Expert Panel
High Gradient – Plasma & Laser Accelerators

Progress report to LDG

R. Assmann & E. Gschwendtner for the expert panel

21 Sep 2021

Reminder: Setup and Persons Involved, Mandate

Expert Panel “High Gradient: Plasma and Laser Accelerators”

Follow-up Panel to Europ. Strategy for Particle Physics
Panel proposes roadmap for use in Particle Physcis

Panel members:
Chair: Ralph Assmann (DESY/INFN)
Deputy Chair: Edda Gschwendtner (CERN)
Kevin Cassou (IN2P3/IJCLab), Sebastien Corde (IP Paris), Laura Corner (Liverpool), Brigitte Cros (CNRS UPSay), Massimo Ferarrio (INFN), Simon Hooker (Oxford), Rasmus Ischebeck (PSI), Andrea Latina (CERN), Olle Lundh (Lund), Patric Muggli (MPI Munich), Phi Nghiem (CEA/IRFU), Jens Osterhoff (DESY), Tor Raubenheimer (SLAC), Arnd Specka (IN2PR/LLR), Jorge Vieira (IST), Matthew Wing (UCL).

Panel associated members:
Cameron Geddes (LBNL), Mark Hogan (SLAC)), Wei Lu (Tsinghua U.) , Pietro Musumeci (UCLA)

Mandate:

- Develop a long-term roadmap for the next 30 years towards a HEP collider or other HEP applications.
- Develop milestones for the next 10 years taking explicitly into account the plans and needs in related scientific fields as well as the capabilities and interests of the stakeholders.
- Establish key R&D needs matched to the existing and planned R&D facilities.
- Give options and scenarios for European activity level and investment.
- Define deliverables until the next European strategy process in 2026, which allow deciding on the continuation of this R&D line for HEP.

Elaborate **consultation process** with 231 registered participants, 3 townhall meetings, > 60 talks and inputs.

Expert Panel Assessment

General considerations

- Advanced accelerators have made **important progress in demonstrating key aspects** of those technologies: energy and quality for laser/electron/proton driven
- **Rapid progress** in underlying technologies, e.g. lasers, feedbacks, nano-control, manufacturing, …
- **Feasibility of a collider remains to be proven:**
    - E.g. scheme for positrons in plasma accelerators still to be demonstrated on paper.
    - Staging designs for high energy remain to be calculated in detail and with all elements, including tolerances, length and cost scaling.
    - Repetition rate issues and efficiency approach to be investigated in detail.
- Therefore: **1st coordinated study to address feasibility** required (layout, theory and simulation). Complemented by **selected technical milestones** of relevance.

STRUCTURE

HIGH GRADIENT PLASMA AND LASER ACCELERATORS

Accelerator R&D Roadmap Pillars

FEASIBILITY, PRE-CDR STUDY

Scope: 1^{st} international, coordinated study for self-consistent analysis of novel technologies and their particle physics reach, intermediate HEP steps, collider feasibility, performance, quantitative cost-size-benefit analysis

Concept: Comparative paper study (main concepts included)

Milestones: Report high energy e^- and e^+ linac module case studies, report physics case(s)

Deliverable: Feasibility and pre-CDR report in 2026 for European, national decision makers

TECHNICAL DEMONSTRATION

Scope: Demonstration of critical feasibility parameters for e^+e^- collider and 1^{st} HEP applications

Concept: Prioritised list of R&D that can be performed at existing, planned R&D infrastructures in national, European, international landscape

Milestones: HQ e^- beam by 2026, HQ e^+ beam by 2032, 15 kHz high eff. beam and power sources by 2037 (sustainability)

Deliverable: Technical readiness level (TRL) report in 2026 for European, national decision makers

INTEGRATION & OUTREACH

Synergy and Integration: Benefits for and synergy with other science fields (e.g. structural biology, materials, lasers, health) and projects (e.g. EuPRAXIA, …)

Access: Establishing framework for well-defined access to distributed accelerator R&D landscape

Innovation: Compact accelerator and laser technology spin-offs and synergies with industry

Training: Involvement and education of next generation engineers and scientists

Common coordinated pre-CDR study for particle physics

(2 MCHF/year personnel funding, 2022 - 2026, 5 years)

2022 - Setup of **simulation tools for electron case studies** (multi-stage) **See talk Jorge Vieira**	**Electron beam physics and simulation models** with certain approximations for 2 or more stages, all interconnections, in/out-coupling, for 15 GeV and 190 GeV, including synchrotron radiation and collective effects
2023 - Setup of **simulation tools for positron case studies** (multi-stage) **See talk Jorge Vieira**	**Positron beam physics and simulation models** with certain approximations for 2 or more stages, all interconnections, in/out-coupling, for 15 GeV and 190 GeV, including synchrotron radiation and collective effects
2024 - DELIVERABLE: Report **electron high energy** case study **See talk Edda Gschwendtner**	**Multi-stage electron accelerator from 175 GeV to 190 GeV**, including full lattice, in/out-coupling, all magnetic elements, correctors, diagnostics, collective effects, synchrotron radiation, estimate of **realistic performance**, estimate of realistic footprint, **estimate of realistic benefits in cost and size**, understanding of **scaling with beam energy for different technologies** (laser-driven, electron-driven, proton-driven, DLA/THz).

Common coordinated pre-CDR study for particle physics

(2 MCHF/year personnel funding, 2022 - 2026, 5 years)

2024 - DELIVERABLE: **Physics Case of an Advanced Collider**	Report from common study group with particle physicists on physics cases of interest at the energy frontier (e+e- collider, gg) and at lower beam energies (e- g collider, dark matter search, …)
2025 - DELIVERABLE: Report **positron high energy** case study See talk Edda Gschwendtner	**Multi-stage positron accelerator from 175 GeV to 190 GeV**, including full lattice, in/out-coupling, all magnetic elements, correctors, diagnostics, collective effects, synchrotron radiation, estimate of **realistic performance**, estimate of realistic footprint, **estimate of realistic benefits in cost and size**, understanding of **scaling with beam energy for different technologies** (laser-driven, electron-driven, proton-driven, DLA/THz).
2025 - DELIVERABLE: Report **low energy study cases** for electrons and positrons	Assessing the **low energy regime** around 15-50 GeV, achievable performance, foot print and cost, **schemes and designs for first particle physics experiments** with novel accelerators, needed R&D demonstration topics for low energy design and needed test facilities
2026 - Study of **spin** preservation and beam-**disruption** mitigation strategies for a plasma-based collider	Assessment of **IP issues** in an advanced collider with ultra-short bunches, benefits for disruption, possibility for spin polarized beams

Common coordinated pre-CDR study for particle physics

(2 MCHF/year personnel funding, 2022 - 2026, 5 years)

2026 - DELIVERABLE: **Pre-CDR and Collider Feasibility Report**	**Input for decision point of European strategy**, brings together work/reports achieved (see earlier). Complemented by report on Technical Readiness Levels (TRL report) for collider components and systems. Preliminary physics case report. **Comparison of performance and readiness for different technologies** (laser, electron, proton driven plasma, DLA/THz) for a possible focus on the most promising path for particle physics. Design of a staging experiment. Report on intermediate steps and need for a dedicated facility. Project plan for a CDR of an advanced collider.

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1.1 Findings: Milestones and Deliverables 2021 - 2024

2021: High quality beams: electron-driven plasma acceleratoı tion of FEL-SASE and seeded exponential growth at 83

– High-quality beams: Laser-driven plasma acceleratoı Demonstration of FEL-SASE at SIOM [2]

2022: Numerical and Theoretical Tools ⟶ Setup of simula stages) with certain approximations

2023: High-quality beams: Laser-driven plasma accelerator-b sion laser-driven plasma FEL site EuPRAXIA

– Positron technical demonstrations ⟶ Demonstration tance, 2% energy spread) positron beam from a plasma MeV level.

– Numerical and Theoretical Tools ⟶ Setup of simula stages) with certain approximations

– Hybrid laser-beam driver schemes: demonstration, stal schemes ⟶ Realization of tuneable PWFA internal i plasma photoguns

– Dielectric accelerator module with high quality beam f MeV beam

2024: Dielectric accelerator module with high quality beam fc tion code capable of simulating a billion accelerating ce

– Hybrid laser-beam driver schemes: demonstration, stal schemes ⟶ Demonstration of emittance and brightnes compared to the initial LWFA output

– High-quality LWFA injector ⟶ Models for nC-level, l validated by simulations

– Advanced plasma photoguns with ultra-low emittance normalized emittance

– High quality beams: electron-driven plasma accelerato tion of FEL saturation at short wavelength (<830 nm)

– Polarized electrons ⟶ Demonstration of polarized ele ization fraction

– Plasma lens R&D ⟶ Demonstration of focusing effe GeV energy range

2024: **DELIVERABLE** ⟶ Report electron high energy cas tron accelerator, cost and footprint) and physics case

1.2 Findings: Milestones and Deliverables 2025 - 2026

2025: Plasma lens R&D ⟶ Development and demonstrati with plasma lenses

– High quality beams: electron-driven plasma accelerat Technical Design Report ready

– High-quality LWFA injector ⟶ Experiments, optimi repetition rate at existing facilities

– Dielectric accelerator module with high quality beam f for applications outside HEP and design and simulate

2026: Plasma lens R&D ⟶ Integration of plasma lenses in

– Advanced plasma photoguns with ultra-low emittance emittance beams with collider-level energy spread and

– Numerical and Theoretical Tools ⟶ Study of spin p strategies for a plasma-based collider

– High average power, high efficiency laser drivers anc laser for driving a high repetition rate test beamline fa

– Positron technical demonstrations ⟶ Demonstrati plasma wake-field at the 1 GeV level

– Development of plasma sources for high-repetition ra sential physics questions, e.g. wakefield process effici

– Dielectric accelerator module with high quality beam late a linear collider at the energy frontier

– High-quality beams: Laser-driven plasma accelerator- PRAXIA Technical Design Report ready

– Proton-driven plasma wakefield acceleration: demons trol, scalability ⟶ Until 2026 AWAKE plans to dem process with an electron bunch and optimize the proces density step to accelerate electrons to multi-GeV ener

– High transformer ratio PWFA for high efficiency and tion over many betatron periods in a plasma module w drive energy), high total efficiency (30% driver to witn the 1 µm level), and narrow energy spread (0.1%)

2026: **DELIVERABLE** ⟶ Pre-CDR and Collider Feasibil by report on Technical Readiness Levels (TRL report) to next **Update of European Strategy for Particle Pl**

1. High-gradient Plasma and Laser Accelerators

1.3 Findings: Milestones and Deliverables 2027 - 2030

2027: Hybrid laser-beam driver schemes: demonstration, sta schemes ⟶ Demonstration of advanced sources such

– Advanced plasma photoguns with ultra-low emittance high-charge (100's of pC to nC, moderate to extreme normalized emittance

– High-quality LWFA injector ⟶ Experimental demon $f_{rep} \leq 100$ Hz

– Staging of electron plasma accelerators including in- ar staging at 5 GeV. Extend the design to its use at 50 G plasma lenses

– Staging of electron plasma accelerators including in- plasma lenses for the high energy beams of 50 GeV an

2028: Advanced plasma photoguns with ultra-low emittance low emittance electron beams from plasma photocatho

– Dielectric accelerator module with high quality beam and feedbacks for DLA: measurement of orbit and prof

– Numerical and Theoretical Tools ⟶ Demonstration stable and efficient numerical models

2029: High quality beams: electron-driven plasma accelera beam-driven EuPRAXIA facility at Frascati in operatic

2030: High average power, high efficiency laser drivers and wavelength (few kW) [3]: pulse energy 50-100J, repeti energy stability (RMS) 0.6–1%, pointing stability (RM

– Dielectric accelerator module with high quality beam fc laser sources, alignment of structures and develop a co

– High-quality beams: Laser-driven plasma accelerato demonstration fully saturated FEL at LUX. EuPRAXIA

– Proton-driven plasma wakefield acceleration: demonst trol, scalability ⟶ In the next 10 years AWAKE ai electron witness bunch to 10 GeV in 10 m with contro the 10 mm-mrad level and percent energy spread, to long, and to demonstrate acceleration in a scalable pla 100 GeV energies

– Plasma lens R&D ⟶ Demonstration of a transversely rection

– High transformer ratio PWFA for high efficiency and l transformer ratio while mitigating beam-plasma instabi

– Numerical and Theoretical Tools ⟶ Start-to-end simu

1.4 Findings: Milestones and Deliverables 2030 - 2037

2030+: Proton-driven plasma wakefield acceleration: demonst trol, scalability ⟶ Starting in 2030, by the successful ready for first high-energy physics applications [5–7]. tion technology could be used in fixed target experime future electron-proton or electron-ion colliders at very acceptable

2031: Polarized electrons ⟶ Increase of the polarization fra

2032: High-quality LWFA injector ⟶ Experimental demoı $f_{rep} > 1$ kHz

– High average power, high efficiency laser drivers and ducing multi-GeV beam energies at kHz rates

2034: Staging of electron plasma accelerators including in- and test complete transfer lines at 50 GeV and 180 GeV

2035: High average power, high efficiency laser drivers and efficient laser for HEP collider stages

– Development of plasma sources for high-repetition rate, technology as close as possible towards that working p for iterative plasma-source development will be require repetition-rate plasma accelerator research. Each iterat with sustained operation at a repetition rate conducive w e.g. 10 kHz.

– Development of plasma sources for high-repetition rate, per stage are pushed into the relevant multi−10 to 1 consistent with the outcome of the proposed conceptual

2037: High-quality LWFA injector ⟶ Experimental demoı $f_{rep} > 10$ kHz

Thank you

Input and findings: **56 proposed milestones and deliverables for R&D until 2037**. To be discussed further and prioritized in next step of the roadmap process.

Evaluation

No.	Criterion	Sub-criterion	Evaluation points
1	**Impact on Future Particle Physics Infrastructures**		**0 - 6**
a		*Importance for achieving required performance parameters (integrated luminosity, background, …)*	*0, 1, 2*
b		*Importance for removing potential road-blocks, building intermediate demonstration steps*	*0, 1, 2*
c		*Importance for sustainability (energy consumption, facility size, environmental impact, ...)*	*0, 1, 2*
2	**Feasibility of the proposed R&D project**		**0 - 4**
a		*Scientific & technical readiness*	*0, 1, 2*
b		*Existing funding support*	*0, 1, 2*
3	**Strategic importance**		**0 - 6**
a		*Relevance for next European Strategy decisions*	*0, 2, 4*
b		*Importance for national, regional and European strategies*	*0, 1, 2*

Expert Panel Identified 9 Draft Technical Milestones

until Next Strategy Update in 2027

- Panel used the input received (many thanks again), evaluation criteria and expert assessment
- We tried to identify milestones of **importance for particle physics** – aimed to address needs and to build trust
- Milestones should be **detailed, realistic and achievable by 2026**
- Milestones should convince particle physics in 2027 that our field **achieved the agreed goals and is on a good track** towards demonstrating a collider and intermediate particle physics experiments
- Will present **draft milestones** in the following: comments and suggestion for final process are invited

Particle Physics Interest – See Collider Goals

provide e^- and e^+ beams in the TeV energy regime and produce > 10^{34} cm^{-2} s^{-1} luminosity

Parameter	Unit	PWFA	LWFA	DLA
Bunch charge	nC	1.6	0.64	4.8×10^{-6}
Number of bunches per train	-	1	1	159
Repetition rate of train	kHz	15	15	20,000
Convoluted normalized emittance ($\gamma\sqrt{\epsilon_h\epsilon_v}$)	nm-rad	592	100	0.1
Beam power at 5 GeV	kW	120	48	76
Beam power at 190 GeV	kW	4,560	1,824	2,900
Beam power at 1 TeV	kW	24,000	9,600	15,264
Relative energy spread	%		$\leq$0.35	
Polarization	%		80 (for e^-)	
Efficiency wall-plug to beam (includes drivers)	%		>10	
Luminosity regime (simple scaled calculation)	$10^{34}cm^{-2}s^{-1}$	1.1	1.0	1.9

from expert panel interim report

How and when can we arrive at readiness for for high energy particle physics?

Milestones Plasma Beam Sources (towards collider needs)

Topic	**Funding (material budget)**	**Needed funding**	**Milestones to be achieved by 2026**	**Far term goal**
Compact, stable **electron beam source** for plasma accelerators (scalable to collider rep rate of 15 kHz)			Electron beam with 50-250 MeV, 10-100 Hz, sub-micron emittance, 30-100 pC	15 kHz, >500 pC, <100nm emittance, fs bunch
Compact, stable **positron beam source** for plasma accelerators (possibly scalable to collider rep rate of 15 kHz) **See talk Gianluca Sarri**			Positron beam with 10 MeV, 5-10 micron emittance, 4% energy spread, 1 pC	15 kHz, >500 pC, <100nm emittance, fs bunch

Milestones Plasma Accelerator Module (towards collider needs)

Topic	**Funding (material budget)**	**Needed funding**	**Milestones to be achieved by 2026**	**Far term goal**
High repetition rate plasma accelerator module (scalable to collider rep rate of 15 kHz)			At least 1 kHz characterized, robust lifetime (>1e9 shots), only plasma cell, w/o full rep rate beam test, include cooling - power handling assessment	15 kHz repetition rate
High efficiency, electron-driven plasma accelerator module (scalable to 50% efficiency in energy transfer)			Beam demonstration of high efficiency PWFA module, excited by a train of drivers	50% transfer efficiency from stored energy beam driver to stored energy beam witness
High charge, high quality plasma accelerator module, driven by laser pulses (scalable to 1 nC)			Energy >500 MeV, charge 500 pC, sub % energy spread, micron normalized emittance (tests including LWFA injection)	accelerator module with 1 nC high quality beam (outcome
Scalable plasma source (rowards several metres length)			Several metres long prototype with required plasma density and stability.	10s to 100s metres of plasma source

See talk Arie Irman

Milestone Plasma Laser Driver (towards collider needs)

Topic	**Funding (material budget)**	**Needed funding**	**Milestones to be achieved by 2026**	**Far term goal**
High repetition rate, high peak power **laser**			Demonstration of kW average power (e.g. 100Hz, 10J, <100fs or 1kHz, 1J , <100fs or another combination/scheme) Ti:sapp laser pulse	15 kHz rep rate, >100 Tera-Watt, 30% wall plug efficiency

Milestone Plasma Spin Polarization (towards collider needs)

Topic	Funding (material budget)	Needed funding	Milestones to be achieved by 2026	Far term goal
Spin polarized beams for a plasma-based collider (proof of principle)			Demonstration of polarized electron beams from plasma with 10-20% polarization fraction	Polarization 85%

Milestone DLA/THz Accelerator (towards collider needs)

Topic	**Funding (material budget)**	**Needed funding**	**Milestones to be achieved by 2026**	**Far term goal**
Scaling of DLA/THz accelerators for high energy			Dielectric 10 MeV with increased acceleration length and at least 2 stages	massively scalable many stage (1e6) design printed on a chip

Complemented by US Programs

See talk Pietro Musumeci

Facility or Project	Funding (material budget, maybe plus pre-invest)	Milestones that might be achieved by 2027, in time for next European strategy update (relevant for PP)	Milestones that might be achieved beyond 2027 (relevant for PP)
BELLA (LBNL, US)		**Multi-GeV electron staging of two LPA modules with high coupling efficiency and emittance preservation**; **10 GeV high-quality electron beams from a single stage**; high brightness electron beams from laser-triggered injection; active feedback stabilization of LPA with machine learning/AI techniques; **high efficiency multi-kHz lasers** to the few hundred mJ level; studies of positron capture and acceleration in plasmas; demonstration of LPA-driven light sources (XUV FEL, gamma-ray Thomson source); **conceptual design studies of a plasma-based colliders**.	**High efficiency multi-kHz lasers** at the J level and beyond; operation of a user facility based on multi-kHz LPA; R&D to further improve electron beam quality and stability from LPAs; **positron acceleration and staging** in plasmas; science experiments using LPA-driven sources of particles and photons; integrated design studies of plasma collider.
FACET-II (SLAC, US) See talk Mark Hogan for e+		Single plasma stage with combined parameters: **10 GeV energy gain** of witness bunch in one meter plasma, normalized emittance preservation at few micron level, percent level energy spread and **>30% overall energy transfer** from drive to witness bunch; Development of ultra-high brightness plasma-based injector with **10's nm emittance** as proxy for collider level emittance beams; characterize mechanisms for emittance growth in PWFA and demonstrate mitigations; measurement of plasma target recovery time to inform maximum repetition rate in collider designs; development of single shot ML/AI virtual diagnostics for extreme beams; construction of **facility upgrade to deliver 10GeV positrons and electrons** to experimental area	Commissioning of facility upgrades that deliver 10 GeV electrons and positrons to the experimental area within one plasma period for studies of **electron-driven plasma acceleration of positrons**

Complemented by Milestones in **Ongoing Projects**

aimed at other applications (synergy) and funded from other science fields

Facility or Project	**Funding** (material budget, maybe plus pre-invest)	**Milestones that might be achieved by 2027, in time for next European strategy update (relevant for PP)**	**Milestones that might be achieved beyond 2027 (relevant for PP)**
APOLLON (France)	**60-100 M€**	Feasibility study of **LWFA electron source at 100pC level**, tunable energy range up to GeV, physics study of positron source from LWFA electrons	*none scheduled [potential for demonstration of 10 GeV LWF acceleration module, and **2 stage multi-GeV** experiment, effective implementation is limited by insufficient laser beam availability for this type of program]*
AWAKE (CERN)		Demonstrate the **seeding of the self-modulation process** with an electron bunch. Optimize the process of generation of wakefields using a plasma density step to maintain large wakefields at the GV/m level and **accelerate electrons to multi-GeV** energies.	*Demonstrate the acceleration of an electron witness bunch **to 10GeV in 10m** with control of the incoming normalized emittance at the 10mm-mrad level and percent energy spread. Develop scalable plasma sources 50–100 m long, and demonstrate acceleration in a scalable plasma source (helicon or discharge) to **50 to 100 GeV** energies.*
EuPRAXIA (European, ESFRI project)	**569 M€** (110 M€ secured)	**TDR** for plasma electron accelerator, FEL and positron user facility. Report from EU funded **preparatory phase project** (laser-based site, legal model, financial model, access rules, innovation model).	*2029: Electron beam-driven EuPRAXIA FEL at Frascati in **operation with users**. 2030: EuPRAXIA laser-driven facility operates at several GeV with **users**. EuPRAXIA laser at 800nm wavelength (few kW) [3]: pulse energy 50-100J, repetition rate 20-100Hz, pulse duration 50-60fs, energy stability (RMS) 0.6–1%, pointing stability (RMS) 0.1 μrad. **Two stage, 5 GeV** HQ e- bunch, FEL operation.*

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SPARC-LAB (Italy)	**7 M€** (6 M€ secured)	*1)* ***High efficiency, electron-driven plasma accelerator module***, (driven by a train of 4 Drivers, with ramped bunch charge, total charge up to 300 pC, GV/m accelerating gradient, fs scale synchronization). *2)* ***High repetition rate plasma accelerator module*** (off-line capillary discharge/vacuum system characteriszation at kHz repetition rate) *3)* ***High charge, high quality plasma accelerator module, driven by laser pulses*** (LWFA module with external electron bunch injection suitable to test also staging configuration with fs scale synchronization)	To be defined in the framework of EuPRAXIA@SPARC_LAB collaboration
CLARA (UK)	**£33.4 M** (£27.9 M secured)	**2023:** CLARA Phase 2 + FEBE beamline construction completed. **2024:** Beam commissioning and first user access period completed. **2024-2027:** user-led science programme with programmatic access: 1) plasma acceleration (**beam-driven wakefield, external injection laser-driven wakefield**) and **structure wakefield acceleration**; 2) post-acceleration beam capture and 6D phase-space characterisation; 3) tailored multi-bunch delivery to FEBE for beam-driven acceleration; 4) **beam-driven acceleration at 400 Hz**.	**2027+:** Demonstration of plasma-driven FEL on FEBE beamline.
PALLAS (France)	**10.86M€** (8.45M€ secured) for phase 1	**phase 1 : high quality laser-plasma electron injector for staging**, 10Hz, 10-50pC, 150-250MeV, ≤1um emn, conceptual design study for 1 stage > 1 GeV, preparing post 2027	**phase 2** : laser driven **staging at GeV level**, 10Hz level depending of budget possibilty.

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DESY-KALDERA (Germany)		**kW-average power drive laser (1J@1kHz)** for LPA; application-ready LPA injector: GeV-scale energy, sub-percent energy spread, kHz level electron beams; pilot-application soft-X-ray FEL; active feedback/feedforward stabilization (including machine learning techniques)	
DESY-FLASHForward (Germany)		**Single, beam-driven plasma-booster stage** with beam-quaity preservation at 0.1% energy spread, 2 μm norm. emittance, 40% overall efficiency at the 1 to 2 GeV energy level and 100 pC witness charge (**FEL quality**); exploration of plasma physics for the kHz to GHz repetition rate regime; development of high-average power plasma sources; active feedback / feedforward stabilization (including machine learning techniques)	Booster stage average power extended to 10 kW level drive beam in ILC-like bunch pattern; application as FEL booster module for FLASH to extend photon science reach
DESY-PETRA-IV Plasma injector (The Moon Shot) (Germany)			**6 GeV LPA PETRA-IV injector** with sub-1% energy bandwidth-jitter-envelope, 24/7 operation, and up to 3.2 nC / s charge delivery
DESY-The Mars Shot (Germany)			**~10 stage**, self-stabilized, scalable plasma accelerator in the **10 - 20 GeV** range to drive a hard X-ray FEL and LUXE-style nonlinear QED studies

Complemented by Milestones in **Ongoing Projects**

aimed at other applications (synergy) and funded from other science fields

Facility or Project	**Funding** (material budget, maybe plus pre-invest)	**Milestones that might be achieved by 2027, in time for next European strategy update (relevant for PP)**	**Milestones that might be achieved beyond 2027 (relevant for PP)**
ELI (European)			
EPAC (UK)			
HZDR (Germany)			
CLEAR (CERN)			
CALA (Germany)			
SCAPA (UK)			
Your (the missing facility)			
…			

Still collecting input…

Please contact us for EXCEL template if you want to add a relevant facility

Conclusion

- We presented the **draft structure of our roadmap** „high gradient plasma and laser accelerators“for particle physics
- Highest priority: **Coordinated feasibility study for high energy physics** – quite some paper work to be done (minimum requirement: it must work on paper and in simulation).
  - This **must be an international, common effort with US and Asia**. Report by 2027.
- Complemented by:
  - **Nine detailed technical R&D milestones** to be achieved by 2027, in time for the next European stratgey.
  - **US program** with additional (complementary) milestones.
  - Milestones in **ongoing advanced accelerator projects and/or facilities**.
- Here: only quick run through (apologies): → Edda will give some detail on some of our roadmap components.

Thank you for your attention!