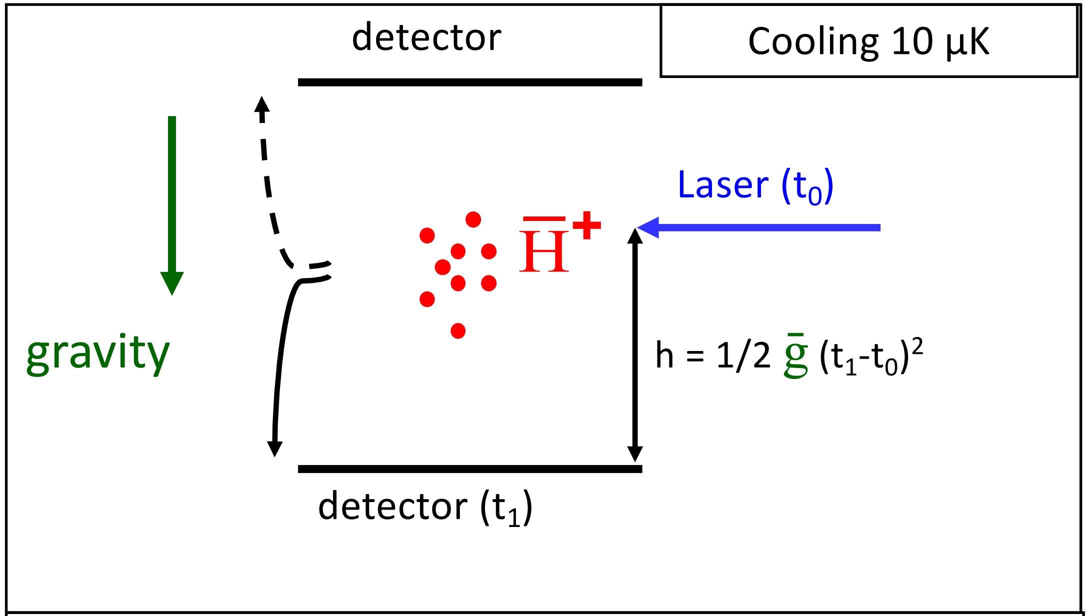
GBAR status report 2020

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

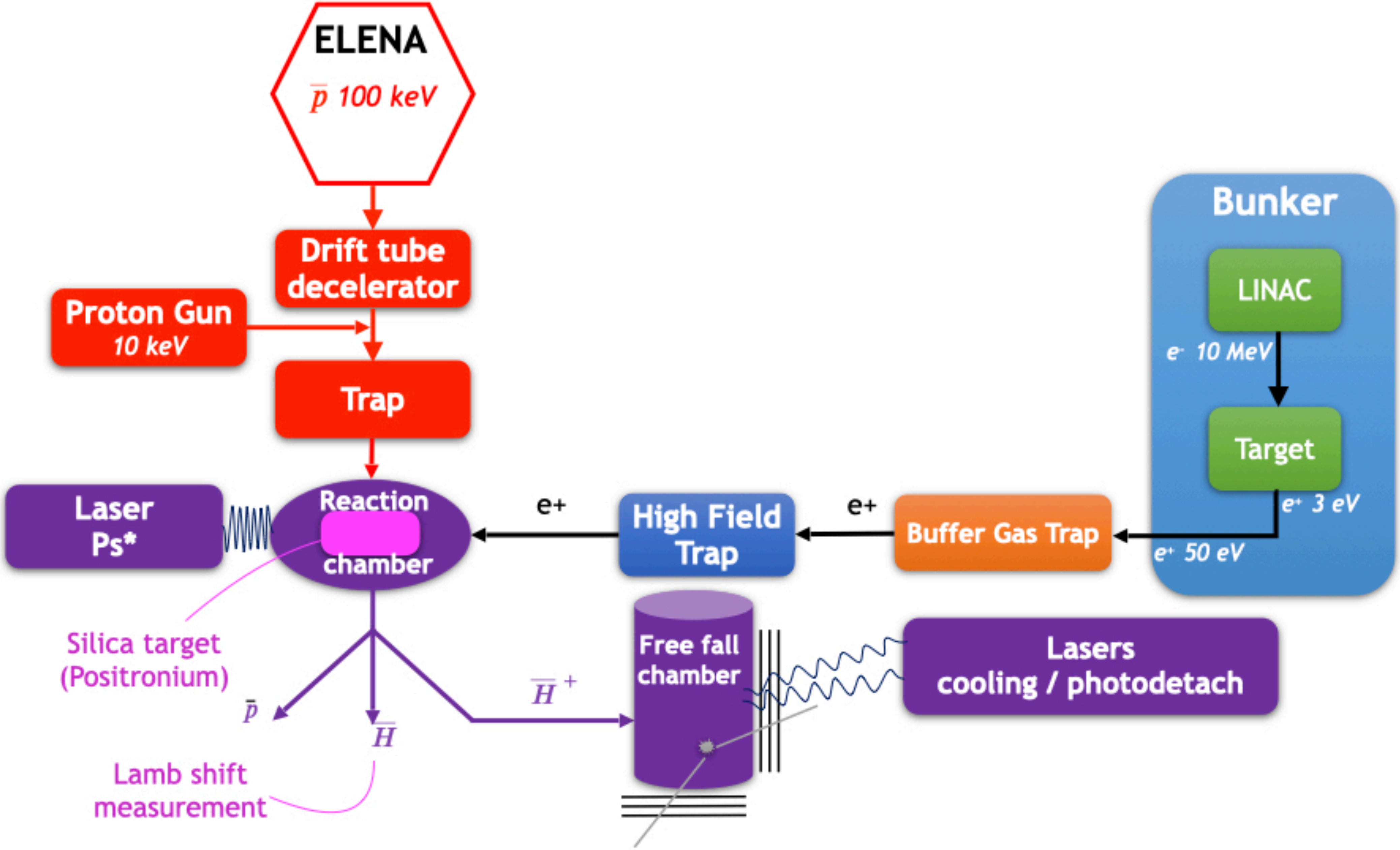
Beam production

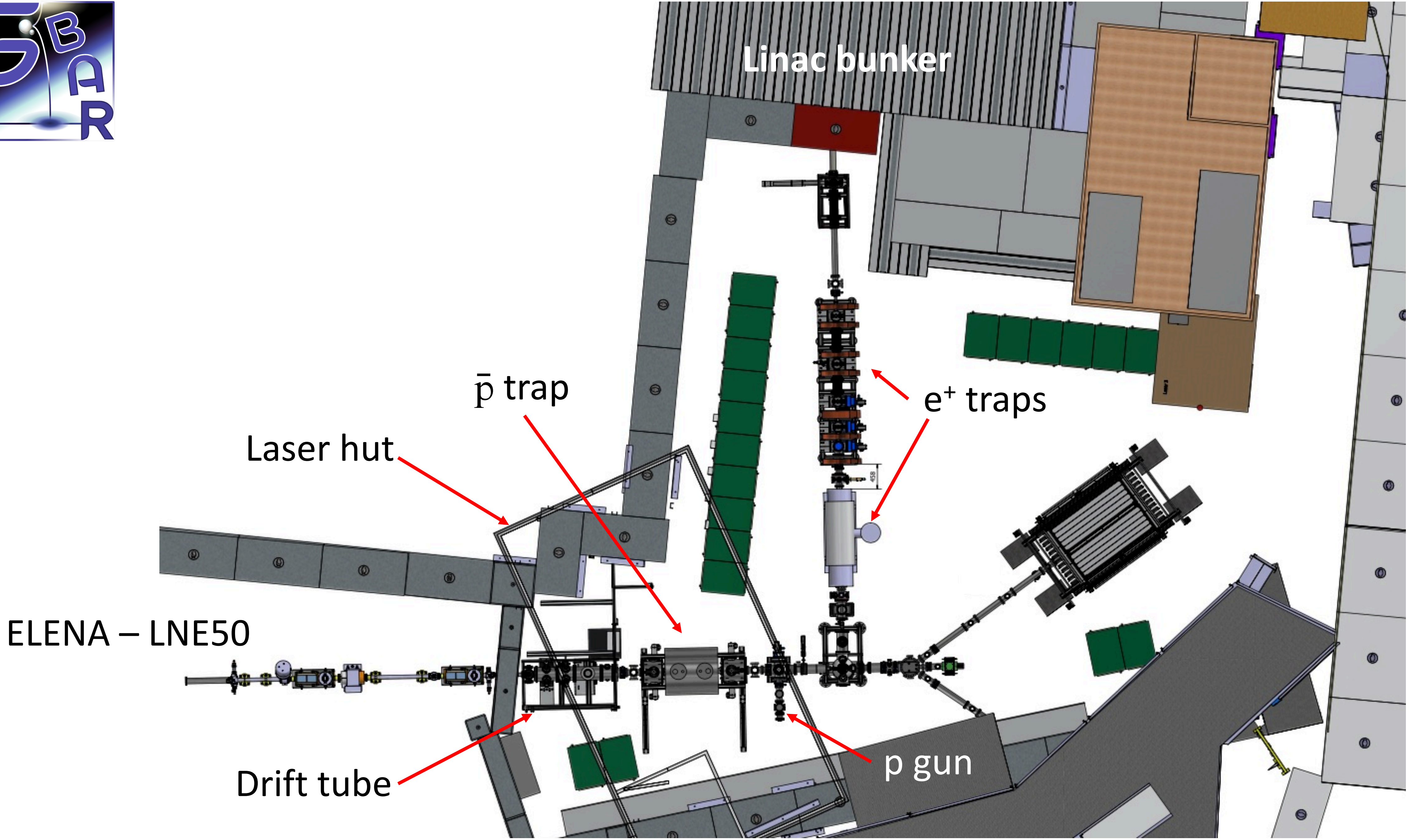
- instead of 3-body process with 2 e^+
- use Ps = e^+e^- , twice
- excite Ps (n=3)

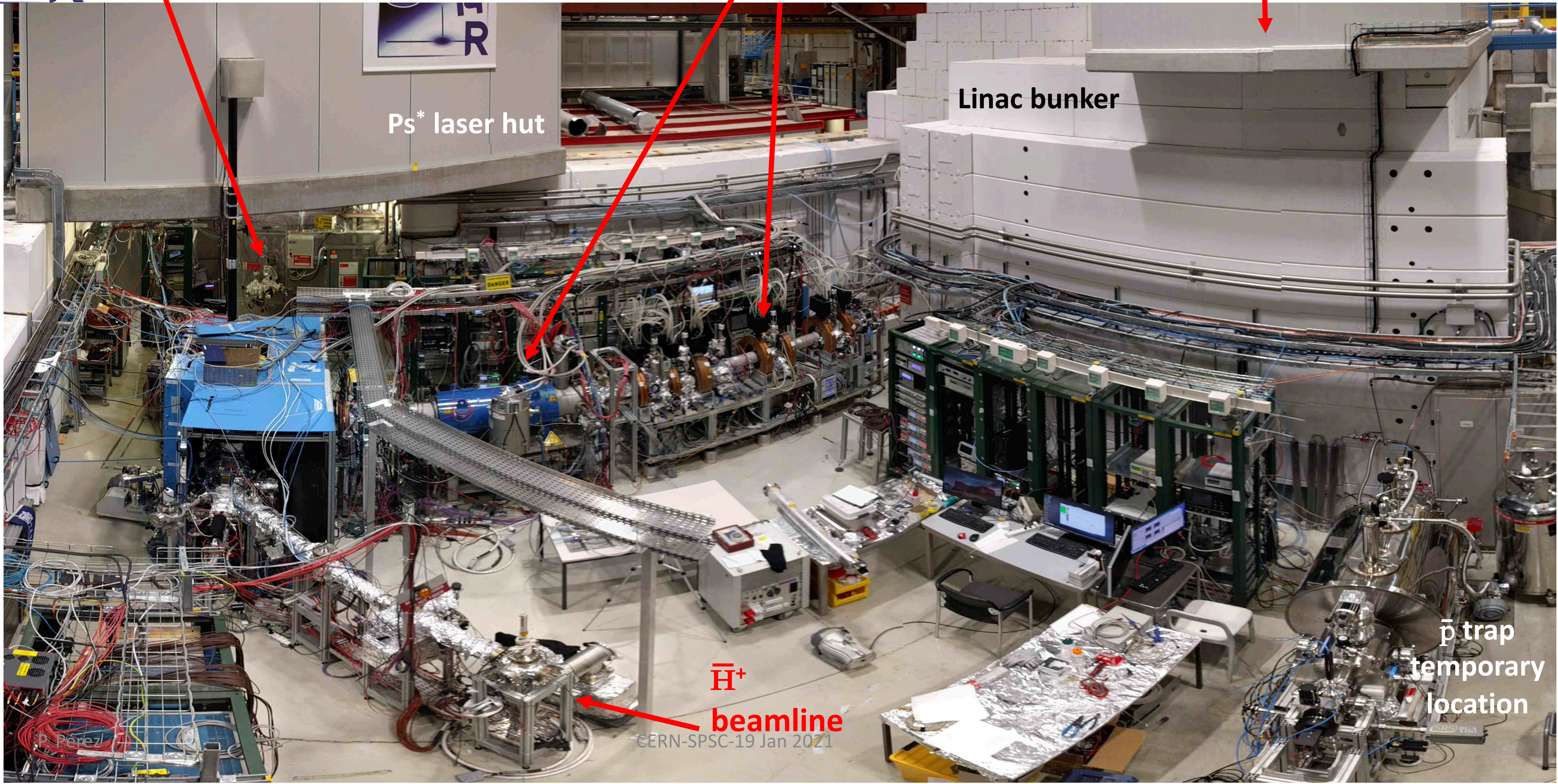
$$\bar{p} + Ps \rightarrow \bar{H} + e^-$$

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

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


ELENA
$\bar{p}$ 100 keV
Drift tube decelerator
Proton Gun
10 keV
Trap
Laser
Ps*
Reaction chamber
e+
High Field Trap
e+
Buffer Gas Trap
Bunker
LINAC
e- 10 MeV
Target
e+ 3 eV
e+ 50 eV
Silica target
(Positronium)
$\bar{p}$
$\bar{H}$
$\bar{H}^+$
Lamb shift
measurement
Free fall chamber
Lasers
cooling / photodetach


Linac bunker
p̄ trap
e⁺ traps
Laser hut
ELENA – LNE50
Drift tube
p gun

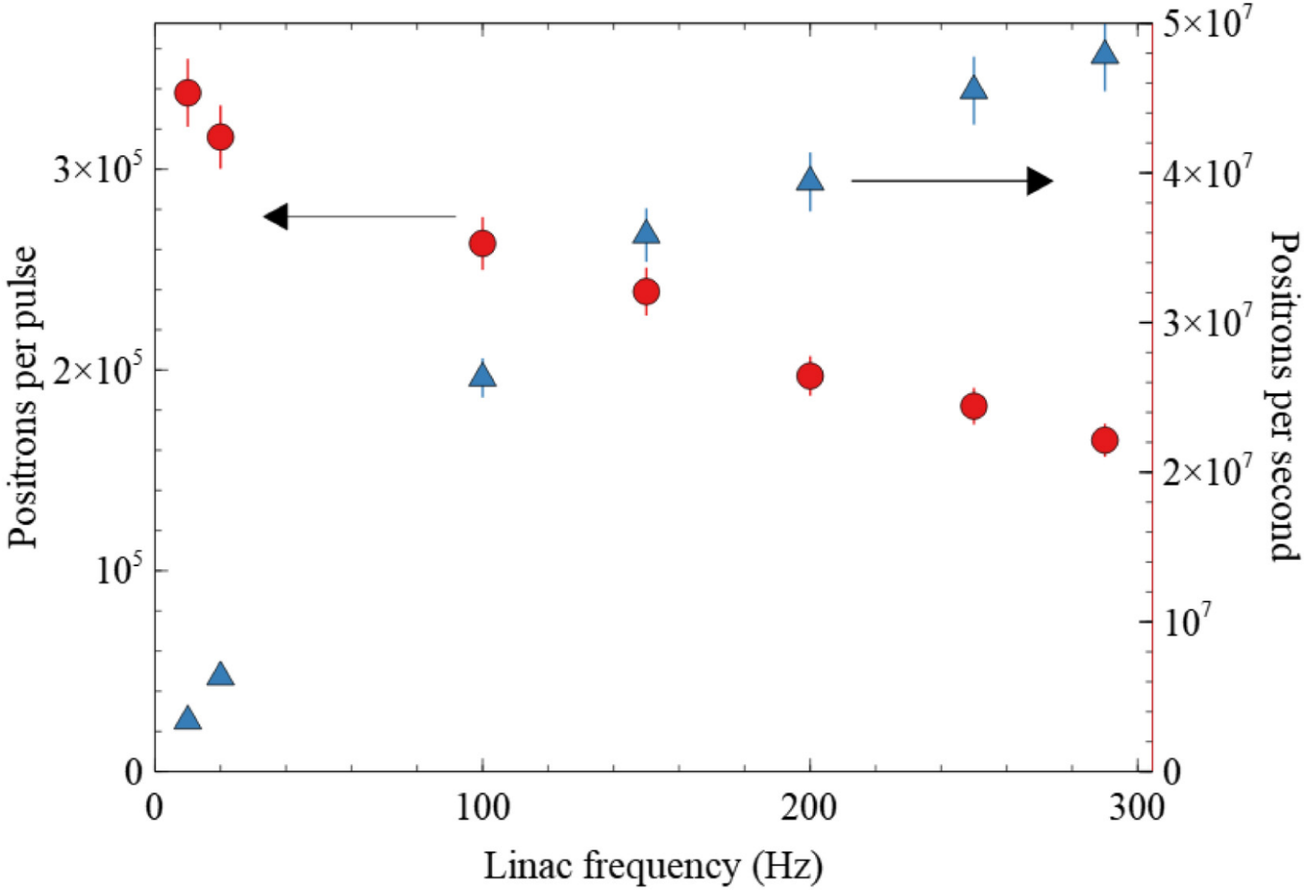


Drift tube
Positron traps
Ion cooling
laser hut
Ps* laser hut
Linac bunker
$\bar{H}^+$
beamline
$\bar{p}$ trap
temporary
location

Positron flux

- 9 MeV, 300 mA, 2.5µs, 1-300 Hz
- 3.4×10^5 e^+ / pulse @10Hz

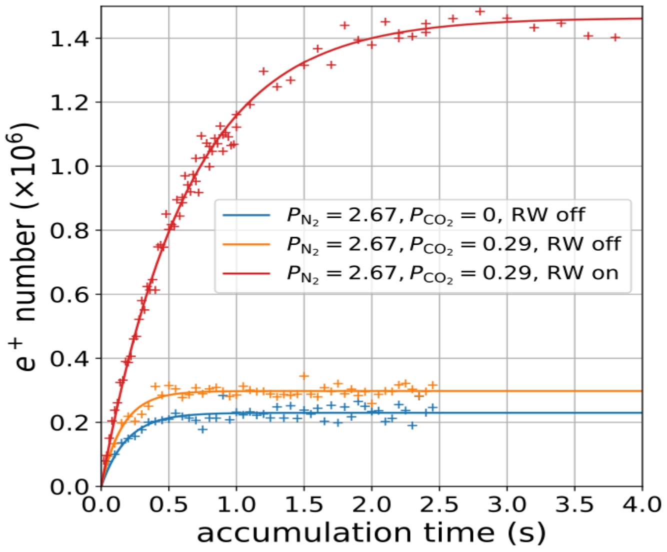
  → factor 2 drop @300 Hz
- Reached 5×10^7 e^+ / s (300 Hz)
- Worked @200 Hz in 2020
- Final commissioning 2021
- Plans to improve moderation
- Goal 3×10^8 e^+ / s

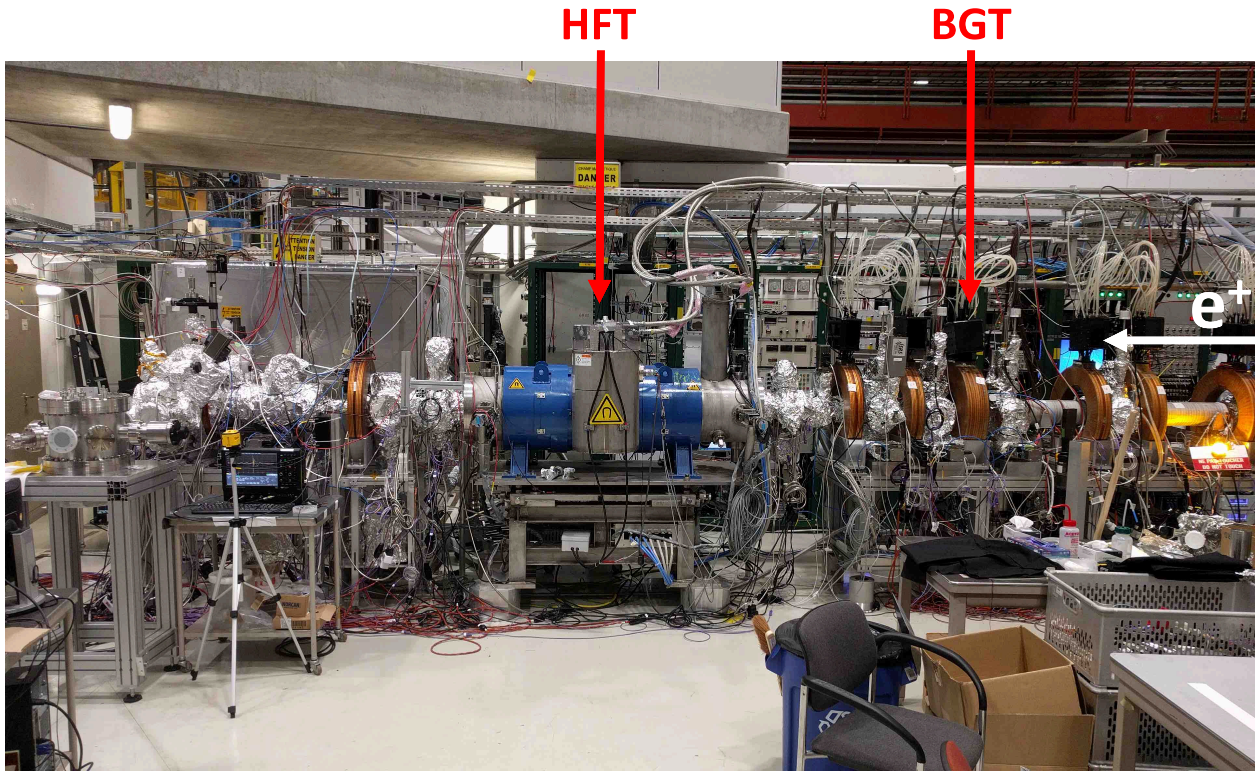


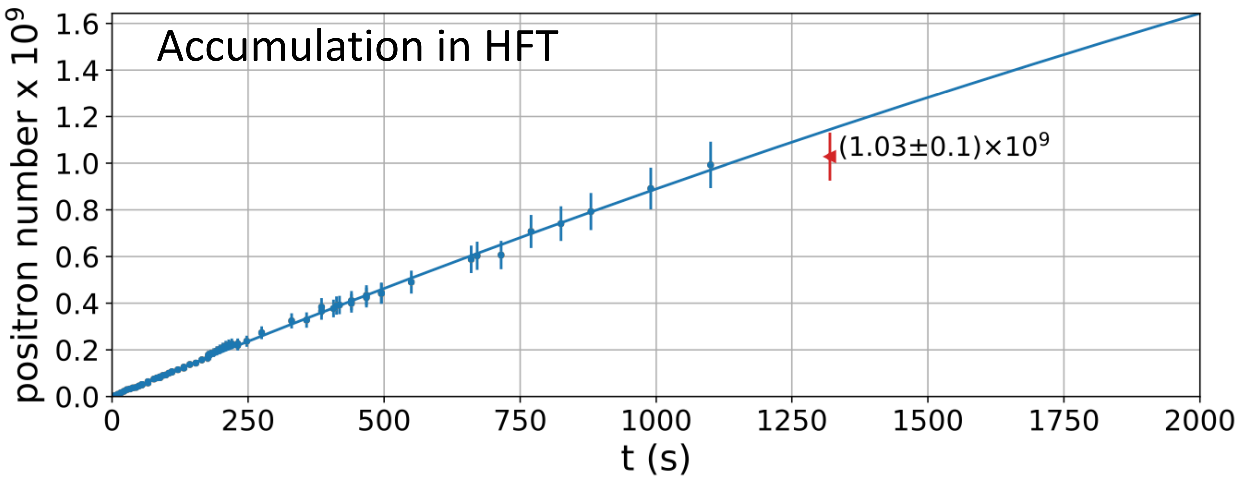
M. Charlton et al., NIM, A 985 (2021) 164657

Positron traps

Effect of rotating wall in BGT







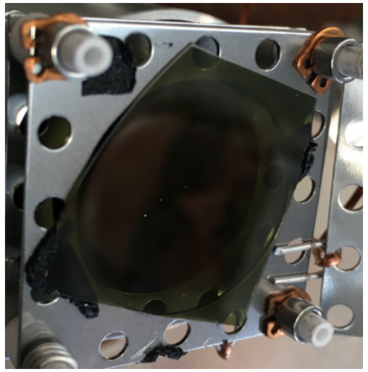
With linac at 200 Hz → 1×10^9 e^+ in 1100 s

Goal: accumulate 3×10^{10} e^+ in 110 s

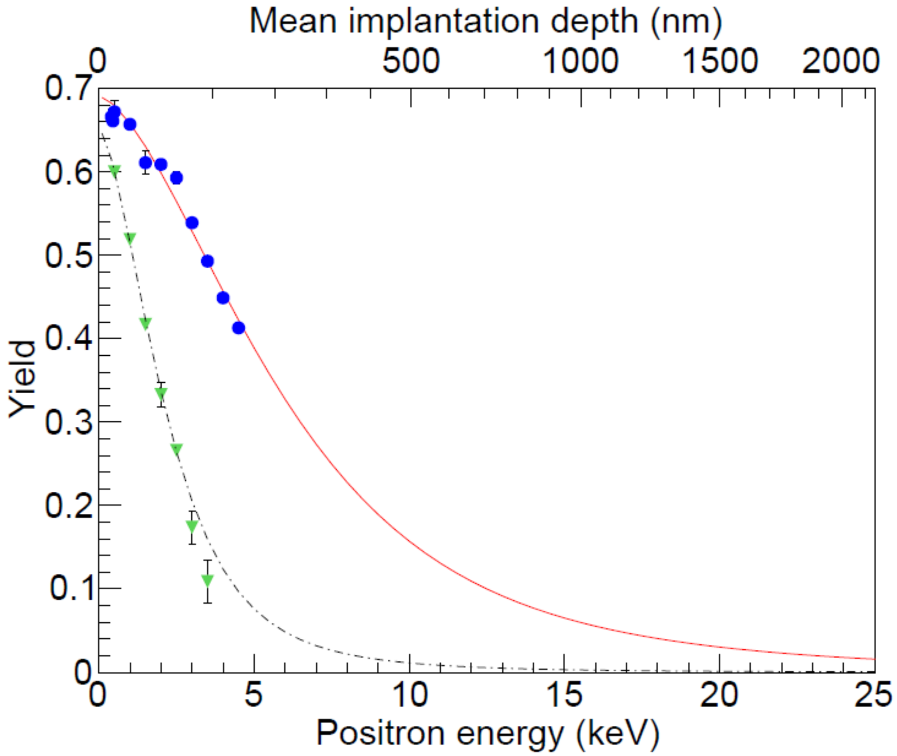
Present total efficiency 3%

Replacement of BGT 1st stage by SiC re-moderator

- Uses pulsed time structure of primary positron beam
- Potentially one order of magnitude gain wrt present efficiency
- Requires bunching 2.5 µs to 700 ns
- Re-moderator efficiency: 60-70 %
- Feasibility studies will be performed at the beginning of 2021
- Challenge: exit from the trap (requires fast removal of the remoderator)

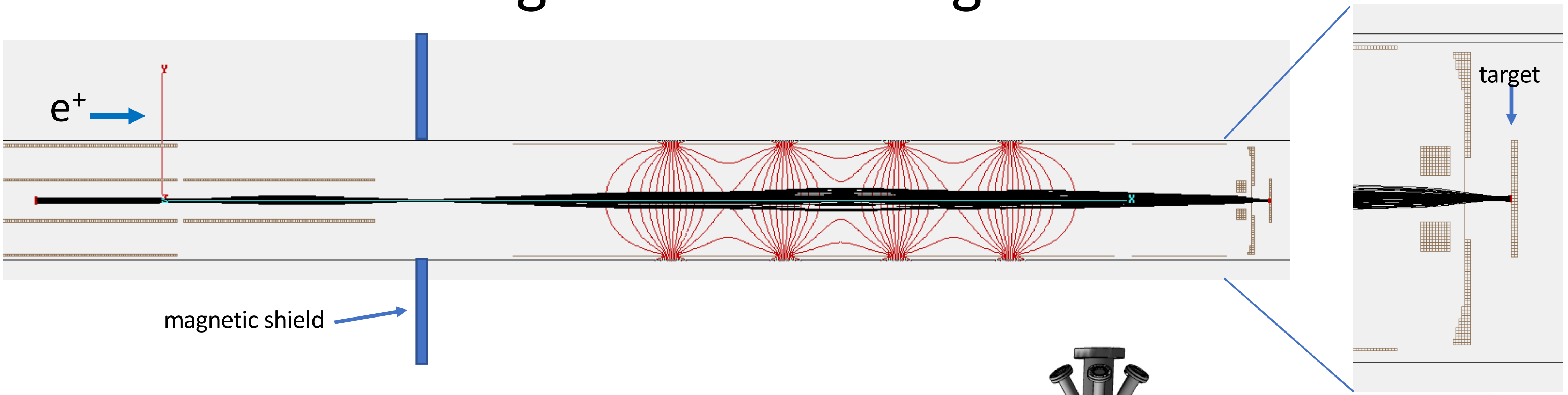


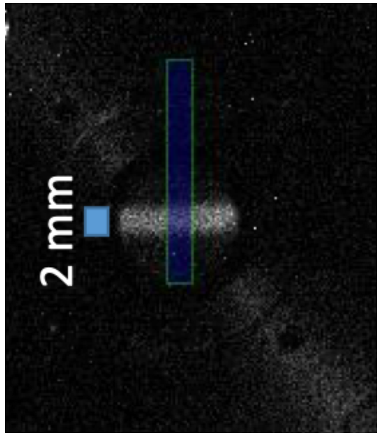
High quality SiC wafer on a sample holder



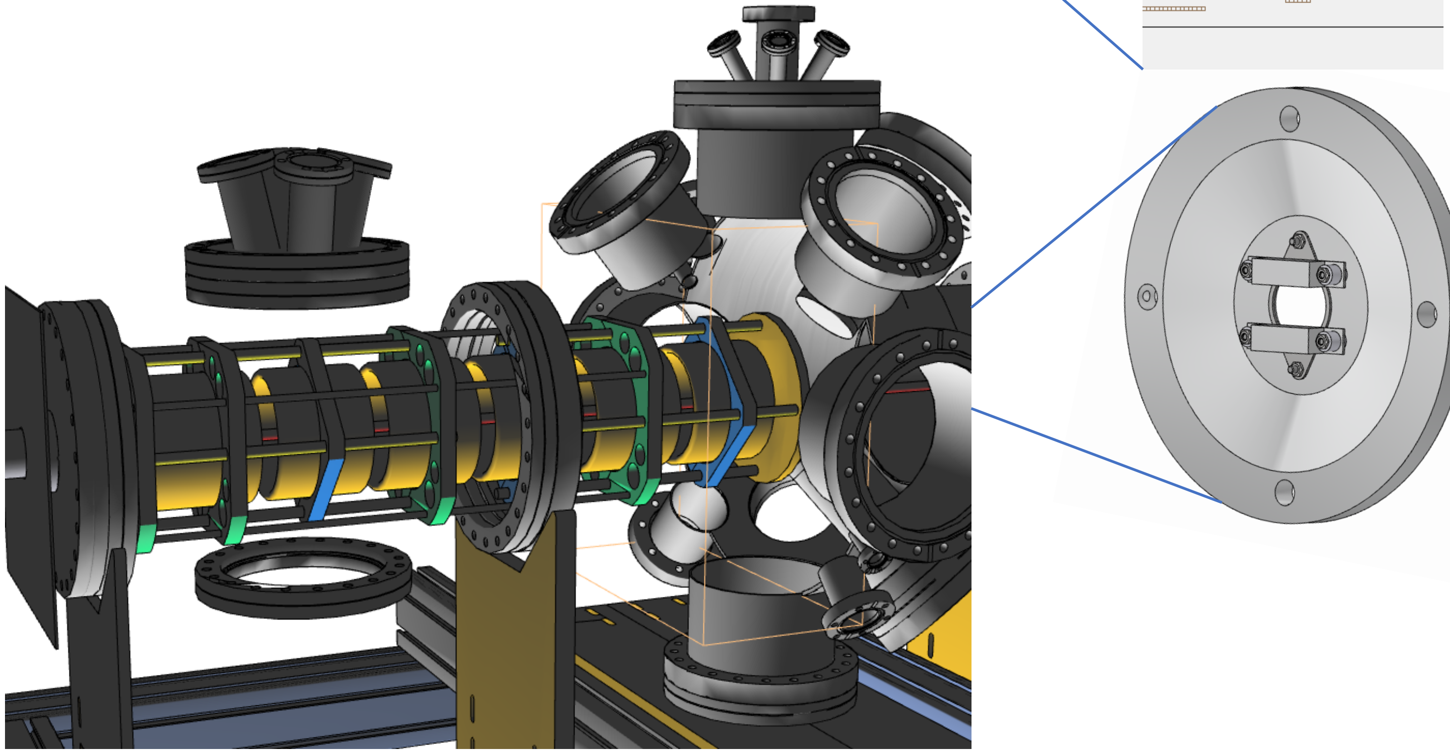
A.M.M Leite et al., Journal of Physics: Conf. Series 791, 012005 (2017)

Focusing e$^+$ beam to target

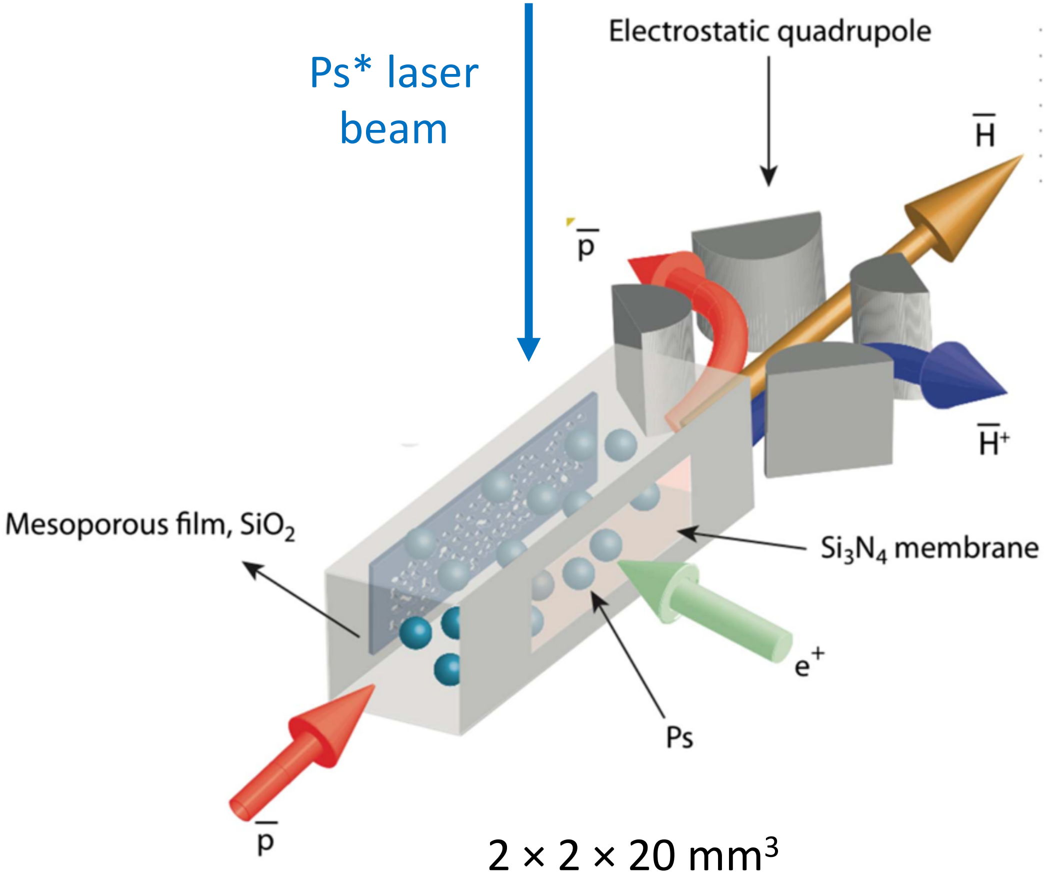


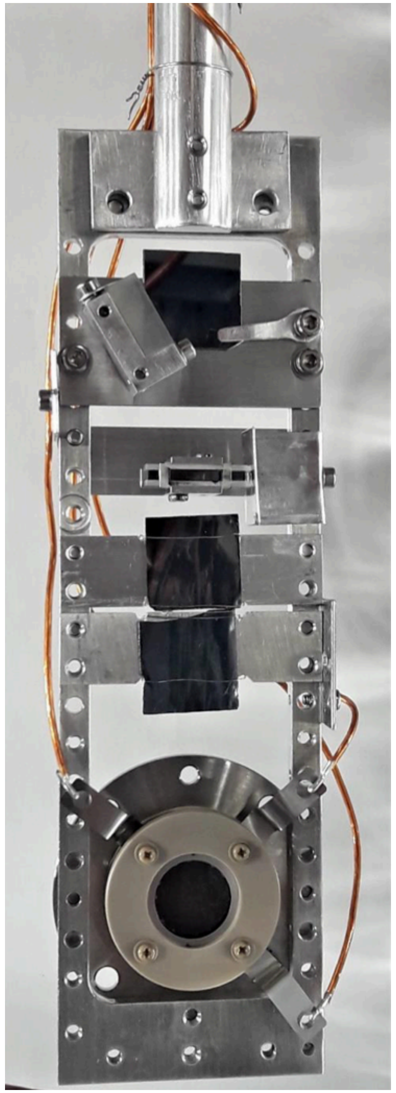


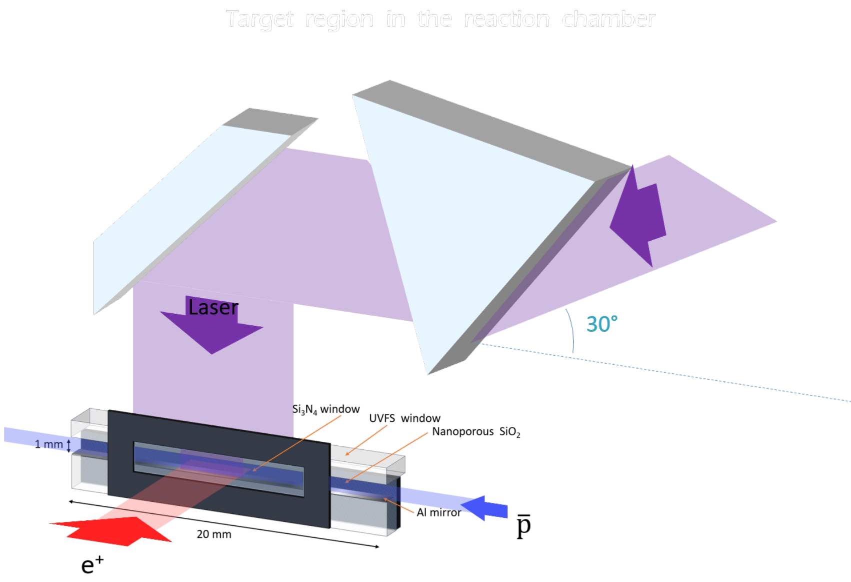
Observed e$^+$ beam spot
@ target position
(10^7 e$^+$)



Focusing beams to target

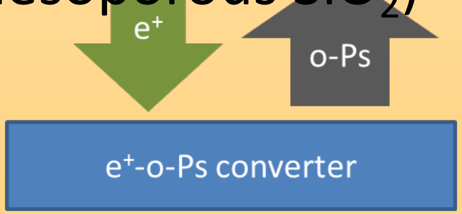


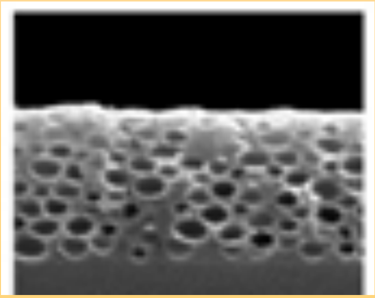




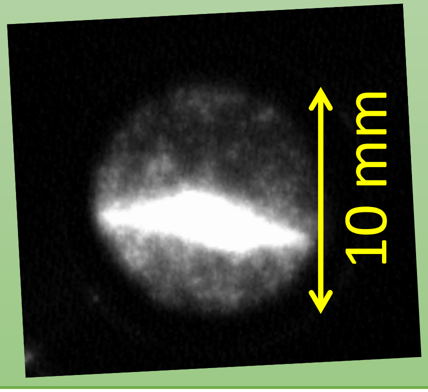
First ortho-positronium signal at GBAR@CERN

Positron-positronium converter (mesoporous SiO_2)

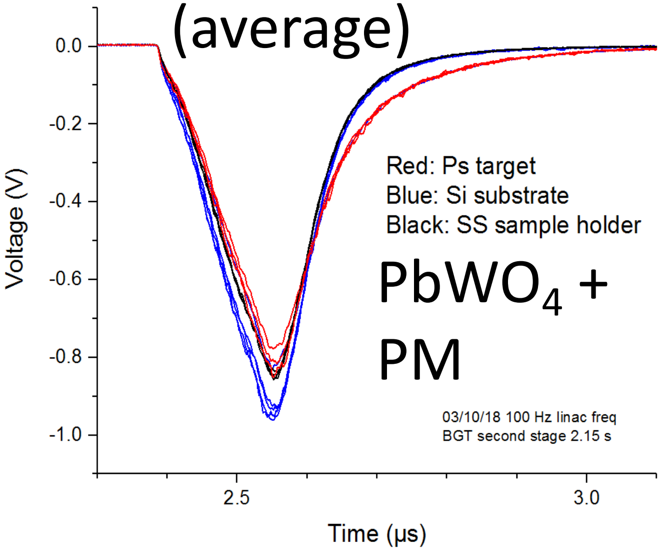


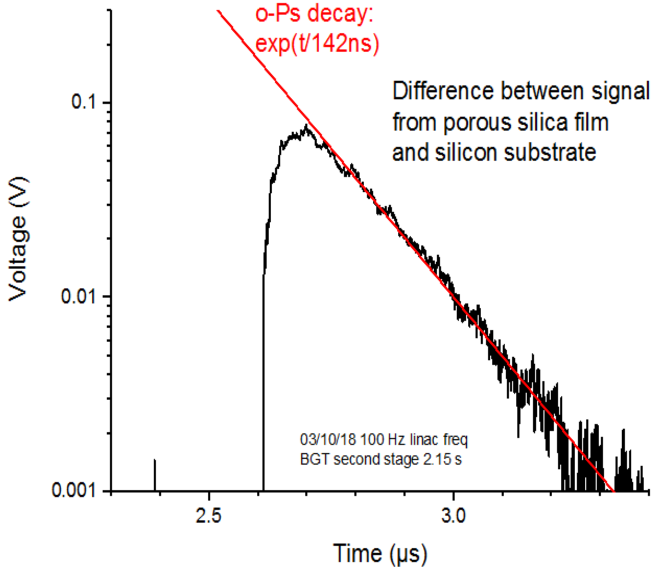


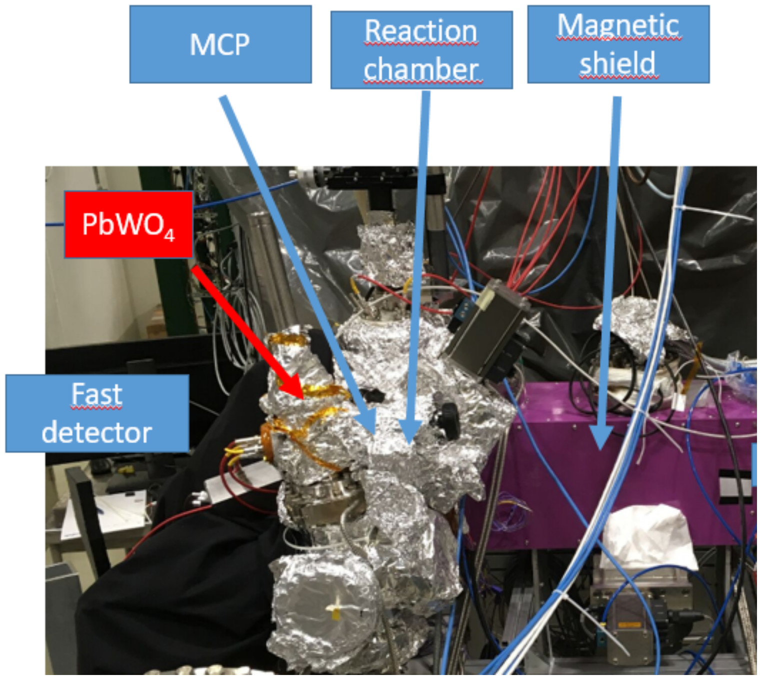
Positron beam spot on the



Raw signal (average)

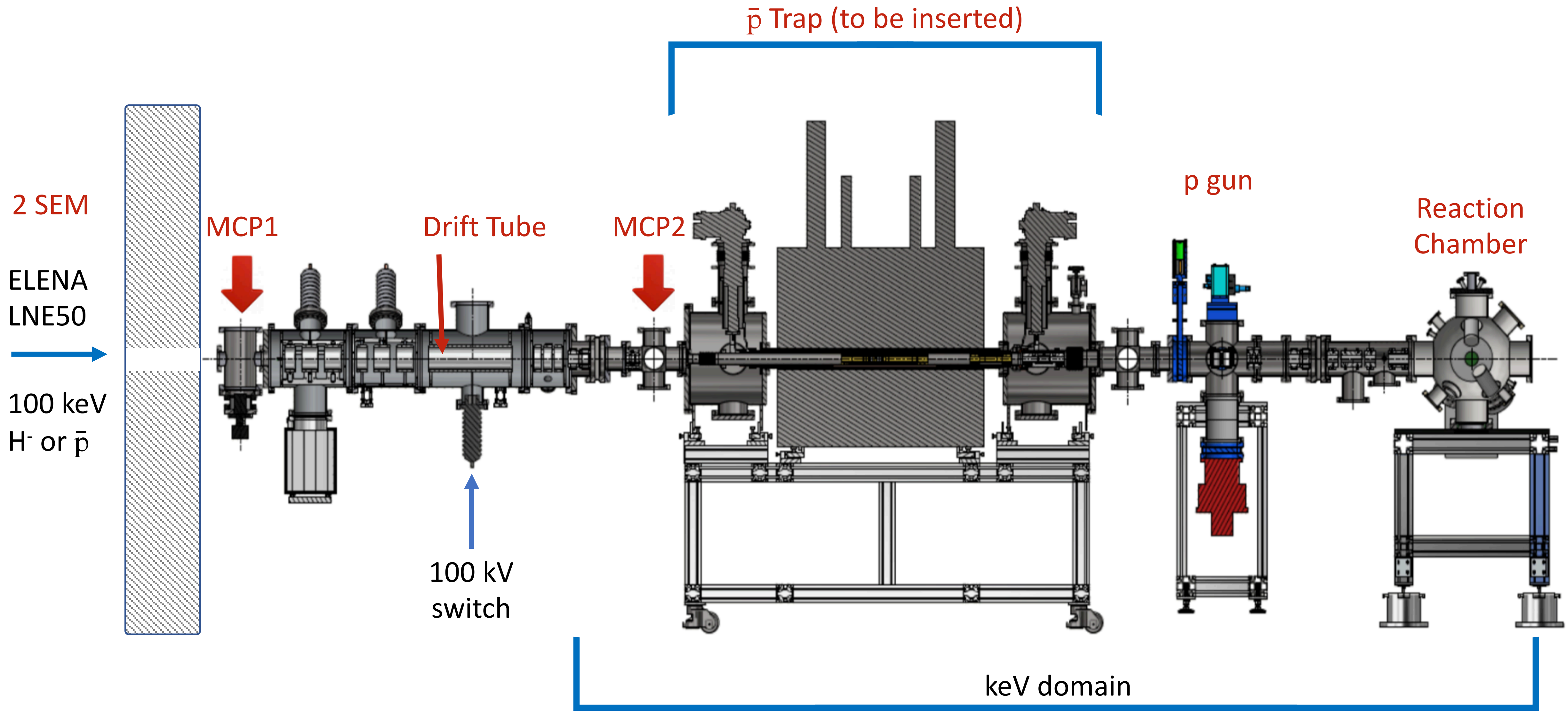






Differential signal showing oPs lifetime

Antiproton beam line

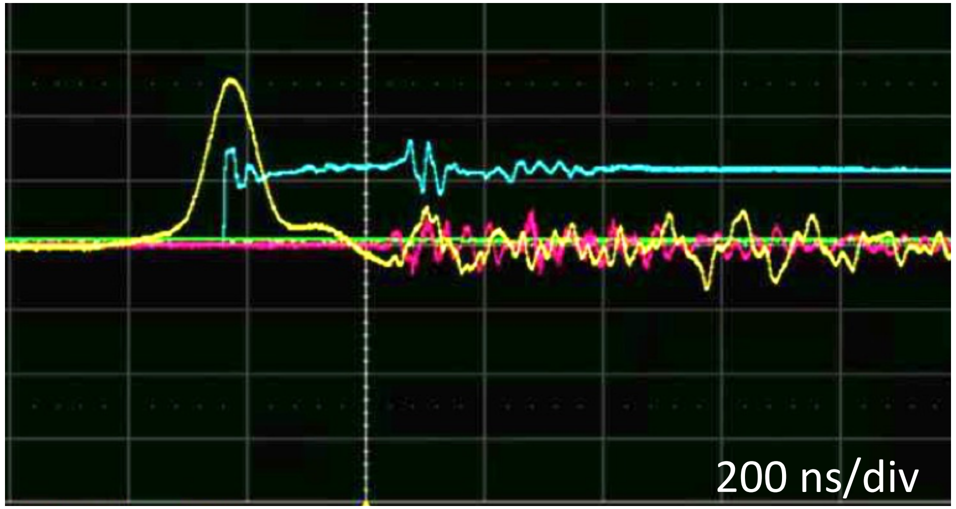


ELENA H^- beam steering and deceleration

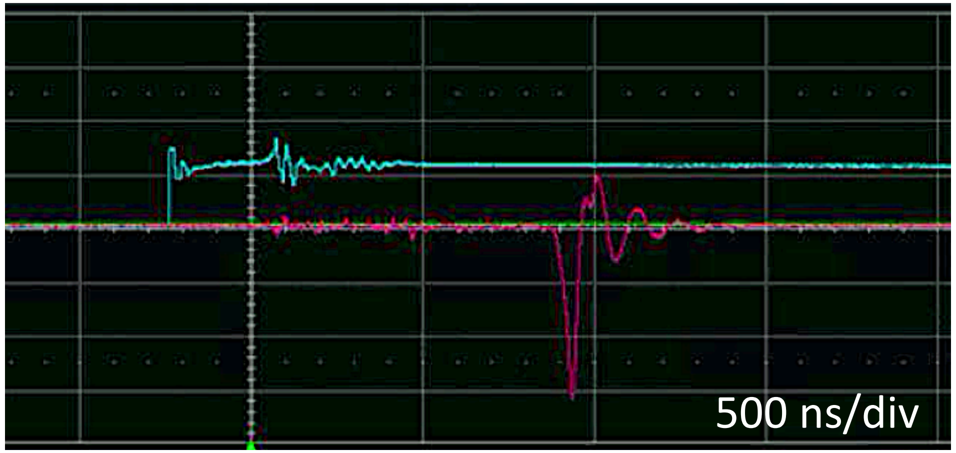
<u>H^- beam from ELENA</u>
Emittances without e- cooling
ε_{H} ~ 4 mm × mrad
ε_{V} ~ 1.5 mm × mrad
expected with cooling for $\bar{p}$ 1 mm × mrad

<u>Requirements for drift tube deceleration:</u>
-centering → knob provided by AD/ELENA team
-bunch length (σ) 75 ns → 45 ns with bunch rotation
-time jitter 20 ns must be improved

Pulse in MCP1 after bunch rotation

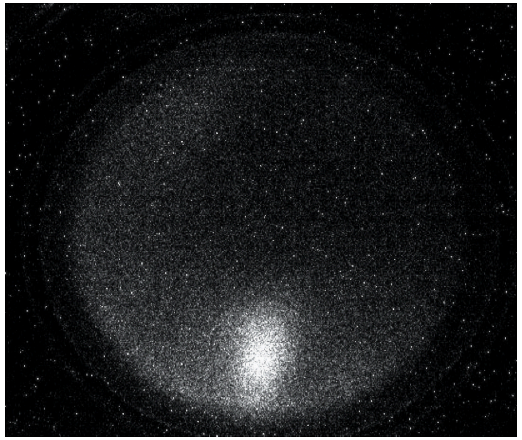


decelerated to 8 keV in MCP2



decelerated beam spot in MCP2
Displacement due to charge up

Sparks in drift tube to be reduced

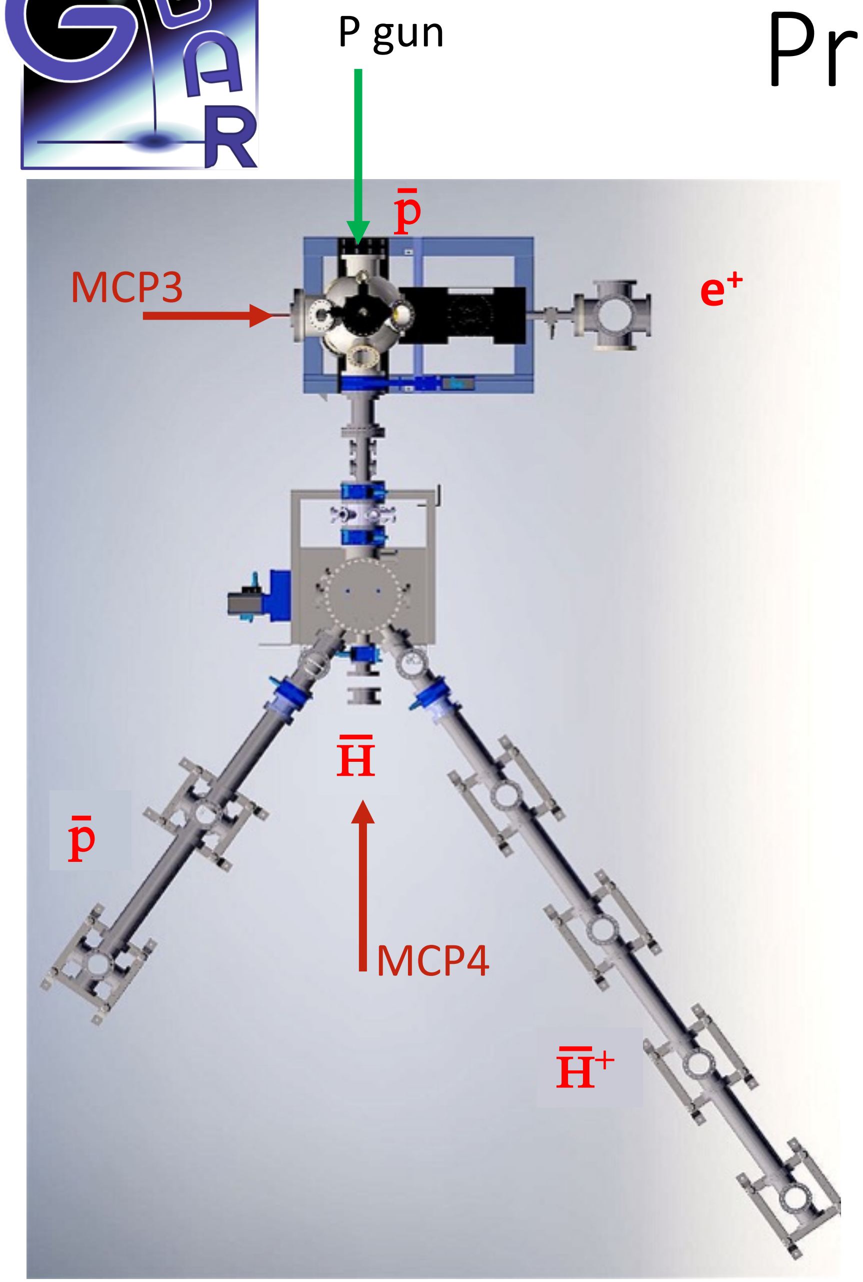


Antiproton trap (Korean groups)

Superconducting magnet 3 to 7 T (LHe/LN2)
Cold electrode system (cryoheads)

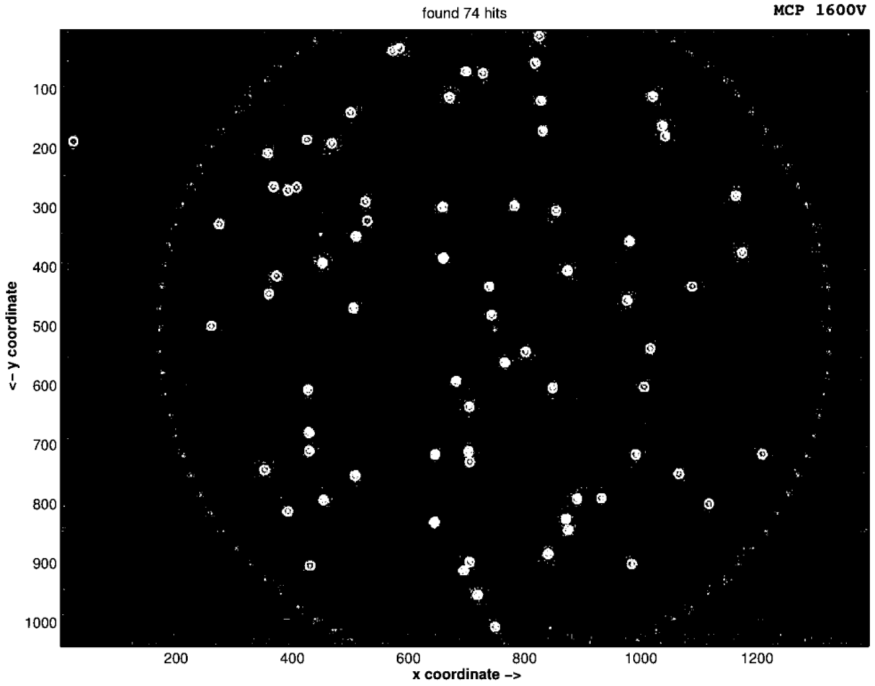
Being tested with electrons before insertion in final position

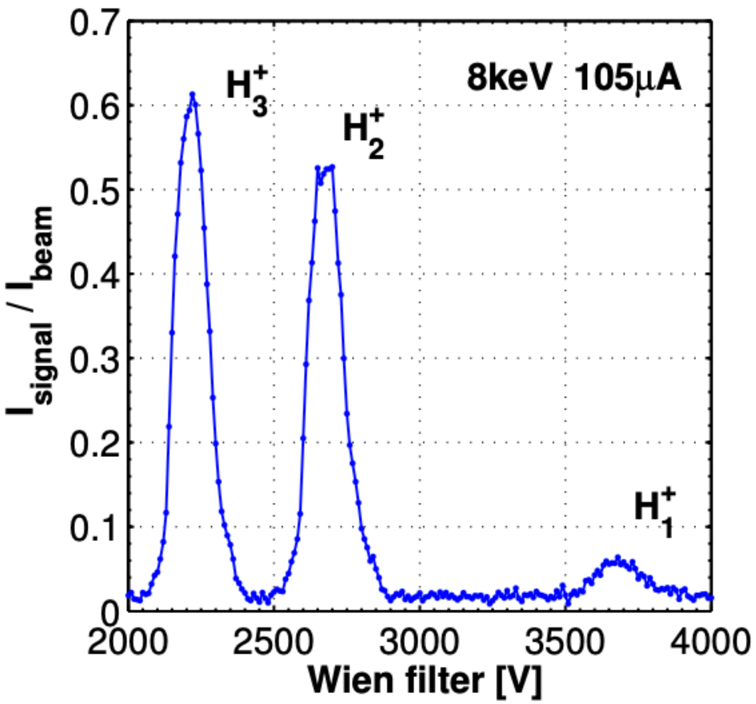
Proton beam



4-8 keV
5μA protons

Interaction of p with residual gas
→ H of same energy
→ detected in MCP 4

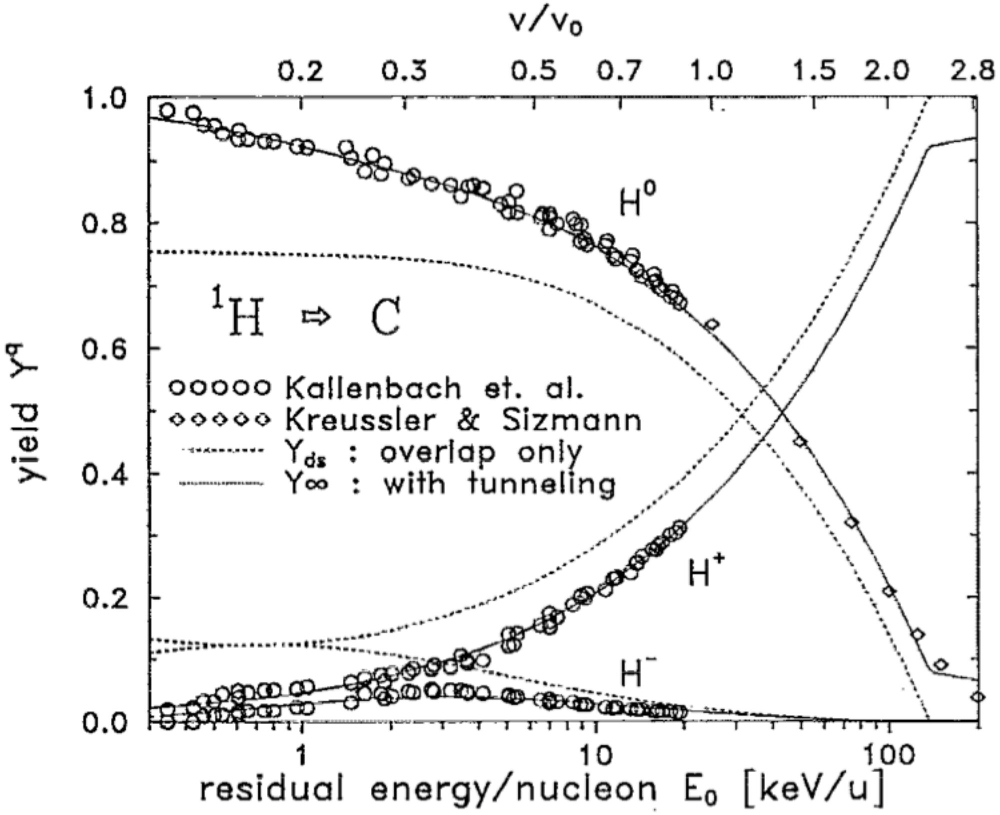




Hydrogen beam

p + C (10 nm) → H @6 keV   80% efficiency

Study with high statistics   H + Ps → $H^- + e^+$



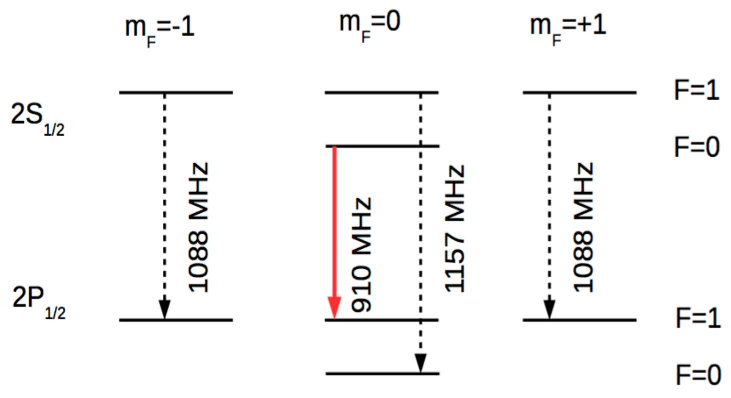
M. Gonin et al. Rev. Sci. Instr. **65**, 648 (1994)

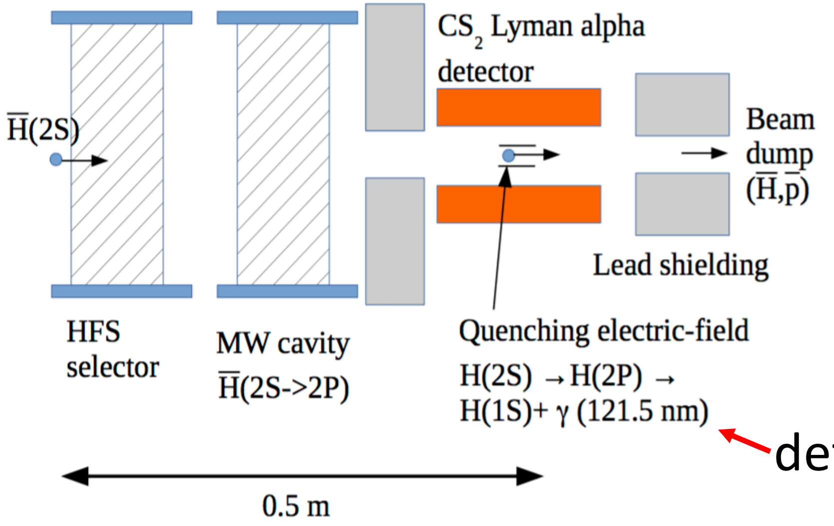
<u>Also</u>:

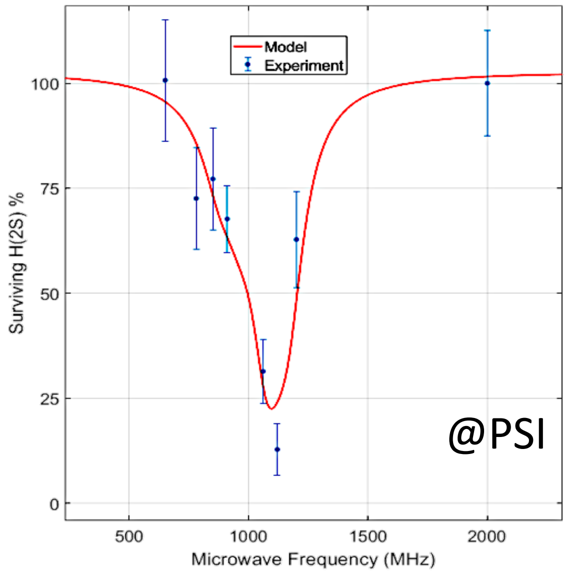
10% of H in 2S state

→ study of Lambshift measurement systematics

$\bar{\text{H}}$ Lamb shift (ETHZ & U. Tokyo)







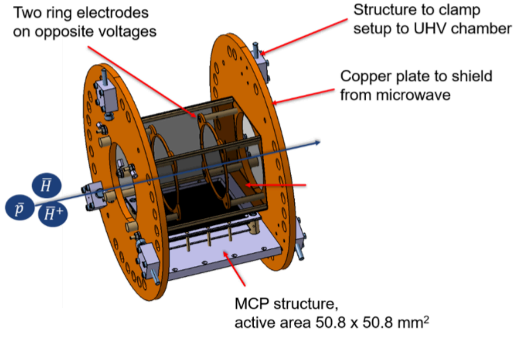
detect those γs

Measure quenched fraction as a function of microwave frequency

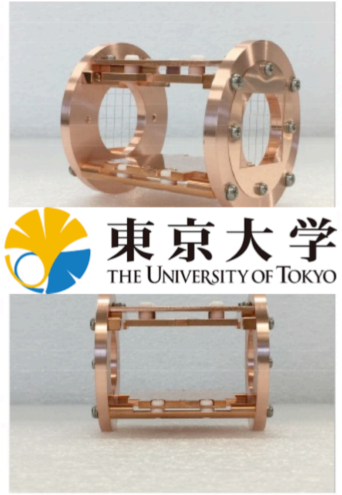
4 months data → 100 ppm on line center

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

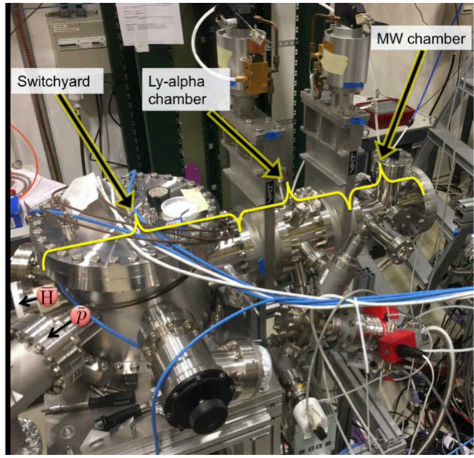
Phys. Rev. D 94, 052008 (2016)



Ly-a setup



MW cavity



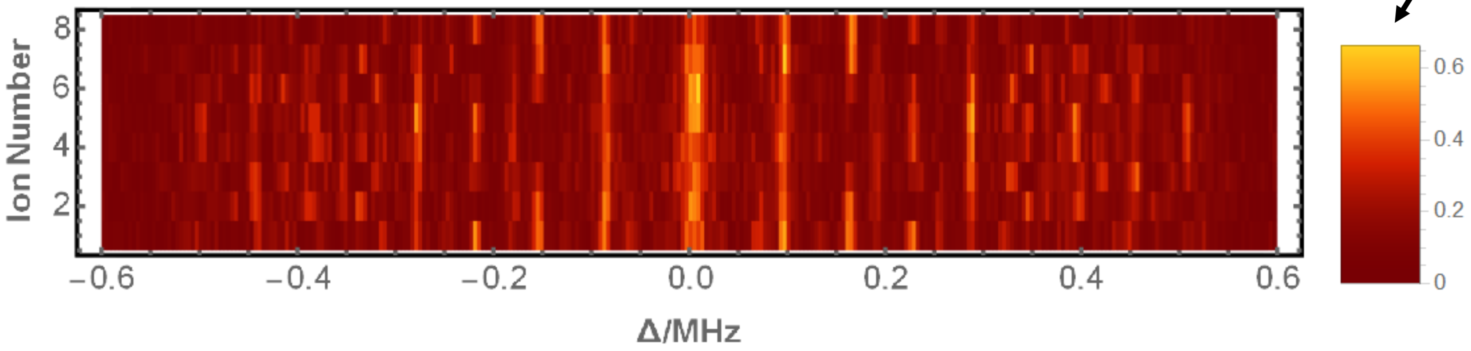
Setup in GBAR zone, Oct. 2018

Cooling of ions at MAINZ (JGUM group)

Polarisation Gradient Cooling → all crystal modes cooled at once
Raman Side Band Cooling → sequence of 200 laser pulses needed

Demonstration of sub-Doppler temperatures of all vibrational modes by PGC
→ applied to Ca^+ as model for Be^+

Sideband spectroscopy of an 8-ion Ca^+ crystal.



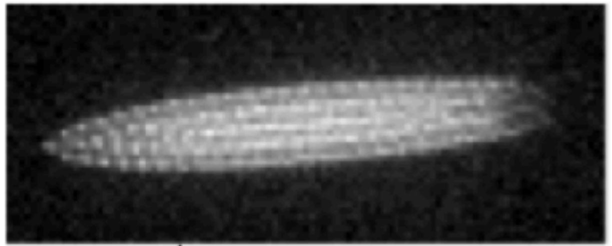
Excitation probability

Detuning from carrier transition

S. Ejtemaee and P. C. Haljan, Phys. Rev. Lett. 119, 043001 (2017); M. K. Joshi et al, New J. Phys. 22, 103013 (2020)

Injection of ions into cold Coulomb crystal at PARIS (LKB group)

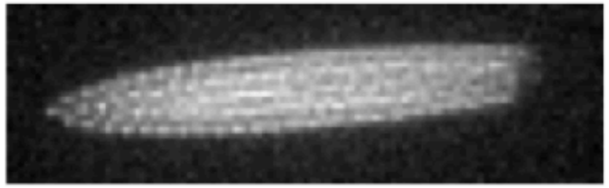
Prepare
Sr^+ crystal



Sr^+ initial crystal

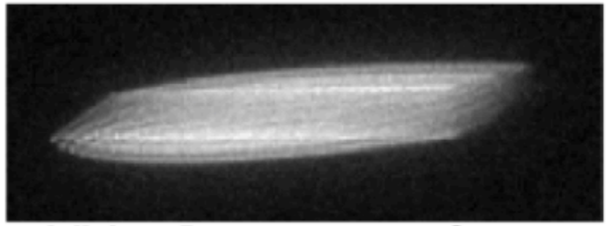
Mass ratio
$Sr^+/Be^+ = 88/9$

Testbed for
$Be^+/\overline{H}^+ = 8/1$



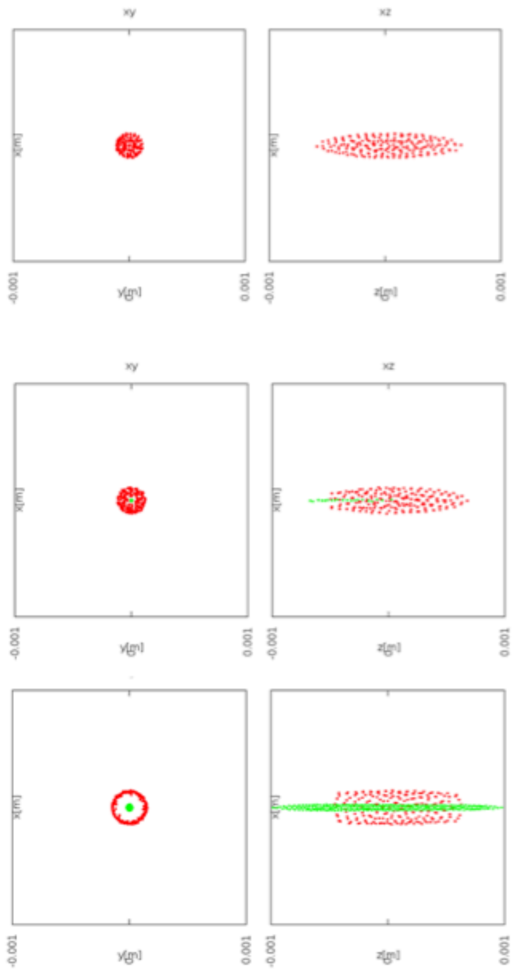
UV on, 3 min

Inject
0.6 eV Be^+



UV + Be oven on, 3 min

numerical simulations of steady-state

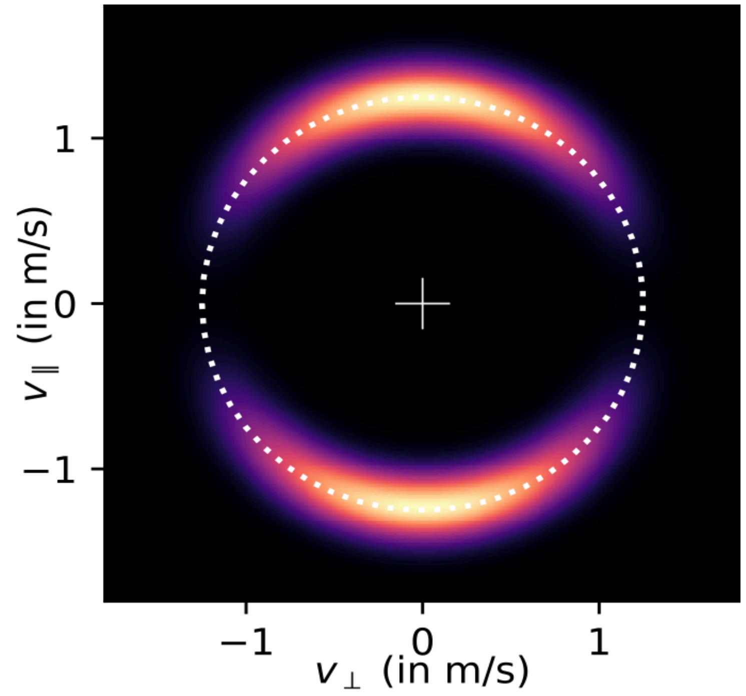


pure Sr^+ N=200

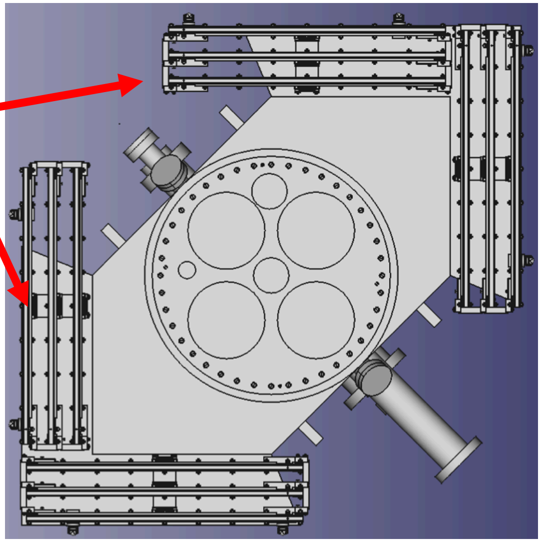
N=200 Sr^+ ; N=100 Be^+

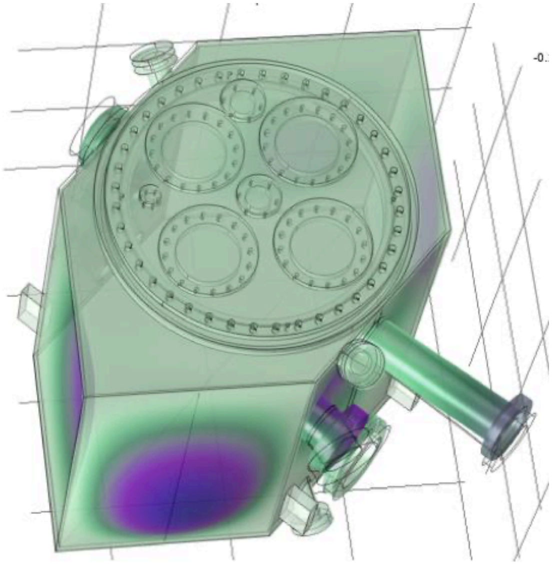
N=200 Sr^+ ; N=250 Be^+

Design free fall chamber



Tracker chambers

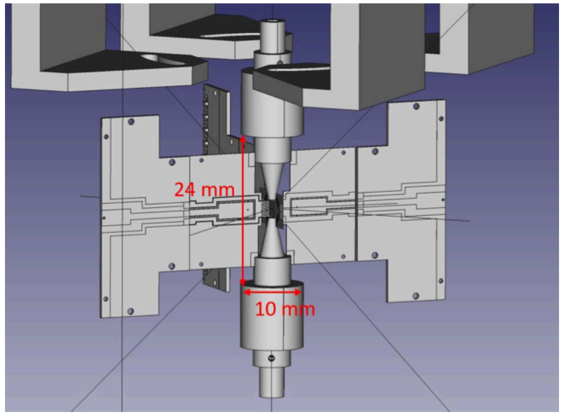




$\boldsymbol{\delta}$E = 30 μeV
Photo detachment
Pulse 500 μs

Ground state of the ion trap : $\simeq$ 0.44 m/s for f =1 MHz
Photon recoil : fixed value $\simeq$ 0.24 m/s
Photoelectron recoil : $\sqrt{0.323\ \delta E/\mu eV}$ m/s
Polarisation → favoured direction → separate free fall zone from obstacles

Shadows due to electrodes, obstacles…



Plans

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

- Install (anti)proton trap

- Switch to antiprotons
- Example without $\bar{p}$ trapping:
- 6 keV, 10^6 $\bar{p}$, 2 x 10^8 e^+, $\boldsymbol{\sigma}$ = 10^{16} cm^2 → 2 $\bar{H}$ per pulse

- In 2022, increase in e^+ trapping efficiency, use $\bar{p}$ trap + Ps excitation → 10^3 $\bar{H}$ per pulse
  → Lambshift 100 kHz

GBAR collaboration

B. Argence[1], P. Blumer[2], M. Charlton[3], J. Choi[4], M. Chung[5], P. Cladé[1], P. Comini[6], P. Crivelli[2], P-P. Crépin[1], O. Dalkarov[7], P. Debu[6], L. Dodd[3], A. Douillet[1,8], P. Froelich[9], J. Gafriller[10], N. Garoum[11], S. Guellati[1], J. Heinrich[1], P-A. Hervieux[12], L. Hilico[1,8], P. Indelicato[1], G. Janka[2], S. Jonsell[9], J-P. Karr[1,8], B. Kim[4], S. Kim[4], E-S. Kim[13], A. Kleyheeg[10], Y. Ko[14], T. Kosinski[15], N. Kuroda[16], B. Latacz[6], H. Lee[4], J. Lee[14], A. Leite[6], E. Lim[13], L. Liszkay[6], T. Louvradoux[1], D. Lunney[17], K. Lévêque[12], G. Manfredi[12], B. Mansoulié[6], M. Matusiak[15], G. Mornacchi[10], V. Nesvizhevsky[18], F. Nez[1], S. Niang[6], R. Nishi[16], S. Nourbaksh[10], B. Ohayon[2], K. Park[4], N. Paul[1], P. Pérez[6], B. Radics[2], C. Regenfus[2], S. Reynaud[1], C. Roumegou[17], O. Rousselle[1], J-Y. Roussé[6], A. Rubbia[2], J. Rzadkiewicz[15], Y. Sacquin[6], F. Schmidt-Kaler[19], M. Staszczak[15], T. Takumi[16], B. Tuchming[6], B. Vallage[6], D.P. Van der Werf[3], A. Voronin[7], A. Welker[10], S. Wolf[19], D. Won[4], S. Wronka[15], Y. Yamazaki[20], K-H. Yoo[5]