The ATHENA Experiment

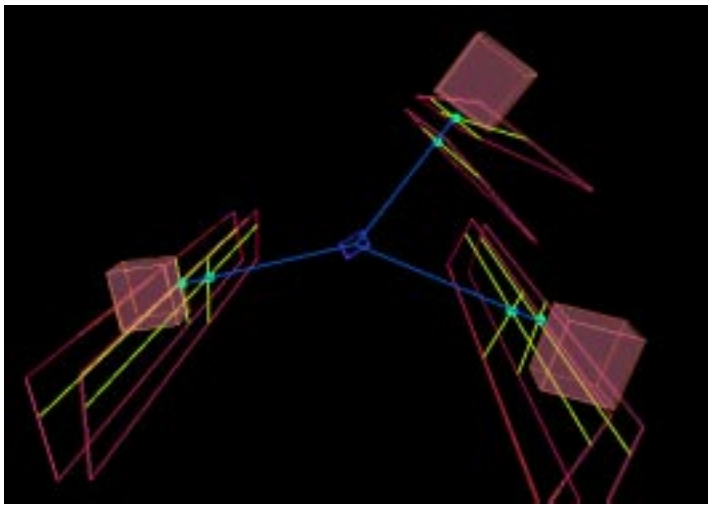
Blois

20 June 2002

Michael Doser / CERN

e^+ ACCUMULATOR

ANTIHYDROGEN DETECTOR

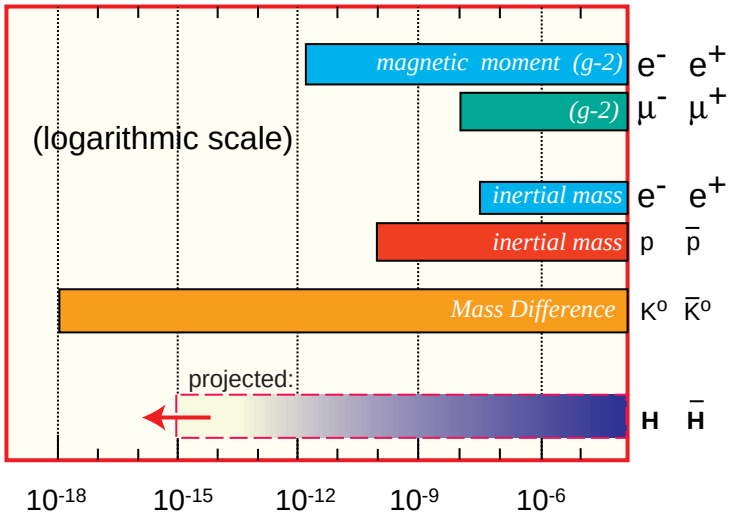


Overview - Goals

1) Produce slow antihydrogen atoms
2) Compare properties of hydrogen and antihydrogen with very high precision

Any local quantum field theory, obeying Lorentz invariance and usual spin-statistics connection → CPT Invariance ✶ ✶ ✶

Some of the most precise CPT Tests



Overview - Collaboration

Athena / AD-1 Collaboration

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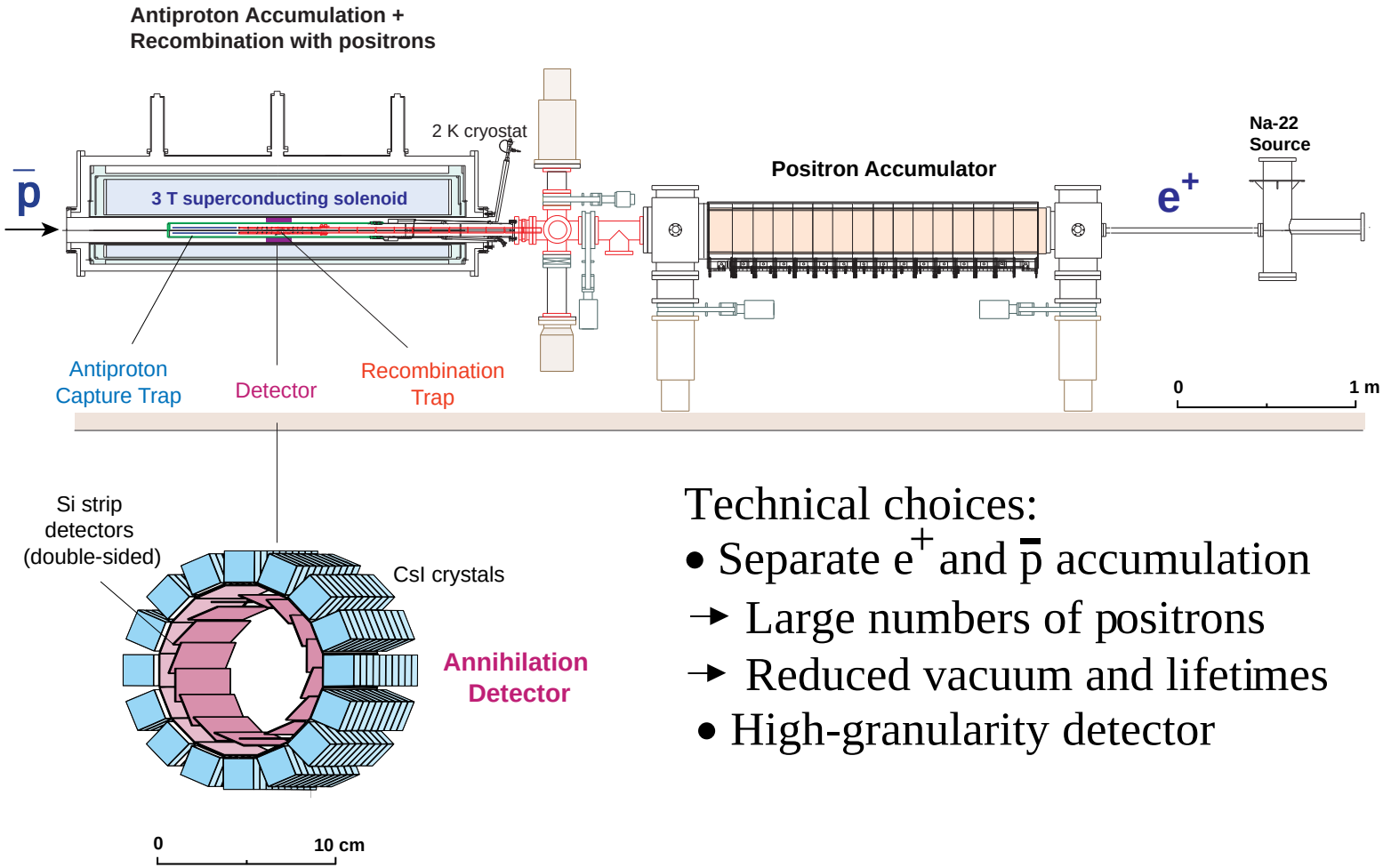
Overview - Apparatus

ATHENA / AD-1 : Antihydrogen Production

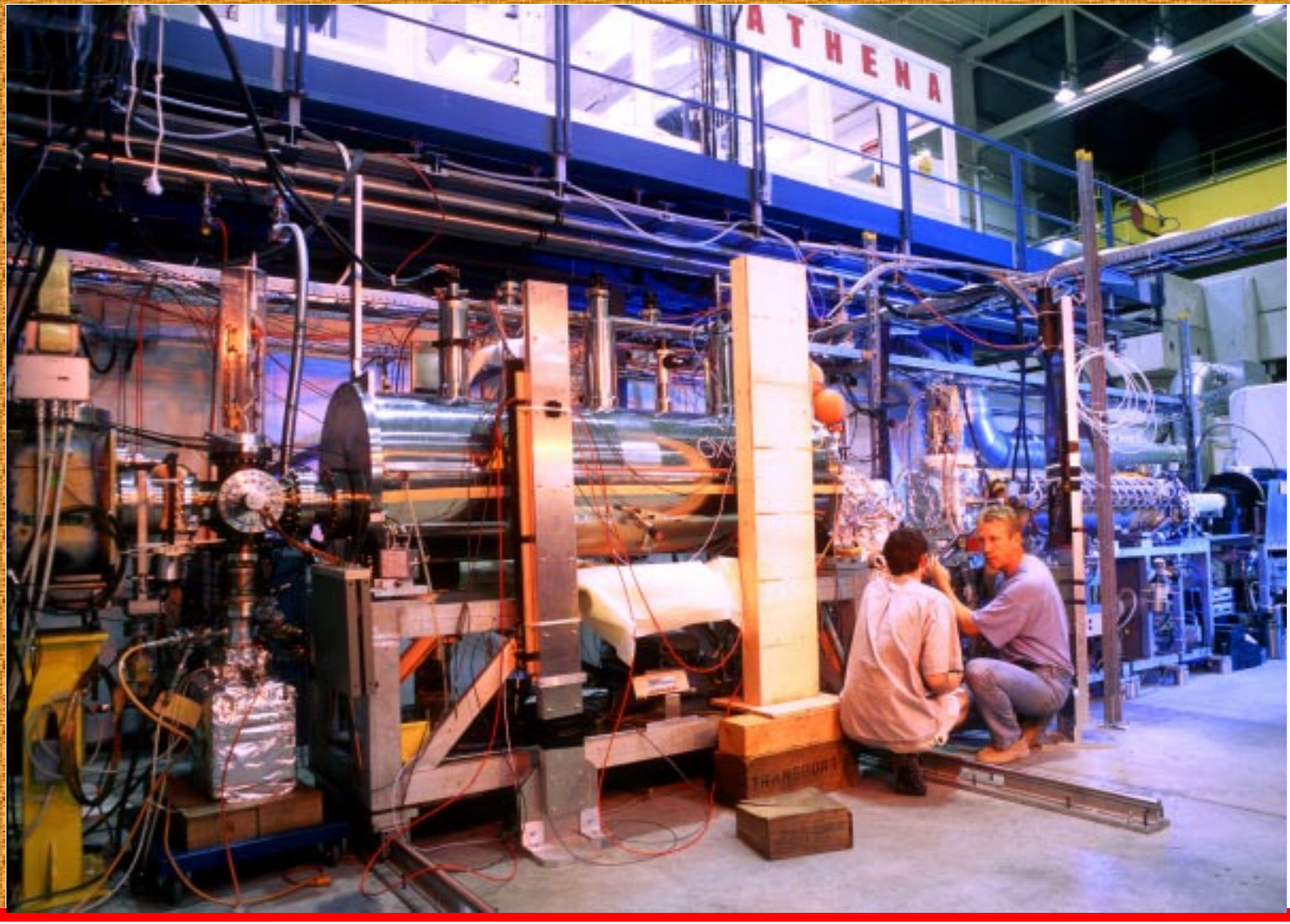


Technical choices:

- Separate e^+ and $\bar{p}$ accumulation
  - → Large numbers of positrons
  - → Reduced vacuum and lifetimes
- High-granularity detector

Overview - Apparatus

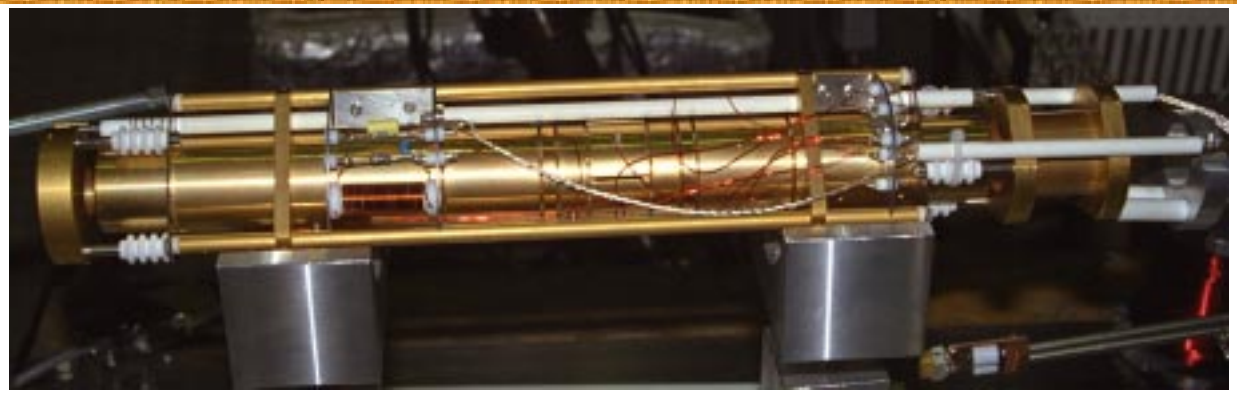
- **Overview**
- **Antiprotons**
  - **Capture**
  - **Cooling**
- **Positrons**
  - **accumulation rate**
  - **transfer**
  - **lifetime**
- **Detector**
  - **Tracking**
  - **511 keV**
- **Summary**
- **Outlook**



Principal achievements 2001

- $2 \cdot 10^4$ antiprotons captured and cooled in antiproton capture trap
- These antiprotons transferred and captured in recombination trap
- Multiple AD shots stacked without significant losses
- 150 million positrons accumulated per 5 minute cycle
- 25 million positrons stored in recombination trap for several hours
- Antihydrogen detector fully commissioned
- Antiproton vertex resolution $\sigma \sim$ 3-4 mm ("antiproton tomography")
- 511 keV peak from positrons observed *in situ*

Antiprotons - Capture and Cooling



Antiproton capture trap

5.3 MeV antiproton bunch from AD

Degrading (± 4 μ Al)

Capture

- switch to - 5 kV in 200 ns
- 20,000 antiprotons / AD shot (ε ~10^{-3})

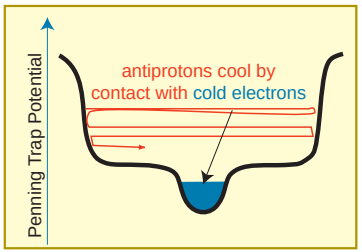
Cooling with electrons (τ ~ 20-30 s)

Stacking of four AD shots

- no significant losses

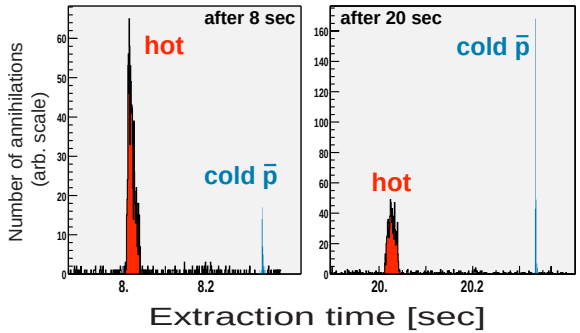
Transfer to recombination trap (ε = 80 %)

⇒ Proposal target achieved



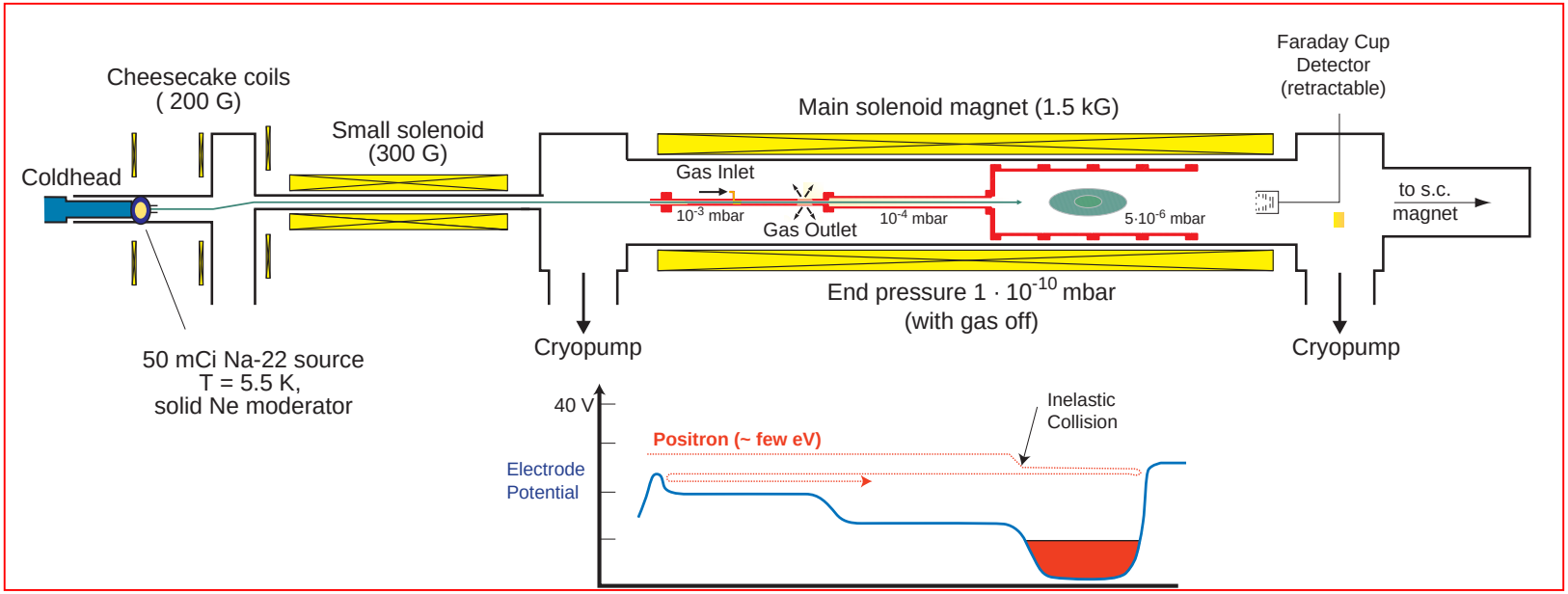
Electron cooling of antiprotons

Antiproton Capture + Cooling



Positron Accumulation (1)

- High rate, stand-alone positron accumulator (~ 10^6 e^+/sec)
- Positron moderation: solid Ne layer and buffer gas (N_2)
- **1.8 GBq** (50 mCi) Na-22 source
- **improved tuning** of capture parameters
- **plasma compression** with rotating wall



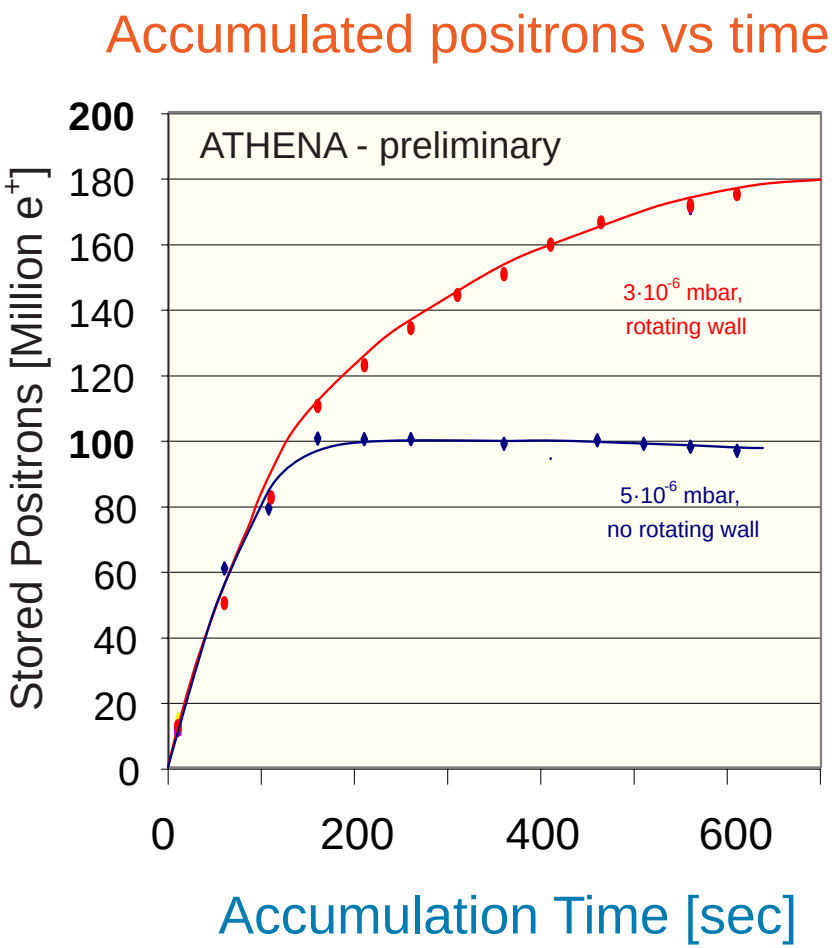
Scheme of ATHENA Positron Accumulator

Positron Accumulation (2)

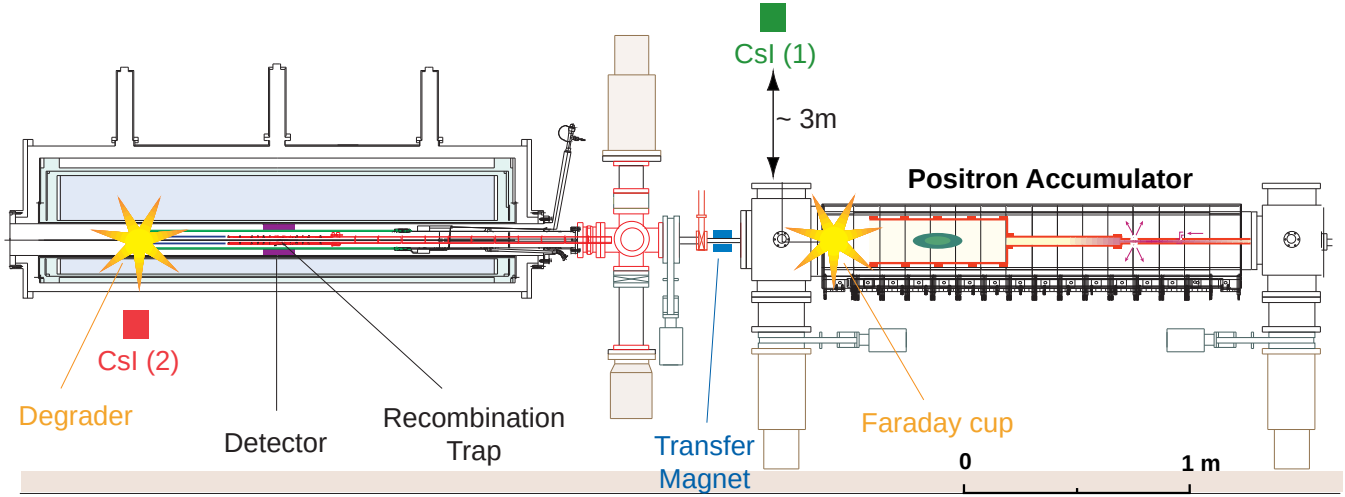
- **Accumulation rate ~ 10^6 e^+/sec**

- With rotating wall compression:
  - **150 M positrons stored per 5 min**
  - Up to 200 M positrons in trap

- Without rotating wall:
  - 100 M positrons stored per 3 min



Positron Transfer

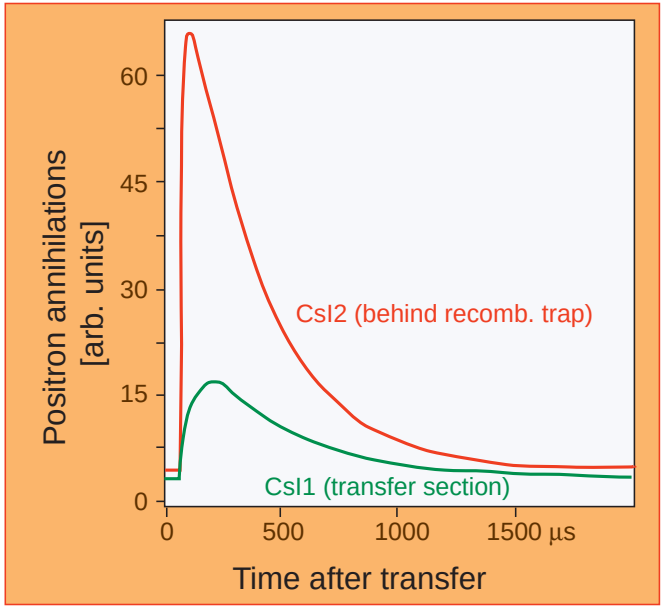


Scheme of positron transfer efficiency measurements

- **Transfer**
  - accelerate positrons ~ 20 V
  - pulse transfer magnet (1.2 T)
  - monitor CsI counters 1, 2

- **Result:**

  > 50 % transfer efficiency

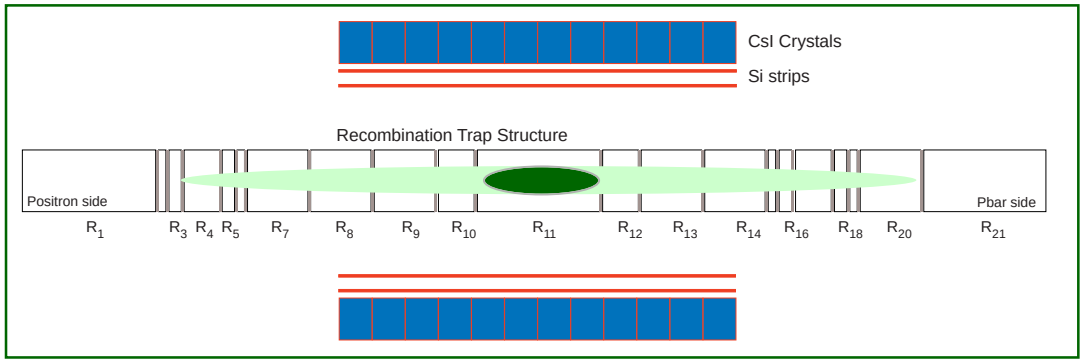


Positrons in recombination trap

- **Capture**

switch end electrodes ~ 3μs after injection

"squeeze" into center



Recombination trap and antihydrogen detector. In green, positron cloud after injection (light) and compression (dark)

- **Positron Lifetime**

several hours (harmonic potential)

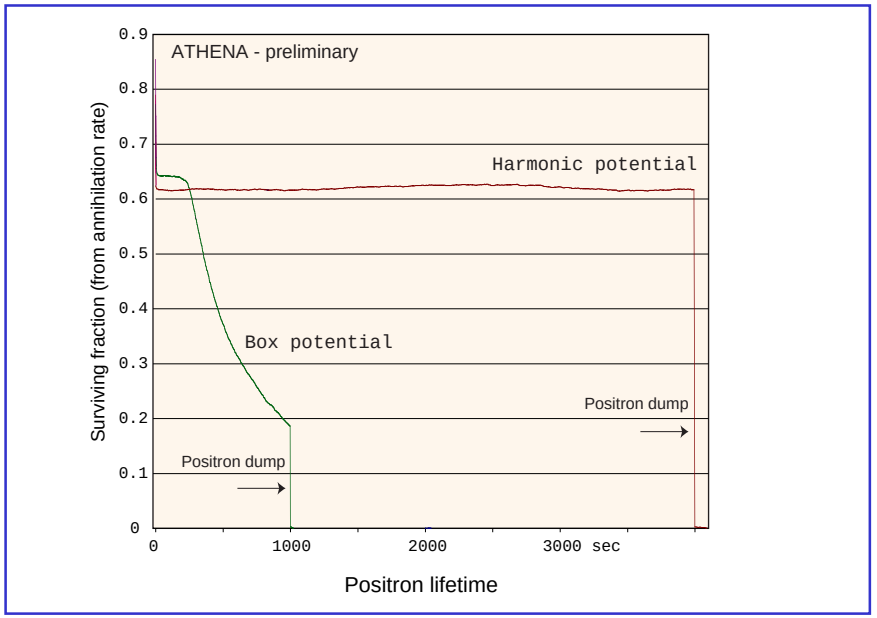
- **Diagnostics**

Tuned circuit

Collective modes ("drive and read")

Extraction on Phosphor screen + CCD

Extraction on Faraday cups



Antihydrogen Detector

GOAL

Vertex from tracking of charged particles

Identification of 511 keV gammas

Time- and space coincidence of tracks + gammas

High rate capability (trigger: 1 MHz, readout: 100 Hz)

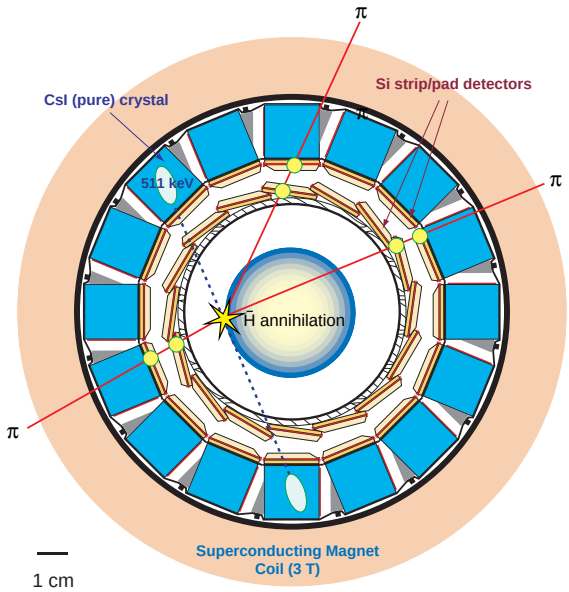
DESIGN

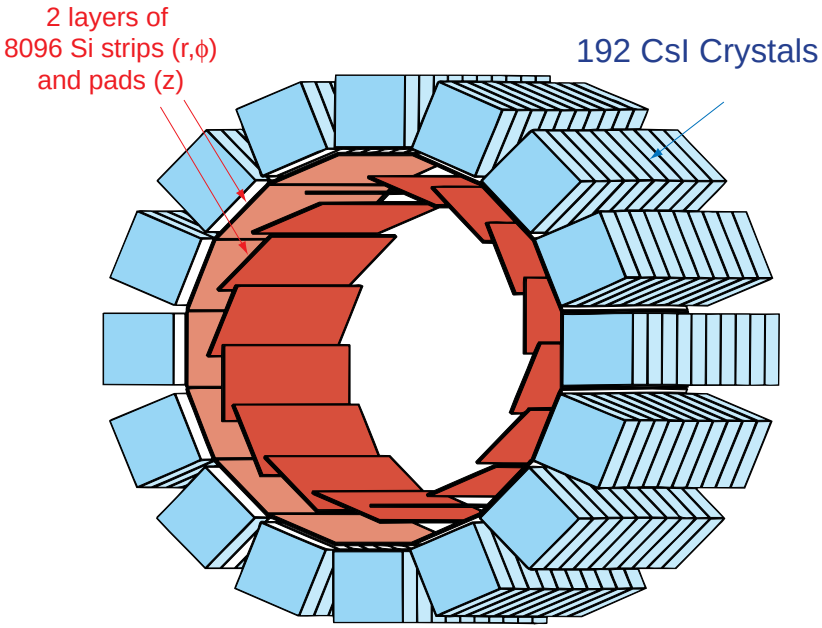
Compact (radial dimension ~ 3 cm)

Large solid angle (> 70 %)

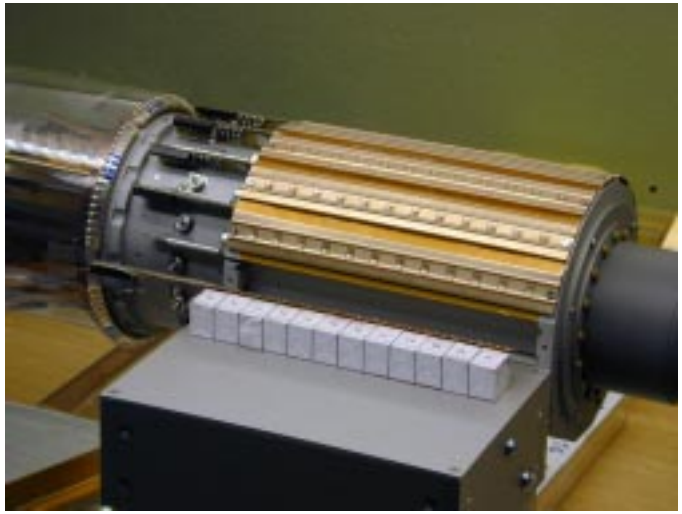
High granularity (8 K strips, 192 crystals)

Operation at T ~ 140 K, B = 3 Tesla





Antihydrogen Detector - R&D, Installation



Low temperature behaviour?

Significant R & D on low temperature effects of:

- light yield of pure CsI (**50,000 photons / MeV @ 80 K**,
  to be compared with 3,200 / MeV @ 300 K)
- expansion coefficients (kapton, silicon, ceramics)
- electronic components (capacitors, amplifiers**)**

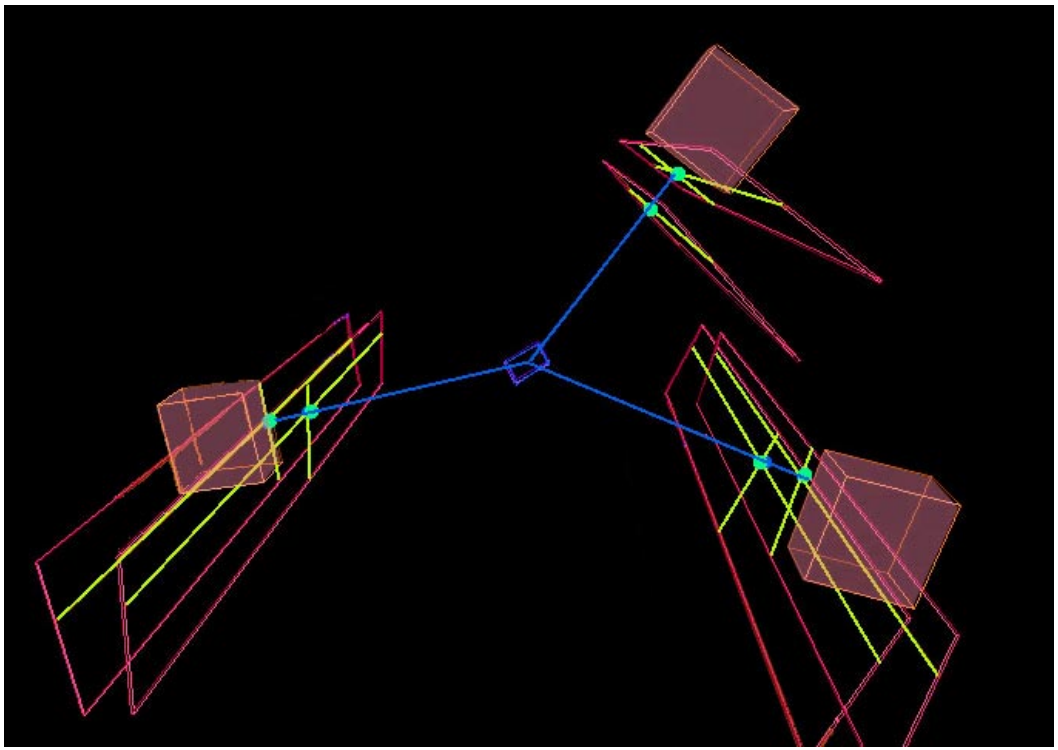
Full detector installed and commissioned Aug. 2001

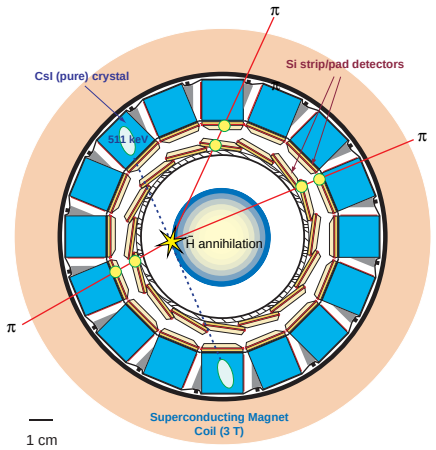
Crystal readout upgrade (better S:N) March 2002

Antihydrogen Detector - Antiprotons

Antiproton Annihilation (example)

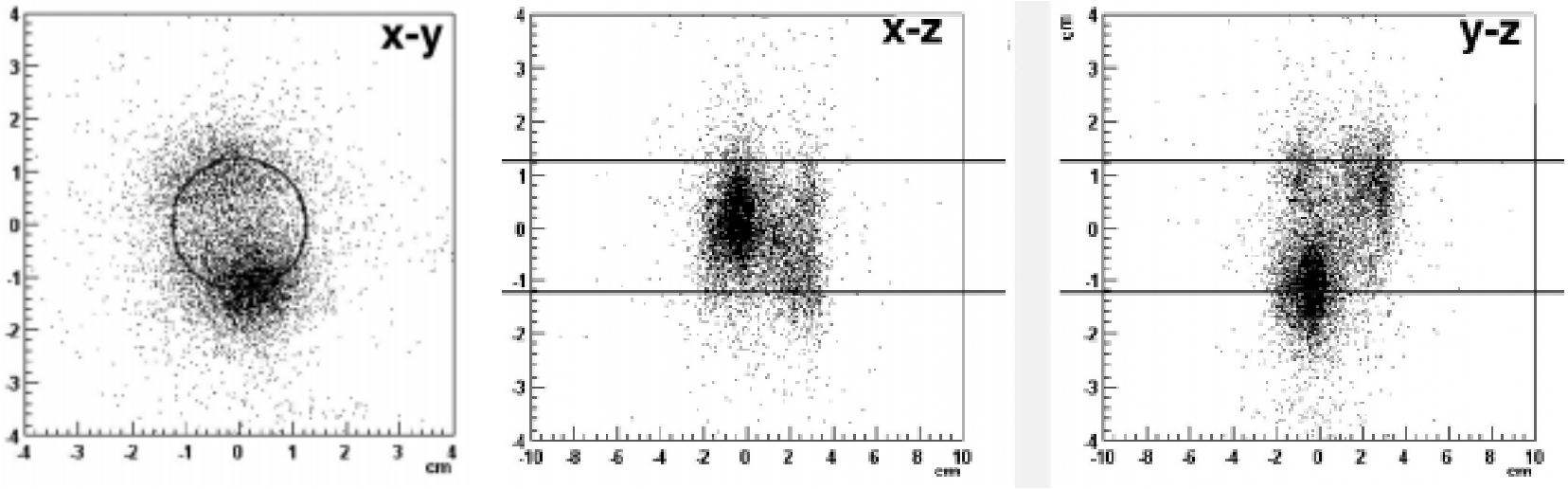
- into three charged particles
- hits on strips (r-phi) and pads (z) , inner/outer layer
- 3 crystals hit by tracks
- vertex reconstruction σ ~ 3-4 mm (curvature @ 3 T)





Antihydrogen Detector - Tomography

"Antiproton Annihilation Tomography" (AAT)



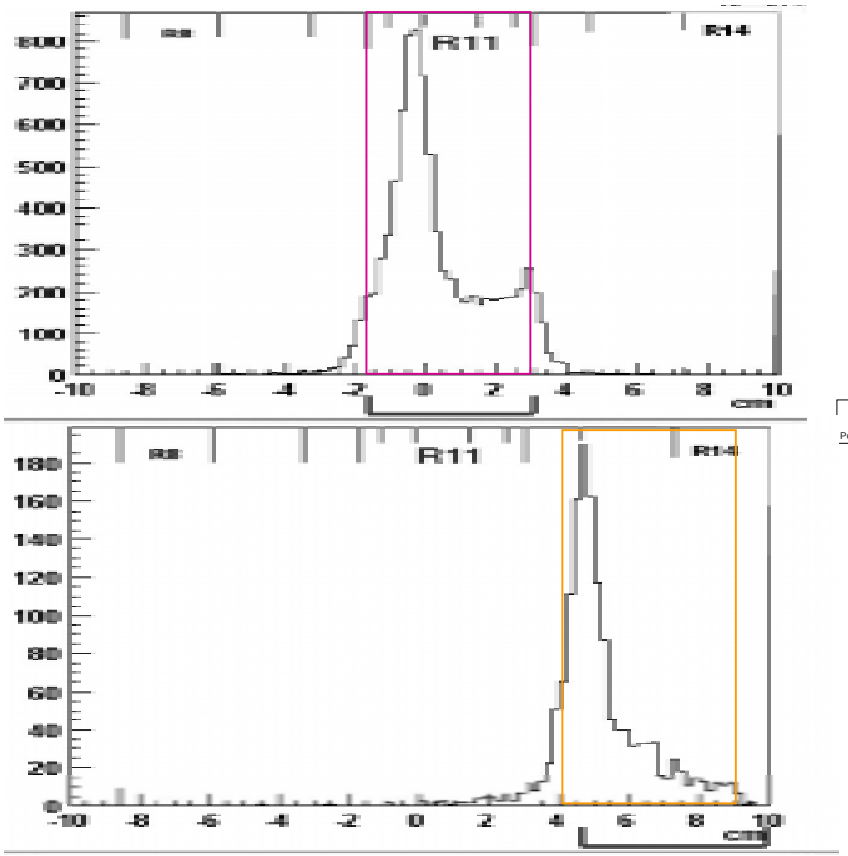
Transverse view **Side view** **Top view**

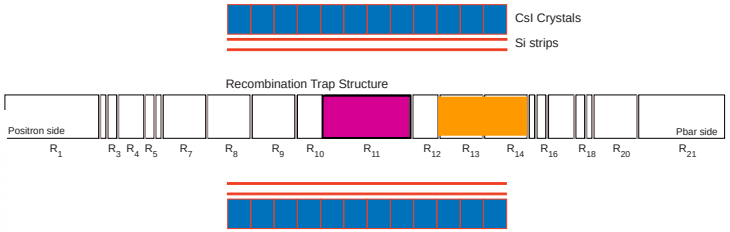
Antiproton cloud expands - antiprotons annihilate on local microscopic elevations of trap electrodes on their tangential trajectory

Antihydrogen Detector - Z Position

- Overview
- Antiprotons
  - Capture
  - Cooling
- Positrons
  - accumulation rate
  - transfer
  - lifetime
- Detector
  - Tracking
  - 511 keV
- Summary
- Outlook

Monitor shifts in antiproton position along z-axis





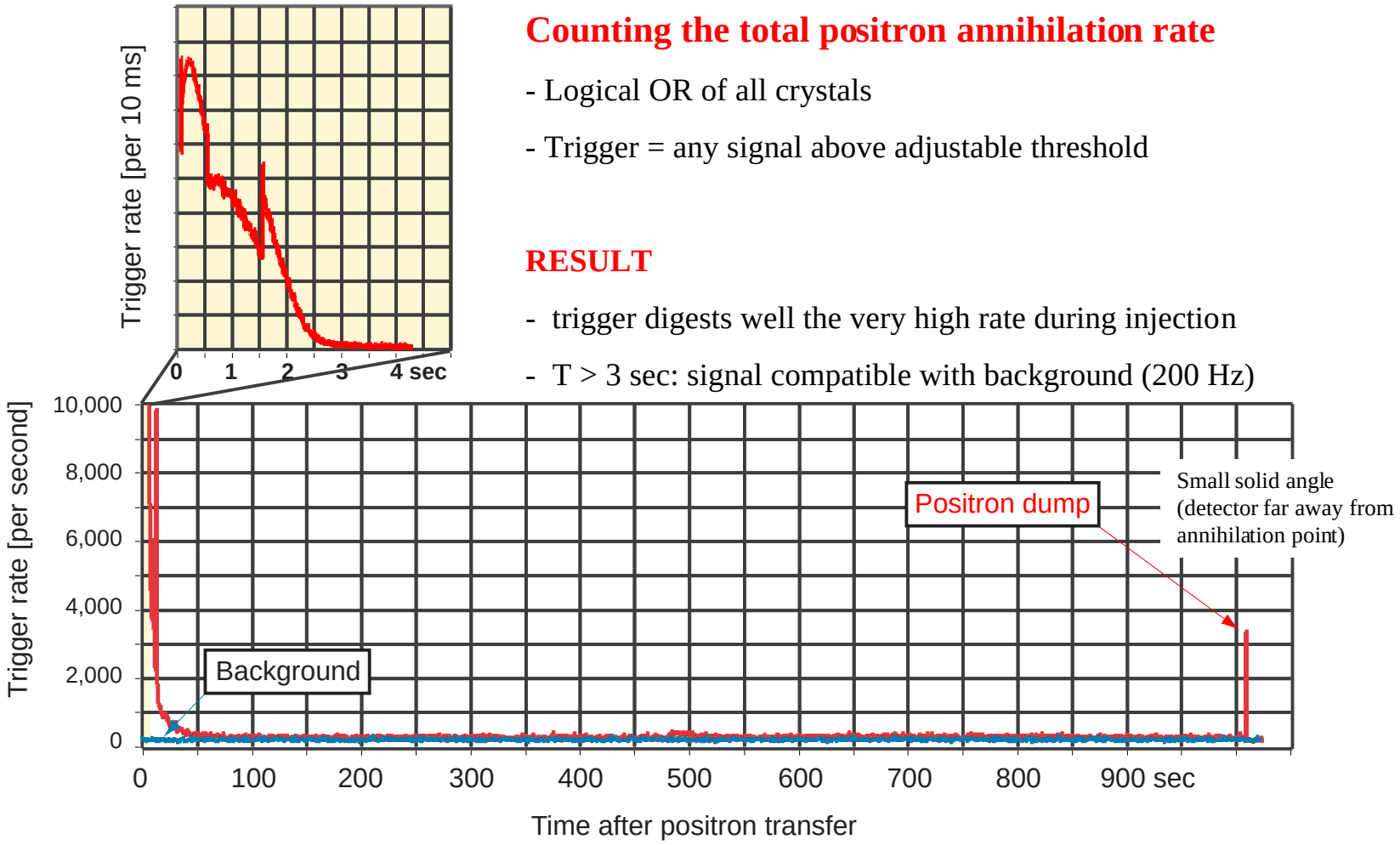
Antihydrogen Detector - Positron Trigger

Counting the total positron annihilation rate

- Logical OR of all crystals
- Trigger = any signal above adjustable threshold

RESULT

- trigger digests well the very high rate during injection
- T > 3 sec: signal compatible with background (200 Hz)

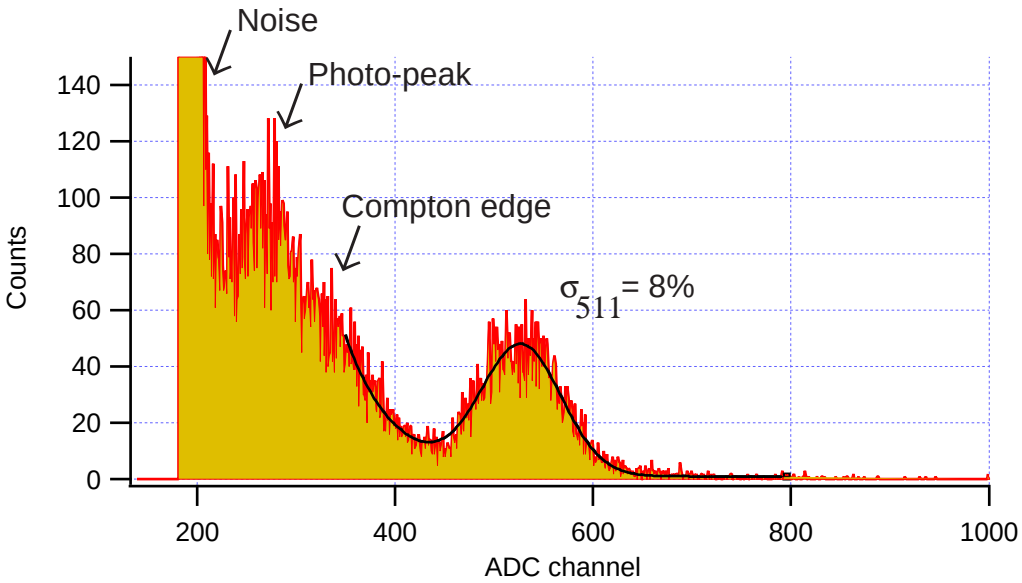


Positron annihilation rate in calorimeter

Antihydrogen Detector - Gamma Energy

Energy spectrum of CsI crystal

- Clear peak at 511 keV, Compton edge, photo peak
- Good separation from background; Signal:Noise ~ 100
- Sufficient for clean antihydrogen detection
- uses avalanche photodiodes (10x improvement over photodiodes)

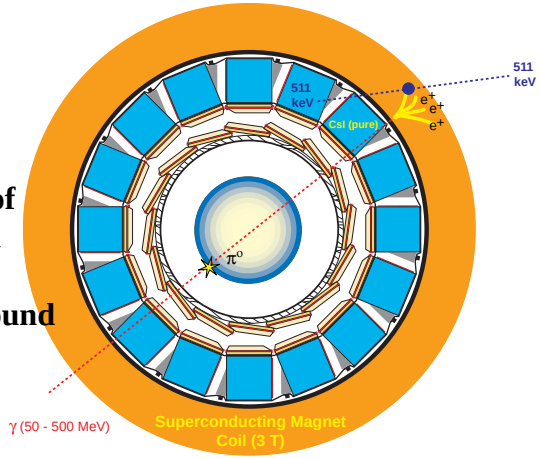


Antihydrogen - Background

511 keV background from antiproton annihilation

- Antiproton annihilation produces neutral pions
- Decay gammas (5-500 MeV) convert in magnet
- Secondary positrons in shower annihilate
- Homogeneous, coincident 511 keV background
- Fake 'antihydrogen' events !

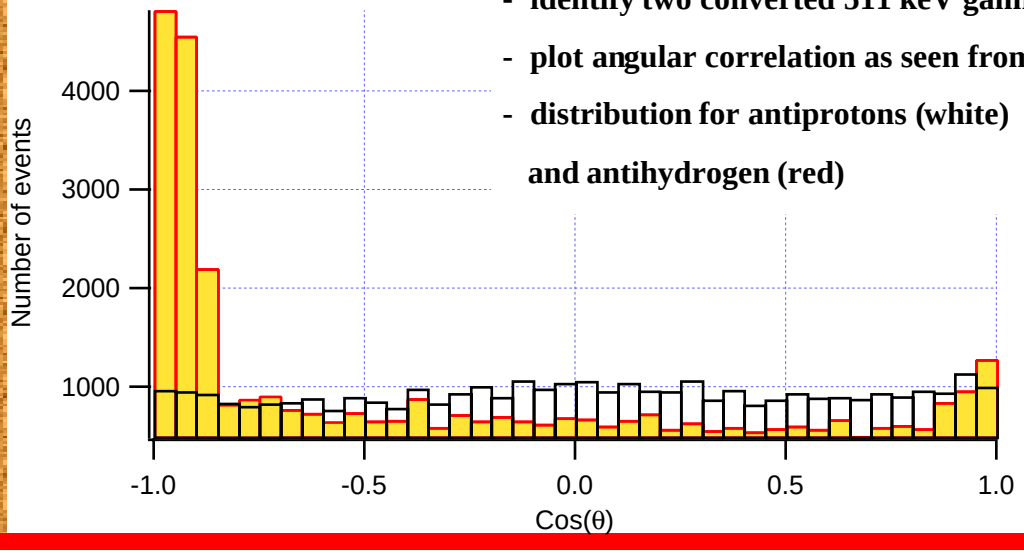
Origin of 511 keV background



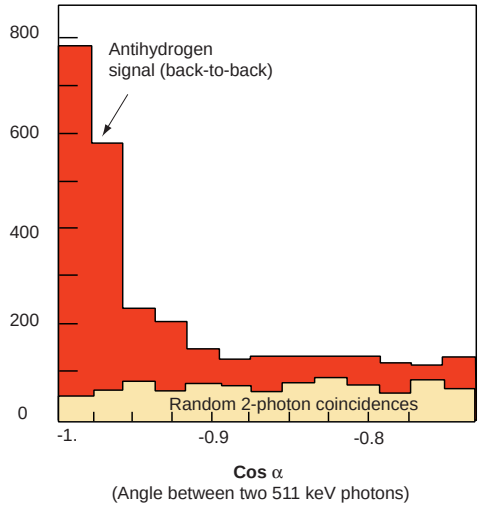
Antihydrogen signal

- measure charged vertex position
- identify two converted 511 keV gammas
- plot angular correlation as seen from vertex
- distribution for antiprotons (white) and antihydrogen (red)

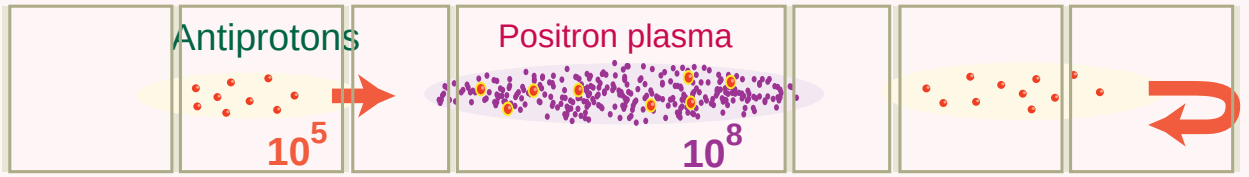
^{22}Na measurement



MC simulation result



Antihydrogen Recombination



Recombination by driving antiprotons through positron plasma

- **spontaneous recombination has small cross-section -> many repetitions needed**
- **antiprotons loose kinetic energy (~ 1 - 50 meV) for each crossing**
- **get "stuck" in potential pockets outside positron plasma, if not driven out**
- **positrons are heated when antiprotons cross; plasma cools down "slowly" (~ 400 msec)**
- **Antihydrogen rate = balance between drive frequency and positron equilibrium temperature**

Summary

Current status of ATHENA:

All milestones needed for antihydrogen production are in reach:

- 10^5 antiprotons captured, stacked, cooled and transferred

$> 10^8$ positrons accumulated and transferred

- Several hours lifetime
- Detector measures charged tracks and identifies 511 keV gammas
- Plasma diagnostics tools are in place (destructive and non-destructive)
- Experiment started up last Thursday

Outlook

Main goals for 2002

- Store 10^5 $\bar{p}$ and 10^8 e^+ simultaneously in recombination trap (τ ~ hours)
- Drive antiprotons through positron plasma with f ~ 10 - 1000 Hz

  (but also try other recombination schemes)
- Provide unambiguous evidence for antihydrogen production
- Optimize formation rate
- Measure energy distribution of antihydrogen (fraction below 0.05 meV !)
- Installation of 1S-2S laser equipment (243 nm)

Resonant photo-ionization

- Antihydrogen is formed in positron plasma
- Emerges with ~ 1-100 meV
- Two photon excitation of 1S-2S transition

- In resonance - third photon absorption leads to ionisation
- Photo-ionized antihydrogen cannot escape trap
- Signal: Decrease of antihydrogen intensity in resonance