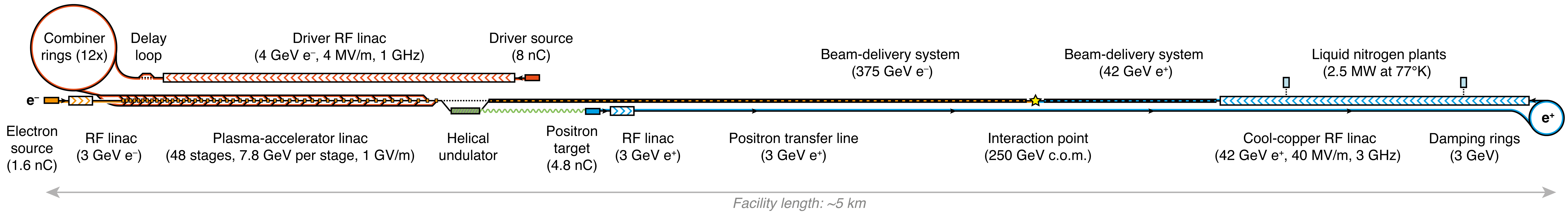


HALHF: A Hybrid, Asymmetric, Linear Higgs Factory

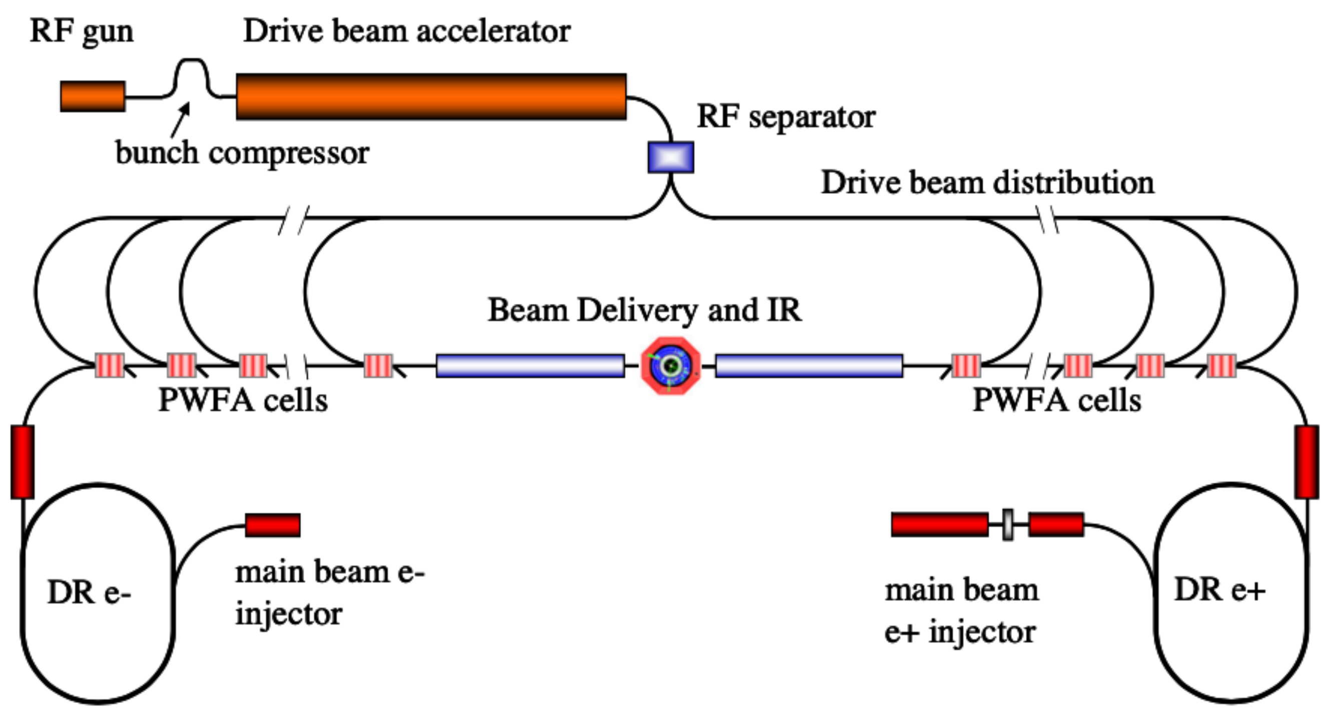
Richard D'Arcy **on behalf of the HALHF collaboration**

John Adams Institute, University of Oxford

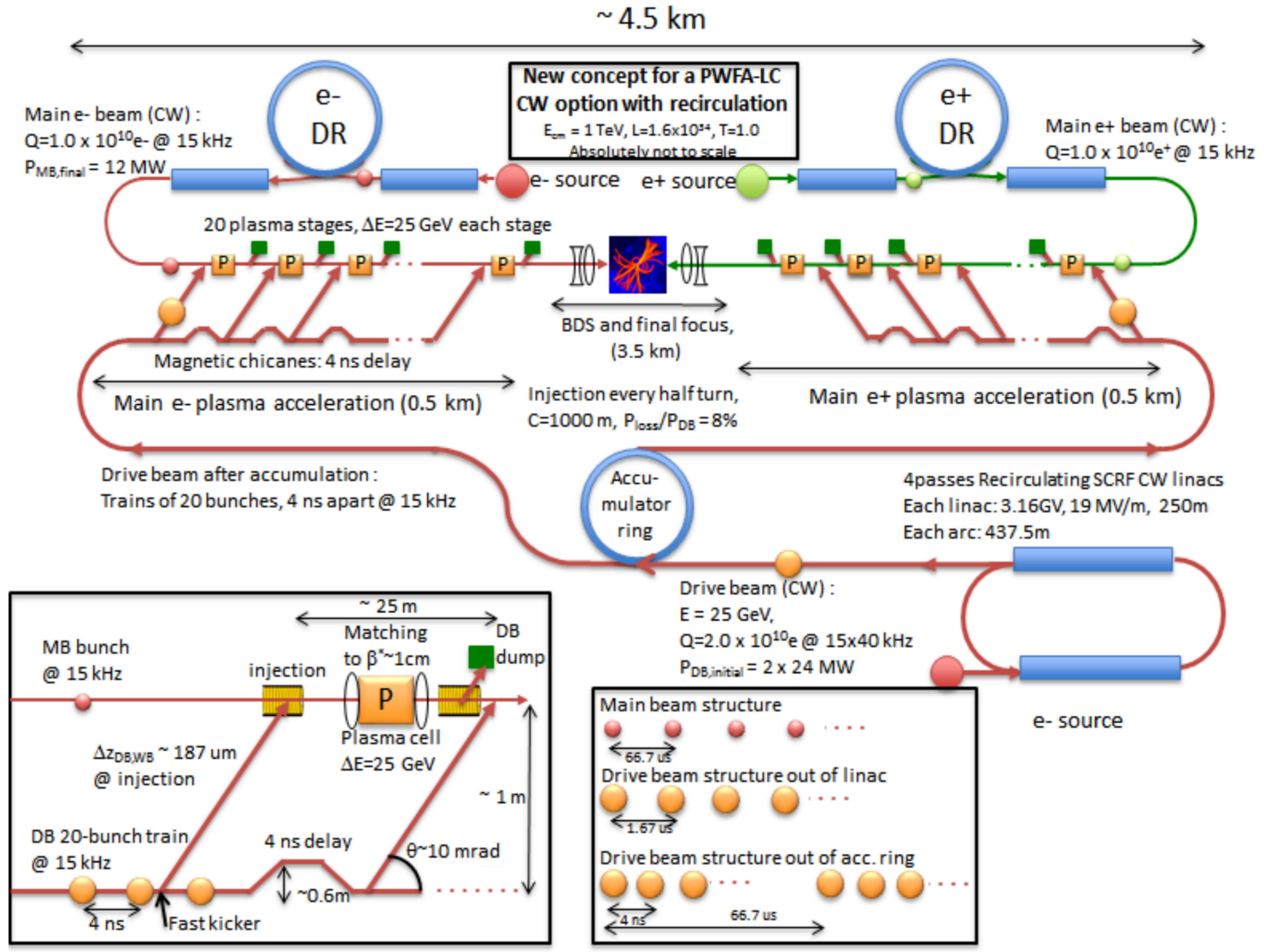
22nd September 2025 | European Advanced Accelerators Conference 2025

Developing a credible plasma-based e+e– collider design

- Particle physics is approaching a post-LHC era with a desire for precision study of the Standard Model
- **Could plasma get us there quicker and cheaper?**
- Excellent progress in plasma R&D suggests hope for a plasma-based e^+e^- collider
- Several proposals over the past decades:
  - *Rosenzweig et al. (1996)*
  - *Pei et al. (2009)*
  - *Schroeder et al. (2010)*
  - *Adli et al. (2013) ➞ Snowmass submission*
- **Very useful exercises to focus R&D**
- Still one key stumbling block identified…



Source: Pei et al., Proc. PAC (2009)

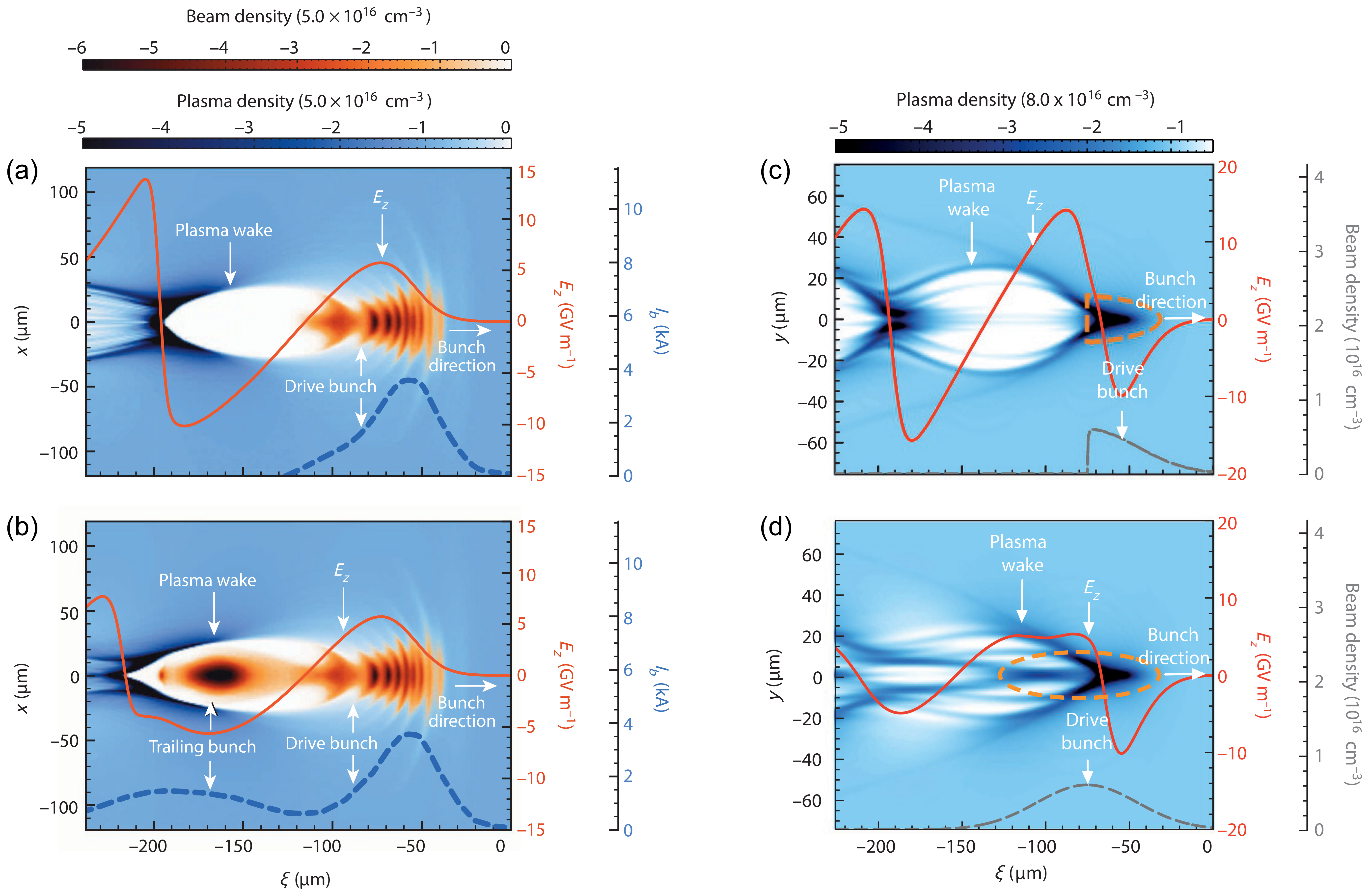


Source: Adli et al., Proc. Snowmass (2013)

Positron acceleration in plasma

Not currently suitable for colliders

- Plasmas are charge asymmetric
  - No "blowout regime" for e+
- **Main challenge**: Electron motion (equivalent to ion motion for e+, but plasma electrons are lighter)
- Positron acceleration has been demonstrated experimentally



Source: Litos *et al.*, Nature **515** (2014), Corde *et al.*, Nature **524** (2015).

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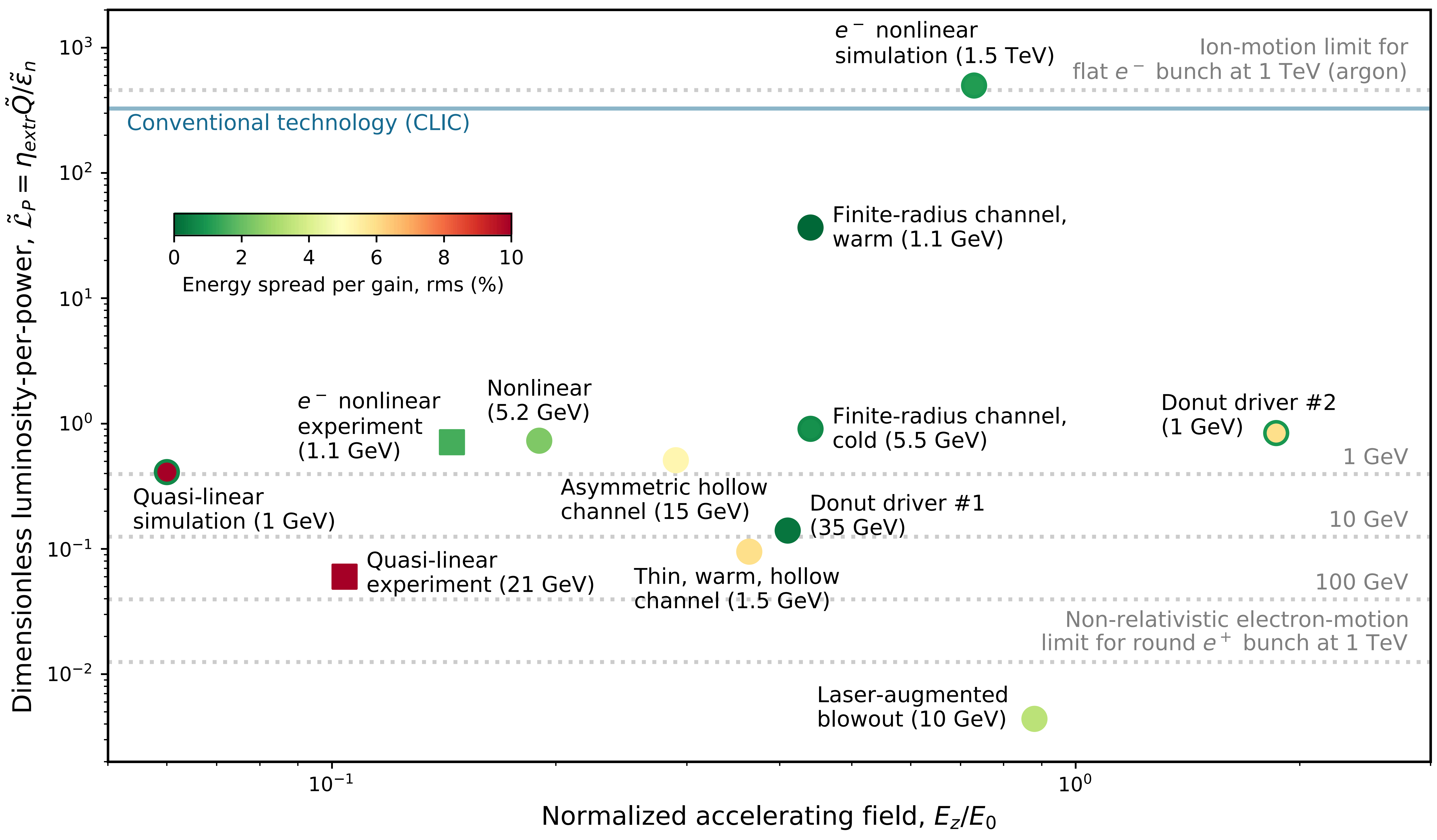
- Positron acceleration has been demonstrated experimentally
- However, luminosity per power still orders of magnitude below RF and e^- plasma acceleration



Recent review: Cao, Lindstrøm, Adli, Corde & Gessner, PRAB 27, 034801 (2024)

The pragmatic approach:

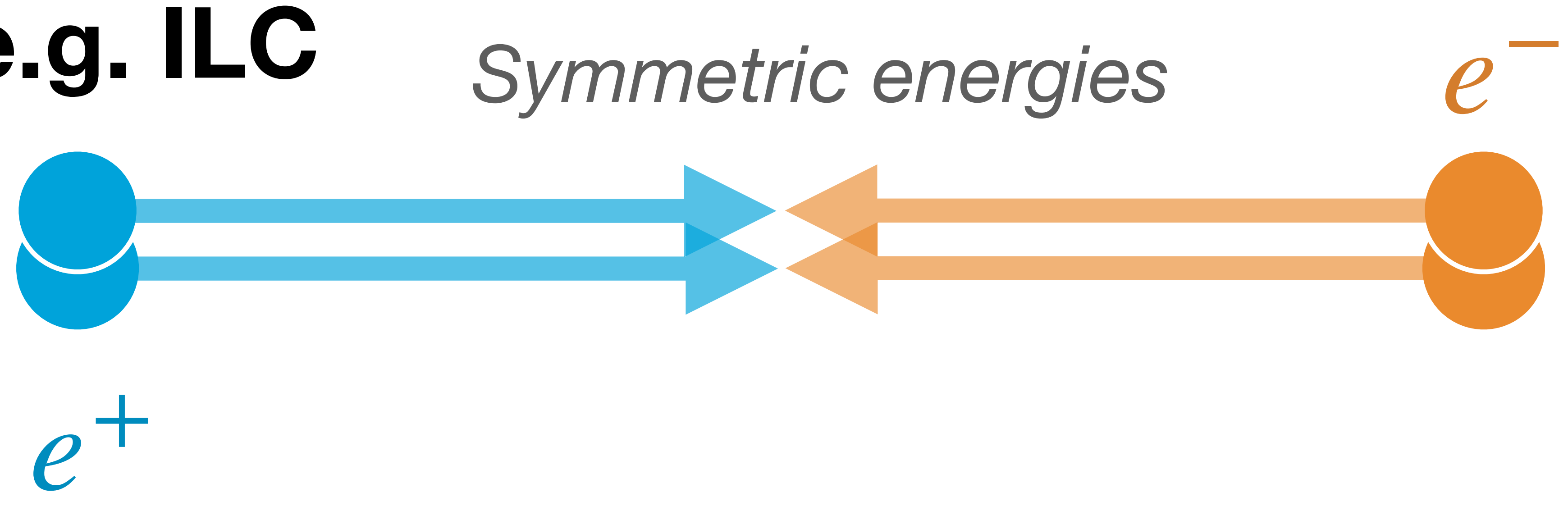
use **plasma** to **accelerate electrons**

but **RF** to **accelerate positrons**

An asymmetric collider: can it work?

The more asymmetric, the better?

e.g. ILC



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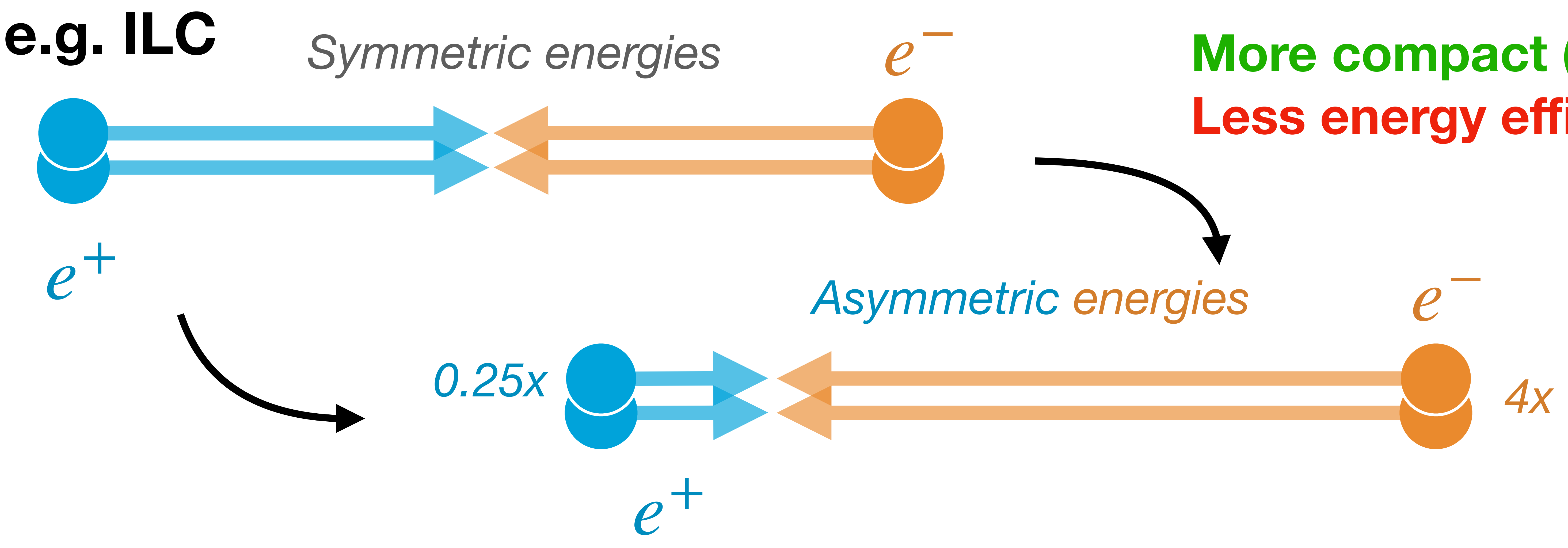
$$\frac{P}{P_0} = \frac{N_{e^-}E_{e^-} + N_{e^+}E_{e^+}}{N\sqrt{s}}$$



More compact (PWFA for high-energy e⁻)

Less energy efficient (boosts products)

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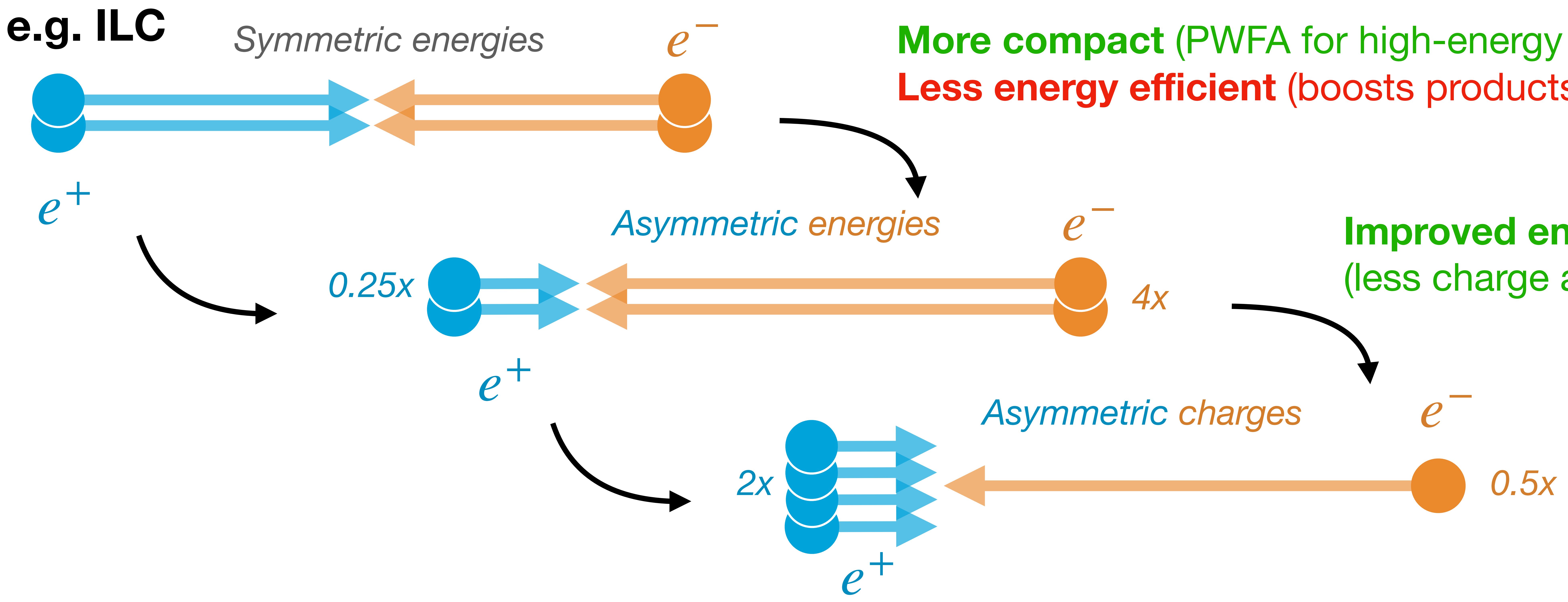
More compact (PWFA for high-energy e^-)

Less energy efficient (boosts products)

Improved energy efficiency
(less charge at high energy)



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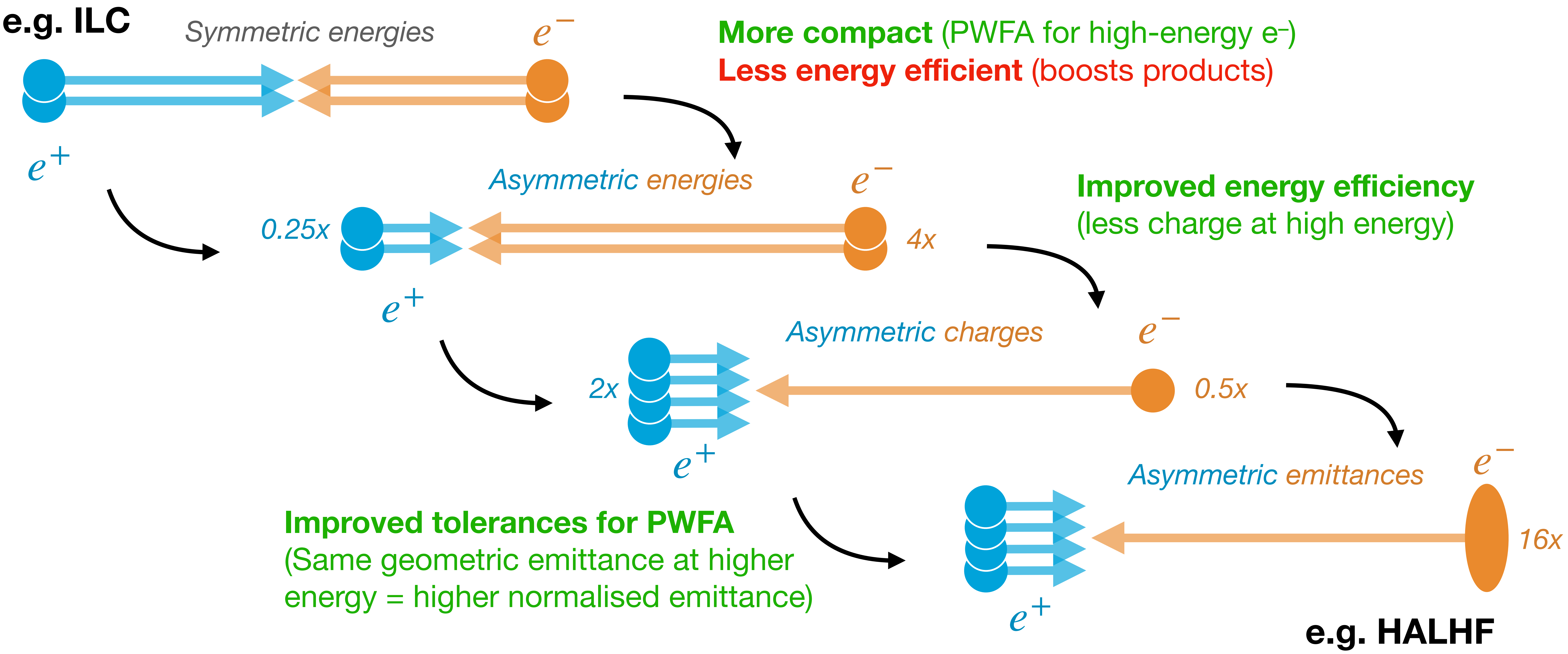
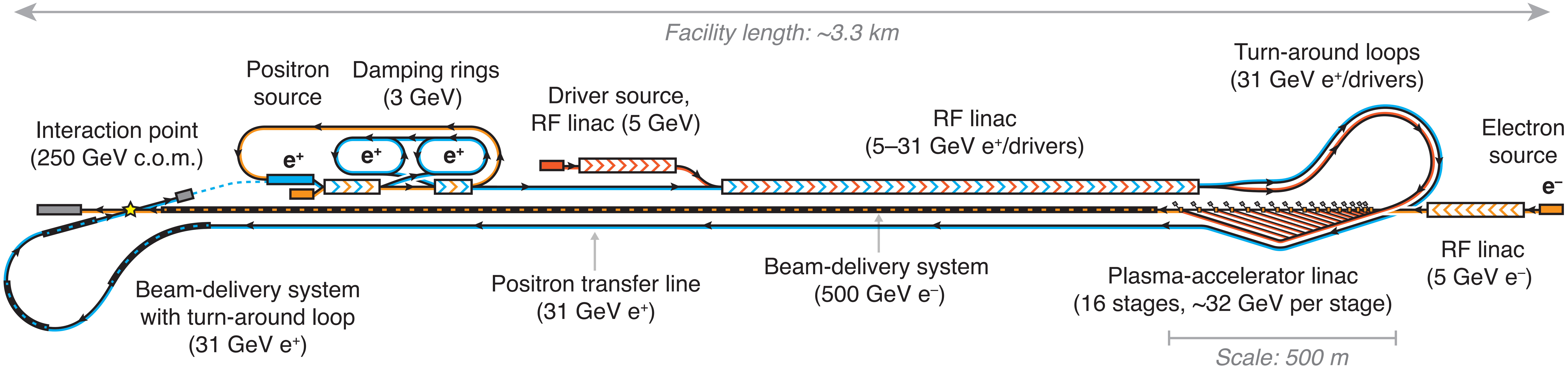


HALHF: a hybrid, asymmetric collider concept (2023)

Plasma acceleration for electrons + RF acceleration for positrons



Source: **Foster, D'Arcy & Lindstrøm, New. J. Phys. 25, 093037 (2023)**

- Schematic conceived '*by hand*' by three physicists ➞ *far from perfect*
- Provided a platform for discussion and optimisation with the community

Identifying issues…

… in the April snow (Oslo)…

> A long laundry list of major and minor issues

> Dominated by:

> > Combined RF linac for positrons and electron drivers (*difficult*)

> > Effects of synchrotron radiation in the turnarounds (*underestimated*)

Identifying issues… and solutions

… in the April snow (Oslo)… in the October sun (Sicily)

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> Dominated by:

> > Combined RF linac for positrons and electron drivers (difficult)

> > Effects of synchrotron radiation in the turnarounds (underestimated)

> Some solutions were already found

> > Cross-plane emittance mixing

> > > Diederichs *et al.*, PRL **133** (2024)

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See Maxence Thévenet's talk: Mon 17:40 (PS1)

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- Others discussed for integration in to a re-baselining of the original concept

See Maxence Thévenet's talk: Mon 17:40 (PS1)

Calculating and optimising collider cost

Defining a reasonable optimisation metric

E. Adli et al. *"HALHF: a hybrid, asymmetric, linear Higgs factory using plasma- and RF-based acceleration. Backup Document"*, arXiv:2503.23489

> Developed a cost model, accounting for the cost of all collider subsystems—scaled per length (and/or power) based on ILC/CLIC costs

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> Defining a reasonable optimisation metric is non-trivial:

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> Used Bayesian optimisation to find minimum cost—fewer than 100 iterations typically sufficient to find the global minimum

HALHF 2.0 — an updated baseline design (2025)

Example outputs of the cost-optimisation algorithm

> **Visualising the Bayesian-optimised working point in terms of "Full programme cost":**

> Varying a single parameter around the working point

> Optimised for cost: **3.8B CHF**

> ~60% of CLIC

> ~40% of ILC

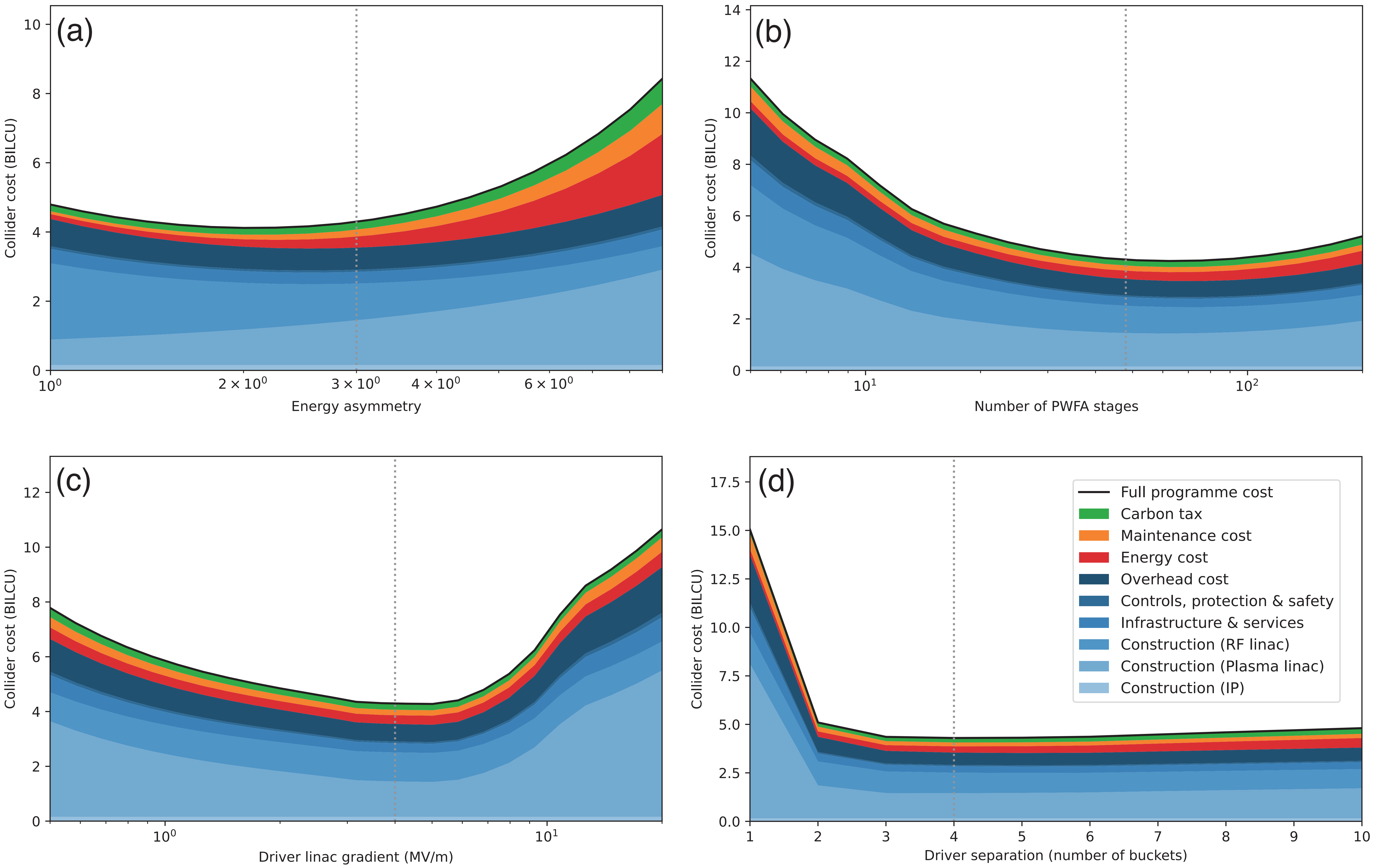

Image source: Lindstrøm, et al., Proceedings of IPAC 2025 (Taipei, Taiwan), p. 53

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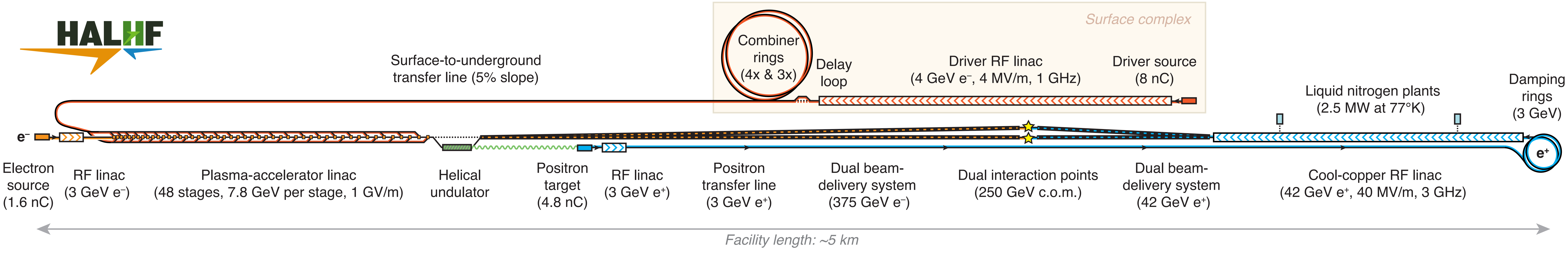
Prepared for the ESPPU input (https://arxiv.org/abs/2503.19880)



Source: Foster et al., Phys. Open 23, 100261 (2025)

- Separate RF linacs for e- drivers (high I_{avg}, low E_z) and e^+ beams (low I_{avg}, high E_z):
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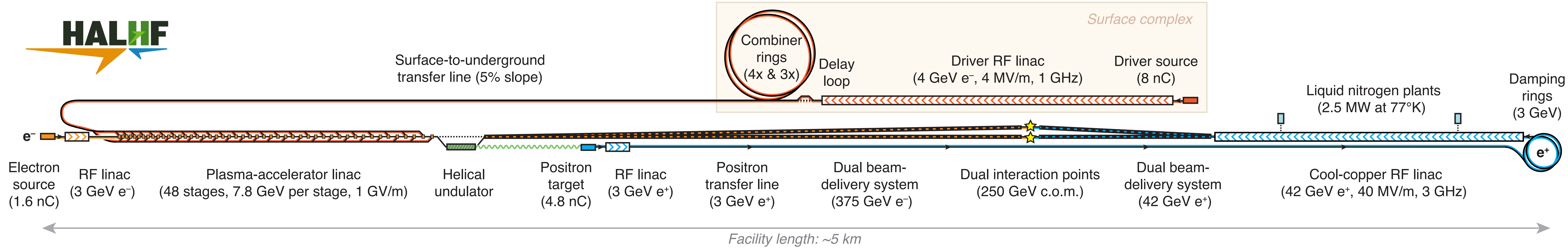

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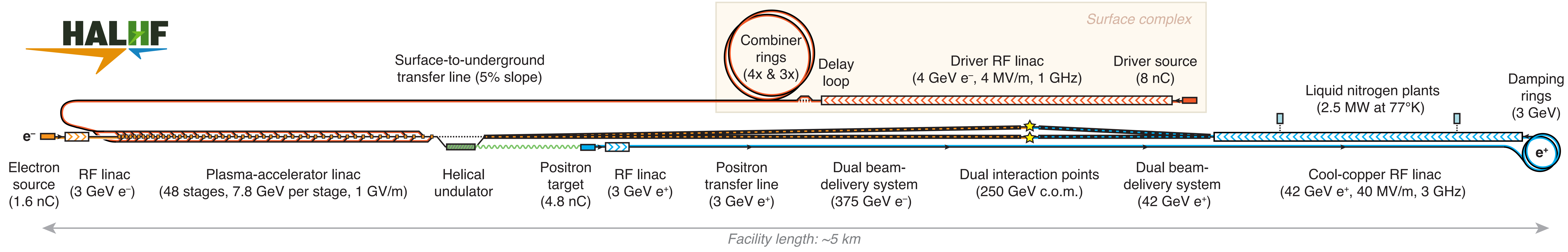

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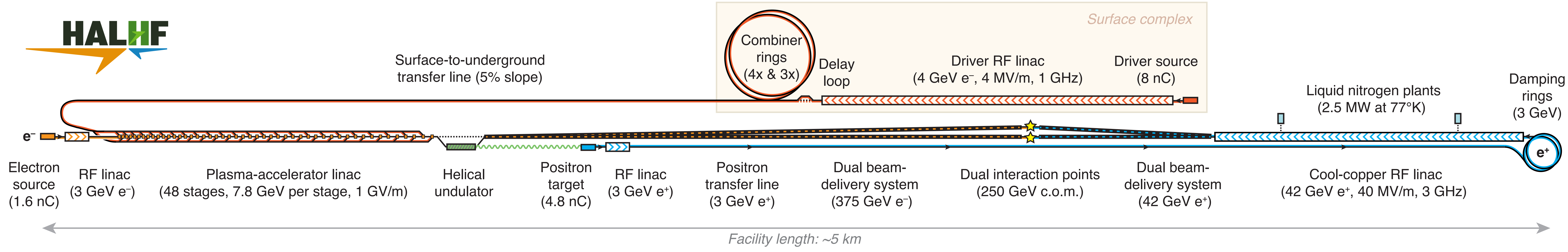

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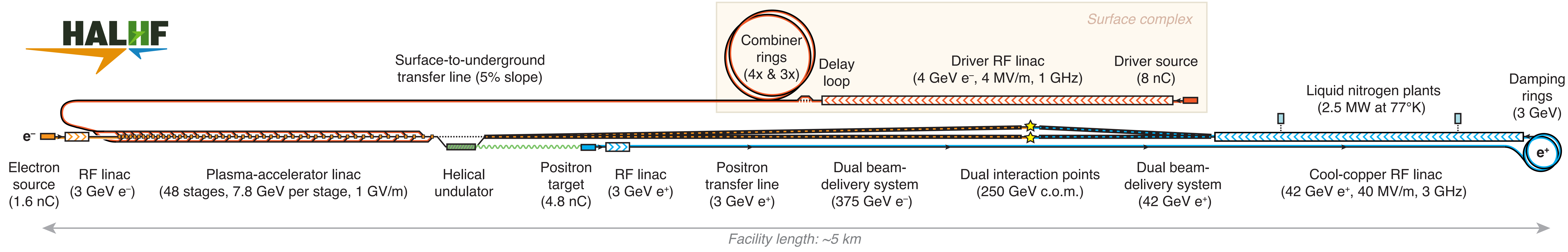

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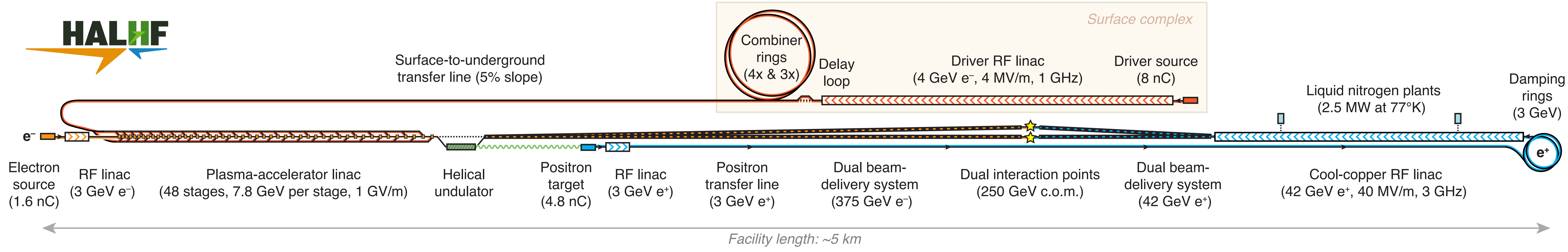

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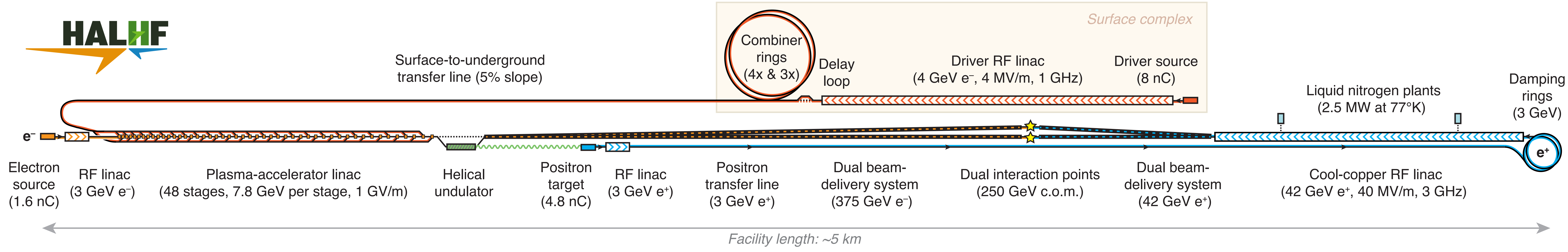

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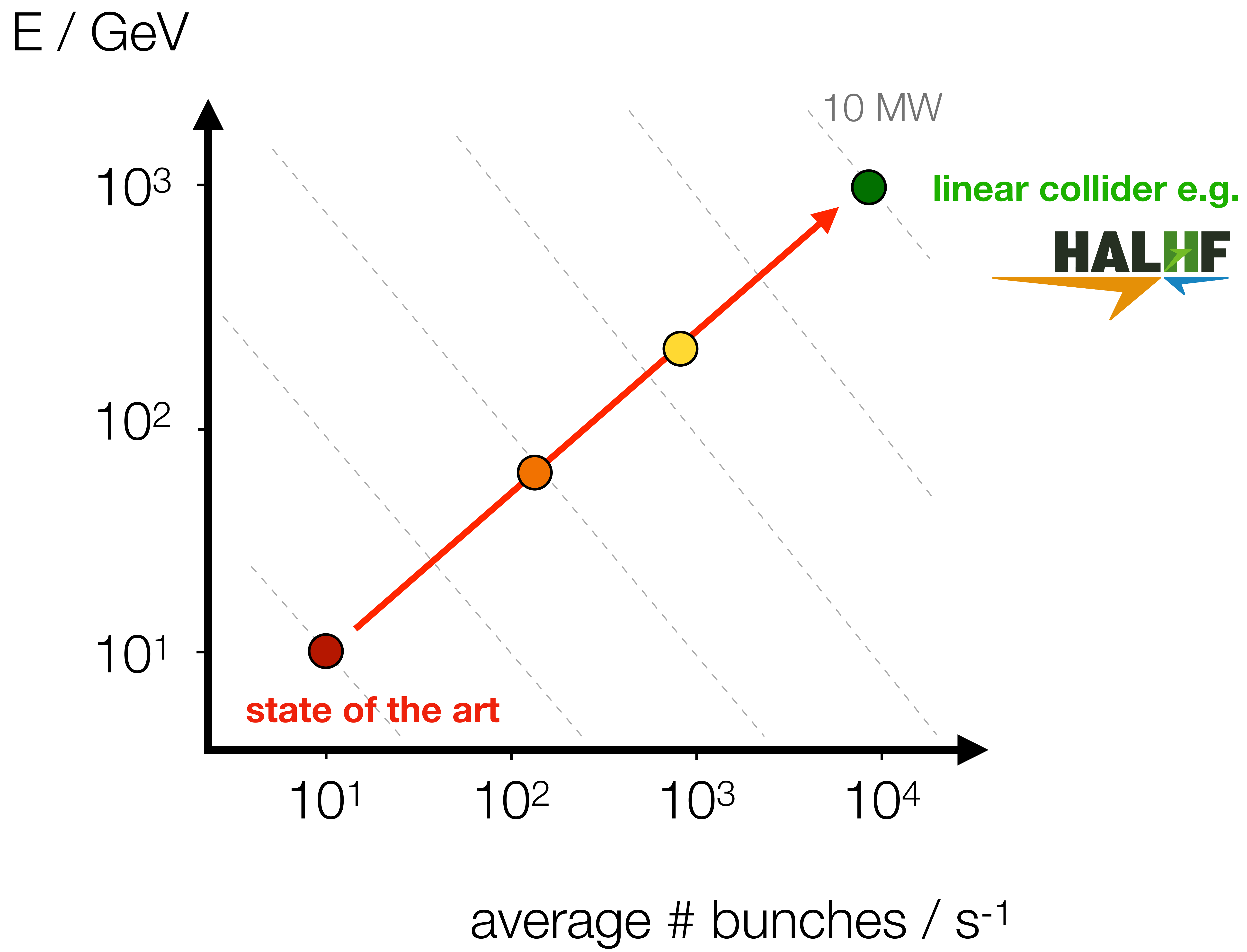
- Two interaction points/detectors
- Surface and underground complexes

Major (plasma) R&D topics under investigation

Pushing the state-of-the-art in staging (*energy*) and repetition rate (*luminosity*)



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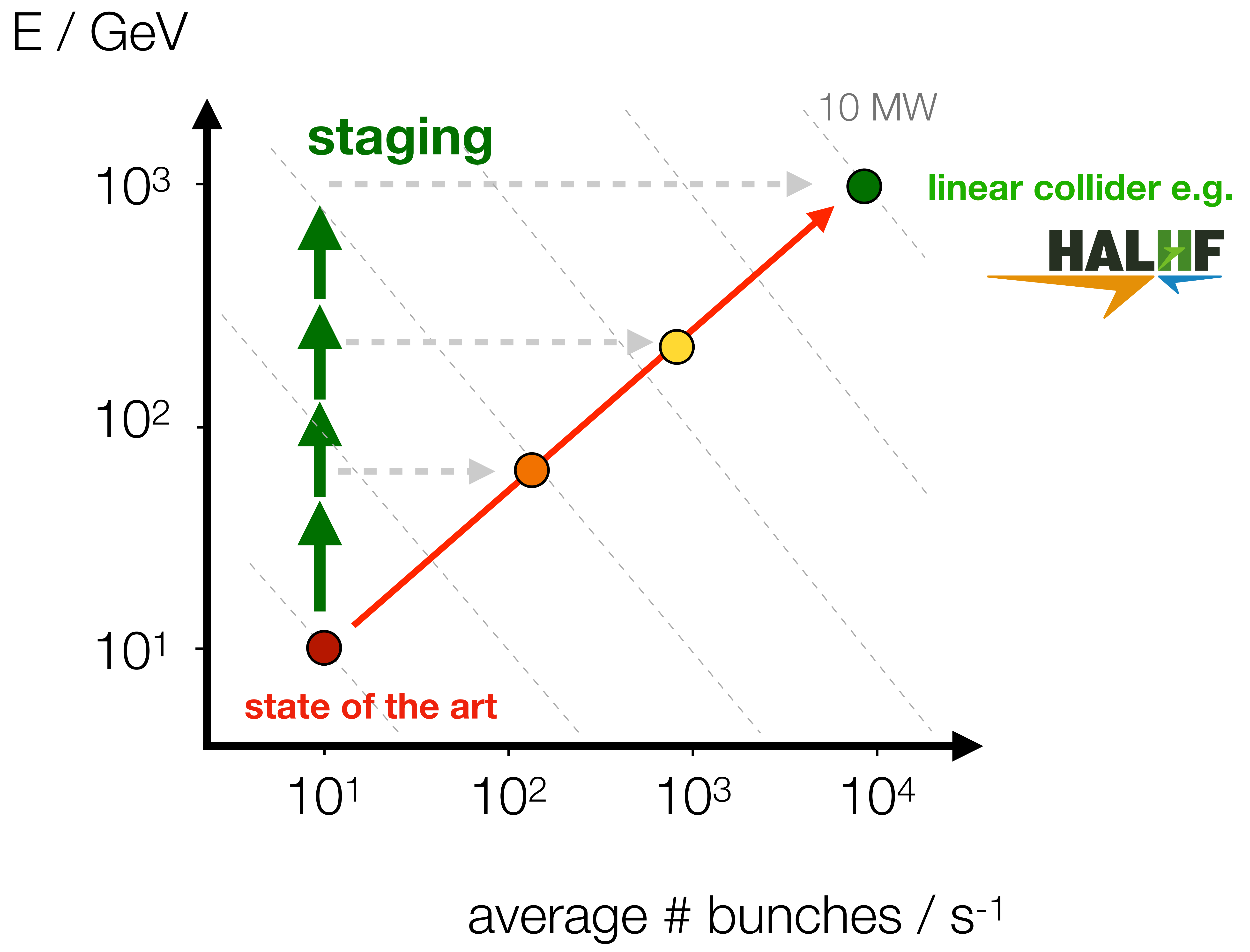
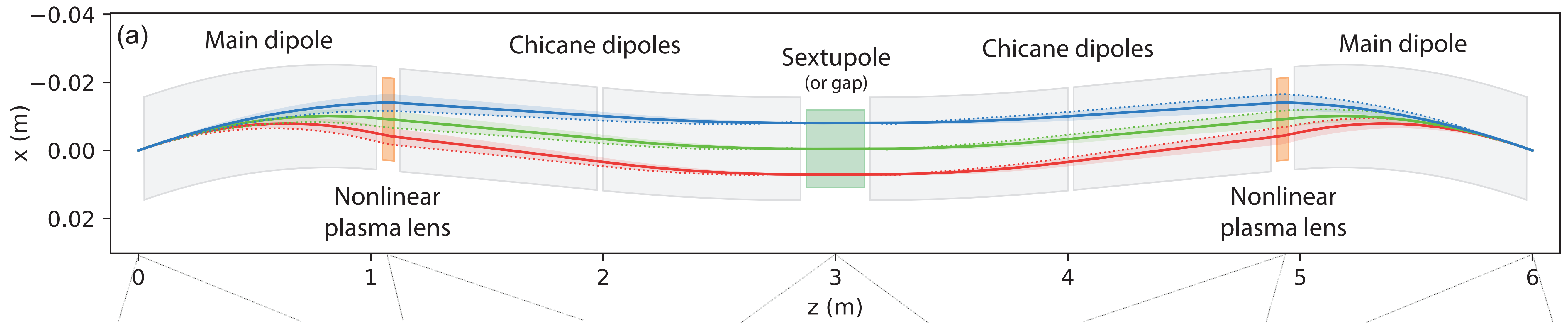


- **Staging**
  - Multiple stages are required to reach high energies → ***48 stages for HALHF***
  - Energy gain in a single stage is limited by the driver energy and transformer ratio → ***4 GeV x 2 for HALHF***
  - **Novel energy-scalable optics are needed to preserve beam quality**

R&D topic — Reaching high energy

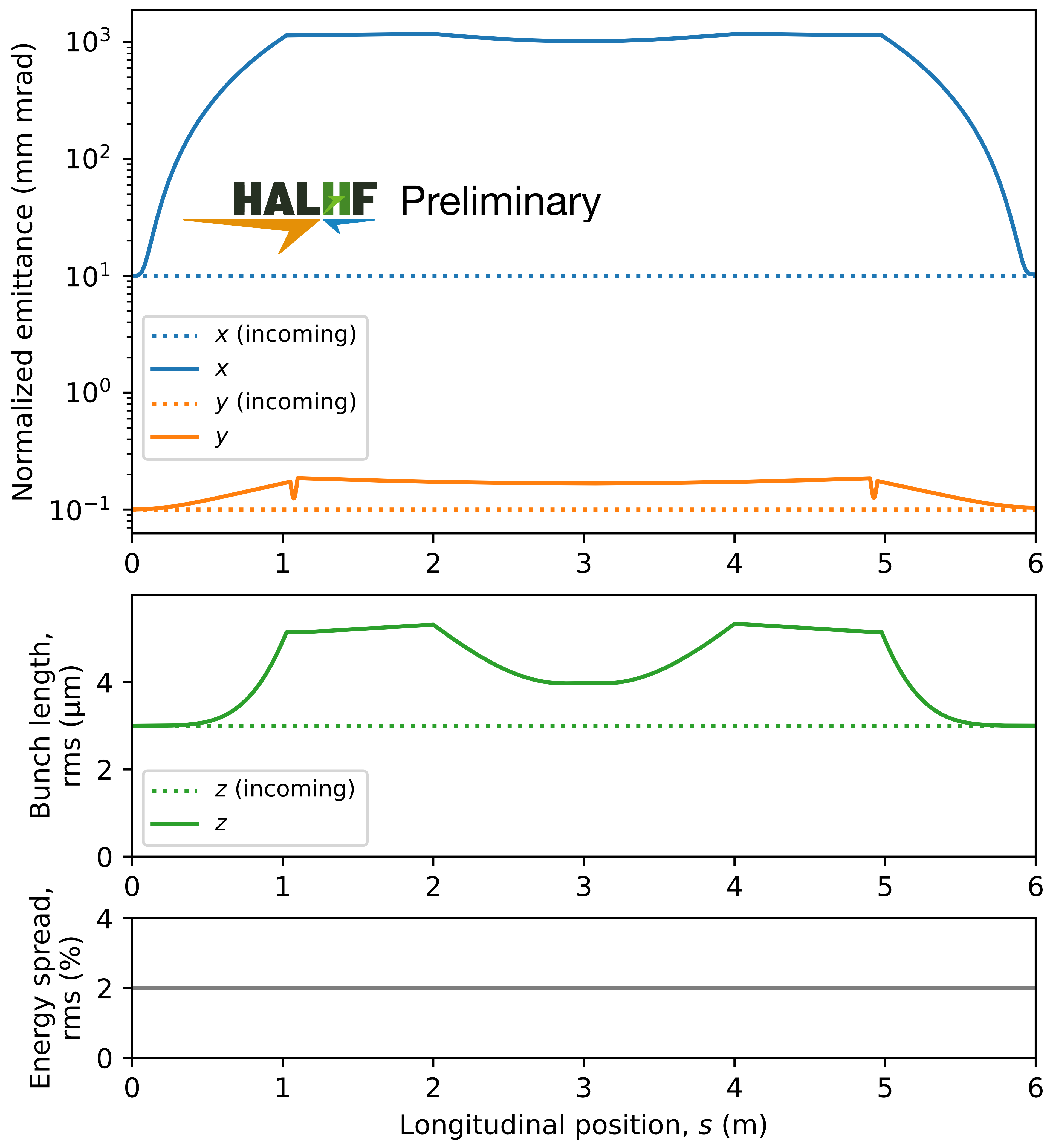
Tackling the staging problem with achromatic optics

- The combination of large energy spread and high divergence necessitates achromatic optics.
- New achromatic solution proposed, based on local chromaticity correction (*with* ***nonlinear*** *plasma lenses*) in a chicane



Source: Lindstrøm et al. (manuscript in preparation)

10 GeV example



Staging optics simulation (ImpactX) showing full beam-quality preservation for a 2% rms energy spread.
Source: Lindstrøm et al. (manuscript in preparation)

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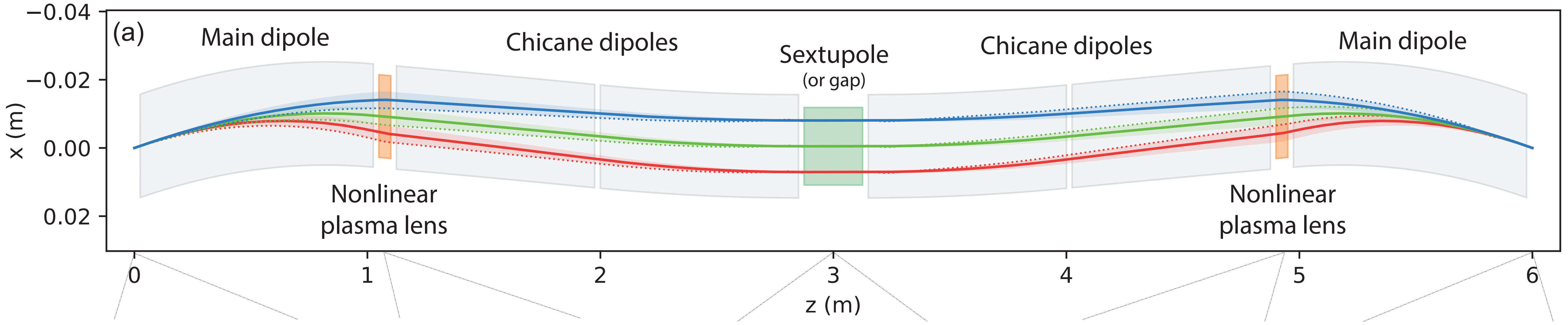

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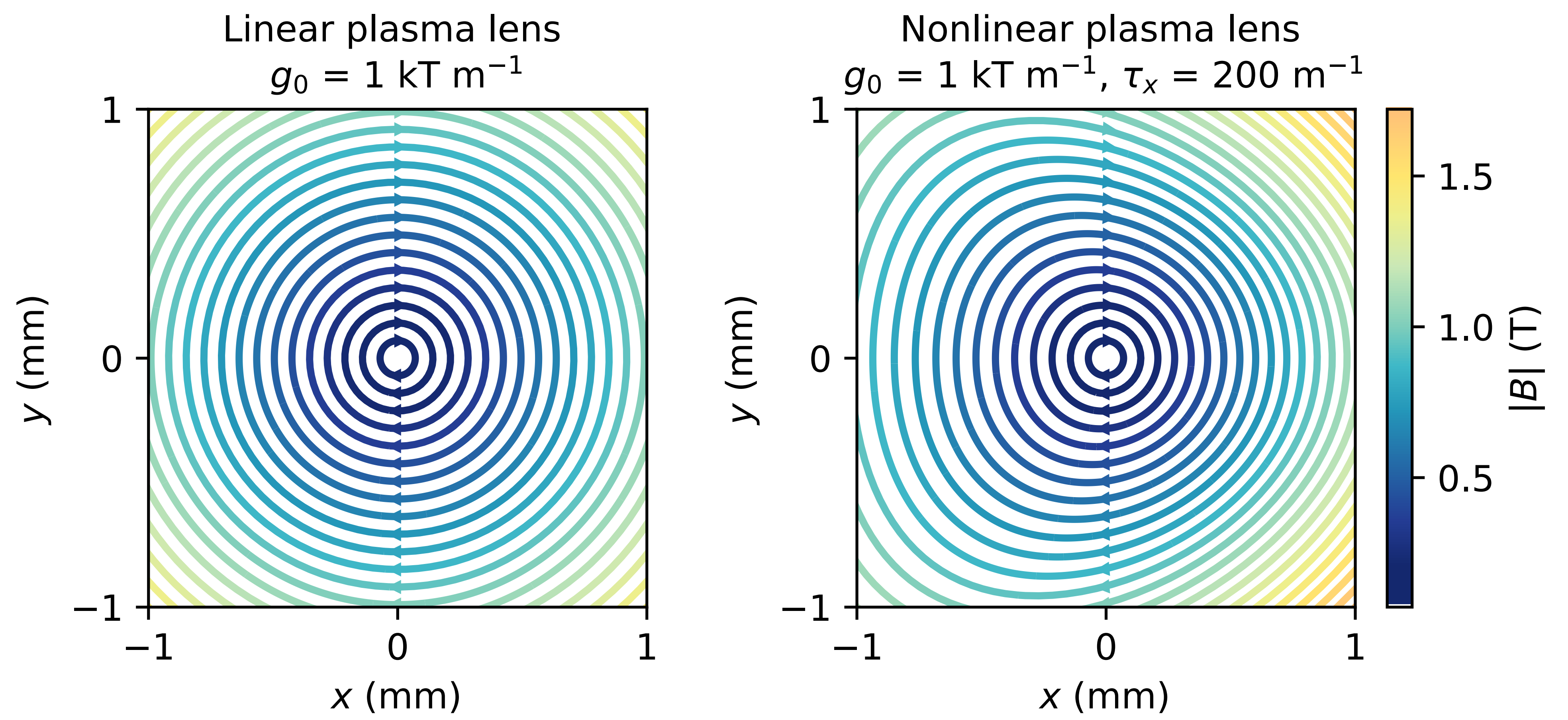

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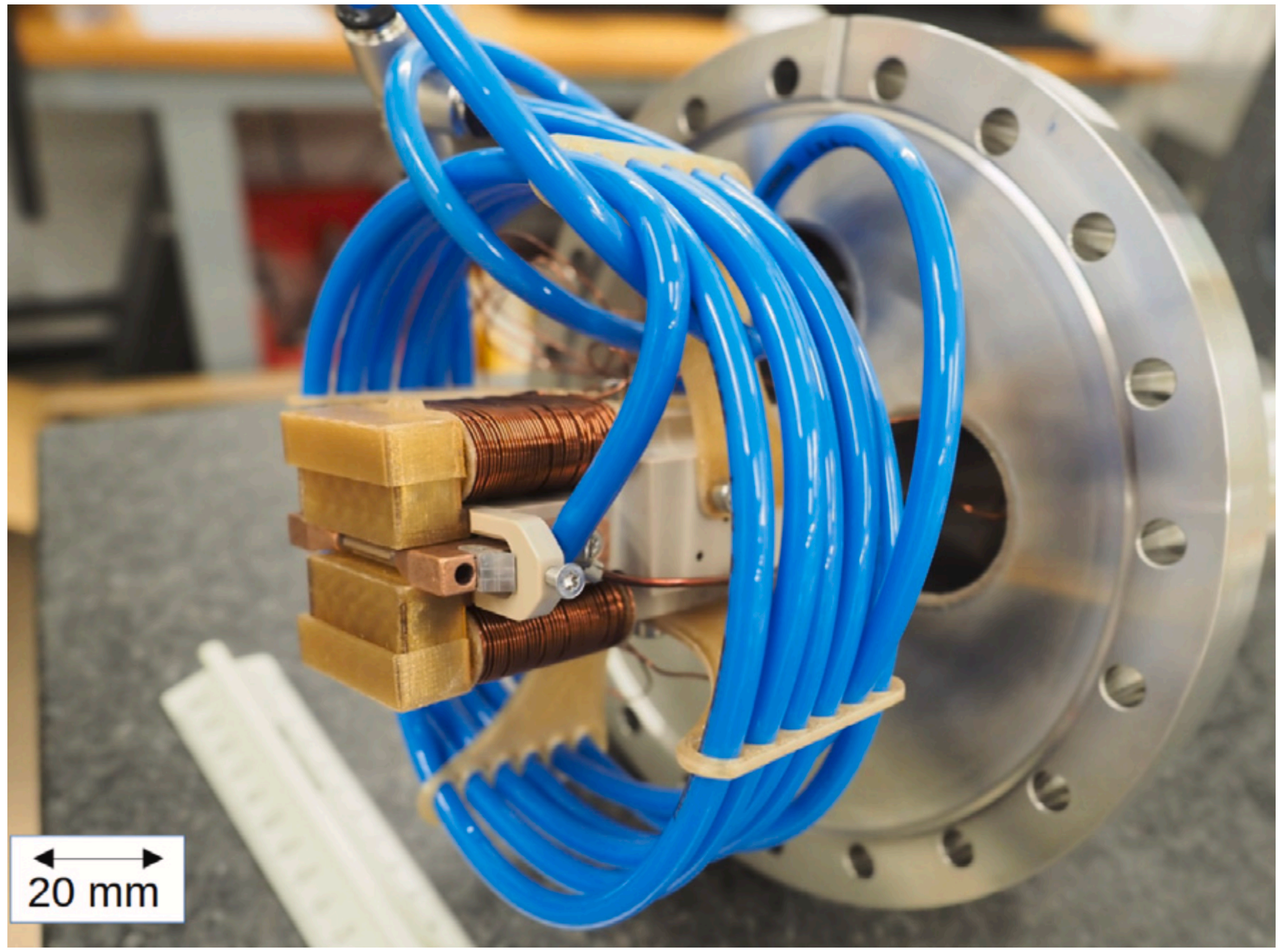

SPARTA nonlinear plasma lens (Uni. Oslo).
Source: Drobniak et al. NIM A 1072, 170223 (2025)

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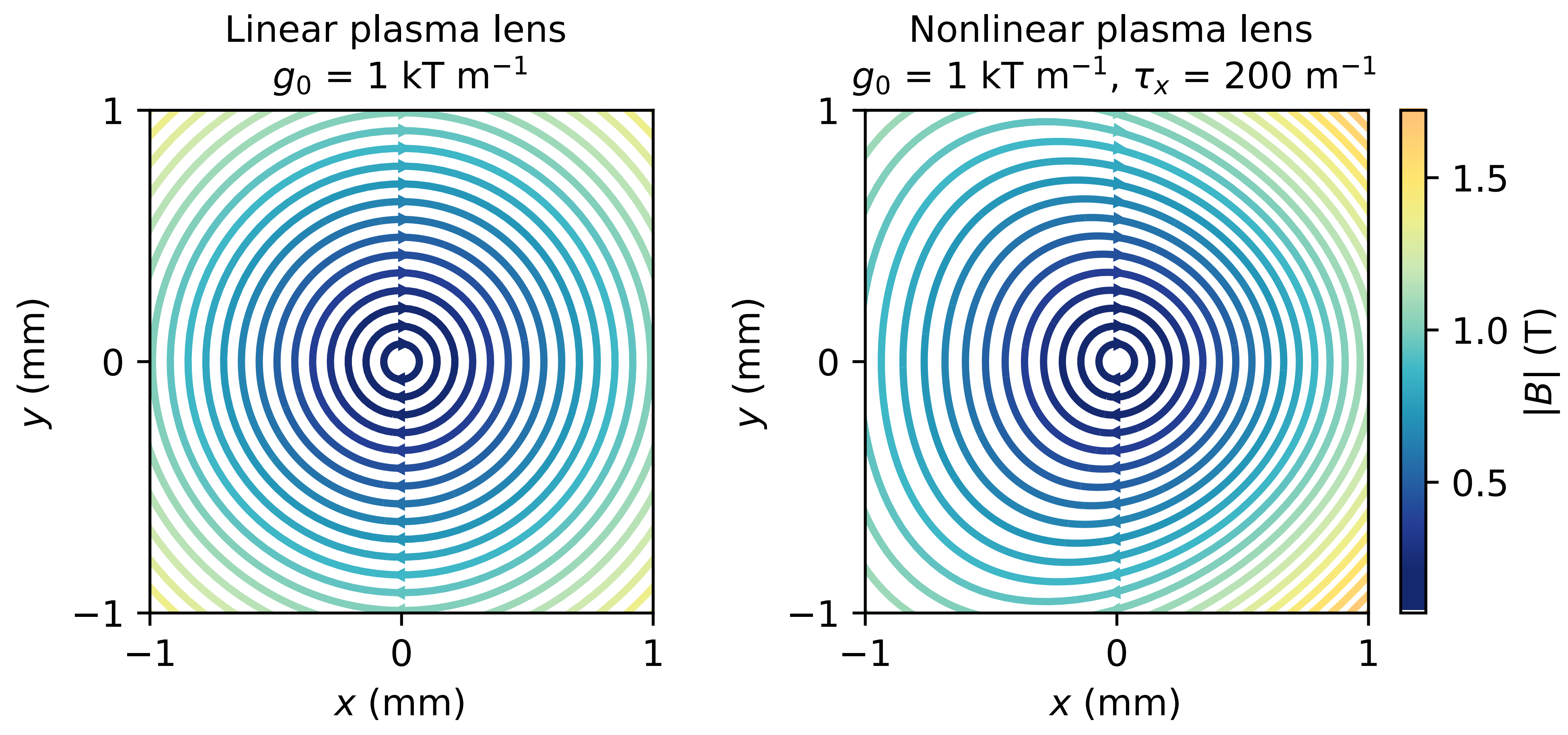

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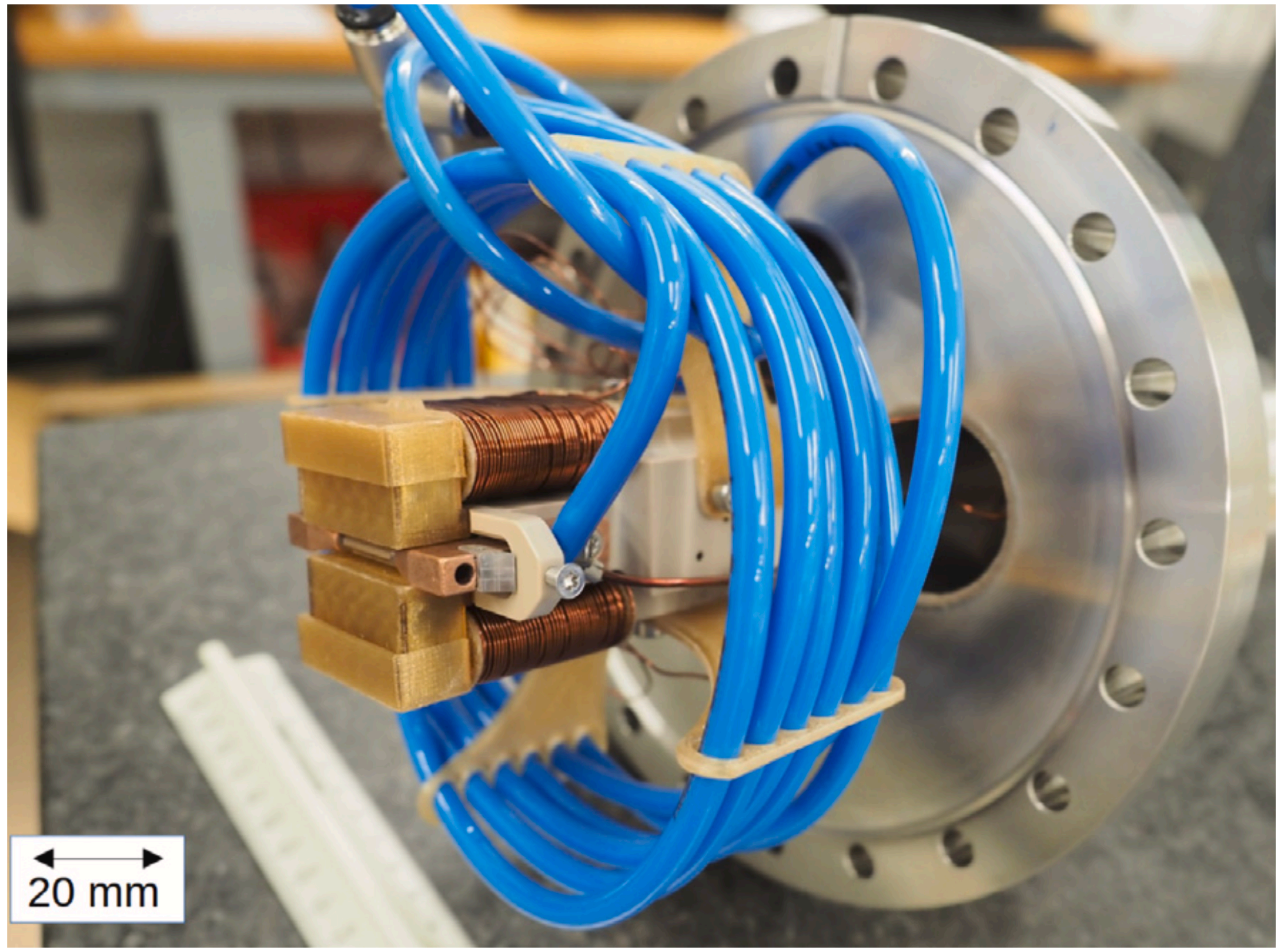

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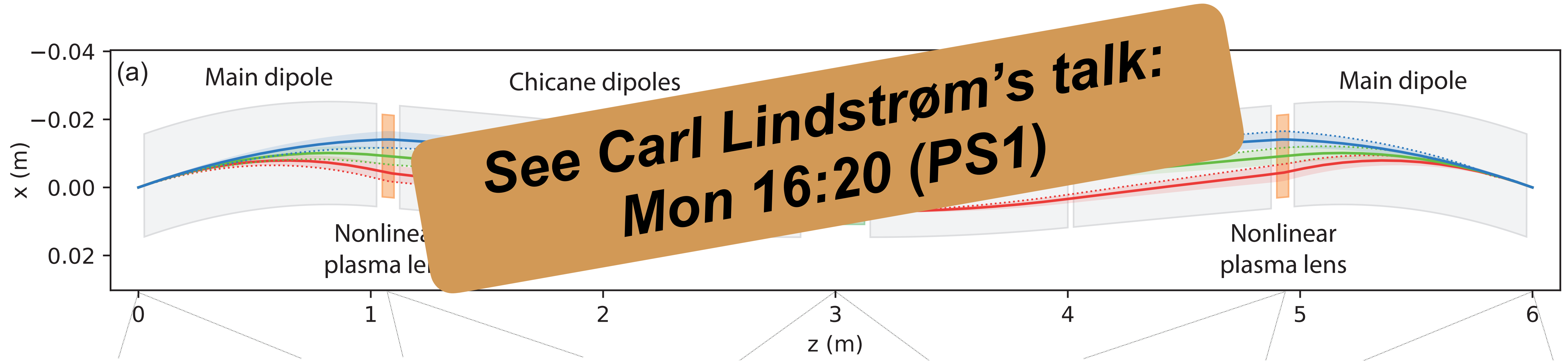

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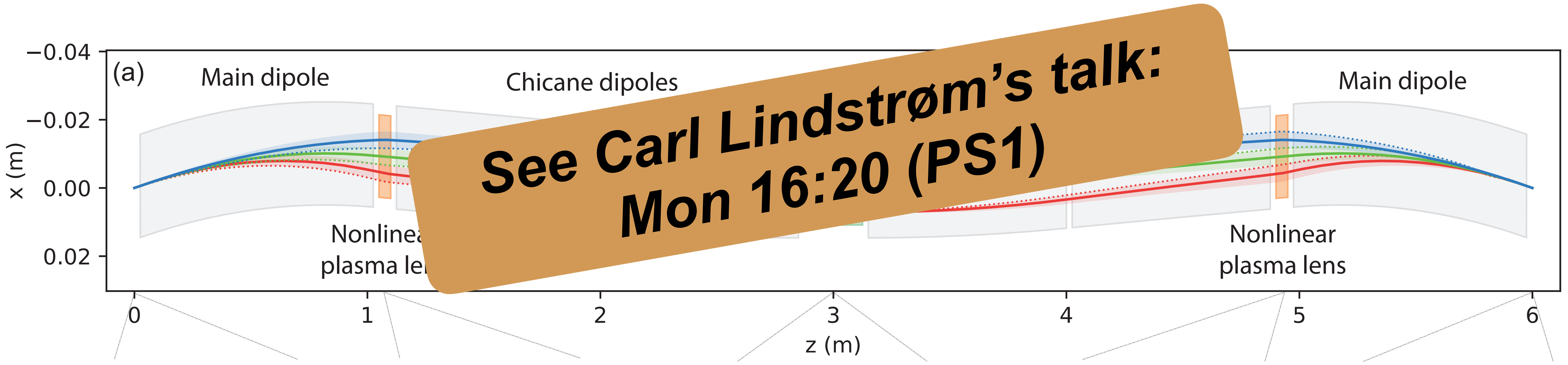

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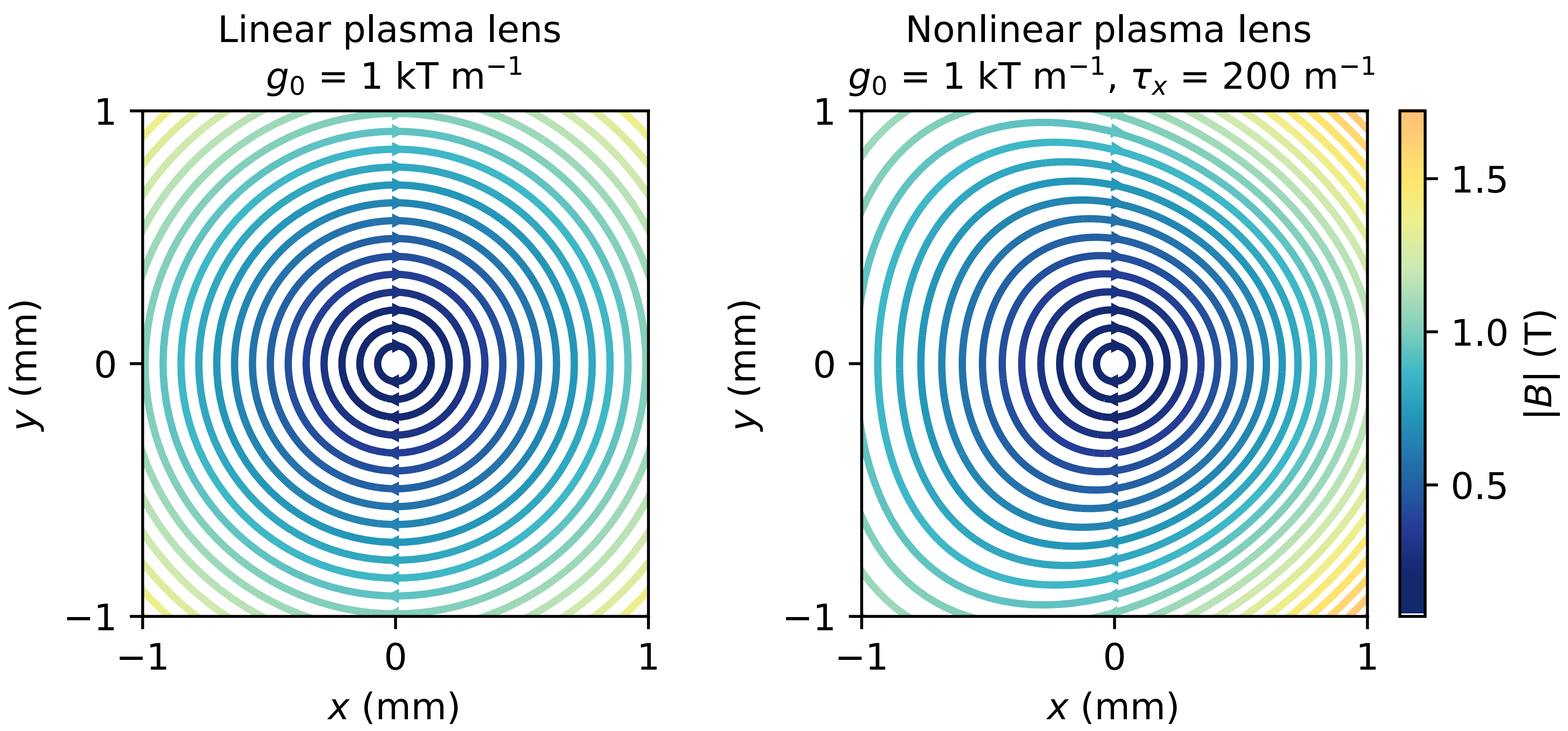

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R&D topic — Reaching high energy

High energy staging and synchrotron radiation

- The staging optics solution scales with energy:
  - Increase all lengths by $L \sim \sqrt{E}$
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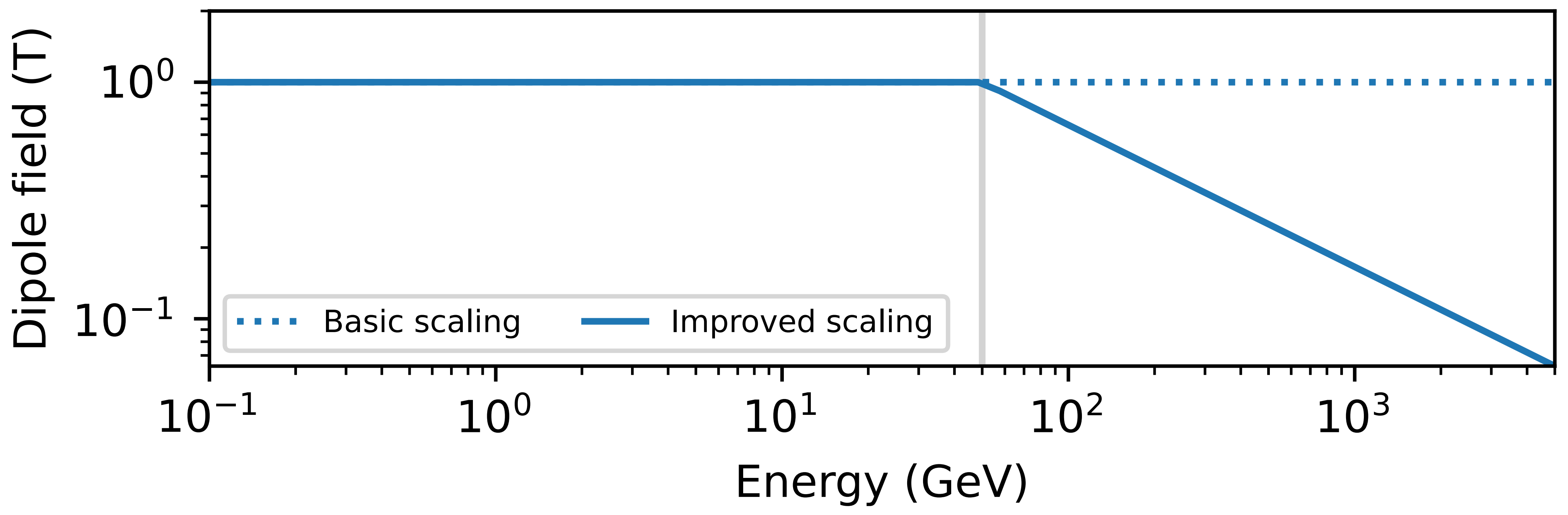

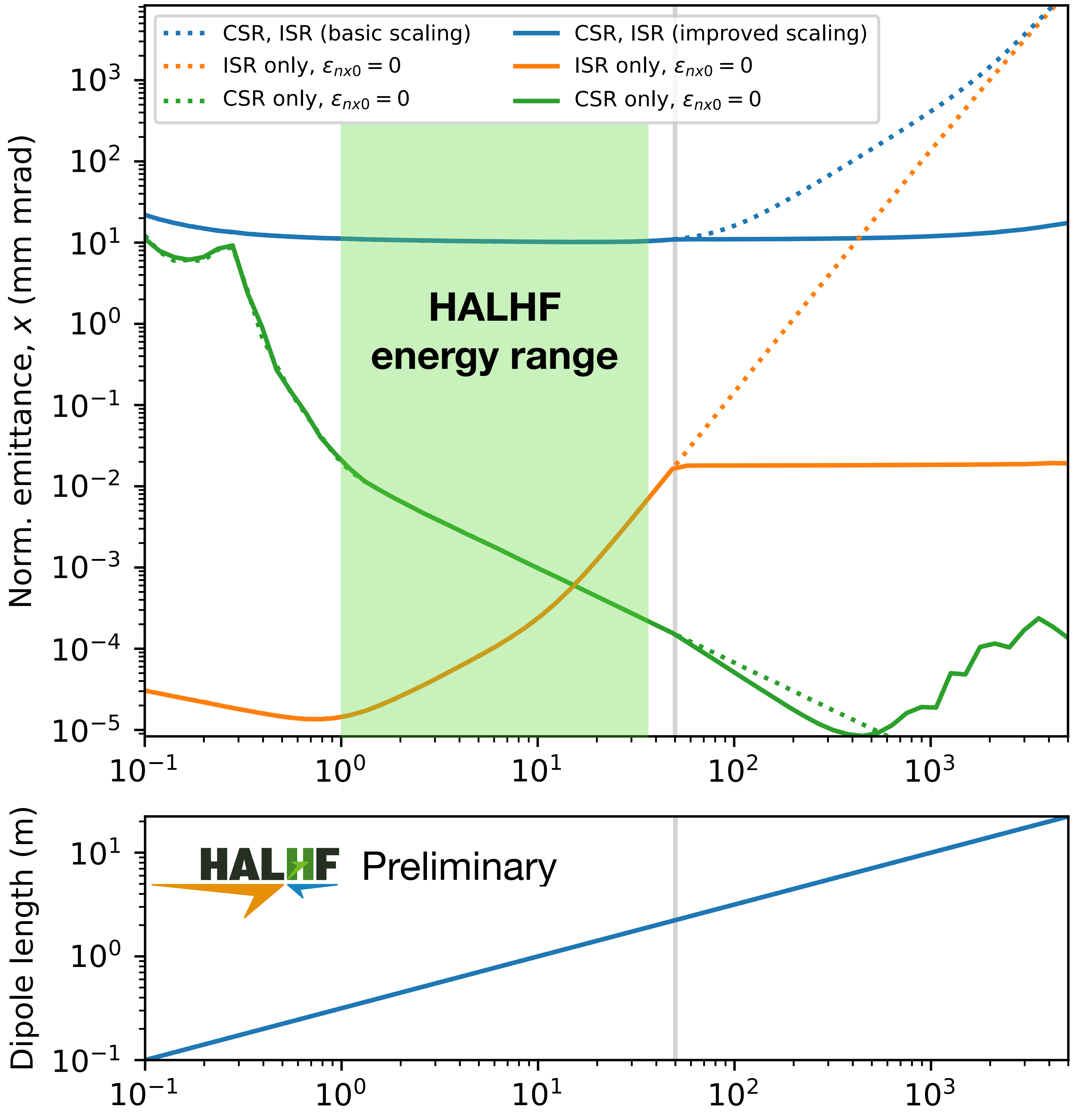

Simulated using ImpactX (starting at 10 mm mrad) including SFQED effects (3rd order). **Source: Lindstrøm et al. (manuscript in preparation)**

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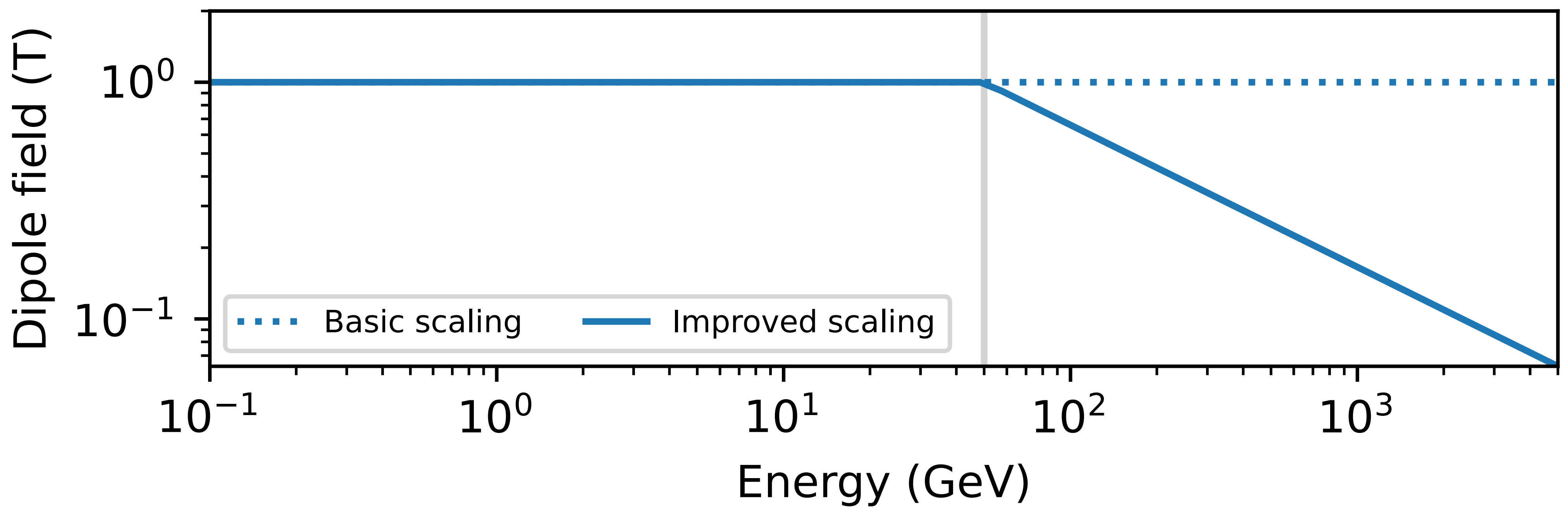

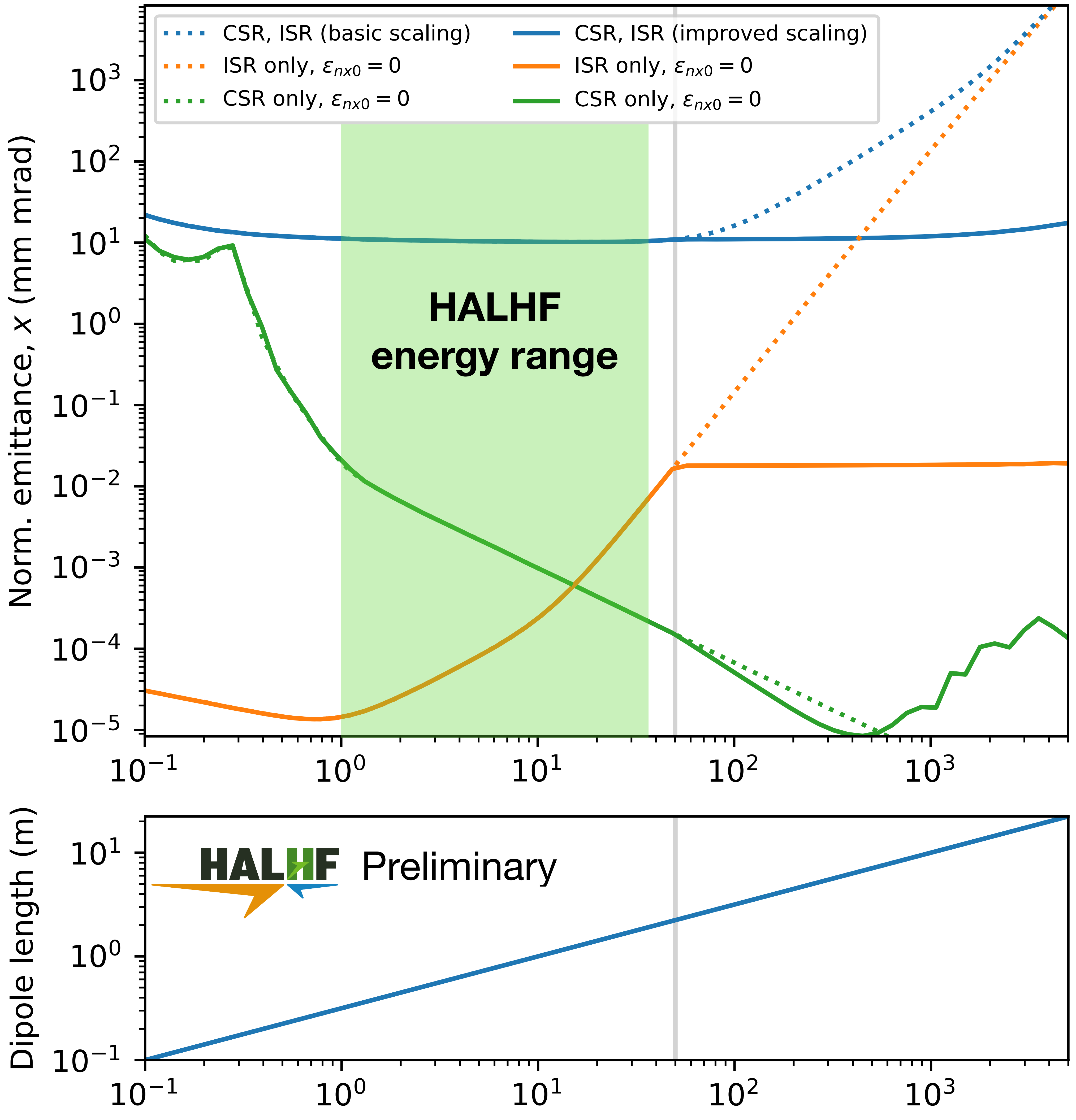

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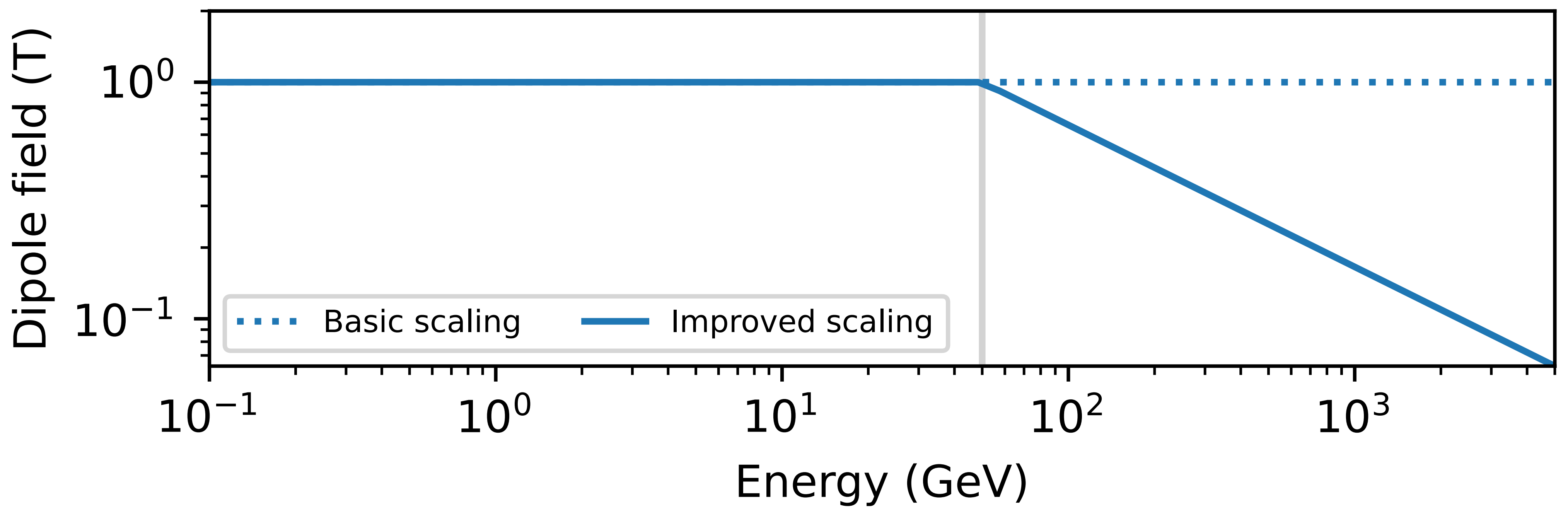
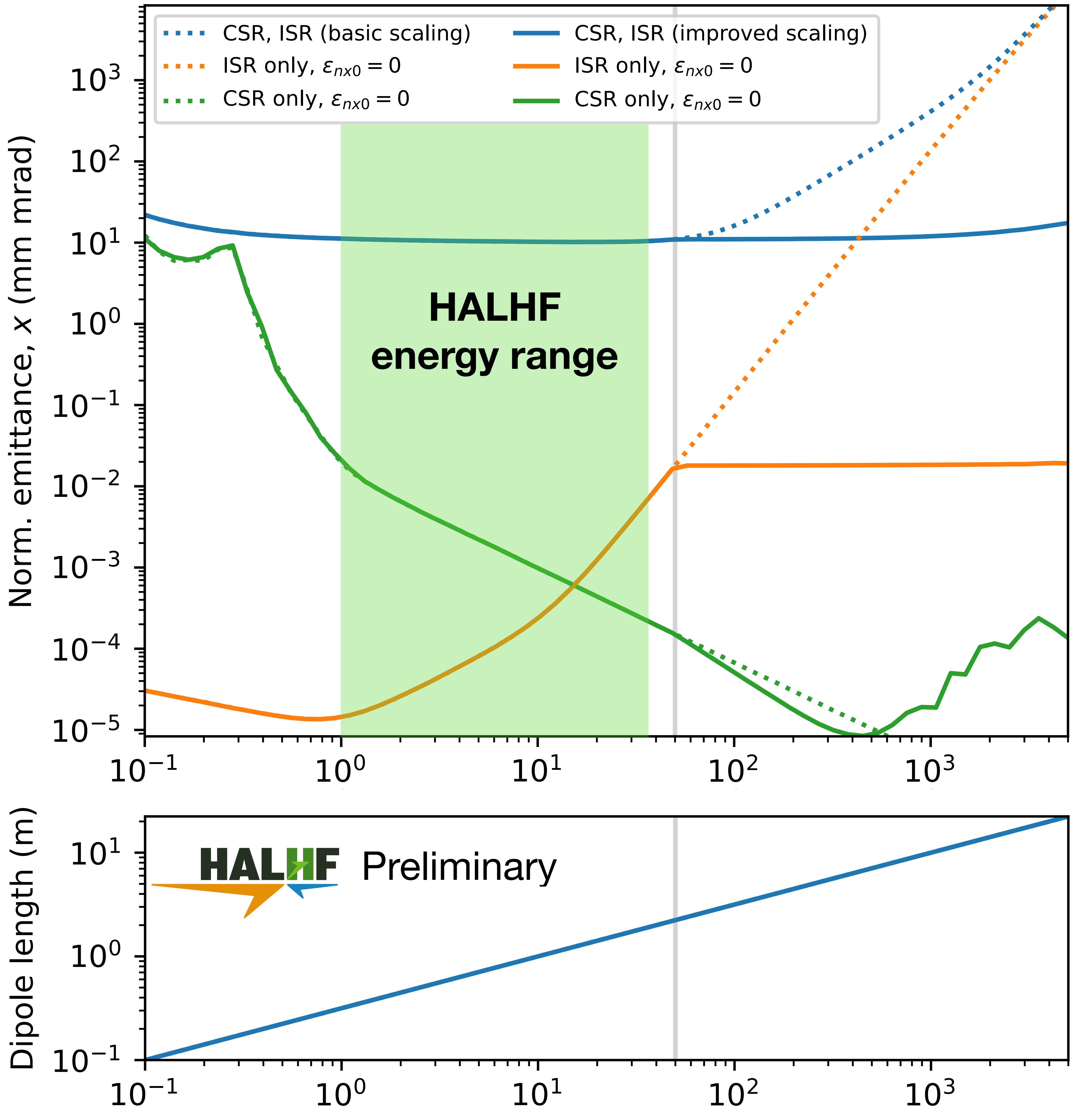
- Incoherent SR (ISR) disruptive at high energies — suppress by ramping down dipoles ($B \sim E^{-\frac{3}{5}}$)



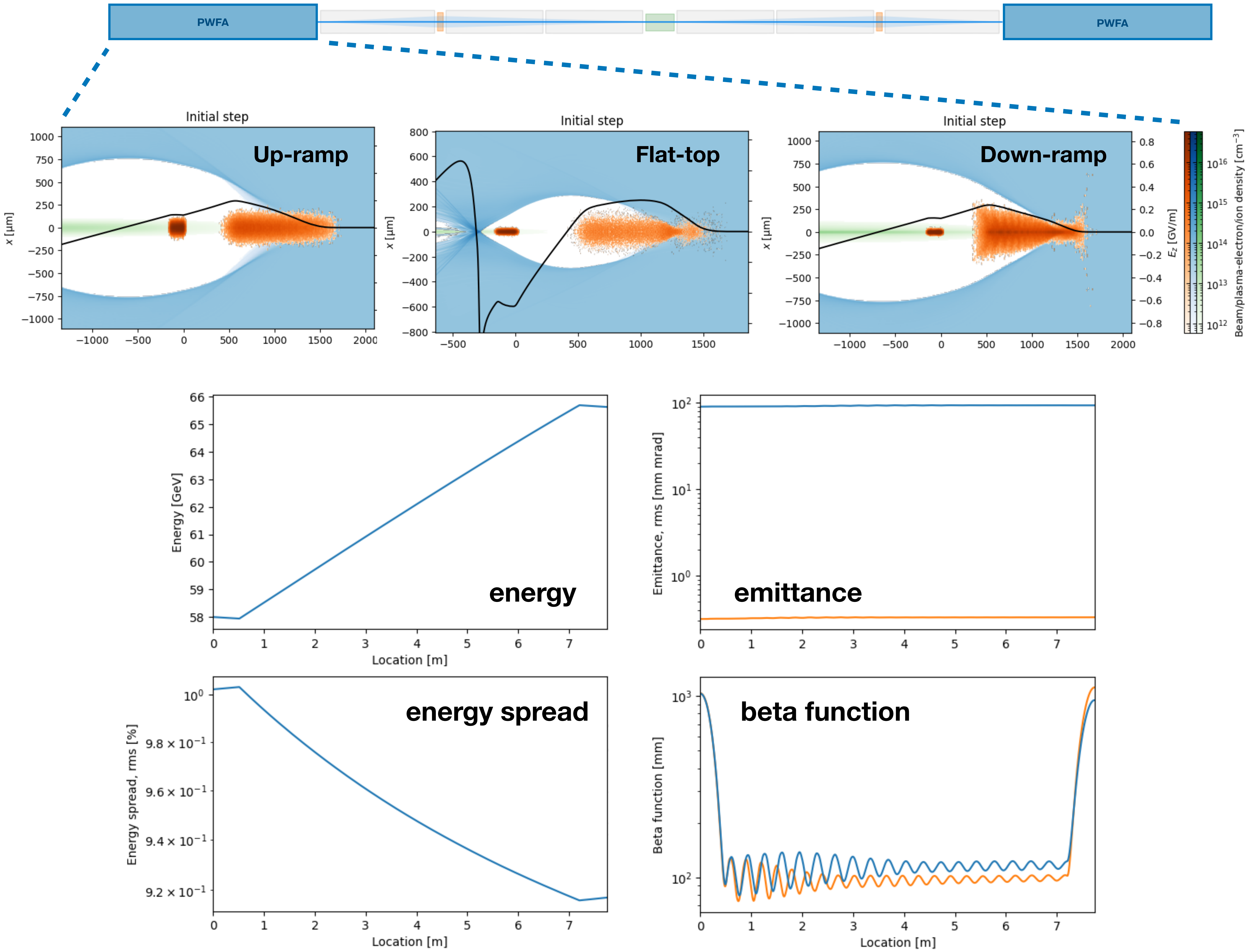


Simulated using ImpactX (starting at 10 mm mrad) including SFQED effects (3rd order). **Source: Lindstrøm et al. (manuscript in preparation)**

R&D topic — Reaching high energy

Toward self-consistent S2E simulations

- **Plasma-acceleration simulations performed in HiPACE++**
  - Example for the 7th HALHF stage (**58–66 GeV**)
  - Includes ion motion, beam ionisation, ++
  - Preserves beam quality (energy spread and emittance)



ABEL — the Adaptable Beginning-to-End Linac simulation framework

> **A start-to-end simulation framework**, using OpenPMD

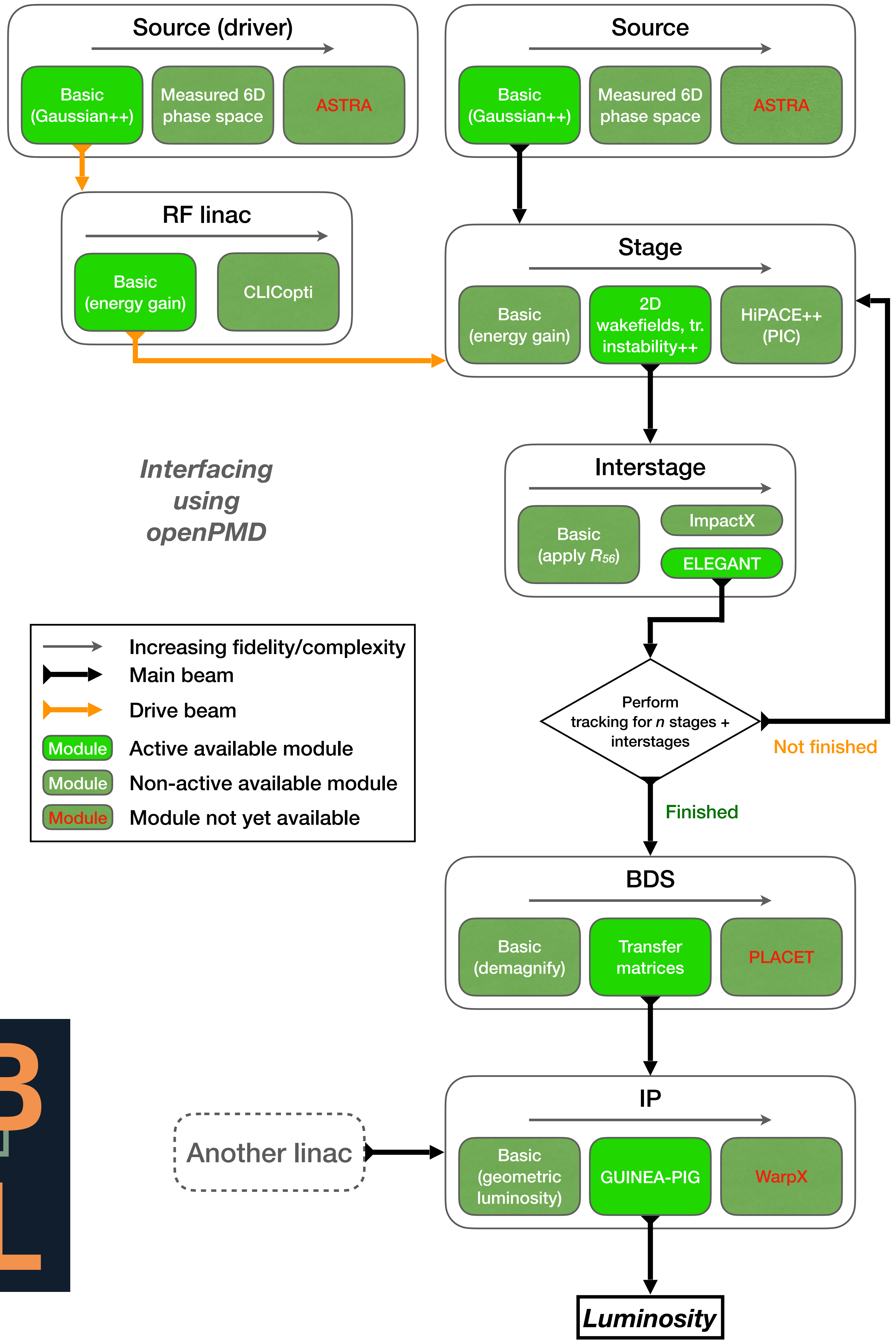
> **Running codes via wrappers** (also submits HPC jobs etc.)
— HiPACE++, WakeT, ImpactX, GUINEAPIG, ELEGANT, CLICopti

> **“System code”** (term borrowed from e.g. fusion)
— integrated cost modelling (*crucial in cost-optimisation of HALHF*)
— machine layouts

> Adaptable implementations
— **choose fidelity versus speed** for each subsystem

> Run simulations as experiments
— run simulations with **multiple shots**, including random jitter
— perform **automated scans** (one-liner)
— perform **parameter optimisations**

> **Ready for release!** Tutorial this week at EAAC…



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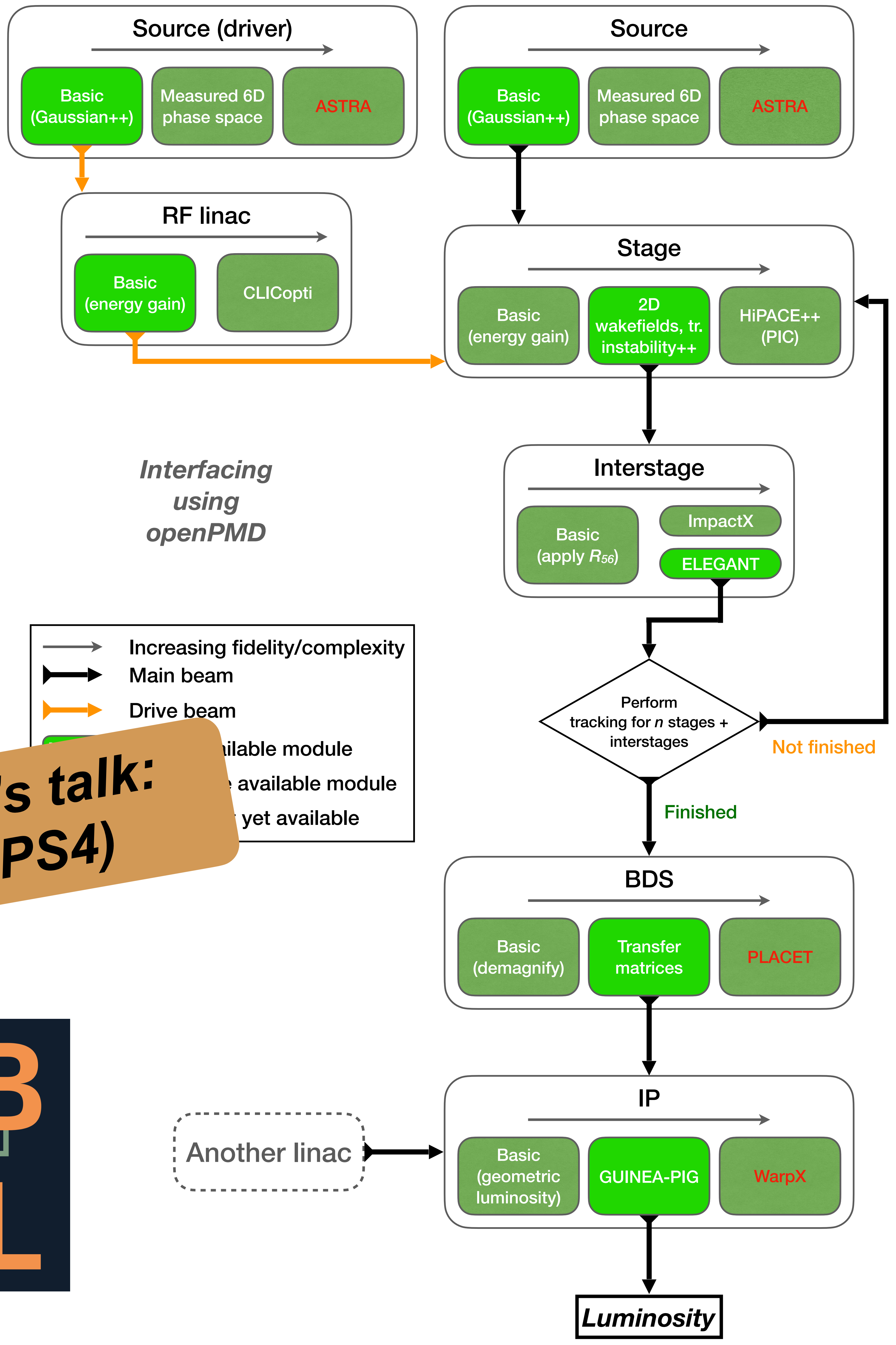
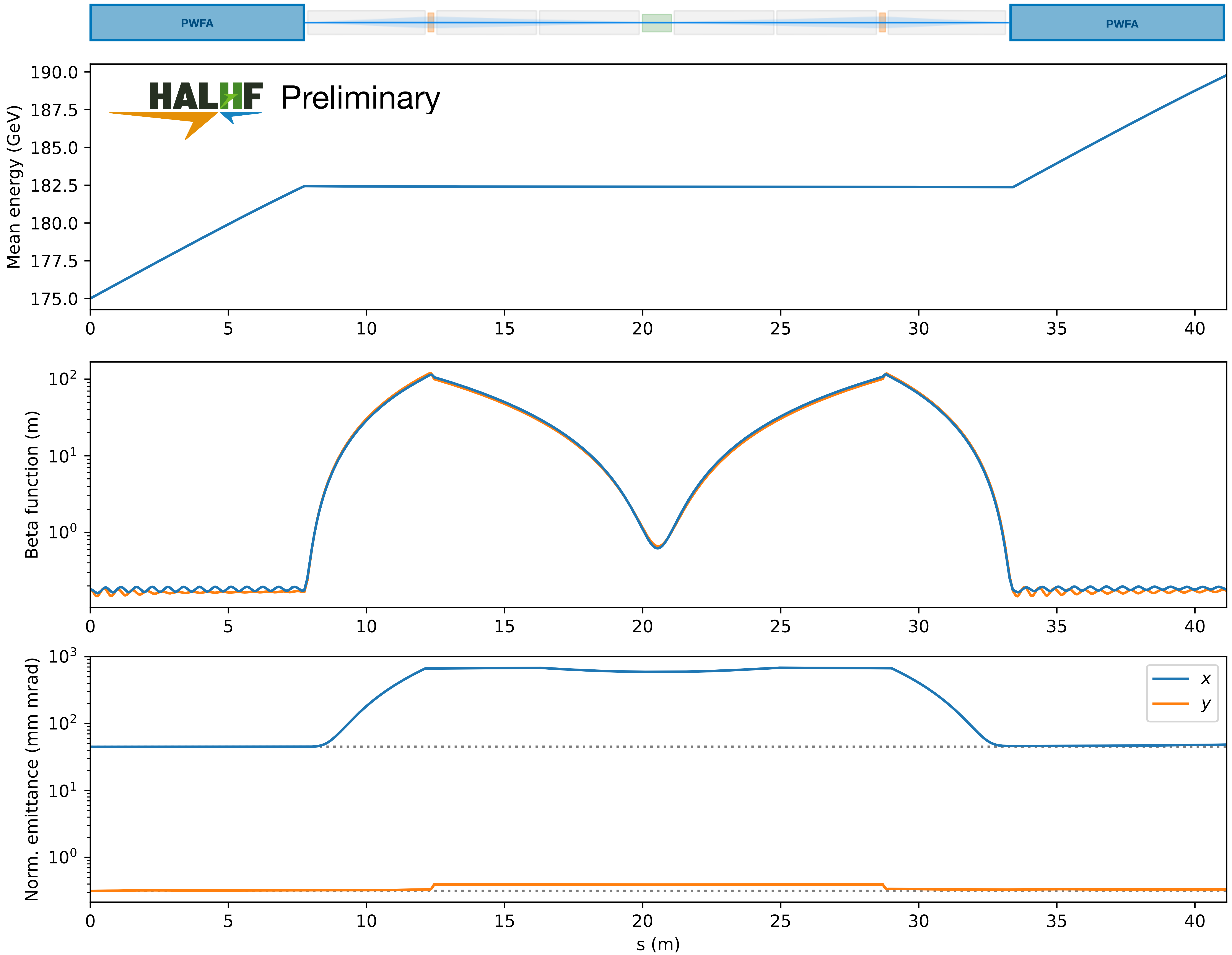
See Ben Chen’s talk: Tues 16:20 (PS4)



R&D topic — Reaching high energy

Toward self-consistent S2E simulations

- **Self-consistent two-stage simulation (HiPACE++ and ImpactX) between 175–190 GeV**
  - Corresponds to the middle stages of HALHF 250 GeV
  - Preserves beam quality (in both PWFA and interstage)



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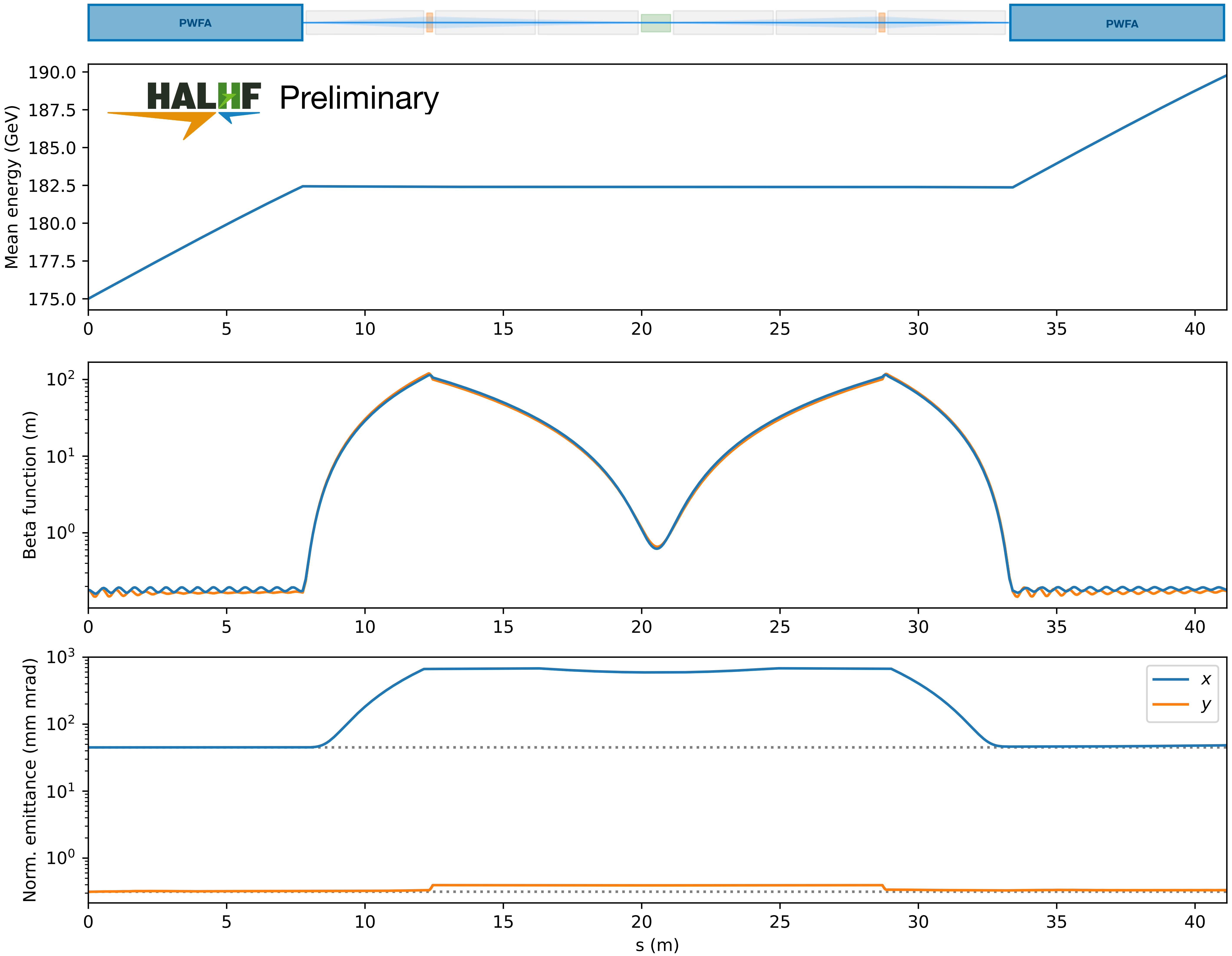

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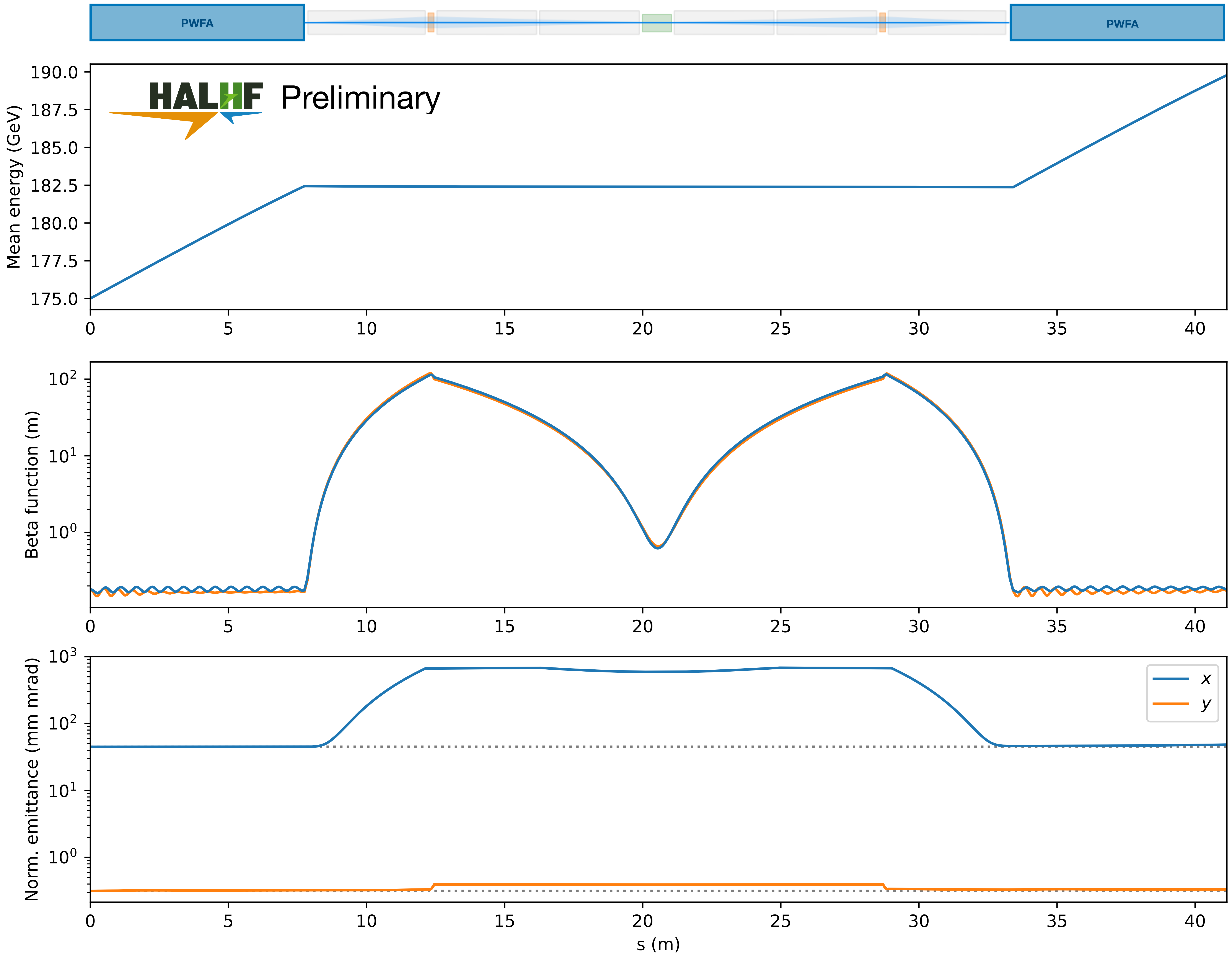
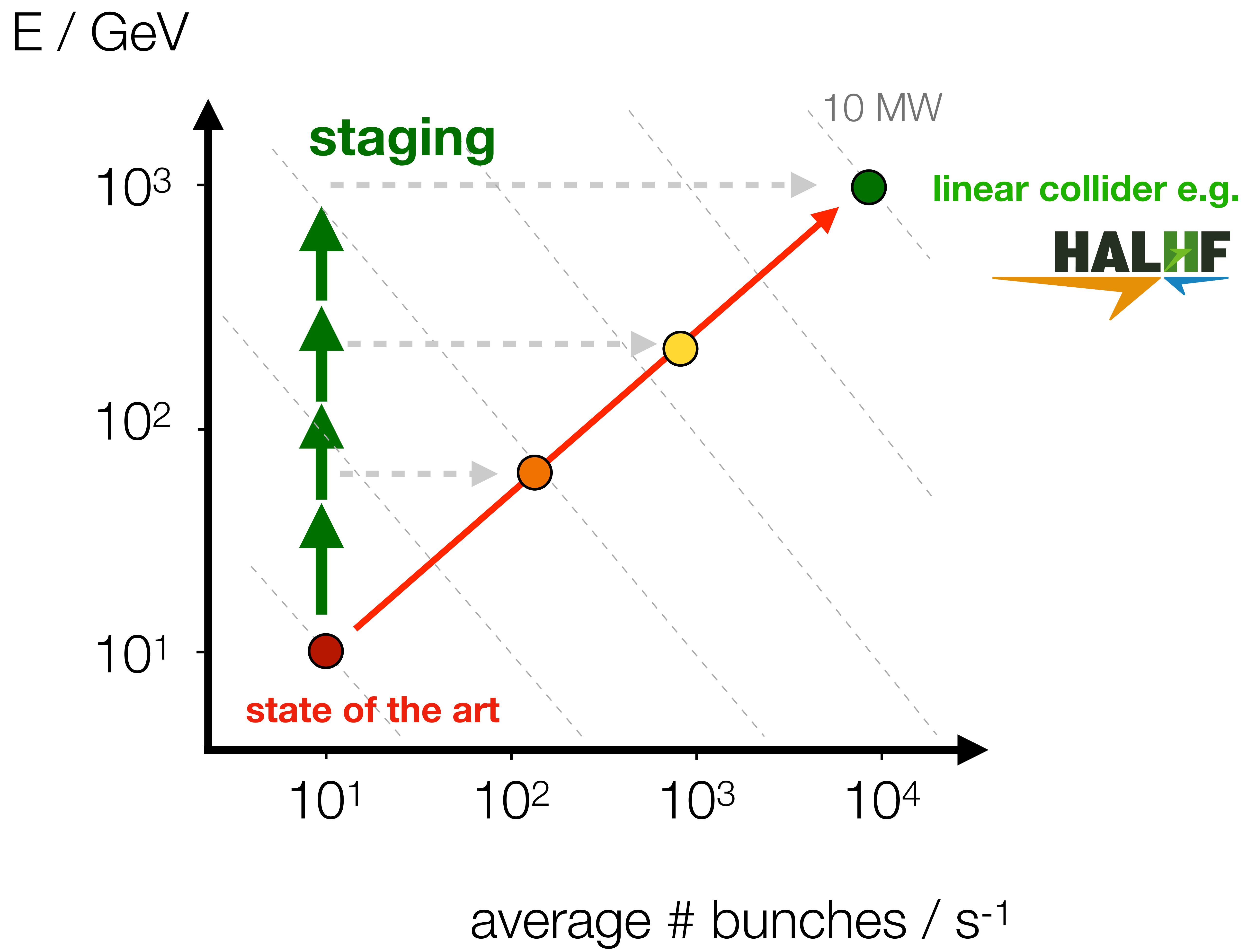
- **Next**: Preparing for the full HALHF run (simulate all 48 stages)



Major (plasma) R&D topics under investigation

Pushing the state-of-the-art in staging (*energy*) and repetition rate (*luminosity*)



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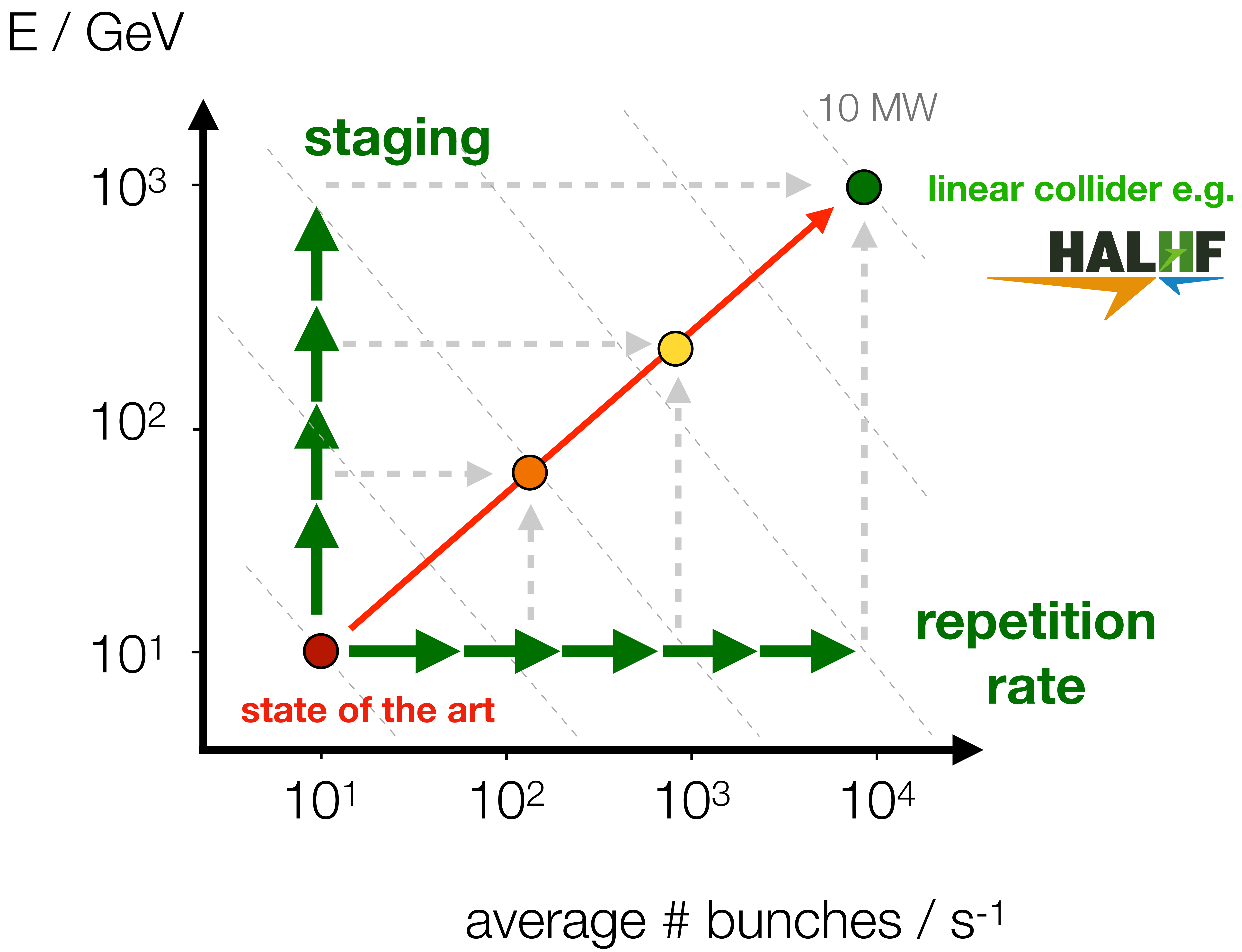
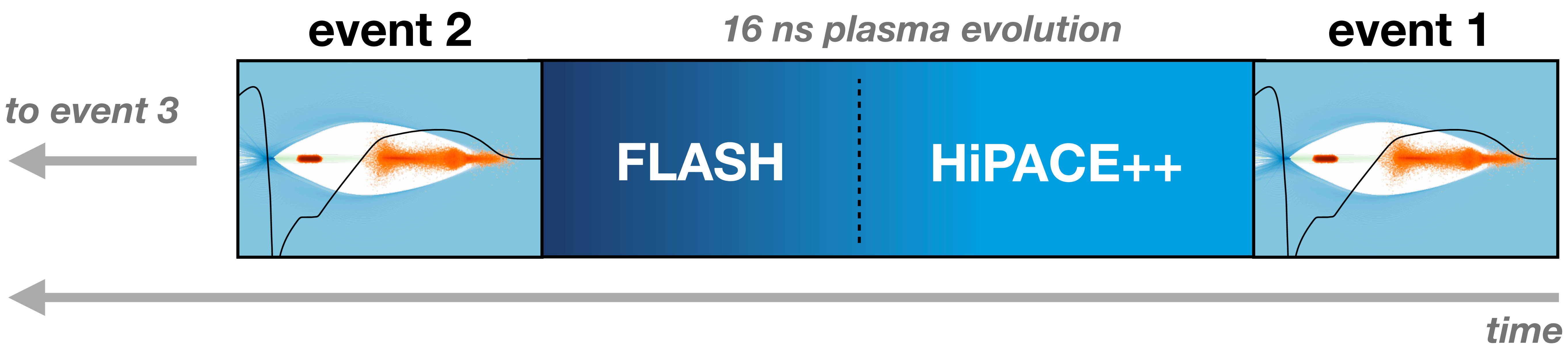


- **High repetition rate**
  - Each HALHF bunch [train] deposits ~10 J [~16 kJ] of energy in the plasma ➞ ***Where does that energy go/how does it affect the next wakes?***
  - Max. average-power deposition of ~40 kW/m in the modules ➞ ***How should this be managed?***
  - **Novel simulation, diagnostic, and cooling methods required**

R&D topic — Reaching high luminosity

Simulating plasma evolution and investigating temperature effects

> Need self-consistent simulations of plasma evolution between acceleration events (*16 ns at HALHF*)
  > Temporal analogue of two plasma stages
  > Computationally expensive (prohibitive?)
> New fast/cheap scheme based on QSA PIC + Fluid



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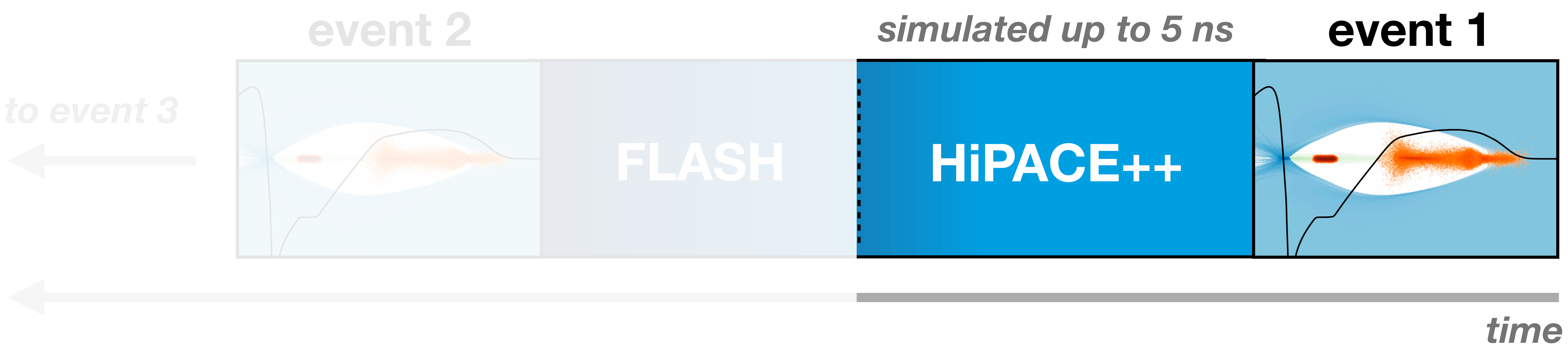
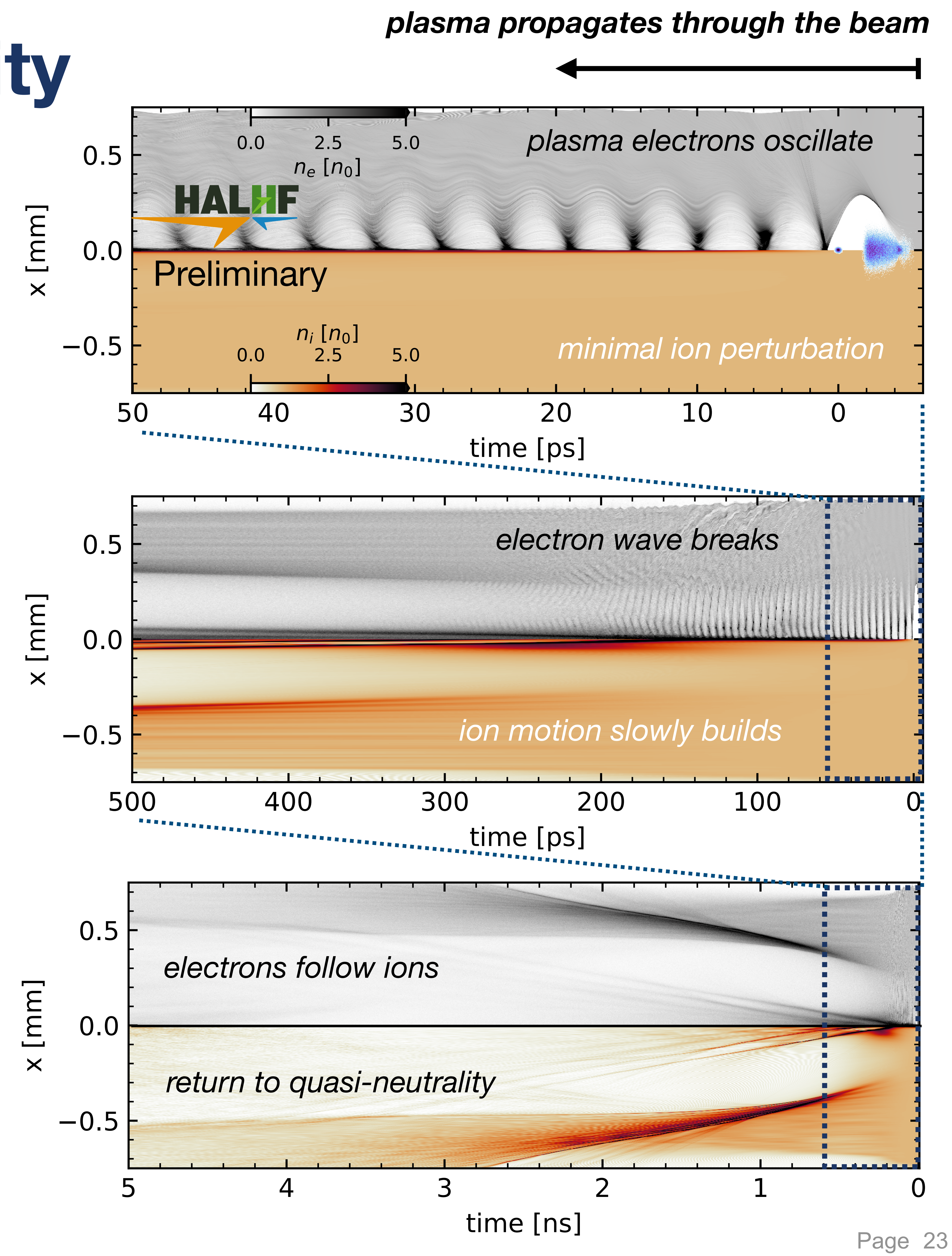


- Benchmarked against 3D PIC over short timescales
- **Next**: Benchmark for longer timescales + against experimental results e.g. D'Arcy *et al.*, Nature **603** (2022)



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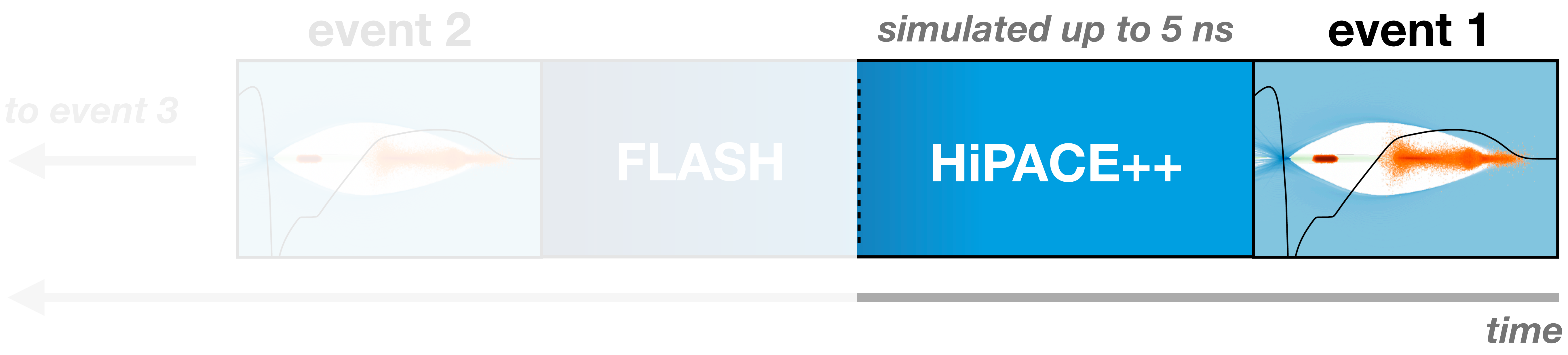

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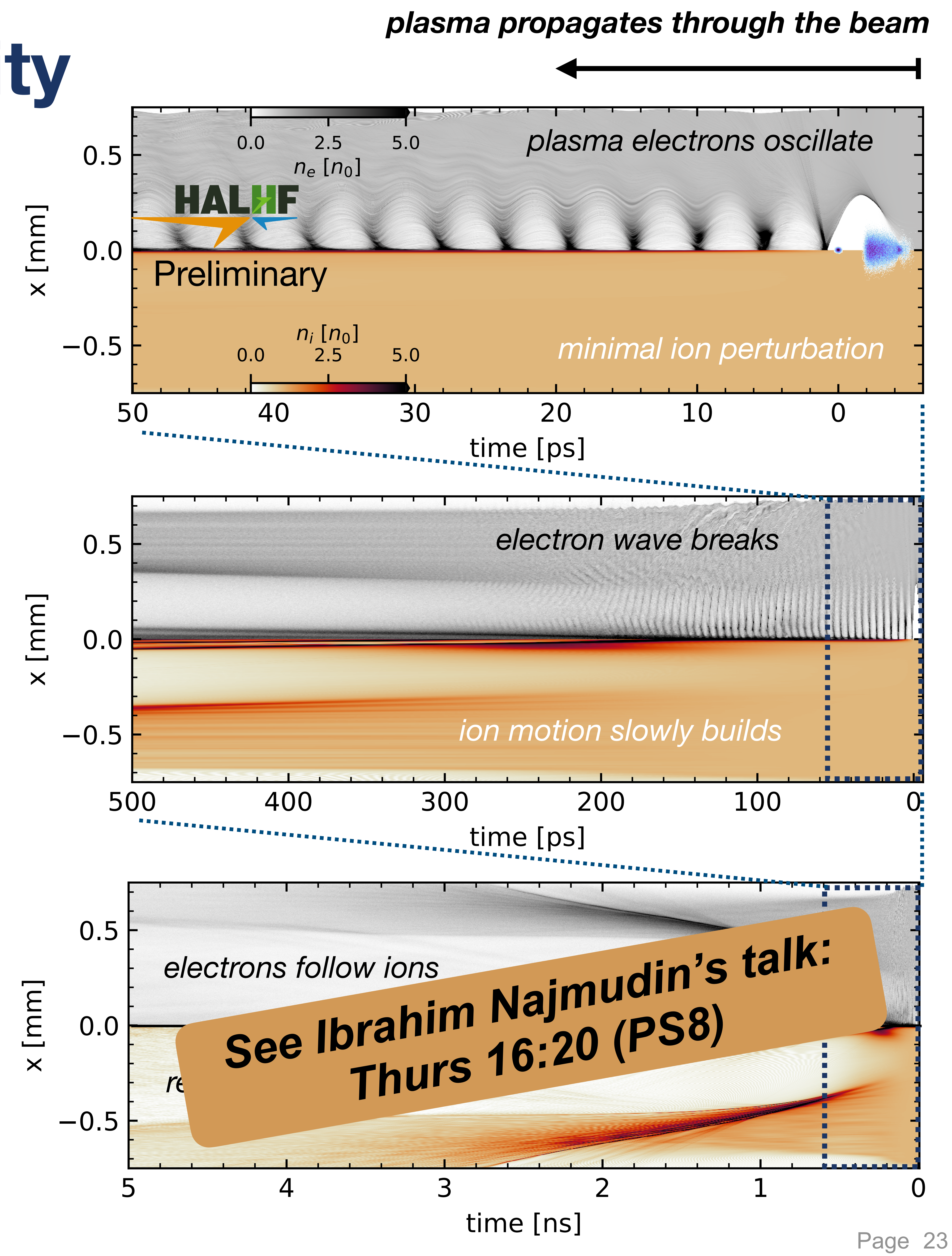
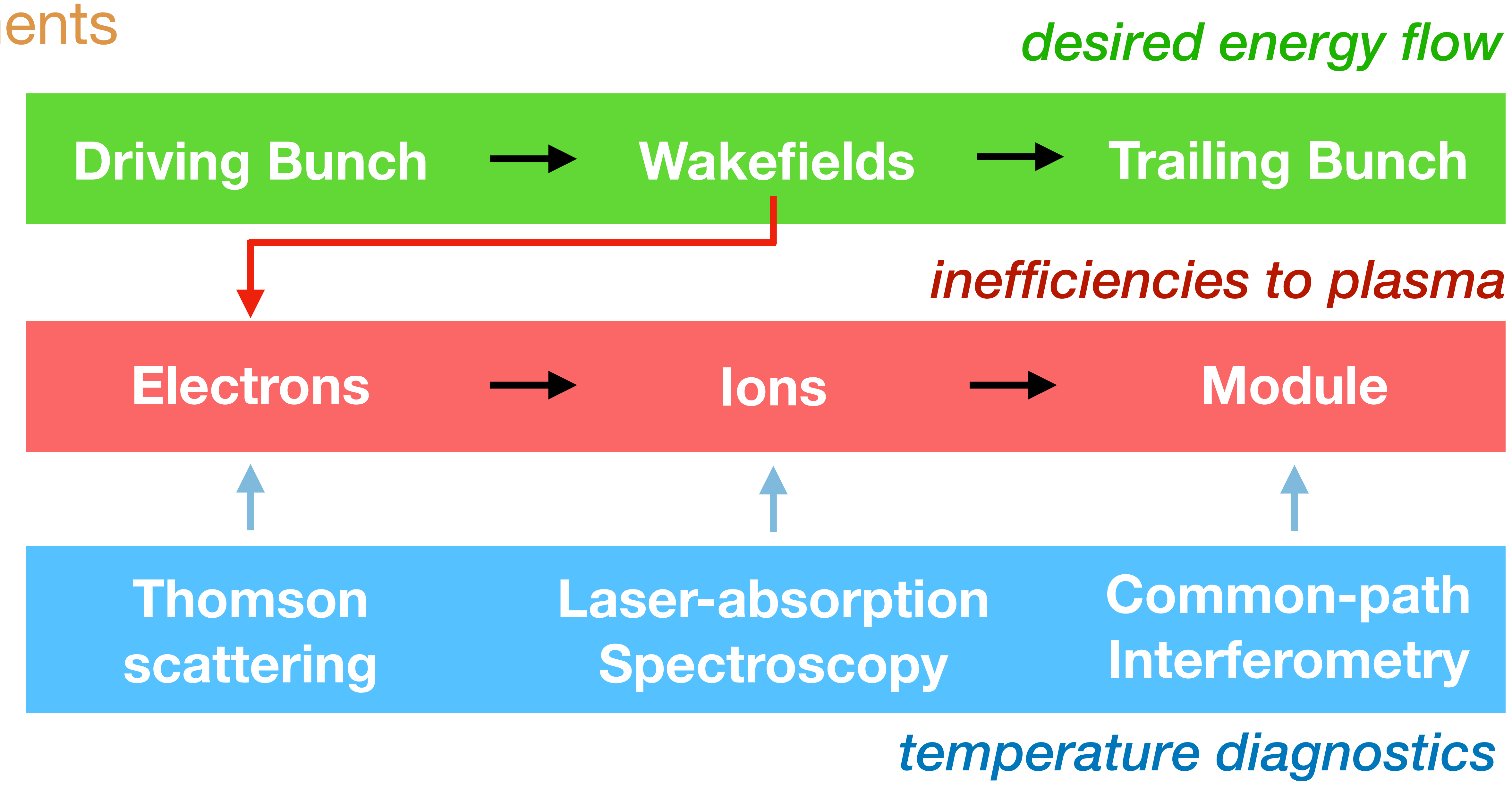


R&D topic — Reaching high luminosity

Novel diagnostic package for direct temperature measurements

- **Need (direct) temperature diagnostics** of all inefficient energy-transport channels
- **All-optical diagnostics** for non-invasive implementation at different plasma facilities
- Diagnostic package being developed and benchmarked in a dedicated Oxford laboratory



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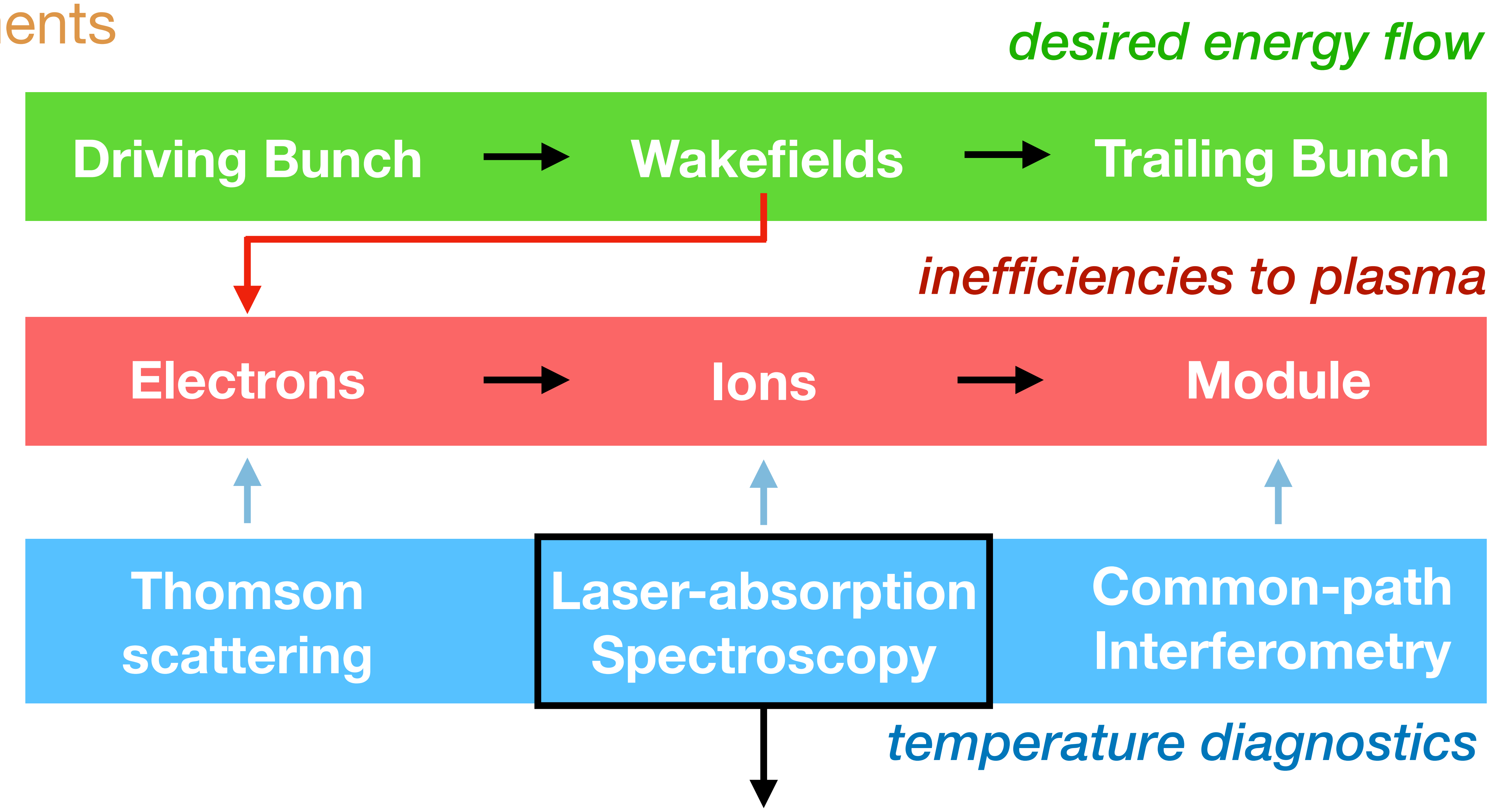
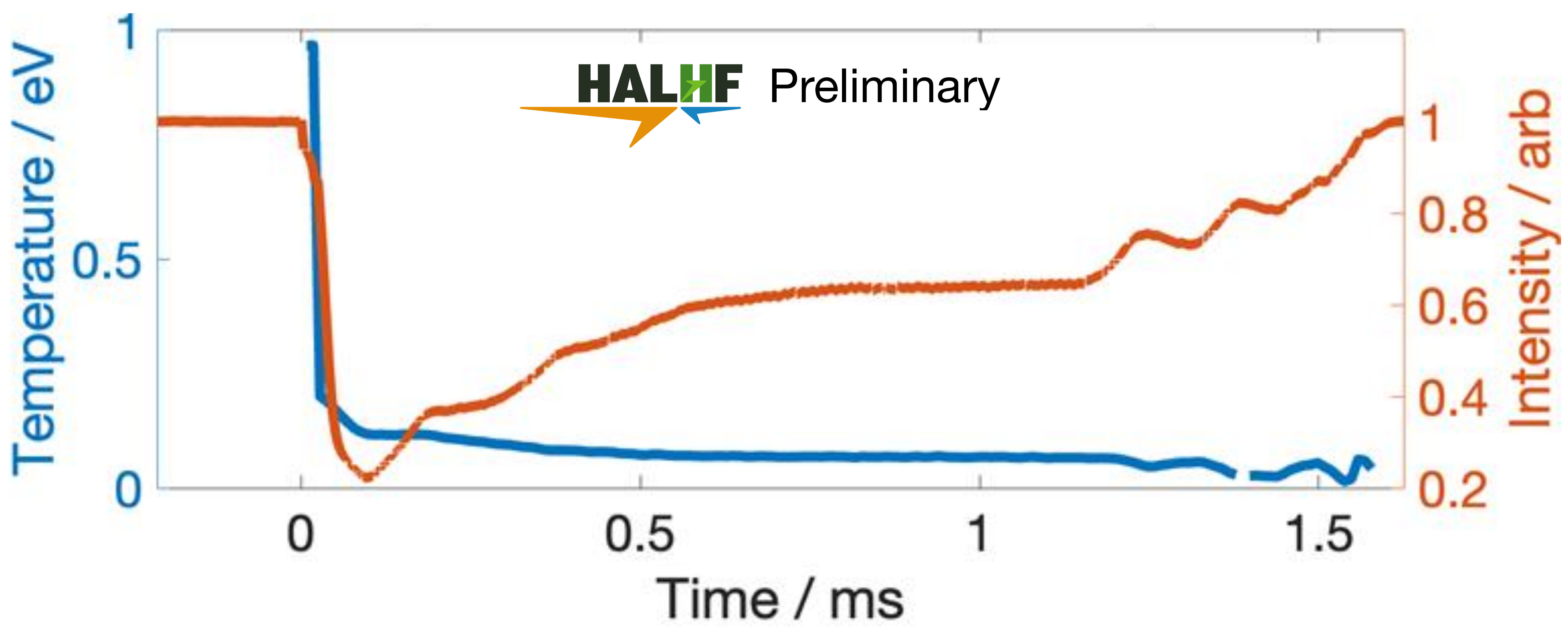


> Doppler broadening of (*narrow-bandwidth CW*) laser-absorption spectrum gives temperature information (*with ns resolution*)

> First tests on Ar plasma neutrals (*long-living*)

> **Next**: Measure plasma-ion (H^+, Ar^+) temperature in a discharge capillary



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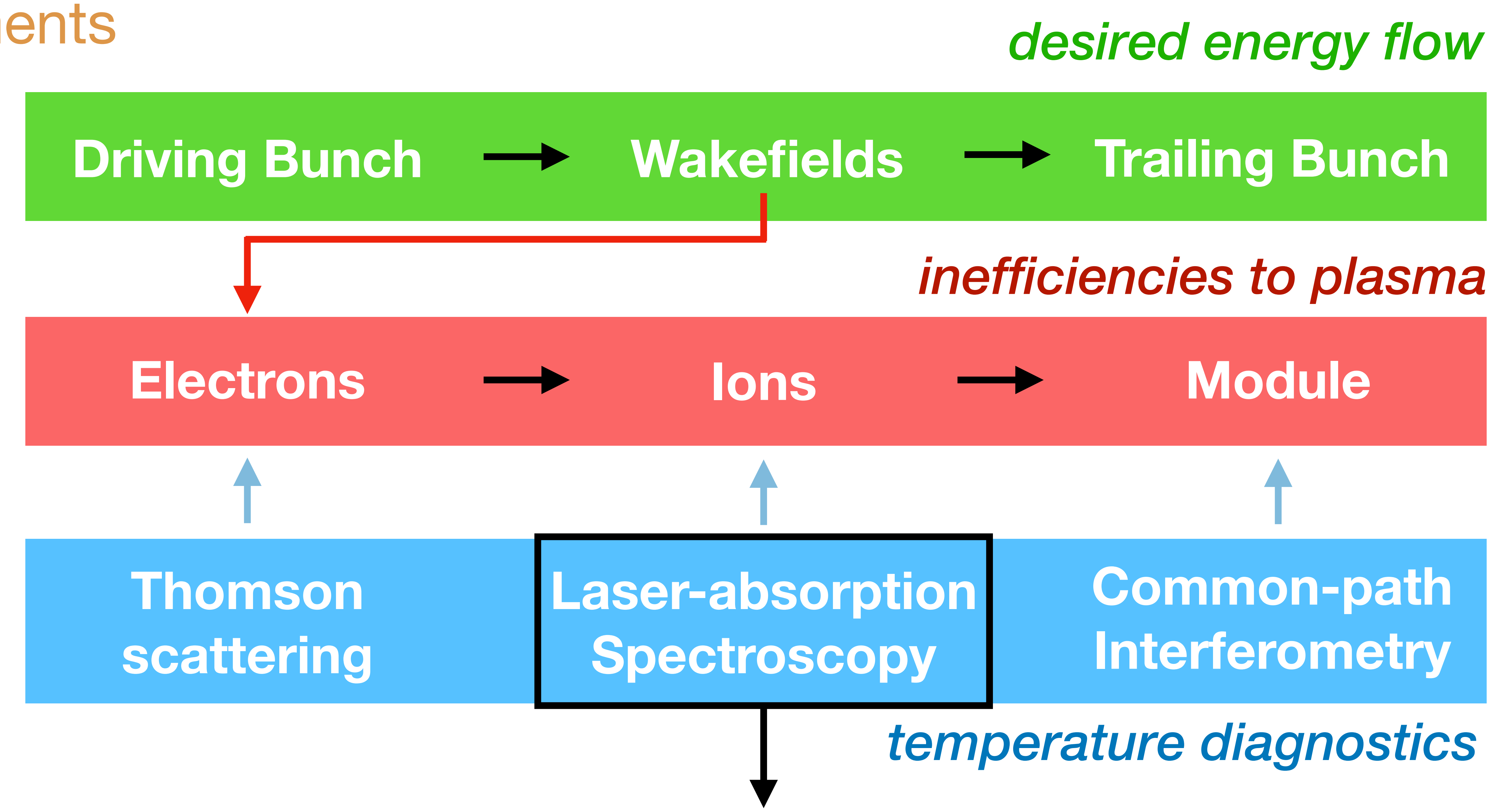

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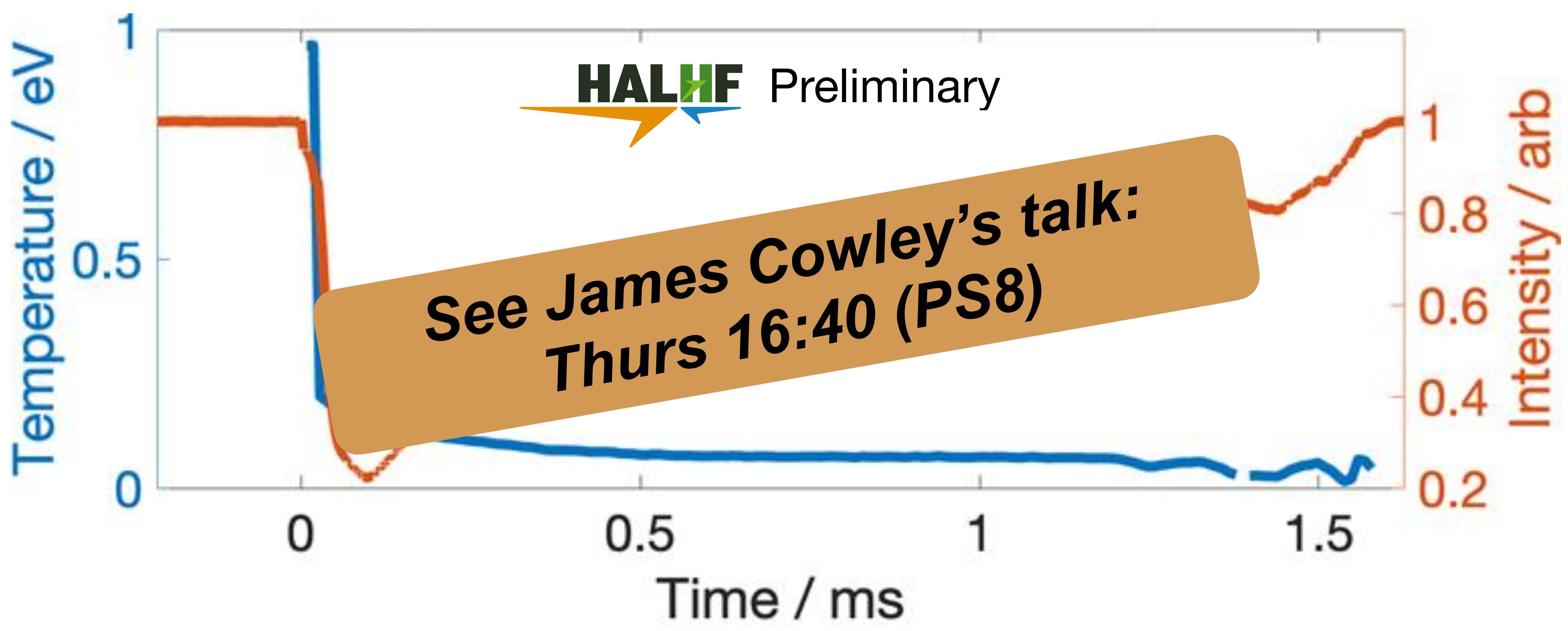
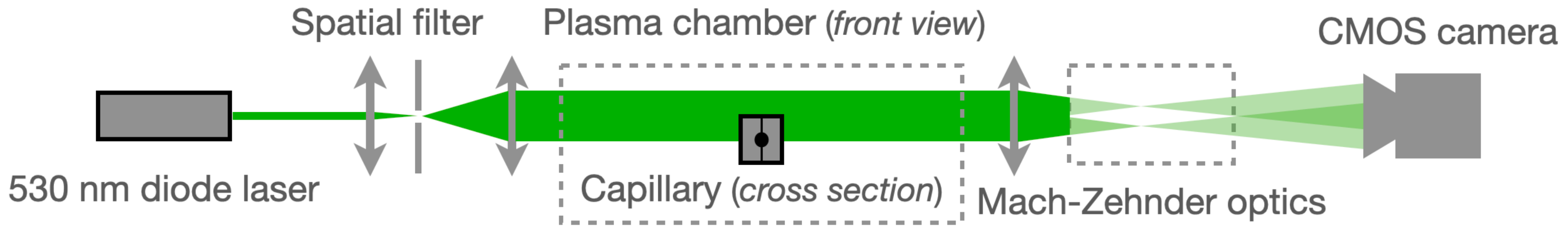
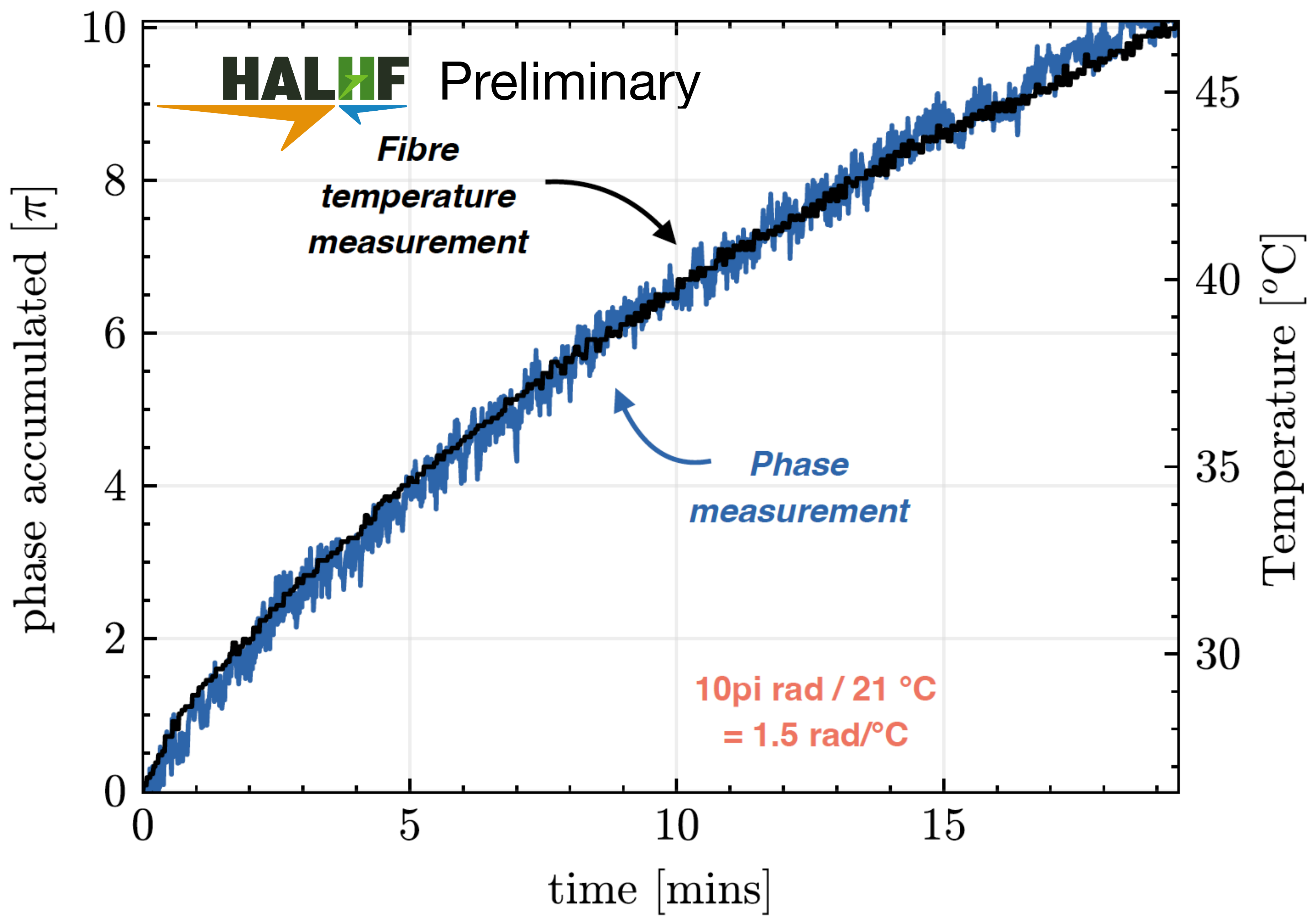


R&D topic — Reaching high luminosity

Developing designs for temperature-stabilised plasma modules



- Temperature evolution of a discharge capillary by tracking the temperature-dependent phase shift from heating/expanding sapphire plates
  - Laser path: half through the cell, half above it
  - Interference fringes between two portions gives **radial temperature evolution**
- Calibrated against thermocouples in DESY ADVANCE Lab
- **Next**: Measure cell temperature evolution at a plasma accelerator (*ideally multiple with different parameters*)



R&D topic — Reaching high luminosity

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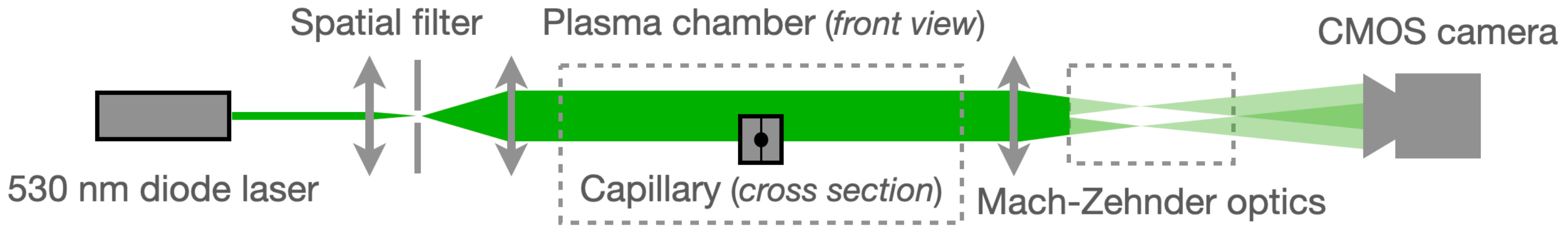

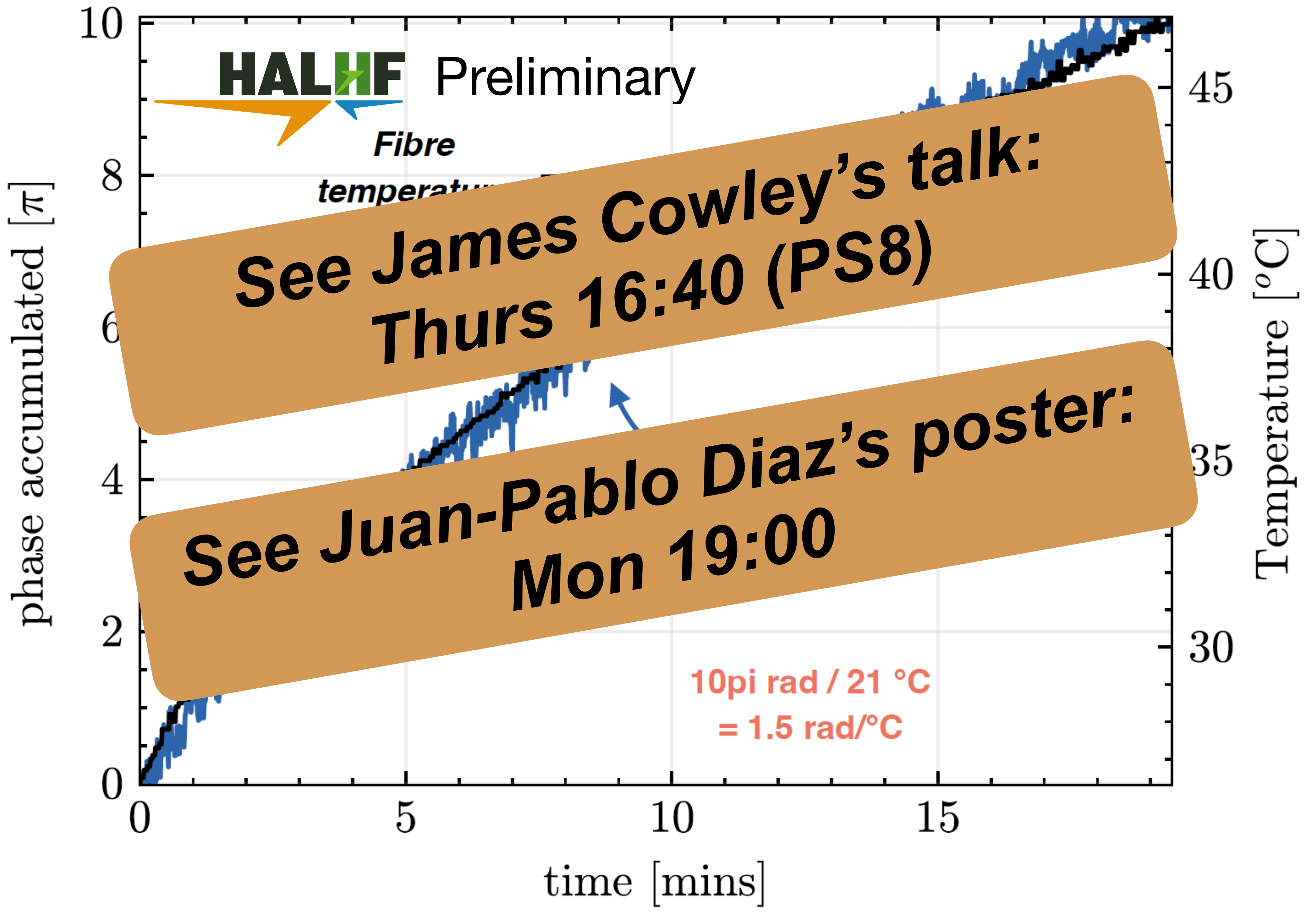

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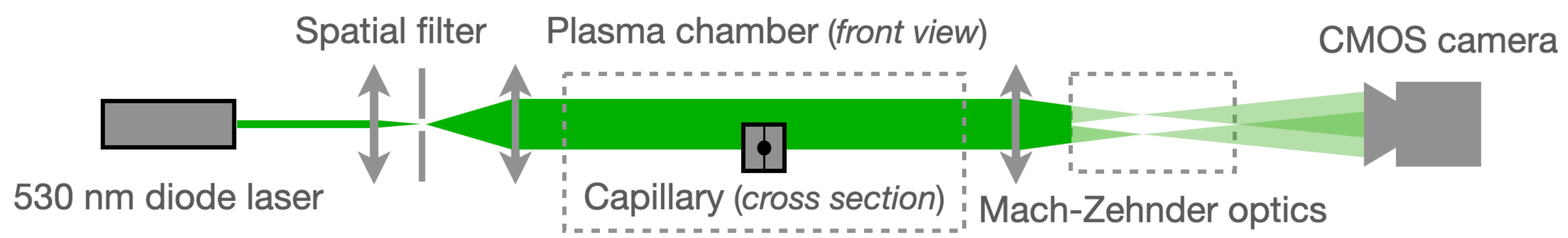
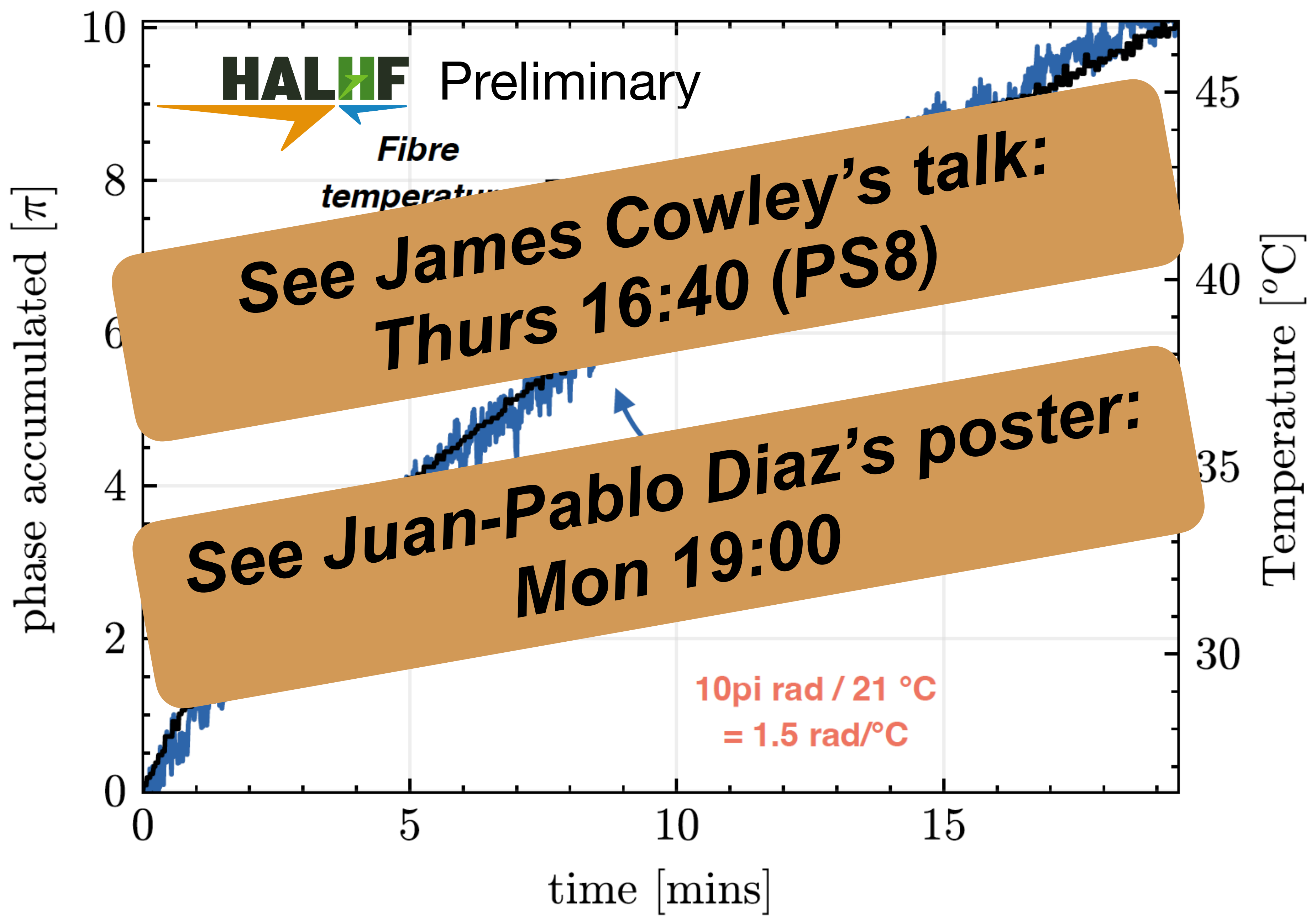
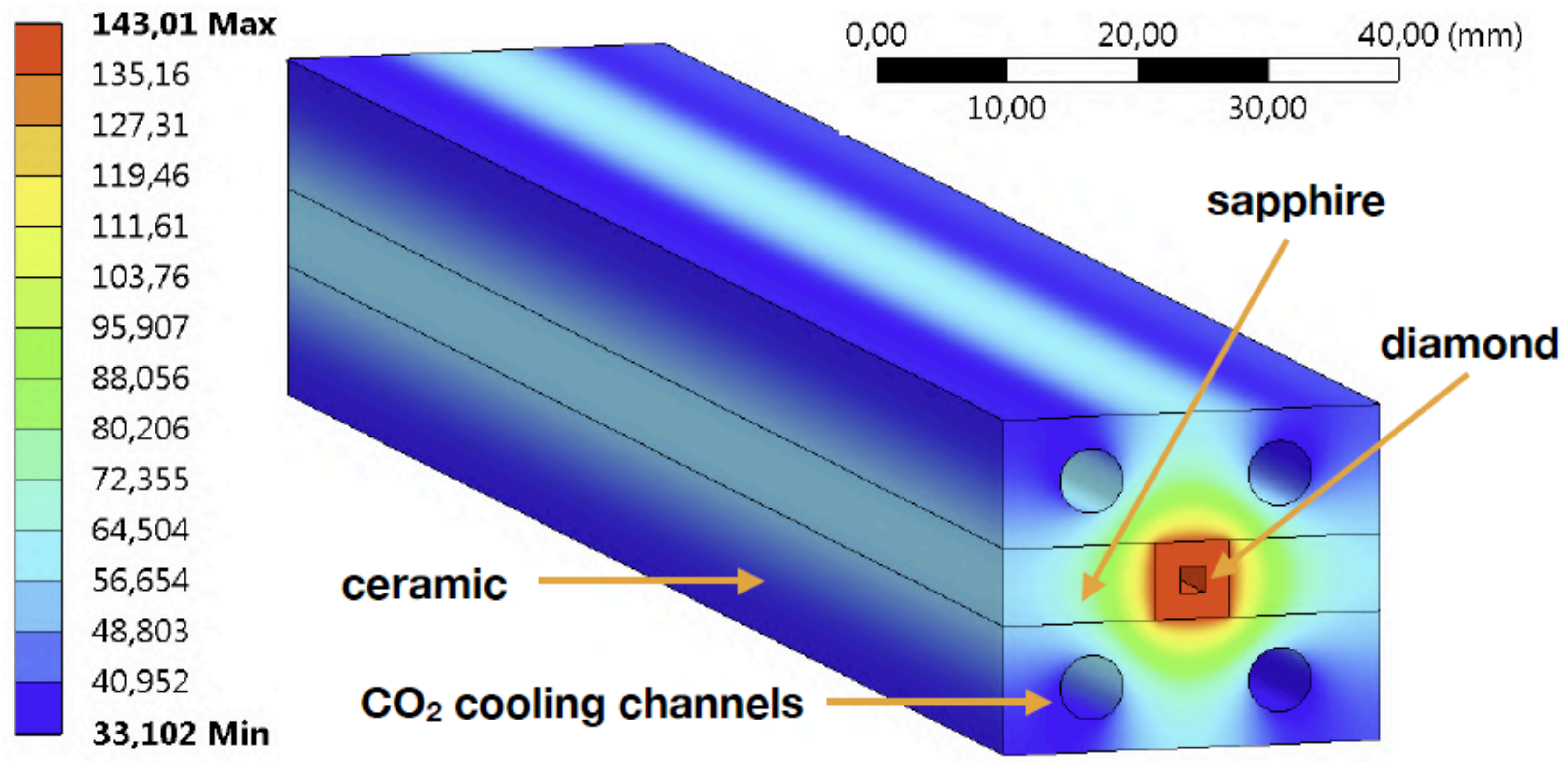
- Results with discharge already informing cooled-cell designs
- **Next**: Design a source capable of managing the power







From *then* to *now* — a summary (https://arxiv.org/abs/2509.07910)

Evolution of the plasma-based collider concept over the last decade (towards HALHF)

- **What has changed since Snowmass 2013?**
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  - Emittance-preserving **interstage optic schemes** have been devised
  - **Plasma recovery** and **plasma-source cooling** have been taken in to account
  - **Integrated codes** have leveraged **developments in PIC** (GPU operation, mesh refinement, etc.) to perform full plasma linac simulations
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RF Tech

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See Erik Adli's talk:
Wed 17:20 (PS9)

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Plasma R&D outlook

Future *Demonstrations* and *Demonstrators* (not all by HALHF!)

- *Demonstrations*
  - The **idealised single plasma stage** (beam quality, large energy gain, high overall efficiency)
  - Beam-quality-preserving **staging** of two plasma accelerators
  - High-repetition-rate **(>MHz) plasma acceleration** of long bunch trains
  - Single-stage **polarisation** demonstration
  - Working solution for **driver distributions** and delays
  - Scheme for **driver dumping** and radiation safety

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- ***Demonstrators***
  - Dedicated **multi-stage** plasma facility (*with application to e.g. SFQED*)
    - Upgrade to include **high-average-power** RF and plasma stages
    - Upgrade to include increased beam **quality** and spin **polarisation**

Summary

> **The HALHF concept proposes a smaller, cheaper, greener, quicker Higgs factory in Europe**

> **Builds on previous plasma-collider concepts** plus excellent R&D performed since

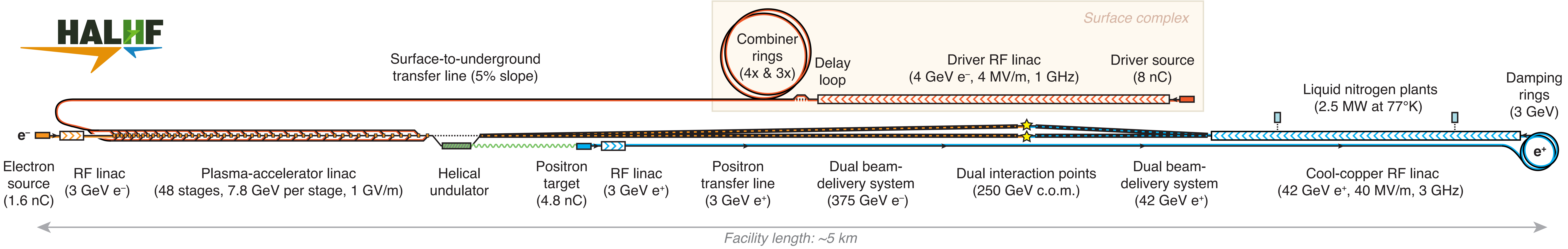
> **High risk/high reward:** Less mature than RF technology but significantly cheaper

> **Consolidates R&D prioritisation**: Provides context for the need to reach high energy / luminosity

> **Much targeted (plasma & RF) R&D still required:** 10-15 yrs of significant work / demonstrations

> **Community involvement is key to further success:** Please reach out if you'd like to get involved!

https://jai.web.ox.ac.uk/halhf



Source: Foster et al., Phys. Open 23, 100261 (2025)

Backup slides

HALHF 2.0 parameter table (part 1)

Machine parameters	*Unit*	*Value (250 GeV)*		*Value (380 GeV)*		*Value (550 GeV)*	
Centre-of-mass energy	GeV	250		380		550	
Centre-of-mass boost		1.67		1.67		1.67	
Bunches per train		160		160		160	
Train repetition rate	Hz	100		100		100	
Average collision rate	kHz	16		16		16	
Luminosity	$\text{cm}^{-2}\,\text{s}^{-1}$	1.2×10^{34}		1.7×10^{34}		2.5×10^{34}	
Luminosity fraction in top 1%		63%		53%		46%	
Quantum parameter (Υ)		0.9		1.6		2.8	
Estimated total power usage	MW	106		154		218	
Total site length	km	4.9		6.5		8.4	
Colliding-beam parameters		e^-	e^+	e^-	e^+	e^-	e^+
Beam energy	GeV	375	41.7	570	63.3	825	91.7
Bunch population	10^{10}	1	3	1	3	1	3
Bunch length in linacs (rms)	μm	40	150	40	150	40	150
Bunch length at IP (rms)	μm	150		150		150	
Energy spread (rms)	%	0.15		0.15		0.15	
Horizontal emittance (norm.)	μm	90	10	90	10	90	10
Vertical emittance (norm.)	μm	0.32	0.035	0.32	0.035	0.32	0.035
IP horizontal beta function	mm	3.3		3.3		3.3	
IP vertical beta function	mm	0.1		0.1		0.1	
IP horizontal beam size (rms)	nm	636		519		429	
IP vertical beam size (rms)	nm	6.6		5.2		4.4	
Average beam power delivered	MW	9.6	3.2	14.6	4.9	21.1	7.0
Bunch separation	ns	16		16		16	
Average beam current	µA	26	77	26	77	26	77
Positron cool-copper RF linac parameters (S-band)							
Average cavity gradient	MV/m	40		40		40	
Average gradient	MV/m	36		36		36	
Wall-plug-to-beam efficiency	%	11		11		11	
RF power	MW	11.7		17.8		25.8	
Cooling power	MW	17.9		27.3		39.5	
Total power	MW	29.6		45.1		65.3	
Klystron peak power	MW	67		67		67	
Number of klystrons		321		452		678	
RF frequency	GHz	3		3		3	
Operating Temperature	K	77		77		77	
Length (after damping ring, starting at 3 GeV)	km	1.1		1.7		2.5	

HALHF 2.0 parameter table (part 2)

Driver linac RF parameters (L-band)				
Average cavity gradient	MV/m	4	4	4
Average gradient	MV/m	3	3	3
Wall-plug-to-beam efficiency	%	55	55	55
RF power usage	MW	42.9	66.0	96.4
Klystron peak power	MW	21	21	21
Number of klystrons		409	630	919
RF frequency	GHz	1	1	1
Length	km	1.3	1.9	2.8
Combiner Ring parameters				
Delay loop length	m	1.5	1.5	1.5
CR1 diameter	m	244	244	244
CR2 diameter	m	244	244	244
PWFA linac and drive-beam parameters				
Number of stages		48	48	48
Plasma density	cm^{-3}	6×10^{14}	6×10^{14}	6×10^{14}
In-plasma accel. gradient	GV/m	1	1	1
Av. gradient (incl. optics)	GV/m	0.33	0.38	0.43
Transformer ratio		2	2	2
Length per stage	m	7.8	11.8	17.1
Energy gain per stage	GeV	7.8	11.8	17.1
Initial injection energy	GeV	3	3	3
Driver energy	GeV	4	5.9	8.6
Driver bunch population	10^{10}	5.0	5.0	5.0
Driver bunch length (rms)	μm	253	253	253
Driver average beam power	MW	23.8	36.2	52.6
Driver bunch separation	ns	4	4	4
Driver-to-wake efficiency	%	80	80	80
Wake-to-beam efficiency	%	50	50	50
Driver-to-beam efficiency	%	40	40	40
Wallplug-to-beam efficiency	%	22	22	22
Cooling req. per stage length	kW/m	38.4	38.4	38.4
Length	km	1.1	1.5	1.9

Cost estimates for HALHF 2.0

E. Adli et al. ***"HALHF: a hybrid, asymmetric, linear Higgs factory using plasma- and RF-based acceleration"*****, arXiv:2503.19880**

Based on ILC and CLIC

- Driver RF linac is a major cost driver for the machine (~30%; 50% incl. e^+ linac)
  - Drivers: ~22 CHF/watt beam power
  - Positrons: ~167 CHF/watt beam power
- PWFA linac is not a cost driver (~7%)
  - Driver distribution is the cost driver
- BDS and IP (~13%) adds
- Civil engineering adds ~25% to the machine cost, other overheads ~30%
  - Cooling and ventilation is expensive (~3.6 CHF/watt wall-plug power)

Domain	*Sub-domain*	*Cost [MILCU]* 250 GeV	380 GeV	550 GeV
Main-beam production	Electron source (photocathode, polarized)	82	82	82
	Electron injector linac	22	22	22
	Positron source (helical undulator, polarized)	178	178	178
	Positron injector linac	32	32	32
	Positron transport	55	74	96
	Positron damping rings (2x)	200	200	200
Drive-beam production	Electron source	10	10	10
	Driver linac modules	113	173	254
	Driver linac RF	325	501	731
	Frequency multiplication (combiner rings)	127	127	127
	Driver transport (surface-to-underground)	24	25	26
Electron linac (PWFA)	Plasma modules	17	26	38
	Interstage transport	30	37	44
	Driver delay chicanes	90	120	155
	Driver beam dumps	11	17	25
Positron linac (cool-copper RF)	Cool-copper linac modules	113	176	259
	Cool-copper linac RF	298	465	683
	LN_2 reliquification plants	34	53	78
Beam delivery and post collision lines (dual IPs)	Electron beam delivery systems (2x)	158	194	234
	Positron beam delivery systems (2x)	53	65	78
	Final focus, experimental area	20	20	20
	Post collision lines/dumps	45	64	88
Civil engineering	Surface driver and complex	63	92	130
	Surface-to-underground tunnel	31	31	31
	Electron arm tunnel	44	59	75
	Positron arm and damping ring tunnels	54	77	106
	Beam-delivery systems	164	201	243
	Interaction region	154	154	154
Infrastructure and services	Electrical distribution	104	125	150
	Survey and alignment	80	96	116
	Cooling and ventilation	302	439	622
	Transport / installation	24	29	35
Machine control, protection and safety systems	Safety systems	30	36	43
	Machine control infrastructure	60	72	87
	Machine protection	6	7	9
	Access safety & control system	9	11	14
Total (in 2012 MILCU)		**3162**	**4090**	**5275**
Total (in 2024 Swiss francs)		**3.8 BCHF**	**4.9 BCHF**	**6.3 BCHF**

Cost model table (part 1)

Cost element (per length)	Cost/length (kILCU/m)	Length (m) 250 GeV	380 GeV	550 GeV	Ref.	Comment
Accelerating structures	115.00	2,052	3,102	4,474	CLIC	Assumed same for L- & S-band.
Damping rings	260.00	767	767	767	CLIC	Two rings in one tunnel.
Combiner ring	79.00	1,535	1,535	1,535	CLIC	Two rings in one tunnel.
Beam-delivery system	40.44	5,196	6,406	7,707	ILC	Doubled for dual IP
Post-BDS beamline	40.44	346	427	514	ILC	Costed as BDS.
Turn-arounds	40.44	213	213	213	ILC	Costed as BDS
Instrumented beamline	15.40	437	666	966	ILC	In between acc. structures.
Transfer line	15.40	6,087	7,294	8,732	ILC	Costed as instrum. beamline. Driver and e^+ transfer lines.
Plasma cells	46.20	375	570	825		$3\times$ instrumented beamline
Interstage optics	40.44	738	910	1095		Costed as BDS
Driver-distribution system (both sides of plasma linac)	40.44	2,226	2,960	3,840		Costed as BDS. One on each side of the plasma linac.
Tunnel (4.0 m inner diam.)	11.89	2,713	2,713	2,713	CLIC	Outer diameter 5.1 m. Surface-to-underground and turnaround.
Tunnel (5.6 m inner diam.)	20.19	560	560	560	CLIC	Outer diameter 6.7 m. Damping ring and e^+ source and injector.
Tunnel (8.0 m inner diam.)	37.15	4,951	6,525	8,403	CLIC	Outer diameter 9.1 m. e^- injector, plasma linac, e^+ RF linac, BDS.
Surface building	33.26	1,267	1,944	2,830	CLIC	Used for drive-beam linac
Cut-and-cover tunnel	9.86	2,035	2,712	3,597	CLIC	Used for drive-beam linac and combiner rings

Cost element (per volume)	Cost/volume (kILCU/m^3)	Volume (m^3) 250 GeV	380 GeV	550 GeV	Ref.	Comment
Tunnel (boring machine)	0.573	397,190	499,546	621,641	CLIC	Based on outer diameter.
Tunnel widening (excavation)	0.45	148,699	183,328	220,556	FCC	Used in dual BDS widening.
Cut-and-cover tunnel	0.45	44,589	59,423	78,814		Estimate based on tunnel area.

Cost model table (part 2)

Cost element (per power)	Cost/power (MILCU/MW)	Power (MW) 250 GeV	380 GeV	550 GeV	Ref.	Comment
Main beam dumps	2.39	12.8	19.5	28.2	ILC	
Driver dumps	2.39	4.8	7.3	10.6		Based on main beam dumps
LN2 re-liquification plant	13.5	2.5	3.9	5.8	C^3	Per power at cryo temp. (∼15% cooling eff. at 77 K)
Klystron (S-band)	0.009	20,787	31,173	44,775	C^3	Peak power
Modulator (S-band)	0.006	20,787	31,173	44,775	C^3	Peak power
Klystron (L-band)	0.015	8,528	13,137	19,165	CLIC	Peak power
Modulator (L-band)	3.9	42.8	66.0	96.3	CLIC	Average power

Cost element (individual)	Cost (MILCU)	Power (MW) 250 GeV	380 GeV	550 GeV	Ref.	Comment
Klystron (S-band, injectors)	0.351	21	21	21	C^3	39 MW peak, 28 kW avg.
Modulator (S-band, injectors)	0.234	21	21	21	C^3	39 MW peak, 28 kW avg.
Klystron (S-band, main linac)	0.603	298	453	656	C^3	67 MW peak, 38 kW avg.
Modulator (S-band, main linac)	0.402	298	453	656	C^3	67 MW peak, 38 kW avg.
Klystron (L-band, driver linac)	0.409	409	630	919	CLIC	21 MW peak, 105 kW avg.
Modulator (L-band, driver linac)	0.313	409	630	919	CLIC	21 MW peak, 105 kW avg.
Waveguides	0.0273	728	1,104	1,596	CLIC	Assumed same for L- & S-band
Low-level RF components	0.0455	728	1,104	1,596	CLIC	Assumed same for L- & S-band
Combiner ring RF kickers	1	6	6	6		Rough estimate (no source).
Polarized positron source	178	1	1	1	ILC	Helical undulator and target. ILC cost minus the RF injector.
Polarized electron source	82	1	1	1	ILC	Photocathode gun. ILC cost minus the RF injector.
Driver source	10	1	1	1		Thermionic gun with relaxed performance. Rough estimate only without source.
Dual IP interaction area	154	1	1	1	CLIC	
Experimental area	20	1	1	1	CLIC	