AEgIS/AD-6
Antihydrogen experiment: Gravity, Interferometry and Spectroscopy

Status report for 2015 and outlook for 2016 and beyond

Michael Doser / CERN
on behalf of the AEgIS collaboration

AEgIS collaboration

IPNL, Lyon

Stefan Meyer Institut, Austria

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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

INFN Padova/Trento, Italy

ETH Zurich, Switzerland

Topics

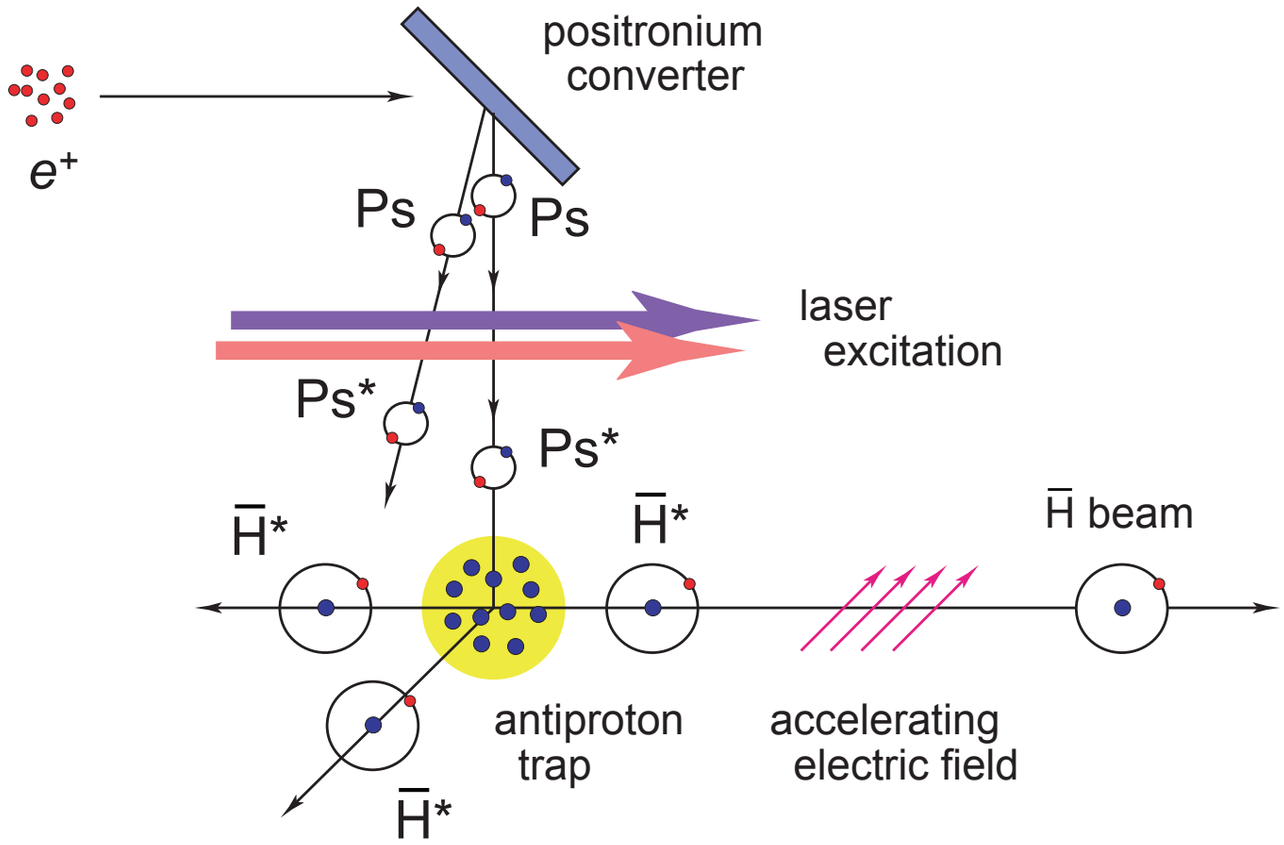
Schematic overview

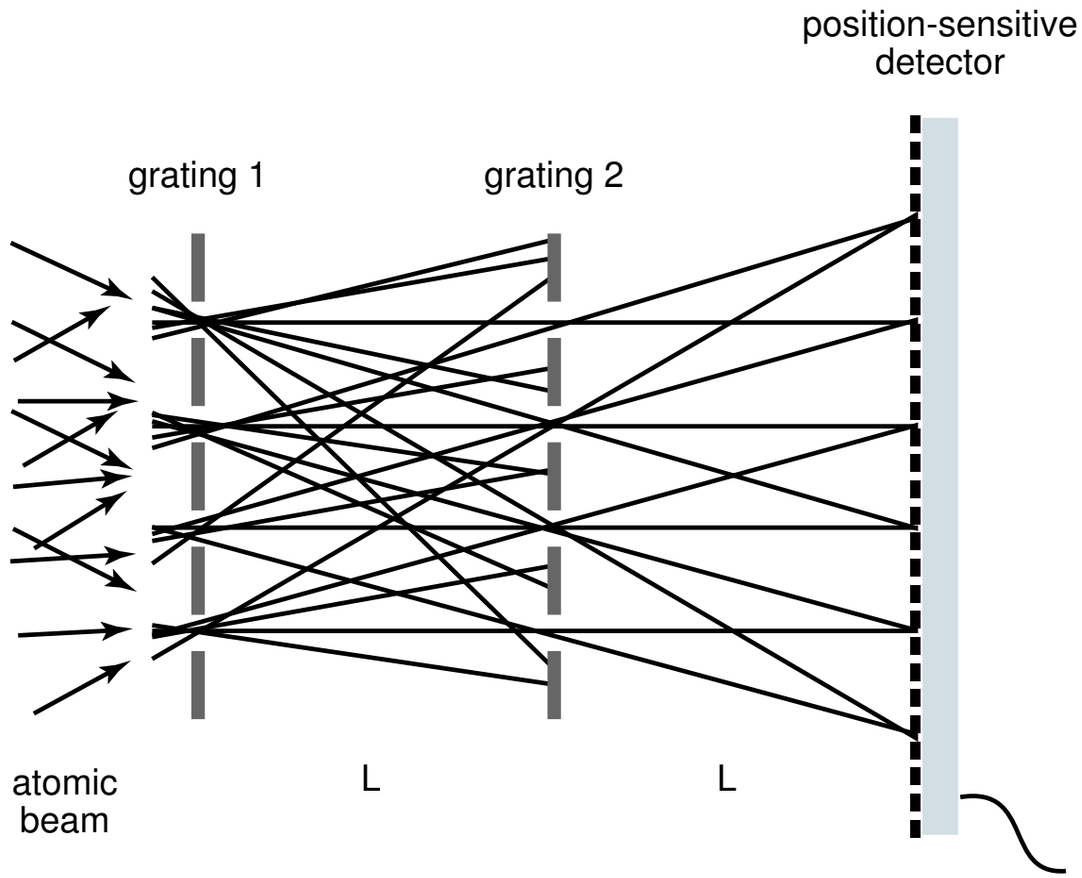
Results of measurements with positrons & positronium

Results of measurements with antiprotons

Outlook

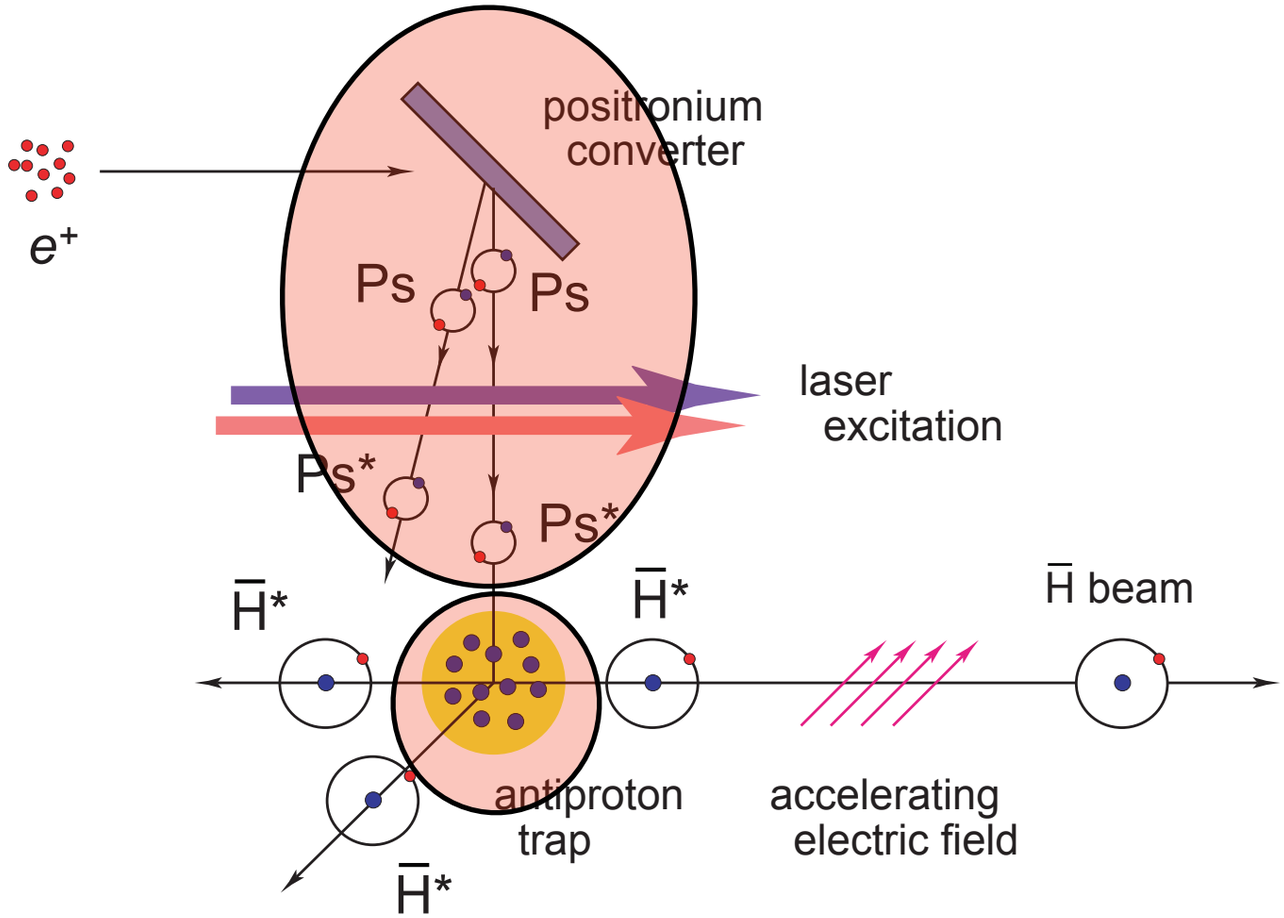
Schematic overview

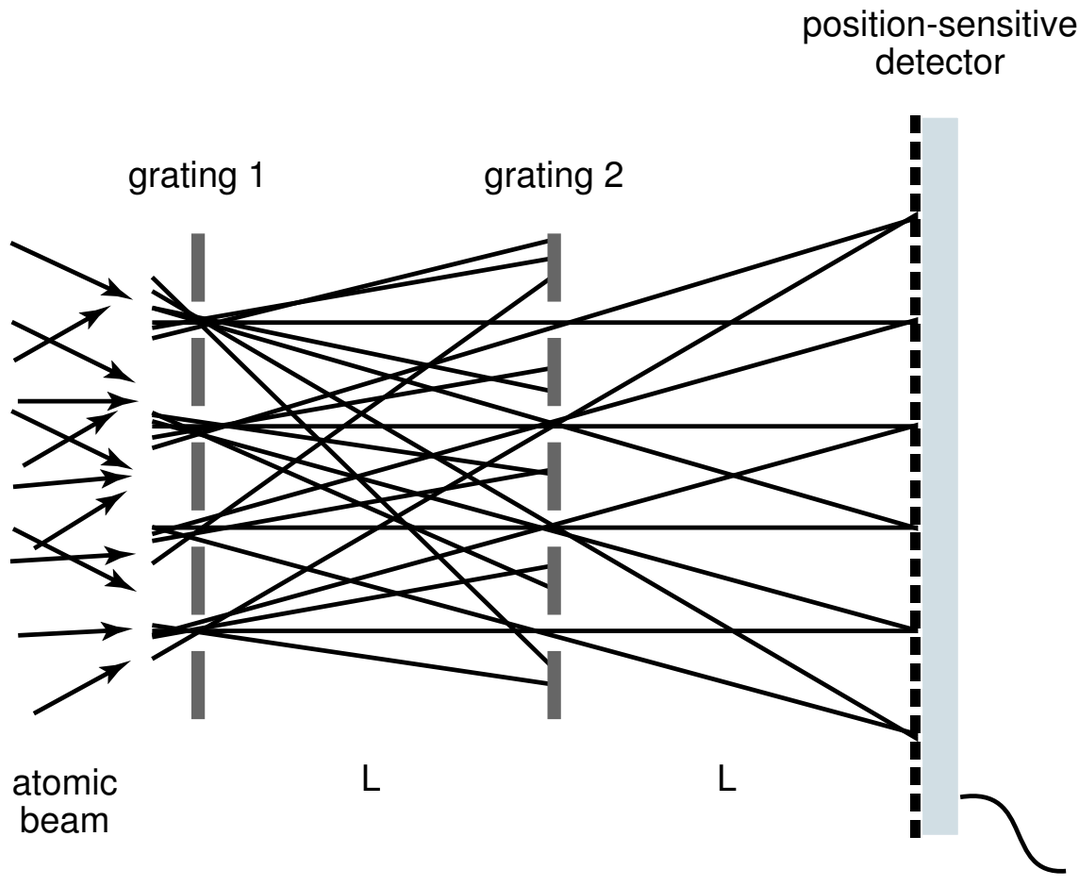




Physics goals: measurement of the gravitational interaction between matter and antimatter, $\bar{H}$ spectroscopy, ...

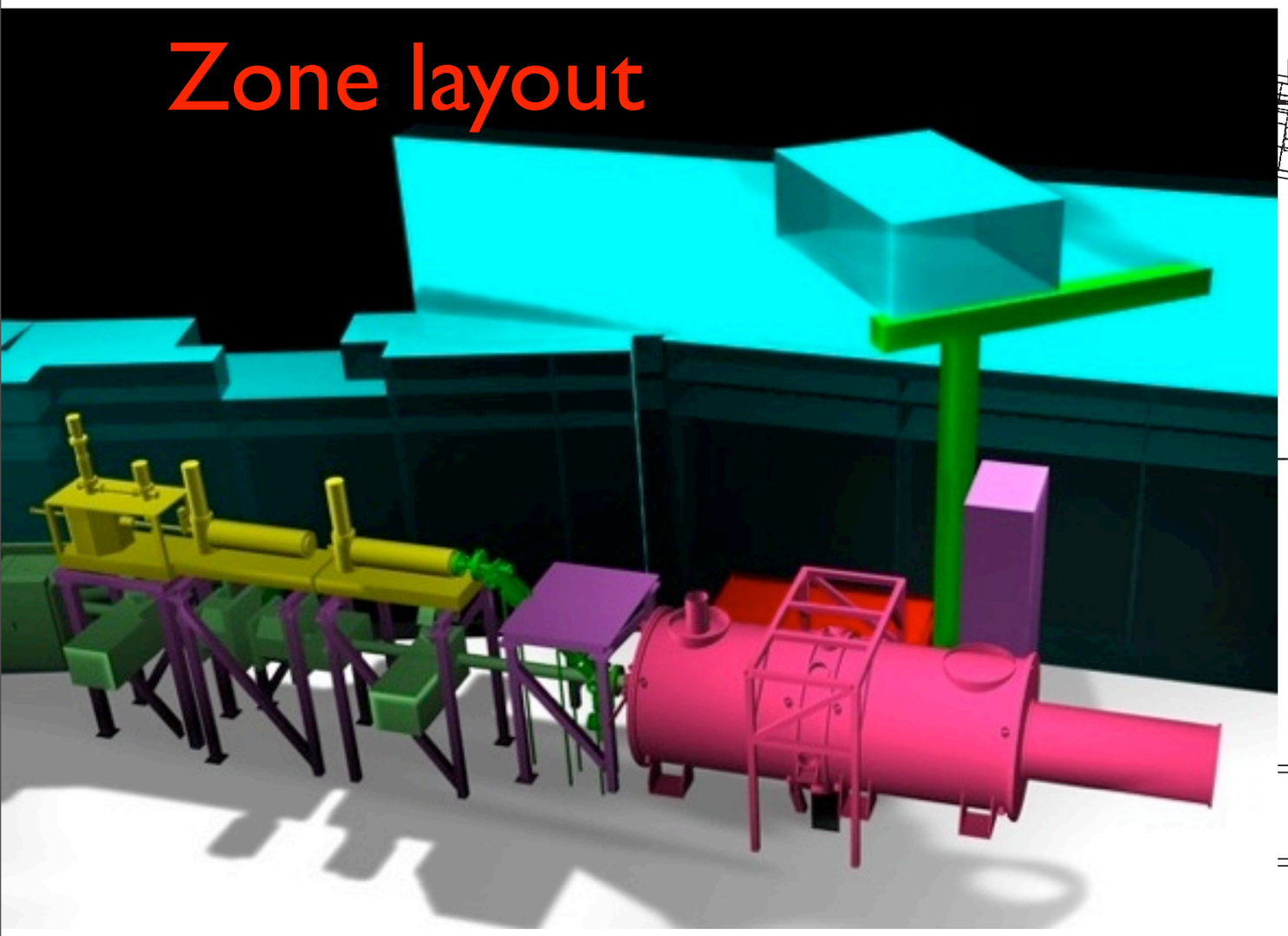
Schematic overview

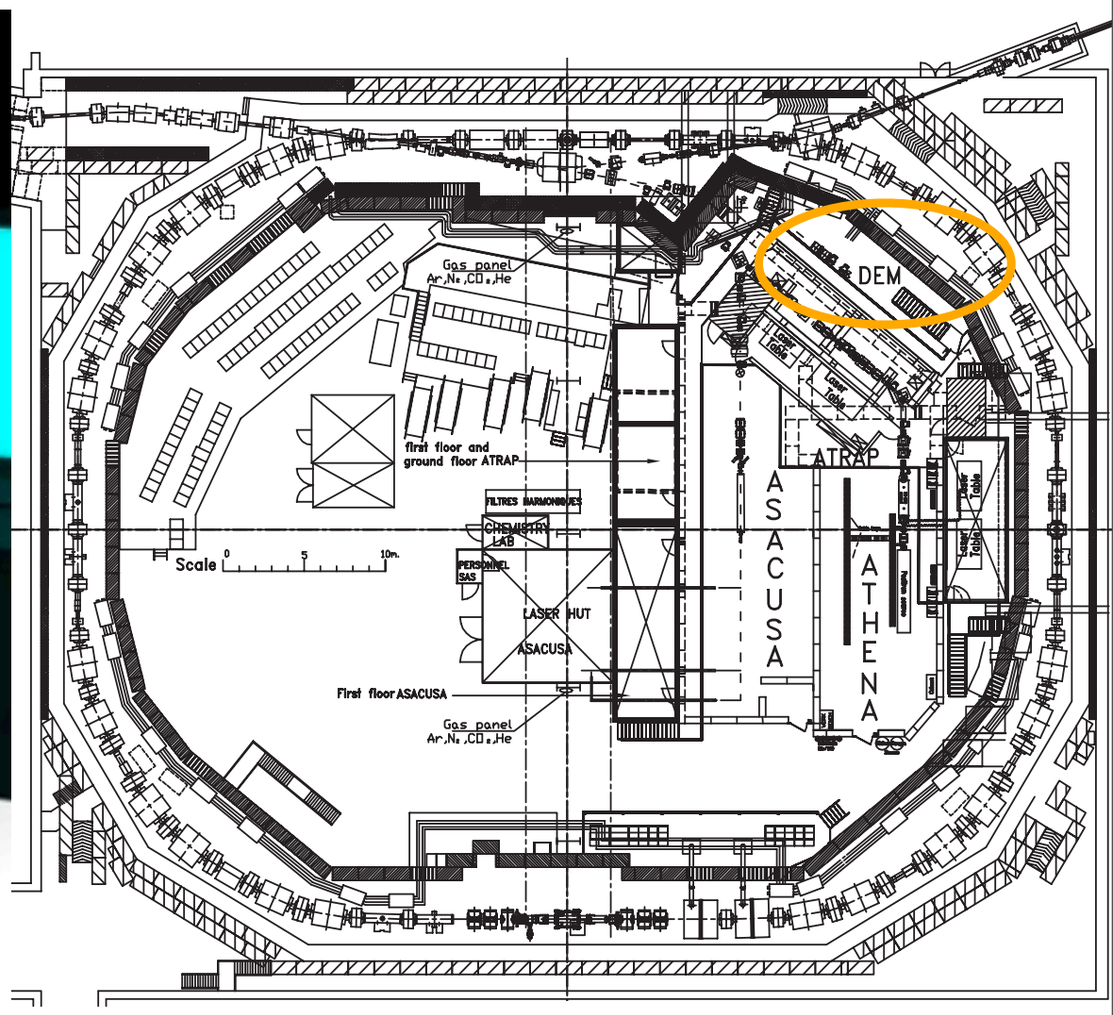


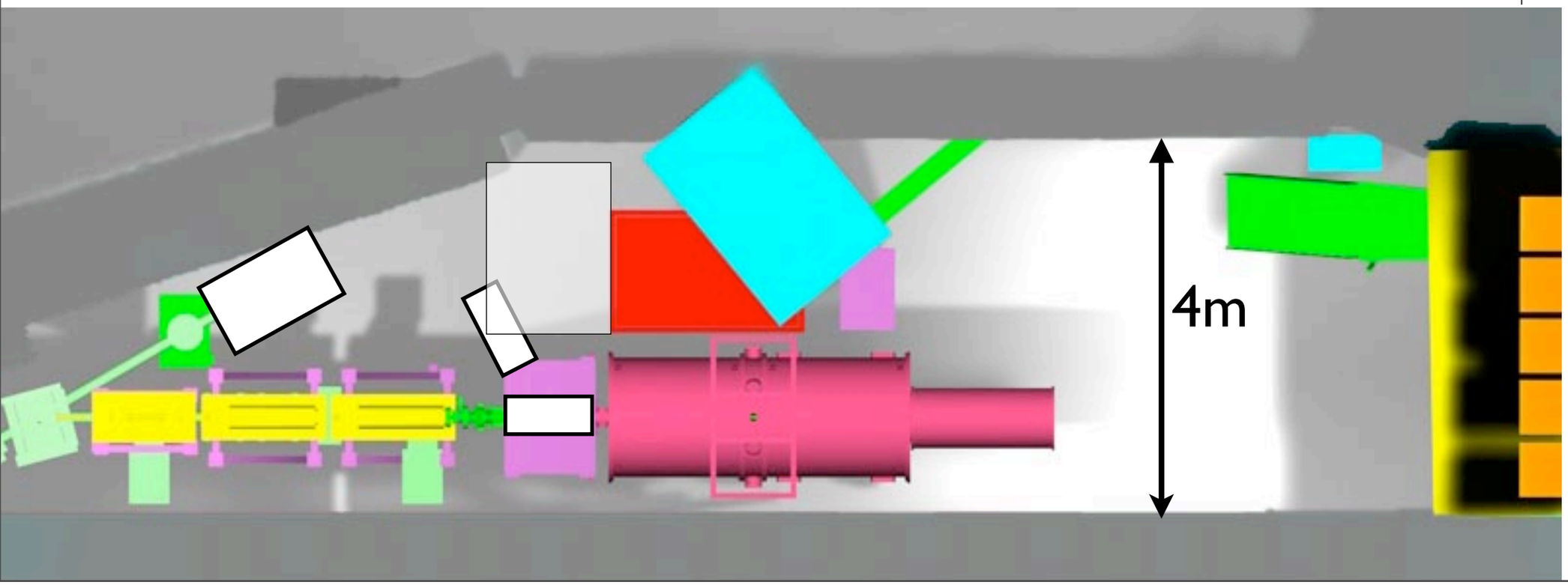


Physics goals: measurement of the gravitational interaction between matter and antimatter, $\bar{H}$ spectroscopy, ...

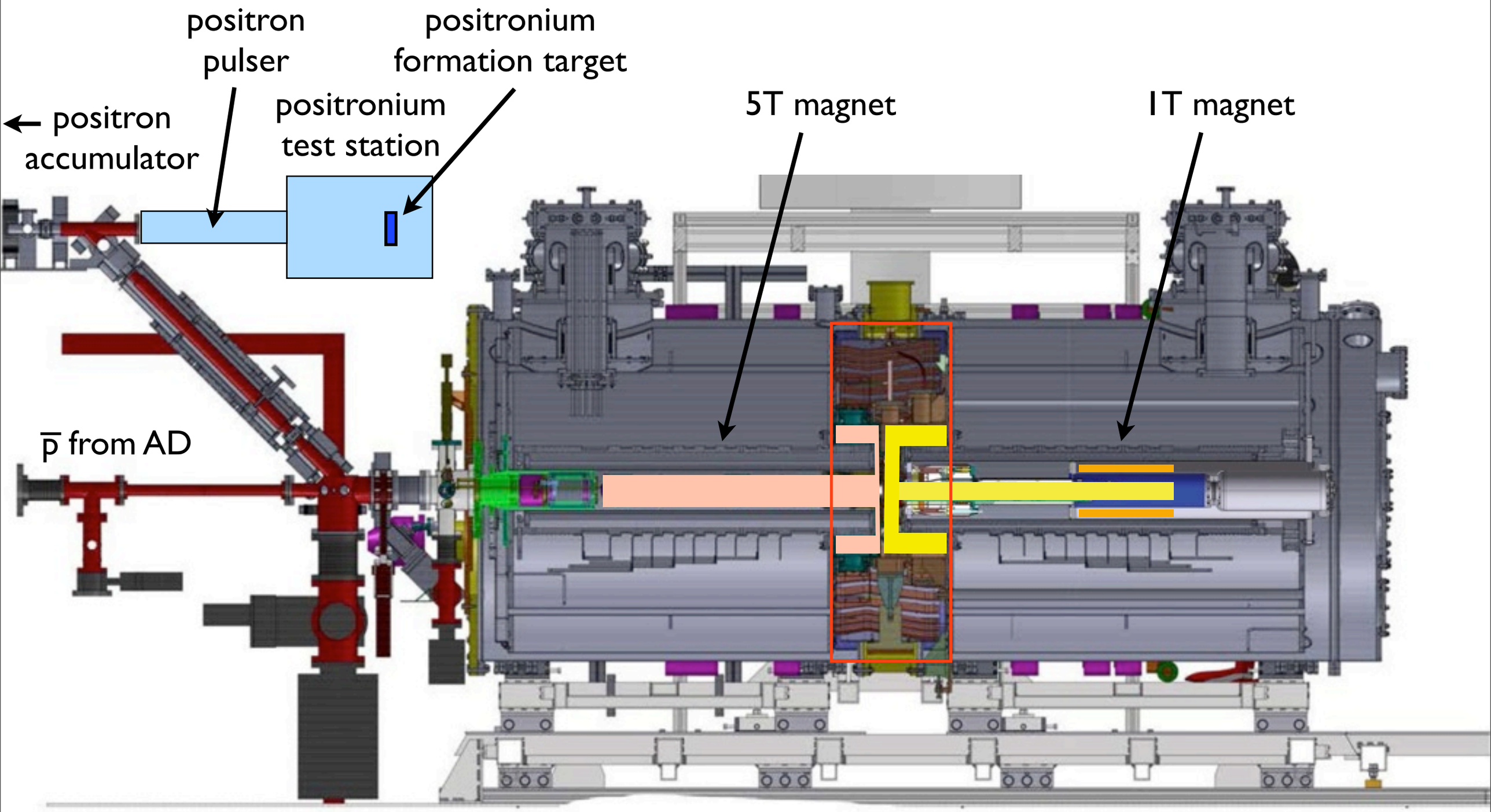
Zone layout




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

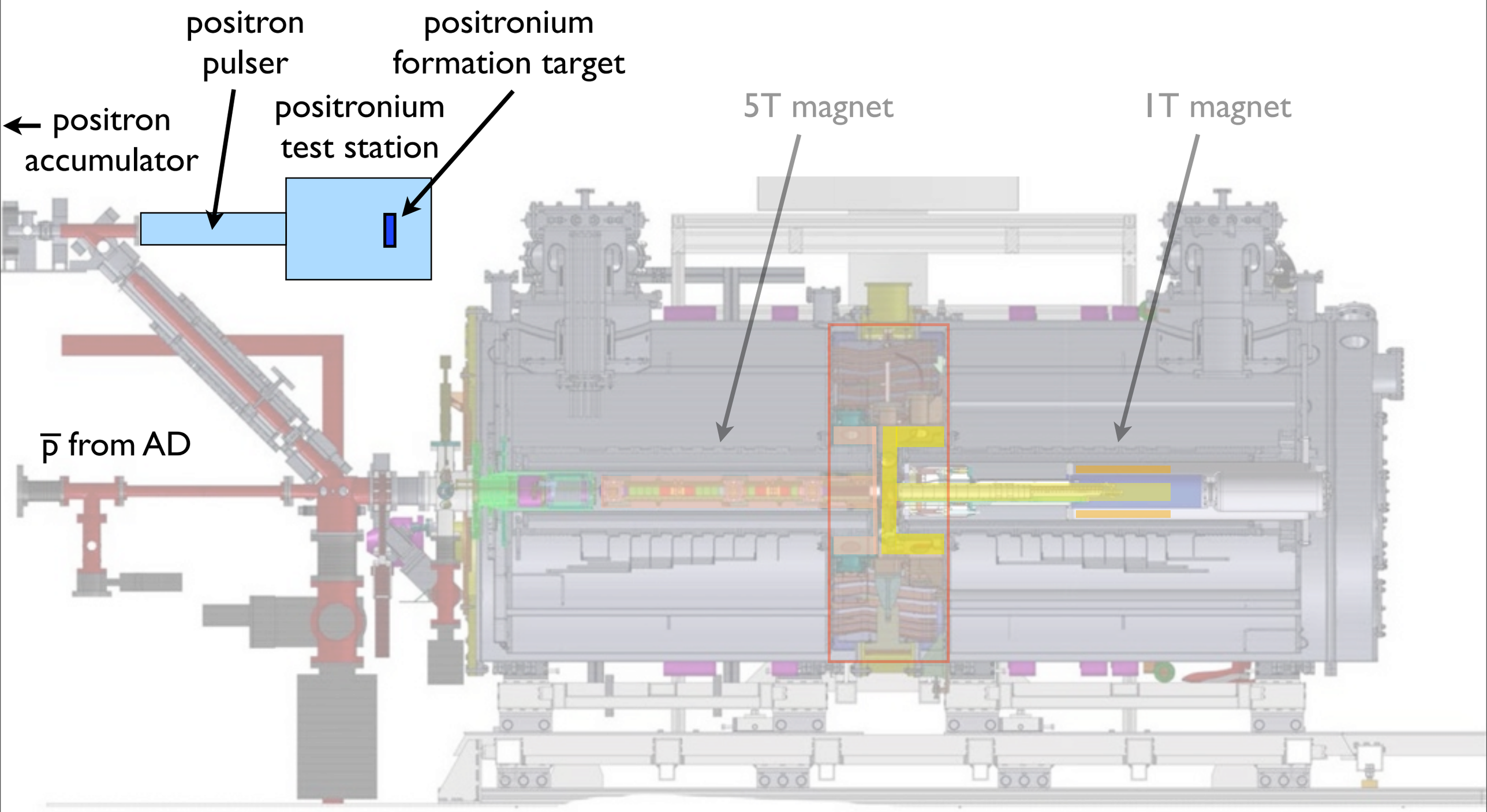

4m

Central apparatus design

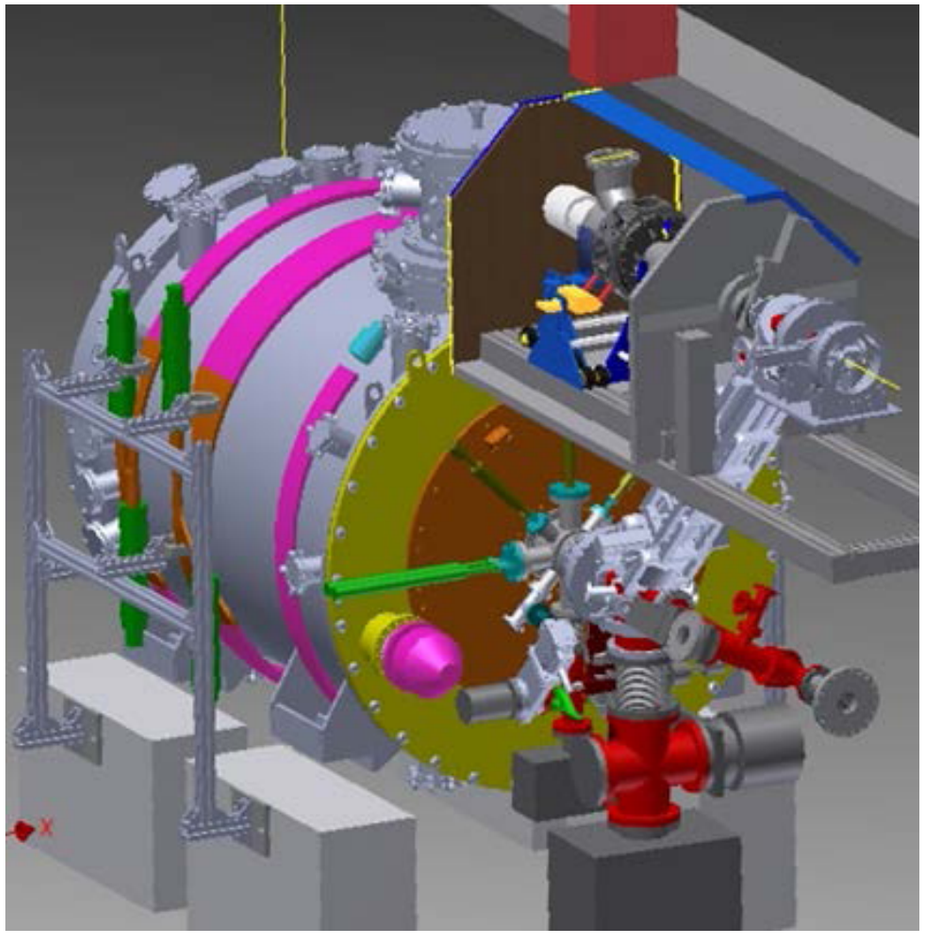


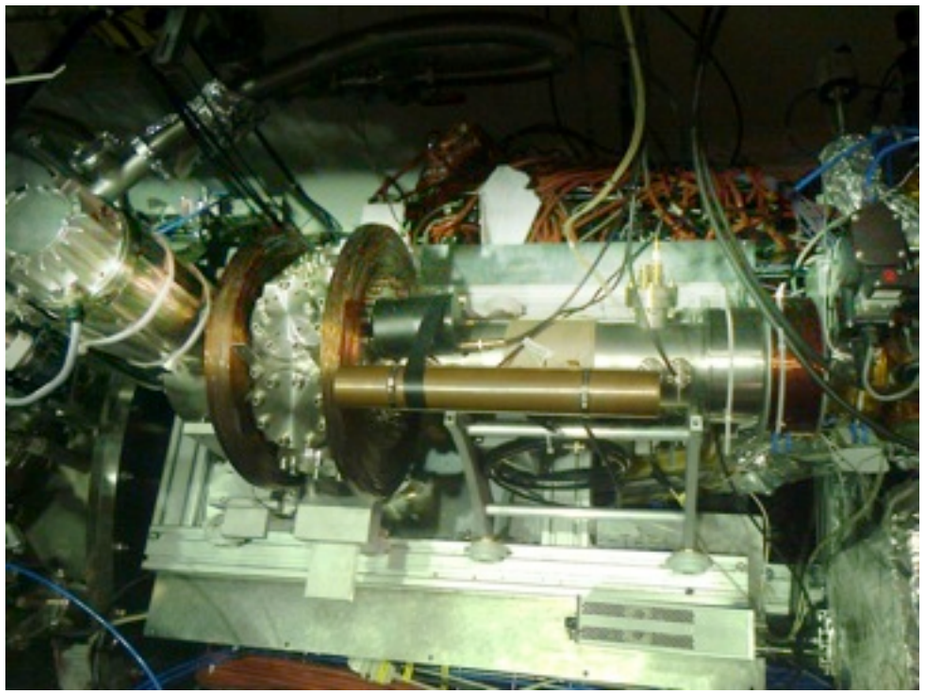
already well exercised in 2014

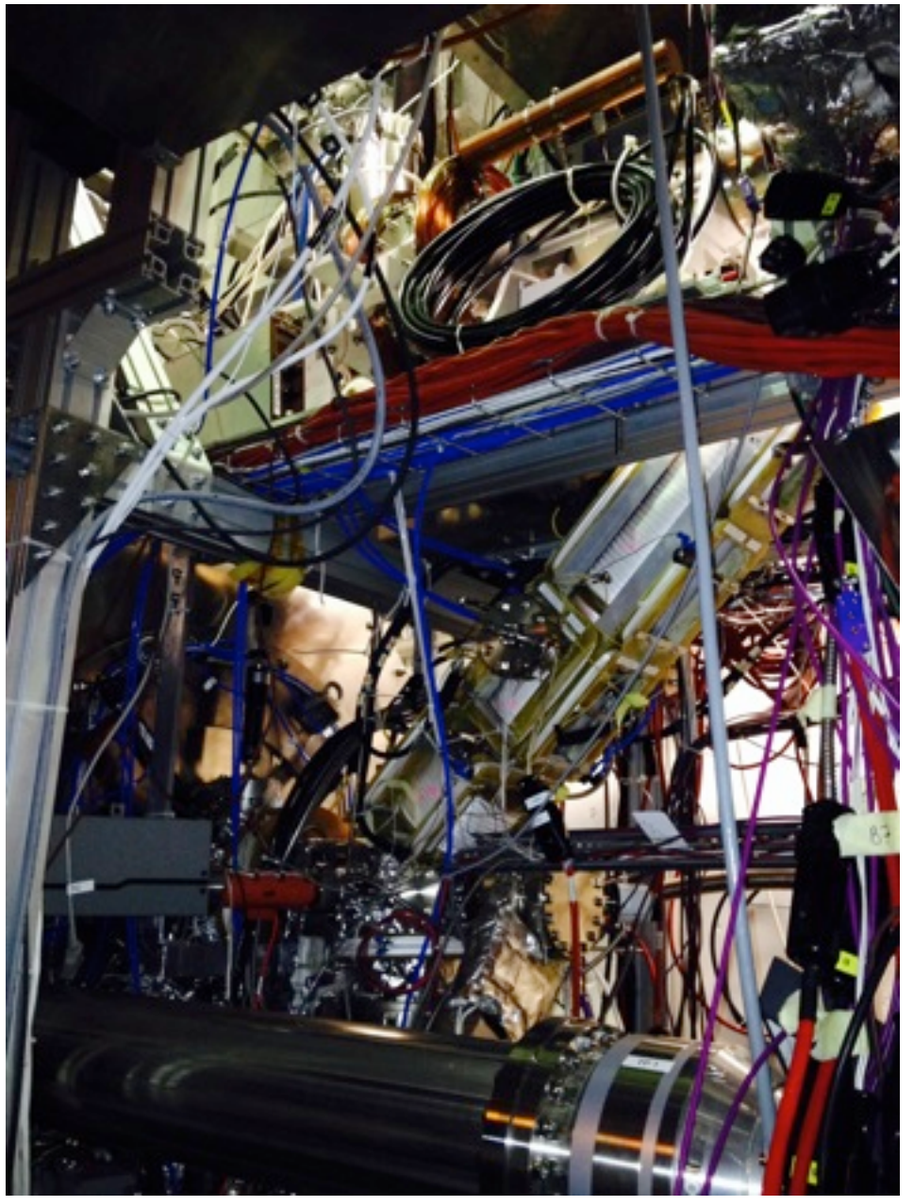
Positronium formation and excitation



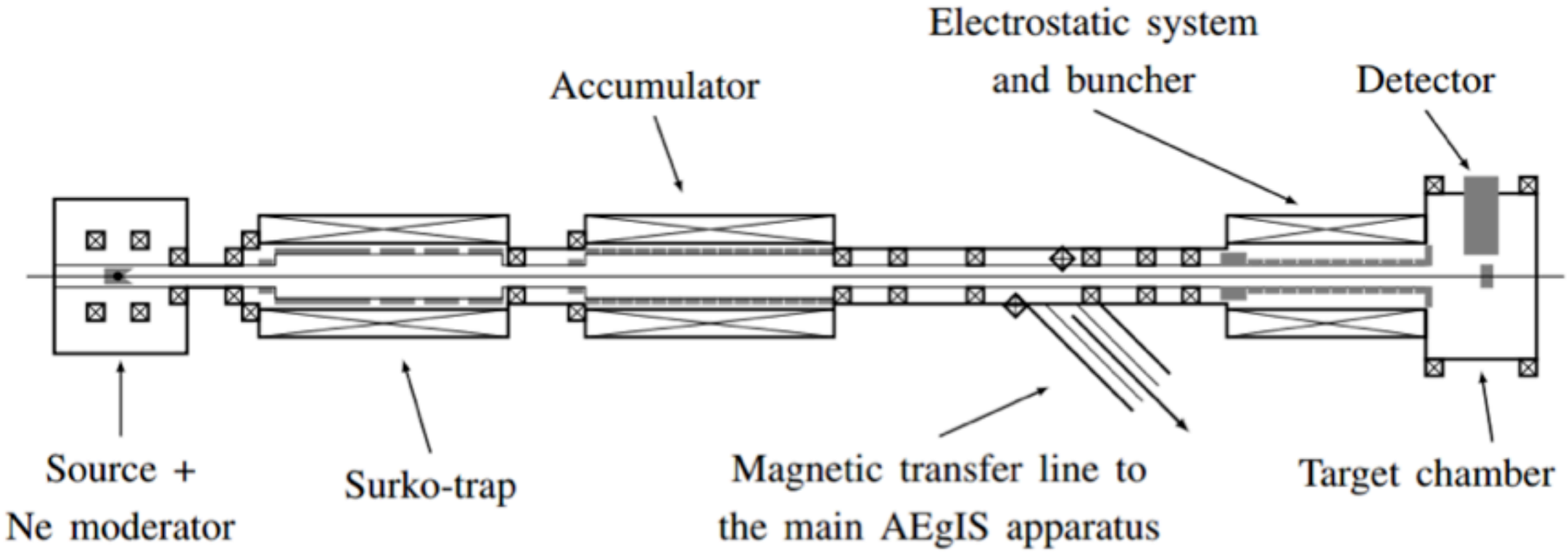
Positronium test station:



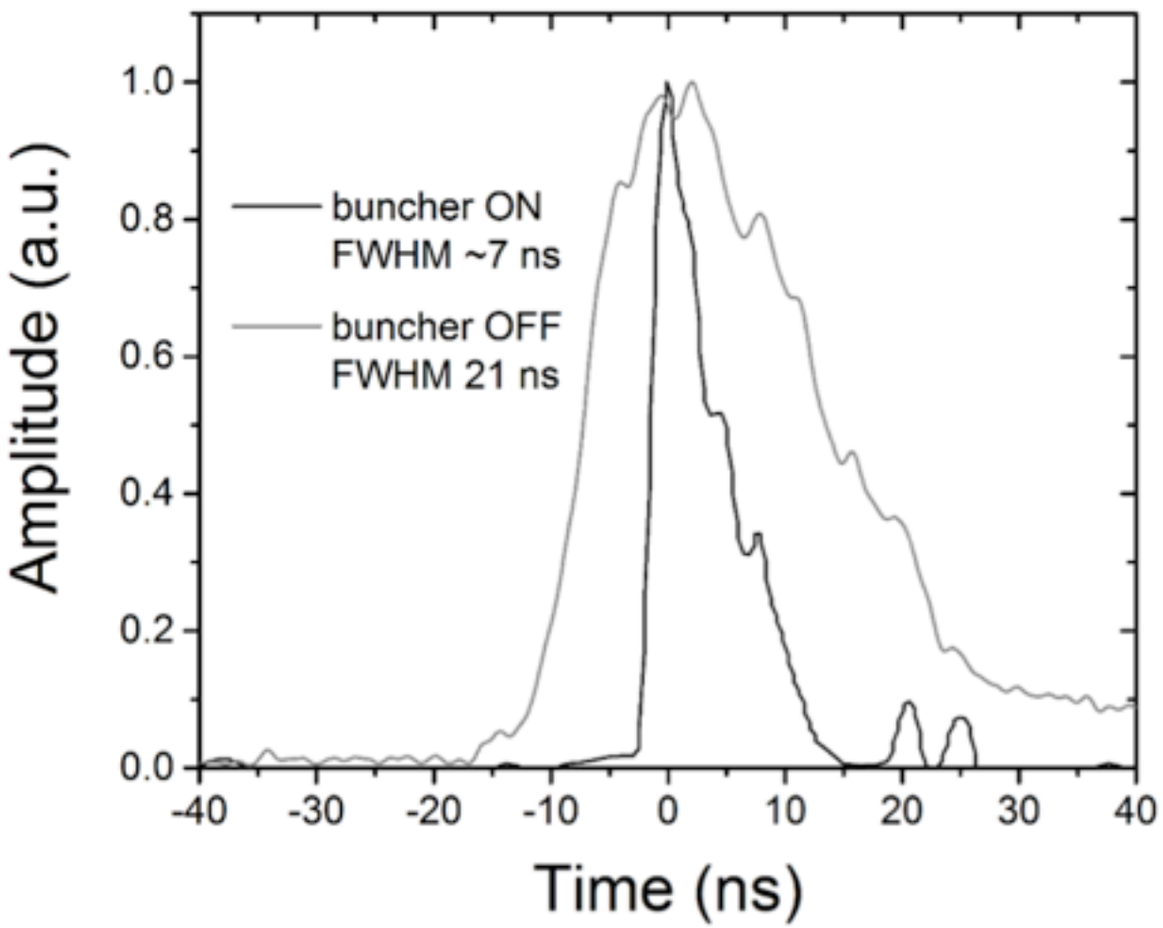




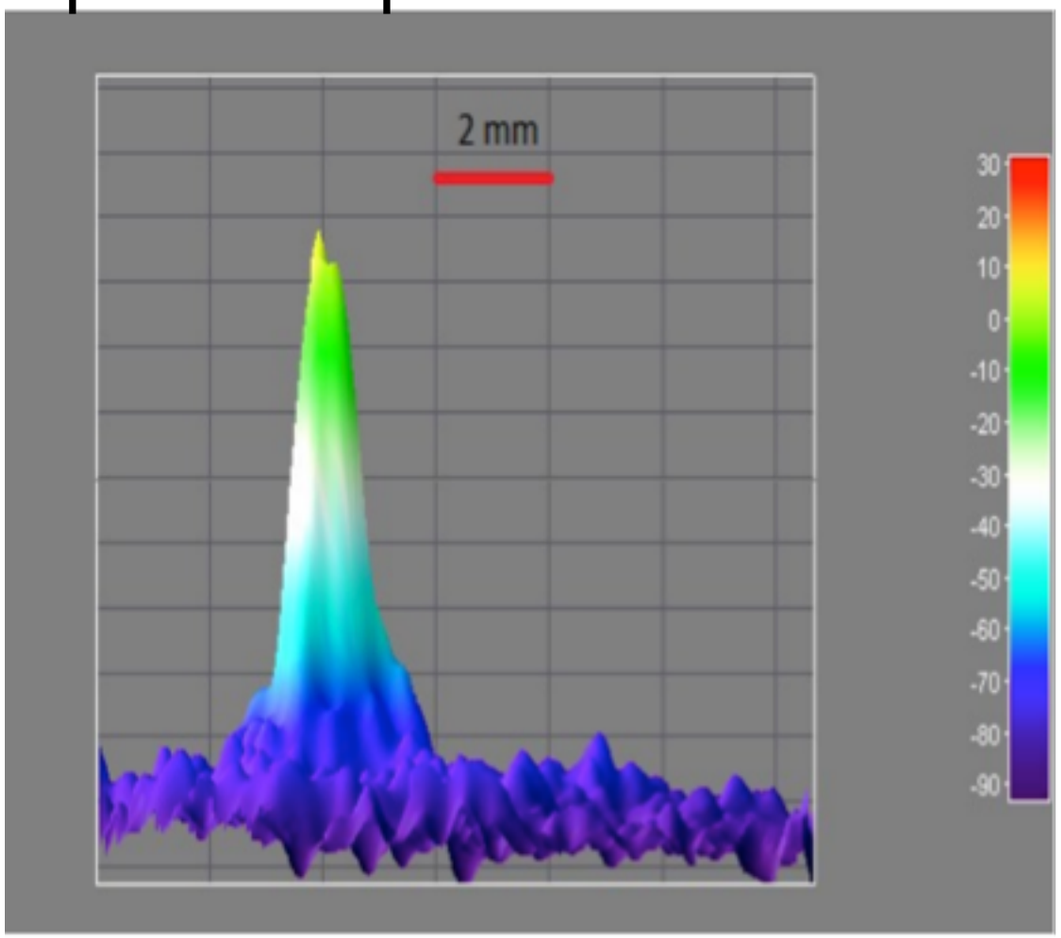
Commissioning started at the end of 2014



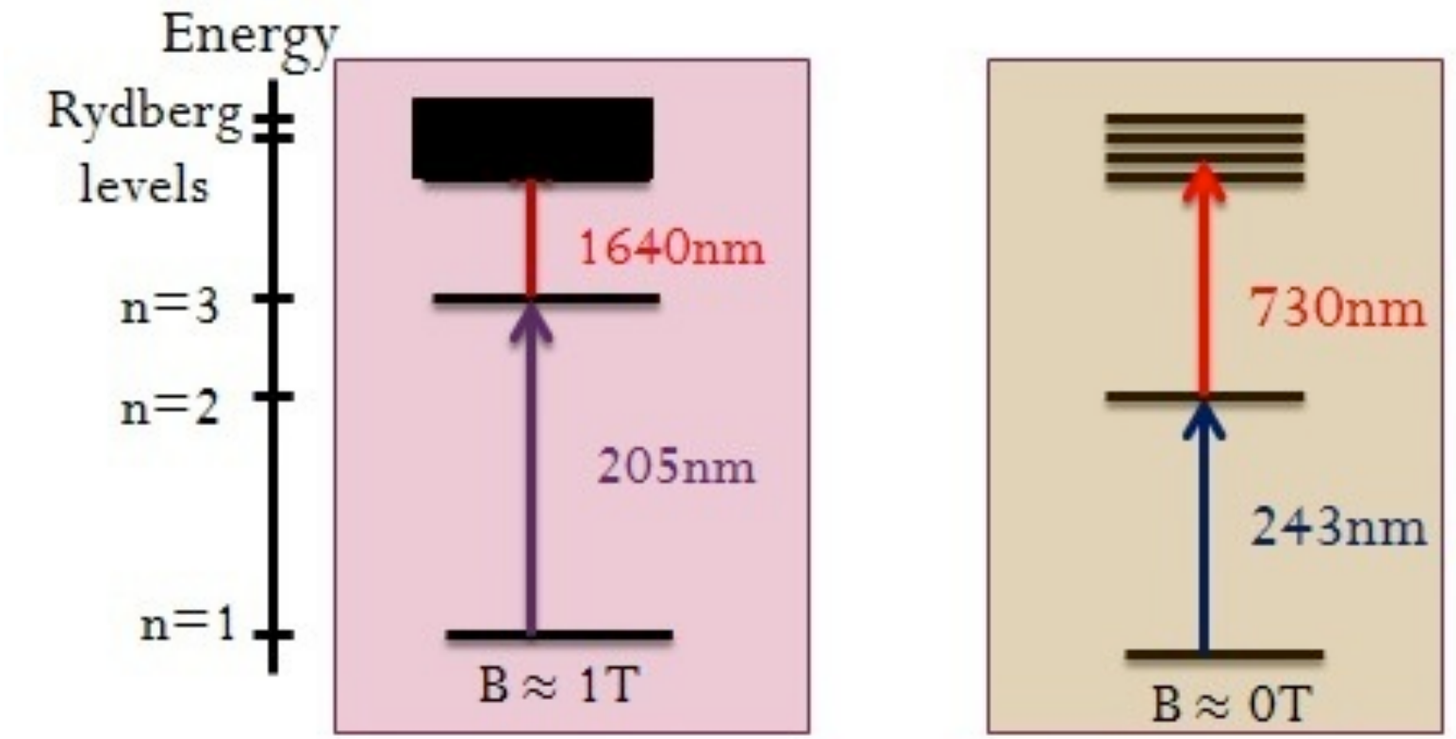
temporal compression



spatial compression



Ps excitation laser system(s)



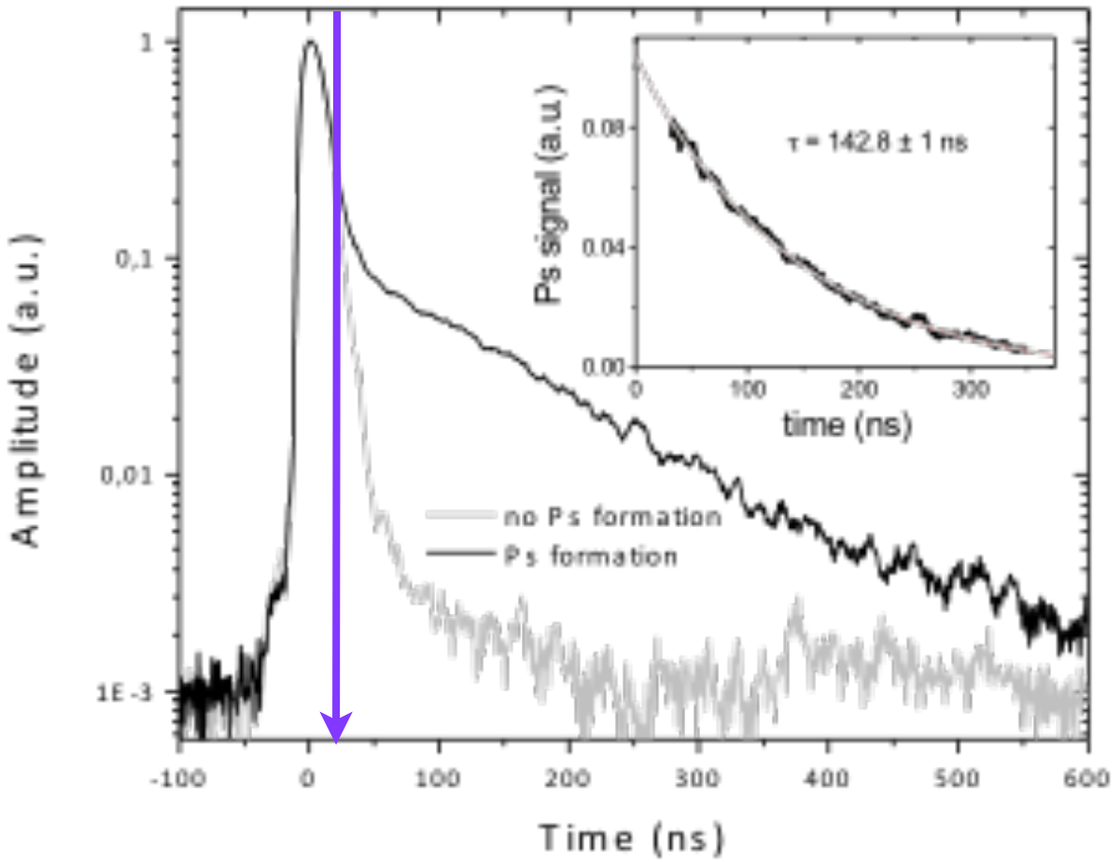
Broad-band laser installation completed in 2013

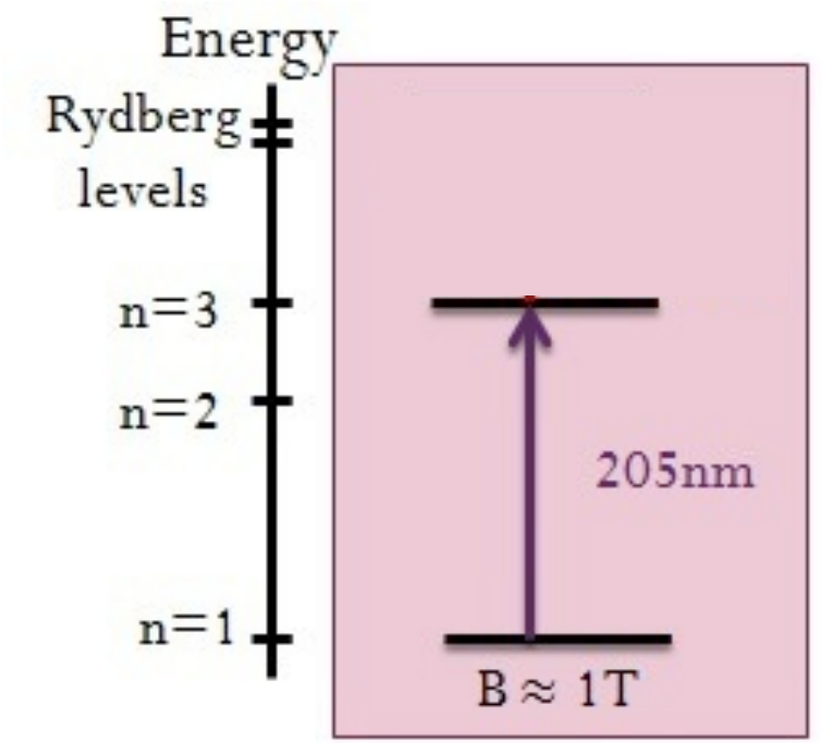
- alignment and tuning:
- measurements of monochromaticity
- measurements of intensity profile

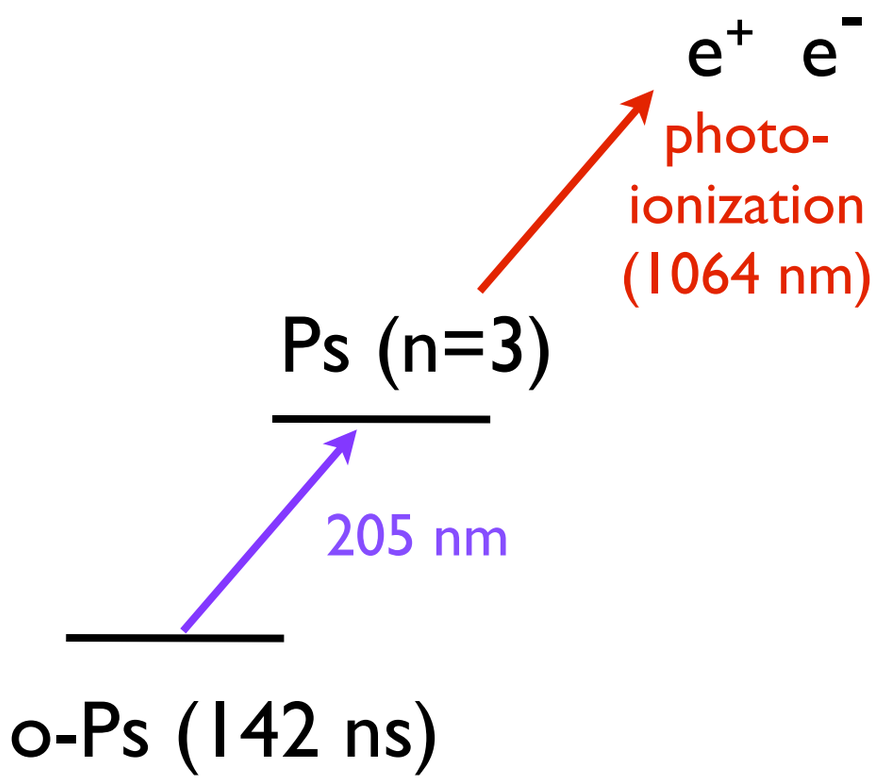
commissioned in 2014

→ ready for Ps formation and spectroscopy in spring 2015

Ps excitation into n=3



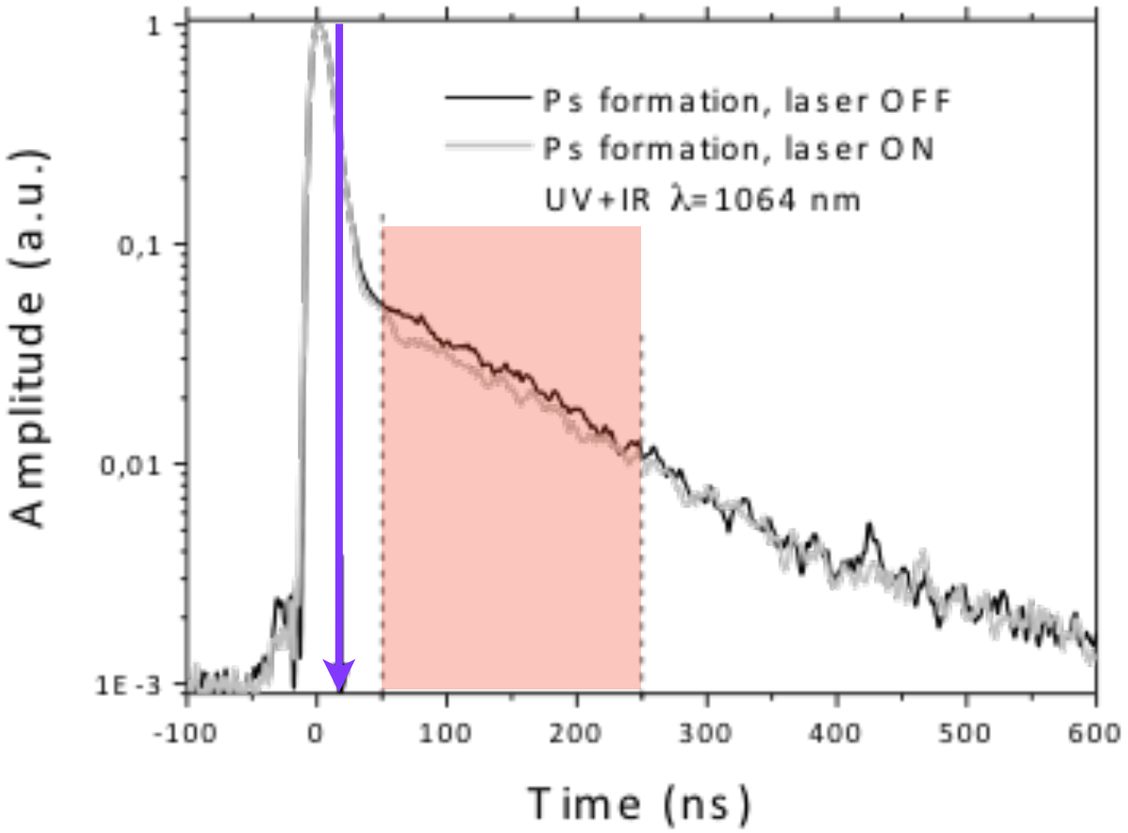


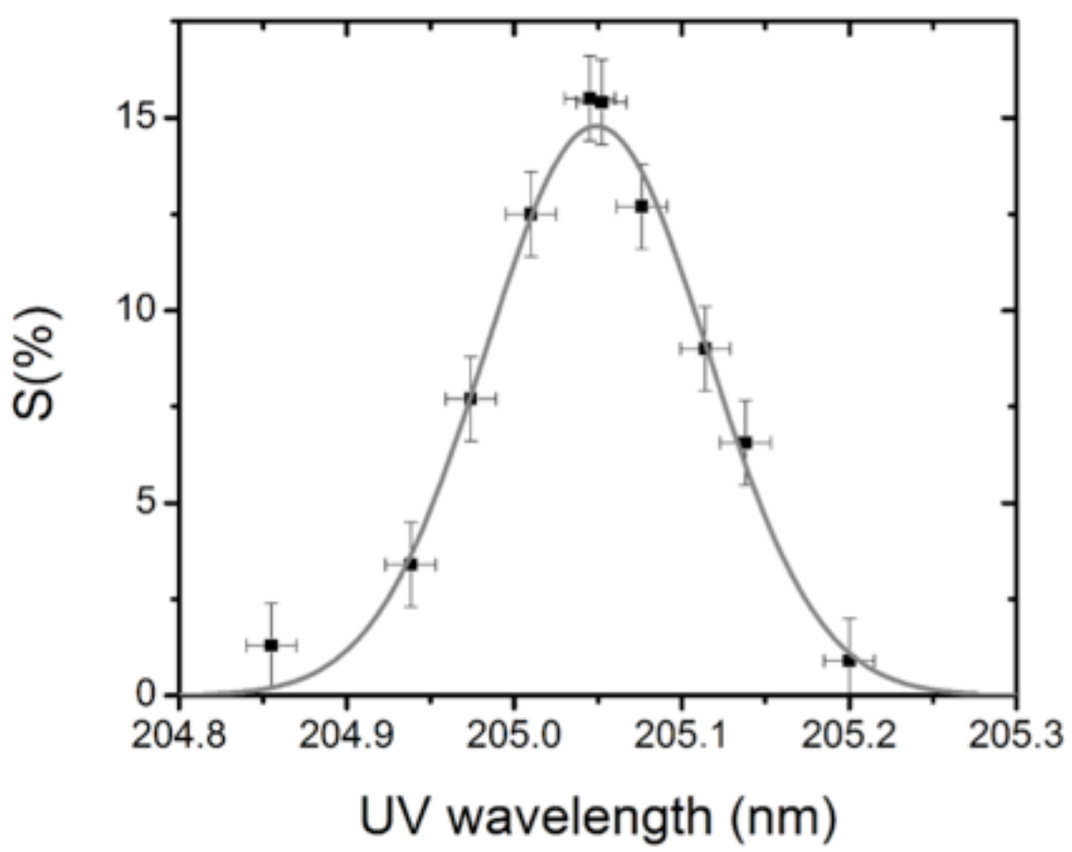


expect decrease of o-Ps population on resonance

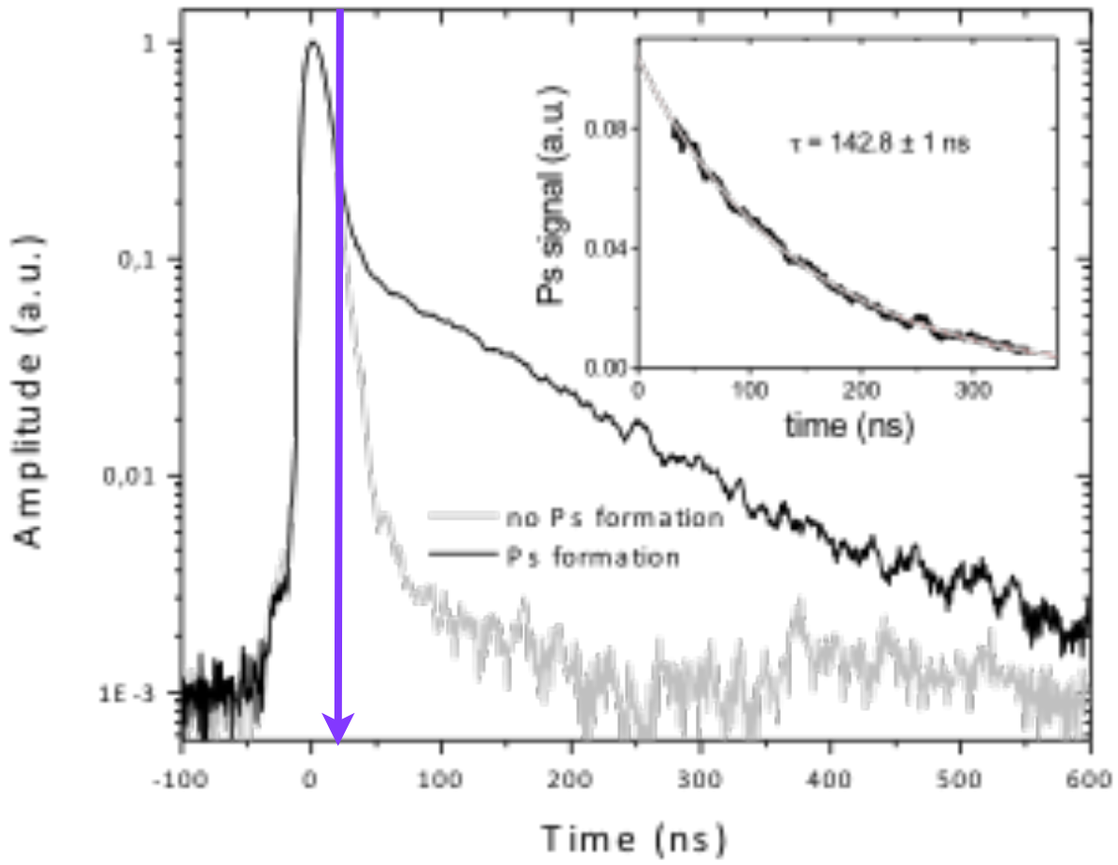
➔ *decrease* in (delayed) annihilation rate

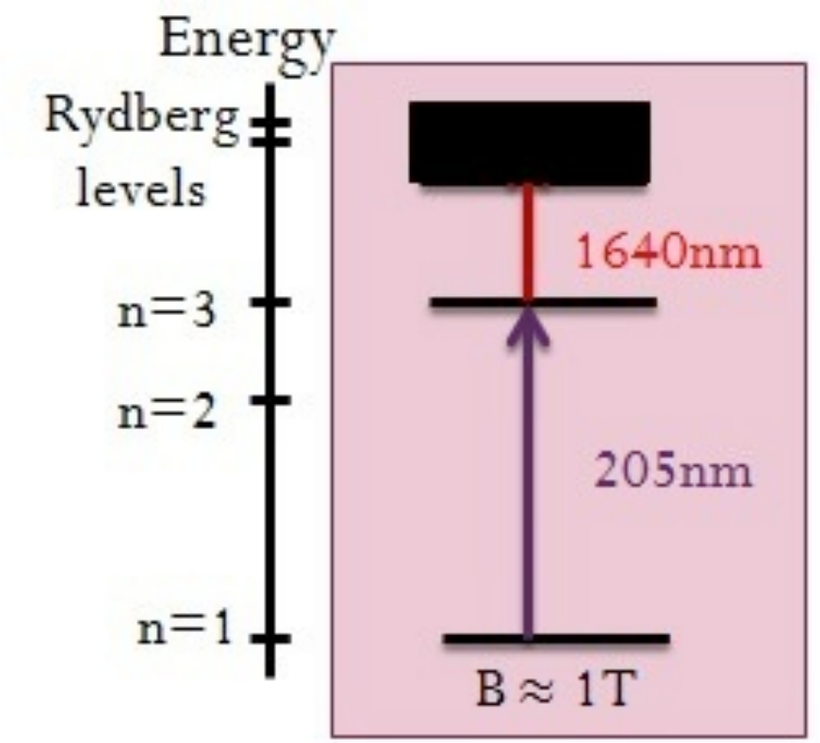
Measurement of Ps decay signal, alternating UV on/off, and scanning over UV wavelength





Ps excitation from n=3 into n~15





Ps* (n=15, Θ~ μs)

~1700 nm

Ps (n=3)

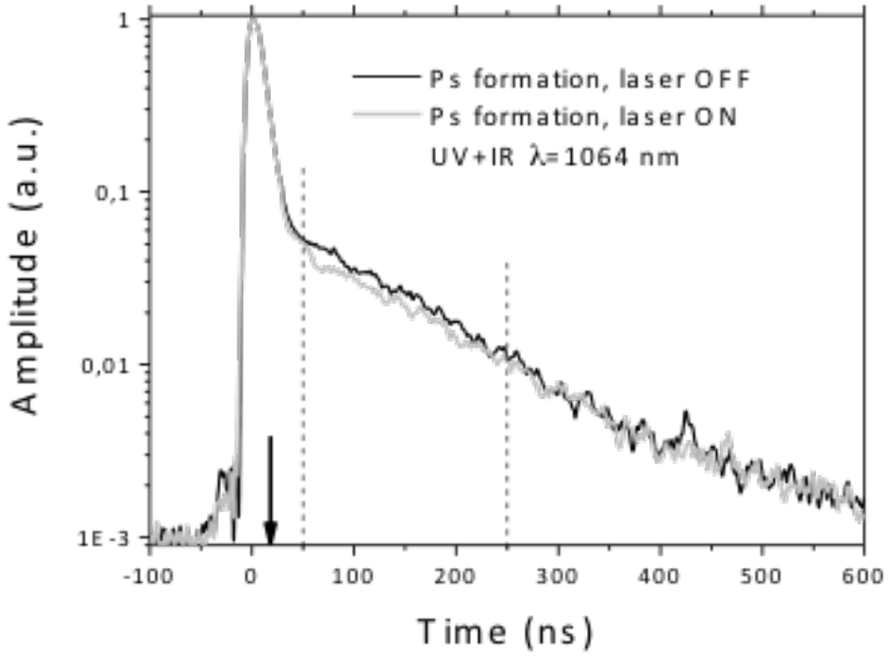
205 nm

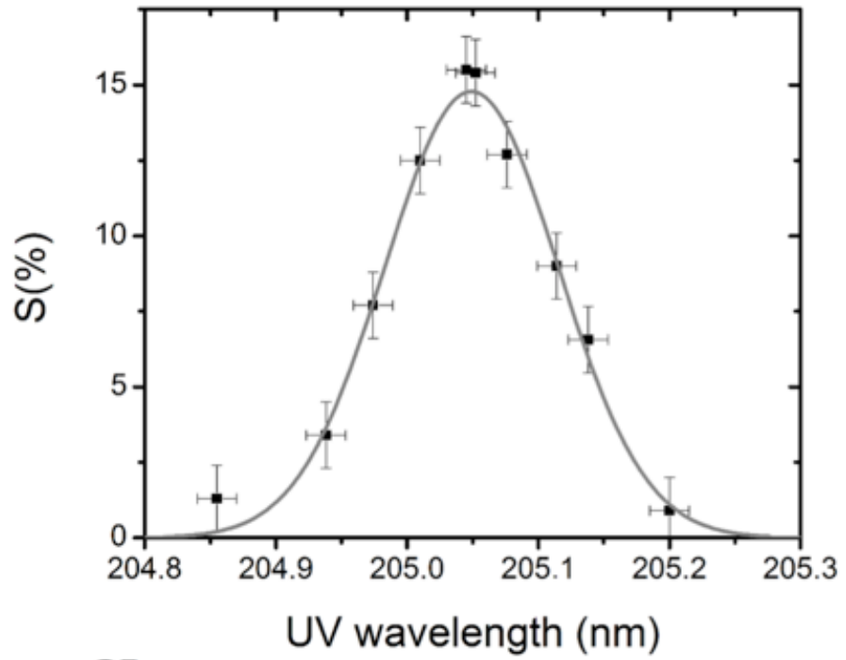
o-Ps (142 ns)

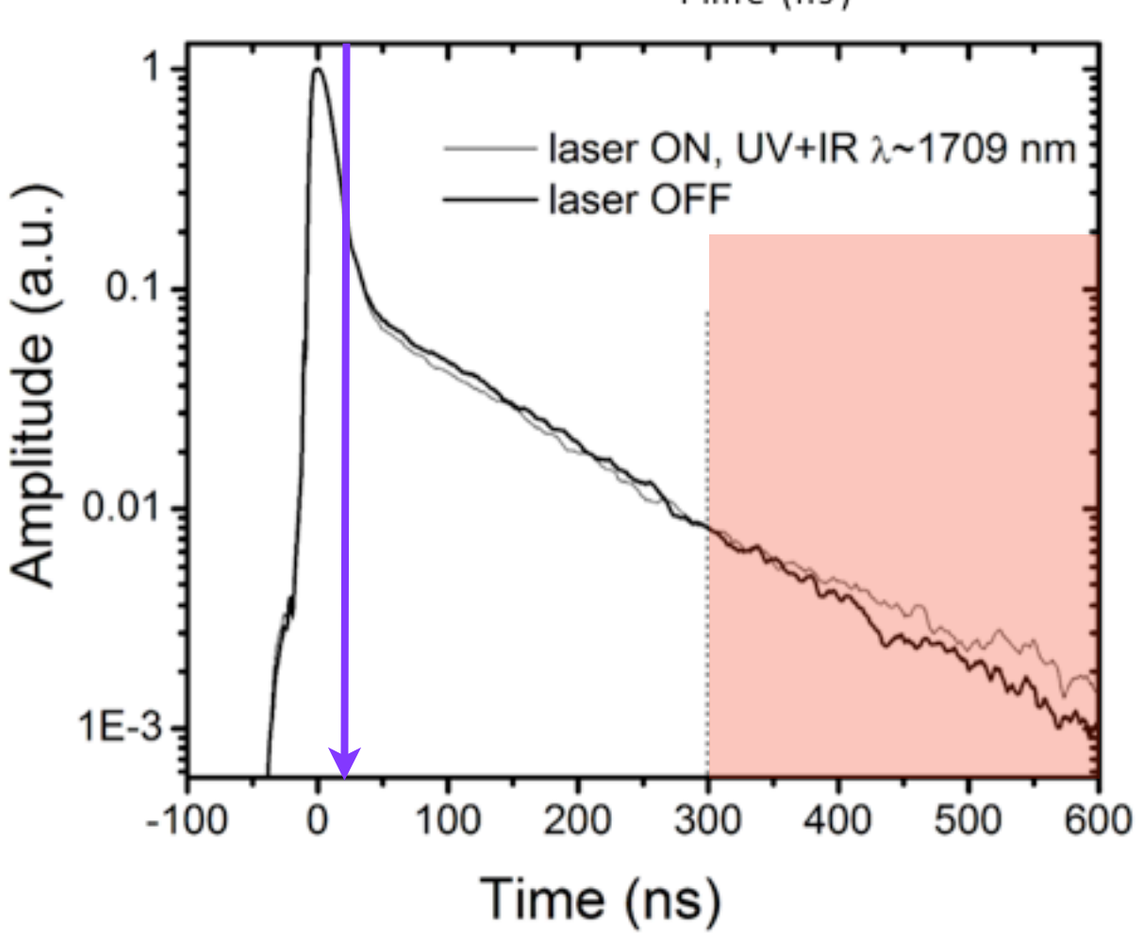
expect decrease of o-Ps population on resonance and appearance of long-lived Ps*

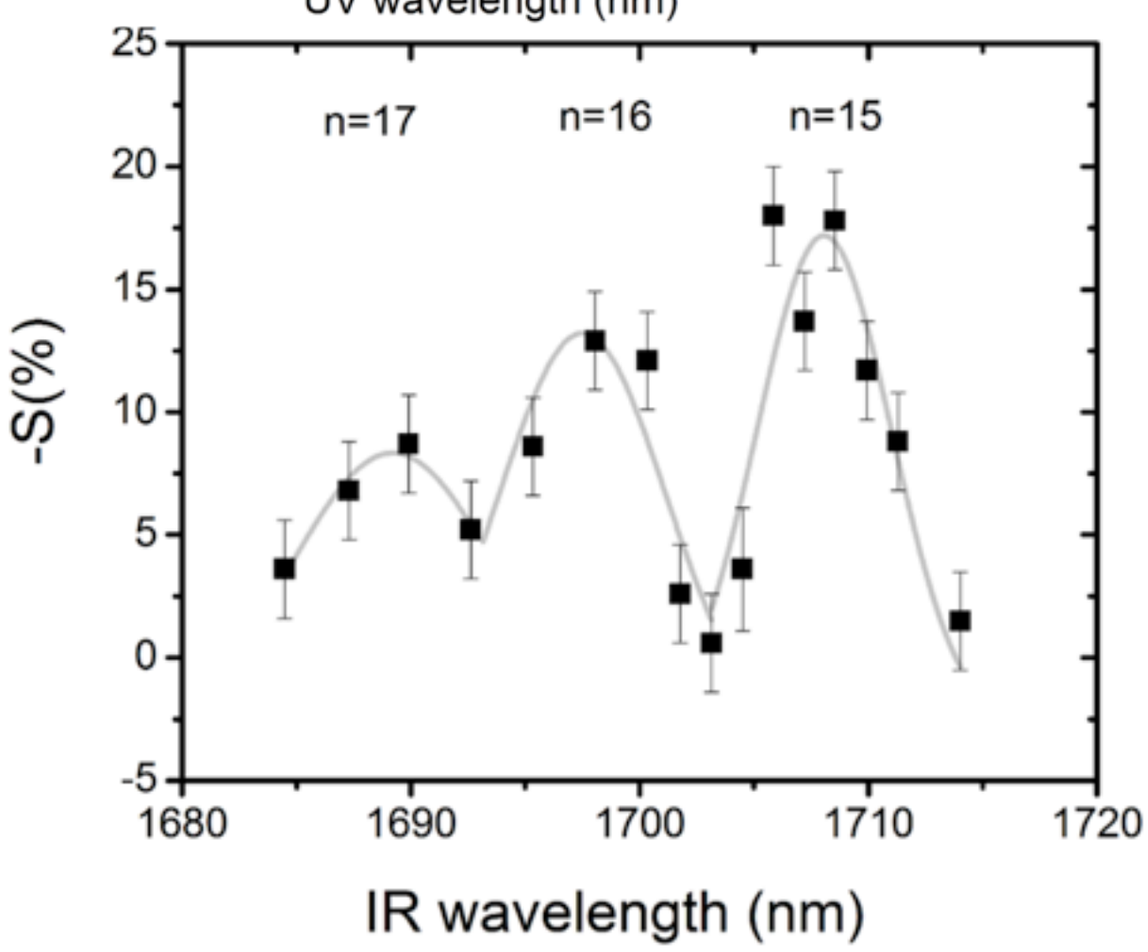
➔ *increase* in (very delayed) annihilation rate

Measurement of Ps decay signal, alternating UV+IR on/off, and scanning over IR wavelength

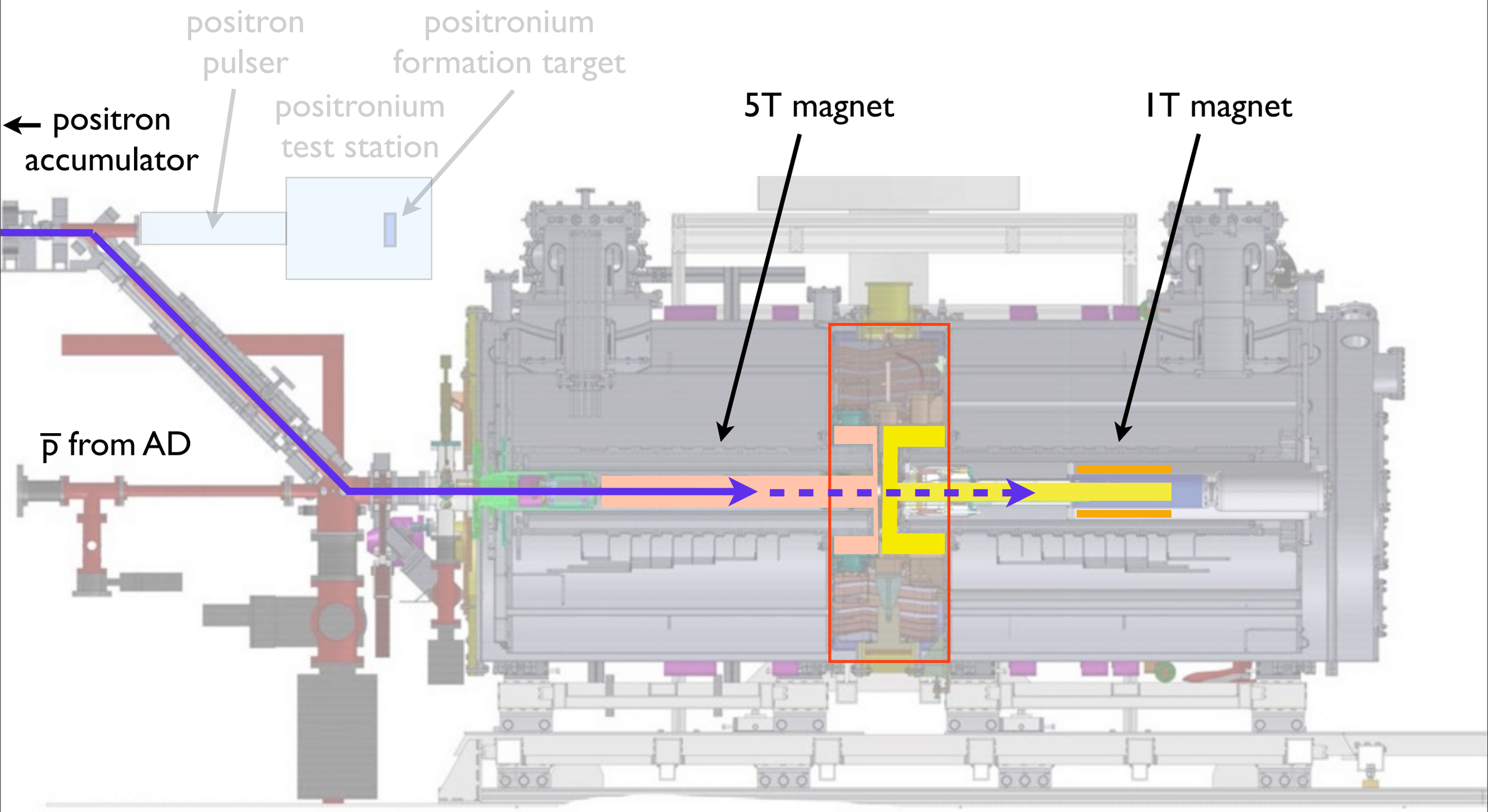




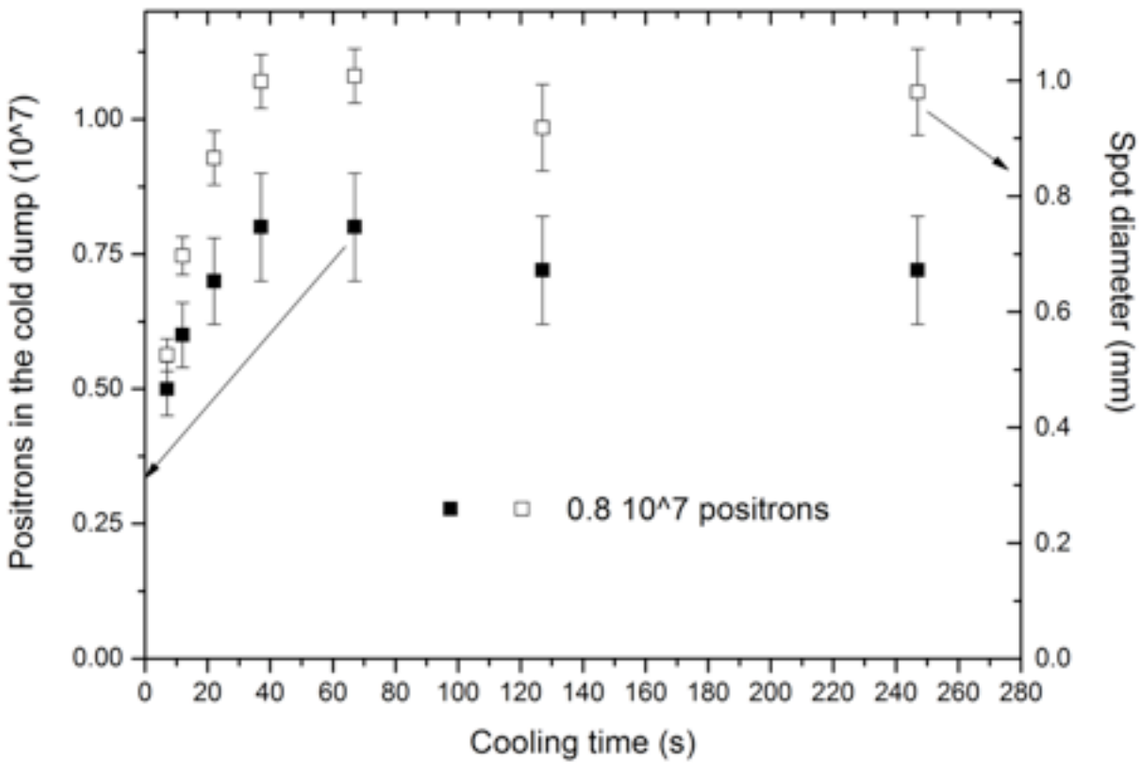




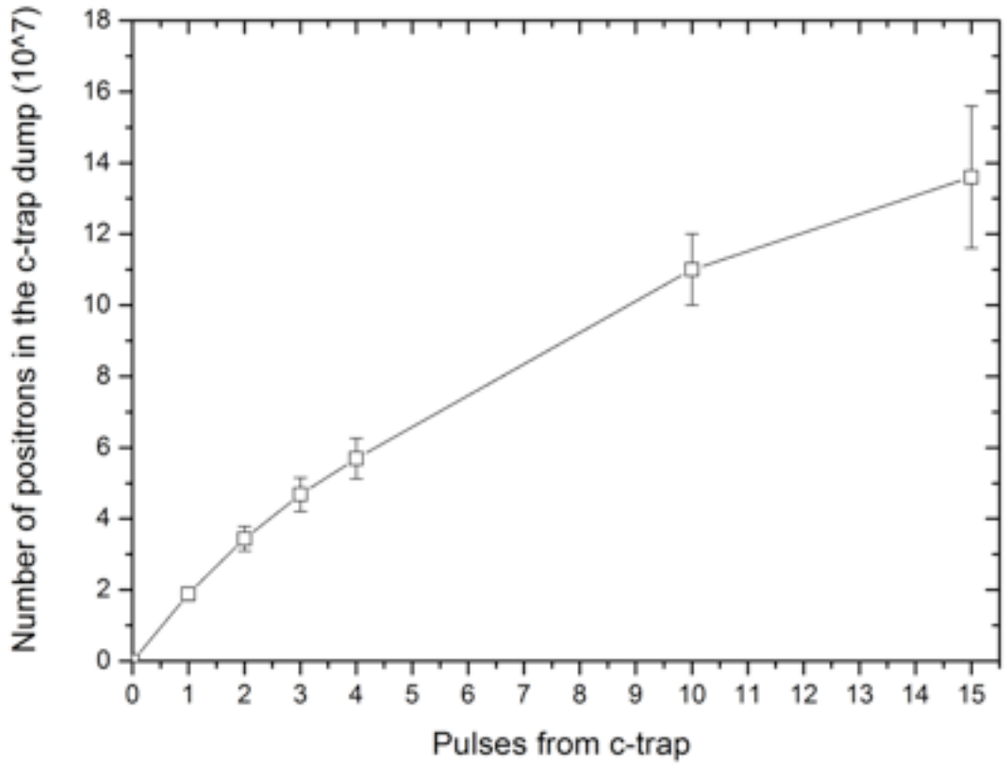
Positrons in the main apparatus



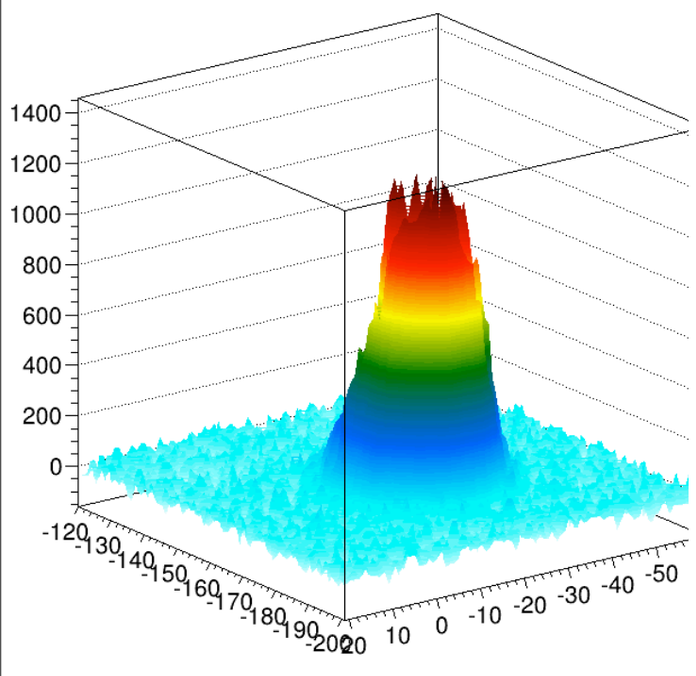
Cooling in 5T



Stacking in 5T

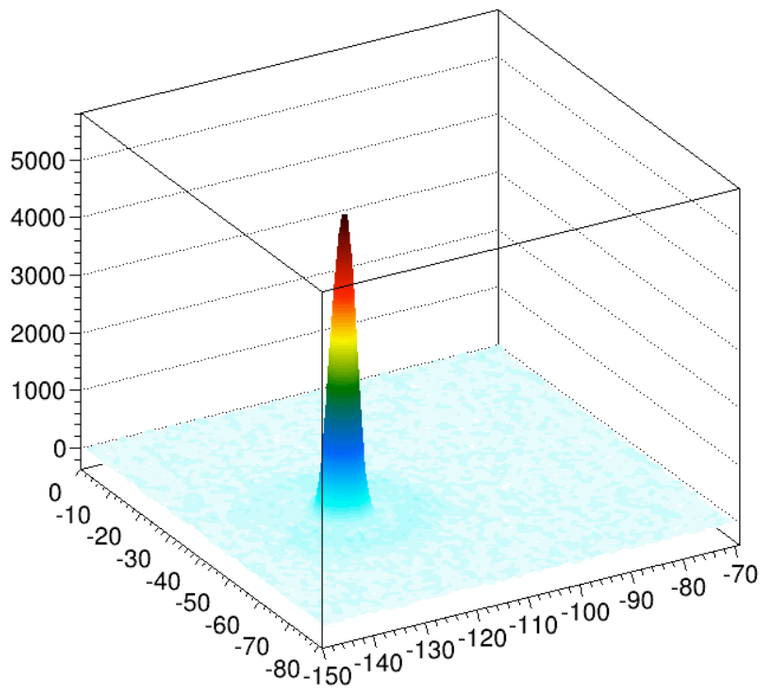


d=5mm



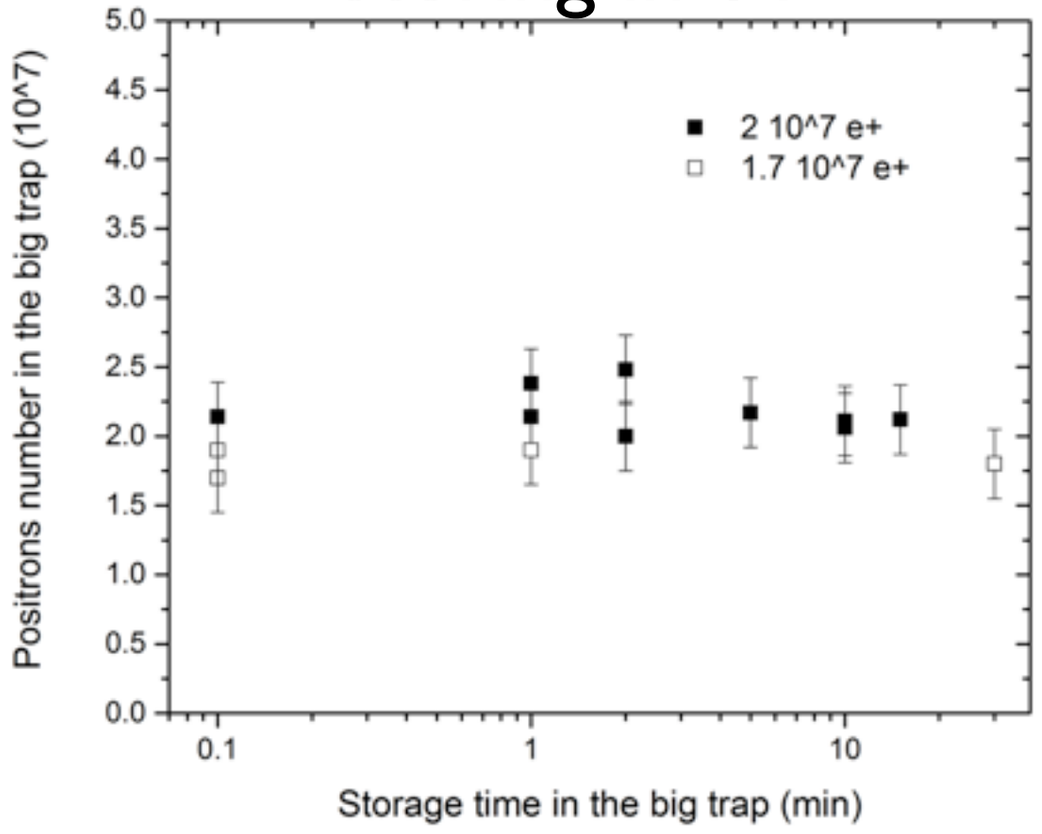
direct

d=0.14mm, ρ=10¹⁰/cm³

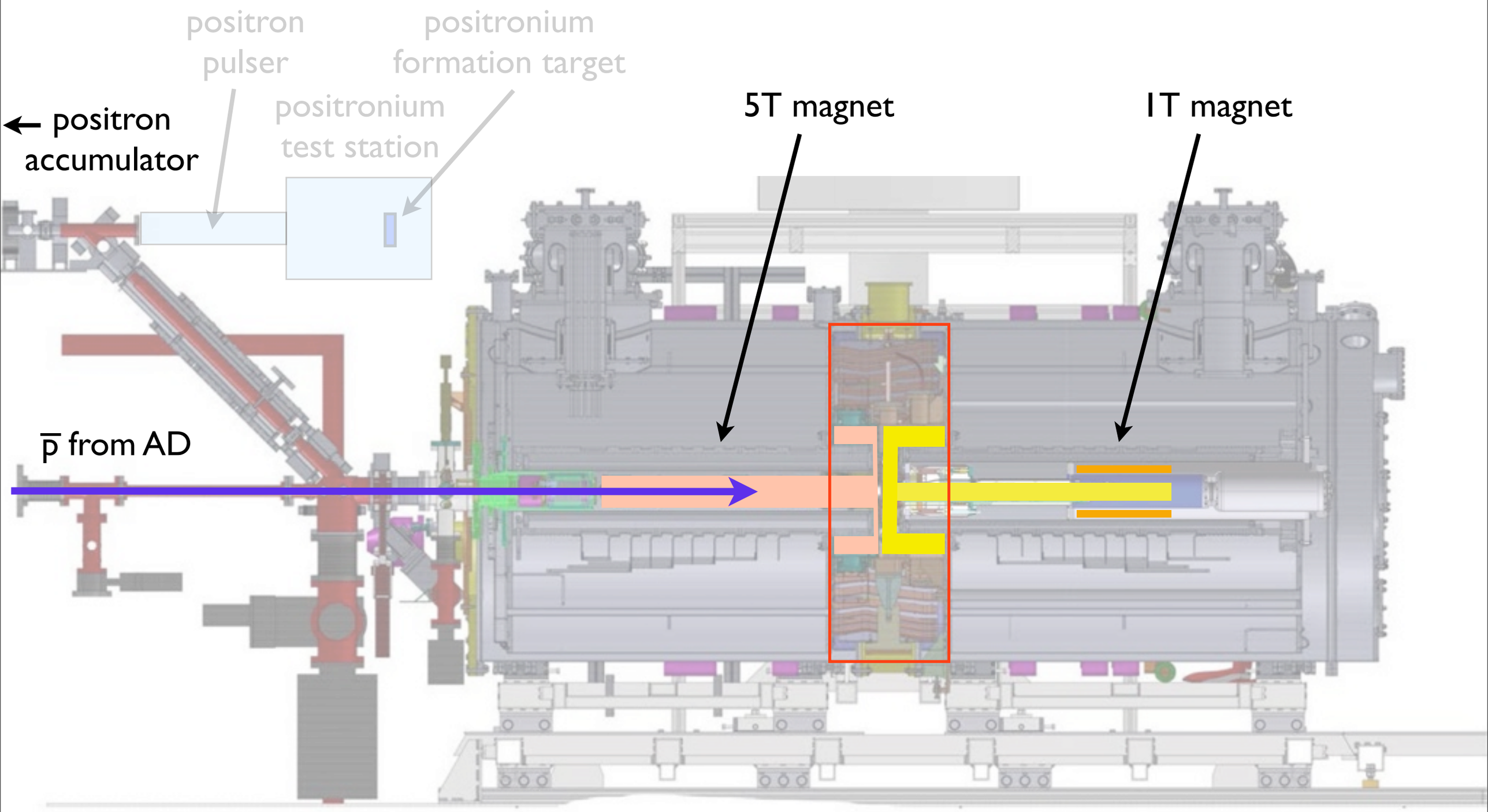


trap, cool, compress

Storing in IT



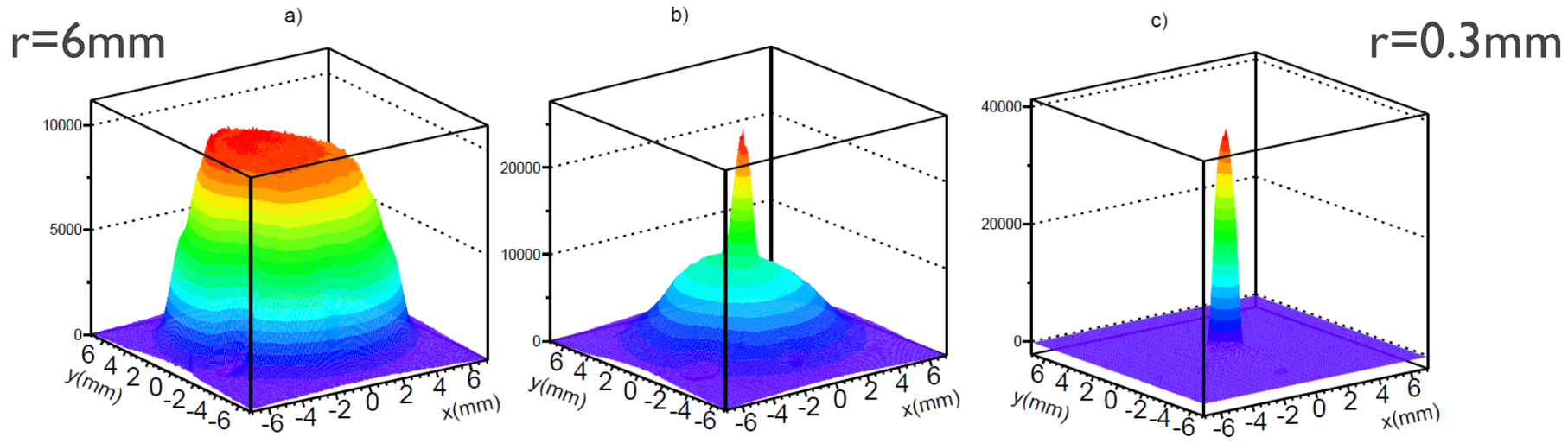
Antiprotons in the main apparatus



Antiproton runs: 2015 (Jul - Nov)

Electrons: plasma manipulations already exercised in spring 2014:

effect of
rotating wall



goal: implement all steps needed to produce antihydrogen:

cooling in 5T, compression in 5T, transfer into 1T, compression in 1T, transfer into production trap

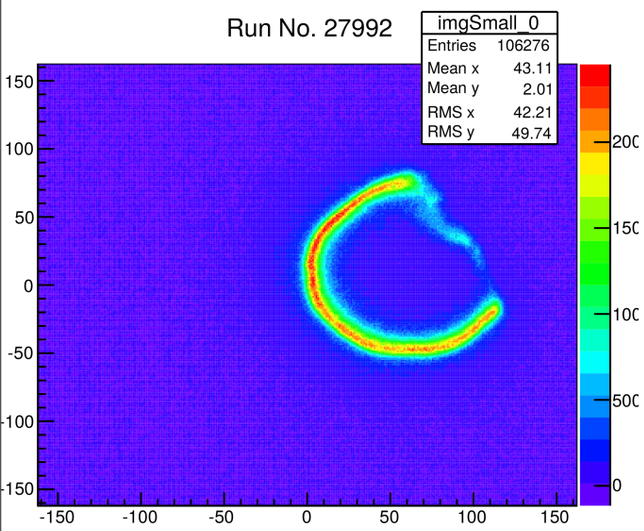
diagnostics, understanding of plasma processes and characteristics

antiprotons imaged on MCP

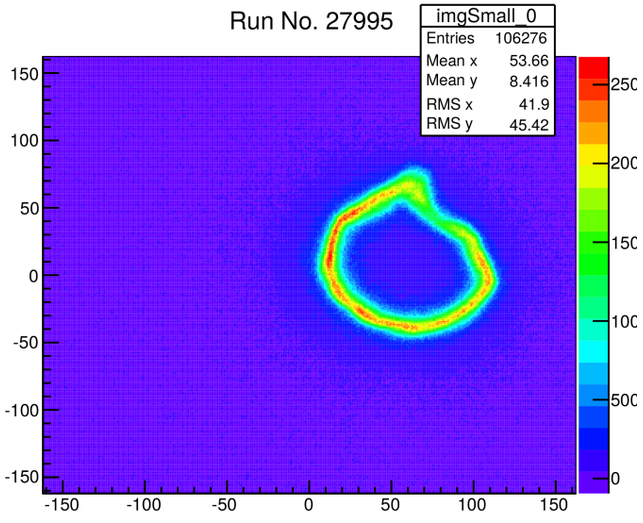
measured cooling efficiency (>60%) ⇋ plasma size

compression efficiency > 80% (f(RW parameters and procedures))

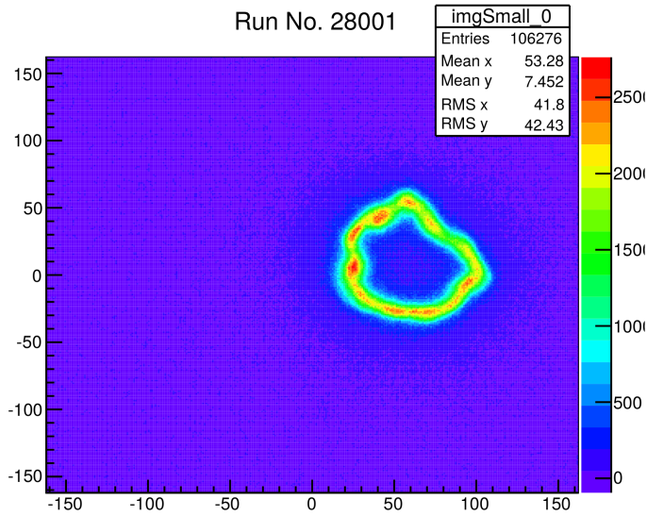
400 kHz

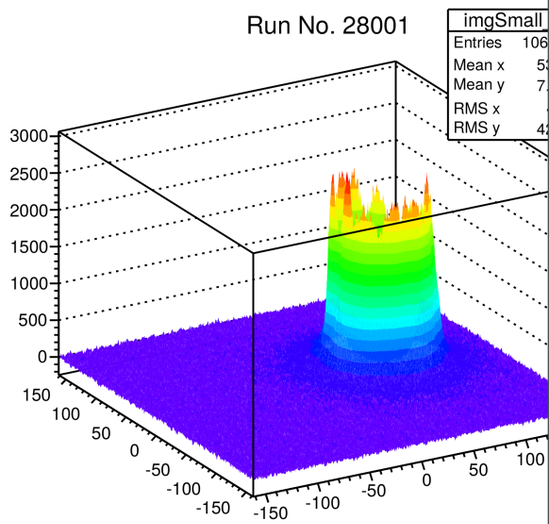


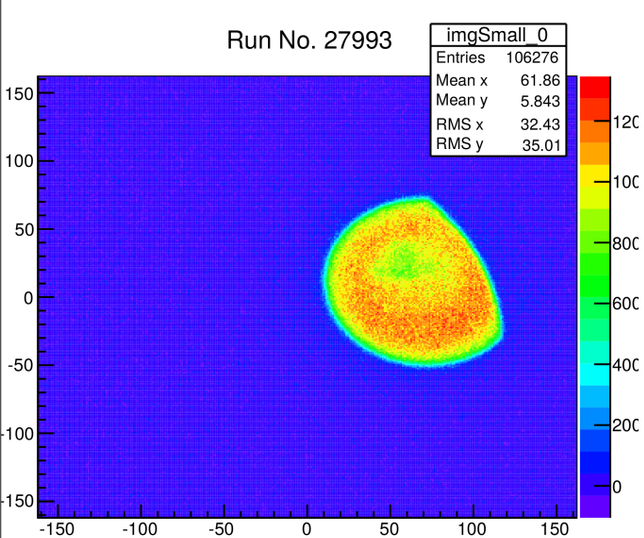
600 kHz

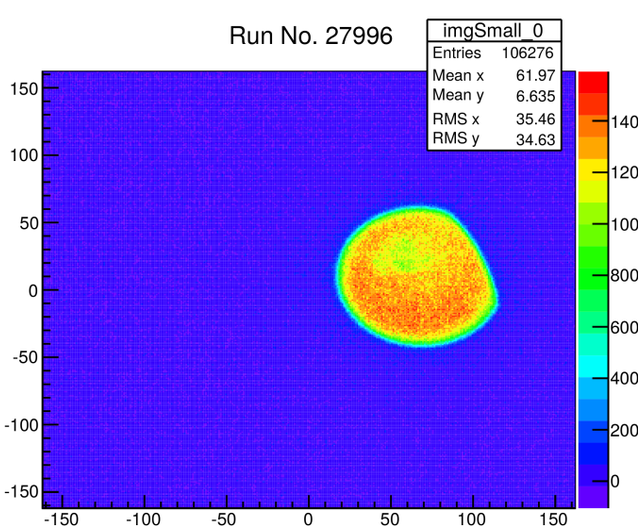


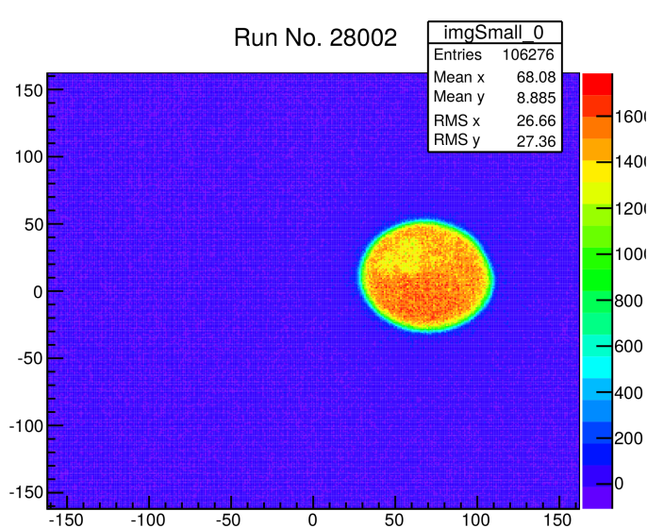
1 MHz

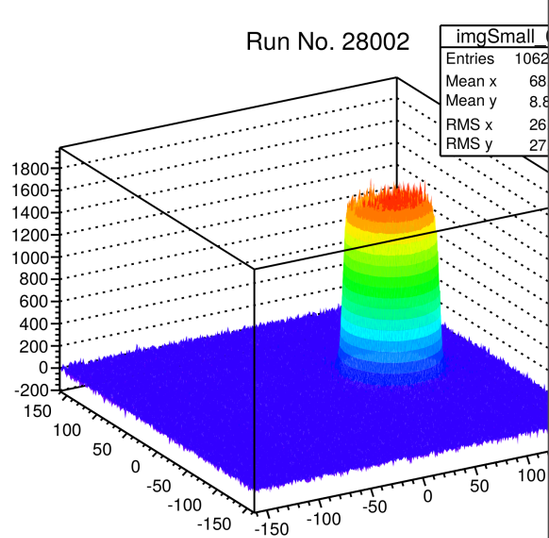












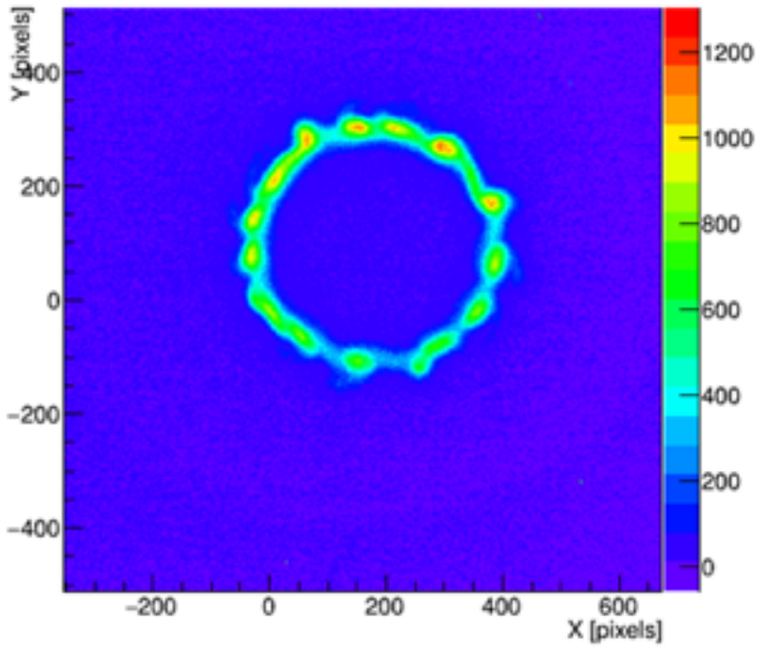
Centrifugal separation observation:

➟ Allows for temperature estimate

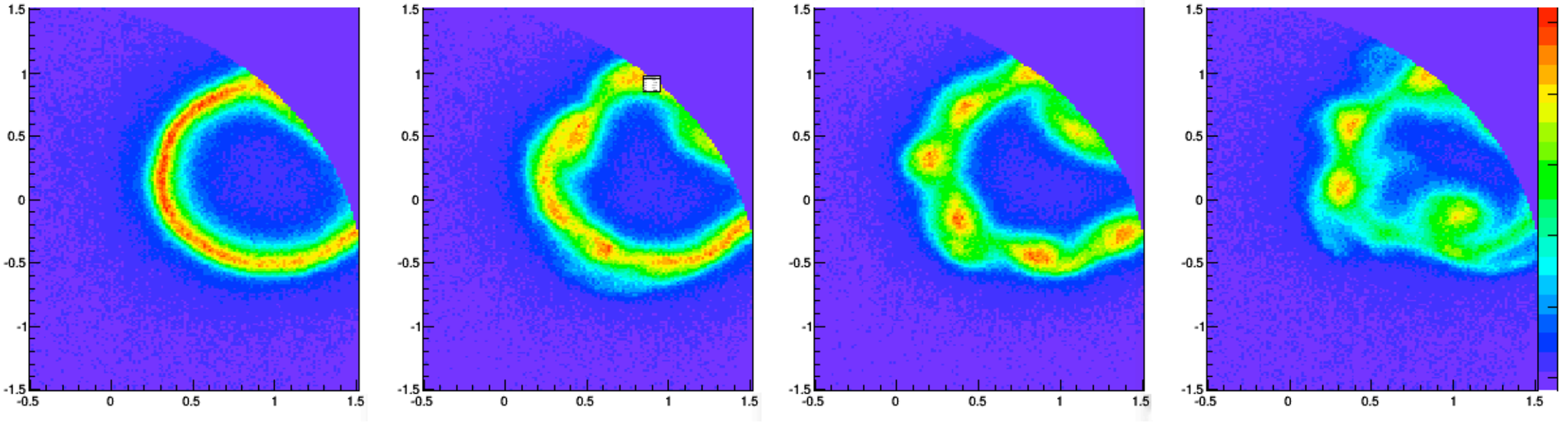
➟ from measured e^- density we estimate T_{min} which corresponds to traps' temperature of 10K

➟ achieved $\bar{p}$ density ~ $10^{13}/m^3$

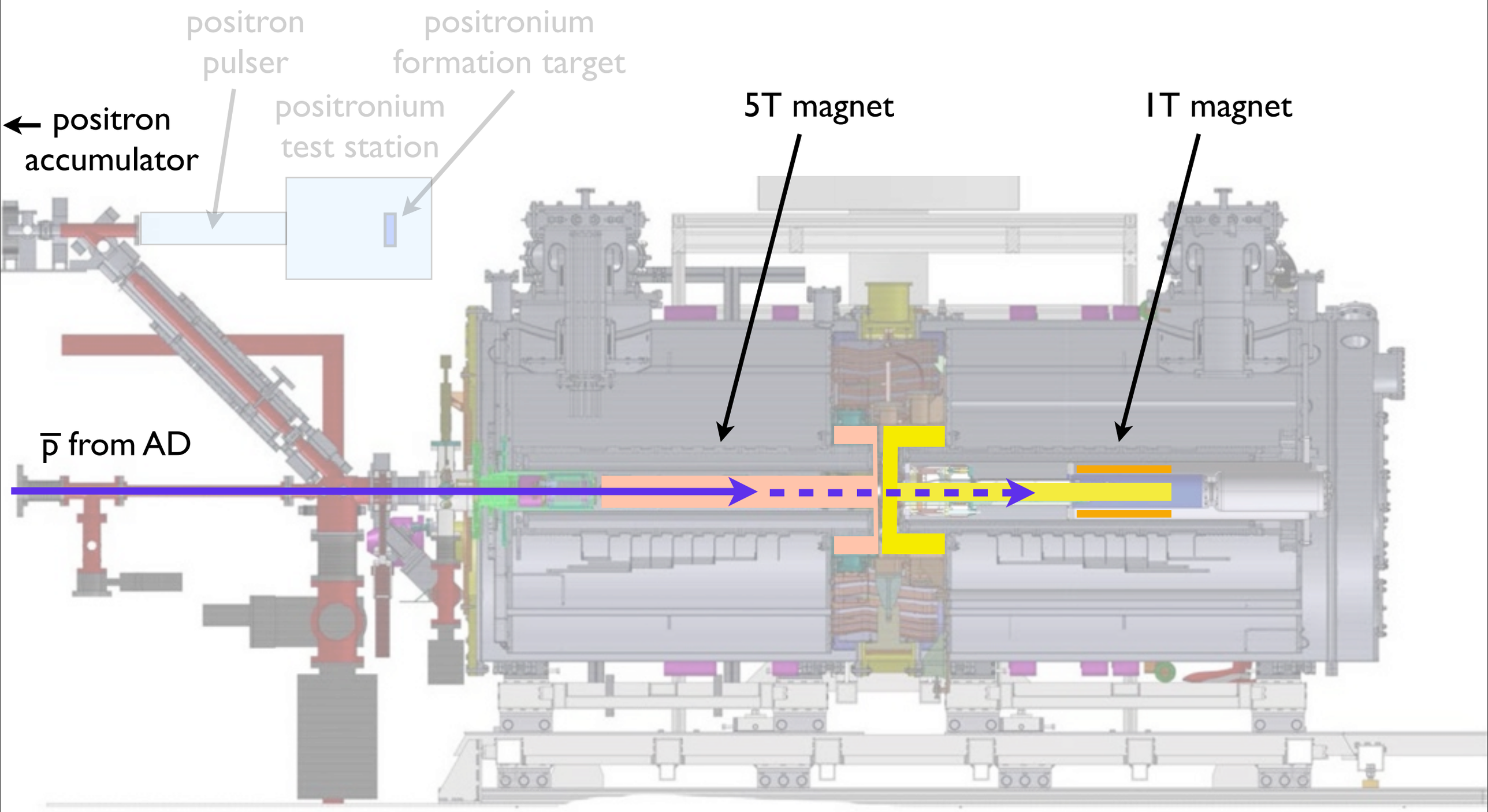
➟ $\bar{p}$ plasma



Collapse of $\bar{p}$ shell over ~ 100's μs via Kelvin-Helmholtz instability



September: antiprotons into the 1T magnet ...



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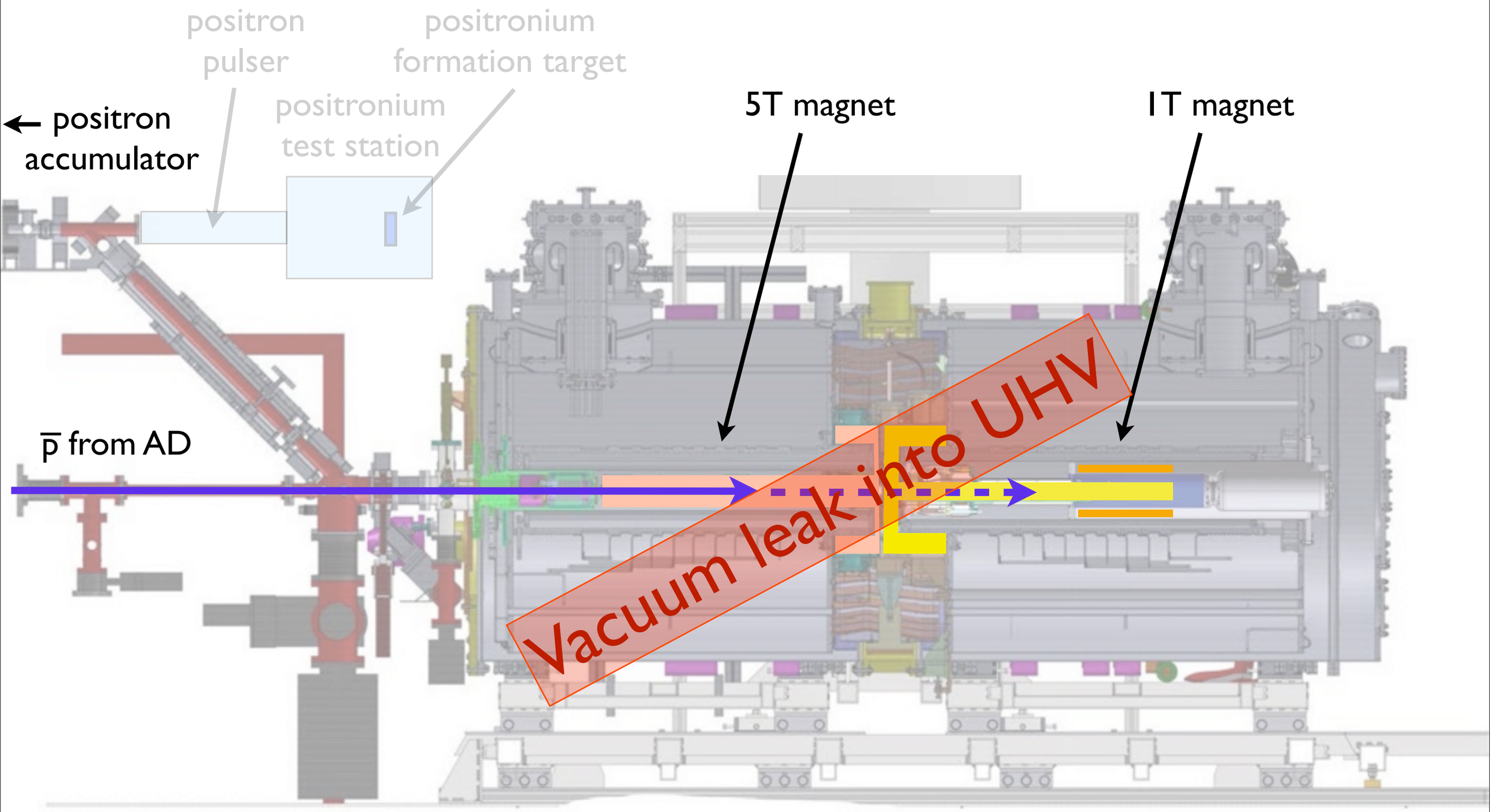
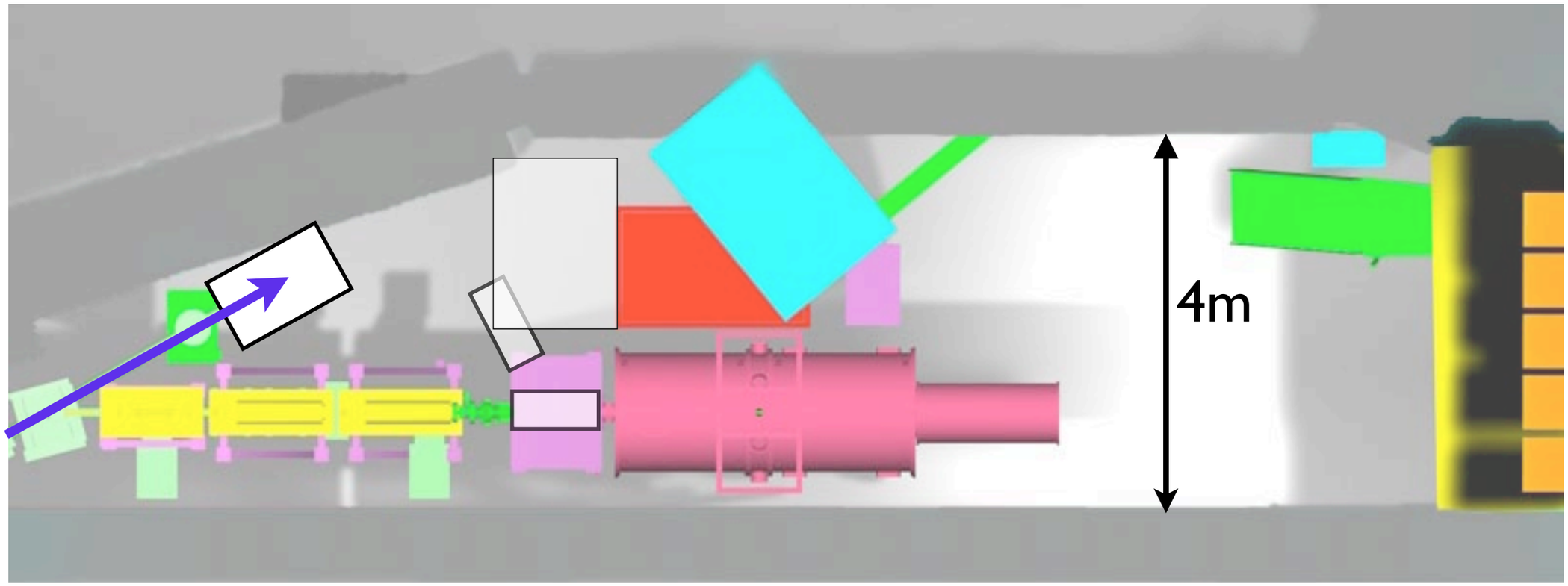


antiproton lifetime below 100 s → only (combined) plasma procedures in 5T

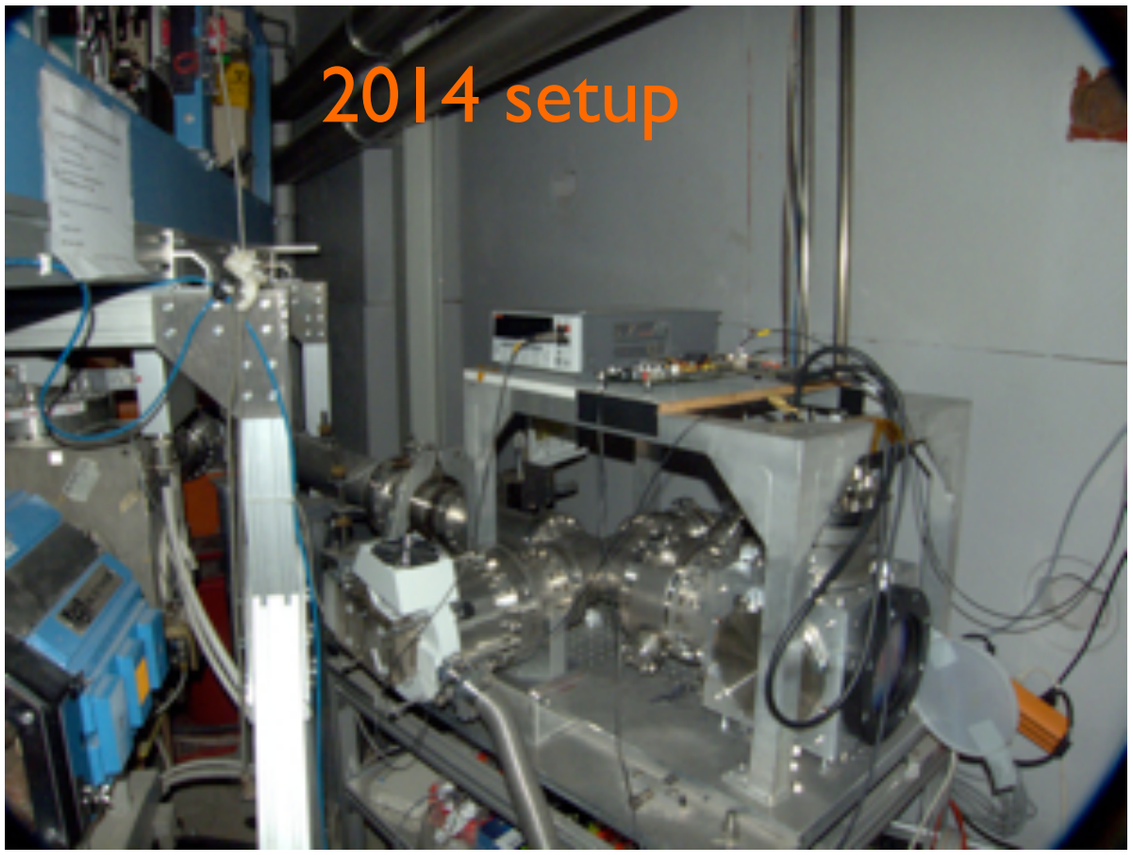
Parallel antiproton measurements

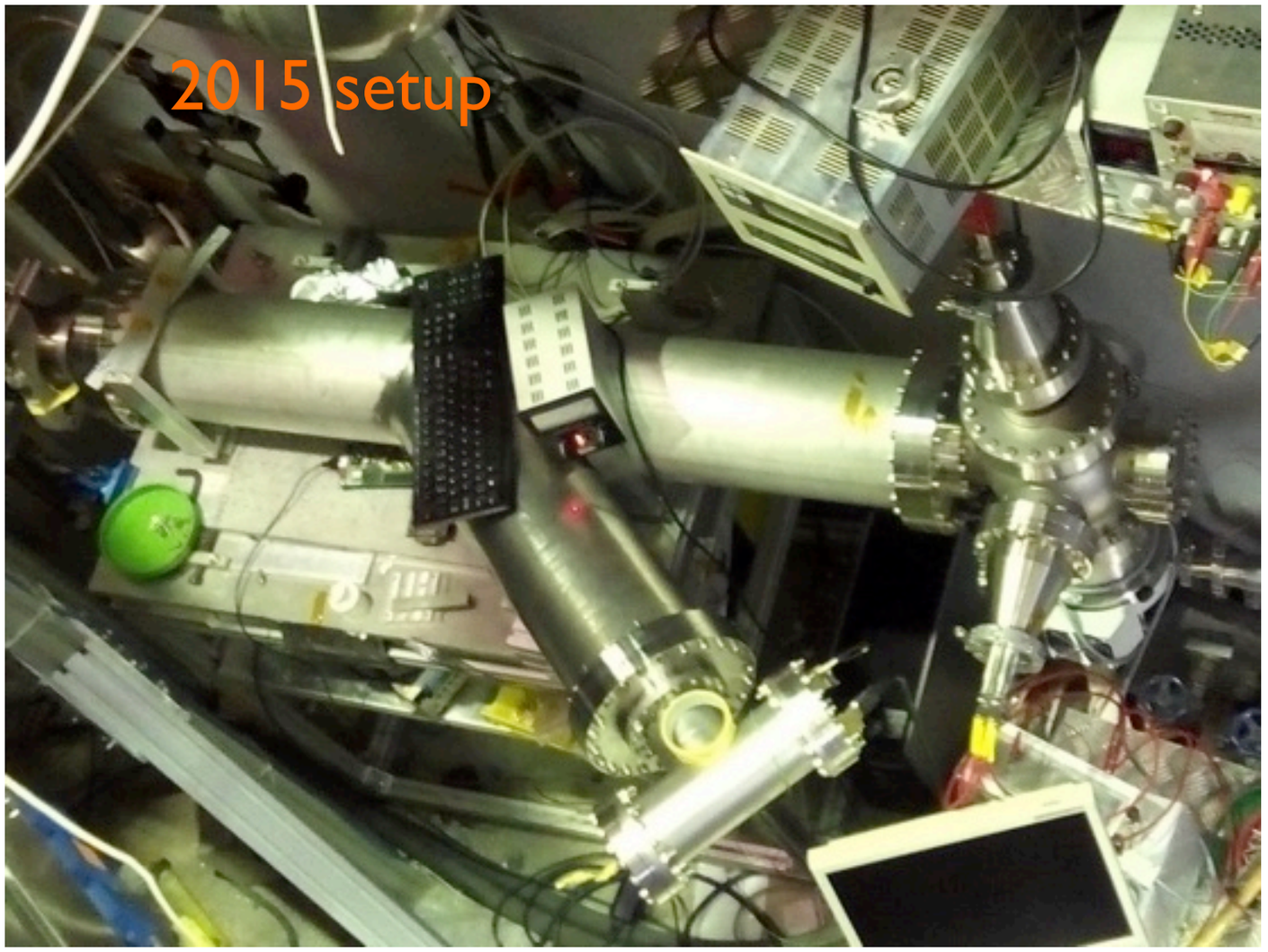


Antiproton runs: 2015 (and data from 2014)

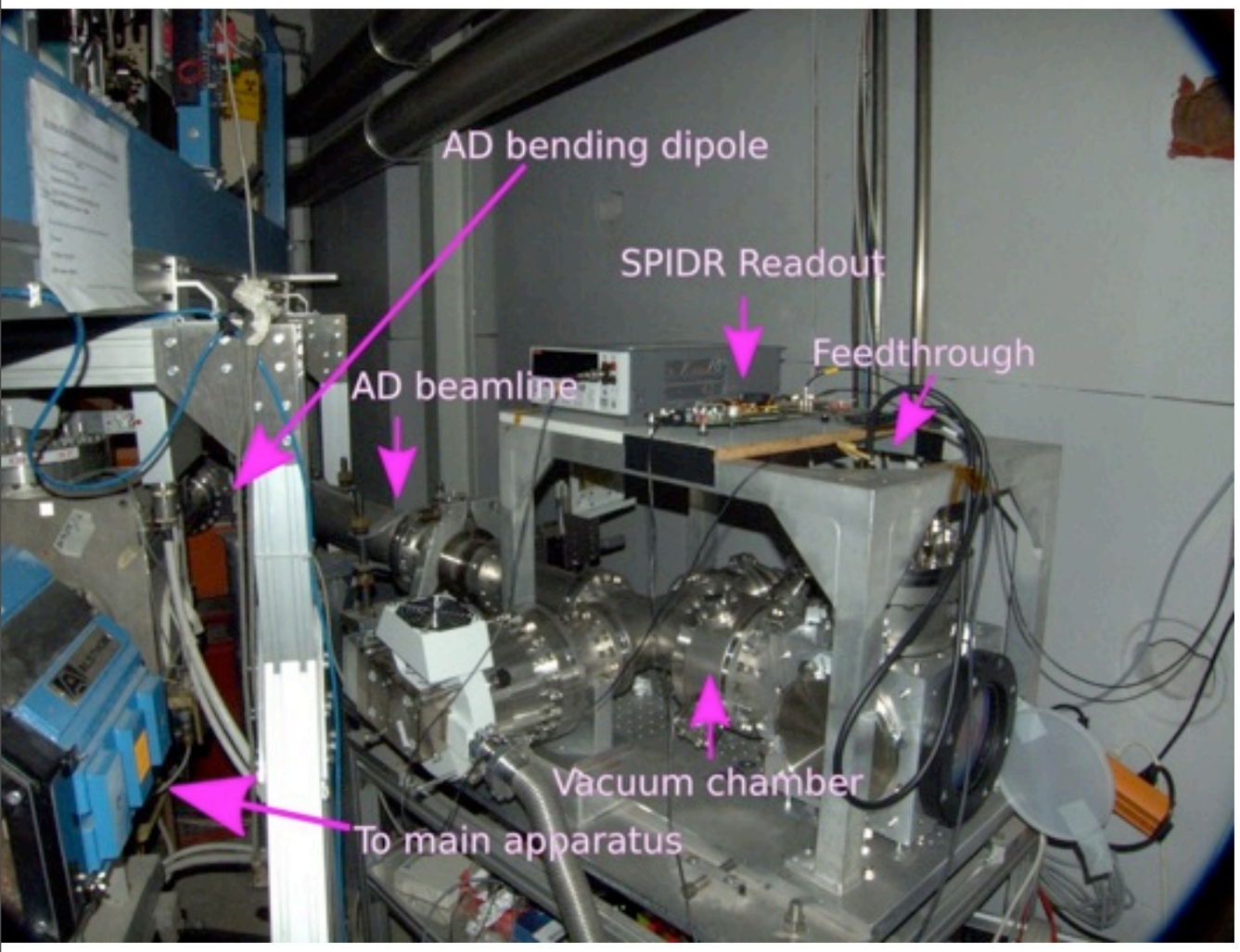
Parasitic tests: explore/validate different candidate technologies for the (downstream) antihydrogen detector by annihilating (low energy) antiprotons in the detectors

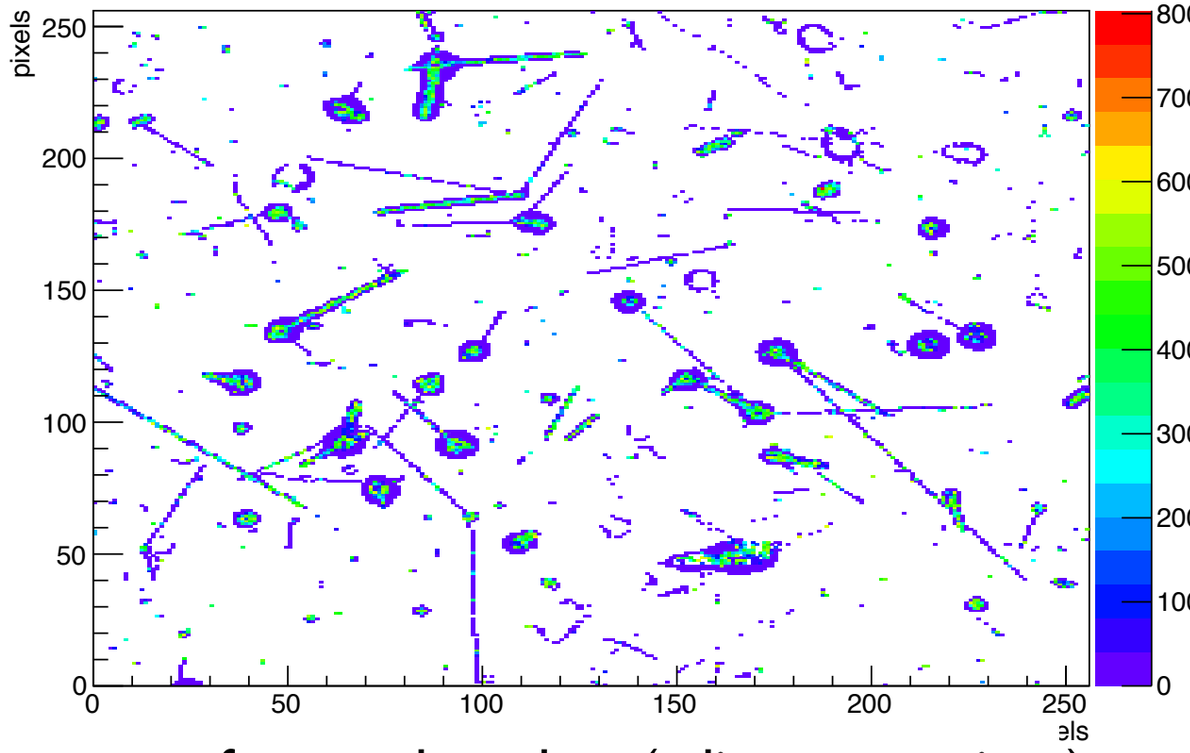
understand nuclear fragmentation (required for determining $\bar{H}$ detection efficiency) ➔ foil+emulsion



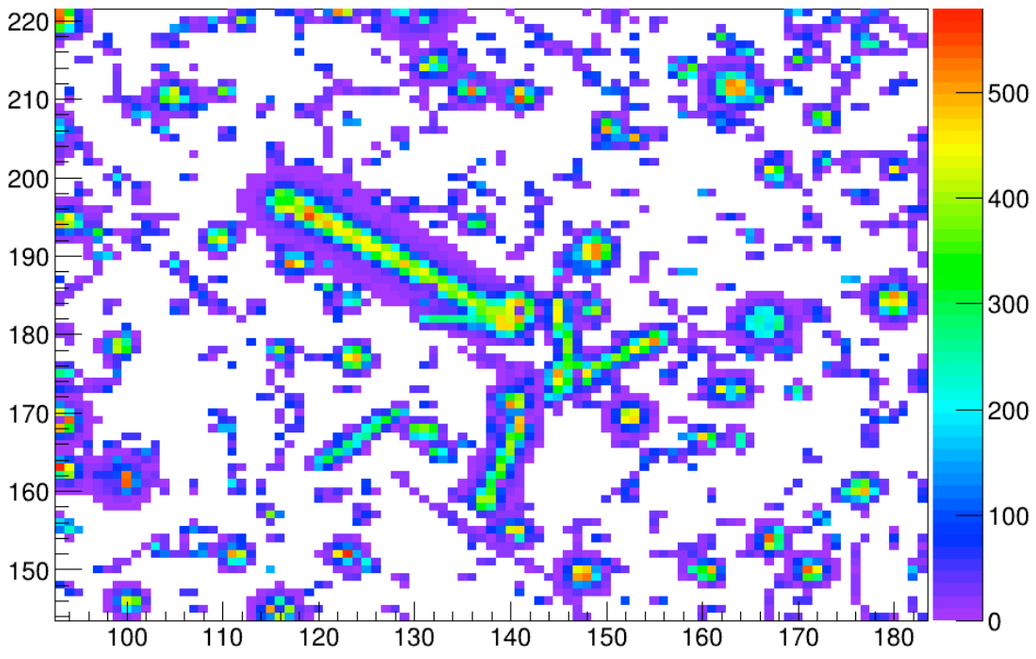


2014: first tests of Timepix3 Silicon detectors (high dynamic range, granularity (55 μm), time resolution (1.2 ns)) + 300 μm sensor



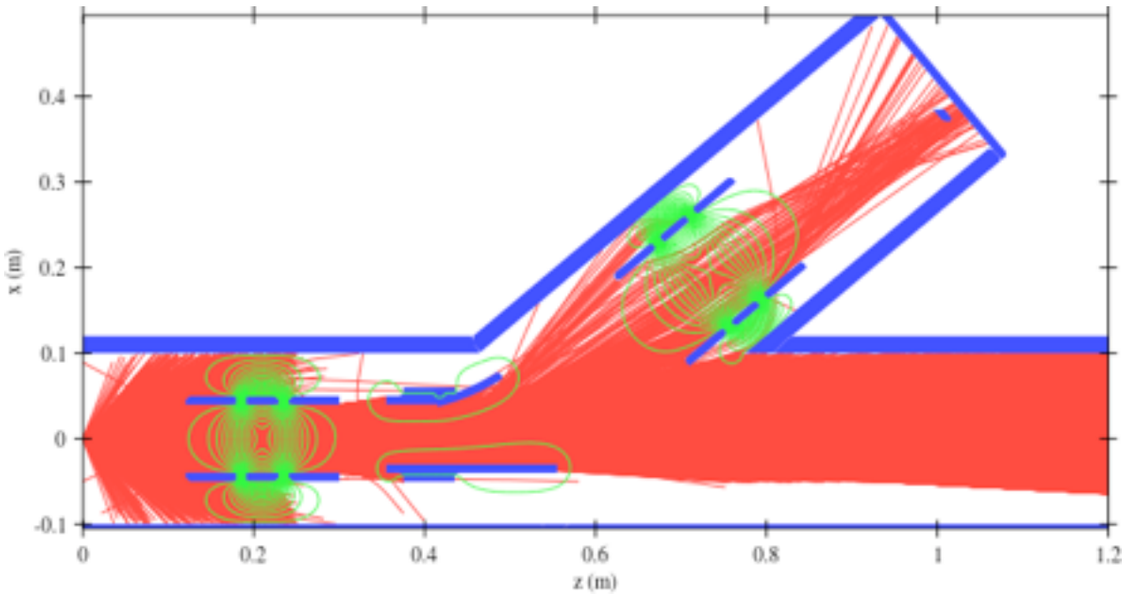


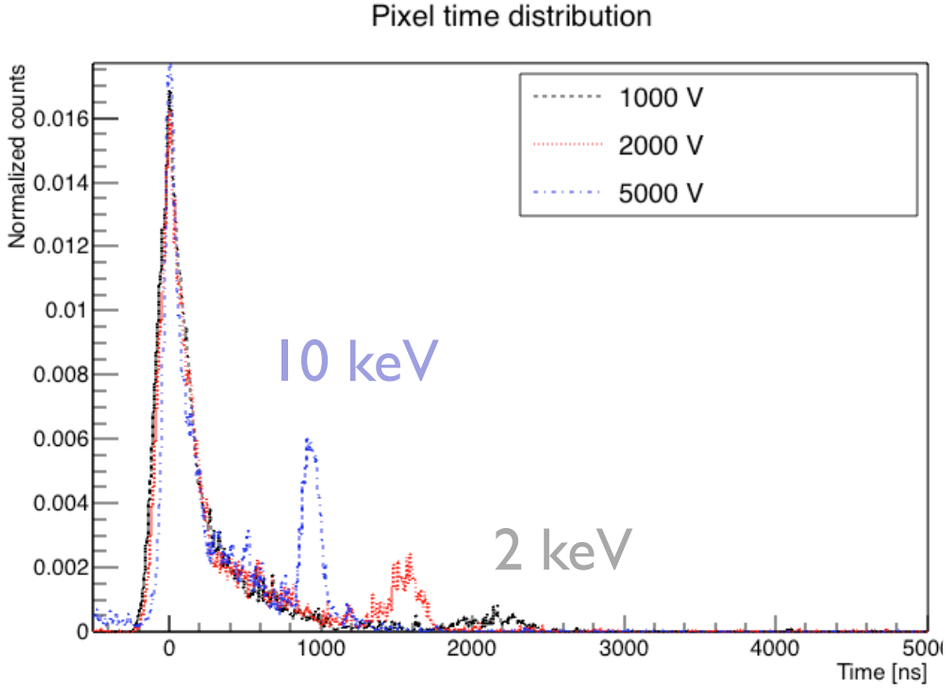
zoom for another shot (adjacent vertices)

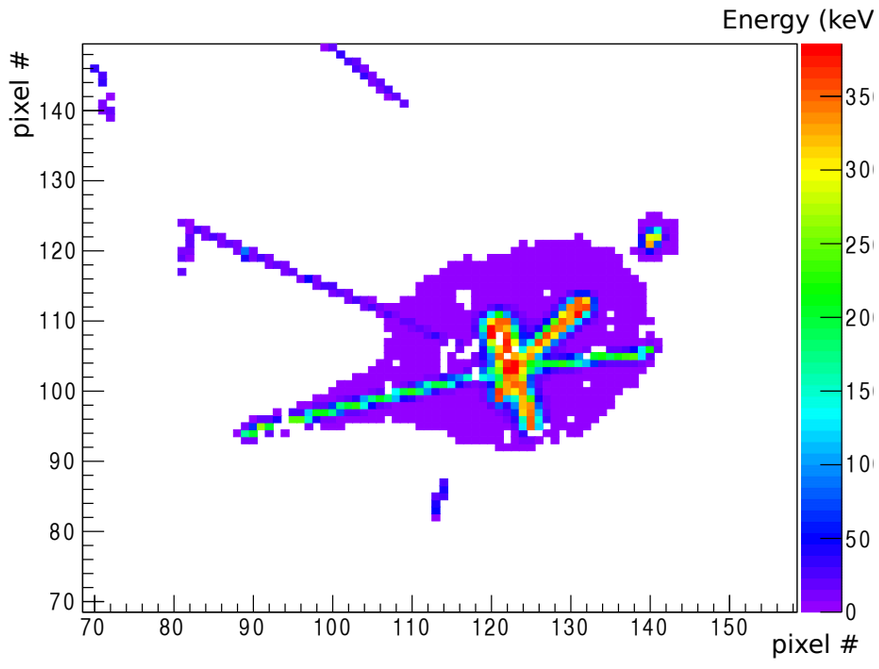


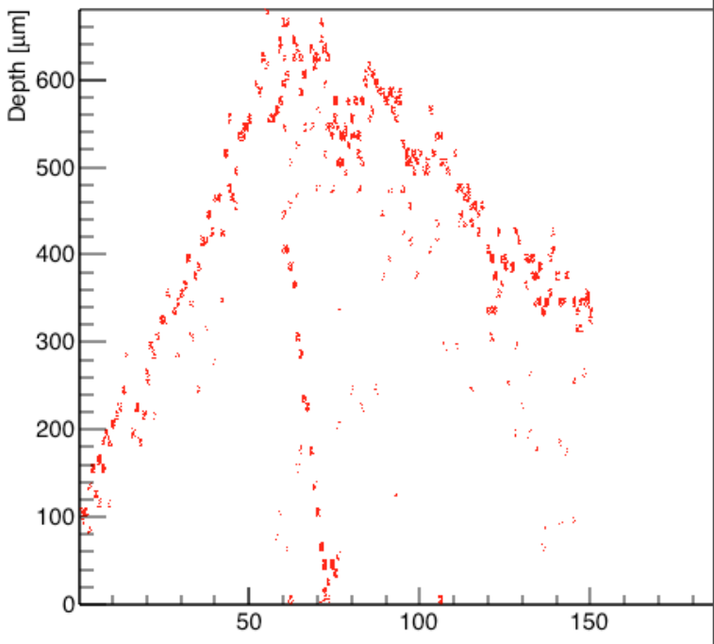
- cluster size, energy deposit
- compare with Geant4 (fragmentation models): fragment ID, range, ...
- improved vertex association to emulsion in hybrid detector (σ ~ 20 μm)

Use of a clean, low-energy (few keV) antiproton beam for detector studies



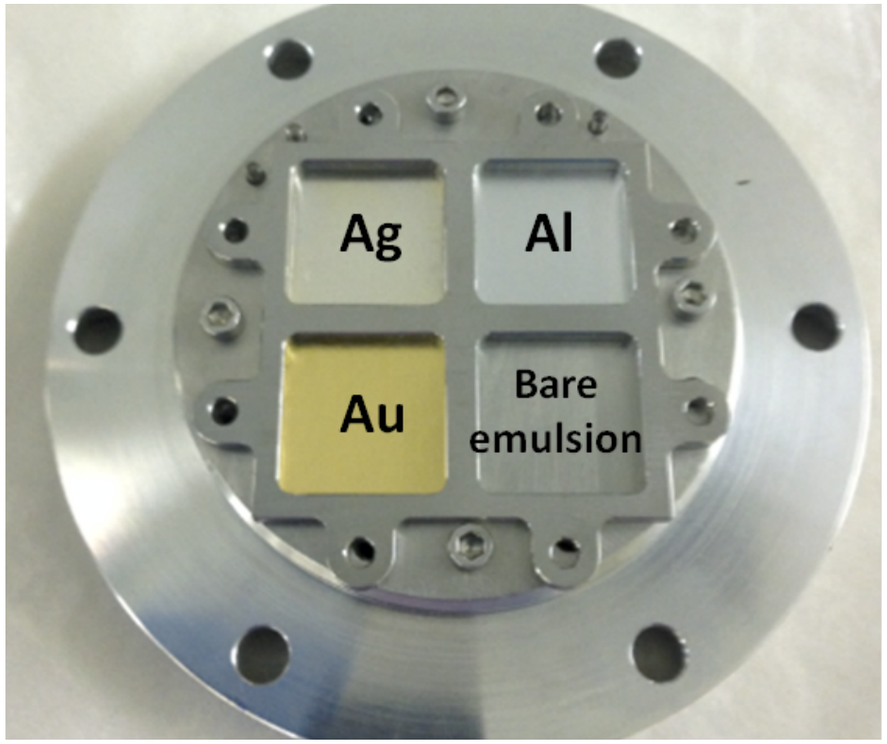


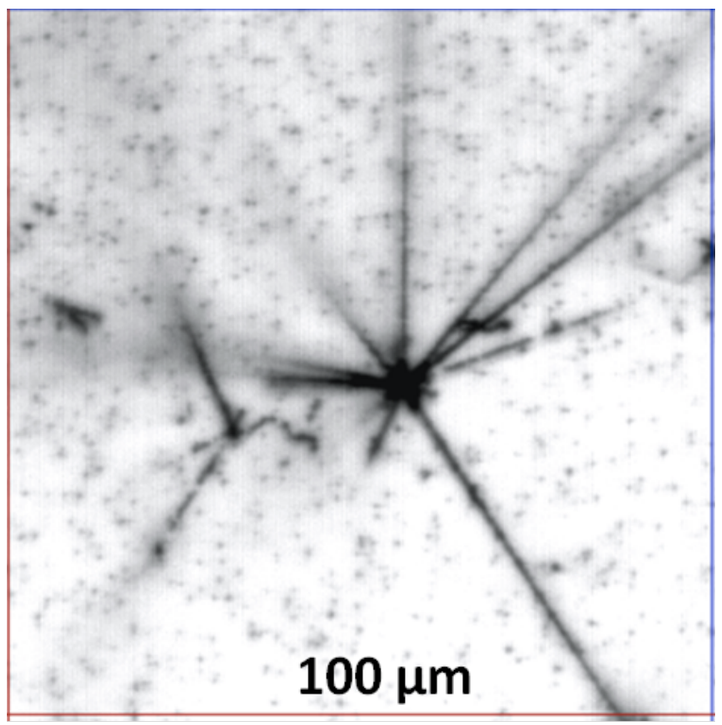


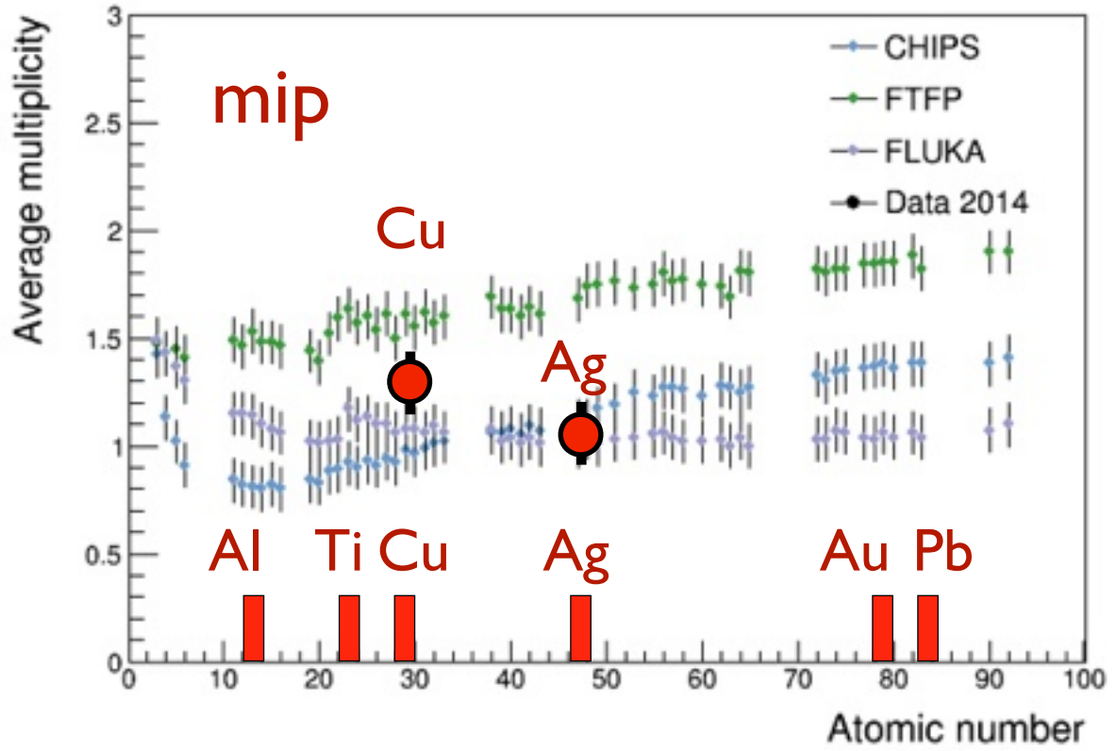


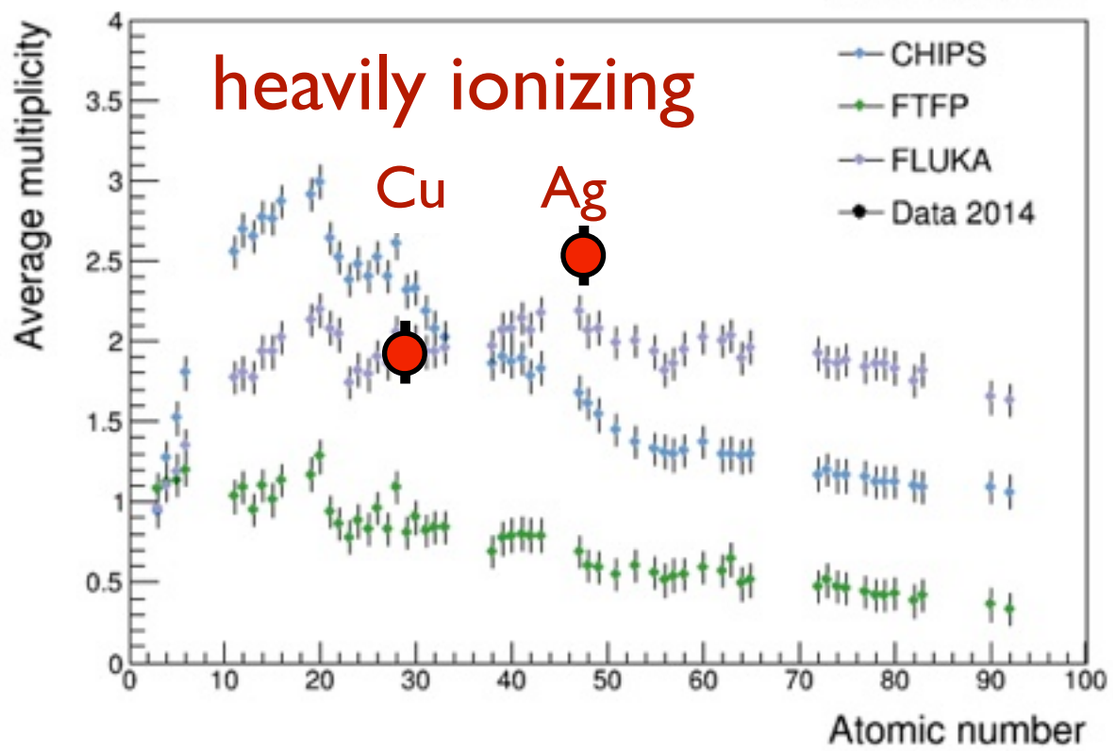
Emulsion: annihilation in emulsion & in thin foils of different composition

Analysis of 2014 parasitic measurements: comparison of data (# of mip's, strongly ionizing fragments) with Geant4, FLUKA



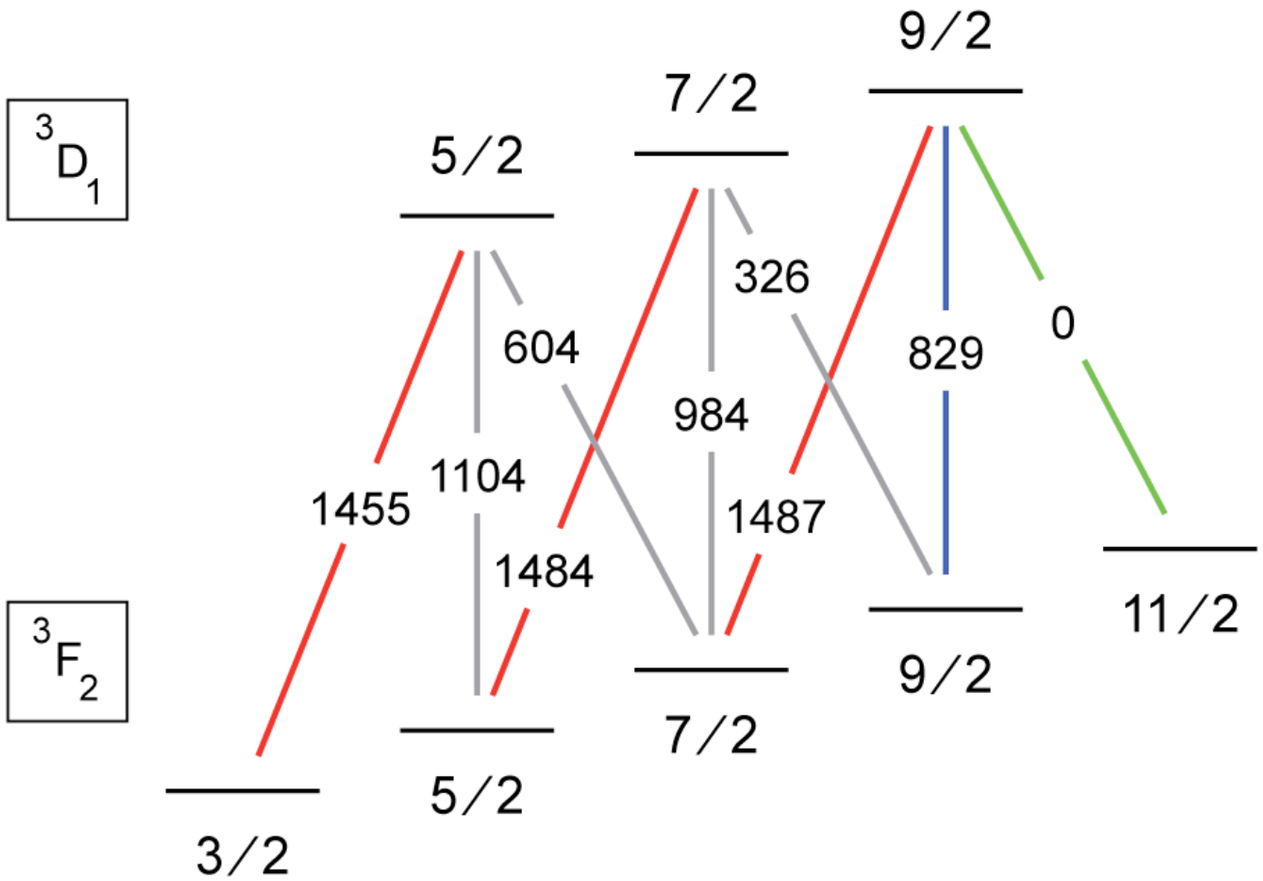


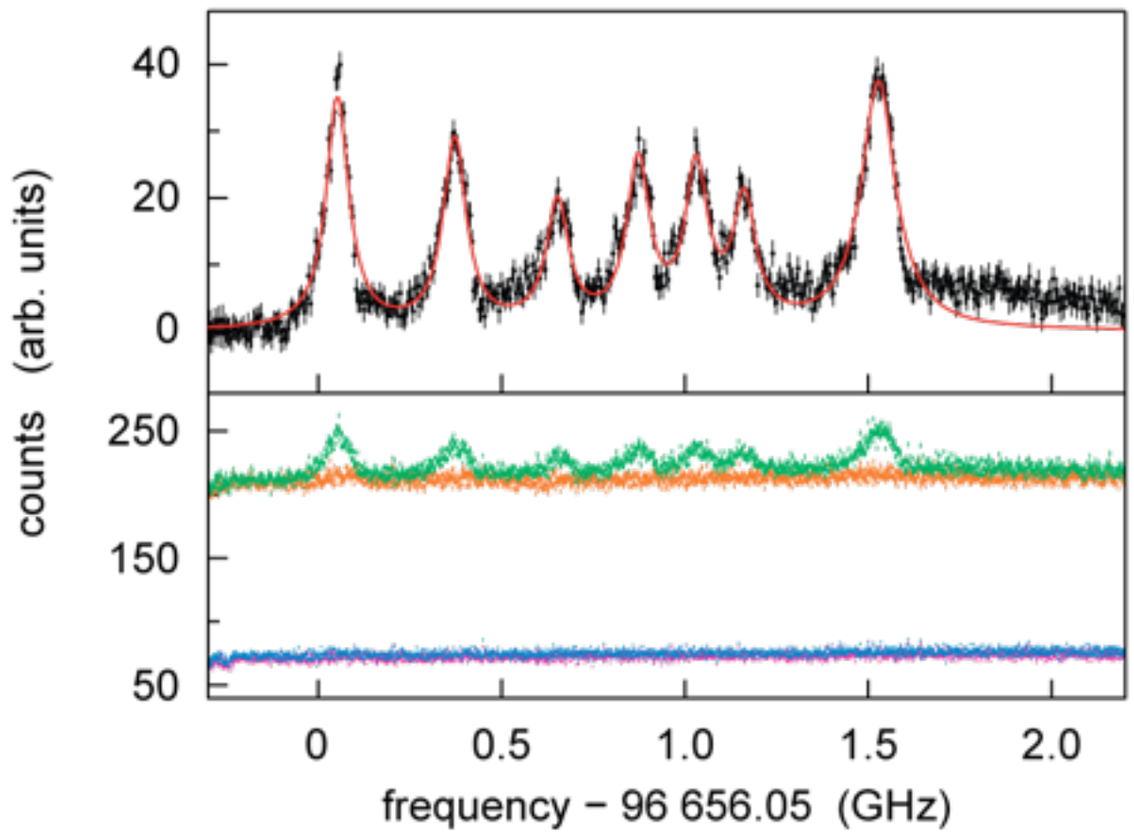




In parallel to these activities at CERN: work on laser-cooling of anions (→ sympathetic cooling of antiprotons)

ongoing work in Heidelberg with La^-: HF transitions fully characterized
transition (cooling) rate of several kHz
(only) 3 laser wavelengths required for cooling





- next step: trapping, cooling of La^-

Conclusion and outlook

Apparatus was at the aimed-for operating point (temperature, vacuum) at the beginning of 2015; vacuum problem developed at start of summer

Vacuum leak repair is highest priority

Many procedures now working (Ps formation, Ps excitation, antiproton cooling and compression), but many remain to be commissioned

Parasitic measurements were very successful - essential information is being obtained to design optimal deflectometer+detector layout; will be pursued

We have had several very busy years, and 2016 will not be any easier, requiring a sustained effort with the now-existing infrastructure.

beam request for 2016 : pro rata share of the antiproton beam

request for 2017 & 2018 (start of ELENA): stay in current zone w/ ELENA

request for 2019 (start of LS2): move apparatus to new larger zone