GBAR status report 2018

Irfu

Laboratoire Kastler Brossel
Physique quantique et applications

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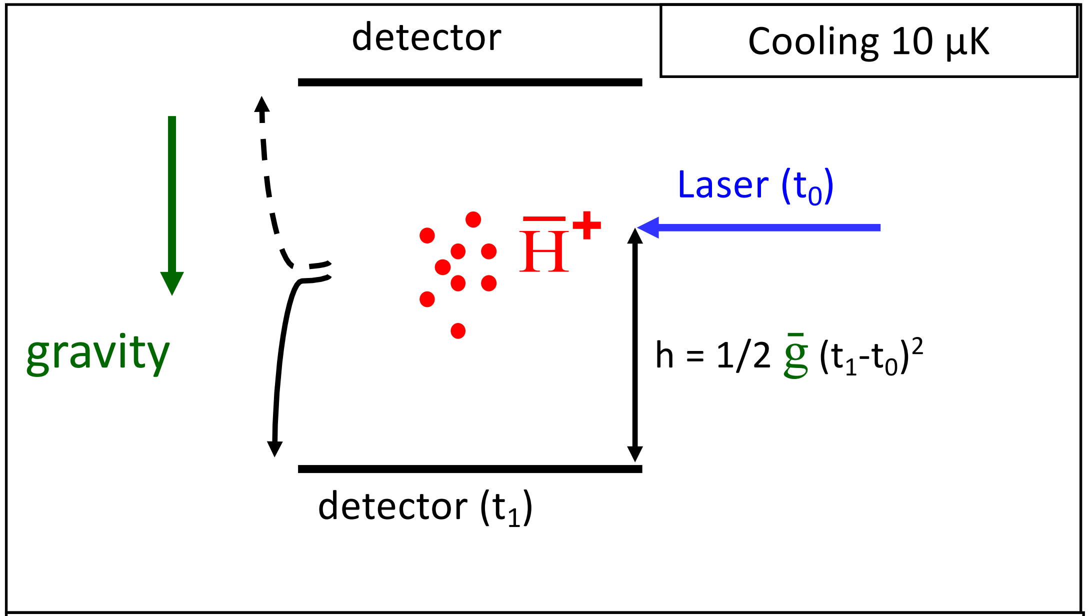
Principle

- $\bar{H}^+ \;=\; \bar{p}\, e^+ e^+$
- Sympathetic cooling with Be^+ → 10 μK
- Photodetachment of e^+
- Time of flight (h = 10 cm → Δt = 0.14 s)



J.Walz & T. Hänsch,
General Relativity and Gravitation, **36** (2004) 561

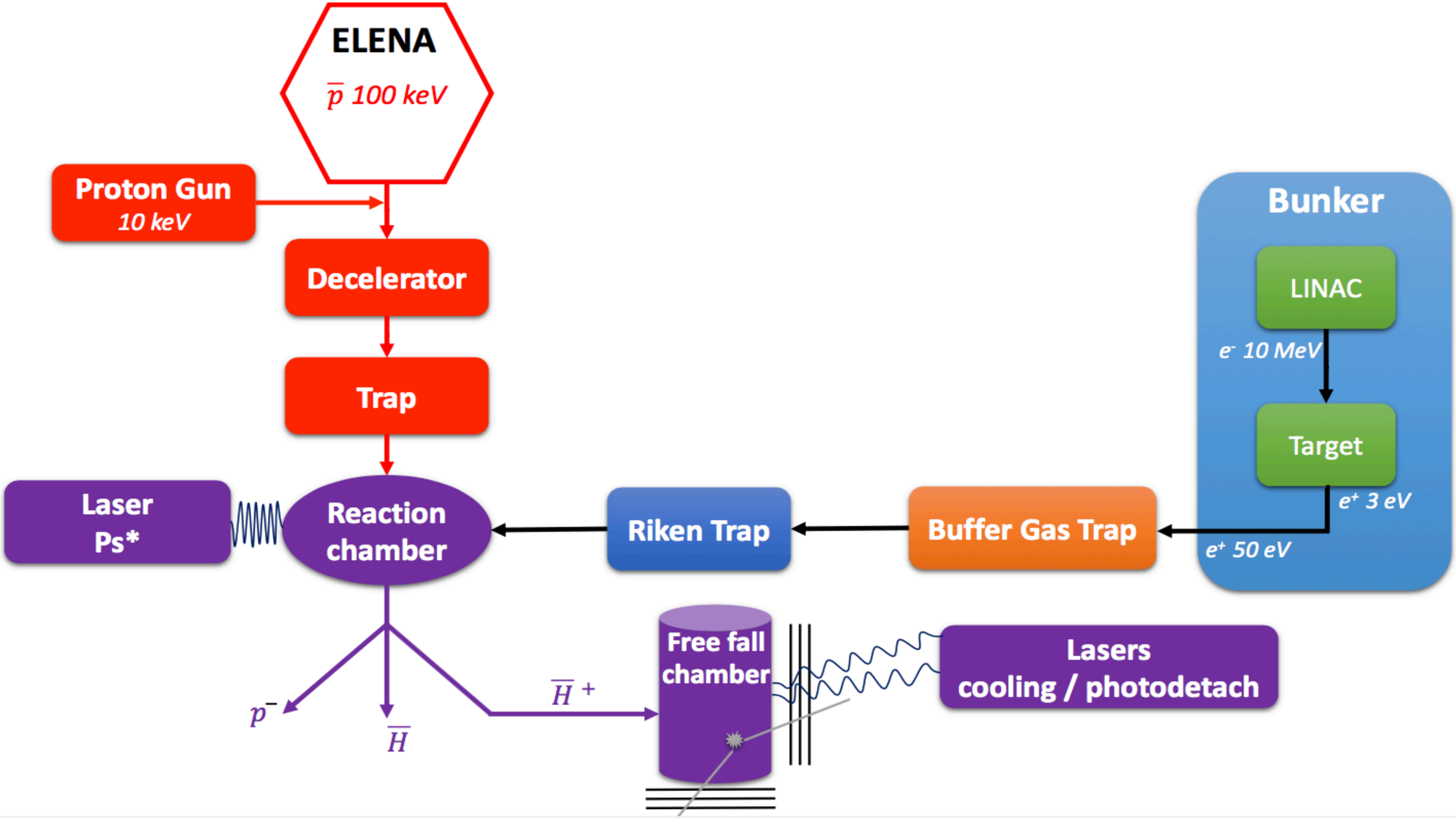
Beam production

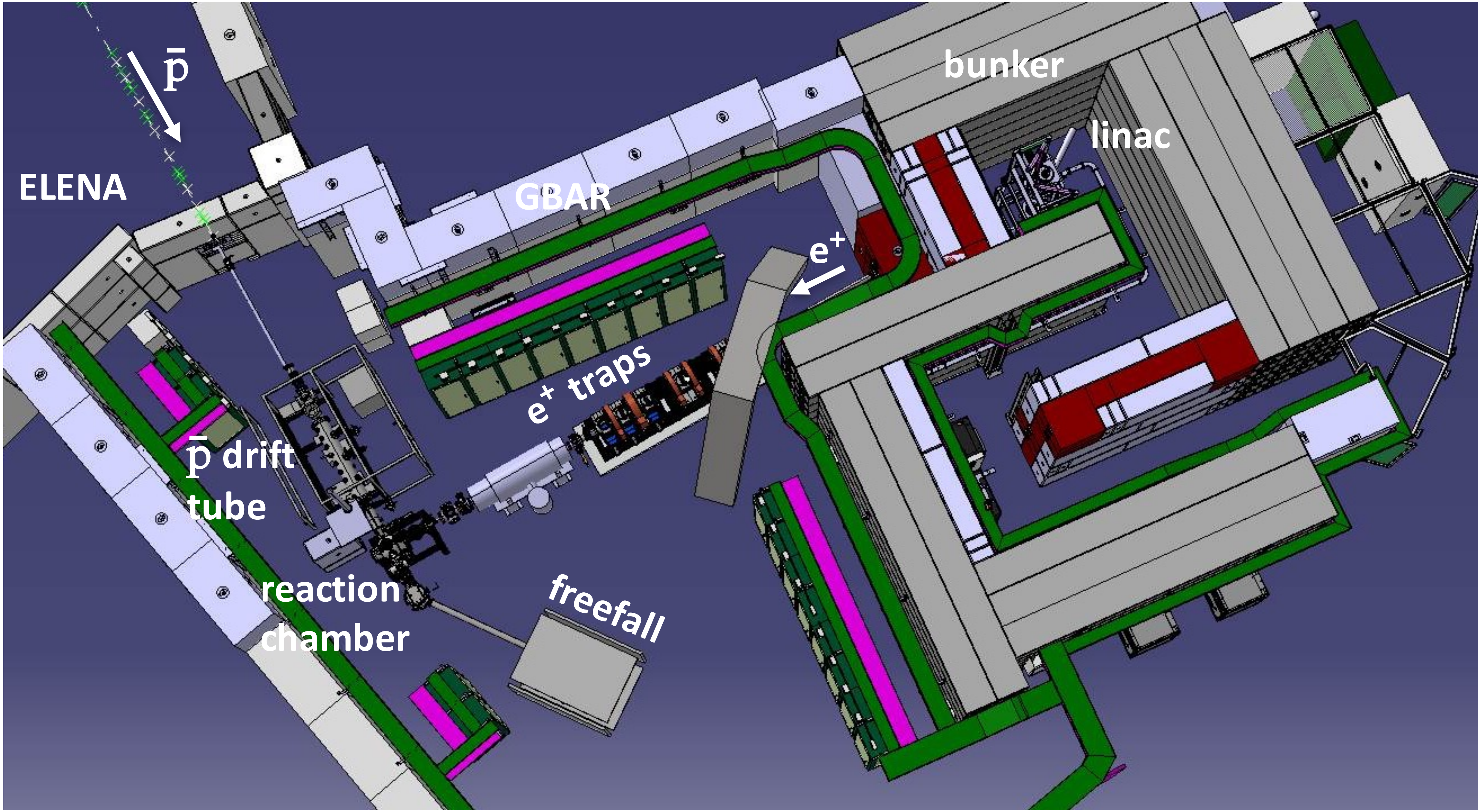
- instead of 3-body process with 2 e^+
- use $Ps = e^+e^-$, twice
- excite Ps (n=3)

$$\bar{p} + Ps \rightarrow \bar{H} + e^-$$

$$\bar{H} + Ps \rightarrow \bar{H}^+ + e^-$$

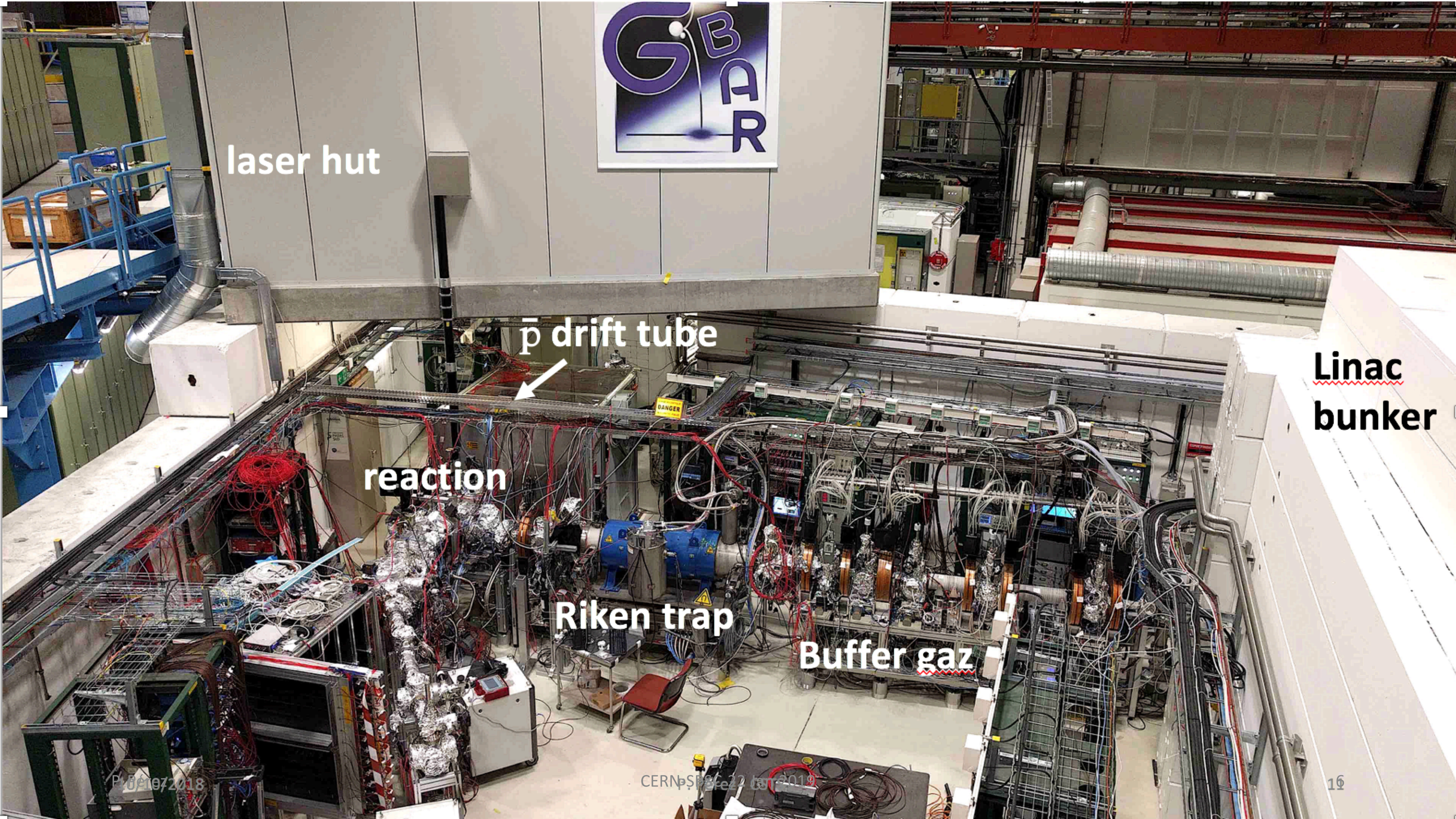
P.Pérez & A. Rosowsky, NIM **A 532** (2004) 523


ELENA
$\overline{p}$ 100 keV
Proton Gun
10 keV
Decelerator
Trap
Bunker
LINAC
e^- 10 MeV
Target
e^+ 3 eV
e^+ 50 eV
Laser
Ps*
Reaction chamber
Riken Trap
Buffer Gas Trap
p^-
$\overline{H}$
$\overline{H}^+$
Free fall chamber
Lasers
cooling / photodetach



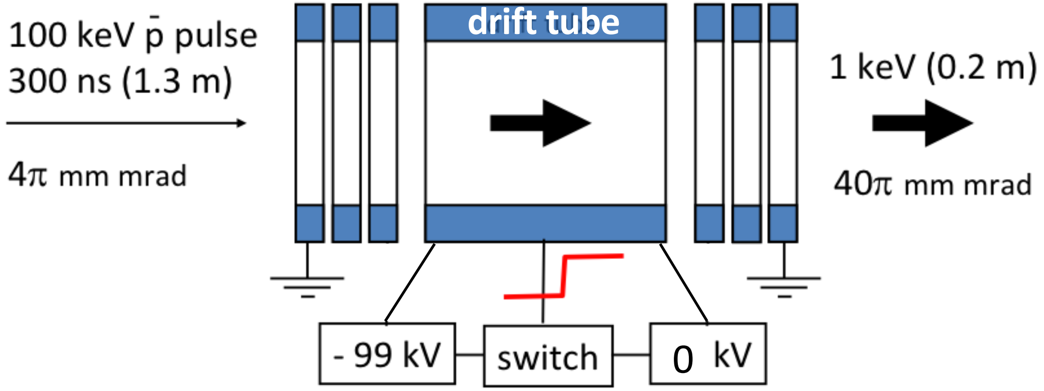
$\bar{p}$
ELENA
GBAR
bunker
linac
e^+
e^+ traps
$\bar{p}$ drift tube
reaction chamber
freefall

March 2017


laser hut
$\bar{p}$ drift tube
Linac
bunker
reaction
Riken trap
Buffer gaz

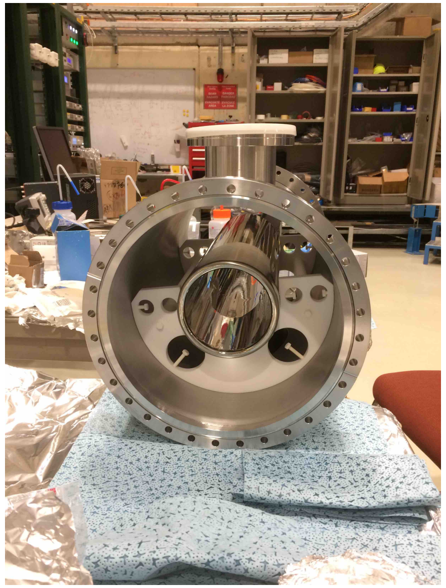
(anti)proton drift tube decelerator

$100\,\mathrm{keV} \rightarrow 1 - 10\,\mathrm{keV}$



beams from ELENA
p̄ every 110 s
H^- 5 s

Vacuum chamber re-built
10^{-9} to 10^{-10} mbar

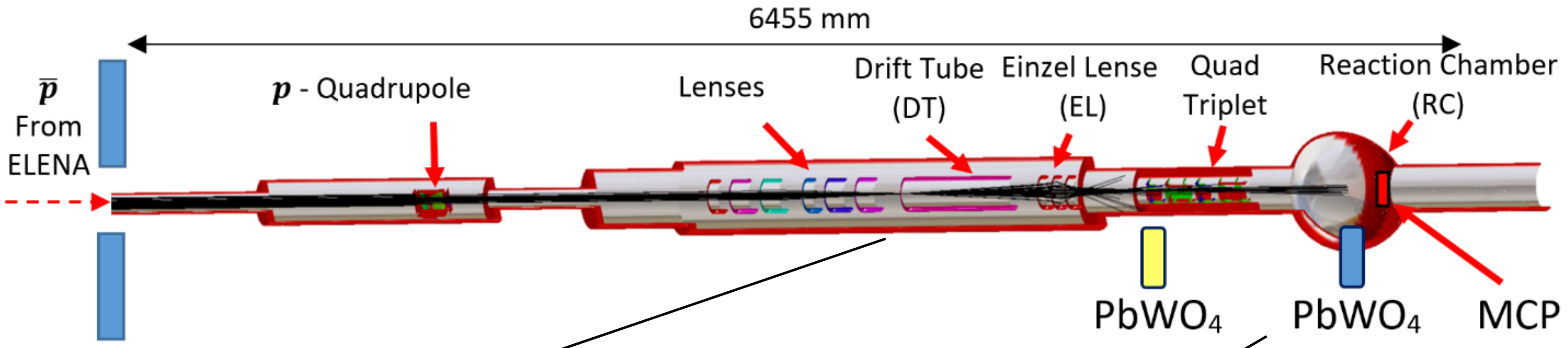


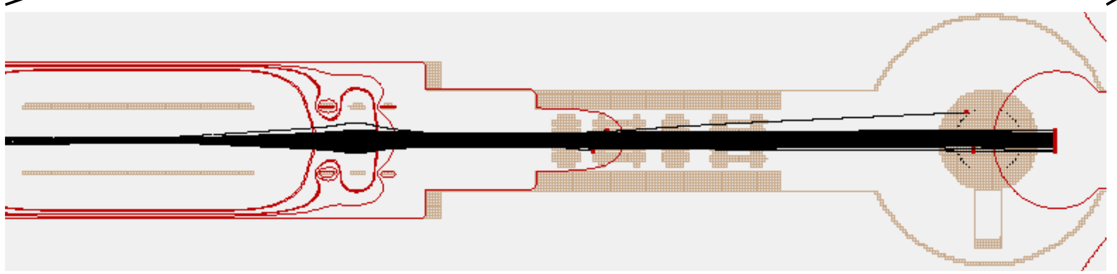
drift tube 40 cm

decelerator during assembly

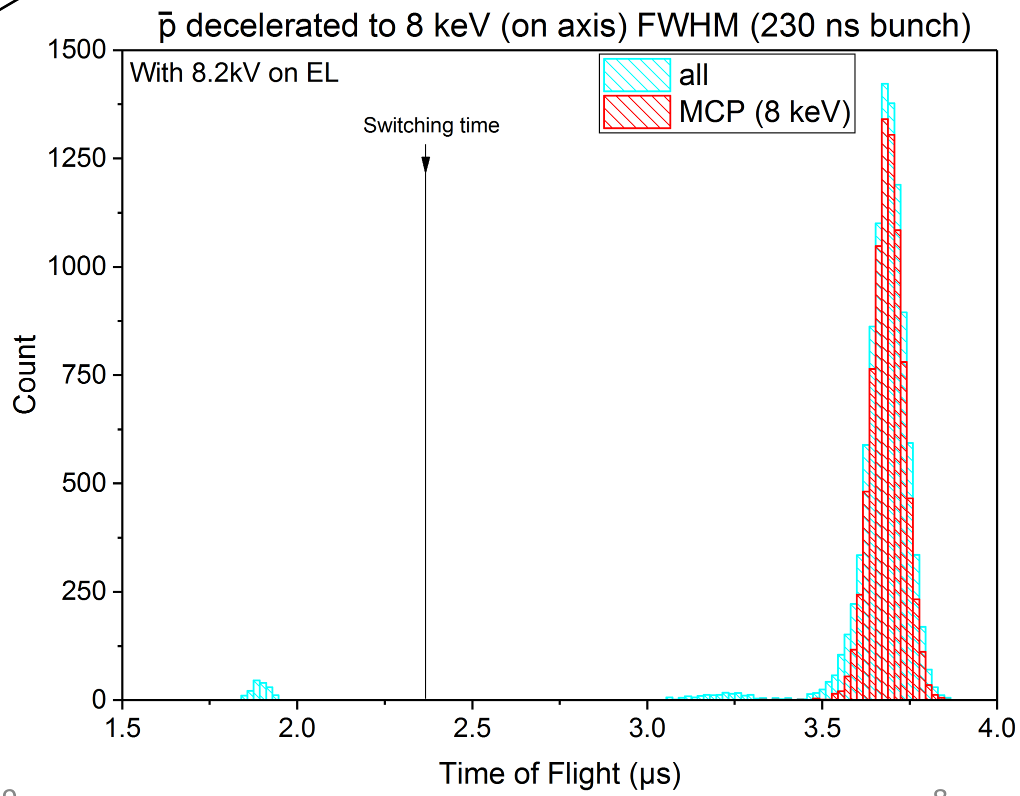
100 keV → 228 ns/m

10 keV → 722 ns/m





simulation



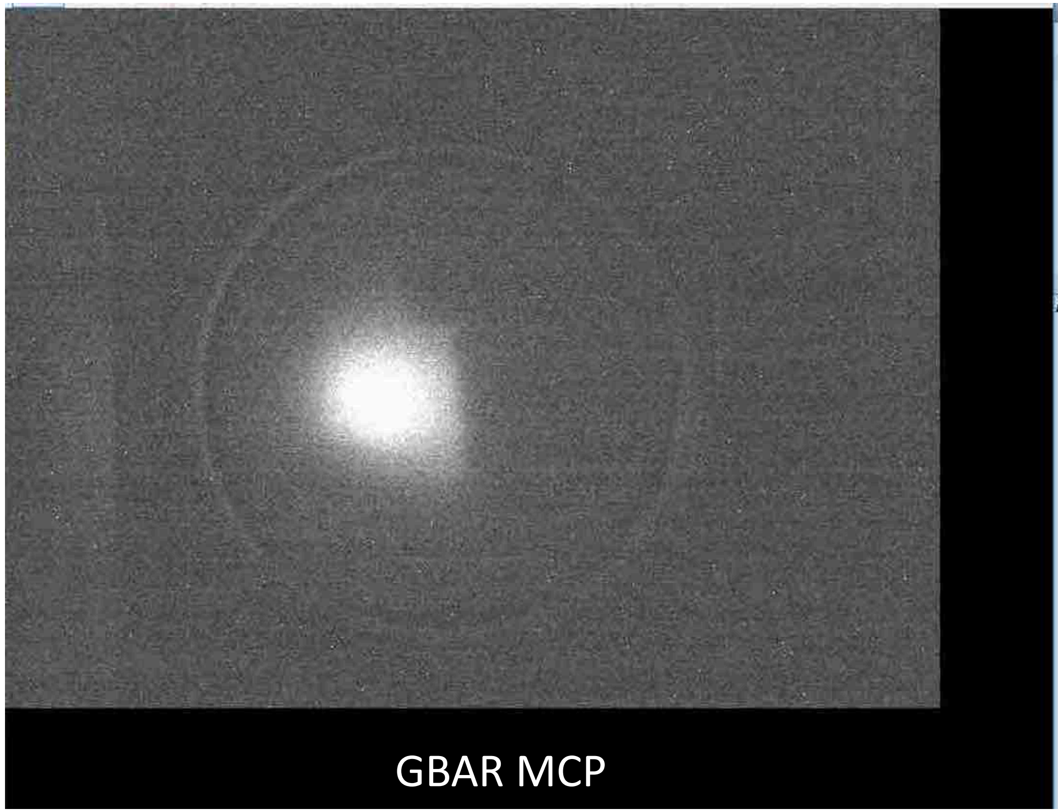
Beam Size = FWHM (5 mm)

Transversal Energy Spread = 1 keV

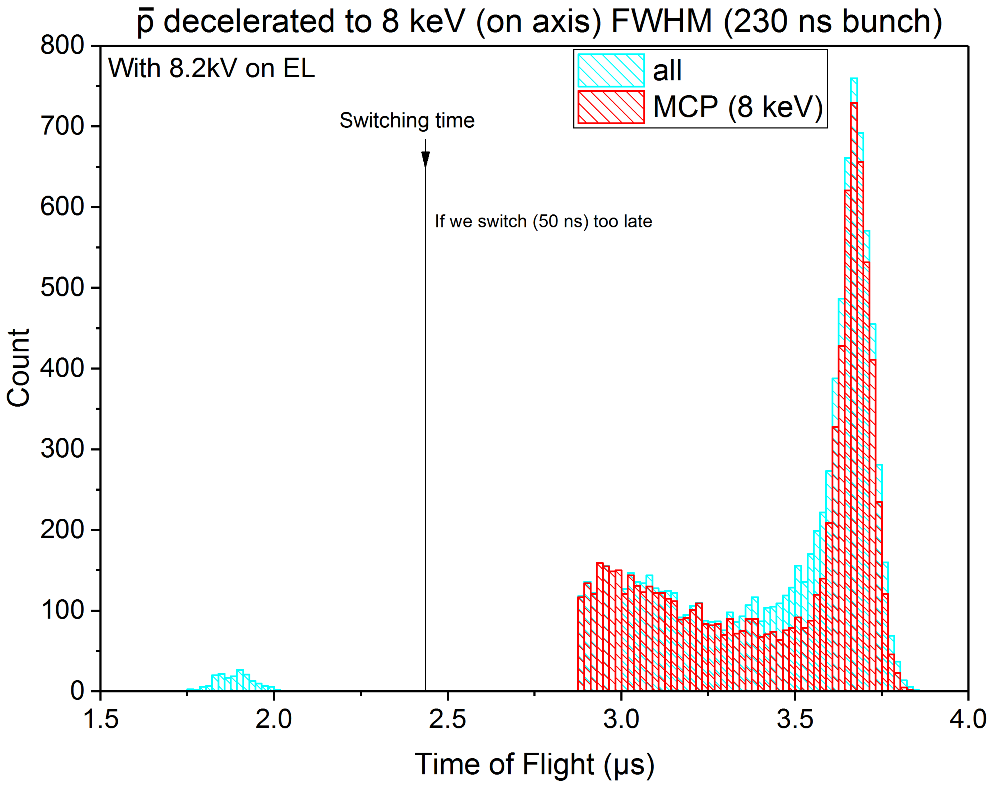
Beam on axis

Beam spot size 3x3 mm @ target 95% efficiency

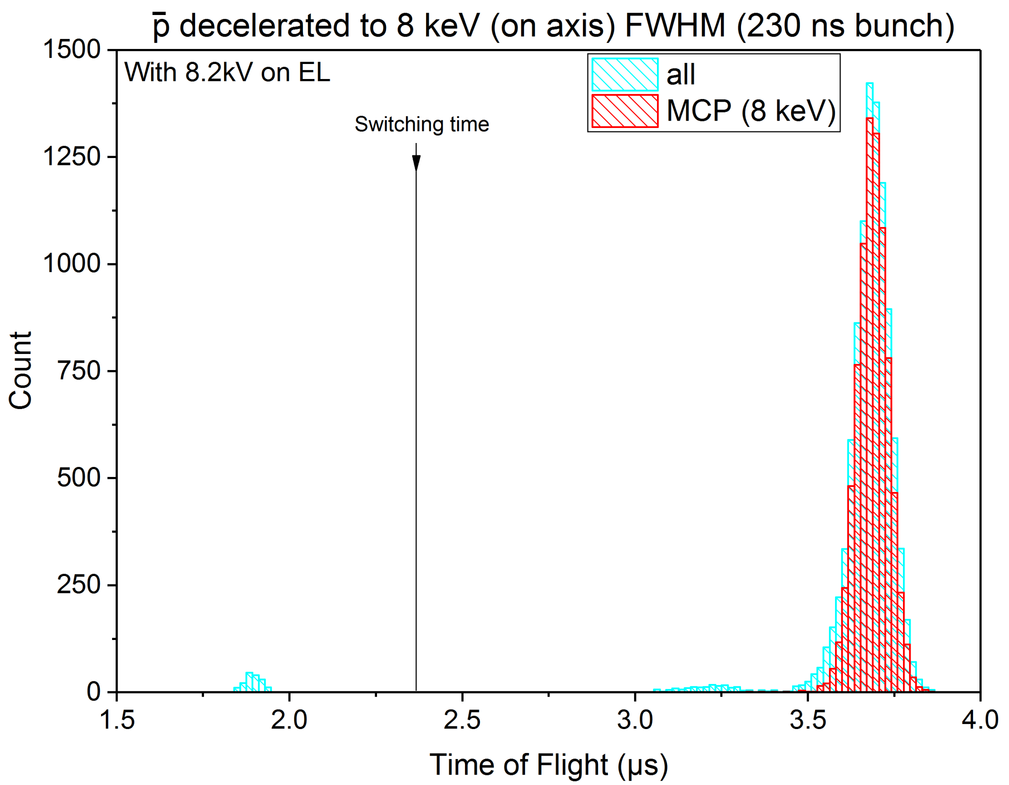
First beam July 20 2018



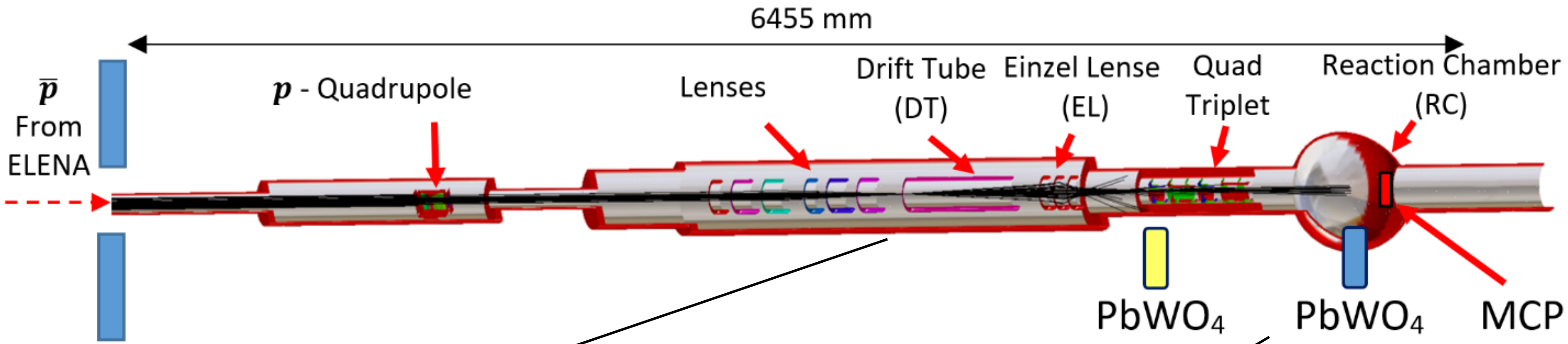
Beam spot size 3x3 mm @ target 95% efficiency

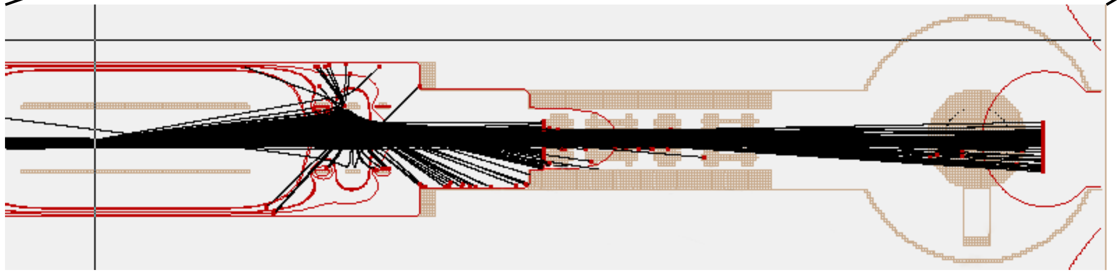


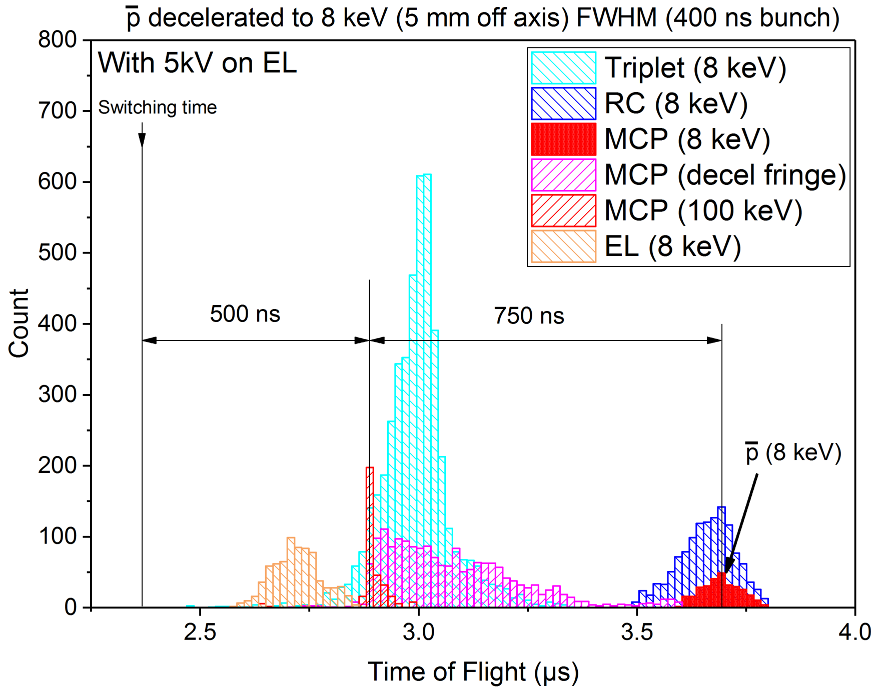
50 ns late switching



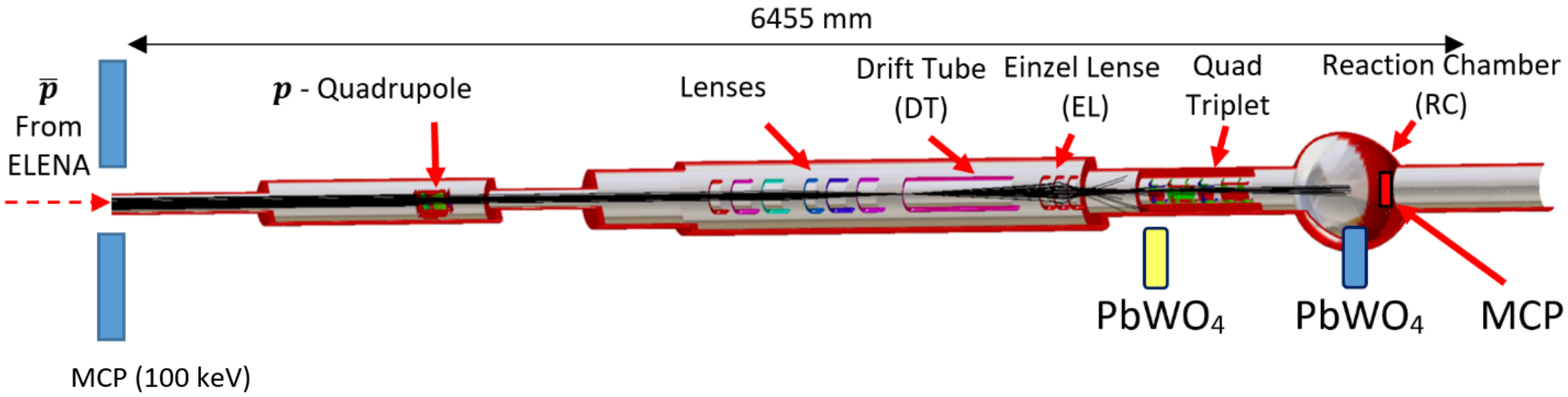
Correct switching
What GBAR is capable of.



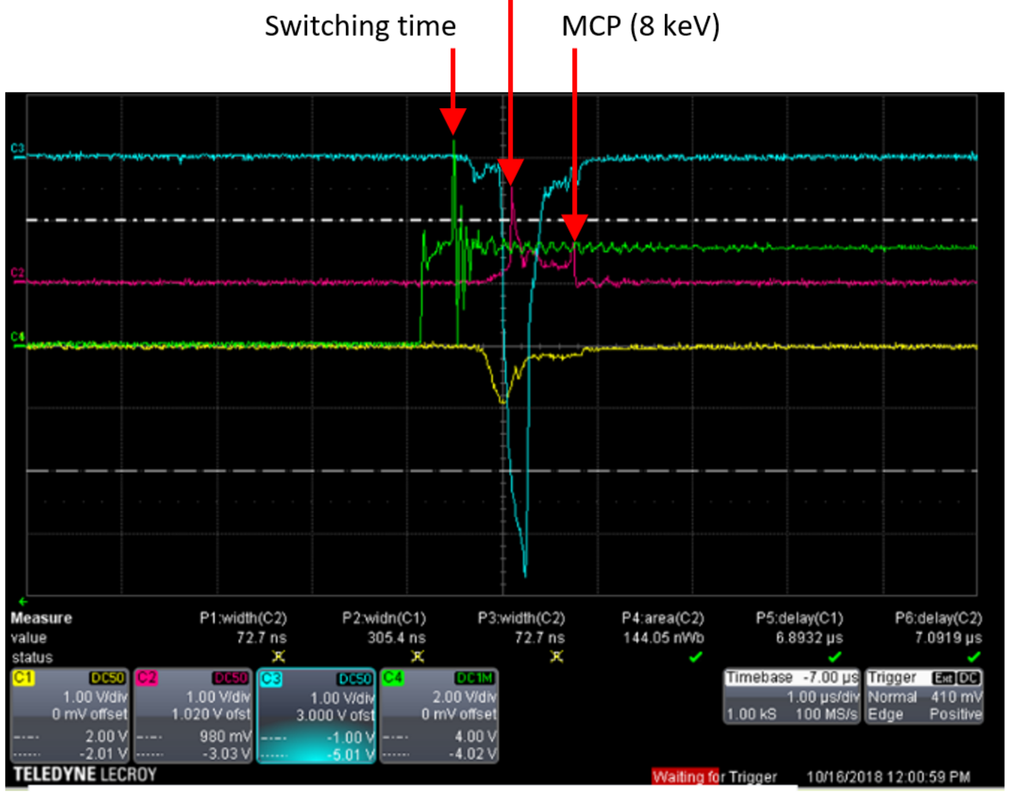




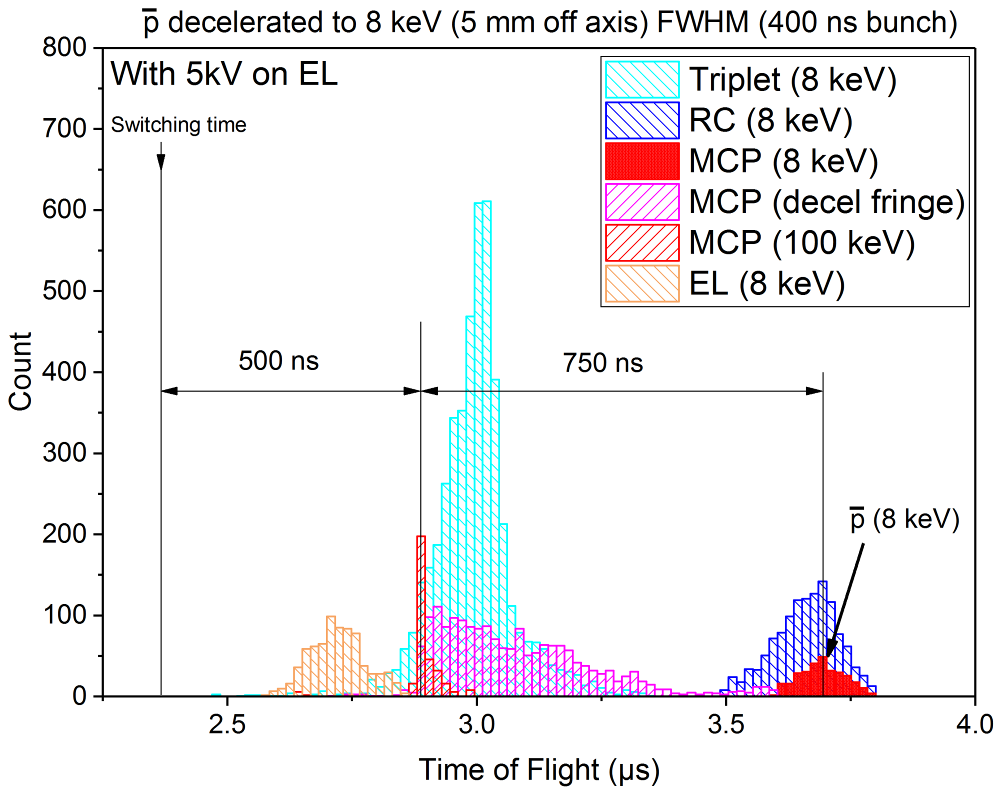
Beam Size = FWHM (5 mm)
Transversal Energy Spread = 1 keV
Beam off centered by 5 mm



6455 mm
$\bar{p}$
From
ELENA
p - Quadrupole
Lenses
Drift Tube
(DT)
Einzel Lense
(EL)
Quad
Triplet
Reaction Chamber
(RC)
$PbWO_4$
$PbWO_4$
MCP
MCP (100 keV)



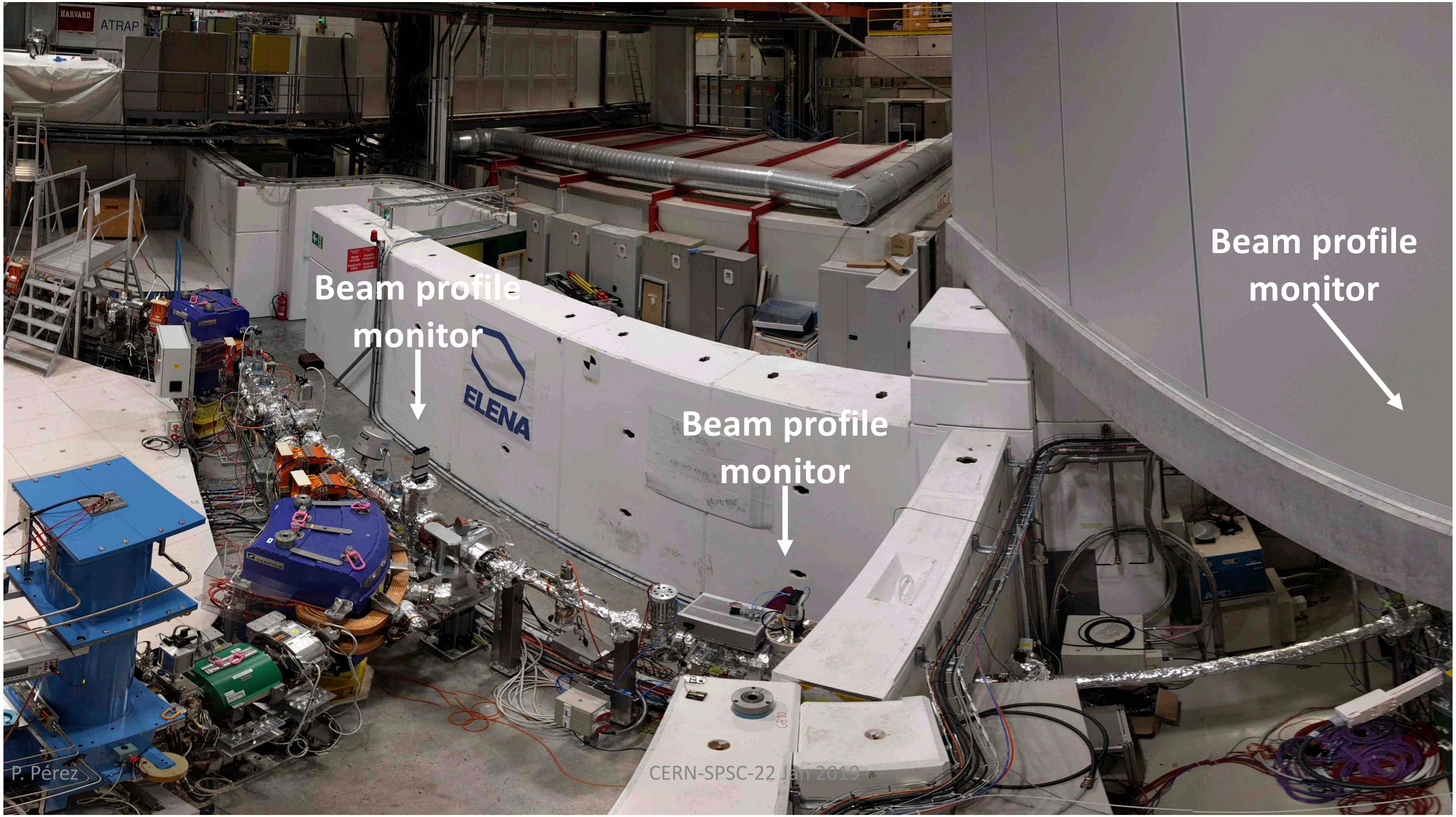
Switching time
MCP (8 keV)
Measure
value
status
P1:width(C2)
72.7 ns
P2:width(C1)
305.4 ns
P3:width(C2)
72.7 ns
P4:area(C2)
144.05 nWb
P5:delay(C1)
6.8932 µs
P6:delay(C2)
7.0919 µs
Timebase -7.00 µs
1.00 µs/div
1.00 kS 100 MS/s
Trigger
Normal 410 mV
Edge Positive
TELEDYNE LECROY
Waiting for Trigger
10/16/2018 12:00:59 PM



p̄ decelerated to 8 keV (5 mm off axis) FWHM (400 ns bunch)
With 5kV on EL
Switching time
500 ns
750 ns
Triplet (8 keV)
RC (8 keV)
MCP (8 keV)
MCP (decel fringe)
MCP (100 keV)
EL (8 keV)
p̄ (8 keV)
Count
Time of Flight (µs)
0
100
200
300
400
500
600
700
800
2.5
3.0
3.5
4.0

Beam monitors are essential to steer the beam

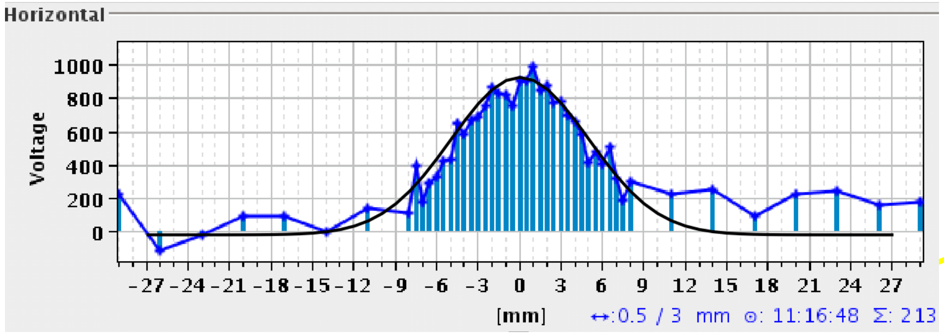
The H^- source would have been a valuable tool to this aim (5 s instead of 110 s repetition rate)



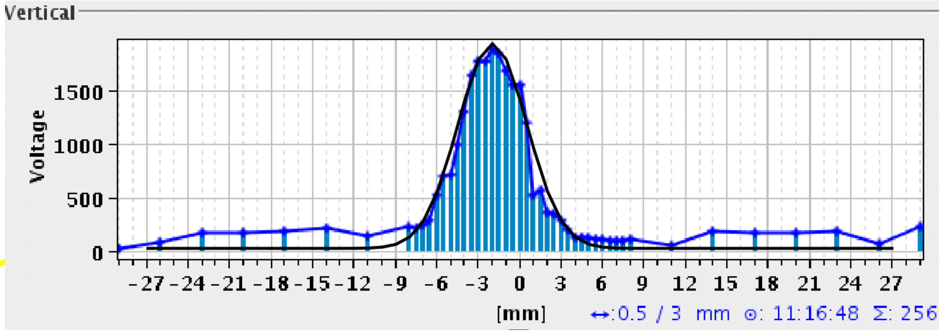
Recent Results from Commissioning

Observation of antiproton beams at extraction with h=1

- Profiles in the GBAR line



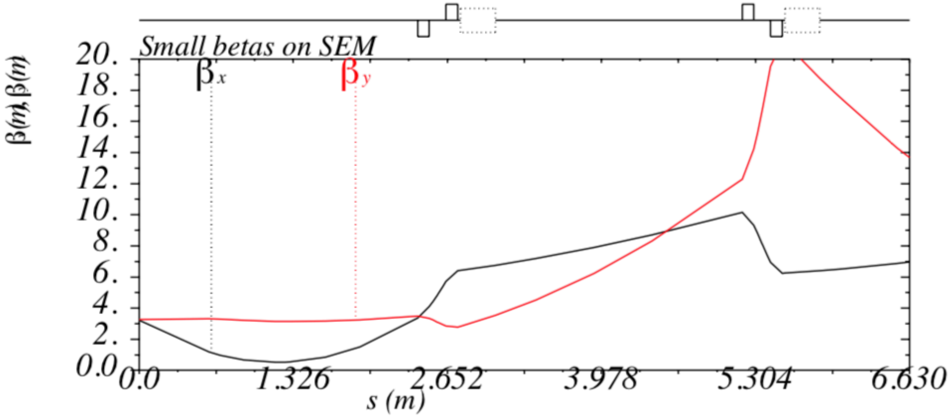
Gaussian fit by hand with $\sigma_H =$ 5 mm



Gaussian fit by hand with $\sigma_V =$ 2.5 mm

- Acquisitions with second monitor LNE.BSGWA.5020 in GBAR line

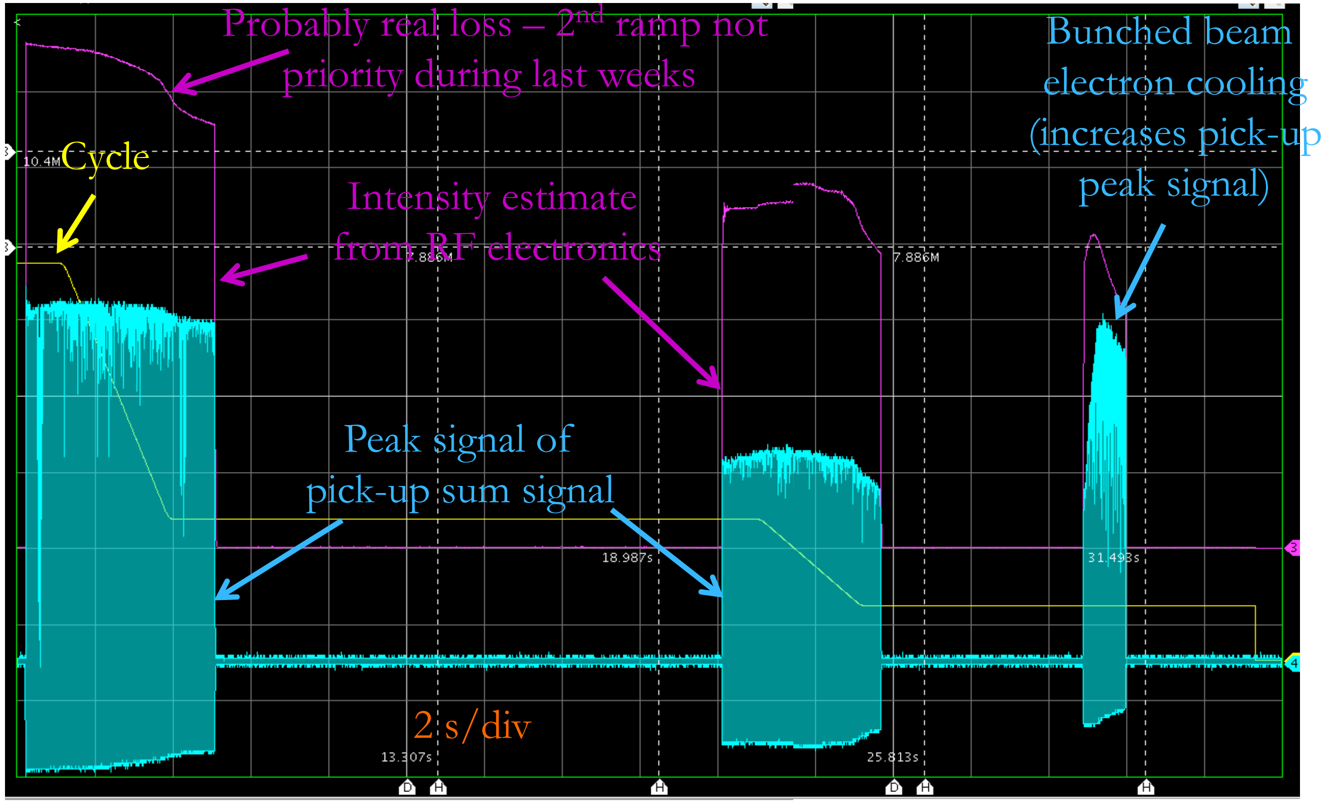
- Beam sizes with voltages of first two quads of line set to zero
  - β_H = 6 m gives rms emittance ε_H = 4.1 um (slightly overestimated without taking dispersion into account)
  - β_V = 4 m gives rms emittance ε_V = 1.5 um



Recent Results from Commissioning

Observation from the very last day with beam in 2018

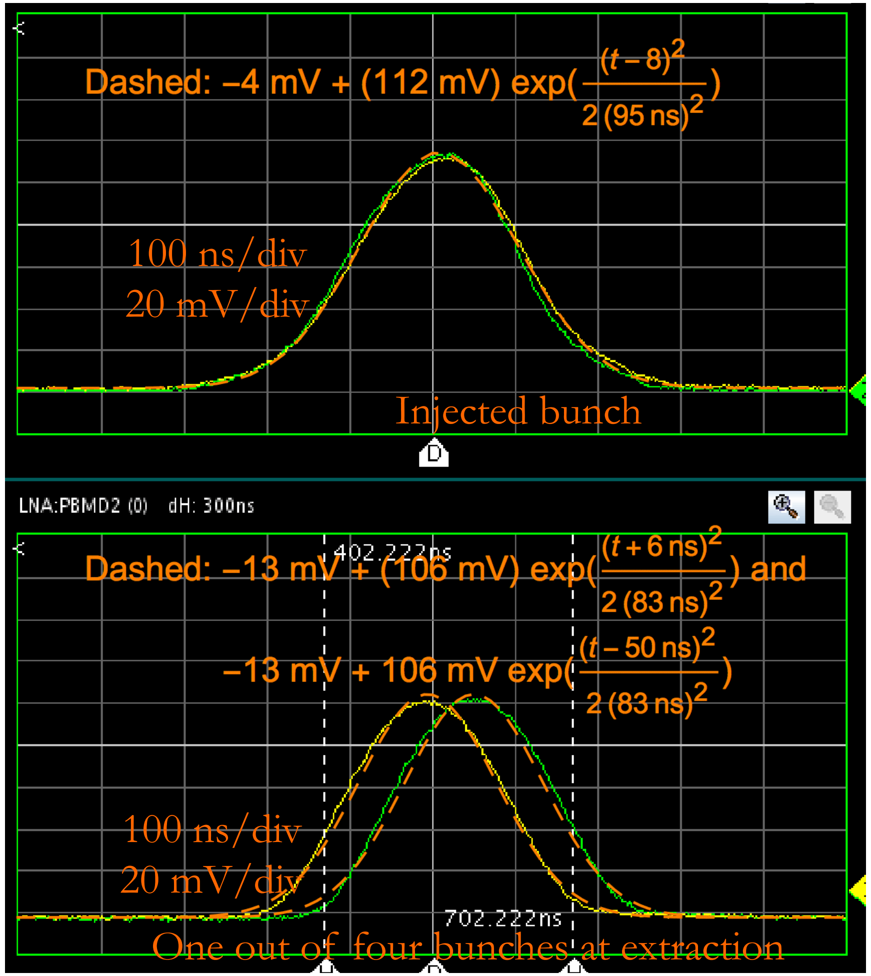
- Higher harmonics h=2 and h=4 finally possible after upgrade of RF control
  - Main motivation losses after re-bunching with >1 10^7 antiprotons with short bunches
  - Of interest for observation along 2nd ramp (increased efficiency not expected)



  - Whole cycle with beam combining two acquisitions (2nd with slightly higher intensity)
    - Improved efficiency (close to 50%)

Recent Results from Commissioning

Observation from the very last day with beam in 2018

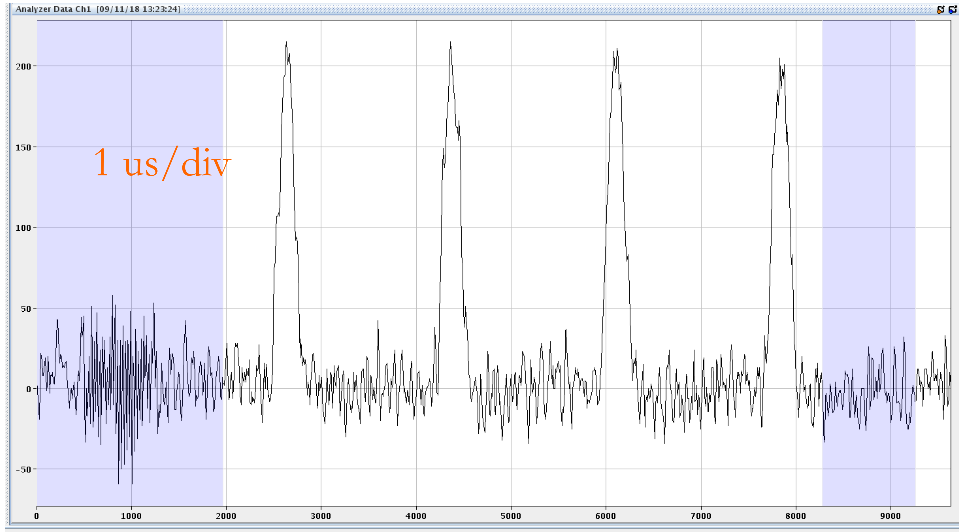


Position pick-up sum signals

- From sum signal of electro-static pick-ups (10 % uncertainty of calibration)
  - 3.7 10^7 antiprotons injected (consistent with data from AD running very well
  - Four bunches, each with 0.43 10^7 antiprotons at extraction

  => Efficiency about 46 %

- Total intensity estimated by “beam current transformer” in line about 1 10^7 antiprotons
  - Real loss or acquisition problem?

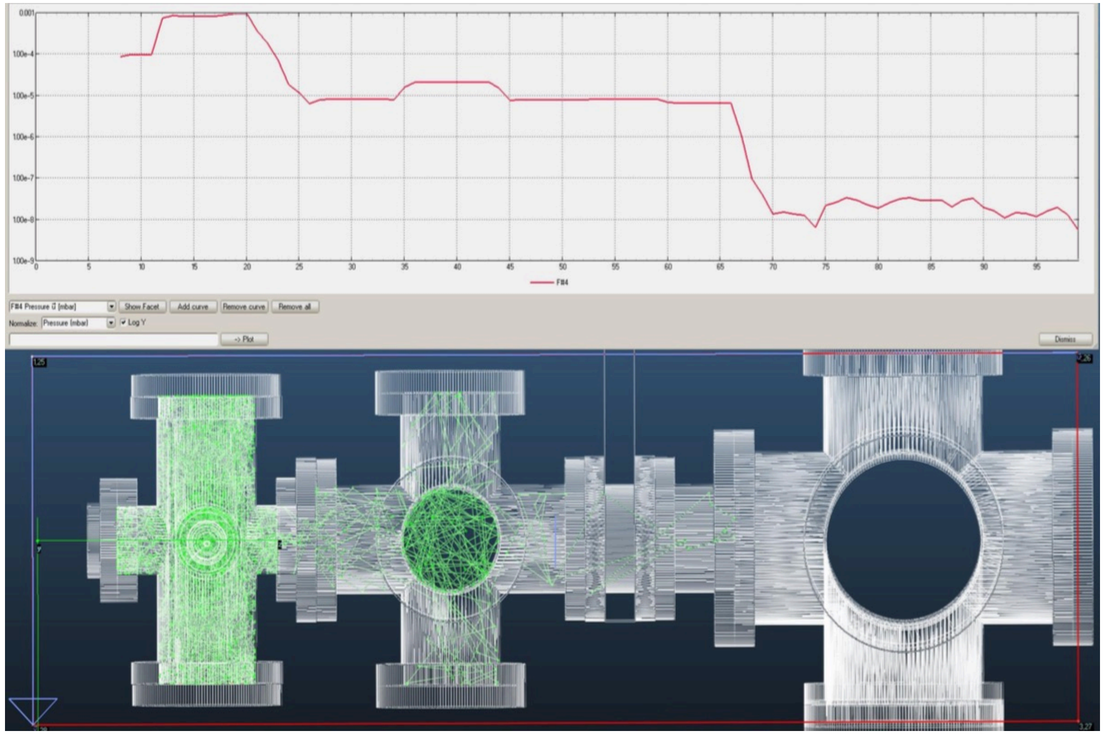


Proton beam

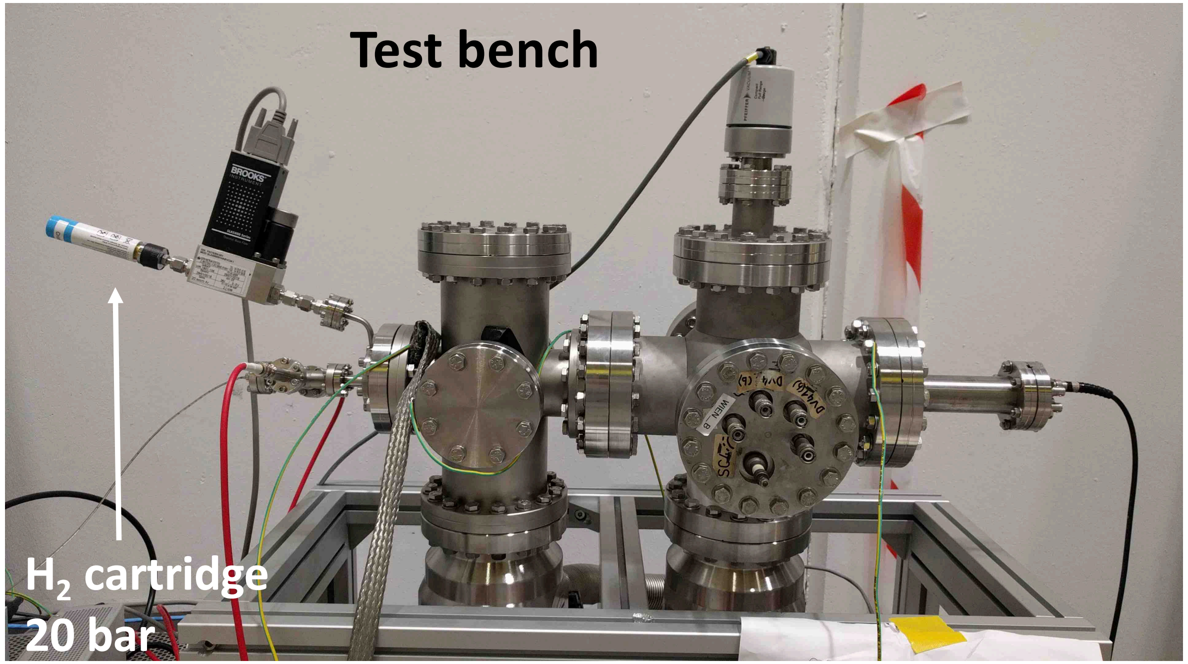
Will be used during LS2 to study

$p + P_s \rightarrow H + e^+$ and $H + P_s \rightarrow H^- + e^+$

ECR source



pumping & restrictions → 10^{-8} mbar

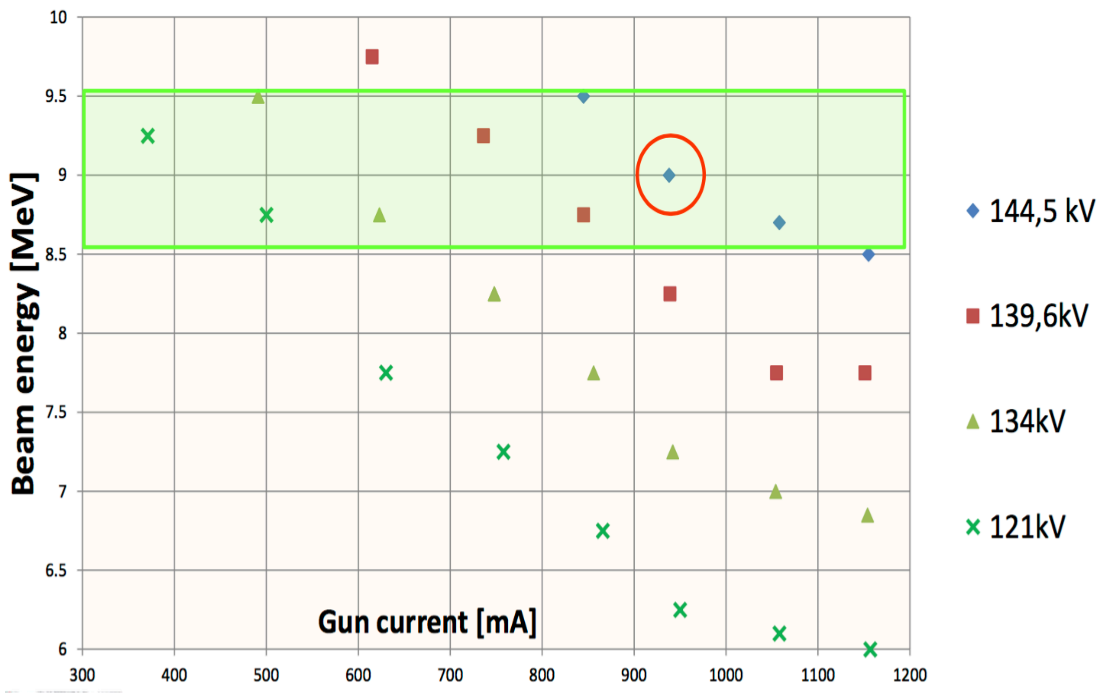


30 μA protons separated from H_2^+/H_3^+/neutrals by Wien filter

electron linac

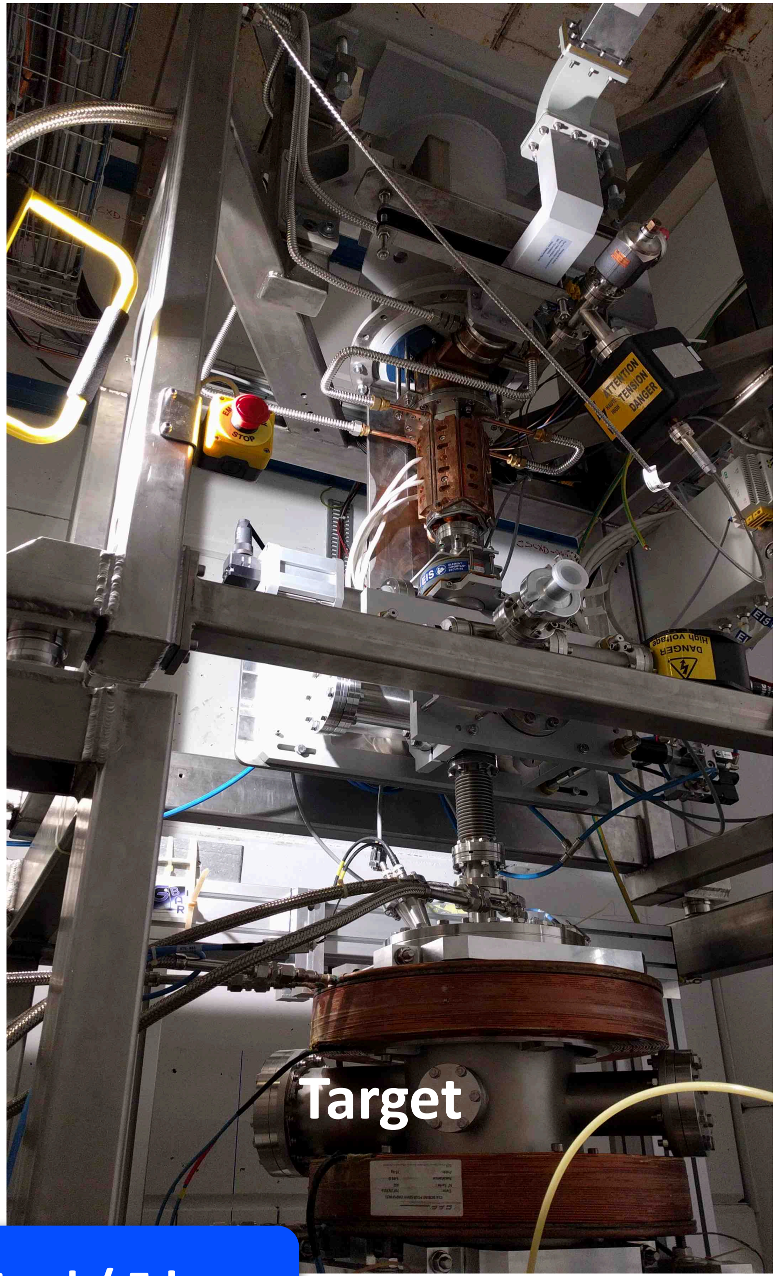
activation above 10 MeV !

330 mA peak



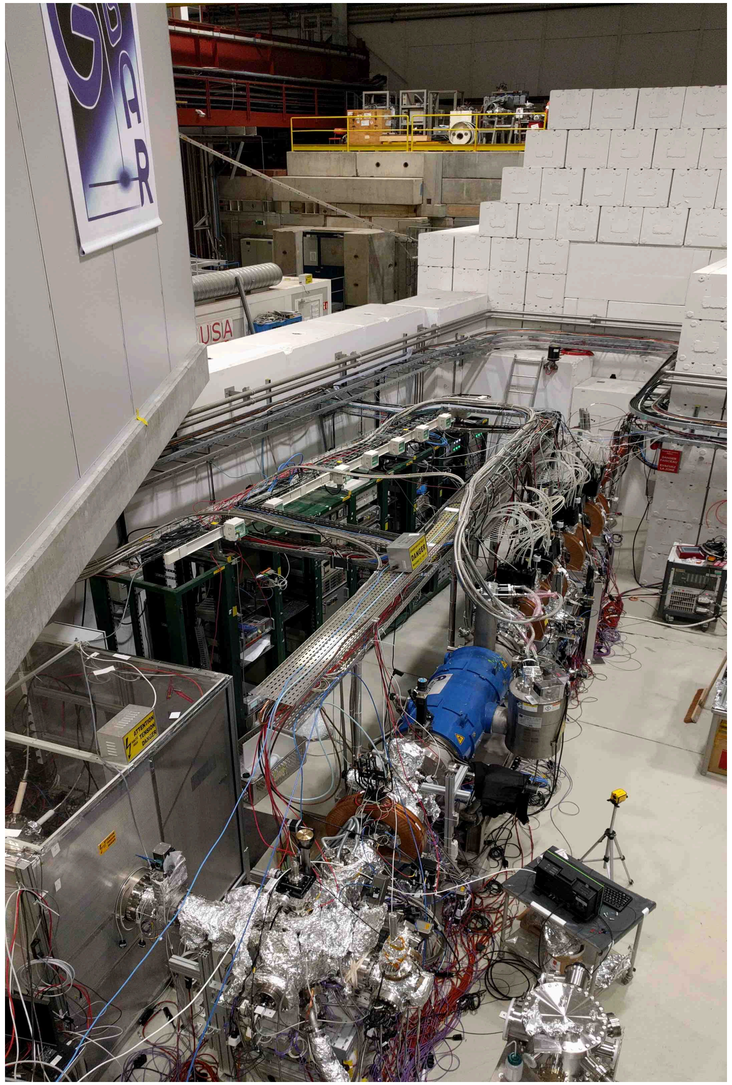
operation point set using a magnetic spectrometer

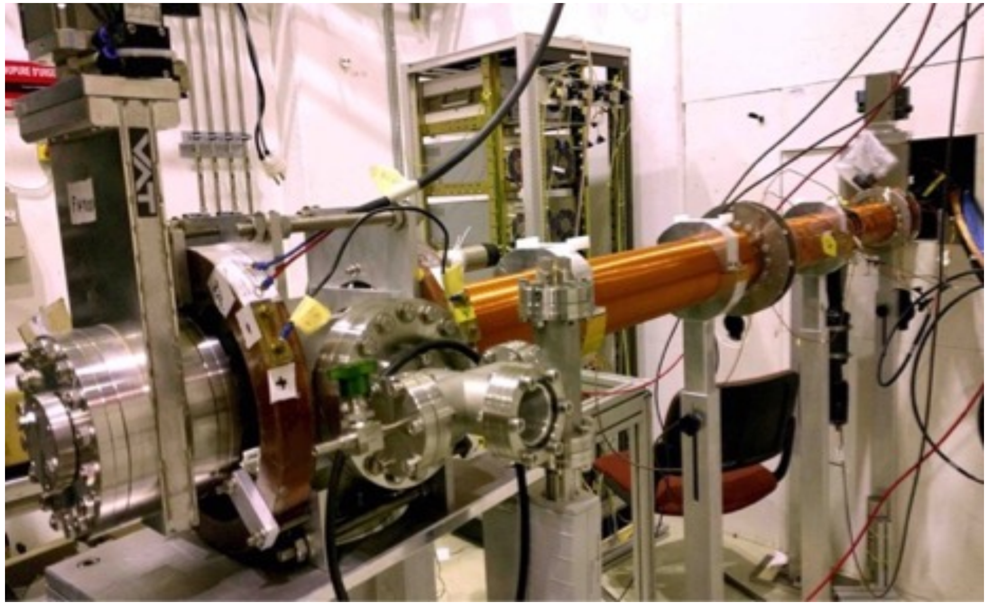
- Tungsten target → 1 MeV positrons
- Tungsten mesh moderator → 3 eV positrons



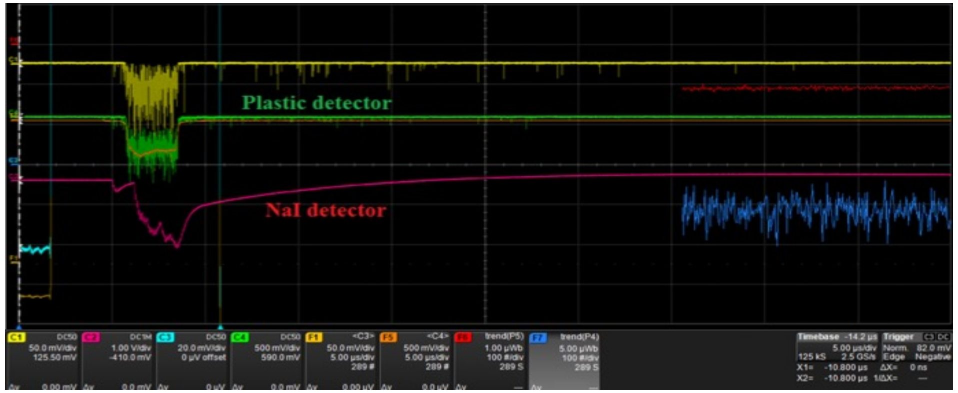
1 Mrad / 5 h

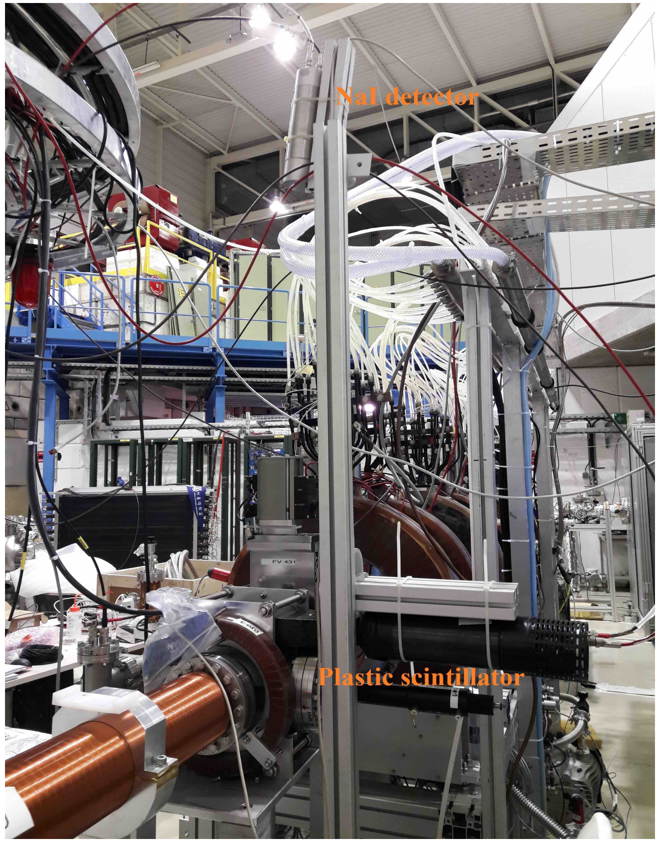
Measuring positron flux





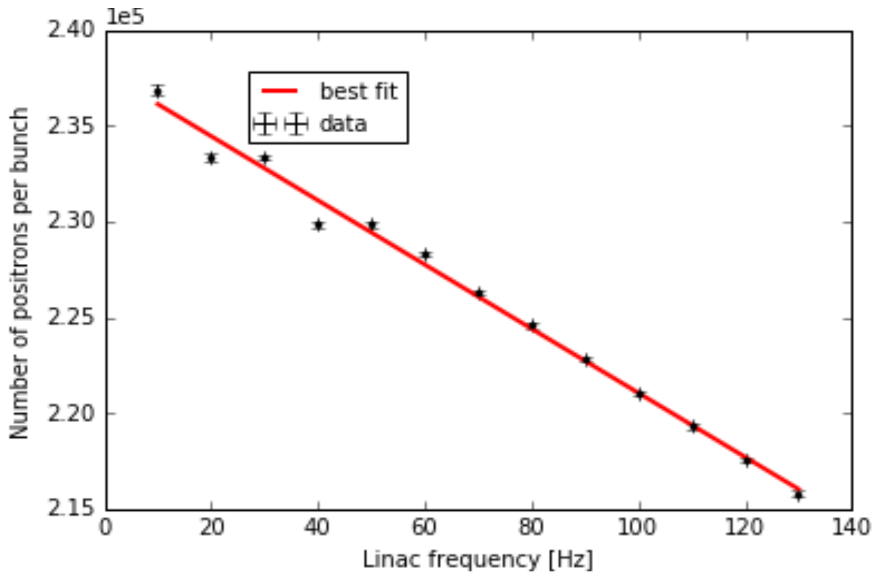
e^+ beam line exiting the bunker

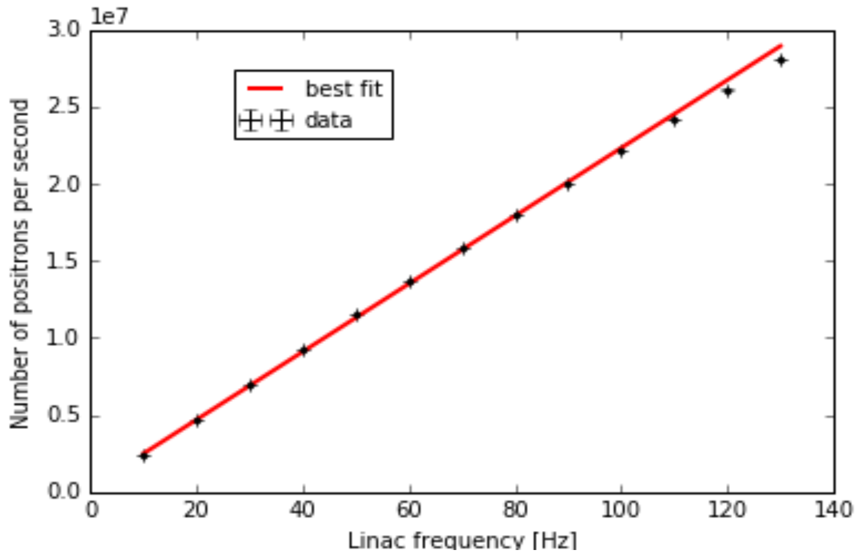




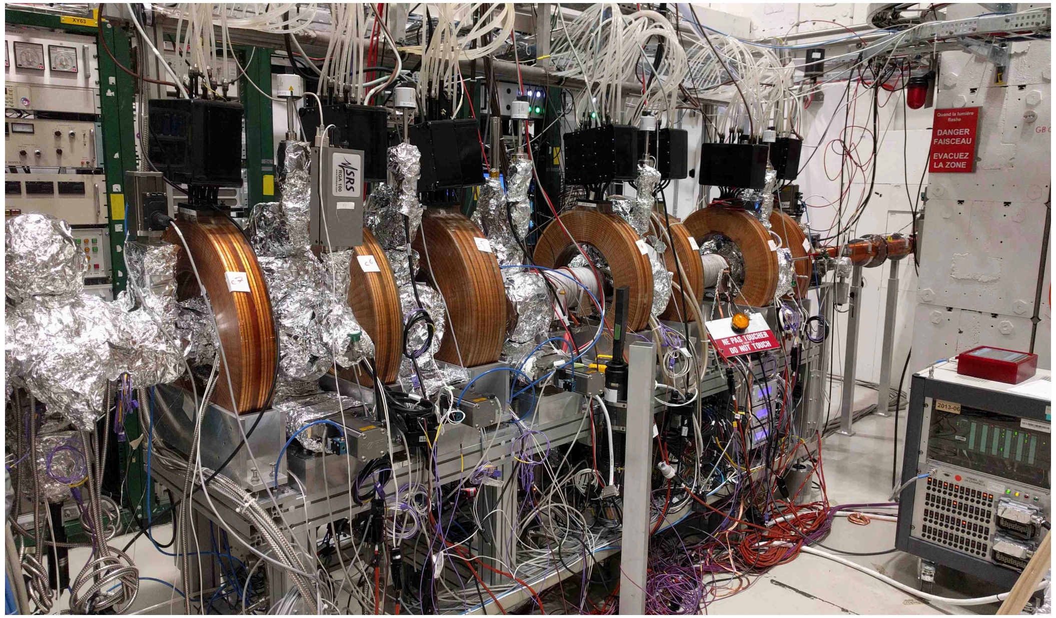
Positron flux

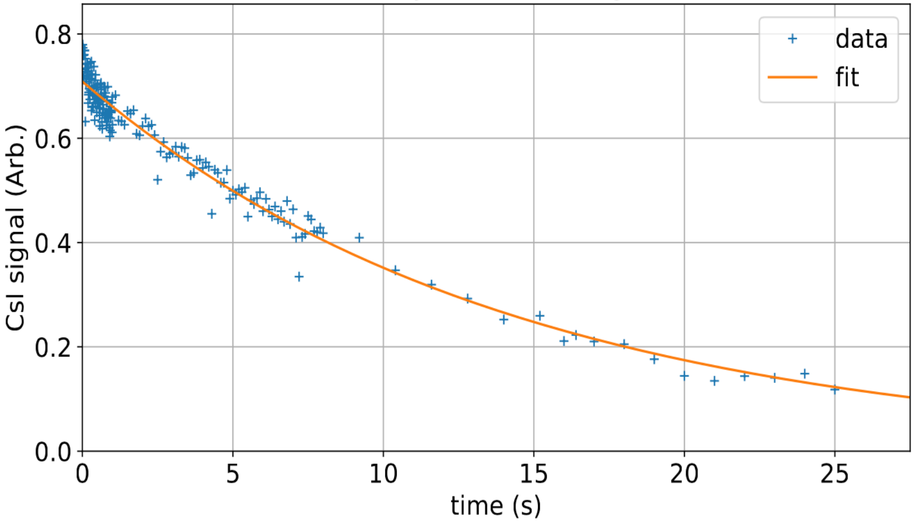
- Ran periodically during 2018
- 3×10^5 e^+ / pulse initially
- 10% loss per bunch from 10 to 130 Hz
- At end of year 2×10^7 e^+ / s (100 Hz)
- Final commissioning in 2019
- Extrapolation to 300 Hz → 6×10^7 e^+ / s
- Will improve moderation (x 2 ?)
- Goal 3×10^8 e^+ / s

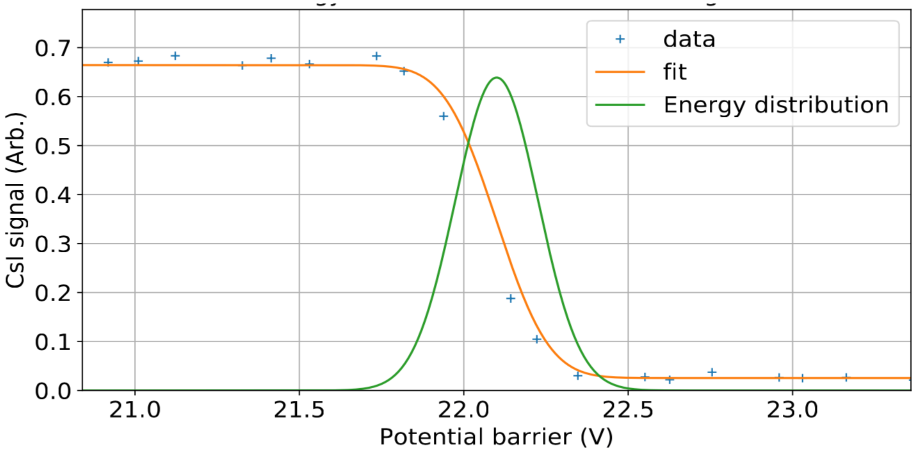




Buffer Gas trap

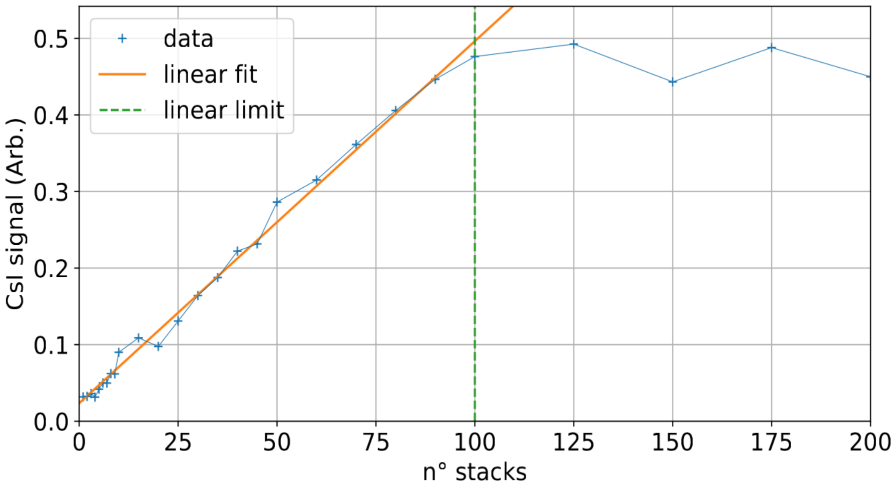




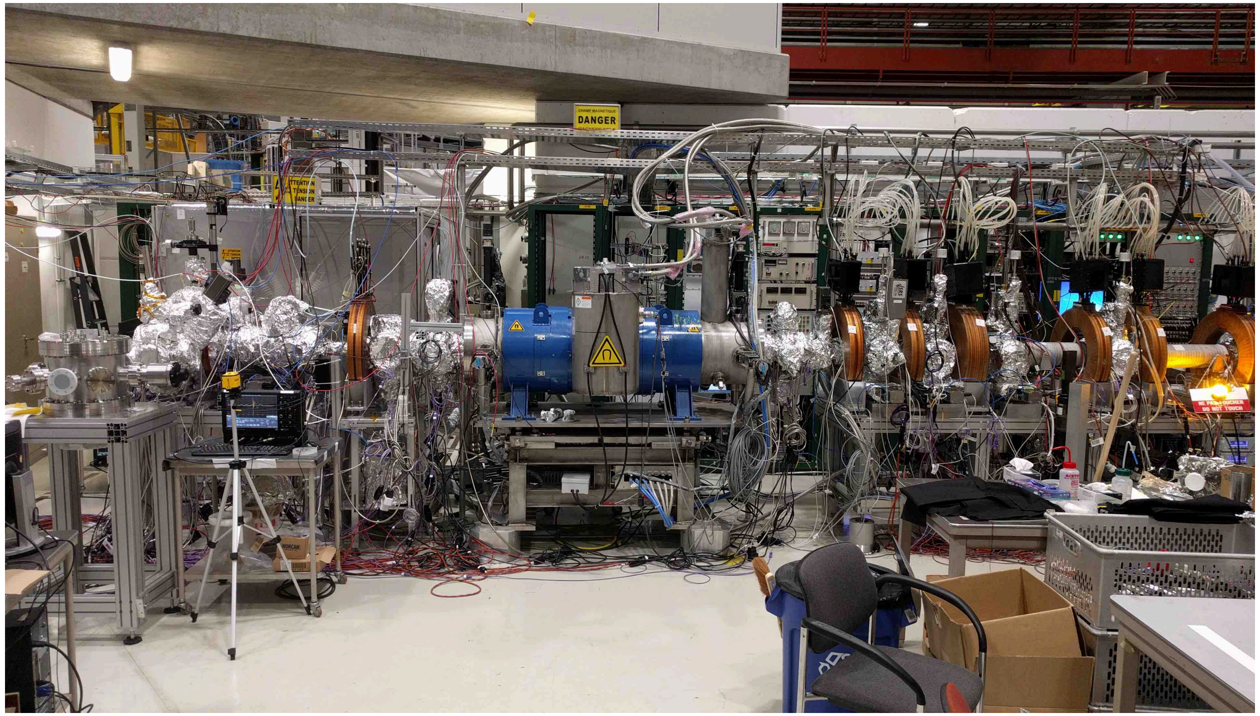


N_2 with CO_2 cooling gas
present trapping efficiency 5 ± 0.5% (goal 20-25%)
lifetime 0.6 s (stage 1) and 14s (stage 3)
ΔE = 130 meV (stdev)
80 bunches from linac stacked and transferred

High field positron trap



saturation above 100 stacks from buffer gas trap with present potential well shape



With linac at 100 Hz → 1 x 10^8 e^+ in 100 s

<u>Goal:</u>

accumulate 3 x 10^{10} e^+ in 110 s

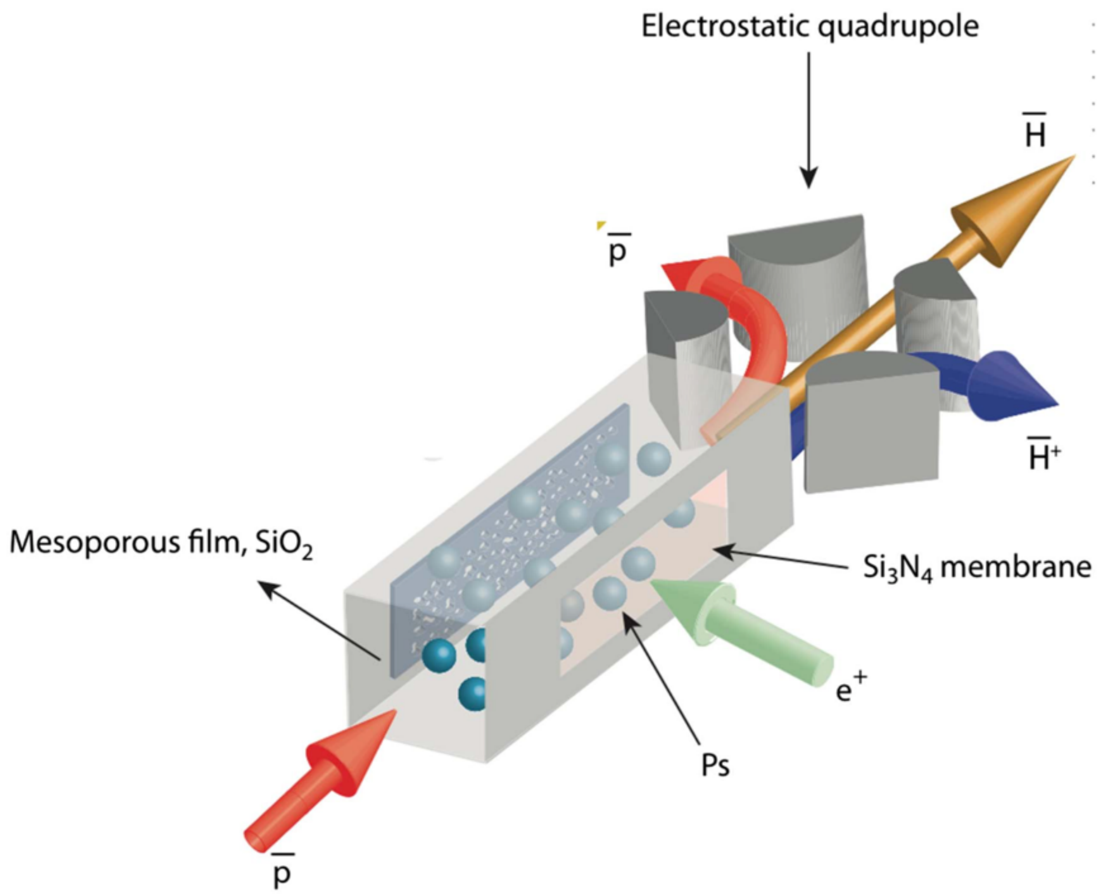
e^+ lifetime in trap > 20 min

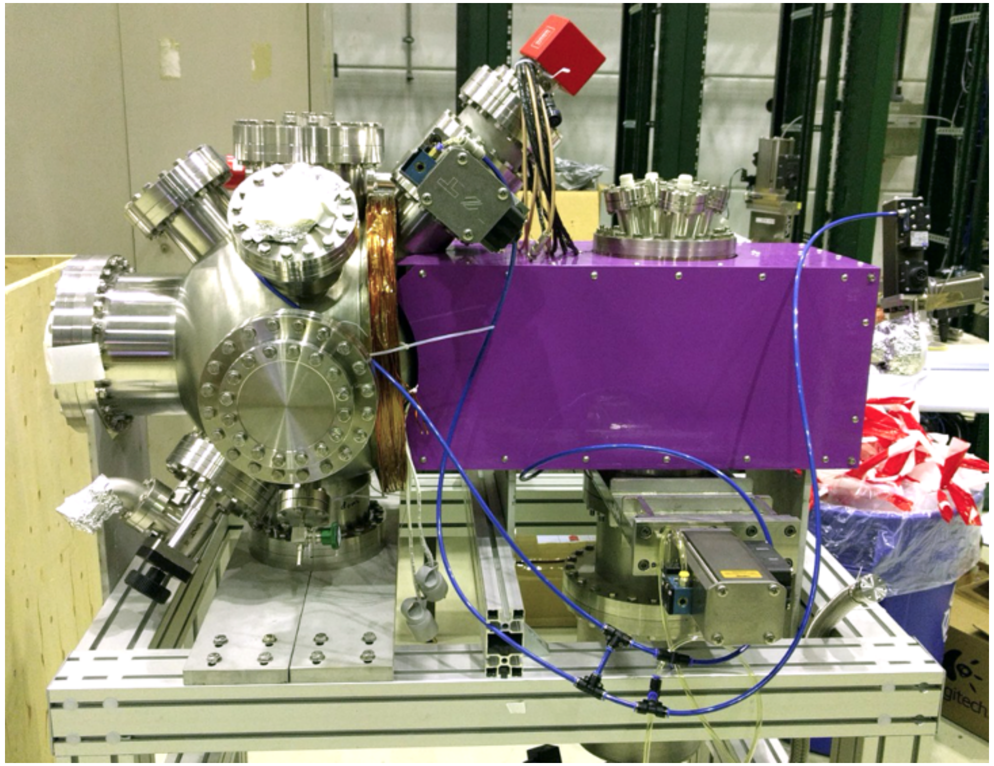
plasma diameter 80 μm using rotating wall (3 MHz / 1 V)

Reaction chamber (Anti-ion production)

$$p + Ps \rightarrow H + e^{+}$$
$$H + Ps \rightarrow H^{-} + e^{+}$$

$$\bar{p} + Ps \rightarrow \bar{H} + e^{-}$$
$$\bar{H} + Ps \rightarrow \bar{H}^{+} + e^{-}$$

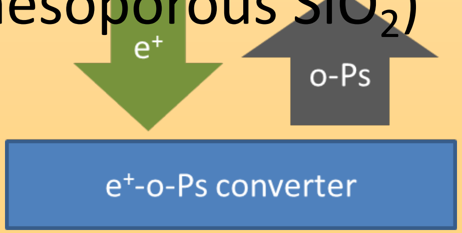


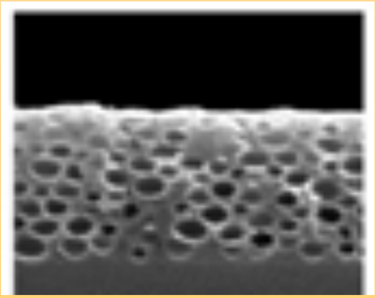


reaction chamber

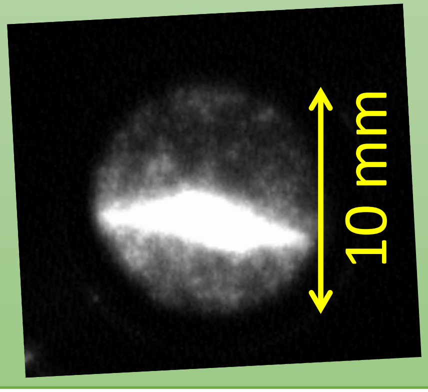
First ortho-positronium signal at GBAR@CERN

Positron-positronium converter (mesoporous SiO_2)

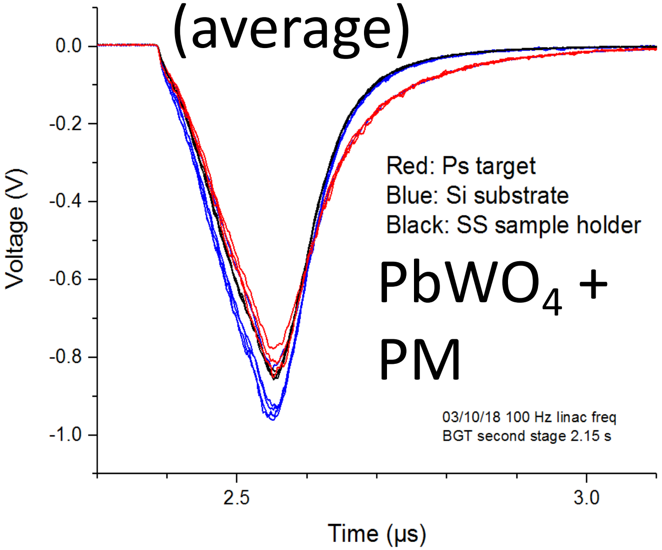


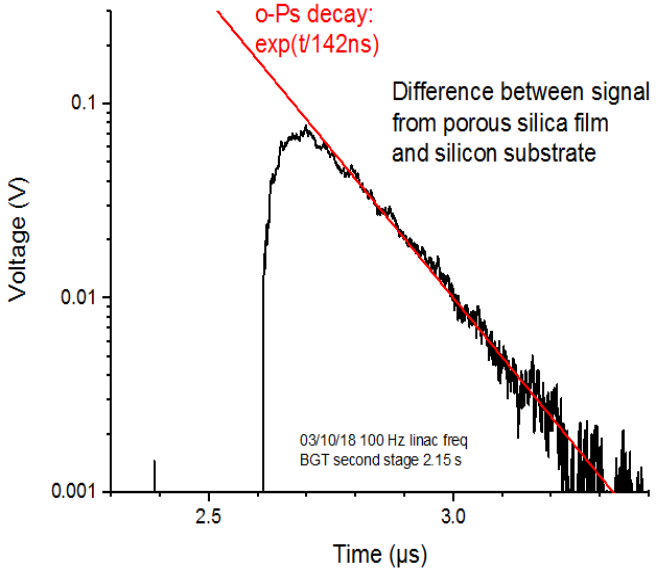


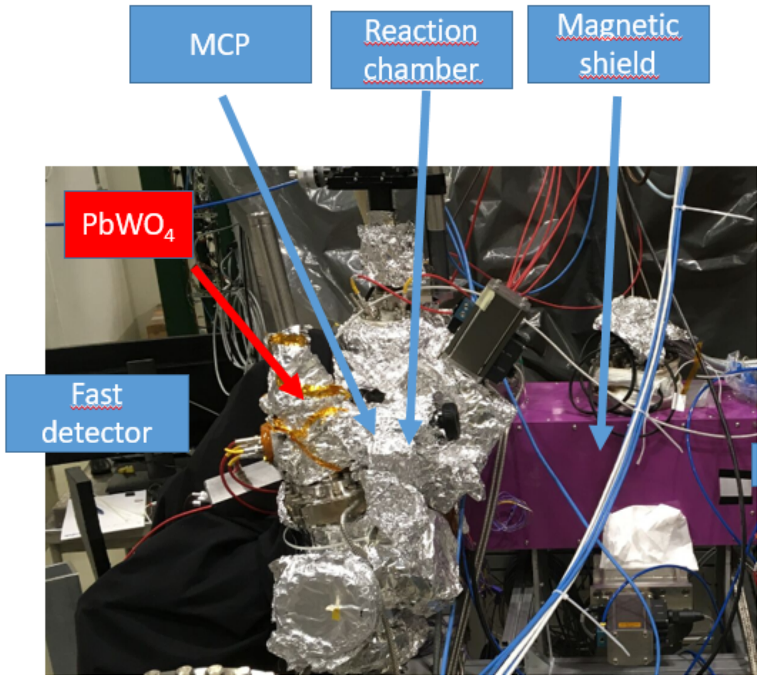
Positron beam spot on the



Raw signal (average)

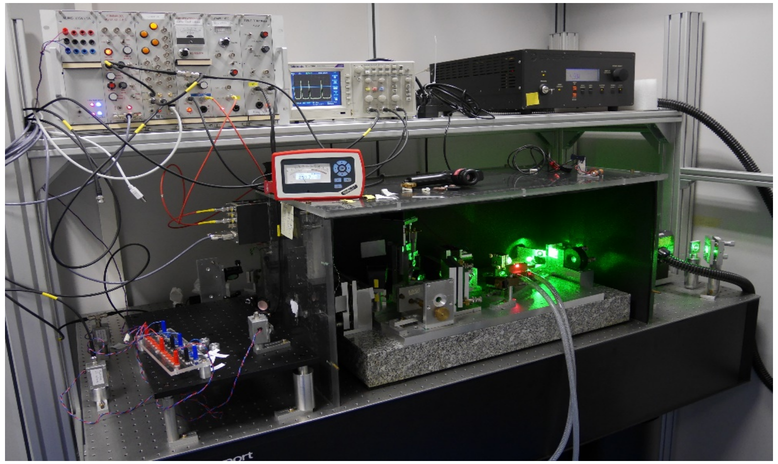




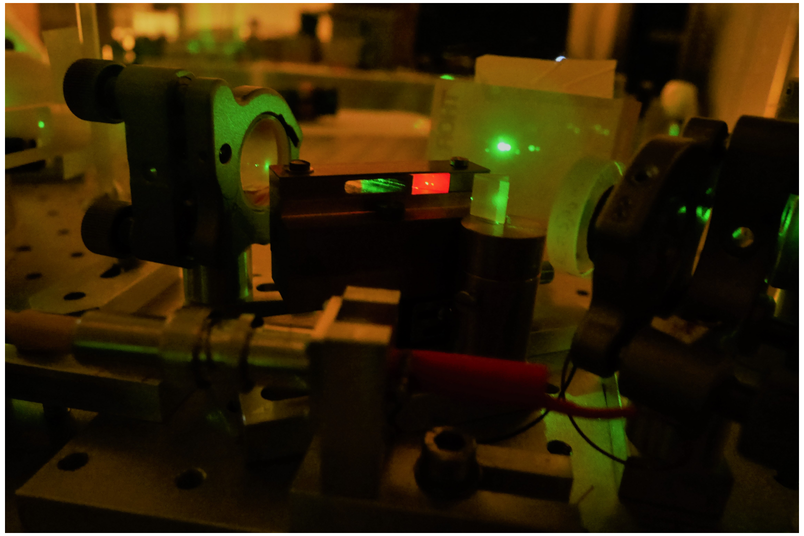


Differential signal showing oPs lifetime

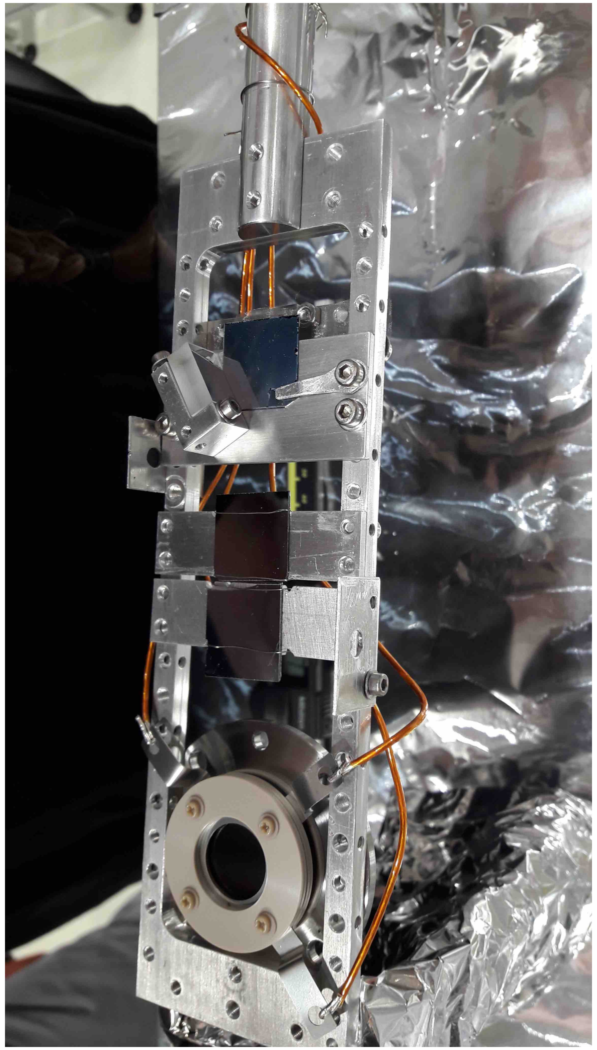
Ps excitation laser



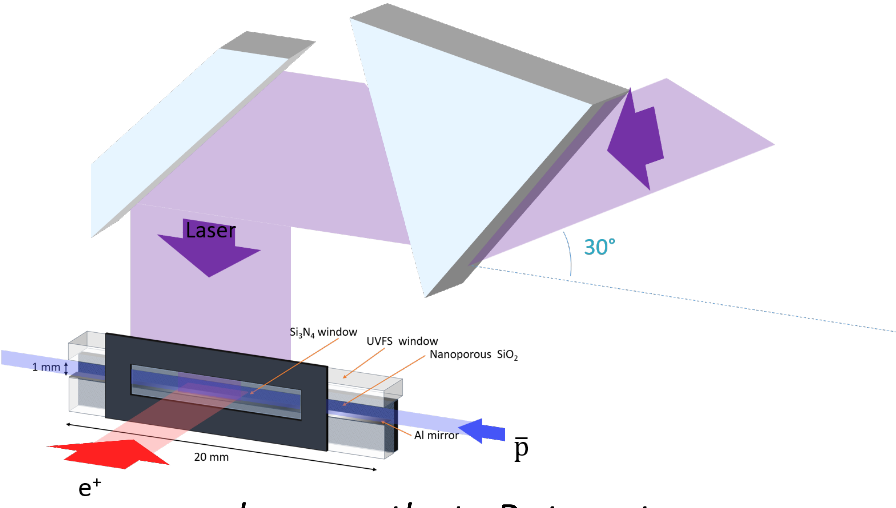
CW TiSa seeder, 260 mW at 820 nm



TiSa oscillator, >5 mJ at 820 nm



sample holder, MCP, mirror



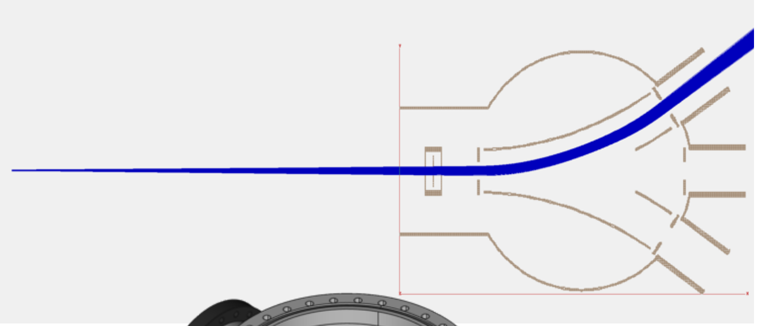
beam paths to Ps target

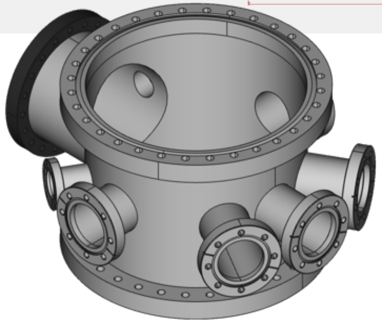
CW TiSa seeder and oscillator cavity
5 mJ @ 820 nm
after ampli 26 mJ
6 mJ @ 410 nm

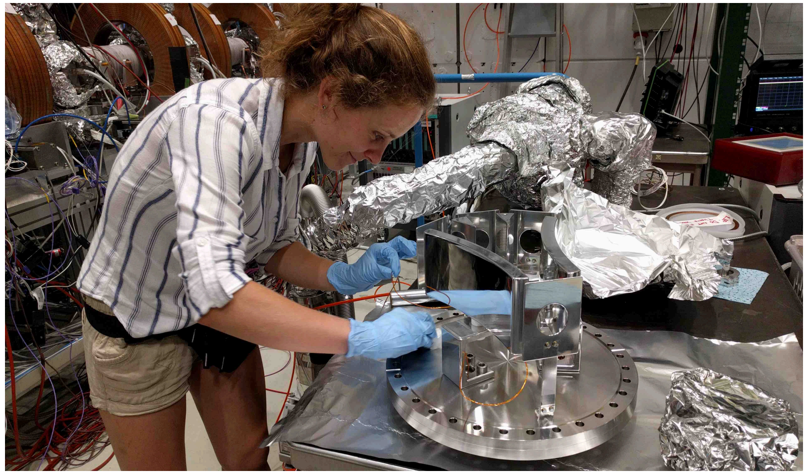
<u>LS2</u>:

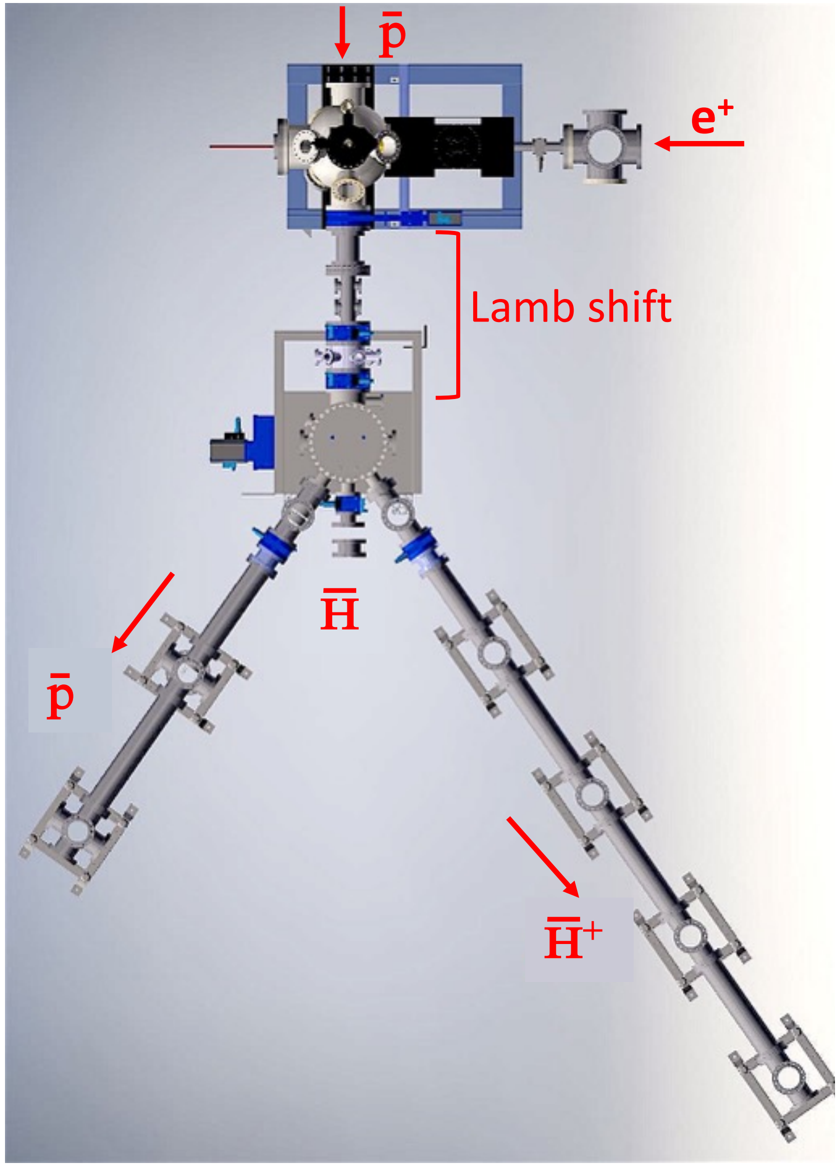
- use 1S-3S to ionise fully Ps and study its properties
- 1S-3D to measure enhancement of cross-section

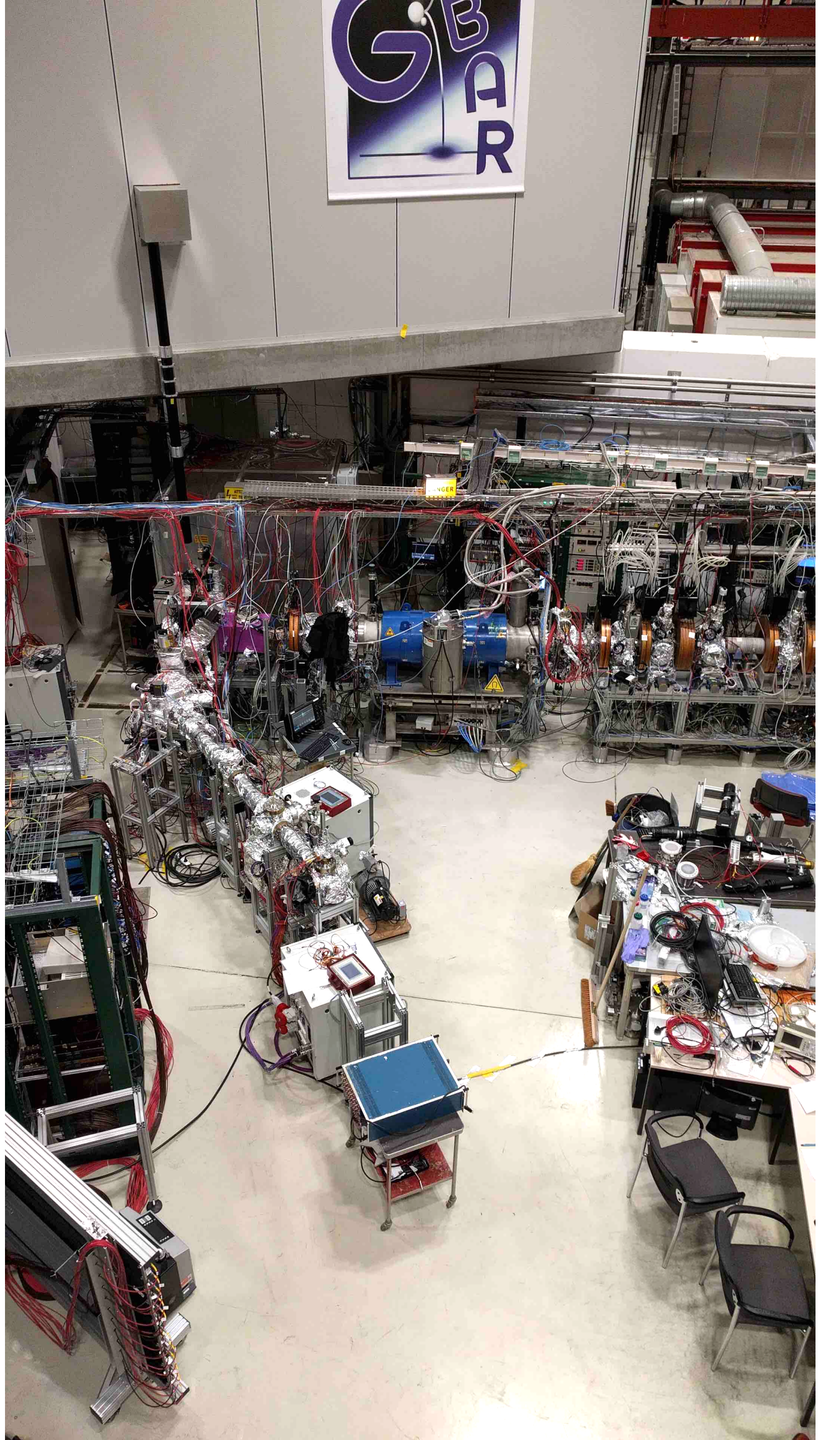
Beam distribution



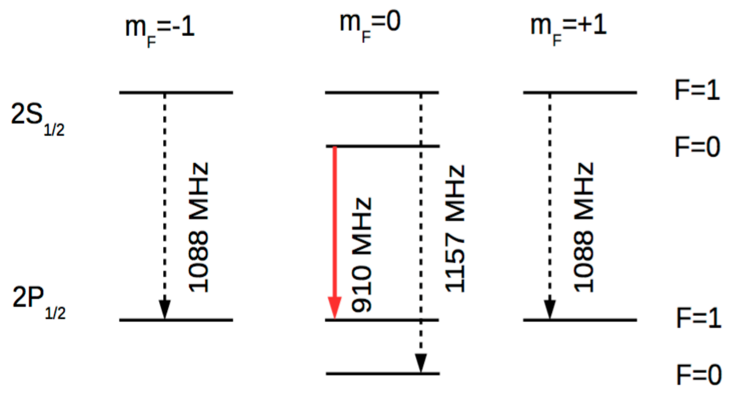


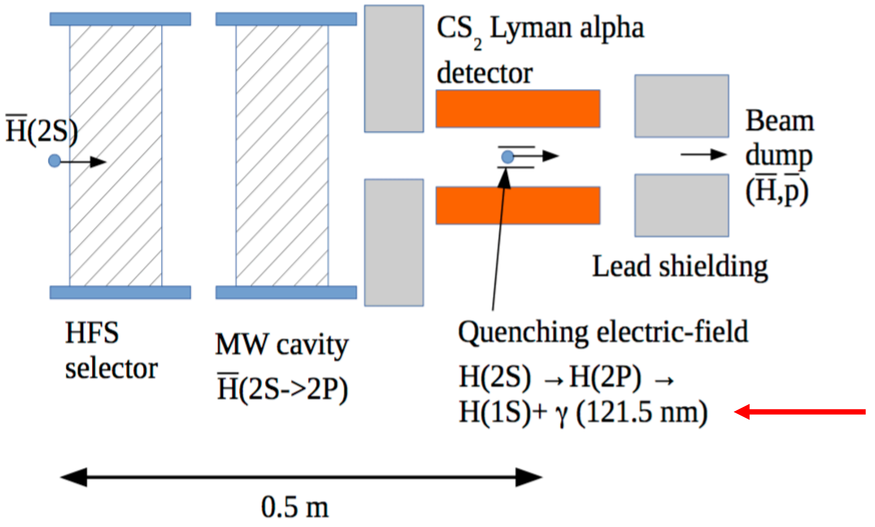






$\bar{H}$ Lamb shift





detect those γs

Measure quenched fraction as a function of microwave frequency

4 months data → 100 ppm on line center

$$\Delta E = \frac{1}{12}\,\alpha^4 m_r^3 r_p^2$$ → 10% on $\bar{\mathrm{p}}$ radius

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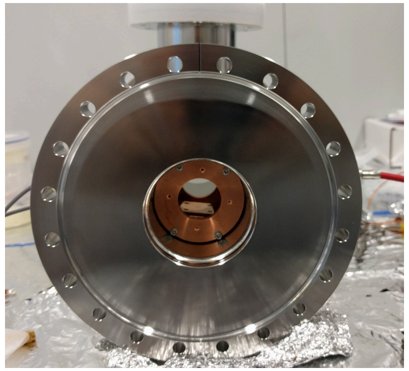
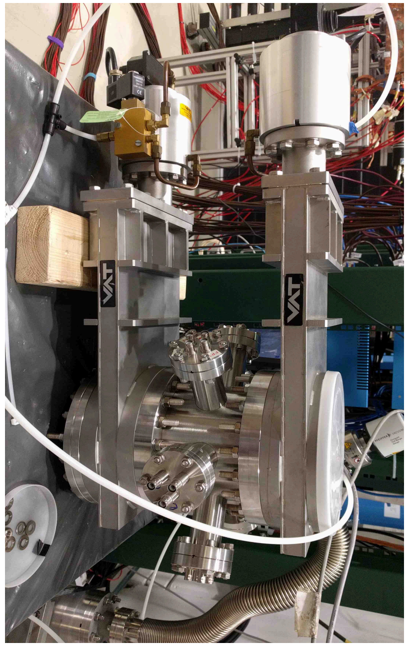
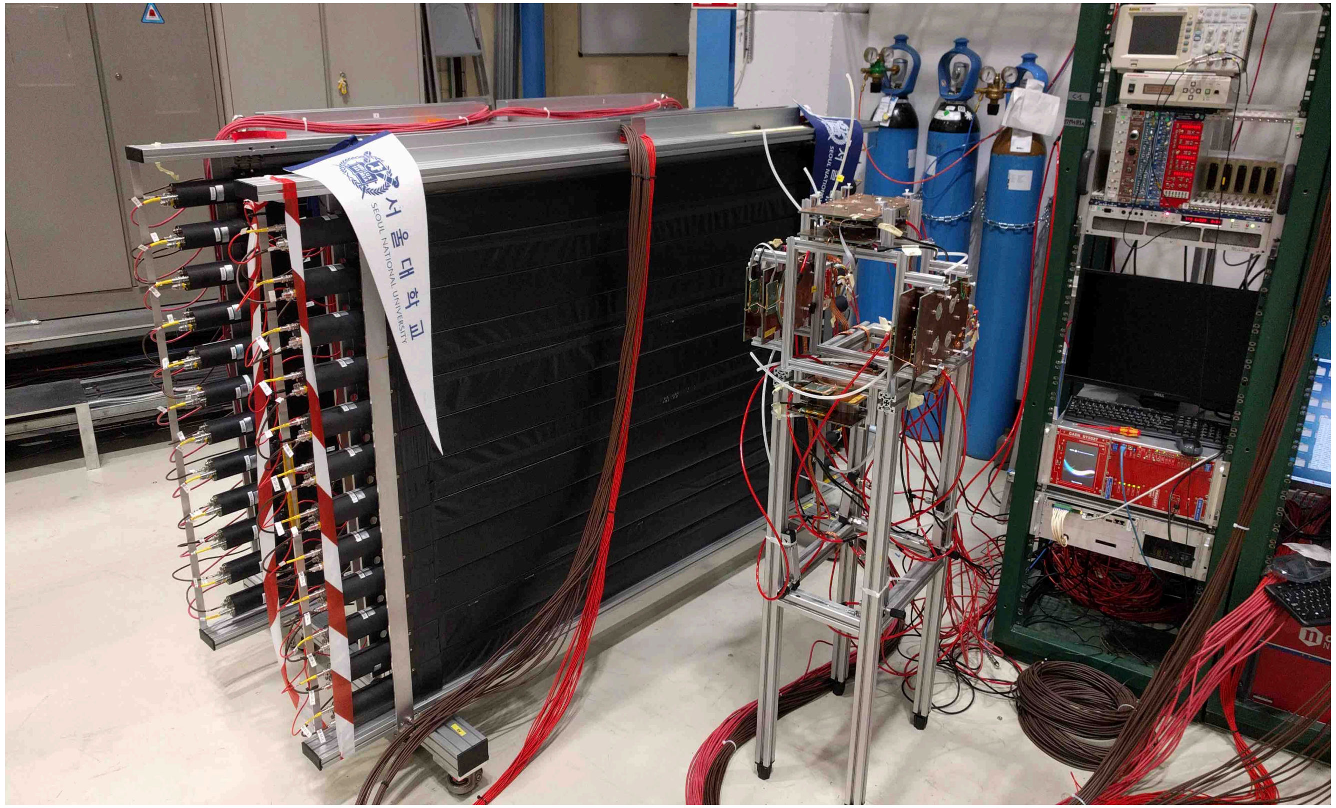


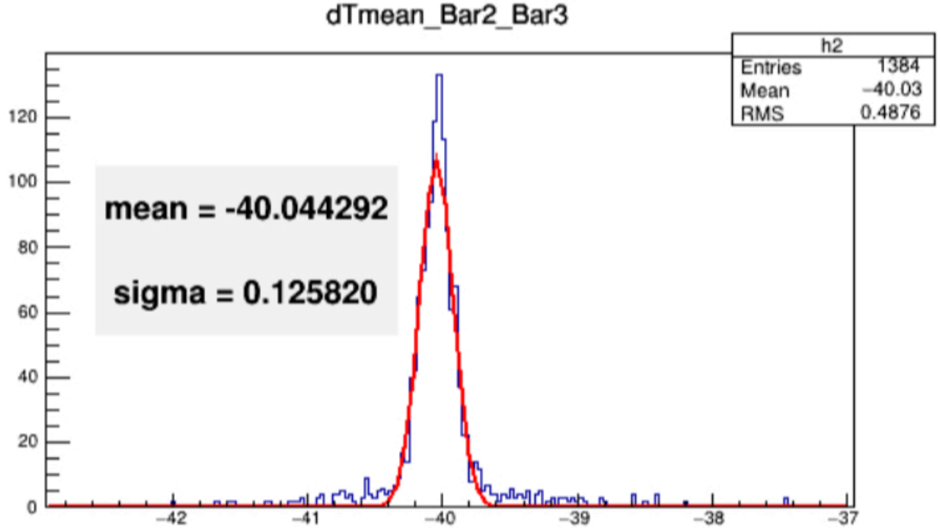
microwave cavity



CsI coated MCPs

TOF & Tracker





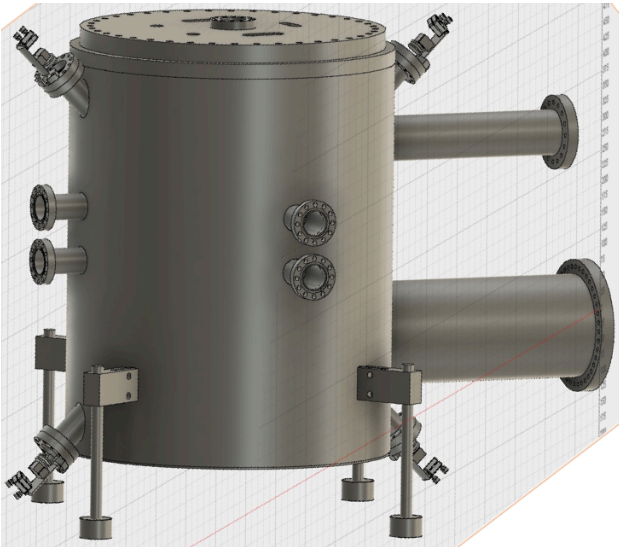
→ 80 ps resolution
allows to distinguish up-down particles

TOF planes
170 cm × 10cm × 5cm

test tracker

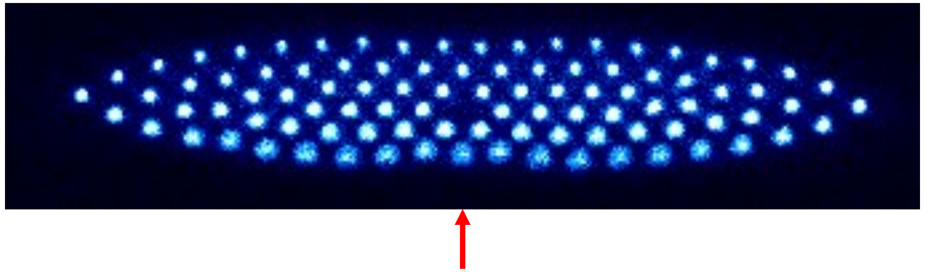
Test micromegas from ETHZ (x5 multiplexing)
19 XY planes 50 cm x 50 cm from Irfu and ETHZ were tested successfully with DREAM electronics

meanwhile in the institutes

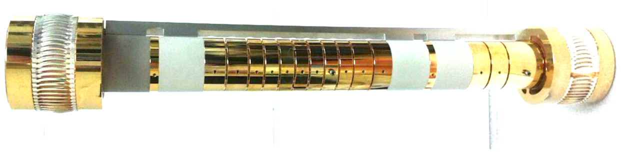


sketch of free fall chamber

- Be^+ Doppler cooling
- H_2^+/ B_e^+ (9/2 mass ratio) and B_e^+ / Sr^+ (87/9) sympathetic cooling achieved
- Ca^+ Doppler
- Ca^+ ground state Raman side band achieved
- Ca^+-Be^+ ion pair ground state Raman side band ongoing



dark ion in capture trap (H_2^+ or H_3^+)

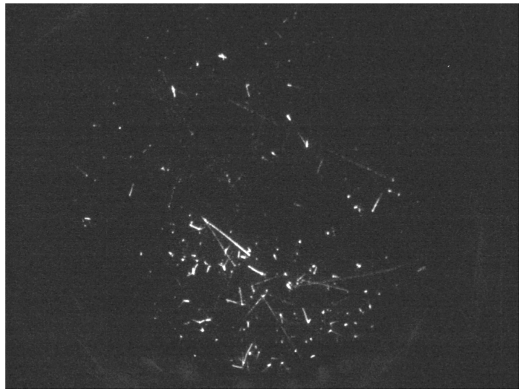


antiproton magnet and trap

Plans for LS2

- Measure H/H^- production rates using protons → optimise processes
- Measure Lamb shift on hydrogen

- Install (anti)proton trap and recycling of (anti)protons
- Install free-fall chamber and cooling/photodetachment lasers
- Cool protons in Be^+ ?
- Install detection of free fall
- Centralised DAQ/control



antiprotons interacting in MCP

GBAR collaboration

M. Charlton,[1] J. Choi,[2] M. Chung,[3] P. Cladé,[4] P. Comini,[5] P. Crivelli,[6] P-P. Crépin,[4] O. Dalkarov,[7] P. Debu,[5] L. Dodd,[1]
A. Douillet,[4] S. Guellati,[4] J. Heinrich,[4] P-A. Hervieux,[8] A. Husson,[9] P. Indelicato,[4] G. Janka,[6] S. Jonsell,[10] J-P. Karr,[4]
K. Khabarova,[7] B. Kim,[2] E-S. Kim,[11] S. Kim,[2] Y. Ko,[12] N. Kolachevski,[7] T. Kosinsky,[13] N. Kuroda,[14] B. Latacz,[5]
H. Lee,[2] J. Lee,[12] A. Leite,[5] E. Lim,[11] L. Liszkay,[5] T. Louvradoux,[4] D. Lunney,[9] K. Lévêque,[8] G. Manfredi,[8]
B. Mansoulié,[5] M. Matusiak,[13] G. Mornacchi,[15] V.V. Nesvizhevsky,[16] F. Nez,[4] S. Niang,[5] R. Nishi,[14]
S. Nourbaksh,[15] K. Park,[2] P. Pérez,[5] B. Radics,[6] C. Regenfus ,[6] S. Reynaud,[4] J-Y. Roussé,[5] A. Rubbia,[6]
J. Rzadkiewicz,[13] Y. Sacquin,[5] F. Schmidt-Kaler,[17] N. Sillitoe,[4] M. Staszczak,[13] B. Vallage,[5] D-P. van der Werf,[1]
A. Voronin,[7] A. Welker,[15] S. Wolf,[17] D. Won,[2] S. Wronka,[13] Y. Yamazaki,[18] K-H. Yoo[3]