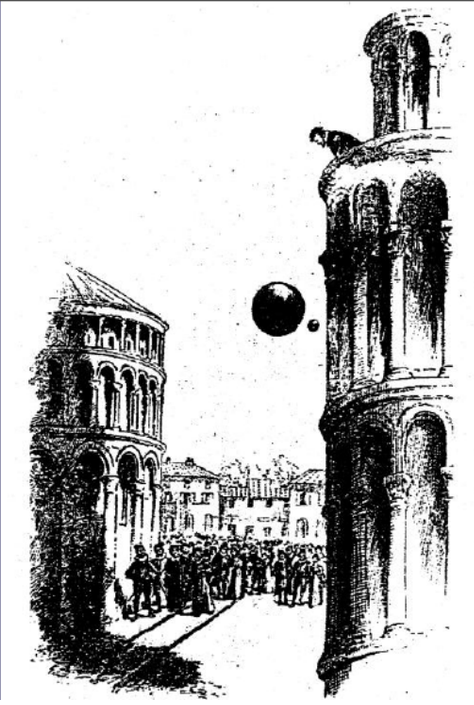


The AEgIS/AD-6
(Antihydrogen Experiment: Gravity, Interferometry and Spectroscopy)

experiment at the CERN antiproton decelerator

Michael Doser / CERN
on behalf of the AEgIS collaboration

AEgIS collaboration

IPNL, Lyon

Stefan Meyer Institut, Austria

INFN Firenze, Italy

CERN, Switzerland

INFN Genova, Italy

MPI-K, Heidelberg, Germany

U of Heidelberg, Germany

INFN Milano, Italy

Politecnico di Milano, Italy

INR, Moscow, Russia

U of Bergen, Norway

University College London, UK

Laboratoire Aimé Cotton, Orsay, France

U of Oslo, Norway

INFN Pavia/Brescia, Italy

Czech Technical U, Prague, Czech Republic

University Bern, Switzerland

University Zürich, Switzerland

INFN Padova/Trento, Italy

ETH Zurich, Switzerland

Topics

Schematic overview

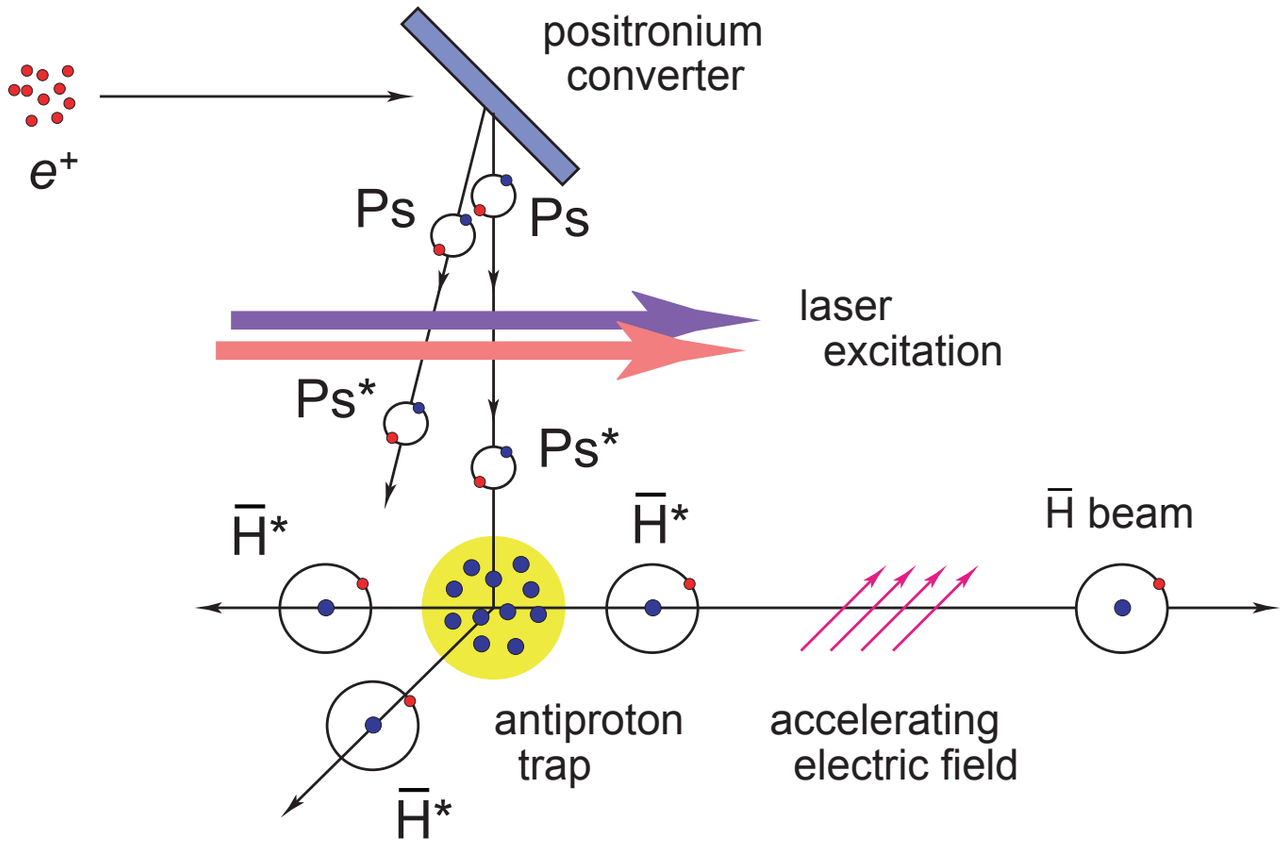
Status of experimental apparatus

Results of measurements with antiprotons in 2012

Outlook for 2014 and coming years

Schematic overview: pulsed horizontal beam of $\bar{H}$

production: charge exchange



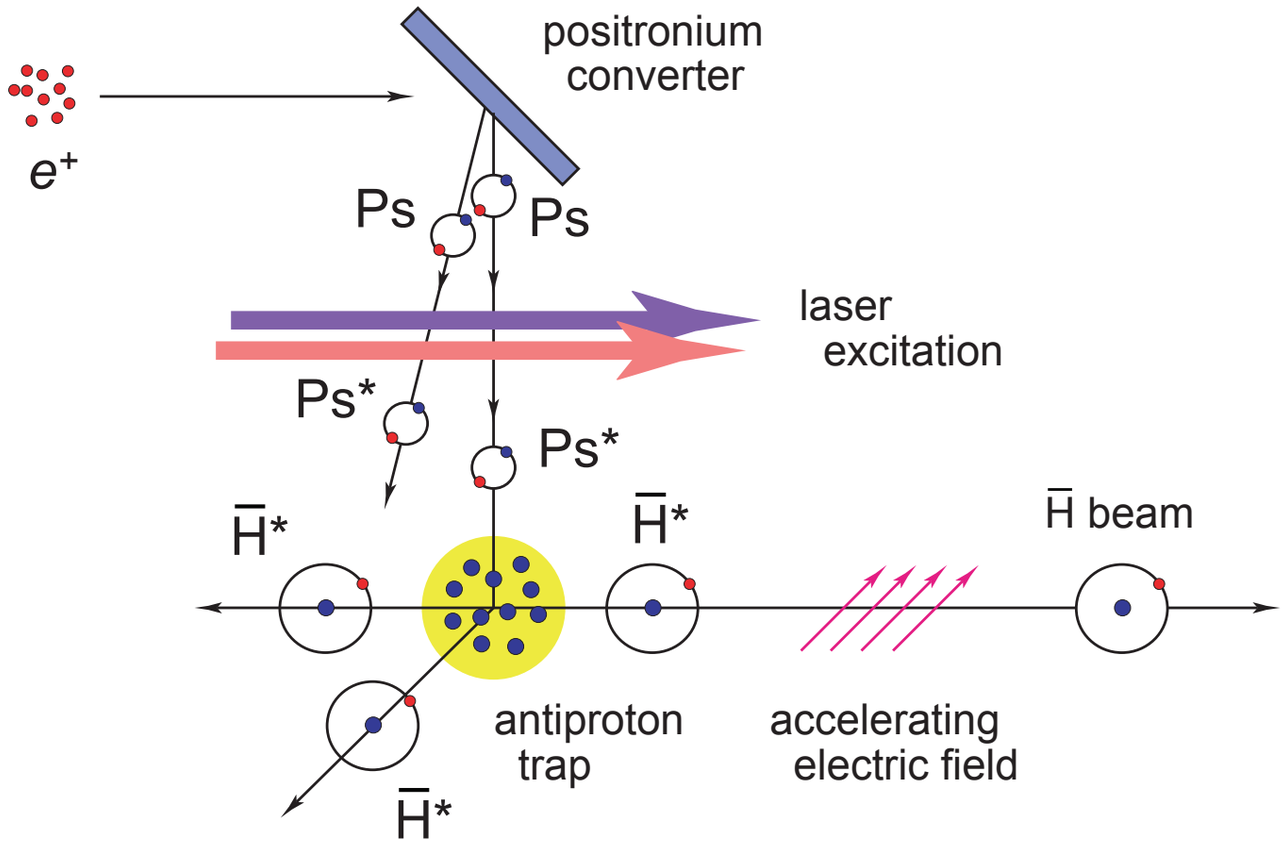
$\sigma \approx a_0 n^4$

time-of-flight: pulsed production

beam divergence: ultra-cold $\bar{p}$

Schematic overview: pulsed horizontal beam of $\bar{H}$

beam formation: Stark acceleration



$$\sigma \approx a_0 n^4$$

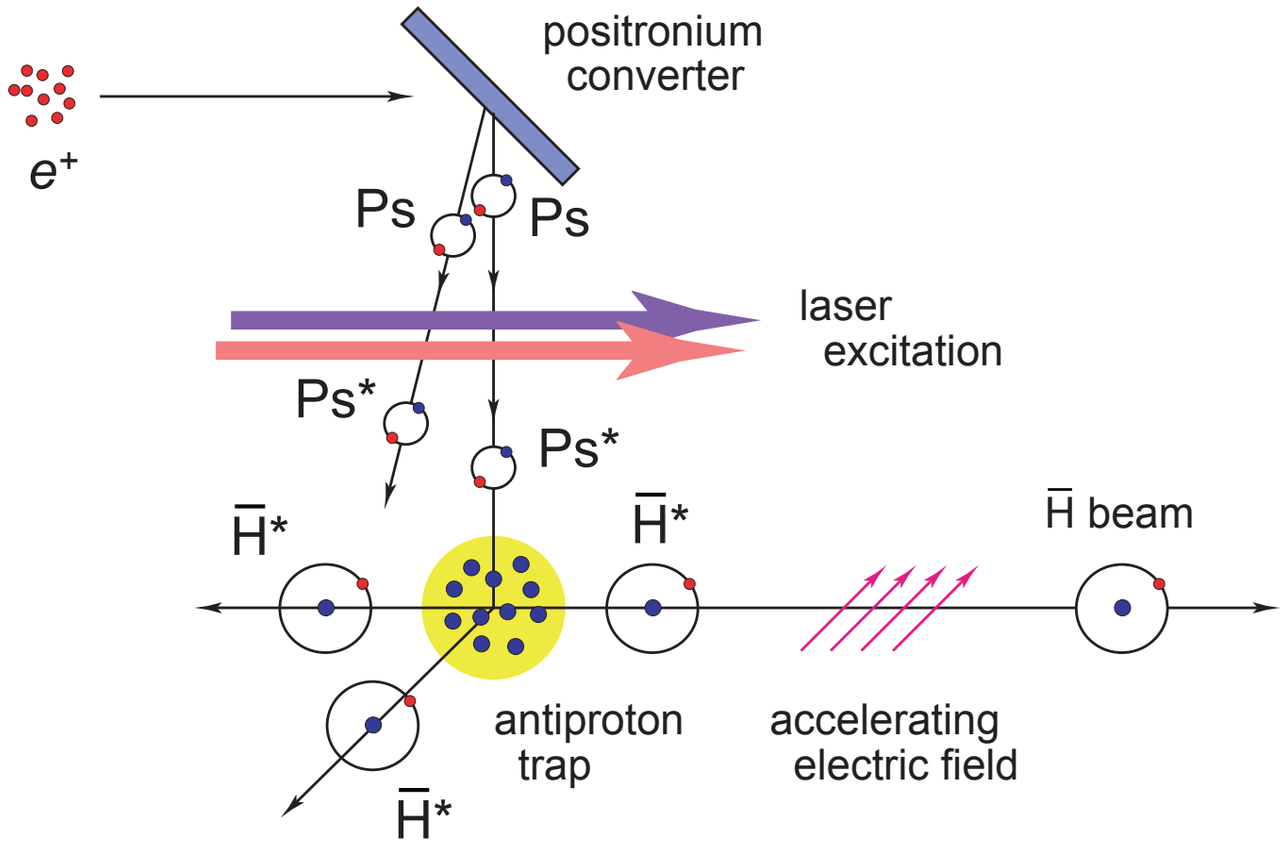
$$F = -\frac{3}{2} n k \vec{\nabla} E$$

time-of-flight: pulsed production

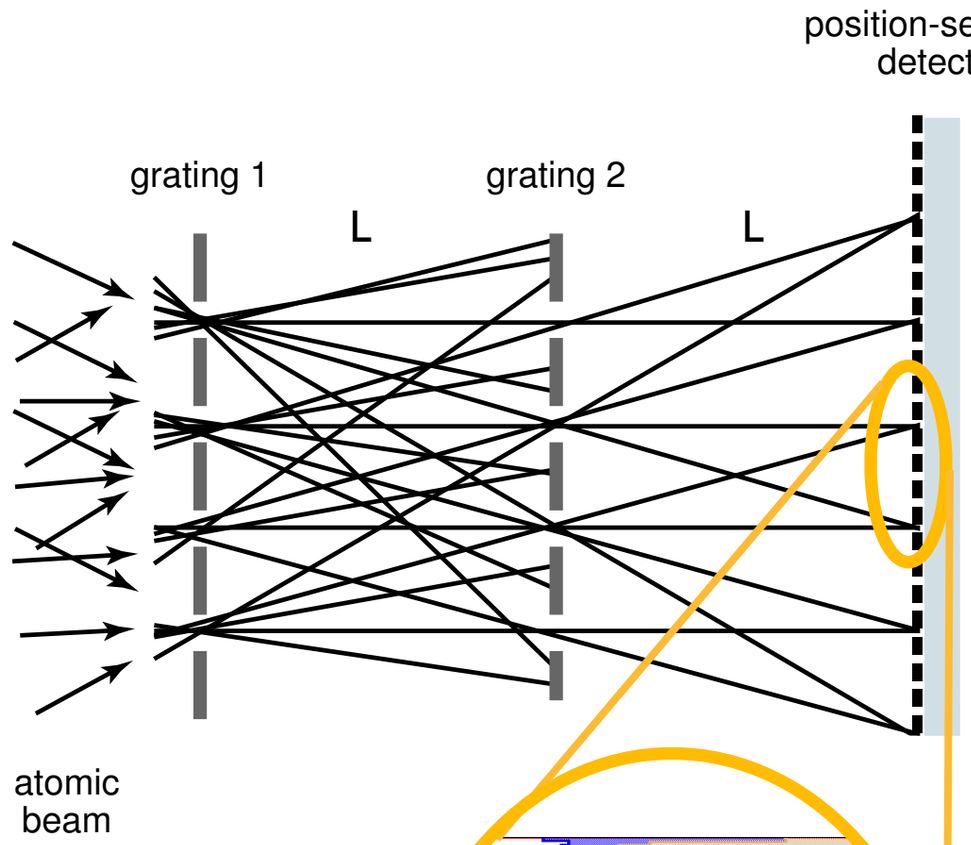
beam divergence: ultra-cold $\bar{p}$

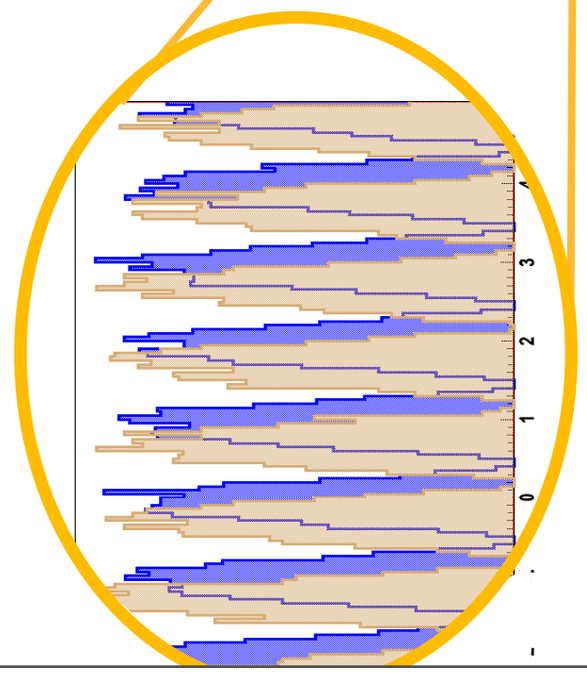
Schematic overview: pulsed horizontal beam of $\bar{H}$

beam formation: Stark acceleration



measurement: deflectometer





$\sigma \approx a_0 n^4$

$F = -\frac{3}{2} n k \vec{\nabla} E$

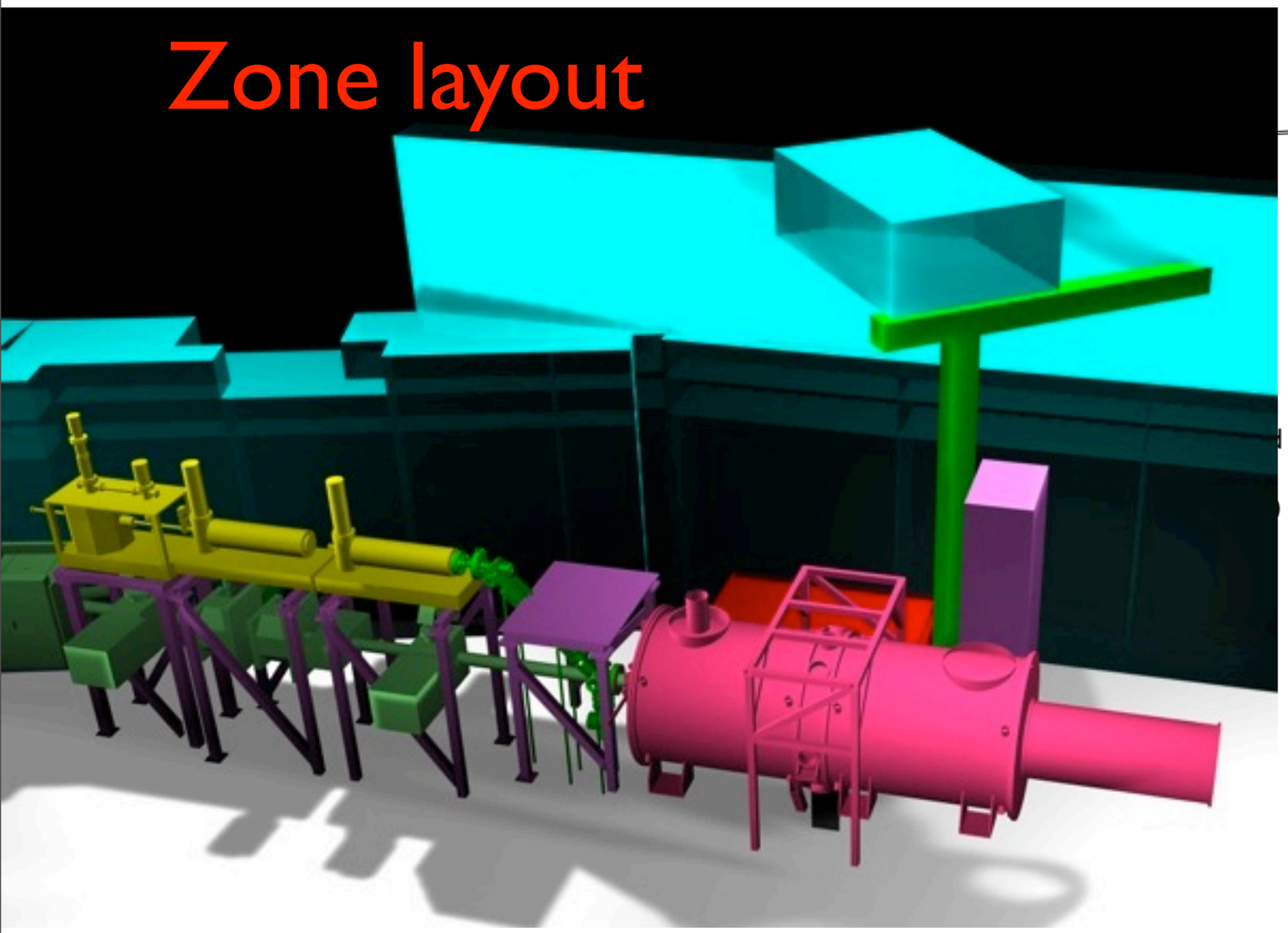
time-of-flight: pulsed production

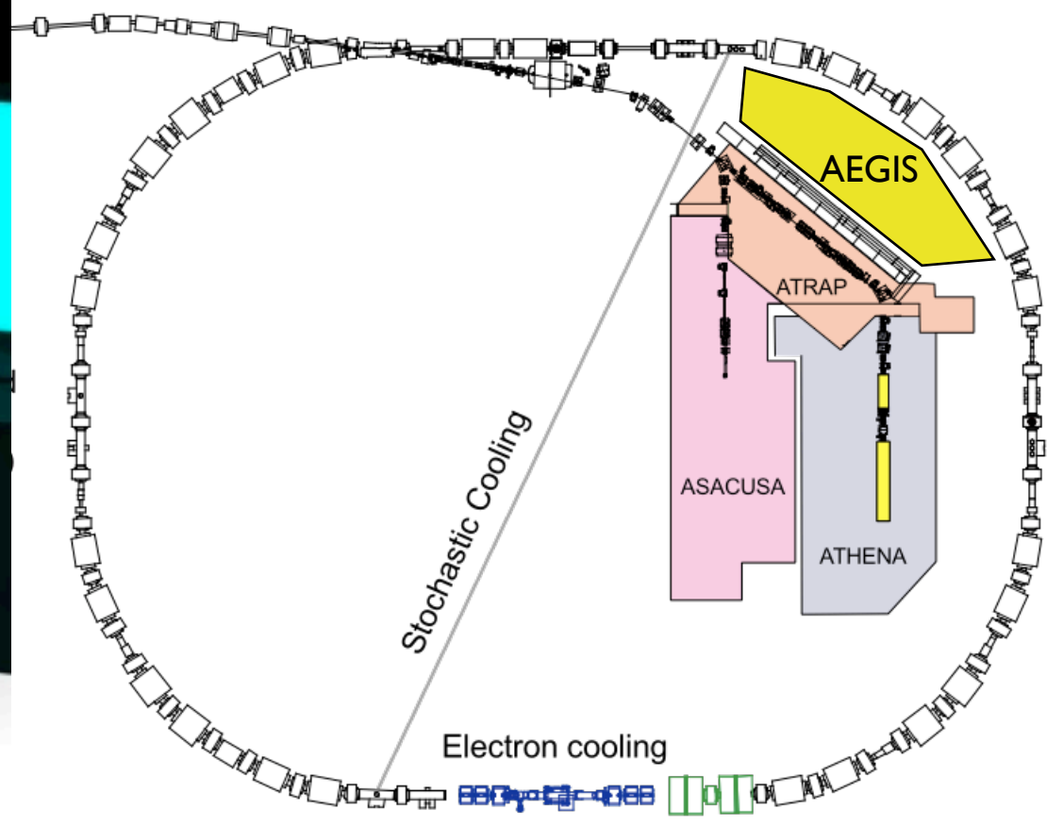
beam divergence: ultra-cold $\bar{p}$

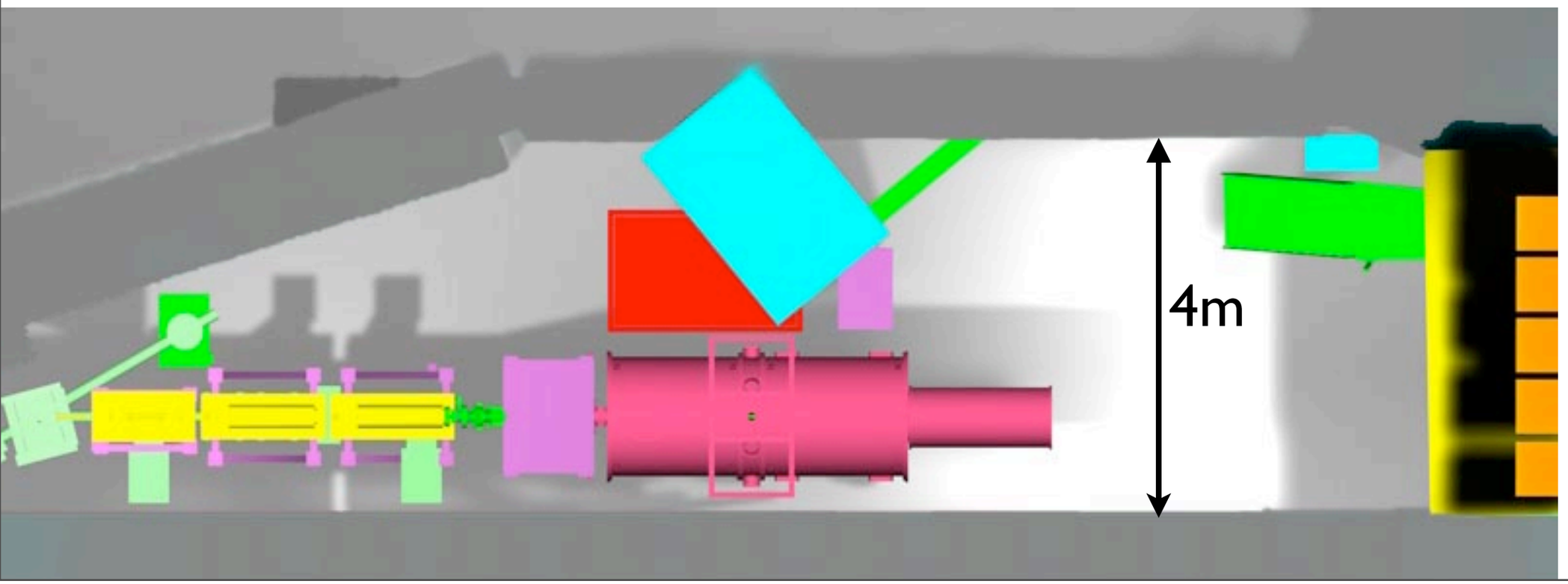
Physics goals:

gravity:	absolute measurement of g($\bar{H}$) to 1%	WEP
spectroscopy:	HFS($\bar{H}$) to 10^{-6}	CPT
	precision spectroscopy of Ps and Ps*	QED
	spectroscopy of $\bar{H}$ (1s-2s, Rydberg levels)	CPT

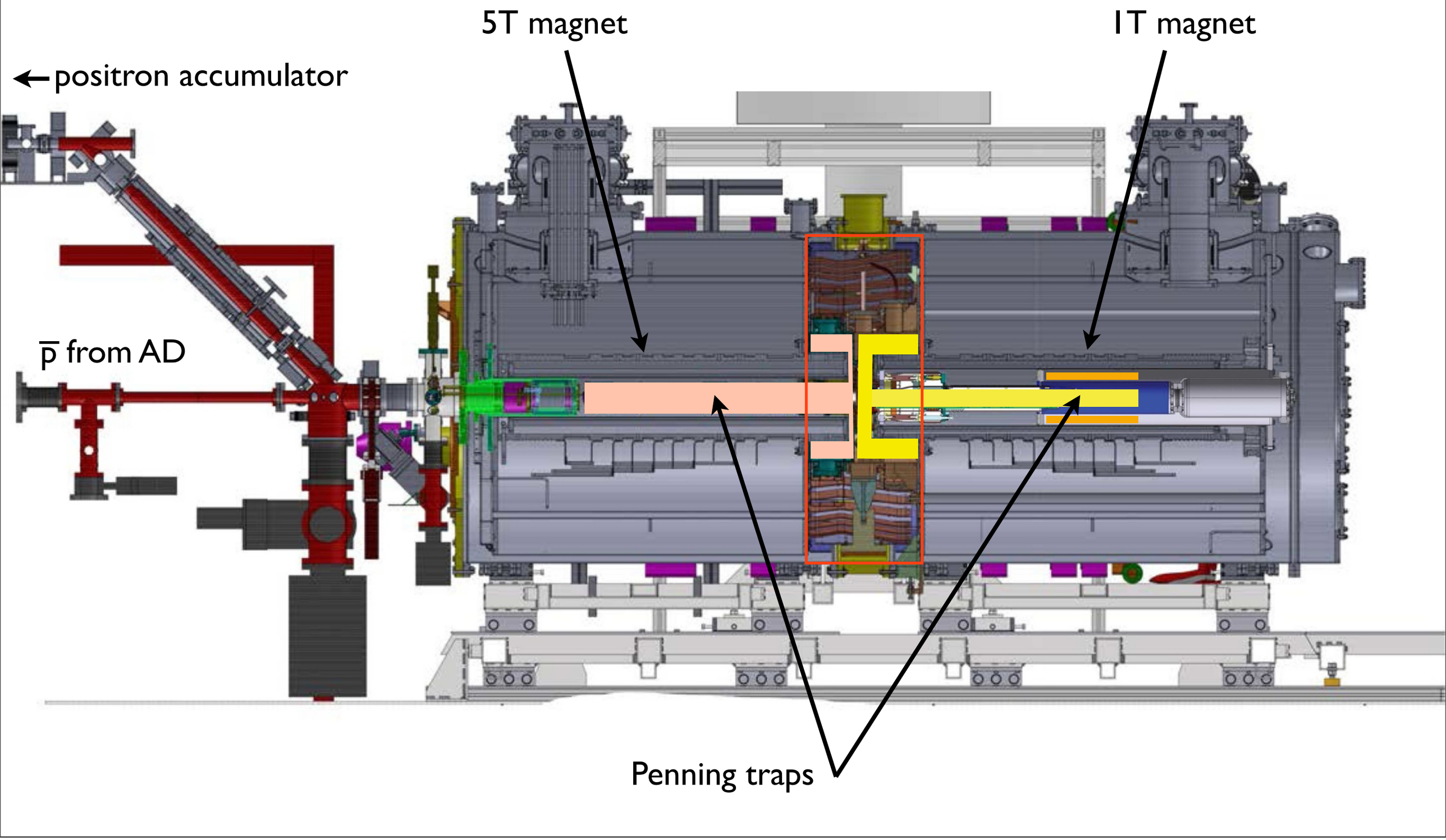
Zone layout



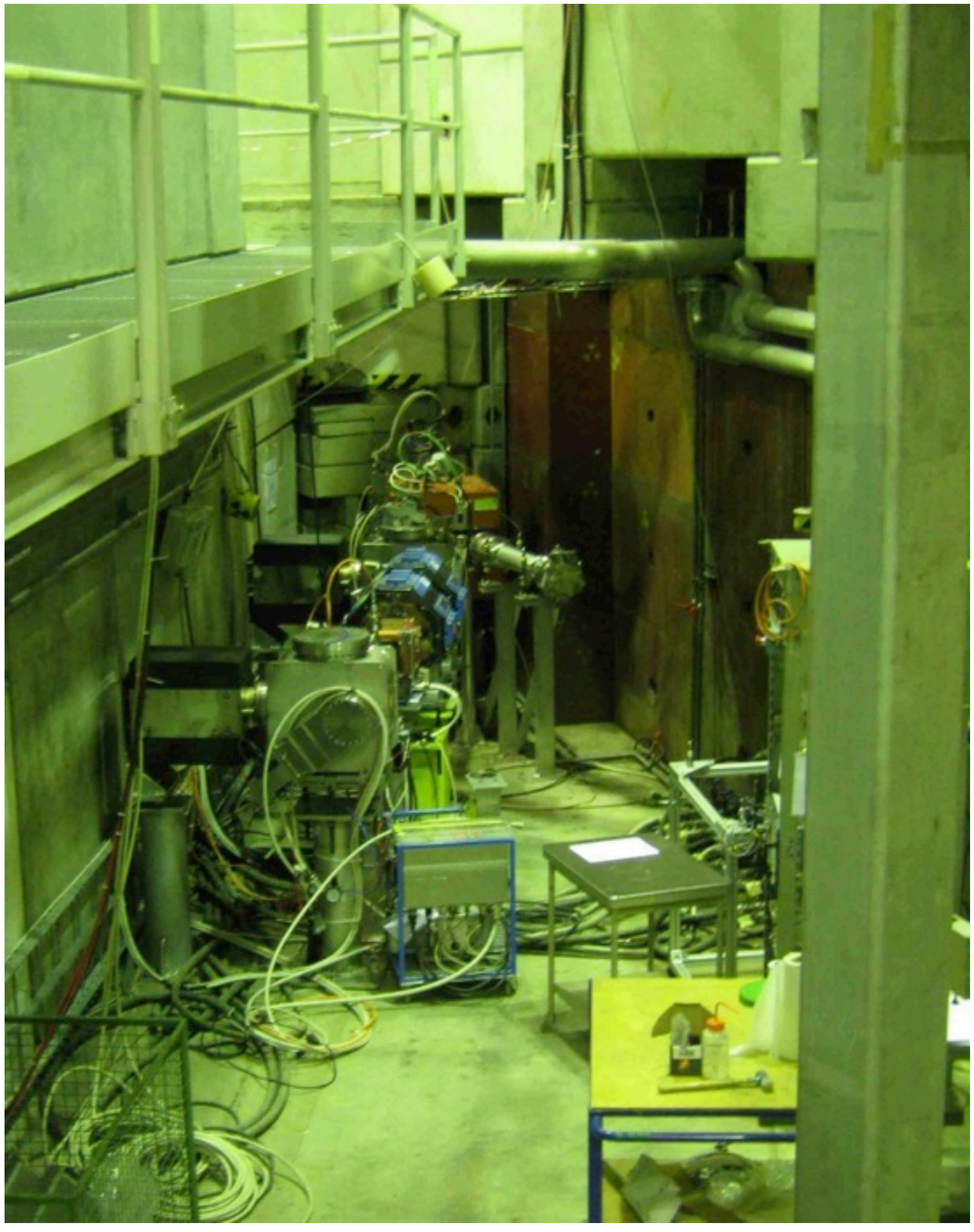

AEGIS
ATRAP
ASACUSA
ATHENA
Stochastic Cooling
Electron cooling


4m

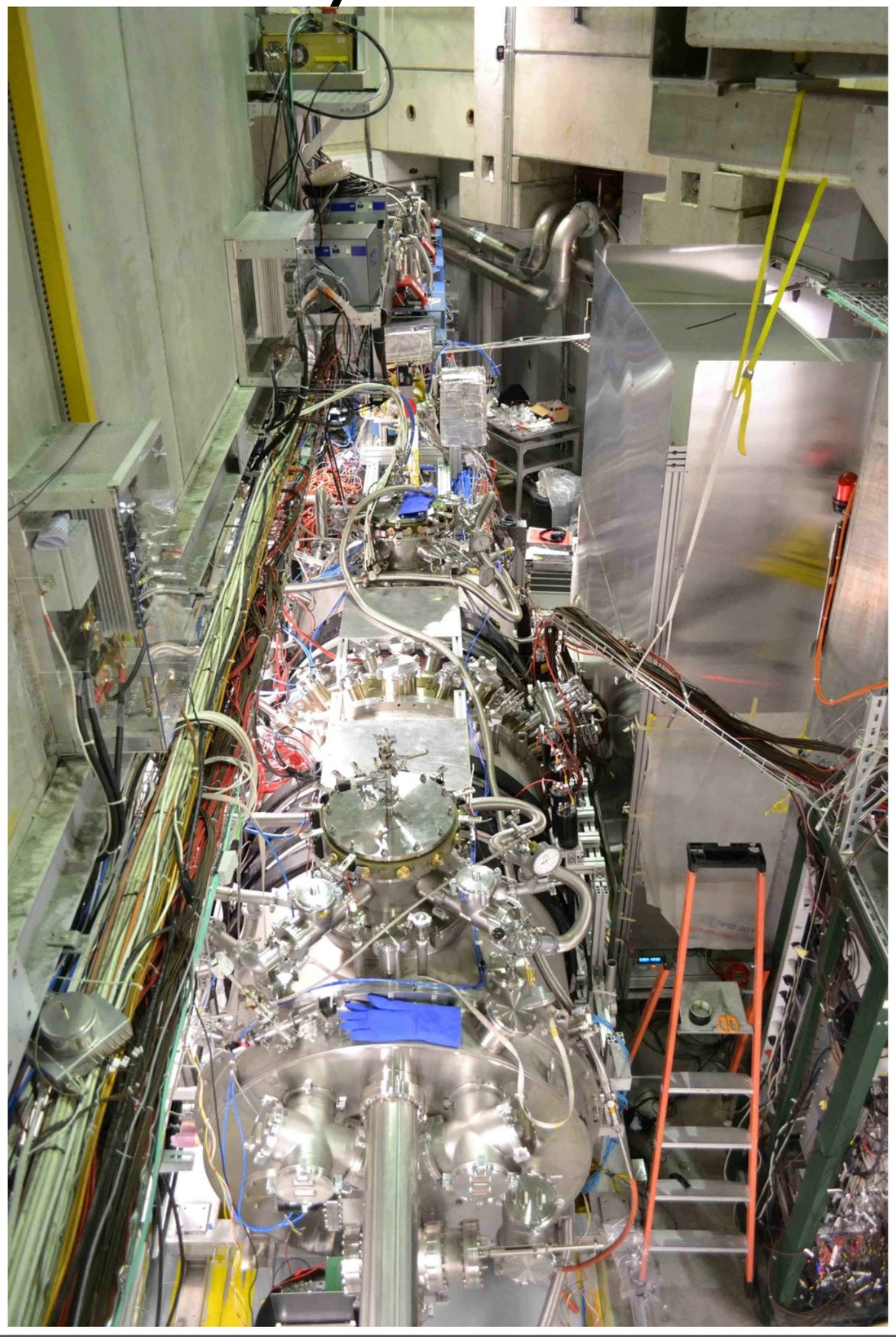
Central apparatus design



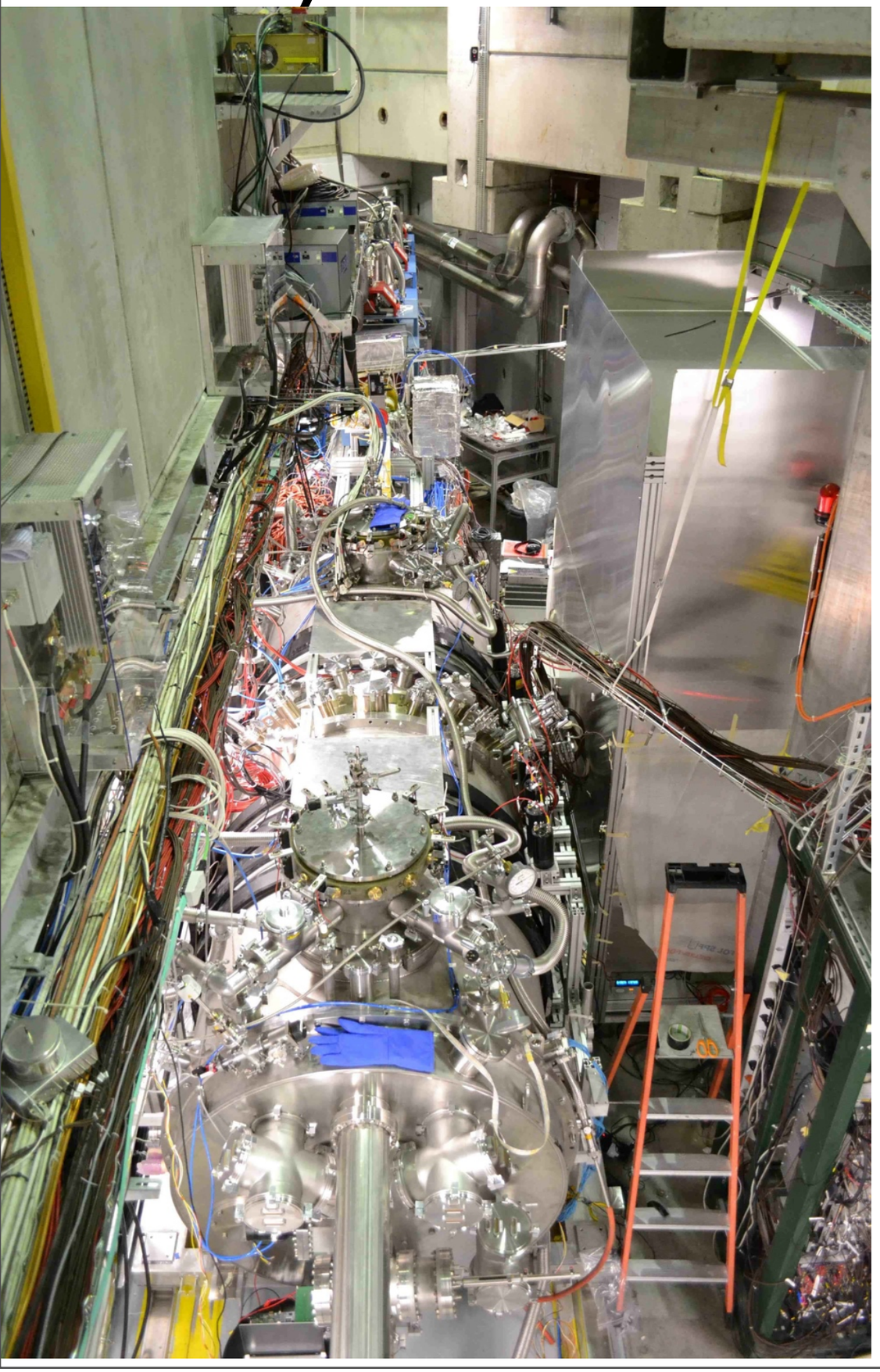
Zone layout early 2011



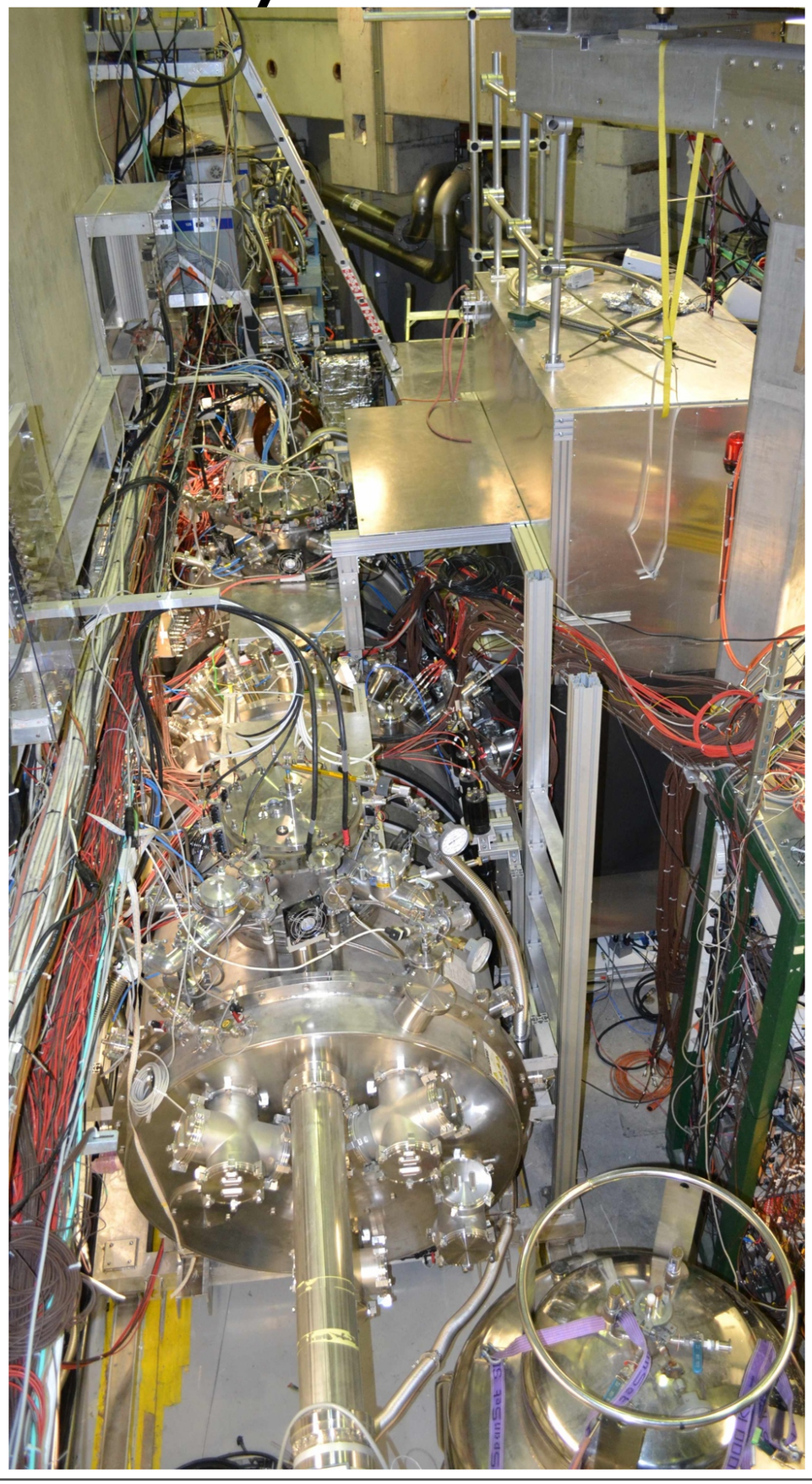
Zone layout late 2012



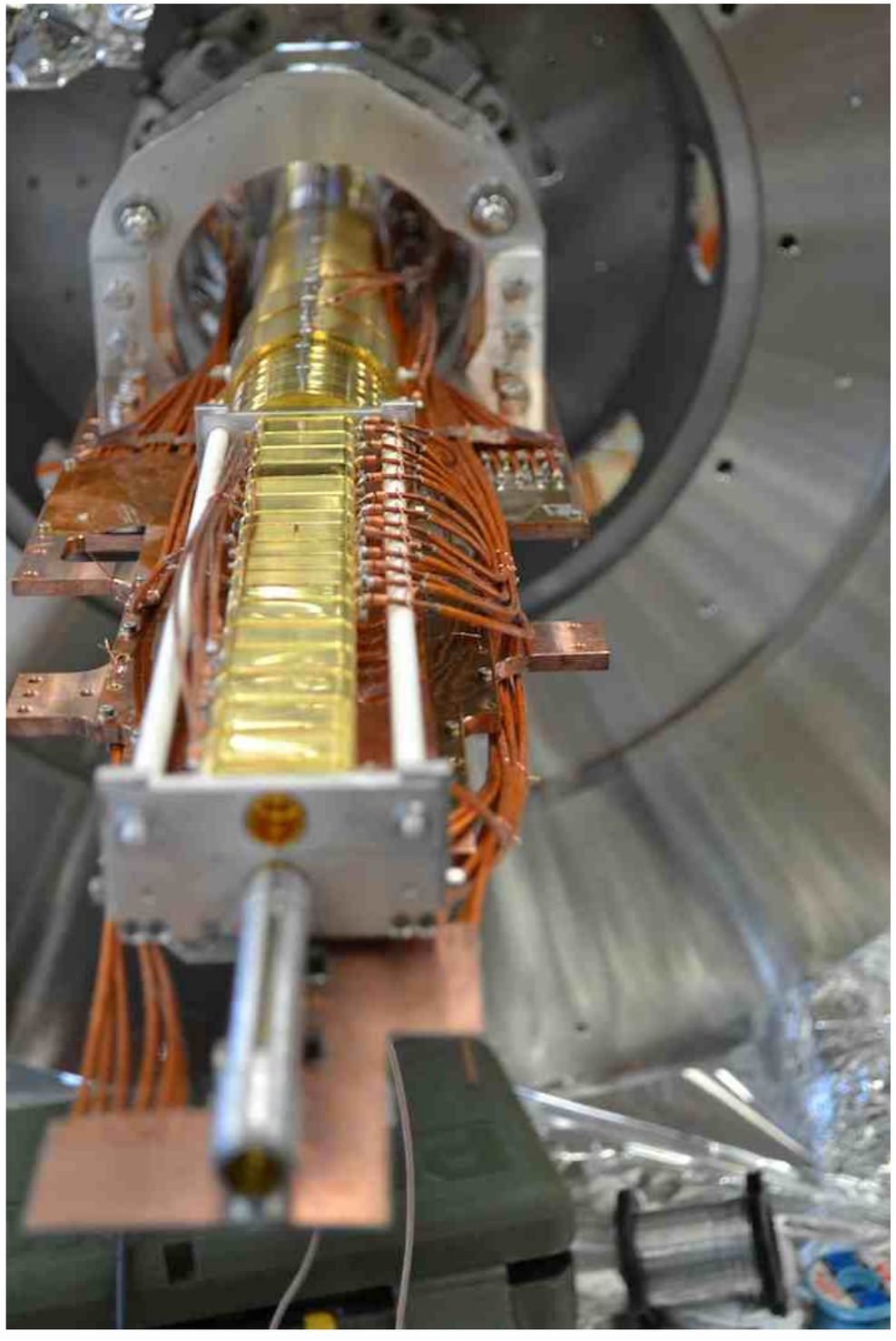
Zone layout late 2012

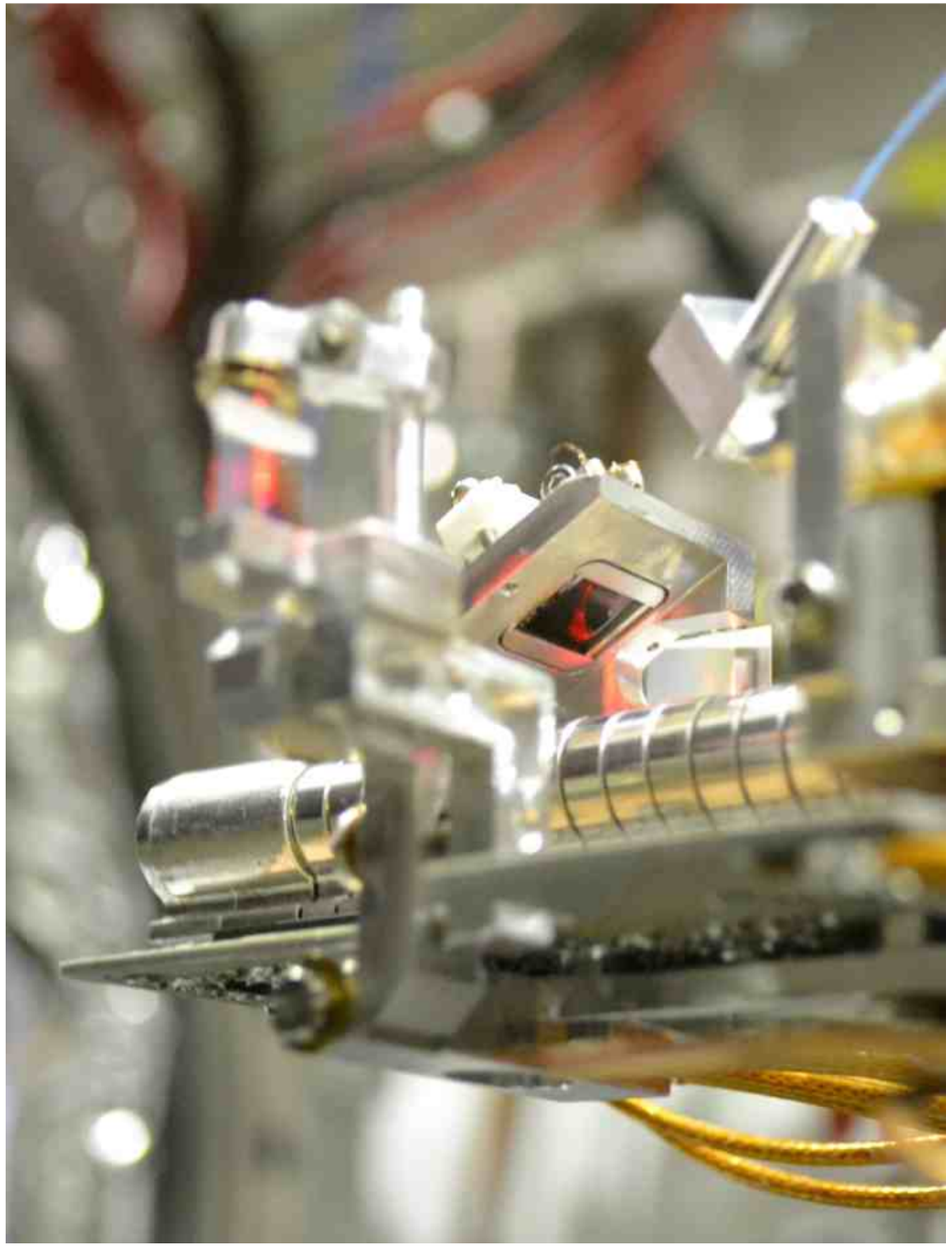


Zone layout late 2013



IT Formation Traps

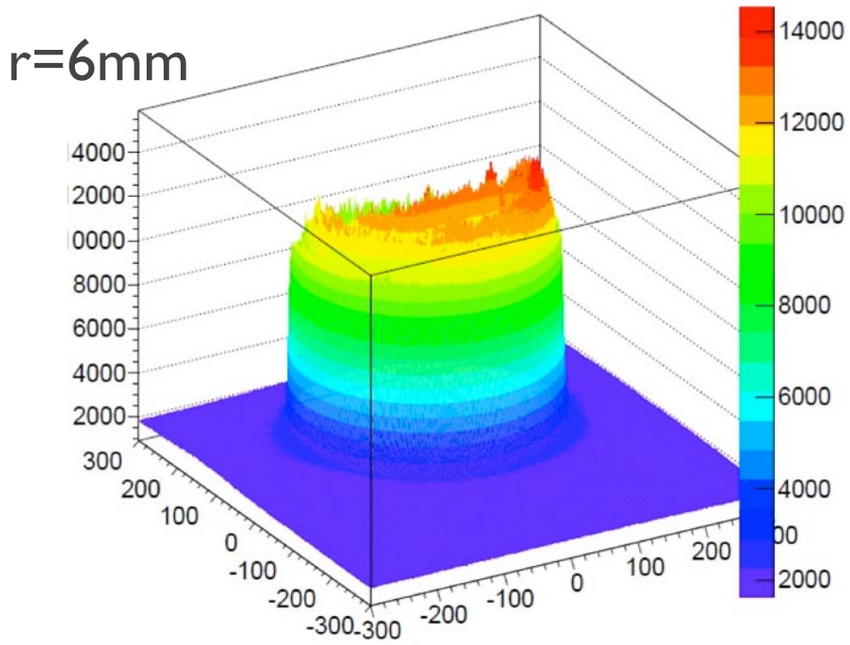




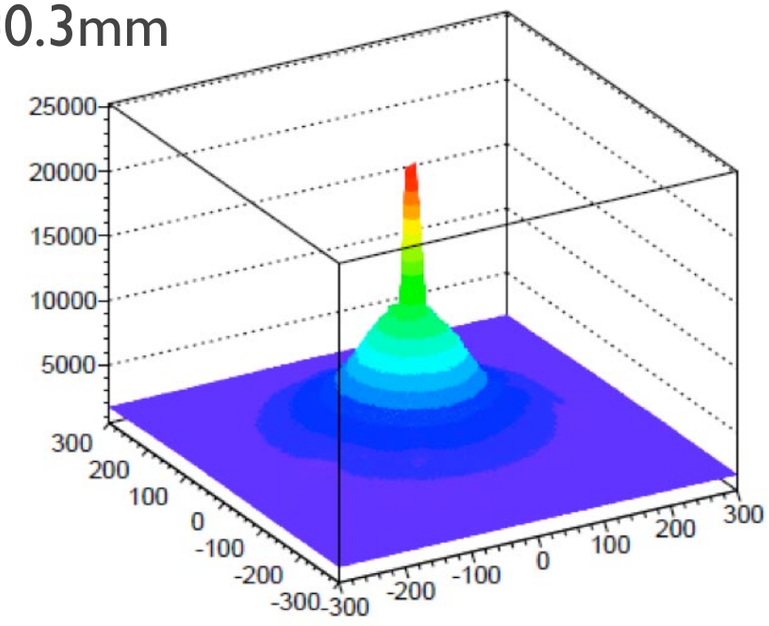
Electrons: plasma manipulations

rotating wall

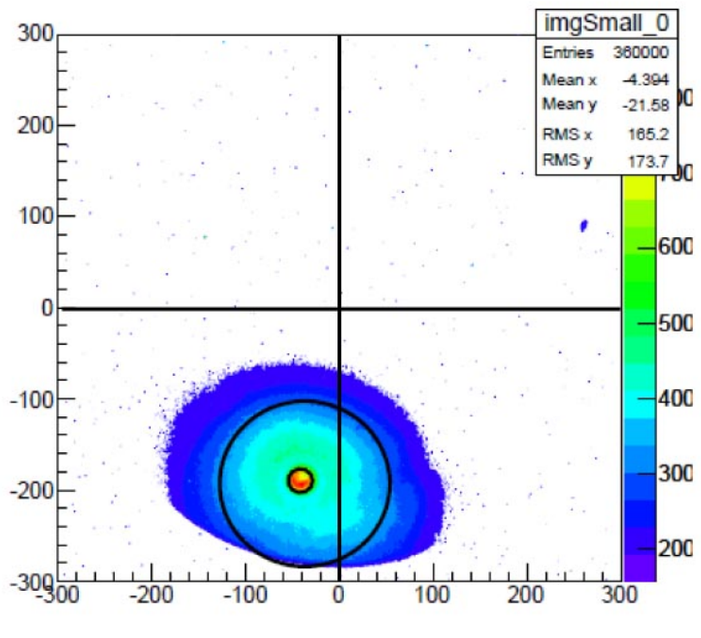
r=6mm

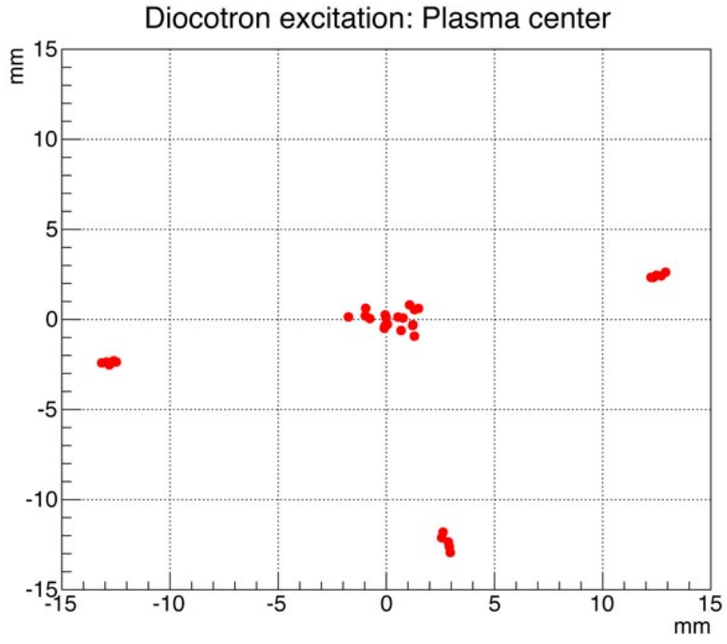


r=0.3mm



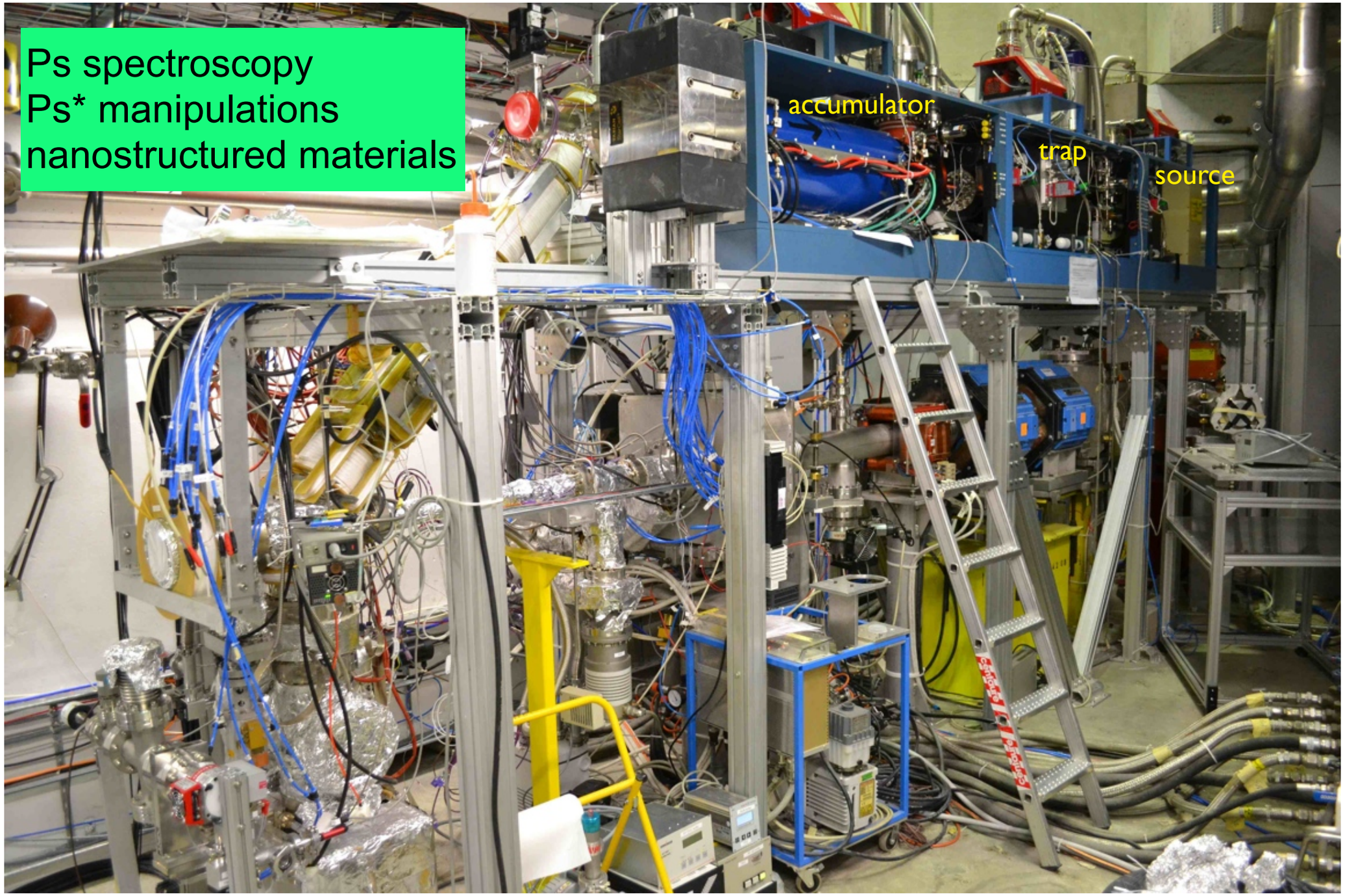
diocotron excitation





Positrons: transfer and capture (80%)

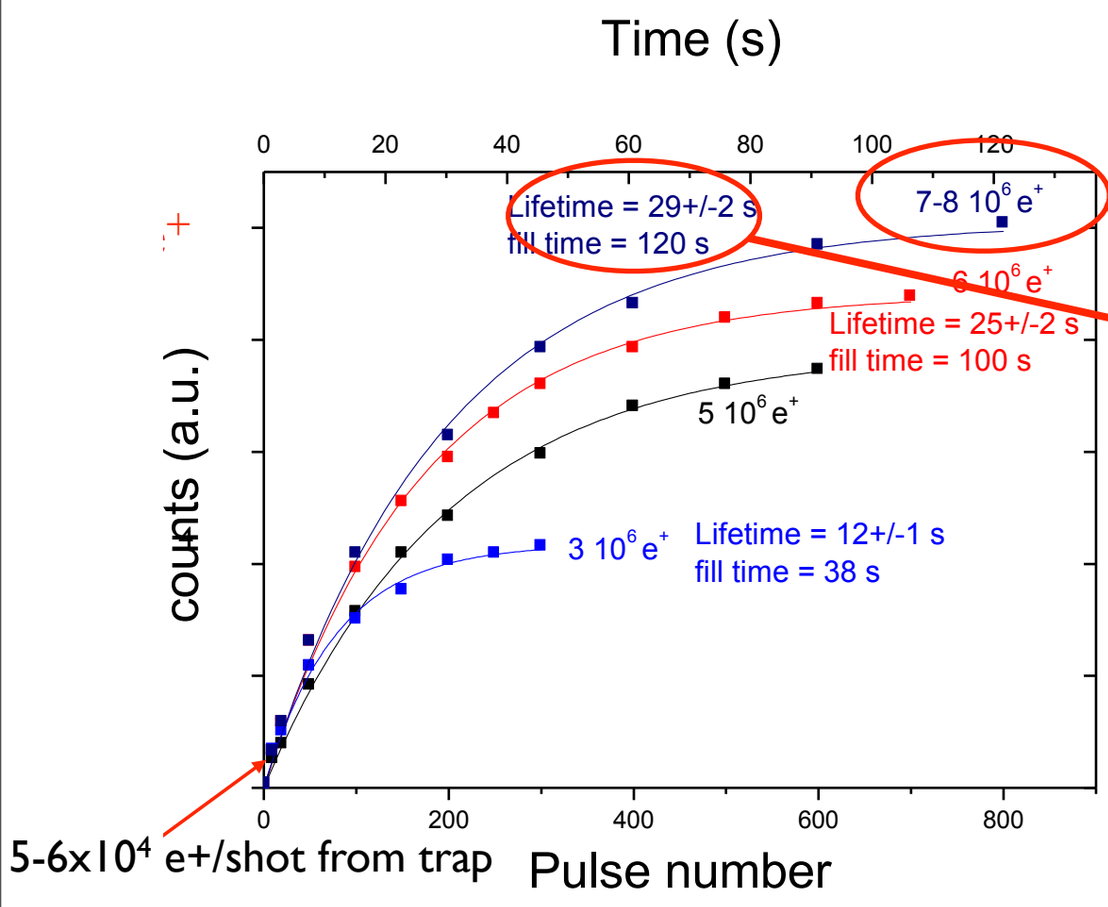
Positron system

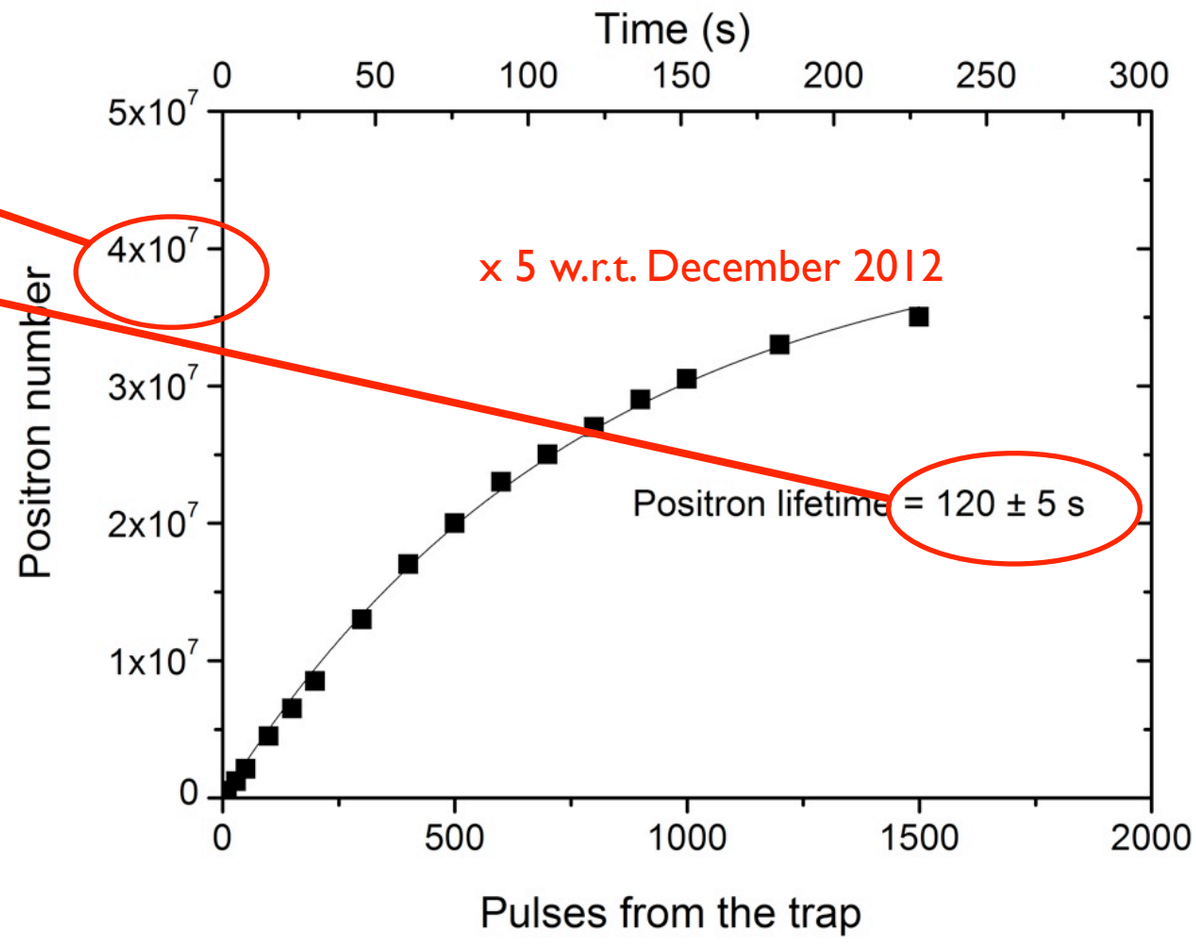


Completed and first operation in October 2012

Positron system: systematic work during 2013

Alignment, magnetic shielding, vacuum, control SW ...

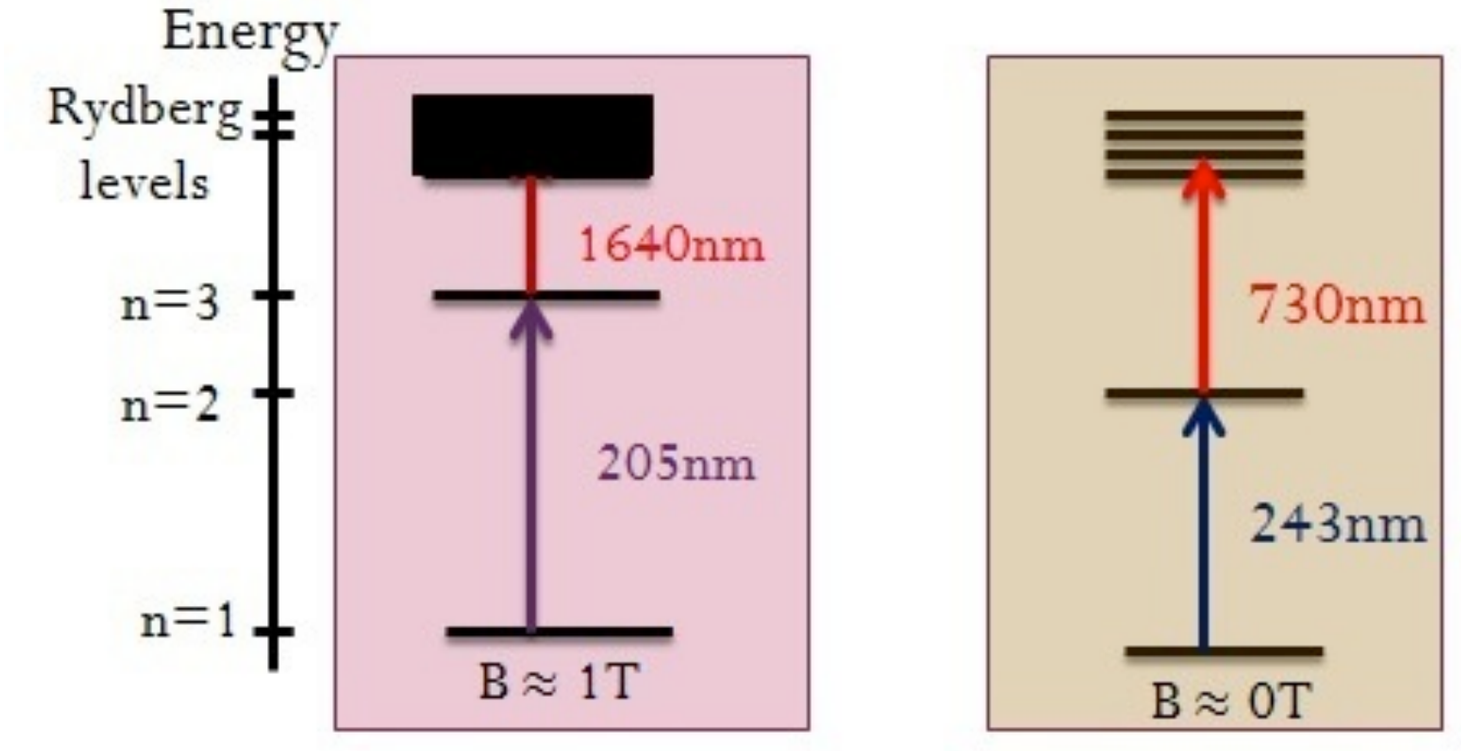




Improvements in rates and lifetimes

4 x 10^7 e^+ extracted in pulses of ~ 7ns

Ps excitation laser system(s)



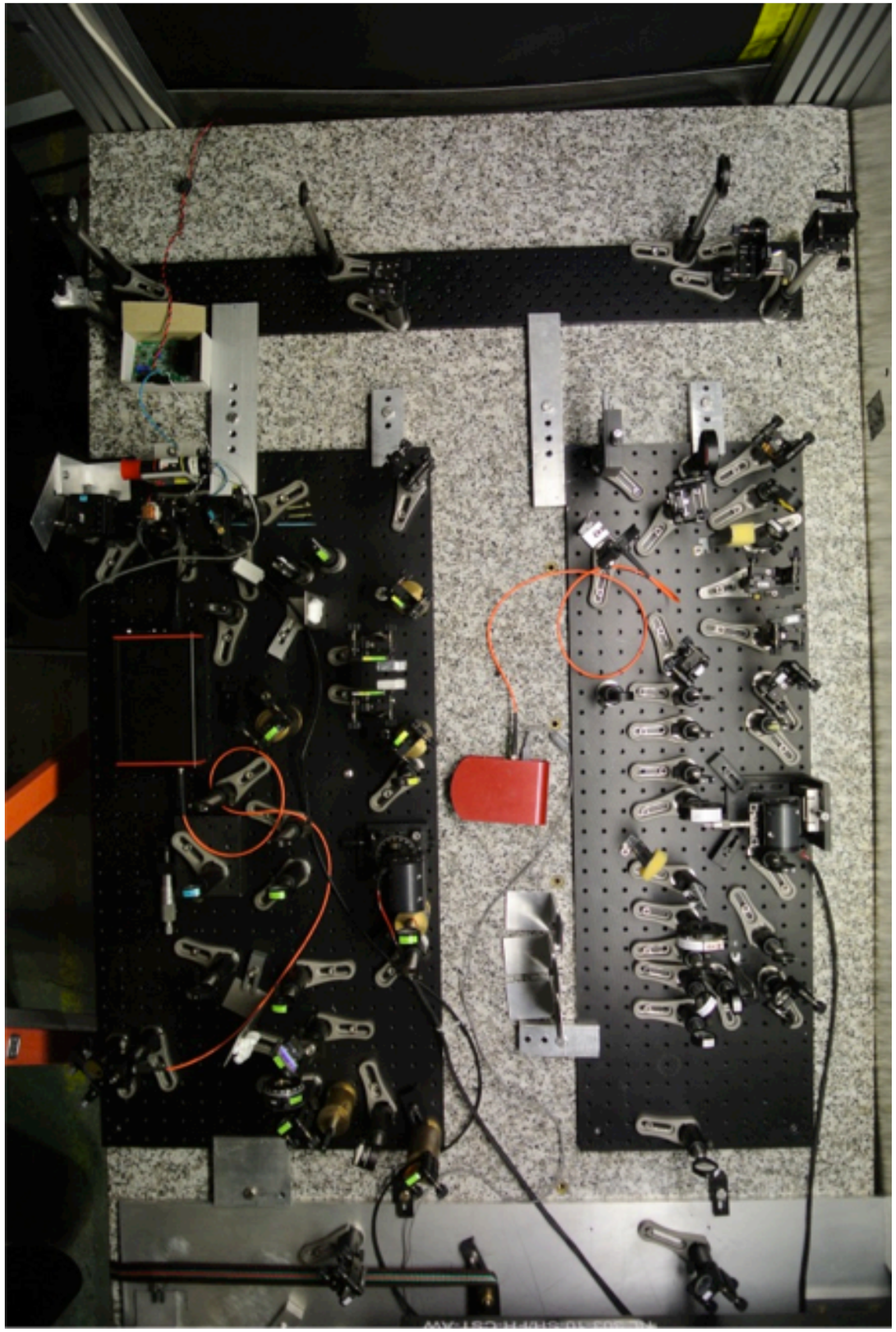
Broad-band laser installation completed and commissioned in 2013:

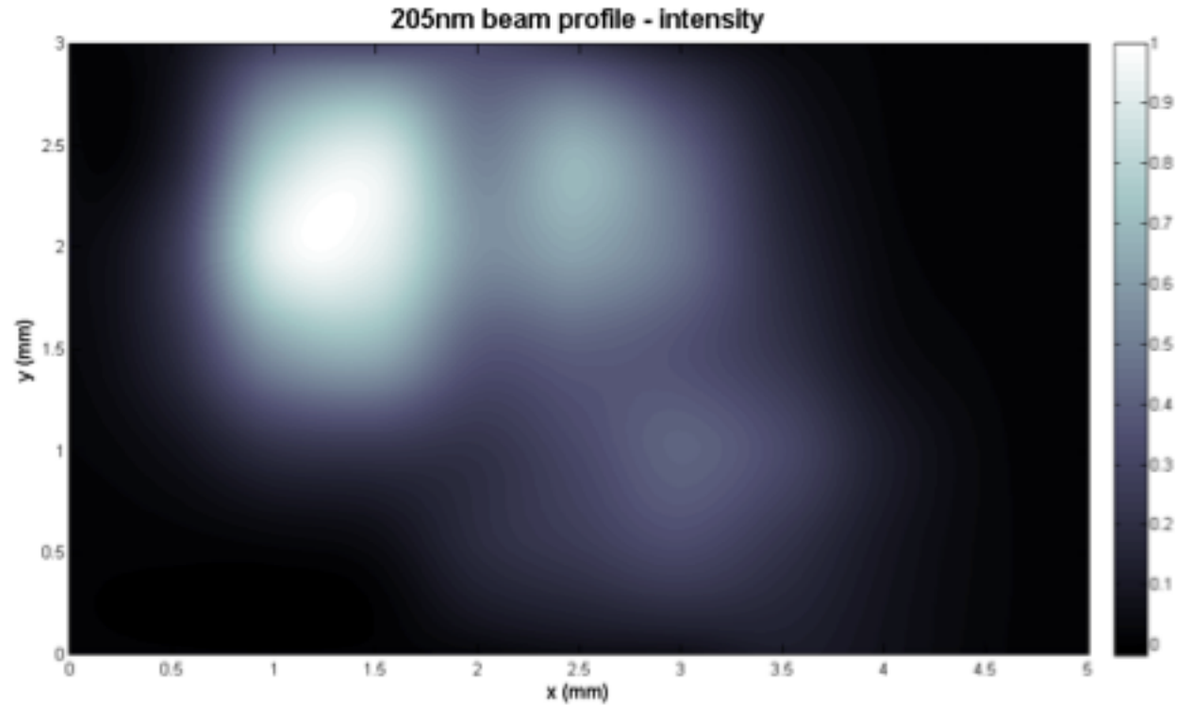
- alignment and tuning:

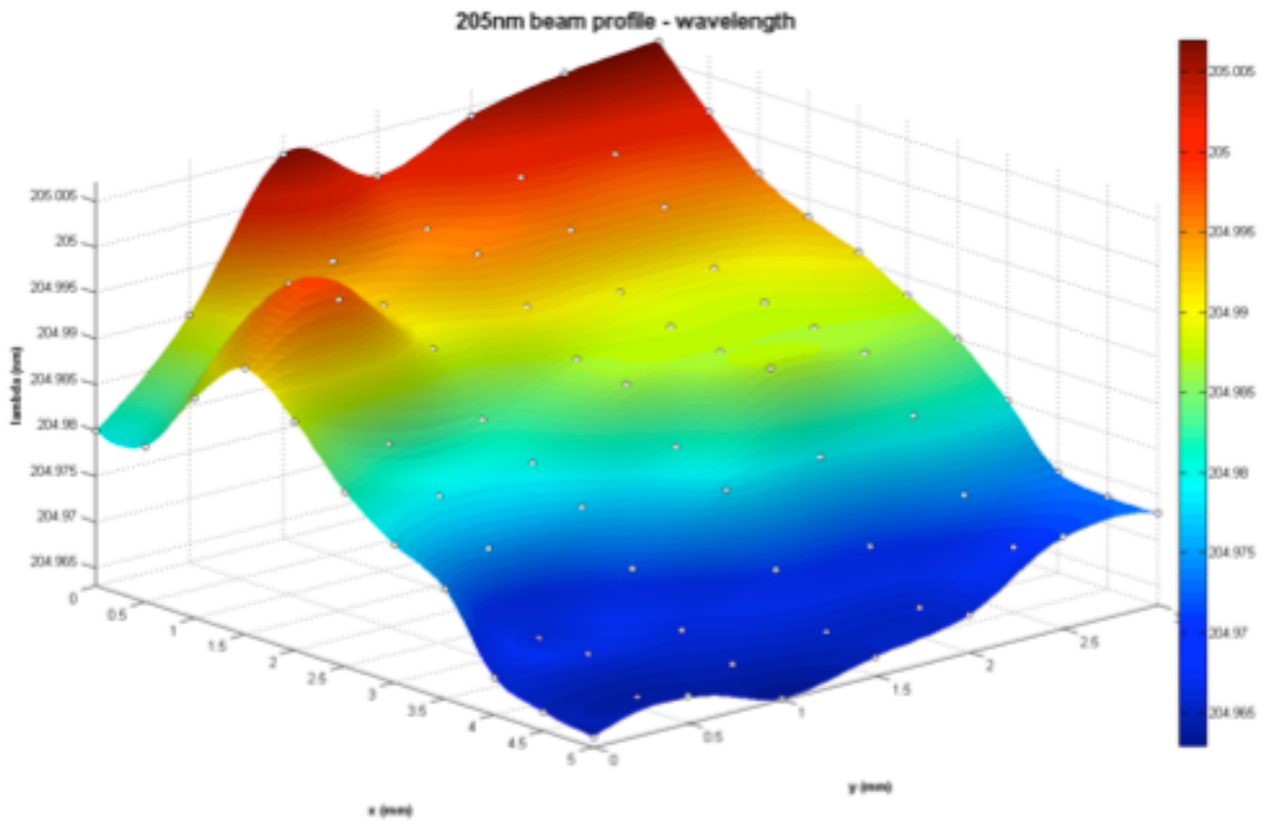
Transition	Wavelength	Est. saturation energy	Max. produced energy
1 → 3	205 nm	32 μJ	106 μJ
3 → 26	1664 nm	350 μJ	4000 μJ

- measurements of monochromaticity
- measurements of intensity profile

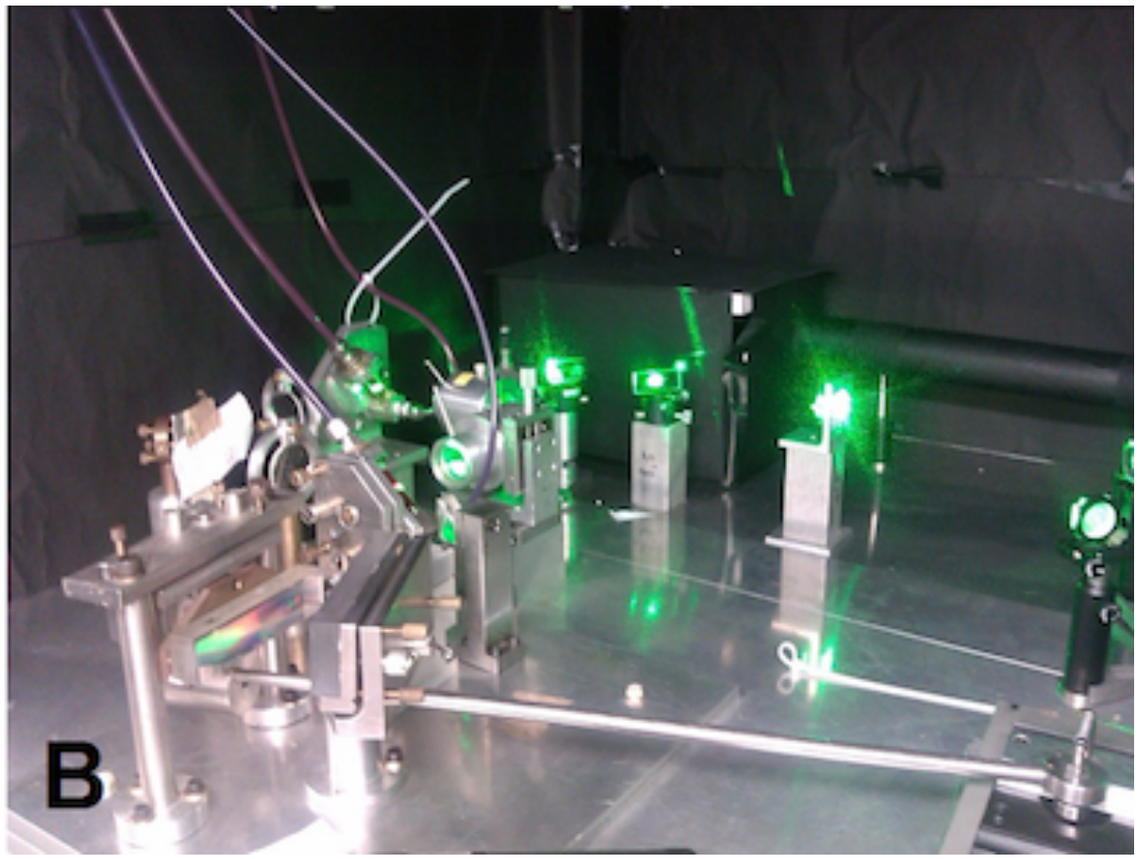
Broad-band laser fully installed and commissioned in 2013:







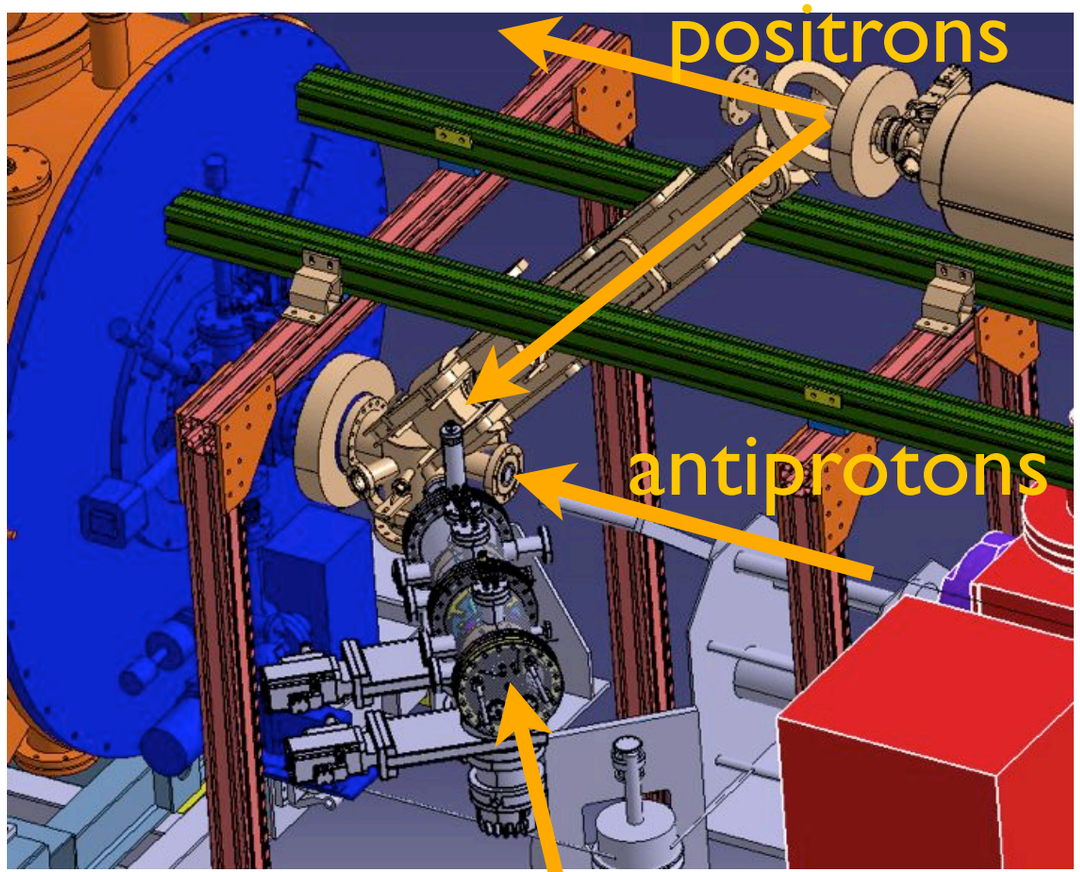
Narrow-band laser installed and commissioned in 2014:

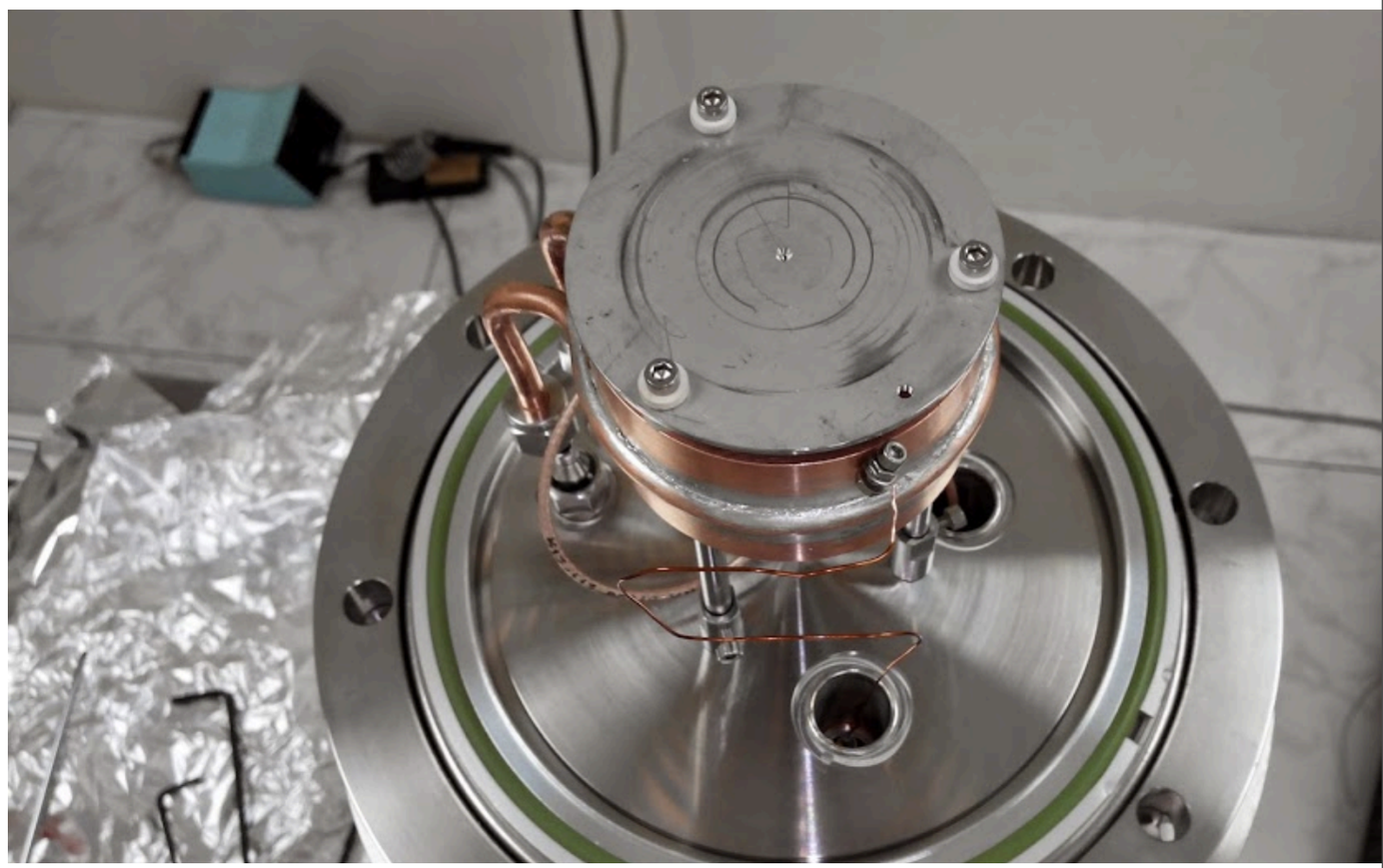


- set-up with same pump laser as broad-band system
- wavelengths being set up
- dedicated pump laser installed

ongoing work: Proton source

$$p + Ps \longrightarrow H + e^-$$

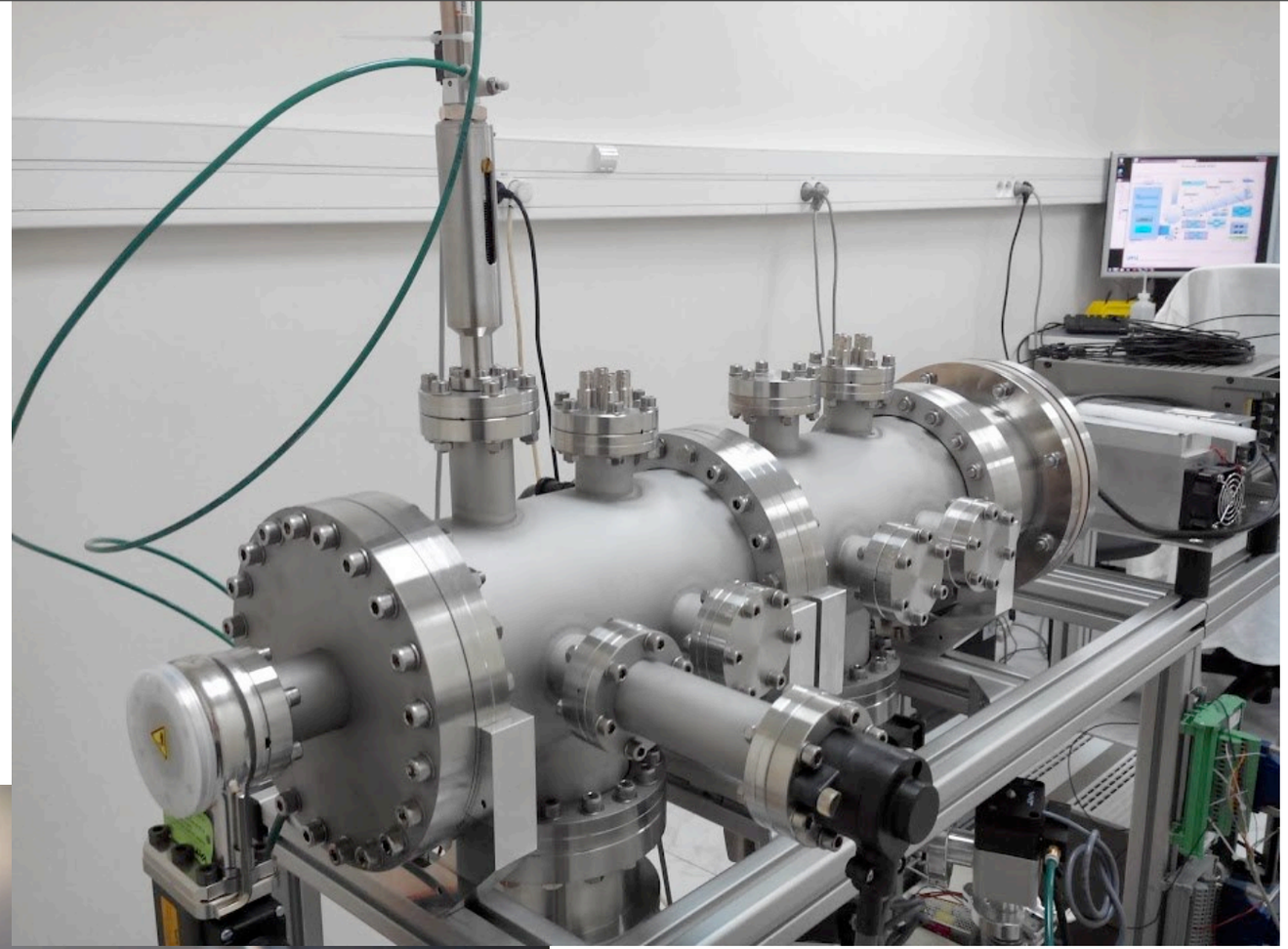


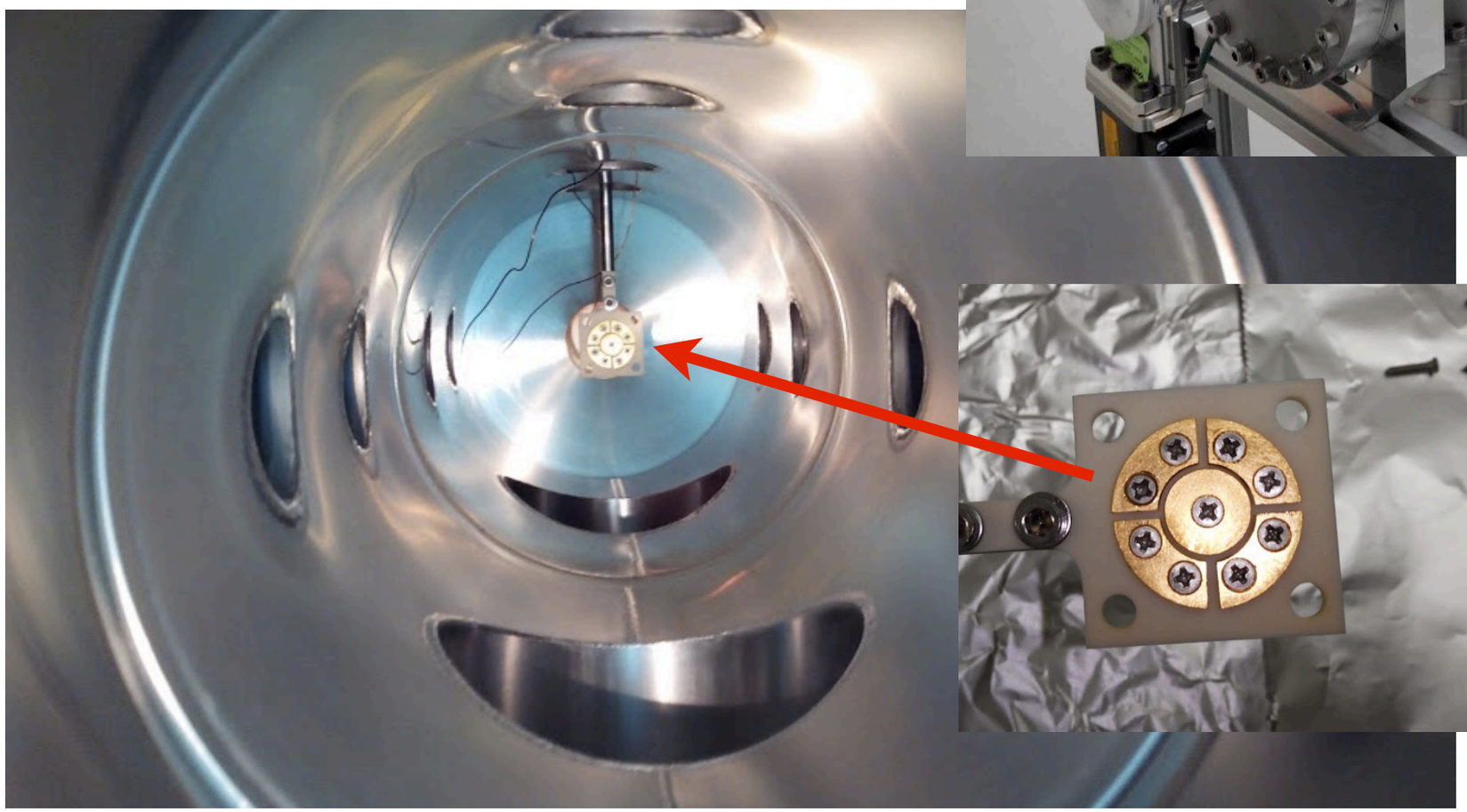


Hydrogen plasma cavity

testing completed, being shipped to CERN,
ready for installation during next weeks

Test set-up in Lyon

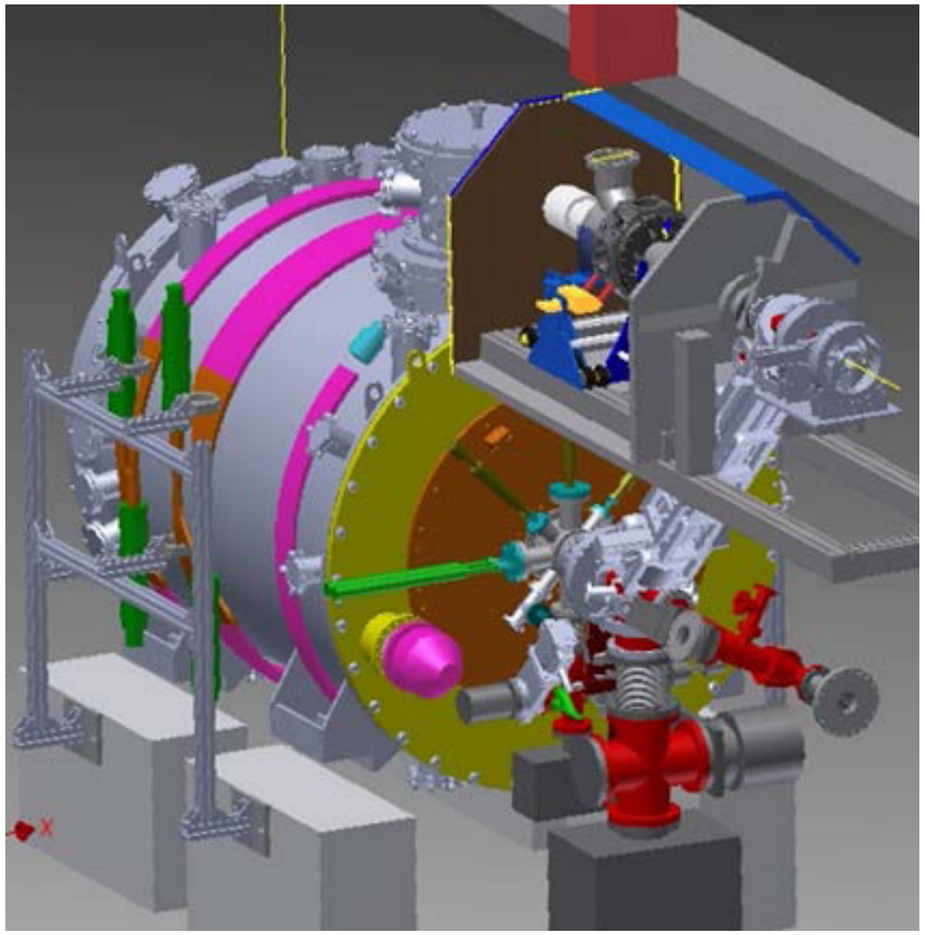


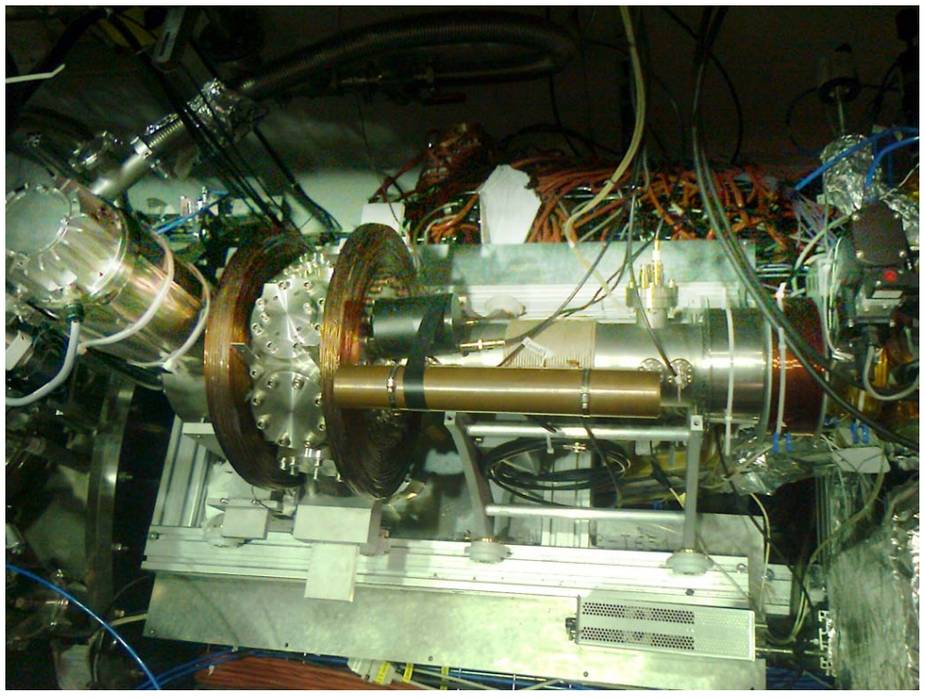


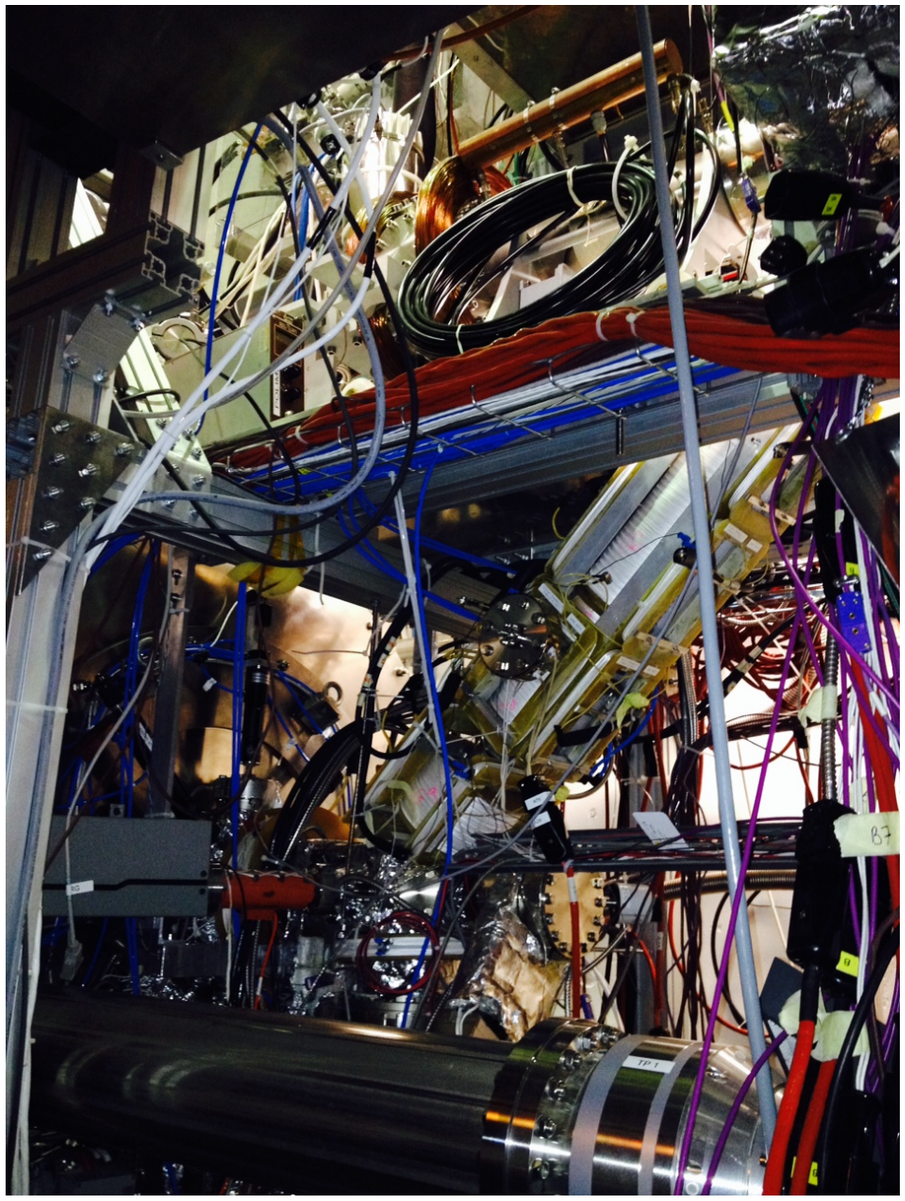
Faraday cup

Proton beam: I = 300 nA (grounded Faraday cup) (@2x10^{-5} mbar)

Positronium test station: installation and commissioning

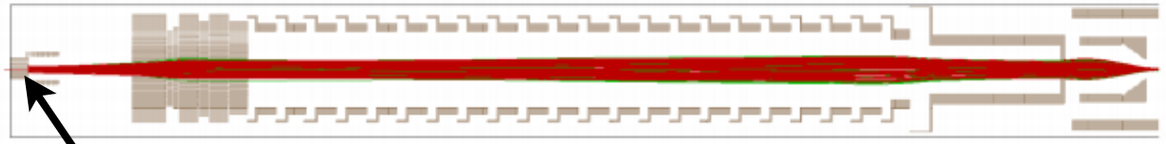


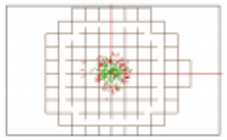


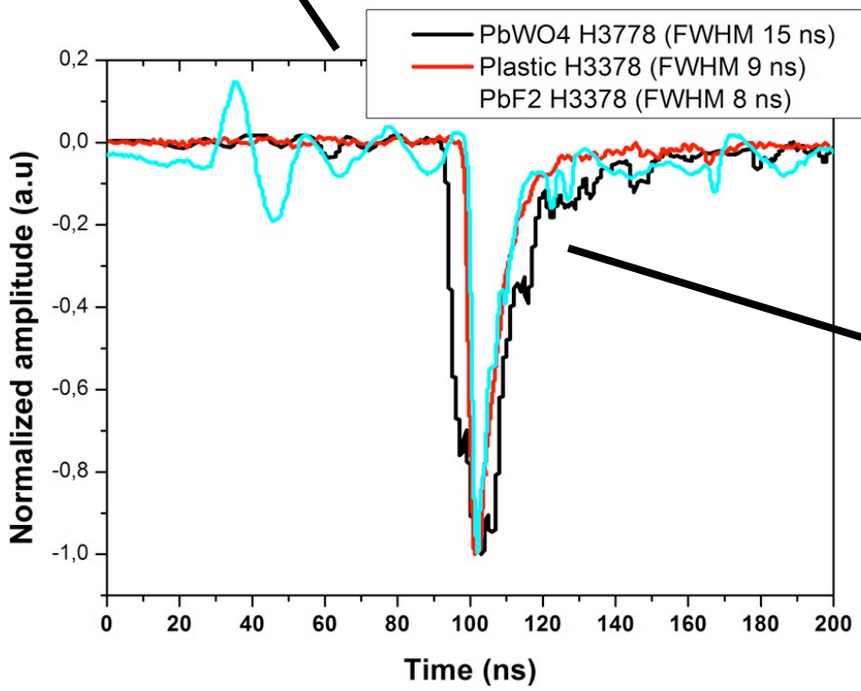


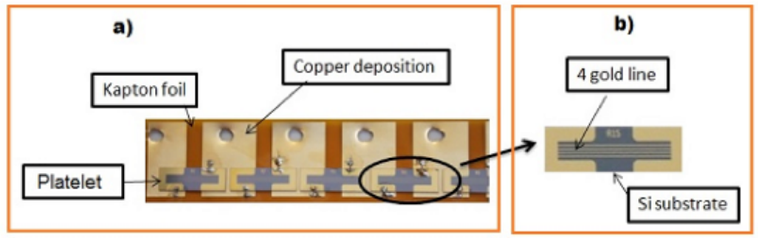
magnetic shielding will be installed in June for simultaneous operation with 5T magnet

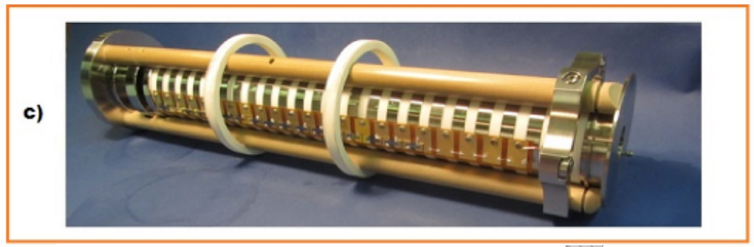
Positronium test station: installation and commissioning

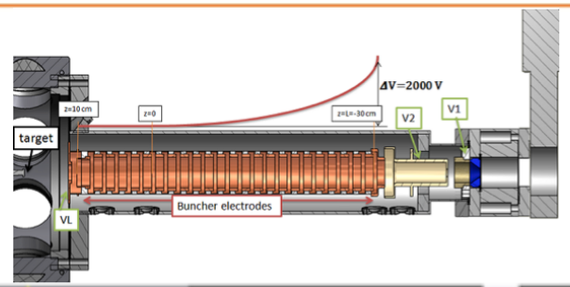


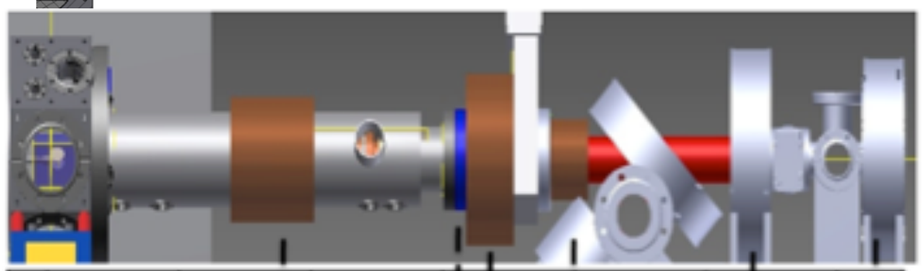


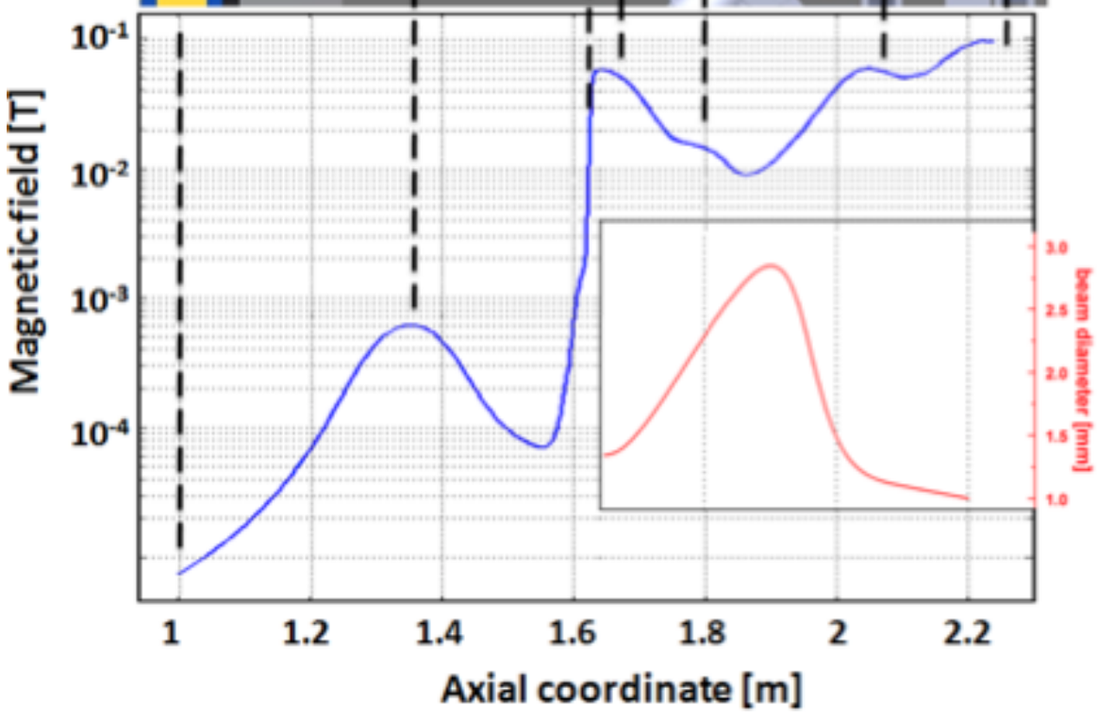










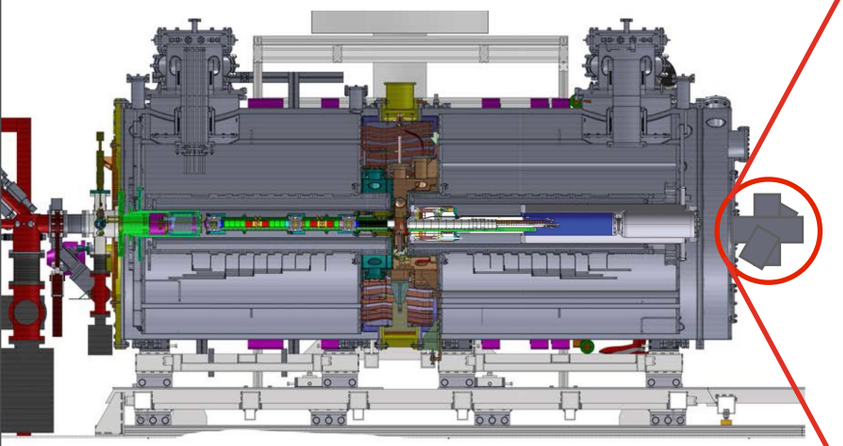


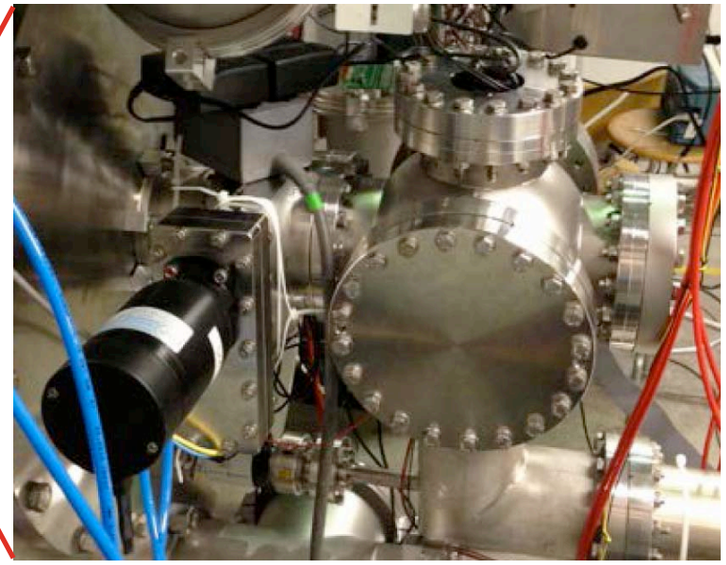
pulse length without HV pulse: 11 ns

pulse captured by HV pulse: 7 ns (goal: 3ns)

Antiproton runs: data analyzed in 2013

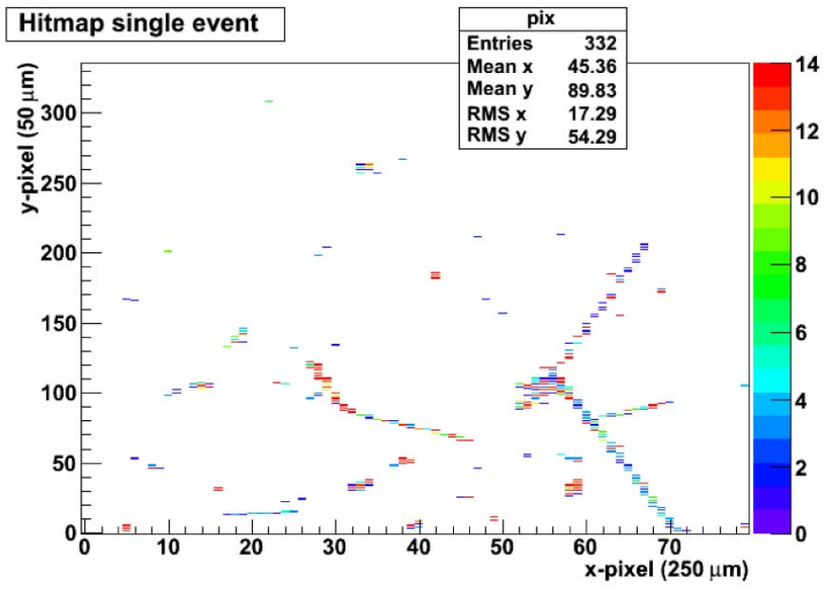
Parasitic tests:



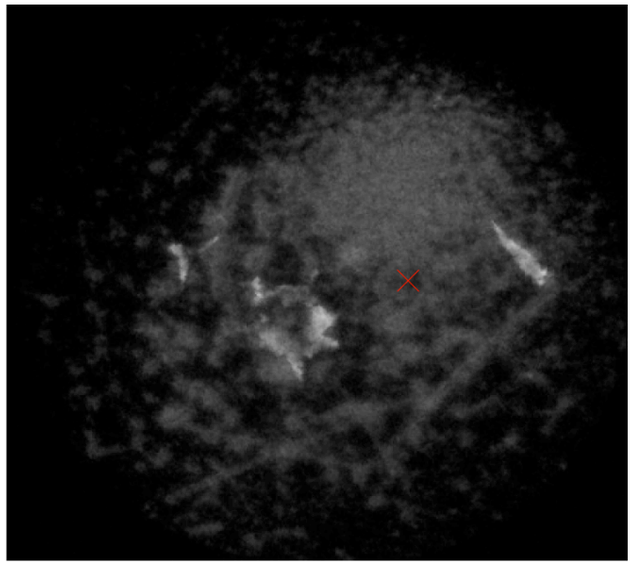


explore/validate different candidate technologies for the (downstream) antihydrogen detector by annihilating (low energy) antiprotons in the detectors

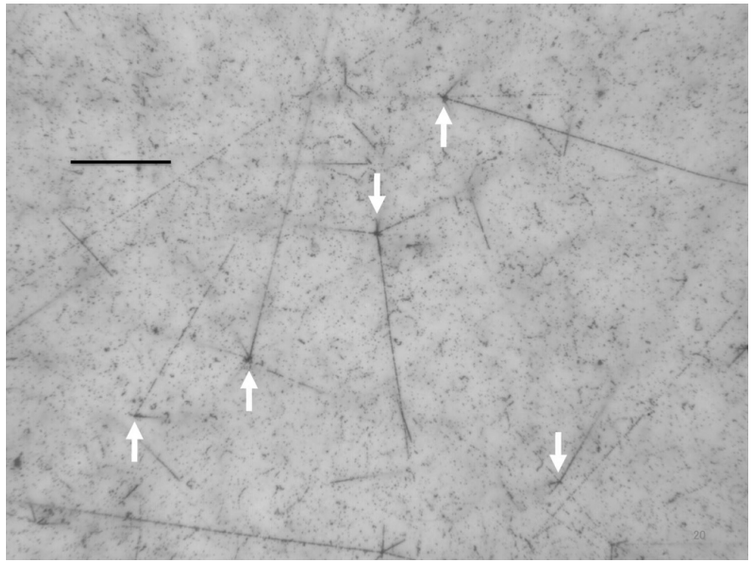
Silicon detectors (strip, pixel)



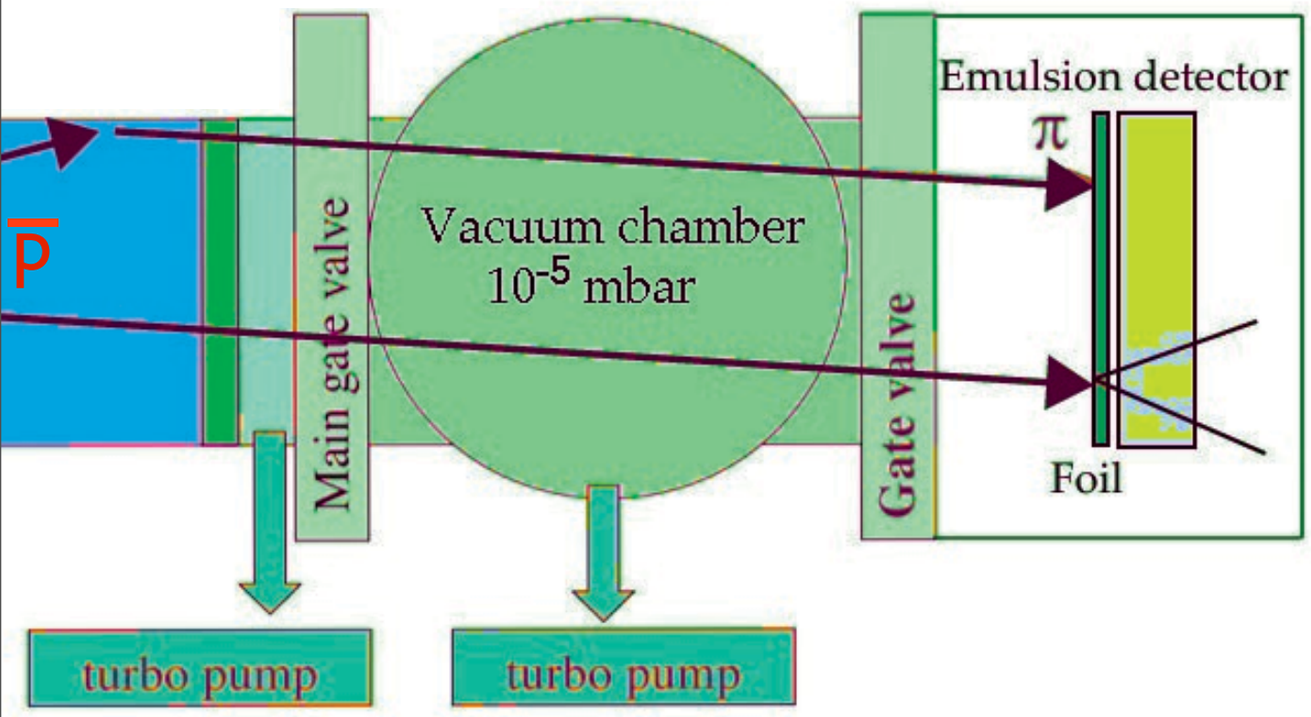
MCP



emulsions



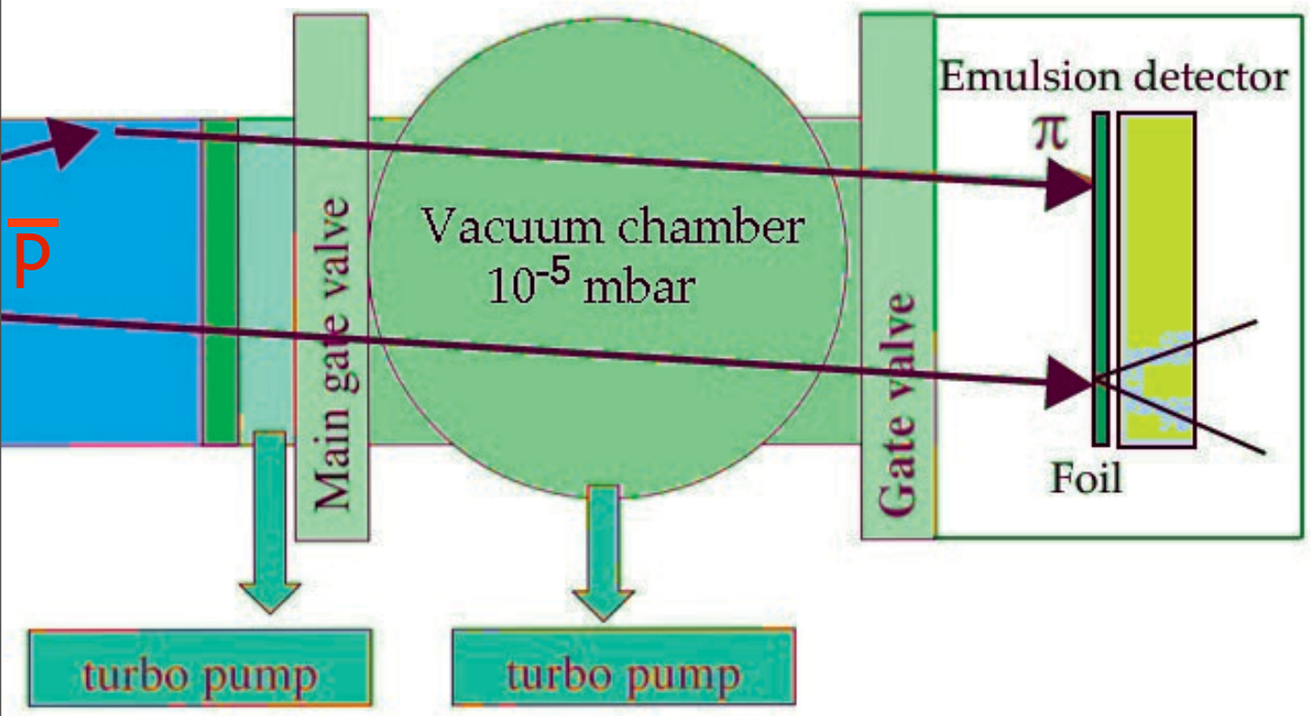
Emulsion: annihilation in emulsion & in thin foils of different composition



develop emulsion
scan (depth-focus)
digitize
reconstruct in 3D

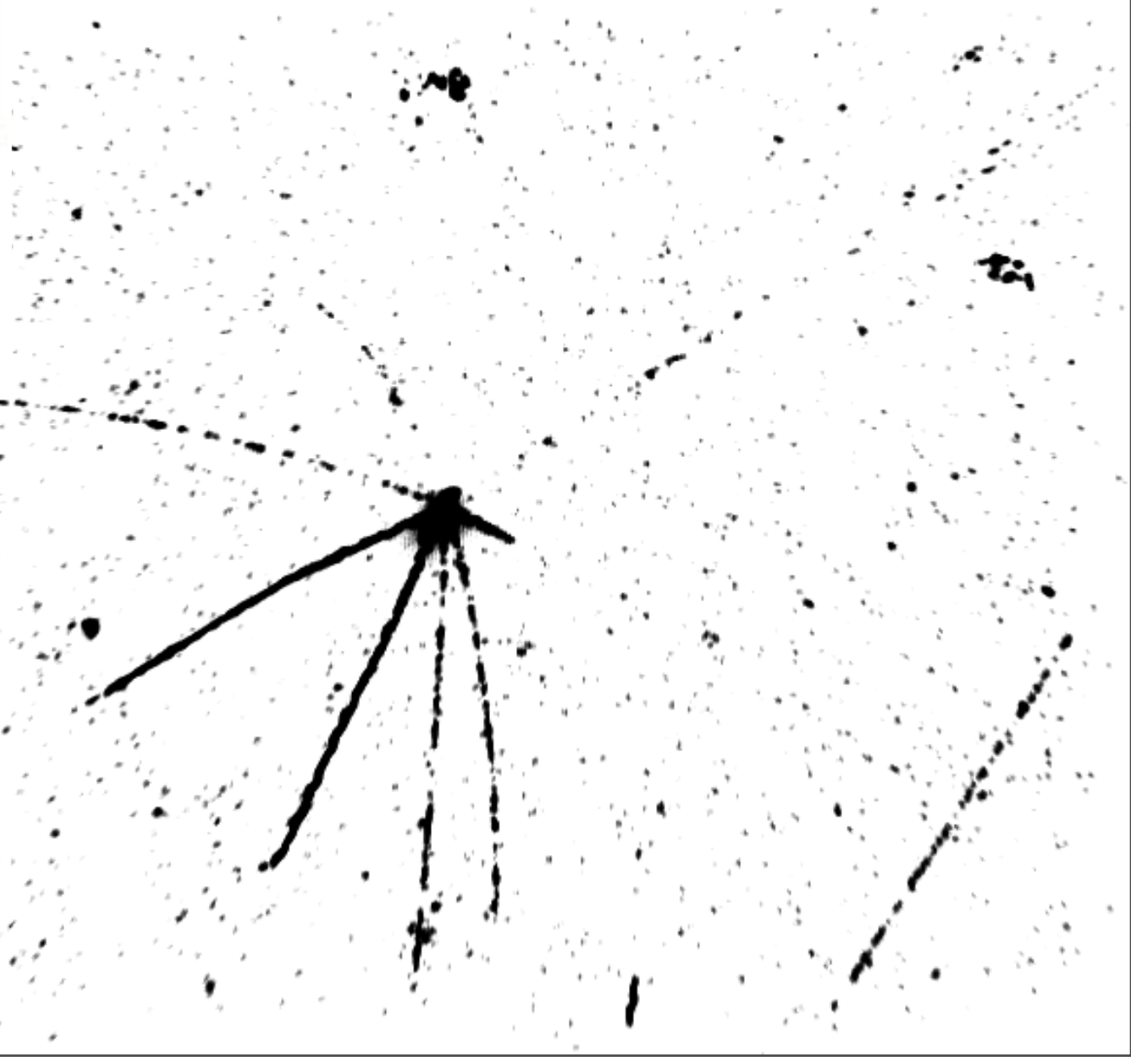
high rez (~0.1μm) 3D tracker

Emulsion: annihilation in emulsion & in thin foils of different composition

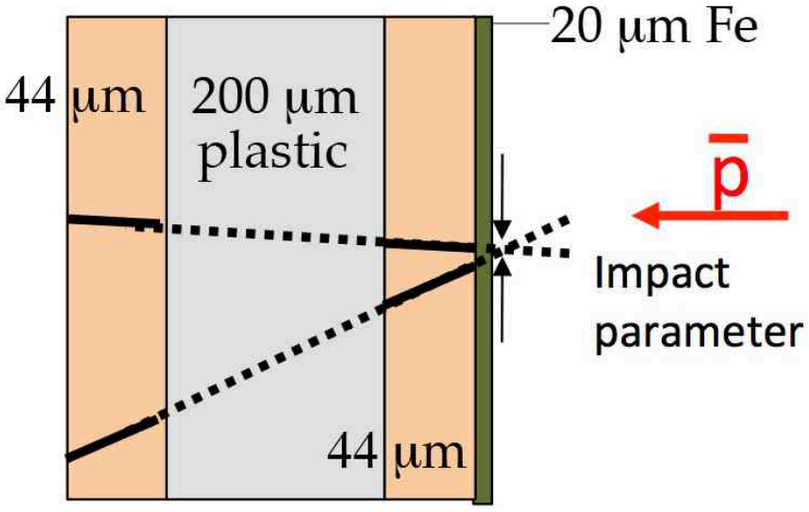


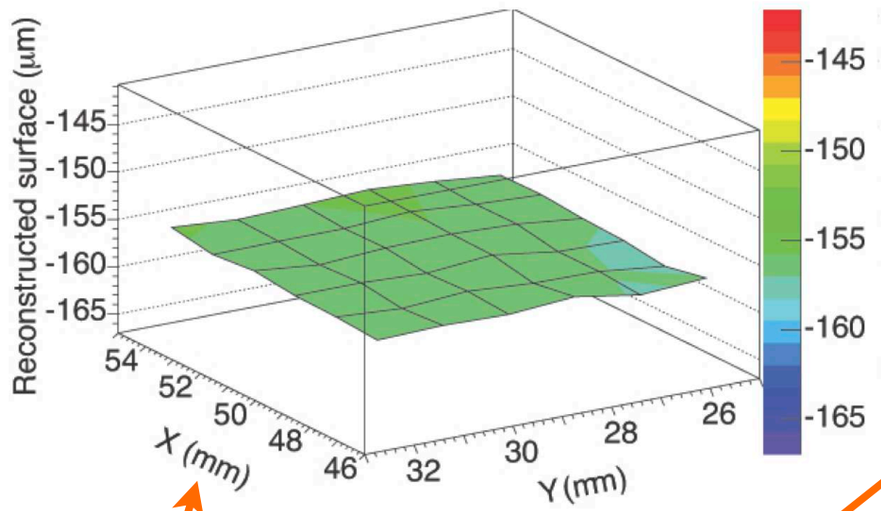
develop emulsion
scan (depth-focus)
digitize
reconstruct in 3D

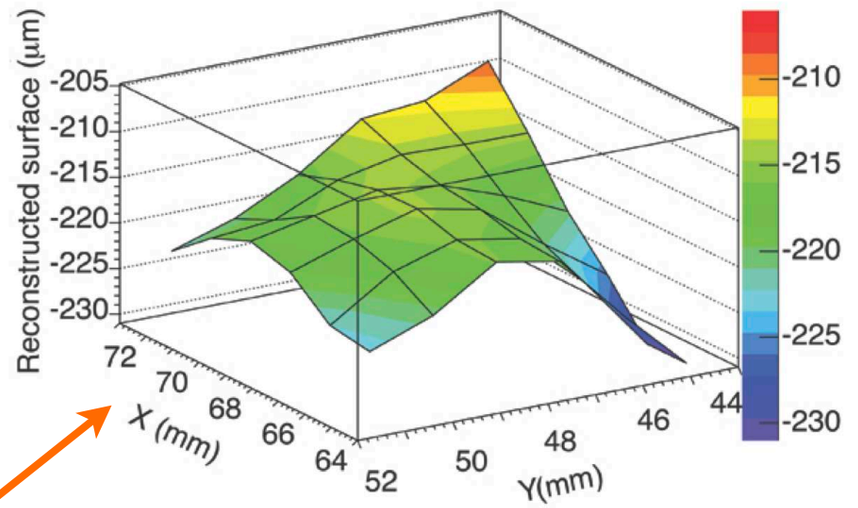
high rez (~0.1μm) 3D tracker



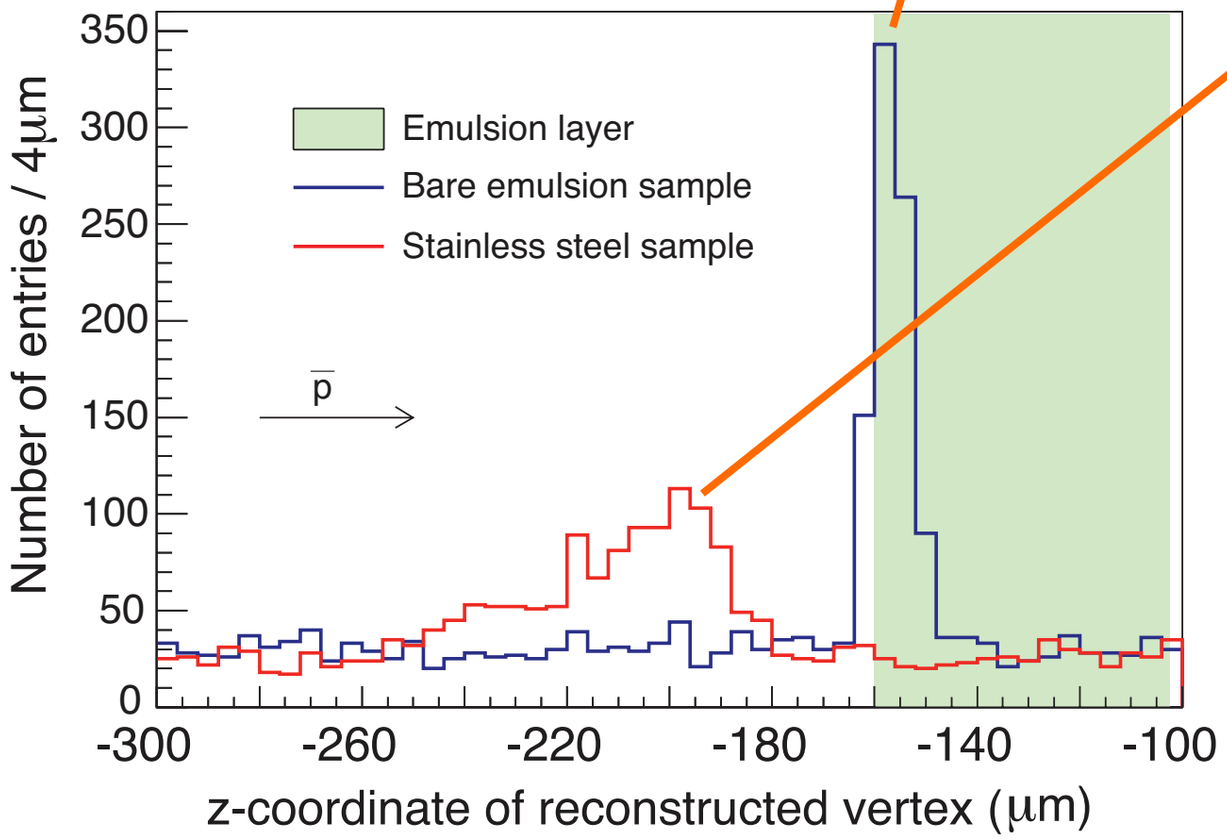
Emulsion: annihilation in emulsion & in thin foils of different composition



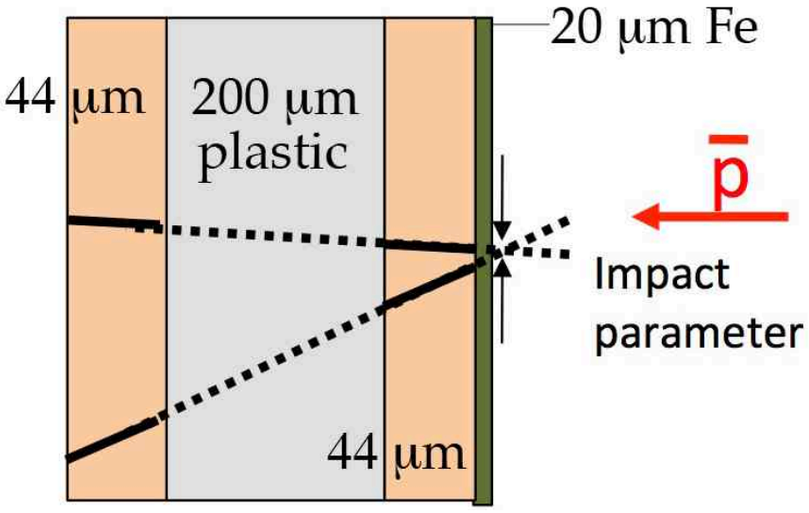


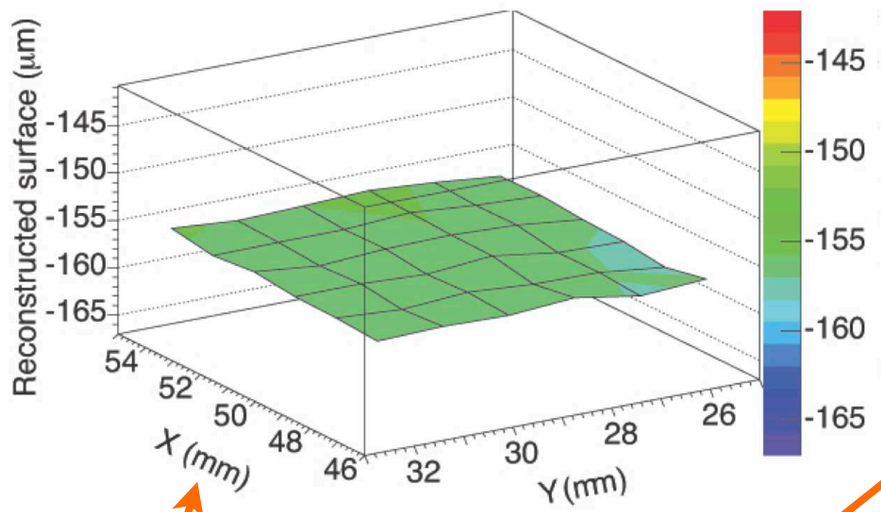


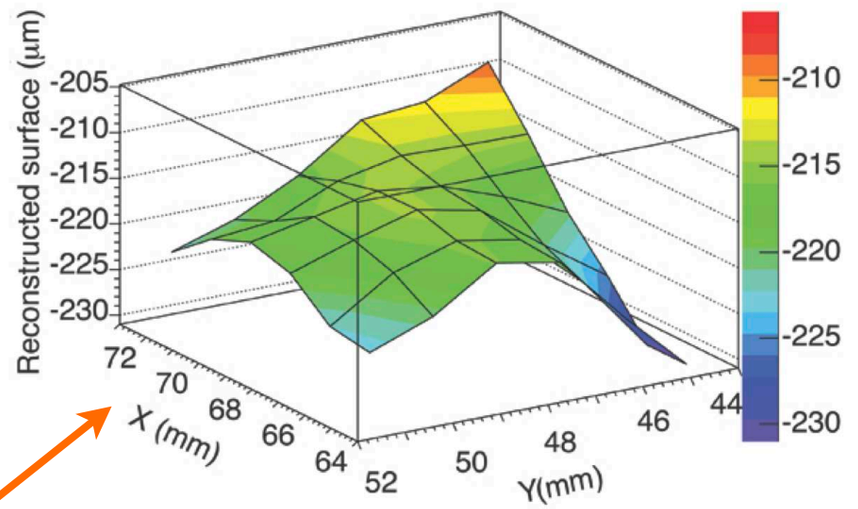
resolution in flight direction



Emulsion: annihilation in emulsion & in thin foils of different composition

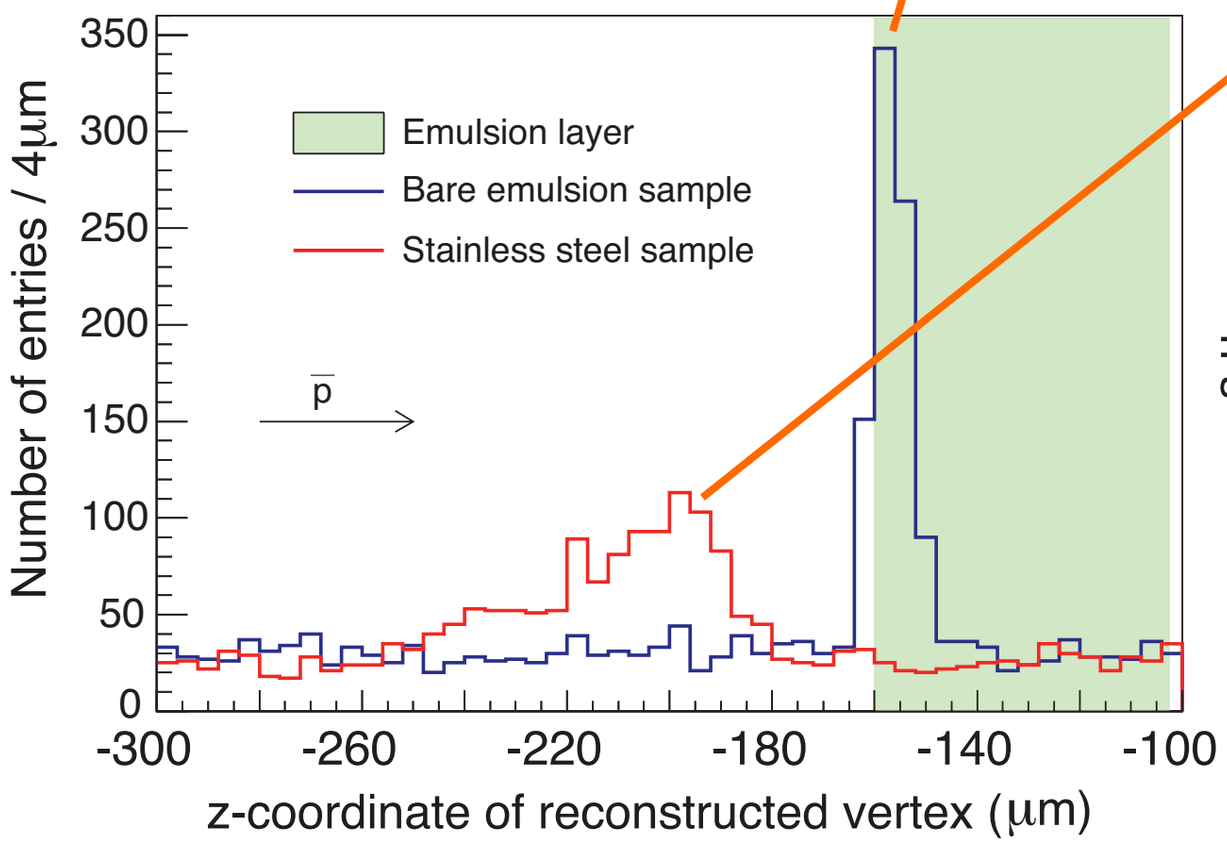


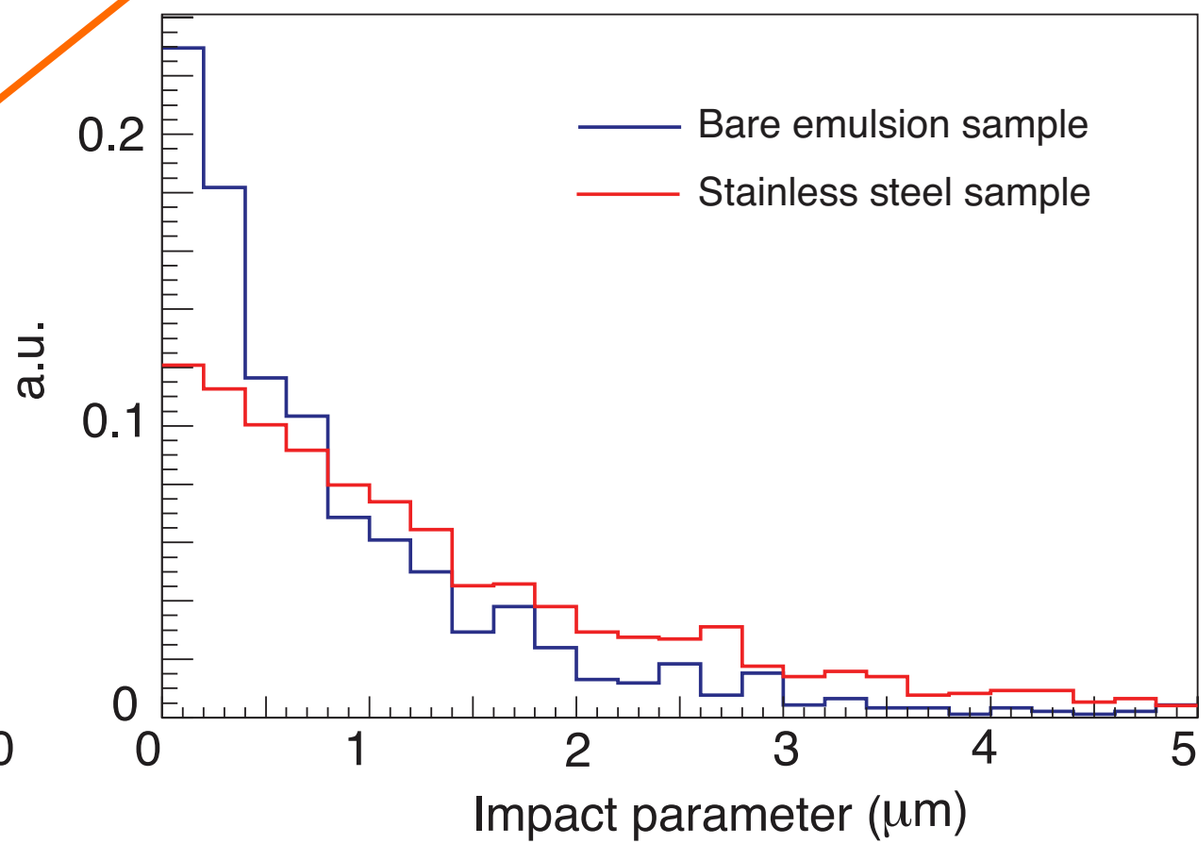




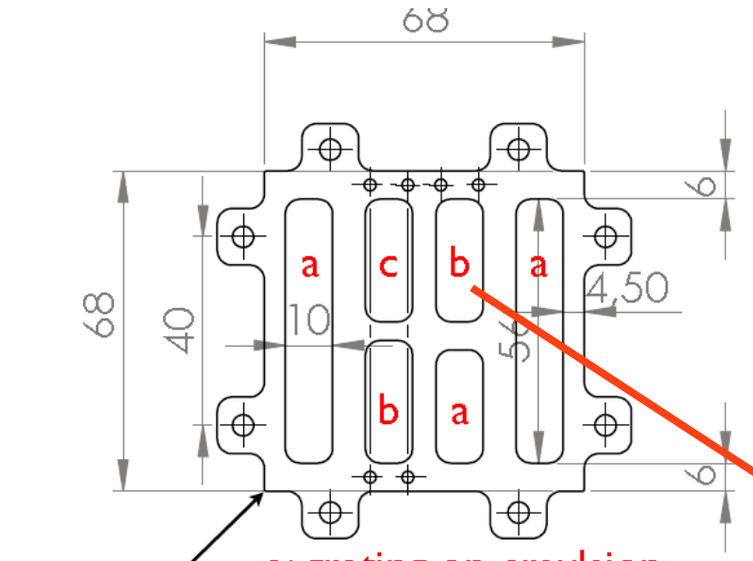
resolution in flight direction

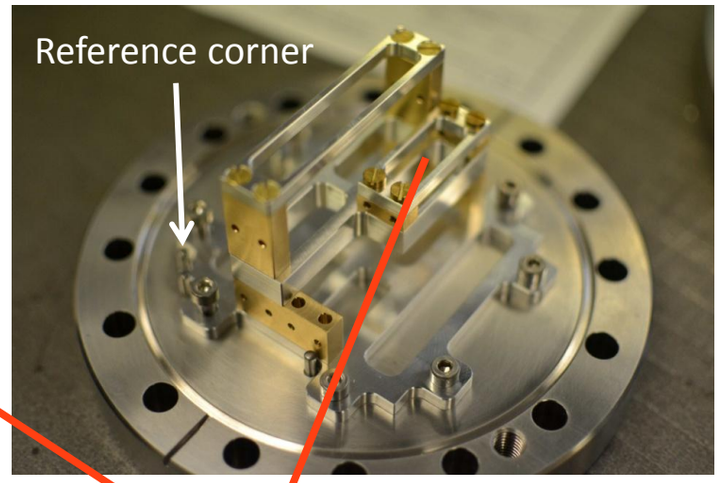
effect of thin foil on impact parameter





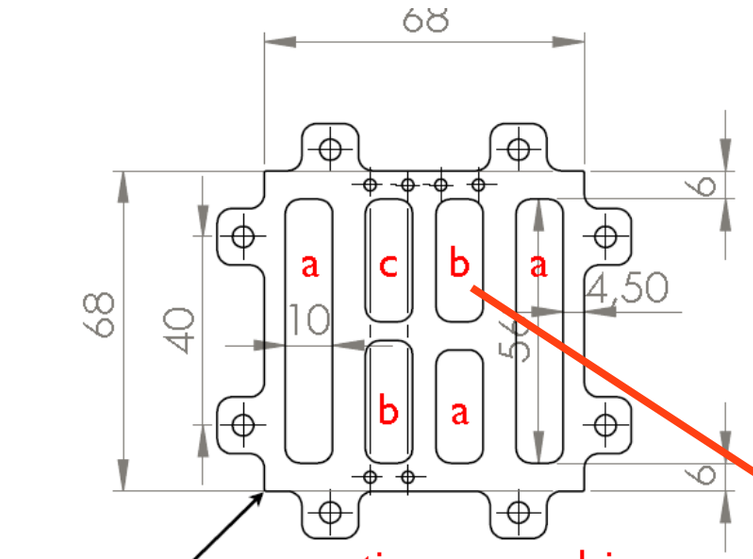
Test of moiré deflectometer with antiprotons

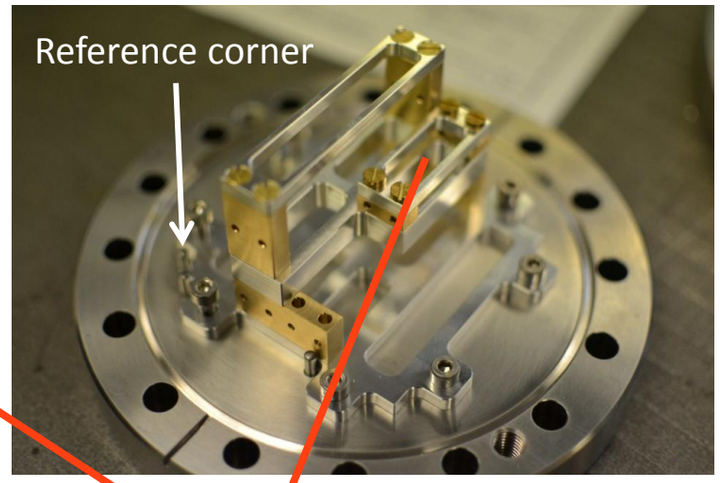




first look at data in zone b)
353 vertices in ~ 1 cm^2

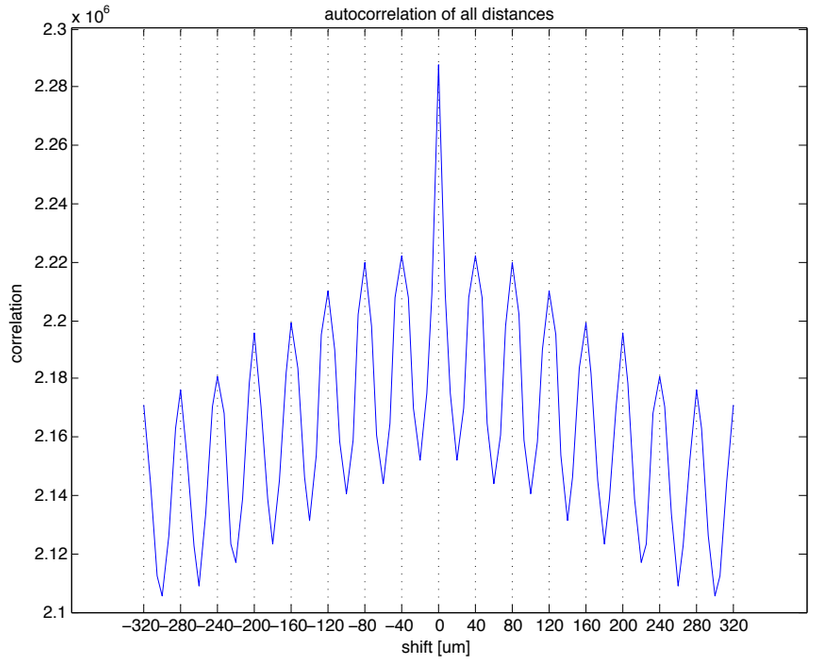
Test of moiré deflectometer with antiprotons

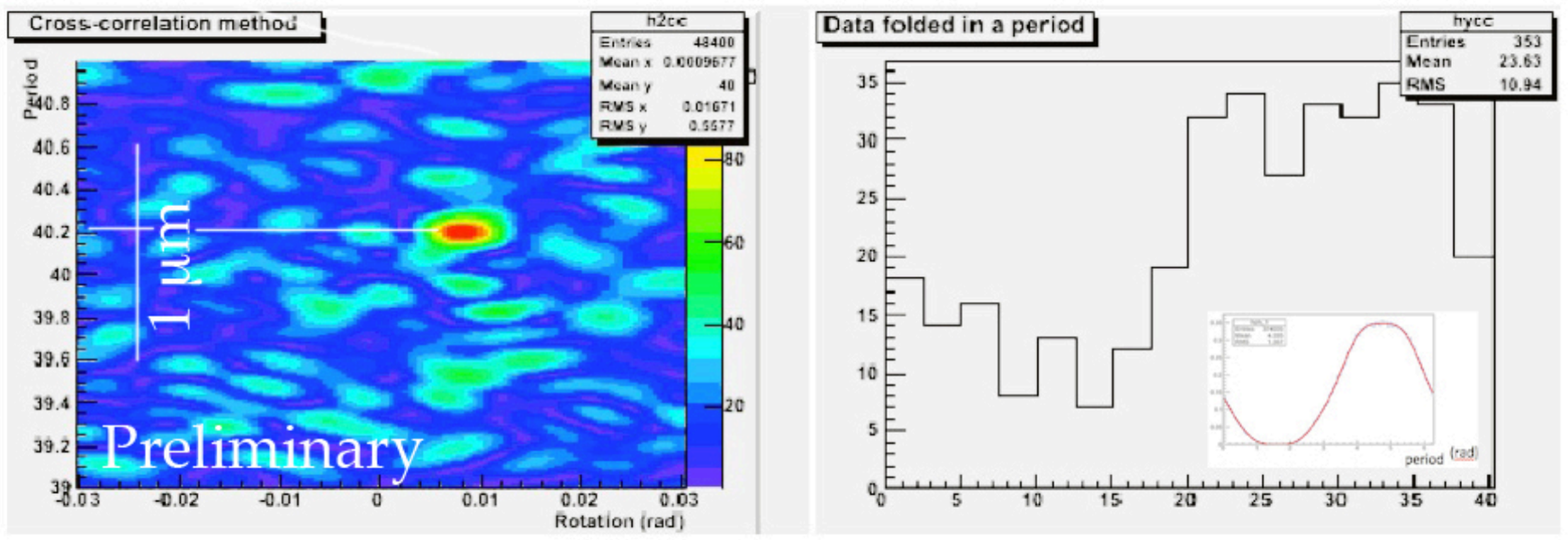




first look at data in zone b)
353 vertices in ~ 1 cm^2

vertex-to-vertex autocorrelation





pitch [μm]

rotation [rad]

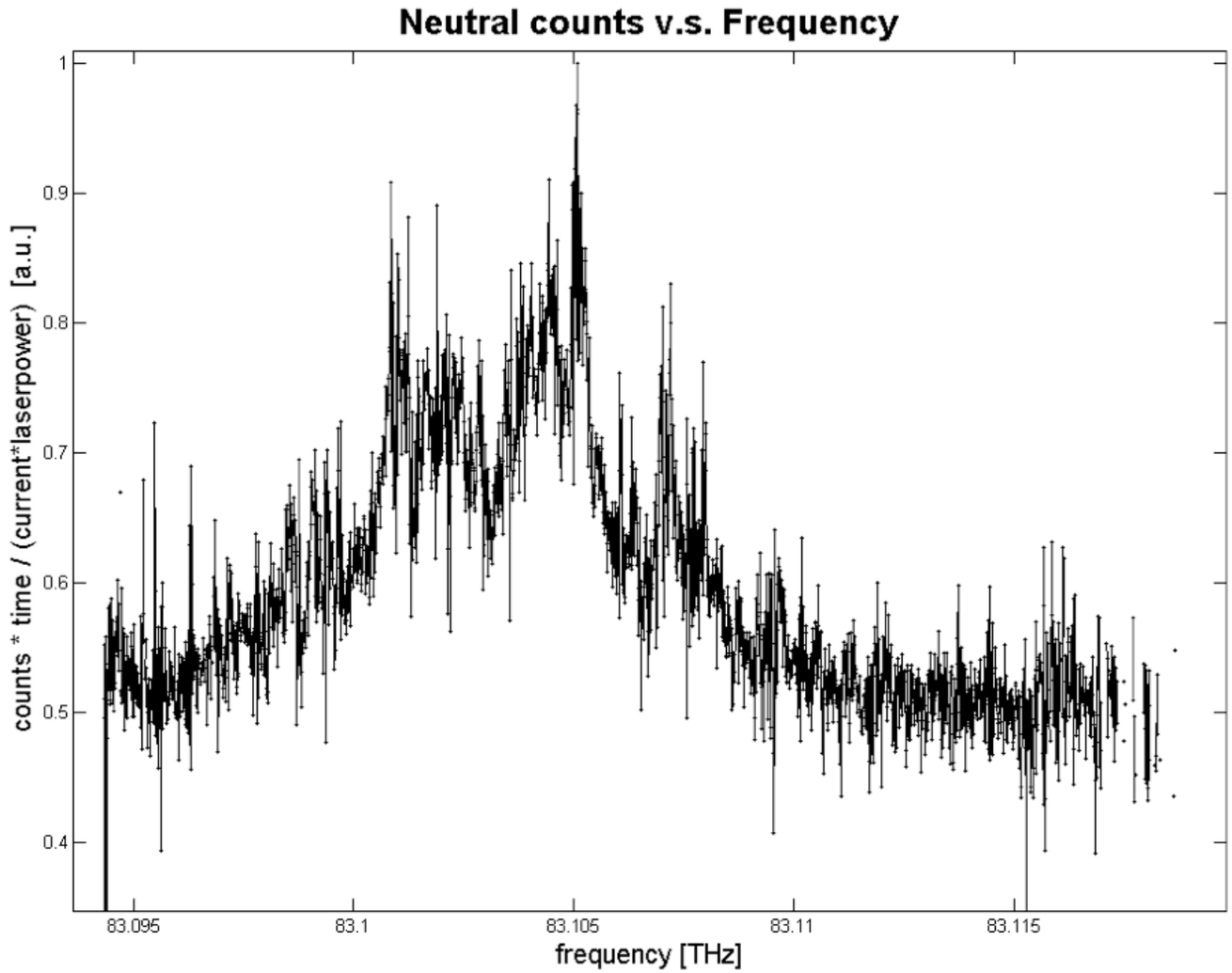
pitch [μm]

First demonstration of the moiré deflectometer technique with antiprotons
(subm. for publication)

In parallel: work on laser-cooling of anions
(→ sympathetic cooling of antiprotons)

essential for low-temperature (<100 mK) antihydrogen !

- ongoing work in Heidelberg with Os^-, La^-
- stable, relatively intense La^- source: spectroscopy started



Outlook for 2014/2015

remainder of year:

- work toward formation and characterization of Ps, Ps*
- Ps spectroscopy (test station)
- work towards $\bar{H}$ formation
- design work on downstream module (beyond 1T magnet)
- R&D work on downstream antihydrogen detector
- R&D work on cooling of antiprotons

goal for summer 2015: be in a position to try to form antihydrogen beam

Outlook for 2016-2018

goal: gravity measurement to 1%, first HFS spectroscopy

Outlook beyond 2019

goal: gravity measurement to ppm level, via atomic fountain; requires significant advances in obtaining ultra-cold antihydrogen, in trapping in B=0, ...