irfu SPP
cea
saclay

Gravitation et Antimatière

Est-ce que l'accélération de la pesanteur terrestre a la même valeur, le même signe pour la matière et l'antimatière ?

Comment le mesurer ? Illustration par un projet d'expérience.

Principe d'équivalence faible

"Si un corps neutre de test est placé en un point de l'espace-temps avec une vitesse initiale, alors sa trajectoire sera indépendante de sa structure interne et de sa ***composition****."*

⇔ Simultanéité de la chute des corps

⇔ Egalité masse inerte et masse grave

CEA/DSM/IRFU

SACM *J-M Rey, A. Curtoni, O. Delferrierre, L. Liszkay*

SEDI *J-P. Bard, P. Legou, X. Coppolani*

SENAC *V. Blideanu*

SIS *M. Carty, Y. Sauce*

SPP *B. Mansoulié, J-P. Pansart, P. Pérez, Y. Sacquin*

CEA/DSM/IRAMIS *C. Corbel*

AIST *R. Suzuki, T. Ohdaira*

ETHZ *P. Crivelli, U. Gendotti, A. Rubbia*

RIKEN *M. Hassan, A. Mohri, H. Saitoh, Y. Yamazaki*

CNRS/CERI *M.F. Barthe, P. Desgardin*

CNRS/LCPME *M. Etienne, A. Walcarius*

CNRS/LMPC *V. Valtchev*

ECOLE POLYTECHNIQUE *J-P. Boilot*

Theory and Experiment

$$V = -G\frac{mm'}{r}(1 \mp a\ e^{-\frac{r}{v}} + b\ e^{-\frac{r}{s}})$$

Newton — Supergravity : component of repulsive gravity

J. Scherk, Phys. Lett. B (1979) 265.

–Experimental Constraints : range < 1 pc *Bellucci & Faraboni, Phys. Lett. B 377 (1996) 55.*

Indirect limits

K_0 - $\bar{K}_0$	SN1987a	Cyclotron frequency p/$\bar{p}$

Direct Tests

Charged antimatter *e^+ or $\bar{p}$ (e.m. shielding)*

Neutral antimatter

$\bar{n}$ hard to slow down	*Ps short lifetime*
$\bar{H}$ cooling limit mK	*$\bar{H}^+$ cooling limit μK*

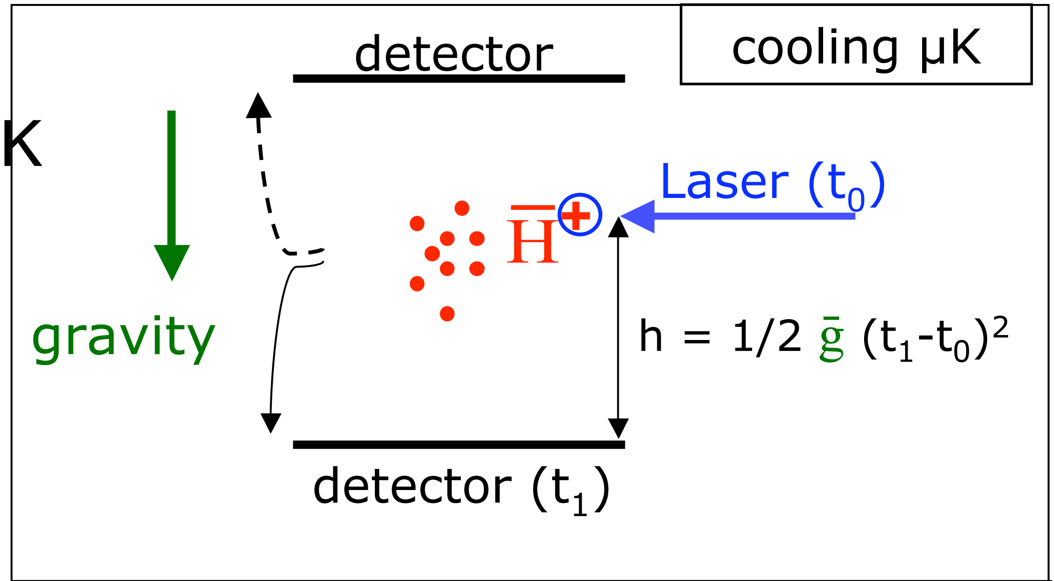
AEGIS(CERN), AGE(FNAL)

No direct measurement exists

Using $\bar{H}^+$ *(J.Walz & T.Hänsch)*

- Capture ion $\bar{H}^+$ → cooling few μK
- Ejection of extra e^+ with laser
- Time of flight

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



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

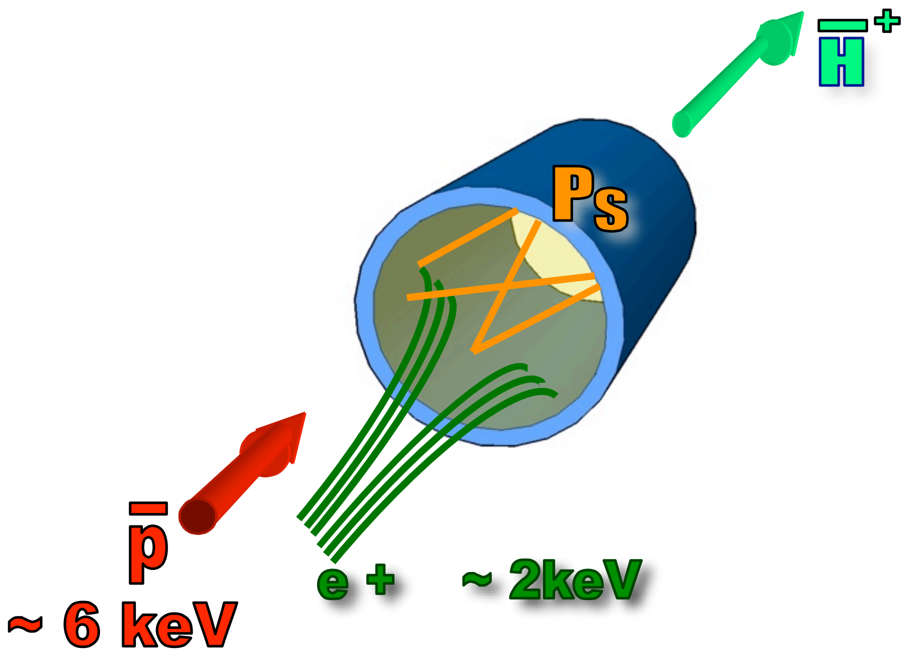
Relative Precision on $\bar{g}$:

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

$h = 10$ cm → $\Delta t = 143$ ms

How to produce $\bar{H}^+$

In $e^+ \rightarrow Ps$ converter :
High density of Ps ~ 10^{12} cm^{-2} in a few ns



Standard Method						
$\bar{p}$	+	e^+	$\rightarrow$	$\bar{H}^*$		
New Method						
$\bar{p}$	+	Ps	$\rightarrow$	$\bar{H}$	+	e^-
$\bar{H}$	+	Ps	$\rightarrow$	$\bar{H}^+$	+	e^-

➔ extraction in ≤ 50 ns of $10^{10\text{-}11}$ e^+ from positron trap

and defocus towards converter

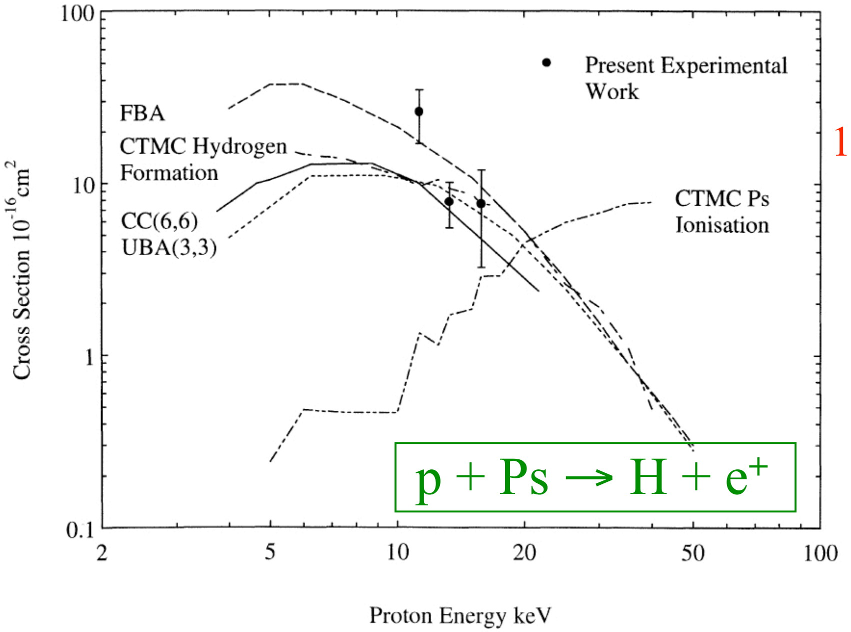
Note: *cross-section* $\propto n^4$

If Ps is excited to n=4, all $\bar{p}$ are transformed into $\bar{H}$ for $E(\bar{p}) << 1$ keV

Binding energy Ps(n=3) ~ 0.75 eV ~ Binding E of $\bar{H}^+$

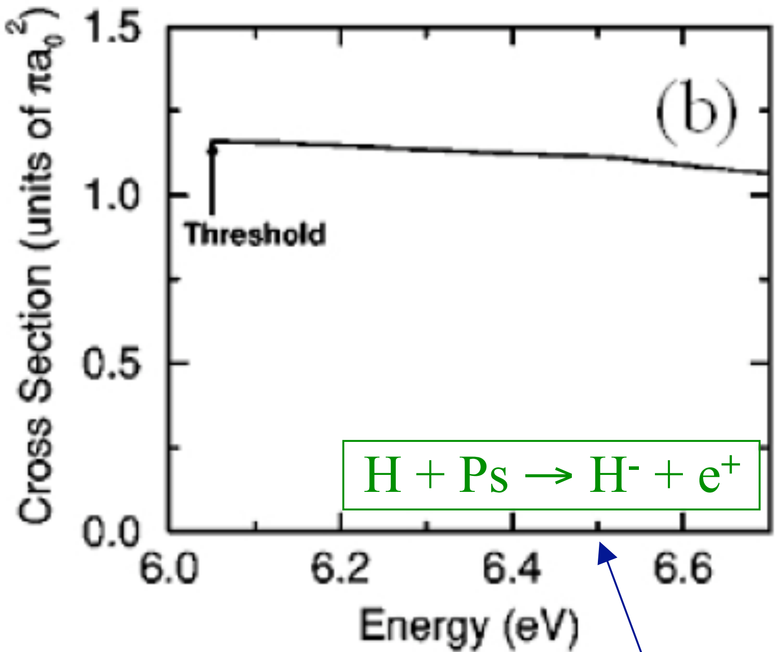
Cross-sections on P_s

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



10^{-15} cm^2

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



10^{-16} cm^2

E (p) = 6 keV in Ps frame

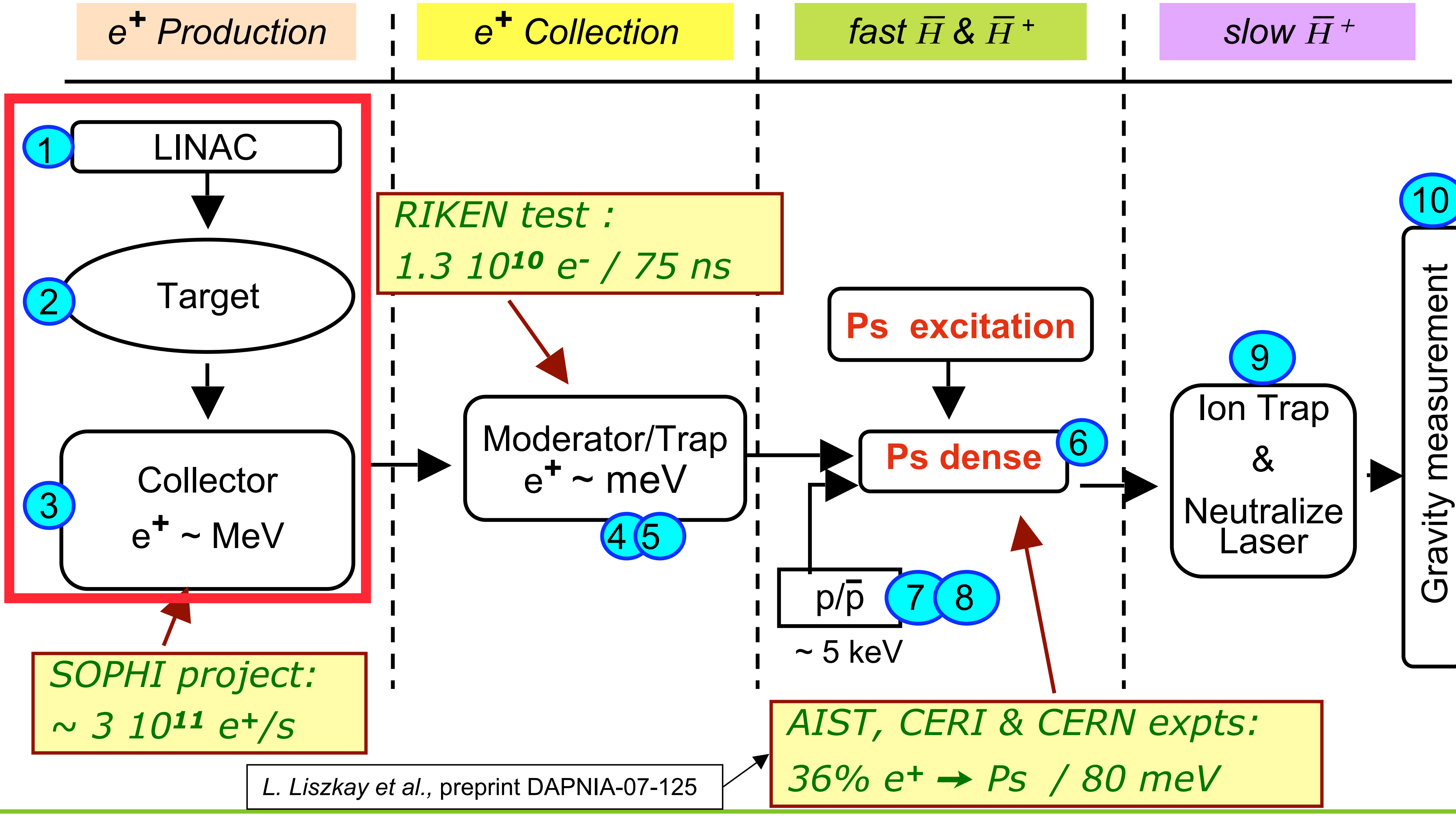
ASACUSA
12 AD shots →

$10^7\ \bar{p}$

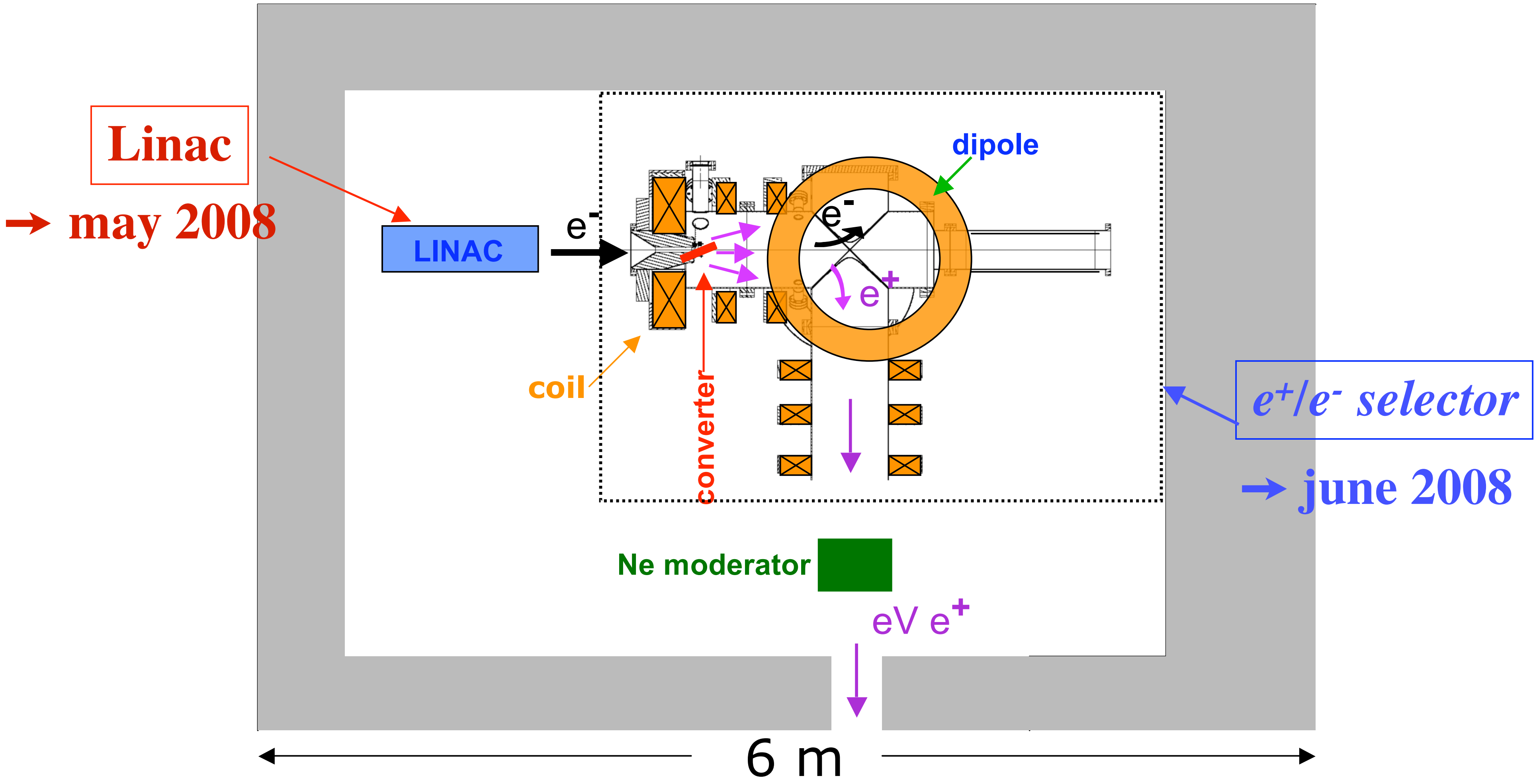
$10^{12}\ P_s$ at/cm^2 } → $10^4\ \bar{H}$, $1\ \bar{H}^+$

Gravity Experiment with $\overline{H}^+$

P.Pérez and A. Rosowsky, Nucl. Inst. Meth. A 545 (2005) 20-30.



Project of intense e+ source



http://www-dapnia.cea.fr/Phocea/Vie_des_labos/Ast/ast_technique.php?id_ast=784

Industrial Linac

E (e-) = 6 MeV (< neutron activation threshold)

ν = 220 Hz

I = 0.2 mA

bunch length 2 - 4 µs

Magnetron 1.9 MW peak

Total electric power 35 kVA

RF frequency 3 GHz

Acceleration length 21 cm

Beam diameter 1 mm , 6 mm at target

Overall dimensions 1 m x 1 m x 0.8 m

LINAC TECHNOLOGIES

Install May 2008

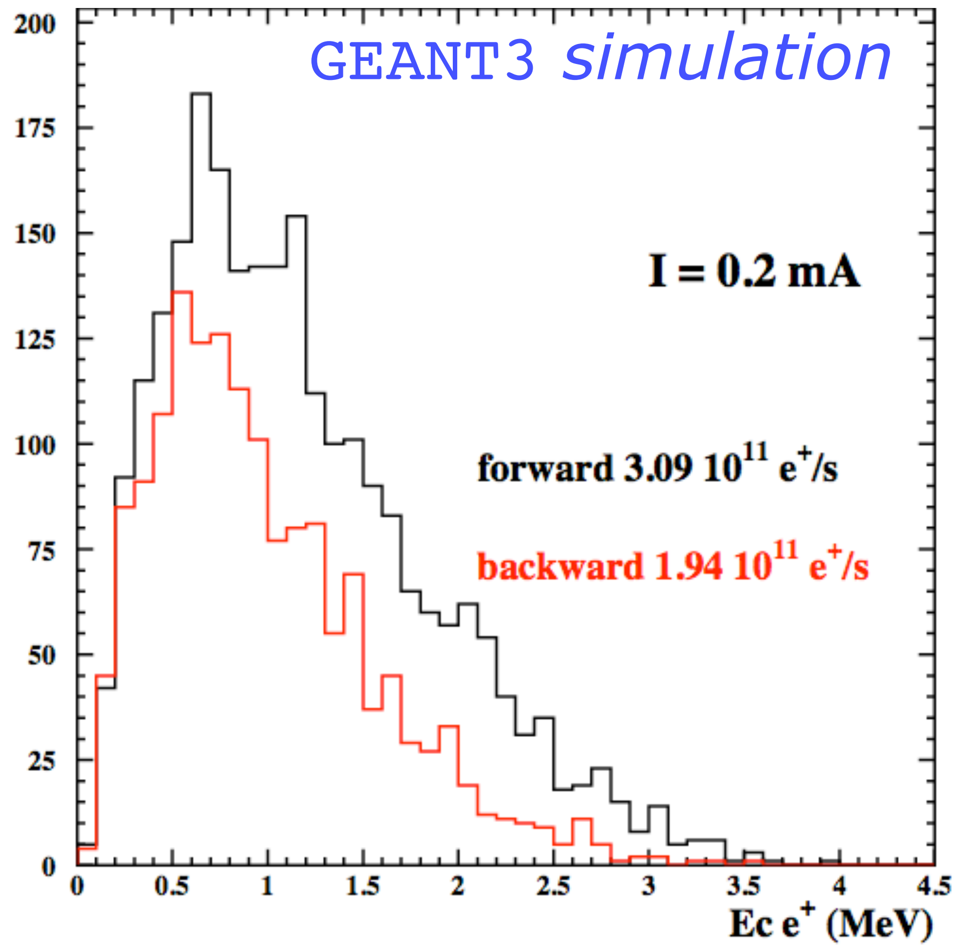
e^+ production and transport

Yields with I = 0.2 mA

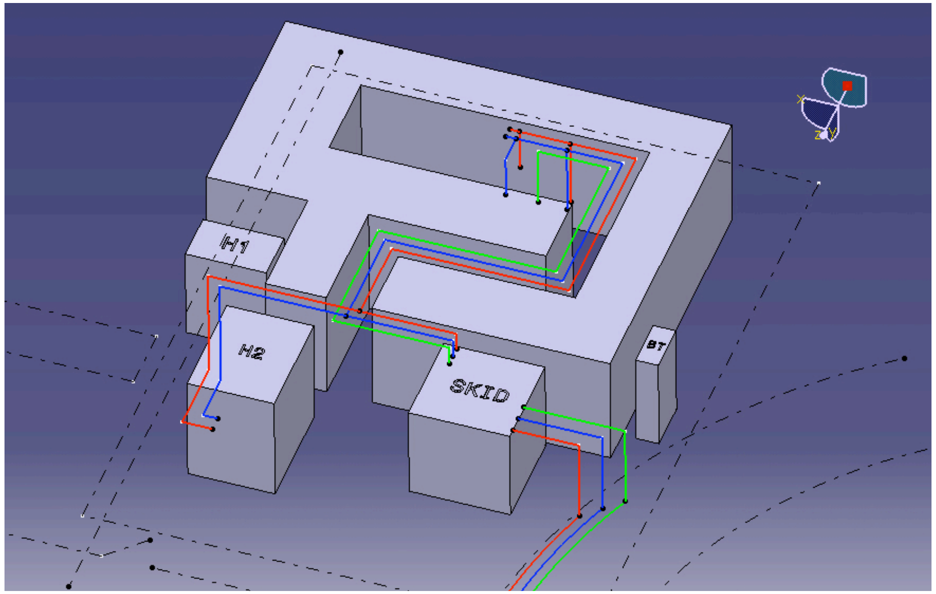
- W moderator $\varepsilon = 10^{-4}$
  > 10^7 slow e^+/s

- Ne moderator
  transport efficiency 55%
  > 10^8 slow e^+/s

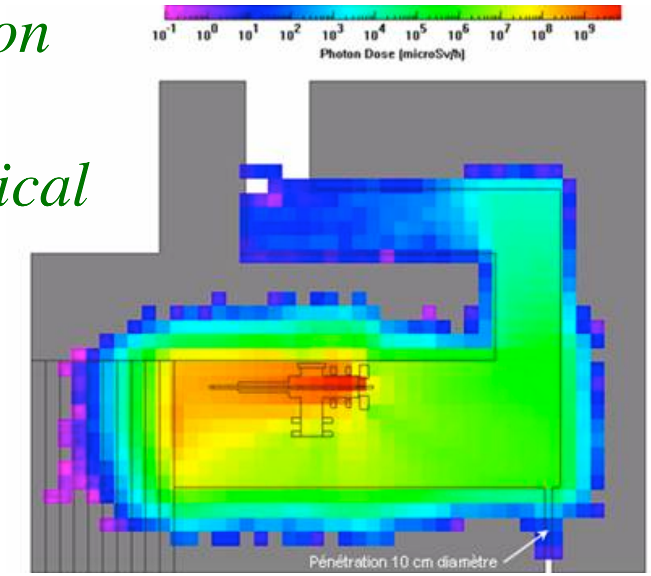
- Large beam size to be reduced for trap filling



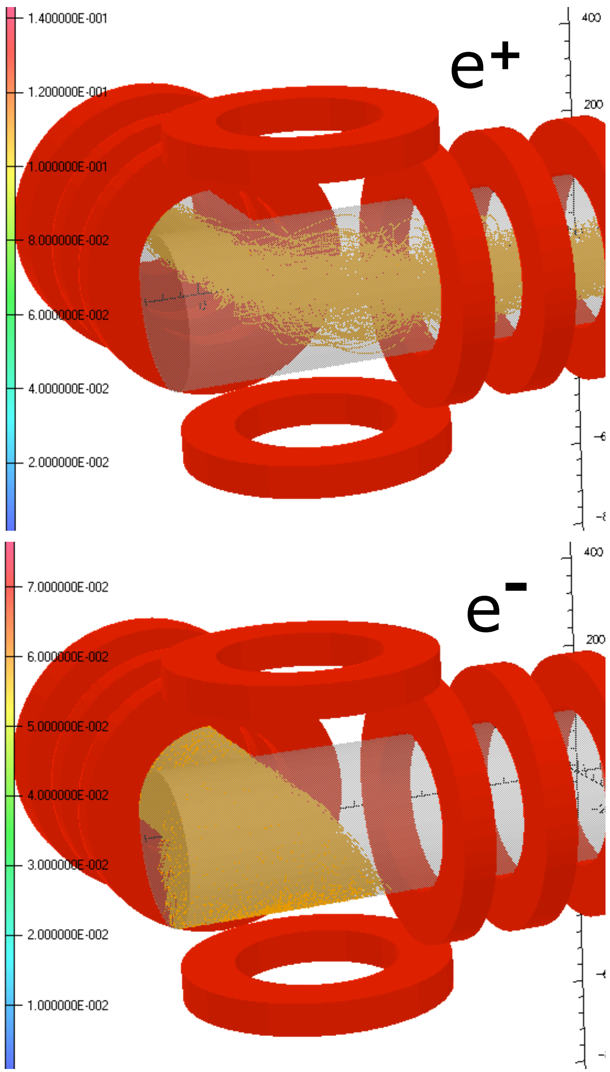
Installation Hall 126 (Saclay)

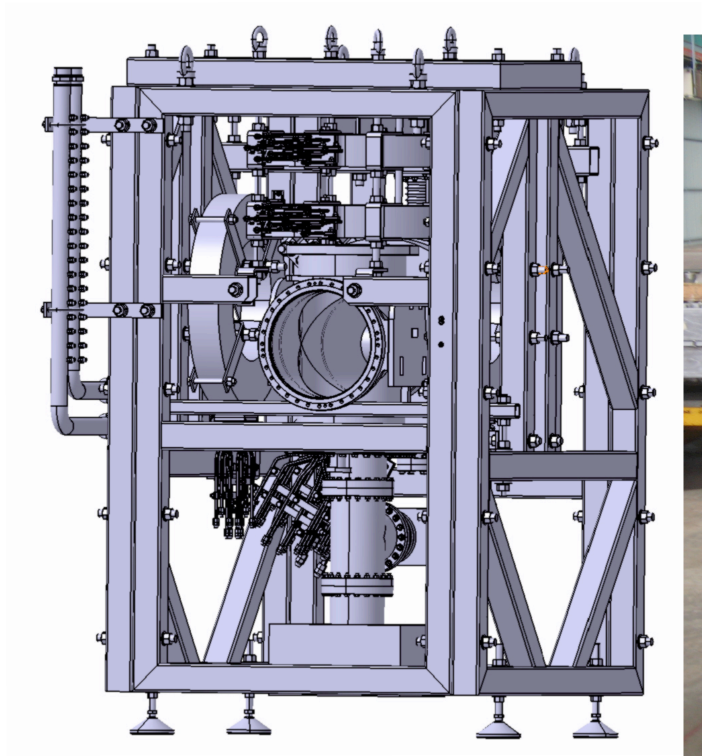


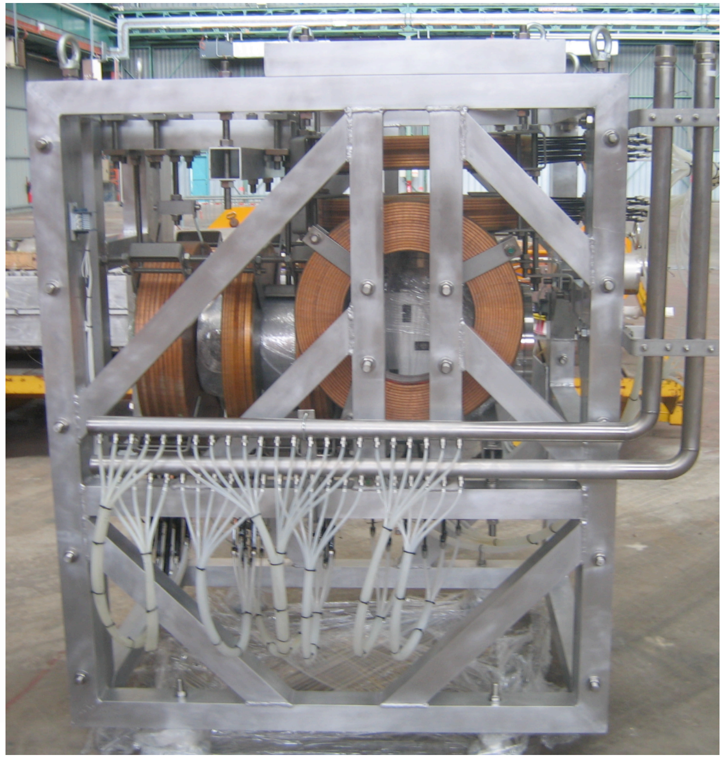
Simulation for radiological safety



e^+/e^- selector







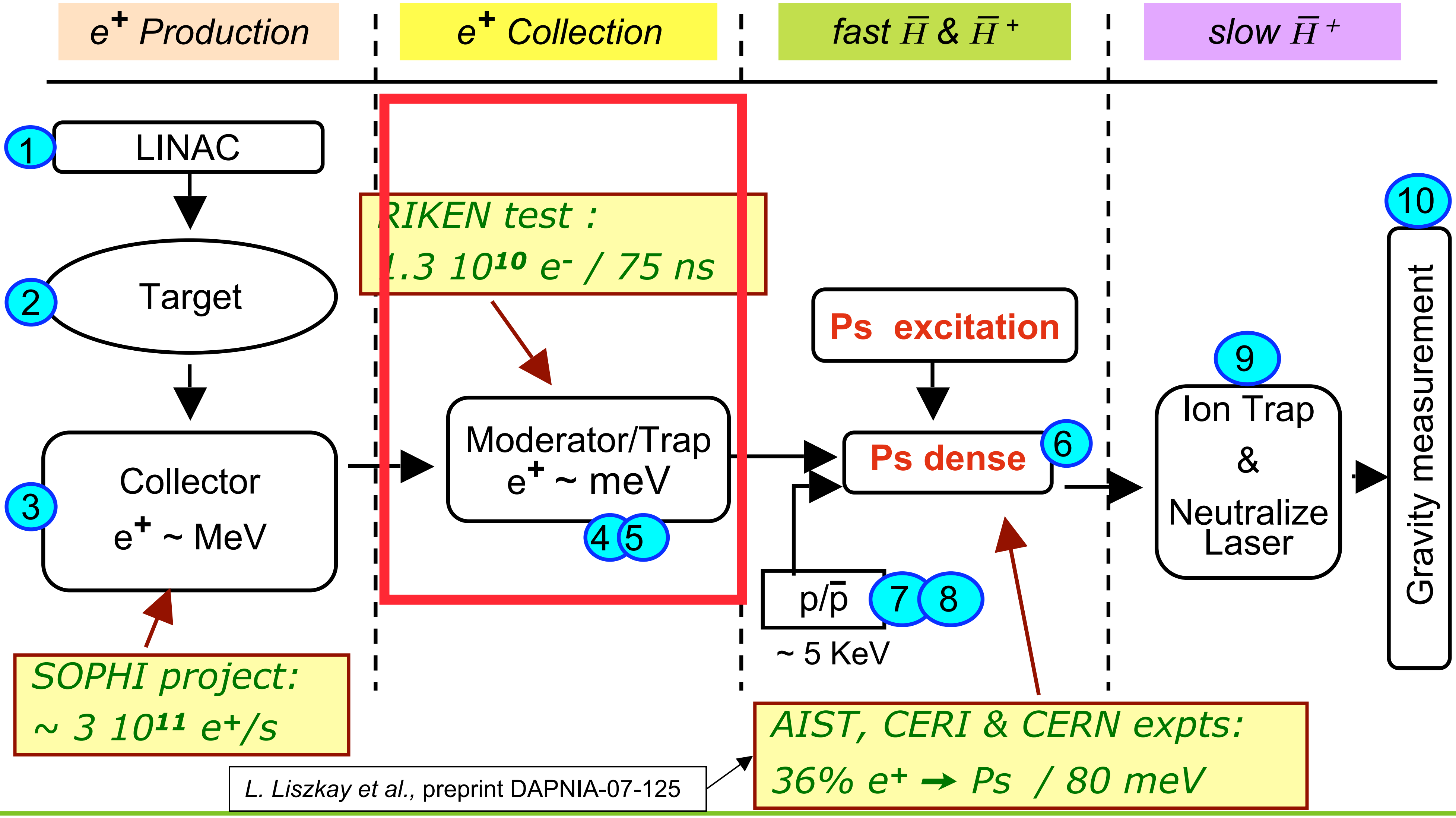
Being installed now

Applications des Positons Lents

Défauts matériaux
Graser ou Laser 511 keV
Stockage d'énergie ?
Propulsion (USAF, NASA)
Imagerie Médicale

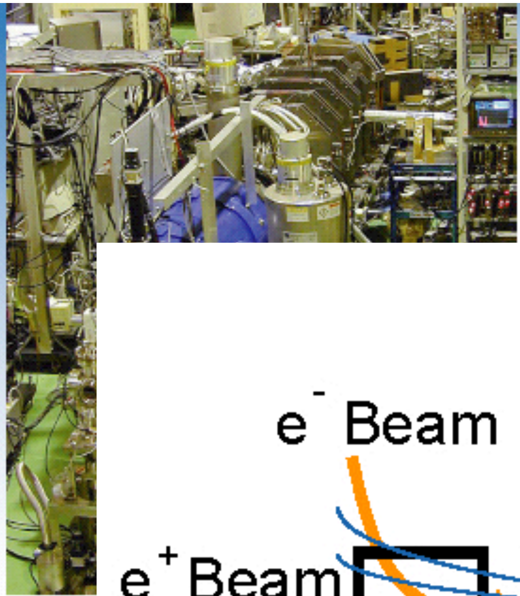
Gravity Experiment with $\overline{\text{H}}^+$

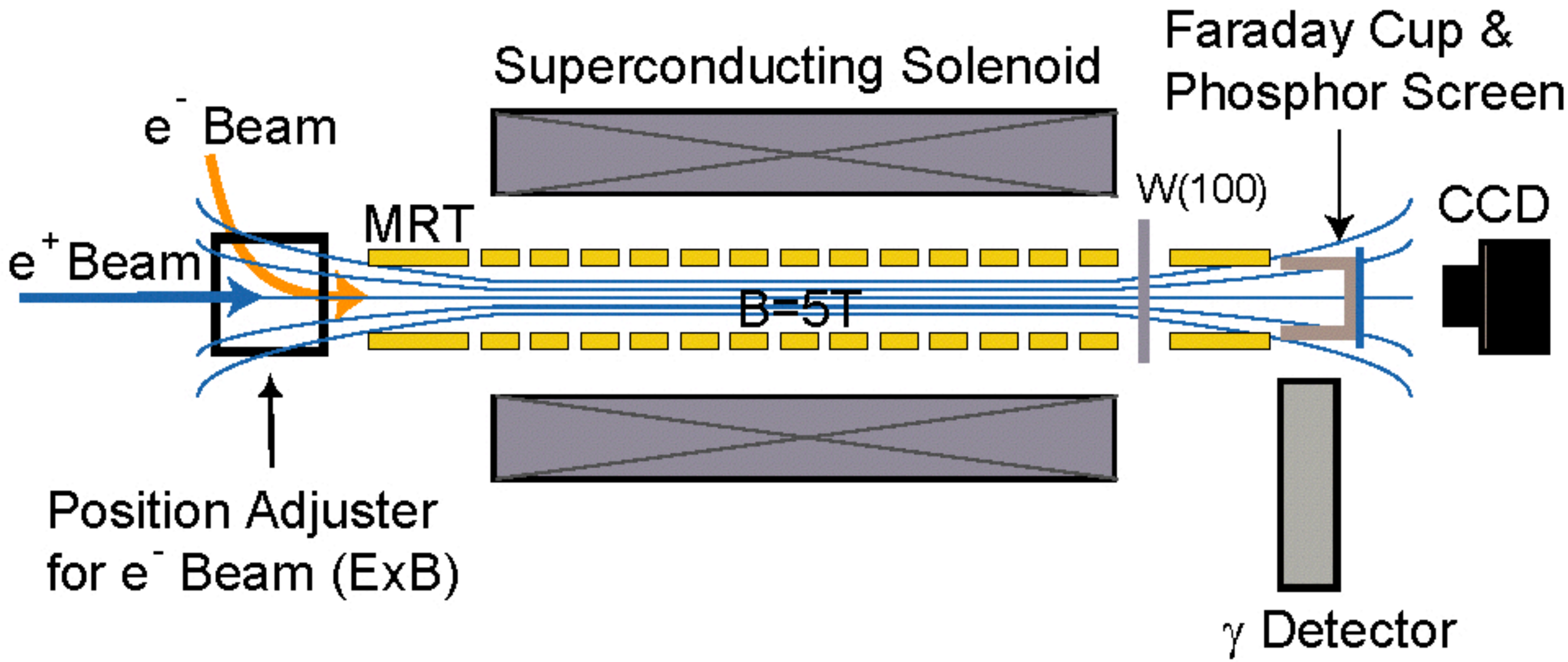
P.Pérez and A. Rosowsky, Nucl. Inst. Meth. A 545 (2005) 20-30.



RIKEN MRT trap

電子プラズマを用いた陽電子蓄積装置の開発





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RIKEN Proj
Cold HCI bear

Requiremer
* Positrons of
* UHV (<10⁻¹¹

e+
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Distribution
Emitted e+

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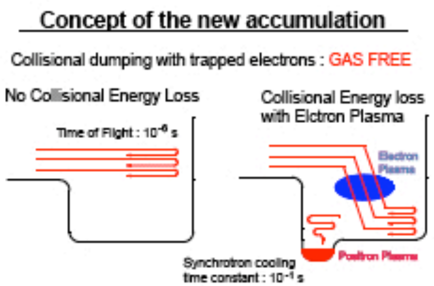
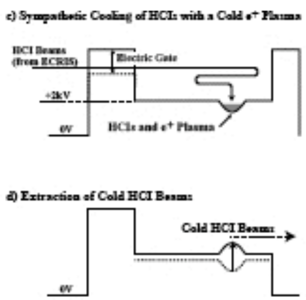
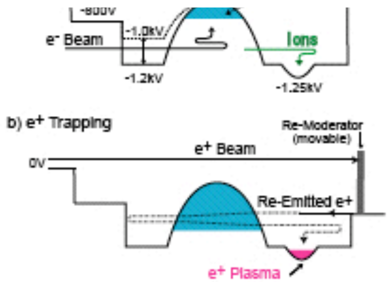
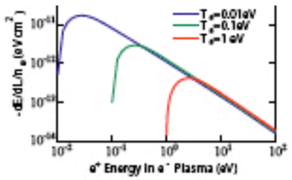








$-dE/dL(eV/cm) = \alpha\, n_e(cm^{-3}) / E(eV)$ (α=~1.5×10^{-12} if T_e <E)

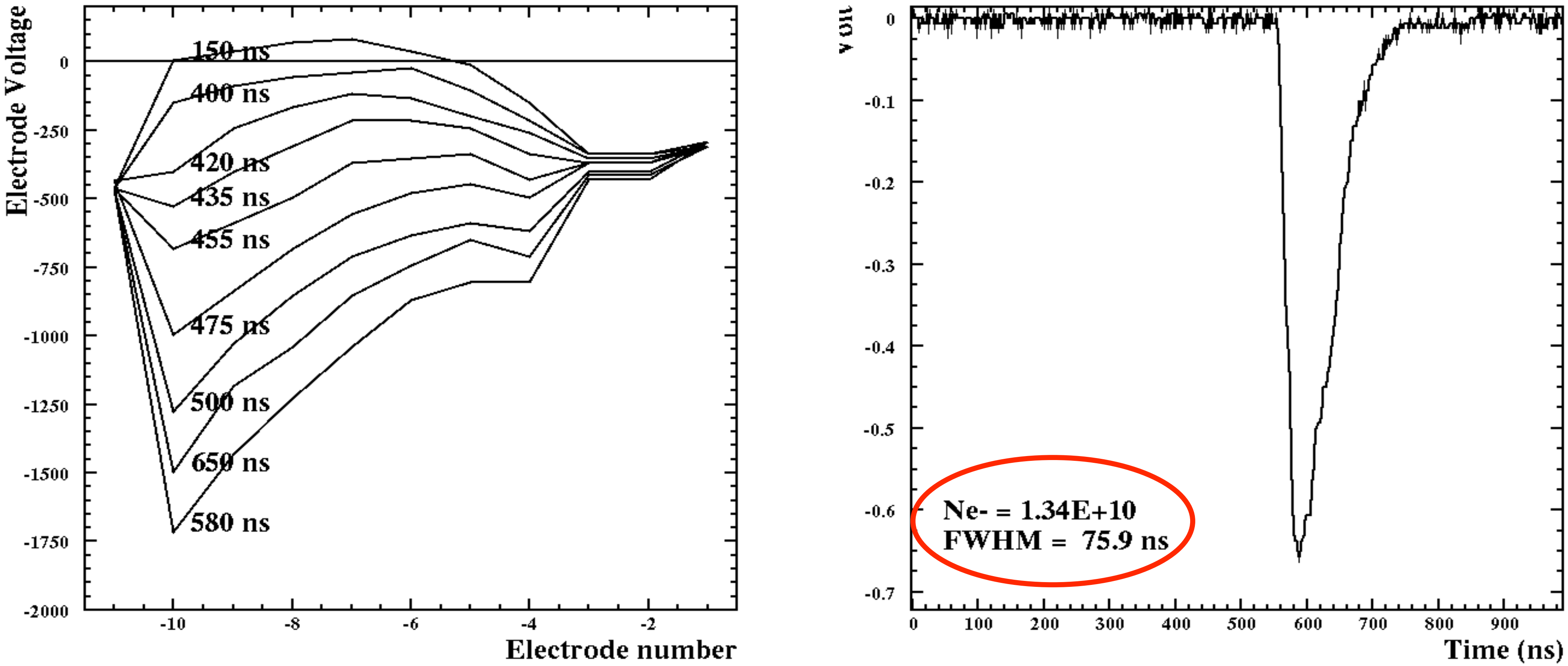
Required Condition:
$E_{ac} < (\Delta E/2) + (\alpha\, n_e L / \Delta E)$

EI: e+ Injection Energy
ΔE: Required Energy Loss (~3eV)
n_e: e- Plasma Density
L : e- Plasma Length

Fast extraction from trap

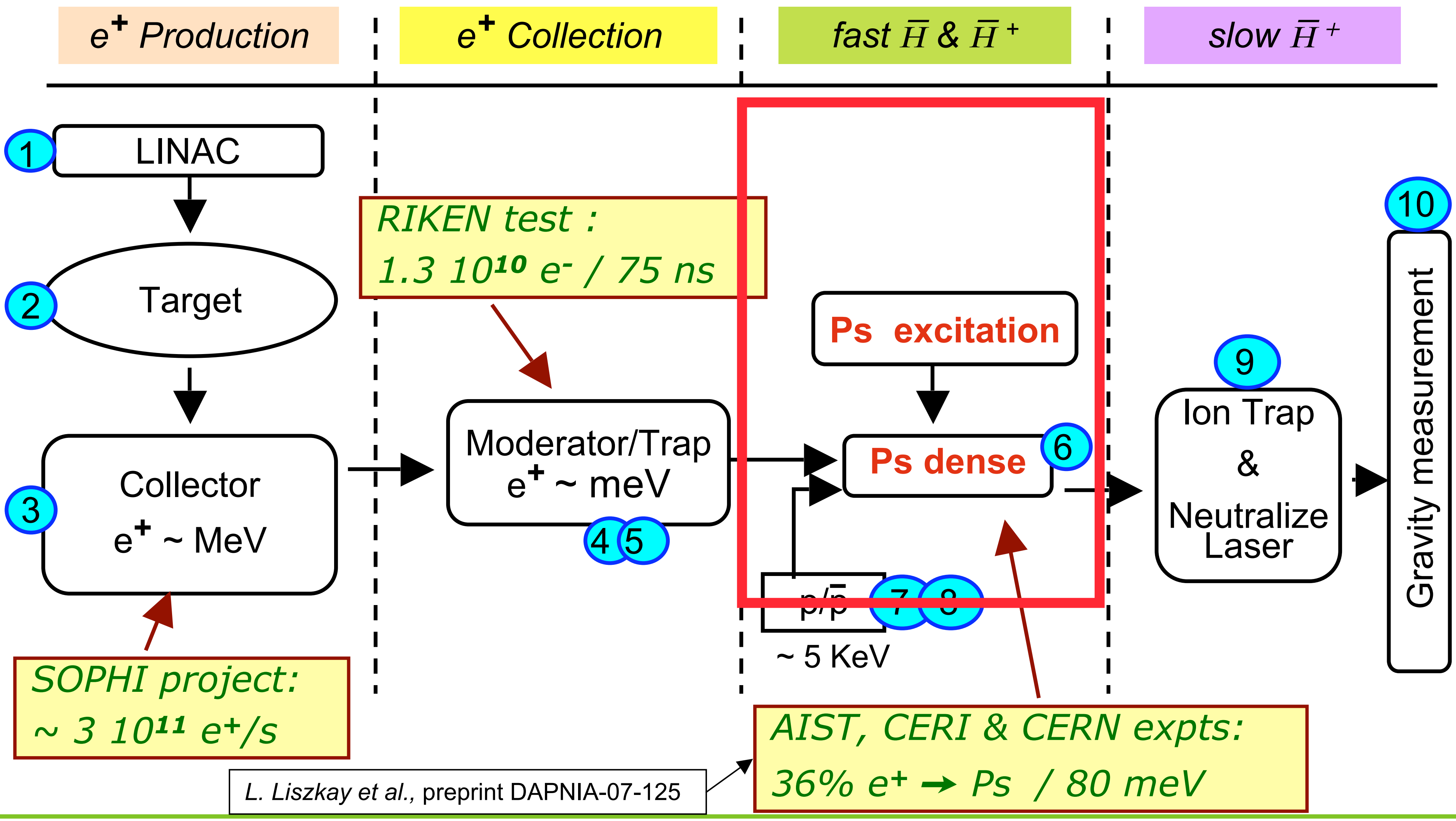
T. Hassan, A. Mohri, P. Pérez, H. Saitoh, Y. Yamazaki

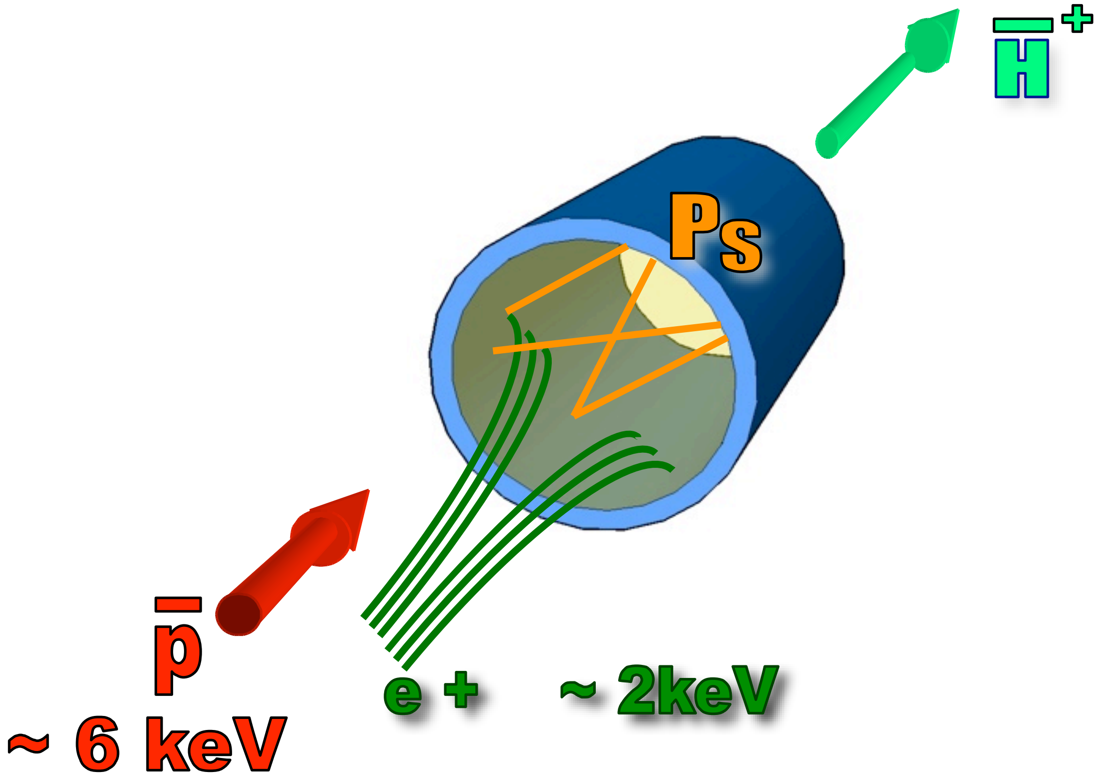
RIKEN MRT Test of fast ejection with electrons (Nov ‘05)
Apply fast deformation of potential well
Limitation due to speed of switch → **Buncher (< 10 ns)**



Gravity Experiment with $\overline{H}^+$

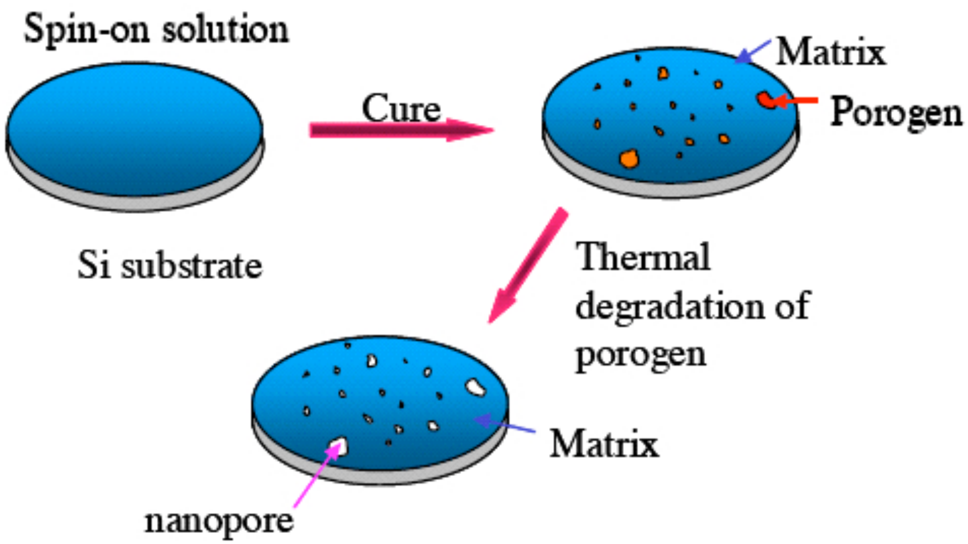
P.Pérez and A. Rosowsky, Nucl. Inst. Meth. A 545 (2005) 20-30.

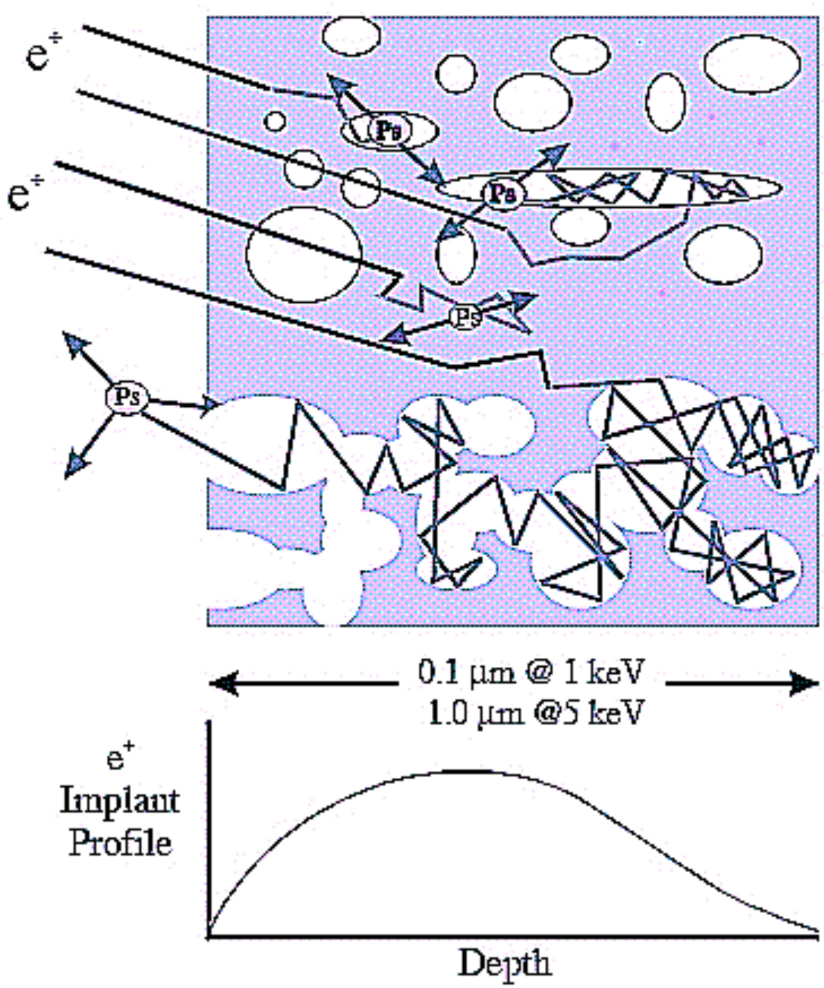




$\overline{H}^+$
Ps
$\overline{p}$
~ 6 keV
e +
~ 2keV

Porous SiO_2 as converter





<u>Samples prepared by</u>:

M. Etienne, A Walcarius	*CNRS/LCPME Nancy*
V. Valtchev	*CNRS/LMPC Mulhouse*
J-P. Boilot	*Ecole Polytechnique*
L. Liszkay	*CEA/Saclay*

Materials: porous layers made by the sol-gel method

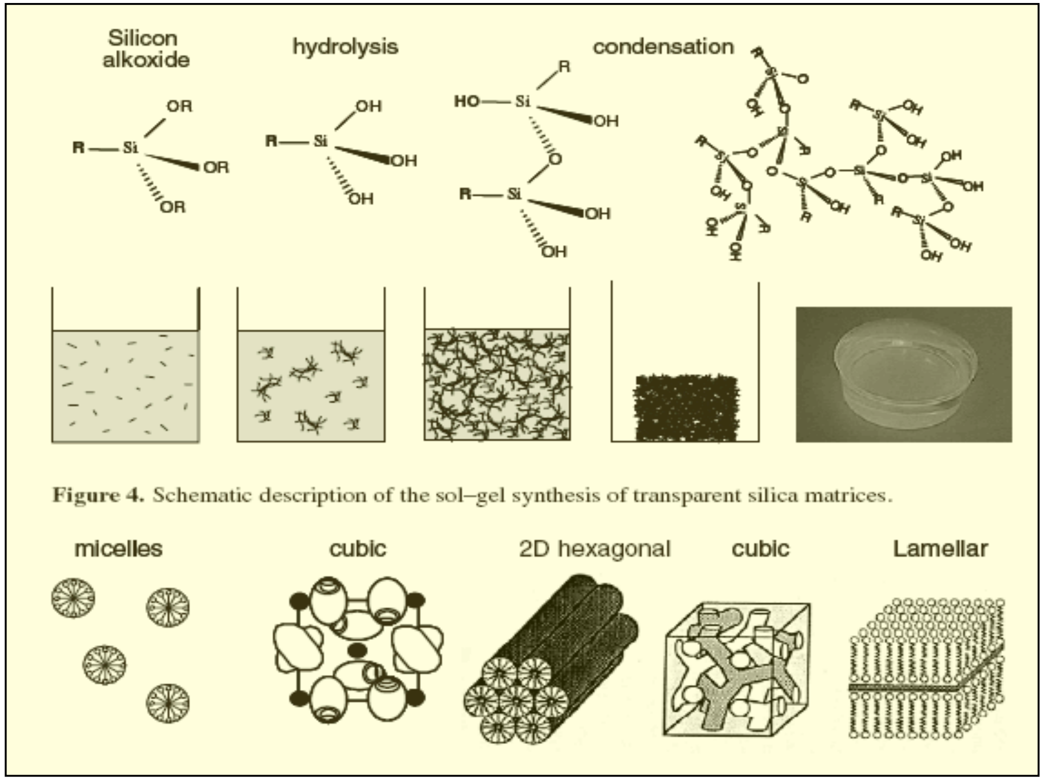
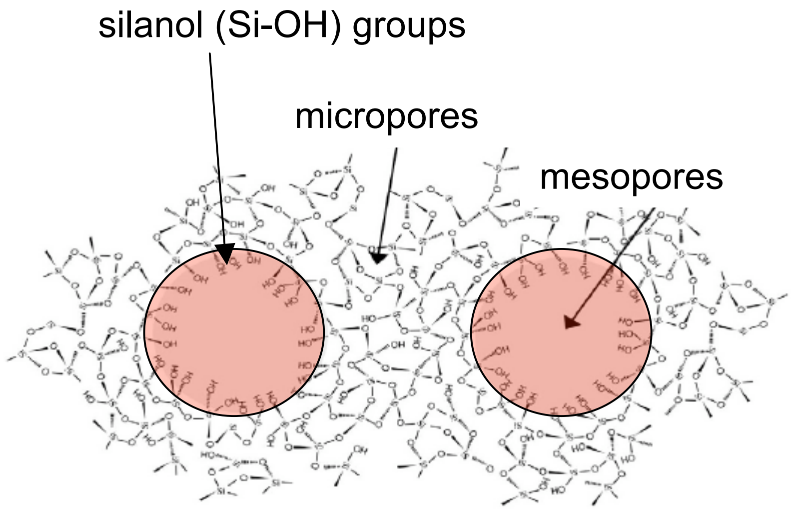


Figure 4. Schematic description of the sol–gel synthesis of transparent silica matrices.

silicon: TEOS, (tetraethoxysilane)

porogen: polymer or surfactant (removed by solvent or heating)

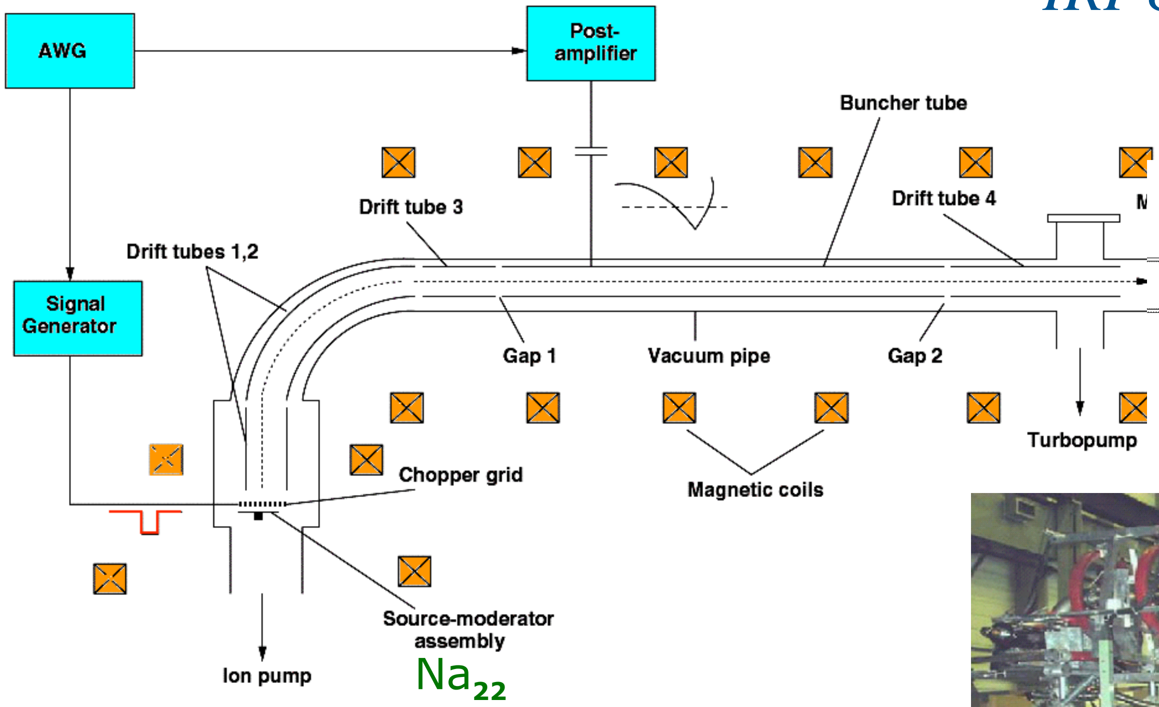


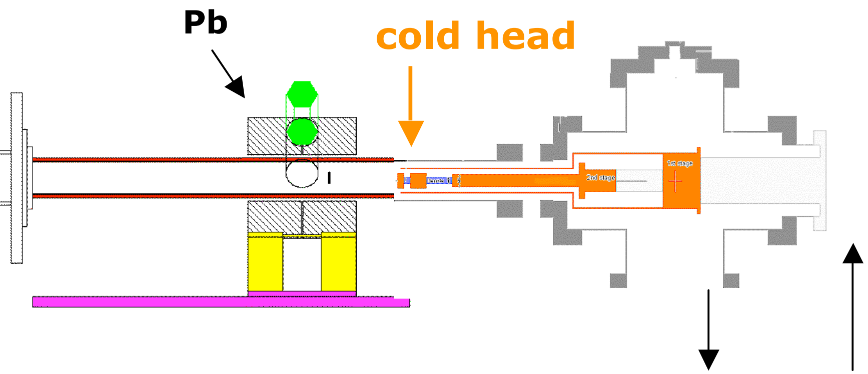
- deposition by spin coating (300-500 nm thickness)
- removal of porogen by heating in air at 400 °C
- pure SiO_2 structure (amorphous walls)

Slow e^+ beams

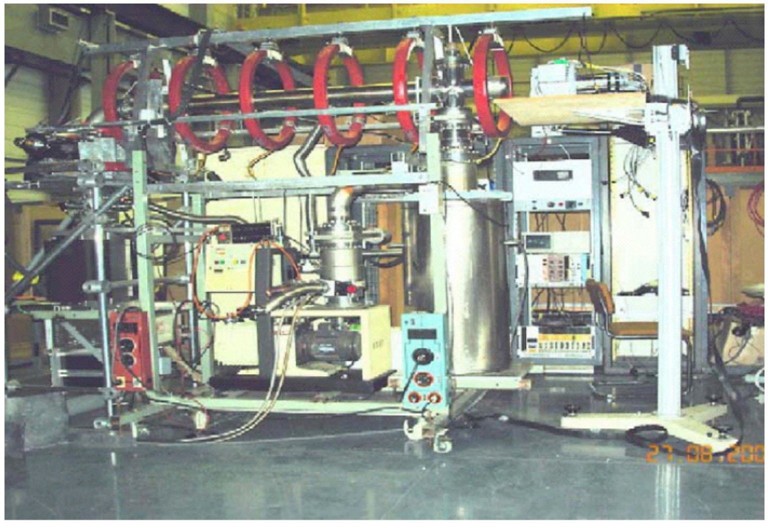
AIST Tsukuba
(R. Suzuki, T. Ohdaira)

E.T.H Zurich (A. Rubbia, U. Gendotti)
IRFU Saclay (P. Crivelli, L. Liszkay)



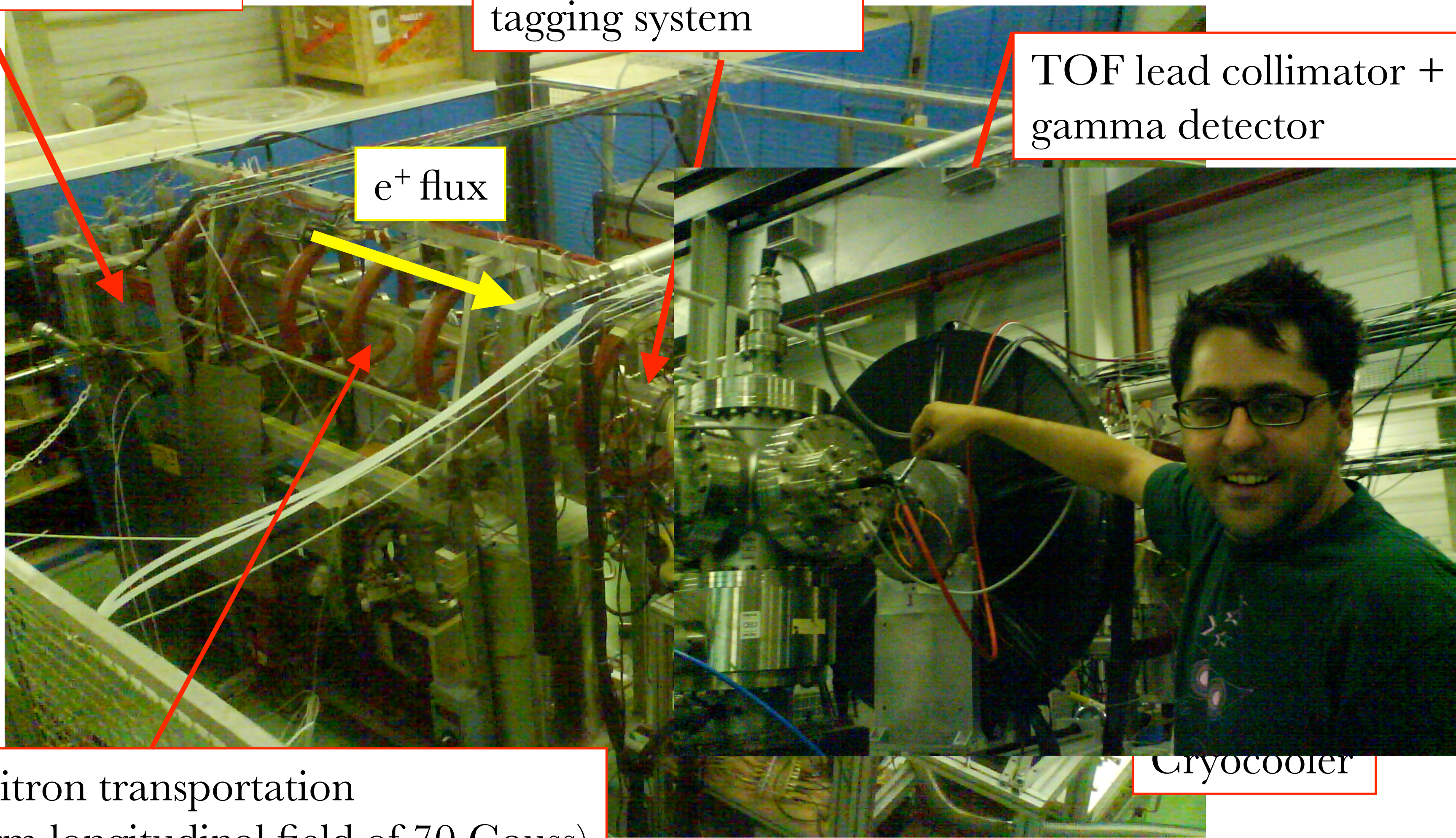


CNRS-CERI, Orléans
(L. Liszkay, M-F. Barthe)

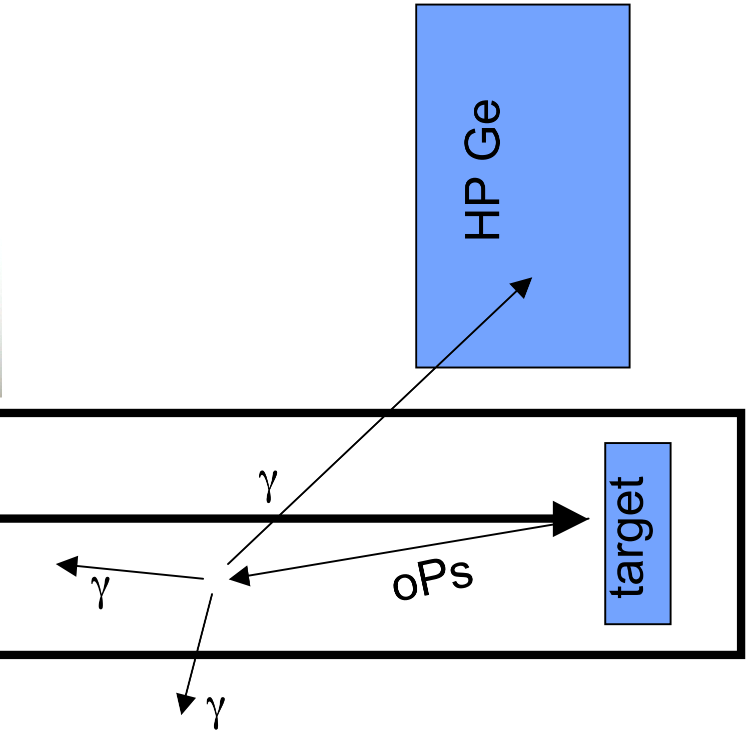


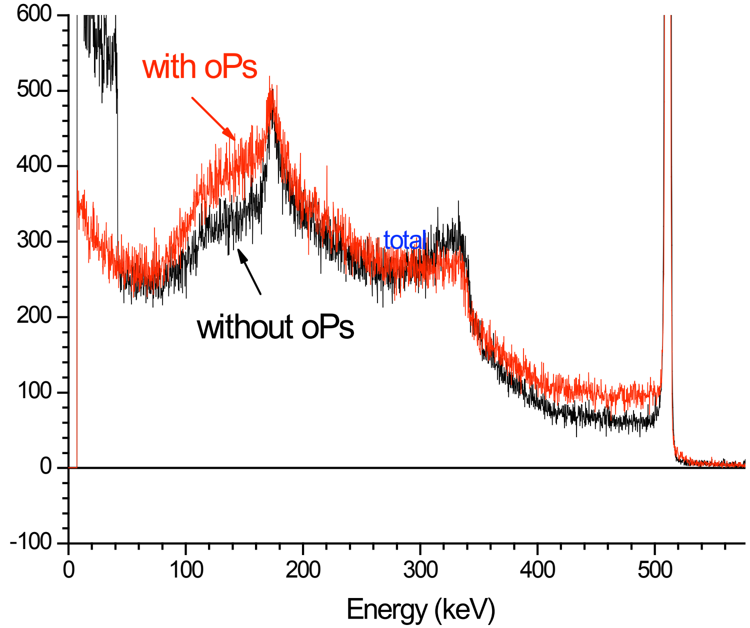
N. Alberola et al., Nucl. Instr. Meth. A 560 (2006) 524.

CERN slow e^+ beam



Measure of conversion efficiency $e^+ \rightarrow Ps$ (3 γ fraction)





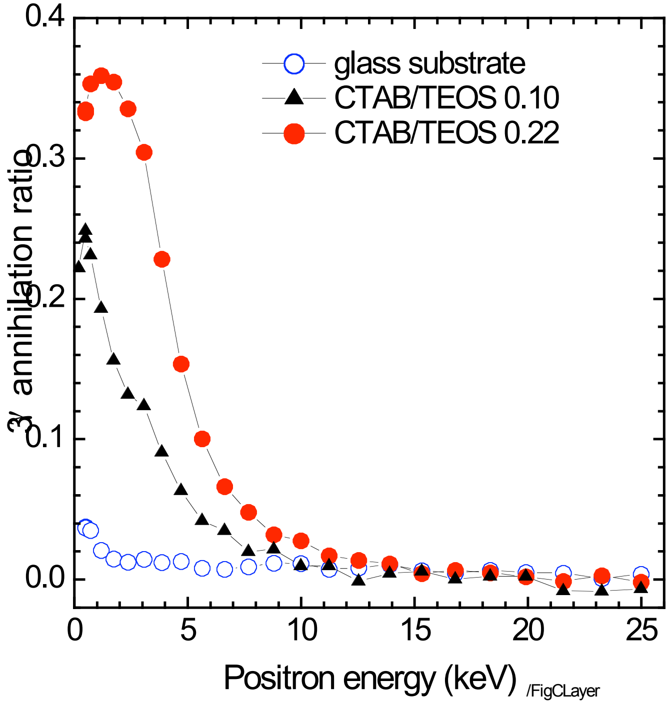
measures at CNRS/CERI, Orléans, France

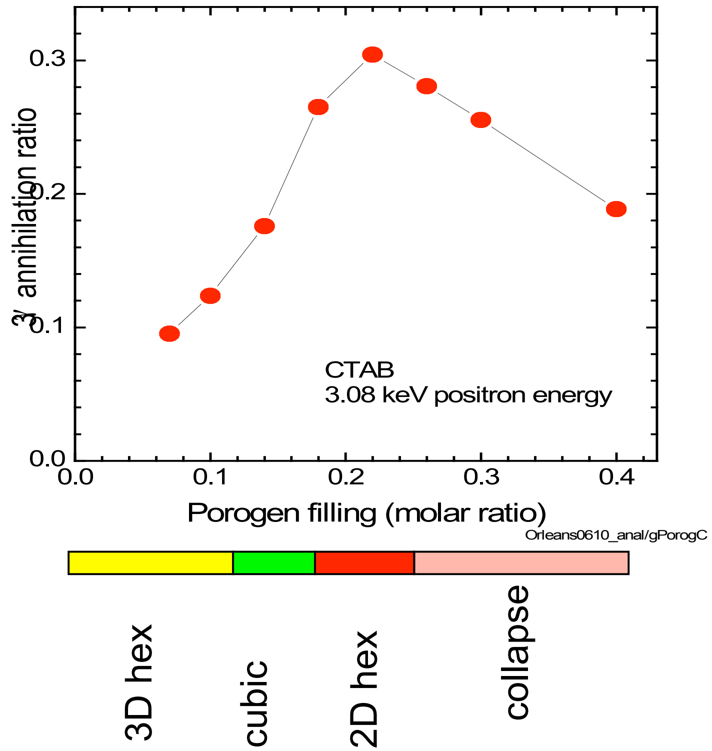
L. Liszkay preprint DAPNIA-07-125

SLOPOS-11 Workshop, Orléans 9-13/07/2007, to be published in Appl. Surf. Sci.

result: ~ 36 % 3 γ annihilation fraction → emitted oPs

Porous layer with 2 nm pores (CTAB)



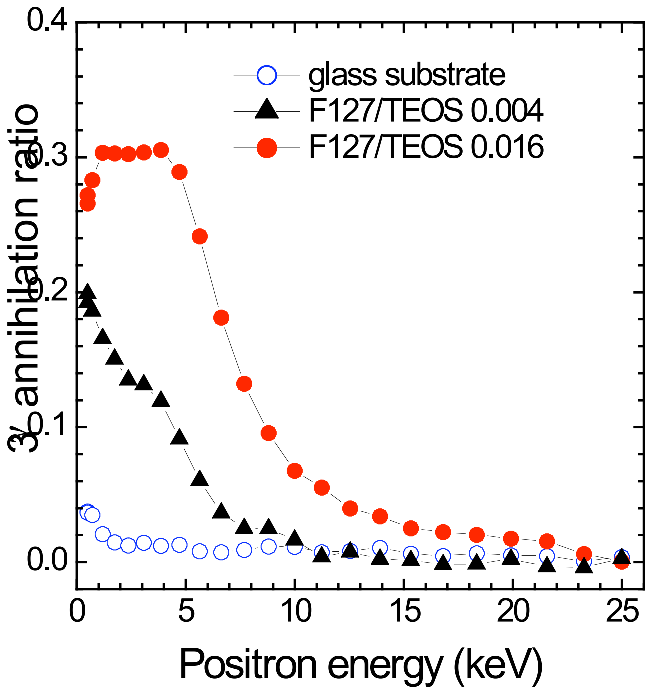


• low porogen content: closed pores

• high porogen content: oPs emission into vacuum

oPs emission highest at 2D hex symmetry but no evidence for direct structure dependence

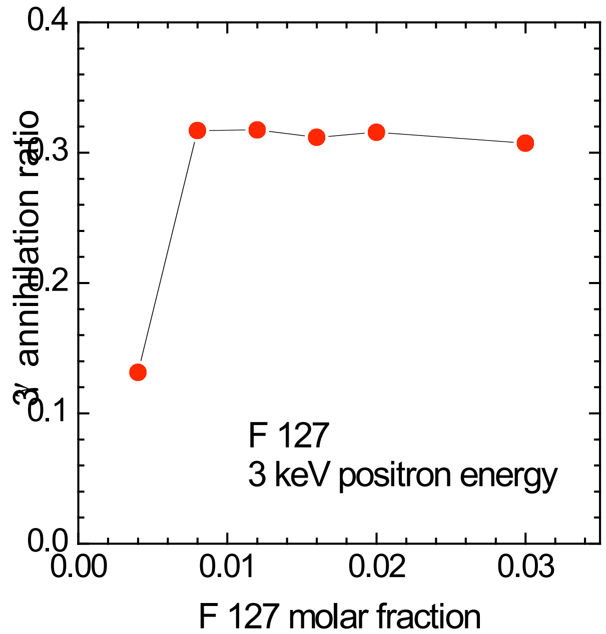
Porous layer with 6 nm diam. pores (F 127)



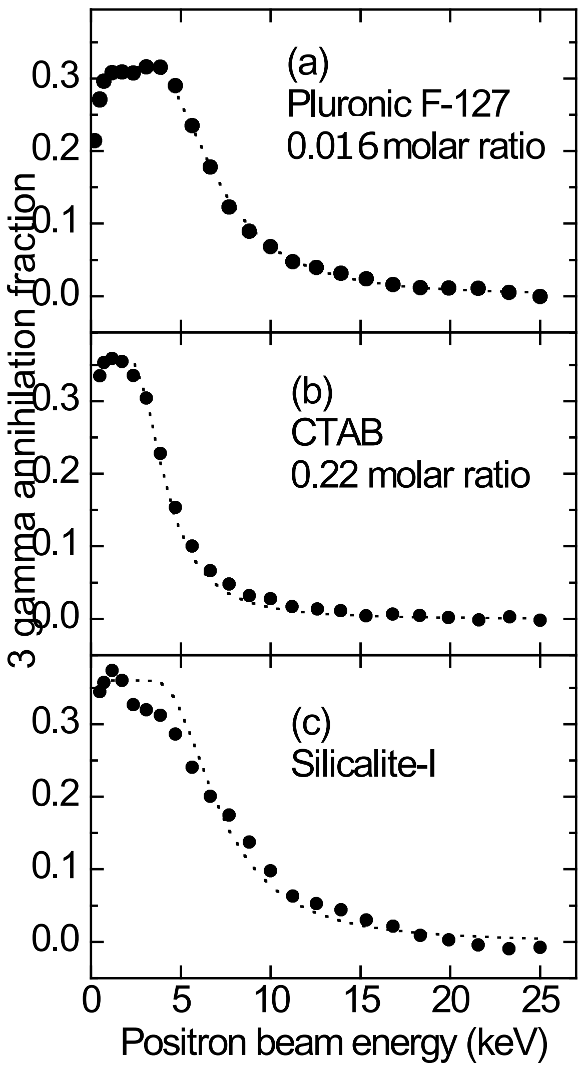
• low porogen content: annihilation in the pores

• high porogen content: highly interconnected pore system
→ oPs emission into vacuum

• constant 3 gamma annihilation fraction at high porogen content
→ open pore system, saturated oPs production

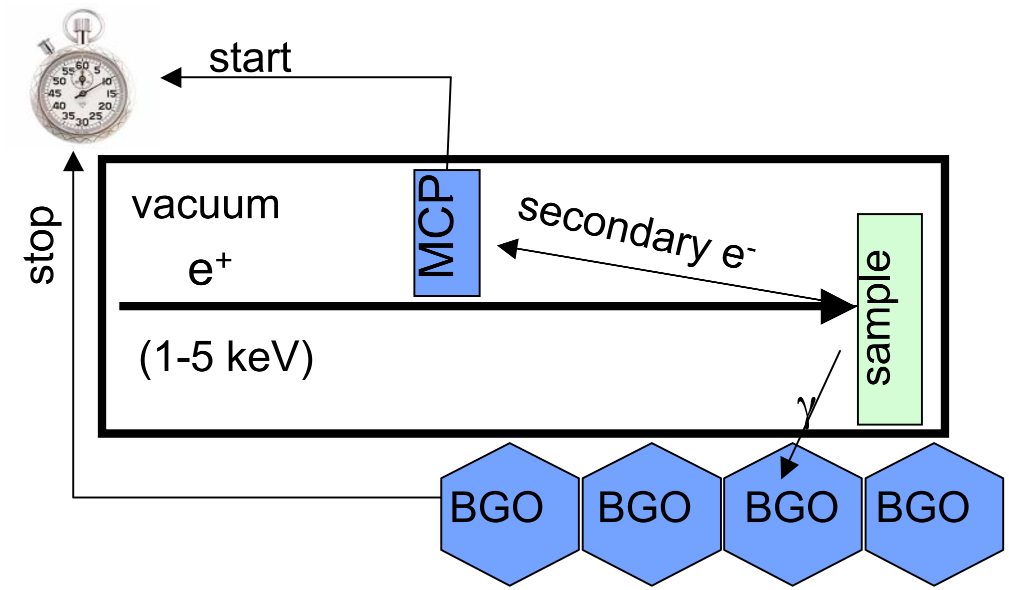


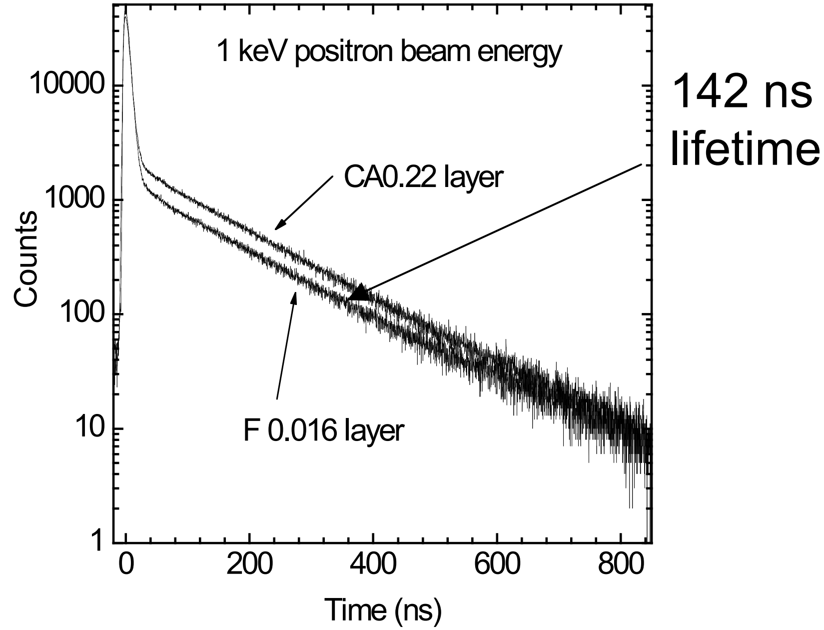
Comparison of the 3 gamma annihilation fraction

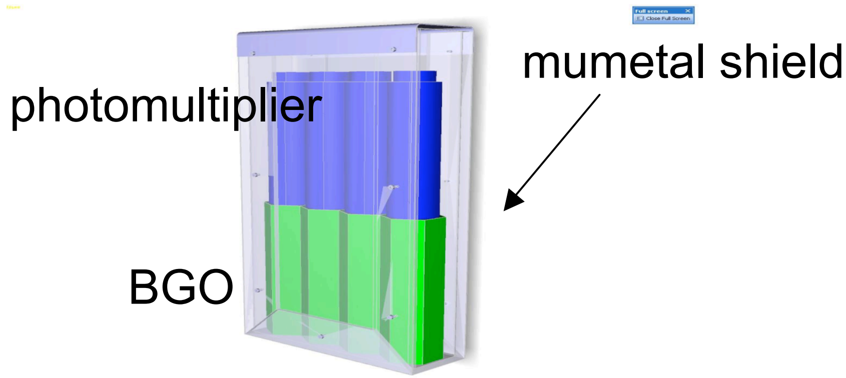


similar max. 3 gamma fraction

Measure conversion efficiency $e^+ \rightarrow$ Ps (lifetime)



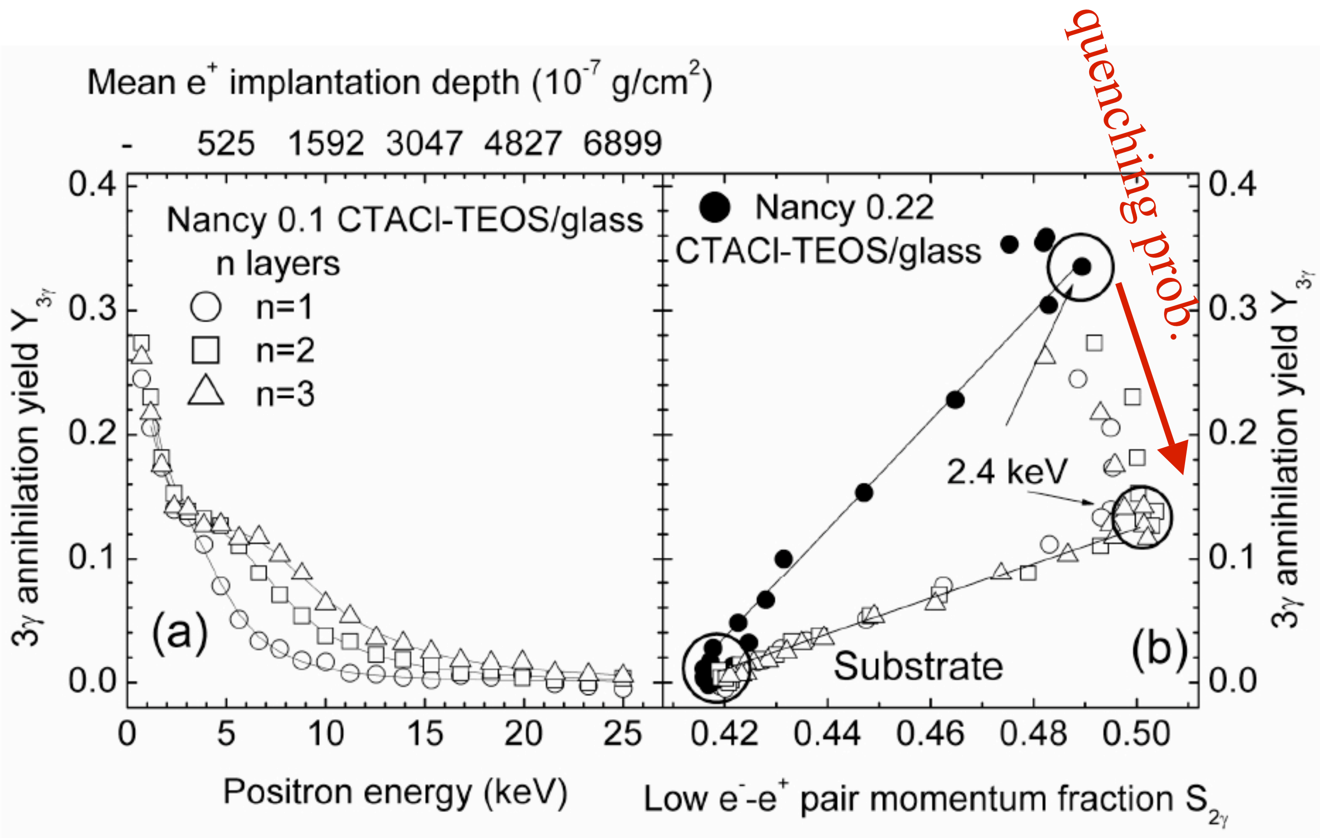


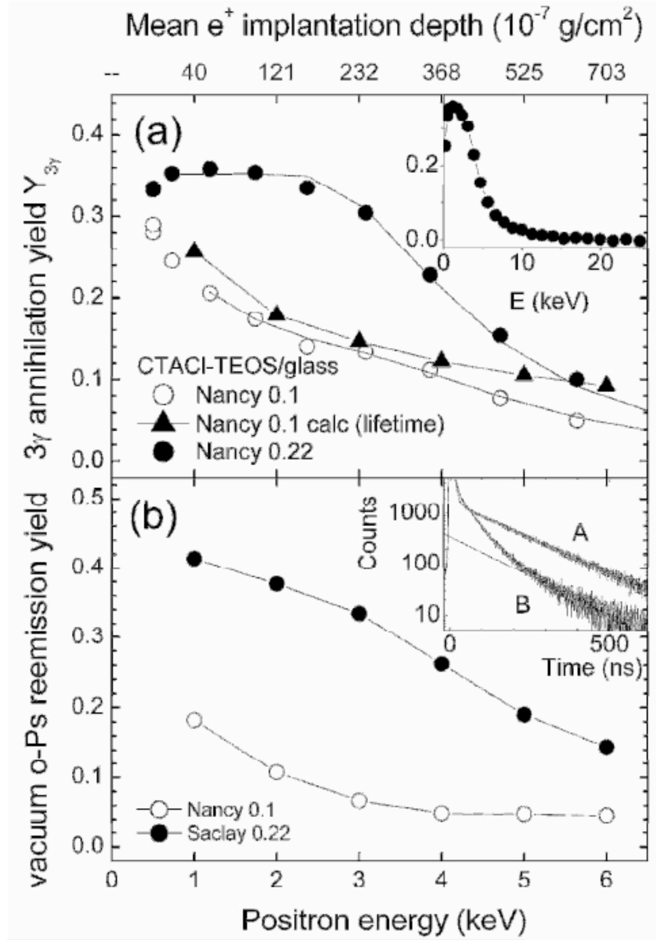


L. Liszkay, P. Crivelli (Saclay)
U. Gendotti (ETHZ)

Positronium reemission yield from mesostructured silica films

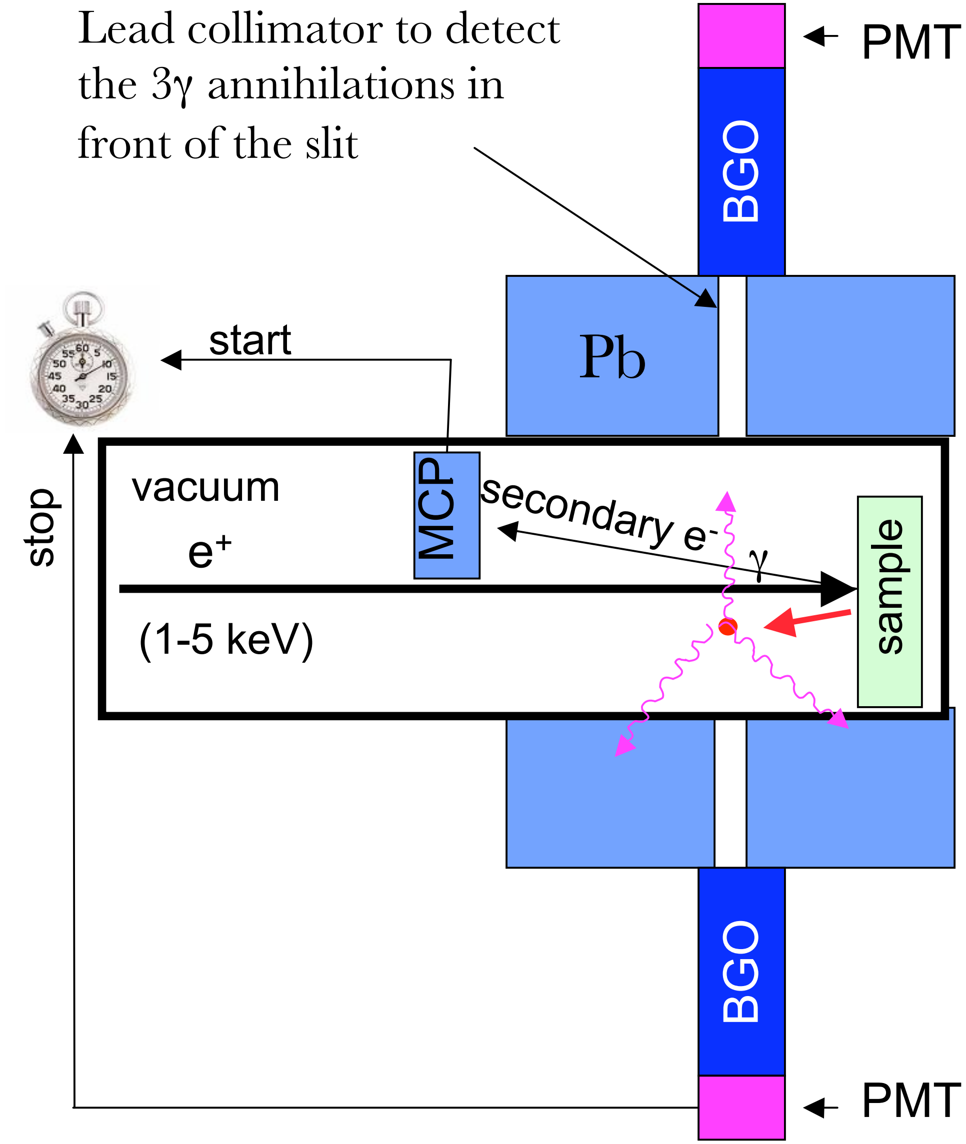
L.Liszkay et al., Appl. Phys. Lett. **92** (2008) 063114

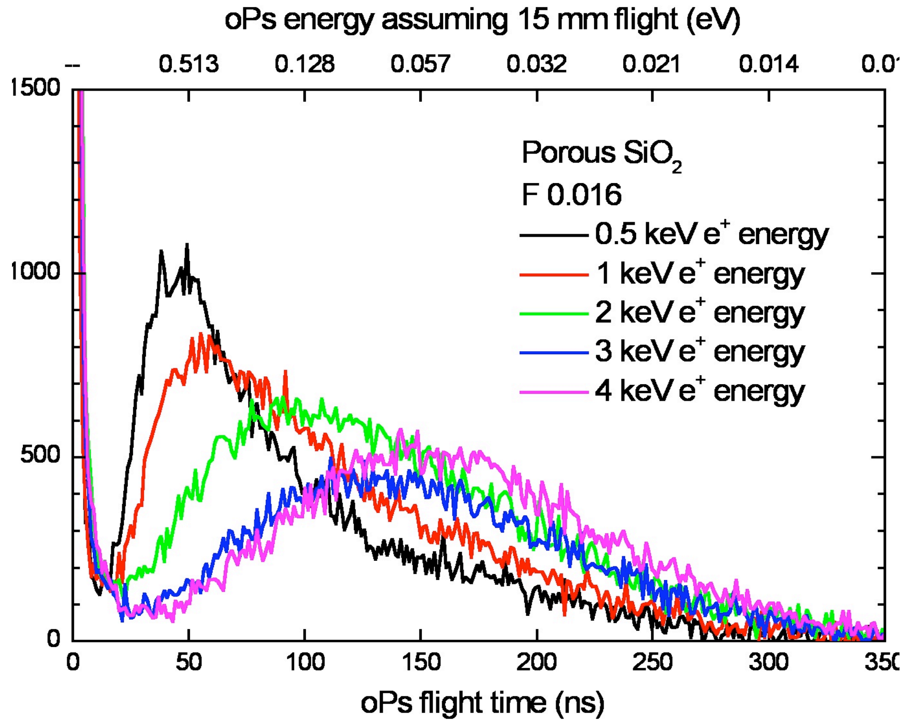




Measure conversion efficiency $e^+ \rightarrow Ps$ (time of flight)

Lead collimator to detect the 3γ annihilations in front of the slit





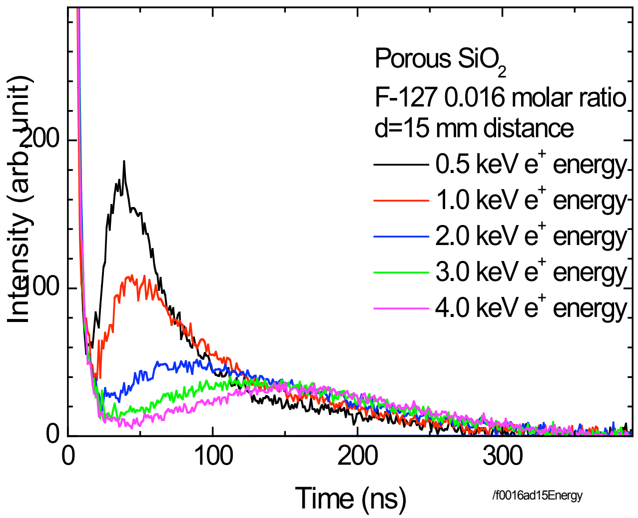
L. Liszkay (Saclay)

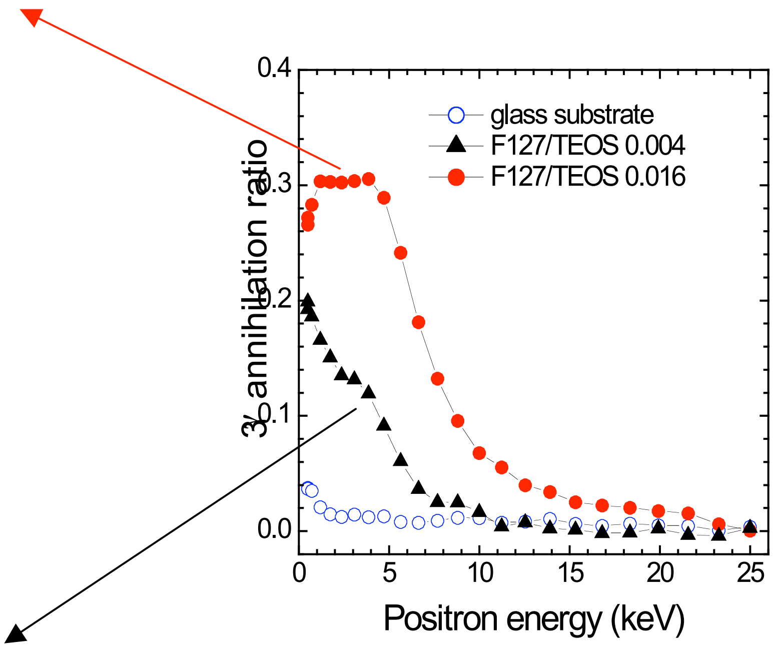
P. Crivelli, U. Gendotti (ETHZ)

R. Suzuki, T. Ohdaira (AIST Tsukuba)

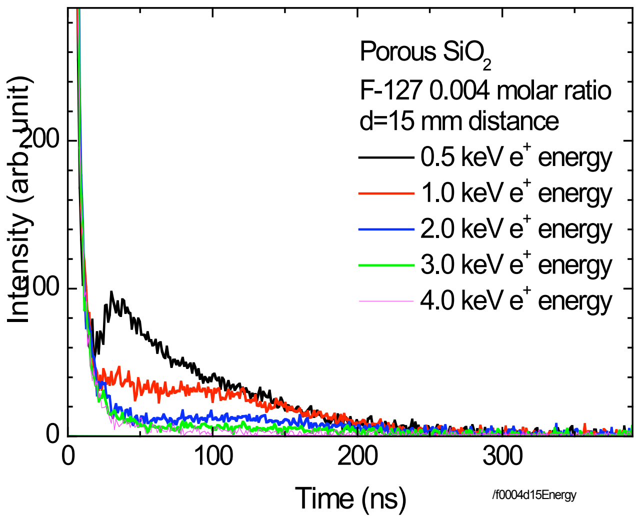
Time of flight: open and closed pore system

open pore system





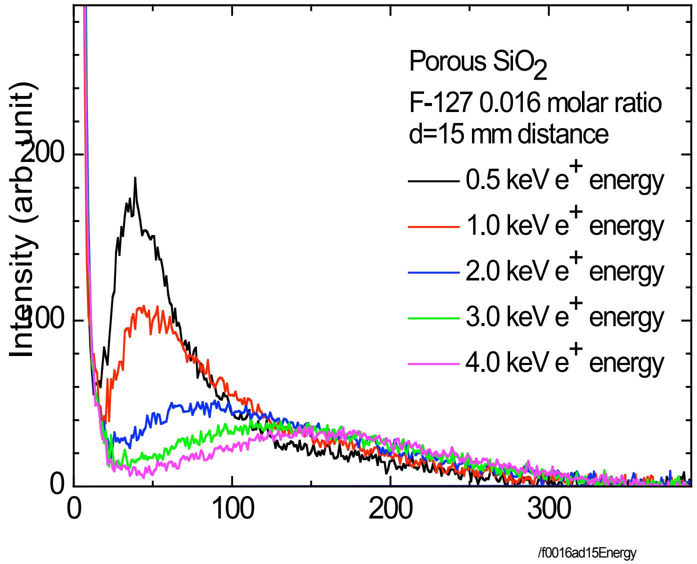
closed pore system



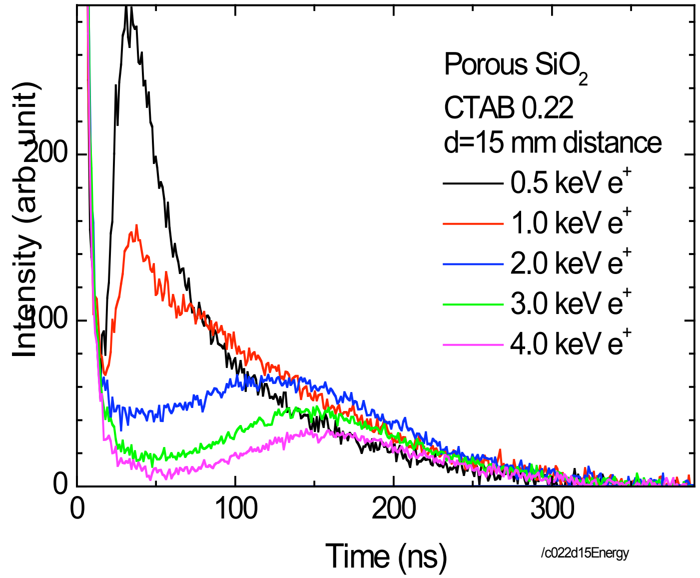
(*TOF meas. from R. Suzuki, AIST, Tsukuba*)

Time of flight: F 127 and CTACl – templated layers

F 127 grown layer



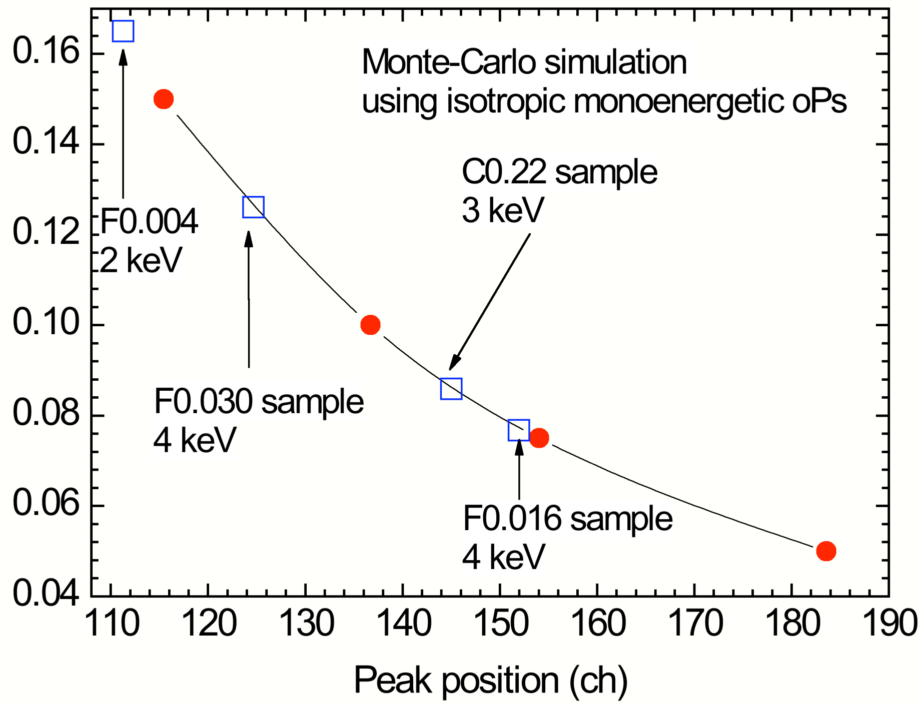
CTACl grown layer

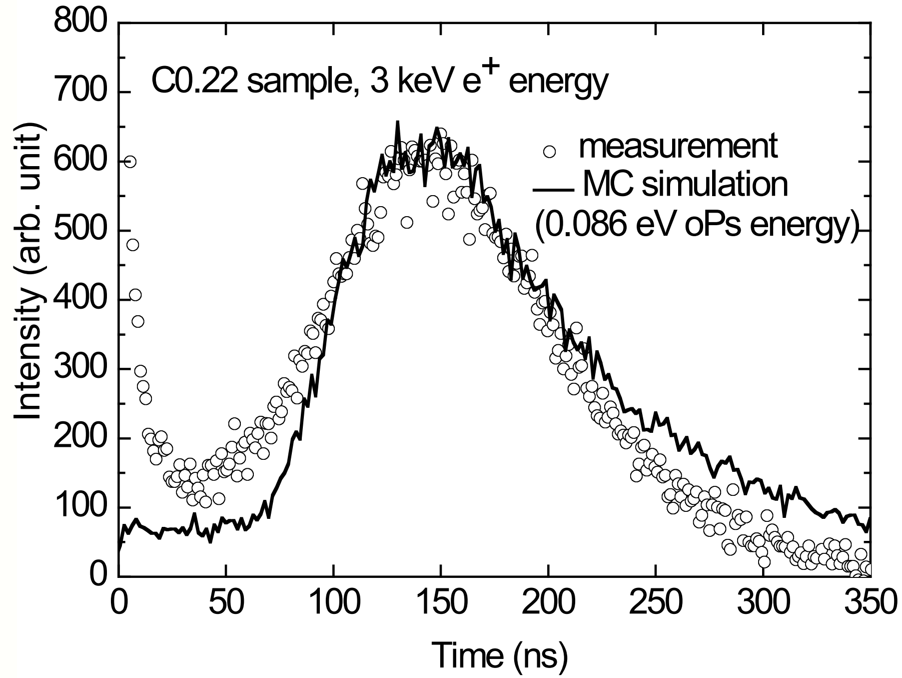


- 0.5 – 1 keV: ~ 1 eV oPs energy
- 3 – 4 keV: ~ 100 meV oPs energy
- no complete oPs thermalization
- 3 – 4 keV: ~ same emission efficiency
- nearly independent from pore size

(TOF meas. from R. Suzuki, AIST, Tsukuba)

Determination of the oPs energy by TOF: Monte-Carlo calculations

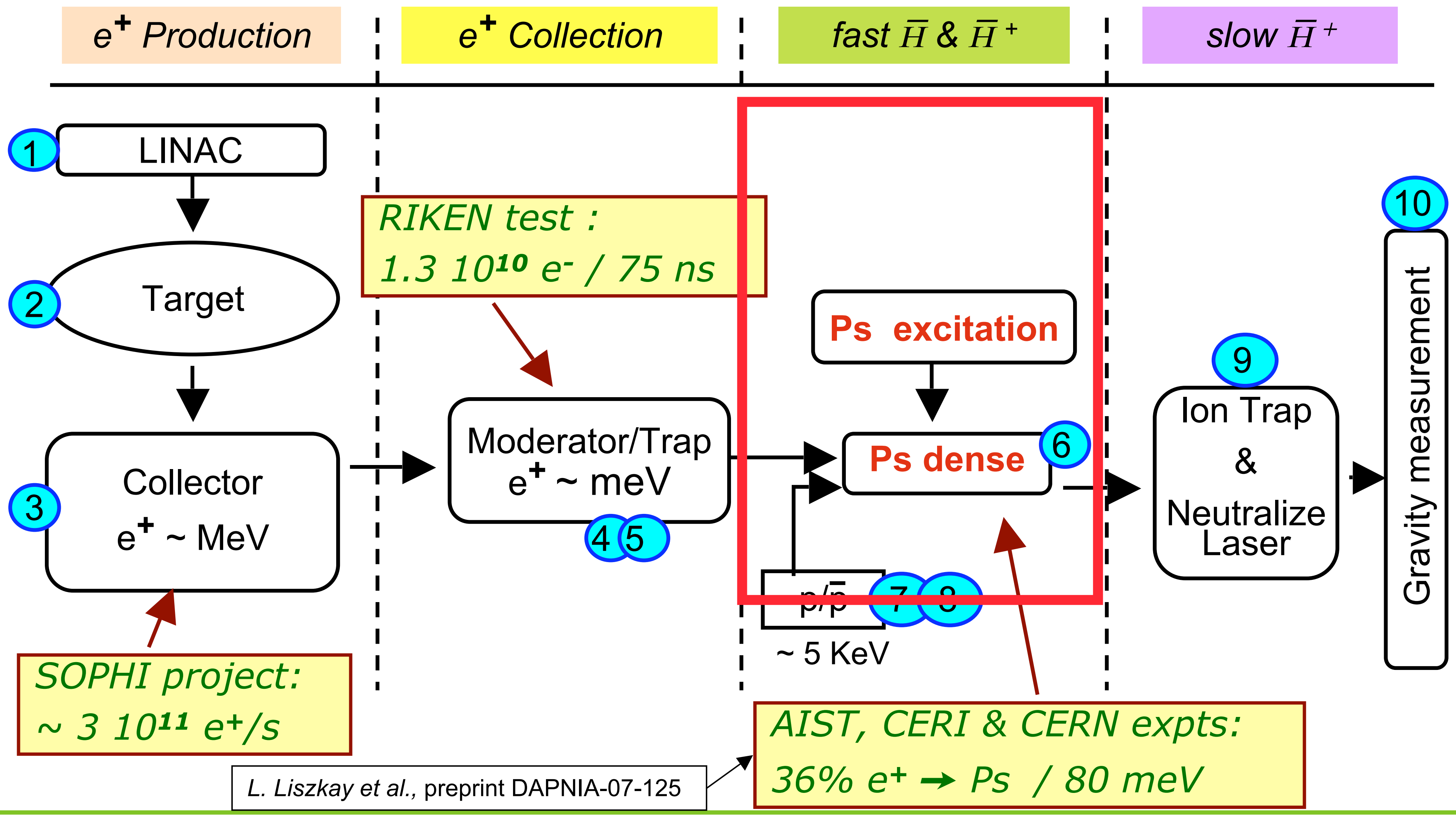




MC model using the GEANT 4 program package

Gravity Experiment with $\overline{H}^{+}$

P.Pérez and A. Rosowsky, Nucl. Inst. Meth. A 545 (2005) 20-30.



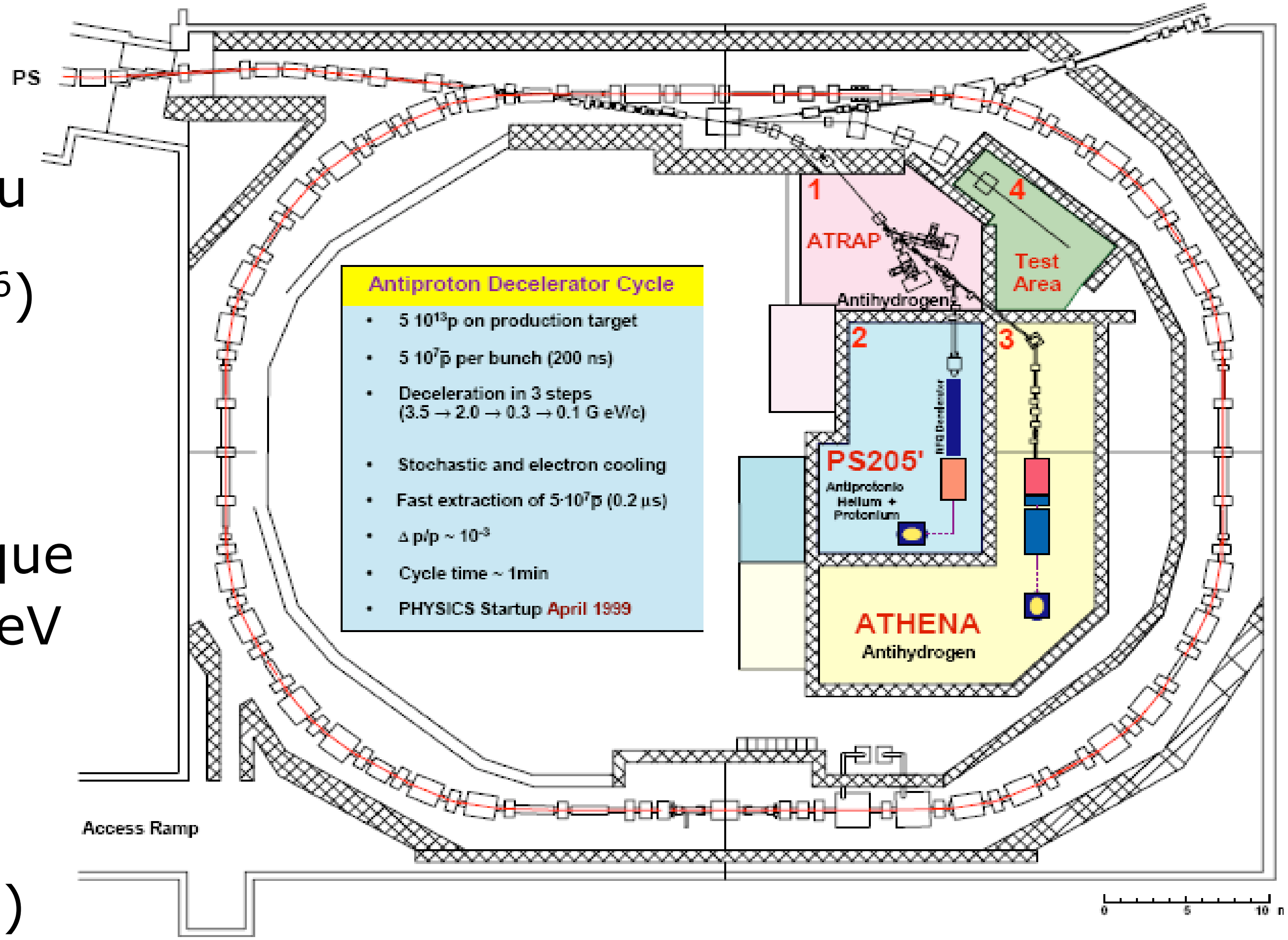
Fabrication du faisceau de $\bar{p}$

10^{13} p /min (24 GeV)+ Cu

➞ ~ 10^{7} $\bar{p}$ /min (ε ~10^{-6})

RF pour décélérer avec refroidissement stochastique et electron cooling ➞ 5 MeV

Feuilles W (ε ~10^{-3})
RFQD(ASACUSA) (ε ~10^{-1})
➞ 10 KeV ➞ stockage dans piège de Penning ➞ éjection



CERN Antiproton Decelerator (AD)

Letter of Intent to the CERN-SPSC-2007-038

A new path to measure antimatter free fall

P. Pérez, L. Liszkay, B. Mansoulié, J.M.Rey
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Atomic Physics Laboratory, RIKEN, Wako 351-01, Japan

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membres d'ASACUSA

Submitted 30-nov-2007 *15-jan-2008: encouraged to submit a proposal with ASACUSA*

Proposal AEGIS (gravitation with $\overline{\mathrm{H}}$*) accepted by SPSC 15-jan-2008

Summary

Converter shaping tests	June 2008
Fast e^+ beam	June 2008
Slow e^+ beam (W moderator)	Dec 2008
Neon moderator	2009
Trapping (wo buffer gaz)	2009

Depending on available money,

duplicate/improve or move slow e^+ source to CERN experiment(s) ?

Propose $\overline{H}^+$ experiment in ASACUSA framework (Nov. 2008)

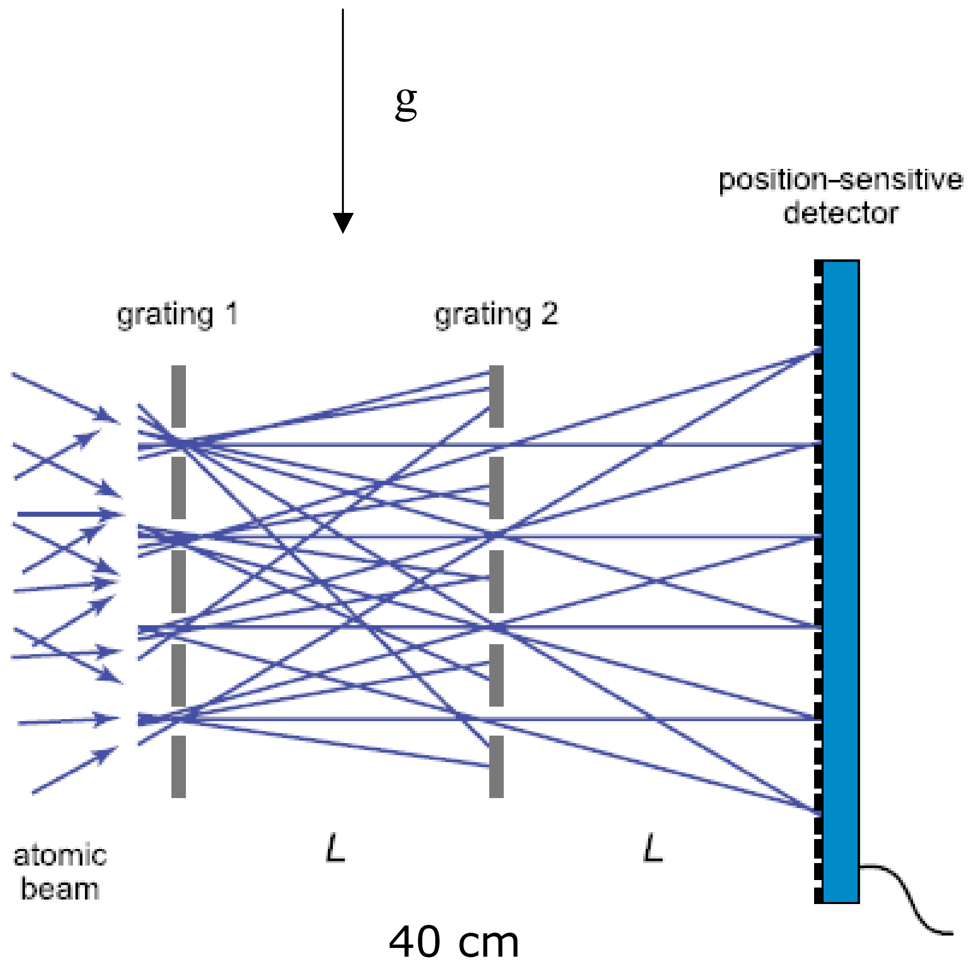
Backups

Utilisation de $\bar{\mathrm{H}}$ (proposition AEGIS)

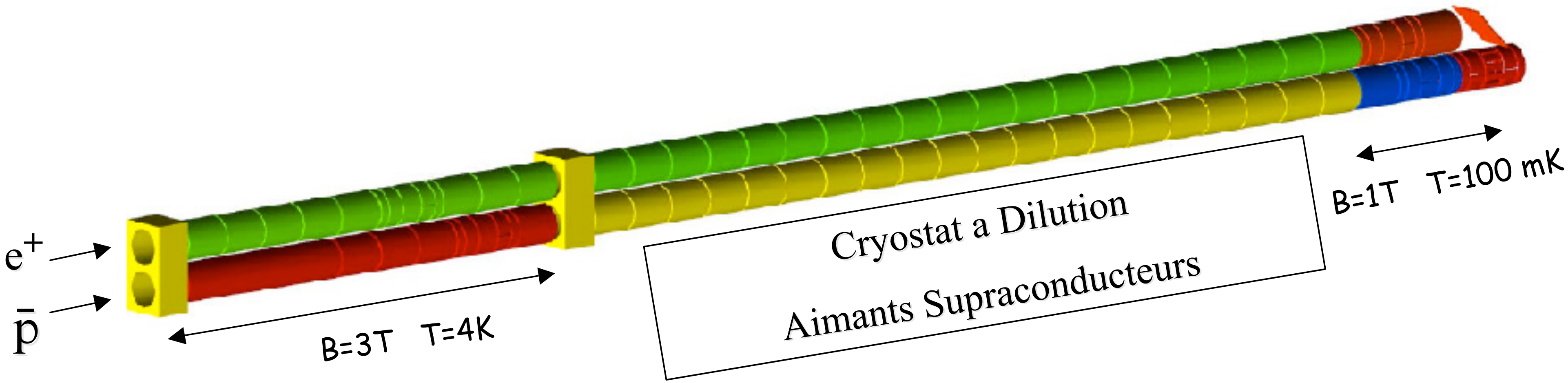
La taille transverse du faisceau de $\bar{\mathrm{H}}$ neutres est de l'ordre de plusieurs cm

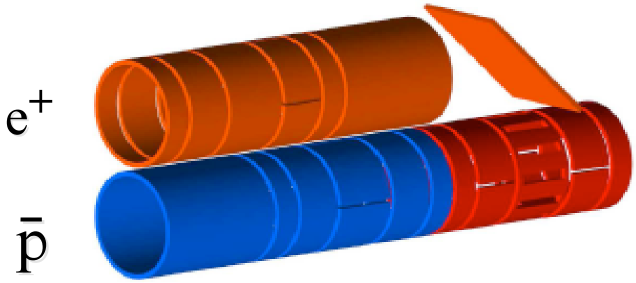
En utilisant des grilles fils horizontaux ➞ distribution sensible à g tout en acceptant une grande taille de faisceau

Mesure du temps de vol entre les grilles

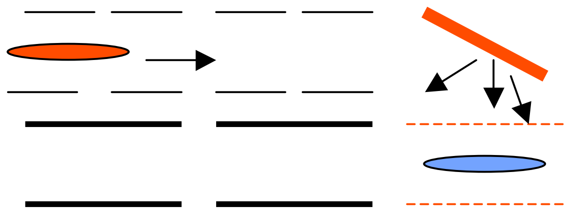


Fabrication de $\bar{H}$* dans AEGIS





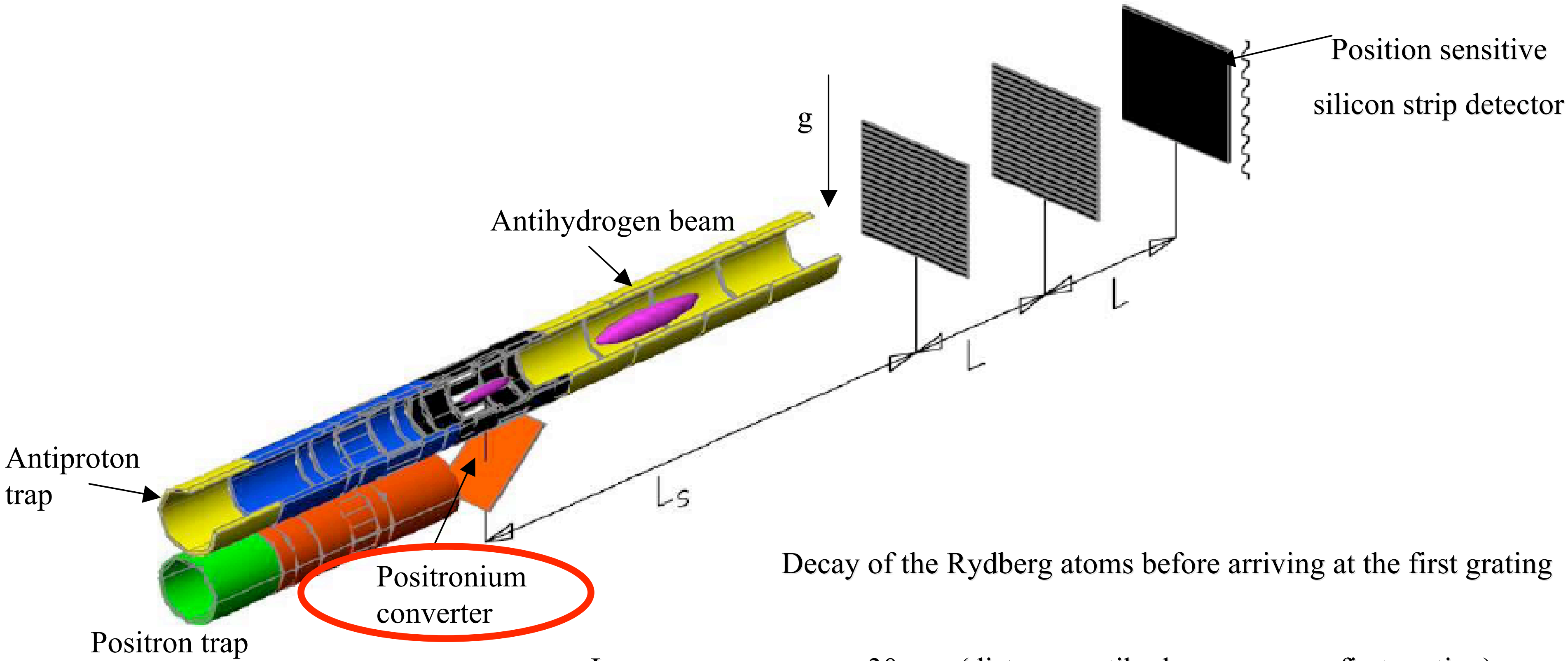
- Temps de préparation $\bar{p}$ et e^+: ~ 100-200 s (= 1cycle)
- 100 - 1000 $\bar{H}$ / (cycle d'AEGIS)
- mesure de la vitesse de $\bar{H}$ par temps de vol



← 5 10^6 Ps* à 10 K par excitation laser (60 mJ / 5 ns)

← 10^5 $\bar{p}$ à 100 mK (v = 50 m/s)

Vue d'ensemble AEGIS



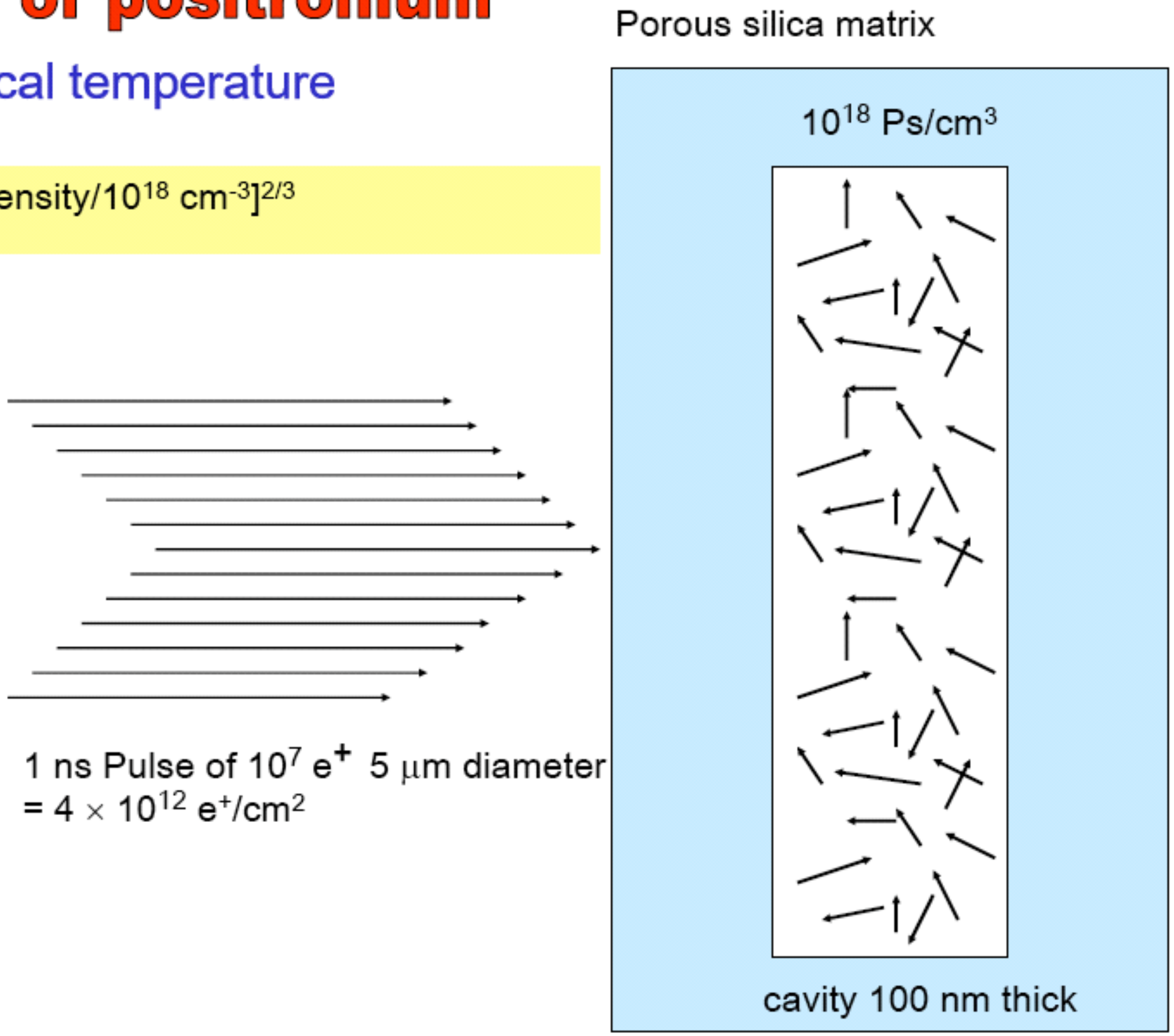
Decay of the Rydberg atoms before arriving at the first grating

Ls	30 cm (distance antihydrogen source-first grating)
Grating distance L	40 cm
Grating size:	20 x 20 cm^2
Grating period:	a=80 µm
Grating transparency:	30%

C. BEC of positronium

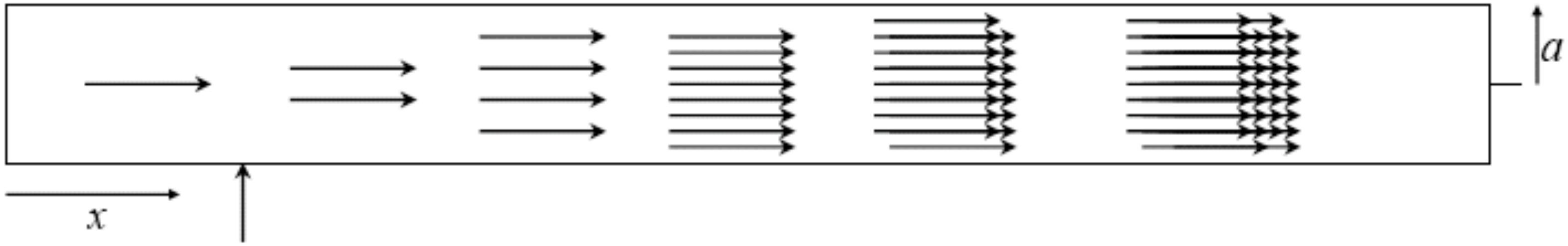
BEC critical temperature

$T_C = 15\ K \times [\text{density}/10^{18}\ cm^{-3}]^{2/3}$



Traveling wave annihilation laser

A.P. Mills, UC Riverside



•A photon traveling through a gas of Ps at rest with density n gathers more photons into its mode because of stimulated annihilation.

•Initially, the number M of photons in the laser mode grows exponentially with x, the distance traveled:

$$M = \exp\{n\sigma_s x\}.$$

•The Ps has to have very slow velocities so that the Doppler shift of the annihilation photons is less than the line width $v/c < \Delta E/E = \alpha^5/2 = 10^{-11}$.

•The **only possibility** is for the Ps to be in the ground state of its container, i.e. in the **Bose-Einstein condensed state**, as pointed out by Liang and Dermer.