Electron-beam driver based accelerators

Critical questions the community can address at existing facilities in the next three years

Jens Osterhoff, Richard D'Arcy

DESY. Accelerator Division

March 23rd, 2023

ALEGRO Workshop, DESY

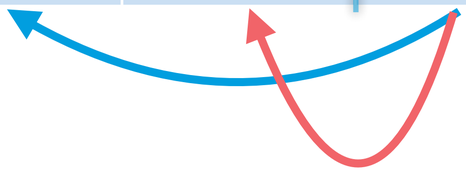
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Collider is the ultimate challenge, requires specific solutions

Ballpark requirements and state-of-the-art

	FEL	Collider	Current
Charge per bunch (nC)	0.01 - 0.1	0.1 - 1	0.01 - 0.1
Energy gain (GeV)	0.1 - 10	1000	0.1 - 10
Energy spread (%)	0.1	0.1	0.1
Wall-plug efficiency (%)	< 0.1 - 10	10	< 0.1
Emittance (μm)	0.1 - 1	0.01	0.1 - 1
Rep. rate (Hz)	10^1 - 10^6	10^4 - 10^5	10^1
Avg. beam power (W)	10^1 - 10^6	10^6	10^1
Continuous run	24/1 - 24/7	24/365	24/1
Parameter stability	0.1%	0.1%	1%



- *highest energy:* **staging of plasma modules**
- *lowest emittance:* precision beam and plasma control
- *efficiency:* high wall-plug efficiency (energy recovery?)
- *rep. rate and avg. power:* kW/cm thermal plasma management
- ***positron acceleration*** *with exquisite quality*
- ***beam polarization*** *maintenance*
- *computing capabilities for full start-to-end optimization*

Needs a coordinated worldwide effort and funding

→ for a self-consistent collider design

→ to demonstrate viability of technical concepts

FEL-quality demonstrator stage more or less realized (all key parameters simultaneously)

Needs solutions specifically developed for particle colliders

FLASHForward focuses on FEL booster with impact on HEP

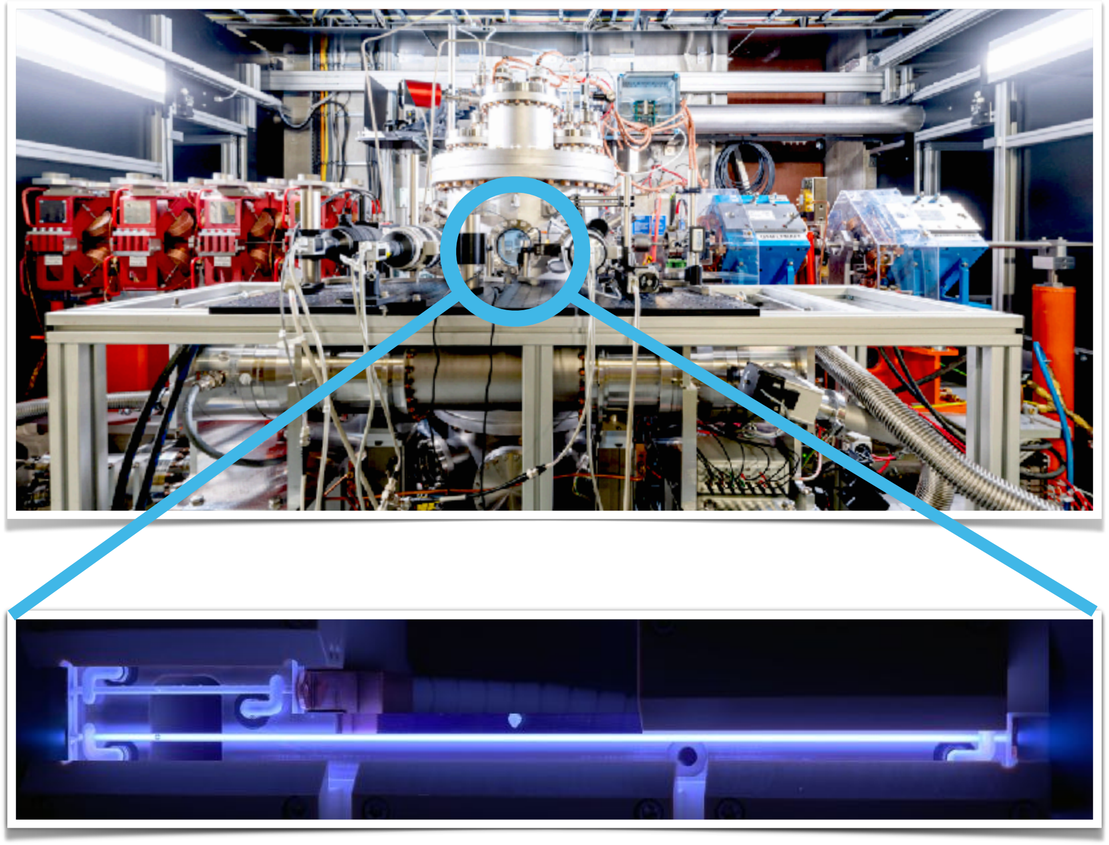
Drive towards an idealised high-average-power plasma stage for FEL

> **FLASHForward primarily motivated by FEL goals**
beam-quality-preserving acceleration
of *low-charge* and *short bunches* with *high peak current*

> Many goals over the next 3 years with potential impact to HEP:

- ***Efficiency*** → 20% overall energy-transfer efficiency from driver to trailing bunch
- ***Beam quality*** → preservation of 6D beam quality with ever larger energy gain (>GeV)
- ***Repetition rate*** → plasma stages capable of facilitating acceleration of MHz bunch trains
- ***Average power*** → temperature-controlled plasma stages capable of facilitating 10 kW average-power acceleration
- ***Stability*** → quantification and mitigation of instabilities in plasma arising from the linac and plasma generation

FLASHForward central interaction chamber (2018-2022)



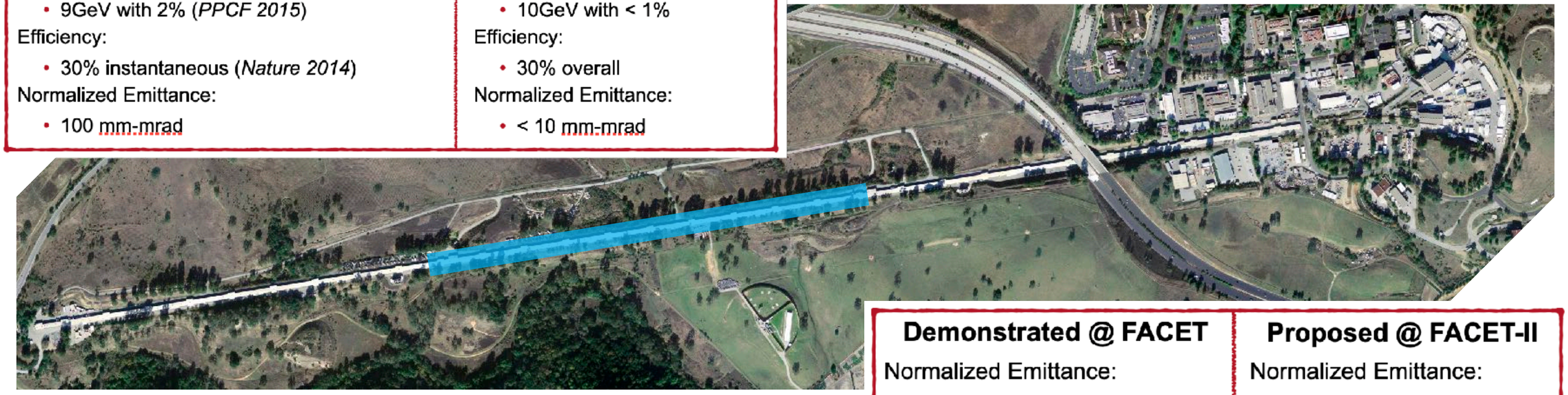
FLASHForward plasma sources (2020-2022)

FACET-II is Pursuing Studies Relevant to Plasma Based Linear Colliders

Beam-driven plasma wakefield acceleration with electrons (now) and positrons (~2027)

Demonstrated @ FACET	Proposed @ FACET-II
Gradient:	Gradient:
• >100GeV/m (*Nature Communications 2016*)	• >10GeV/m
Energy Gain & Energy Spread:	Energy Gain & Energy Spread:
• 9GeV with 2% (*PPCF 2015*)	• 10GeV with < 1%
Efficiency:	Efficiency:
• 30% instantaneous (*Nature 2014*)	• 30% overall
Normalized Emittance:	Normalized Emittance:
• 100 mm-mrad	• < 10 mm-mrad

FACET-II experiments are focused on 10GeV stage with high-energy extraction, high-efficiency and preserving beam emittance ~10μm level



Development of high-brightness plasma-based injectors

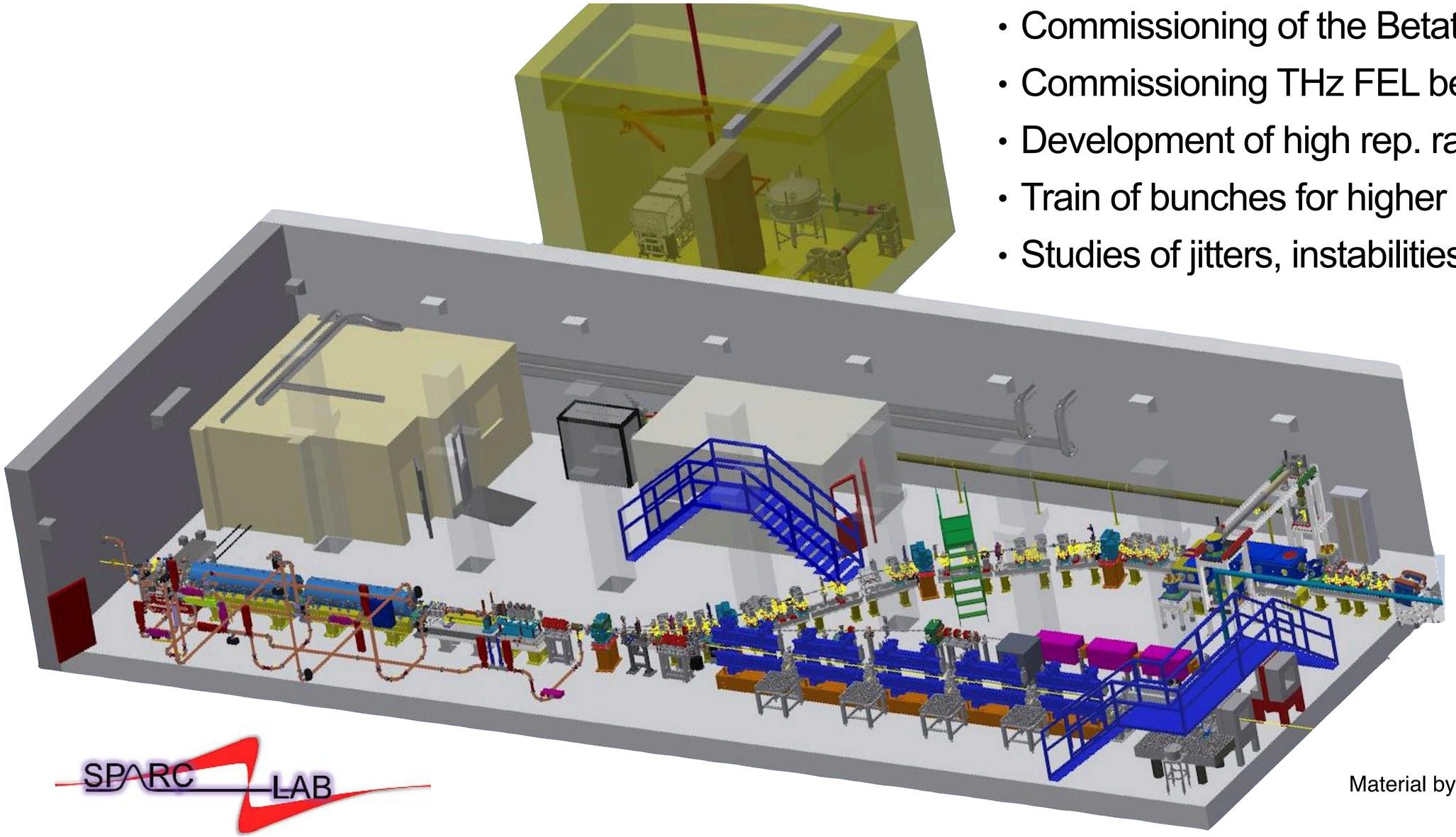
Demonstrated @ FACET	Proposed @ FACET-II
Normalized Emittance:	Normalized Emittance:
• 1.5 mm-mrad	• 0.01 mm-mrad
Bunch Charge & Duration:	Bunch Charge & Duration:
• 20pC & 100fs	• 20pC & 20fs
Energy & Energy Spread:	Energy & Energy Spread:
• 0.5 GeV with 2%	• > 1 GeV with 1%

Beam Brightness scales with plasma density. Short FACET-II bunches are predicted to enable collider level emittance beams

SLAC

Material by Mark Hogan

SPARC_Lab plans towards EuPRAXIA



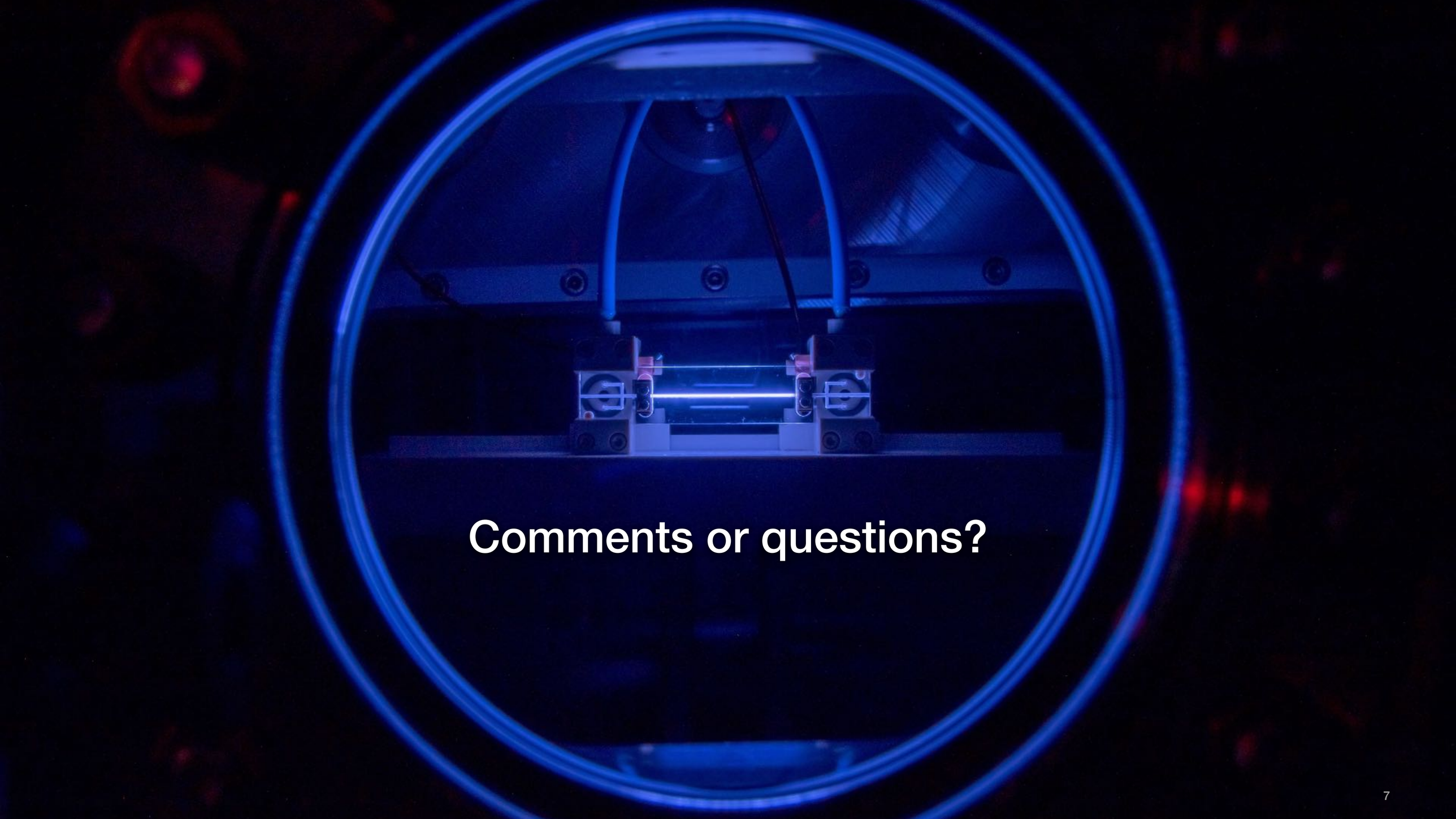
- Commissioning of the Betatron radiation source
- Commissioning THz FEL beamline
- Development of high rep. rate plasma module
- Train of bunches for higher efficiency
- Studies of jitters, instabilities and efficiency

Material by Massimo Ferrario

Can we do more in the next three years?

Currently, electron-beam-driven facilities in Europe do not focus on research for particle physics

- PWFA facilities are pre-existing, relatively rigid with running programs
- Difficult to change trajectory significantly on few-year time scale
- *Good news:* a lot of relevant research is going to be done at FACET-II, FLASHForward, SPARC_Lab
- Additional scientific personnel (2 FTEs / year) funded through the EPPS Roadmap initiative could utilize existing facilities
  - working points of higher relevance for particle physics
  - with high charge (approaching nC-level) and maximized total efficiency (whilst preserving beam quality)
  - to maximize success of planned relevant experiments
- Should be part of a European/global design effort, project the paper study onto future benchmark experiments and demonstrator-facility requirements



Comments or questions?