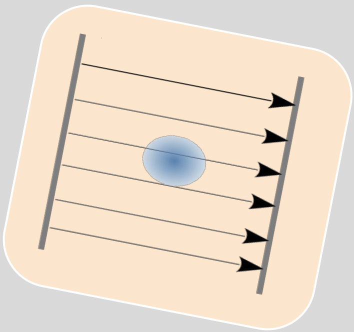
A Feedback controller for the **RF-KO** Method for Slow Extraction for **NIMMS Helium Synchrotron**



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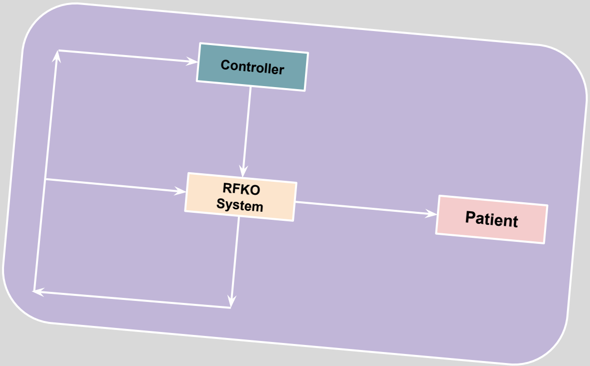
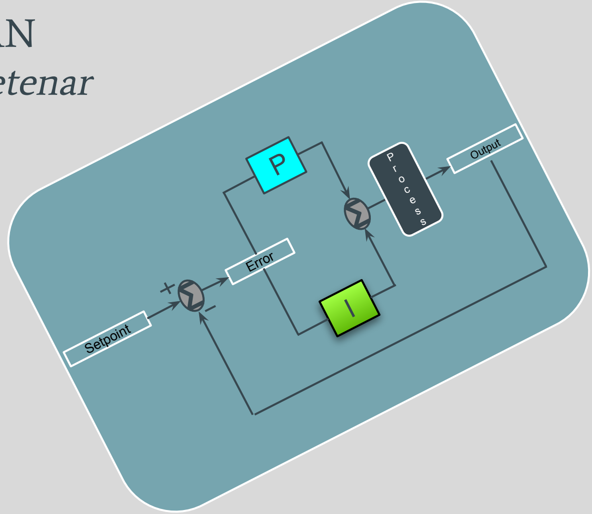


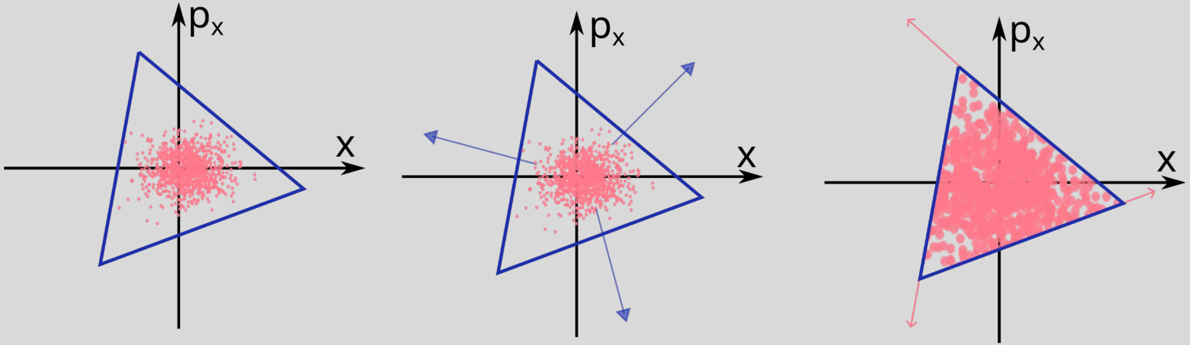


Extraction

- Slow Extraction
- Fast extraction

In general we push the particles out of their stability triangle

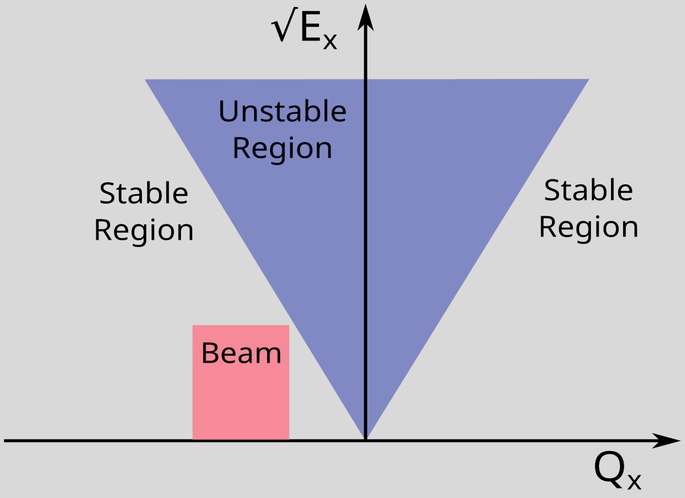
In our case we need constant spill to hit the tumor so we need slow

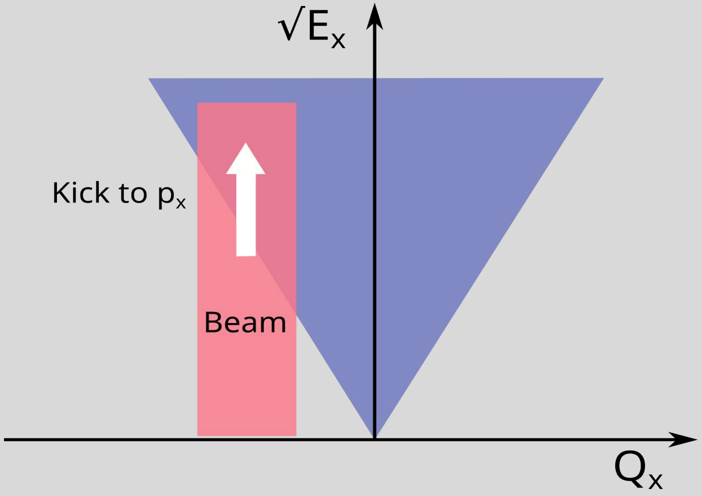


Slow Extraction

It's the process of extraction the beam little by little in every turn so we create a constant flow of particles from the accelerator (uniform spill).

We want Slow Extraction in order to hit the tumor with a beam that has duration and specific energy.

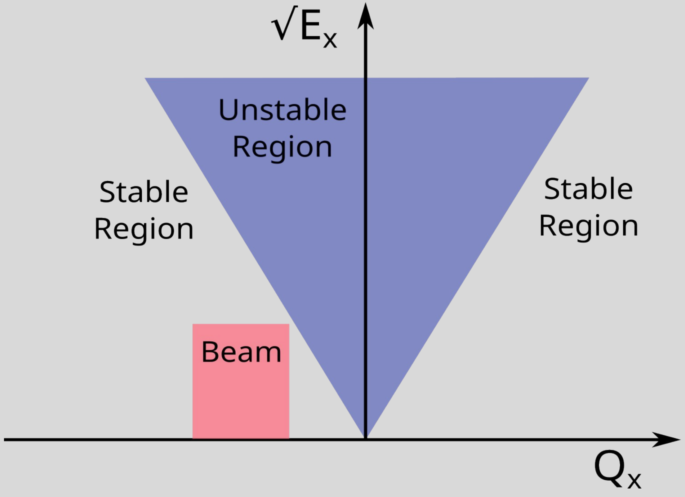


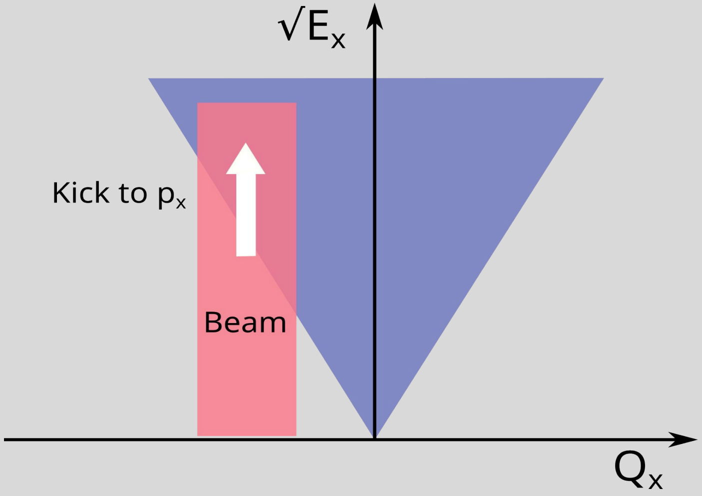


RFKO Method

In order to achieve slow extraction this we apply a controlled voltage kick.

The kick should be updated every time the extraction rate is different than the expected one.



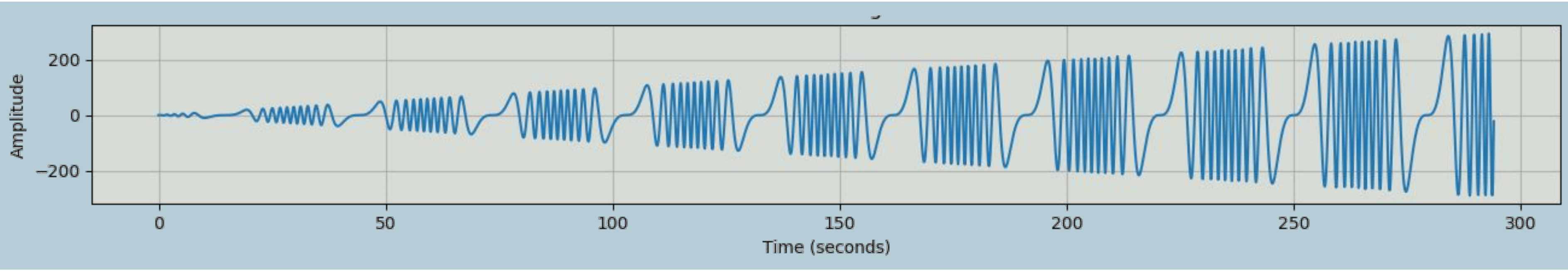


Our Voltage kick

We have AC, that means we need to take into consideration both Amplitude and Frequency.

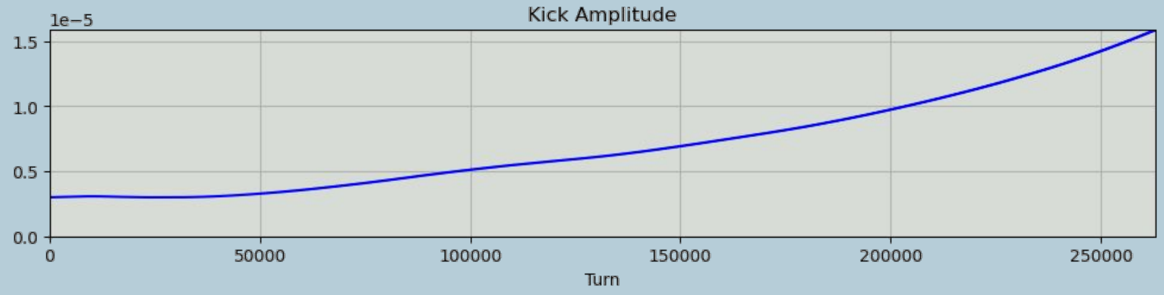
So ..

➔ Amplitude Modulation
➔ Frequency Modulation



Amplitude Modulation

- ➔ Use a PI controller for the Voltage Amplitude.
- ➔ If we have more extraction rate-> decrease
- ➔ If we have smaller extraction rate-> increase

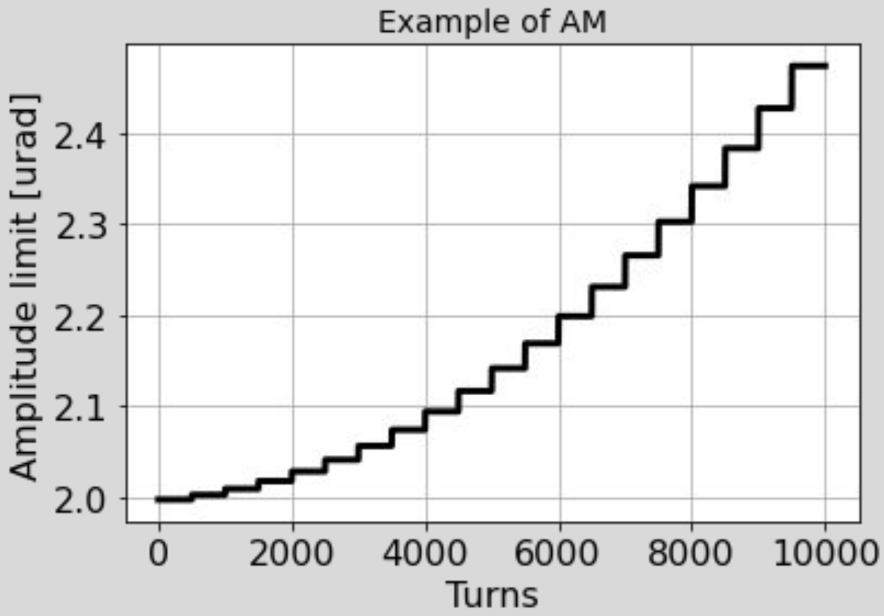


Amplitude Modulation

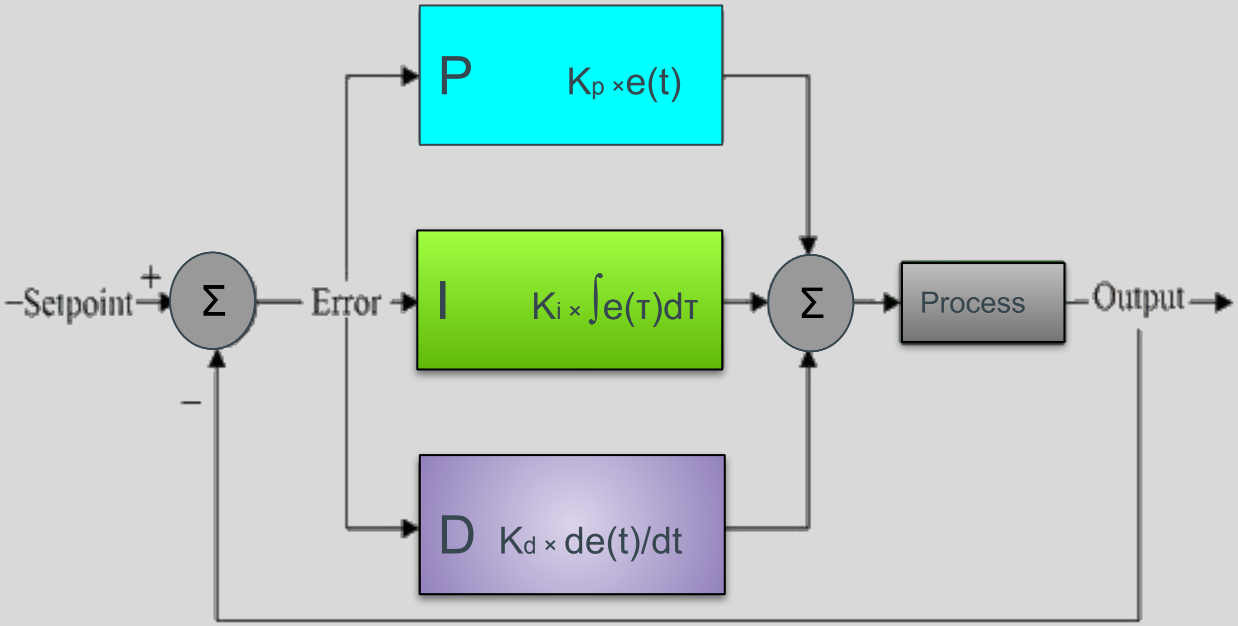
Use a PI controller for the Voltage Amplitude.

If we have more extraction rate-> decrease

If we have smaller extraction rate-> increase

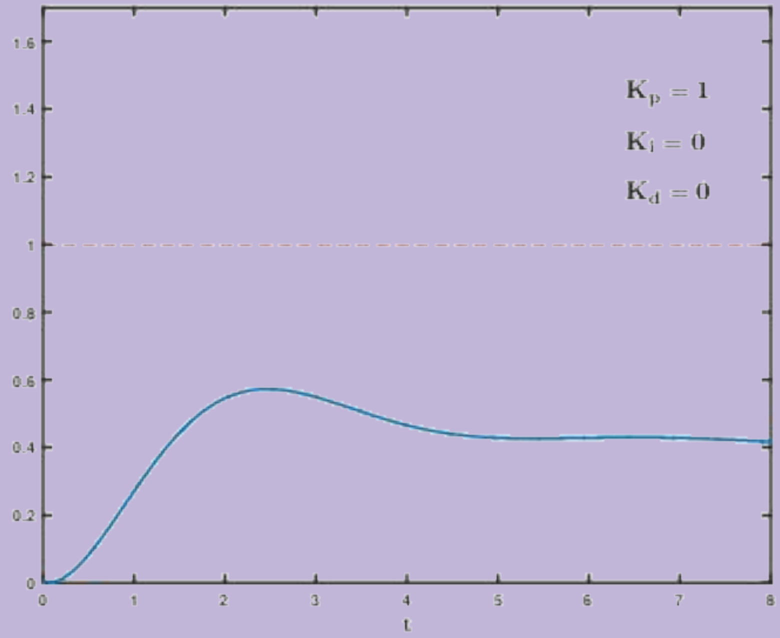


PID Controller



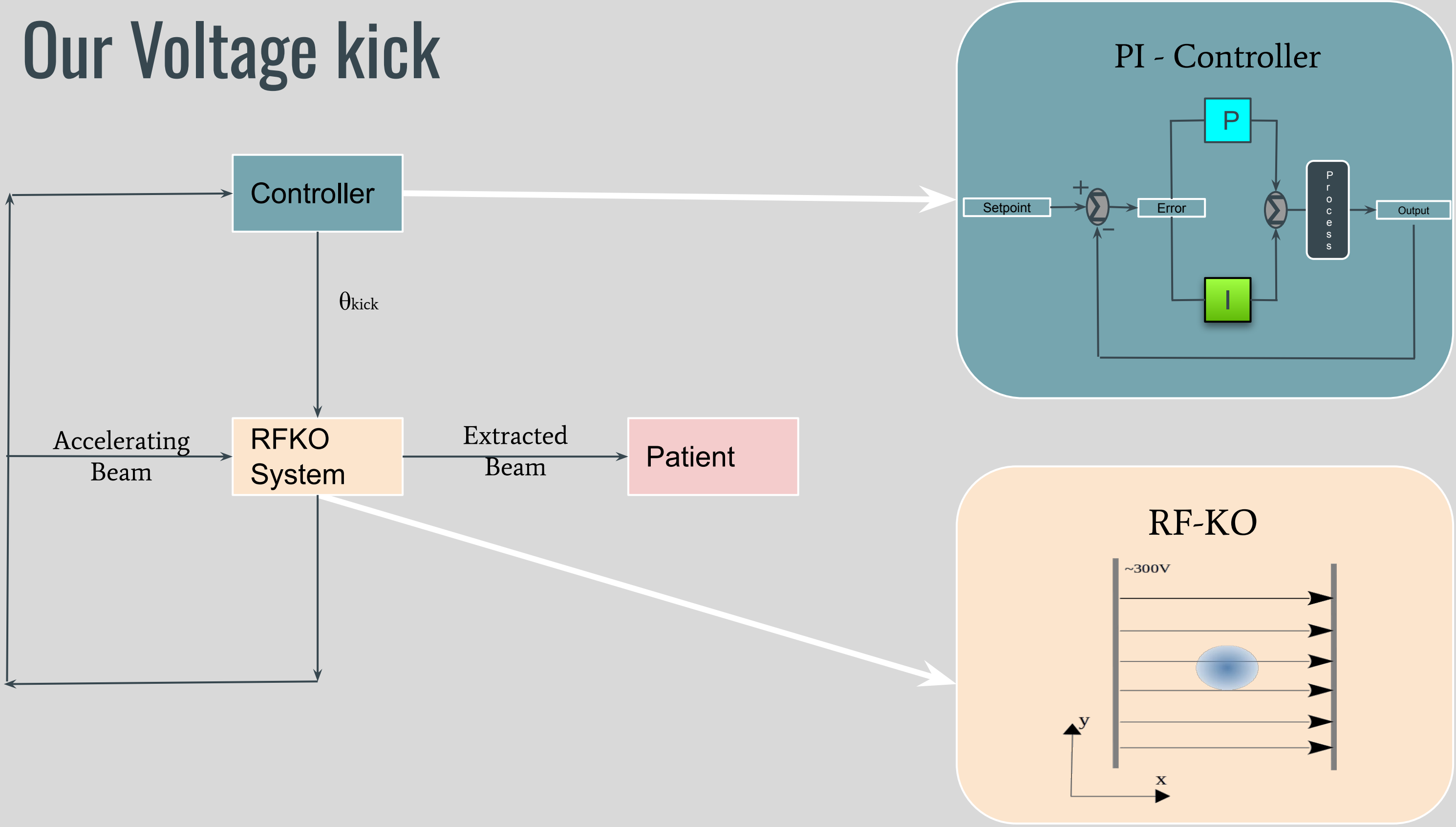
e(t) : error function

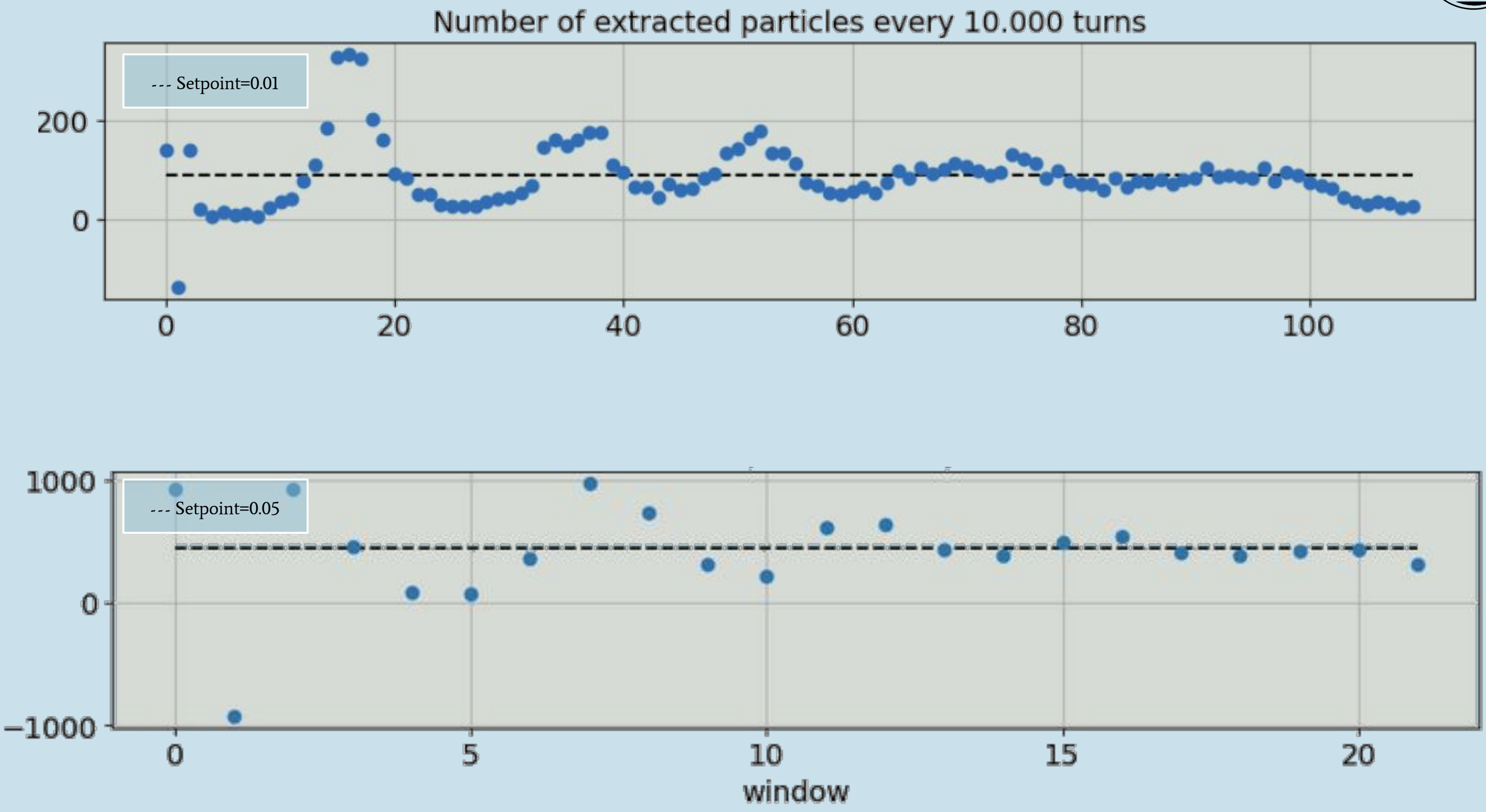
PID Controller



Wikipedia

Our Voltage kick




Number of extracted particles every 10.000 turns
--- Setpoint=0.01
200
0
0
20
40
60
80
100
1000
--- Setpoint=0.05
0
−1000
0
5
10
15
20
window

Frequency Modulation

To extract the particles we need to put hit the in their tune frequency

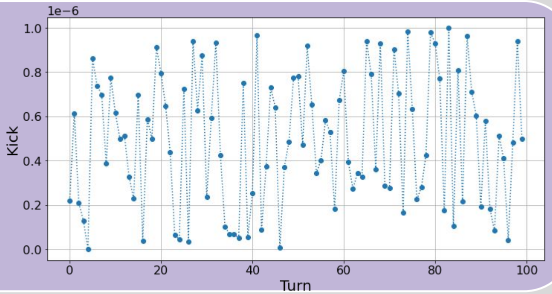
We don’t have only one tune so we need a way to affect all particles, so we change the voltage constantly, with:

1. Random numbers
2. Sinwave in resonance
3. Sinwave in resonance with same random noise
4. Modulator signal
5. Chirp Method
6. BPSK

To extract the particles we need to put hit the in their tune frequency. We dont have only one tune so we need a way to effect all particles, so we change the voltage all the time, with:

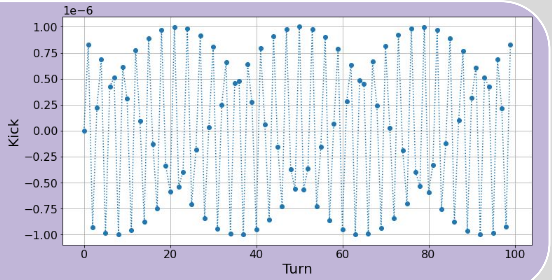
Random

Commonly used as white-noise



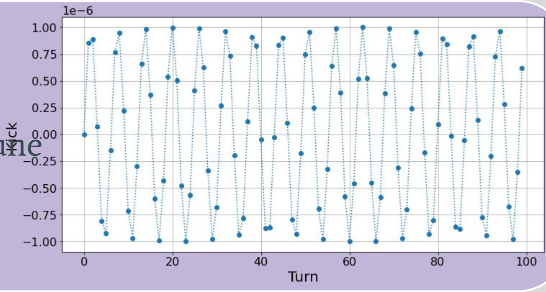
Sine wave 1:

At frequency Qx of beam

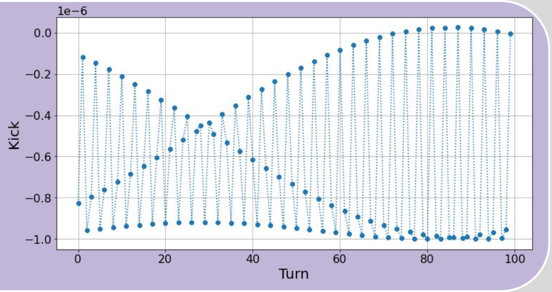


Sine wave 2:

Random noise matching beam tune distribution

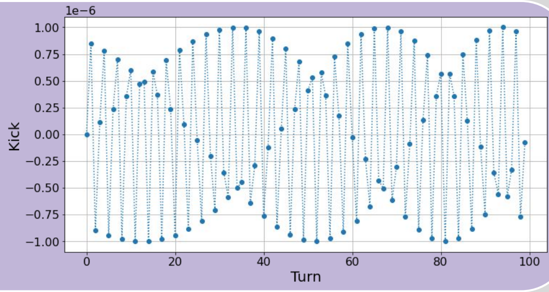


Modulator signal



Chirp Method

Used in PS and HIMAC



My Simulation

PI Controller

My error

Step Parameter

Calculate Kick

Frequency Modulation

Tracking

Xsuite

Helium Synchrotron

Blackbox

Wrote a Beam Interact function to calculate number of particles extracted per window (defined by the electrostatic septum), and fed this into your controller

Controller gives a increase to the px coordinate of the 6D particle beam

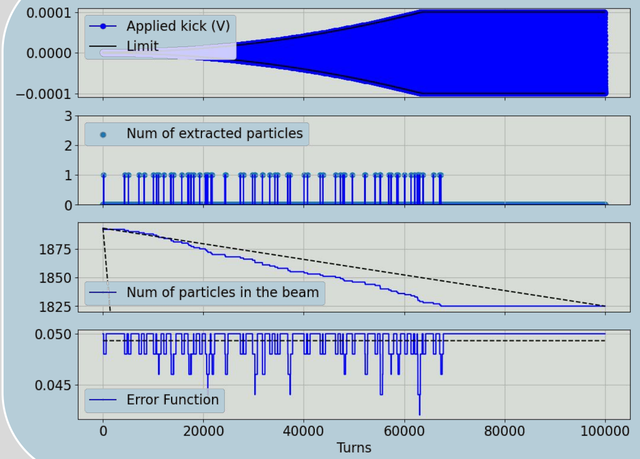
First Approach: Sine Wave 1

Manually changing the parameters (Kp, Ki, setpoint) of PI controller

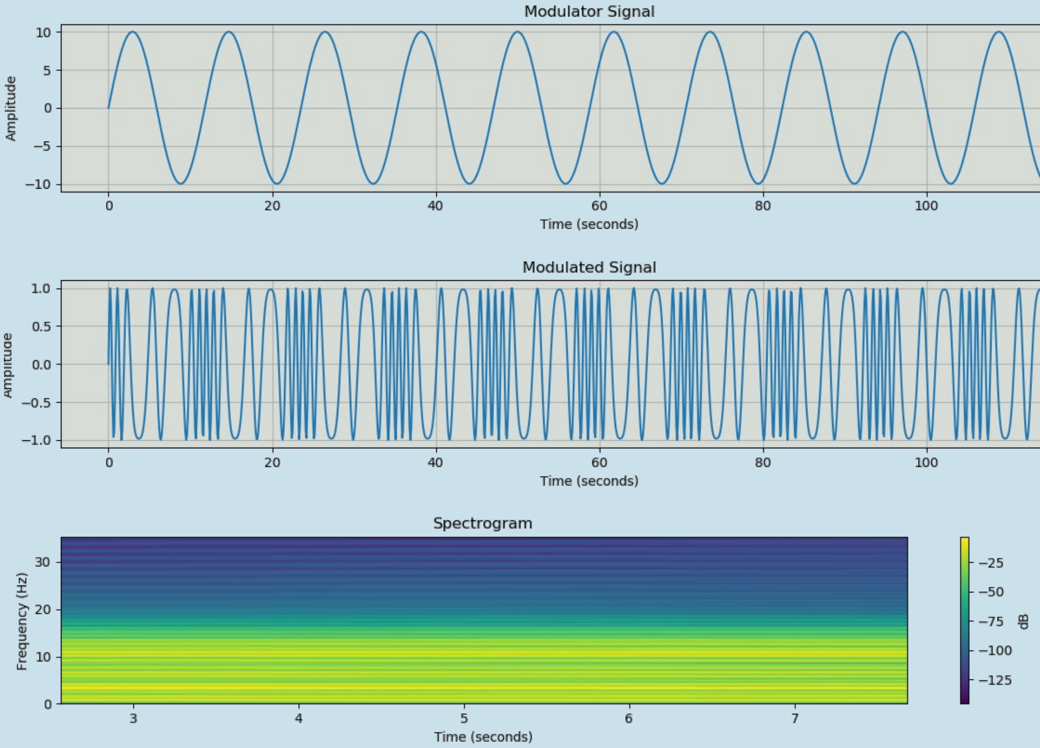
-> found we have extraction only while our voltage is increasing

->we have always ONLY 60-80 particles extracted until amplitude too big

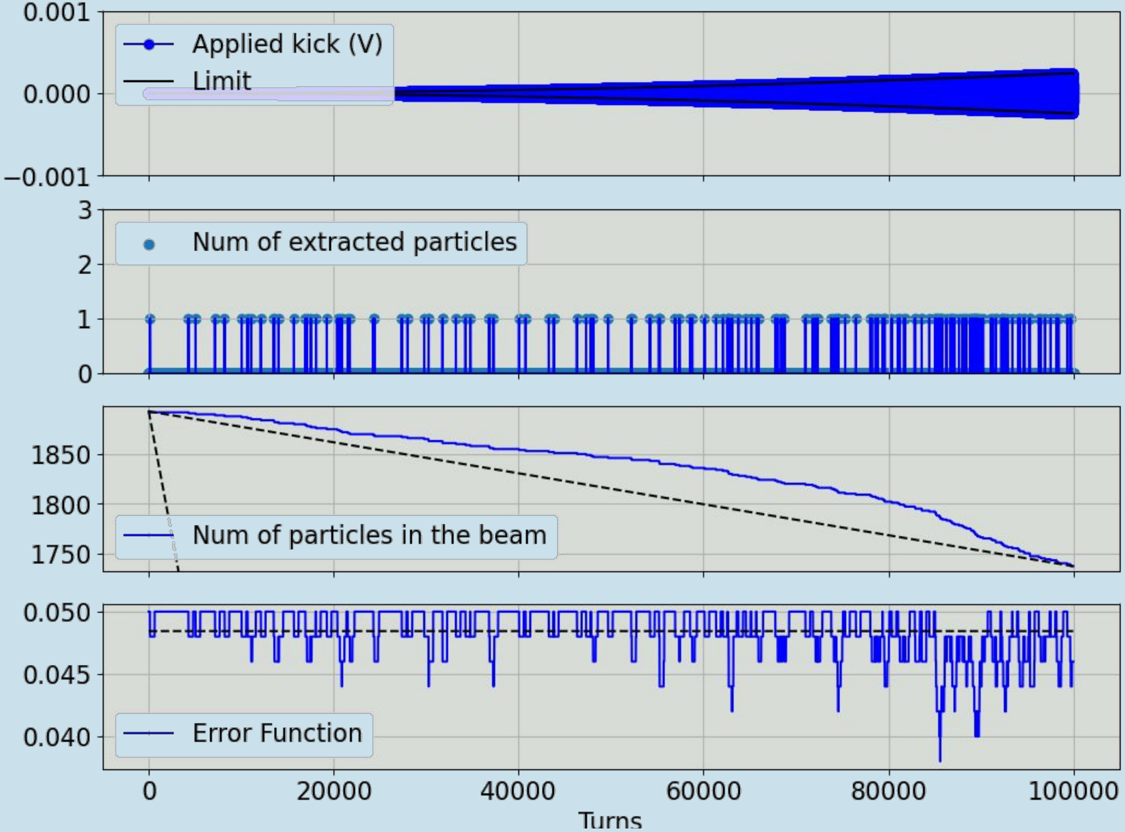
-> it looks the same either for 10^3 or 10^5 turns



Modulator Signal example - given to the controller



Modulator Signal - Controller Result



Realpoint~0.1*Setpoint

Fine tuning

Chirp Method

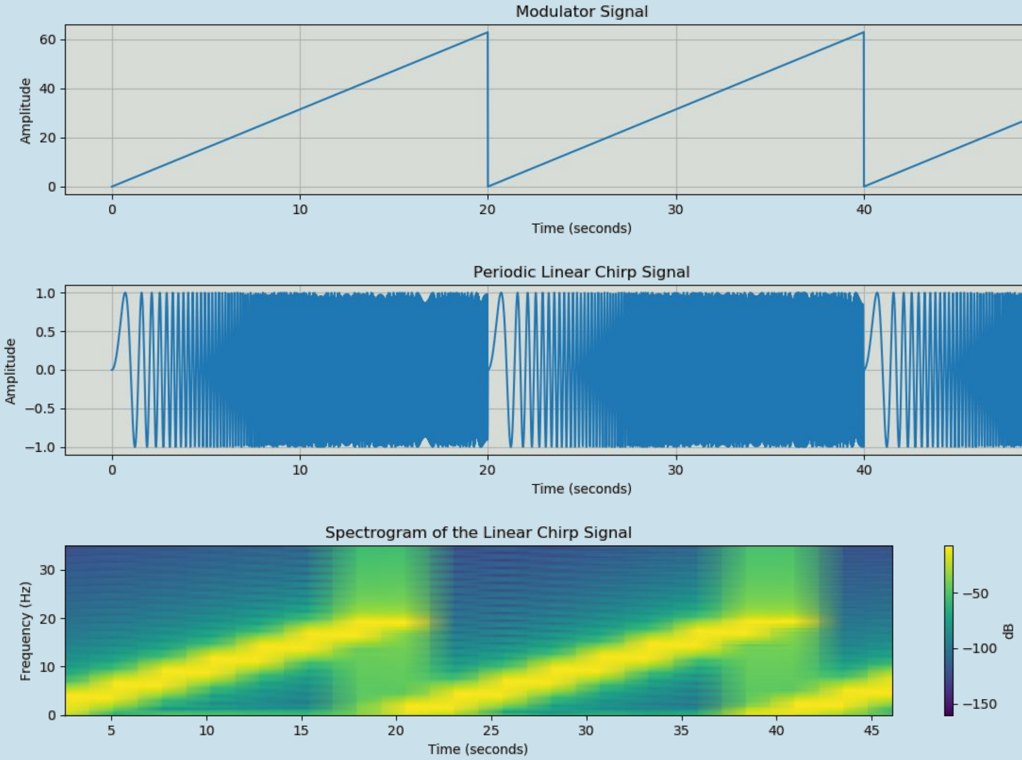
Manual changing the parameters of pi controller

-> all the particles are extracted

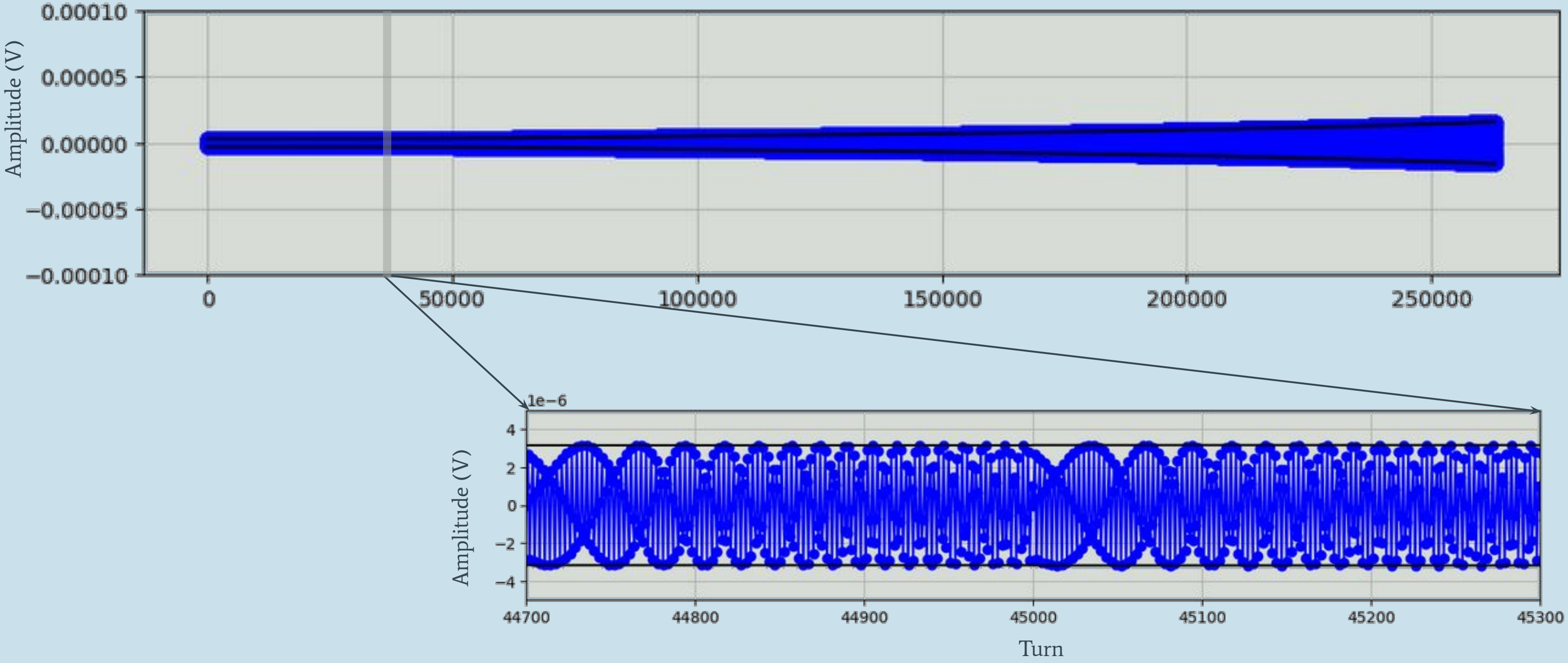
-> it looks like the controller is trying to reach the setpoint

->we have big fluctuation maybe because the parameters are not optimized

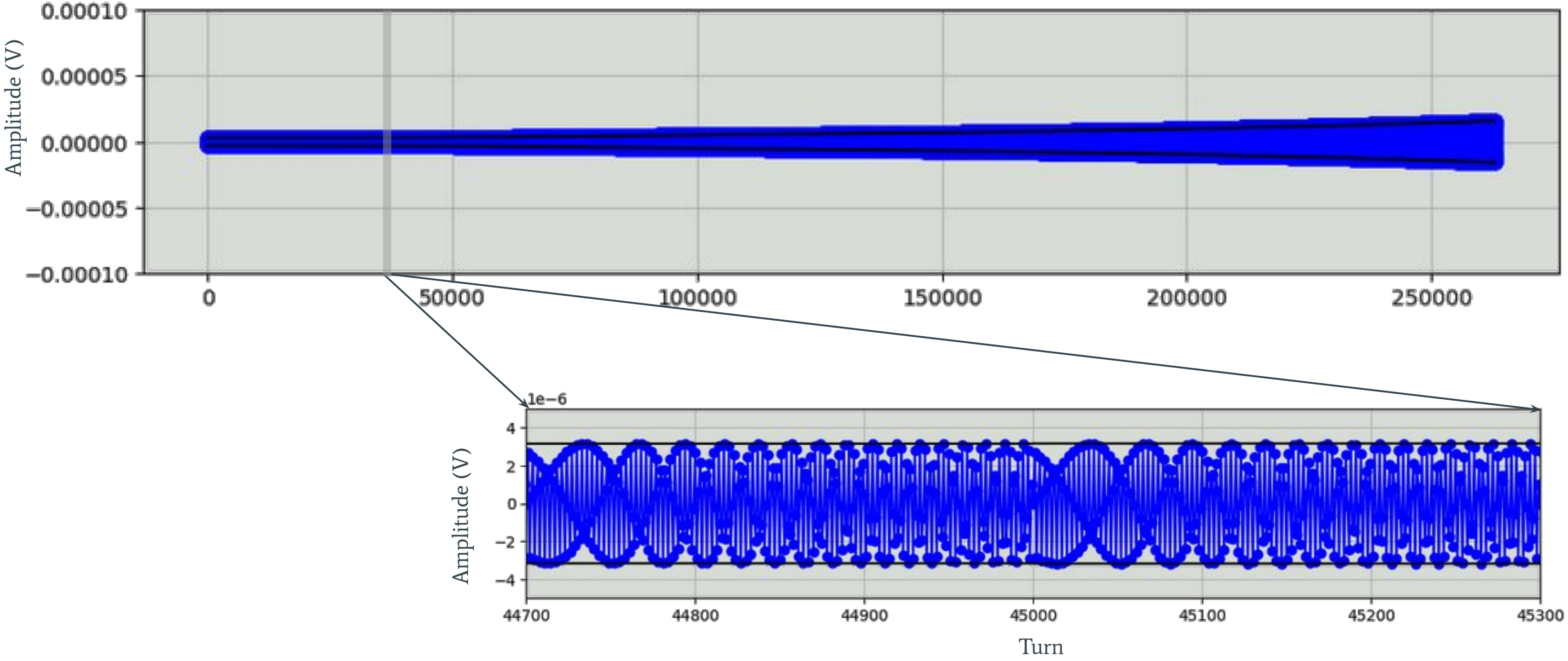
Chirp Signal example - given to the controller



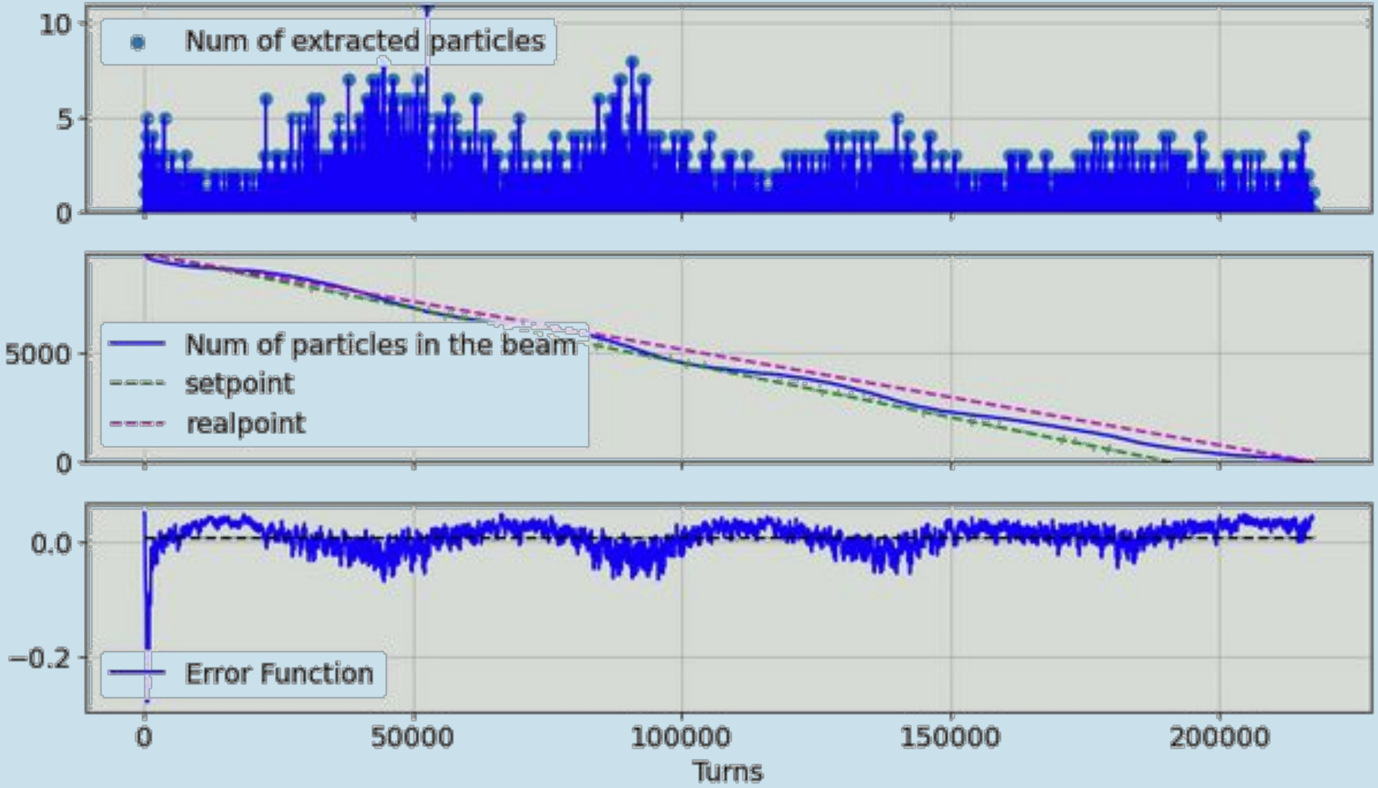
Chirp Signal example - given to the controller



Chirp Signal example - given to the controller



Chirp Signal controller result

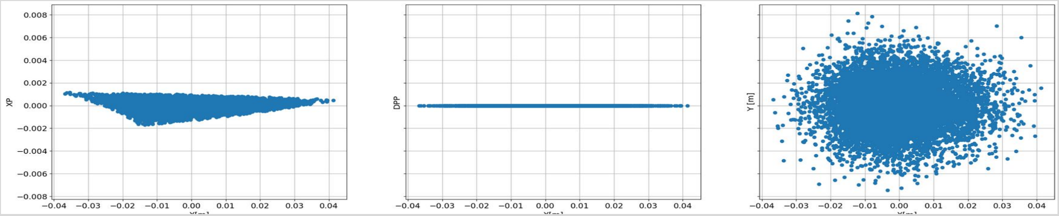


Realpoint-Setpoint ~ 13%

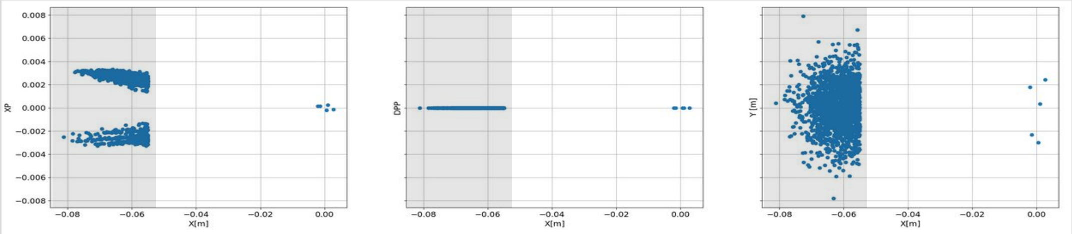
The importance of Frequency Modulation:
- High amplitude = beam blow-up

Septum at -55 mm 'extracts' particles above this amplitude

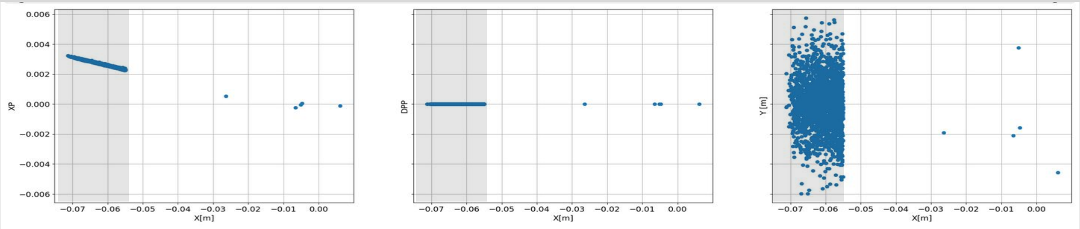
Initial Beam



Final Beam Case 1
Kick too high



Final Beam Case 2
Extracted beam as expected



The importance of Frequency Modulation:
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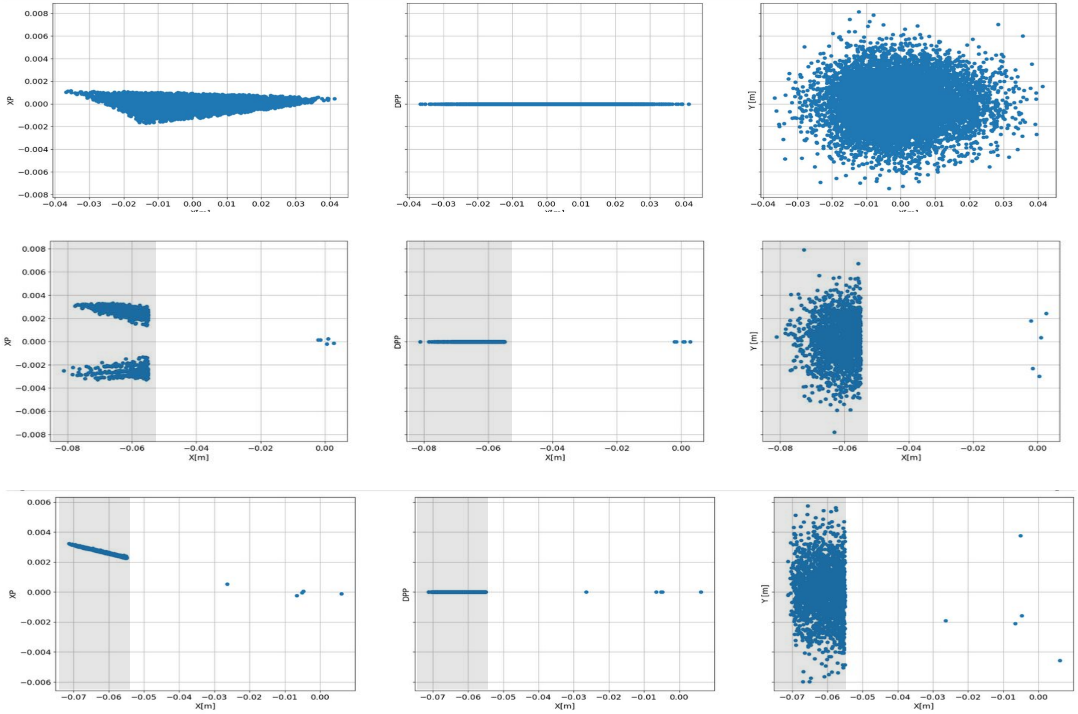
Initial Beam

Final Beam Case 1
Kick too high

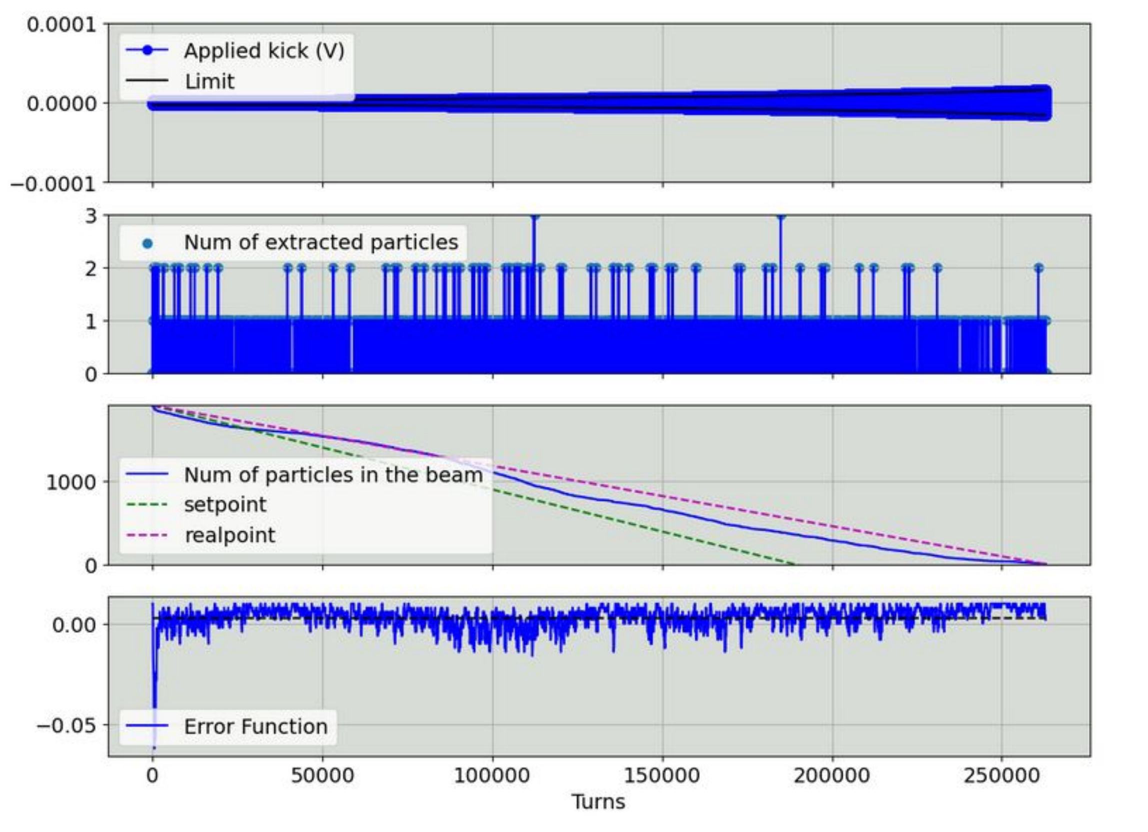
Final Beam Case 2
Extracted beam as expected



Septum at -55 mm 'extracts' particles above this amplitude

RESULTS

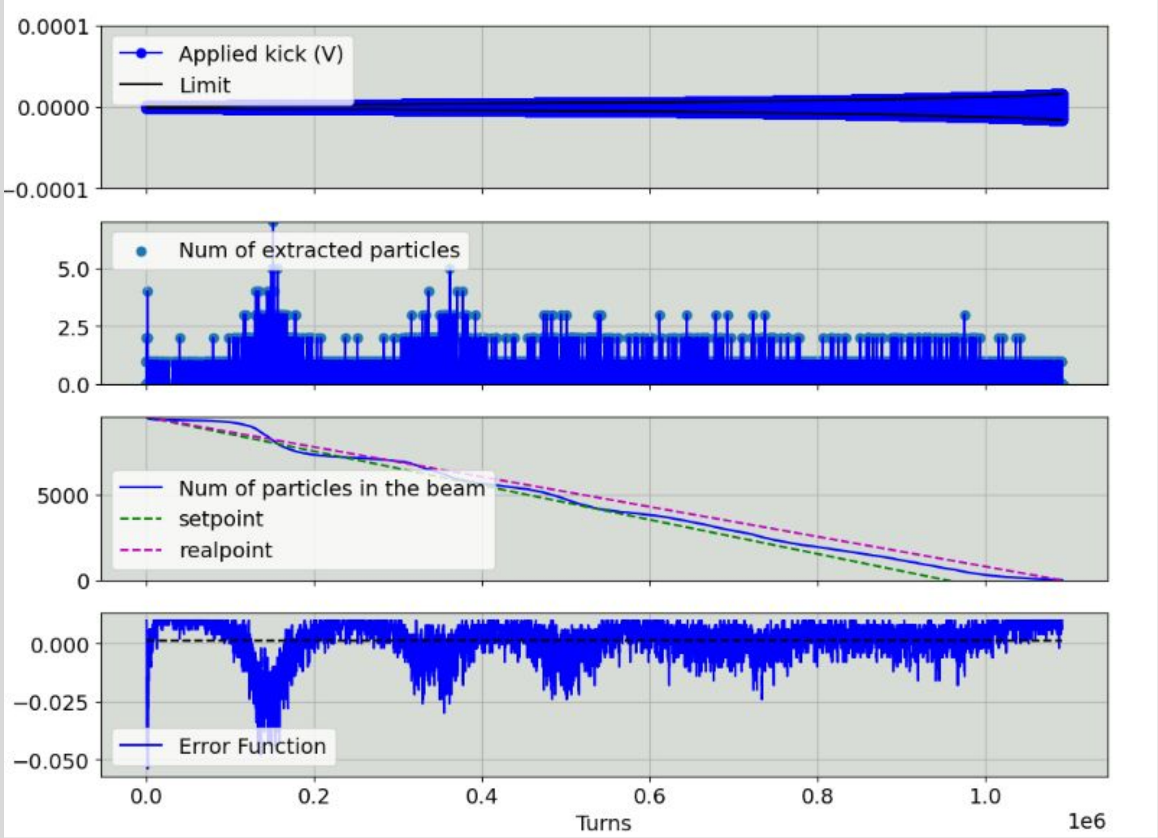
Chirp Result - 2000 particles



Question: Does it scale with number of particles?

NIMMS needs 10^10 particles

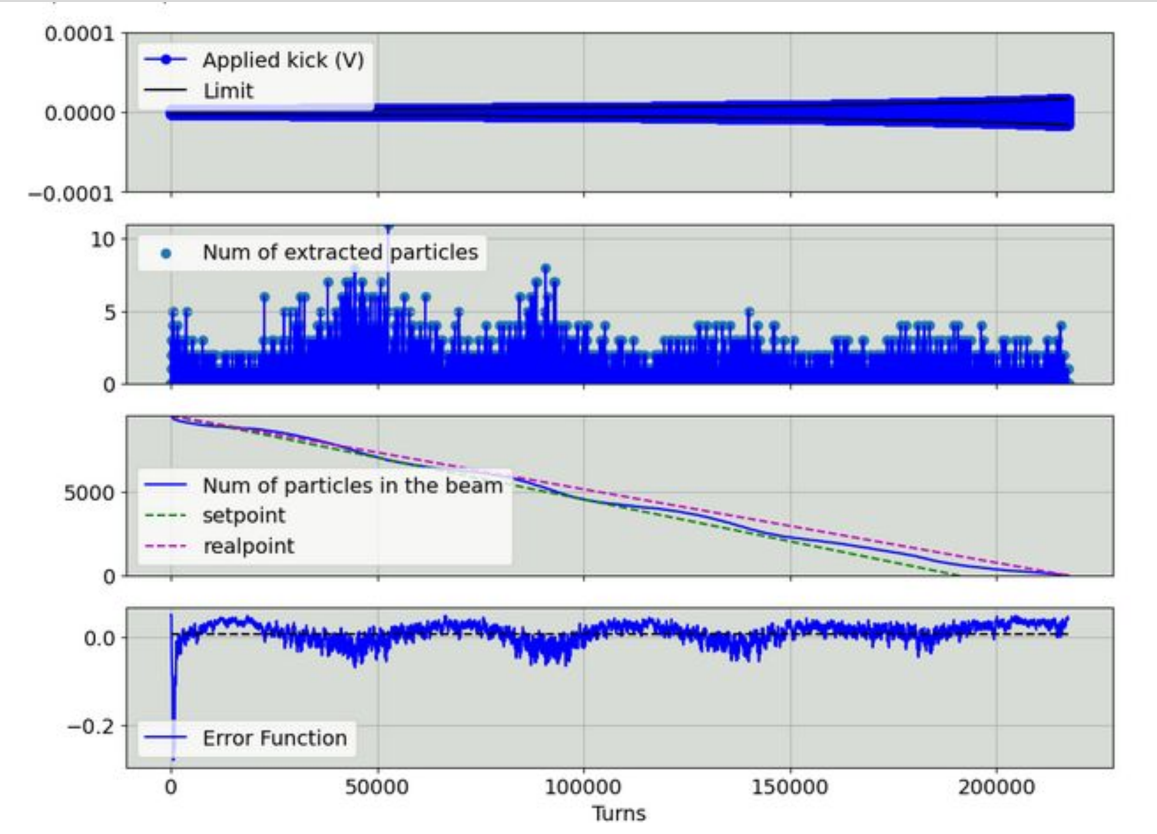
Chirp Result - 10000 particles



Need to re-optimise!

5x more particles, so need 5x faster rate (setpoint)

Chirp Result - 10000 particles - 5x setpoint

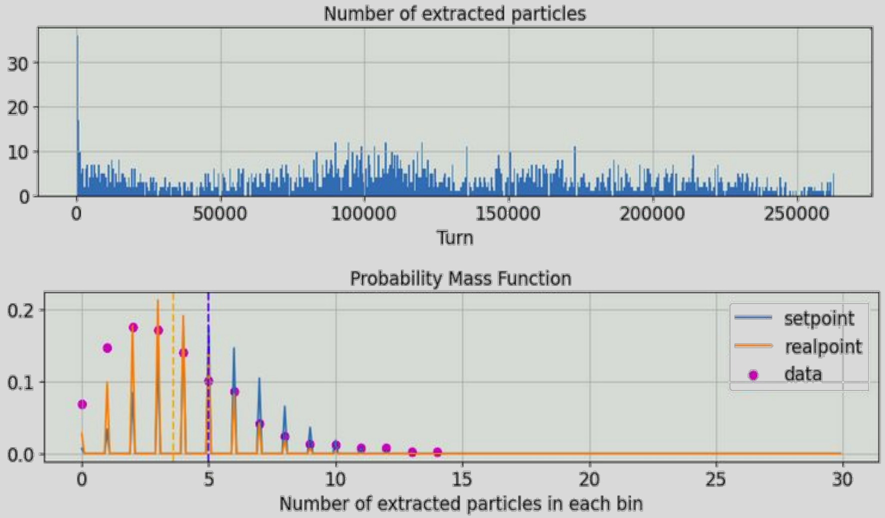


Reduced error and oscillation size

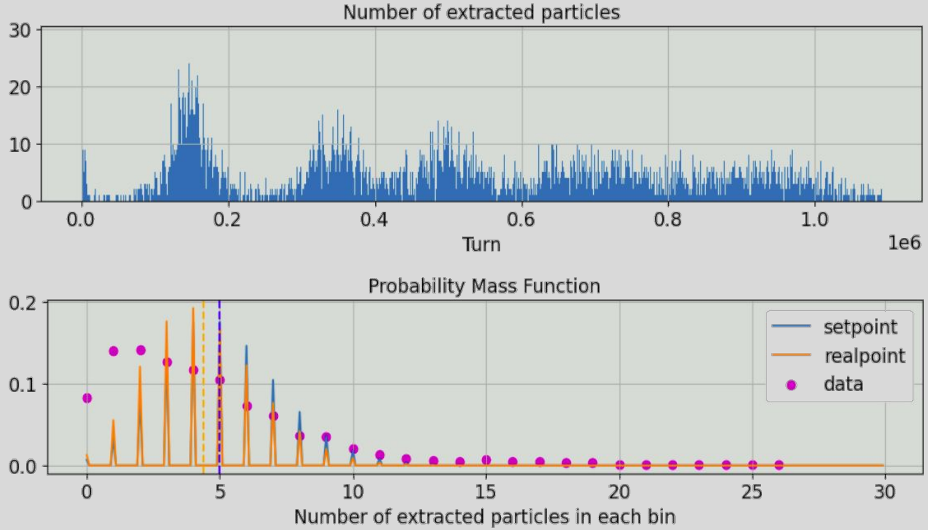
Spill Characteristic: Probability Mass Function

We are trying to control how many particles are extracted per window of 500 turns.
These effect is related to a Poisson distribution

Chirp Result - 2000 particles



Chirp Result - 10000 particles



Spill Characteristic: Duty Factor

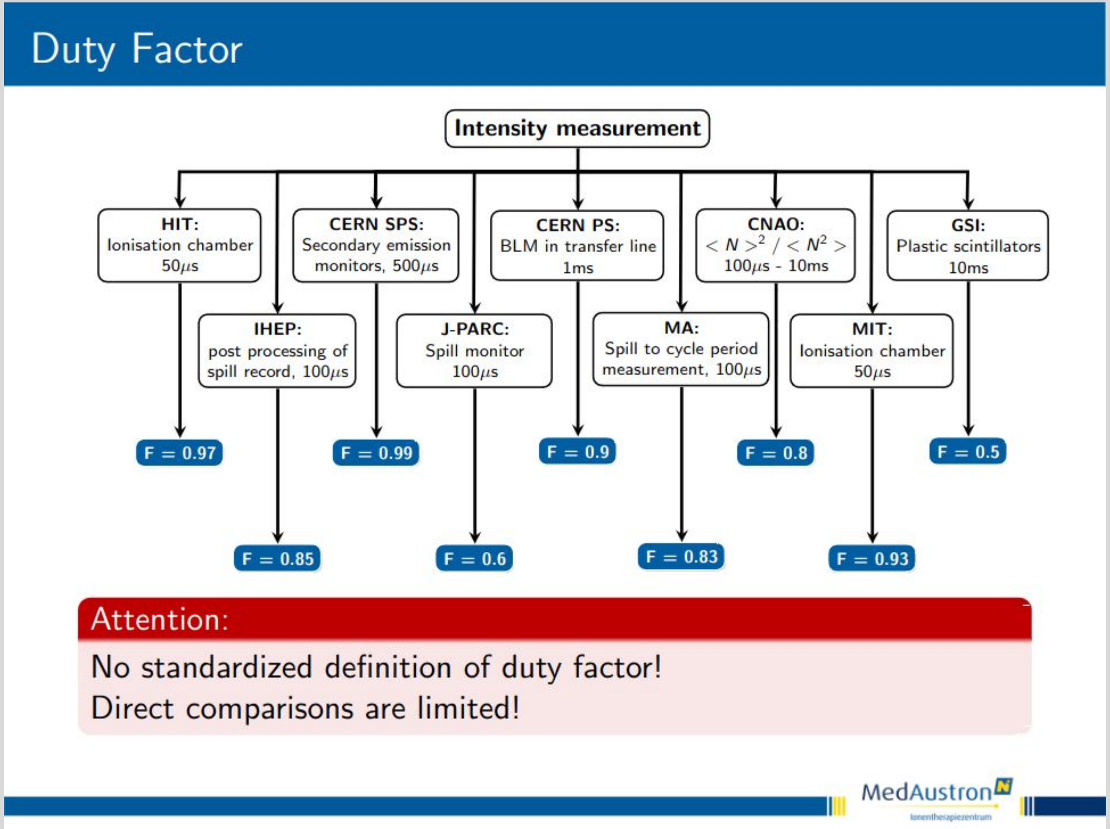
Why is it important? Only for comparing

It means nothing!

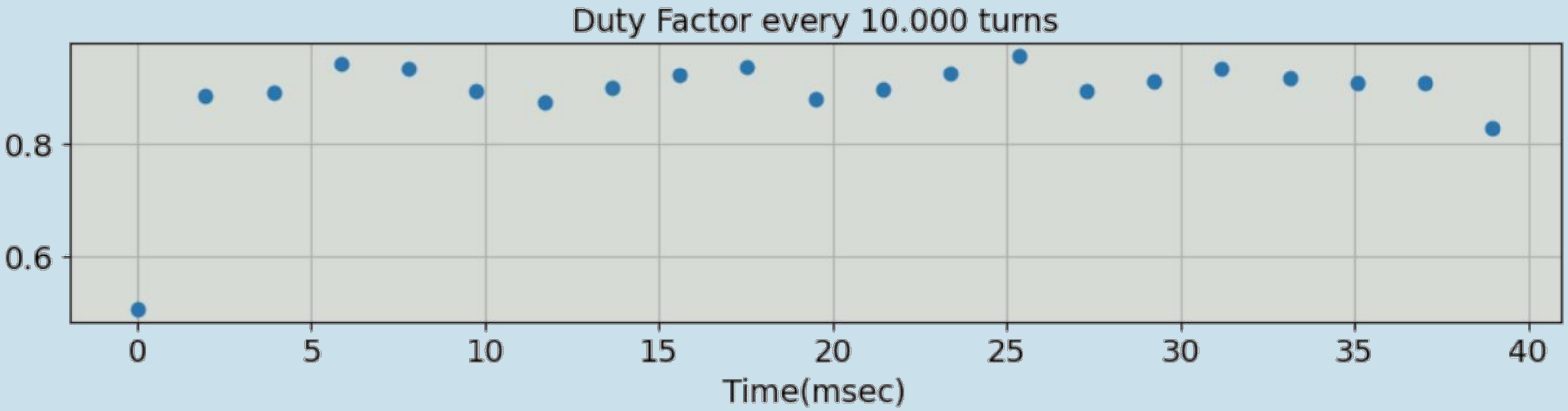
Measured F_av = 0.88758

$$\frac{\sum (N_p/T)^2}{\sum ((N_p/T)^2)}$$

Florian Kühteubl. *Evaluation of the Slow Extraction Survey* (2022)
https://conference-indico.kek.jp/event/163/contributions



Chirp Result - 10000 particles + 5x setpoint



Measured F_av = 0.88758

Conclusions:

Now on:

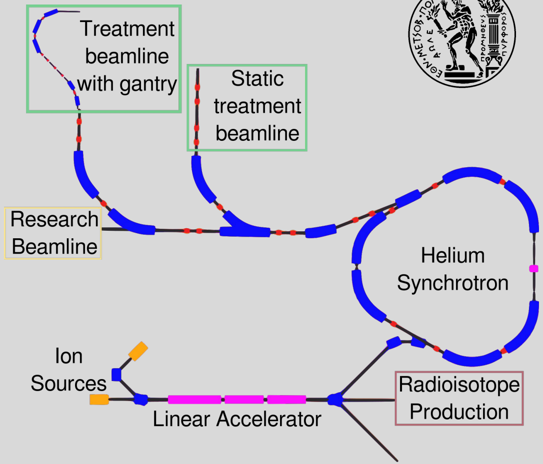
- Rewriting it in C in Xsuite rather than Python to be faster
- This tools will be used to instantly extract from every Helium Synchrotron setting (num. particles, emittance, sextupole strength, tune distance etc.)
- Before, each RF-KO was hand-optimised from a 8-variable function
- Already have other interested users from Xsuite community to make it into a full element

Further improvement can be made:

- D part of PID controller
- Feedforward System
- Further optimisation of parameters

Extra Slides

Helium Synchrotron Extraction Details

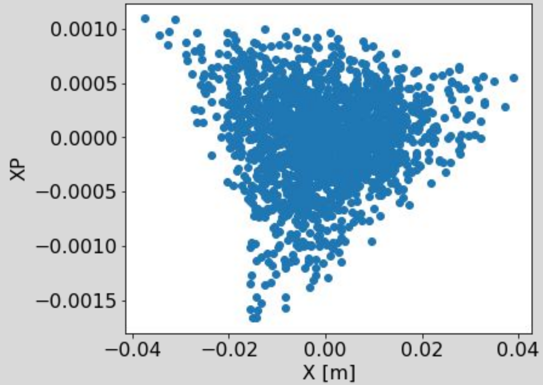


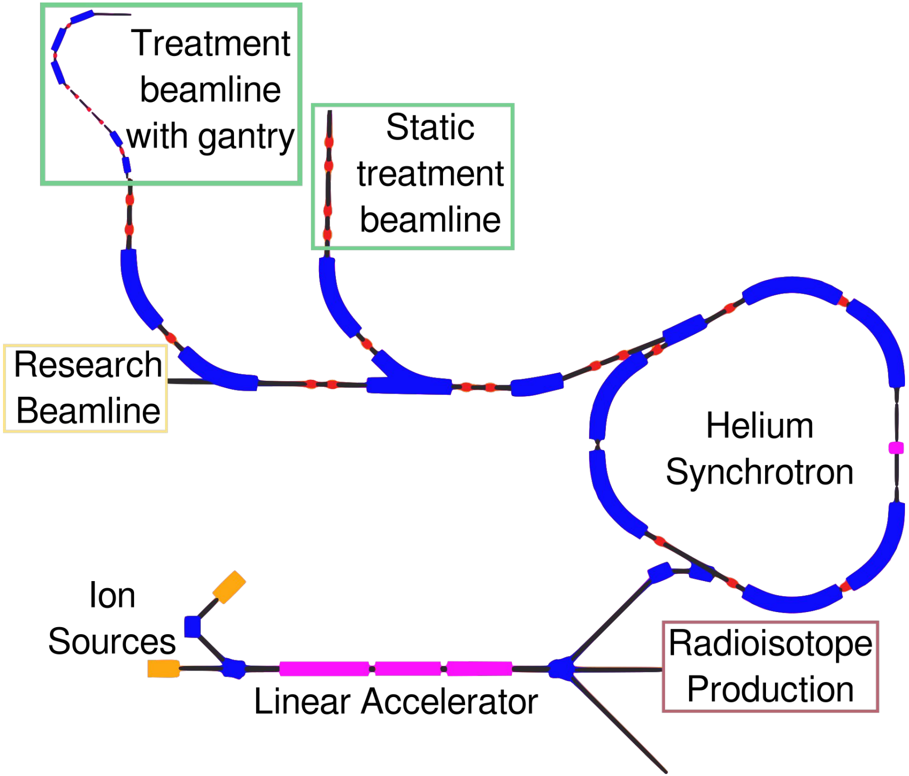
Simulations performed in Xsuite. Whole accelerator is a ‘blackbox’, but uses the following specifications:

- Resonant sextupole & injection septa in straight-section 1
- Magnetic extraction septa in straight-section 2
- Electrostatic septum in straight-section 3

Tunes (x,y)	2.655, 0.705
Chroma (x,y)	-6.382, -3.273
Emittance_n (x,y)	5, 1 [mm.mrad]
Res sextupole k2	**-1**
ES Septum X_lim	-55 [mm]
delta p/p	**0**

For simplicity, simulation tracking starts and ends at electrostatic septum, using stable beam that has already circulated for 10,000 turns.




Treatment
beamline
with gantry
Static
treatment
beamline
Research
Beamline
Helium
Synchrotron
Ion
Sources
Linear Accelerator
Radioisotope
Production