Undulator-based THz source

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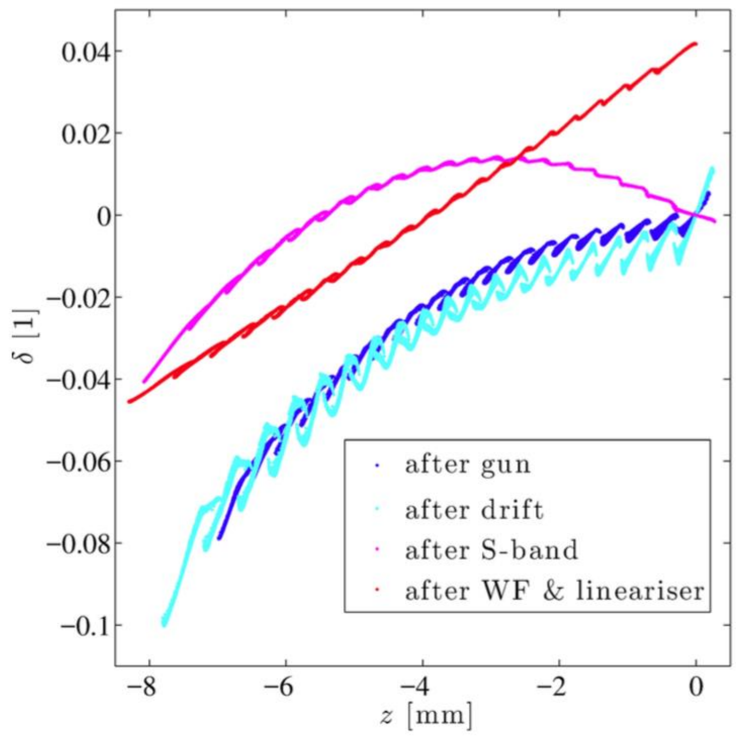
Overview



1. Introduction
2. Comb beam generation
1. Test scenario for CALIFES
2. Conclusions

1. Introduction

THz source for SwissFEL

Motivation:

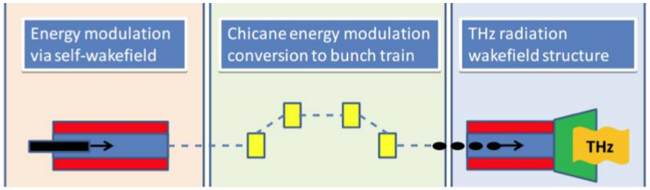
- Vibrations within the material lattice occur manly in the THz regime:
  - Free electrons (plasmon)
  - Lattice vibrations (phonon)
  - Spin coupling (magnon)
  - ...
- To study these effects, material excitation with THz source.

Request from material scientists:

- f_{THz} = 1 – 20 THz (λ_{THz} = 300 – 15µm)
- $E_p \approx$ 100µJ
- $\Delta\omega/\omega_0$ < 10% (pref. 5%)
- Phase locked
- f_{rep} = 100Hz

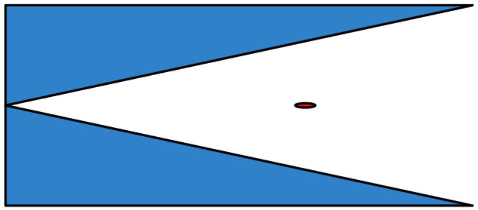
Option 1: THz source based on wakefield modulation

Principle:



1. Energy modulation via wakefield of dielectric structure.
2. Conversion into intensity modulation via bunch compressor.
3. Energy extraction via a second structure (PETS principle).

Tuning:



Advantages:

- Bunch of SwissFEL would be used for source.
- Construction and operation cost is nearly negligible.

Studied by Simona Bettoni

Option 2: Undulator-based THZ source

Undulator parameter:

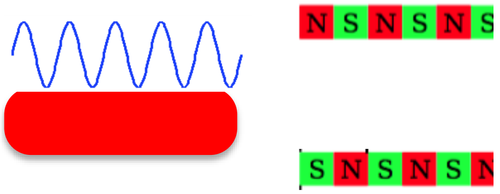
- Challenge to go to so large λ_{THz}.

$$\lambda_{THz} = \frac{\lambda_u}{2\gamma^2}(1 + K_0^2)$$

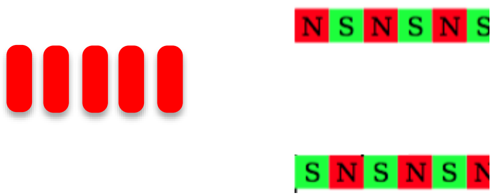
- Helical undulator (symmetric strong natural focusing).
- γ = 50 (E_b=25MeV, space charge).
- λ_u = 6cm (compactness).
- K_0 = 0.75 - 4.9 (for tuning); equals to B_0 = 0.09T – 0.88T.
- Q = 1nC charge necessary.

Phase locking:

- **SASE:** easy, but no phase locking.
- **Seeding:** THz lasers not quite strong enough.

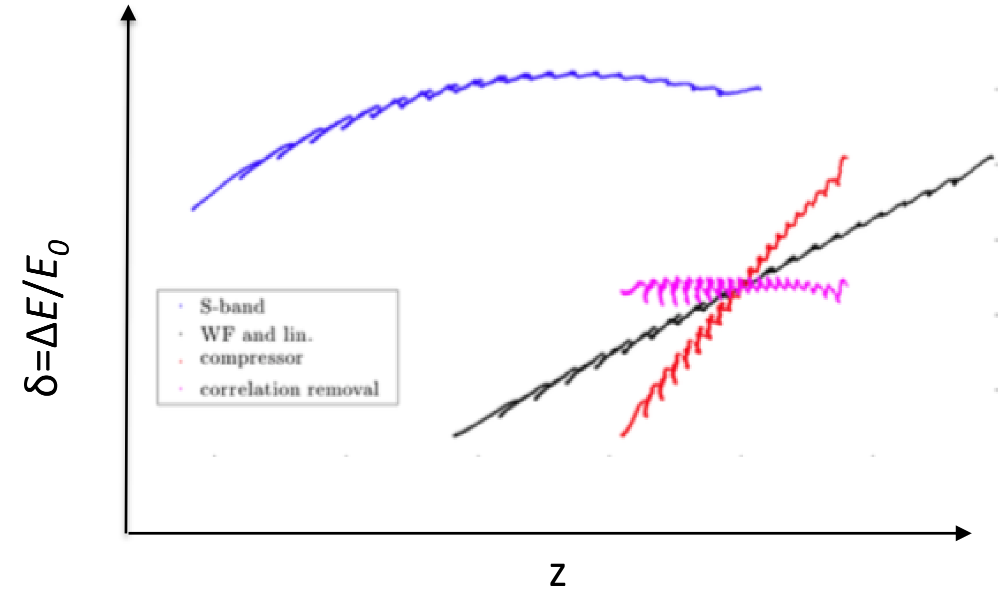


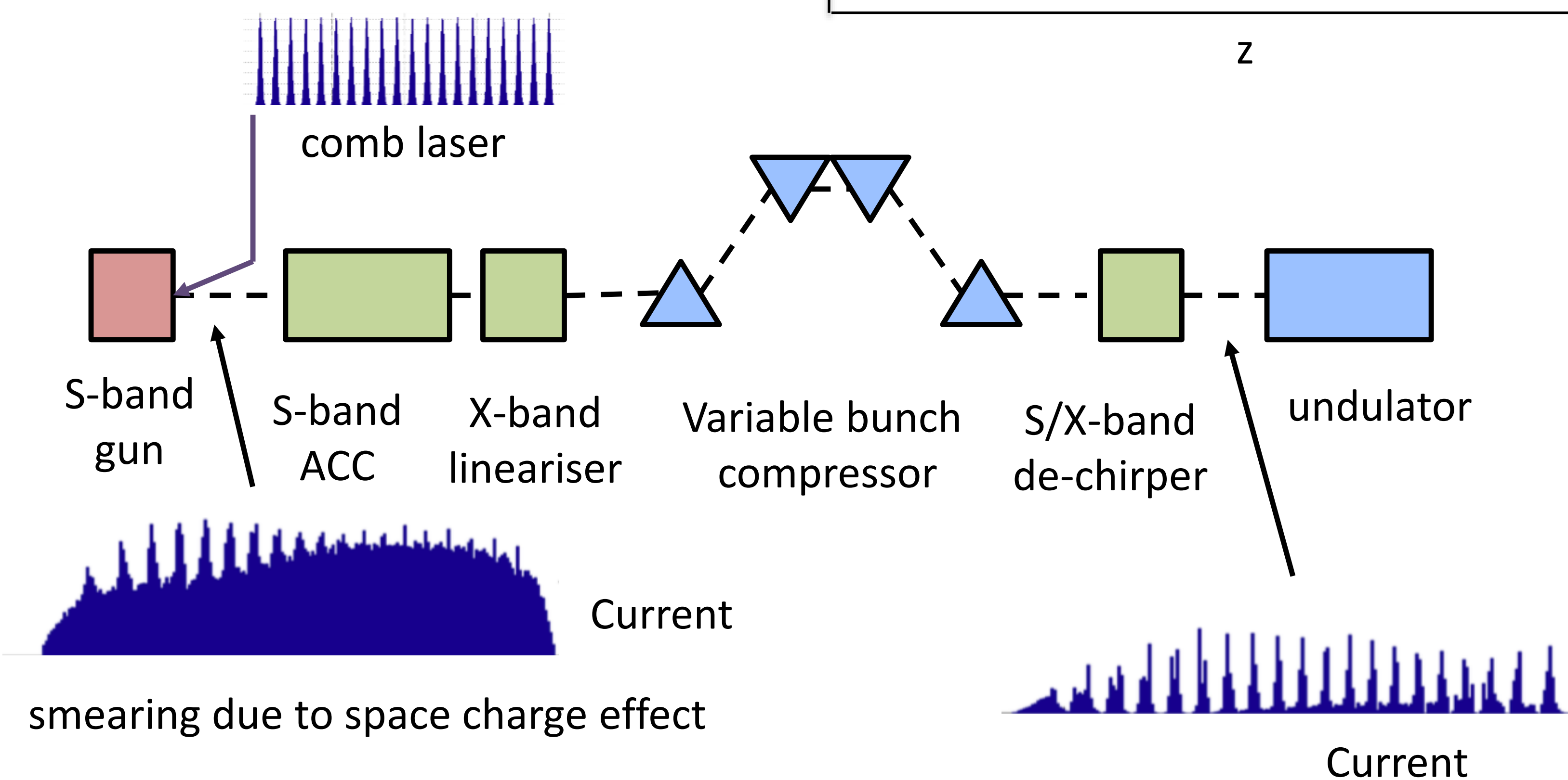
- **Comb beam:** create bunching before undulator.



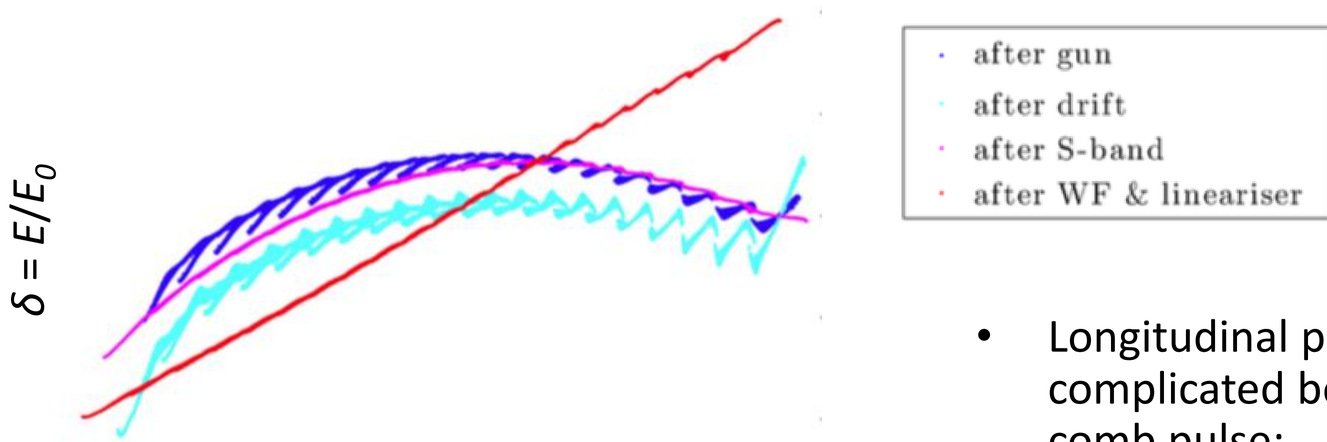
2. Comb beam generation

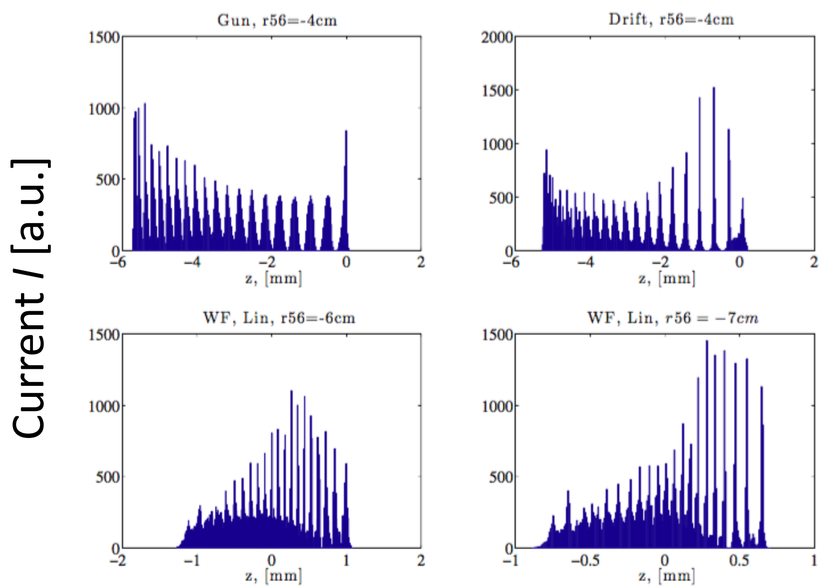
Comb beam facility





Longitudinal phase space

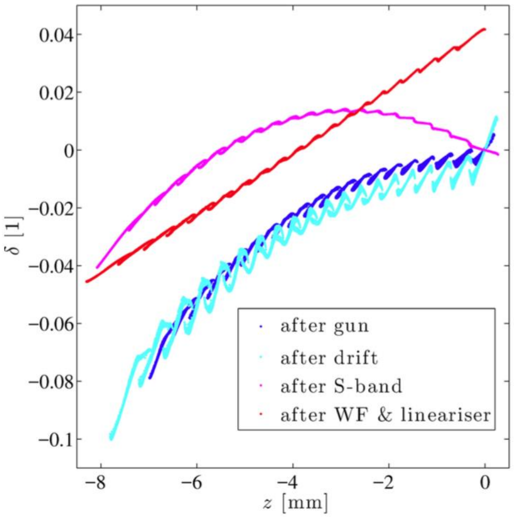


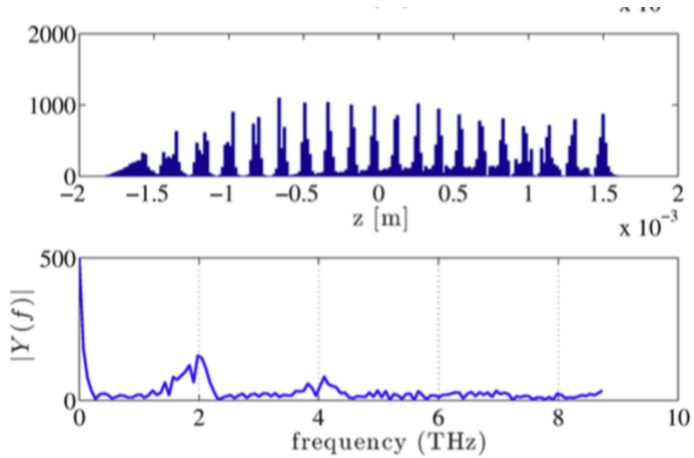


- Longitudinal phase space is complicated because of long comb pulse:
  - Long. space charge smearing.
  - RF curvature.
  - Variable RF compression.
  - Charge dependence.
- At SPARC experiment with 2 or 4 bunches, here 16 bunches.
- Challenge to find a setup with equally spaced bunches at undulator.

Operational considerations

- A setup for a uniform charge profile has been found:
    - 1nC, 20 pulses, 10° gun phase, R_{56} = -3.5 cm





- It will be difficult enough to create a proper bunching at one frequency.
- Proposition to keep tuning manageable:
    - Keep beam setting before bunch compressor fixed.
    - Separation of linearisation and compression: no dogleg with sextupoles.
- But this will create only one specific bunching (see next slide).

Frequency tuning

- Tuning with variable R_{56} of BC (pulse length change).
- Re-bunching only achieved for very limited frequency range.
- Undulator simulations show that also a not re-bunched beam can be used, since the remaining energy modulation converts to bunching in undulator.

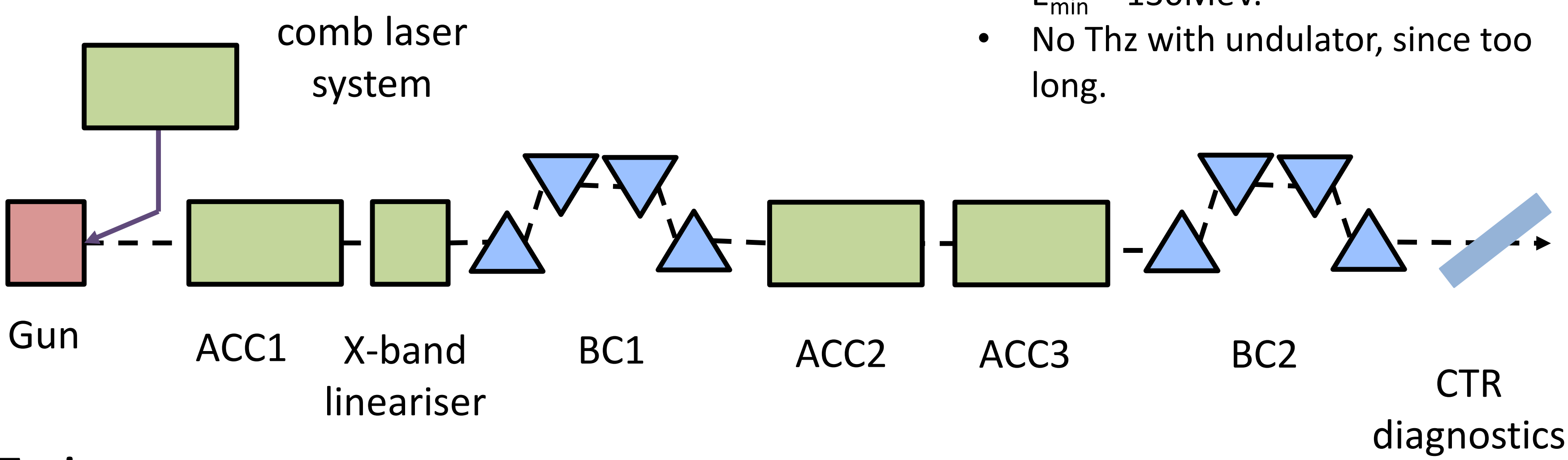
- Challenges of a compression with factor 1 – 20:
  - With current setup, frequency range still limited to 1 – 4 THz, since energy modulation will smear too much above.
  - To increase range, an strong increase of the energy chirp would help, since smaller R_{56} can be used. This would be in general beneficial for the challenging bunch compression of a factor 20.
  - Also, higher-order non-linearities may become a problem at one point.

3. Test scenario for CALIFES

Facility layout

Limitation:

- E_{min} = 130MeV.
- No Thz with undulator, since too long.



Tuning:

- BC1: Variable R_{56} to bring bunch to right length (frequency).
- ACC2, ACC3: phase change can be used to de-chirper, but additional acceleration is at the moment unavoidable.
- BC2: creates bunching by tilting up the energy spread from longitudinal space charge.

New hardware:

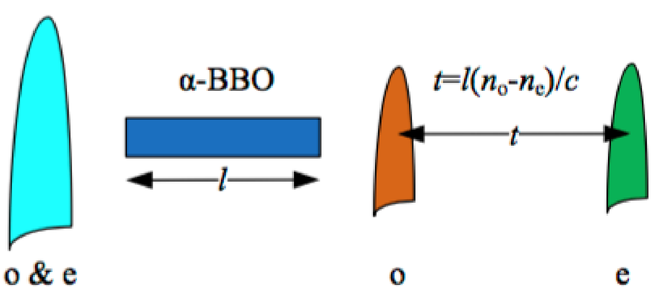
- Comb laser system.
- X-band lineariser.
- BC1 between ACC1 and ACC2.
- BC2.
- CTR diagnostics.
- If ACC2, ACC3 could be freely tuned, THz could be created in undulator.

UV laser stacking

Laser stacking principle:

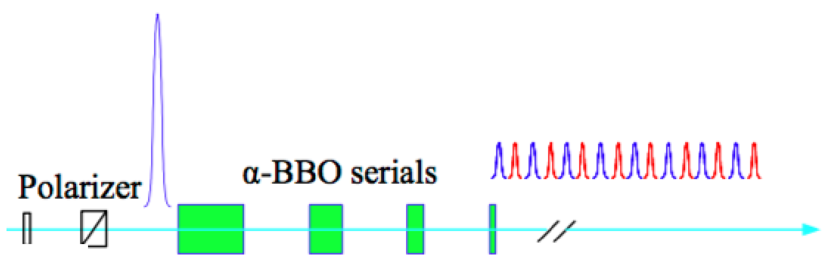
- Birefringent crystal (α-BBO).
- Different indices of refraction in different directions.
- Vertically and horizontally polarised light will be differently delayed.
- 2mm crystal = 1ps delay.

4 α-BBO with different lengths that are 45° rotated w.r.t. to each other.



Full laser facility

- Cathodes needs UV laser pulse.
- 3x up-conversion from IR laser
- For 1Thz Pulse length must be ≈0.5ps FWHM.
- **Problem: Current Nd:YAG system ≈8-10ps. We need Ti:Sa system!**
- Baseline 1THz. Could it be increased to 5Thz (see next slide)?

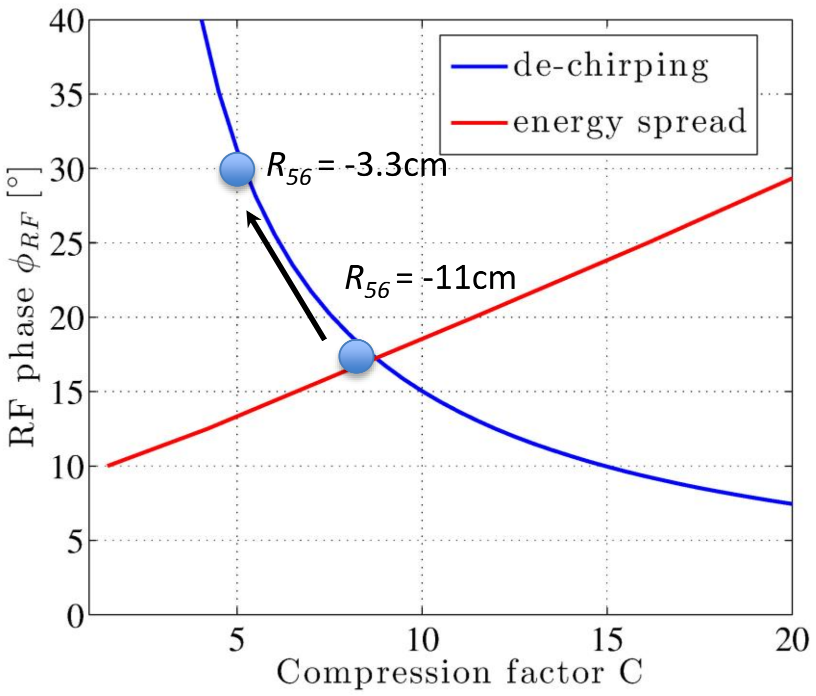


Taken from L. Yan, IPAC10, WEPD051.

Bunch compressor specification

- Limit for compression factor C:
  - Removal of energy chirp after compression.
  - Initial energy spread.
- Maximal C≈5.
  - This already assumes ϕ_{RF}=90° in ACC2 and ACC3.
  - General limitation for tuning range.
- **Bunch compressor:**
  - L = 0.75m.
  - Θ = 15°.
  - $\Delta\varepsilon_{x,CSR}$ = 1.7%.

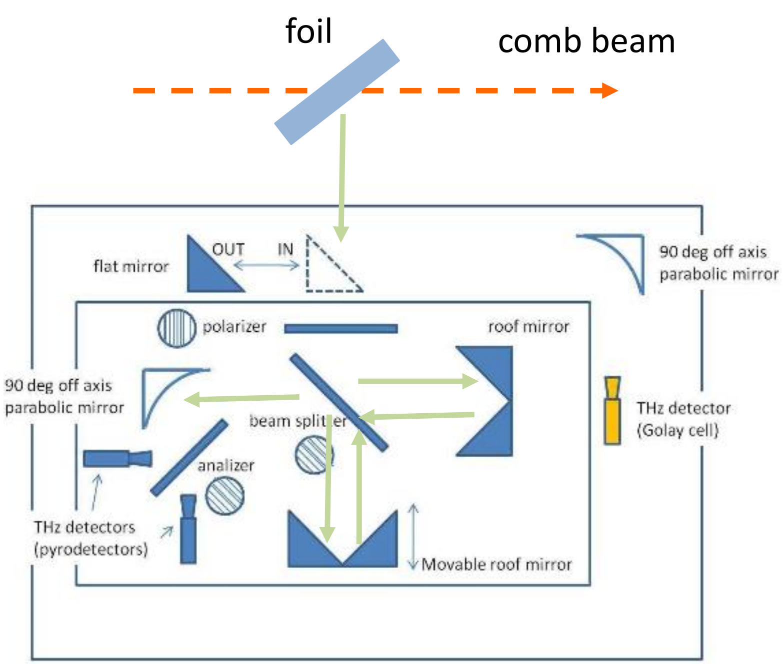
- No estimate for second BC yet.



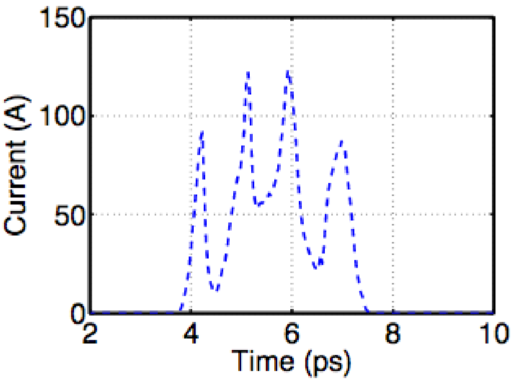
- **How could 1-20 THz be reached at all?**
  - Full range at once seems impossible.
  - Two laser and gun setups: 1 and 5 THz.
  - Tune with BC with C=1-5.
  - Laser pulse length < 100 fs FWHM

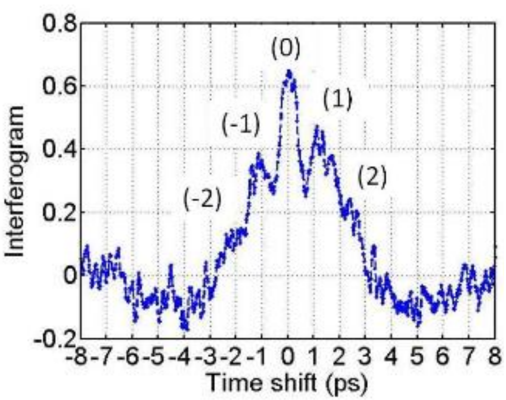
Diagnostics

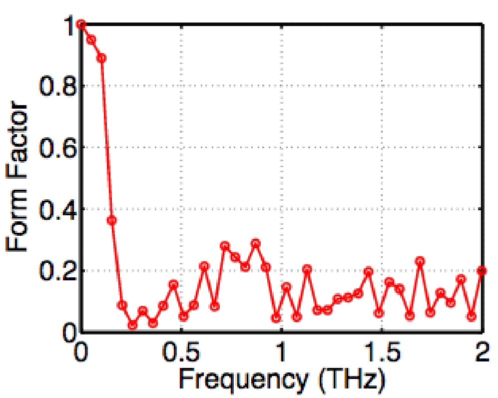
- At SPARC a the following system has been used.
- CTR due to a metal coated foil.
- Interferometer creates autocorrelation function
- Scanning measurement.



Autocorrelation measurement







Taken from E. Chiadroni et al, IPAC11 THPS101

4. Conclusions

- Two THz source concept for the SwissFEL under study.
- Report on the comb-beam undulator-based THz source.

- Challenges:
  - To get a uniform enough longitudinal phase space.
  - At SPAC with max. 4 bunches. Here with 16 bunches.
  - Additionally, bunch length should be tuned without destroying energy modulation.
- It would be necessary to test these concept, since it is a significant step w.r.t. performed experiments.

- **Additional equipment:**
  - Comb laser system (new Ti:Sa laser), X-band lineariser, 2xBC, CTR diagnostics,
  - Preferable individual RF setting for ACC1, ACC2

Thank you for your attention!