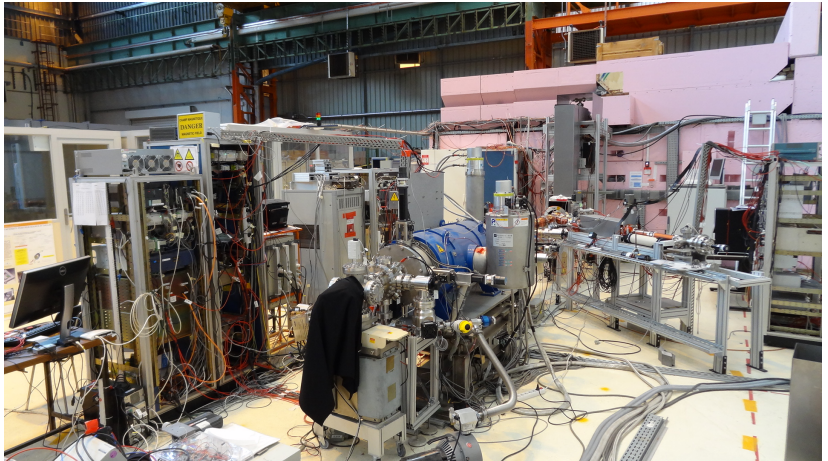# Towards (anti)hydrogen production

Amélia Leite

SPP/Irfu, Cea Saclay

OUTLINE

- ▶ Motivation for GBAR

- ▶ GBAR in 3 steps

- ▶ How do we produce (anti)hydrogen?

- ▶ Positron production and accumulation

- ▶ Positronium

- ▶ Proton source

- ▶ Conclusion

MOTIVATION

Weak Equivalence Principle is a cornerstone of relativity
↓
Never been tested with Antimatter
↓
Absence of primordial antimatter in the observable Universe
→ Different behaviour of antimatter under gravity?
⇓
GBAR: **G**ravitational **B**ehaviour of **A**ntihydrogen at **R**est
↓
$\bar{g}$ measurement

GBAR: GRAVITATIONAL BEHAVIOUR OF ANTIHYDROGEN AT REST

Measure the acceleration of $\bar{H}$ in free fall

$$\Delta z = \frac{1}{2}\frac{m_g}{m_i}g(\Delta t)^2 + v_{0,z}\Delta t$$

m_g gravitational mass of $\bar{H}$

m_i inertial mass of $\bar{H}$

Δt free fall time

Δz free fall height

g gravitational acceleration

$v_{0,z}$ initial vertical velocity

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Original idea:

Use $\bar{H}^+$ ions to achieve μK temperature (0.1 m/s) by sympathetic cooling $\rightarrow$ e$^+$ photodetachment $\rightarrow \bar{H}$ free fall
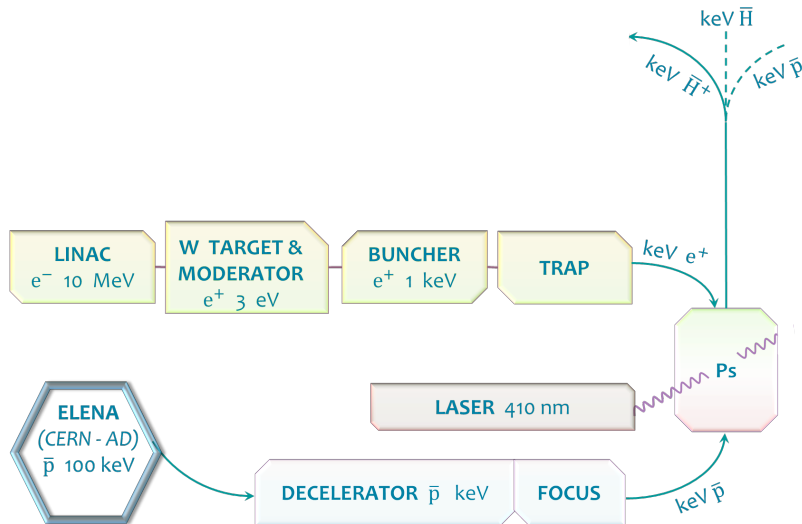
GBAR in 3 steps

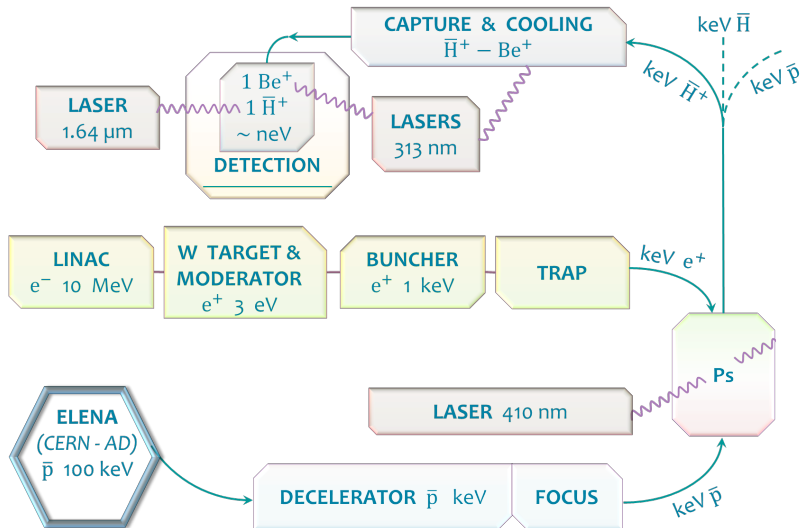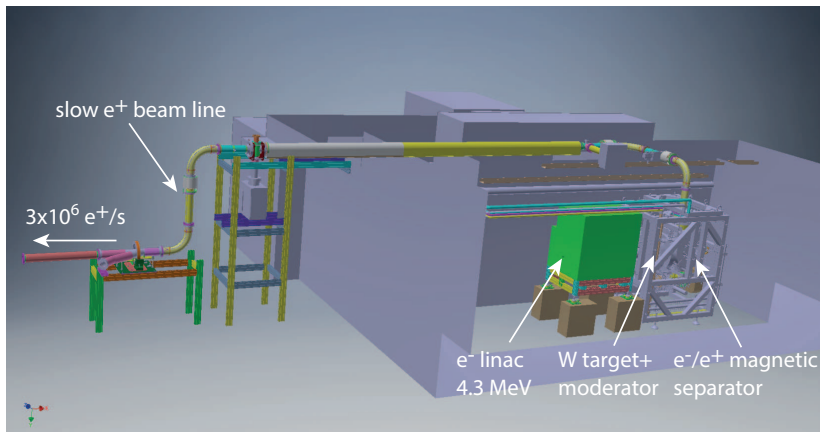ELENA
(CERN - AD)
$\bar{p}$ 100 keV

DECELERATOR $\bar{p}$ keV FOCUS

GBAR in 3 steps

GBAR IN 3 STEPS

GBAR @ Saclay

slow e⁺ beam line

3×10^6 e⁺/s
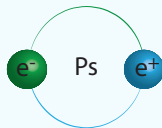
e⁻ linac
4.3 MeV

W target+
moderator

e⁻/e⁺ magnetic
separator

Cross section measurements

1. Hydrogen and negative hydrogen ion production

$p + Ps \rightarrow H + e^+$ @Cea
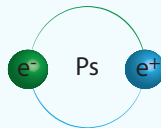
$H + Ps \rightarrow H^- + e^+$ @Cern

CROSS SECTION MEASUREMENTS

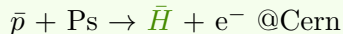## 1. Hydrogen and negative hydrogen ion production

$p + Ps \rightarrow H + e^+$ @Cea

$H + Ps \rightarrow H^- + e^+$ @Cern

2. Antihydrogen and antihydrogen ion production
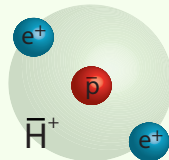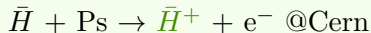
$\bar{p} + Ps \rightarrow \bar{H} + e^-$ @Cern

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

POSITRON ACCUMULATION

Buffer gas trap

Charged particles can be stored in a Penning trap ad eternum (if your trap is good enough!)

Yet the e^+ need to loose enough energy $\rightarrow$ use a buffer gas for inelastic collisions: $e^+_{8-11eV} + N_2 \rightarrow e^+ + N_2^*$

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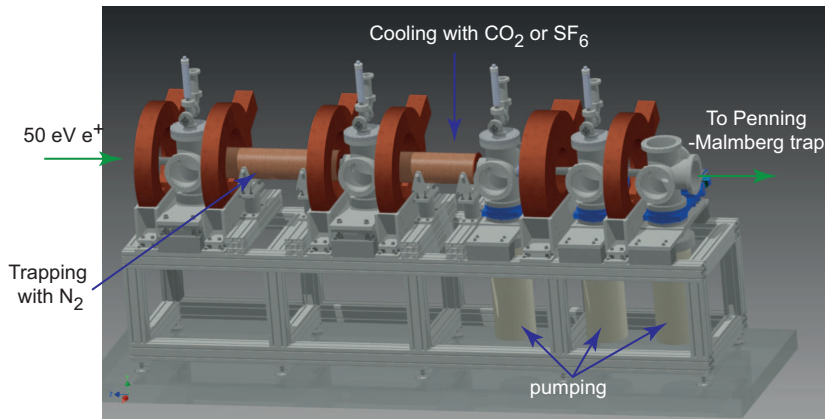
Penning-Malmberg trap

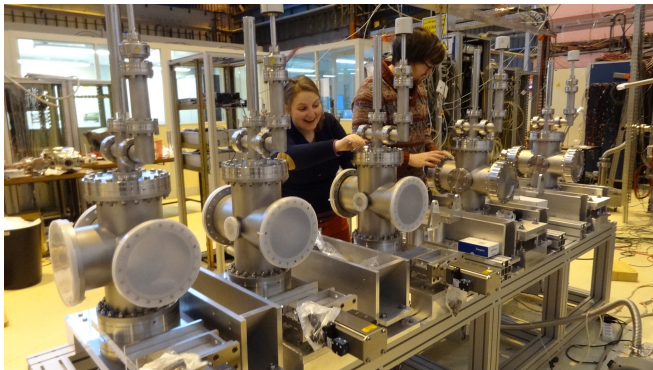Store e^+ bunches and form a plasma with 10^{10} e^+

Buffer gas trap

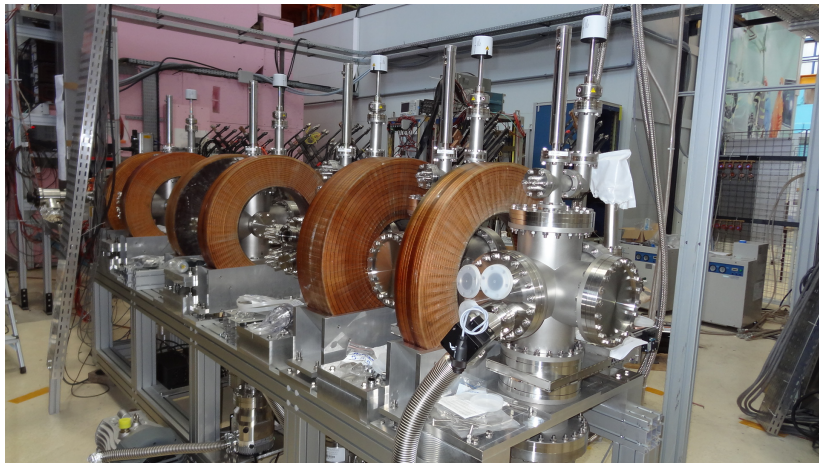Two stage trap with a third stage accumulator
Efficiency $\sim$ 20% to 30%

Buffer gas trap

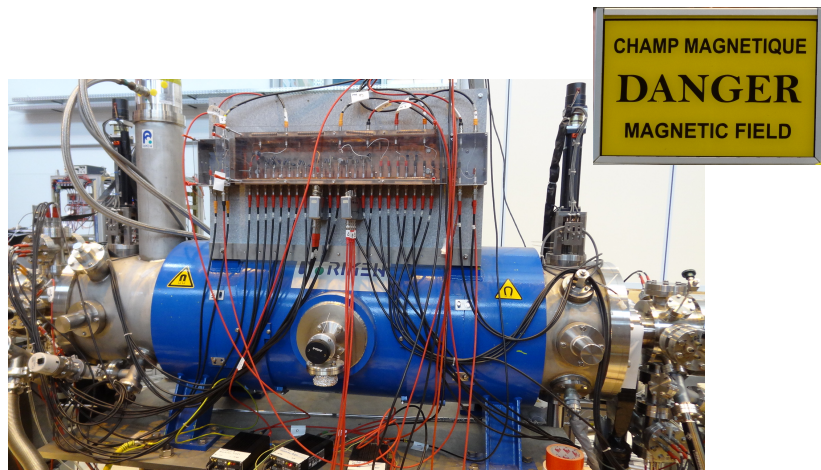We are slowly building the trap from scratch...

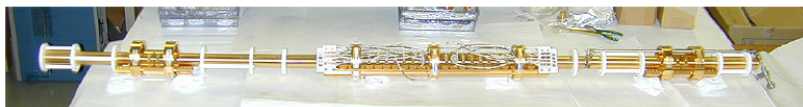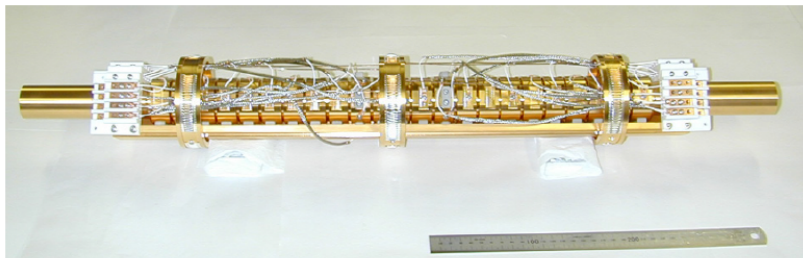# Buffer gas trap

Now it looks better but it's not ready yet!

Penning-Malmberg trap
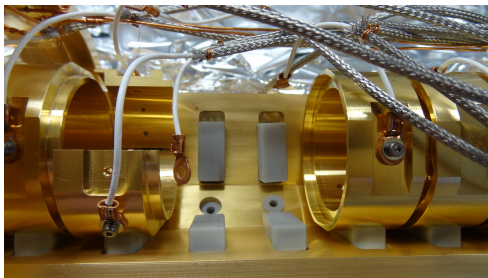
Superconducting magnet: 5T → radial confinement

Penning-Malmberg trap

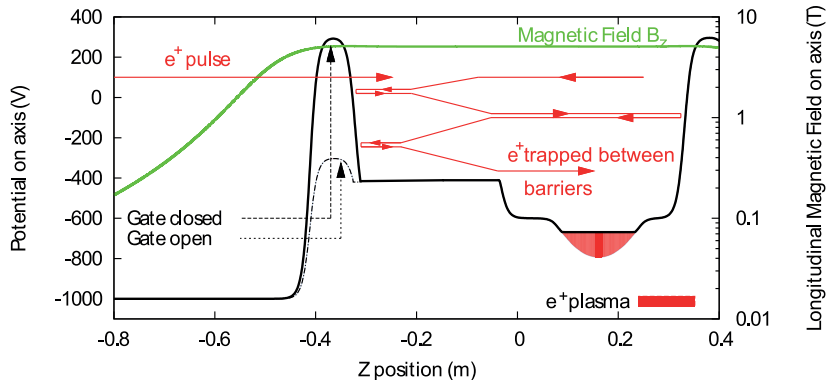27 annular electrodes: electrostatic field $\rightarrow$ longitudinal confinement
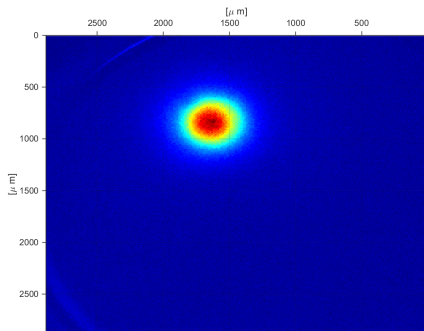
Penning-Malmberg trap

ACCUMULATION TECHNIQUE

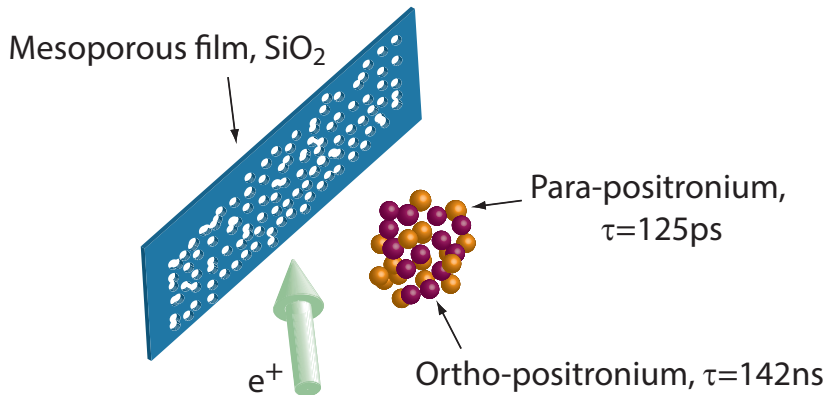e^+ injection $\rightarrow$ e^+ confinement + stacking $\rightarrow$ e^+ ejection

ACCUMULATION TECHNIQUE

e^+ injection $\rightarrow$ e^+ confinement + stacking $\rightarrow$ e^+ ejection

POSITRONIUM PRODUCTION

Mesoporous film, SiO$_2$

Para-positronium,
τ=125ps

Ortho-positronium, τ=142ns

e$^+$

PROTON SOURCE

REACTION SCHEME

Electrostatic quadrupole

Faraday cup

H

p

Camera

Microchannel plate detector
& Phosphor screen

H⁻

Mesoporous film, SiO₂

Si₃N₄ membrane

e⁺

Ps

Camera

p
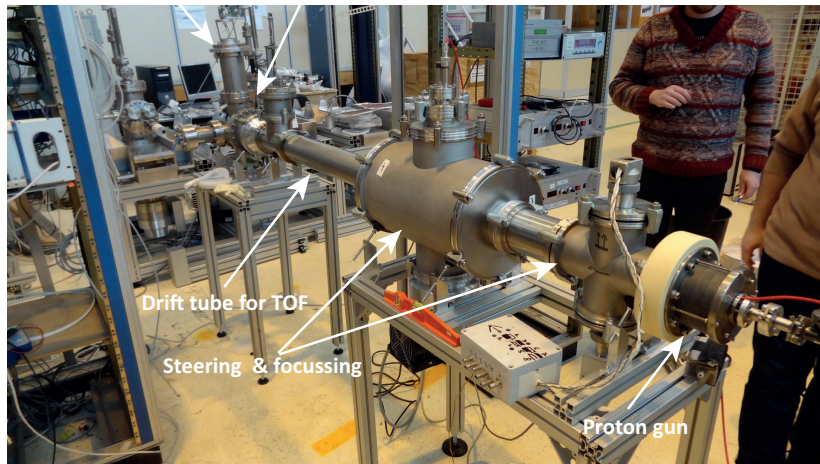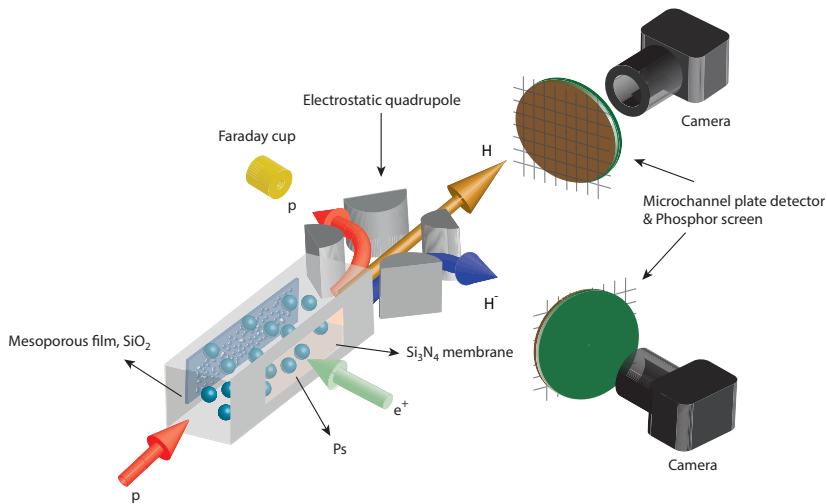
Conclusion

- ▶ Setup assembly in progress

- ▶ Commission during summer

- ▶ Stay tuned for hydrogen production next fall!
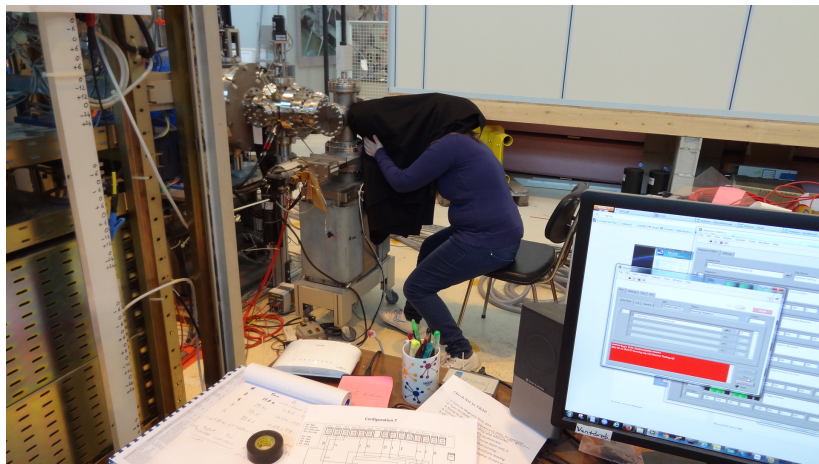
Thank you!

Questions?

Extra Slides

GBAR vs AEGIS

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

GBAR: cooled $\bar{H}^+ \rightarrow$ slow $\bar{H}$
L = 0.1 m and $v_{\bar{H}} = 0.5$ m/s $\Rightarrow 20$ cm
($T_{\bar{H}} \sim 10\,\mu K \sim 7neV$)

AEGIS: $\bar{H}$ beam
L = 1 m and $v_{\bar{H}} = 500$ m/s $\Rightarrow 20\,\mu$m
($T_{\bar{H}} \sim 100\,mK \sim 7\,\mu eV$)

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

H
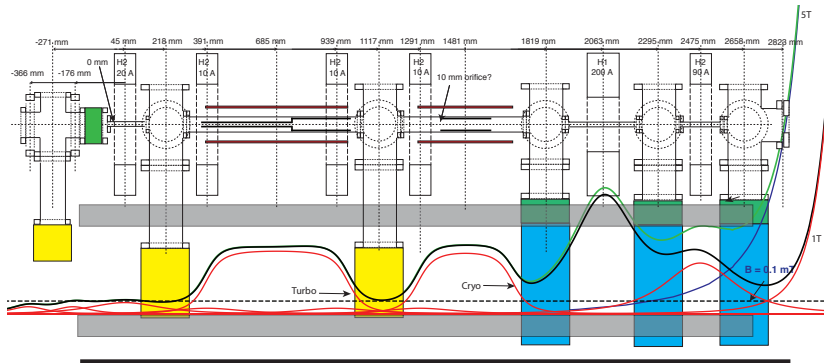
$$h\, =\, v_z^0 t + \frac{1}{2}\frac{m_g}{m_i}gt^2\, =\, v_z^0\left(\frac{L}{v_h}\right) + \frac{1}{2}\frac{m_g}{m_i}g\left(\frac{L}{v_h}\right)^2$$

L

Equivalence principle

"The trajectory of a point mass in a gravitational field depends only on its initial position and velocity, and is independent of its composition and structure."

Buffer gas trap

Positronium production

Mesoporous film

- ▶ pure silica (SiO_2) with nanometer size pores
- ▶ emits orho-positronium ($\sim$10 meV) upon implantation of e^+ ($\sim$keV)
- ▶ high ($\sim$30%) efficiency

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- high ($\sim$30%) efficiency

Ps cloud density:

@Cea: 10^{10} Ps/cm^3
@Cern: 10^{12} Ps/cm^3

Positronium production & spectroscopy

Spectroscopy

Detection of the fluorescence light:

  3D to 2P transition $\rightarrow$ infra-red photon at 1312nm

  2P to 1S transition $\rightarrow$ UV photon at 243nm

Positronium production & spectroscopy

Spectroscopy

Detection of the fluorescence light:

    3D to 2P transition → infra-red photon at 1312nm
    2P to 1S transition → UV photon at 243nm

Detectors:

Annihilation → scintillators Fluorescence → optical fibers + photomultipliers

Hydrogen detection
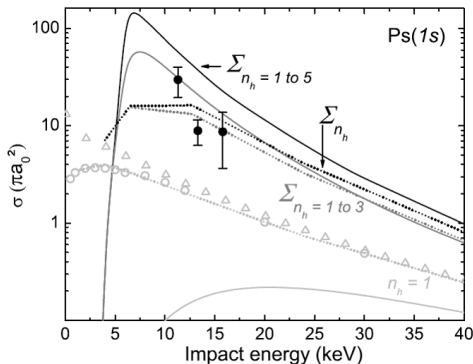
Background sources

- ▶ Gamma radiaton from e^+ and Ps annihilation

- ▶ MCP noise

- ▶ Charged particles - separated by TOF

CROSS SECTION MEASUREMENTS

Only one previous study on $p + Ps \rightarrow H + e^+$ for p energies 11.3, 13.3 and 15.8 keV with a total of **211 events**

Merrison et al, Phys. Rev. Letters 78,2728 (1997)