Status and Plans of the AWAKE Experiment

139th Meeting of the SPSC, 13th October 2020

Edda Gschwendtner, CERN

Outline

- Introduction
  - Proton driven plasma wakefield acceleration
  - AWAKE Run 1
- Overview of AWAKE Run 2
- Stages of AWAKE Run 2
  - AWAKE Run 2a: Demonstrate Electron Seeding of Self-Modulation in First Plasma Cell
  - Preparation for Run 2a during LS2
  - AWAKE Run 2b: Demonstrate Stabilization of Micro-Bunches with a Density Step
  - AWAKE Run 2c: Demonstrate Electron Acceleration and Emittance Preservation
  - AWAKE Run 2d: Demonstrate Scalable Plasma Sources
- Summary

Since last SPSC Meeting October 2019

- November 2019: Intermediate Review at CERN
    - Strong support from CERN management expressed for AWAKE.
    - **CERN is committed to Run 2 and budget is foreseen in the CERN's MTP for the next 10 years (16MCHF)**
    - But, with current resources profile electron acceleration cannot be done before LS3.

    ➔ Stage the AWAKE Run 2 program and prepare a Cost and Schedule Review for March 2021 in order to define in details the budget and personnel profile for the next 10 years.
- March 2020: Covid-19 restrictions set in.
- June 2020: Council approves Strategy Update.
    - *"Accelerator R&D is crucial to prepare the future collider programme…. The roadmap should also consider: R&D for an effective breakthrough in plasma acceleration schemes,…"*

AWAKE has been very active!

➔ Physics program of entire AWAKE Run 2 is well defined following the recommendations of the 2019 review to adapt to the already existing budget profile in CERN's MTP.

➔ Stages of AWAKE Run 2 are clear.

➔ We start with the first phase of Run 2 in 2021 using SPS proton beam.

➔ LS2 program has well advanced, included lots of preparations for next year's run.

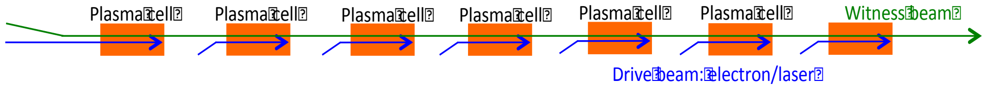
➔ Design of different phases of full program has well advanced so that it can be presented in the CSR in March 2021.

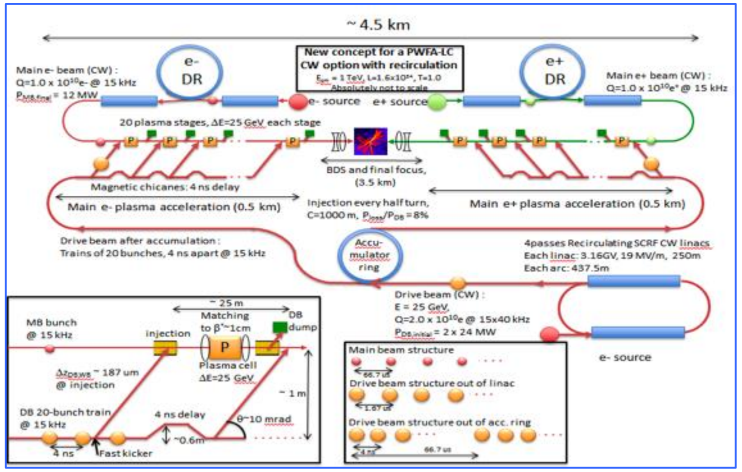
Introduction – Acceleration to HEP Energies in PWA

Drive beams:
Lasers: ~40 J/pulse
Electron drive beam: 30 J/bunch
Proton drive beam: SPS 19kJ/pulse, LHC 300kJ/bunch

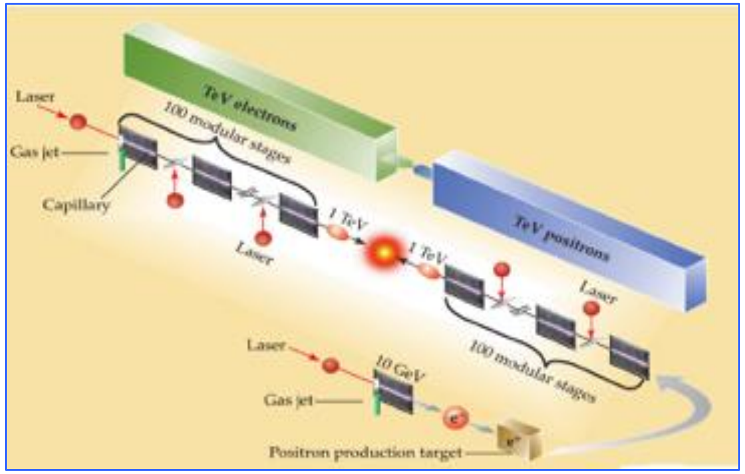
Witness beams:
Electrons: 10^{10} particles @ 1 TeV ~few kJ

- **Electron/laser driven PWA**: need several stages
  - effective gradient reduced because of long sections between accelerating elements….





E. Adli et. al.,arXiv:1308.1145 (2013)

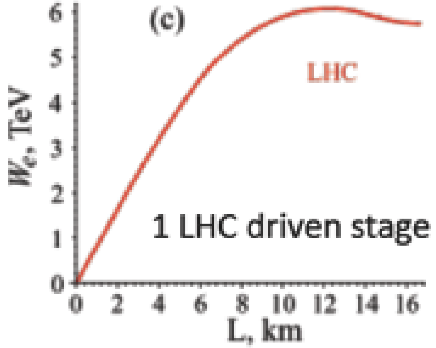


Leemans & Esarey, Phys. Today 63 #3 (2009)

➔ Challenges: staging, matching, tolerances, driver technologies, efficiencies

- **Proton driven PWA**: large energy content in proton bunches ➔ allows to consider single stage acceleration:
  - A single SPS/LHC bunch could produce an ILC bunch in a single PDWA stage.

Dephasing:
SPS: ~70 m
LHC: ~few km
FCC: ~∞



A. Caldwell and K. V. Lotov, Phys. Plasmas **18,** 103101 (2011)

➔ Challenges: long plasma sources , efficiency

Drive Beams in Plasma Wakefield Acceleration

In order to create plasma wakefields efficiently, the drive bunch length has to be short compared to the plasma wavelength. → Relatively easy for **Laser** and **Electron** bunches.

$$E_{acc} = 110 \; \frac{MV}{m} \; \frac{N/(2 \times 10^{10})}{(\sigma_z / 0.6mm)^2}$$

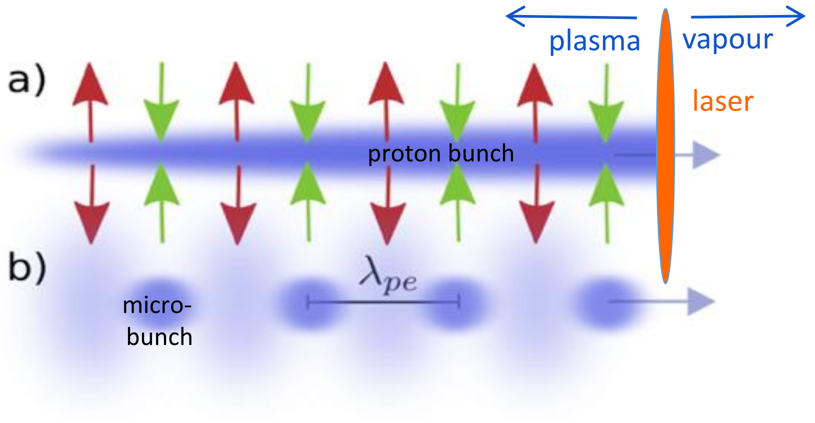
Proton beam as drive beam**:** CERN SPS proton bunch: very long! (σ_z = 12 cm) → much longer than plasma wavelength (λ = 1mm), but rely on self-modulation of the proton beam

Self-Modulation of a Long Proton Beam:

a) Bunch drives wakefields at the initial seed value when entering plasma.

- **Initial wakefields act back** on the proton bunch itself. → On-axis density is modulated. → Contribution to the wakefields is $\propto n_b$.

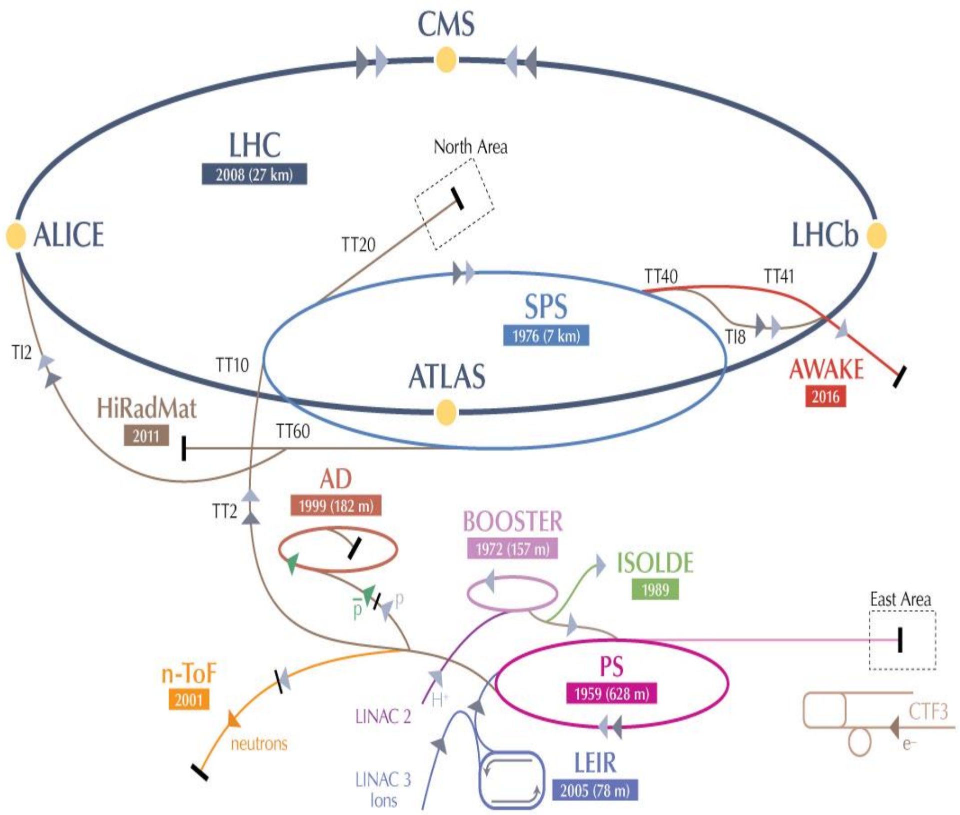
b) Density modulation on-axis → **micro-bunches**. → separated by plasma wavelength λ_{pe} → drives wakefields resonantly.



AWAKE: Seeding of the instability by

- Placing a laser close to the center of the proton bunch
- Laser ionizes vapour to produce plasma
- Sharp start of beam/plasma interaction
- → Seeding with ionization front

AWAKE at CERN



Advanced WAKEfield Experiment

- Proof-of-Principle Accelerator R&D experiment at CERN to study proton driven plasma wakefield acceleration.
- Final Goal: Design high quality & high energy electron accelerator based on acquired knowledge.
- Approved in August 2013

AWAKE Run 1 (2016-2018):

✓ 1st milestone: Demonstrate seeded self-modulation of the proton bunch in plasma (2016/17)

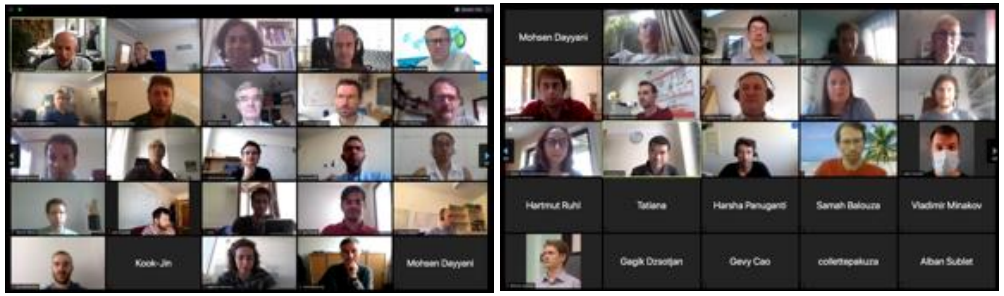
✓ 2nd milestone: Demonstrate electron acceleration in plasma wakefield driven by a self-modulated proton bunch. (2018)

AWAKE Run 2: Accelerate an electron beam to high energies (gradient of 0.5-1GV/m) while preserving the electron beam quality and demonstrate scalable plasm source technology.

Once AWAKE Run 2 demonstrated: Use the AWAKE-like technology for first applications: fixed target experiments.

AWAKE

AWAKE Collaboration: 22 institutes world-wide:

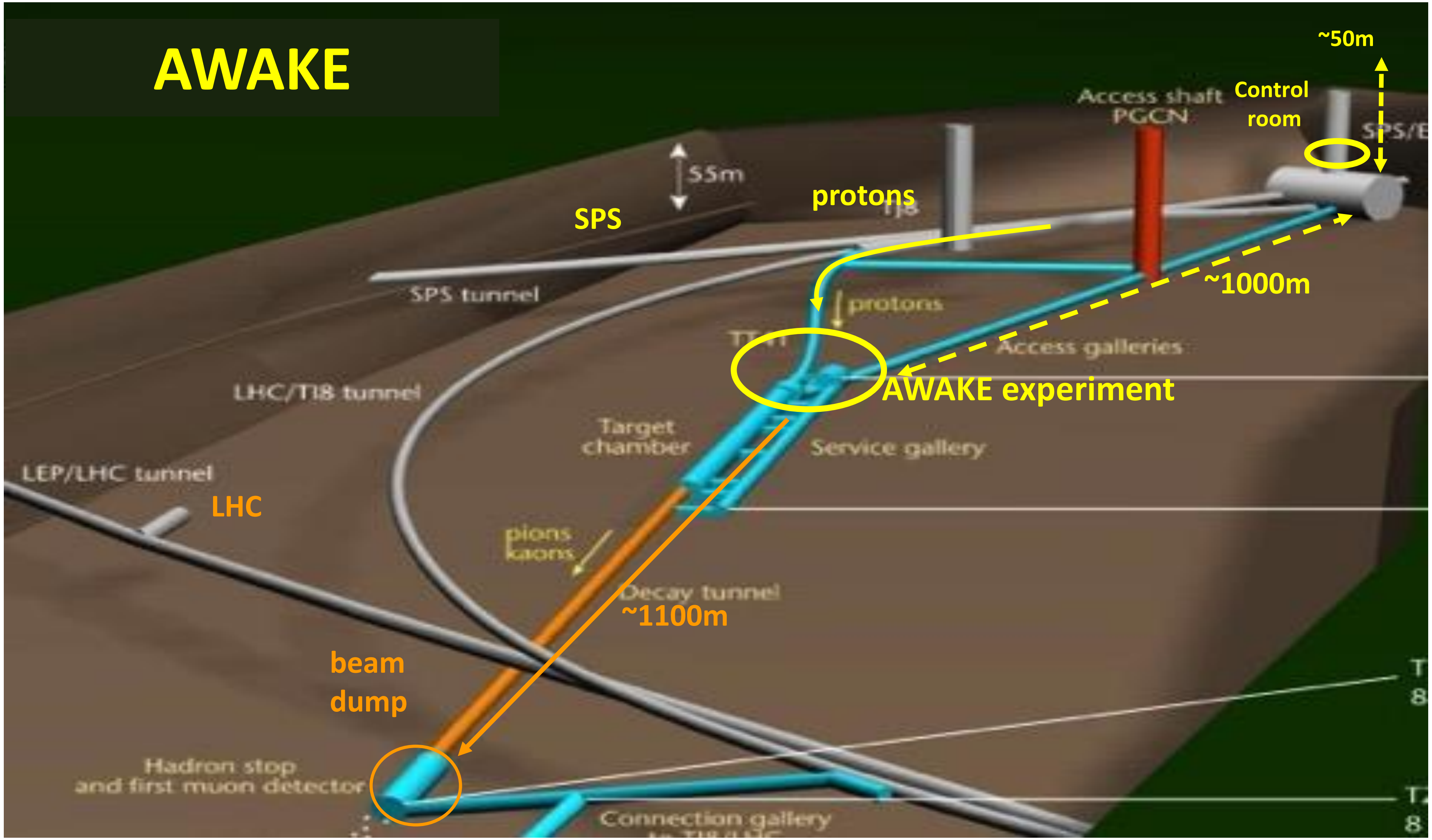


- CERN, Geneva, Switzerland
- Swiss Plasma Center group of EPFL, Lausanne, Switzerland
- University of Oslo, Oslo, Norway
- Wigner Institute, Budapest
- Max Planck Institute for Physics, Munich, Germany
- Max Planck Institute for Plasma Physics, Greifswald, Germany
- Philipps-Universität Marburg, Marburg, Germany
- Heinrich-Heine-University of Düsseldorf, Düsseldorf, Germany
- Ludwig-Maximilians-Universität, Munich, Germany
- UCL, London, UK
- University of Manchester, Manchester, UK
- Cockcroft Institute, Daresbury, UK
- Lancaster University, Lancaster, UK
- Oxford University, UK
- University of Liverpool, Liverpool, UK
- ISCTE - Instituto Universitéario de Lisboa, Portugal
- GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal
- Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia
- Novosibirsk State University, Novosibirsk, Russia
- TRIUMF, Vancouver, Canada
- University of Wisconsin, Madison, US
- UNIST, Ulsan, Republic of Korea

Associate members:

- Unversity of Jena, Germany

AWAKE at CERN



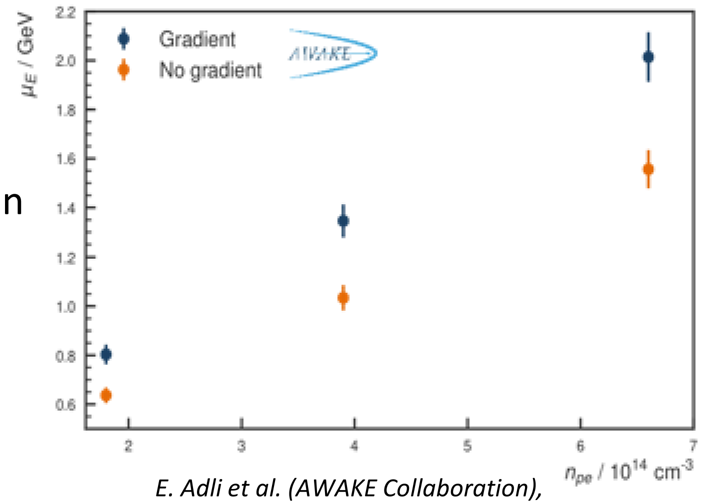
AWAKE installed in CERN underground area

AWAKE Run 1

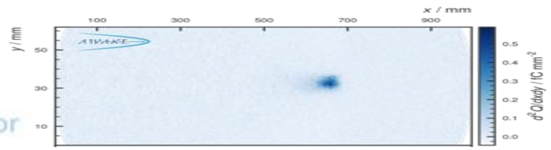
AWAKE has demonstrated during Run 1 (2016-2018) that the seeded self-modulation is a reliable and robust process and that electrons can be accelerated with high gradients.

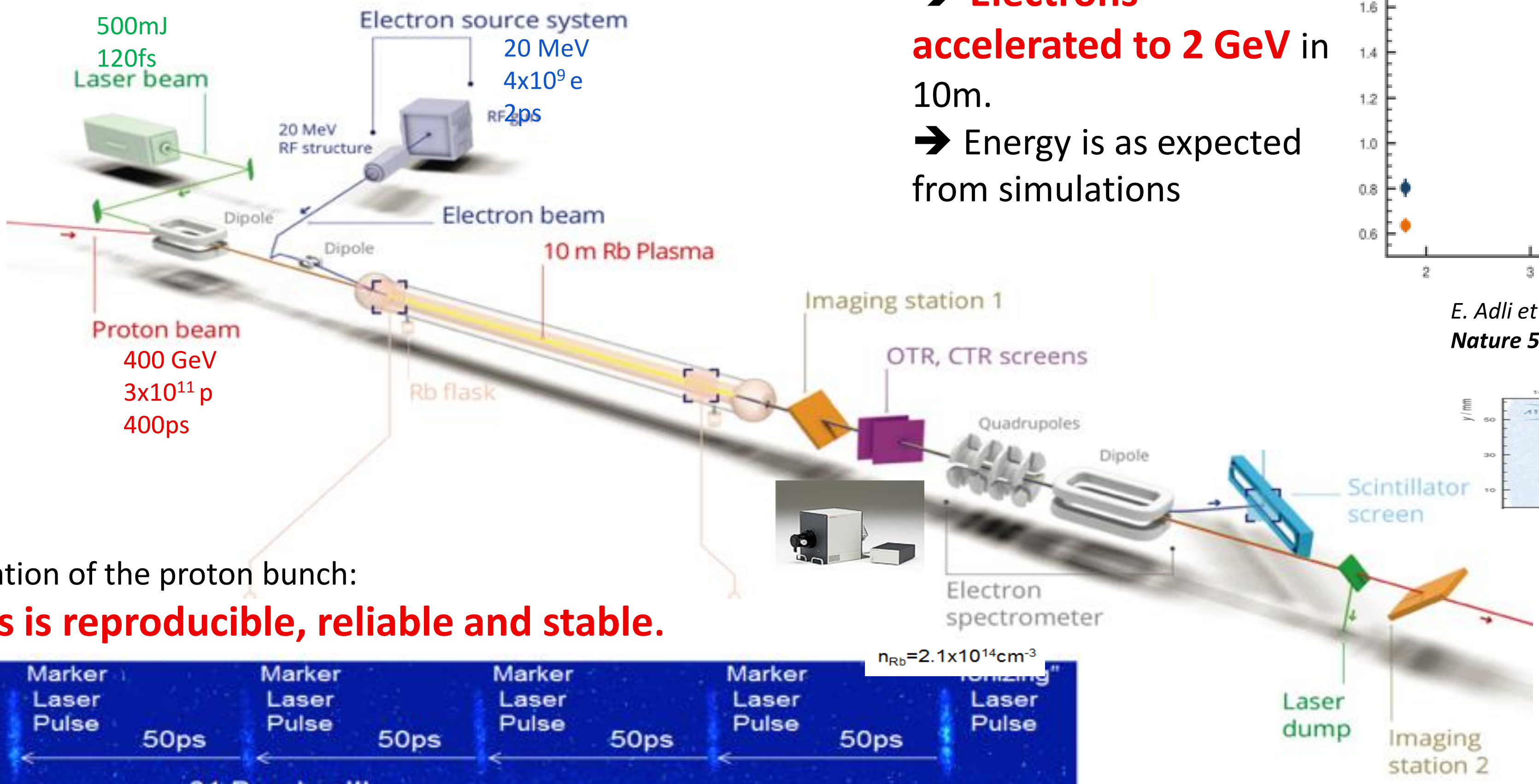
➔ **Electrons accelerated to 2 GeV** in 10m.

➔ Energy is as expected from simulations



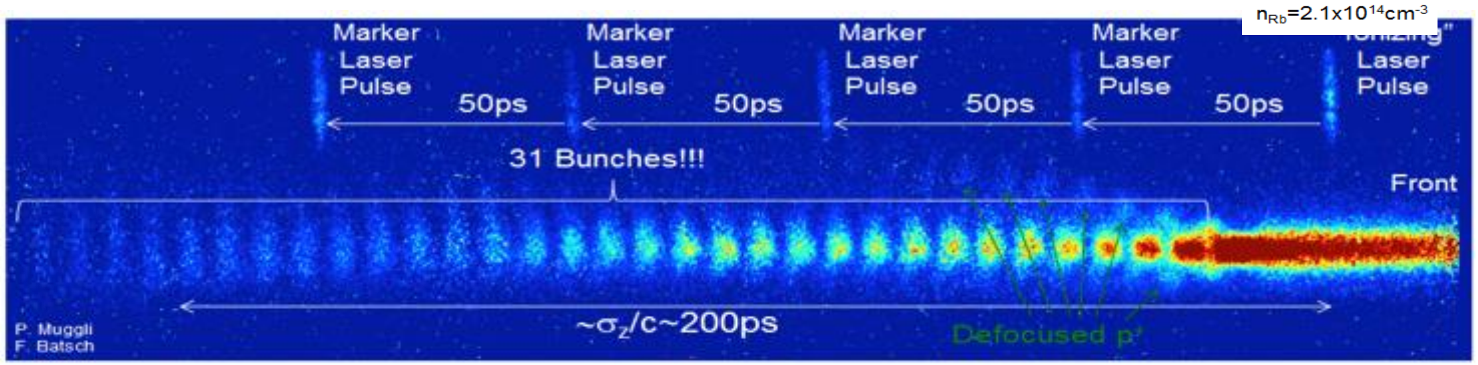
E. Adli et al. (AWAKE Collaboration), ***Nature 561****, 363–367 (2018)*





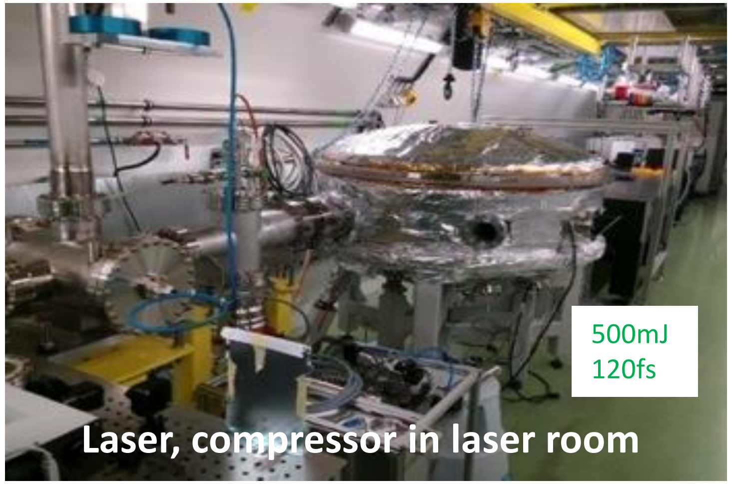
Seeded self-modulation of the proton bunch:

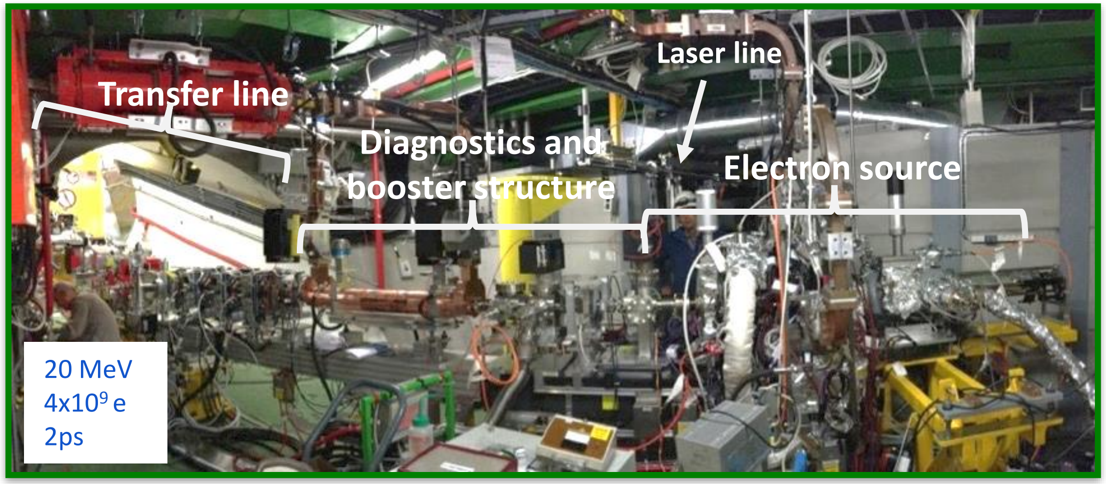
➔ **SSM process is reproducible, reliable and stable.**

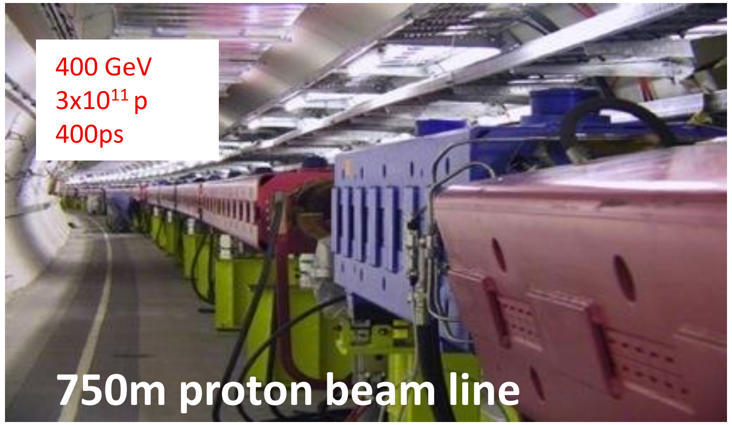


E. Adli et al. (AWAKE Collaboration), ***Phys. Rev. Lett. 122, 054802 (2019).***
M. Turner et al. (AWAKE Collaboration) ***PRL, 122, 054801 (2019).***

Key Ingredients of AWAKE







Run 1 Papers in 2020

Submitted papers in 2020:

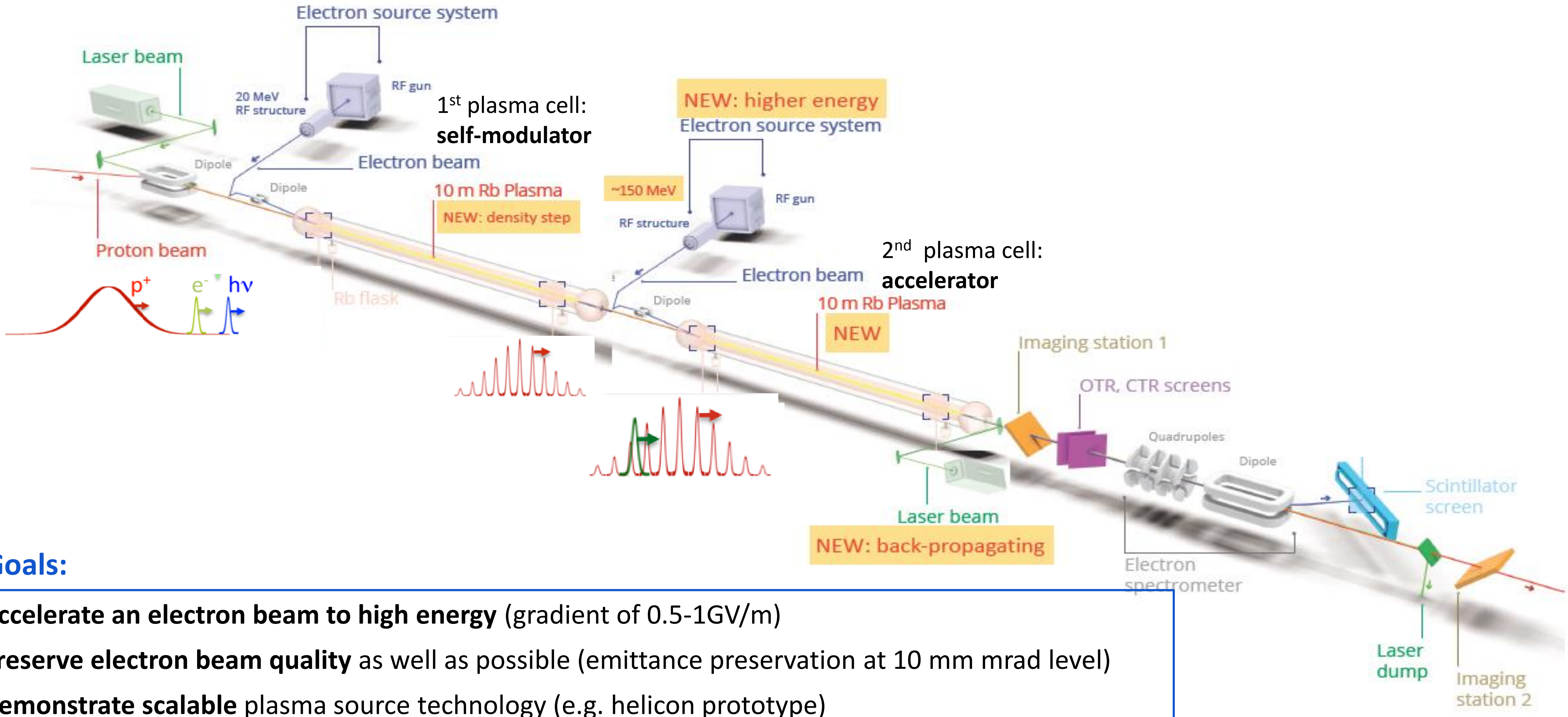
- Experimental study of wakefields driven by a self-modulating proton bunch in plasma, by M. Turner, P. Muggli et al. (AWAKE Collaboration), Phys. Rev. Accel. Beams 23, 081302 (2020)
- Proton bunch self-modulation in plasma with density gradient, F. Braunmueller, T. Nechaeva et al. (AWAKE Collaboration), submitted to Phys. Rev. Lett. July 30 (2020).
- Experimental study of extended timescale dynamics of a plasma wakefield driven by a self-modulated proton bunch, by J. Chappell et al. (AWAKE Collaboration), submitted to Phys. Rev. Accel. Beams. (2020)
- Evolution of a plasma column measured through modulation of a high-energy proton beam, by S. Gessner et al. (AWAKE Collaboration), submitted to Phys. Rev. E (2020).
- Proton beam defocusing in AWAKE: comparison of simulations and measurements, by A.A. Gorn, M. Turner et al. (AWAKE Collaboration), submitted to Plasma Phys. Control Fusion (2020).

Papers almost ready for submission:

- Transition between instability and seed self-modulation of a relativistic particle bunch in plasma
- Observation of the coupling between self-modulation and hose instability of a long proton bunch in plasma
- Self-modulation analysis
- Effect of plasma density gradient on the self-modulation of a proton bunch
- Long wavelength hosing
- Acceleration and capture data analysis

AWAKE Run 2

➔ Demonstrate possibility to use AWAKE scheme for high energy physics applications in mid-term future!



Goals:

Accelerate an electron beam to high energy (gradient of 0.5-1GV/m)

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

Demonstrate scalable plasma source technology (e.g. helicon prototype)

Phases of AWAKE Run 2

Run 2 a) Demonstrate electron seeding of self-modulation in first plasma cell

- Predicted by simulations, but not yet fully explored in data (small sample in 2018)

➔ Find best parameters to work reliably and phase-stable.

Run 2 b) Demonstrate the stabilization of the micro-bunches with a density step

- Design and install new plasma cell (SSM source)

➔ Show levelling of strong acceleration field

} Can be done in existing AWAKE facility

Run 2 c) Demonstrate electron acceleration and emittance preservation

- ***Expand the experimental area (CNGS dismantling)***
- New electron source and beam line
- New plasma cell (ACC cell)
- New laser to 2nd plasma cell
- New diagnostics

➔ Experimental program to demonstrate simultaneous energy gain and good emittance

Run 2 d) Demonstrate scalable plasma sources

- Laboratory developments in dedicated plasma labs

➔ Proof-of-concept in AWAKE experiment

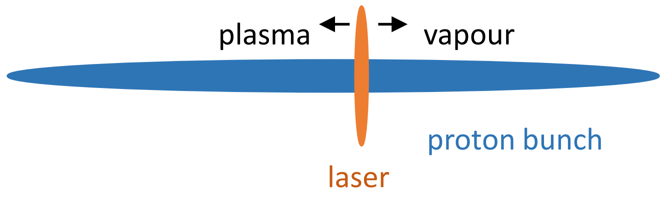
Proposed dates: 2021/22	2023/24	End 2024/2025	2025/2026	2027/2028/…	
2a): electron seeded self-modulation	2b): density step plasma cell	2c) Clear out CNGS target area	2c) installation/ commissioning	2c) electron acceleration	2d) scalable plasma source

CERN LS3: 2025, 2026

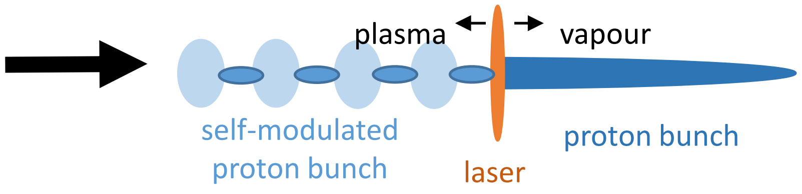
Run 2a: Demonstrate Electron Seeding of Self-Modulation in First Plasma Cell

Why electron seeding?

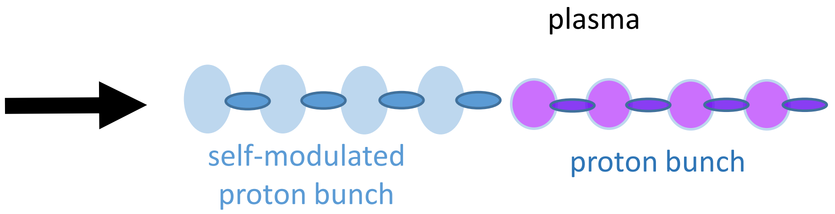
Entrance first plasma:



Exit first plasma:



In the second pre-ionized plasma:



Self-modulation instability (SMI) of the front,
Seeded self-modulation (SSM) of the back!

Issue in Run 2c:
the second plasma is pre-ionized: front of the bunch can go through SMI and interfere with the SSM-ed back of the bunch

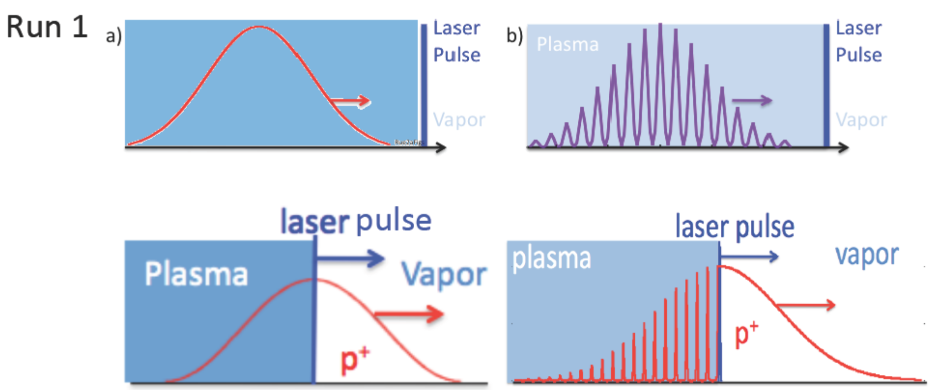
Run 2a: Demonstrate Electron Seeding of Self-Modulation in First Plasma Cell

Why electron seeding?

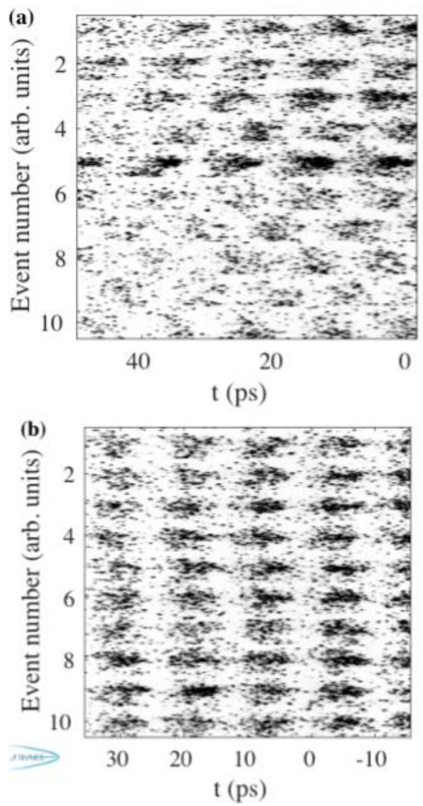
Issue in Run 2c:
the second plasma is pre-ionized: front of the bunch can go through SMI and interfere with the SSM-ed back of the bunch

Why not seeding the entire proton bunch with the laser? → phase not reproducible

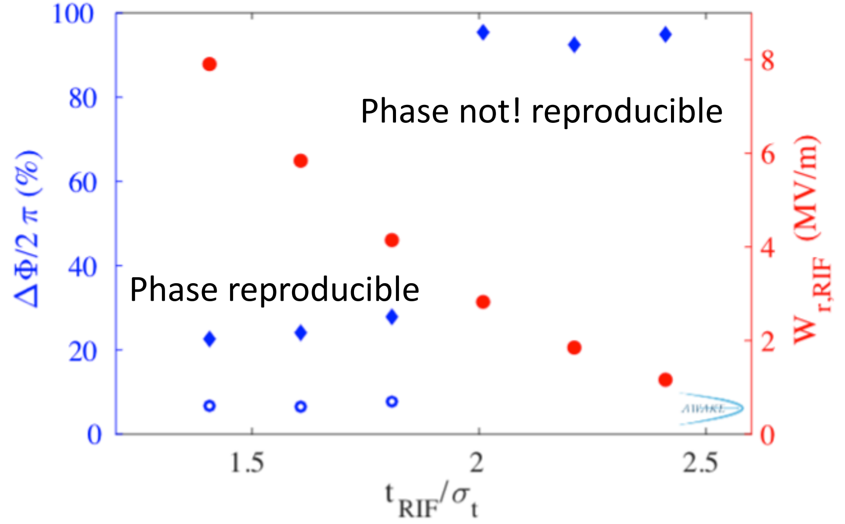
Phase not reproducible
(no seeding)



Phase reproducible
(seeding)



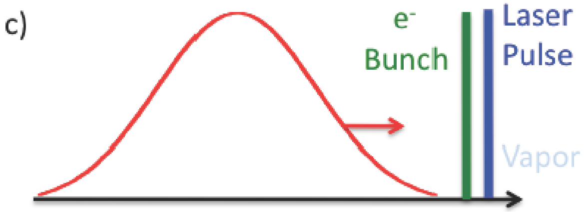
F. Batsch, to be submitted

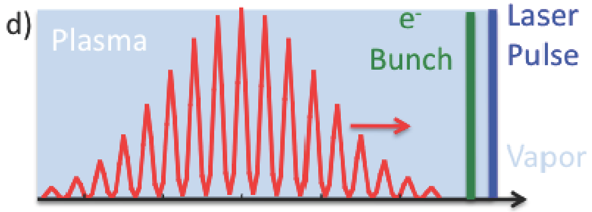


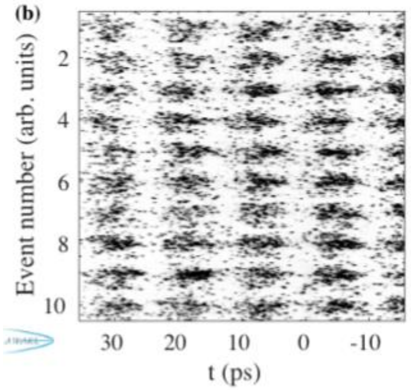
Run 2a: Demonstrate Electron Seeding of Self-Modulation in First Plasma Cell

Why electron seeding?

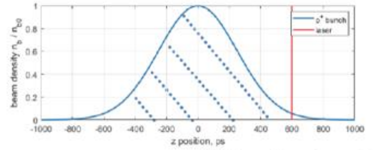
Electron bunch seeding:
→ Modulates entire proton bunch with phase reproducibility

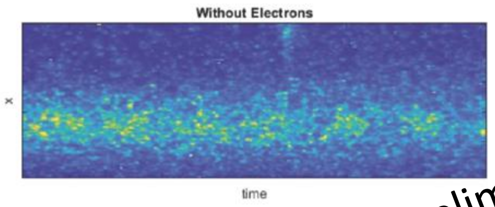






First attempts during AWAKE Run 1 in 2018, results ambigious…:

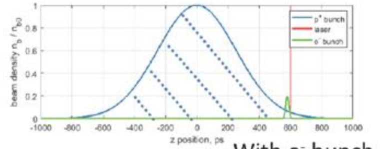


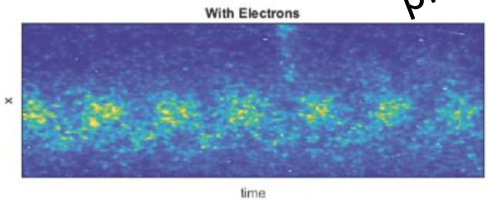


Without e^- bunch

A.-M. Bachmann, 2018

preliminary



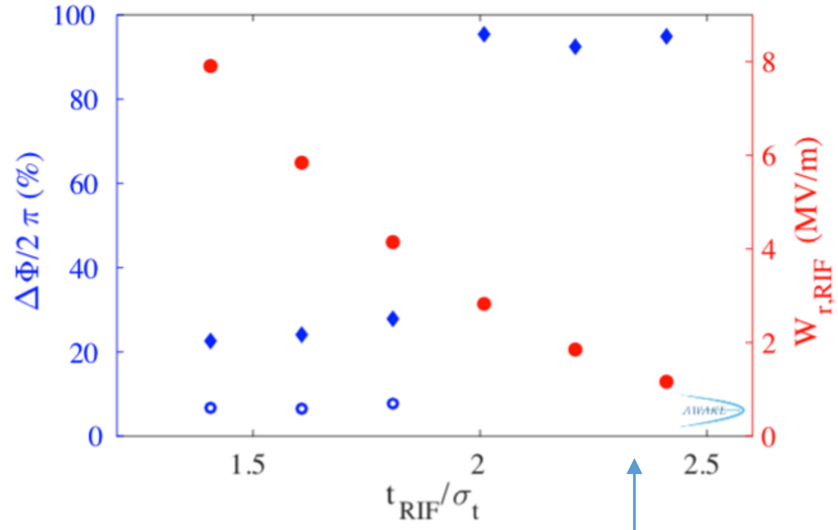


With e^- bunch

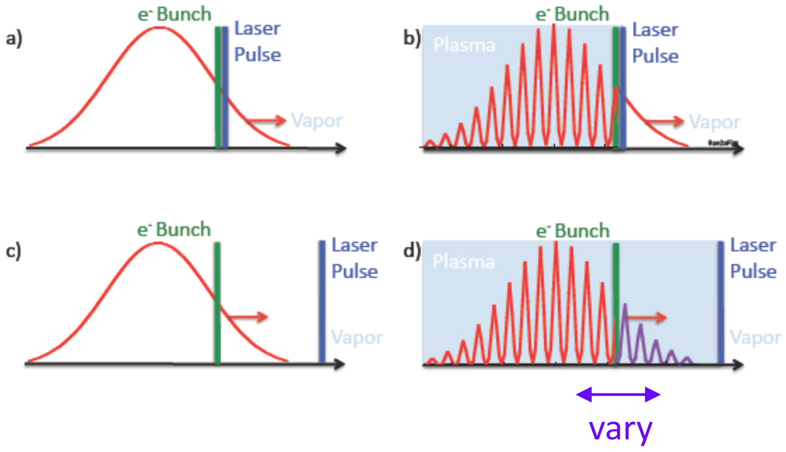
Run 2a: Demonstrate Electron Seeding of Self-Modulation in First Plasma Cell

Goals of Run 2a:

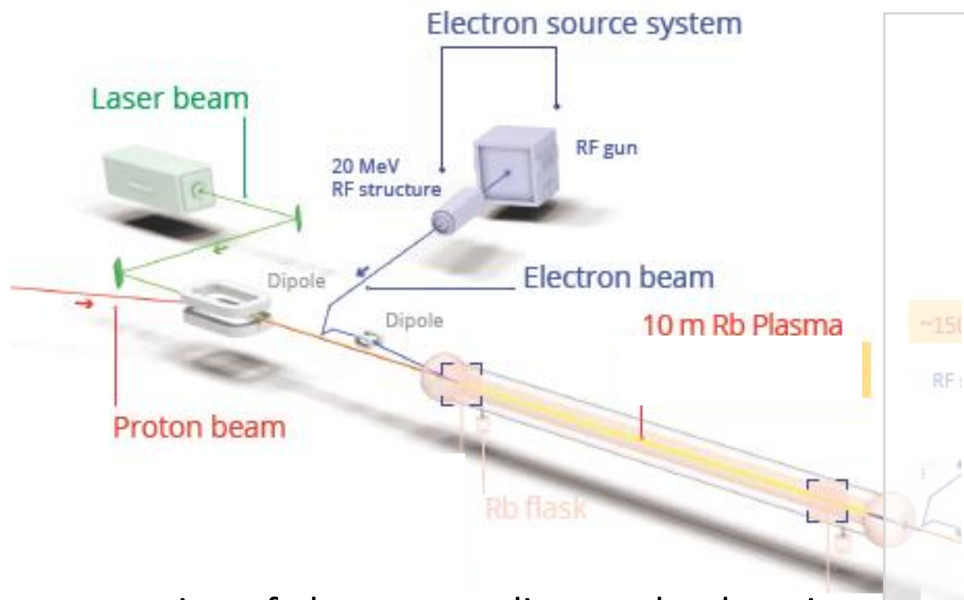
- Demonstrate phase stability with the electron bunch seeding
- Determine crucial parameters, show transition of SSM and SMI
- Study front SMI influence on back SSM
- Better understand SSM/SMI
- Better understand hosing, seeding with electron bunch misalignment



e⁻ bunch parameters: N(Q), σ_r ,σ_z , ε



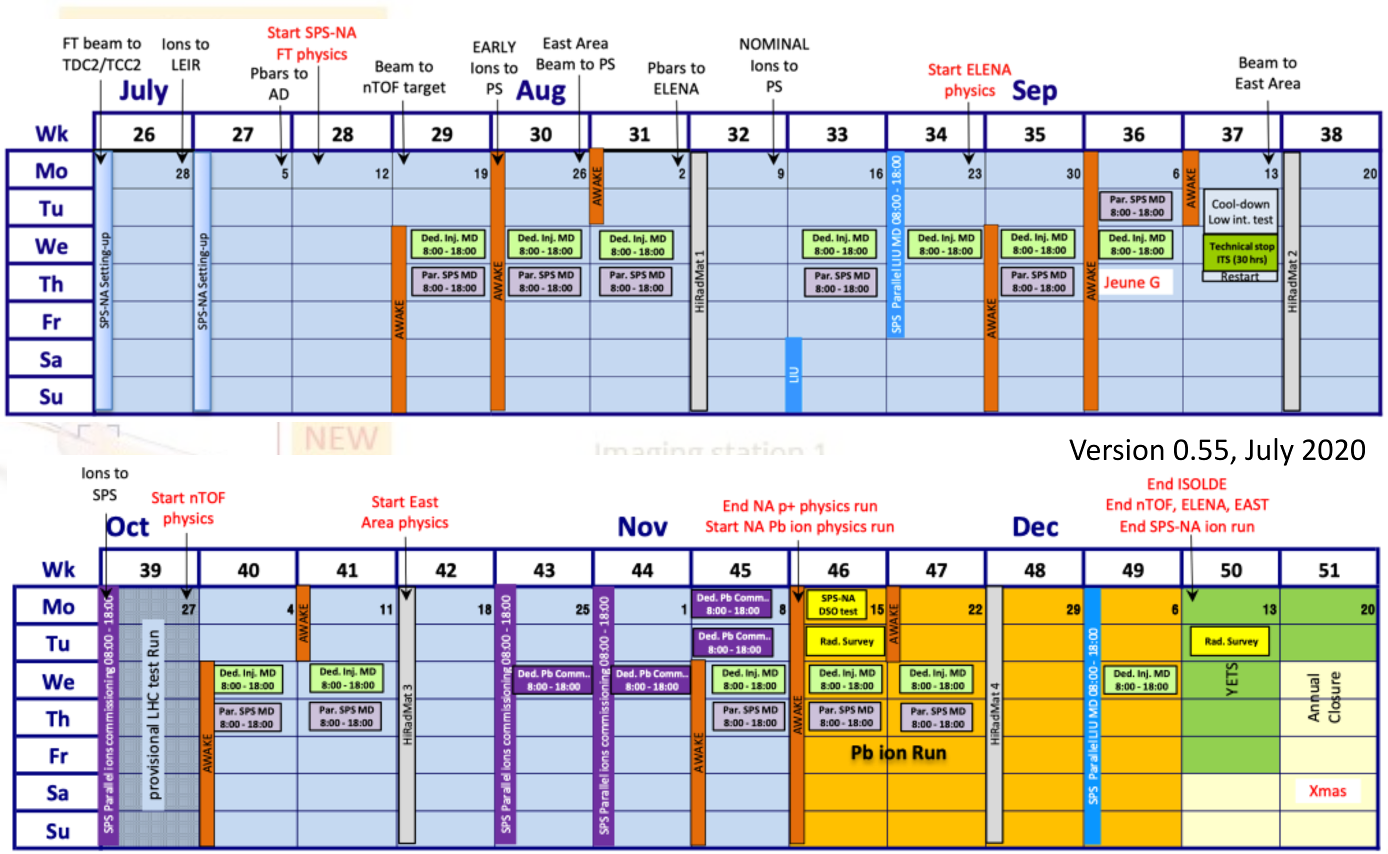
Run 2a: Demonstrate Electron Seeding of Self-Modulation in First Plasma Cell



Demonstration of electron seeding can be done in existing AWAKE facility

→ Physics program in 2021/22

Beam request:
→ 12 weeks per year



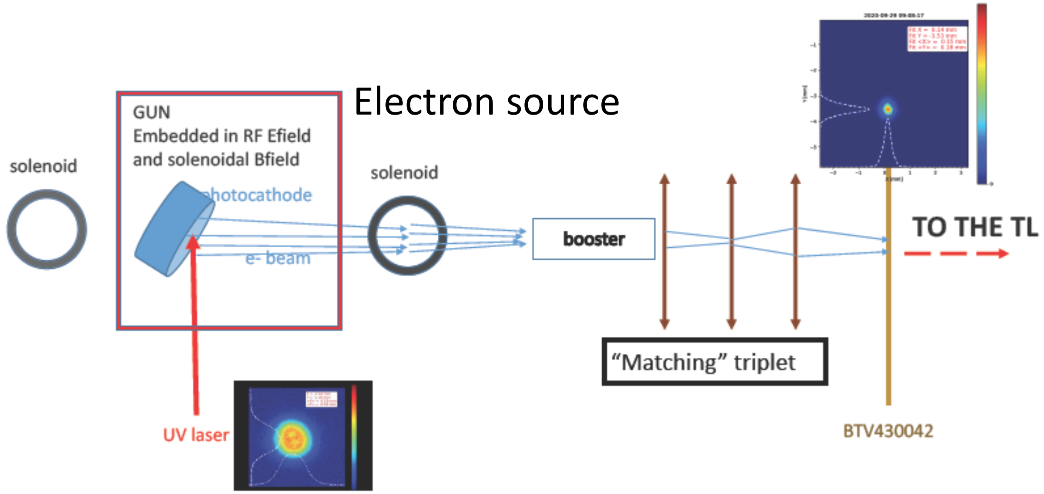
SPS Schedule 2021 (after Covid-19):
We request 8 weeks of beam time (originally 12 weeks)
→ Difficult to perform physics program with less beam-time.

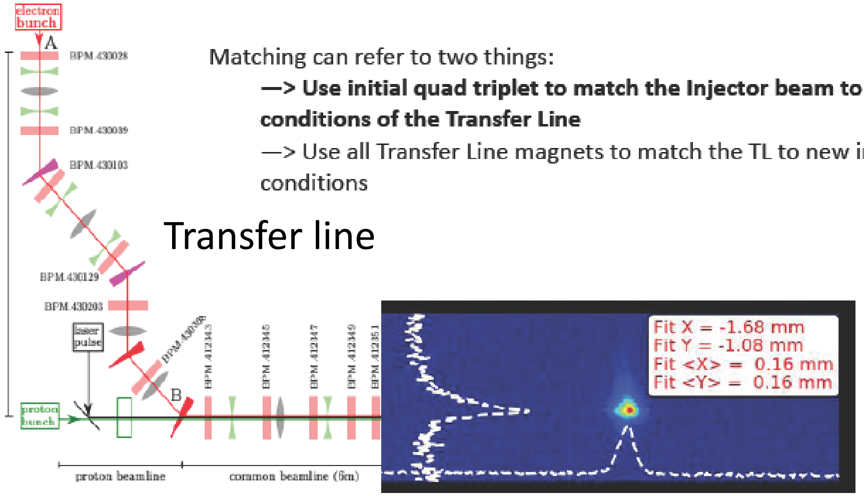
Preparations for Run 2a during LS2

Measurement Program to prepare for the AWAKE run 2021 during LS2:

- Repeatably setup the injector and beamline over the full range of available parameters and days to perform controlled and reproducible electron beam seeded self-modulation of the proton beam.

- **‘Human Learning’:** Find magnet currents which take the measured optics to the target optics
  - Establish a procedure to match the electron injector to the transfer line
  - Estimate beam properties (beam size) at the plasma entrance for every setup and provide round beam with waist at plasma entrance for 3 different reference charges.





Matching can refer to two things:

—> Use initial quad triplet to match the Injector beam to the initial conditions of the Transfer Line

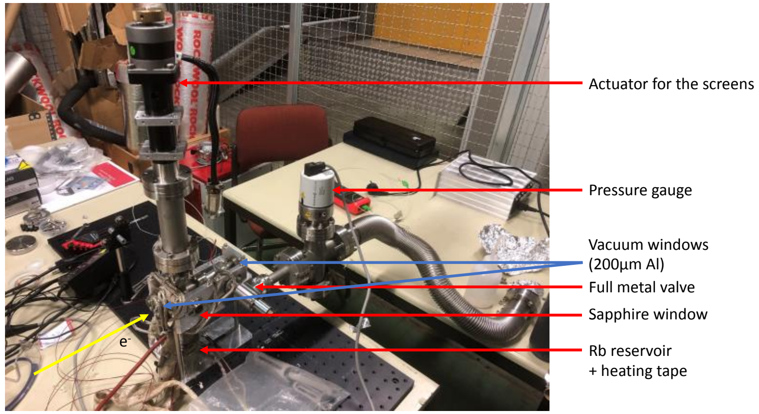
—> Use all Transfer Line magnets to match the TL to new initial/target conditions

L. Verra, G. Zevi Della Porta, S. Doebert, F. Velotti, R. Ramjiawan, V. Kain

- **’Machine Learning’:** Find magnet currents which take the measured beam size to the target beam size
  - Testing numerical optimisers and reinforcement learning (RL) agents on different cases: Automatic steering and automatic transfer line optics matching.
  - AWAKE used as production example for the full CERN accelerator complex as first integration of ML algorithms in CERN Control Centre.

Preparations for Run 2a during LS2

- Beam Instrumentation for electron beam line
  - Development of Diffracted Cherenkov Radiation BPMs.
    - → installation in common proton/electron beam line before the plasma cell in 2021.
    - Allows to measure the position of the ps – long electron bunch in presence of much more intense (~F3) and longer proton bunch.
  - Upgrade of digital-camera DAQ system to improve synchronization and replace analogue system.
  - Replace Chromox screens used for transverse profile measurement with YAG screens (better resolution and faster time response)
  - Study screen installation inside the vapour source expansion volume → tests in CLEAR.

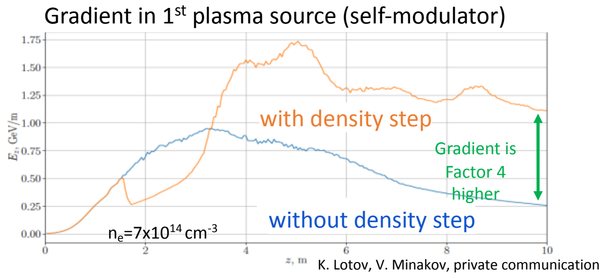


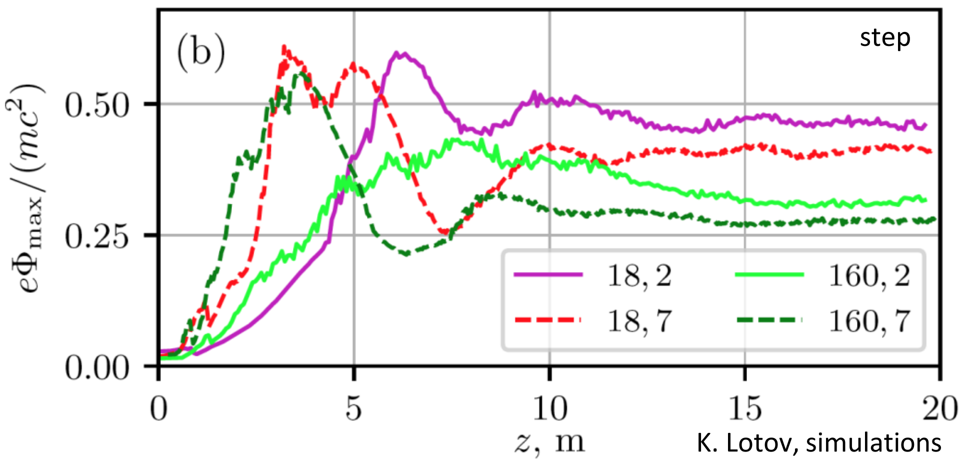
- New clean room in EHN1 test stand
  - Used for development and tests of optical diagnostics for plasma and electron beam injection area.

Run 2b: Demonstrate Stabilization of Micro-Bunches with a Density Step

Why a density step in vapour source?

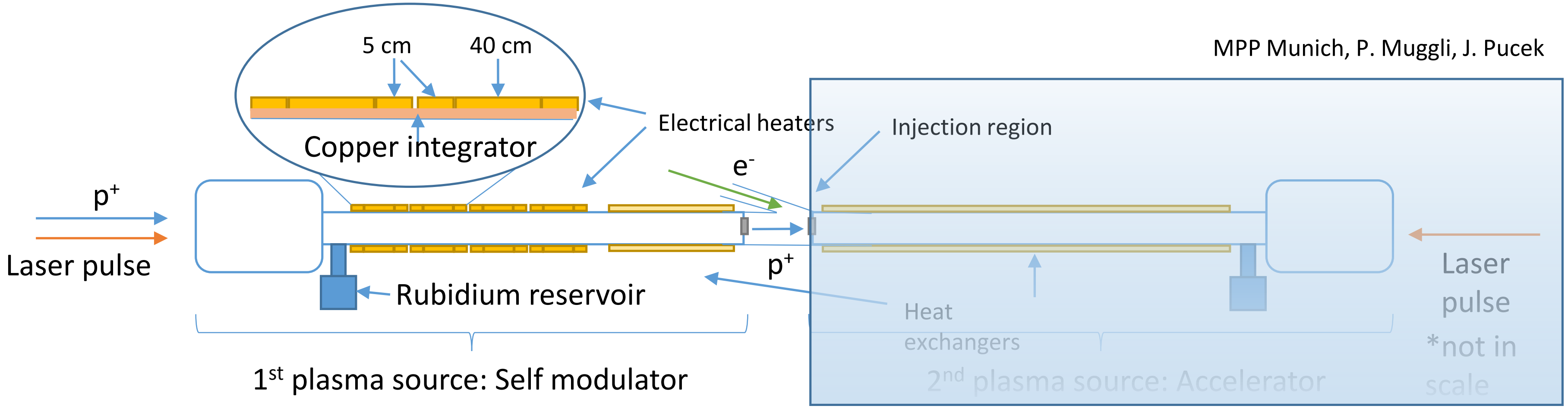
- In constant plasma, wakefield amplitude decreases after saturation.
- In a plasma with density step within the SM grow: wakefield amplitude maintains larger after saturation.





➔ Install a new plasma source with density step capability

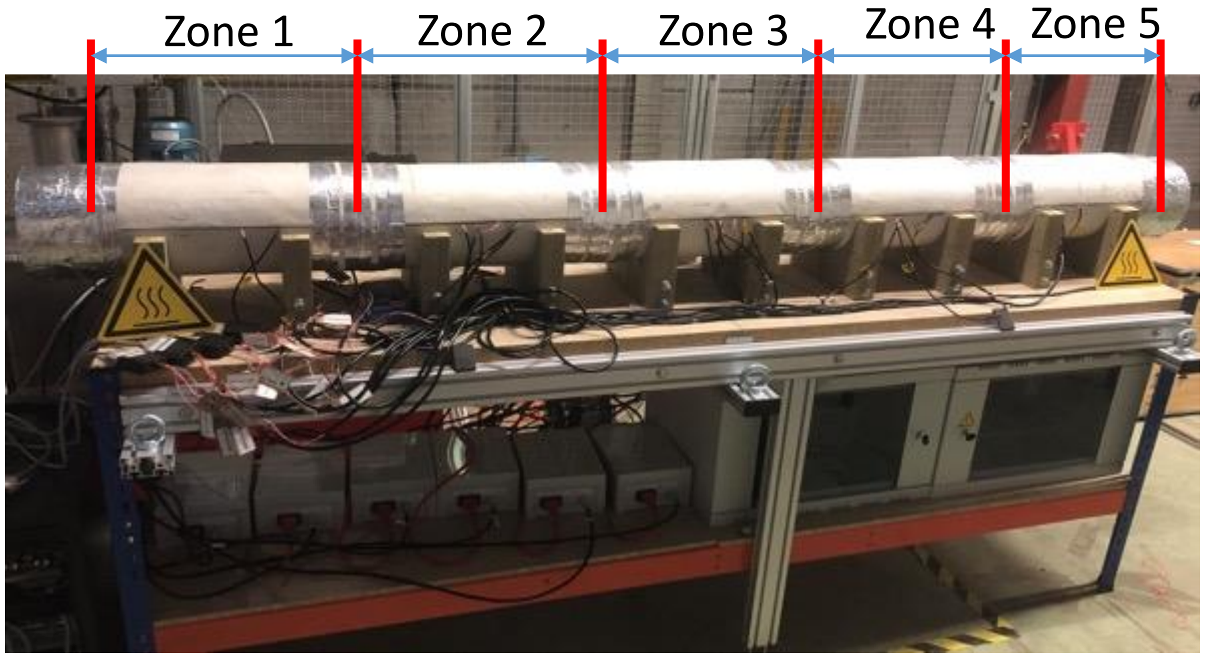
➔ Install novel plasma diagnostics to allow measurement of plasma 'wave' directly (i.e. THz plasma density perturbation diagnostics).



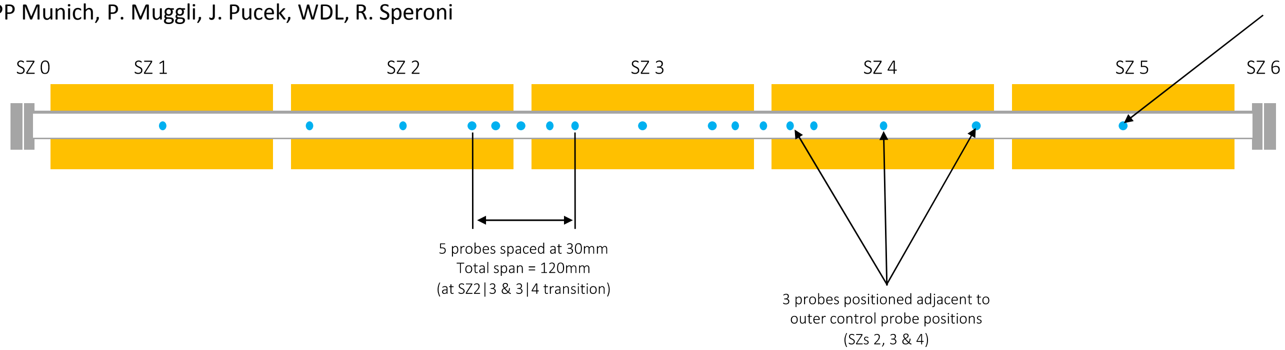
Run 2b: Demonstrate Stabilization of Micro-Bunches with a Density Step

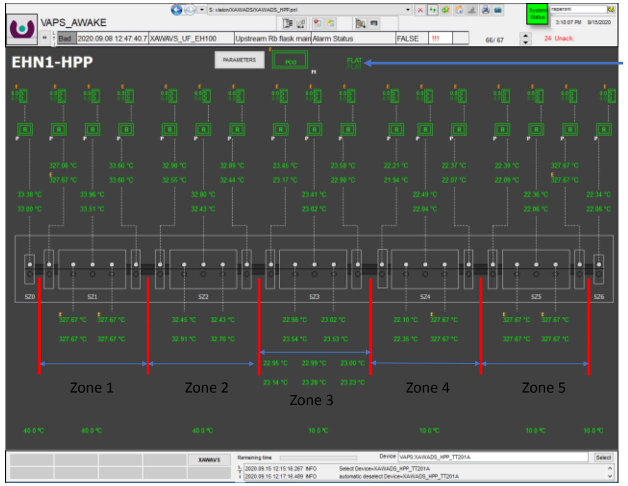
➔ Design and install new plasma cell (SSM source)

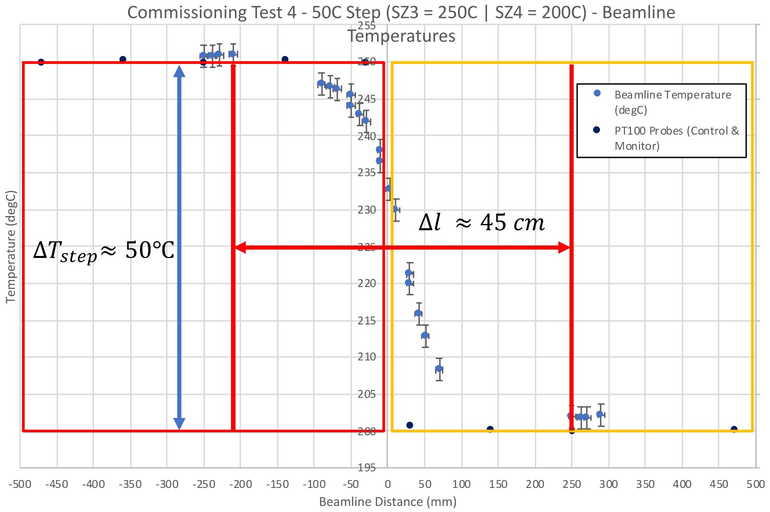
Prototype setup in test stand in EHN1!
System connected to Siemens control system
Good results for performance and control



MPP Munich, P. Muggli, J. Pucek, WDL, R. Speroni



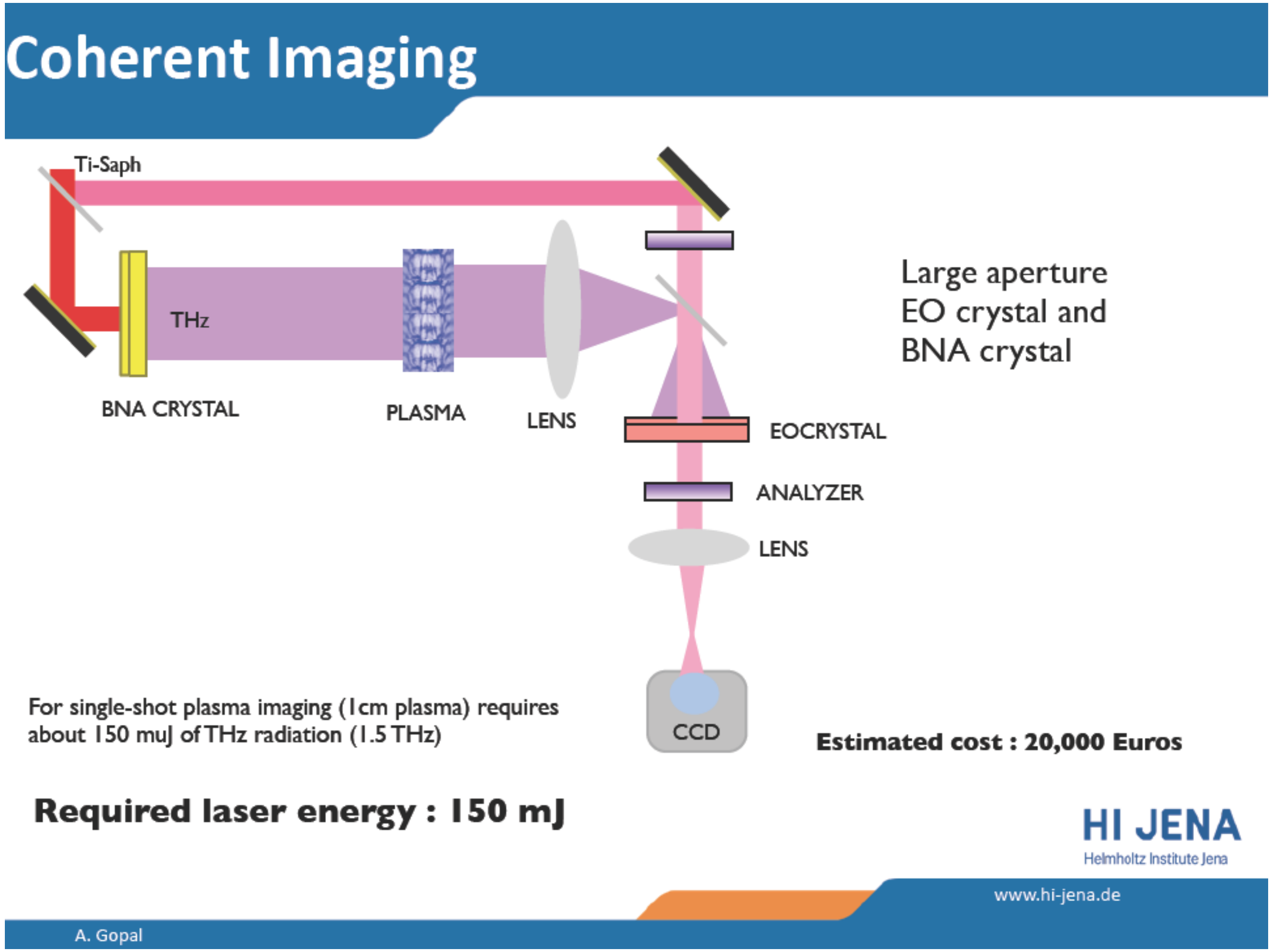




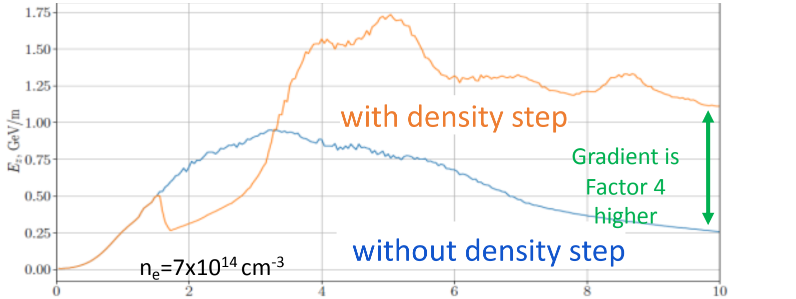
WDL's results

Run 2b: Demonstrate Stabilization of Micro-Bunches with a Density Step

THz Diagnostics

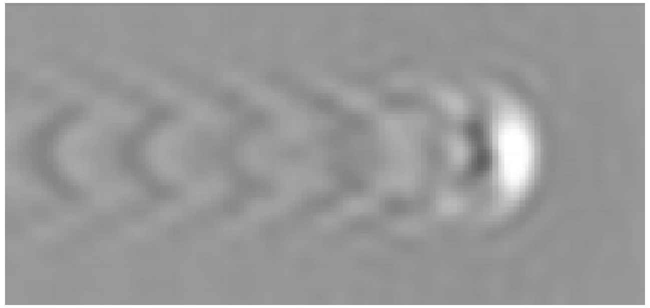


Gradient in 1st plasma source (self-modulator)



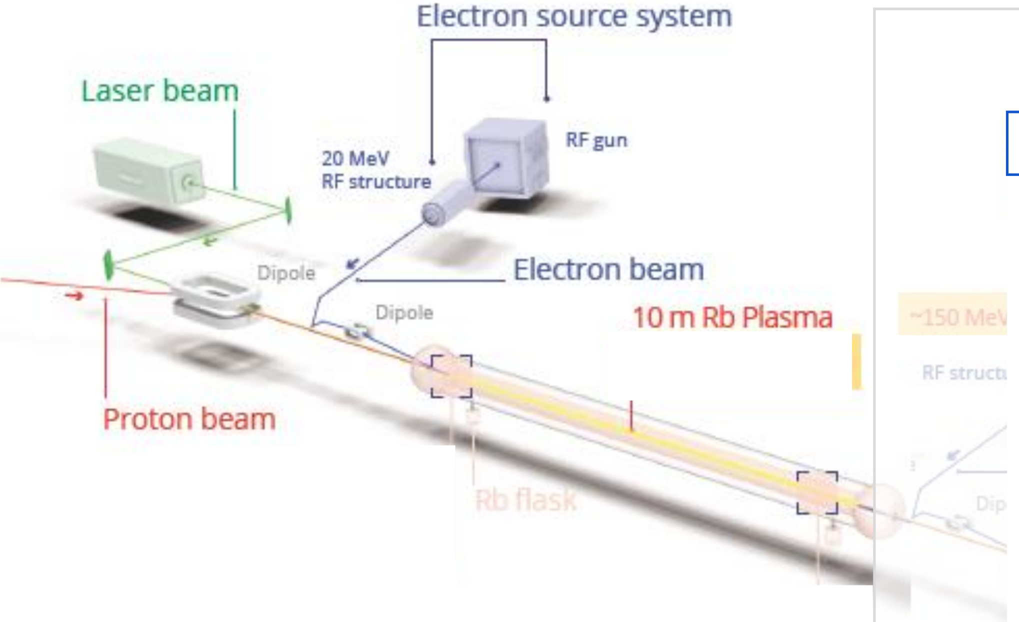
K. Lotov, V. Minakov, private communication

Siminos PPFC 58 (2016) 065004



Institute of Optics & Quantum Electronics JENA

Run 2b: Demonstrate Stabilization of Micro-Bunches with a Density Step



Run 2b program:

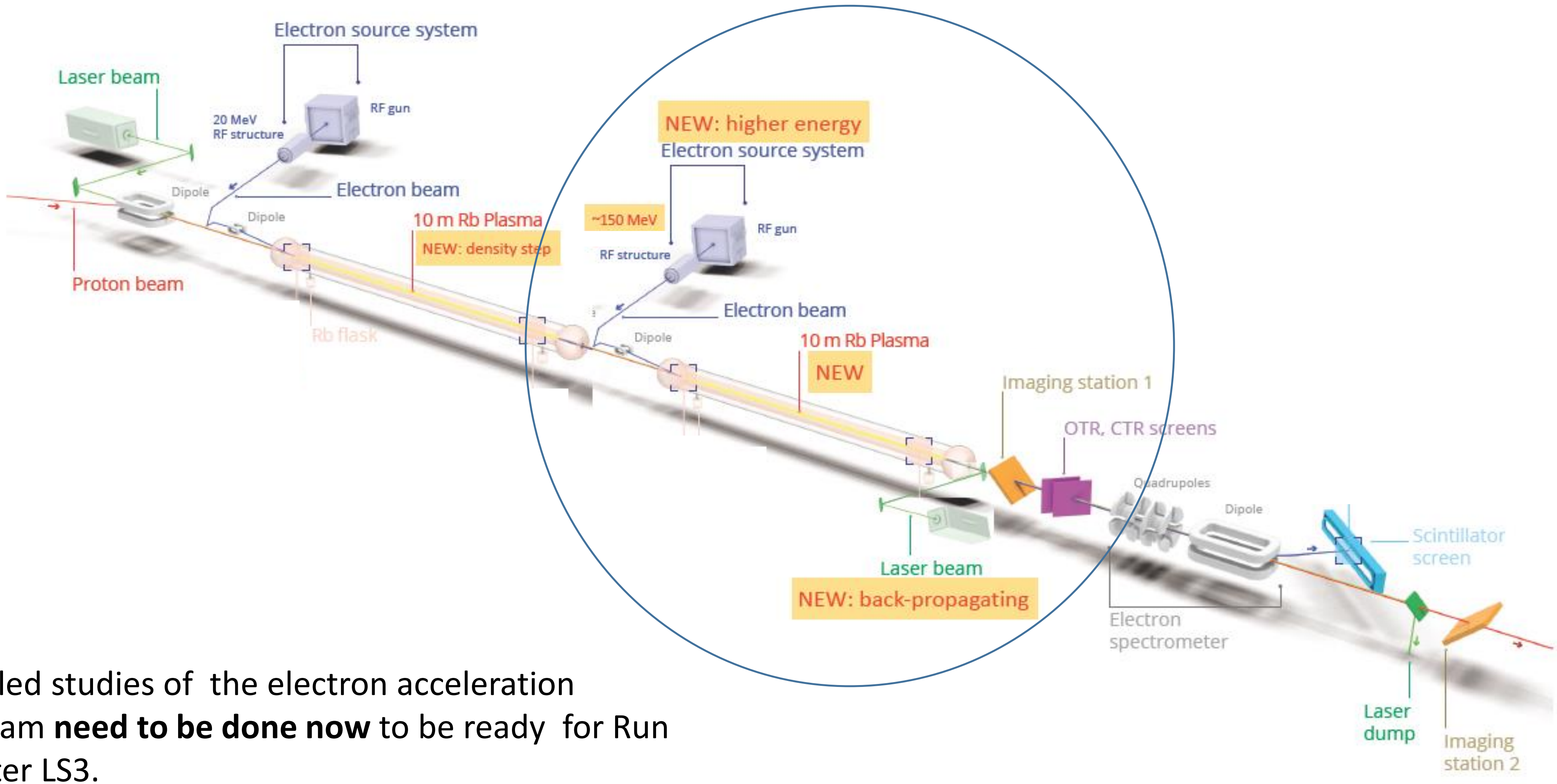
- ➔ Install a new plasma source with density step capability
- ➔ Install novel plasma diagnostics to allow measurement of plasma 'wave' directly (i.e. THz plasma density perturbation diagnostics, Fourier domain diagnostics (FDH)).
- ➔ Study effect of plasma density step on SMI and SSM with THz shadowgraph
- ➔ Electron bunch seeding w/wo density step
- ➔ Study effects on proton bunch (modulation frequency, hosing, halo size, etc…)
- ➔ Study change in energy gain for externally injected electrons.

Design, build and install new 1st plasma source (self-modulator) with a density step (Installation during YETS 2022/23)

➔ Show levelling of strong acceleration field

➔ Physics program foreseen for 2023/24

Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

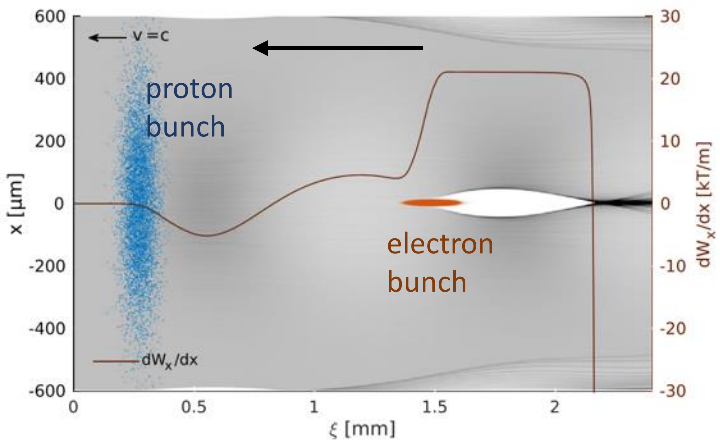


Detailed studies of the electron acceleration program **need to be done now** to be ready for Run 2c after LS3.

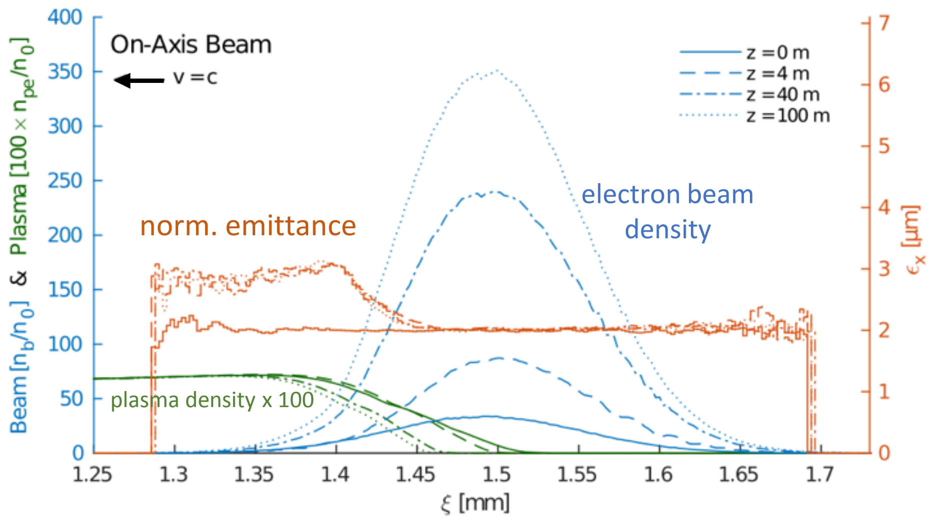
Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

Why a new electron beam?

- **Blow-out** regime: create a ‘bubble’ → linear focusing → Emittance is preserved during acceleration
- **Beam loading**: reach small ∂E/E
- **Match** electron beam transverse properties to the plasma: preserve emittance



V. Berglyd Olsen, E. Adli, P. Muggli,
Phys. Rev. Accel. Beams, 21 (2018) 011301



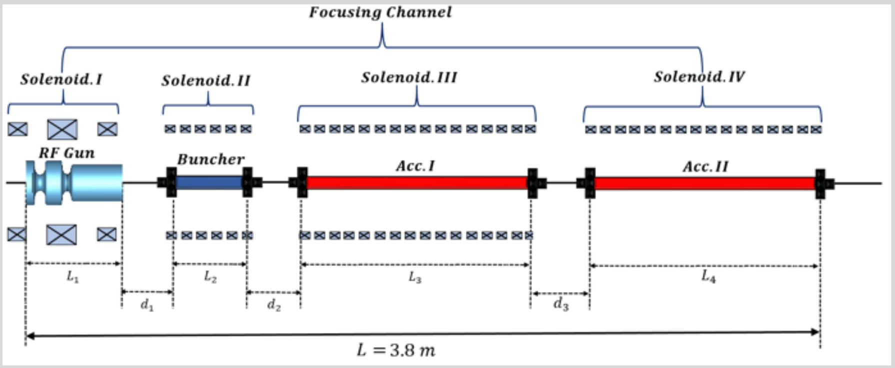
➔ The injection of a compact electron bunch at the right phase allows the propagation over long distances with no emittance growth (apart from the head of the bunch)

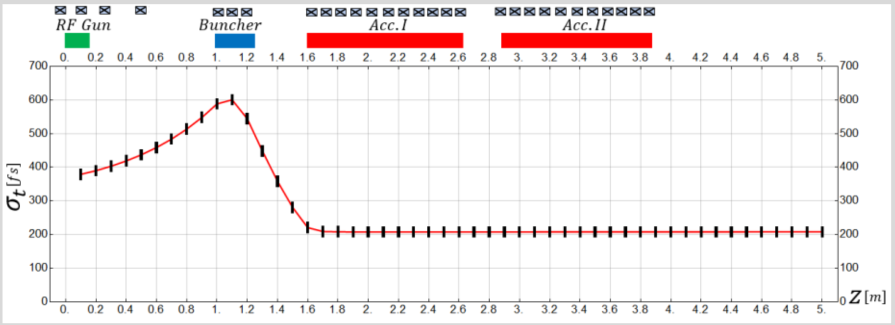
Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

New electron source

	Beam Energy	Energy Spread	Energy stability	RMS Bunch Length	Bunch Charge	Emittance	Beam size plasma focus
Injector 1	18.5 MeV	0.5 %	1 x 10^{-2}	$\approx 2-3\ ps$	$100 - 600$ pC	2 - 5 μm	~ 190 μm
Injector 2	150 MeV	0.2 %	1 x 10^{-3} ?	$\approx 200-300\ fs$	100 pC	2 μm	5.75 μm

→ based on X-band
→ Well advanced design
→ Prototyping together with CLEAR

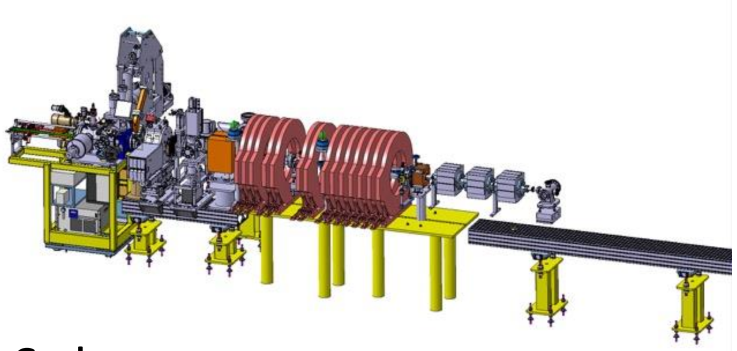




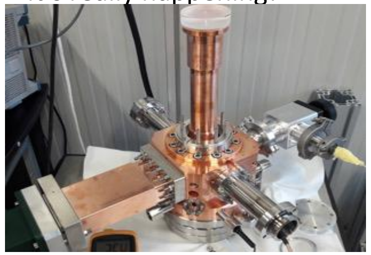
S. Doebert, M. Dayyani Kelisani, L. Garolfi

Injector Prototype together with CLEAR

- INFN contribution to CLEAR in the framework of a CLIC collaboration agreement
- Profit from existing infrastructure and hardware to add x-band structure to demonstrate velocity bunching and generation of ultra short bunches
- Ideal test bed for challenging AWAKE bunch length diagnostics
- Will allow to address challenges early on and saving money and commissioning time in tunnel



It's really happening!



Gun assembly at INFN

Goals:

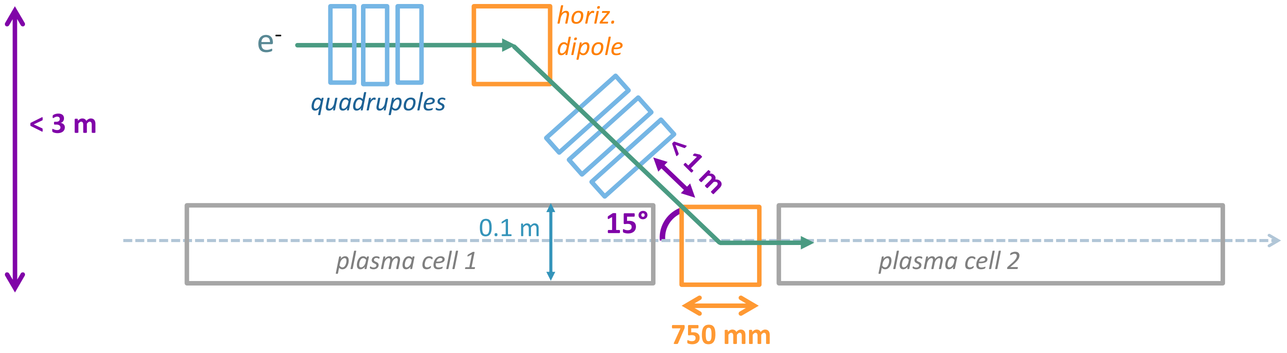
- Demonstrate velocity bunching with x-band and emittance preservation/control
  - Show reliable high gradient x-band operation
  - Study mechanical/integration aspects
  - Test diagnostics
  - Optimise final design for AWAKE
  - Get team together, gain momentum for challenging AWAKE Run2 injector

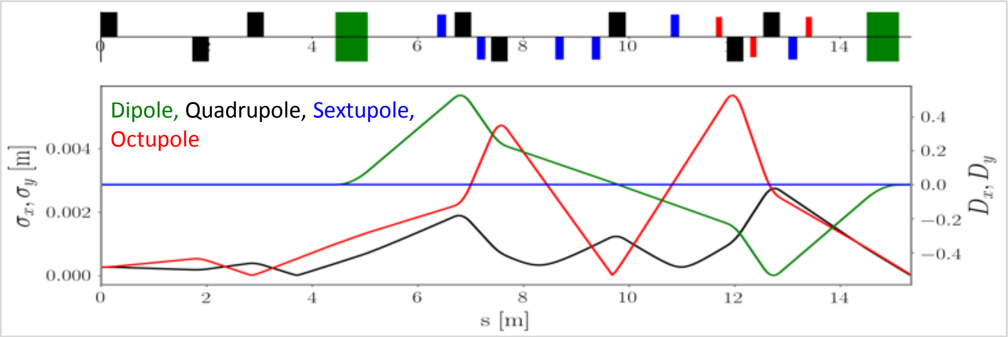
Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

New electron beam line

R. Ramjiawan, F. Velotti

→ Requirement of β = 5 mm at injection.
→ Require a module which is achromatic, with no bunch lengthening.
→ Limit of ~ 3m width set by tunnel width
→ Dipole bending angle > 15° so beam-pipe doesn't hit plasma cell
→ Dipole-quadrupole spacing > 1 m





Design optimised to meet matching condition at plasma merge-point:

$$\sigma = \sqrt{4.87\ \mathrm{mm} \times \epsilon}$$

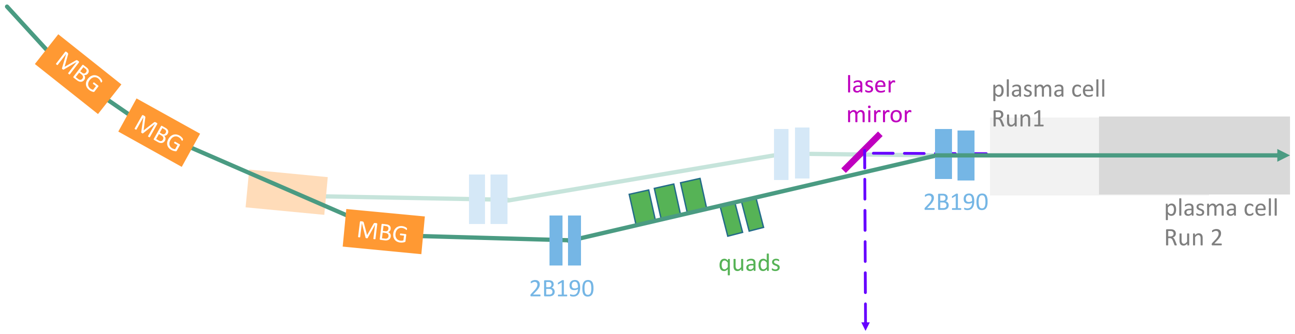
→ Tight tolerances for magnet alignments, magnetic field strength errors and BPM resolution
→ Study effect of momentum jitter

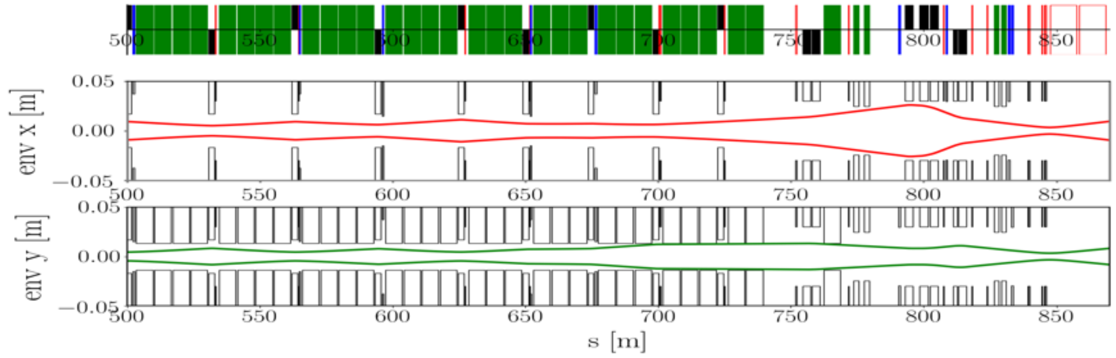
Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

Proton line

R. Ramjiawan, F. Velotti

- → Move the plasma cell by +40m, with the laser mirror kept approximately the same distance from the plasma cell as for Run 1.
- → Laser chicane design allows for the laser-mirror to be within 27m of the plasma cell.
- → Aperture tight, beam envelope within a few mm of vertical magnet apertures.

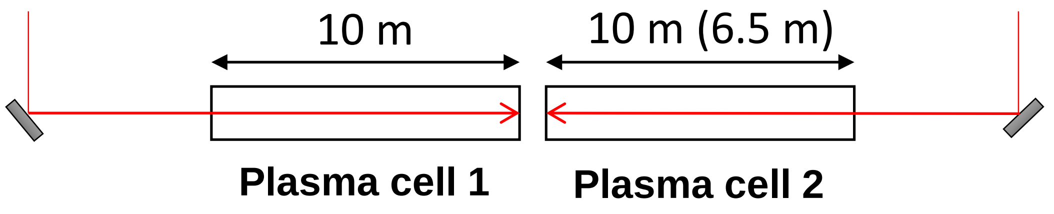




The preliminary specifications for alignment tolerances seem beyond what the SPS and the TL can do – it needs significant upgrade to meet them.

Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

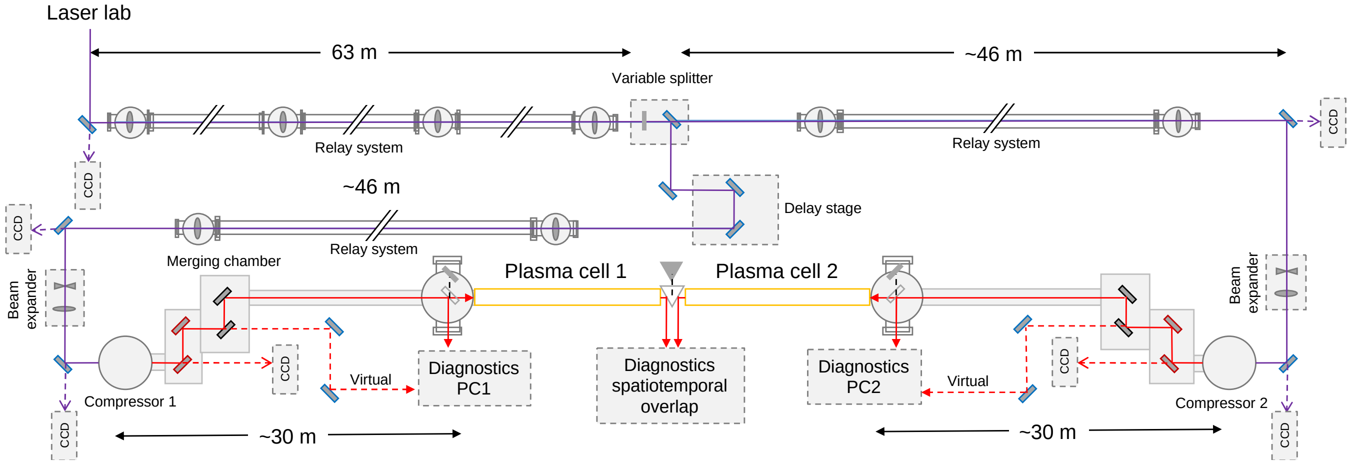
Laser system



IR Laser beam for ionization of second vapour source will be injected from its downstream counter-propagating to the proton beam.

Use same laser as used in Run 1 by splitting its output beam on two branches. → allows independent beam optimization wrt power, focus, timing.

- Major developments:
  - Relocation of compressors
  - Relay image system for beams delivery
  - Timing synchronisation, spatial overlap and new diagnostics



V. Fedosseev, E. Granados, H. Panuganti, J. Moody, MPP

UV laser for the 2nd electron source:

Preferable option is to use a separate laser (as in CLEAR) due to:

- Synchronization with ionizing laser without additional delay lines (~ 80 m extra)
- Location of compressors and harmonic stages (laser lab, near gun?) → better pointing stability
- Higher energy of UV pulse
- Possibility to produce electron beams independently of the main laser status

Laser beam line to electron gun 2:
λ ~ 260-267 nm
t pulse = 0.2-10 ps
E ~ 0.5 uJ

Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

Diagnostics

- Proton and electron-proton line before 1st plasma cell:
  - positions of electrons in common line shall be measured in presence of proton beam at least on two locations. Requirements to be defined. CERN, U. Oxford and TRIUMF developing a prototype to be tested in Run 2a.
- 150 MeV electron line
  a) Beam position
    - 500-100 nm resolution (before –in dogleg)
    - New requirement to guarantee pointing accuracy. CERN BI / TRIUMF?

  b) Beam size
    - Similar performance of TT43 BTVS? 50 um magnified pixel size, PSF inside the pixel
    - Visualisation at 1-2 Hz, "burst mode"
    - CERN BI (standard development)

  c) Bunch length
    - Measured "as close as possible" to the end of the line.
    - Typical BL: 200 fs sigma. Resolution 20 fs (10%)? Interceptive? Bunch by bunch?
    - Studies ongoing: CChDR (Manchester/ RHUL), Coherent imaging (ULiv), EOS (CERN)

  d) Bunch charge

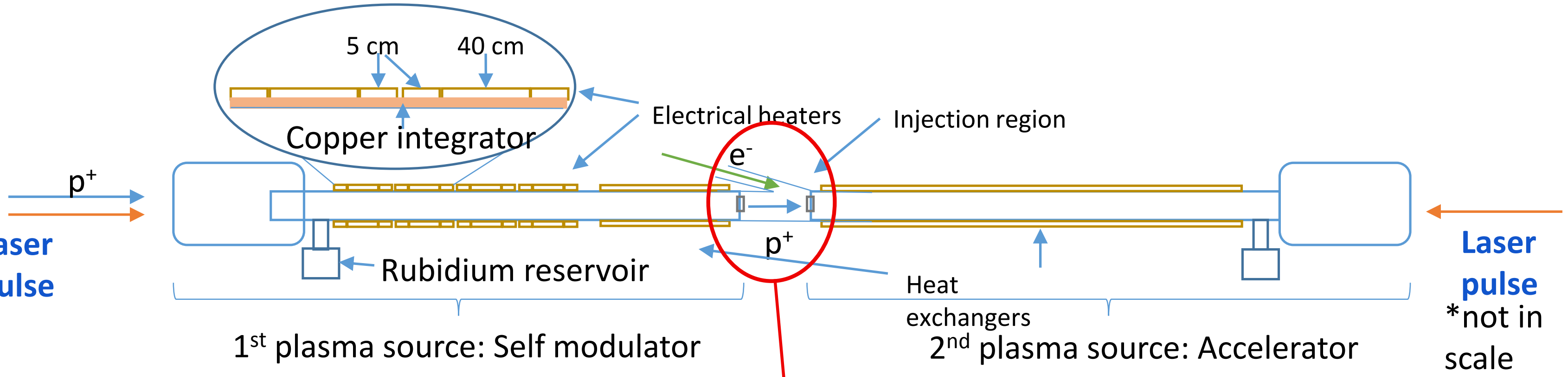
- Between plasma cells
  - position of modulated proton bunch
  - position of 150 MeV electron bunch between dipole and 2nd plasma cells also in presence of the modulated or unmodulated proton bunch
  - due to space limitations, instruments integrated in dipole
- 2nd plasma cell
  - Beam size of 150 MeV electron beam. Typical size will be 6 um sigma, so ~1 um resolution will be needed.
    - Possible technique: visibility of vertically polarized OTR if screen can be put in Rb vapour (CERN MPI test). Possible utilization of intermediate images on DMD (block p+ beam) (U. Liverpool)
    - electron beam position derived from beam image?
- Experimental area after 2nd plasma cell
  - emittance measurement
  - in case of upgrade of any existing diagnostics: spectrometer, proton halo, longitudinal profile of modulated proton

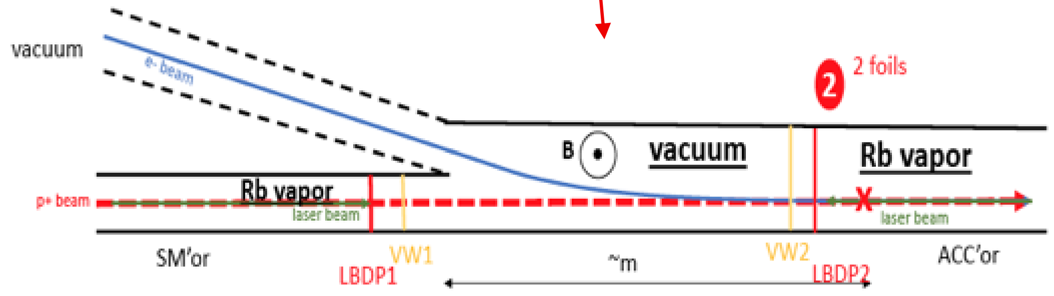
S. Mazzoni, E. Senes, M. Bergamaschi, C. Pakuza, +UK, TRIUMF

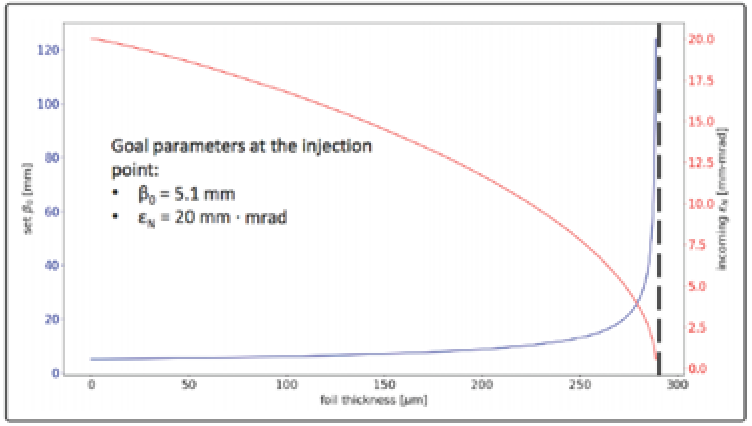
Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

New plasma cell (Accelerator)

MPP Munich, P. Muggli, J. Pucek, WDL







Use window/foil to increase beta-function of incoming beam

Complex injection region:

- Magnets
- Diagnostics for beam size, waist, pointing, time of arrival
- Windows
- Matching of electron beam to plasma

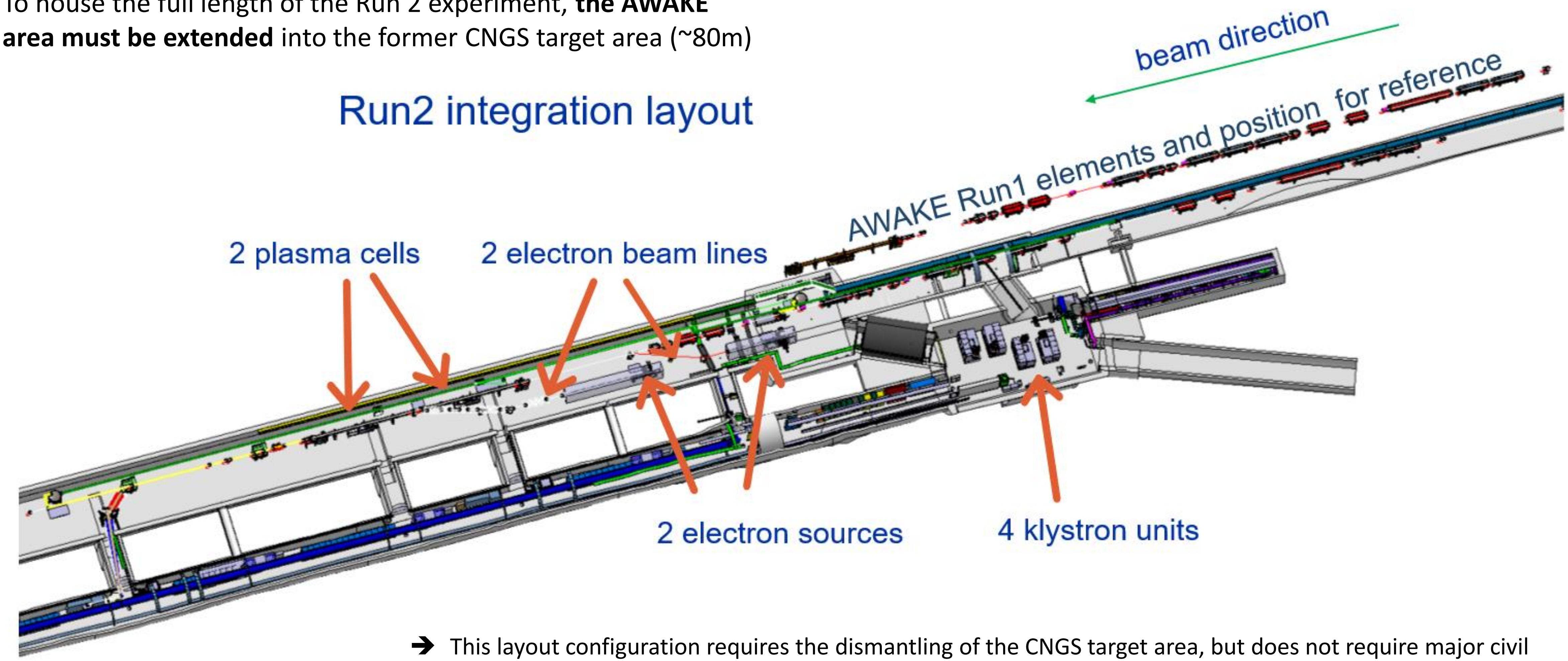
✚ No plasma ramp with backward ionization

→ Test of Rb exposed OTR screens planned in CLEAR

Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

CNGS dismantling

To house the full length of the Run 2 experiment, **the AWAKE area must be extended** into the former CNGS target area (~80m)



A. Pardons, P. Wiwattananon, V. Clerc

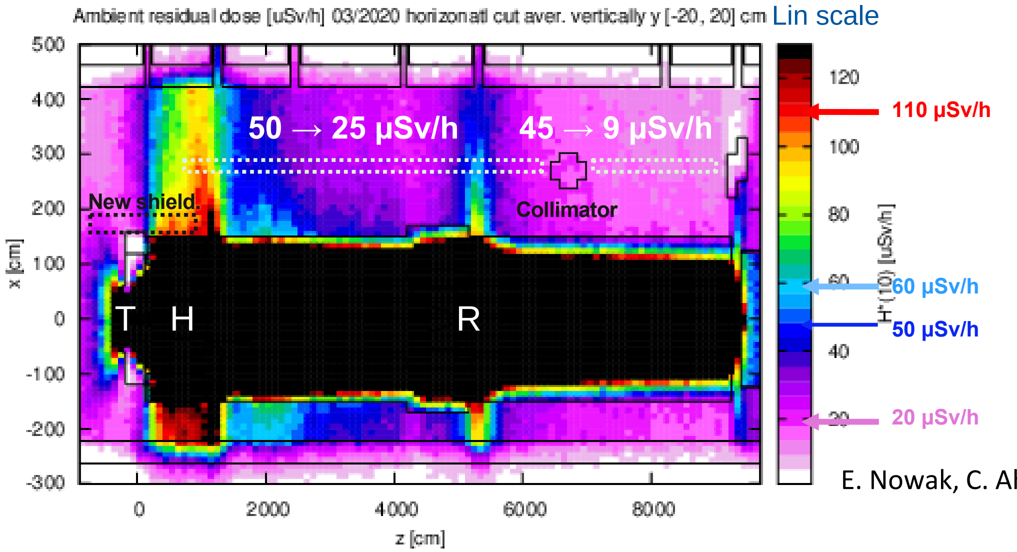
- ➔ This layout configuration requires the dismantling of the CNGS target area, but does not require major civil engineering or structural works.
- ➔ Integration studies well advanced.

Run 2c: Demonstrate Electron Acceleration and Emittance Preservation

CNGS dismantling

→ **CNGS dismantling (study) is essential for AWAKE Run 2:** Major impact on both cost and schedule → pre-study started in 2020 to assess feasibility and define resources as well as time needed to fully dismantle the CNGS target cavern TCC4 and convert it into a facility ready for AWAKE Run 2 installation.

Radiation protection studies ongoing:
Needed for radioactive waste disposal, internal transport and shipping, storage and handling of the most radioactive equipment during dismantling process.



E. Nowak, C. Ahdida


CNGS target area during installation

→ MC FLUKA simulations of residual dose rate levels agree well with measured values
→ Detailed analysis of nuclide inventory done. → relevant to characterize radioactive waste and to define its correct elimination path.
→ Gamma spectroscopy and X-ray fluorescence analysis of concrete samples from CNGS wall, floor and shielding was done

Run 2d: Demonstrate Scalable Plasma Sources

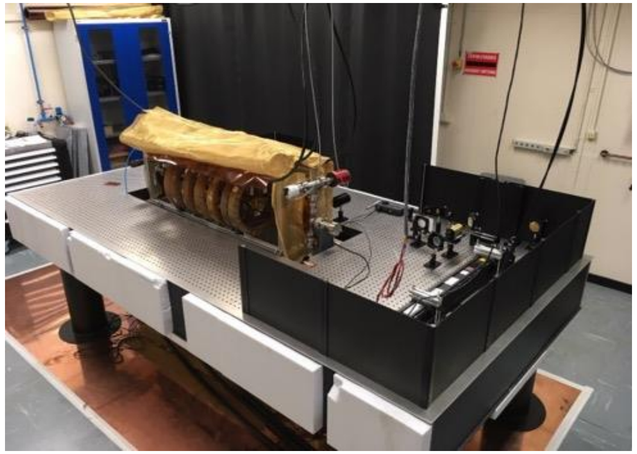
Plasma Source Development

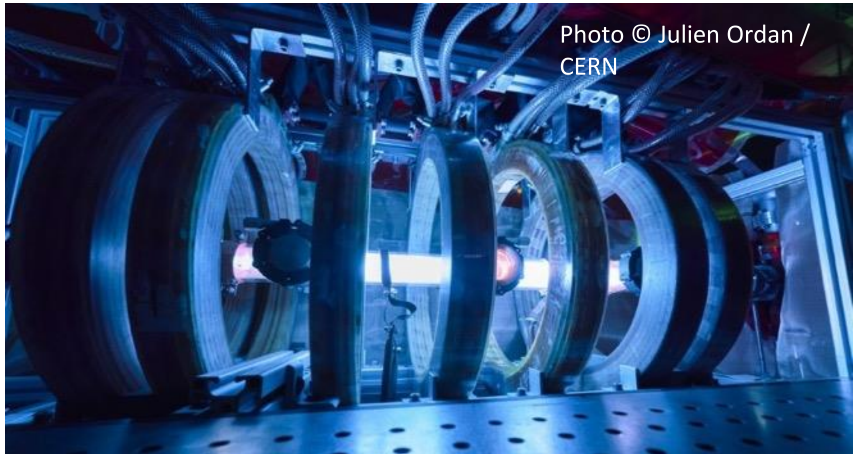
- **Helicon plasma cell** → wave heated plasma
  Density needed for AWAKE achieved at the IPP in Greifswald.
  This 1m long prototype has been moved to CERN in 2019 into a new laboratory.

- **Discharge plasma source** → high current arc plasma → Collaboration between CERN and IST, Lisbon. → Prototype installed in 2020.
  → Study uniformity and scalability at CERN.
  → Use new diagnostics to understand features of plasma.

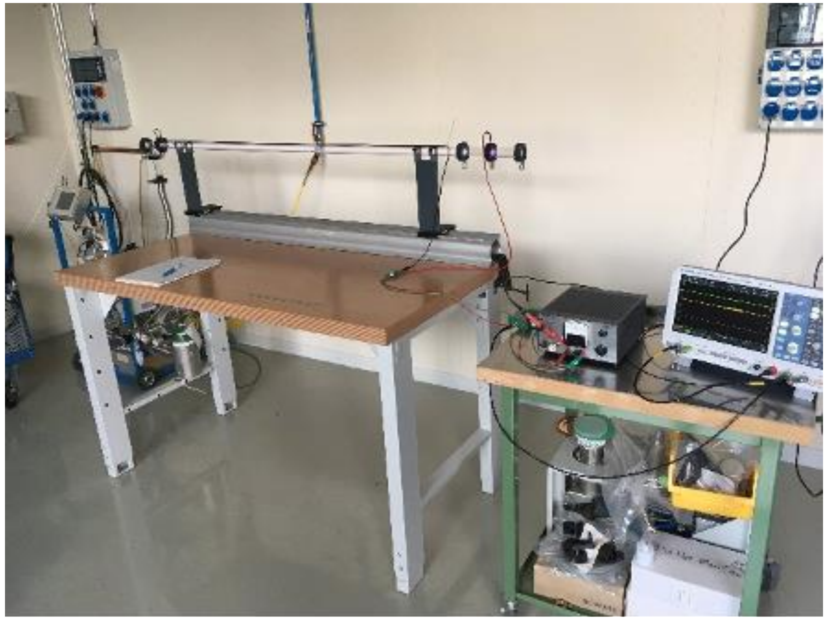
Final goal: Propose a design for a scalable, several meter long plasma cell for Run 2d).

1 m helicon plasma source at CERN





1 m helicon plasma cell from IPP-Greifswald @ CERN


1.6m discharge plasma cell setup at CERN

A. Sublet, + IPP Greifswald, SPC Lausanne, Univ. Wisconsin, IST Lisbon

Summary

- Following the recommendation of the 2019 review, the physics program of the entire AWAKE Run 2 has been staged in order to fit better the budget profile foreseen by the CERN management for the next 10 years for Run 2.
- The physics program is well defined.
  - Starting in 2021 we perform measurements with the (modified) Run 1 setup of Run 2a and Run 2b
    - For 2021 we request 8 weeks of proton beam time.
  - In parallel detailed studies of the electron acceleration program **need to be done now** for specifications, procurement, installation, etc… to be ready for preparing Run 2c in LS3
    - design, prototype and build equipment for Run 2c
    - Assess feasibility of CNGS dismantling

  ➔ The entire Run 2 program will be presented to the CERN management in a **C&S review in March 2021** so that the needed resources are reprofiled in details in the CERN MTP and studies can advance to be ready for AWAKE Run 2c.

- LS2 program has well advanced and preparations for next year's run are well under way.
- Several papers (5) on AWAKE Run 1 data analysis submitted to PRL, PRAB,… Further papers will soon be submitted.

Proposed dates:	2021/22	2023/24	End 2024/2025	2025/2026	2027/2028/…	
	2a): electron seeded self-modulation	**2b): density step plasma cell**	**2c) Clear out CNGS target area**	**2c) installation/ commissioning**	**2c) electron acceleration**	**2d) scalable plasma source**

CERN LS3: 2025, 2026