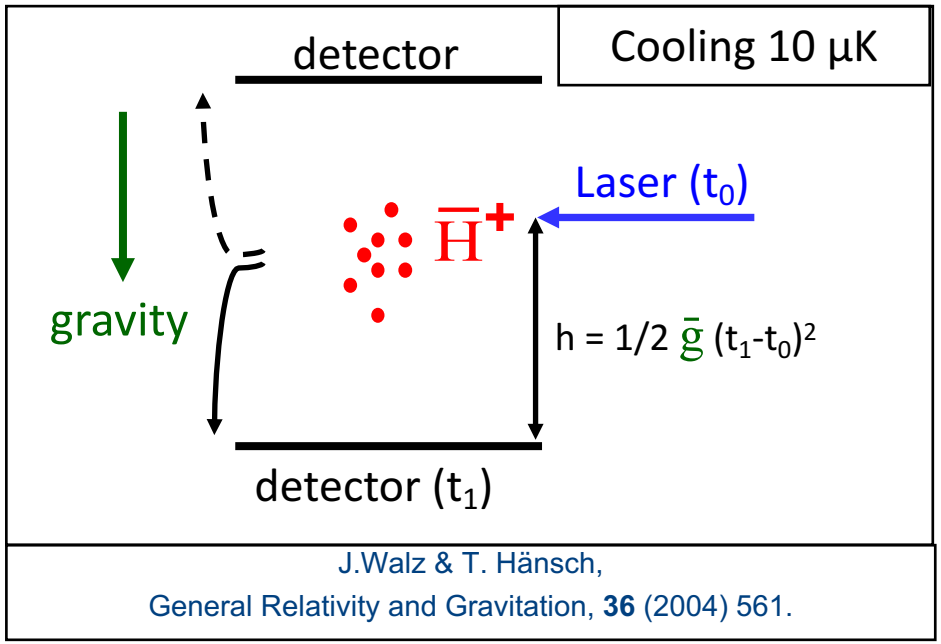
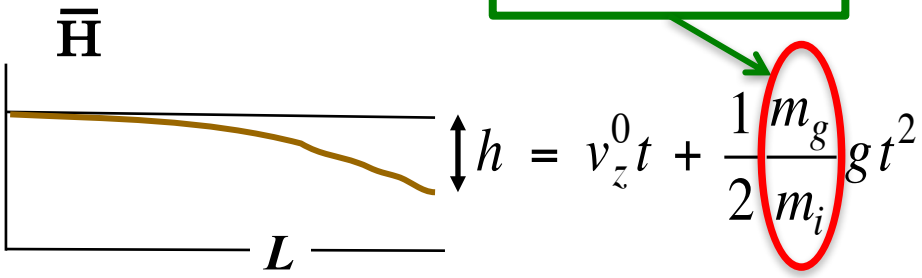
GBAR principle: cool $\bar{H}^+$ to get ultra-slow $\bar{H}$

- $\bar{H}^+ = \bar{p}\, e^+ e^+$
- Sympathetic cooling with $Be^+ \rightarrow 10\ \mu K$
- Photodetachment of e^+
- Time of flight



$$m_i \vec{a} = m_g \vec{g}$$



L	0.1 m
h	10 cm
Δt	143 ms
v_h	0.5 m/s
T_H	20 µK ~ 7 neV

Goal

$$\frac{\Delta g}{g} \leq 1\%$$

A recipe to produce anti ions

Standard $\bar{H}$ production via 3-body process

$$\bar{p} + e^+ + e^+ \rightarrow \bar{H}^* + e^+$$

bound e^+e^- → 3-body

demonstrated by ATRAP (2004)

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

Idea for GBAR:
2nd charge exchange reaction

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

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

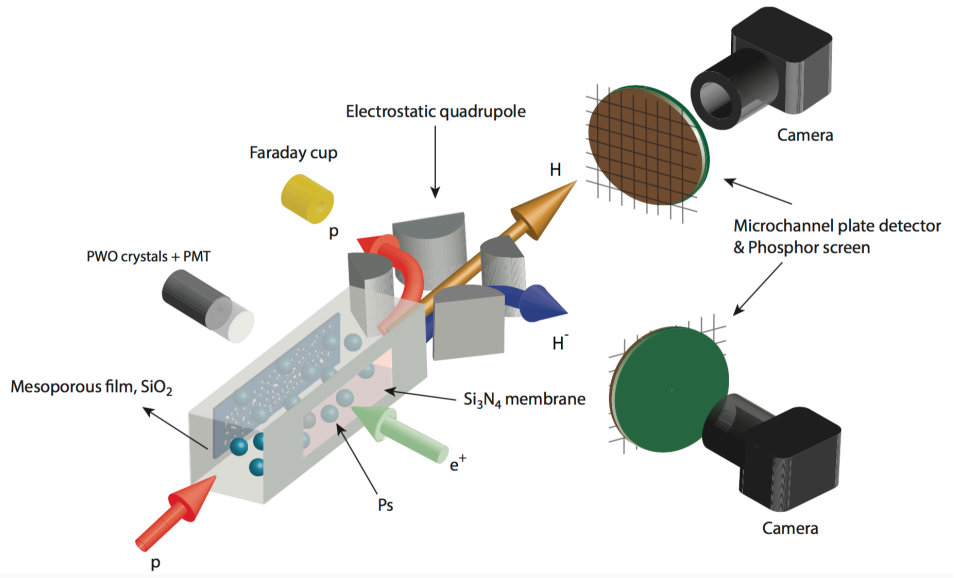
Binding energy of $\bar{H}^+$ = 0.75 eV = energy level of Ps(n=3)

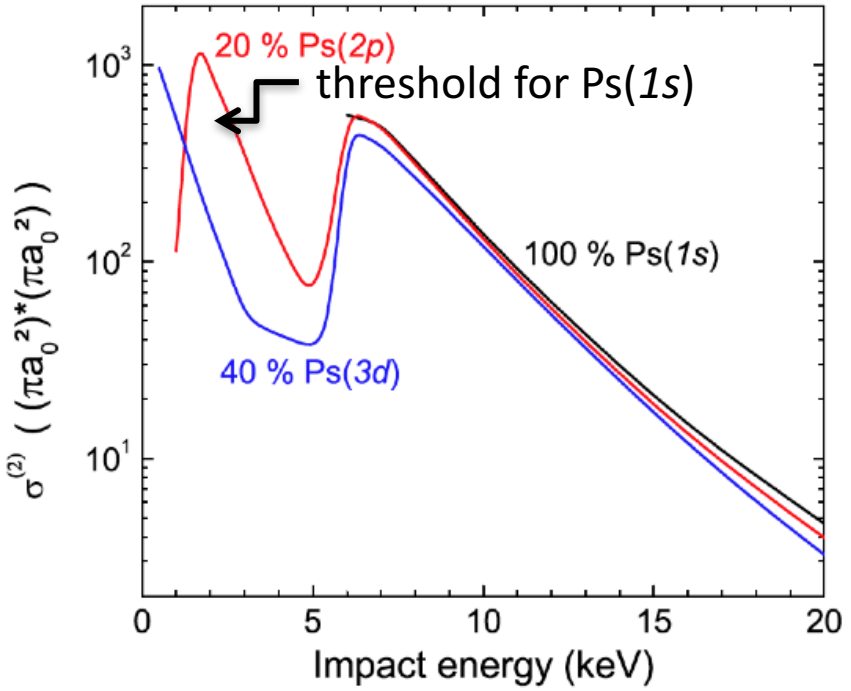
→ Expect cross-section enhancement if Ps excited to n=3

$\bar{H}^+$ production

CERN provides per bunch every 110 s

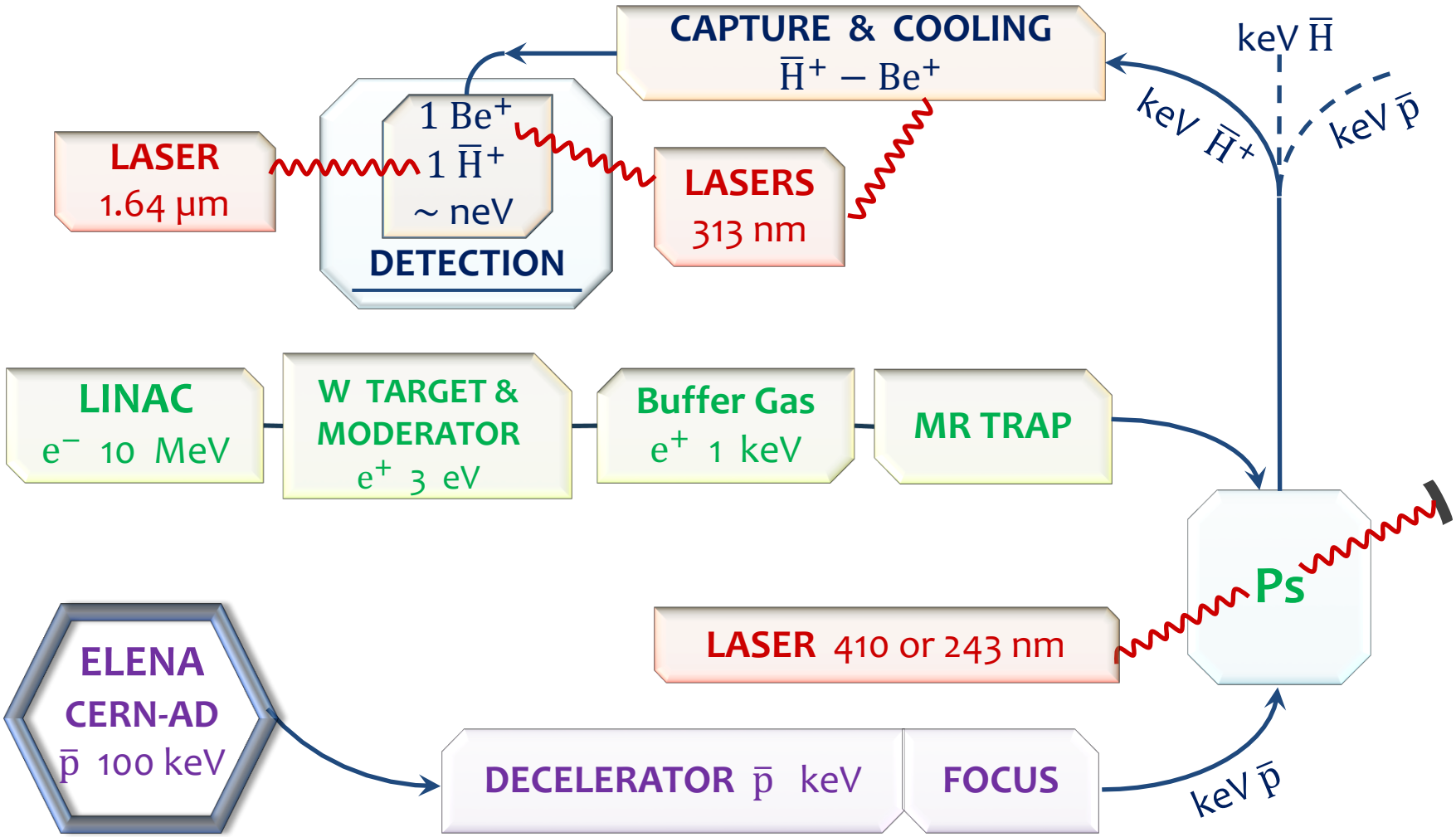
→ ~0.5 10^7 $\bar{p}$ and 10^{12} P_S /cm² → 10^4 $\bar{H}$, 1 $\bar{H}^+$





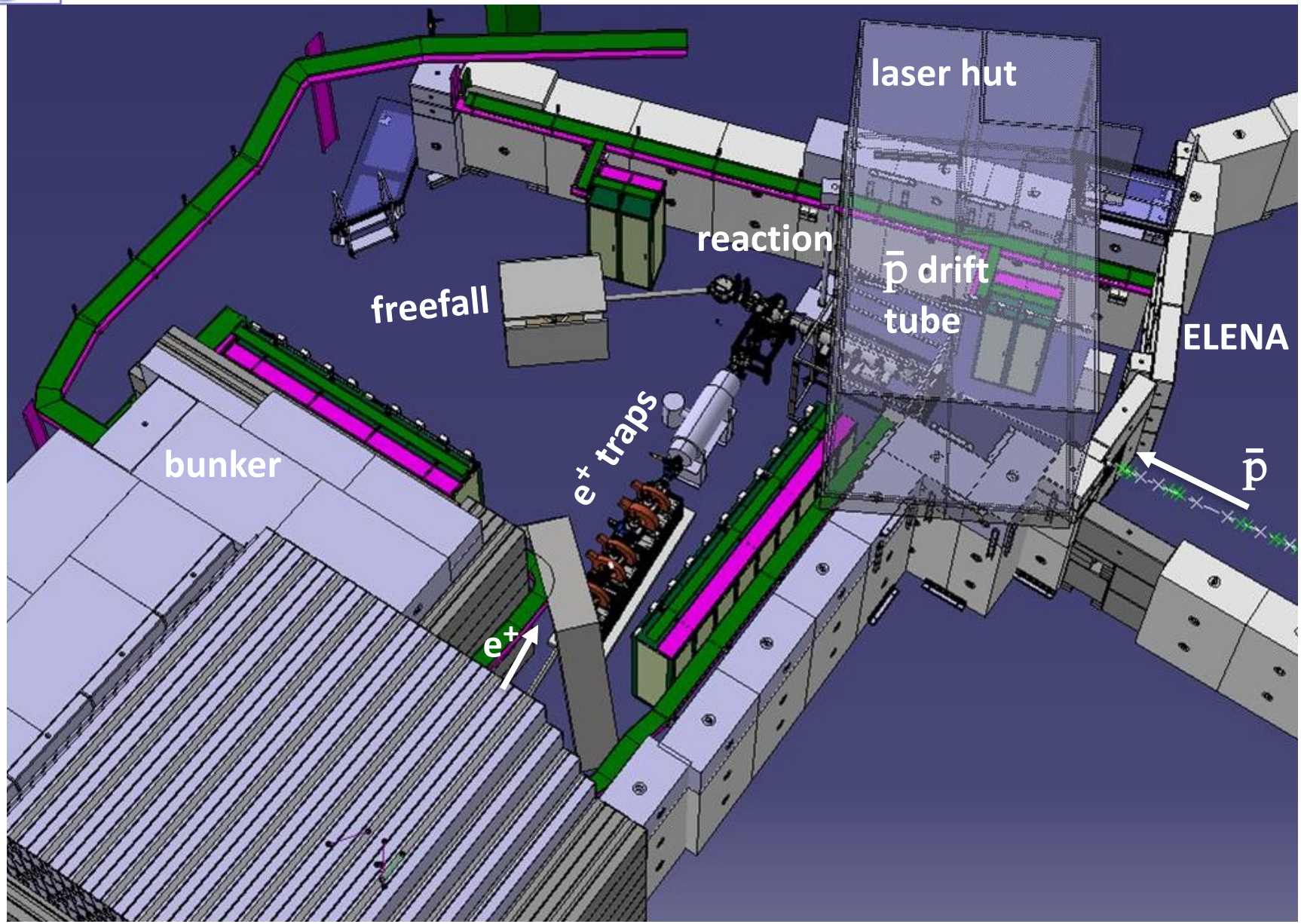
P. Comini and P-A. Hervieux, J. Phys.: Conf. Ser. **443**, 012007 (2013)
P. Comini, P-A. Hervieux and F. Biraben, LEAP 2013

synoptic view

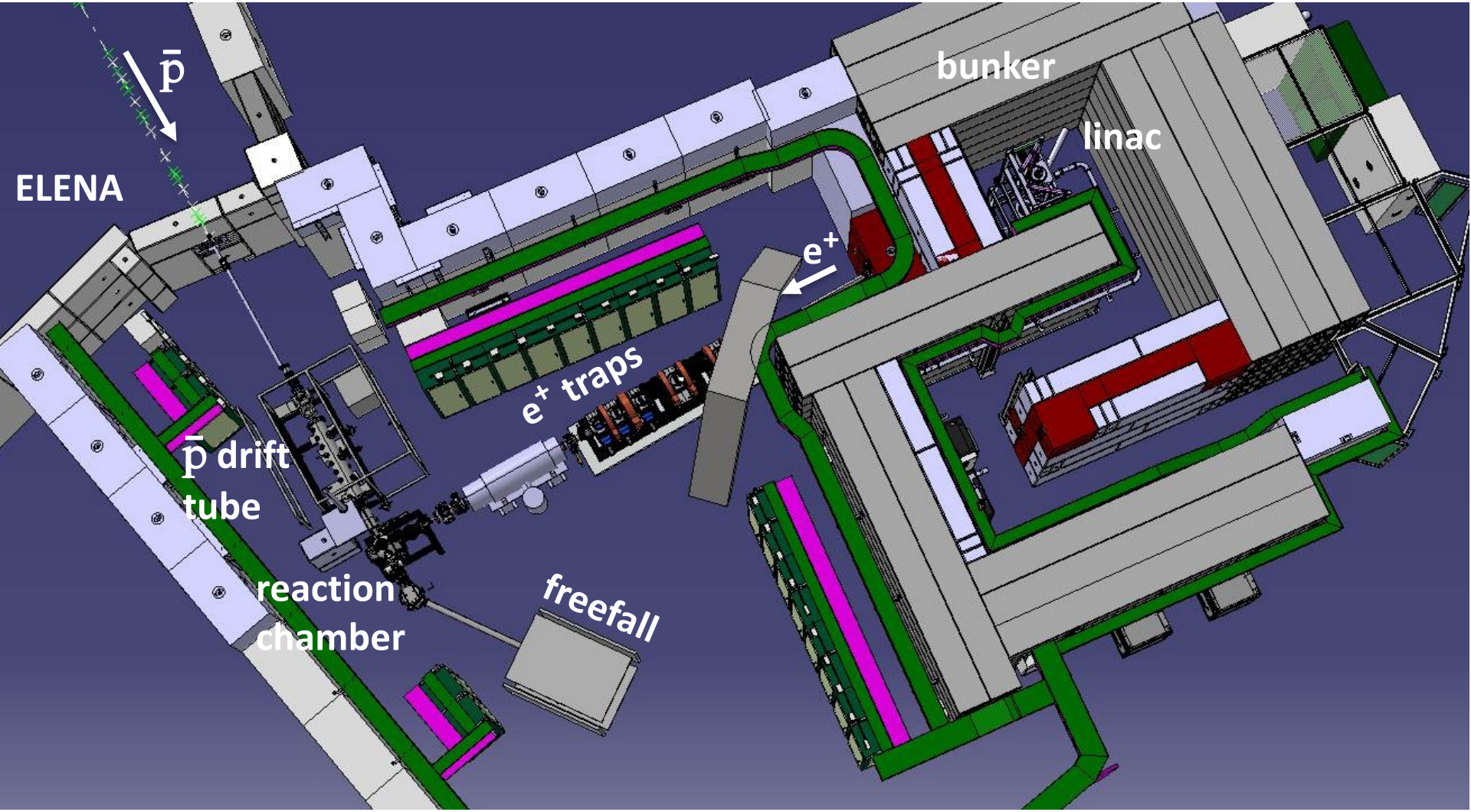


Layout

D. Desforge
O. Choisnet

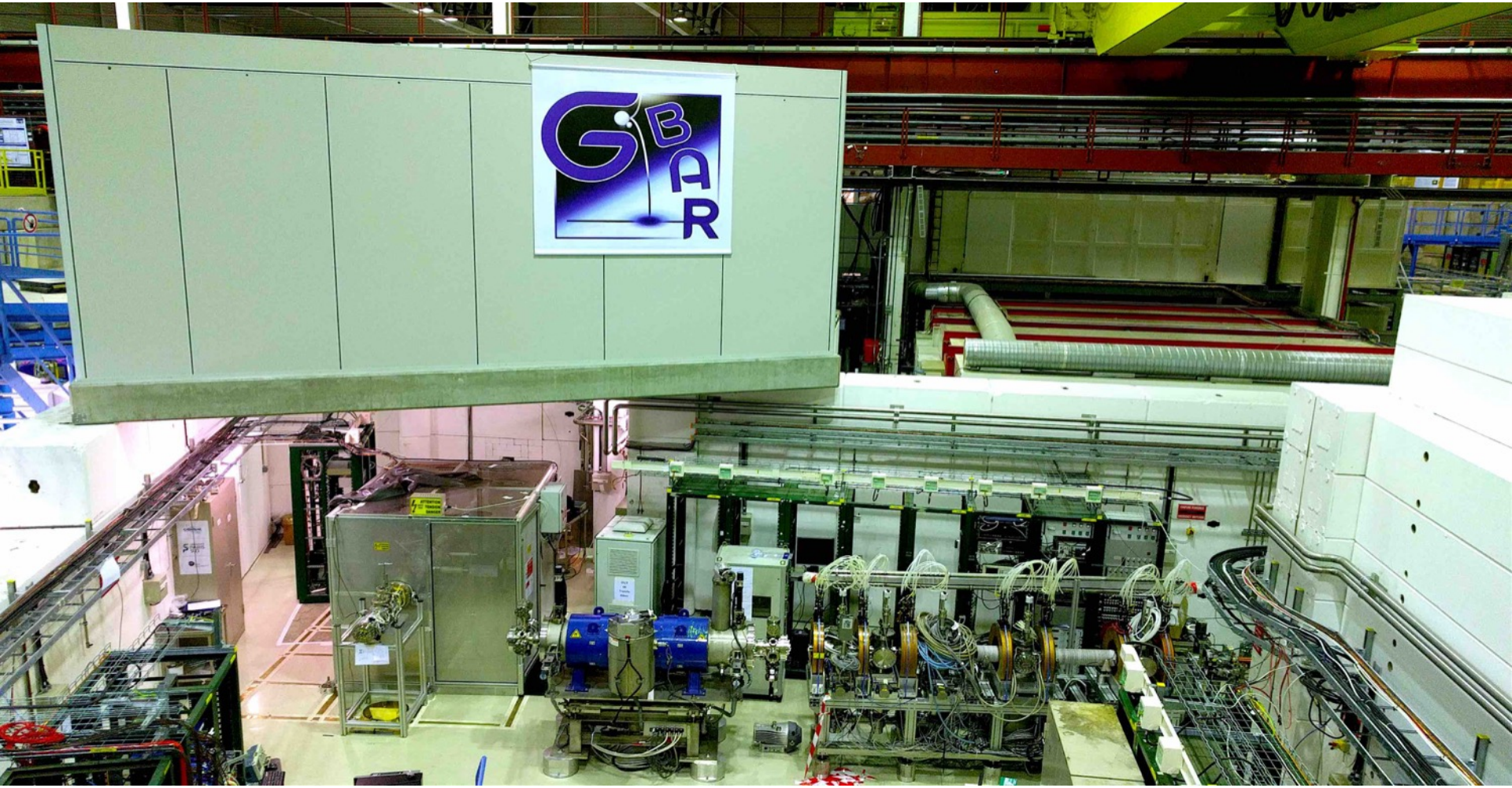


Layout


p̄
ELENA
bunker
linac
e+
e+ traps
p̄ drift tube
reaction chamber
freefall

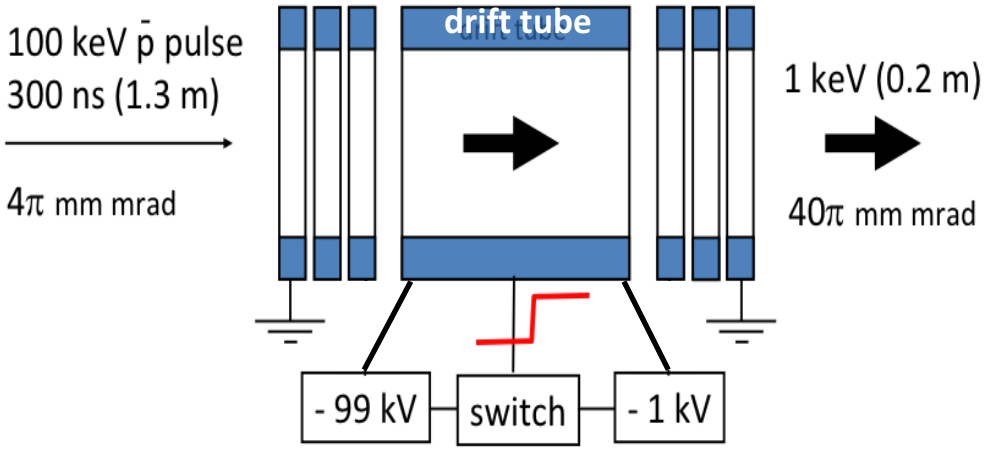
Installation

G. Mornacchi
J-Y. Roussé



Proton/antiproton decelerator

D. Lunney
A. Husson



Tested and ready for 100 kV switching

Vacuum 5 10^{-9} mbar OK for passage of $\bar{p}$ but too high for ELENA

Chamber will be changed before April 2018 → 10^{-10} mbar

Proton gun for tests

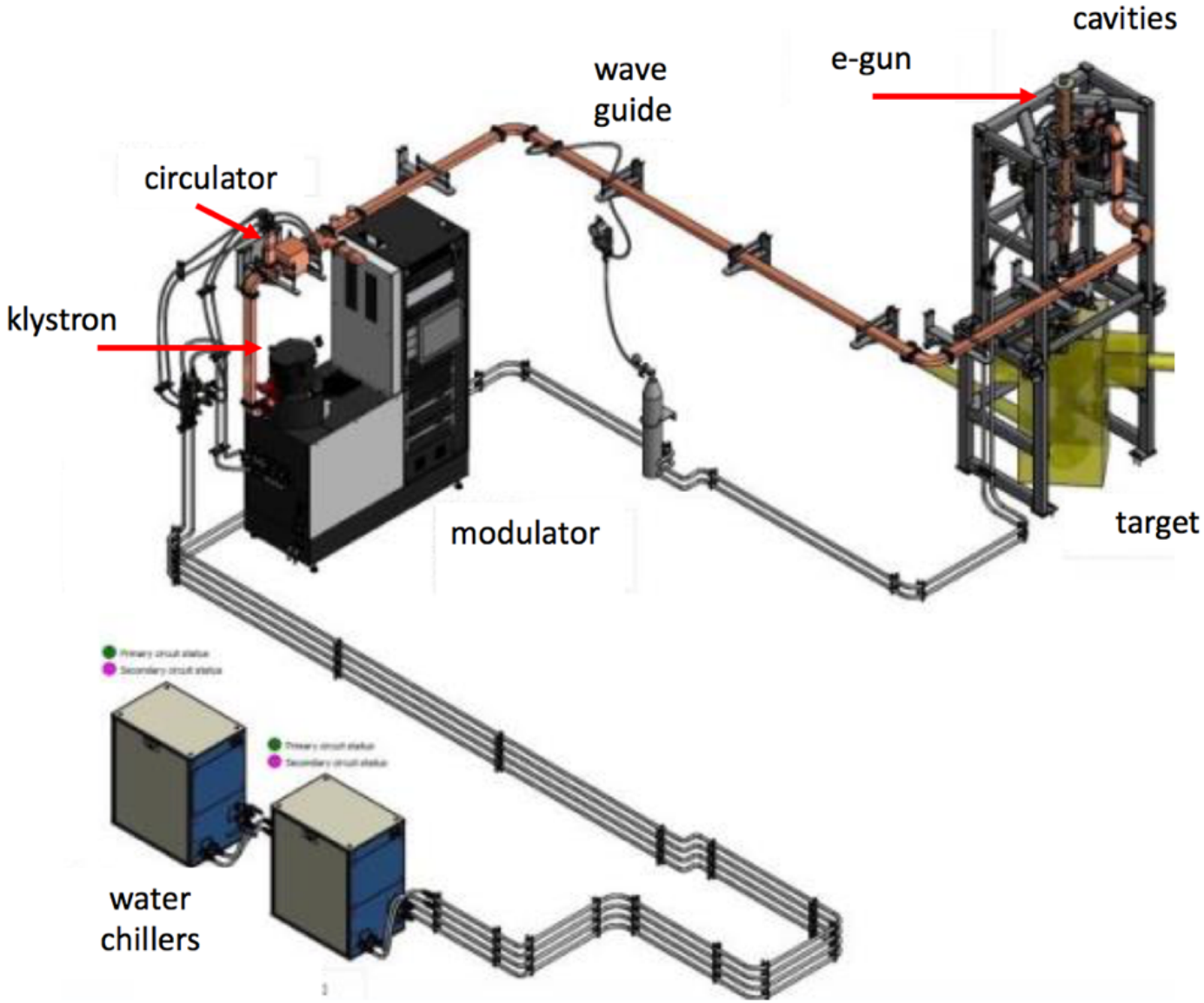
$\bar{p}$ trap from Korea

S. Kim et al.

- 7 T superconducting magnet with active shielding
- will be operated at 3 T
- being equipped → trap
- now at Korea University Seoul
- to be tested with electrons in Korea
- then transport to CERN in 2018?

Electron Linac

M. Matusiak
S. Wronka



Electron Linac

M. Matusiak
S. Wronka

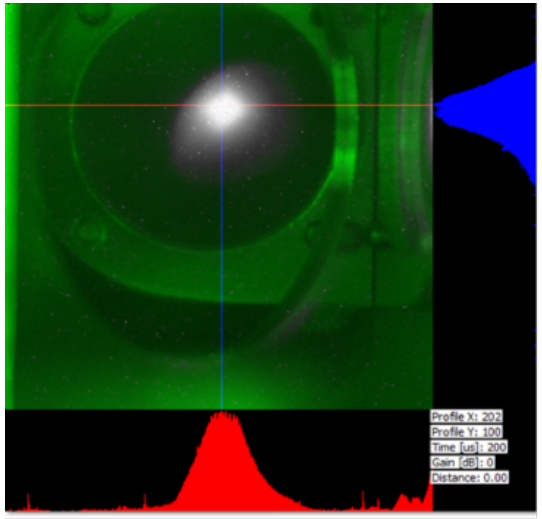
- installation started in February 2017
- temporary accelerating cavity structure
- destruction of heat exchangers due to > 20 bar water pressure bursts
- leaks in wave guide → procurement delay
- extensive safety documentation
- two operation modes depend on repetition rate:
  - < 3 Hz allow working in exp. zone
  - 3-300 Hz zone patrolled, work in remote control
- radiation shield tested with RP

  → OK after few adjustments
- beam permit approved for October 2017

Electron Linac

M. Matusiak
S. Wronka

RF waveform and pulses from gun and BCT



beam spot on YAG screen

- first beam in October 2017
- beam energy measured with magnetic spectrometer
- set operating point at 8.3 MeV / 100 mA to keep safety margin

  (activation threshold ~10 MeV)
- repetition rate limited to 100 Hz due to target outgassing

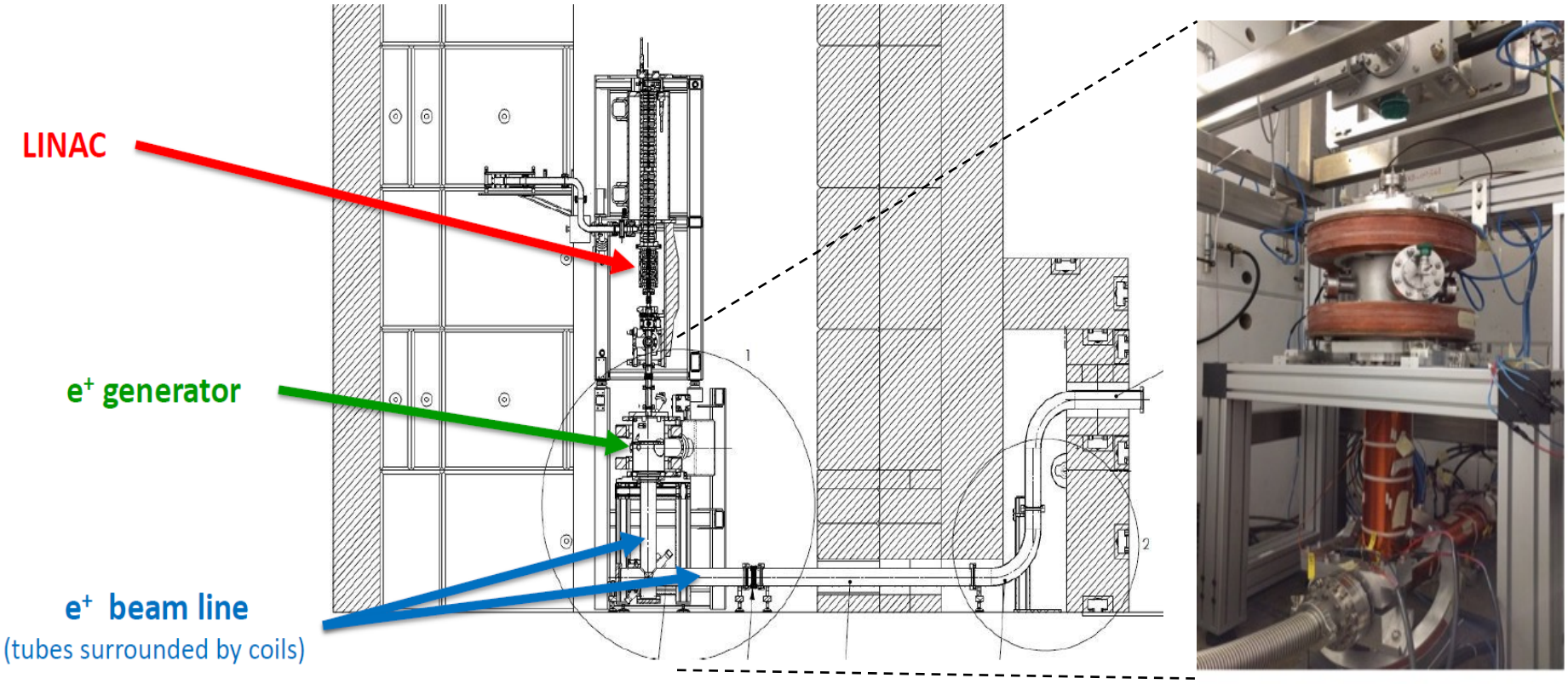
Electron Linac

M. Matusiak
S. Wronka

- final accelerating structure completed at NCBJ
- new gun → 1 A/4 μs pulses
- tests OK at 300 mA peak / 7.5 MeV → 10 MeV
- installation starts Feb. 12 (3 weeks)

Positron production

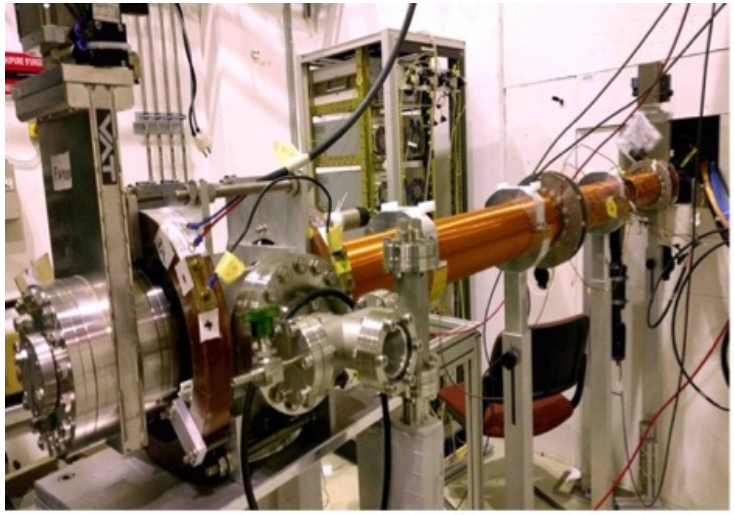
L. Liszkay
Y. Sacquin, B. Latacz



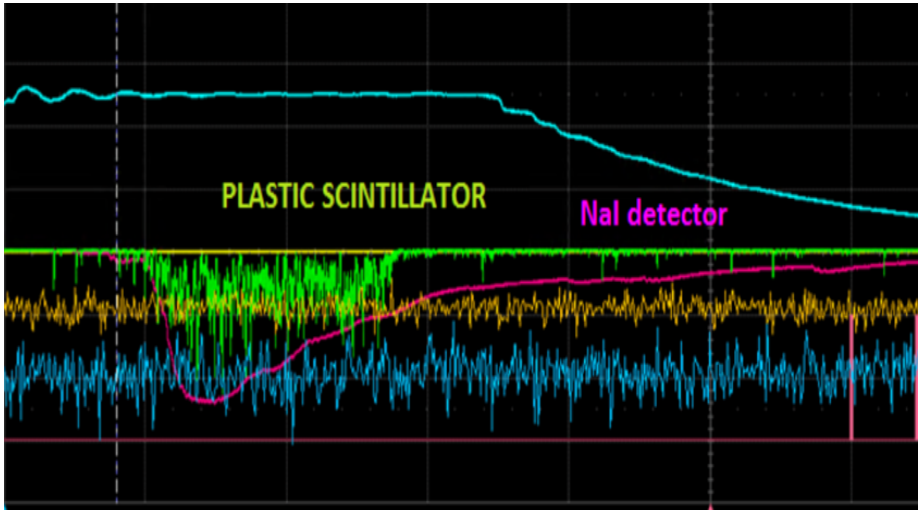
- Tungsten target is water cooled
- Tungsten mesh moderator
- slow positrons are guided outside the bunker using 8 mT solenoids and coils

Positron measurement

L. Liszkay
Y. Sacquin, B. Latacz



e^+ beam line exiting the bunker



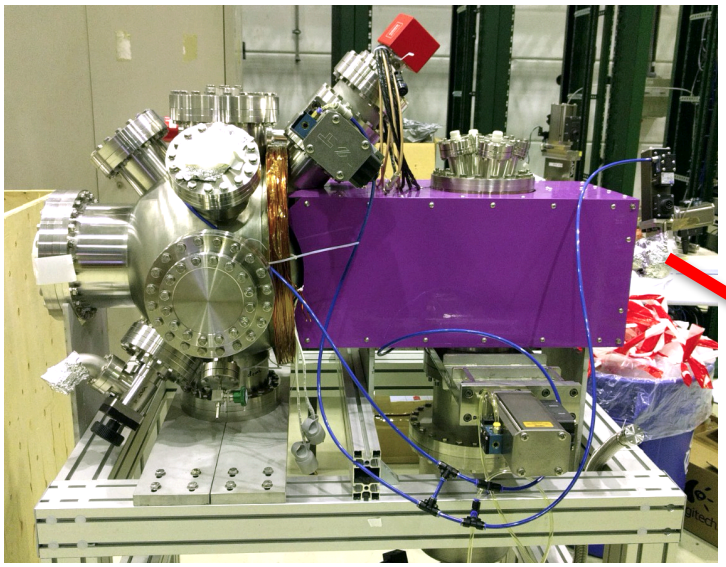
first e^+ signals on Nov. 17

- slow positrons hit a target outside the bunker and produce 2 gammas of 511 keV
- gamma detection with NaI or plastic scintillator
- energy measured with retarding potential grid
- 3.7 10^4 e^+ / pulse
- outgassing limited in 2017, ready to proceed to higher linac power
- energy spread 1.3 eV (std dev.) suitable for buffer gas trapping

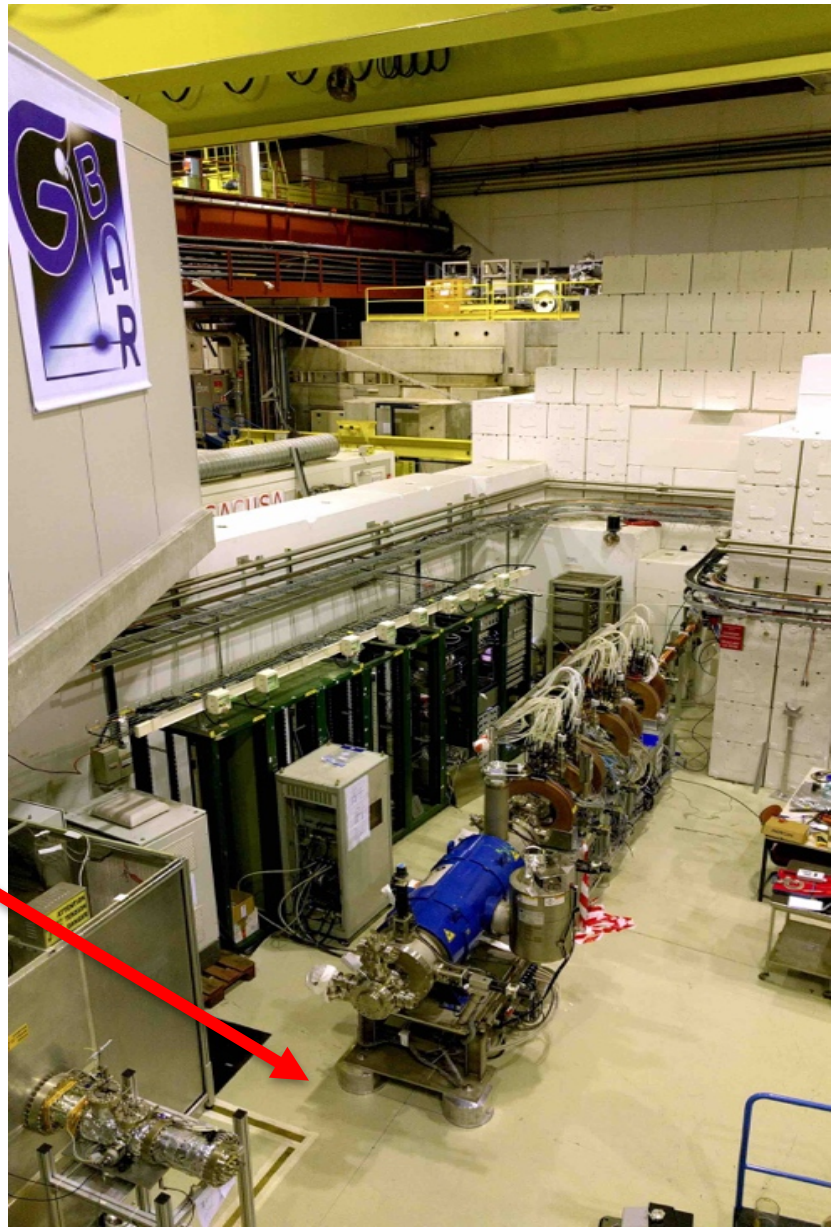
Positron trapping

D. van der Werf
L. Liszkay

- Buffer Gas Trap built & tested at Saclay
- High field Trap from RIKEN repaired (cryoheads)
- aligned in exp. zone
- being commissioned for trapping

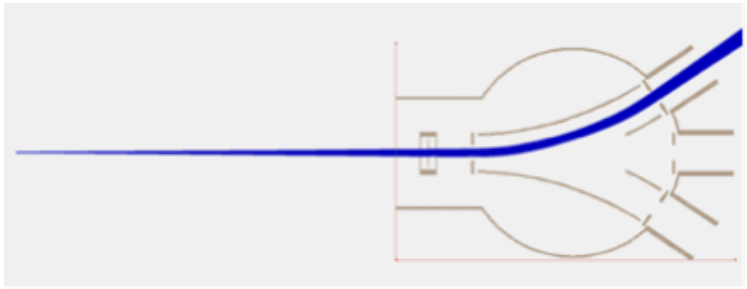


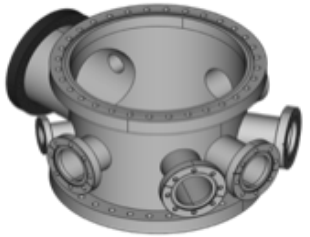
reaction chamber ready for installation



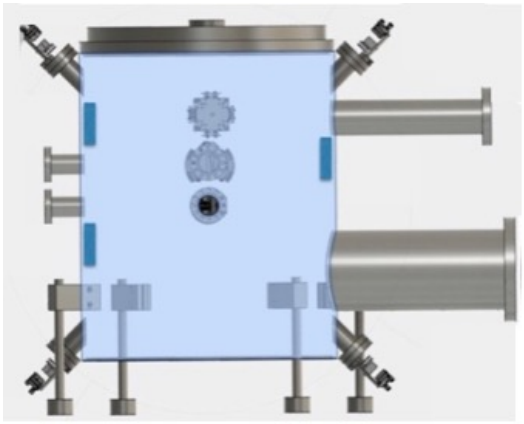
Other items in preparation

switchyard to distribute $\bar{p}$, $\overline{H}$ and $\overline{H}^+$

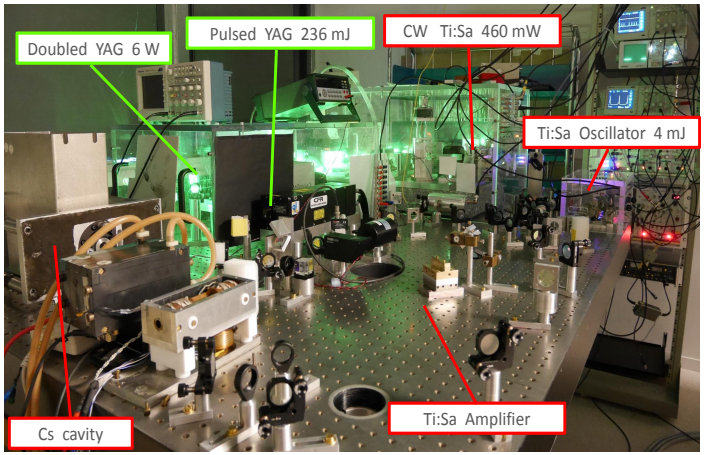




free fall chamber



Ps excitation laser

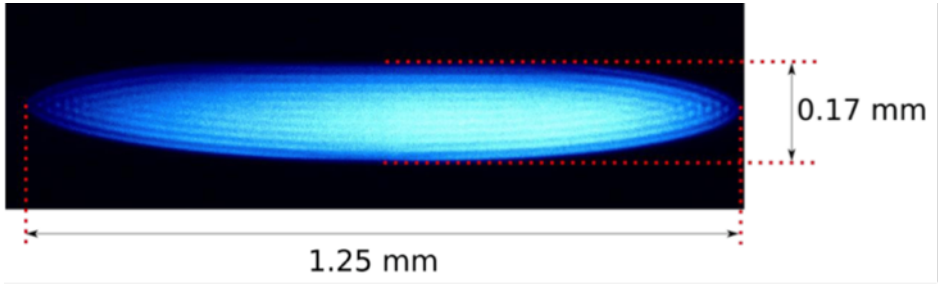


Be^+ cooling towards H_2^+ cooling

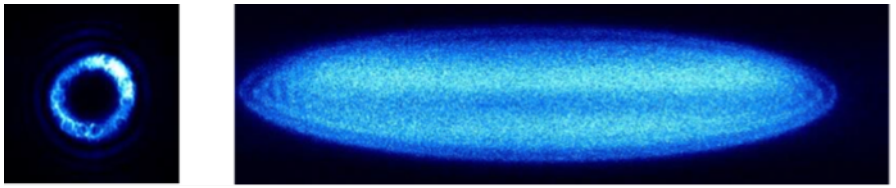
LKB team

LKB Paris-Jussieu

Be^+ crystal

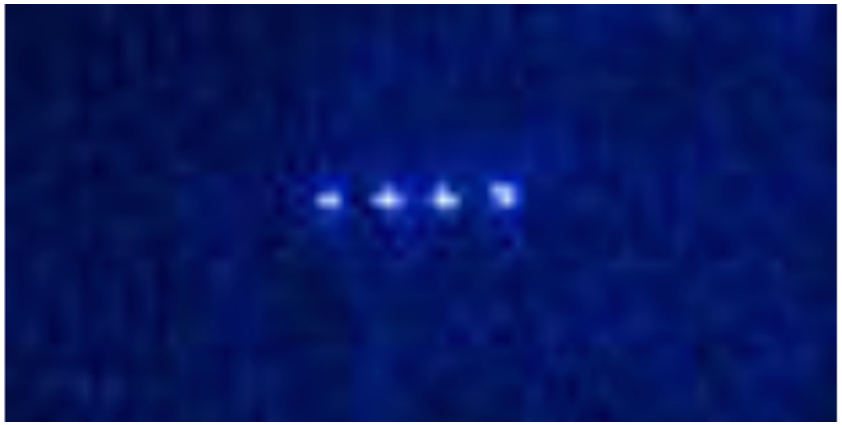


Hollow crystal

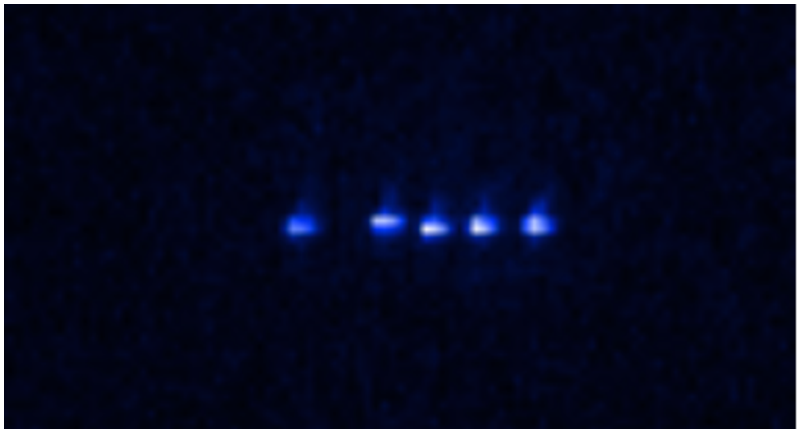


Mixed crystals

S. Wolf
F. Schmidt-Kaler

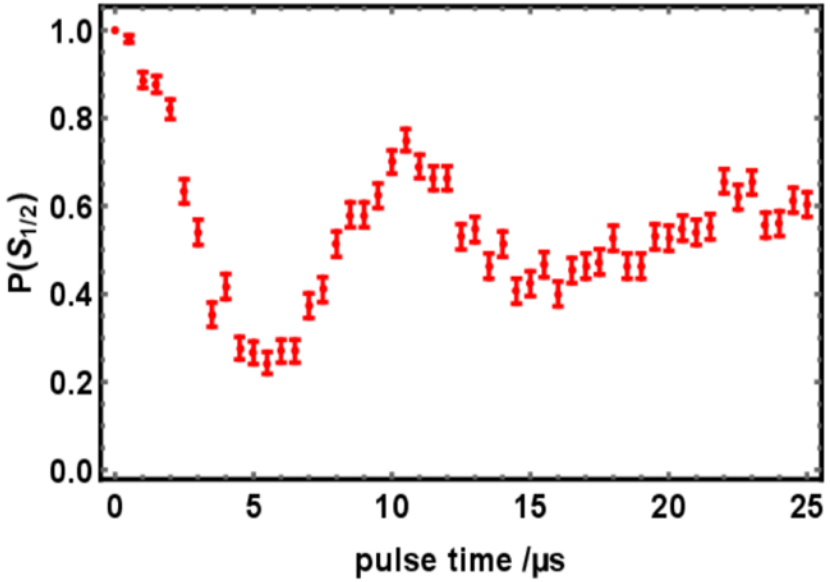


fluorescent Be^+ crystal



Ca^+ crystal with dark Be^+ ion

Rabi-flops on axial COM mode of a mixed crystal



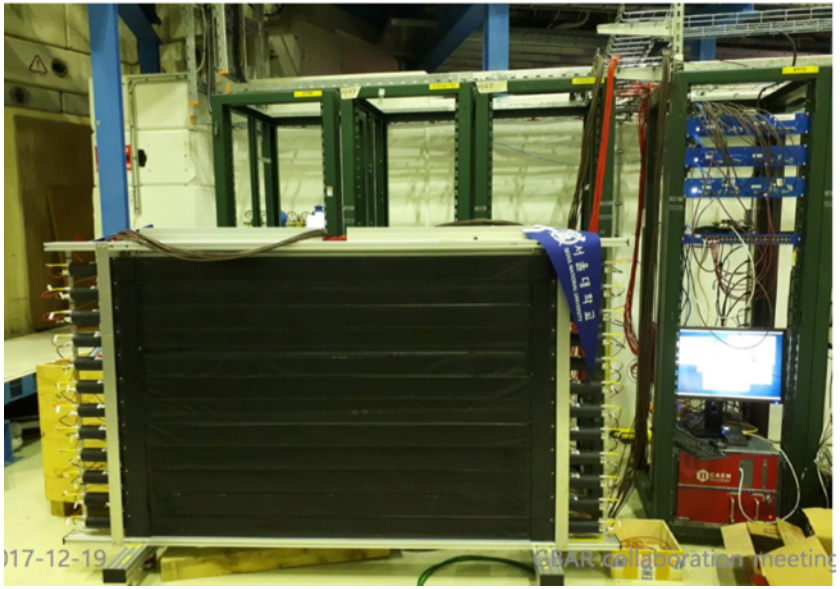
Mainz –JGUM lab

Detection

First plane of TOF counters operational

time resolution 80 ps

→ can distinguish particles going up from down, i.e. annihilations occurring at top or bottom of free-fall vessel or cosmic rays



a plane of TOF bars from SNU

Five double planes of MicroMegas chambers made

Increase of gap from 5 mm to 10 mm

Change gas mixture → Ar/CF4/Isobutane (96/2/2)

→ better than 96 % efficiency per X/Y plane

Outlook

- final linac
- drift tube decelerator with 10 kV protons,
  then ~100 keV H^- from ELENA
- e^+ traps
- Ps in reaction chamber
- Ps* laser
- first $\bar{p}$ for physics (June-July?)
- antihydrogen beam in 2018 ?

GBAR Collaboration

D. Banerjee, F. Biraben, M. Charlton, M. Chung, P. Cladé, P. Comini, P.-P. Crépin, P. Crivelli, O. Dalkarov, P. Debu, L. Dodd, A. Douillet, G. Dufour, P. Dupré, P. Froelich, S. Guellati, R. Guérout, J. M. Heinrich, P.-A. Hervieux, L. Hilico, A. Husson, J. Hwang, P. Indelicato, G. Janka, S. Jonsell, J.-P. Karr, K. Khabarova, B.H. Kim, S.K. Kim, Y. Kim, E. Kim, N. Kolachevsky, N. Kuroda, A. Lambrecht, B. Latacz, A. Lee, J. Lee, A.M.M. Leite, K. Lévêque, L. Liszkay, P. Lotrus, T. Louvradoux, D. Lunney, N. Madsen, G. Manfredi, B. Mansoulié, Y. Matsuda, A. Mohri, G. Mornacchi, V. Nesvizhevsky, F. Nez, K. Park, P. Pérez, B. Radics, C. Regenfus, J.-M. Rey, J.-M. Reymond, S. Reynaud, J-Y Roussé, A. Rubbia, J. Rzadkiewicz, Y. Sacquin, F. Schmidt-Kaler, N. Sillitoe, M. Staszczak, H. Torii, B. Vallage, M. Valdes, D.P. van der Werf , A. Voronin, S. Wolf, S. Wronka, Y. Yamazaki

Irfu

Laboratoire Kastler Brossel
Physique quantique et applications

P.N.Lebedev Physical Institute of the Russian Academy of Science

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Stockholm University

RIKEN

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東京大学
THE UNIVERSITY OF TOKYO

IPCMS

ibs Institute for Basic Science

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KOREA UNIVERSITY