Test for matter – antimatter imbalance in the Universe by studying neutral trapped antihydrogen atoms. Experiment DAQ & Controls

AVA - CERN, Geneva, June 29th 2018

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

University of Aarhus, Denmark

University of California Berkeley, USA

University of Wales Swansea, UK

NRCN - Nucl. Res. Center Negev, Israel

University of British Columbia, Canada

RIKEN, Japan

Federal University of Rio de Janeiro, Brazil

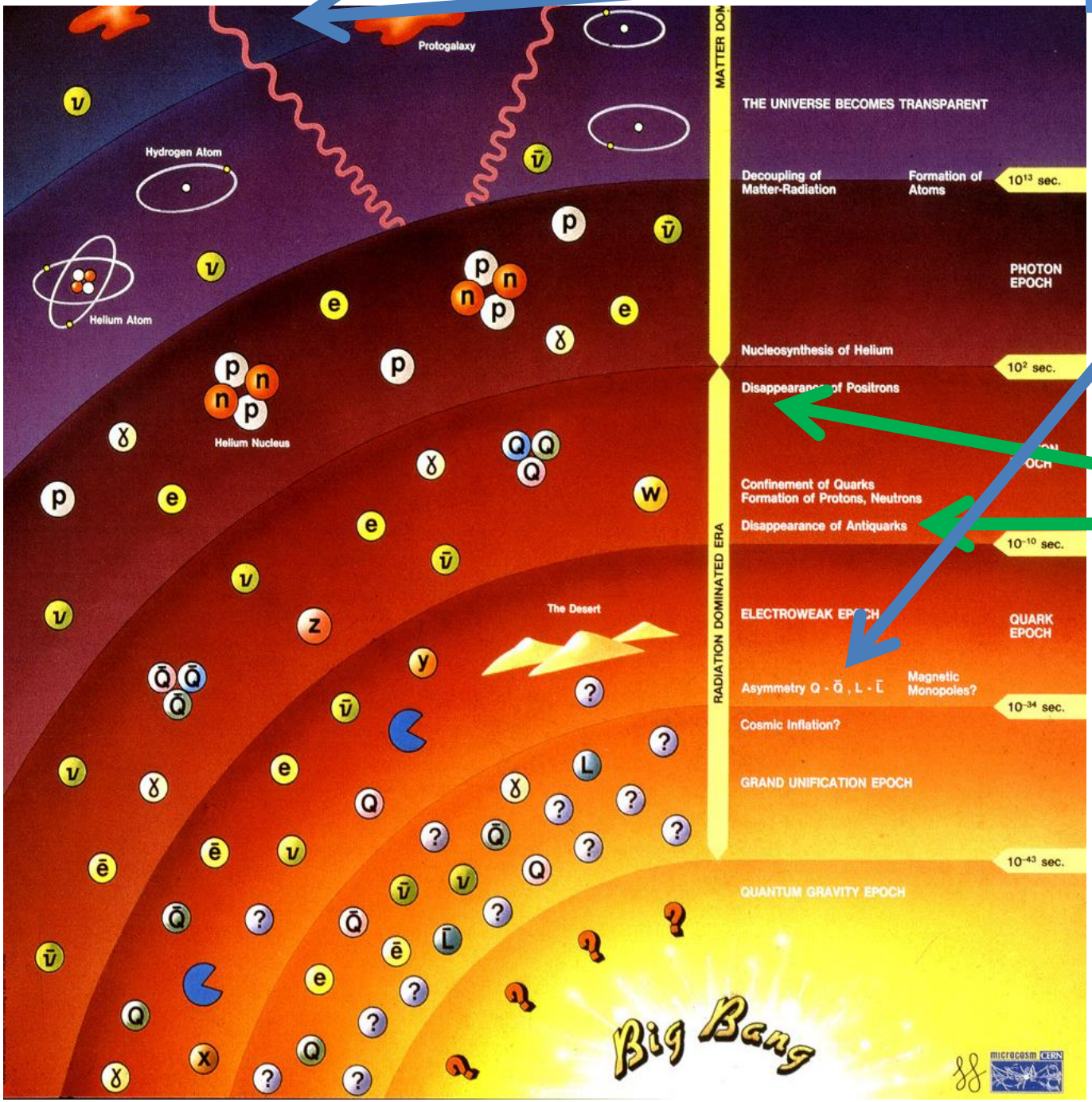
Simon Fraser University, Canada

TRIUMF, Canada

University of Tokyo, Japan

ALPHA probe for the anti – 'World'

ALPHA probes beyond here



HEP experiments

The reason(s) for these events are not understood

Overview of the experimental goal

- Ultimate long term goal 1S-2S comparison of antihydrogen atomic transition between hydrogen

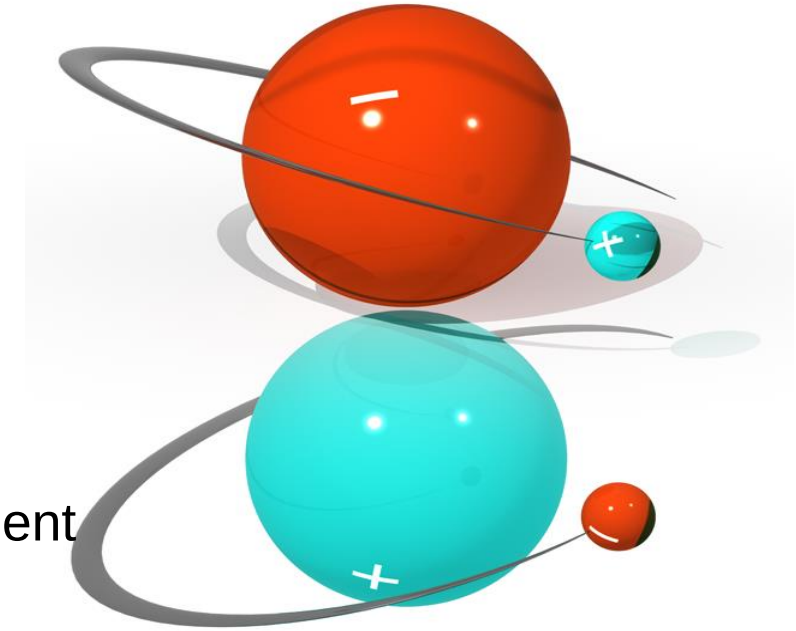
- Haench et al. Currently measured at 10^{-15} precision. One of the best studied physical systems

- => 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 @ 5.3 MeV antiprotons

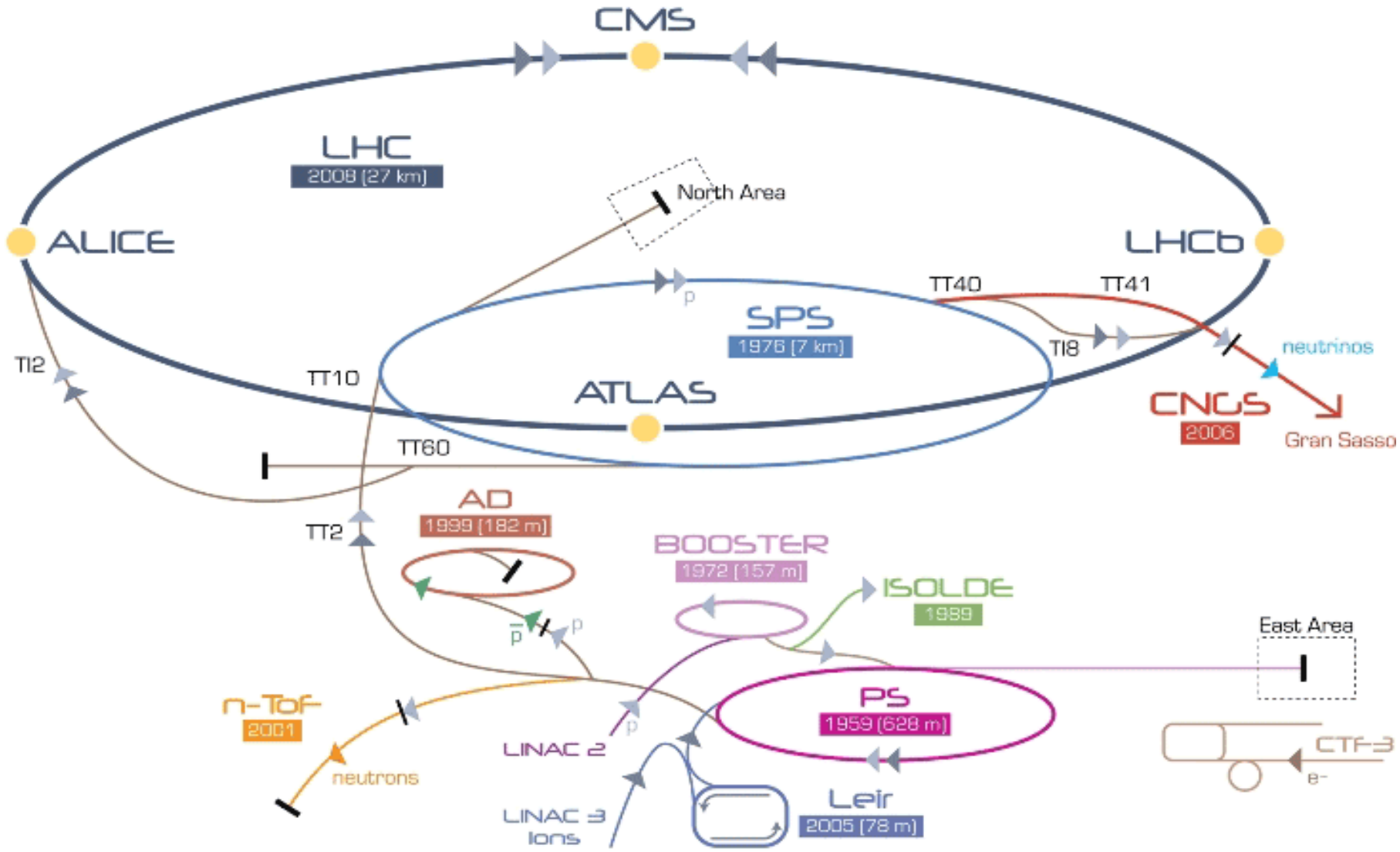
- Physics is based on effective detection of single (anti)atom annihilation events



Making antihydrogen – the ingredients are:

- Antiprotons
- Positrons

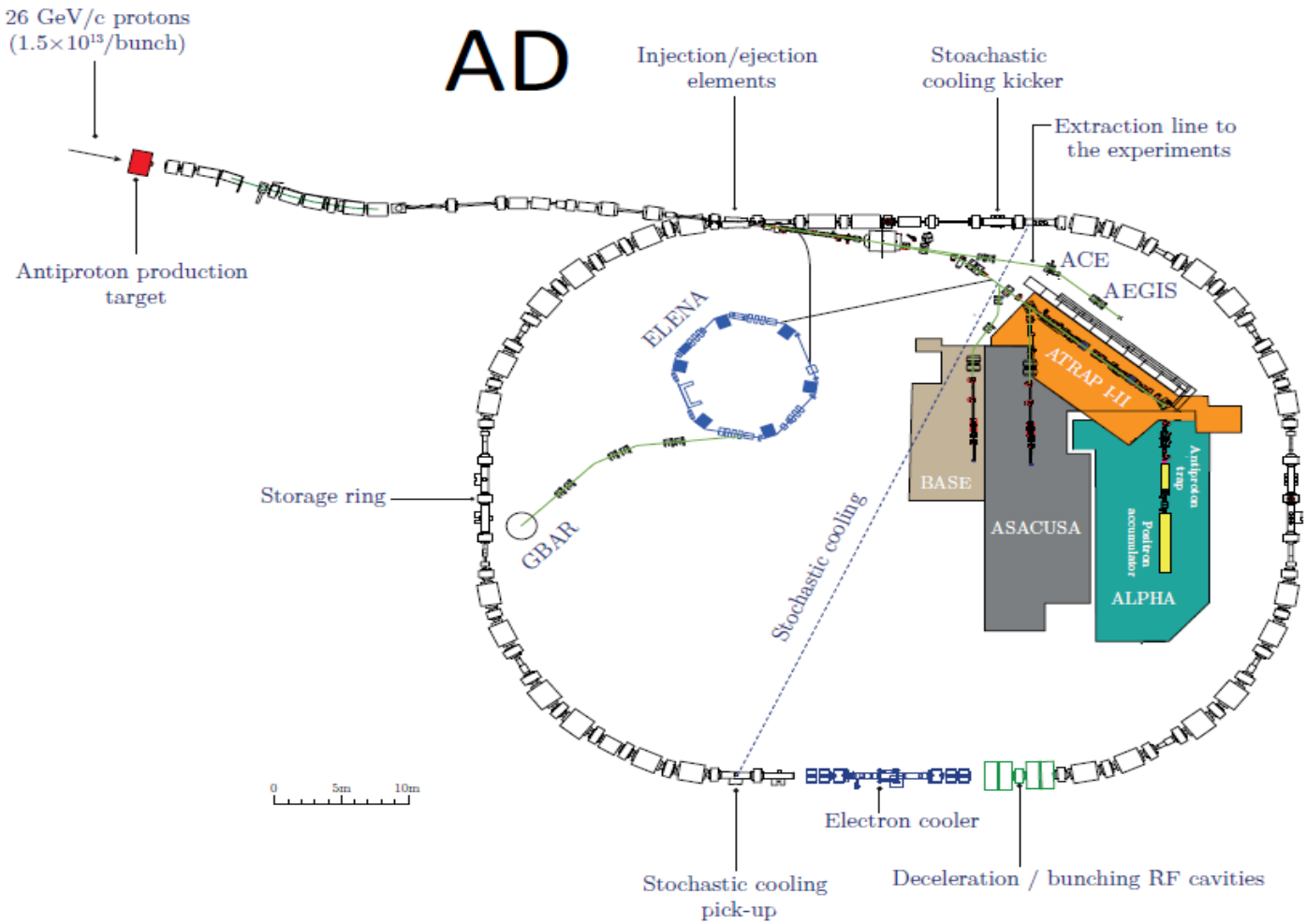
Simple, but in real life, somewhat tricky.



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



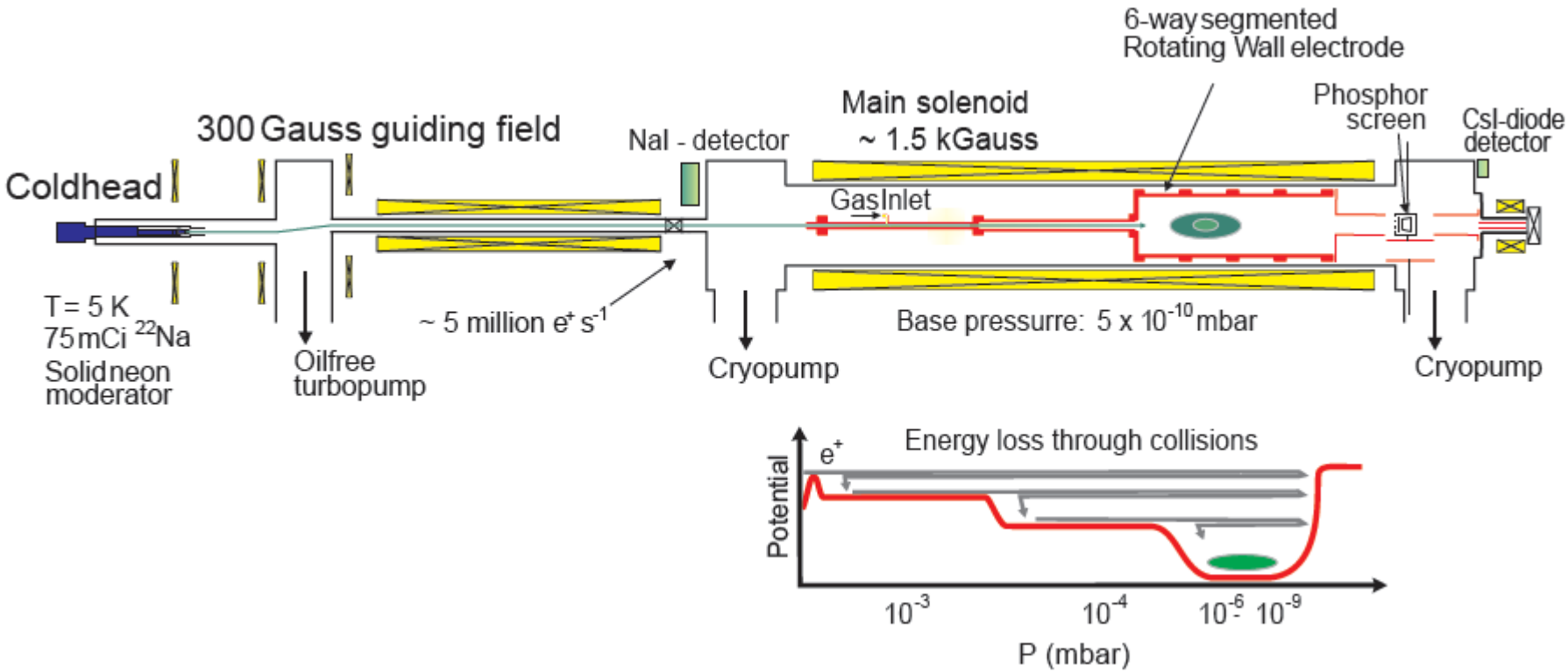
PS production beam 1.5×10^{13} protons/cycle at 26 GeV/c

5×10^{7} pbars injected at 3.57 GeV/c

Stochastic and electron cooling, cycle 100s

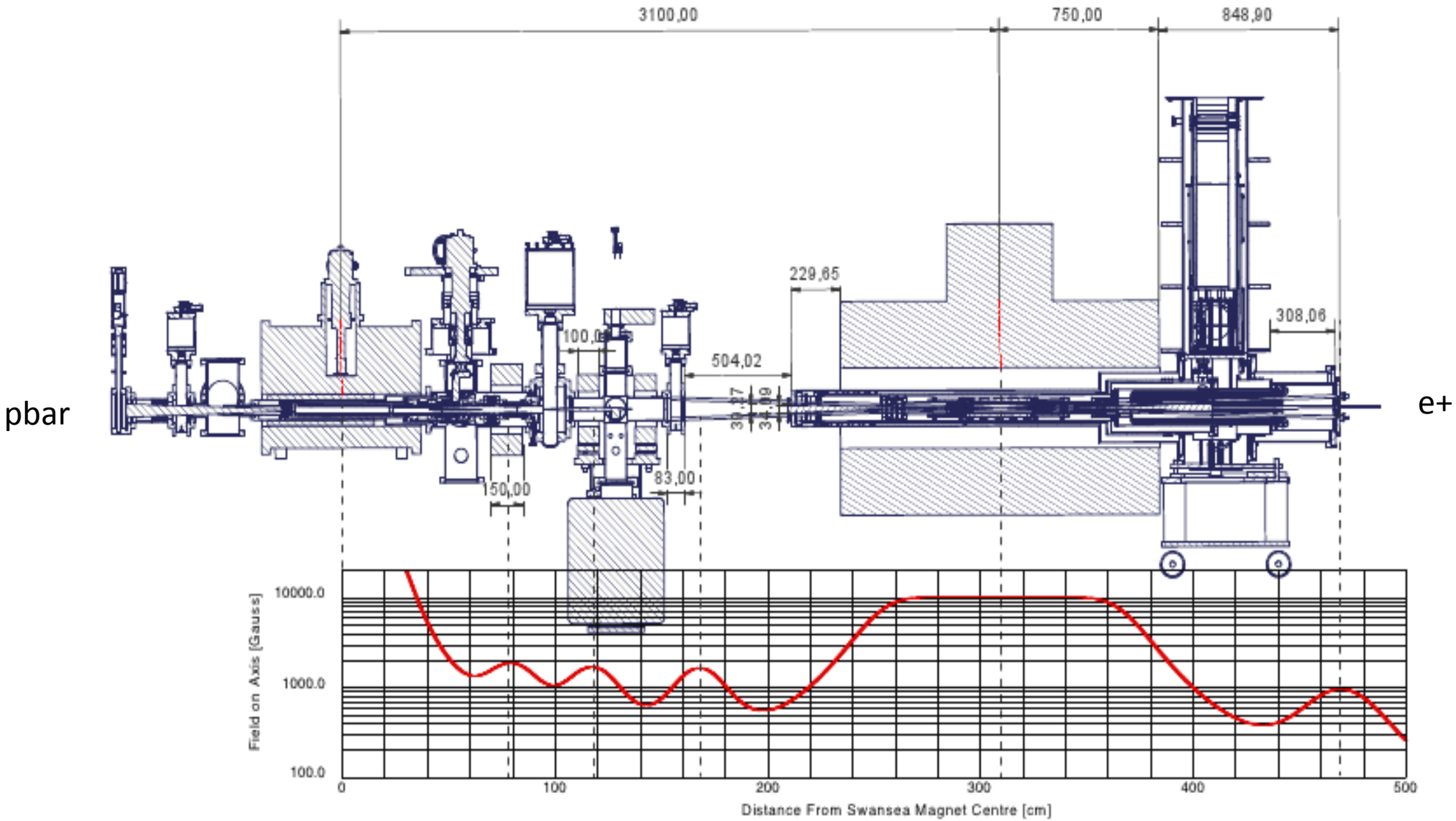
Extract 3×10^{7} pbars every 100s at 100/300/500 Mev/c (5.3/47/126 MeV)

POSITRONS

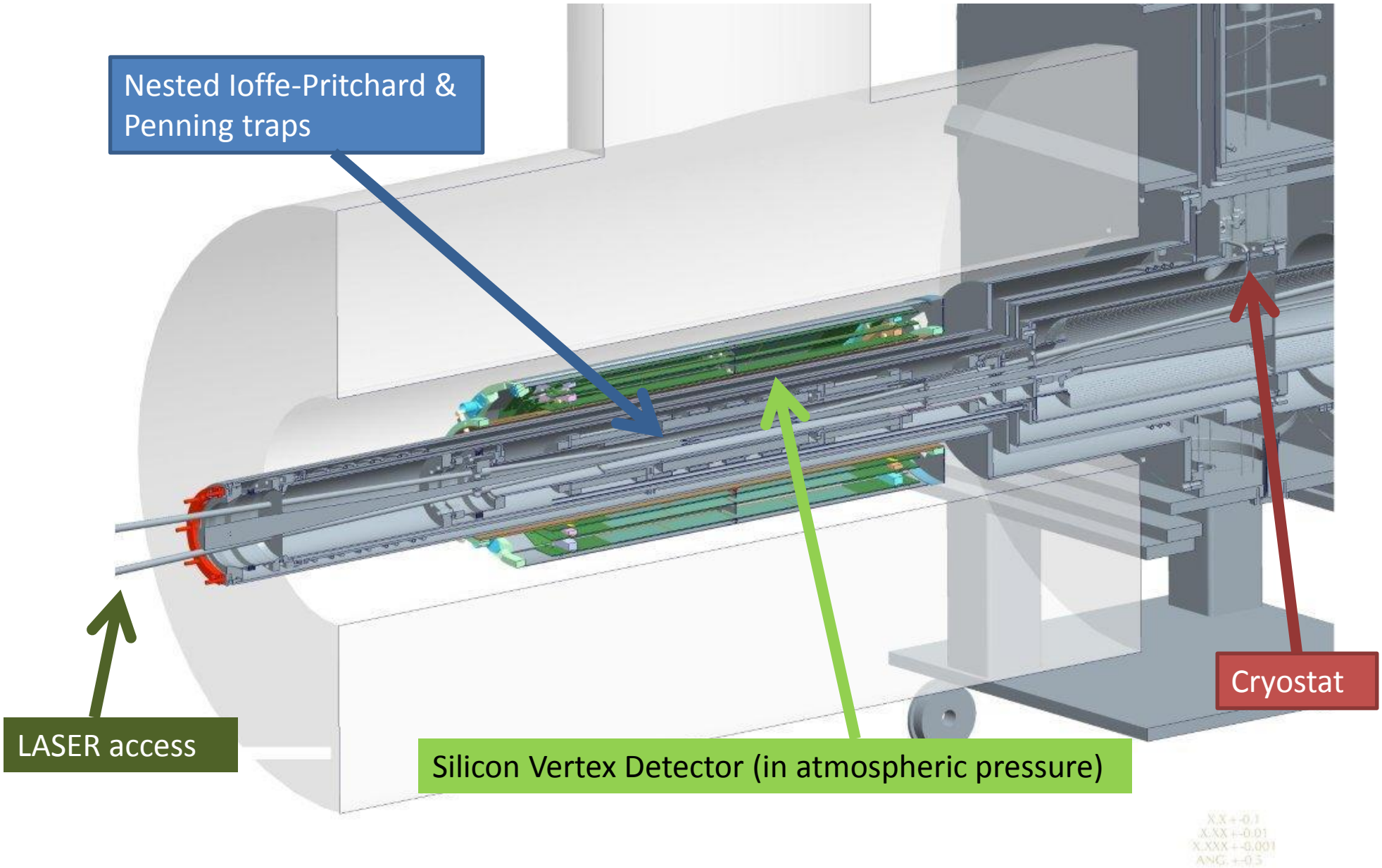

6-way segmented
Rotating Wall electrode
Main solenoid
~ 1.5 kGauss
Phosphor
screen
CsI-diode
detector
300 Gauss guiding field
NaI - detector
Coldhead
Gas Inlet
T = 5 K
75 mCi ^{22}Na
Solid neon
moderator
Oilfree
turbopump
~ 5 million e^+ s^{-1}
Cryopump
Base pressurre: 5 x 10^{-10} mbar
Cryopump
Energy loss through collisions
e^+
Potential
10^{-3}
10^{-4}
10^{-6}
10^{-9}
P (mbar)

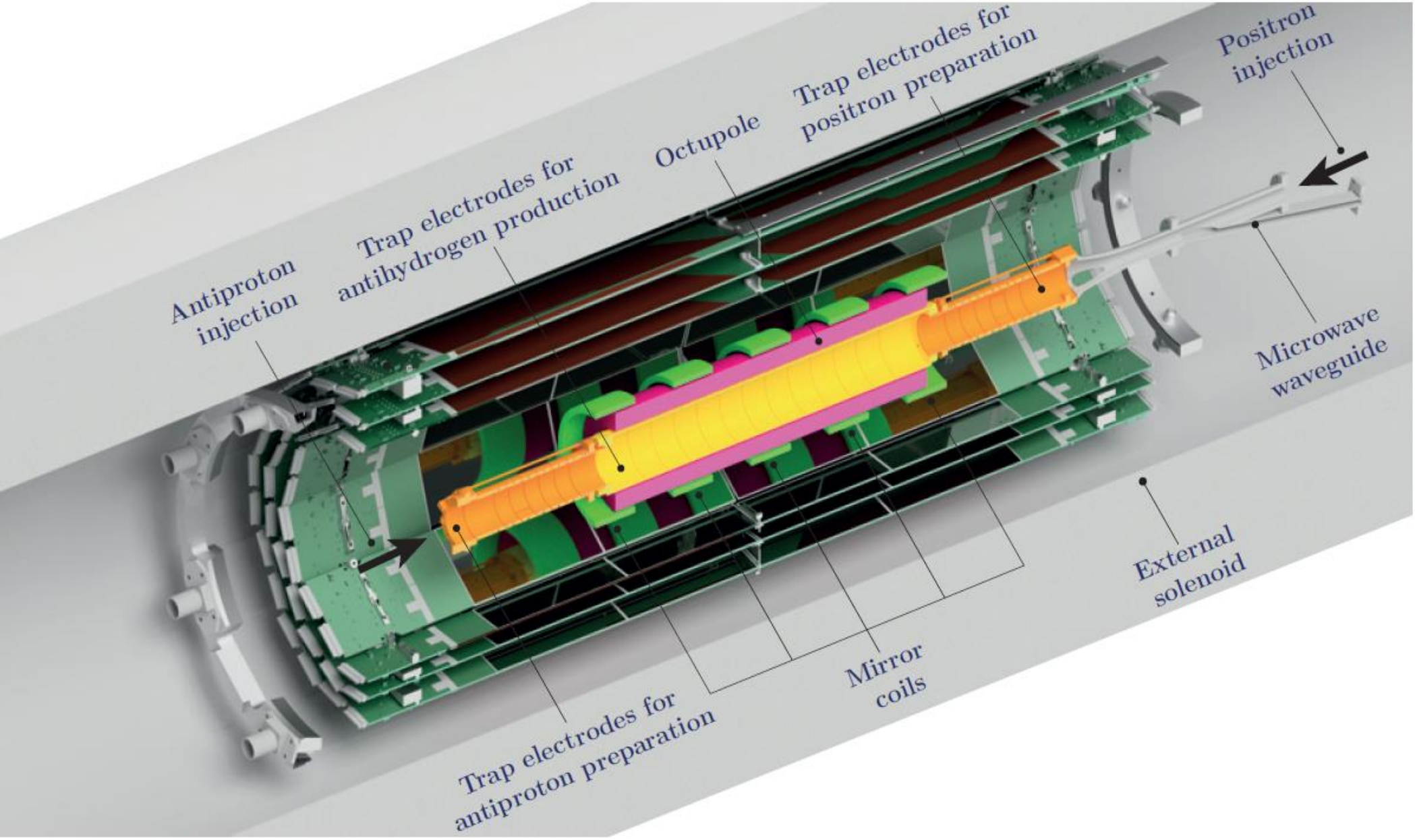
Transfer magnets

ALPHA - 2

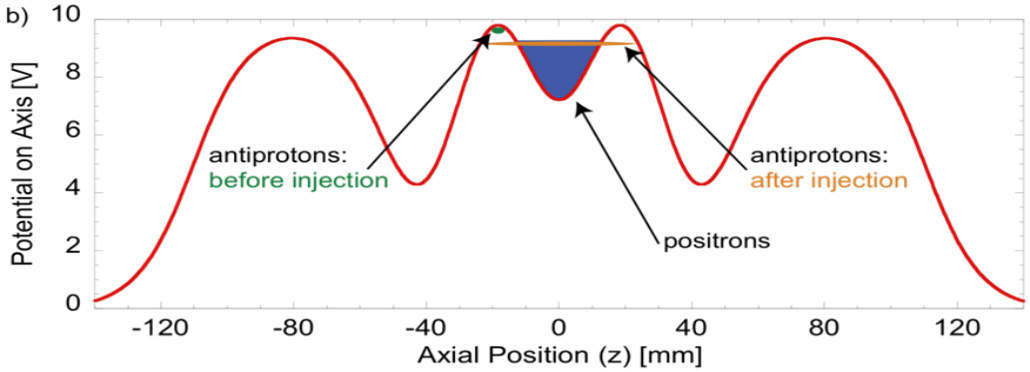


Neutral trap cut-through




Antiproton injection
Trap electrodes for antihydrogen production
Octupole
Trap electrodes for positron preparation
Positron injection
Microwave waveguide
External solenoid
Mirror coils
Trap electrodes for antiproton preparation

Antihydrogen production in A2



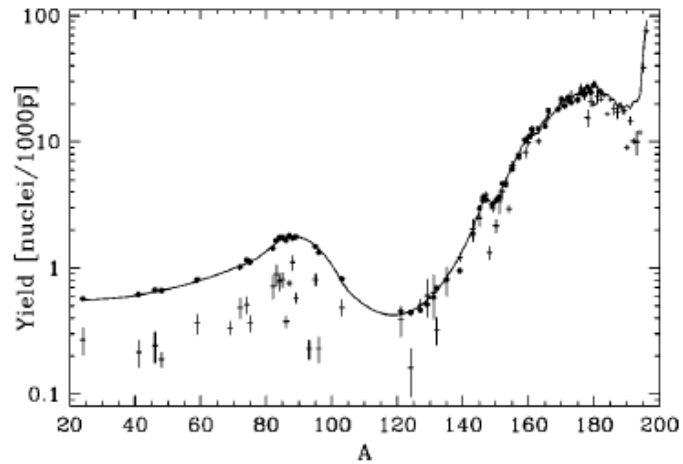
- Starting point is ~10^5 antiprotons less than 60K and ~2M positrons at about 15K
- Mix these by autoresonantly exciting the antiproton plasma or by direct mixing.
- As result, some 10^5 antihydrogen atoms are created.
- In average less than 15 remains in the 0.5K neutral trap
- This cycle takes about 15-20 mins

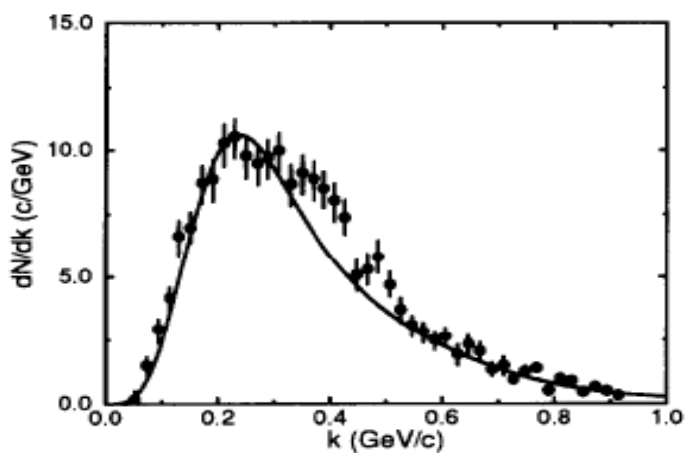
- During this process neutral trap is being turned on

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
- In practice only the detectable charged high energy pions penetrate into detector region

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





Physical Review C 66, 044616 (2002)
Physics Letters B 357 (I 995) 446-450

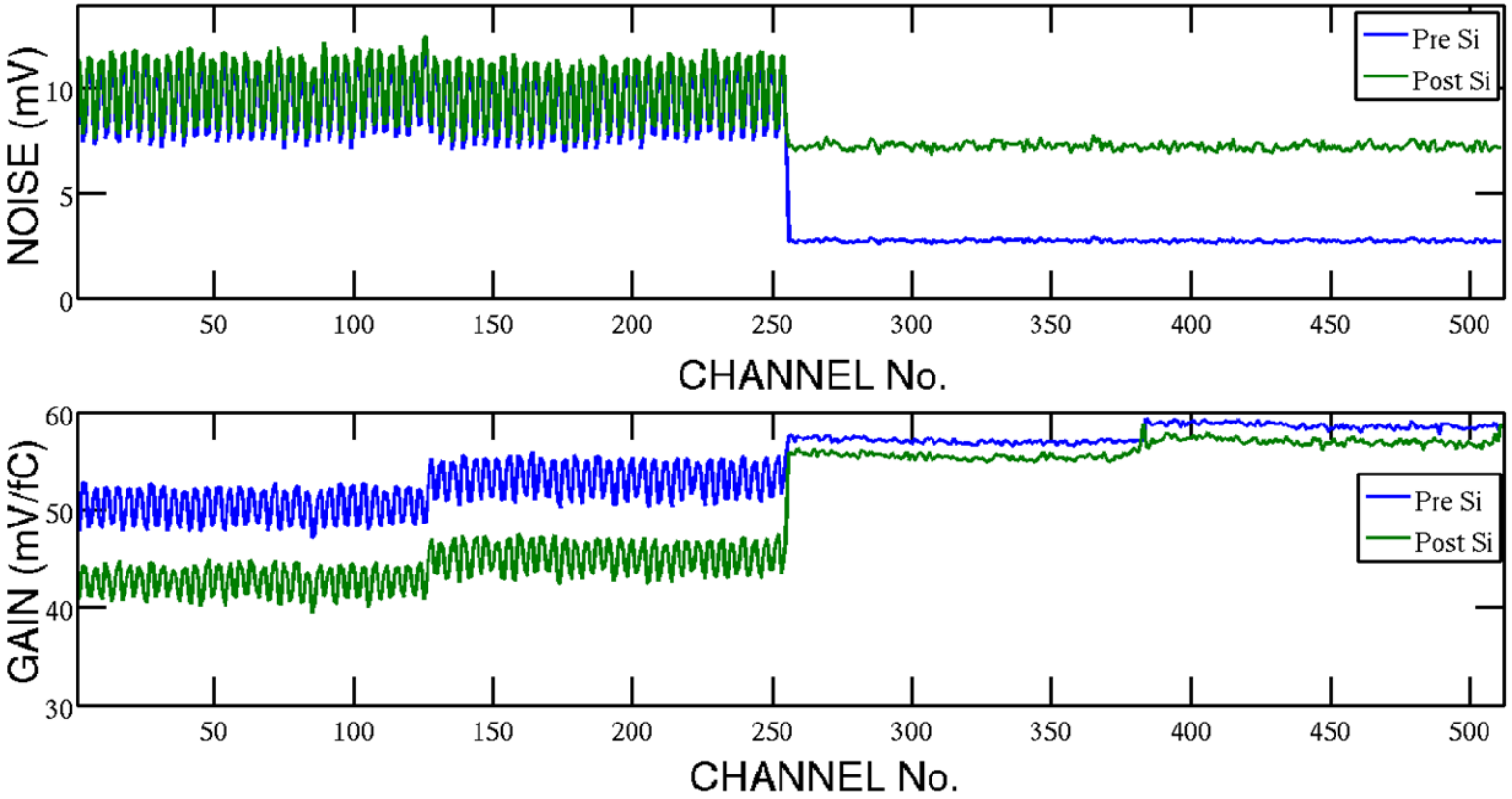
ALPHA -hybrids

- 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

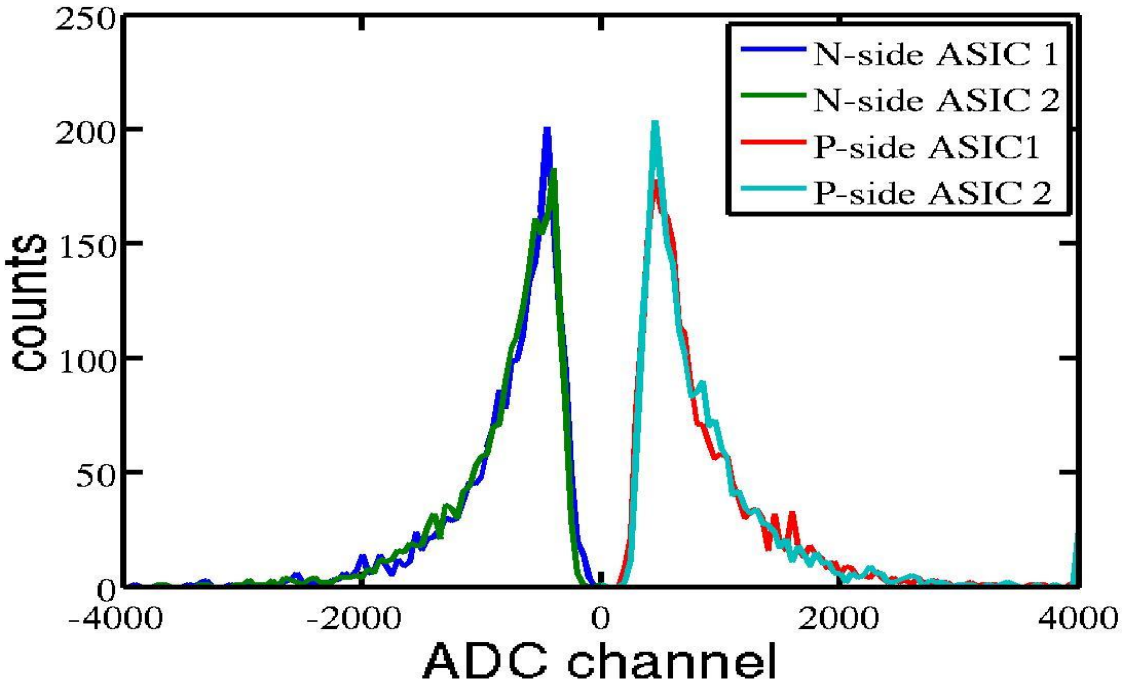
- Four Va1Ta 128 channel ASICs
- Fast trigger shaper (75ns) / slow analogue shaper (typically 1μs)
- Programmable shaping parameters
- Dynamic range ±10 MIPs

Hybrid performance – test pulse



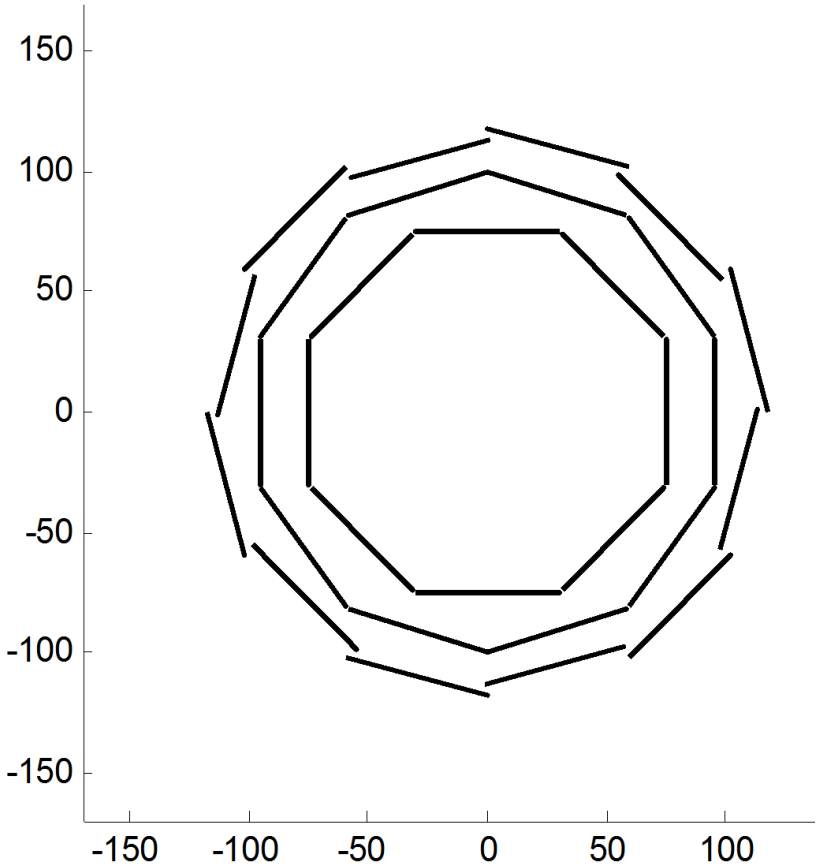
Estimated S/N:
- P-side 28
- N -side 16

Hybrid performance – MIPs (cosmics)

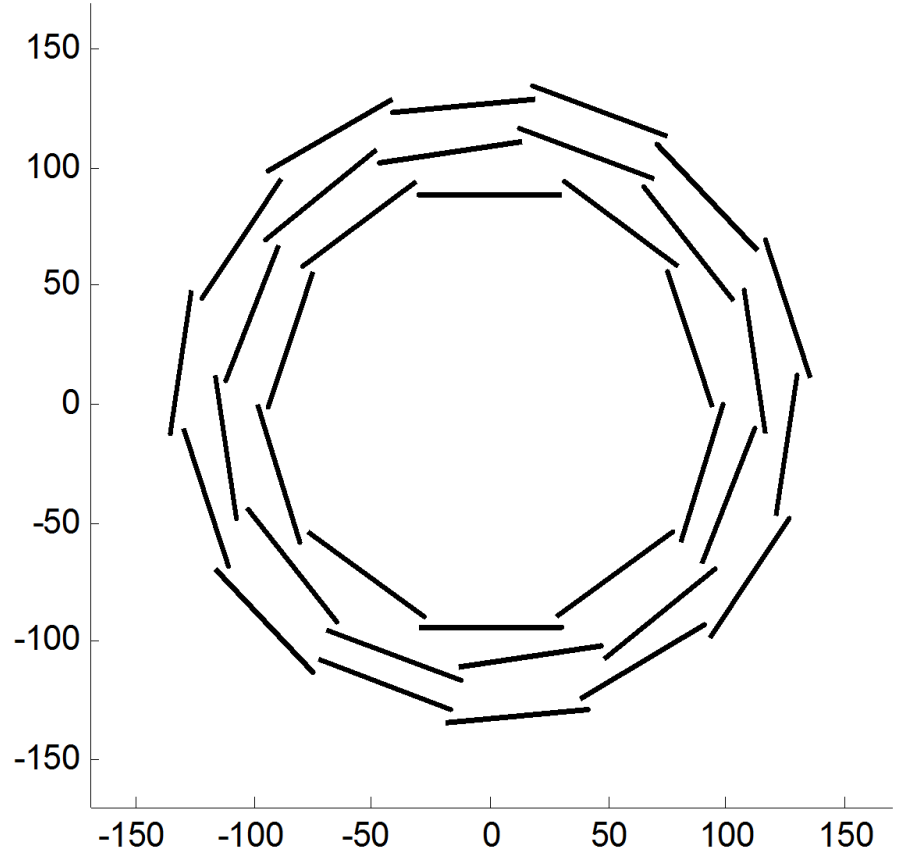


S/N; median of the Landau distribution / RMS noise
- S/N p-side 33
- S/N n-side 15

ALPHA1 – ALPHA2 upgrade geometry

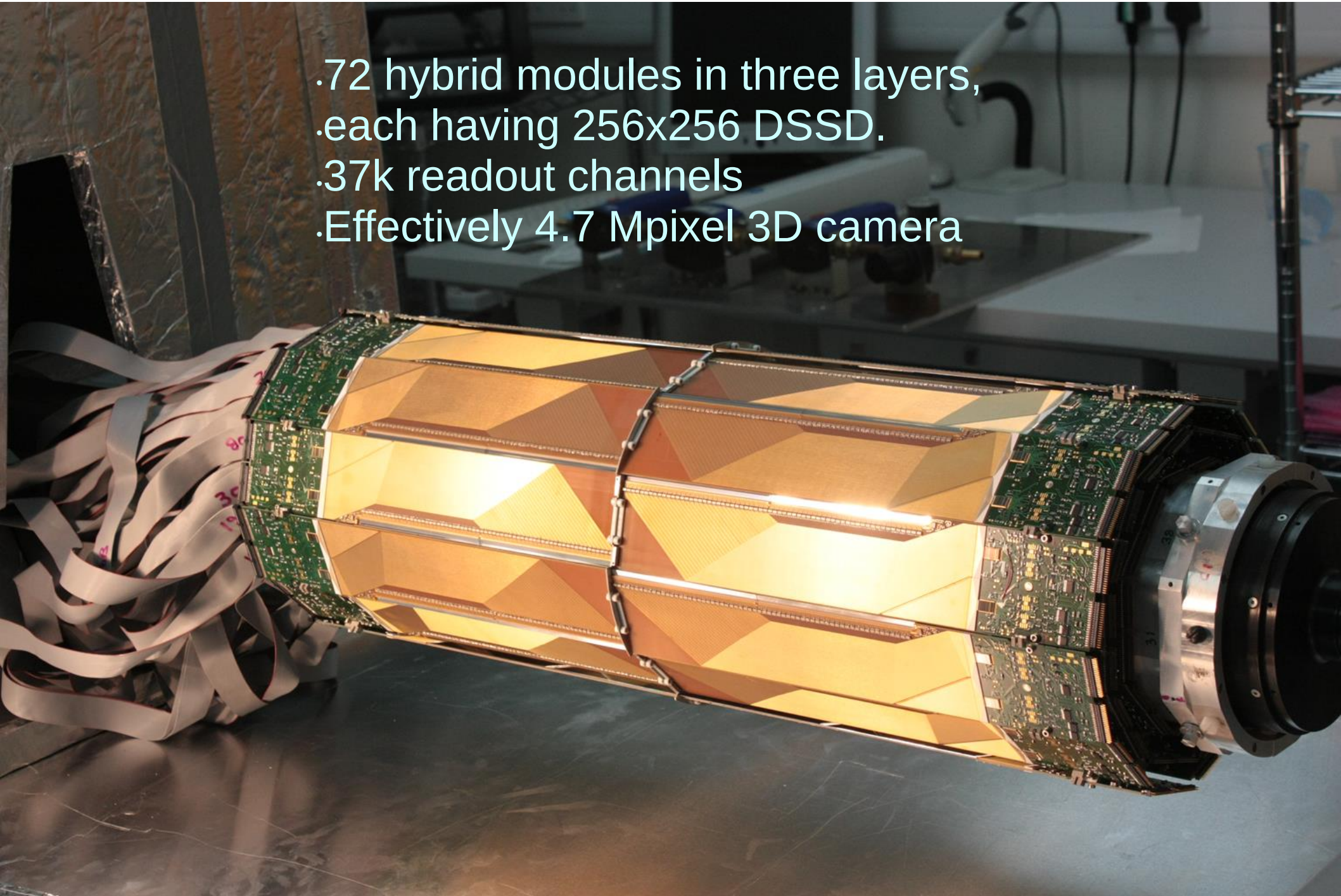


8 – 10 – 12 Inner
75mm, Outer 127mm

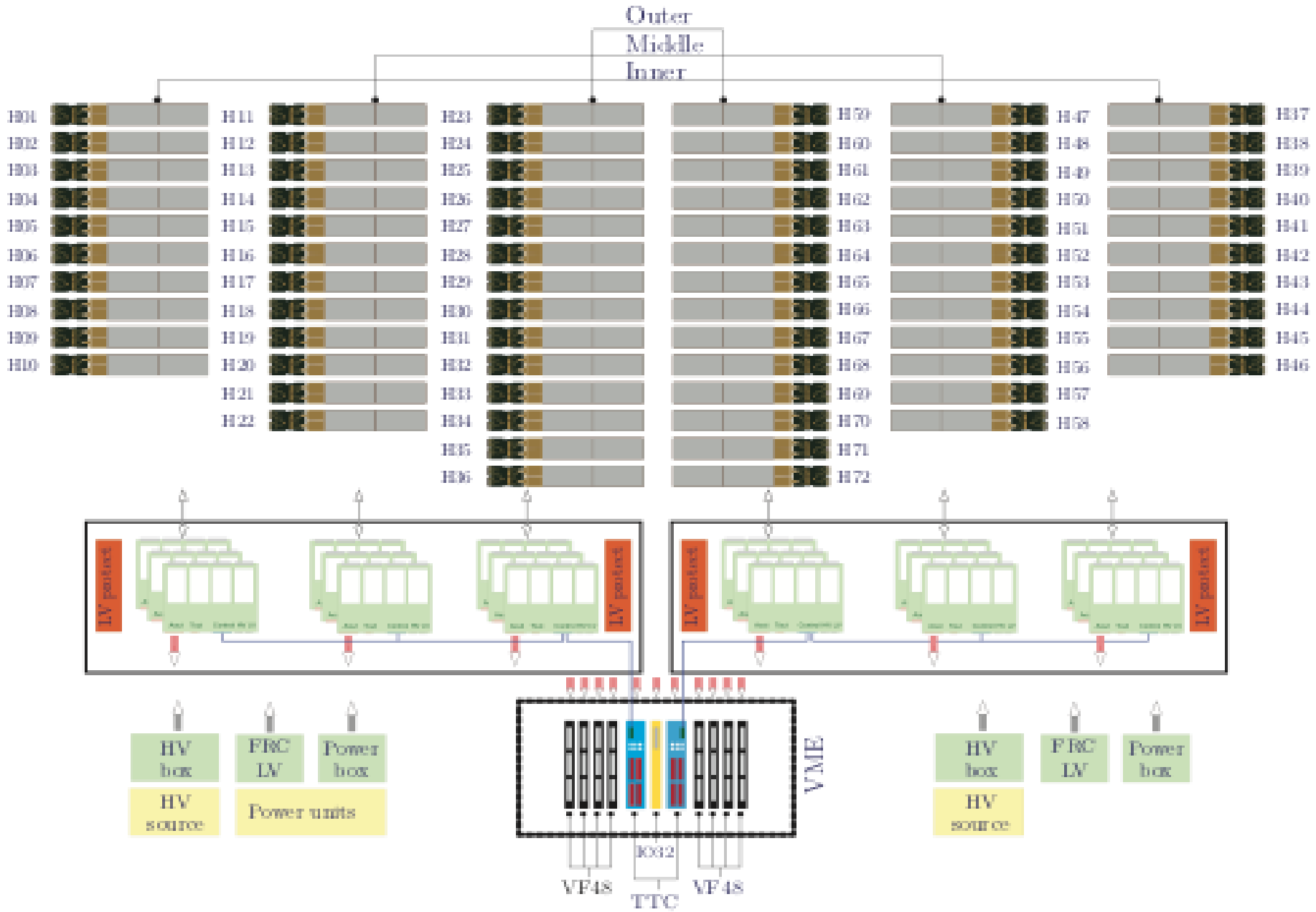


10 – 12 -14 Inner
89mm, Outer 133mm

Silicon Vertex Detector (SVD) upgrade for ALPHA-2



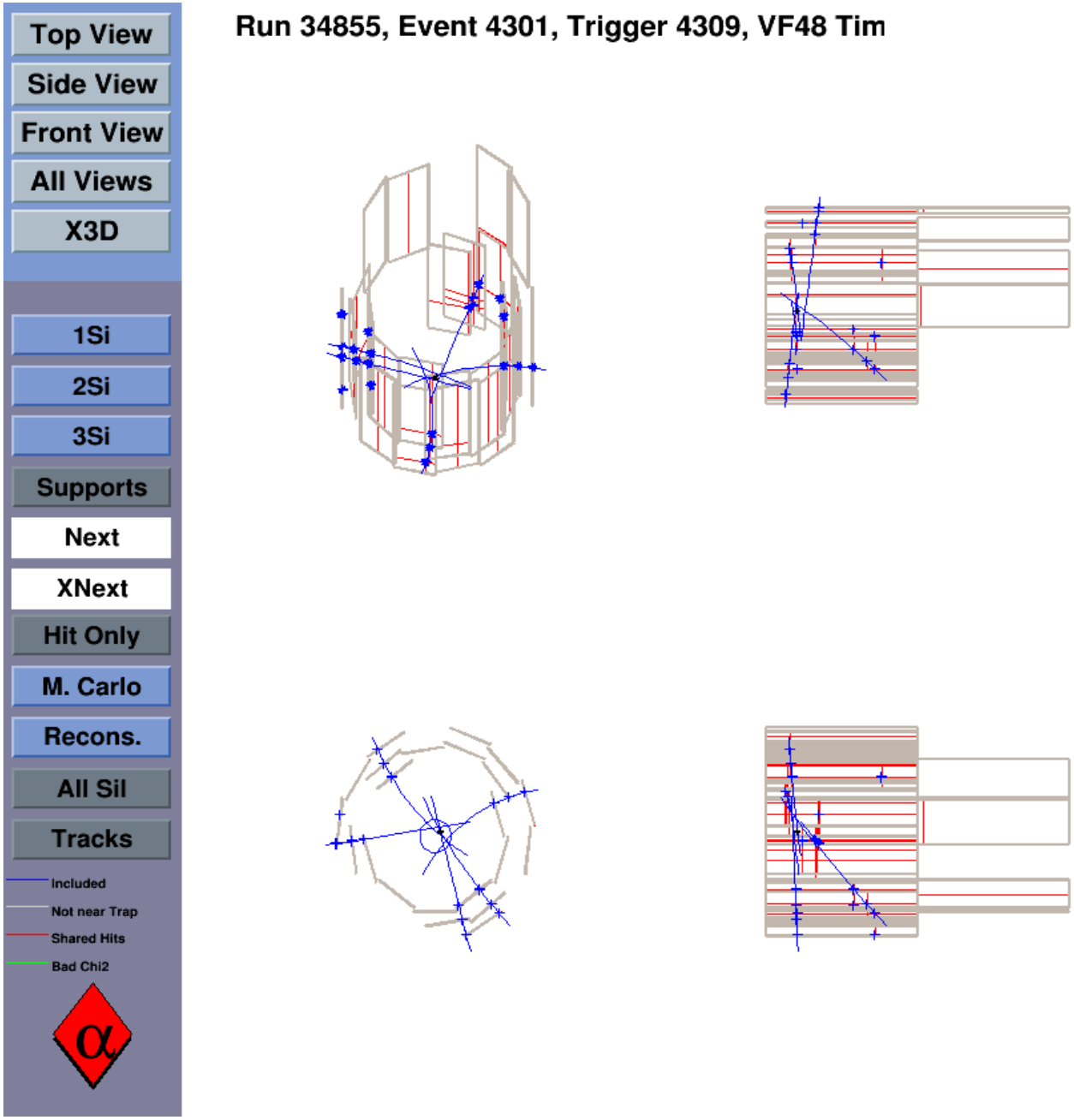
DAQ Scheme


Outer
Middle
Inner
LV patch
HV box
HV source
FRC LV
Power box
Power units
VME
VF48
TTC
VF48

Annihilation event as seen by the SVD

- We achieve spatial resolution of ~6mm

- cosmic background can be rejected down to mHz level



Brief history of antihydrogen

- 1995 Antihydrogen produced at CERN's 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 trapped antihydrogen (ALPHA)

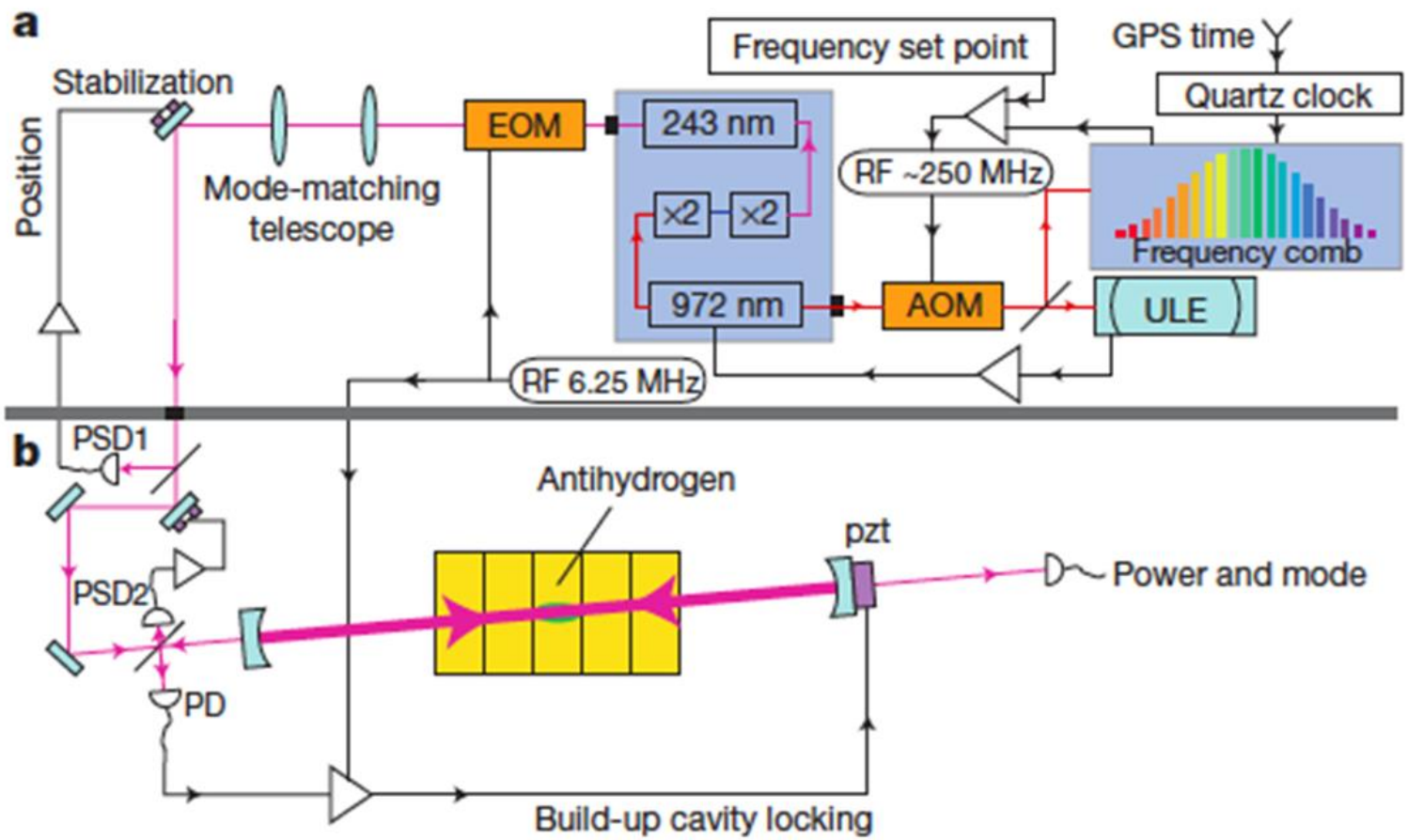
ALPHA highlights paving way for precision measurements of the properties of antihydrogen

- 2010 Trapped Antihydrogen, *Nature* **468**, 673–676 (02 December 2010)
- 2011 Confinement of Hbar for 1000 seconds, *Nature Physics* **7**, 558–564 (2011)
- 2012 Resonant quantum transitions in trapped antihydrogen atoms, *Nature* **483**, 439–443 (22 March 2012) & observation of the hyperfine spectrum in antihydrogen, *Nature 548, 66–69 (03 August 2017)*
- 2013 Description and first application of new technique to measure the gravitational mass of antihydrogen*, Nature Communications*, **4**, 1785 (2013)
- 2014 & 2016 An experimental limit on the charge of antihydrogen *Nature Communications* **5**, 3955 (2014), *Nature* **529**, 373–376 (2016)

ALPHA 1 => ALPHA 2 (Laser access)

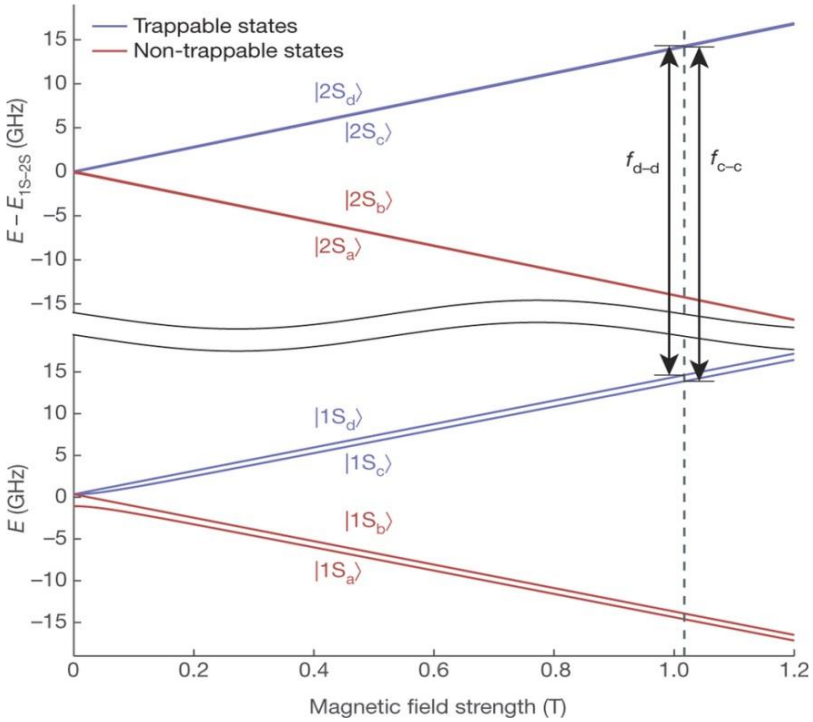
- **2017 Observation of the 1S–2S transition in trapped antihydrogen,** *Nature* **541**, 506–510 (26 January 2017) – First laser probe on antihydroden.
- 2018 Characterization of the 1S–2S transition in antihydrogen, Nature (doi: 10.1038/s41586-018-0017-2).

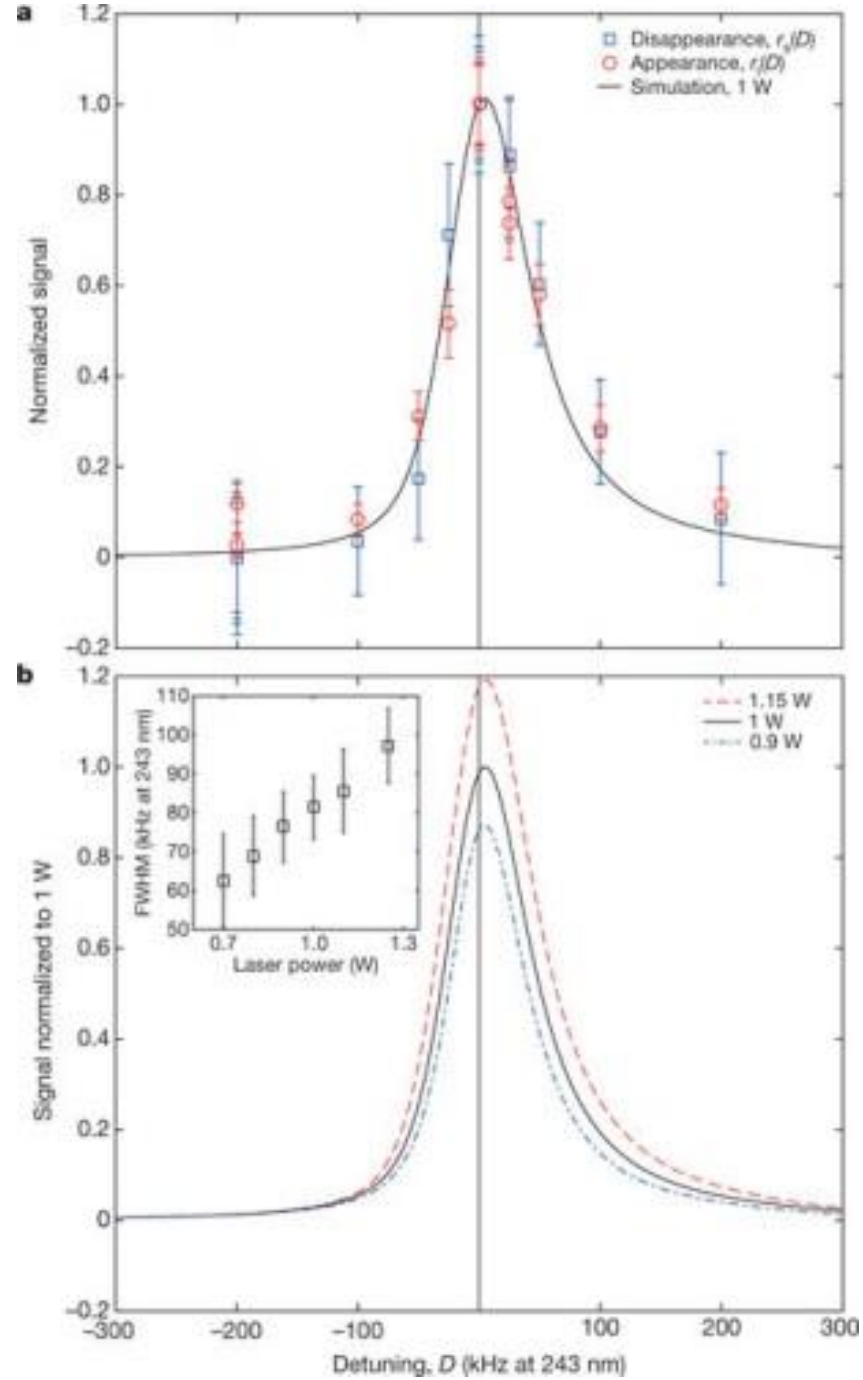
ALPHA-2 1S-2S Laser



243 nm CW UV –laser. Beam directed through the neutral atom trap. Locked in the enhancement cavity. Estimated continuous power 1W. Additional 121nm laser also installed

1S-2S Spectroscopy



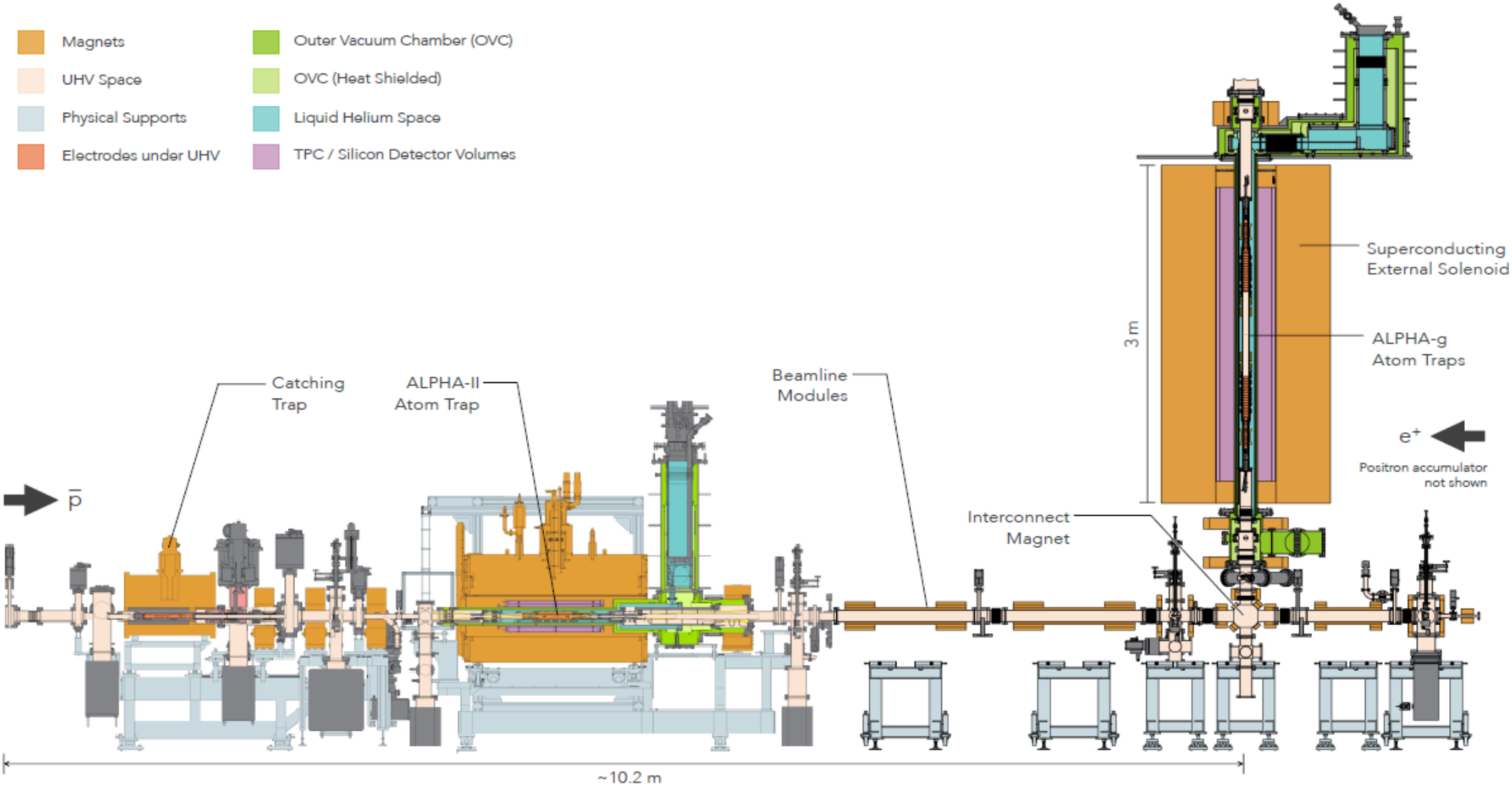


Antihydrogen exposed to 243 nm ~1W CW laser for 300 s. After this the neutral trap 'magnetic bottle' is released in 1.5s fast magnet ramp down. Results indicate antihydrogen 1S-2S atomic transition is the same compared to hydrogen with relative precision of 2x10-12. Physics run 2018 => further lineshape measurement for improved precision

Conclusions

- After 10 years of operation ALPHA produced the first element in the anti-periodic table and manages to trap and manipulate cold neutral antihydrogen and examine it in a well established and controlled way
- ALPHA 2 facilitates lasers of 243nm, 121nm and μ-wave access
- ALPHA uses a unique Silicon Vertex Detector which is capable of recording single atom annihilation events
- First optical measurements of 1S-2S Antihydrogen atomic transition => Ongoing: Optical lineshape measurement for enhanced precision and preparing for antimatter gravity measurements

ALPHA –g layout



Thank you for your attention!