Recommissioning of the CERN injector complex beam instrumentation

Ray VENESS

On behalf of the CERN Beam Instrumentation Group

Contents

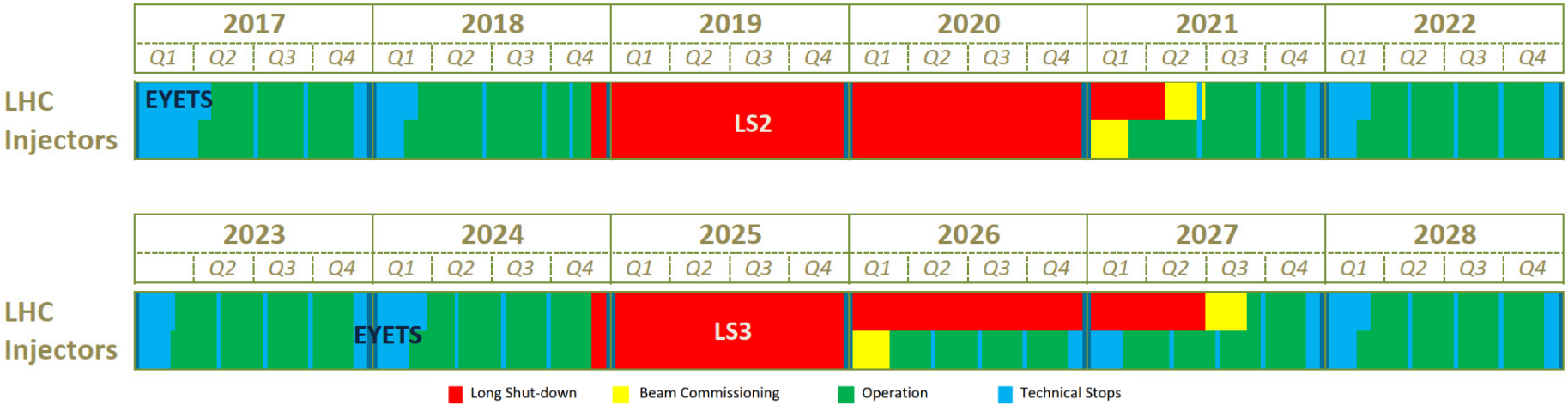
- Introduction
  - Long-term accelerator plans
  - Objectives of the recent accelerator complex shutdown
  - Concequent changes to beam instrumentation
- Some technical highlights from the shutdown and commissioning:
  - References to papers in this conference
  - Selected new instruments
- Summary

CERN commissioning contributions to this conference

IBIC 2021

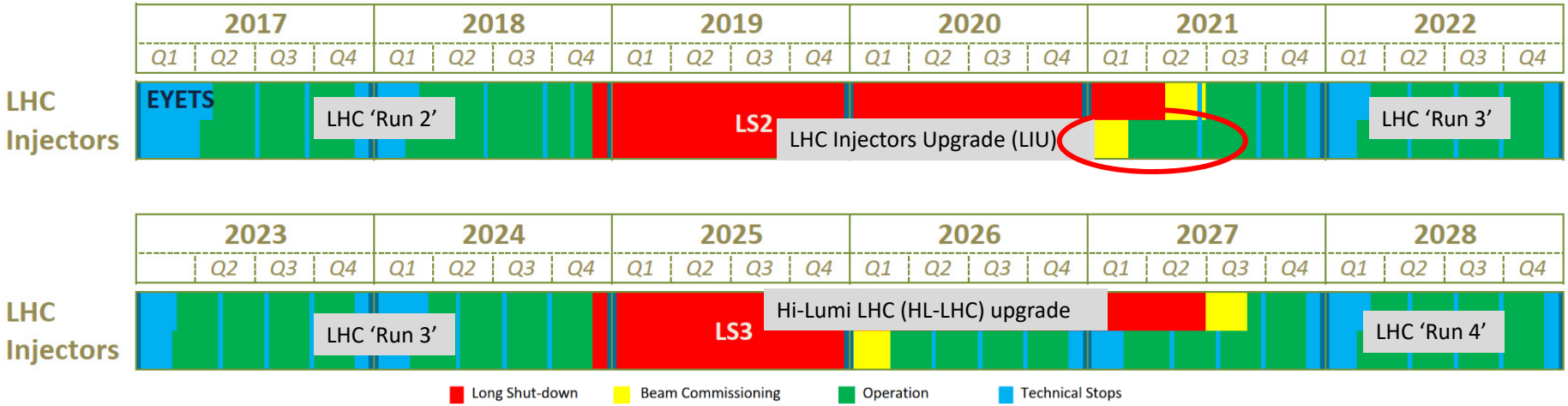
- WEPP24 • **PSB HO-H- monitor calibration and commissioning.** *A.Navarro and F.Roncarolo*
- TUOA05 • **Commissioning of the Timepix3 based beam gas ionization profile monitors for the CERN Proton Synchrotron.** *H.Sandberg et al.*
- TUPP22 • **New CERN SPS beam dump imaging system.** *S.Burger et al.*
- MOPP23 • **The commissioning of ALPS, the new beam position monitoring system of CERNs Super Proton Synchrotron.** *A.Boccardi et al.*
- TUPP32 • **The Beam Loss Monitoring System after LHC Injectors Upgrade at CERN.** *M.Saccani et al.*
- TUPP18 • **Commissioning of the LHC Injectors BWS Upgrade.** *J.Emery et al.*

CERN long-term accelerator schedule



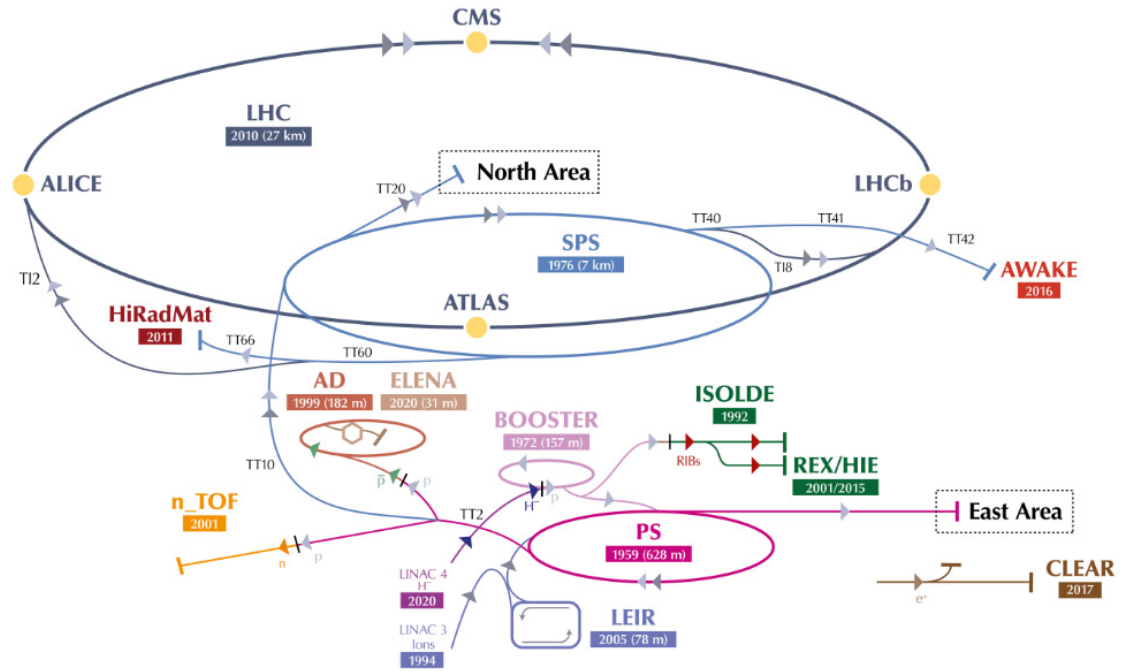
CERN long-term accelerator schedule, January 2020. CERN EDMS ACC-PM-MS-0004

CERN long-term accelerator schedule



CERN long-term accelerator schedule, January 2020. CERN EDMS ACC-PM-MS-0004

The CERN accelerator complex
Complexe des accélérateurs du CERN



H⁻ (hydrogen anions) · p (protons) · ions · RIBs (Radioactive Ion Beams) · n (neutrons) · $\bar{p}$ (antiprotons) · e^- (electrons)

LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE - Radioactive EXperiment/High Intensity and Energy ISOLDE // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials

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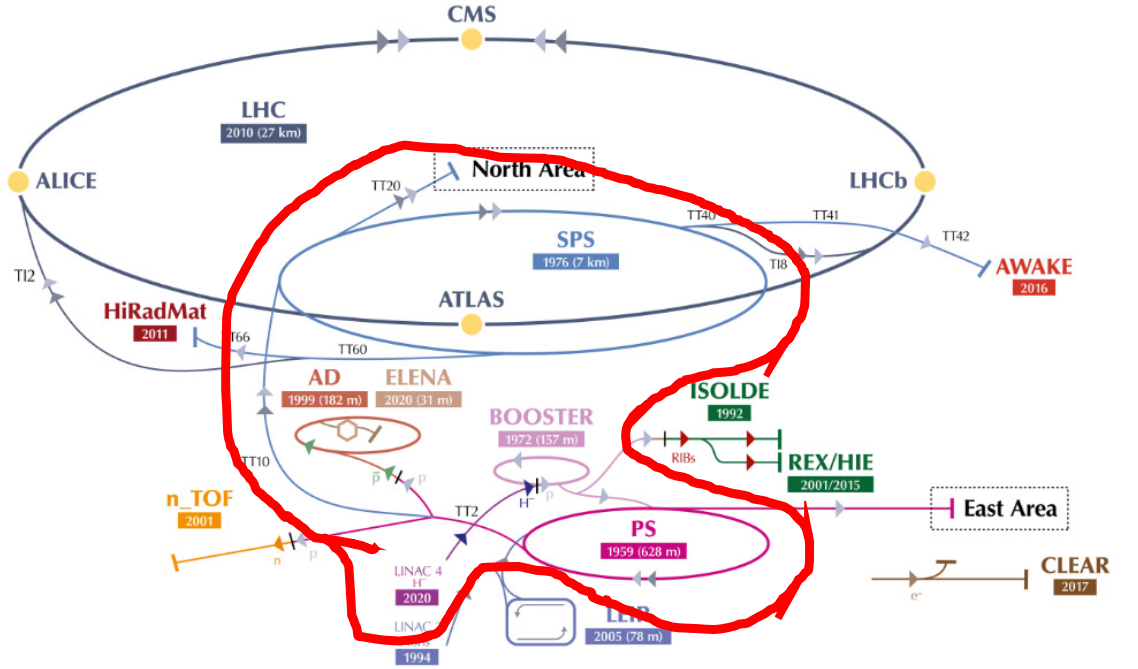

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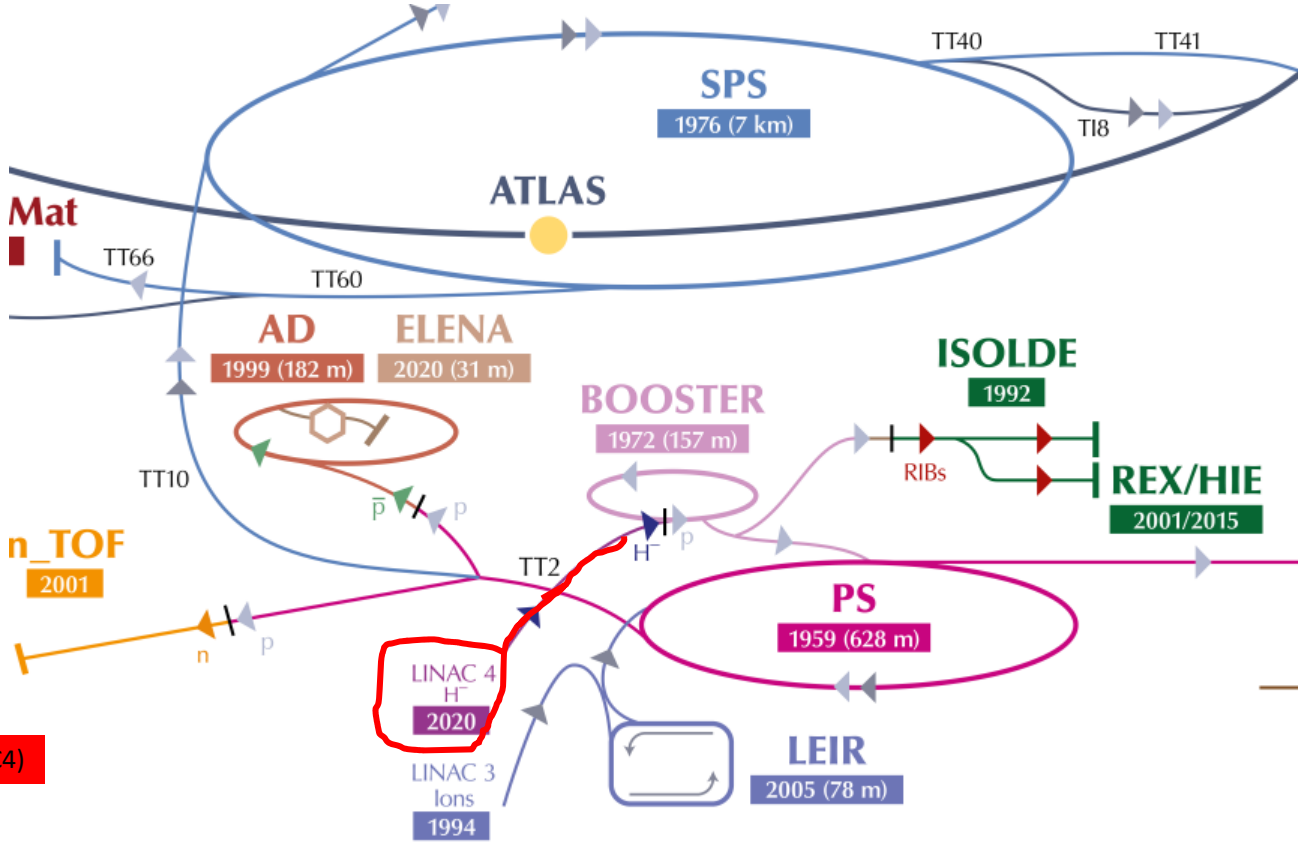
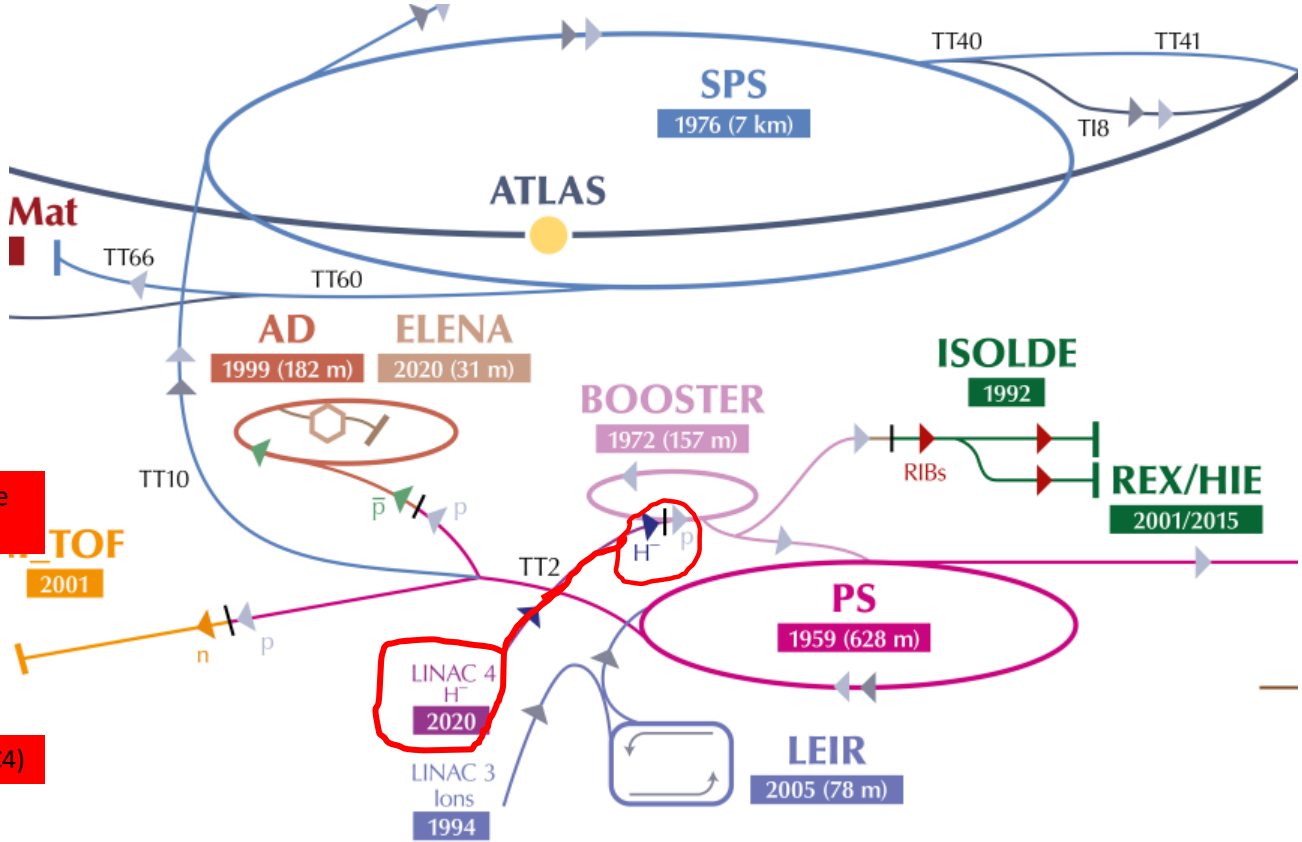
Focussing on:
- **LHC injectors**
- **Protons**

Not covering:
- **LHC ring**
- **Ion injection chain**
- **Antiproton chain**
- **Fixed target lines**

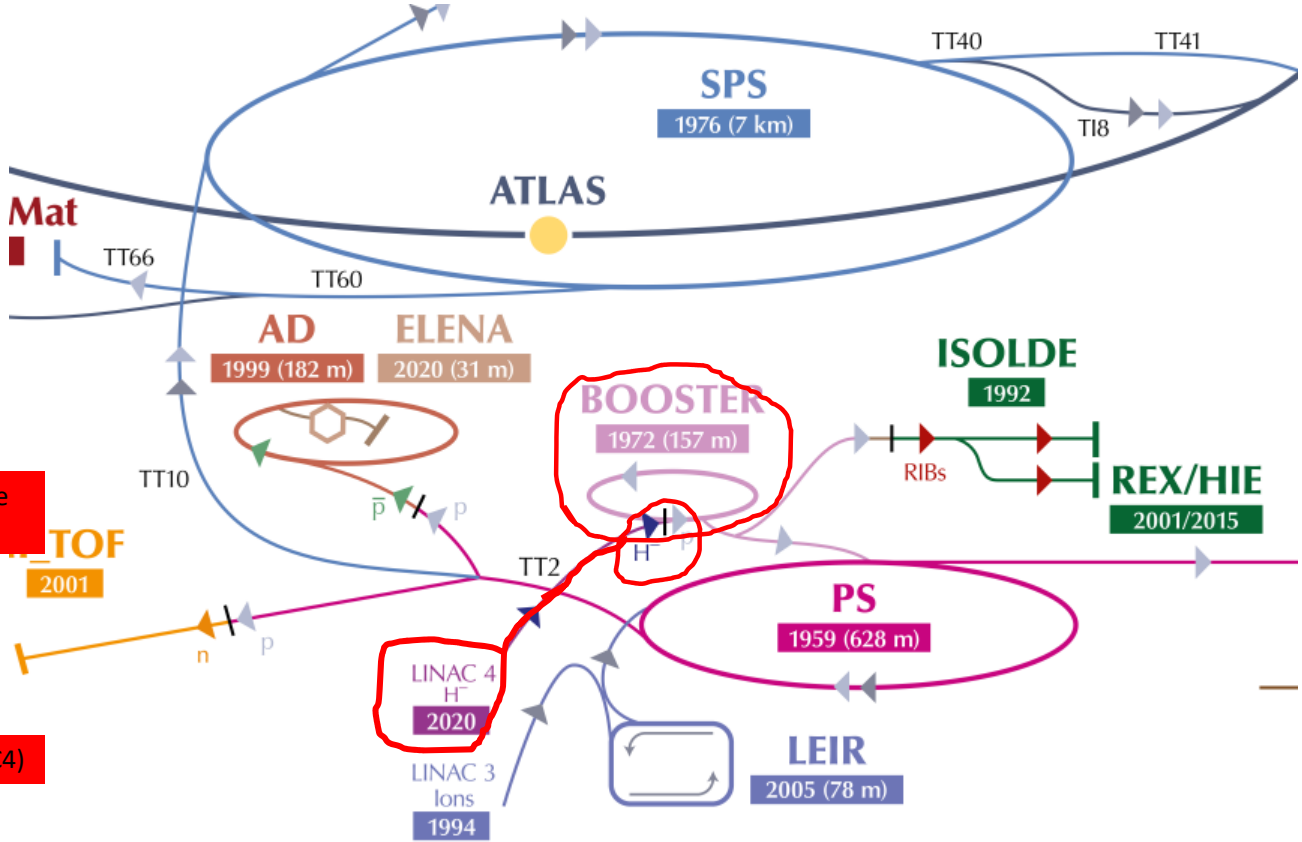


New H- LINAC (LINAC4)



New charge exchange injection to PSB

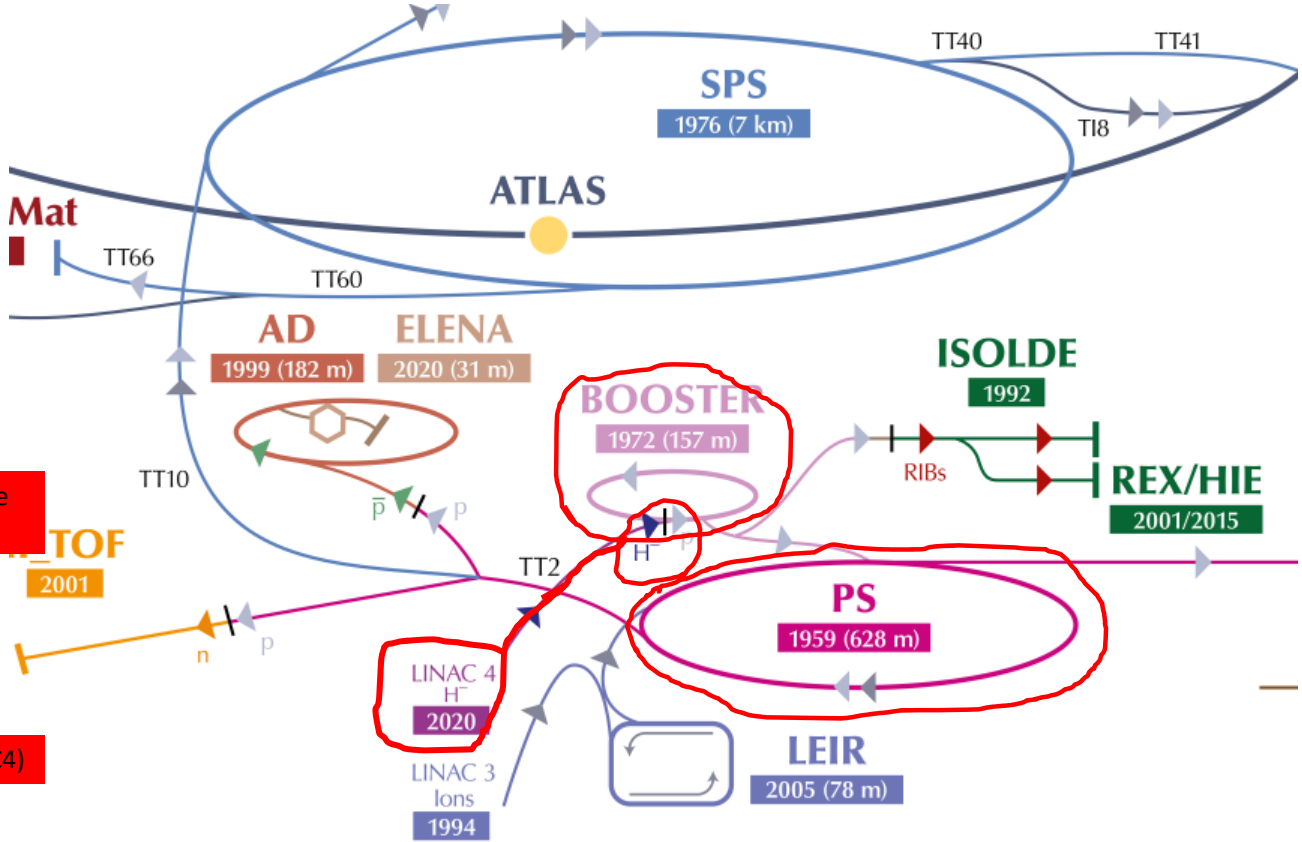
New H- LINAC (LINAC4)



New charge exchange injection to PSB

New H- LINAC (LINAC4)

Booster (PSB) energy upgrade



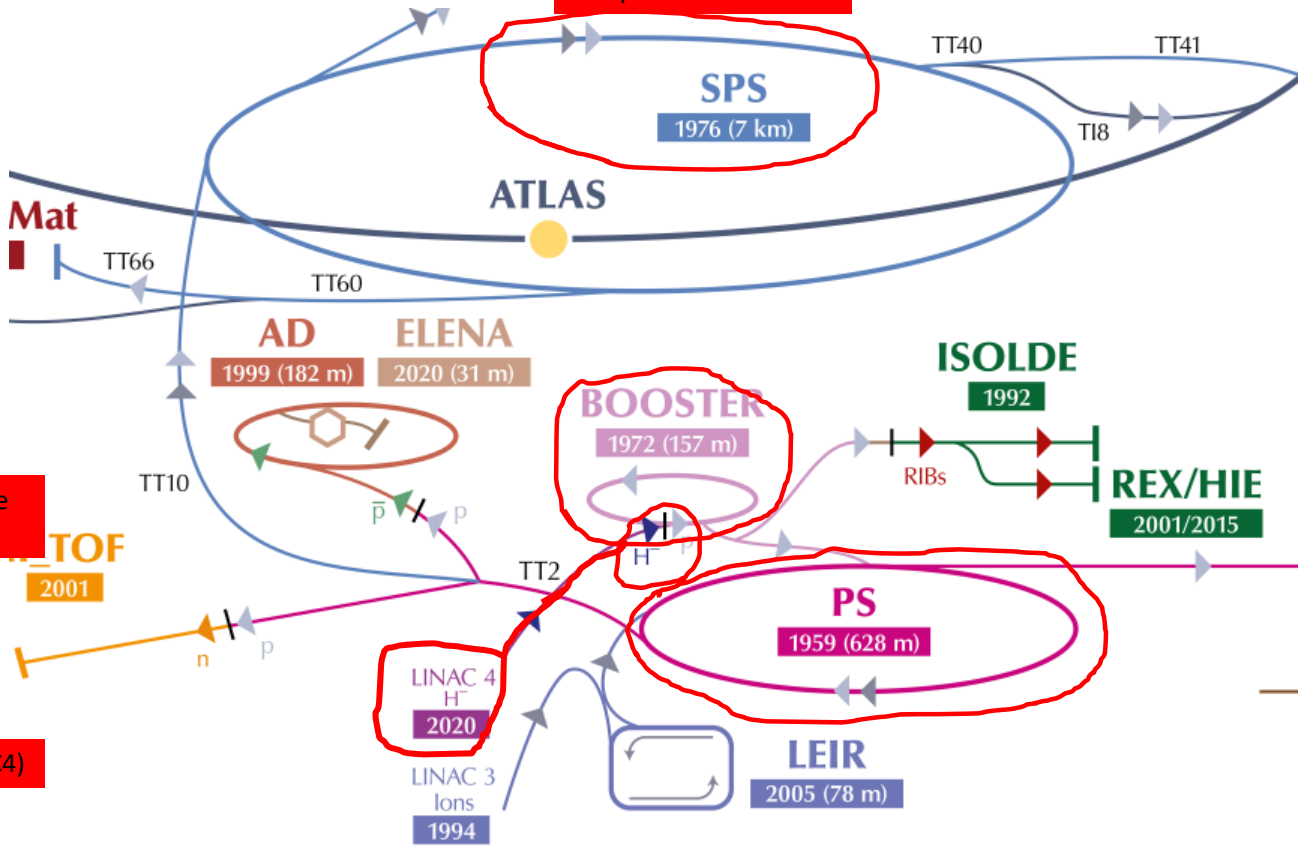
New charge exchange injection to PSB

New H- LINAC (LINAC4)

Booster (PSB) energy upgrade

Proton synchrotron (PS) energy upgrade

New internal beam dump in the SPS



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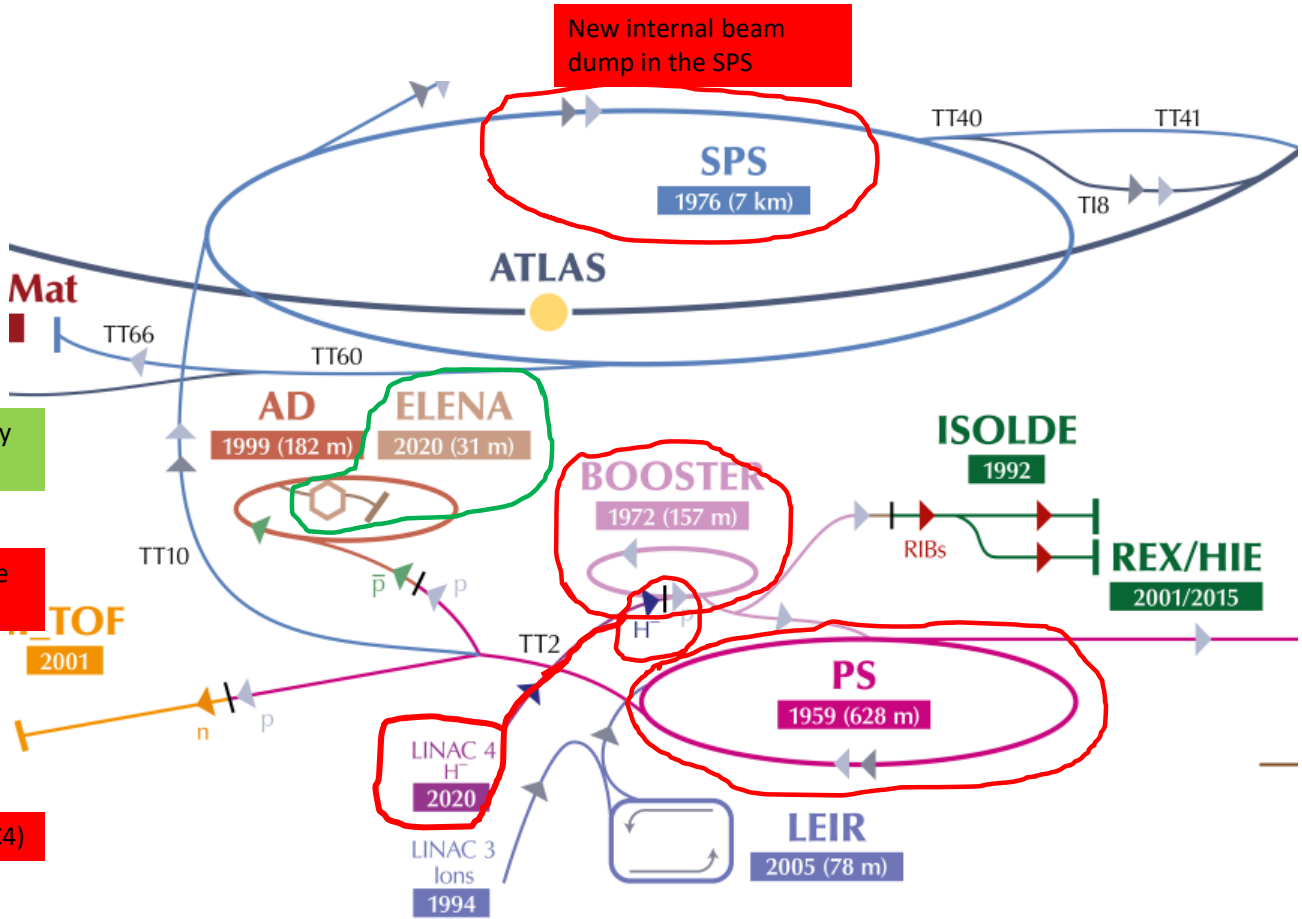
Booster (PSB) energy upgrade

Proton synchrotron (PS) energy upgrade



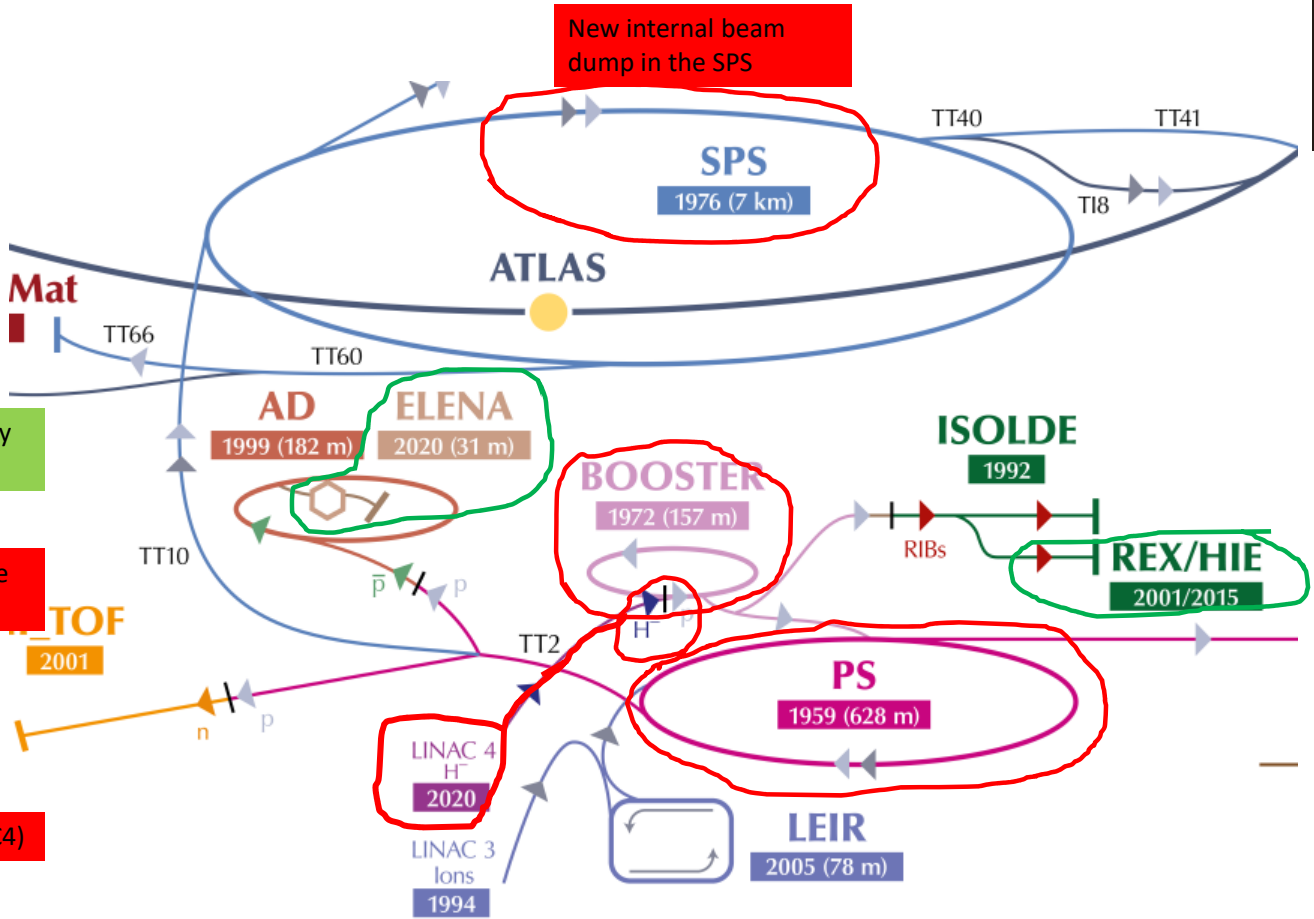
New extra-low energy antiproton ring

New charge exchange injection to PSB

New H- LINAC (LINAC4)

Booster (PSB) energy upgrade

Proton synchrotron (PS) energy upgrade



New extra-low energy antiproton ring

New charge exchange injection to PSB

New H- LINAC (LINAC4)

Extensions to HIE-ISOLDE

Booster (PSB) energy upgrade

Proton synchrotron (PS) energy upgrade

Target beam parameters for the injectors upgrade

Achievable proton beam characteristics at injection for the post-LIU accelerators [*]

Machine	Kinematic energy (GeV)	Number of bunches	Distance between bunches (ns)	Bunch intensity (10e11 p/b)	Transverse emittance (m)	Bunch length (ns)
PSB	0.16	1/ring		29.6	1.5	650
PS	2	2+4	284	28.1	1.6	205
SPS	25	4x72	25	2.2	1.7	4.2
LHC	449	10x288	25	2	1.9	1.65

Increased from 50 MeV

Increased from 1.4 GeV

cf. 1.15 achieved in Run 2**

cf. 2.5 achieved in Run 2**

- New H- injection into the PSB
- Higher energy transfer into PS
- Higher bunch intensities in all machines
- Smaller transverse emittances in all machines

* "LHC Injectors Upgrade, Technical Design Report, Vol.1: Protons." http://dx.doi.org/10.17181/CERN.7NHR.6HGC

**"LHC injectors Upgrade Project: Towards new territory beam parameters." M.Meddahi et al. http://dx.doi.org/10.18429/JACoW-IPAC2019-THXPLM1

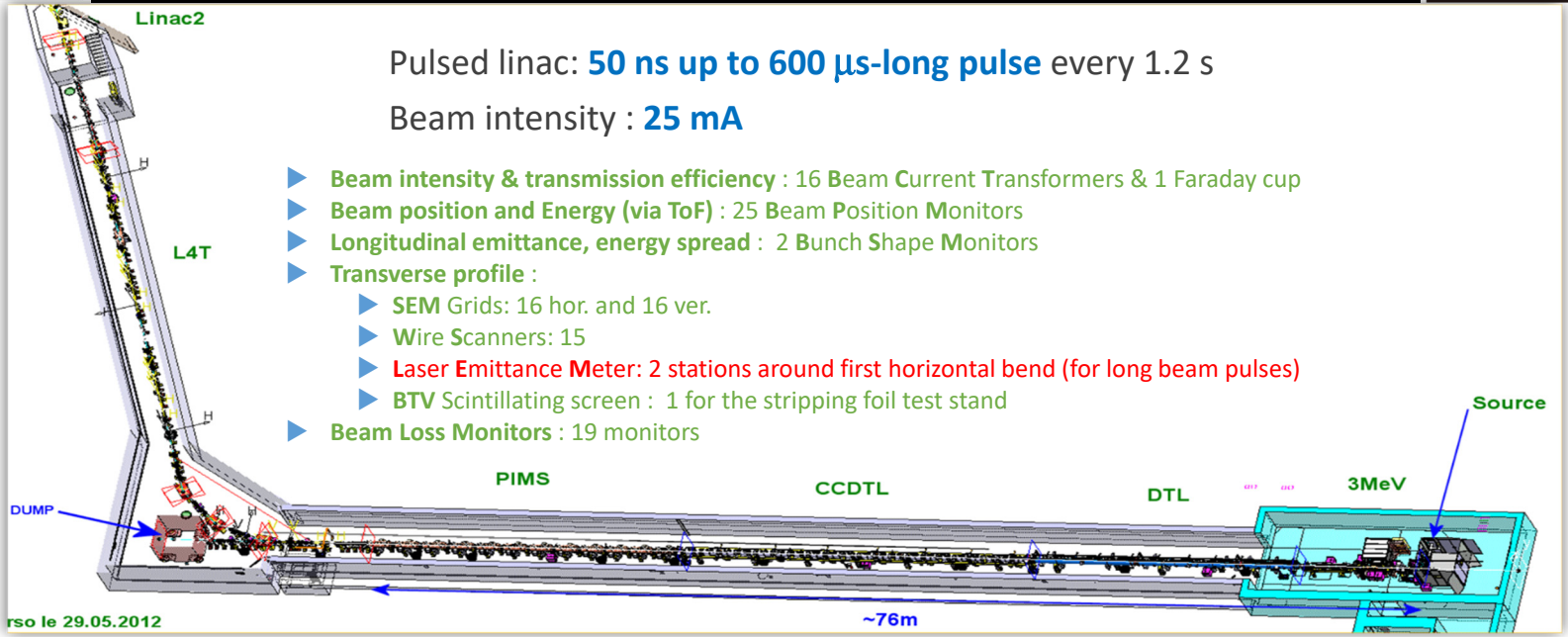
Long Shutdown 2 for Beam Instrumentation

- LHC injectors Upgrade Project (LIU)
  - 49 new in-vacuum instruments built for installation in LS2
  - LINAC4 as a new operational machine
  - SPS beam dump. New and re-configured instruments, removed and re-installed beamlines
  - New SPS BPM readout system (ALPS)
- Accelerator Consolidation (CONS) and maintenance
  - 25 new instruments in the LHC chain from CONS project
  - New BPM interlock electronics
  - 348 new beam-loss monitor chambers and electronics
  - Replaced much of the obsolete instrumentation in ISOLDE
  - All of the ~7000 BI instrument park requires inspection or maintenance with rare access to some instruments due to long injector shutdown
- LHC (Maintenance and upgrade prototyping)
  - 1500+ BLMs and 850 cable trays removed and re-installed
  - Two new prototype instruments in LHC (BRAND,BGC)
- Non-LHC chain
  - New extra-low energy Pbar ring (ELENA) and HIE-ISOLDE extensions
- Overall
  - Total of 152 new in-vacuum instruments designed, built and installed in LS2

Machine/ Complex	'New for old' replacements	Additional instruments
LINAC 4	-	36
PSB	20	12
PS	9	2
SPS	4	3
LHC	3	1
ISOLDE/HIE	20	11
ELENA	-	31
TOTAL	**56**	**96**

In-vacuum instruments newly commissioned for operation post LS2

New H- LINAC (LINAC 4)



Pulsed linac: **50 ns up to 600 µs-long pulse** every 1.2 s

Beam intensity : **25 mA**

- **Beam intensity & transmission efficiency** : 16 **B**eam **C**urrent **T**ransformers & 1 Faraday cup
- **Beam position and Energy (via ToF)** : 25 **B**eam **P**osition **M**onitors
- **Longitudinal emittance, energy spread** : 2 **B**unch **S**hape **M**onitors
- **Transverse profile** :
  - **SEM** Grids: 16 hor. and 16 ver.
  - **W**ire **S**canners: 15
  - **L**aser **E**mittance **M**eter: 2 stations around first horizontal bend (for long beam pulses)
  - **BTV** Scintillating screen : 1 for the stripping foil test stand
- **Beam Loss Monitors** : 19 monitors

J. Tan, **"LINAC4 diagnostics experience during commissioning".** ARIES workshop on Experiences During Hadron LINAC Commissioning, 2021,
F.Roncarolo et al. **"Commissioning the new CERN beam instrumentation following the upgrade of the LHC injector chain".** IPAC 2021

New ‘laser wire’ emittance meter in LINAC4

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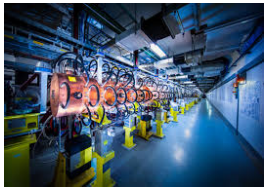
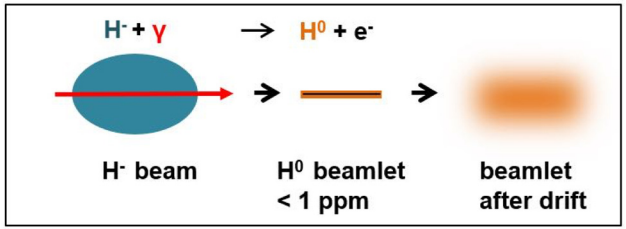
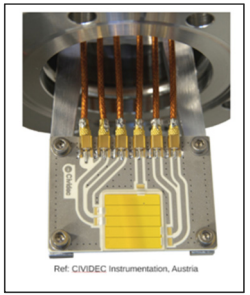


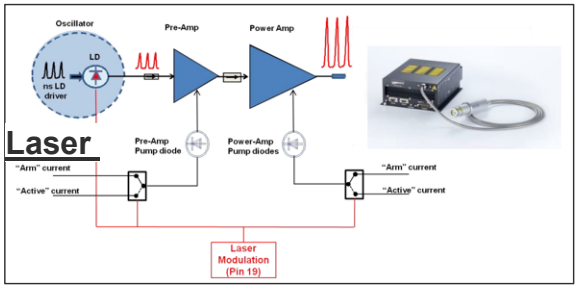
L4@CERN

Principle:

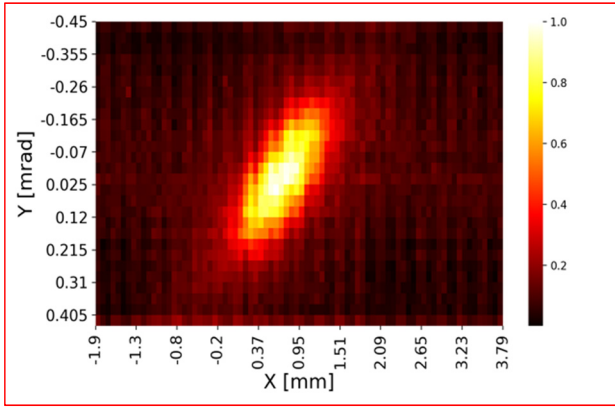


Diamond detector





Emittance measurement in 2021



- Minimally invasive with only a few % of intercepted particles being stripped
- Pulse freq: 35 to 500 kHz
- Line width: 1 to 5nm

T. Hofmann et al, Nucl. Inst. and Meth. in Phys. Res. Section A: 903, p. 140-146 (2018)

PSB charge exchange Injection instruments

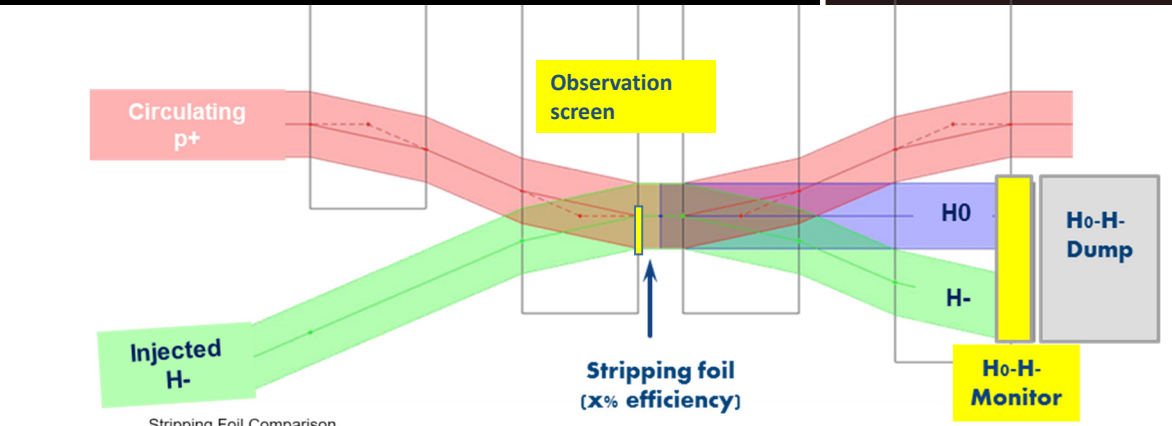
See poster: WEPP24

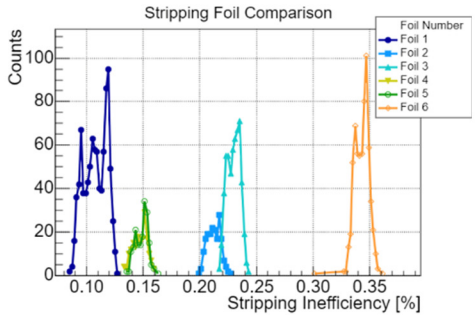
H0-H- monitor required to:

1. Warn about stripping foil degradation (continuous monitoring function)
2. protect dedicated internal dump (interlock function)

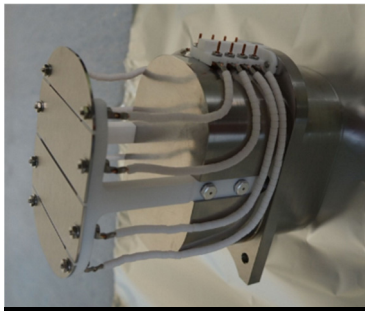
Stripping foil observation screen with rad-hard camera:

1. Measures beam position during set-up
2. Monitors integrity of the foils





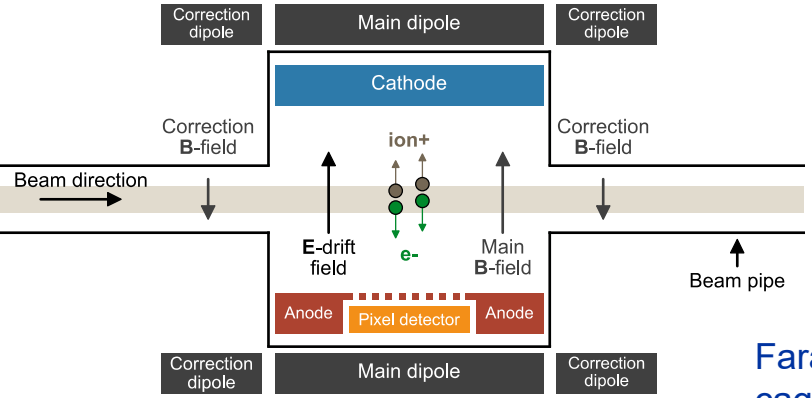
Stripping inefficiencies of different foil types measured by the H0/H- monitor

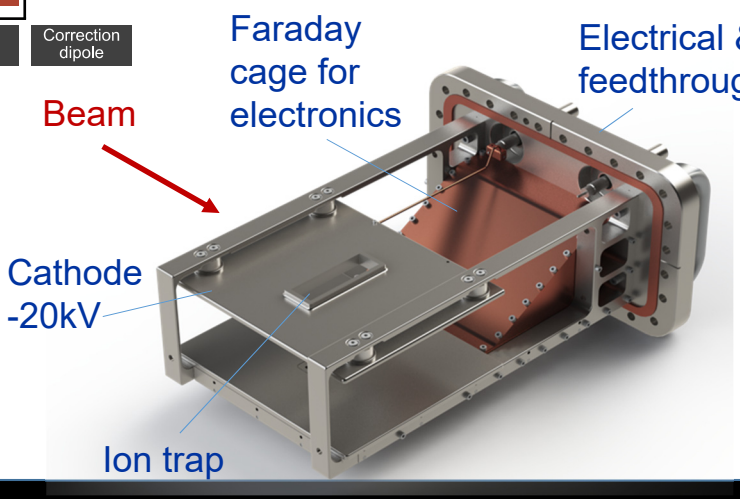


H0/H- monitor with 4 cables Ti stripping plates

New PS beam-gas ionisation profile monitors

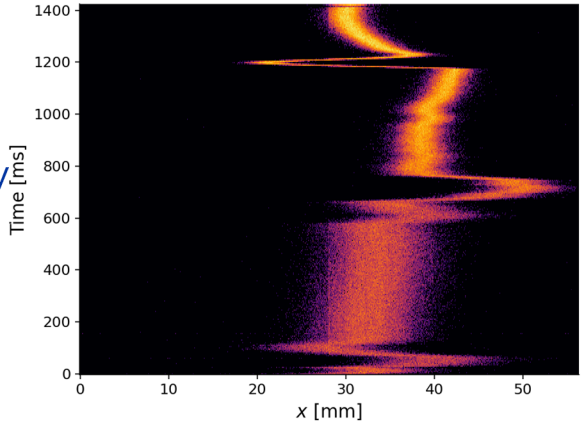
See talk: TUOA05





- First use of active semiconductor instruments in a CERN injector ring
- H and V devices now installed and operating with beam

Beam position and size



600 horizontal profiles of an LHC-type beam, measured through the 1.2 second PS cycle (May 2021)

New SPS beam dump imaging system

See poster: TUPP22

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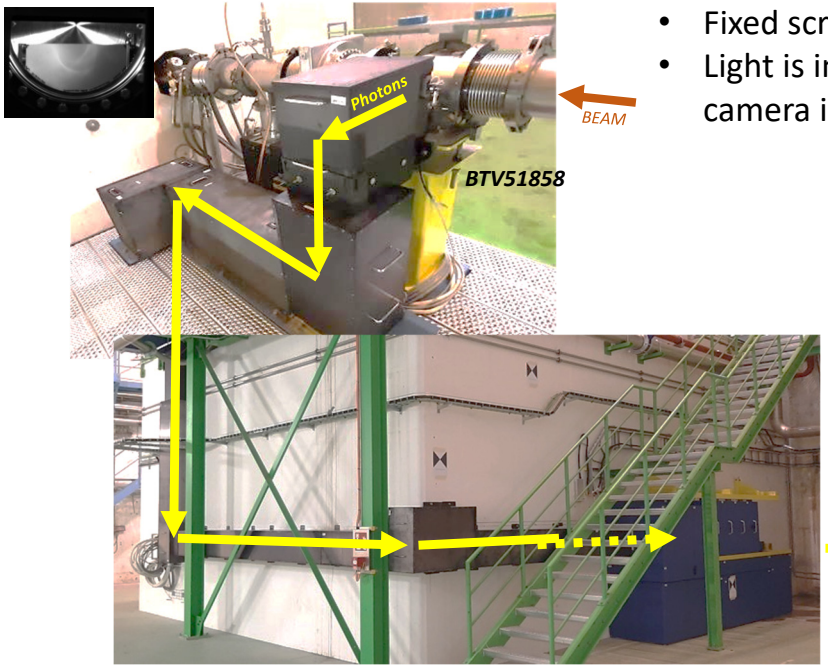
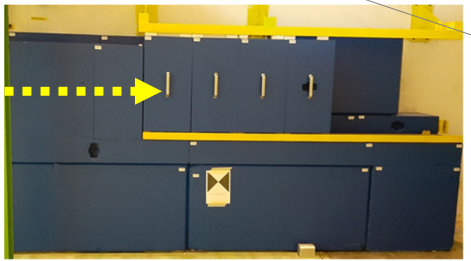
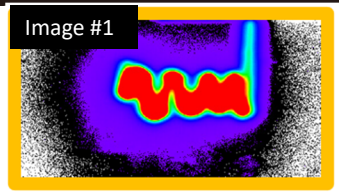
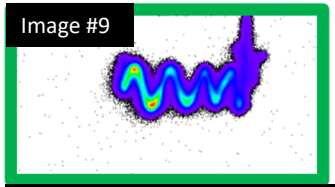
- ‘Operation critical’ observation device in a highly active area
- Fixed screen, intercepting just the extracted beam
- Light is imaged via a 17m long optical chamber, with camera in a shielded hutch









Automated image selection taking advantage of slow CROMOX decay time

New orbit system electronics for the SPS (ALPS)

See poster: MOPP23

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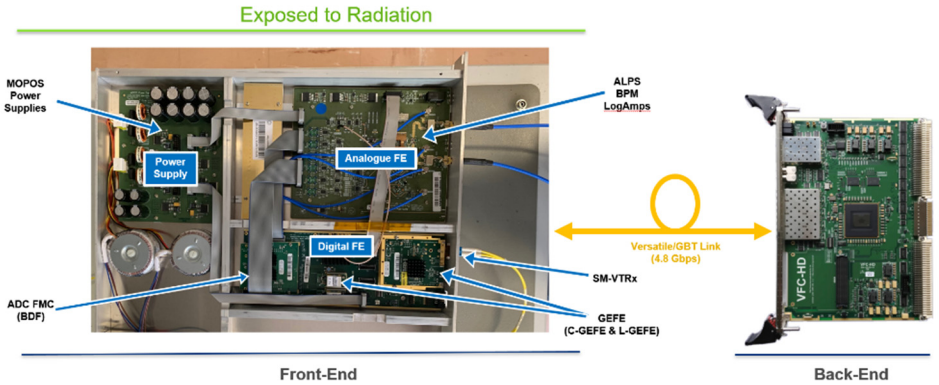
- A Logarithmic Positioning System (ALPS) for the SPS, consisting of:
  - 240 radiation-tolerant front-end electronics systems installed around the SPS ring during LS2
  - 60 back-end boards using a CERN-design ‘VME Front-end Card’ (VFC)
- Extensive prototype testing during Run 2
  - First roll-out of VFC, a new CERN standard, now being used in other instruments such as the new wire scanners
- Successfully used from first beam for the SPS beam commissioning
  - Measured multi-bunch turn-by-turn resolution of 7 µm measured in vertical plane

Injection during beam commissioning

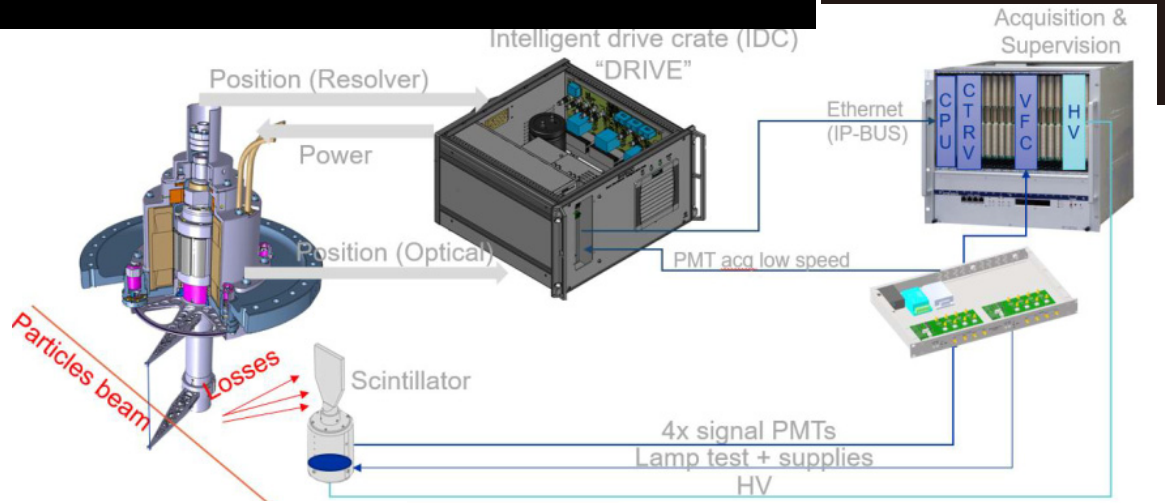
ALPS electronics



New Fast Wire Scanners for the PSB, PS and SPS

See talk: TUPP18

- 17 new 20 ms^{-1} scanners installed and operating
  - Wire position from optical disc encoding
  - 4 PMTs coupled to same scintillator with different optical density filters
  - Fast digital integration (500MS/s) to allow bunch per bunch profile measurements
  - Standardised designs for mechanics, electronics and software
- Extensively prototyped with beam before series production



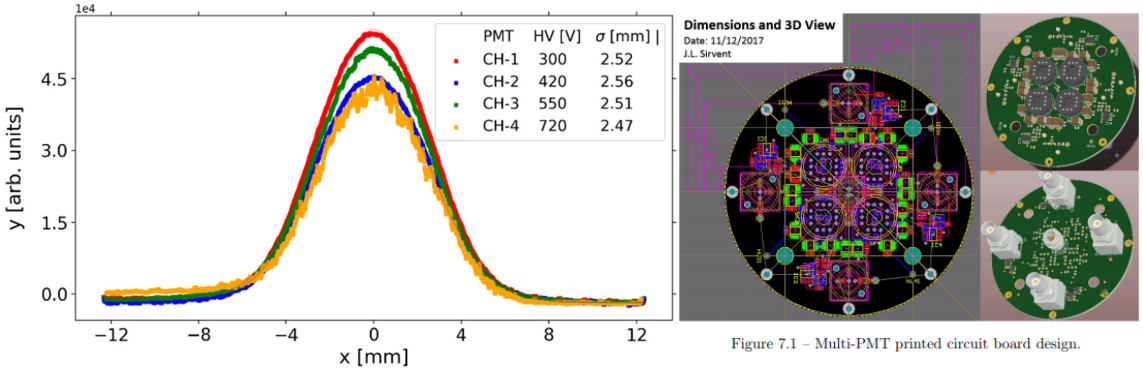
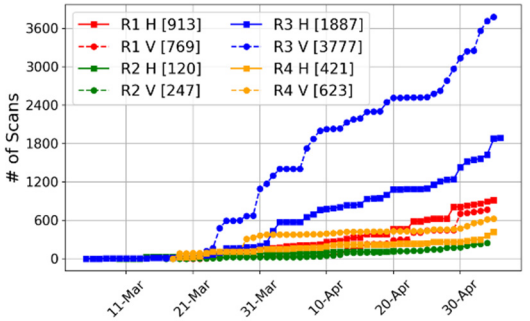


Figure 7.1 – Multi-PMT printed circuit board design.

4-channel PMT card takes simultaneous acquisitions to allow for 'high dynamic range' signal



Instruments heavily used for accelerator optimisation from first beam (PSB shown)

Beam-loss monitoring (BLM) activities

See poster: TUPP32

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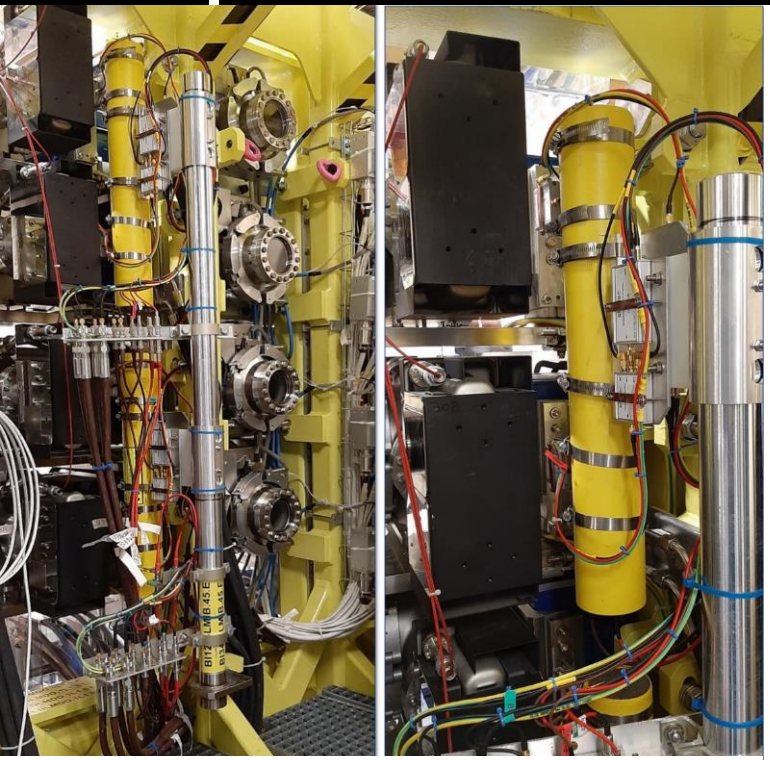
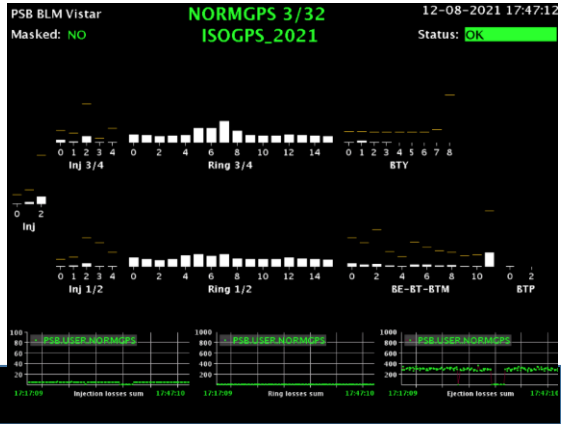


New monitors in the PS Booster

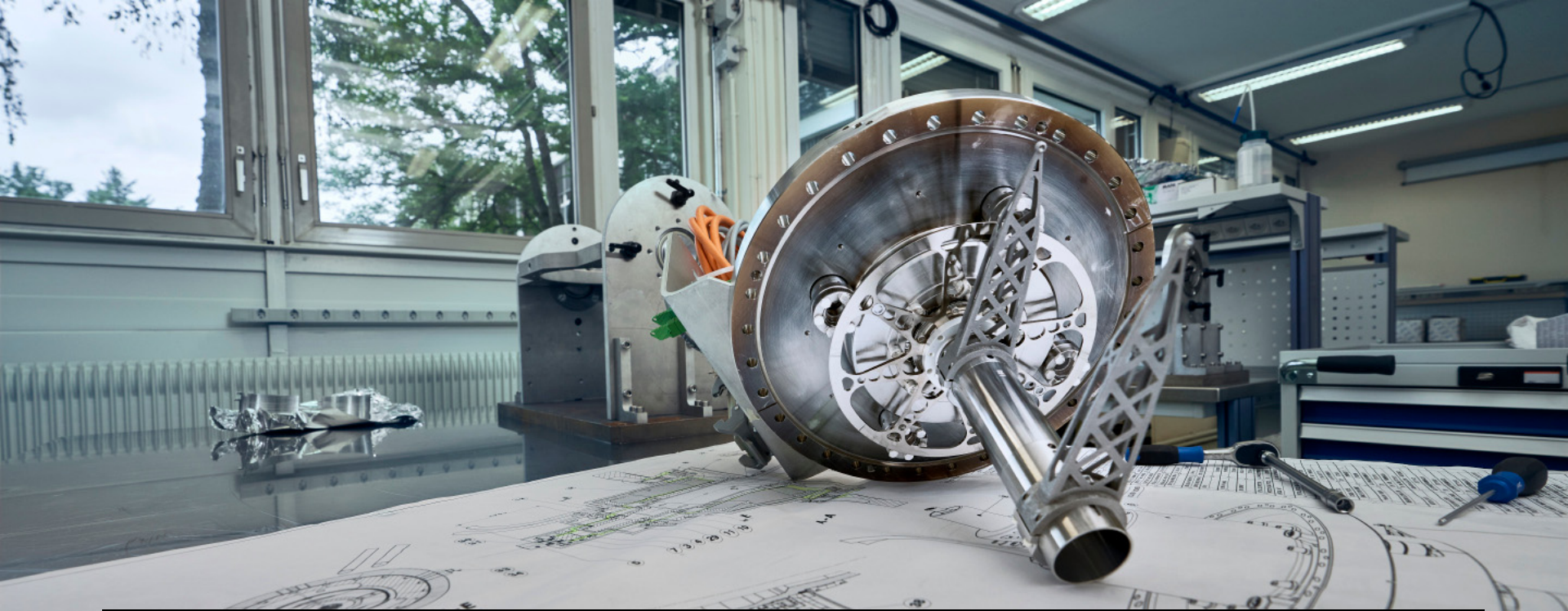
- New scope BLMs
  - 348 new monitors, with new electronics and software in the injectors
  - Automatic fast protection against excessive beam loss and measurement of losses for machine set-up
  - Two measurement techniques to cover the 2×10^{10} input range
- Staged installation and commissioning
  - Prototypes installed and operated from 2015
  - Dry-runs with operations teams
  - Successfully operating from first beams
  - Some issues of synchronous and asynchronous noise being addressed

Operational applications in LINAC4 (above) and PSB (below)



Summary

- Long Shutdown 2 saw probably the most complete set of changes and upgrades in the 60-year history of the CERN injector complex
  - 152 new in-vacuum instruments built and installed as well as 348 new beam-loss monitors
  - Two new machines (LINAC4 and ELENA) put into operation
- Commissioning has been remarkably successful
  - All instruments, including new design concepts, were available when needed by operations
  - There are six papers at this conference covering commissioning of specific instruments
  - Commissioning is still ongoing, with performance optimisation in progress and some non-critical issues to be resolved
  - Key common elements in this success have been testing of prototypes with beam and preparing by working closely with operations teams
- CERN BI group took the opportunity to replace obsolete instruments, electronics and software with new standards
  - Expecting efficiency gains for our limited number of expert personnel
  - …but compensated by the increase of 96 new instruments to operate and maintain post-shutdown



Thanks to the many people, both at CERN and our collaborating institutes around the world, who have made this commissioning a success