HL-LHC transverse beam stability studies – some updates

18th HiLumi WP2 Task 2.4 meeting

10. December 2014, CERN

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Overview

- Study of the double harmonic RF system
  - We include a number of damping mechanisms
    - Chromaticity
    - Octupoles
    - Transverse damper
  - What are the new instability thresholds?
- Study the impact of the additional impedance introduced by crab cavities
  - Can we reproduce the single bunch growth rates computed earlier with DELPHI?

Parameters

- HL-LHC parameters used for the simulations
- Free parameters:
  - Intensity
  - Chromaticity
  - Relative phase between RF harmonics
  - Damper gain

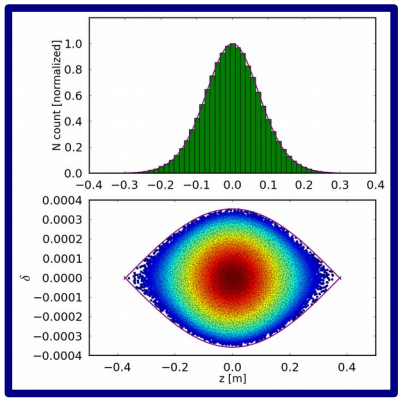
Macroparticles	500 000
Slices	500
Turns	$< 300\,000$
Energy	7 TeV
α	3.225e-4
Q_x	62.31
Q_y	60.32
β_x	65.98 m
β_y	71.53 m
$\varepsilon_x^{(n)}$	2.5 µm
$\varepsilon_y^{(n)}$	2.5 µm

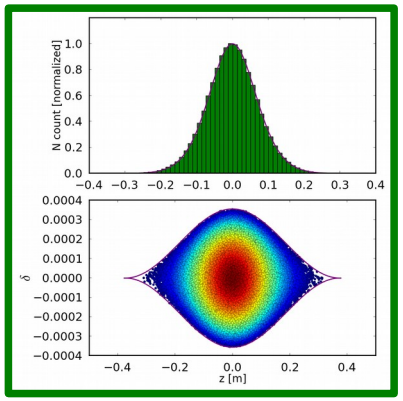
RF parameters

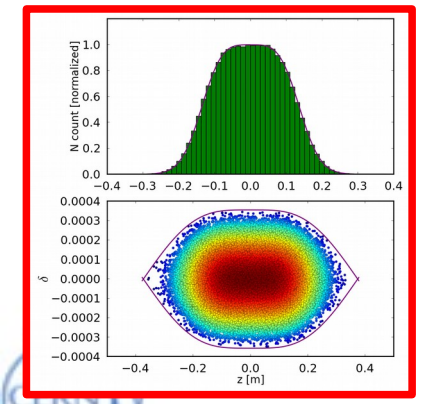
- HL-LHC parameters used for the simulations
- Free parameters:
  - Intensity
  - Chromaticity
  - Relative phase between RF harmonics
  - Damper gain

	Single RF	BSM	BLM
V_{400}	16 MV	16 MV	16 MV
V_{800}	0 MV	8 MV	-8 MV
ε_z	2.5 eV s	2.5 eV s	2.5 eV s
Δ_t	1.005 ns	0.926 ns	1.217 ns
ΔE	0.22e-3	0.256e-3	0.172e-3

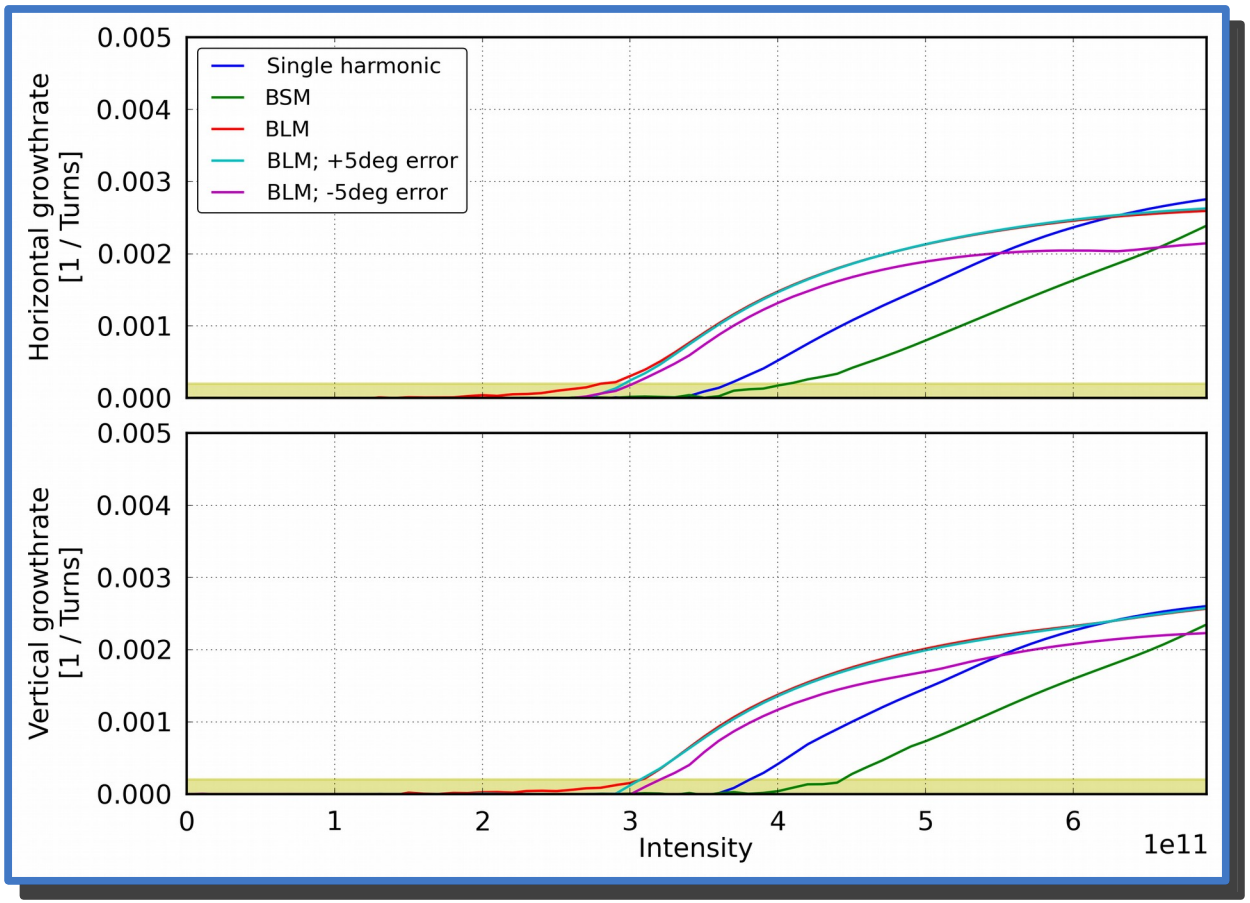
TMCI and growth rates

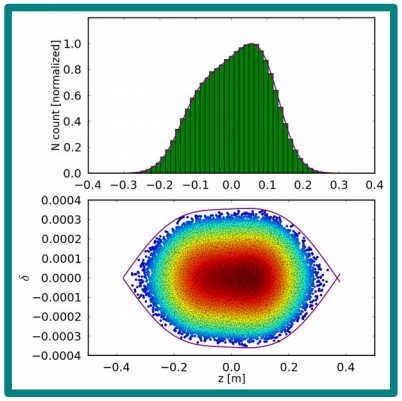


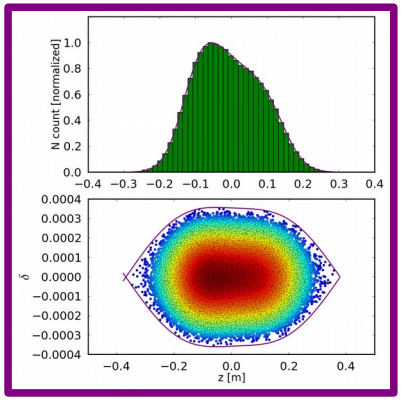




Q': 0 → TMCI







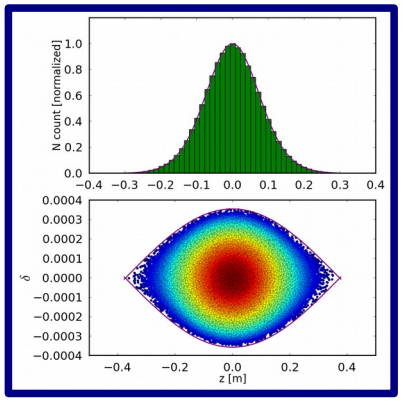
Parameters

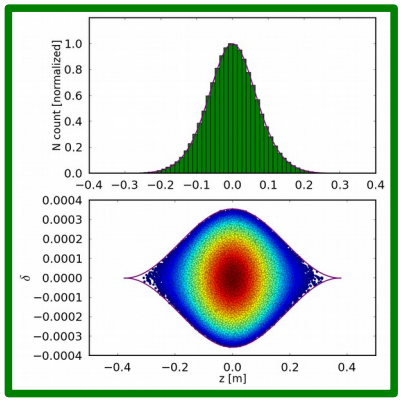
- HL-LHC parameters used for the simulations
- Free parameters:
  - Intensity
  - ~~Chromaticity~~
  - Relative phase between RF harmonics
  - ~~Damper gain~~

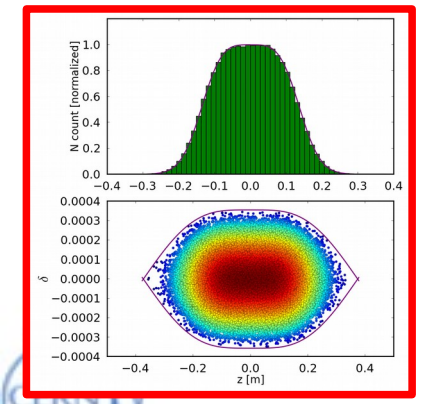
- HL-LHC parameters used for the simulations
- Free parameters:
  - Intensity
  - Qx', Qy' = 15
  - Relative phase between RF harmonics
  - tau_x, tau_y = 50
  - Octupoles, LOF = +550 A

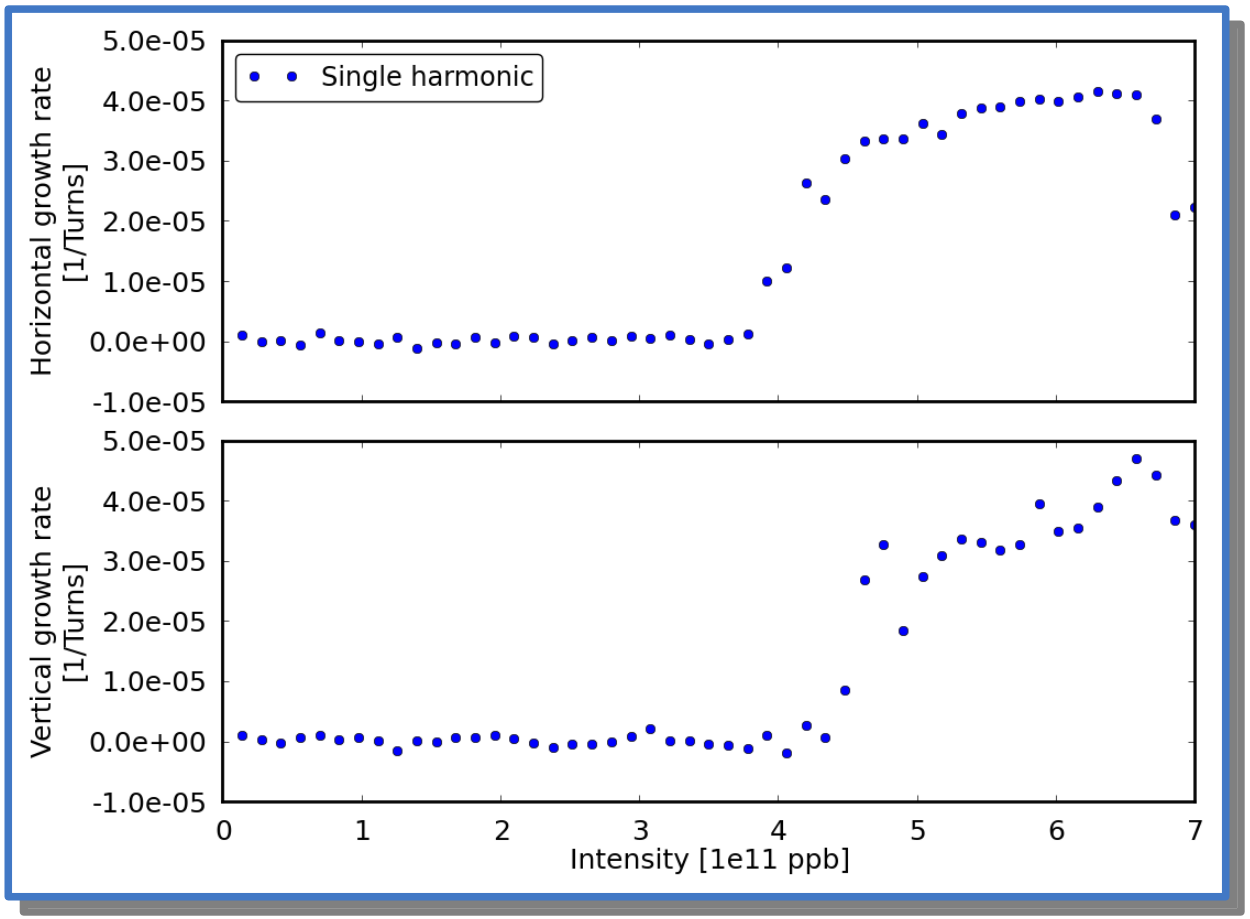
G-rates with damping mechanisms

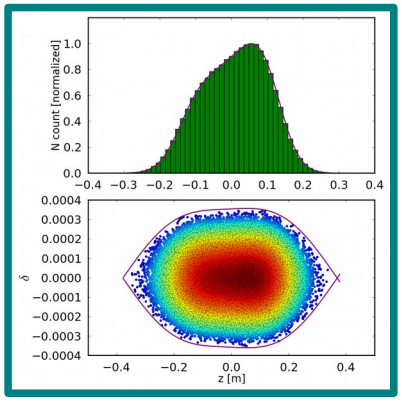
Q': 15; LOF: +550 A; Damper gain: 50 turns

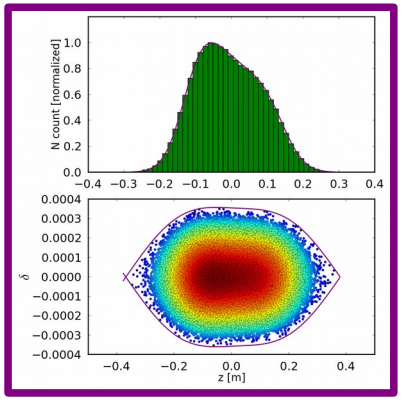












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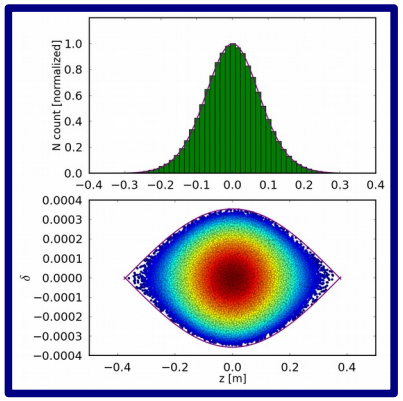

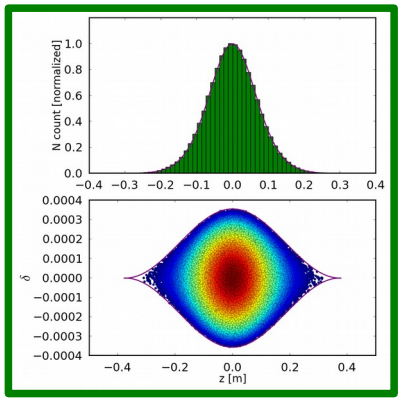

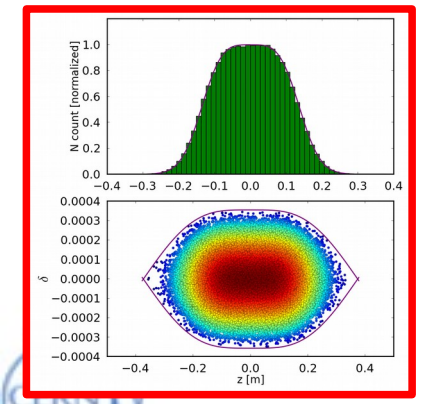

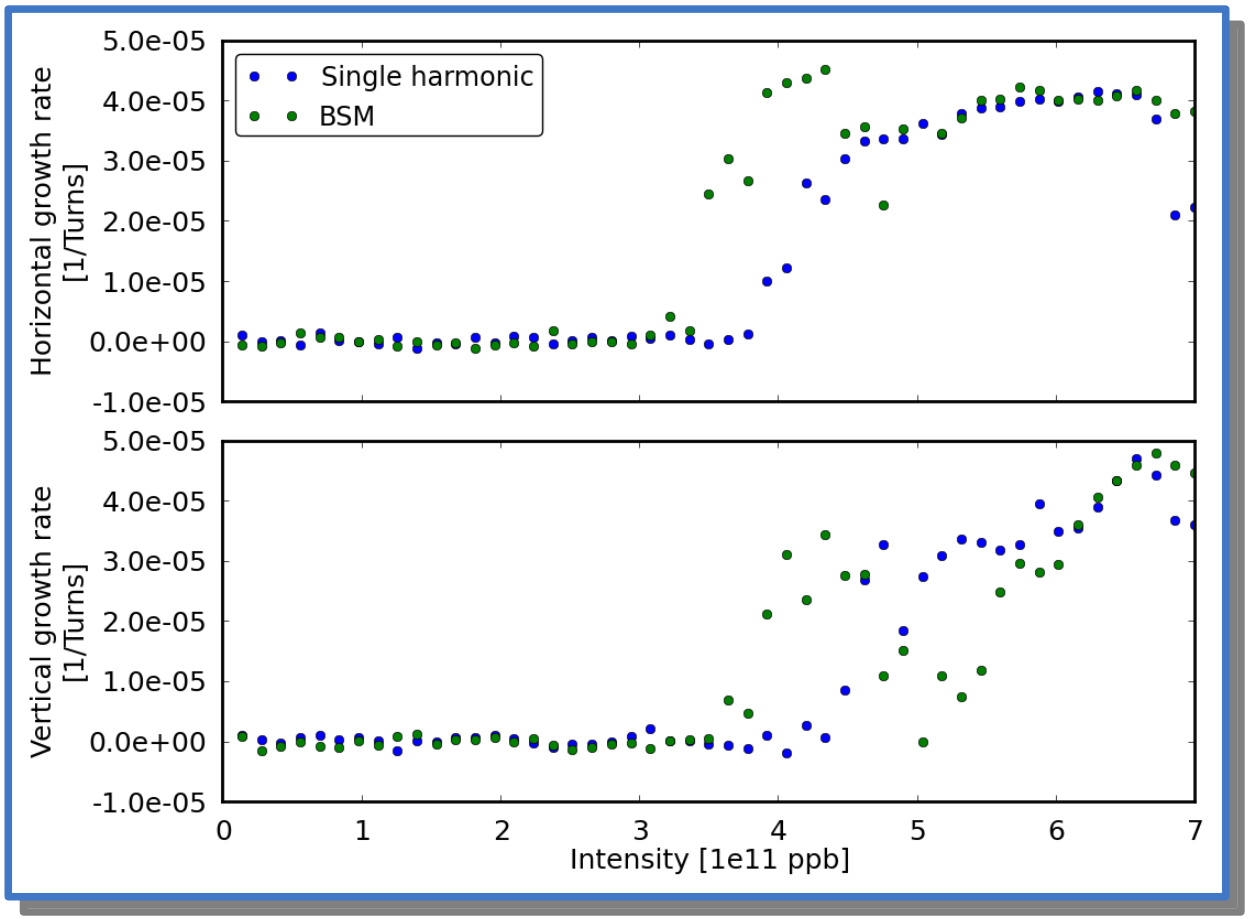

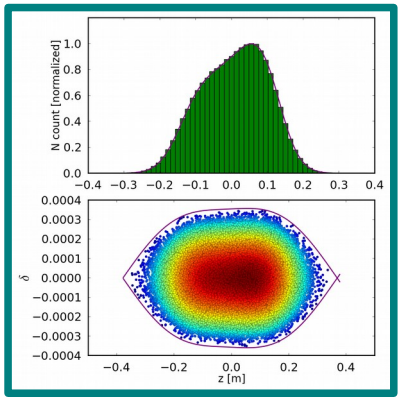

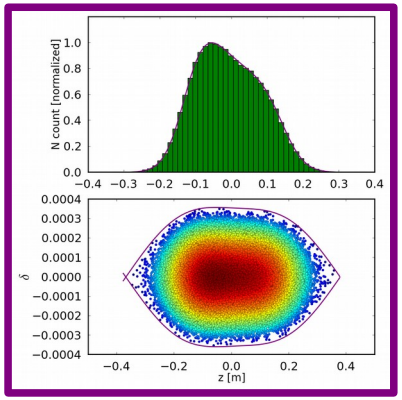

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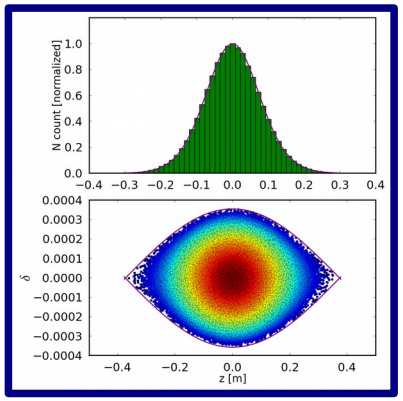
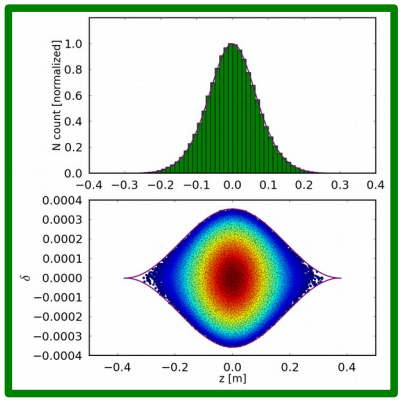
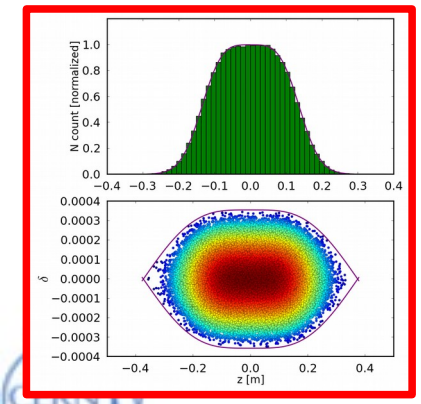
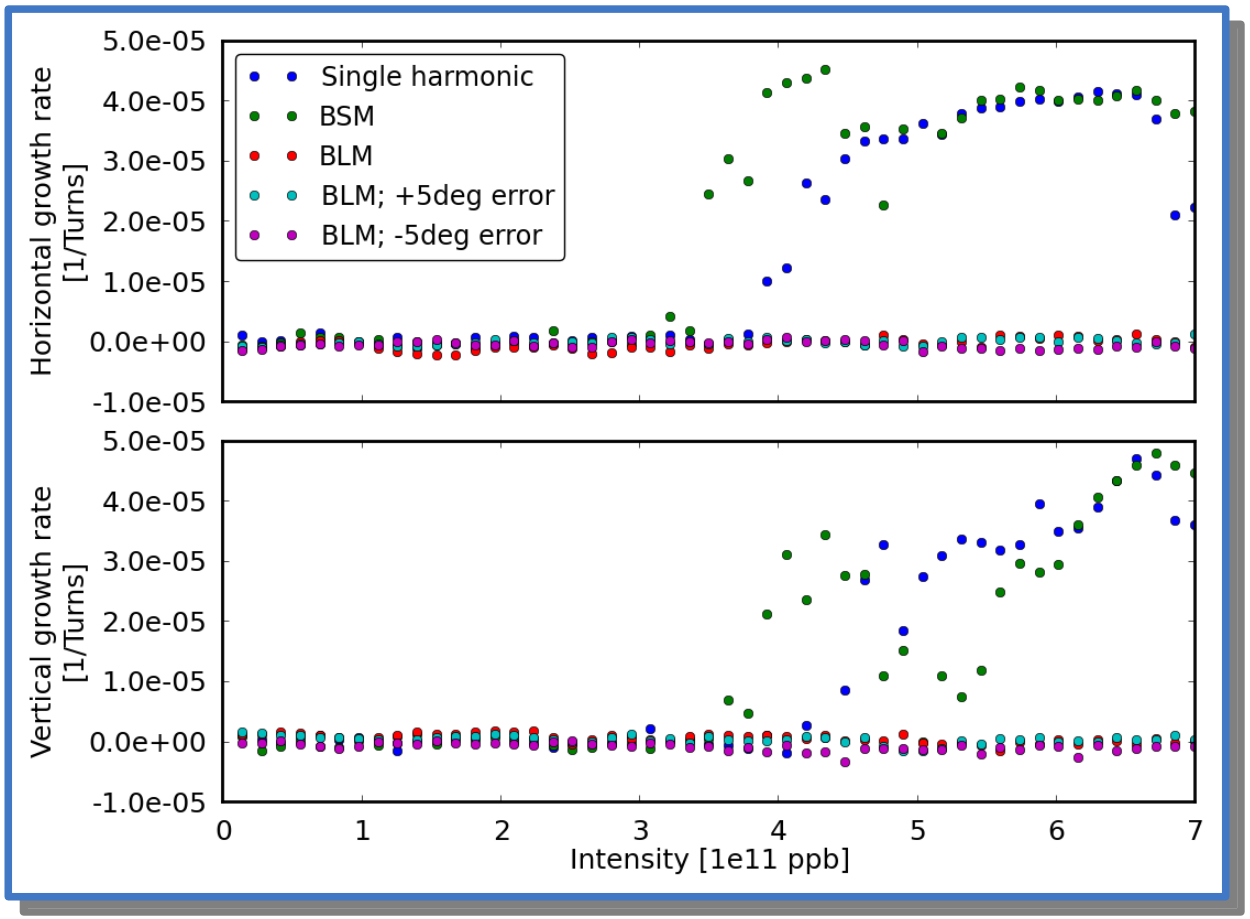
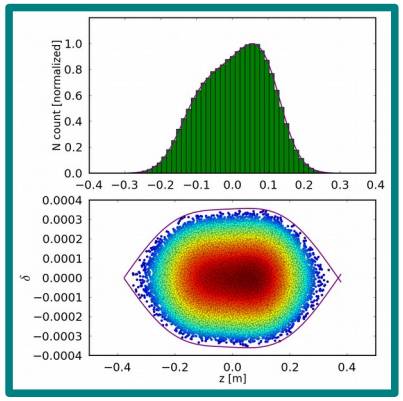
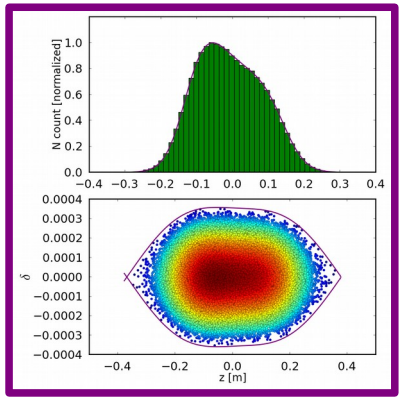






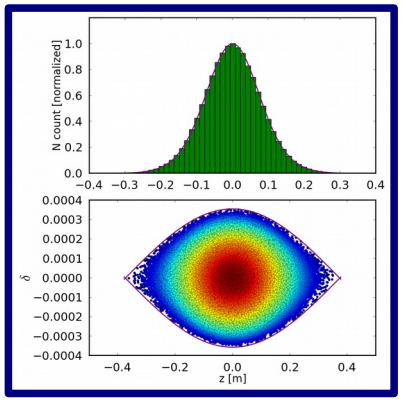


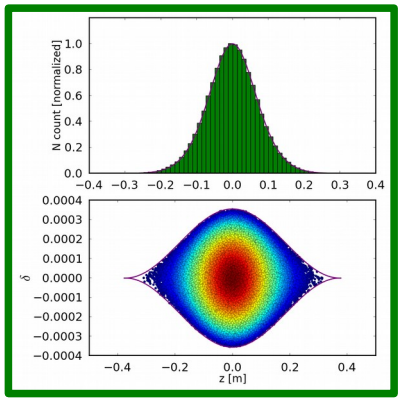


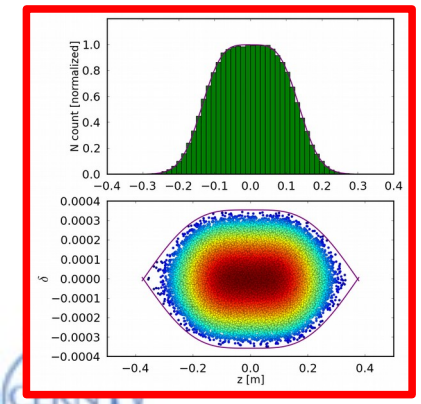


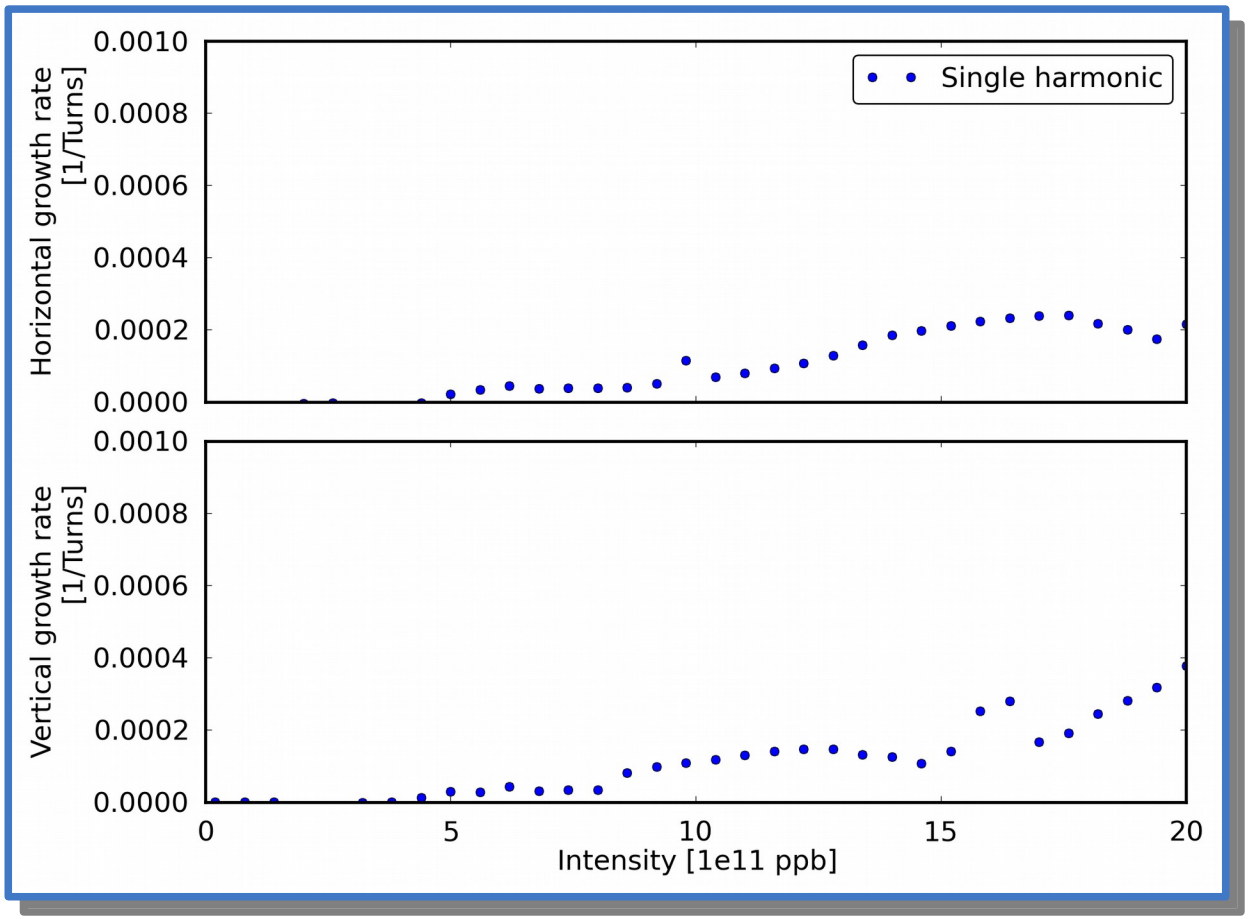
G-rates with damping mechanisms

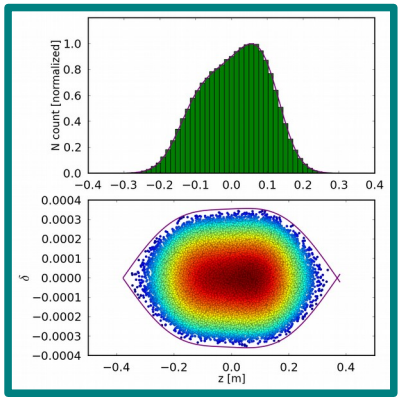
Scan range increased: 7e11 ppb → 20e11 ppb

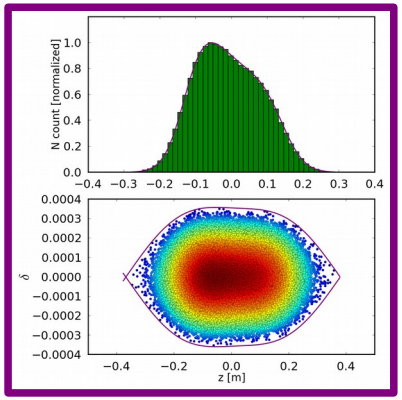












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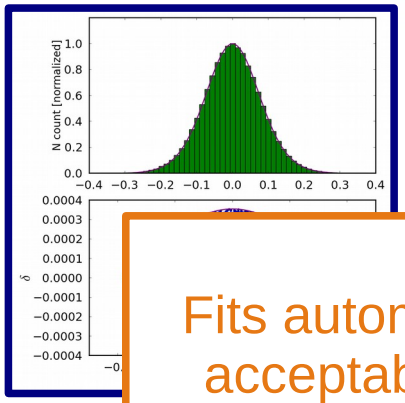
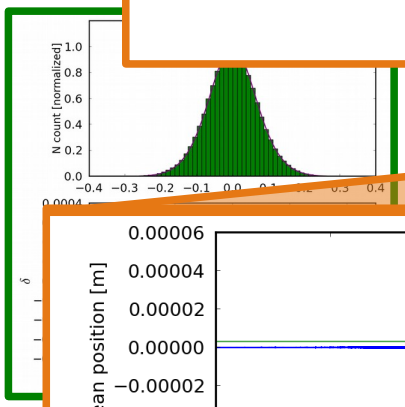
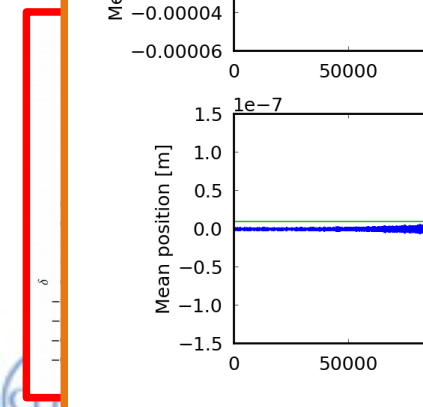
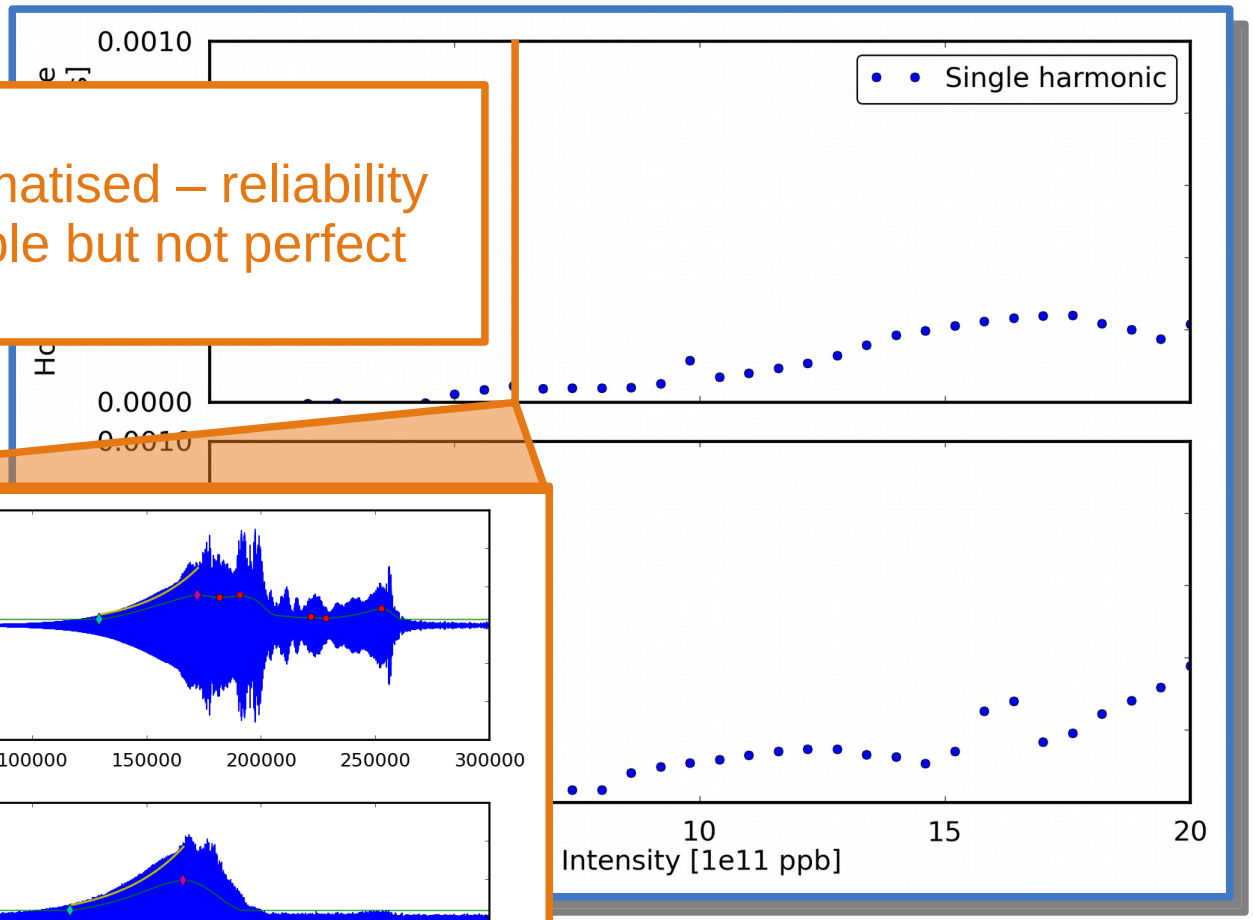
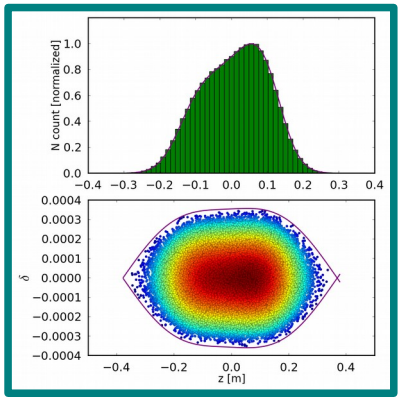
Fits automatised – reliability acceptable but not perfect

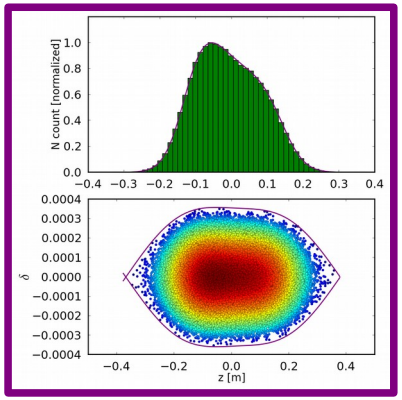












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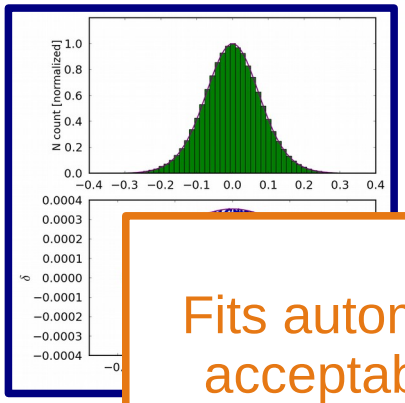

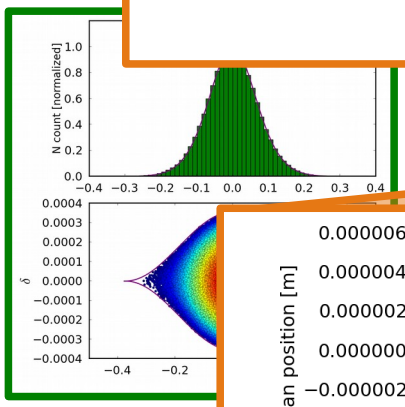

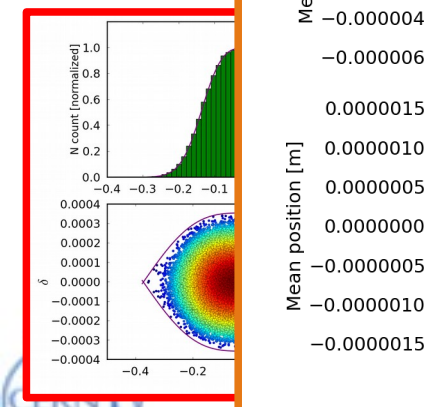

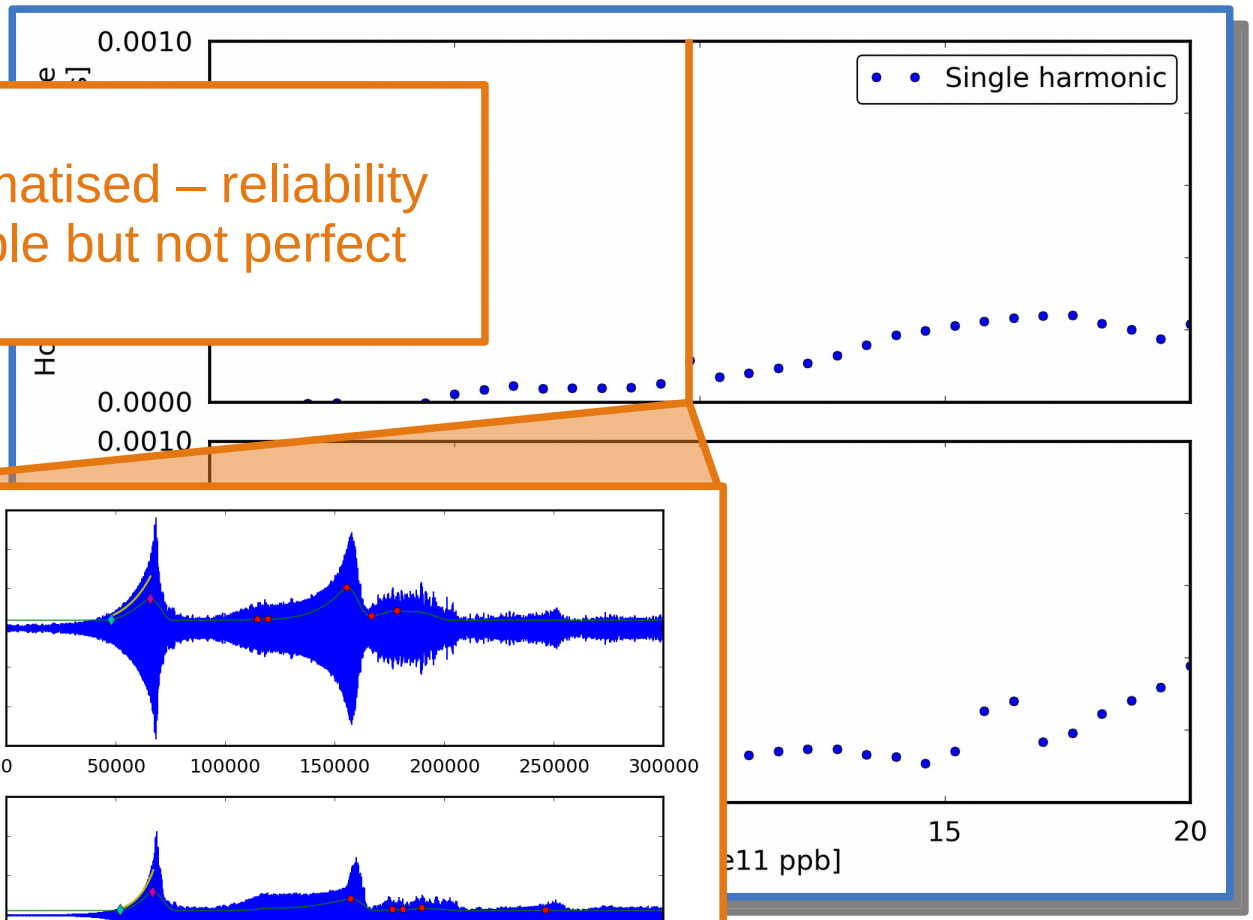

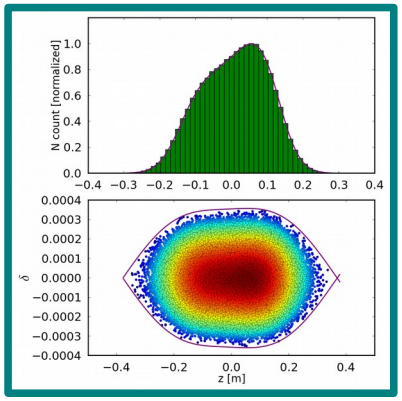

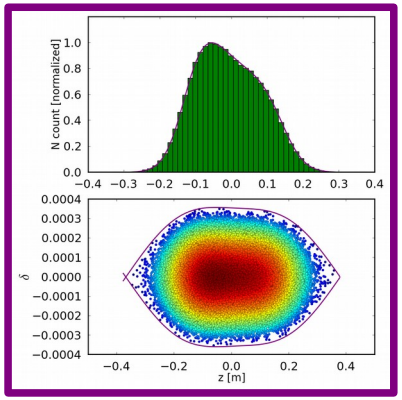

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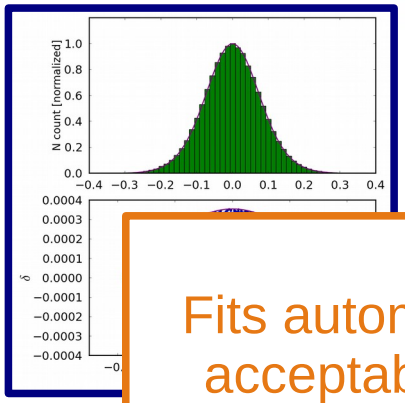

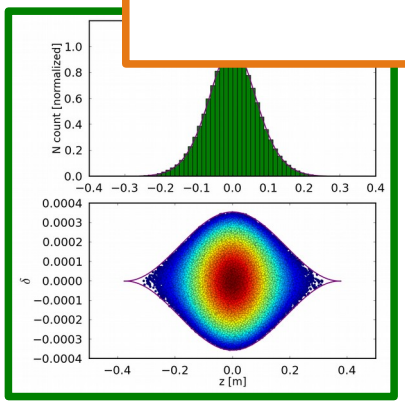

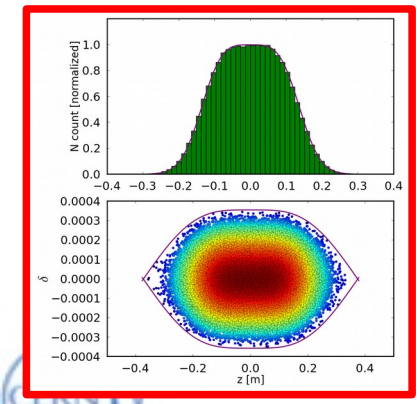

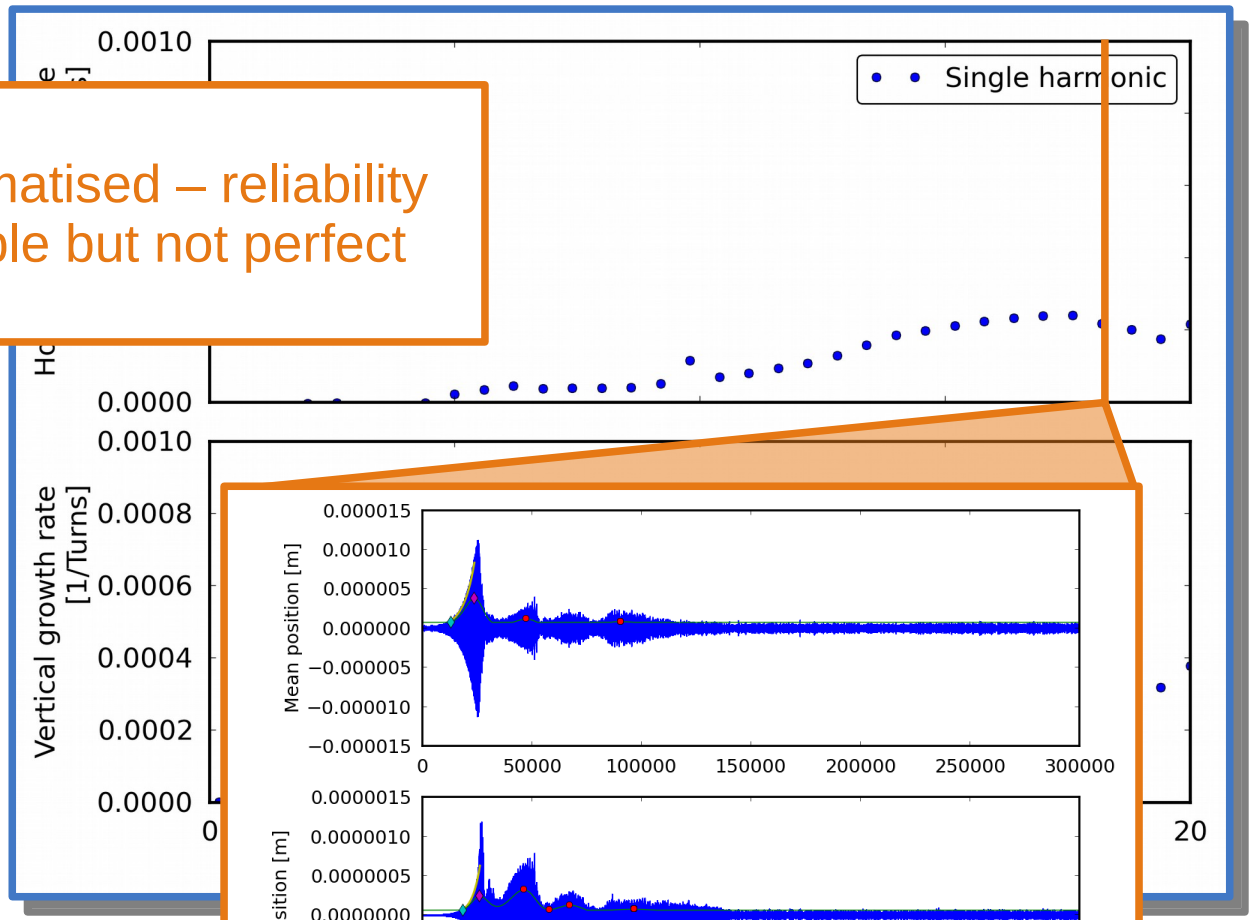

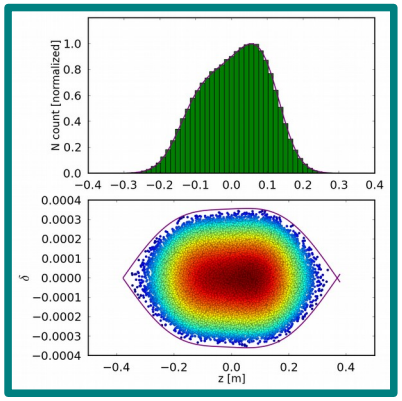

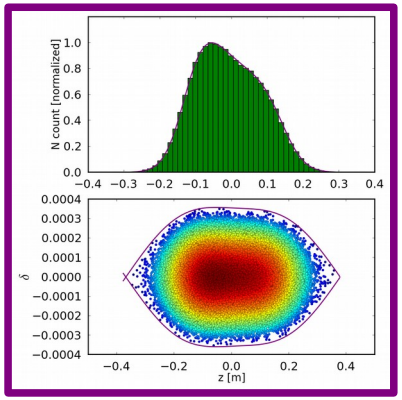

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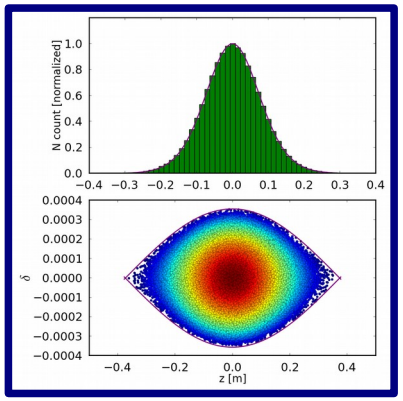

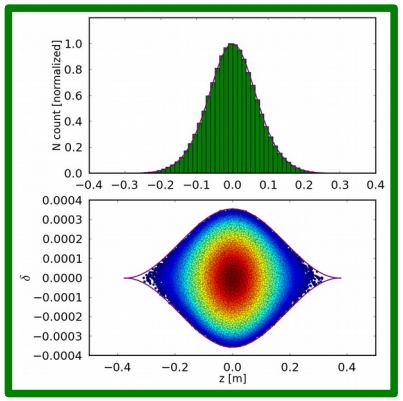

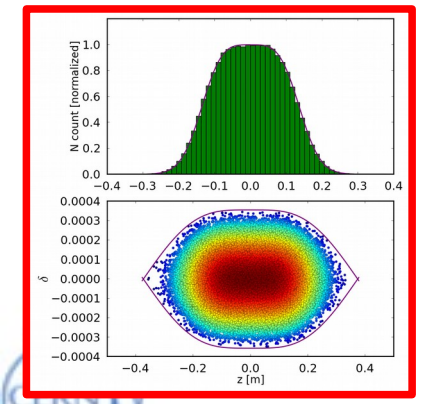

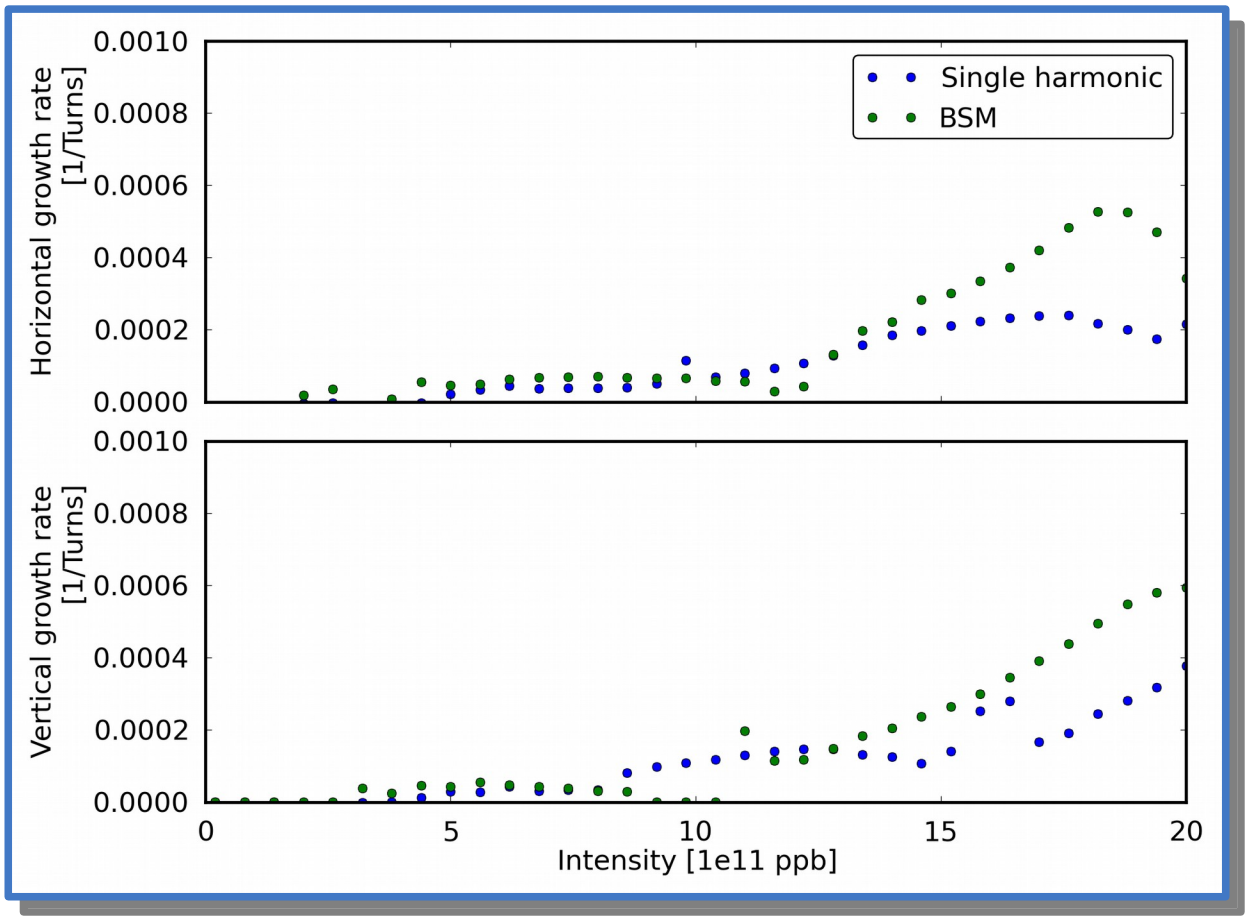

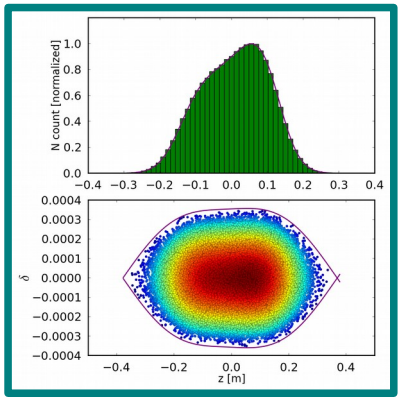

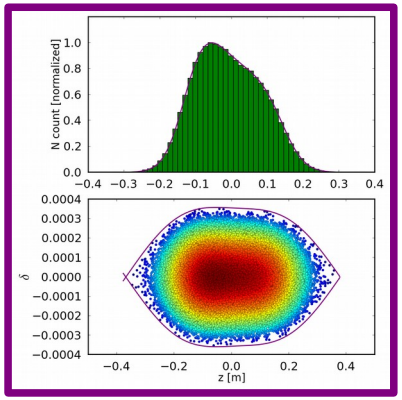

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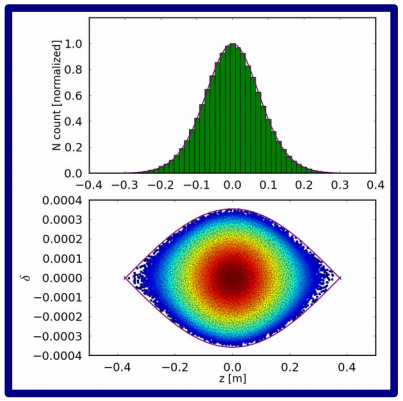
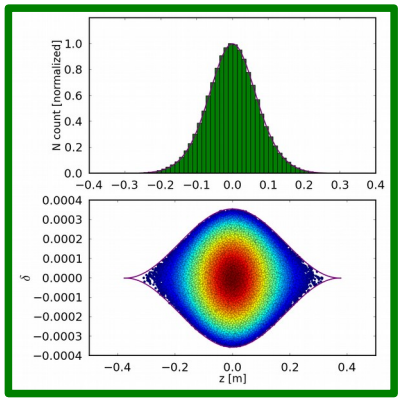
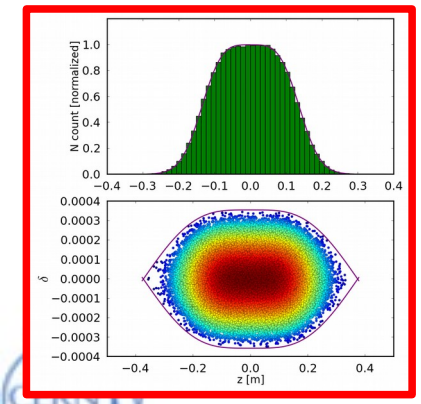
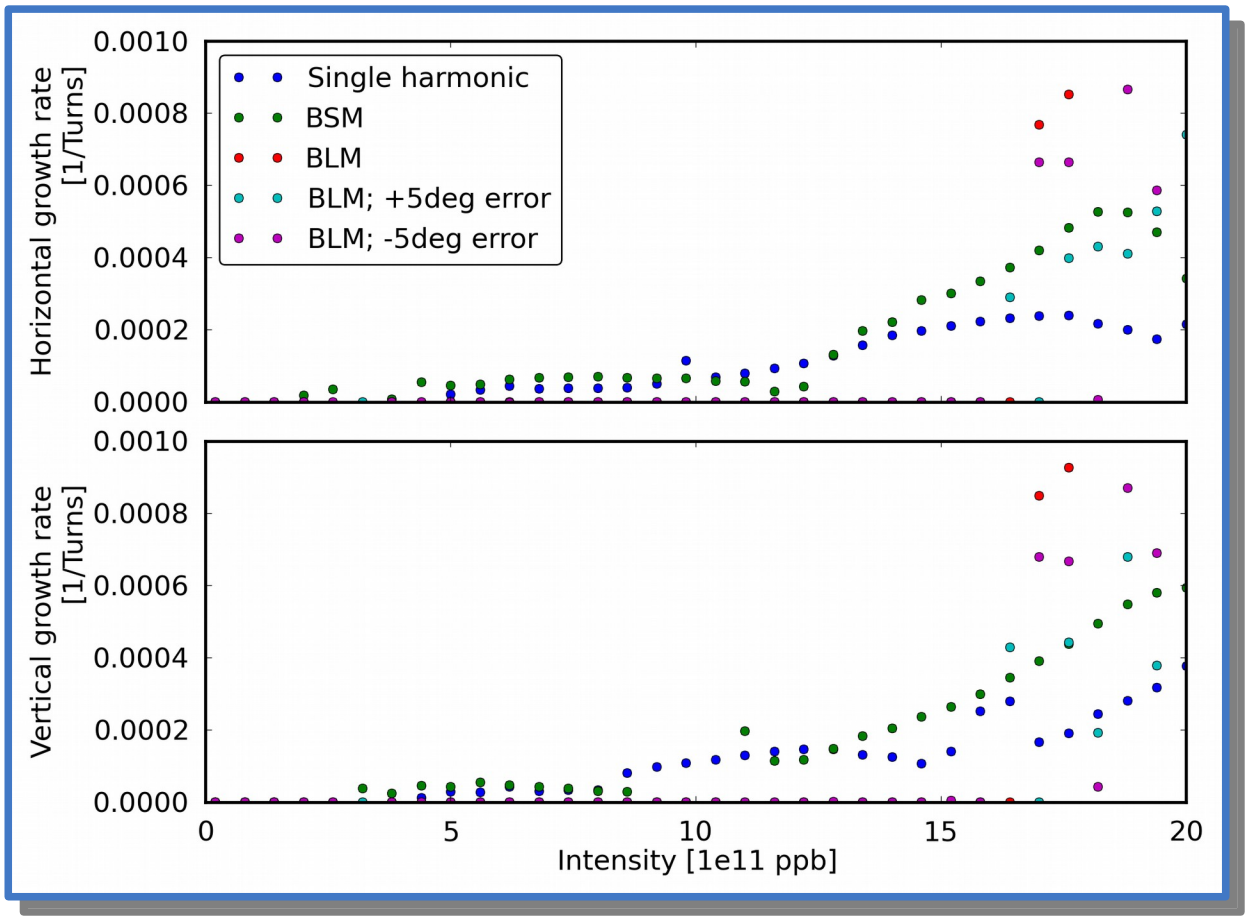
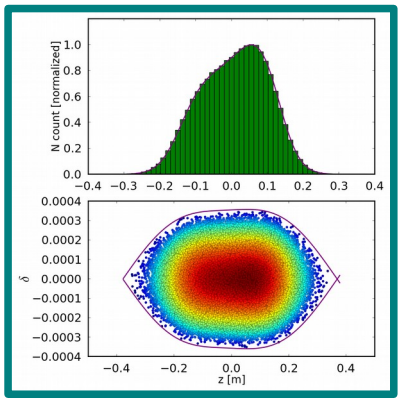
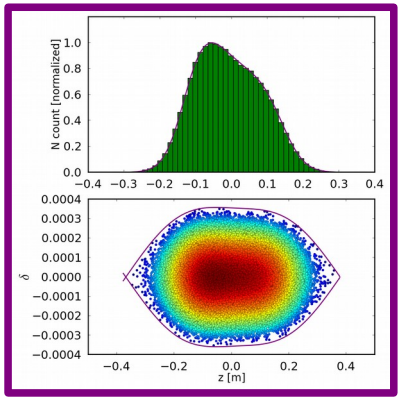






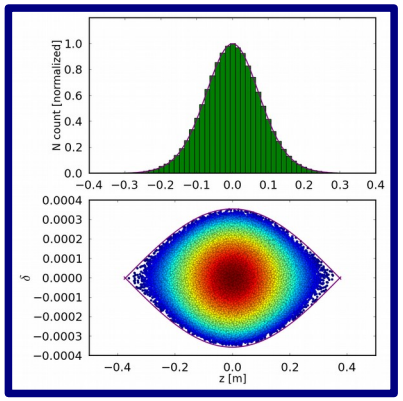


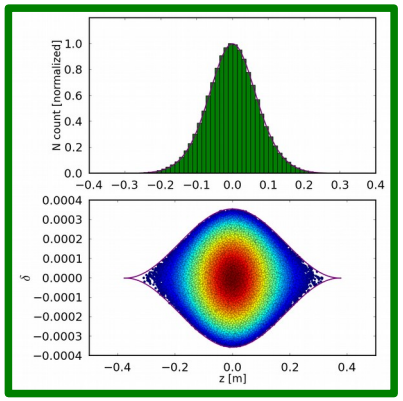


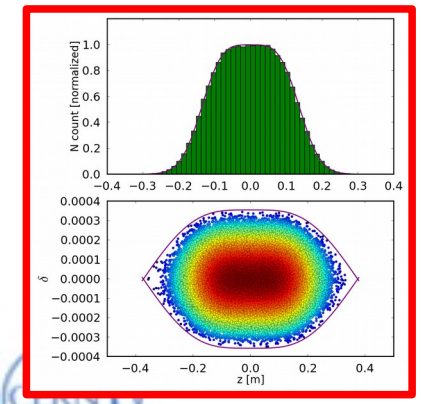


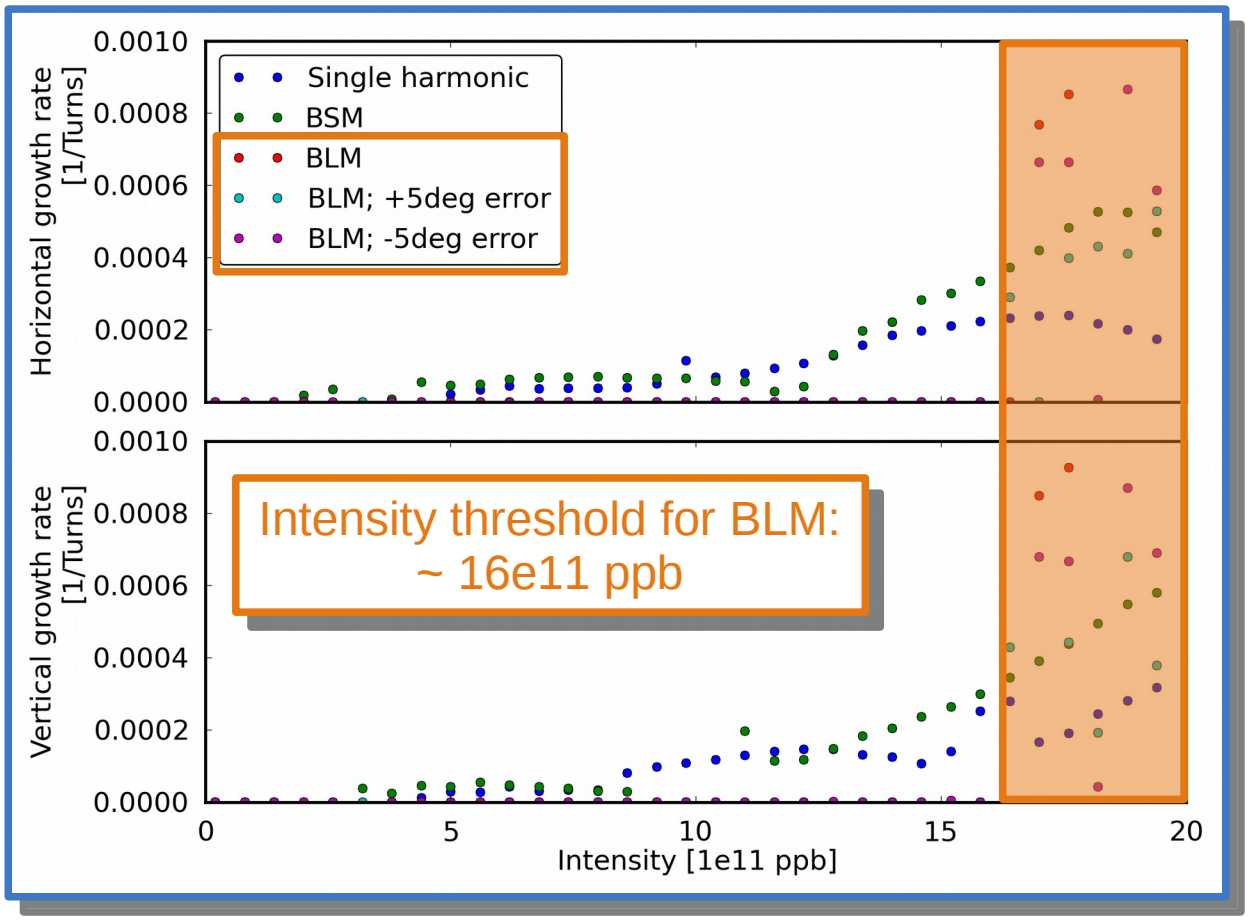
G-rates with damping mechanisms

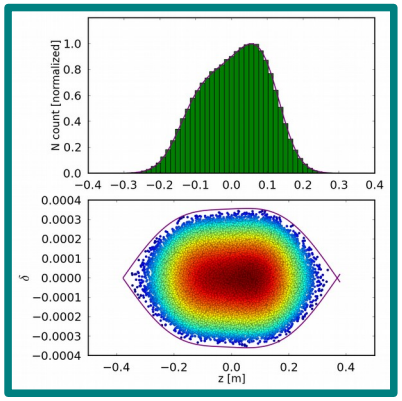
Scan range increased: 7e11 ppb → 20e11 ppb

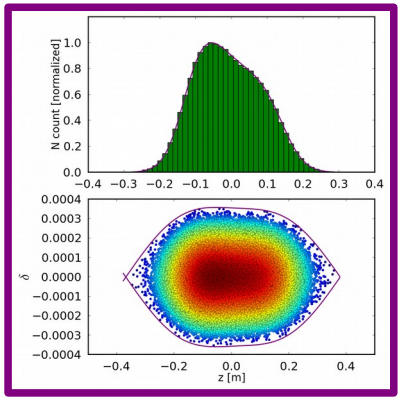






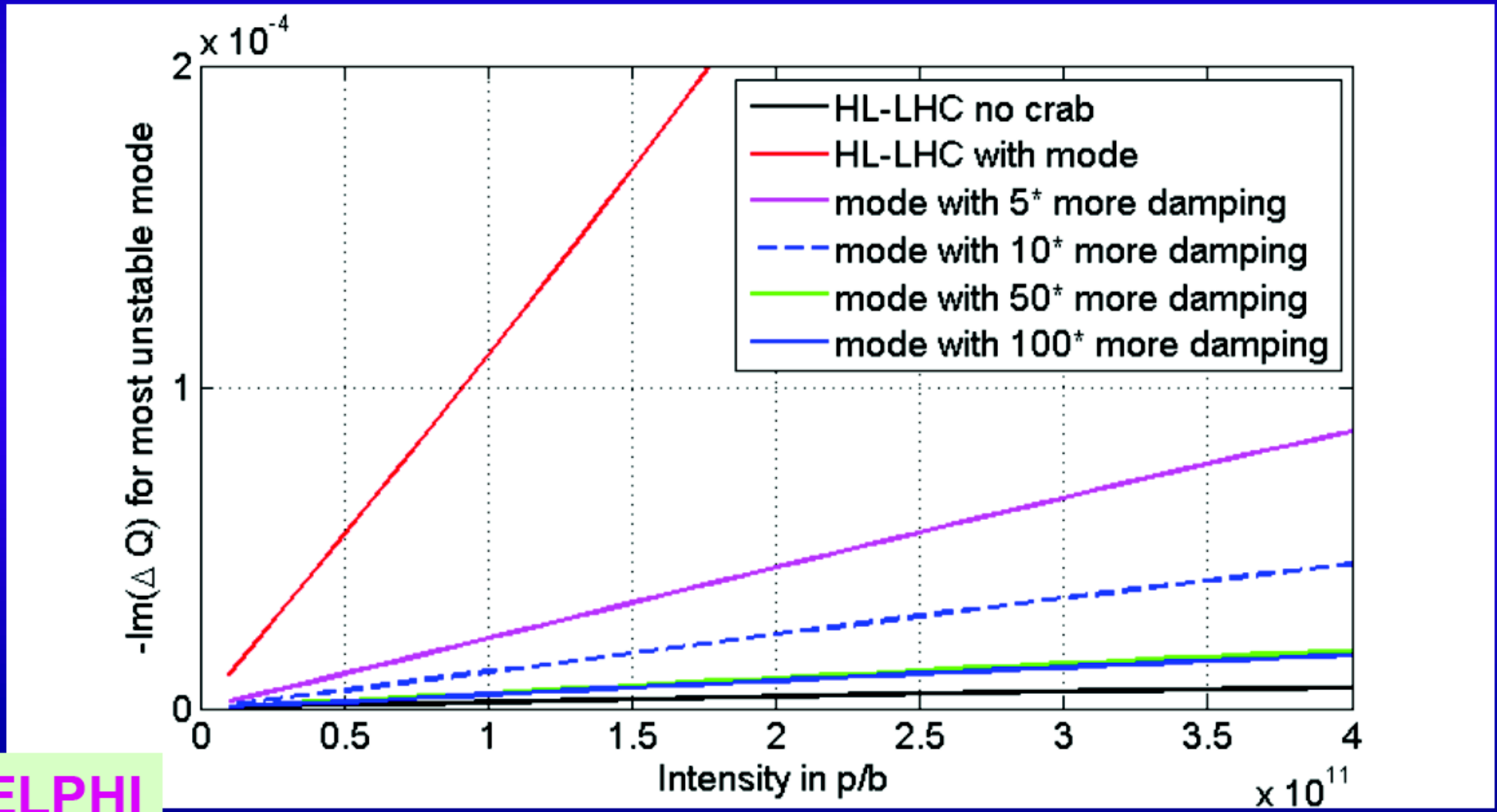






The impact of crab cavities – comparison with previous studies (DELPHI)

DELPHI results



DELPHI

Parameters

- HL-LHC parameters used for the simulations
- Free parameters:
  - Intensity
  - Chromaticity = 15
  - Linear single RF
  - Damper gain = 50

Macroparticles	500 000
Slices	500
Turns	$<$ 300 000
Energy	7 TeV
α	3.225e-4
Q_x	62.31
Q_y	60.32
β_x	65.98 m
β_y	71.53 m
$\varepsilon_x^{(n)}$	2.5 µm
$\varepsilon_y^{(n)}$	2.5 µm

Simulation setup

- Used classical HL-LHC impedance wake table
- Wake table with crabs was not (yet) available
- Trivially solved in PyHEADTAIL by simply concatenating a resonator wake to the existing wake fields

Macroparticles	500 000
Slices	500
Turns	$< 300\,000$
Qs	0.002045
α	3.225e-4
R_{shunt}	1.4 GΩ/m
f_r	800 MHz
Q	1000

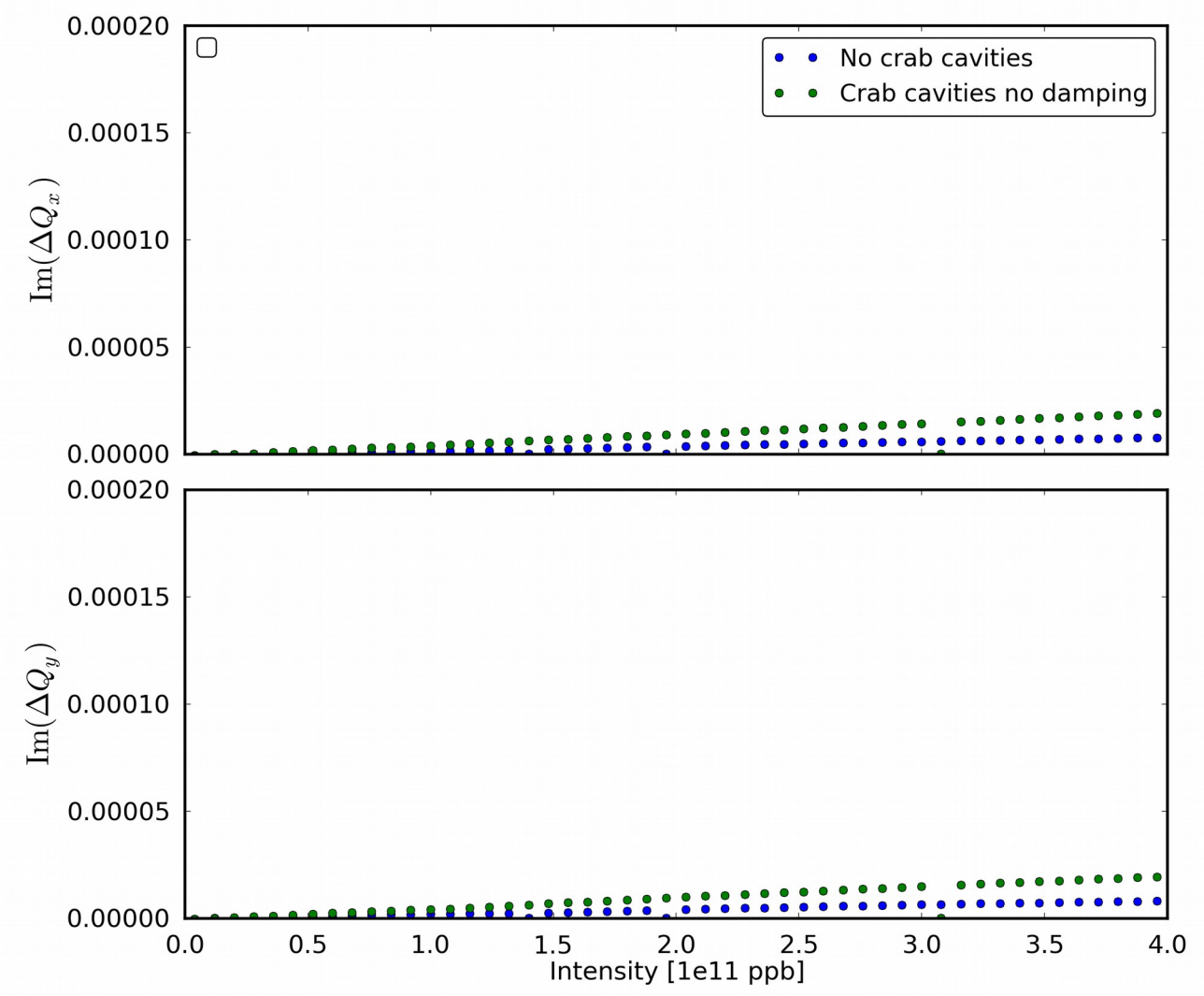
Simulation setup

- Used classical HI
  impedance wake
- Wake table with c
  not (yet) available
- Trivially solved in
  PyHEADTAIL by
  concatenating a r
  wake to the existi
  fields

```
# CREATE WAKES
# ============
R_shunt    = 1.4e9
frequency = 800e6
Q          = 1000

wakefile_columns     = ['time', 'dipole_x', 'dipole_y', 'quadrupole_x', 'quadrupole_y', '
wake_table           = WakeTable(wakefilepath+'wakeforhdtl_PyZbase_Allthemachine_7TeV_B1_
circ_resonator_wake  = CircularResonator(R_shunt, frequency, Q)
wake_field           = WakeField(slicer_for_wakefields, wake_table, circ_resonator_wake)

# CREATE DAMPER
# =============
dampingrate_x = 50
dampingrate_y = 50
damper = TransverseDamper(dampingrate_x, dampingrate_y)
```

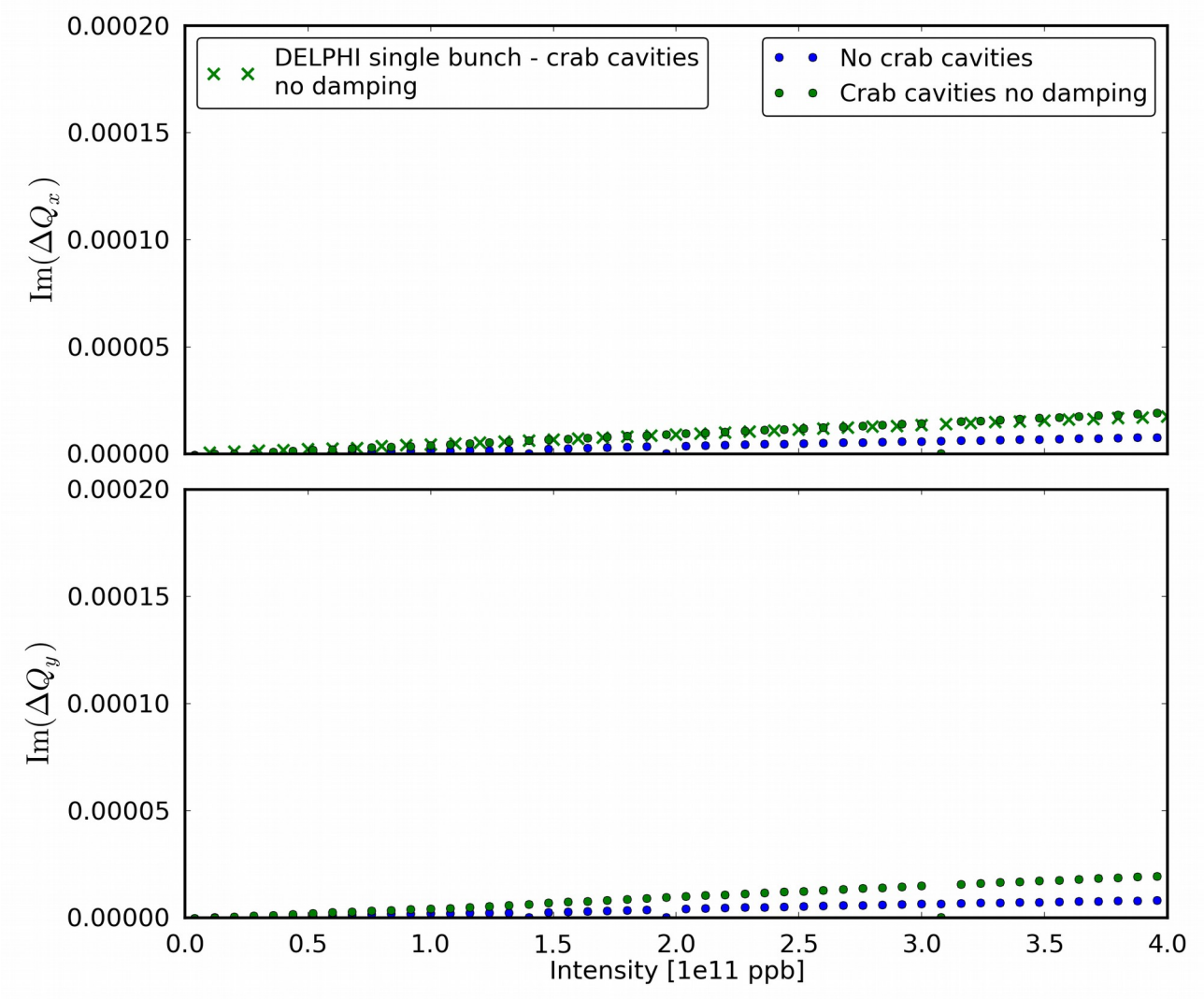
```
# TRACKING LOOP
# =============
one_turn_map = [transverse_map[0]] + [longitudinal_map] + [wake_field] + [damper]
print '\n--> Begin tracking...\n'
for i in range(n_turns):
    t0 = time.clock()
    for m in one_turn_map:
        m.track(bunch)

    bunchmonitor.dump(bunch)

    if i%20 is not 0:
        continue

    print '{:4d} \t {:+3e} \t {:+3e} \t {:+3e} \t {:3e} \t {:3e} \t {:3f} \t {:3f} \t {:3
unch.epsn_x(), bunch.epsn_y(), bunch.epsn_z(), bunch.sigma_z(), bunch.sigma_dp(), str(time
 main.py<2>      84% (162,0)     (Py AC Outl)
```

Compare PyHEADTAIL - DELPHI



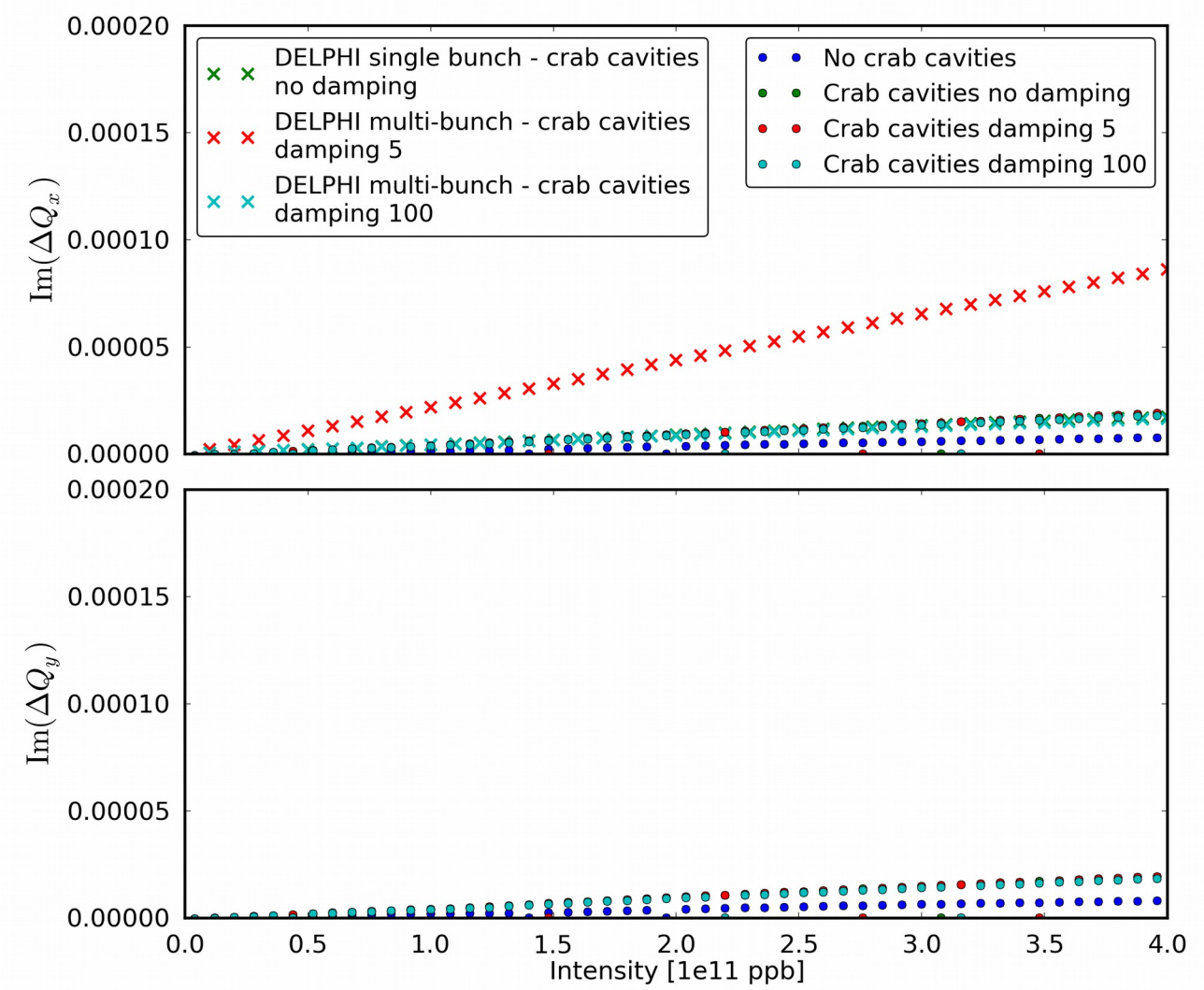
- Crab cavity impedance leads to a factor ~2 increase in growth rates

Compare PyHEADTAIL - DELPHI



- Crab cavity impedance leads to a factor ~2 increase in growth rates
- Crab cavity single bunch growth rates reproduced from DELPHI (horizontal)

Compare PyHEADTAIL - DELPHI



- Crab cavity impedance leads to a factor ~2 increase in growth rates
- Crab cavity single bunch growth rates reproduced from DELPHI (horizontal)
- HOM damping has marginal effect for single bunch
- HOM damping has significant effect for multi-bunch
- HOM damping of >50 reduces growth rates to single bunch growth rates

Conclusions

- Stability thresholds with damping elements:
  - Q' = 15, LOF = 550 A, Damper gain = 50 turns
  - Single RF: 4e11
  - BSM: 3.5e11
  - BLM 16e11
- PyHEADTAIL vs. DELPHI imaginary tuneshift evaluation with crab cavities
  - Excellent agreement (single bunch)
  - Addition of crab cavities increases the single bunch instability growth rates by roughly a factor 2