Creative Electron

www.creativeelectron.com

San Marcos, CA 92078

Radiation Effects on Electronic Components

Dr. Bill Cardoso, President

Dr. Marcos Turqueti, VP of Engineering

Made in USA

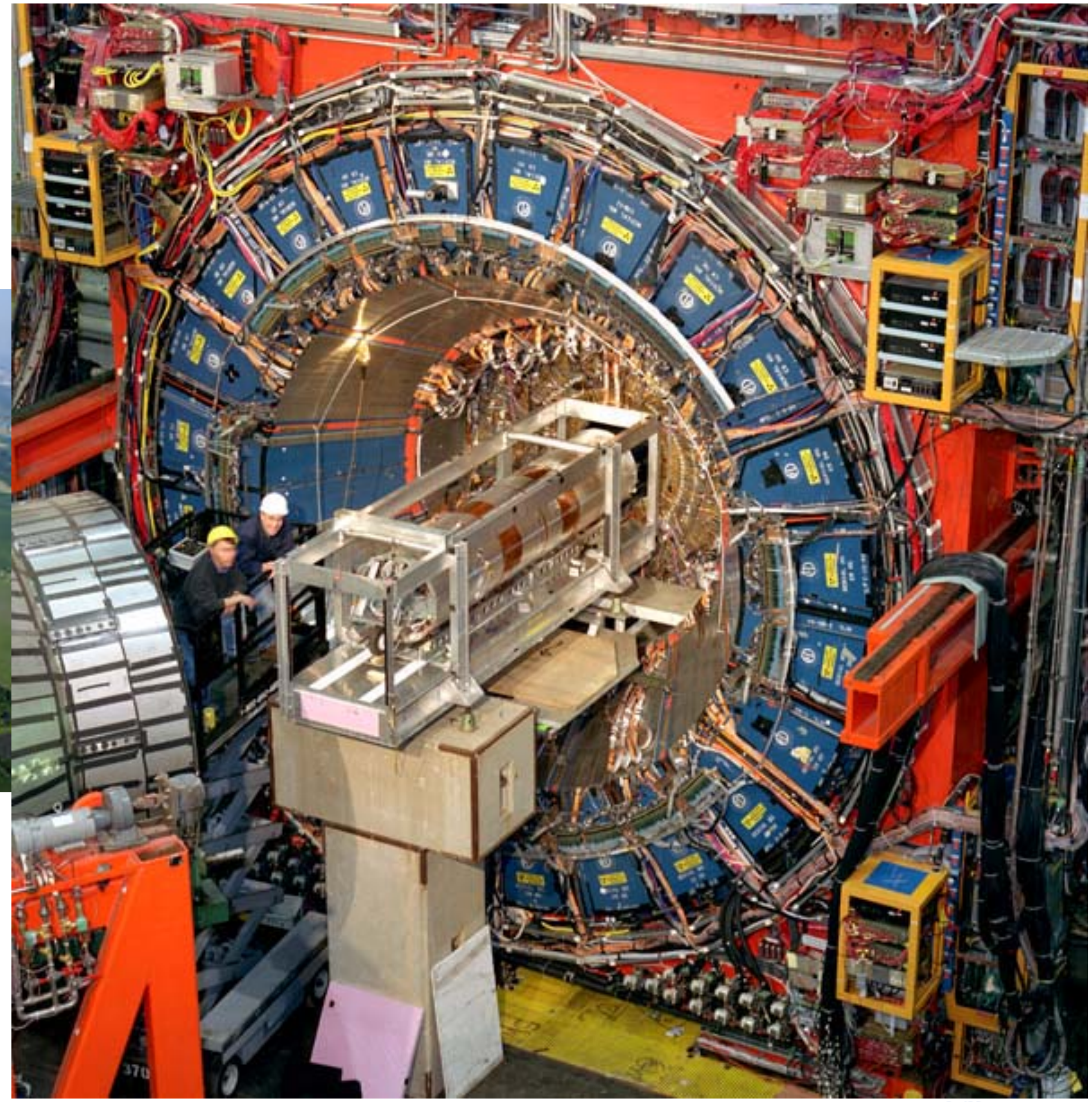
Creative Electron

Corporate Profile

Mission: *Improve our nation's ability to defend itself from domestic and foreign threats by pioneering reliable solutions for counterfeit detection.*

Clients include:
DHS, NIH, NSF, NASA, DOE, ONR, DARPA, Navy, defense and aerospace contractors

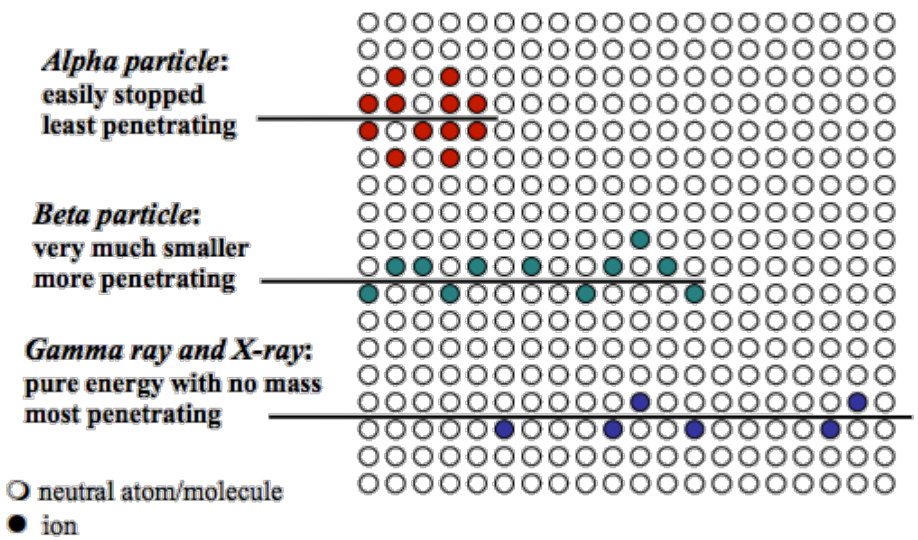
Our work at Fermi National Accelerator Laboratory – Fermilab



Not all radiation is equal

Characteristic	Radiation ($E_K = 1$ MeV)				
	Alpha (α)	Proton (p)	Beta (β) or Electron (e)	Photon (γ or X ray)	Neutron (n)
Symbol	${}^4_2\alpha$ or He^{2+}	${}^1_1p$ or H^{1+}	${}^0_{-1}e$ or β	${}^0_0\gamma$	${}^1_0n$
Charge	+2	+1	–1	neutral	neutral
Ionization	Direct	Direct	Direct	Indirect	Indirect
Mass (amu)	4.001506	1.007276	0.00054858	—	1.008665
Velocity (cm/sec)	6.944×10^8	1.38×10^9	2.82×10^{10}	$c=2.998\times10^{10}$	1.38×10^9
Speed of Light	2.3%	4.6%	94.1%	100%	4.6%
Range in Air	0.56 cm	1.81 cm	319 cm	82,000 cm*	39,250 cm*

* range based on a 99.9% reduction



K. E. Holbert, Radiation Effects Damage

What kind of ionizing radiation semiconductors are most frequently subject to?

- **Electromagnetic:**
  - X-rays
  - Gamma rays
- **Subatomic particles:**
  - Protons
  - Neutrons
  - Electrons
  - Pions
  - Muons

What are the sources of exposure for semiconductors?

- **Background**
  - Terrestrial: dependent on location.
  - Cosmic : dependent on altitude.
- **Man made**
  - Inspection on airports, ports, post offices, and delivery companies.
  - Inspection for quality assurance, failure analysis, and counterfeit detection.

What are the factors that increase the probability of component damage?

- **Radiation type:** Larger particles have higher probability of damage due to their cross section. Electromagnetic radiation such as gamma or x-rays need a huge amount of energy to cause bulk damage on silicon.

- **Energy:** The energy will be one of the main factors that will define the probability of interaction with matter.

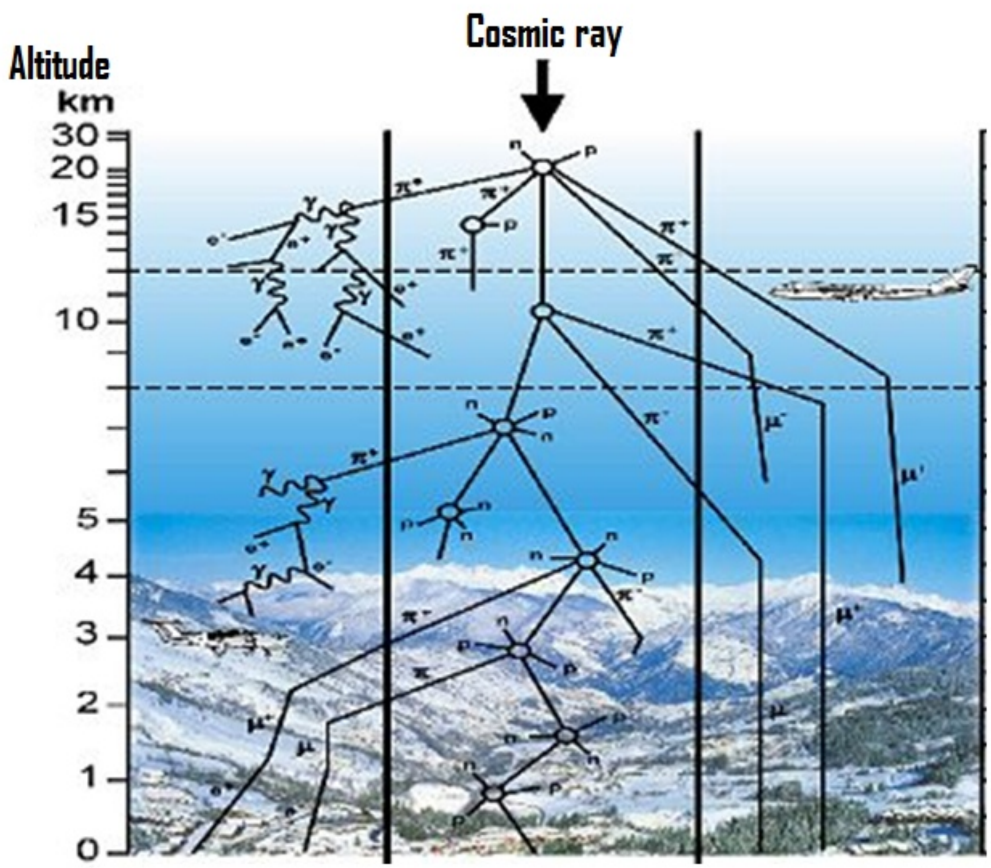
- **Radiation flux:** Higher fluxes will increase the probability of damaged if the minimum energy threshold is reached.

- **Exposure time:** The time of exposure combine with the three factors above will define the total dose that the part is submitted.

What kind of damage radiation can cause on semiconductors?

- **Bulk damage :** Occurs when the energy transferred to the silicon atom is sufficient to remove it from the crystal lattice. This damage is permanent. The great majority of currently available X-ray inspection systems simple don't have enough energy to cause this kind of damage.
- **Surface damage :** the passage of ionizing radiation in the silicon oxide on semiconductors causes the built up of trapped charge in the oxide layers of the semiconductor. With time, or high flux, the e-h pairs created in the oxide either recombine or move towards the SiO_2-Si interface, altering the characteristics of the semiconductor.
- **Single event upset :** is a change of logical state caused by passage of radiation. This does not cause permanent damage on the semiconductor. It has potential to alter microcode or configware resident on certain devices such as FPGA's and memory circuits.

Putting radiation exposure in perspective: Transportation exposure



An average of 0.6 mrem per hour at cruise altitude.
Radiation type: Neutrons, protons, pions, muons, and gamma.

When cosmic rays enter the Earth's atmosphere they collide with molecules, mainly oxygen and nitrogen, to produce a cascade of billions of lighter particles, a so-called air shower.

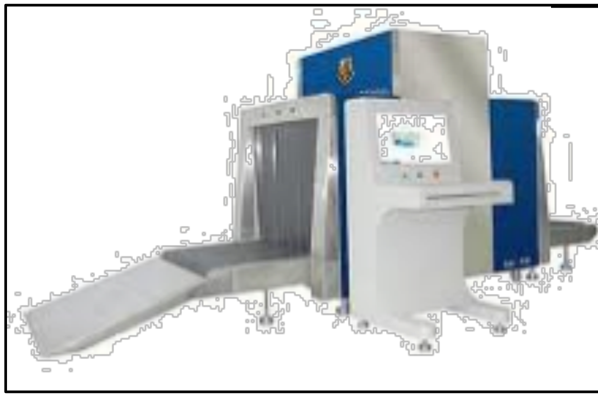
Creative Electron

Putting radiation exposure in perspective: Mandatory inspection

- Any kind of cargo (including electronic parts) can go under mandatory x-ray inspection in ports of entry and airports.
- It is not unusual to have electronic components being inspected with x-ray machines several times when moving from one country to another.
- Port and airport x-ray machines are not designed to limit the amount of radiation cargo is exposed to.
  - Exposure due to this systems can easily accumulate to several hundreds of milirems.

Creative Electron

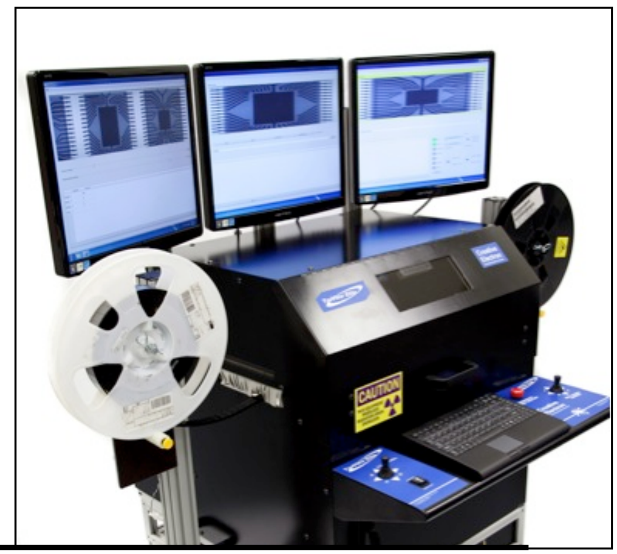
Example – Component travelling from Asia to USA



Cargo 160kV

Port of exit/entry
1MeV~6MeV

Flight ~10mRem



Counterfeit detection ~ 50mRem

Putting radiation exposure in perspective: Counterfeit and quality control X-ray systems

- Typically X-ray systems deployed for counterfeit detection and quality control are in the range of 80kV to 120kV.
- A good digital image can be achieved with a exposure time between 200 and 500ms.
- Considering a system that exposes its parts for 1.5s at 80kV as a benchmark. Each inspected part will receive on average 50mRem of total dose.

Automation is key to reduce exposure

- Each component exposed to radiation for only 1.5s
- Automated image acquisition
- No human interference to take image of each component

Putting radiation exposure in perspective: Airplane parts

- Aircrafts like the Boeing 737 usually fly at least 50,000 hours during their lifetime. That accounts for an average total dose of around 30,000 mRem due to background radiation.

Summary

- Particles (protons, electrons) cause more damage to semiconductors than photons (x-ray)
- X-ray inspection systems used for counterfeit detection don't have enough energy (<120kV) to cause bulk damage to silicon
- Radiation type, power, distance, and time matters a lot
- Automated systems expose components to an average of 50mRem (0.050Rem)
- Most components show failures starting at least few thousands of Rem, or millions of mRem
- Commercial airplanes are exposed to ~30,000mRem of background radiation that has more particles than what's found in x-ray cabinet
- Wide safety margin to inspect components using x-rays
- Most radiation tolerance tests are done with particles, not photons

Our background in the subject (1)

- **First look at the beam test results of the FPIX2 readout chip for the BTeV silicon pixel detector**
  IEEE Transactions on Nuclear Science, Volume 53, Issue 1, Part 2, Feb. 2006 Page(s):409 – 413
- **First prototype of a silicon microstrip detector with the data-driven readout chip FSSR2 for a tracking-based trigger system**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment Volume 572, Issue 1 , 1 March 2007, Pages 388-391
- **First prototype of a silicon microstrip detector with the data-driven readout chip FSSR2 for a tracking-based trigger system**
  Frontier Detectors for Frontier Physics - Proceedings of the 10th Pisa Meeting on Advanced Detectors
- **Radiation tolerance of prototype BTeV pixel detector readout chips**
  IEEE Transactions on Nuclear Science, Volume 49, Issue 6, Part 1, Dec. 2002 Page(s):2895 – 2901
- **CDF run IIb silicon vertex detector DAQ upgrade**
  IEEE Transactions on Nuclear Science, Volume 51, Issue 6, Part 1, Dec. 2004 Page(s):3047 – 3054
- **CDF run IIb silicon detector: the innermost layer**
  IEEE Transactions on Nuclear Science, Volume 51, Issue 5, Part 1, Oct. 2004 Page(s):2215 – 2219
- **CDF run IIb silicon: design and testing**
  IEEE Transactions on Nuclear Science, Volume 51, Issue 5, Part 1, Oct. 2004 Page(s):2209 – 2214
- **Pixel multichip module design for a high energy physics experiment**
  IEEE Transactions on Nuclear Science, Volume 51, Issue 5, Part 1, Oct. 2004 Page(s):2168 – 2173
- **Sensors for the CDF Run2b silicon detector**
  IEEE Transactions on Nuclear Science, Volume 51, Issue 4, Part 1, Aug. 2004 Page(s):1546 – 1554
- **Stave design and testing**
  IEEE Nuclear Science Symposium and Medical Imaging Conference, Portland, Oregon, October 19-24, 2003.

Our background in the subject (2)

- **Silicon sensors for the CDF run IIb detector,**
  IEEE Nuclear Science Symposium and Medical Imaging Conference, Portland, Oregon, October 19-24, 2003.
- **The BTeV pixel detector system**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. A501, pp. 131-137, 2003.
- **Single event upset rate of 140Mb/s pixel data serializer**
  Particle Accelerator Conference, Portland, Oregon, May 12-16, 2003.
- **The BTeV pixel and microstrip detectors**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. A511, pp. 48-51, 2003.
- **The BTeV pixel detector and trigger system**
  Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, vol. 115, pp. 331-336, 2003.
- **Radiation tolerance of prototype BTeV pixel detector readout chips**
  IEEE Transactions on Nuclear Science, vol. 49, no. 6, pp. 2895-2901, December 2002
- **First bench-test results on irradiated BTeV hybrid silicon pixel detector prototypes**
  IEEE Nuclear Science Symposium and Medical Imaging Conference, Norfolk, Virginia. November 10-16, 2002
- **The BTeV pixel and microstrip detectors**
  11th International Workshop on Vertex Detectors, Kona, Kailua, Hawaii, pp. 3-8, November 2002.
- **BTeV pixel system**
  International Workshop on Semiconductor Pixel Detectors for Particle Physics and X-rays, Carmel, California, September 9-12, 2002.
- **Overview of the BTeV pixel detector**
  International Workshop on Semiconductor Pixel Detectors for Particle Physics and X-rays, Carmel, California, September 9-12, 2002.

Our background in the subject (3)

- **Radiation tolerance of prototype BTeV pixel detector readout chips**
  IEEE Nuclear and Space Radiation Effects Conference, Phoenix, Arizona, 15-19 July 2002.
- **Silicon detector upgrades for the Tevatron run 2**
  31st International Conference on High energy Physics, Amsterdam, July 24-31, 2002.
- **Radiation tolerance of prototype BTeV pixel detector readout chips**
  2002 IEEE Nuclear and Space Radiation Effects Conference, Phoenix, Arizona. July 15-19, 2002
- **The BTeV pixel detector and trigger system**
  5th International Conference on Hyperons, Charm and Beauty Hadrons, Vancouver, Canada, 25-29 June 2002
- **The BTeV vertex trigger**
  8th International Conference on B-Physics at Hadron Machines, Santiago de Compostela, Galicia, Spain, June 17-21, 2002.
- **Development of a readout technique for the high data rate BTeV pixel detector at Fermilab**
  IEEE Transactions on Nuclear Science, vol. 49, no. 3, pp. 1185-1189, June 2002.
- **The BTeV pixel detector system**
  American Physical Society's 2002 Meeting of the Division of Particles and Fields, Williamsburg, Virginia. May 24-28, 2002.
- **CDF for run IIb**
  American Physical Society's 2002 Meeting of the Division of Particles and Fields, Williamsburg, Virginia. May 24-28, 2002.
- **Development of a high density pixel multichip module at Fermilab**
  Invited paper published in the IEEE Transactions on Advanced Packaging, vol. 25, no. 1, pp. 36-42, February 2002.
- **Beam test of BTeV pixel detectors**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 473, pp. 119-123, 2001.
- **Development of a readout technique for the high data rate BTeV pixel detector at Fermilab**
  IEEE Nuclear Science Symposium and Medical Imaging Conference, San Diego, California. 4-10 November, 2001.

Our background in the subject (4)

- **The BTeV pixel detector system**
  10th International Workshop on Vertex Detectors, Brunnen, Switzerland, September 23-28, 2001.
- **Performance of prototype BTeV silicon pixel detectors in a high energy pion beam**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 485, pp. 411-425, 2000.
- **Beam test results of the BTeV silicon pixel detector**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 465, pp. 125-130, 2000.
- **Single event effects in the pixel readout chip for BTeV**
  10th International Workshop on Vertex Detectors (Vertex 2001), Brunnen, Switzerland. September 23-28, 2001.
- **Radiation tolerance studies of BTeV pixel readout chip prototypes**
  7th Workshop on Electronics for the LHC Experiments, Stockholm, Sweden, September 10-14, 2001.
- **Development of the pixel detector module for the BTeV experiment at Fermilab**
  7th Workshop on Electronics for the LHC Experiments, Stockholm, Sweden, September 10-14, 2001.
- **Development of a high density pixel multichip module at Fermilab**
  51st IEEE Electronic Components & Technology Conference, Orlando, May 29 - June 1, 2001.
- **Overview of the BTeV pixel detector**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 465, pp. 34-39, 2001.
- **Single event effects in the pixel readout chip for BTeV**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. A501, pp. 183-188, 2001.
- **Beam test results of the BTeV silicon pixel detector**
  IEEE Nuclear Science Symposium and Medical Imaging Conference, Lyon, France, October 15-20, 2000.

Our background in the subject (5)

- **The BTeV pixel detector and trigger system**
  7th International Conference on B-Physics at Hadron Machines, Sea of Galilee, Kibbutz Maagan, Israel, September 13-18, 2000.
- **Beam test of BTeV pixel detector**
  Invited talk at 9th International Workshop on Vertex Detectors, Homestead, Michigan, September 10-15, 2000.
- **Beam test results of the BTeV silicon pixel detector**
  30th International Conference on High-Energy Physics, Osaka, Japan July 27 - August 2, 2000.
- **Development of high data readout rate pixel module and detector hybridization at Fermilab**
  International Workshop on Semiconductor Pixel Detectors for Particles and X-Rays, Genova, Italy, June 5-8, 2000.
- **Overview of the BTeV pixel detector**
  International Workshop on Semiconductor Pixel Detectors for Particles and X-Rays, Genova, Italy, June 5-8, 2000.
- **Beam test results of the BTeV silicon pixel detector**
  International Workshop on Semiconductor Pixel Detectors for Particles and X-Rays, Genova, Italy, June 5-8, 2000.
- **Development of high data readout rate pixel module and detector hybridization at Fermilab**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 465, pp. 224-228, 2000.
- **The BTeV pixel vertex detector**
  Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 446, pp. 235-239, 2000.