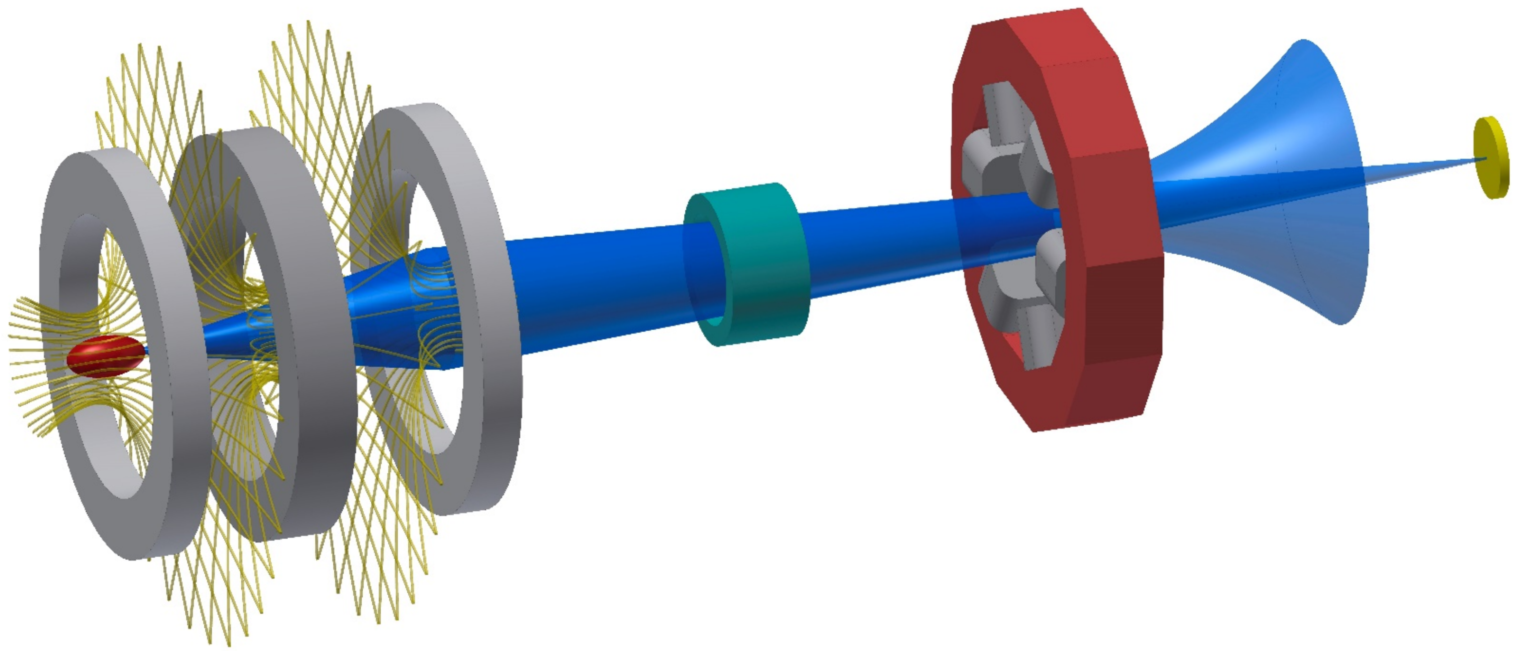
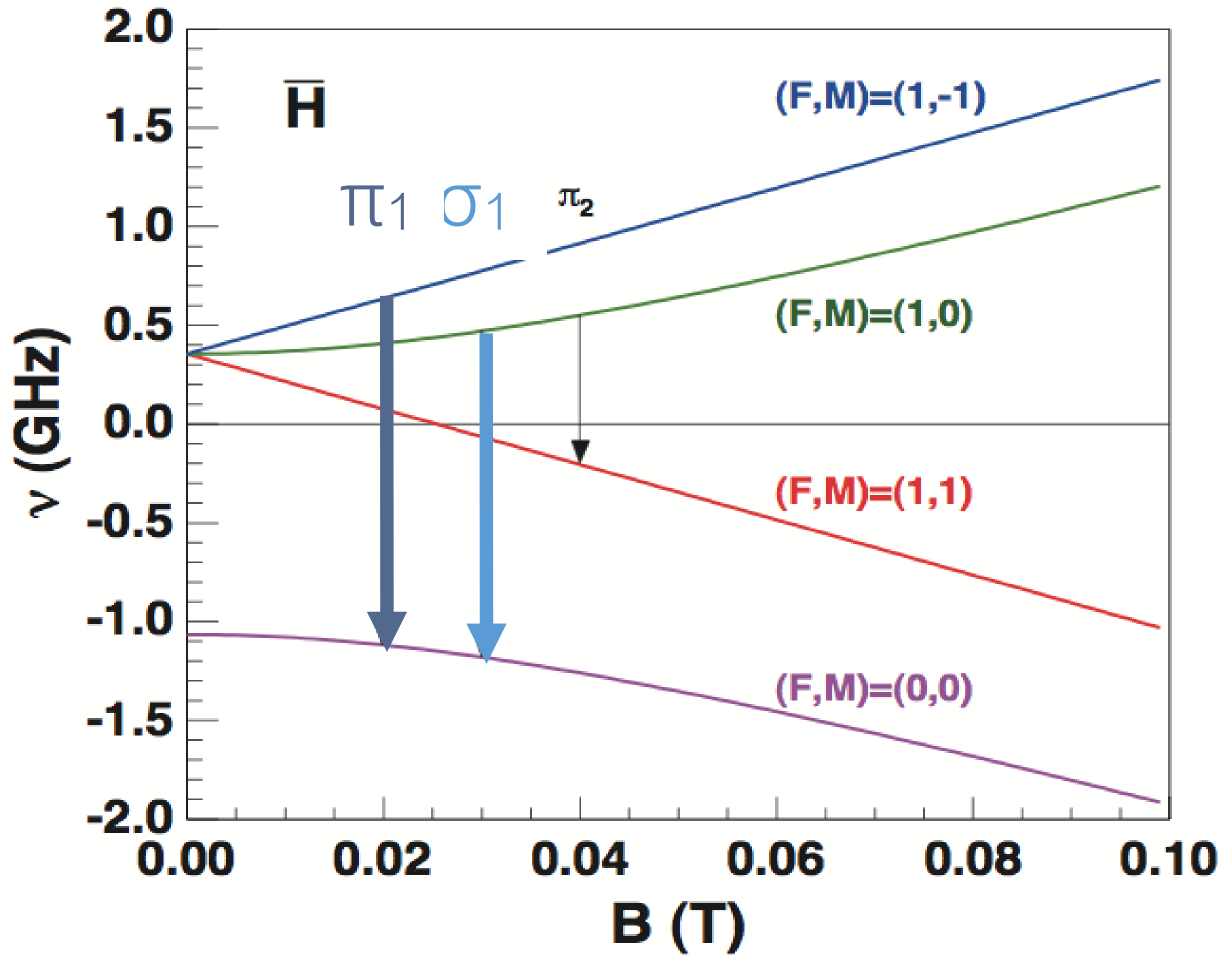
In-beam HFS spectroscopy





- In-beam measurement of the ground-state hyperfine structure of antihydrogen to 1 ppm during run 3
  - Improve intensity & ground-state fraction of polarized slow (~50 K) $\bar{H}$ beam created by three-body recombination
- Develop Ramsey method with H and apply it to $\bar{H}$ during run 4, goal: factor 20

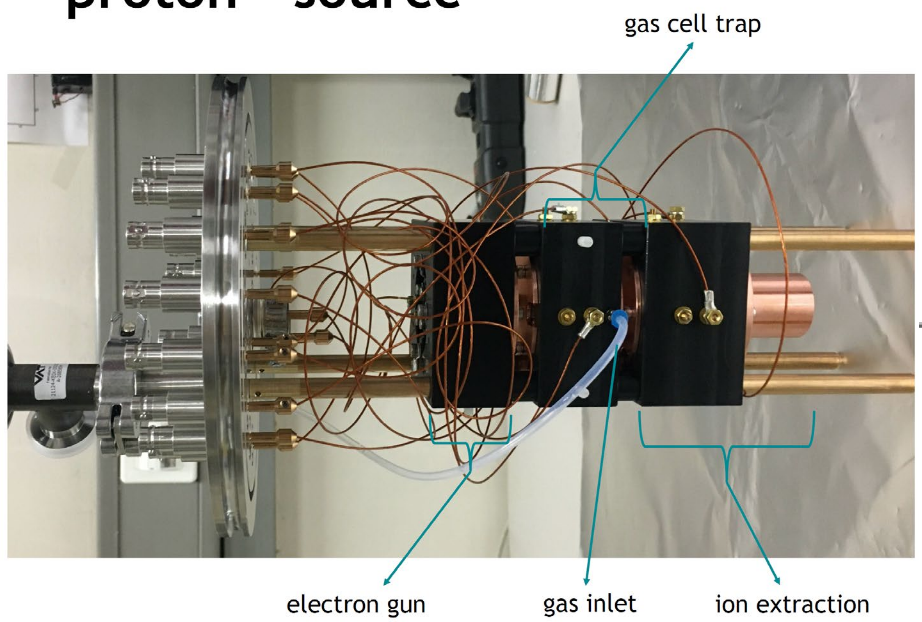
- 1 ppm precision gives insight into antiproton structure
- π transition is sensitive to SME
- Method was verified with H beam to ppb precision

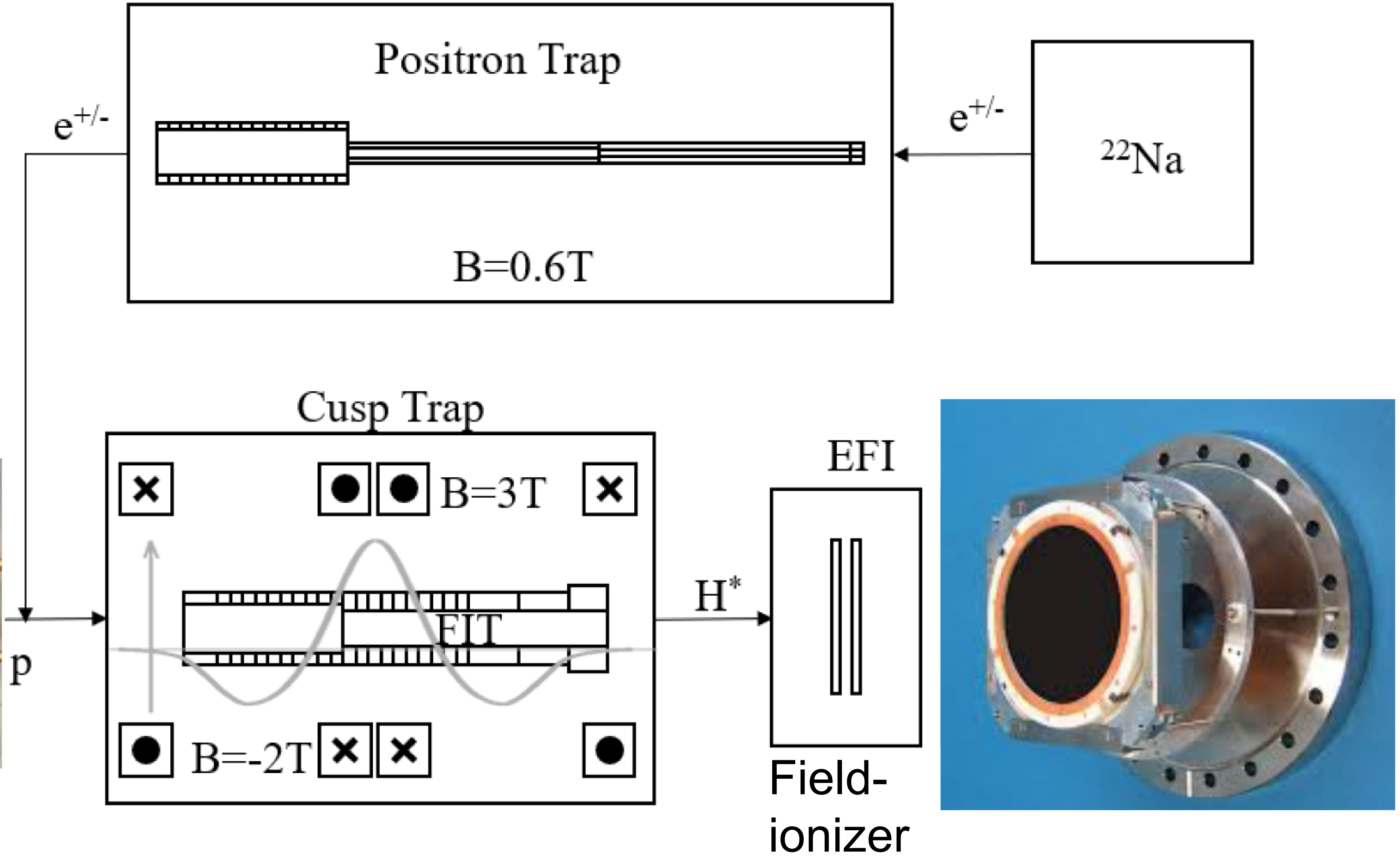
ASACUSA proposal for ELENA SPSC-P-307-ADD-2 https://cds.cern.ch/record/2691506/files/SPSC-P-307-ADD-2.pdf

Mixing studies with matter (2020+)

Der Wissenschaftsfonds.
Einzelprojekt P32468-N36
W1252-N27

proton - source





MCP
DLD40

Three-body mixing

- Rate is sensitive to e^+ temperature and density ρ:
  - cool e^+ to $T < 20$ K
- Simulations: rate, ground-state fraction increase with lower T, higher ρ

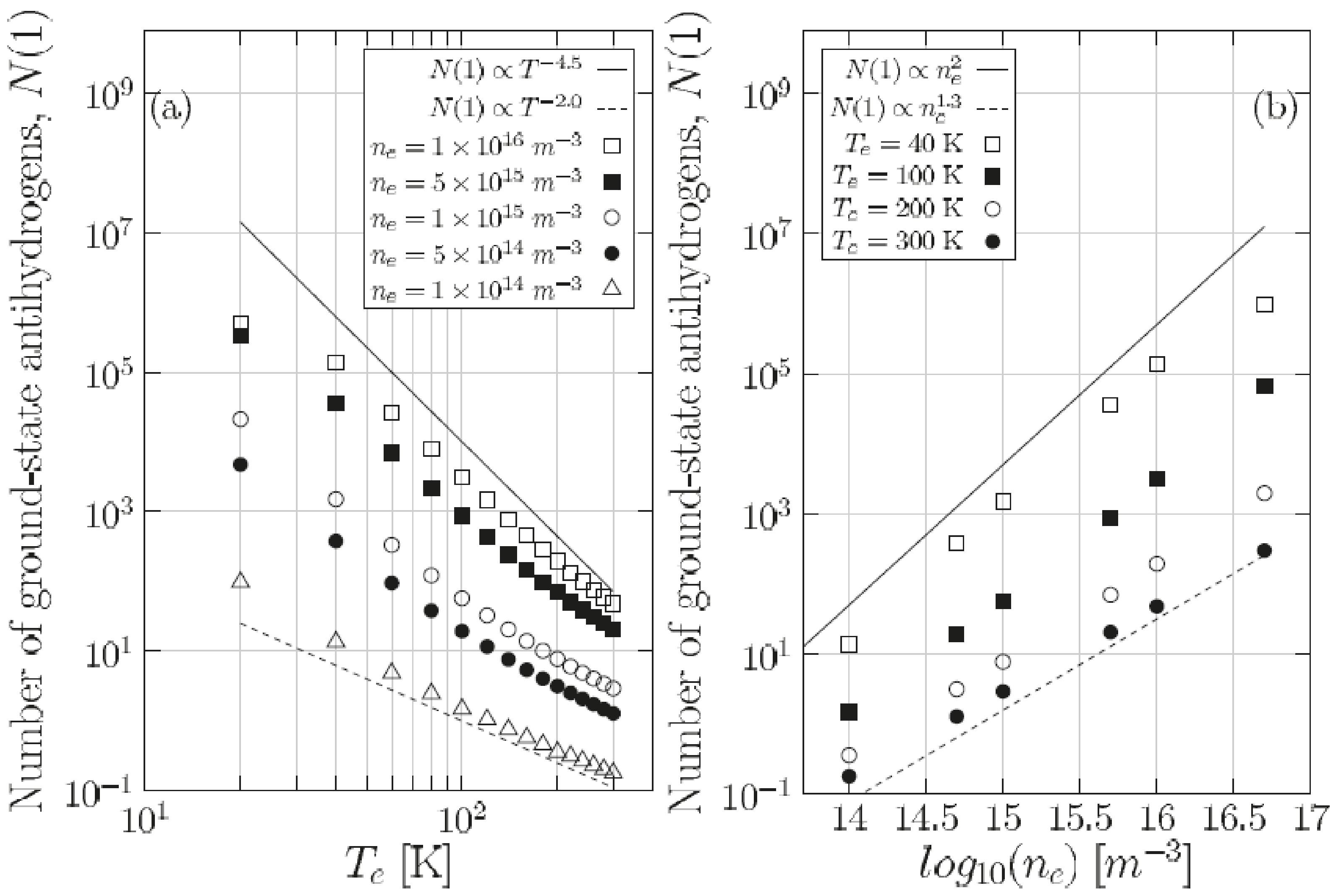
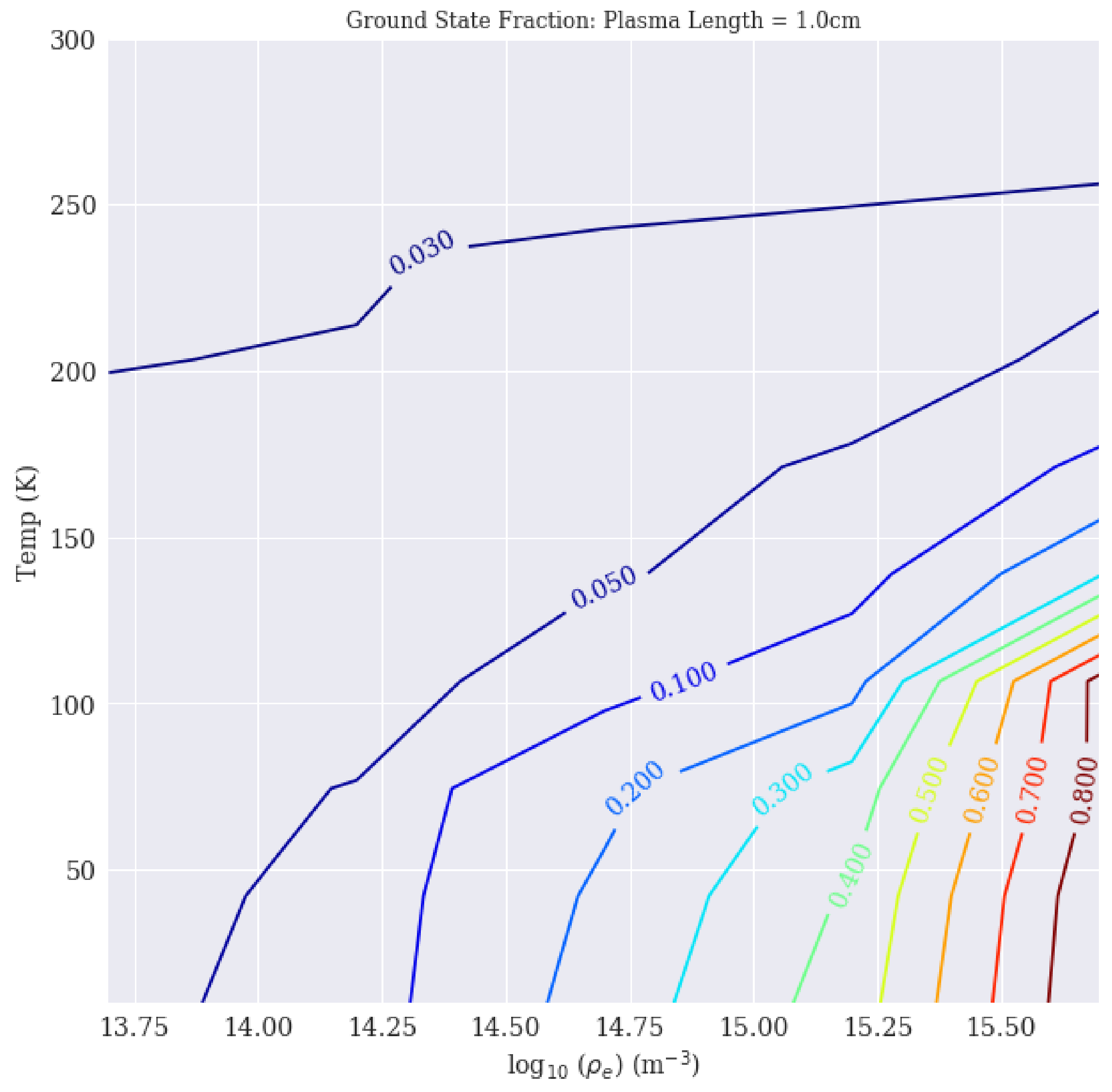


FIG. 6. Dependence of ground-state antihydrogen atoms on positron temperature (a) and density (b) for various positron density and temperature values (respectively) after 1 ms of flight. The $\propto n_e^2 T_e^{-4.5}$ (solid line) and $\propto n_e^{1.3} T^{-2.0}$ (dashed line) scaling behaviors are indicated for reference.

Radics, B., Murtagh, D. J., Yamazaki, Y. & Robicheaux, F. Phys. Rev. A ***90,*** *032704 (2014).*

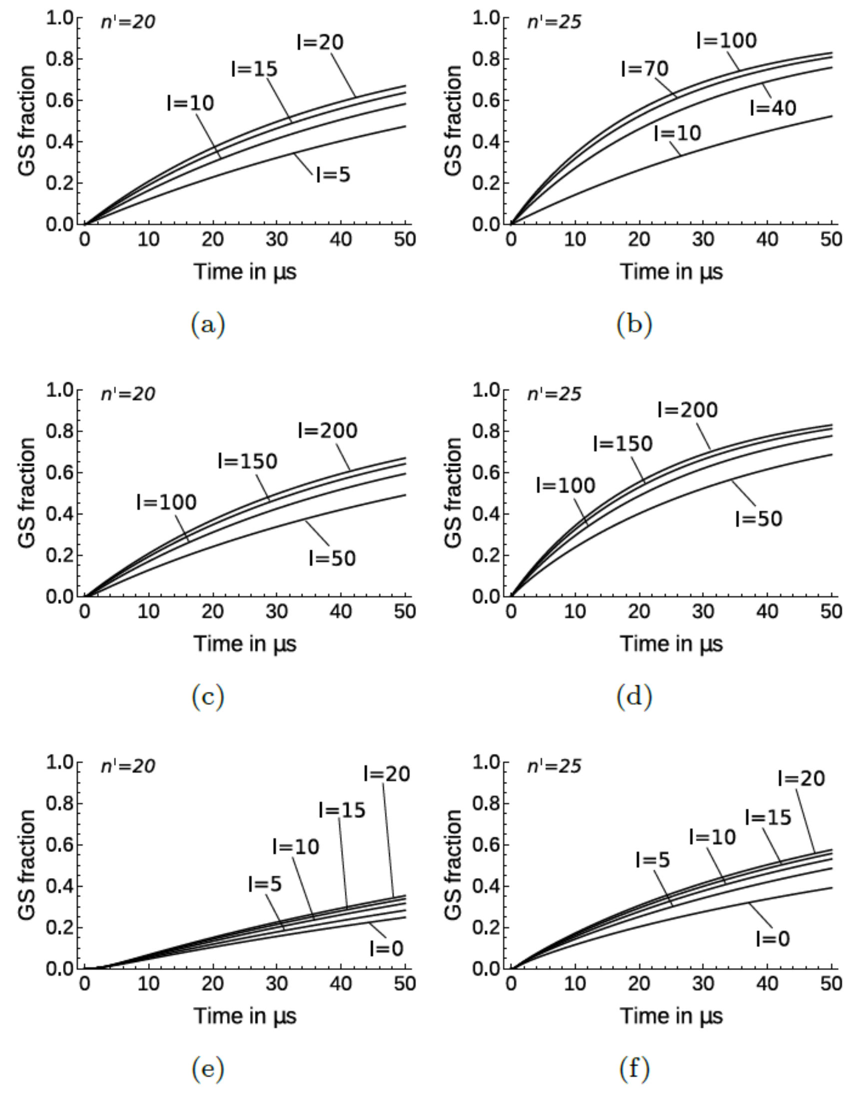
Possible deexcitation schemes

- Additional cold e– plasma, deexcitation by collisions

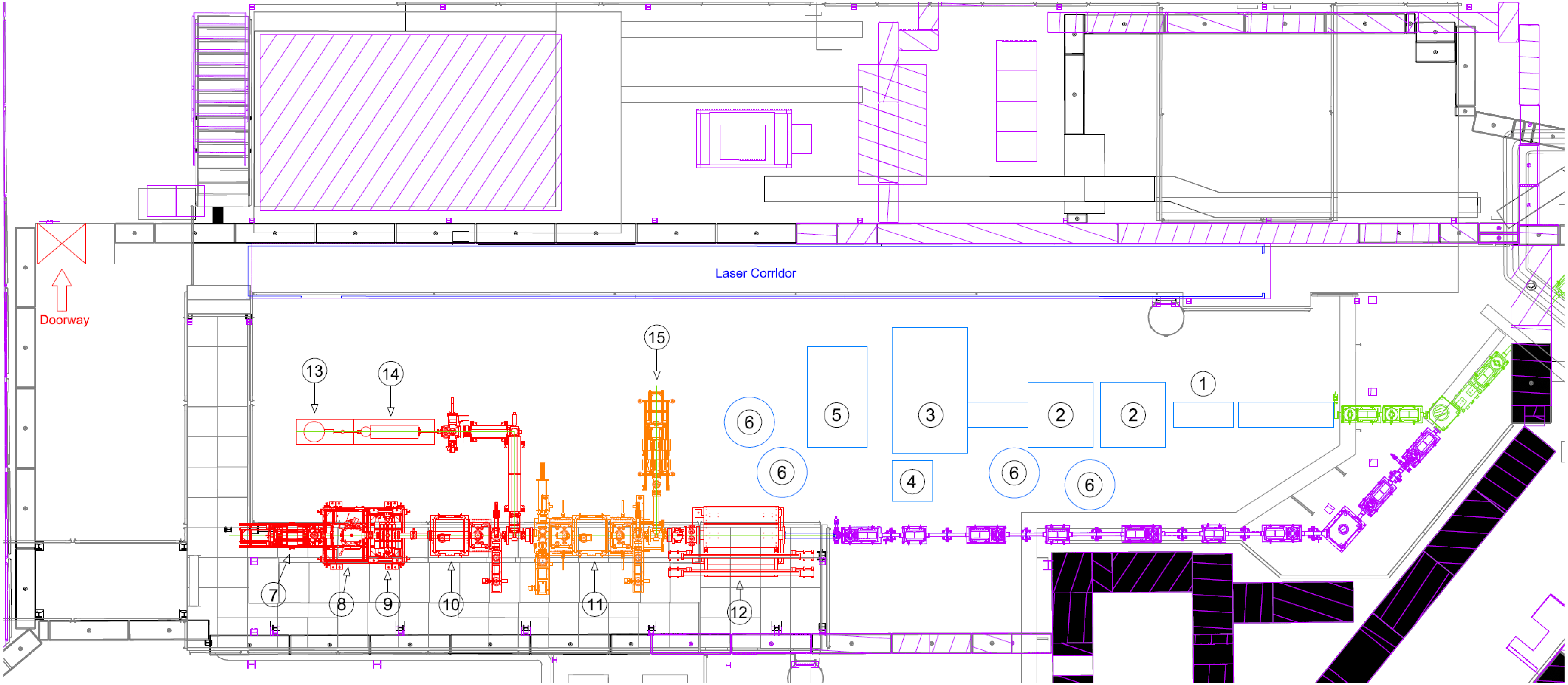


Simulation D. Murtagh

- Combination of THz radiation, microwave and laser deexcitation
  https://arxiv.org/abs/1912.03163

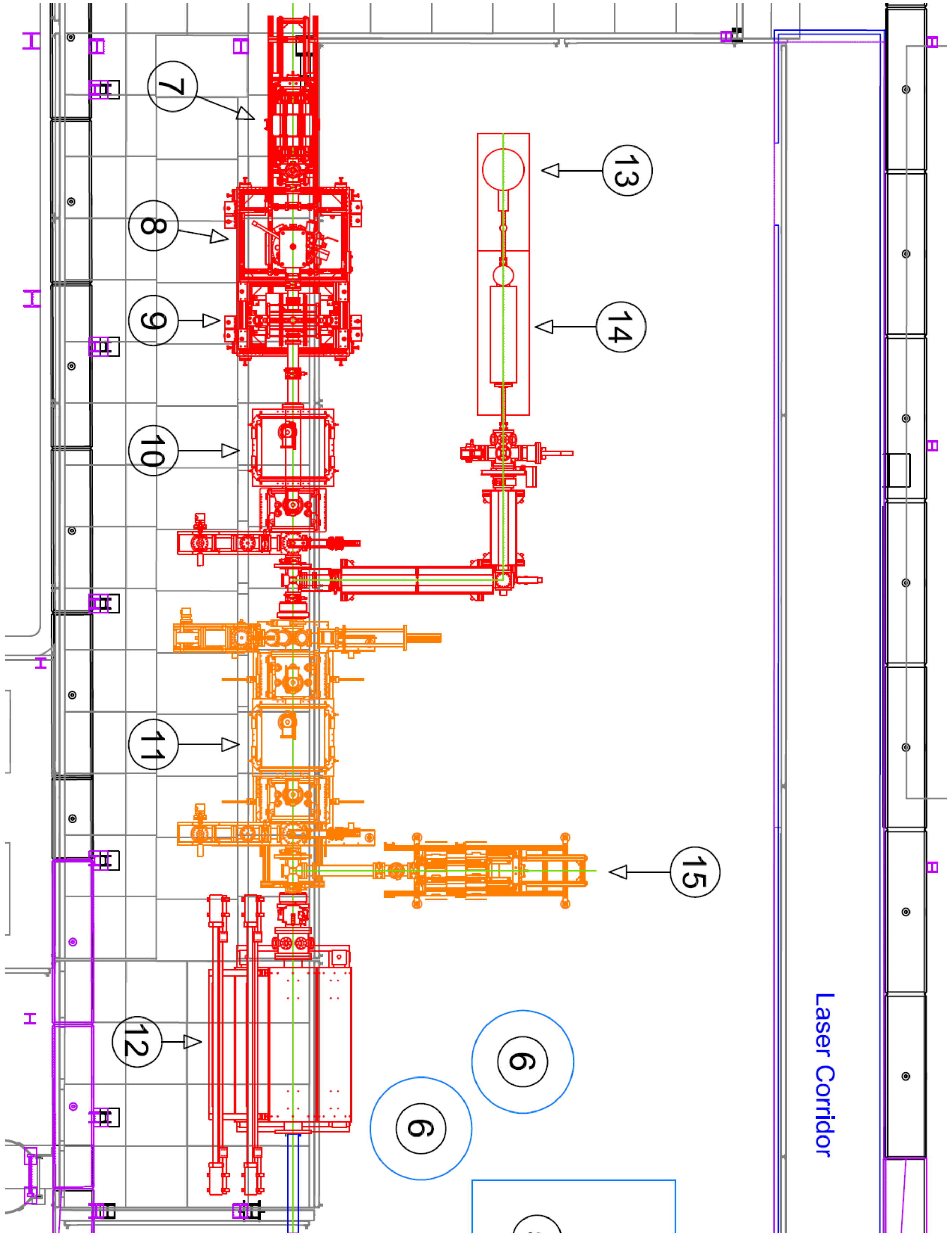


ASACUSA area



Slow extraction plans

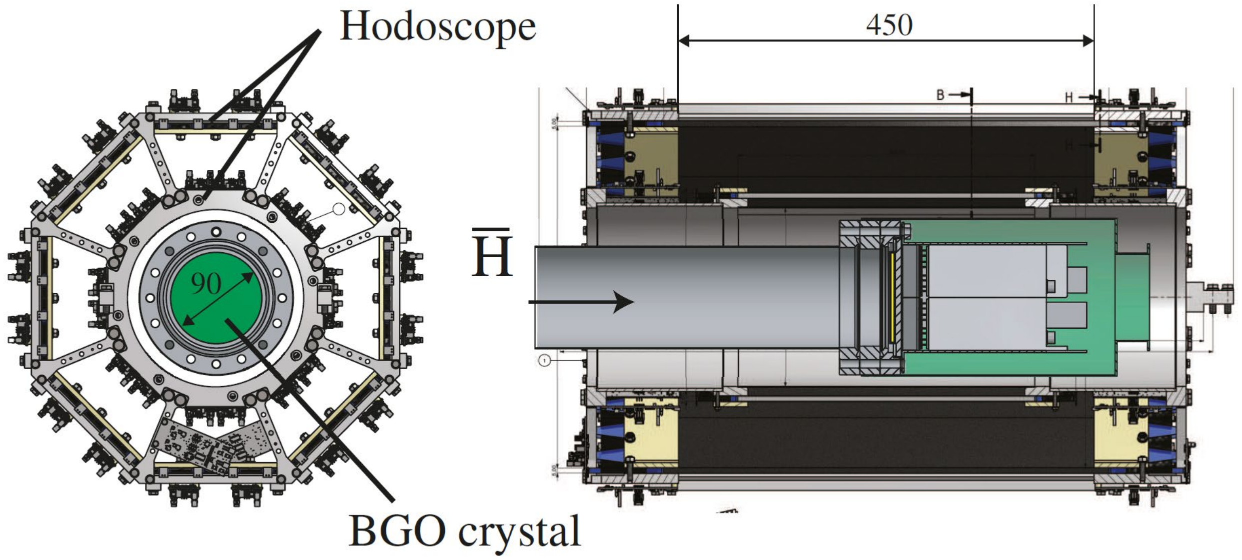
- Permanent installation of SE beam line possible
- Continuation of fragmentation studies (benchmark for MC codes)
- New ideas & proposals, also from other collaborations
  - Pontecorvo reaction
  - $\bar{p}$ annihilation cross sections
- To be explored

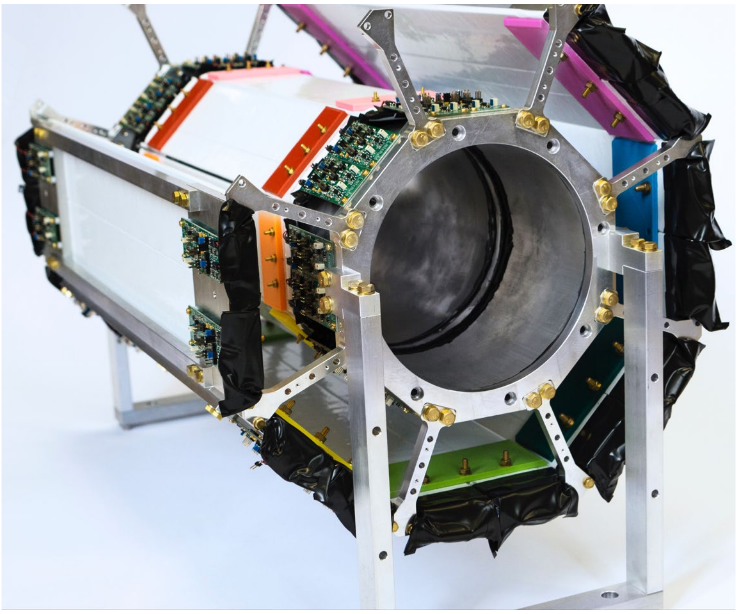


Spares

$\bar{\mathrm{H}}$ detector analysis of 2016 data

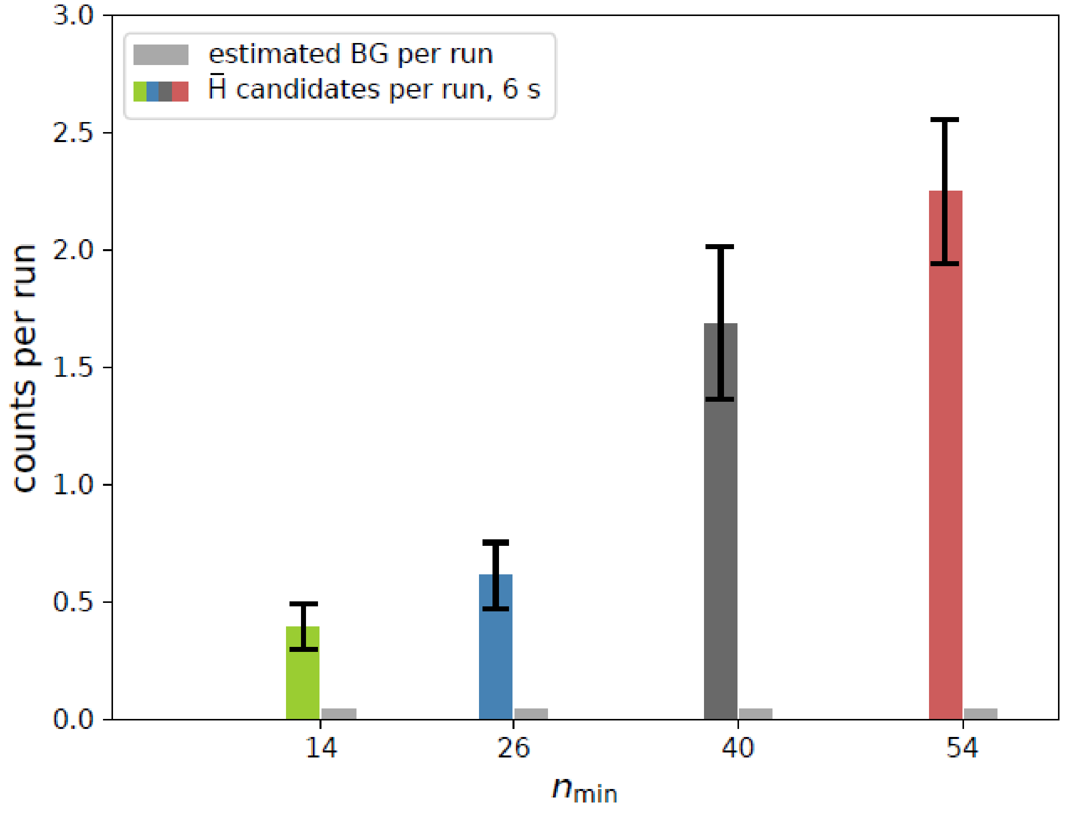
- Direct injection scheme
- 2D BGO & track fitting





- Machine learning optimization
  - Cosmics rejection 98,4%
  - False positive rate: 0.0077(15) s^{-1}
  - $\bar{p}$ efficiency 80(1)%

n<14 rate 0.16 → **0.395(96)/cycle**
P-value significance 4.5σ → **6.8 σ**
17 evts/5 shifts: 4σ poisson
τ(n=14 →n=1) ~ 50 µs
Needed: 2000 $\bar{\mathrm{H}}$(1S)/B_{ext} for 1 ppm

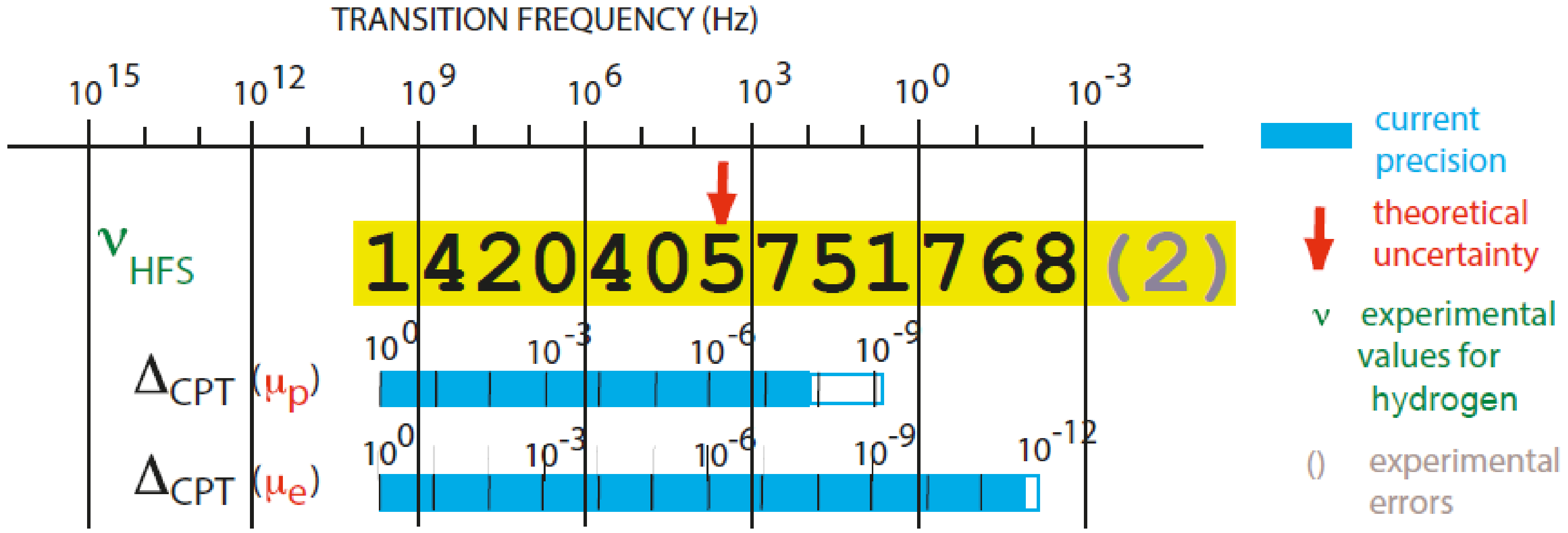


B. Kolbinger, Ph.D. thesis, 2019

Ground-State Hyperfine Splitting of H/$\bar{\mathrm{H}}$

- spin-spin interaction positron - antiproton
- Leading: Fermi contact term

$$\nu_F = \frac{16}{3}\left(\frac{M_p}{M_p + m_e}\right)^3 \frac{m_e}{M_p} \frac{\mu_p}{\mu_N} \alpha^2 c\, Ry$$



Hydrogen HFS and QED: finite size effects

H: deviation from Fermi contact term:	–32.77(1) ppm
finite electric & magnetic radius (Zemach corrections):	–41.43(44) ppm
polarizability of p/p̄	+1.88(64) ppm
remaining deviation theory-experiment:	+0.86(78) ppm

C. E. Carlson et al., *PRA 78, 022517 (2008)*

Finite size effect of proton/antiproton important below ~ 10 ppm