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Beam stacking at KURNS

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KURNS beam stacking

Step 1: One bunch only

Subject	Preparation	Measurements
Debunch adiabatically the 1st bunch	• Determine RF profile (frequency and voltage) to minimise dp/p after debunch • Fix energy for debunching (two or three).	• dp/p measurement • Feasibility and accuracy
Rebunch the coasting beam	• Determine RF profile (frequency and voltage) to minimise longitudinal emittance	• Beam intensity measurement • Longitudinal tomography measurement
Repeat debunch and rebunch process	• Same above	• **Beam intensity**, **dp/p** increase at debunch, **longitudinal emittance** increase at rebunch vs. the number of process

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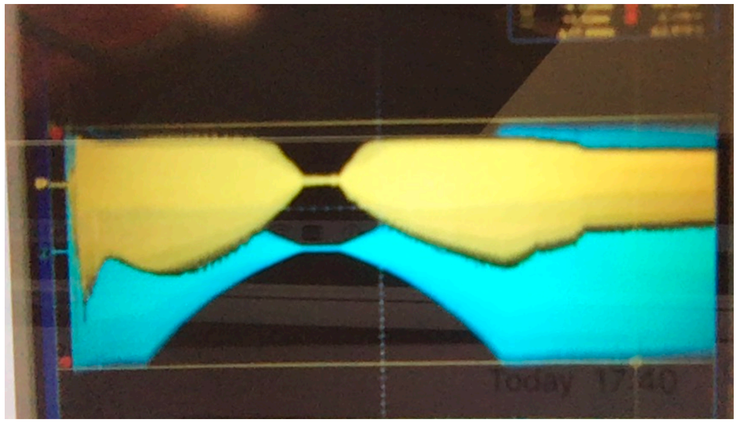
What would be the AWG requirements?

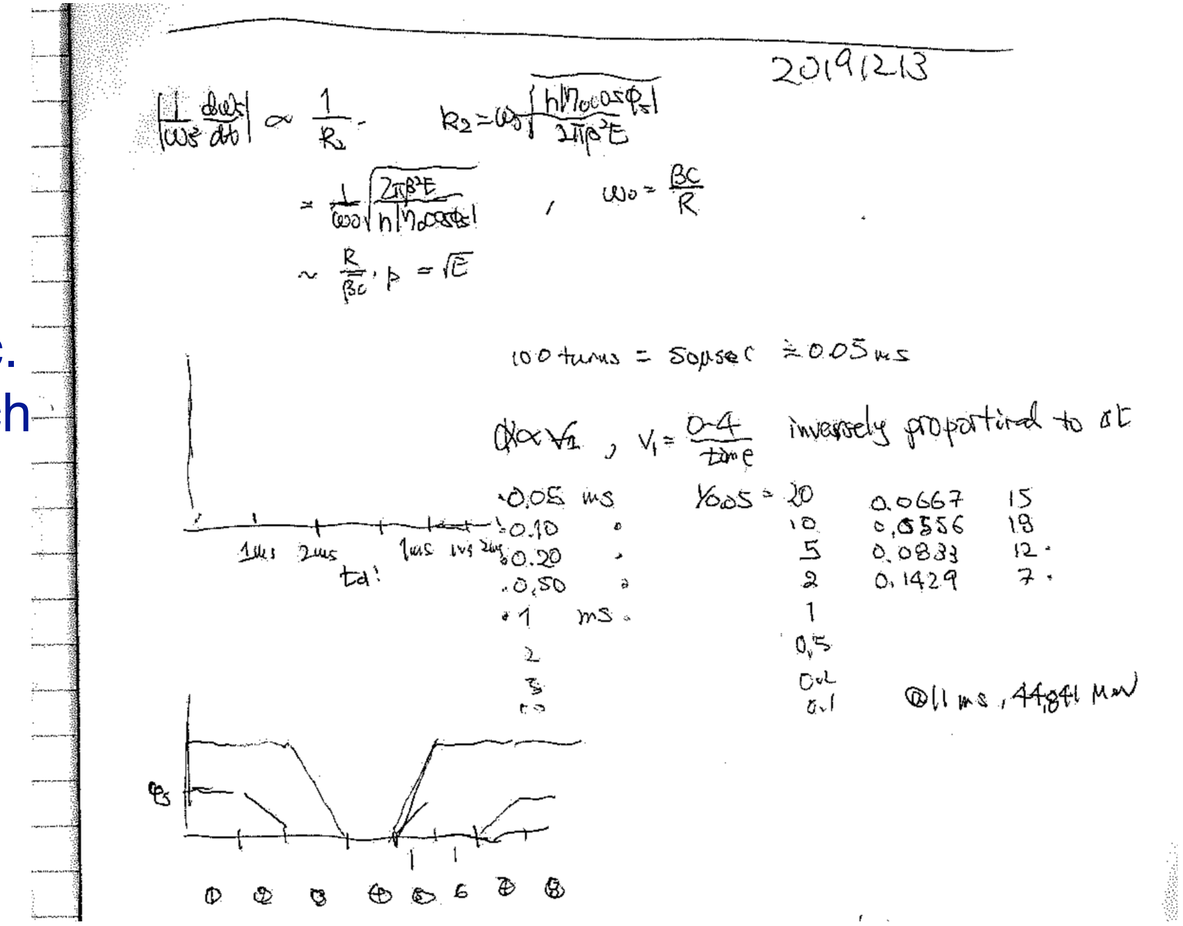
Time scale, e.g. step 1

- Whole process
  - Capture and acceleration, ~ 5ms
  - Transition of phis, ~ 1ms
  - Transition of voltage (debunching), ~ 1-10ms
  - Coasting beam, ~ 2ms
  - Transition of voltage (rebunching), ~ 1-10ms
    - and
  - dp/p measurement process
    - If phase displacement, ~ 5ms
- Total < 30 ms
  - Debunch and rebunch can be more adiabatic.
  - Another ~ 10ms to add more cycle of debunch and rebunch.



yellow: bunch monitor

blue: RF signal



AWG specifications

- Tektronix AWG430 or AWG5002C?
- Specifications
  - 200 MS/s
  - 16 bit DA
  - 4M-word memory
- Questions to Uesugi-san
  - With clock of 40MS/s, the total time can be covered is 100 ms?
  - Any additional memory so that clock can increase?
  - When RF frequency is 4 MHz, one wave form is specified by 10 points. Is it enough?
  - Maximum one cycle length will be 50 ms (20 Hz) because of ion source?
  - Shunt impedance (or equivalently voltage per RF power) is a function of frequency. Is the coefficient still the same?

Backups

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A bit more details

- Energy of beam stacking.
    - Twice or close to twice in beta
    - The same beta ratio of ISIS-II
    - Something else
- RF programme involved (sum of several segments)
    - Capture and acceleration
    - Transition of phis
    - Transition of voltage (debunching)
    - Coasting beam
    - Transition of voltage (rebunching)
        - and
    - dp/p measurement process (rebunching and tomography, phase displacement or something else)
- Optimisation of debunching and rebunching process by simulation.
- Develop or modify GUI script making AWG script.

Revised plan, our wish

- 1~2 weeks in January 2023, (16-27 January)
  - Test of AWG script
  - Test of dp/p measurement
  - Step 1 data taking
- Entirely remote or one or two persons travel, who can go?

- 2 weeks in March 2023
  - Step 2 and 3 data taking
- Ideally 2 persons per week

- I will have a meeting with JAEA and KURNS next Monday to negotiate.

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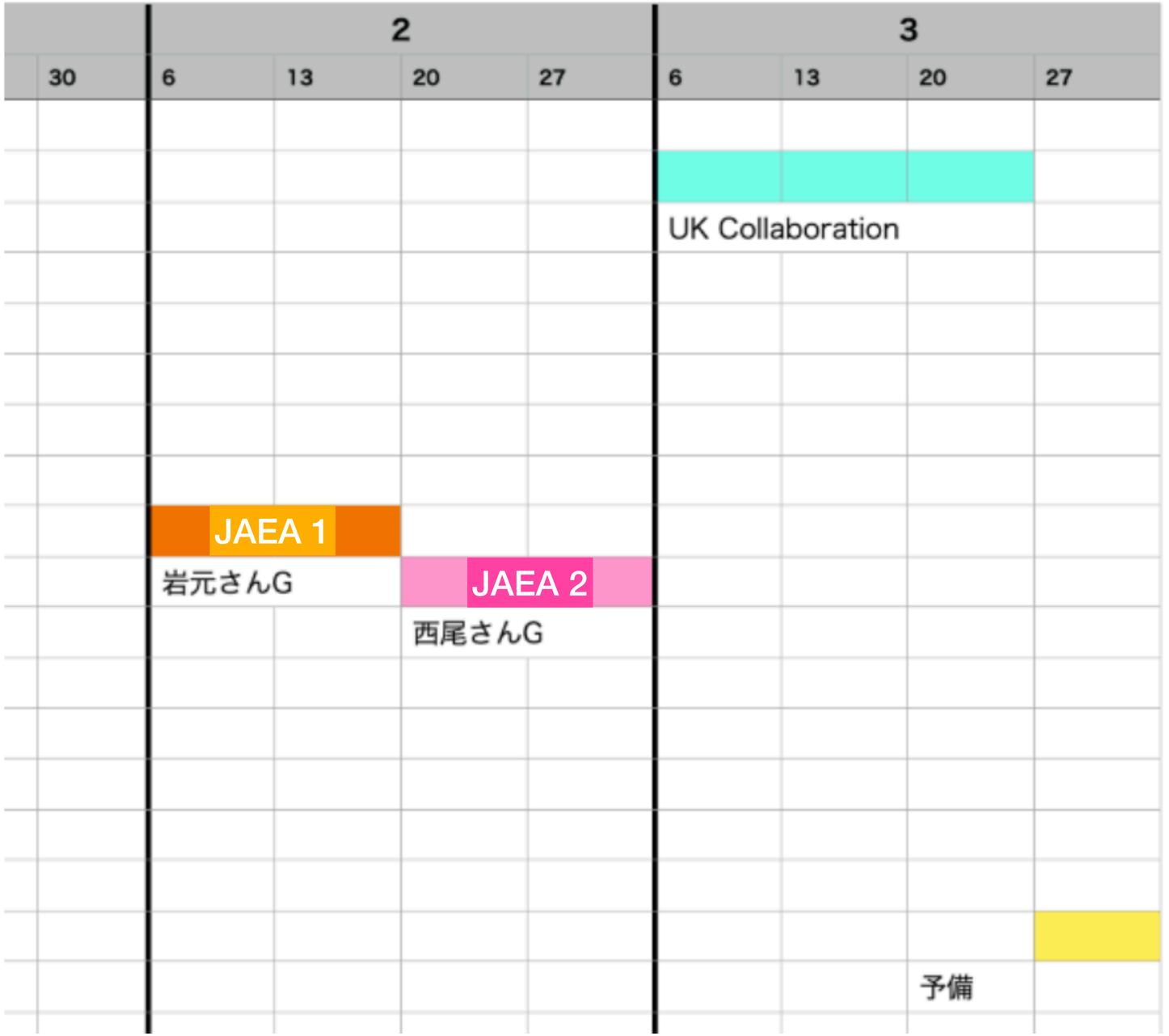
Agreed schedule

- 3 weeks in March 2023
  - Main part of experiment

- 1~2 weeks in 16~27 January 2023
  - Test of AWG
  - Check diagnostics
  - Test of dp/p measurement
  - Step 1 if possible
  - Emi's experiment
  - (Tune measurement by Max?)



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Before January 2023, 7 weeks, revised 2

- 12 - 16 December **(Friday 16 December at 9:00, internal group + Uesugi meeting)**
  - Final optimised RF cycle programme at least for step 1 or step 2, 3 (DK, CJ, send to TU).
  - Prepare ideal or compromised AWG script (JB, SM, DK).
- 5 - 9 December (Thursday 8 December at 9:00, KURNS meeting?)
- 28 November - 2 December **(Thursday 1 December at 9:00, internal group + Uesugi meeting)**
  - Select or prioritise dp/p measurement (EY, JB, SM, DK, CR)
  - Any issues if AWG script can be written for the pattern we need (JB, SM, DK).
- 21 - 25 November
- 14 - 18 November **(Friday 18 November at 9:00, internal group + Uesugi meeting)**
  - dp/p measurement update (EY, JB, SM, DK, CR)
  - First proposal of complete RF cycle programme for step 3 (DK, CJ, send to TU)
- 7 - 11 November **(Thursday 10 November at 9:00, KURNS meeting)**
- 31 October - 4 November **(Friday 4 November at 9:00, internal group + Uesugi meeting)**
  - dp/p measurement update (EY, JB, SM, DK, CR)
  - RF cycle programme update (DK, CJ)
  - Schottky measurement preliminary result (EY, from YI and TU)
- 24 - 28 October

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Step 2: One coasting beam and an empty bucket

Subject	Preparation	Measurements
After debunching at E1, increase RF voltage with frequency at several points between injection and E1.	• Simulation to see how the coasting beam is affected. • When E1 is increased and RF frequency ratio approach 2, how quickly interference grows?	• dp/p measurement vs time (time scale should be determined by simulation)
Increase the energy of an empty bucket and adiabatically decrease voltage as if the beam is accelerated and debunched.	• Simulation to see how the coasting beam is affected.	• dp/p measurement
(optionally) rebunch the coasting beam	• Same with one bunch	• Beam intensity measurement • Longitudinal tomography measurement

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A bit more details

- Energy of beam stacking.
    - Twice or close to twice in beta
    - The same beta ratio of ISIS-II
    - Something else
- RF programme involved (sum of several segments)
    - Capture and acceleration
    - Transition of phis
    - Transition of voltage (debunching)
    - Coasting beam
    - acceleration of empty bucket
    - Transition of phis
    - Transition of voltage (debunching)
        - and
    - dp/p measurement process (rebunching and tomography, phase displacement or something else)
- Optimisation of 2nd beam (empty bucket) stacking by simulation.
- Develop or modify GUI script making AWG script.

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Step 3: One coasting beam and another accelerating beam

Subject	Preparation	Measurements
Increase the energy of the 2nd beam and adiabatically decrease voltage.	• Simulation to see how the coasting beam is affected and the 2nd beam is added.	• dp/p measurement
Rebunch the coasting beam from two acceleration.	• Determine RF profile (frequency and voltage) to minimise longitudinal emittance	• Beam intensity measurement • Longitudinal tomography measurement
Repeat debunch and rebunch process (similar to measurement with one bunch but different dp/p)		• **Beam intensity**, **dp/p** increase at debunch, **longitudinal emittance** increase at rebunch vs. the number of process

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A bit more details

- Energy of beam stacking.
    - Twice or close to twice in beta
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    - Capture and acceleration
    - Transition of phis
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    - Coasting beam
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    - Transition of phis
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    - dp/p measurement process (rebunching and tomography, phase displacement or something else)
- Optimisation of 2nd beam stacking by simulation.
- Develop or modify GUI script making AWG script.

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Backups

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One bunch only

Subject	Preparation	Measurements
Debunch adiabatically the 1st bunch	• Determine RF profile (frequency and voltage) to minimise dp/p after debunch	• dp/p measurement • Transverse beam profile measurement
Rebunch the coasting beam	• Determine RF profile (frequency and voltage) to minimise longitudinal emittance	• Beam intensity measurement • Longitudinal tomography measurement • Transverse beam profile measurement
Repeat debunch and rebunch process	• Same above	• **Beam intensity**, **dp/p** increase at debunch, **longitudinal emittance** increase at rebunch and **transverse beam profile** increase vs. the number of process

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A bit more details

- Evaluate different dp/p measurement methods.
  - Feasibility
  - Accuracy

- Probably no time for transverse size measurement.

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One coasting beam and an empty bucket

Subject	Preparation	Measurements
After debunching at E1, increase RF voltage with frequency at several points between injection and E1.	• Simulation to see how the coasting beam is affected. • When E1 is increased and RF frequency ratio approach 2, how quickly interference grows?	• dp/p measurement vs time (time scale should be determined by simulation) • Transverse beam profile measurement
Increase the energy of an empty bucket and adiabatically decrease voltage as if the beam is accelerated and debunched.	• Simulation to see how the coasting beam is affected.	• dp/p measurement • Transverse beam profile measurement
(optionally) rebunch the coasting beam	• Same with one bunch	• Beam intensity measurement • Longitudinal tomography measurement • Transverse beam profile measurement

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A bit more details

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- RF programme involved (sum of several segments)
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One coasting beam and another accelerating beam

Subject	Preparation	Measurements
Increase the energy of the 2nd beam and adiabatically decrease voltage.	• Simulation to see how the coasting beam is affected and the 2nd beam is added.	• dp/p measurement • Transverse beam profile measurement
Rebunch the coasting beam from two acceleration.	• Determine RF profile (frequency and voltage) to minimise longitudinal emittance	• Beam intensity measurement • Longitudinal tomography measurement • Transverse beam profile measurement
Repeat debunch and rebunch process (similar to measurement with one bunch but different dp/p)		• **Beam intensity**, **dp/p** increase at debunch, **longitudinal emittance** increase at rebunch and **transverse beam profile** increase vs. the number of process

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    - dp/p measurement process (rebunching and tomography, phase displacement or something else)
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Before the experiments

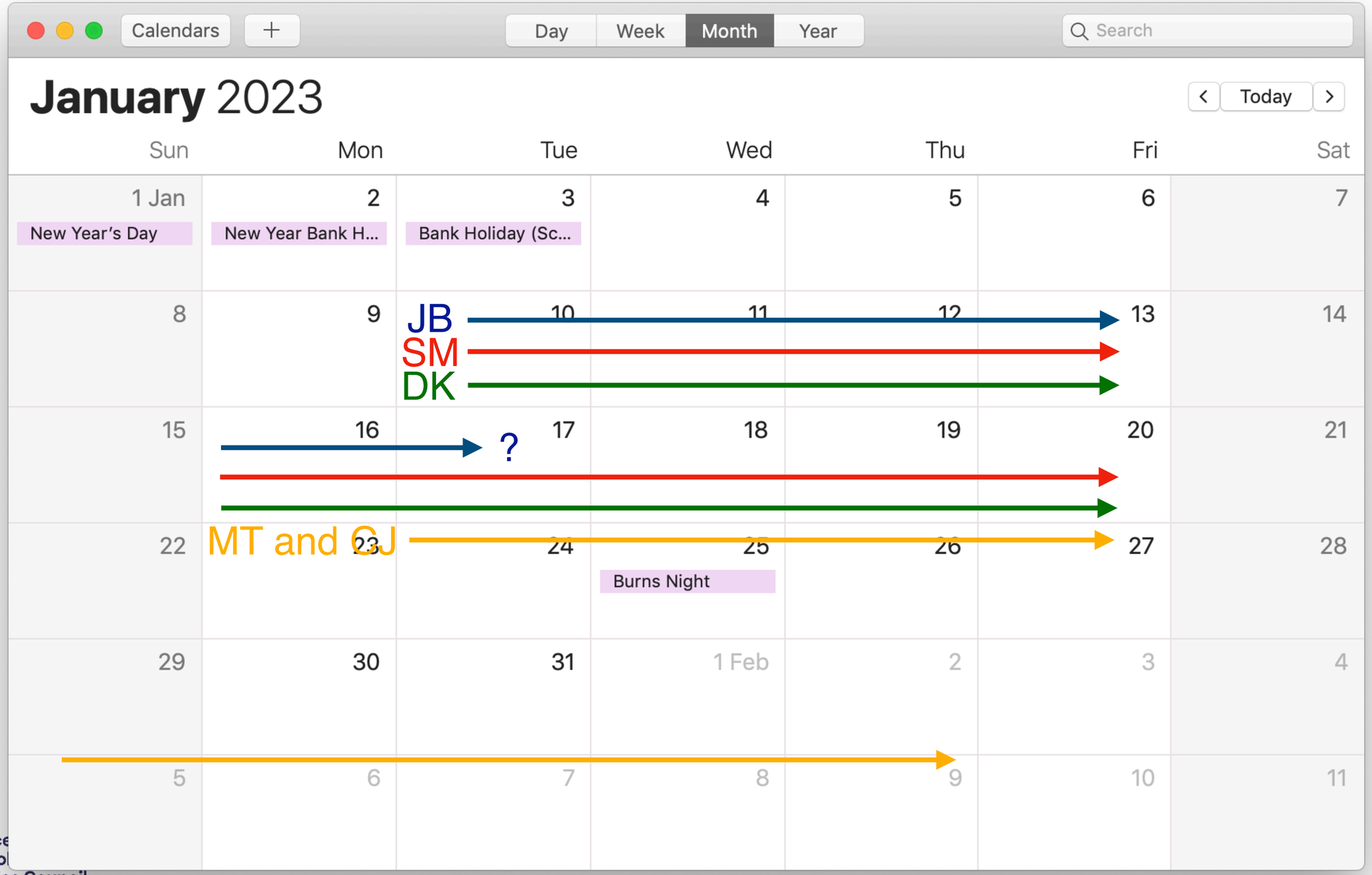
- A lot of simulation study to optimise RF profile for debunch, rebunch and merging.
- Prepare AWG input to operate the RF cavity as we want.

- GUI making AWG scripts should be tested before the experiment (only a few examples should be sufficient).

- More discussion and study on how to measure dp/p. The entire experiment is not useful unless we have a good idea of measuring dp/p. (how dp/p of a coasting beam can be related from dp/p of a bunched beam?)

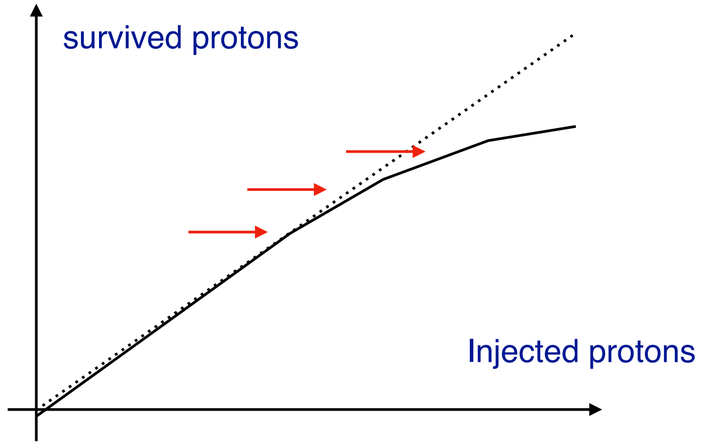
- This may be the last chance of KURNS experiment. Publication has to be made.
- I feel that preparation time is very limited before Christmas (January). FFA eternal design review will be early next year. I wonder the postponing the experiment is sensible (Easter 2023 is 9 April).

Very tentative travel plan



Milestones of the FETS-FFA project is to answer …

1. How many protons can we **accumulate** without beam loss at injection?	2. How many protons can we **accelerate** without beam loss to the top energy?
3a. How many protons can we **accumulate** without beam loss **by beam stacking** at the top energy?	3b. How many protons can we **capture** and **extract** without beam loss **after beam stacking**?



- We will define the meaning of “without beam loss” later (e.g. 5%, 1%, or 0.1%).
- It depends on diagnostics, stability of the hardware, injector (FETS) performance, etc.

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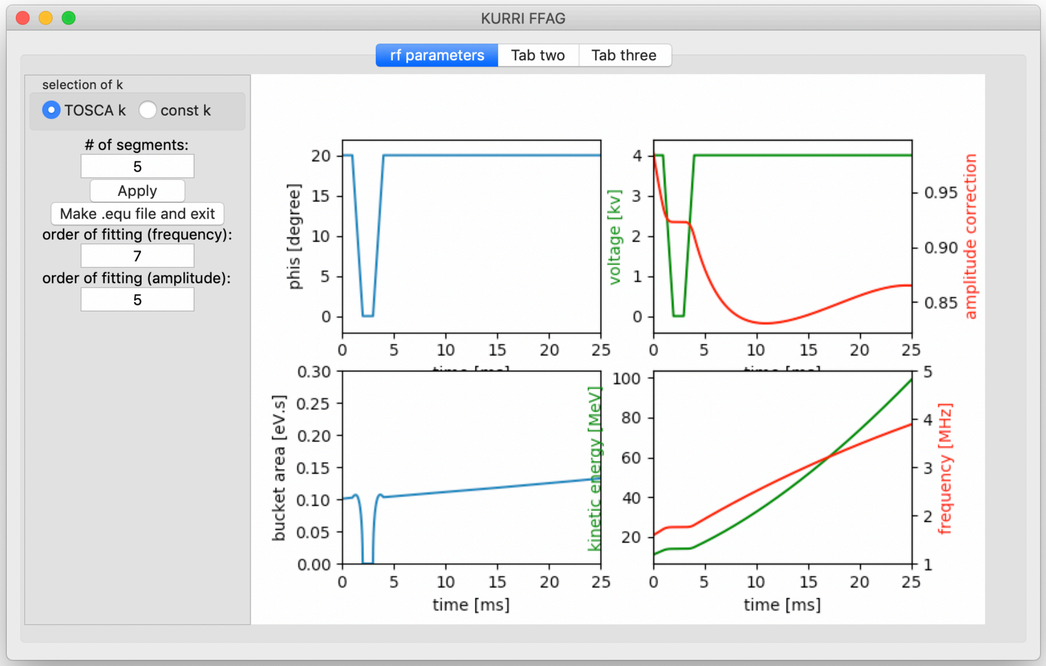
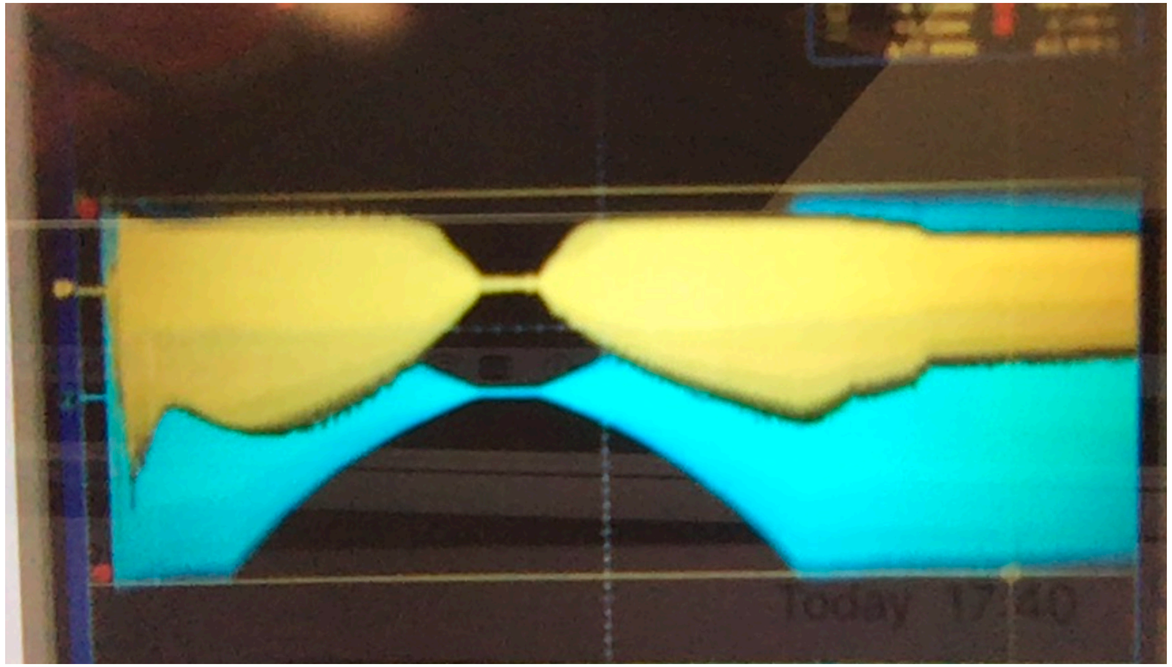
- Accelerate 1st bunch to final energy E1
- Debunch adiabatically the 1st bunch
- Characterise the coasting beam (momentum spread with empty bucket?)
- Recapture the coasting beam, measure it, redebunch it
- Measure the interference of the accelerating RF (no beam) on the coasting beam
- Inject & accelerate a second bunch to E2<E1
- Debunch adiabatically the second bunch
- Characterise the coasting beam
- Recapture the resulting total beam
- Measure the beam

RF script and bunch monitor signal from 2019 experiment





yellow: bunch monitor

blue: RF signal

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- Measure the beam

Parameters

Radius	4.54 m
RF frequency	1.6 ~ 5.2 MHz
Revolution time	0.625 ~ 0.192 micro s
Beta (11 MeV, 18 MeV)	0.1518, 0.1931 (ratio=1.27)
Beta (11 MeV, 47 MeV)	0.1518, 0.3052 (ratio=2.01)
Beta (0.4 GeV, 1.2 GeV)	0.7131, 0.8986 (ratio=1.26)

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