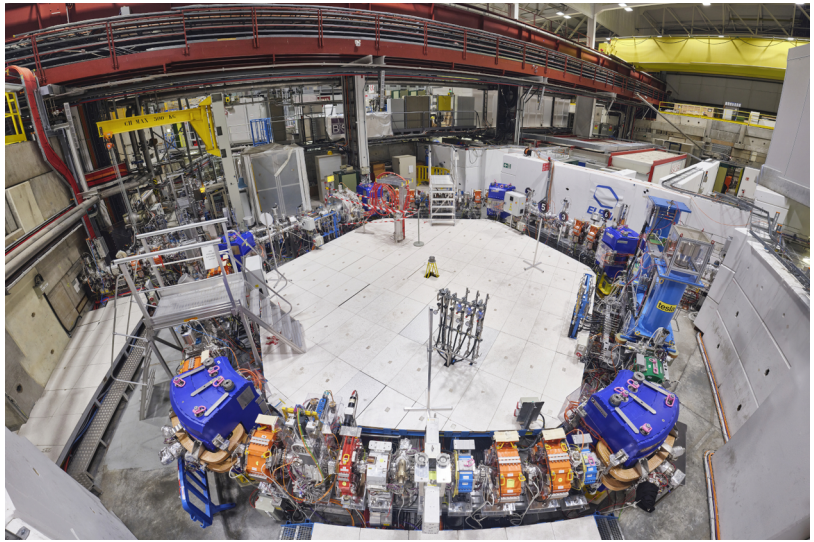
ELENA (**E**xtra **L**ow **EN**ergy **A**ntiproton): from commissioning to operation

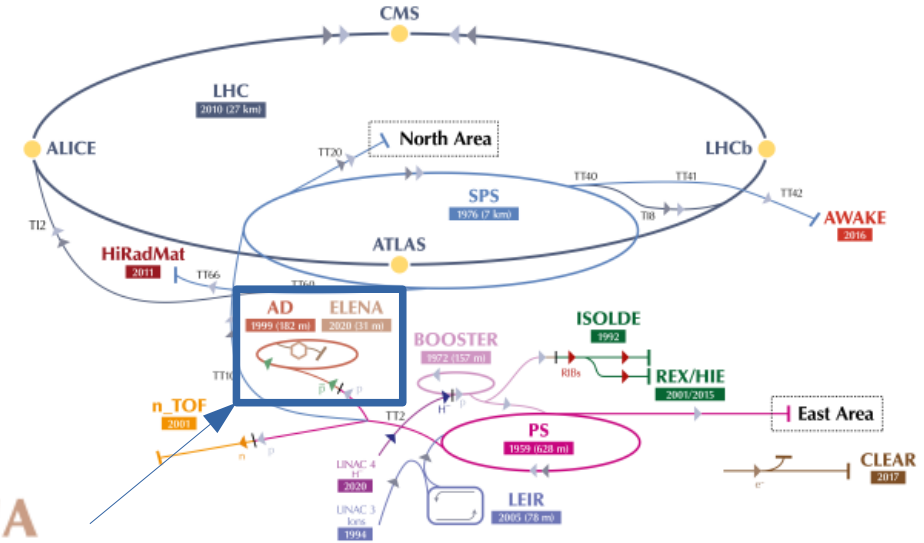
L. Ponce



On behalf of the operation and commissioning teams with special thanks to D. Gamba, C. Carli and Y. Dutheil

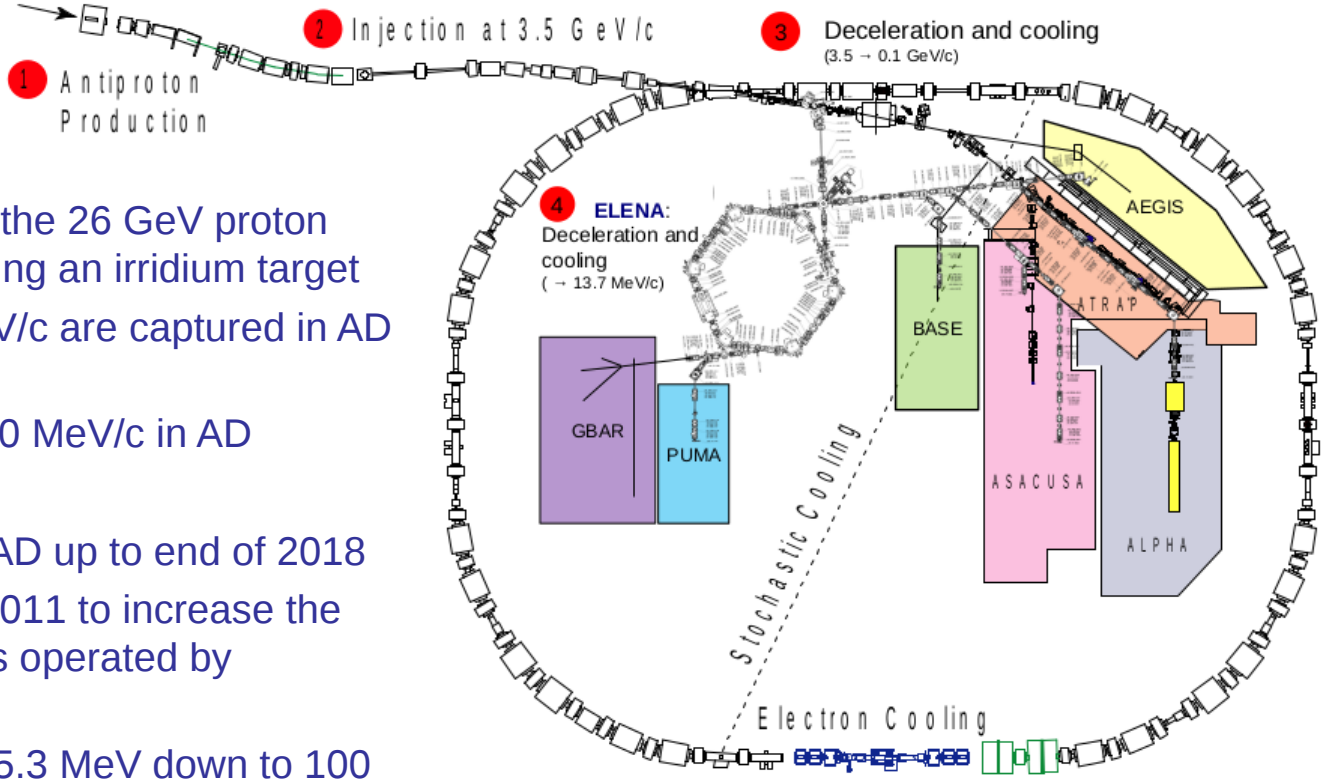
Outlines

- Introduction
- Beam commissioning timeline
- Operation overview
- Beam performances of the first physics run



The CERN accelerator complex

Introduction: CERN Antiproton factory



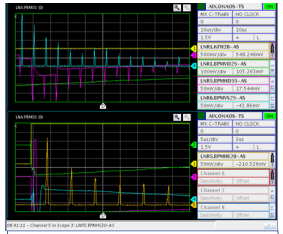
- Antiprotons are produced by the 26 GeV proton beam from CERN PS impacting an iridium target
- 3.5 10^7 antiprotons at 3.5 GeV/c are captured in AD (Antiproton Decelerator)
- Antiproton deceleration to 100 MeV/c in AD

- 5 experiments connected to AD up to end of 2018
- ELENA project approved in 2011 to increase the capture efficiency of the traps operated by experiments
  - further deceleration from 5.3 MeV down to 100 keV kinetic energy

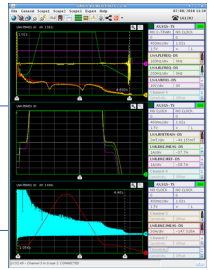
ELENA: Extra Low ENergy Antiproton

- Small 30.4 m circumference synchrotron connected after AD to decelerate antiprotons from 5.3 MeV to 100 keV
- Magnetic elements in the ring and electro-static ones in the transfer lines:
  - 125 m of beam lines to deliver beam to 8 different users
- Local 100 keV H^- ion source:
  - Instrumental for commissioning of the transfer lines
- Electron cooling to preserve low transverse and longitudinal emittances during deceleration
- Available intensity distributed into 4 bunches sent to up to 4 experiments

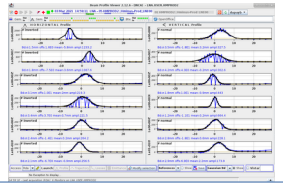
Commissioning timeline:



Mid november:
First injection of H^-



2018: Setting-up of acceleration/deceleration cycle



2020: beam commissioning of transfer lines

H- operation

Installation activities

Antiproton operation

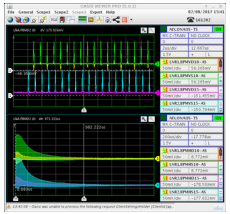
e-cooler installation

2016	2017	2018	2019	2020	2021

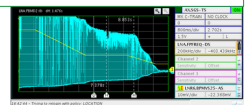
CERN Long Shutdown 2: no antiproton
Installation of new transfer lines

June 2017:
first pbars injection

August 2017:
pbars circulating

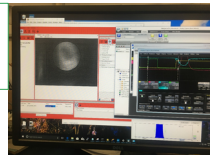


22/05/2018: first pbars at 100 keV

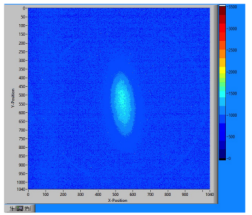


Decision to connect all users to ELENA

20/07/2018: **1st Pbar beam observed at entrance of Gbar**



28th August 2021:
Start of first physics run



phosphor screen upstream of ALPHA catching trap

ELENA planning adjusted to general CERN planning

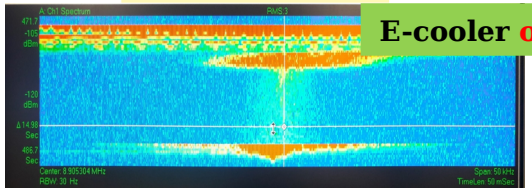
A closer look at 2018 beam commissioning

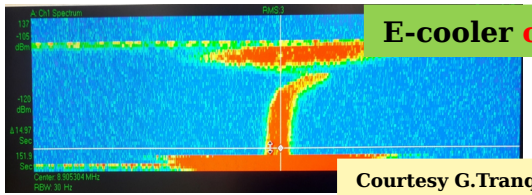
- Commissioning plan with alternance of H- and pbars:
  - 3 pbar shift/week planned till end of July
  - Setting-up of accelerating/decelerating H- cycle
- Progress with ELENA despite issues with beam(s) availability:
  - 65% machine availabilty for AD affecting physics as well as ELENA commissioning with antiprotons (pbars)
  - H^- operation compromised due to several breakdowns of the source High Voltage isolation transformer

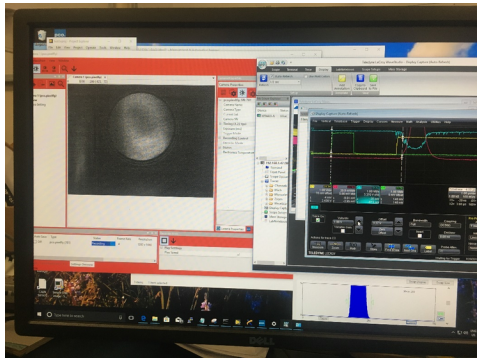
- ELENA start-up end of April – equipped with electron cooler
  - 22/05: first beam observed at 100 keV after tune corrections throughout the cycle
  - 2/7: first signs of effect of electron cooling, first in longitudinal and transverse planes a couple of weeks later
  - 20/7: first antiprotons received by the first user of ELENA

- Reasonable deceleration efficiency (~45%), beam survival at 100 keV and transfer to GBAR obtained the last week of the run:
  => Decision confirmed to connect all users to ELENA

Schottky signal



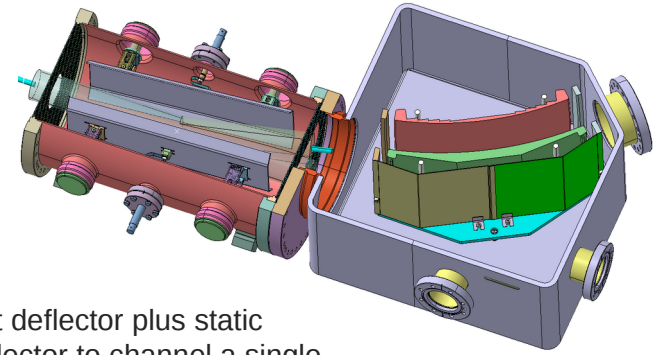




Pbars observed in Gbar

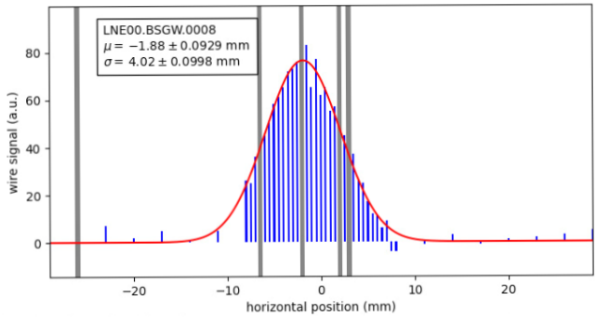
During LS2: Installation of new extraction lines

- Installation of new beam lines to transport and distribute bunches to every experimental area:
  - 239 electrostatic elements, almost 500 power converters
  - Fast deflector proved capable of deflecting single bunch with rise & fall time < 1us
  - More than 40 beam profile monitors:
    - Partially interceptive micro-wire grids for measurement of the beam size and position
    - The comprehensive coverage of the lines was critical for commissionning
- Complex timing system to distribute available bunches to up to four experiments in the same cycle



fast deflector plus static deflector to channel a single bunch towards a different line

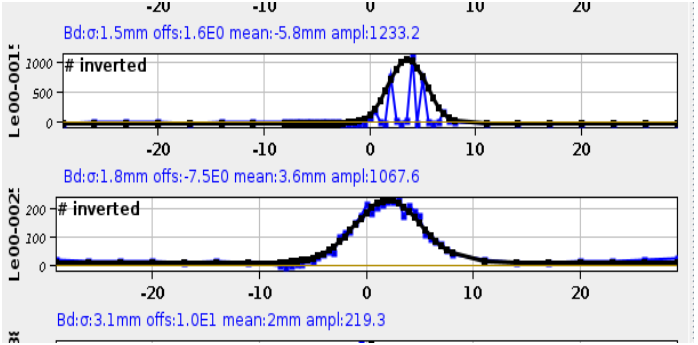
1 bunch in LNE50 2 bunches in LNE00 1 bunch not extracted

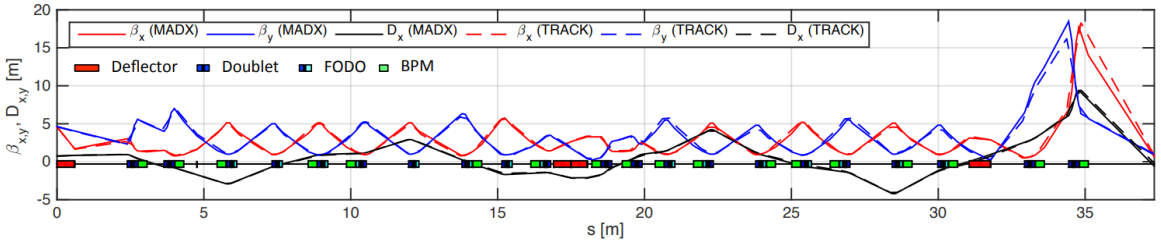


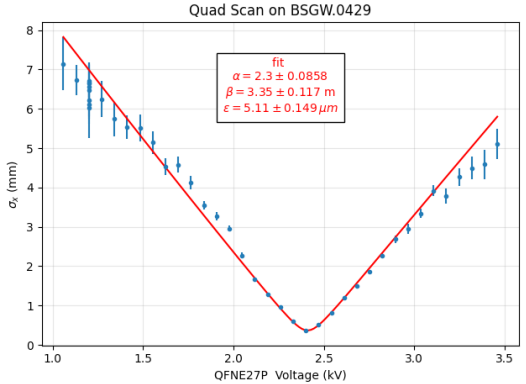
Example of a horizontal profile taken just after extraction

2020-2021: Extraction lines beam commissioning

- Characterization of beam profile monitors:
  - Found several wires in several monitors not working, but overall quality sufficient for commissioning
- Modelling and commissioning
  - Extensive modelling of the optical effects of the electrostatic devices during the design using tracking tools
  - Systematic optical characterisation of the beam delivered to every line was done during commissioning
  - No rematching as measured optics found close to design







Comparison at the end of the longest line of a tracking-based model from 2015 and a measurement taken in 2021 agree within 20% without corrections

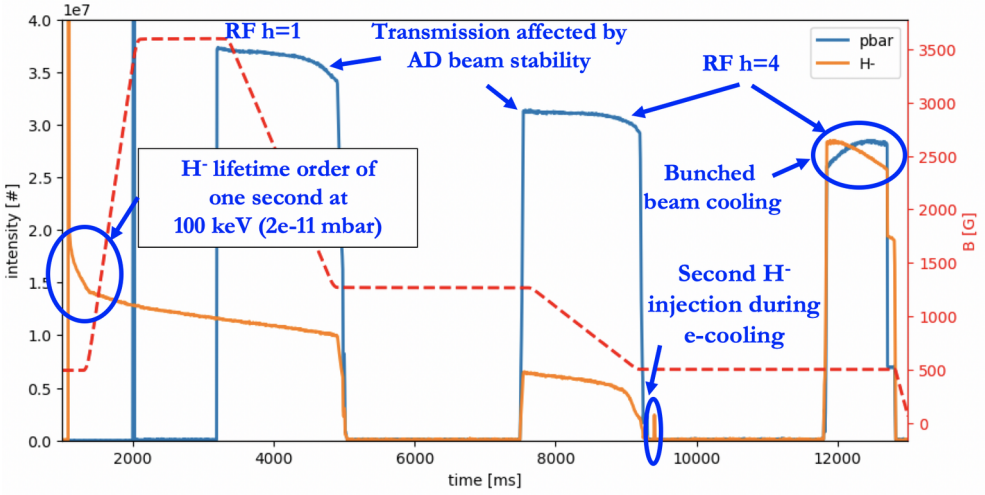
M.A. Fraser, et. al., Beam dynamics studies of the ELENA electrostatic transfer lines, IPAC15, Richmond, VA, USA

Operation overview: pbars cycle

- Operational deceleration cycle is 13 s long:
  - Injection pbars from AD at 100 MeV/c
  - Deceleration to 35 MeV/c on RF h=1,
  - Electron cooling of debunched beam at 35 MeV/c
  - Rebunching and deceleration to 13.7 MeV/c on h=4
  - Electron cooling of debunched beam at 13.7 MeV/c
  - Re-bunching on h=4 with e-cooling on

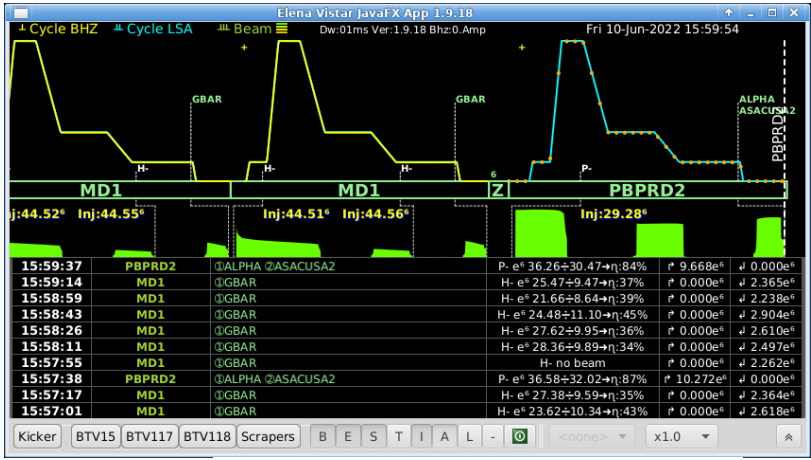
Intensity measurement available only for bunched beam

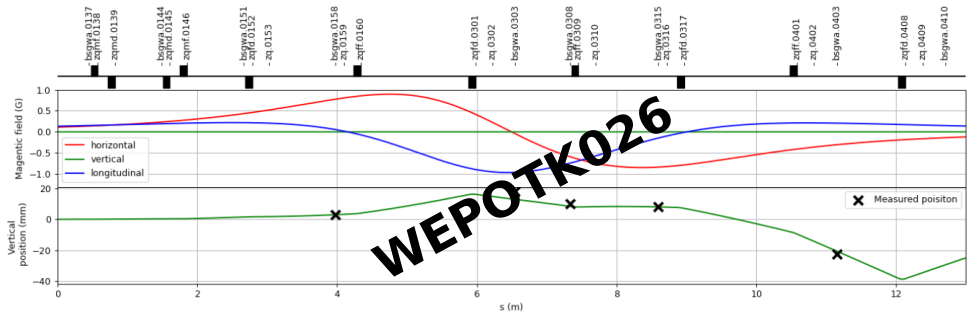
Cycle optimized using mimic cycle with H^- ion beam, including the e-cooling setting-up in 2020-2021

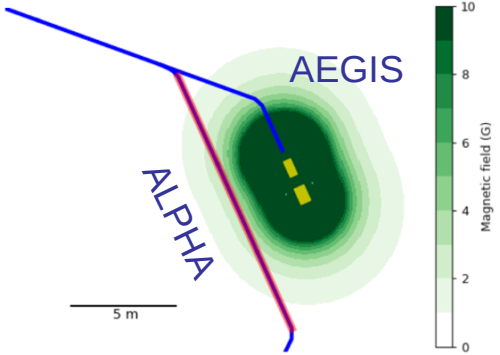


Operation overview: operation mode

- ELENA cycle short compared to AD cycle (~2min)
  - H- cycles possible between antiproton cycle
- New mode of operation with respect to pre-LS2 time:
  - Four bunches per cycle sent to up to 4 users
- The extra low energy of the beam makes it very sensitive to stray magnetic fields:
  - stray field generated by the AEGIS experiment caused large distortions of the trajectory in ALPHA





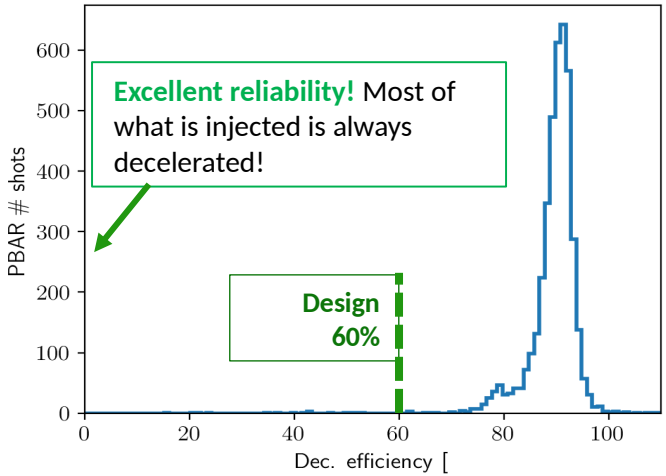


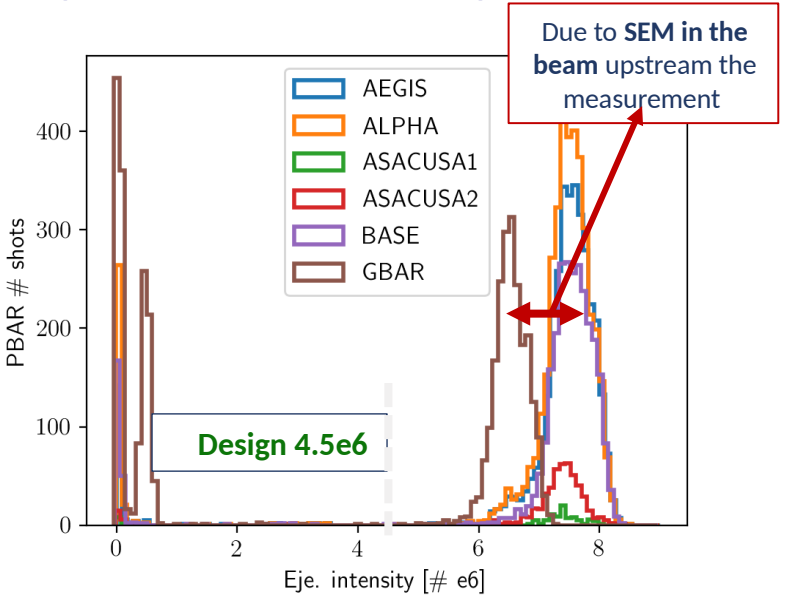
1 G.m of transverse integrated magnetic field induces a deviation of around 2 mrad

Y. Dutheil, et. al., Commissioning of the ELENA electrostatic transfer lines for the Antimatter Facility at CERN, WEPOTK026, IPAC22, Bangkok, Thailand

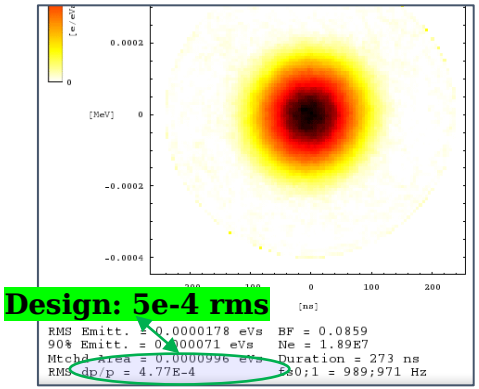
Beam performance: delivered pbars

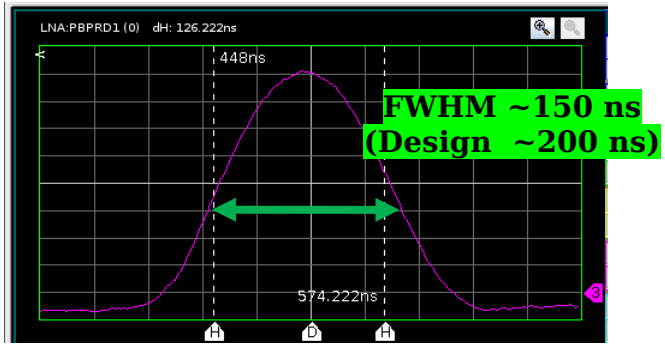
- ELENA deceleration efficiency and delivered bunch intensities well above design values (despite lower intensity from AD than 2018):
  - Uncertainty (of 10-15%) on calibration/signal treatment of instruments (measurement with optimistic calibration)
  - Profile monitors are semi-interceptive device (about 10 % beam loss per monitor)

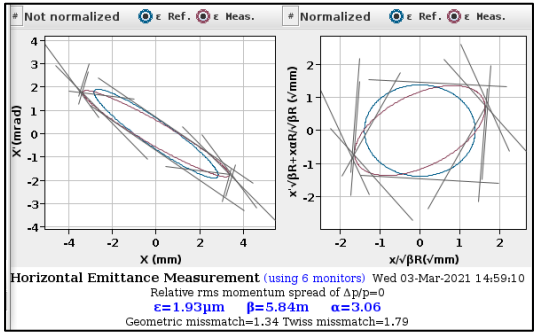




Beam performance: extracted antiproton parameters







- Energy spread and bunch length within or better than design
  - Bunch length could be further reduced with bunch rotation at expense of energy spread
- Typical emittances of 2 μm rms are about factor 2 larger than design (factor ~2 better than 2018 estimate!)
  - Working on adjusting the length of bunched beam cooling before extraction in ELENA to get smaller emittance
  - We observed clear emittance-intensity dependance to be investigated

=> **Overall reached close to nominal beam characteristics**

Beam parameters summary

Parameter	design	Achieved in 2021
Q_x/Q_y	~2.3/~1.3	2.37/1.85
Cycle duration [s]	20	13
Injected intensity [pbars]	3e7	>3.2e7
Deceleration efficiency [%]	60	85
Extracted bunches	4	4
Bunch population [pbars]	4.5e6	> 6e6
$\triangle p/p_0$	5e-4	4.5e-4
Bunch length (rms) [ns]	75	<75
Transverse emittances x/y [μm]	1.2/0.75	~2/~2

Summary

- **ELENA** and its new **transfer lines** have been **successfully commissioned during summer 2021**
  - **From autumn 2021 new era for antimatter physics with** 100 keV antiproton beams delivered to all experiments

- **Beam characteristics very close to design values**:
  - Easy to get **shorter bunches** than design, but transverse **emittances still a factor 2 bigger than nominal**
  - **Higher intensities than design** in ELENA

- **Extremely useful first run** in 2021 for both **operation and users** :
  - Experience gained on operation with **4 bunches available** on demand **at any time** to any experiments
  - Experience during the commissioning strongly validated the early choice of using electrostatic devices only for the transfer lines
  - Pretty **good orbit stability** of beam delivery in transfer lines:
    - Still **strong impact of experiment magnetic fields** when switching **on/off**
  - **H^- source operation very useful** for **ELENA** and **transfer line** set-up, but also for **experiment** setup/optimization (higher repetition rate)

Thank you