Antimatière aux basses énergies

Pauline Comini

16 – 10 – 2017

Pour les 10 prochaines années au DPhP :

Antimatière aux basses énergies

Antimatière : tests CPT, QED, gravitation

	antiproton	antihydrogène	positronium	muonium
Passé	$\mu_{\bar{p}}$ *0.8 ppm*	$q_{\bar{H}}$	m_{e+}/m_{e-}	$m_{\mu+}/m_{e-}$ *8.10^{-7}*
	$m_{\bar{p}}$	1S-2S	q_{e+}/q_{e-}	$q_{\mu+}/q_{e-}$
	$q_{\bar{p}}/m_{\bar{p}}$	Transitions HF	1S-2S *2.10^{-9}*, ...	1S-2S *3.10^{-9}*
	$m_{\bar{p}}/m_{e-}$ *8.10^{-10}*	$-65 < \bar{g}/g < 110$	Transitions HF	
Futur	Amélioration de la précision : **BASE, ASACUSA**	GS-HFS : **ASCUSA** 1S-2S: **ALPHA, ATRAP** Lamb shift : **GBAR ?** $\bar{g}$: **AEgIS**, **ALPHA**, **GBAR**	Spectroscopie : **UCL**, **ETHZ**, **Université de Tokyo**, **GBAR ?** $\bar{g}$: **UCL**, **GBAR ?**	Spectroscopie : **PSI** $\bar{g}$: **PSI**

Antimatière aux basses énergies

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		$\bar{g}$: **AEgIS**, **ALPHA**, **GBAR**	$\bar{g}$: **UCL**, **GBAR ?**	$\bar{g}$: **PSI**

Antimatière + Gravité

Pour les 10 prochaines années au DPhP :

$\bar{H}$ au µK

Source intense de positronium

$\bar{H}$ naturellement produit à l'état 2S

Pour les 10 prochaines années au DPhP :

$\bar{H}$ au µK

Mesure à 1 % de $\bar{g}$ ...
... et au-delà

Source intense de positronium

$\bar{H}$ naturellement produit à l'état 2S

Upgrade : quantum gravitational states

Ultra – low energy $\bar{H}$ ➡ look for quantum effects

Reflection upon surfaces : Casimir-Polder potential barrier

For 1 m/s and 10 cm free fall height, non negligeable !

Problem ? No, can be used for measurements

Quantum gravitational states

Gravitational potential + Casimir-Polder :
➡ Hbar in potential well
Spectrum of discrete heights

1st excited state at 14 µm
lifetime : ~ 0.1 s

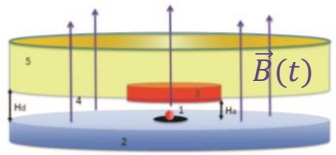
Already observed for ultra-cold neutrons

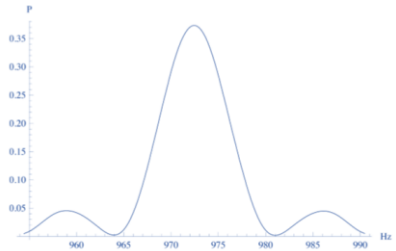
Exprimental possibilities

Velocity selector

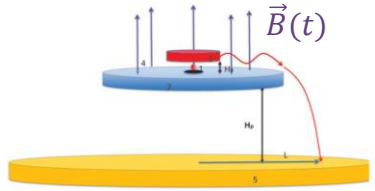
Collimator with decreasing height

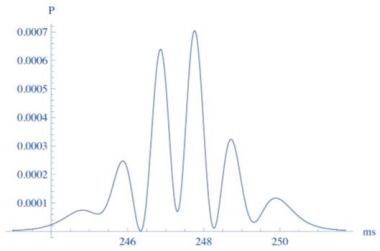
Spectrocopy





Interferometry





Precision : 10^{-4} for 1000 events

A. Yu. Voronin et al., Int. J. Mod. Phys. Conf. Ser. **30**, 1460266 (2014)

Pour les 10 prochaines années au DPhP :

$\bar{H}$ au µK

Mesure à 1 % de $\bar{g}$ ...
... et au-delà

Source intense de positronium

$\bar{H}$ naturellement produit à l'état 2S

Mesure du Lamb shift et rayon de l'antiproton

Antihydrogen beam

$$\bar{p} + Ps(n_p, l_p) \rightarrow \bar{H}(n_h, l_h) + e^-$$ ➡ Antihydrogen beam for free !

Lamb shift & $\bar{p}$ charge radius

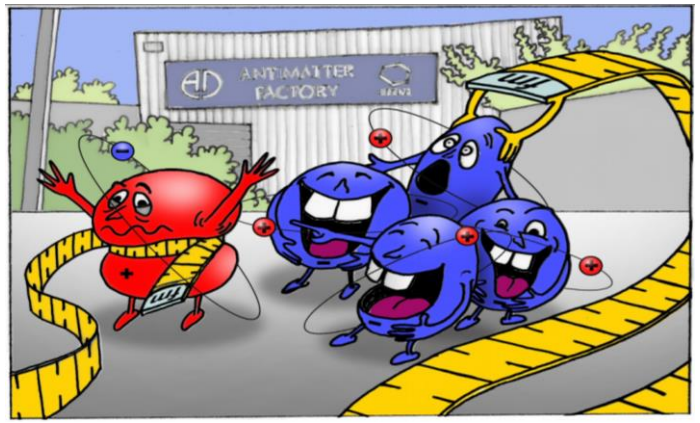
$\Delta\nu_{Lamb}$ = 1057.845(9) MHz Lundeen & Pipkin (1980)
Charge proton radius ➡ correction to Lamb shift $\Delta E = \frac{1}{12}\alpha^4 m_r^3 r_p^2$

Current effort to improve Lamb shift measurement in H ➡ 1 % on r_p

With GBAR starting kit : ~10 $\bar{H}(2S)$ expected / ELENA pulse

MW transition $2S^{1/2} \rightarrow 2P^{1/2}$ + quenching & Lyman-α detection
~ 100 event / day on resonance

➡ Lamb shift in $\bar{H}$ at 10^{-4}
$\bar{p}$ charge radius at 10 %



P. Crivelli et al., Phys. Rev. D **94**, 052008 (2016)

Pour les 10 prochaines années au DPhP :

$\bar{H}$ au µK

Mesure à 1 % de $\bar{g}$ ...
... et au-delà

Source intense de positronium

Spectroscopie 1S-2S...
... mais aussi
états quantiques gravitationnels

$\bar{H}$ naturellement produit à l'état 2S

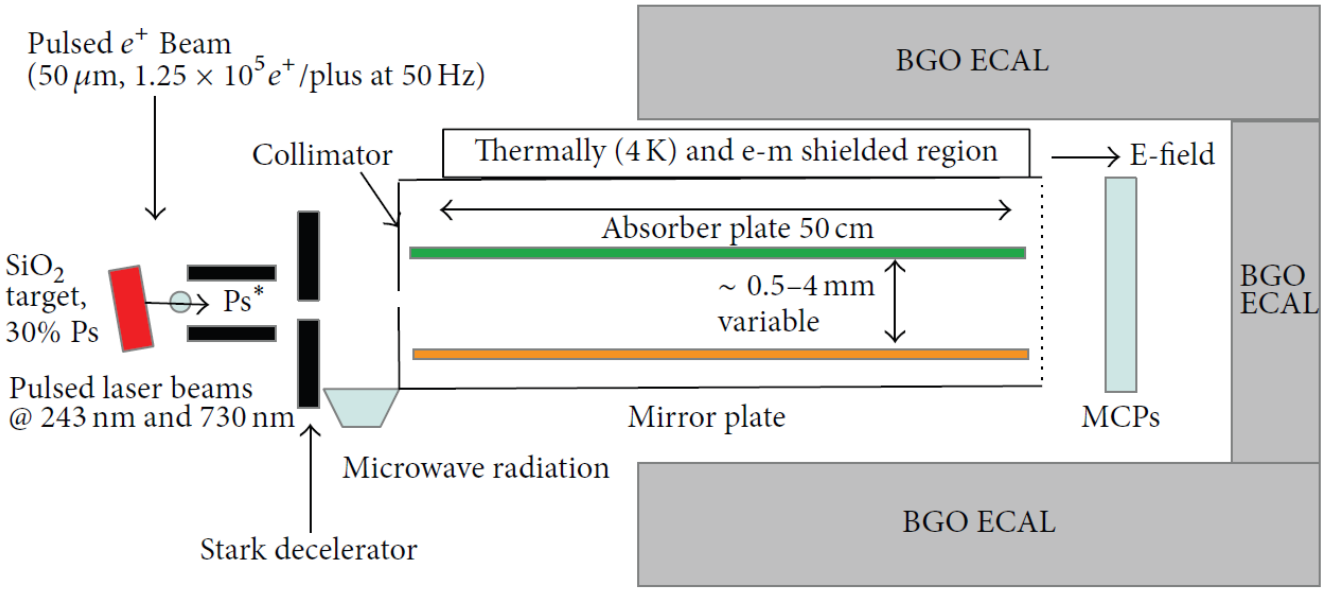
Mesure du Lamb shift et rayon de l'antiproton

Etats quantiques gravitationnels du positronium

Mesure à 3 % de $\bar{g}$
en 3 mois

Meilleure source de Ps sur GBAR

A noter :
le muonium peut être efficacement produit comme le positronium avec de la silice nanoporeuse



P. Crivelli *et al.*, Advances in High Energy Physics 2015, 173572 (2014)

Conclusion

La physique de l'antimatière à basse énergie est en plein essor

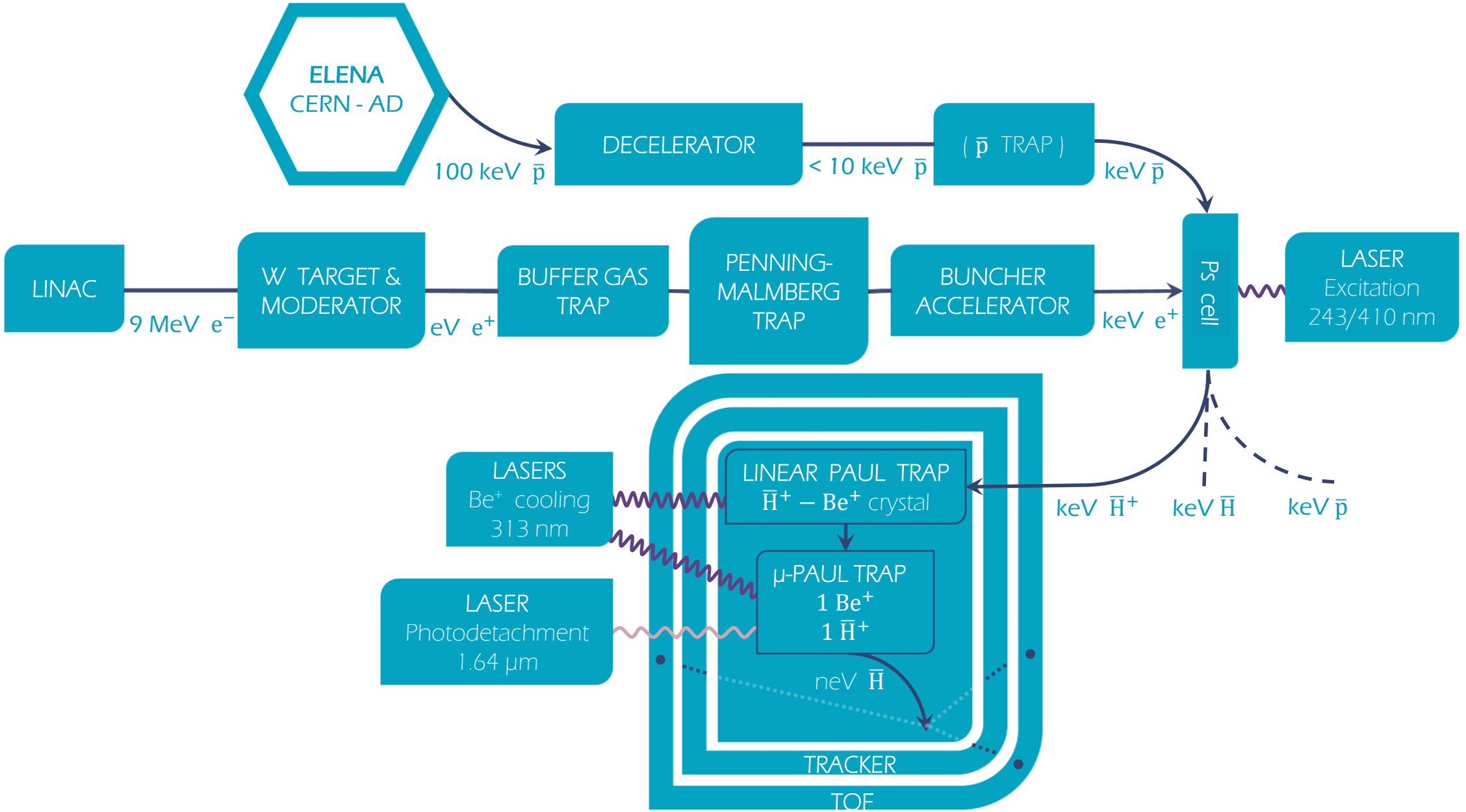
En particulier, possibilité d'une mesure directe de l'effet de la gravitation terrestre sur l'antimatière

GBAR peut atteindre une précision de 1 % sur $\bar{g}$ (2021)

et un upgrade est déjà prévu pour atteindre au moins 0,01 % (2025 à 2030)

En parallèle, GBAR peut travailler sur la spectroscopie de $\bar{H}$ et de Ps (2019 - 2021)

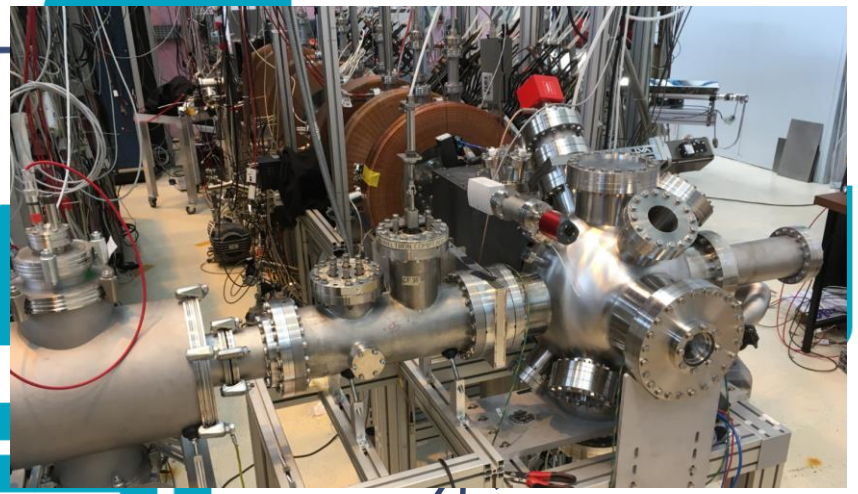
Antimatière aux basses énergies



Antimatière aux basses énergies

ELENA
CERN - AD

W TARGET &
MODERATOR



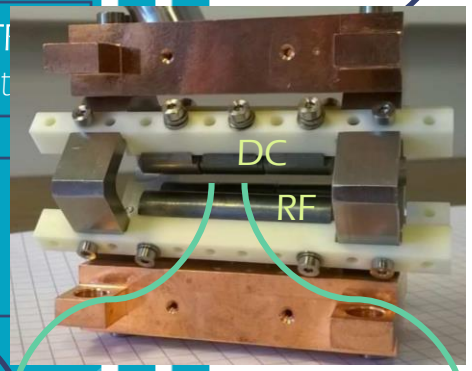
LASERS
Be^+ cooling
313 nm

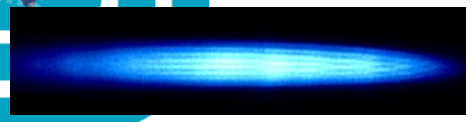
LINEAR PAUL TR
$\bar{H}^+ - Be^+$ cryst

LASER
Photodetachment
1.64 μm

μ-PAUL TRAP
$1\ Be^+$
$1\ \bar{H}^+$

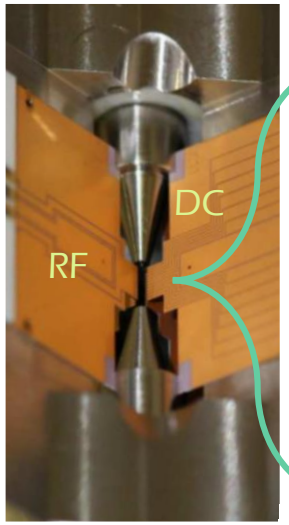
neV $\bar{H}$

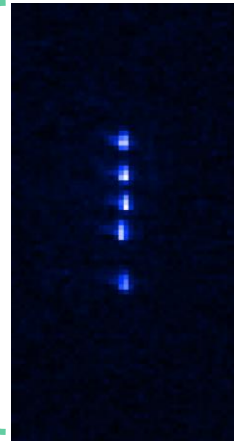


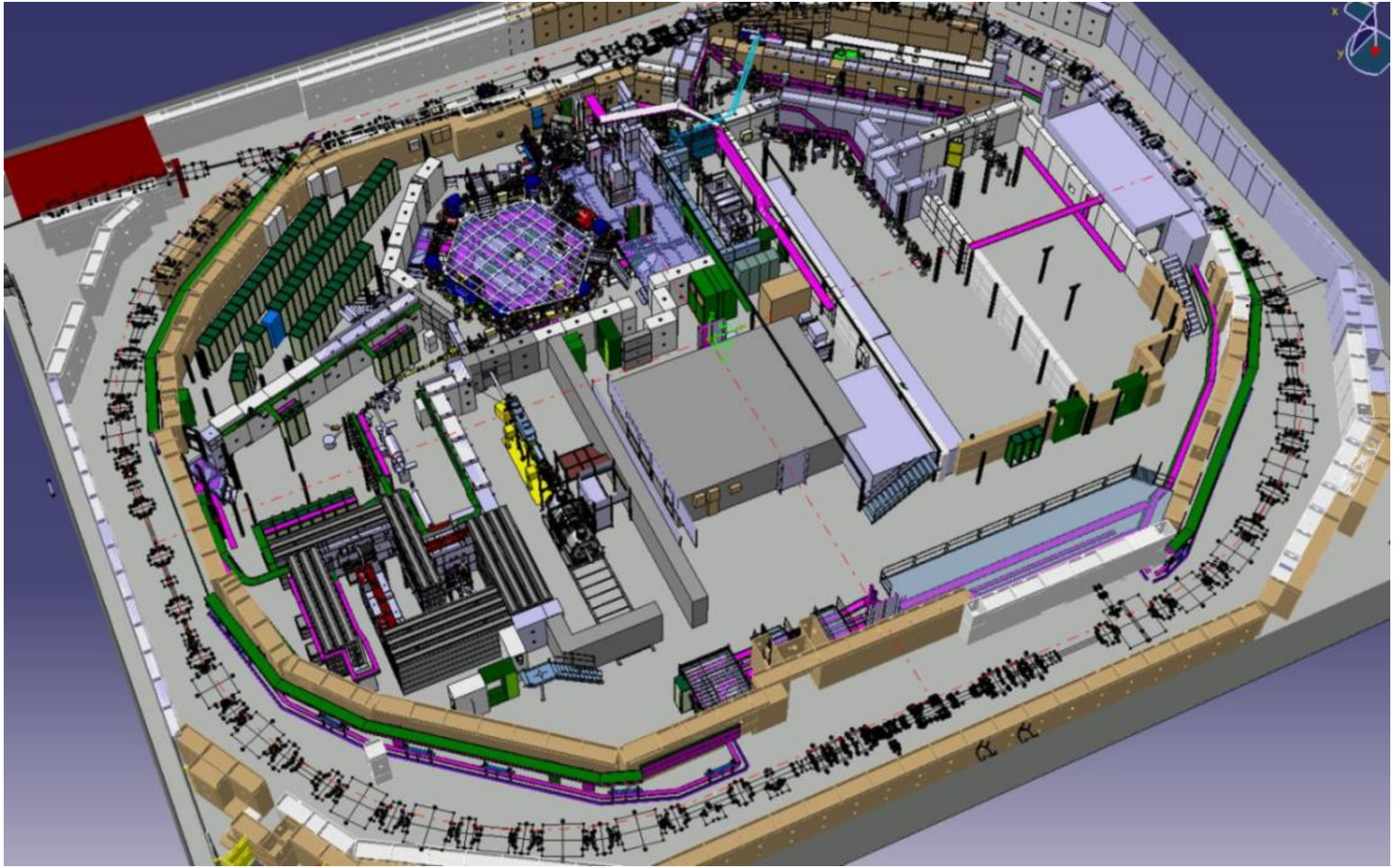


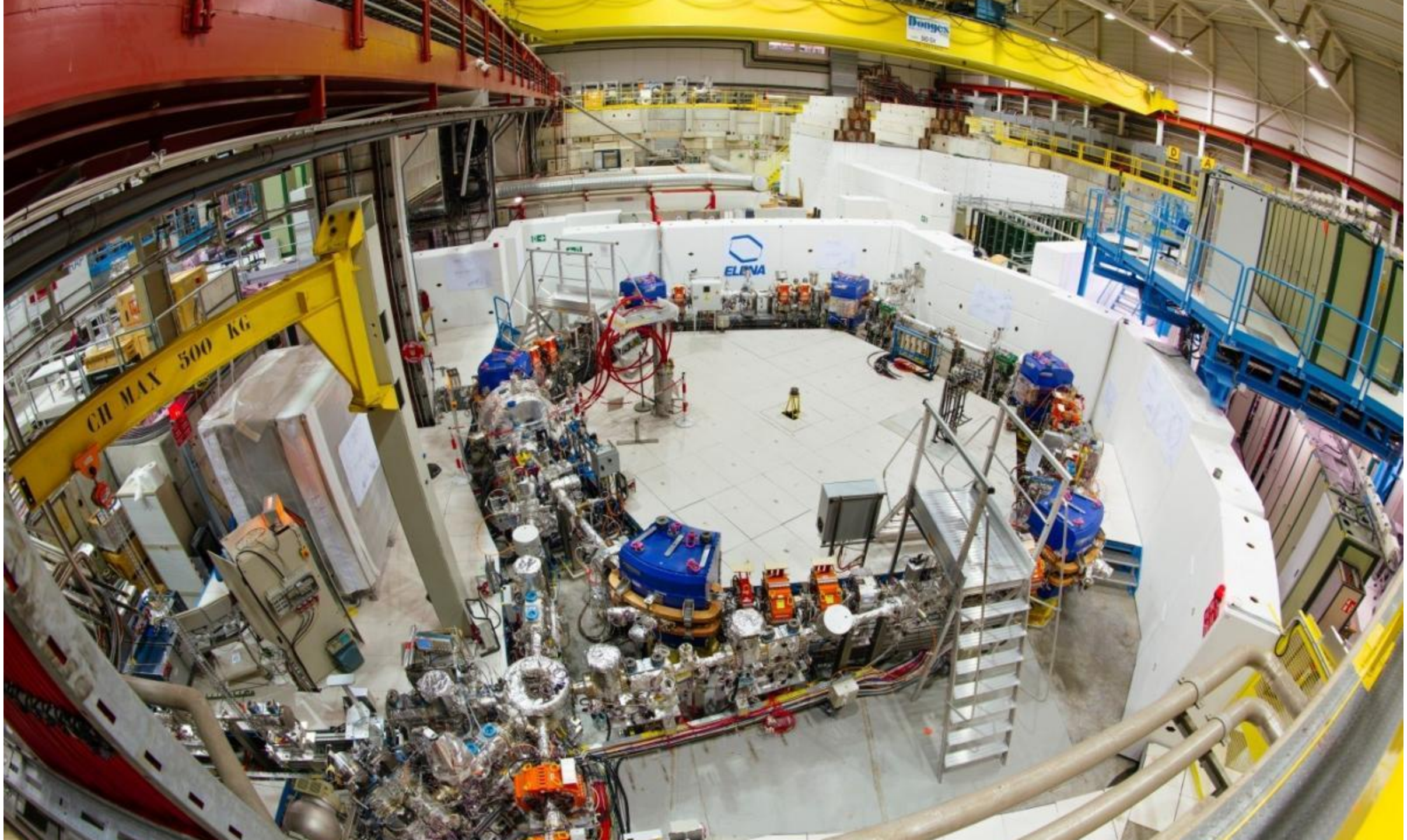
TRACKER

TOF








CH MAX 500 KG
ELENA

Antimatière aux basses énergies

2017

- Linac commissionning
- Decelerator tests
- 1st $\bar{p}$
- Beam dump
- Positron trap installation
- Reaction chamber installation
- End detectors tests
- Install 1st Ps excitation laser

2018

- Trap commissioning
- p / $\bar{p}$ focussing in RC
- Dense Ps cloud
- 1st $\bar{H}$
- Free fall chamber & detector production
- Full remote supervision
- 1st $\bar{H}^+$ detection
- Antiproton trap installation

2019 - 2020

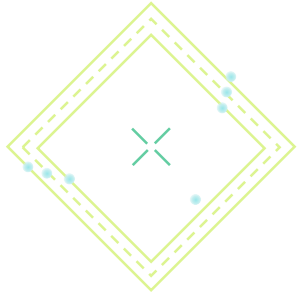
Long shut down

- Cross section measurement with protons or H-
- Ps spectroscopy
- Free fall chamber and detectors installation
- Cooling laser installation

?

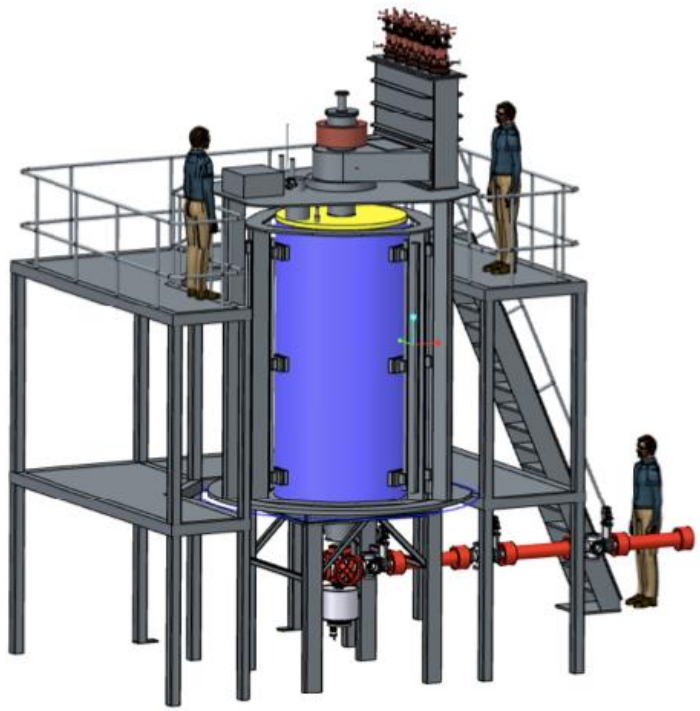
2020 and beyond

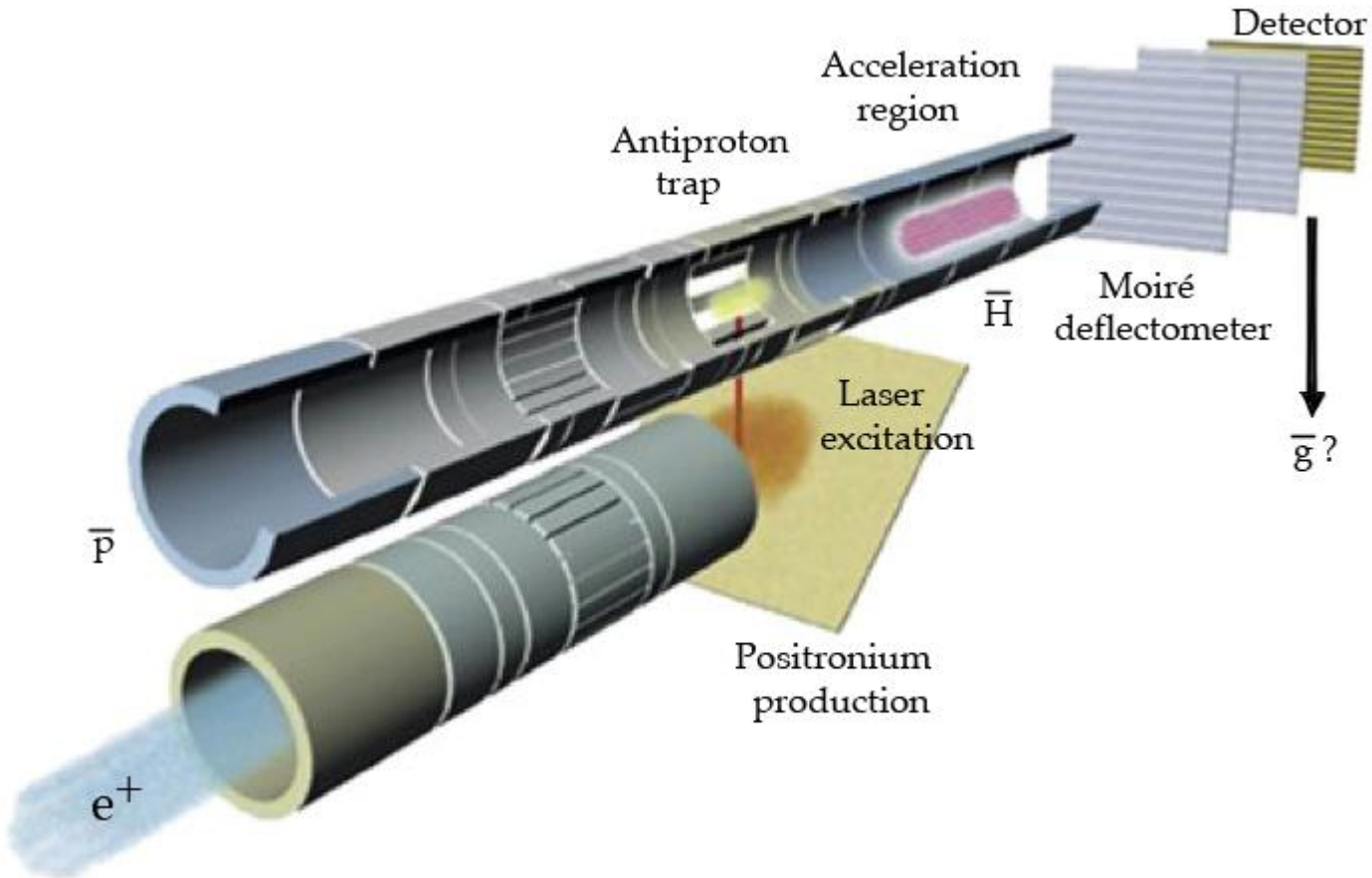
- Detector calibration with p
- 1st trapped $\bar{H}^+$
- 1st $\bar{H}^+$ at mK
- 1st $\bar{H}^+$ at µK
- 1st free fall of µK $\bar{H}$
- 1st $\bar{H}$ quantum reflection

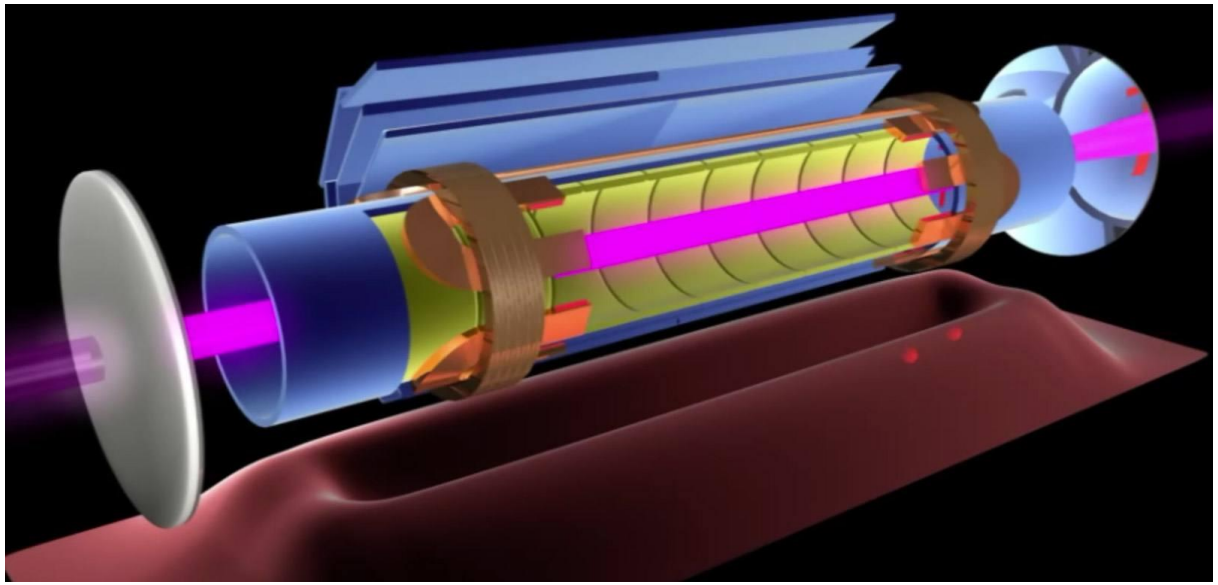


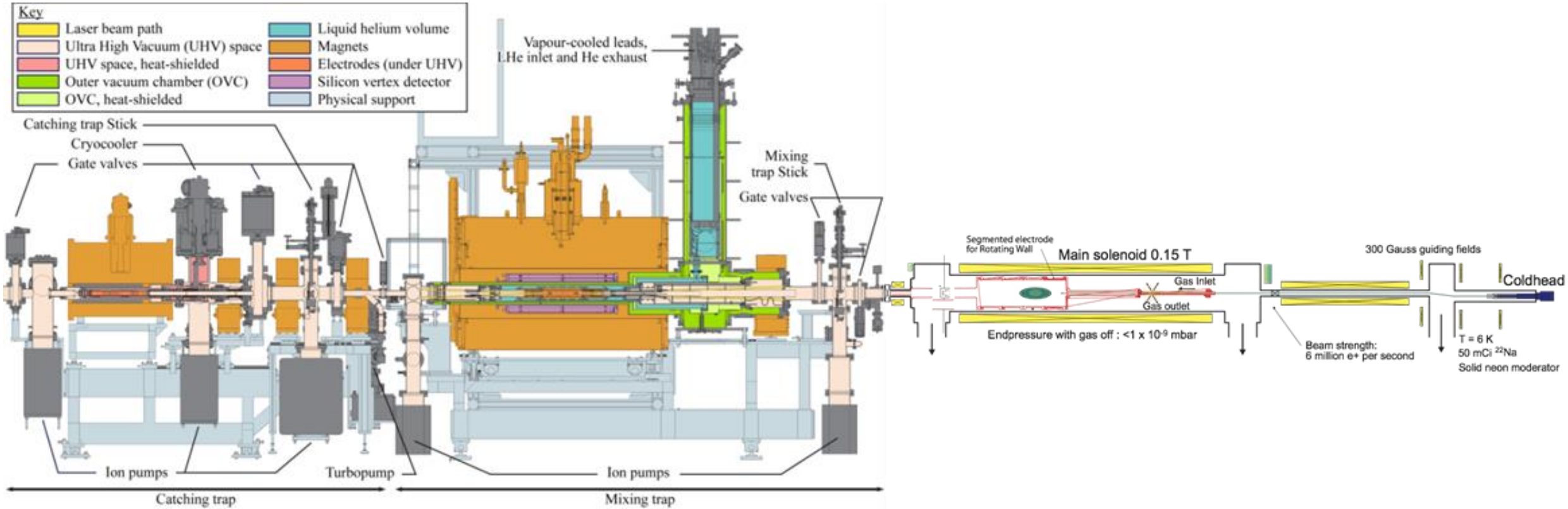
ALPHA-g: Precision gravitational measurements with antihydrogen

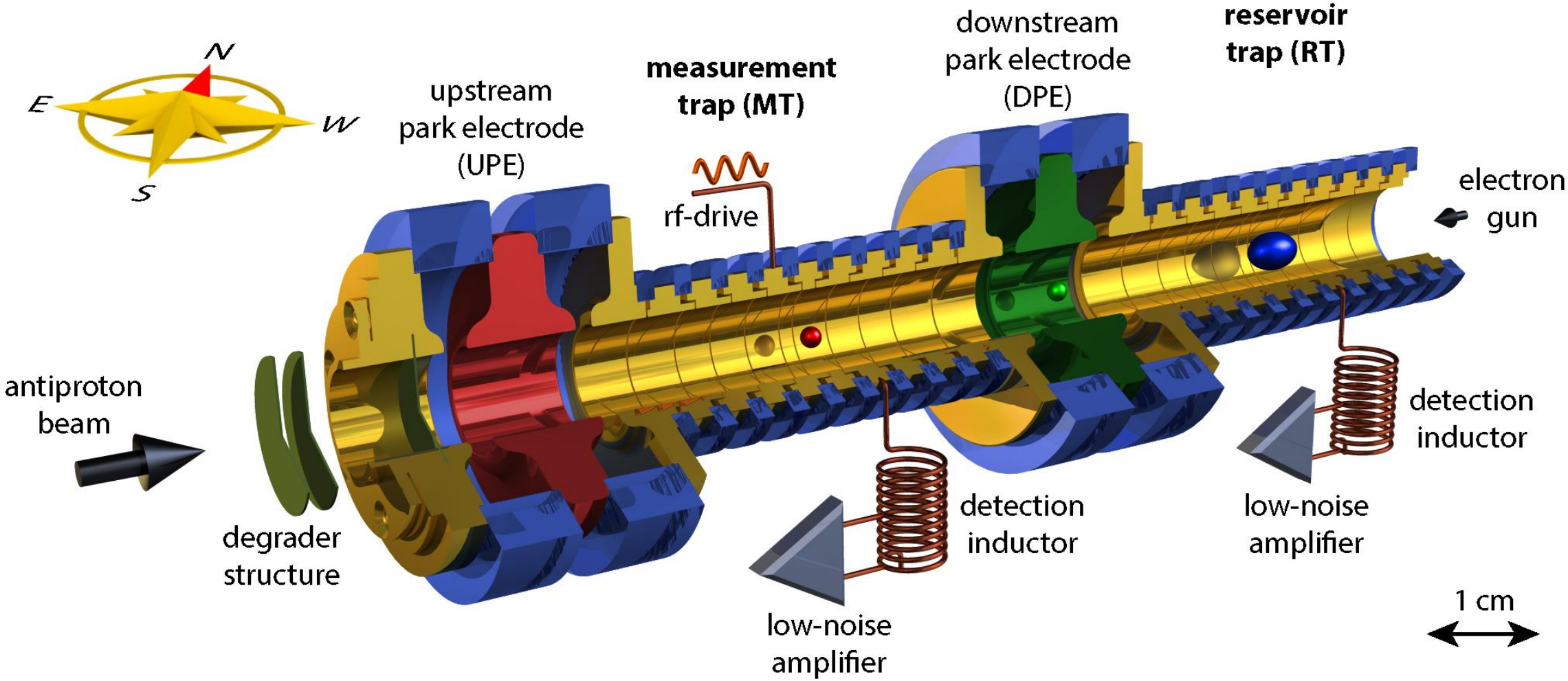
- ~ 2 m tall antihydrogen trap
- Release + detect falling Hbar
- Measure sign of gbar
  - ~ 1 year
- Measure gbar a ~ 1%
  - 4 - 5 years




Detector
Acceleration region
Antiproton trap
$\overline{H}$
Moiré deflectometer
Laser excitation
$\overline{g}$?
$\overline{p}$
Positronium production
e^+




Key
Laser beam path
Ultra High Vacuum (UHV) space
UHV space, heat-shielded
Outer vacuum chamber (OVC)
OVC, heat-shielded
Liquid helium volume
Magnets
Electrodes (under UHV)
Silicon vertex detector
Physical support
Vapour-cooled leads, LHe inlet and He exhaust
Catching trap Stick
Cryocooler
Gate valves
Mixing trap Stick
Gate valves
Ion pumps
Turbopump
Ion pumps
Catching trap
Mixing trap
Segmented electrode for Rotating Wall
Main solenoid 0.15 T
Gas inlet
Gas outlet
Endpressure with gas off : <1 x 10-9 mbar
300 Gauss guiding fields
Coldhead
Beam strength:
6 million e+ per second
T = 6 K
50 mCi 22Na
Solid neon moderator


N
E
W
S
upstream
park electrode
(UPE)
measurement
trap (MT)
downstream
park electrode
(DPE)
reservoir
trap (RT)
rf-drive
electron
gun
antiproton
beam
degrader
structure
detection
inductor
low-noise
amplifier
detection
inductor
low-noise
amplifier
1 cm