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Beam dynamics overview

Fourth SwissFEL Performance Workshop, 26 January 2022

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Achievements 2021: Aramis

Standard SASE:

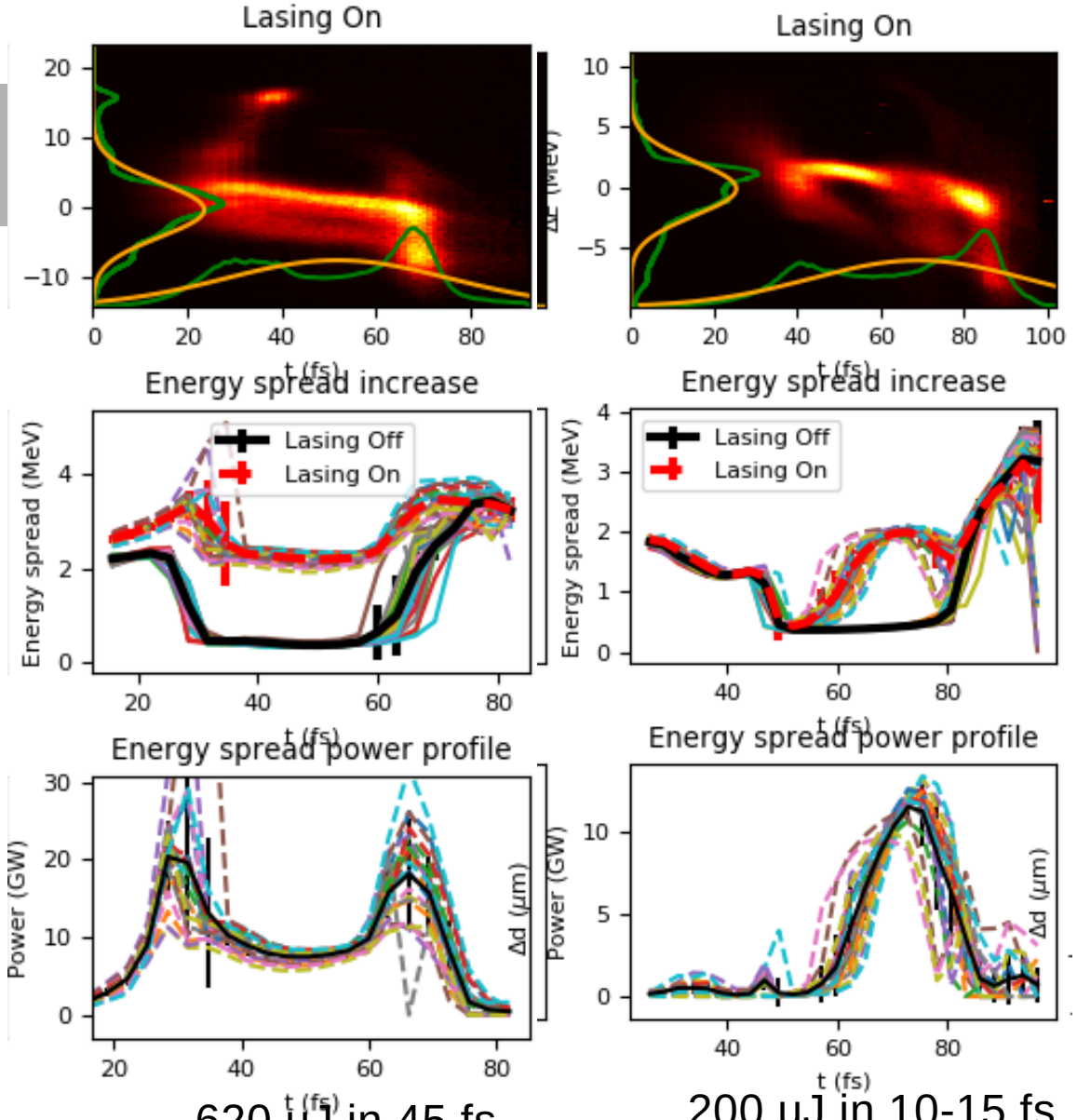
- Record pulse energies: 1 mJ at 11.3 keV, 1.4 mJ at 7.5 keV
- Lasing at high photon energies: 100 uJ at 15 keV, 230 uJ at 14 keV (w/o full optimization)

Special operation modes:

- Short pulses with tunable duration (down to 10 fs FWHM) with transverse beam tilt (used in experiments)
- Demonstration of 2-colors in Aramis with laser emittance spoiler (laser group)
- Demonstration of non-invasive pulse trains (between 2-3 to 6-7 short pulses) with laser heater modulation (together with laser group)

Short pulses for Aramis

Reconstructed FEL power profile for long and short pulse



620 uJ in 45 fs

200 uJ in 10-15 fs

- Down to 10-15 fs FWHM, 10-20 GW of power
- **Generation**: compression plus tilted beam using S30CB15 passive structure (tunable pulse duration)
- **Measurement**: post-undulator passive streaker
- Used in two different experiments (Alvra at 11 keV in October, Bernina for 3 keV in December).
- Suitable for parallel operation

Achievements 2021: Athos

"Standard" SASE:

- Reduction of saturation length with optical klystron and circular polarization
- Record pulse energies: 3 mJ for 550 eV, 2 mJ for 870 eV
- Lasing for almost the whole design photon energy range: 250 eV to 1.6 keV (300 uJ w/o full optimization)
- Variable polarization (used in experiment)

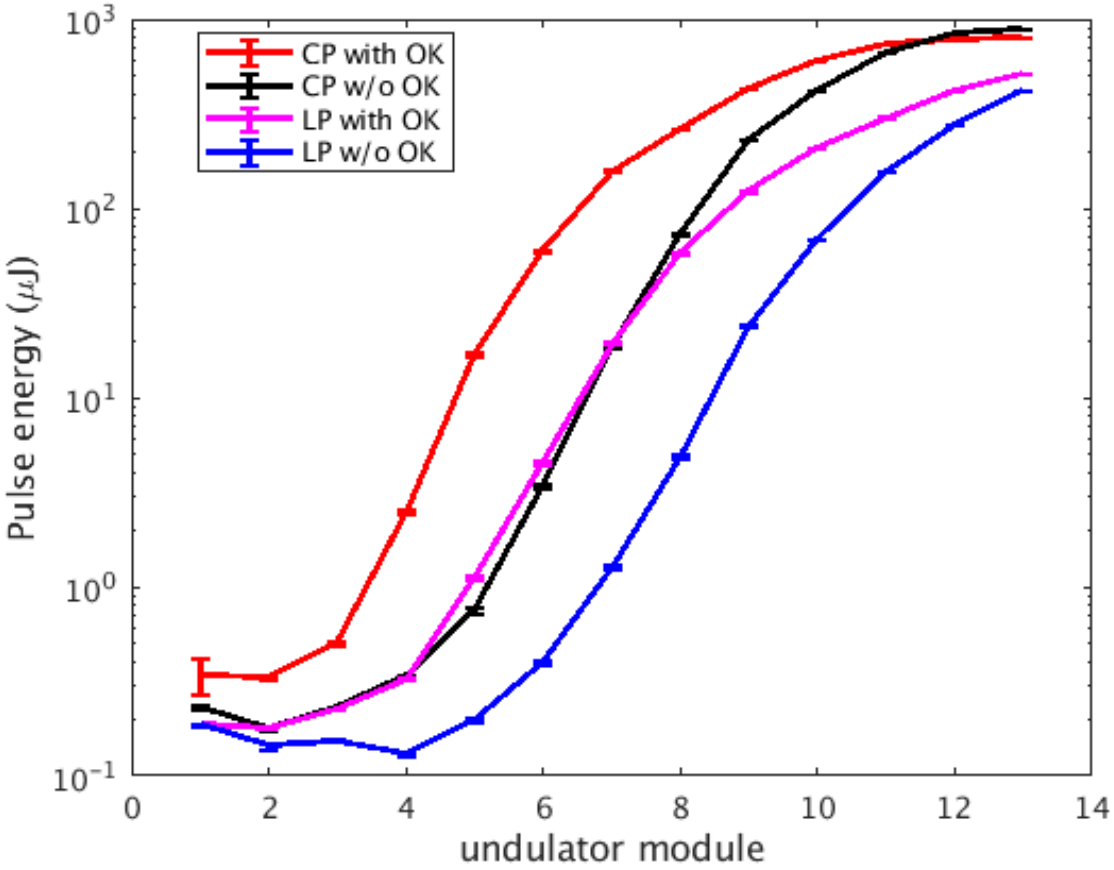
Special operation modes:

- Short pulses with tilted beam (used in experiment)
- Tunable 2-colors (used in experiment)
- First studies on:
  - Short pulses with high power (CROSS project) (should be used in experiments)
  - HB-SASE using PMOS (should become standard mode)

Gain curve studies in Athos

- Optical klystron helps to reduce the saturation length between 15 and 30% (in both circular and linear polarization)
- Circular polarization offers a shorter saturation length and higher saturation power than linear polarization
- Standard operation: optical klystron and circular polarization
- Necessary for 2-color mode

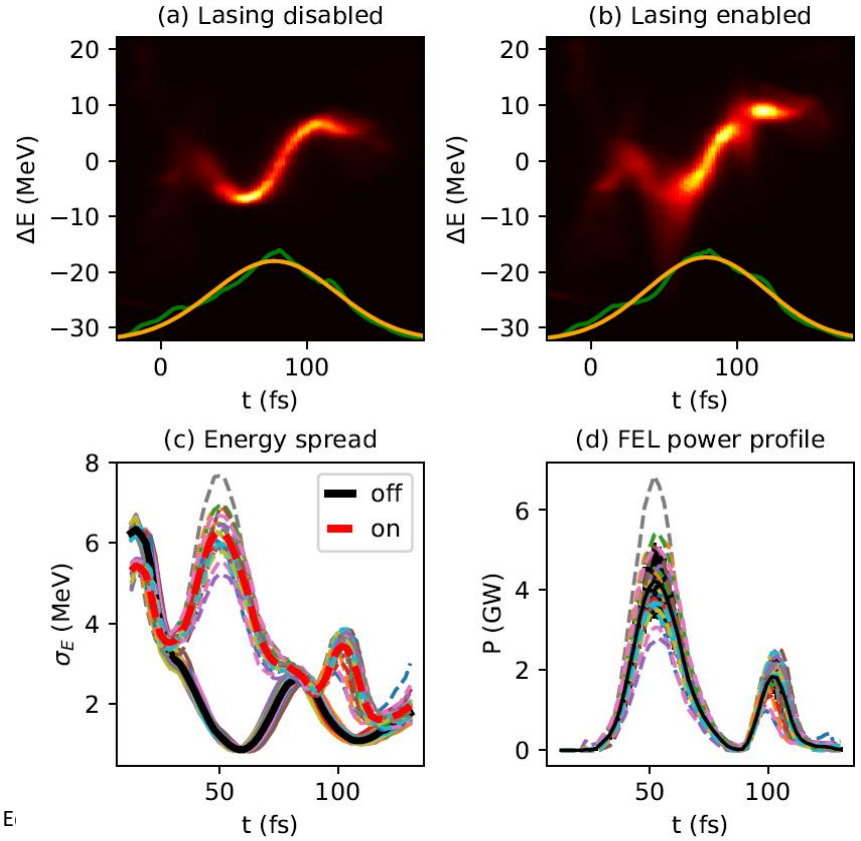
Gain curve for circular (CP) and linear (LP) polarization, with and without optical klystron (OK). 960 eV.



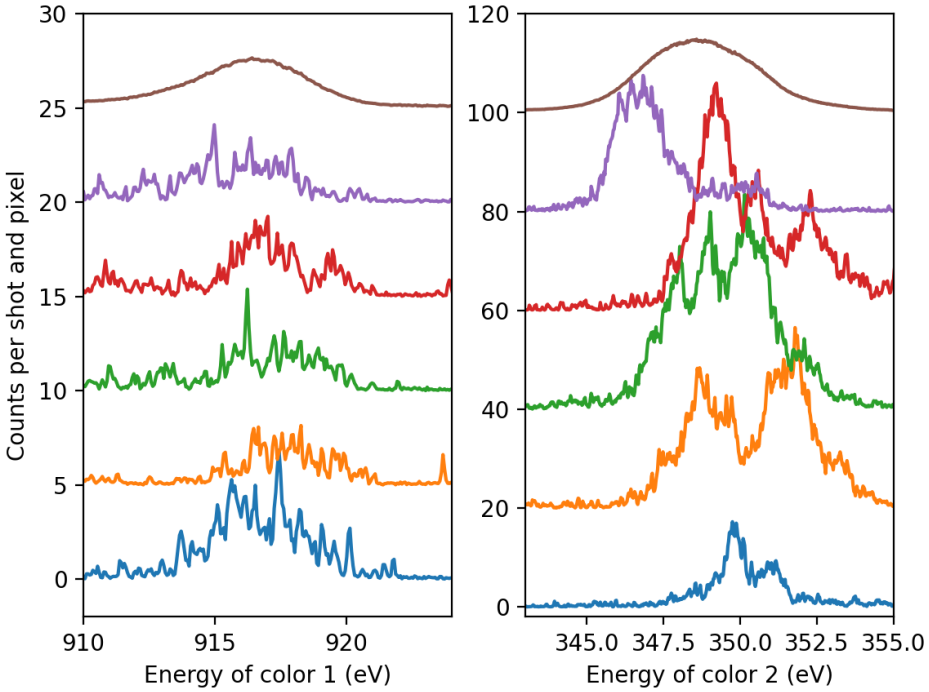
Largely tunable two-colors in Athos

- Shown 350 eV / 915 eV, -30 to 500 fs, ~GW power, down to fs duration
- **Generation**: split undulator configuration, with and without fresh-slice
- **Measurement**: streaking with post-undulator structure or with same tilt to make fresh-slice / Maloja spectrometers
- Used in Maloja pilot experiment

Reconstruction of FEL power profile

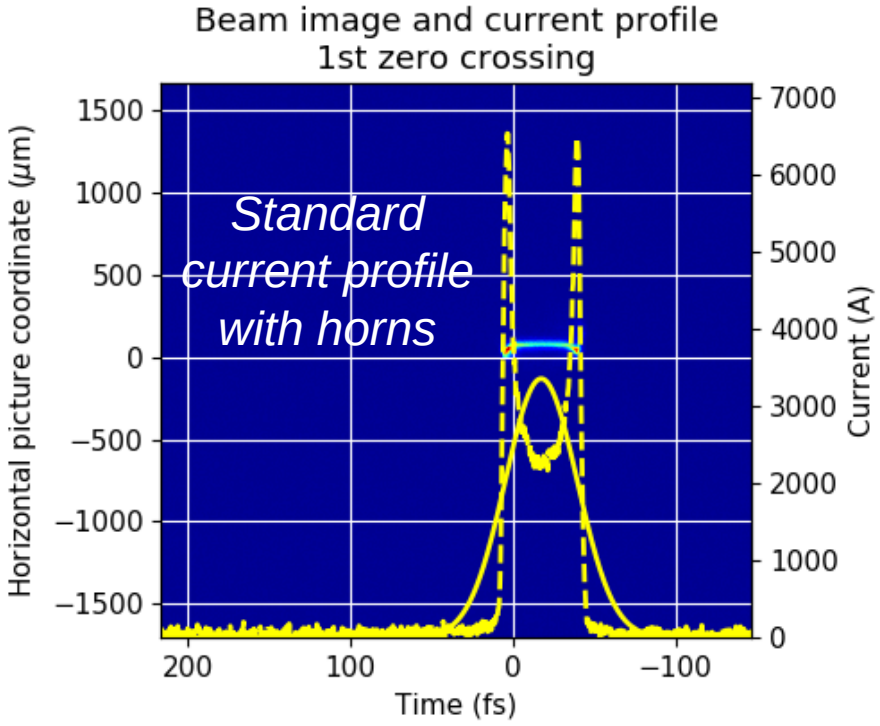


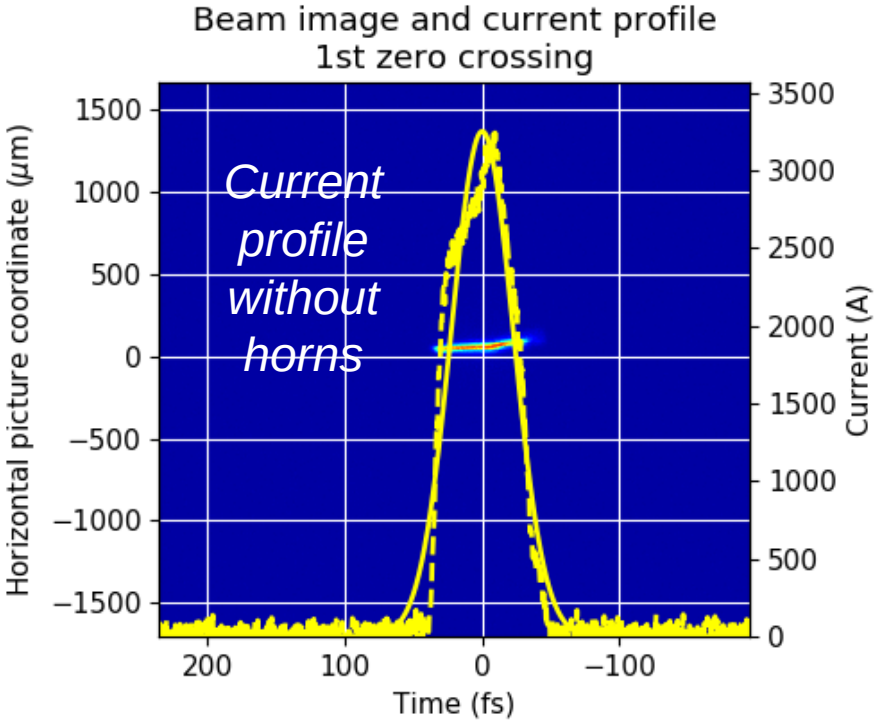
Average (top) and single-shot spectral measurements



Achievements 2021: general

- Demonstrated operation without “horns”
  - Removed by scrapping part of the beam in BC1 (~20 % of the charge). Requires shielding in BC1 for routine operation
  - Performance similar as with horns: 1.2 mJ at 7.5 keV (w/o full optimization).
  - Fundamental for more stable operation with less losses in both Aramis and Athos.





Achievements 2021: general

- All shown progress compatible with parallel operation. To be studied: large-bandwidth and ultra-short pulses in Aramis
- Improved post-undulator passive streaker diagnostics (presently almost in routine operation)
- Energy spread studies: comparison between different cathode regions (Cs2Te and “Cu”) → equivalent values (3 keV at 1 pC) → large energy spread is not due to cathode but to other effects (micro-bunching and intra-beam scattering).
- Emittance/optics studies:
  - Compare laser heater optics with and without undulator → equivalent results → we keep the undulator in
  - Slice emittance and optics vs beta-function in BC1 and BC2: present optics close to best performance → further improvements in progress
  - Improved screen resolution at end of linac 3 allows better emittance measurements (from 25-30 um to ~10 um in size). Wish to have such screens in certain locations (e.g. injector dump)

What allowed record performance?

- BBA to make all undulators to contribute to the FEL process
- Energy spread improvements (already in 2020) → higher peak current and short pulses possible (mostly important for Aramis)
- Systematic optimization of important variables (e.g. laser profile and phase shifters)

Main issues

- Optimal performance not continuously achieved. Improved with BBA.
- Athos losses (including dark current). Improvements:
  - BBA
  - Alignment and movement of components (R. Ganter)
  - Optics/beam quality improvements
  - (Limits increased)
- Hardware: post-undulator RF deflector in Athos not yet operational, C-band station in Athos not fully operational
- Transverse coupling in Athos undulators (under investigation)

Plans for 2022

Aramis: maintain top performance

Athos:

- Maintain top performance
- Further reduction of losses (dark current gun collimator?, horns removal)
- Finalize commissioning: post-undulator RF, C-band, dechirpers at nominal settings, improve lookup table for undulator kick correction, etc.
- Standard operation with minimum bandwidth
- Develop new modes: HB-SASE, high-power and short pulses (multi-stage amplification), HERO phase 1 (ESASE)

General:

- Establish standard operation with removed horns (higher stability and reproducibility, less losses, faster setup)
- Study parallel operation with large bandwidth and ultrashort pulses in Aramis

Plans beyond 2022

- Develop new modes for Athos: ultra-large bandwidth (TGU), HERO phase 2 (EEHG), etc.
- Improve energy spread (crucial for HERO and Porthos). It requires moving BC1 upstream of present location
- Energy upgrade of SwissFEL to ~7 GeV (PSAC recommendation). 2 RF stations in linac 1 (requires moving BC1 upstream, in synergy with previous point) and 1 RF station in linac 3
- Beam extraction after linac 3 for P3 project (CERN collaboration to demonstrate a positron source) and Porthos
- Porthos project

Conclusion

- Significant achievements in 2021 in both beamlines: record pulse energies, short pulses, tunable polarization and 2-colors in Athos, etc.

- Plans for 2022:
  - Keep top performance in Aramis and Athos
  - Athos: further reduce losses, finalize standard commissioning and new modes
  - Remove horns for better operation

Final comments

- All progress thanks to many groups and people (operations, system experts, MC, PSD). Good team work is key for good results and for a good mood!

- Operations improved significantly over the last year: faster and better startups, better performance of "standard operator", great to have Marco, etc. → further improvements welcome (e.g. improve "standard operator" performance)

- Manpower situation in BD group:
  - A. Malyzhenkov left Dec. 21, E. Ferrari will leave in few days
  - Only 2 people (plus 1 postdoc and 2 PhDs) from Feb. 1st (a 3rd scientist should come soon).
  - At least 4 persons required to support operation, improve machine performance, develop/implement new modes, and design Porthos.

- Input from PSD always welcome w.r.t. performance and development of new modes