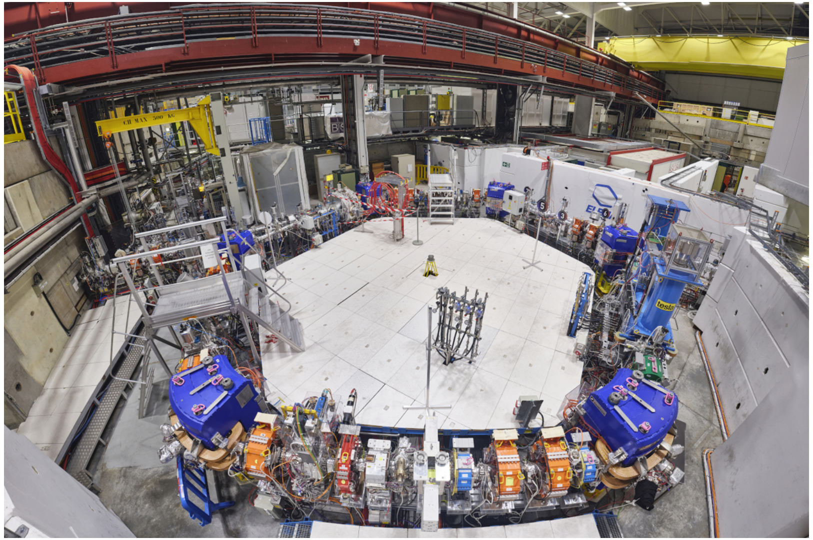
ELENA (**E**xtra **L**ow **EN**ergy **A**ntiproton): from commissioning to operation

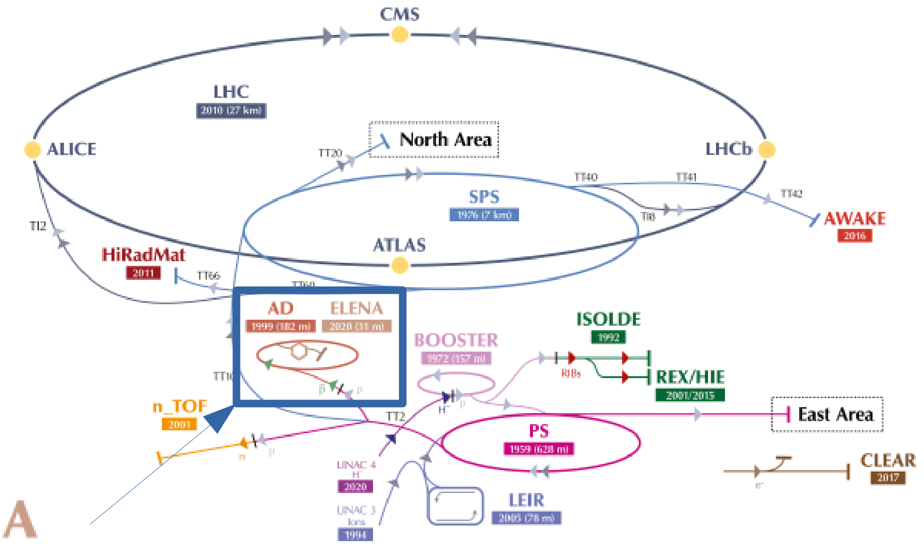
L. Ponce



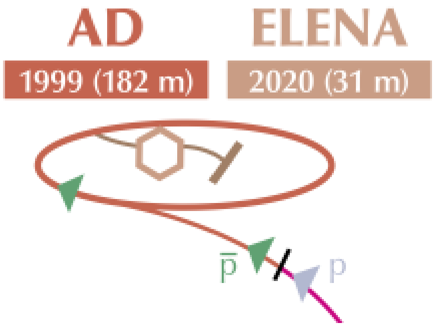
On behalf of the operation and commissioning teams
with special thanks to D. Gamba, C. Carli and Y. Dutheil

Outlines

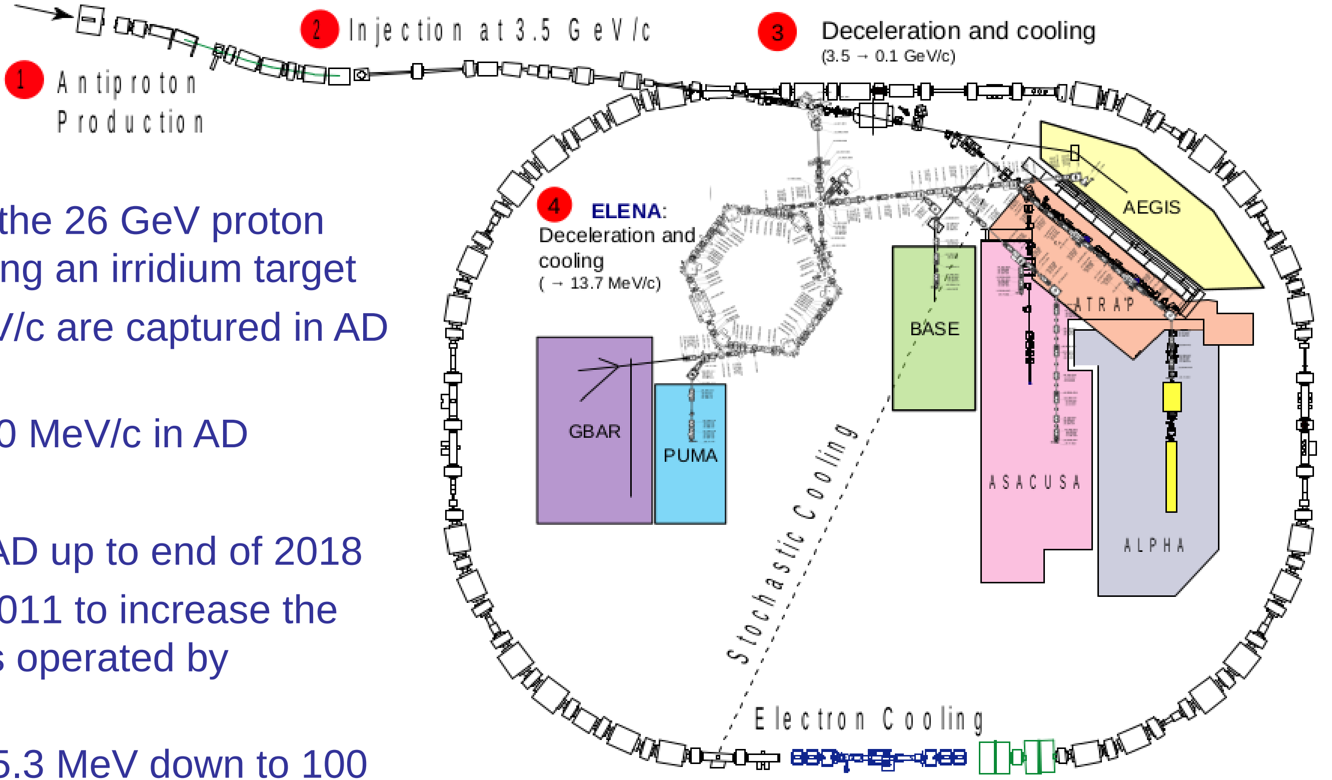
- Introduction
- Beam commissioning timeline
- Operation overview
- Beam performances of the first physics run



The CERN accelerator complex



Introduction: CERN Antiproton factory

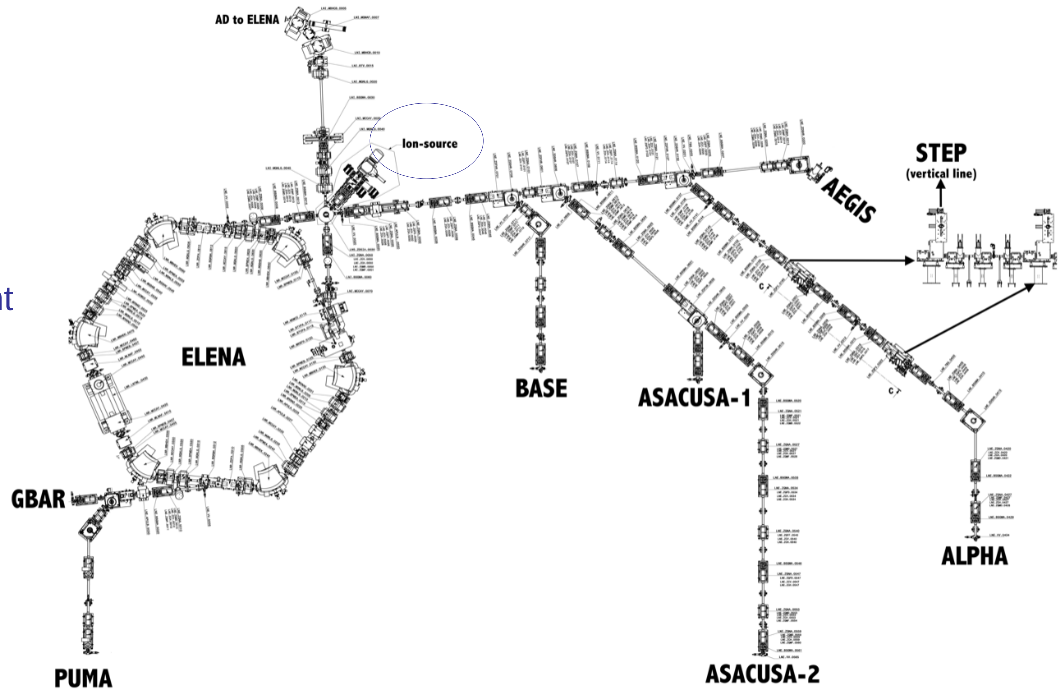


- Antiprotons are produced by the 26 GeV proton beam from CERN PS impacting an irridium target
- 3.5 10^7 antiprotons at 3.5 GeV/c are captured in AD (Antiproton Decelerator)
- Antiproton deceleration to 100 MeV/c in AD

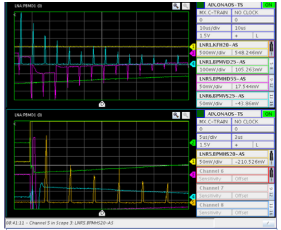
- 5 experiments connected to AD up to end of 2018
- ELENA project approved in 2011 to increase the capture efficiency of the traps operated by experiments
  - further deceleration from 5.3 MeV down to 100 keV kinetic energy

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

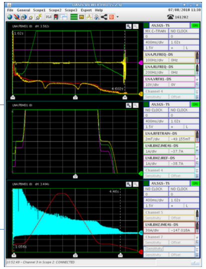


Commissioning timeline:

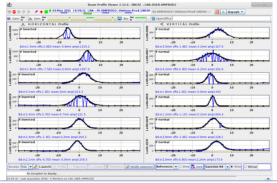


Mid november:
First injection of H^-

2018: Setting-up of acceleration/deceleration cycle



e-cooler installation



2020: beam commissioning of transfer lines

H- operation

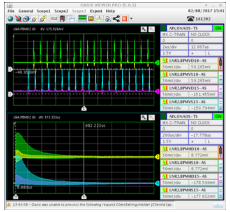
Installation activities

Antiproton operation

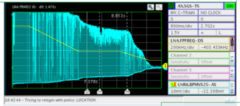
2016 | 2017 | 2018 | 2019 | 2020 | 2021

June 2017:
first pbars injection

August 2017:
pbars circulating



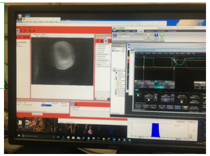
22/05/2018: first pbars at 100 keV



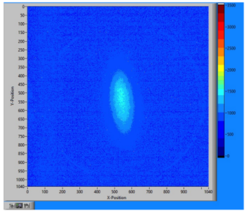
CERN Long Shutdown 2: no antiproton
Installation of new transfer lines

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

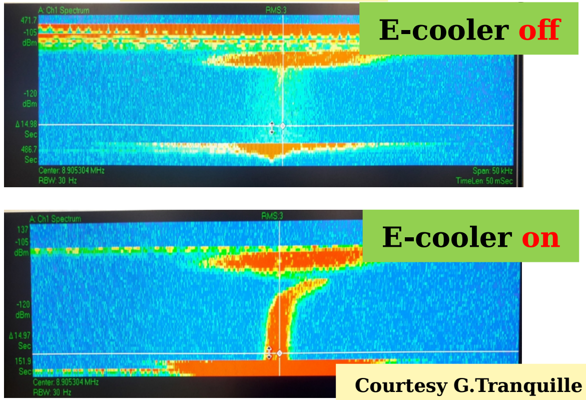
- Commissioning plan with alternance of H- and pbars:
  - 3 pbar shift/week planned till end of July
  - Setting-up of accelerating/decelerating H- cycle
- Progress with ELENA despite issues with beam(s) availability:
  - 65% machine availabilty for AD affecting physics as well as ELENA commissioning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

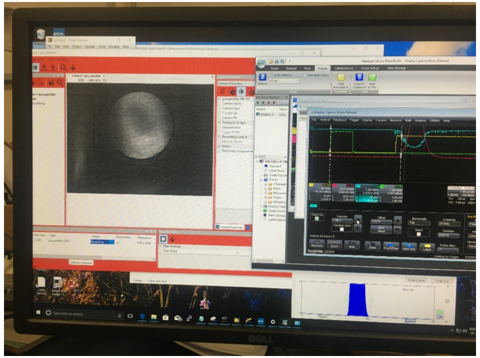
- ELENA start-up end of April – equipped with electron cooler
  - 22/05: first beam observed at 100 keV after tune corrections throughout the cycle
  - 2/7: first signs of effect of electron cooling, first in longitudinal and transverse planes a couple of weeks later
  - 20/7: first antiprotons received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

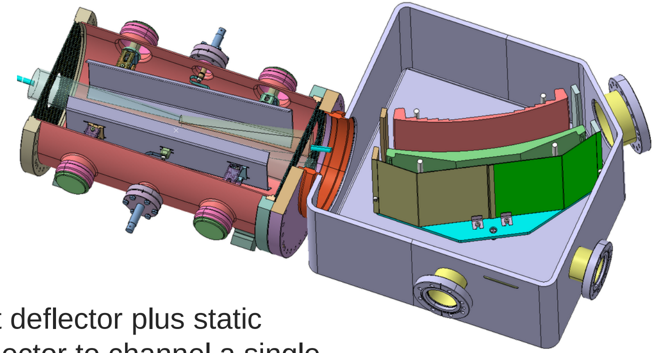




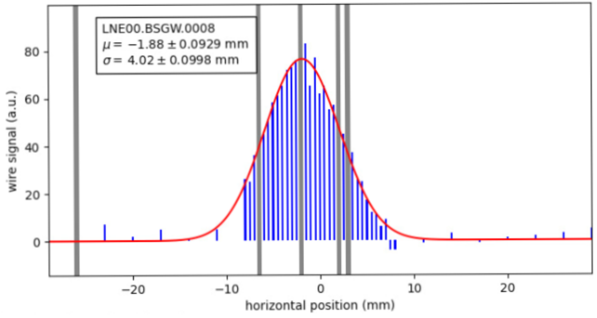
Pbars observed in Gbar

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



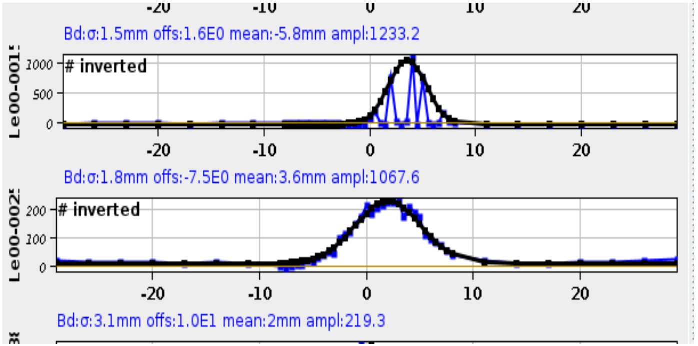
fast deflector plus static deflector to channel a single bunch towards a different line



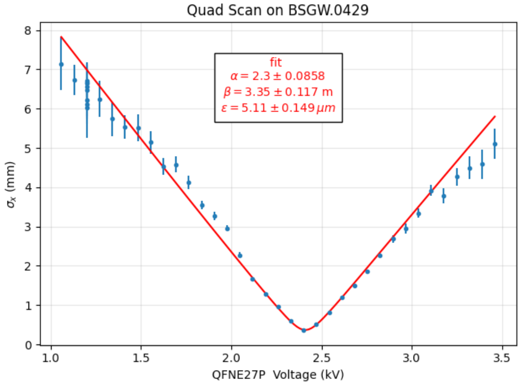
Example of a horizontal profile taken just after extraction

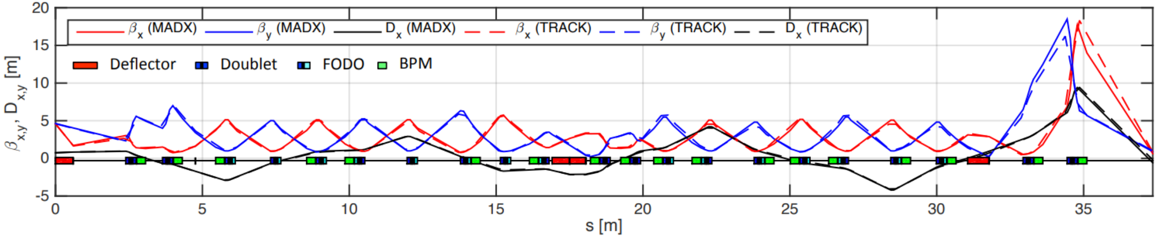
1 bunch in LNE50 2 bunches in LNE00 1 bunch not extracted

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

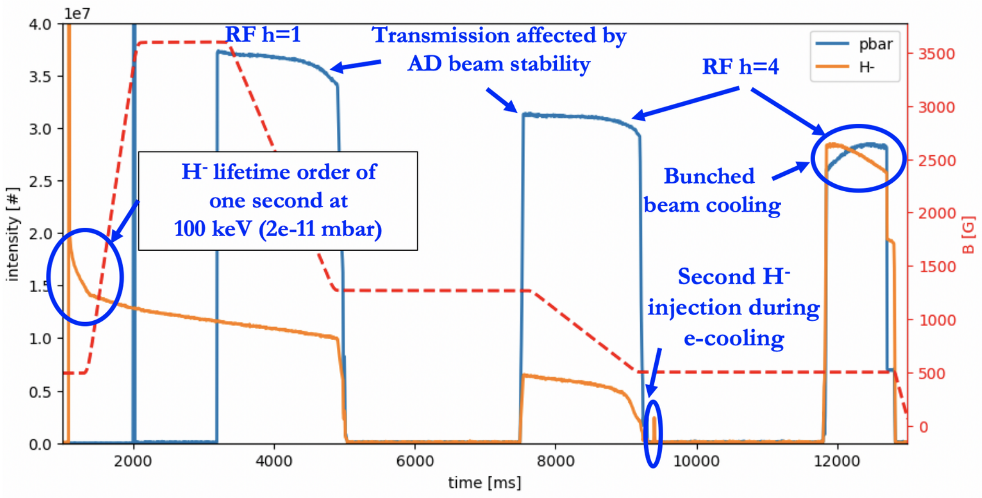
M.A. Fraser, et. al., Beam dynamics studies of the ELENA electrostatic transfer lines, IPAC15, Richmond, VA, USA

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

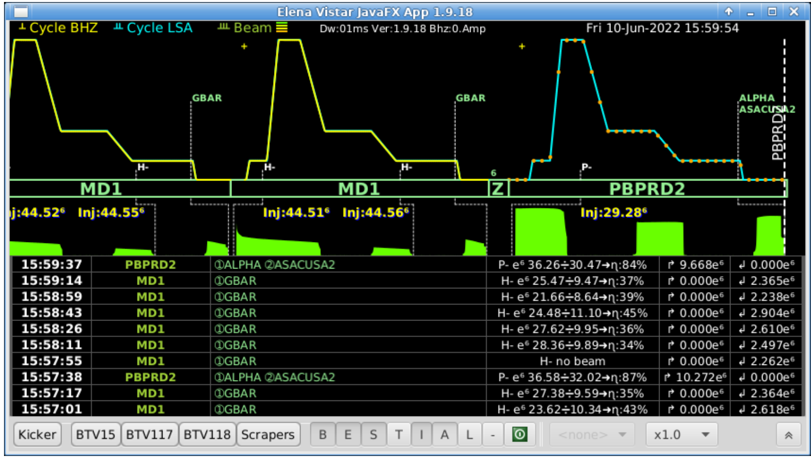
Intensity measurement available only for bunched beam

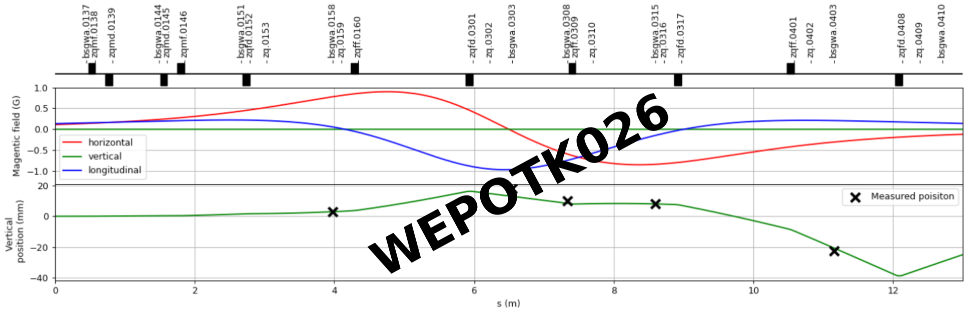
Cycle optimized using mimic cycle with H^- ion beam, including the e-cooling setting-up in 2020-2021



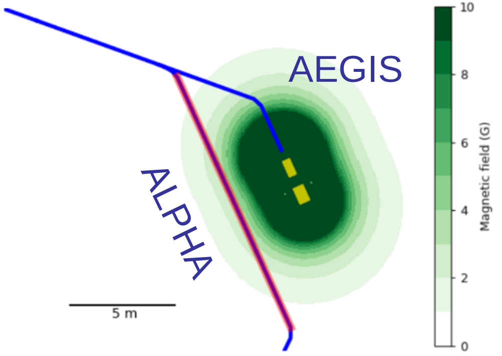
Operation overview: operation mode

- 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





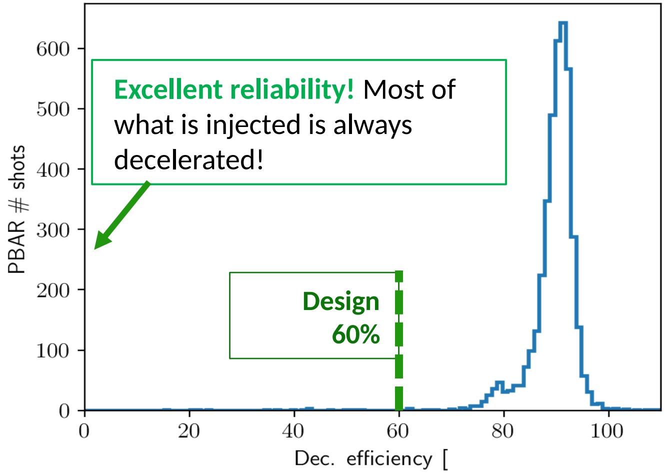
Y. Dutheil, et. al., Commissioning of the ELENA electrostatic transfer lines for the Antimatter Facility at CERN, WEPOTK026, IPAC22, Bangkok, Thailand

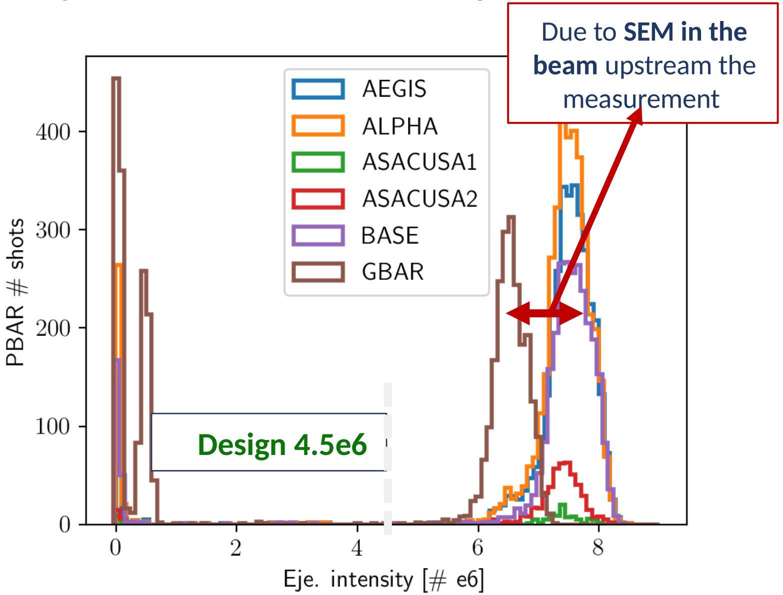


1 G.m of transverse integrated magnetic field induces a deviation of around 2 mrad

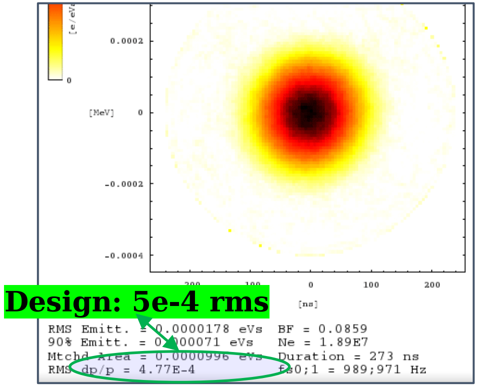
Beam performance: delivered pbars

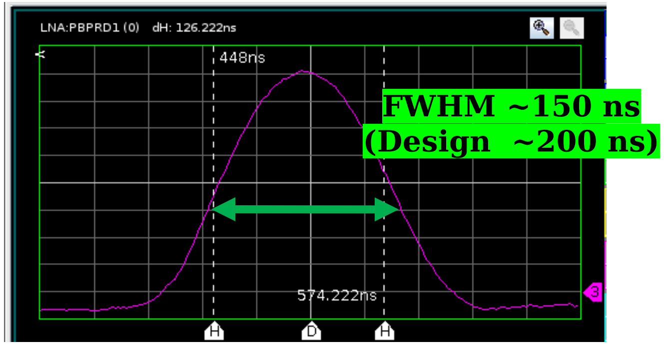
- ELENA deceleration efficiency and delivered bunch intensities well above design values (despite lower intensity from AD than 2018):
  - Uncertainty (of 10-15%) on calibration/signal treatment of instruments (measurement with optimistic calibration)
  - Profile monitors are semi-interceptive device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

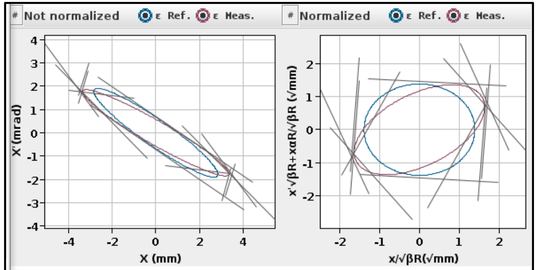




Beam performance: extracted antiproton parameters







Horizontal Emittance Measurement (using 6 monitors) Wed 03-Mar-2021 14:59:10
Relative rms momentum spread of Δp/p=0
ε=1.93μm β=5.84m α=3.06
Geometric missmatch=1.34 Twiss missmatch=1.79

- 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
$\Delta p/p_0$	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