Development of a Low Energy Positron Source and an Efficient Positron-Positronium Converter for Positively Charged Antihydrogen Production

MURANAKA Tomoko

1st December 2008

Seminar SPP

Bat: 141 IRFU/CEA-Saclay

e^+ source at CEA-Saclay
IRFU

Ps production at CERN
ETHZ / IRAMIS/ AIST

OUTLINE

- Introduction
  - Motivation: gravitational measurement on antimatter system
  - Positive anti-hydrogen ion production
- Positron production @ Saclay
  - Electron linear accelerator (LINAC)
  - Electron - positron convertor
  - Positron trap
- Ortho-positronium production @ CERN
  - Positron - ortho-positronium converter
  - oPs formation in a glass tube
- Summary & Outlook

MOTIVATION : gravity measurement on antimatter

Do we really understand gravity?

- The gravitational acceleration $\Delta g/g = 10^{-10}$

- The gravitational interaction of antimatter has not been conclusively observed!

- Violation of the equivalence principle?

How to measure it?

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EXPERIMENTS

No direct measurement exists

- Indirect measurement:
  - Supernova 1987A (164,000 light years away)
    - Neutrino / anti-neutrino were detected simultaneously??
    - Identification of neutrino/anti-neutrino...??
    - Statistical accuracy... cannot be improved!
- Direct measurement (idea):
  - electron / positron
    - m/q is too small -> electromagnetic effects is much larger
  - Other antiparticles
    - Annihilation, high initial energy...

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➡ Heavier + colder antimatter

ANTIHYDROGEN

- Neutral $\overline{\mathrm{H}}$
  - ✓ Electromagnetic shielding
  - ? Temperature (dispersion v_h and v_v)

Cooling limit (theoretically):
$\sim$ mK

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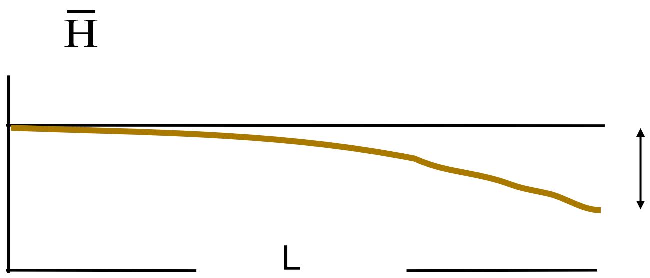

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  - Proposed configuration (AEGIS, CERN)
    - $v_h \sim 500$ m/s
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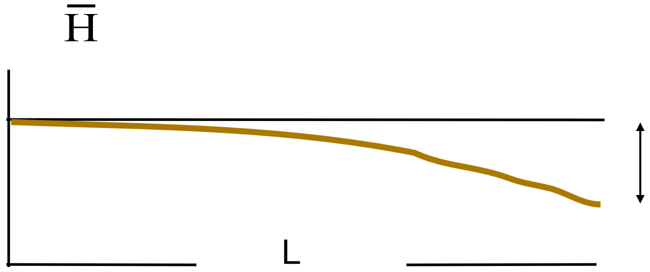

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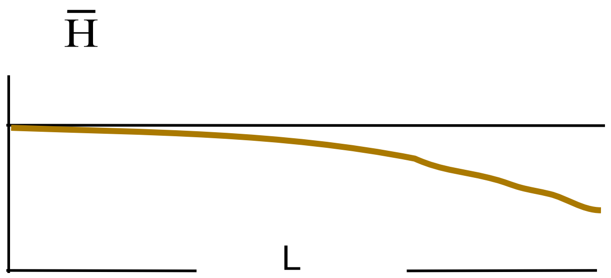

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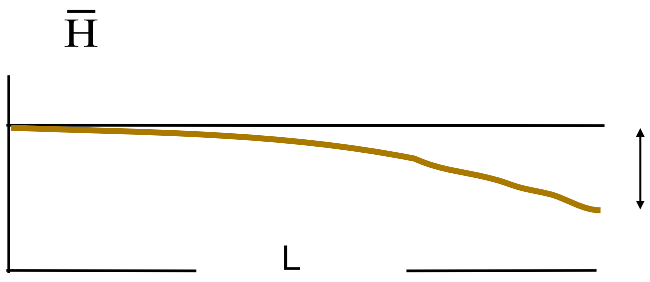

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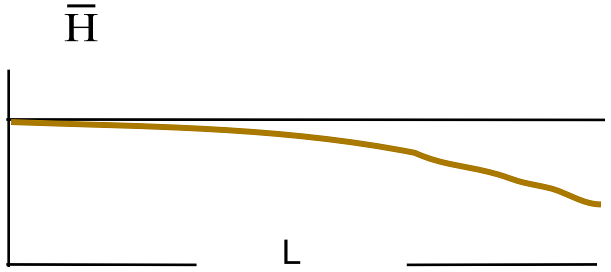

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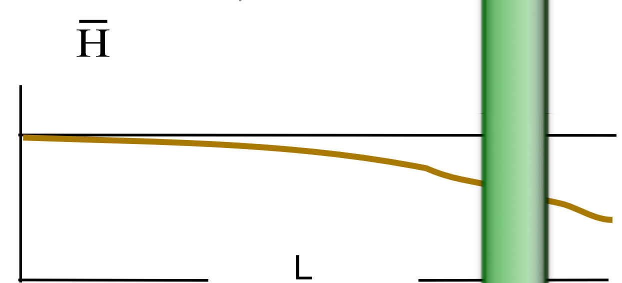

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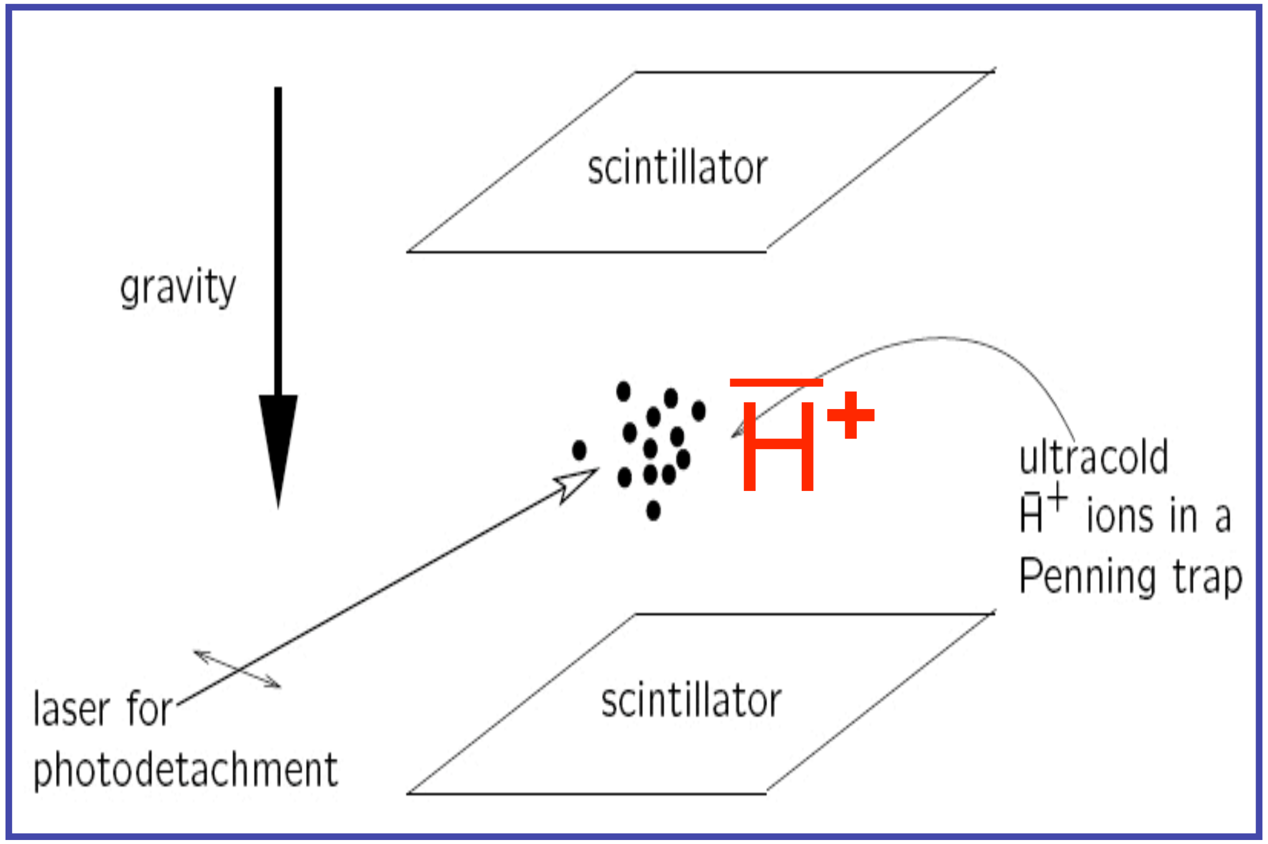
USING ANTIHYDROGEN ION!



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

$\overline{H}^+$ ion in trap	$\Delta g/g$
$5\cdot10^5$	0.001
$1\cdot10^4$	0.006
$1\cdot10^3$	0.02

- Produce charged $\overline{H}^+$ ($\bar{p}e^+e^+$)
- Decelerate
- Trap and cooling to few μK
- Remove one of e^+ by a short laser pulse (trigger)
- Detect annihilation signal (detectors on both sides) (end signal)
- Observable: Time of Flight (TOF) of ultra-cold ion $\overline{H}$
- **No recoils in the direction of gravity (photon absorption, e^+ detachment)**

$\bar{H}^+$ PRODUCTION

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

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

H. Poth
Appl. Phys. A 43, 287-293 (1987)

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Antigravity experiment

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$\bar{H}^+$ → Antigravity experiment

Deceleration
Trapping
Cooling
Neutralization

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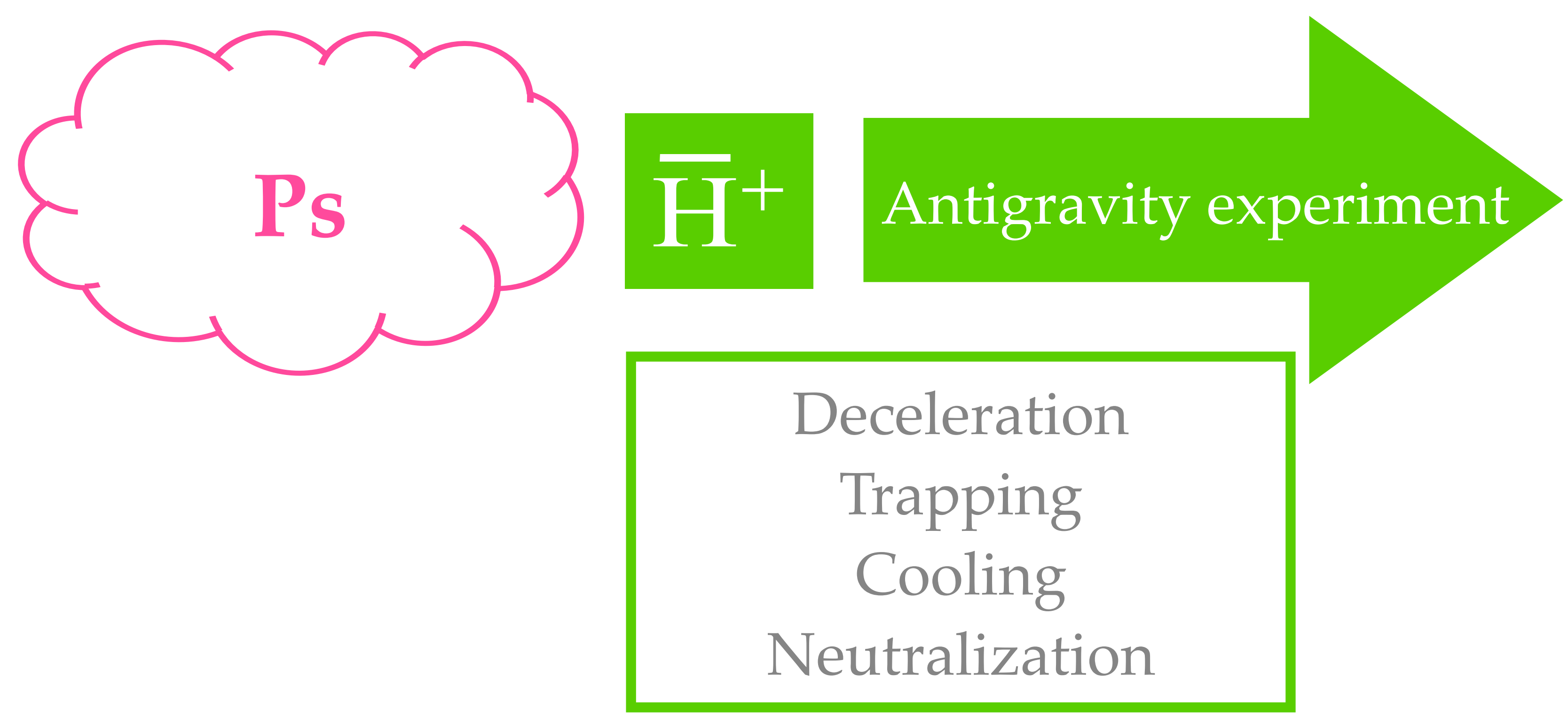

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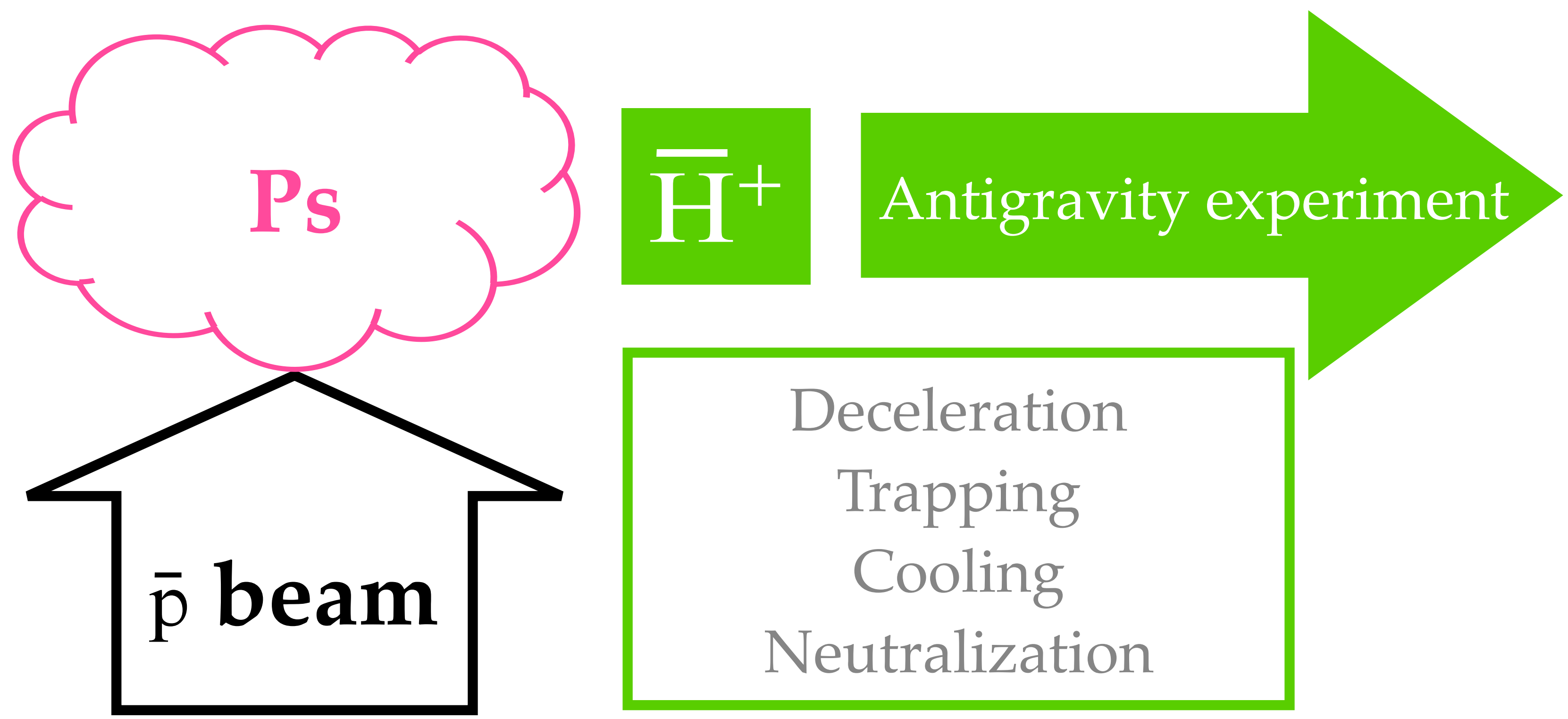

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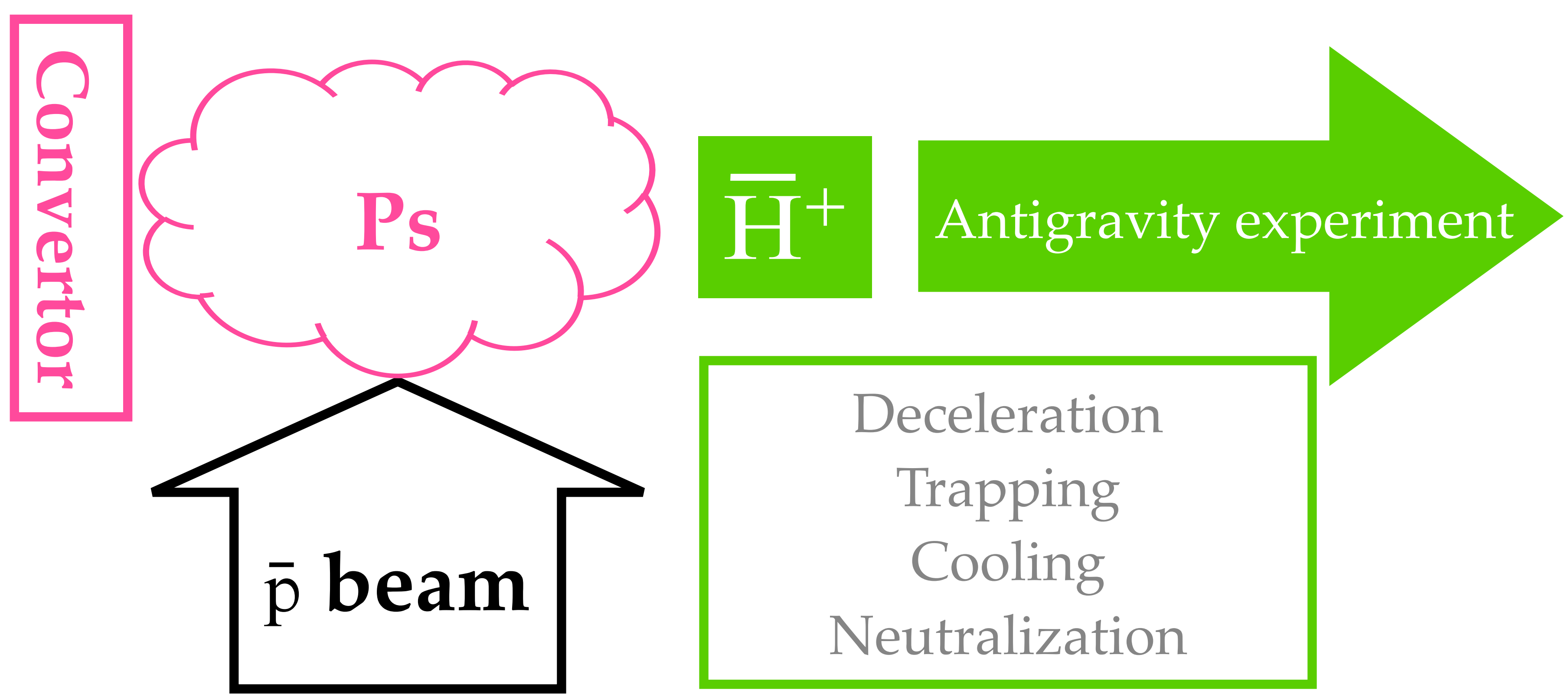

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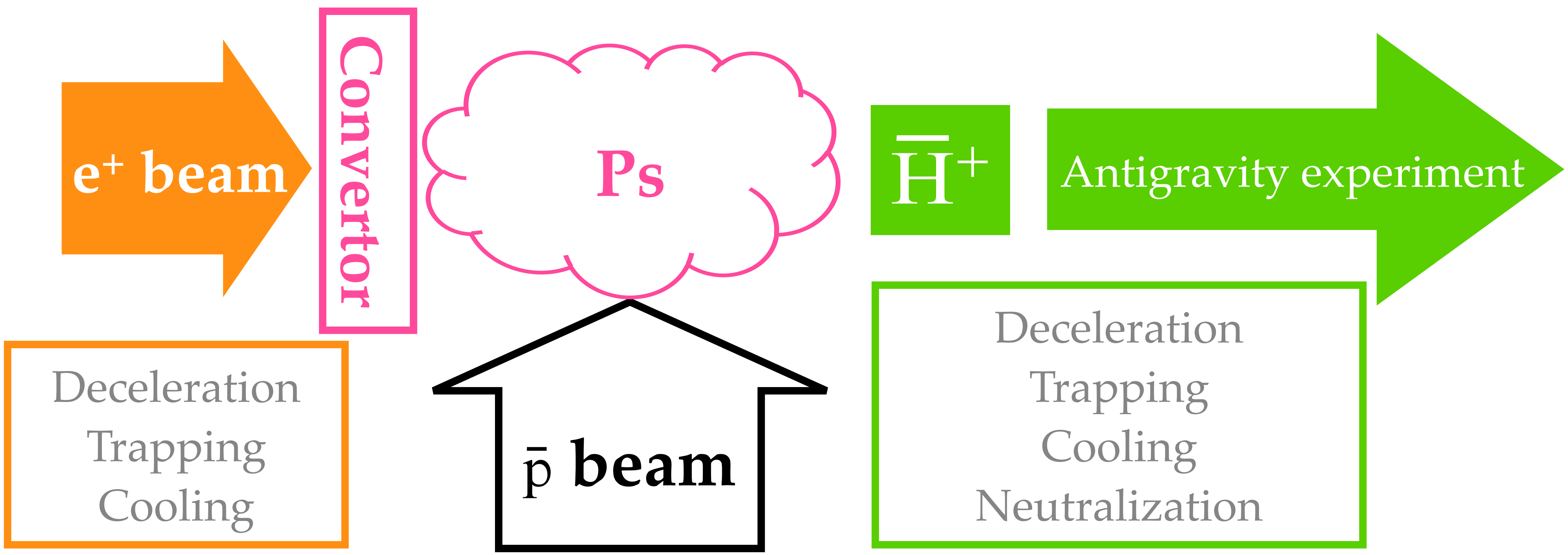

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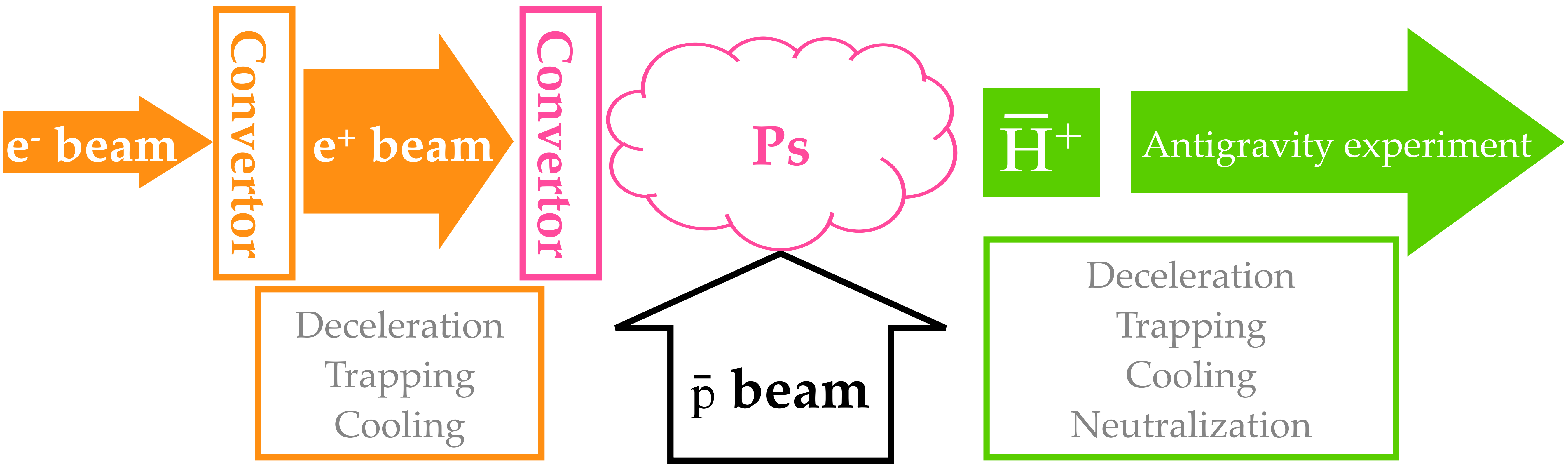

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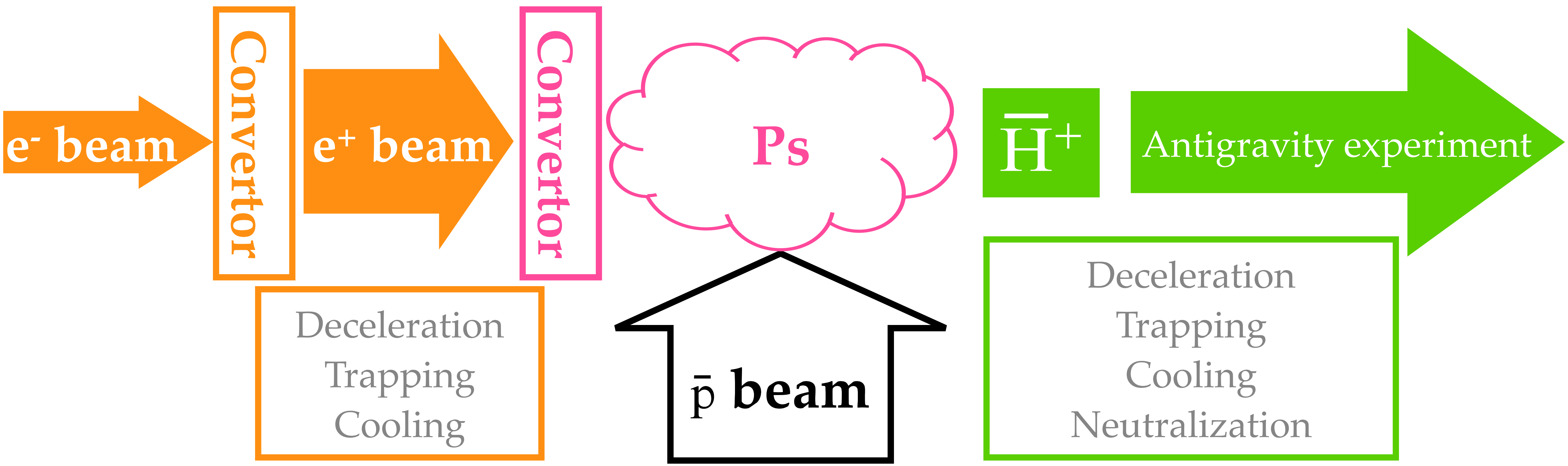

$\bar{p}$ BEAM FROM CERN AD

- AD
  - 10^{13} p / min (24 GeV)+ Cu
  - ~ 10^7 $\bar{p}$ / min   (ε ~10^{-6})
  - Stochastic/electron cooling ~ 5 MeV
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  - W Foil (ε ~10^{-3})
  - RFQD (ε ~10^{-1}) ~ 50 keV
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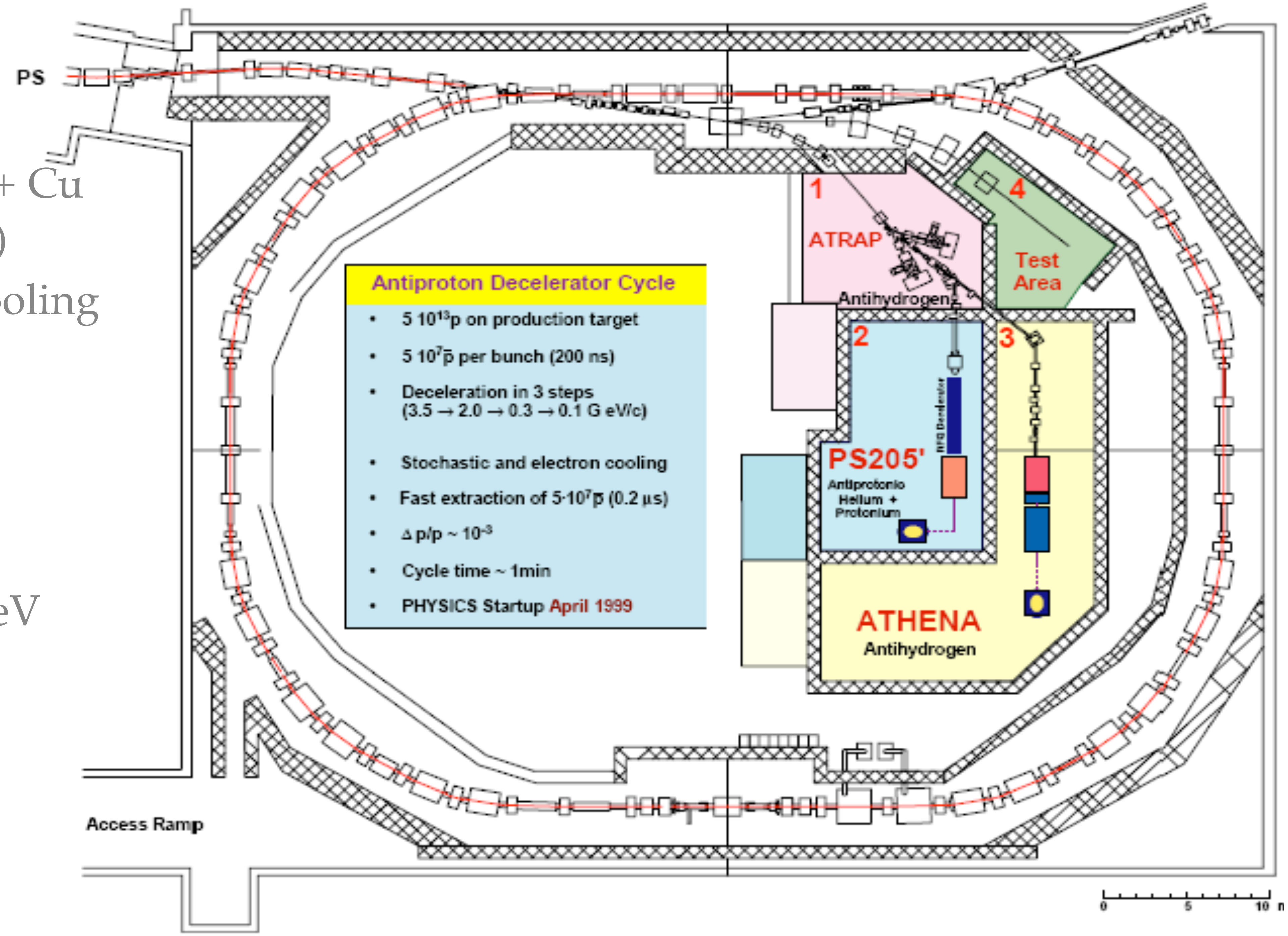

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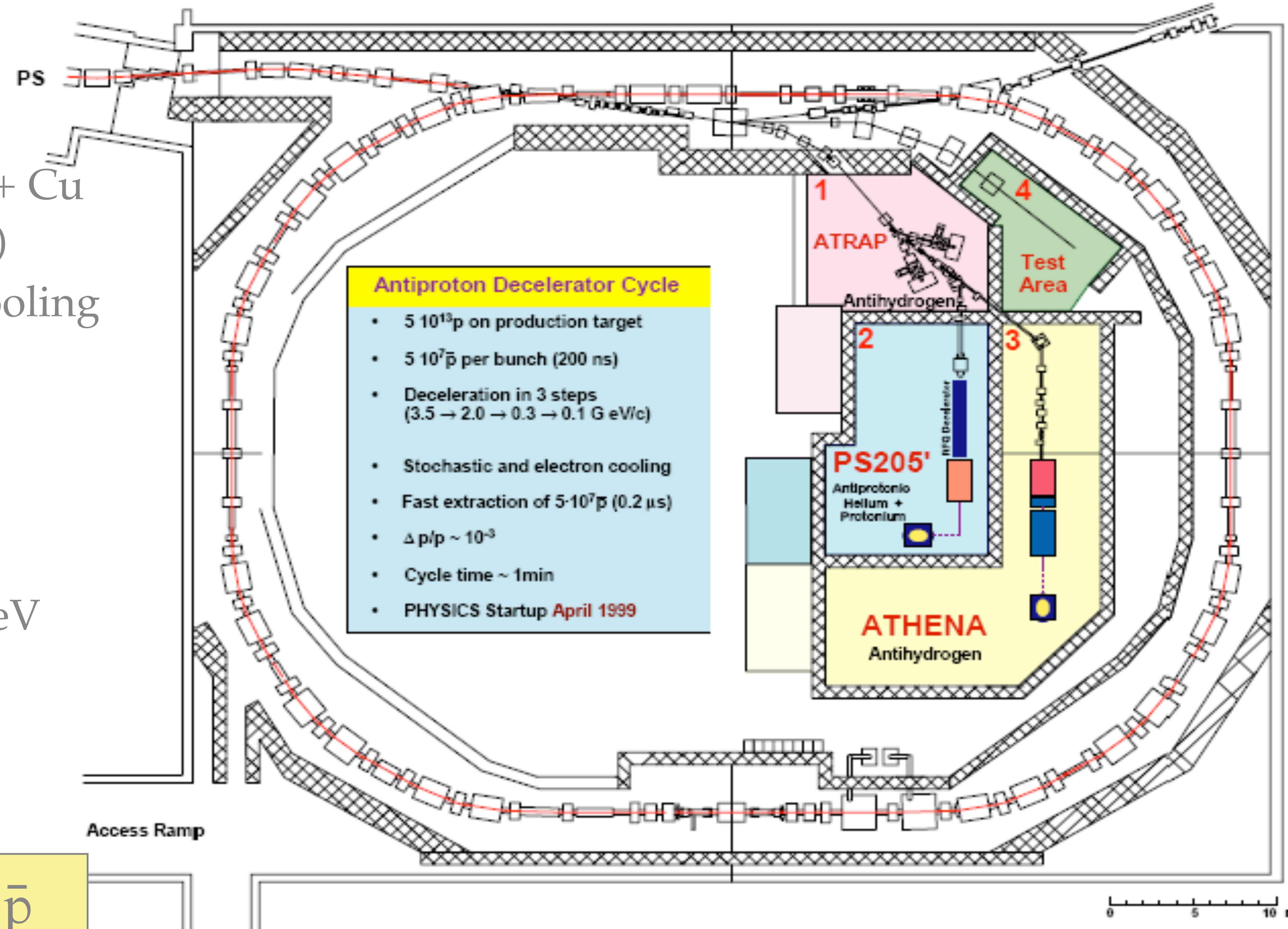

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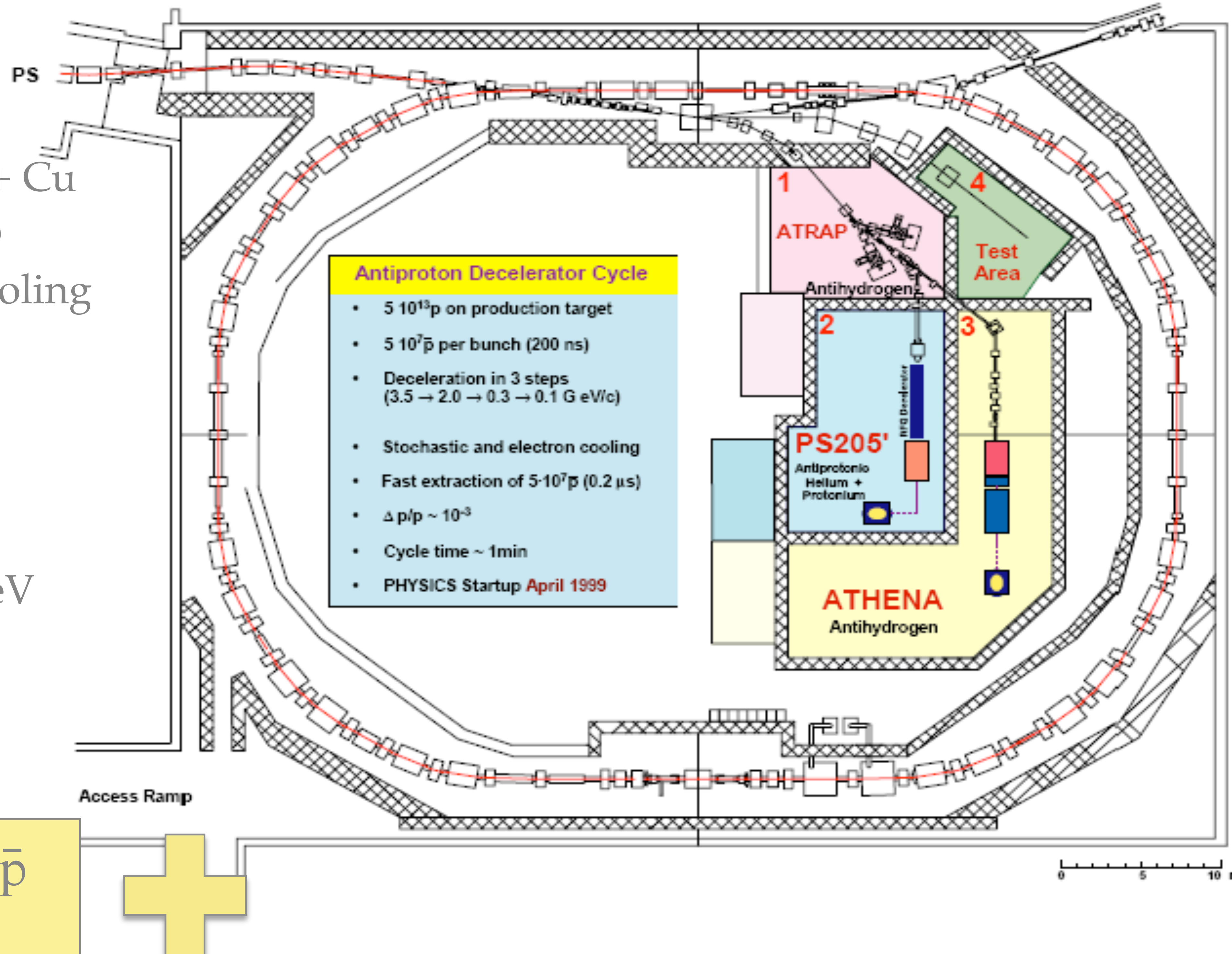

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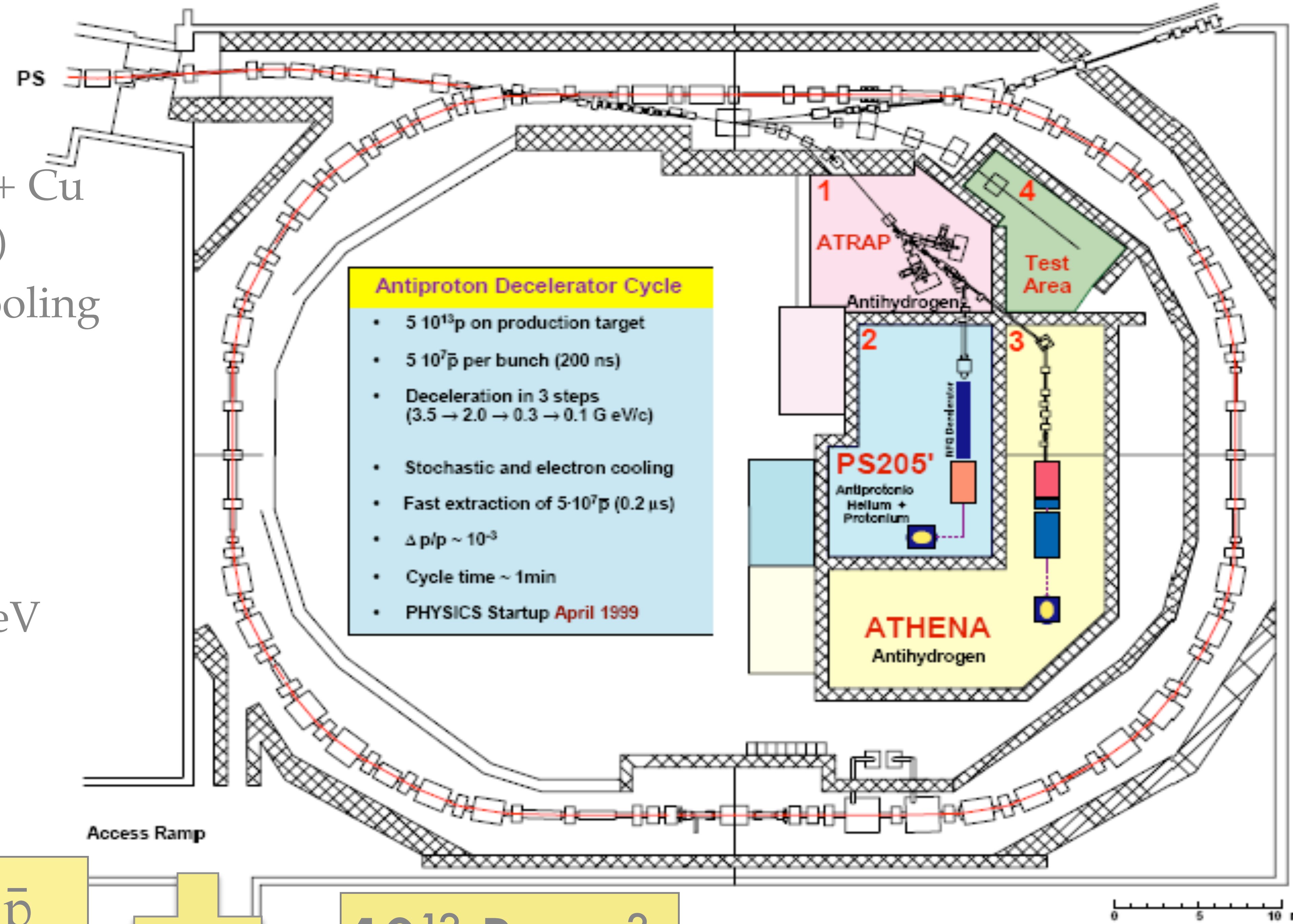

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+

10^{12} P_s cm^{-2}

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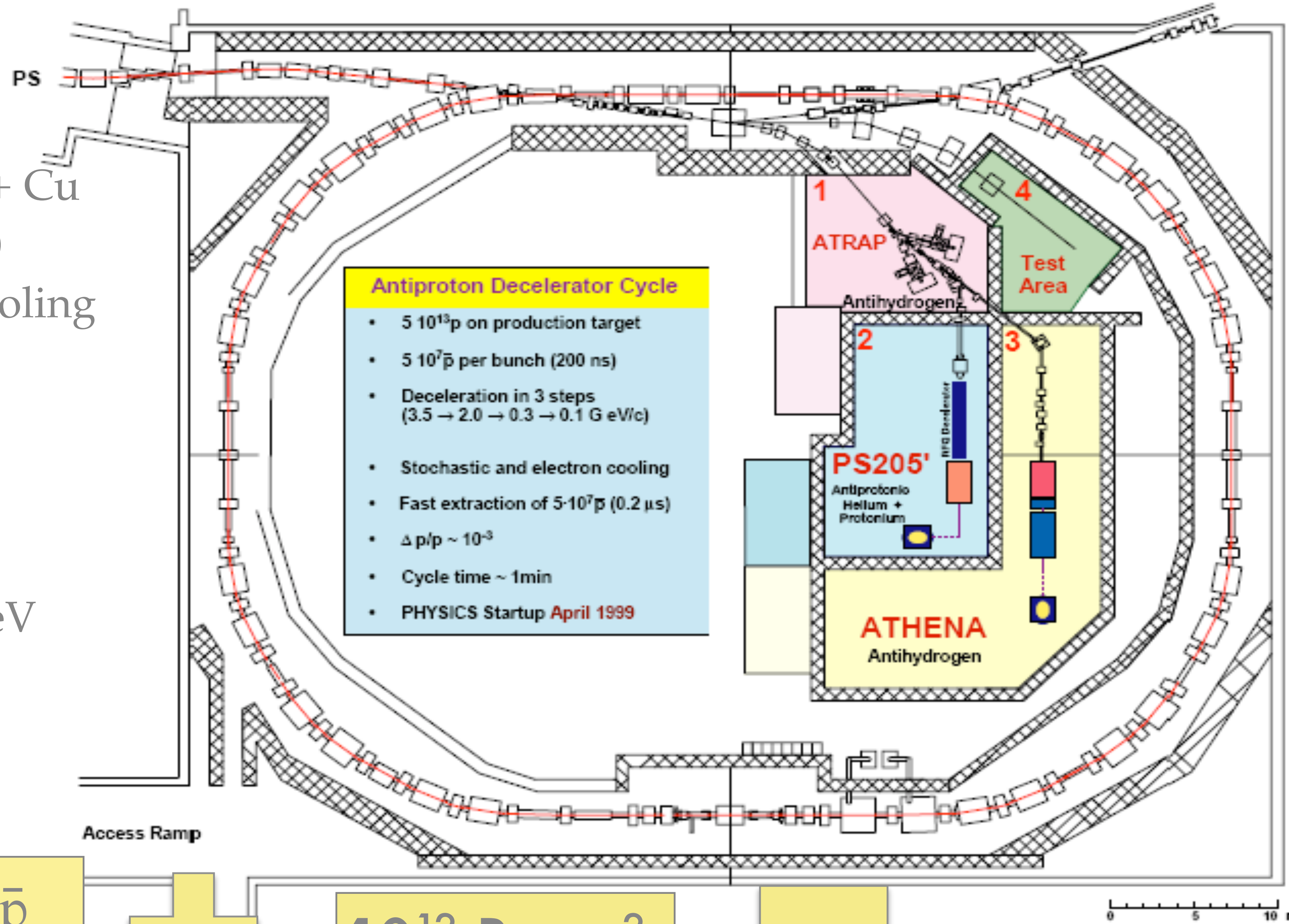

12 AD shot: 10^{7} $\bar{p}$ (20 min.) + 10^{12} P_s cm^{-2} =

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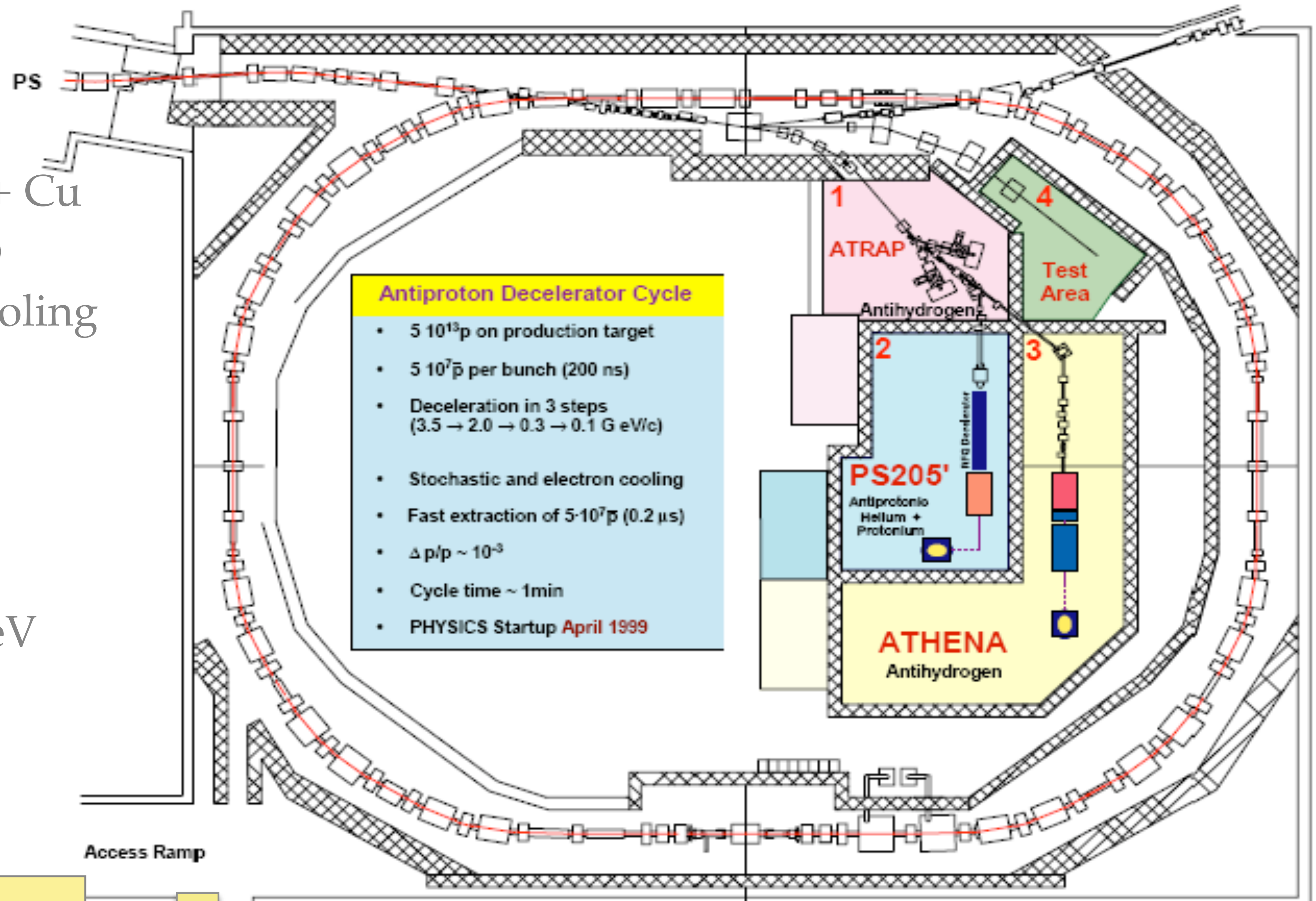

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=

1 $\bar{H}^+$

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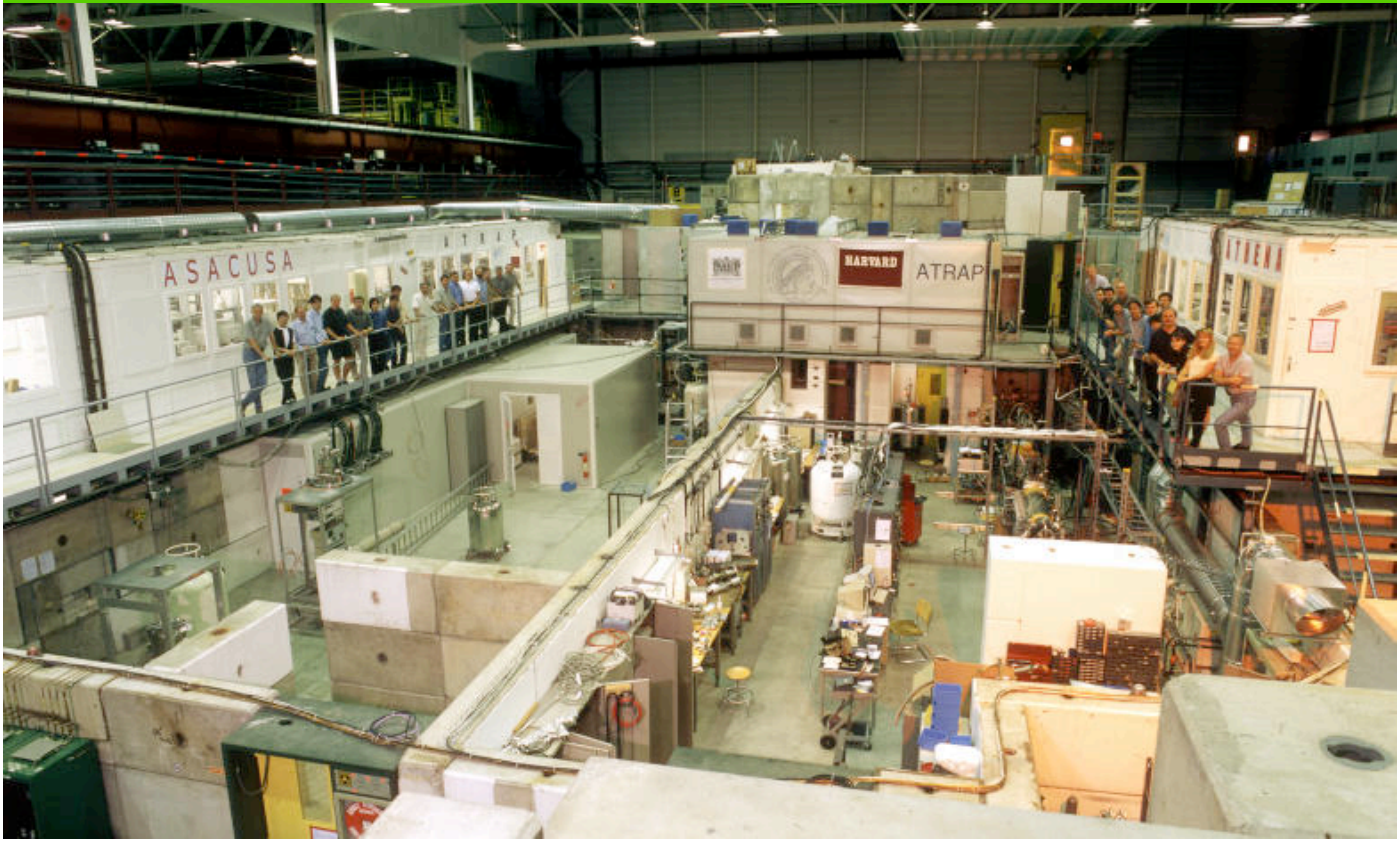


STEPS FOR GRAVITY EXPERIMENT ON $\bar{\mathrm{H}}^+$

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

e^+ production

e$^-$ source (LINAC)

Convertor e^-/e^+

Separator e^-/e^+

SOPHI project
e^+: ~$10^{11}s^{-1}$, MeV

e^+ collection

e^+ moderator

Penning trap

e^+: ~meV
ex:
$1.3 \cdot 10^{10}$ e^-/75 ns
at RIKEN

Ps production

Convertor e^+/Ps

Collision with $\bar{p}$

35% e+ -> Ps
(80meV)
AIST & CERN,
$\bar{p}$: ~ 5 keV

10^{12} P_s/cm^2: $1\bar{\mathrm{H}}^+$

slow $\bar{\mathrm{H}}^+$

$\bar{\mathrm{H}}^+$
trapping
cooling

Laser injection
(neutralization)

Gravity measurement

10^5 $\bar{\mathrm{H}}^+$:
0.1% accuracy

L. Liszkay et al., preprint DAPNIA-07-125

e^+ PRODUCTION (Saclay)

- Requirements:
  - High Intensity
  - Low energy
  - Transportable

to be installed in
CERN AD ASACUSA beam line:

$\sim 10^8\ s^{-1}$

~meV

~room size

➡ ~~Radioactive source~~: practically the intensity of emitted e^+ cannot be enough high

➡ ~~Existing accelerator~~: too big!

➡ (relatively) low energy electron source + convertor

PROJECT at Saclay

Linac (SELMA)

↓

Beam profiler

↓

W target (Convertor e^+/e^-)

↓

e^+/e^- separation (SOPHI)

↓

e+ moderator

↓

Trap

↓

CERN

installed at Salle 126

Accelerator + chamber construction with SACM / SIS / SEDI

SPP
PEREZ Patrice
SAQUIN Yves
LISZKAY Laszlo
DUPRE Pierre
RUIZ Nicolas

Material research

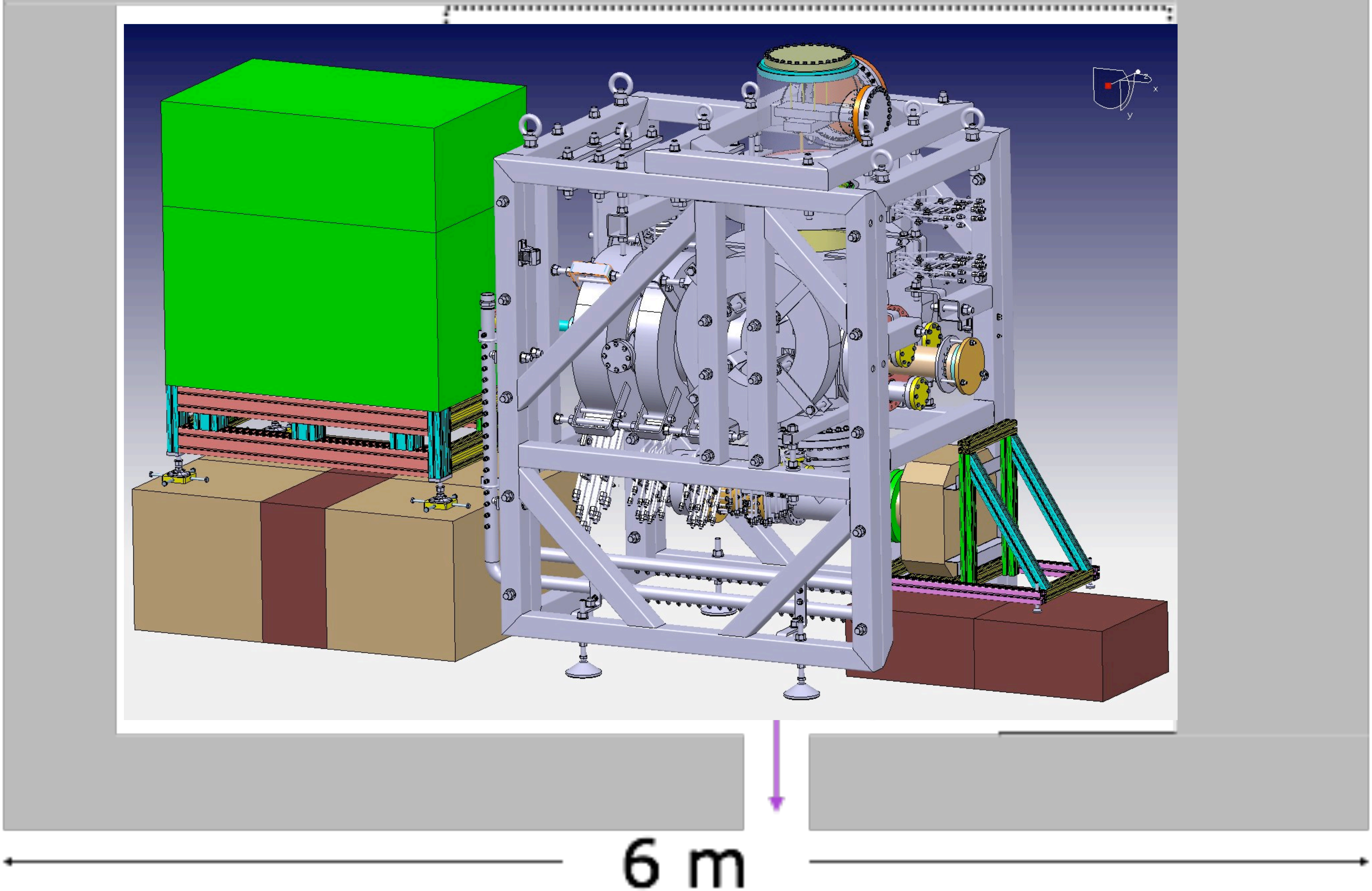
Trap

↓

Chopper/buncher/accelerator

→ Experiments with IRAMIS

Schematic drawing of e^+ production setup



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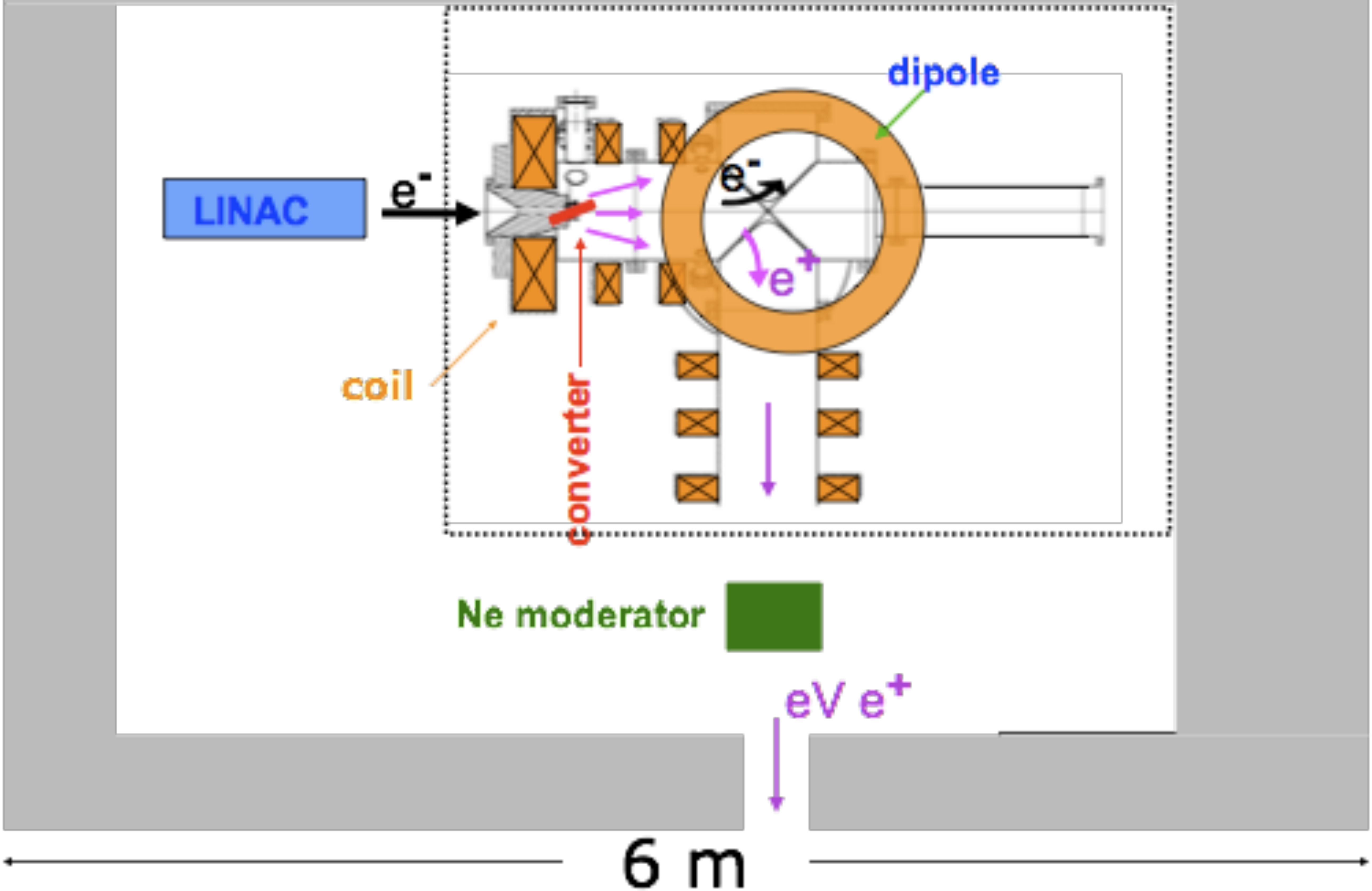
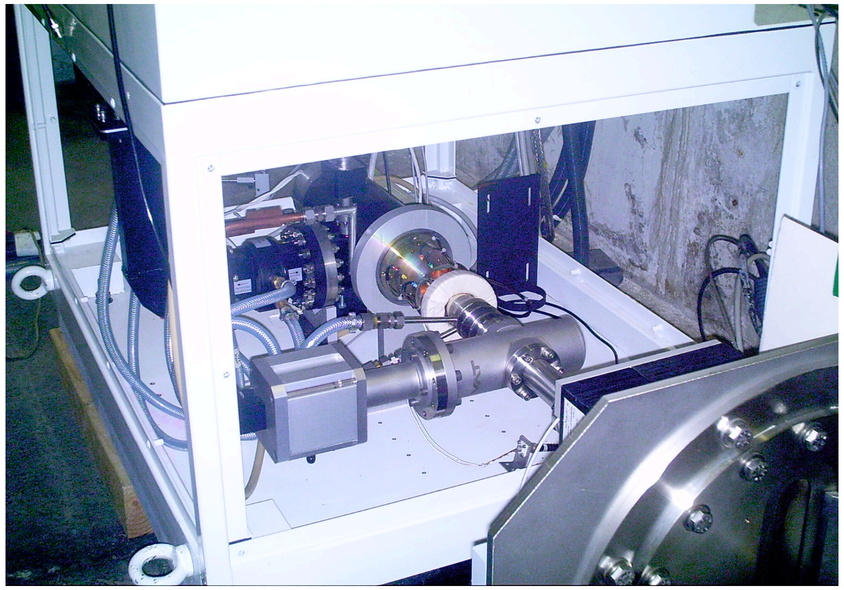


ELECTRON SOURCE: LINAC

- E (e^-) ~ 6 MeV (< neutron activation threshold)
- ν = 200 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



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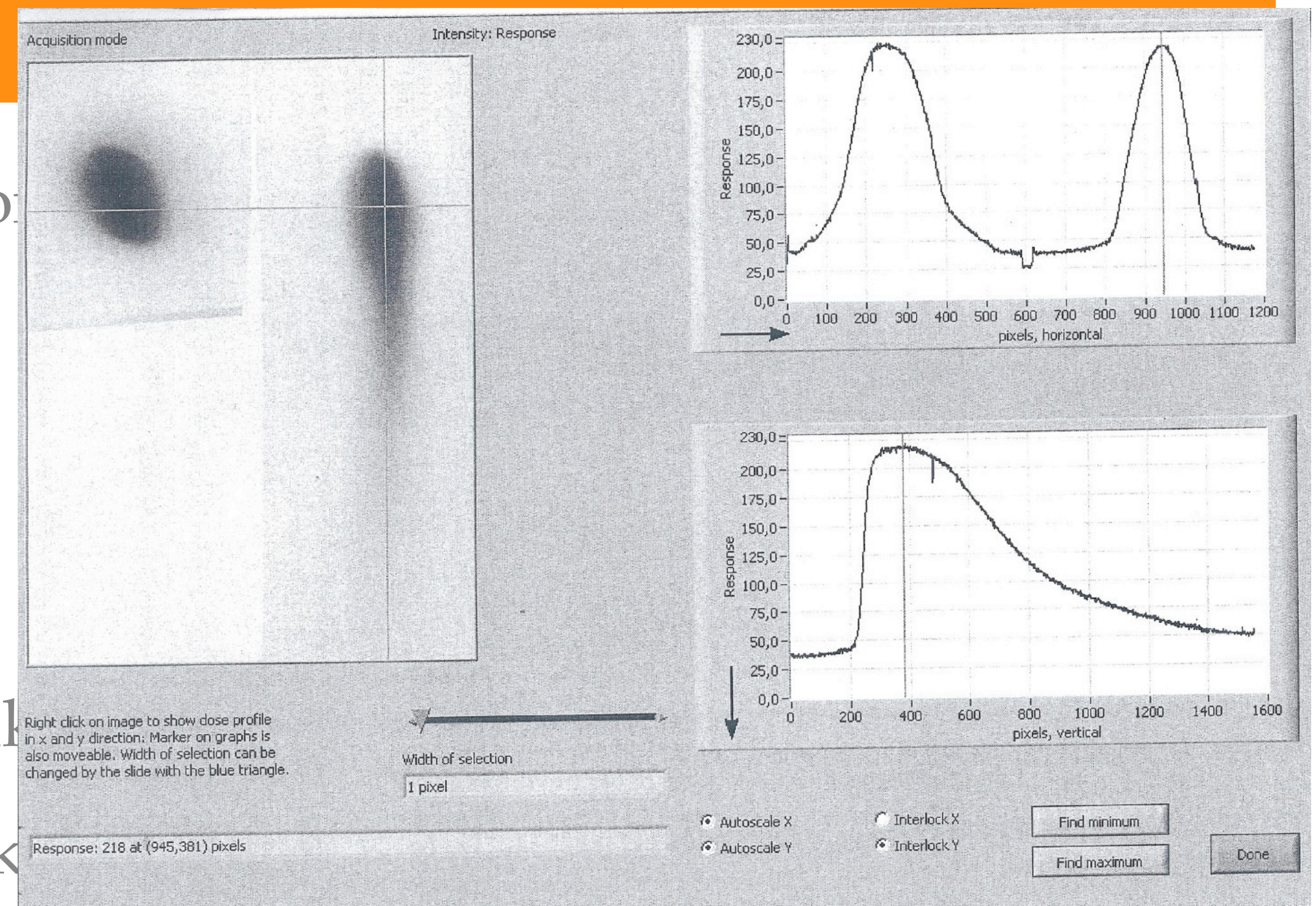

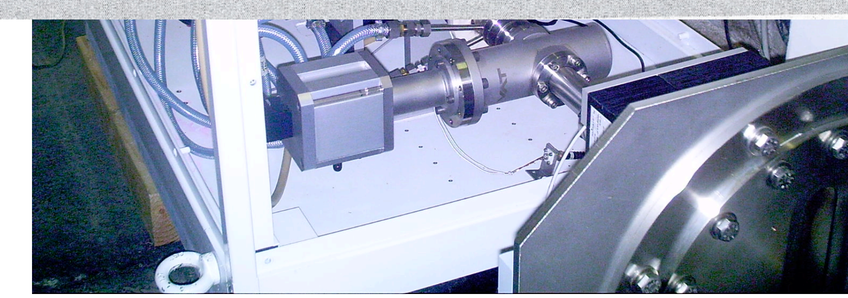

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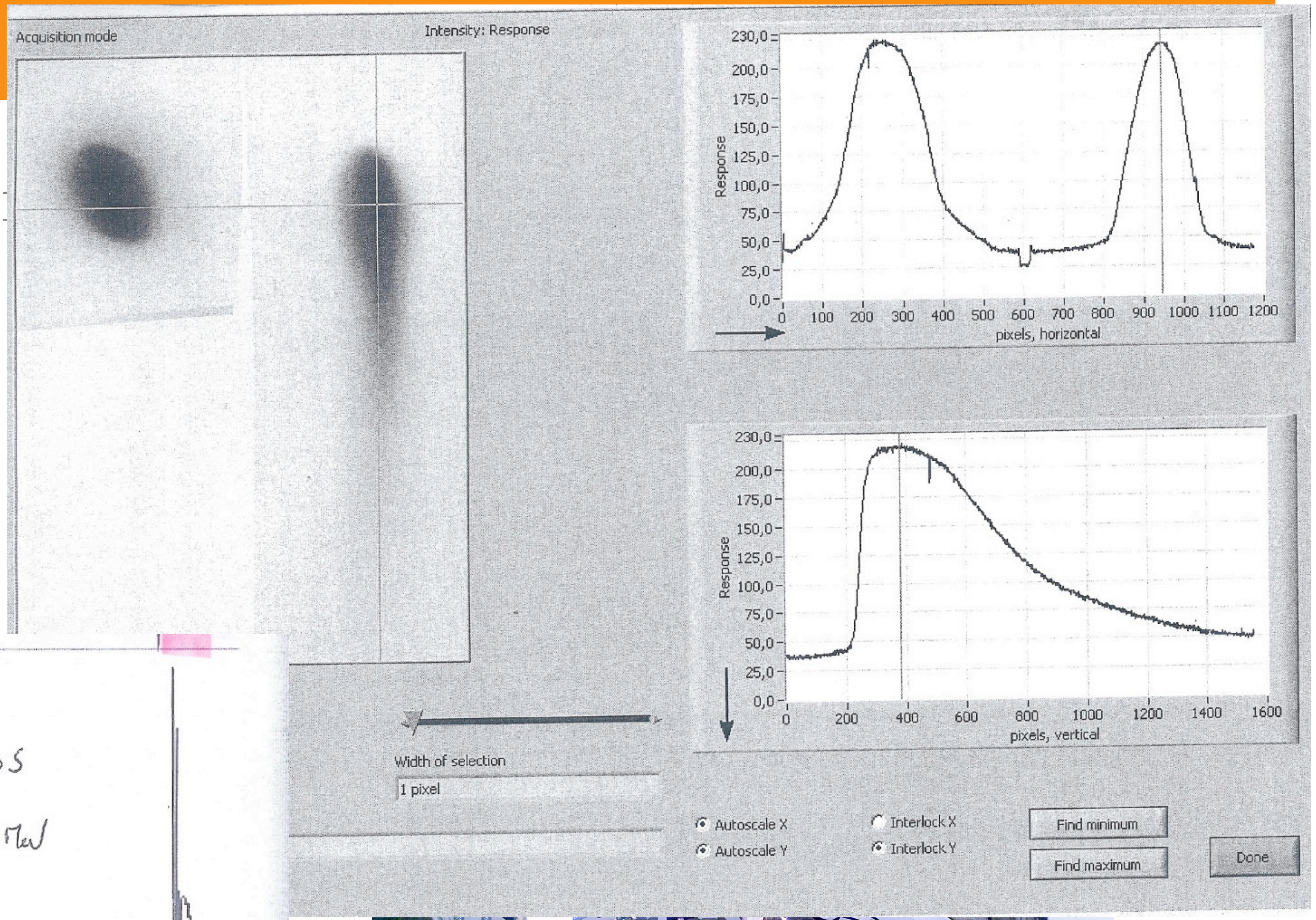
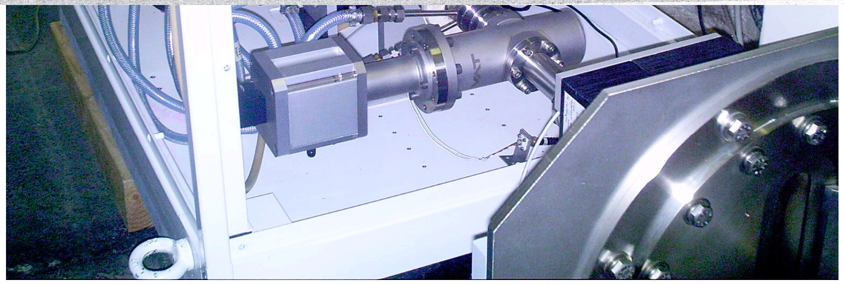
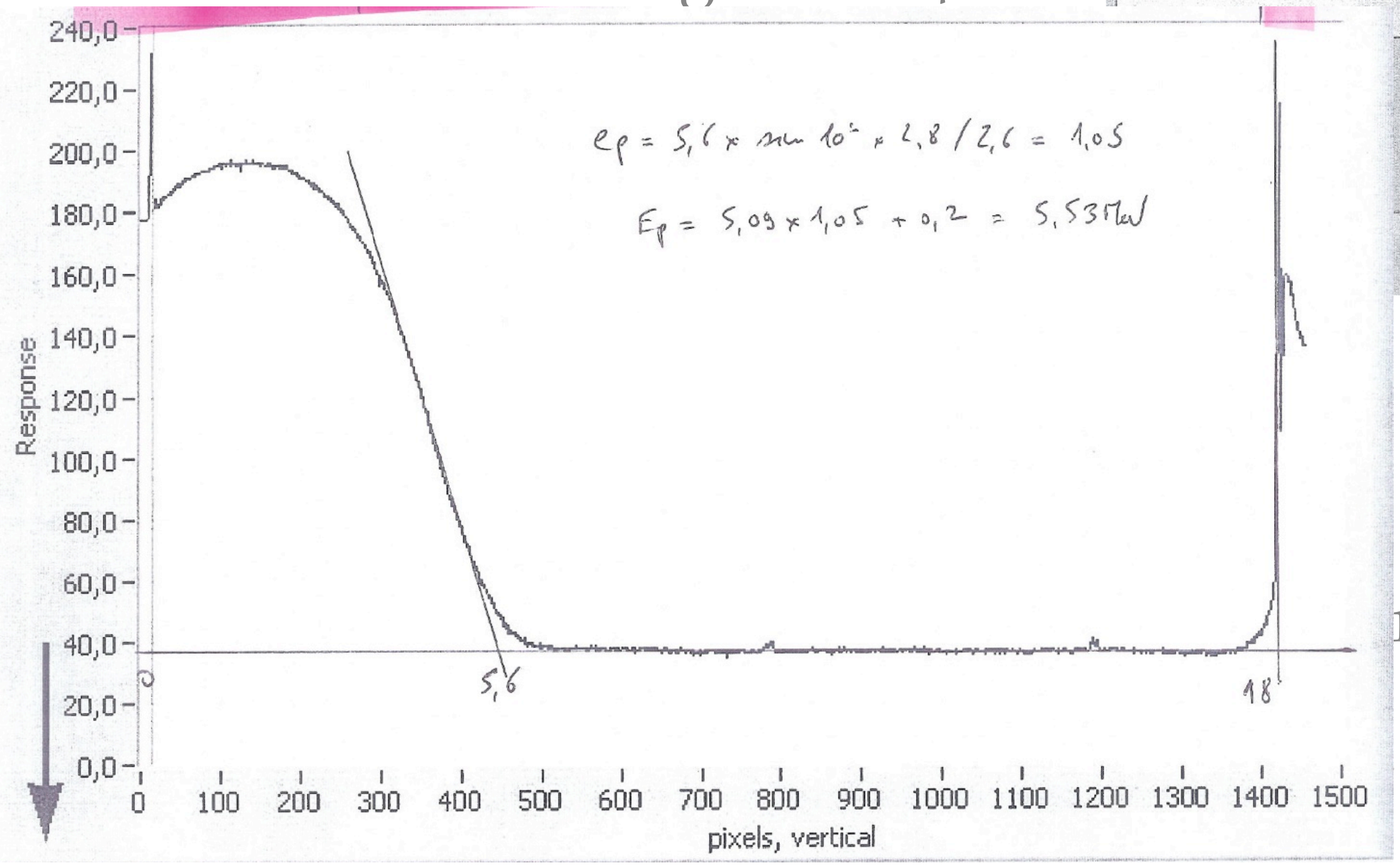






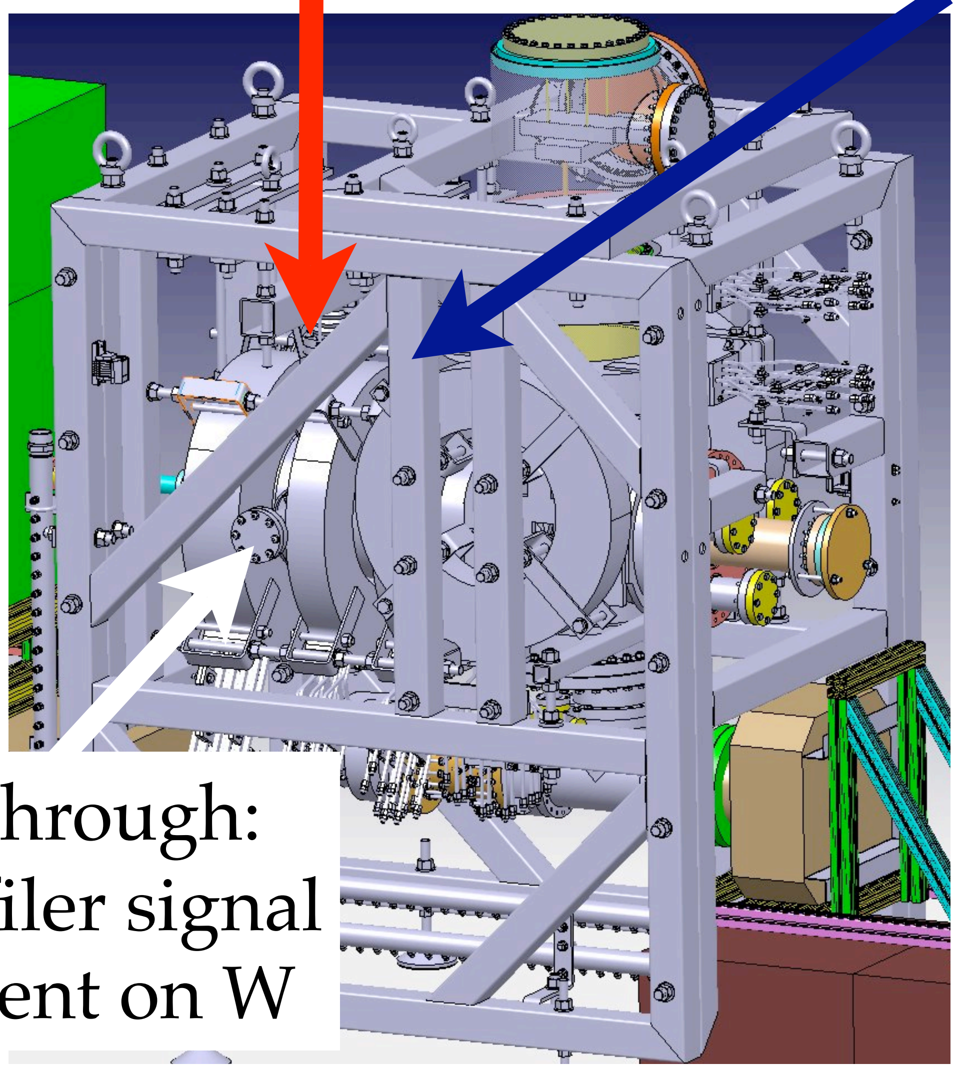
rget

8 m

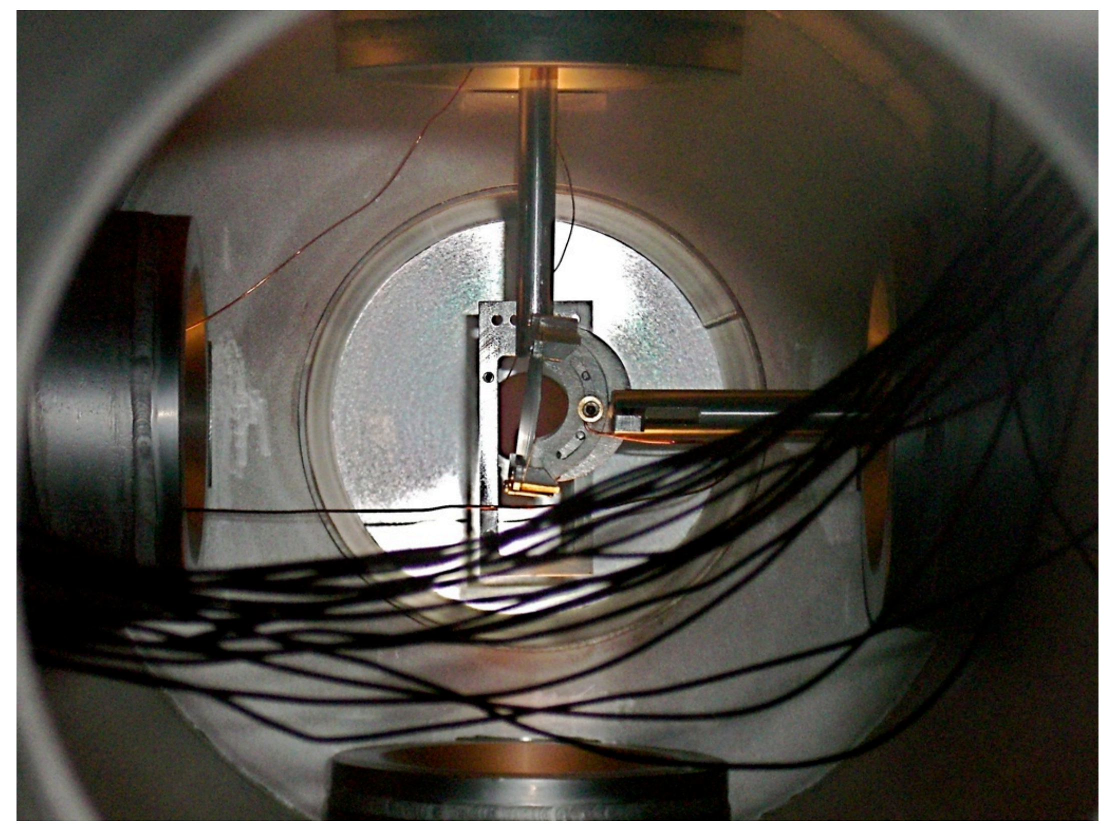
BEAM PROFILER, e^-/e^+ CONVERTOR

Stepping motor +
e^- beam profiler

e^-/e^+ convertor
W foil: 6 x 6 cm^2
200 μm-th
5 deg. to beam ax.



Feedthrough:
- profiler signal
- current on W



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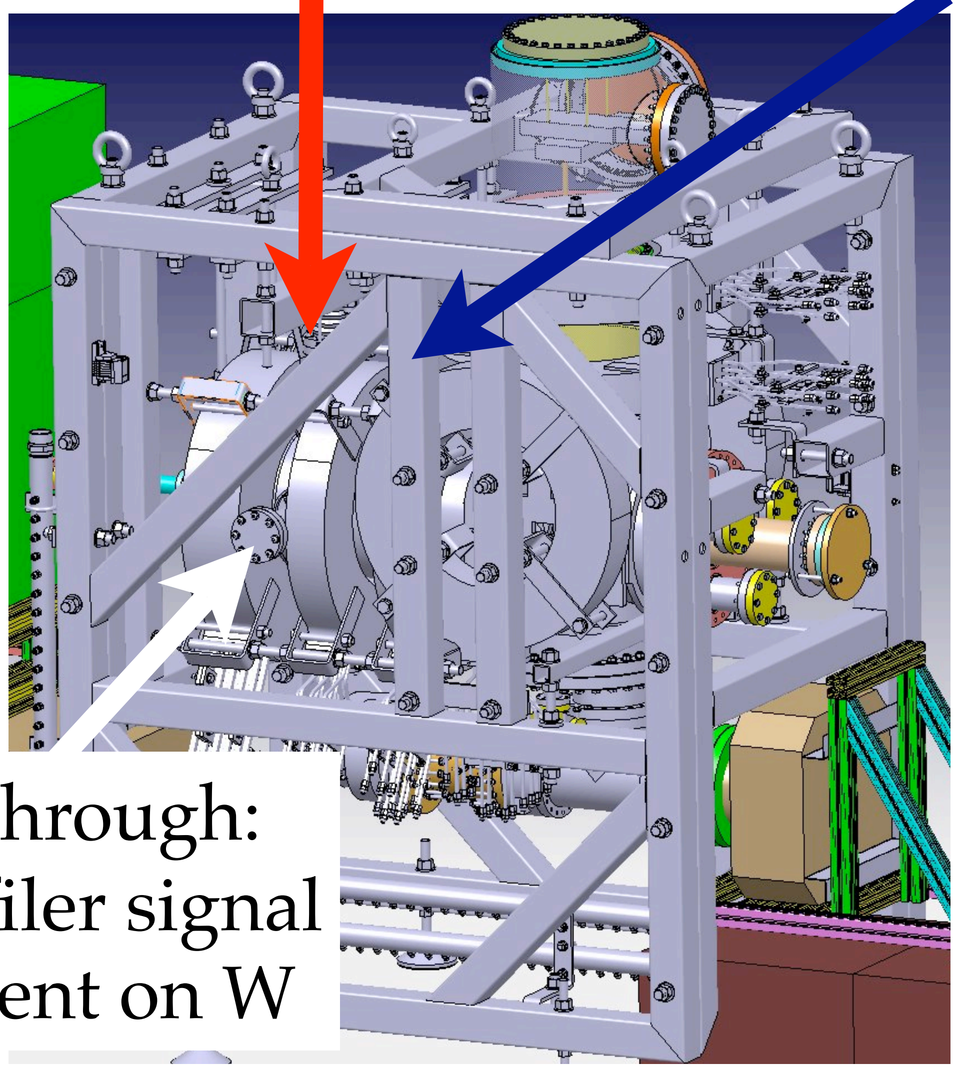

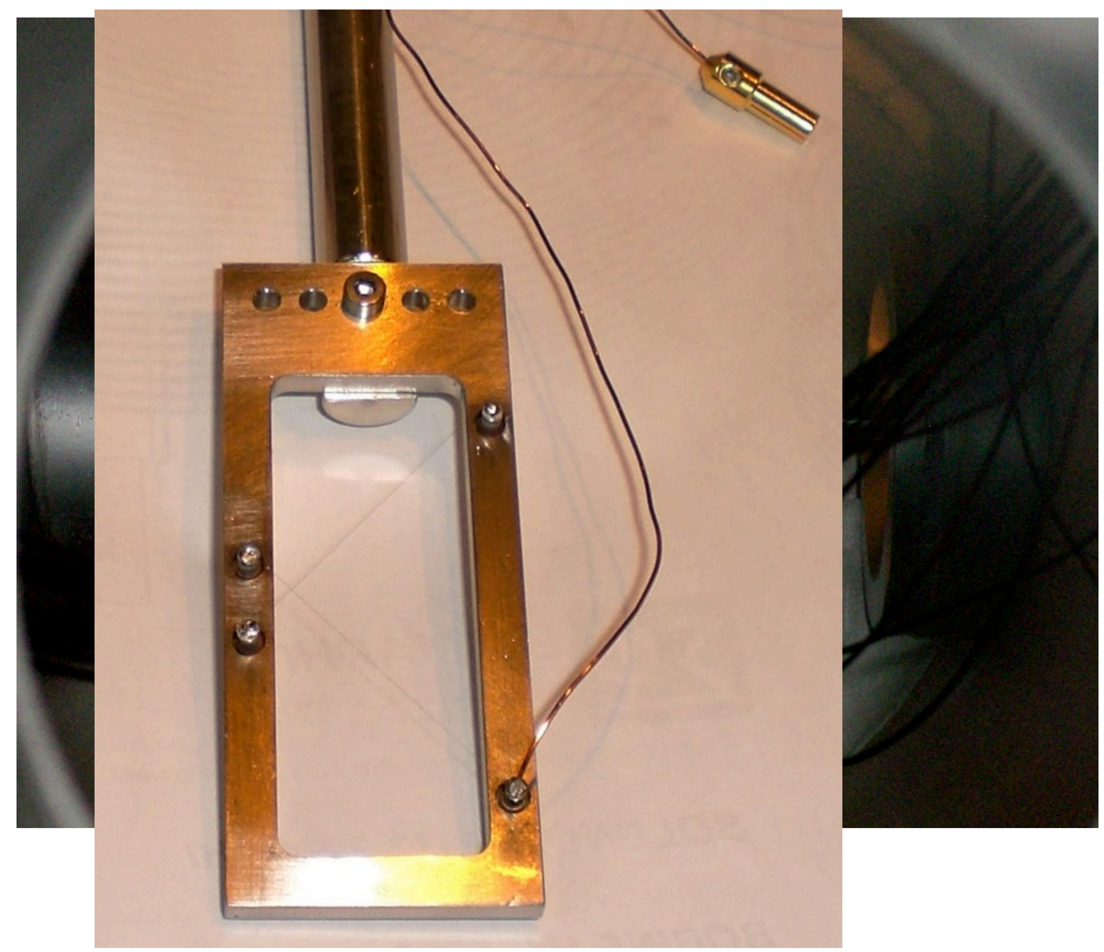

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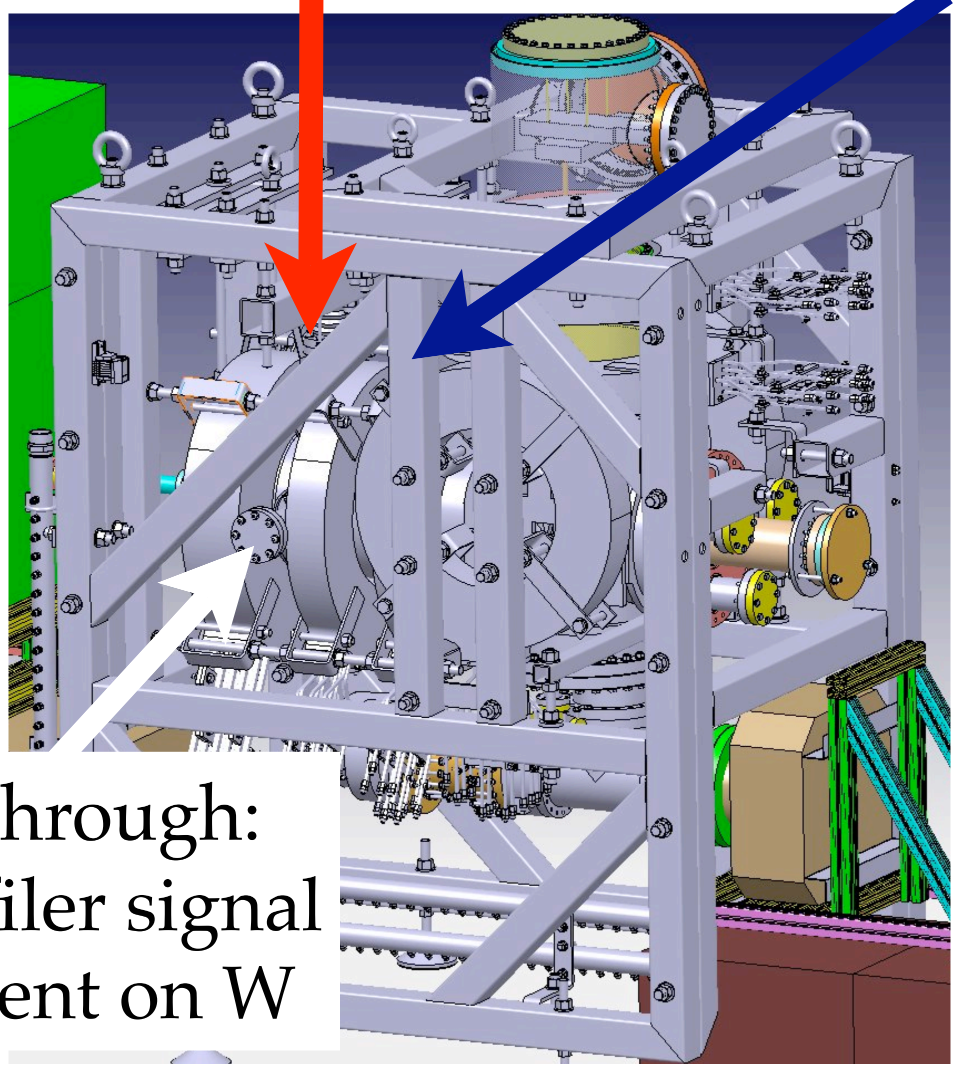

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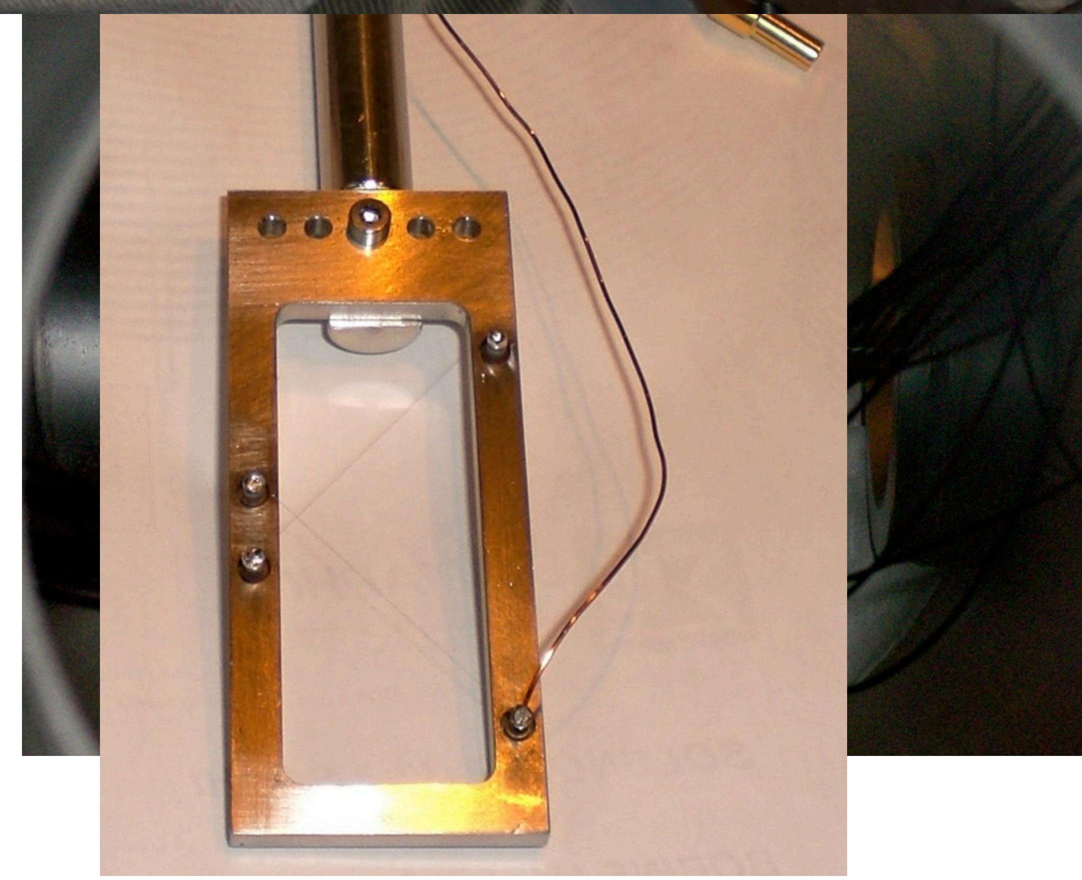

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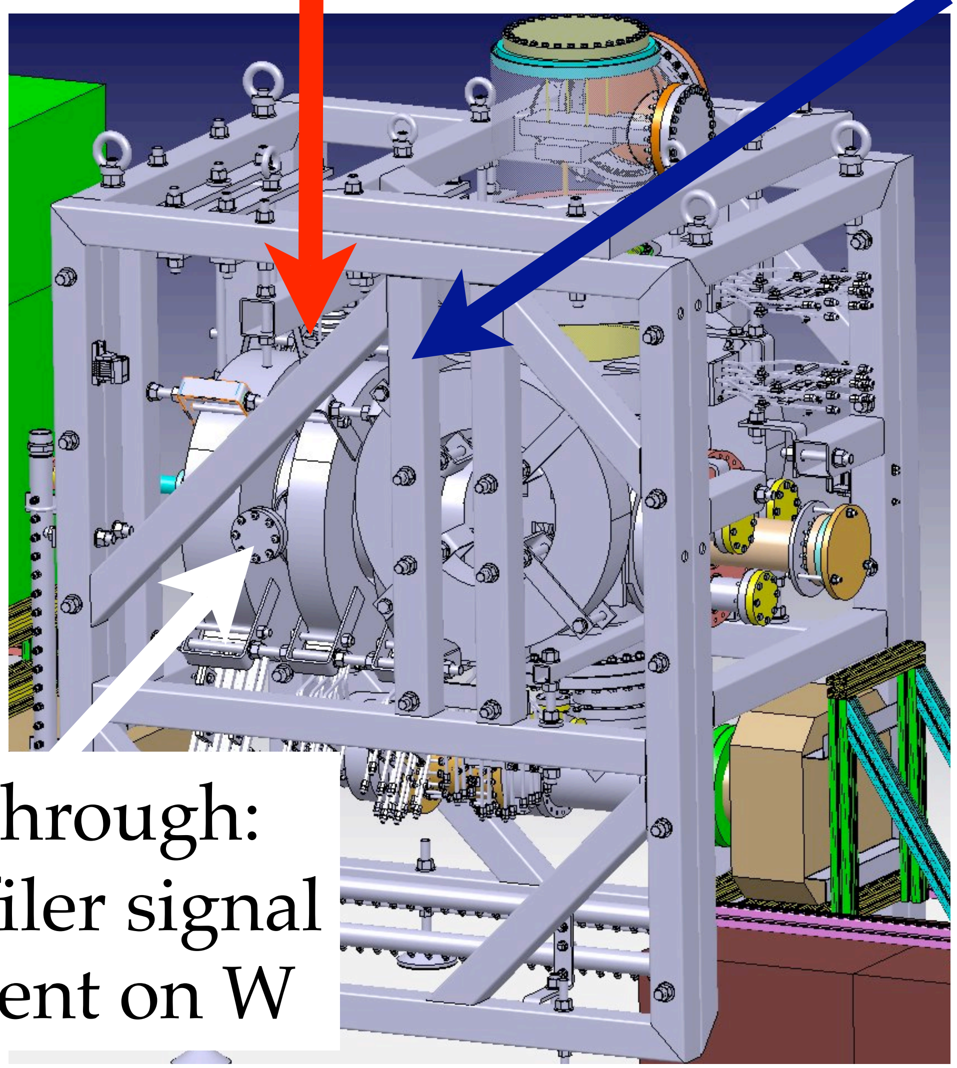

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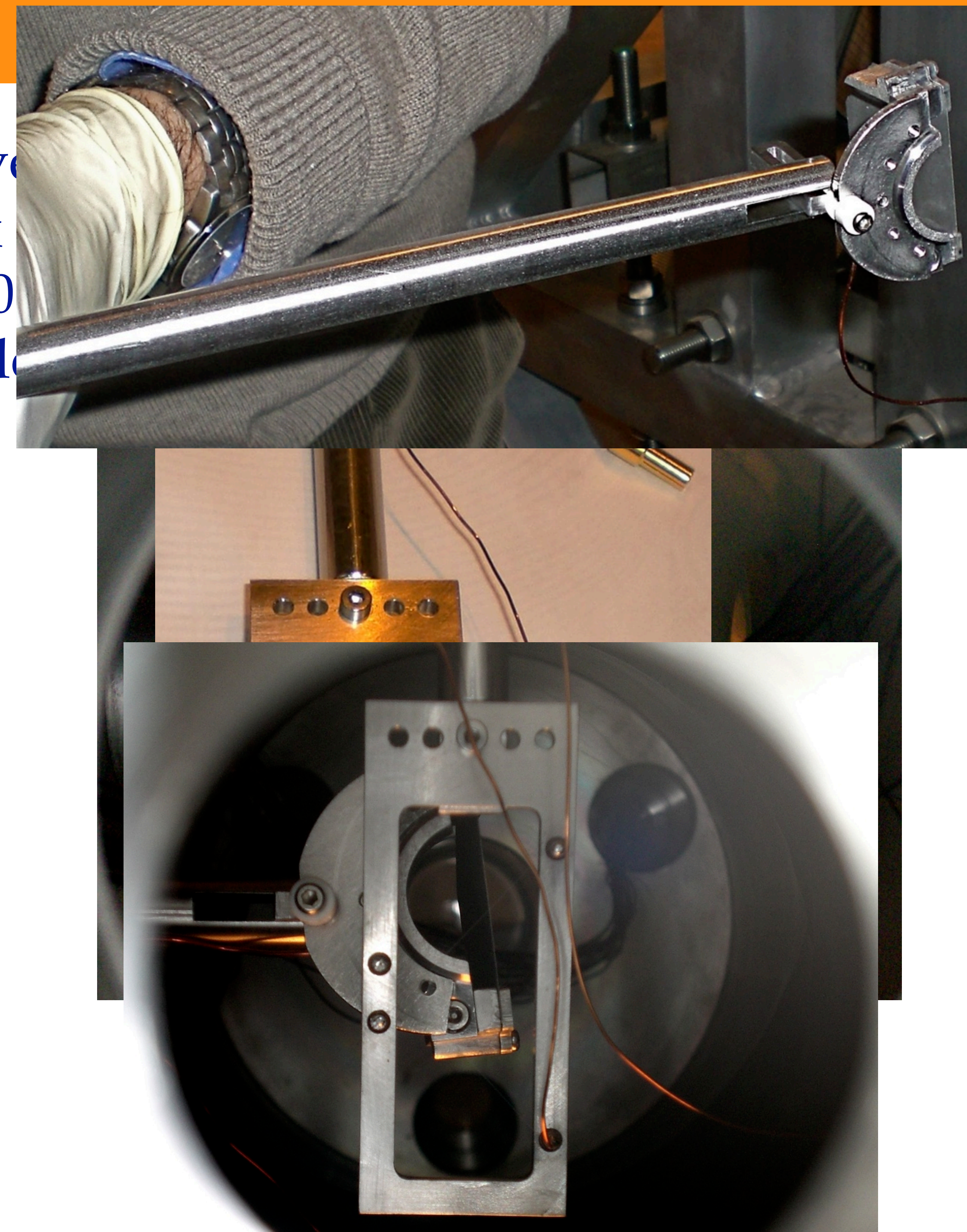
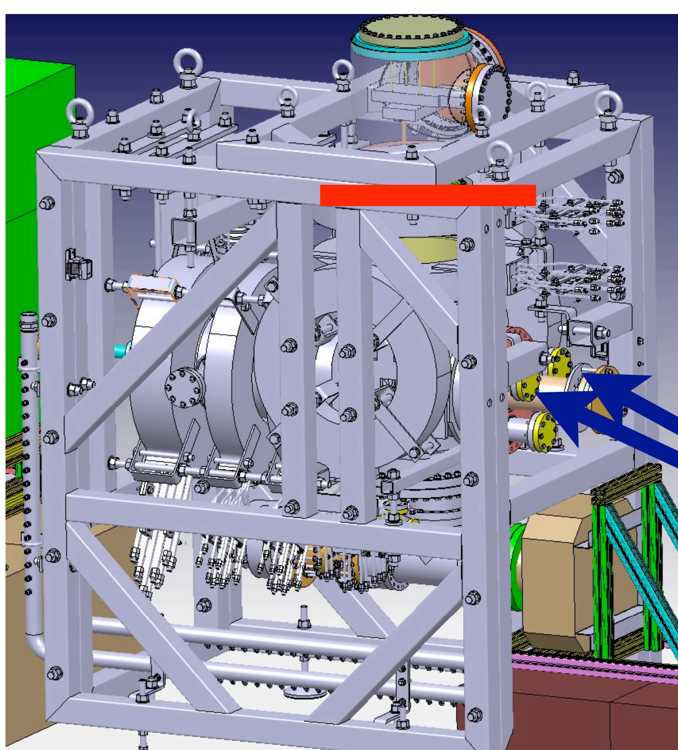
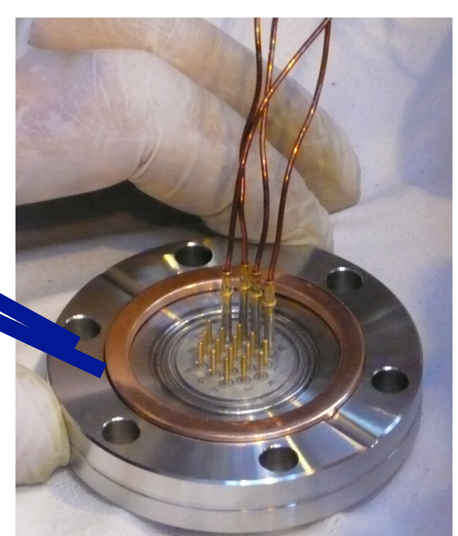
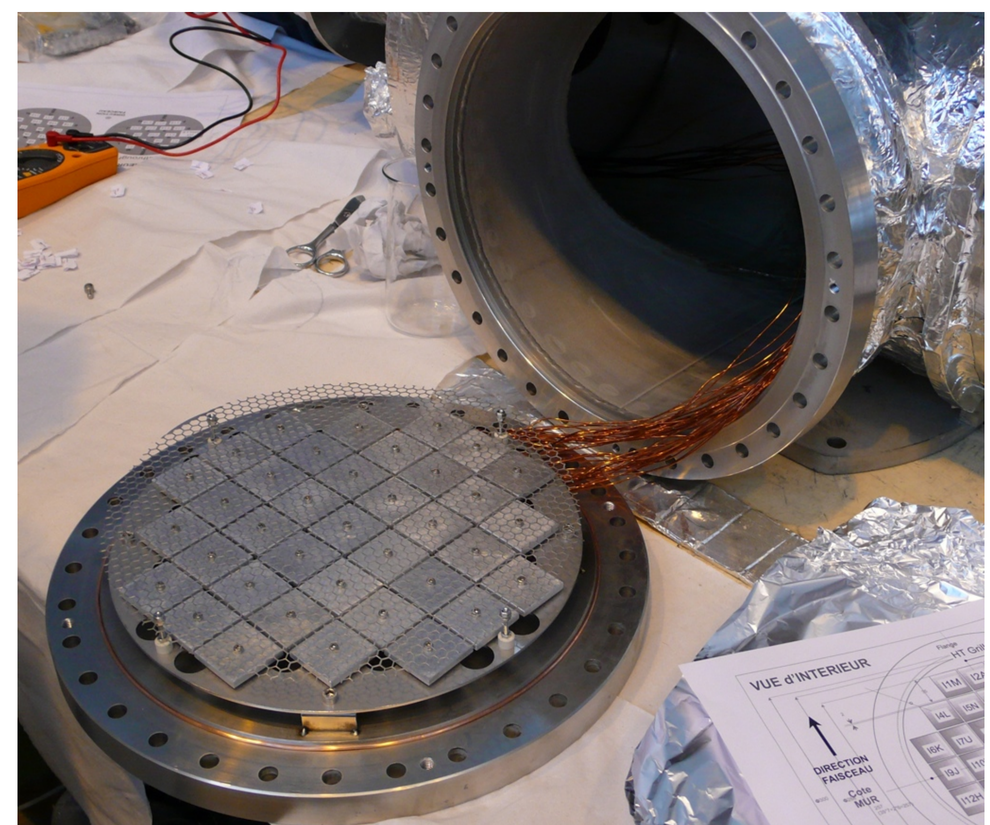


e^+ DETECTOR

- e^+ position observation for optimization
- 37 Al plates, 4 x 4 cm^2, 5 mm-th, covering 700 cm2
- Mounted on the upper-side flange CF 300
- e^+ extraction by grid 5mm holes, 100V
- Acquisition: USB connected NI ADC + Labview







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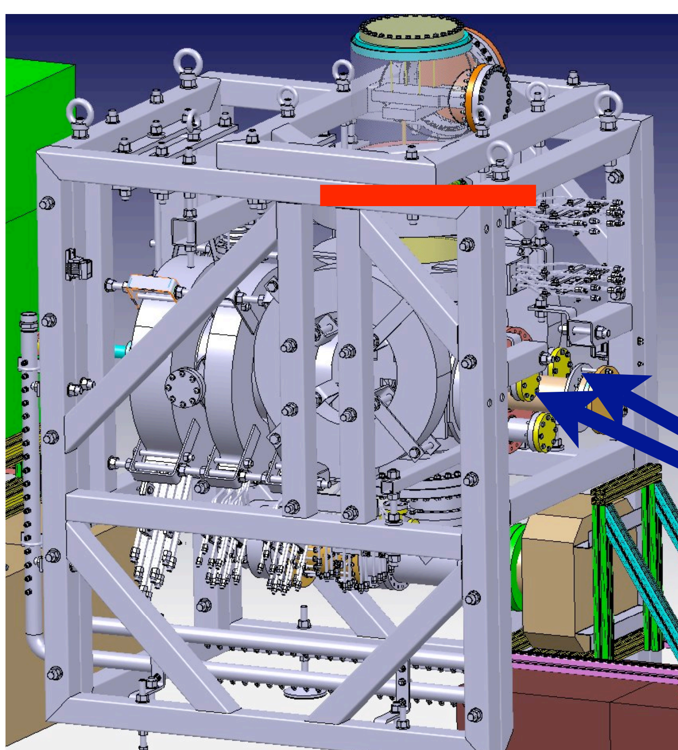
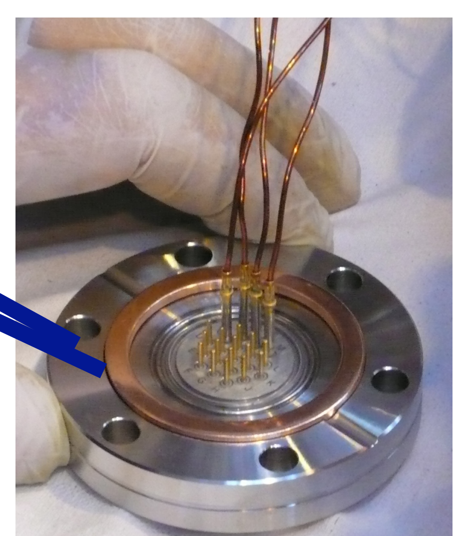
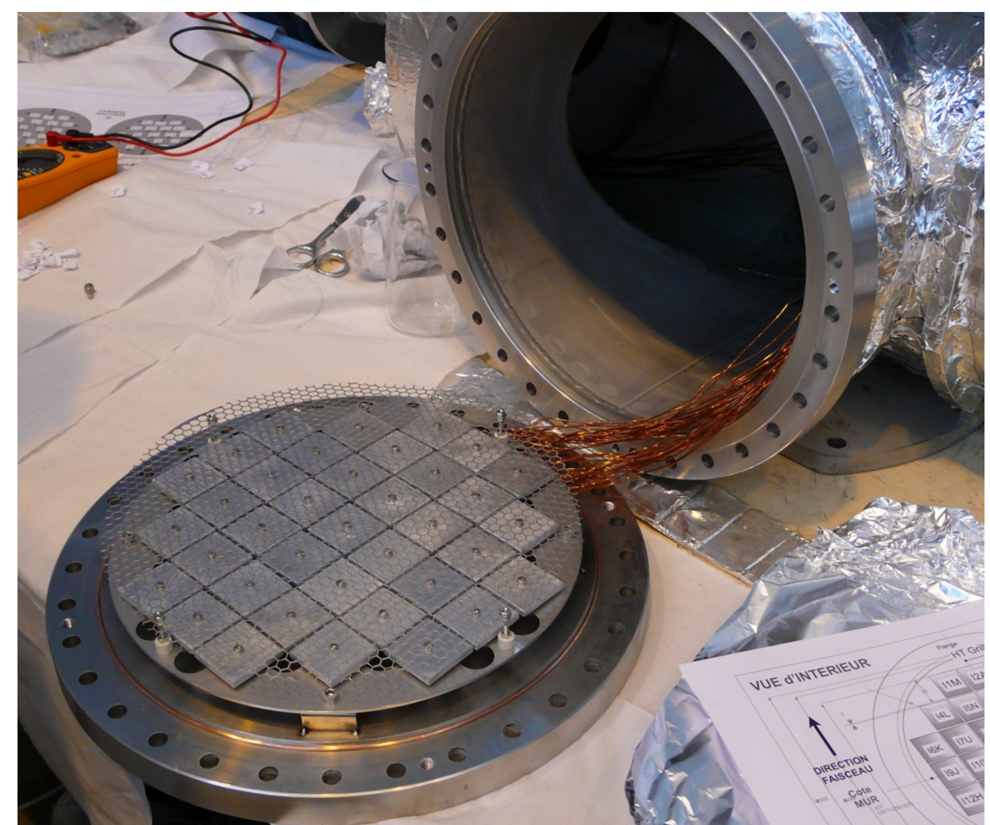




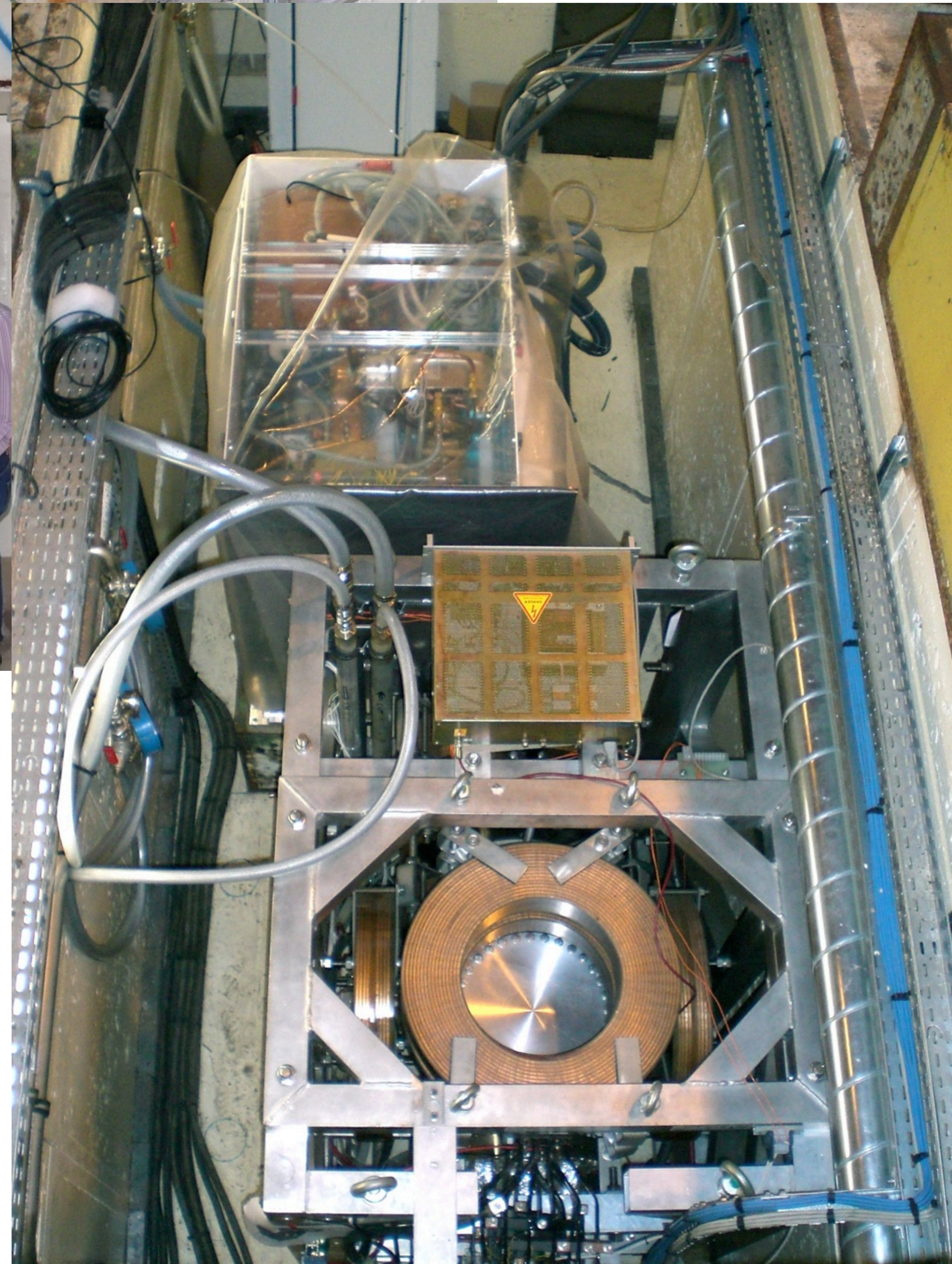


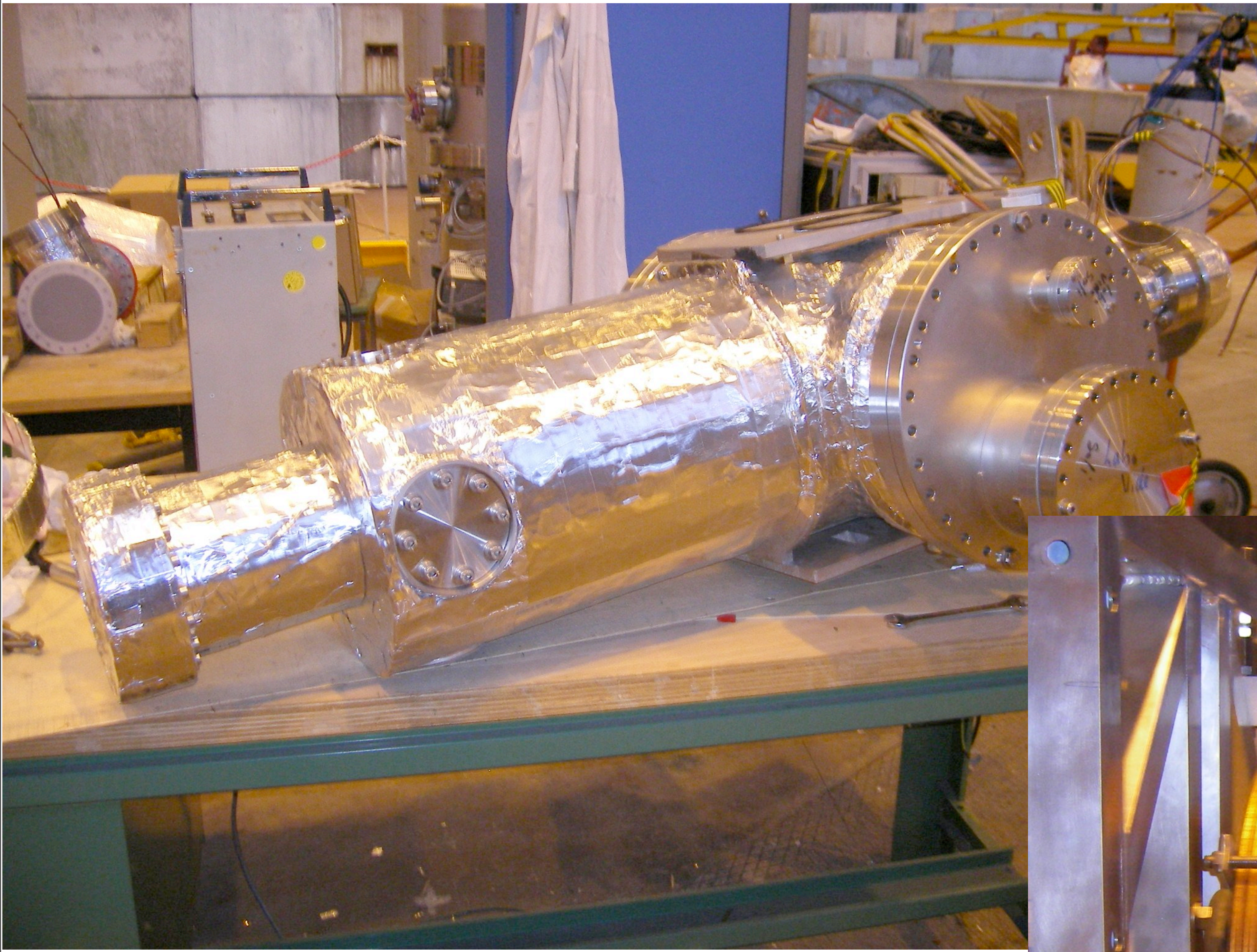

336
357
344
327

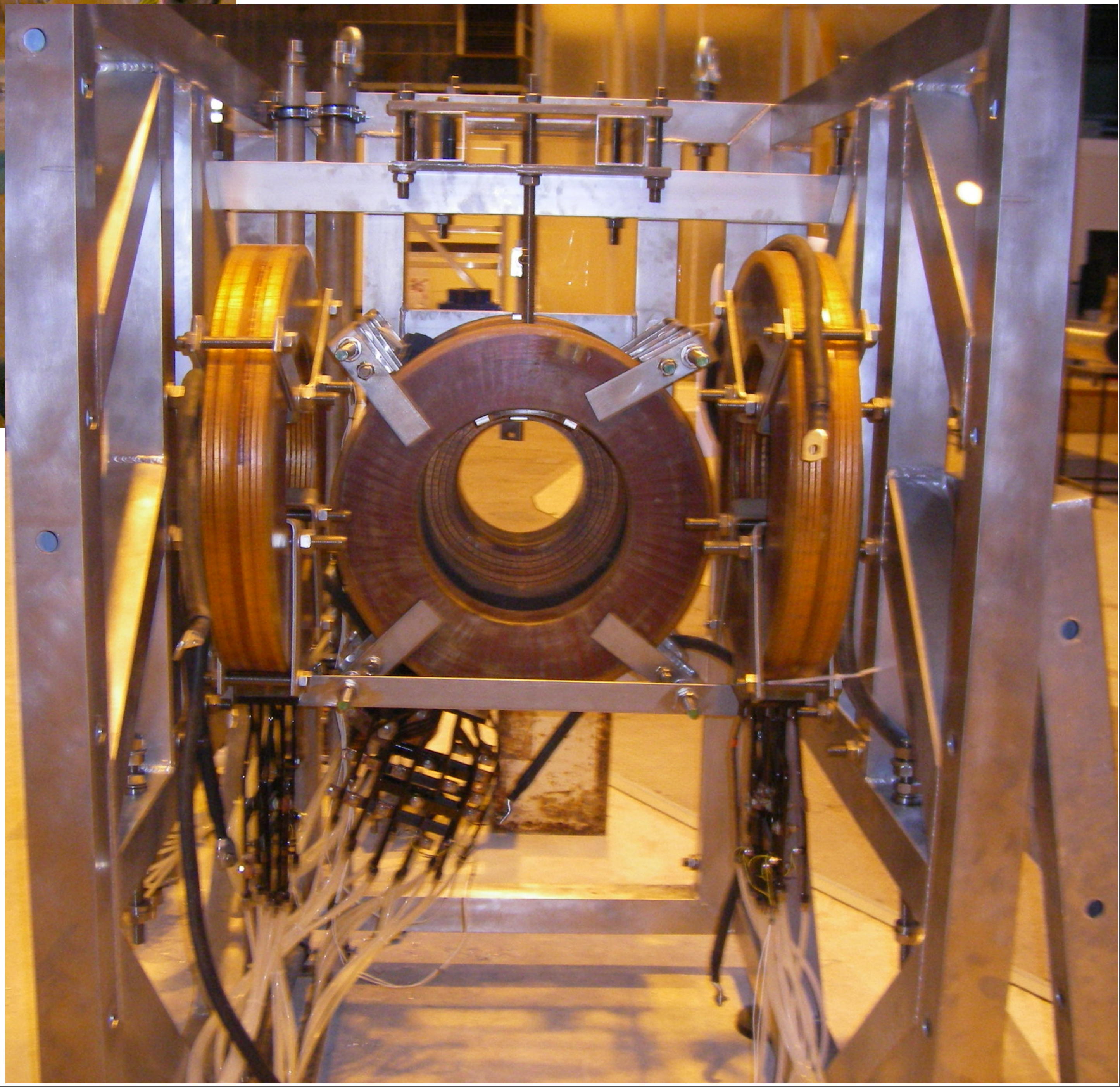

336
357

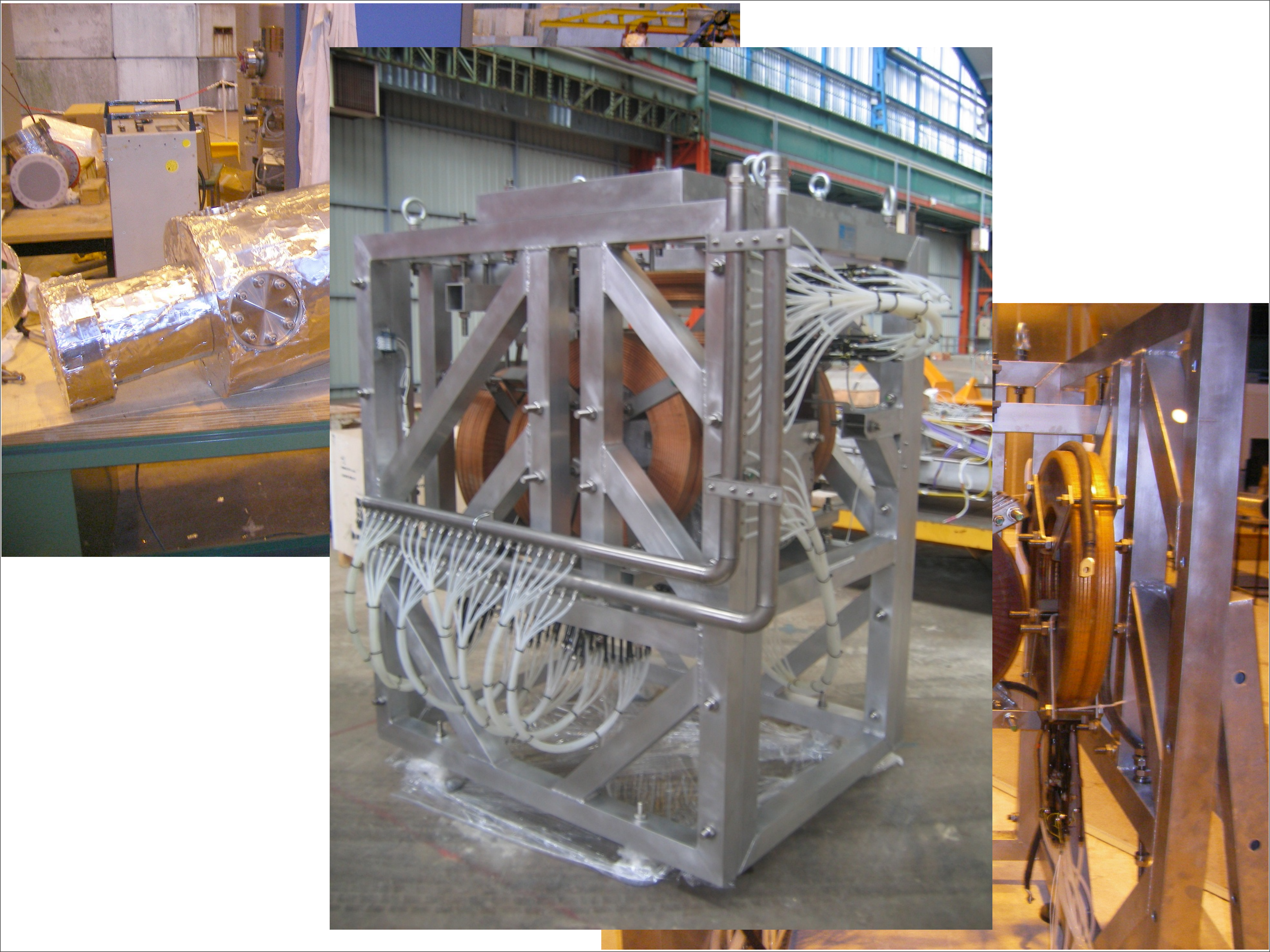

E


E









NEXT STEP

- **e^+ detection -> in 2 weeks!**
- Performance study, optimization -> in 2 months
  - Stability, intensity, size of e^-/e^+ beam
  - New e^+ detector (energy of e^+, precise position)
- Moderator -> spring 2009
  - Try with W, Ne solid

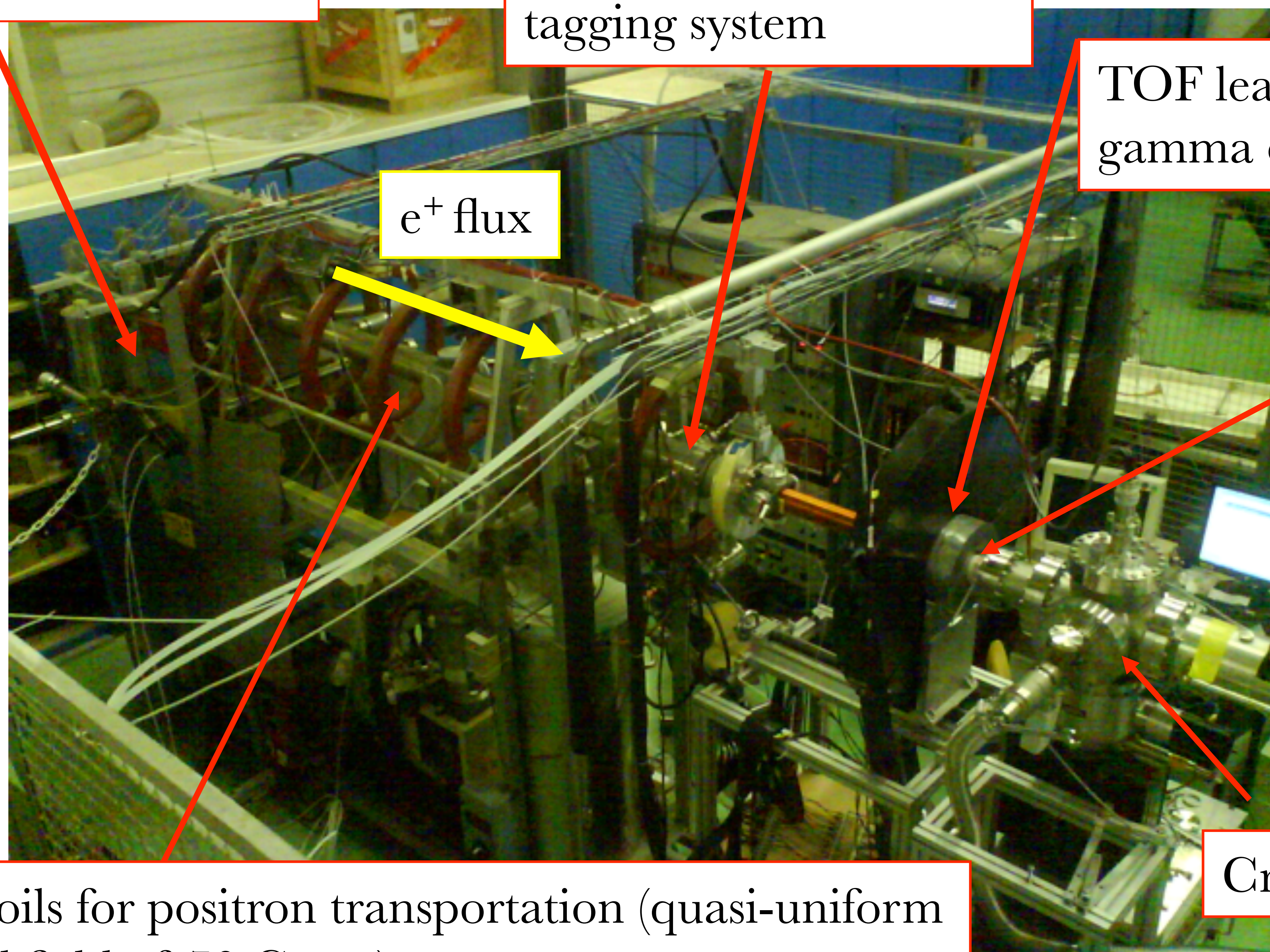
oPs FORMATION STUDY (CERN)

- Only oPs can be used (τ_{oPs}=142 ns τ_{pPs}=125 ps)
  free path of pPs being too short
- High e^+ - oPs conversion efficiency
- No annihilation or oPs quenching
- Effective density **near the converter surface**
  E(oPs) = 3 eV ~ 10 cm flight in 142 ns
  30 meV ~ 1 cm flight in 142 ns

  ➡ Thermal oPs needed

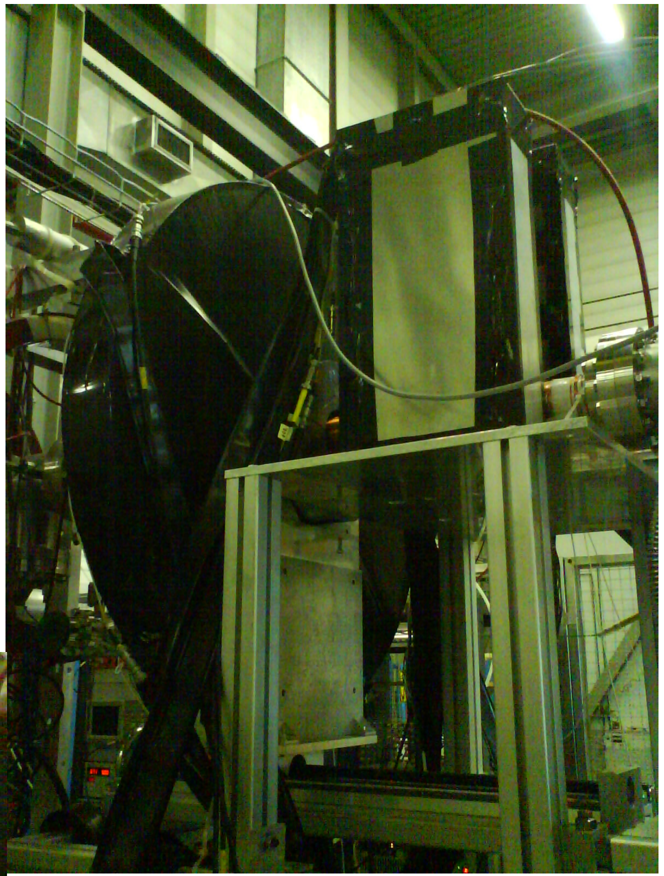
- Good configuration to collide with $\bar{p}$

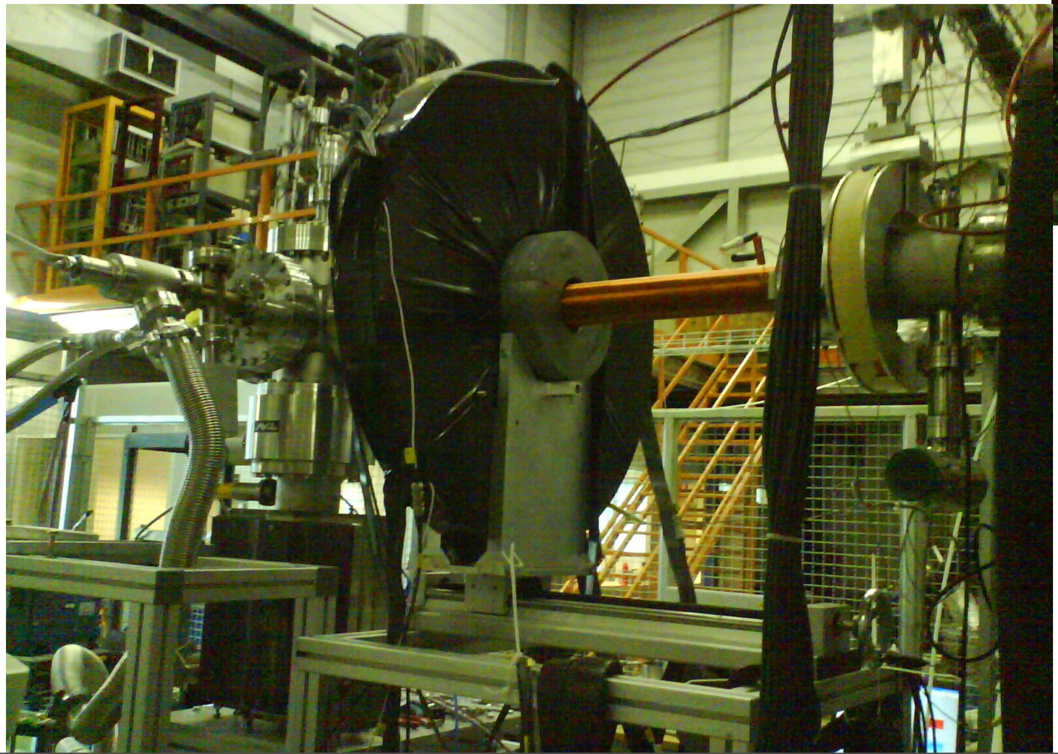
EXPERIMENTAL SETUP



oPs ANNIHILATION DECECTOR

- PALS (Positron Annihilation Lifetime Spectrometry)
  - Fraction of reemitted oPs to injected e^+
  - 2 x 4 BGO scintillator
- TOF (Time Of Flight)
  - Velocity distribution of reemitted oPs in vacuum
  - Lead collimator + 5 BGO





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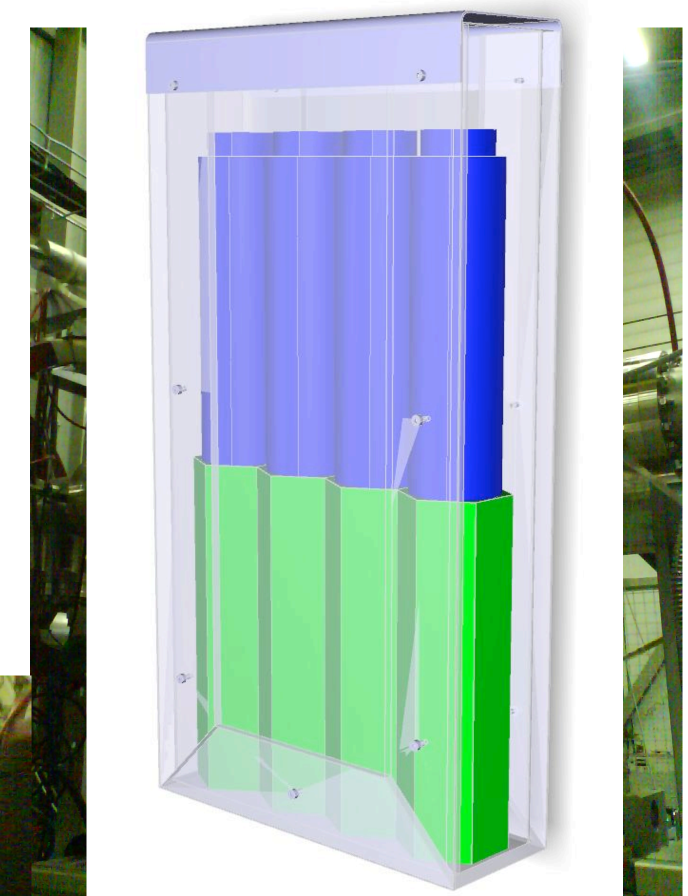

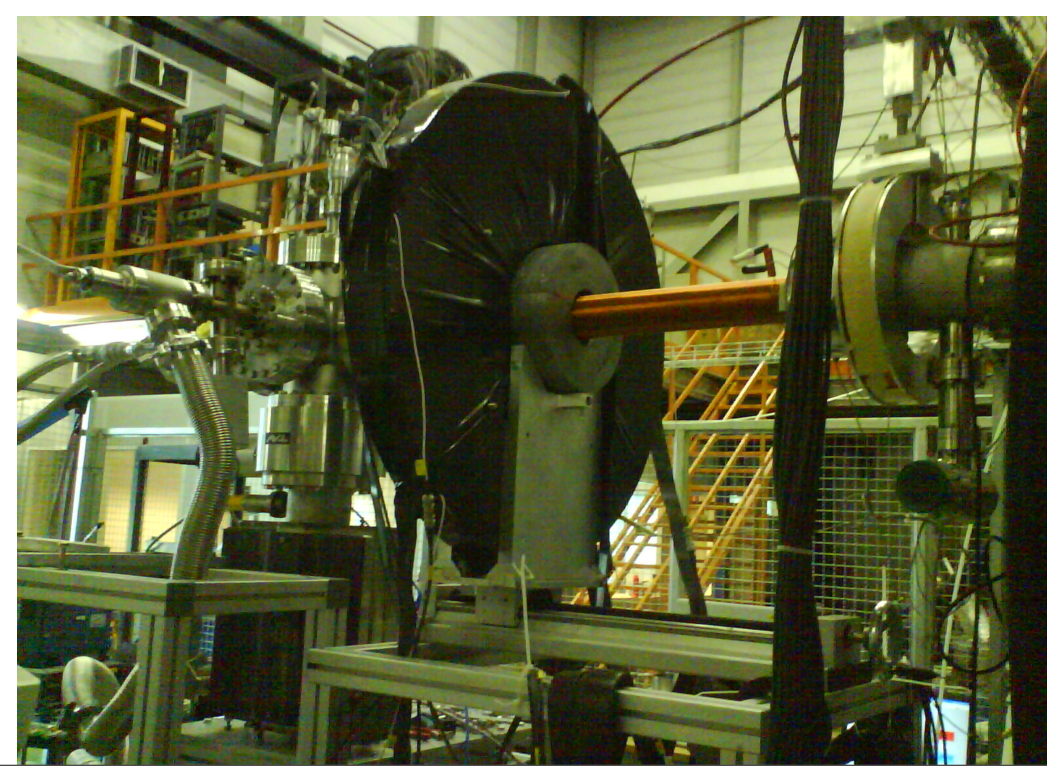

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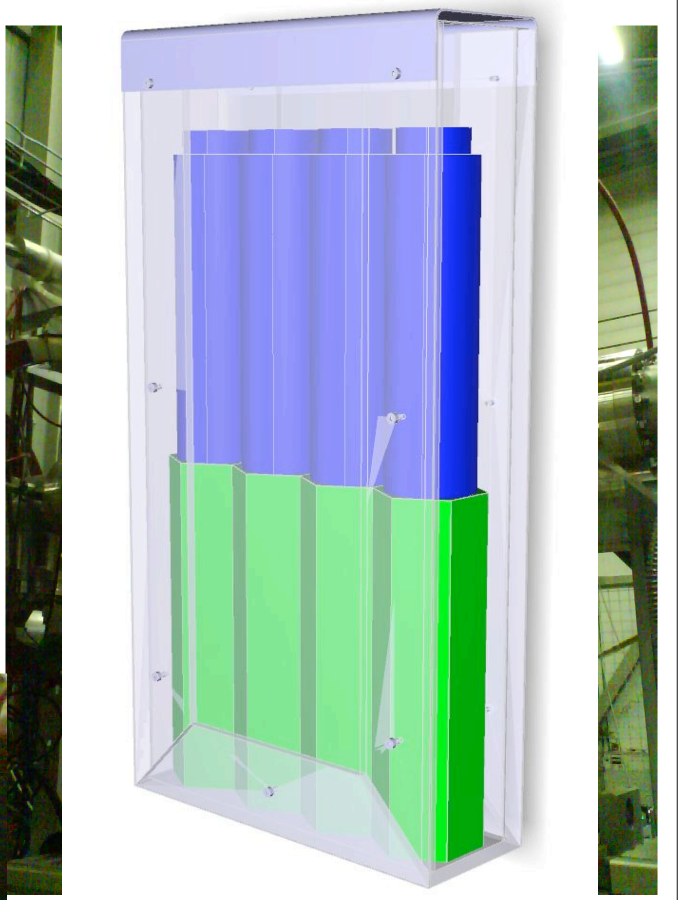
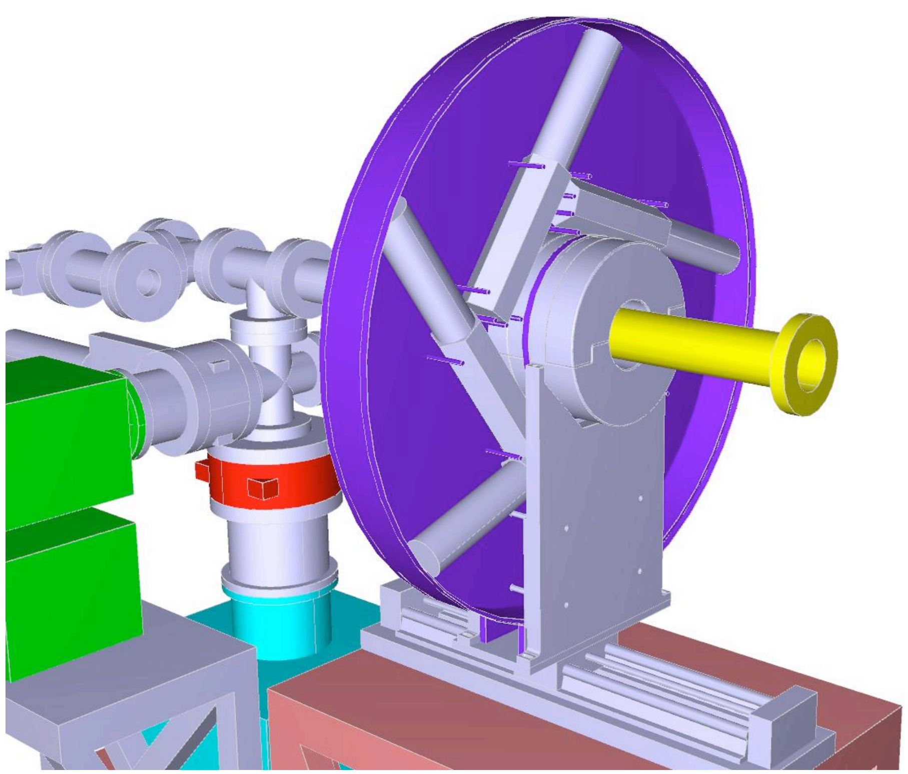
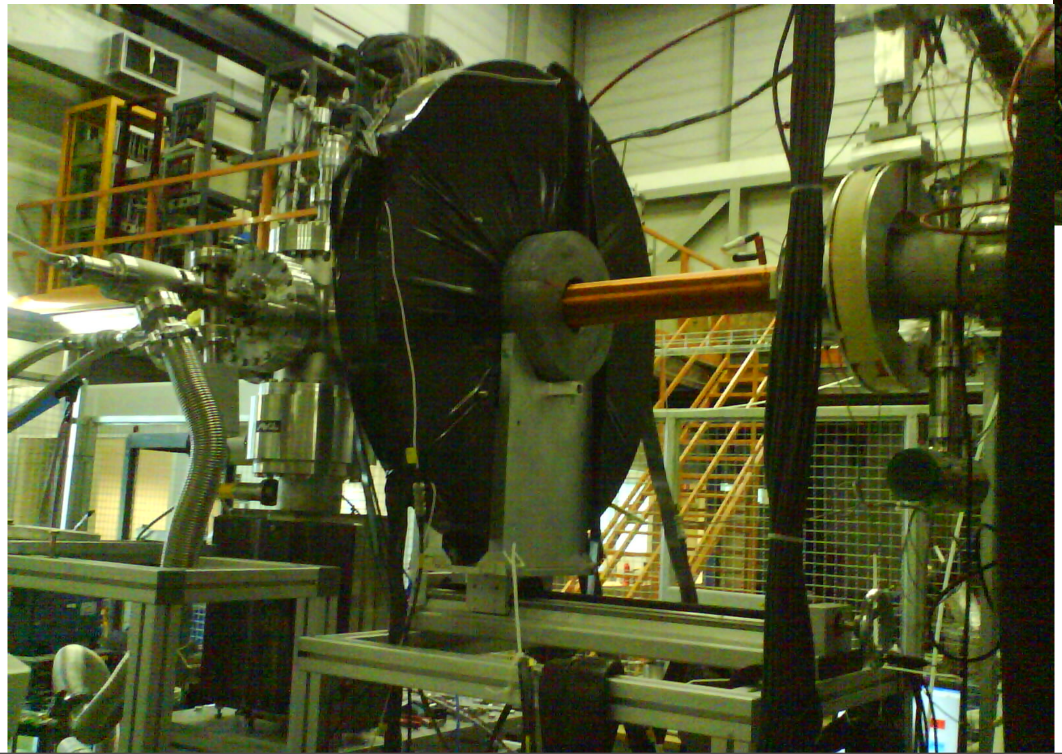




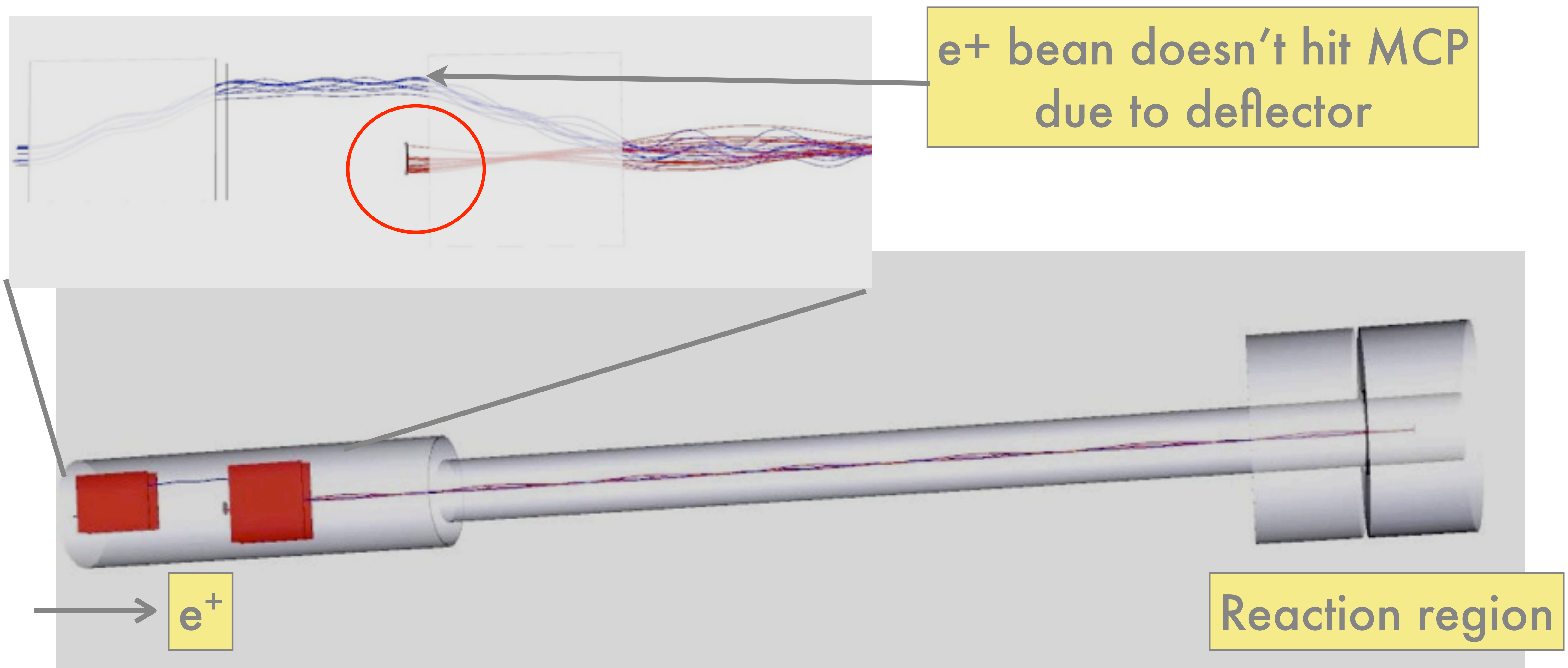


TRIGGER

- Secondary electrons emitted by hitting the target surface

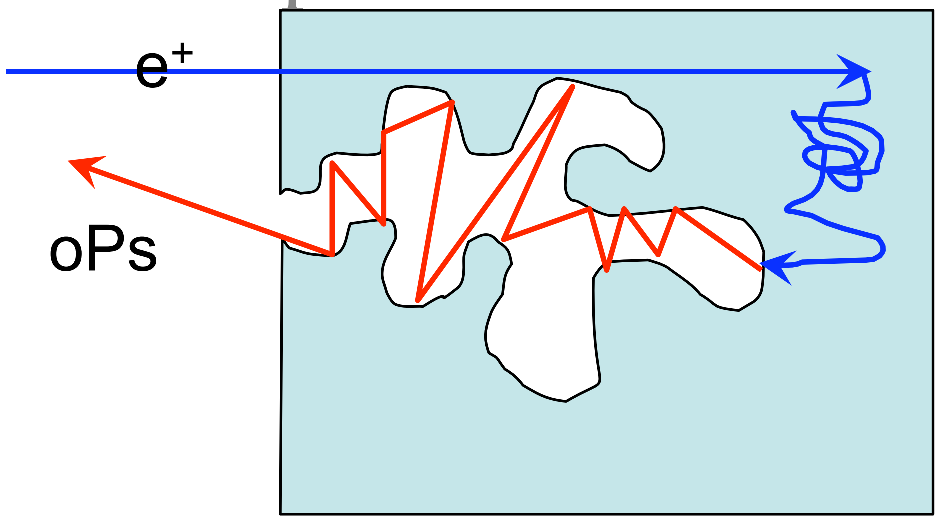
➡ Time t_0 for the Ps formation in the target

➡ Detected with a micro-channel-plate (MCP).



POROUS MATERIALS AS A CONVETOR

- oPs slowing down during collisions with the pore walls and molecules on the internal surfaces

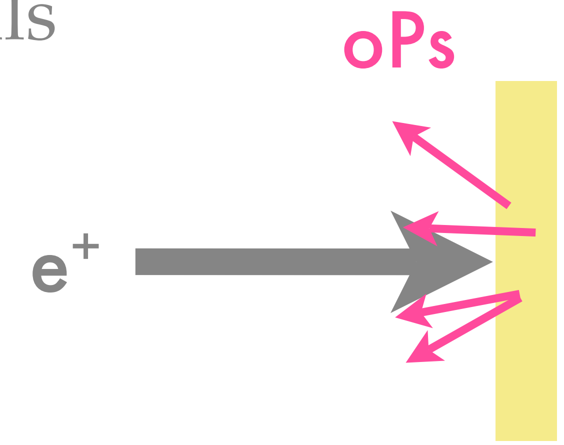


- Advantages:
  - Existing and well developed technology of layer deposition
  - Reproducible emission, ~ 10^{-8} mbar vacuum sufficient
- Problems:
  - No proof for complete thermalization
  - Conversion efficiency seems to be limited ~ 35 % (?)
  - Difficult to measure conversion efficiency (oPs ann. in layer)

PREPARE THE CONVERTOR

- Deposition by spin coating (300-500 nm thickness)
- Heating in air at 130 °C to fix
- Removal of porogen by heating in air at 400 °C
- Pure SiO_2 structure (amorphous walls)

- Previous experiments:
  - 2 x 2 cm^2 plate-type convertor with several materials
  - ~ 35% of conversion efficiency, ~ 100 meV
  - **Cannot collide with $\bar{p}$!**



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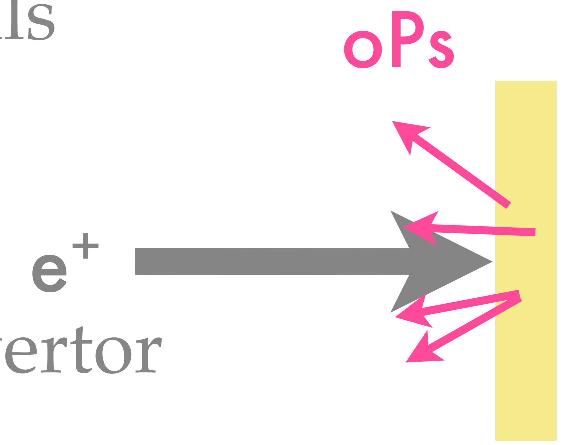
- New configuration (from summer 08): tube-type convertor
  - Secondary electron trigger? -> C foil (15nm-th)
  - Conversion efficiency?



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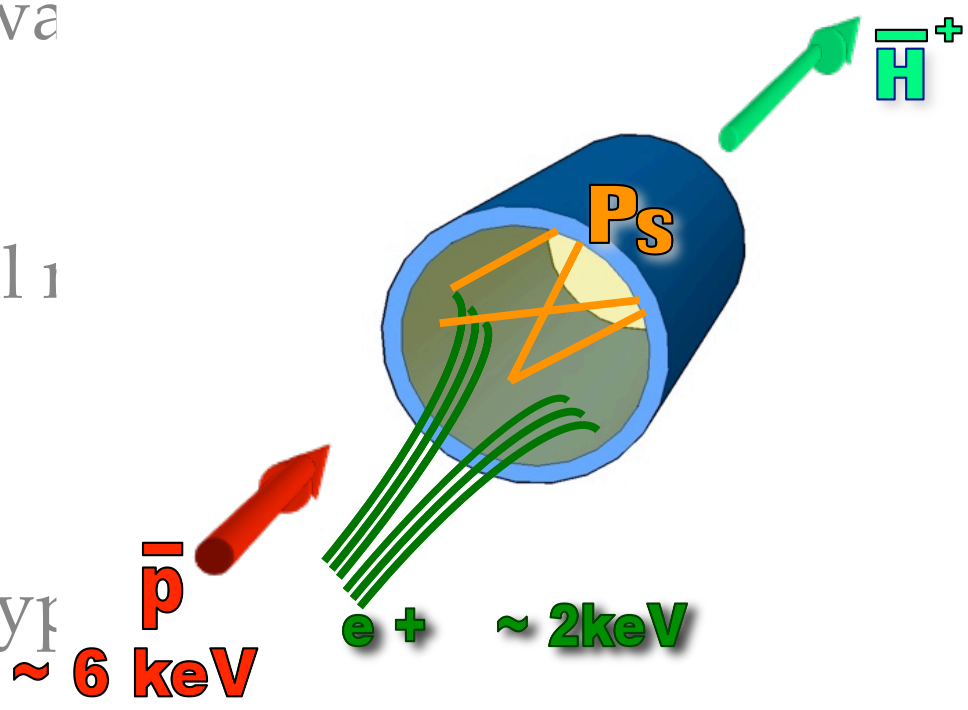

PREPARE THE CONVERTOR

- HV on C foil and tube 1 - 4 keV to extract e^+
- Diameter 1cm
- Length ~ 5cm
- Scattering after C foil

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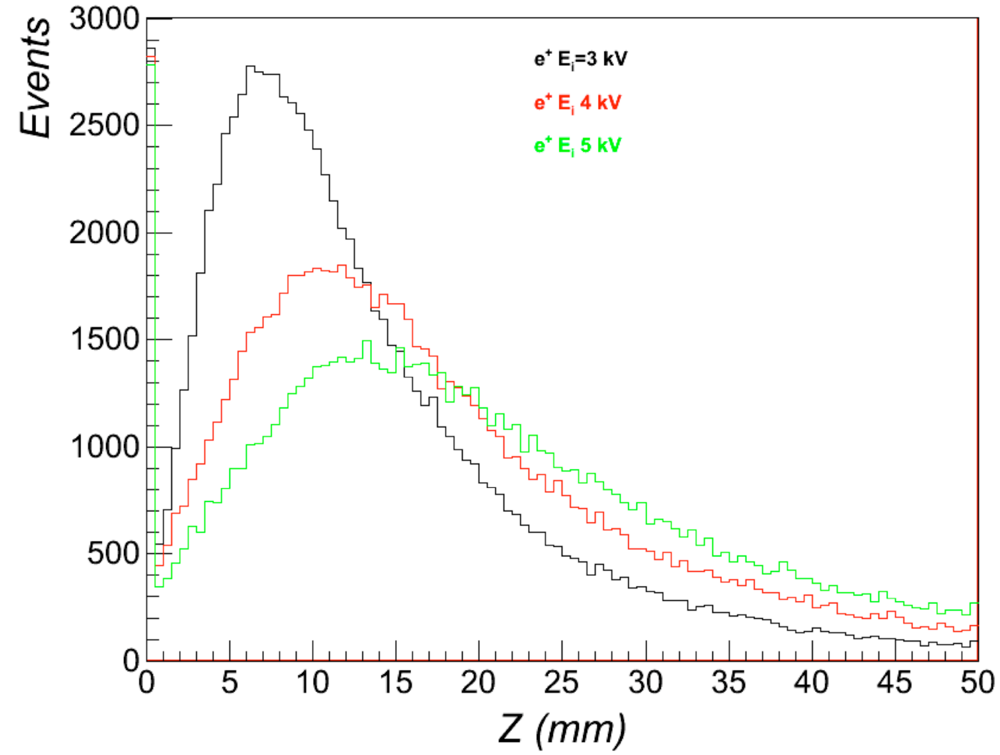
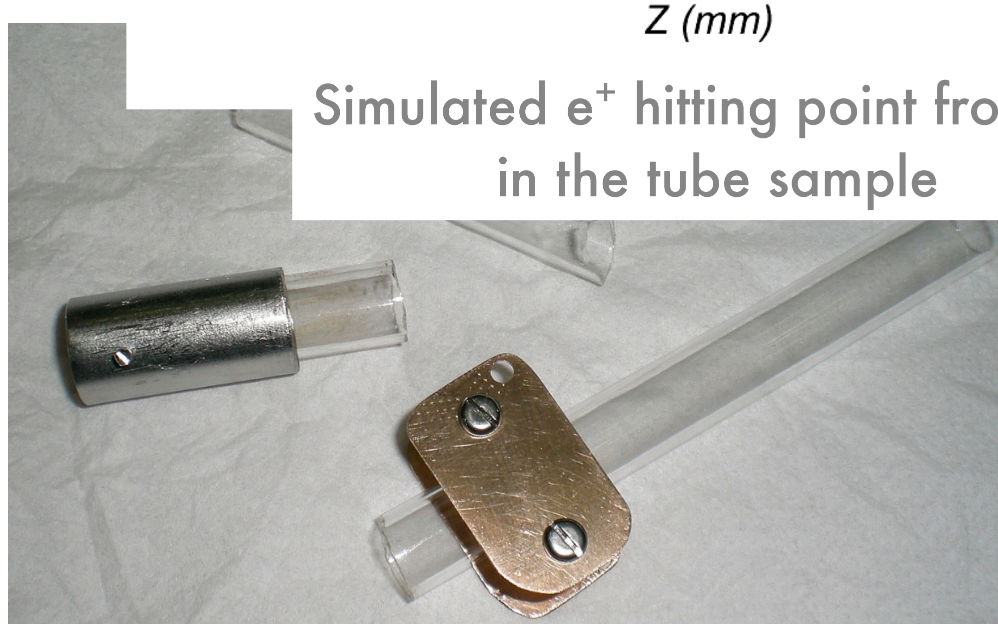
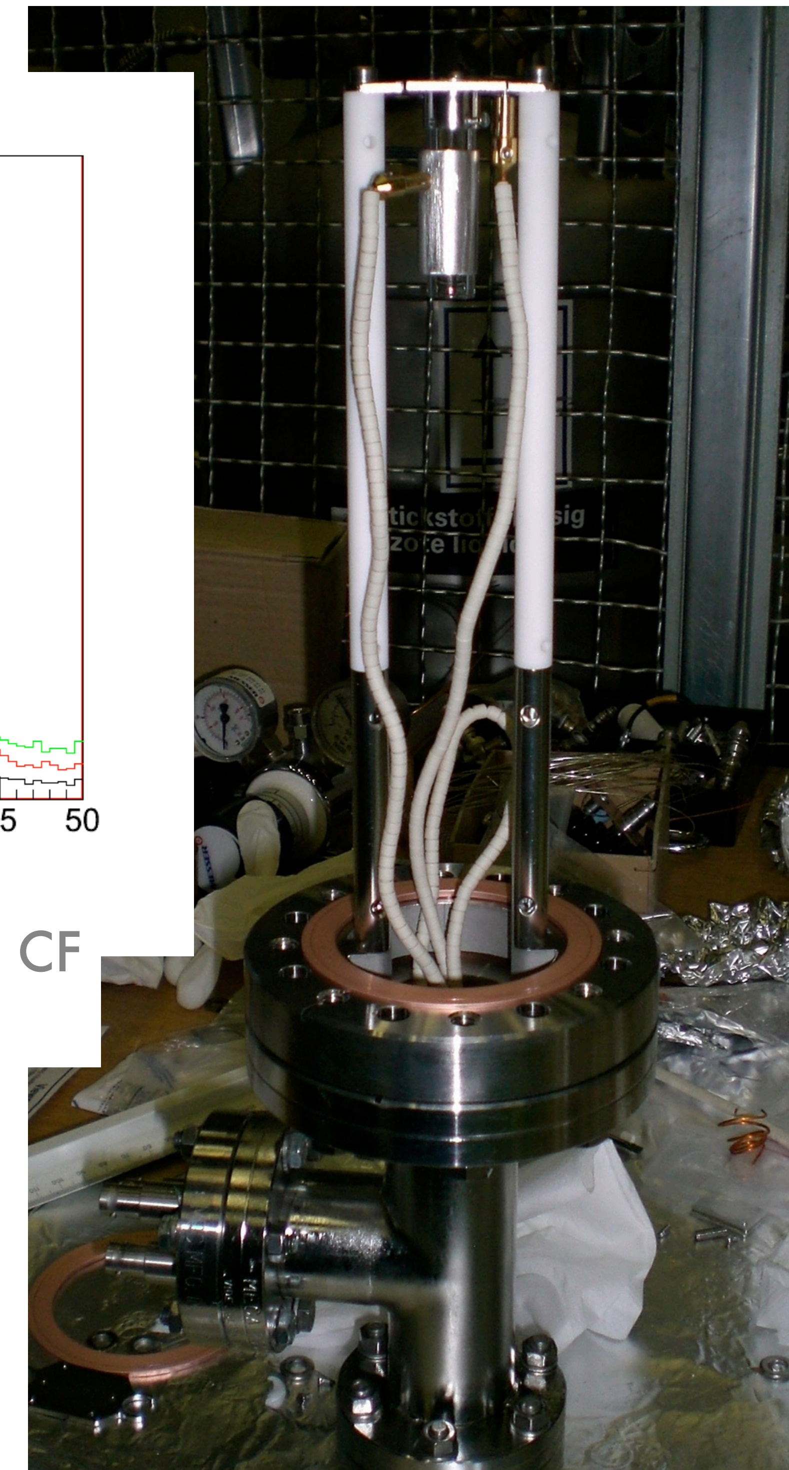
- Diameter 1cm
- Length ~ 5cm
- Scattering after C



Simulated e^+ hitting point from CF in the tube sample



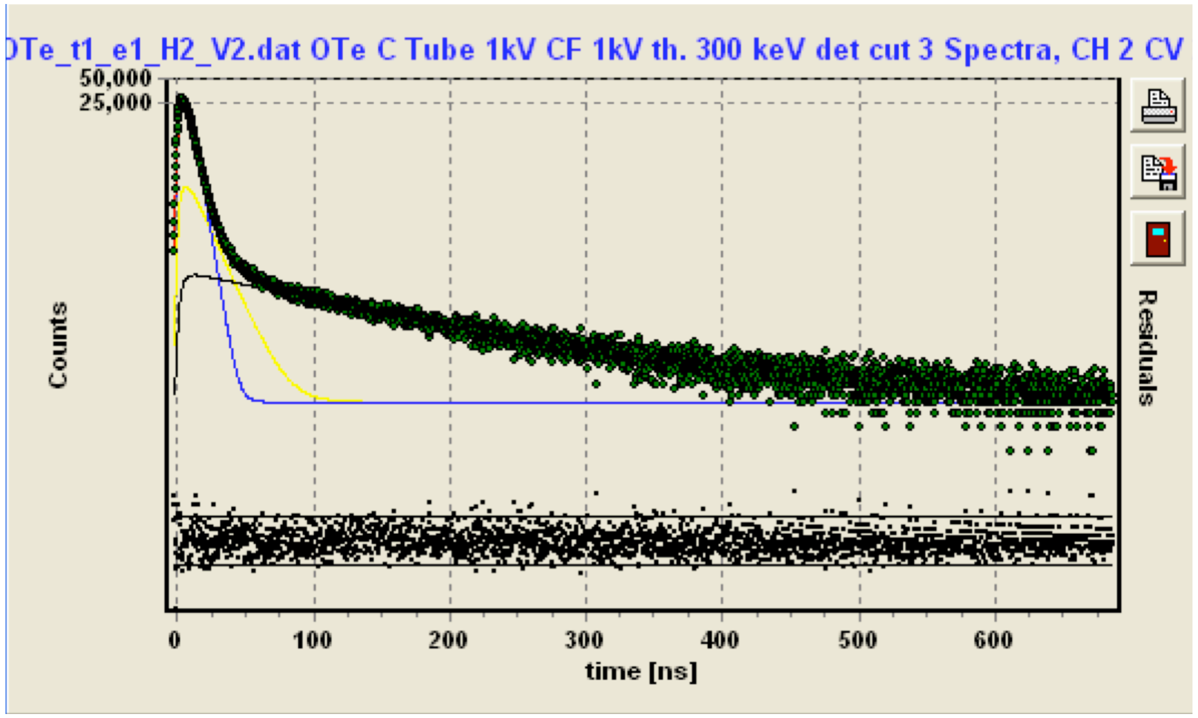


HOT DATA

oPs FRACTION

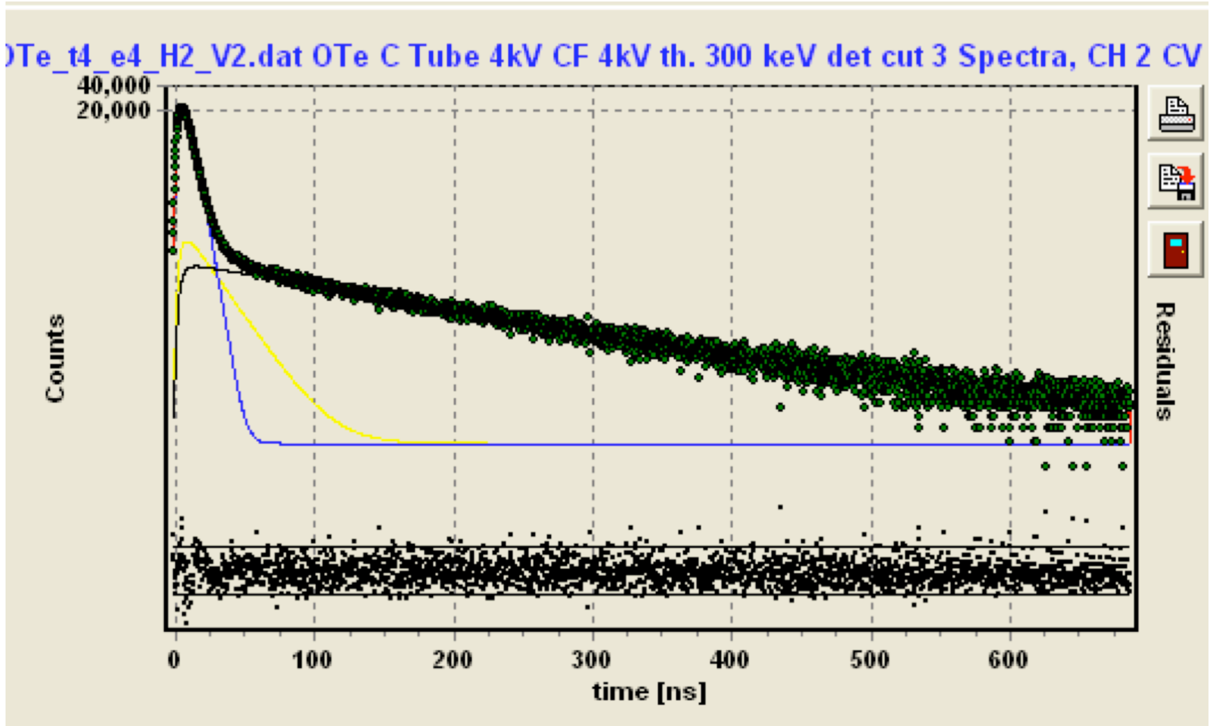
C foil: 1kV, Tube 1kV

intensities [%]	lifetimes [ns]
12.52(0.39)	11.30(0.23)
81.19(0.37)	3.696(0.039)
6.295(0.052)	115.3(1.2)



C foil: 4kV, Tube 4kV

intensities [%]	lifetimes [ns]
4.96(0.33)	17.834(0.096)
80.49(0.30)	3.8(1.0)
14.55(0.13)	144.78(0.21)



SUMMARY / OUTLOOK

- e^+ source is almost installed at Saclay
  - First e^- will be in this week
  - First e^+ will be detected in 2 weeks
  - Optimization
  - Moderator installation for low-energy beam
  - Penning trap installation for high intensity
- oPs is formed in tube type samples
  - Configuration study
  - Fix the best condition, combination of extraction HV
  - Improve the preparation method
- Collaboration for $\bar{p}$ beam