The Spin Dynamics Simulation Suite POLE

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Bundesministerium
für Bildung
und Forschung

universitätbonn

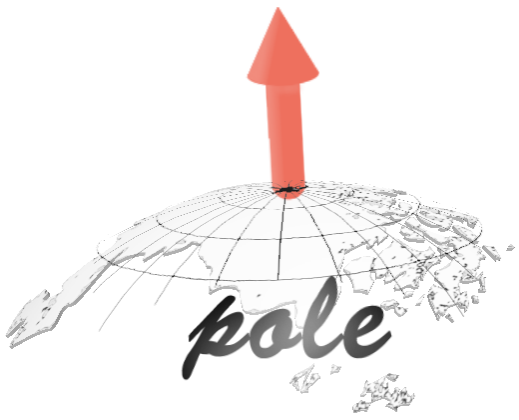
ELSA

Purpose of POLE

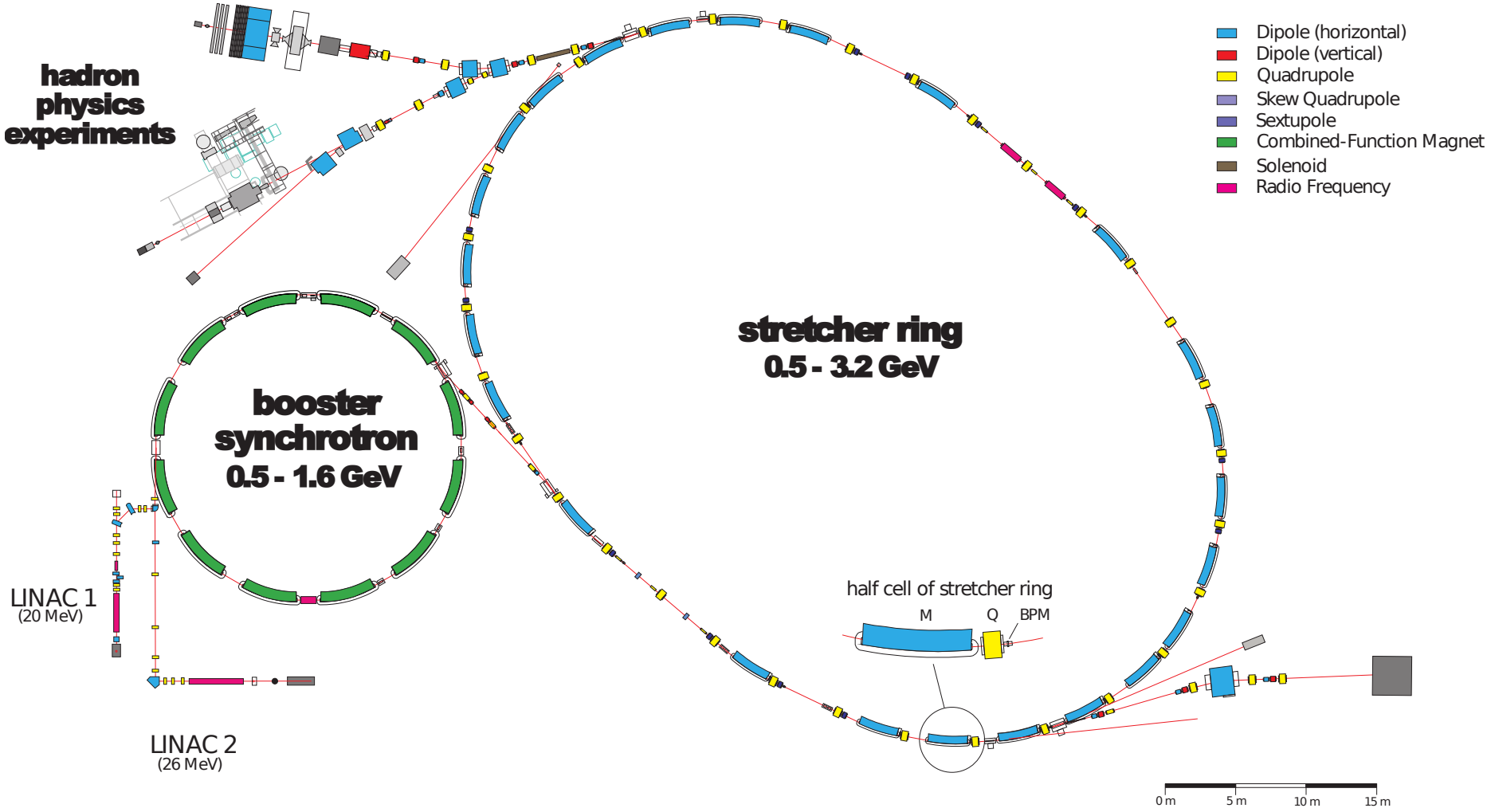
Simulating polarization

- energy of some GeV
- time scale $<$ seconds
- energy ramps

- crossing isolated depolarizing resonances
- synchrotron motion & radiation effects
- not: equilibrium polarization



Electron Stretcher Accelerator



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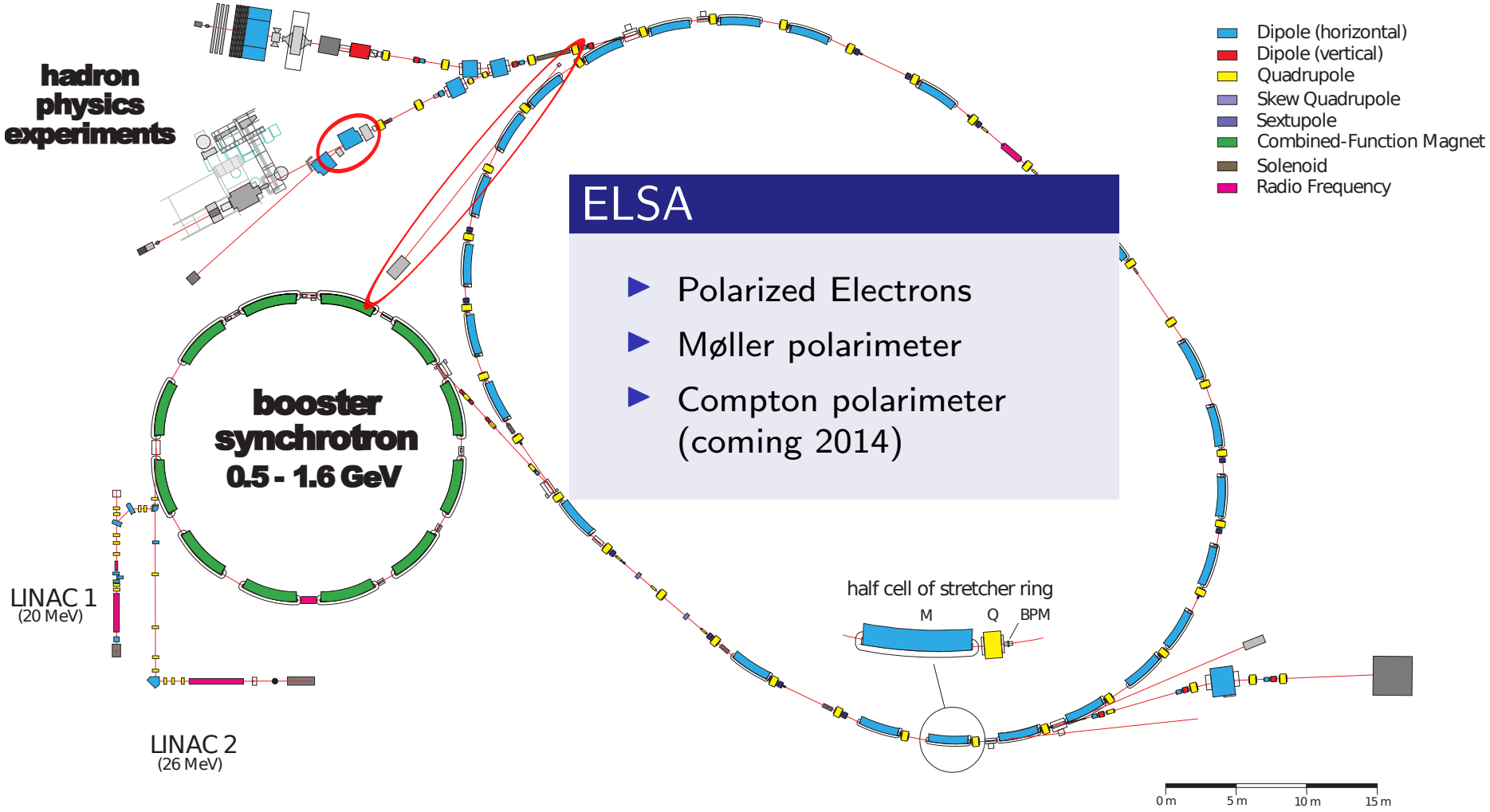
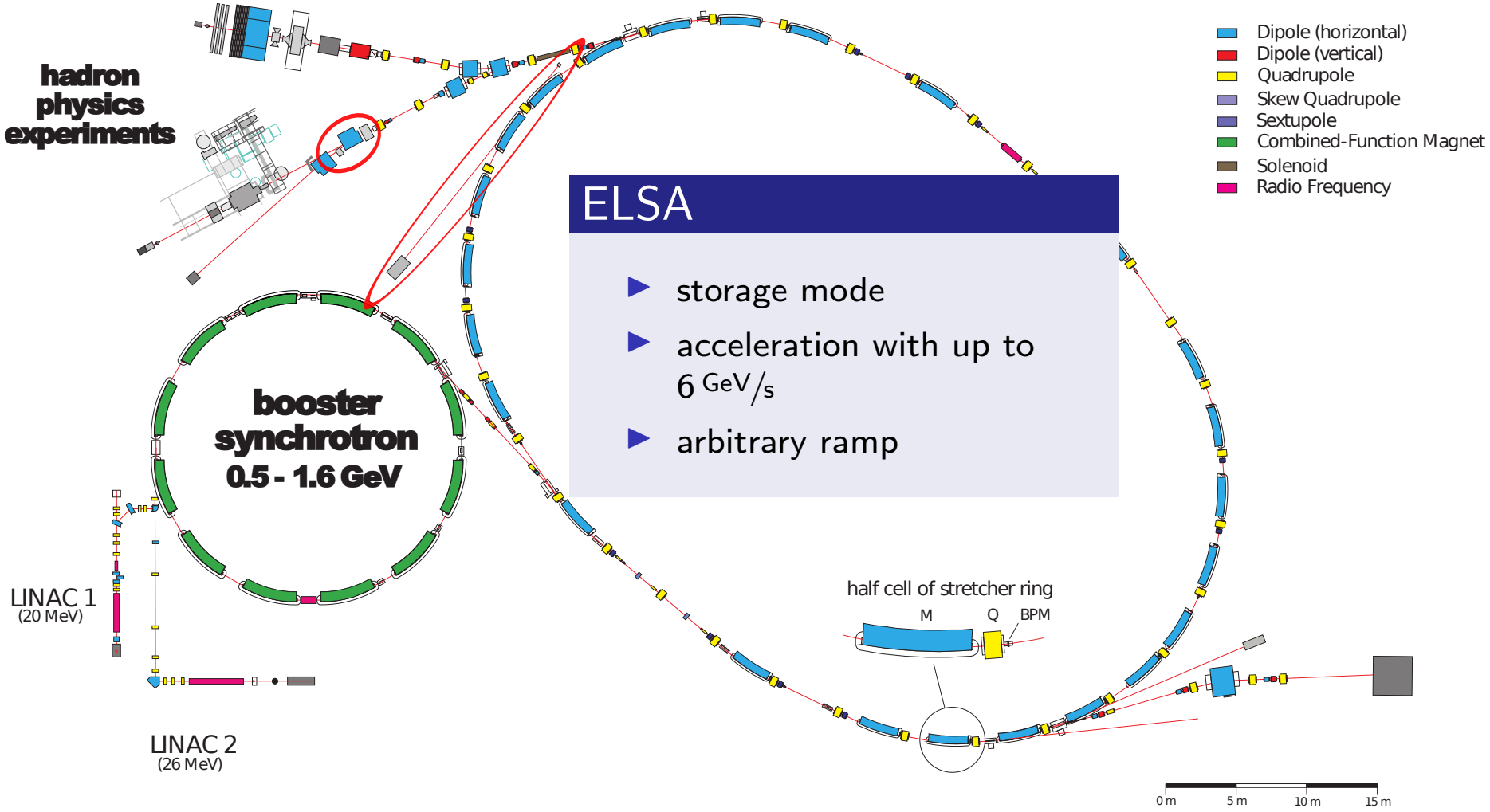


ELSA

- Polarized Electrons
- Møller polarimeter
- Compton polarimeter (coming 2014)

Electron Stretcher Accelerator



ELSA

- storage mode
- acceleration with up to 6 GeV/s
- arbitrary ramp

Purpose of POLE

fast

- ✓ 'get an idea'
- ✓ systematic parameter studies
- ✓ balance accuracy against computing time

accessible

- ✓ regular desktop PCs
- ✓ using MAD-X & Elegant
- ✓ open source release

The basic concept of POLE

Thomas-BMT equation

$$\frac{\mathrm{d}}{\mathrm{d}t}\vec{S}(t) \approx c \cdot \vec{S}(t) \times \left[(1+\gamma(t)a)\,\vec{\tilde{B}}_{\perp}(t) \;+\; (1+a)\,\vec{\tilde{B}}_{\parallel}(t)\right]$$

with $\vec{\tilde{B}} := \frac{e}{p}\vec{B}$

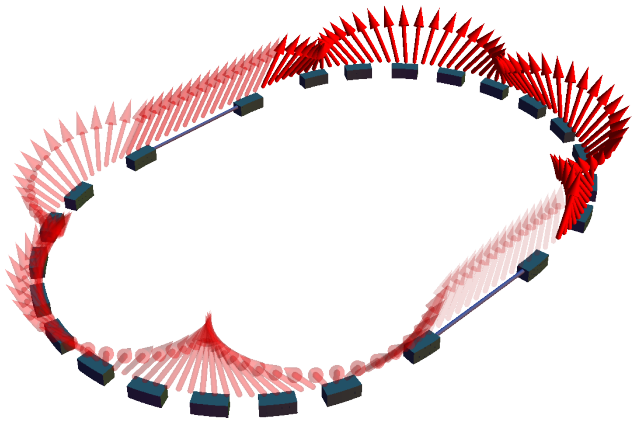
- Runge-Kutta algorithm, adaptive step size
- Polarization

$$\vec{P} = \frac{1}{N}\sum_{i=1}^{N}\vec{S}_i$$

The basic concept of POLE

crossing **integer resonances** at $\gamma(t)a \in \mathbb{N}$

- driven by $\vec{B}_x(t)$ with revolution harmonic frequencies

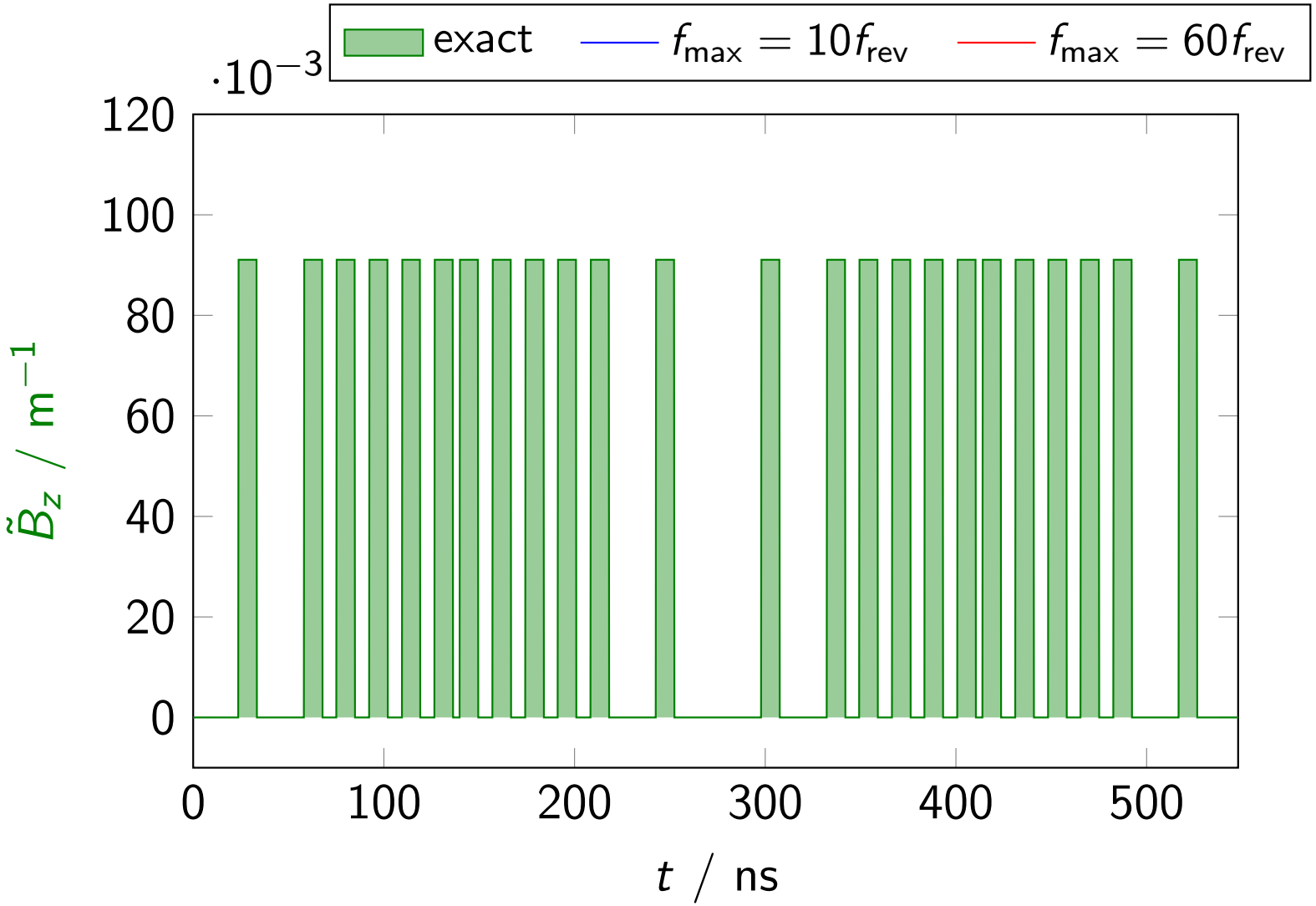


Magnetic Field as Fourier Series

$$\tilde{B}(t) \approx \sum_i A_i \cos(2\pi f_i \cdot t + \varphi_i) \quad \text{with} \quad f_i = i \cdot f_{\text{rev}}$$

Frequency filtering of magnetic fields

Vertical magnetic fields (one revolution)



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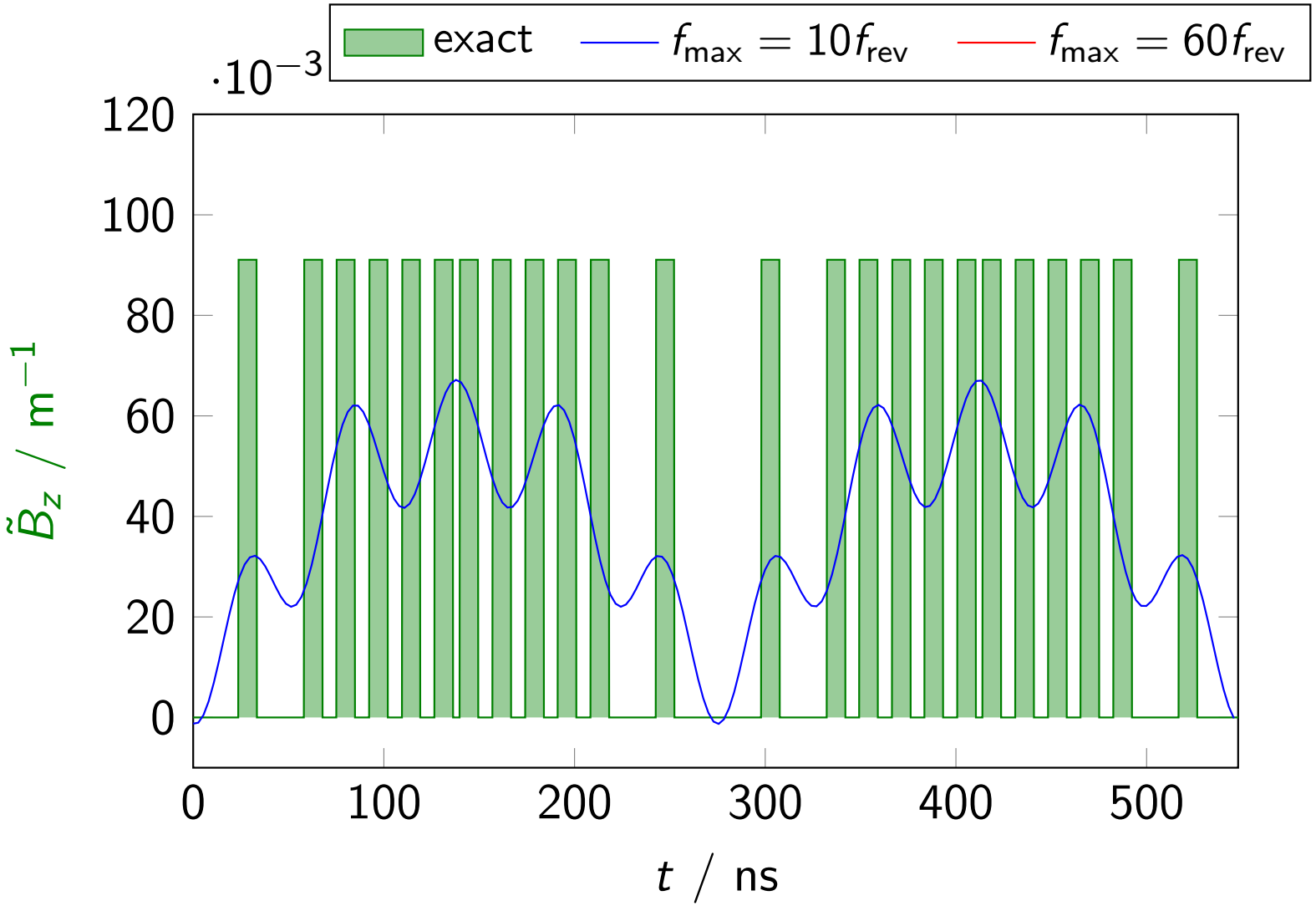

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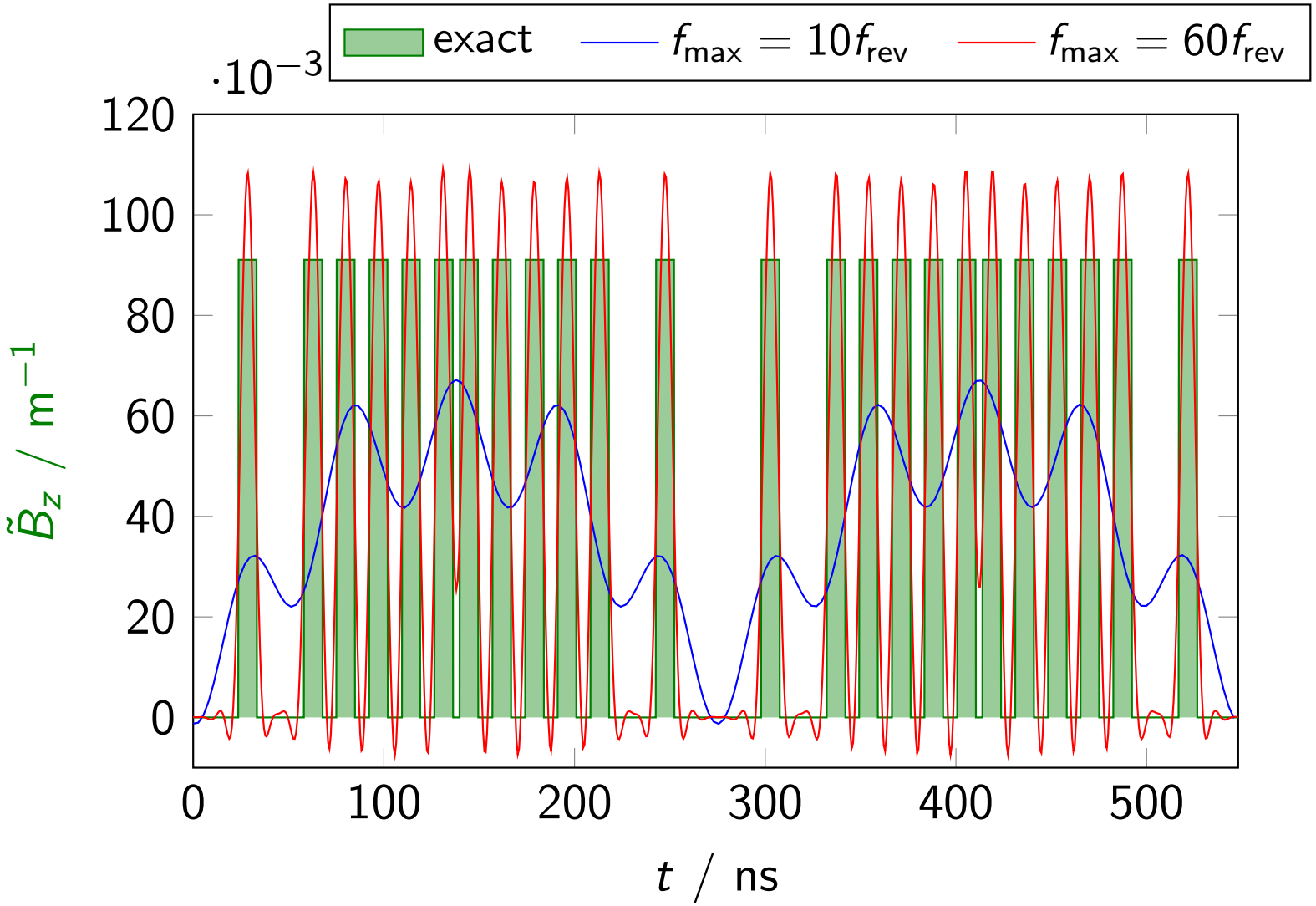
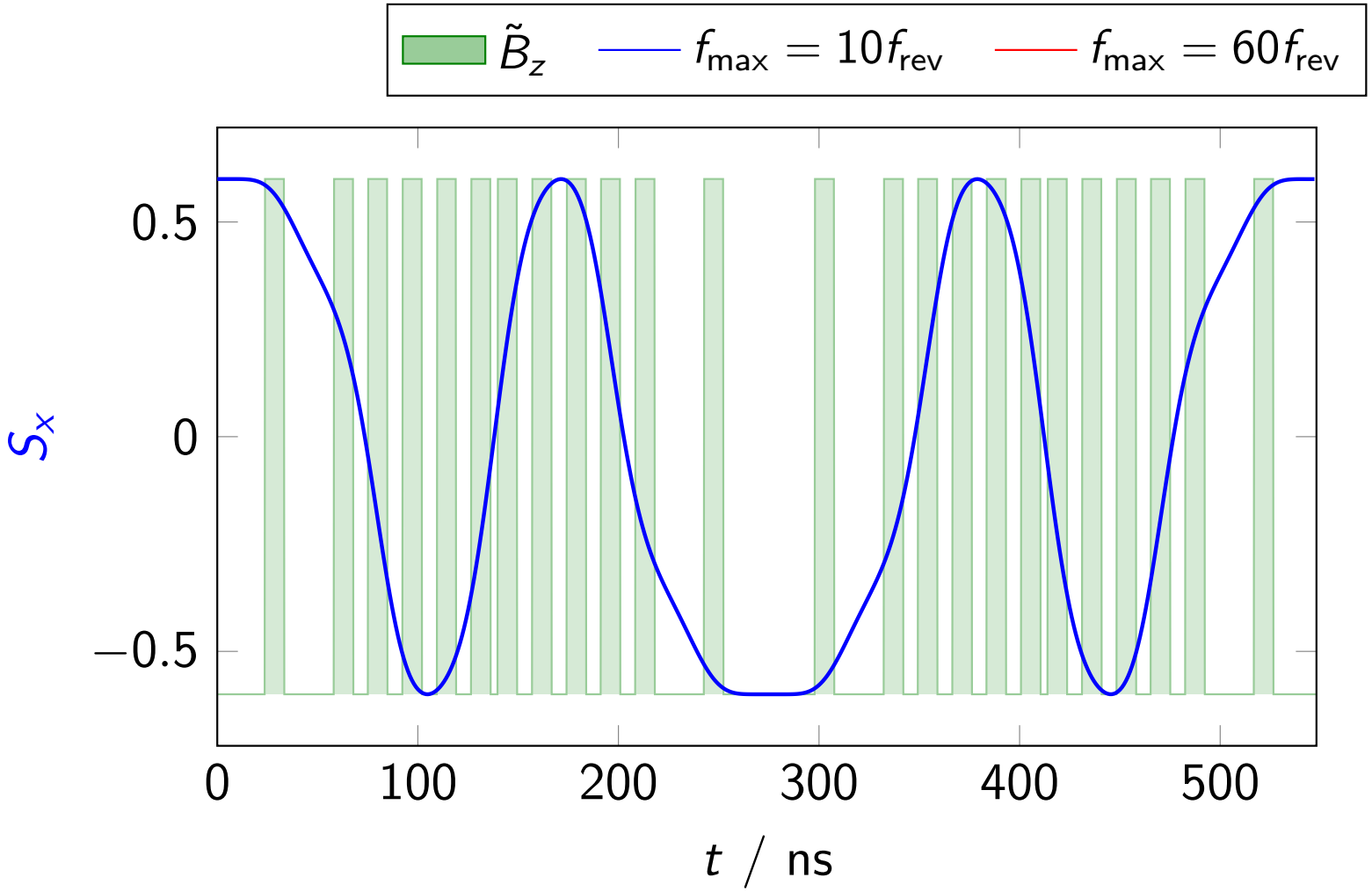


Frequency filtering of magnetic fields

Spin precession during one revolution ($\gamma a = 3$)



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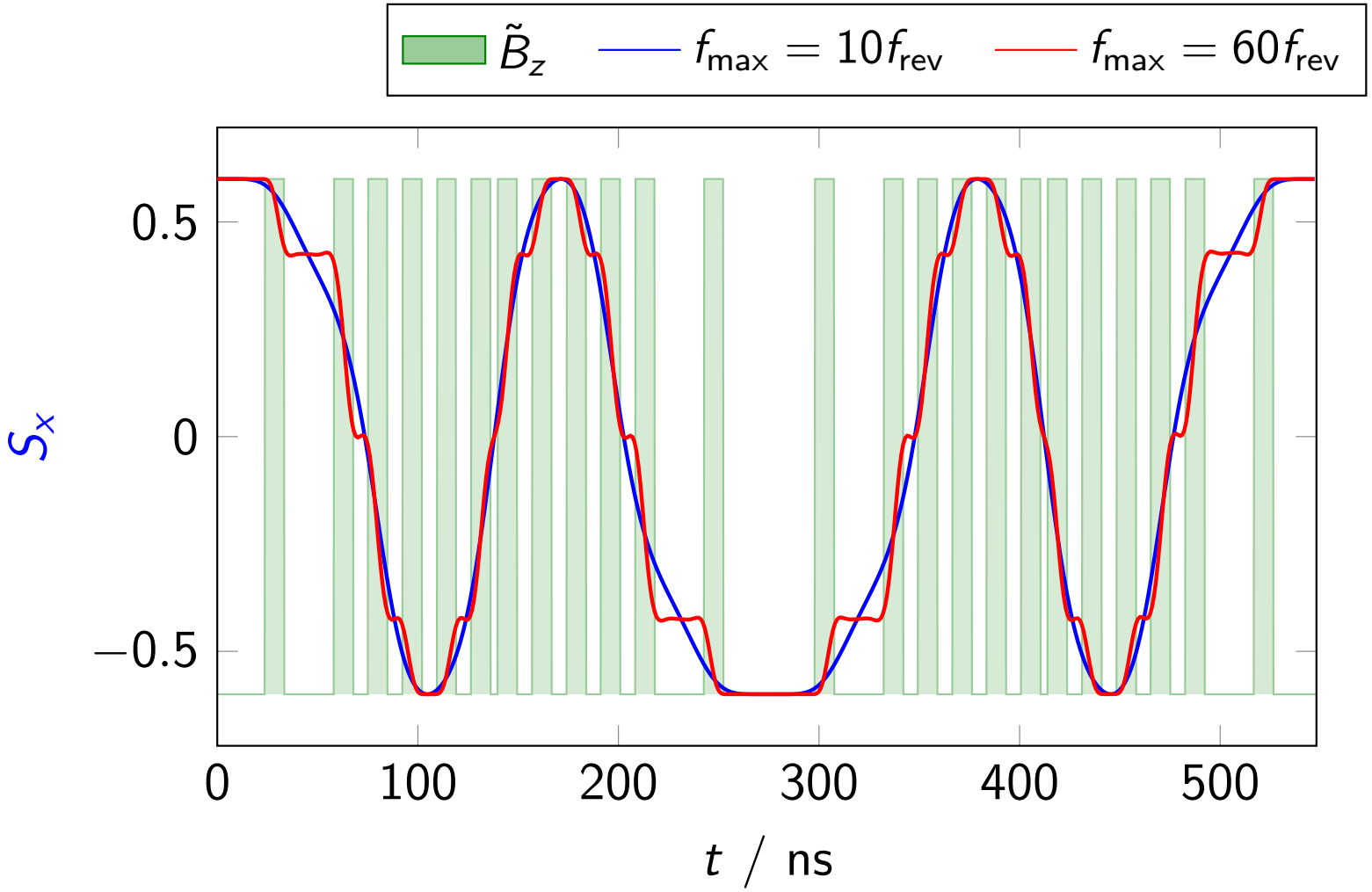
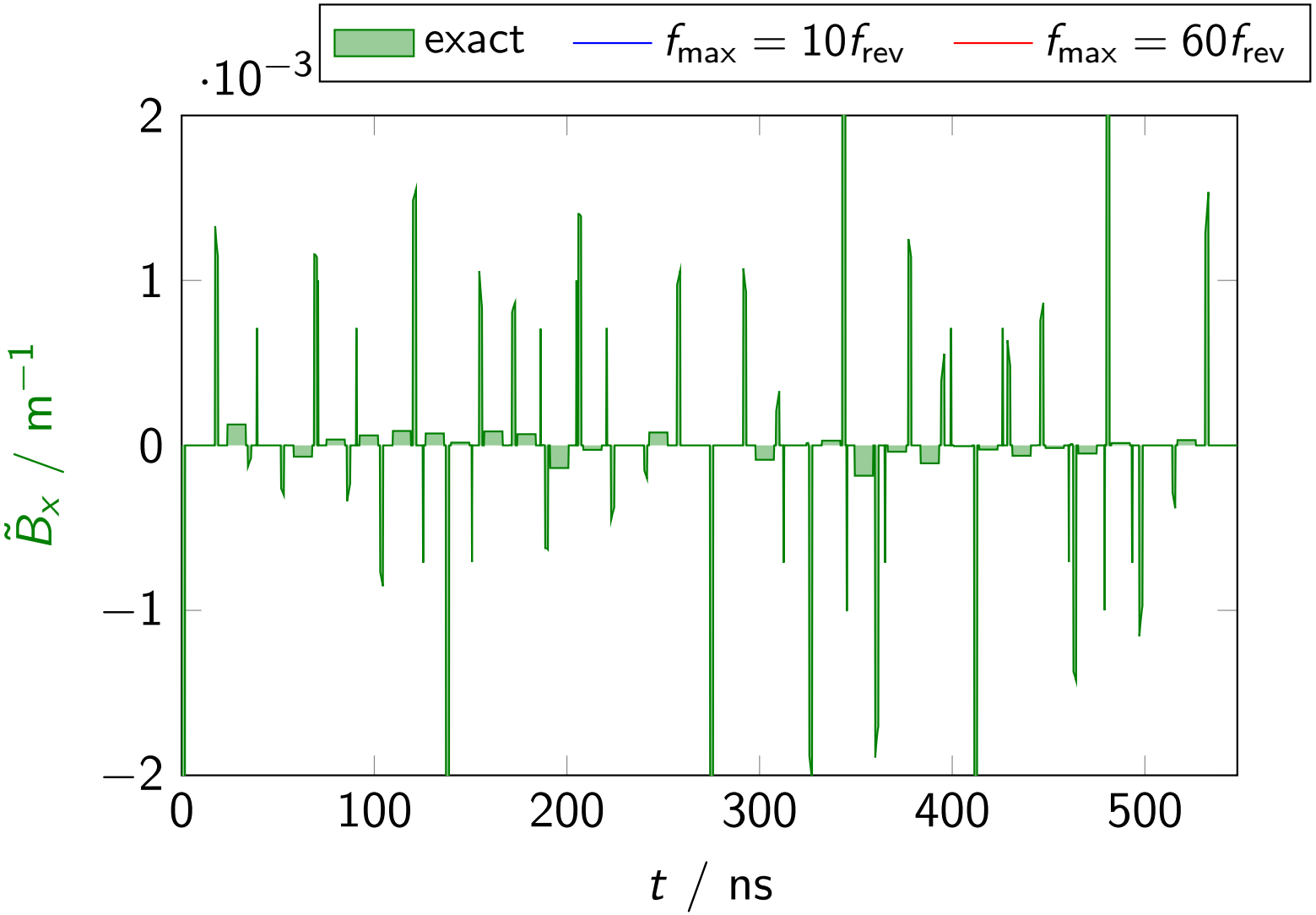


Frequency filtering of magnetic fields

Horizontal magnetic fields



Frequency filtering of magnetic fields

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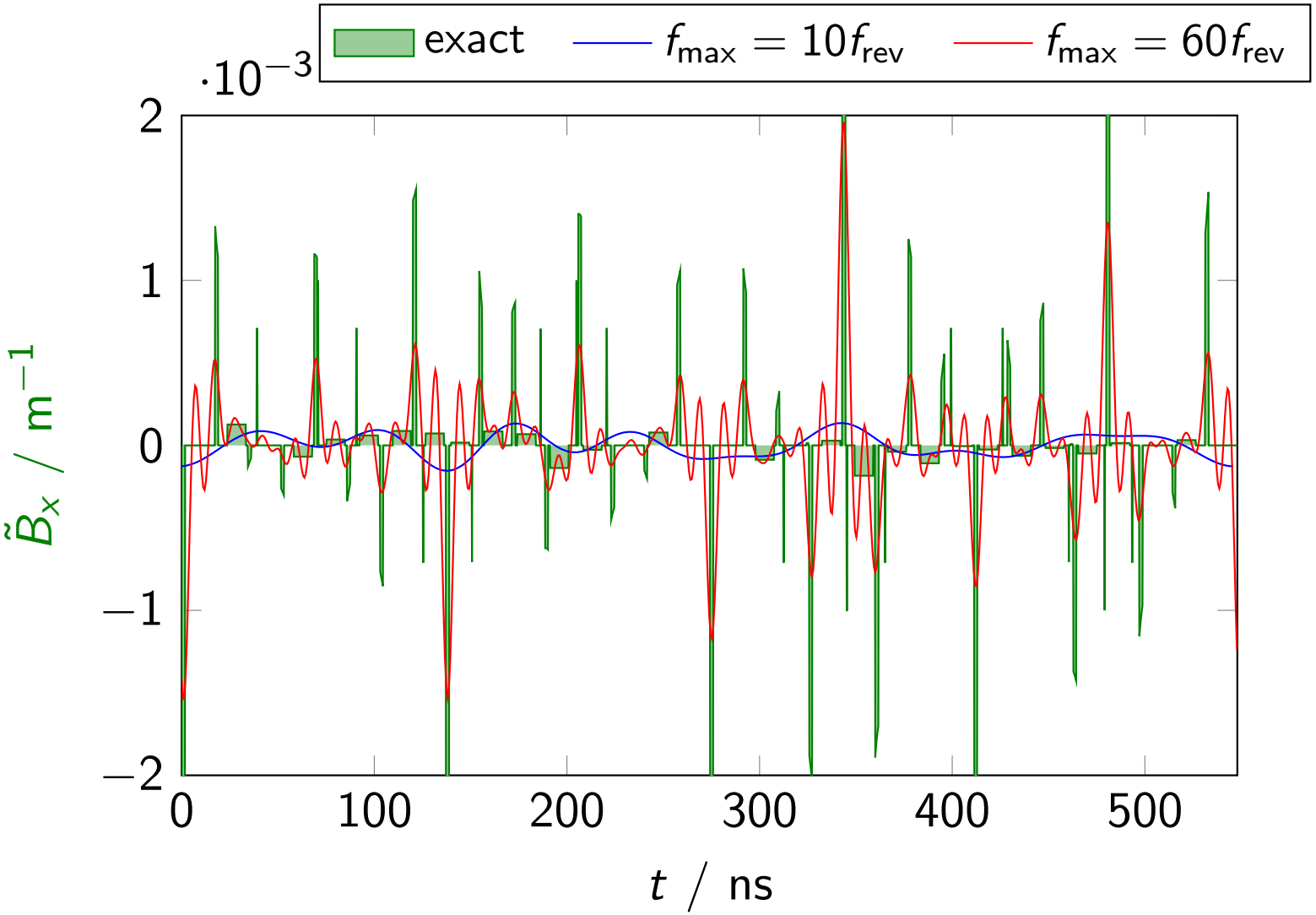
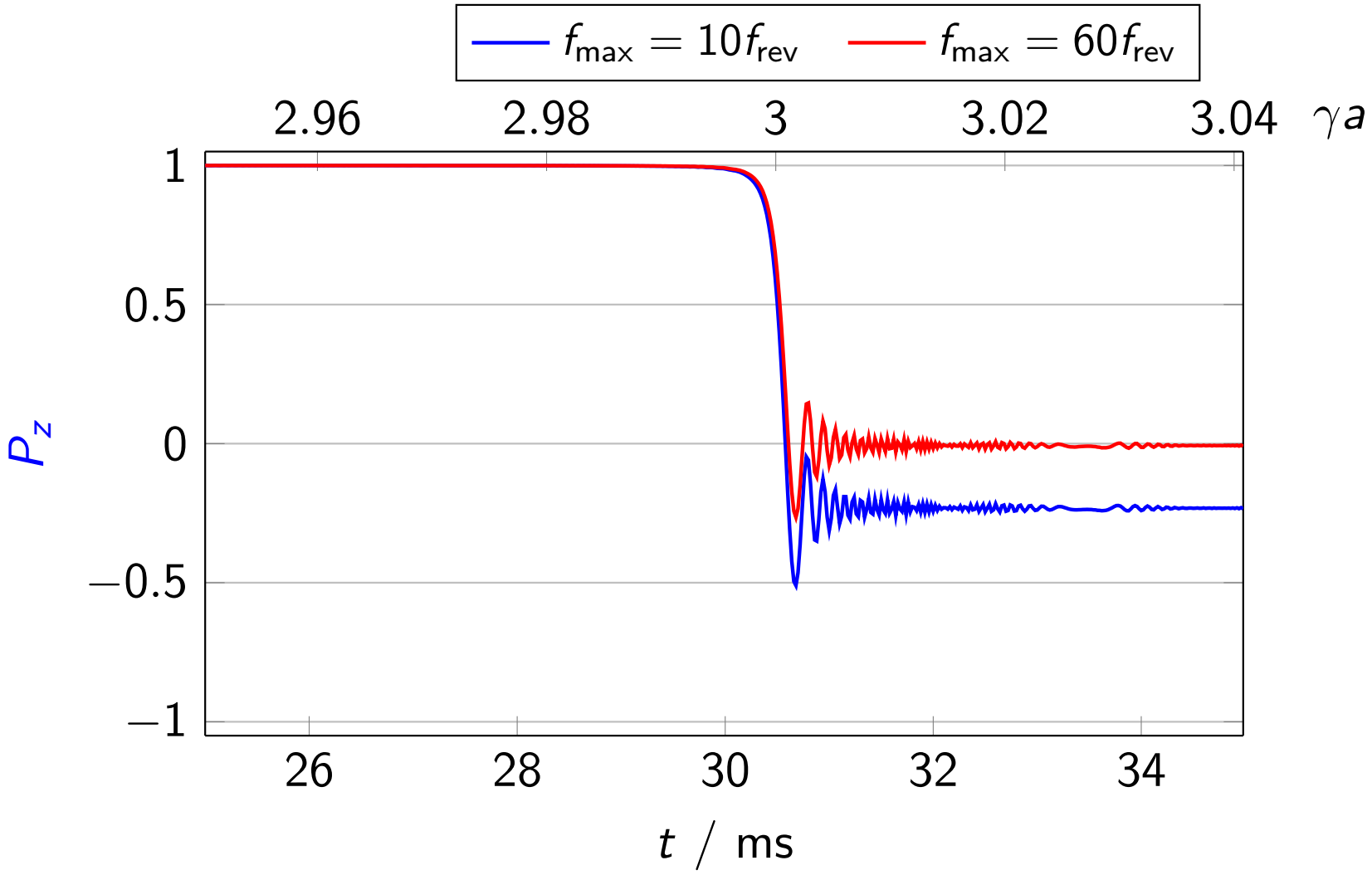


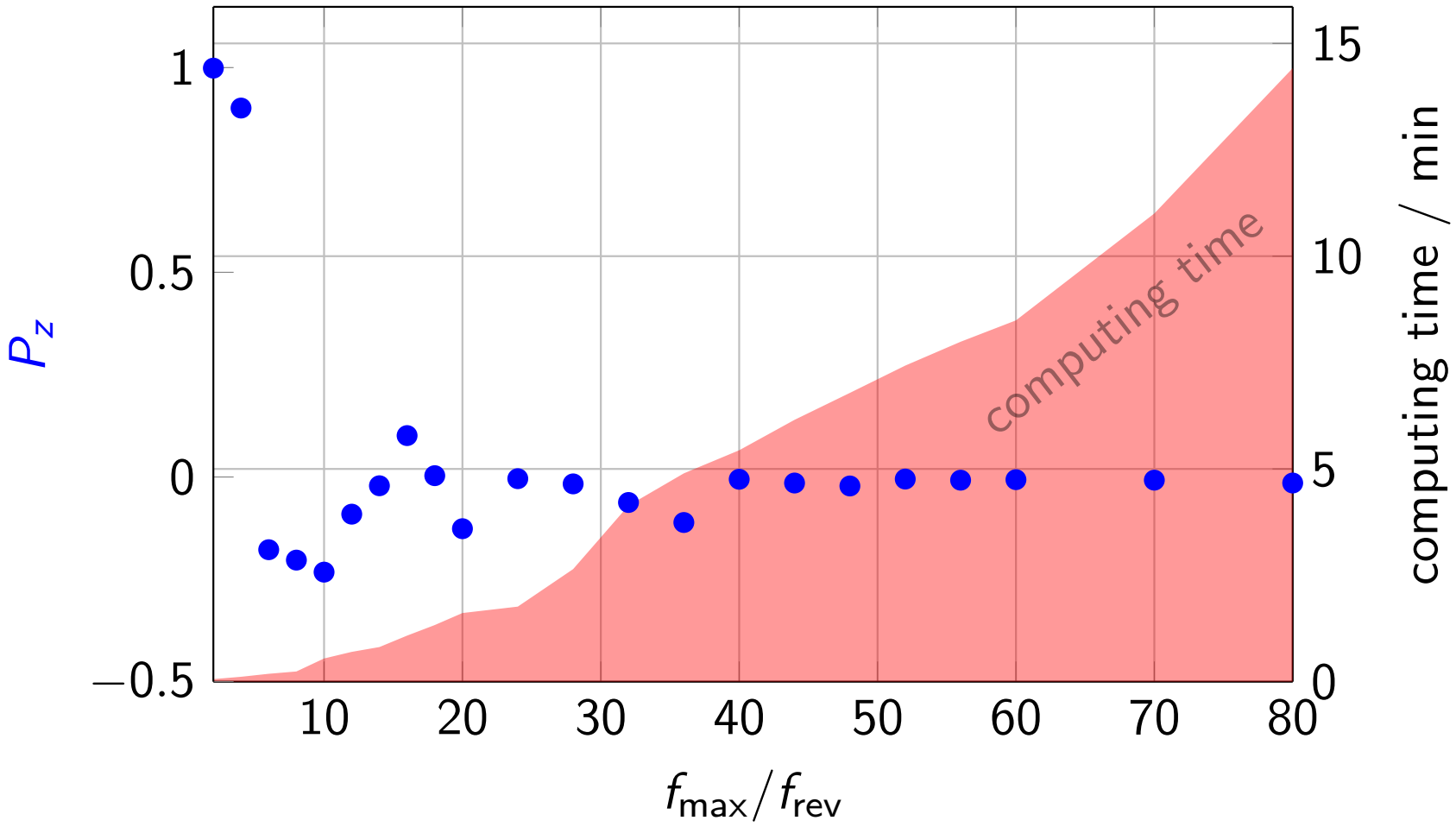
Frequency filtering of magnetic fields

Vertical Polarization while crossing Integer Resonance $\gamma a = 3$ with 4 $^{\mathrm{GeV}}/_{\mathrm{s}}$



Frequency filtering of magnetic fields

Convergence of polarization after crossing $\gamma a = 3$



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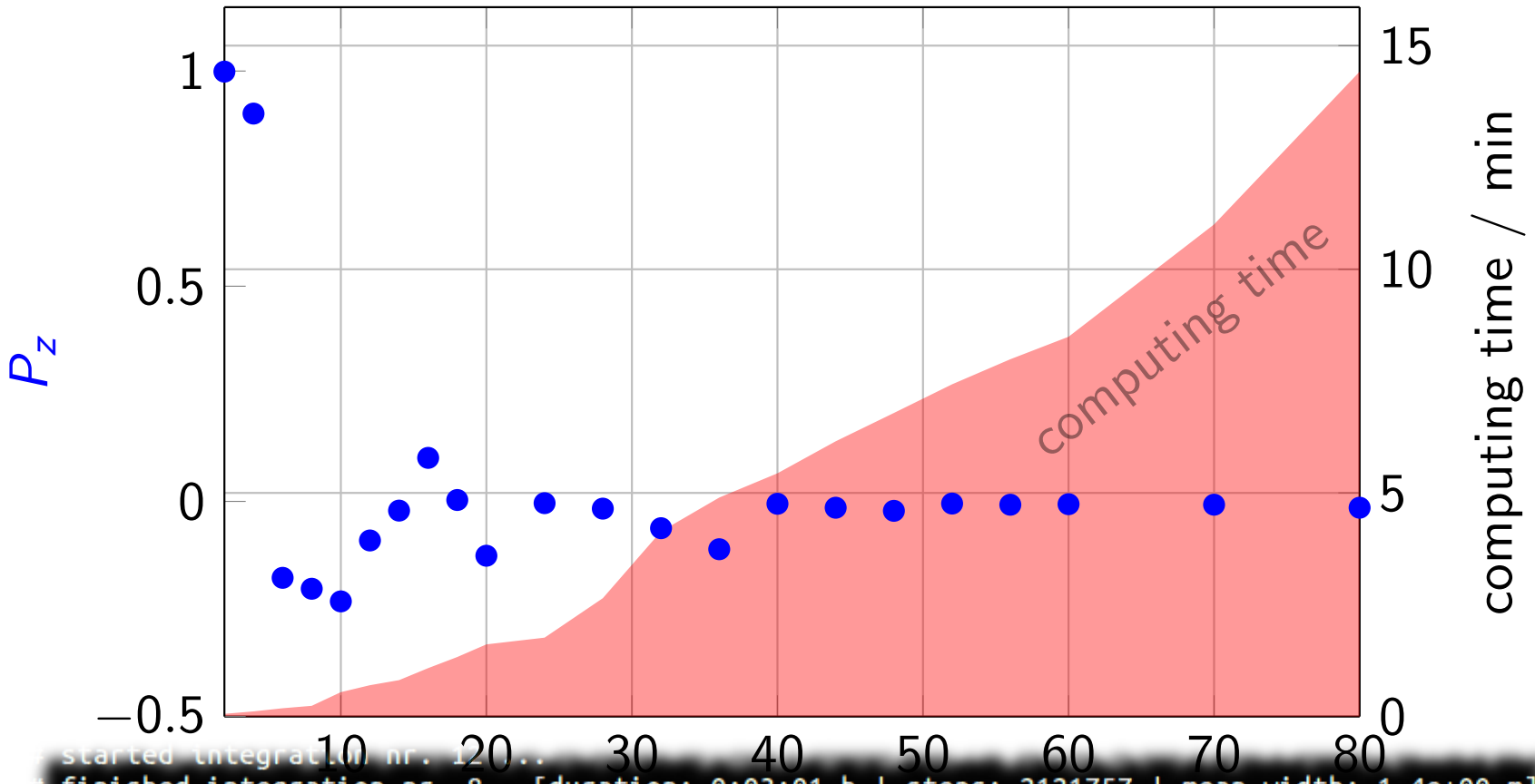
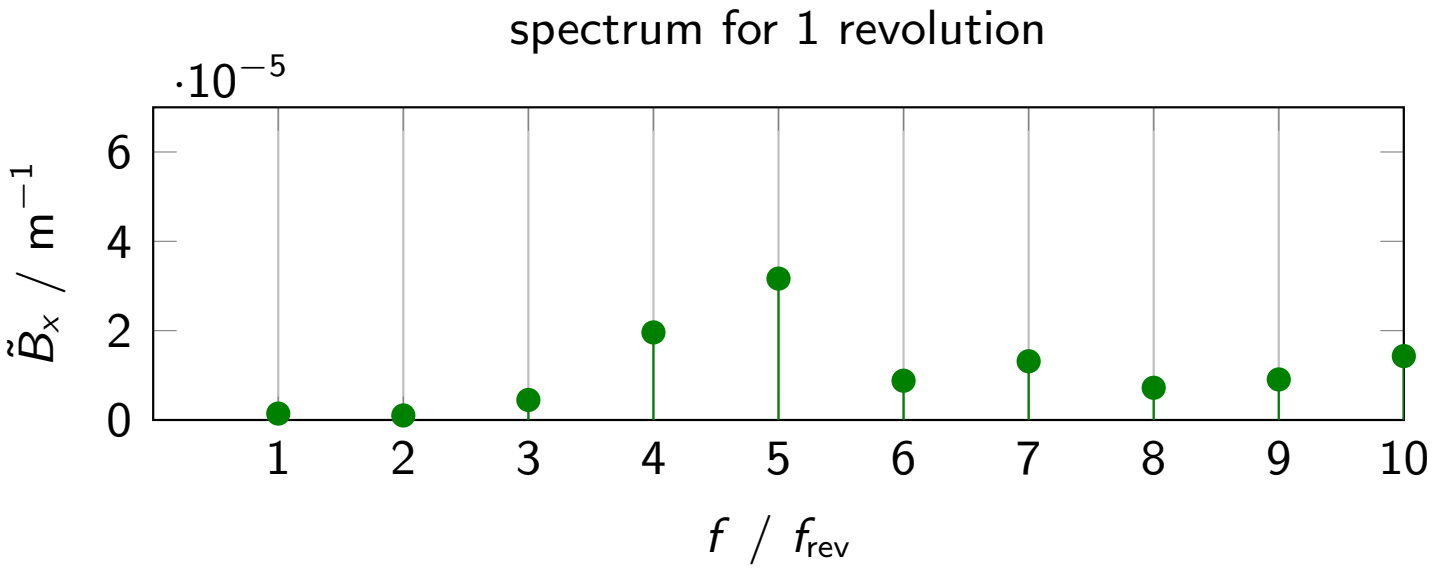



```
# started integration nr. 12 ...
# finished integration nr. 8   [duration: 0:03:01 h | steps: 2121757 | mean width: 1.4e+00 m]
# started integration nr. 13 ...
# finished integration nr. 6   [duration: 0:03:01 h | steps: 2122947 | mean width: 1.4e+00 m]
# started integration nr. 14 ...
# finished integration nr. 4   [duration: 0:03:01 h | steps: 2123260 | mean width: 1.4e+00 m]
# started integration nr. 15 ...
```

The basic concept of POLE

crossing **intrinsic resonances** at $\gamma a = k_x Q_x + k_z Q_z + kP$

- driven by tune $\Rightarrow$ particle trajectories



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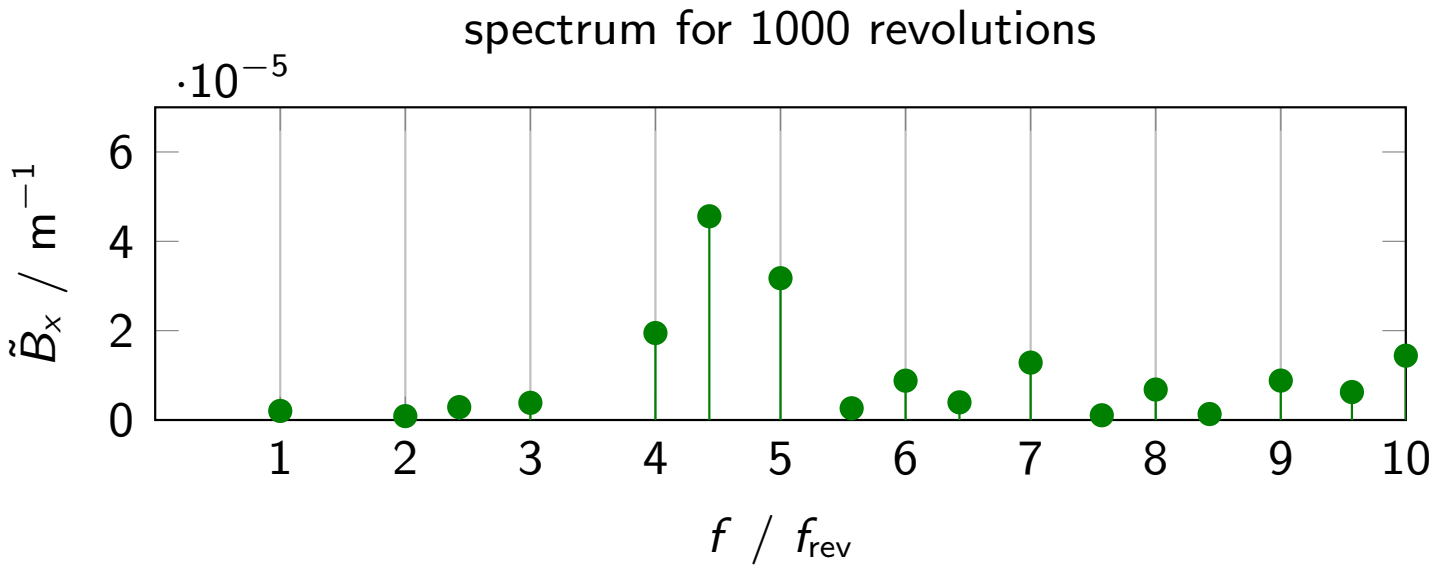

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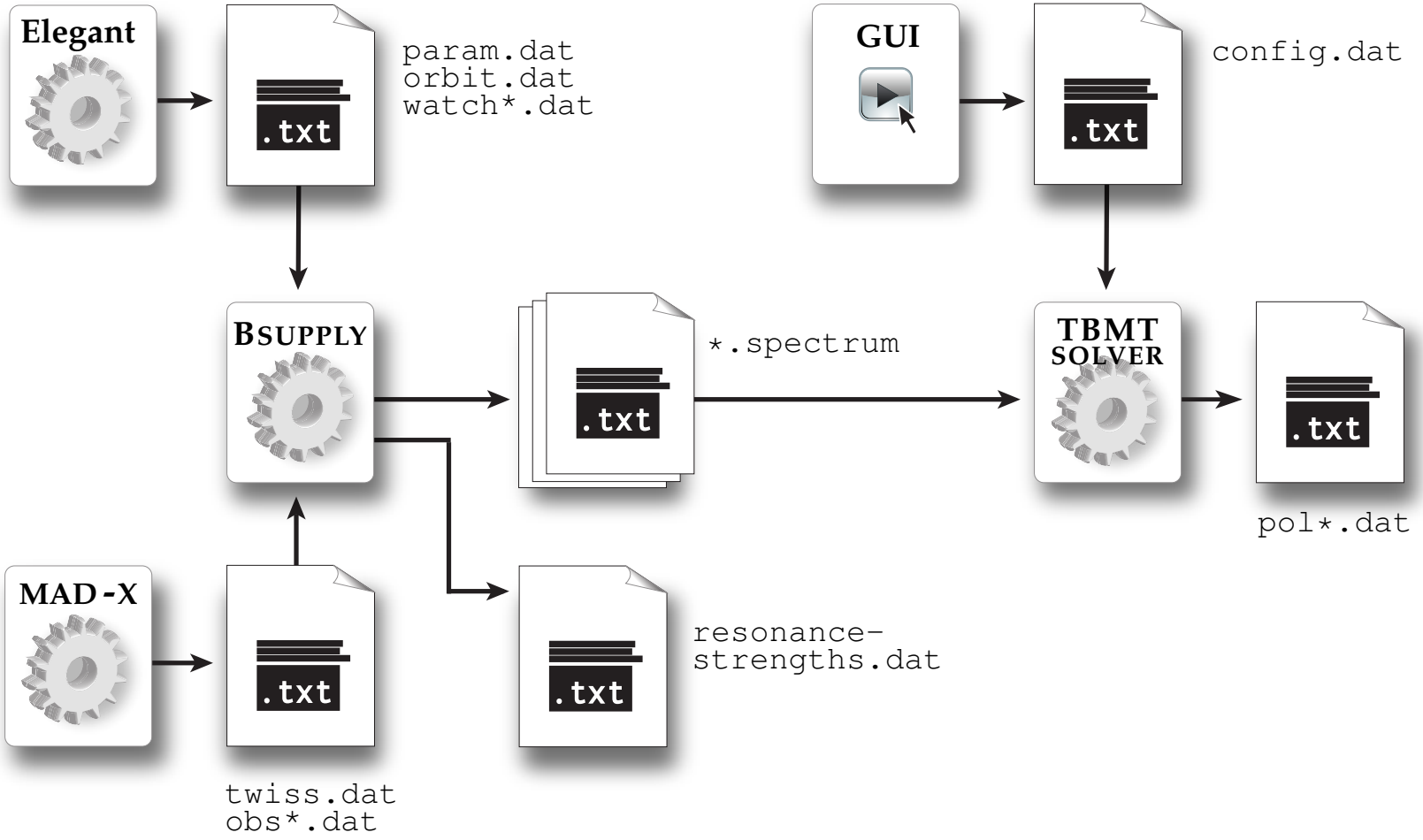
Composition of POLE



Bsupply

Exemplary program output

```
-------------------------------------------
Bsupply: calculate magnetic field & spectrum
-------------------------------------------
* 16440 sampling points along ring
* maximum frequency used for B-field evaluation: fmax_x=fmax_z=30
* B-field amplitudes only used if above 2e-06 1/m
* 24 dipoles, 40 quadrupoles, 12 sextupoles, 30 kickers read
  from /home/schmidt/Projects/crossing_present/madx/madx.twiss
* 40 BPMs(@Quad) read
  from /home/schmidt/Projects/crossing_present/madx/madx.twiss
* trajectory of particle 1 read at 33 observation points for 1000 turns
-------------------------------------------
Calculate field distribution...
Calculate spectra (FFT)...
-------------------------------------------
* Wrote /home/schmidt/Projects/crossing_present/inout/lattice.dat
* Wrote /home/schmidt/Projects/crossing_present/inout/bpms.dat
* Wrote /home/schmidt/Projects/crossing_present/inout/trajectory.dat
* Wrote /home/schmidt/Projects/crossing_present/inout/vcorrs.dat
* Wrote /home/schmidt/Projects/crossing_present/inout/interp_bpms.dat
* Wrote /home/schmidt/Projects/crossing_present/inout/eval_x.dat
* Wrote /home/schmidt/Projects/crossing_present/inout/eval_z.dat
* Wrote /home/schmidt/Projects/crossing_present/inout/dipolelengths.dat
* Wrote [      48 frequency components] /home/schmidt/Projects/crossing_present/inout/horizontal.spectrum
* Wrote [      35 frequency components] /home/schmidt/Projects/crossing_present/inout/vertical.spectrum
* Wrote [       0 frequency components] /home/schmidt/Projects/crossing_present/inout/longitudinal.spectrum
-------------------------------------------
Finished. (Output in /home/schmidt/Projects/crossing_present/inout/)
```

TBMTsolver configuration

Graphical User Interface

Folder Edit View Jump to...

Gnuplot hspec

Gnuplot vspec

Gnuplot lspec

Gnuplot ht

Gnuplot vt

Gnuplot lt

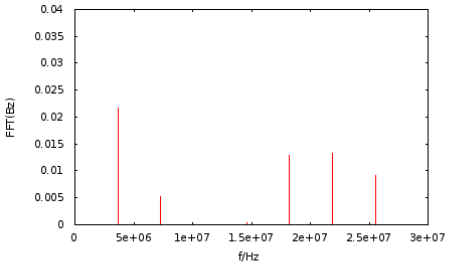


Figure 1: Verification of magnetic field via plotting in frequency respective in time domain.

1.2 General Parameters

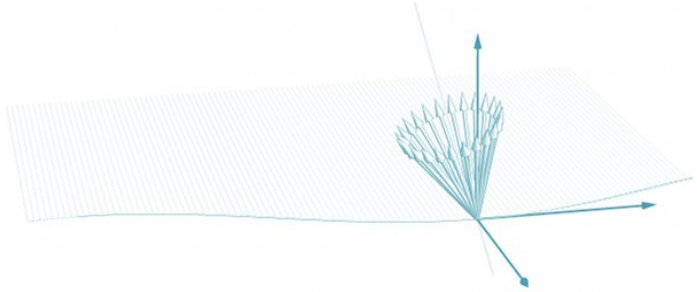
Urgently needed parameters have to be merged into a config-file called "project_path/inout/config_tbmt.dat". The definition of the initial center energy "InitialEnergy [GeV]" and the energy increment per second "RampingSpeed [GeV/s]" are the most clear parameters in this context. So is the observed time interval in between the start time "TimeStart [s]" and the end time "TimeStop [s]" (see Config 2).

InitialEnergy [GeV]:	1.2
RampingSpeed [GeV/s]:	4.0
RampStop [true/false]:	false
a*gamma @ Rampstop:	6.005
TimeStart [s]:	0.025
TimeStop [s]:	0.035

Config 2: Setup of the start energy and the energy gain per second. The start- and stop time define the

log:

```
found FreqArg1:
found FreqArg2:
found PhaseBehaviour:
found PhasArg1:
found PhasArg2:
```



The default presetting of the orientation of the spin ensemble is a cone-like distribution. The definition of such a cone is given by the number of particle spins, by the orientation and the length of the polarization vector, certainly of smaller length than one. The length of the polarization vector defines the "StartPolarization", the direction vector is parallel to the polarization vector "DirectionPolarization", is given by three entries (x,z,s) and has not to be normalized.

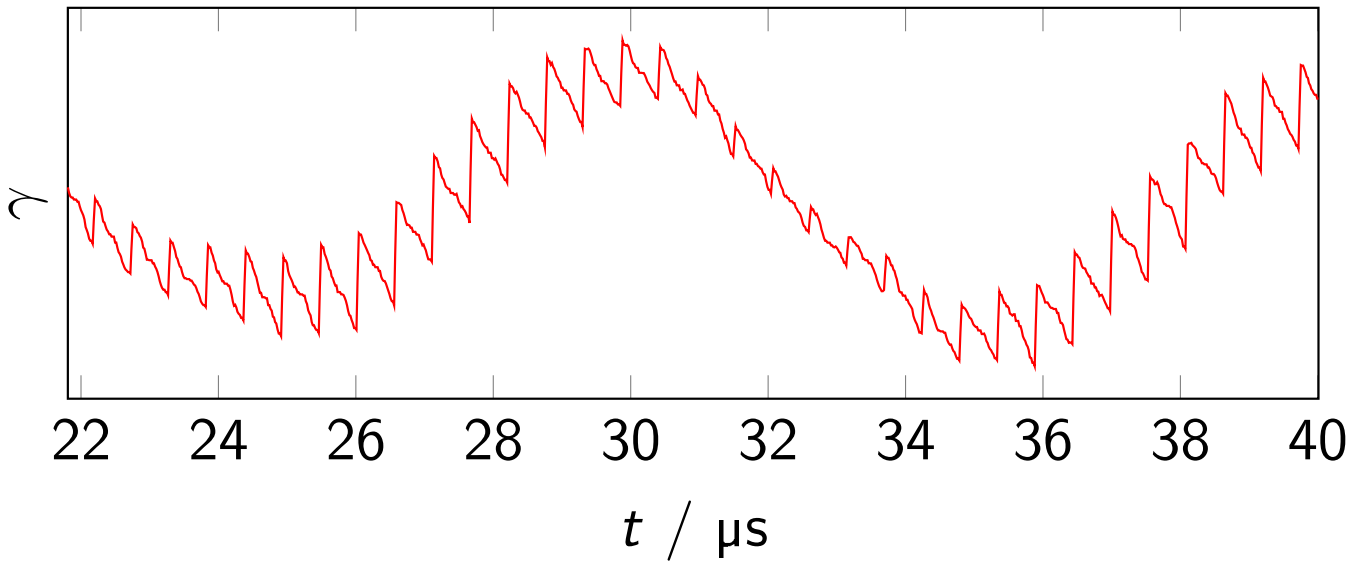
StartPolarization:	0.9					
DirectionPolarization:	direct_x:	0.0	direct_z:	1.0	direct_s:	0.0
NumberParticles:	1000					

Config 5: Description of the orientation of the ensemble of particle spins.

AmplitudeBehavior:	gaussian	center:	1.5	sigma:	0.5
PhaseBehavior:	uniform	lower limit:	0	upper limit:	359
FrequencyBehavior:	linear	initial:	0	final:	92400

Config 6: Details studies of decoherent spin motion demand varying start settings of each spin. Therefore, you can adjust a deterministic or (uniform or gaussian) random distribution (if nothing is checked, the default value is 0).

Synchrotron motion & Depolarization



Thomas-BMT equation

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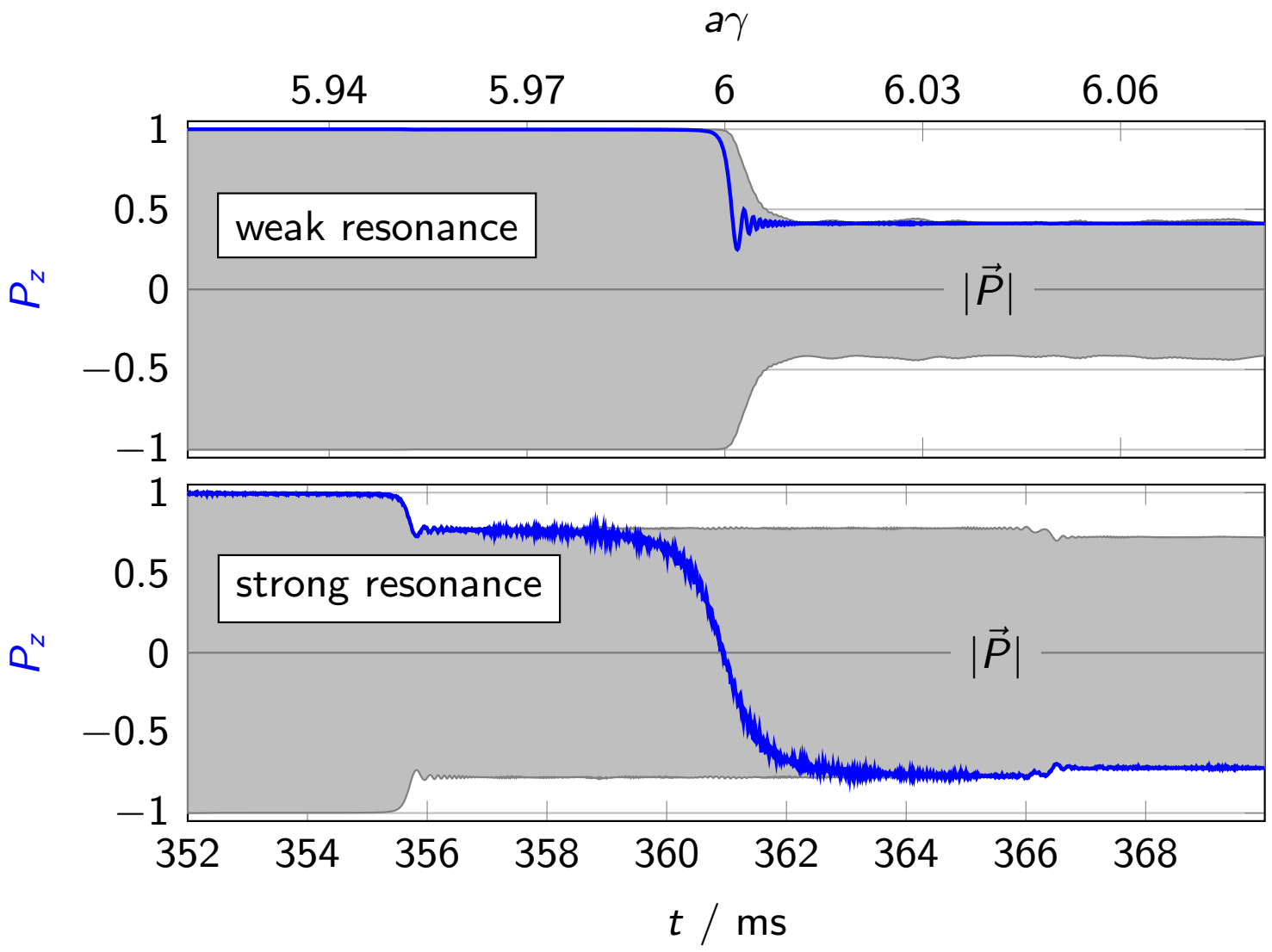
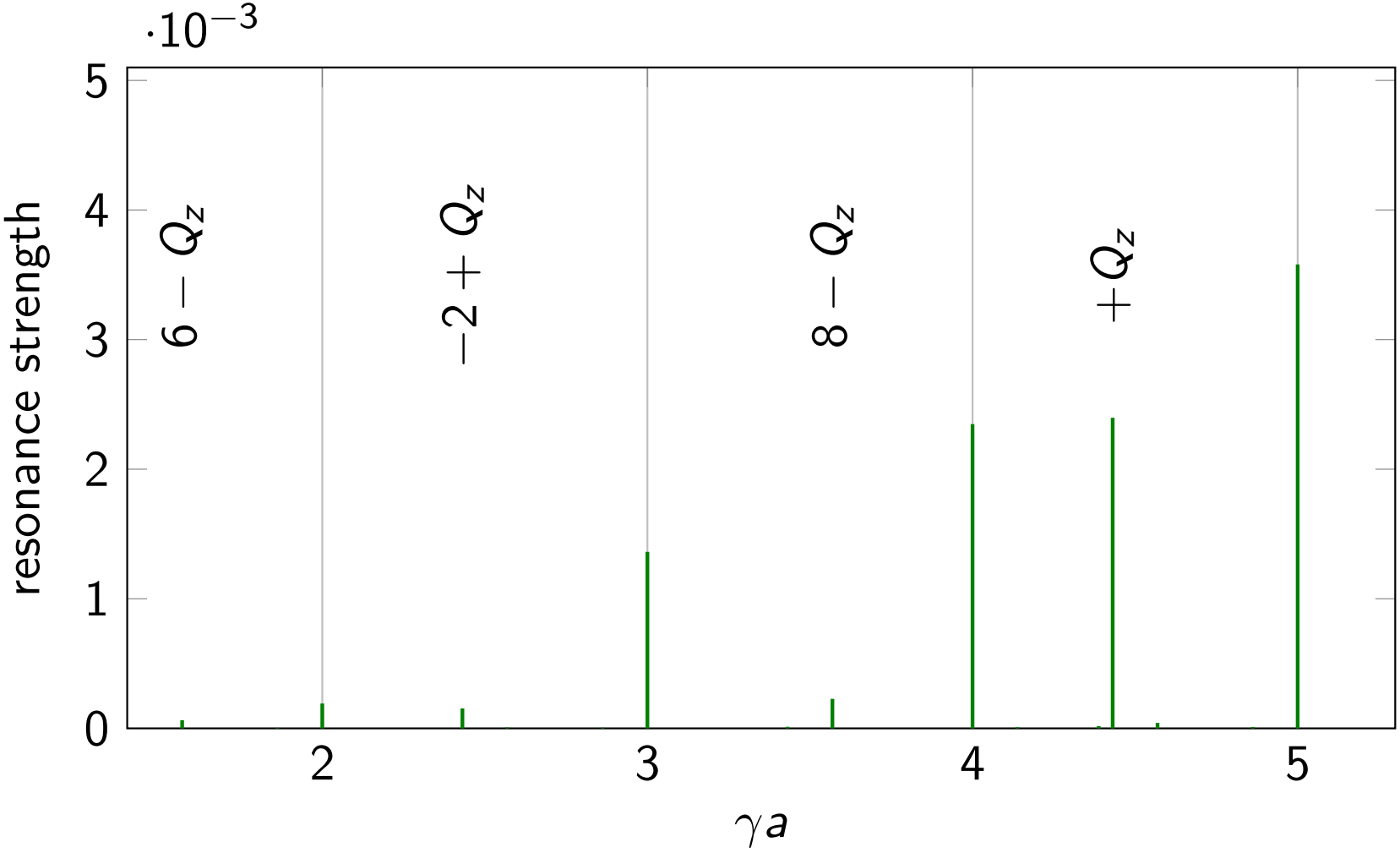
Depolarization



Resonance Strengths

'get an idea' of depolarizing resonances - immediately from a MAD-X or Elegant lattice



Summary & Outlook

- ✓ resonance crossing (*some minutes*)
- ✓ 'get an idea' of resonance strengths (*some seconds*)
- ✓ depolarization if $\vec{P} \nparallel \vec{B}_{\text{guide}}$
- ✓ ... based on MAD-X or Elegant & running on regular desktop PCs

coming:

- benchmarking at ELSA
- open source release

Interested in testing POLE?

`schmidt@physik.uni-bonn.de`

Thank you for your attention!

Interested in testing POLE?

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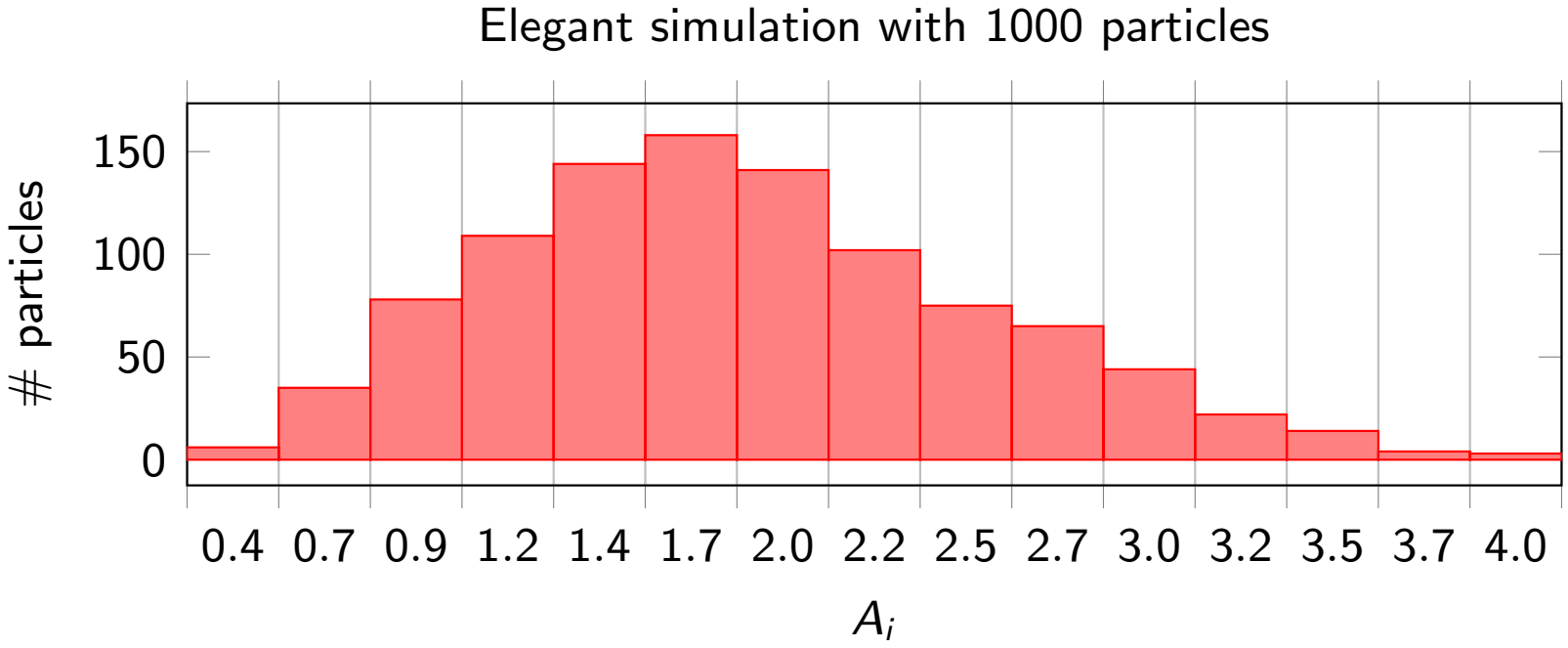
Model: synchrotron oscillation

$$\gamma_i(t) = \gamma_0(t) + \underline{A_i \cos(\omega_i t + \phi_i)}$$

- Gaussian distributed A_i & ω_i
- uniformly distributed ϕ_i



Model: synchrotron oscillation

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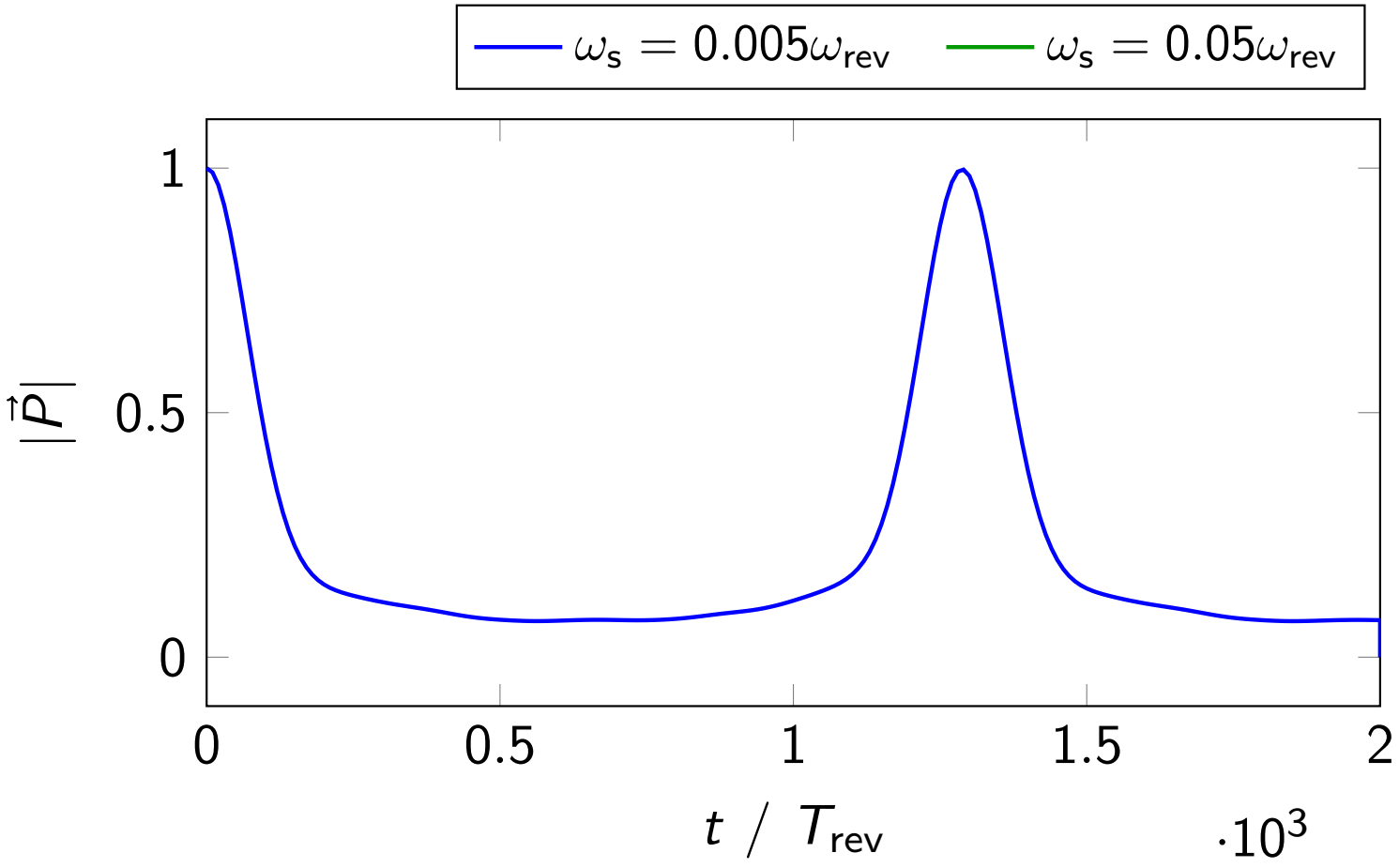

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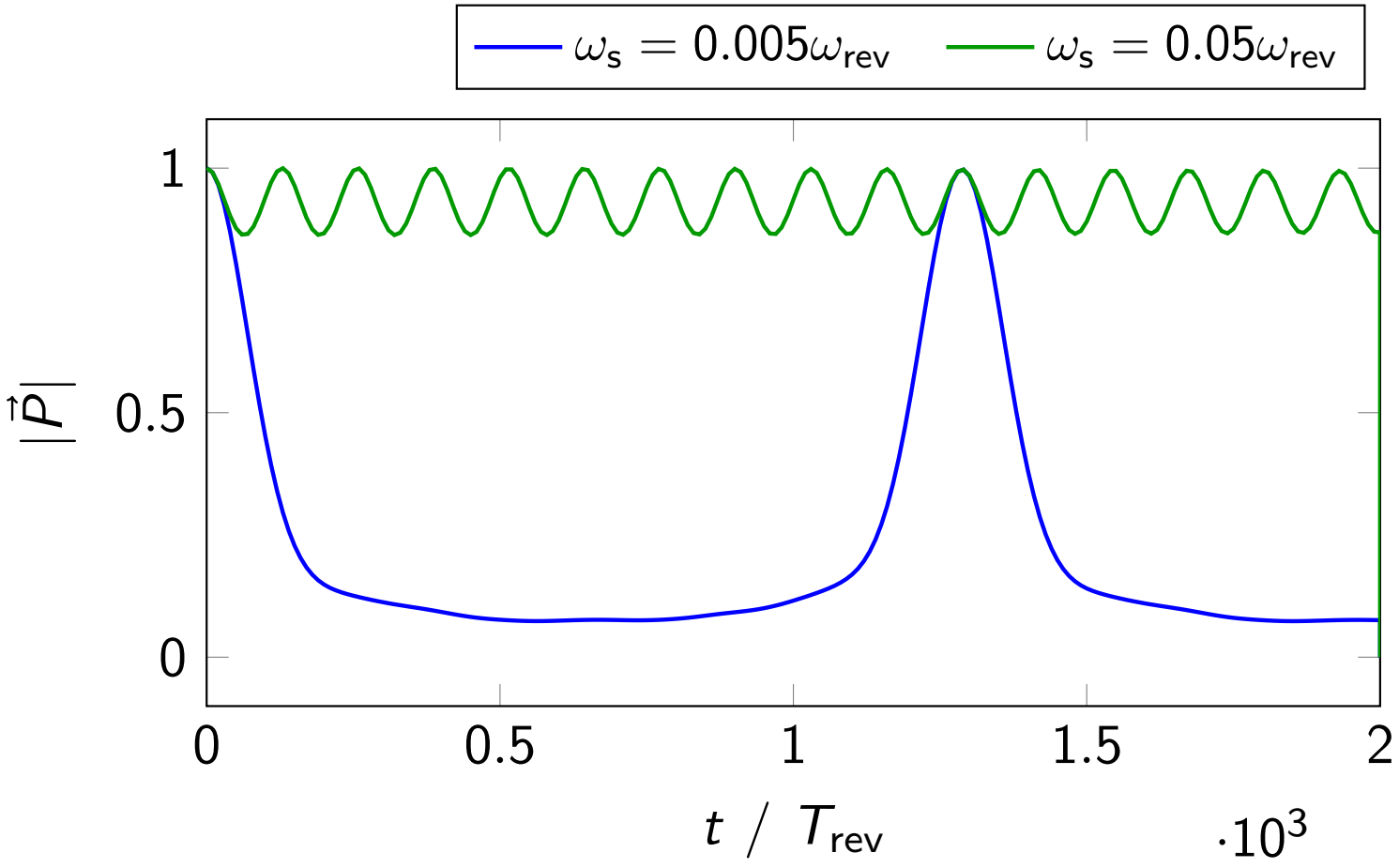

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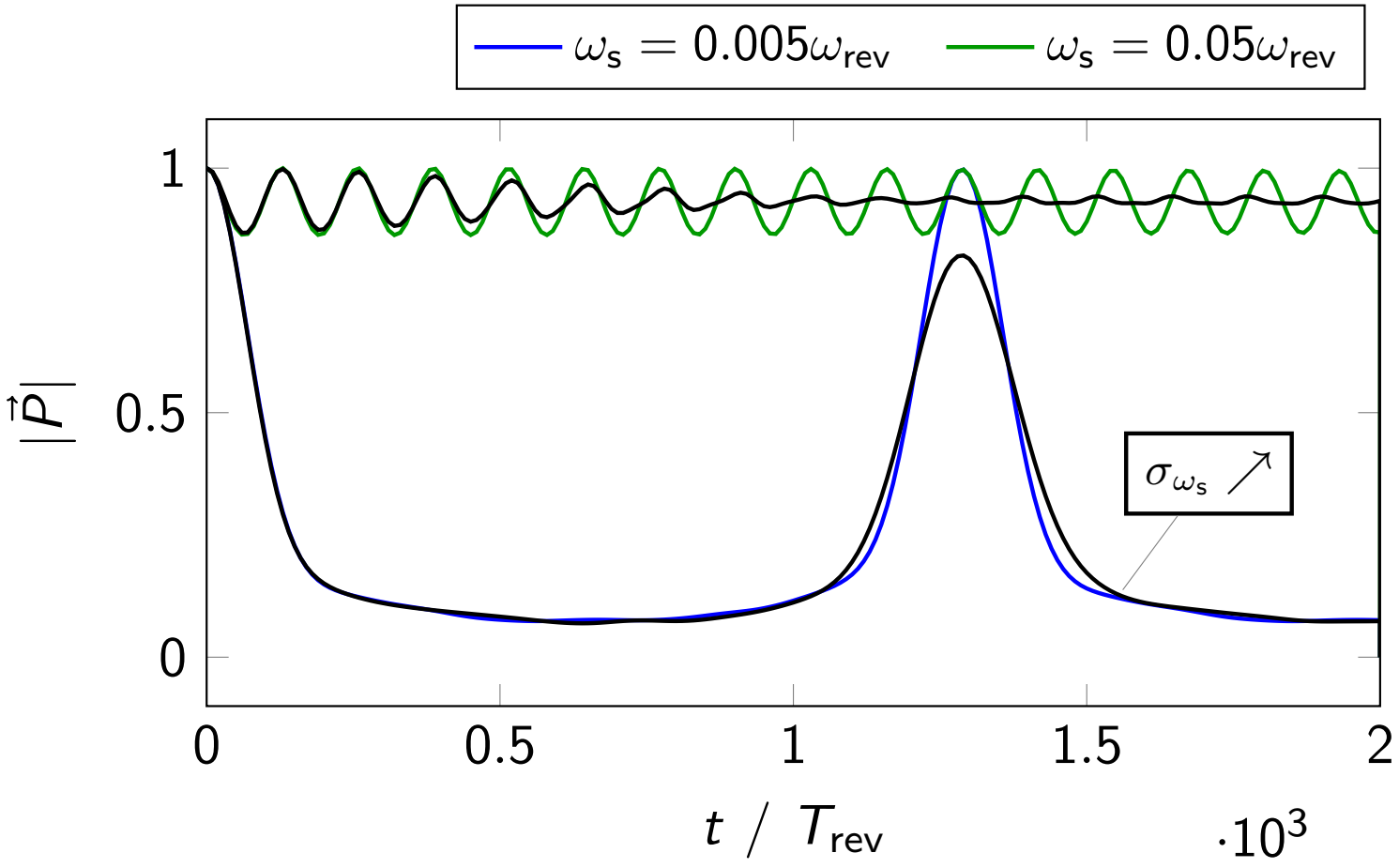

Model: constant energy offset

$$\gamma_i(t) = \gamma_0(t) + A_i \cos(\omega_i t + \phi_i) + \underline{A_i}$$