Realization of the optimal beam dilution pattern of the FCC-hh ring using beating frequencies

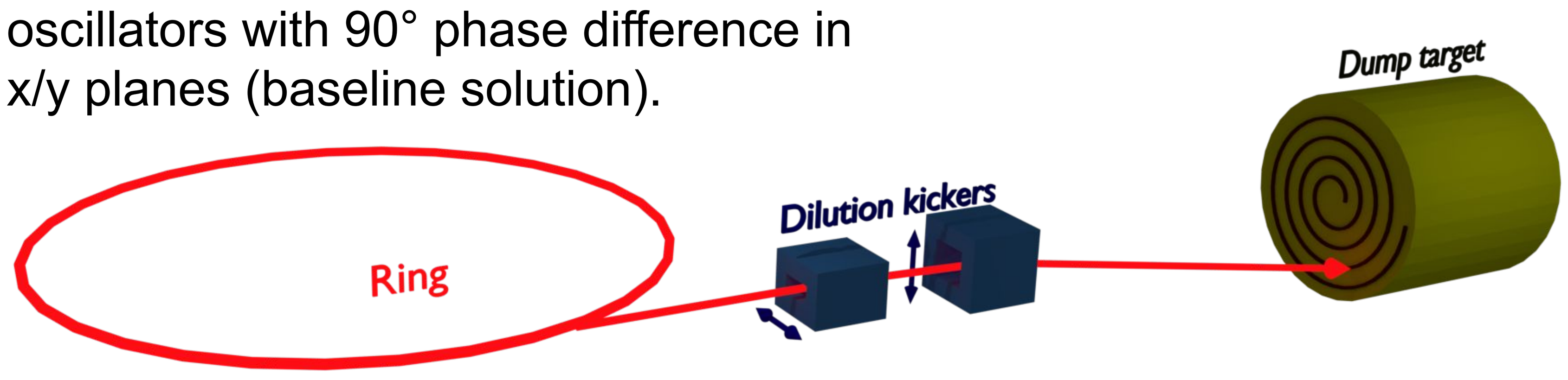
Benedek Facskó <facsko.benedek@gmail.com>, Dániel Barna <barna.daniel@wigner.mta.hu>
(Wigner Research Centre for Physics, Budapest)
Anton Lechner <anton.lechner@cern.ch> (CERN)

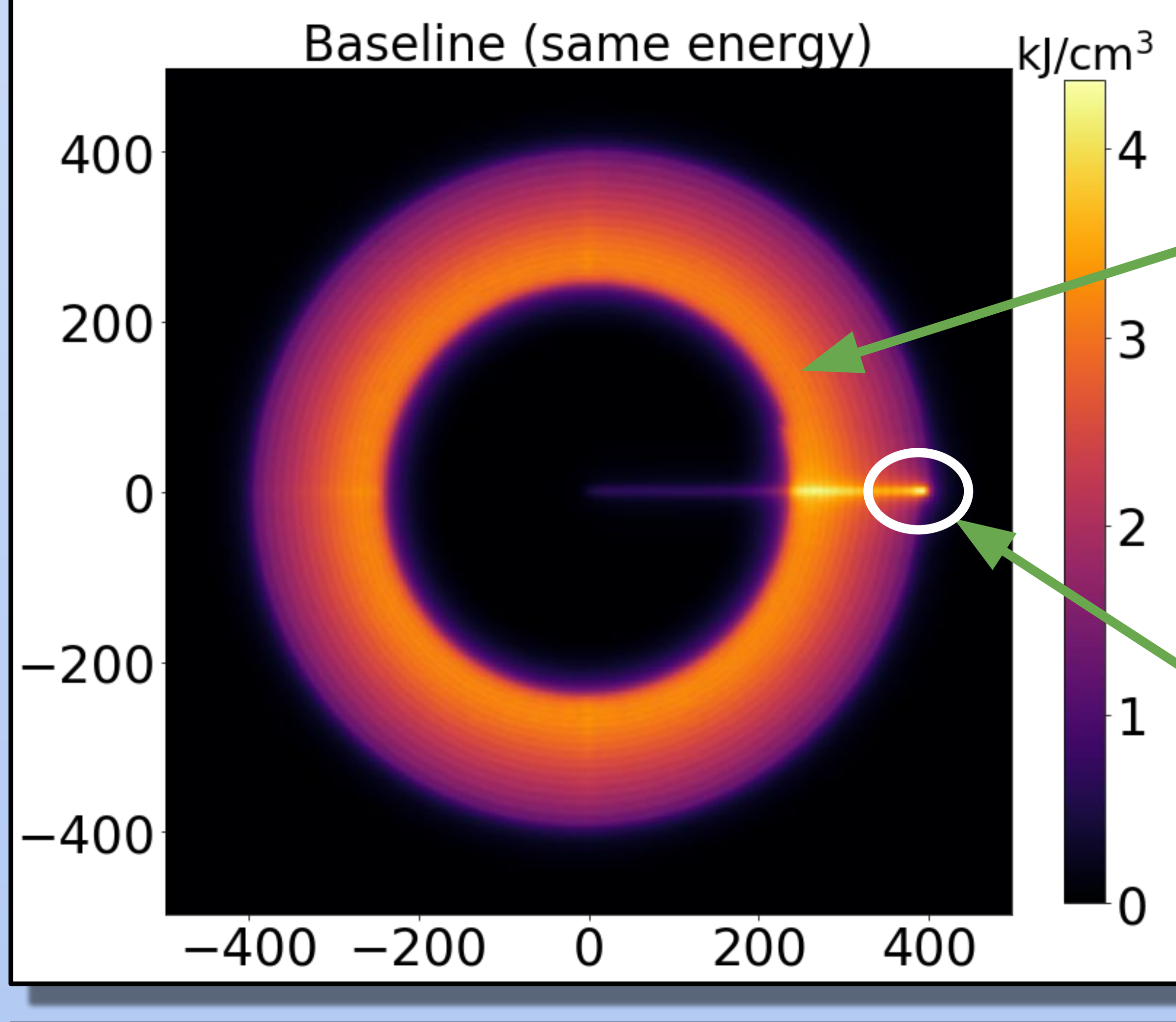
1. Abstract

In order to avoid the damage of the dump target of the FCC-hh ring, the beam will be swept over its surface using dilution kickers oscillating in the x/y planes with 90° phase difference, and an amplitude changing with time. Whereas the natural time-dependence of the amplitude is the exponential decay of a damped oscillating circuit, the optimal shape must have increasing pitch towards smaller radii, to produce a flat energy deposition density. Deviations from the optimal shape lead to increased requirements on kicker power, dump target size, or material damage threshold. We propose the realization of the optimal pattern using two beating frequencies. This method has the advantage of using very simple circuitry (independent damped oscillators) which interfere only in their effect on the beam. Besides the demonstration of the concept, a sensitivity analysis to the circuit parameters will be presented.

2. The problem

Extracted beam must be distributed over the surface of the dump target to avoid damage. Simplest idea is a spiral, realized by damped oscillators with 90° phase difference in x/y planes (baseline solution).





Exponential decay of damped oscillation leads to small pitch, too high energy deposition density at small radii

For an asynchronous dump: X-kicker reaches maximum and hesitates, Y-kicker has not started yet. Subsequent bunches overlap. High energy density

3. Proposed solution & analysis method

Use **two beating frequencies** to synthesize the ideal pattern:

$$F(t) = A_1 \exp(-t/\tau) \sin(2\pi f t) + A_2 \exp[-(t-\Delta t)/\tau] \cos[2\pi (f+\Delta f)(t-\Delta t)]$$

(Same waveform delayed by 90° in y plane).

Advantages:

- **Simple hardware**, same as for baseline solution
- Individual **modules uncoupled**, they interact only on the beam

Fix parameters: f = 50 kHz, $Q = 2\pi f \tau = 200$ (Q-factor of damped circuit). A_1 and A_2 (kicker amplitude) measured in [m], can be scaled to [Tm] (teslameter) by tunnel length.

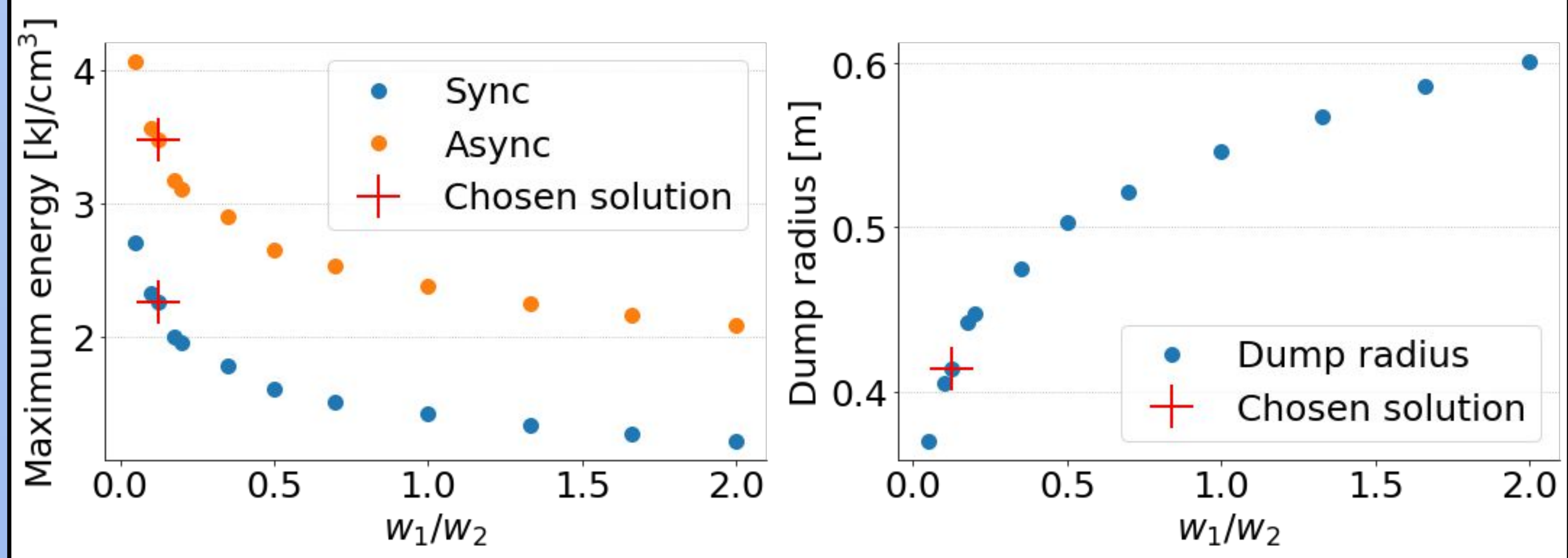
2D energy deposition map: convolution of dump pattern with single-bunch energy deposition profile. Minimize **penalty function** vs. free parameters:

$$w_1(E_{max}/E_0)^2 + w_2(S/S_0)^2$$

where E_{max} is **maximum energy**, S is maximum excursion (**dump radius**), E_0=2500 J/cm^3 (half of damage threshold to account for self-crossing pattern of async dump) and S_0=0.6 m are normalization factors. $w_1+w_2=1$ are weights.

4. Optimum energy and dump radius

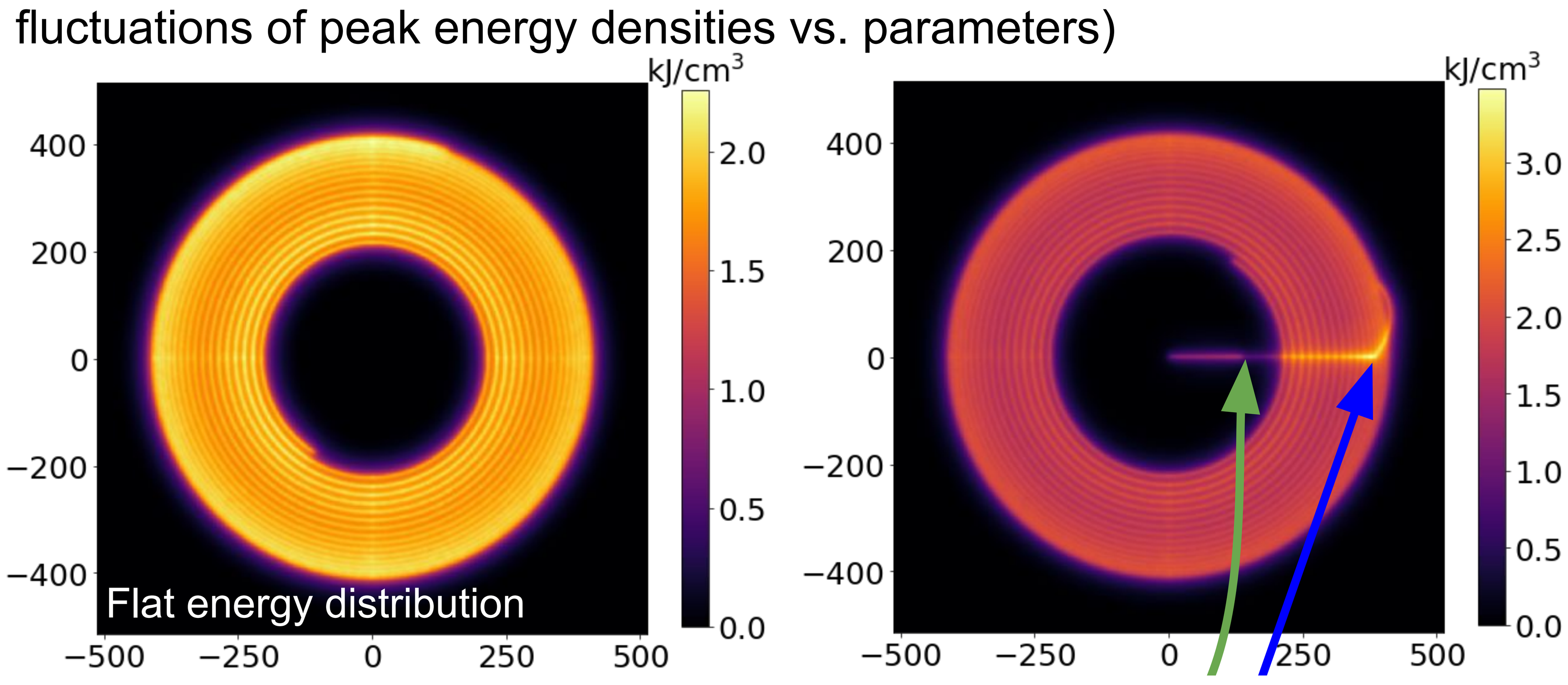
Changing weight ratio w_1/w_2 the algorithm prefers either small energy deposit or small dumpsize.



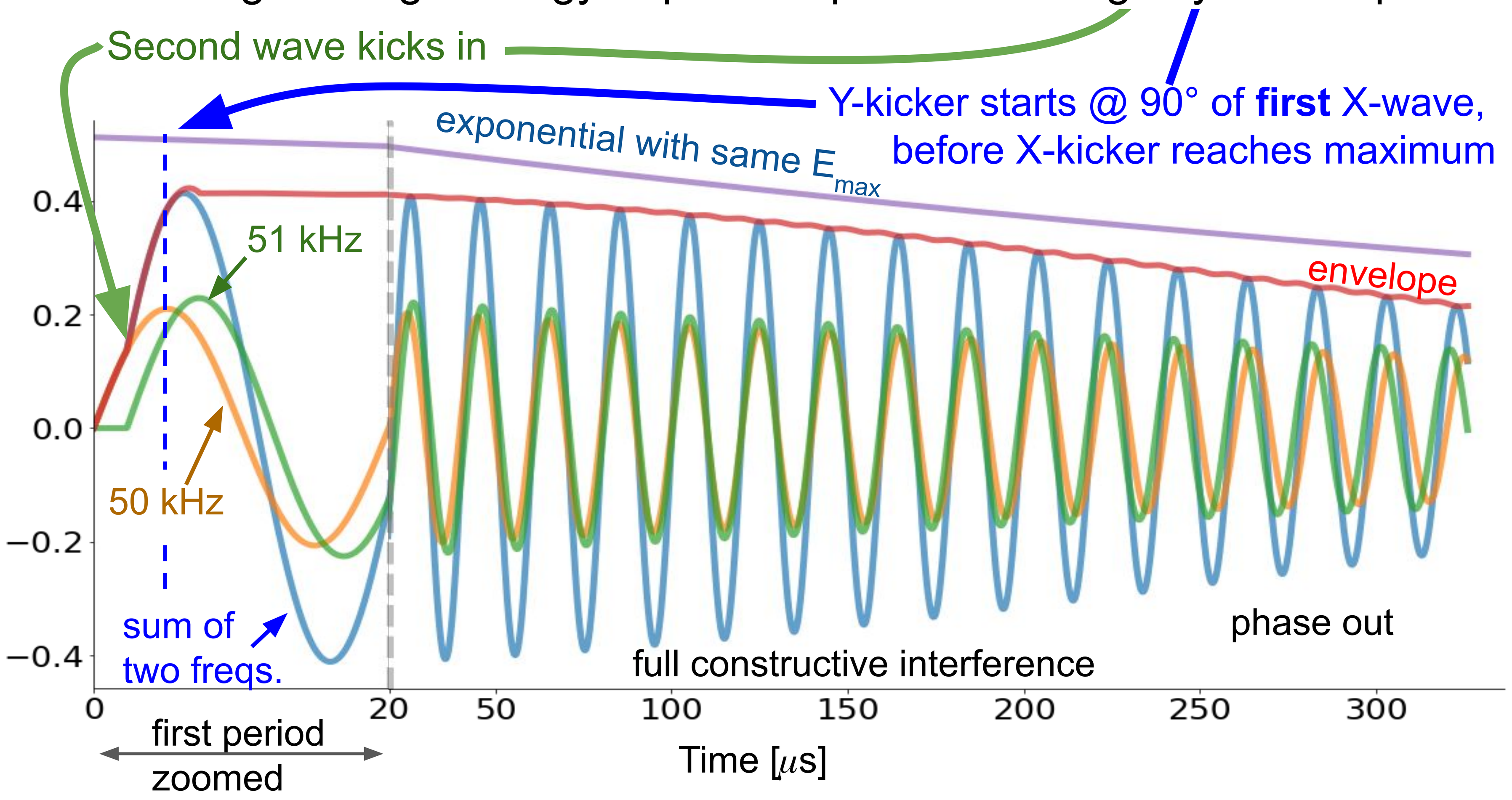
Chosen solution at w_1/w_2=0.125: safely below damage threshold, and has a small dump size.
Easy tuning in the "energy-dumpsize" trade-off.

5. Results and comparison

Analysis using fill pattern without gaps (overestimating energy, removing fluctuations of peak energy densities vs. parameters)



Bonus: mitigates high energy deposition problem during async. dump



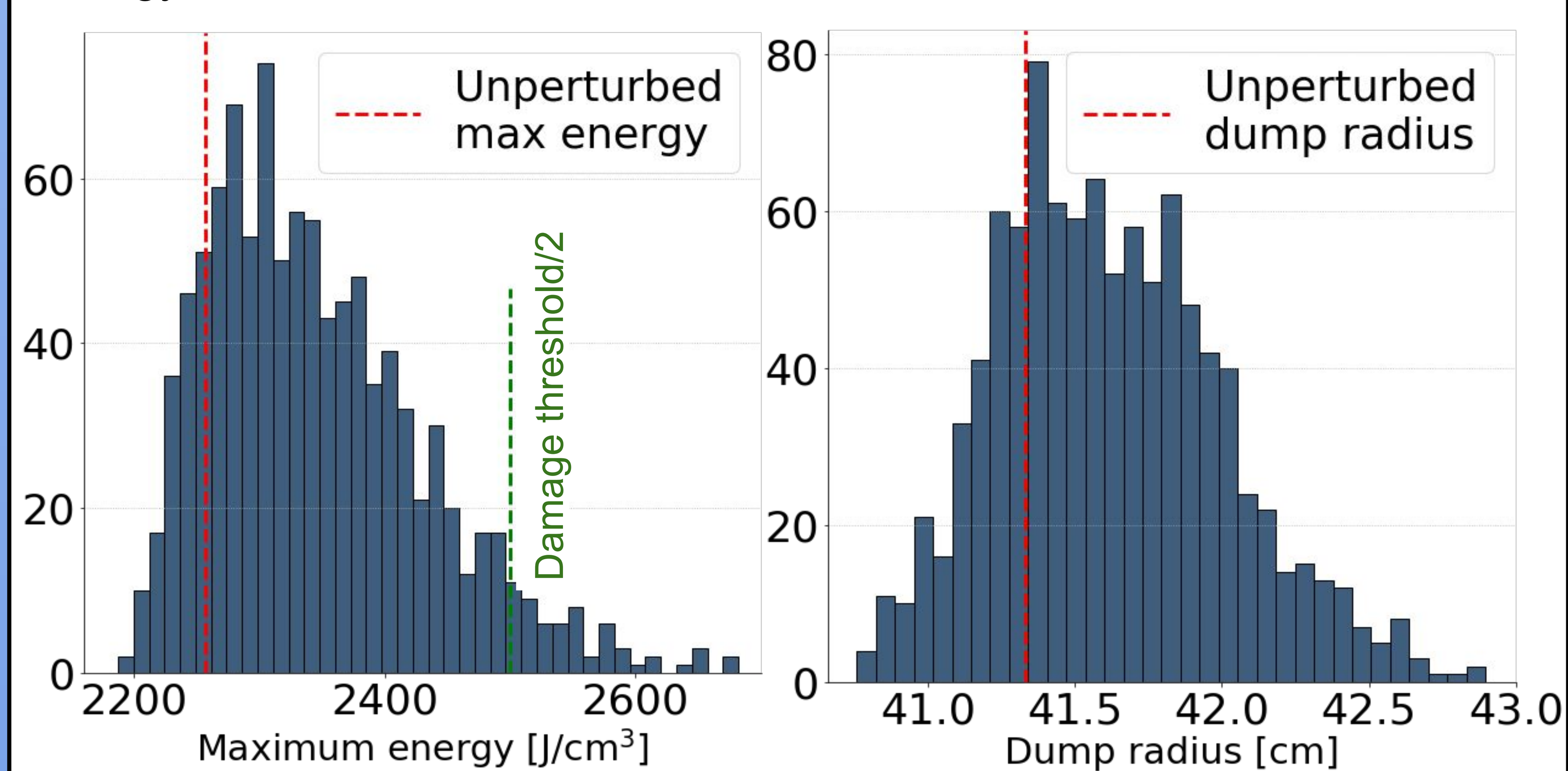
Compared to the exponential decay with

- same max. energy: **23% smaller radius, 16% less total kicker power**.
- same dump radius: 46% less max energy at the cost of 7% more total kicker power. 18% less energy for async. beam dump.

6. Sensitivity analysis

The kicker system would be composed of multiple modules (in each plane, for each frequencies). Individual modules can have scattered parameters. 1000 patterns were generated with parameter errors with a normal distribution (σ = 2% for amplitudes, 0.2% for frequencies and 250 ns time jitter).

The large majority of the tests are below the maximum acceptable energy level.



8. Conclusions

Using two beating frequencies for beam dilution can significantly decrease the required total kicker power and dump target size w.r.t. a simple damped oscillator. It also helps to decrease the high energy deposition for asynchronous dumps. This method does not require a more complicated hardware than the baseline solution.

Acknowledgements

The authors are grateful for the help of Mike Barnes, Laurent Ducimetière, Elisabeth Renner. This work was supported by the Hungarian National Research, Development and Innovation Office under grant #K124945. D.B. was supported by the János Bolyai Scholarship of the Hungarian Academy of Sciences.