A new path toward gravity experiments with $\bar{H}$

hep-ex-0411077, to appear in Nucl. Inst. Meth. A

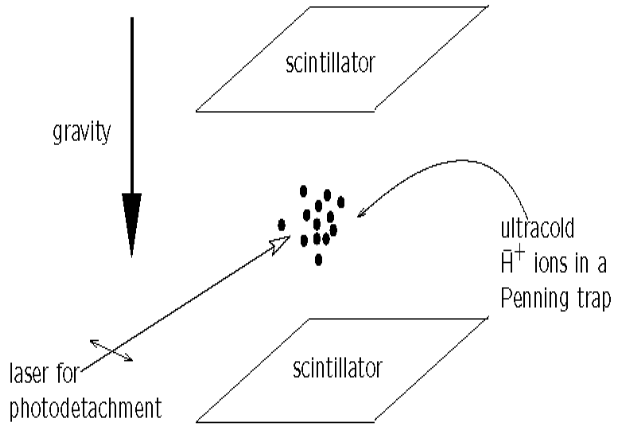
Outline:

- Goal: measure g for $\bar{H}$
- Reactions to produce the ion $\bar{H}^+$ using Ps
- Getting the required Ps density
- Challenges
- Overall Scheme

Measure g for $\bar{H}$ as proposed by Walz et Hänsch

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

- Capture the ion $\bar{H}^+$ → cooling µK
- De-ionisation via laser
- Vertical time of flight
- Relative precision on g:



→ 5 10^5 $\bar{H}$ in the ion trap → $\Delta g/g = 0.001$

→ 10^4 → = 0.006

→ 10^3 → = 0.02

Syst. error dominated by $\bar{H}^+$ temperature

Production: atoms & ions

- Radiative Recombination (RR) $ne \lesssim 10^{8}\ cm^{-3}$

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

- Laser Induced Radiative Recombination (LIRR)

$p + e^{-} + h\nu \rightarrow H + 2h\nu$ | $\bar{p} + e^{+} + h\nu \rightarrow \bar{H} + 2h\nu$

- 3 Body reactions (3BDY) $ne \gtrsim 10^{9}\ cm^{-3}$

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

CERN

$e^{+} + e^{-} + e^{\pm} \rightarrow P_S^{*} + e^{\pm}$ & e^{+} + metal $\rightarrow P_S$

- Charge exchange with Positronium (CXPS)

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

$H + P_S \rightarrow H^{-} + e^{+}$ | $\bar{H} + P_S \rightarrow \bar{H}^{+} + e^{-}$

proposal

Matter | Anti-matter

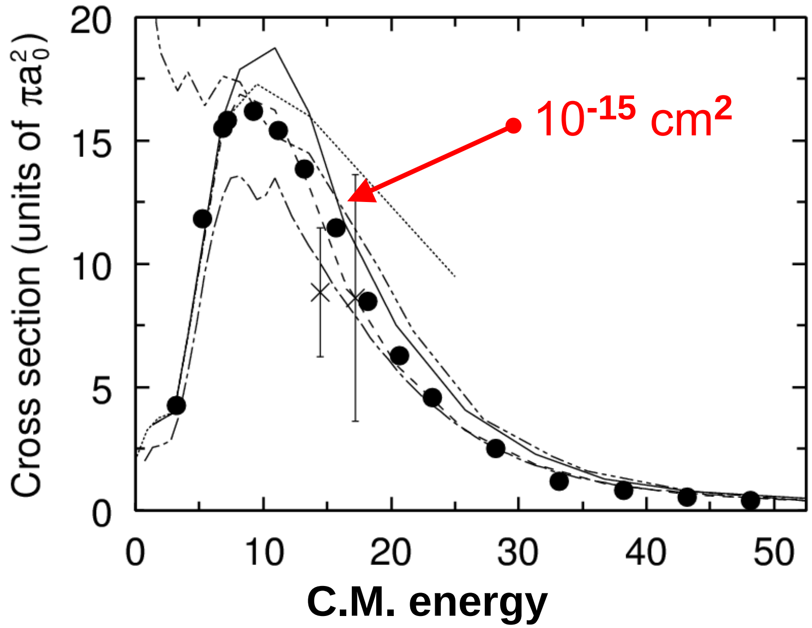
Ion $\bar{H}^{+}$ & 1D $\Rightarrow$ P_s target

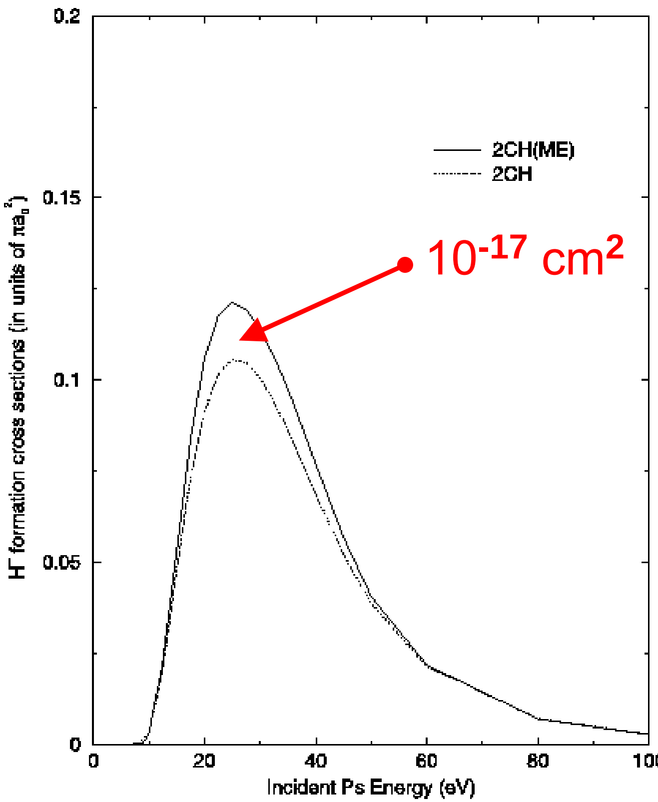
N.Yamanaka & Y. Kino, Phys. Rev. A 65, 062709

P.K. Biswas, J.Phys. B: At. Mol. Opt. Phys. 34 (2001) 4831

$p + P_S \rightarrow H + e^+$

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





Overlap of cross sections
for E(p) ~10-20 keV

10^{13} P_S at/cm^3 → 10^{-7} $\overline{H}^+$
per incident antiproton

Comparison with other methods

- ATHENA style
  - $\bar{H}$ production efficiency ~ 17% per $\bar{p}$ of 10-20 KeV
  - 90% produced in very excited states (3 body) and in 4π

    → *not usable for gravity experiments*
- ATRAP style
  - Cesium, Ps^* → $\bar{H}^*$ in 4π, laser control of excitation level
- Using Ps
  - **T = 25 meV & transitory regime**
  - ε ~ 0.3% but,
  - Reaction on P_s → $\bar{H}$ *non excited & in small solid angle*

Scheme of experiment

$e^+ + W \rightarrow P_s$

(*in vicinity of tungsten: density of $P_s \sim 10^{13}$ cm^{-3}*)

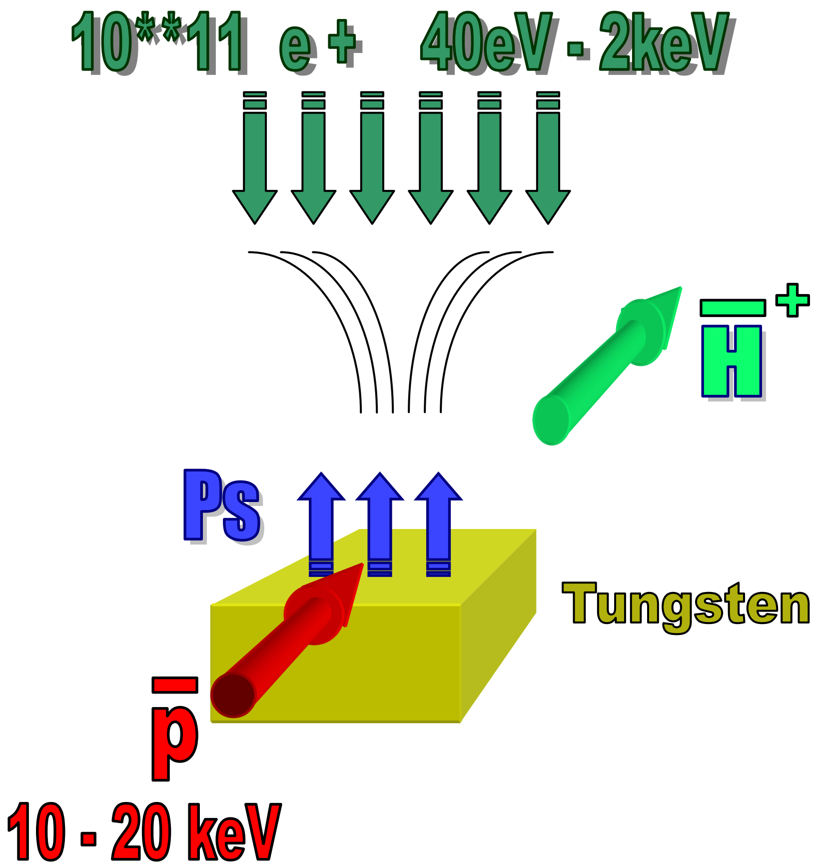
efficiency ~ 50%

P_s lifetime

→ dump in < 100 ns

$E_c (P_s) \sim 0.2$ eV

P_s in 1S state mainly



Positronium target in 3 steps

1. Production $Ne^+ \geq 10^{11}$, T ~ 25 meV

   → new source of e^+

   → Buffer-gaz + high field trap (Surko-Greaves) loaded in 100 s

2. Accumulation of e^+ near Ps converter

   → Storage of plasma (possibility for neutralization)

   E (octupole) + B ($\Rightarrow\Leftarrow$) :“ MCEO trap” (Mohri-Yamazaki et al)

3. Charge separation & focalisation e^+ + metal → P_S

   → Conversion of e^+ into flux of P_S(1S) from metal converter

New source of slow e^+

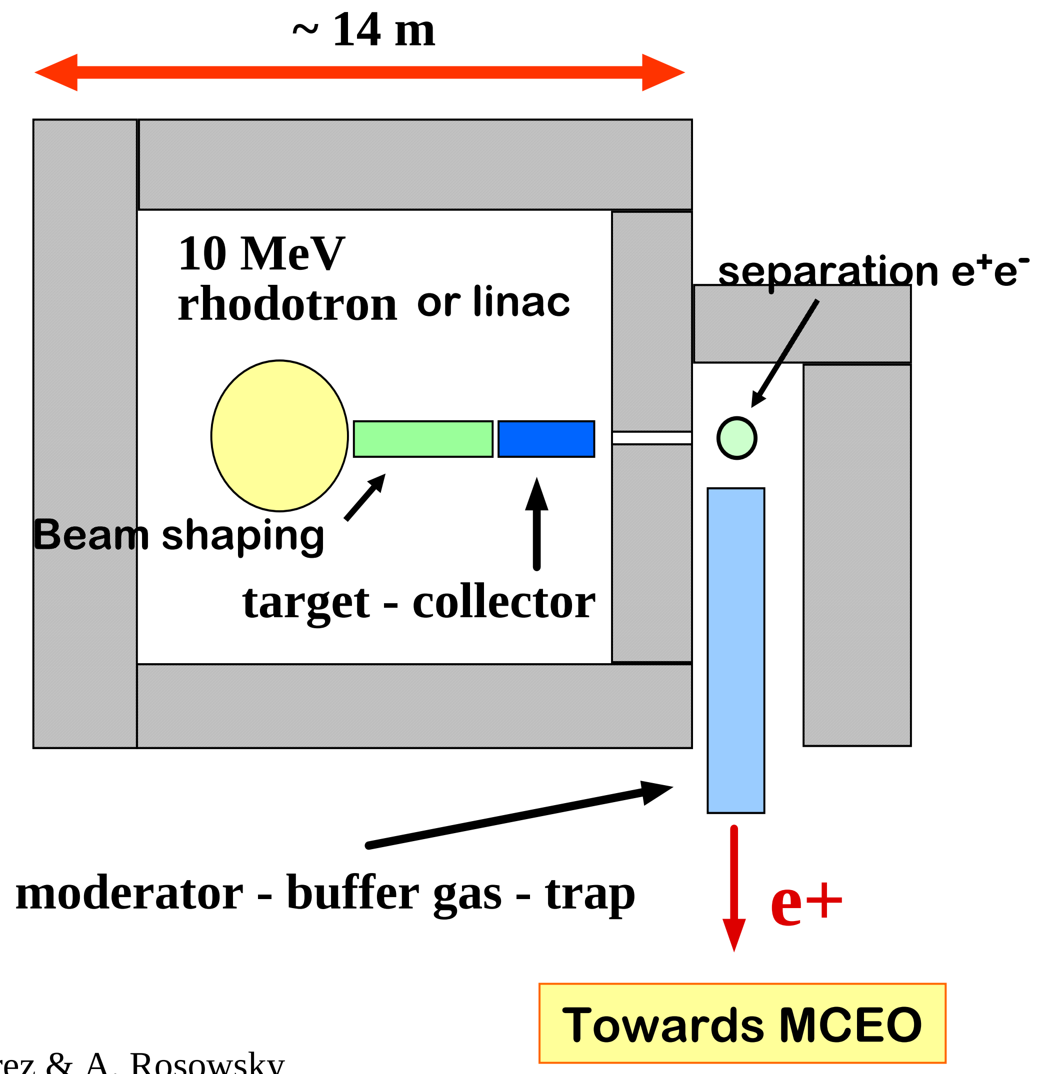
See talk by A. Rosowsky

~10^{12} e^+/s < 1 MeV

~10^9 e^+/s after traps

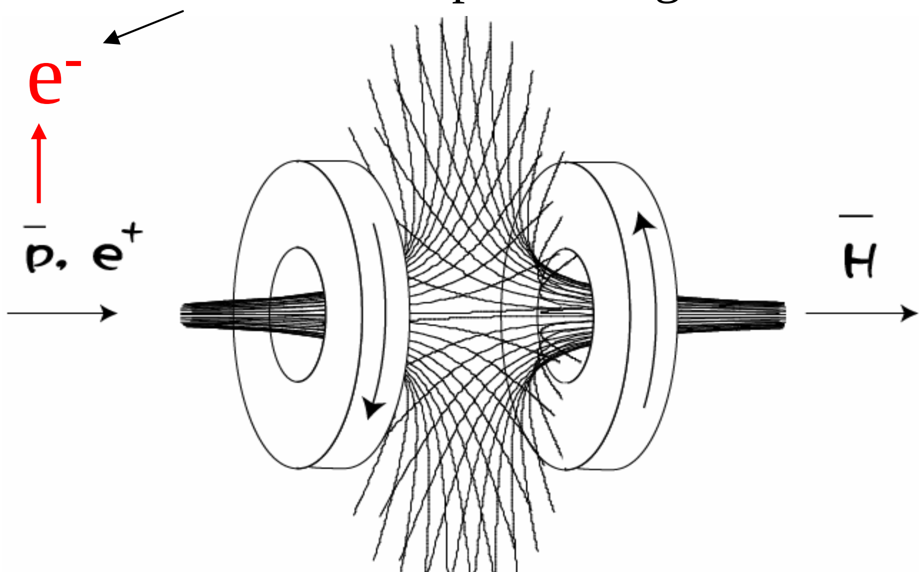
Fill high field trap in 100 s

Unload trap in < 1s

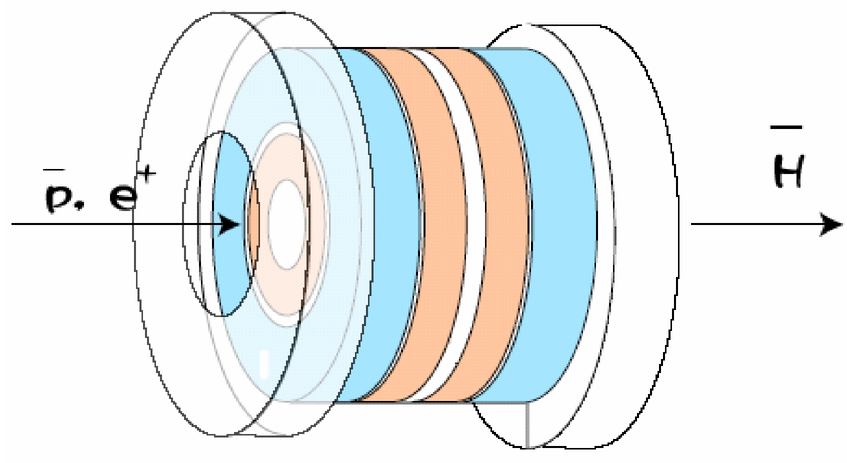


Adapt MCEO trap to e^+, e^-

Neutralisation of space charge



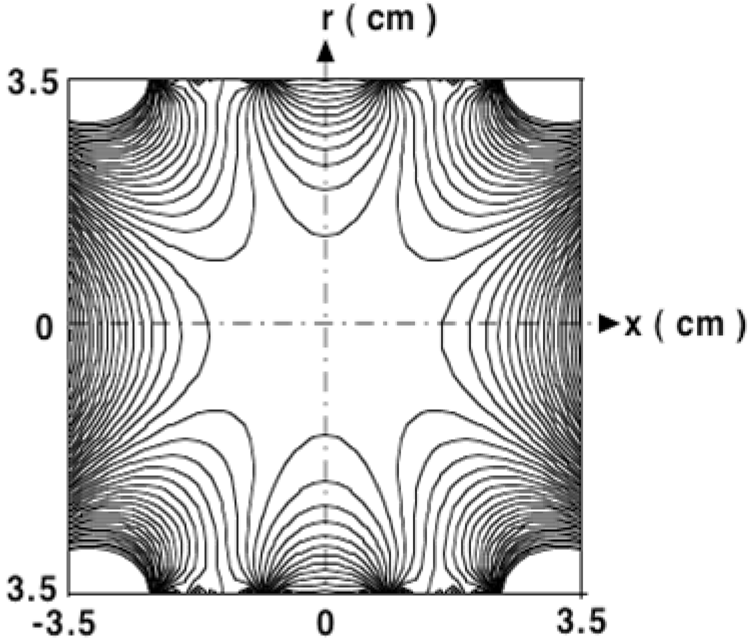
B quadrupole



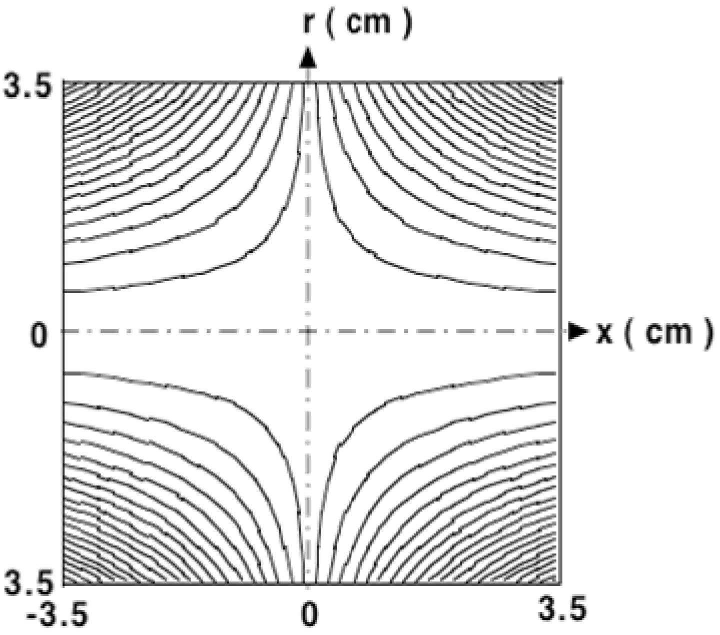
E octupole

<u>Challenge</u>: accumulate 10^{11} e^+ and then dump on W in 10 to 50 ns

E & B fields



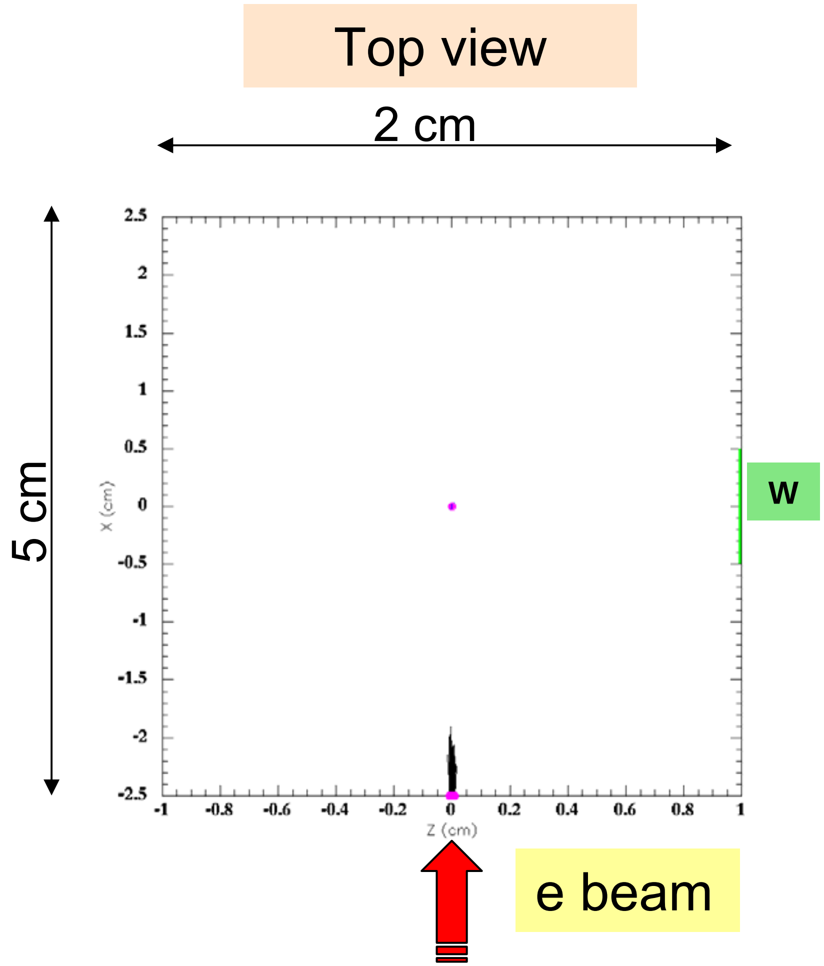
$\vec{E}$



$\vec{B}$

A. Mohri et al., Jpn. J. Appl. Phys. **37** (1998) L1553.

Simulation MCEO



simulations are only inertial

→ determine dimensions

& minimum field strength

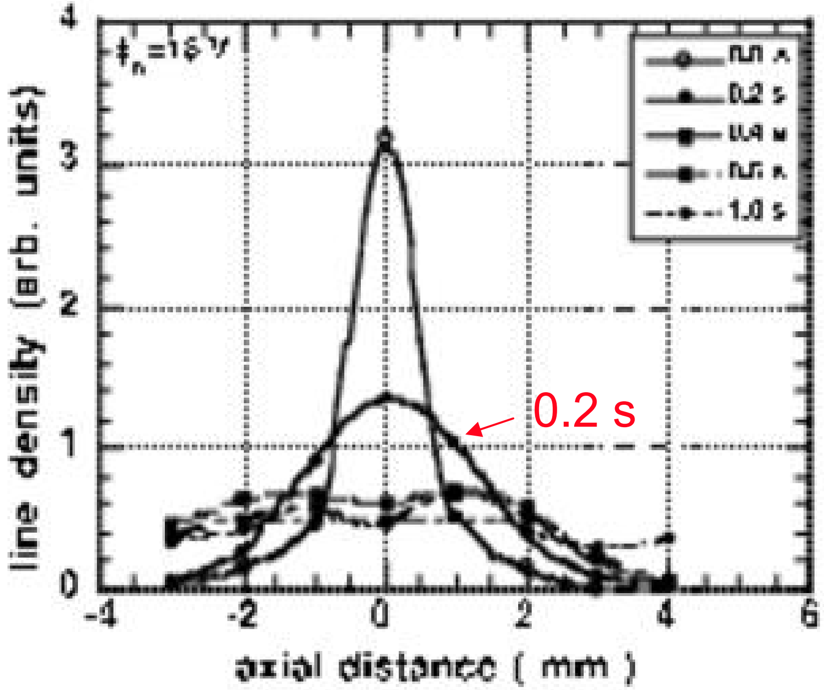
Plasma challenges

Brillouin flow equilibrium

→ 10^{11} cm^{-3} for 0.2 T

transitory regime

A. Mohri et al., ECA **24B** (2000) 149.

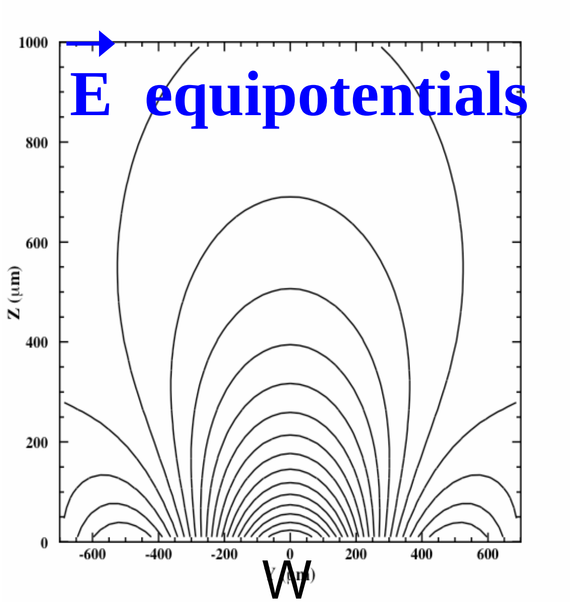


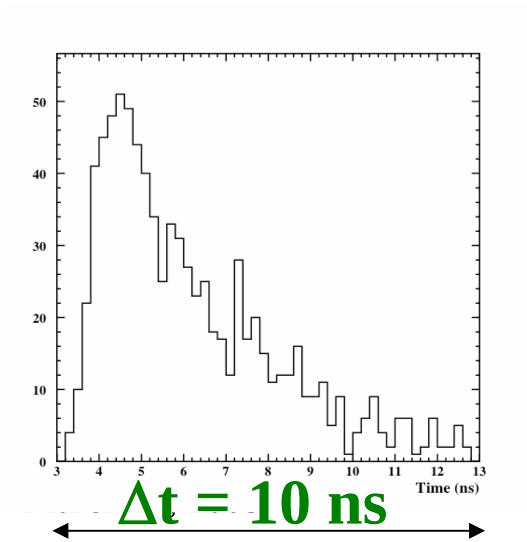
Exceed Brillouin limit ?

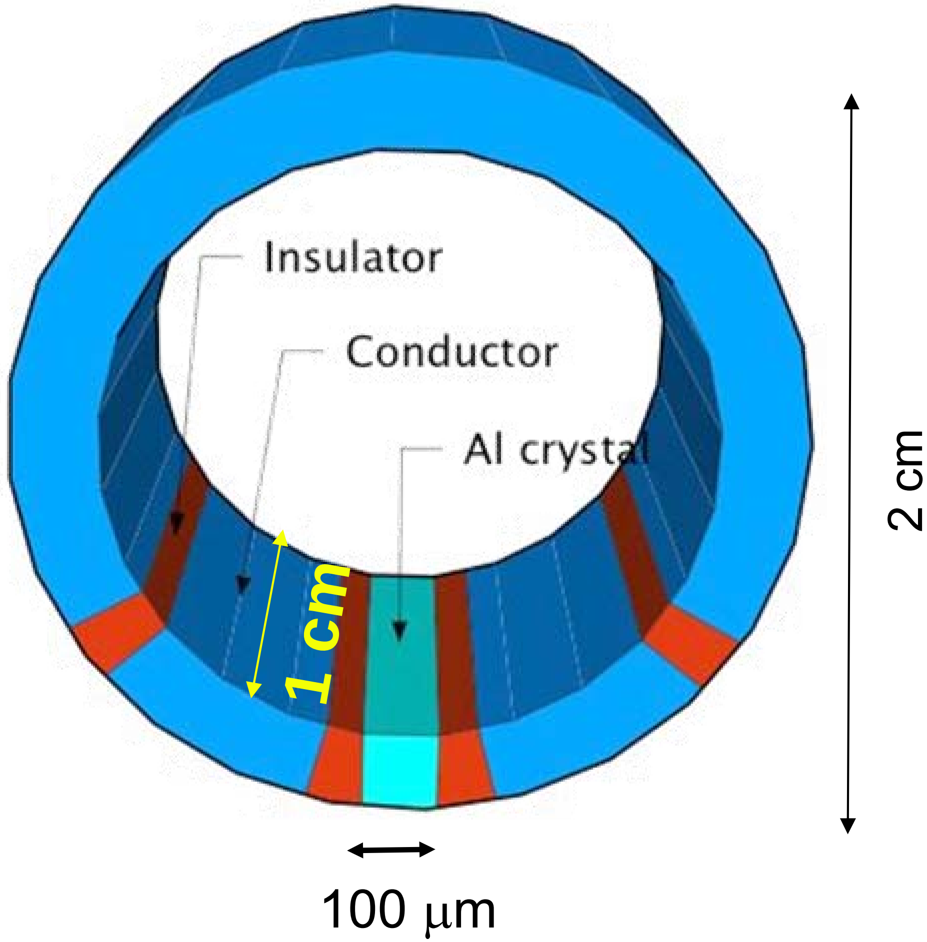
L Turner & DC Barnes, PRL **70** (1993) 798

→ study a range of B field strengths: 200 Gauss to ~ 0.2 T

Ps converter in central electrode



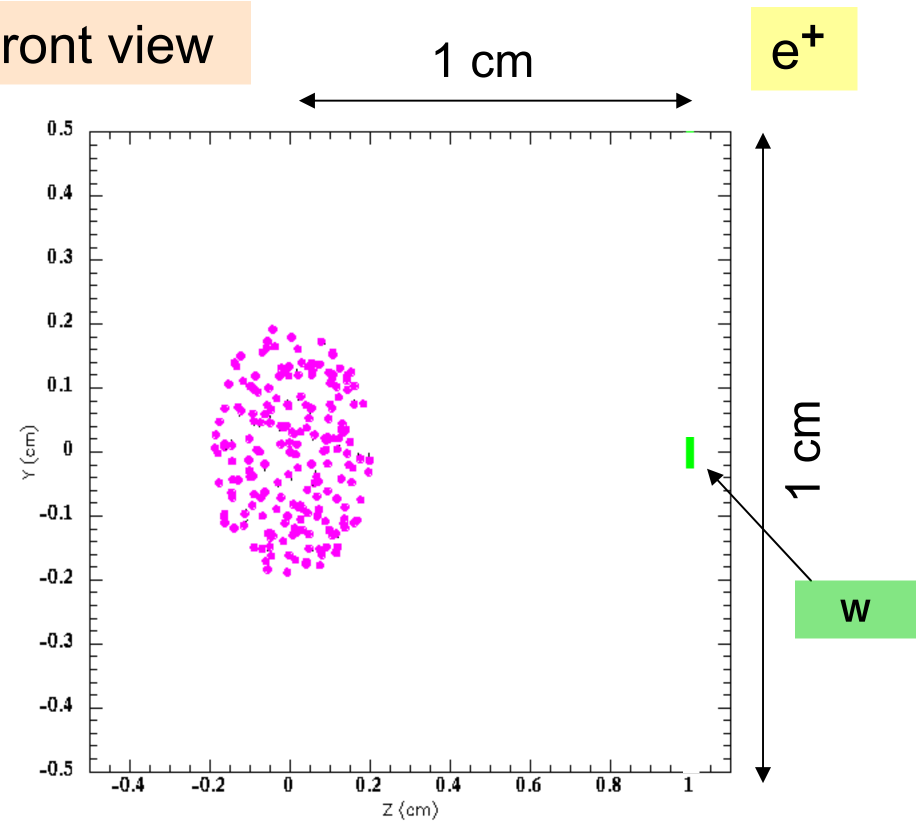




P. Pérez & A. Rosowsky

Simulation of e^+ dump

Front view

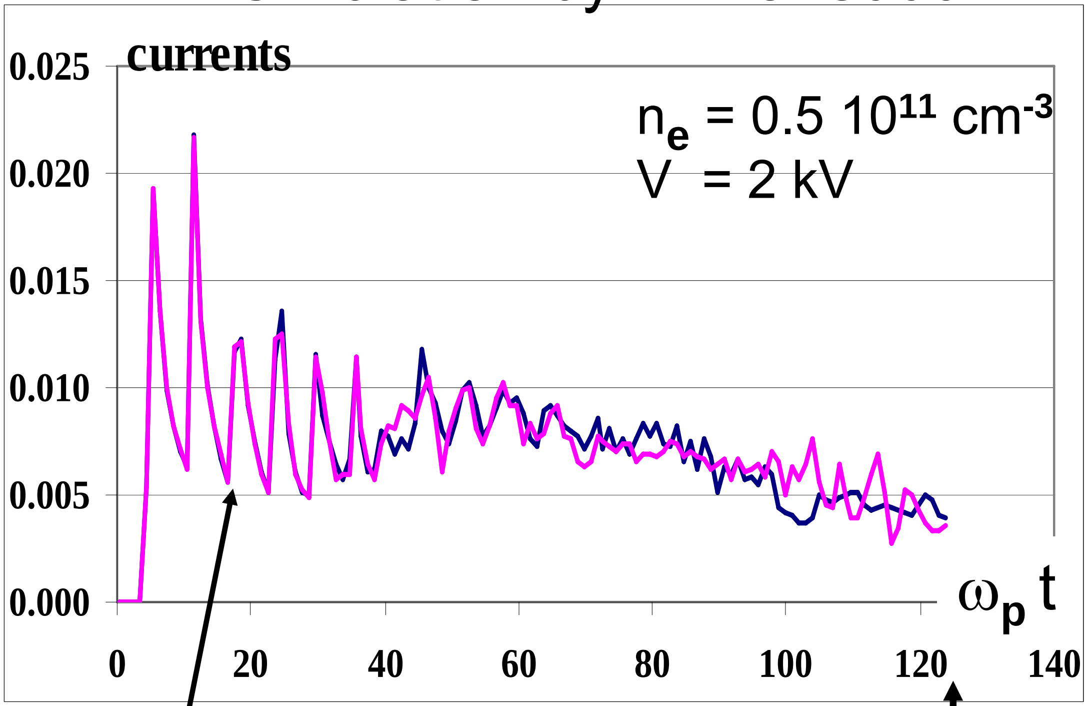


Plasma erosion

- Neutralisation with e^- within ~ 0.1 s

- Erosion near Ps converter

1D simulation by F. Doneddu



use tuning to ω_p resonance to amplify extraction ?

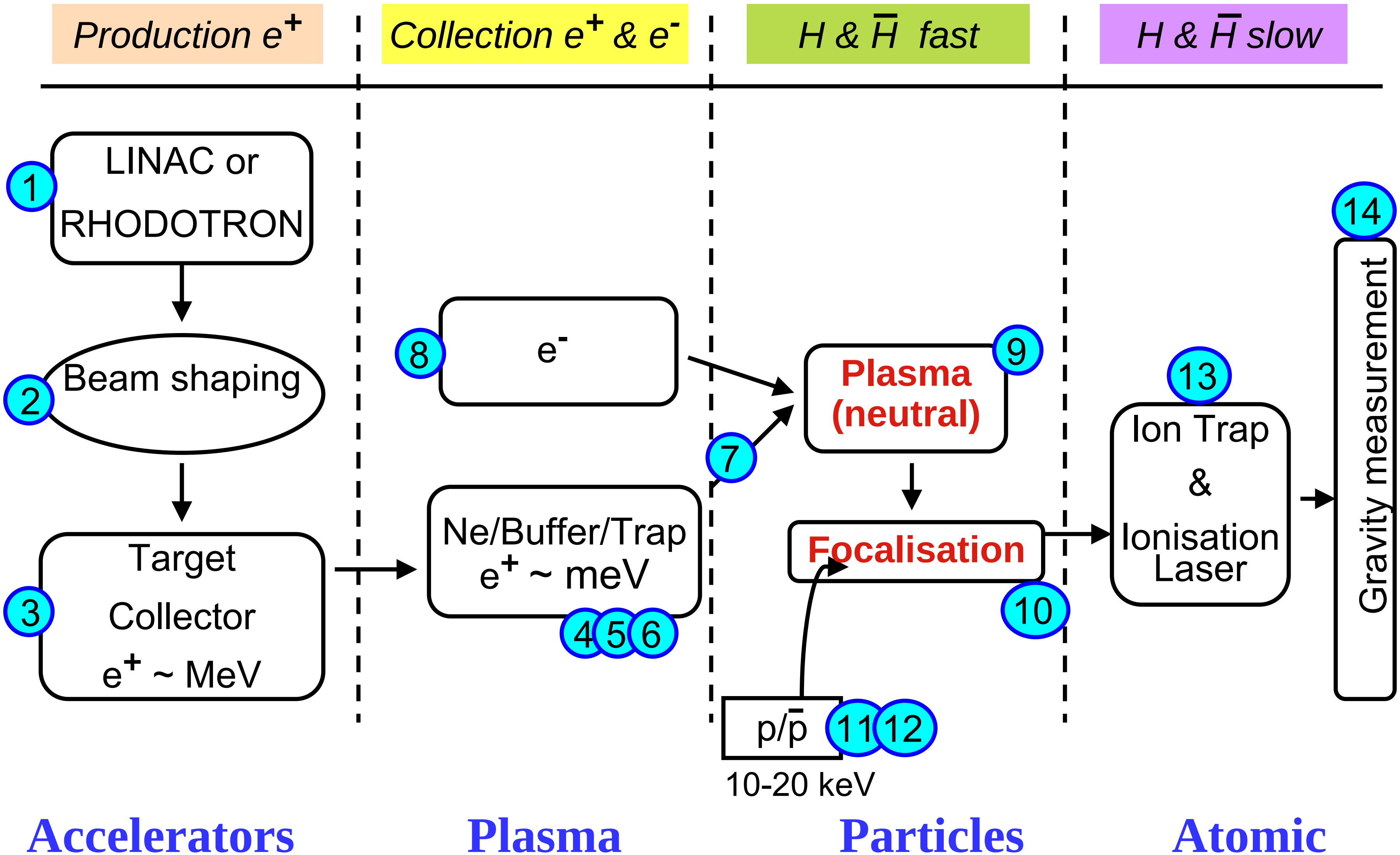
≡ 10 ns

Antiproton beam

- E ~ 10-20 KeV :

  - Project ELENA at CERN/AD → 100 KeV + foils in 2007-2010 ?
  - FLAIR at GSI-Darmstadt → 5 KeV in 2012 (approved)
  - JPARC in construction in Japan → 1st beam 2008

Overall scheme

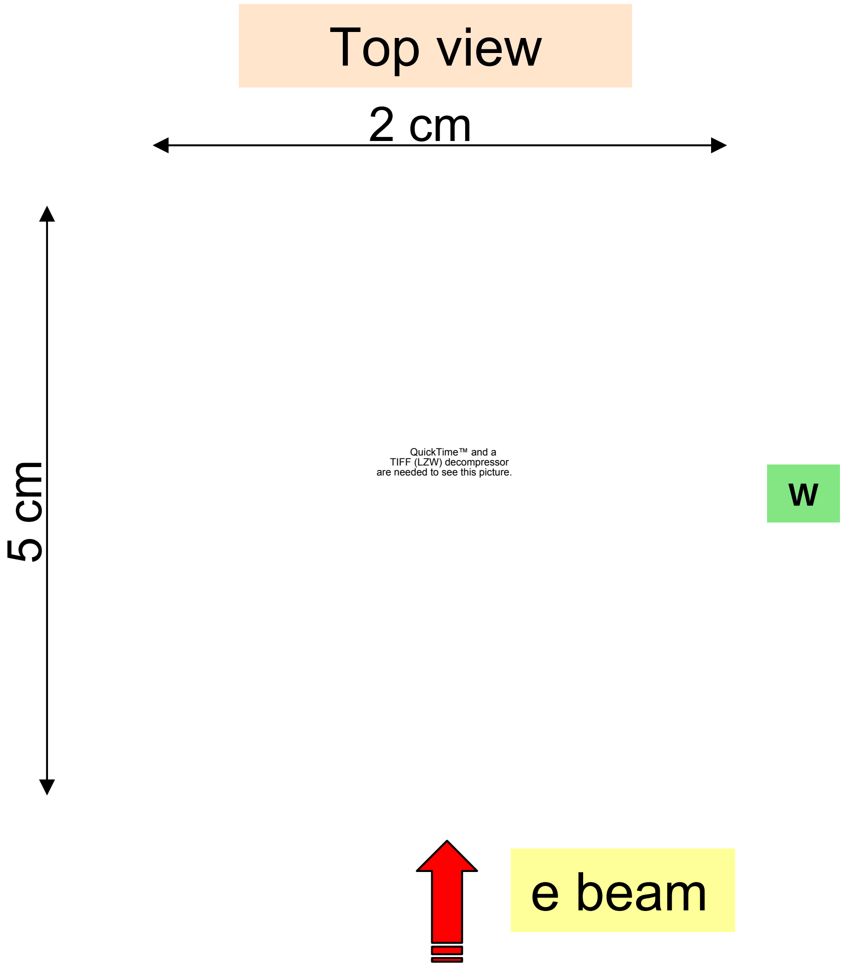


Summary

Proposal:

- 10-20 keV $\bar{p}$ combine with $P_s(1S)$ “at rest”
- $\bar{H}$ (1S) & $\bar{H}^+$ produced in small solid angle
- e+ plasma stored in MCEO < 1s, T > room temp.
- Challenges
- P_s produced may provide interesting physics itself

Simulation MCEO



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