Physics

Observation of High-Energy Deuterium-Tritium Fusion Gamma Rays Using Gas Cherenkov Detectors

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Presentation Scope

- History
- Nuclear physics
- Deuterium-tritium inertial fusion implosions
- Why Cherenkov photons?
- Gas Cherenkov Detector (GCD) physics and design
- High-energy fusion gamma observation
- Model/instrument validation
- High-bandwidth demonstration
- Future work

ICF thermonuclear burn can be measured by fusion neutron or fusion gamma-ray diagnostics

- Fusion of Hydrogen isotopes
  - Deuterium and Tritium
- Very rapid thermonuclear burn
  - Picoseconds to 250 ps
- Burn occurs earlier than induced backgrounds
  - Time discrimination possible
- Neutron burn measurements suffer from Doppler broadening
- Gamma burn measurements are more direct

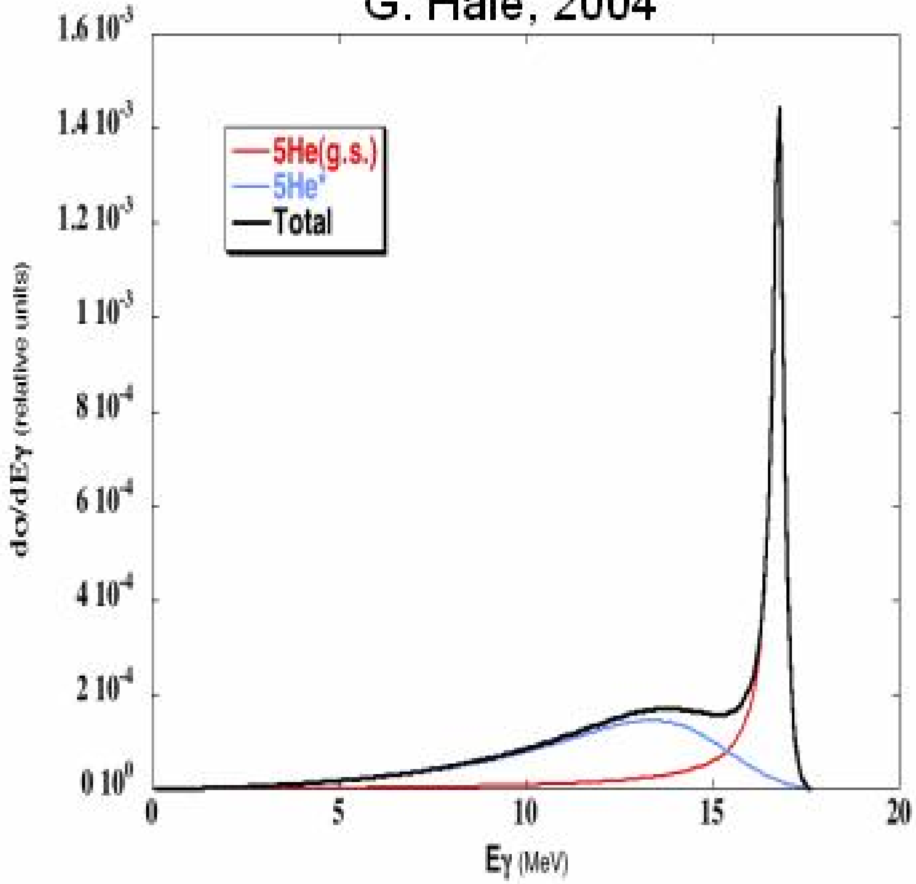
D + T

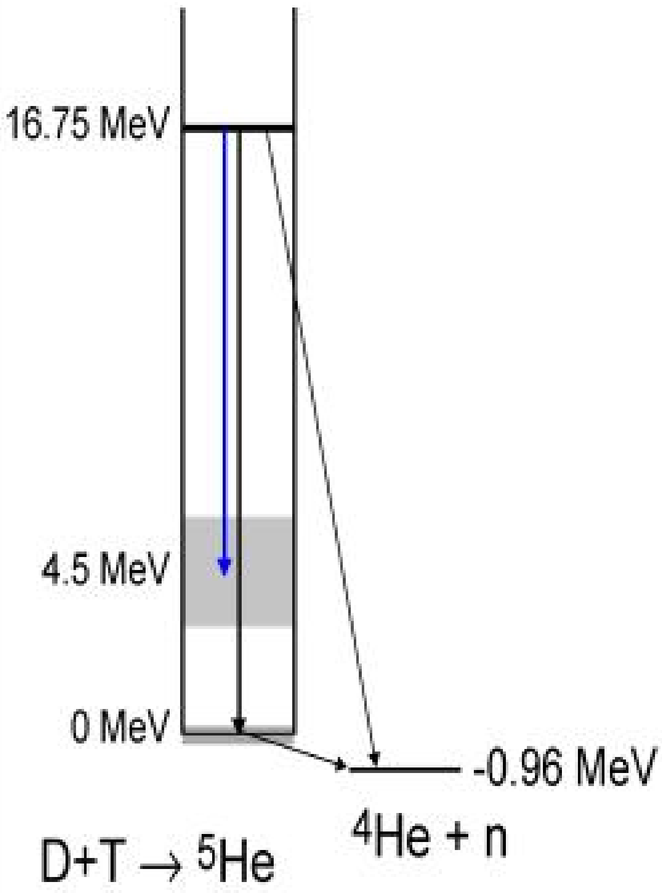
→ 0.99999: ${}_0n^1$(14.1 MeV) + ^{4}He

→ ~10^{-5}: γ(16.7 5MeV)(12 MeV?) + ^{5}He

Calculated spectrum of $^5He^*$ shows possible 12 MeV γ-rays

G. Hale, 2004

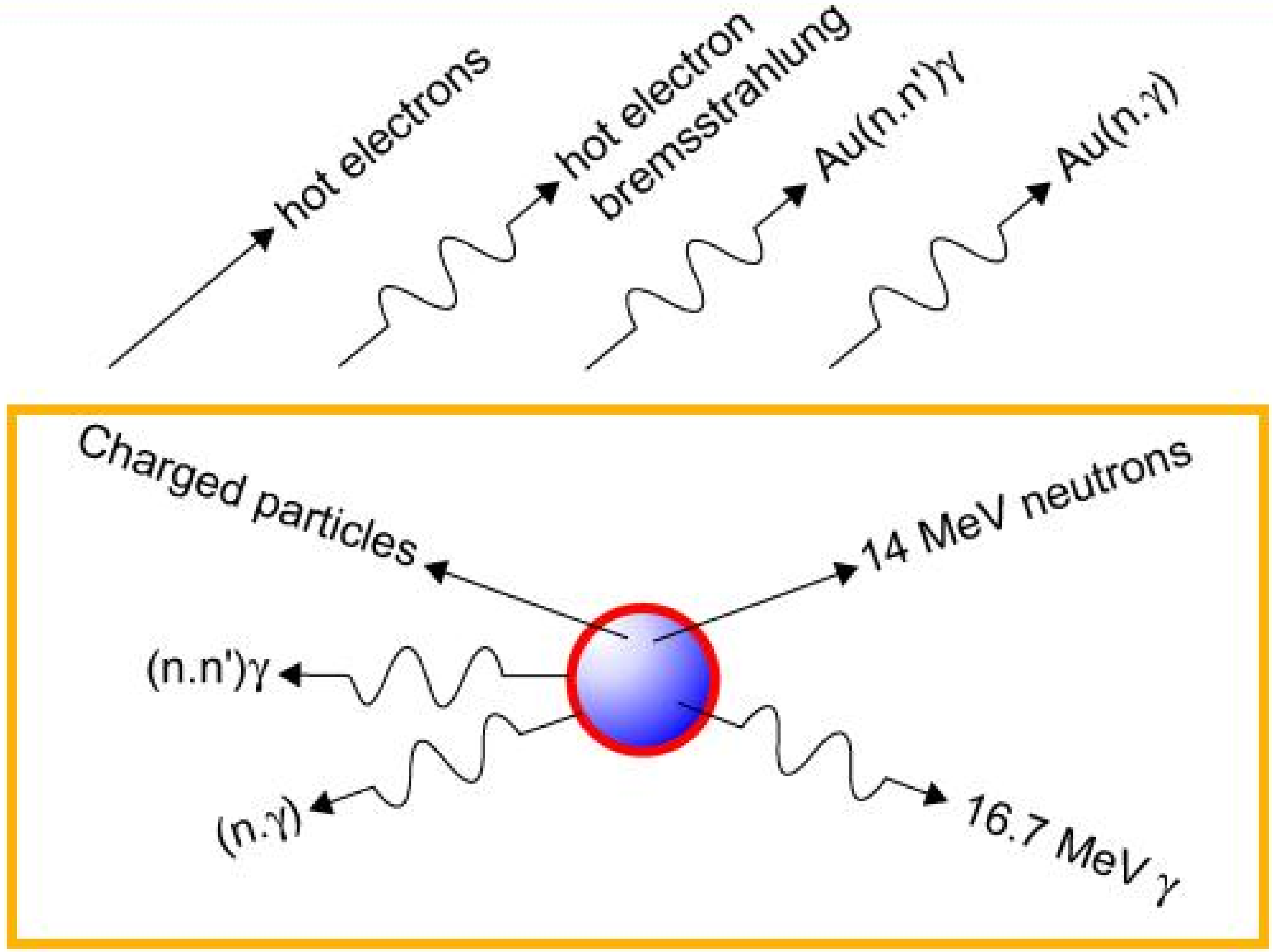




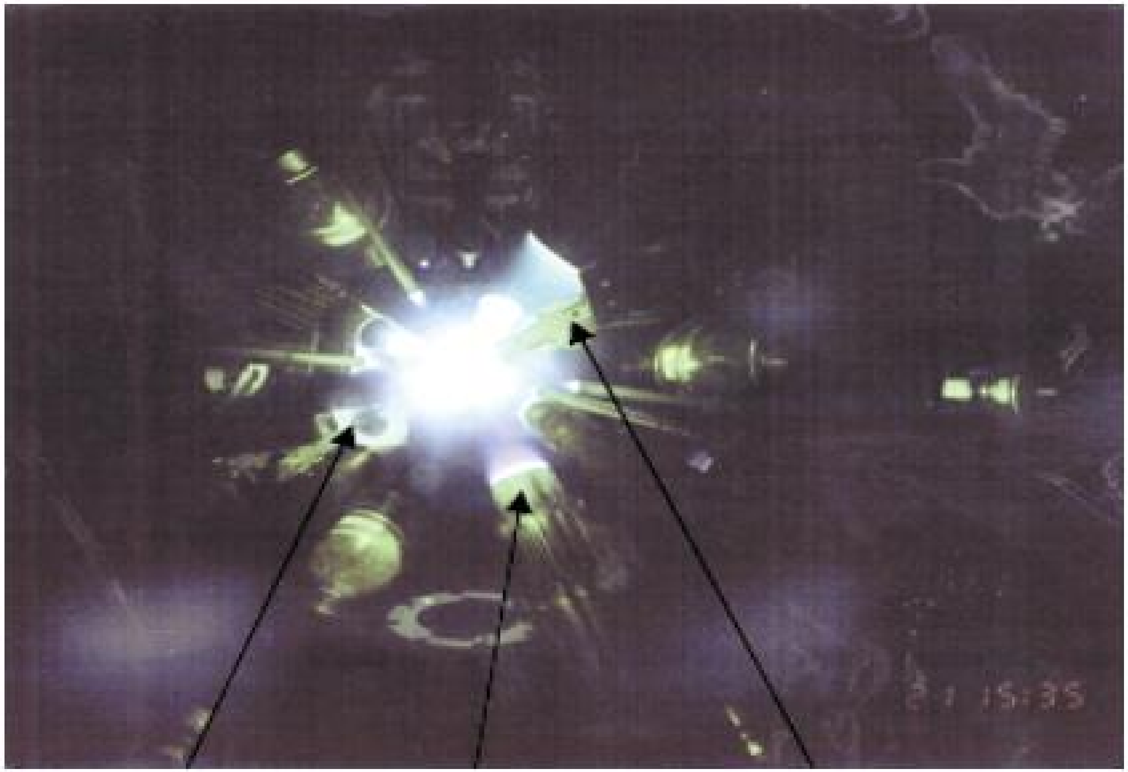
The Lab for Laser Energetics (LLE) OMEGA target chamber provides a "big-science" setting

High-yield capsules are often ~1000 micron glass micro-balloons

Direct and indirect drive D-T fusion implosions produce a variety of products



The LLE OMEGA laser target chamber presents a very complex environment

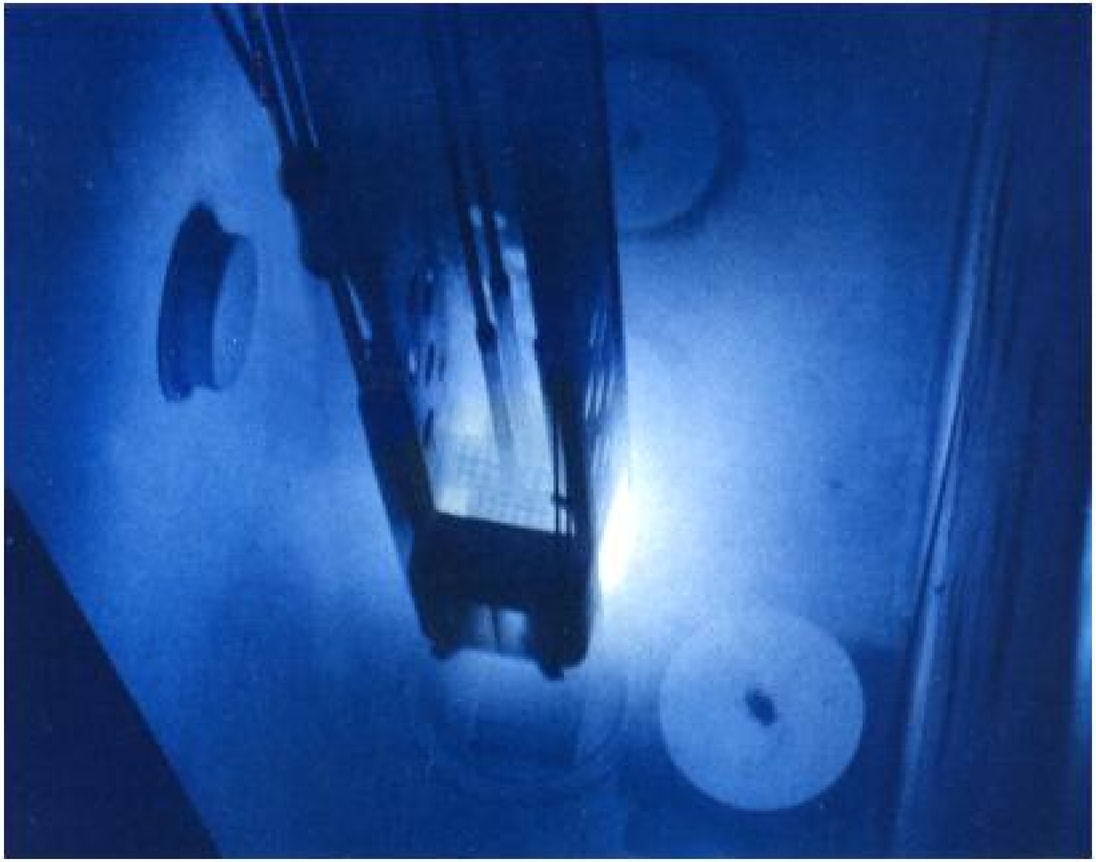


Neutron Imager

Gas Cherenkov Detector

X-ray camera

Fusion gammas can also be converted to Cherenkov light

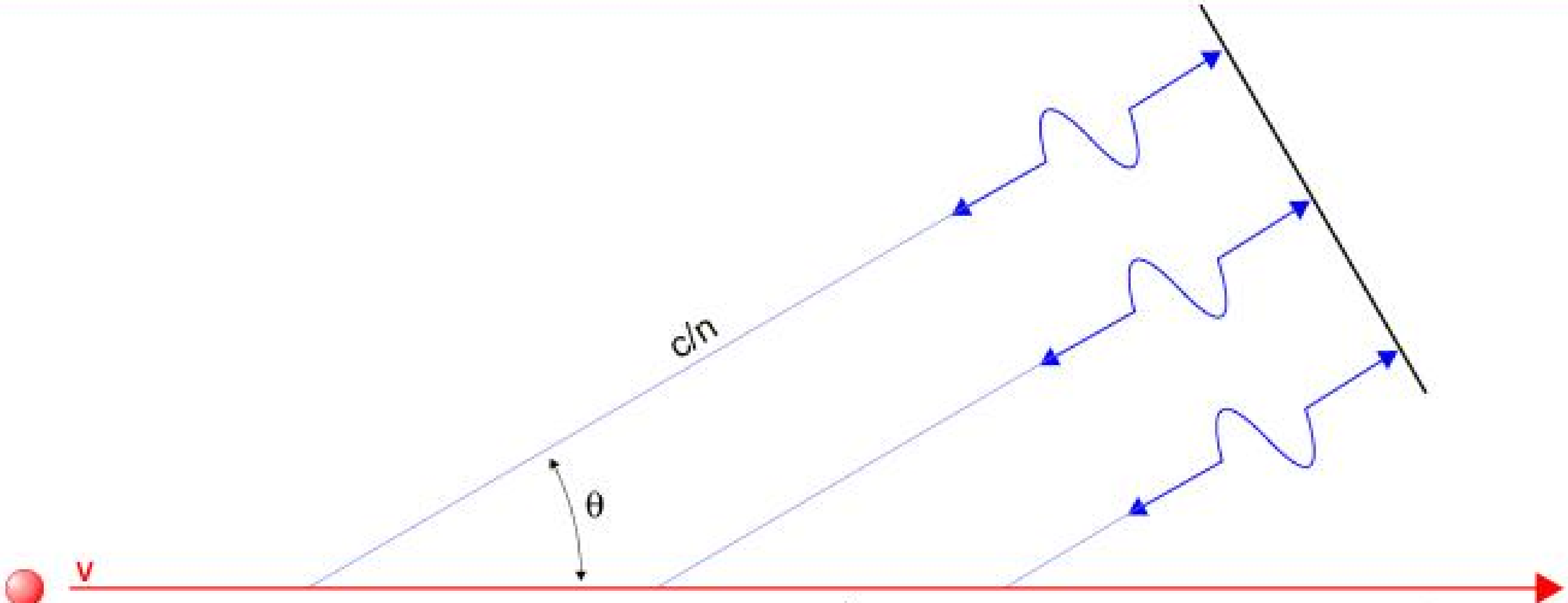


* Picture from Jelly, *Cherenkov Radiation*, Pergamon Press, 1958.

Why a gas Cherenkov detector?

- Relatively "simple" design
- Dramatically improved time resolution possible
- **Optical Cherenkov light**
- Improved light collection
- Thresholding flexibility
- Time separation of signals

Cherenkov light can be used to indicate presence of the 16.75 MeV γ ray



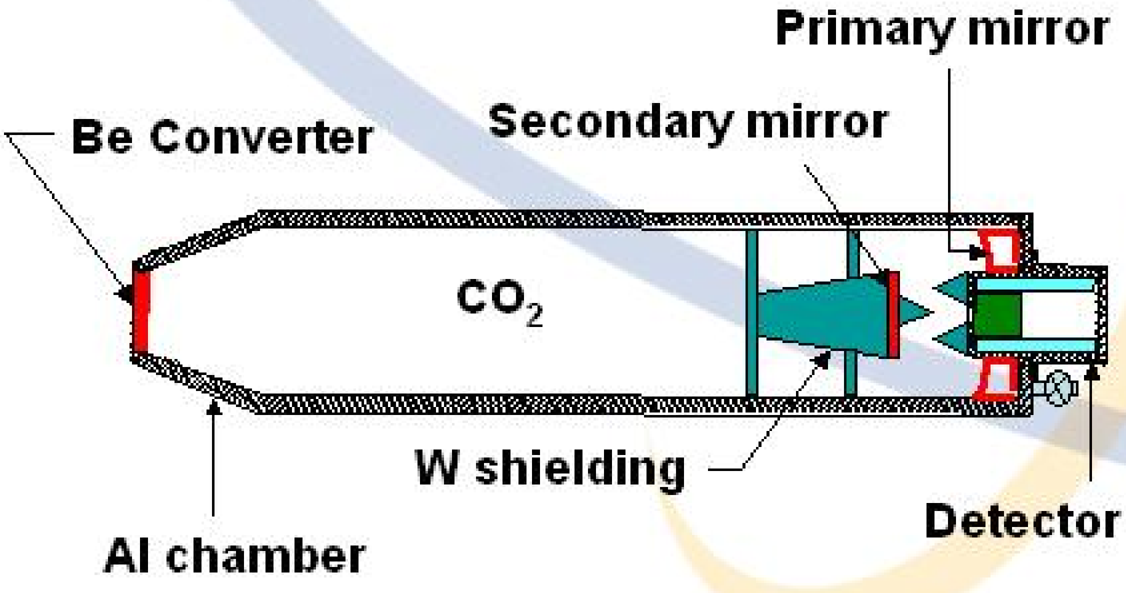
$$\cos\theta = \frac{c}{n\,v} = \frac{1}{n\,\beta}$$

n = 1.000835 → threshold electron energy of 12 MeV

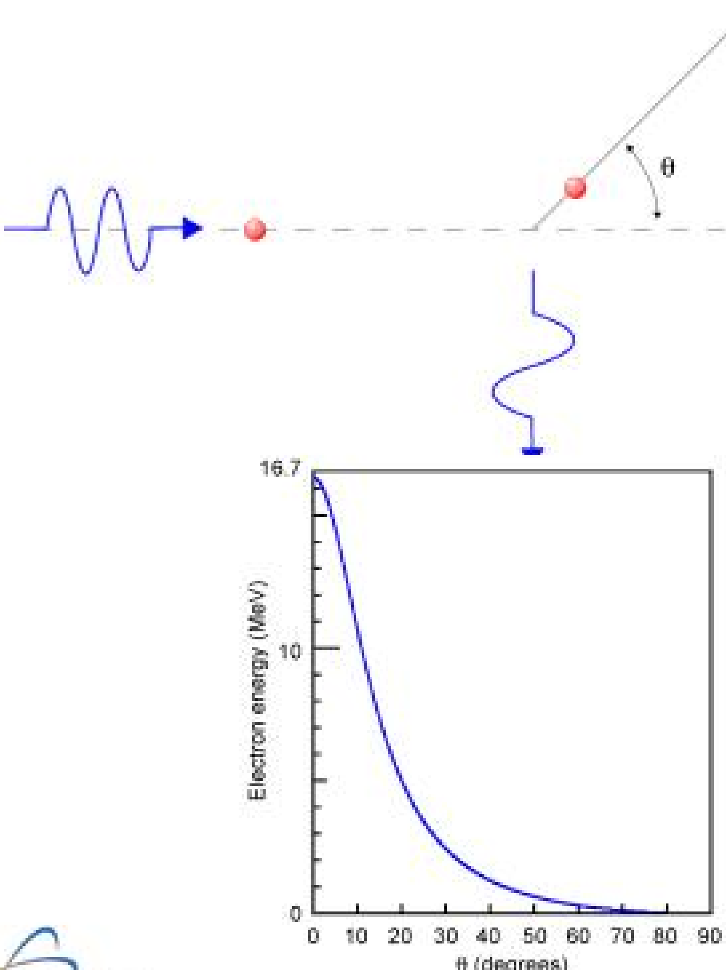
16.45 MeV electron produces Cherenkov light at 1.6°

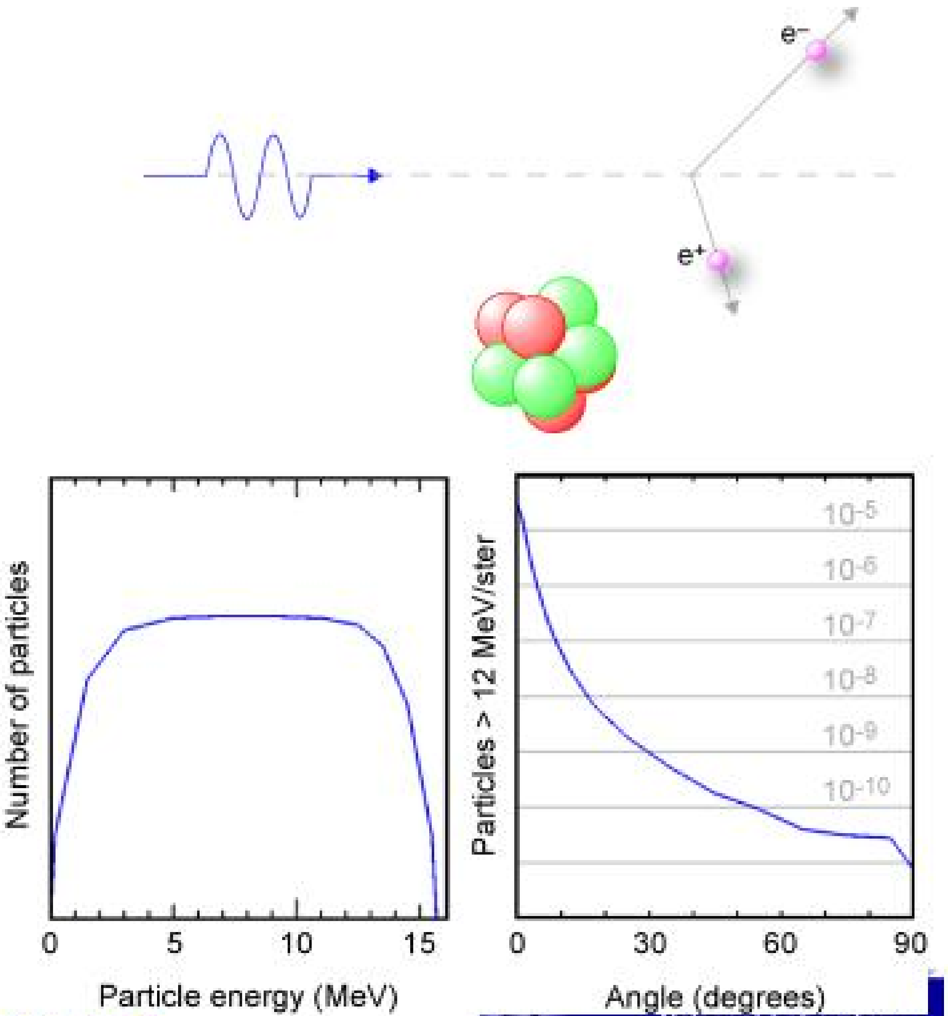
GCD1 successfully tested at Idaho State Univ LINAC and at OMEGA laser at Lab for Laser Energetics, Univ of Rochester

Detector Configuration

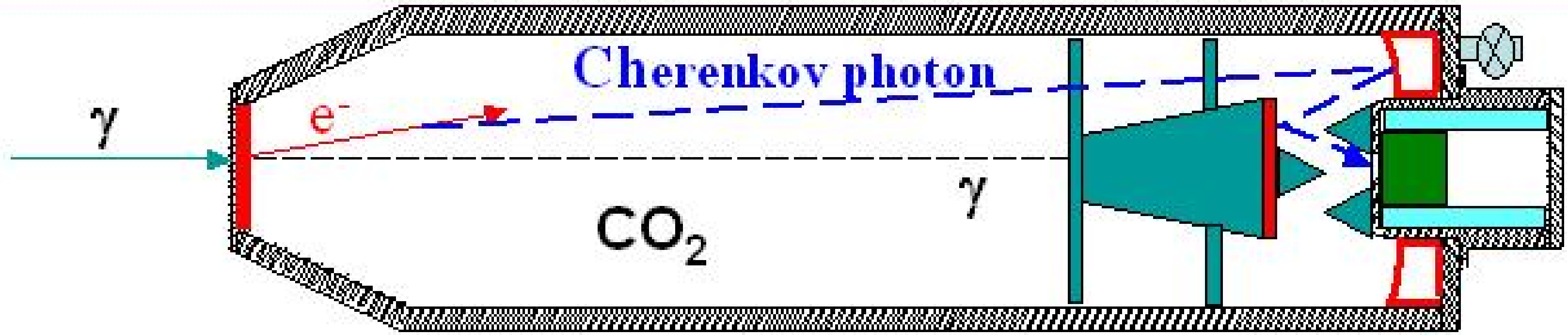


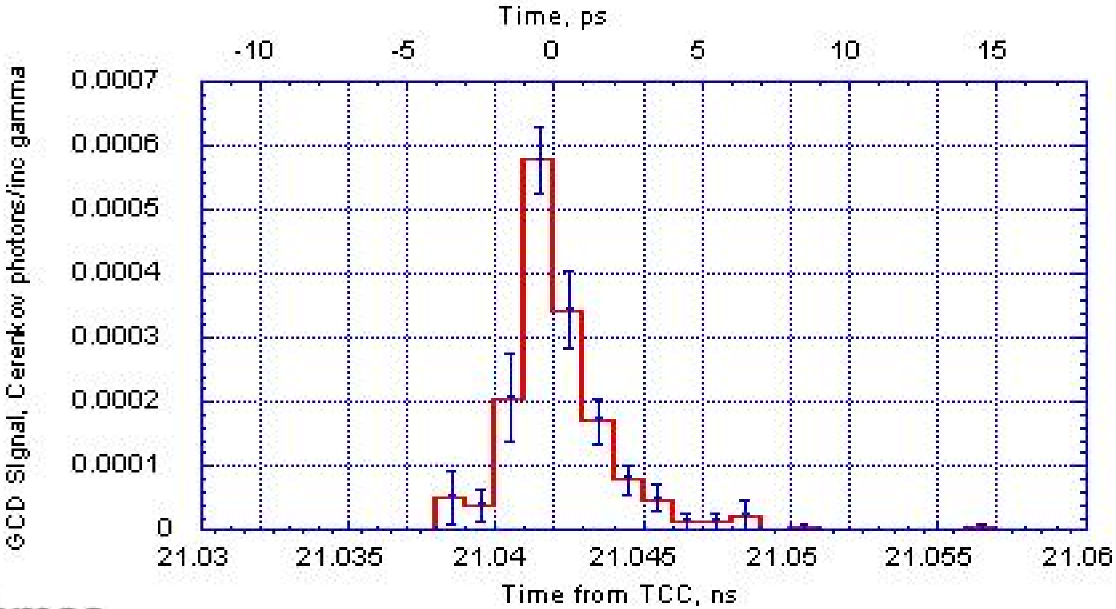
Compton and pair production electrons are main sources for Cherenkov production





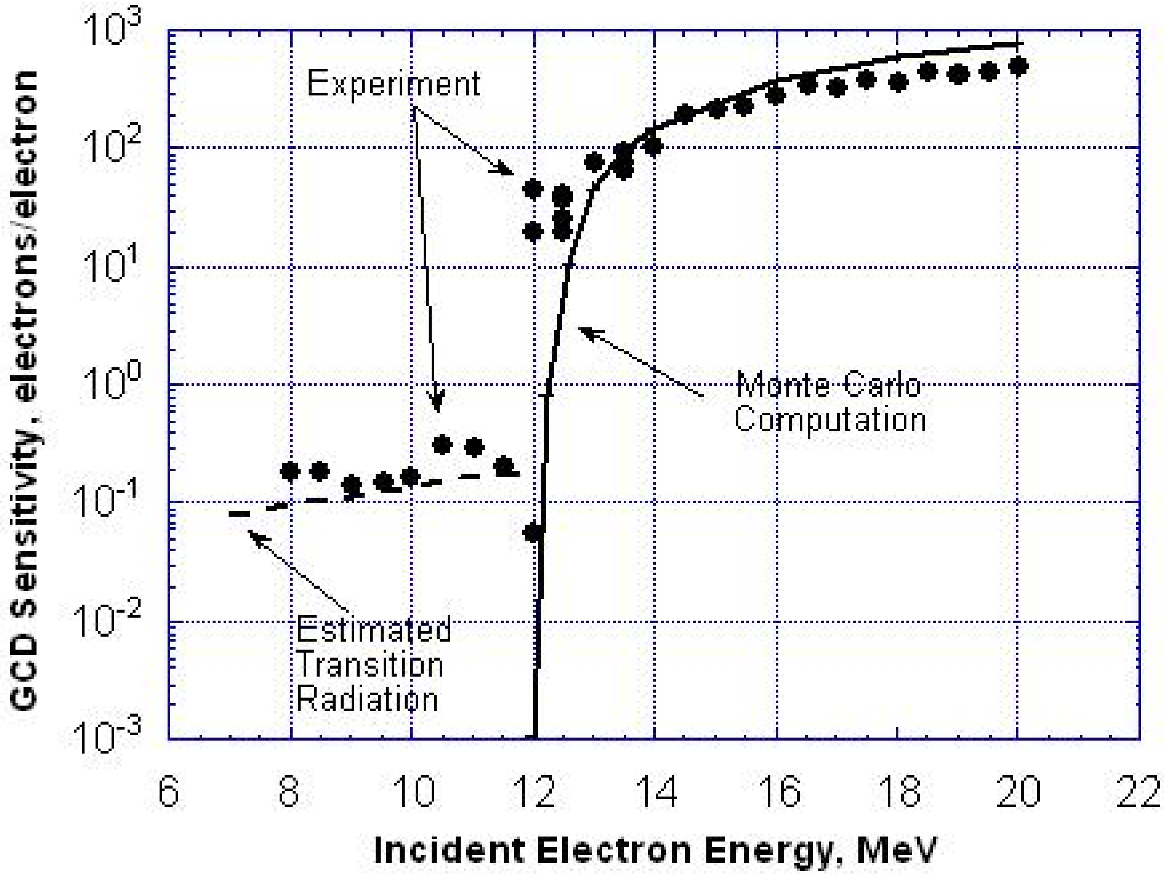
Monte Carlo simulations provided gas Cherenkov detector (GCD) system design guidance



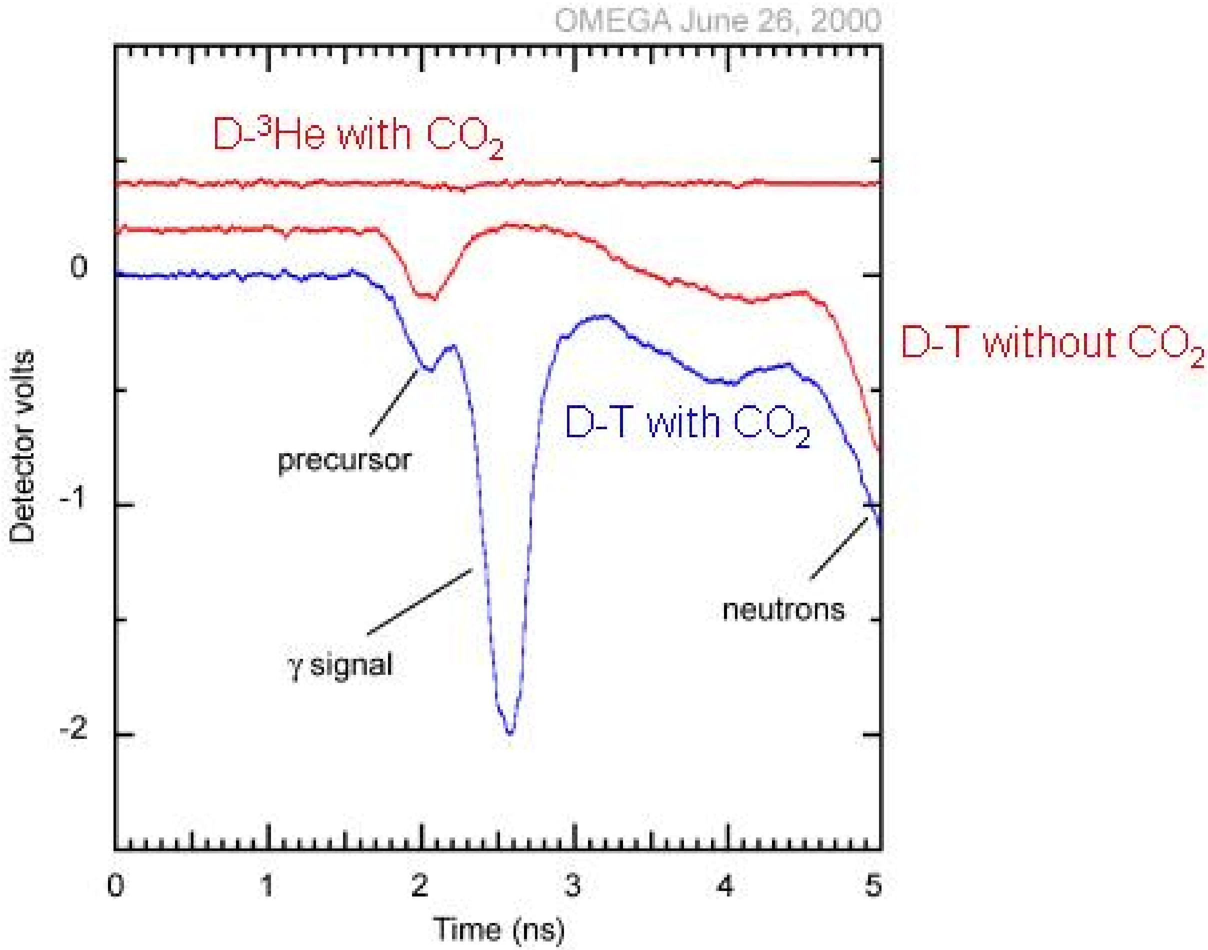


Monte Carlo simulations show time response for gas cell to be < 10 ps

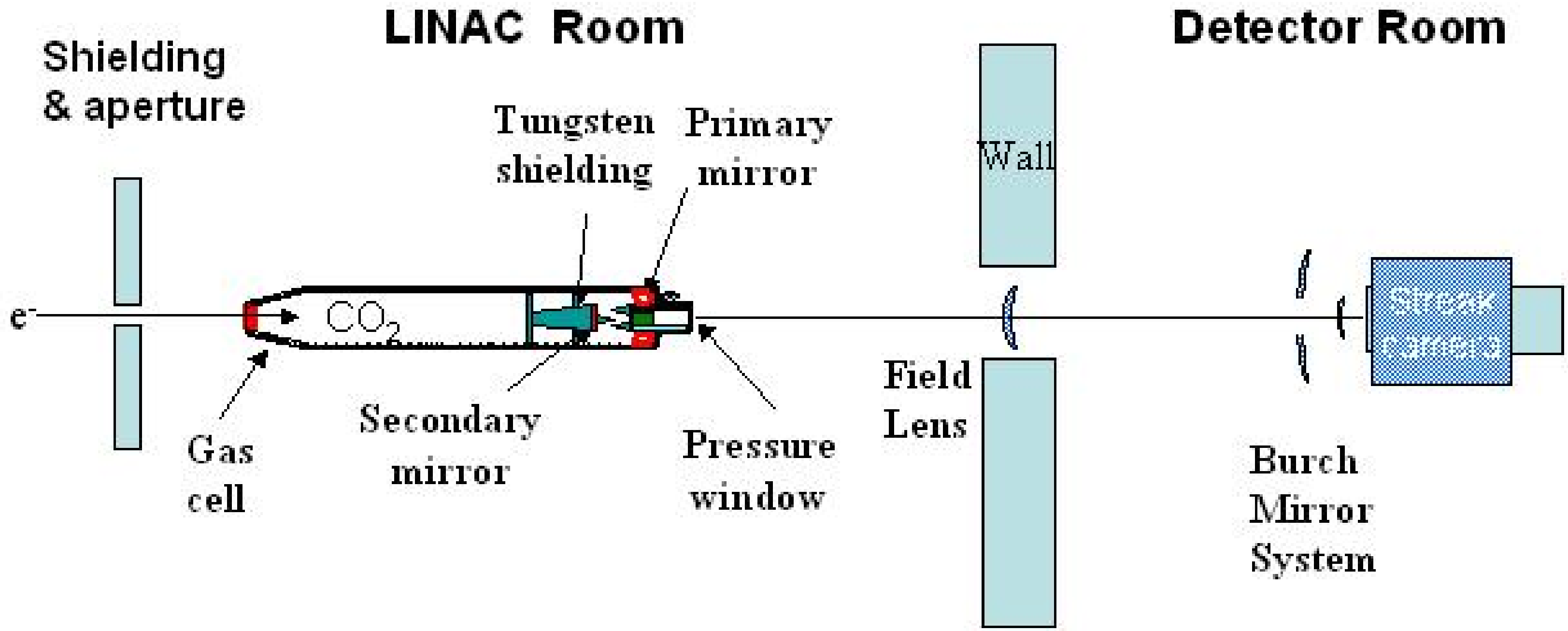
The GCD threshold curve has been measured at the ISU LINAC and calculated with Monte Carlo



Unambiguous observation of the 16.75 MeV D-T fusion γ ray was accomplished



The Idaho State University LINAC electron source was used to establish system time response for our streak camera system



Experimental parameters

— Cell pressure: 0–100 psi (pounds per square inch)

— Electron energy: 10–20 MeV

The ISU LINAC provided a variable high-energy electron source

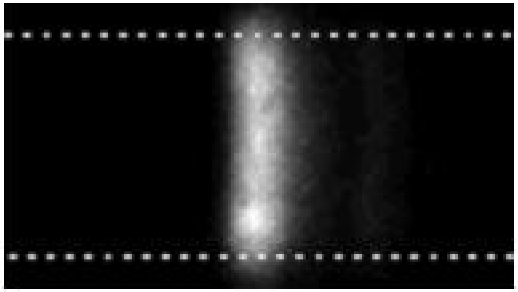
Monte Carlo simulations form a cornerstone for our gas Cherenkov detector design and analysis

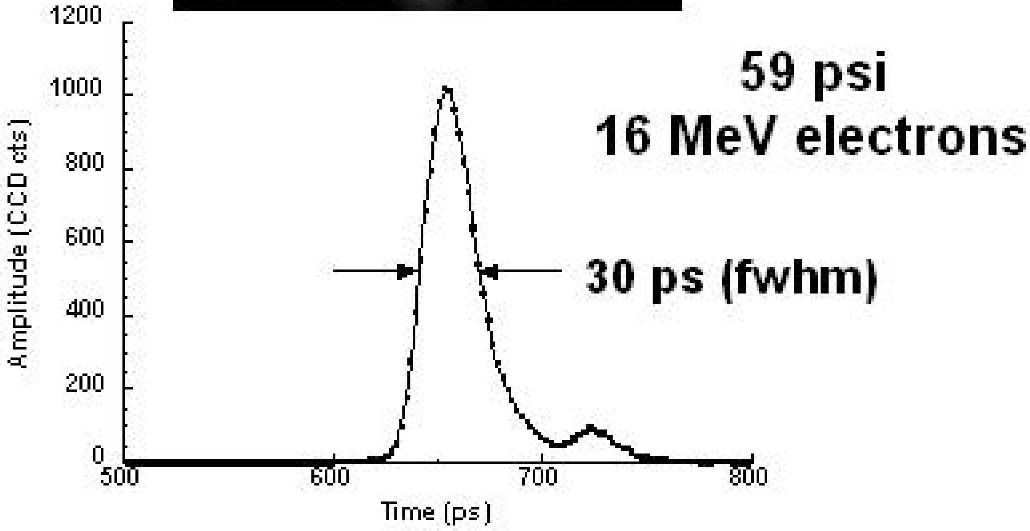
Computer Simulations

- 3-dimensional ACCEPT code of Integrated Tiger Series Modified to include time, Cherenkov and Transition radiation
  - Full Compton cross section with angle and energy distribution
  - Full pair production cross section with angle and energy distribution
  - Optical ray tracing with wavelength dependence
    - End to end simulation including all optics
- Produce virtual source of Cherenkov light to include time, position, and direction of each photon—then iterate with optics package
- Beryllium best converter material

LINAC electrons produced 20–40 ps Cherenkov pulses from gas cell

Typical pulse recorded with 10-ps streak camera





Summary of accomplishments and future considerations

- We've observed high-energy fusion γ rays from D-T implosions
  - Proof-of-principle accomplished at Omega Laser Facility
    - MCP/photomultiplier system
- Demonstrated desired high-bandwidth operation
  - ~30 ps streaked resolution at LINAC
- Present + future:
  - Pursuing burn physics ignition experiments
  - Pursuing fundamental physics of fusion reactions
  - Fusion gamma and neutron burn with one instrument

We will actively pursue immediate and long-term prospects

Omega Burn-physics Experiments [LANL, LLNL]

NIF Diagnostic Development

NIF Experiments

2004 — **2006** — **2010**

Omega Fundamental D-T Reaction Physics

High-bandwidth burn-history measurements using high-energy D-T fusion γ rays are now feasible!

Selected Publications

J. M. Mack, R. R. Berggren, S. E. Caldwell, S. C. Evans, J. R. Faulkner, Jr., R. A. Lerche, J. A. Oertel, C. S. Young" Observation of high energy deuterium-tritium fusion gamma rays using gas Cherenkov detectors," Nuclear Instruments and Methods in Physics Research A 513 (2003) 566–572.

S.E. Caldwell, R.R. Berggren, B.A. Davis, S.C. Evans, J.R. Faulkner, Jr., J.A. Garcia, R.L. Griffith, D.K. Lash, R.A. Lerche, J.M. Mack, G.L. Morgan, K.J. Moy, J.A. Oertel, R.E. Sturges, C.S. Young, Rev. Sci. Inst., 74, #3, March, 2003.

R. R. Berggren, S. E. Caldwell, J. R. Faulkner,Jr, R. A. Lerche, J. M. Mack, K. J. Moy, J. A. Oertel, and C. S. Young, Rev. Sci. Instrum., Vol 72, No. 1, January 2001.

J. M. Mack and C. S. Young, First International Conference On Inertial Fusion Sciences and Applications, ENSCPB-University Bordeaux 1-France, 17 September 1999.

S. E. Caldwell, S. S. Han, J. R. Joseph, T. L. Petersen, and C. S. Young," Burn History Measurements in Laser Based Fusion," Rev. Sci. Instrum., Vol. 68, No. 1, January 1997.

J. M. Mack, M. Jain, and T. M. Jordan," Monte Carlo Simulation of Gas Cerenkov Detectors," IEEE Transactions on Nuclear Science, Vol. NS-32, No 1, p. 668, February 1985.