The AEgIS Experiment

Measuring the Gravitational Interaction of Antimatter

Andreas Knecht / CERN

on behalf of the AEgIS collaboration

LEAP 2013, 10/6/2013

AEgIS Collaboration

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INFN, Università degli Studi and Politecnico Milano, Italy

INFN Pavia-Brescia, Italy

INR Moscow, Russia

Université Claude Bernard, Lyon, France

University of Oslo and University of Bergen, Norway

Czech Technical University, Prague, Czech Republic

INFN Padova-Trento, Italy

ETH Zurich, Switzerland

Laboratoire Aimé Cotton, Orsay, France

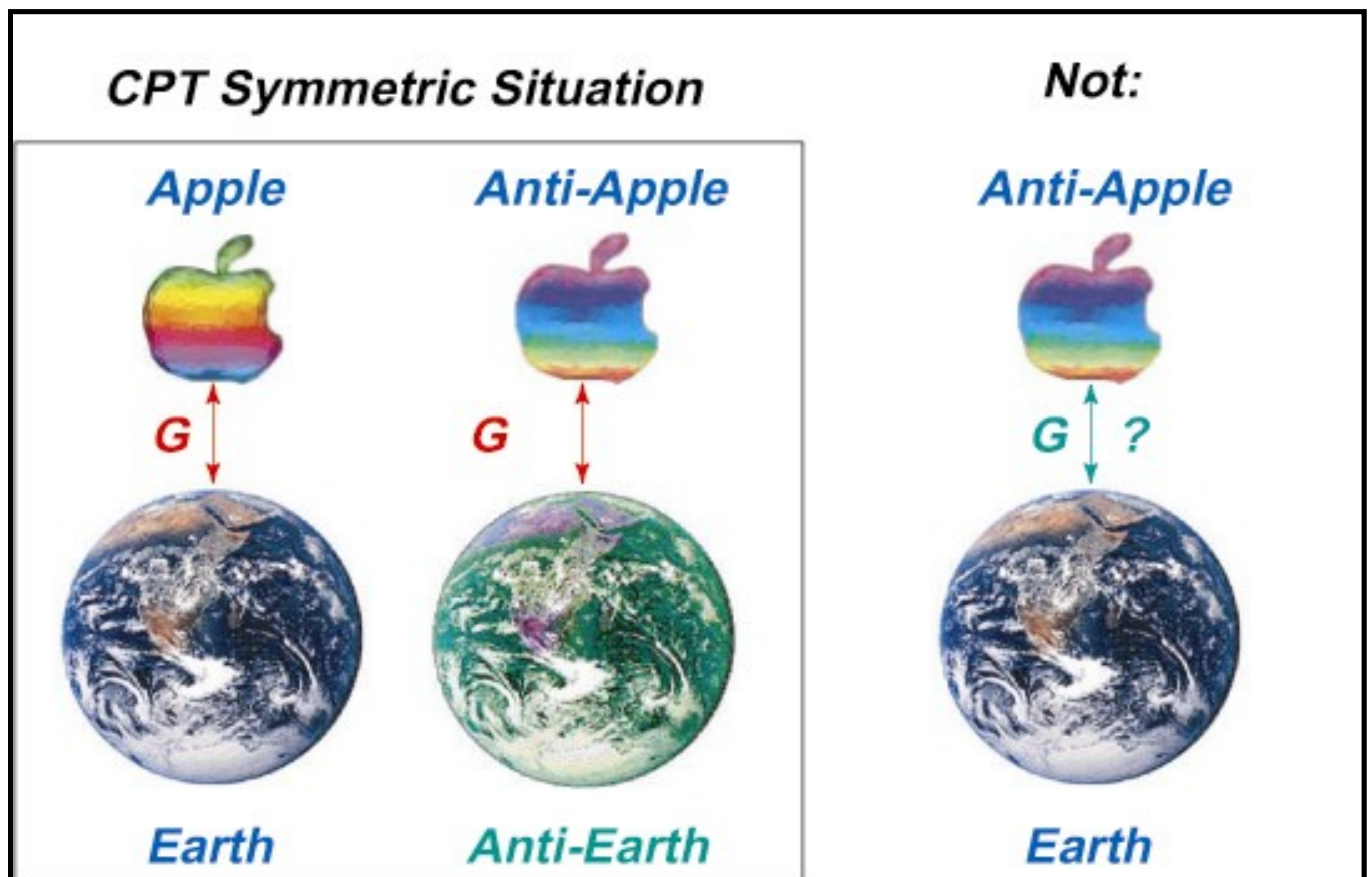
University College, London, United Kingdom

Stefan Meyer Institut, Vienna, Austria

University of Bern, Switzerland

Motivation

- First direct test of the Weak Equivalence Principle involving antimatter
  - Direct tests so far only for matter systems
  - Validity for antimatter inferred from heavily debated indirect arguments
  - Theory could accommodate differences
    (e. g. through potential including gravivector and graviscalar)



Nieto and Goldman, Phys. Rep. 205, 221 (1991)
Amole et al., Nat. Comm. 4:1785 (2013)

Motivation

And quite generally:
Experimental test of the gravitational interaction in a new sector - one for the textbooks (and for the public)!

AEgIS Experimental Goal

- Primary goal:
  - Measurement of gravitational acceleration **g** for antihydrogen with 1% accuracy

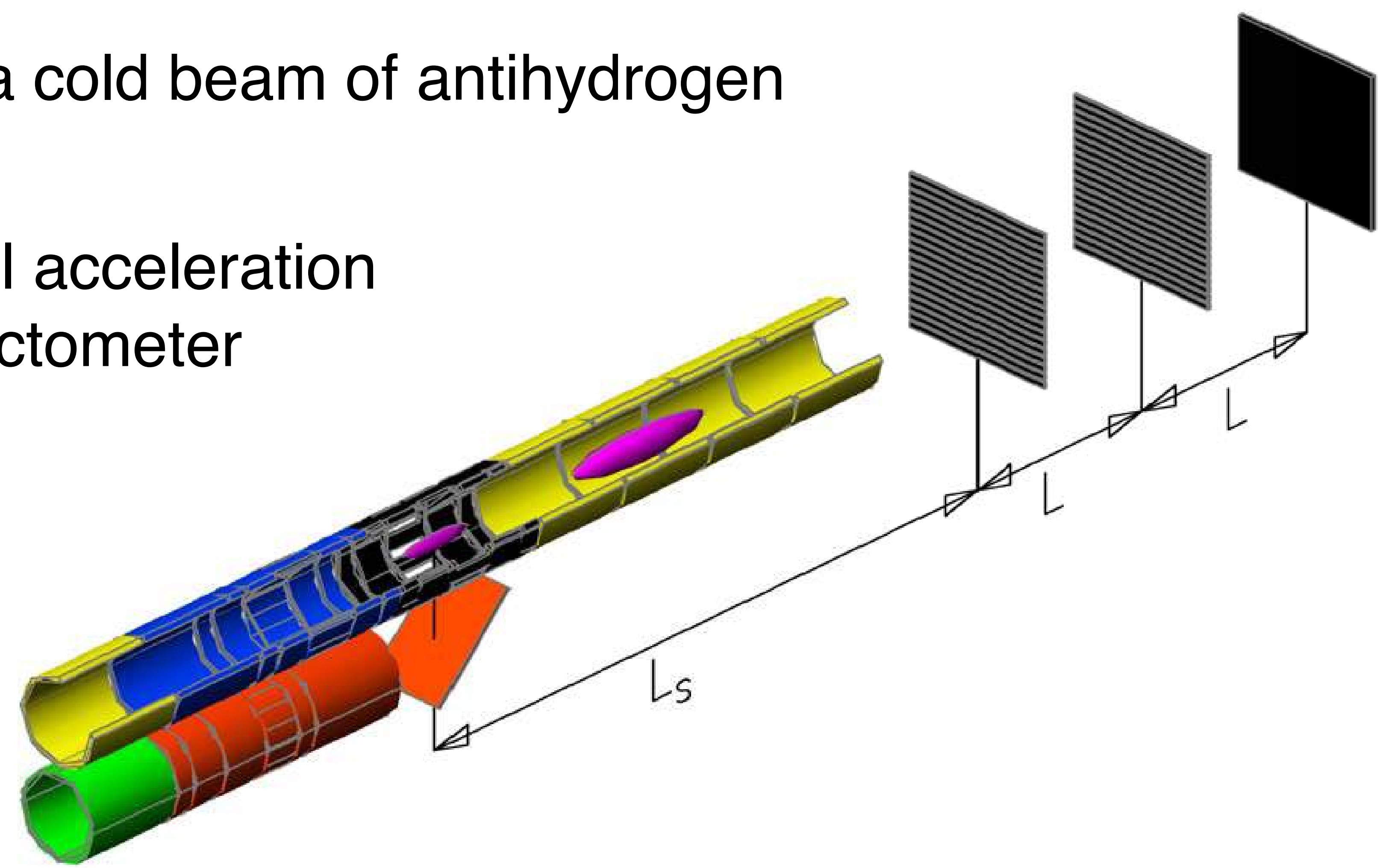
- Secondary goals:
  - Spectroscopy of antihydrogen
  - Study of Rydberg atoms
  - Positronium physics: formation, excitation, spectroscopy

AEgIS Experimental Strategy

- Produce ultra cold antiprotons
- Form positronium by interaction of positrons with a porous target (pulsed)
- Laser excite Ps to get Rydberg Ps (pulsed)
- Form Rydberg cold antihydrogen (pulsed) by $Ps^* + \overline{p} \rightarrow \overline{H}^* + e^-$
- Stark accelerate the antihydrogen with inhomogeneous electric fields

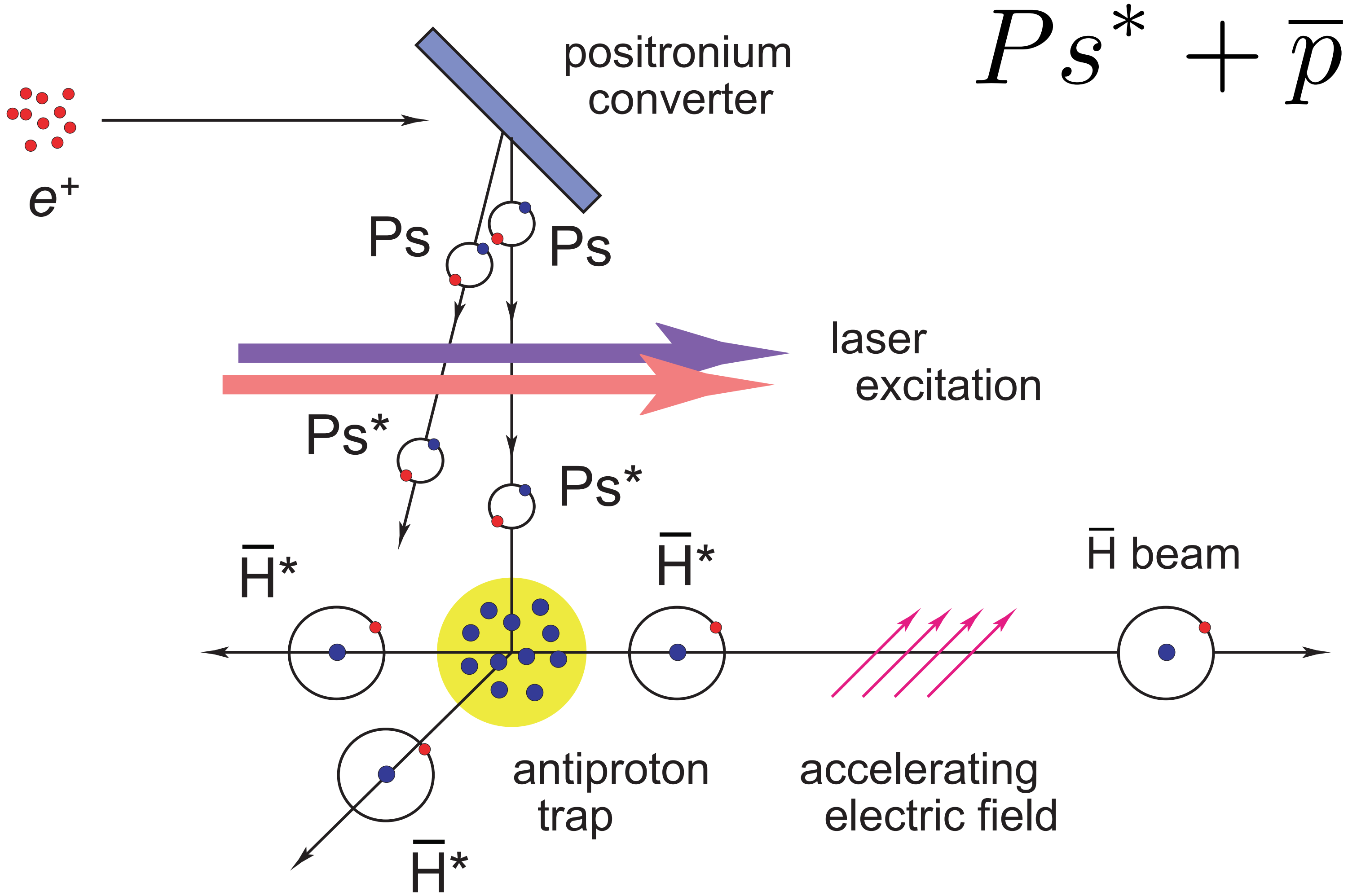
→ Pulsed production of a cold beam of antihydrogen

- Measure the gravitational acceleration in a classical moiré deflectometer

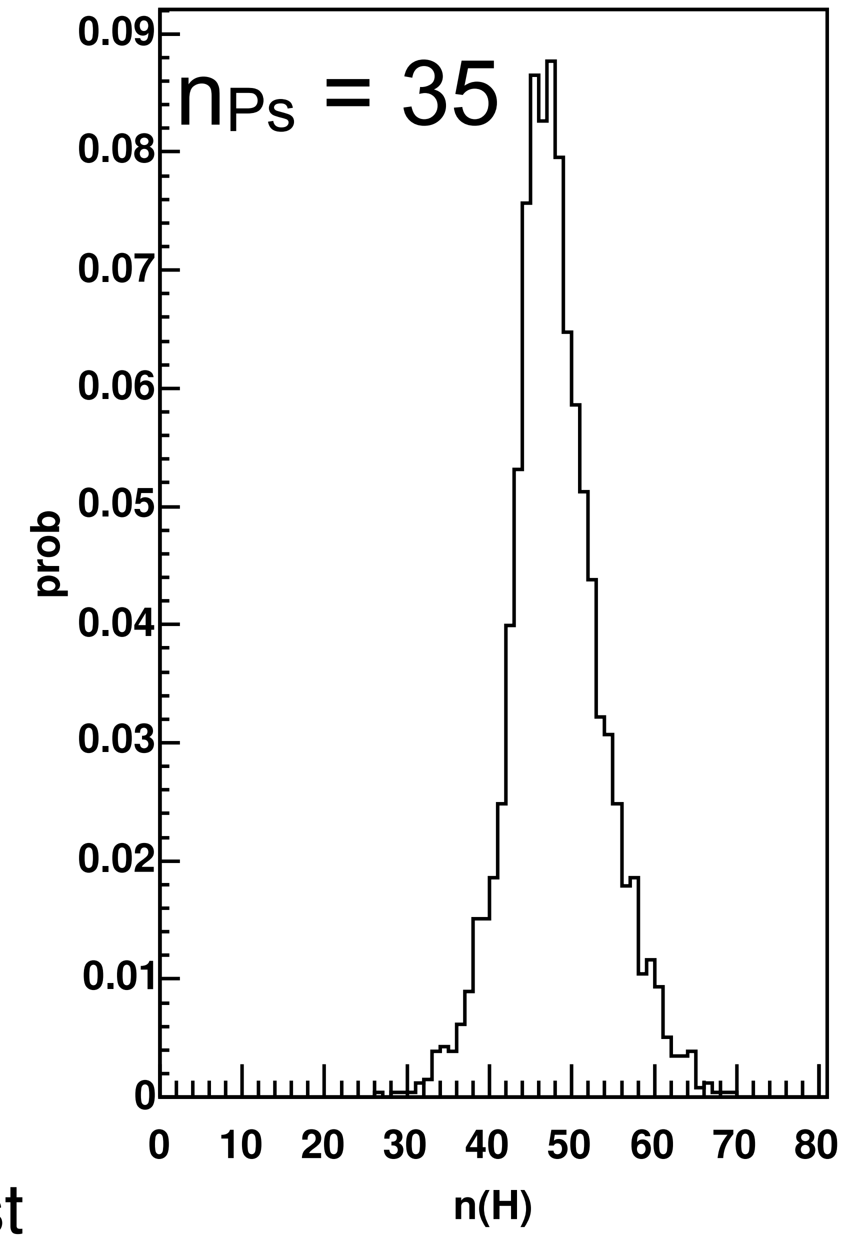


Storry et al., PRL **93**, 263401 (2004)
Vliegen and Merkt, J. Phys. B: At. Mol. Opt. Phys. **39**, L241 (2006)

Antihydrogen Formation

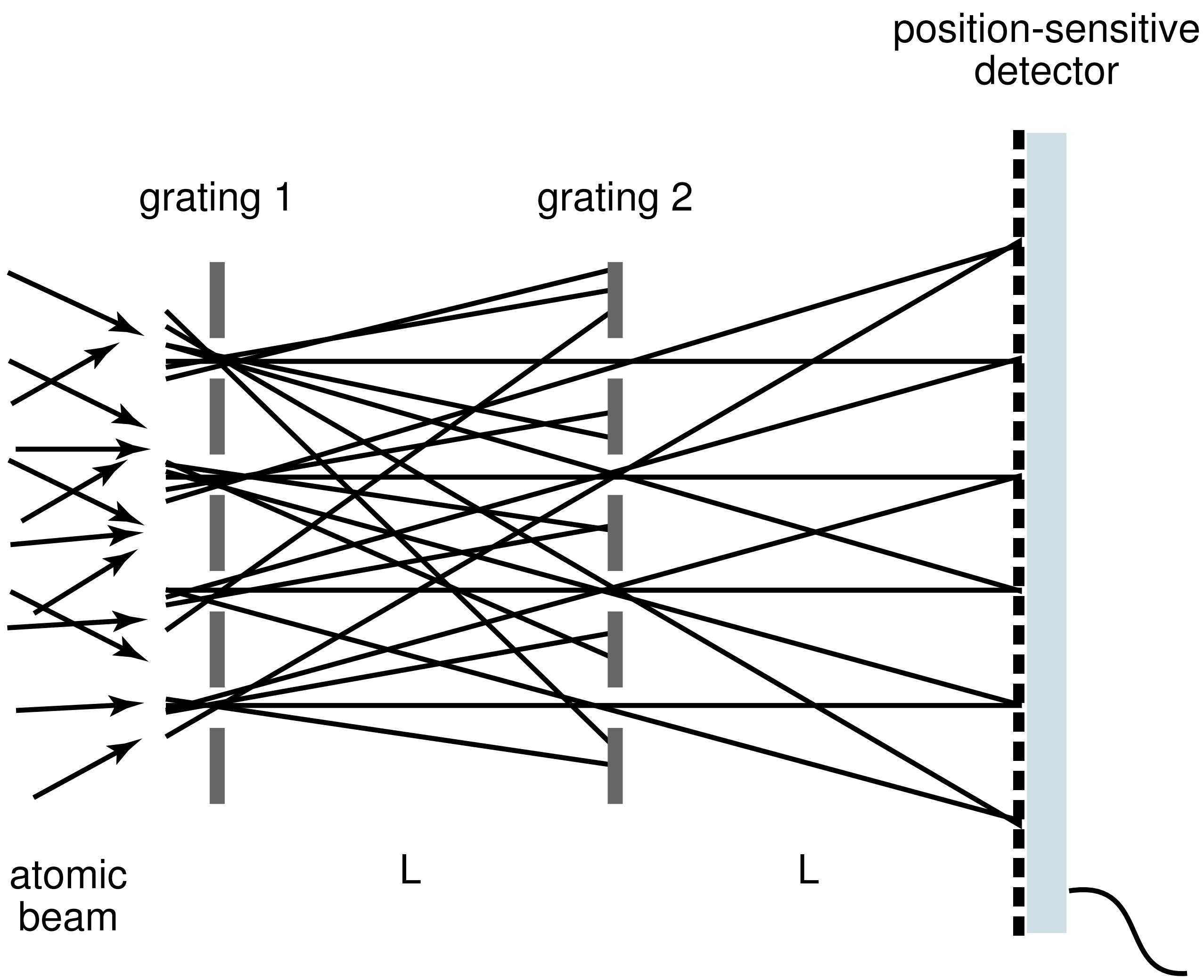


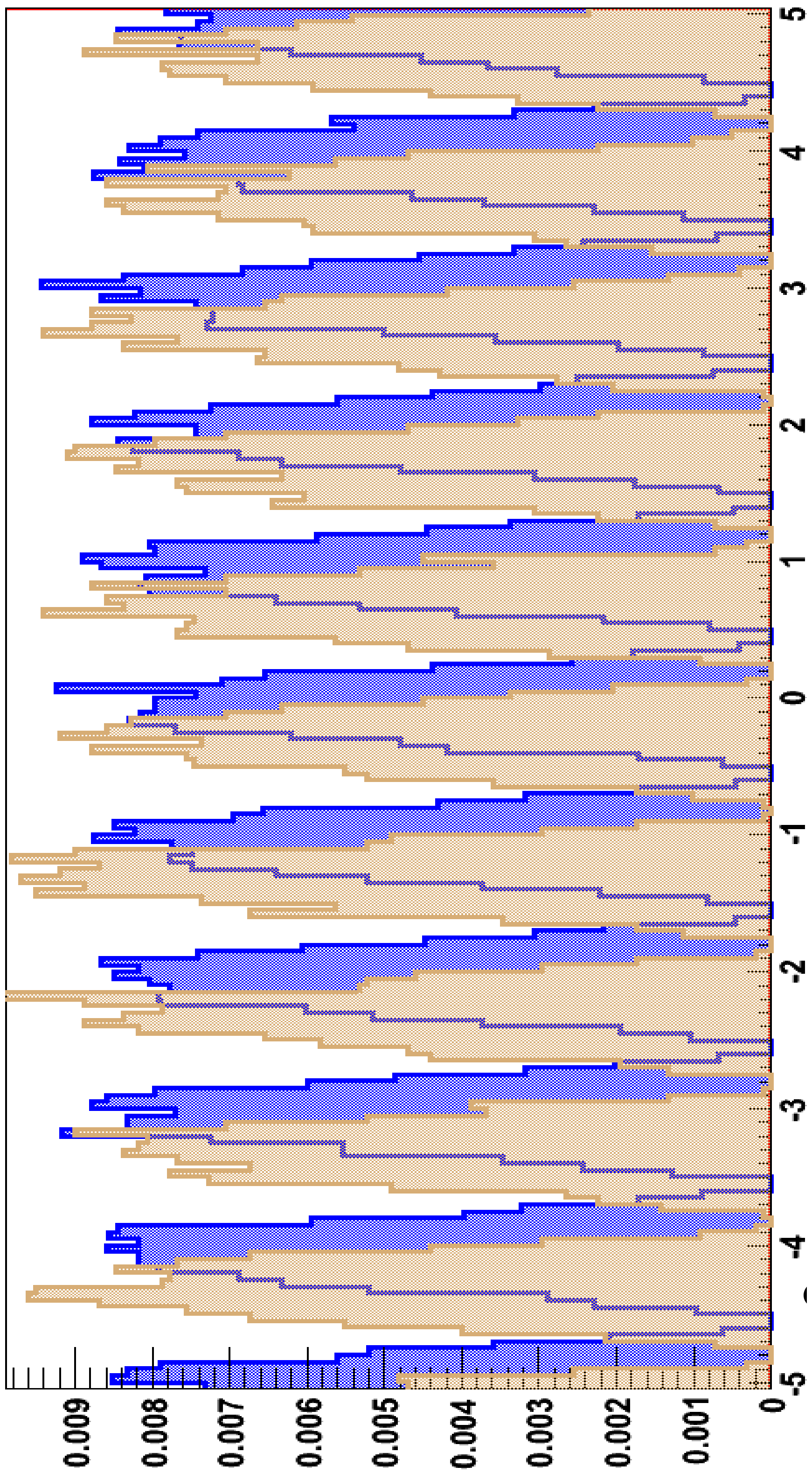
$$Ps^* + \overline{p} \longrightarrow \overline{H}^* + e^-$$



- Positronium charge exchange technique:
  - Large cross-section, scales as n^4
  - Narrow and defined final state distribution
  - Antihydrogen production from antiprotons at rest

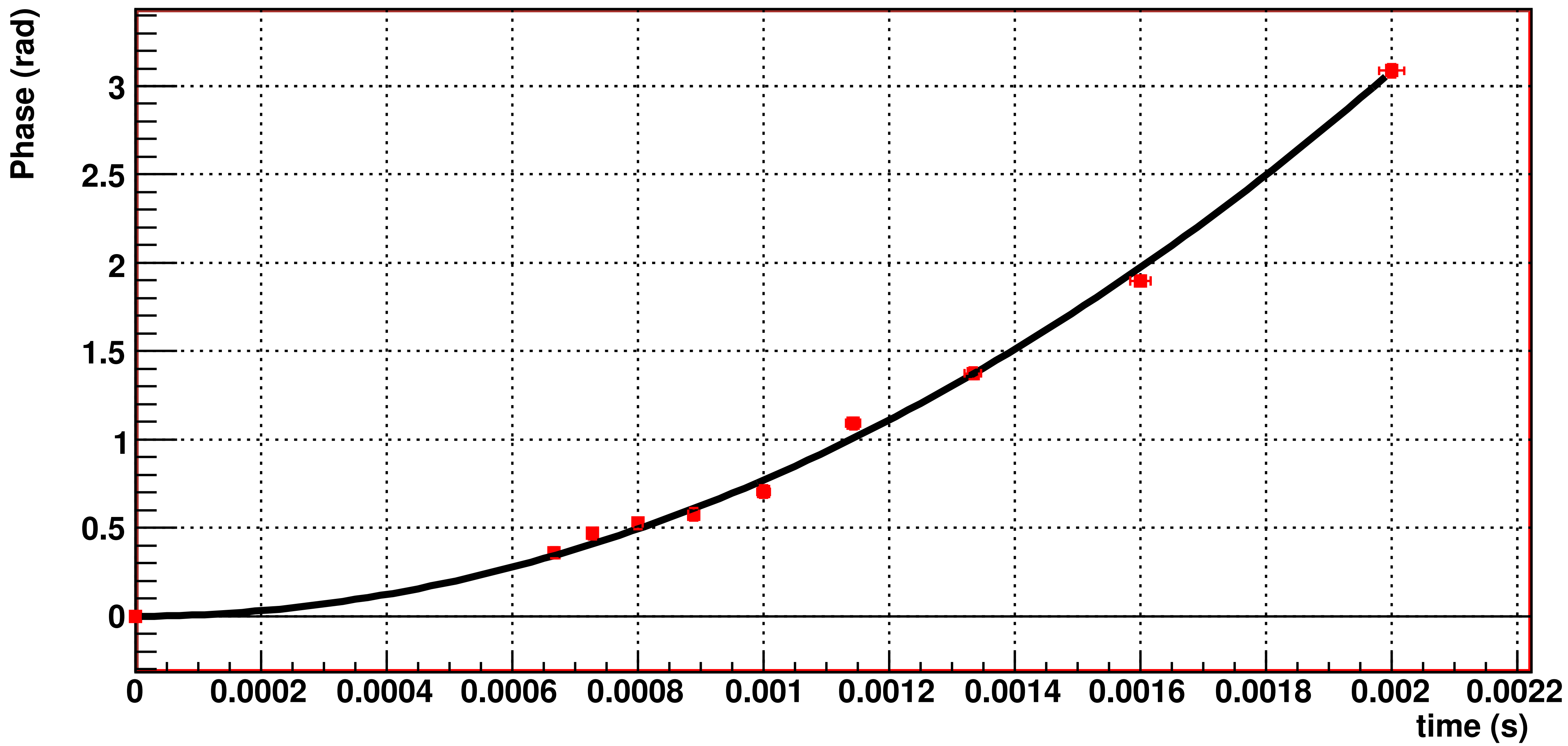
Moiré Deflectometer





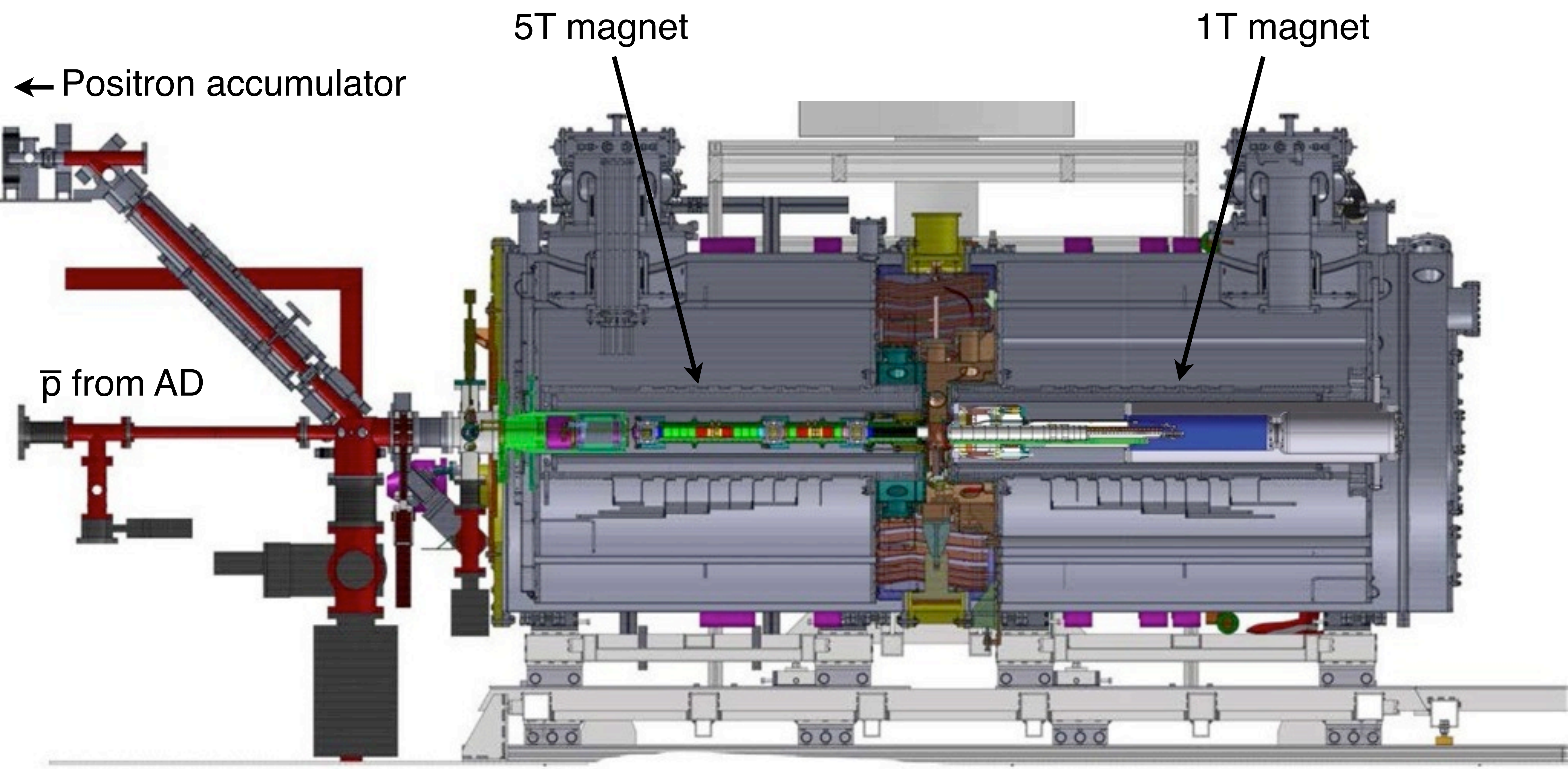
- Classical deflectometer (shadow mask)
- Third grating replaced by position-sensitive detector

Moiré Deflectometer

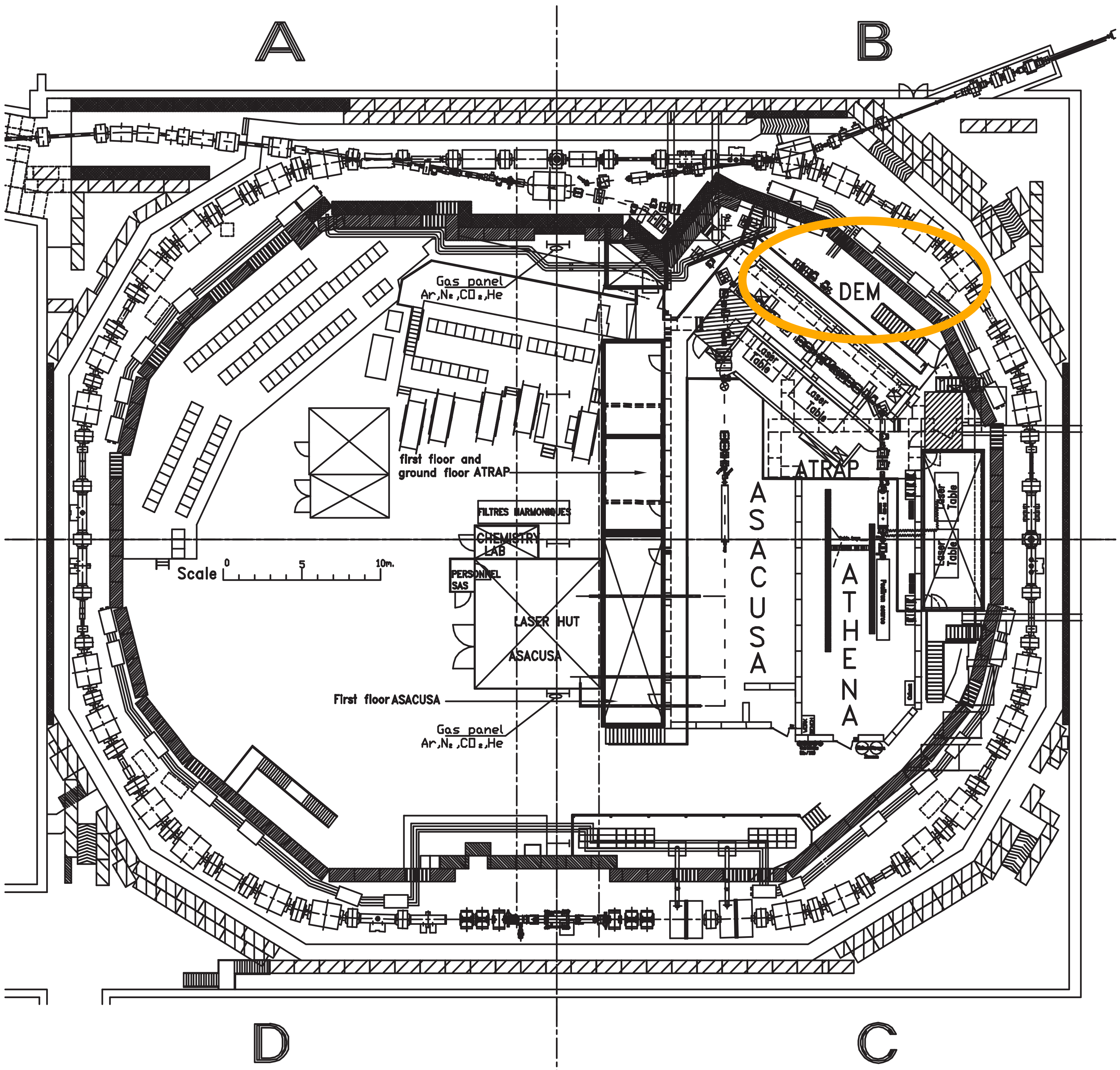


- Phase shift as a function of time (velocity of antihydrogen) gives gravitational acceleration: $\Delta z \sim gt^2$

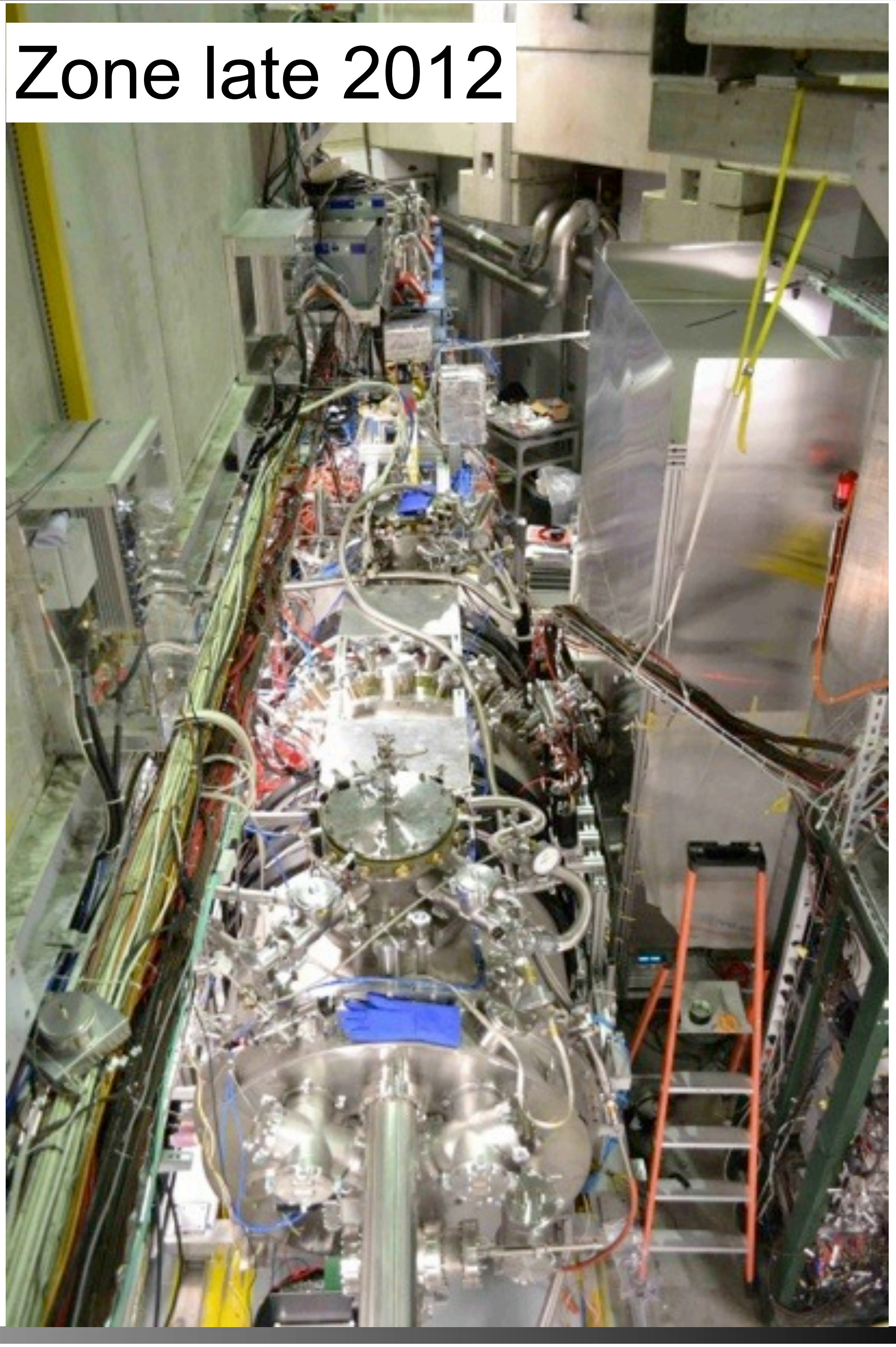
Experimental Apparatus



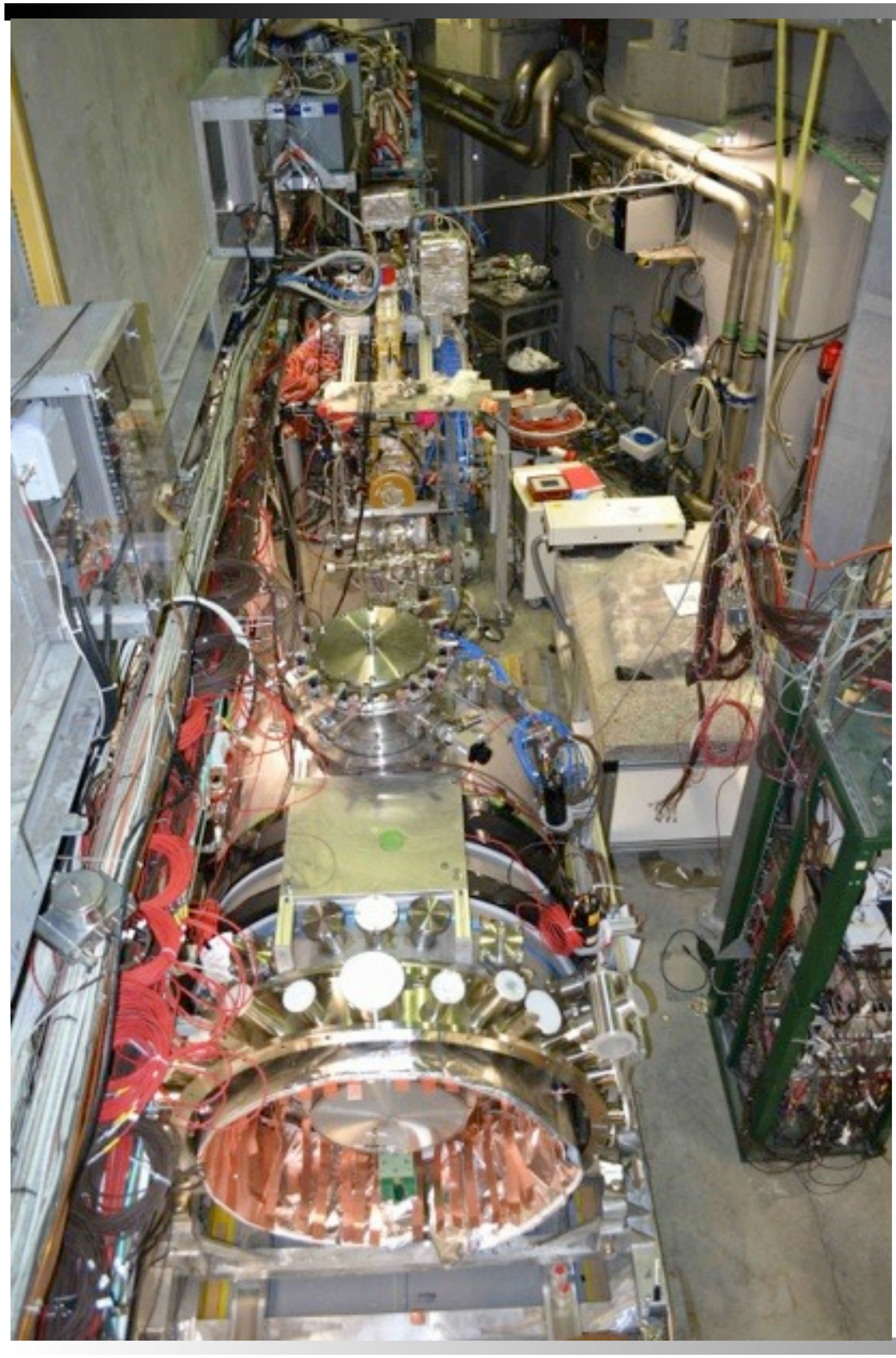
Location

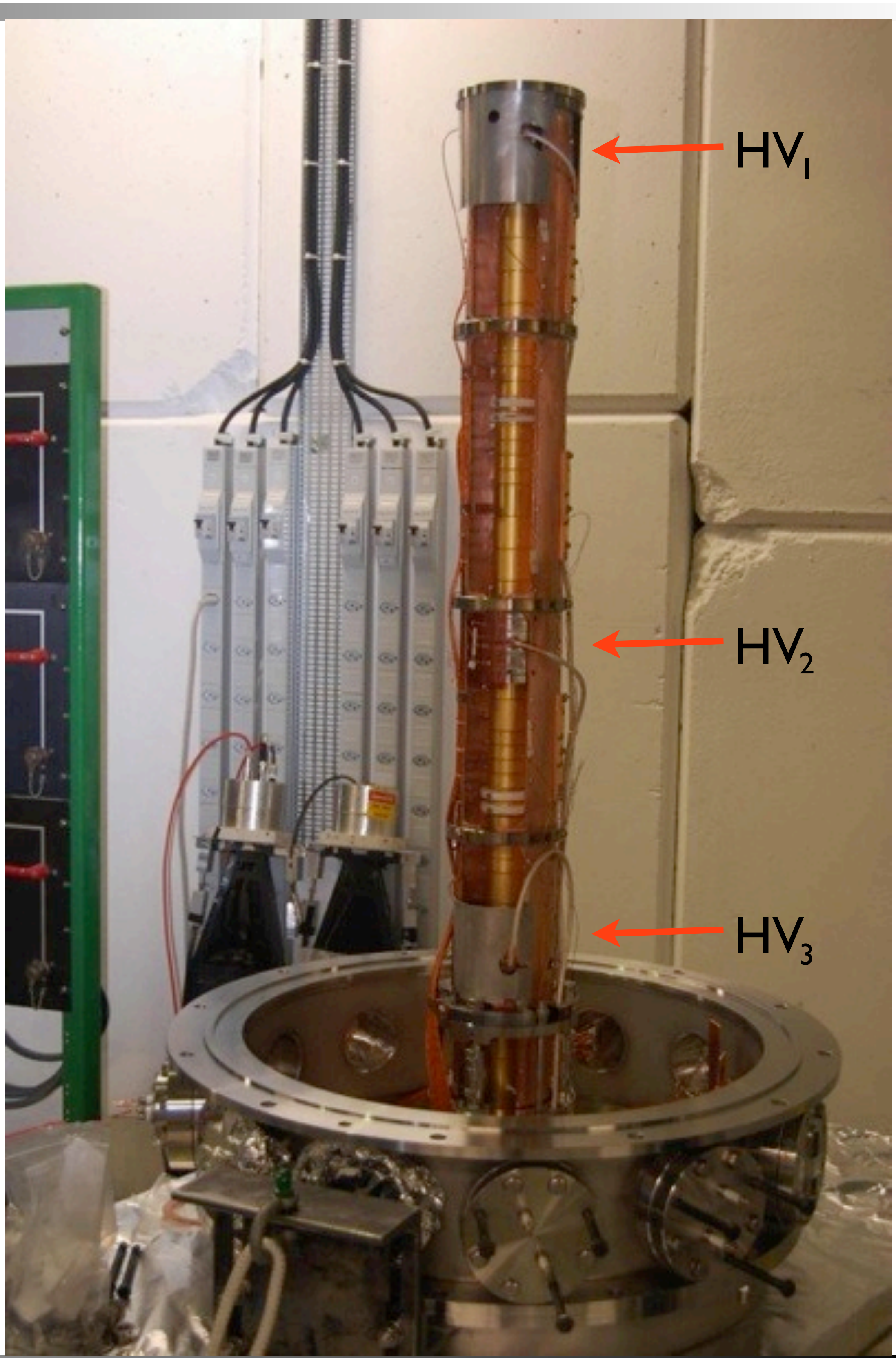

A
B
C
D
DEM
Gas panel
Ar,N₂,CO₂,He
first floor and
ground floor ATRAP
FILTRES HARMONIQUES
CHEMISTRY LAB
PERSONNEL SAS
LASER HUT
ASACUSA
First floor ASACUSA
Scale
0
5
10m.
ATRAP
ASACUSA
ATHENA
Laser Table

Experimental Installation

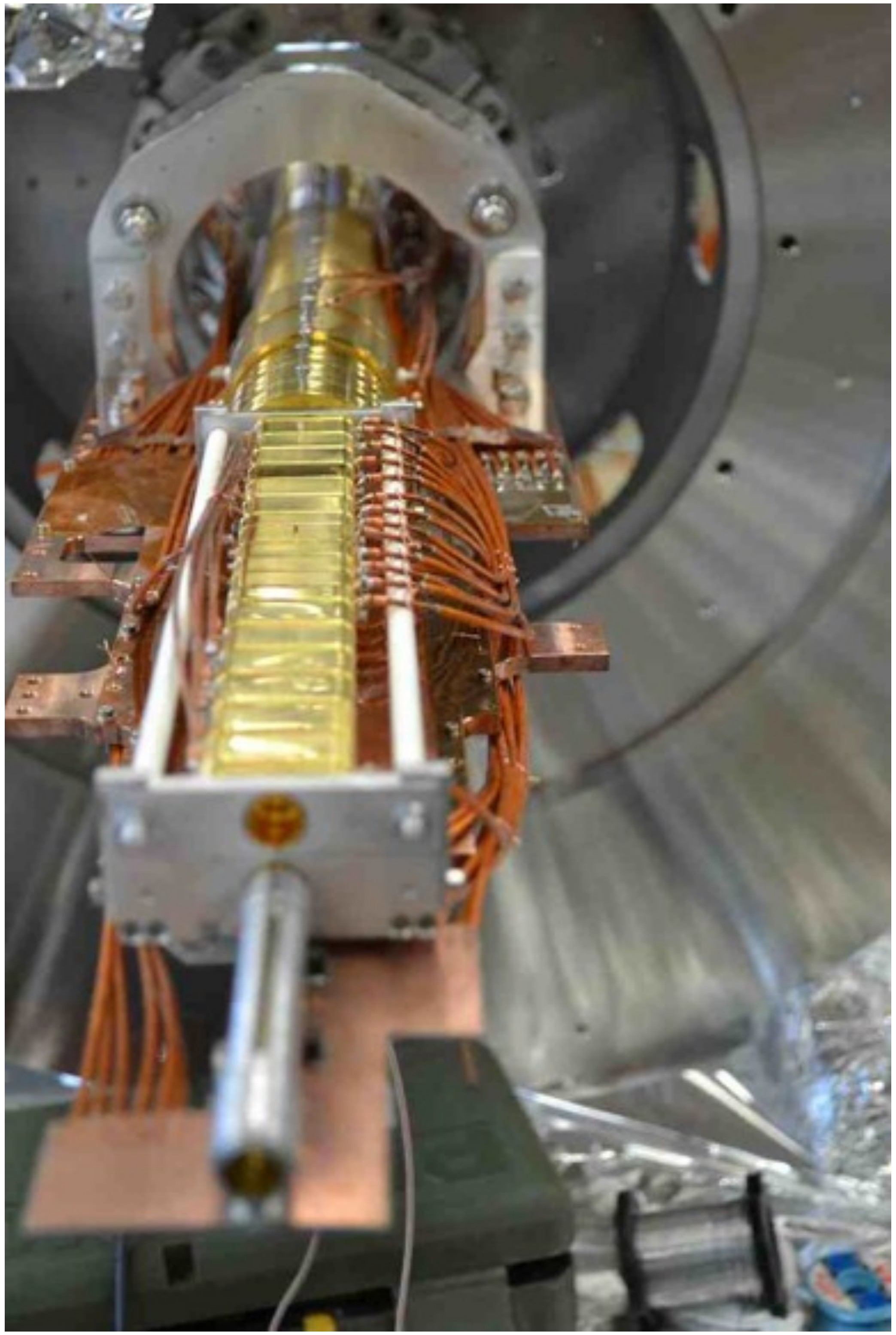


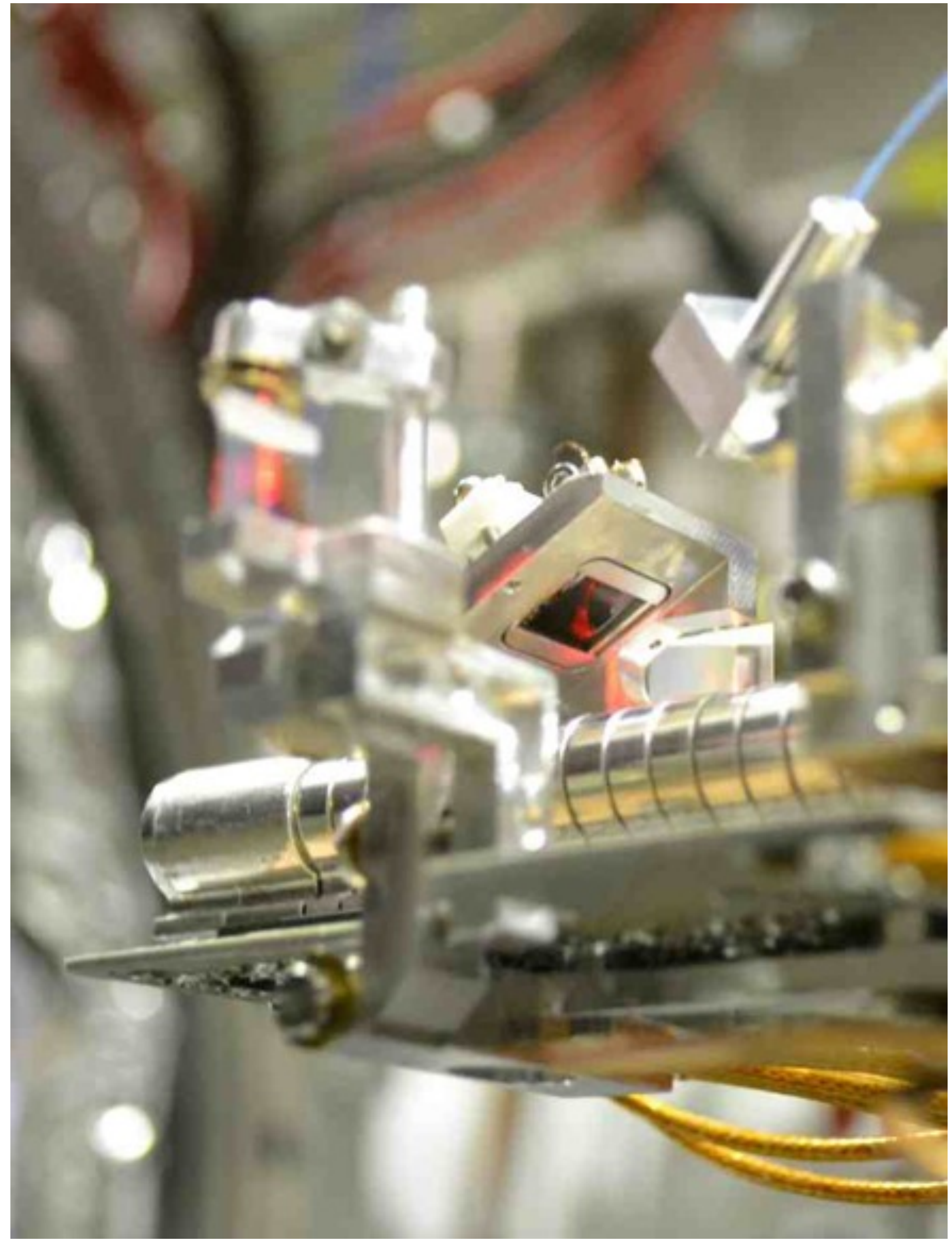
5T Catching Traps



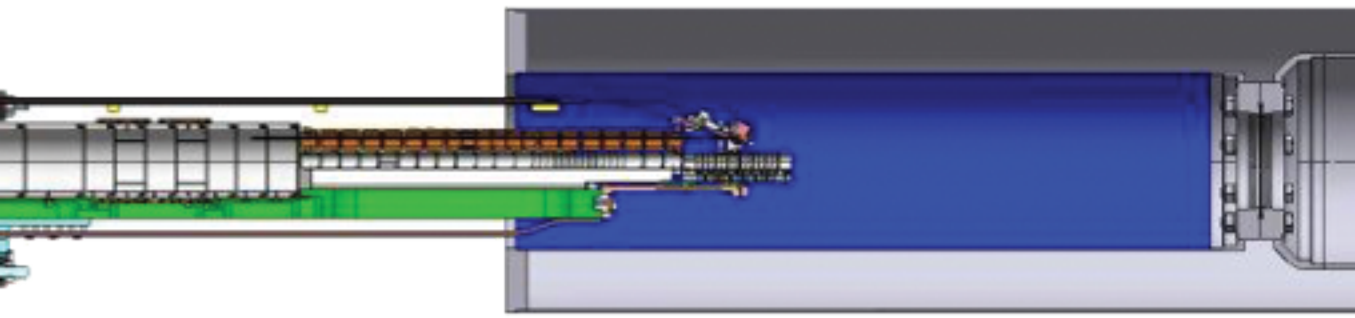


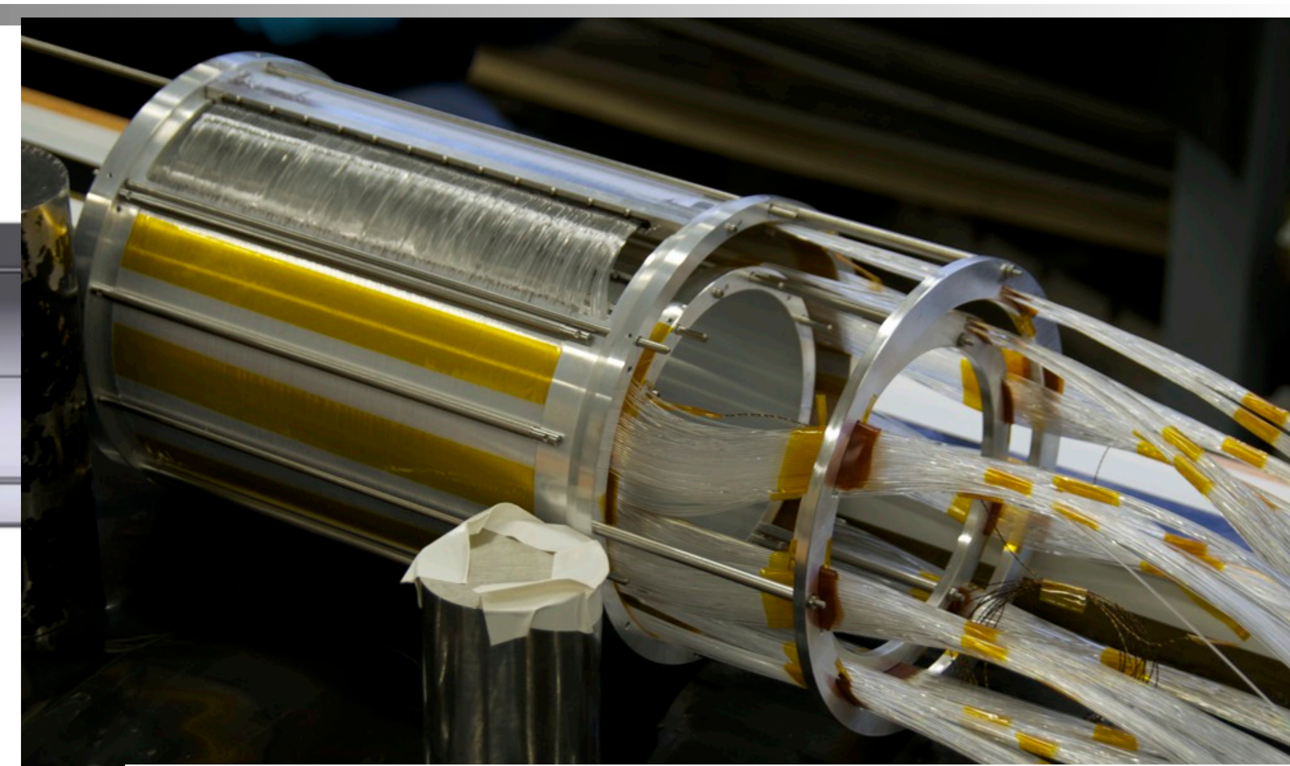
I T Formation Traps



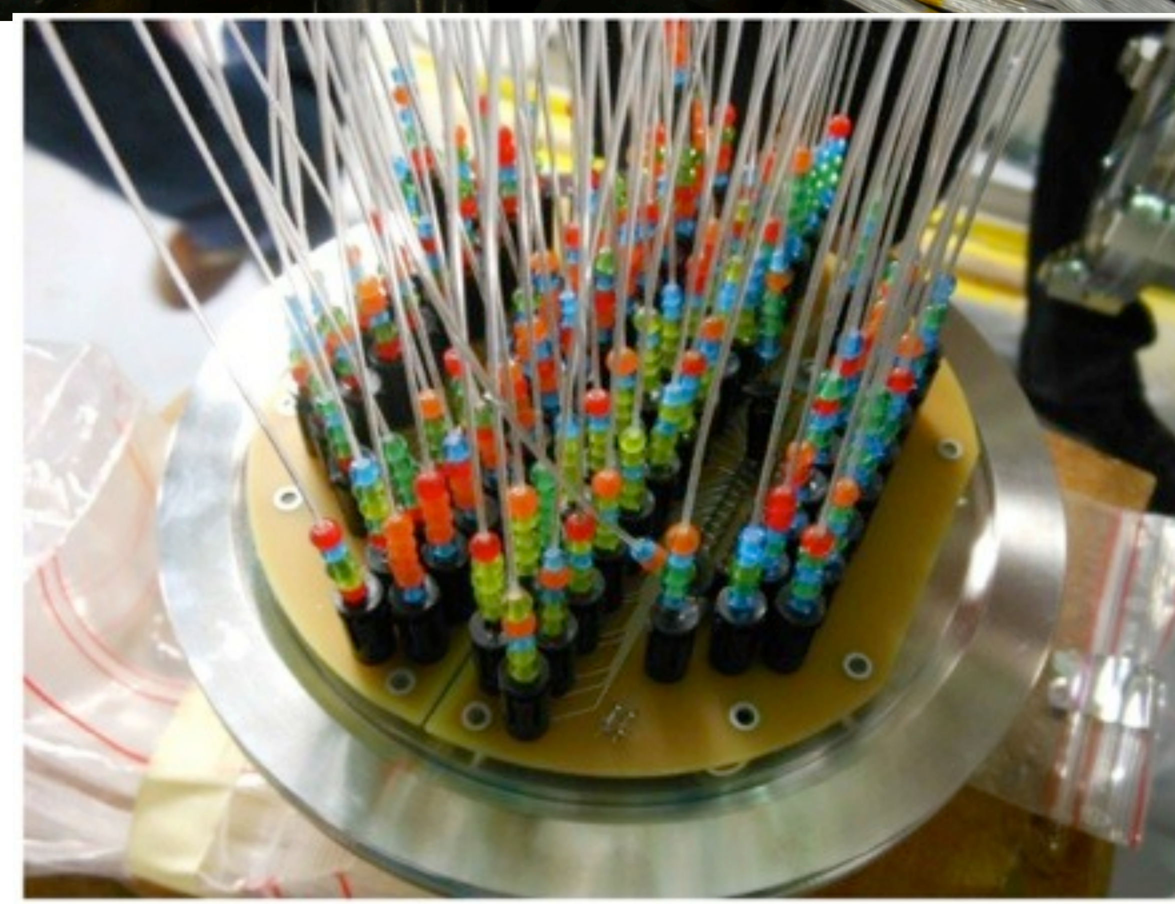


Central Antihydrogen Detector

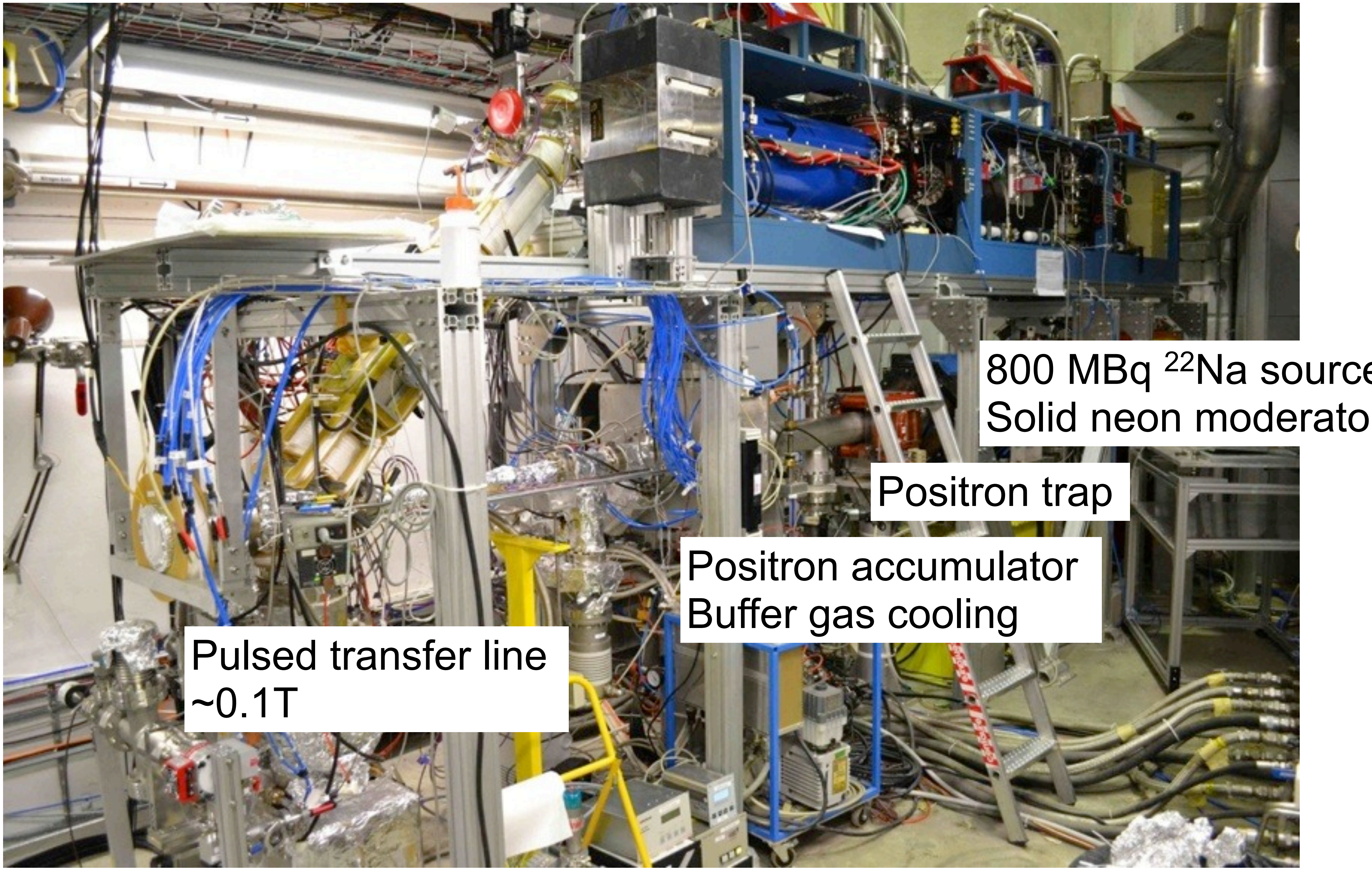




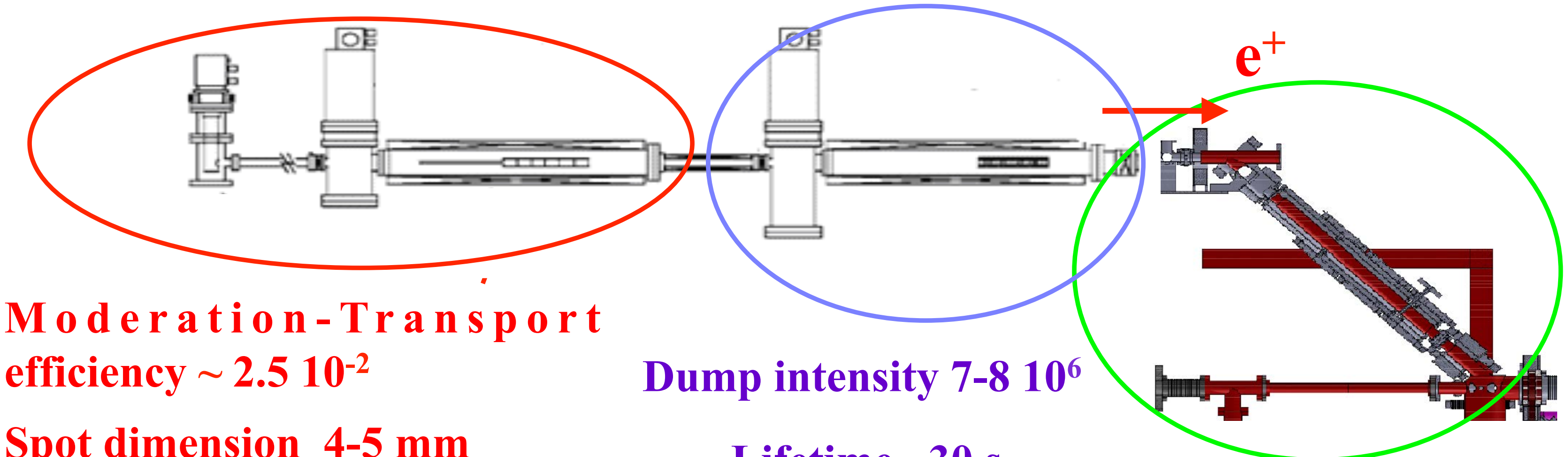
- Scintillating fibre detector operating at 4K
- 800 channels readout by SiPM
- 200 MHz readout detecting hit pattern



Positron System



Positron System



Moderation-Transport efficiency ~ 2.5 10^{-2}

Spot dimension 4-5 mm

Trapping-dumping efficiency ~ 0.14

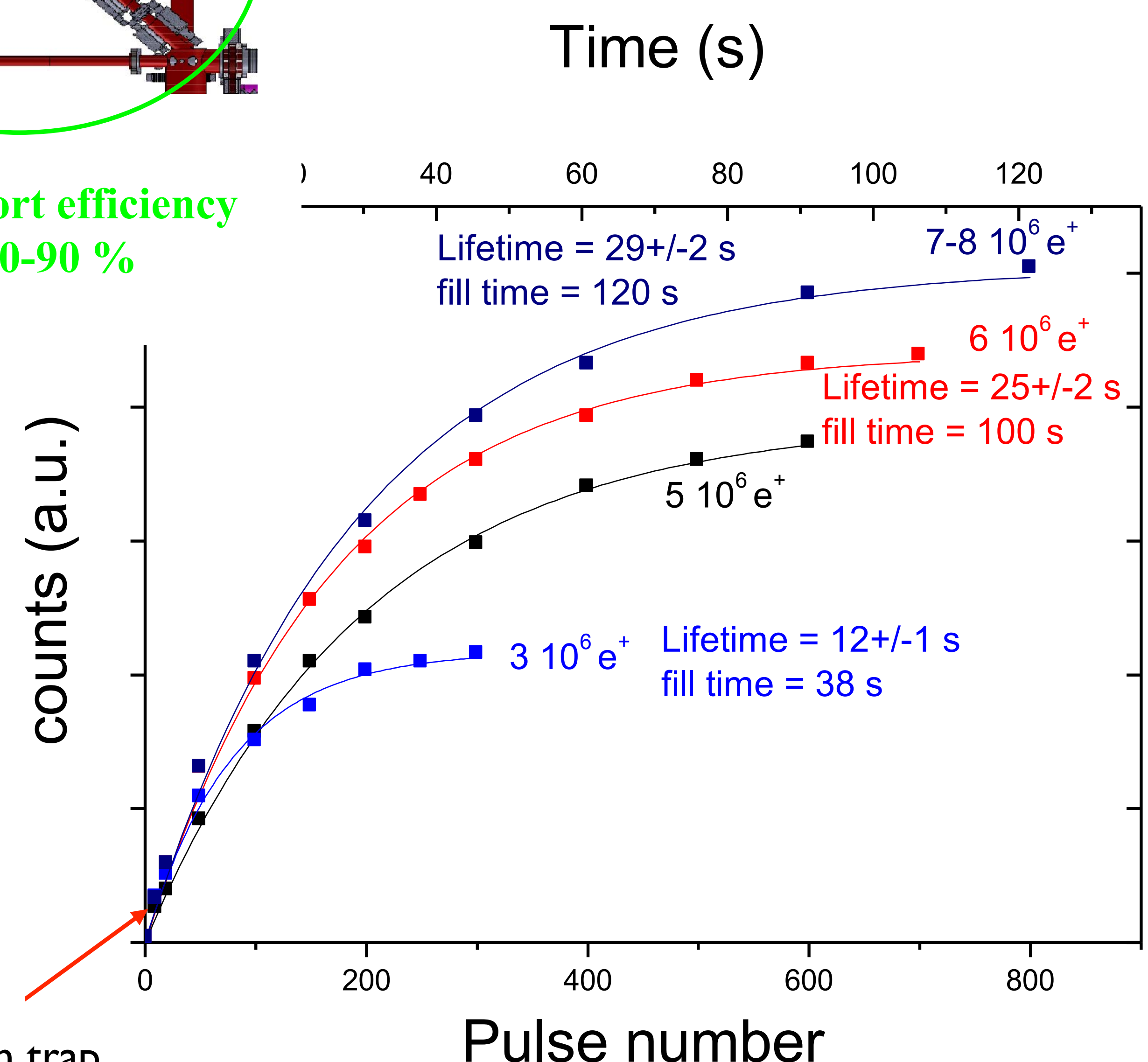
Spot dimension 1-2 mm

Dump intensity 7-8 10^6

Lifetime ~30 s

Fill time ~120 s

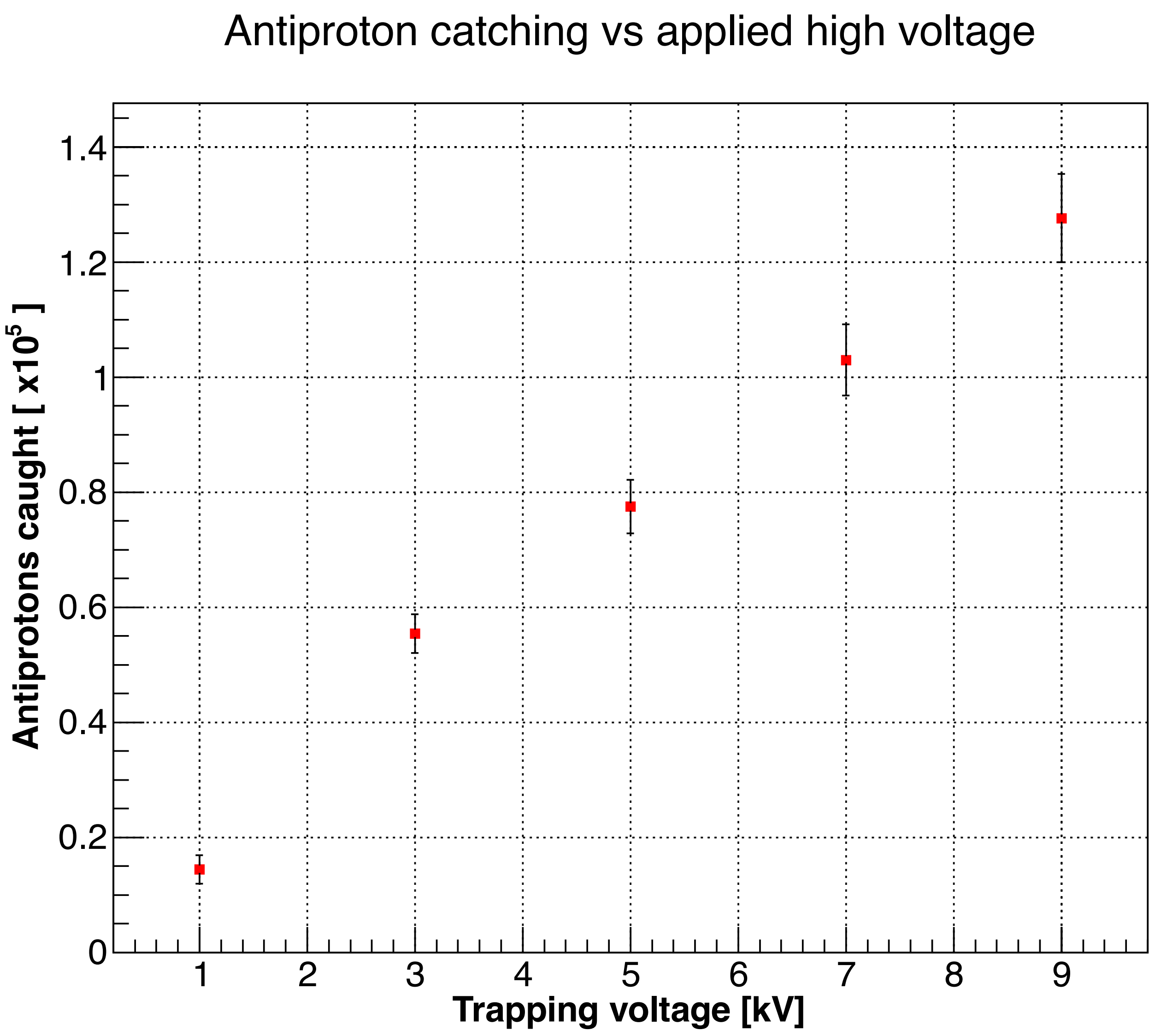
Transport efficiency ~80-90 %

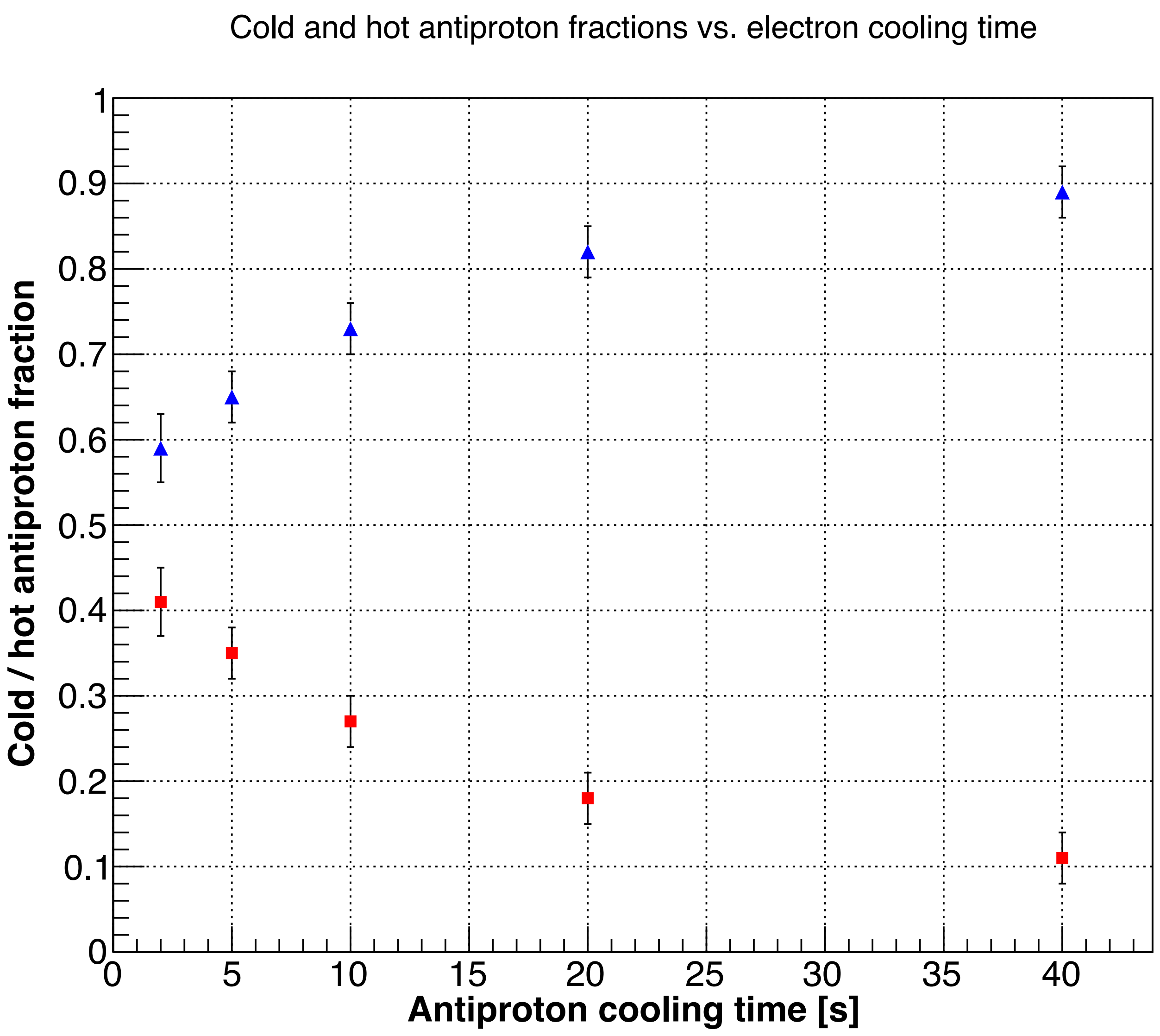


5-6 x 10^4 e^+ from trap

- Ongoing work to increase rates and efficiencies

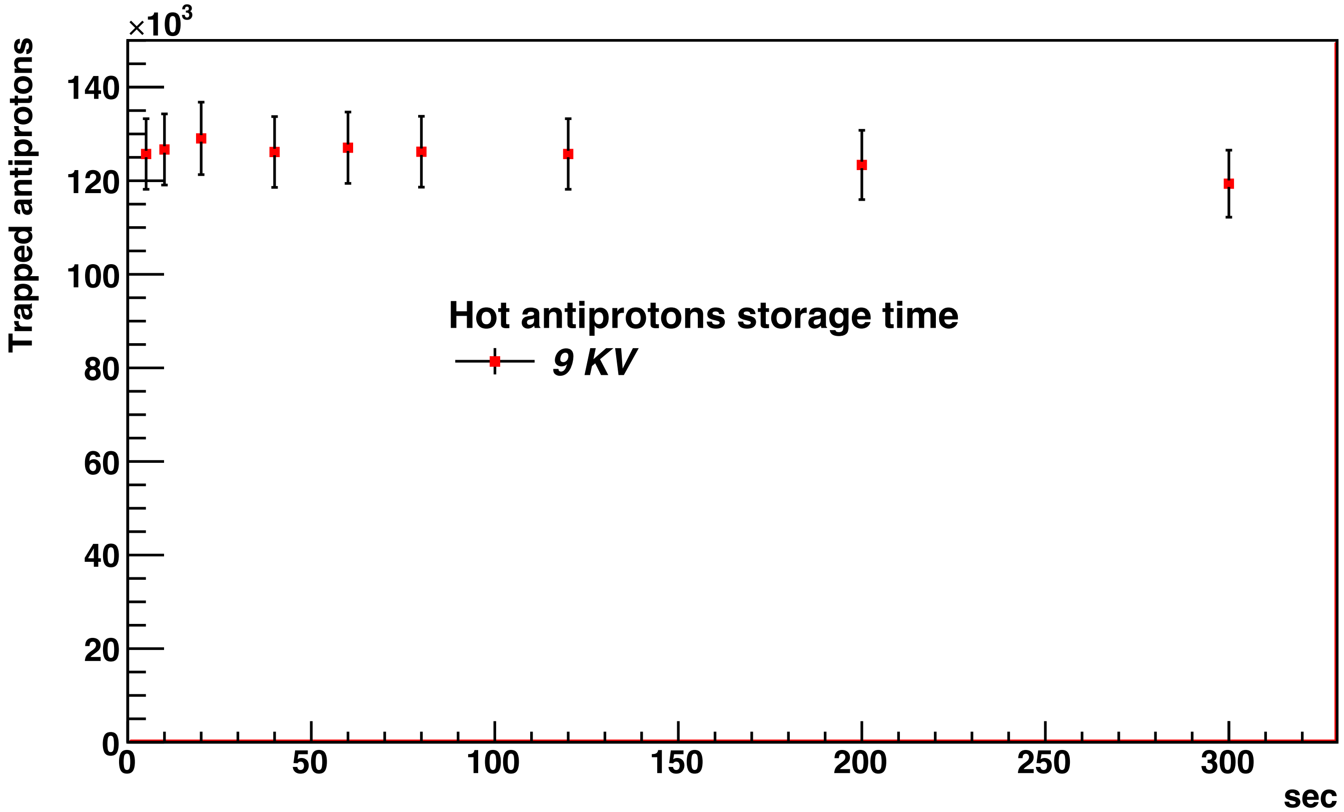
Commissioning Results

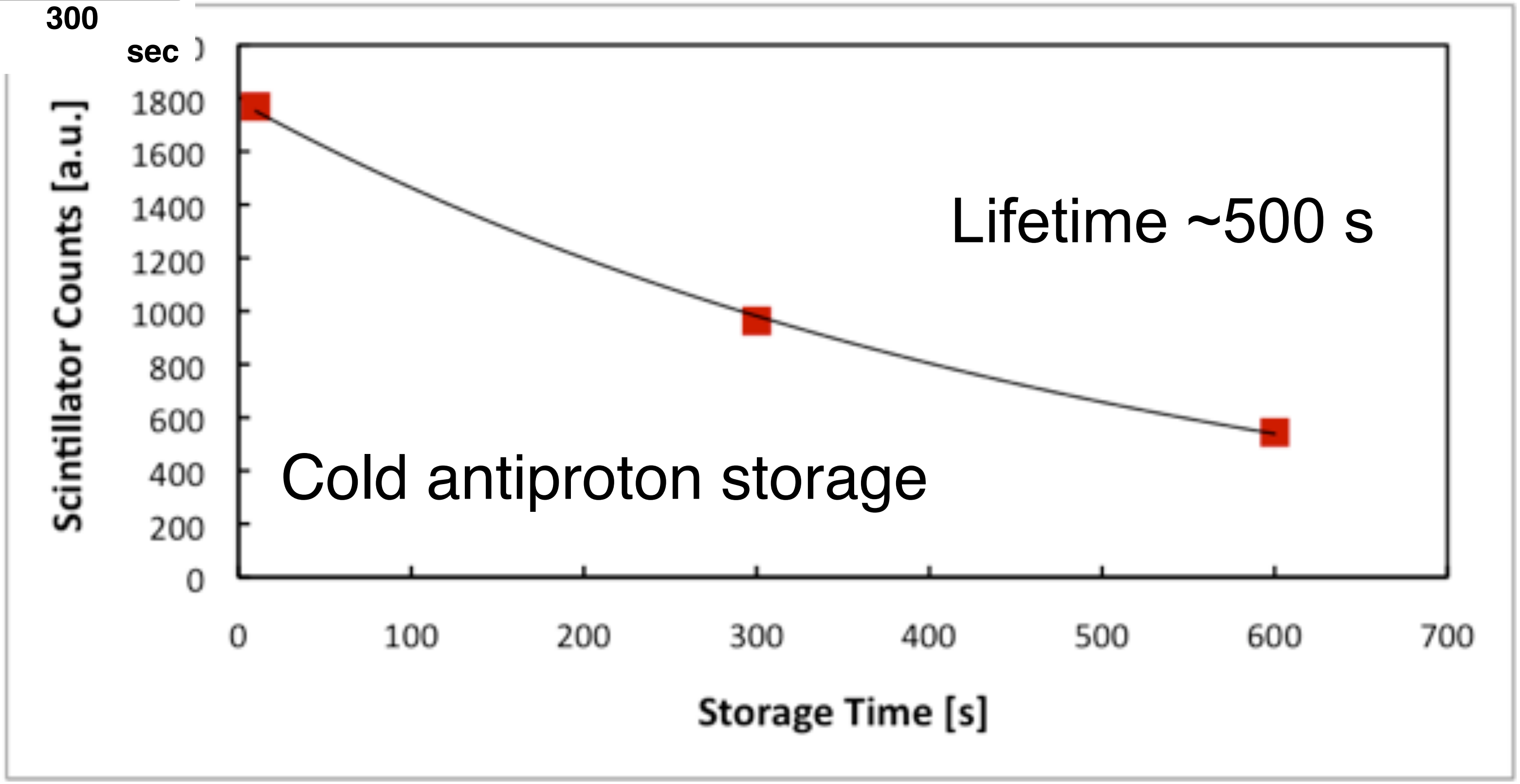




- Trapping, cooling

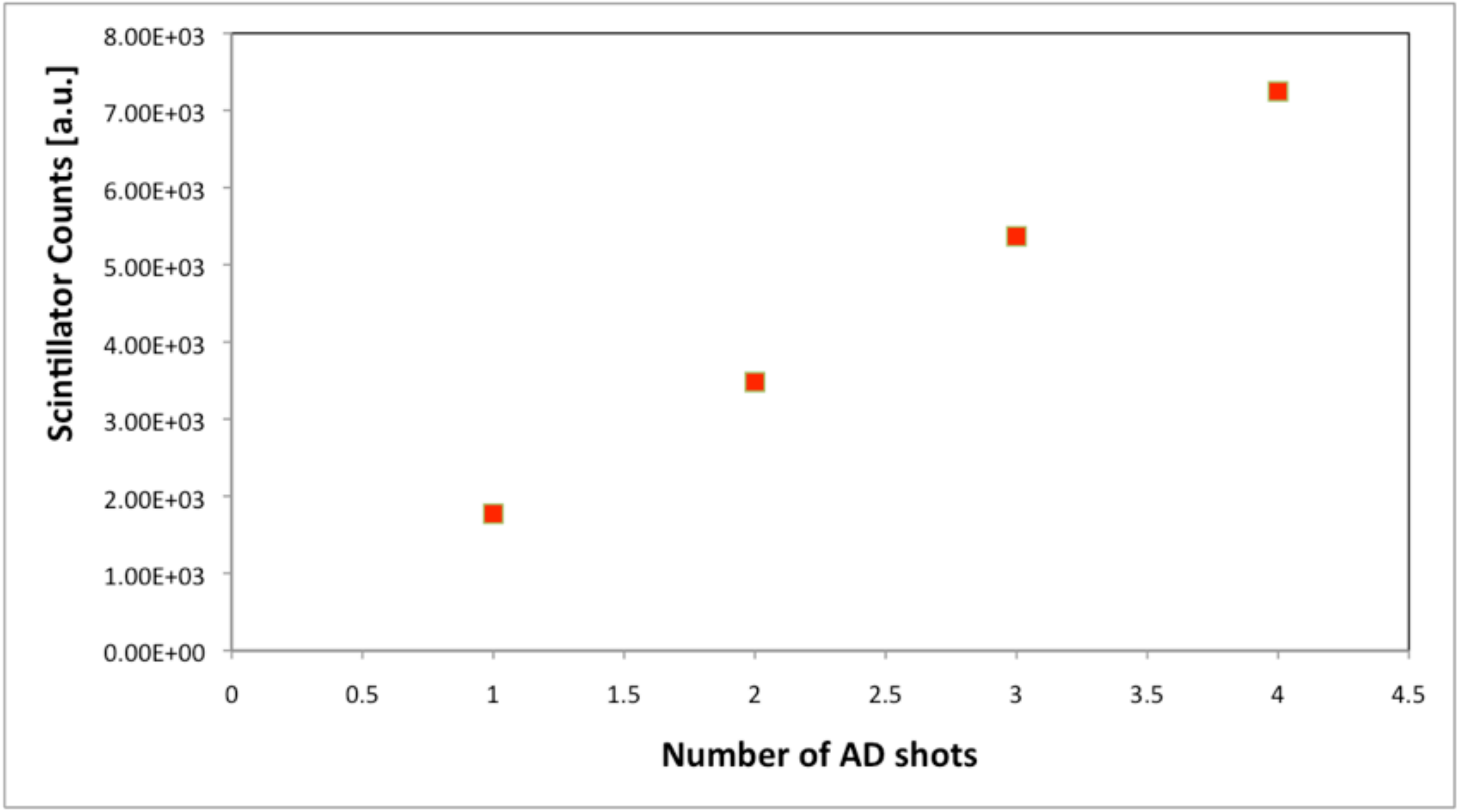
Commissioning Results





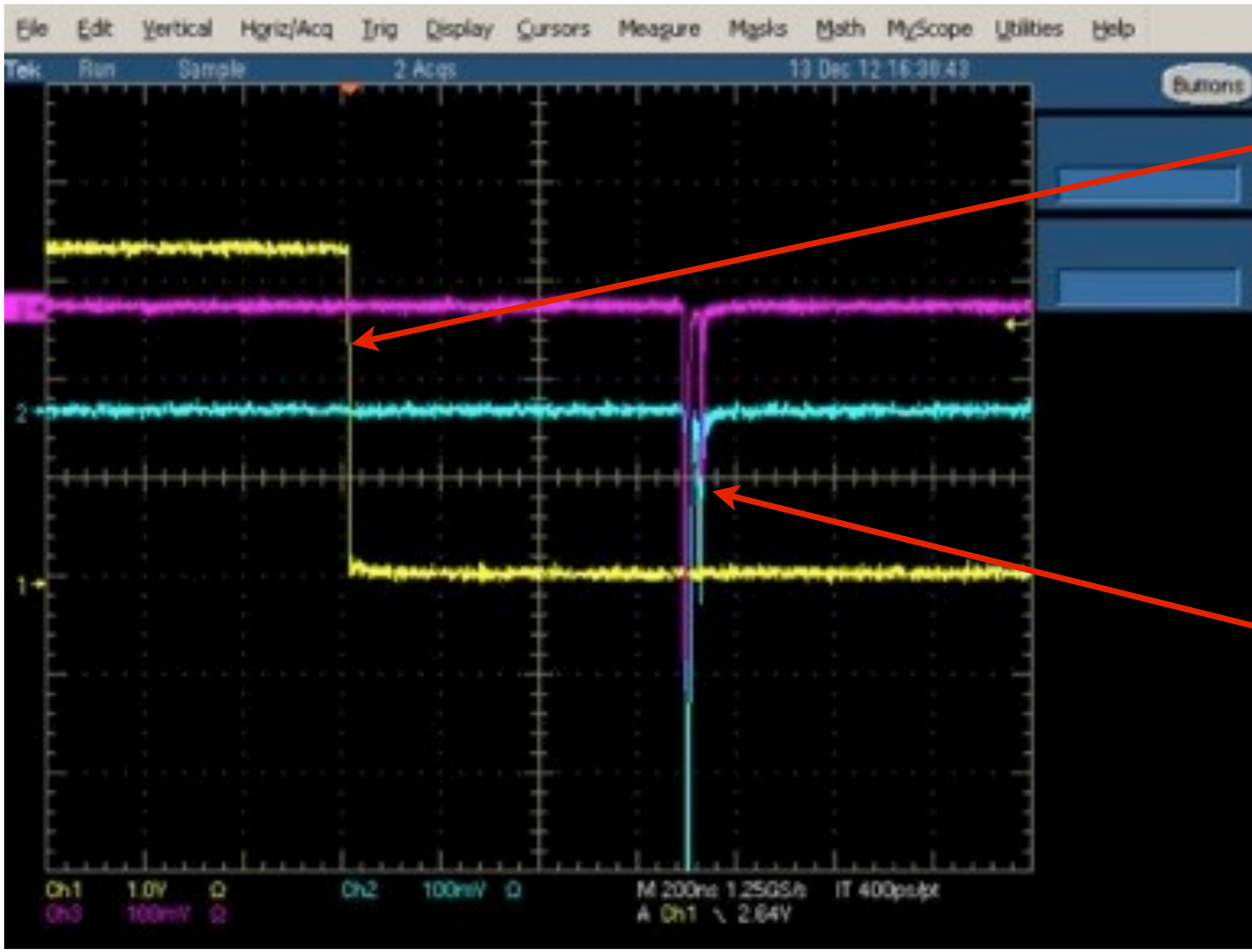
- Storing

Commissioning Results



- Manipulations

Commissioning Results



Extraction pulse from accumulator

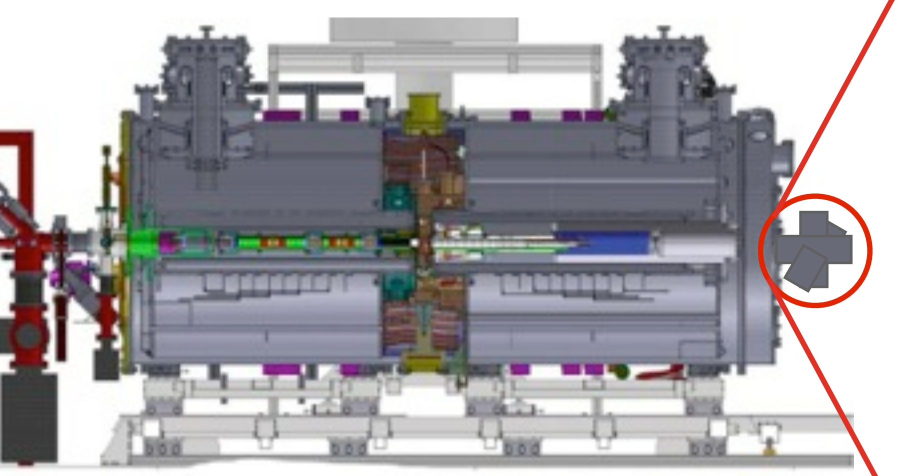
Scintillator pulses from positron annihilation in 1T

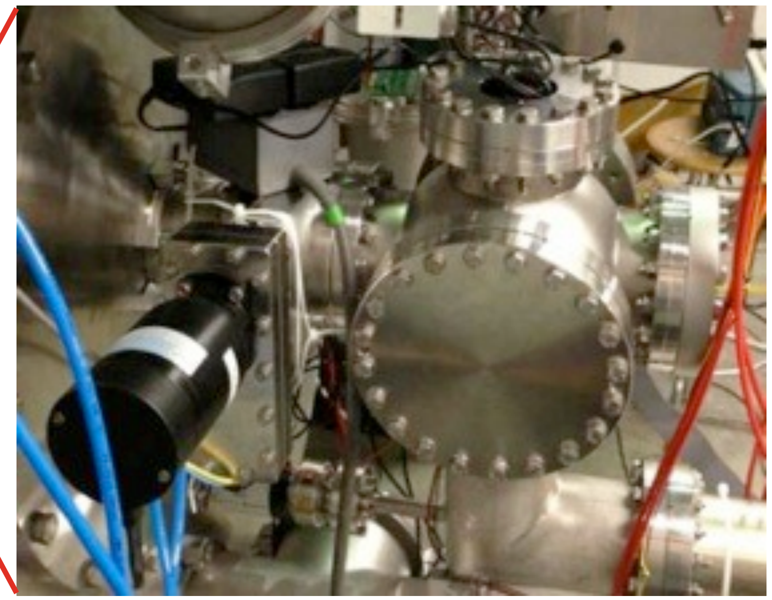
- Positron transfers through transfer line and 5T into 1T magnet

Detector Tests

Parasitic tests:

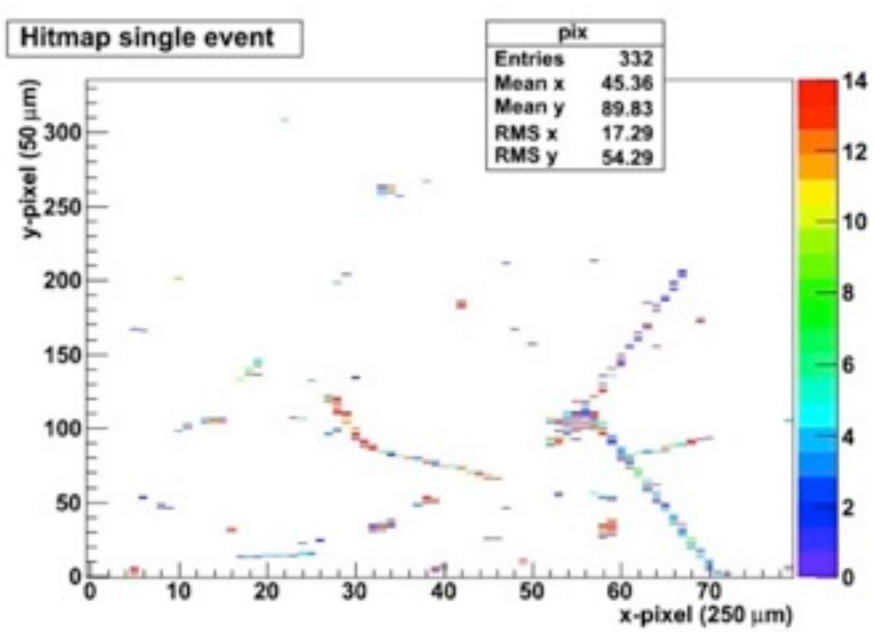
See poster by O. Karamyshev



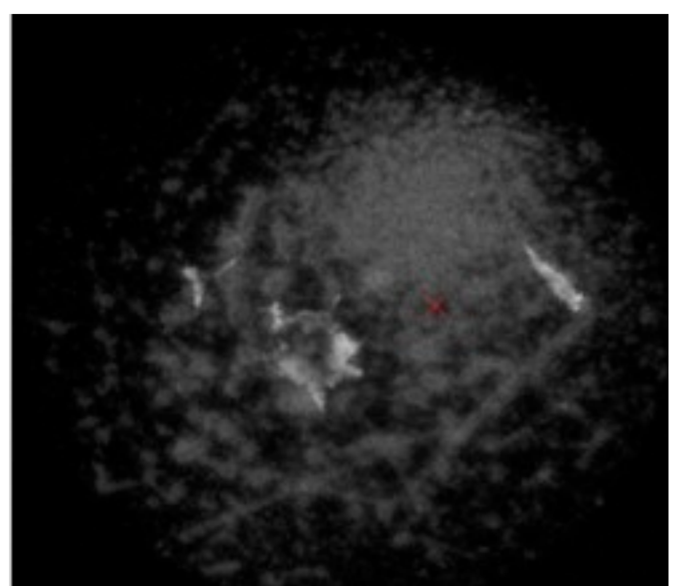


Explore different candidate technologies for the (downstream) antihydrogen detector

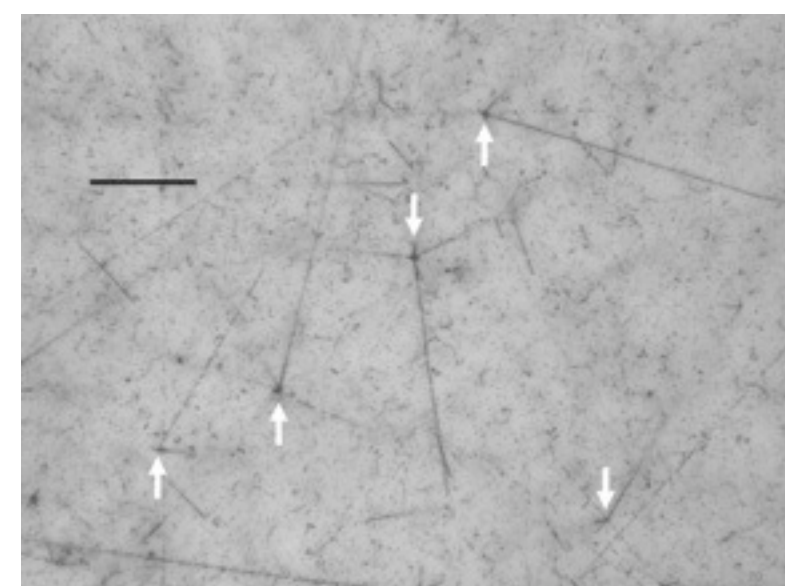
Silicon detectors (strip, pixel)



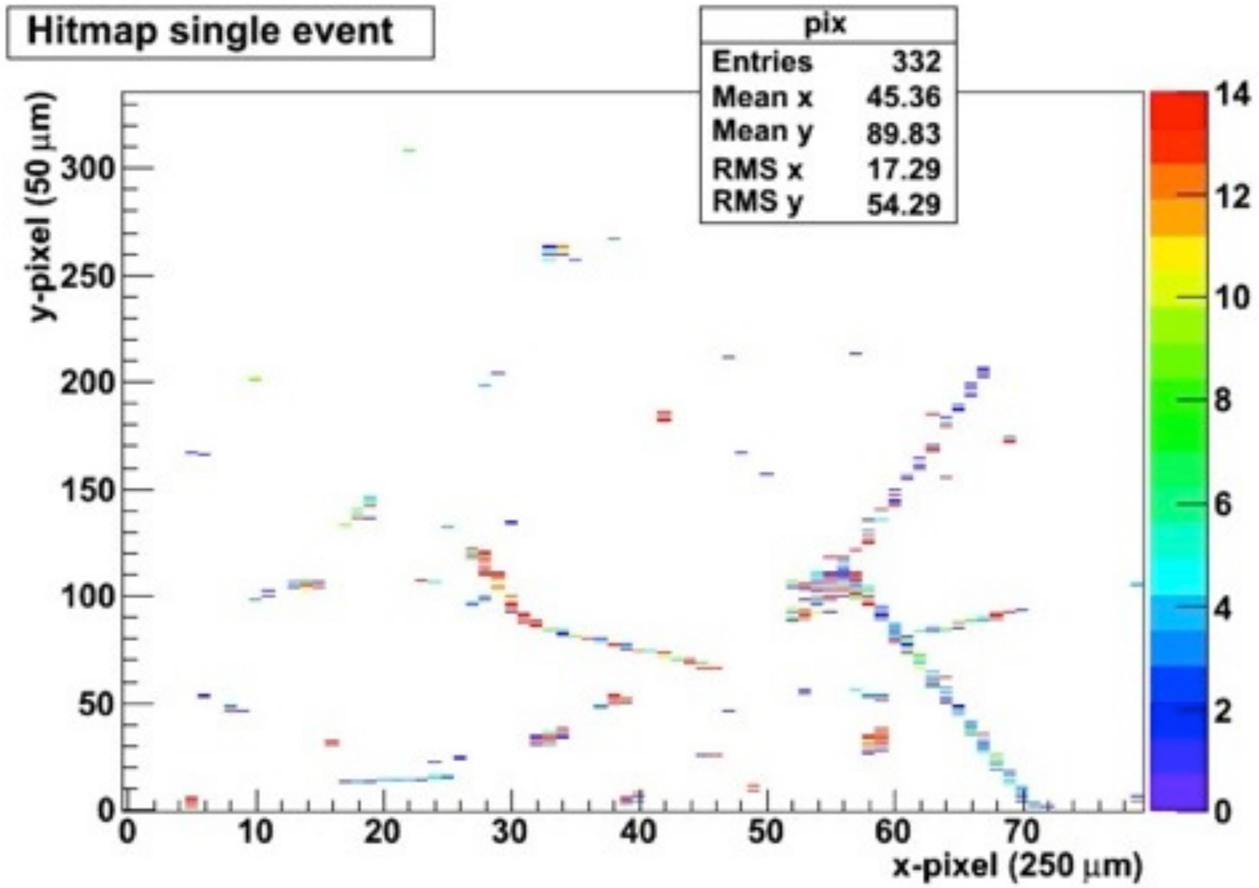
MCP

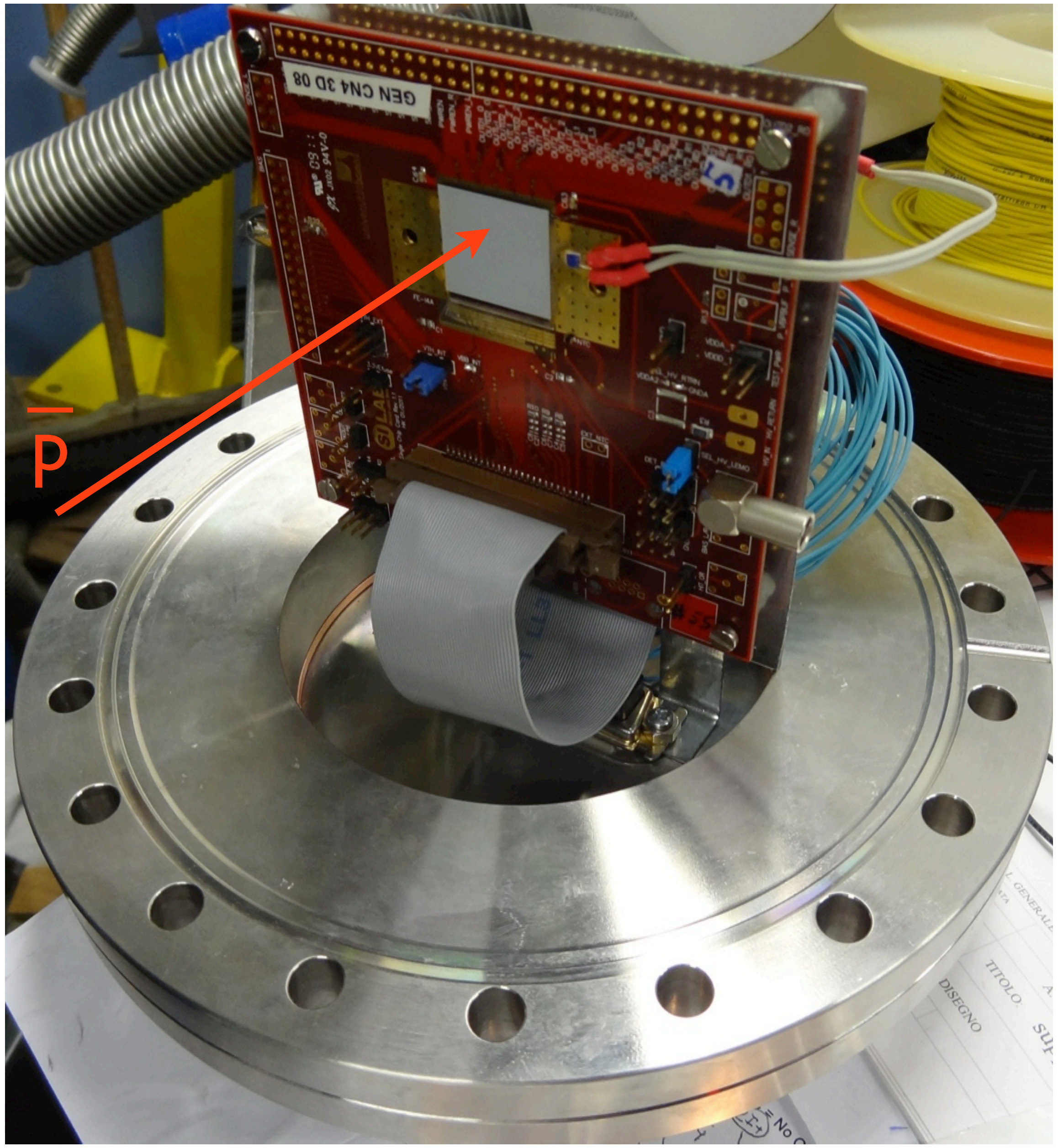


Emulsions



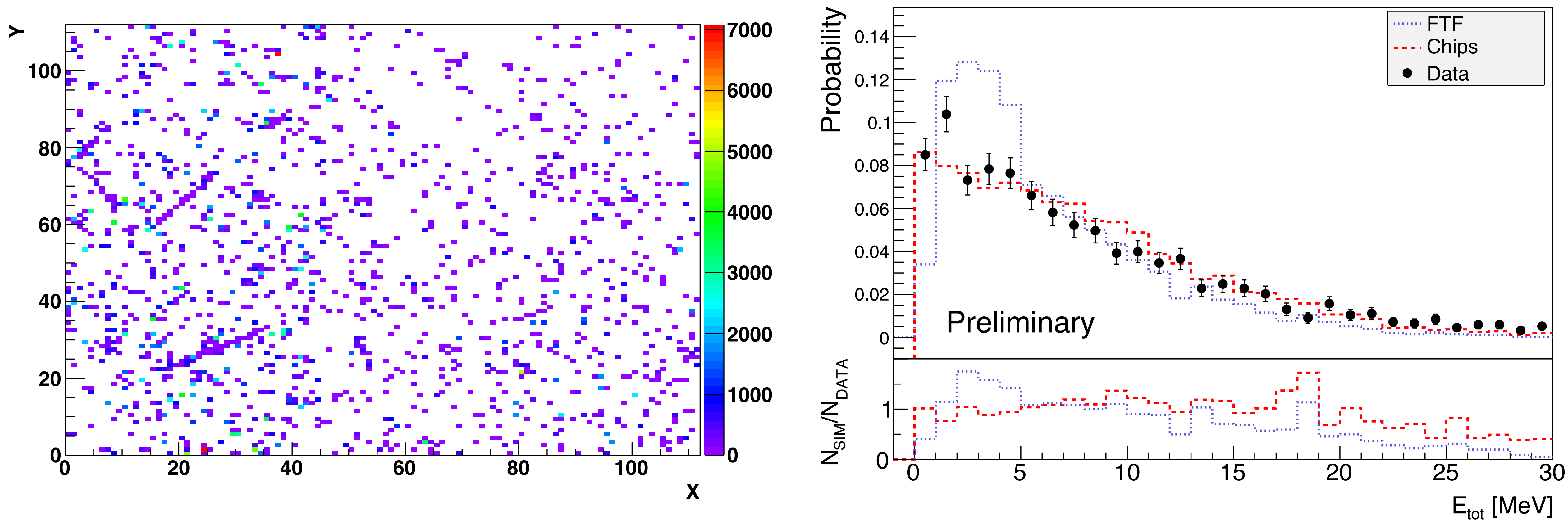
Silicon Detectors





- 3D pixel sensor designed for the ATLAS upgrade
- Also tested: strip sensor, Mimotera

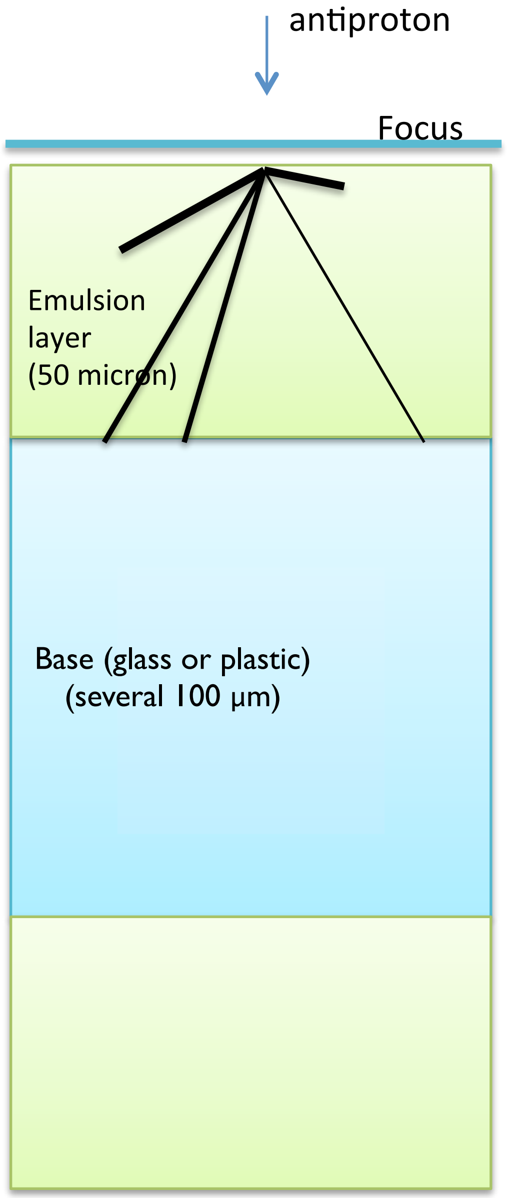
Mimotera Detector

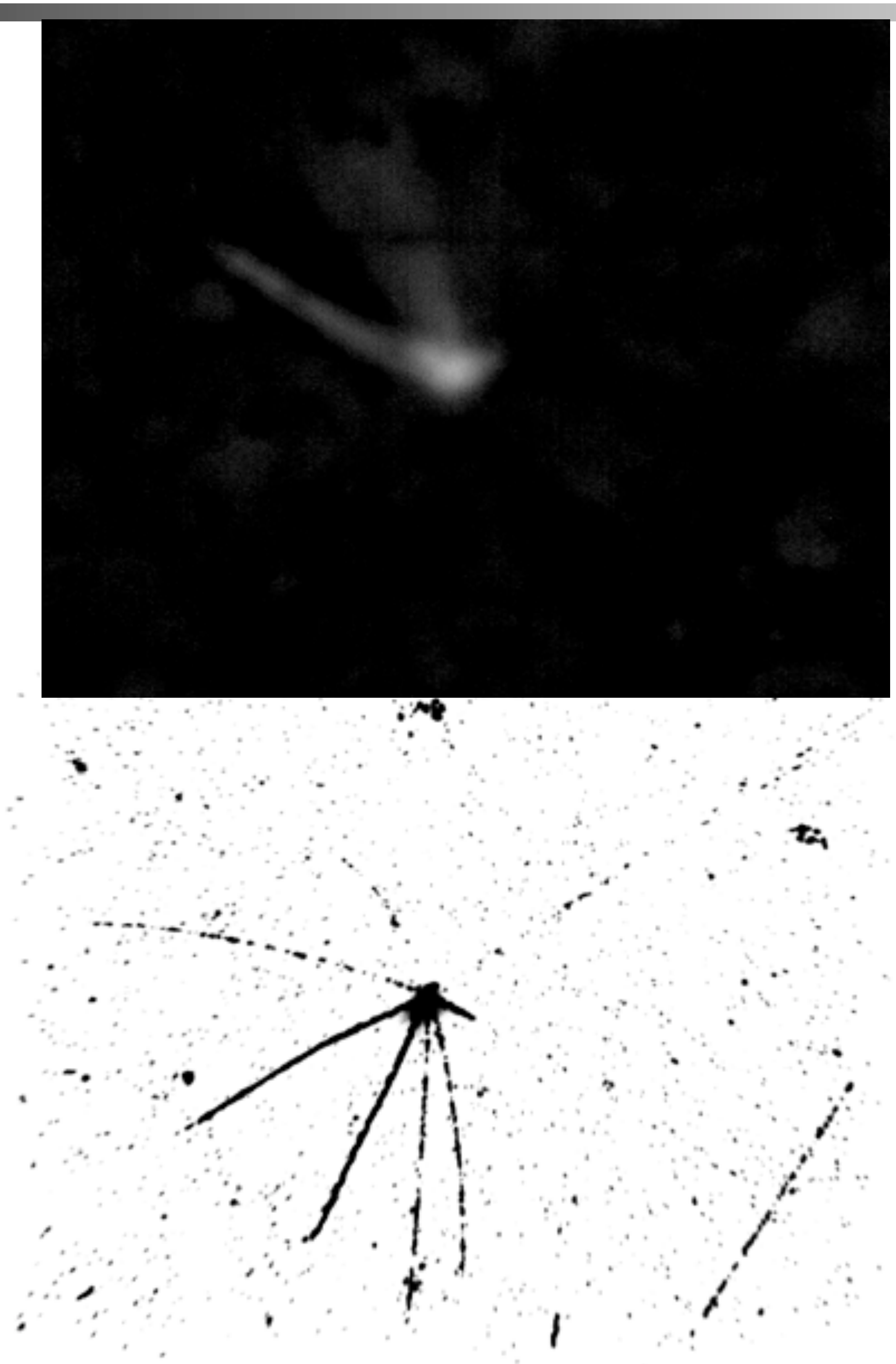


- 112 x 112 silicon pixel detector, 153 µm x 153 µm, 15 µm active depth
- Detailed comparison of data vs simulation
- Test of Monte Carlo treatment of antiproton annihilations on bare silicon

Publication forthcoming!

Emulsions





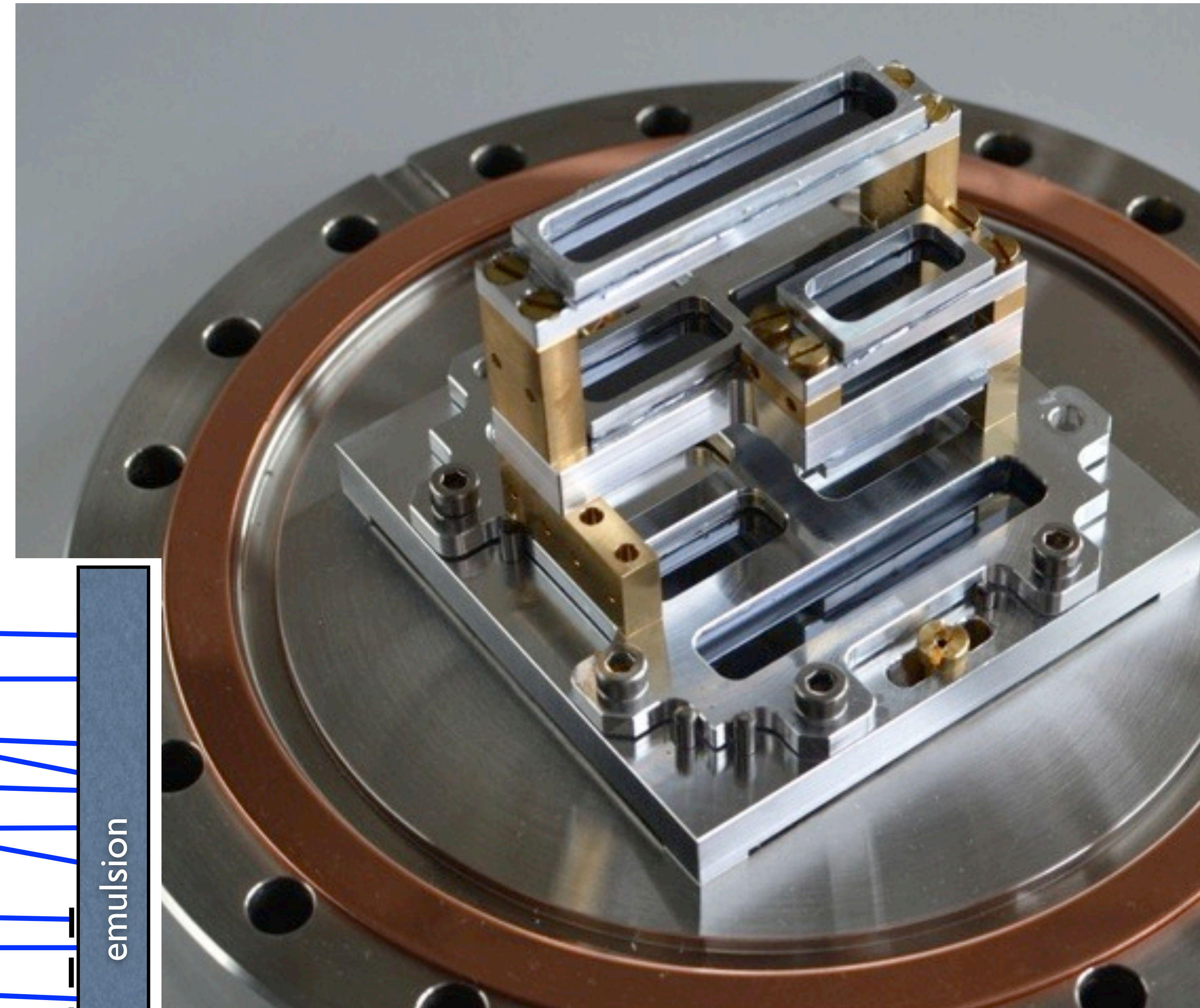
- Exposure of emulsion
- Development in dark room
- Scanning on automated microscopes

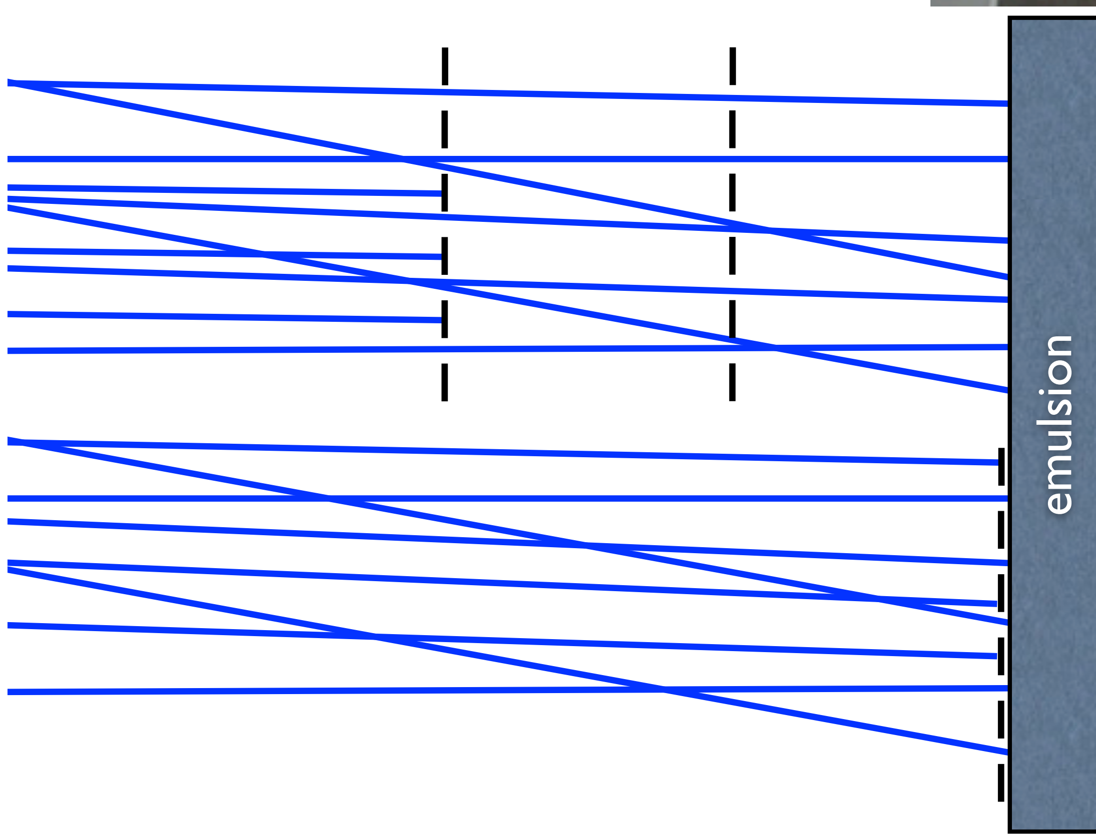
- Offline track and vertex finding algorithms
- 1 μm vertex resolution

See talk by J. Storey Friday @ 9:55 am

First Test of Moiré Deflectometer

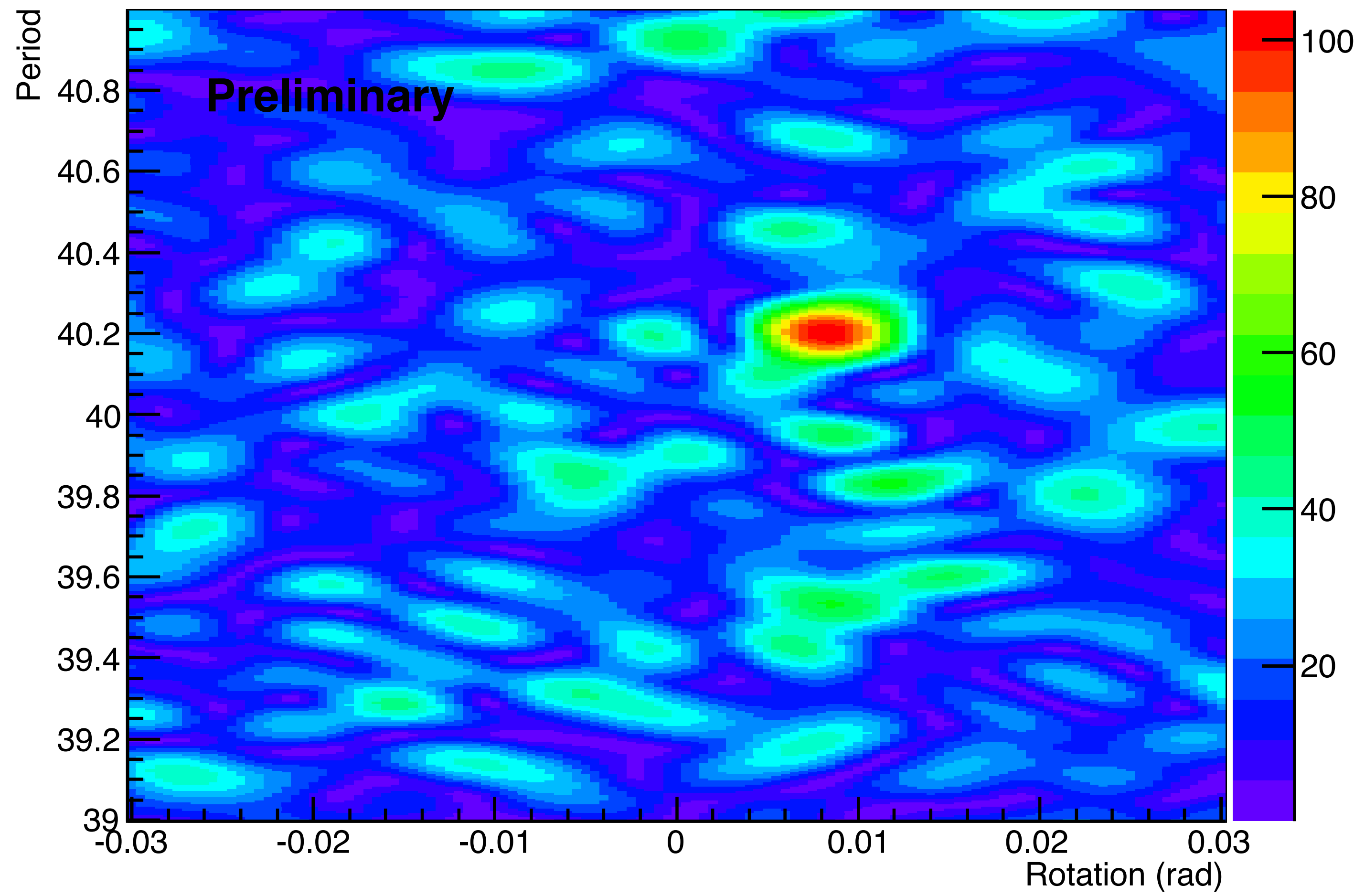
- ~100 keV antiprotons
- 7 hour exposure
- Bare emulsion behind deflectometer





First Test of Moiré Deflectometer

- Antiproton fringes observed
- Alignment of gratings using light and single grating
- Promising results!



Publication forthcoming!

Conclusions and Outlook

- Installation of apparatus largely completed and commissioned
- Parasitic measurements essential in converging to an optimal deflectometer/detector layout
- Next steps:
  - Install proton source, hydrogen detector
  - Commission Rydberg positronium formation
  - Work on hydrogen formation/characterization

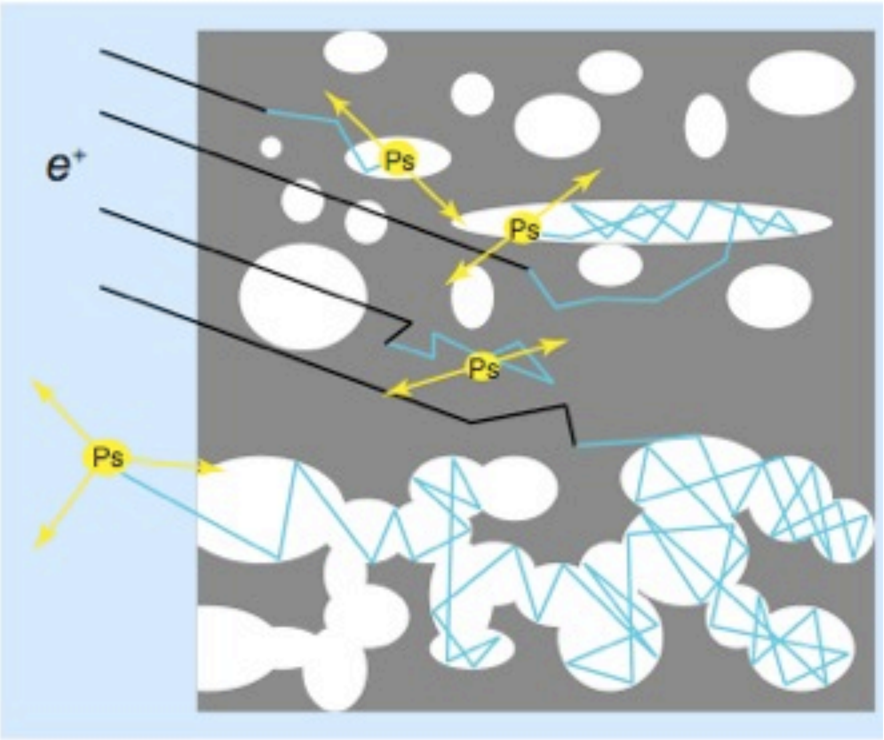
  - Goal: Be ready for antihydrogen beam formation in summer 2014!

Backup

Positronium target - parameters

Ps formation in nanoporous insulators:

- Implanted positrons scatter off atoms and electrons, slow to eV in few ns
- Positronium formation by capture of bound electrons or free electron from collisions
- Reduced dielectric strength in defects
  ⇒ accumulation of positronium in voids
- If pores are fully interconnected, (almost) all *ortho*-Ps diffuses out of the film



[D. W. Gidley *et al.*, Annu. Rev. Mater. Res. **36** (2006) 49]

⇒ **High-efficiency positronium converter**

ortho-Ps yield and energy (velocity) distribution depend on

- Converter material
- Implantation depth (energy)
- Target temperature

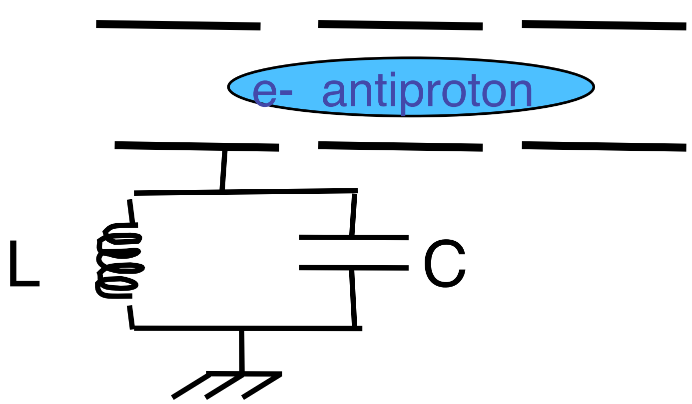
Ultracold antiprotons

Antiprotons in the trap cannot be directly cooled to 100 mK

Cool antiprotons by collisions with a partner particle stored in the same trap that can be cooled

electrons

Resistive cooling with a resonant tuned circuit + radiation cooling



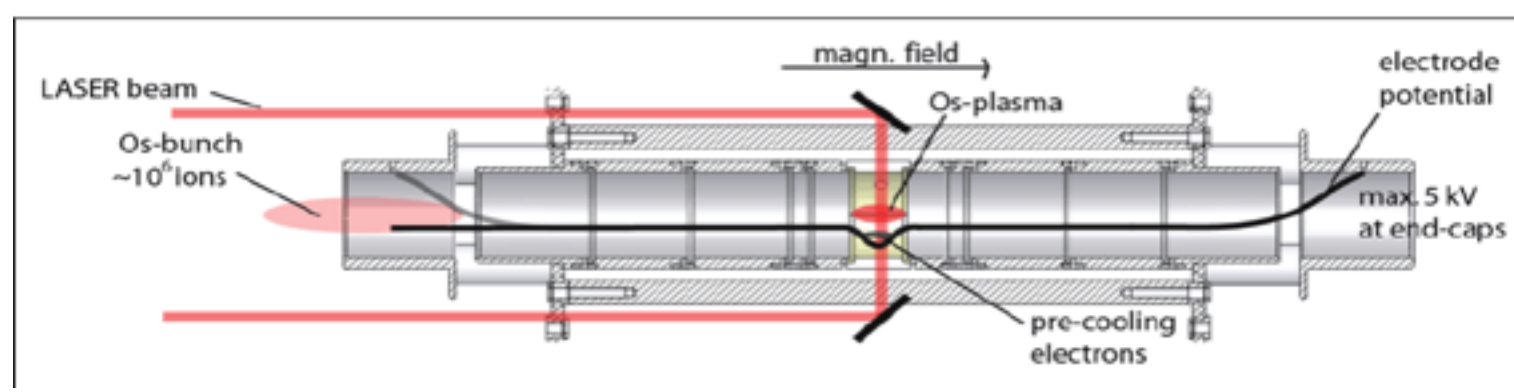
antiprotons

Embedded electron cooling, adiabatic cooling, evaporative cooling, ...

Negative ions: La^-

Laser cooling of La^-

Ultimate temperature: 240 nK



- A demonstration of laser cooling of negative ions is needed
- Experiment in progress at MPI (members of AEGIS)

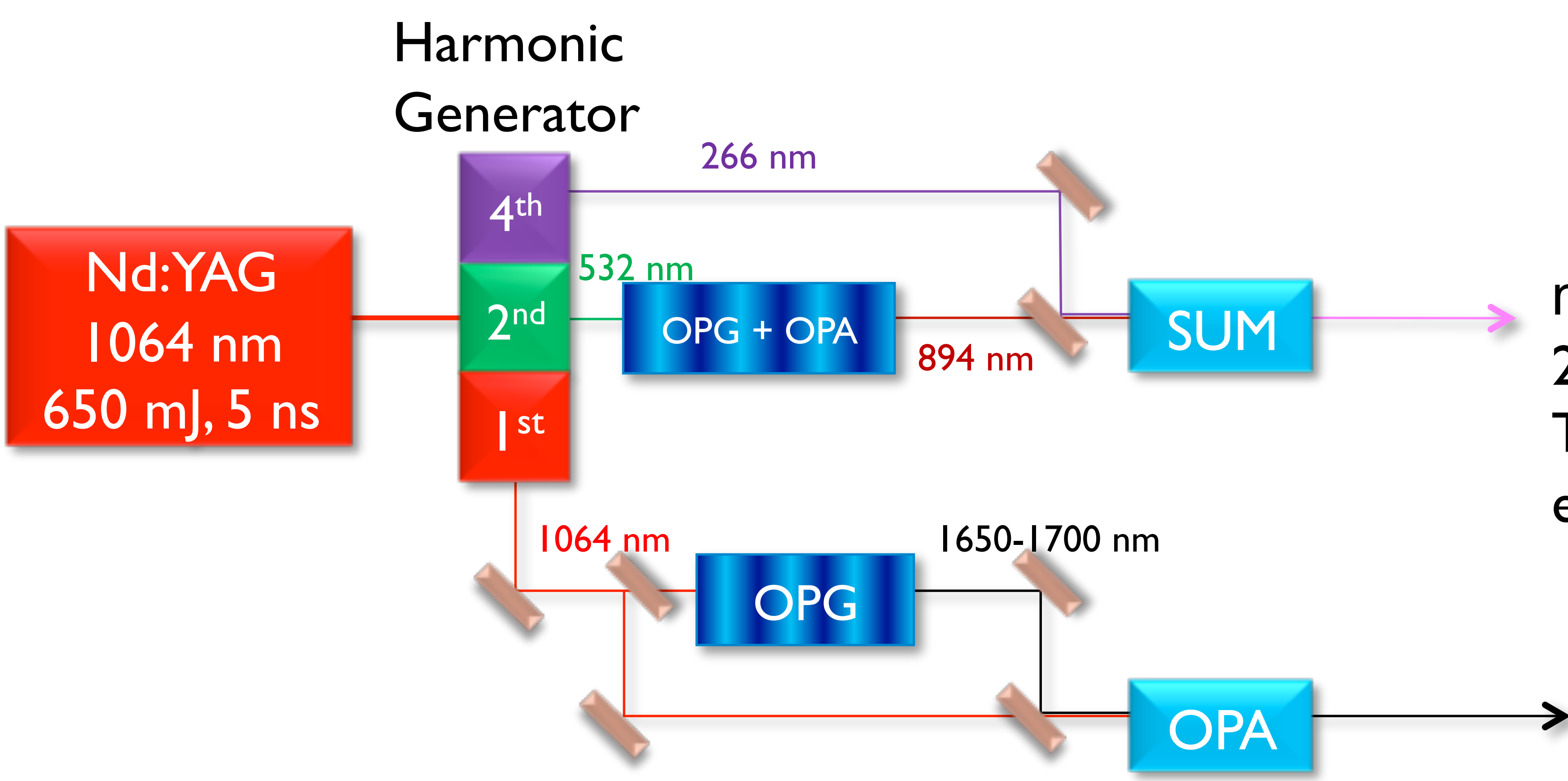
Lasers

Rydberg excitation via a simultaneous two step incoherent process:
1 → 3 → Rydberg (wavelengths: 205 nm and 1650 - 1700 nm)

Main effects of level broadening:

1 → 3: Doppler effect (~0.04 nm) due to velocity distribution of Ps

3 → Rydberg: Motional Stark effect (makes a quasi-continuum from n=17, each level is broadened to many nm) due to Ps movement in a strong **B** field



n=1 → n=3
205 nm
Transition saturation energy: ~2 μJ

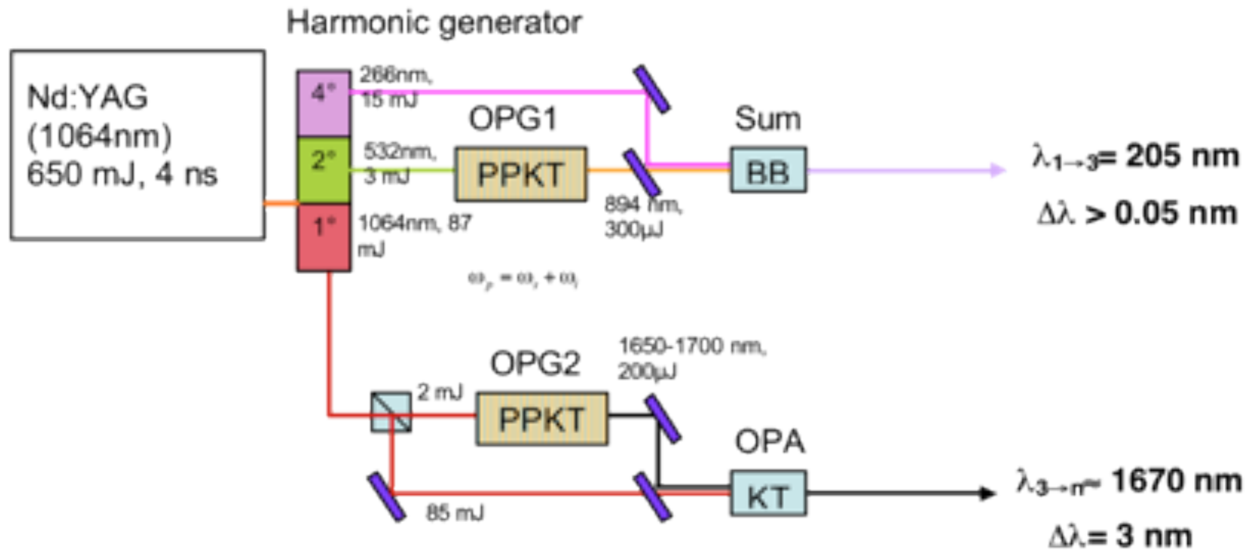
n=3 → Rydberg
1650-1700 nm
Transition saturation energy: ~0.2 mJ

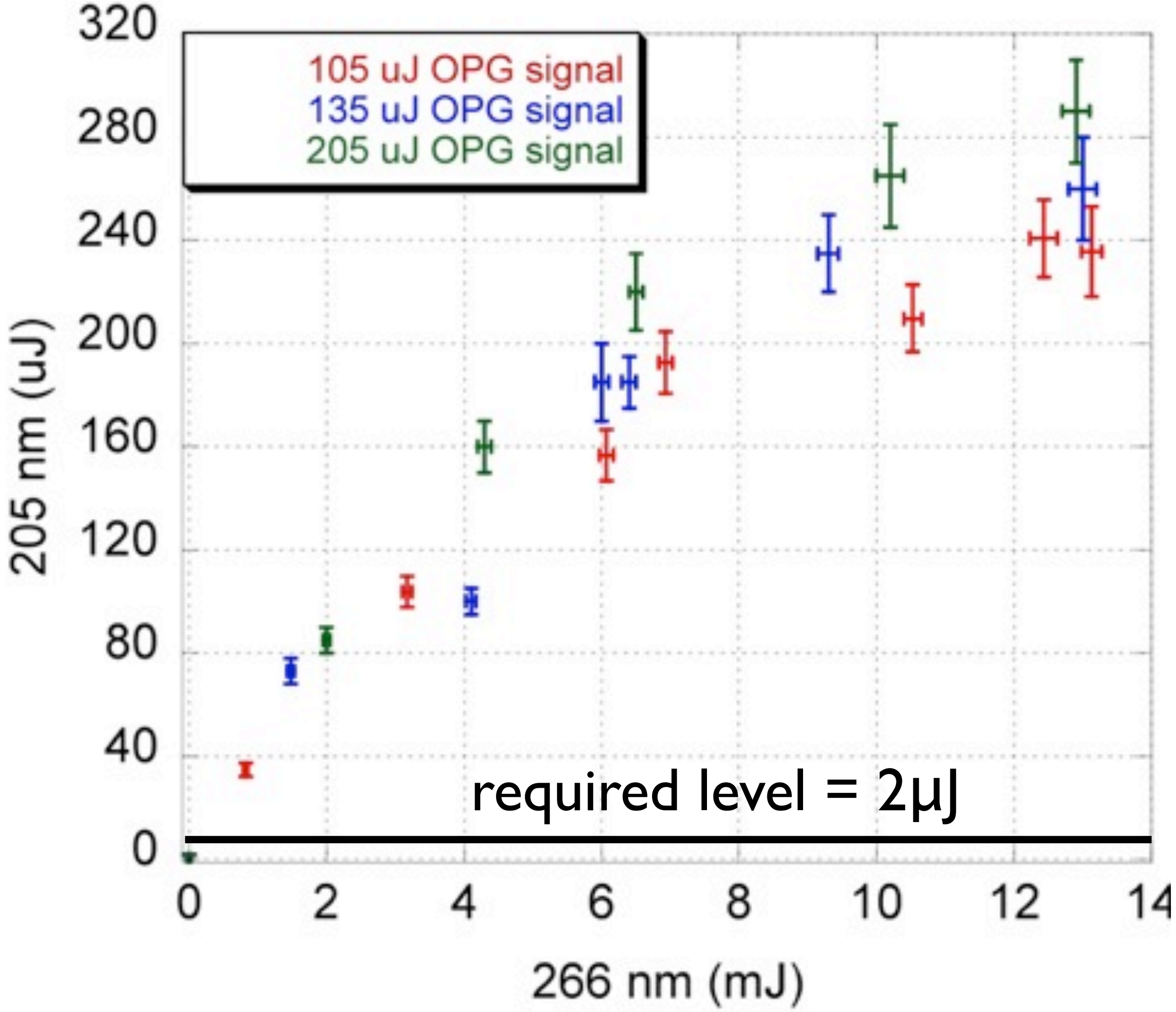
Laser source and harmonic generator:

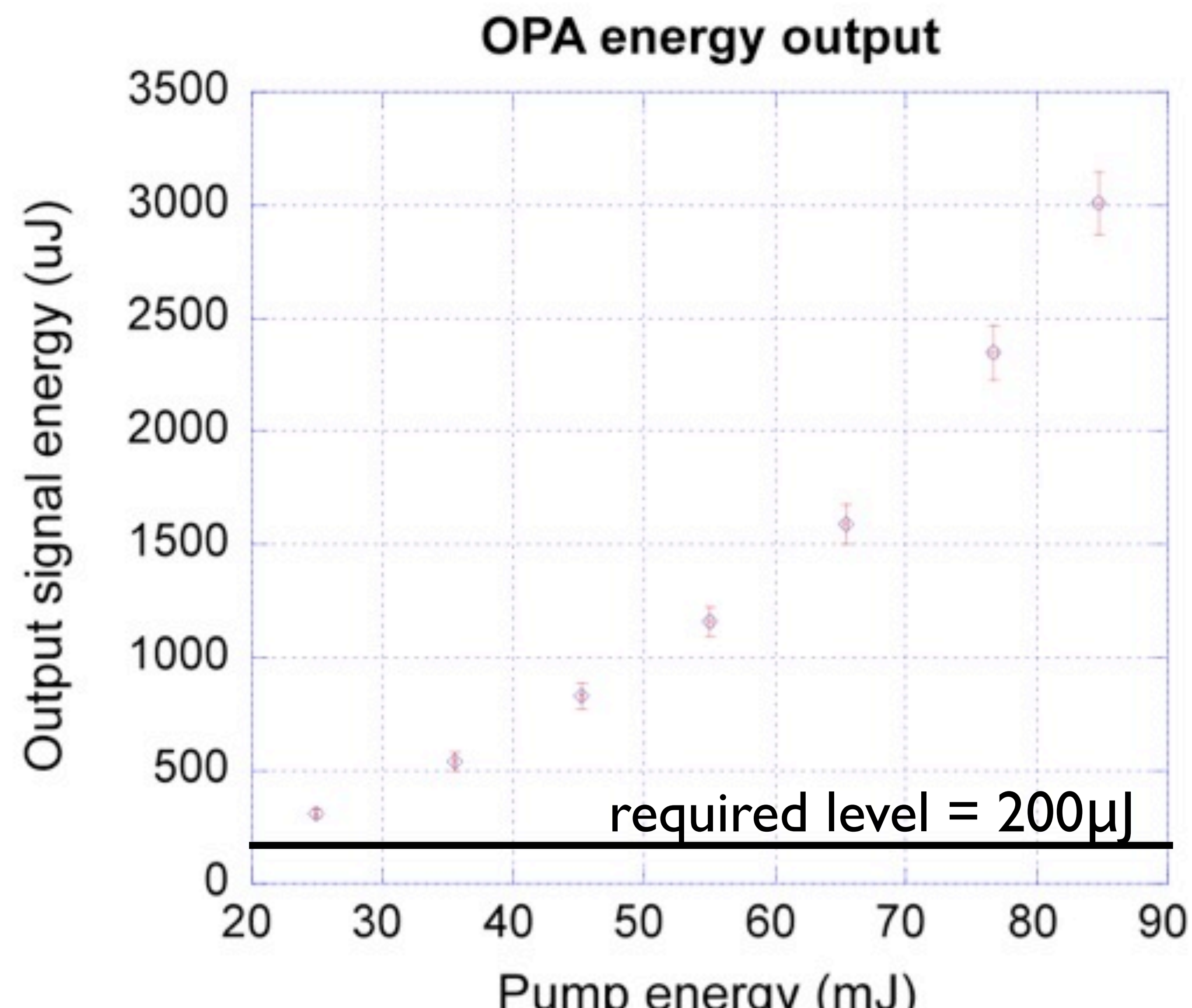
components delivered in April 2011
(pumping laser delivered in autumn 2011)

Goal of the apparatus:
About 10 times the saturation energy

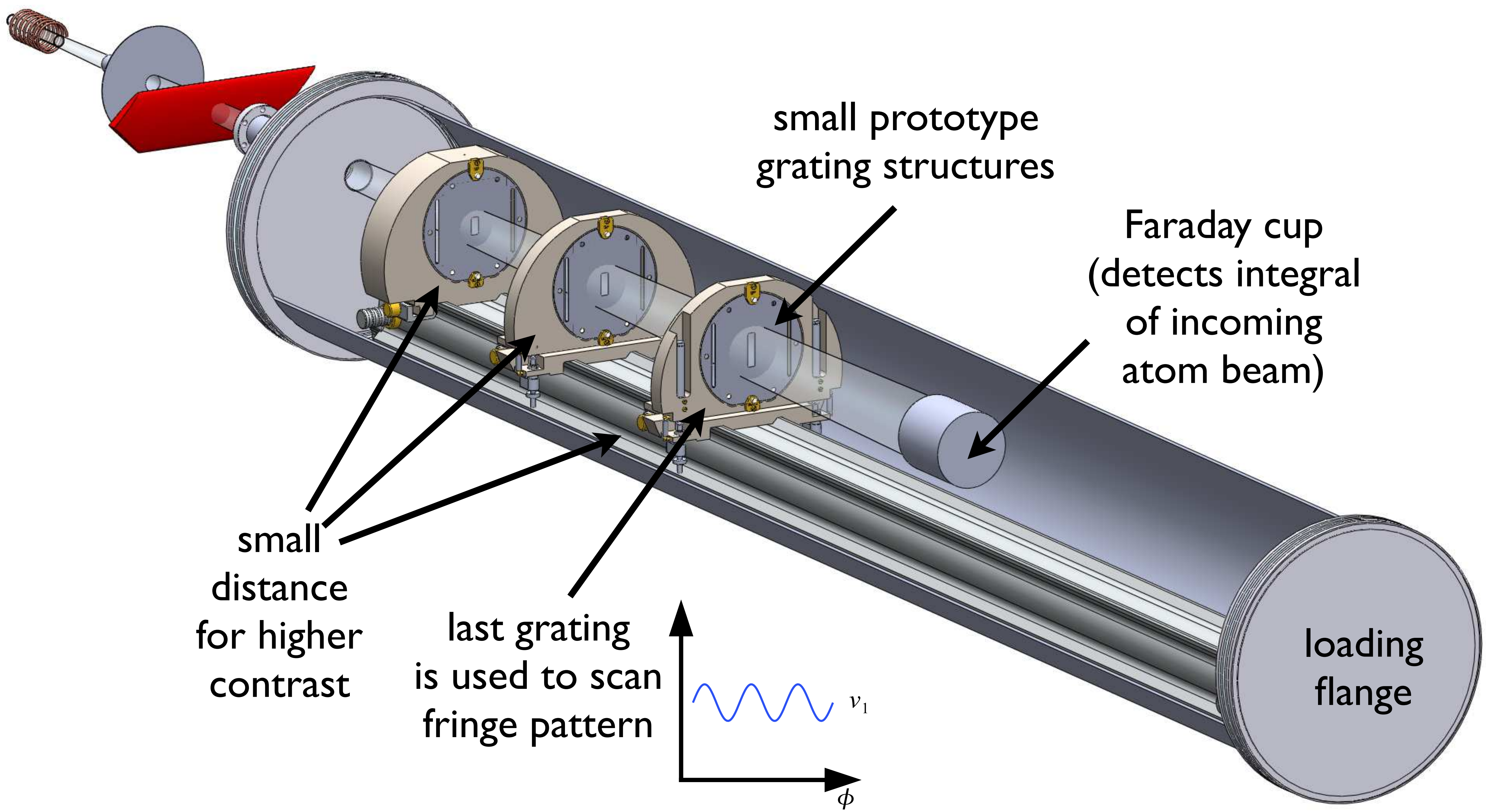
Laser system: power tests







Moiré deflectometer: first tests



Moiré deflectometer: 6” (full size) grating prototype