FEL Applications

Accelerator Research and Development
ARD
A program by the Helmholtz association

JÜLICH FORSCHUNGSZENTRUM

GSI

KIT Karlsruhe Institute of Technology

DESY

HZB Helmholtz Zentrum Berlin

HZDR

HI Jena
Helmholtz Institute Jena

Andreas R. Maier
Univ. Hamburg, CFEL
for the ATHENA team

UHH

HELMHOLTZ GEMEINSCHAFT

Outline – FEL Applications

1. Injection Concepts for LWFA
2. Challenges for Plasma-FELs
3. FEL Schemes
4. Conclusion & Outlook

Which is the better concept?

external vs. internal injection

internal injection

- intrinsic (sub)-fs synchronization
- supports ultra-high currents
- difficult to control injected phase-space volume
- ...

external injection

- external synchronization of laser and RF
- current limited by gun performance
- good control over injected phase-space volume
- ...

What is really better?
Who knows...

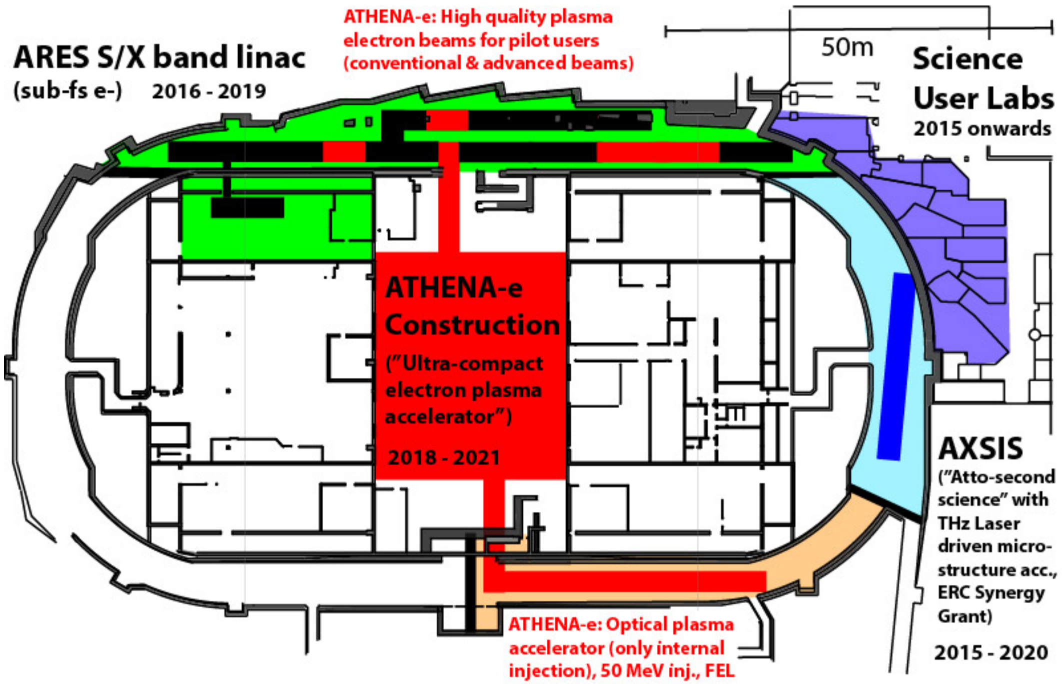
Let’s do both

external and internal injection

- ATHENAe has the goal to develop plasma-based electron beams of good quality. It uniquely allows the direct comparison of external and internal injection concepts with great flexibility.

- Once we successfully demonstrate good beam quality it would be very interesting to try an FEL experiment.

- Lets see, what might be possible...

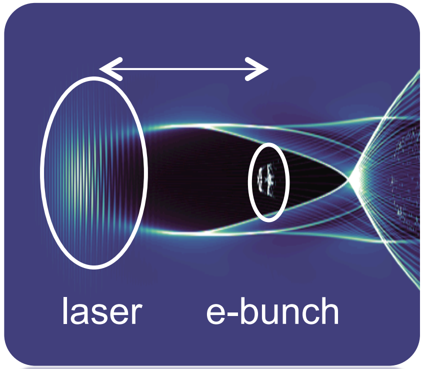


Plasma-FELs

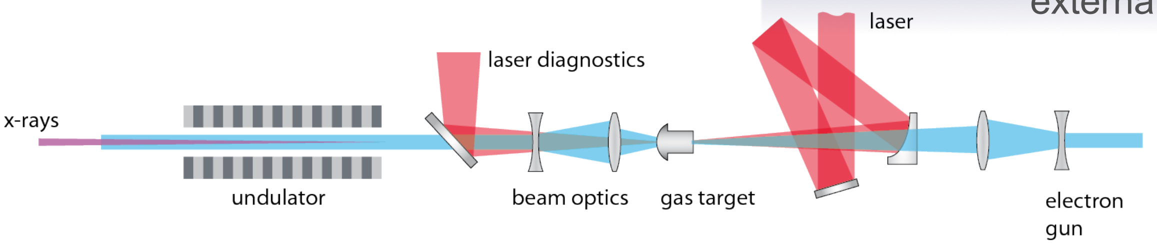
Challenges

Plasma-based FELs

challenges



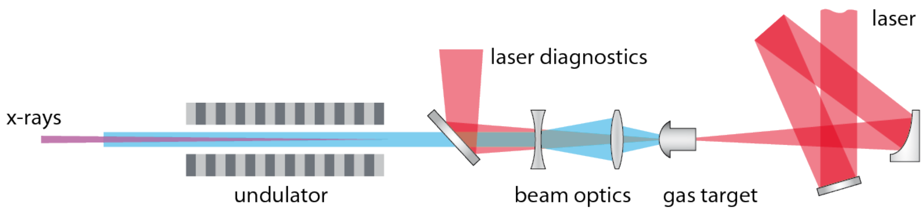
external injection



external synchronization of RF and laser w/ fs-accuracy

Plasma-based FELs

challenges

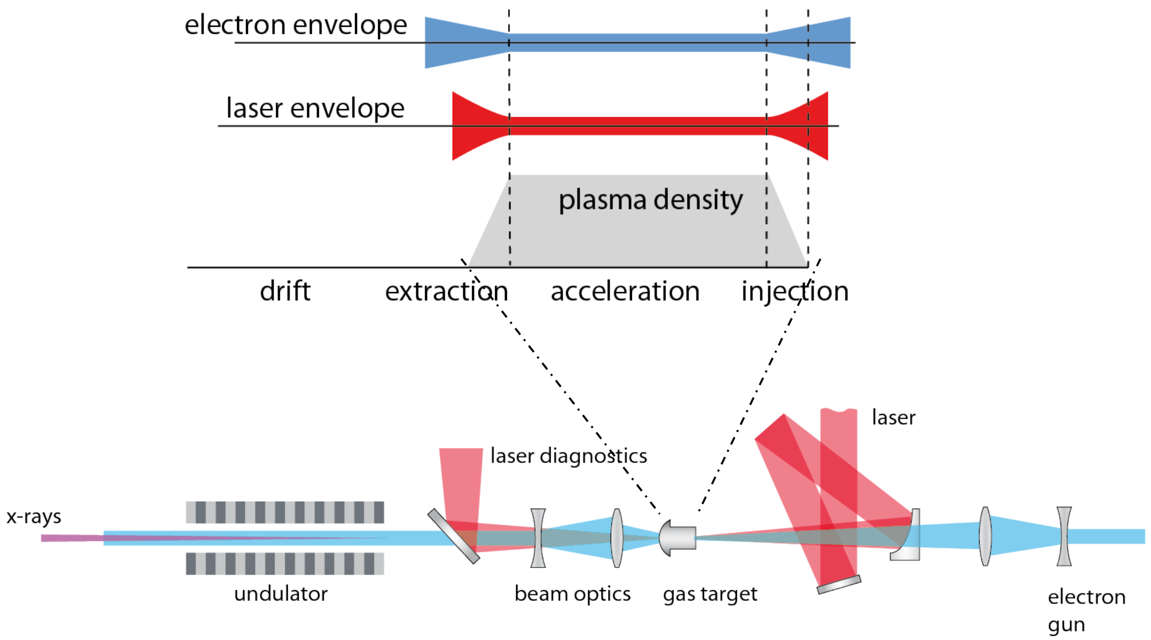


laser operation
w/ high stability in parameters and high availability

external synchronization
of RF and laser w/ fs-accuracy

Plasma-based FELs

challenges



extraction: reducing divergence (emittance growth)

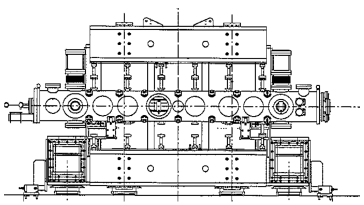
injection: matching to extreme focussing forces (ext. inj.) or controlling the injected phase space (int. inj.)

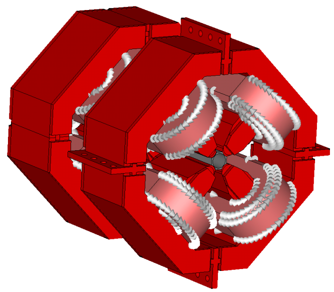
laser operation w/ high stability in parameters and high availability

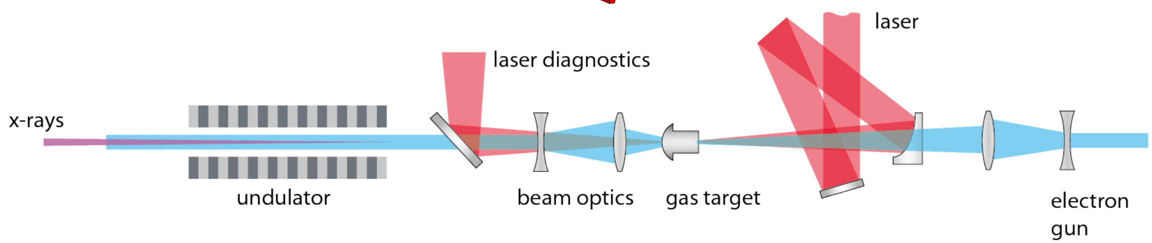
external synchronization of RF and laser w/ fs-accuracy

Plasma-based FELs

challenges







optimized **undulator design**

transport & diagnostics: phase space manipulation

extraction: reducing divergence (emittance growth)

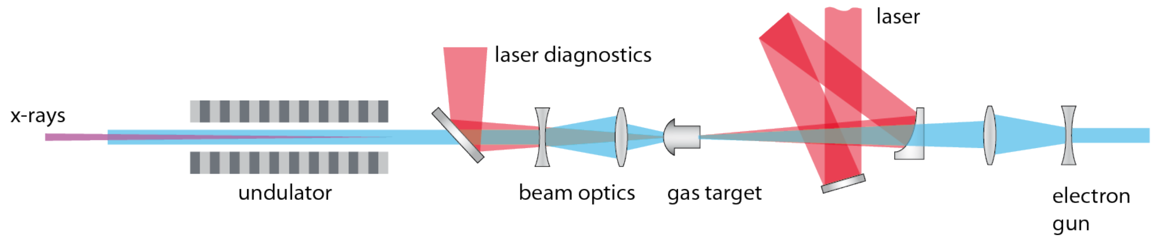
injection: matching to extreme focussing forces (ext. inj.) or controlling the injected phase space (int. inj.)

laser operation w/ high stability in parameters and high availability

external synchronization of RF and laser w/ fs-accuracy

Plasma-based FELs

partners



- To face these challenges we need a broad range of know-how.
- Within ATHENAe all partners provide their unique expertise to key components of the beamline.
- The combination of expertise is a key advantage.

examples:

- DESY: electron gun, beamline instrumentation
- HI Jena: target diagnostics
- HZB: undulator
- UHH and HZDR: LWFA
- Jülich: target
- ...

Plasma-based FELs

challenges

once we show stable, good-quality plasma-based beams, we should be prepared for different scenarios:

external injection schemes have tendency for
- very short-bunches
- „low“ charge

as stable plasma acceleration requires ultra-short bunches

→ scheme A

internal injection schemes have tendency for
- larger energy spread
- highr charge

as injected phase space is more difficult to control

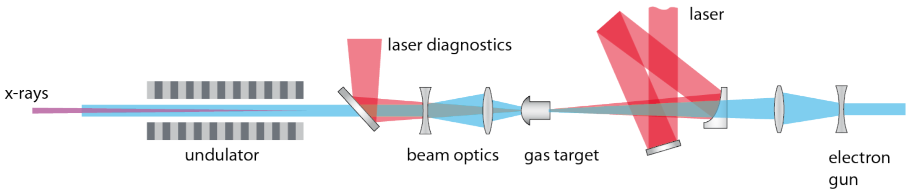
→ scheme B

Plasma-FELs

Scheme A

Scheme A

parameters



This is not yet a design study, but first estimates look promising. The feasibility of the following realistic high-current working points for ARES will be investiagted.

ARES LINAC could be operated with several parameter sets.

set 1	set 2
$Q = 13\,\mathrm{pC}$	$Q = 25\,\mathrm{pC}$
$\sigma_z = 1\,\mu\mathrm{m}$	$\sigma_z = 1\,\mu\mathrm{m}$
$I_{\mathrm{peak}} = 1.6\,\mathrm{kA}$	$I_{\mathrm{peak}} = 3\,\mathrm{kA}$
$\sigma_\gamma/\gamma = 0.2\,\%$	$\sigma_\gamma/\gamma = 0.2\,\%$
$\epsilon_n = 0.2\,\mu\mathrm{m}$	$\epsilon_n = 0.2\,\mu\mathrm{m}$
@ 100 MeV after the LINAC	@ 250-270 MeV after the LINAC

Scheme A

parameters

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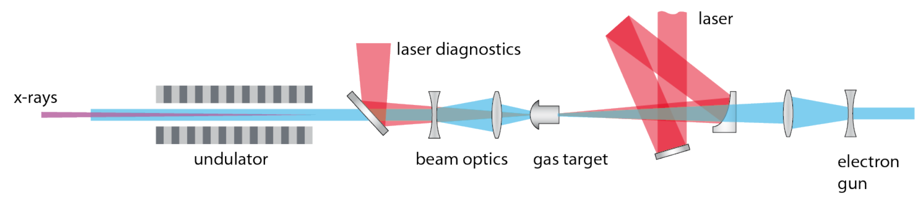


set 1

$$Q = 13\,\mathrm{pC}$$
$$\sigma_z = 1\,\mu\mathrm{m}$$
$$I_{\mathrm{peak}} = 1.6\,\mathrm{kA}$$
$$\sigma_\gamma/\gamma = 0.2\,\%$$
$$\epsilon_n = 0.2\,\mu\mathrm{m}$$

@ 100 MeV
after the LINAC

set 2

$$Q = 25\,\mathrm{pC}$$
$$\sigma_z = 1\,\mu\mathrm{m}$$
$$I_{\mathrm{peak}} = 3\,\mathrm{kA}$$
$$\sigma_\gamma/\gamma = 0.2\,\%$$
$$\epsilon_n = 0.2\,\mu\mathrm{m}$$

@ 250-270 MeV
after the LINAC

- boost this beam in the plasma to ~1GeV
- reduce energy spread accordingly

Scheme A

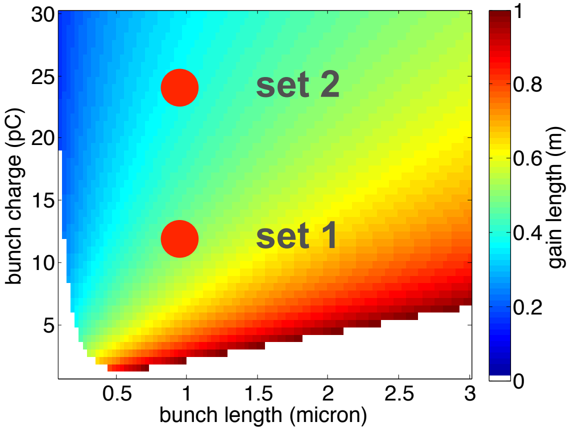
what is possible

- slippage is a major problem
- short wavelengths required due to short bunchlength.
- ~ 0.5 m gain length seems feasible
- saturation possible within 10 m undulator (but more space required)

- future proof: we have the space for a future (pilot) user area

- there are still many ways for improving the parameter set (esp. undulator parameters)

- but first scenarios looks very promising



$$\lambda = 4\,\mathrm{nm}$$
$$K = 1$$
$$\lambda_u = 15\,\mathrm{mm}$$
$$E = 850\,\mathrm{MeV}$$
$$\sigma_\gamma/\gamma = 0.025\,\%$$

Ming Xie backed with GENESIS simulations

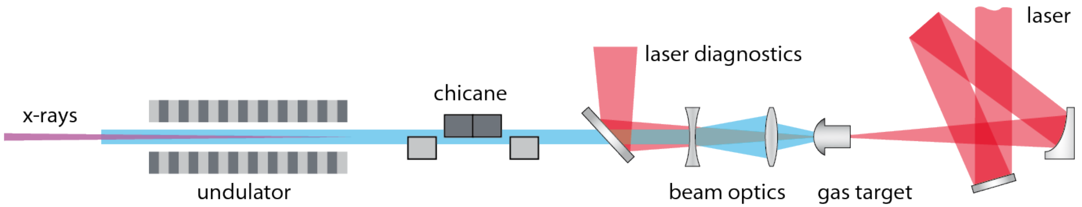
Plasma-FELs

Scheme B

Scheme B

if we still have a large energy spread…

- concept follows A. R. Maier et al., PRX 2, 031019 (2012)
- similar to Z. Huang et al., PRL 109, 204801 (2012)
- see also C. Schroeder et al., FEL Proc 2013, MOPSO69



- for energy spread dominated cases: stretch the bunch
- reduced energy spread wins over lower current

$$\sigma_z \rightarrow n \times \sigma_z$$
$$I \rightarrow I/n$$
$$\sigma_{\gamma,\mathrm{slice}} \rightarrow \sigma_{\gamma,\mathrm{slice}}/n$$
$$\rho \rightarrow \rho/n^{1/3}$$

Scheme B

if we still have a large energy spread…

- works with very „bad“ beams as a first test
- detectable gain within 2 m

$$Q = 5\,\mathrm{pC}$$
$$\sigma_z = 1\mu\mathrm{m}$$
$$\sigma_\gamma/\gamma = 1\,\%$$
$$\epsilon_n = 0.2\,\mu\mathrm{m}$$
$$E = 300\,\mathrm{MeV}$$

→

$$\lambda = 100\,\mathrm{nm}$$
$$K = 3$$
$$\lambda_u = 15\,\mathrm{mm}$$

- but can also generate full saturation FELs
- requires ~10 m undulator

$$Q = 10\,\mathrm{pC}$$
$$\sigma_z = 0.7\,\mu\mathrm{m}$$
$$\sigma_\gamma/\gamma = 3\,\%$$
$$\epsilon_n = 0.1\,\mu\mathrm{m}$$
$$E = 500\,\mathrm{MeV}$$

→

$$\lambda = 30\,\mathrm{nm}$$
$$K = 1.9$$
$$\lambda_u = 22\,\mathrm{mm}$$
$$L_g = 0.3\,\mathrm{m}$$

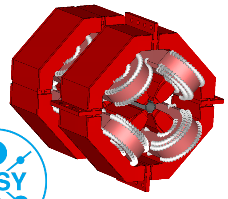
C. Schroeder et al., FEL Proc 2013, MOPSO69

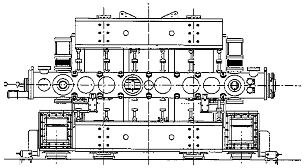
Plasma-FELs

Conclusion & Outlook

Conclusion & Outlook

- detailed design studies required
- especially for the undulator design:
  TGU concept? cryogenic? helical? even optical?
- but an FEL – even in saturation – seems possible

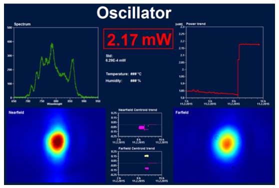


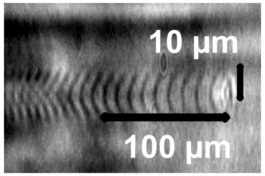


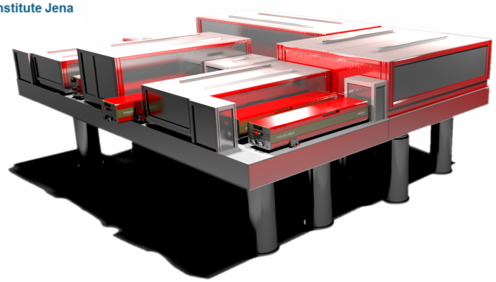
examples: undulator development, beamline instrumentation, laser integration into controlls system, target diagnostics and development...

ATHENA provides unique possibilities:

- project requires expertise, that is not available at a single institue
- cooperative approach within Helmholtz is huge advantage to international competitors







Thanks.