Physics and Society–The Future:

Nuclear and Accelerator Science Education and Research Enhancement

An Overview

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Abstract

- **At A Fundamental Level, Our Understanding Of The Physics And Engineering Technology Which Governs The Construction And Operation Of Various Types Of Accelerators Is Very Good And Has Resulted In The Development Of Many Practical Applications Ranging From Basic Research In High Energy Particle Physics To Oncological Treatments In Humans To The Irradiation Of Food.**

- **However, It Is Also True That Our Understanding Of How To Create, Utilize, And Incorporate Nuclear And Accelerator Based Methodologies Which Are Operationally Inexpensive, Compact In Size, But Yet Application-effective, Will Clearly Require Much More Effort In The Future. In Addition, Even For Those Current Applications Which Are More Or Less Tested And Proven Such As Proton Therapy, The Requisite Associated Supporting Infrastructure (Administrative/Governmental, Hardware, Software, Educational, And Computational) Is Not Generally Available Or Affordable To Many Member States On A Sufficient Consistent Basis.**

Abstract (continued)

- **In this presentation, we provide an overview of issues associated with the enhancement of nuclear and accelerator science education and training with an emphasis on internet–computer-computational related ways which show promise in not only definitively increasing the quantity and quality of people who could go on to become professional well-trained experts, mentors, and researchers in their own right, but who could also constitute the future highly skilled personnel foundation for promulgation of their knowledge to others.**

PRESENTATION OUTLINE

- **Generic Accelerator Types**
- **Accelerator Applications—Basic Research and Practical**
  - **Particle Beam Related**
  - **Light Source Related**
- **Requisite Supporting Infrastructure for Effective" Accelerator Research and Application Usage**
  - **Governmental**
  - **Administrative**
  - **Hardware-Based**
  - **Software-Based**
  - ***Educational***

Generic Accelerator Types

- Electrostatic
  - Cockcroft-Walton
  - Van de Graaff
- Induction
  - Induction LINAC
  - Betatron
- Radio-Frequency (RF)
  - LINAC
  - Quadrupole (RFQ)
  - Cyclotron
    - Isochronous
    - Synchrocyclotron
  - Microtron
  - Synchrotron
- Colliders and Storage Rings
- Synchrotron Light Sources

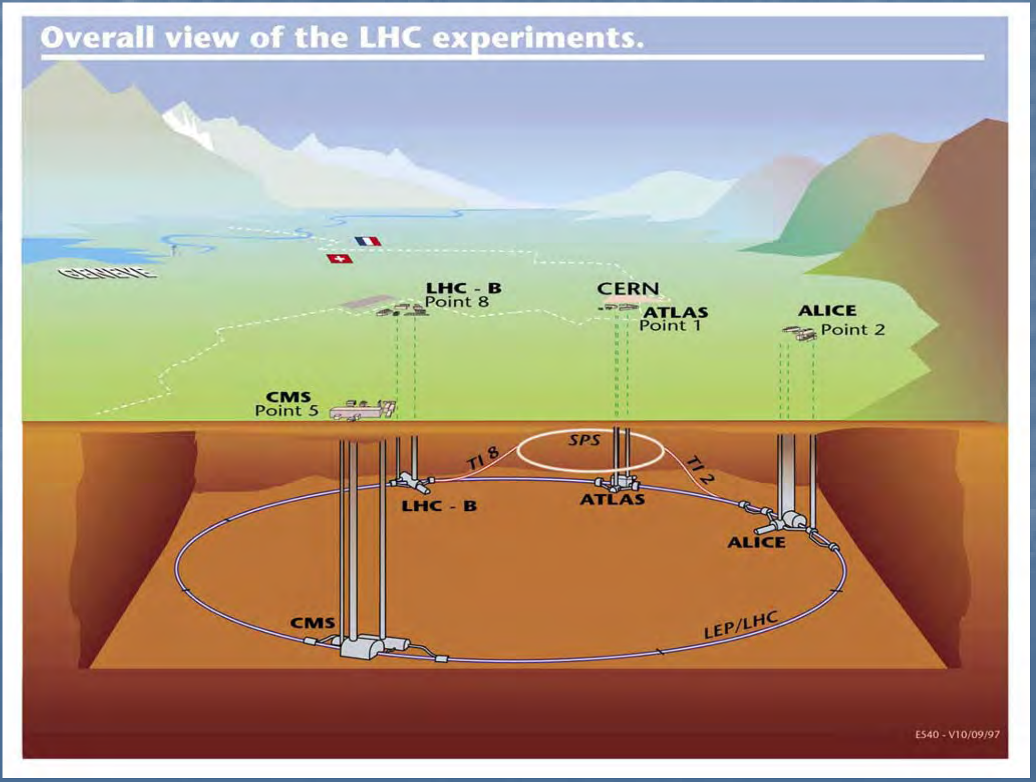
Accelerator Applications—Basic Frontier Research Using Beams

- Particle and Nuclear Physics--Large Hadron Collider (LHC), at CERN, in Geneva, Switzerland

Accelerator Applications—Basic Frontier Research Using Beams

- **Particle and Nuclear Physics- -Large Hadron Collider (LHC), at CERN, in Geneva, Switzerland**

SCHEMATIC OF LHC EXPERIMENTS



Particle Beam Fundamental Constituents

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor		Mass GeV/c²	Electric charge
ν_e	electron neutrino	$<1\times10^{-8}$	0
e	electron	0.000511	–1
ν_μ	muon neutrino	<0.0002	0
μ	muon	0.106	–1
ν_τ	tau neutrino	<0.02	0
τ	tau	1.7771	–1

Quarks spin = 1/2

Flavor		Approx. Mass GeV/c²	Electric charge
u	up	0.003	2/3
d	down	0.006	–1/3
c	charm	1.3	2/3
s	strange	0.1	–1/3
t	top	175	2/3
b	bottom	4.3	–1/3

Particle Beam Fundamental Constituents

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1		
Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	-1
W^+	80.4	$+1$
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Accelerator Applications—Using Beams

EXAMPLE: PROTON and NEUTRON THERAPY

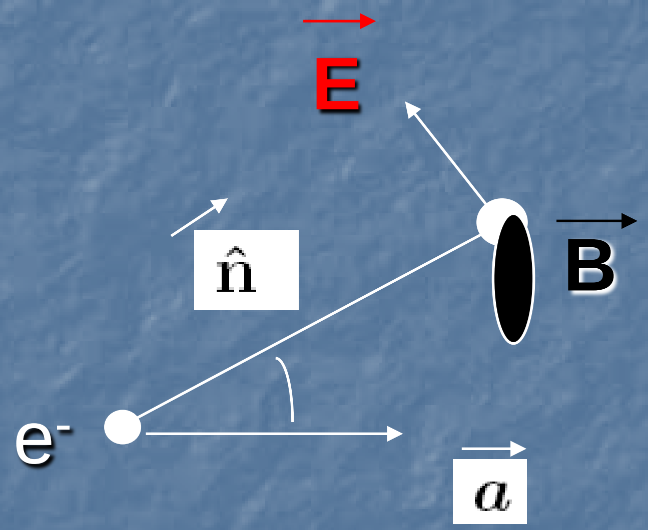
(iThemba LABS)

SOME RADIOISOTOPE PRODUCTION TARGETS
(iThemba LABS)

Accelerator Applications—Synchrotron Light Sources

- **Synchrotron Radiation**

FIRST, CONSIDER A NONRELATIVISTIC ELECTRON ACCELERATED ALONG A STRAIGHT LINE.



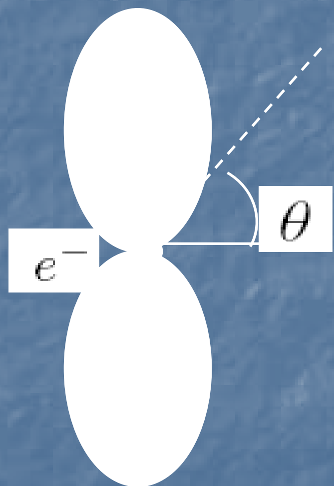
DIPOLE RADIATION PATTERN NON-RELATIVISTIC

ENERGY FLUX IS GIVEN BY THE

POYNTING VECTOR

$$\vec{\mathbf{S}} = \frac{c}{4\pi}\vec{\mathbf{E}} \times \vec{\mathbf{B}}$$

in cgs units

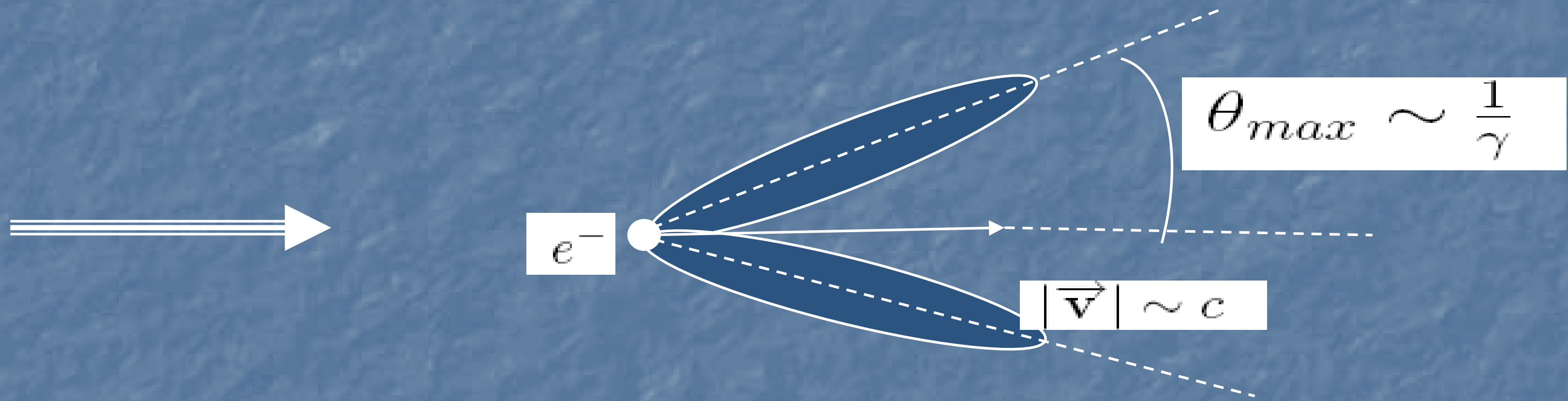


Power spectrum

$$\frac{dP}{d\Omega} = \frac{e^2}{4\pi c^3}\, \boldsymbol{a}^2 \sin^2\theta$$

RADIATION PATTERN FOR A RELATIVISTIC PARTICLE

For the acceleration of the relativistic particle:



where from Einstein's theory of Special Relativity

$$E = \gamma m_0 c^2$$

EXAMPLE: 1 GeV ELECTRON

TYPICAL OF SYNCHROTRON LIGHT SOURCES

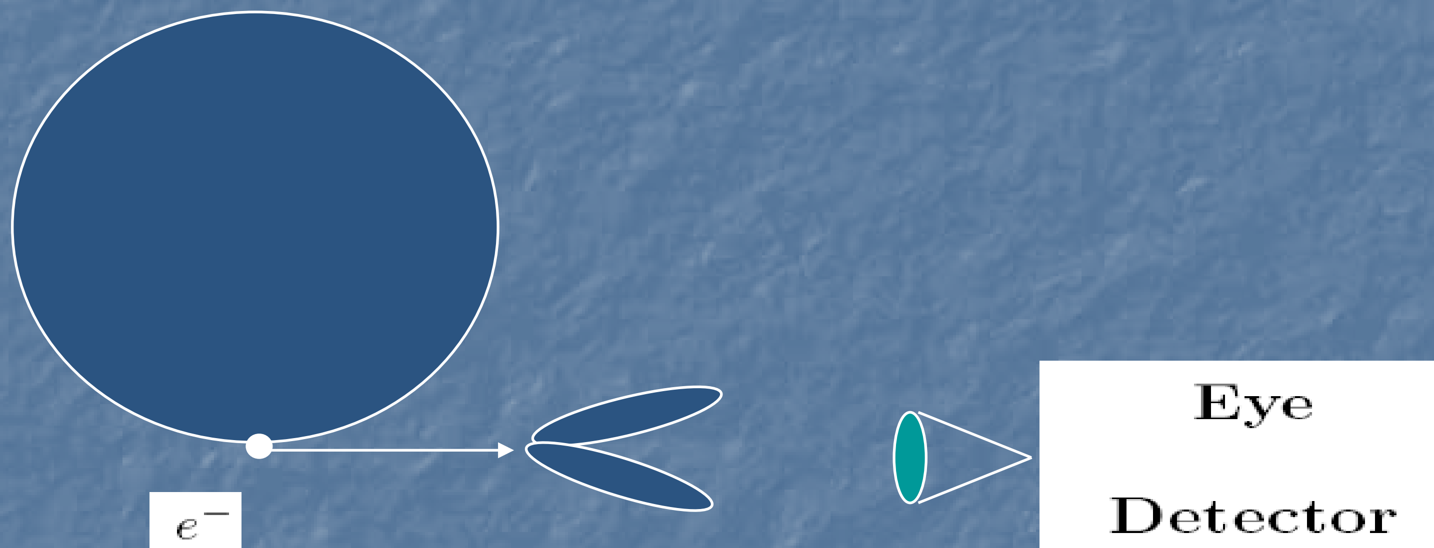
$$\gamma \sim \frac{1000MeV}{0.5MeV} \sim 2000$$

$$\theta_{max} \sim 0.0005 \textbf{ radians} \sim .03 \textbf{ degrees}$$

Radiation is essentially in forward direction!

CONSIDER ACCELERATION ALONG CIRCULAR PATH

Peaking of radiation along $\vec{v}$ is still observed.



Seems like e^- has a flashlight fixed to its head!

FOR ELECTRONS, LINEAR IS BETTER!

- Synchrotron radiation power due to linear acceleration

$$P_{\parallel} = \frac{2}{3}\frac{q^2}{m^2c^3}\left(\frac{d\mathbf{p}_{\parallel}}{dt}\right)^2$$

(Independent of particle's energy)

- Synchrotron radiation power due to circular (transverse) acceleration

$$P_{\perp} = \frac{2}{3}\frac{q^2}{m^2c^3}\gamma^2\left(\frac{d\mathbf{p}_{\perp}}{dt}\right)^2$$

Ratio of Power Radiated to Power Supplied for Linear Acceleration

$$\frac{P}{(dE/dt)} = \frac{2}{3}\frac{e^2}{m^2c^3}\frac{1}{v}\frac{dE}{dx} \rightarrow \frac{2}{3}\frac{(e^2/mc^2)}{mc^2}\frac{dE}{dx}$$

- Negligible unless electron losses rest mass within a distance of its classical radius.
- Corresponds to 2×10^{14} MeV/meter.
- State of art dE/dx ~ 10-100 MeV/m.
- Radiation losses are negligible when linearly accelerating either an electron or proton beam.

WHAT ABOUT PROTON CIRCULAR ACCELERATORS?

$$\textbf{Synchrotron radiation power} \sim \frac{1}{m^2}$$

$$\mathbf{m}_e \sim \tfrac{1}{2}\ \mathbf{MeV}$$

while

$$\mathbf{m}_p \sim 1000\ \mathbf{MeV}$$

Thus,

$$P^e \sim 2 \times 10^6\, P^p.$$

Big problem for circular e^- accelerators!

But not a problem for circular proton accelerators

$\Longrightarrow$ Fermilab's Tevatron.

An Epiphany!

- Someone recognized that the photons being discarded by an electron beam could be useful for irradiating targets.
- High energy and nuclear physicists started performing their usual experiments while others parasitically used the X-Rays produced at the bending magnets. (1st generation synchrotron light sources)
- Then physicists and engineers began building accelerators dedicated entirely for X-Rays from the bending magnets. (2^{nd} gen.)
- To increase the number and variety of X-Ray beams, scientists started installing insertion devices: Pioneered by Herman Winick *et al.* at Stanford Linear Accelerator Center (SLAC) (3^{rd} generation)

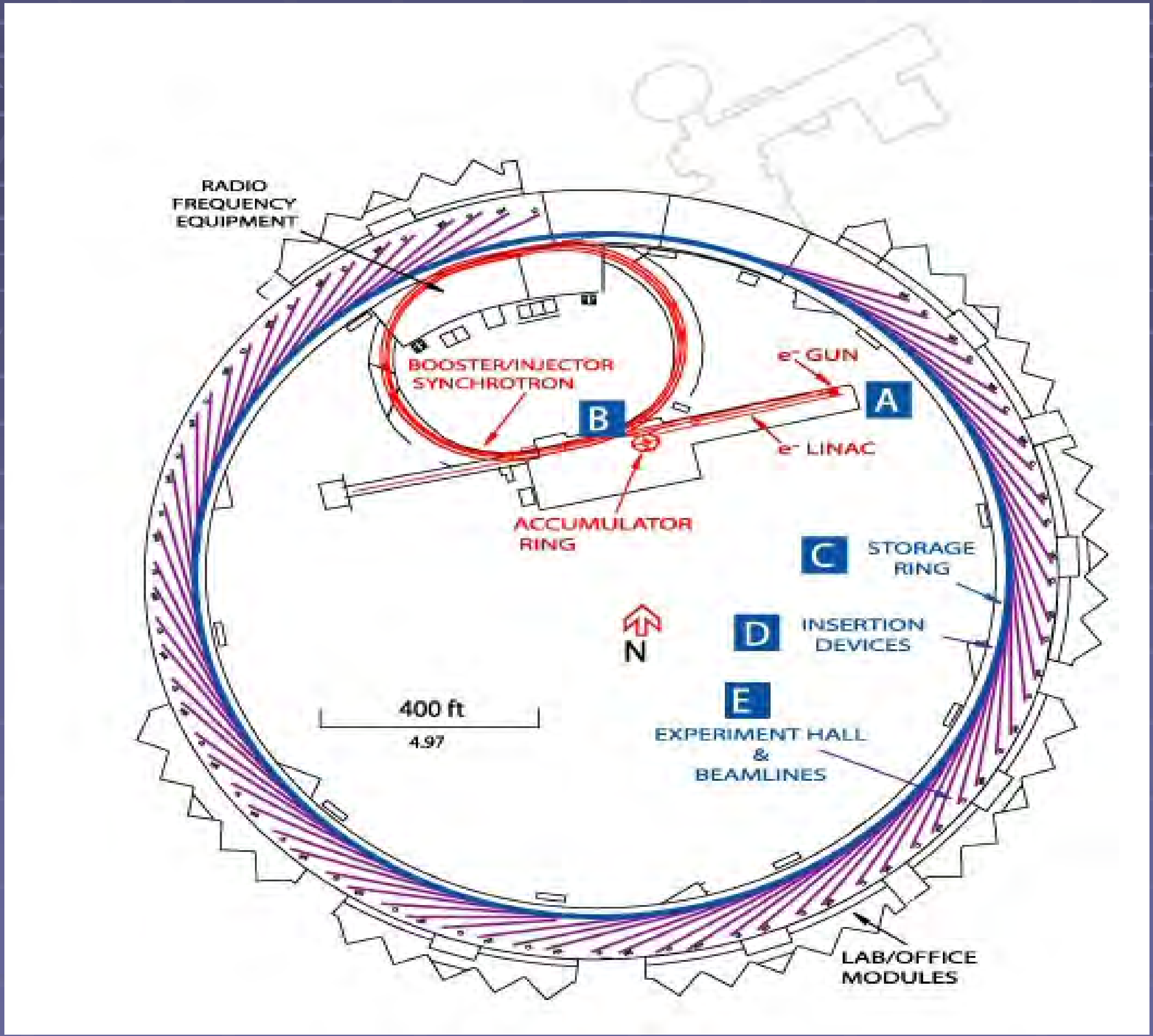
GOOD NEWS!

Radiation in synchrotrons spans the region of the electromagnetic spectrum from the infrared to hard X-ray regimes.

Precisely what is needed to pursue a variety of studies, including materials, protein structure, chemistry, and even industrial applications.

ADVANCED PHOTON SOURCE (APS) ARGONNE NATIONAL LABORATORY

APS BEAMLINES



Other Applications

- First, we must state that there are many, many extremely important accelerator applications, facilities, and proposed facilities which we have either not discussed at all or just touched upon in this talk for reasons of brevity. They include:
- Dielectric Wall Accelerators (DWA) for use in Compact Proton Therapy;
- Further development of Superconducting Synchrotron Proton Beam Radio-Therapy (PBRT);
- Next Generation Light Sources (Self-Amplified Spontaneous Emission Free-electron Lasers [SASE-FELs]) and their applications;
- The ***African Laser Centre*** (ALC) has been adopted by the ***New Partnership for Africa's Development*** (NEPAD) as a Center of Excellence where one of its long-term goals is to assist in bringing advanced light sources to Africa: FELs, petawatt lasers, and synchrotron light sources;

Other Applications (continued)

- **Femtosecond Chemistry** **(From the Linac Coherent Light Source (LCLS))**

  - **Chemical reactions between small molecules are by nature ultra-fast, but the time sequence of these reactions can be captured with the ultra-fast pulses of SASE-FELs.**

  - **Photosynthesis involves such ultra-fast reactions. A better understanding of photosynthesis has implications for future energy sources and for agriculture, which will be important for Africa.**

  - **Possibility to intercede during chemical reactions to produce novel compounds.**

Other Applications (continued-1)

Nanoscience/nanotechnology (LCLS)

- Modern technology (electronic devices, computer chips, and liquid crystal displays on watches) uses nanoscale materials.
- Those materials consist of simple constituents arranged in complex man-made ways, all on a very tiny scale.
- Often, what is interesting about these molecules is that they change with time in a useful way. (For example, the molecules in a LCD display change their alignment, dictating which numerals appear on the face.)
- How those states change and how the change is induced can be better studied with the ultra-fast X-Ray pulses from SASE-FELs.
- As technological devices continue to get smaller and faster, better understanding such nanoscale processes will help to build better technology.

Other Applications (continued-2)

- **Biological Systems (LCLS)**
  - **Using x-rays to study the atomic structures of biological molecules such as proteins has turned out to be invaluable for understanding their roles in life processes;**
  - **Often, the atomic structure of a molecule is crucial to its biological activity;**
  - **Nowadays, drug molecules can be created to fit the shape of certain human biological molecules and thereby deliver their effect in a very specific way;**
  - **This is only possible with the knowledge of the structures of the molecules, most often obtained from synchrotron radiation studies;**
  - **But the X-Ray diffraction process used to study molecular structure has its limitations; the radiation quickly destroys the molecule being studied;**

Other Applications (continued-3)

- **Biological Systems (LCLS)**
  - **Researchers have found a way to work around this destruction: molecules like proteins are formed into crystals (containing millions of neatly ordered, identical copies of the molecule) so that many molecules are simultaneously examined, thus spreading the radiation damage around;**
  - **Though this technique has been extremely useful, the crystals are often very difficult to create, and with many molecules, it may be impossible;**
  - **But SASE-FELs offer another way to work around the radiation damage problem: the extremely bright and ultra-short x-ray pulse can give a picture of just several hundred molecules nearly instantly, before they are destroyed, so that the molecules can be studied in their normal wet environments and no crystallization is necessary.**

Materials for Mid-IR Quantum Cascade Lasers (QCLs) and Sensors

Anthony M. Johnson, UMBC
Director, Center for Advanced Studies in Photonics Research (CASPR)
Prof. of CSEE and Physics
MIRTHE Deputy Director
Novel Mid-Infrared Materials Research Thrust Leader

- Compare and optimize growth of superlattices, QC lasers and structures and QW infrared photodetectors (QWIPs)
- Push the limits on material quality by careful study of essential growth parameters in close feedback with refined materials characterization techniques
  - Optical and ultrafast optical spectroscopy – Near-IR and Mid-IR (UMBC)

NSF Engineering Research Center – Mid-Infrared Technologies for Health and the Environment (MIRTHE)

Other Applications (continued-5)

What / Who is MIRTHE ?

- World-class, interdisciplinary team of engineers, chemists, physicists, environmental and bioengineers, medical doctors, and educators, in academia and industry

Goals:

- Research, development, and technology transfer to industry of unprecedented mid-IR (3 – 30 μm) optical trace-gas sensing systems for environmental applications , homeland security, and medical applications.
- Formation of a vibrant community for learning and teaching, providing the best education with interdisciplinary breadth for a new generation of highly educated, practice-oriented, competitive, and diverse U.S. workforce.

Other Applications (continued-6)

- **Light-Ion and Hadron Radiation Therapy**
  - **Treat cancerous tumors by bombarding them with protons or heavy charged ion beams;**
  - **Very good results obtained by groups worldwide including iThemba Labs, Europe and Japan (carbon ions);**

EBASI
RECOMMENDATIONS—The Future

Governmental and Administrative Infrastructure Requirements

- **Mission Statement Which Enunciates Succinctly And Clearly What The Organization Wishes To Accomplish.**

- **Accessible Information Which Provides One With An Idea As To The Interdependencies Of The Organization With Its Local Or Other Governing Bodies As Well As Its Basic Organizational Structure.**

Hardware-Based Infrastructure Requirements

- DON’T RE-INVENT THE WHEEL
  - Emulate The One-laptop-per-child Computer (OLPC) Project.
  - Partner With Existing Organizations To Scale Such Hardware To The Level Where It Can Support Browsers Which Then Allow One To Utilize The Internet.
  - Create Machines Which Are Suitable For Research And On-line Education (Wireless)
  - Hardware Scale-ups Should Support Several Available Open-source Computational And Publishing Software.

Software-Based Infrastructure Requirements

- DON'T RE-INVENT THE WHEEL
  - Emulate/Partner with The One-laptop-per-child Computer (OLPC) Project in order to create machines which are suitable for research and on-line education (wireless)
  - Partner With Existing Organizations To Scale Such Software that It Can Support Browsers Which Then Allow One To Utilize The Internet wirelessly.
  - Software Should Support Open-source Computational And Publishing Software such as AXIOM, MiKTeX, Ghostscript, etc..

Education Infrastructure Requirements

- DON'T RE-INVENT THE WHEEL
  - Emulate/Partner/Collaborate With Organizations Which Already Have Experience In Delivering And Disseminating Educational Material Via The Internet At Affordable Prices. Such A Company Might Be WebAssign© (Associated With The North Carolina State University System)
  - Partner With Existing Organizations To Scale/Create Software Browser Interfaces Which Then Allow One To Utilize The Internet Wirelessly For Computations Which Could Even Be Performed Remotely And/Or Modularly.
  - Software Should Support Open-source Computational And Publishing Software Such As AXIOM, Miktex, Ghostscript, Open Office.
  - One Would Now Have Available Access To Extensive Scientific and Mathematical Databases (Open-Access Publishing) Such As arXiv.Org (Now At Cornell University , Formerly At Los Alamos National Laboratory, Often Contains Preprints Which Are Essentially Identical To Their Published Counterparts).

What is WebAssign©?

(Note: We have no business/financial connection at all with WebAssign©, it is used as a model which meets most of the EBASI criteria for the enhancement of nuclear science education and training in all Member States and in particular developing countries)

- Hosted on-line homework/assessment system accessible through browsers;
- Textbook (e-book as well is possible) database of algorithmically randomized pre-coded (one may create one's own as well) problems/solutions with or without individual student real-time response;
- Assignments, progress assessment, exams (automatic/manual), labs, on-line posts for student access with automatic or instructor scoring.

EBASI
RECOMMENDATIONS—The Future

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Extra Backup Slides

CASPR
CENTER FOR ADVANCED STUDIES IN PHOTONICS RESEARCH

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Dr. Anthony M. Johnson, Director
Center for Advanced Studies in Photonics Research (**CASPR**)
University of Maryland, Baltimore County (**UMBC**), USA
2002 President of the Optical Society of America
EBASI Council Member since 1988

Applied Physics PhD student Raymond Edziah, Physics Scholar Exchange student from the University of Cape Coast, Ghana presented his research results at this year's prestigious international laser conference known as CLEO (Conference on Lasers and Electro-Optics) held in Baltimore, Maryland, USA (May 6 – 11, 2007). This conference featured more than 1,500 talks on the latest cutting-edge optics and photonics research and Raymond's presentation was entitled "100X Enhancement of the Nonlinear Index of Refraction of Sulfur-Doped CS_2 over Pure CS_2" He is also in the process of submitting a paper for publication while at the same time applying for a provisional patent to protect his findings as he proceeds with some further detailed investigations and graduation from UMBC with a PhD in 2008.

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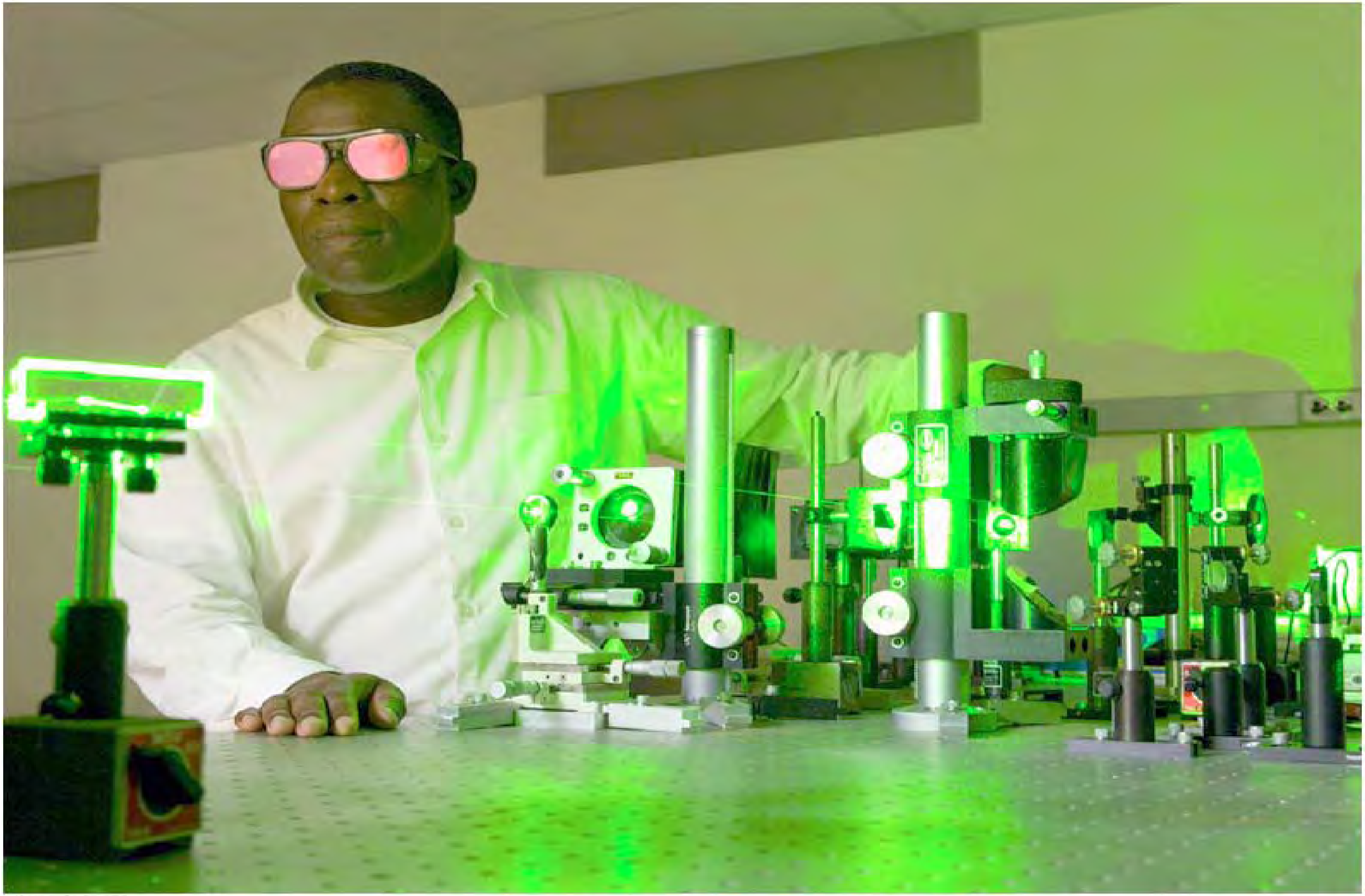
Mr. Raymond Edziah, Physics Scholar Exchange student from the University of Cape Coast, Ghana will complete his PhD in Applied Physics at UMBC in 2008.



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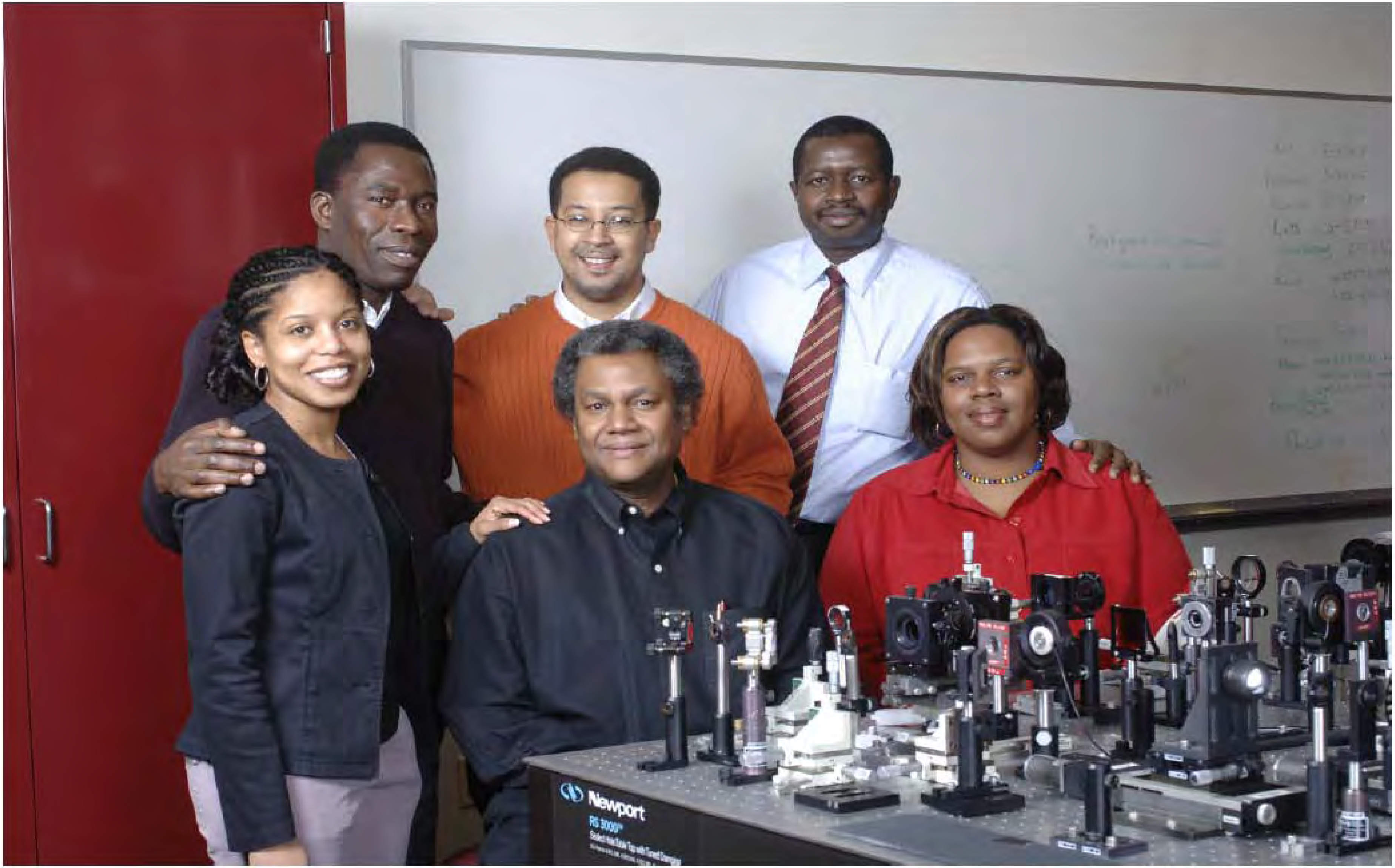
Ultrafast Optics & Optoelectronics Laboratory



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BIRTH OF ALC

- The ALC was formally Launched in Johannesburg at the November 6, 2003, NEPAD Ministerial Conference on Science and Technology.
- NEPAD has adopted the ALC as its Center of Excellence in Laser Science and Technology.
- African Ministers of Science and Technology have pledged US$20 Million to ALC over next 5 years.

ANNUAL GENERAL MEETING (AUGUST 2006)

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