# Beam Simulations for FLUTE, a Linac Based Compact THz Source

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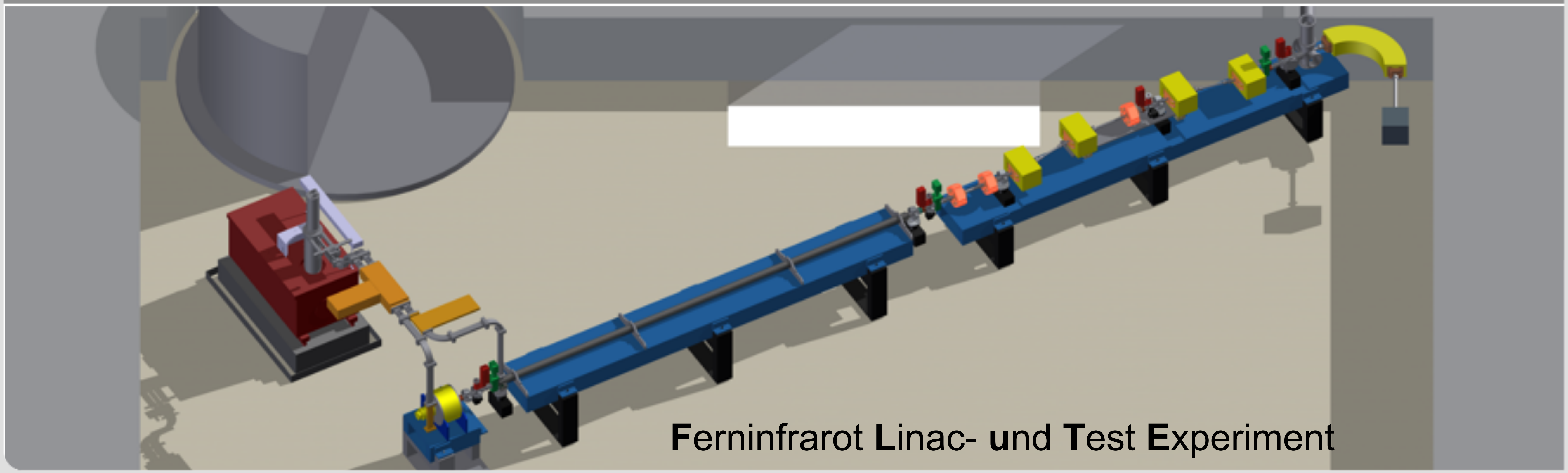
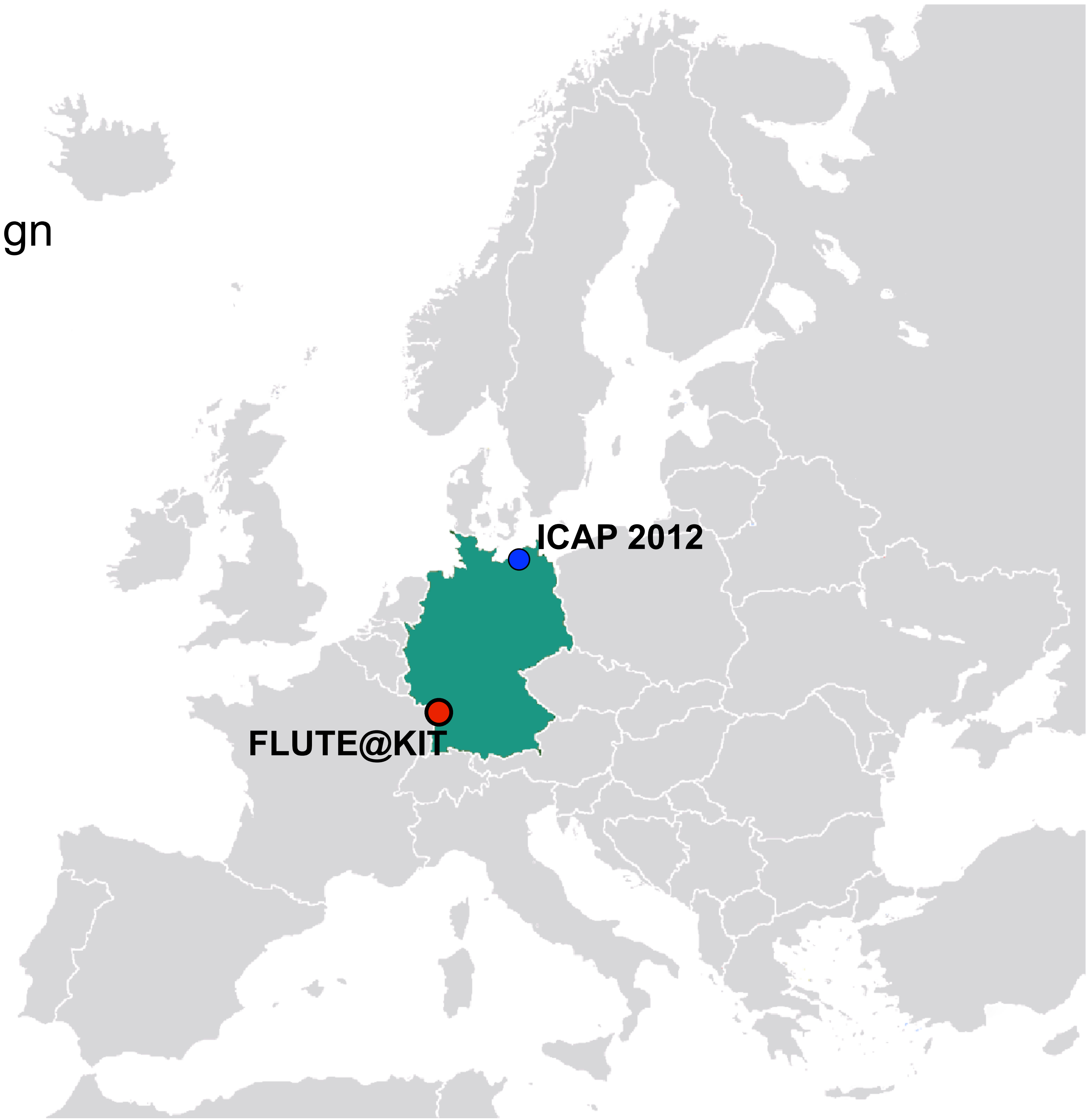


**F**erninfrarot **L**inac- **u**nd **T**est **E**xperiment

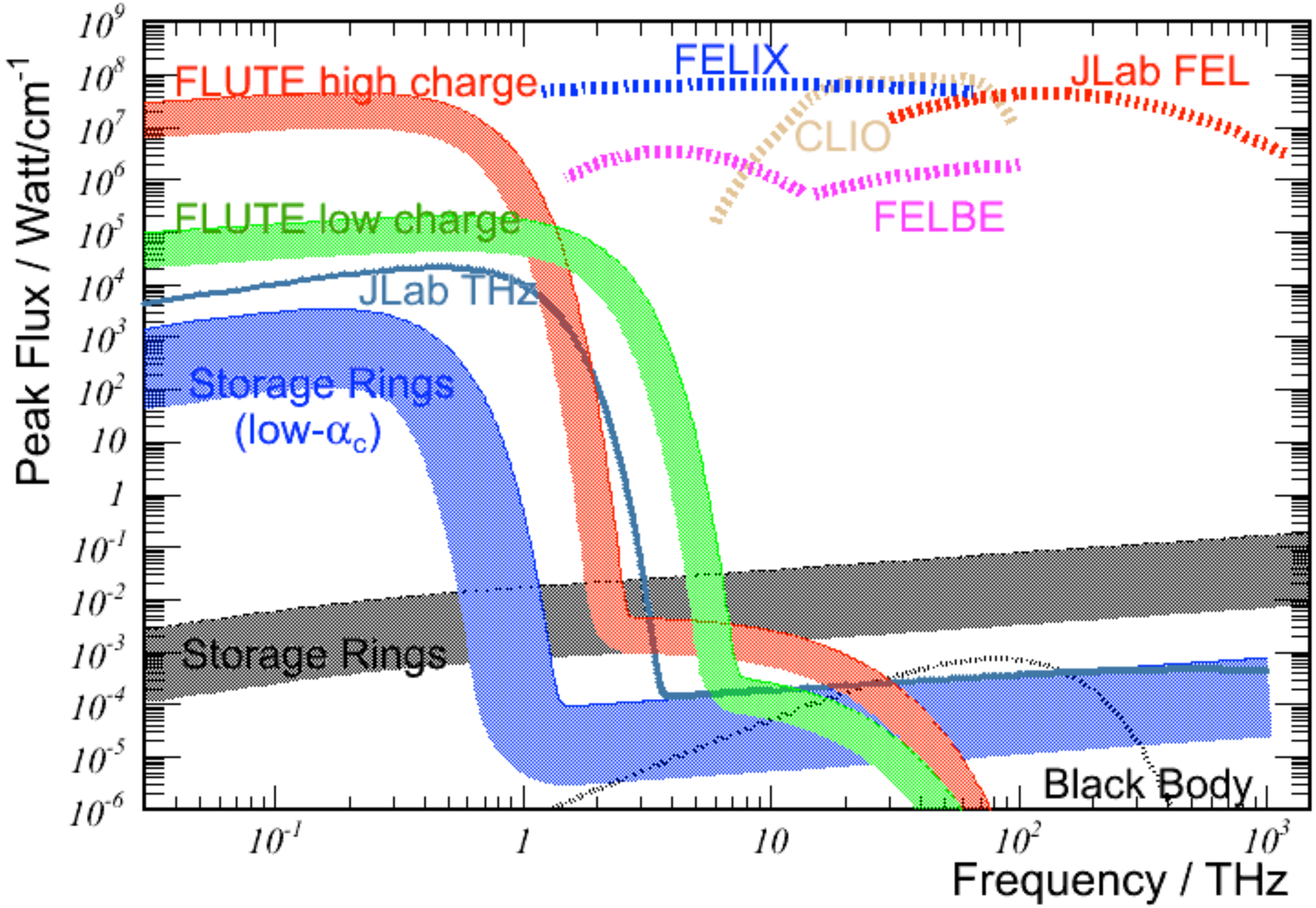
# Outline

- Motivation
- Linac and bunch compression design
- Simulations
  - Tools
  - Optimization
  - Error studies
- Outlook



# Motivation
# From the users point of view

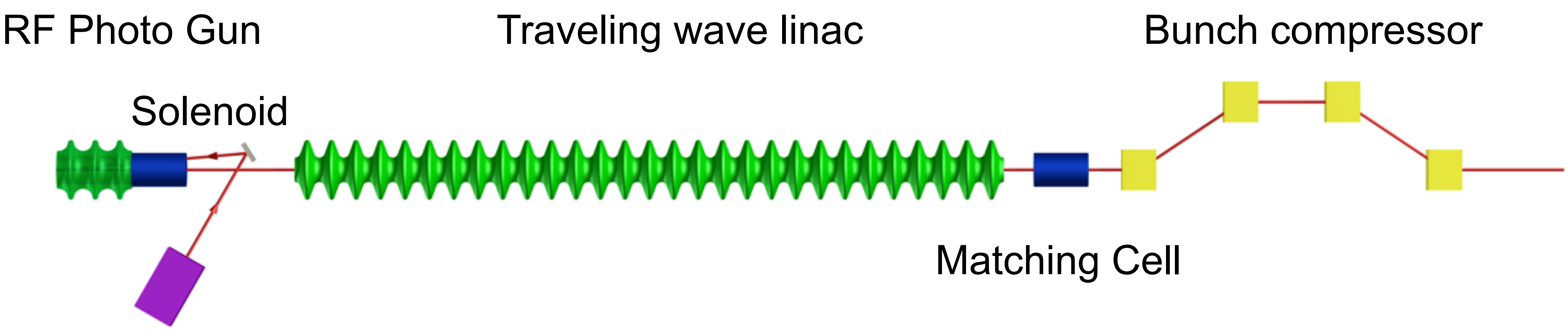
- Single cycle (broadband) THz pulses and very high peak electric fields of the order of $3\times10^8$ V/m



# Motivation
## From the accelerator science point of view

- Study for a future compact, broadband accelerator based THz source
- Serve as a test bench for new beam diagnostic methods and tools
- Compare different coherent radiation generation schemes in simulation and experiment:
  - Coherent Synchrotron Radiation (CSR)
  - Coherent Transition Radiation (CTR)
  - Coherent Edge Radiation (CER)
- Systematic bunch compression studies:
  - Different compression schemes
  - Large charge range up to several nC per bunch → Study space charge and CSR induced effects and instabilities
- Test facility for accelerator studies within the Helmholtz “ARD“ initiative

# General linac layout



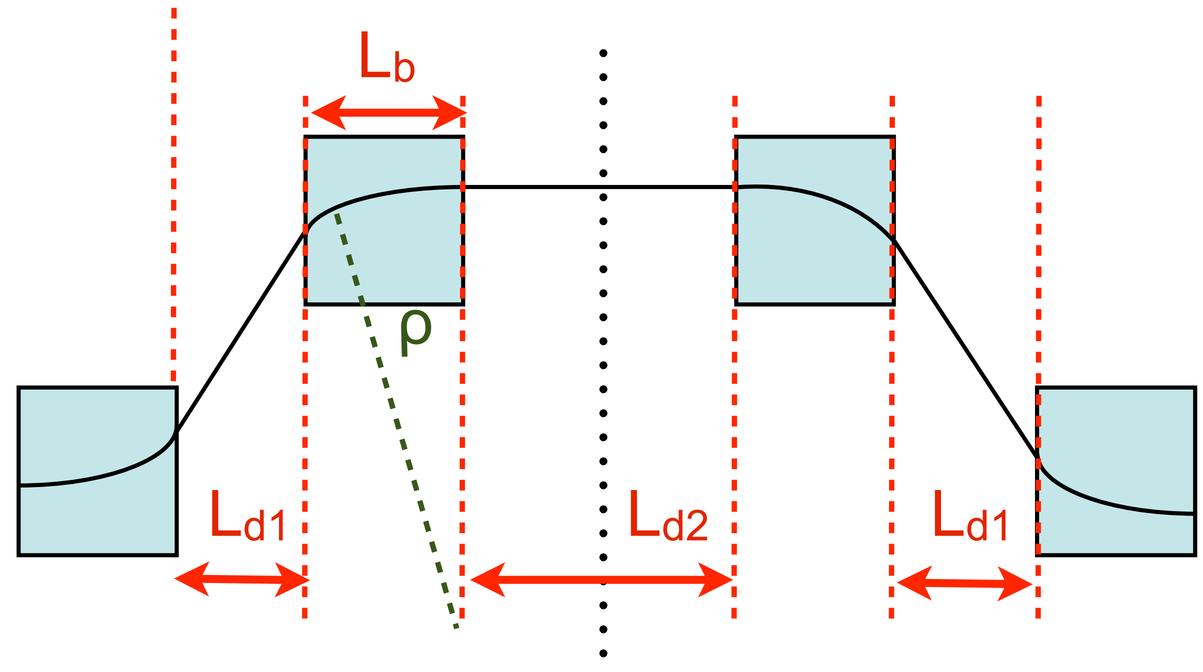

| Laser | Unit | Value |
|---|---|---|
| Max. wavelength | nm | 266 |
| Energy on cathode | mJ | 0.6 |
| Laser pulse length | ps | ≤4 |
| Laser spot size | mm | 2.25 |
| | | |
| | | |

| Gun | Unit | Value |
|---|---|---|
| Frequency | GHz | 2.998 |
| Cells | | 2.5 |
| Peak E-Field | MV/m | ~100 |
| Peak power | MW | ~20 |
| Output energy | MeV | 7 |
| Bunch charge | nC | ≤3 |

| Linac | Unit | Value |
|---|---|---|
| Frequency | GHz | 2.998 |
| Length | m | 5.2 |
| Acc. gradient | MV/m | ~10 |
| Peak power | MW | ~20 |
| Output energy | MeV | ~41 |
| Max. Rep. Rate | Hz | 10-100 |

## Bunch compressor

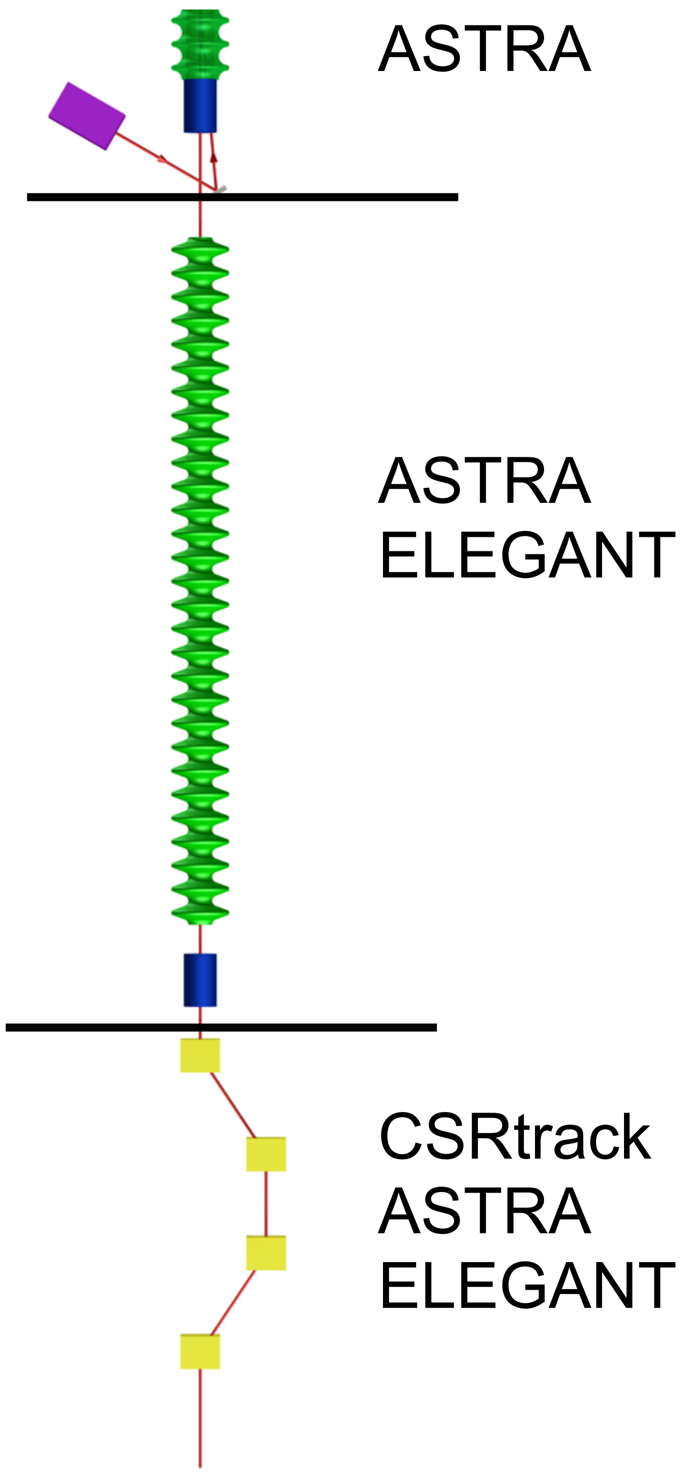
- Goal: compress a negative chirped beam
- Phase one design
  - 4 bending magnets
  - Same length and strength
  - Mirror symmetry
- Beam dynamics effects
  - CSR
  - Space charge
- Present Layout
  - $L_{d1}$ = 0.5 m
  - $L_{d2}$ = 1.0 m
  - $L_b$ = 0.3 m
  - ρ(p) = 1.8 to 2.2 m (charge dependent)
  - $R_{56}$ = 29 to 36 mm



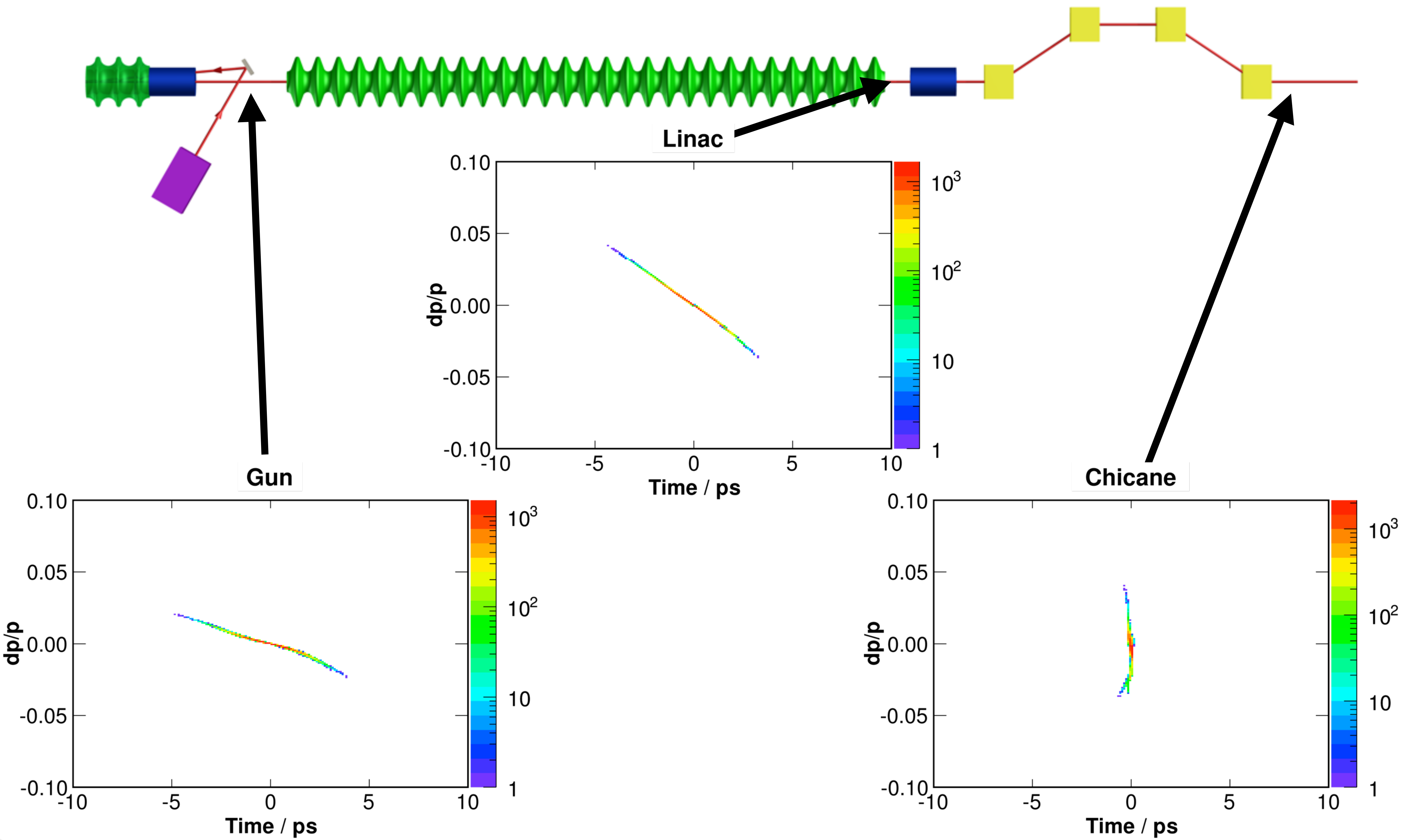

$$R_{56}(p) = 2\frac{L_\mathrm{b}^2}{\rho(p)^2}\left(\frac{2}{3}L_\mathrm{b} + L_\mathrm{d1}\right)$$

## Beam dynamics simulation tool chain

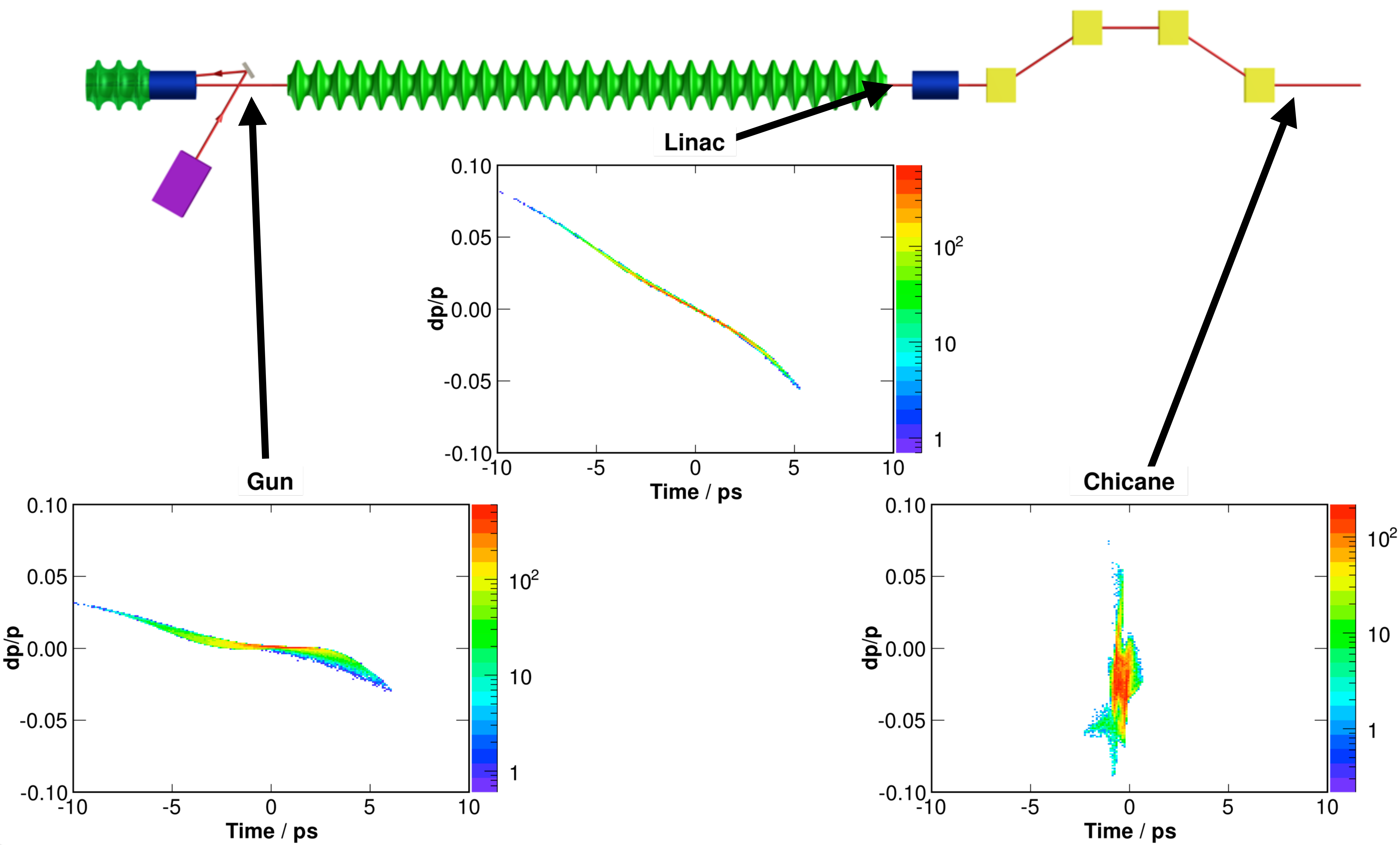
- Gun
  - ASTRA
    - Generated input distribution: $5 \cdot 10^3$ - $10^6$ macro particle
    - Space charge effects - cylindrical symmetry
- Linac
  - ASTRA
    - Space charge effects - cylindrical symmetry
  - ELEGANT
    - Wakes (planed)
- Bunch Compressor
  - ASTRA
    - Space charge effects - 3D
  - CSRtrack
    - CSR effects
    - Space charge effects
  - ELEGANT
    - CSR effects (in preparation)



# Longitudinal phase space evolution for 100 pC



# Longitudinal phase space evolution for 3 nC

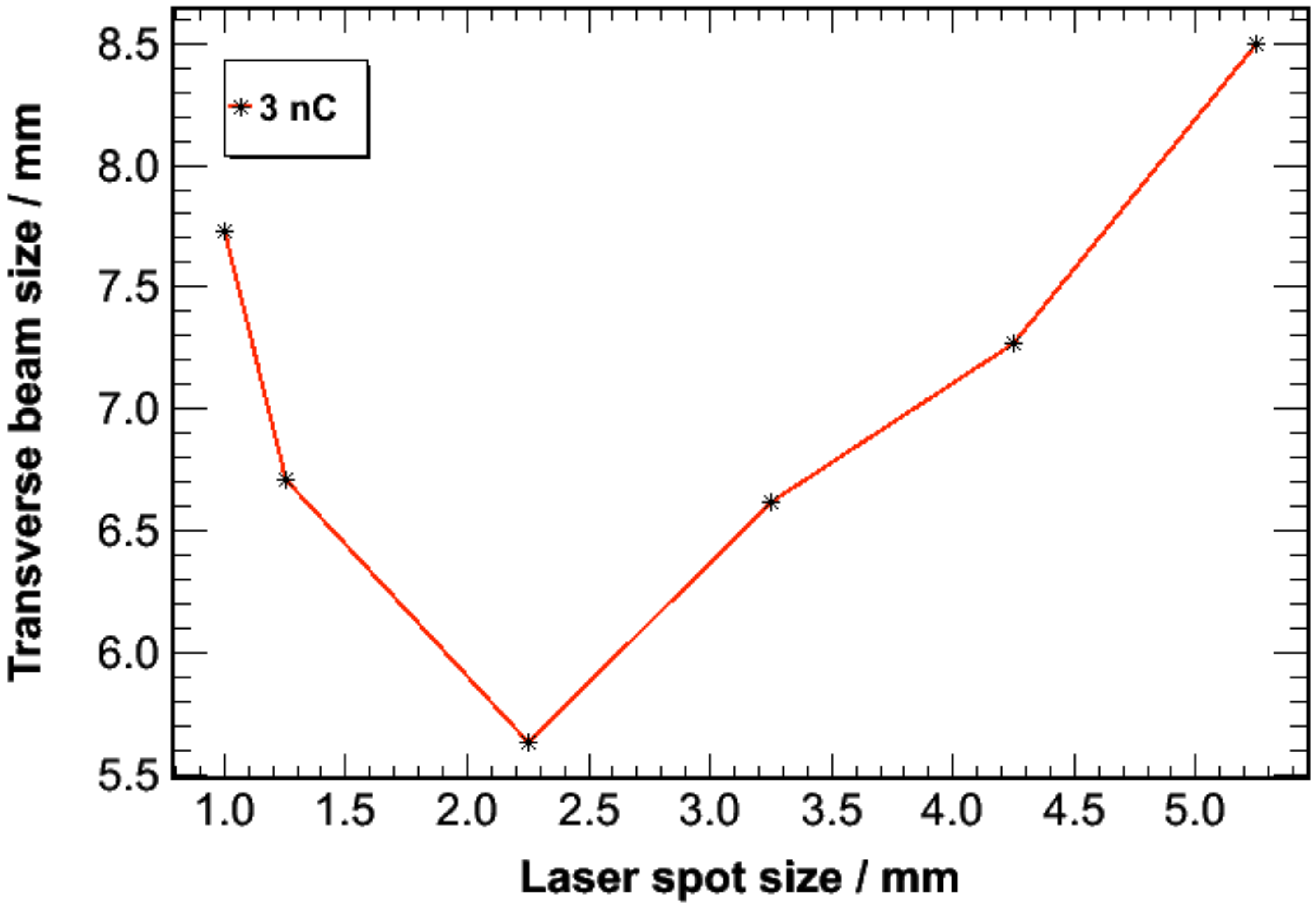


## Parameter scans and optimization

- Global goal: **Minimize the bunch length**
- Parameters to optimize as function of the bunch charge:
  - Laser
    - Pulse length and profile
    - Spot size and transverse distribution
  - RF
    - Gun RF phase
    - Linac RF phase
  - Bunch compressor
    - Magnet length
    - Drift space
    - Bending radius
  - Focusing elements
    - Solenoid strength
    - Matching cell
  - Element position
- Method used up to now: **Parameter scans**

## Laser spot size optimization

- A Gaussian distribution is taken for the laser in the transverse plane as well as temporal




| Parameter | Unit | Value |
|---|---|---|
| Charge | nC | 3 |
| Laser pulse length | ps | 4 |
| Laser spot size | mm | 2.25 |
| Solenoid | T | 0.05 |

## ASTRA vs. CSRtrack

- Optimize bunch compressor bending radius ρ for different bunch charges independently in ASTRA and CSRtrack
  - Magnet length and drift space between magnets is 50 cm in this study
  - ASTRA: 3D space charge with 1 Million macro particles
  - CSRtrack: 3D space charge and CSR with 50000 macro particles

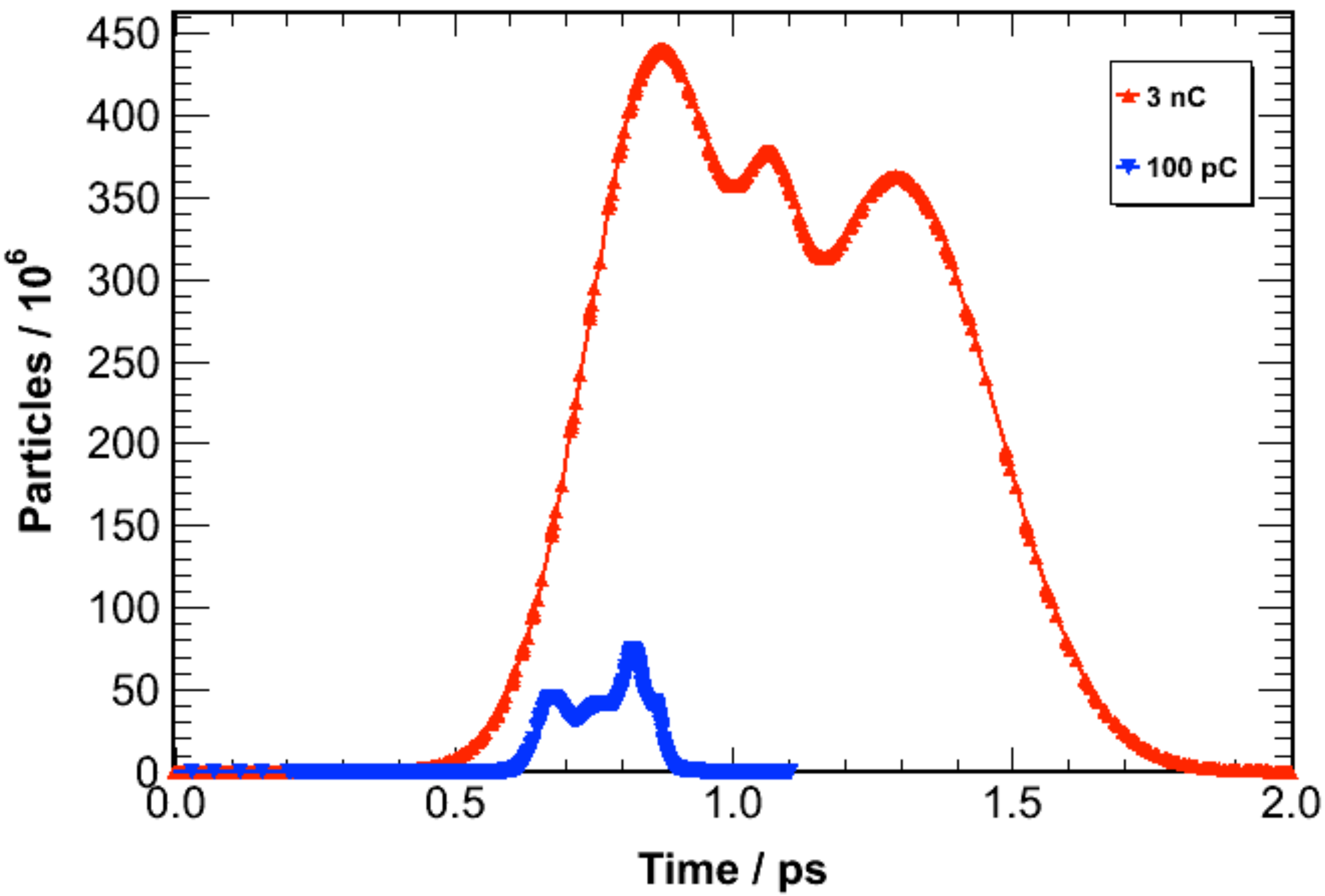
| Charge | Laser pulse | ASTRA bunch length | CSRtrack bunch length | ASTRA ρ | CSRtrack ρ |
|---|---|---|---|---|---|
| pC | ps | fs | fs | m | m |
| 1 | 1 | 14.33 | 14.78 | 3.9 | 3.9 |
| 100 | 4 | 173.33 | 171.16 | 3.85 | 3.9 |
| 3000 | 4 | 250.00 | 429.6 | 3.45 | 3.4 |

# Optimization

- Parameters optimized using parameter scans
  - Laser spot size and pulse length
  - Bending radius

| Charge | Laser pulse | Laser spot size | Bending radius | $R_{56}$ | Bunch length |
|---|---|---|---|---|---|
| pC | ps | mm | m | mm | fs |
| 3000 | 4 | 2.25 | 1.9 | 36.1 | 183 |
| 1000 | 3 | 1.5 | 1.95 | 34.2 | 112 |
| 100 | 2 | 0.5 | 2.1 | 29.4 | 52 |
| 1 | 1 | 0.05 | 2.15 | 28 | 15 |

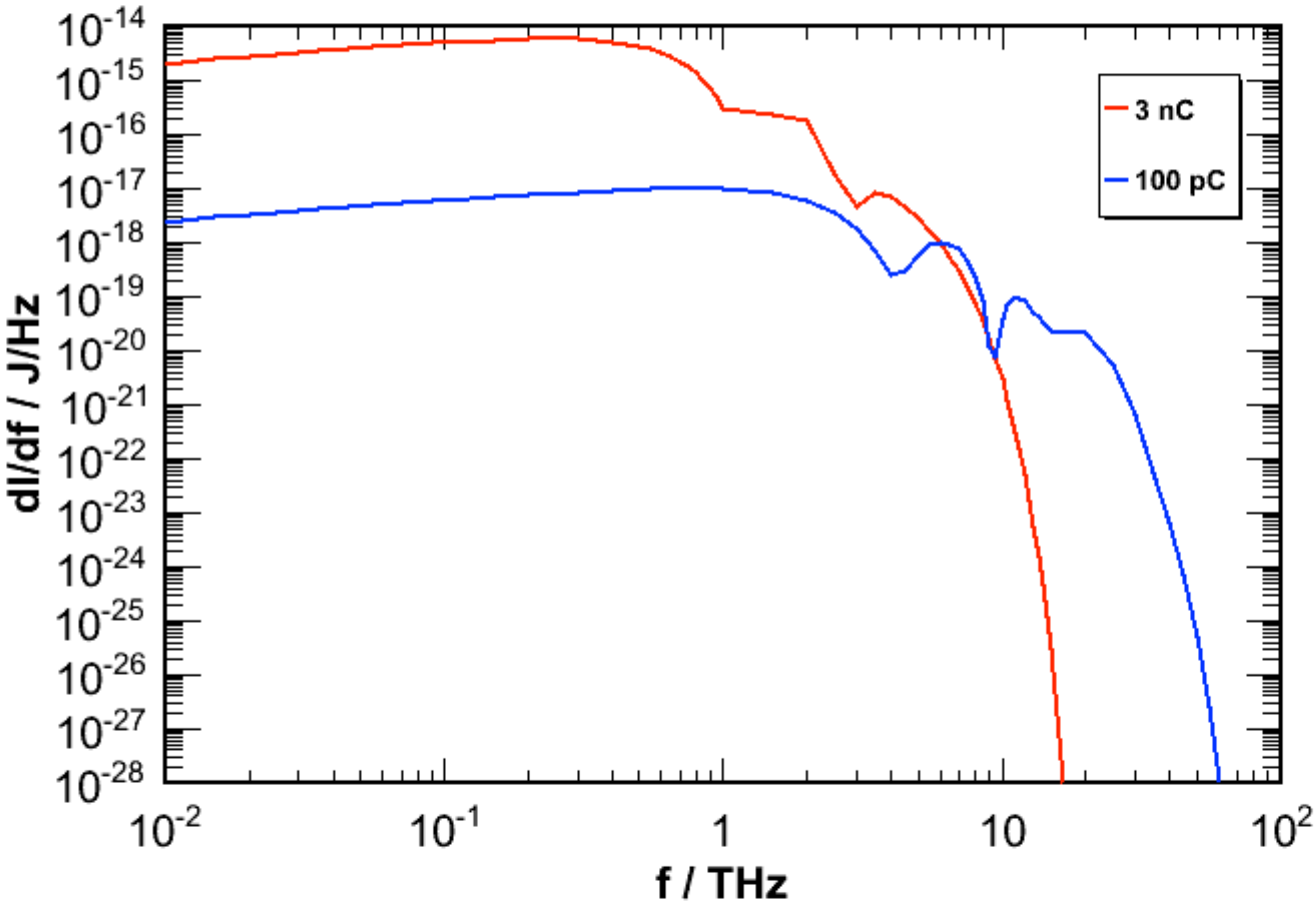
# Simulated longitudinal bunch shape after chicane




- Derive analytically CSR, CER and CTR spectrum from these distributions

***M. Schwarz, IPAC12, MOPPP003***

# Coherent synchrotron radiation spectrum

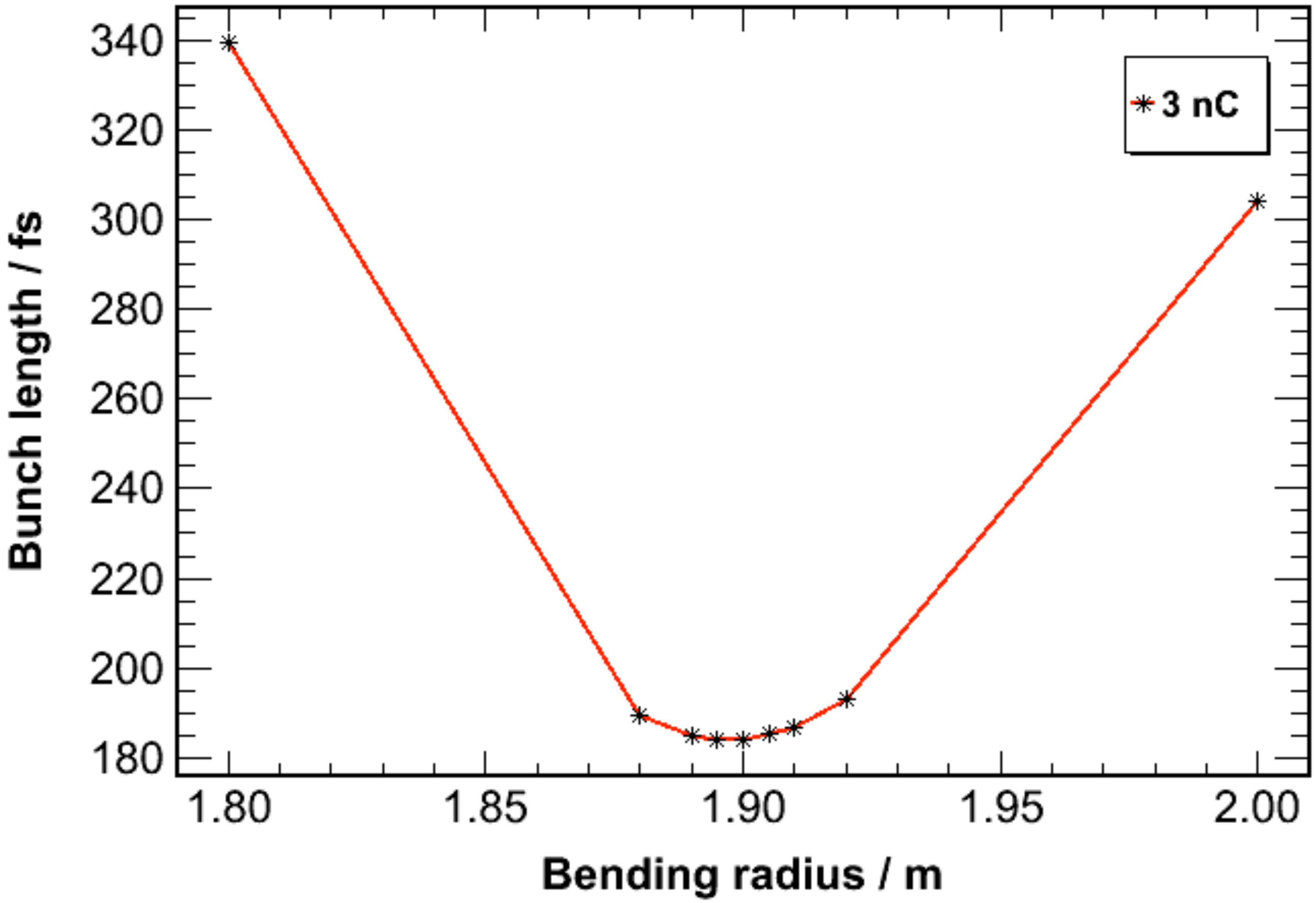


## Error studies

- Magnet errors
  - Power supply
  - Field
  - Alignment
- RF and timing errors
  - Amplitude
  - Phase
  - Synchronization
    - RF to laser
    - Beam to experiment / diagnostic
- Laser shot to shot errors
  - Intensity
  - Spot position
  - Time jitter
- Element alignment errors

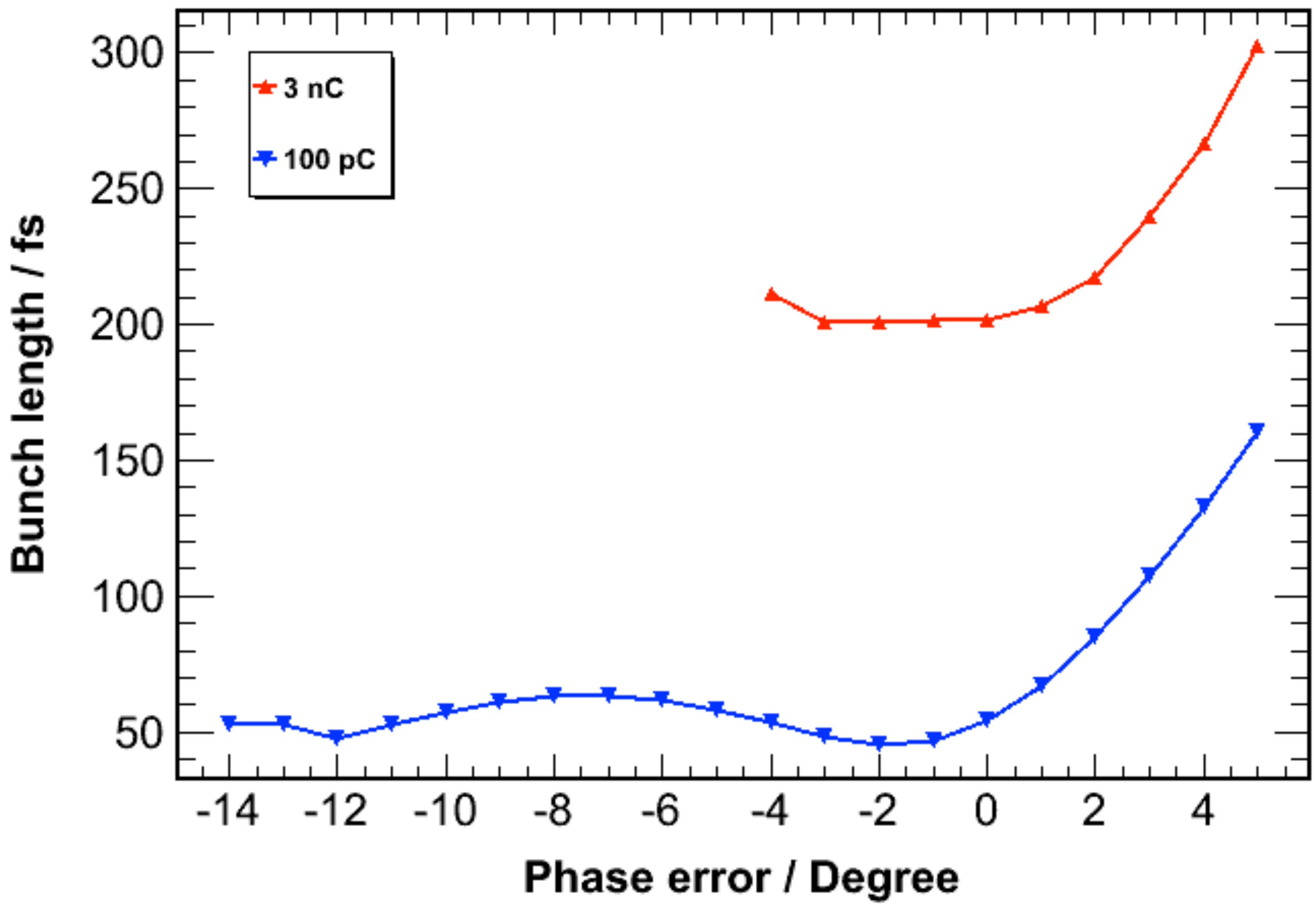
## Bend power supply error study

- The compression depends on the bending field
- The bending radius is direct proportional to the magnet current
- Current stability better than $5 \cdot 10^{-3}$ is needed



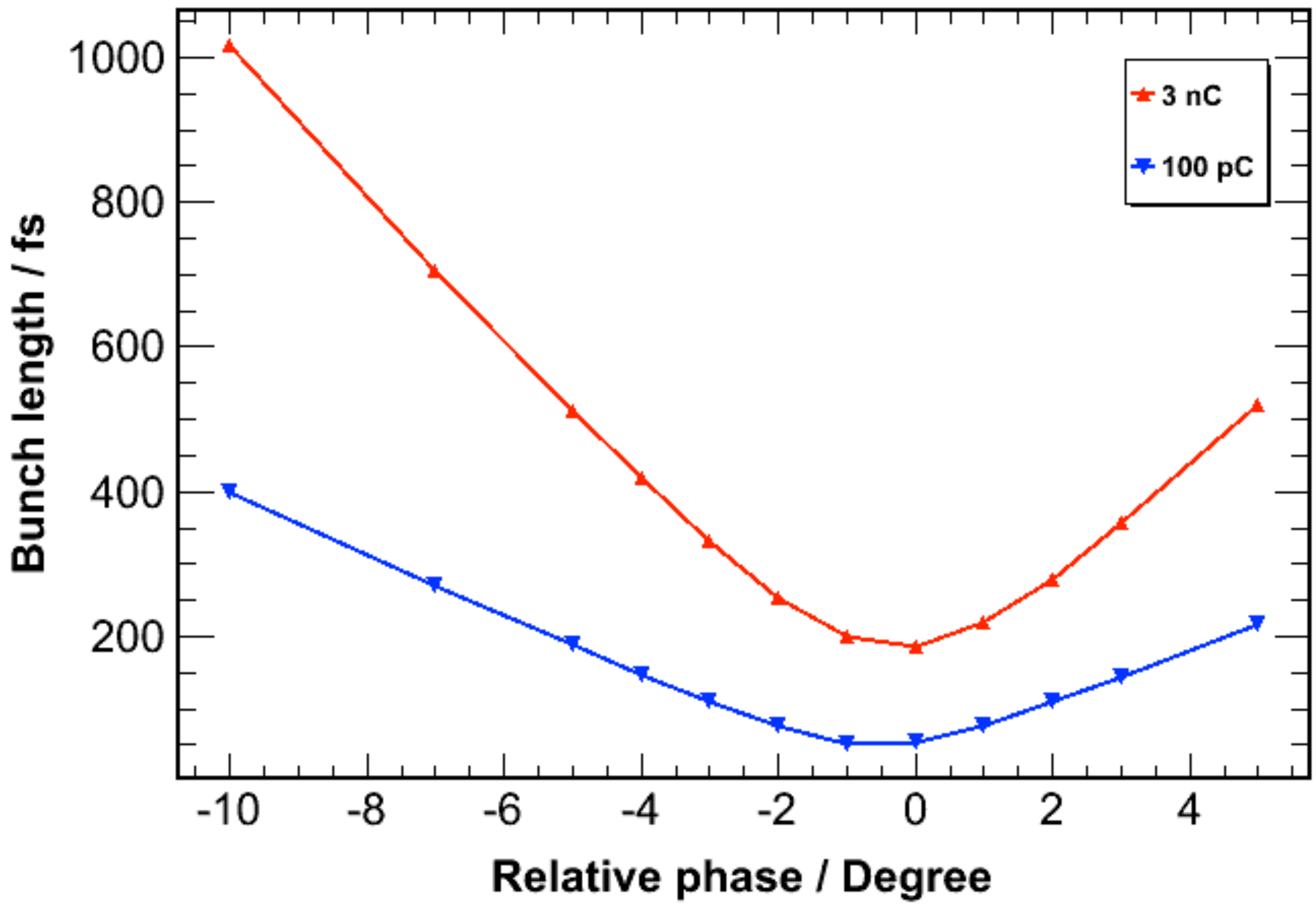
## Synchronisation RF with laser

- Vary phase between RF and laser



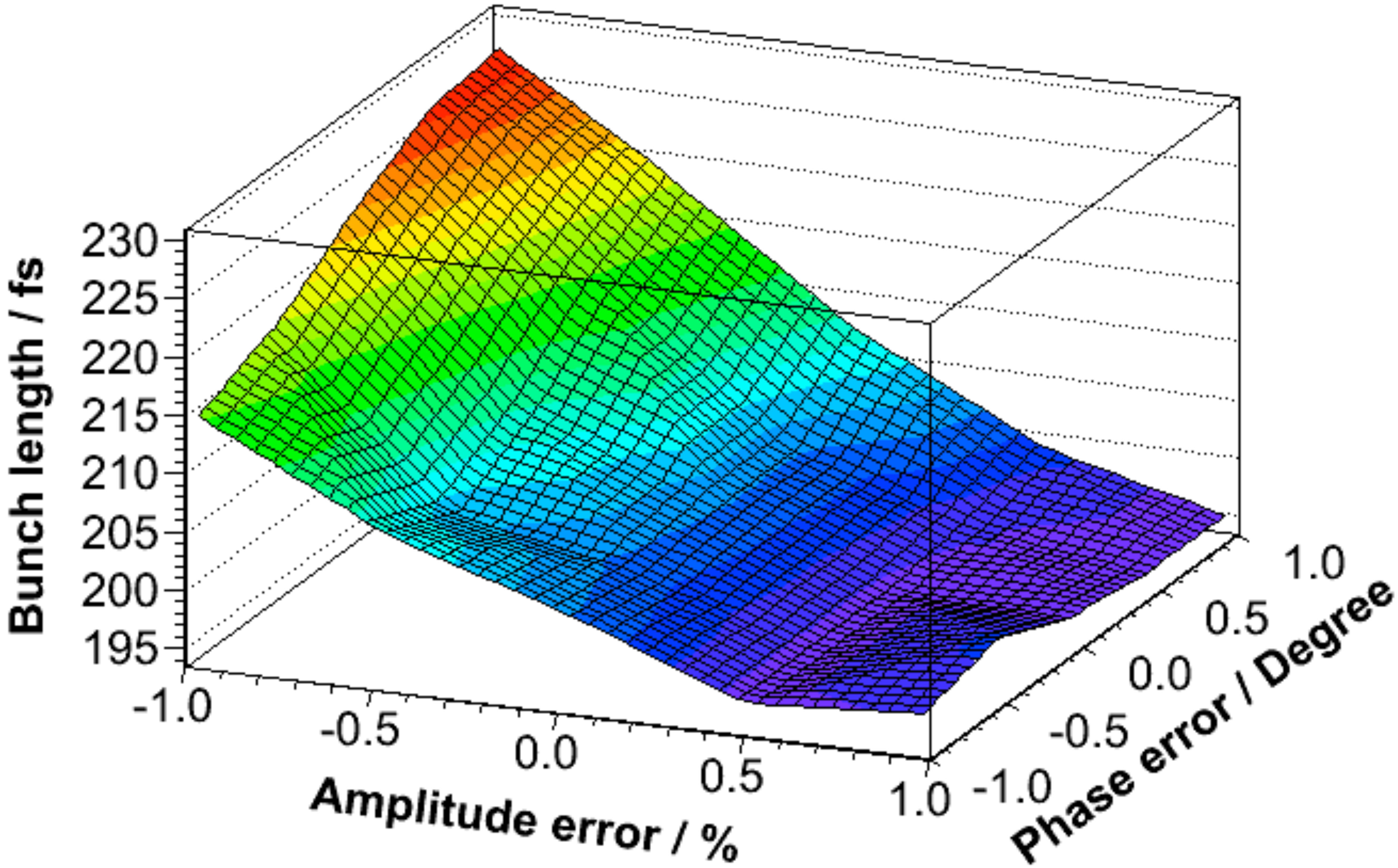
# RF linac phase scan

- Constant phase in gun (reference working point)
- Scan phase in linac relative to working point



## RF error studies

- Vary phase and amplitude together in gun and linac
- Bunch charge: 3 nC



# Outlook

- Finish start to end error studies to define tolerances for the power supplies, LLRF system and alignment
- Additional studies with ELEGANT and optimization with Multiobjective genetic algorithms (MOGA)
  - See also talk of M. Streichert TUABC2
- Finalize the linac layout including all devices (pumps, diagnostics, etc.)

## Thank you for your attention!

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