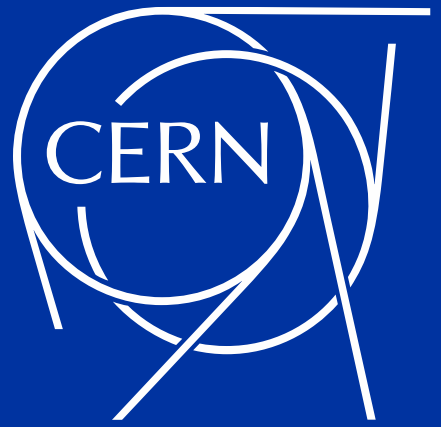

HiRadMat and AWAKE feedback & outlook for 2024

A. Goillot on behalf of the HiRadMat team

M. Turner, G. Zevi Della Porta on behalf of the AWAKE collaboration

6st December 2023 - JAPW 2023

Outline

- **Facility and Plans**
- **2023 Physics Highlights**
- **2023 Beam Feedback**
- **2024 Beam Requests**

- Facility and Plans
- 2023 Physics Highlights
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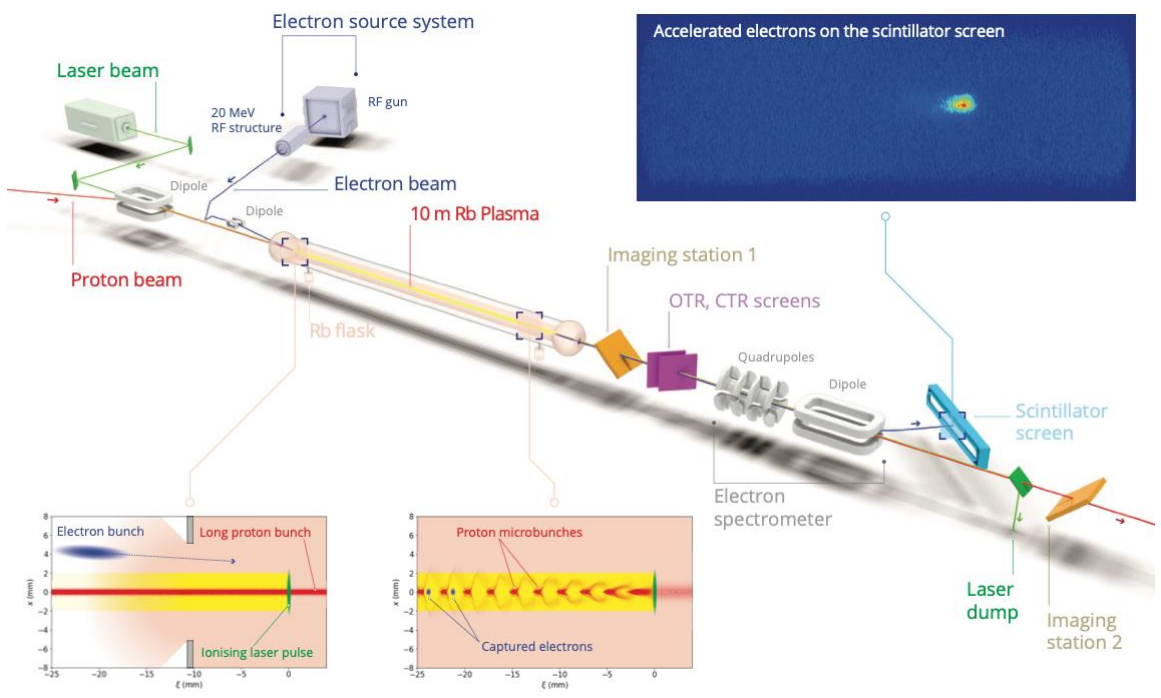
AWAKE Facility

Proton-driven plasma wakefield acceleration of electrons

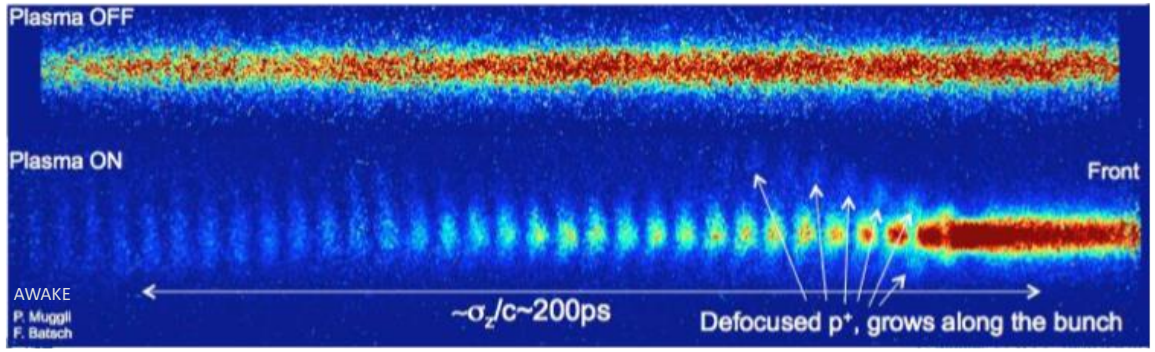
1. Laser ionizes Rb vapor, forming a plasma
2. Rb plasma creates micro-bunches in the proton beam
3. Micro-bunched proton beam excites plasma wakefields
4. Wakefields accelerate and focus electrons



AWAKE Run 1: Proof of principle

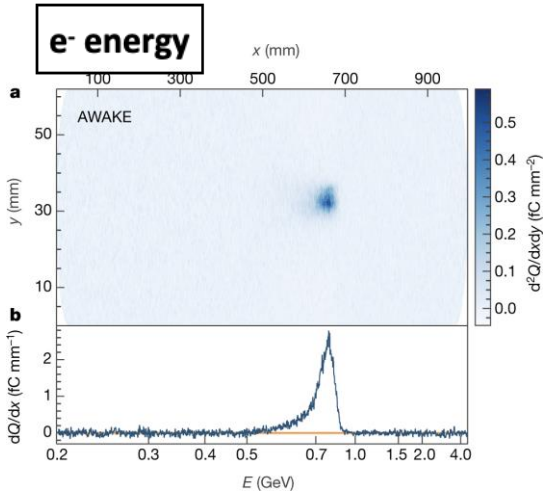
2016-17: first seeded self-modulation of proton bunch

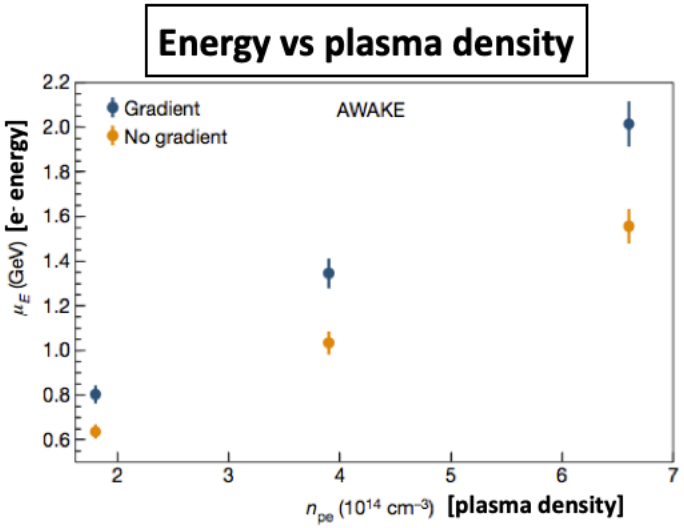
→ Demonstration that SPS bunch can be used for acceleration



AWAKE Collaboration, PRL 122, 054802 (2019)

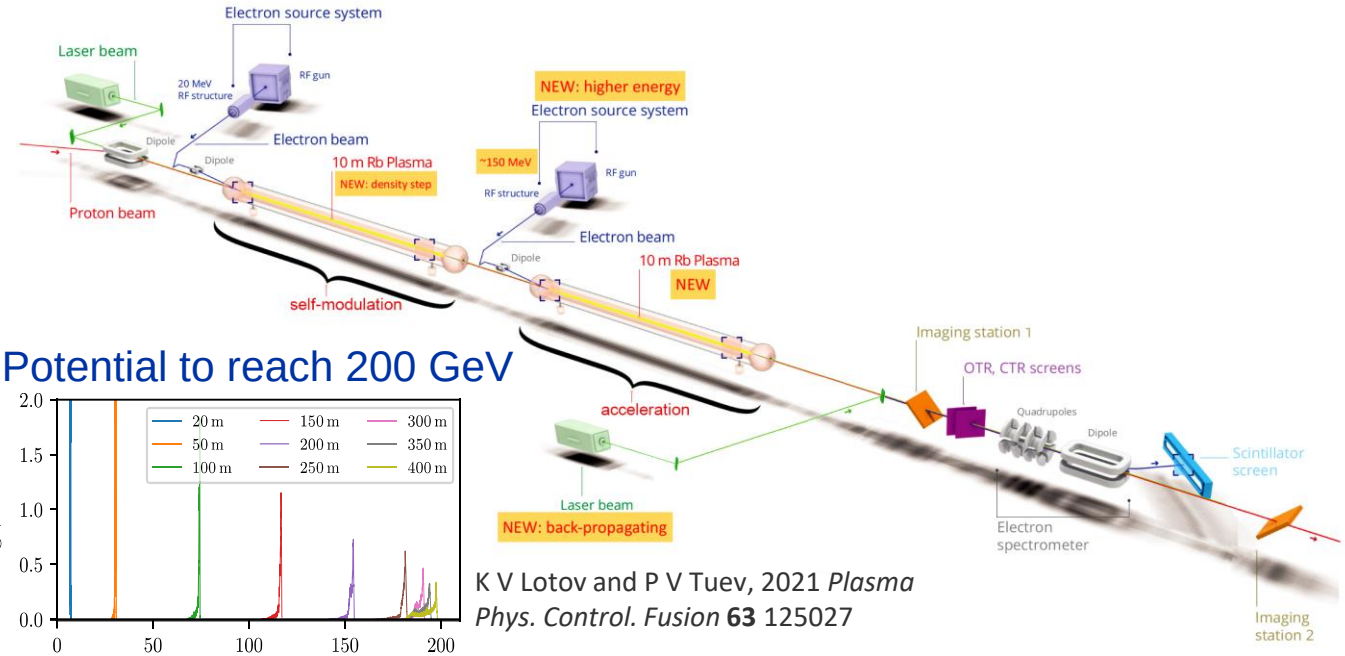
2018: acceleration from 19 MeV to 2GeV





AWAKE Collaboration, Nature 561, 363 (2018)

AWAKE Run 2 (2021 – 2030): Towards an Accelerator



Potential to reach 200 GeV

K V Lotov and P V Tuev, 2021 *Plasma Phys. Control. Fusion* **63** 125027

- **Run 2a (2021/22):** demonstrate the seeding of the self-modulation of the entire proton bunch with an electron bunch
- → **Run 2b (2023/24):** maintain large wakefield amplitudes over long plasma distances using a **step in the plasma density**
- **CNGS dismantling** and installation of Run 2c (2025/26/27)
- **Run 2c (after LS3, 2028/29):** demonstrate electron acceleration and emittance control of externally injected electrons
- **Run 2d (2029/30..):** development of scalable plasma sources to hundreds of meters length
- → Propose first applications for particle physics experiments with 50-200 GeV electron bunches!

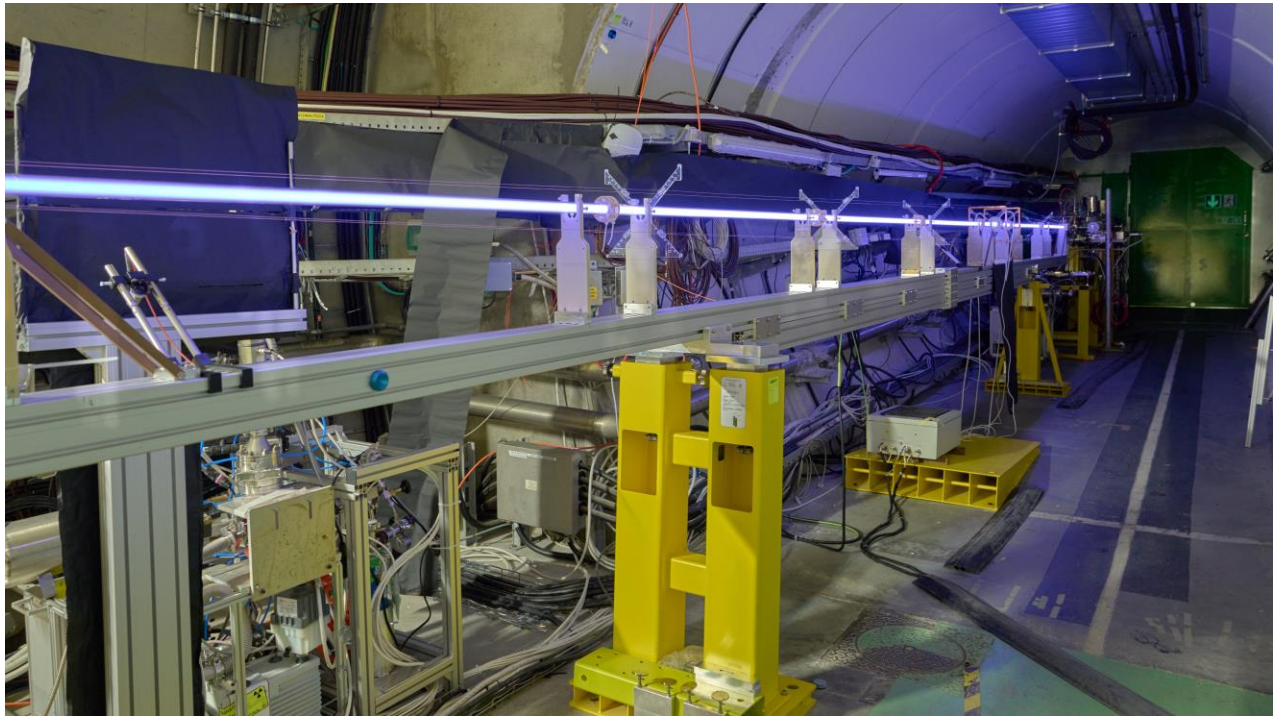
AWAKE 2023: Discharge Plasma Source (DPS)

3-week test of a *scalable* plasma technology (candidate for Run 2d)

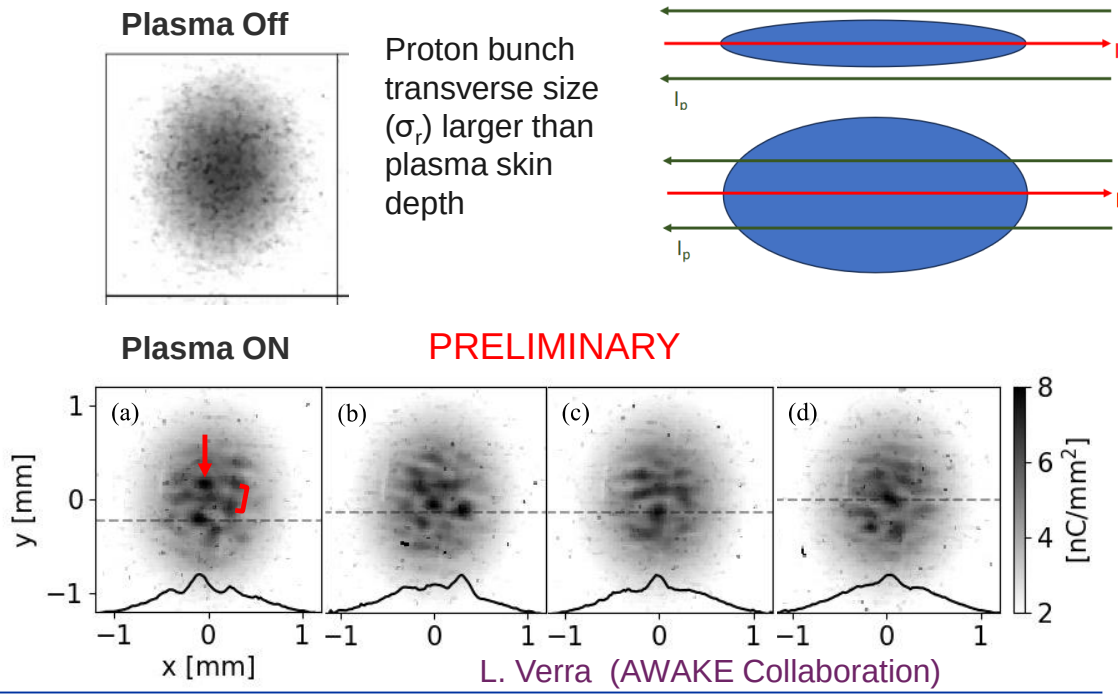
→ Successful operation of 10 m source: self-modulation over a range of plasma densities

→ Unique physics program: Ion Motion, Plasma Light, Transverse filamentation

Gas-filled glass tube + electric discharge



Developed dedicated p^+ optics (wide bunch) to study transverse filamentation in high-density plasma

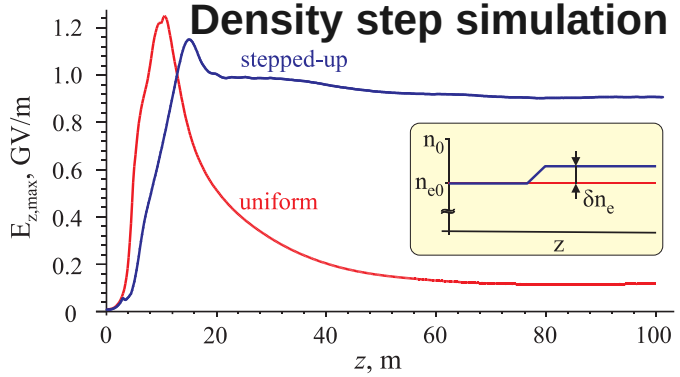


AWAKE 2023: Density Step Plasma Source

Study the effect of a density step on wakefields at long distances

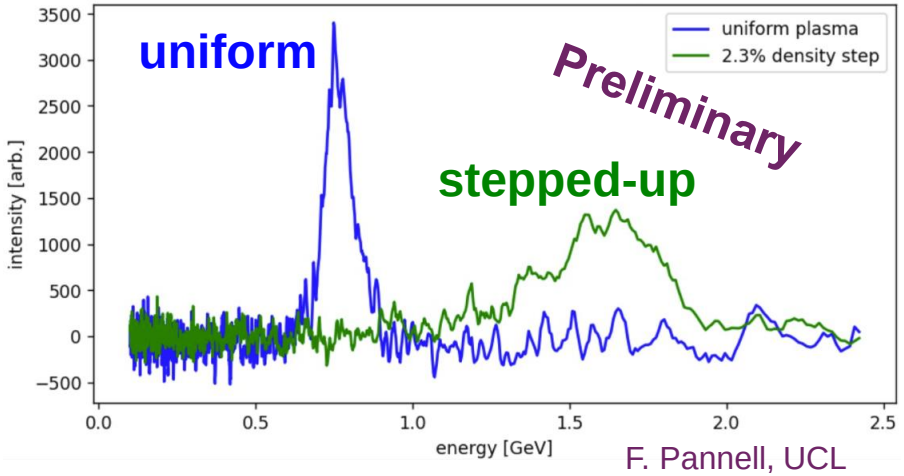
→ Successful operation : variable step position (0-5 m) and height (0-10%)
→ New diagnostics: measure Plasma Light enhancement by wakefields
→ Use Plasma Light and Acceleration to optimize density step

Density step simulation



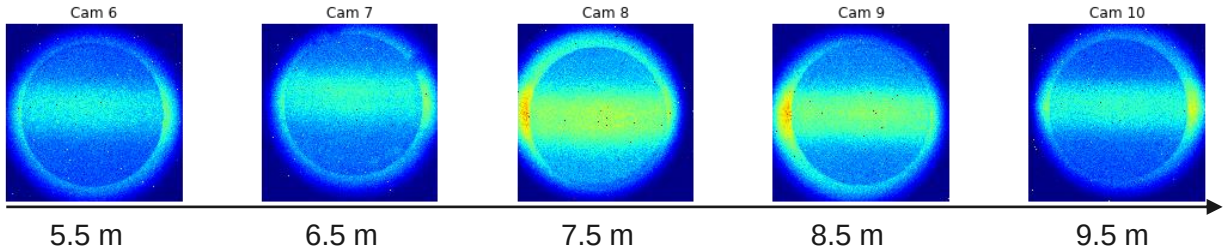
Rubidium vapor source with Density Step + laser

Energy of accelerated electrons



F. Pannell, UCL

Plasma Light



M. Turner, CERN

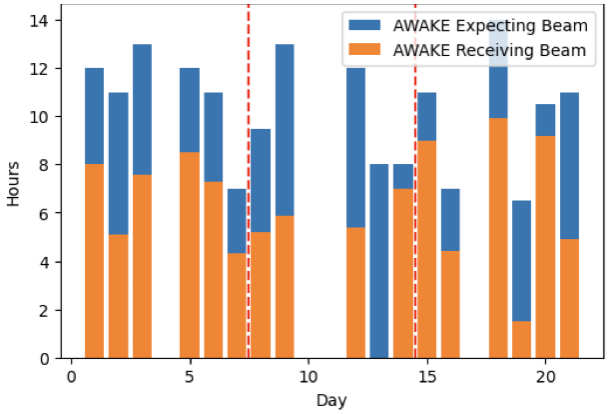
AWAKE: Feedback for 2023

- **AWAKE is very happy of the support from all technical groups involved in the experiment infrastructure and from the SPS operation team!**

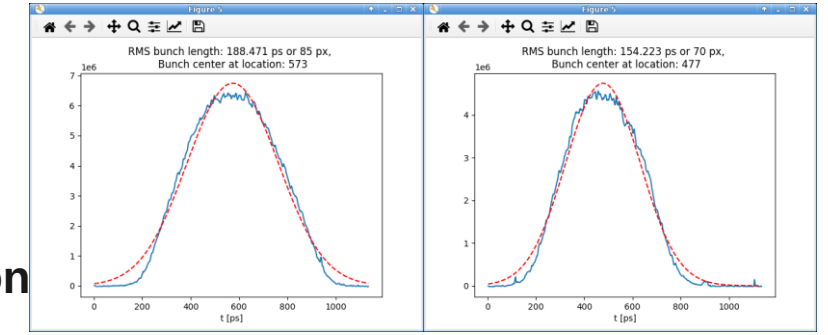
- **Run for 2 out of 3 shifts. Only in supercycle when needed**
  - After injector issues, LHC fills and AWAKE interventions, we receive **between 6 and 10 hours of beam per day** (600-1200 extractions)

- **Only recurring p^+ beam issue: unstable longitudinal profiles**
  - Occasional event-to-event and day-to-day changes in **length/shape of proton bunch**, even after days of stable running
  - Require tuning by SPS RF, while monitoring by AWAKE
    - → AWAKE streak camera is more sensitive than BQM
    - → Improved monitoring (PS cavities, SPS BQM at injection) planned
    - → See dedicated summary and proposals by I. Karpov at SPS MPC: https://indico.cern.ch/event/1349652/

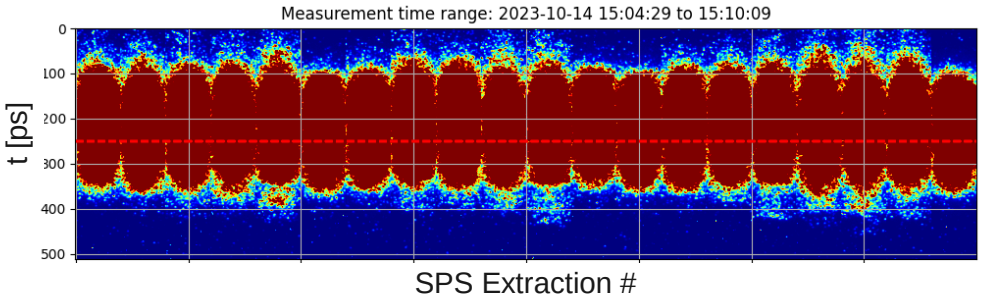
Hours of beam in May Run



Avg. bunch z profile: Oct 19 and Oct 21



Bunch z profile changing from event to event



AWAKE: Progress on 2022 Feedback/Requests

- **Progress on desiderata from 2022 JAPW**
  - Speed up fine alignment of proton beam
    - FE Interlock threshold increased to avoid losing supercycles after every correction
  - Stable beam with higher repetition rate in dedicated periods
    - Agreement in principle, but only for pre-defined periods set days in advance. Difficult to plan.
    - High repetition mode used successfully when NA was out of commission
  - Continue maintaining availability of laser and electron beams during YETS
    - Added to official injector schedule. Worked smoothly thanks to detailed coordination w.r.t. YETS activities
  - [LS3] Upgrade of power converter to reduce proton beam jitter for Run 2c (2028+)
    - Upgrade TT40/41 converters and MSE expected to increase usable extractions in Run 2c from 3% to 30%
    - Improvement in jitter observed after LS2: AWAKE is continuing dedicated data-taking for jitter measurements to pinpoint the most relevant power converters

AWAKE Outlook and Requests for 2024

- **2024 will be the last year of AWAKE data taking until the end of LS3**
  - No protons expected in 2025 in baseline planning: CNGS dismantling (1.5 years), LS3, then Run 2c
- **2024 will be a “production” year: few hardware interventions**
  - Aim for stable Electron and Laser beams in collaboration with relevant CERN groups: BE-ABT, SY-STI
  - Expect stable and reproducible performance from proton beam
  - Day-to-day stability in bunch shape needed for precision measurements over multiple days
- **Interested in testing new RF configuration for shorter beam**
  - Developed by SPS RF team. Not necessary for 2024 physics goals, but potentially useful for Run 2c
- **Further improvements in communication: automated flag for “usable beam”**
  - Communication with CCC on SPS issues has greatly improved, but AWAKE often discovers injector issues (SPS or upstream) while looking at physics plots, before operators notice
  - Develop (SPS+AWAKE) a “usable beam” flag: combine diagnostics+status to quickly spot known issues

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- **Facility and Plans**
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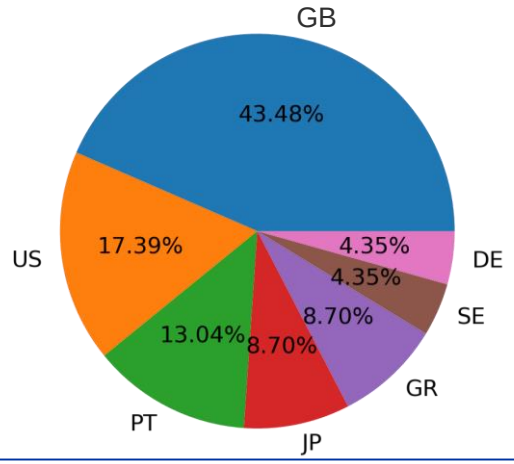
HiRadMat Facility

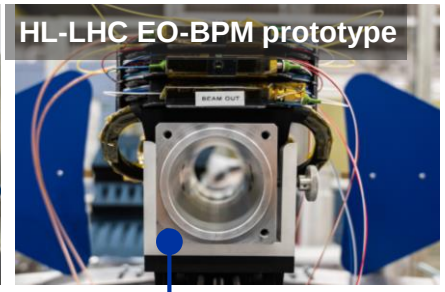
Short-pulse high-energy proton irradiation facility

LHC-like Beam Parameters

Up to 288 bunches, **≤1.6×10^{11} protons per bunch**
≤4.6×10^{13} protons per pulse at **440 GeV/c (3.2 MJ)**
~**1.5 ns** long bunches, 25 ns bunch spacing
Beam size at target: **≥0.25 mm** (1 σ)

- **Maximum flexibility to accommodate many requests**
- **Completed a total of 44 experiments since 2012**
- **Supported more than 20 external users during 240 days of transnational access during one operational year**





Targetry **Beam diagnostics** **Beam intercepting devices**
Superconducting magnets, Particle detectors, Plasma physics

Experiments

Beam Diagnostics
Transverse spot size
Bunch-to-bunch beam position
Beam losses

Test Stands
Remote plug'n'play
~300 signal connections
Cooling water, vacuum, press. air

HiRadMat Highlights 2023

- **HRMT62 FIREBALL – Uni. of Oxford** ☑ Completed

  Reproduce electron-positron enriched astrophysical jet in lab

  Nature physics paper submission

  https://home.cern/news/news/experiments/fireball-hiradmat

- **HRMT58 ATLAS-ITk – JSI, EP-UAT** ☐ First test completed, development ongoing

  Initial test of ATLAS-ITk BCM prototype with LHC-like beams

- **HRMT25 TPSG4 - SY/ABT** ☑ Completed

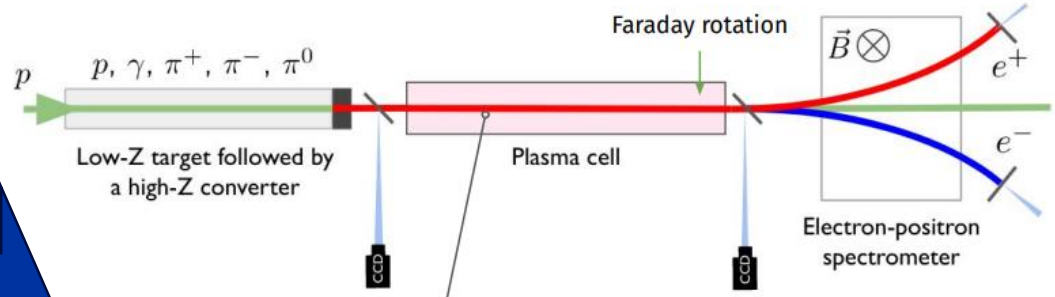
  Test the MSE protection element (diluter) in case of accident scenario in HL-LHC and validate the simulations

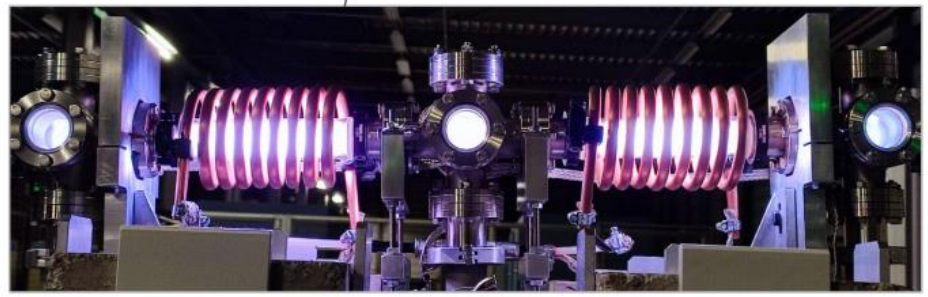
- **HRMT55 BLM3 – ESS, GSI/FAIR, SY-BI** ☑ Ongoing

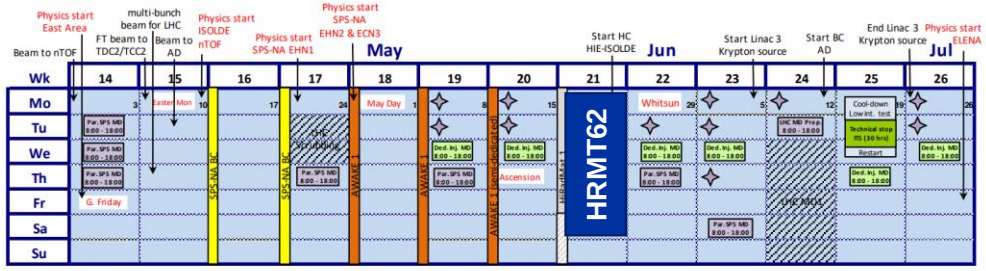
  Qualification of production BLMs for CERN, ESS, GSI/FAIR

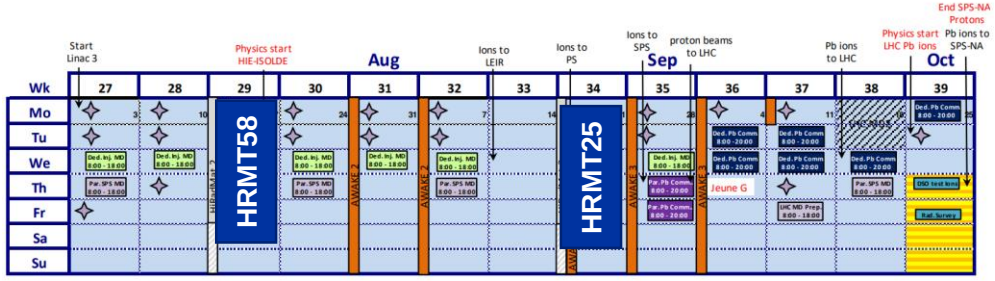
- **HRMT59 SMAUG follow-up exp – TE-VSC, SY-STI, BE-EA**

  Assessment of Si_3N_4 1µm thick beam windows ☑ Completed







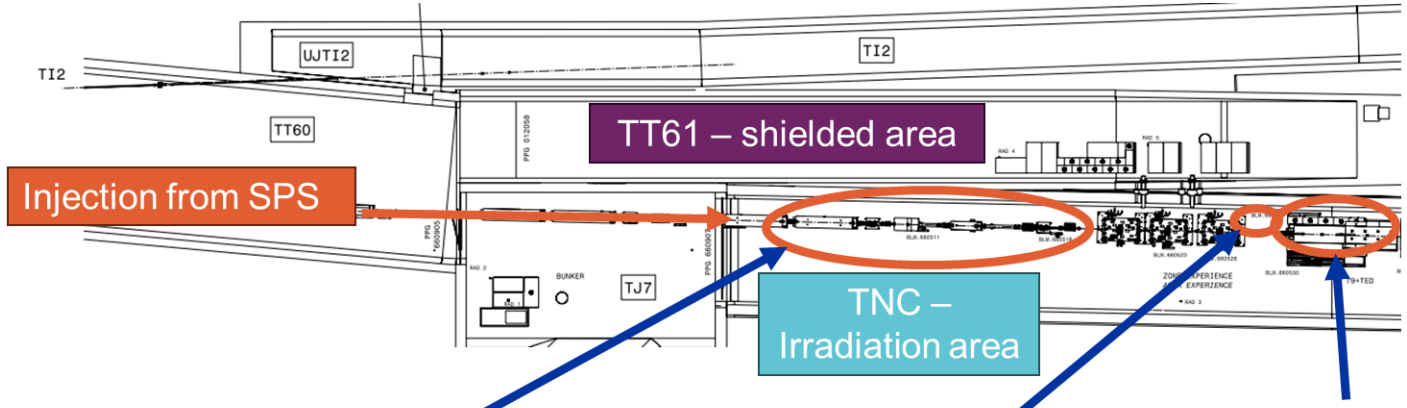


HiRadMat Upgrade Study Group

Goal: Identify necessary upgrades to safely deliver LIU beam intensities to HiRadMat with the same minimum beam spot size that is available today.

- **Study group involves all stakeholders, support teams and users:**

  BE-EA, SPS-OP, SY-ABT, SY-BI, HSE-RP, BE-CEM, TE-VSC, SY-STI, EN-MME



- **Partition of the beam line vacuum sector**
  - Be → glassy C
  - To separate this chamber from the extraction line
  - Vacuum recovering easier
- **Beam diagnostic**
  - New downstream BTV
  - Beam angle
- **Beam dump**
  - Extension of the dump vacuum tank outside the shielding
  - Adoption of Be plates in structural grades as dump windows.

2023
Decision on and implementation of HiRadMat upgrades

2023/24
Works

2024
LIU beams at HRMT
3 Experiments waiting

2024++
Standard operation with LIU beams

HiRadMat dump upgrade

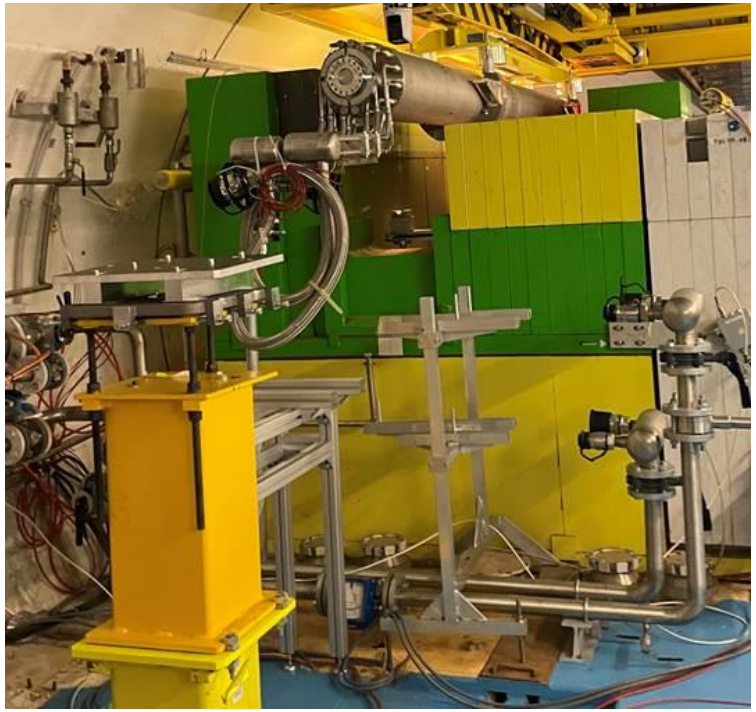
Courtesy: N. Solieri (SY/STI)

With the aim to modify the dump to:

- Avoid the failures
- Make fixing easier

Shielding dismantling …

… dump handling …



… until storage place

HiRadMat Outlook for 2024+

- **5 experiments for 2024 (Schedule refinement still ongoing)**

- **HRMT64 FIREBALL2 – Univ. of Oxford**

  Electron/positron pair beam-driven plasma filamentation instabilities

- **HRMT65 HL-TDE – SY-STI** *LIU beam requests*

  HL-LHC dump material qualification

  Two weeks of run

- **HRMT66 SMAUG-2 – TE-VSC, SY-STI, BE-EA**

  Verification of HRMT LIU beam window designs

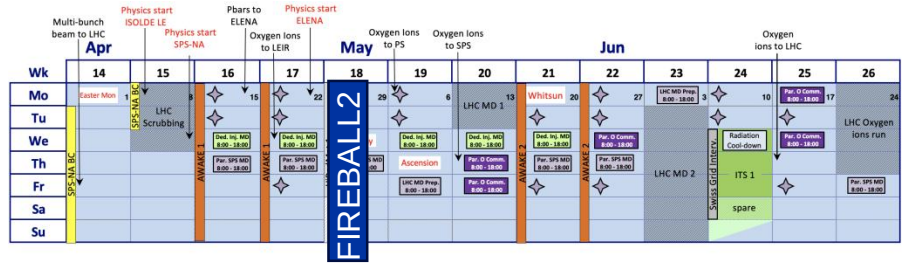
- **HRMT55 BLM3 – ESS, GSI/FAIR, SY-BI**

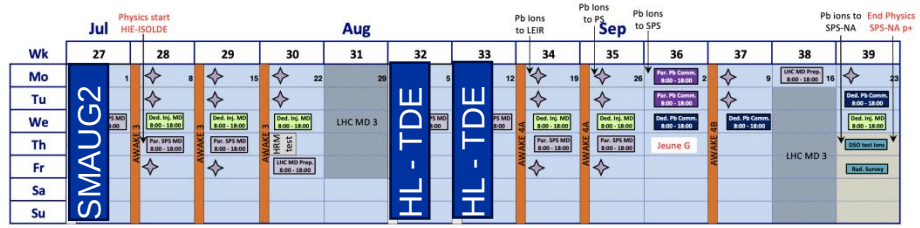
  Qualification of production BLMs for CERN, ESS, GSI/FAIR

- **ATLAS-ITk – JSI, EP-UAT**

  Continued test of ATLAS-ITk BCM prototype with LHC-like beams

  To be confirmed/parasitic





2025 – Experiments

- **CRY3 – SY-STI, INFN** *LIU beam requests*

  Robustness of pre-irradiated Si crystals for beam steering

- **RaDIATE2 – Fermilab**

  Mitigate radiation damage to accelerator materials

- **ScCoils – TE/MPE**

  Identify damage mechanisms in multilayer, impregnated coils due to instantaneous beam impact.

- **DPA – J-PARC/KEK, TE-MPE**

  Displacement damage cross-section measurements at 440 GeV/c

HiRadMat Operational Feedback 2023

- **HiRadMat runs in 2023 very smooth thanks to:**
  - **Excellent communication** with BE-OP to anticipate stable beam conditions (PSB, PS, SPS), and LHC for coordination concerning filling and accessing
  - Running without parallel activities **extremely beneficial**
- **All experiments finished before the end of the scheduled week, <u>all weekends returned to physics</u>, AWAKE & MDs also recuperated days from the HiRadMat weeks**
  - Large appreciation from the experiments for this flexibility of the injector complex
- **Nonetheless, operation of HiRadMat is anything but routine**
  - Stakes are high: experiments need to complete their program within one week and have no contingency.
    - Typical preparation time for HiRadMat experiment : at least a year in advance

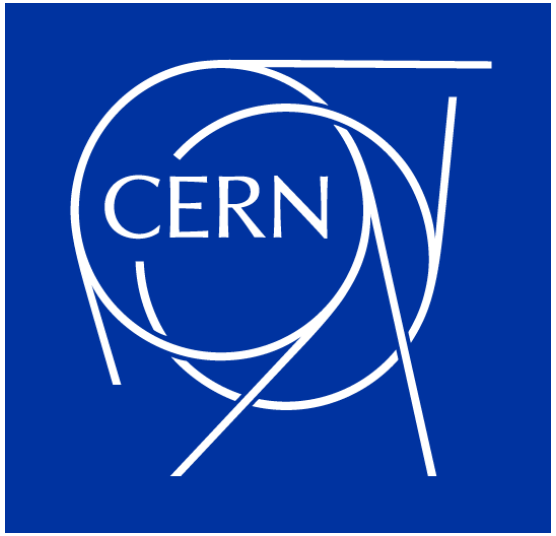
Flashback of HiRadMat Desiderata in 2022

- **AWAKE beam parameters available at HiRadMat (3×10^{11} ppb, 1 ns bunch length)**
  - Necessity for HRMT62 experiment in 2023! ☑ Achieved
- **Better understanding of the beam uncertainties**
  - Enhance understanding of uncertainties of HiRadMat optics
  - From 2024: Tolerances on the beam parameters to be defined in advance by the experimental teams in collaboration with BE/OP and SY/ABT depending on the experiment criticality.
- **Faster change-over between HiRadMat cycles and faster SPS SC changes in general**
  - Increase efficiency, reduce amount of non-extracted HiRadMat cycles to benefit other users as well
- **Extraction with momenta < 440 GeV/c but same time structure**
  - A small taskforce has been established (BE-EA, SY-ABT & BE-OP) and tests are to be scheduled ideally before LS3.

New request:

- **Pre-commissioning of available optics a few hours the week before the actual experiment, in case of challenging optics or configurations → week 32/33 in 2024**

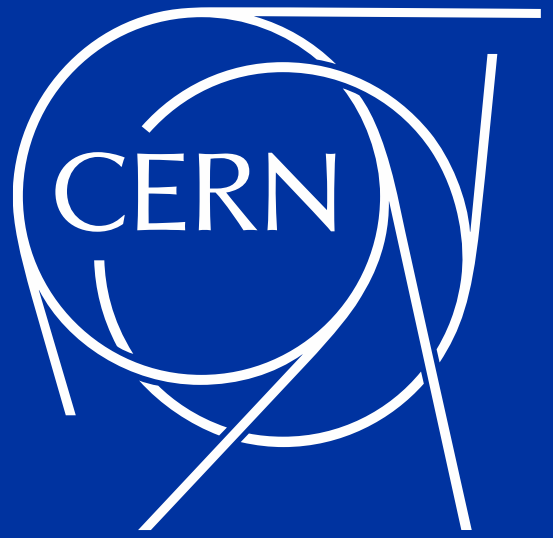
A big thank you to all the groups along the ATS sector for their dedication and help in the operation of HiRadMat facility since 2011!



SY-ABT BE-OP EN-HE BE-EA

TE-MPE BE-GM BE-CEM HSE-RP

SY-STI EN-MME SY-BI BE-ASR


CERN

Long Term Trajectory jitter for AWAKE after LS3

IEFC 2021

- **Proton trajectory jitter acceptable for current physics objectives, but not for Run 2c**

  2026+ much stricter requirements for Electron/proton alignment

  Key parameter to avoid electron charge loss and emittance growth in the acceleration phase

- **Main source of jitter are the magnet power converters**

Only 3% usable shots if not improved by Run 2c

- **Discussions and preliminary studies underway, countermeasures proposed**
  - Upgrade of converters output filters to reach Class 3 performance
  - Upgrade of all Control Electronics in TT41/TT41 to FGC3

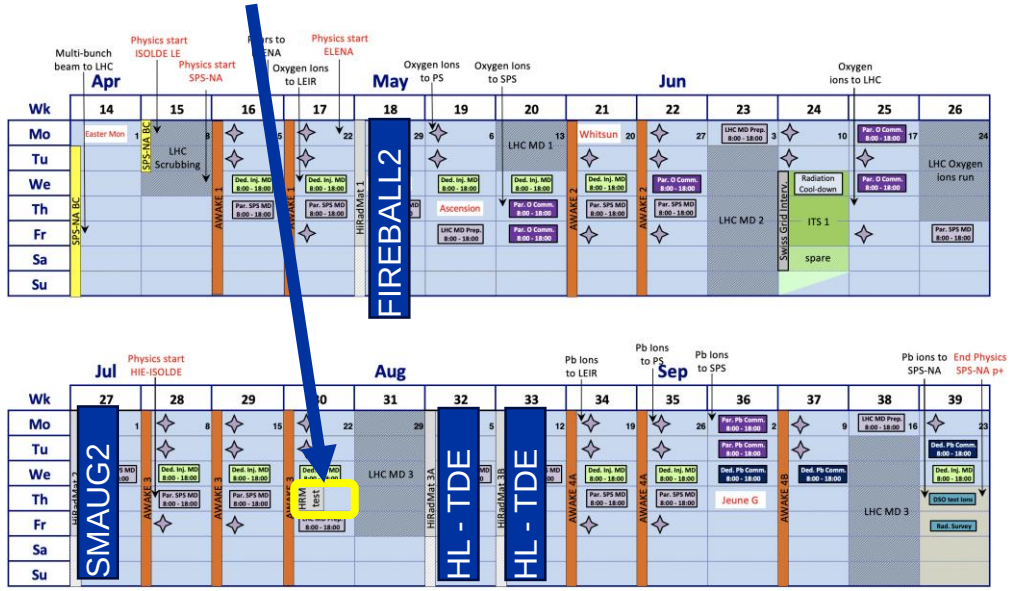
  ~15%

  - Upgrade of MSE: synergy with LHC and NA in the context of SPS-CONS project
    - Perform upgrades **already during LS3?**

~30% usable shots

HiRadMat Requests

- **Pre-commissioning of available optics a few hours the week before the actual experiment, in case of challenging optics or configurations → week 32/33 in 2024**



User feedbacks:

- **High intensity 2.3e11 ppb & 228 bunches**