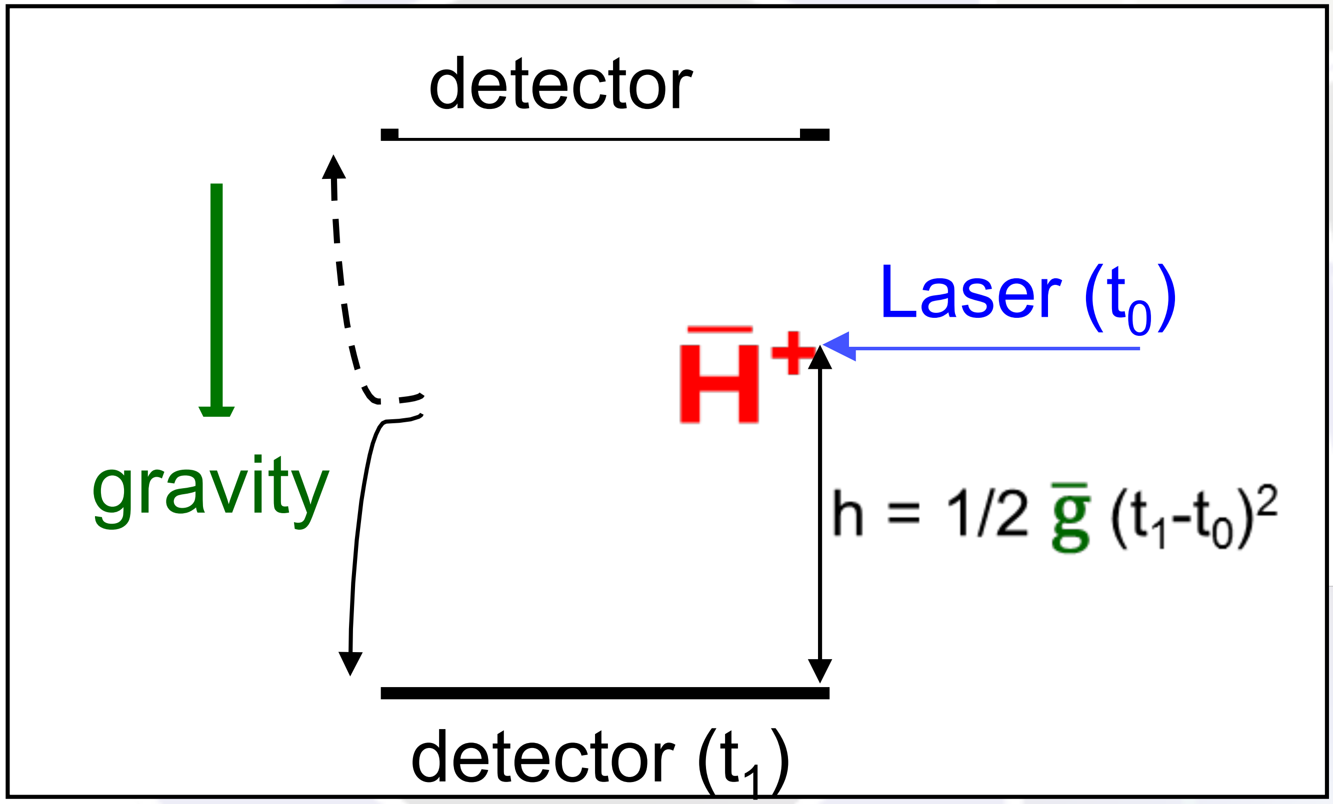
The GBAR experiment

Dirk van der Werf

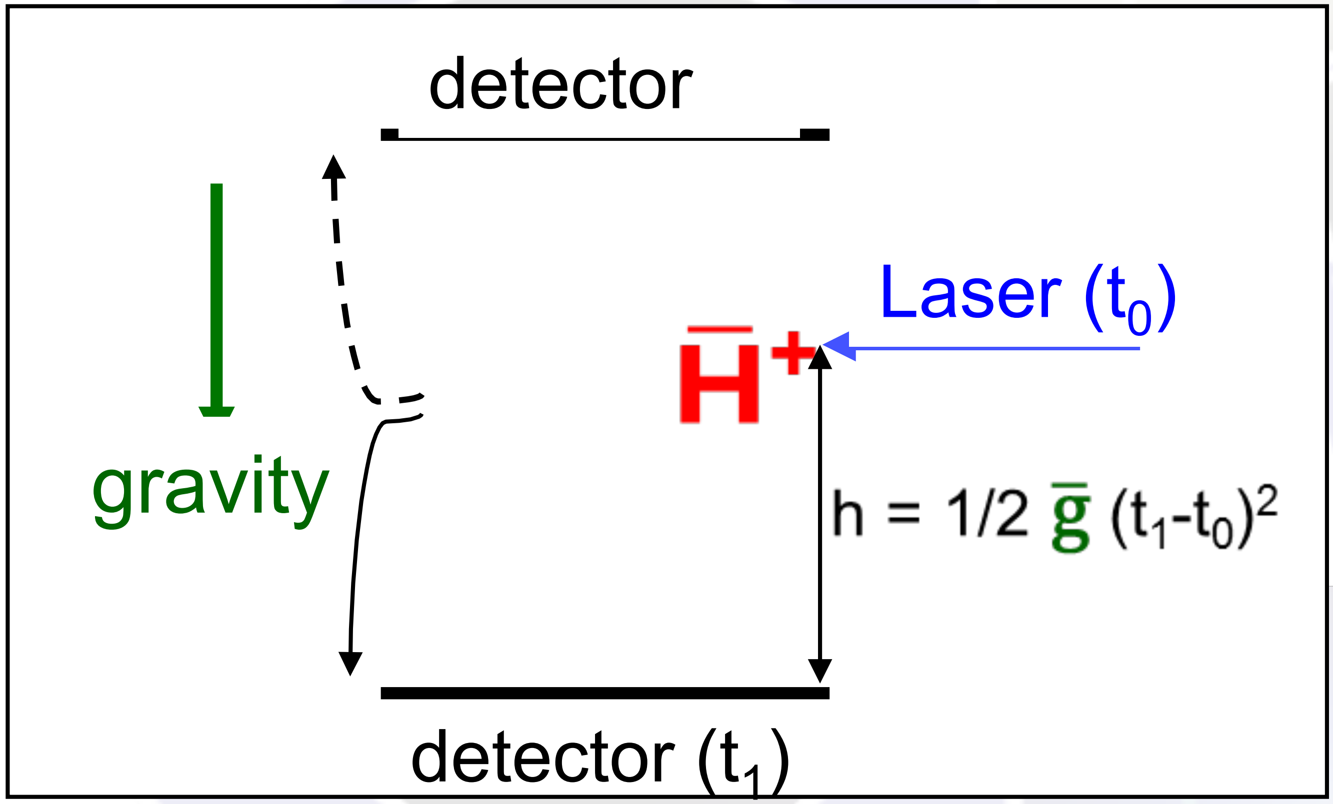
Swansea University
Prifysgol Abertawe

principle



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

principle



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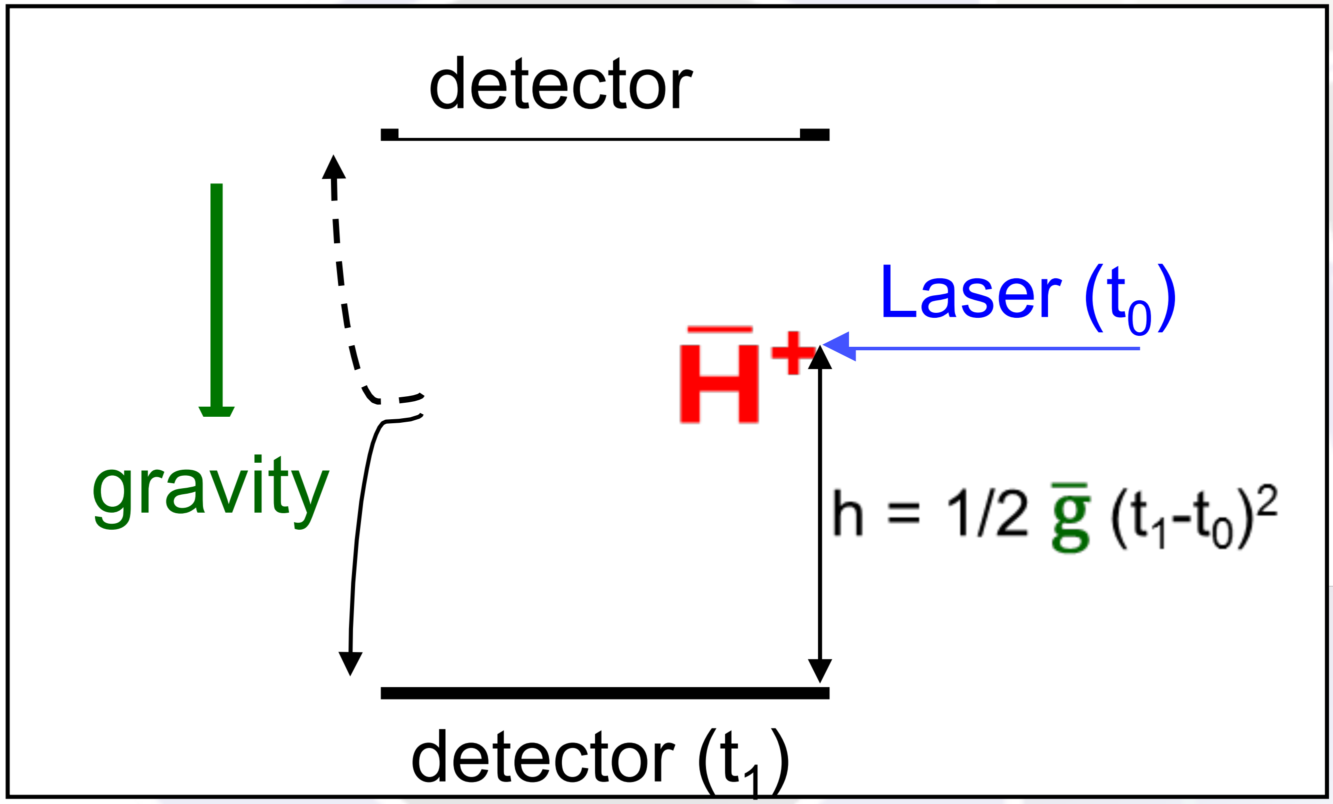
$$z = z_0 + v_{z0}t + \frac{1}{2}\bar{g}t^2$$

principle



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$$z = z_0 + v_{z0}t + \frac{1}{2}\bar{g}t^2$$

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

Desired range

How?

- Produce $\overline{\mathrm{H}}^{+}$ via two reactions:

$$\overline{\mathrm{p}} + \mathrm{Ps} \rightarrow \overline{\mathrm{H}} + \mathrm{e}^{-} \quad (1)$$

$$\overline{\mathrm{H}} + \mathrm{Ps} \rightarrow \overline{\mathrm{H}}^{+} + \mathrm{e}^{-} \quad (2)$$

How?

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- Trap it in a Paul trap and sympathetically cool the anti-ion with Be^{+}

How?

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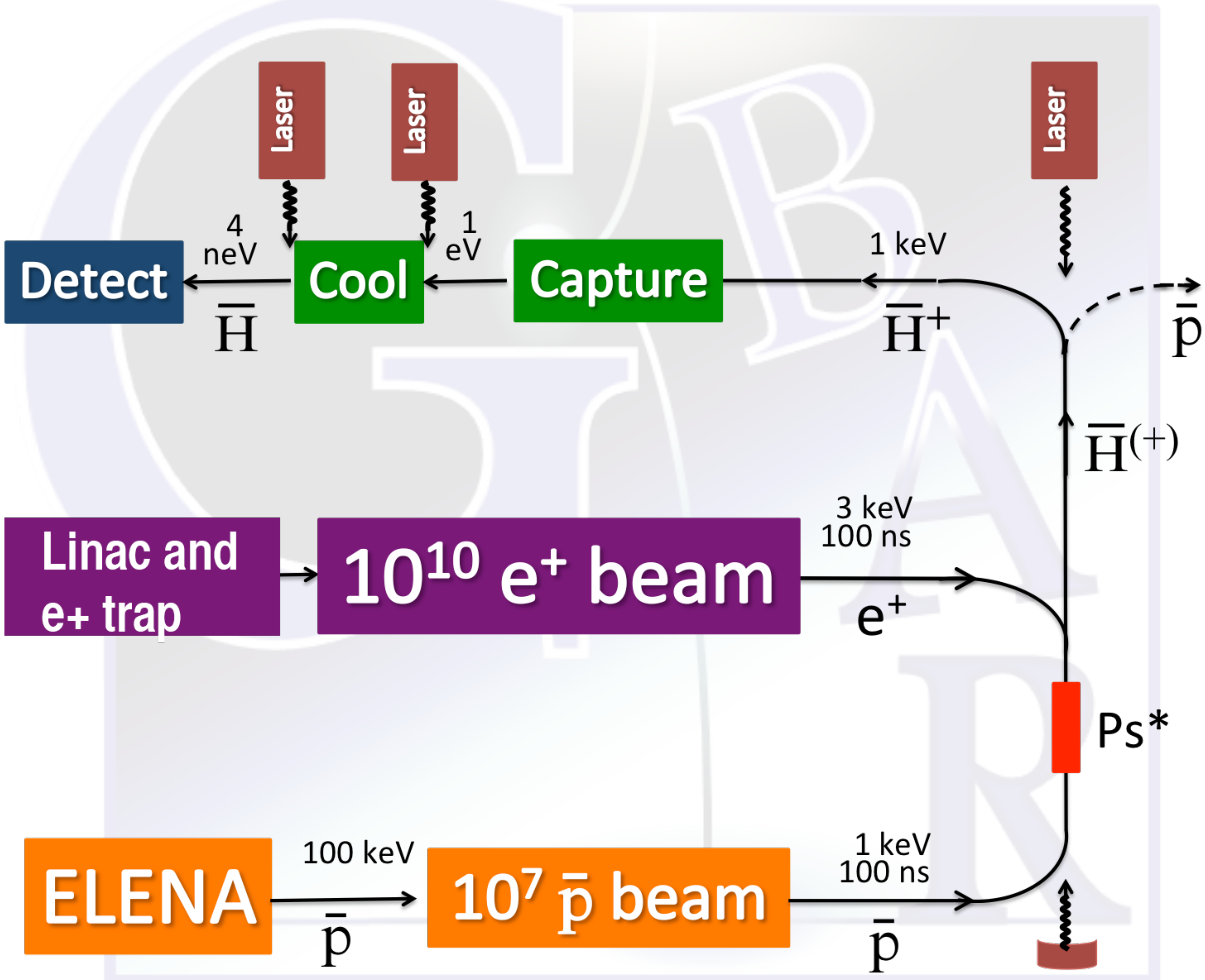
$$\overline{\mathrm{H}} + \mathrm{Ps} \rightarrow \overline{\mathrm{H}}^{+} + \mathrm{e}^{-} \quad (2)$$

- Trap it in a Paul trap and sympathetically cool the anti-ion with Be^{+}

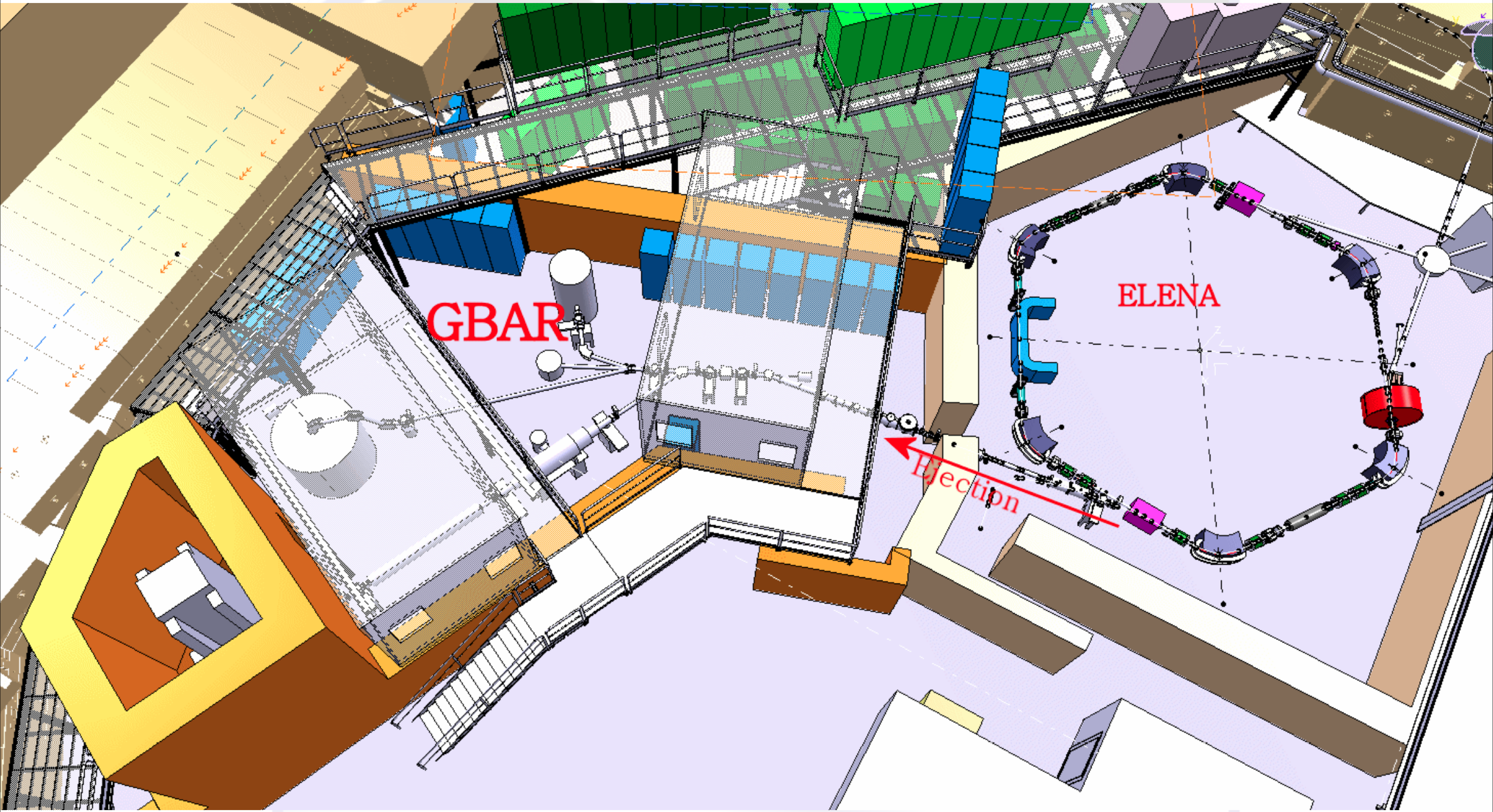
- Detach the second positron with a laser pulse and let the $\overline{\mathrm{H}}$ "fall"

Schematic

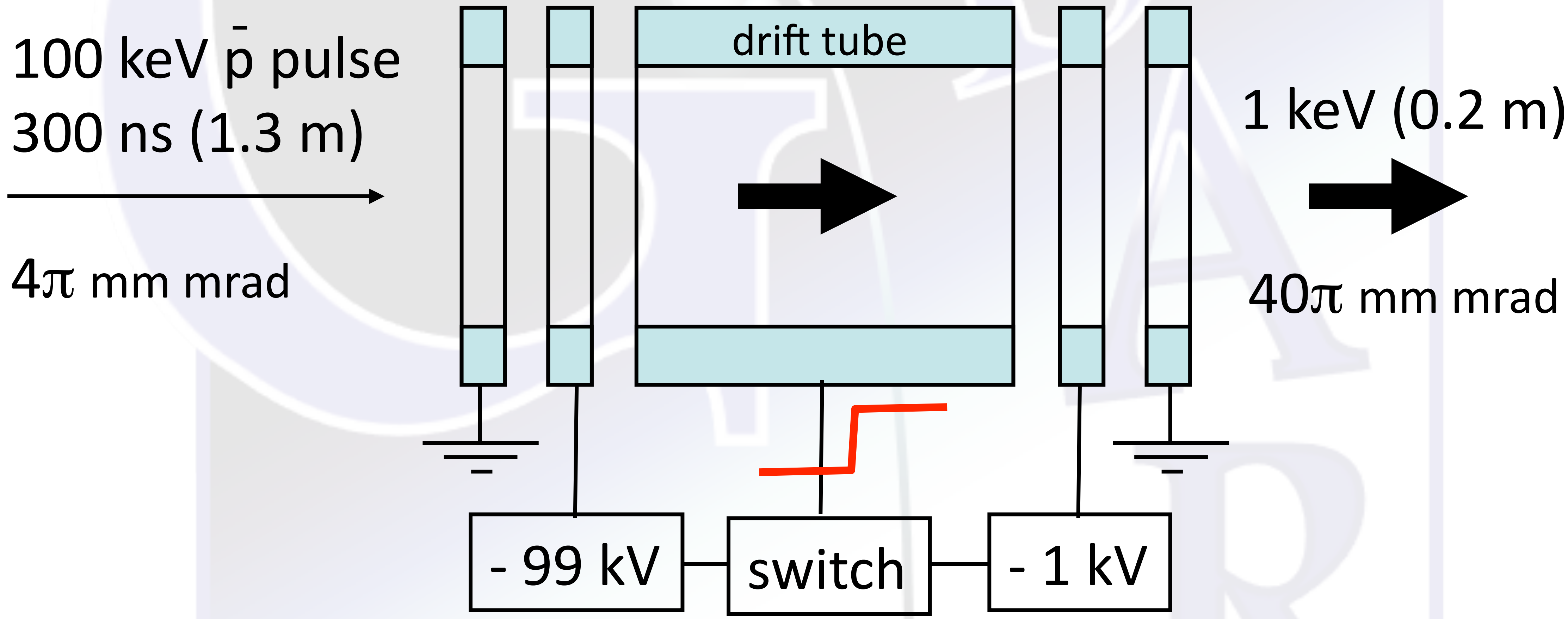


Laser
Laser
Laser
4
neV
1
eV
1 keV
Detect
Cool
Capture
$\bar{H}$
$\bar{H}^+$
$\bar{p}$
$\bar{H}^{(+)}$
Linac and
e+ trap
10^{10} e^+ beam
3 keV
100 ns
e^+
Ps*
ELENA
100 keV
$\bar{p}$
10^7 $\bar{p}$ beam
1 keV
100 ns
$\bar{p}$

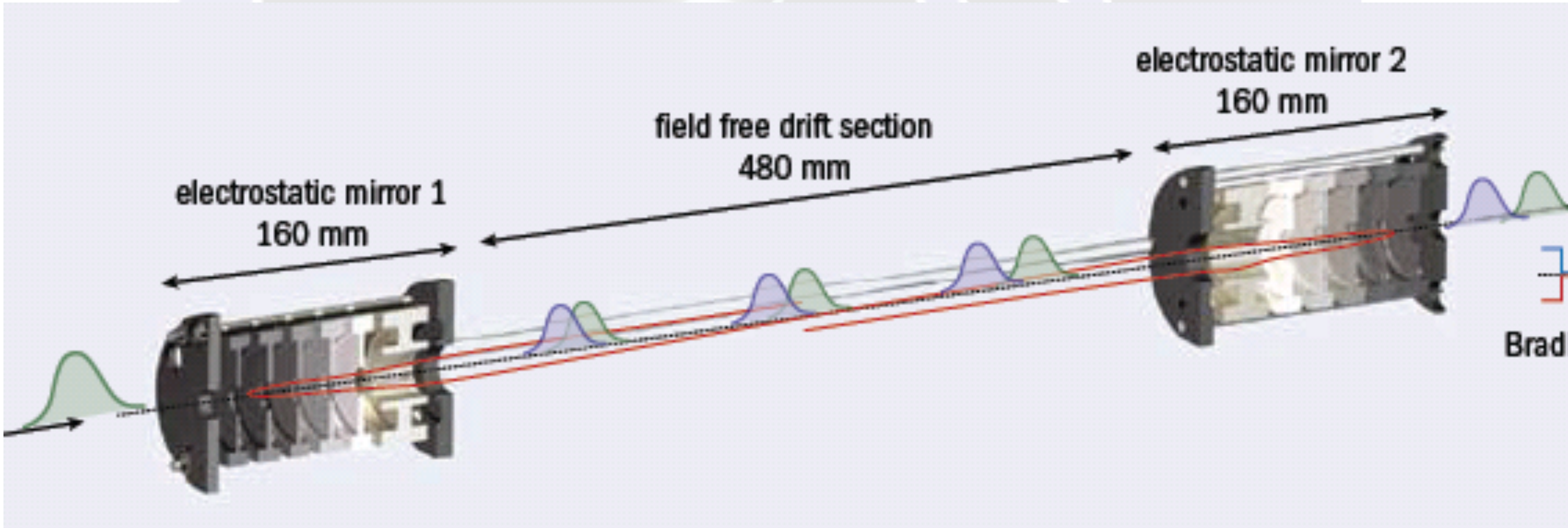
GBAR Layout



Drift tube


100 keV $\bar{p}$ pulse
300 ns (1.3 m)
4π mm mrad
drift tube
1 keV (0.2 m)
40π mm mrad
- 99 kV
switch
- 1 kV

Multi-Reflection Time-of-Flight separator (Electrostatic Ion Beam Trap)



R. N. Wolf et al. IJMS (2013)

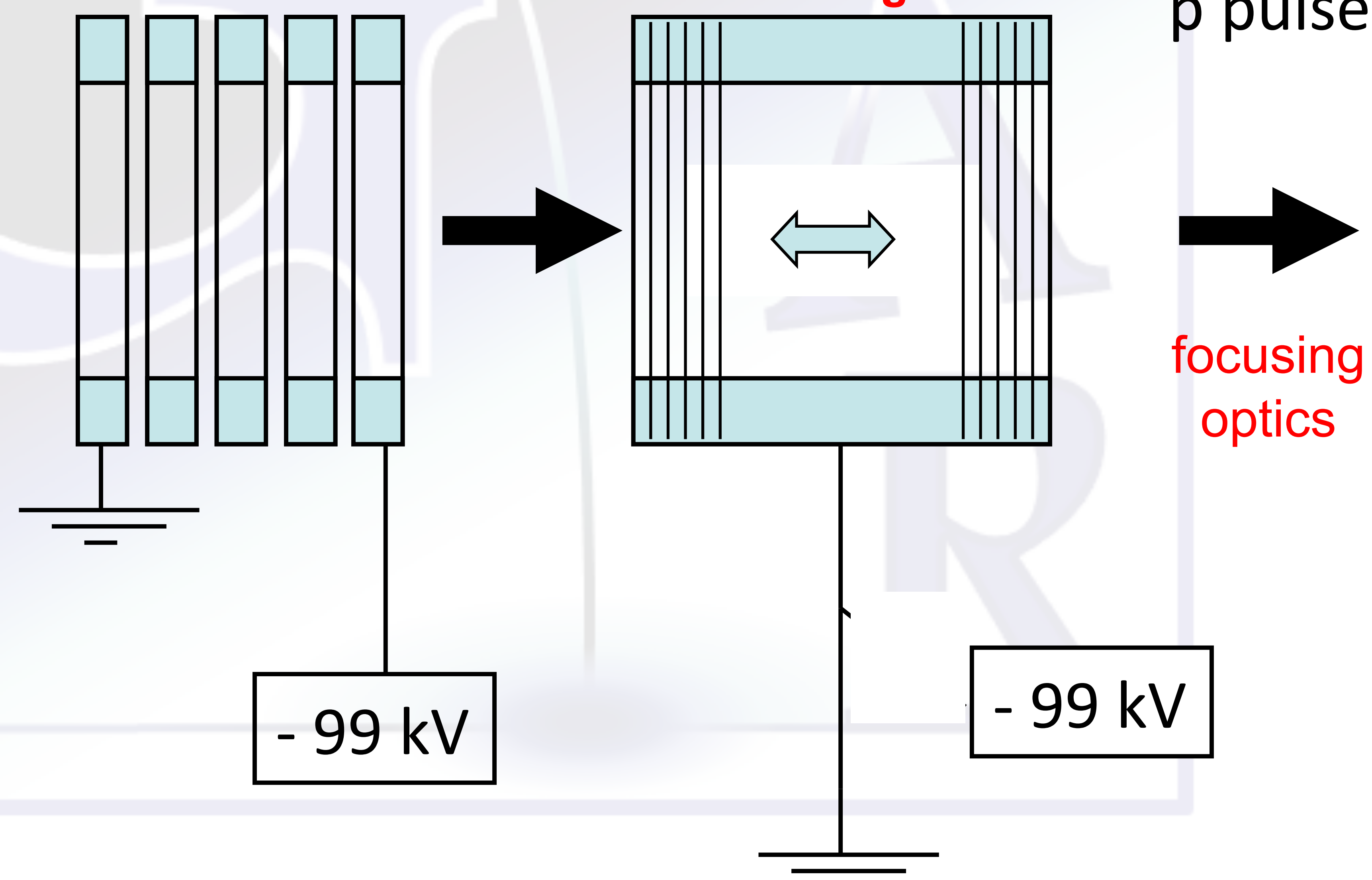
Deceleration and pulsed drift tube/mirror: another concept

From ELENA:
100 keV $\bar{p}$ pulse
300 ns (1.3 m)
4π mm mrad

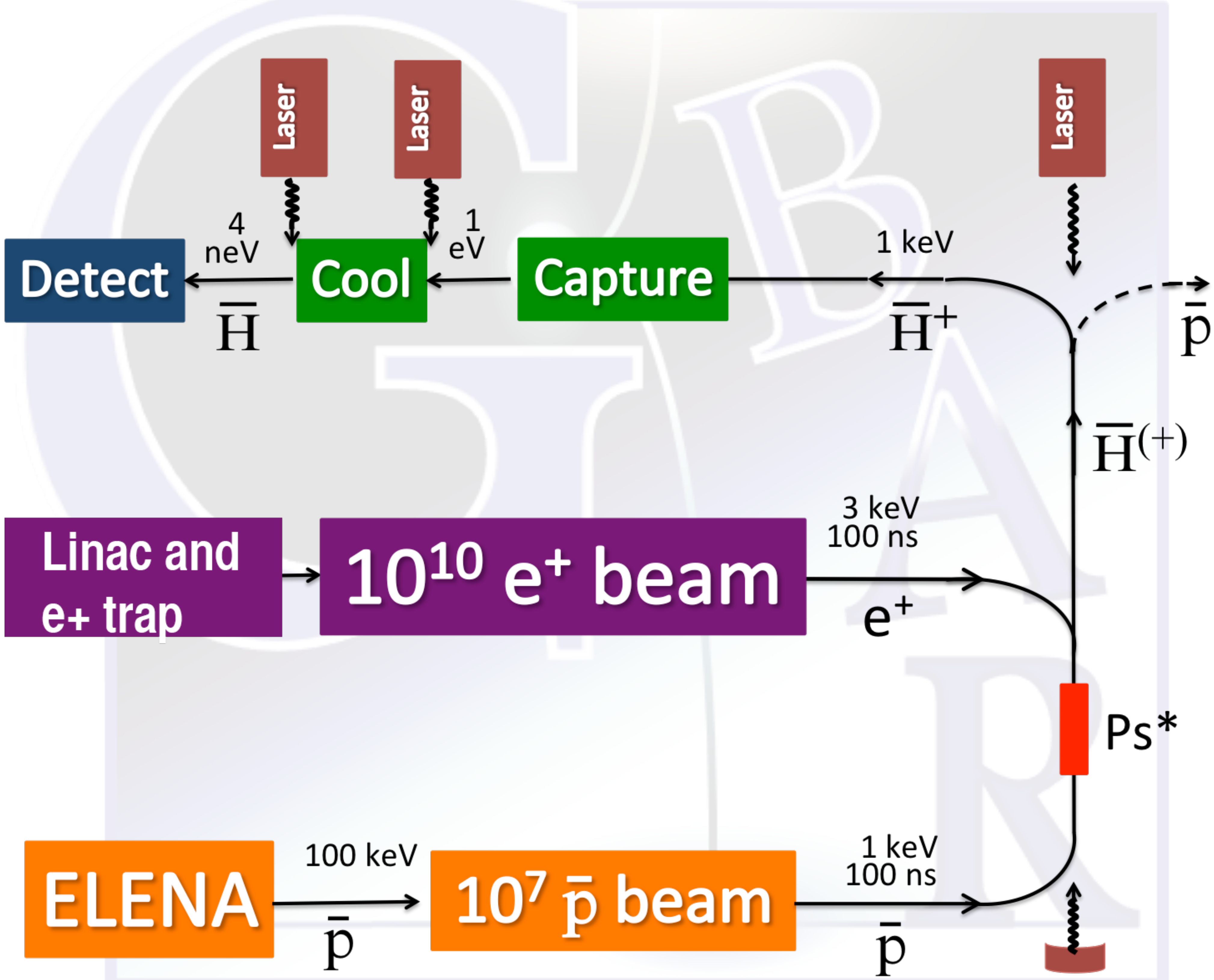
1 keV
0.2 m
40π mm mrad

resistive (stochastic?) cooling!

1-keV
$\bar{p}$ pulse



Schematic



Laser
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Detect
4 neV
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ELENA
100 keV
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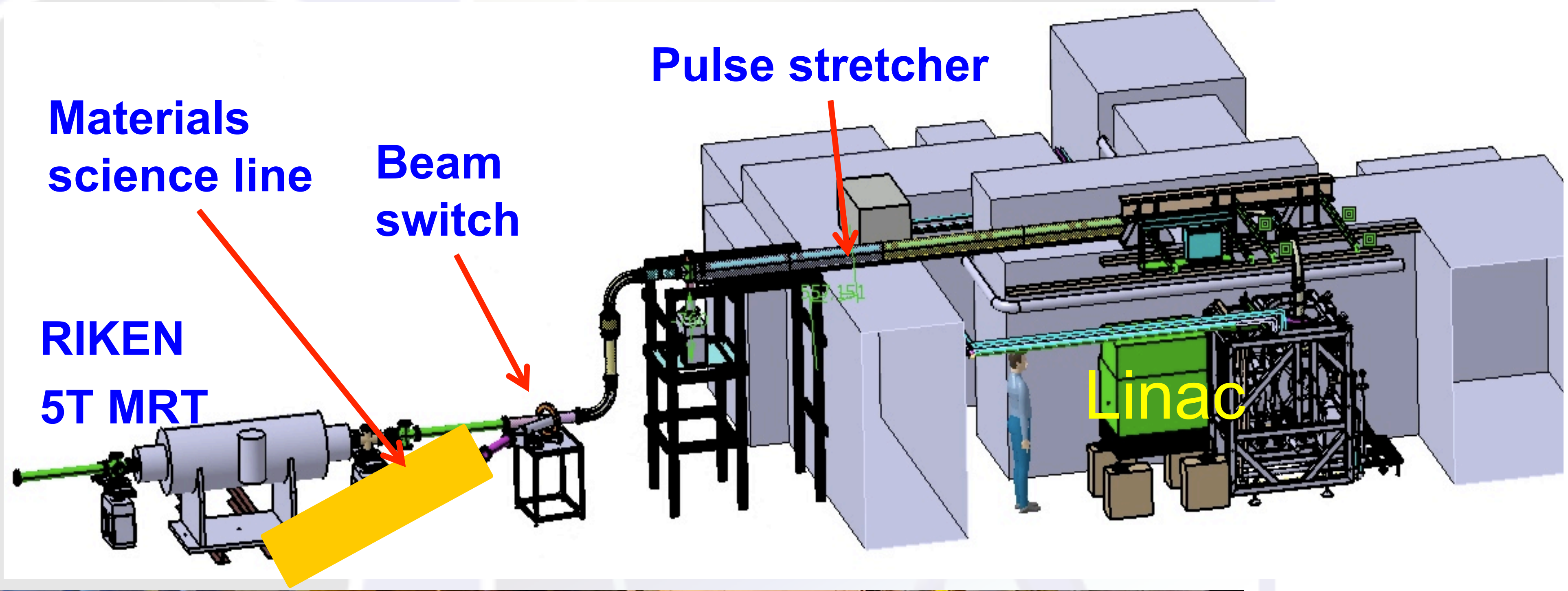
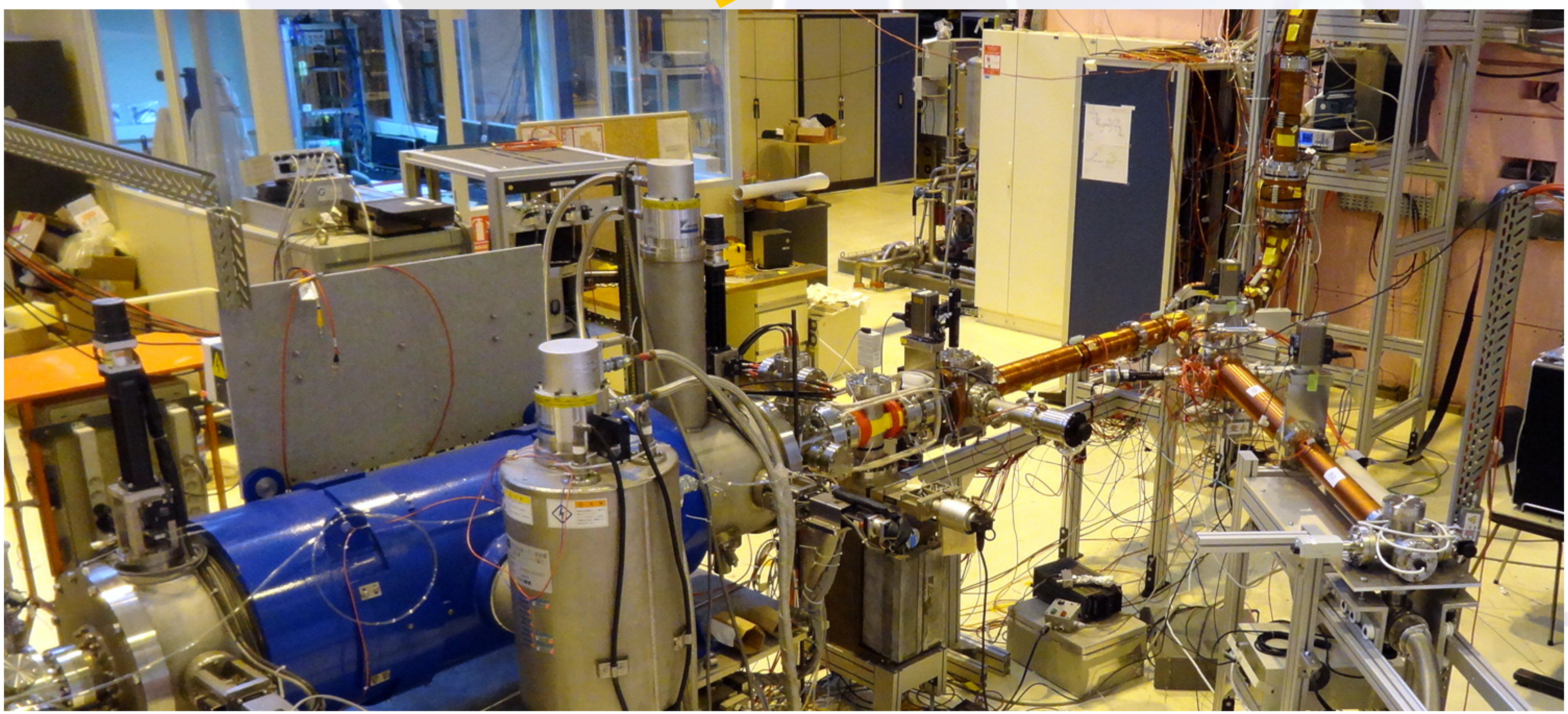
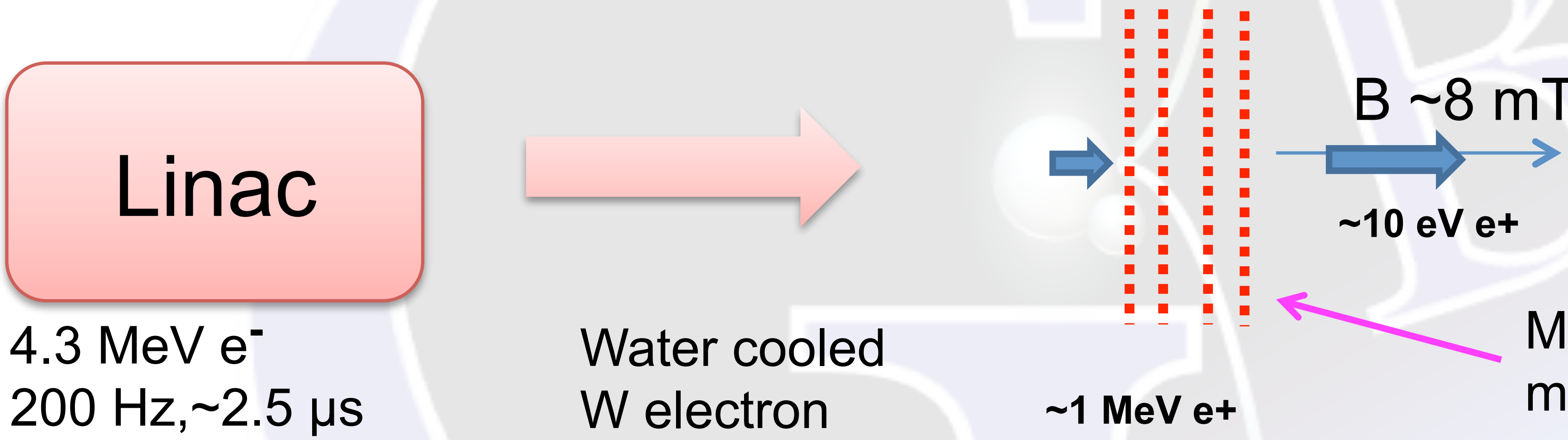
10^7 $\bar{p}$ beam
1 keV
100 ns
$\bar{p}$

Test experiment at Saclay





Production of moderated positrons



4.3 MeV e^-
200 Hz,~2.5 μs
~140 mA (peak)

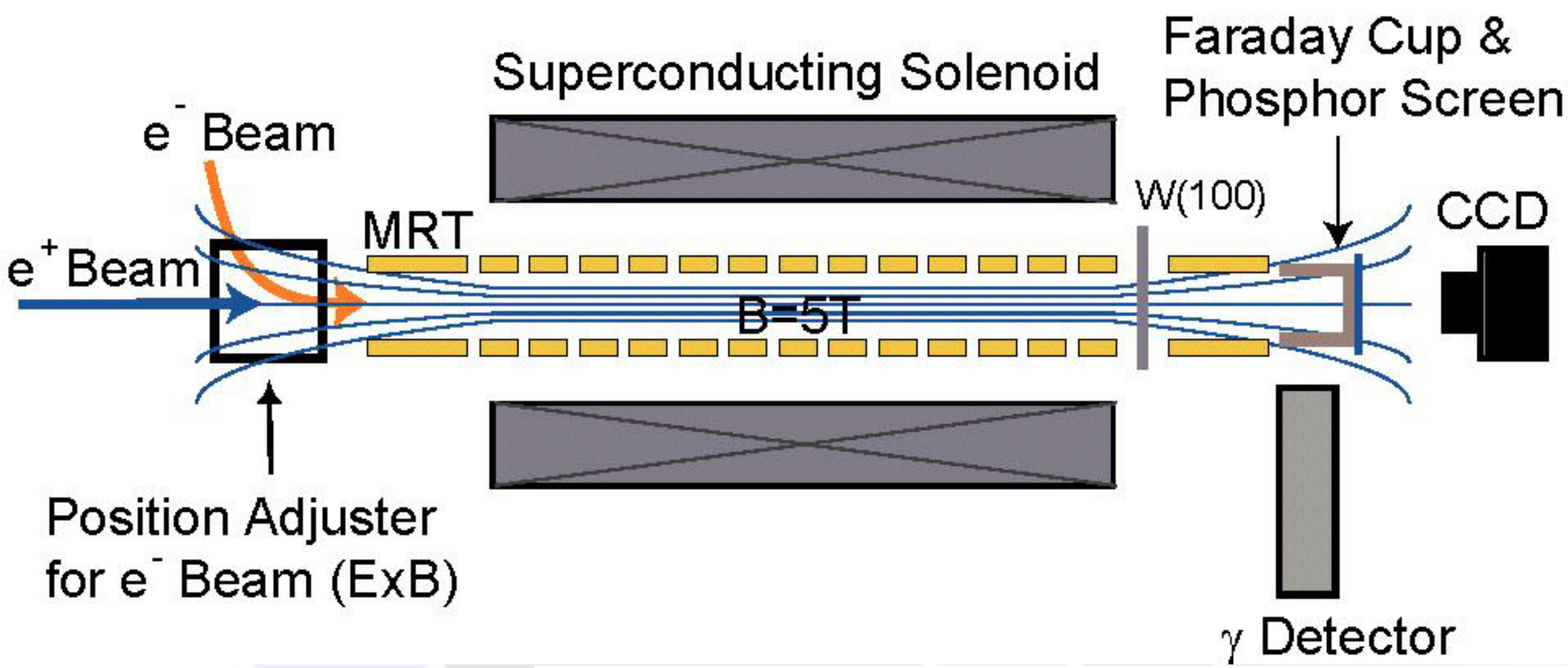
Water cooled
W electron
target

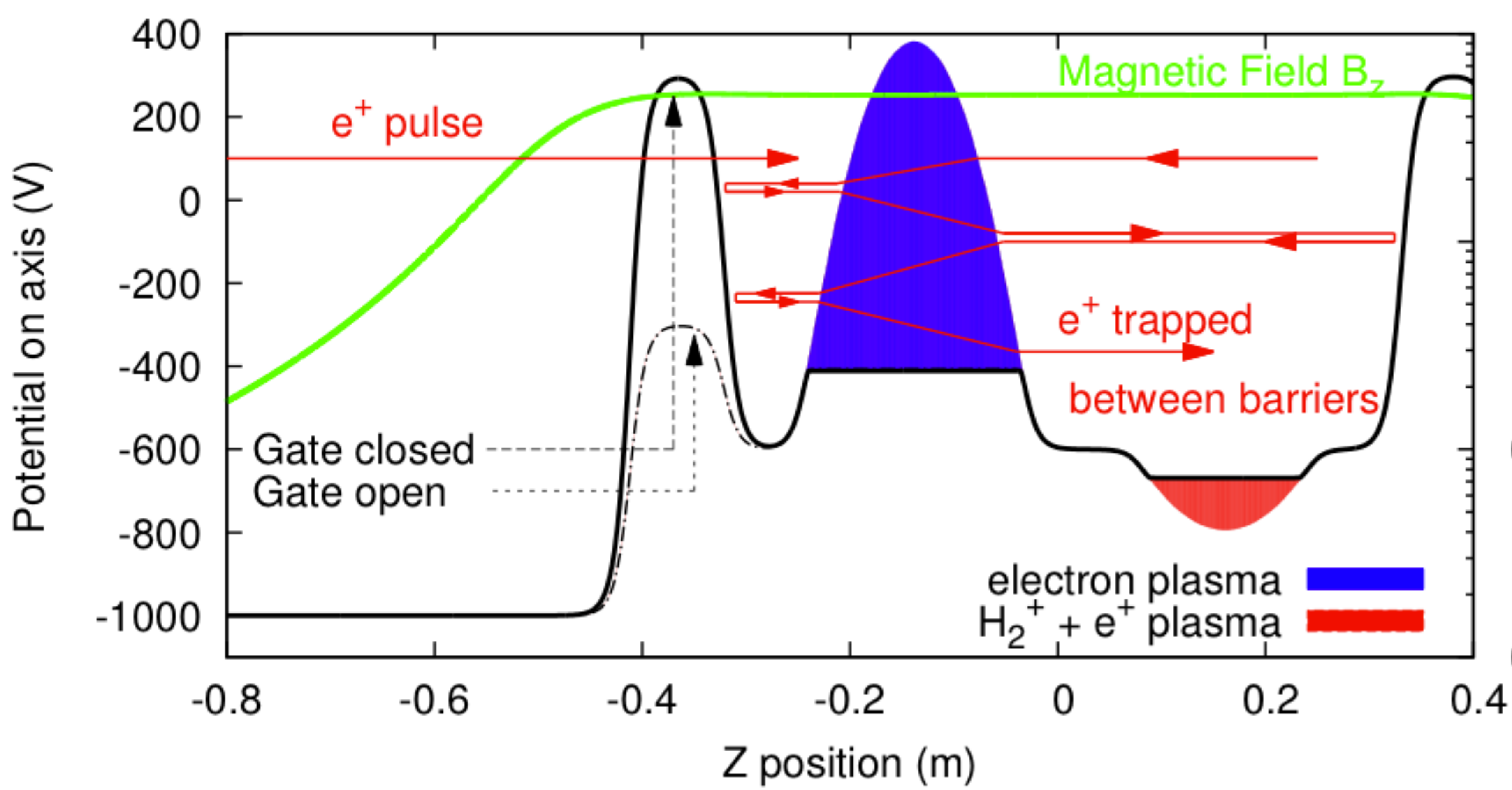
Moderator: Annealed W
mesh (~10 μm)

Present slow e^+ rate	$3.2\ 10^6\ s^{-1}$
Extrap. to 10 MeV linac	$4.3\ 10^7\ s^{-1}$
target value	$2.8\ 10^8\ s^{-1}$

- Present work on a new linac for Cern installation: 18 MeV, 300 Hz, 2 μs, 200 mA peak
- New W moderator designed; Ne moderator to be studied

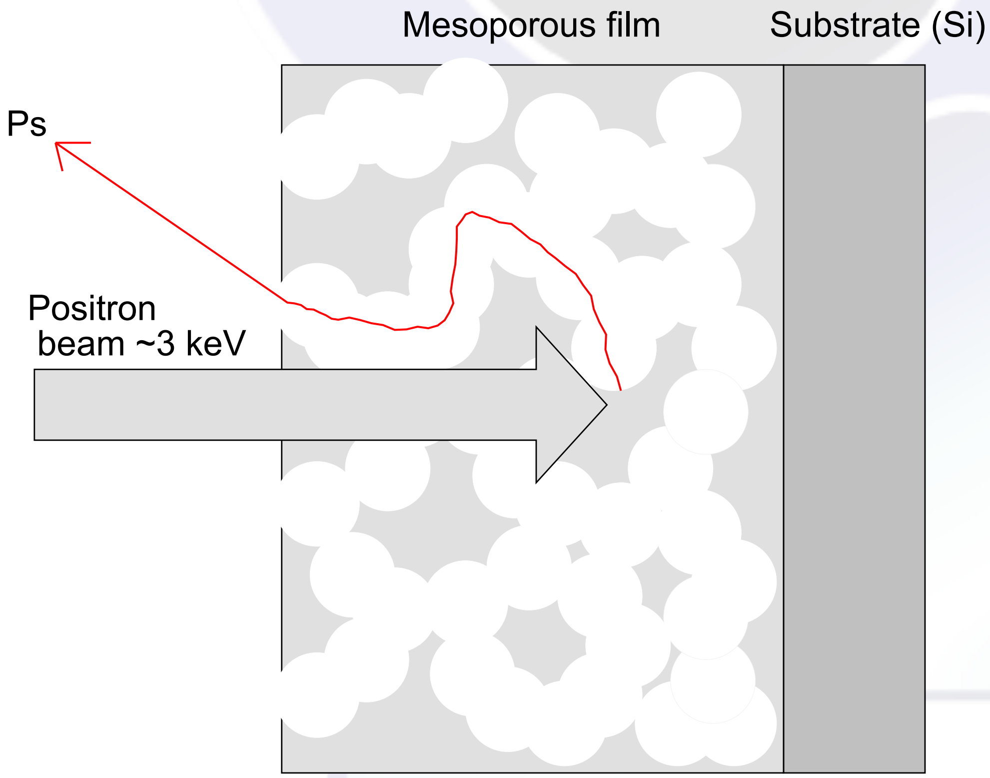
Positron trapping - MRT





Interaction area

- Positrons are converted into positronium
- Part of the Ps atoms will be excited (see later), i. e. laser radiation needs to be introduced
- Antiprotons will "shoot" through the positronium cloud to form $\overline{H}^{+}$



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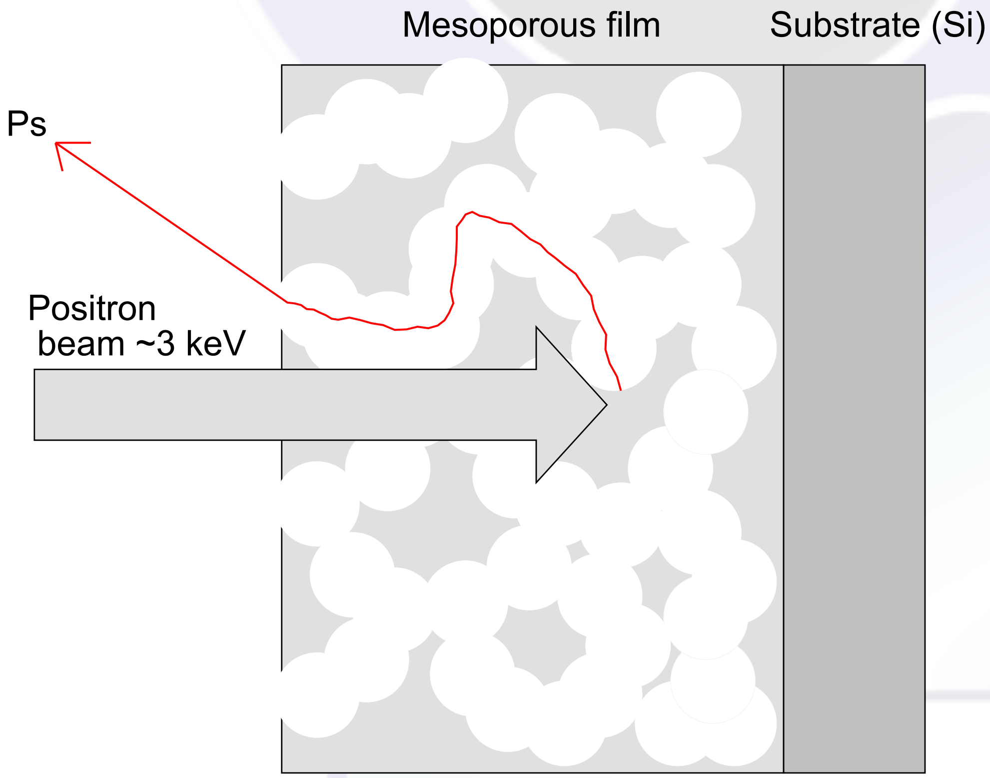
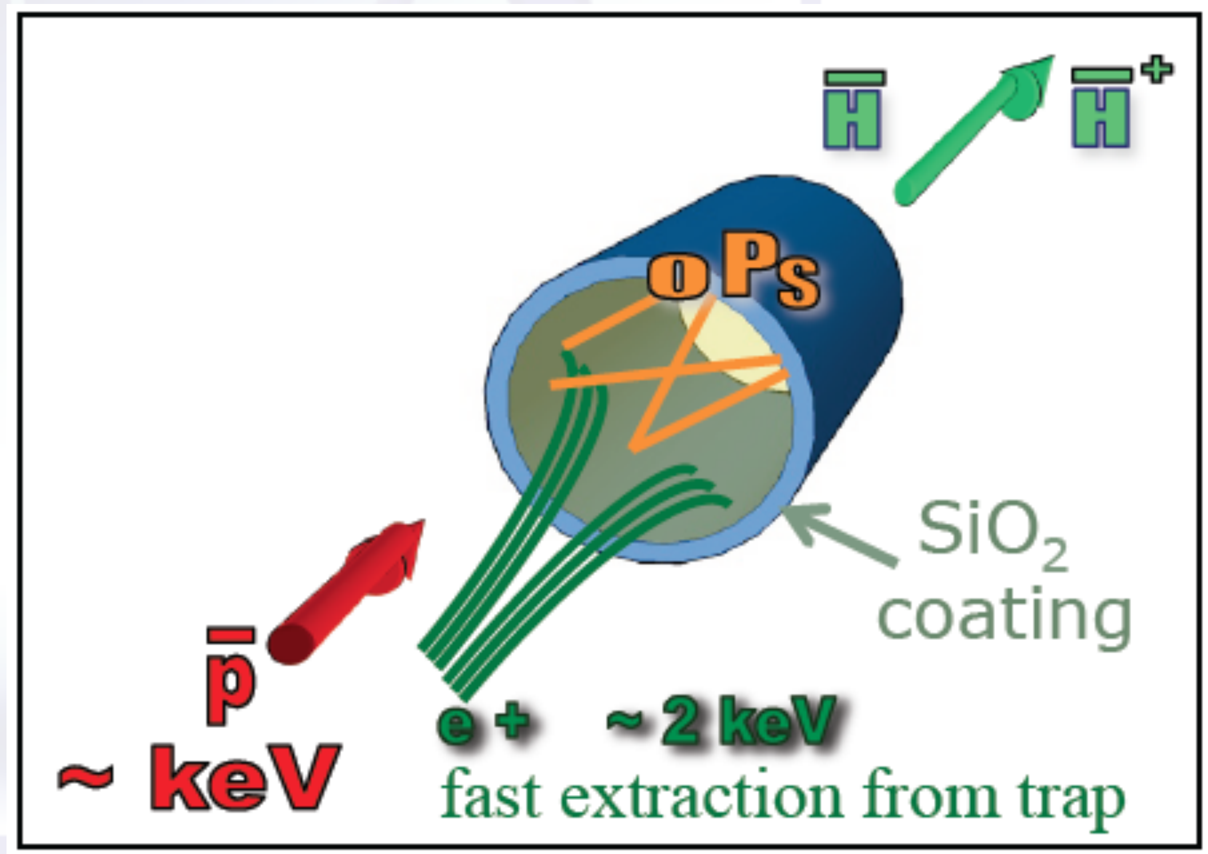
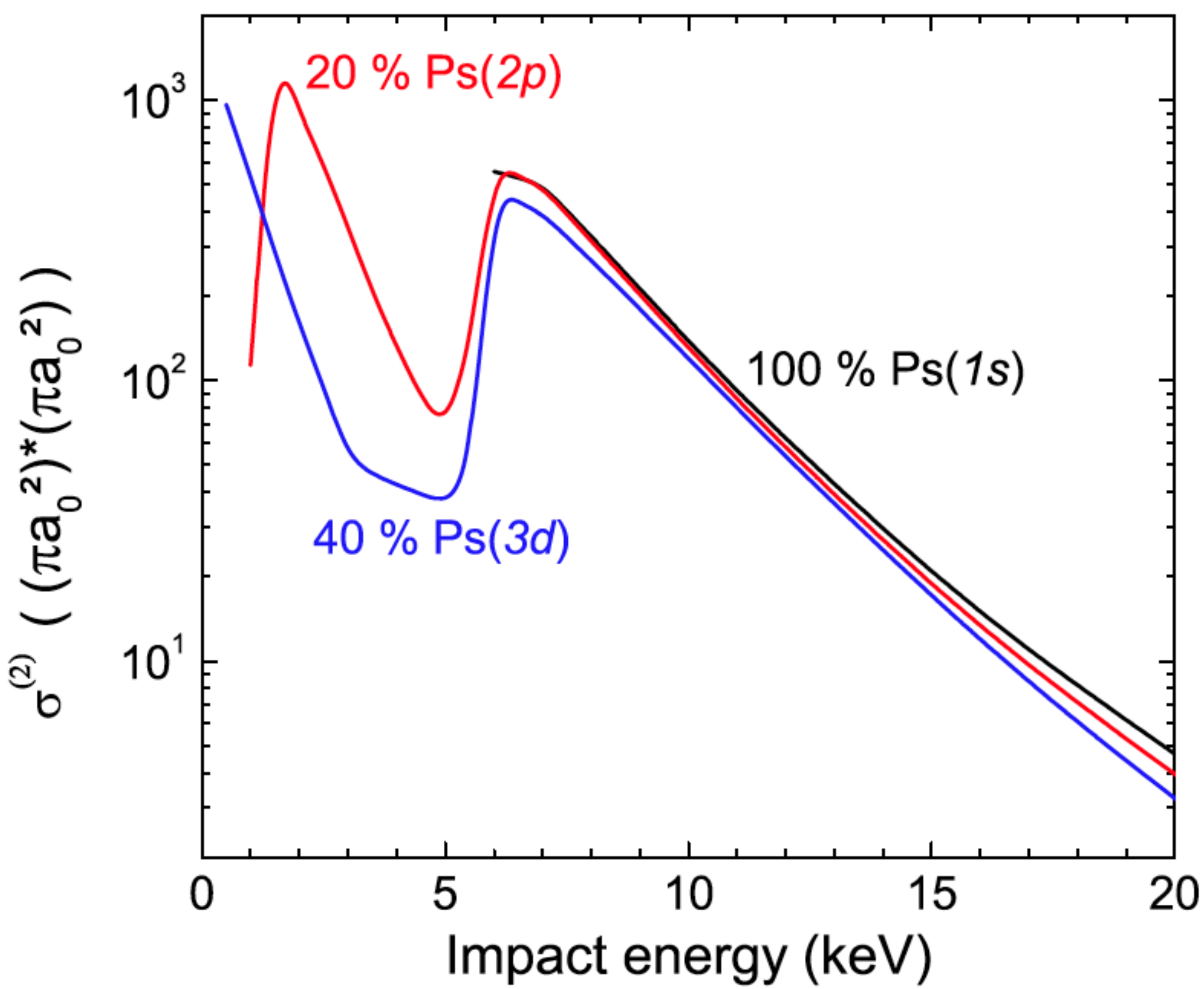
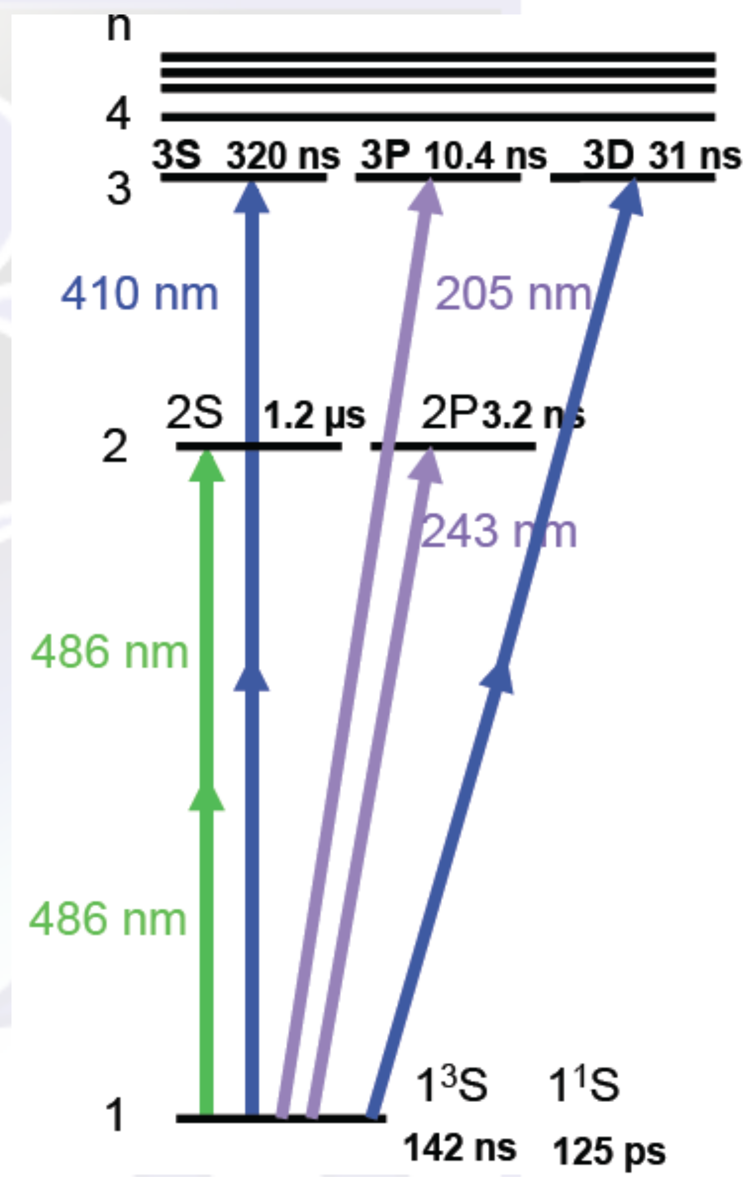




Overall $\overline{H}^+$ formation cross sections

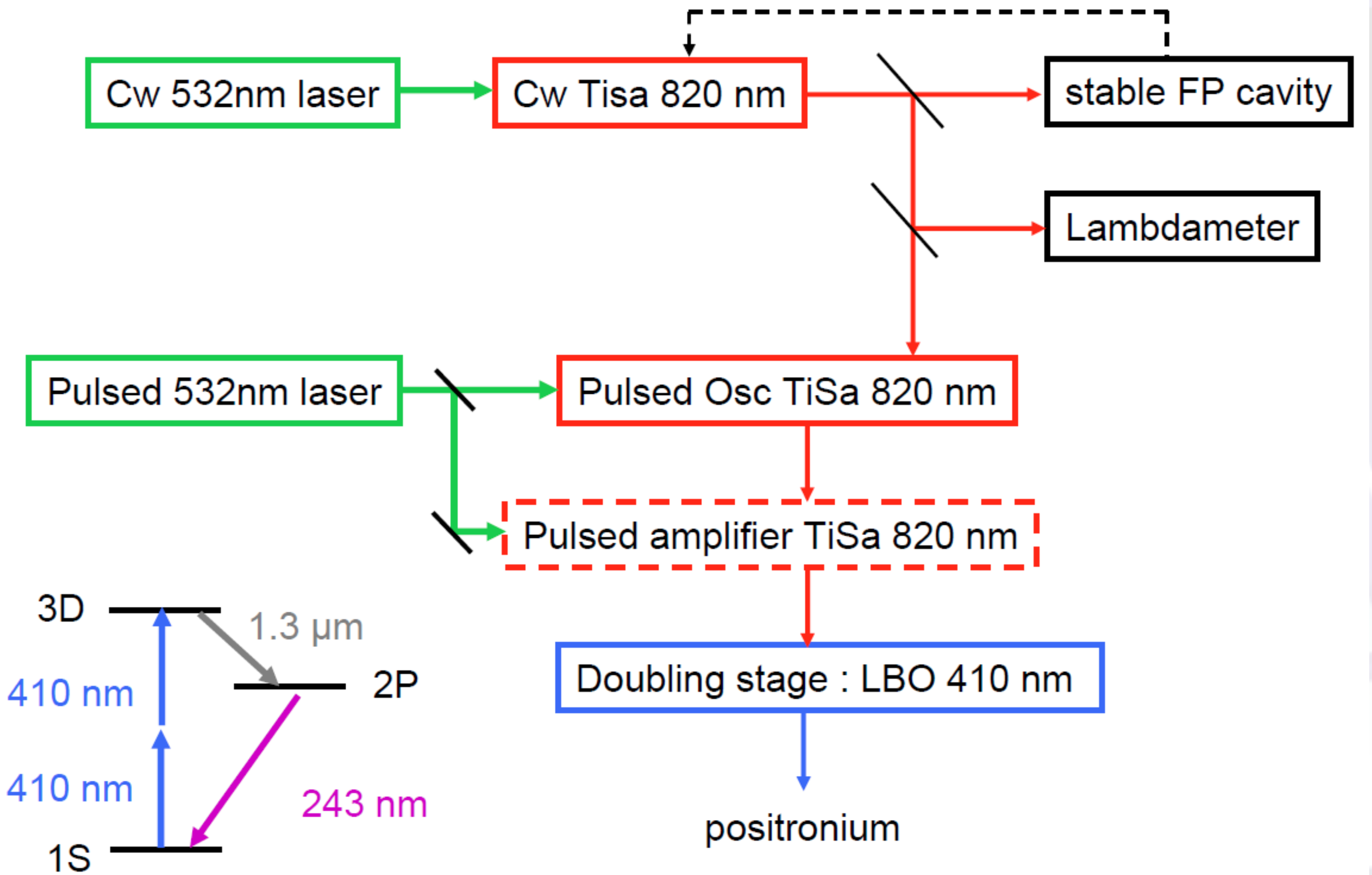




For a pulse of 3 x 10^6 antiprotons:

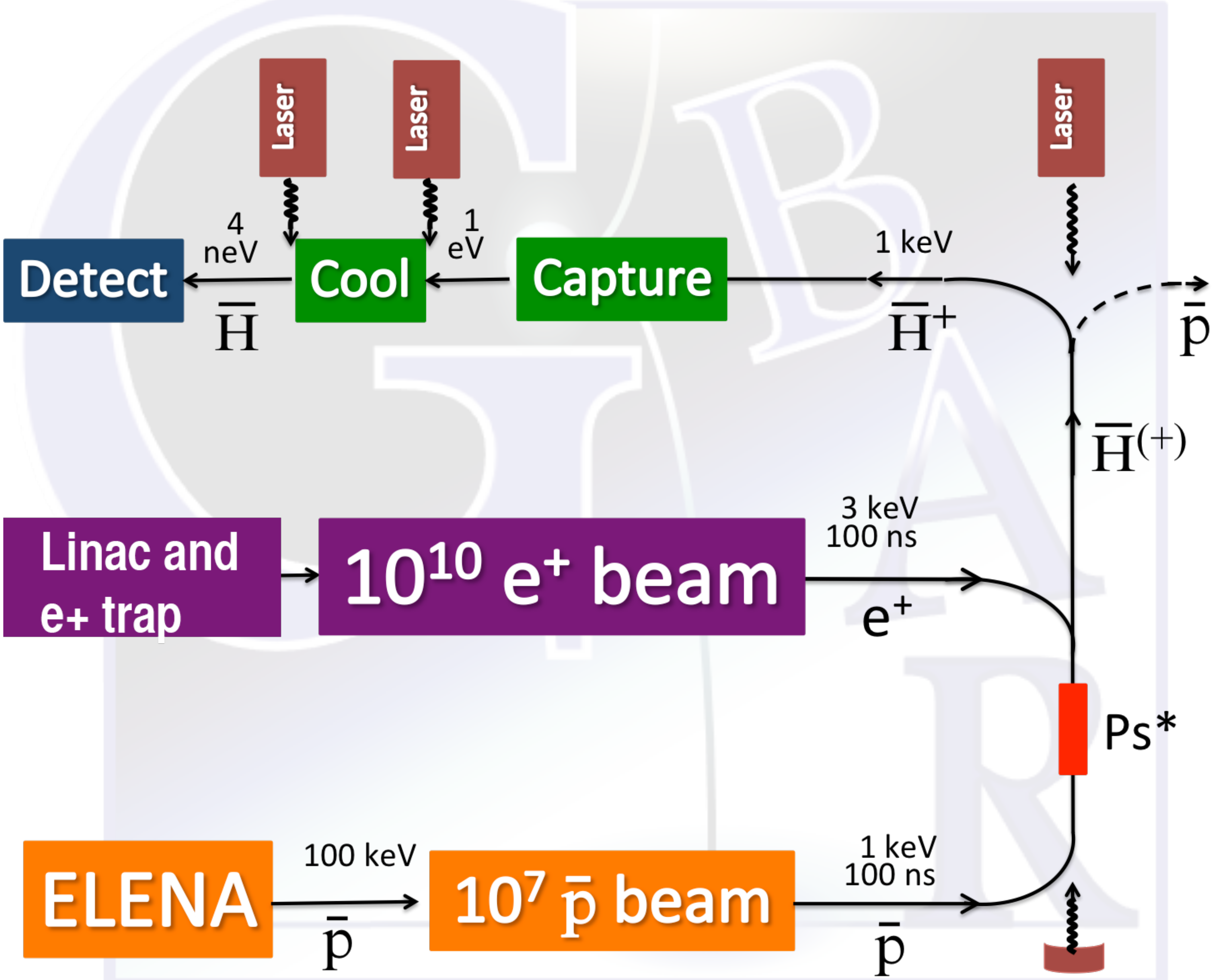
- 1.2 $\overline{H}^+$ for 1 keV $\overline{p}$ + Ps(*3d*)
- 3 $\overline{H}^+$ for 2 keV $\overline{p}$ + Ps(*2p*)
- 0.9 $\overline{H}^+$ for 6 keV $\overline{p}$ + Ps(*1s*)

Status of 410 nm laser



- Ps excitation to 3d level : two photon excitation with 410 nm laser
- Presently assembled at LKB
- Will be installed at Saclay end 2013
- Studying a laser for 2p excitation

Schematic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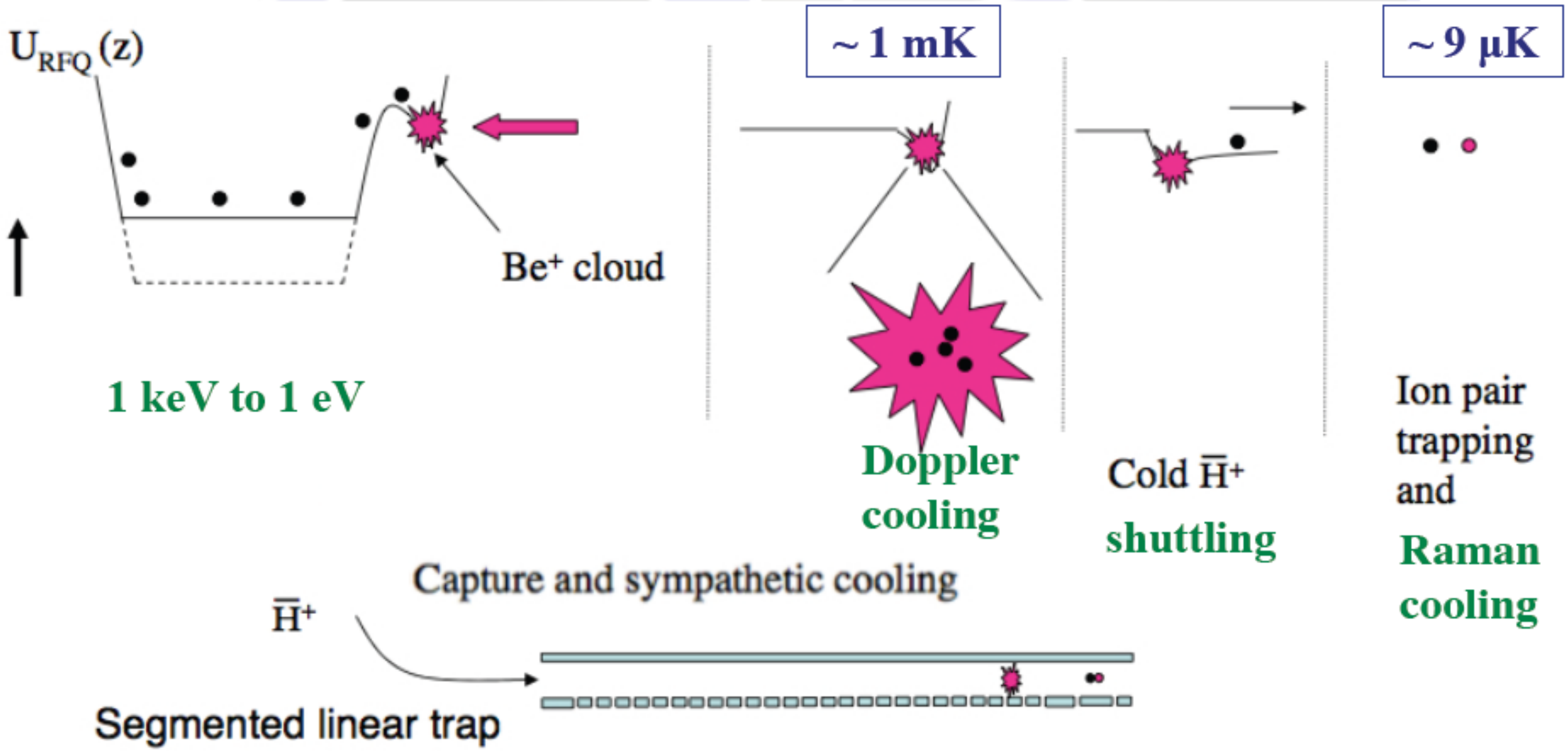
10¹⁰ e+ beam
3 keV
100 ns
e+
Ps*
ELENA
100 keV
p̄
10⁷ p̄ beam
1 keV
100 ns
p̄

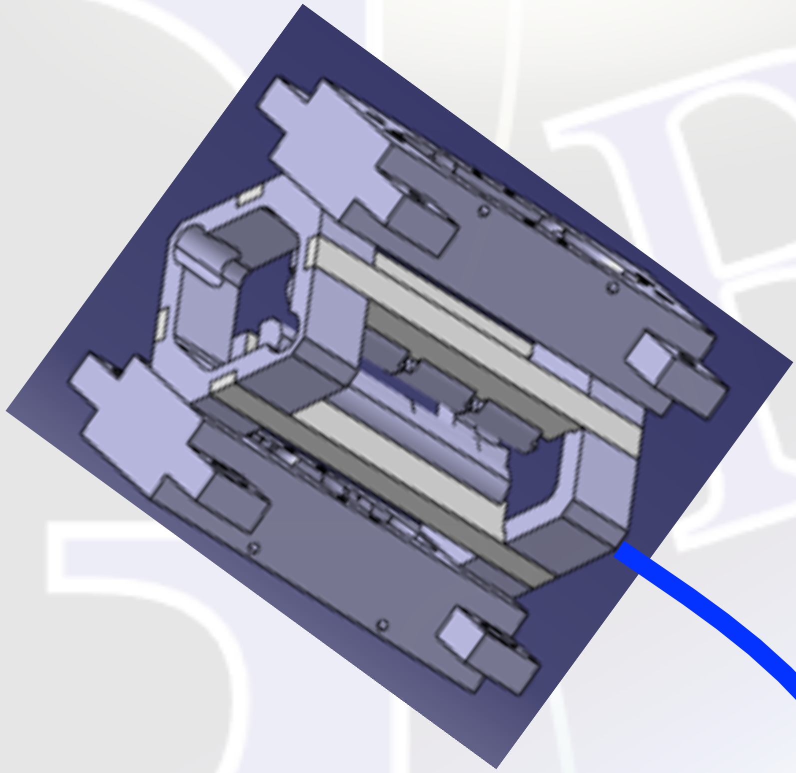
Cooling challenge



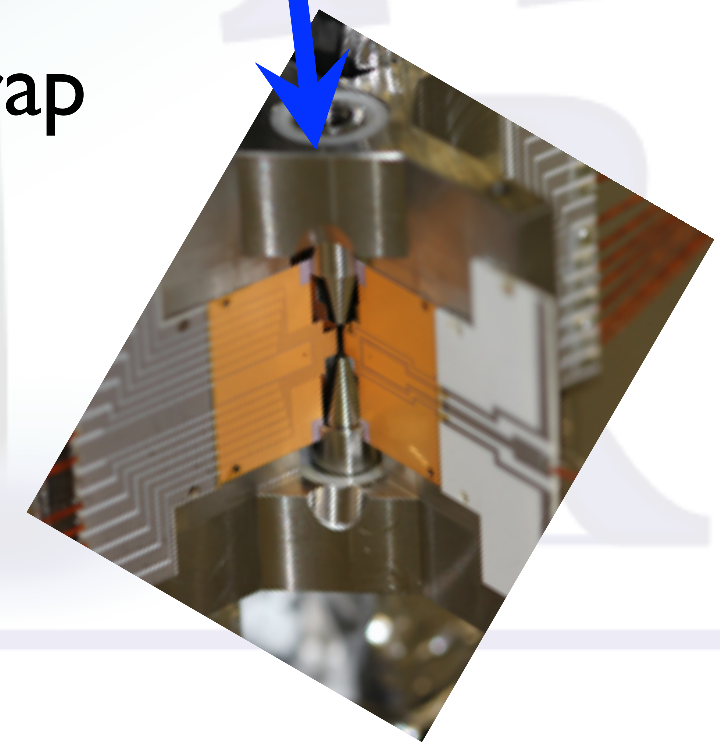
NIST group
M. D. Barrett, ..., D. Wineland, PRA ***68****, 042302 (2003)*
Sympathetic cooling of $^9Be^+$ and $^{24}Mg^+$ for quantum logic

Catching & precision traps

Capture trap



Precision trap



See talk of Hilico this afternoon

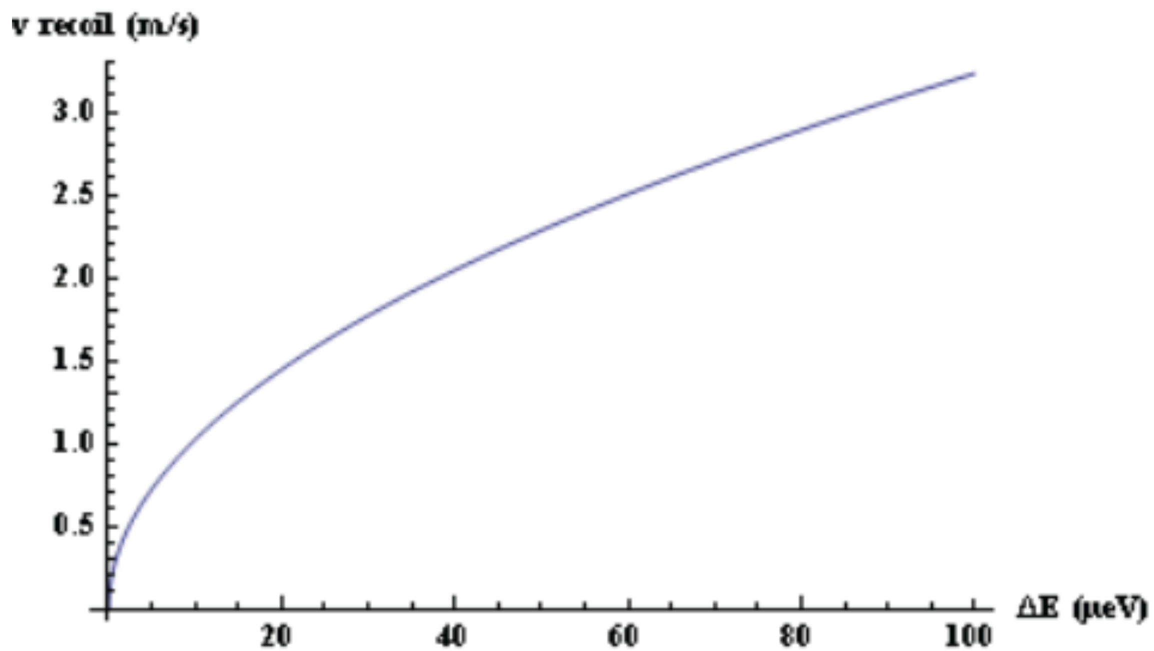
Photo detachment

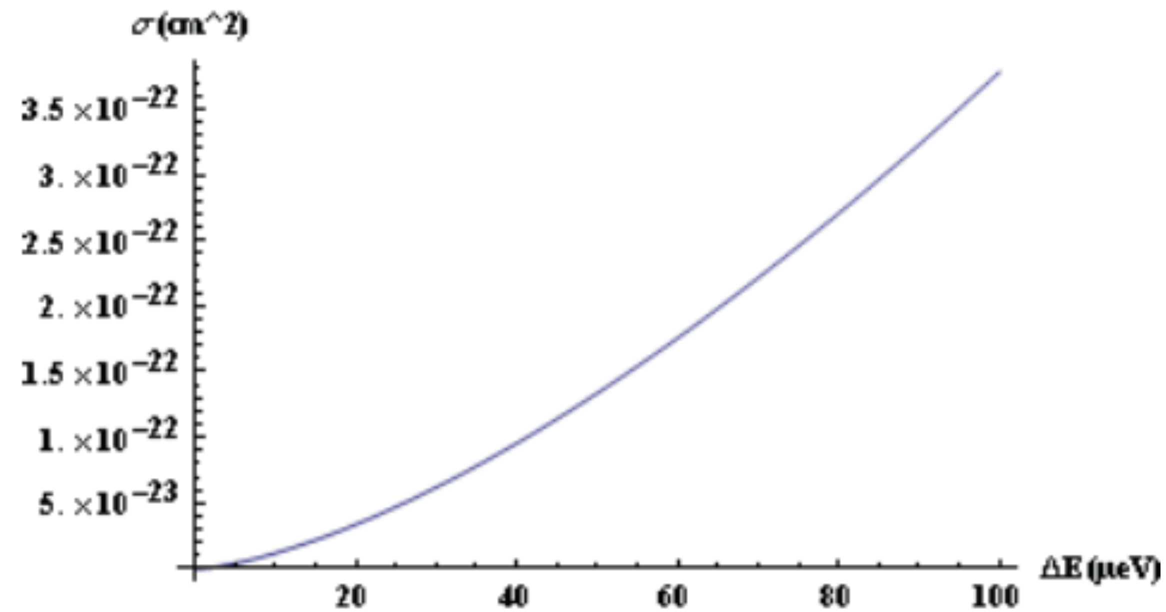
$\overline{H}^+$ binding energy 0.76 eV => p_γ ~ 0.76 eV/c close to threshold

Recoil due to absorption: $v_{recoil} = p_\gamma / m_H = 0.2$ m/s => 4 cm for 0.2 s fall

Recoil due to e^+ emission

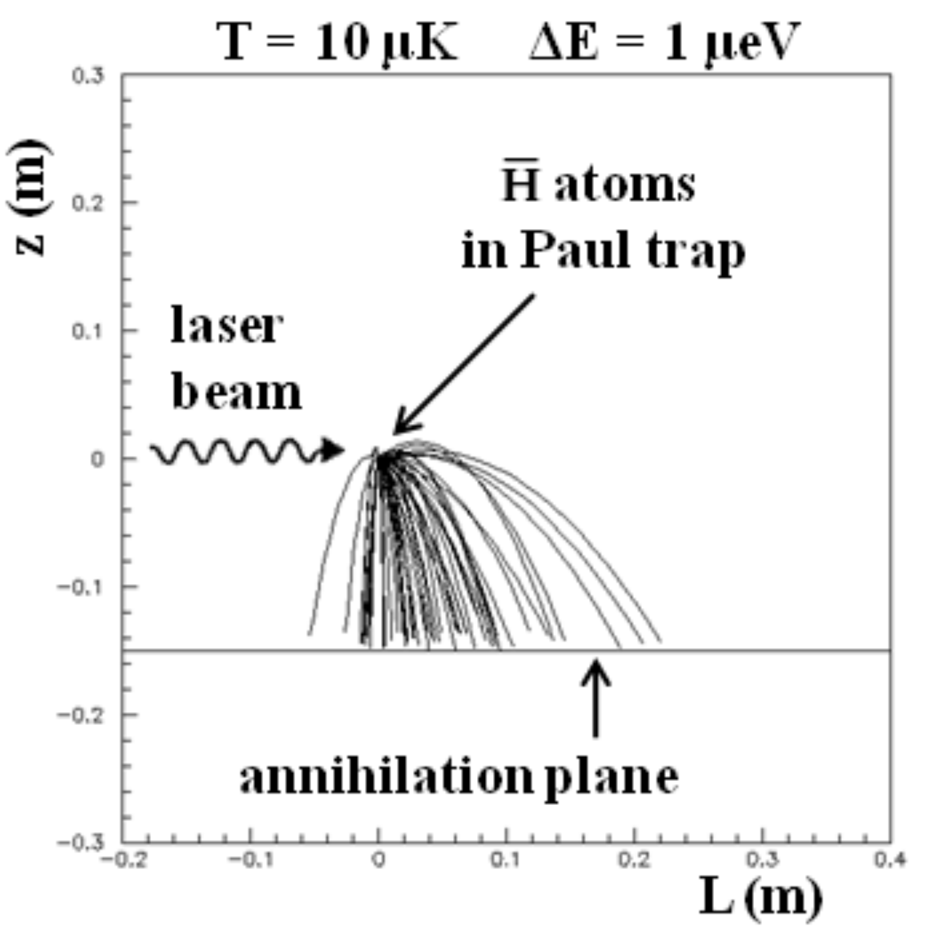
$E_c = E_\gamma - 0.76$ => $v_{recoil} = \sqrt{\frac{2m_e E_c}{m_H}}$ ~ 0.3 m/s for $E_c = 1$ µeV

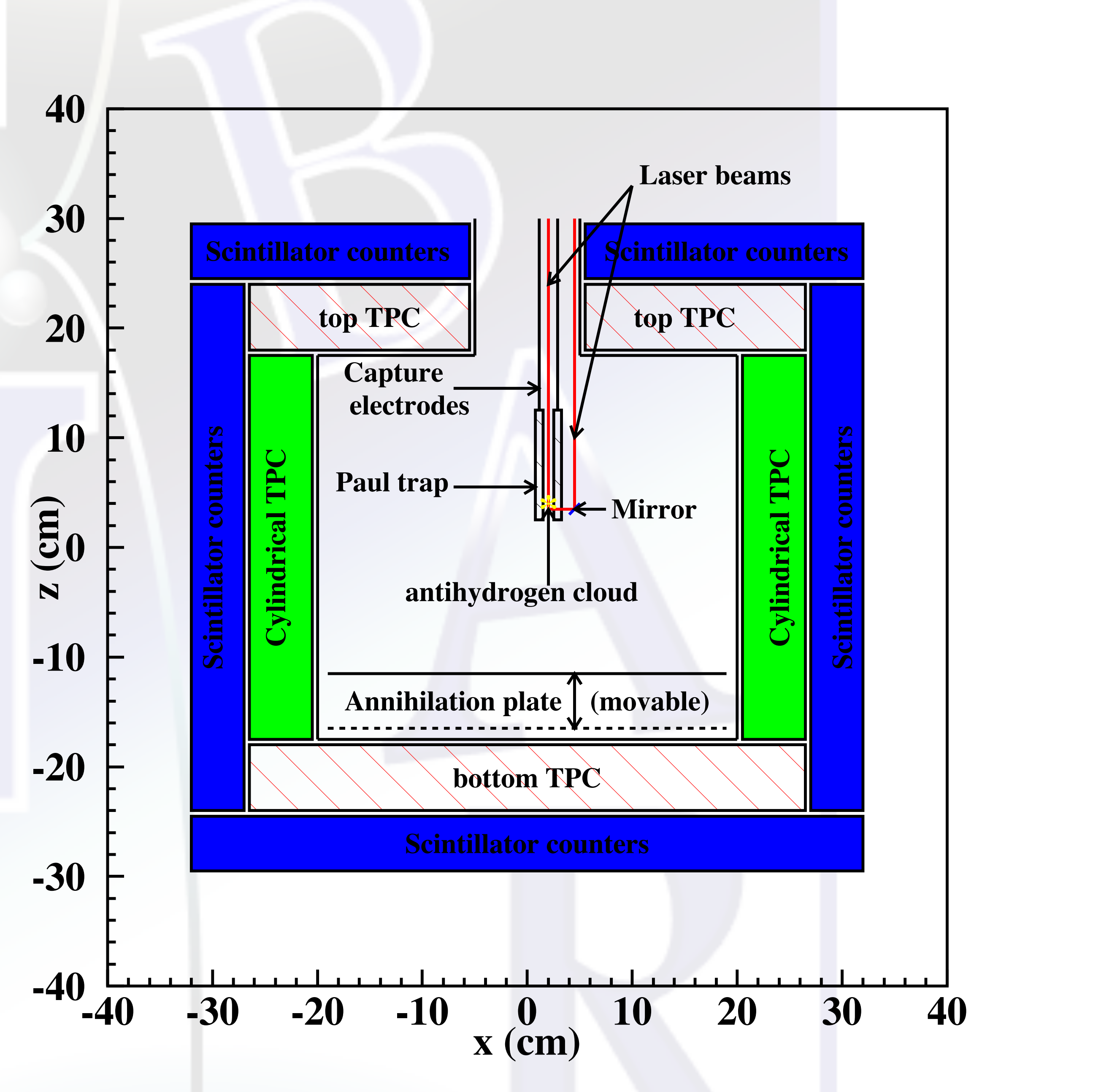




1 W laser, 150 µs shots, 99% efficiency

Detection





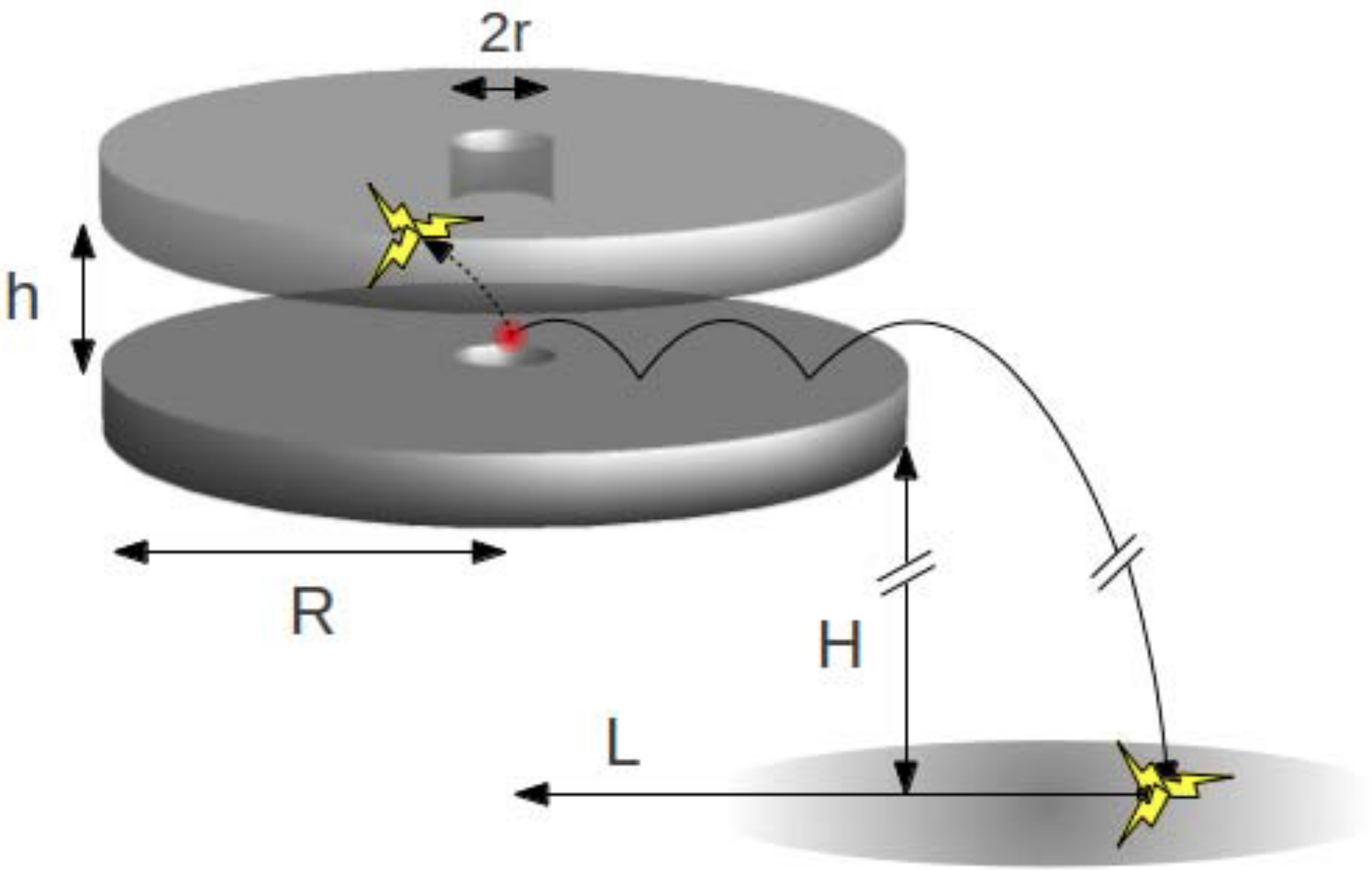
Detection requirement:

- TOF precision : 150 μs
- Annihilation vertex precision : 1 mm
- Background rejection through event topology

Scheme under design: TPC with micromegas chamber (as in T2K near detector)

$$\frac{\Delta\bar{g}}{\bar{g}} \approx 10^{-2}$$

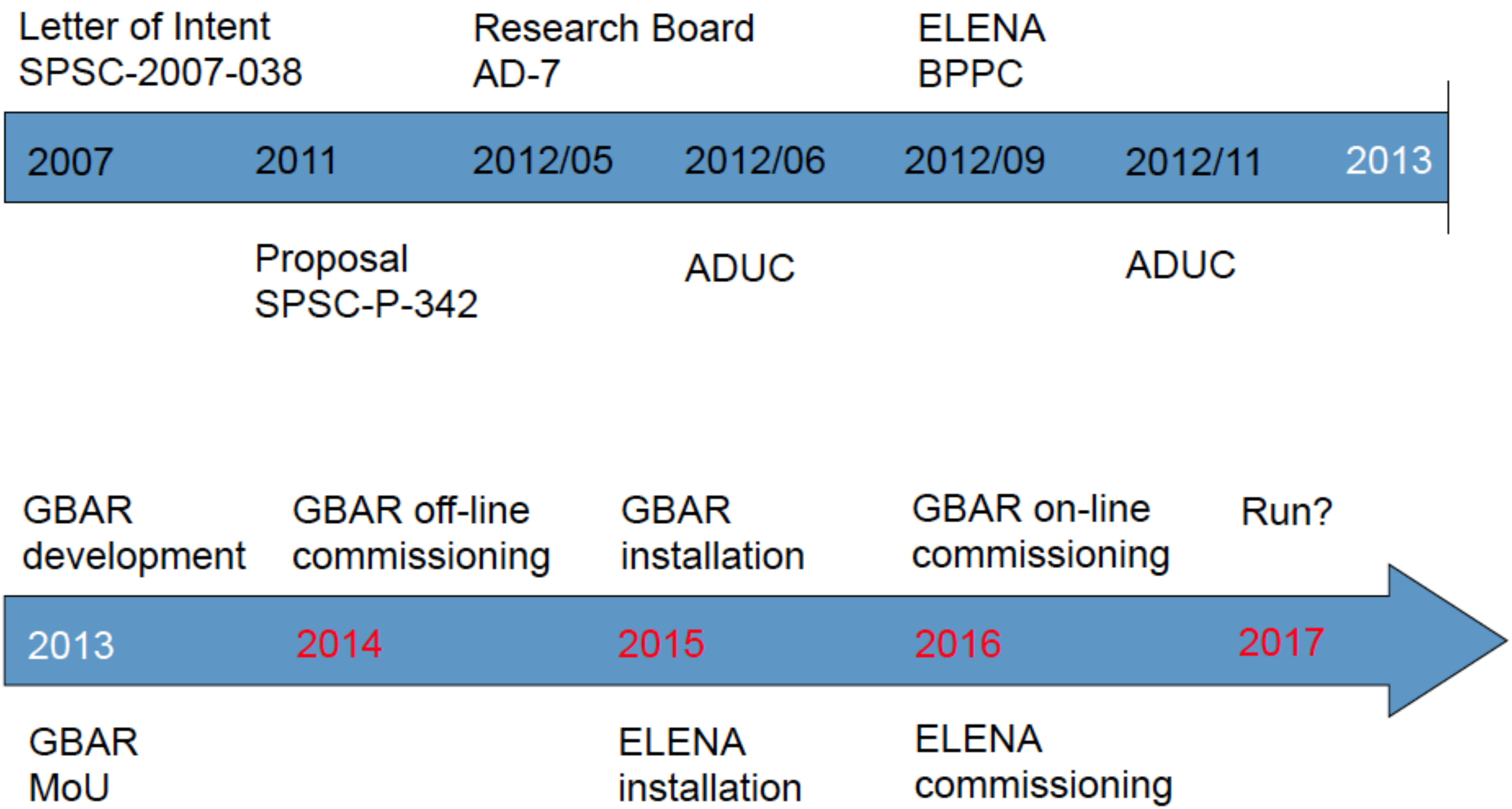
Quantum Reflection



$$\frac{\Delta \overline{g}}{\overline{g}} \lesssim 10^{-3}$$

See talks of Dufour and Voronin this afternoon

GBAR timeline



GBAR

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IN2P3
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