

GBAR (Gravitational Behaviour of Antihydrogen at Rest)

Proposal CERN-SPSC-2011-029 ; SPSC-P-342

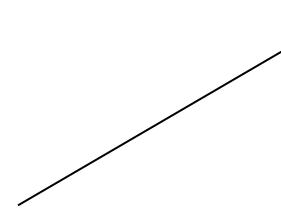


P.N.Lebedev Physical
Institute of the Russian
Academy of Science

Low velocity for free fall measurement

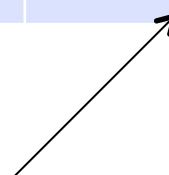
Classical free fall:
$$z = z^0 + \vec{v}_z^0 t + \frac{1}{2} gt^2$$

Main perturbation



Velocity fluctuation	100 m/s	3 m/s	0.1 m/s
Temperature equivalent	1 K	1 mK	1 μK

Recoil limit of Ly_α laser cooling of Hydrogen

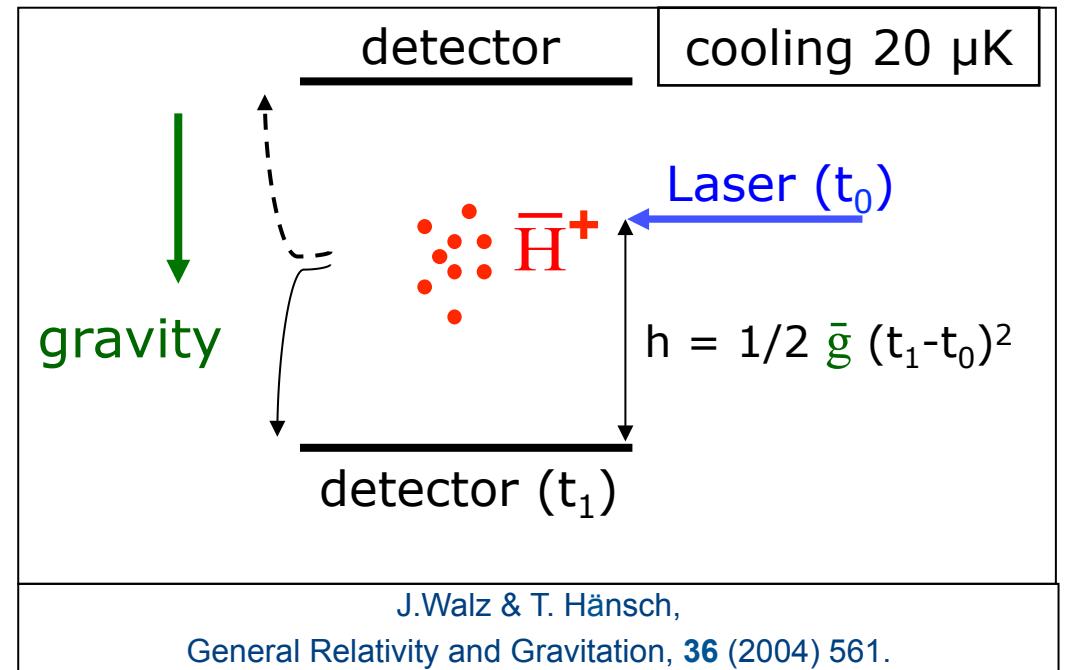


Using \bar{H}^+ to get \bar{H} atoms

- Produce ion \bar{H}^+
- Sympathetic cooling 20 μK
- Photodetachment of e^+
- Time of flight

Error dominated by temperature of \bar{H}^+

Relative Precision on \bar{g} :



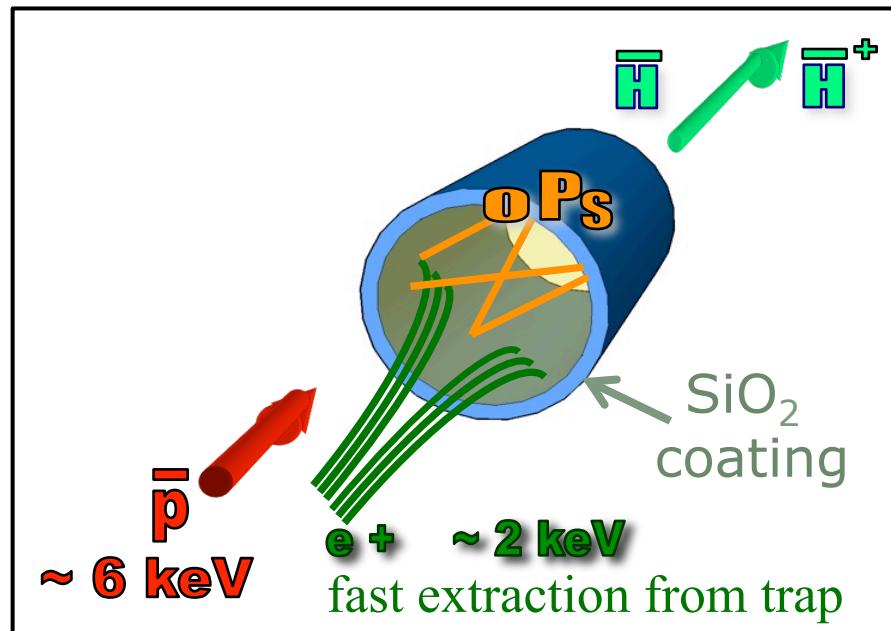
\bar{H}^+ in ion trap	$\Delta g/g$
$5 \cdot 10^5$	0.001
10^4	0.006
10^3	0.02

$$h = 10 \text{ cm} \rightarrow \Delta t = 143 \text{ ms}$$

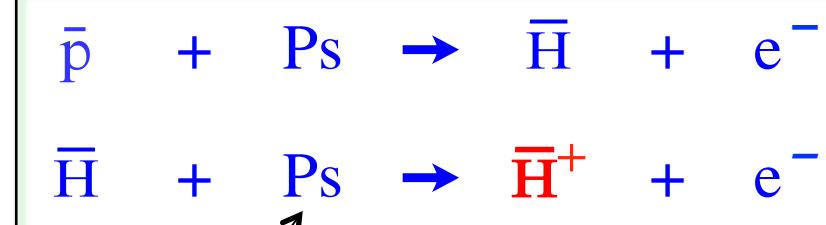
$$h = 1 \text{ mm} \rightarrow \Delta t = 14 \text{ ms}$$

\bar{H} Production via \bar{H}^+

Standard production



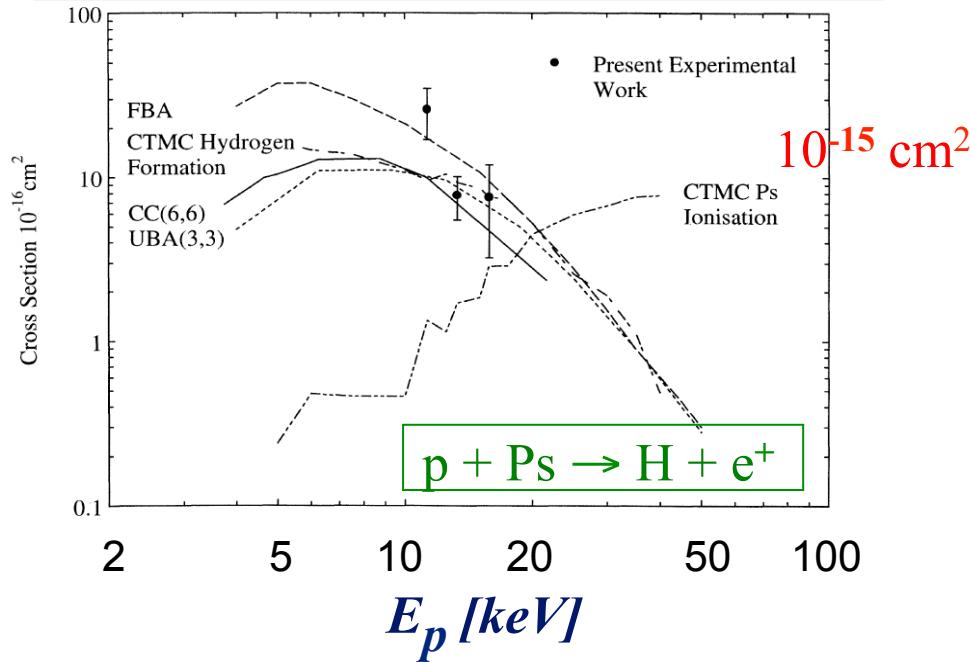
\bar{H}^+ Formation



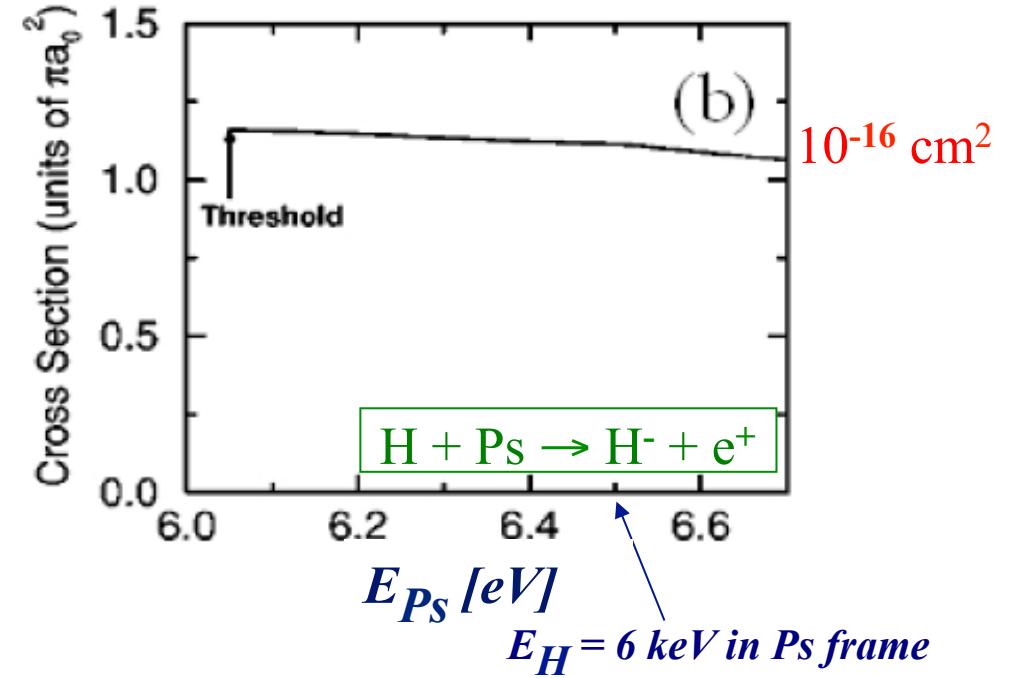
Ortho-positronium

Cross-sections on Ps

J. P. Merrison et al., Phys. Rev. Lett. **78**, 2728 (1997)



H.R.J. Walters and C. Starett, Phys. Stat. Sol. **C**, 1-8 (2007)



Enhancement of cross-section via Ps excitation

Binding energy of $H^- = 0.76 \text{ eV}$

\approx same as Ps ($n=3$)



Resonant enhancement

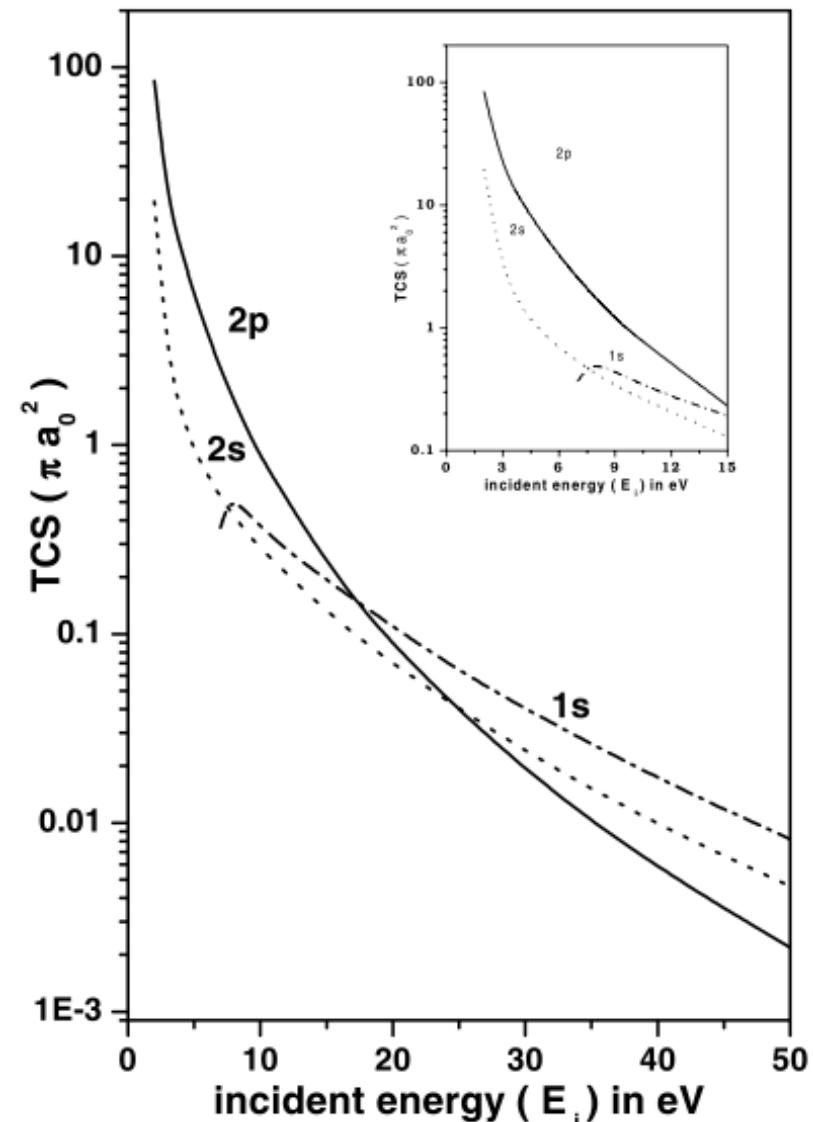


Excite fraction of Ps to $n=3$

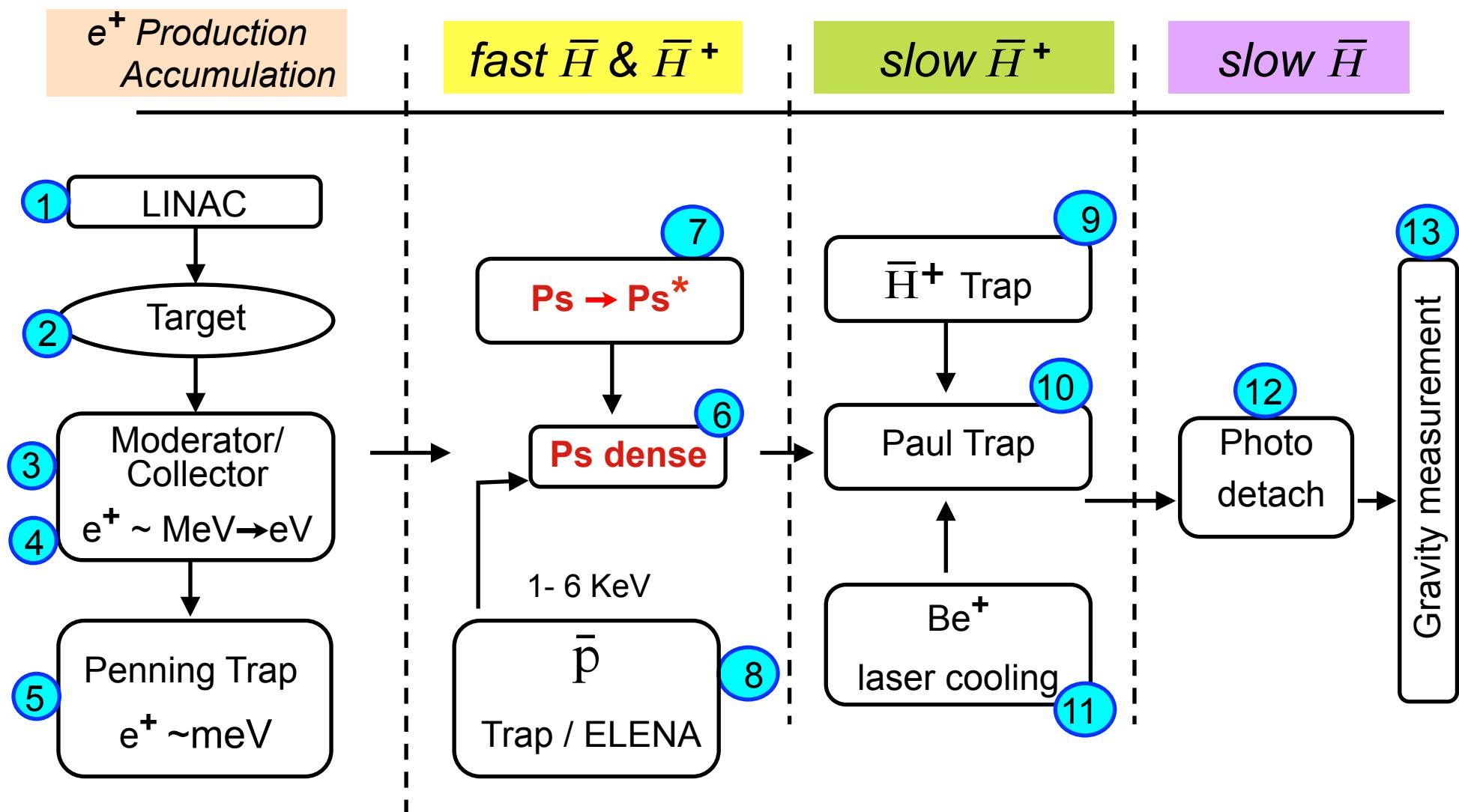
Calculations for $n=2$ by:

S. Roy and C. Sinha, Eur. Phys. J. **D** 47, 327 (2008).

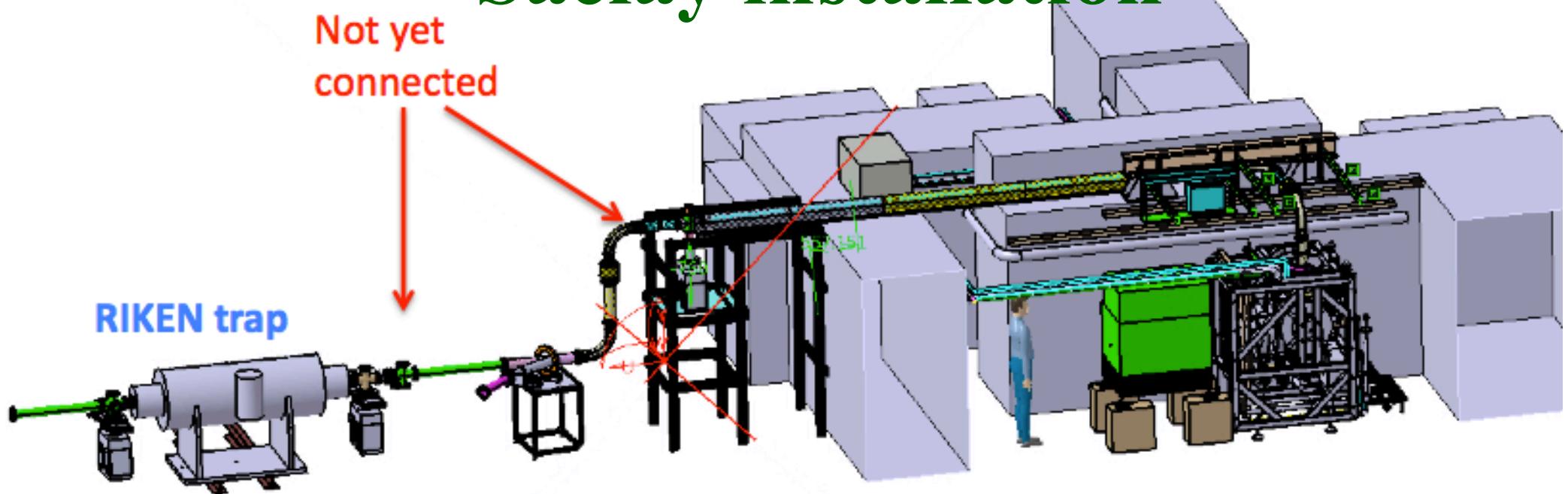
*calculations underway for $n=3$
to optimize \bar{p} incident energy*



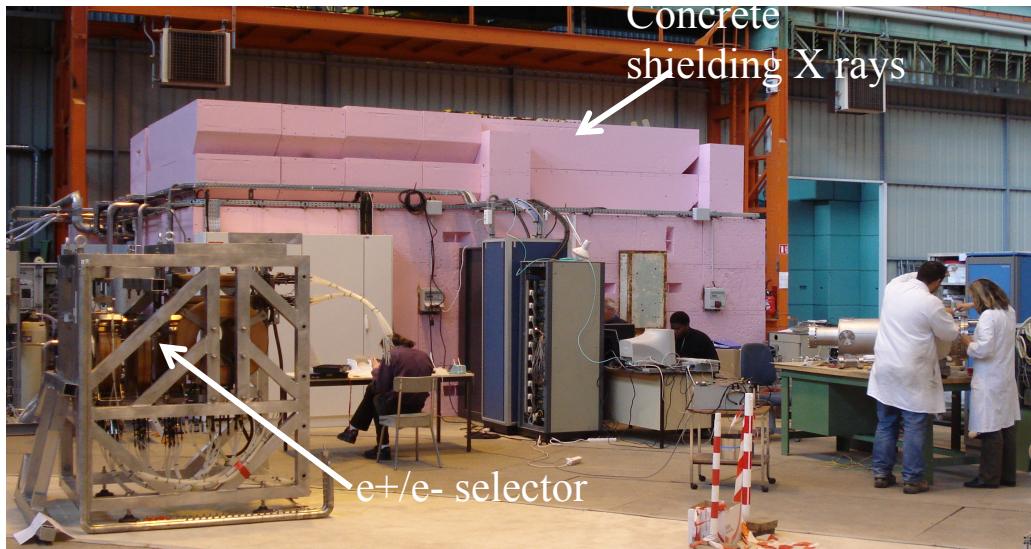
Synoptic Scheme



Saclay installation

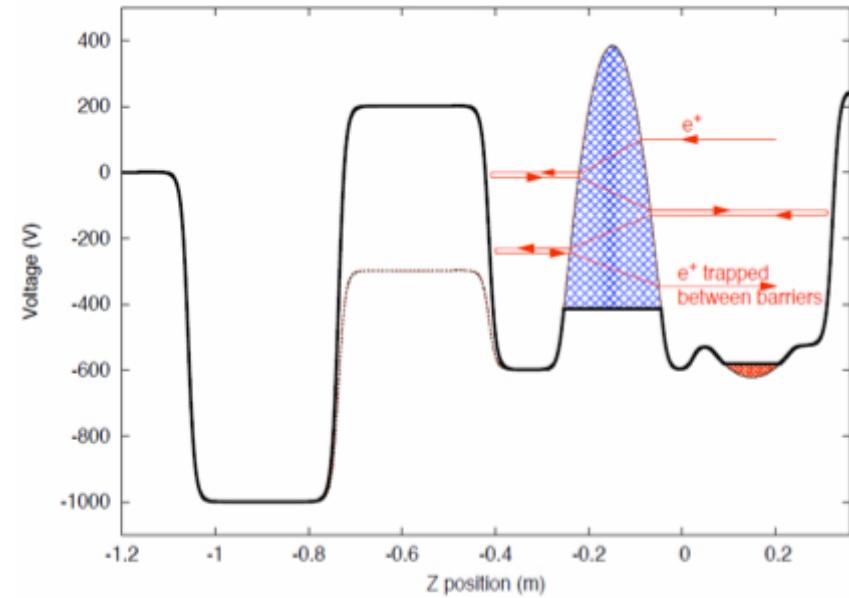
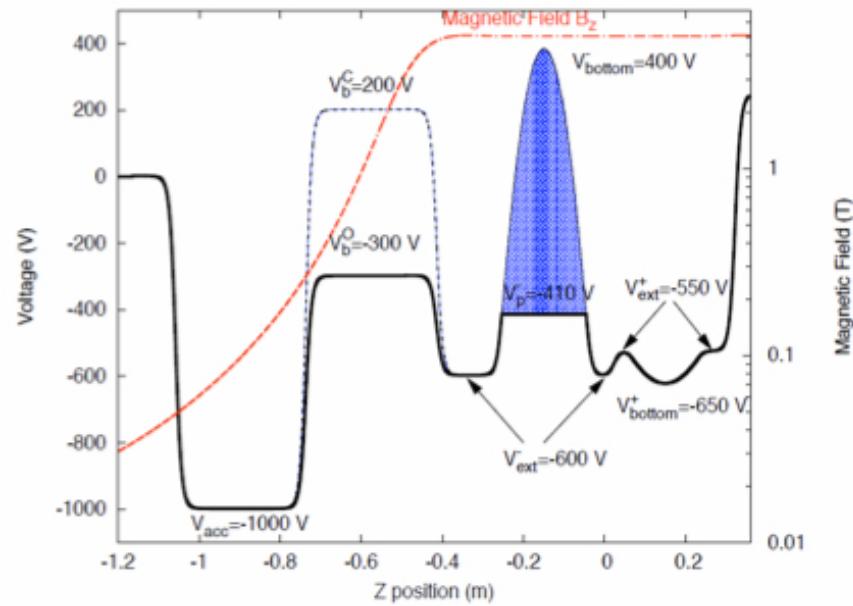


Electron Linac



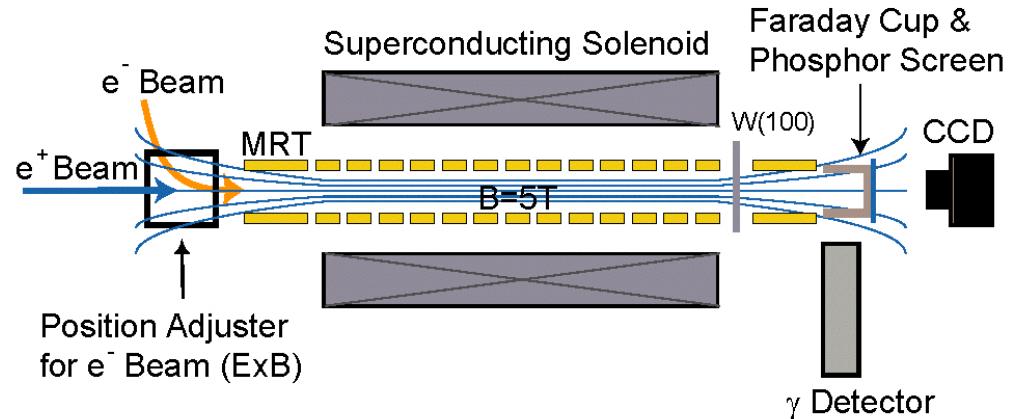
Demonstrator e^- Linac
 $E_c = 5.5 \text{ MeV}$
 $I_{\text{measured}} = 0.14 \text{ mA}$

RIKEN Penning Trap adapted to pulses from Linac

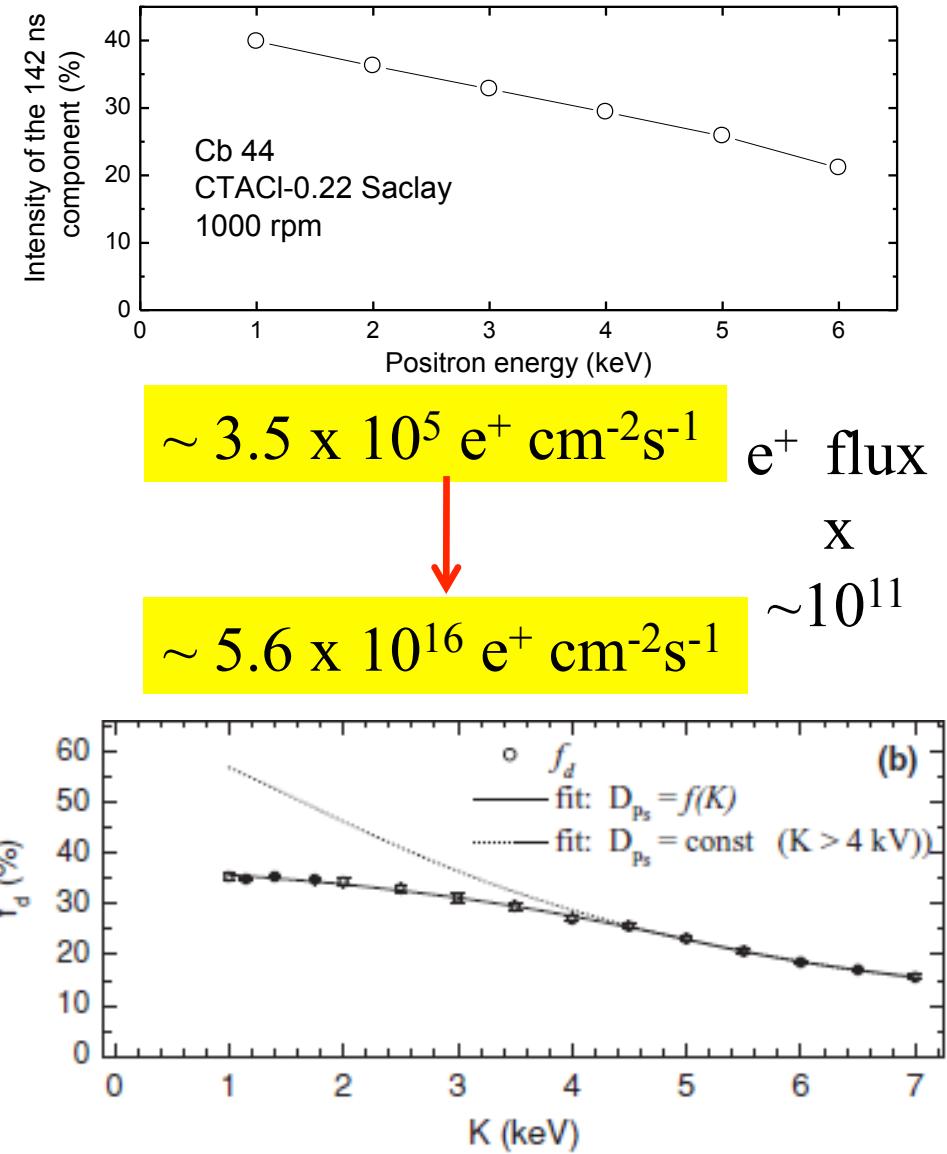
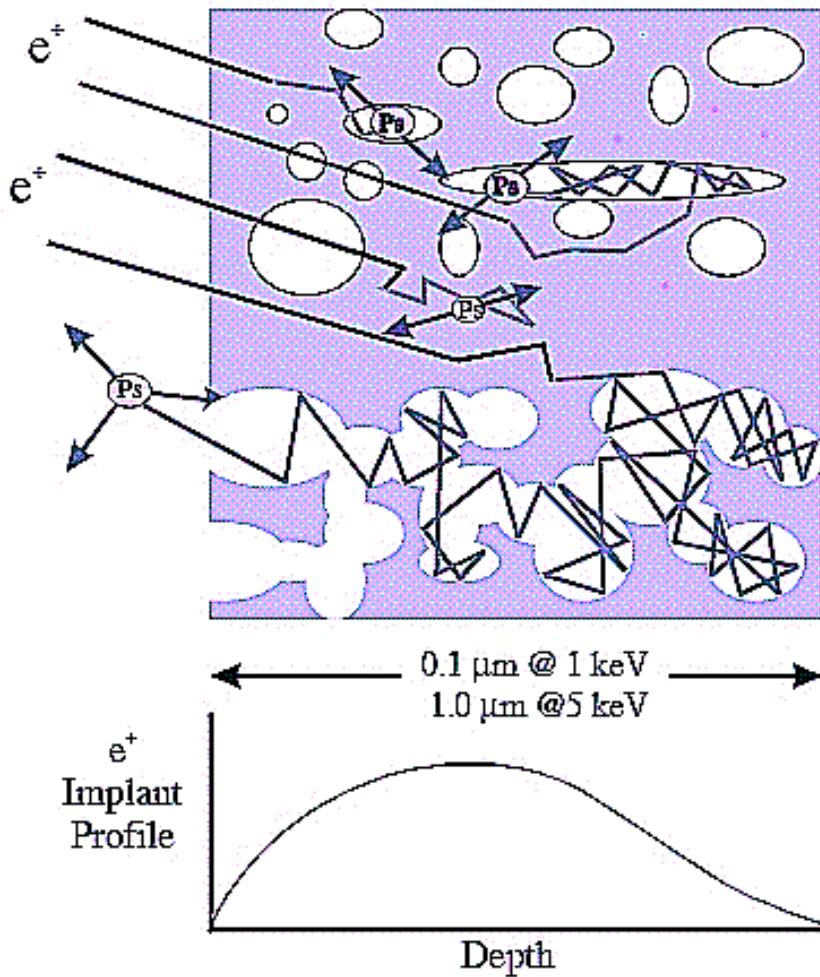


N. Oshima *et al.*,
Phys. Rev. Lett. 93, 196001 (2004)

P. Dupré, Thesis, U. of Paris 6, (2011)

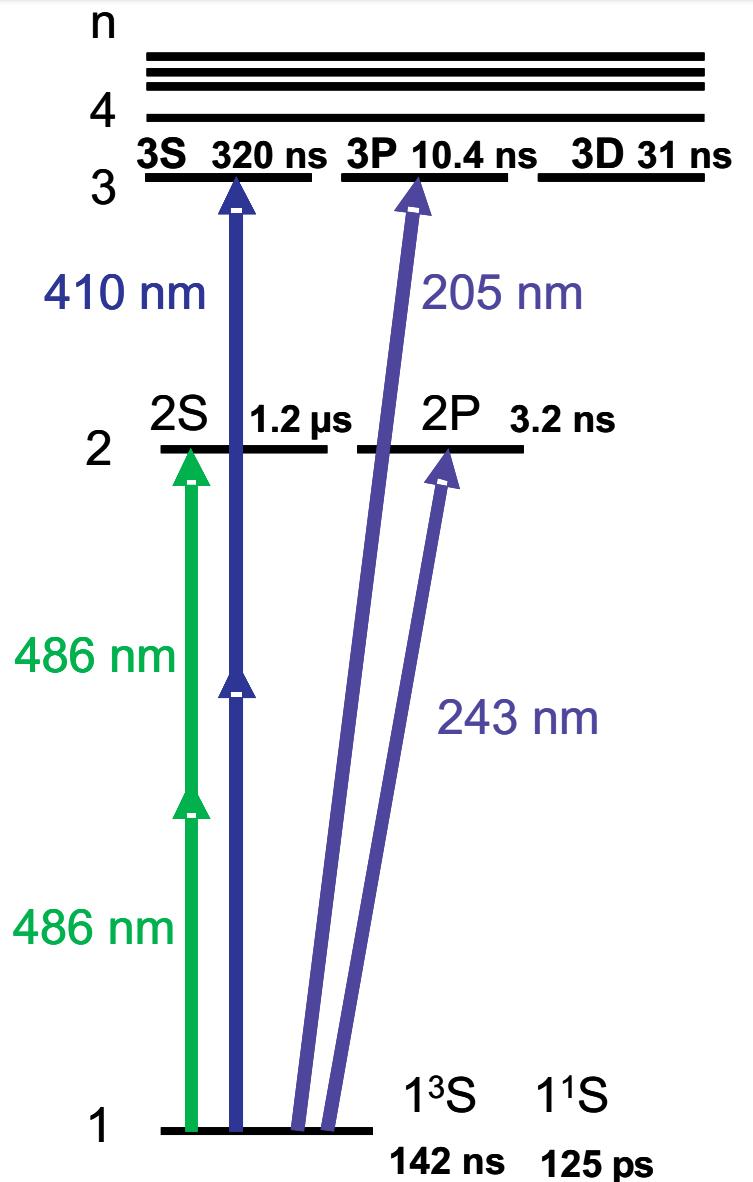
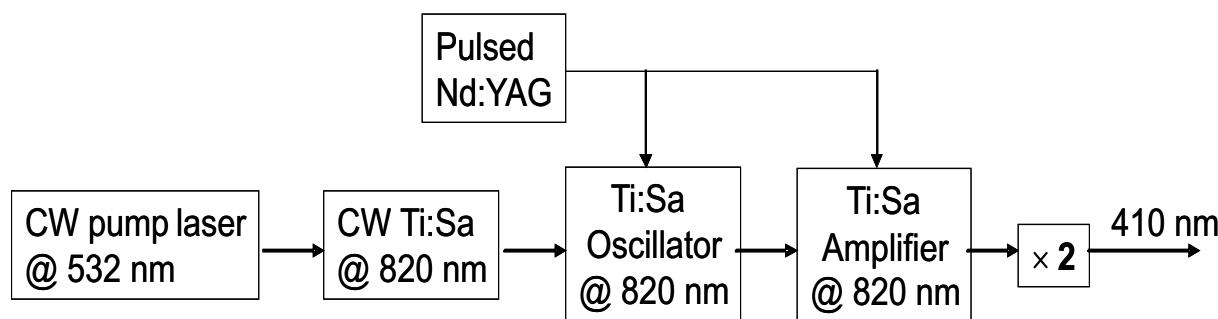


Porous SiO_2 as e^+ / Ps converter

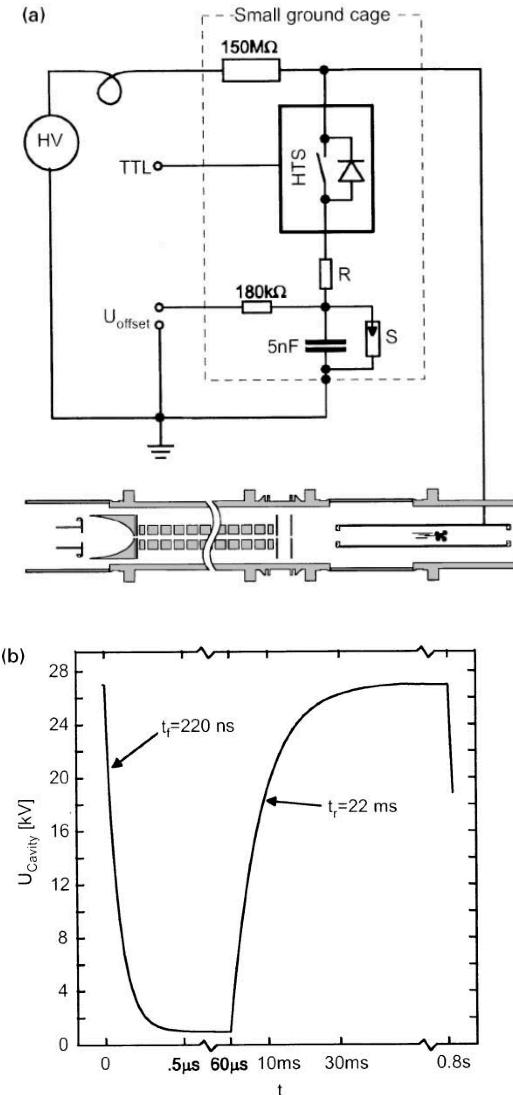


No loss in conversion efficiency in spite of the 10^{11} intensity factor

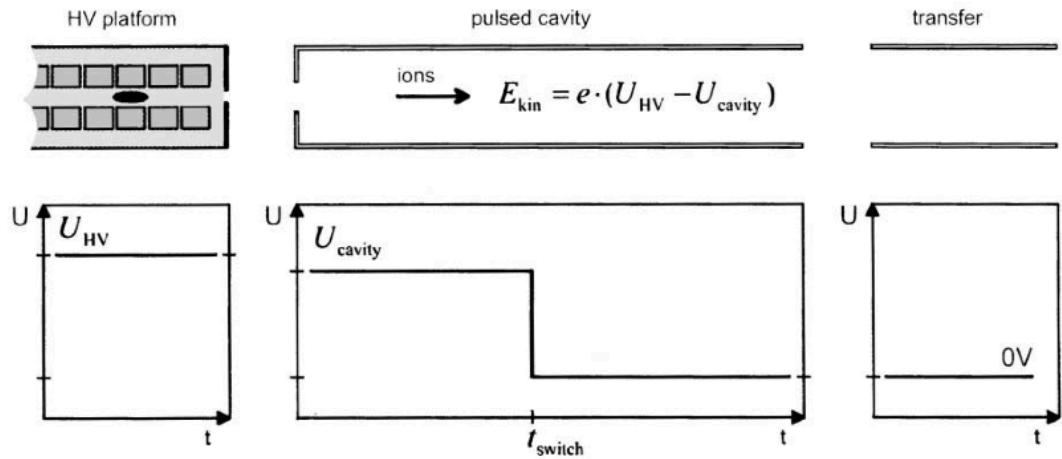
Ps excitation



\bar{p} deceleration

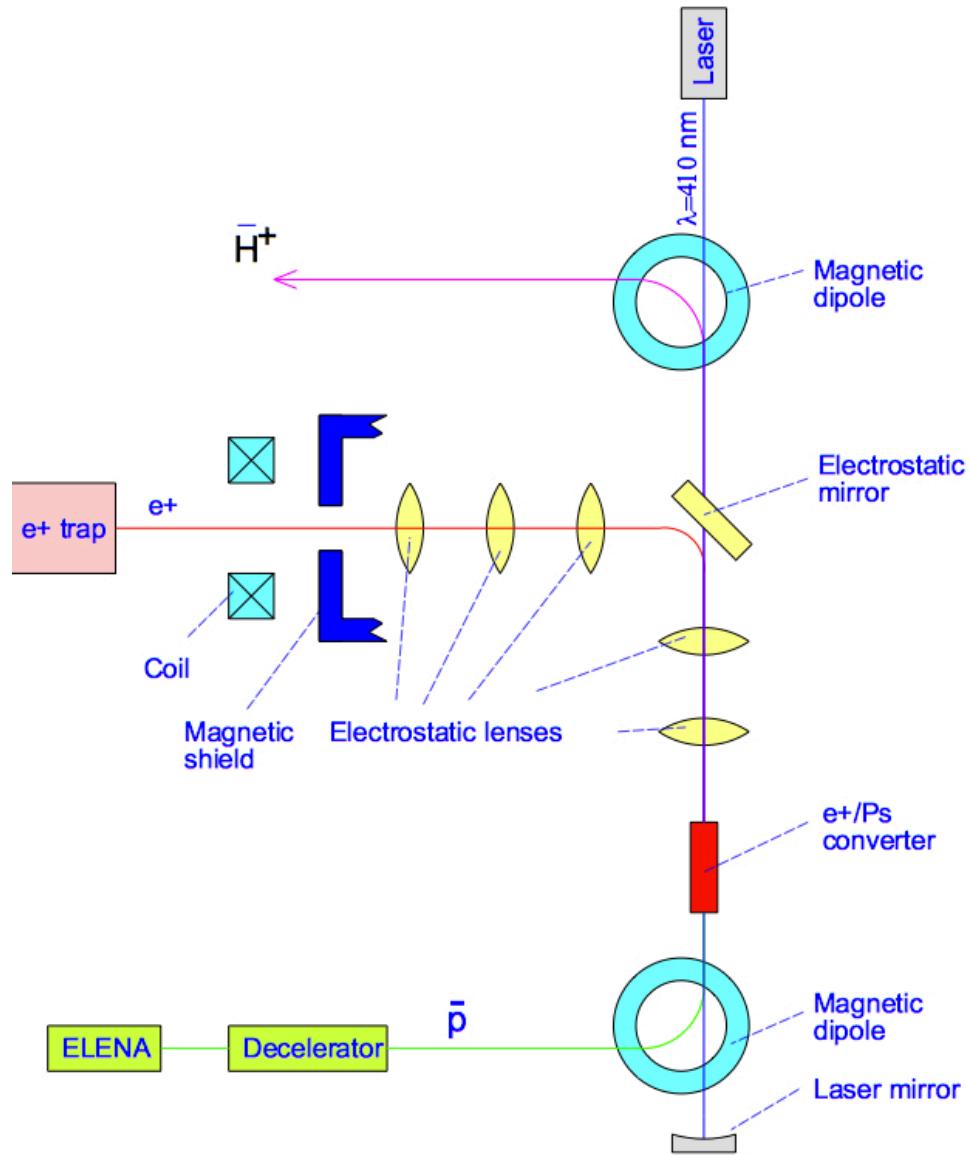


Scheme adapted from ISOLTRAP
F. Herfurth et al., NIMA 469 (2001) 254.

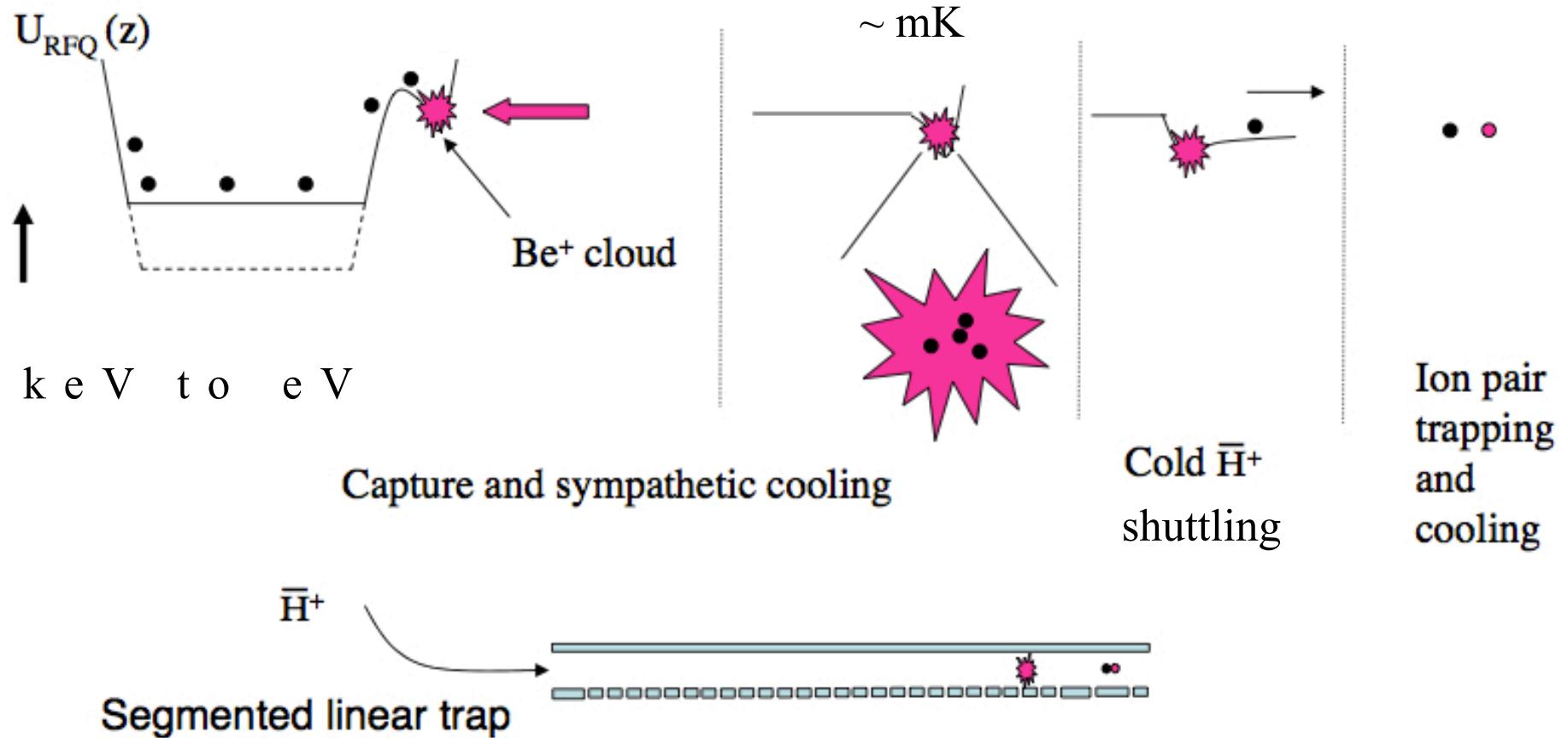


\bar{p} accumulation trap can be added

Reaction region



\bar{H}^+ cooling challenge



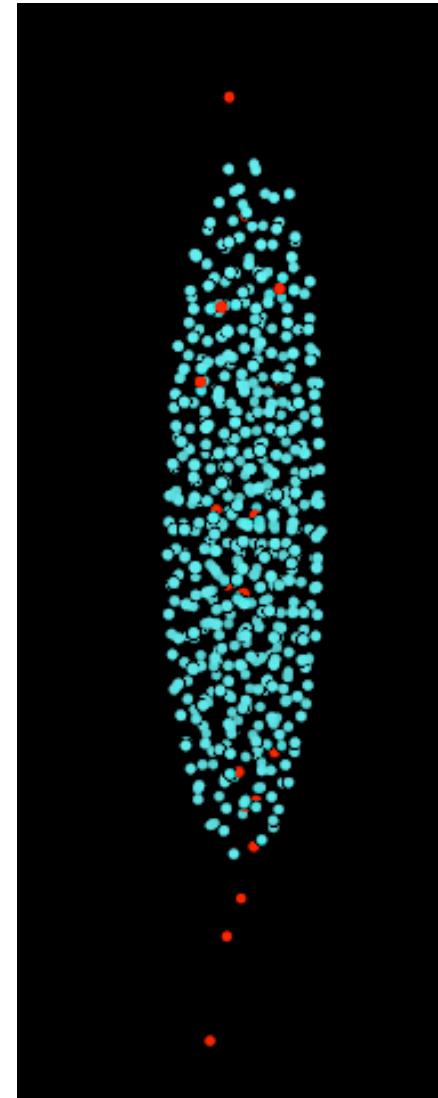
i.e. quantum regime of
coupled harmonic oscillators

$$E = \hbar\omega \approx 4 \text{ neV}$$

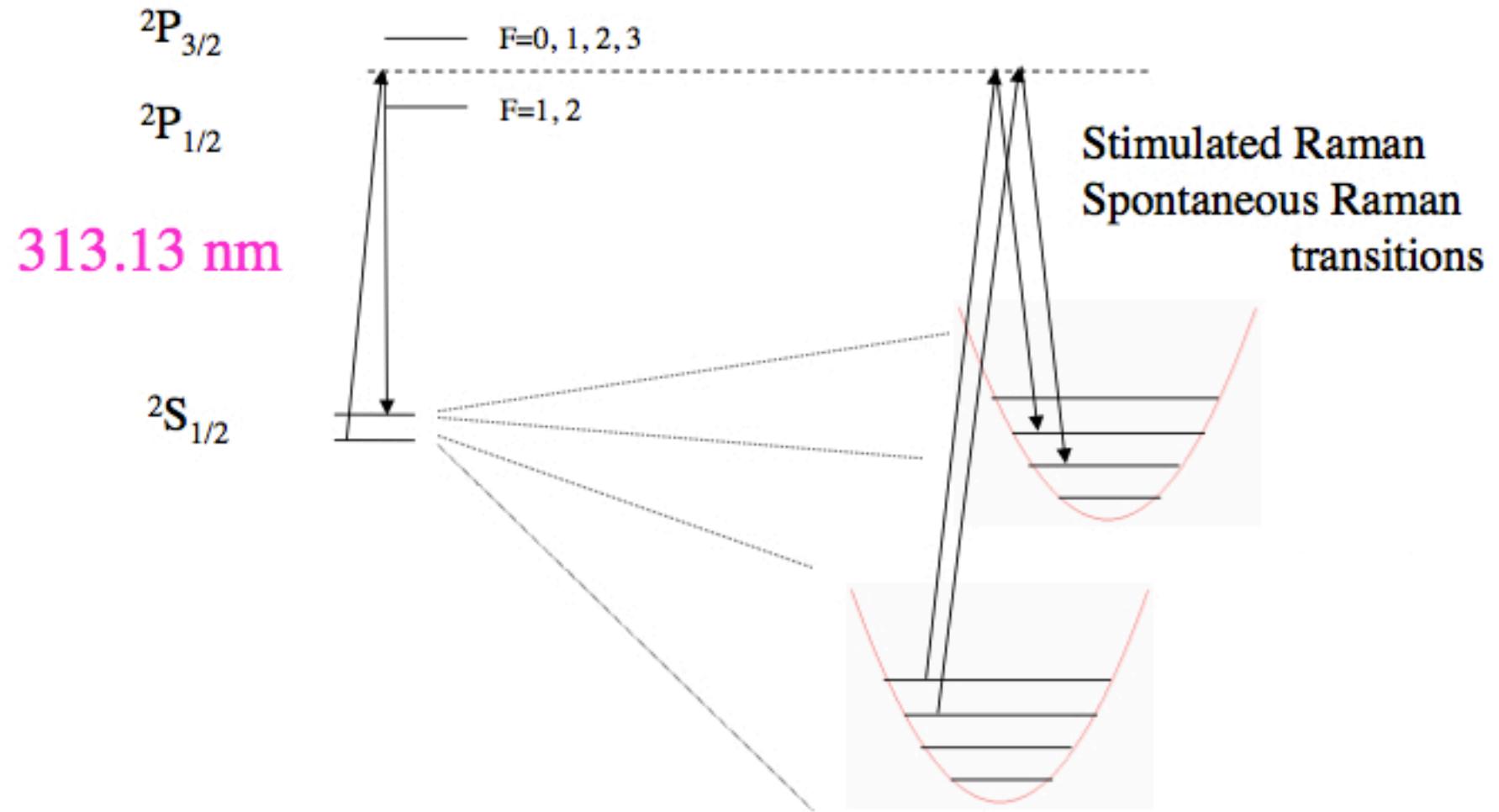
$$\Delta v = \sqrt{\frac{\hbar\omega}{2m}} \approx 0.44 \text{ ms}^{-1}$$

\bar{H}^+ sympathetic cooling

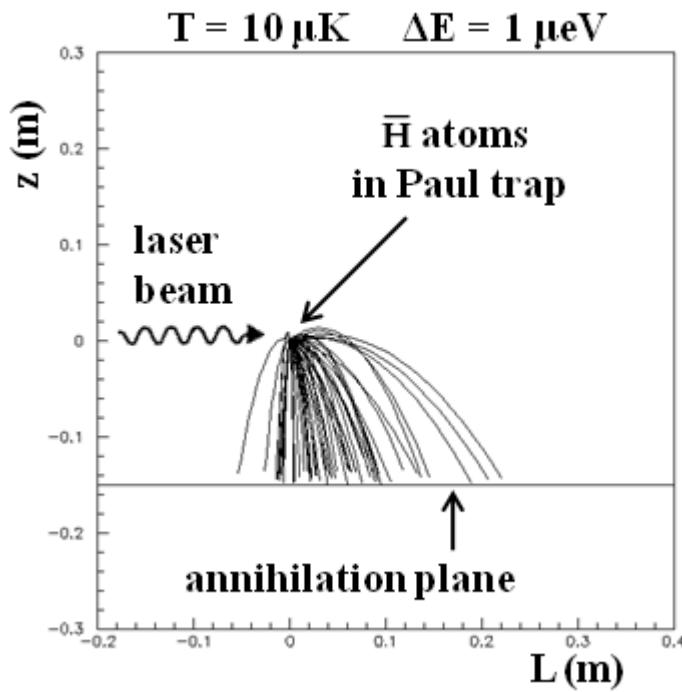
Simulation of Be^+ cooling in RF trap with micro-motion



sub-Doppler cooling



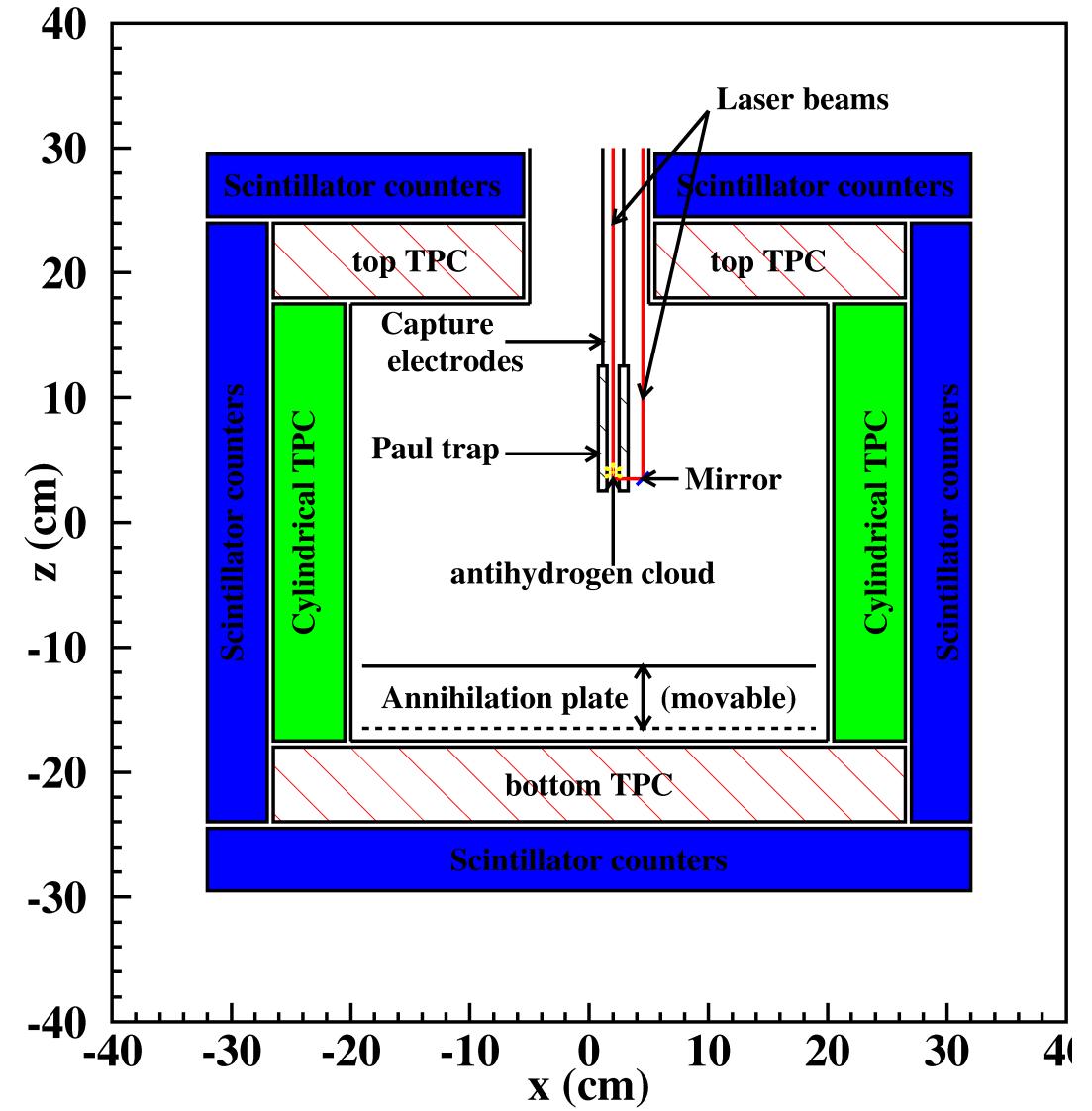
\bar{H} free fall detection



Measure:

- TOF
- arrival position

- ejected e^+ direction
- \Rightarrow cross-check of initial temperature



Using quantum states

Possibility to trap ultra cold \bar{H} using quantum reflection ? => improve $\Delta\bar{g} / \bar{g}$ by several orders of magnitude ?

A. Yu. Voronin, P. Froelich, and V. V. Nesvizhevsky, Phys. Rev. A **83**, 032903 (2011)

See talks by A. Yu. Voronin, and V. V. Nesvizhevsky

Expected efficiencies

Electrons						
Linac frequency	Mean current	Pulse current	Pulse duration	Electrons per pulse	Electron rate (s^{-1})	
300 Hz	0.2 mA	0.33 A	2 μs	4.2×10^{12}	1.25×10^{15}	
Positrons						
Production efficiency (at 10 MeV)	Transport efficiency	Fast positrons per pulse	Fast positron rate (s^{-1})	Moderation efficiency	Slow positrons per pulse	Slow positron rate (s^{-1})
5.5×10^{-4}	80 %	1.8×10^9	5.5×10^{11}	5×10^{-4}	9.2×10^5	2.8×10^8
Positron storage						
Trapping efficiency	Injection time	Stored positrons				
70 %	110 s	2.1×10^{10}				
Positronium						
Production efficiency	Tube section	Tube length	Positronium density	Loss fraction from Ps decay		
35 %	1 mm^2	1 cm	$7.4 \times 10^{11} \text{ cm}^{-3}$	0.5		
Antihydrogen positive ions						
Antiprotons per pulse	Deceleration and bunching efficiency	Production cross section of the $\bar{\text{H}}$ atom	Production cross section of the $\bar{\text{H}}^+$ ion	$\bar{\text{H}}$ per pulse	$\bar{\text{H}}^+$ per pulse	
6×10^6	80 %	$4.4 \cdot 10^{-16} \text{ cm}^2$	$8.8 \cdot 10^{-15} \text{ cm}^2$	3.9×10^2	0.32	
Antihydrogen atoms						
$\bar{\text{H}}^+$ Trapping efficiency	Cooling efficiency	cold $\bar{\text{H}}^+$ per pulse	Photodetachment efficiency	Detector acceptance	$\bar{\text{H}}$ events per pulse	$\bar{\text{H}}$ event rate (s^{-1})
100 %	70 %	0.2	99 %	65 %	0.14	1.3×10^{-3}

Outlook

Proposal submitted to CERN scientific committee, discussed October 25

Would start with ELENA operation in 2016

Several studies to be conducted in parallel:

- e^+ production & accumulation
- Ps target
- \bar{p} deceleration or accumulation
- interaction region
- H^- capture
- sympathetic cooling on p or H_2^+
- free fall detection
- quantum states adaptation