioned during last years. Concerted effort started last year to restart slow extraction due to new users and requirements.
- Loss reduction with COSE (also SPS): "Constant Optics Slow Extraction", i.e. optics are constantly change according to beam energy which changes due to momentum selective extraction by tune sweep.
- Use of empty bucket channelling for spill improvement:
  - Rf frequency slightly mismatched from $n\times$revolution frequency but touches momentum range of particles in beam.
  - Particles pulled through phase space between empty buckets. Resulting tune change drives particles towards resonance.
  - Spill smoothing like with bunched beam extraction but beam stays unbunched.

Monday: Overview talks

Vladimir Nagaslaev: SX for Mu2e at Fermilab

- Beam of high energy and intensity with short bunches:
  - 10^{12} protons per spill with kinetic energy $E_{\mathrm{kin}} = 8\ \mathrm{GeV}$.
  - Spill duration $t_{\mathrm{spill}} = 43\ \mathrm{ms}$.
  - Full bunching, less than 10^{-10} outside buckets.
- Delivery ring with circumference $C = 505\ \mathrm{m}$. Extraction with tune sweep using resonance at $Q_{x,r} = 29/3 = 9.66667$.
- Requirement of beam loss $< 2\ \%$.
  $\rightarrow 50\ \%$ of losses in extraction region.

Monday: Overview talks

David Ondreka: Slow extraction of intense heavy ion beams at FAIR

- Spill improvement at SIS18:
  - Transit time dependence, artificial spill ripple ("wobble"), and applying emittance exchange → presentation of R. Singh.
  - Bunching also with high frequency cavity → presentation of S. Sorge.
  - Macro-spill feedback → presentation of R. Steinhagen.
- Electro-static septa:
  - Voltage measurement with X-ray → presentation of B. Gålnander.
  - Sparking for high particle numbers.
  - Wire survival
- SIS100 challenges
  - magnet multipoles, in particular 12-pole in qudrupoles.
  - alternative working points to avoid "forbidden" energies due to transition energy.

Tuesday

Medical facilities and applications

- K. Noda (HIMAC): Overview over Japanese facilities with hadron synchrotron for cancer therapy. Japan is very advanced in ion beam cancer therapy, four centres.
- M. Pullia (CNAO):
  - Spill quality: Empty bucket channelling, air coil quadrupole to counteract tune ripples in quadrupoles. $\rightarrow$ possible because of low energy in medical machines.
  - Usage of rf ko extraction besides betatron core.
- C. Cortes (HIT):
  - Comprehensive investigation of beam response to weak rf ko excitation as function of frequency.
  - Application of rf ko excitation during extraction at frequency wit high beam response $\rightarrow$ achieved significant reduction of spill micro structures.

Tuesday

Medical facilities and applications

- E. Benedetto (CERN):
  - NIMMS (Next Ion Medical Machine Study) launched at CERN as successor of PIMMS (Proton Ion Medical Machine Study, CERN 1999).
    Goals: intensity increase, reduction of footprint, and cost reduction.
  - Related to SEEIST project (South East European International Institute for Sustainable Technologies): Partnership of former Yugoslavian countries, Albania, Bulgaria, and Greece for accelerator technology development. Main focus on medical applications.
- R. Taylor (CERN) $\rightarrow$ presentation related to NIMMS:
  - Introduced slow extraction simulation toolkit "Sloexlab".
  - Powerful in visualising processes of extraction (Jupyter). Based on tracking (MADX).
  - No parallel tracking. Moderate simulation performance.

Tuesday

Non-medical presentations

- F. Kühteubl (MedAustron): New evaluation of extraction survey.
  - New comparison of slow extraction of many facilities.
  - More comprehensive than survey from 2016, i.e. comparison of many details: extraction method, ring size, energy range, working point, chromaticity, dominant ripple frequencies, ripple control schemes, use of feedback or not, and finally also duty factor as measure for spill quality.
  - Lowest duty factor: SIS18.
    Comment P. Forck: SIS18 has fastest sampling rate which reduces duty factor.
- K. Brown (BNL) on AGS and BNL as "High Energy Effects Testing Facility"
  - Heavy ion operation up to $E = 2\ \mathrm{GeV/u}$.
  - Extraction efficiency not an issue because low intensities.
  - Closer collaboration in code development proposed. Start with list of used codes.

Wednesday, Spill quality

- M. Pari (CERN)
  - Slow extraction frequency response investigations.
  - Distinction between linear and non-linear ripple superposition: linear as long as tune change direction does not change by ripple $\rightarrow$ SPS with tune sweep extraction.
  - Tracking applying Henon maps (= one turn maps + sextupole kick) is sufficient.
- R. Singh (GSI): Summary of spill structure mitigation at SIS18.
  High resolution measurements with plastic scintillation counter, influence of transit time distribution according to choice of sextupole strength, minimisation of beam emittance and emittance exchange, external tune modulation ("wobble"), bunched beam extraction.
- R. Muto (J-PARC):
  - Spill structure control by feedback and fast quadrupole magnets for spill macro shape, and rf ko noise for spill micro structure control.
  - Interesting topic because probably applicable for SIS18.

Wednesday, Spill quality

- A. Naranyan (FNAL) on Machine learning in spill regulation for Mu2e
  Often used keyword: reinforcement learning
  technique that enables agent to interact with environment by trial and error using feedback from its own actions and experience.
- S. Sorge (GSI): Macroscopic spill structures by crossing synchro-betatron resonances while changing tune during tune sweep slow extraction.
  - Simulation study for present SIS18 conditions and use of high frequency rf cavity for spill structure reduction. Results look promising.
  - Comment: Phenomenon of synchro-betatron resonances known but rarely visible.
- R. Steinhagen on cycle-to-cycle feedback for tuning spill macro structure.
  $\rightarrow$ Feedback and control systems.
- P. Arrutia (CERN) on rf channelling with barrier buckets st the PS.
  Advantage to usual rf buckets:
  Long and flat bunches and complete control of bunch spacing.

Thursday

Electro-static septa and other instrumentation

- F. Belhan (CERN) on first operational experience with new upgraded electro-static septa in SPS. Remarkable detail: straightness of the septa had suffered during the long time of operation leading to higher effective thickness.
- J. Borburgh (CERN) on material research for septa at CERN.
  Side information: chromium anodisation, probably, soon prohibited in Europe. Affects also choice of septum materials.
- Y. Arakaki (J-PARC) on status and development of electro-static septa at J-PARC.
- F. Roncarolo (CERN) on plans for instrumentation for SX at CERN.
  - Among other things fast scintillation detectors with acquisition rate ≈ 200 MHz.
  - Probably base for fast spill feedback regulation.

Thursday

Electro-static septa and other instrumentation

- B. Gålnander (GSI) on electrode gap voltage measurement of SIS18 electro-static septum.
  - Measurement of cut-off of x-ray bremsstrahlung spectrum.
  - Measurement revealed gap voltage to be significantly lower than assumed
    $\rightarrow$ important because of reduced deflection angle.
  - Comparison with same measurement at injection septum, where cut-off of x-ray spectrum found in accordance with expected gap voltage.
- P. Boutachkov (GSI) on development of fast scintillators
  - Aim: looking for alternative to plastic scintillators because of
    limited count rate, max: $2 \cdot 10^7$ pps and
    fast damage due to beam: max. total dose ≈ 54 kGy, exchange after 8 h of beam.
  - Promising candidate: ZnO:In material.
    Pulse duration decreased 25 ns $\rightarrow 800$ ps. Count rate just scaled by that: $6 \cdot 10^9$ pps.
    Max. total dose increased to several 1000 kGy.

Friday, Particle loss minimisation

- F. M. Velotti (CERN) on SPS electro-static septum crystal shadowing.
- Yu. Ivanov (CERN) on bent crystals for the SPS slow extraction.
  Remark: Bent crystal shadowing relies on deflection of beam particles due to atomic layers of crystal. High radiation resistance and large deflection angle of crystals.
- R. Muto on diffusers for J-PARC slow extraction.
  Diffuser is "block" of high Z material, e.g. Ta, before electro-static septum which spreads particle flow towards septum such that particle hit rate on septum is reduced.
  Length: $1 \ldots 2\ \mathrm{mm}$, width: $100 \ldots 200\ \mu\mathrm{m}$.

Particle loss minimisation

- D. Prokopovich (MedAustron) on COSE: Constant Optics Slow Extraction
  - Tune sweep extraction: change of averaged particle momentum during extraction.
  - COSE: adapt strength of all magnets to temporal mean beam momentum and ensure that direction of particle flow towards septum is adapted to tilt of septum in order to minimise cross section and beam loss
    $\rightarrow$ topic seems to be rather control system issue.
- F. M. Velotti on machine learning techniques for accelerator analysis
- V. Kain on accelerator control with advanced algorithms and machine learning.

Summary

Most interesting information on

- Application of rf ko noise for spill structure reduction (J-PARC) because
  - possibly applicable at GSI.
  - should be not difficult to check in simulations.
- Scintillation counter made of ZnO:In material (P. Boutachkov) because higher count rate affects, possibly, requirements to simulations.

- Next slow extraction workshop by end of 2023 or beginning of 2024.
- Location in Europe.
  - First choice: MedAustron (Wiener Neustadt).
  - Alternative: GSI.
- P. Forck will communicate with contact person in MedAustron.