# How to adjust stochastic cooling systems

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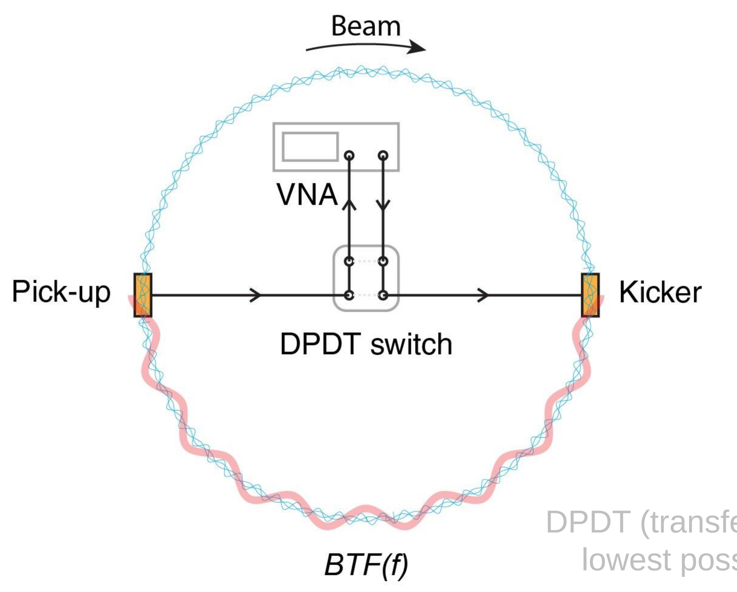
The poster summarizes techniques and algorithms for adjustment of stochastic cooling systems, that have been developed and tested at the COSY accelerator facility (FZ Jülich, Germany). An overall goal was to automate typical time-consuming manual adjustment routines. As a result, a set of algorithms based on a theoretical description of the stochastic cooling process has been developed, which allows accurate and fast automatic adjustment of main system's parameters. The methods have been elaborated and used at COSY during development and testing of stochastic cooling systems for HESR and are planned for further use at the FAIR accelerator complex (GSI, Germany). The methods are quite universal and can be applied or adapted to any similar system.

## Introduction

- An adjustment of a stochastic cooling system is bringing its broadband frequency response to its instantaneous optimum
- Common parameters for adjustment are system gain and delay and optionally a comb filter if it is used
- The developed adjustment techniques for both gain and delay are based on calculating the system transfer function from open loop measurements and using it in Focker-Planck or single particle equations to obtain the optimum values, while the comb filter is adjusted simply iteratively




DPDT (transfer) switch provides the lowest possible insertion delay

- Open-loop measurements produce direct product of beam and system transfer functions, so the latter can be obtained by substituting the BTF and then used in the Fokker-Planck and/or single particle equation to calculate optimum gain and delay:

$$G(f) = \frac{OLM(f)}{BTF(f)} \rightarrow \frac{dx}{dt} = F(G,x,t) + \frac{D(G,x,t)}{x}$$

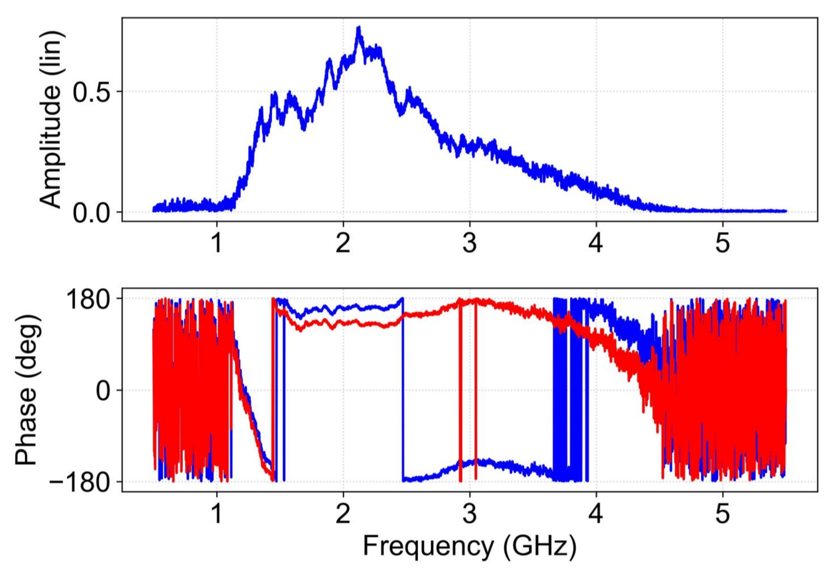
## System delay adjustment

- System delay synchronizes kick with the measured particles and defines the phase slope of the system transfer function
- Flattened phase is a good starting point, but not an optimum, need to correlate phase flatness with amplitude
- Optimum delay can be calculated directly from cooling force after OLM (+ comb filter):

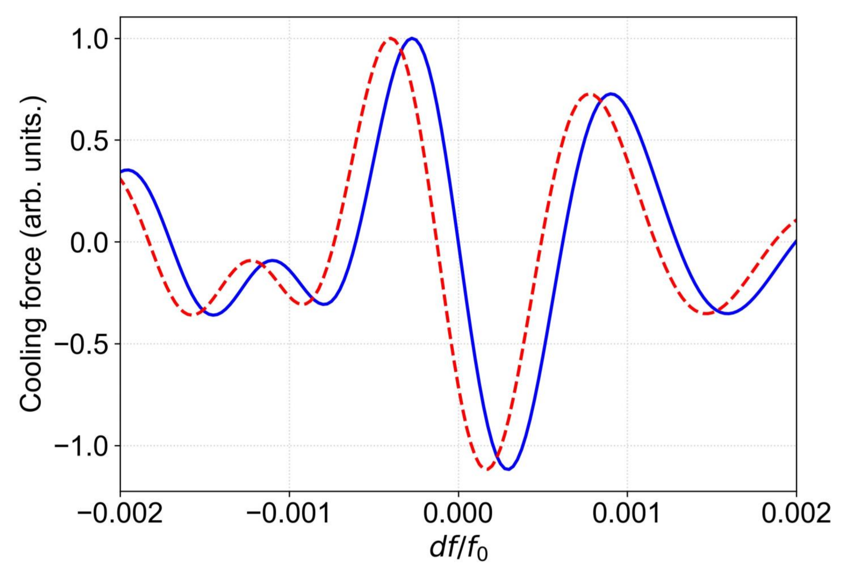
$$F_{cool} \sim f_p \cdot Re \sum_n \frac{G}{1 - G \cdot BTF} e^{i2\pi n f_p T_{pk}(f_p)} = f_p \cdot Re \sum_n n \cdot OLM \cdot e^{-i2\pi n f_p T_{pk} \frac{\eta_{pk}}{\eta} \frac{f_p - f_0}{f_0}}$$

- The developed method for is universal and proved to be robust and accurate
- Adjustment time depends only on the OLM:

~1 s when adjusted from scratch, and ~100-200 ms if only fine-tuning needed




Amplitude and phase of vertical OLM for optimum delay (blue) and flattened phase (red)



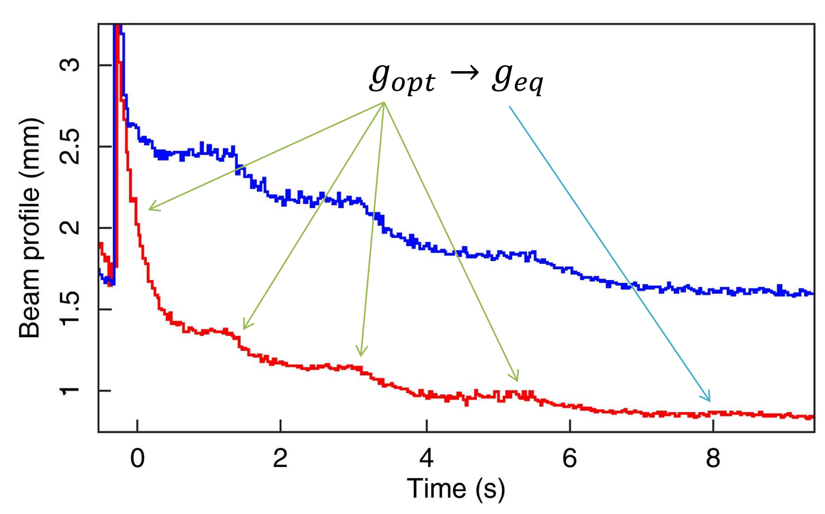

Cooling force calculated with Eq. (2) for optimum delay (blue) and delay, that flattens the phase (blue)

## System gain adjustment

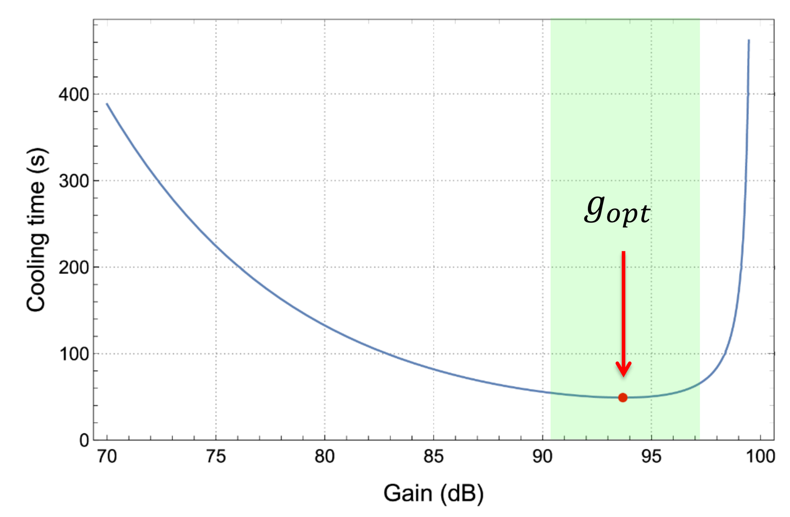
- System gain controls cooling rate and final equilibrium state of the parameter being cooled by balancing the cooling and heating forces
- Optimum gain provides instantaneous fastest cooling rate, but worse final state, and equilibrium gain provides smallest equilibrium, but slower cooling
- Both gain immediately calculated if diffusion due to hardware noises is negligible. Otherwise, it must be estimated from measurements:

$$D_{th} = \frac{1}{2} f_0^2 k (T_{pu} + T_{amp}) Z_0 \sum_n \left|\frac{G_{cl}}{Z_p}\right|^2 \rightarrow \bar{A} \sum_n |G_{cl}|^2 \qquad \frac{dx}{dt} = F + \frac{D_{Sch}}{x} + \frac{\bar{A}}{x} \sum_n |G_{cl}|^2 + C_{IBS}$$

- The developed technique for gain adjustment provides accurate enough results, but may require some adaptation to a specific setup and goal



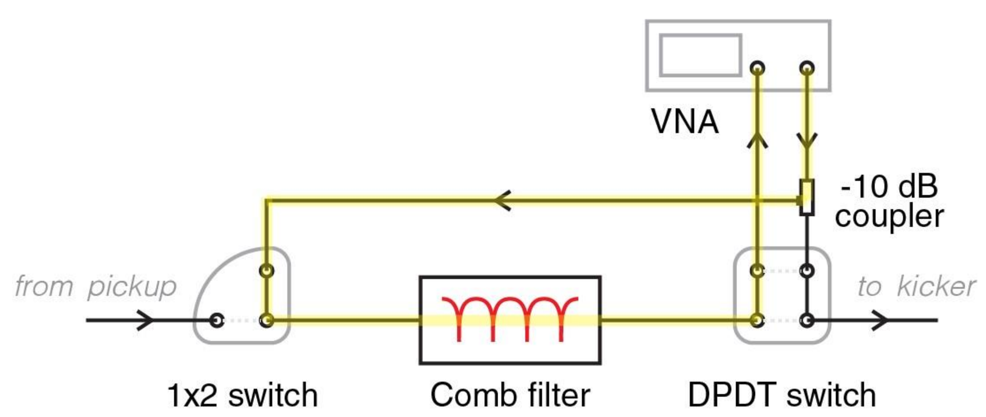

Horizontal (blue) and vertical (red) beam profiles during transverse cooling with stepped gain changing. Each step the gain is reduced by ~3 dB.



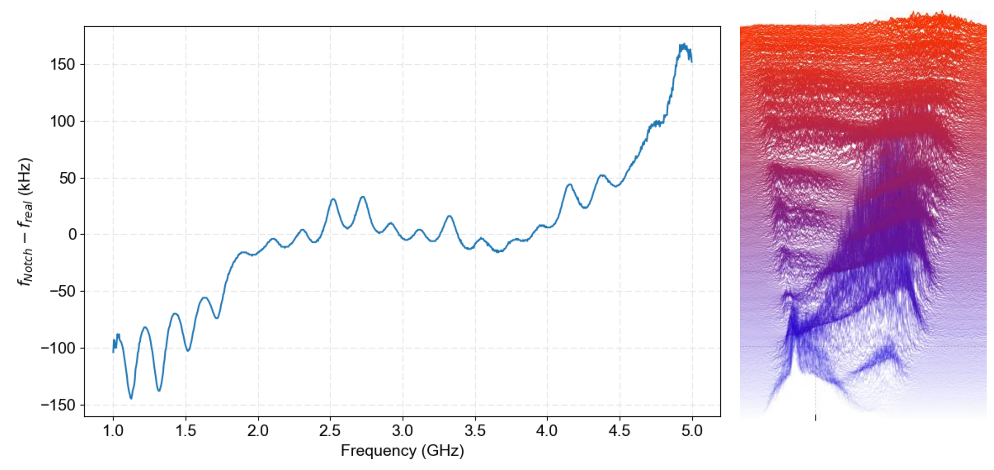

Cooling time vs gain. The resulting accuracy typically should not exceed 1 dB, making the calculation very tolerable to possible errors.

## Comb filter adjustment

- Adjustment is done without the beam, which makes it much easier
- The notch frequency is adjusted iteratively by measuring the current frequency and subsequent delay correction. The notch depth is also adjusted iteratively by varying the attenuation and using a binary search to find the optimum value with a given precision.
- Due to dispersion and mismatch in the filter components both the depths and positions of the notches vary, so these distributions should be measured and used in system delay and gain calculations
- Filter adjustment is fully automatic, adjustment time ~ few seconds if adjusted from scratch and <1 s for fine-tuning




Layout for OLM and additional loop (yellow) for remote comb filter tuning during operation



Notch frequency mismatch in the passband (left) and its influence on the Schottky bands filtering (right) if dp/p is small

## Conclusion

The developed techniques for system gain, system delay and comb filter adjustments significantly simplify, improve, and speed up the set-up of the stochastic cooling system. Full adjustment can be done automatically in a few seconds or less if only fine-tuning is required. While the system gain adjustment may require some adaptation to a specific setup and goal, the techniques for the system delay and comb filter adjustments are sufficiently universal to be applied to any similar system