Feasibility Study of the AWAKE Facility at CERN

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for the CERN AWAKE Project Team and the AWAKE Collaboration

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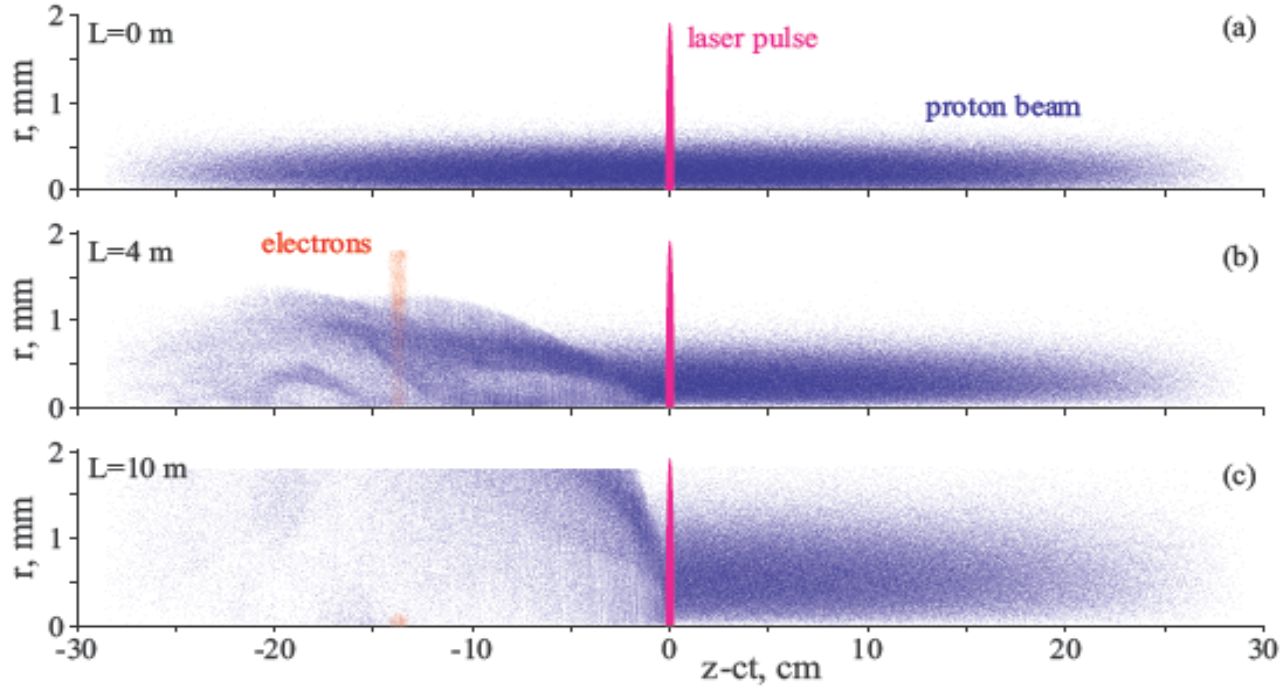
Motivation I

AWAKE – A Proton Driven Plasma Wakefield Acceleration Experiment at CERN

- Proof-of-principle demonstration experiment proposed at CERN.
  - First beam driven wakefield acceleration experiment in Europe and first proton driven PWA experiment world-wide.
- Advantages of using protons as driver: single stage acceleration
  - Higher stored energy available in the driver (~kJ)
  - Electron/laser driven requires many stages to reach the TeV scale.
- Need very short proton bunches (order of ~mm) for strong gradients
  - Today's proton bunches have lengths above ~10cm.
- Producing short proton bunches not possible today w/o major investment.
- instead, modulate a long proton bunch.
  - Microbunches are generated by a transverse modulation of the bunch density (transverse two-stream instability). Naturally spaced at the plasma wavelength, and wakefields are resonantly driven to large amplitudes. → **Self-modulation instability (SMI).**
- → **Direct use of the CERN SPS proton beam!**

Motivation II



Proton beam: drive beam (12cm)

Modulated in micro-bunches (1mm) after ~several meters d… …lectric field.

Laser pulse:

Ionization of plasma and seeding of bunch-modulation.

Using the same laser for electron photo-injector allows for precise phasing … …unches.

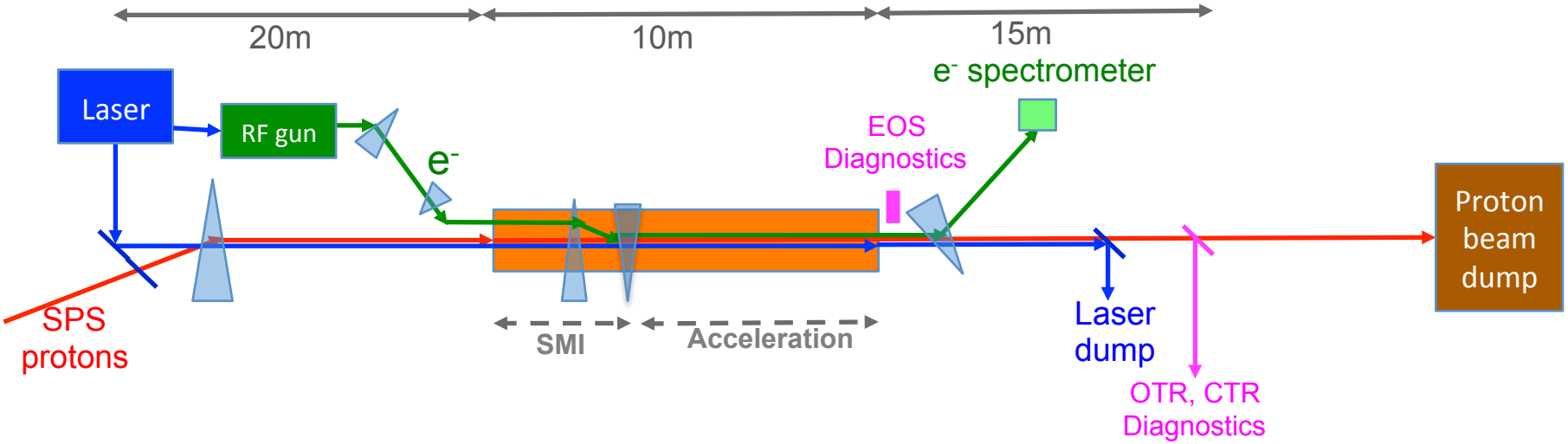
Electron beam: accelerated beam

Injected off-axis some meters downstream along the plasma-cell.

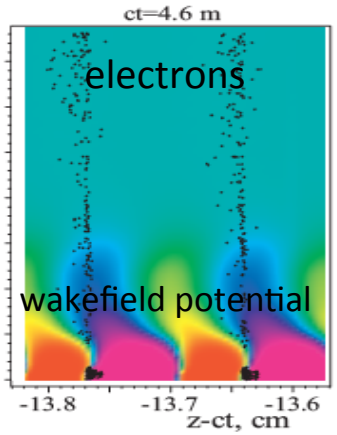
Merges with the proton bunch once the modulation is developed.

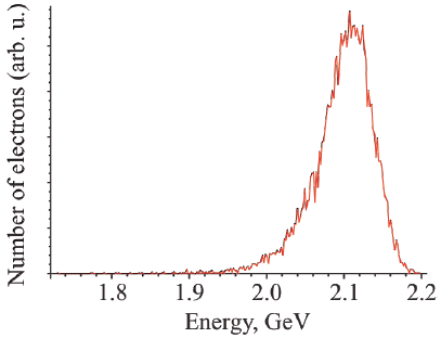
See Plenary talk on AWAKE, Patric Muggli, Tue, 11:40

AWAKE Experimental Layout



- → Inject 10-20 MeV electron beam
- → acceleration of electrons to **multi-GeV energy range** after the plasma exit.





AWAKE Measurement Program

- Perform **benchmark experiments using proton bunches to drive wakefields** for the first time ever.
- Understand the physics of **self-modulation process in plasma.** Compare experimental data with detailed simulations.
- **Probe the accelerating wakefields with externally injected electrons**, including energy spectrum measurements for different injection and plasma parameters.
- Study **the injection dynamics and production of multi-GeV electron** bunches. This will include using a plasma density step to maintain the wakefields at the GV/m level over meter distances.
- Develop **long, scalable and uniform** plasma cells.
- **Develop schemes for the production and acceleration of short proton bunches** for future experiments and accelerators.

Organization

AWAKE is an international scientific collaboration made up of 13 institutes and involving over 50 engineers and physicists (April 2013).
Several institutes (>6) are expressing interest in participating in AWAKE.

- Non-CERN institutes:
  - Provide plasma cells, electron source, plasma & laser & electron beam diagnostics
  - Perform simulation work and data analysis
  - Carry out the experiment.

Chiara Bracco, Tue, 17:12, WG1+4

- CERN is host institute of the AWAKE experiment:
  - Provides proton and electron beam line, laser transport lines, experimental area, associated service, civil engineering
  - Optimize beam parameters
  - Electron beam studies in the plasma cell
  - Responsible for installation, commissioning, operation, maintenance, safety matters during all phases of AWAKE, + dismantling

Helga Timko, Mo, 19:15, WG1

Alexey Petrenko, Mo, 19:00, WG1

Beam Specifications

Proton Beam	Nominal
Beam Energy	**400 GeV**
Bunch intensity	**3×10^{11} p**
Number of bunches	**1**
Repetition rate	**0.03 Hz**
Transverse norm. emittance	**3.5 μm**
Transverse beam size (at b*=5m)	**0.2 mm**
Angle accuracy	**<0.05 mrad**
Pointing accuracy	**<0.5 mm**
Energy spread	**0.1% (rms)**
Bunch length	**12 cm**
Energy in bunch	**21 kJ**

Electron Beam	Value
Beam Energy	**16 MeV**
Bunch intensity	1.25×10^{9} electrons
Bunch length	0.25mm

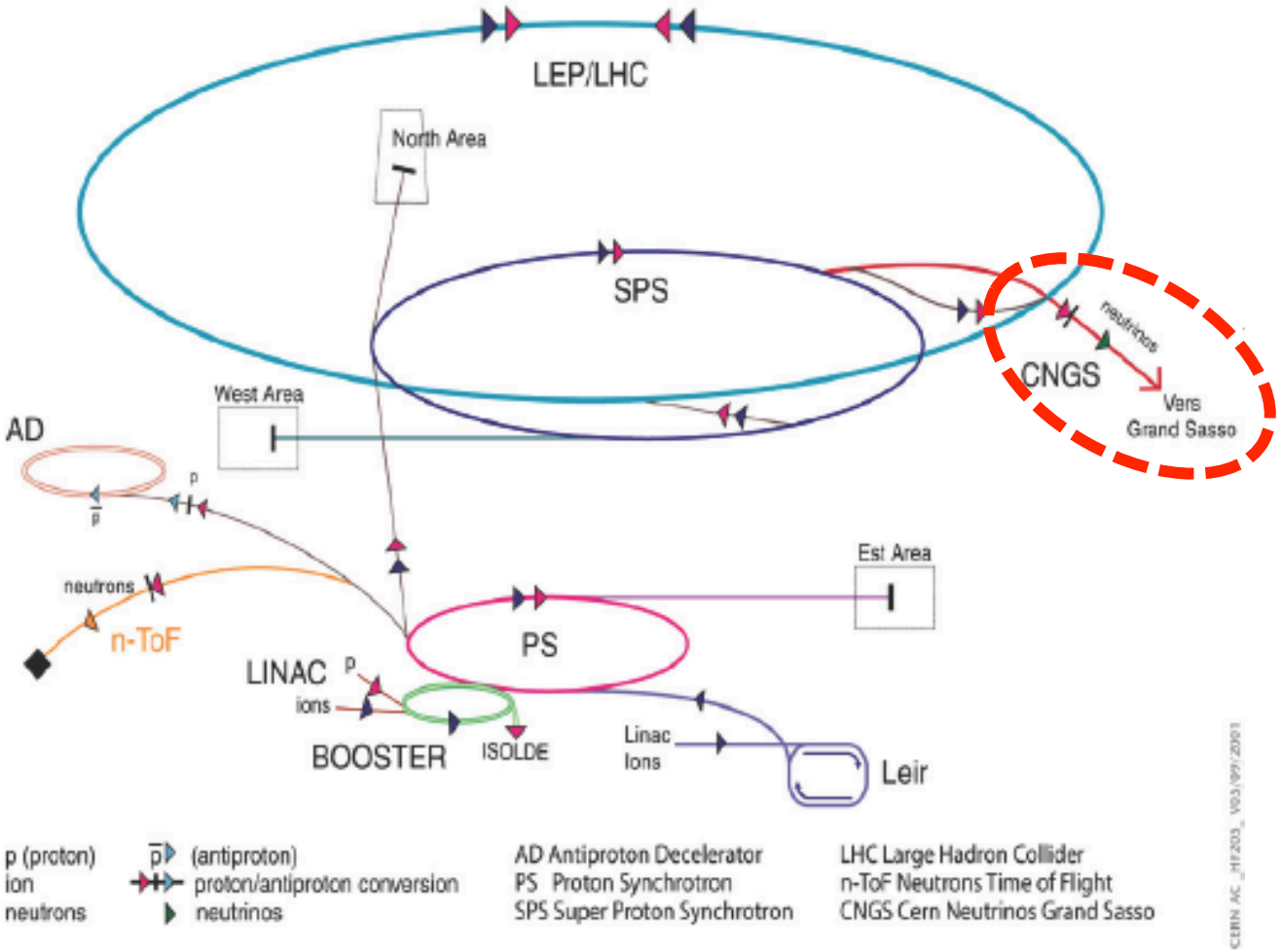
Laser: 30fs, 800nm, ~TW

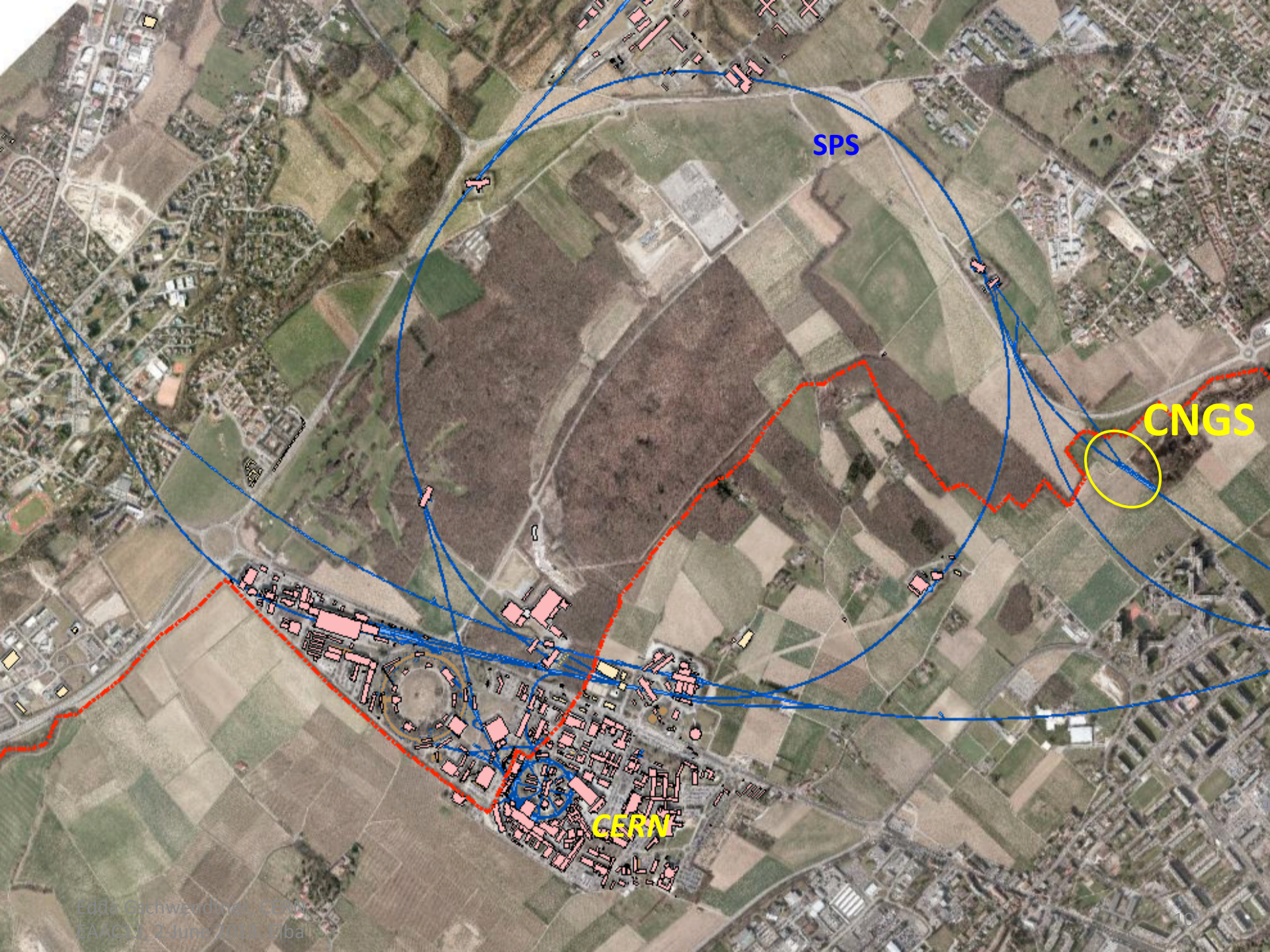
Run-scenario	Nominal
Number of run-periods/year	**4**
Length of run-period	**2 weeks**
Total number of beam shots/year (100% efficiency)	**162000**
Total number of protons/year	**4.86×10^{16} p**

→ Relaxed proton beam requirements for the first years of run
→ However, long-term goal is to get shorter longitudinal beams
(Bunch-compression, Continue MDs!)

→ **R & D facility:** → frequent access to plasma cell, laser, etc… needed.

CERN Accelerator Complex



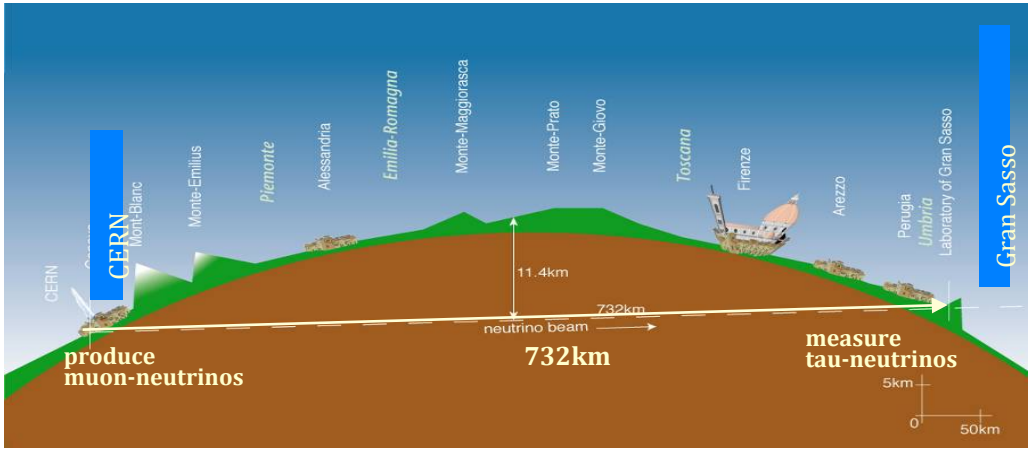

SPS
CNGS
CERN

AWAKE Experiment in the CNGS Facility

CNGS, CERN Neutrinos to Gran Sasso:
Muon neutrinos are produced at CERN.

p (from SPS) + C (target) → (interactions) → π^+, K^+ → (decay in flight) → $\mu^+ + \nu_\mu$

Neutrinos are sent towards Italy to measure the appearance of **tau-neutrinos** in the Gran Sasso experiments.



CNGS approved for 22.5E19 pot → i.e. **5 years** with 4.5E19 pot/yr

CNGS facility was commissioned in 2006 and 2007

From 2008 until 2012 (ie 5 years): delivering 81% of approved protons for neutrino physics

Expect ~8 ν_τ events in OPERA → 2 ν_τ candidates published so far

→ CNGS program has finished and will not restart in 2014 after the CERN Long Shutdown

Comparison CNGS – AWAKE

Parameters	CNGS	AWAKE
Proton beam energy from SPS	400 GeV/c	400 GeV/c
Cycle repetition rate	0.17 Hz	0.03 Hz
Number of extractions/cycle	2	1
Protons per cycle	**2x2.4E13**	**3E11**
Proton pulse length	10.5 μs	1.5 ns
Beam power (max.)	510 kW	640 W
Beam size at target (σ)	0.5mm	0.2mm
Protons/year	**4.5E19**	**4.5E16**

AWAKE:

→ ~Factor **100 less protons/extraction**

→ ~Factor **1000 less protons/year**

CNGS is a **running facility** (since 2006) at the desired beam parameters.

→ Proton beam and secondary beam-line fully equipped and running

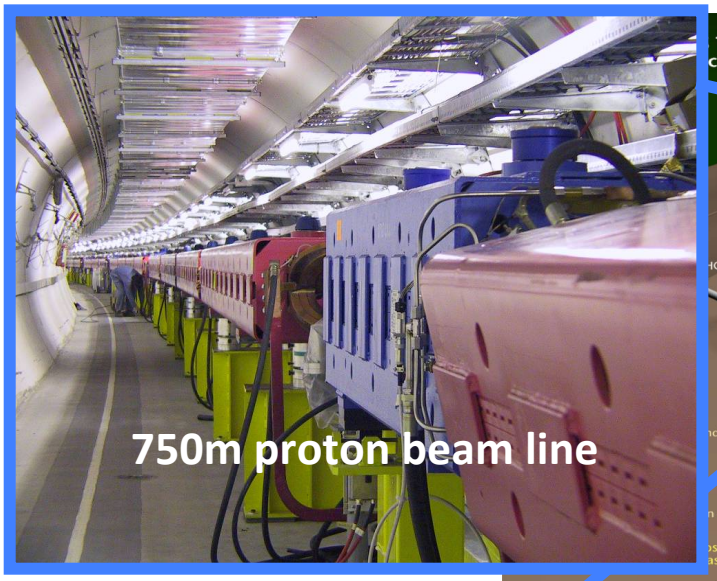
→ All services (CV, EL,…) running

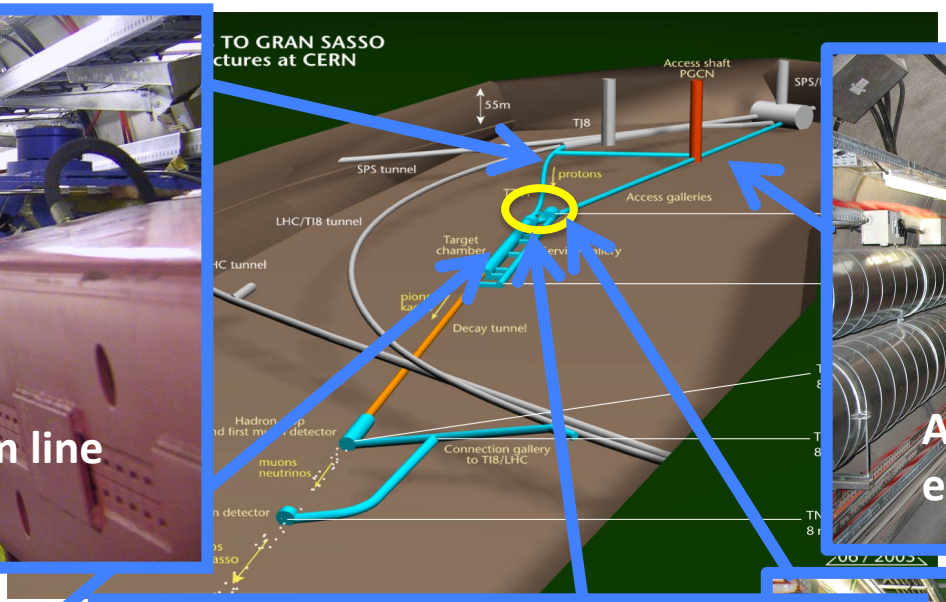
→ Underground facility

→ Adequate site for AWAKE

AWAKE at CNGS

AWAKE at CNGS


750m proton beam line



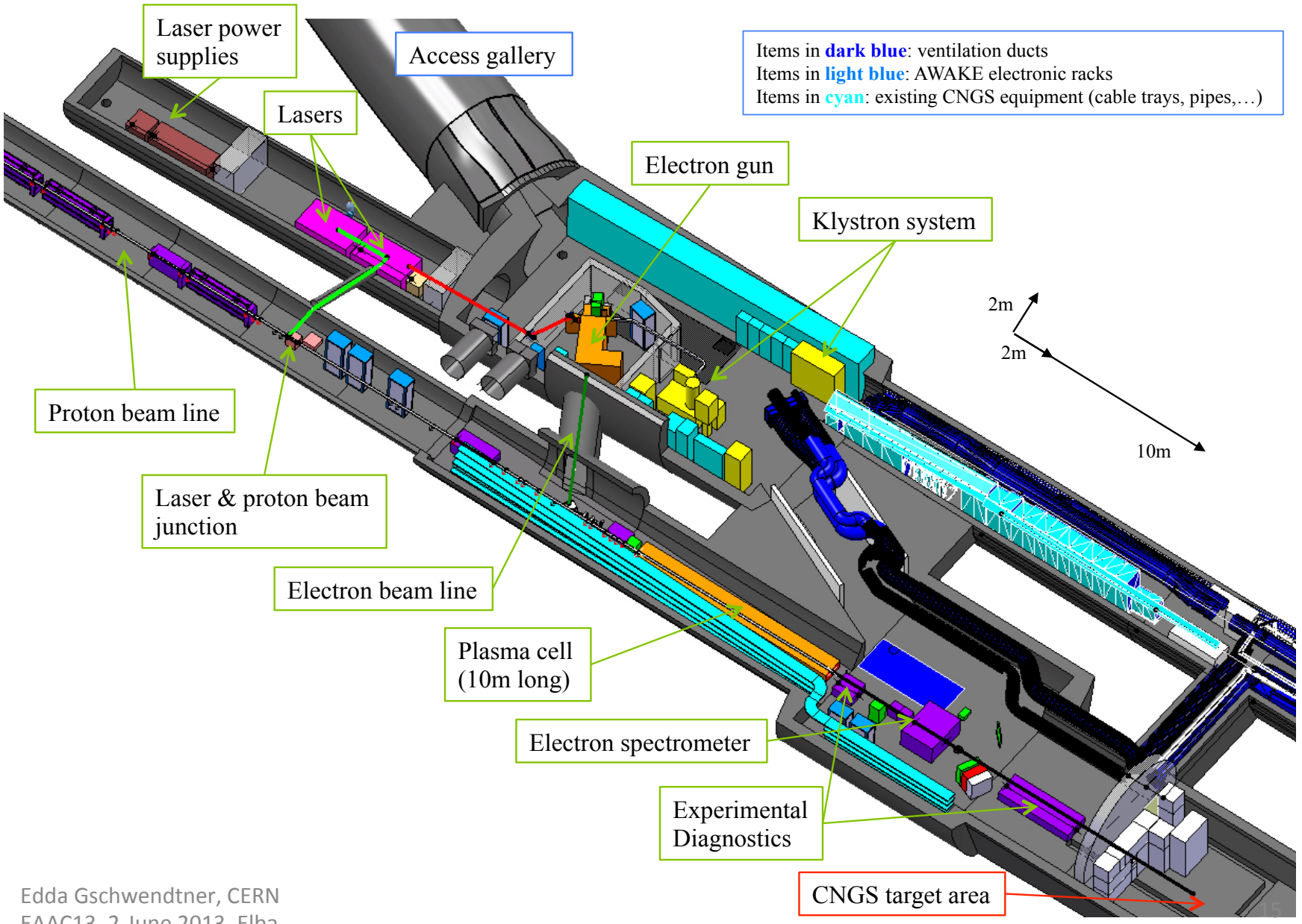

Access gallery to the experimental area


CNGS target area (stays untouched)

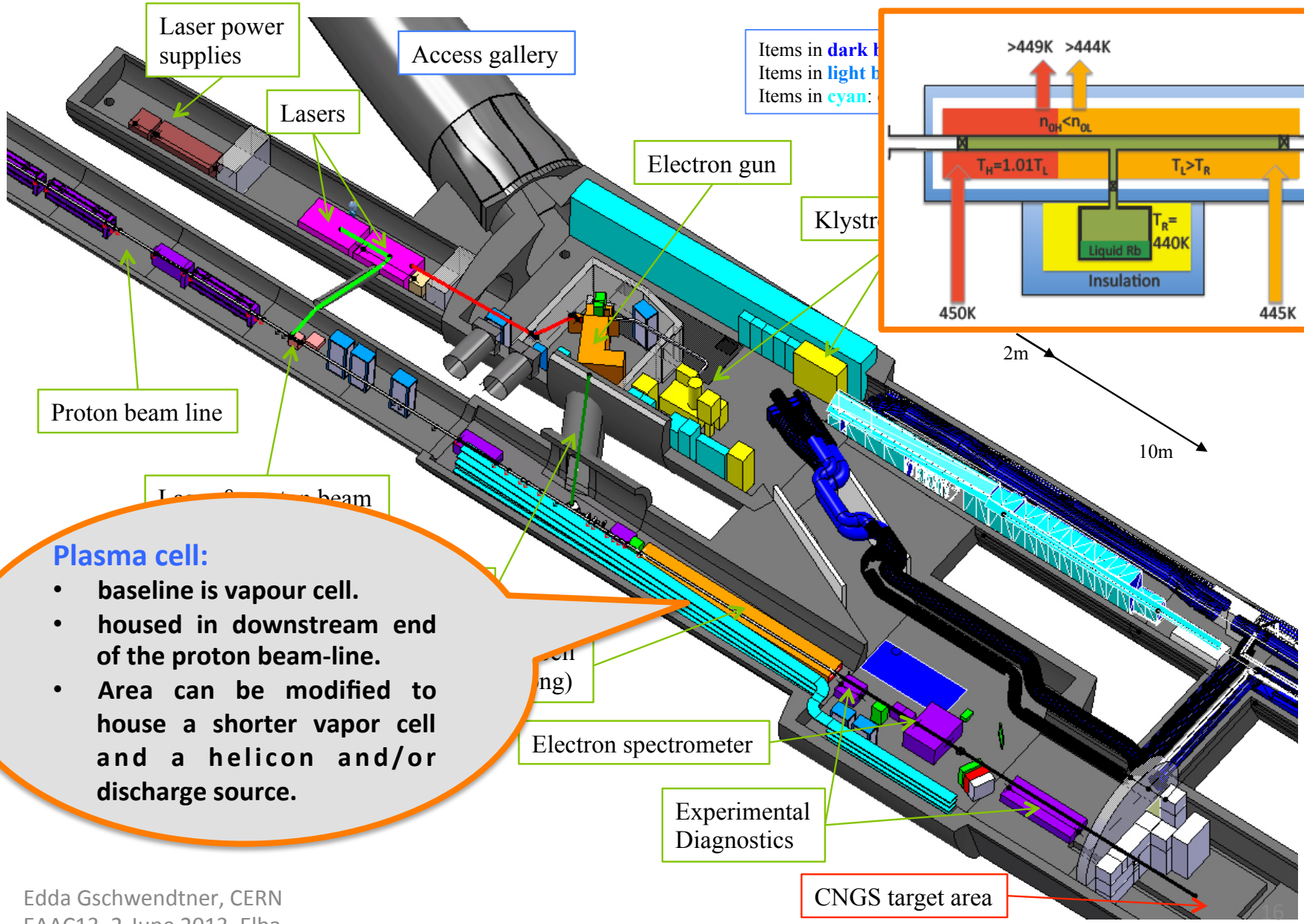

Future AWAKE experimental area (will be emptied)


Electron source area

Layout of the AWAKE Experiment



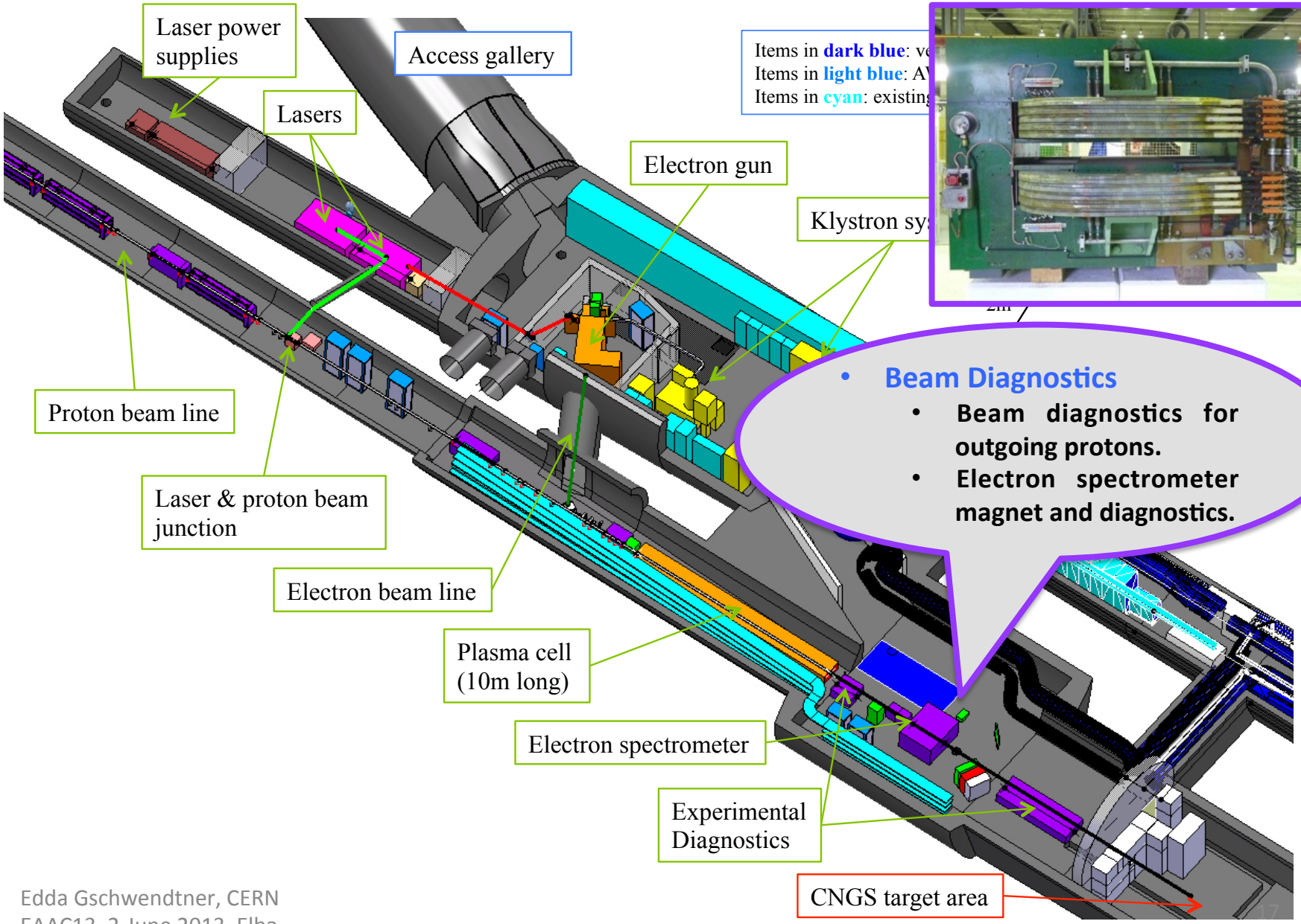
Layout of the AWAKE Experiment



Plasma cell:

- **baseline is vapour cell.**
- **housed in downstream end of the proton beam-line.**
- **Area can be modified to house a shorter vapor cell and a helicon and/or discharge source.**

Layout of the AWAKE Experiment



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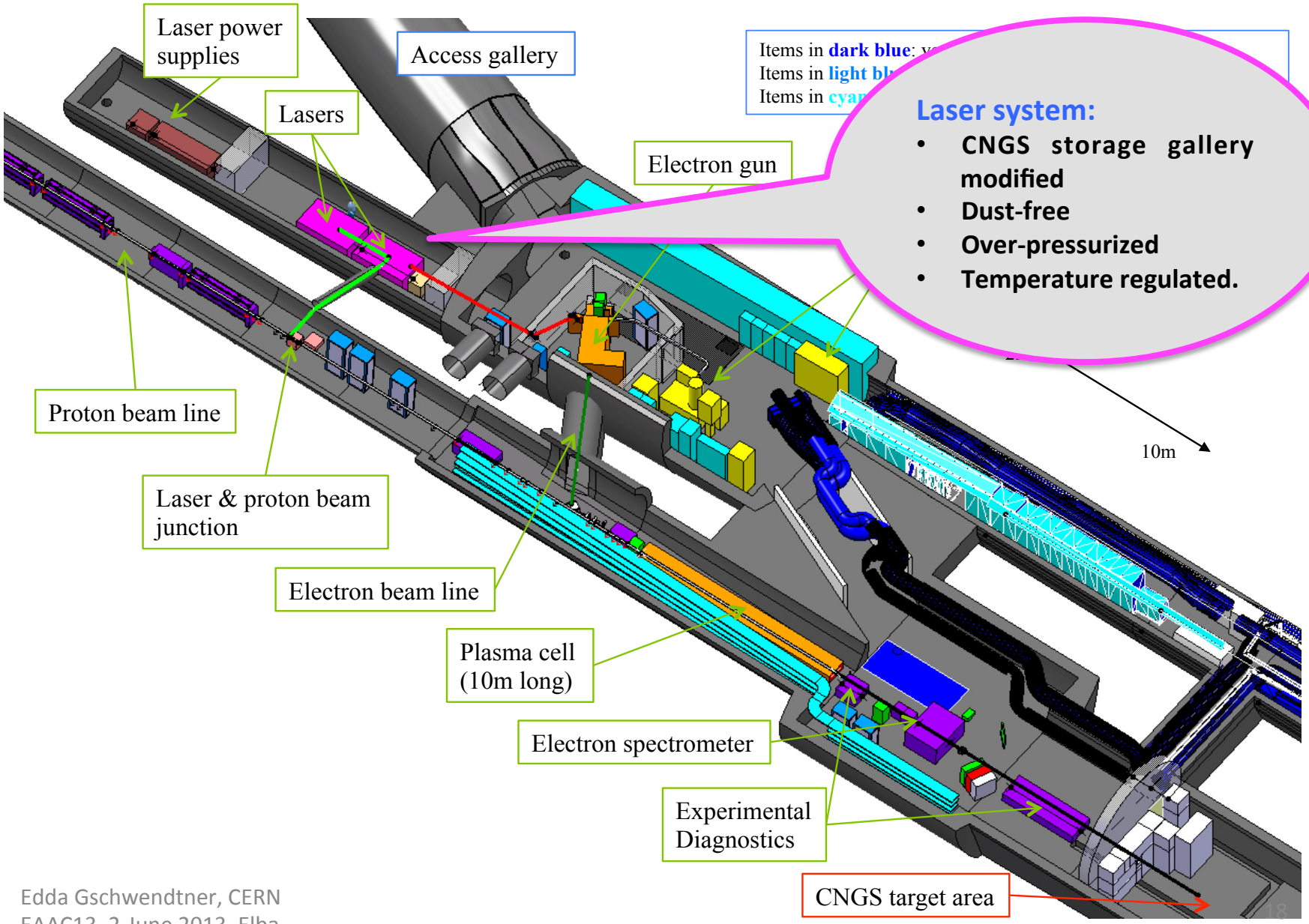

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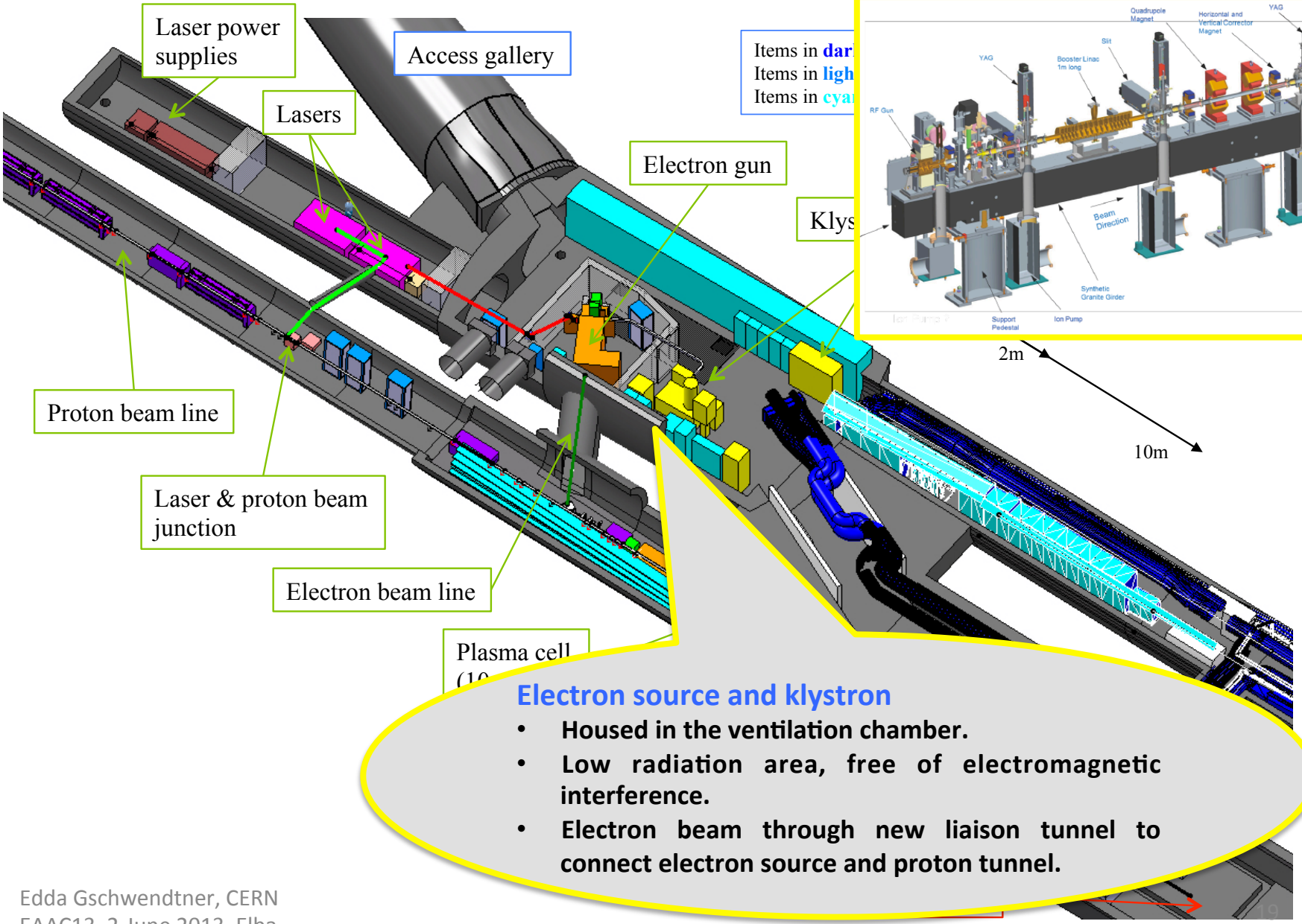
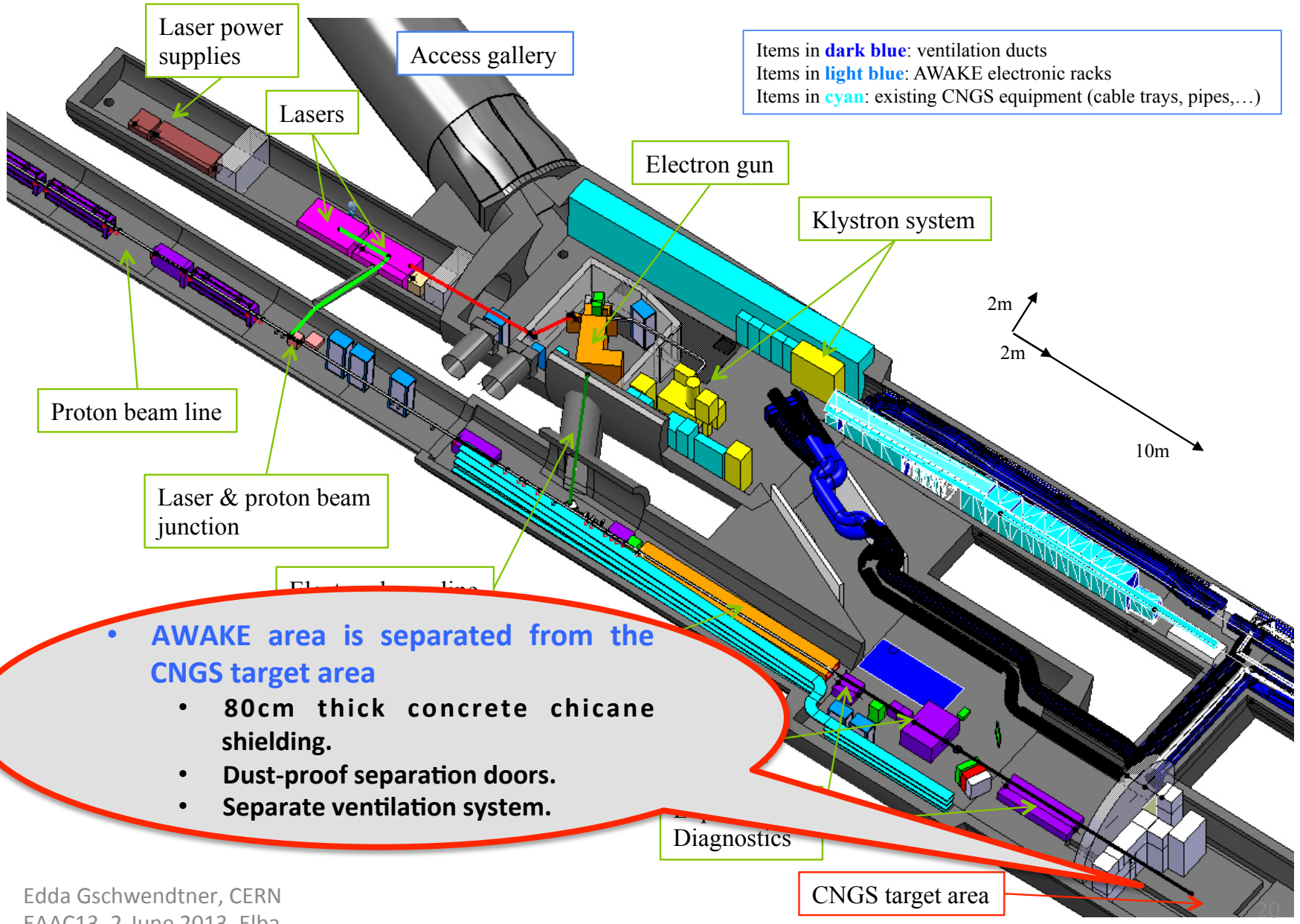


Electron source and klystron

- **Housed in the ventilation chamber.**
- **Low radiation area, free of electromagnetic interference.**
- **Electron beam through new liaison tunnel to connect electron source and proton tunnel.**

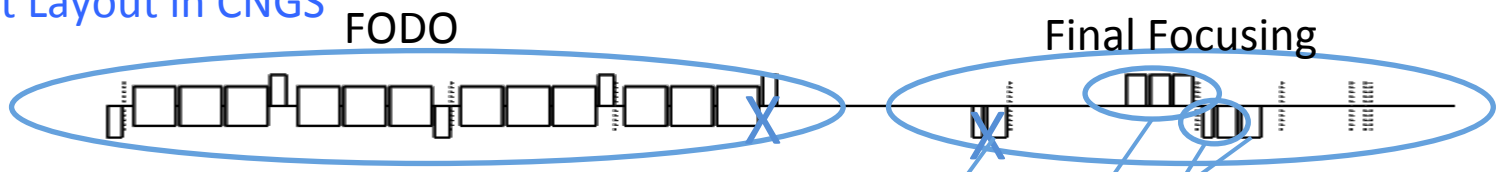
Layout of the AWAKE Experiment



- **AWAKE area is separated from the CNGS target area**
  - **80cm thick concrete chicane shielding.**
  - **Dust-proof separation doors.**
  - **Separate ventilation system.**

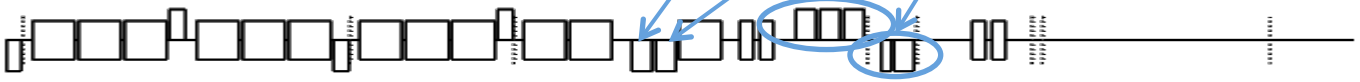
AWAKE Proton Beam Line

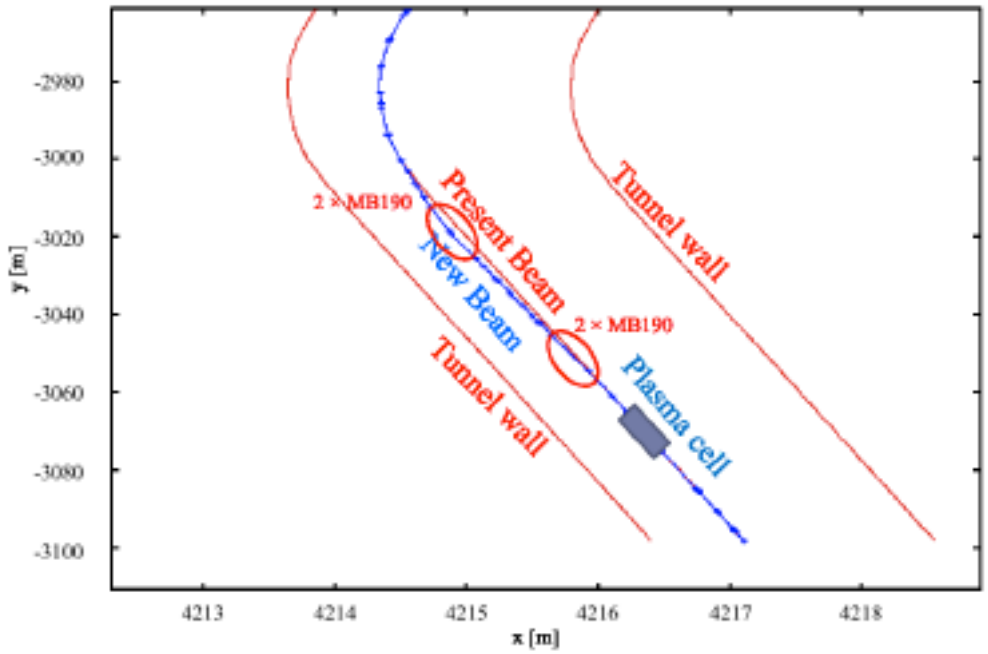
Present Layout in CNGS



Minor changes at the end of the proton-line for new final focusing and interface between the laser and the proton beam

Future Layout for AWAKE





cf. talk by Chiara Bracco, Tue, 17:12, WG1+4

Summary

- AWAKE is an accelerator R&D proof-of-principle experiment
  - Use proton bunches for the first time to drive plasma wakefields.
  - **CERN SPS beam is ideal to perform this R&D**.
  - Self-modulation instability allows for immediate experimentation.

- The feasibility of the AWAKE baseline experiment has been shown.
  - ✓ **Infrastructur**e and **beams** can be made available at CERN in the CNGS facility.
  - ✓ Updated schedule:
    - 2016: probe self-modulation process of protons in plasma.
    - 2017/18: accelerate electrons in the plasma wakefield.
    - Experimental program for 3-4 years.

- Expect approval of the AWAKE experiment during the CERN Council meeting mid June 2013.
  - ✓ Design Report has been submitted to the CERN management in March 2013.