Measurement preparation for $\overline{H}$(-ion) production cross-section from $\bar{p}$ beam and Positronium

Seoul National University

BongHo Kim
for the GBAR collaboration

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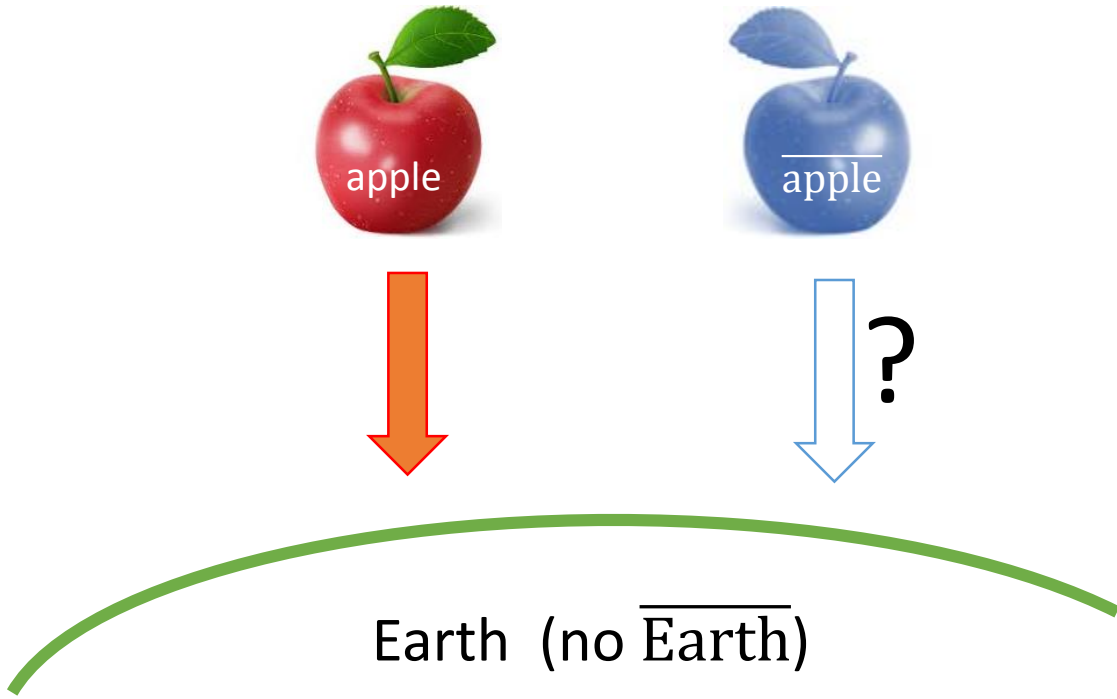
- ❑Summary



❑ Motivation

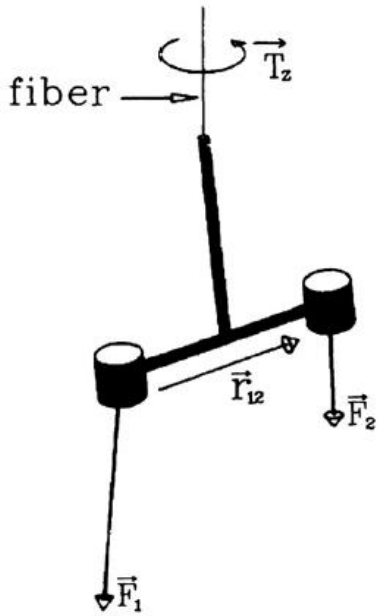
The equivalence principle

$$m_I = m_g$$

$$m_I = \frac{F}{a}, m_g = \frac{F_g}{g} = F_g \frac{R^2}{GM}$$

- The weak equivalence princle

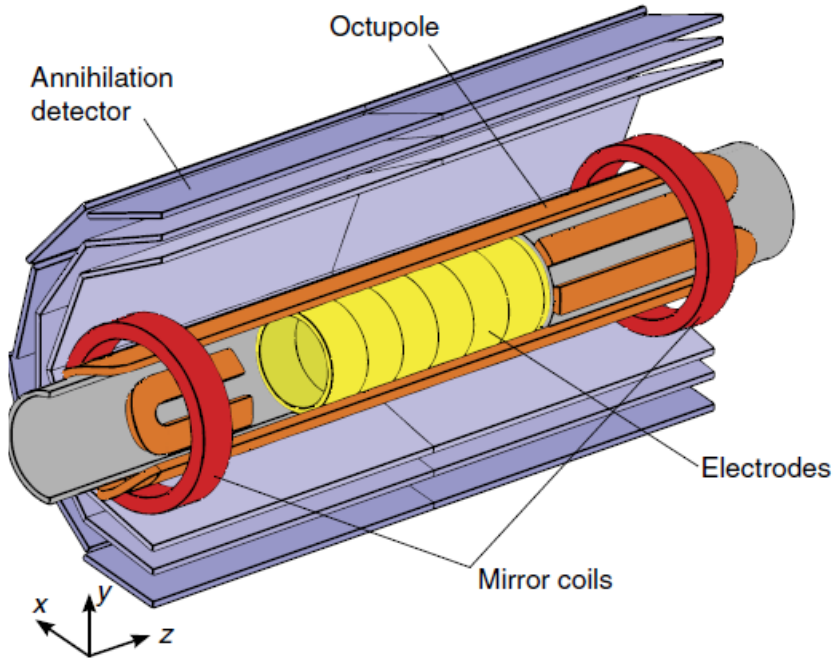
- ‘The trajectory of a point mass in a gravitational field depends only on its initial position and velocity, and is independent of its composition and structure’

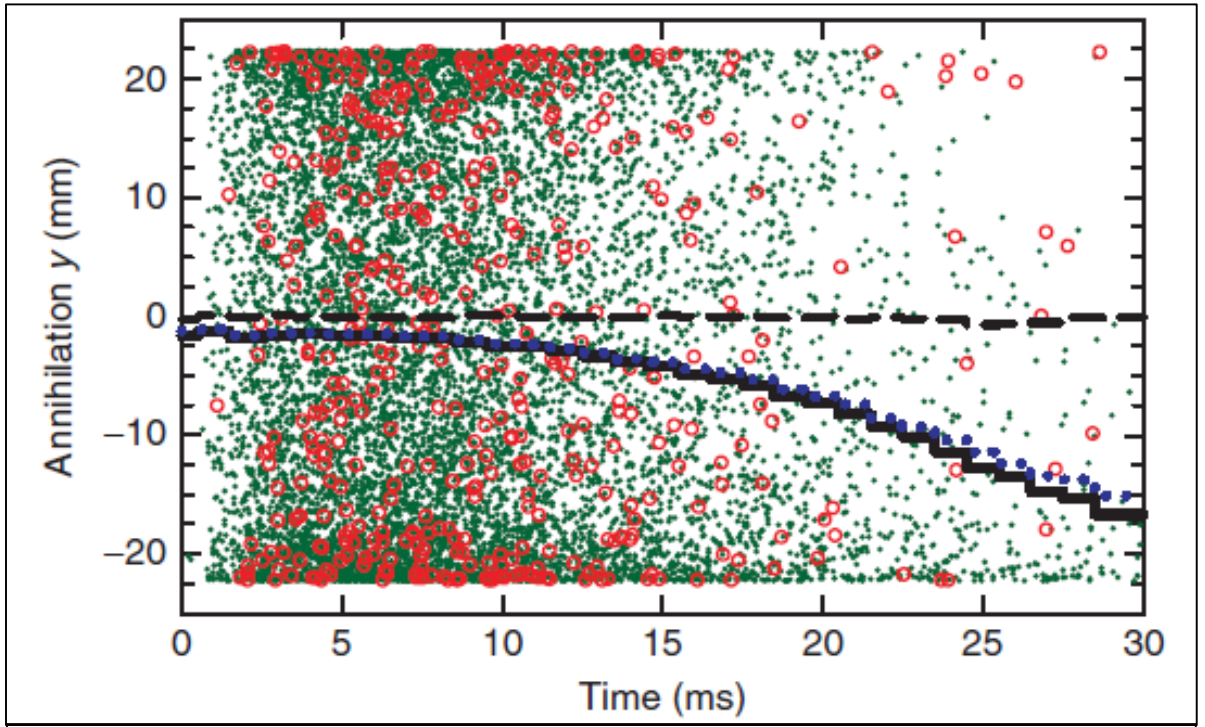


- Verified for matter experiment from free-fall to torsion valance (Eotvos-type). ($\Delta m/m < 10^{-13}$)
- No experimental result for anti-matter’s free falling except Alpha result (2013)

Previous anti-matter experiment – Alpha

Nature communications, 2787 (2013)





- Only one anti-hydrogen experiment was done - Alpha experiment : -65 < F (= m_g/m_i) < 110 (95% significance level)
- No Anti-neutron experiment(hard to decelerate)

Red circle : real data (434 annihilation points)
Green point : simulation
Black solid line : averaged simulation (F=100)
Blue dotted line : averaged simulation with detector smearing (F=100)
Black dashed line : averaged simulation (F=1)

Tow approaches : AEGIS vs GBAR

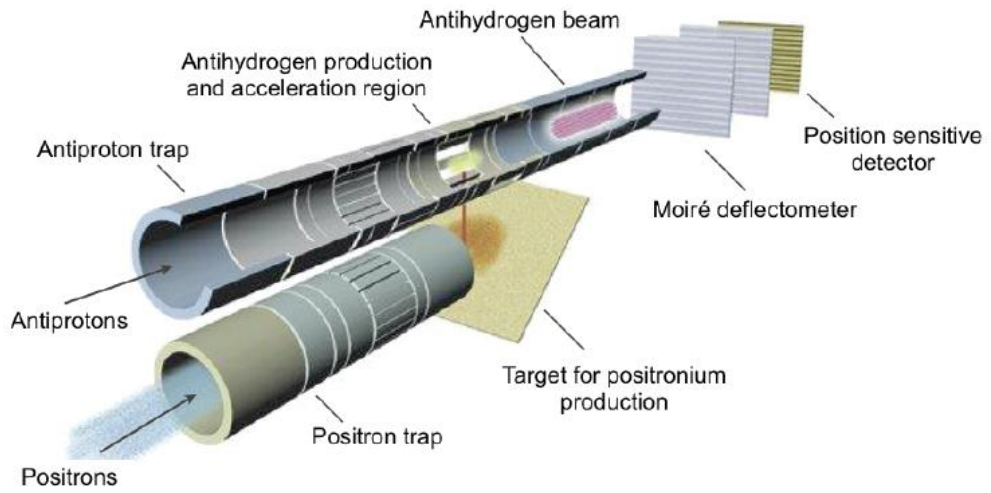
AEGIS

Goal : $\frac{\Delta g}{g} = 1\%$ *precision*

Energy : 100mK

Free fall : 20um

Detection way : quantifying the deflection of beam



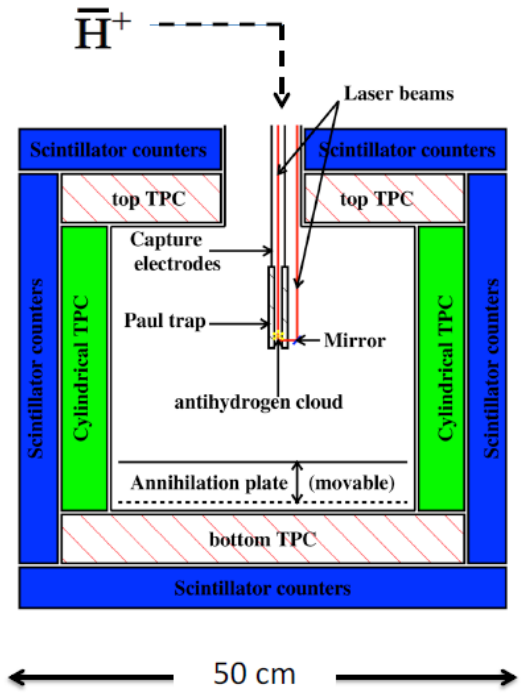
GBAR

Goal : $\frac{\Delta g}{g} = 1\%$ *precision* by 1500# free fall

Energy : 10uK

free fall : 20cm

Detection way : reconstructing annihilation points



GBAR collaboration

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

17 institutes from 9 countries

❑ GBAR overview

GBAR : Gravitational Behaviour of Antihydrogen at Rest

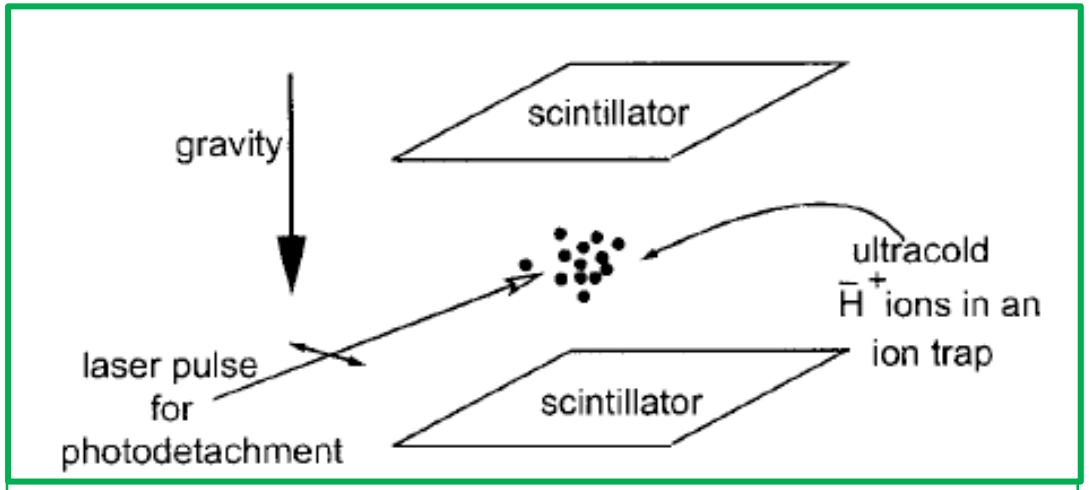
- Generating anti-hydrogens (No charge) ➡ Traping or decelerating neutral anti-matter (ALPHA, AEGIS)

1. Generating anti-hydrogen ions
2. Decelerating anti-hydrogen ions
3. Detaching positron and anti-hydrogen free fall experiment

Idea for GBAR

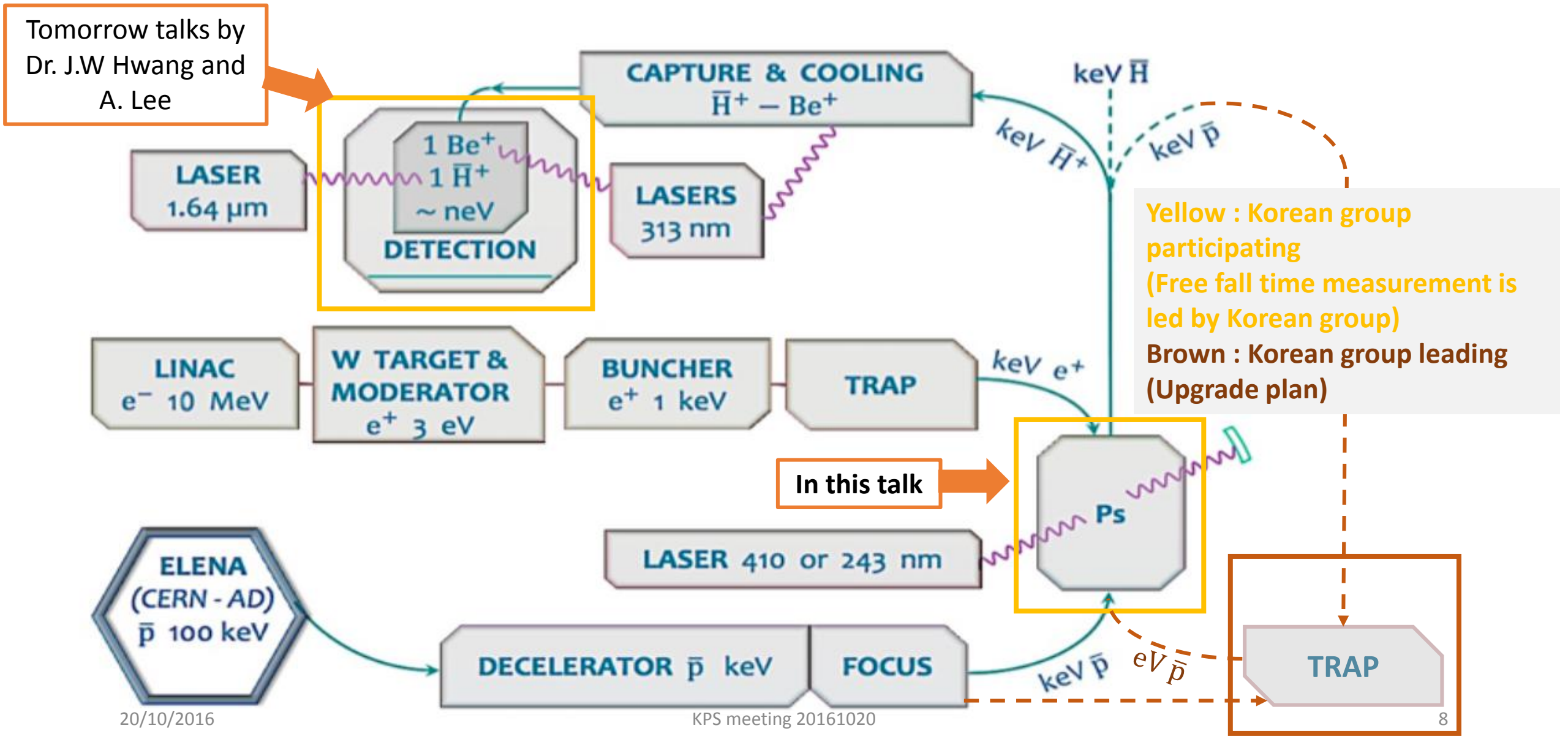
$$\bar{p} + Ps^{(*)} \rightarrow \bar{H}^* + e^-$$

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



Suggested by J.Walz & T. Hansch,
General Relativity and Gravitation, **36** (2004) 561

Beam line overview



❑ $\bar{H}$& $\bar{H}^+$ production cross section measurement

- Cross section measurement for

$$p + Ps^{(*)} \rightarrow H^{(*)} + e^+$$

$$H + Ps^{(*)} \rightarrow H^- + e^+$$

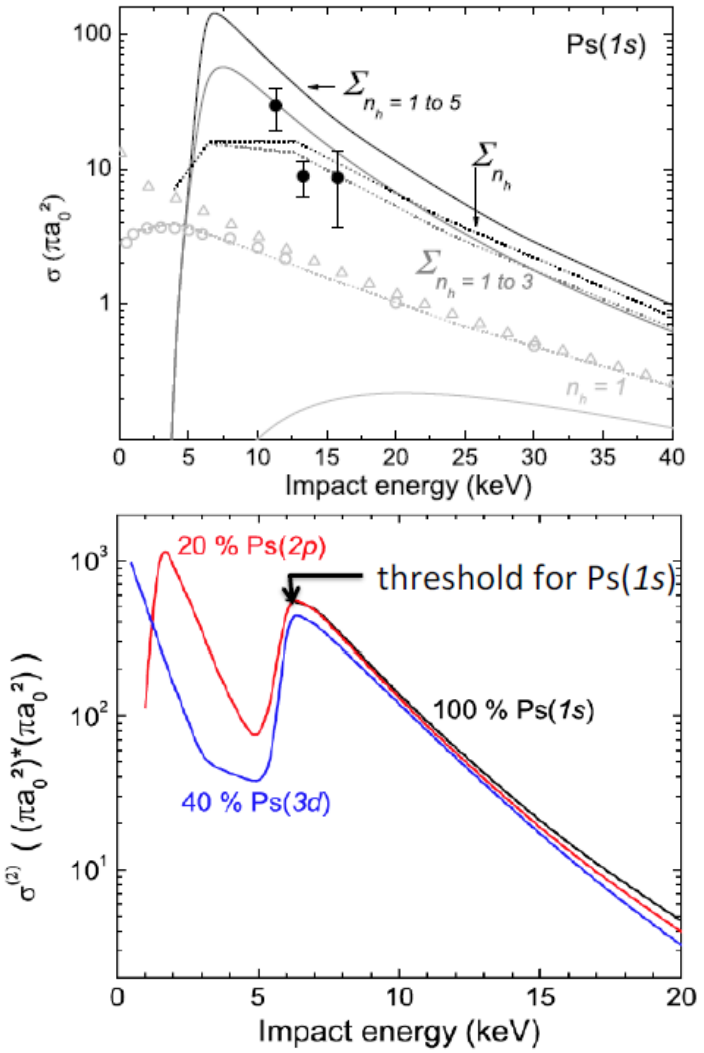
$$\bar{p} + Ps^{(*)} \rightarrow \bar{H}^+ + e^-$$

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

- ELENA facility will supply 100keV antiproton from 2017 (0.5×10^7#(bunch)/110s)
- 10^{12}Ps/cm^2 (aim) →below 1 $\bar{H}^+$ expected (/110s)

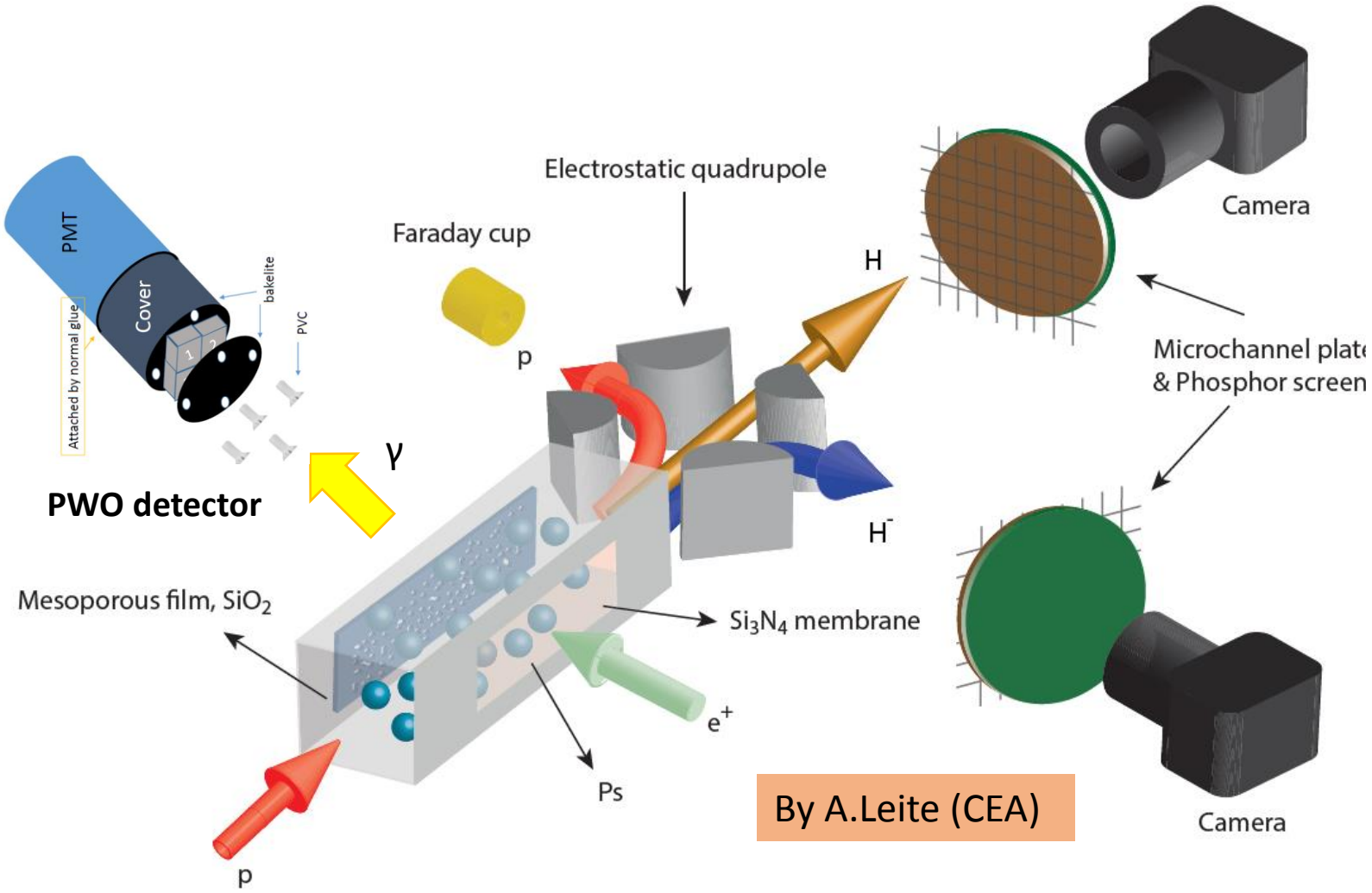
: Dense Ps with well measured cross section for each Ps state is absolutely important. (two collisions by one (anti) proton in Ps cloud)

- We will Measure H and H^+ ion production cross section (CEA Saclay) and compare this with theoretical expectation (IPCMS) in this year. (No experimental data yet (only one measurement for $\bar{H}$ production))



P.Comini and P-A Hervieux, J.Phys.Conf.Ser.443, 012007 (2013)

H& H^- production cross section measurement



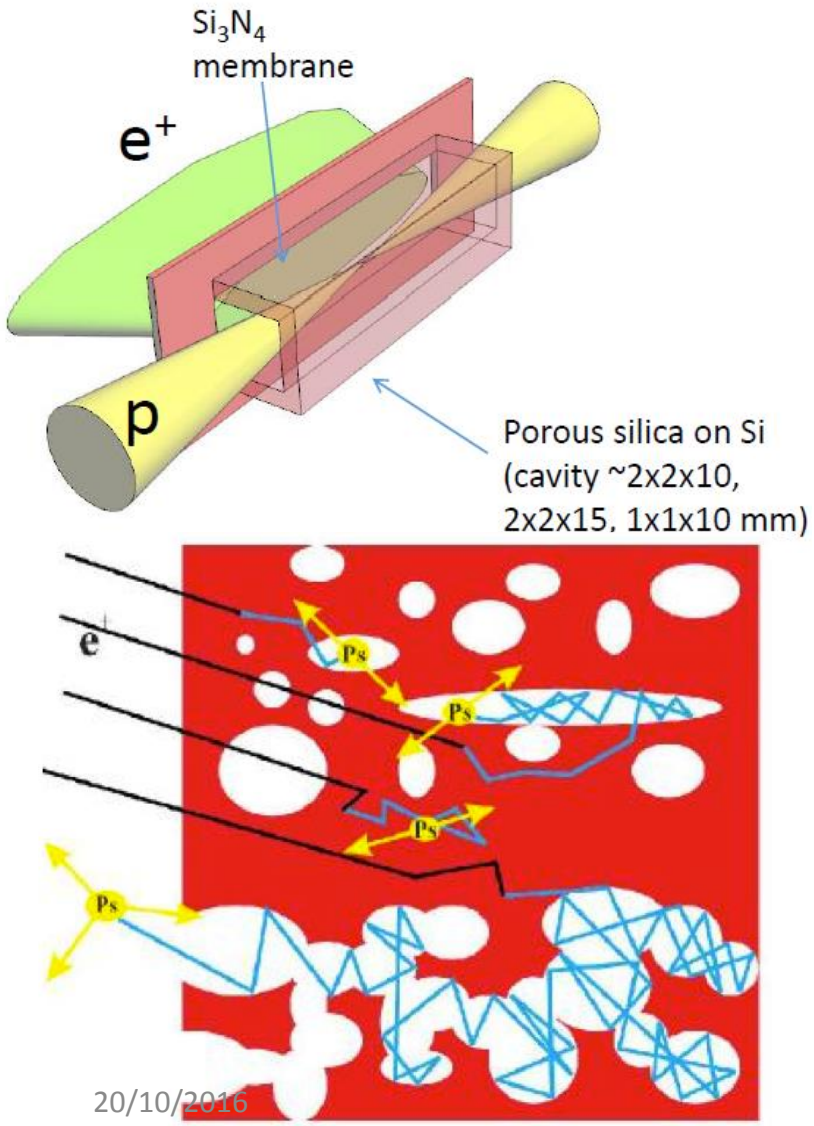
By A.Leite (CEA)

$$\sigma[p + Ps \rightarrow H + e^-] = \frac{\#(H)}{\#(p) \times \#(Ps) \times \varepsilon}$$

#(p) : measured by Faraday cup
#(H) : measured by MCP + CCD assembly
#(H^+) : measured by MCP + CCD assembly
#(Ps) : measured by PWO detector

Beam profile (p) : by MCP + CCD assembly
Beam profile (H): by MCP + CCD assembly
Ps distribution : PWO detector with W block

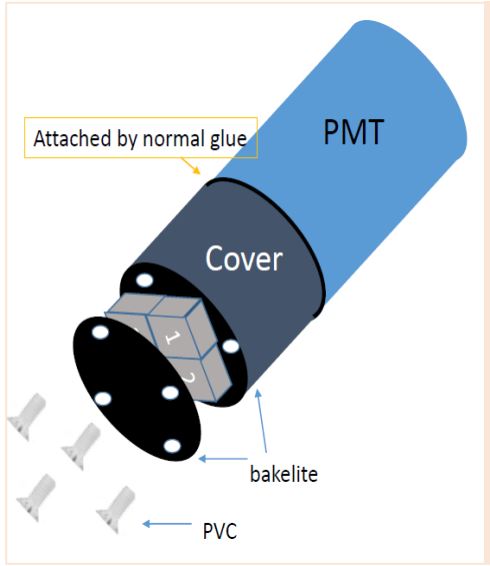
Porous silica Target cavity and Ps formation



- Porous silica target cavity with Si_3N_4 membrane window for e+ beam (goal ~ 3keV, # ~ $10^8 e^+$/bunch).
- Ps cloud (KE ~70meV) will be generated inside target cavity (30~35% of e^+ convert to Ortho-Ps)
- Ps will be reflected at the wall untill decay or escaping cavity.
- Adequate estimation for escaped Ps ratio is requred for optimization.

- Understaning reflection angle of Ps, measurement of Ps's kinetic energy is required.

PWO detector preparation



Specification

- 1 PMT + 4 PWO Crystal (2x2x3.8cm for each)
- Yield 0.7~2.6 [p.e./MeV] acheived with ^{22}Na source before cutting.
- Density : 8.3g/cm3
- Radiation length : 0.9cm
- Decay time : 10~30ns
- Good for high intensity beam measurement

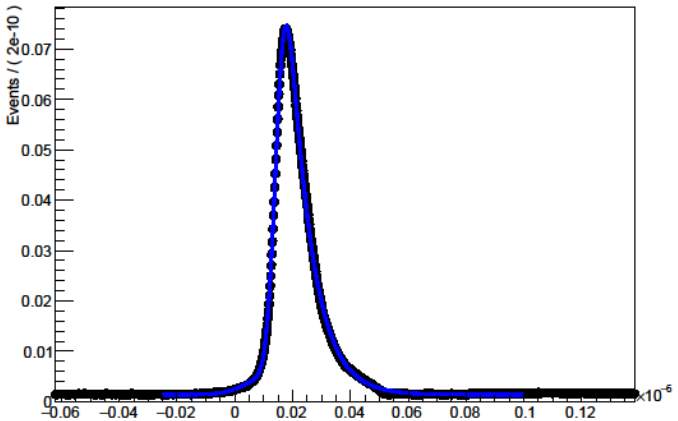
→ Already used may experiments like

CMS, Alice, Penda or positronium detections..

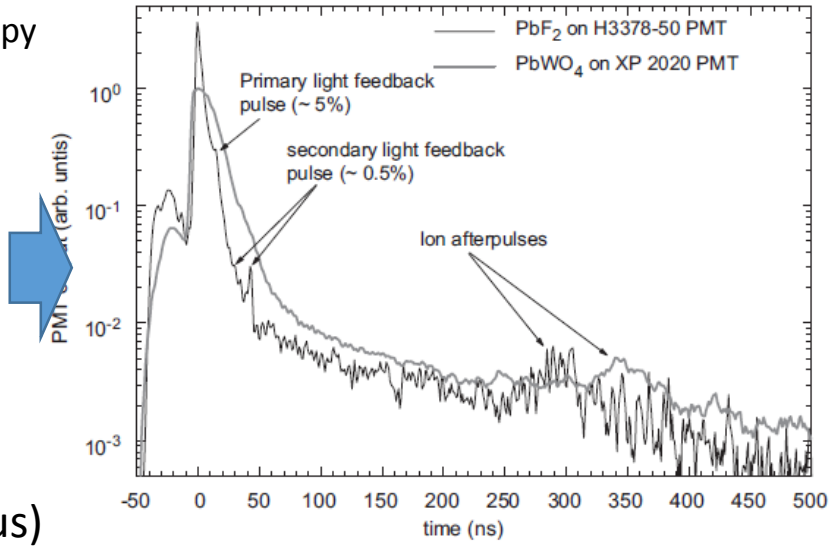
- Efficiency ~100% achieved with 15ns FWHM
- Time spectroscopy method will be used to distinguish annihilation and para-Ps(125ps) background from Ortho-Ps signals (142ns).

(NIM A 580 (2007) 1338)

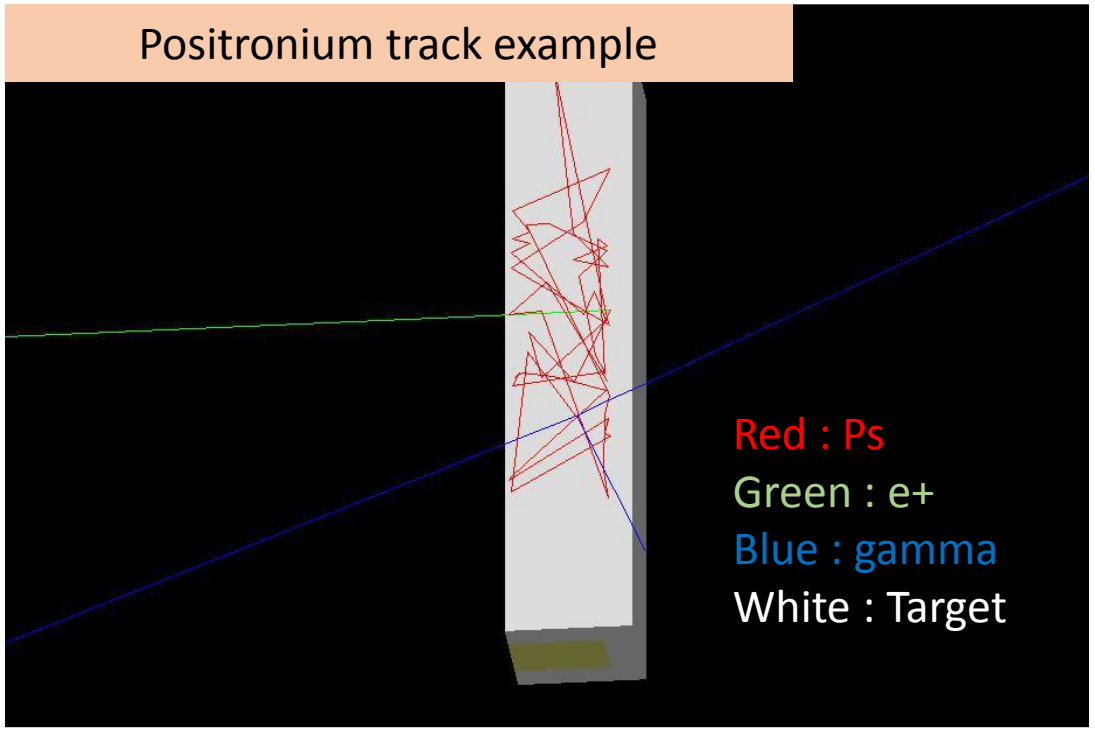
(Averaged) Single 0.511MeV γ time spectroscopy

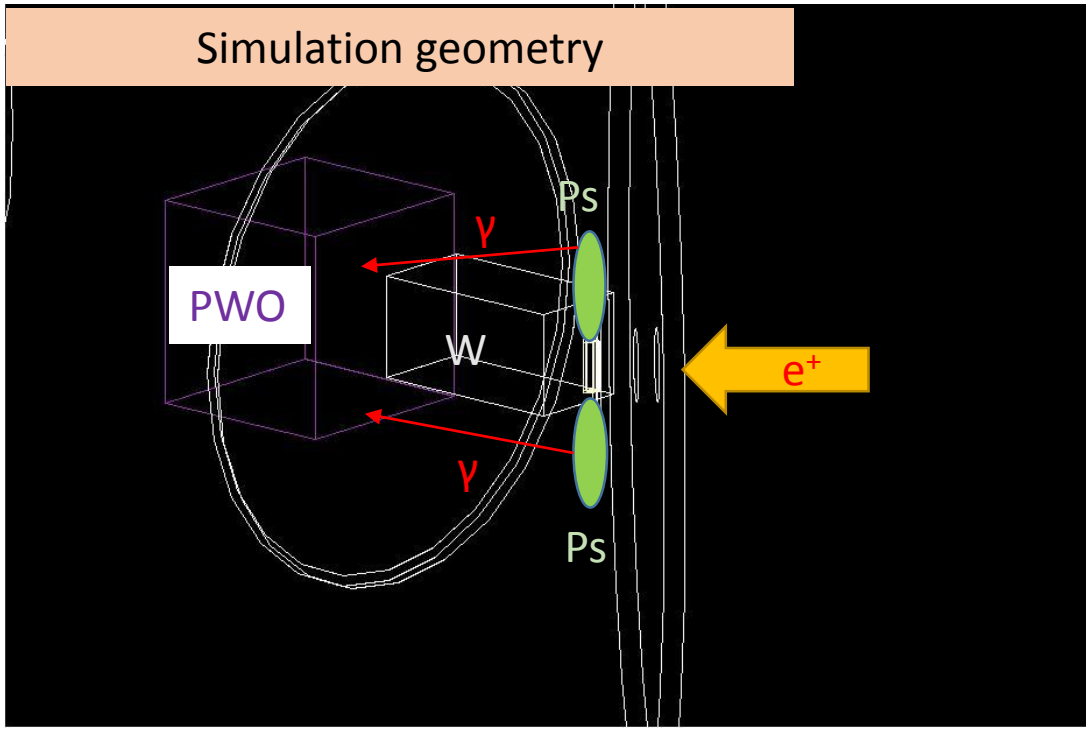


Time (us)



Ps measurement preparation

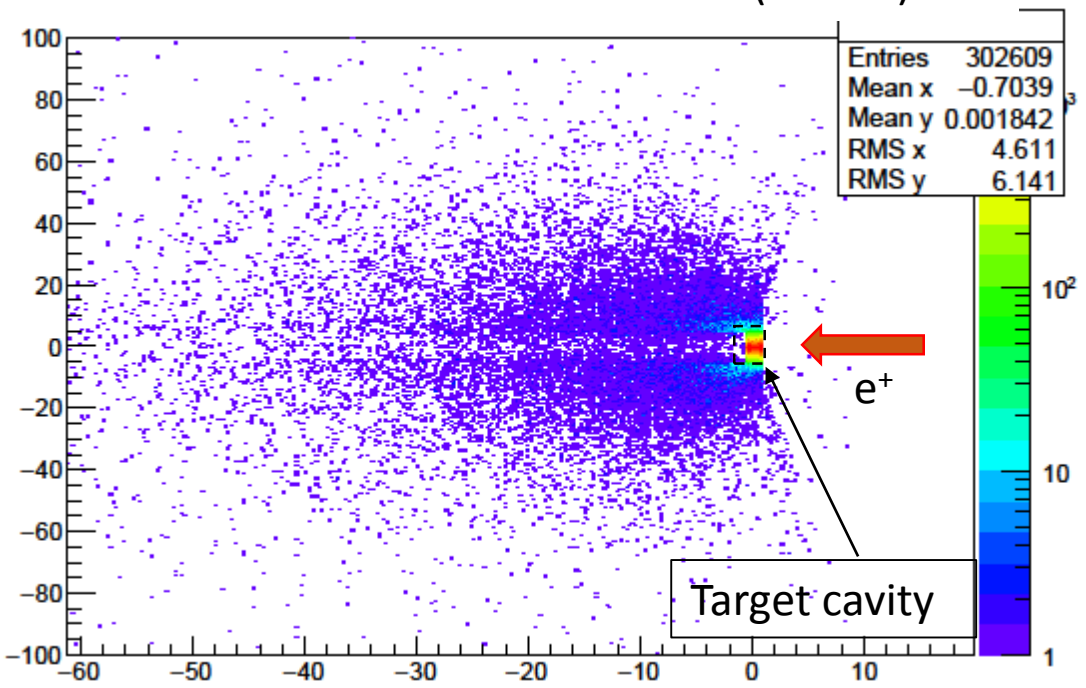




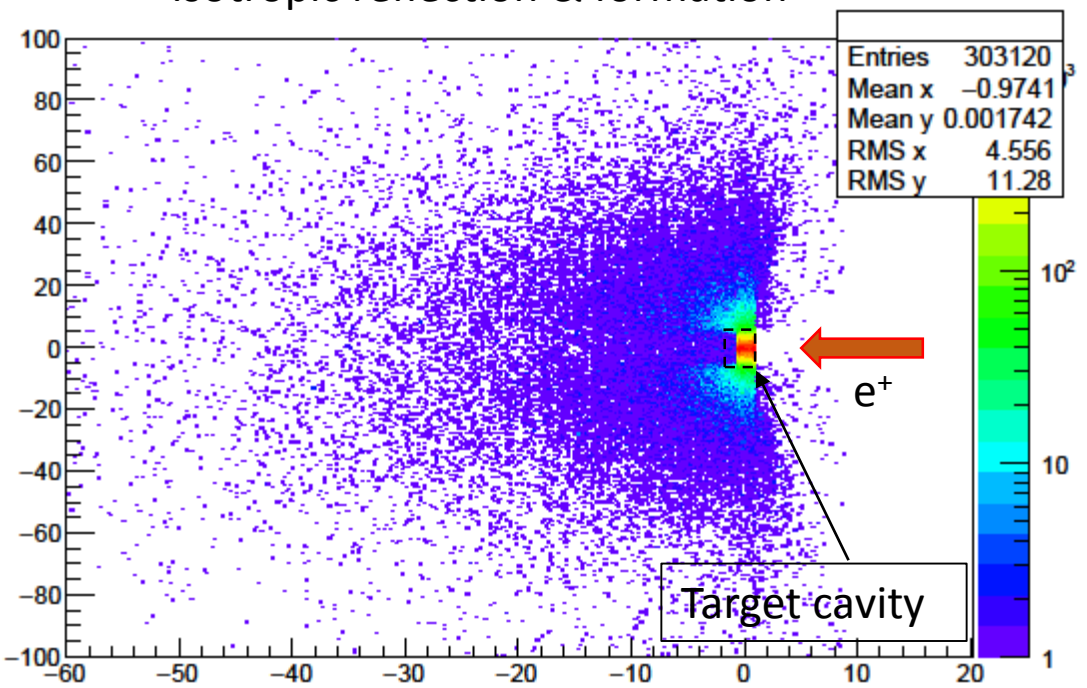
- Simulation has been developed to estimate Ps movement by adding new particle and process (Ortho-Ps) in Geant4 simulation.
- Escaped amount of Ps will be measured as setup in right panel.
- By adding W block in adequate position, we can measure reflecting angle distribution

Positronium distribution at simulation

Cosine reflection & formation(Cosine)



Isotropic reflection & formation

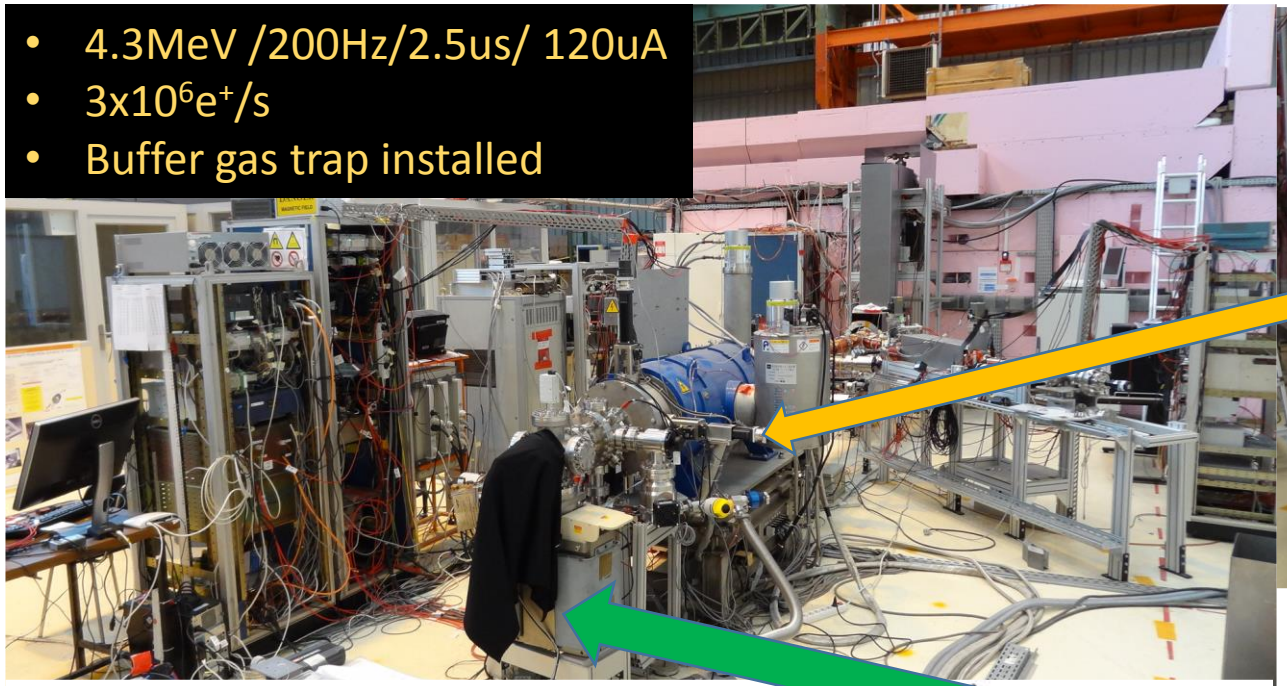


Positronium decay position is simulation by Geant4 with cavity target

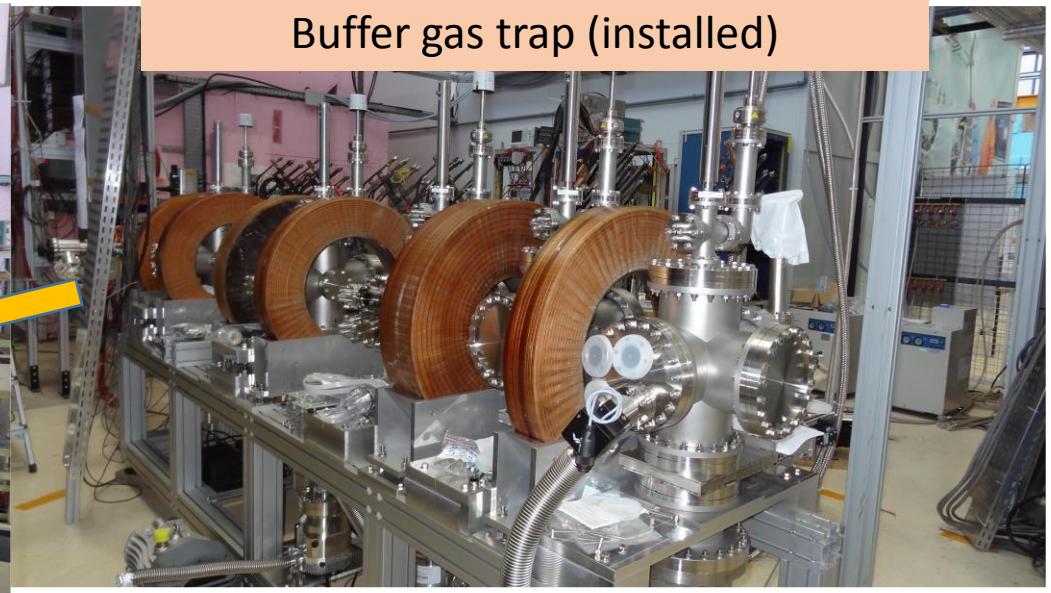
- Cosine (reflection) case : 89.6% of positroniums are remained in cavity before decay
- Isotropic case (reflection) : 72.7% of positronium remain in cavity before decay

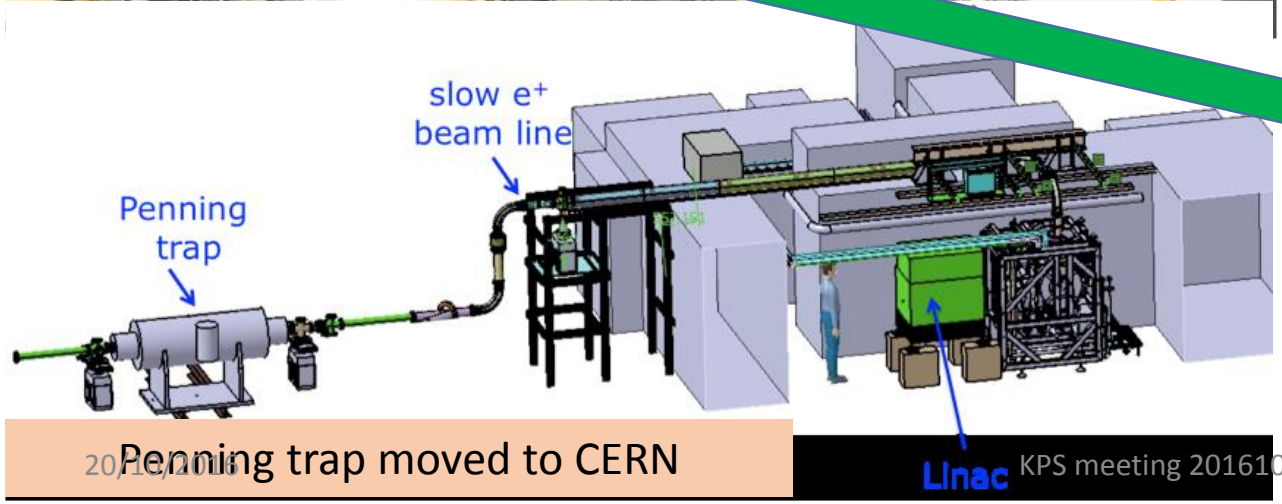
❑ CEA Saclay status

- 4.3MeV /200Hz/2.5us/ 120uA
- $3x10^6 e^+/s$
- Buffer gas trap installed

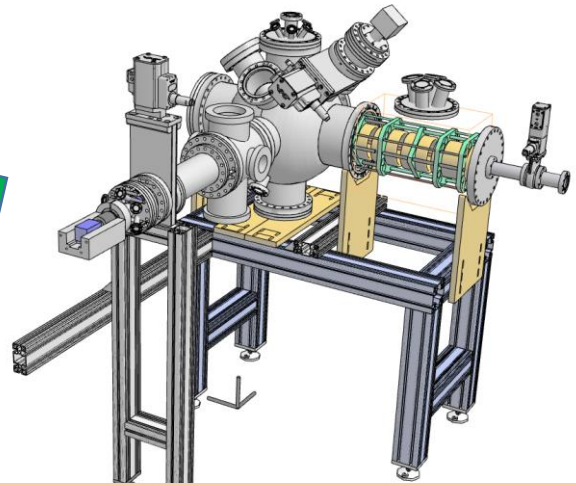


Buffer gas trap (installed)





Penning trap moved to CERN



Ps target chamber (installed)

❑ Status and Summary

- WEP for antimatter will be tested by antimatter's free fall experiment at GBAR.
- To make ultra cold $\overline{\mathrm{H}}$ for free fall experiment, dense Ps and measurement of cross section for each Ps state is required.

- $\sigma\,[p(H)\ +\ (Ortho)\,Ps\ \rightarrow H(H^{+})\ + e^{+}]$ measurement is planned at CEA in this year.

- GBar is Scheduled to start measurement in 2017-2018.

Appendix

- Life time of Positronium

- τ(Ortho-Ps) : 142.5ns
- τ(Para-Ps) : 125ps
- τ(Ps(2p)) : 3.2ns
- τ(Ps(3d)) : 31ns

- Laser duration

410nm : ~50ns duration

243nm : repeatition every couple of ns