Scintillator tiles with SiPM readout for fast timing in SuperKEKB commissioning

July 19th 2017

Outline

- Reminder: Commissioning Phase I
- Excursion into Particle Injection Physics
- The CLAWS Detector
- Summary and Outlook

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

IMPRS YOUNG SCIENTIST WORKSHOP 2017
SCHLOSS RINGBERG - HENDRIK WINDEL

BEAM **E**XORCISM FOR **A** **ST**ABLE BELLE EXPERIMENT **II**

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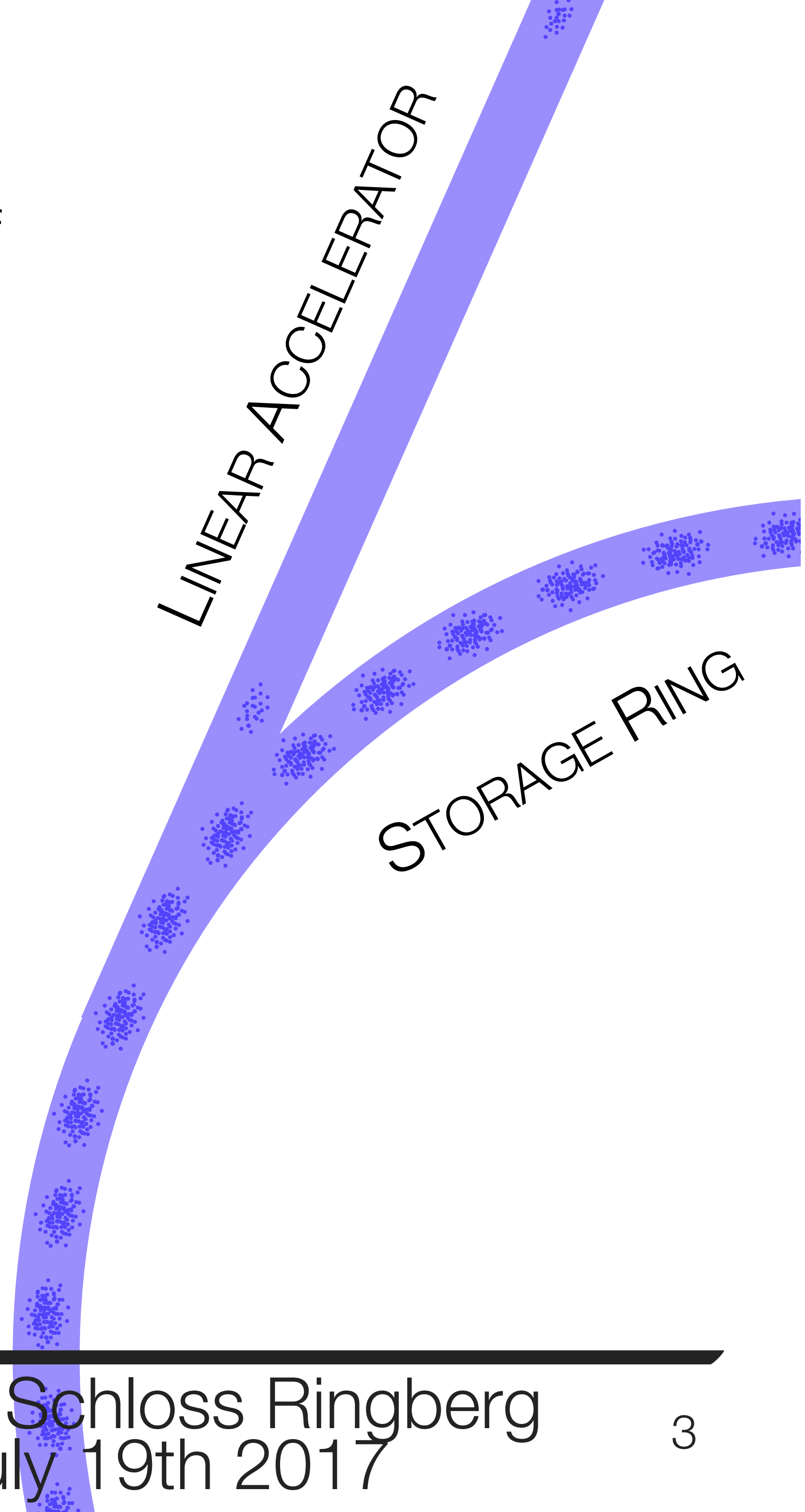
We measure the particle loss of injection bunches.

Why do you inject so often?

To reach the high luminosity, a large beam current is needed. Intra-bunch scattering (Touschek effect~$1/E^3$) results in a low beam life time of ~10min.



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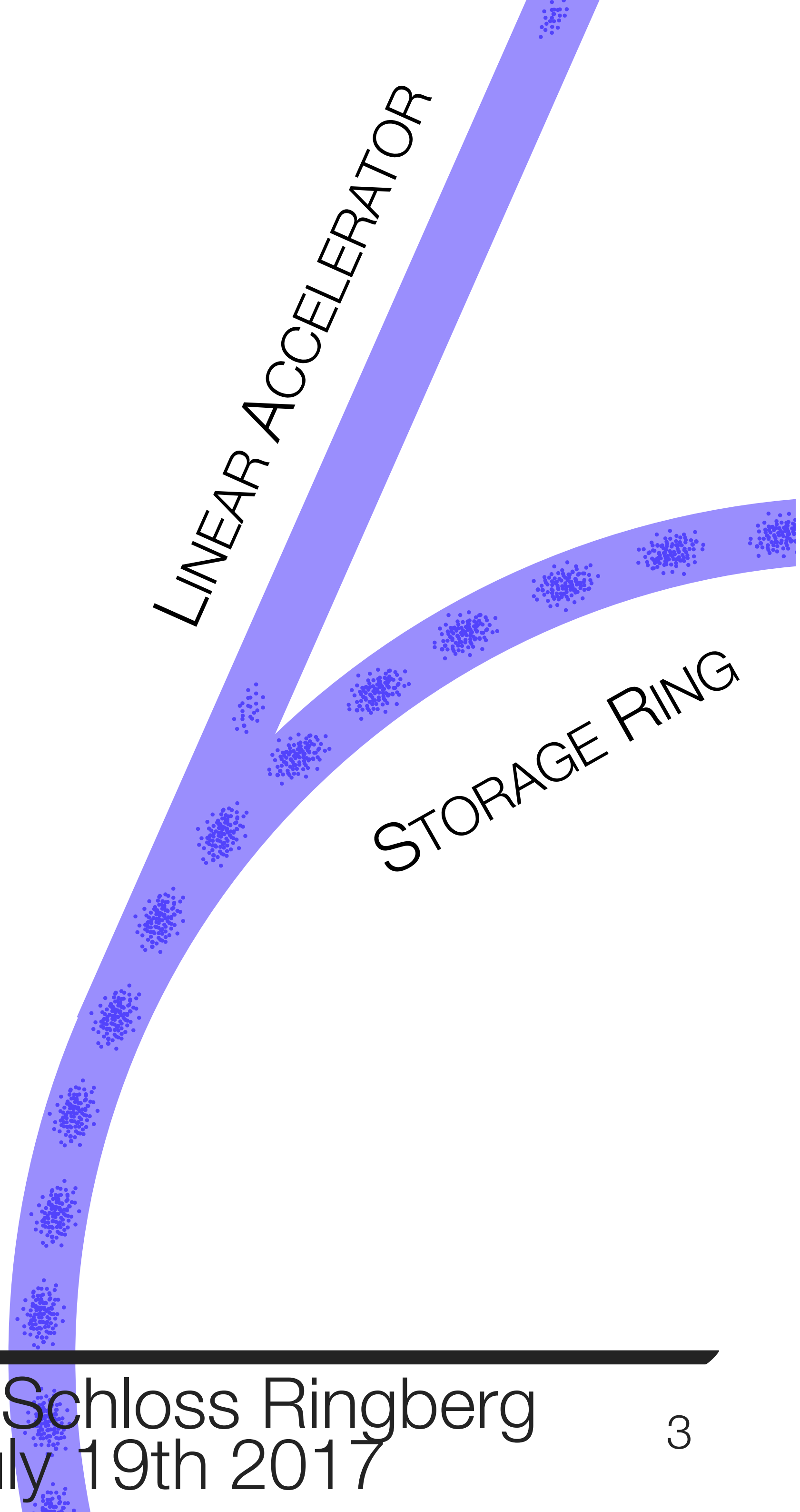
Continuous Top Up Injection Scheme

➡ frequently inject small amounts of beam to replace loss



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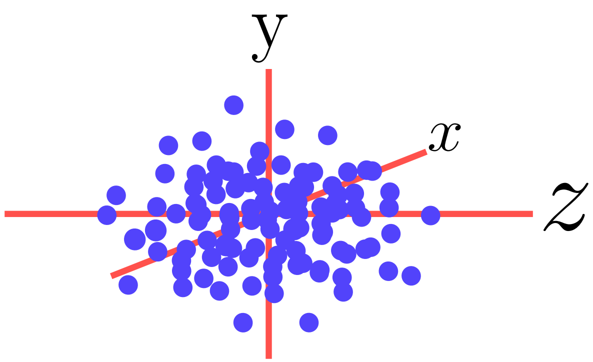
Bunch Properties in a Beam



x: bending plane
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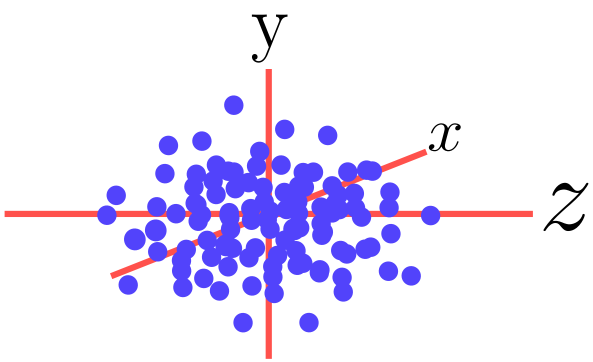

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A SuperKEKB Bunch in Numbers

- bunch length: 5.0 to 6.0 mm
- σ_x = 10 µm, σ_y = 59 nm (at IP)
- 10^{11} electrons per bunch
- 2500 bunches per ring

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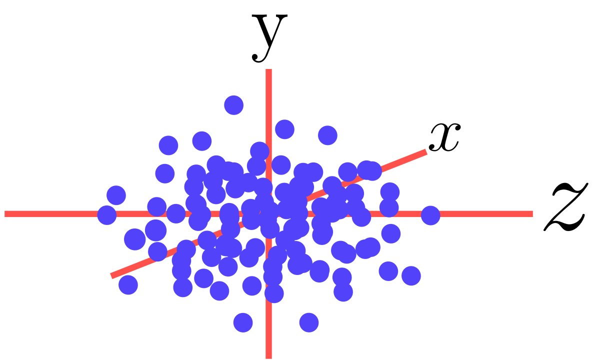

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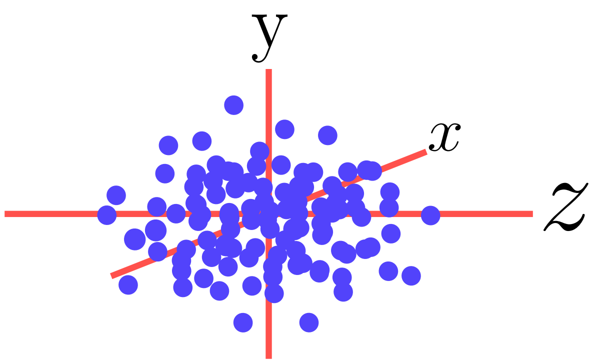

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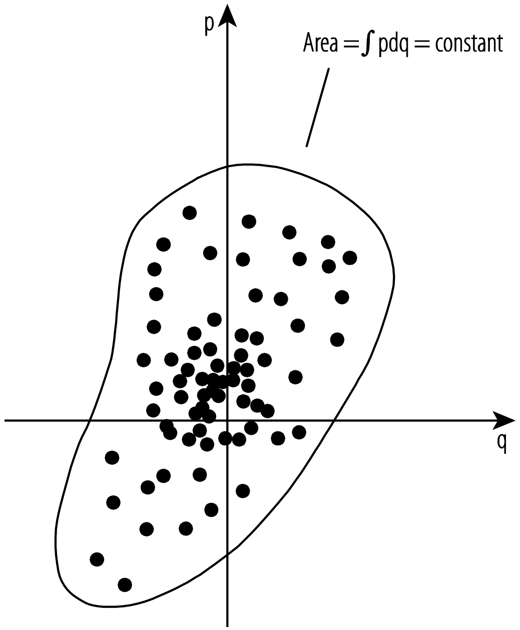

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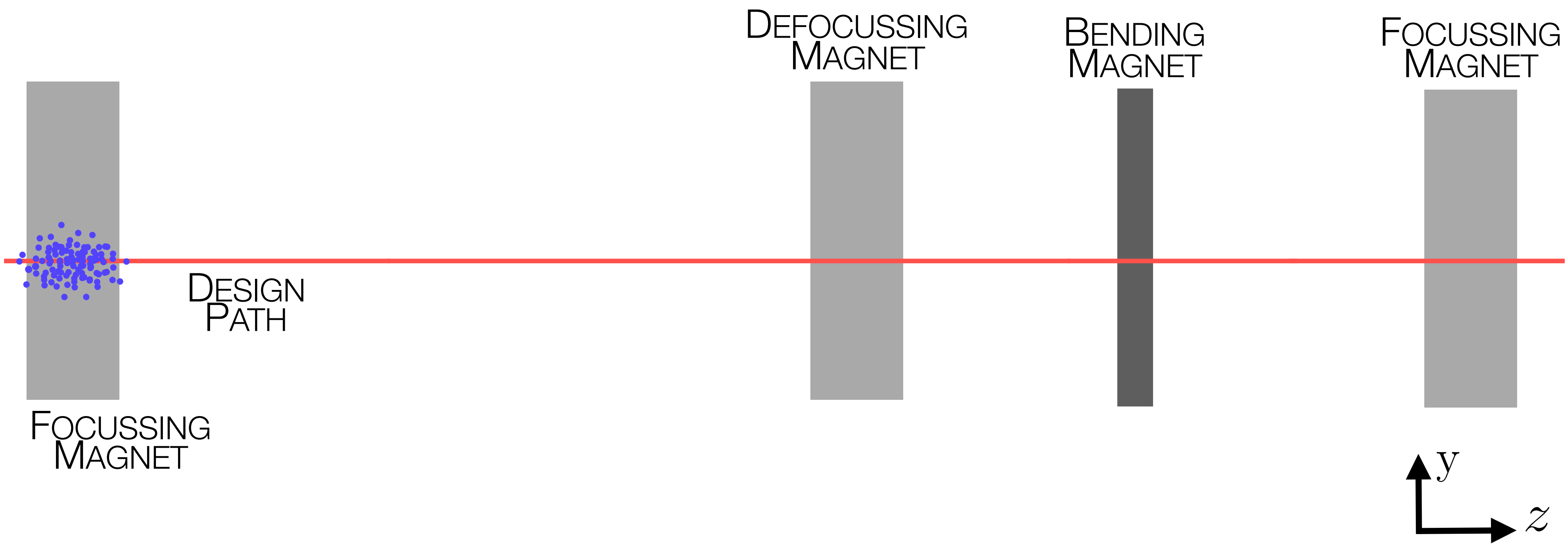

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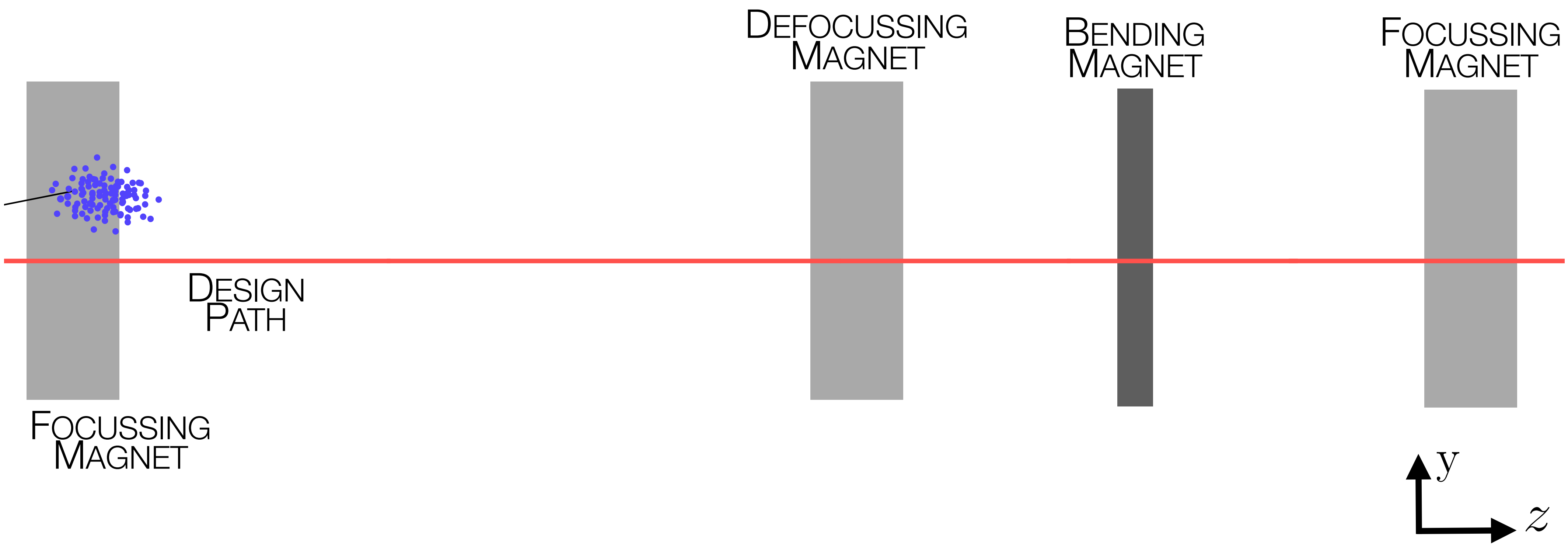

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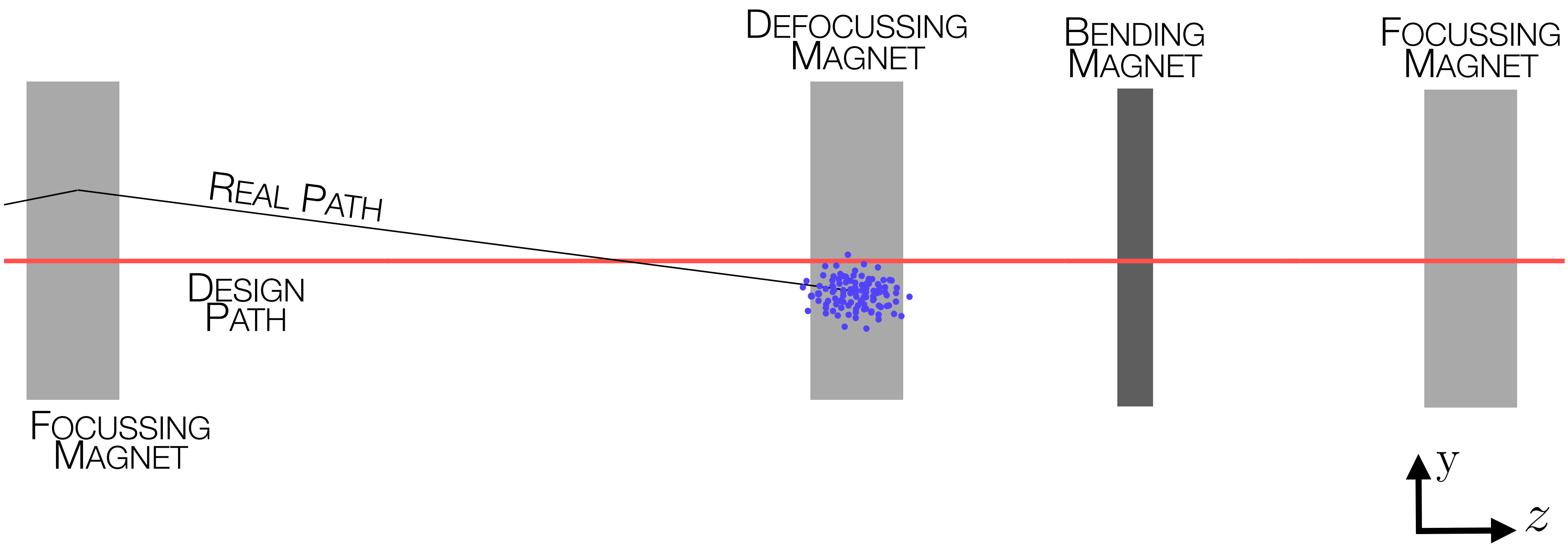

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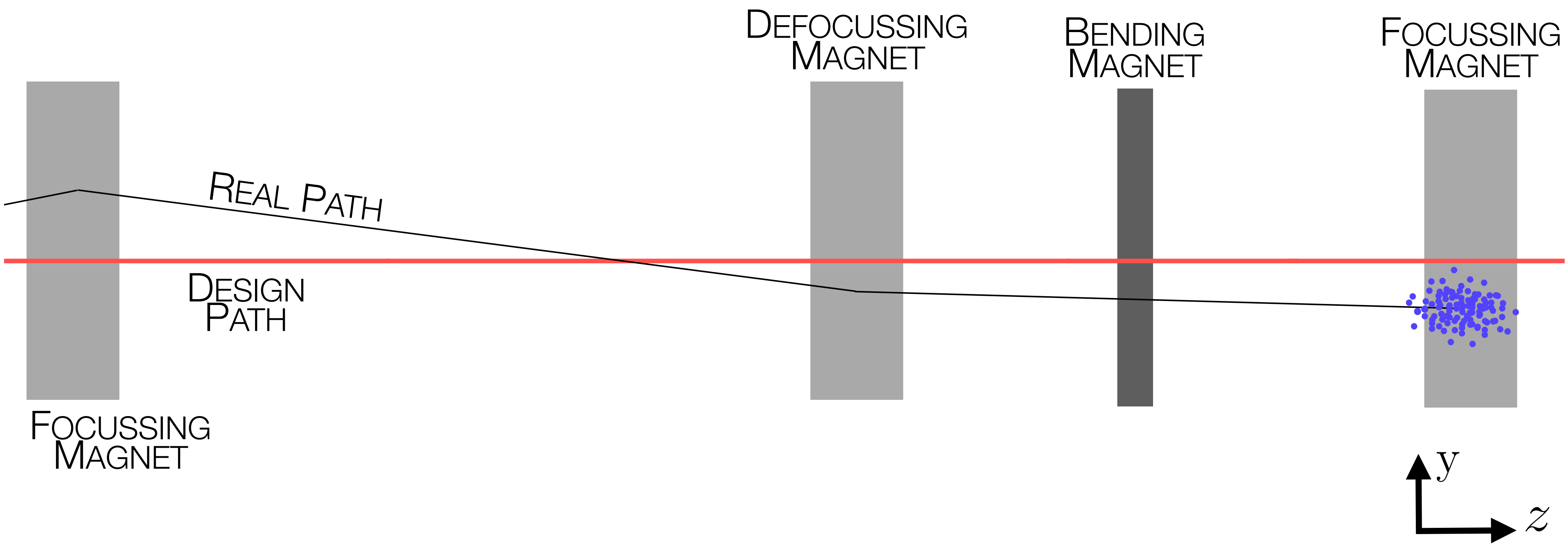

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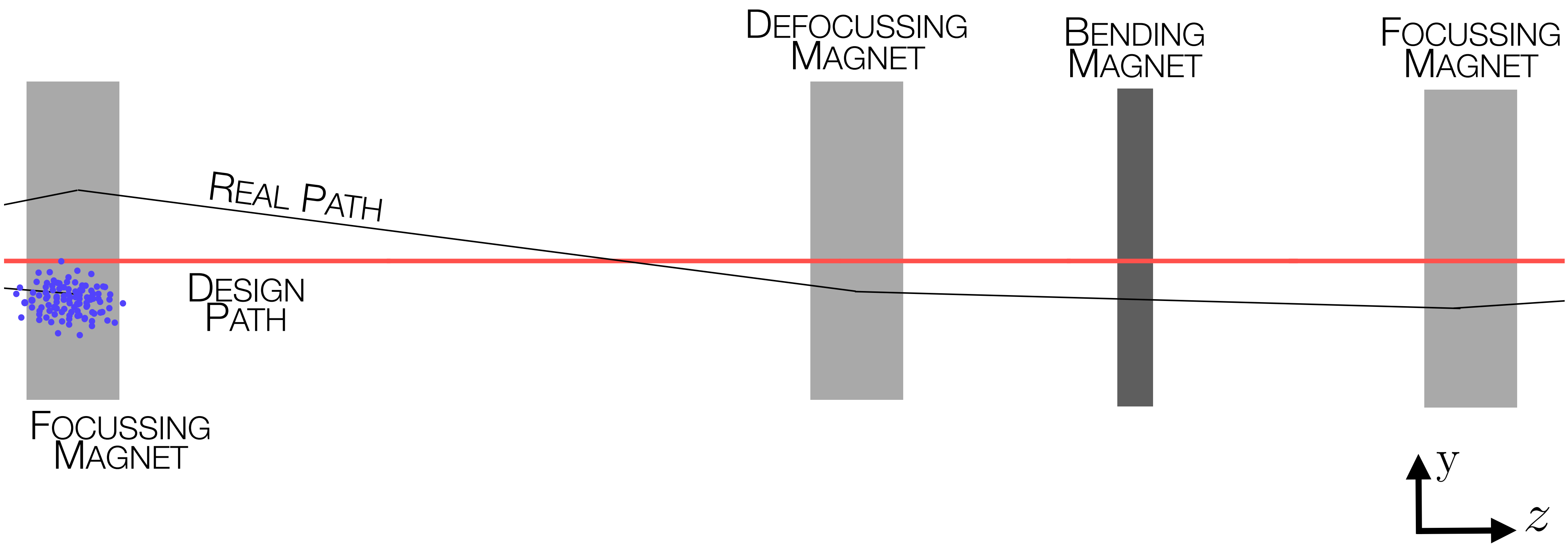

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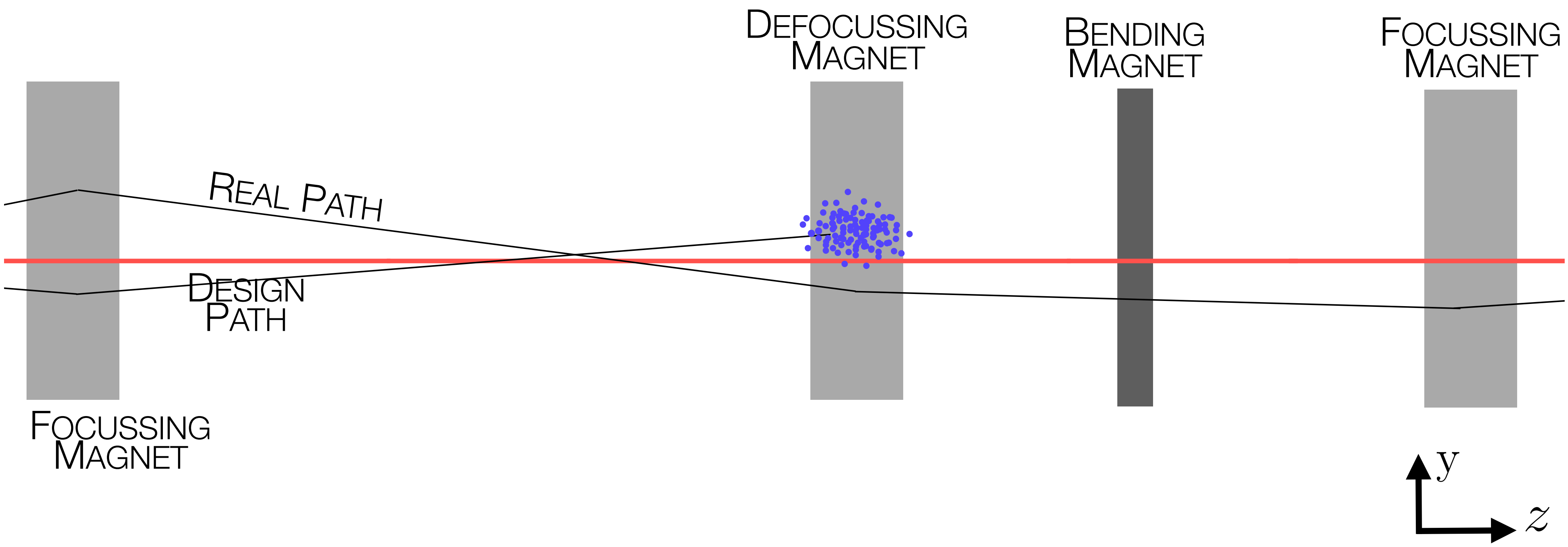

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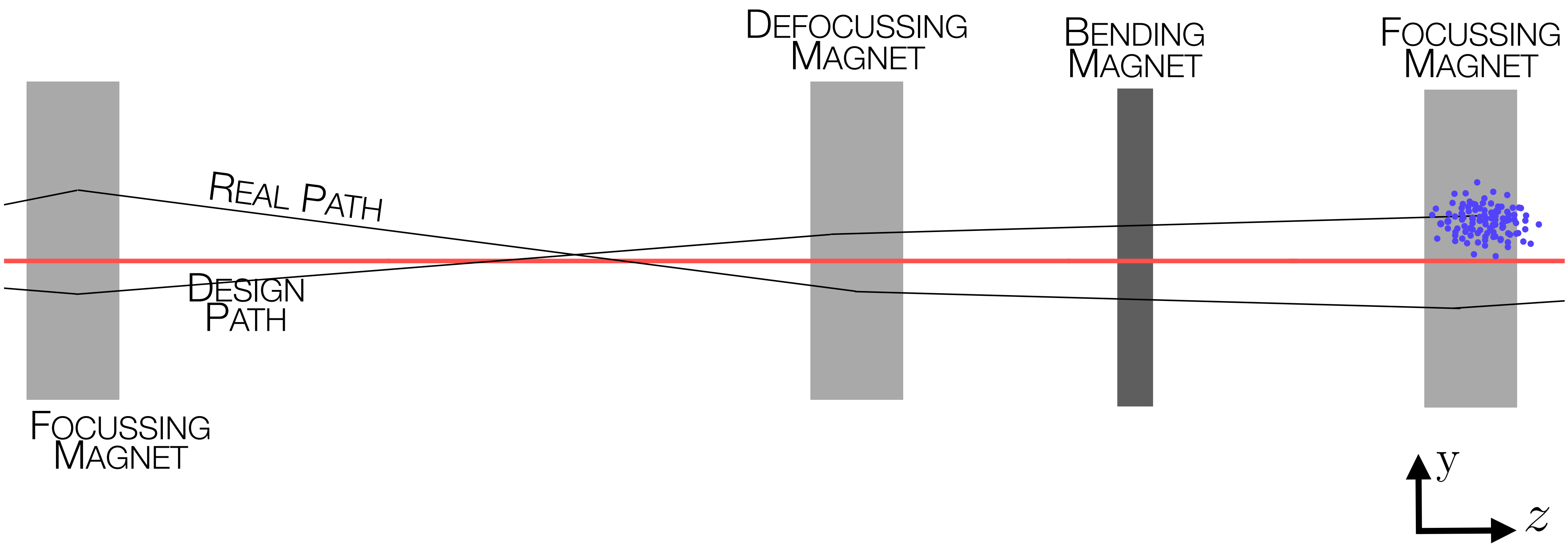

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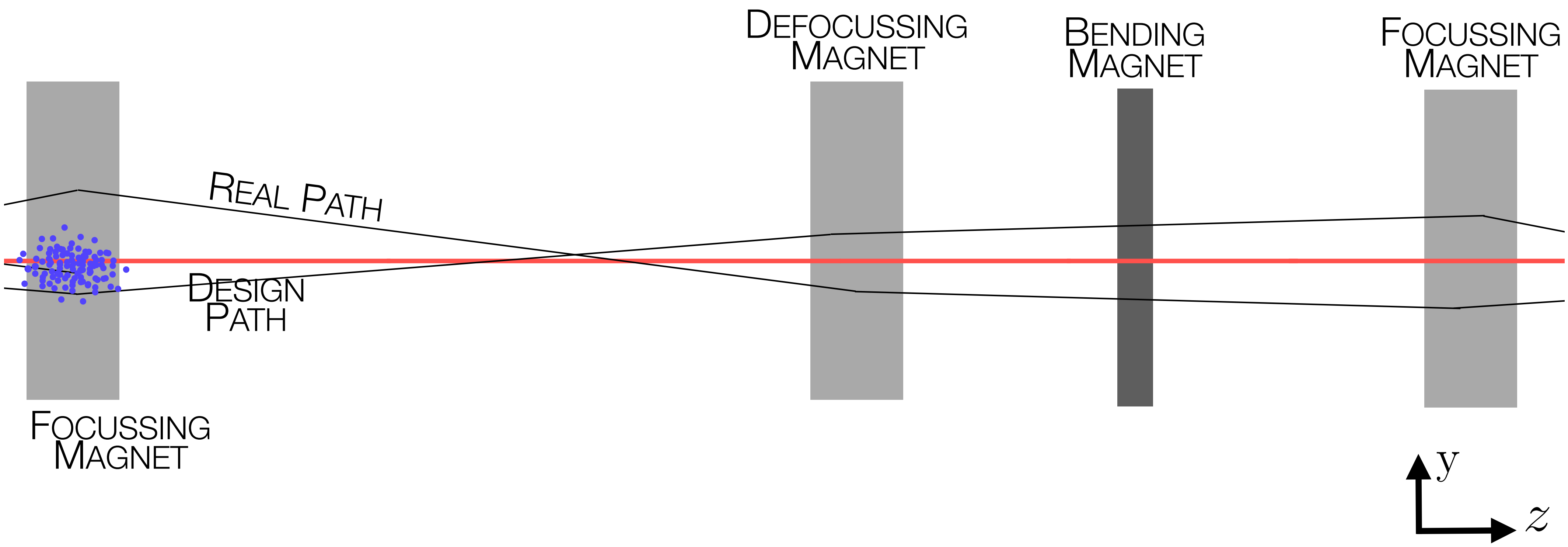

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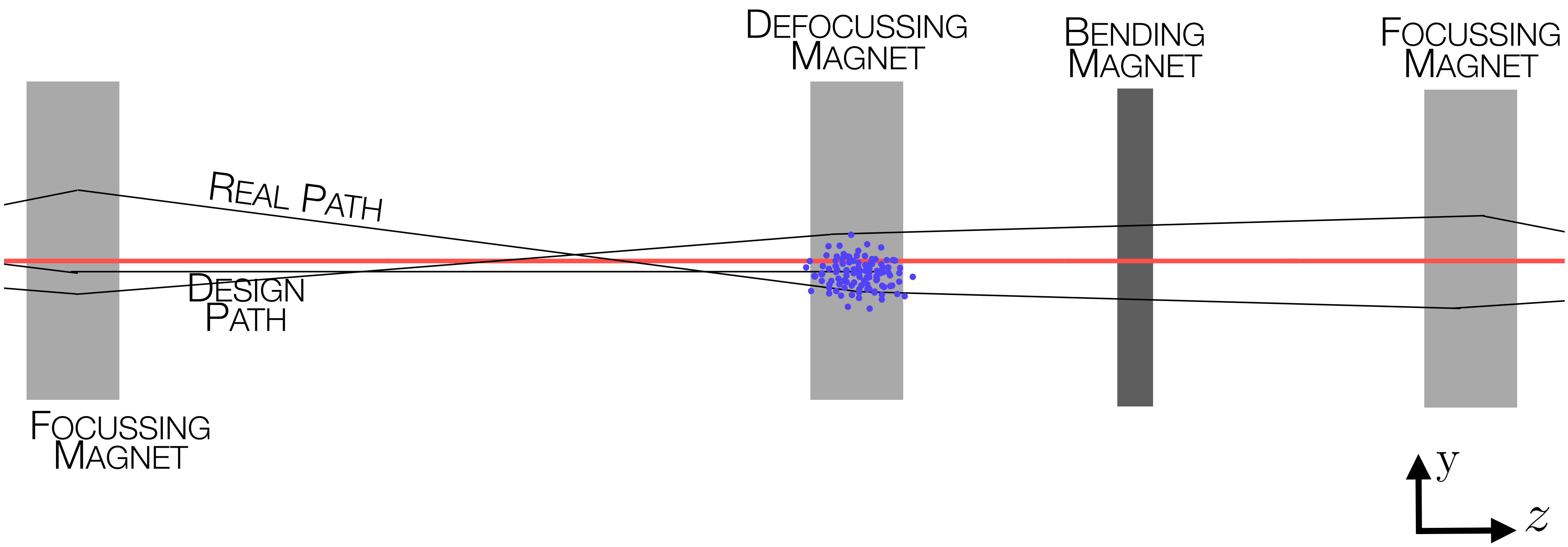

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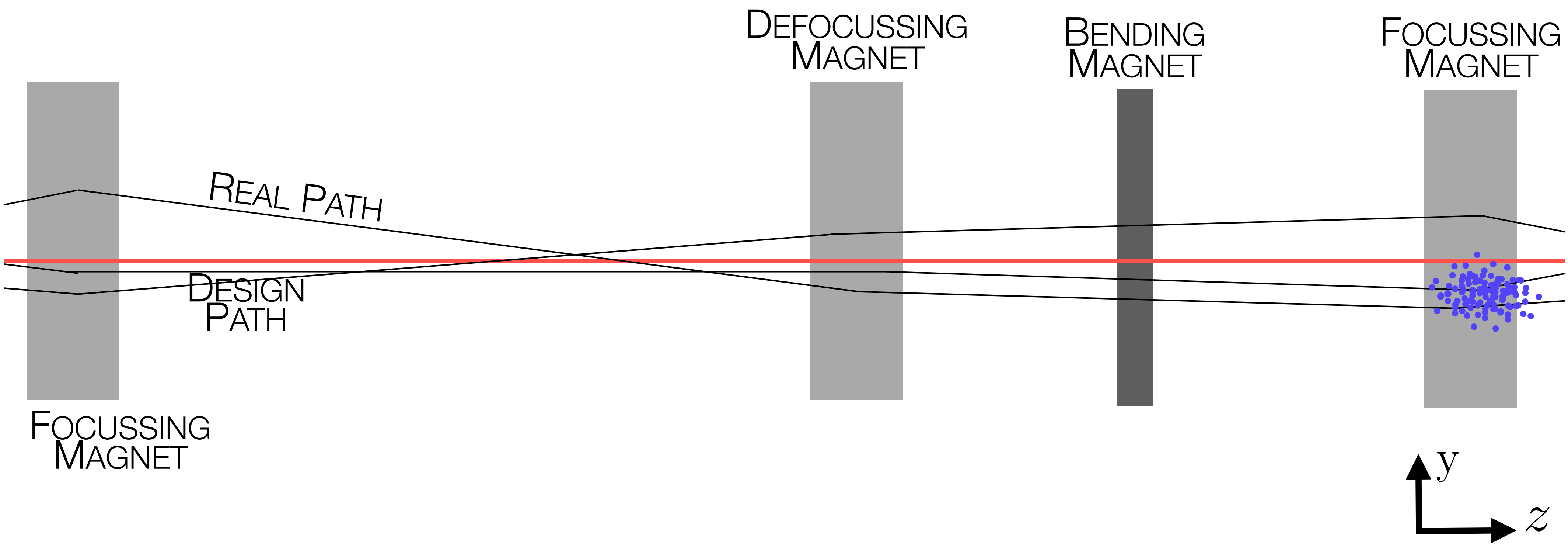

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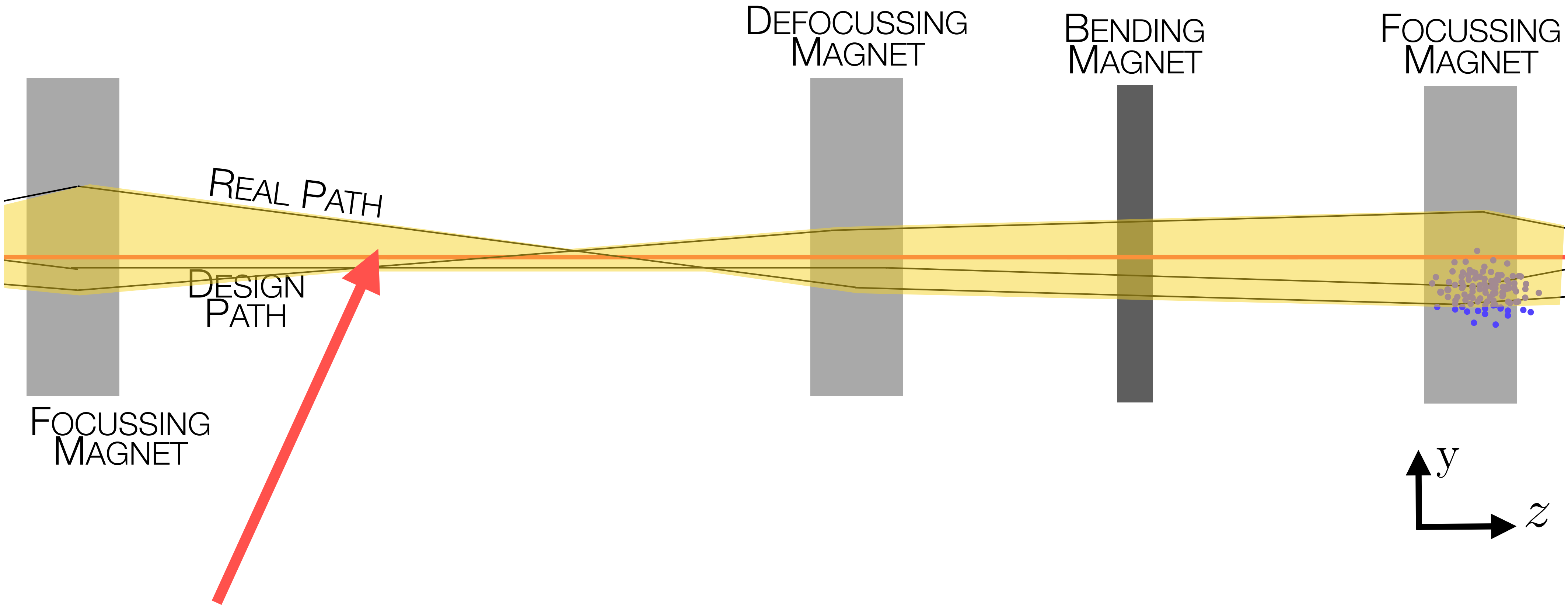


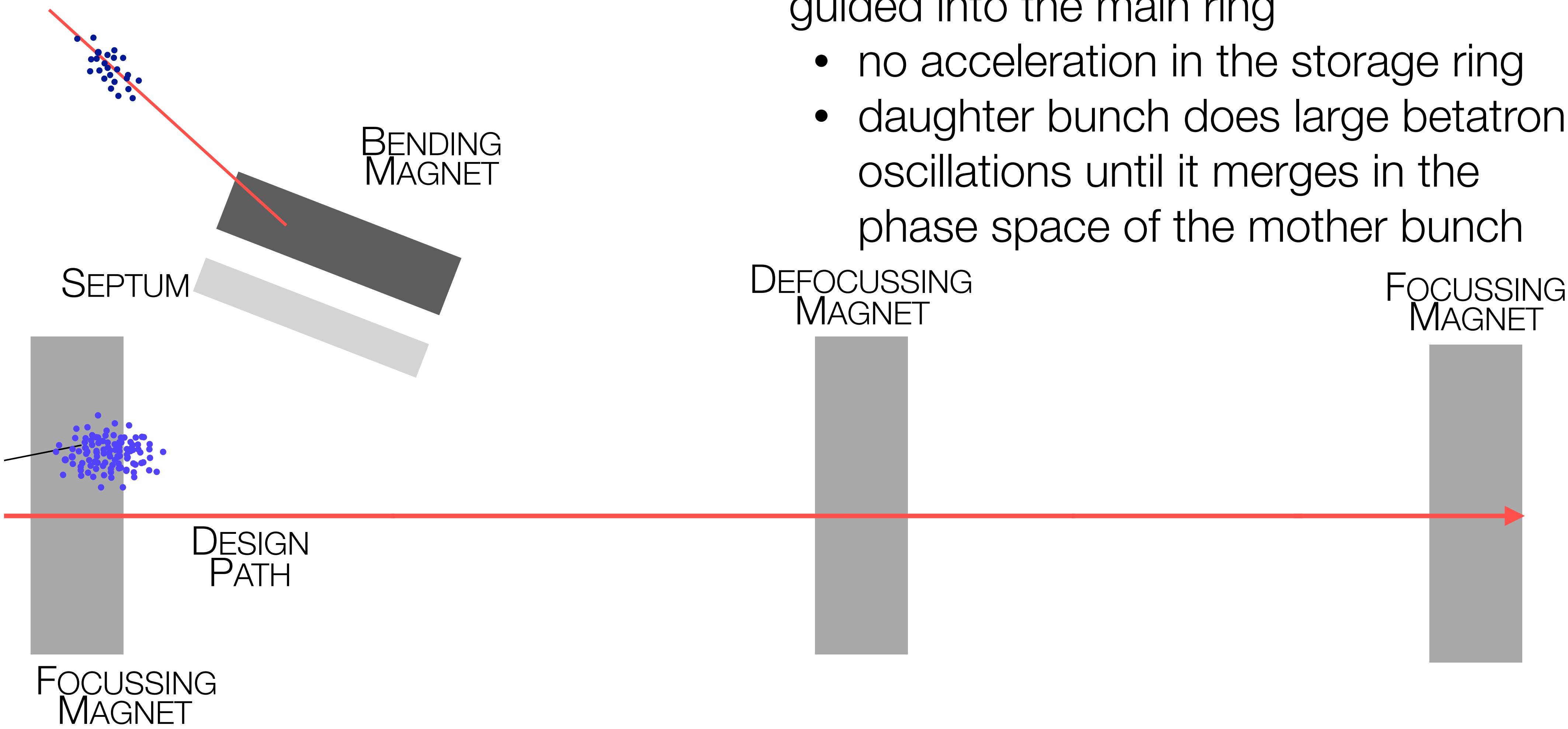
$\beta(z)$ beta function of the beam

- particles oscillate within this envelope around their design path

➡ **betatron oscillation**

Top Up Injection

- daughter bunch with **full energy** is guided into the main ring
  - no acceleration in the storage ring
  - daughter bunch does large betatron oscillations until it merges in the phase space of the mother bunch



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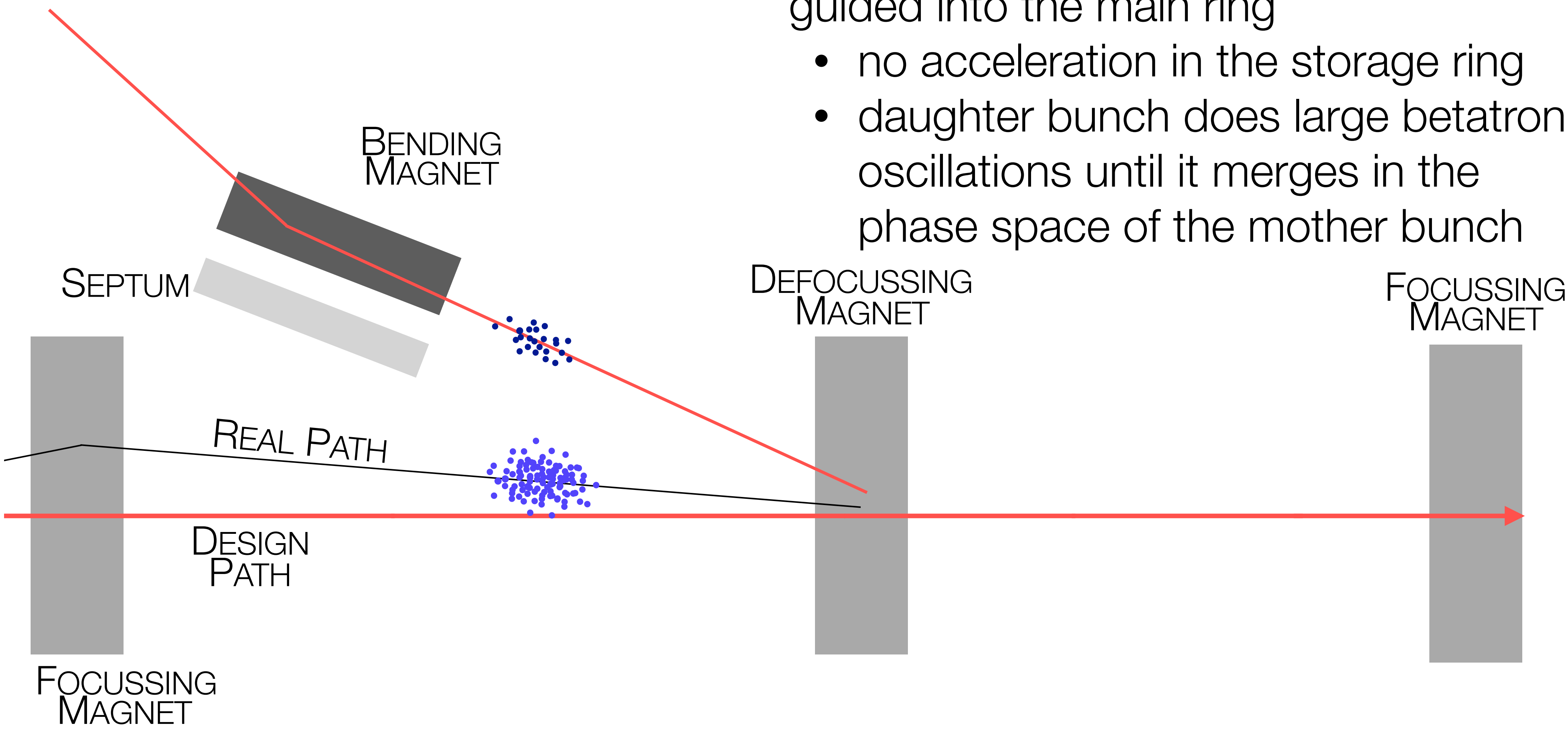

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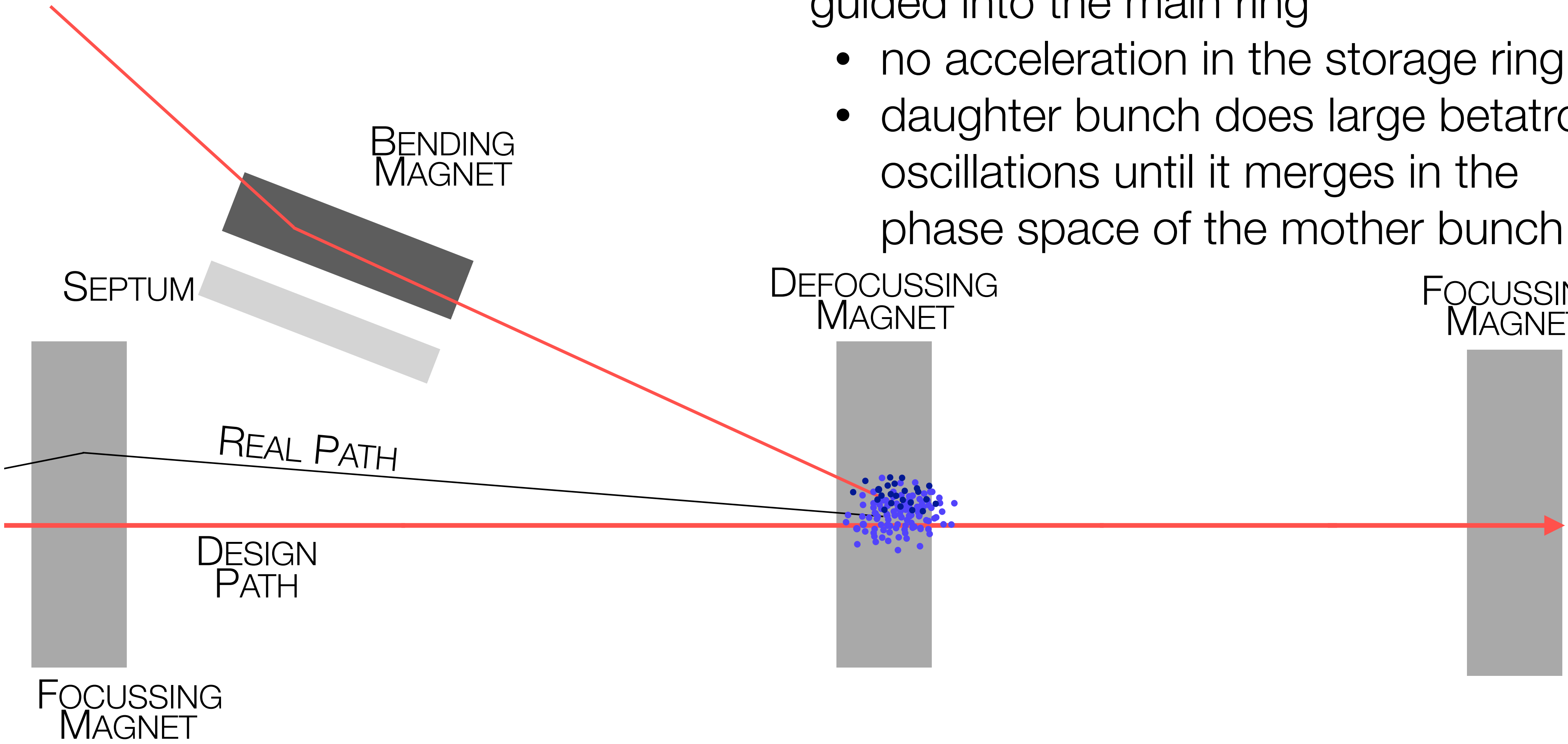

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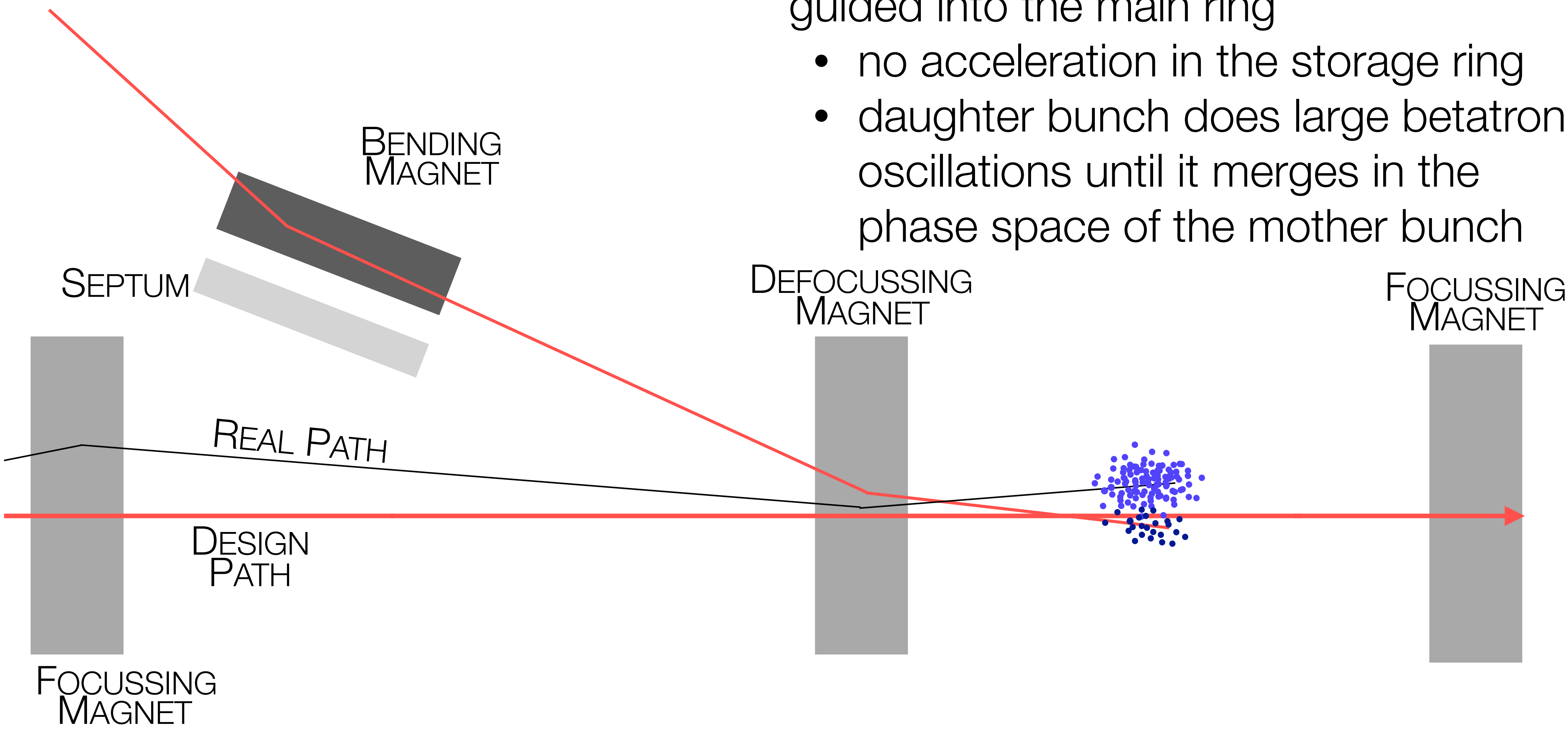

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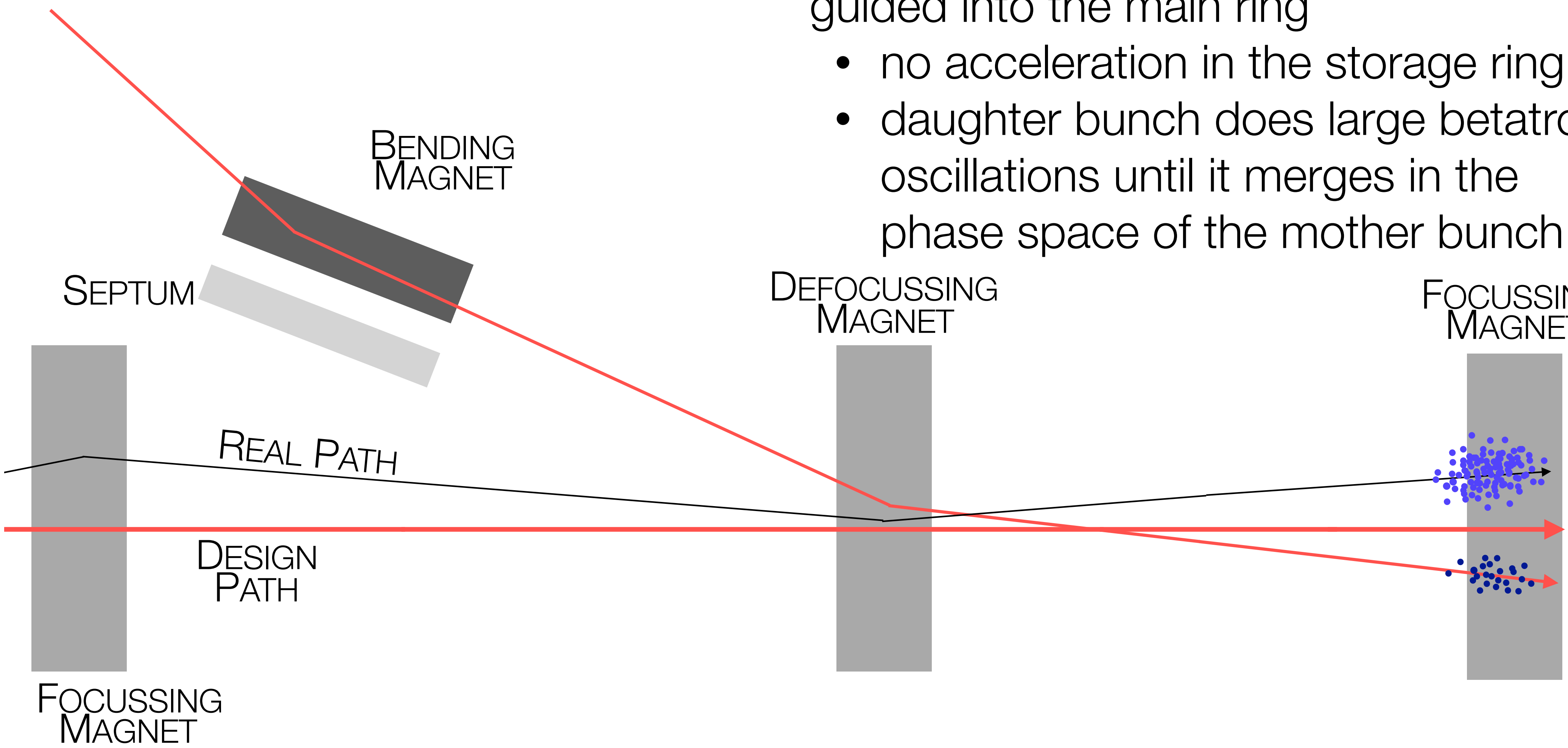

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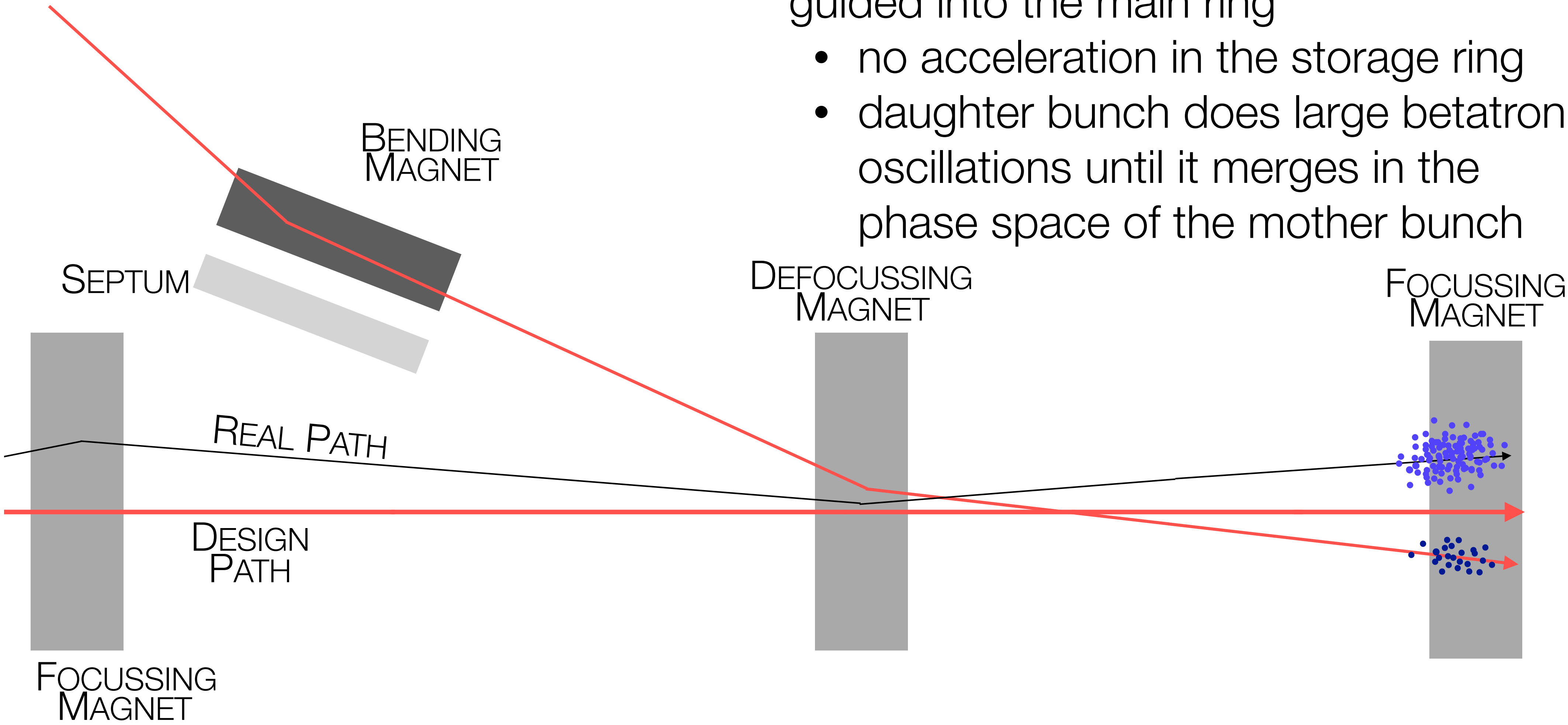

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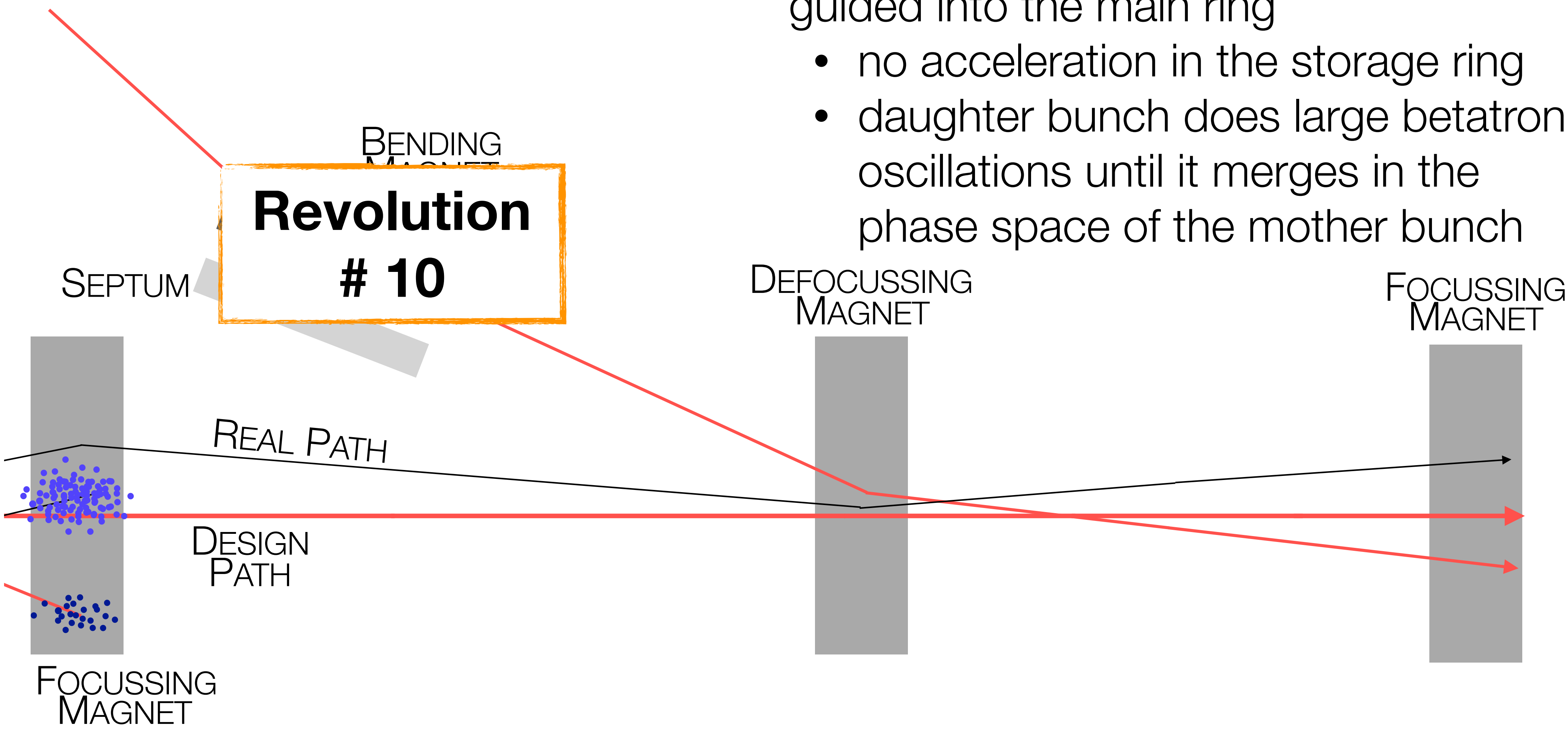

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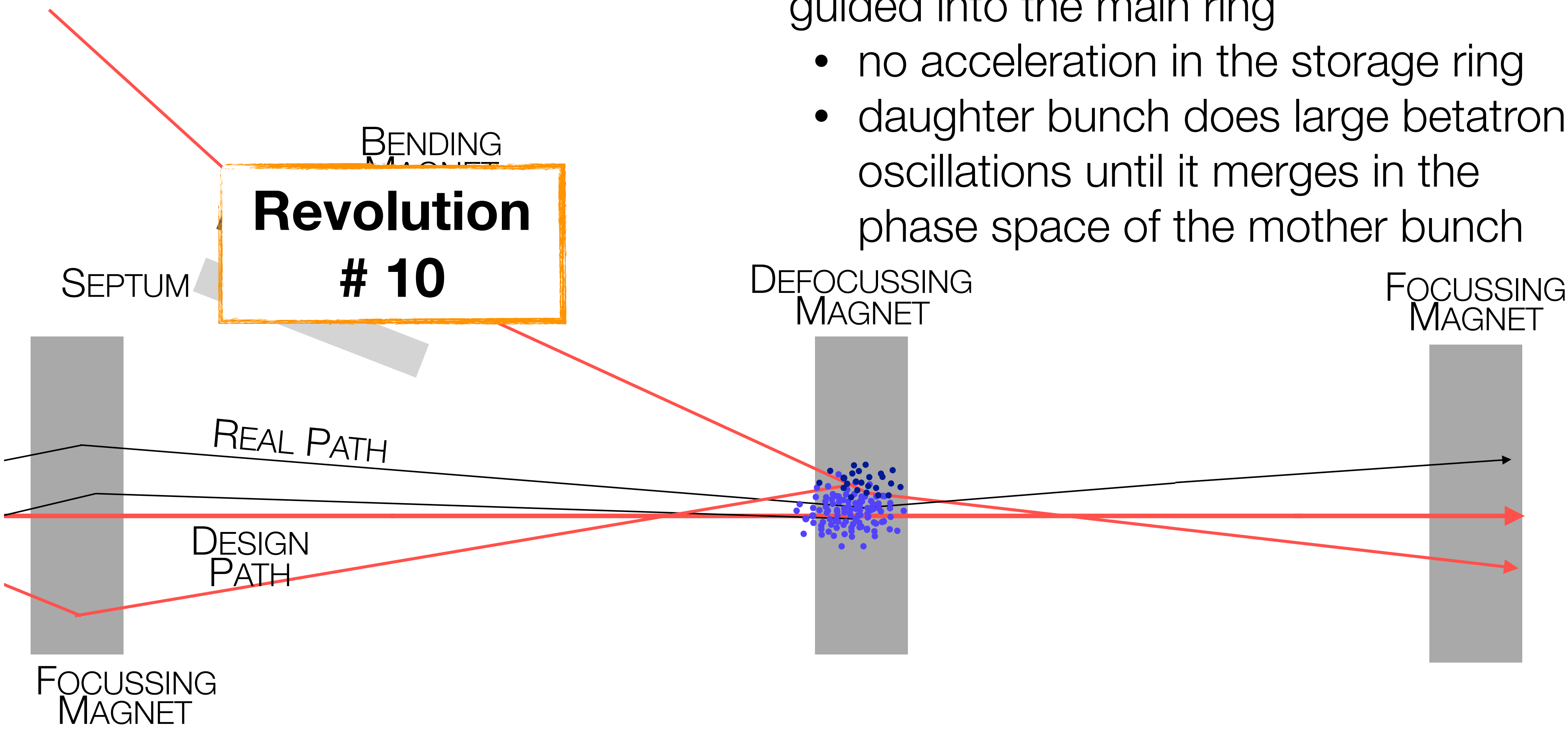

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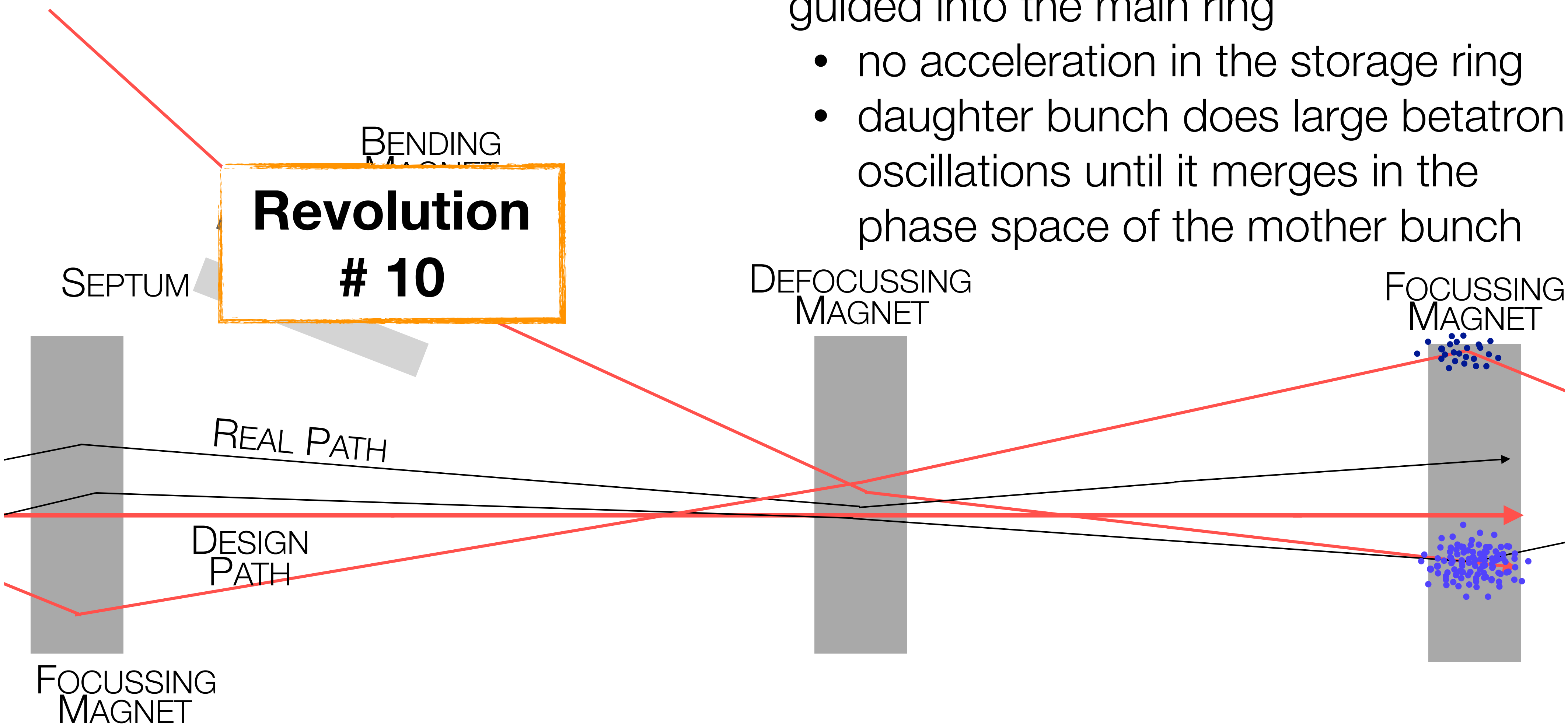

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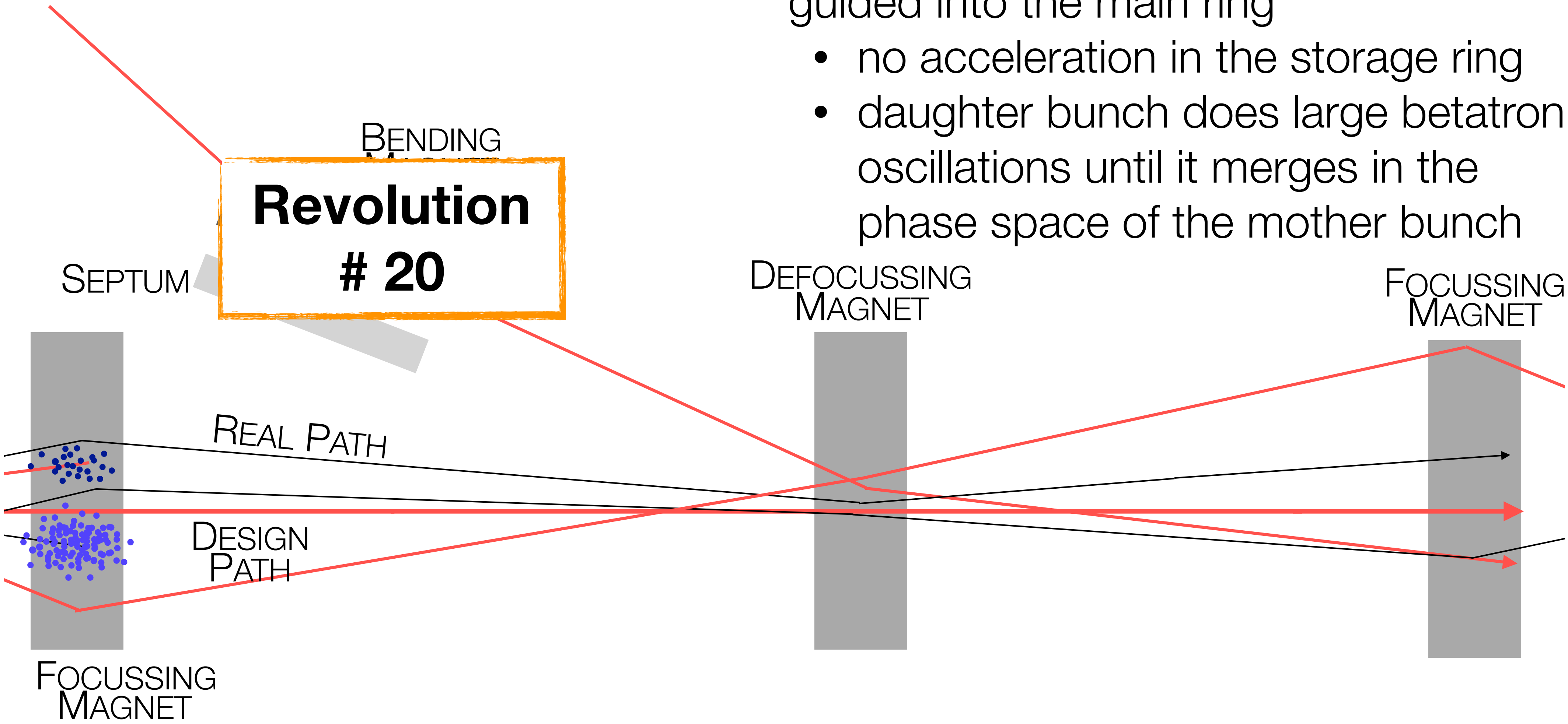

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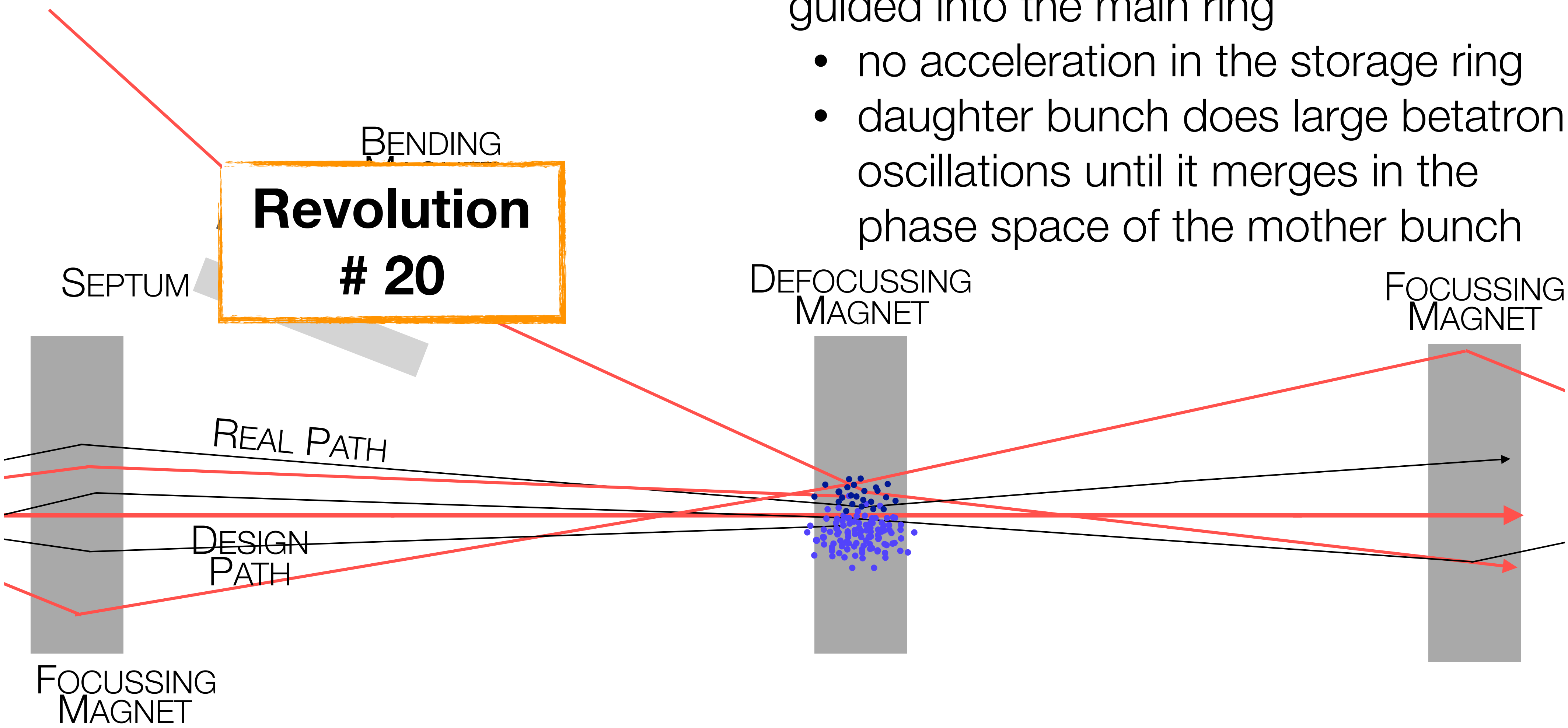

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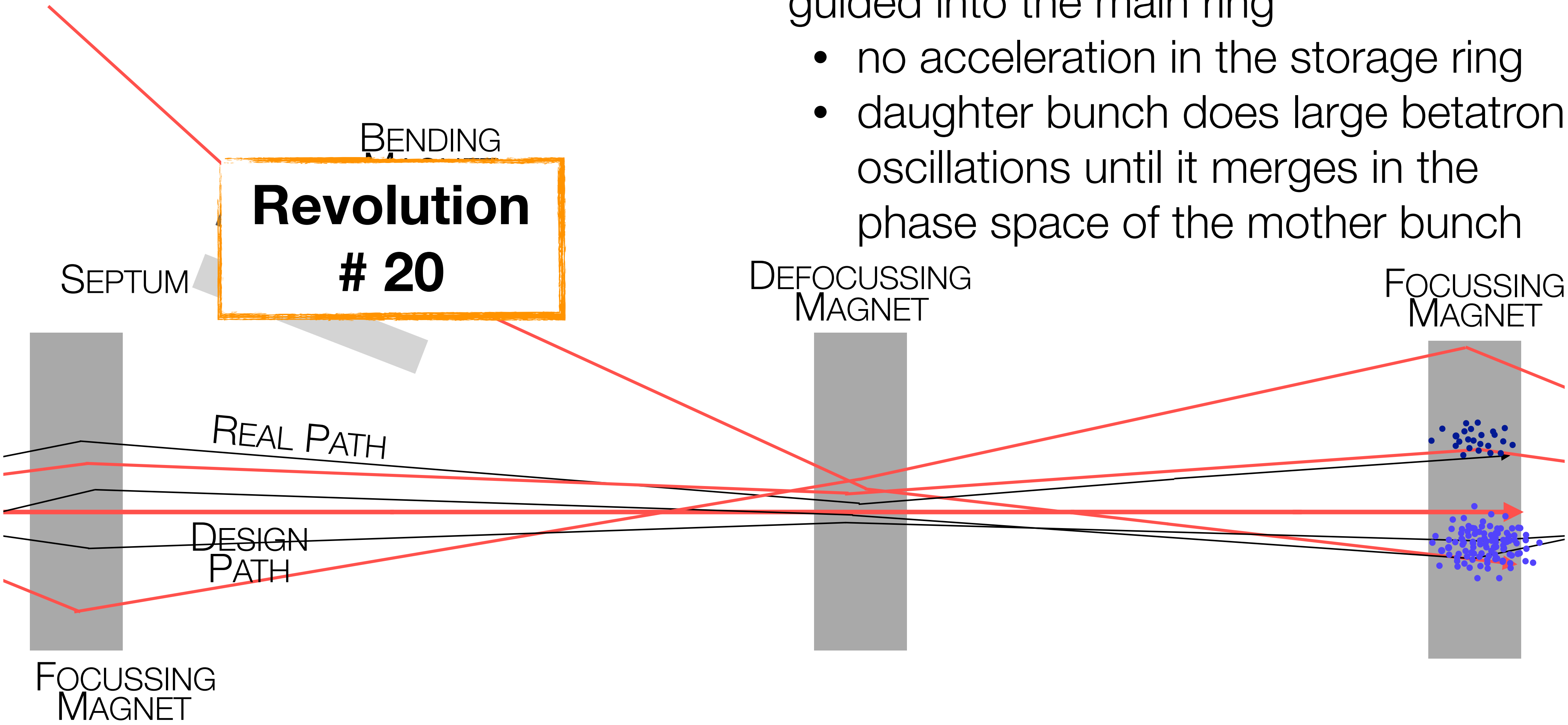

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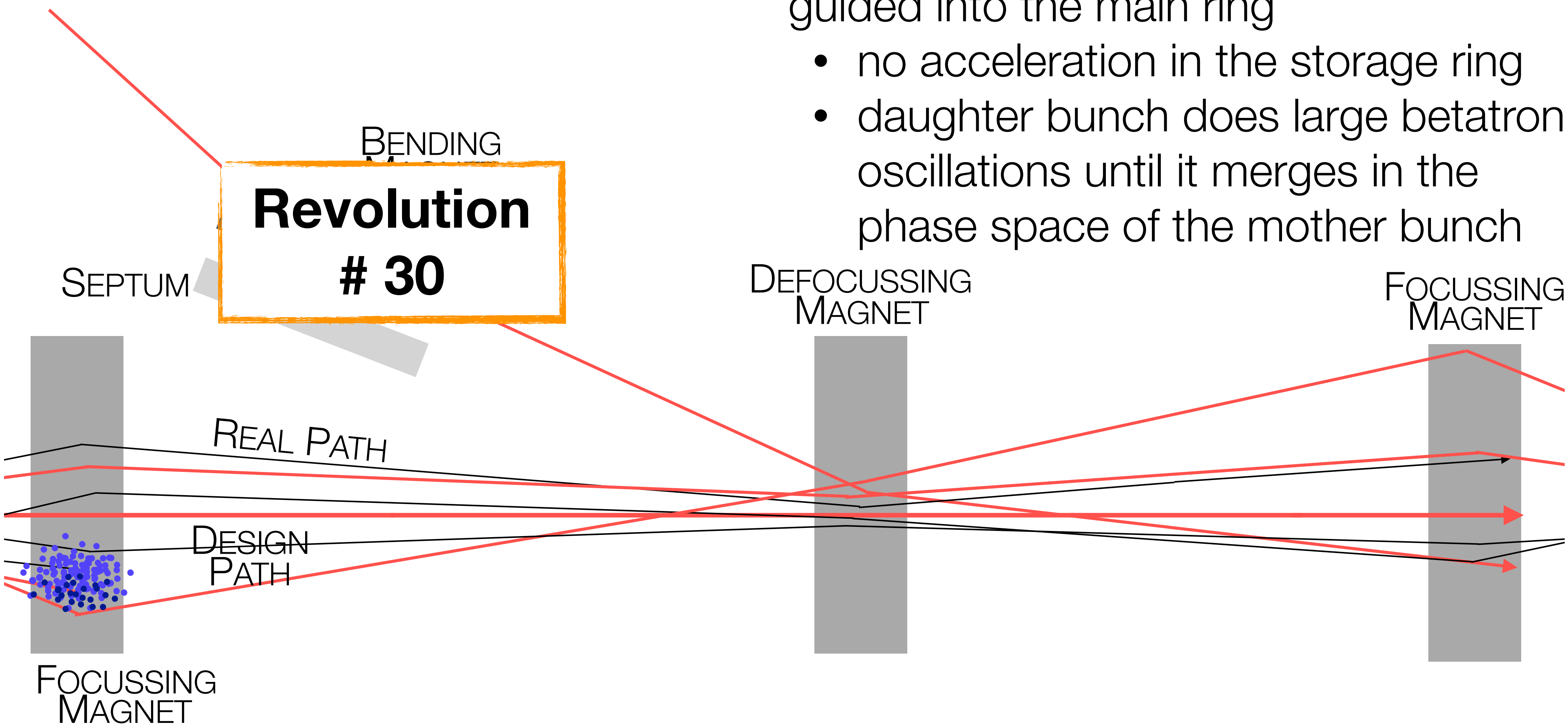

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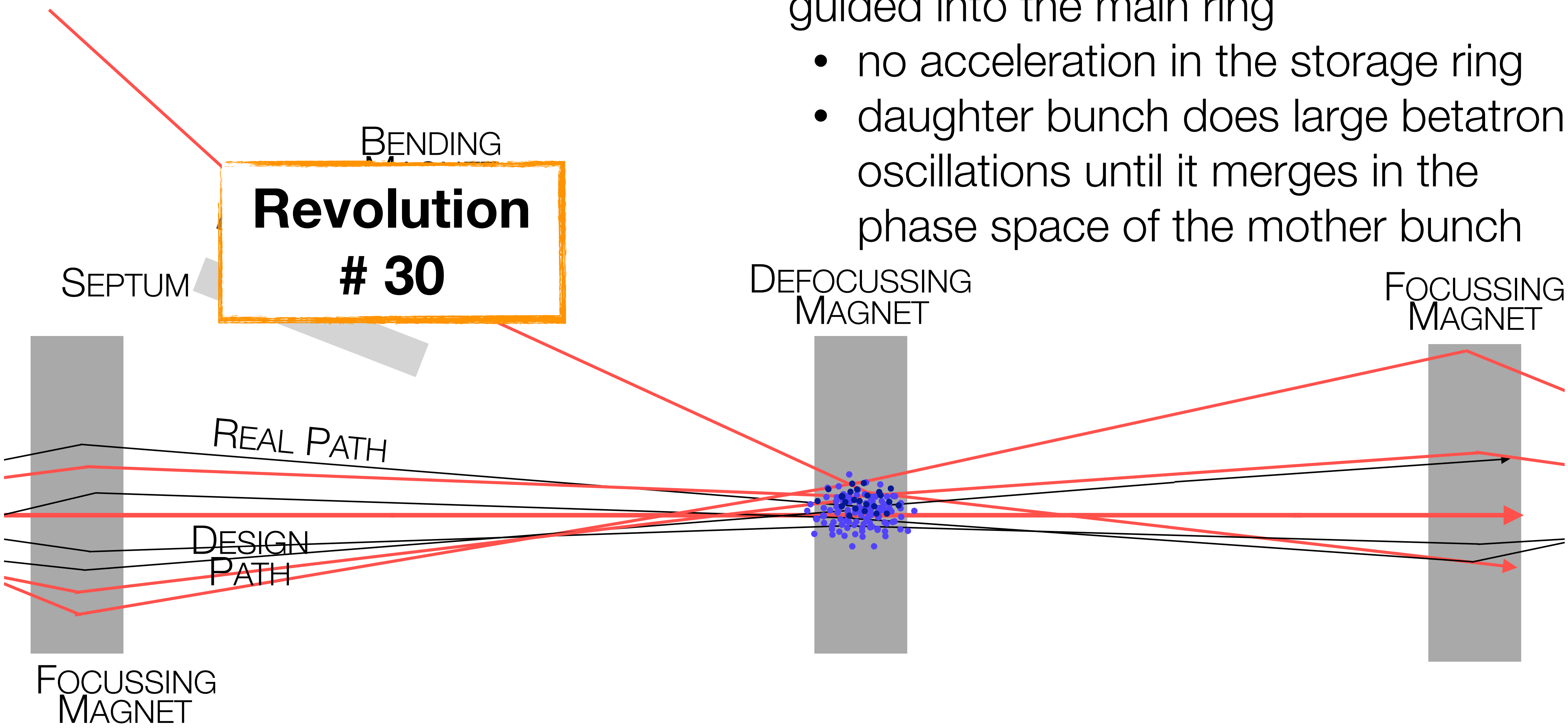

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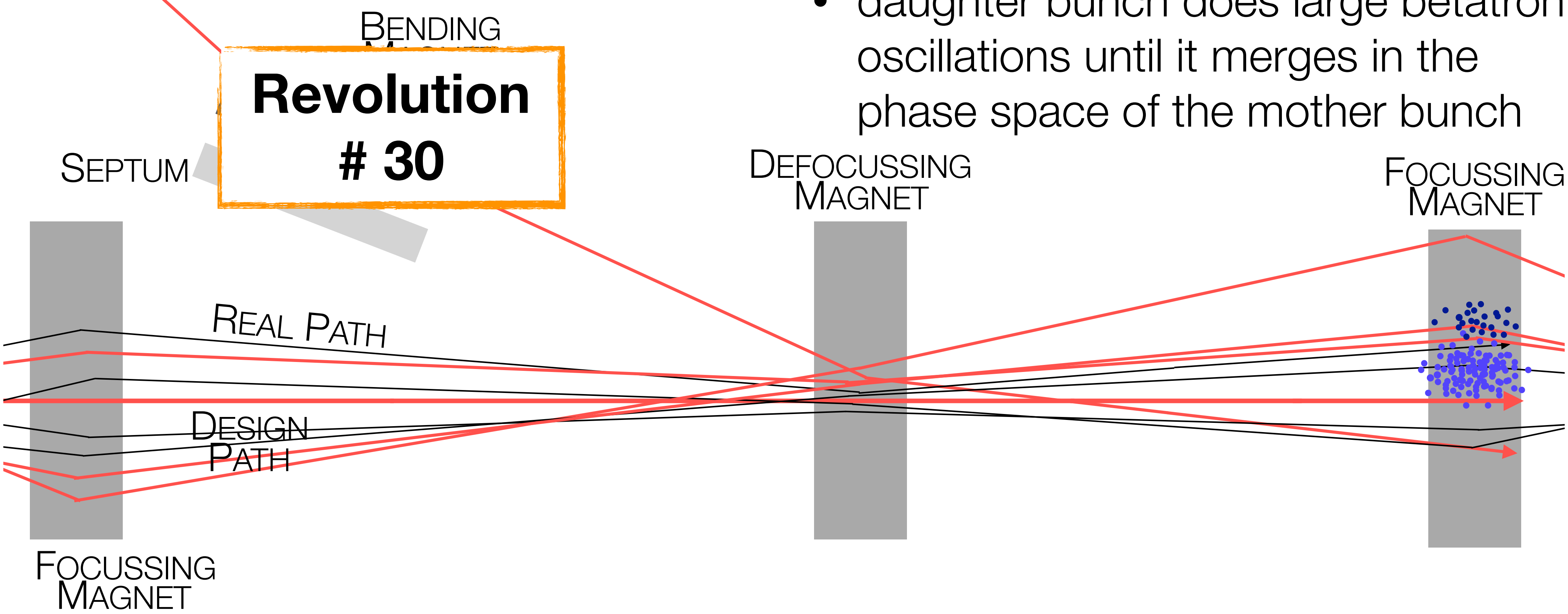

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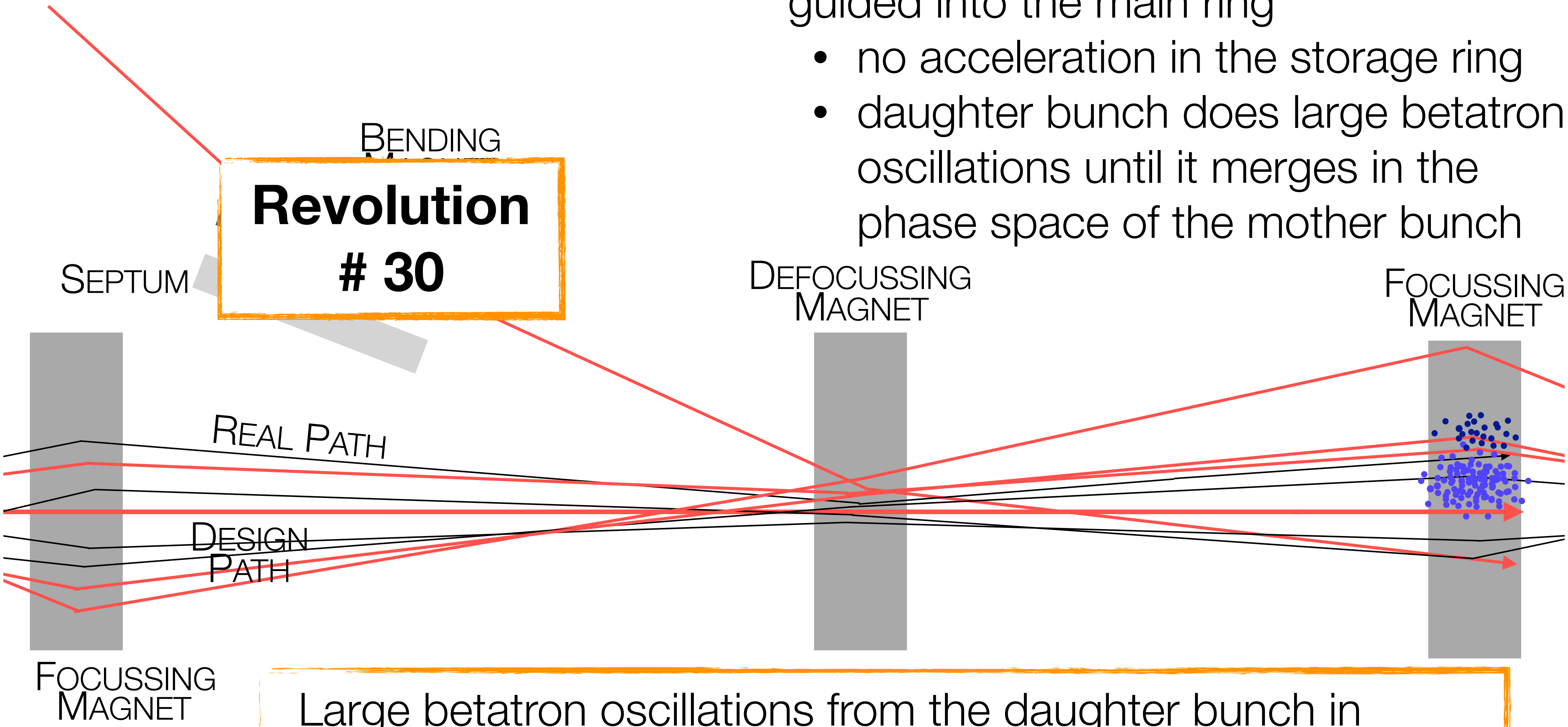


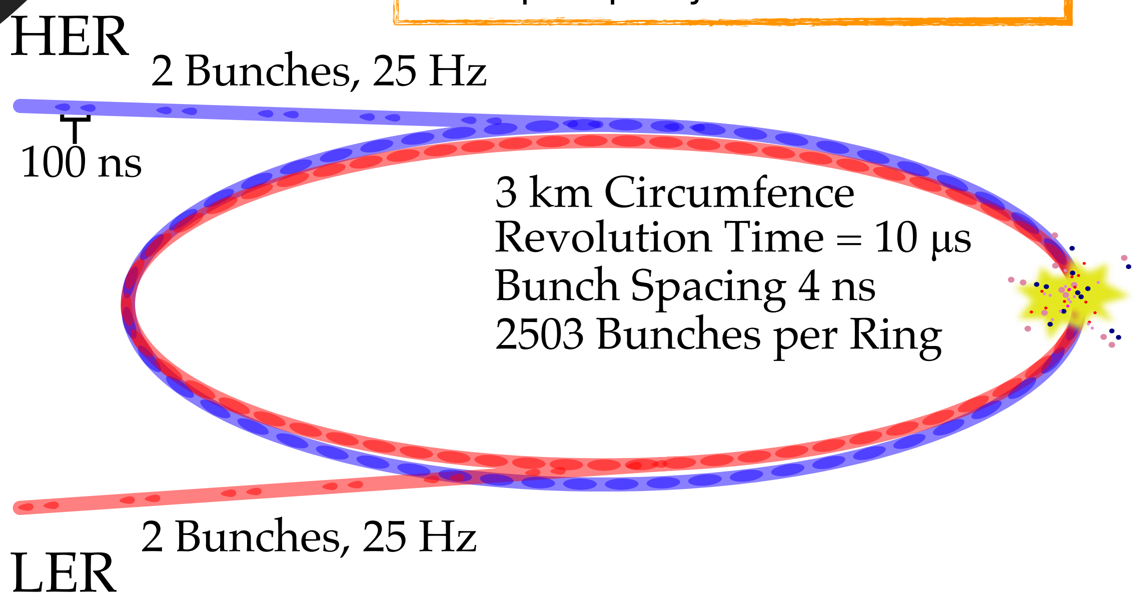
Large betatron oscillations from the daughter bunch in addition to the ones of the mother bunch leads to:

- beam-beam interactions
- contact with beam pipe

➡ large particle loss

What do we measure? Part II

- measurement of particle loss of injection bunches



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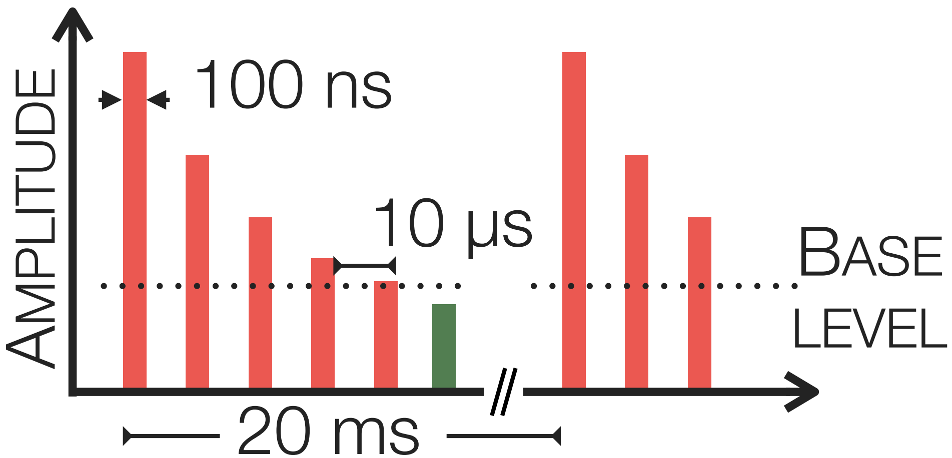

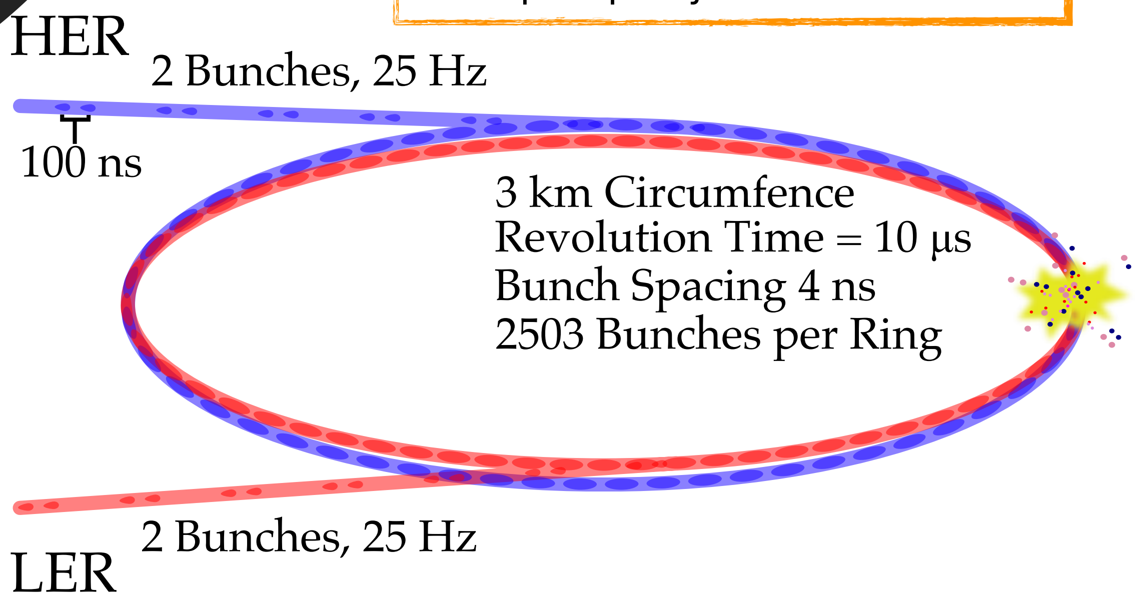

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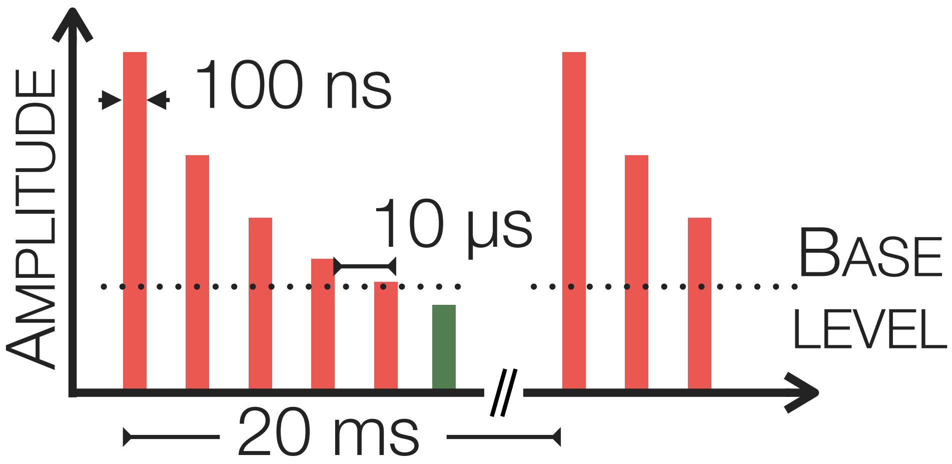

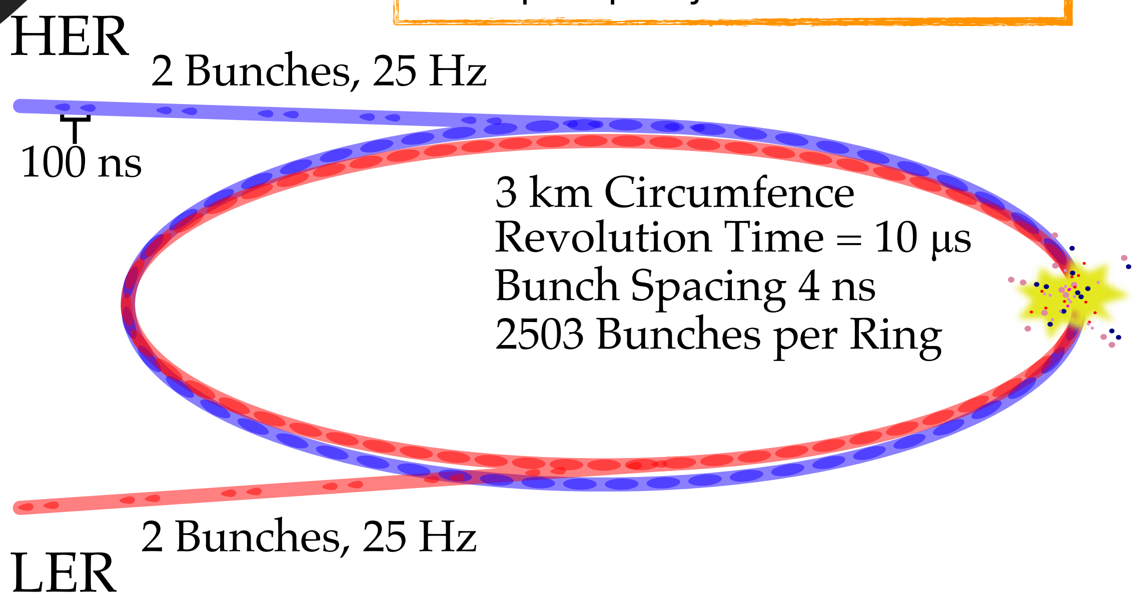

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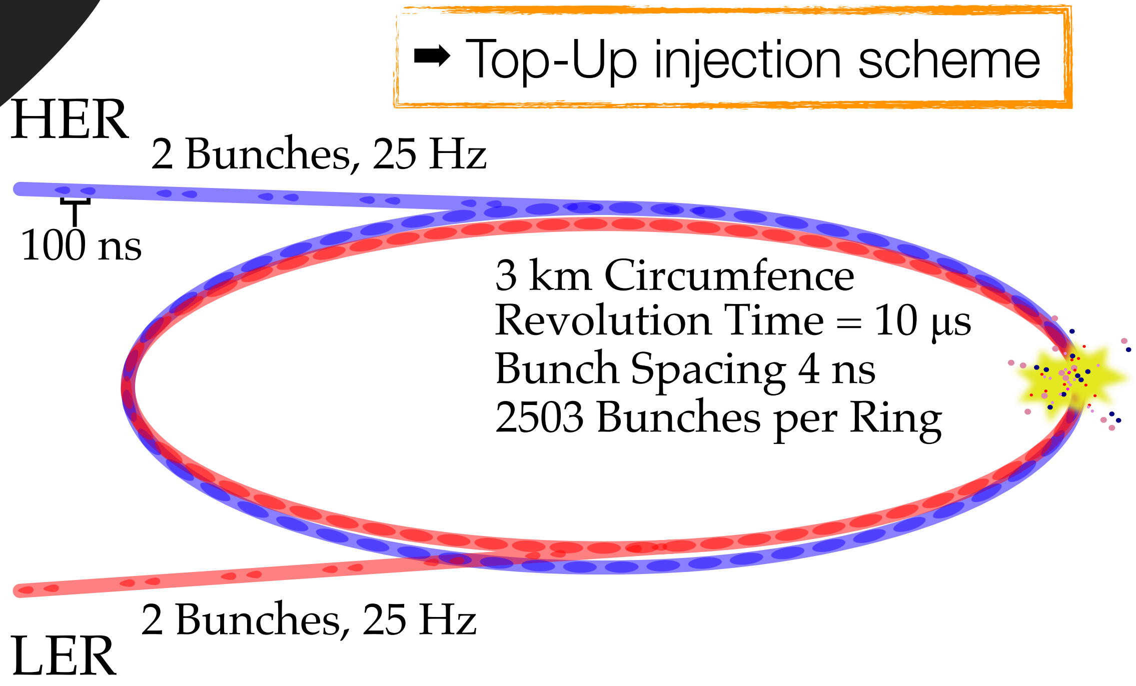

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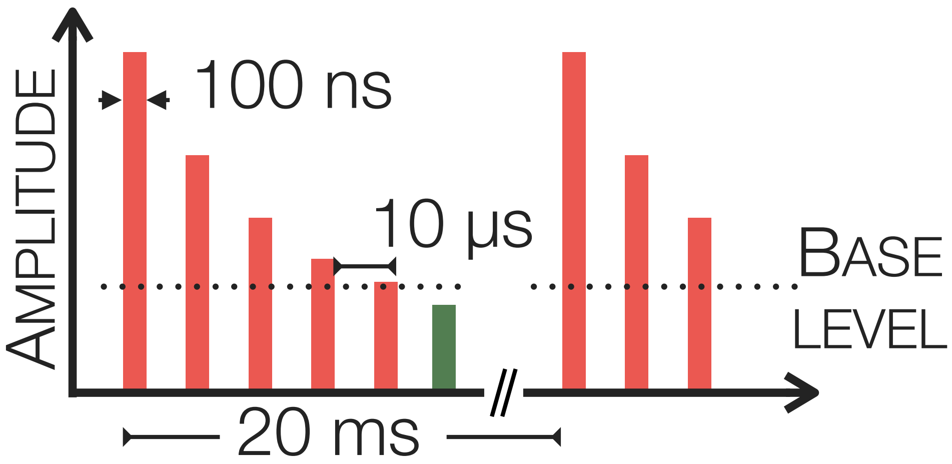

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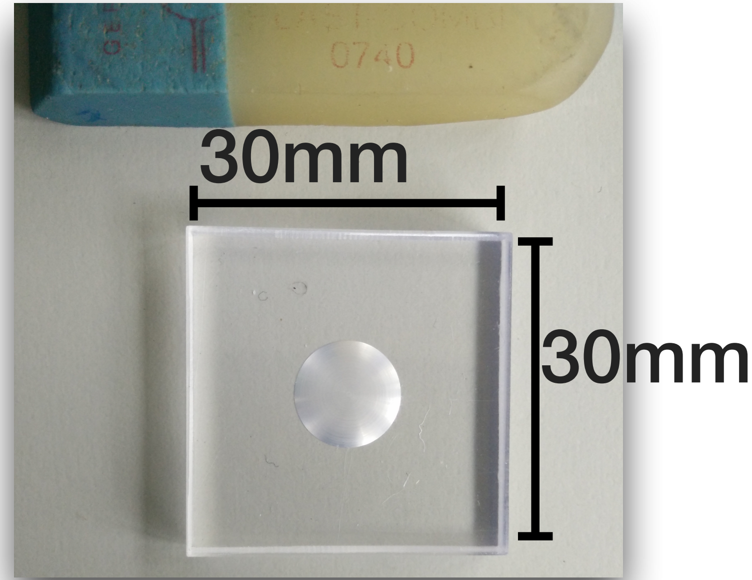
Detector requirements:

- single bunch resolution
  - ➡ sampling time <4 ns
- extended monitoring over multiple particle revolutions
  - ➡ several milliseconds

The Detector
A scintillating tile with SiPM readout



- scintillator shape taken from CALICE hadron calorimeter for ILC
  - material: POPOP doped Polystyrene
  - charged particles (e.g. muons, electrons) cross the tile and collide with molecules and excite them
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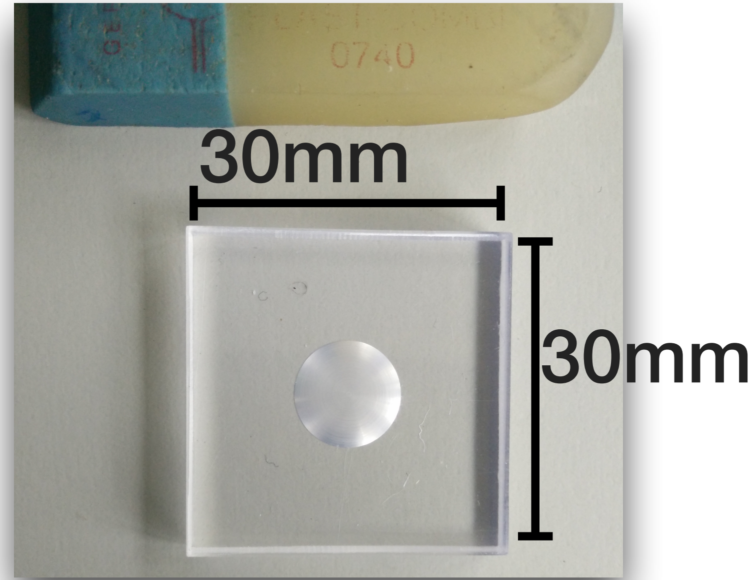

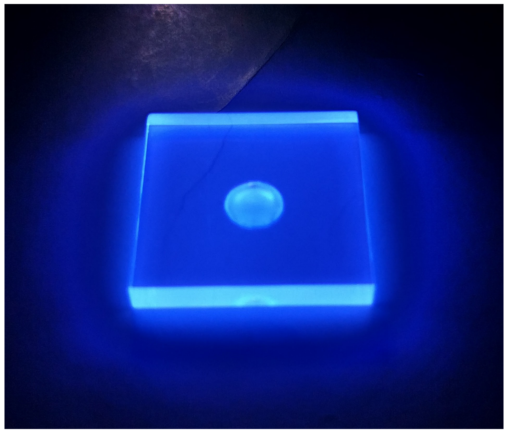

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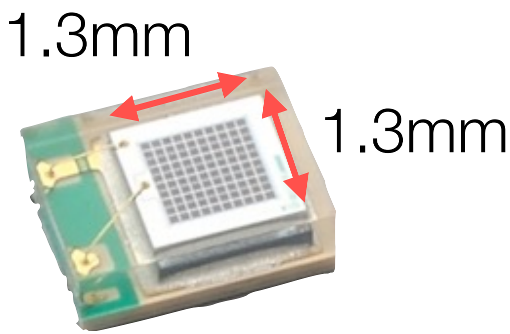

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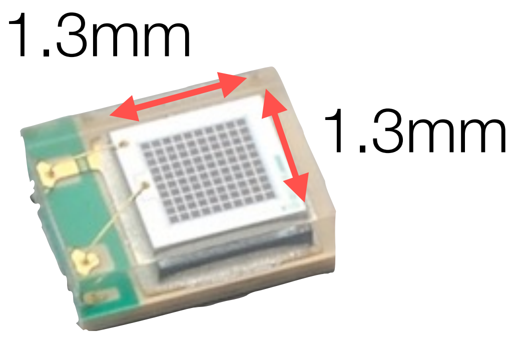

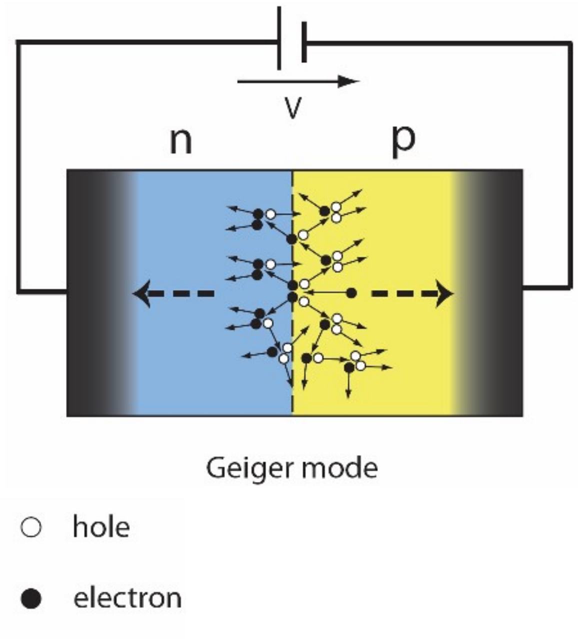

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- working principle:
  - high voltage (~60V) creates a large electrical field
  - photon creates an electron-hole pair
  - while acceleration of the charge carriers to the anode/cathode, collisions of the charge carriers create again new e-h pairs

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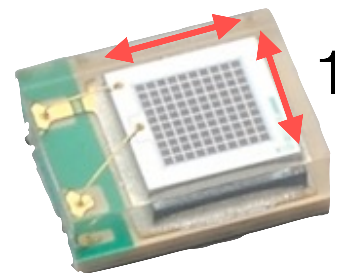

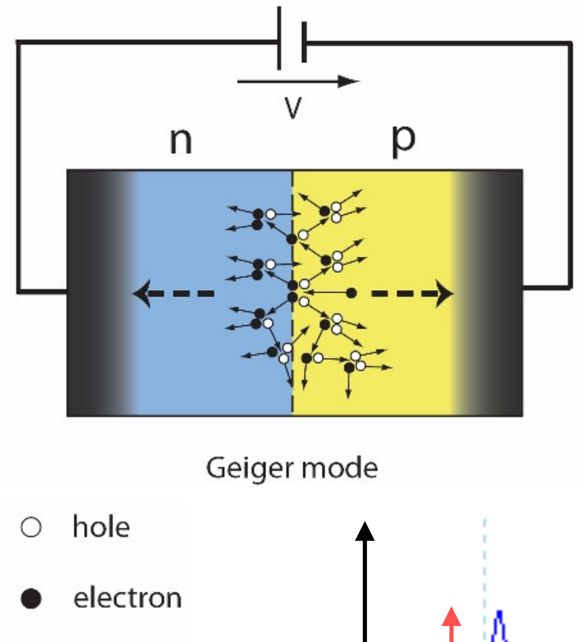

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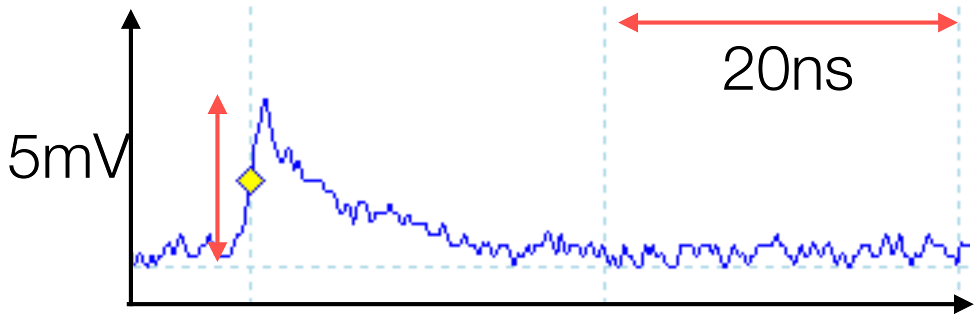

- SiPM signal is a superposition of single pixel signals

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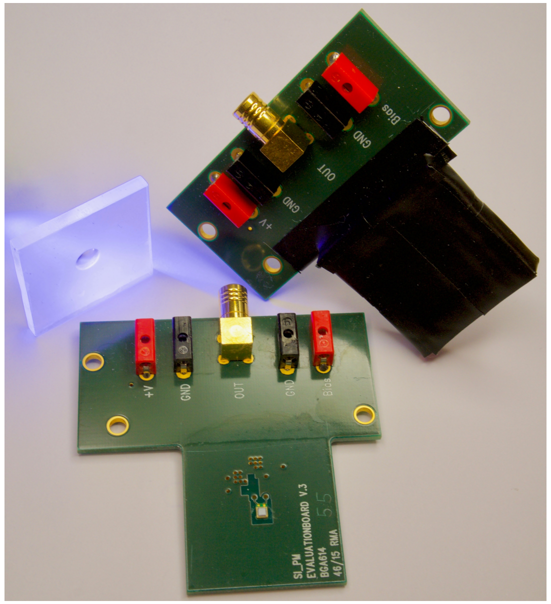
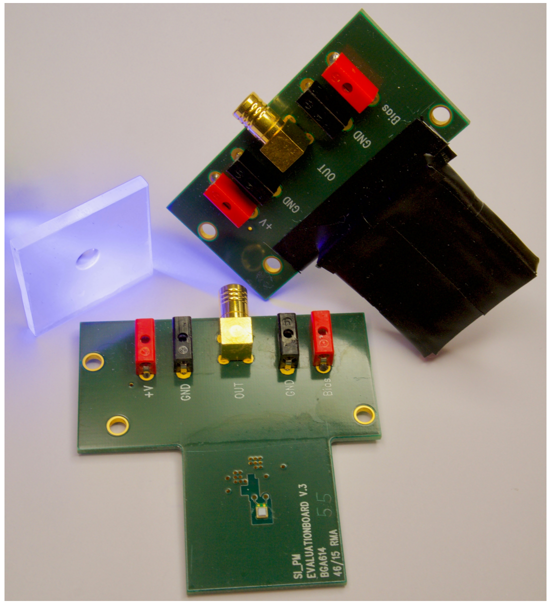
The Detector
A scintillating tile with SiPM readout





- scintillator and SiPM are mounted on PCB with onboard preamplifier
  - light tight wrapped

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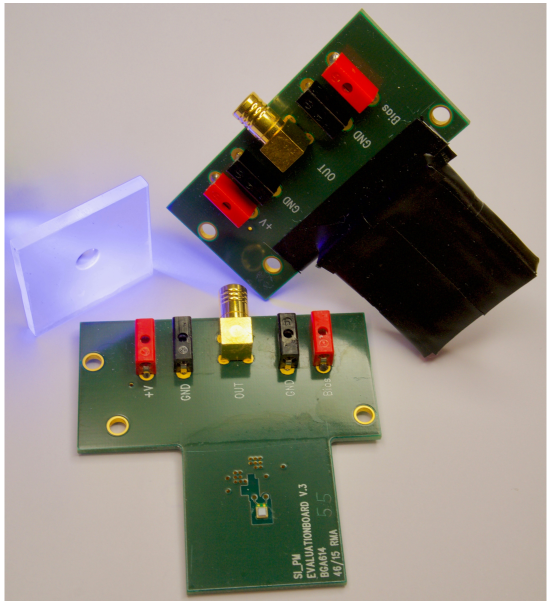

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Picoscope 6404D

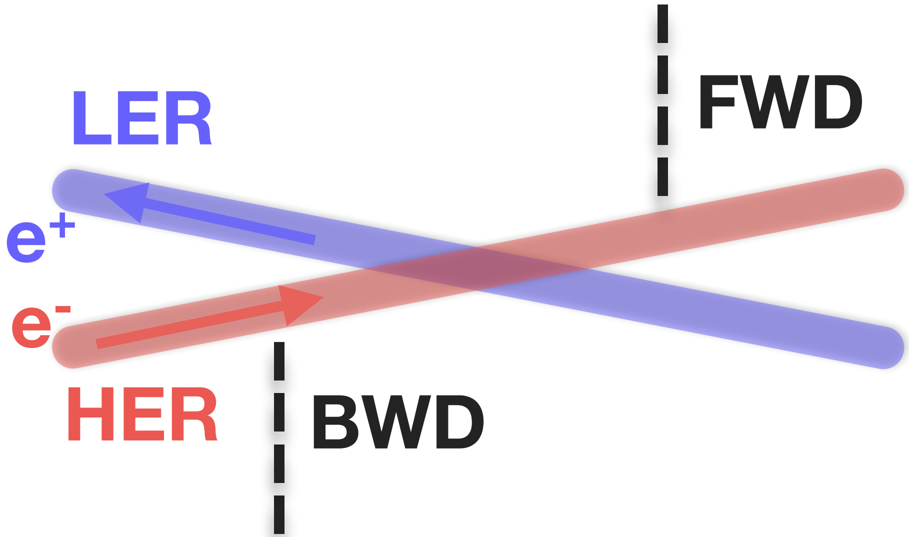
- 4 channel + ext. trigger channel
- 8 bit vertical resolution
- 800 ps sampling time
- records up to 40 ms per channel

SCINTILLATOR LIGHT AND WAVEFORM SENSORS

The CLAWS System

SCINTILLATOR LIGHT AND WAVEFORM SENSORS

- 4 on outer side of ring
- 4 on inner side ring



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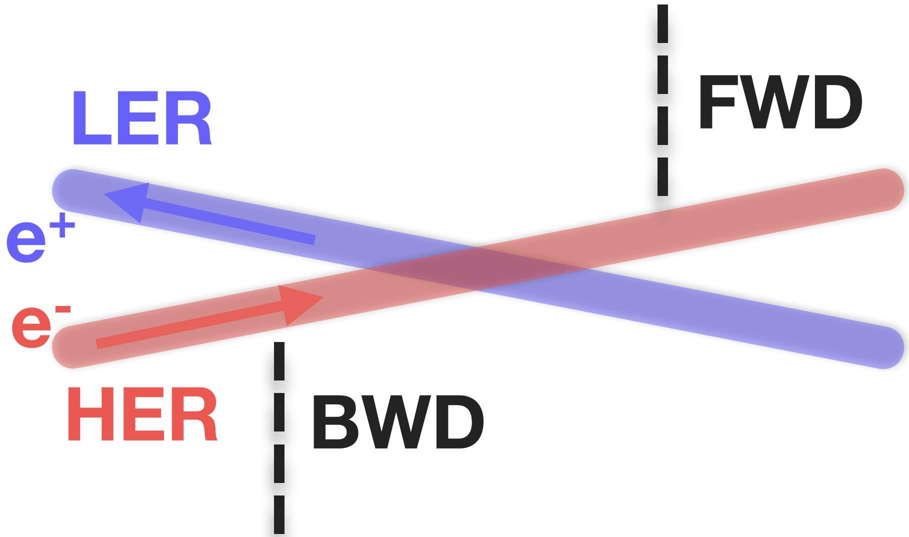

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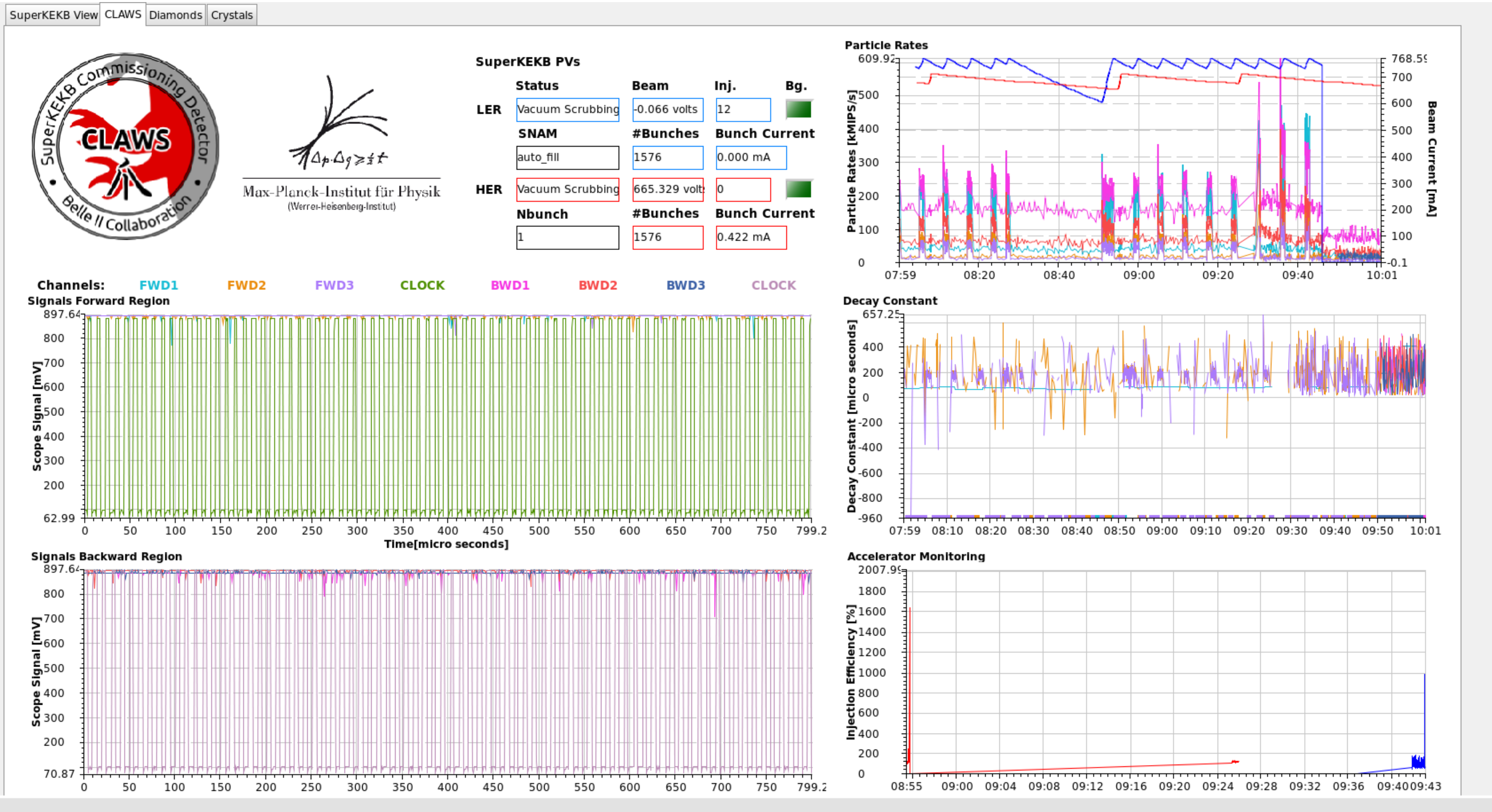
Online Monitor

The Online Monitor



Online Monitor

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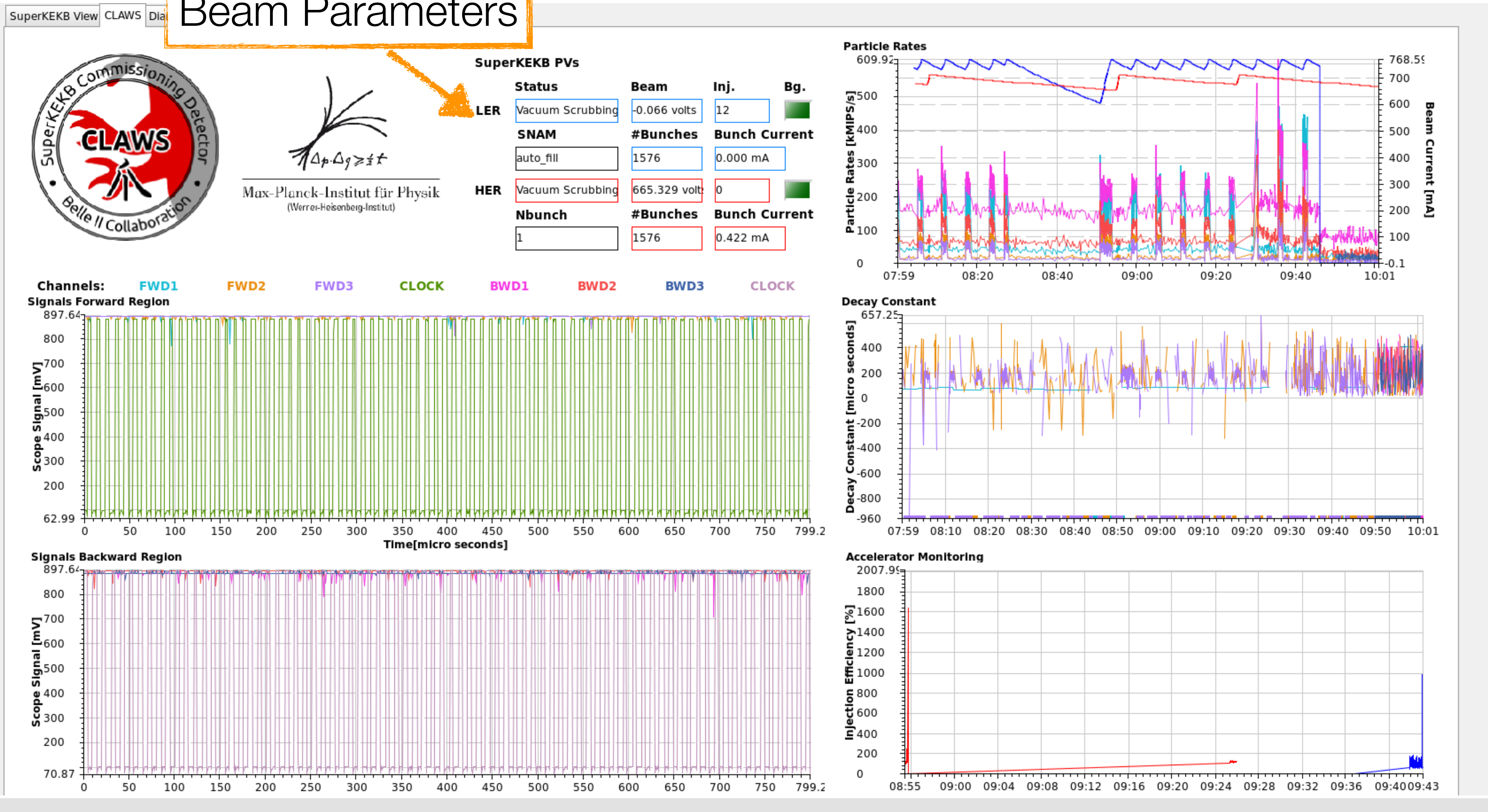
Beam Parameters



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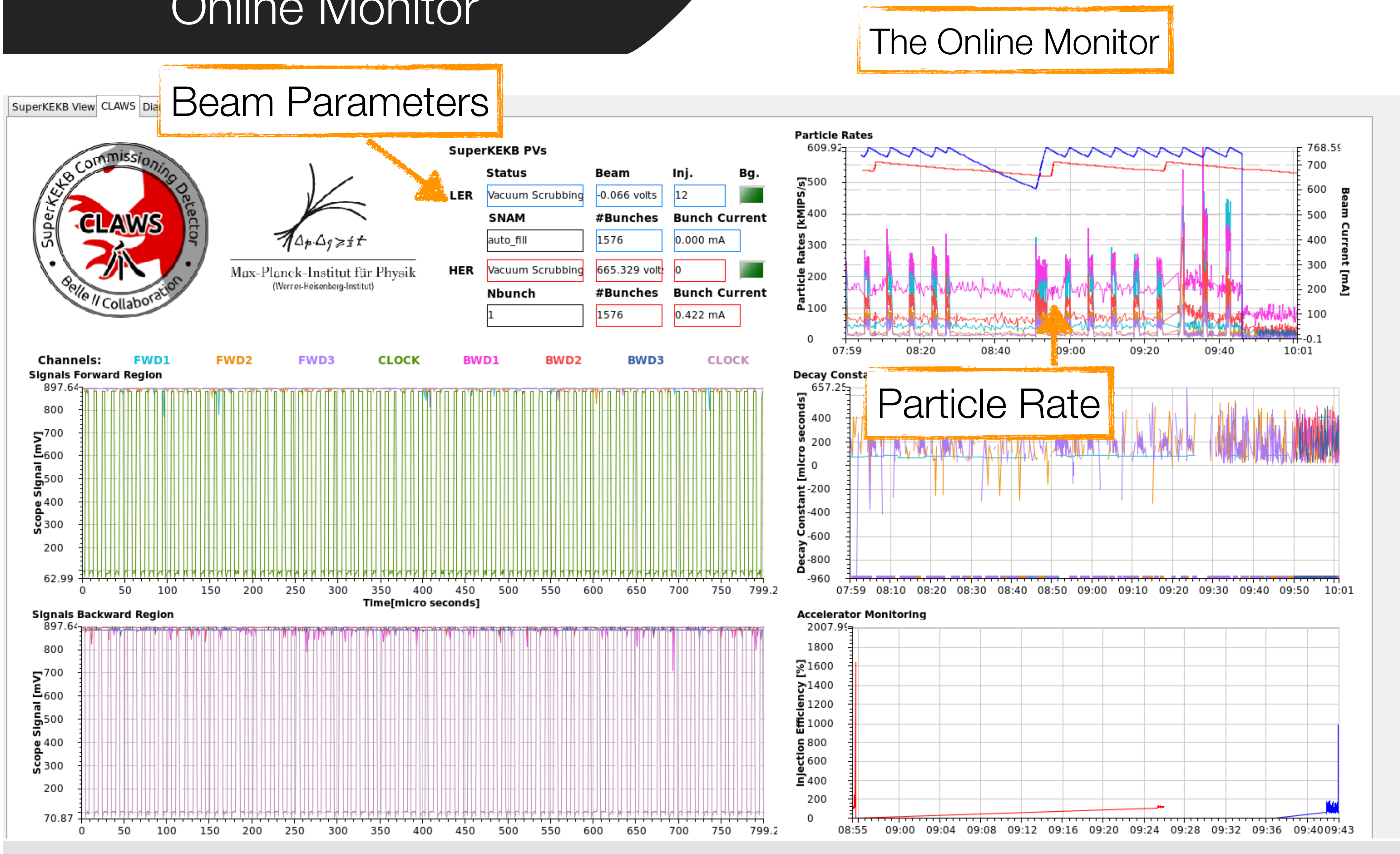

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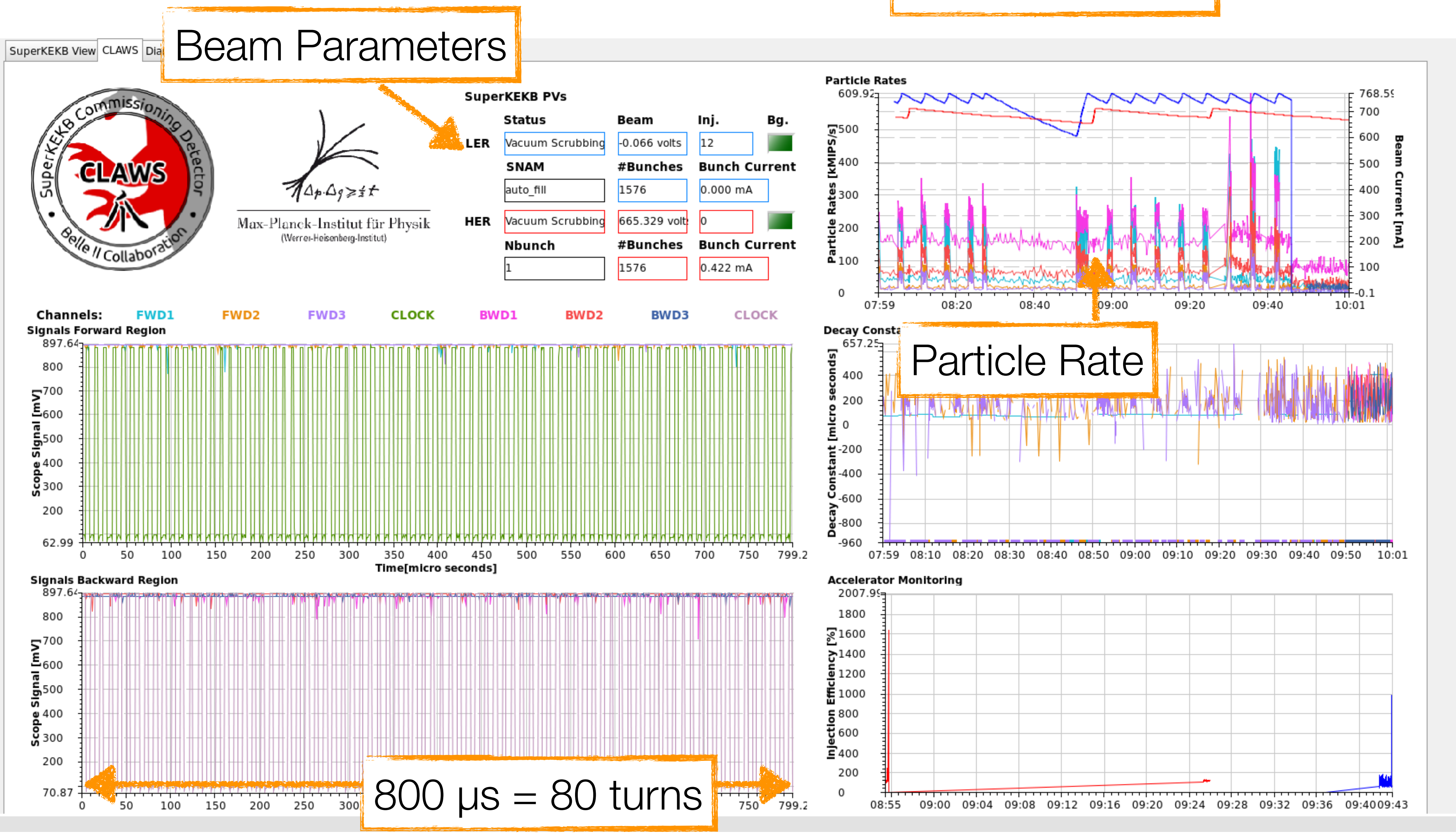

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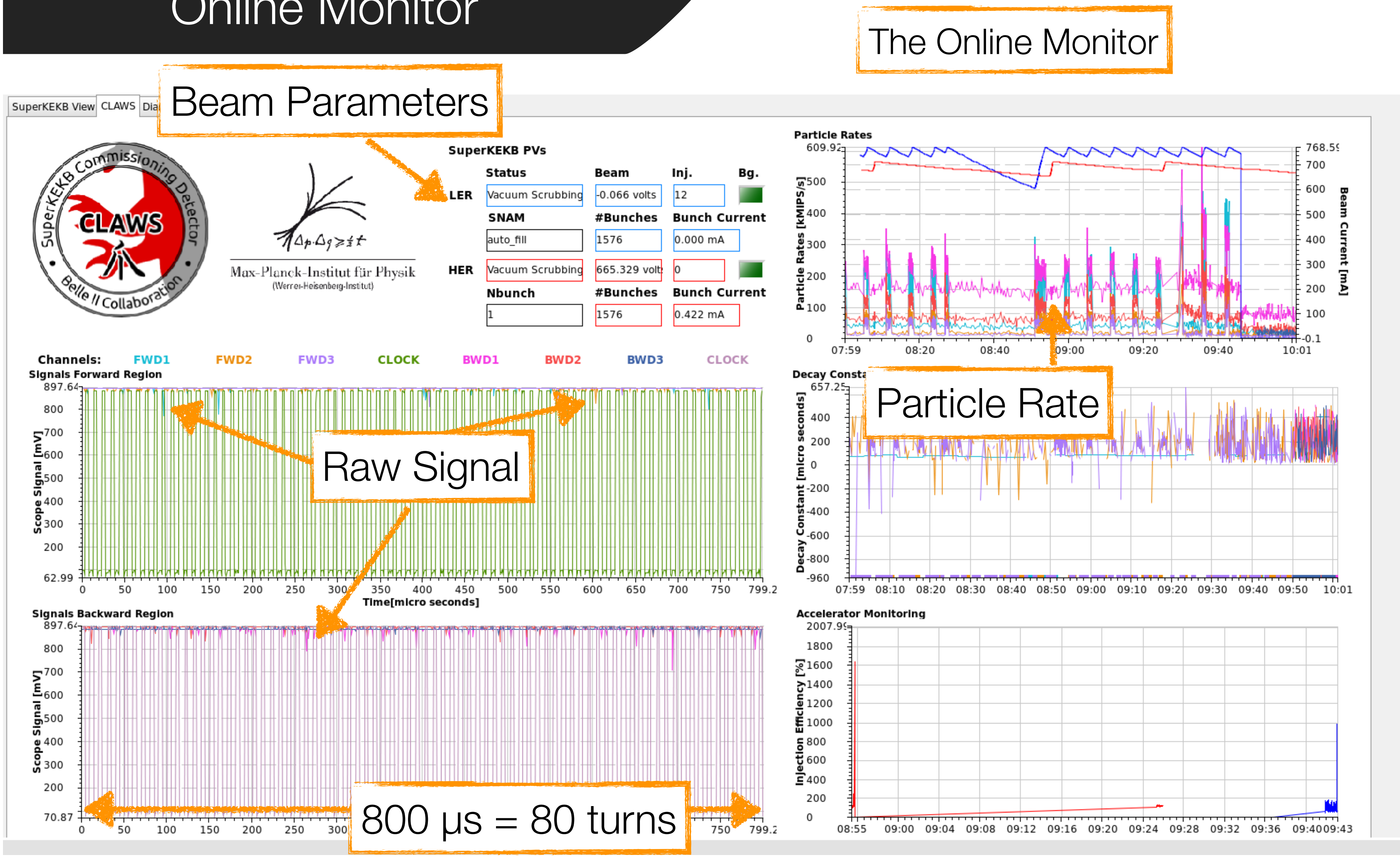
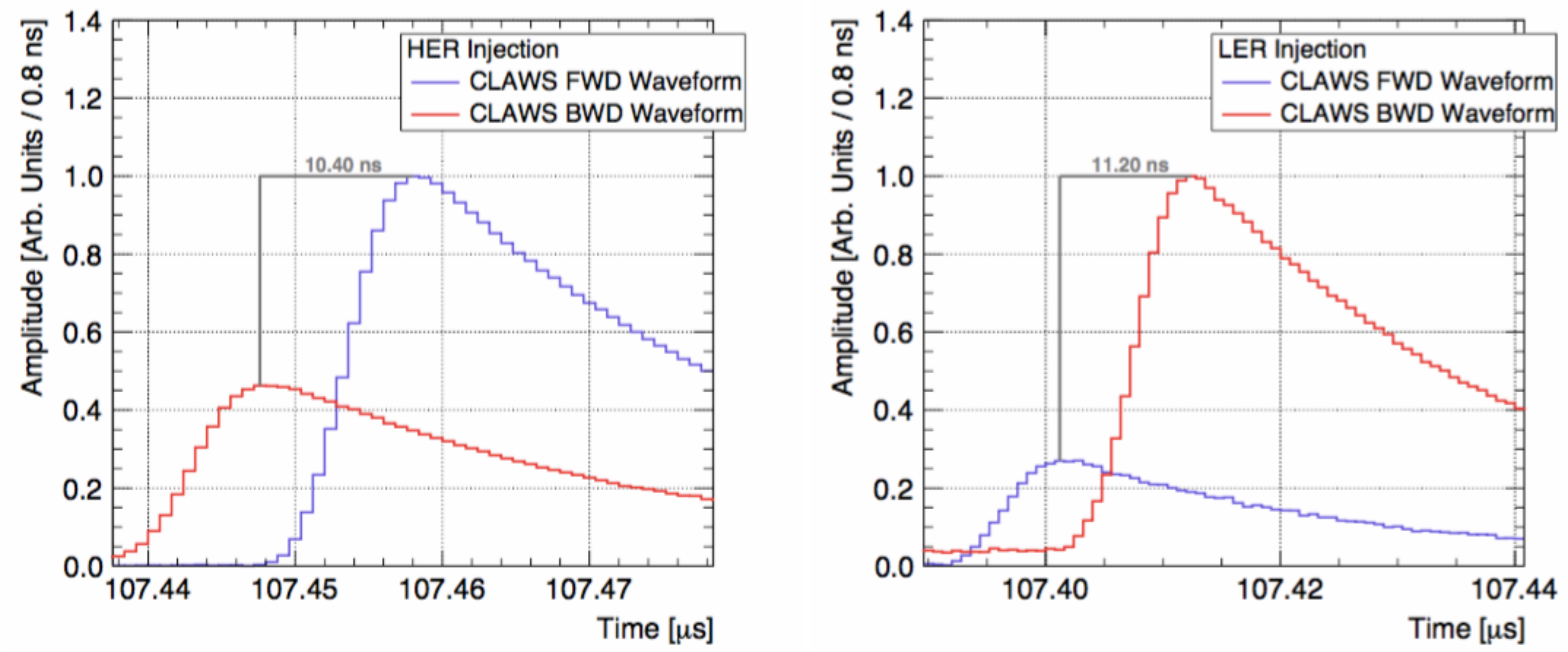


Geometry Check

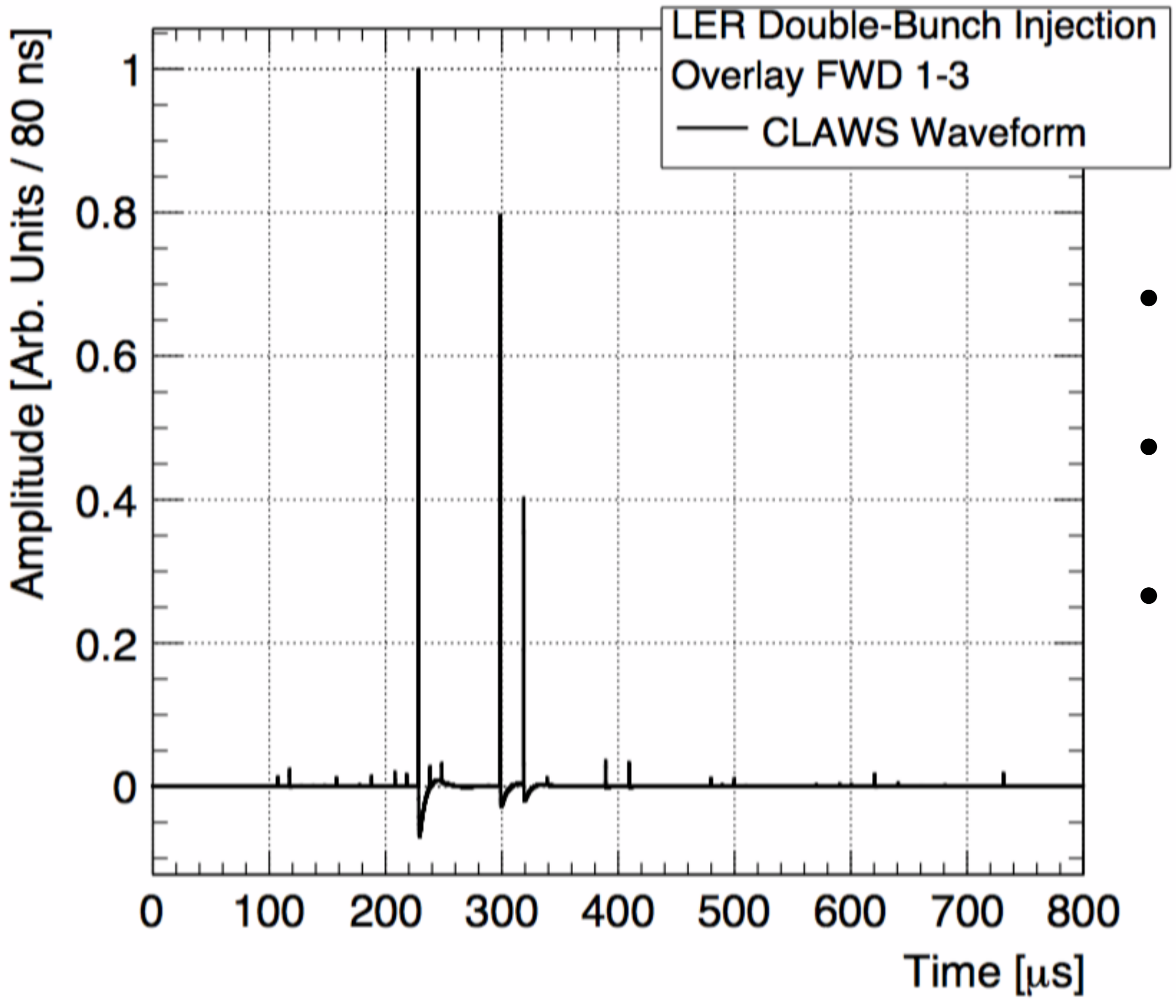
Sanity Check: Speed of light

- forward and backward region are about 3 m apart
  - bunches clearly distinguishable



Time Properties of the Beam

Injection background in LER



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- very large signals starting ~12 turns after first arrival
- signals substantially reduced after 100 μs of high activity

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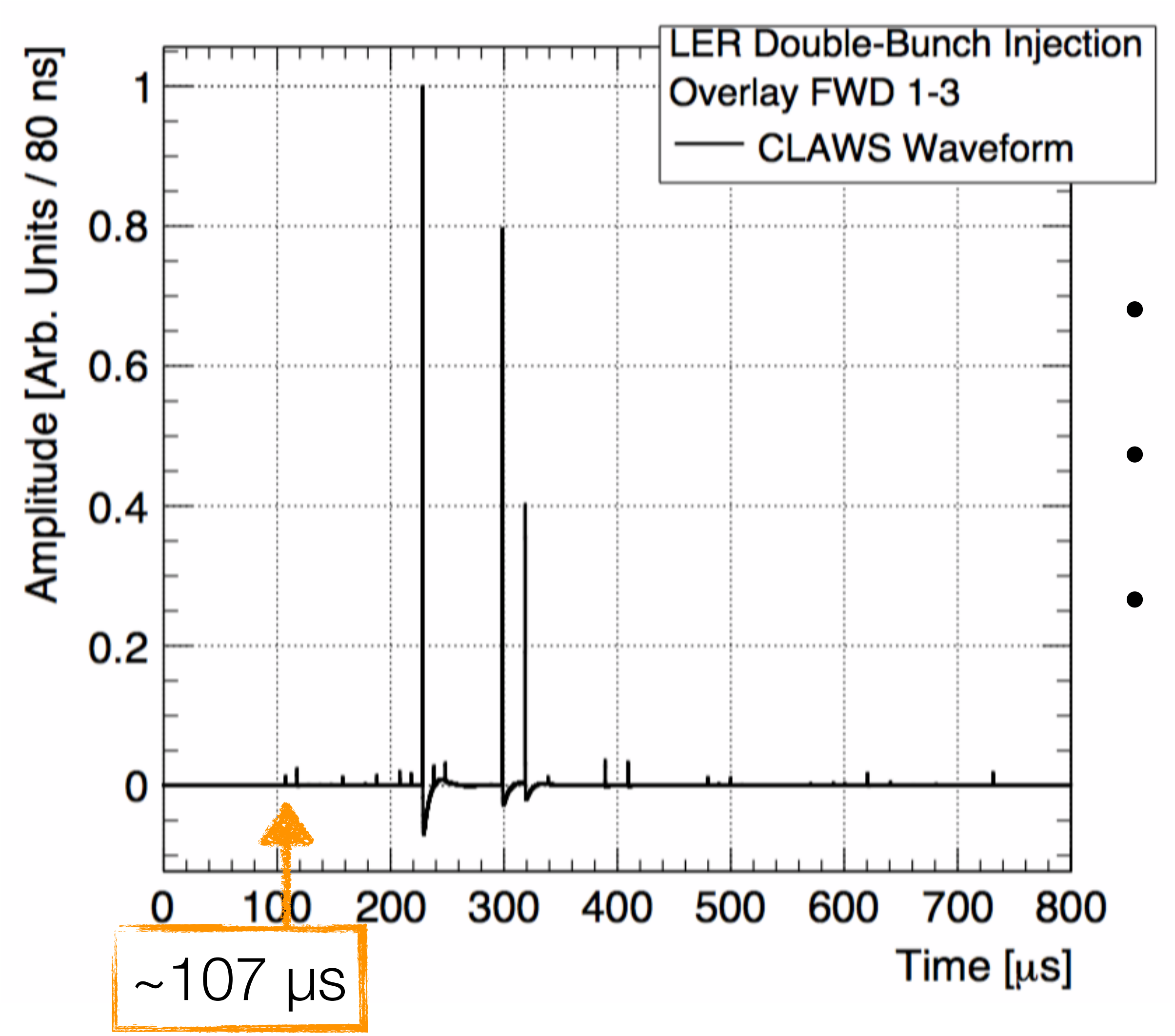

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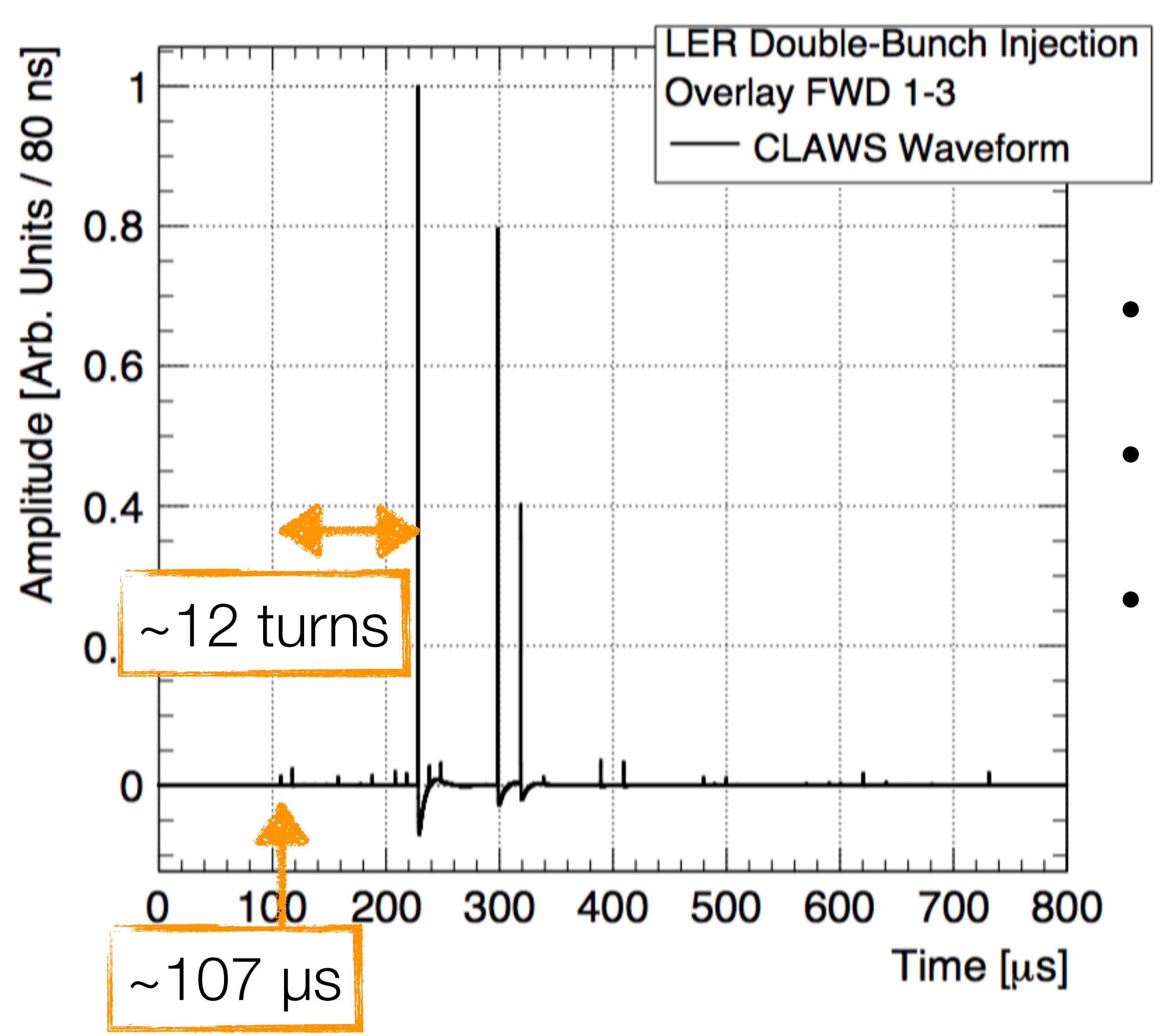

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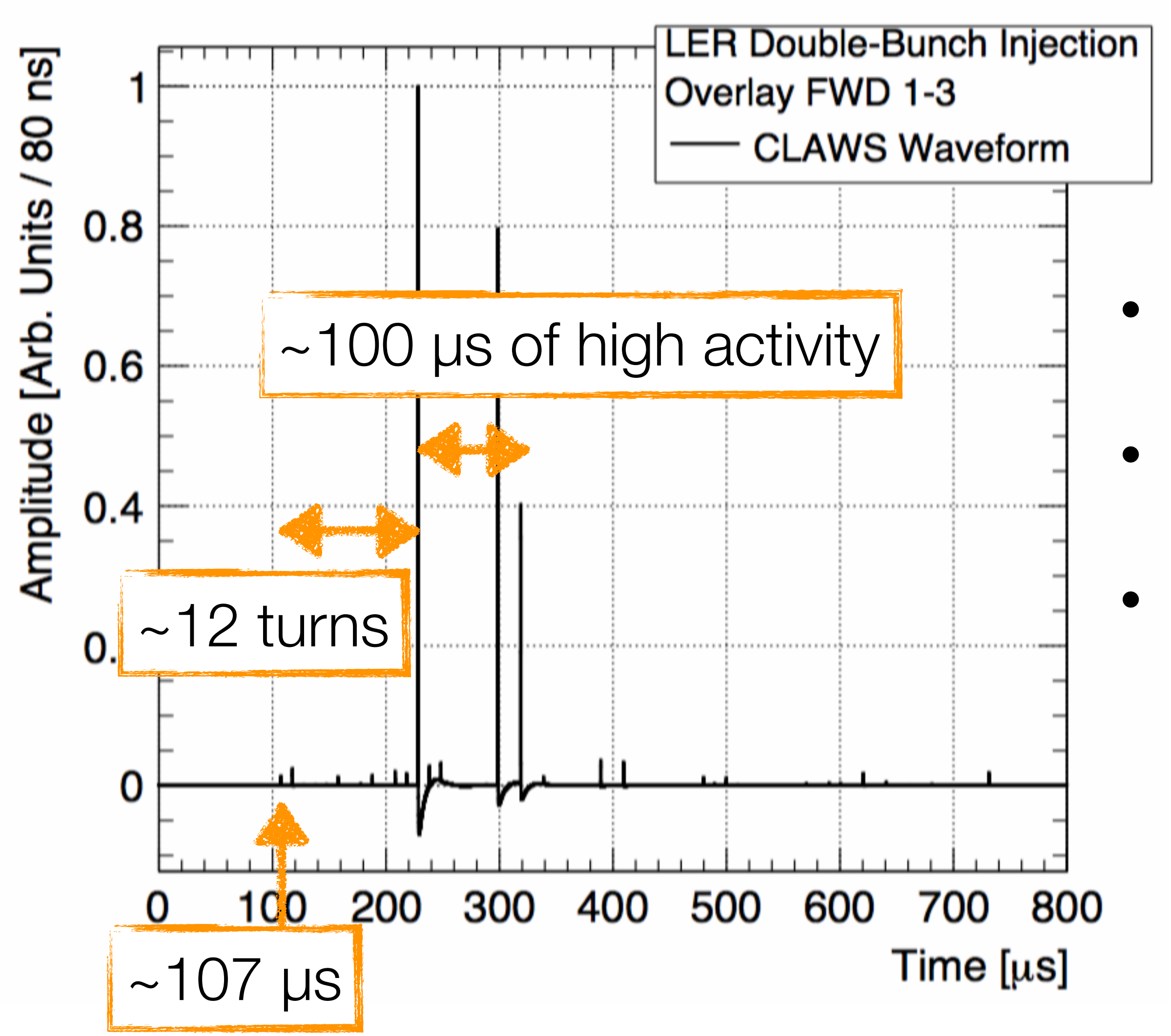

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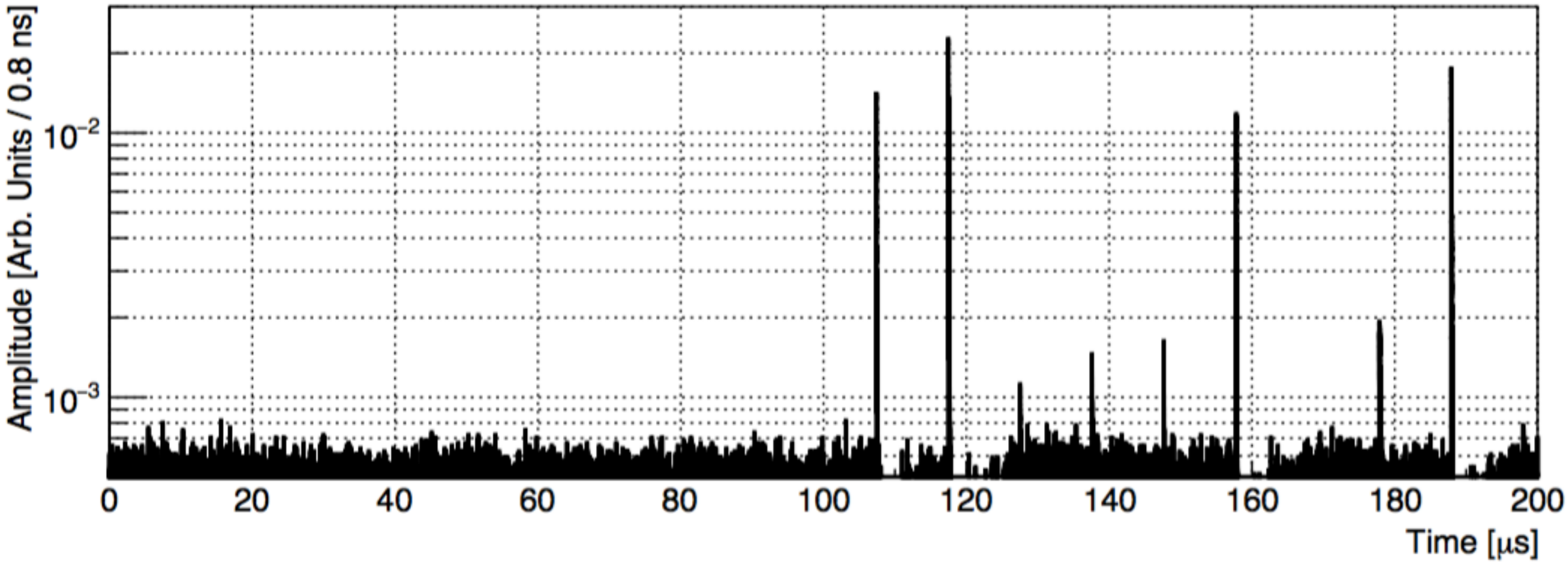
Arrival of First Particles

Injection background in LER with double bunch injection

- zoom into the first 200 µs
  - first signal arrives ~107 µs after trigger
  - mostly after every turn a signal
    - ➡ signal at 167 µs is missing
    - ➡ signal at 197 µs is not clearly visible
    - ➡ Betatron oscillation frequency is 44.59/Turn in LER (horiz.)



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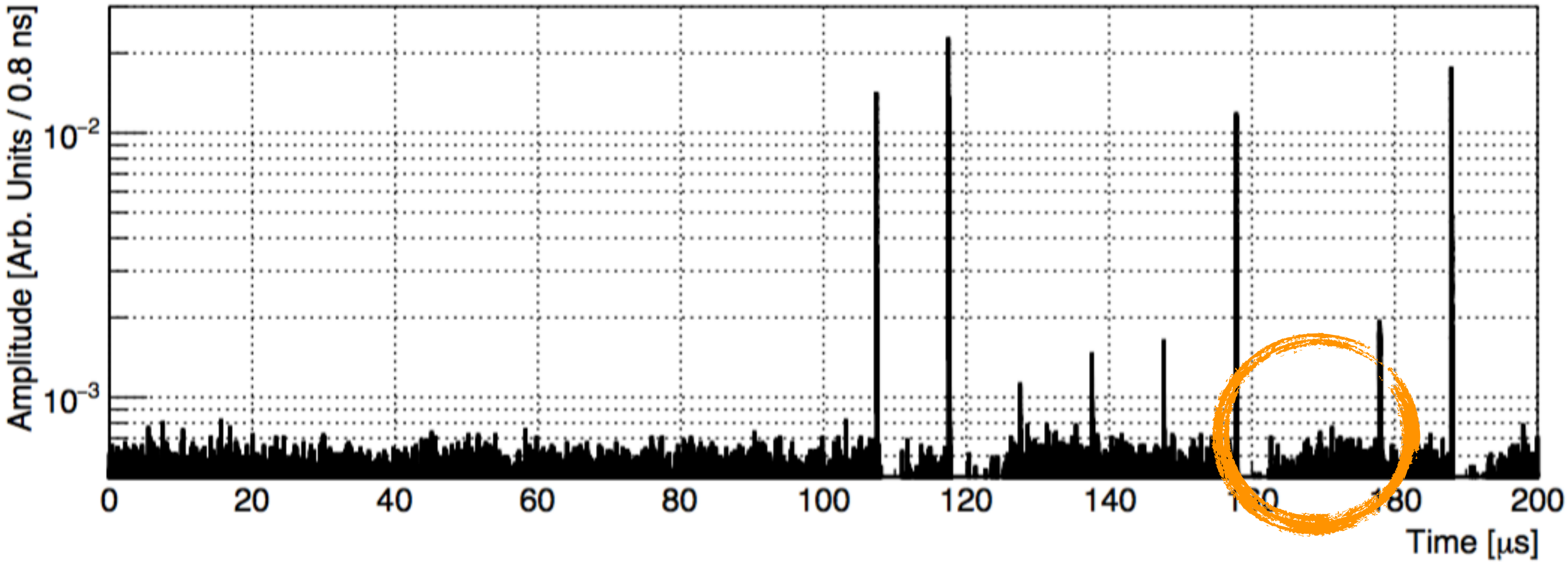

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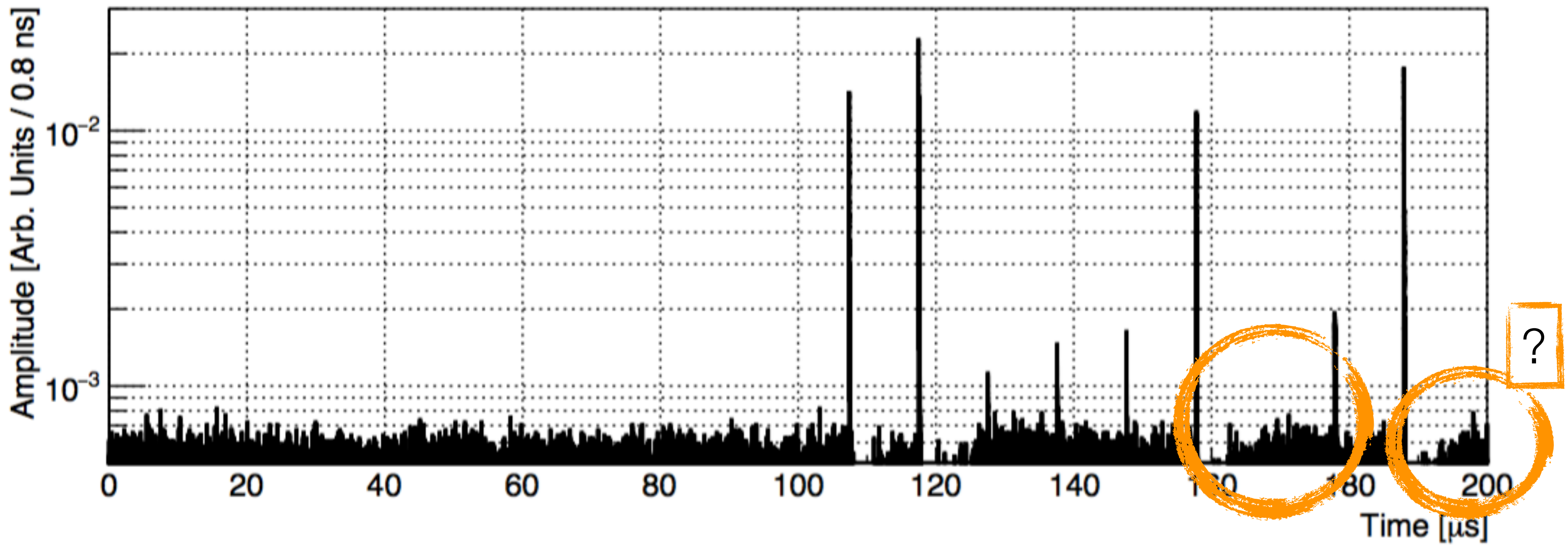
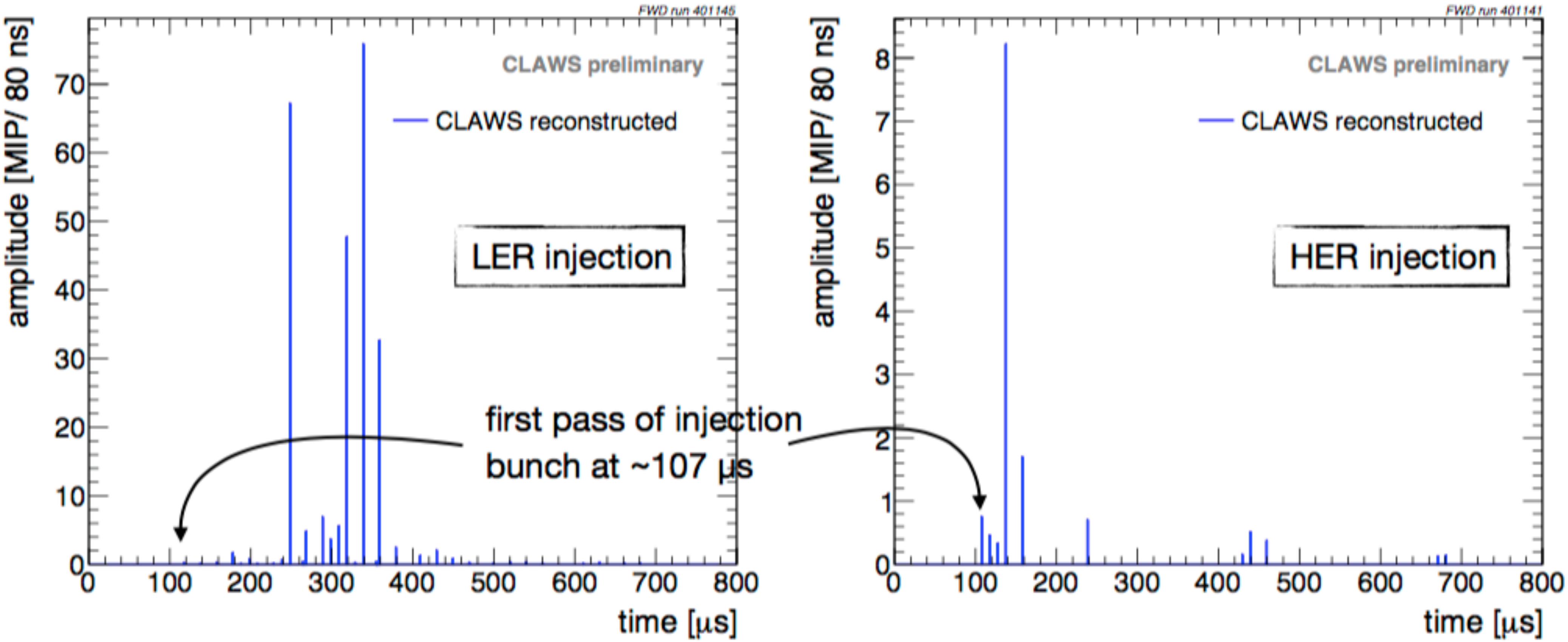


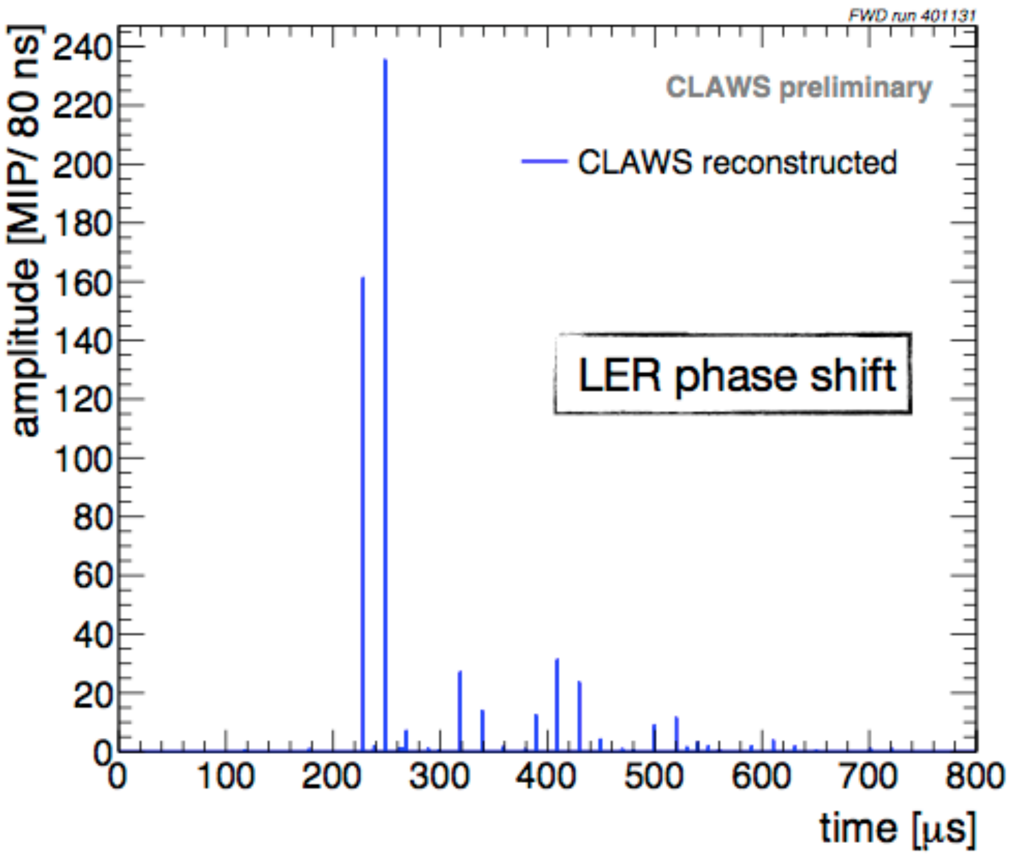
Reference Injection: LER vs HER

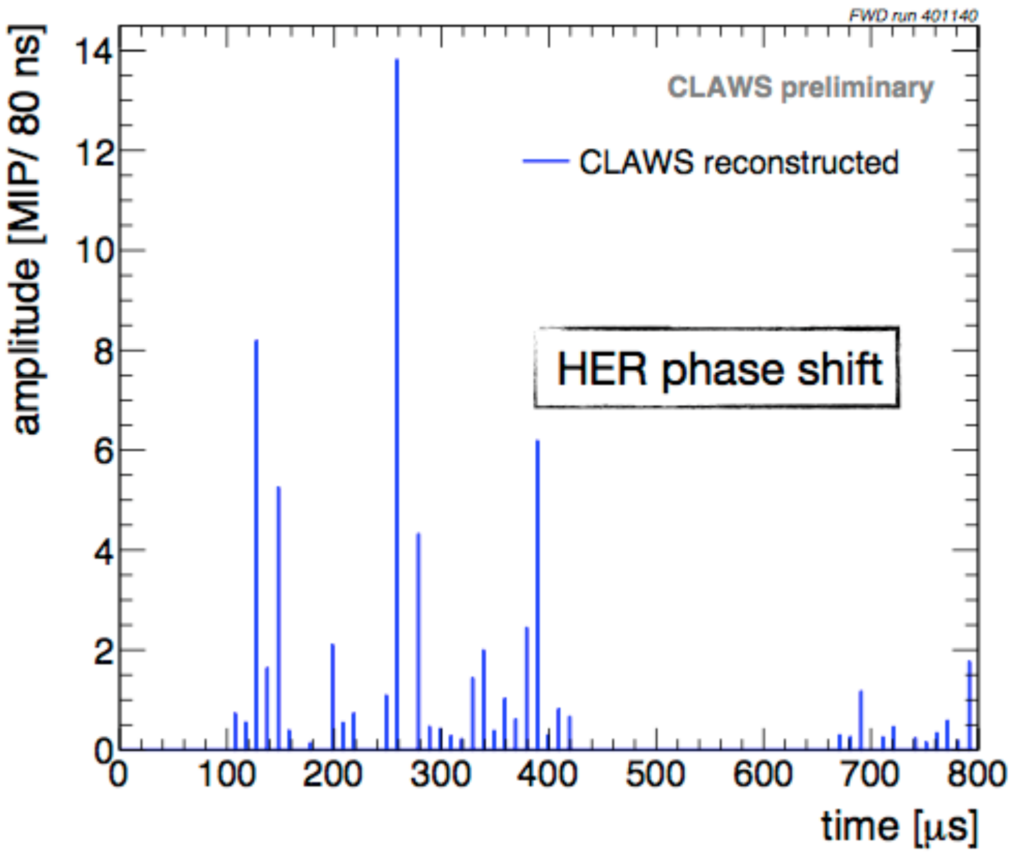
- General observation:
  - ➡ LER injection results in much higher backgrounds than HER injection
  - ➡ very different timing behavior; HER background appears promptly, LER with substantial delay



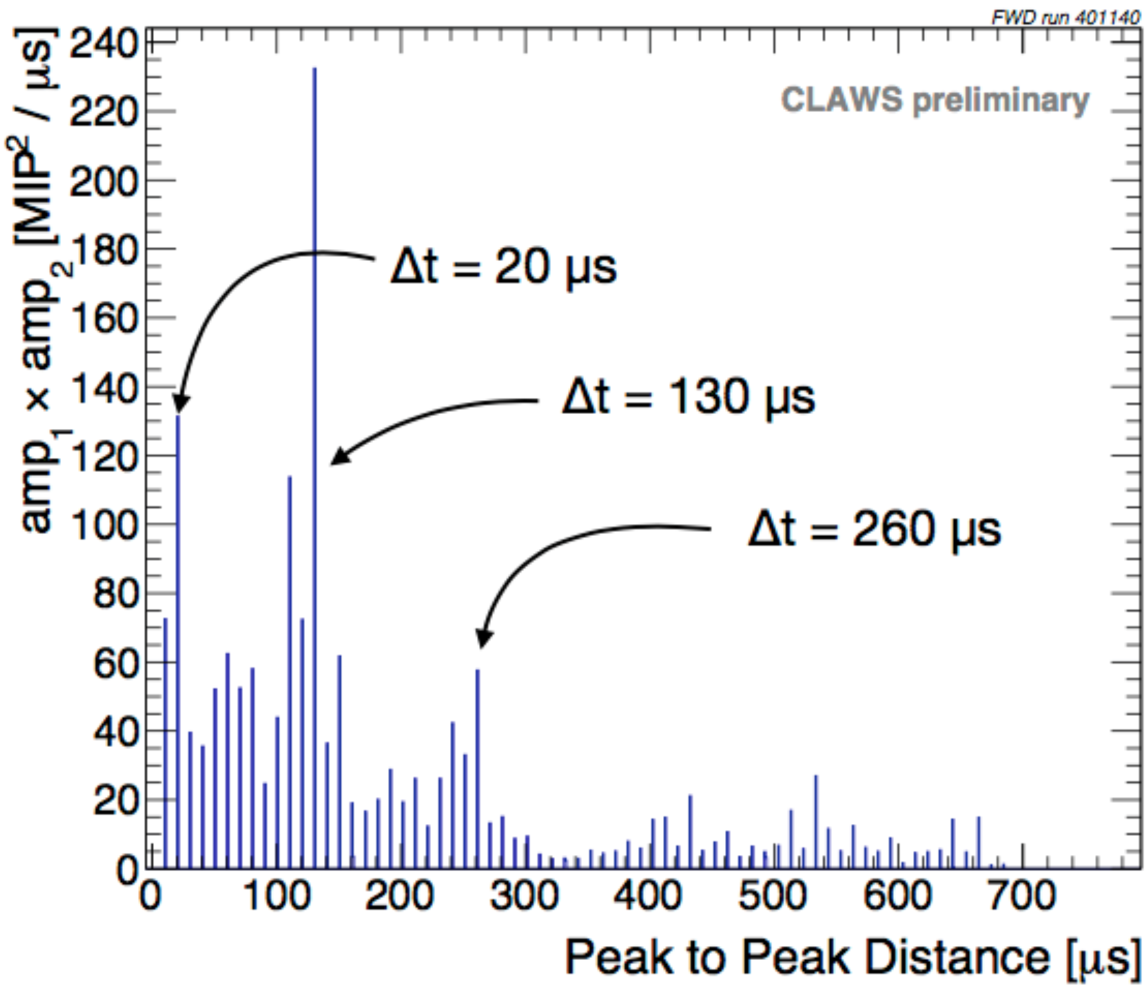
Changing Parameters: Phase Shift

- Substantially increased background
- Some impact on timing properties - phase shift injections used to study timing patterns later





A Closer Look: HER



Identify patterns in the time structure of injection signals:

- plot dt for all bin pairs, weighted by the product of amplitudes
- 130 µs super structure
- on-off pattern in background

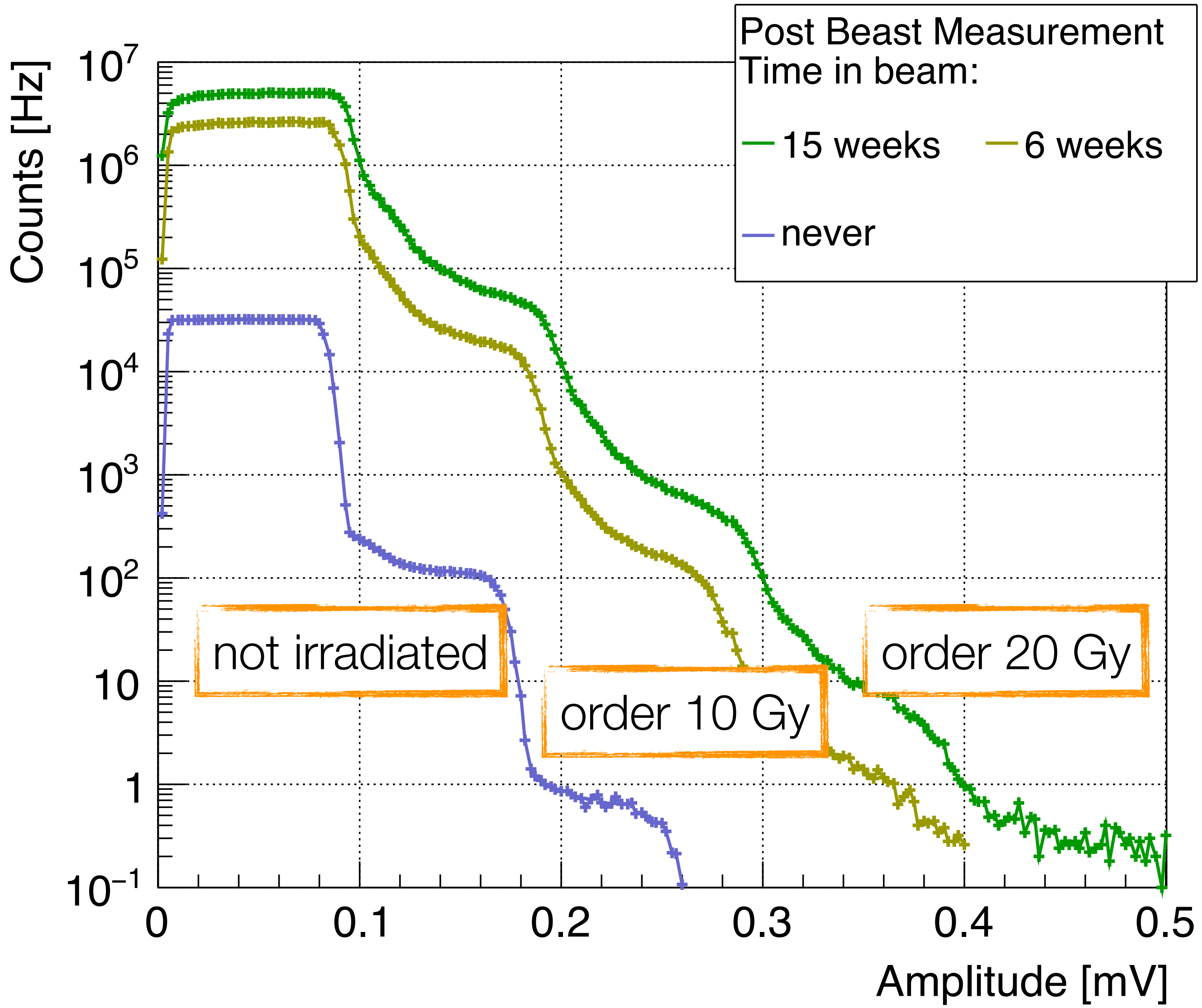
Summary & Outlook

- commissioning of SuperKEKB accelerator started in Feb 2016
- CLAWS - as part of Beast - measured timing properties and particle rates coming from charged particles from injection background
  ➡ the system is capable of measuring the single bunches

- commissioning of SuperKEKB accelerator will continue Feb 2018
  ➡ CLAWS takes part in a modified version

BACKUP!

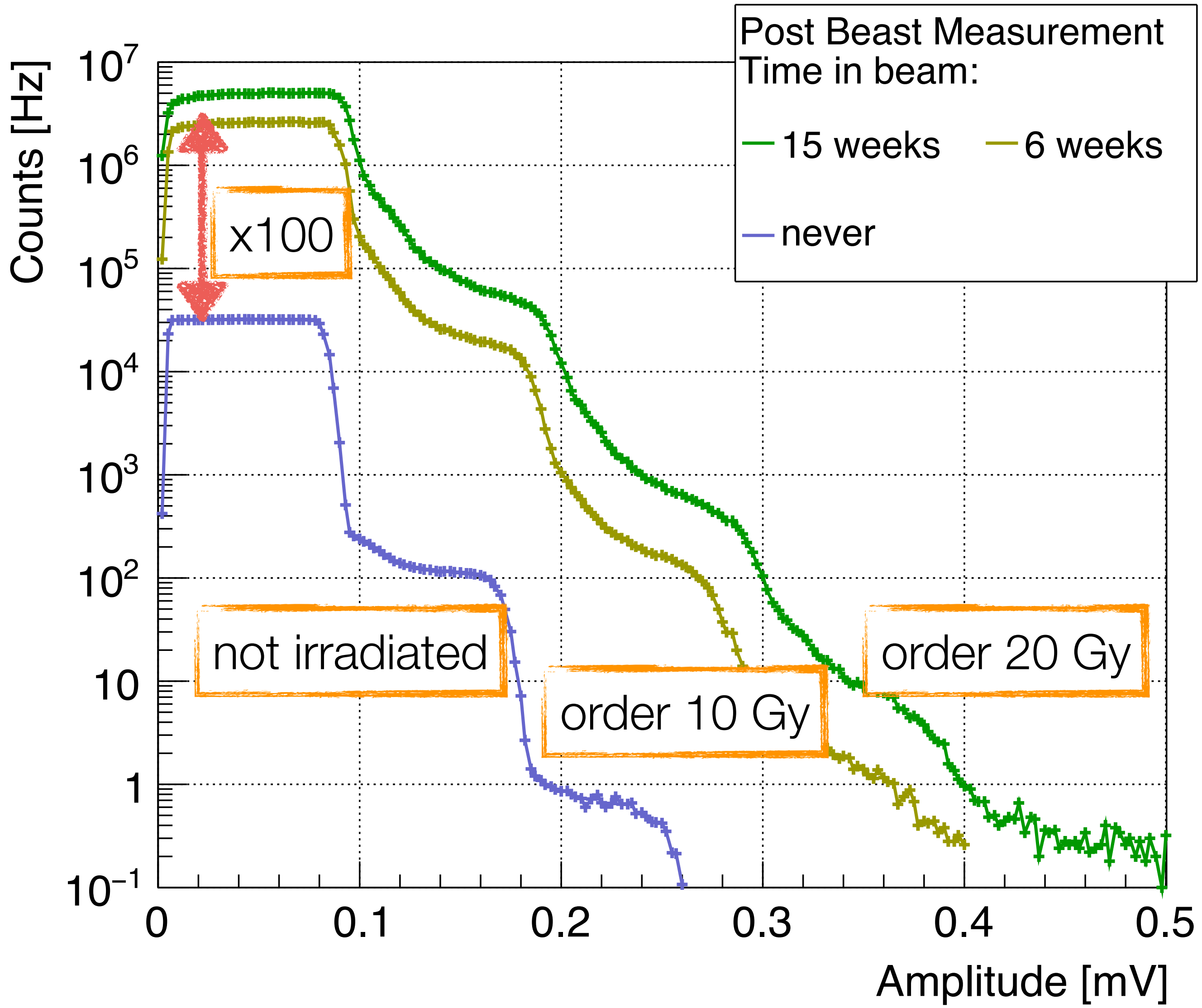
Radiation Effect on CLAWS



SiPM darkrate measurement:

- dark rate raised by factor 100
- photon events smear
- 4 p.e. rate still low
  ➡ no significant impact

Radiation Effect on CLAWS



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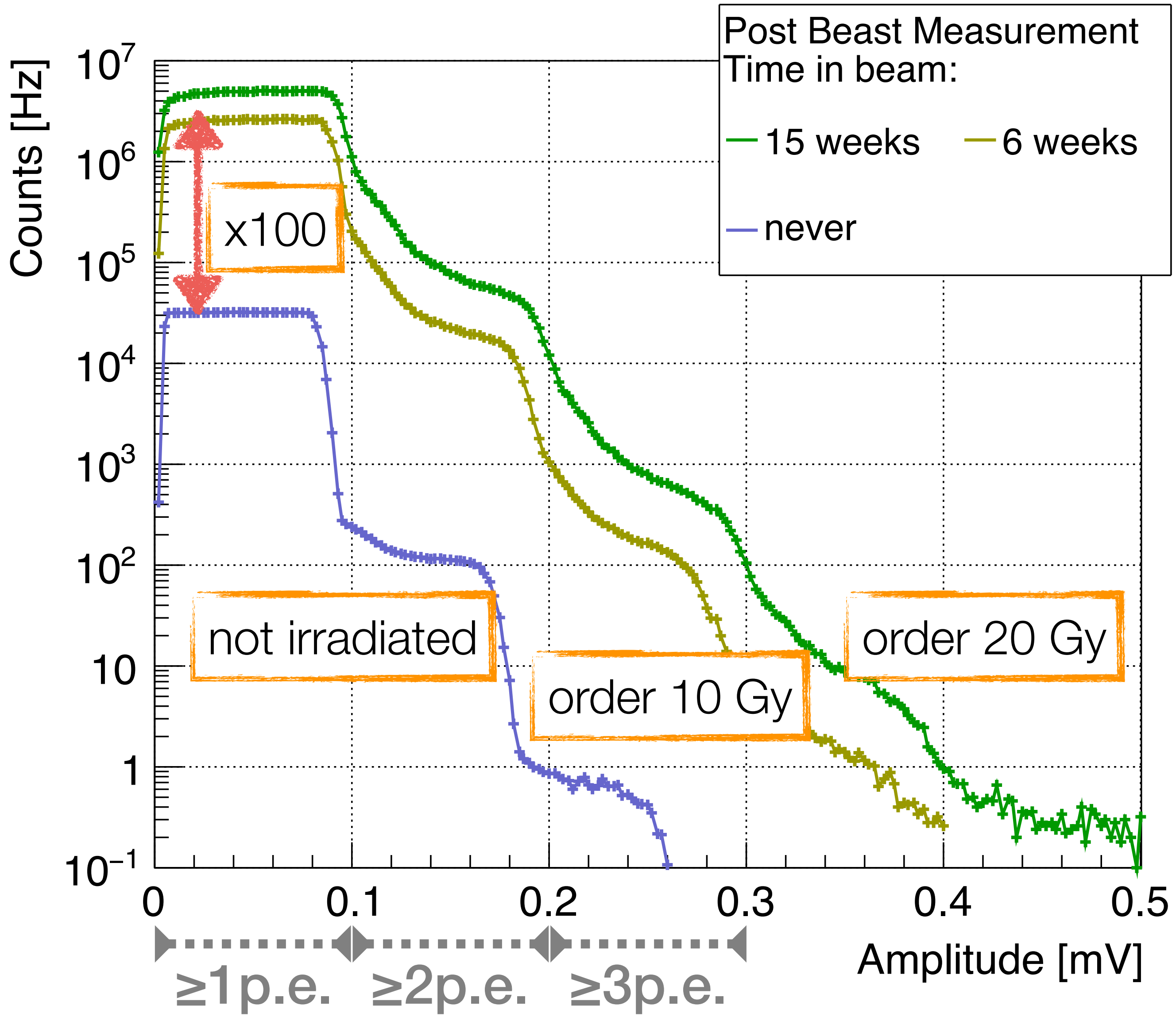

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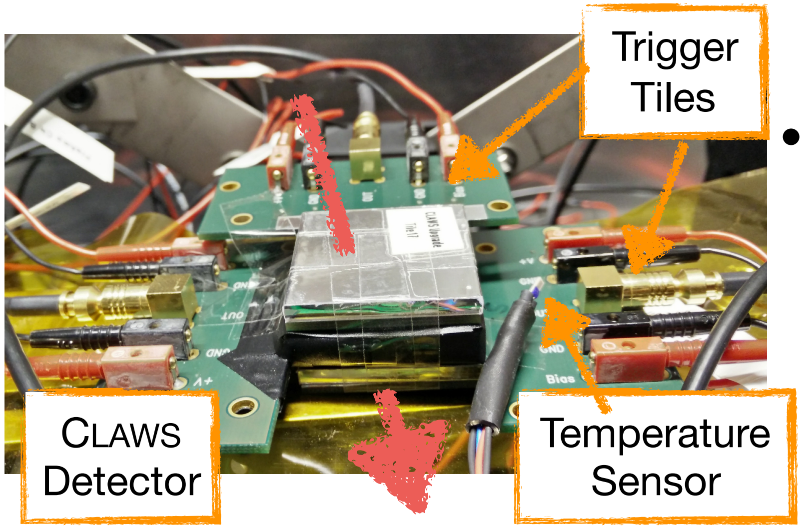
Calibration



- Minimum Ionizing Particle (MIP) calibration

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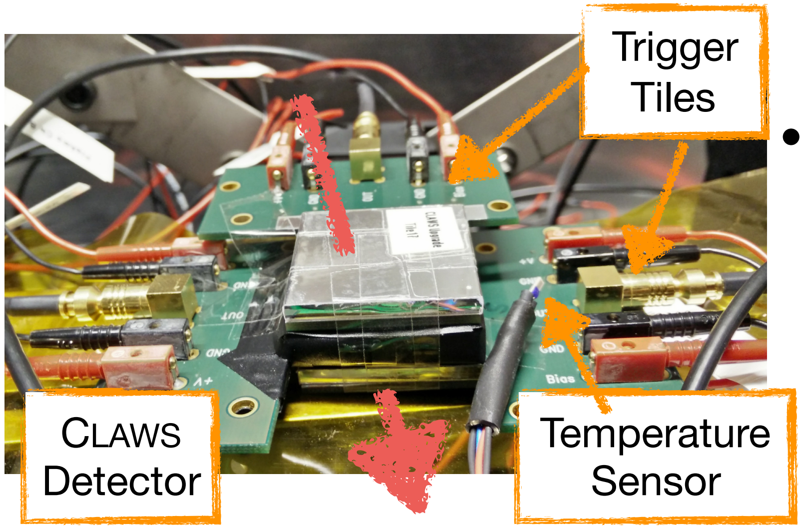

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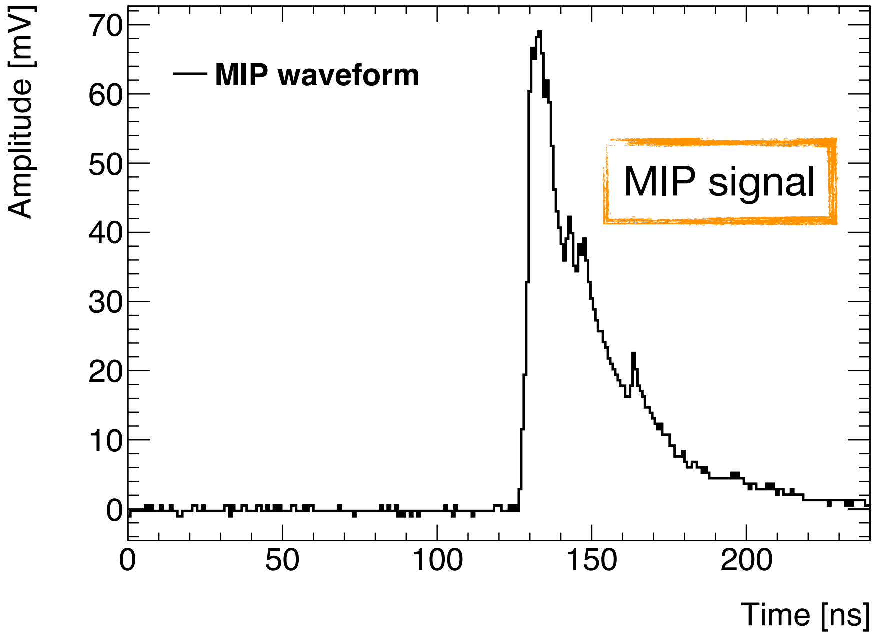

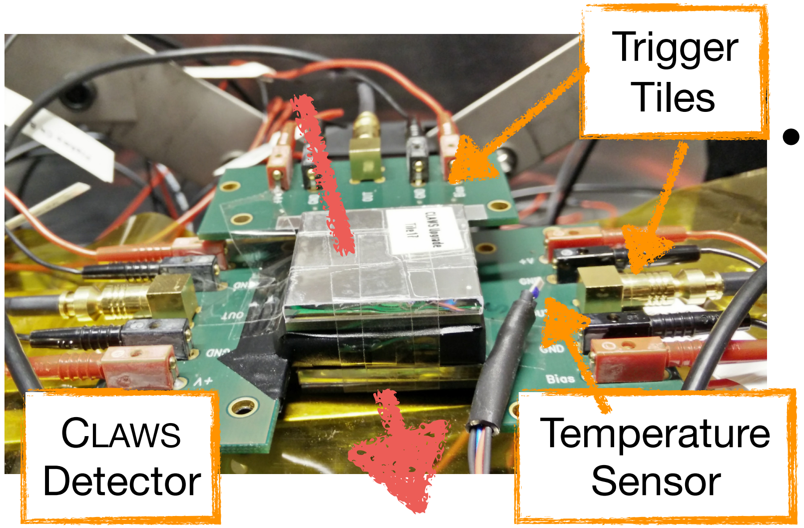

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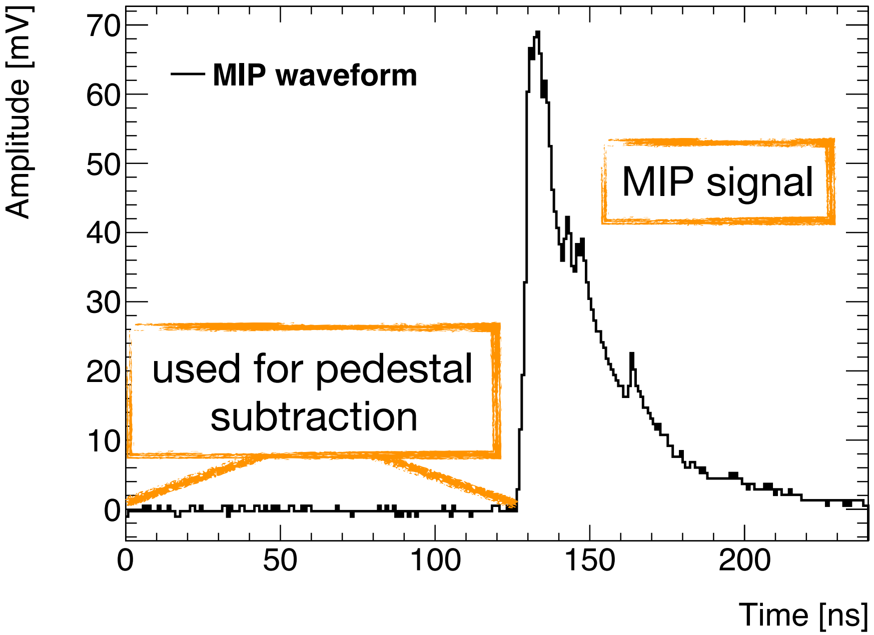

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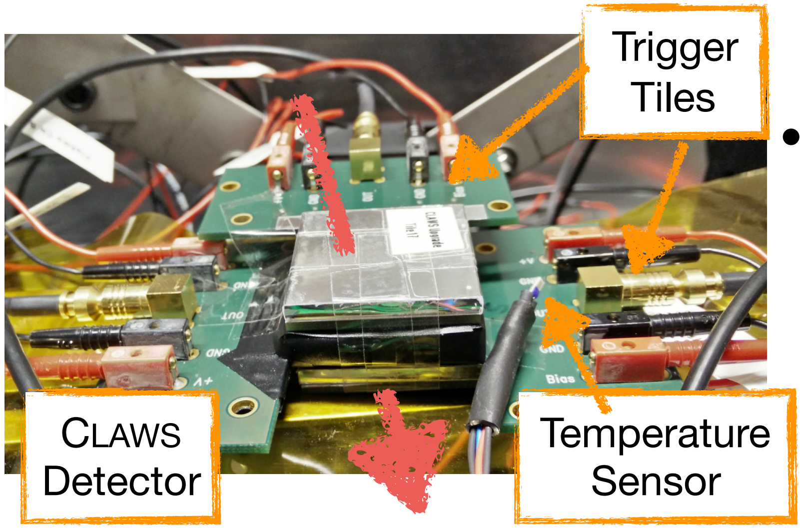

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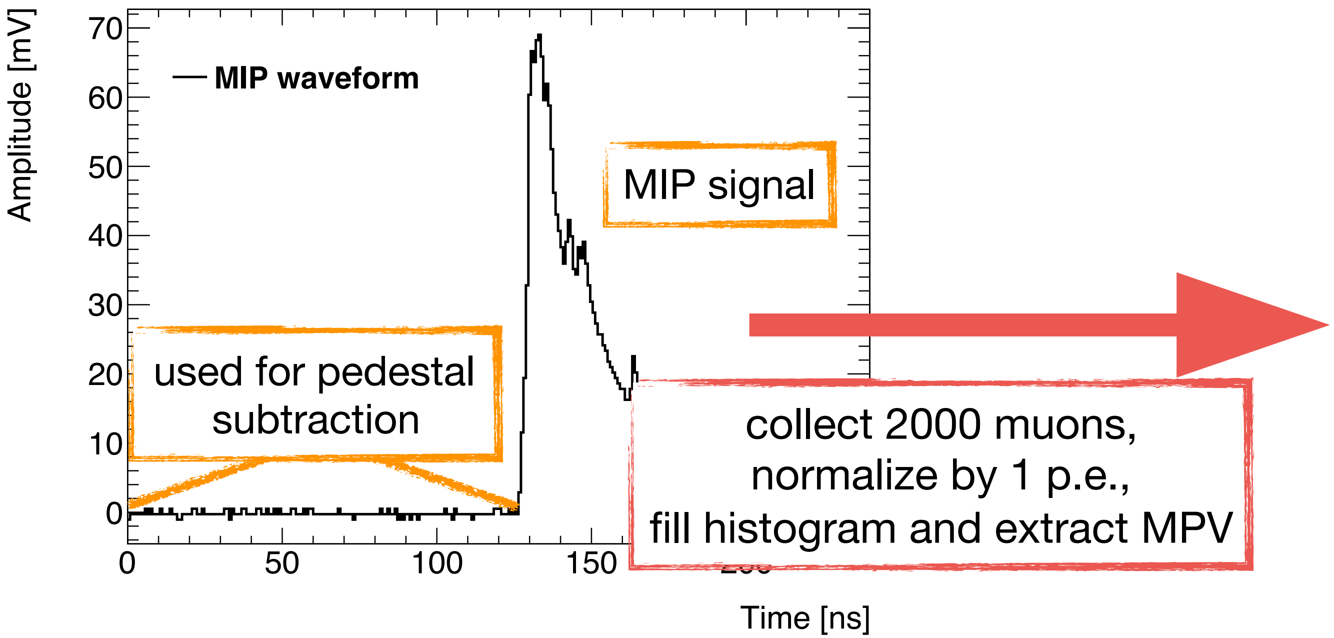

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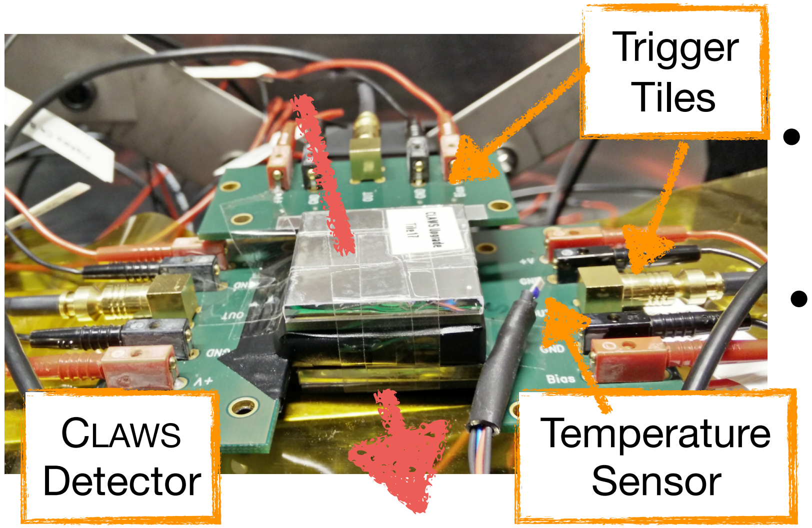
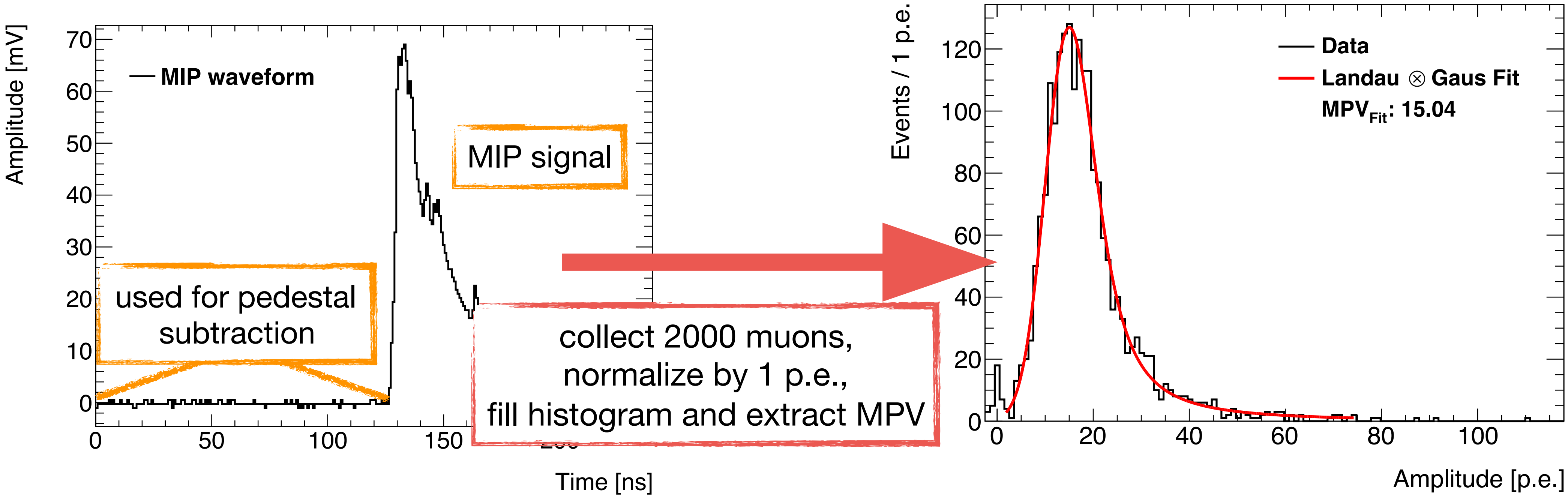


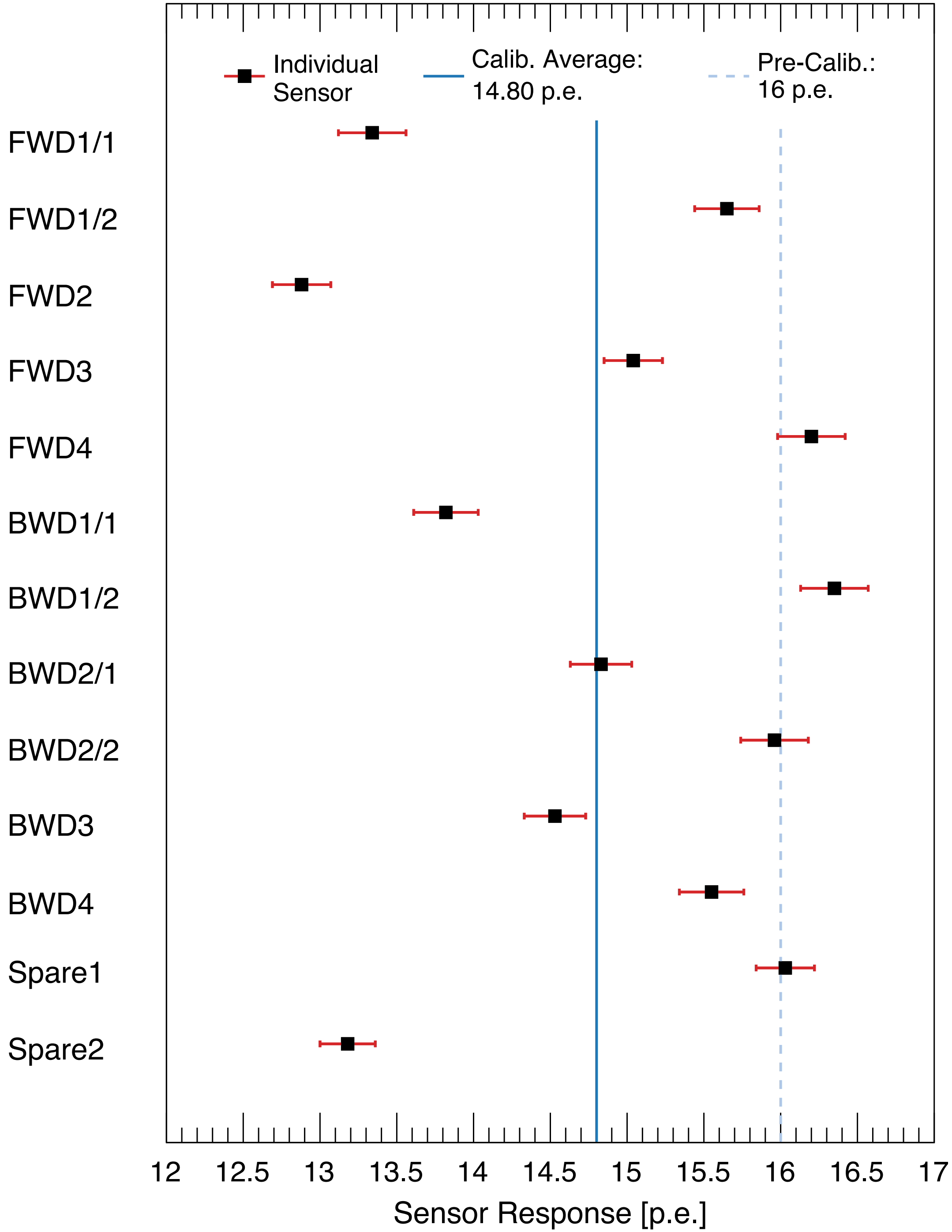
- Minimum Ionizing Particle (MIP) calibration

- follows Landau convoluted Gaussian distribution
  - extraction of the most probable value here: ~15 p.e.



Calibration Results

- final average 14.80 p.e. with ±1.5 p.e. spread
- shown errors are of statistical origin
- systematic error due to packaging much larger



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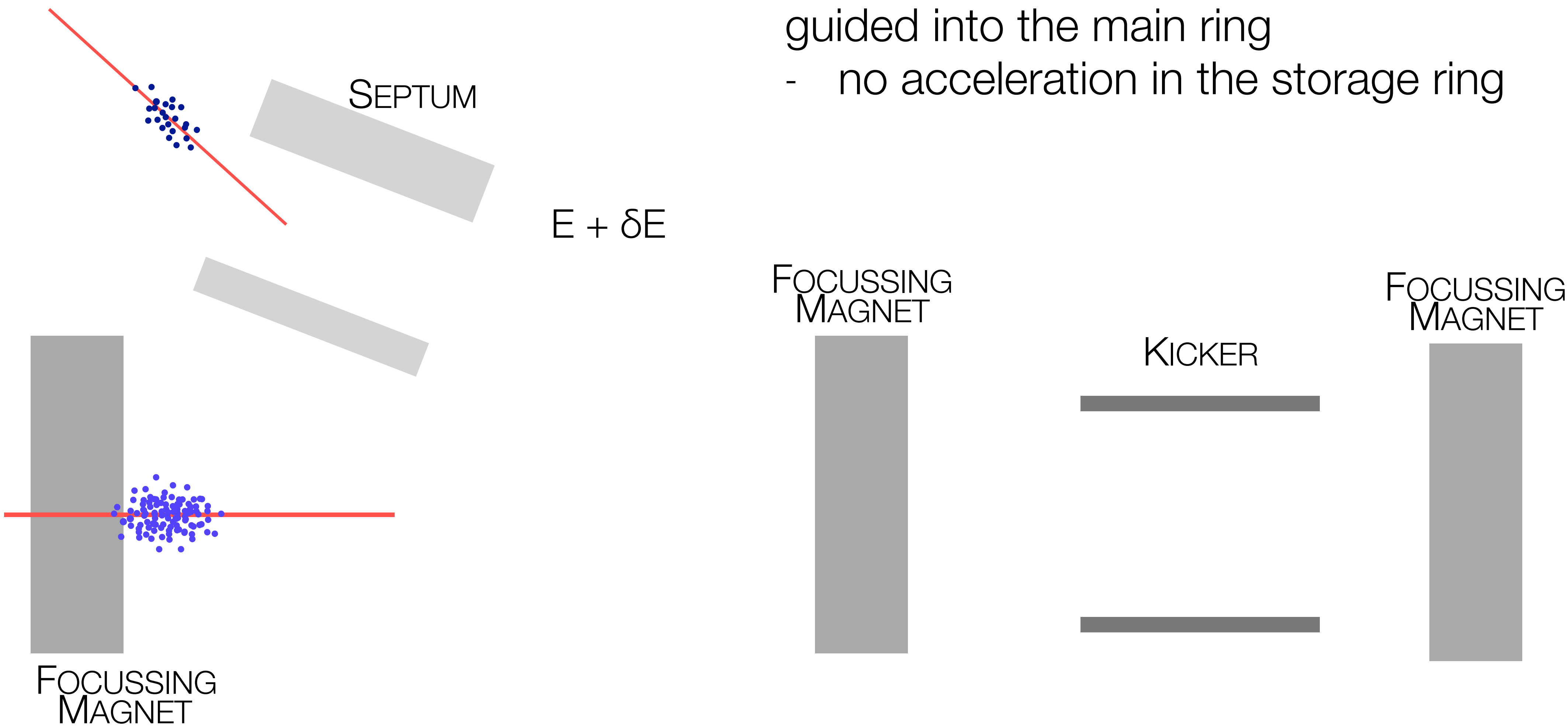
Folientitel

- daughter bunch with **full energy** is guided into the main ring
  - no acceleration in the storage ring



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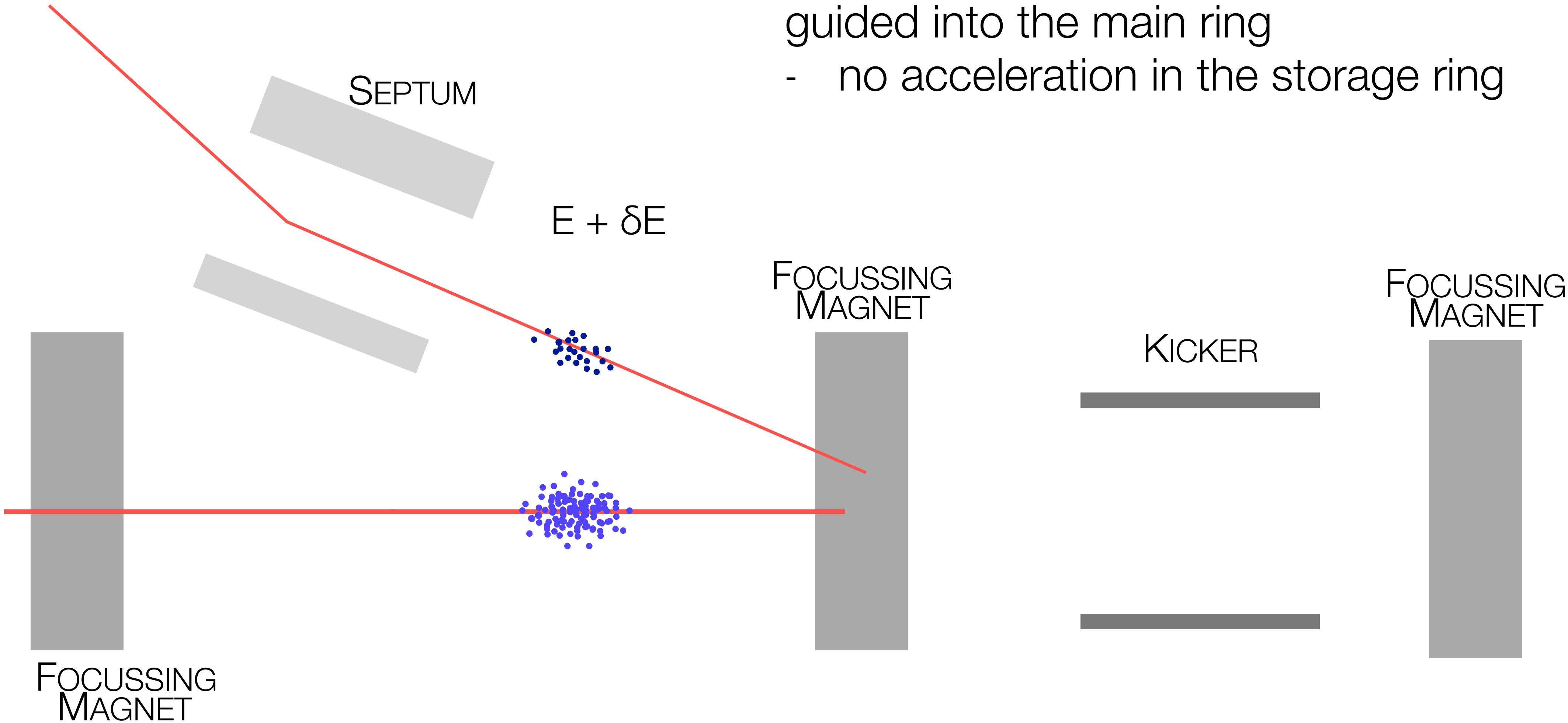

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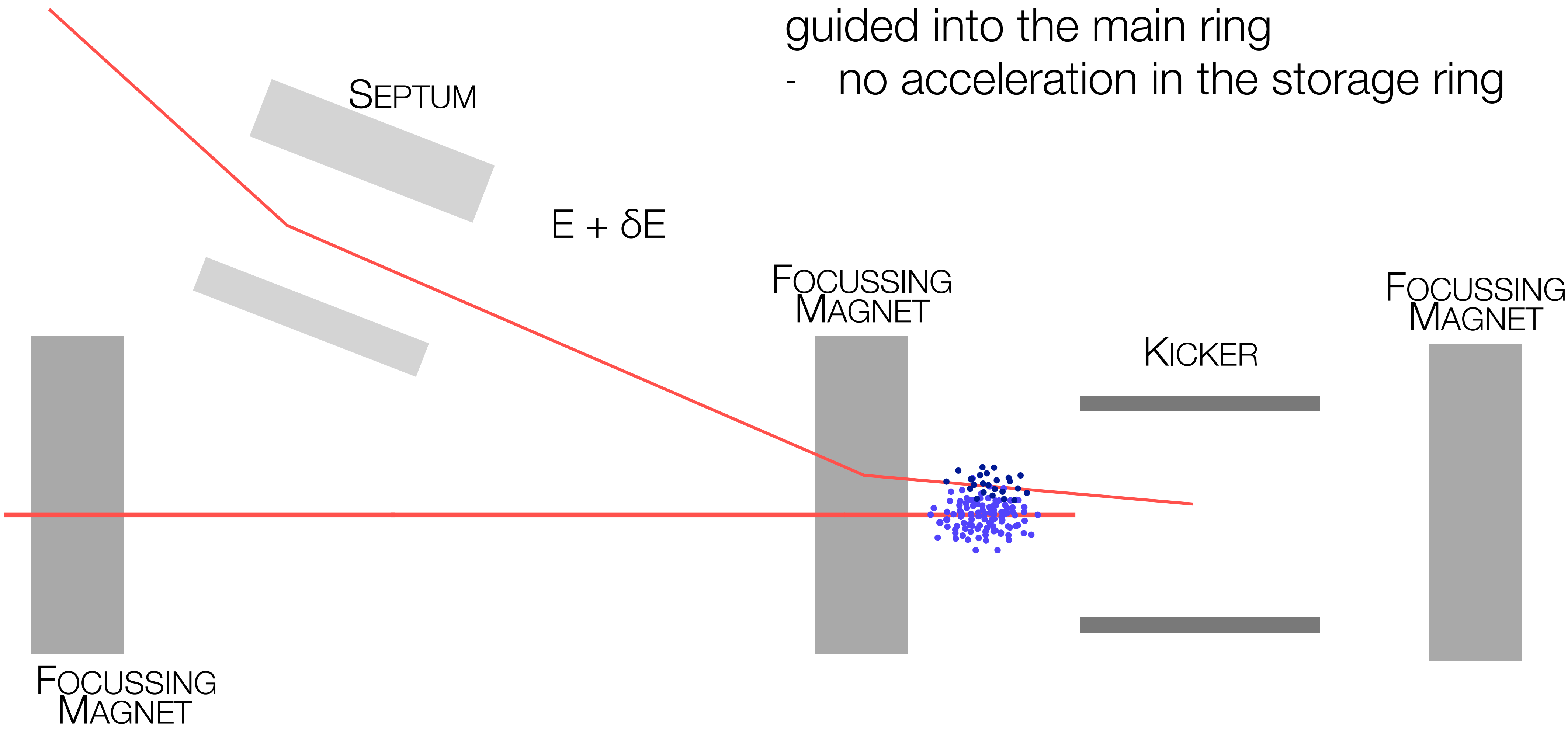

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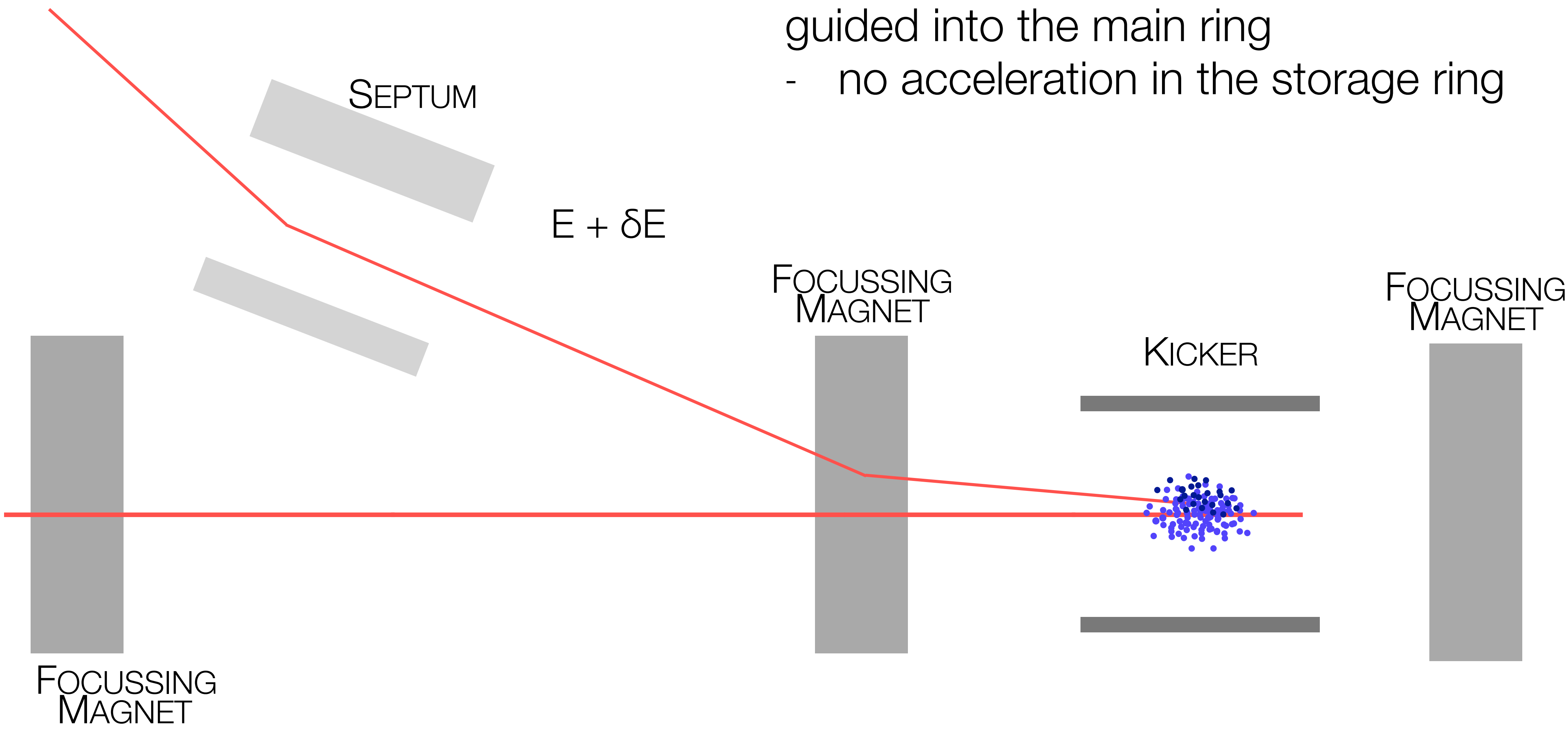

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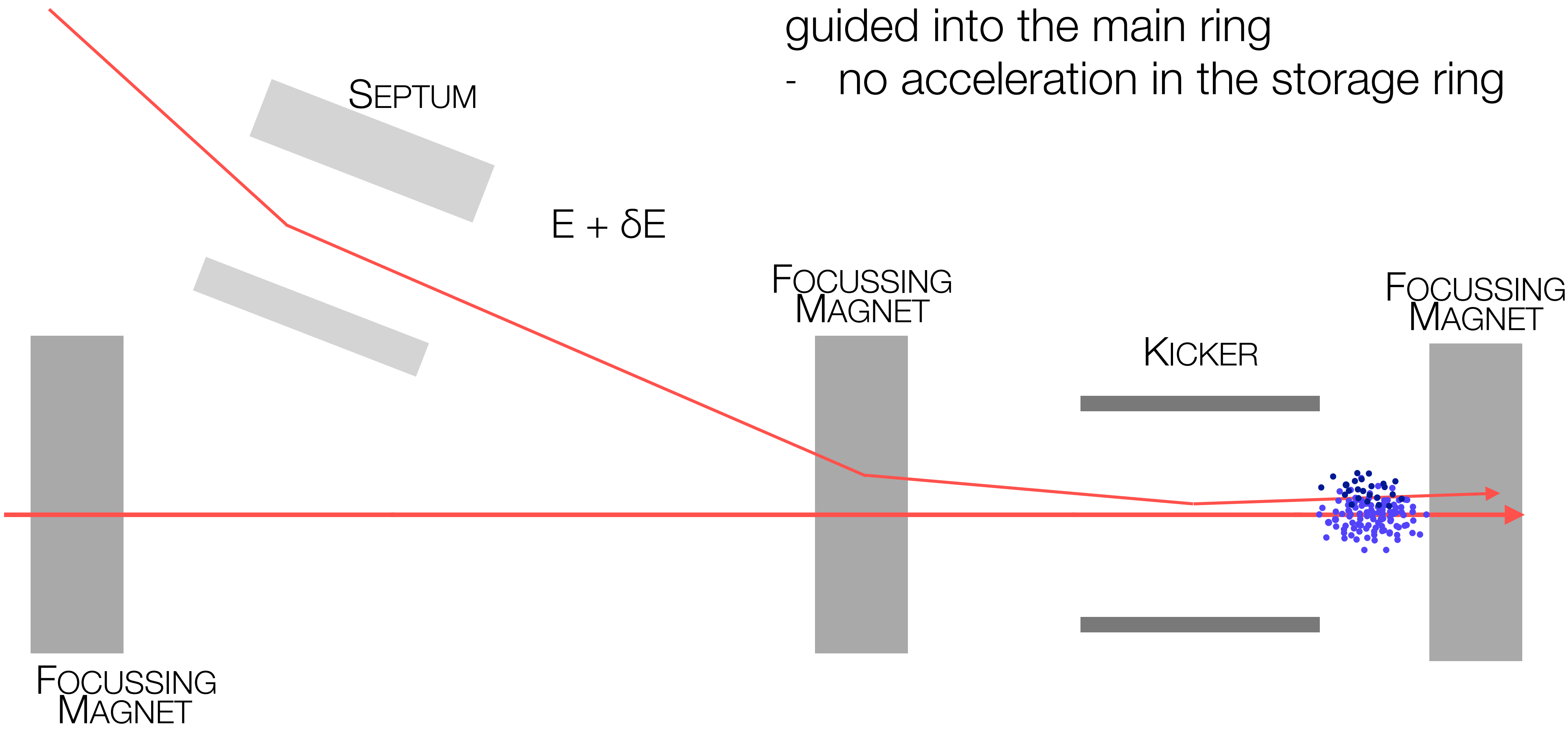

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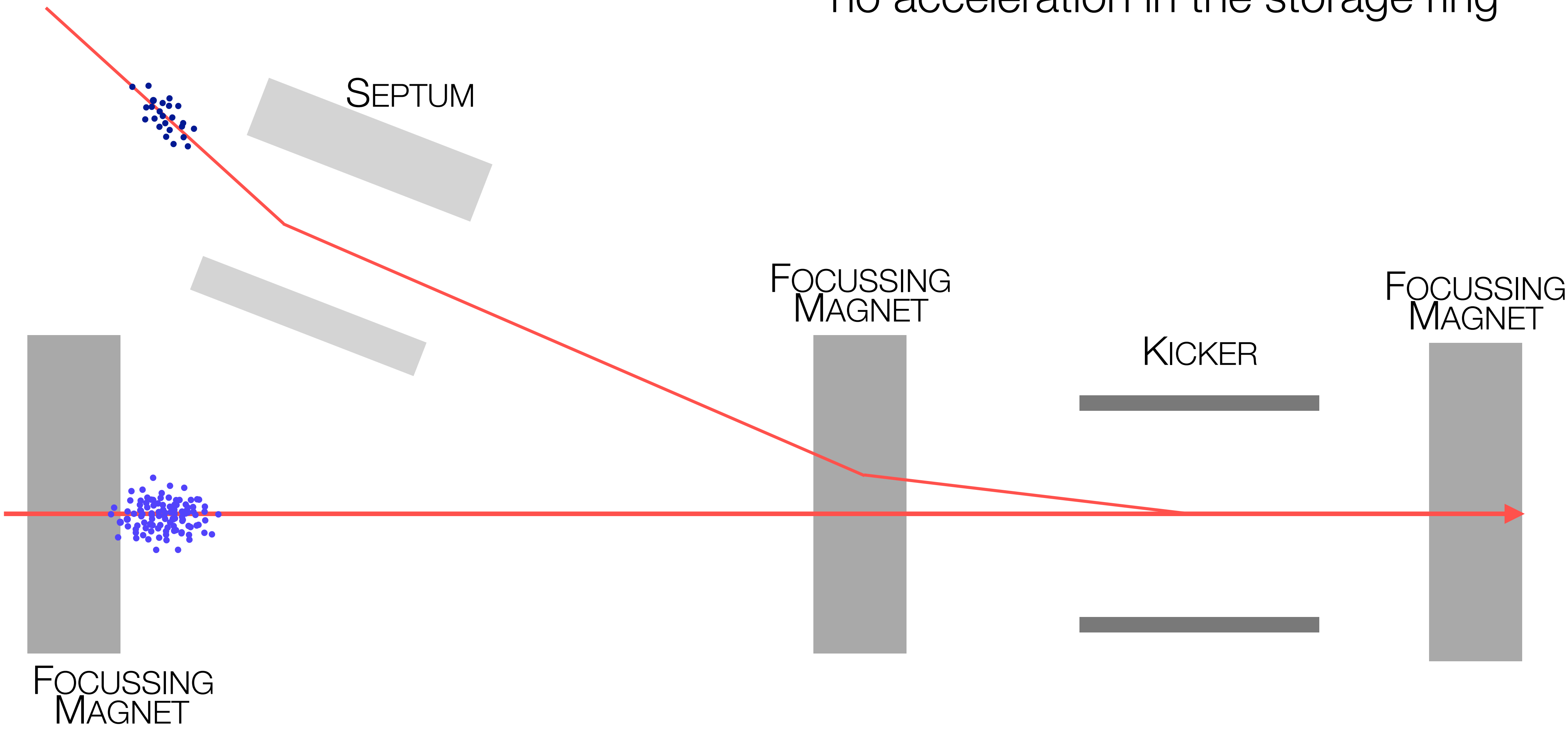

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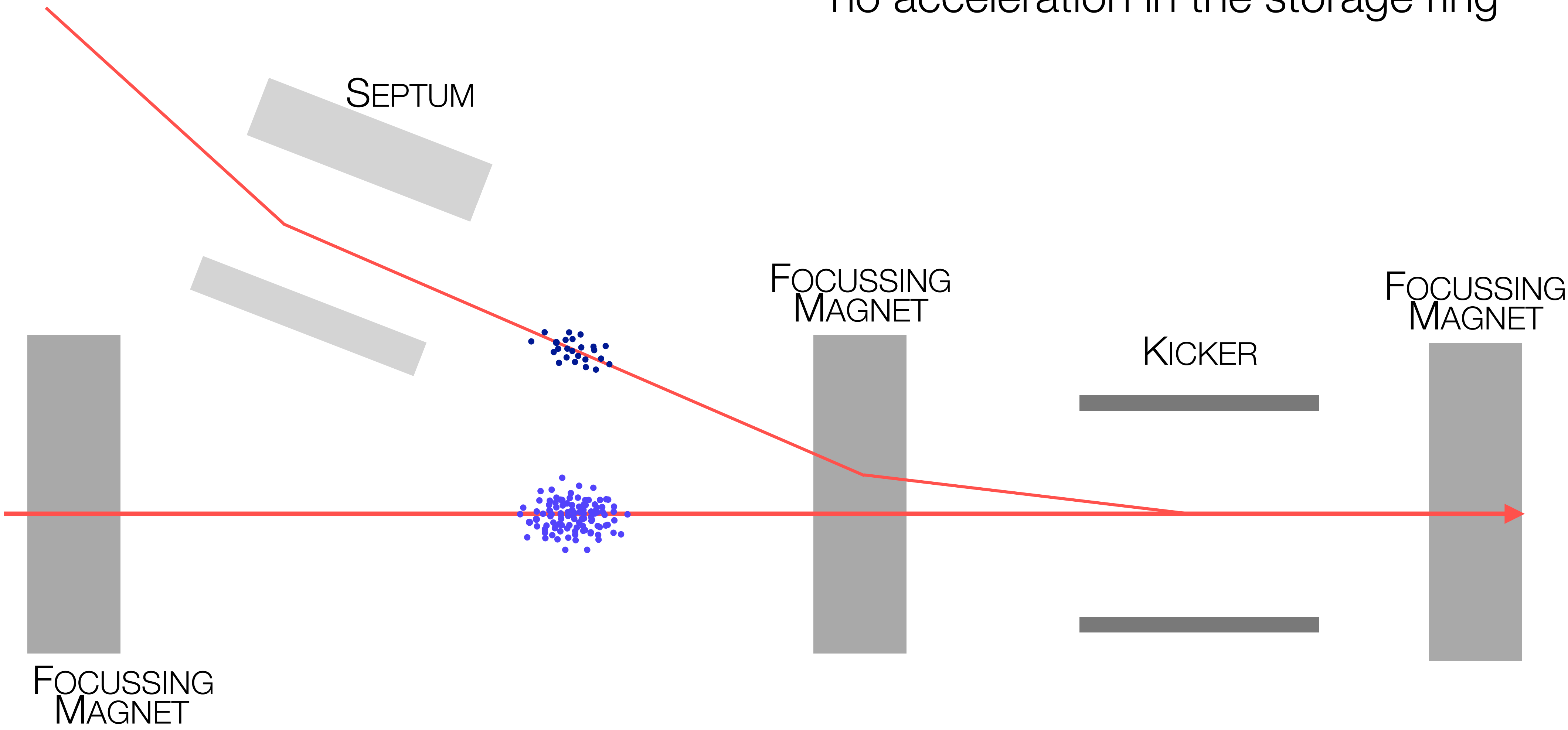

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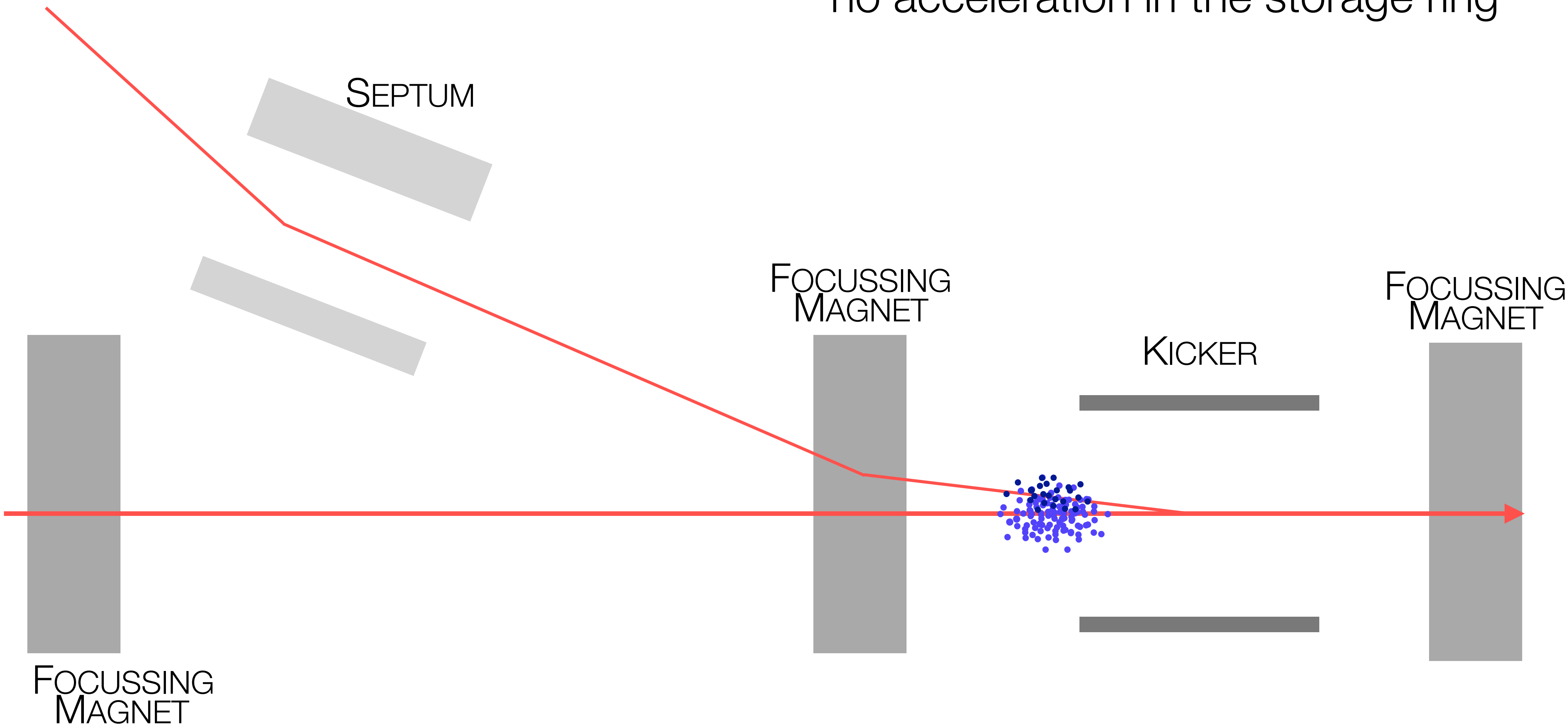

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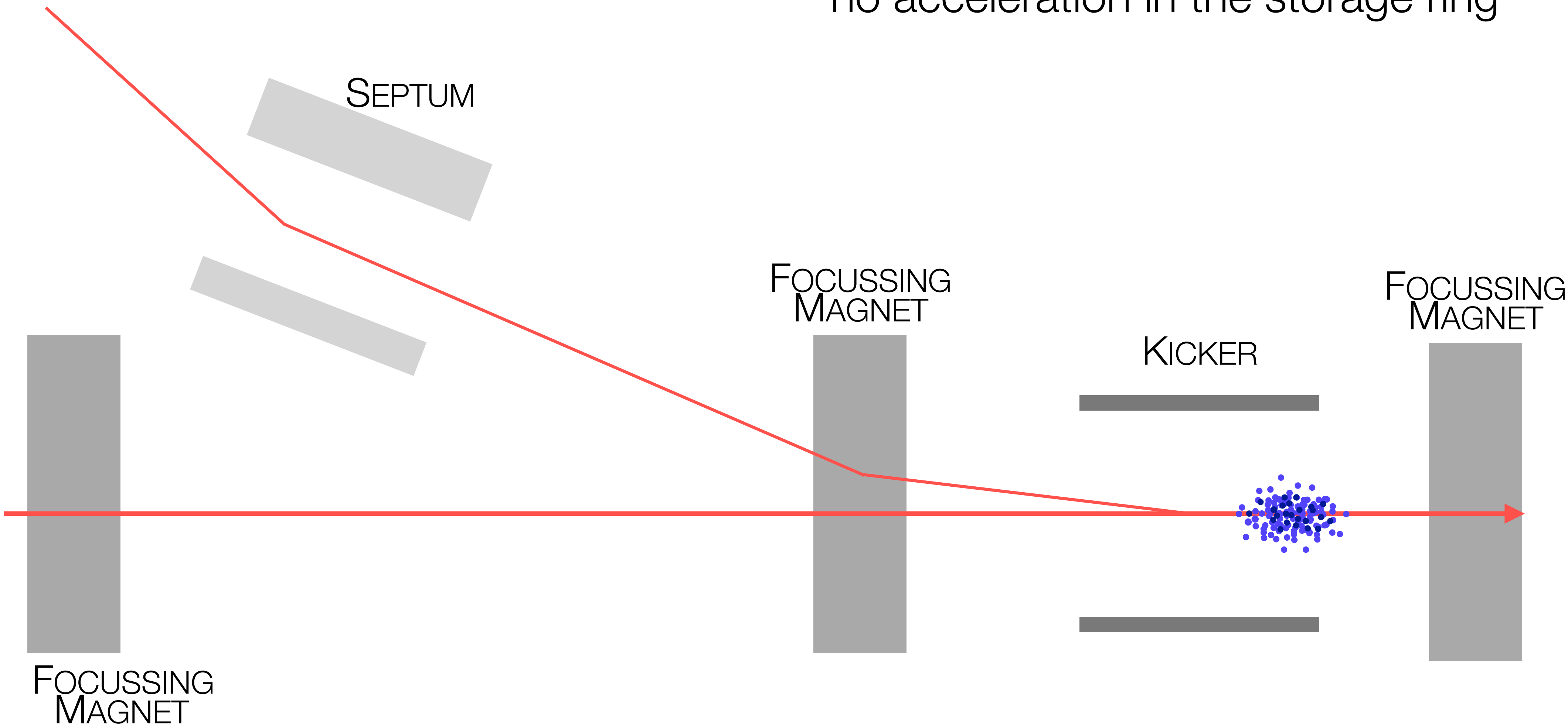

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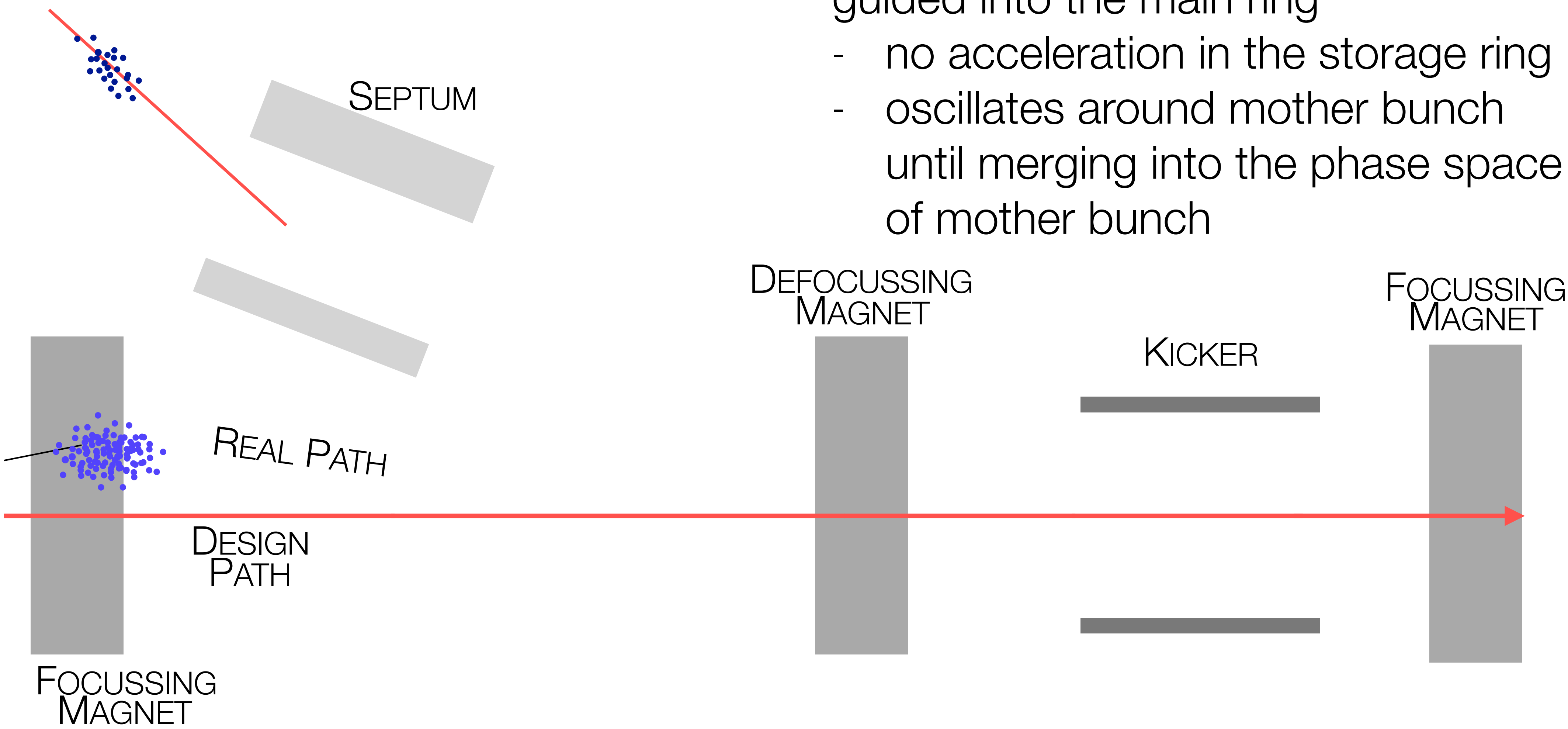
  - oscillates around mother bunch until merging into the phase space of mother bunch



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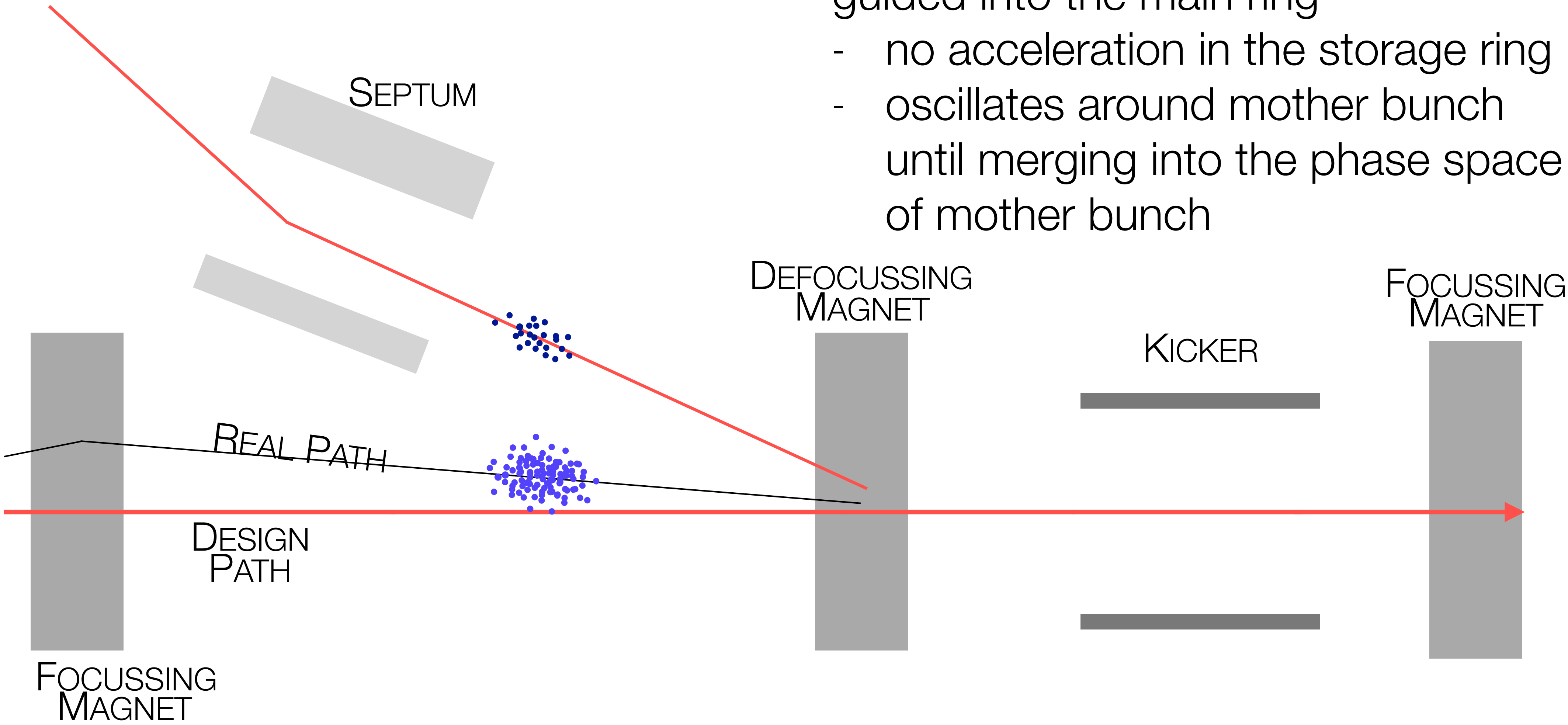

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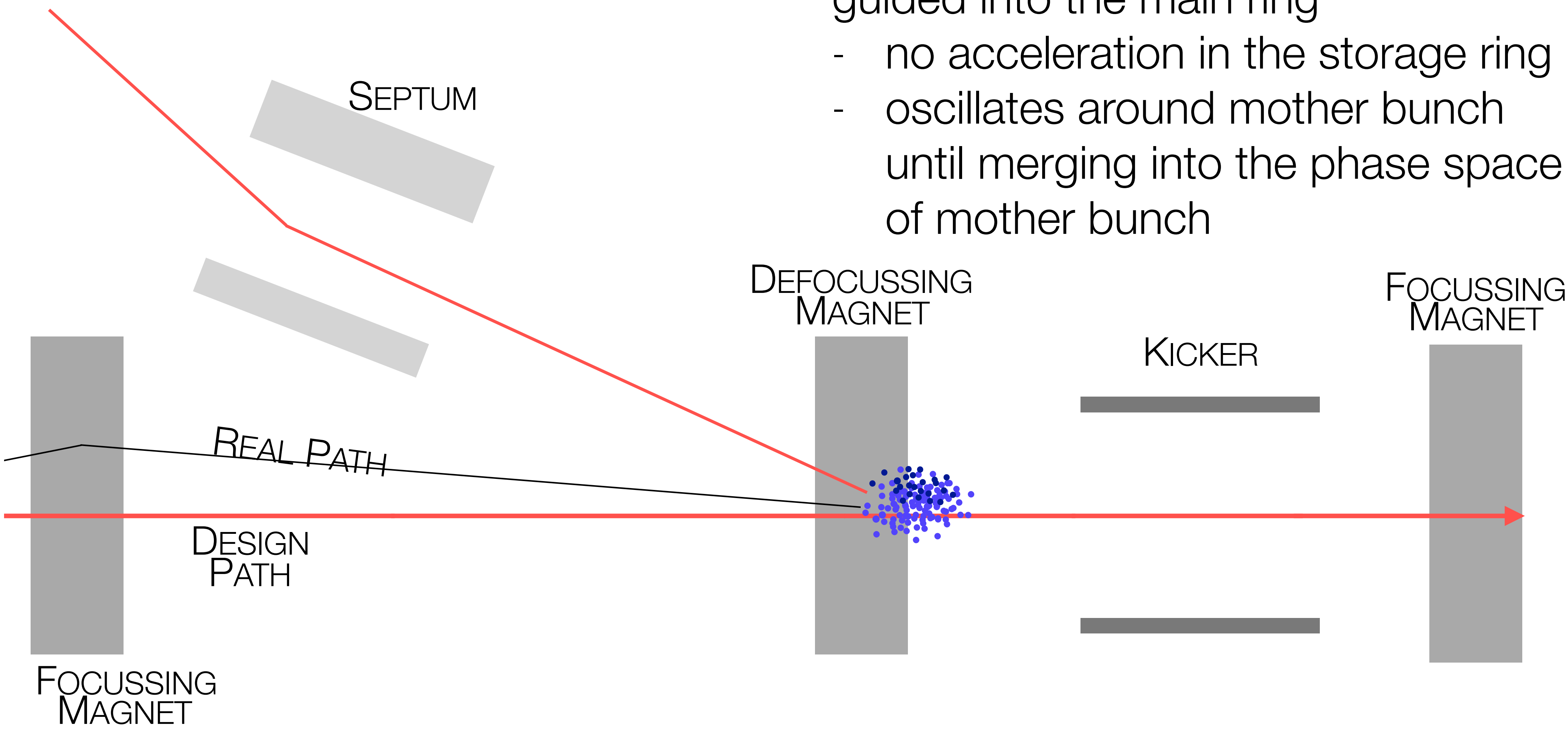

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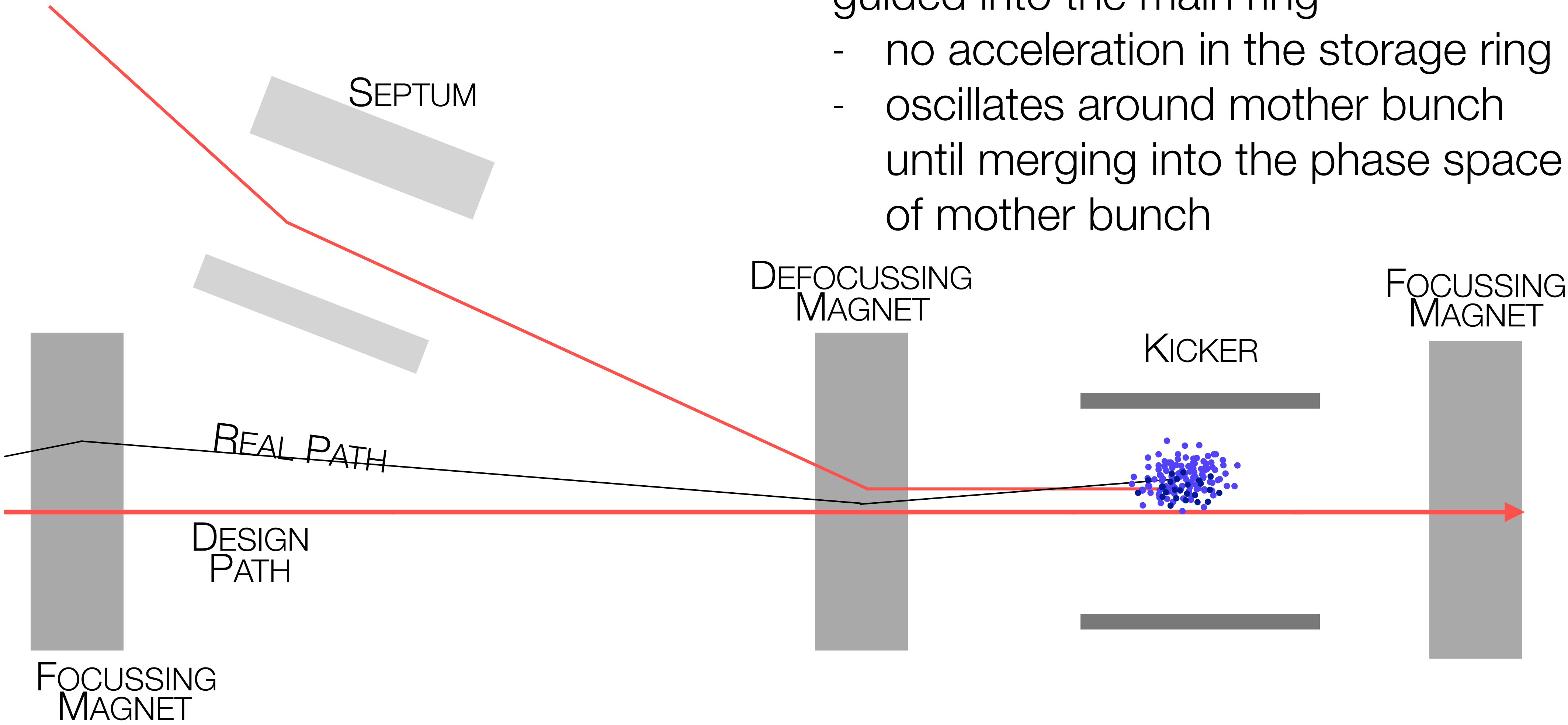

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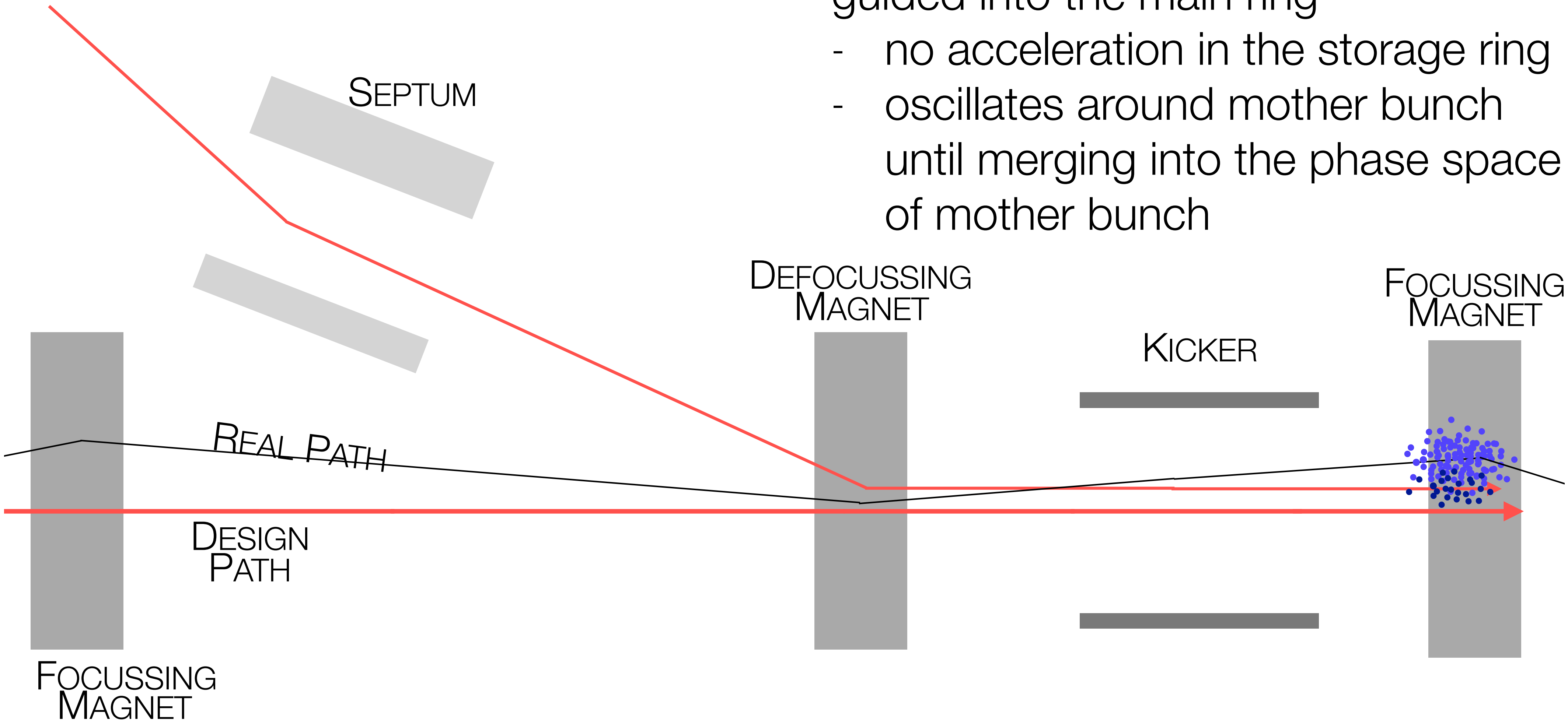

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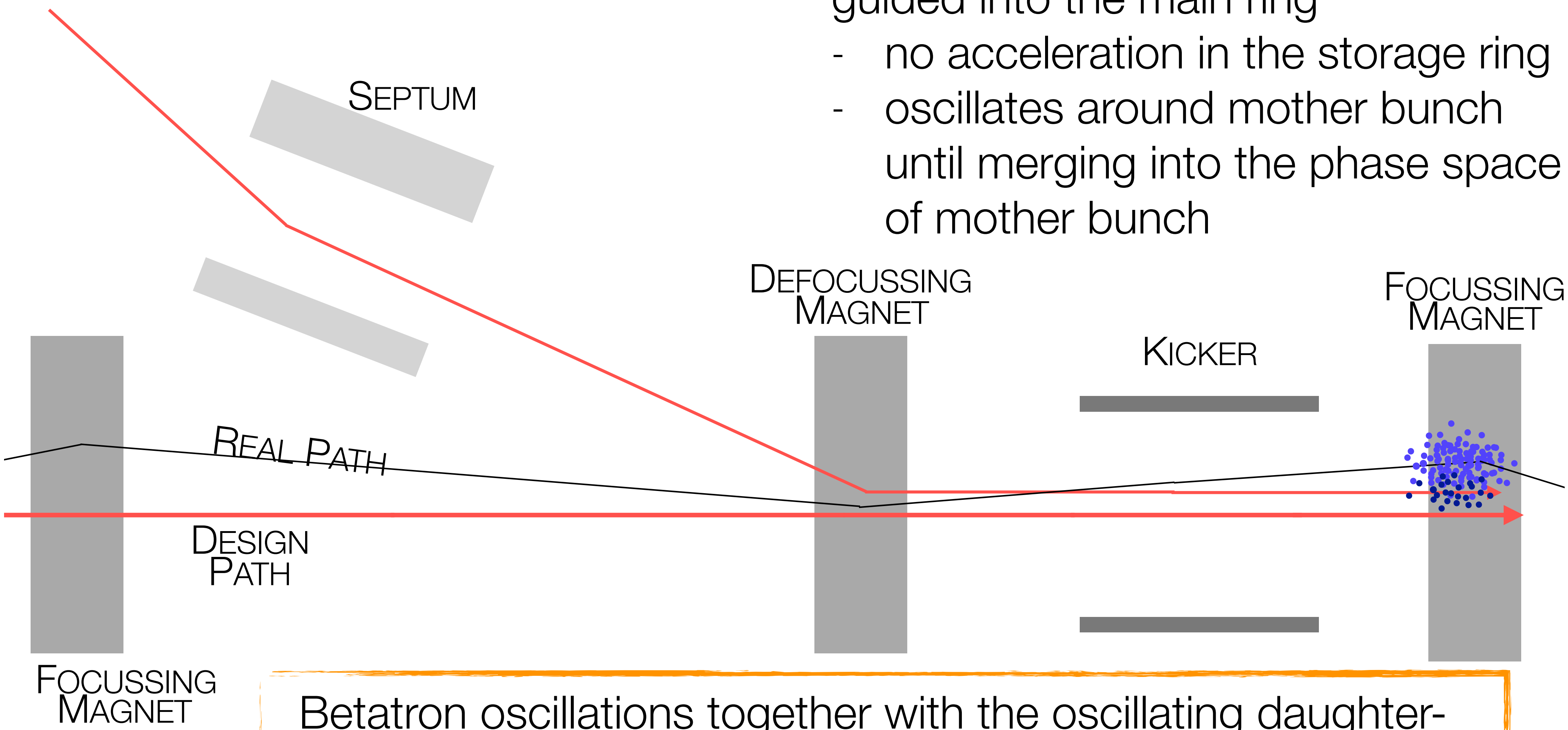

Betatron oscillations together with the oscillating daughter-mother bunches results in a huge particle loss

- beam-beam interactions
- contact with beam pipe