Antihydrogen Detection in the ALPHA -Experiment

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D. Seddon, P. Nolan and the ALPHA
-collaboration

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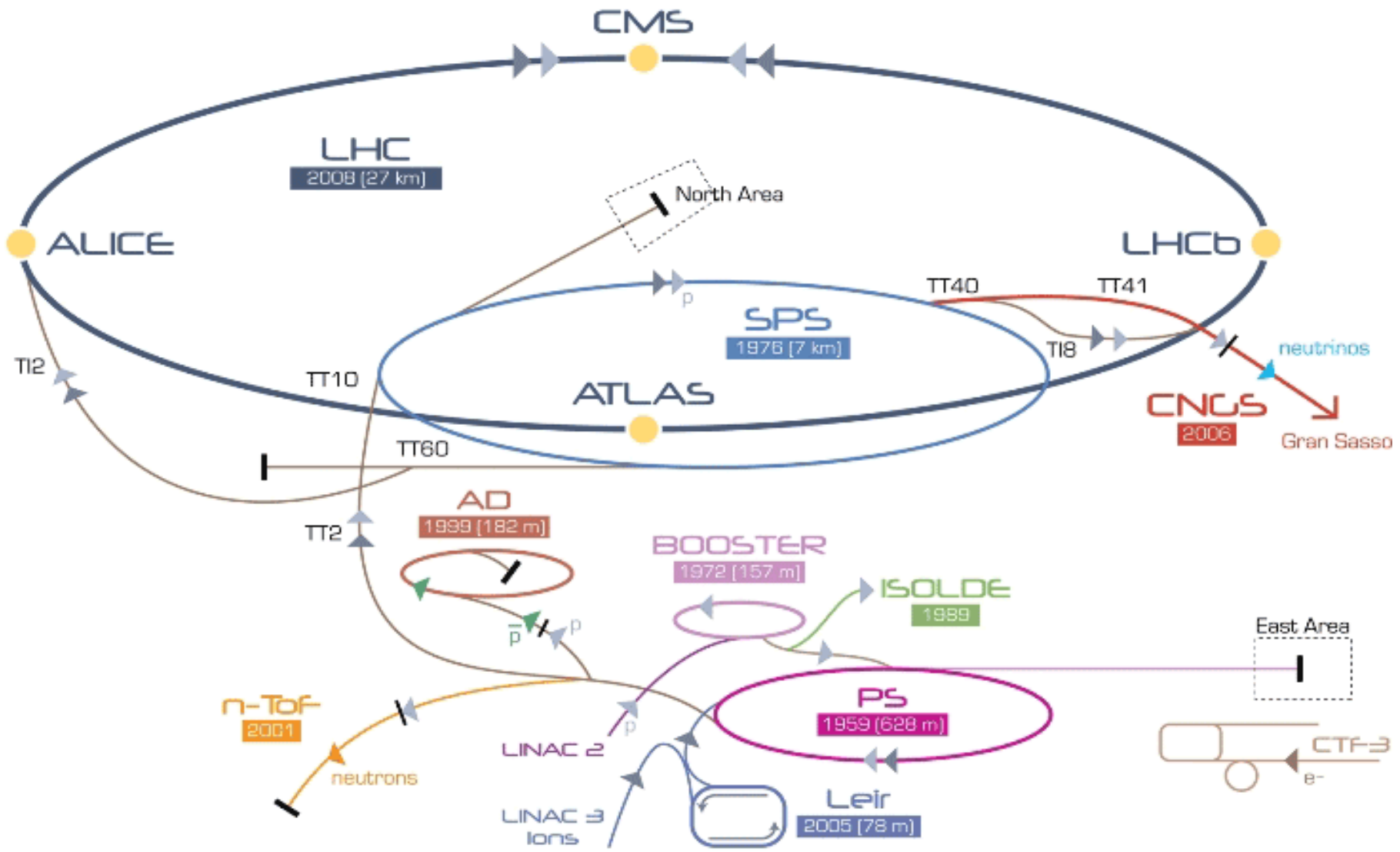
Antihydrogen Laser PHysics Apparatus
http://alpha-new.web.cern.ch/alpha/



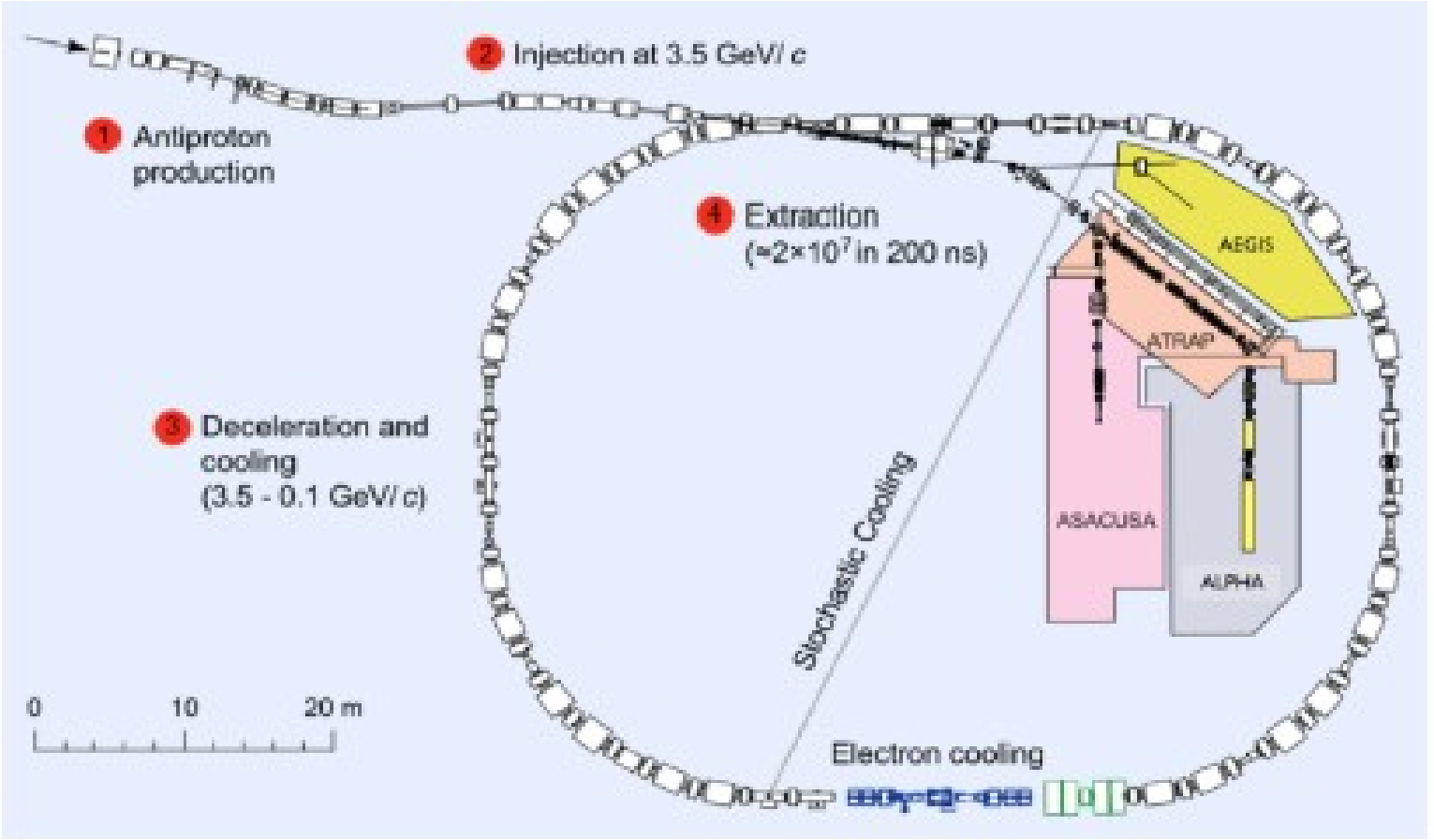
p (proton) ion neutrons p̄ (antiproton) proton/antiproton conversion neutrinos electron

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF-3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice

LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight

AD



PS production beam 1.5x10^{13} protons/cycle at 26 GeV/c
5x10^{7} pbars injected at 3.57 GeV/c
Stochastic and electron cooling, cycle 100s
Extract 3x10^{7} pbars every 100s at 100/300/500 Mev/c (5.3/47/126 MeV)

AD Physics

- AEGIS
  Test of the weak equivalence principle
  Neutral Hbar beam through classical deflectometer
- ACE
  Antiproton hadron therapy experiment
- ATRAP
  Hbar spectroscopy
- ALPHA
  Hbar spectroscopy
- ASACUSA
  Antiprotonic helium / Hbar spectroscopy

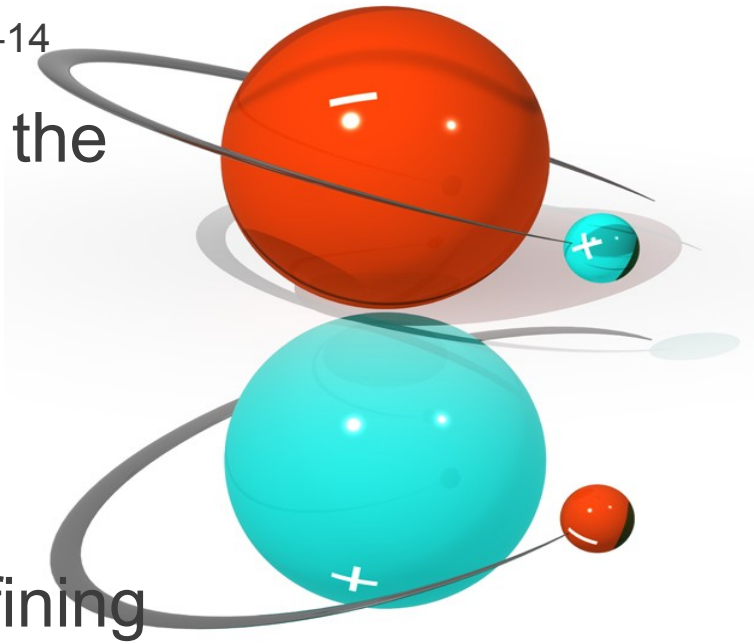
Brief history of antihydrogen

- 1995 Antihydrogen produced at LEAR
- 1997 Subsequently observed at Fermilab's antiproton accumulator
- 2002 ATHENA (later ALPHA) and ATRAP produce first cold (<150 K) antihydrogen – Penning trap
- 2010 trapped antihydrogen at ALPHA – neutral trap
- 2011 Long confinement of the neutral anti-atoms (ALPHA)
- 2011 Antihydrogen in CUSP trap (ASACUSA)
- 2012 Confirmation of long confinement (ATRAP)
- 2012 First spectroscopic measurement on antihydrogen (ALPHA)

Overview of the experimental goal

- Ultimate long term goal 1S-1S antihydrogen atomic transition

- Haench et al. Currently measured at 10^{-14} precision, theoretically up to $10^{-18.}$ One of the best studied physical systems

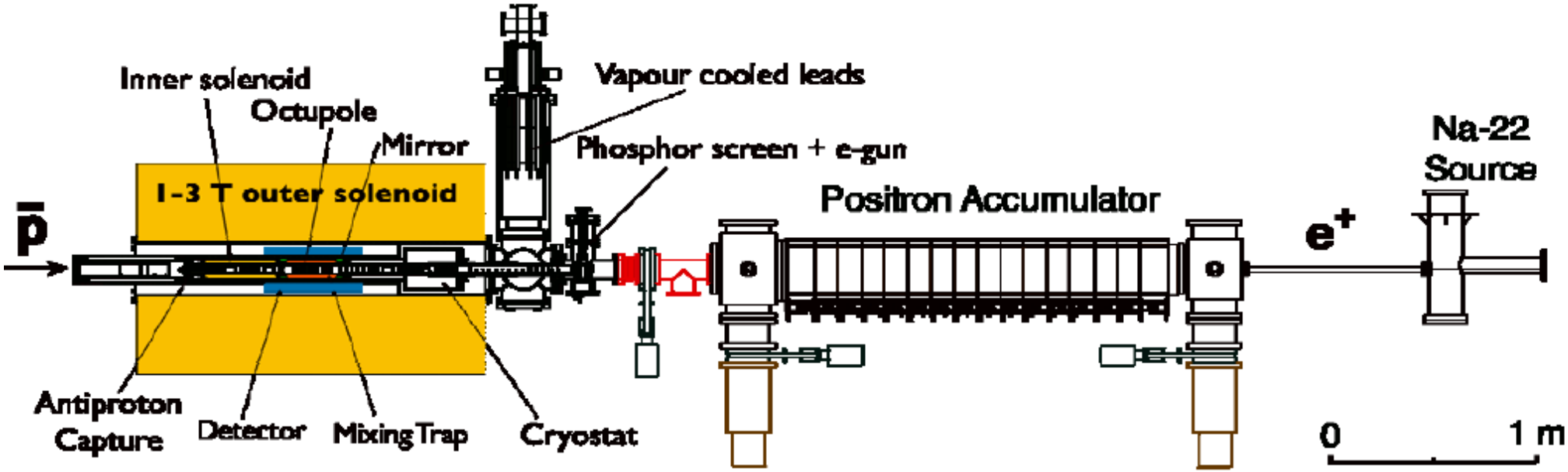


- => Low energy region test for the CPT -symmetry conservation

- Extreme experimental difficulties in confining the antihydrogen

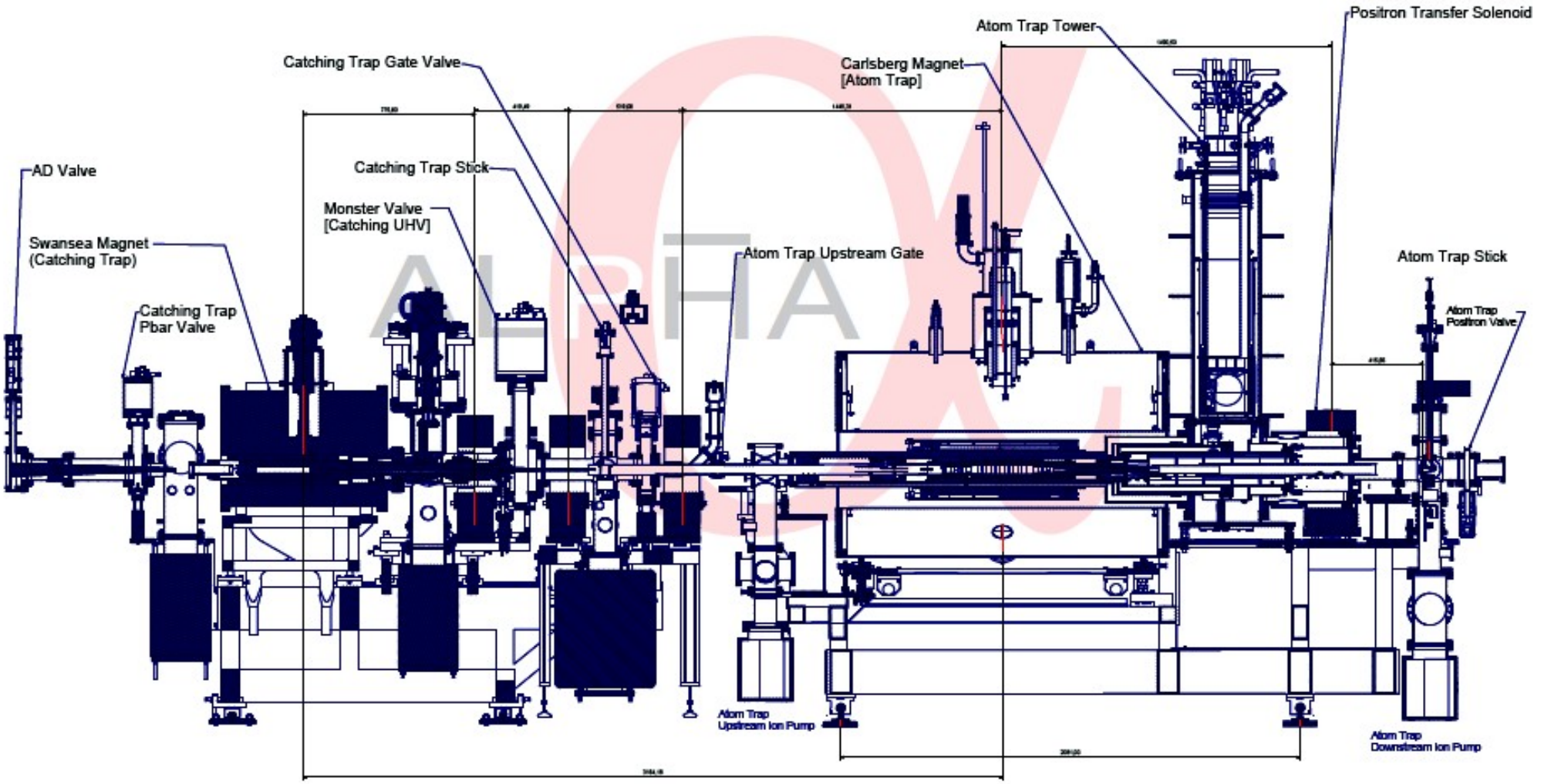
- Need 0.5K stable atoms, starting point at the moment @ 5.3MeV antiprotons

Schematics of the ALPHA apparatus - ALPHA1

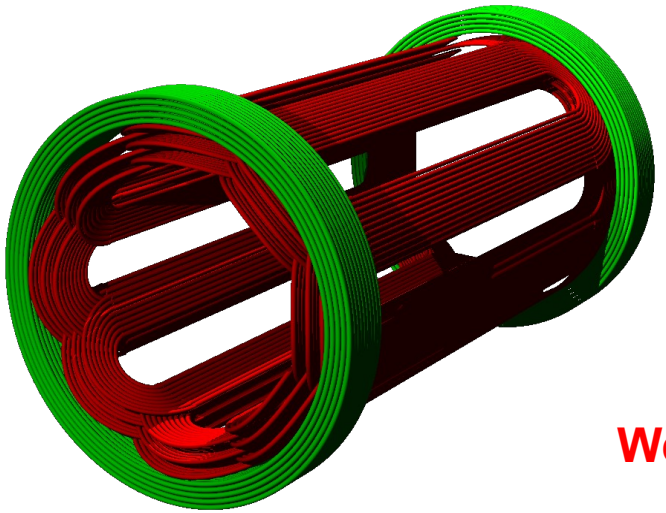


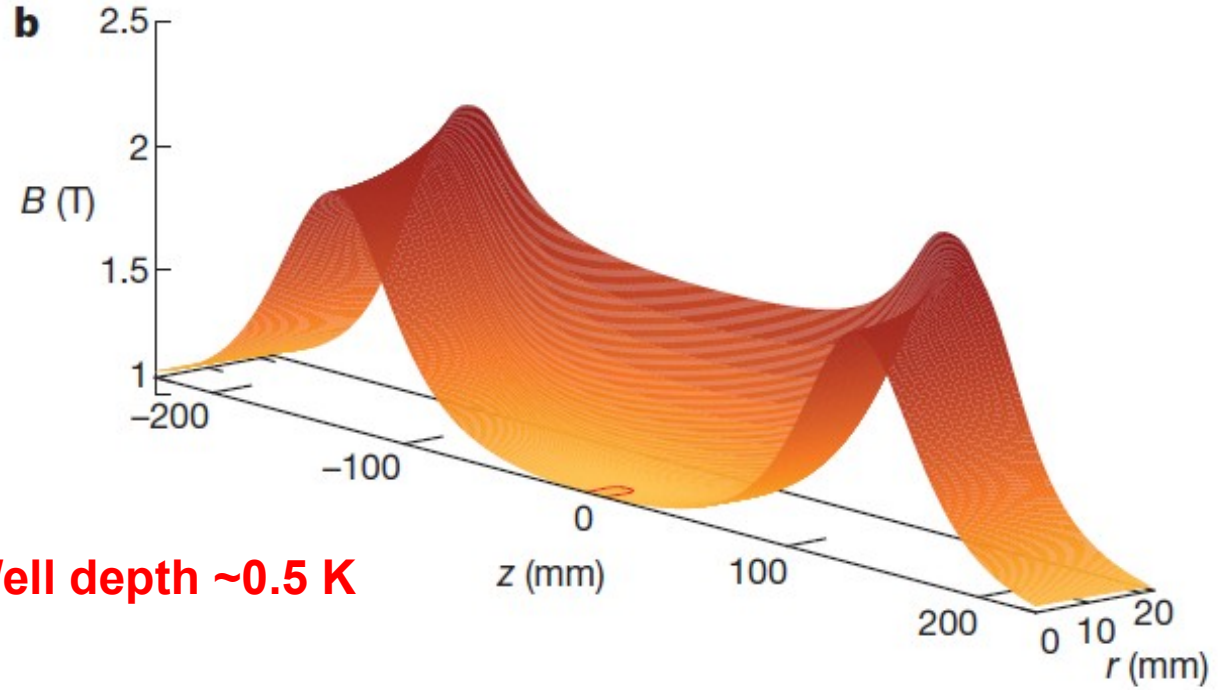
AD: 10-30M pbar/100s, Positron accumulator: 150M/5min

ALPHA2 - upgrade

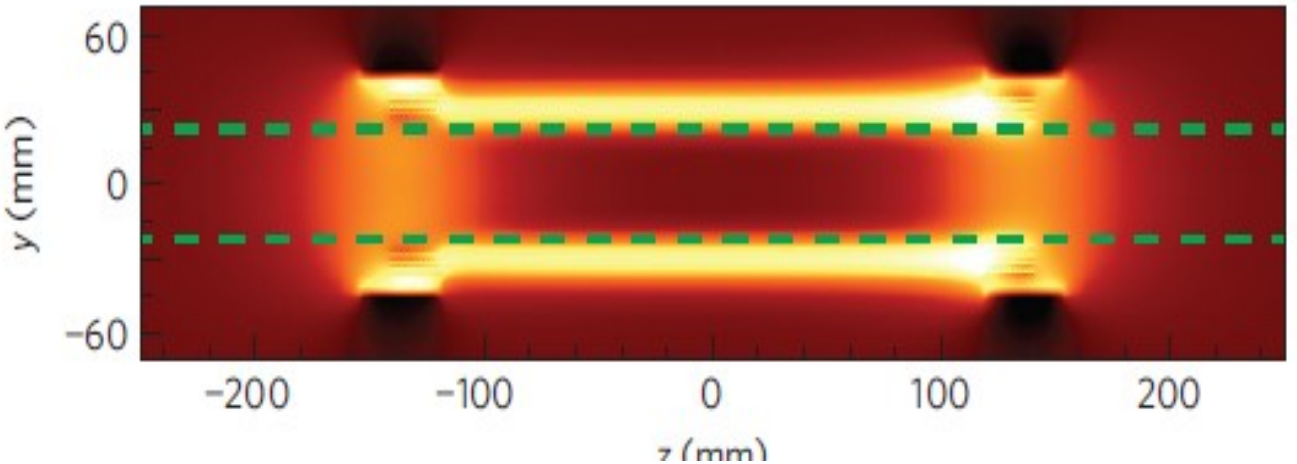


Experimental overview (Neutral)

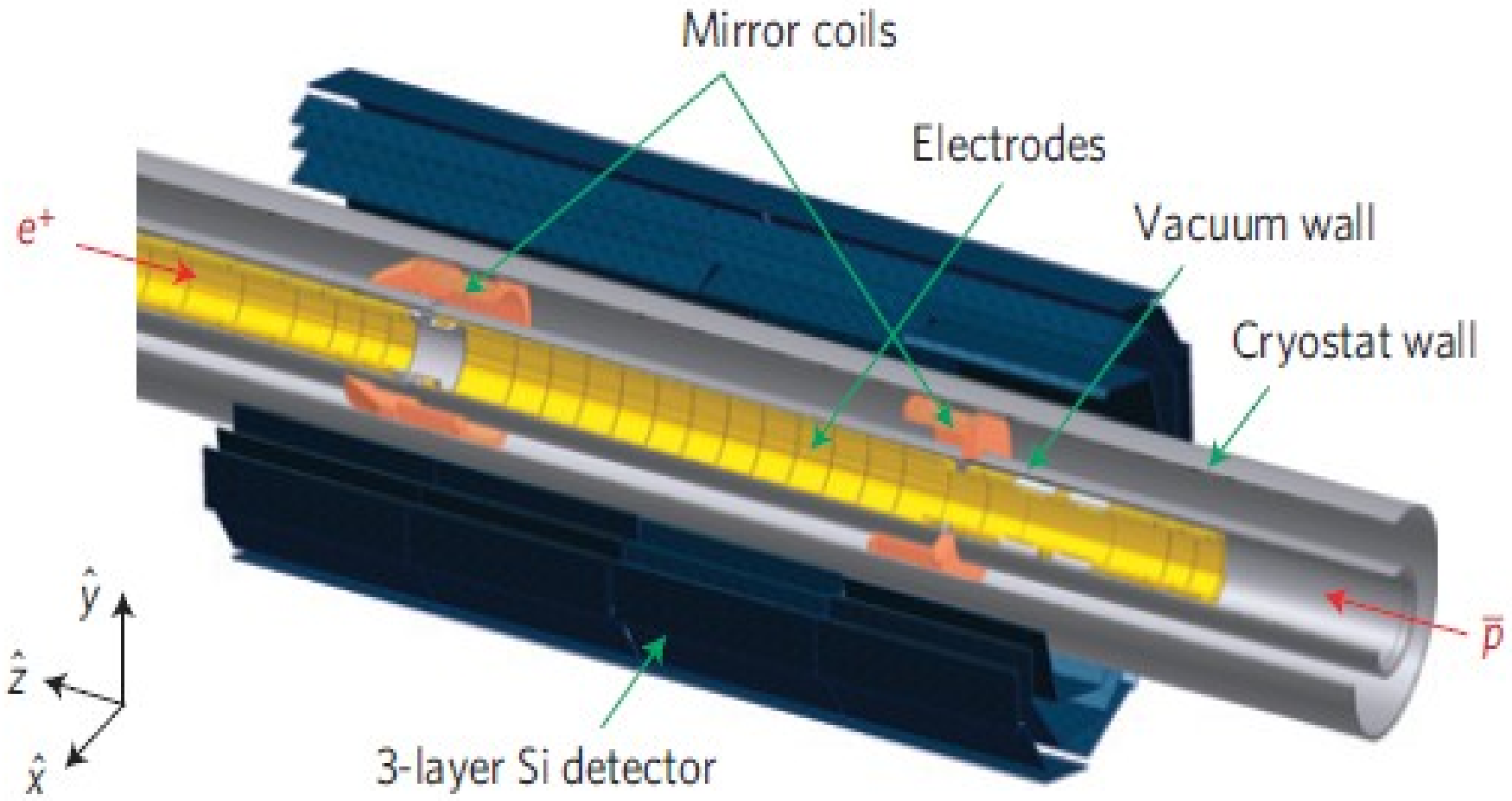




Well depth ~0.5 K



Apparatus overview



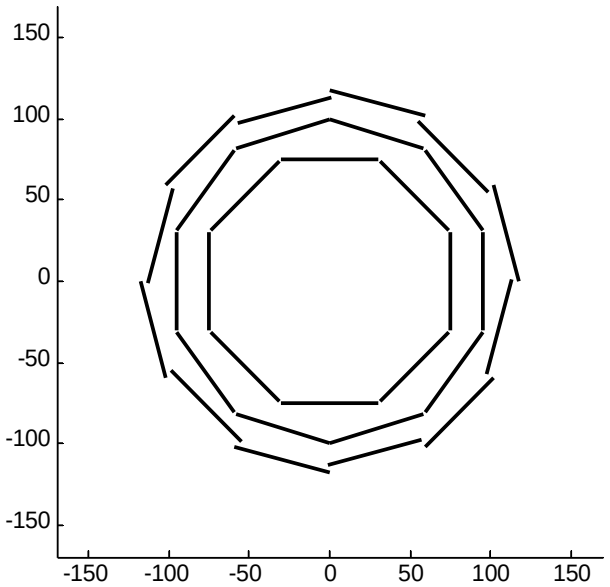
ALPHA -hybrids

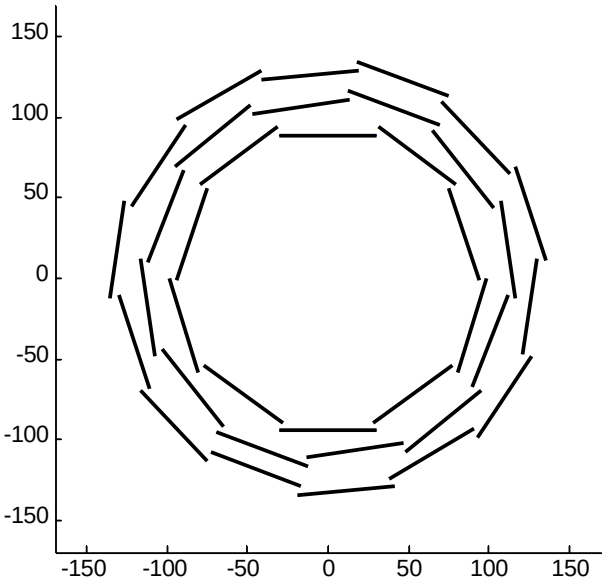
- 300 µm p on n double sided strip detector
- 256x128 strips, pitches 229 / 890 µm
- Sensor size 60x115 mm, active 58x112 mm

- 1600 µm PCB, Nelco 4000 material
- Copper wiring thorough the PCB on the n -side.
- N -side externally AC coupled

- Four Va1Ta 128 channel ASICs
- Fast trigger shaper (75ns) / slow analogue shaper (typically 1µs)
- Programmable shaping parameters
- Dynamic range ±10 MIPs

ALPHA1 – ALPHA2 upgrade



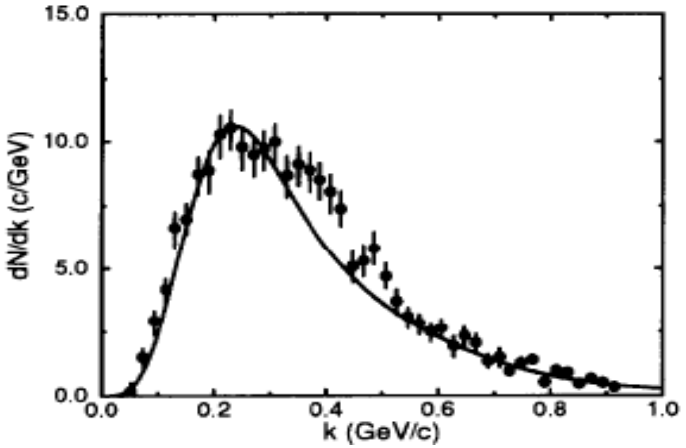


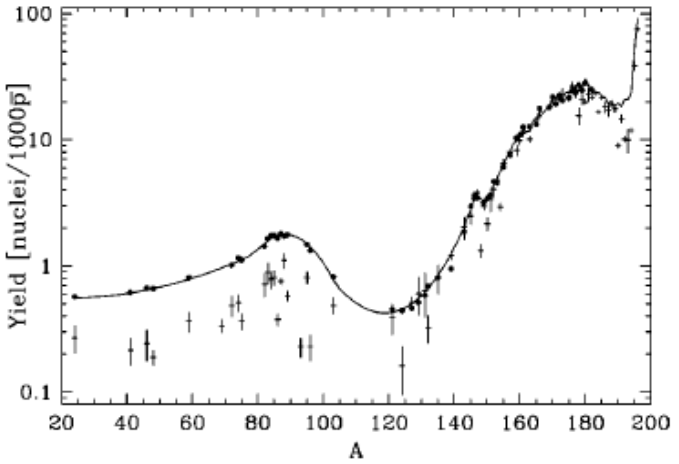
Antiproton annihilation detection principle

- Antiprotons (antihydrogen) annihilates either with the residual gas of the trap vacuum or at the trap walls (gold coated).

- Charged pions are emitted with high multiplicity, in average 3-4

Channel	Theory		
	$I = 0$	$I = 1$	Combined
$\pi^+\pi^-$	0.02	0.0	0.01
$\pi^+\pi^-\pi^0$	0.04	0.6	0.32
$2\pi^+2\pi^-$	9.1	3.0	6.1
$2\pi^+2\pi^-\pi^0$	26.8	19.8	23.3
$3\pi^+3\pi^-$	13.8	3.56	8.7
$3\pi^+3\pi^-\pi^0$	4.38	0.61	2.5
$n\pi^0$, $n > 1$	7.7	15.7	11.7
$\pi^+\pi^-n\pi^0$, $n > 1$	25.1	39.8	32.5
$2\pi^+2\pi^-n\pi^0$, $n > 1$	12.8	17.4	15.2
$3\pi^+3\pi^-n\pi^0$, $n > 1$	0.03	0.014	0.022
% of secondary πs	29.2	31.3	30.3





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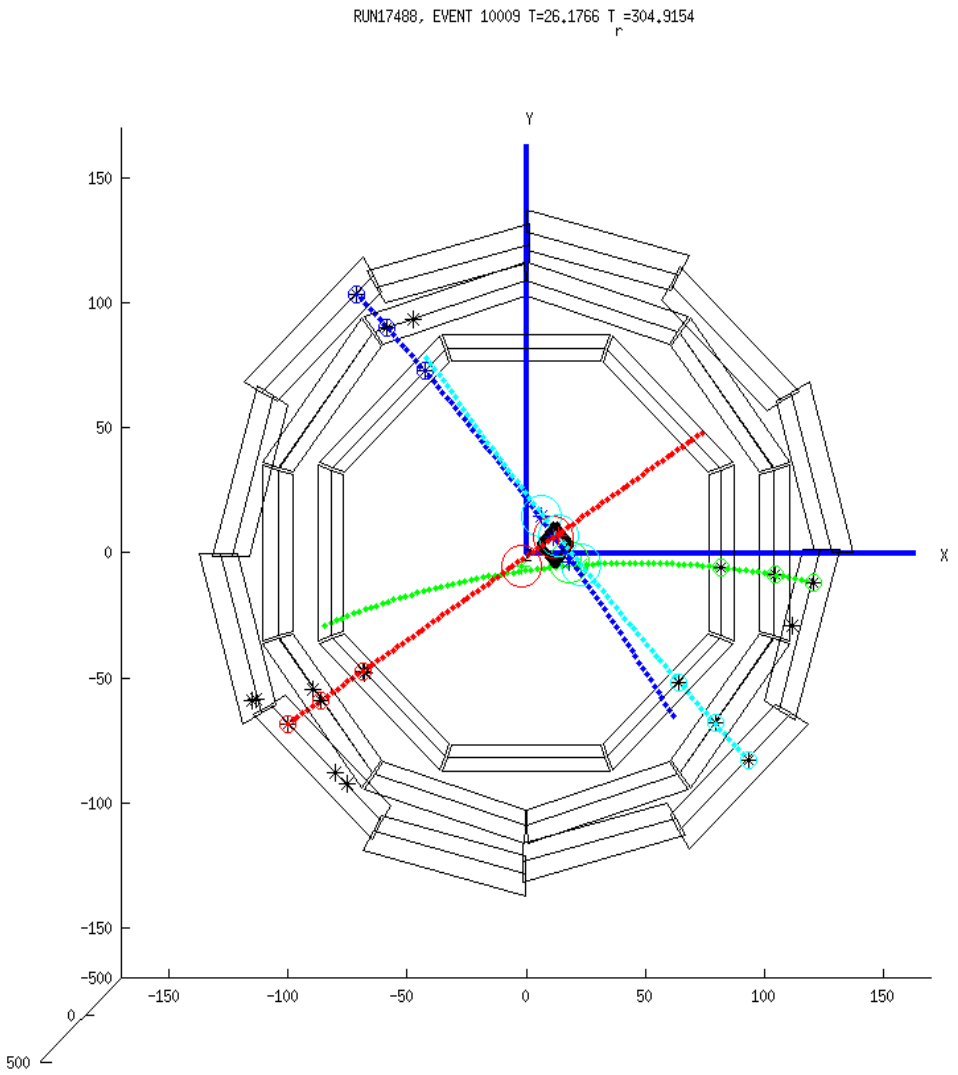
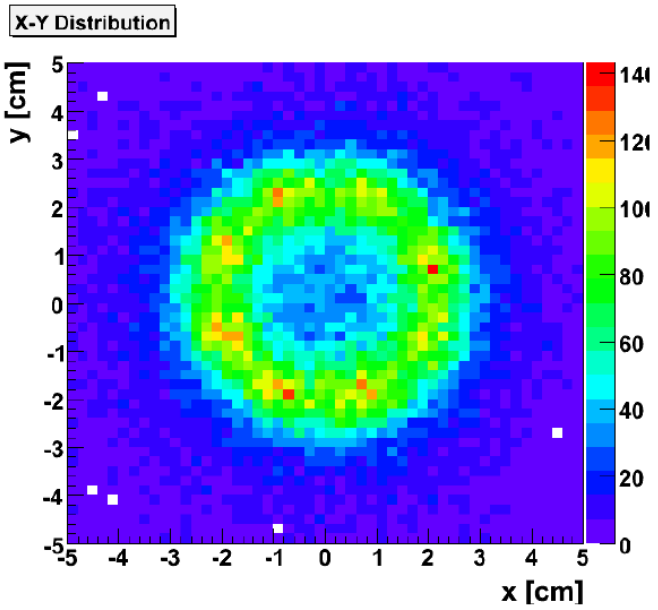
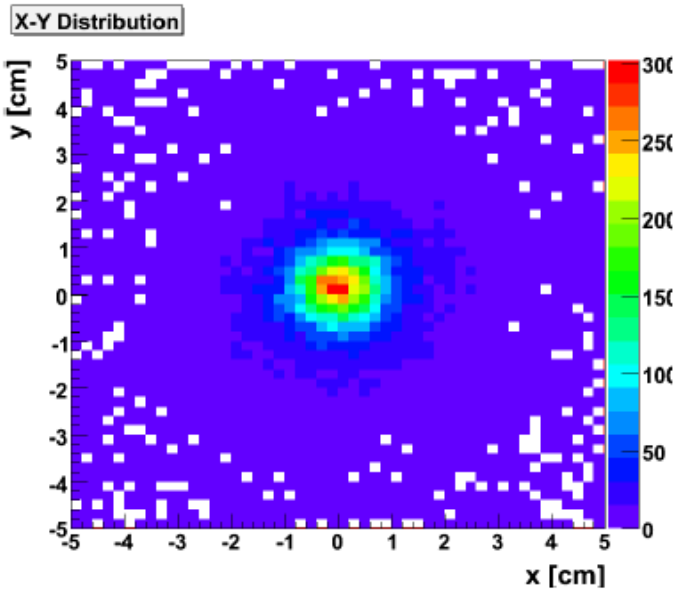
Physics Letters B 357 (I 995) 446-450

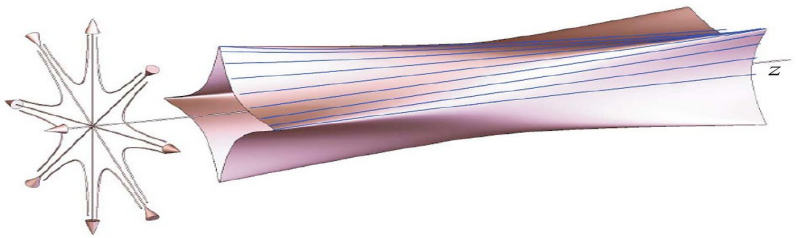
Imaging examples 1

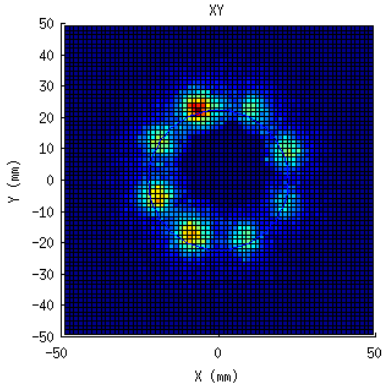


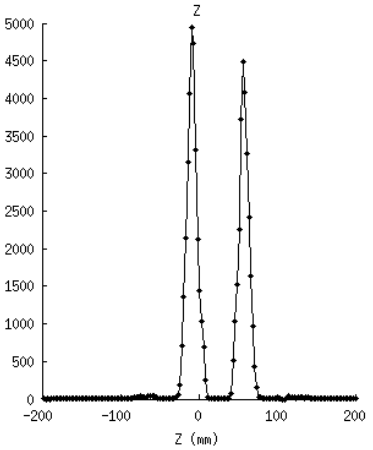


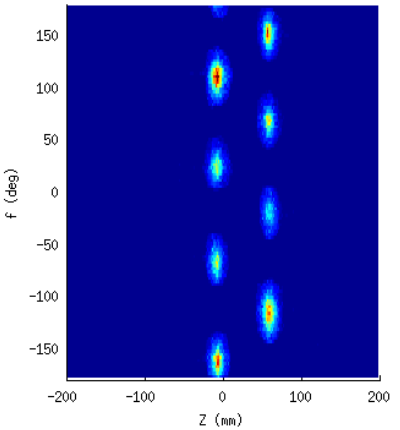


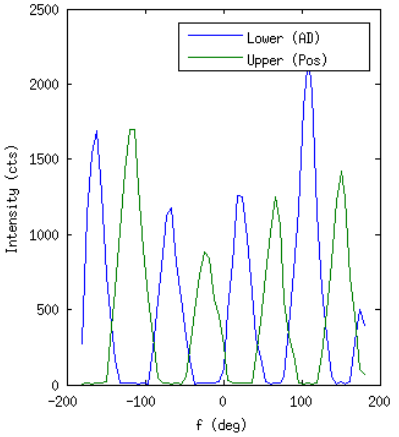
Imaging examples 2

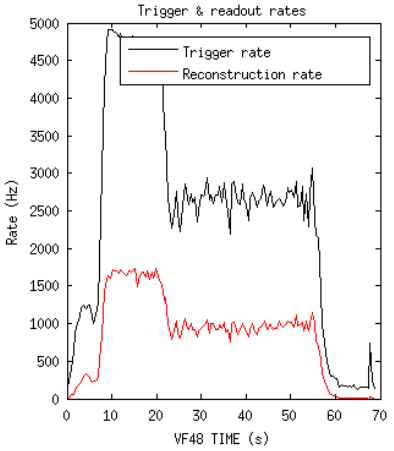


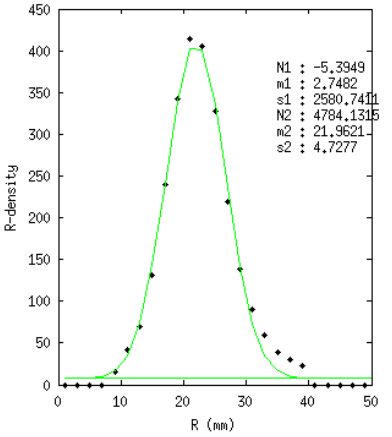




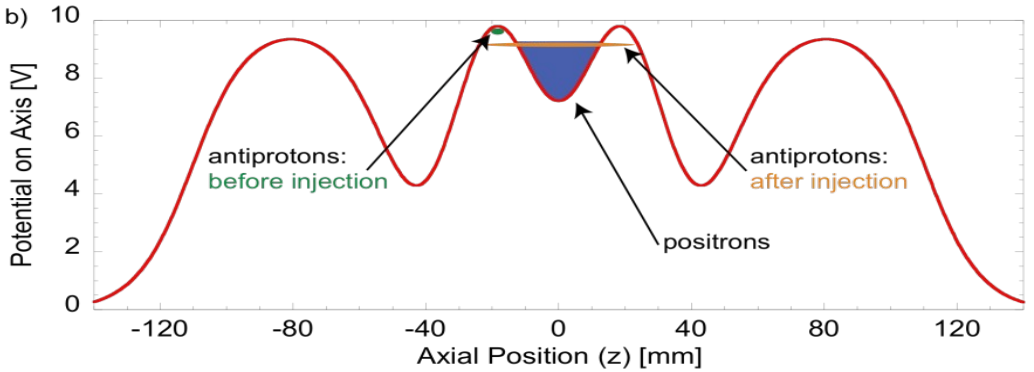


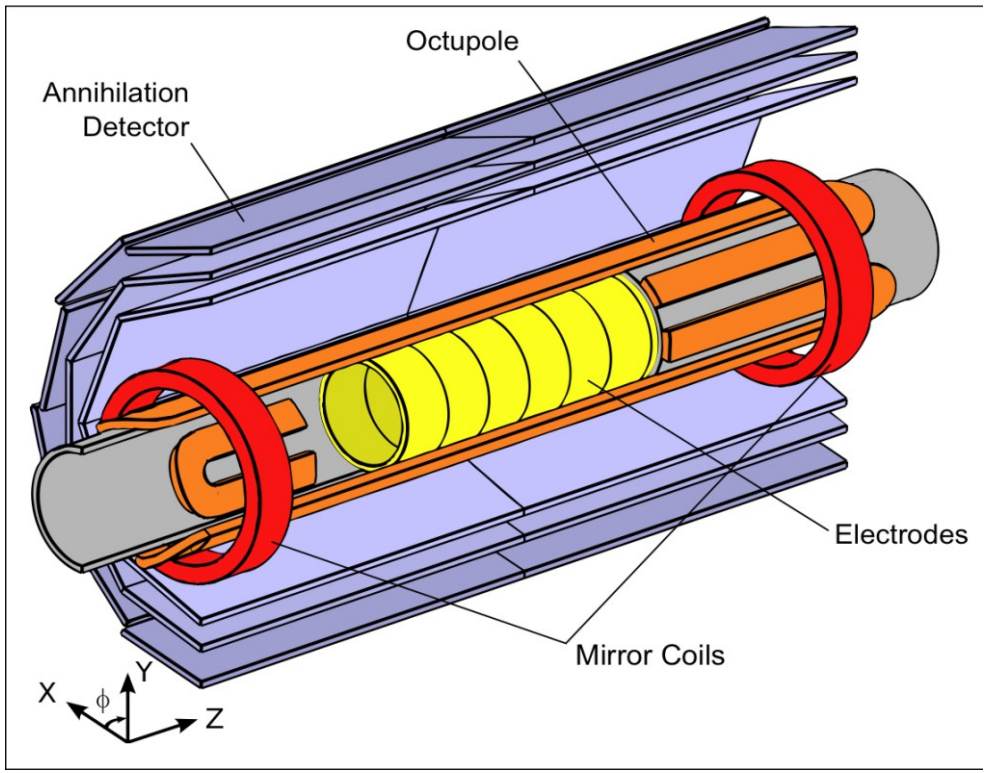






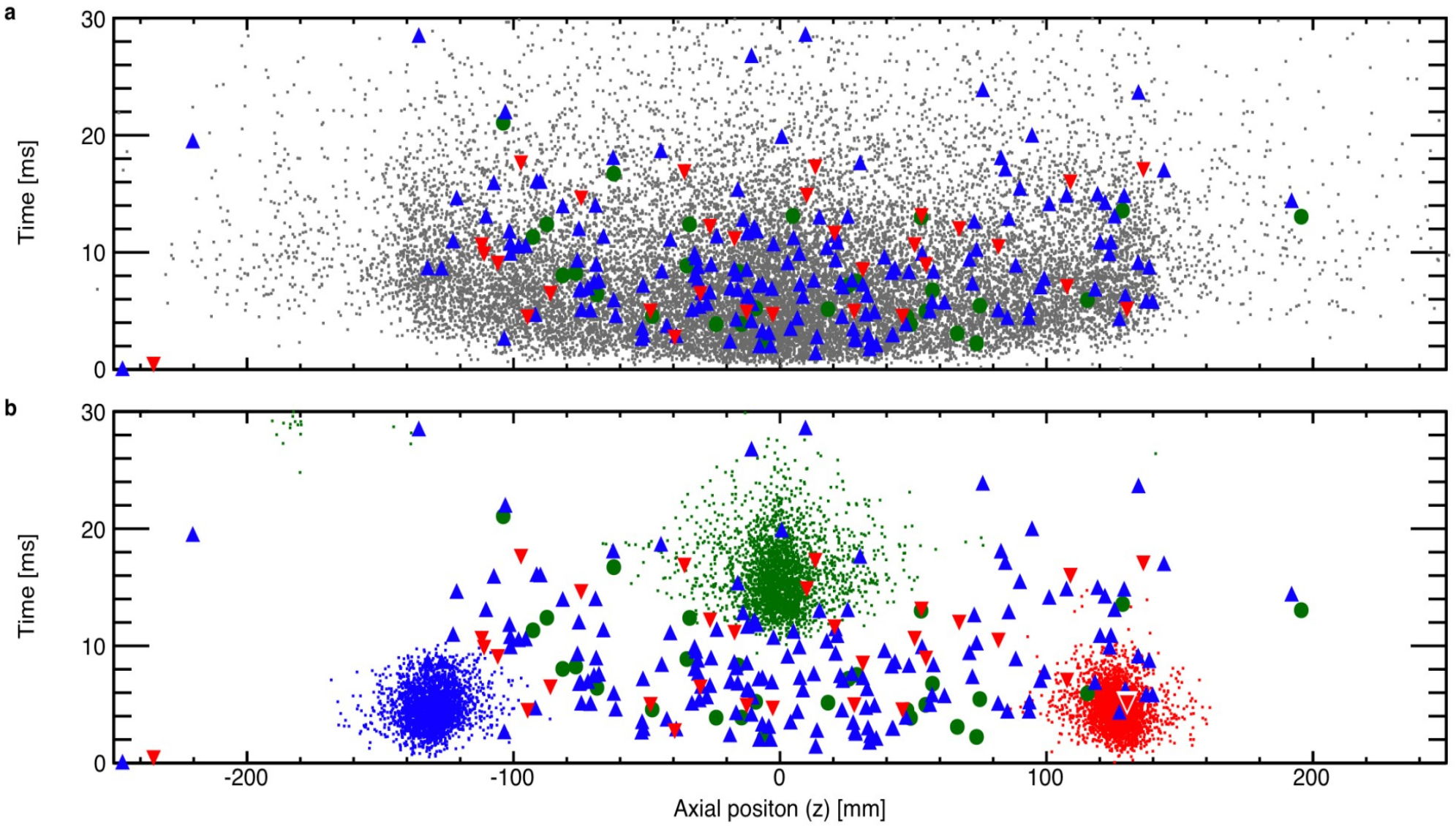
Trapping -2010/2011





·30000 antiprotons at 100 K
·2 M positrons at 40 K, evaporatively cooled.
·Inject antiprotons autoresonantly
·Mix for 1 s. Well depth 0.5K.
·Pulsed fields to clear any mirror-trapped pbars
·Fast shutdown of trap magnets (9 ms)
·Look for annihilating hbar
·Was it really a neutral? Apply bias electric fields.

Neutral antihydrogen



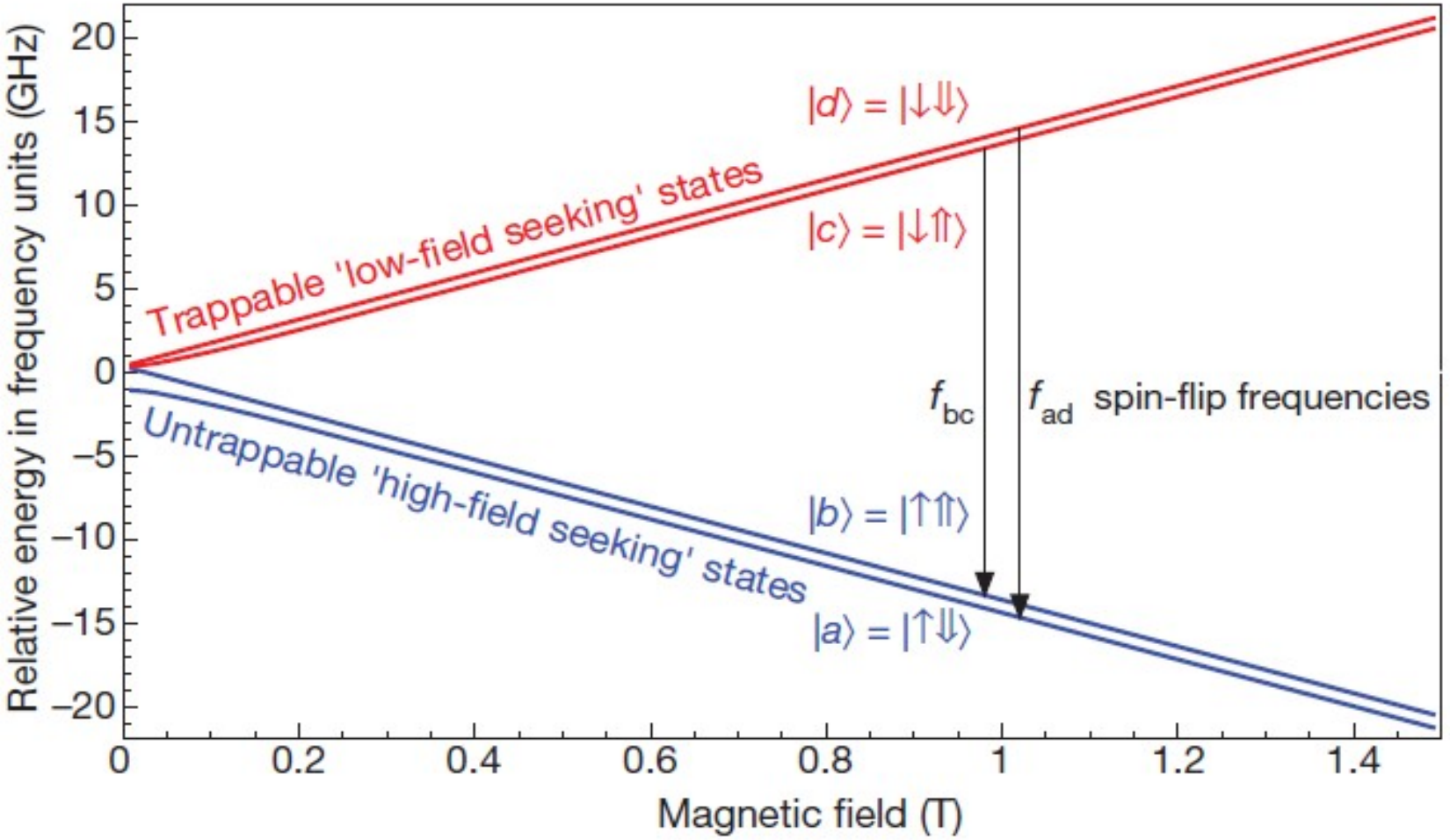
Experimental procedure - microwaves

- Antihydrogen production (autoresonant injection) & trapping in the neutral trap
- Wait 60s – B stabilization
- 180s μ-wave window
- Neutral trap release (quench) – 30ms annihilation window

1) On resonance 2)&4) Off resonance – detune B by 3.5mT (100MHz) 3) On resonance – detune B by 100MHz and μ-waves by 100MHz 5)&6) No μ-waves.

Look data in “apperance” and “disappearance” -mode, 180s μ-wave window and 30 ms quench window, respectively

μ-wave spin-flip principle

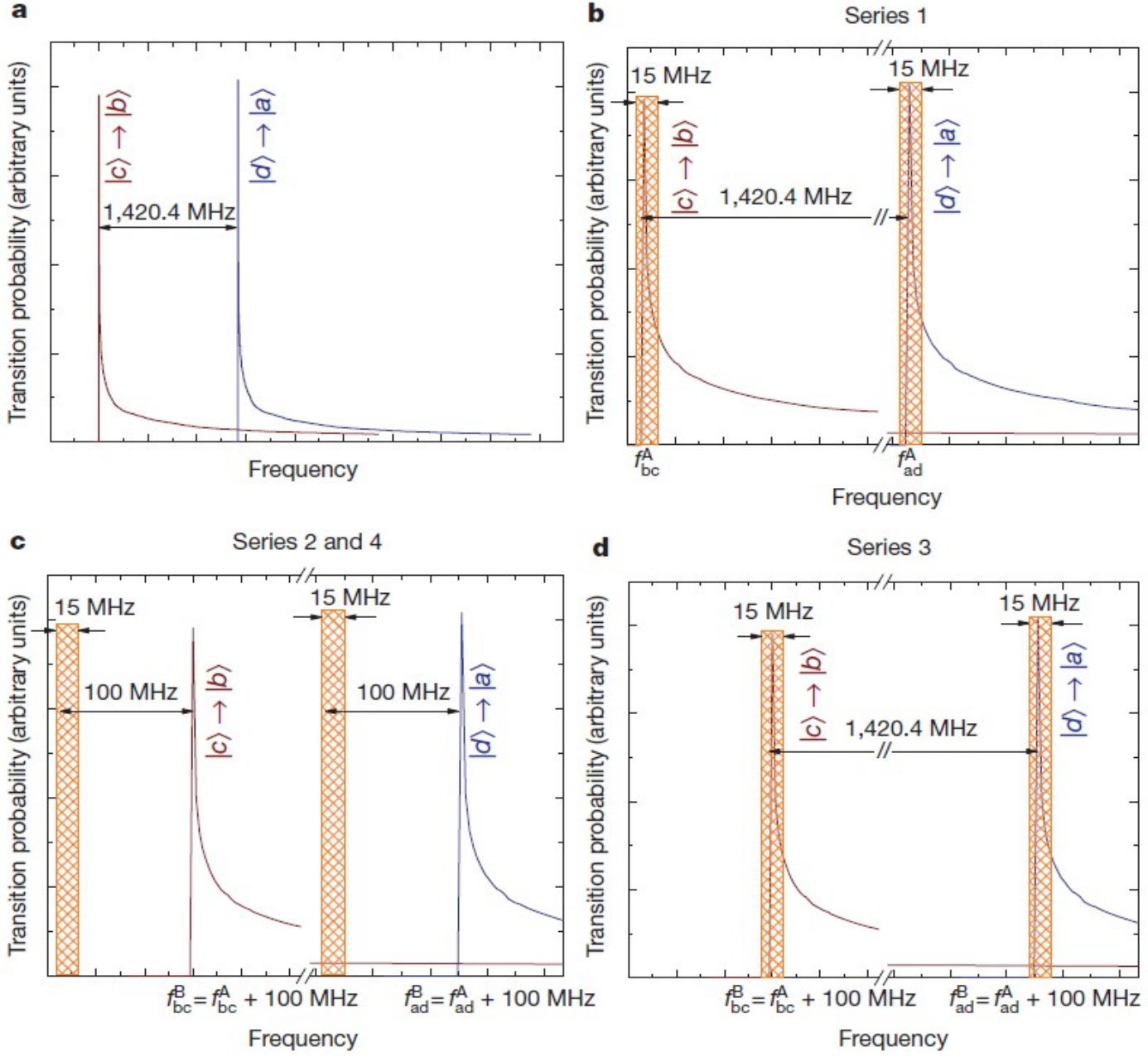


(anti)Hydrogen Hyperfine energy levels – Breit-Rabi diagram

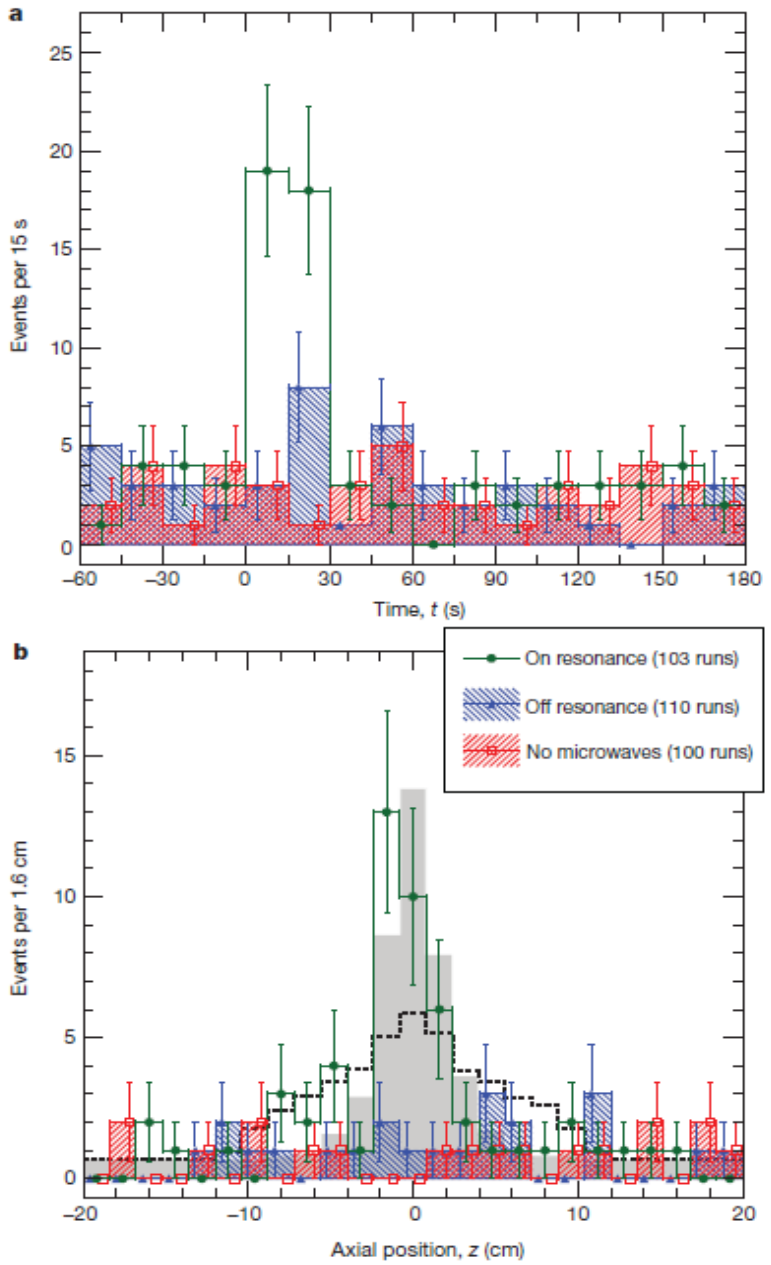
f_{ad} = 29.696 GHz, A = +0MHz, B = +100MHz

f_{bc} = 28.276 GHz

Transition lineshapes & resonance conditions



“Appearance” mode data



- Majority of On-resonance annihilations within 0-30s time window, On-res/no μ-wave p = 2.8×10^{-5}

- Off resonance p = 5.6×10^{-2} (c> state & statistics)

- Use alternative background rejection ~10^{-3} Hz background and 25% event loss

- Annihilation z-distrubution confirmed by singe particle simulations:
gray = annihilations caused by spin-flip
black dashed = annihilations with the residual gas

=>strong need for cosmic background rejection studies

Conclusions

- Trapping & the first spectroscopic measurement of an antimatom – SVD in the main role
- Modest relative precision (4×10^{-3}) = “somewhere there”
- Demonstration of the ability to perform technically challenging measurement, measuring one atom at a time
- Future: line-shape measurements / other spectroscopic measurements, ALPHA-2; laser-spectroscopy / gravitational effects

Many thanks for your attention!