Feasibility Test of Longitudinal Stochastic Cooling for Heavy-Ions in the LHC

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In collaboration with

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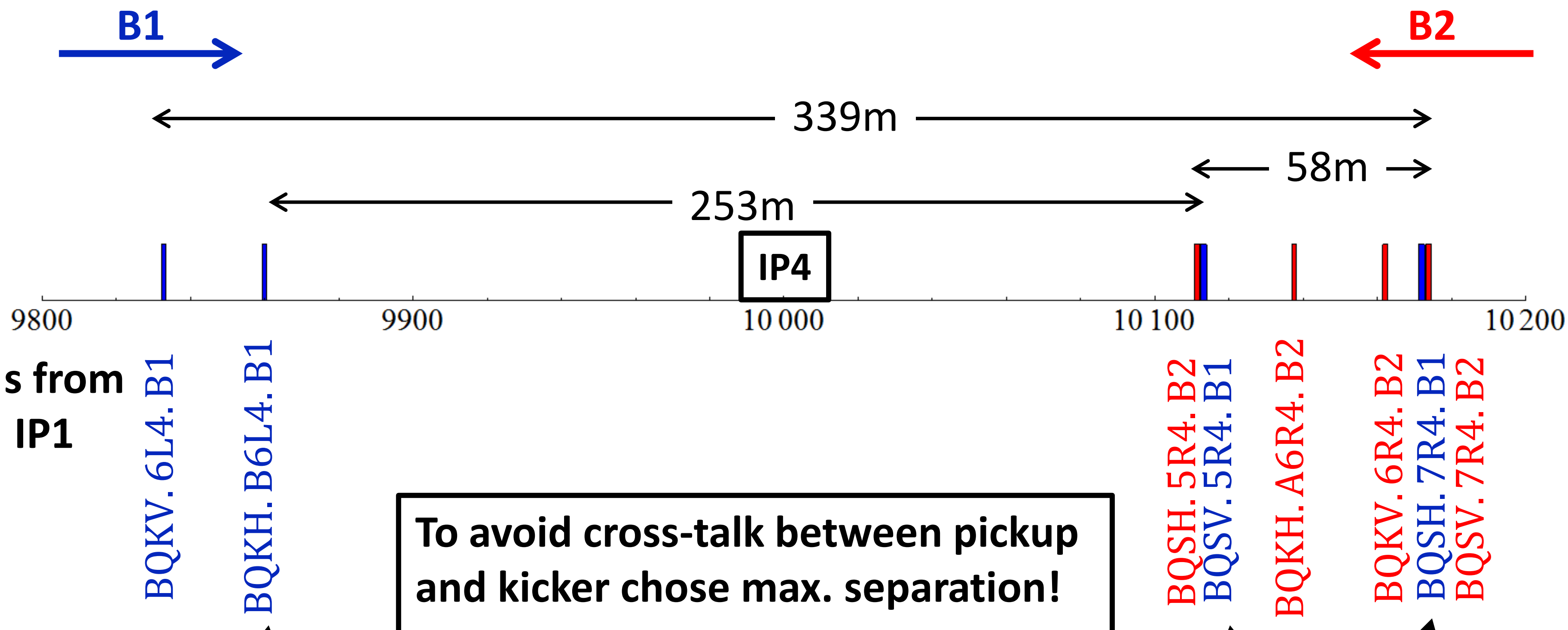
The Idea

- Install reduced **longitudinal stochastic cooling** system in the LHC (IR4) using
  - **existing Schottky Pickups** at 4.8GHz,
  - only **1 longitudinal cavity** at 4.8GHz resonant frequency,
  - + other required equipment (see later).

- **Cool a low intensity Pb-test-bunch** and observe the bunch length reduction over time.

- **Parasitic** experiment:
  - Long commissioning time required!
  - Gate on particular bunch in filling pattern.
  - **Take data for every fill**.

Tunnel Equipment in IR4



Potential Cavity Locations

Schottky Pickups

To avoid cross-talk between pickup and kicker chose max. separation!

Max. equipment separation

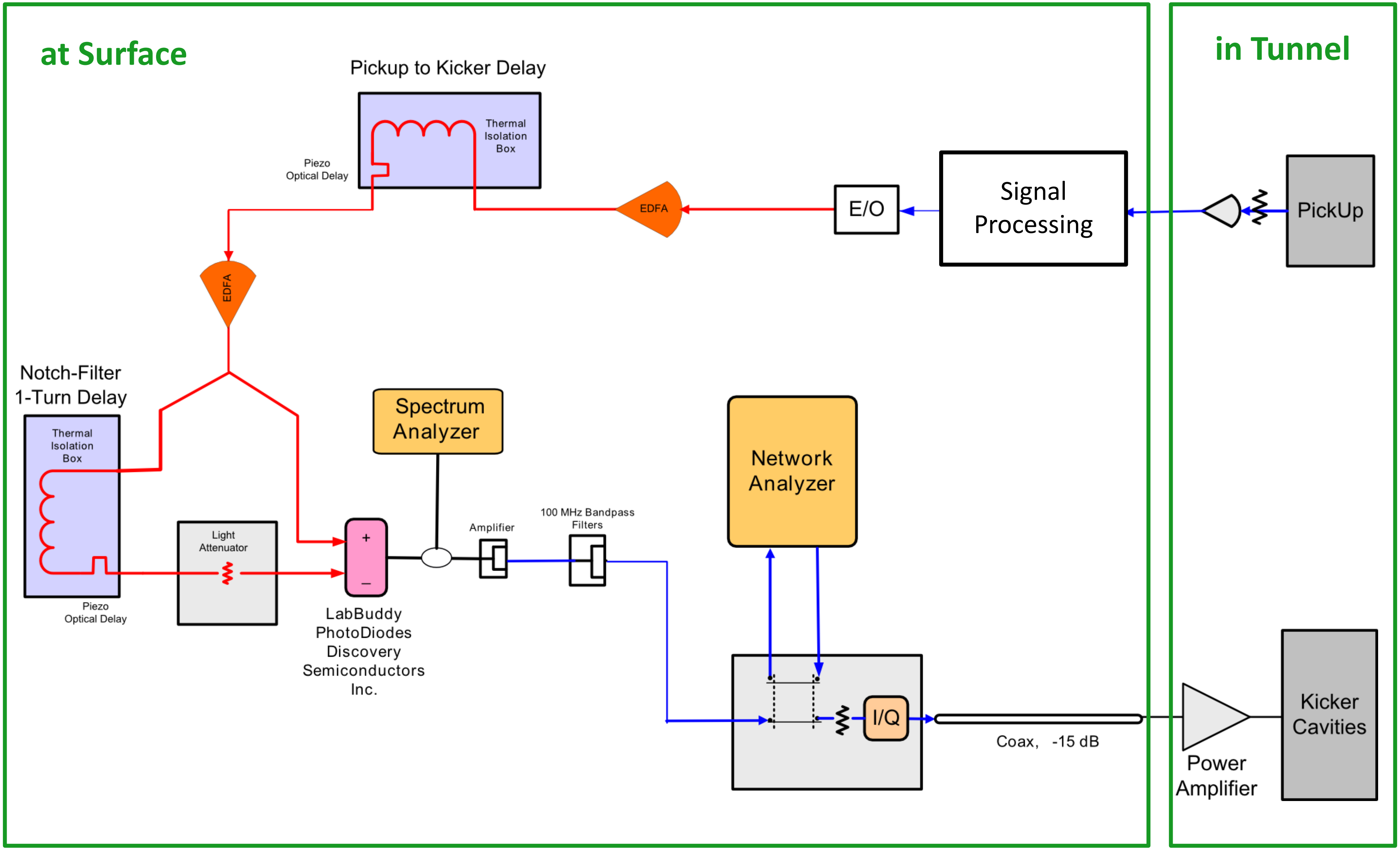
B2: ~60m

B1: ~340m

Note: B1H Schottky pickup gave best signals in the past.

Signal Processing and Transportation

Stochastic Cooling Low Level Block Diagram



Required Hardware

- **Schottky Pickup** at 4.8GHz operated in sum-mode
- **(Transversal filter)**
- **E/O** - Transformation to optical signal
- **Light amplification**
- **Optical cable** - Signal transportation to cavity location
- **Notch filter** (1-turn-delay, combiner and transformation to electrical signal)

} ~54km cable

- **Narrow band-pass filter** at 4.8GHz centre frequency
- **Spectrum and Network analysers**
- **I/Q modulator** for phase and amplitude adjustment
- **Coaxial cable** to power amplifier
- **Power amplifier**
- **Cavity**

Experiment Setup

- **Low intensity** bunch for fast cooling.
- **Non-colliding** bunch for clear signal.
- **Non-cooled witness bunch** for reference:
  - At 6.5Z TeV bunch length naturally shrinks due to **radiation damping**.
  - To distinguish between cooled and non-cooled bunches the cooling rate must be faster than the radiation damping rate!

Experiment Setup

Pilot/First bunch of 1st Train

- Bunch with lowest intensity in filling scheme.
- If spacing to neighbouring bunches is to small, neighbours might be disturbed by cooling.

Injection

Bunch with longest possible observation time.

Only 30min observation.

Flat Top

Colliding! Non-colliding bunch would show cleaner signal.

Fill length for observation.

Additional Low Intensity Bunch

- Intensity can be chosen to enhance cooling.
- No disturbances for other bunches.
- Easy to add witness bunch was equal properties.

Injection

Injection of first bunch just before abort gap.

Over-inject with the last train – no change of filling scheme necessary.

Only 30min observation.

Flat Top

Modify injection scheme! -Potential reduction of total bunch number.

Fill length for observation.

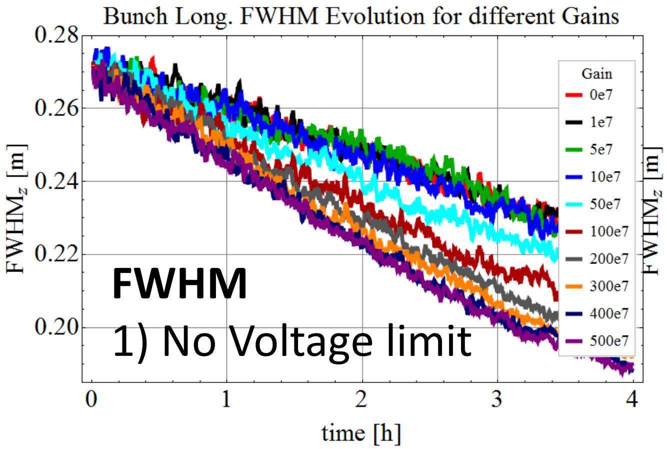
Simulations

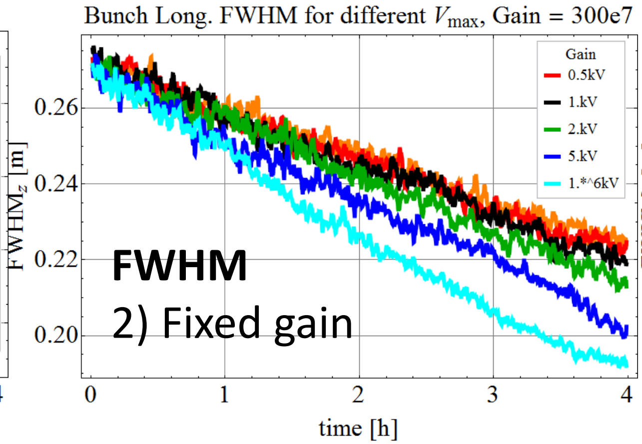
- Test Bunch Parameters:
  - Enhanced cooling for long low intensity bunches
  - $N_b = 10^7$ ions per bunch
  - σ_z = 12.5cm
  - $\varepsilon = 1\mu\text{m}$

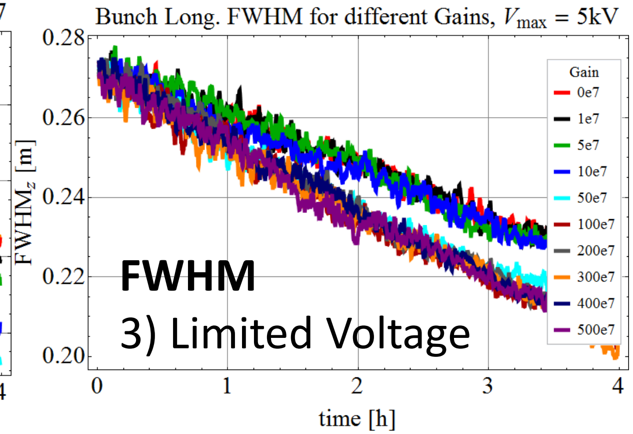
- Cooling efficiency depends on cooling system settings and available kick strength.
  - Too high amplification can lead to instabilities.
  - Kicker voltage is limited by available power.

- Measurement of the FWHM is used to monitor the bunch length in LHC.

Cooling Simulation at Flat Top







1) Find best settings - scan over cooling gains:
   - No further improvement of cooling rate for gains > 300e7.
2) Voltage restrictions - scan over V_{max}:
   - At least 5kV are required to get a sufficient cooling rate.
   - Effect on FWHM is still small.
3) Best Settings for V_{max} = 5kV – scan gains:
   - Bunches split up in two groups:
   - *Inefficient cooling*: almost no change to non-cooled bunch
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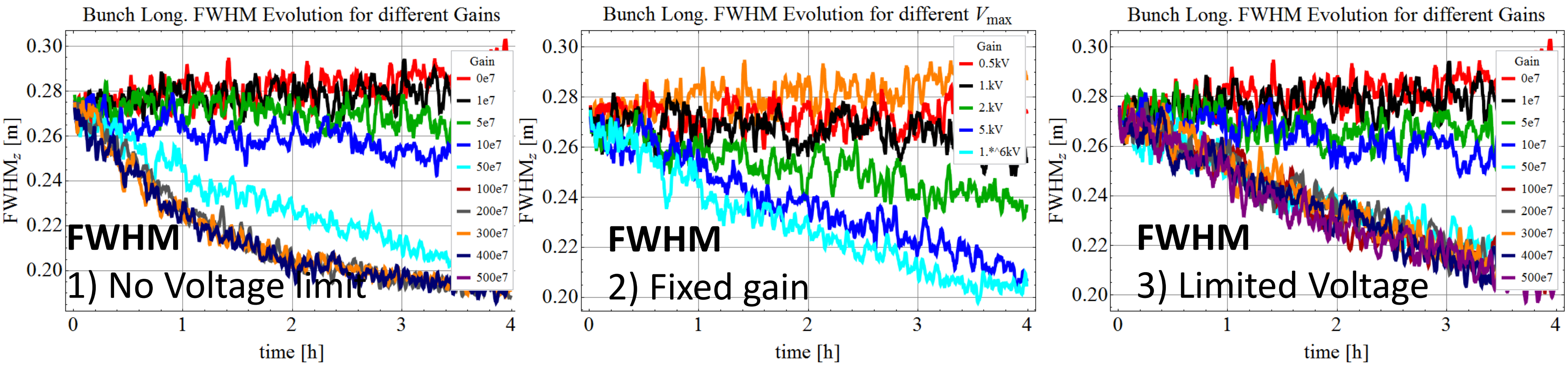
□ V_{max} = 5kV & gain = 50e7

Cooling Simulation at Injection



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Summary

- **Cooling of 1 low intensity bunch in B1 is proposed.**
- Using B1H Schottky pickup in sum-mode.
- Install longitudinal cavity in one of the BQK.B1 positions.
- As parasitic *proof of principle experiment*:
  - Inject additional very low intensity bunch close to the abort gap at the beginning of the **injection** process.
  - Observe cooling while the machine is being filled.
  - Over-inject the cooled bunch with the last injected train before going into the ramp.
- Hardware requires mostly standard installations.
  - Signal processing, filters, cabling, amplifiers,…
  - Pickup already exists and able to be operated in requested mode.
  - Preliminary cavity design already available.
- Highest cost contribution expected from cavity, power amplifier, spectrum and network analysers.

Open Questions

- Operate Schottky pickup in sum mode
  - Signal quality for ions?
  - Microwave background from injection of next train?
- Signal processing:
  - Transversal filter?
- Signal transportation:
  - Dispersion in 2×27km optical cable?
  - Spectral width of signal?
- Can we broaden system bandwidth?
- Detection limit of intensity for beam instrumentation?
  - How low in intensity can we go?

- Cavity design (Filling time, voltage, power amplifier)
  - Excited frequencies must be cut off in cavity beam pipes.

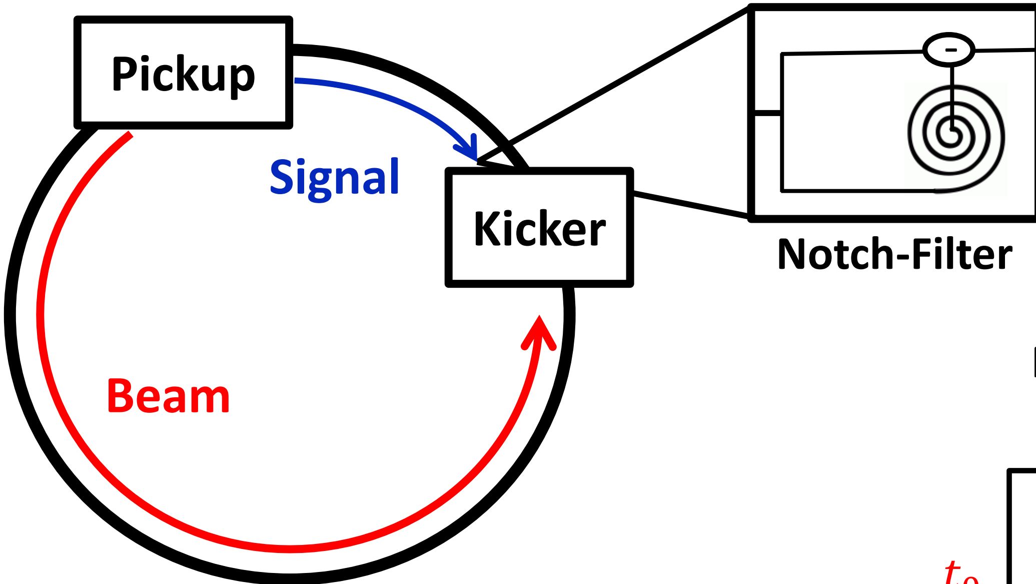
- …

Acknowledgments

- M. Brennen, K. Mernick, S. Verdu Andres (BNL)

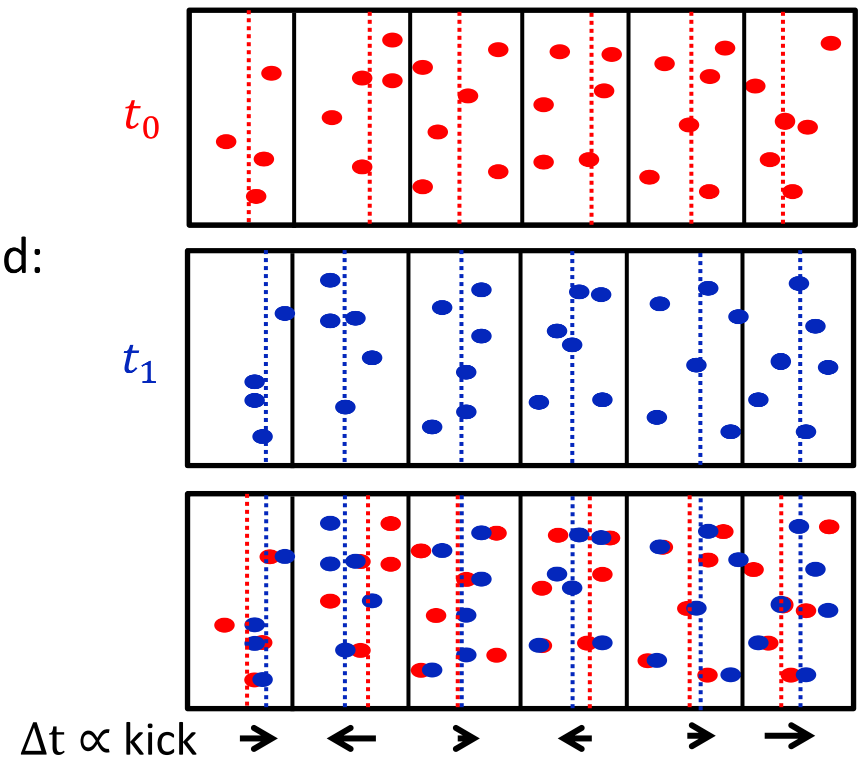
Back-up

Longitudinal Stochastic Cooling Principle



- Particle Position at t_0 (red dots)
- Particle Position at t_1 (blue dots)
- Average of pos. at t_0 (red line)
- Average of pos. at t_1 (blue line)

Measure average arrival time of particle samples



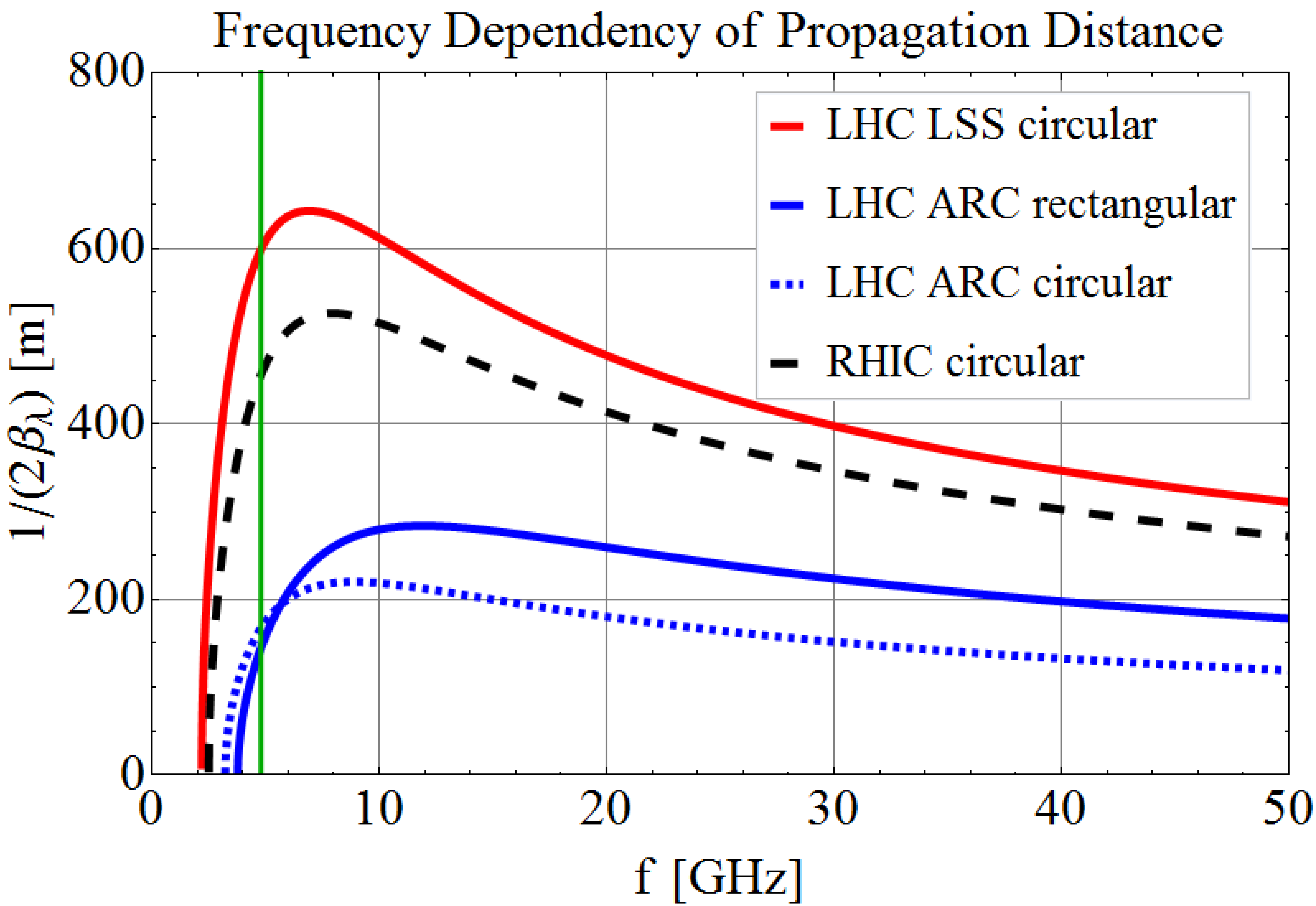
Difference in relative arrival time in consecutive turns due to momentum spread:

$$\Delta t = t_1 - t_0$$

Above transition:

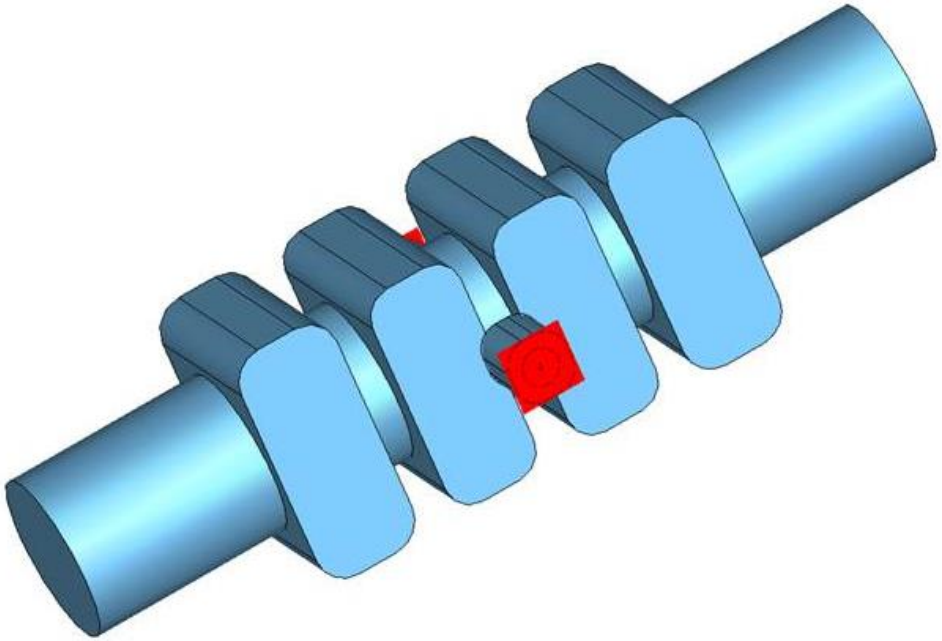
1) $\frac{\Delta p}{p} = 0 \Rightarrow$ requires Kick = 0 $\Rightarrow \Delta t = 0$
2) $\frac{\Delta p}{p} > 0 \Rightarrow$ requires Kick < 0 $\Rightarrow \Delta t < 0$
3) $\frac{\Delta p}{p} < 0 \Rightarrow$ requires Kick > 0 $\Rightarrow \Delta t > 0$

Propagation Distance



First Preliminary Cavity Design

- Resonant freq. = 4.8 GHz
- Kick voltage V = 3 kV (RMS?)
- Power consumption P = 38 W
- filling Time = 111 ns
- loaded Q = 1680
- R/Q = 142 Ohm
- Inner radius r = 20 mm
- Length L = 120 mm
- …



S. Verdu Andres (BNL)

Cooling System Commissioning and Operation

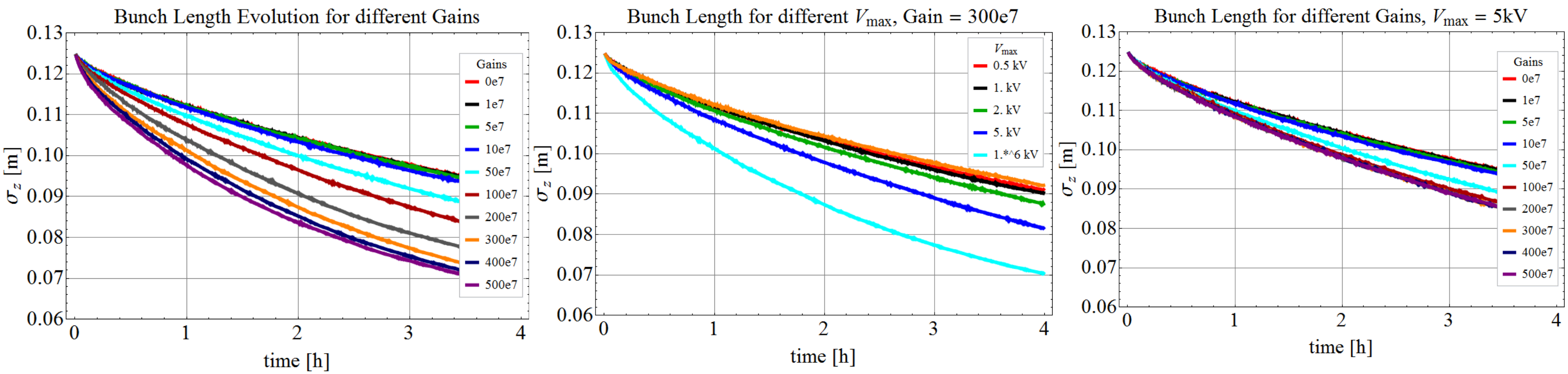
- Measure resonant frequency of the cavity:
  - If necessary adjust by changing temperature with heaters.
  - Could be done without beam.

- Check (beam) positions of pickup and cavity:
  - Beam should be centred in pickup and cavity to achieve best signal, max. kick and avoid beam losses.
  - Move pickup plates as close to the beam as possible to enhance signal.

- Optimise delays and signal positions:
  - Centre revolution line in pickup signal.
  - Adjust 1-turn-delay of Notch-filter to get optimal difference signal (for correct amount and sign of kick).

- Measure reference BTFs and adjust amplitude and phase of the kick with the I/Q modulator.
  - Repeat BTF measurement and adjustment from time to time during the experiment to ensure optimal cooling.
  - Cavity will be not available for cooling during the BTF measurement.

Cooling Simulation at Flat Top



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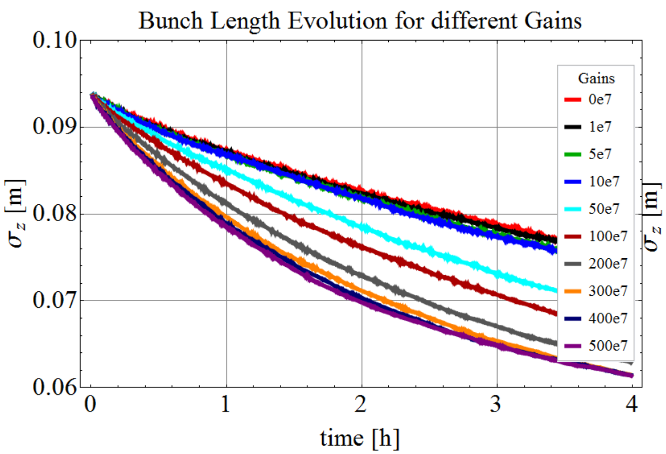
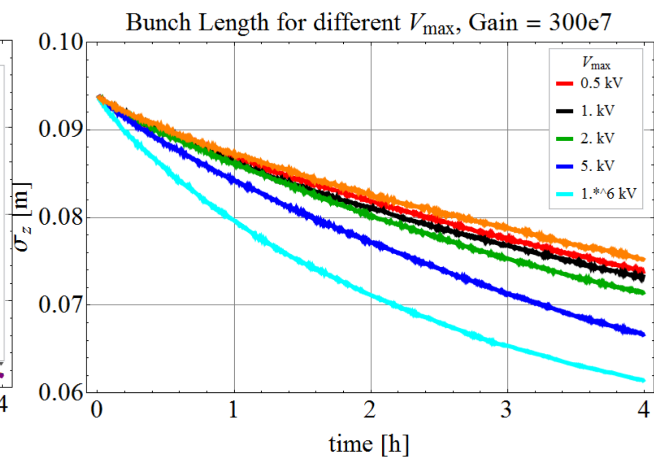
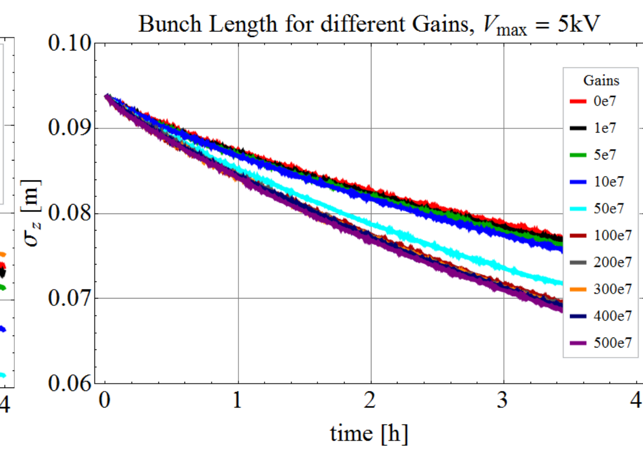
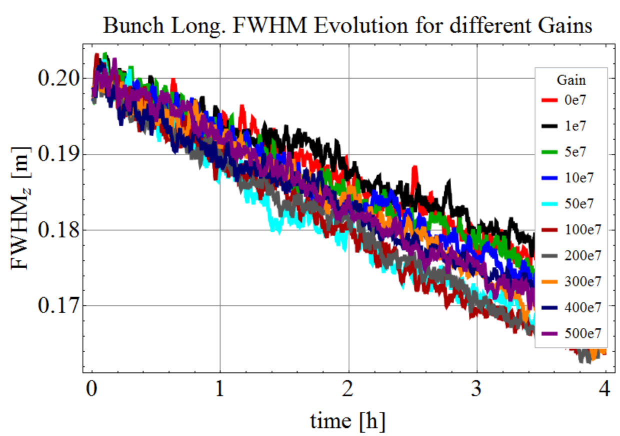
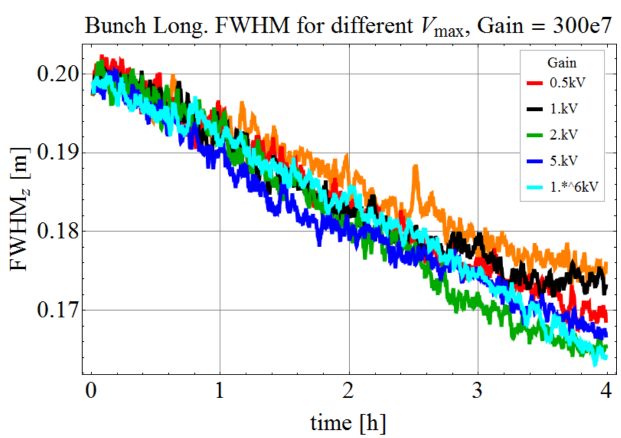
Cooling Simulation Flat Top – short bunches

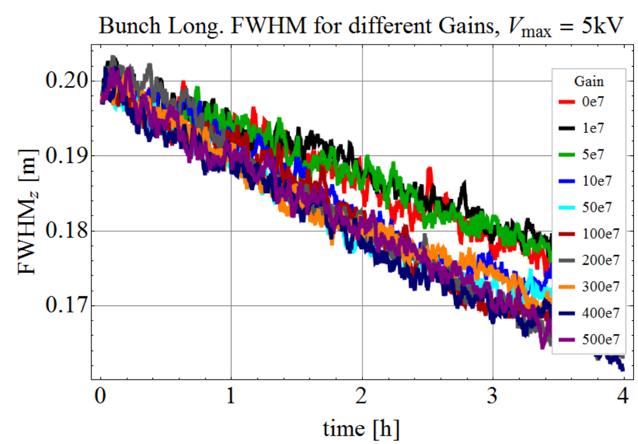




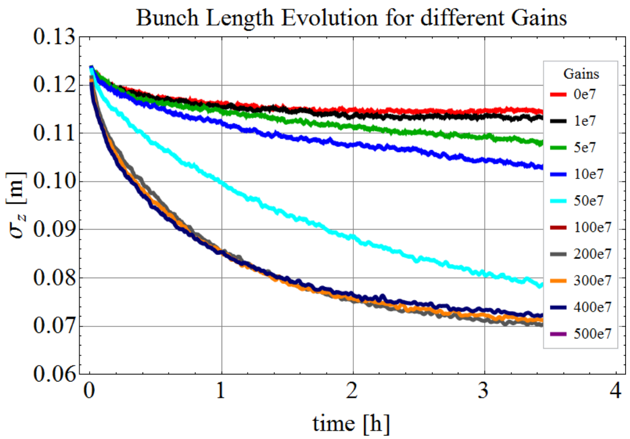


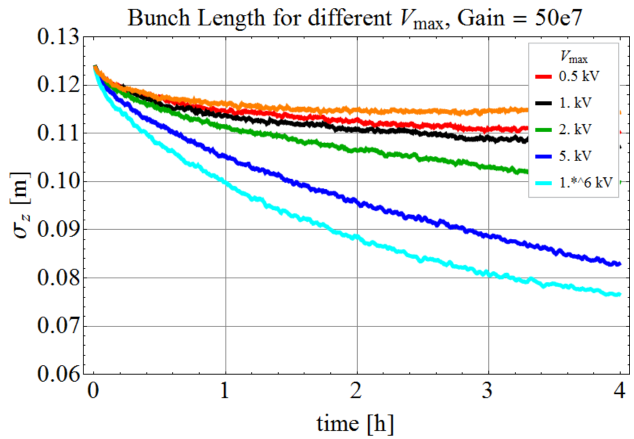


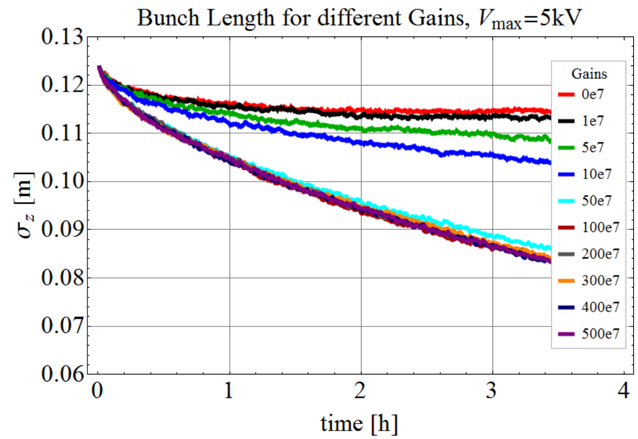




Cooling Simulation at Injection







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