

FLASHFORWARD▶▶ — ENERGY DOUBLING AND BEYOND...

Richard D'Arcy

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Accelerator Research and Development, Matter and Technologies
Helmholtz Association of German Research Centres, Berlin, Germany



HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

The **FLASHForward** team

MPA AND FLA: JOINT M & FH VENTURE

Engineers, IT support, and technicians

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Sven Karstensen
Kai Ludwig
Frank Marutzky
Amir Rahali
Andrej Schleiermacher
Sandra Thiele

Postdocs

Gregory Boyle
Theresa Brümmer
Jimmy Garland
Alexander Knetsch
Carl Lindstrøm
Gregor Loisch
Zeng Ming
Pardis Niknejadi
Kristjan Pöder
Jon Wood

Scientists

Richard D'Arcy
Jens Osterhoff
Bernhard Schmidt
Stephan Wesch

PhD students

Simon Bohlen
Lewis Boulton
James Chappell
Severin Diederichs
Pau Gonzalez
Martin Meisel
Sarah Schröder
Bridget Sheeran
Gabriele Tauscher

Students

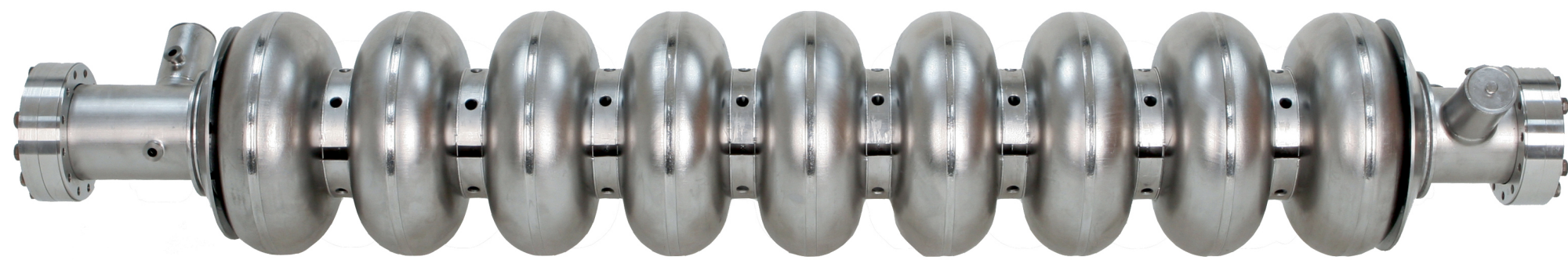
Robin Brabants
Artemis Kontogoula
Jan Lukas Dresselhaus



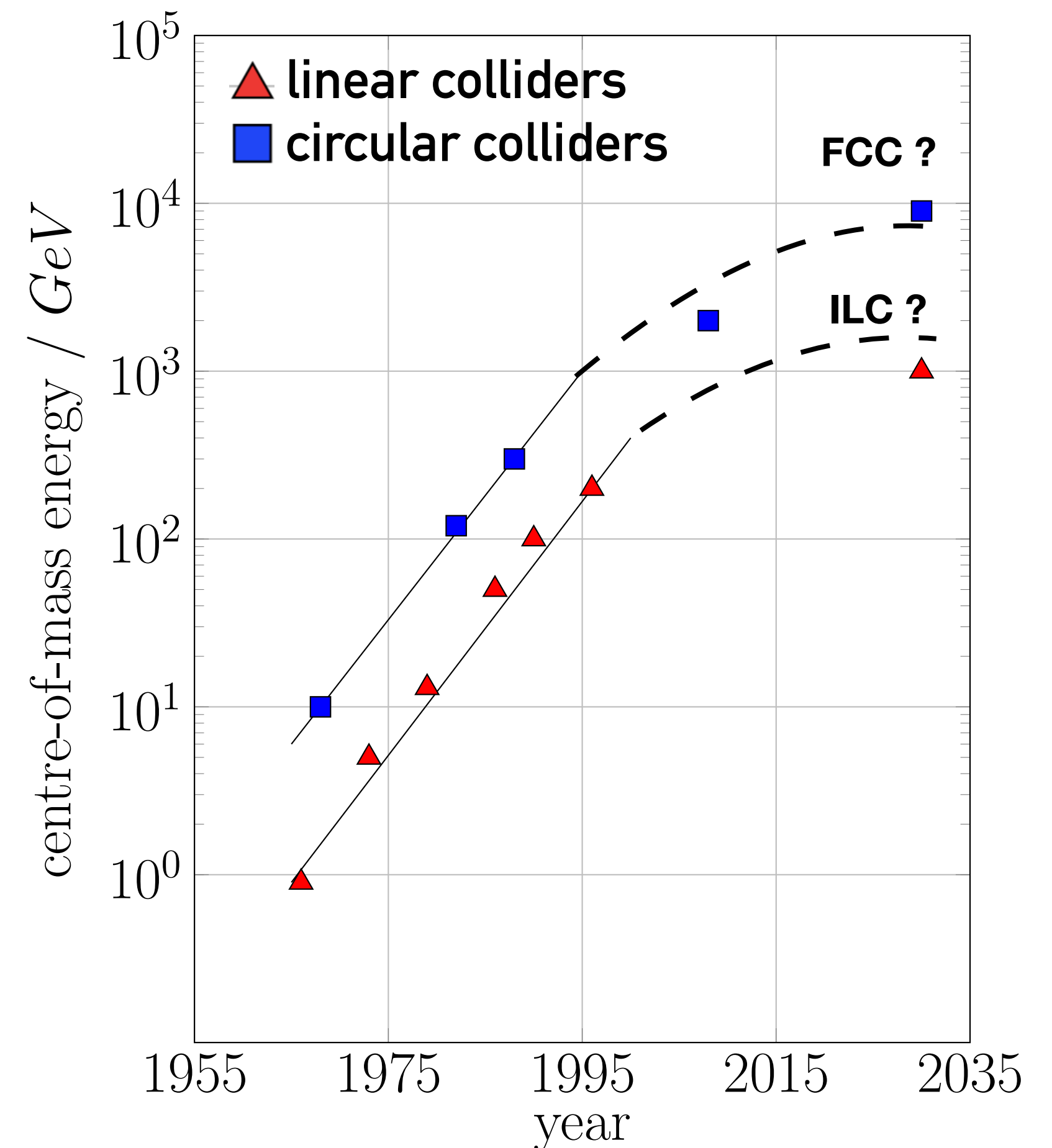
> ... plus many DESY engineering & technical support groups, predominantly from the M department!

CURRENT ACCELERATOR TECHNOLOGY AT A PERFORMANCE PLATEAU

(Superconducting) Radio-frequency cavity

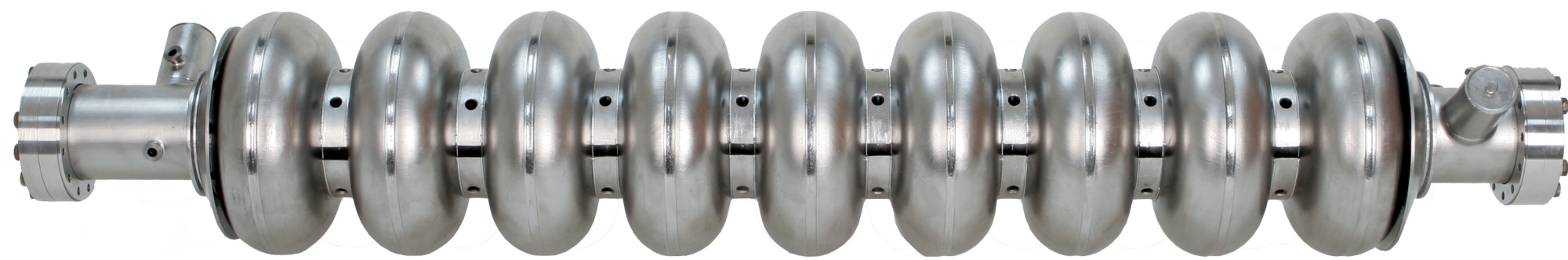


Limited by electrical breakdown to ≈ 100 MV/m



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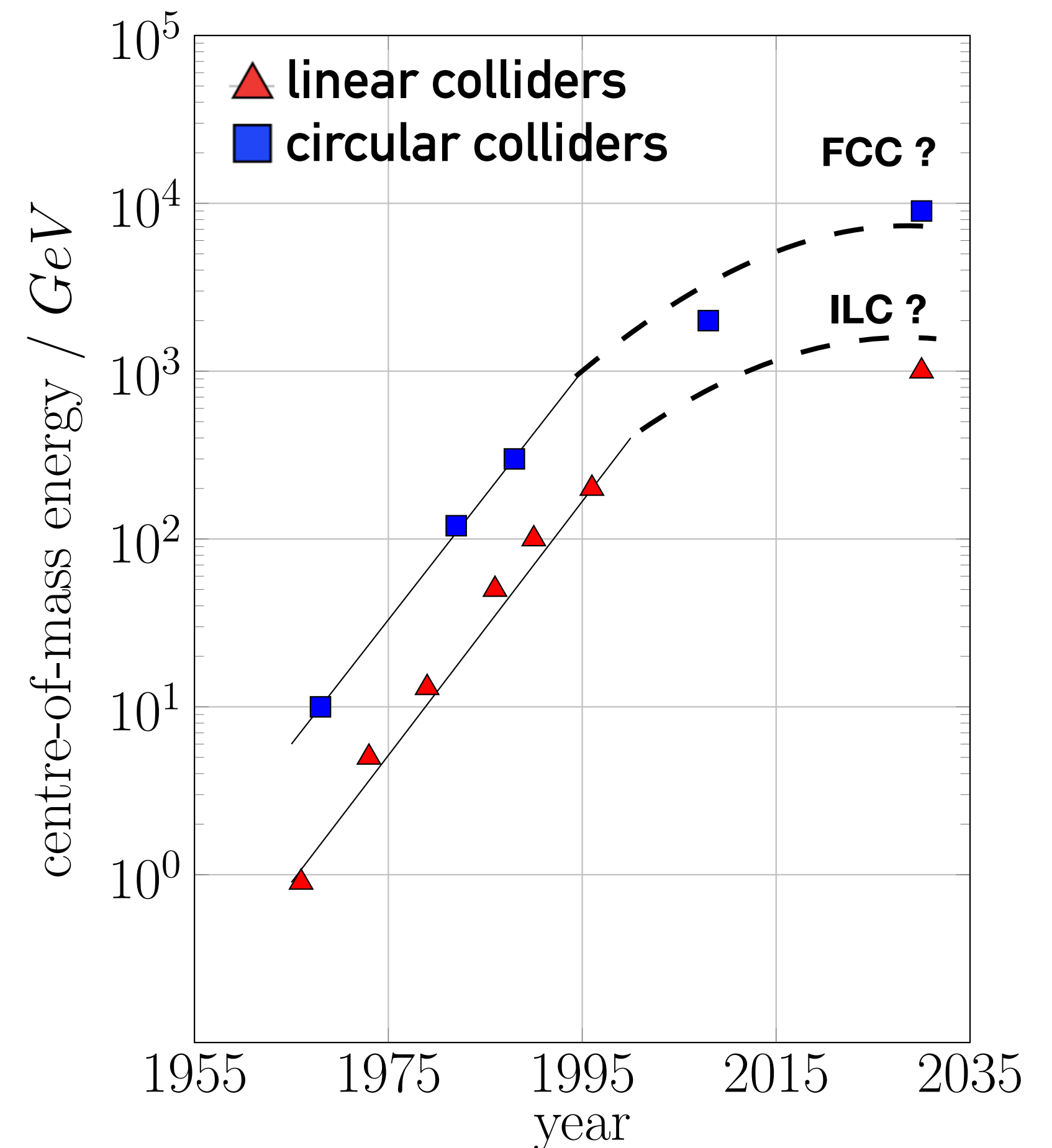
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1 TeV e^+e^- collider example

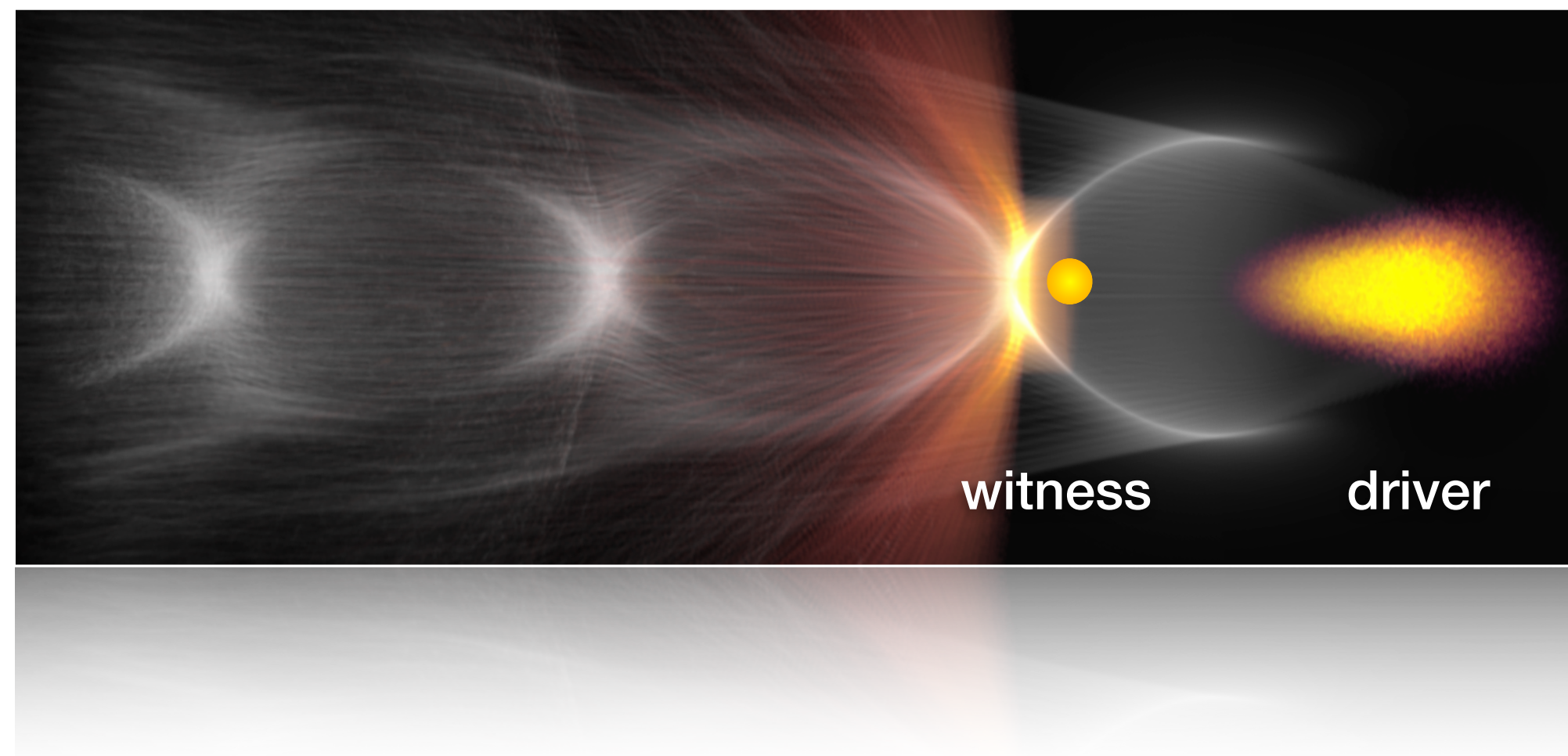
- tens of km of cavities
- >10 billion euros

IS A PARADIGM SHIFT NEEDED?

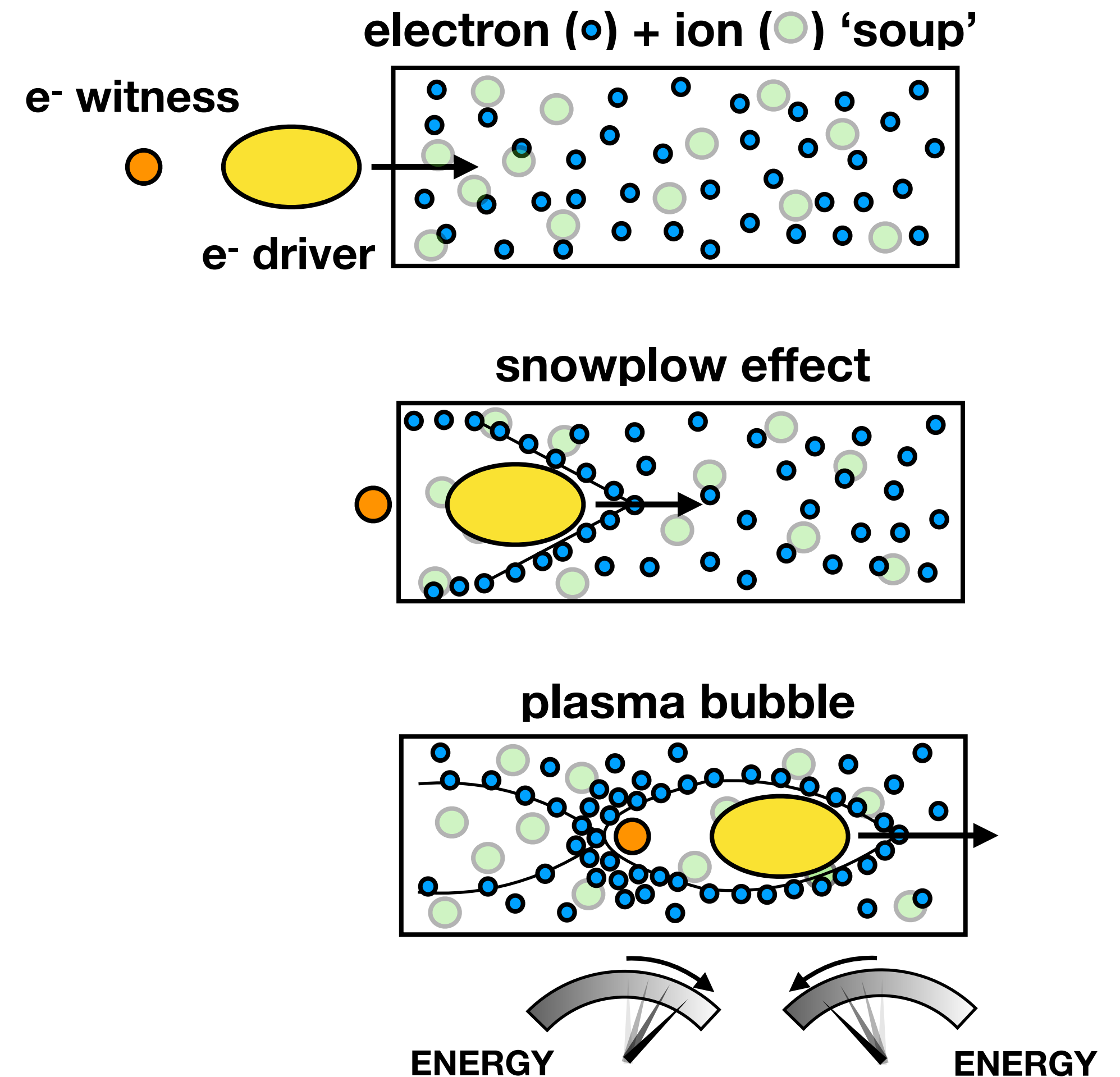


PLASMA-BASED ACCELERATORS: THE PARADIGM SHIFT?

Charge density wave in a plasma

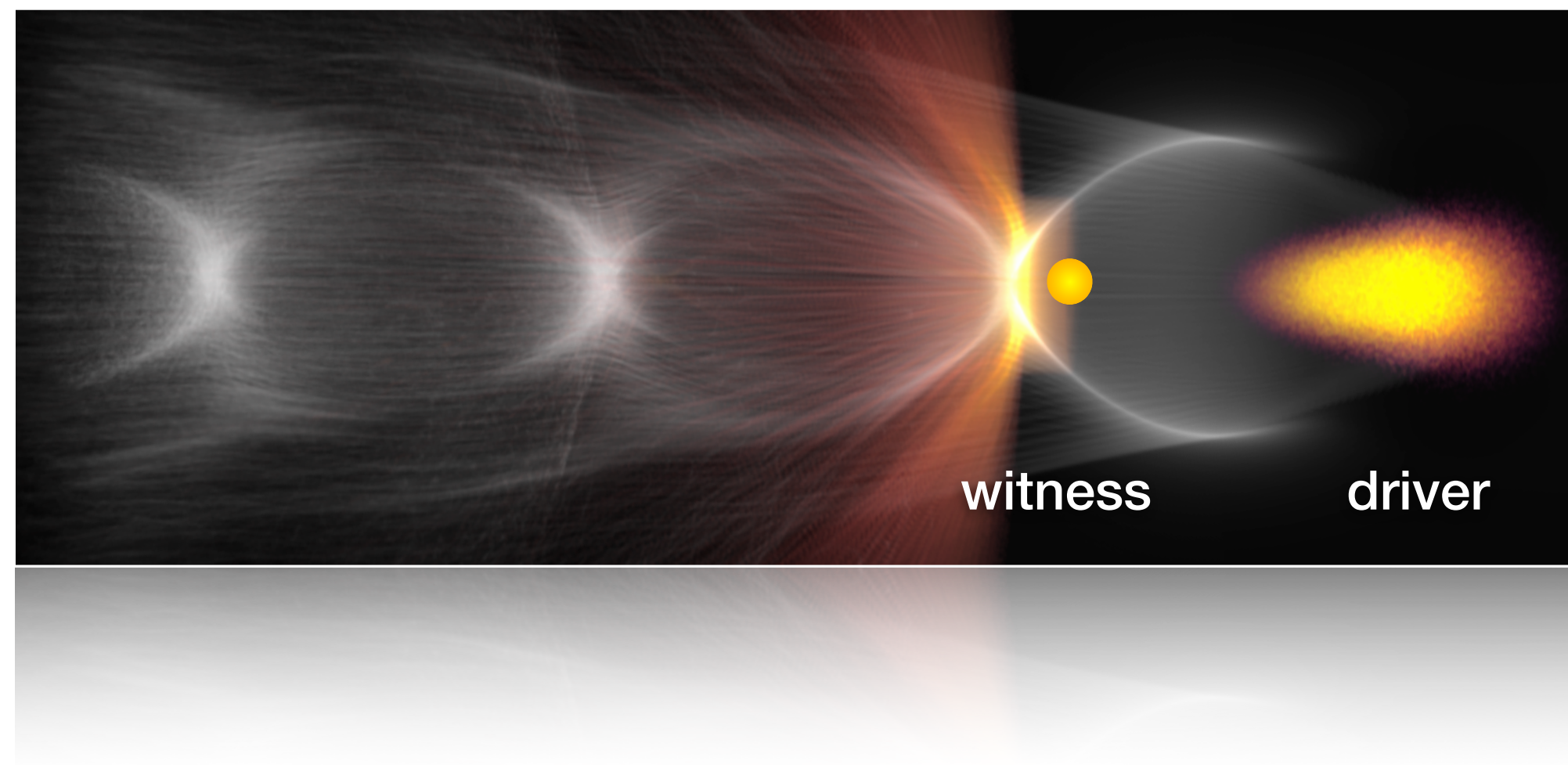


No surface quality limitations



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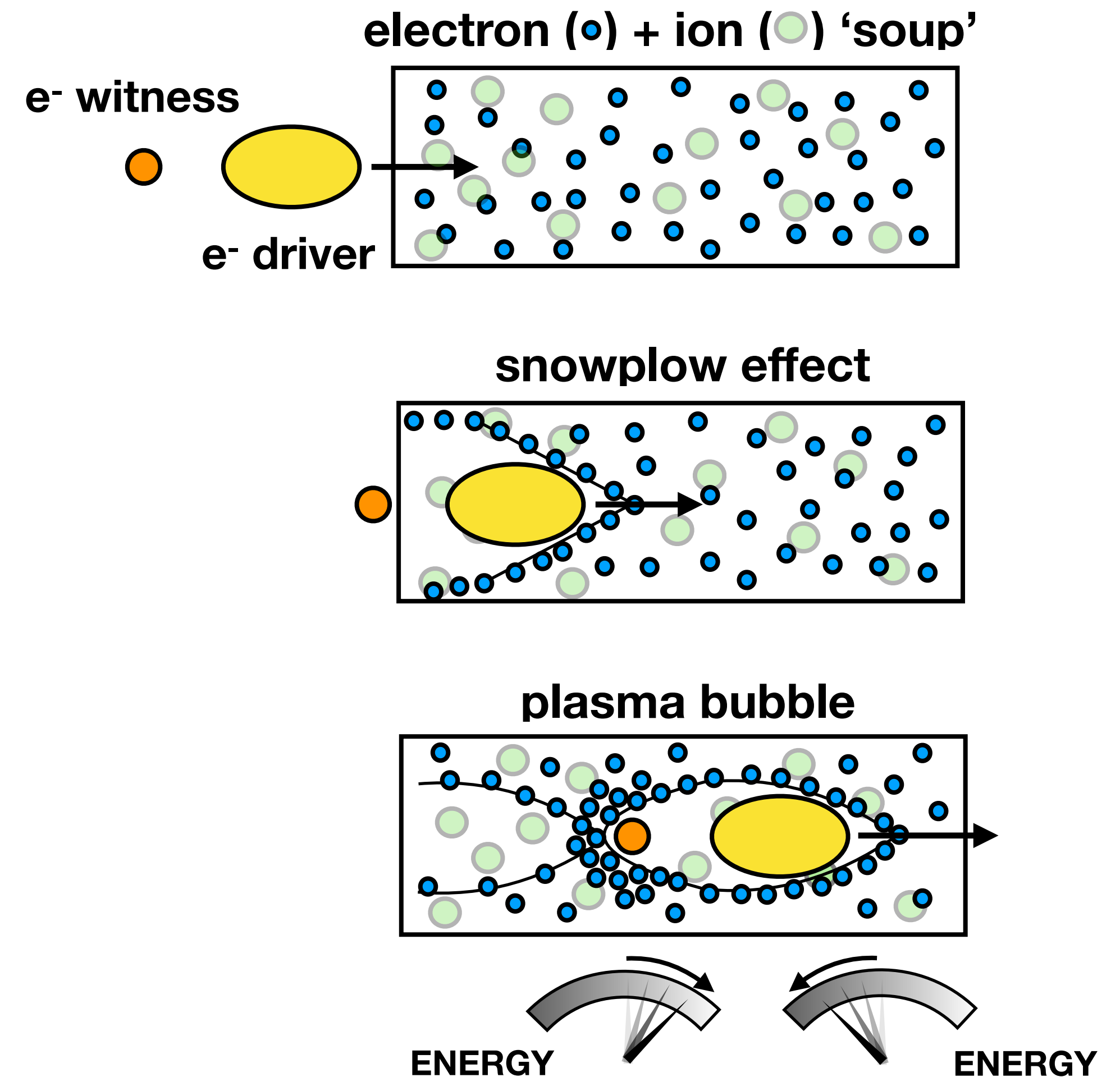


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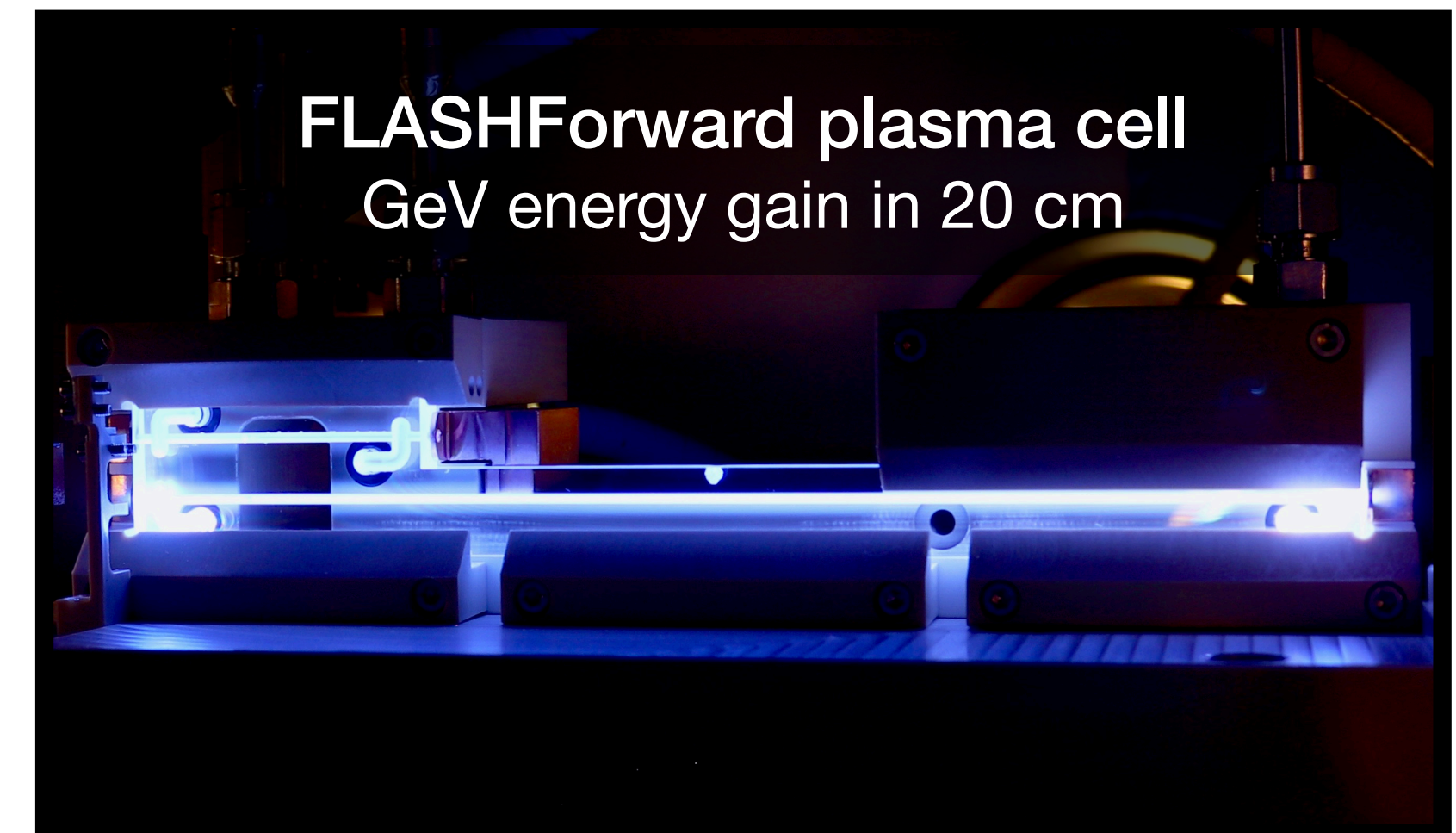
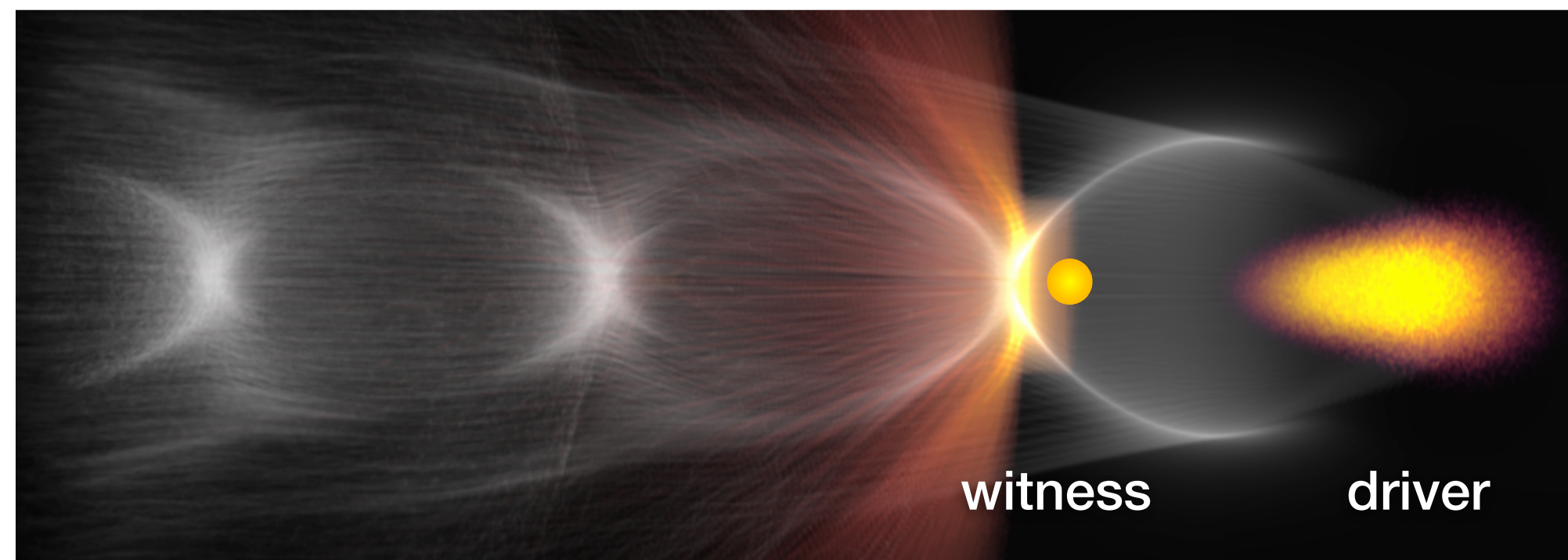
E_z of $\mathcal{O}(1-100 \text{ GV/m})$

THE WAVE OF THE FUTURE?



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Charge density wave in a plasma



No surface quality limitations



E_z of $\mathcal{O}(1-100 \text{ GV/m})$

THE WAVE OF THE FUTURE?

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European X-FEL

17.5 GeV
→ 3400 m

PETRA III

6 GeV
↻ 2300 m



FLASHForward▶▶

PWFA research

FLASH

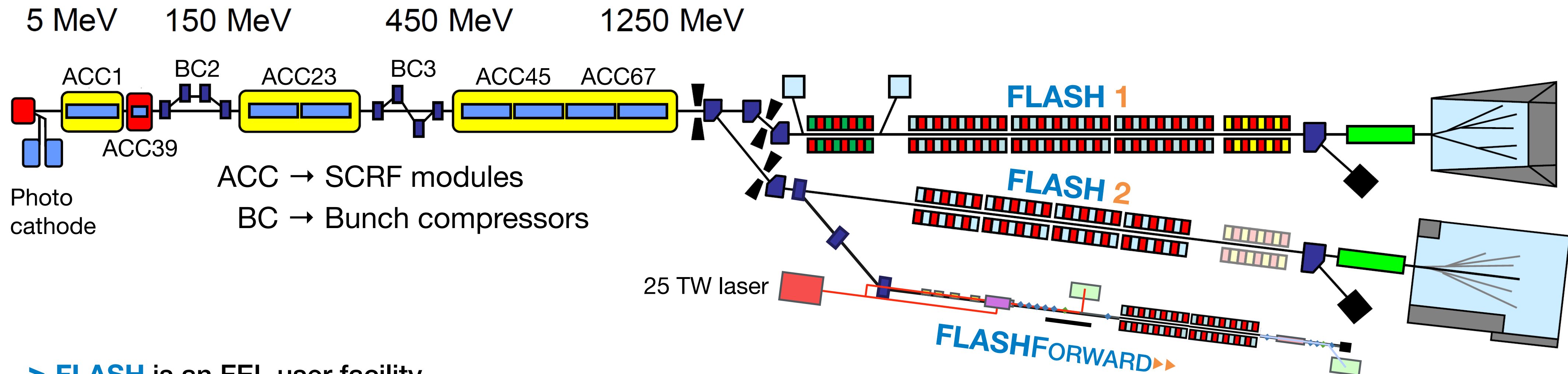
1.25 GeV
→ 315 m

Image Landsat / Copernicus

Google Earth

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A UNIQUE FACILITY FOR HIGH-QUALITY, HIGH-PRECISION, HIGH-AVERAGE-POWER BEAM-DRIVEN PWFA SCIENCE



> **FLASH** is an FEL user facility

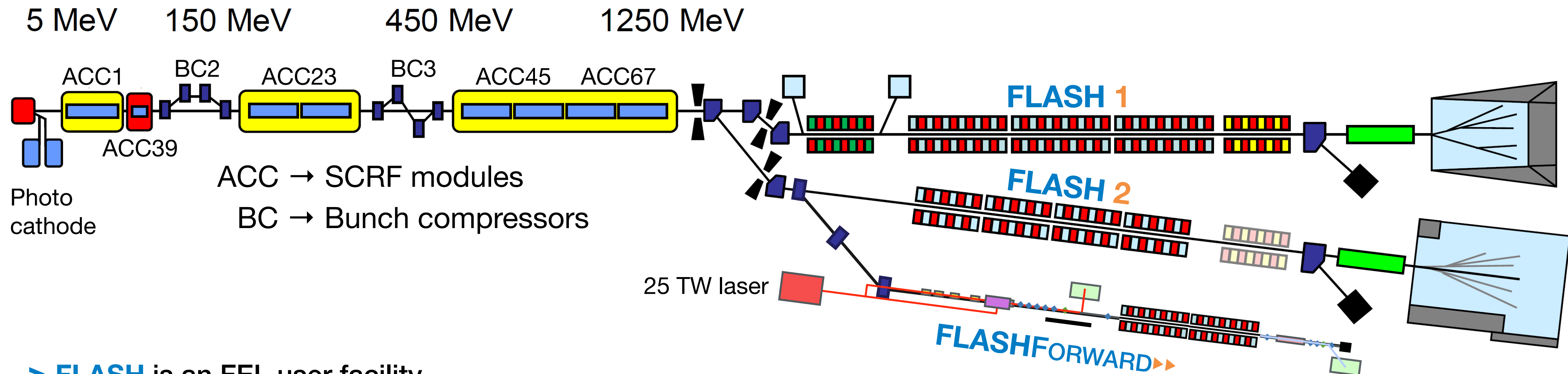
- 10% of beam time (750 h / year) dedicated to accelerator research

> Both share the same superconducting front end based on ILC/XFEL technology

- $\lesssim 1.25$ GeV energy with a few 100 pC at ~ 100 fs rms bunch duration
- ~ 2 μm trans. norm. emittance
- Exquisite stability, timing, and reproducibility through FEL-standard feedback systems
- Up to 3 MHz repetition rates

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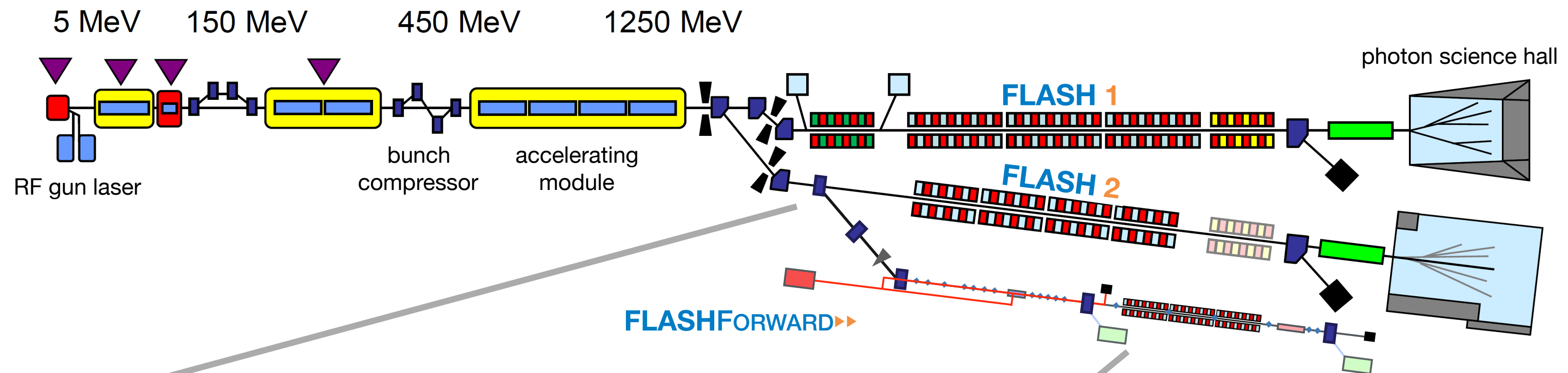
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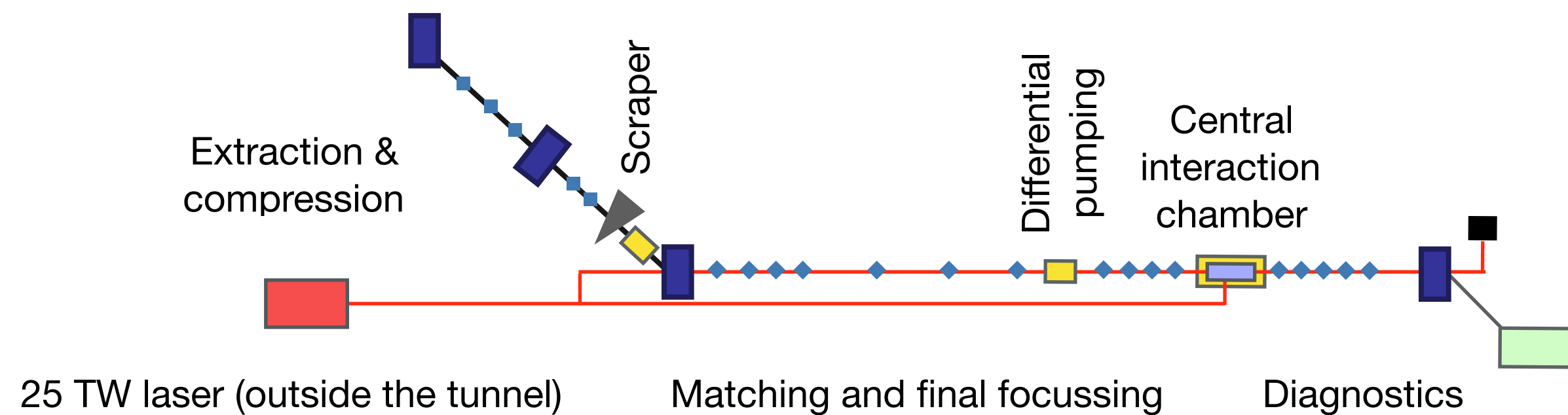
Parameters unique to
FLASHFORWARD▶▶ in
the field of PWFA

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BEAMLINE STATUS UNTIL THE FLASH SUMMER SHUTDOWN OF 2019

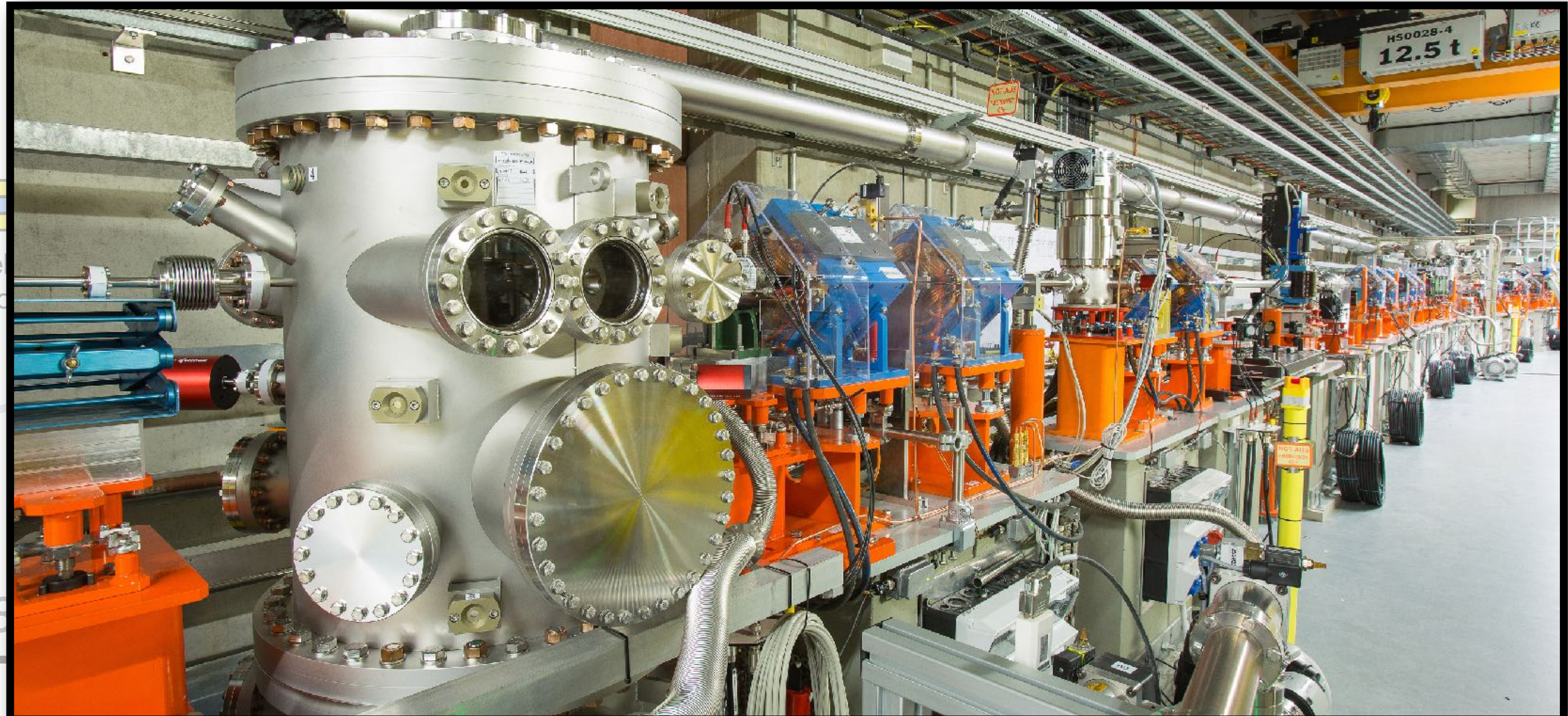
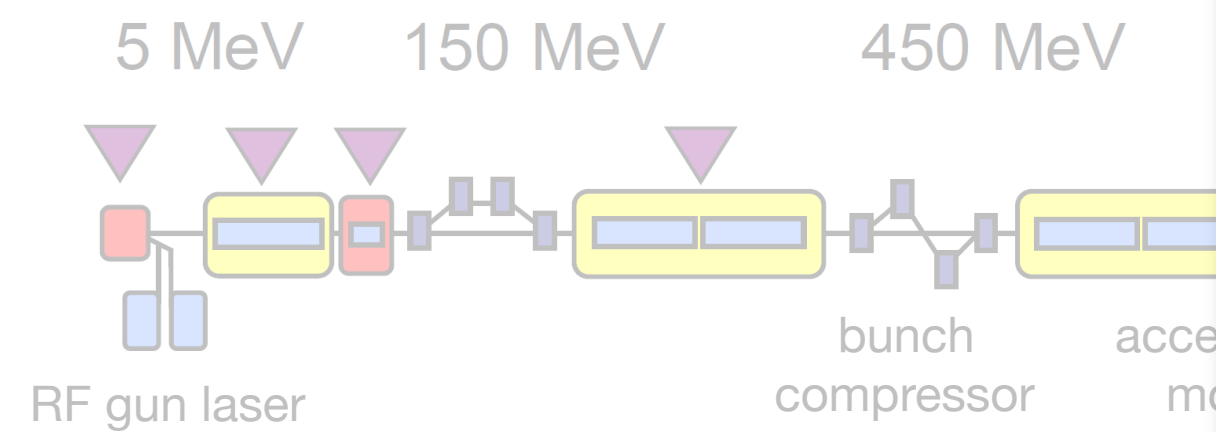


beamline status 2018-2019

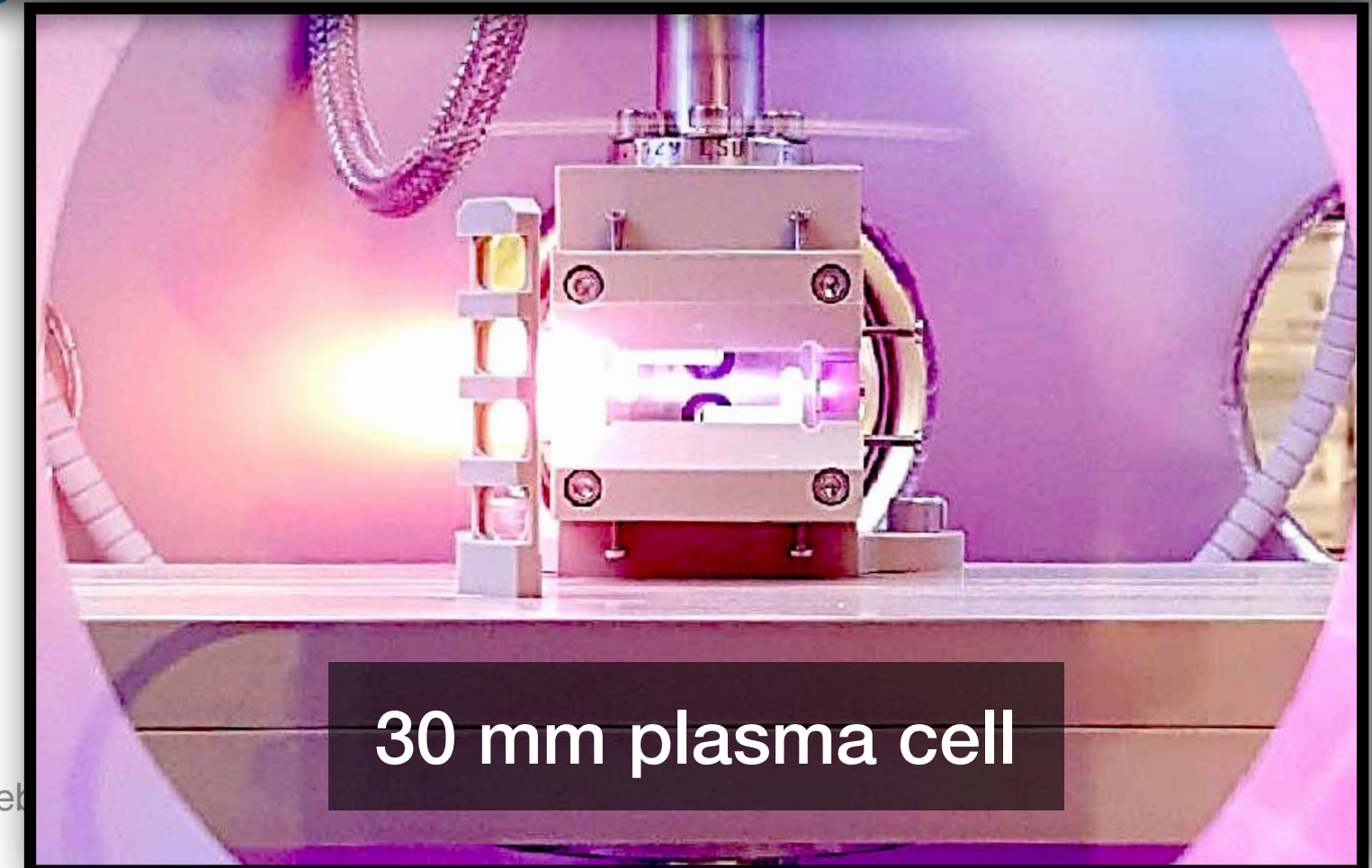
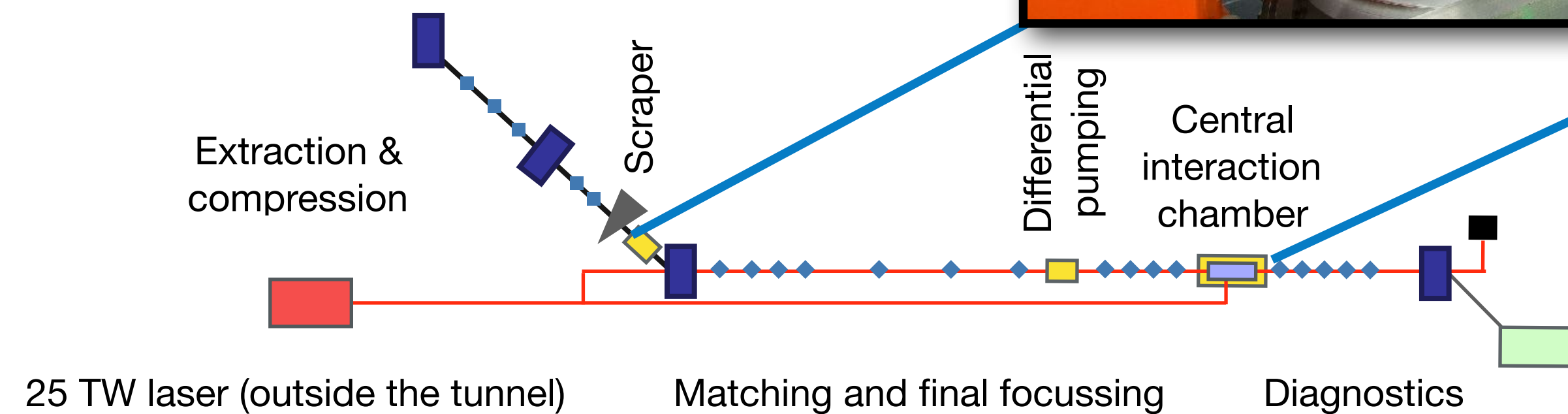


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‘SHORT’ PLASMA CELL USED FOR COMMISSIONING AND PRELIMINARY STUDIES

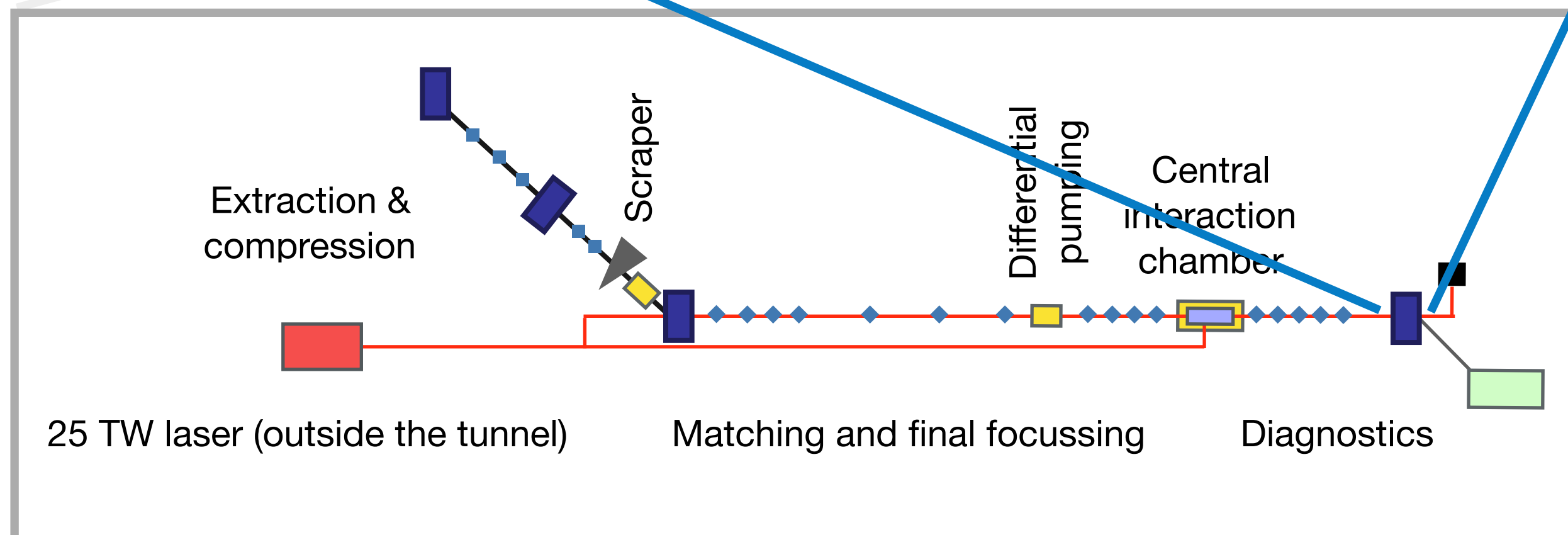
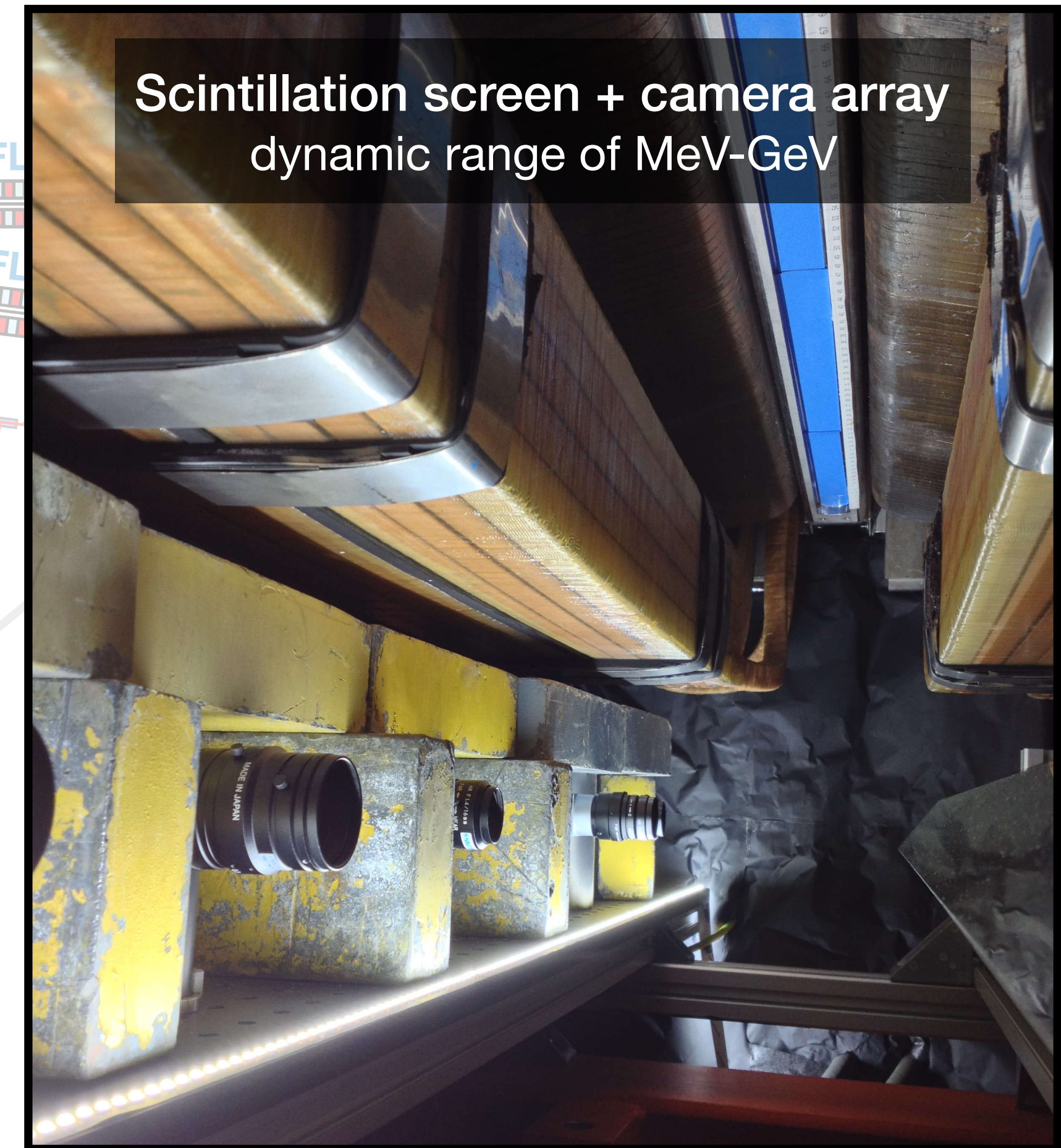
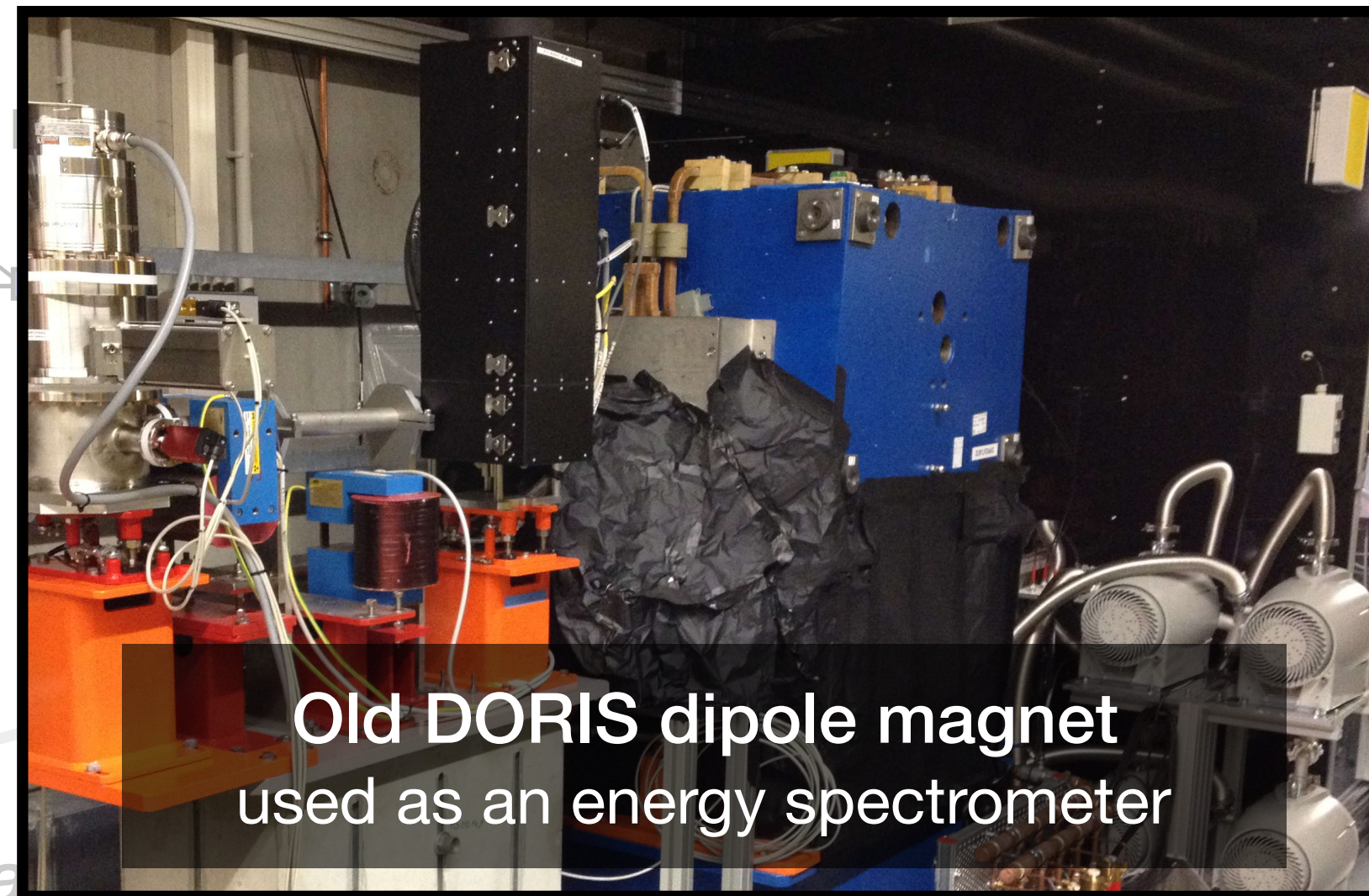
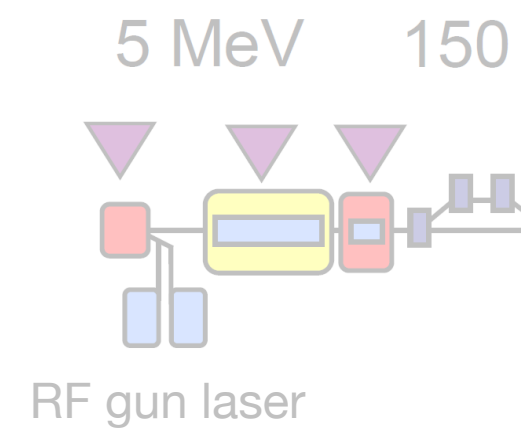


beamline status 2018



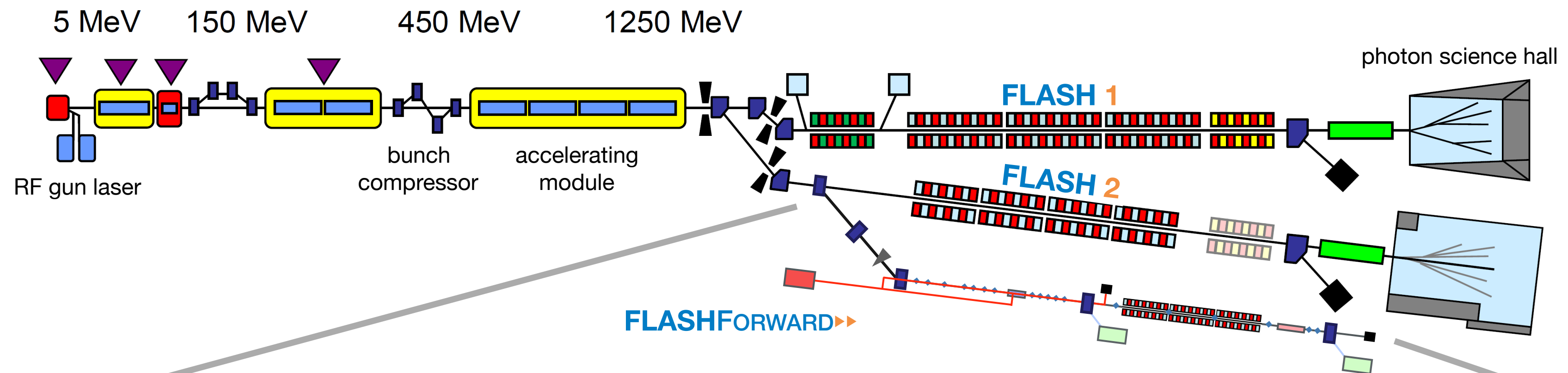
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ELECTRON SPECTROMETER FOR ROBUST ENERGY DIAGNOSTICS

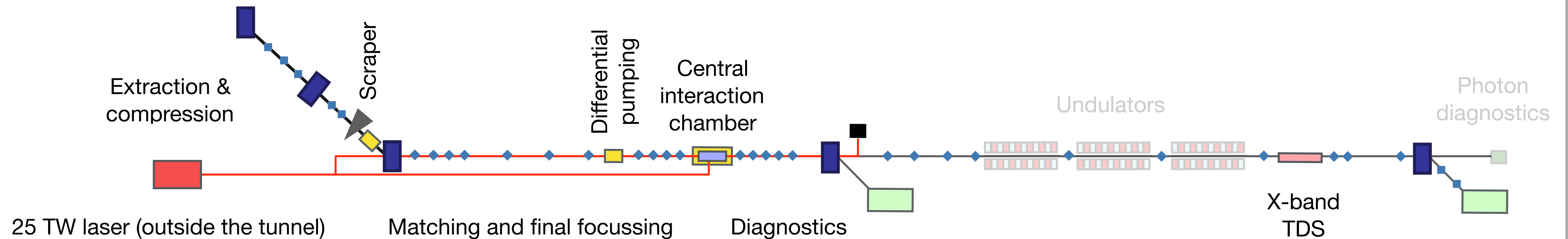


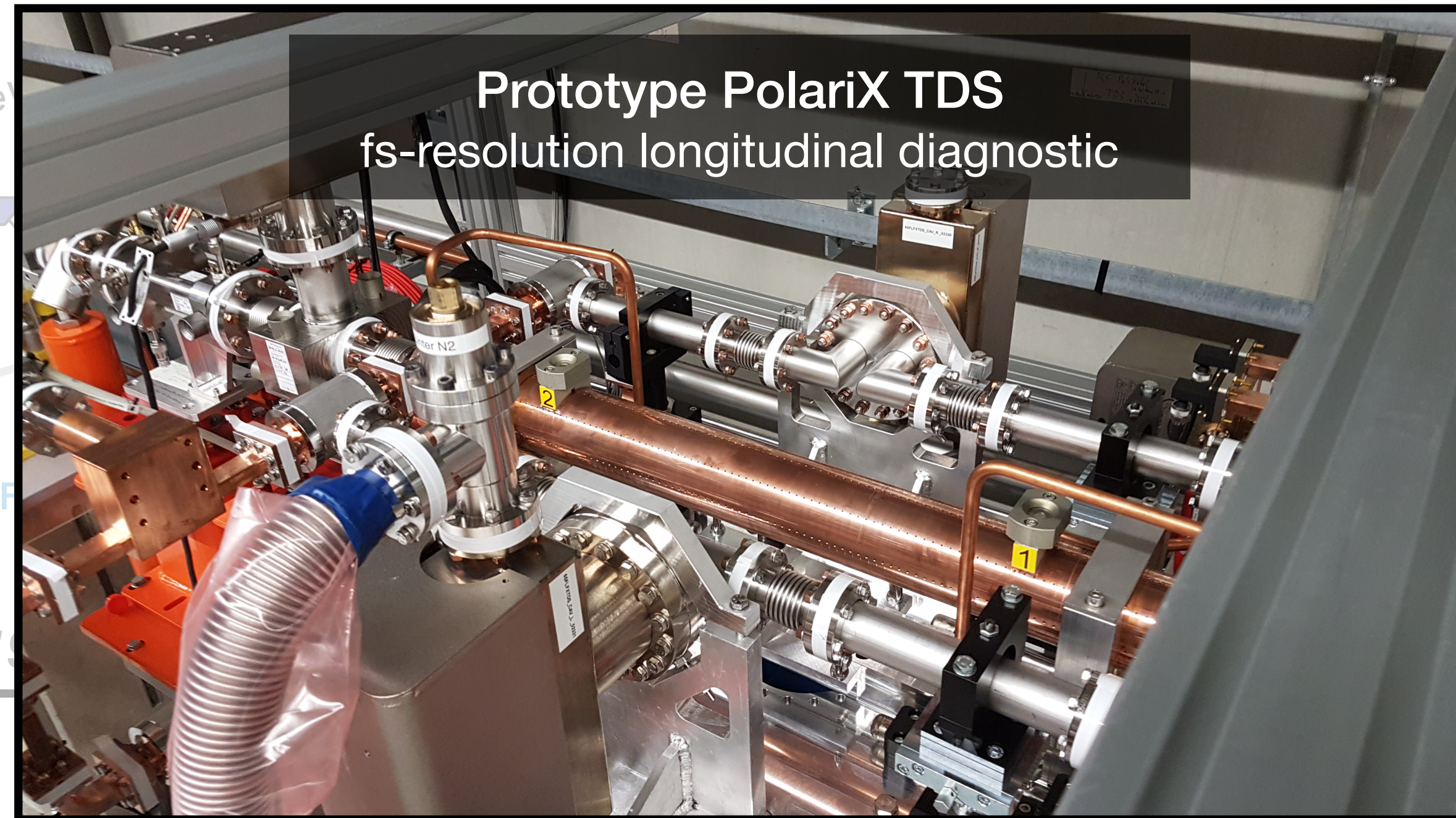
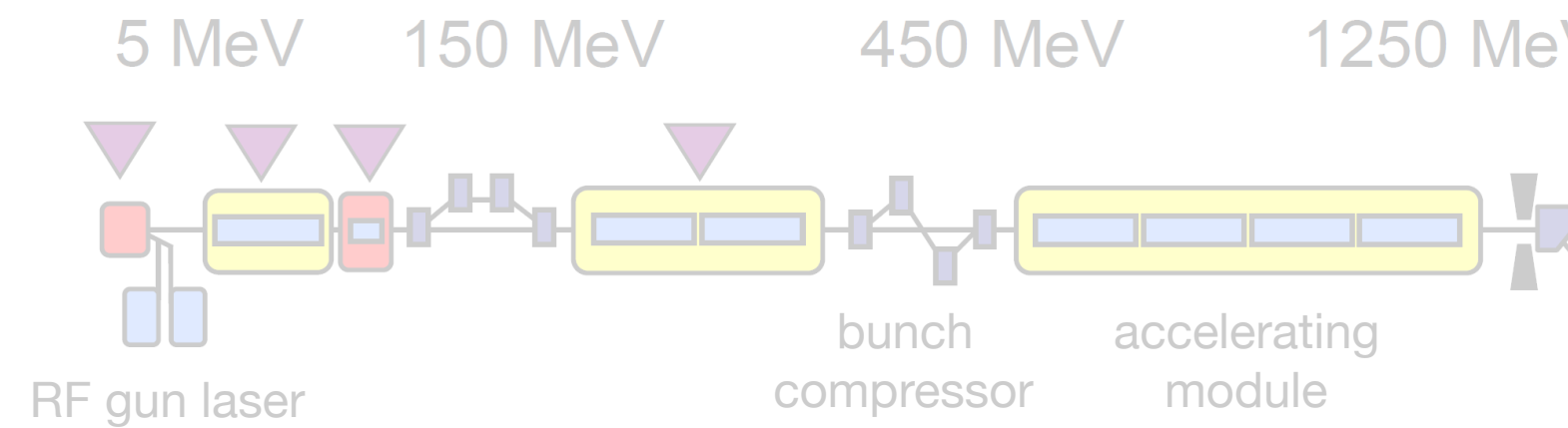
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CURRENT BEAMLINE STATUS

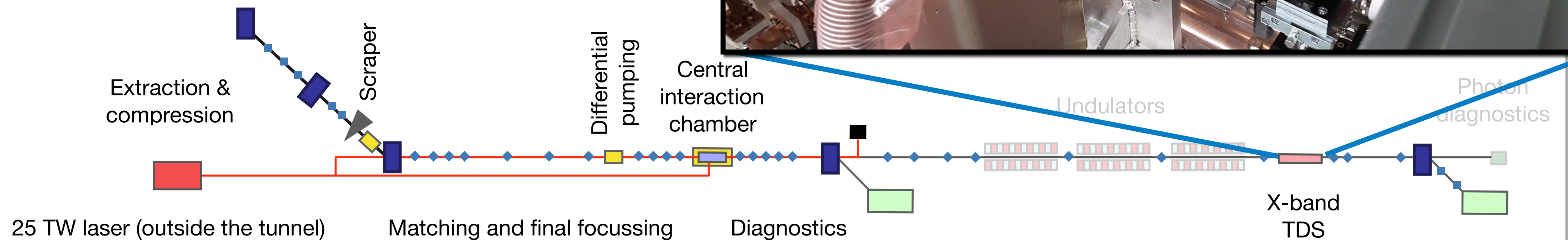


summer 2019 beamline extension



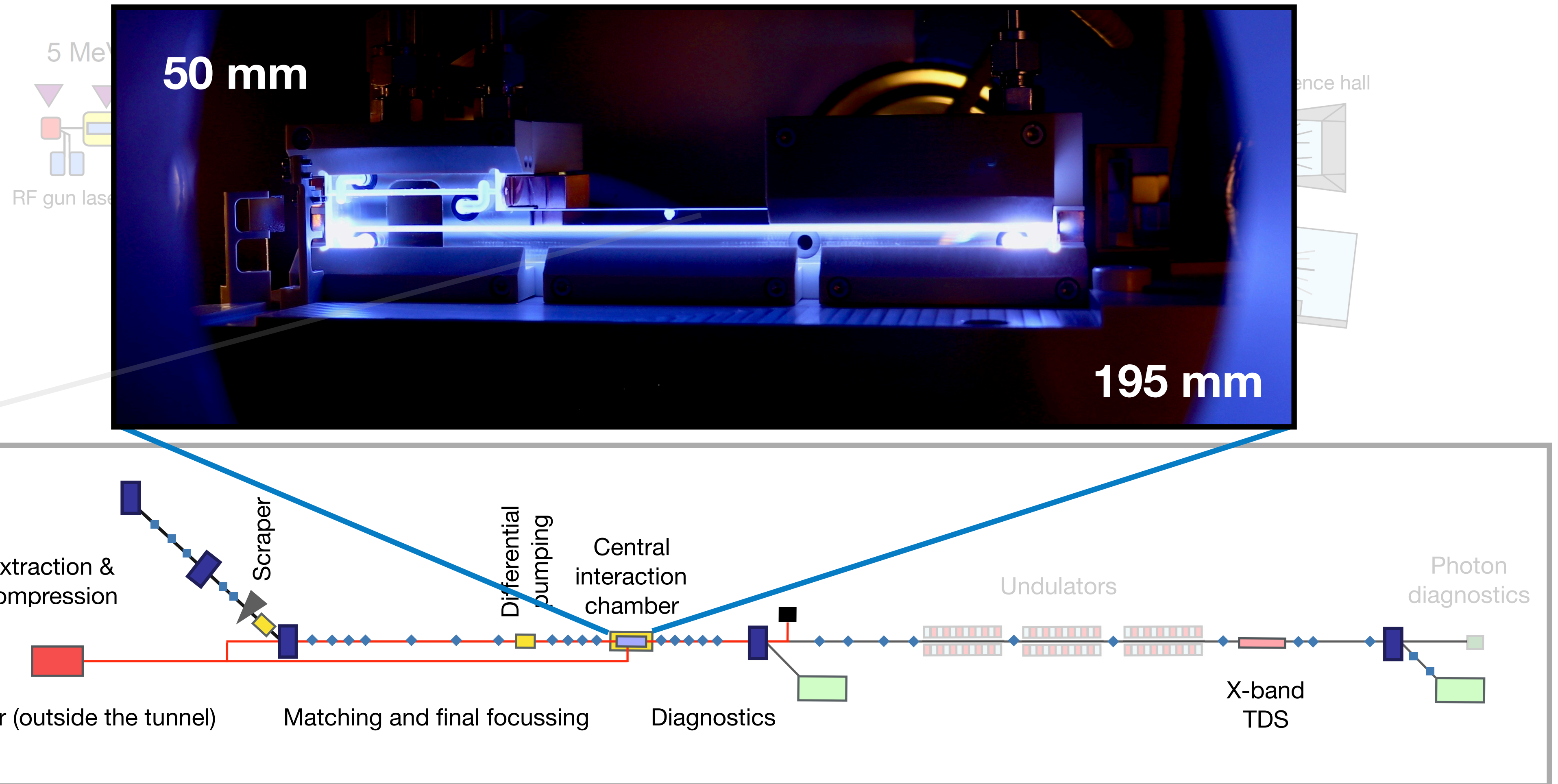


FLASHFORWARD
summer 2019



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LONG/SHORT PLASMA CELL (55/195 MM) UPGRADE FOR LARGE ENERGY GAIN

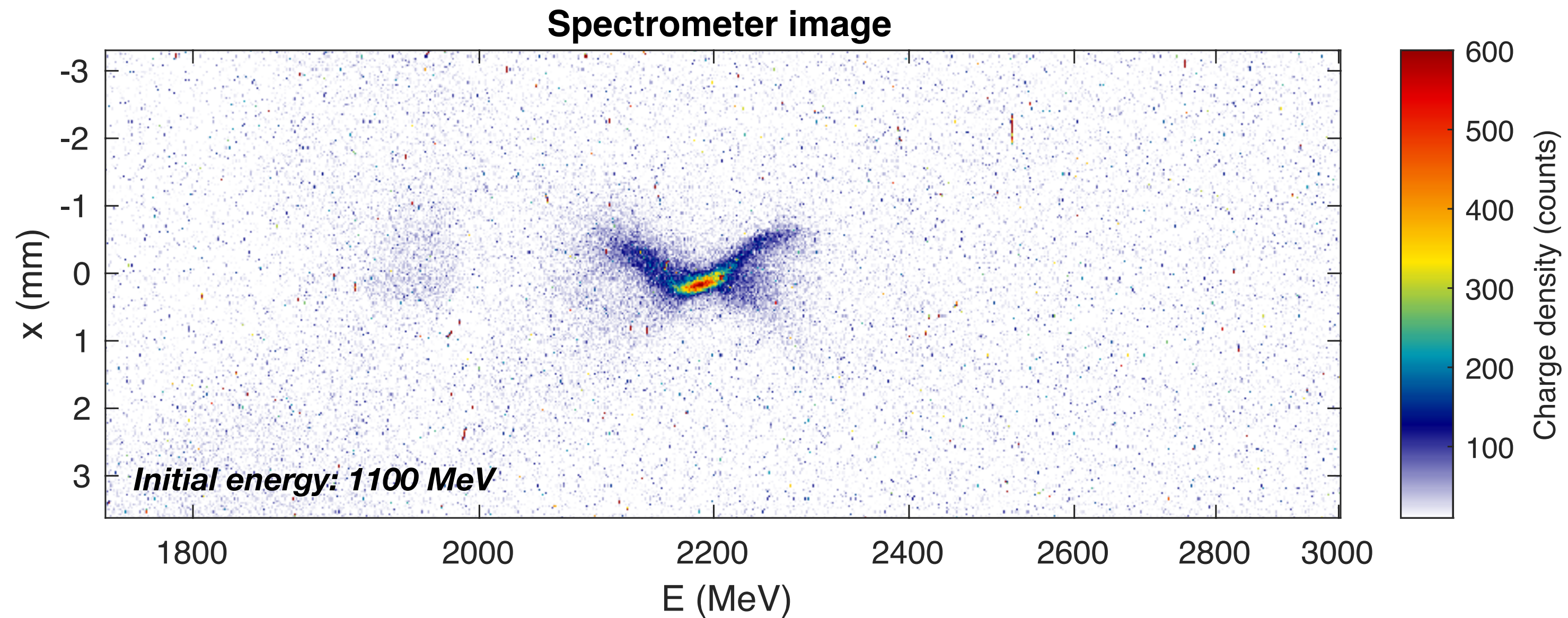


ENERGY DOUBLING AT FLASH

DOUBLING OF (PART OF) THE 1.1 GeV FLASH BUNCH

PI: C. LINDSTRØM

NOVEMBER 2019



- Doubled the energy of a small part of the 1.1 GeV initial bunch, observing up to 2.4 GeV electrons
- Reached the goal of 1 GeV energy gain!
- Sustained ~6 GV/m accelerating gradient
- But high-gradient acceleration is not the only name of the game...

FLASHFORWARD▶▶ EXPERIMENTAL GOALS

MAKING PWFA RESEARCH APPLICATION-READY

- Taking plasma accelerator technology from ‘academia to application’ is a multi-faceted challenge that doesn’t end with high-gradient acceleration

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10 kW stage with >50% efficiency
& witness property conservation

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FLASHFORWARD▶▶

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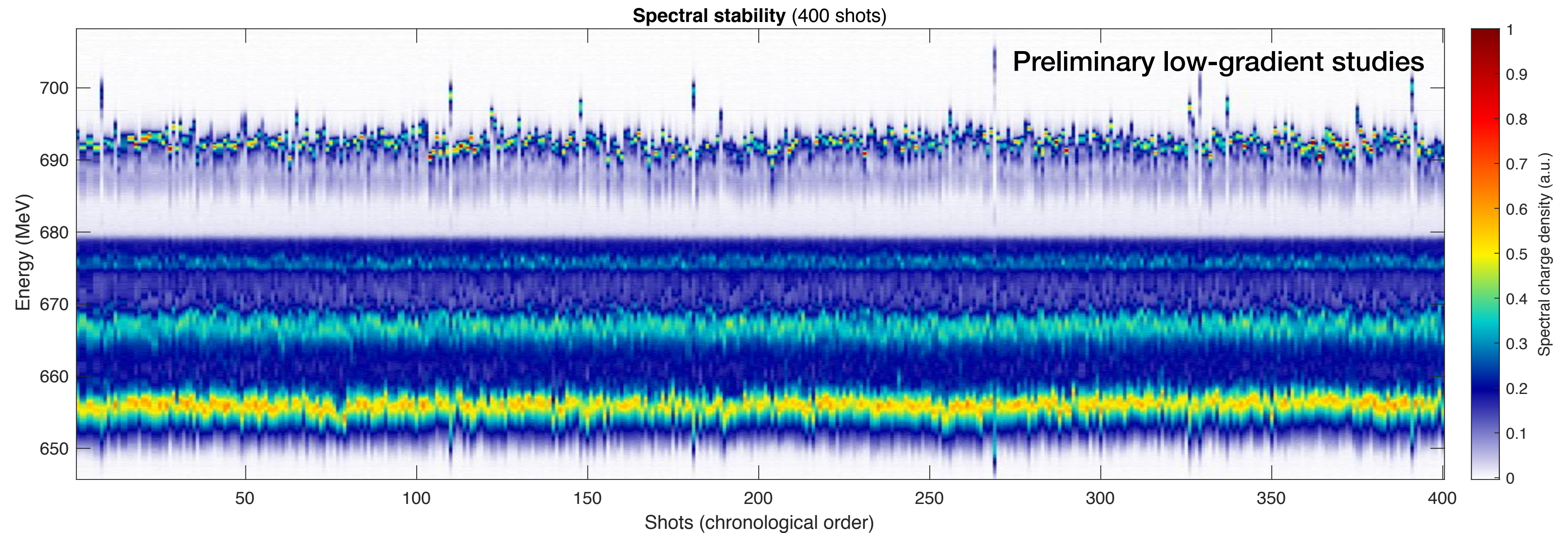
- *High-gradient acceleration*
- Stability and reproducibility
- Beam characterisation
- Emittance preservation
- Low energy spread
- High overall efficiency
- High repetition rate
- High average power

EXQUISITE FLASH SHOT-TO-SHOT STABILITY

FLASH FEEDBACK/FEEDFORWARD SYSTEMS PROVIDE UNPRECEDENTED STABILITY IN PWFA

PI: C. LINDSTRØM

JAN 2019



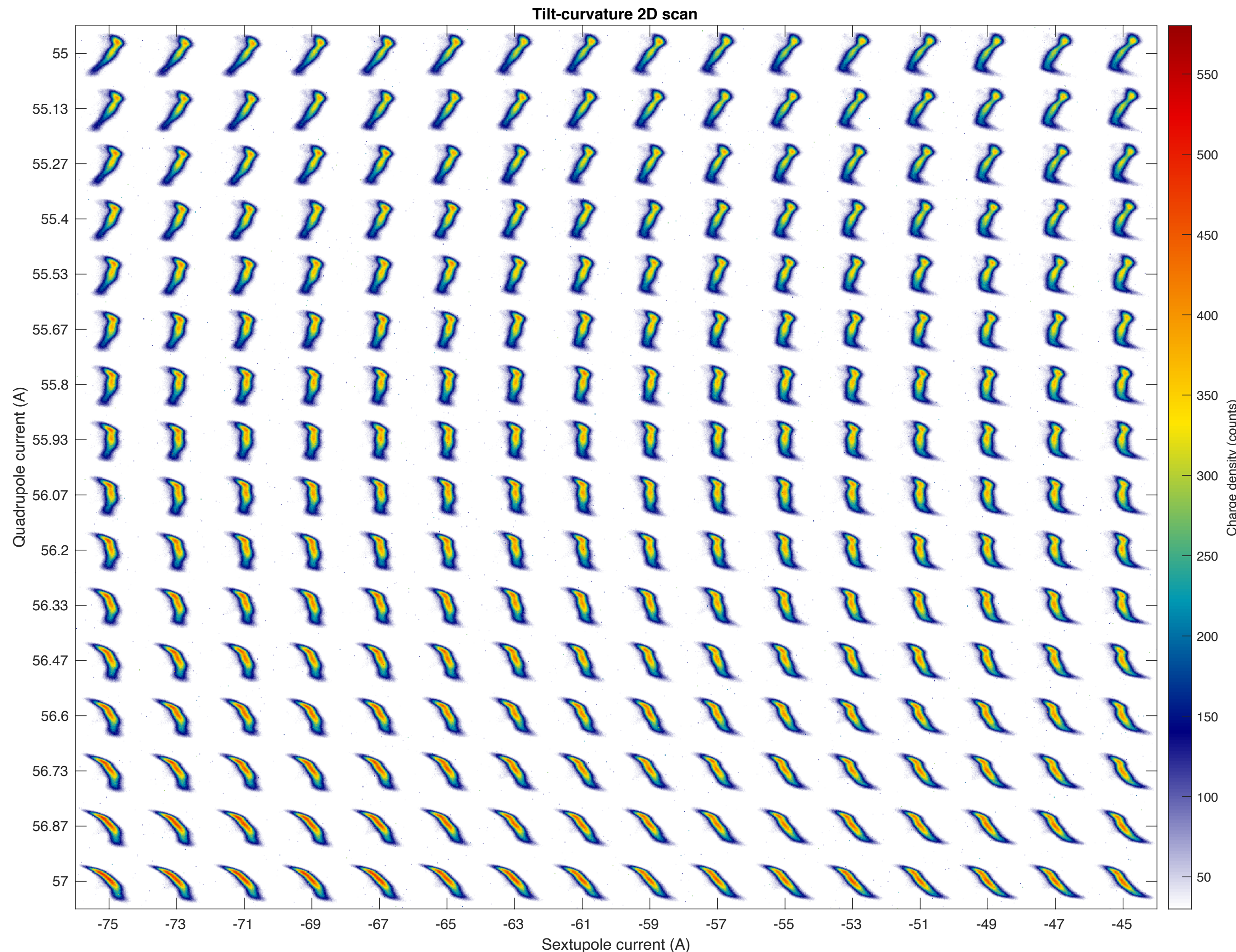
- Extremely stable drive beam with flexible parameters means sources of instability in PWFA process can be isolated, assessed, and optimised
- Energy gain stability = **10% rms minus outliers** → needs to be improved!

CORRECTING HEAD-TO-TAIL BEAM TILTS

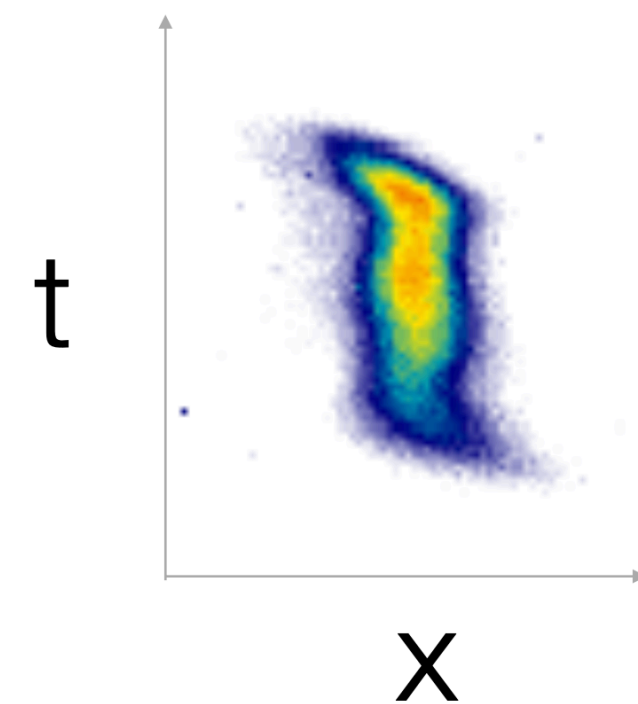
UTILISING THE FF» X-TDS TO CORRECT FOR SOURCES OF INSTABILITY

PI: R. D'ARCY

DECEMBER 2019



- > Head-to-tail centroid offsets can severely harm transmission in a PWFA due to strong transverse focussing fields in plasma
- > Tweaking two magnets in the FLASHForward beamline controls and compensates for the tilt



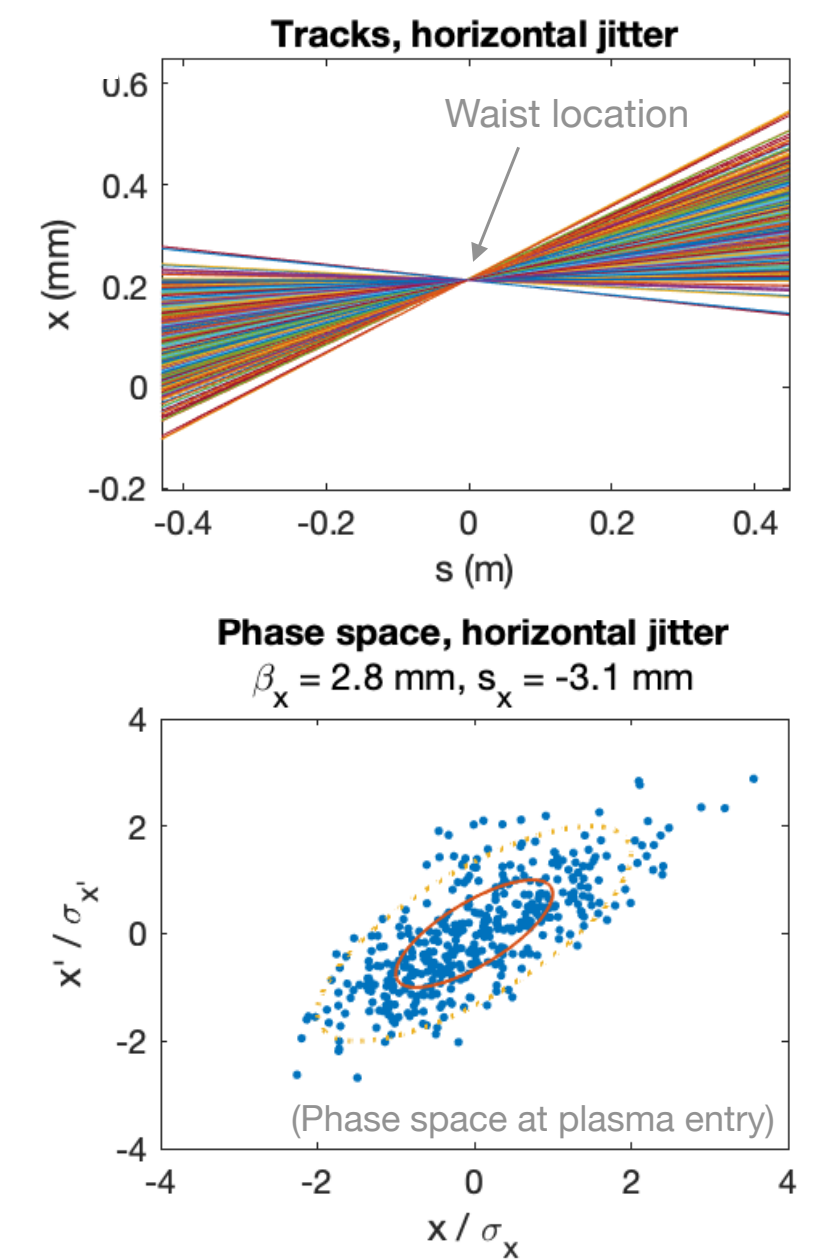
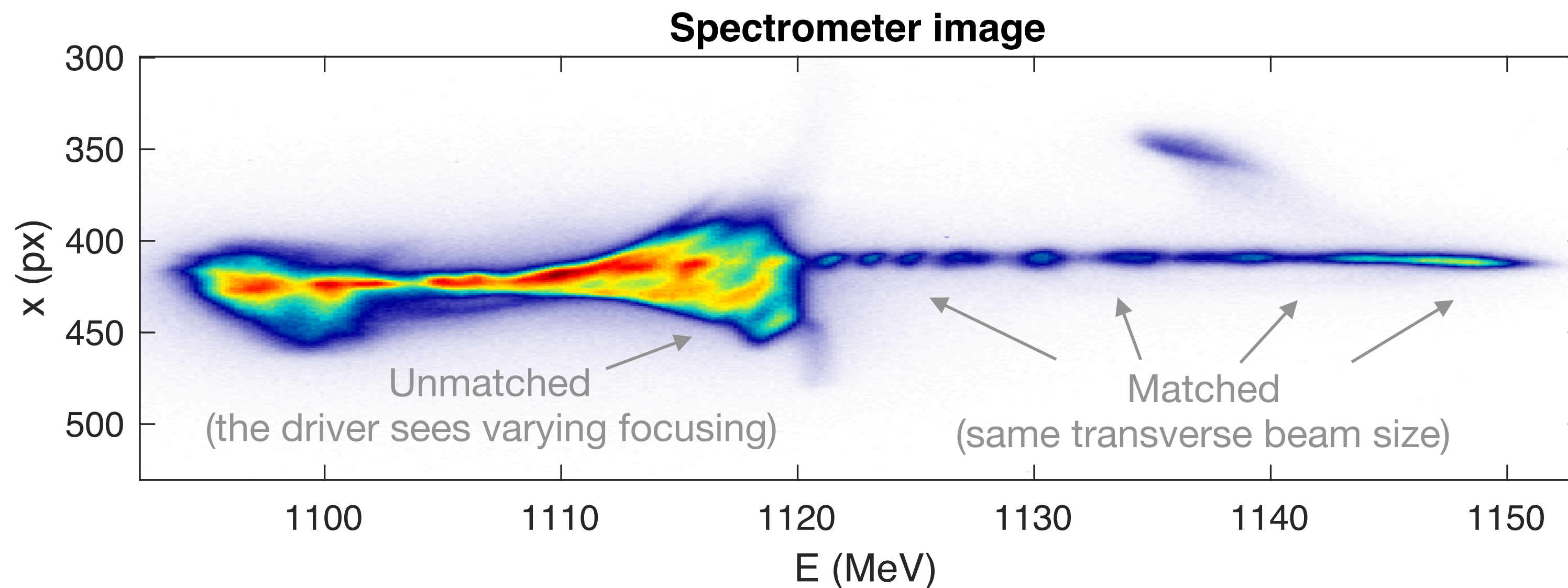
- > Essential milestone for FLASHForward but also for the understanding of collective effects in the FLASH linac

TRANSVERSE MATCHING INTO PLASMA

ESSENTIAL FIRST STEP TOWARDS EMITTANCE CONSERVATION

PI: C. LINDSTRØM

MAY 2019



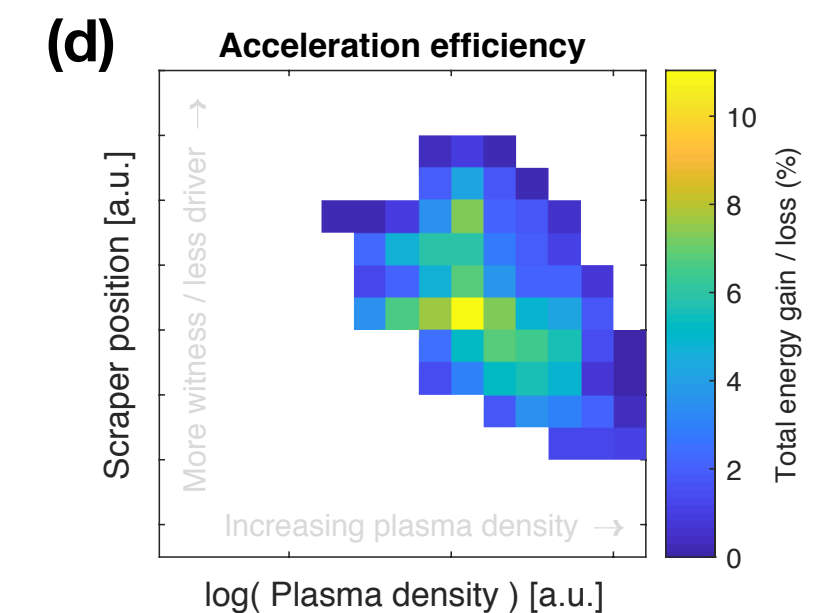
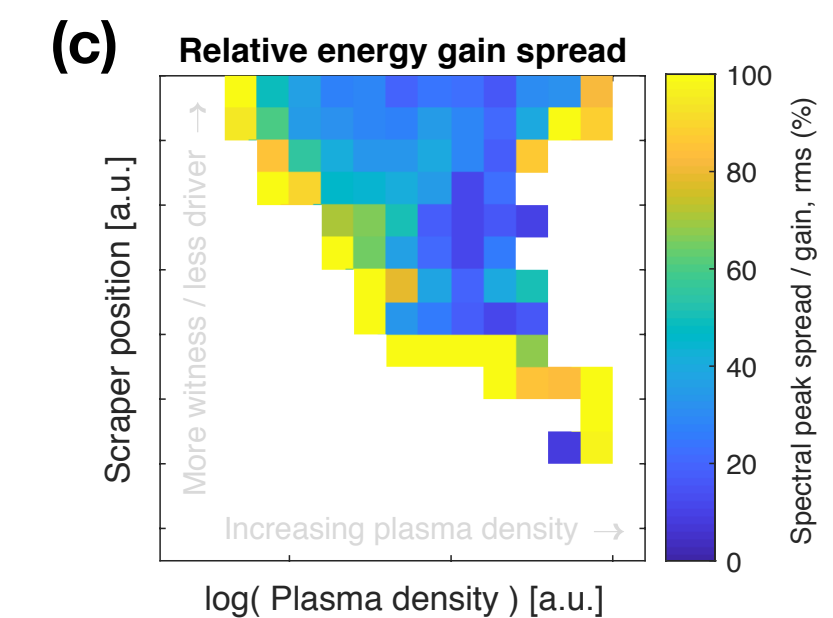
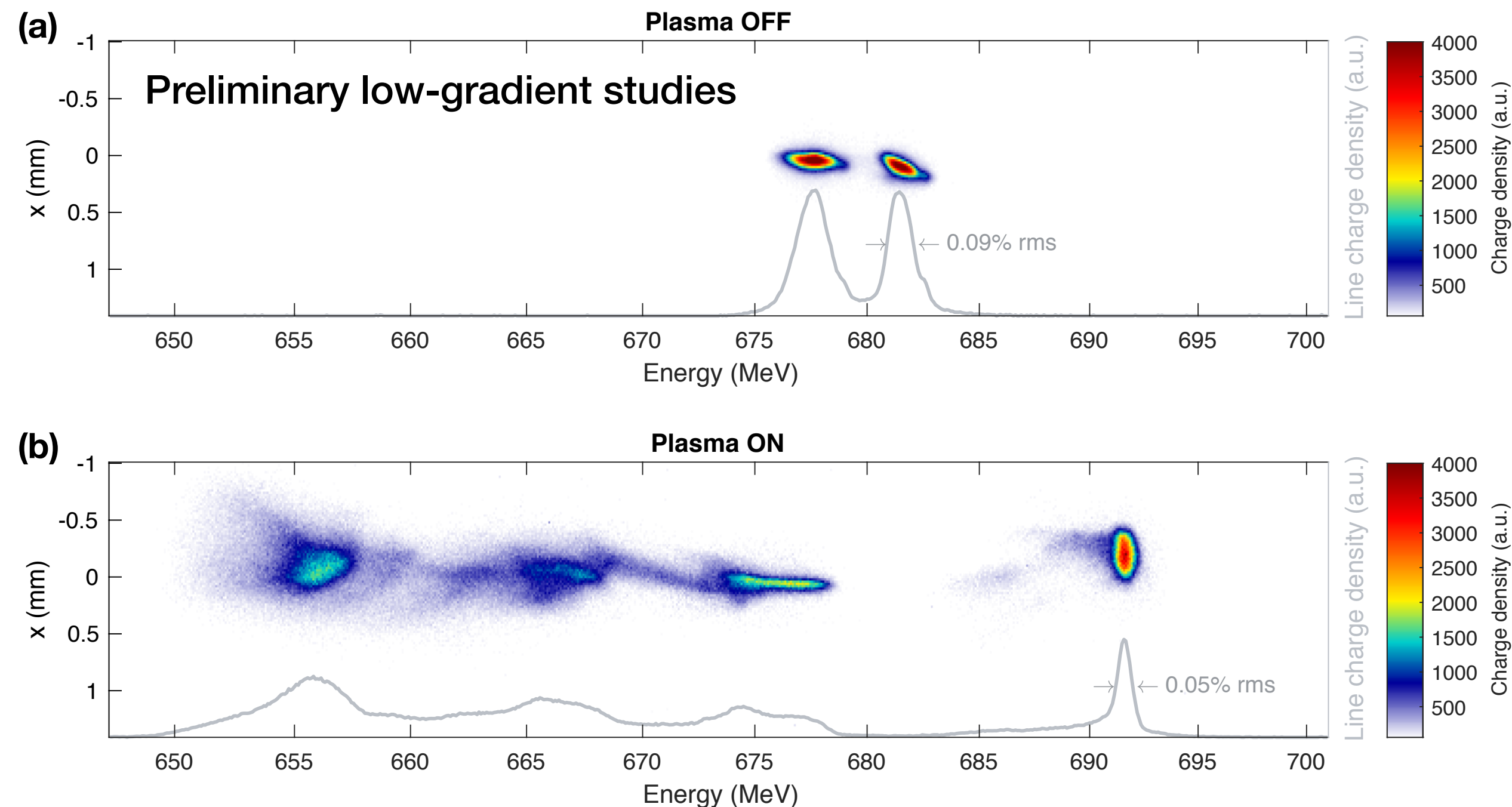
- Big improvements to the beam in-coupling were achieved with mm-scale beta functions at the plasma entry
- We believe the beam beta function was approx. matched to the plasma ($n_e \sim 10^{16}/\text{cc}$, $\beta_{x,y} \sim 3$ mm)
- Important step towards emittance preservation...

LOW ENERGY SPREAD AND OPTIMAL BEAM LOADING

FIRST DEMONSTRATION OF ENERGY-SPREAD CONSERVATION AND REDUCTION!

PI: J. GARLAND

MARCH 2019



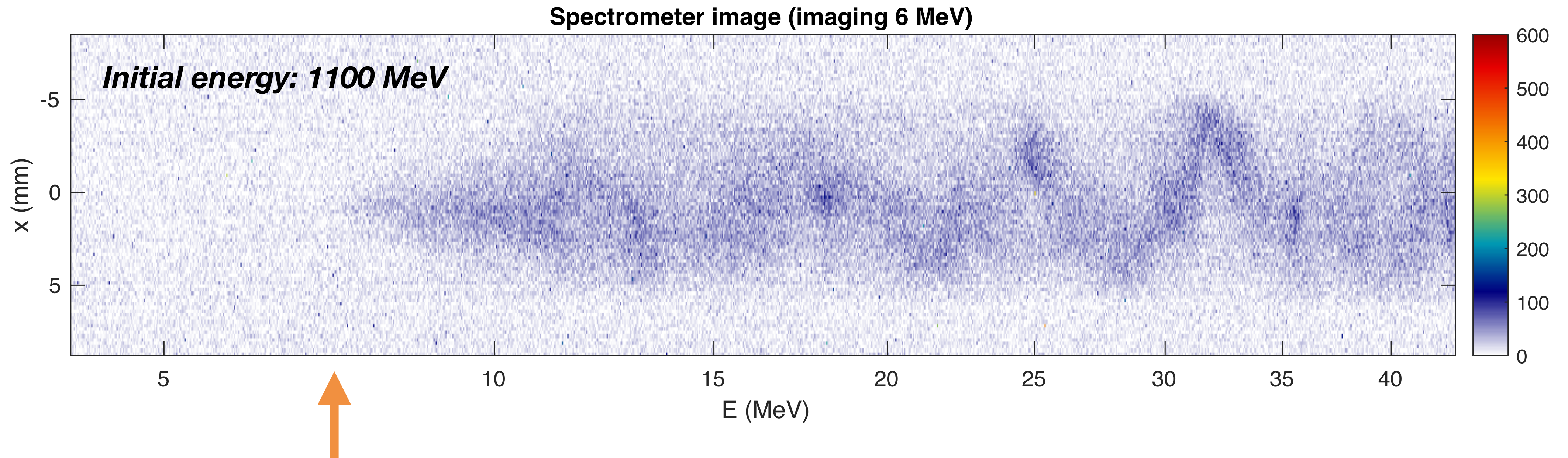
- Can be corrected after plasma with e.g. plasma dechirpers (experimentally demonstrated at FLASHForward in 2018)
- Can also be mitigated by manipulating the electric fields in the plasma through appropriate beam loading
- Initial energy spread (**0.09%**) approximately halved (**0.05%**) (spectral peak)
- Next step to use the X-TDS for longitudinal phase space optimisation and push to GV/m gradients...

ENERGY DEPLETION OF (PART OF) THE DRIVE BUNCH

THE OTHER HALF OF THE HIGH-EFFICIENCY PWFA PUZZLE

PI: C. LINDSTRØM

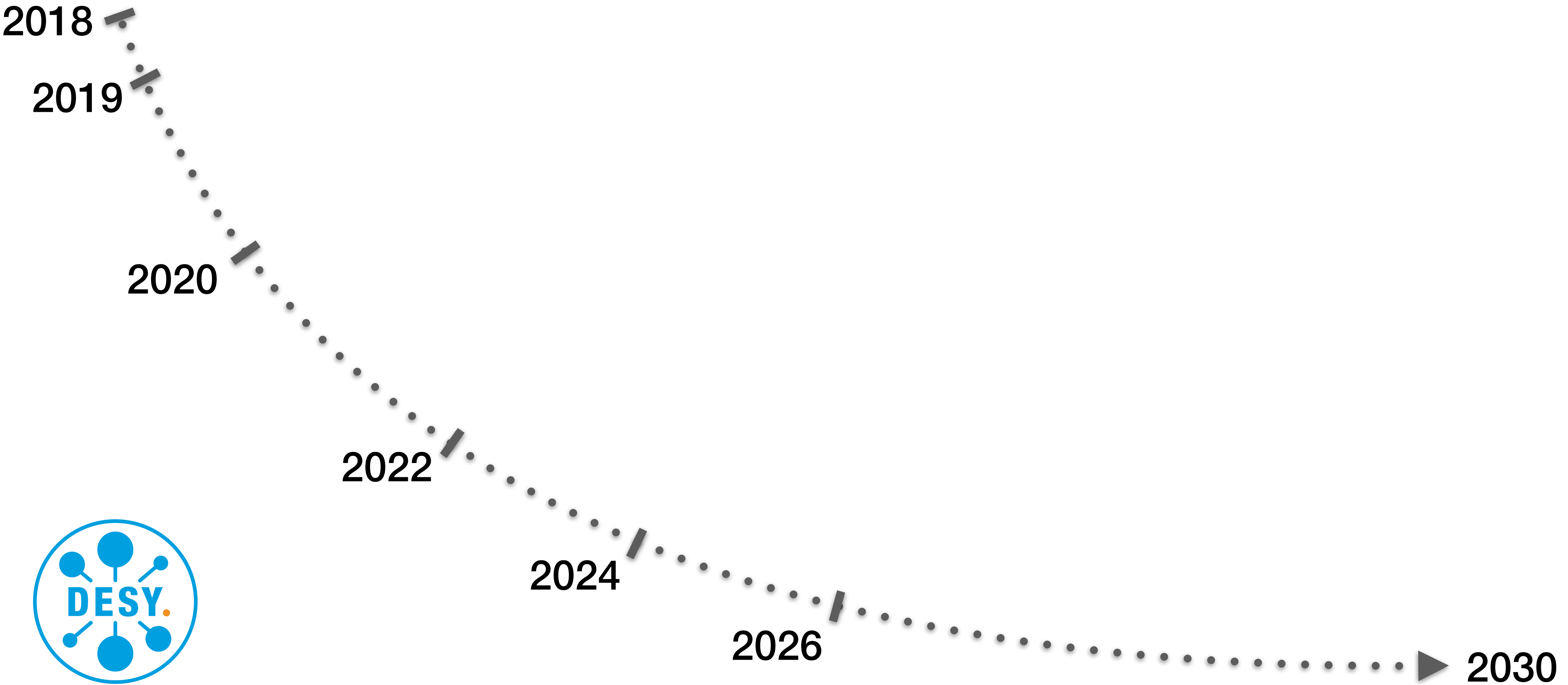
Nov 2019



- Also important to optimise transfer of the drive beam energy to the wake
- Decelerated parts of the 1.1 GeV bunch to rest. Particles below 6 MeV were lost in the beamline
- First observation of energy depletion in a beam-driven plasma accelerator!
- Step towards important goal of high overall efficiency

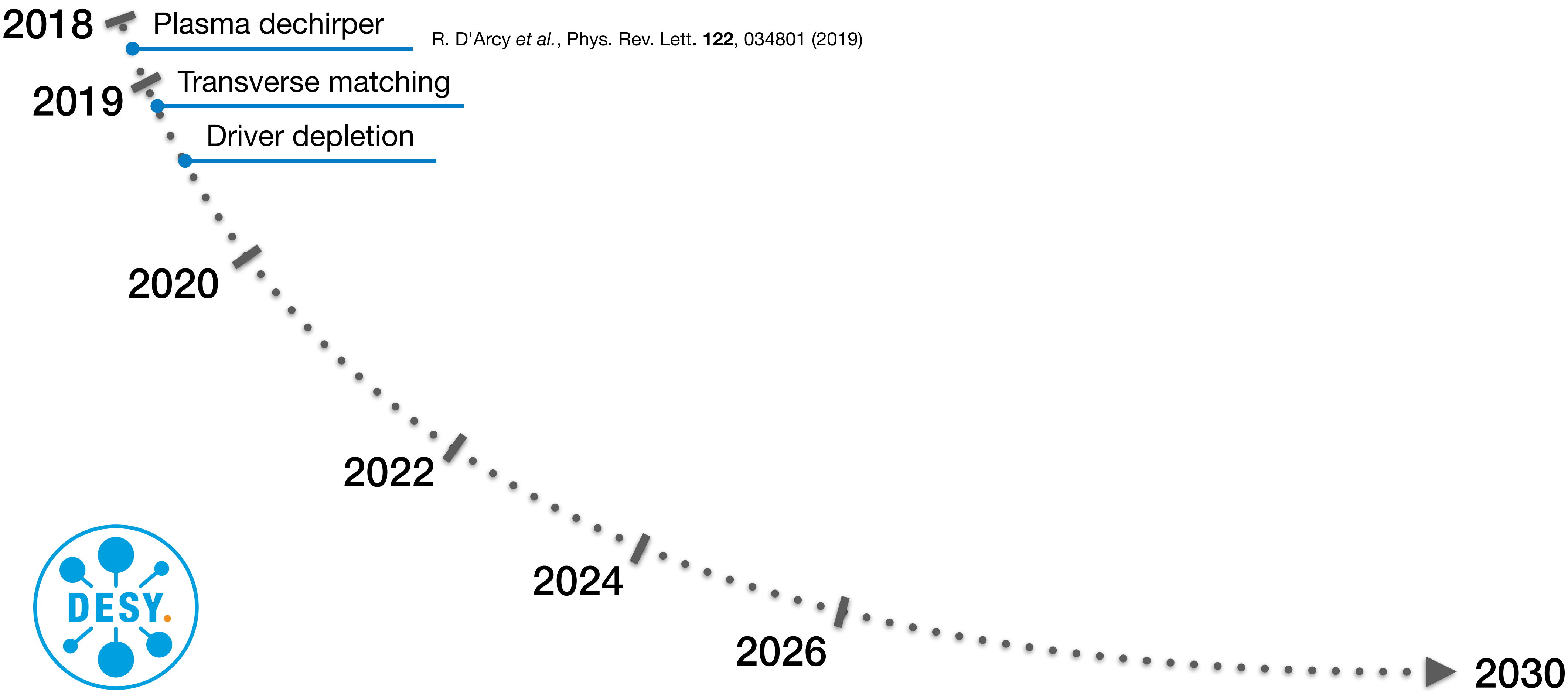
FLASHFORWARD» roadmap

ROADMAP ILLUSTRATING ROUTE TOWARDS FF»'S OVERARCHING GOALS



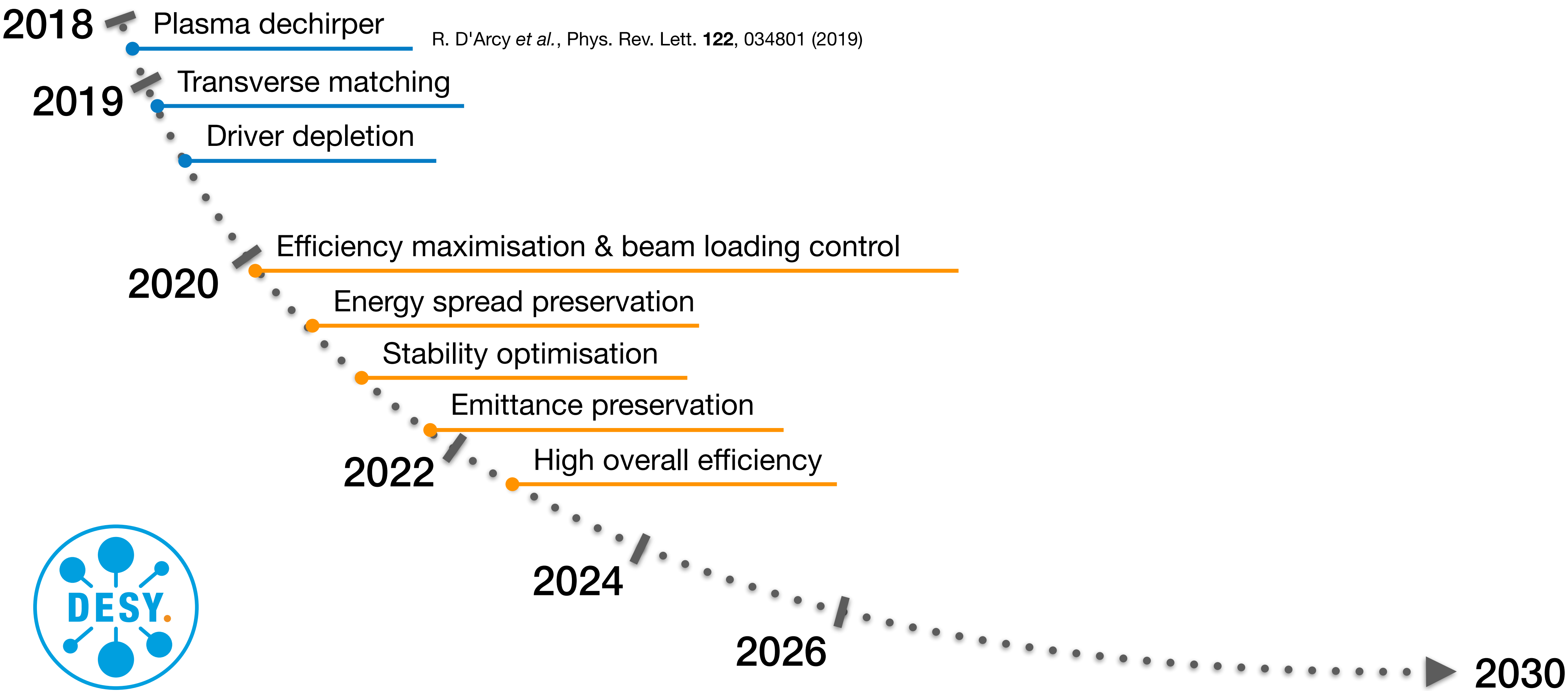
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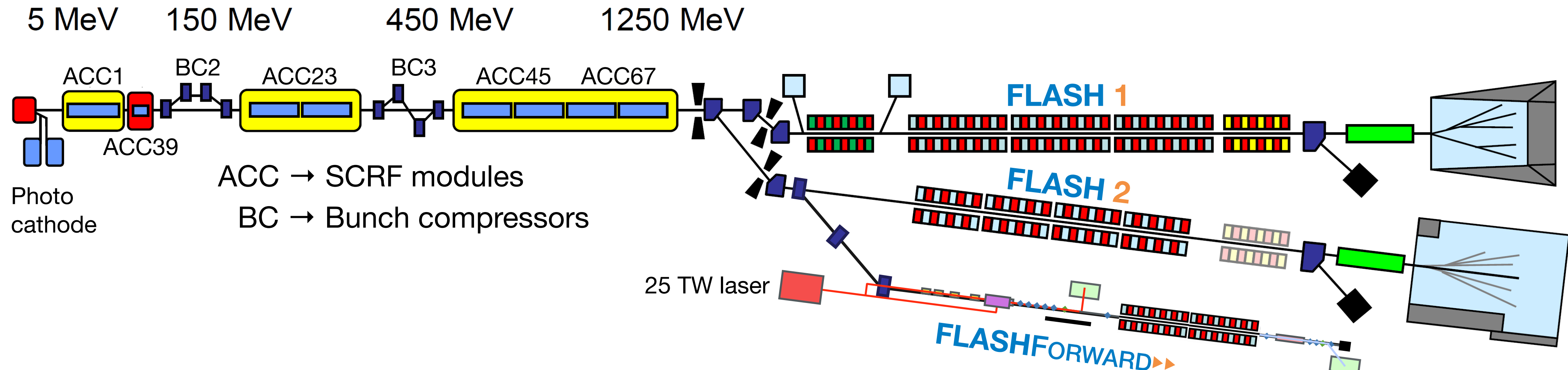
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HIGH-REPETITION-RATE PWFA

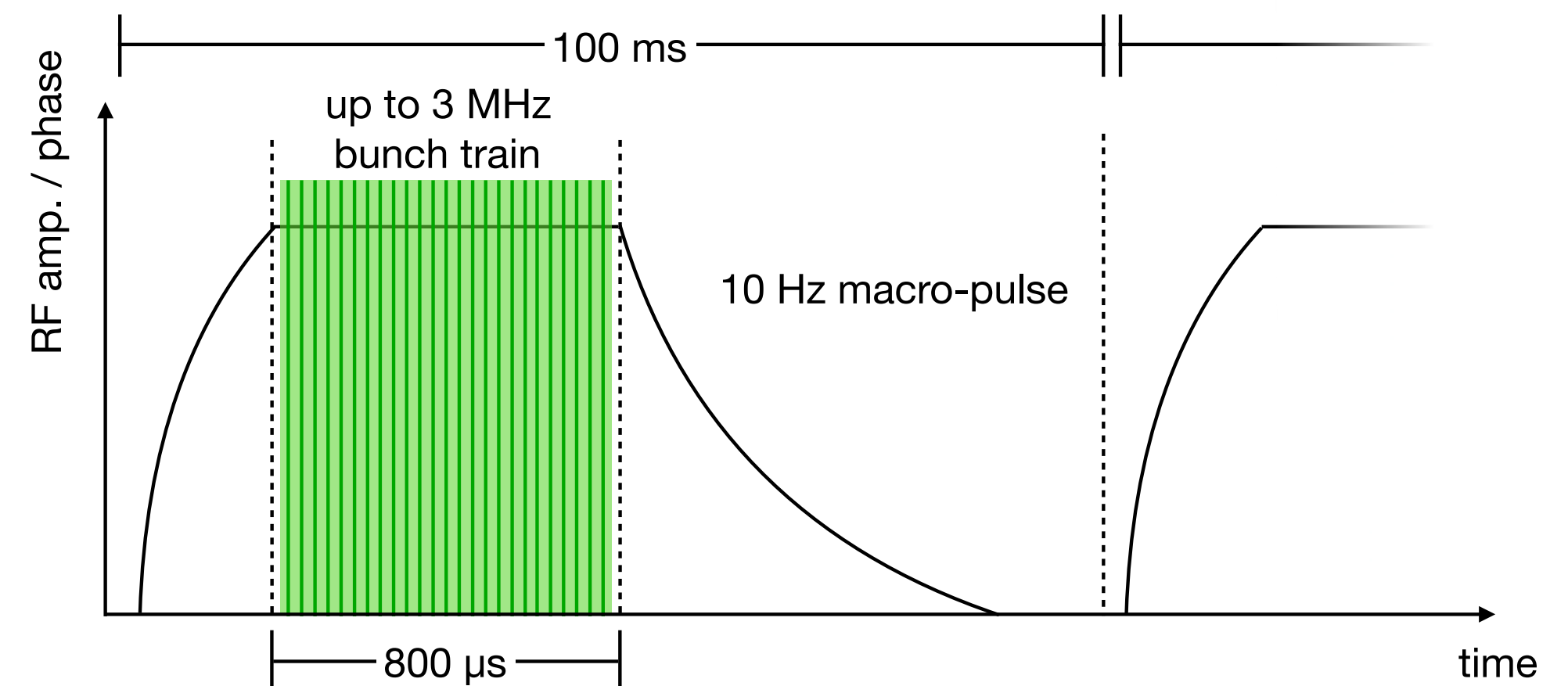
SCALING UP THE IDEAL STAGE TO KHZ-MHZ REPETITION RATES



FLASHForward goal parameters:

- > 1.25 GeV, 1 nC bunches
- > 10 Hz macropulse rep. rate
- > 1 MHz intra-bunch frequency
- > 800 μ s RF flat top

➡ 10 kW average power



Summary

- > **FLASHForward** is a next-generation high impact *experiment* for beam-driven plasma-accelerator research
- > Addressing the major challenges to the field necessary to take PWFA from academia to application
- > A rich harvest of science already reaped with many more exciting results planned in the coming years
- > Progress with installation has been rapid over the last 18 months → special thanks to all the support from M group personnel and FLASH management