PARTI meeting
Fermilab, 08-24-2011

Third integer resonance extraction assisted by RF knock-out (RFKO)

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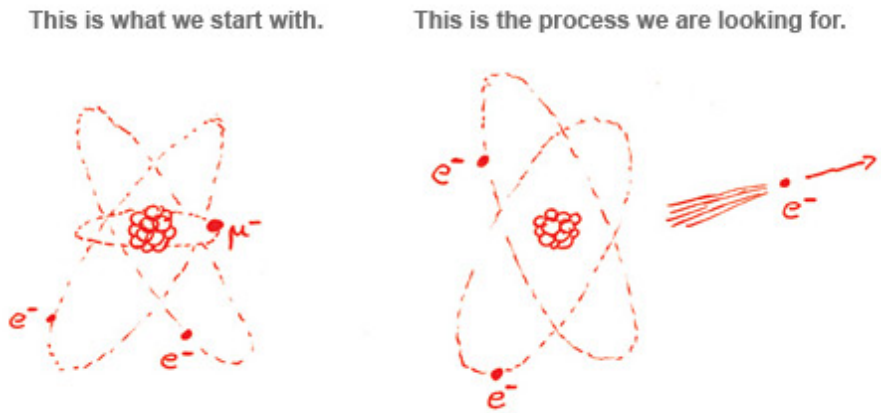
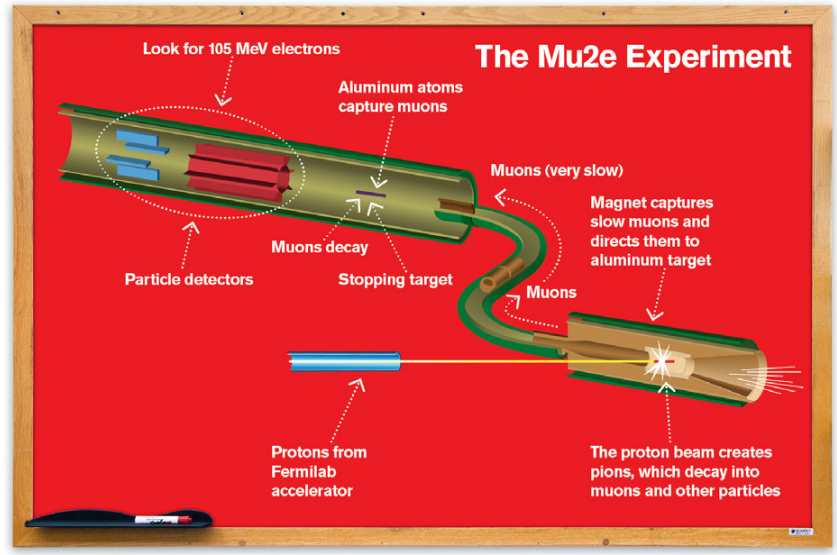
Mu2e experiment

Mu2e is a future project of Fermilab, which is planned to be launched in 2017-2018.



$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$



Charged Lepton Flavor Violation (CLFV) is not explicitly forbidden in the Standard Model (SM), but still remains unobserved.

Why this is important?

Detection of muon to electron conversion is an unmistakable signal of new physics.

What's the difference?

A muon that does not follow the traditional weak-force decay pattern into a lighter electron and two neutrinos, but converts wholly into an electron.

Proton acceleration for Mu2e experiment

What's the problem?

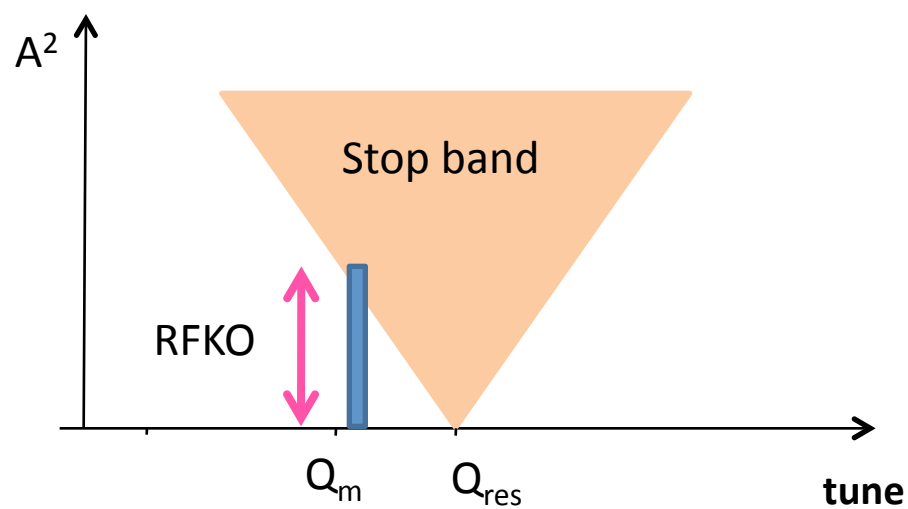
- The Debuncher will operate with beam intensities of 3×10^{12} particles, ≈ four orders larger than its current value
- Presence of large space charge and momentum spread
- Strict requirements: spill uniformity and low particle losses

Third integer resonance extraction

- Is used to extract particles during a large number of turns
- Betatron tune has to be close to the resonance condition - N/3

Radio-Frequency knock-out (RFKO)

We are using RFKO as a feed-back tool for the fine control of the spill rate.



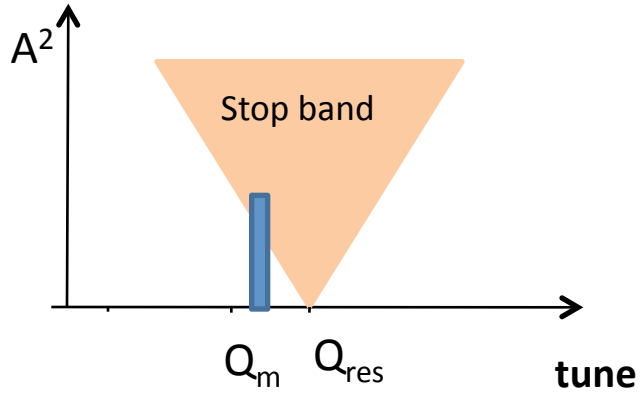
Plans

We should develop a concept of resonance extraction which meets the experimental requirements (uniformity and low beam losses)

Personal goals

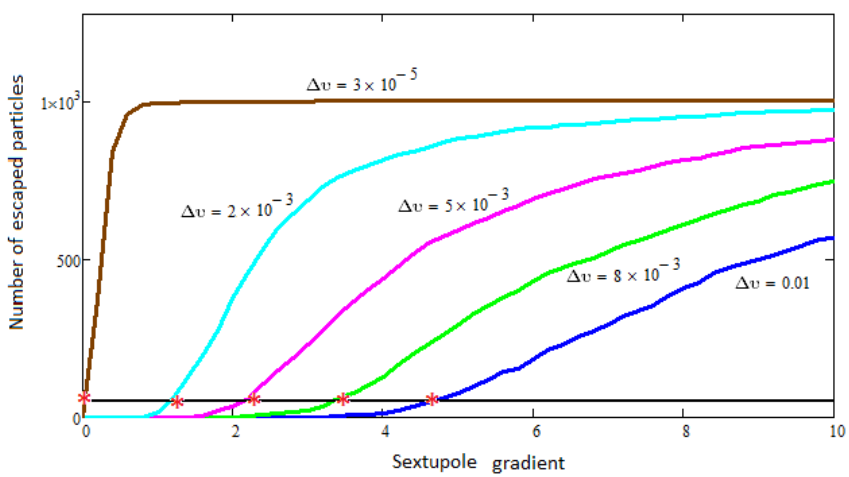
0. Get acquainted with principles of modern accelerator experimental physics
1. Create a numerical model of resonance extraction using Mathcad software
2. Explore different models of controlling the extraction using RFKO
3. Determine optimum strategies for the RFKO FM and AM.

Third integer resonance modeling



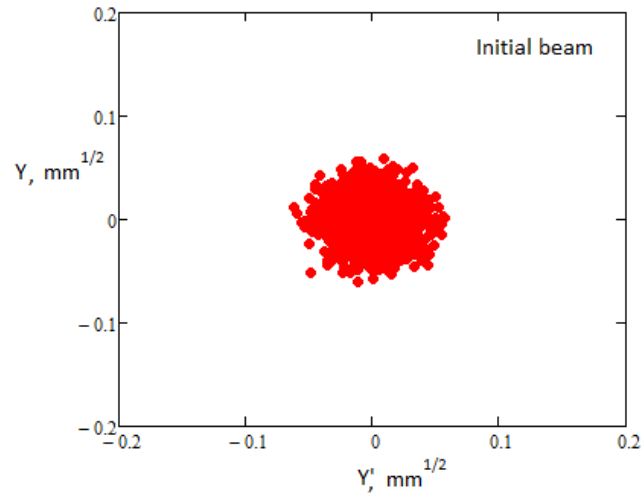
$$(\blacksquare Y@Y')\downarrow N+1=(\blacksquare \cos\theta \,\&\sin\theta \,@-\sin\theta \,\&\cos\theta)((\blacksquare Y@Y')\downarrow N+(\blacksquare 0\,@S*(Y\downarrow N)\uparrow 2))$$

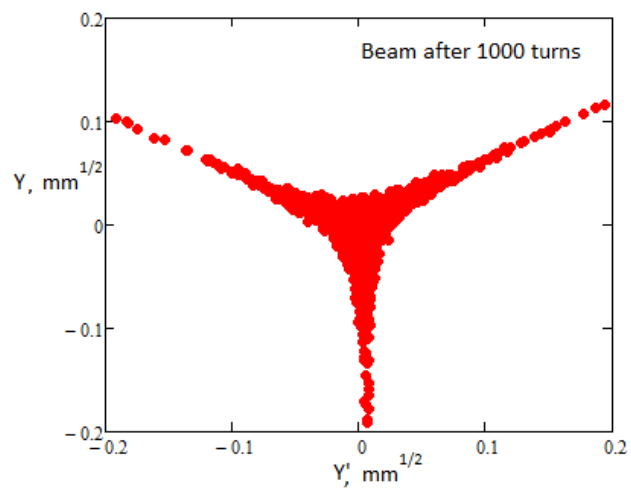
Number of escaped particles versus magnitude of single sextupole kick for different tune shifts



* Expected value for kick to reject 5% of particles

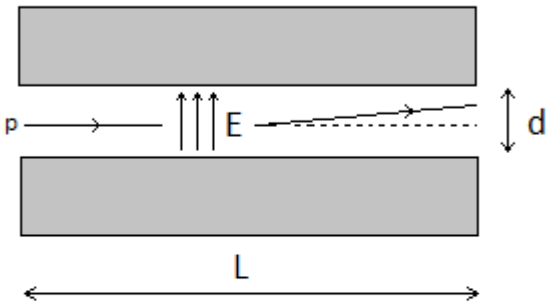
Beam phase plane





RF simulation

RF kicker



ω - Frequency of kicker
fo - frequency of beam's oscillation
R - resistance
W - power

Calculation

$$Y = \frac{x}{\sqrt{\beta}} \qquad Y' = \sqrt{\beta}\left(x + \frac{2x'}{\beta}\right)$$

Normalized coordinates

$$\Delta Y' = \frac{Le\sqrt{2RW\beta}}{\gamma\beta_{rel}mc^2 d}\cos\left(\frac{\omega N}{f_o} + \varphi_o\right)$$

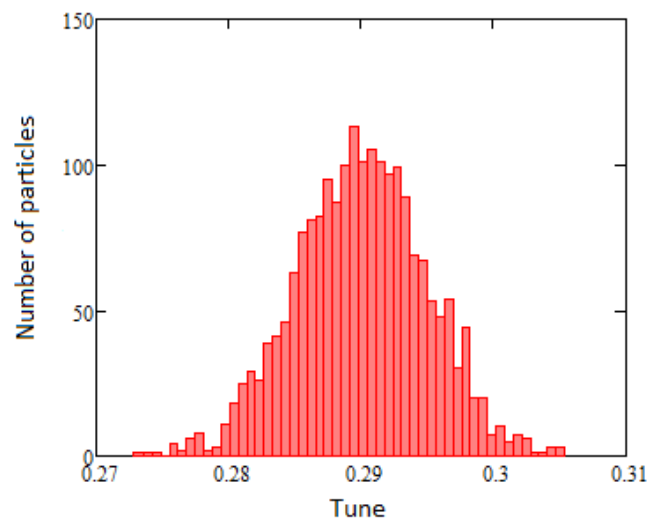
Momentum kick on the single particle

$$\begin{pmatrix} Y \\ Y' \end{pmatrix}_{N+1} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}\left(\begin{pmatrix} Y \\ Y' \end{pmatrix}_N + \begin{pmatrix} 0 \\ \Delta Y'(N) \end{pmatrix}\right)$$

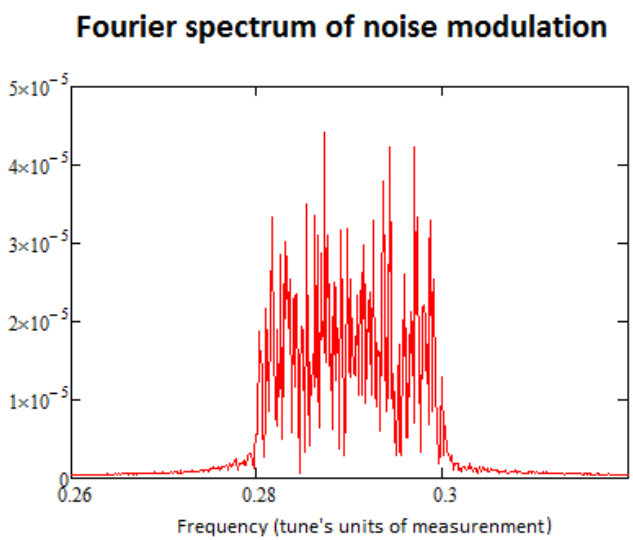
Assumptions

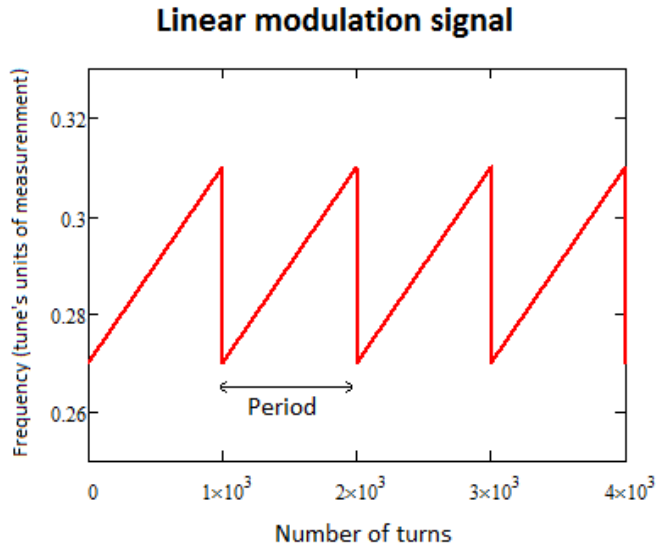
1. Only momentum changes
2. Field is normal to the trajectory
3. Field doesn't change while particle is in the RF kicker

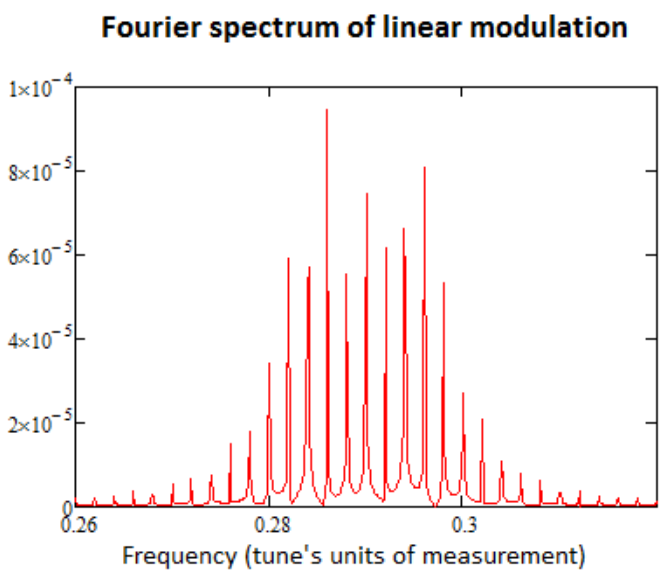
Tune distribution in a beam

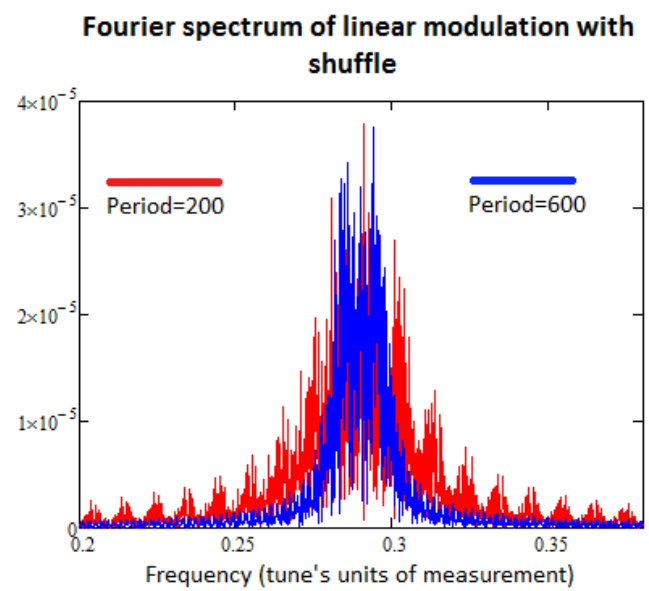


RF signals

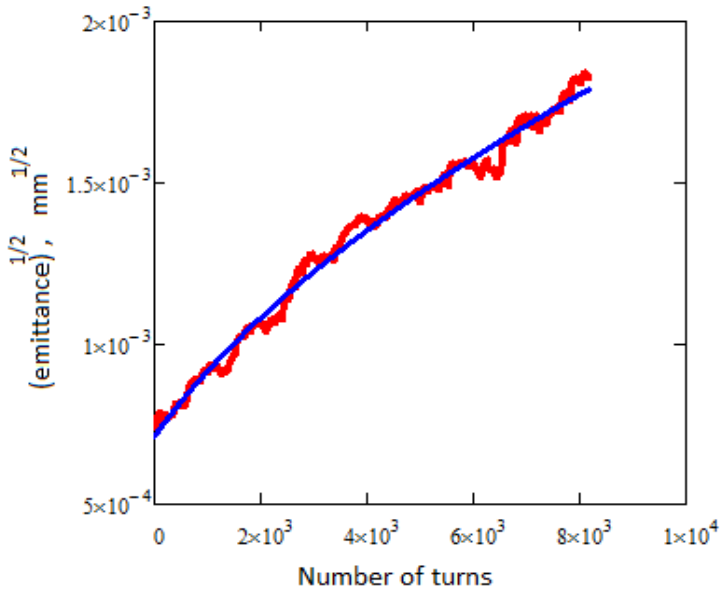

Fourier spectrum of noise modulation
5×10⁻⁵
4×10⁻⁵
3×10⁻⁵
2×10⁻⁵
1×10⁻⁵
0
0.26
0.28
0.3
Frequency (tune's units of measurenment)

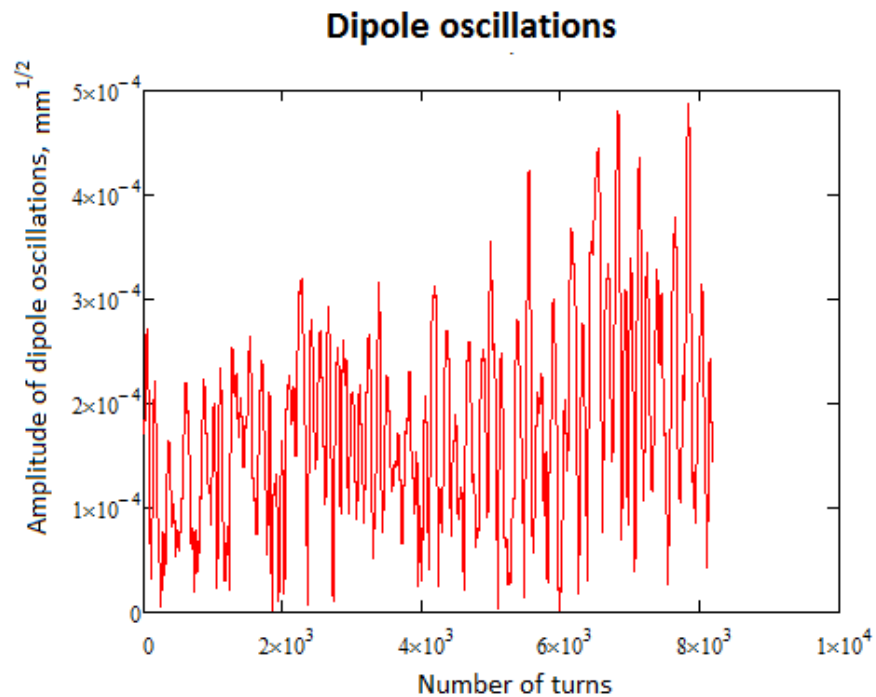

Linear modulation signal
Frequency (tune's units of measurenment)
0.32
0.3
0.28
0.26
Period
0
1×10³
2×10³
3×10³
4×10³
Number of turns


Fourier spectrum of linear modulation
1×10⁻⁴
8×10⁻⁵
6×10⁻⁵
4×10⁻⁵
2×10⁻⁵
0
0.26
0.28
0.3
Frequency (tune's units of measurement)


Fourier spectrum of linear modulation with shuffle
4×10⁻⁵
3×10⁻⁵
2×10⁻⁵
1×10⁻⁵
0
Period=200
Period=600
0.2
0.25
0.3
0.35
Frequency (tune's units of measurement)

Beam size growth





Data from simulation

Approximating curve

Analogy with Brownian motion:

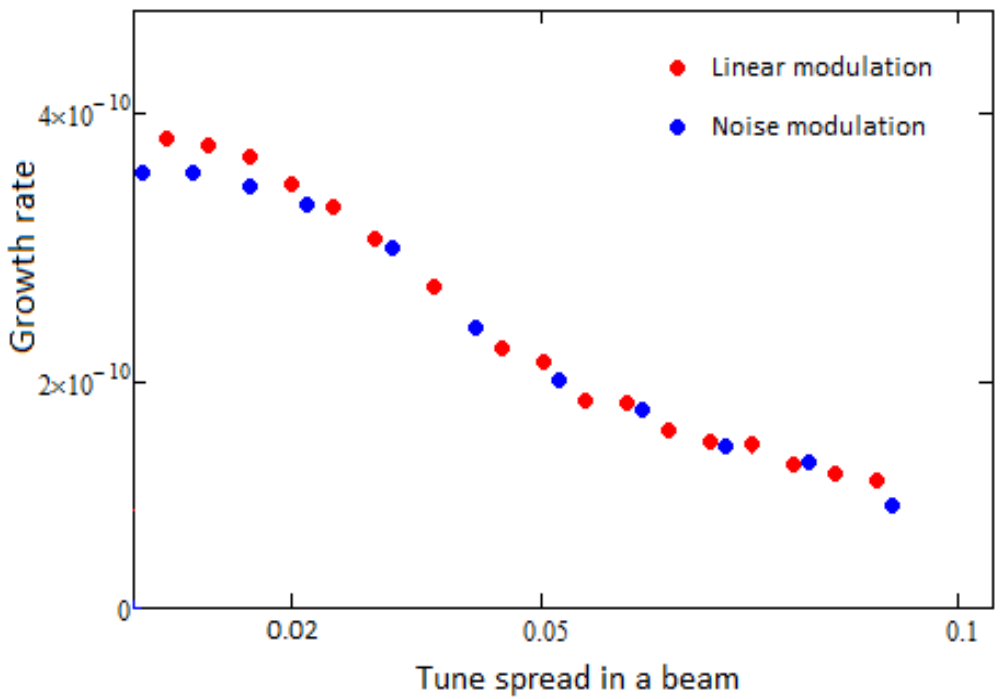
$$X \sim \sqrt{A + B * t}$$

A – initial size of the beam

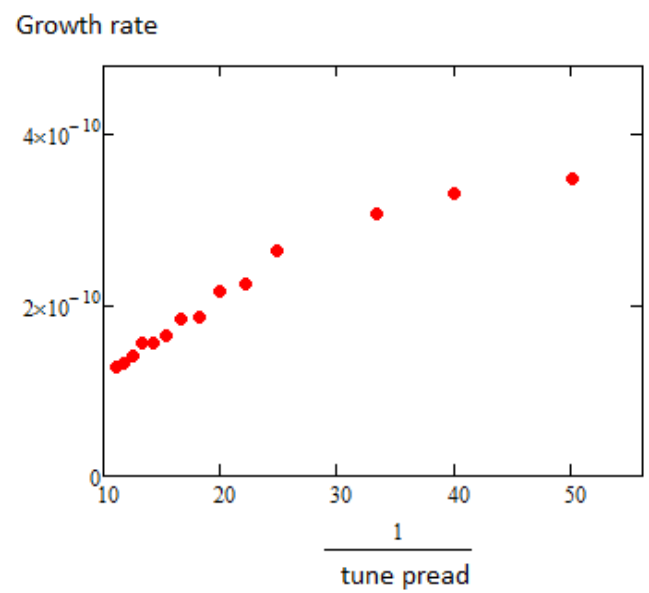
B – growth rate

Optimal strategy

Comparison of 2 modulations



Noise modulation



The spill rate for “narrow” modulations is significantly lower.

Making the modulation wider than tune spread doesn’t look efficient.

Summary

Conclusions

1. Both noise and linear modulation with shuffle perform fast increase in spill rate if used accordingly with optimum strategy

2. The optimum strategy is when modulation bandwidth is taken roughly equal to the tune spread in a beam

3. Further research is needed

Future perspectives

1. Finish the model optimization
2. Take space charge effects into account
3. Combine RF modulation and 3rd resonance modulation