Proposed Laboratory Simulation of Galactic Positron In-Flight Annihilation in Atomic Hydrogen

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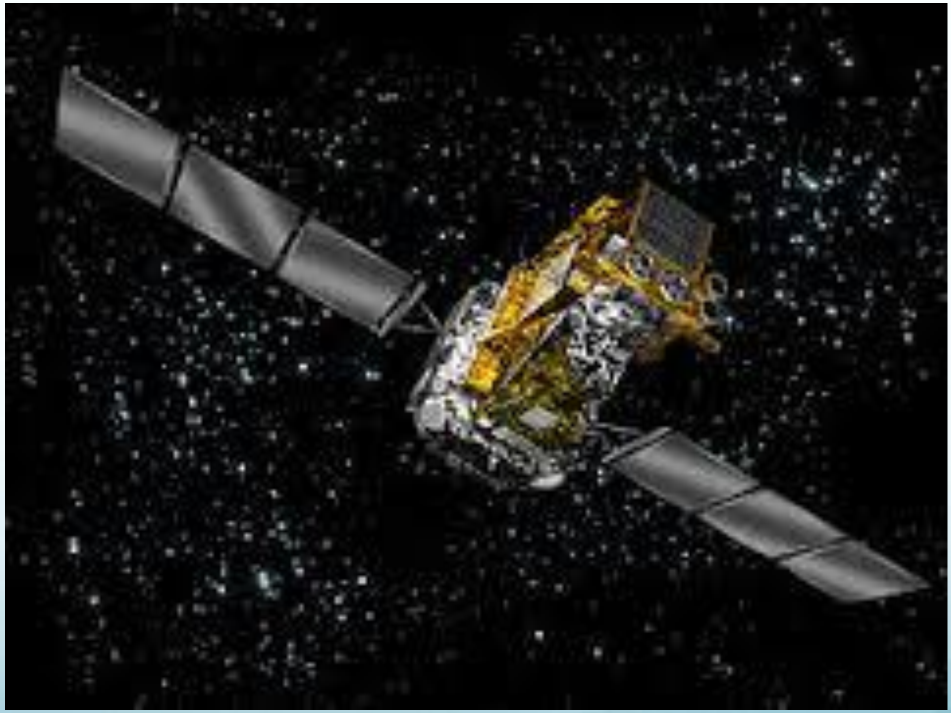
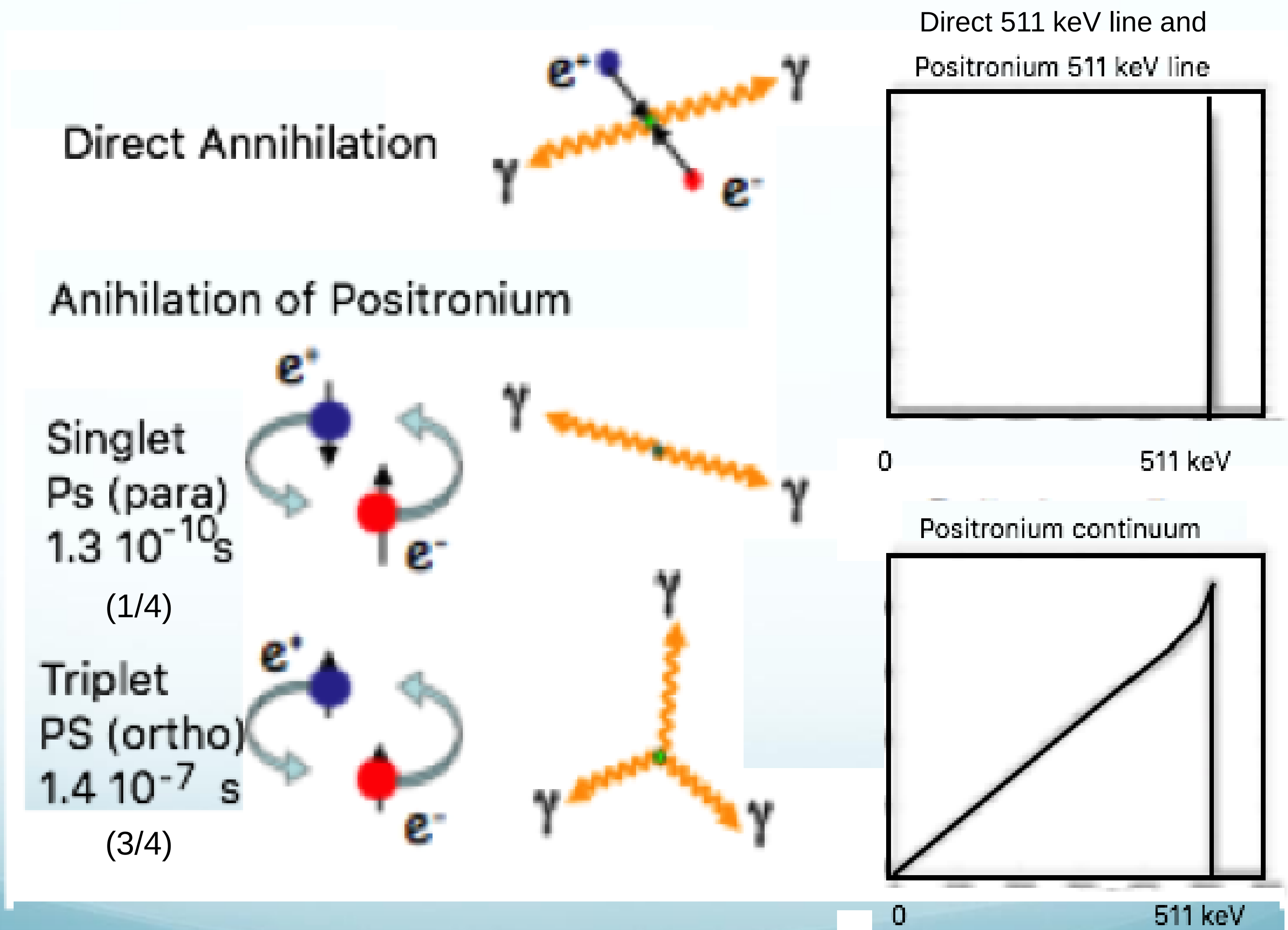
Positron annihilation gamma rays

Positron annihilation at 511 keV coming from the direction of the Galactic Center has been observed since the 1970’s with a succession of gamma ray balloons and telescopes. The most recent data from the SPI/Integral has mapped the galactic center at the 511 keV energy.



Positron/positronium annihilation



after Skinner, 2010

Galactic distribution of the 511 kev line

No. 2, 2010 *INTEGRAL* ANNIHILATION

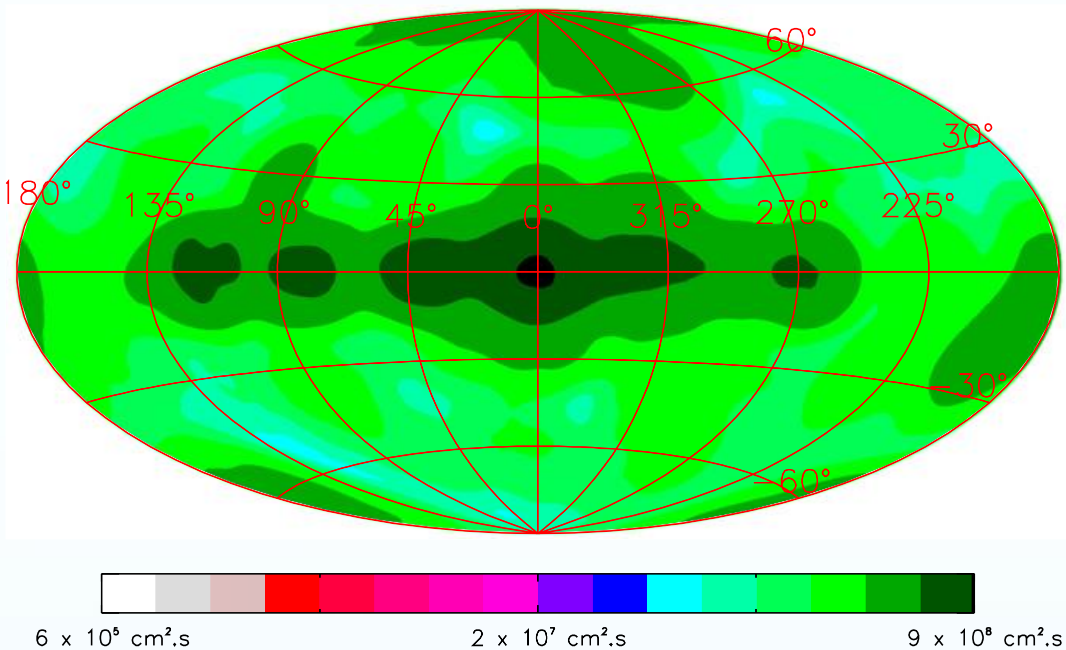
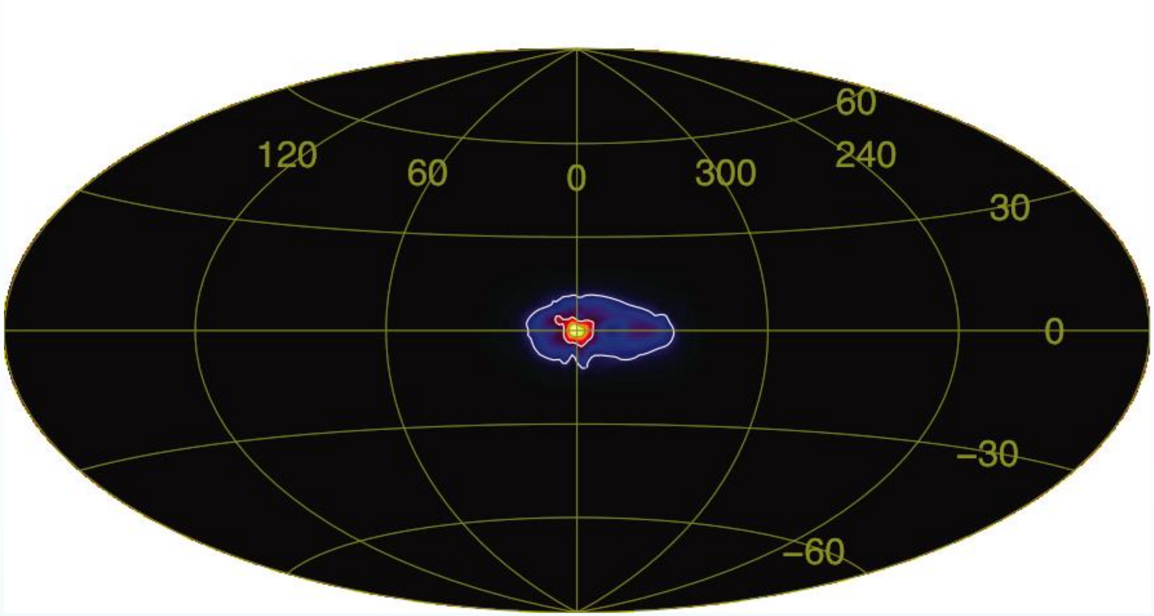


Figure 1. 508.25–513.75 keV *INTEGRAL* SPI exposure map. Units are in cm^2 × s. This map takes into account the differential sensitivity of SPI across its field of view.

(A color version of this figure is available in the online journal.) L. Bouchet, et al. 2010

The central galactic 511 keV ‘bulge’ and surrounding disk



Interpretation of the shape of the 511 keV line in terms of components warm ISM and Galactic continuum emission (Jean et al. (2006).

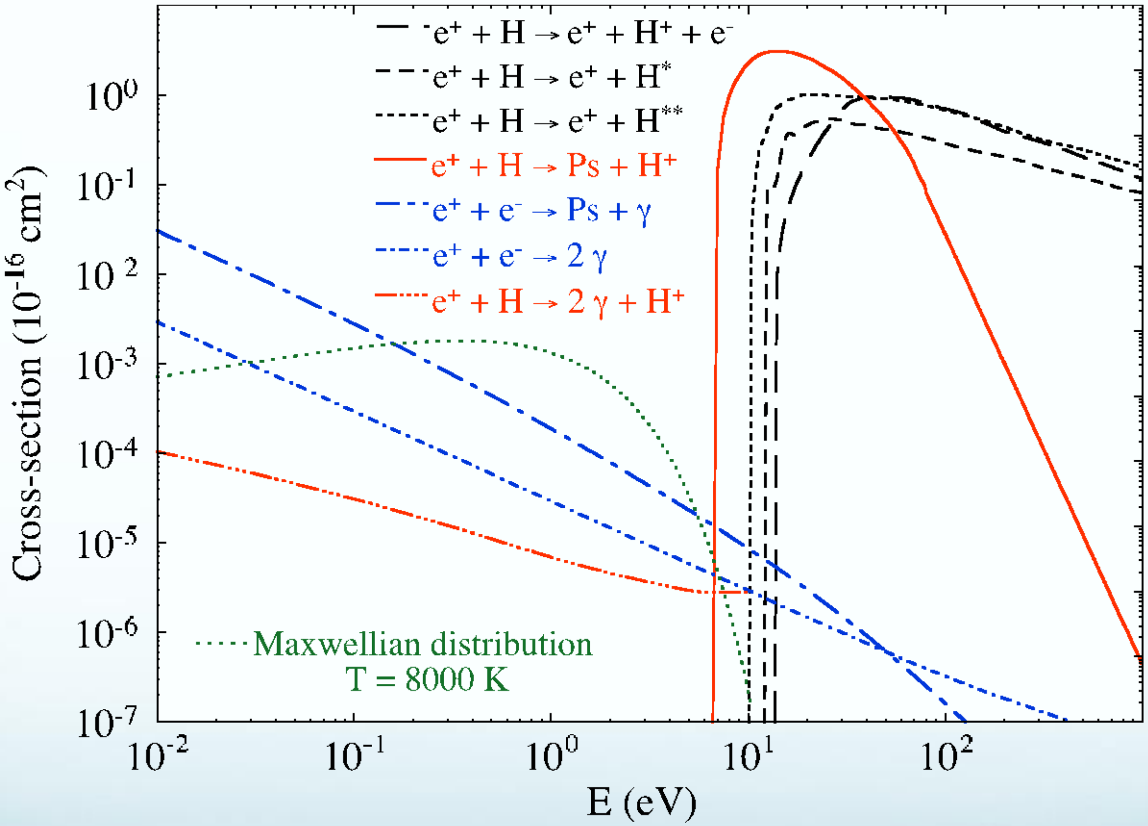
Is the source of positrons possibly high energy cosmic rays? Limits on initial positron energy are likely lower than 10 MeV.

- The flux of the narrow 511 keV line is ~ 10^{-3} photons s^{-1} cm^{-2} translates to to 1.2 x 10^{43} low energy positrons s^{-1}. Cosmic ray production is about 10 times lower, making this source unlikely

- Slow down of high energy positrons is not sufficient to stop positrons before escape from the galaxy. (Skinner, 2010)

- Radiation while slowing is not observed above 511 keV from slowing positrons. < 3 MeV (Beacom et al. 2006).

Interaction cross sections vs. incoming positron energy



Some possible annihilation channels for positrons

- In H, H_2, and He, in-flight Ps annihilation, occurs by charge exchange roughly below 100 eV as positrons slow by inelastic collisions from keV energies.

- Positrons surviving below Ps threshold can annihilate directly with atomic or free electrons

- Surviving positrons can also form Ps with sufficient energy from the Maxwellian thermal distribution. In either case the Doppler profile is narrow for temperatures $<10^6$ K.

Quantities of interest accessible in the laboratory

Three numbers are of interest which can be measured experimentally:

1. The width of the in-flight positronium Doppler broadened spectrum
2. The fraction of positrons that arrive below the Ps formation threshold
3. The Doppler width of the direct annihilation line.

The annihilation line-width of positronium formed by below threshold is thermal distributed. Bussard, et al. 1979.

Table of positron interactions and thresholds

Interaction	Threshold energy eV
---> $e^+ + H \rightarrow Ps + H^+$	6.8
$e^+ + H \rightarrow e^+ + e^- + H^+$	13.6
$e^+ + H \rightarrow e^+ + H^*$	10.2
$e^+ + H \rightarrow e^+ + H^{**}$	12.1
$e^+ + He \rightarrow Ps + He^+$	17.8
$e^+ + He \rightarrow e^+ + e^- + He^+$	24.6
$e^+ + He \rightarrow e^+ + He^*$	21.2
$e^+ + H^2 \rightarrow Ps + H_2^+$	8.6
$e^+ + H^2 \rightarrow e^+ + e^- + H_2^+$	15.4
$e^+ + H_2 \rightarrow e^+ + H_2^*$	12.0

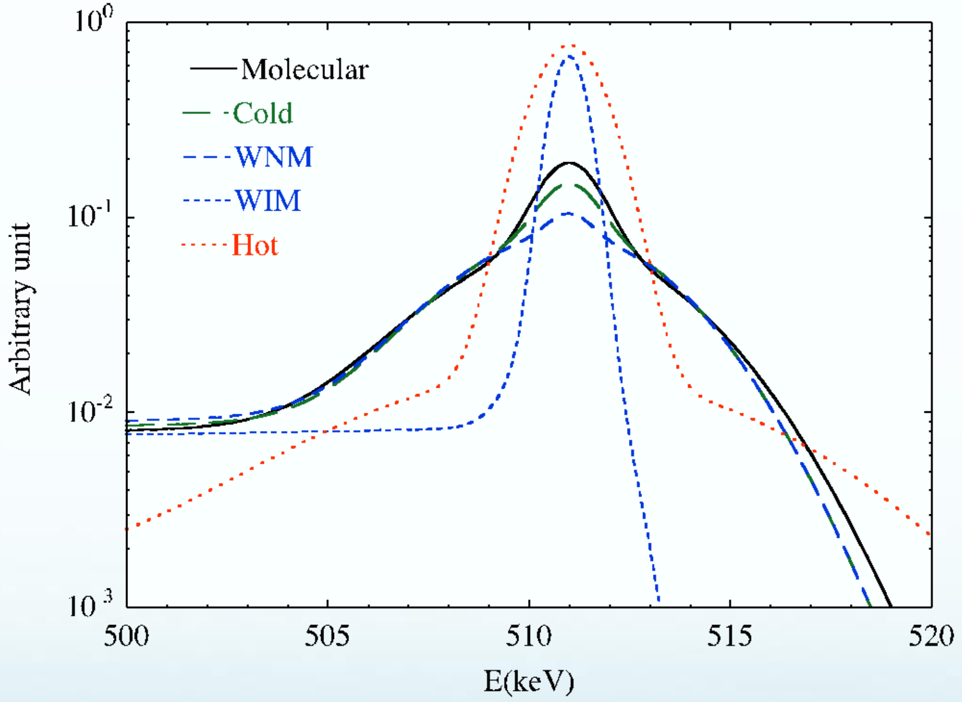
Percentage of positrons forming positronium in flight

	References	H	H_2	He
Monte Carlo	Bussard *et al.* (1979)	95	93	—
Laboratory measurement	Brown and Leventhal (1986)	—*	89.7 ± 0.3	80.7 ± 0.5
Monte Carlo	Wallyn *et al.* (1994)	98	90	—
Monte Carlo	Chapuis *et al.* (1994)	—	—	78
Monte Carlo	Guessoum *et al.* (2005)	95.5	89.6	81.7

Guessom et al. 2005

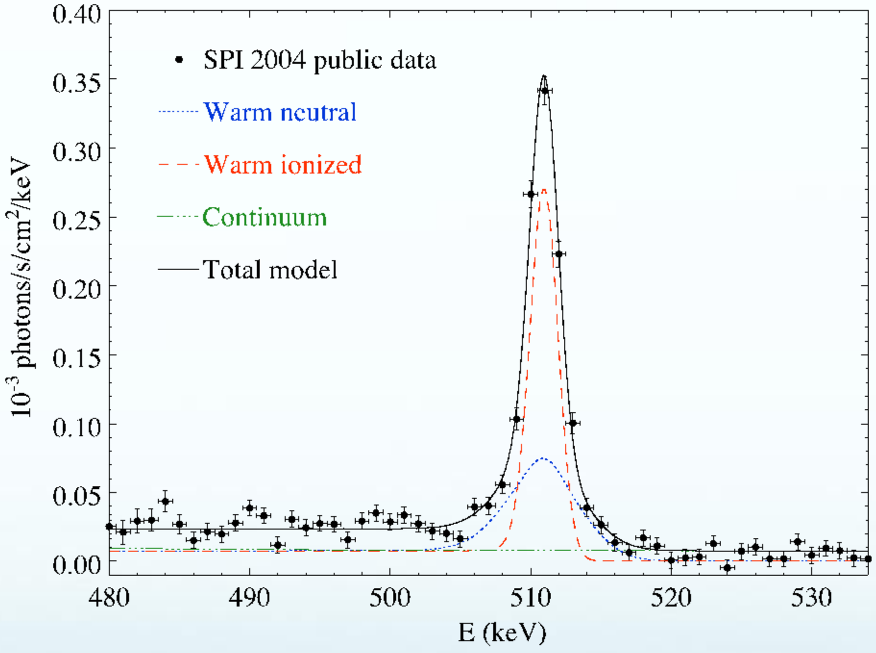
* A second planned experiment: to measure the surviving fraction of positrons in atomic hydrogen, which is 1 minus the percentage of positronium formed in flight.

Characteristic Doppler broadened spectra for various annihilation media (log scale)



The PSI/Integral annihilation spectrum at 511 keV

Fit to several annihilation spectrum models. These models are generally Monte Carlo simulation based on available cross sections for various interactions.



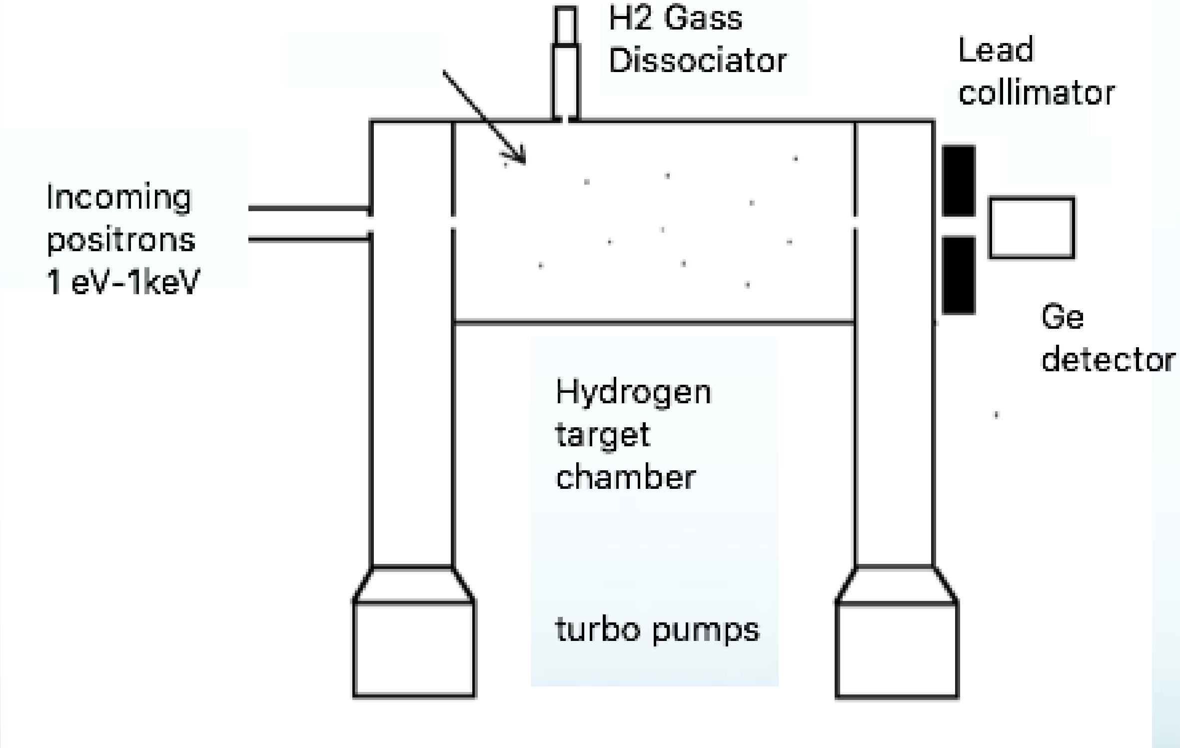
Jean, et al. 2006

Predicted 511 keV linewidths

* Experimental measurement proposed

Process / Medium	Cold & Molecular (T < 100 K)	Warm Neutral (T ~ 8000 K)	Warm Ionized (T ~ 8000 K)	Hot (T ~ 10^6 K)
Charge Exchange with H in-flight	5.8 *	5.8	--	--
Charge Exchange with H_2 in-flight	6.4 *	--	--	--
Charge Exchange with He in-flight	7.4 *	7.4	8.7	--
Charge Exchange with H after thermalization	--	1.16	--	--
Charge Exchange with H_2 after thermalization	--	--	--	--
Charge Exchange with He after thermalization	--	1.22	1.22	--
Direct Annihilation with H	1.56	1.56	--	--
Direct Annihilation with H_2	1.71 *	--	--	--
Direct Annihilation with He	2.50 *	2.50	2.50	--
Radiative Combination	--	--	0.98	11
Direct Annihilation with electrons	--	--	0.98	11
Positronium from grains	1.4	1.4	1.4	1.4
Annihilation in grains	2.0	2.0	2.0	2.0

Proposed experimental arrangement

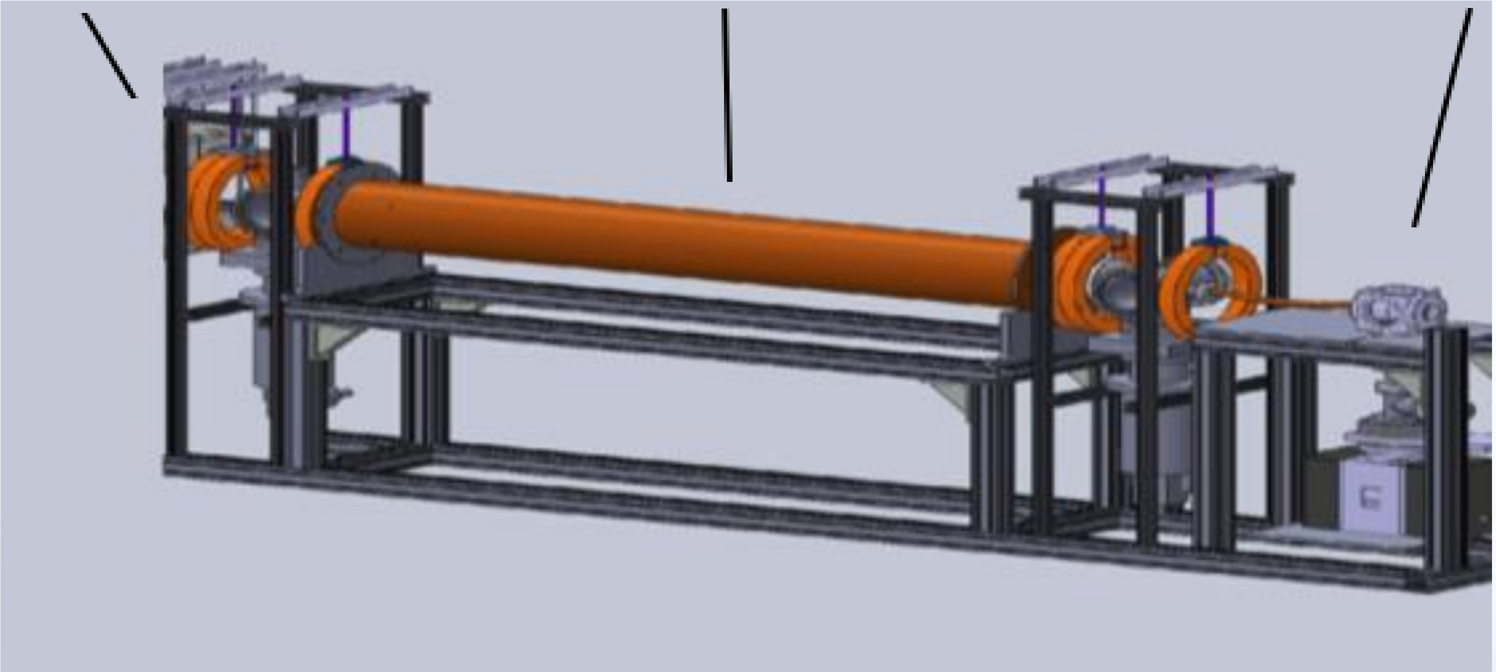


Incoming positron beam and Penning trap

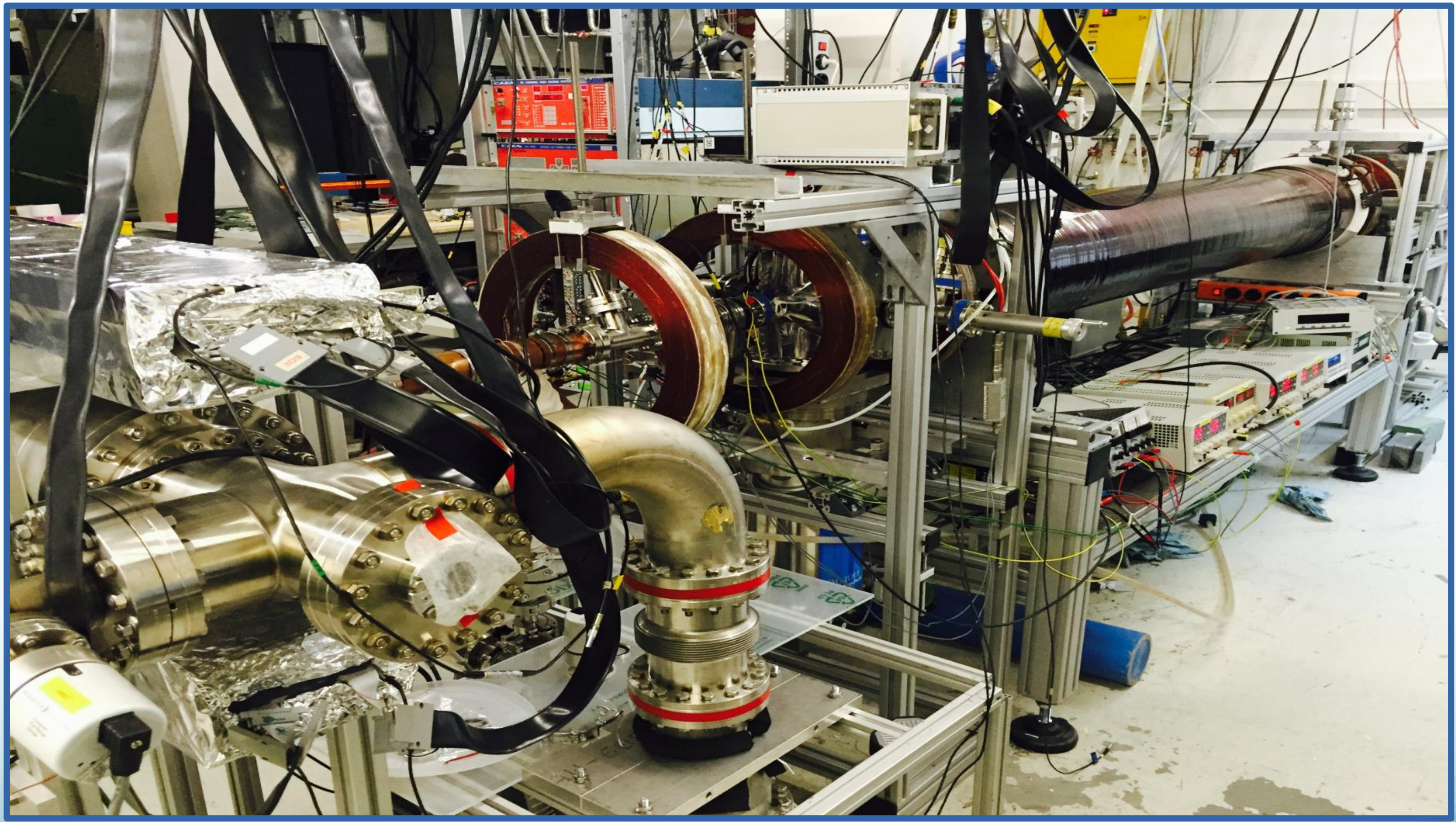
Pulsed positron beam at 1eV-1keV

Trap region solenoid 0.1 T

Solid Ne Moderated Na 22 Positron Source



Low energy positron beam and Penning trap



Positron-H ionization cross section measurements

There is a discrepancy of approximately a factor of two in the present laboratory measurements of the positron-atomic hydrogen impact ionization cross section, which affects the predicted in-flight annihilation line-width. This is further justification for the experimental measurement proposed here.

Figure 3. Positron impact ionization cross sections for aromic hydrogen: ○, present results; ● Spicher *et al* (1990). The line shows the e^- data of Shah *et al* (1987) for comparison.

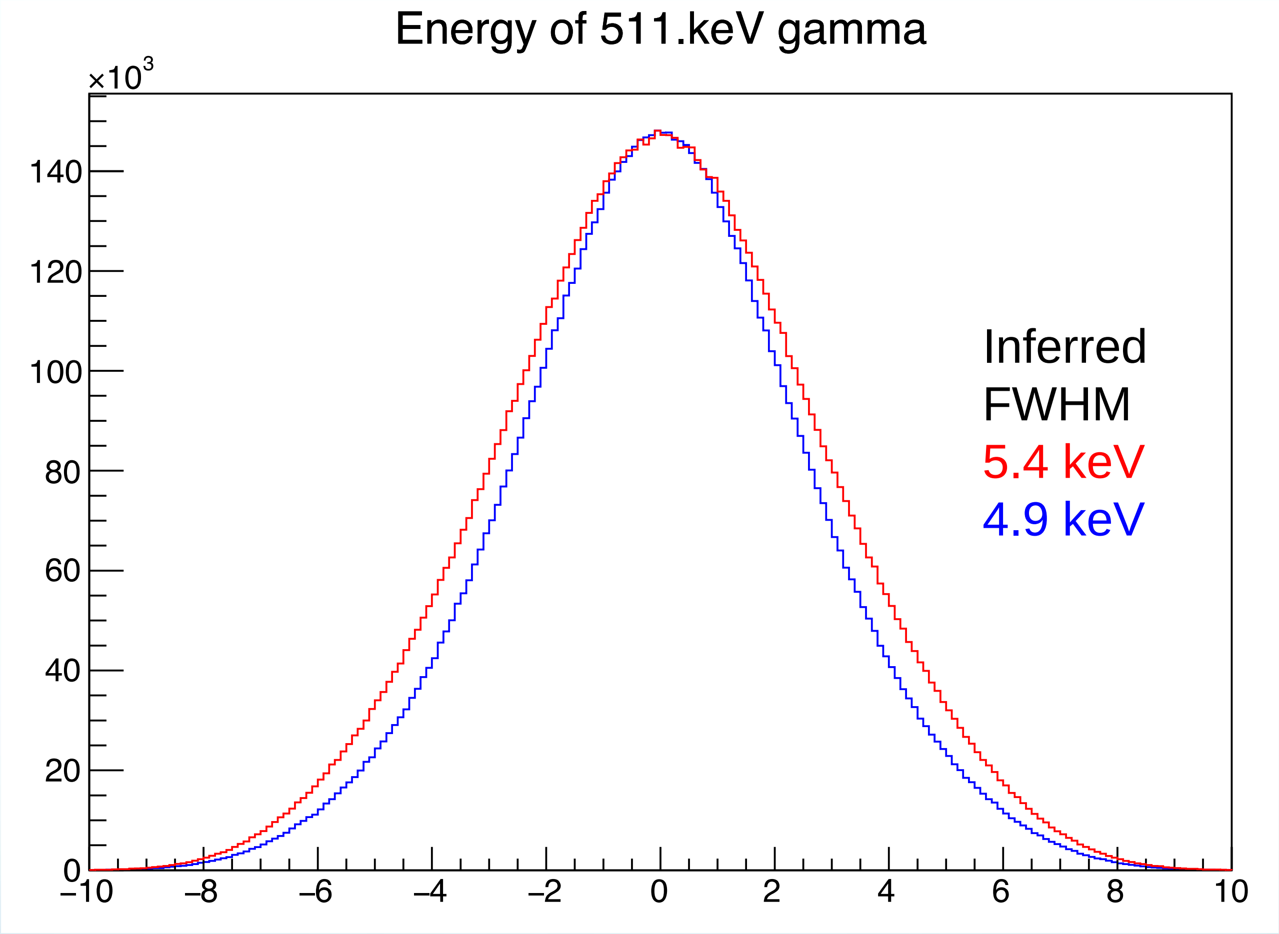
level, particularly below 300 eV. These may be due in part to variations in th 'projectile beam overlap. It is also notable that the energy spread of the e^- bean er than 5 eV FWHM, substantially broader than the 2 eV characteristic of the e^+ e overall agreement is satisfactory we have nevertheless included an additiona y of 10% in our e^+ results because of this discrepancy.

e 3 shows the present e^+–H ionization cross sections along with the earlier dat r *et al* (1990) and, for comparison, those for e^- by Shah *et al* (1987). Th sults diverge significantly from the earlier e^+ data at all energies above 30 eV sistently lower by factors varying from 30–80%. Comparing the results with th ding electron cross sections, the present data show an enhancement at the cros aximum of ~ 1.4× whereas the data of Spicher *et al* (1990) correspond to a facto Furthermore the present data show good convergence with that for e^- at energie an ~ 200 eV. This type of behaviour is similar to that found for other gaseou g. Fromme *et al* 1986, 1988, Knudsen *et al* 1990), although the apparent mergin

● Spicher, 1990

o Jones, Charlton, et al. 1993

Monte Carlo spectra for Positronium annihilation
(for Ps formed by charge exchange in H)



in keV units about 511 keV
smoothed with a Ge detector resolution 1.2 keV

Conclusion

Laboratory measurements of in-flight positron annihilation in H (atomic hydrogen) will be useful at this time to accurately predict this possible component of the Doppler broadened 511 keV annihilation radiation from the Galactic Center region.