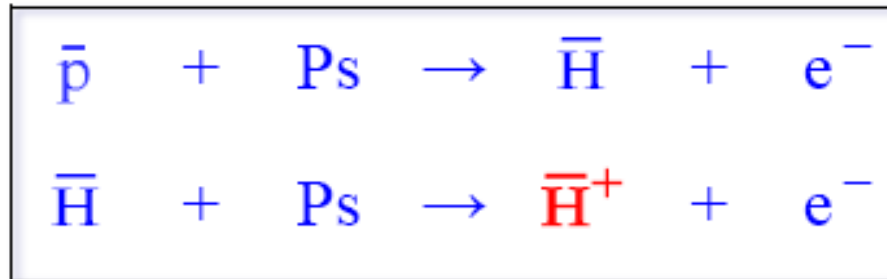
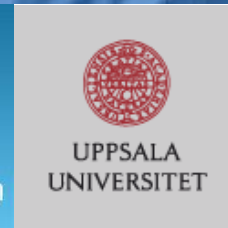


## Gravitational Behaviour of Antihydrogen at Rest

An experiment to test the Weak Equivalence Principle with antimatter , using antihydrogen ions  $\bar{H}^+$



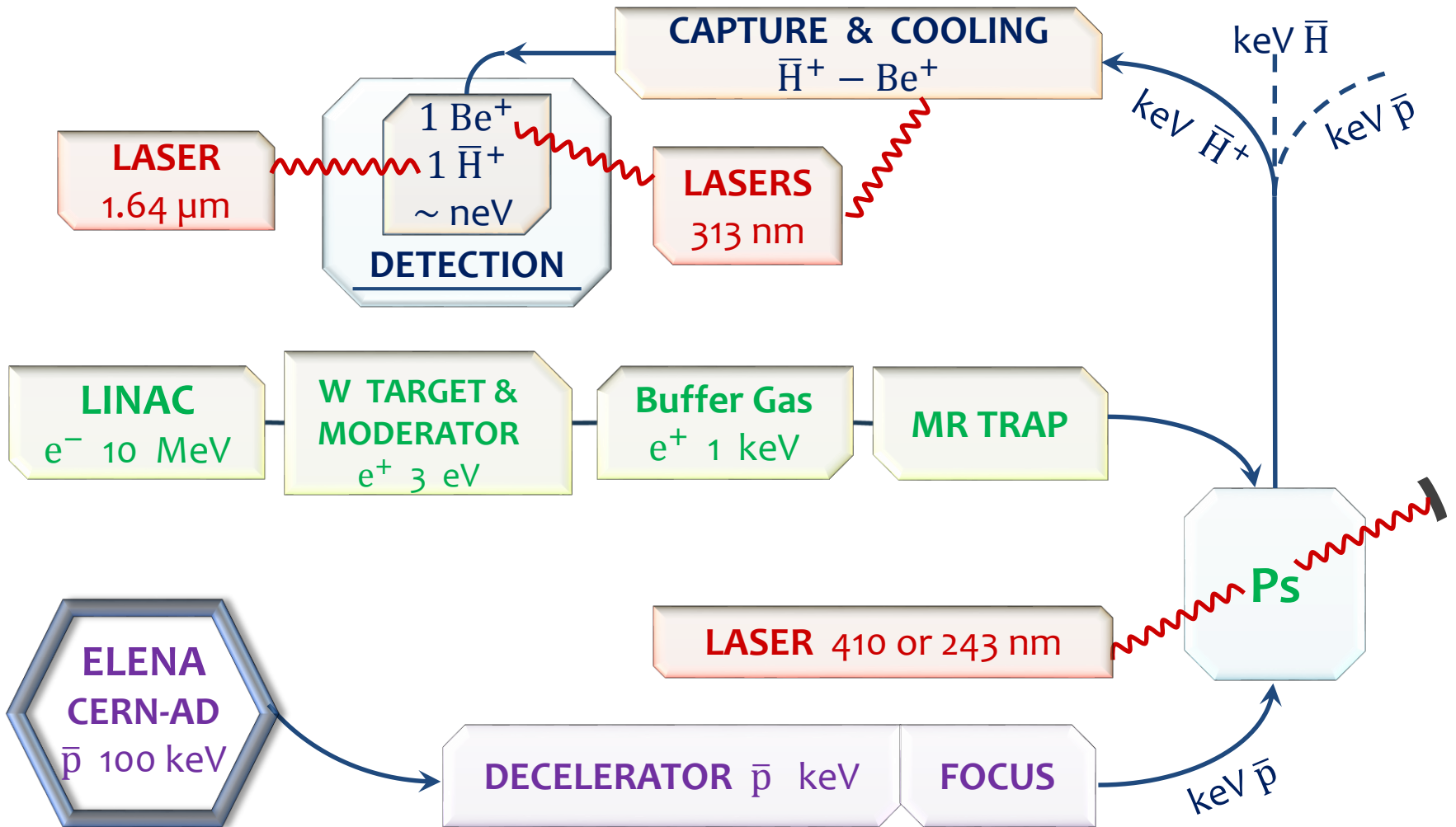
JOHANNES GUTENBERG  
UNIVERSITÄT MAINZ



서울대학교  
SEOUL NATIONAL UNIVERSITY



# GBAR synoptic view

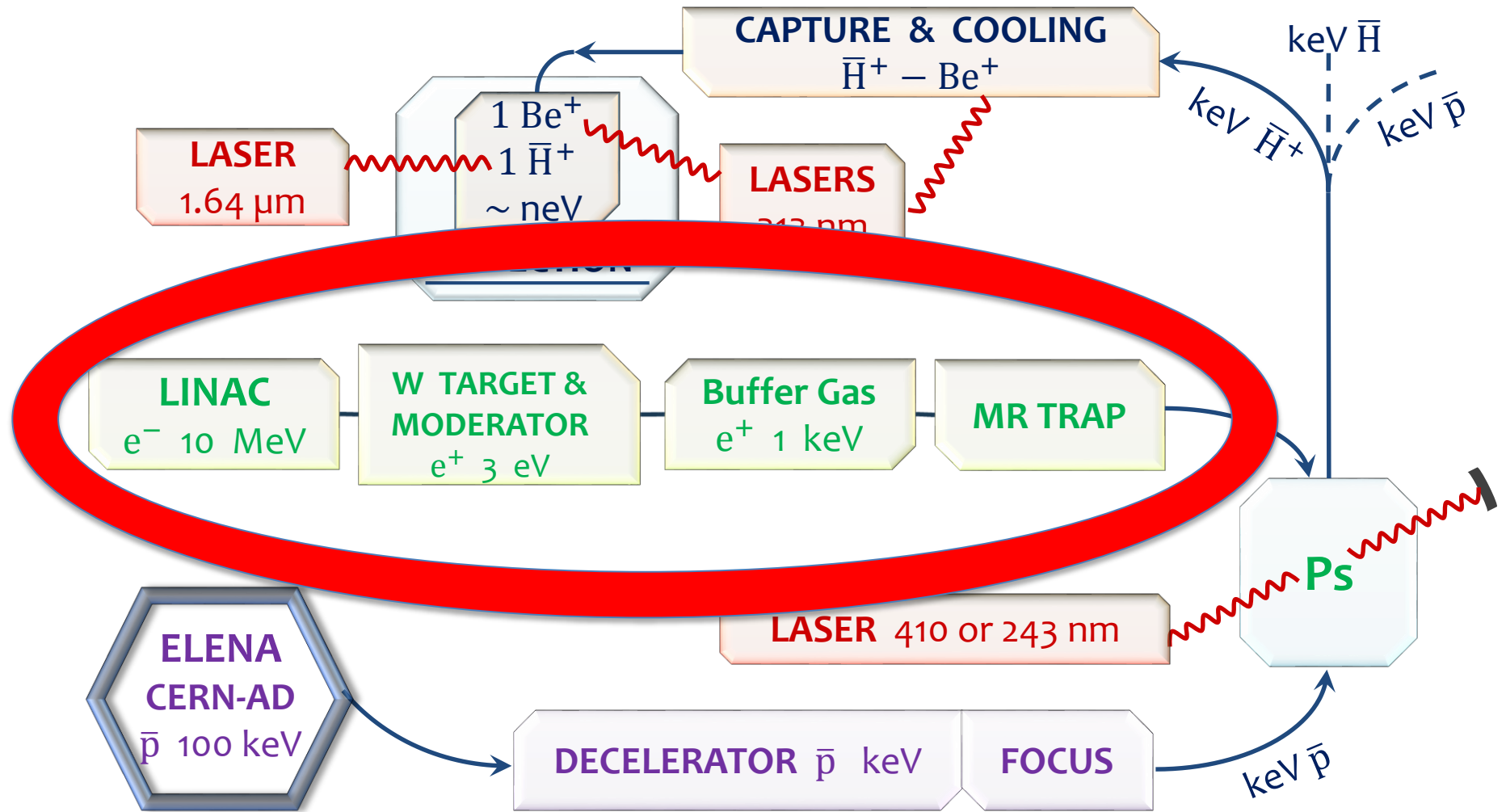




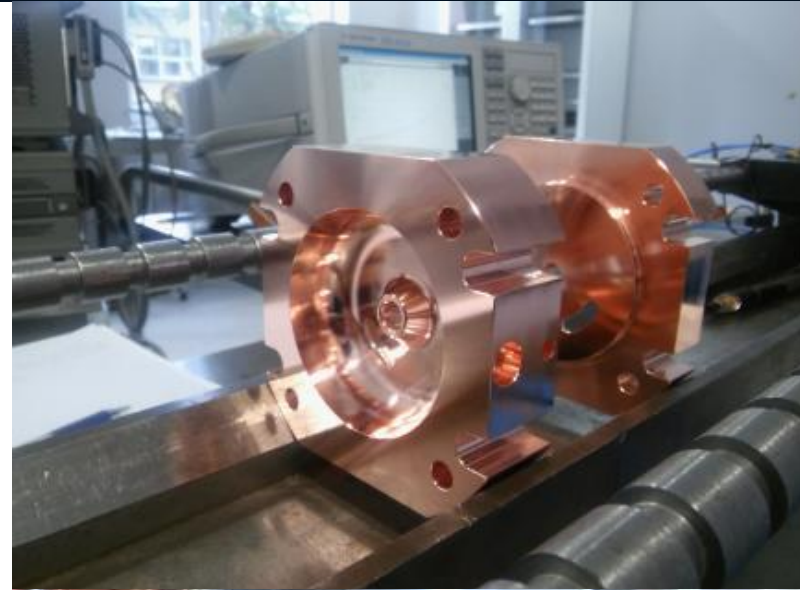
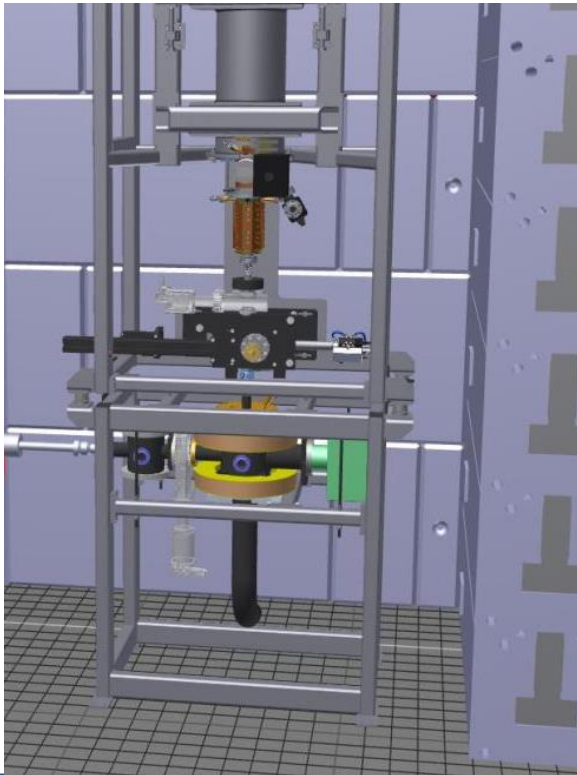
# Overview of 2015 progresses

- Linac /Bunker/Cern installation
- Positron source/beam line /interaction chamber
  - Antiproton deceleration
  - Antihydrogen cooling
    - Free fall detector

# GBAR synoptic view

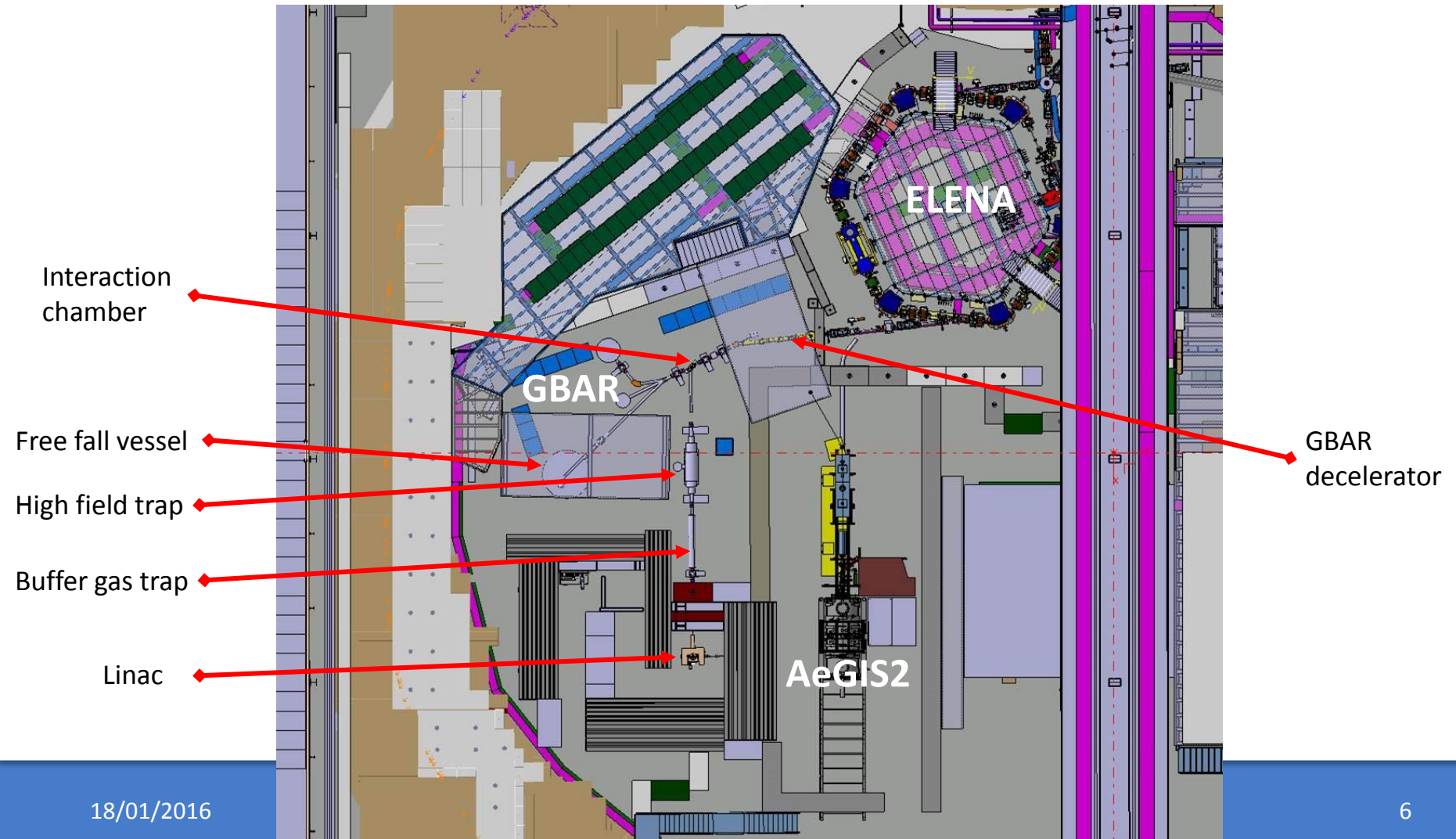


- 9+ MeV/0.2 mA  $e^-$  linac building in progress at NCBJ
- Vertical position (radiation protection)
- Installation: May-June 2016

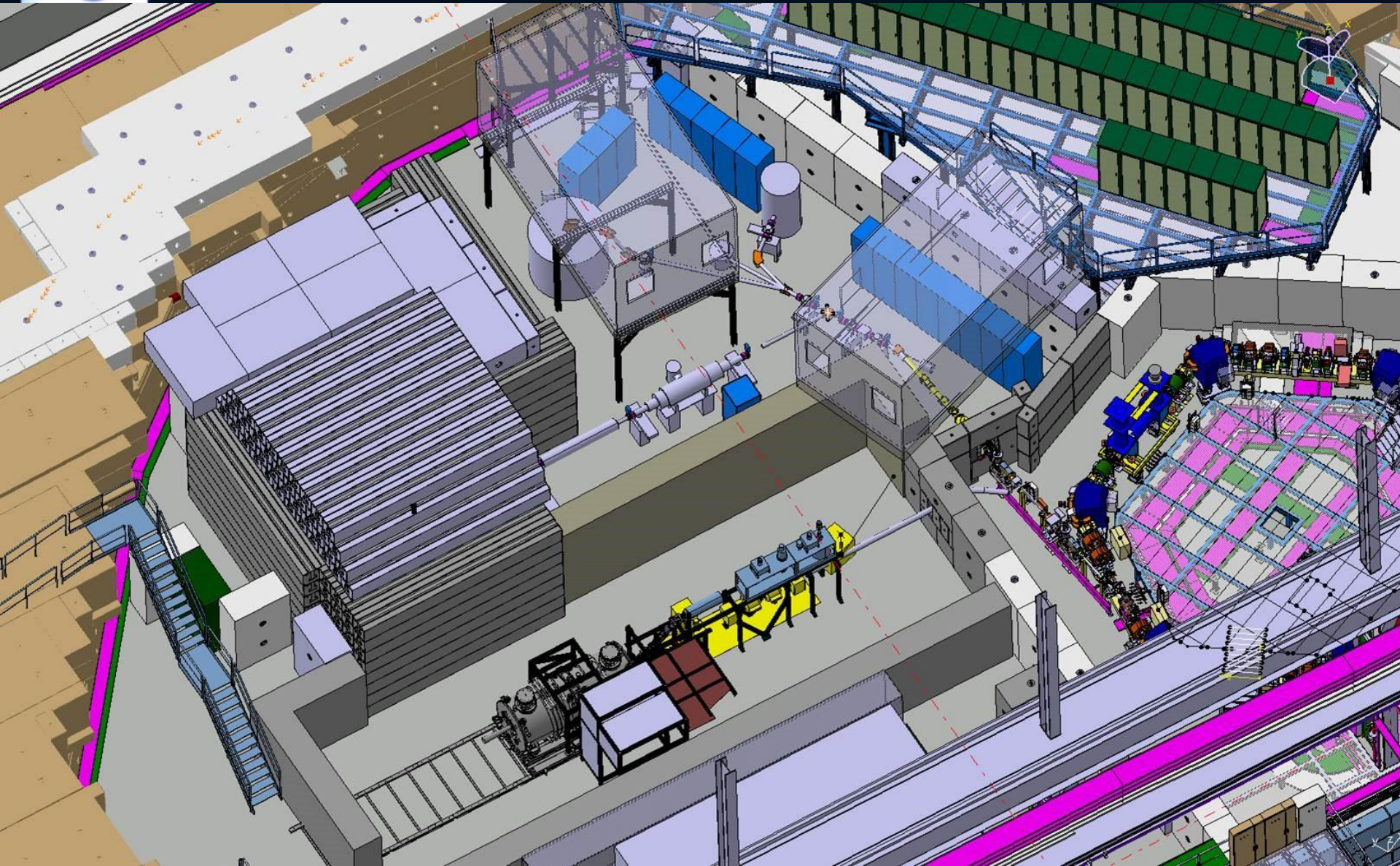


# Linac bunker

- Linac shielding : many different versions (nearly final, now ~1400 t)
  - Will use LEP magnet yokes (cost & availability)
  - Yoke refurbishing started; installation early 2016; careful control of AD level...

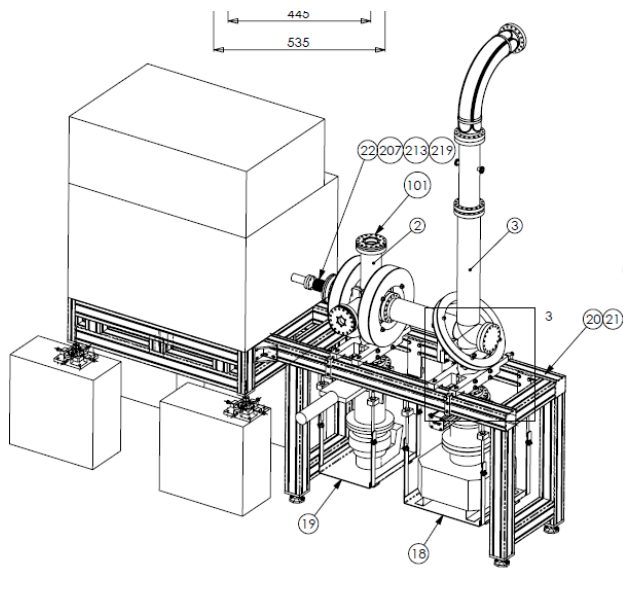


# Linac bunker

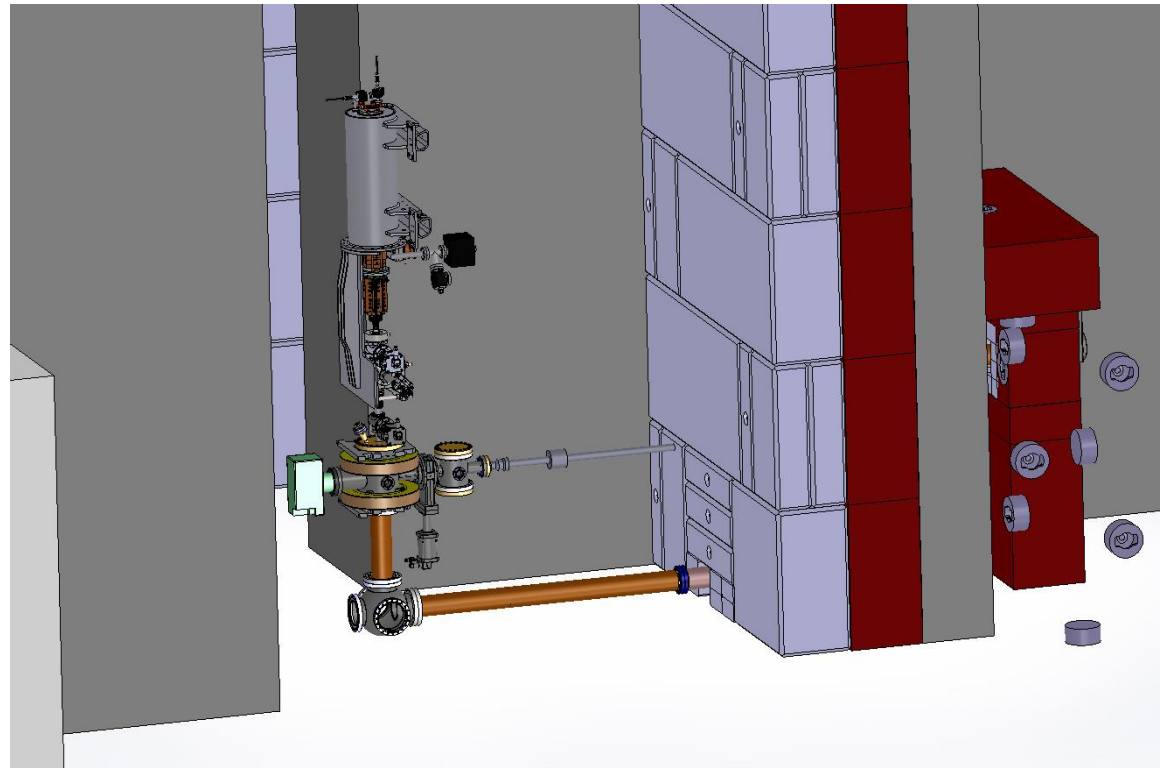


# Positron source/beam line

- A new positron source design will be implemented soon at Saclay facility as a prototype for the Cern installation.
- The GBAR beam line design is completed, tenders are in preparation.



*Design of the new Saclay source*

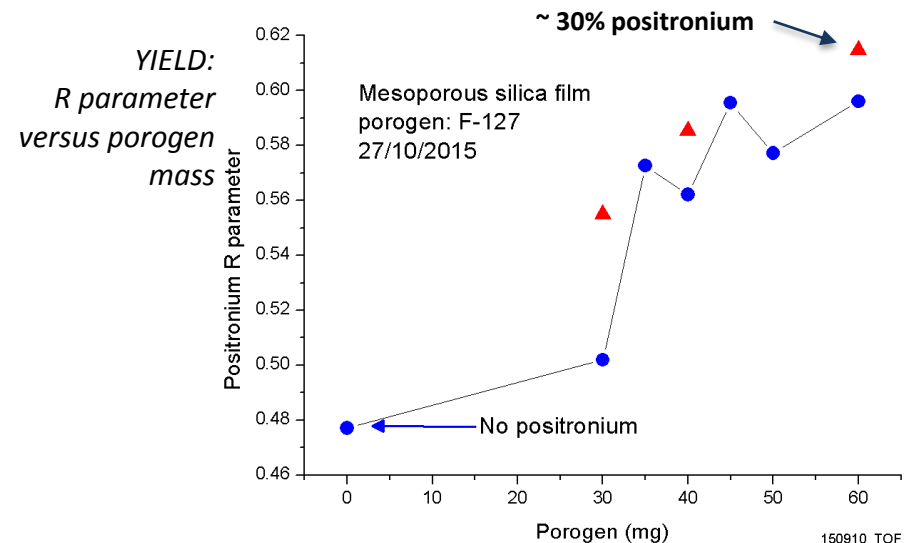
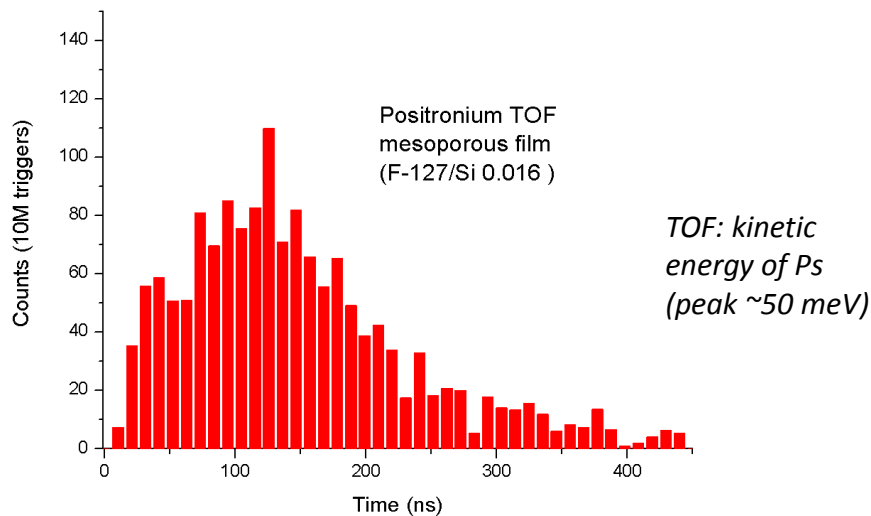
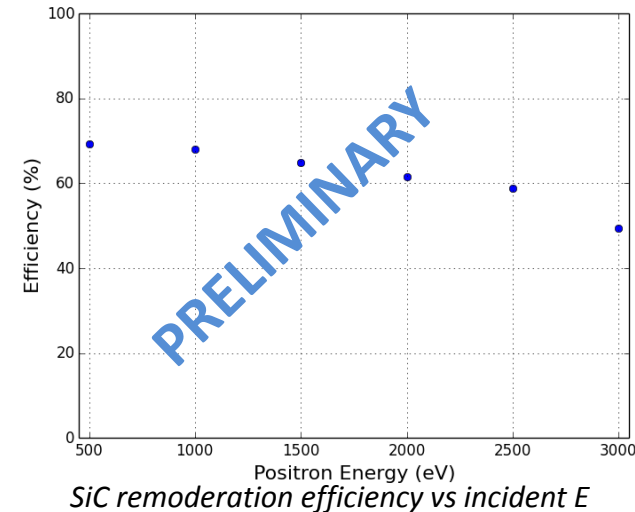


*CERN current implementation of the positron source and beam line*



# $e^+$ moderation, Ps study

- Study with the Saclay positron beam line: qualification of a SiC layer for remoderation.
  - Remoderation efficiency up to  $\sim 70\%$  (Usual W remoderation  $\sim 10\%$ )
  - Commercially available layer
  - New perspectives for improving  $e^+$  beam
- Continue study of different  $e^+$ /positronium converters: improve Ps yield, reduce Ps emission energy...

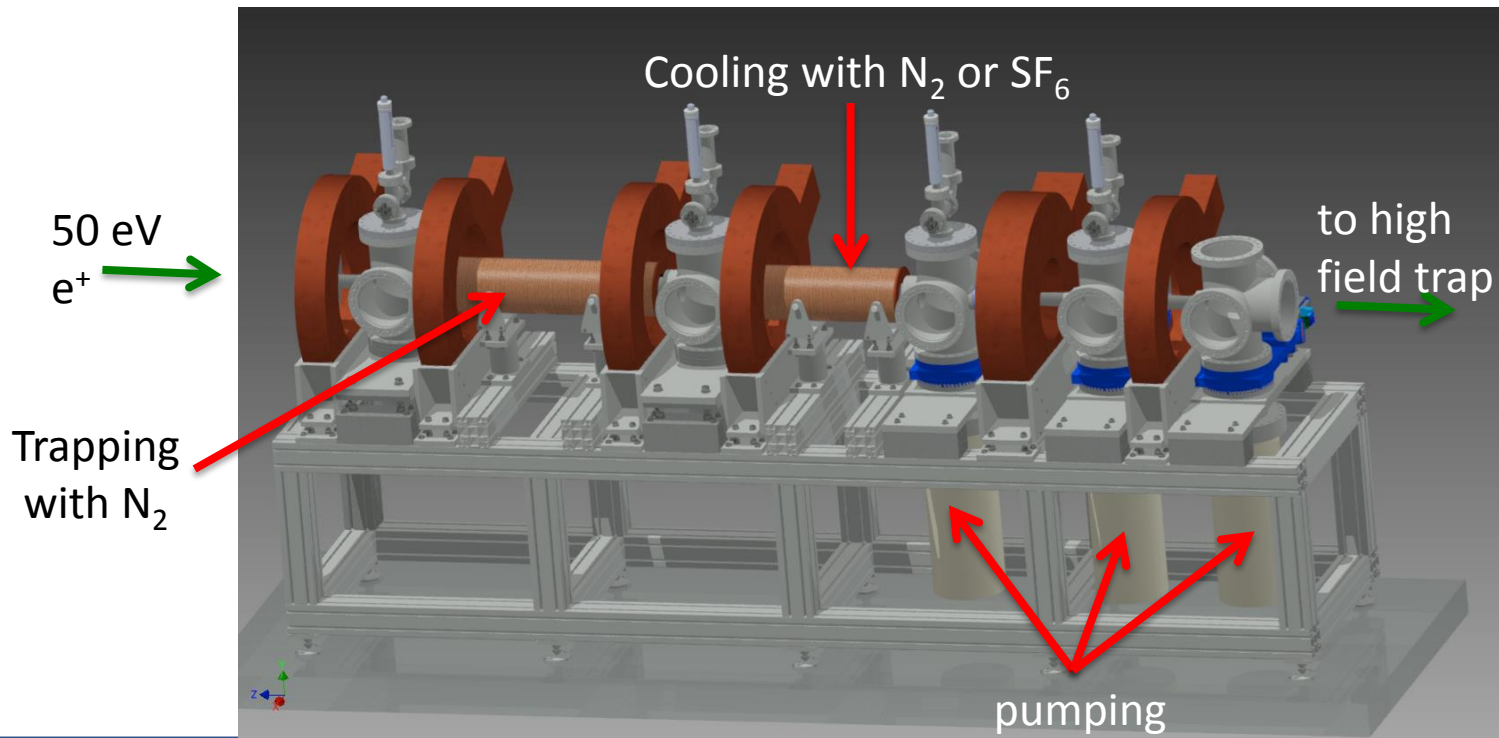


# Positron trapping

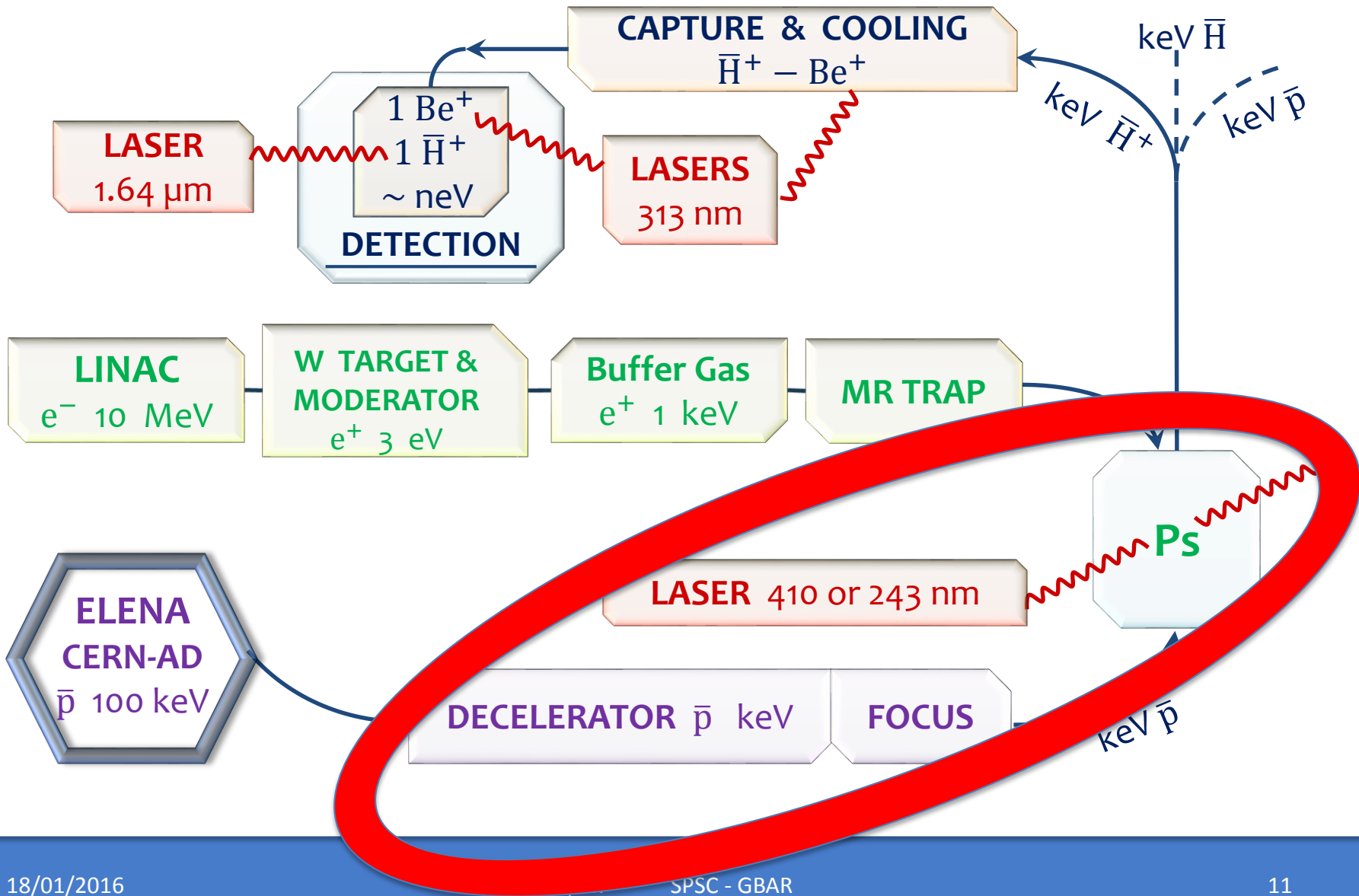
- Electron cooling & trapping efficiency should be  $\sim 75\%$  but not yet achieved
  - Work was going on : calculation of cooling time, alignment of  $e^+$  beam on  $e^-$  plasma, HV instabilities... Delayed for exchange of the MRT SC magnet cryocooling head (No more maintenance for old head) .
- **Buffer gas** cooling ( $N_2$  or  $SF_6$ ) is routinely reaching 25% : GBAR decision to add such a trap as injector to high field trap  $\rightarrow$  guarantee minimal efficiency  $\sim 25\%$

**A new BGT will be constructed and tested at Saclay in 2016**

(Parts ordered , delivery well advanced)

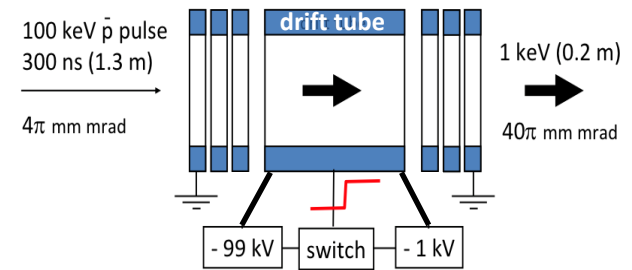


# GBAR synoptic view

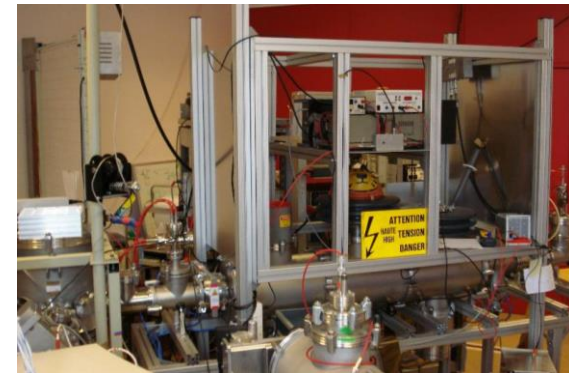
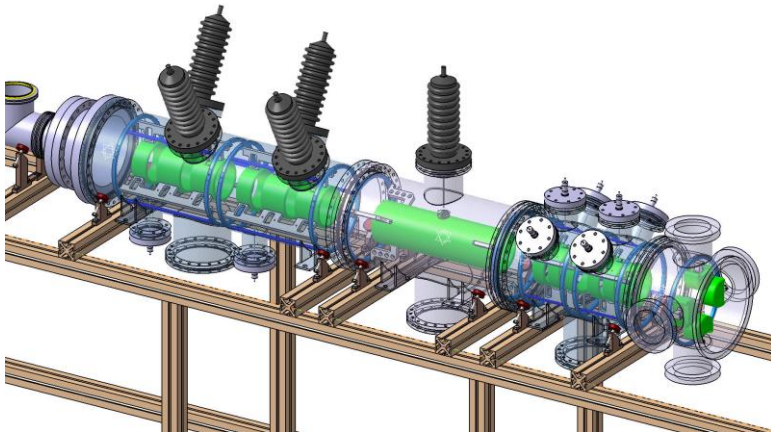


# p/ $\bar{p}$ decelerator

- GBAR needs  $\bar{p}$  at 1-6 keV: Development of an electrostatic decelerator.

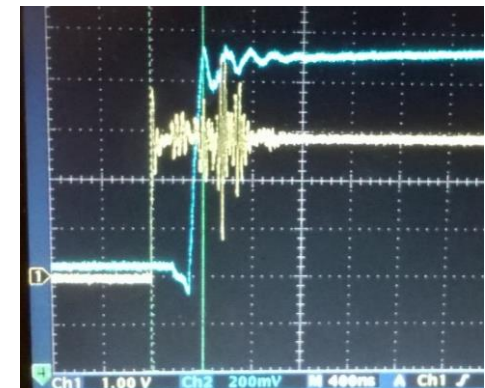


→ Test Bench in CSNSM (Orsay) with protons



→ Switch tested OK at 20 kV;  
now conditioning for 100 kV

- Proton gun to be installed at Saclay, later at CERN, for H/H<sup>-</sup> production study



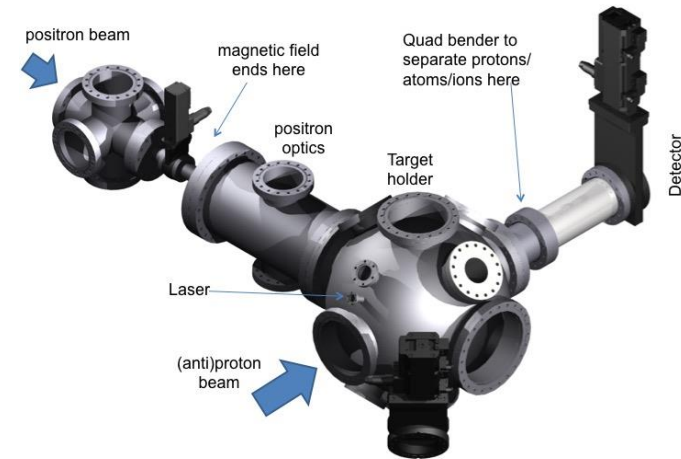
# $p/\bar{p} - Ps$ interaction

- Cross section measurements

Preparation of the interaction chamber for the first measurement at Saclay:

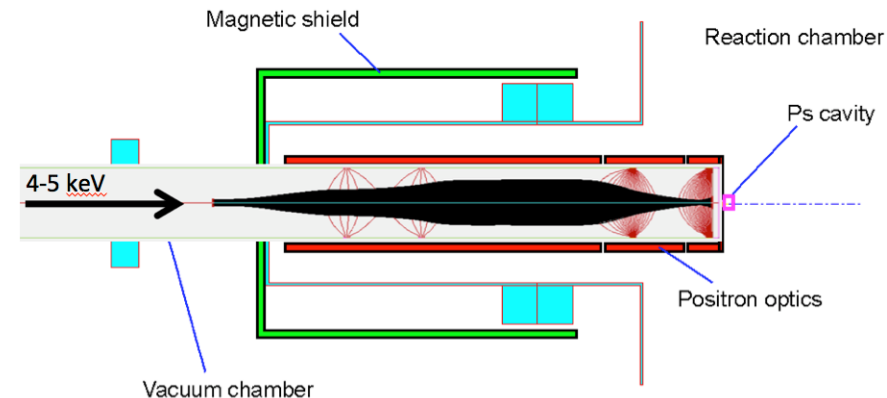


The chamber will be used later on at CERN for H-production measurement, before switching to  $\bar{p}$



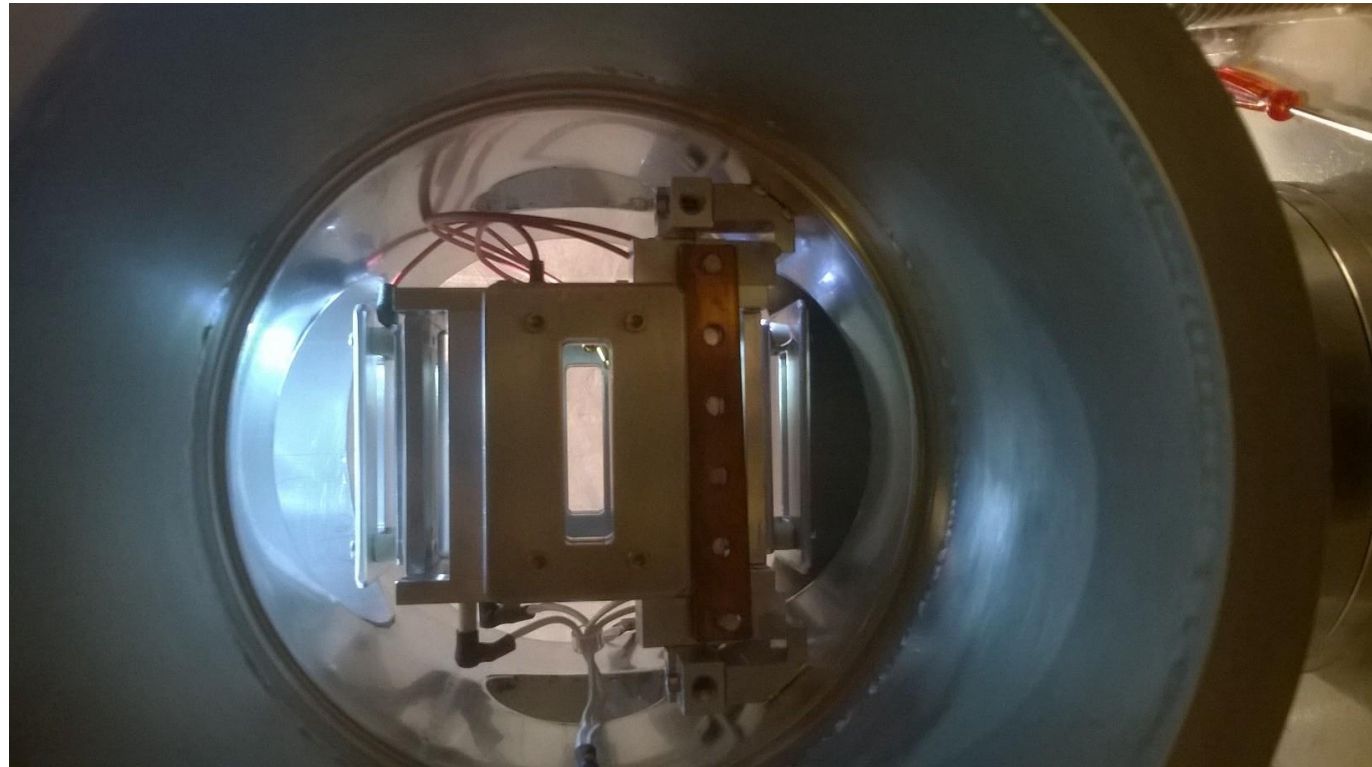
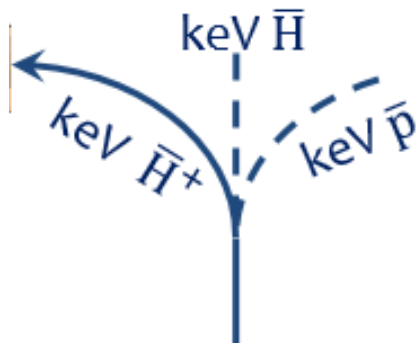
- Positron extraction optics:

Need strong focussing on the Ps converter:  
magnetic shield, Einzel lenses



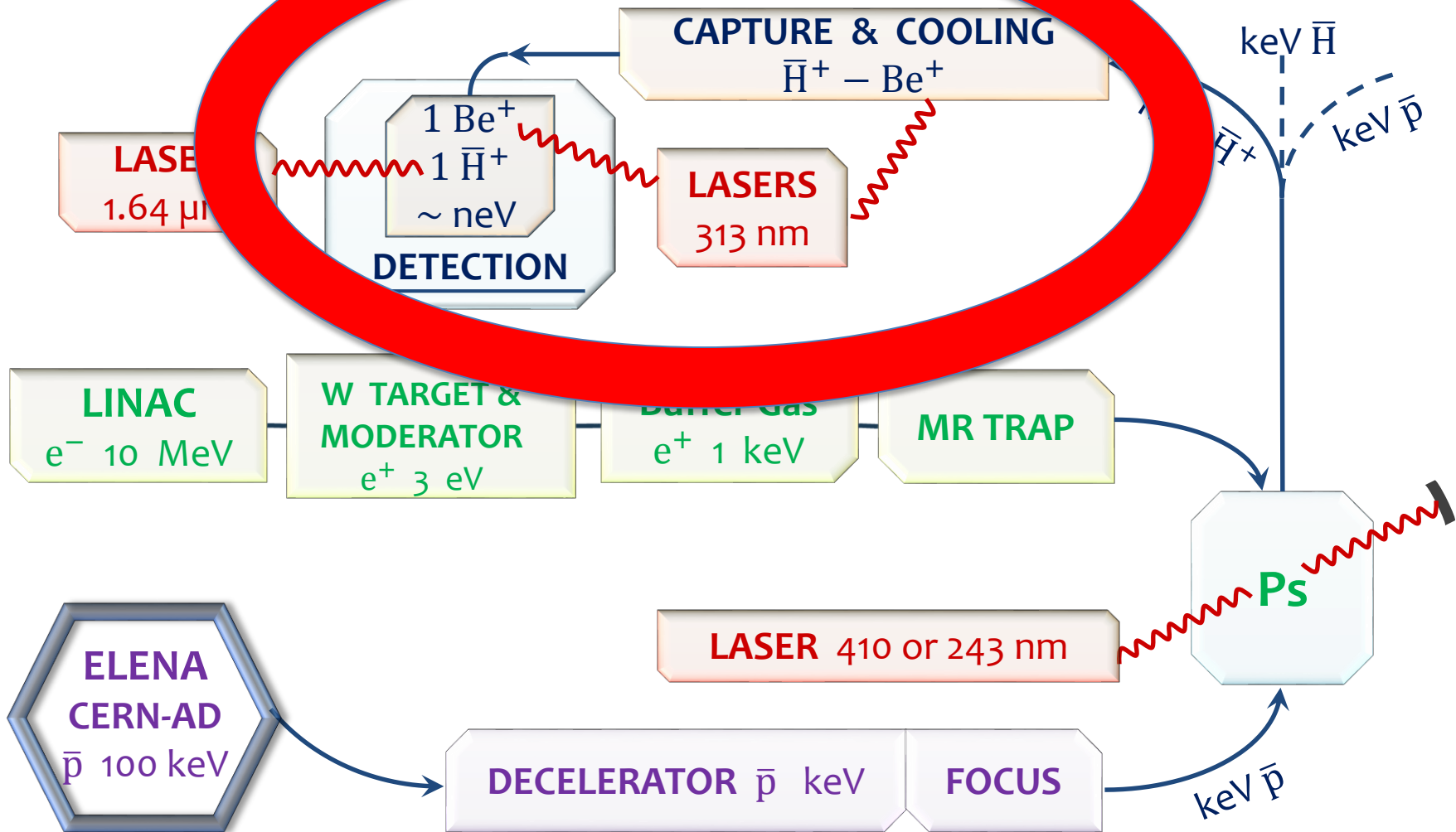
Parts delivery in progress, assembly started, measurement 2<sup>nd</sup> half 2016

# Electrostatic deflector



- Built and presently tested in Orsay.
  - To be used for the H production measurement in Saclay, then at Cern

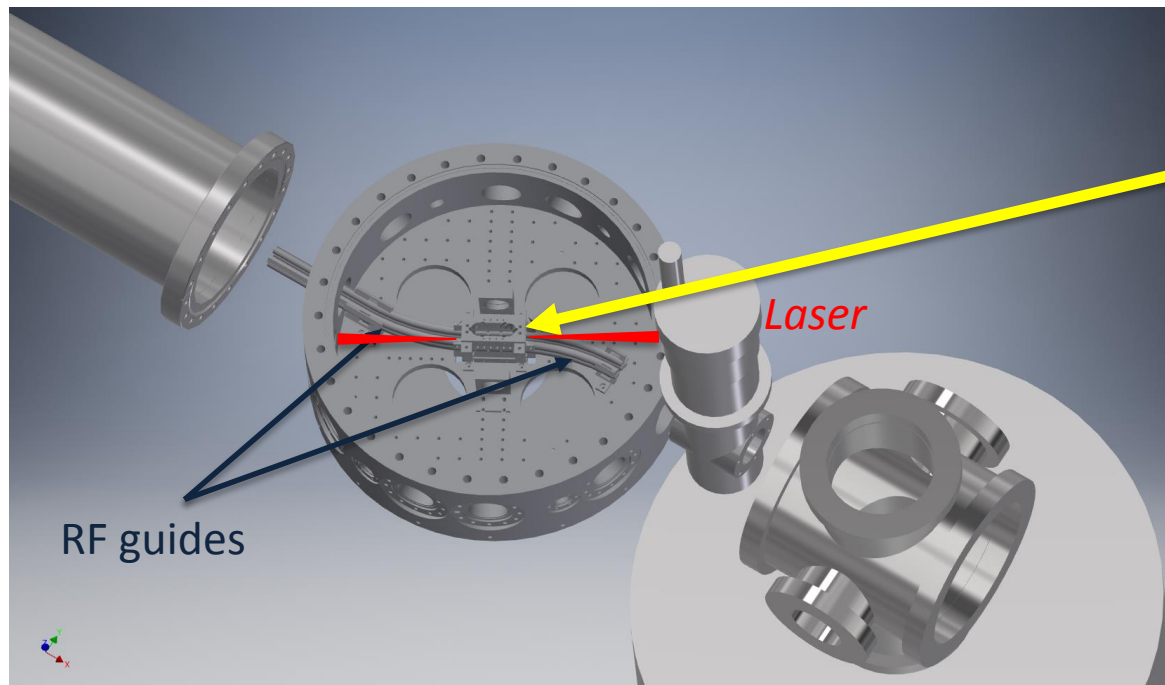
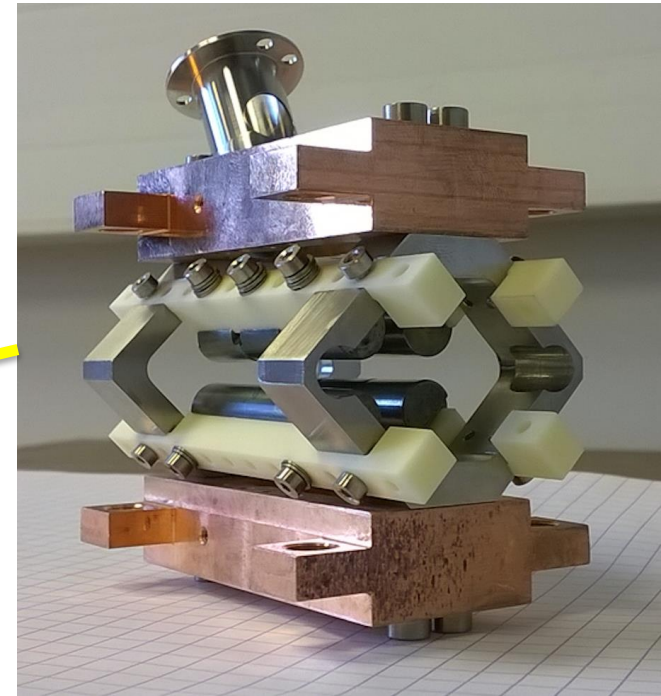
# GBAR synthetic view



# Antihydrogen cooling

## Capture Trap (LKB)

- **Detailed simulations** of sympathetic cooling with laser cooled  $\text{Be}^+$  are developed for different elements. Ion energy is crucial. Tests with  $\text{H}_2^+$  are planned.
- The **capture Paul trap** (first stage of cooling) is being assembled, together with the cooling laser (626 nm DBR master diode  $\rightarrow$  313 nm)



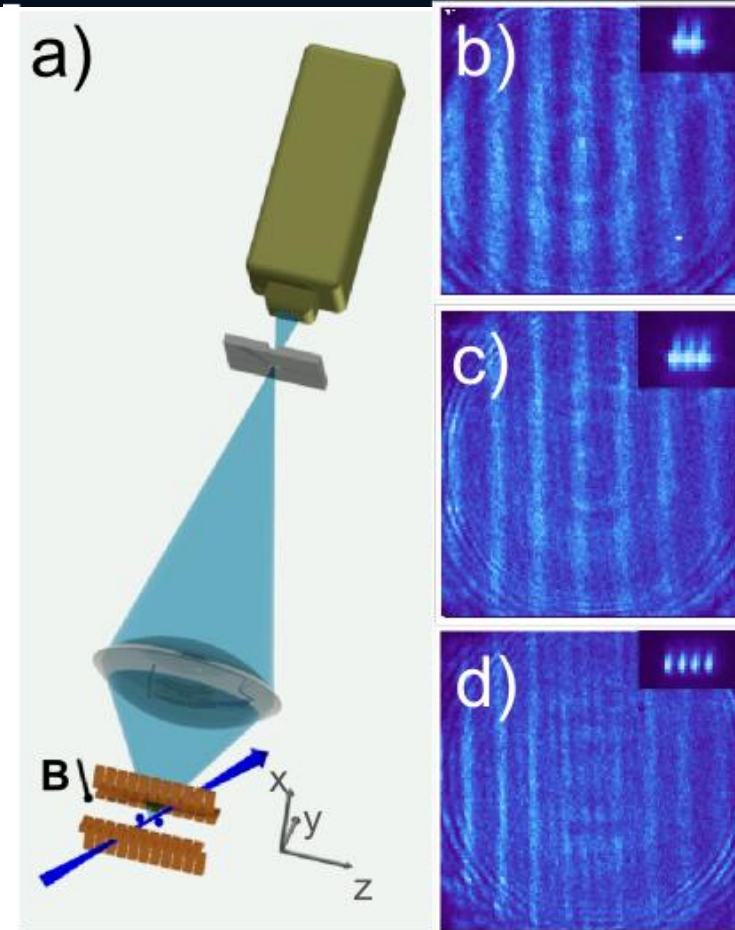
*Integration design of the capture trap*



# Antihydrogen cooling

## Precision Trap (JGU)

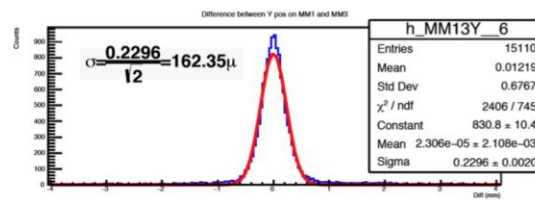
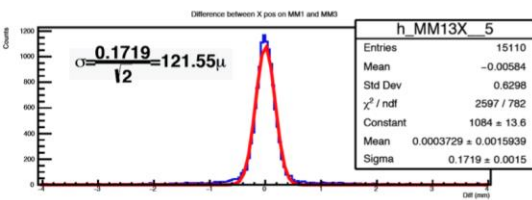
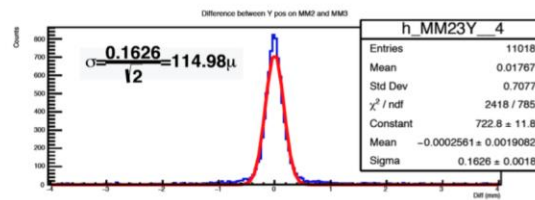
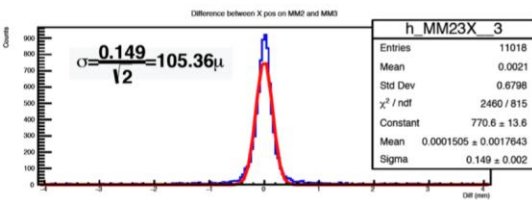
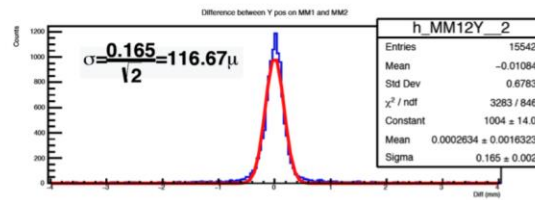
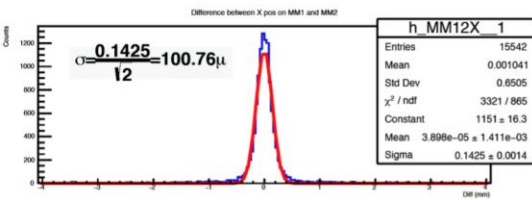
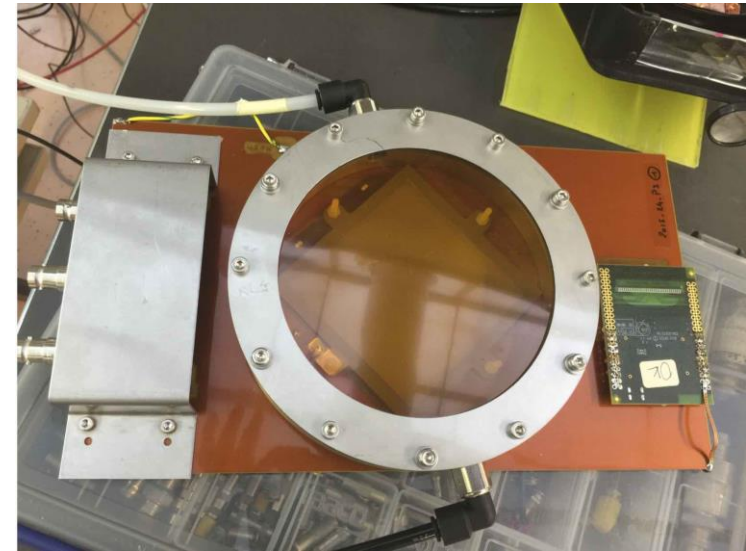
- Study of interference in the light scattered from trapped  $^{40}\text{Ca}^+$  ion crystals
  - Measure of the interference visibility  $\rightarrow$  ion temperature measurement (to be known at the photo detachment)
  - Paper submitted to PRL (ArXiv.1511.08697)
- Ion trap fabrication
  - Improve trap gold coating technique, to reduce parasitic heating (by factor 1000)
  - New trap chips designed and fabricated  $\rightarrow$  improve heating rate
- Loading scheme for  $\text{Be}^+$ 
  - Tested with different wavelength, 350 and 260 nm
  - New proton source to test the injection, capture and cooling of light ions in  $\text{Be}^+$  crystals.
- Lasers
  - Cooling lasers for  $\text{Be}^+$  at 313 nm are ready (one master, one slave, resonance frequency doubler)
  - Set-up second master for line width measurement



*Contrast is temperature dependent*

# Free fall detector

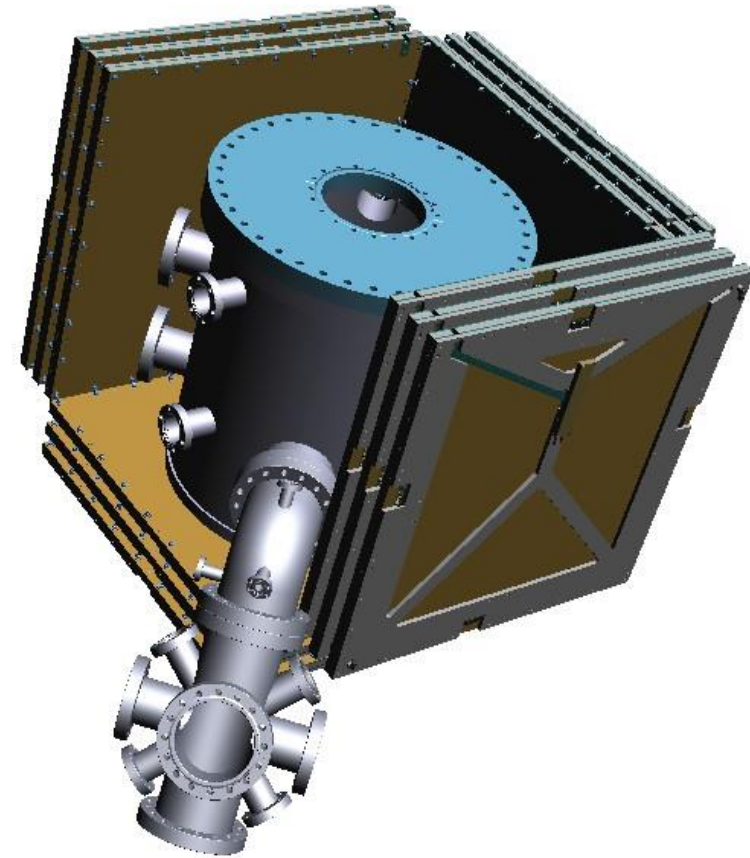
- Prototype built and tested in 2015
  - 3 microstrip Micromegas chamber detectors (MMD), 8x8 cm<sup>2</sup>, with X-Y readout, built at CERN
  - Using the RD51 electronic readout developed at CERN
  - Tested with CR and CERN beams
  - Design to be finalized for the GBAR detector



MMD resolution  
~ 120  $\mu$ m

## GBAR final detector

- Present global design
  - 5 planes of 3MMD, 50x50 cm<sup>2</sup>, with X-Y readout
  - Spatial vertex resolution  $\sim 1.5$  mm
  - CR background being studied
  
- First 3 modules to be built soon
  - With prototype experience
  - 15 modules ready for summer 2017
  
- Scintillator coverage to be designed
  - Contribution from Korean groups.





# Overview of 2015

- The GBAR collaboration got new forces
  - 2 Korean groups
  - New technical coordinator
- All subparts of the experiment are now covered

## GBAR starts installation at CERN in 2016:

- Linac bunker (Jan.-Apr.)
- Linac installation and commissioning (June)
- Installation of the e<sup>+</sup> beam line (Sept.)
- Start installation of the decelerator → aims to be in phase with ELENA commissioning



**THANK YOU**



# GBAR Planning...

| Task                          | Institut; leader               | 2016 |     |     |     |     |     |     |     |     |     |     |     | 2017 |     |     |     |     |     |     |     |     |     |     |     |
|-------------------------------|--------------------------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                               |                                | Jan  | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan  | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| <b>e+ production</b>          |                                |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| Linac Bunker                  | Cem-EN; F. Butin               |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| Linac                         | NCBJ; S. Wronka                |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| e+ source & beam line         | Saclay; L.Liszky               |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| <b>e+ trapping</b>            |                                |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| e+ Buffer Gas Trap            | Swansea/Saclay; D.van der Werf |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| e+ accumulator trap           | Saclay; Y. Sacquin             |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| <b>Ps</b>                     |                                |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| Ps target                     | Saclay; L.Liszky               |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| Ps excitation                 | LKB; F. Nez                    |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| <b>Pbar deceleration</b>      |                                |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| decelerator final             | CSNSM; D. Lunney               |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| Hbar+ transport               | CSNSM; D. Lunney               |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| <b>Hbar+ cooling</b>          |                                |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| capture trap                  | LKB; L. Hilico                 |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| precision trap + chamber      | JGU; F. Schmidt-Kaler          |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| photodetachment               | LKB; L.Hilico                  |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| <b>Detector</b>               |                                |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| Scintillators                 | SNU; S.K. Kim                  |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| Tracker                       | ETHZ; P. Crivelli              |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| <b>Slow control &amp; DAQ</b> |                                |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| Slow Control                  | Saclay; P. Lotrus              |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |
| DAQ                           | Saclay; B. Vallage             |      |     |     |     |     |     |     |     |     |     |     |     |      |     |     |     |     |     |     |     |     |     |     |     |

installation  
commissioning

