Proton-Driven Experiments at AWAKE: Roadmap Related Activities

ALEGRO 2023 Workshop

22 – 24 March 2023

Edda Gschwendtner, CERN

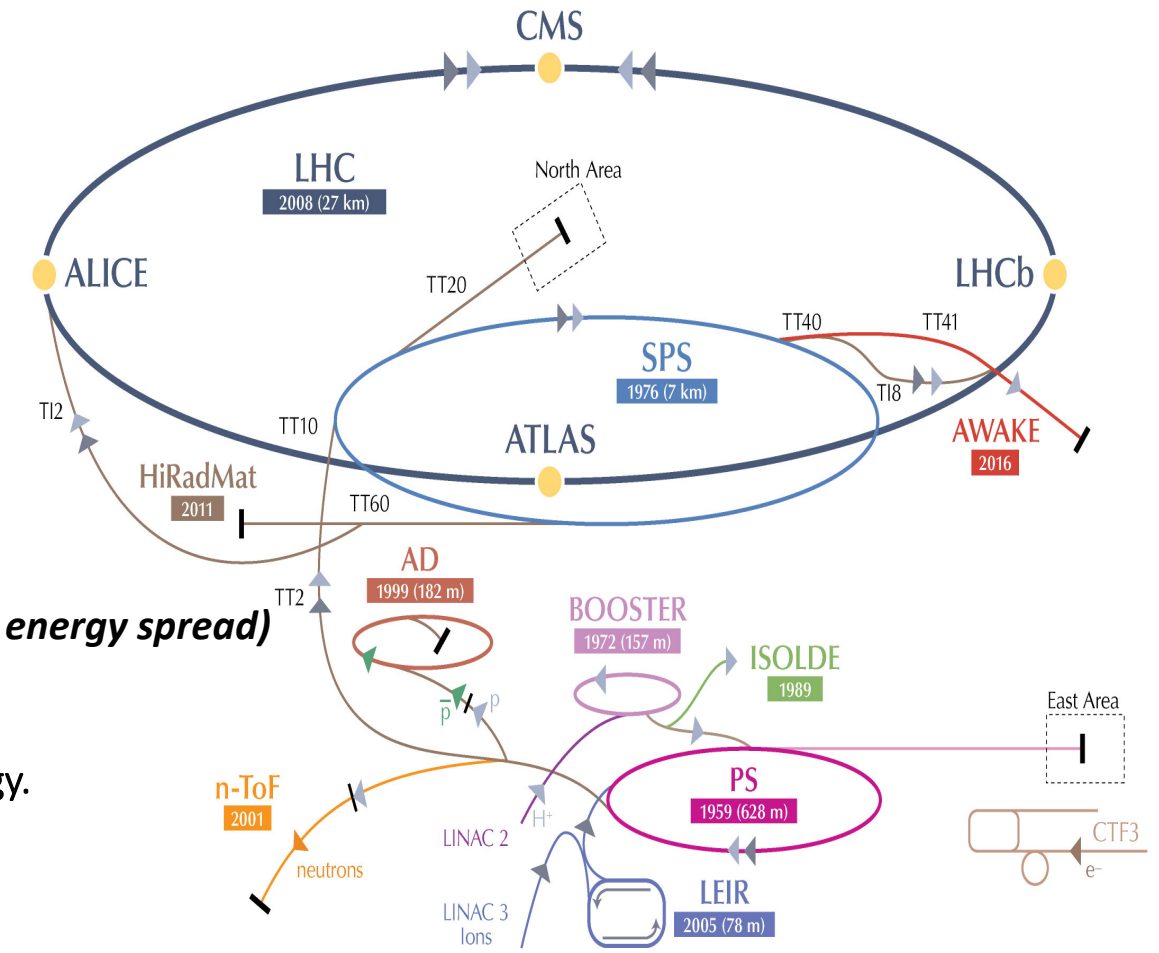
Patric Muggli, MPP

AWAKE at CERN

➔AWAKE is an international Collaboration, consisting of 23 Institutes.

➔Developed a clear scientific roadmap towards first particle physics applications within the next decade.

➔In AWAKE many general issues are studied, which are relevant for concepts that are based on plasma wakefield acceleration.



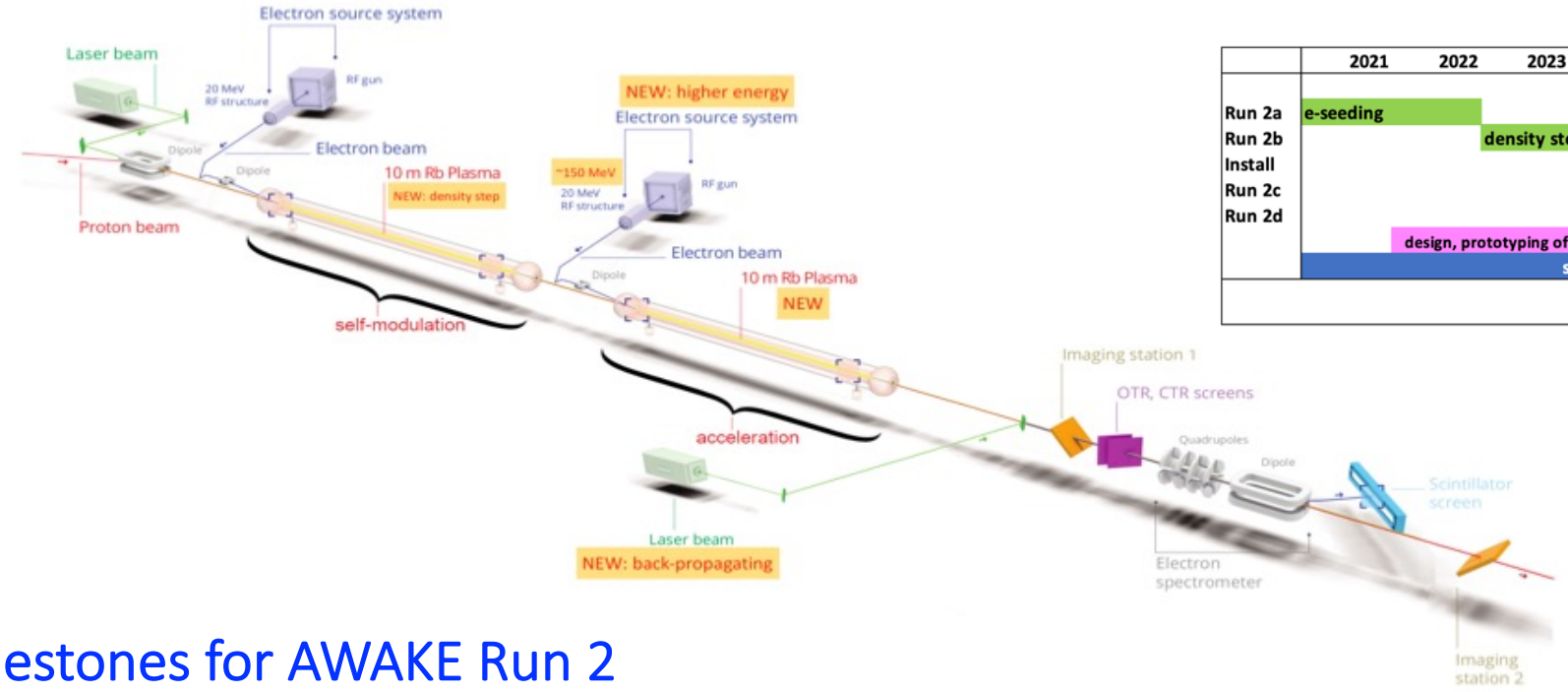
AWAKE Run 2 (2021 – ~2029) Goals:

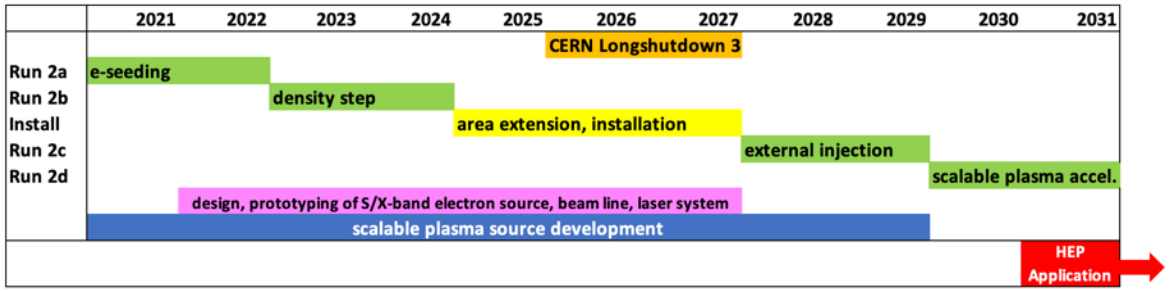
- Accelerate an ***electron beam to high energies (gradient of 0.5-1GV/m)***
- while controlling the ***electron beam quality (1-10 mm-mrad emittance, 10% energy spread)***
- demonstrate ***scalable plasma source technology.***

Once AWAKE Run 2 demonstrated: First application of the AWAKE-like technology.

➔ *develop physics case for particle physics experiments*

AWAKE Run 2 Scientific Roadmap – Milestones





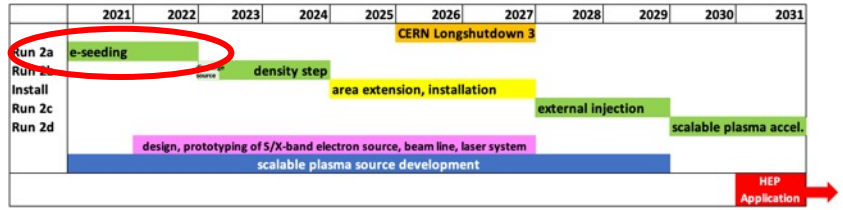
Milestones for AWAKE Run 2

✓ Run 2a (2021-2022): demonstrate the ***seeding of the self-modulation of the entire proton bunch with an electron bunch***

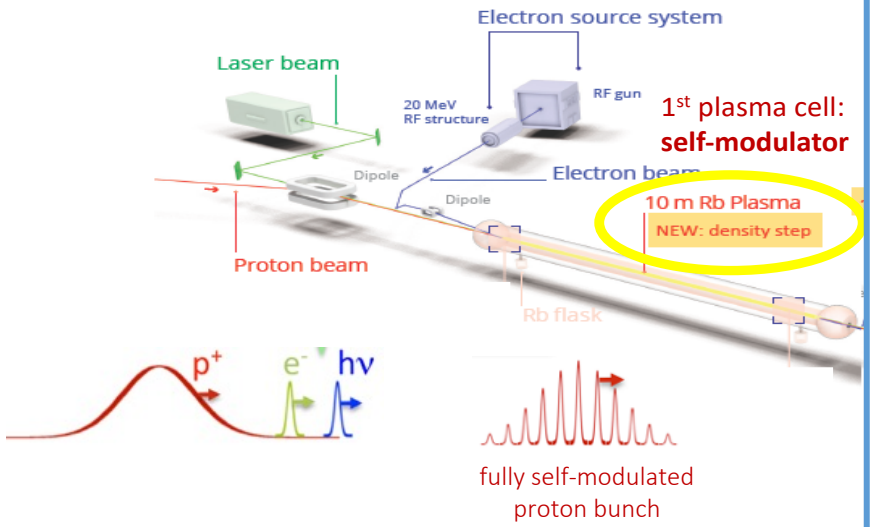
- Run 2b (2023-2024): ***maintain large wakefield amplitudes*** over long plasma distances by introducing a step in the plasma density
- *CERN Long Shutdown LS3 (2025-2027): CNGS dismantling, installation of Run 2c*
- Run 2c (2028-2029): demonstrate ***electron acceleration and emittance control of externally injected electrons***.
- Run 2d (2021-): ***development of scalable plasma sources to 100s meters length with sub-% level plasma density uniformity.***

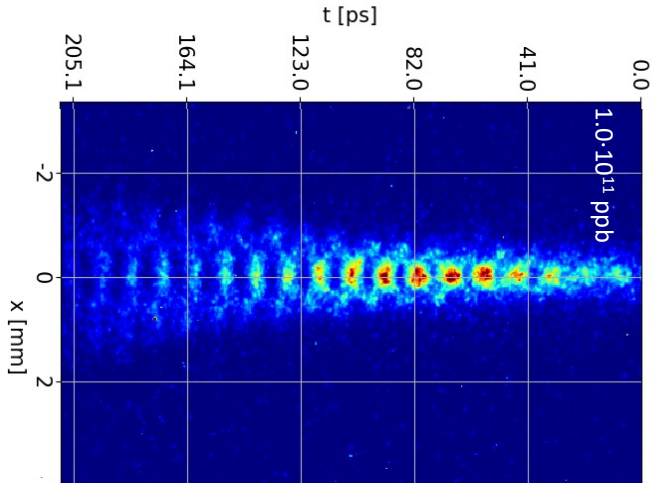
➔ Propose first applications for particle physics experiments with 50-200 GeV electron bunches!

AWAKE Run 2a



➔ ***Demonstrate electron seeding of self-modulation in first plasma cell with phase reproducibility***. ✓

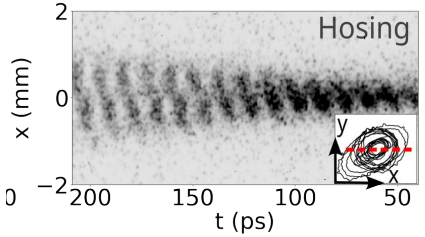




L. Verra et al. (AWAKE Collaboration), Phys. Rev. Lett. 129, 024802 (2022)

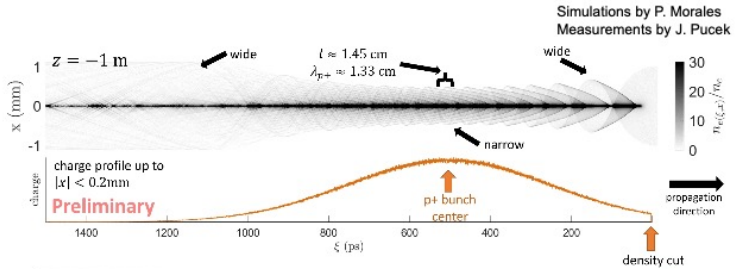
Other Key Challenges:

➔ ***Hosing Instability***

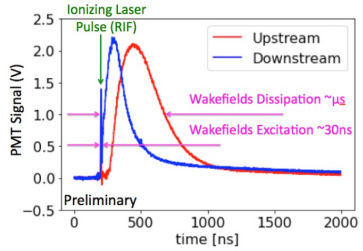


T. Nechaeva, MPP, paper in preparation

➔ ***Plasma Density Ramp***

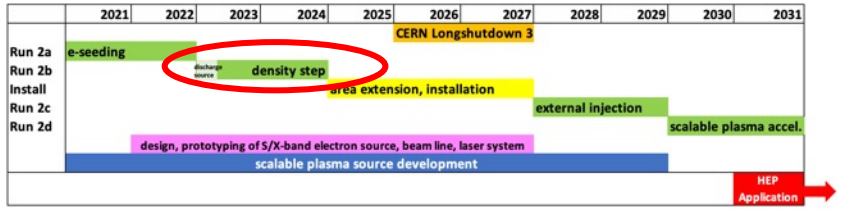


➔ ***Plasma Light***

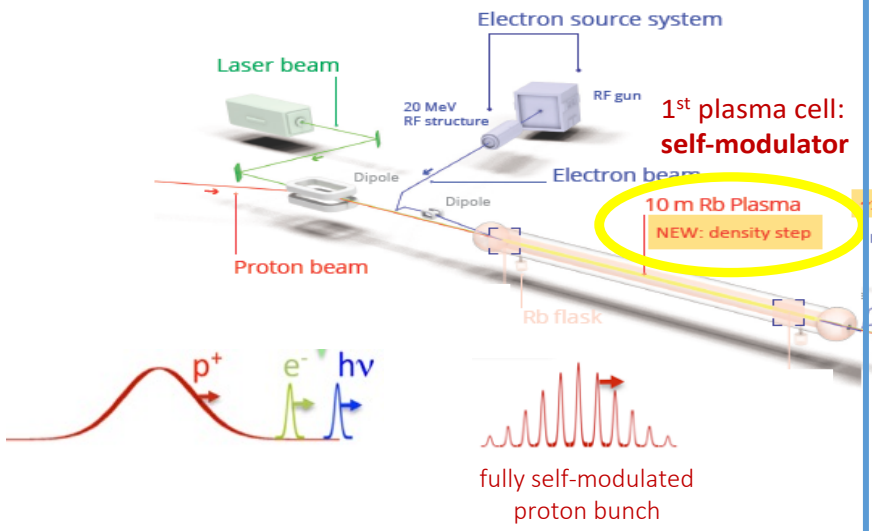


J. Pucek, M. Bergamaschi, MPP

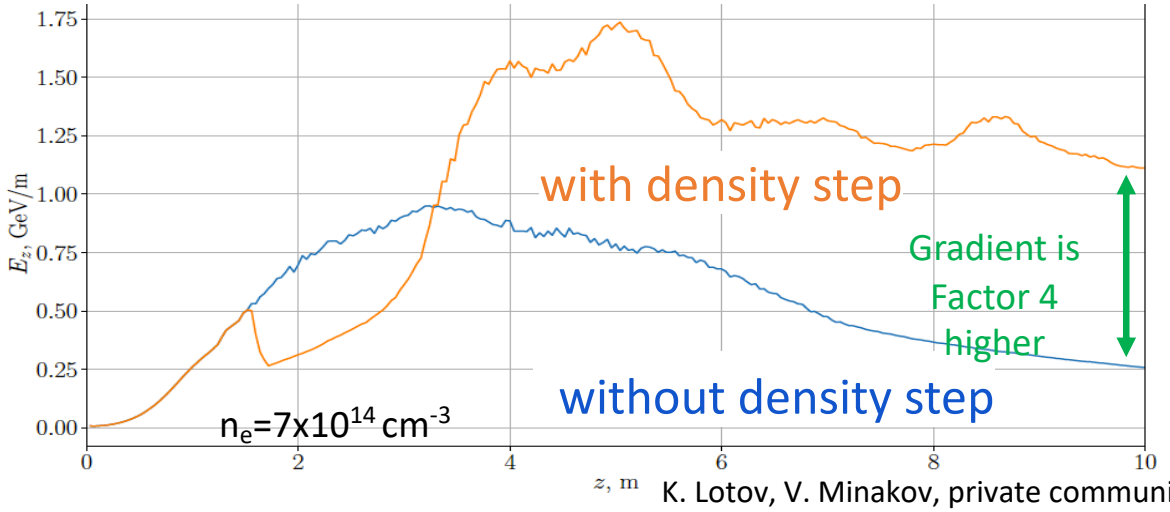
AWAKE Run 2b (2023/24)



Maintain large wakefields



Gradient in 1st plasma source (self-modulator)



K. Lotov, V. Minakov, private communication

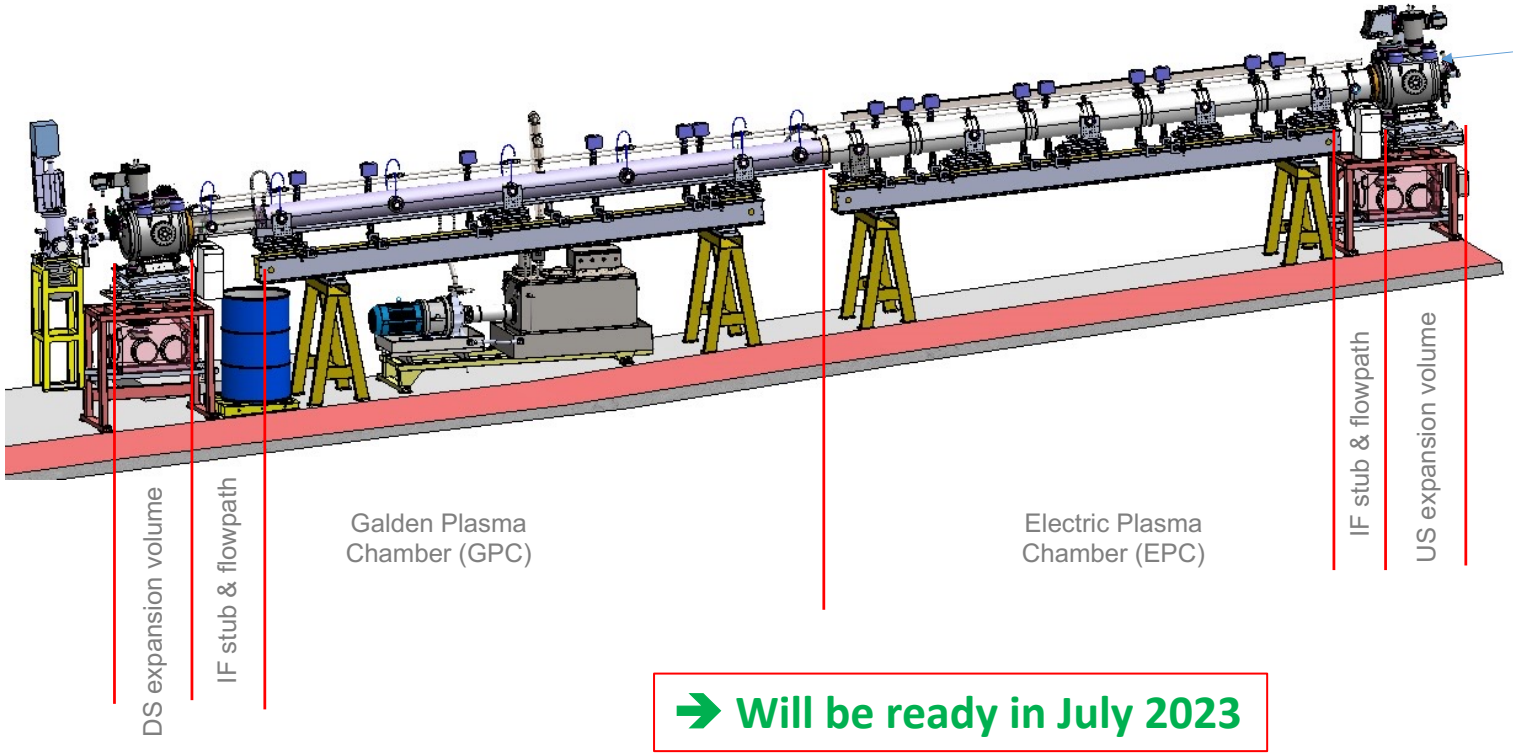
→ In constant-density plasma, wakefield amplitude decreases after saturation.

→ In a plasma with density step within the SM grow: wakefield amplitude **maintains larger** after saturation.

Run 2b (2023-2024) – New Plasma Source with Density Step

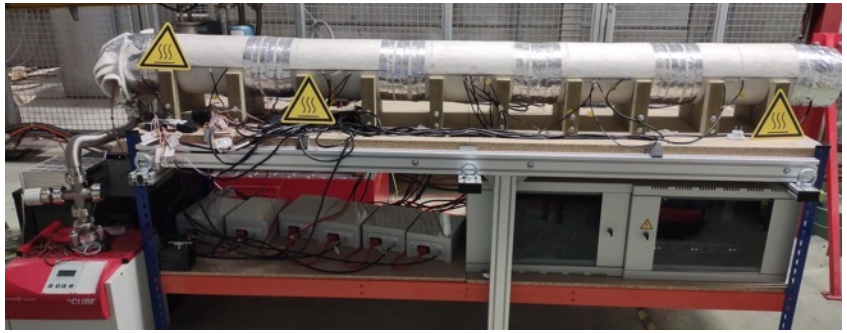
New Rubidium vapor source designed and under construction now.

MPP Munich and WDL, UK



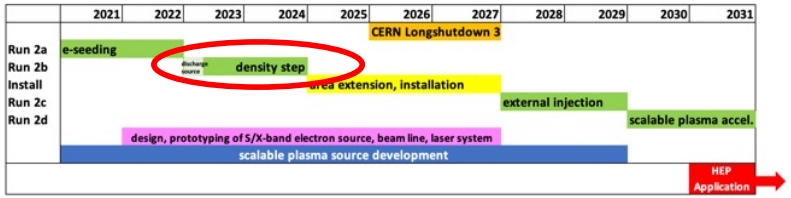
➔ **Will be ready in July 2023**

Stand alone prototype tested at CERN in 2021



M. Bergamaschi, P. Muggli, J. Pucek, MPP & WDL

- Length: ~ 10 m
- Independent electrical heater of 50 cm from 0.25 to 4.75 meters
- 5.3m of galden heated section
- Step height up to ±10%
- 10 diagnostic viewport, for plasma light + 3 for density diagnostic

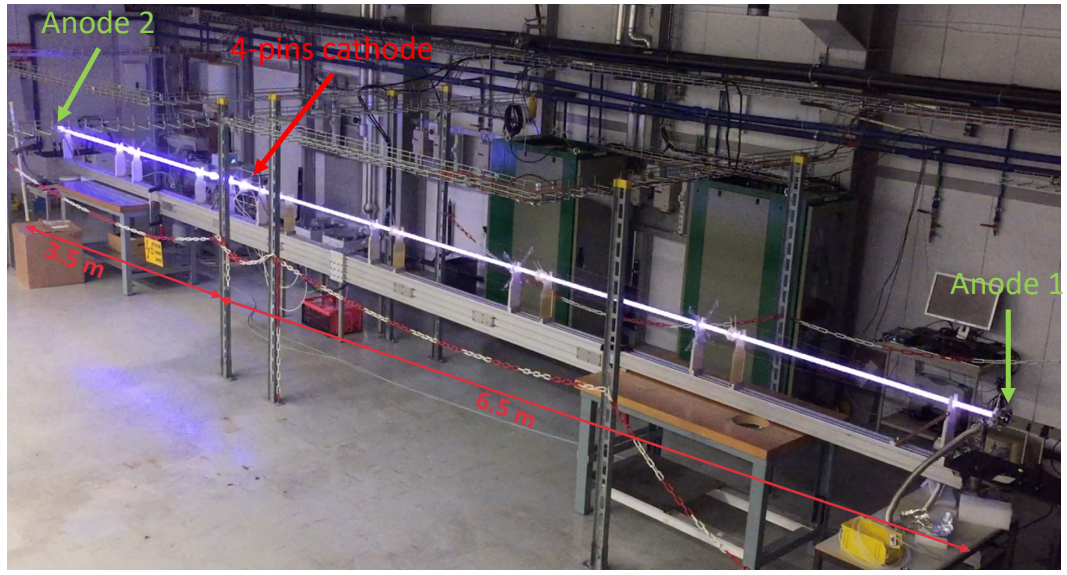


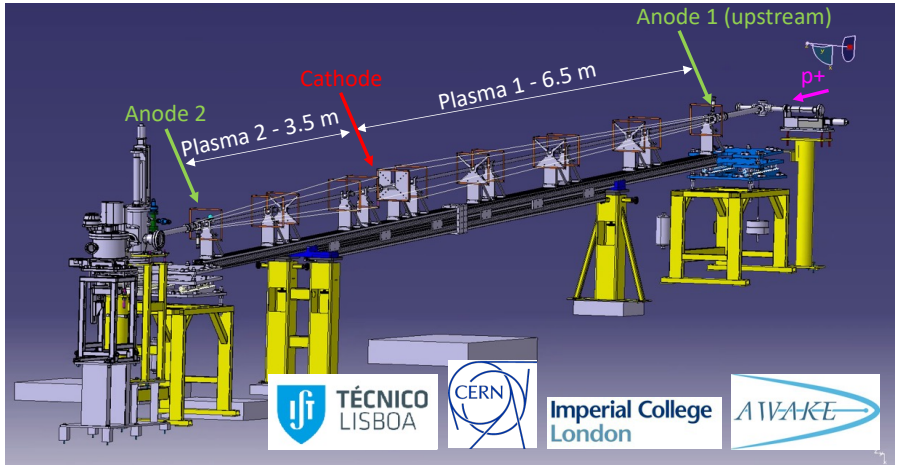
Discharge Plasma Source Tests in May 2023

R&D on ***scalable, several-meter long plasma sources***: discharge plasma and Helicon plasma sources.

Discharge Plasma Source (DPS): possible candidate for 2nd plasma source in Run 2c/d

Unique run in May 2023 with the discharge plasma source. Run is finished after 3 weeks, no 2nd chance

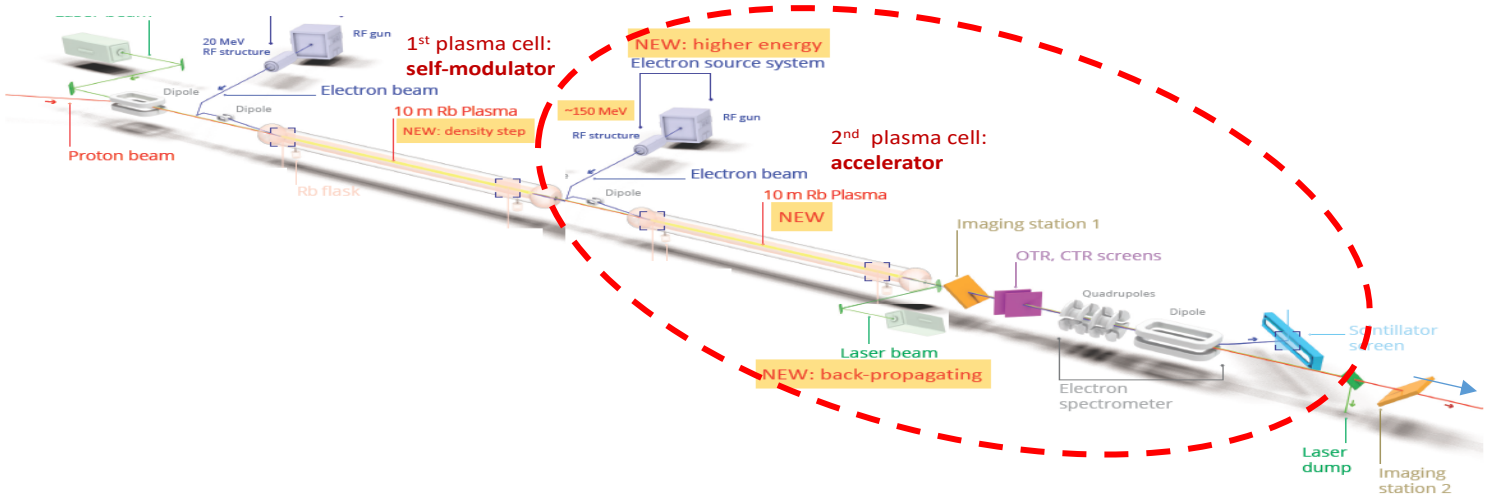


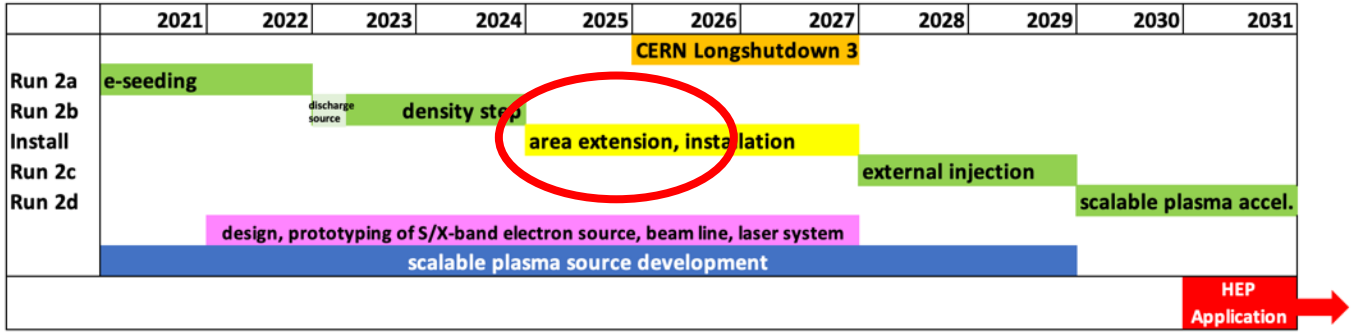


Enables unique physics:

- → Vary plasma density over wide range
- → Study Sel-modulation at different lengths: 6.5m, 3.5m 10m
- → Study plasma ion motion: Ar(40), Xe(131), He(4)
- → Filamentation of very high densities
- → Study plasma light, wakefied amplitude all along the plasma.

Preparing for AWAKE Run 2c, 2d → CNGS Dismantling





Area content (~600m^3):

- ~500 large shielding blocks (0,05-0,6 mSv/h)
- A few high dose-rate elements (2-20mSv/h)
- 70-meter-long aluminum He-tank
- Various supports, ducts…

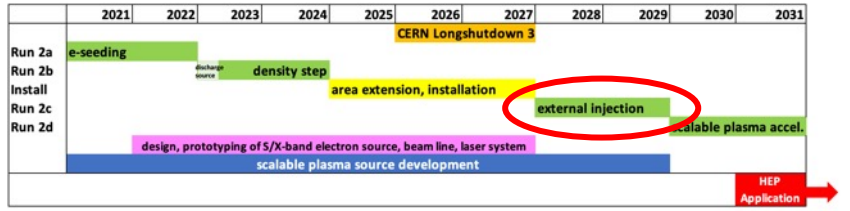
CNGS Dismantling: Q2024 – mid 2026
→ Approved in CERN's Mid-Term Plan (11MCHF)

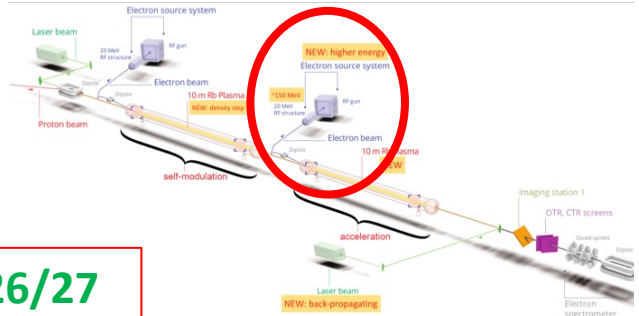
AWAKE Run 2c – Accelerating Electrons

➔ External injection of witness electron

Preserve electron beam quality (emittance preservation at 10 mm mrad level)

Electron parameters must be suitable to reach full blow-out regime (ensure linear focusing), load the wakefields (➔ small ∂E/E), Match to focusing force of the plasma ion column





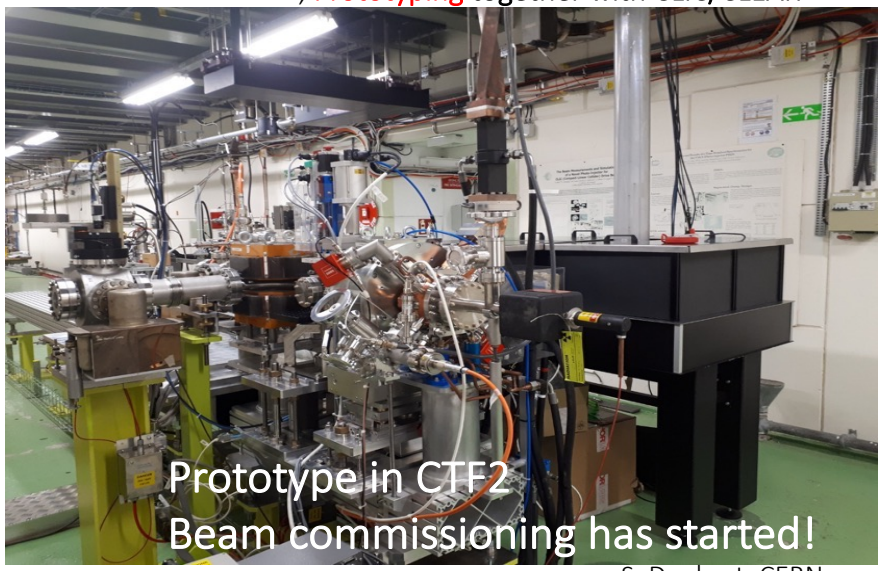
At injection point

Parameter	Nominal value
Dispersion	0
$\sigma_{x,y}$	5.75 µm
Bunch length	200 fs/60 µm
Electron energy	150 MeV
$\epsilon_{x,y}$	<2 mm mrad
Mom. spread	<0.2%
Charge	100 pC

➔ **Studies/Prototyping ongoing to be ready for installation in 2026/27**

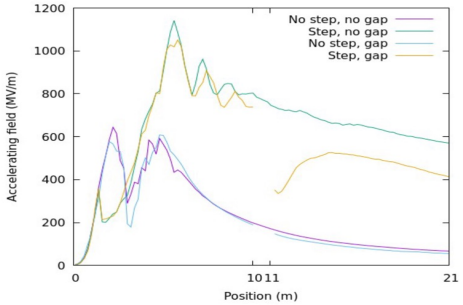
New electron-source:

➔ Based on X-band, Prototyping together with CLIC/CLEAR



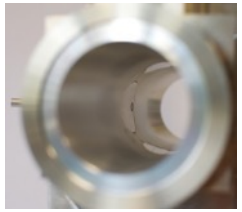
S. Doebert, CERN

Simulations



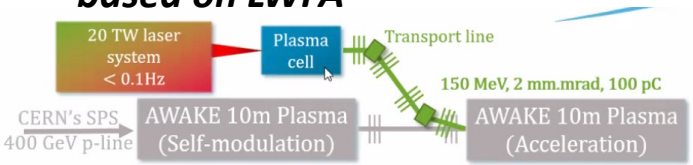
J. Farmer, MPP

Beam Instrumentation



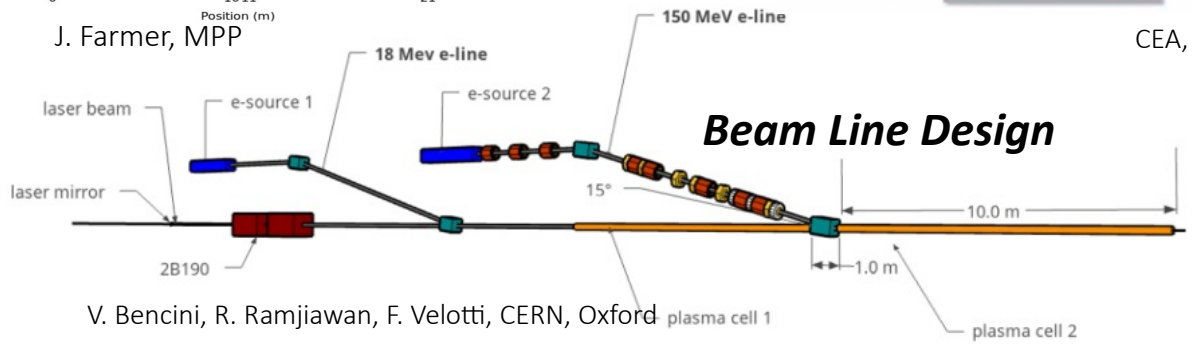
BPMs 10 µm resolution

Alternative e-source studies based on LWFA



CEA, CNRS, Thales, MPP, CERN

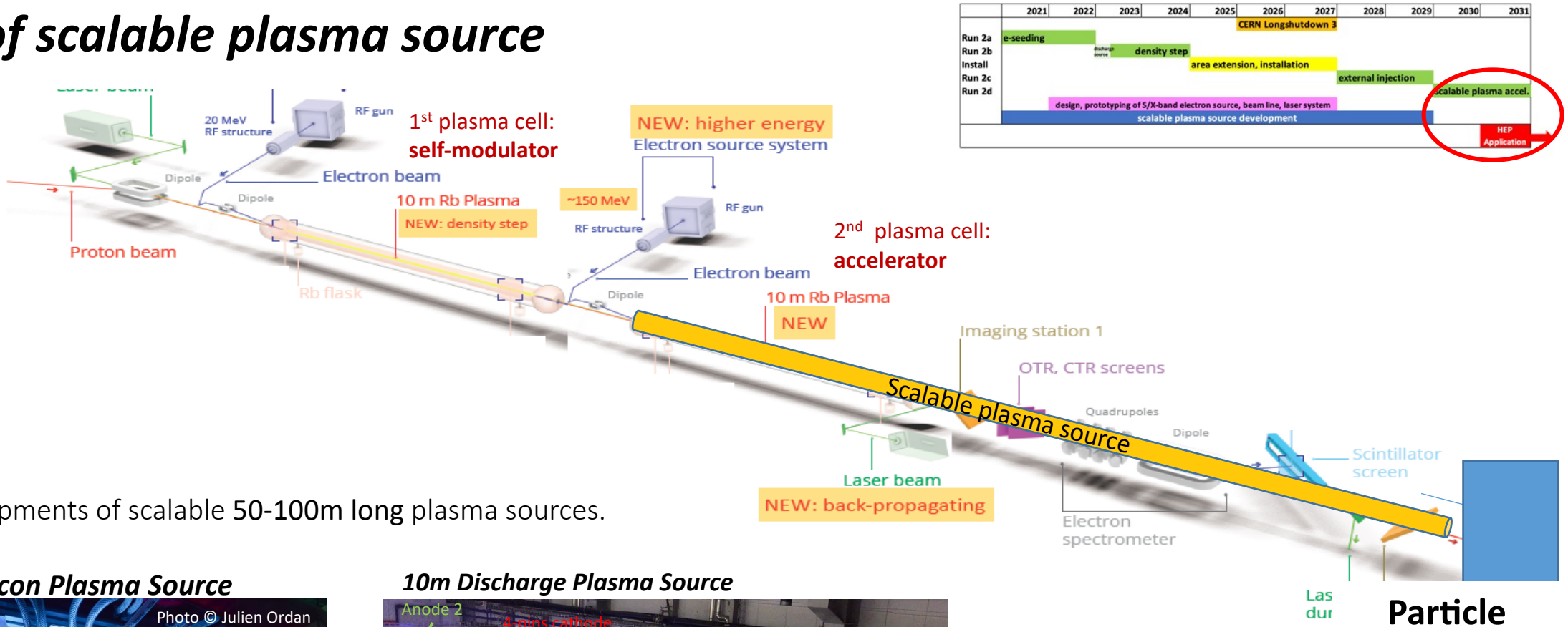
Beam Line Design



V. Bencini, R. Ramjiawan, F. Velotti, CERN, Oxford

AWAKE Run 2d: Towards first Particle Physics Experiments

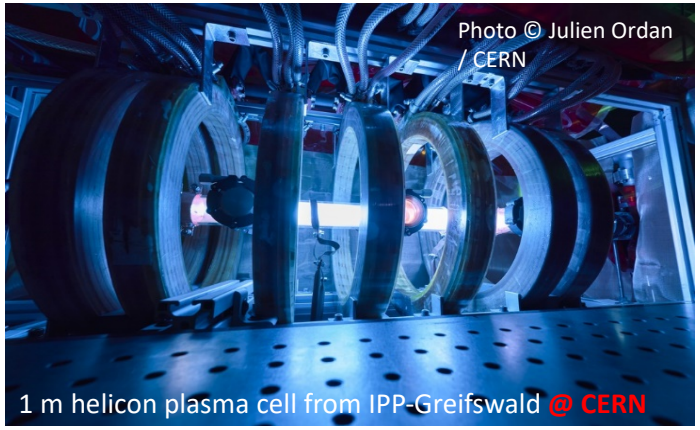
➔ R&D of scalable plasma source



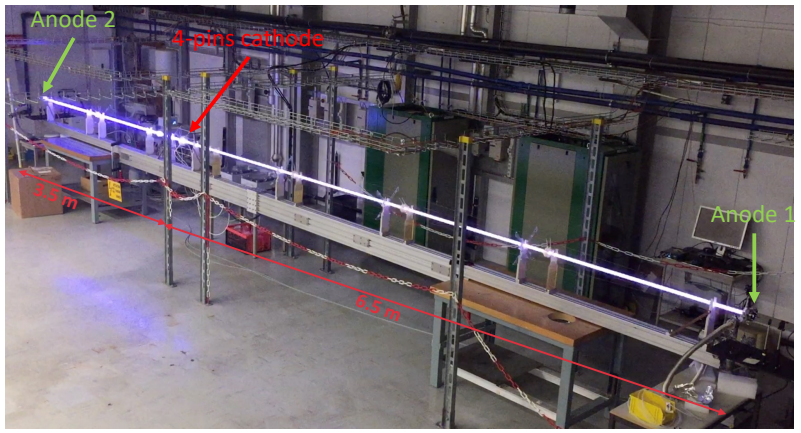
Particle physics experiment

Laboratory developments of scalable **50-100m long** plasma sources.

1m Helicon Plasma Source



10m Discharge Plasma Source



➔ ***Further develop particle physics experiment requirements***

Program and Budget

AWAKE has a clear plan towards first particle physics application

- AWAKE Run 1: Proof-of-Concept
- AWAKE Run 2 (2021-2030): ***aim to high-energy, high-quality electrons and develop scalable plasma sources***

Budget and Workforce Situation at CERN:

- AWAKE has been extended in CERN's timeline until 2030
- CNGS dismantling has been approved in 2022 and is part of the AWAKE project
  - Additional 11MCHF were added
  - Dismantling work starts end 2024
- ~1/2 CERN material budget available for Run 2c-d, still missing other half (~12MCHF).
  - **Request added in this year's CERN Mid-Term-Plan (MTP).**
- Would be good to have a post-doc looking into particle physics applications

- **Contributions from collaborating institutes** are important (UK just got their full **4MPound** grant approved)
  - however, we rely on contributions from collaborating institutes
  - need to continue securing funding for next decade!

Thank You!

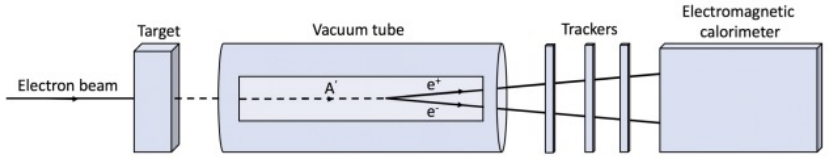
Physics Cases

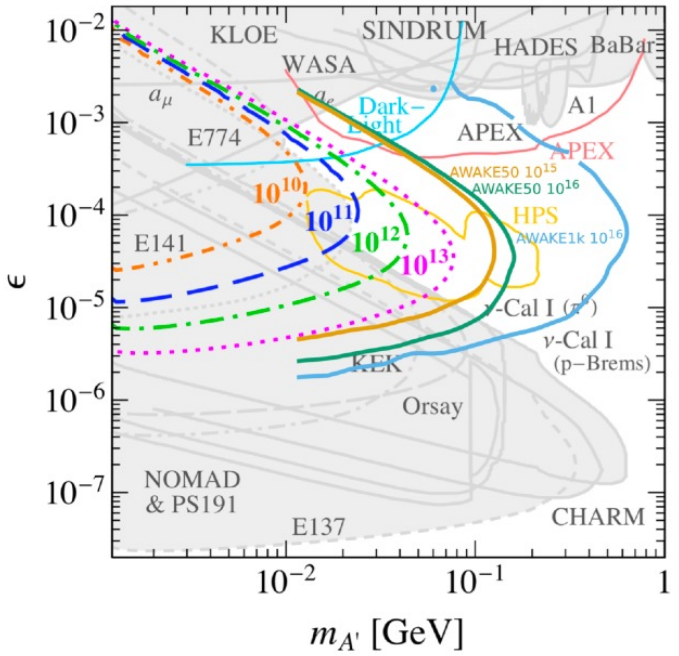
Many opportunities for first particle physics applications in the nearer future:

→ Beam quality sufficient for **fixed target experiments**
→ Currently for O(100) GeV electrons by scattering SPS protons on a target: inefficient and very low yield

➔ **Beam Dump Experiment:** Search for dark photons.

→ Decay of dark photon into visible particles (e.g. e+/e-)





→ Extension of mixing strength of the kinematic coverage for 50 GeV electrons and even more for 1 TeV electrons

➔ Investigate non-linear QED in electron- photon collisions.
➔ Produce TeV-range electrons with an LHC p_+ bunch: use for lower luminosity measurements in electron-proton or electron-ion collisions.

$\mathcal{L}$ **Limited by proton accelerator repetition rate – look for high-cross-section processes to compensate.**

"Particle Physics Applications for proton driven PWA", Allen Caldwell, Tuesday 9:00