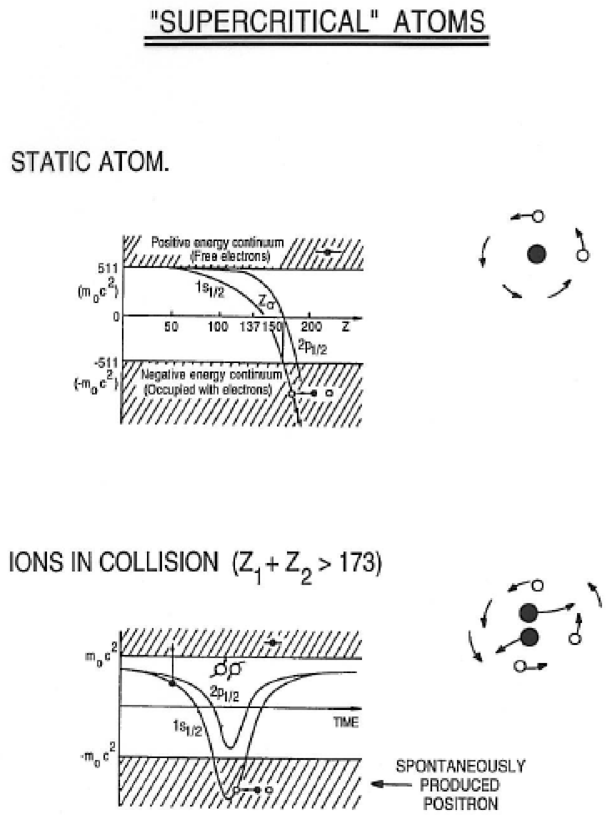
APEX
and the
Uranium Upgrade

Russell Betts

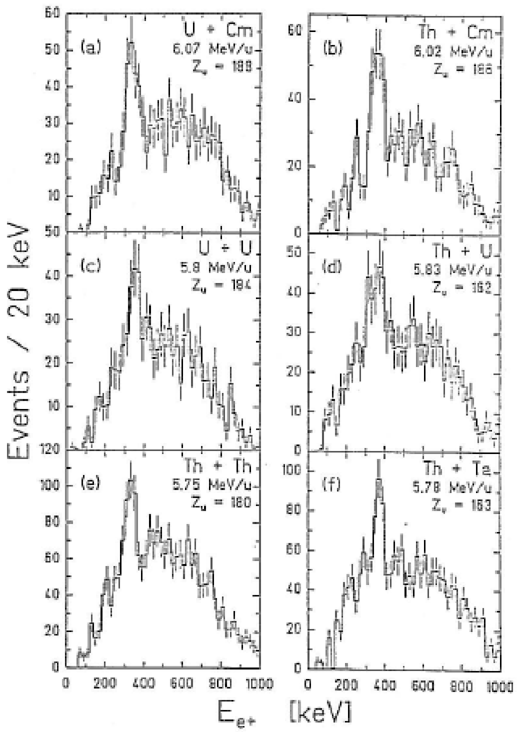
October 22nd , 2010
Physics Division
Argonne National Laboratory

High Field QED ($Z\alpha > 1$)

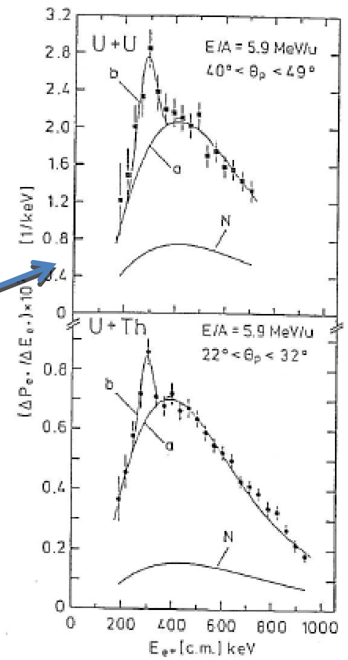


Vacancies Appear as Positrons Spontaneously and Dynamically Produced in Strong Time-Varying EM Fields

GSI Experiments
Singles Positrons

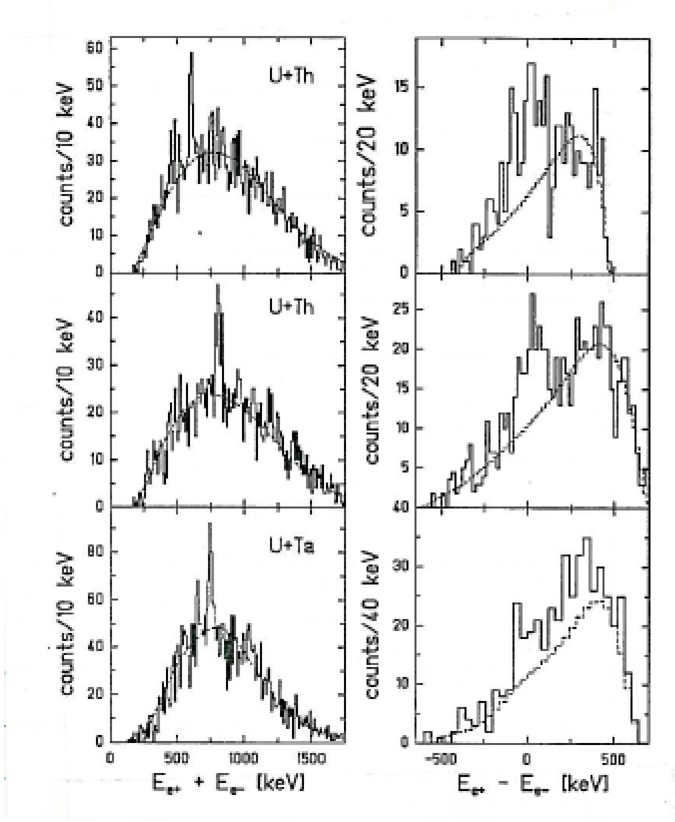


EPOS
and
ORANGE
Experiments



Monoenergetic Emission from Slowly Moving Source ??

GSI Experiments
Coincidence e^+ e^- Pairs



Sharp Sum Energy Lines
Decay of Slow Moving
Neutral Object (M~2MeV)
into Near-Equal-Energy
Back-to-Back Pairs

New Light Scalar Particle ??
Continuum State of Positronium ??
Exotica ??

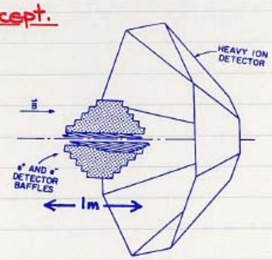
The ATLAS Uranium Upgrade

- ECR Source for High Charge State Uranium
- Lo-β Linacs – Novel Resonator Designs
- Injecting into Existing ATLAS
- ATLAS Positron Experiment (APEX)
  - Large Solid Angle and Efficiency
  - Excellent e^+ e^- Separation (1 in 10^5)
  - High Resolution in Energy and Angle for e^+ e^-
  - Heavy Ion Scattering Measurement
  - High Data Rate (10pnA U)

RB, DG and JS go to see Dave Hendrie

TECHNICAL CHALLENGES.

Possible Concept.



2m DIAMETER SOLENOID

8,000 cm^2 Si DETECTOR

32,000 CHANNELS

EXCELLENT ENERGY RES^{N}

EXCELLENT TIME RES^{N}

- STATE-OF-THE-ART IN ELECTRONICS

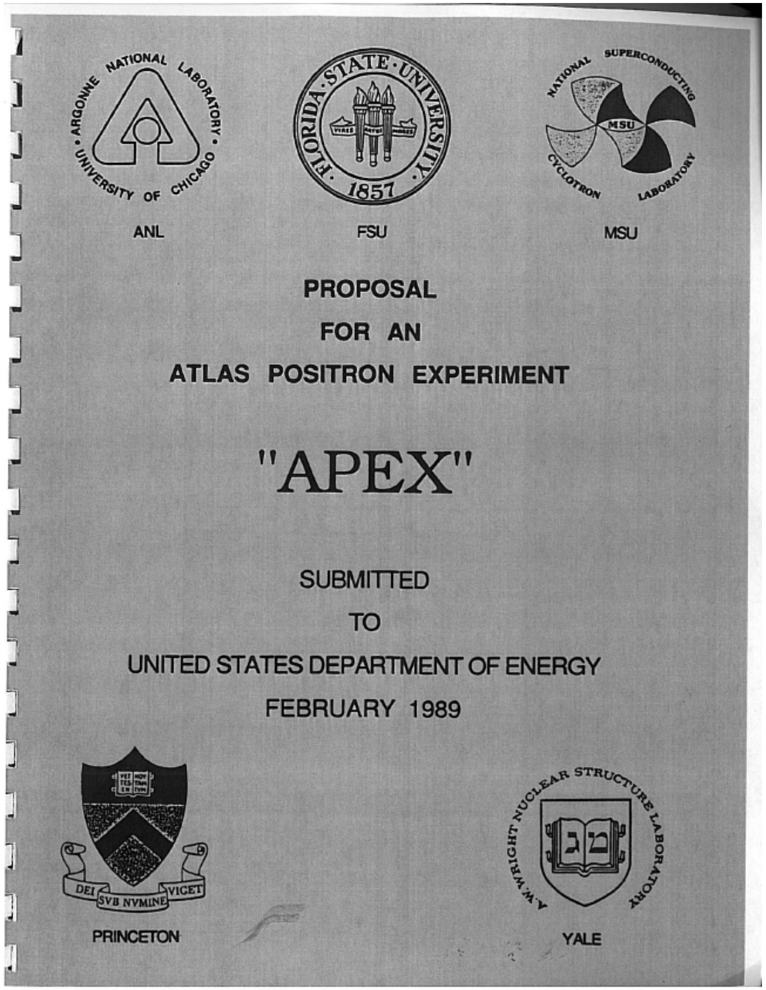
  VLSI CIRCUIT READOUT
  RELATIONSHIP TO "SSC" DEVELOPMENT
  RELATIONSHIP TO "RHIC" DEVELOPMENT.

- \$200 K DEVELOPMENT 1989/90

- \$2 M CONSTRUCTION 1990

An Early Concept

The APEX Proposal



ANL FSU MSU

PROPOSAL

FOR AN

ATLAS POSITRON EXPERIMENT

"APEX"

SUBMITTED

TO

UNITED STATES DEPARTMENT OF ENERGY

FEBRUARY 1989

PRINCETON YALE

&

Chicago

Queen's

Rochester

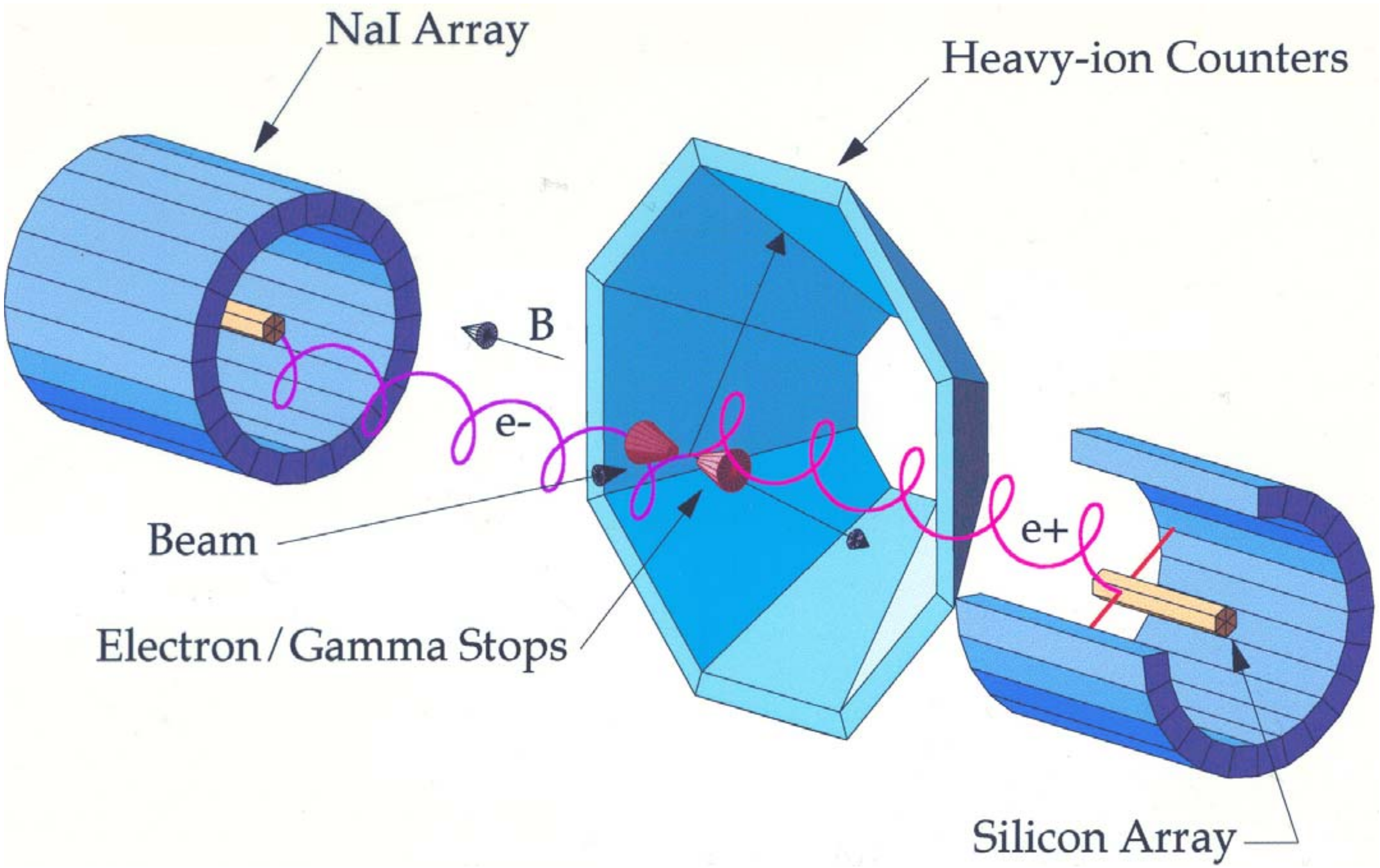
U Washington

$2.34M

Including

Contingency

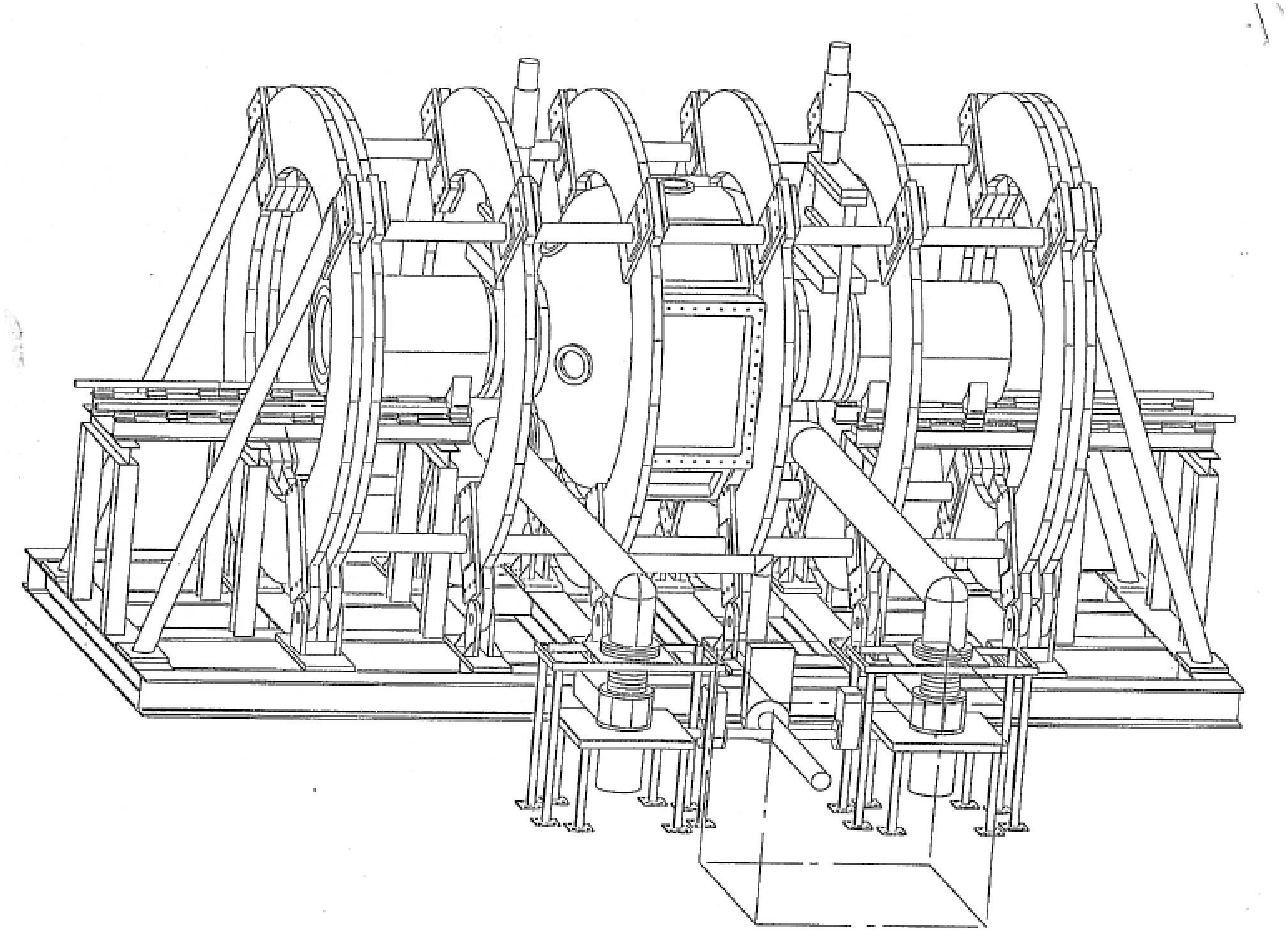
Final APEX Concept



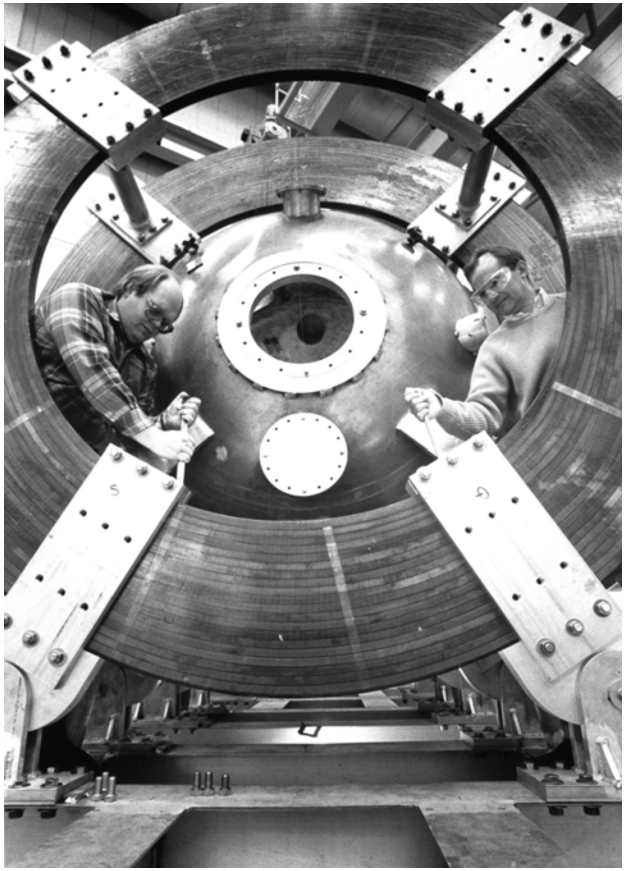
APEX Responsibilities

- Argonne – ATLAS, Project Management, Silicon Arrays
- ANL/Chicago – Trigger Electronics
- Florida State – Rotating Target Wheel
- MSU – Heavy Ion Array, Silicon Preamps, Electronics, Coils
- Princeton – Solenoid and Vacuum Vessel
- U Washington – Silicon Cooling, Monitors
- Yale – Annihilation Radiation Detector

Design

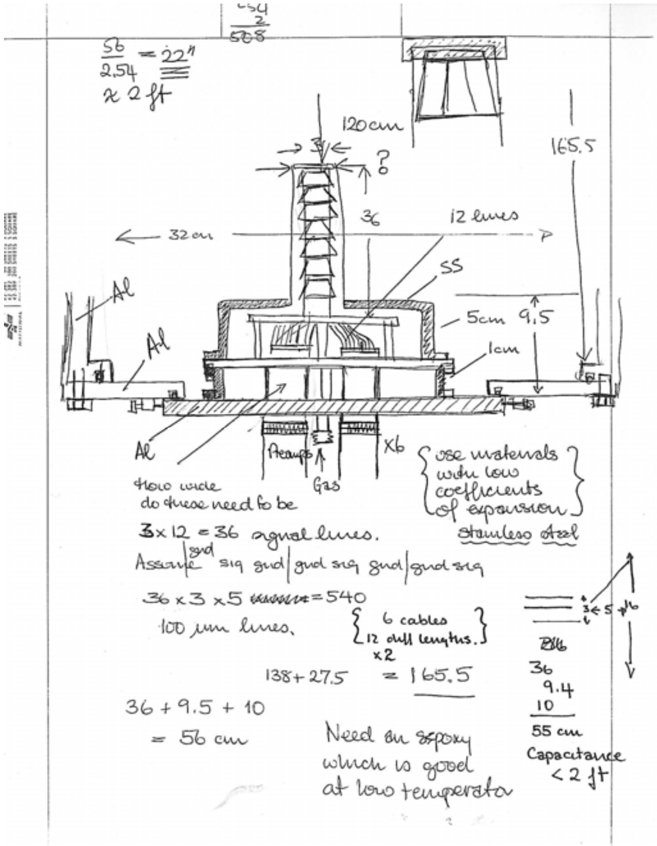


Construction



The Real Thing

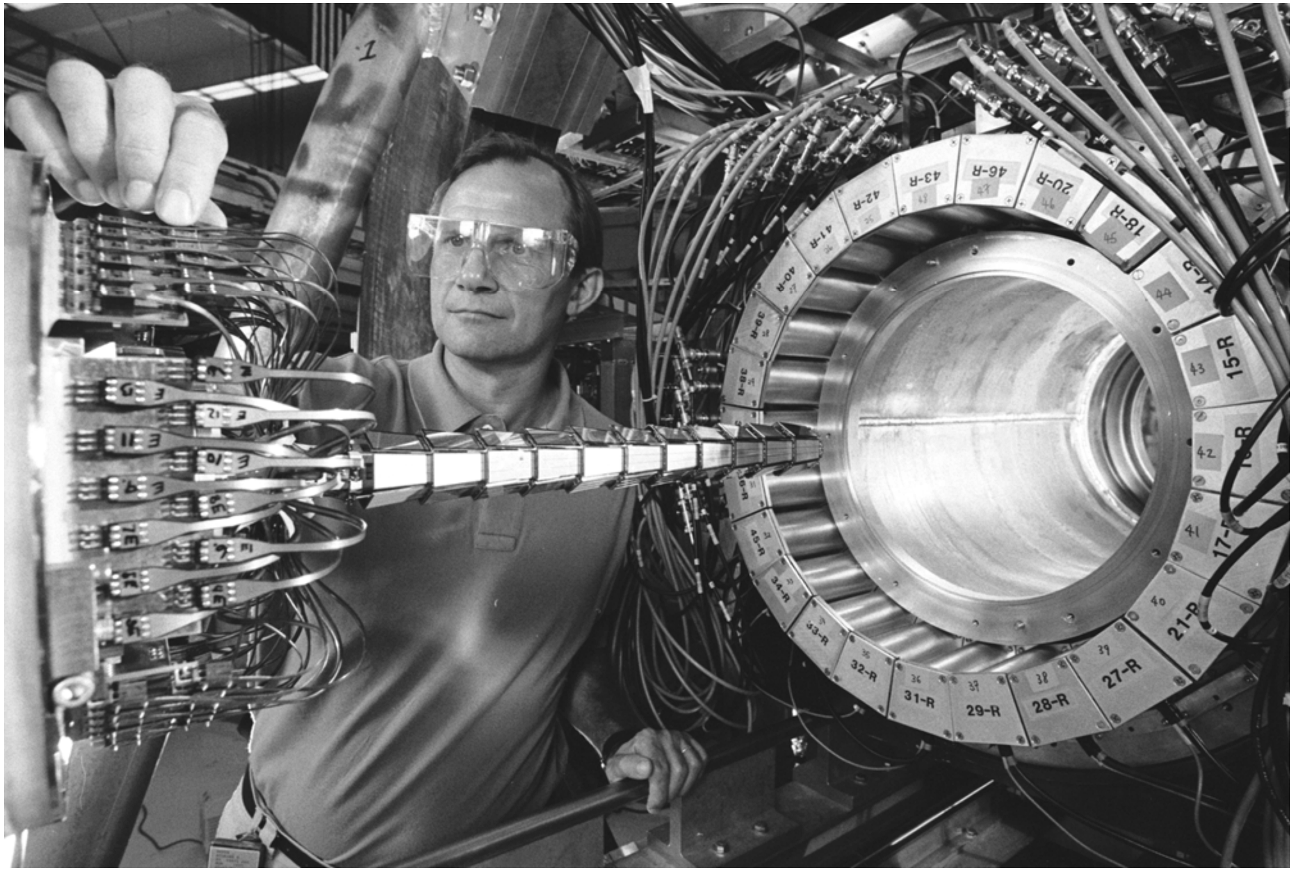
Silicon Array



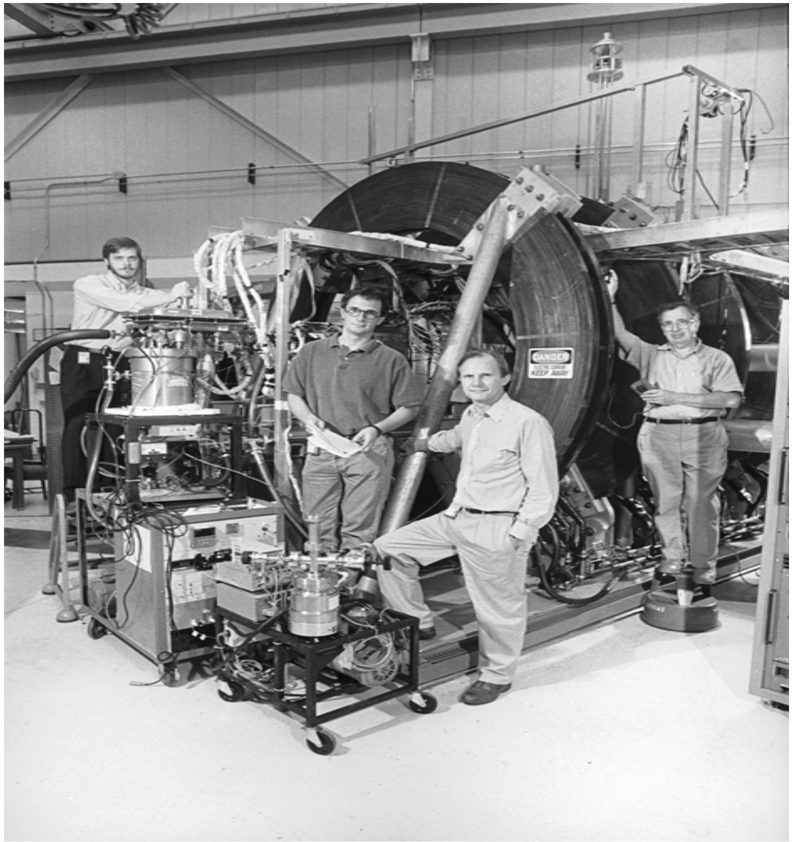
Highly Segmented Silicon
Efficient for 100 keV< E < 1 MeV
Excellent Energy Res <10keV
Excellent Timing < 1ns

1 mm Thick Si
Cool to LN_2 Temperature
In 10^{-6} Torr Vacuum
Custom Preamps
FERA Readout

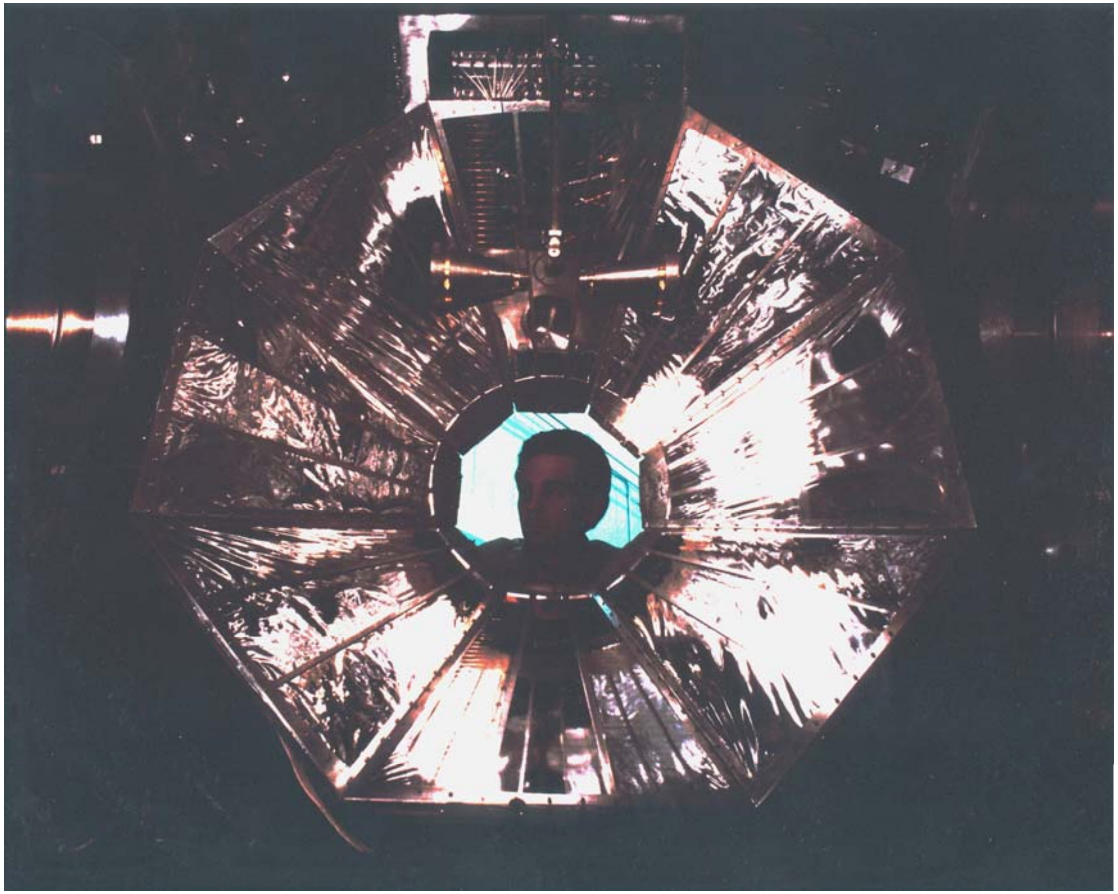
Delicate Adjustment



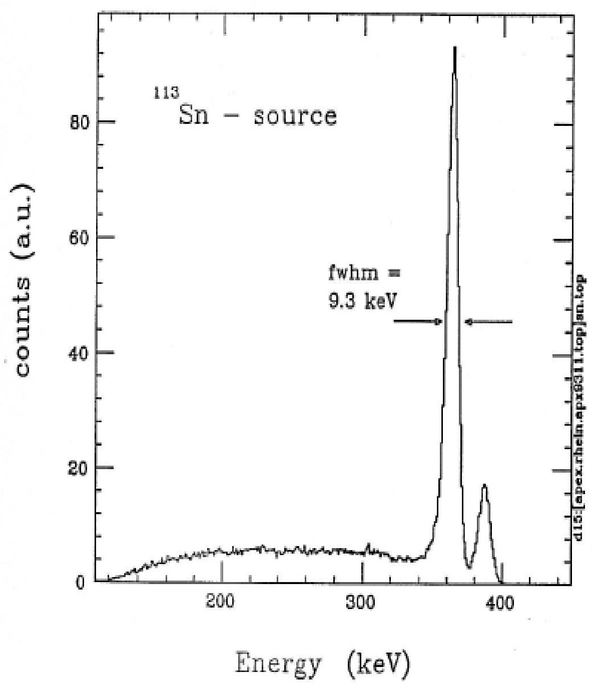
A Handsome (& Young) Crew



Heavy Ion Array & e/Gamma Stops

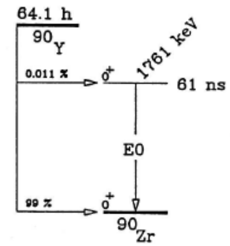


Performance with Sources



E0 transition in ^{90}Zr:

^{90}Y source:

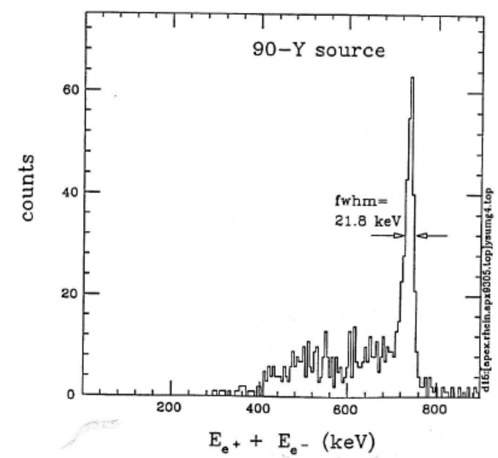


$\dot{a} = 30\ \mu$Ci

$T_1 : E_{e^-}^{max} = 2.28$ MeV, 1.1×10^6 per s.

$T_2 : E_{e^-}^{max} = 520$ keV, 122 per s

$T_3 : E_{e^+,e^-}^{max} = 739$ keV, 38 per s



Tiger Teams !!

ARGONNE
NATIONAL
LABORATORY

INTRA-LABORATORY MEMO

RB copy

January 30, 1991

TO: D. E. Moncton — ALD/APS

FROM: D. S. Gemmell — Director, PHY

SUBJECT: Safety Review of APEX

The Physics Division has conducted a Safety Review of APEX (ATLAS Positron Experiment).

After discussions with John Schiffer (Associate Division Director, PHY) and Russell Betts (APEX Project Manager) I am persuaded that APEX can be operated safely in an installation and testing mode when this is done in accordance with the enclosed documentation.

DSG:bf
Encl.
cc: F. Y. Fradin
J. P. Schiffer
J. R. Specht
R. R. Betts
B. B. Back
J. Unik

3/92 Second Try With Uranium Beam

Target wheel same as before (See page 1)

$^{238}U^{28+}$ from source $\rightarrow$ $^{238}U^{42+}$

E_{TOF} = ? $E_{Si} \simeq$ 1300 MeV I ~ 1.5 nA
estimated from S tune energy

4 enA at exit of ATLAS.

7:00 U-Beam is approaching APEX !

$^{238}U^{28+}$ PII Energy = 285.6 MeV (40.8 MeV $^{34}S^{6+}$)

$^{238}U^{42+}$ Booster = 864.5 MeV (123.5 MeV $^{34}S^{6+}$)

$^{238}U^{42+}$ ATLAS 1307.6 MeV (186.8 MeV $^{34}S^{6+}$)

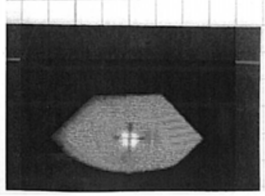
↑ scaled from ^{34}S energies

LE = 150 nA $^{238}U^{28+}$
before Apex = 2 nA $^{238}U^{42+}$
Mag. = 13.766 kG TOF = 1171.37 ± 5.71 MeV = 4.92 MeV/u
E = 1156 MeV 1170.97 ± 4.01
= 4.86 MeV/u 1170.58 ± 4.83
1173.17 ± 4.82

Sept. 3, 1992

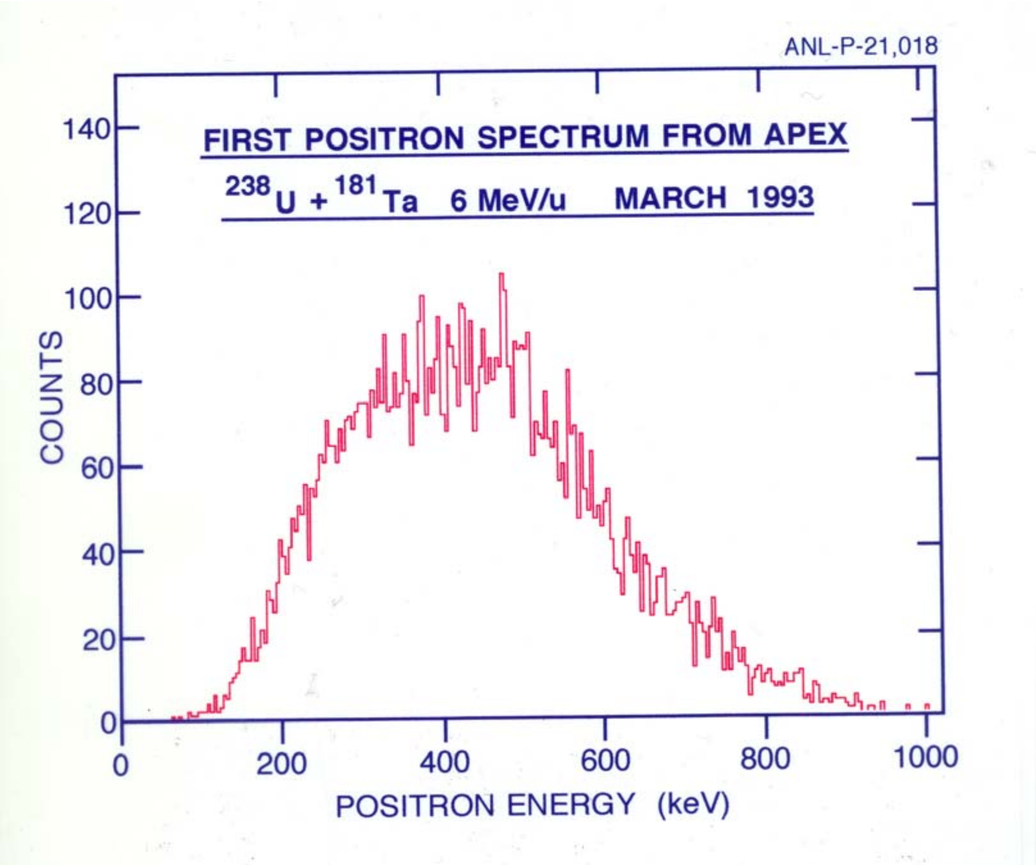
7:17 First ^{238}U beam on the ruby-quartz in APEX

those present: Russell Betts
R.C. Vale Walter Kutschera
K. Wolfgang ...
... Richard ...
... Ray E. Harden
... Bruce Glagola
... John M. Bogaty
... Richard Harkewicz



First Uranium Beam - Sept 3rd 1992

First Positron Spectrum



Summary of GSI Coincidence Results

TABLE I. Summary of experimental characteristics of previously reported $e^+ - e^-$ coincidence lines.

System	$e^+ - e^-$ sum energy (keV)	Line width (keV)	Beam energy (MeV/nucleon)	Energy loss in target (MeV/nucleon)	Cross section (μb/sr) (iso)[a]	(bb)[b]	Original reference
$^{238}U + ^{232}Th$	608 ± 8	25 ± 3	5.86–5.90	0.07	2.7 ± 0.6	1.1 ± 0.3	[20,21]
$^{238}U + ^{232}Th$	760 ± 20	$\leqslant 80$	5.83	0.07	–	–	[18]
$^{238}U + ^{232}Th$	809 ± 8	40 ± 4	5.87–5.90	0.07	3.1 ± 0.7	1.3 ± 0.3	[20,21]
$^{238}U + ^{181}Ta$	625 ± 8	20 ± 3	6.24–6.38	0.10	3.2 ± 0.8	1.3 ± 0.3	[20,21]
$^{238}U + ^{181}Ta$	748 ± 8	33 ± 5	5.93–6.13	0.10	5.7 ± 1.3	2.3 ± 0.5	[20,21]
$^{238}U + ^{181}Ta$	805 ± 8	27 ± 3	6.24–6.38	0.10	3.3 ± 0.8	1.4 ± 0.4	[20,21]
$^{238}U + ^{181}Ta$	≈ 635	≈ 30	6.30	0.24	0.5 ± 0.1	–	[22]

[a]Cross section $d\sigma_{line}/d\Omega_{HI}$ calculated assuming isotropic angular correlation between positron and electron as presented in [23], except for $^{238}U + ^{181}Ta$ 635 keV.
[b]Cross section $d\sigma_{line}/d\Omega_{HI}$ calculated assuming back-to-back positron-electron angular correlation as presented in [23].

APEX Data Taking

TABLE II. APEX integrated luminosities and pair efficiencies for different data sets discussed in the text.

System	Beam energy range[b] (MeV/nucleon)	Average target thickness (μg/cm^2)	Integrated luminosity (μb^{-1})	N_{e^+}	$N_{e^+-e^-}$	Pair ϵ(%) particle	Efficiency[a] ϵ(%) isotropic
^{238}U+ ^{232}Th	5.78–5.95	760	7000	246 000	126 000	1.30	0.90
^{238}U+ ^{181}Ta	5.79–5.95	660	5800	59 000	17 000	0.88	0.61
^{238}U+ ^{181}Ta	5.94–6.10	650	11 000	84 000	25 000	0.84	0.55
^{238}U+ ^{181}Ta	6.13–6.30	700	8600	70 000	16 000	0.55	0.37

[a]Efficiency calculated for a pair line with sum energy of 778 keV.
[b]Beam energy range includes energy loss in the target.

Blowing Out Shroud!
Power Failures!

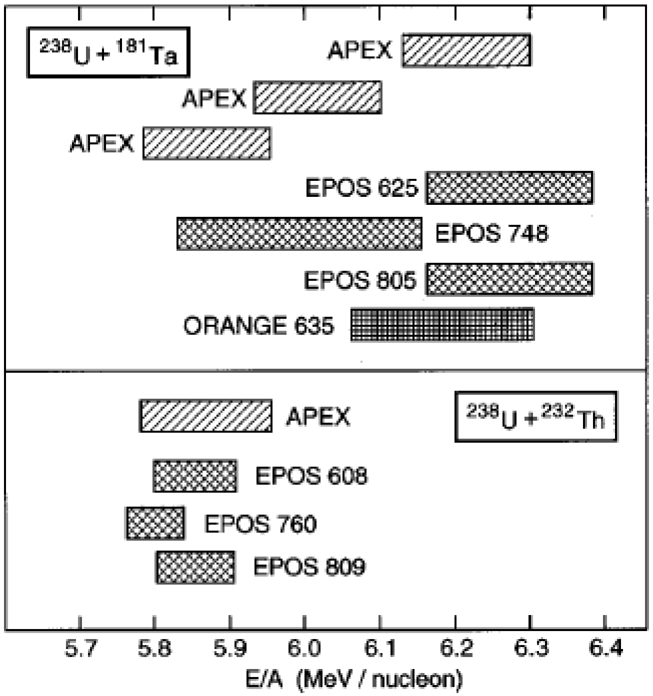


FIG. 21. Energies covered by various experiments reporting $e^+ - e^-$ coincidence lines in heavy-ion collisions.

APEX Singles and Coincidence Data

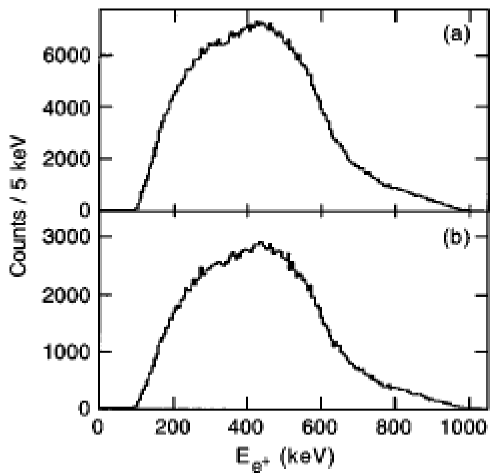
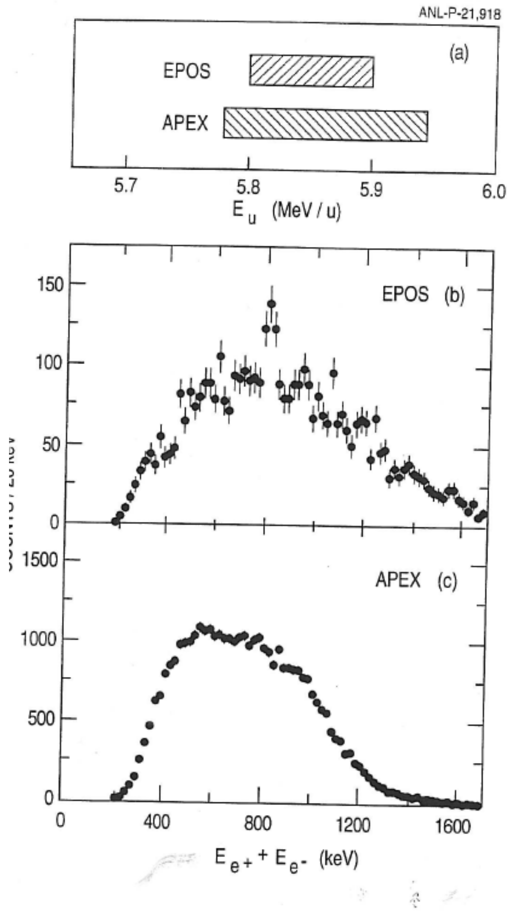


FIG. 4. (a) Energy distribution of positrons produced in the $^{238}U+^{232}Th$ reaction. No positron-heavy-ion coincidence is required. (b) Same as (a) except that two heavy ions are required to be detected in time coincidence with the positron.



APEX Data – No Peaks

Upper Limits on Line Cross Section

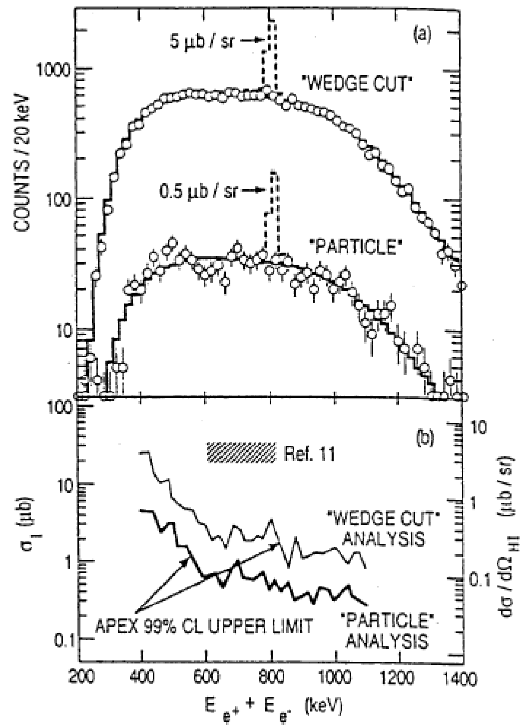


Fig. 42. Sum-energy spectra for $^{238}U + ^{232}Th$ at 5.95 MeV/u analyzed according to the expectations for the isotropic decay of a particle produced at rest in the center of mass. The "particle analysis" was for events with positrons and electrons with an opening angle of approximately 180°. From Ahmad et al. (1995b)

Published Limits

College of Science and Letters
ILLINOIS INSTITUTE OF TECHNOLOGY

An Acid Test

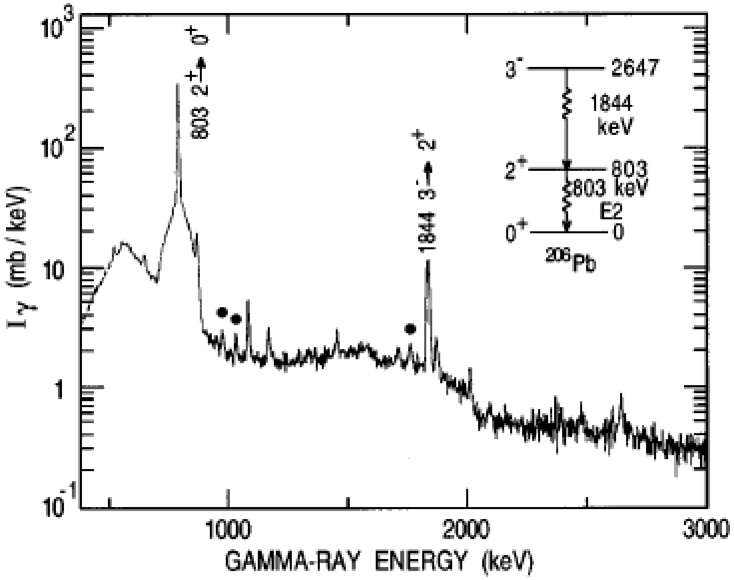


FIG. 1. Spectra from the $^{206}Pb+^{206}Pb$ reaction at 5.90 MeV/nucleon showing the Doppler reconstructed γ-ray spectrum. Transitions associated with the $^{206}Pb(^{206}Pb,^{205}Pb)^{207}Pb$ reaction are marked (●) and occur at a level of 1% of the $^{206}Pb(2^+ \rightarrow 0^+)$ Coulomb excitation. All other peaks arise from the decay of states in ^{206}Pb.

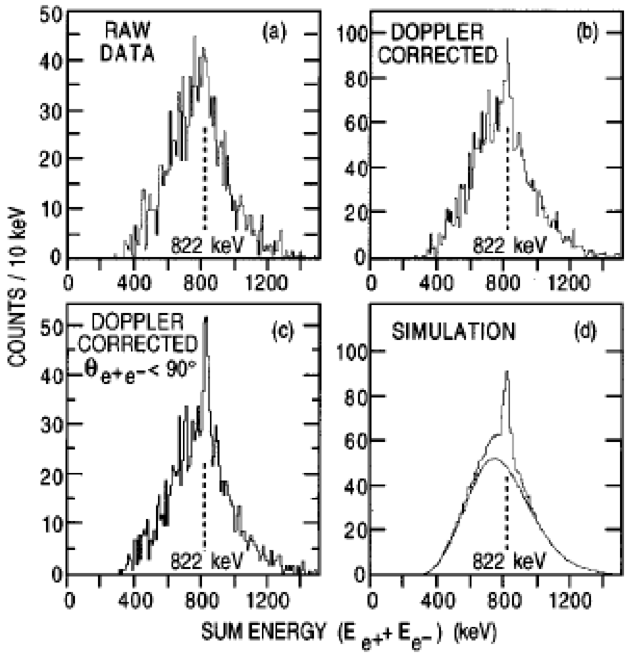


FIG. 2. Sum-energy spectra from $^{206}Pb+^{206}Pb$ at 5.90 MeV/nucleon. (a) The raw data, (b) after Doppler correction for emission from each of the scattered ions, (c) with a further selection on small positron-electron opening angles, and (d) a Monte Carlo simulation of (b).

OXPOS

- GSI and US Experimental Groups Meet at Wadham College, Oxford in 1996
- Cordial and Detailed Discussions

  (+ Good Food and Wine)
- Concluding Statement

"… the statistical significance of the original observations was over estimated …..."

APEX Publications

Anomalous Positrons from Heavy Ion Collisions Past Results and Future Plans
Nucl. Instr. and Meth. B43, 29 (1989)

Nuclear Spectroscopy with Si PIN Diode Detectors at Room Temperature
Nucl. Instr. Meth. A299, 201 (1990)

Positron-Electron Pairs in Heavy Ion Reactions: Status of the APEX Collaboration
Proceedings of Seventh Winter Workshop on Nuclear Dynamics, Key West, Florida

A Fast Low Noise Silicon Detector for Electron Spectroscopy up to 1 MeV
Nucl. Instr. and Meth.

APEX Heavy Ion Counters
Nucl. Instrum. Methods A348, 252-255 (1994)

A Large Solid-Angle Array for Heavy Ions from APEX
Nucl. Instrum. Methods A350, 491-502 (1994)

The ATLAS Positron Experiment - APEX
Proceedings of the 10th Winter Workshop on Nuclear Dynamics, Snowbird, UT

Recent Results from APEX
Proceedings of the Conference on Physics from Large g-Ray Detector Arrays Berkeley, CA,

Positron Production in Heavy Ion Collisions: Current Status of the Problem-II
5th International Conference on Nucleus-Nucleus Collisions, Taormina, Italy

Electronics for the Si Detectors in APEX
Electronics for Future Colliders, Montvale, NJ, May 10-11, 1994

Search for Narrow Sum-Energy Lines in Electron-Positron Pair Emission from Heavy-Ion Collisions near the Coulomb Barrier
Phys.Rev.Letters 75,2658-2661 (1995)

A New Look at Positron Production from Heavy Ion Collisions: Results from APEX
IV International Symposium on Weak and Electromagnetic Interactions in Nuclei, Osaka, Japan

A Solenoidal Spectrometer for Positron-Electron Pairs Produced in Heavy-Ion Collisions
Nucl.Instruments and Methods, A370,539-557 (1996)

The Positron Peak Puzzle - Recent Results from APEX
XXIV Mazurian Lakes School of Physics, Piaski, Poland 1995

Recent Results from APEX
Proceedings of 12th Winter Workshop on Nuclear Dynamics, Snowbird UT 1996

Reply to Comment on APEX
Phys.Rev.Letters 77,2839 (1996)

Search for Monoenergetic Positron Emission from Heavy-Ion Collisions at Coulomb Barrier
Energies
Phys.Rev.Letters 78,618-621 (1997)

The Positron Peak Problem: Results from APEX
International Conference on Nuclear Structure at the Turn of the Century,Crete, Greece

Internal Pair Conversion in Heavy Nuclei
Phys.Rev. C55,R2755 (1997)

Positron Electron Angular Correlations in Internal Pair Conversion
Phys.Rev. C57,R2794 (1998)

Positron Electron Pairs Produced in Heavy Ion Collisions
Phys.Rev. C60, 064601(1999)

THE END !! ??

PHYSICAL REVIEW C, VOLUME 60, 064601

Positron-electron pairs produced in heavy-ion collisions

I. Ahmad,[1] Sam. M. Austin,[2] B. B. Back,[1] R. R. Betts,[1,3] F. P. Calaprice,[4] K. C. Chan,[5] A. Chishti,[6] C. M. Conner,[3] R. W. Dunford,[1] J. D. Fox,[6,*] S. J. Freedman,[1,7] M. Freer,[1,8] S. B. Gazes,[9,10] A. L. Hallin,[11] Th. Happ,[1,12] D. Henderson,[1] N. I. Kaloskamis,[5,†] E. Kashy,[2] W. Kutschera,[1] J. Last,[1] C. J. Lister,[1] M. Liu,[11], M. R. Maier,[8] D. M. Mercer,[2] D. Mikolas,[2] P. A. A. Perera,[9] M. D. Rhein,[1,12] D. E. Roa,[6,‡] J. P. Schiffer,[1,10] T. A. Trainor,[13] P. Wilt,[1] J. S. Winfield,[2,§] M. Wolanski,[1,10,||] F. L. H. Wolfs,[9] A. H. Wuosmaa,[1] A. R. Young,[4] and J. E. Yurkon[2]

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(Received 25 November 1998; published 26 October 1999)

The production of positron-electron pairs in collisions of ^{238}U+^{232}Th at 5.95 MeV/nucleon, and of ^{238}U + ^{181}Ta at 5.95, 6.1, and 6.3 MeV/nucleon, has been studied with the APEX spectrometer at Argonne National Laboratory. Several analyses have been performed to search for sharp structures in sum-energy spectra for positron-electron pairs. Such features have been reported in previous experiments. No statistically convincing evidence for such behavior is observed in the present data. [S0556-2813(99)06311-6]

PACS number(s): 25.70.Bc, 14.80.−j

The End (1999)

Afterword

- APEX and the ATLAS Uranium Upgrade were amazing technical – and political – *tours de force*
- The product of what we do is often the process itself
- To push back the frontiers we have to take chances – sometimes we make mistakes
- We have to keep asking the hard questions