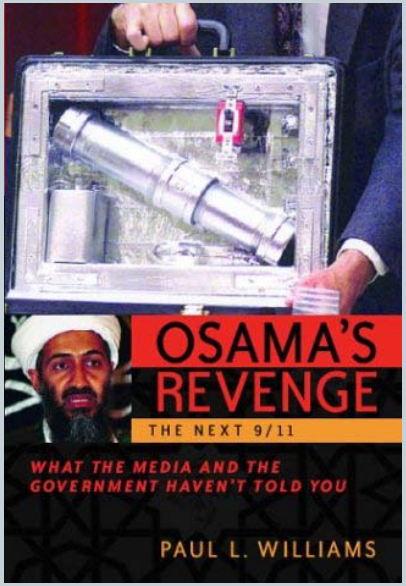
An Interrogation Method using Linearly Polarized Photons

BY JASEN SWANSON

Motivation

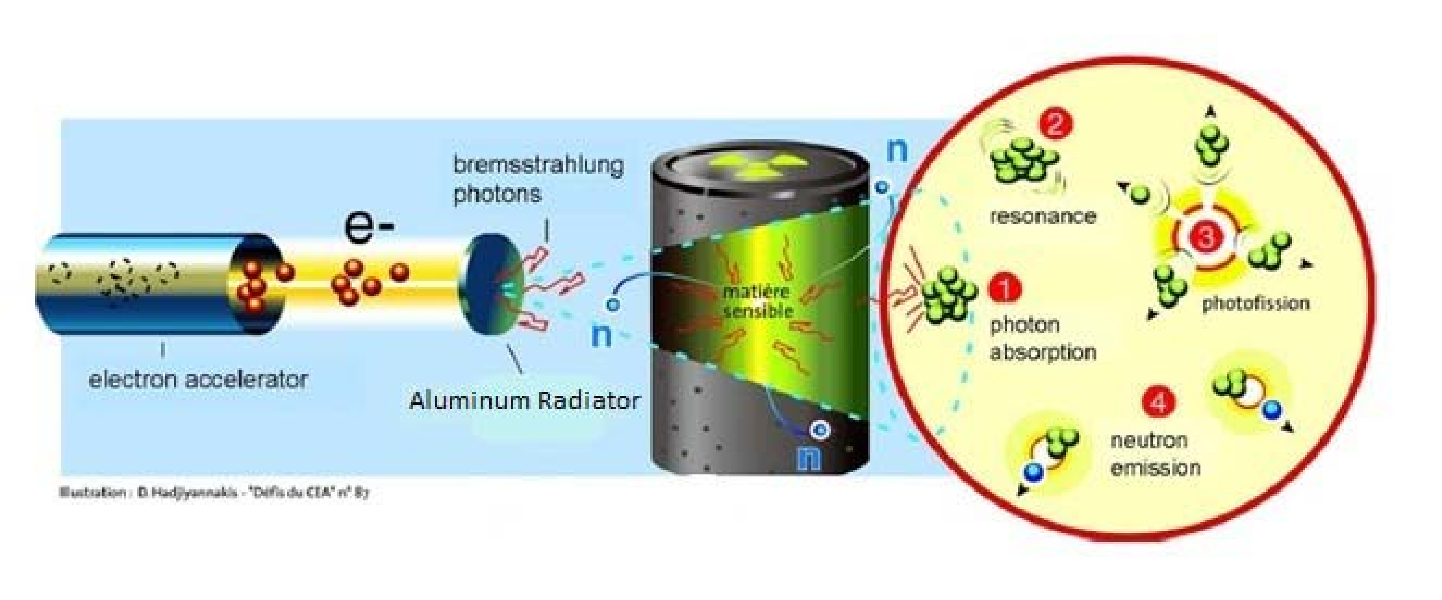
- Big bangs can come in little packages
  - Suitcase bomb
    - 60 x 40 x 20 cm
    - 10.5 kg
    - 500 ton yield
  - Backpack bomb
    - 3 coffee can sized Al canisters in a bag
    - 3 – 5 kiloton yield
- Harmful not only by conventional impact and explosion, but also by the radioactive material emitted into the air
- Billions of dollars of commercial goods pass through ports of the US each month*
  - Impossible to screen every piece of cargo
- Investigating interrogation techniques



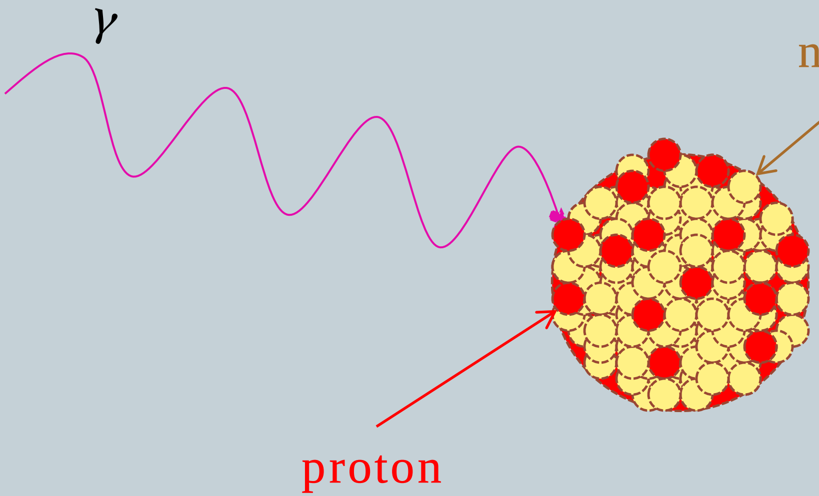
*http://www.transtats.bts.gov/Fields.asp?Table_ID=1358

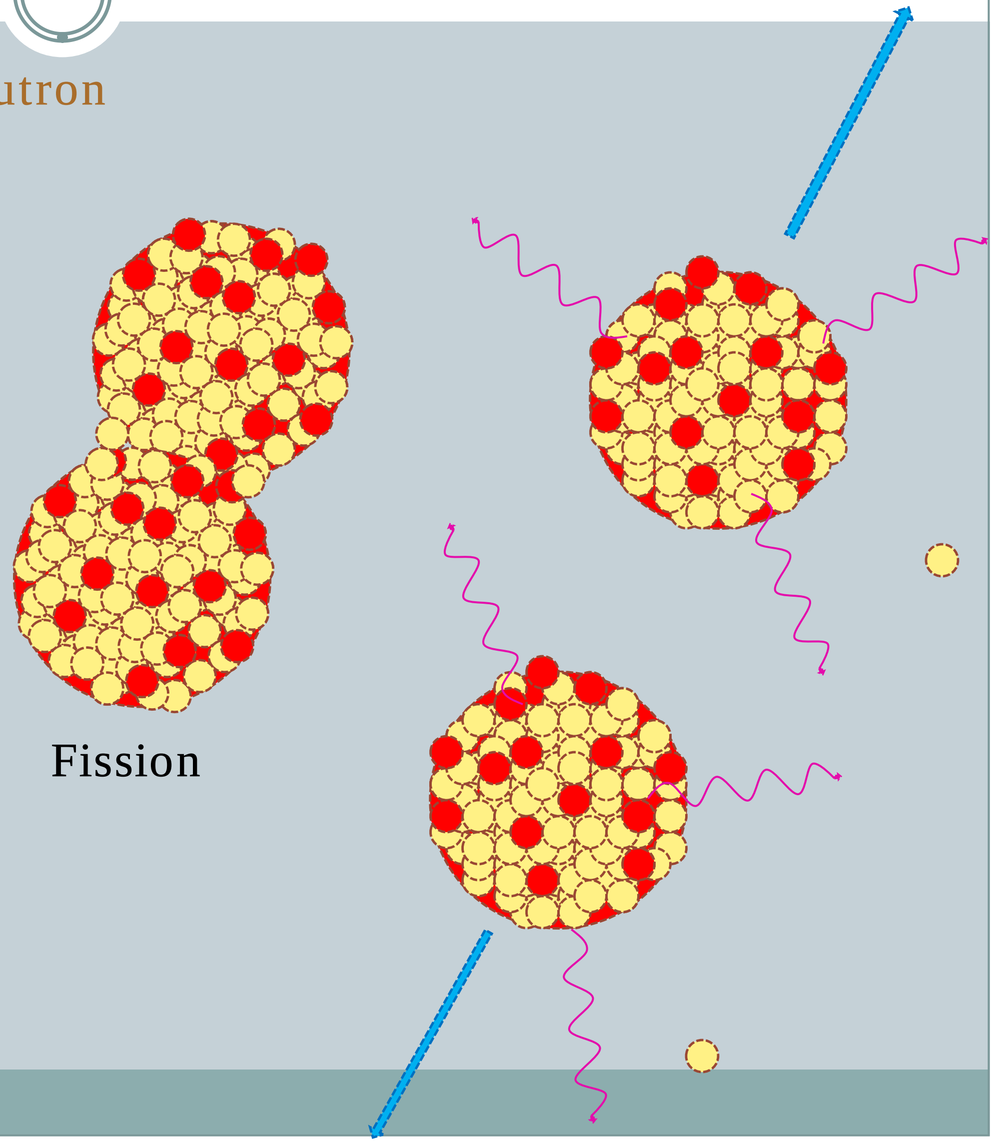
Interrogation Using High Energy Photons

- Photofission to detect actinides
  - Using off-axis Bremsstrahlung technique
  - Measure the angular asymmetries of prompt neutrons from photofission



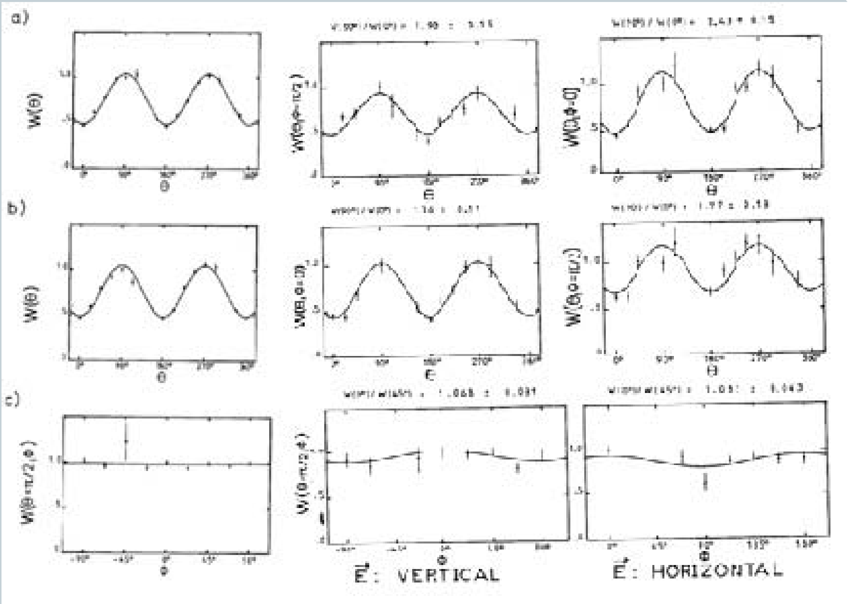
Theory: Photofission





- Standard fission model
- Anisotropic angular distribution of fission fragments
  - Gammas
  - Prompt neutrons

Theory: Photofission with polarized photons



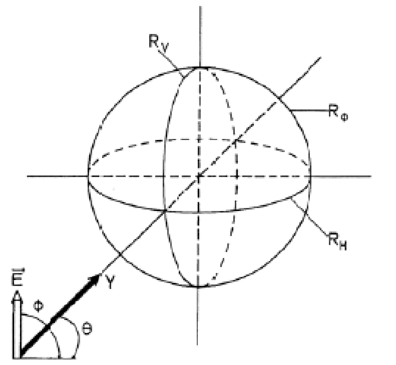
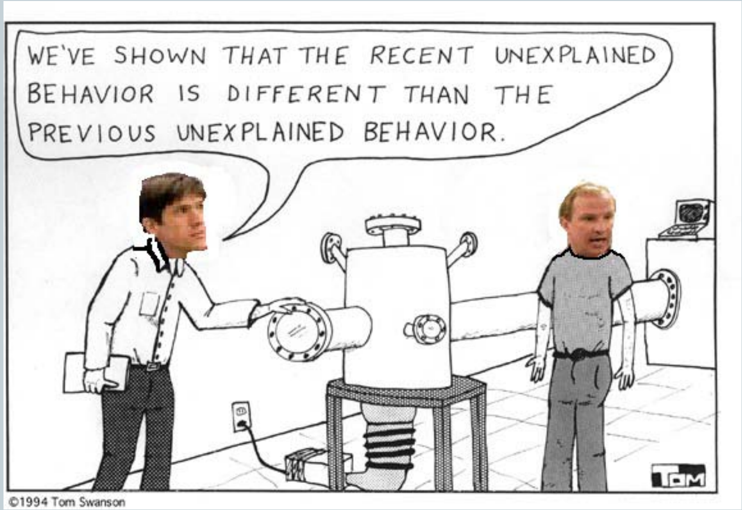


Fig. 4. Detector set up (schematically)

- Unpolarized photons:
  - Identical angular distributions measured by detector rings Rh and Rv.
  - Only dependent on polar angle
    - $W(\theta) = a + b \sin^2\theta$
  - Isotropic angular distributions in the azimuthal angle
- Polarized photons:
  - Two cases of polarization:
    - Electric field vector of the photon is vertical
    - Electric field vector of the photon is horizontal
  - Angular distribution depends on both angles θ and Φ:
    - $W(\theta, \Phi) = A0 + A2(P2(\cos\theta) +$
      $+ P\gamma f2(1,1)\cos 2\Phi \;\; P^2 2(\cos\theta))$
      - Pγ is the degree of photon polarization
      - $f2(1,1) = 3\sin^2\theta$
      - Φ is the azimuthal angle
        - Φ = 0 parallel to **E**
        - Φ = π/2 perpendicular to **E**
- Preferred direction corresponding to the electric field vector of the photon

R. Ratzek et al. Photofission with Polarized Photons //*Z. Phys. A.-Atoms and Nuclei. 1982, v. A308, p. 63-71.*

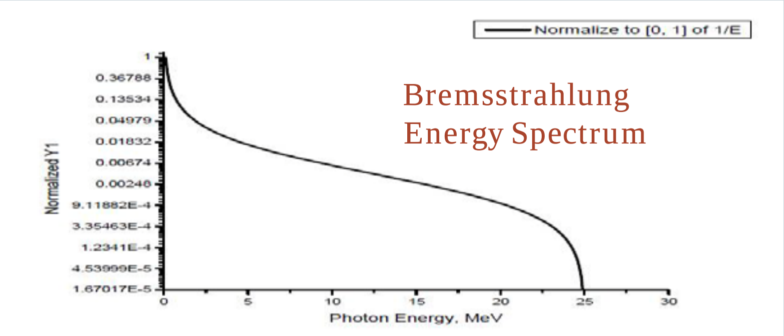
Test Run

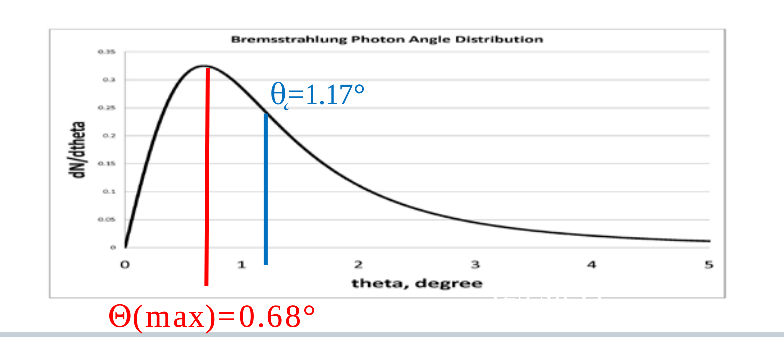


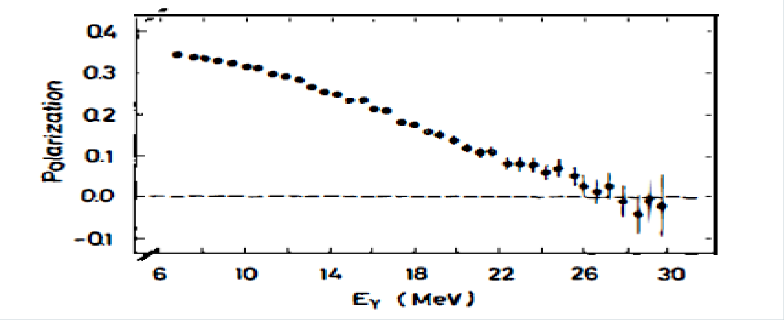
- Short Pulsed Linac at the Idaho Accelerator Center
  - Accelerator parameters
    - 1.3 GHz L-band traveling-wave linac
    - 25 MeV
    - 150 Hz rep rate
    - 2 ns *pulse width*

Polarized Photon Production

- e⁻ strikes a thin aluminum radiator (1/2 mil = 12.5μm) producing bremsstrahlung radiation
  - off axis from the incident beam is polarized
- highest degree of polarization within the bremsstrahlung cone is at $\theta = m_e c^2 / E_{beam} = 1.17°$

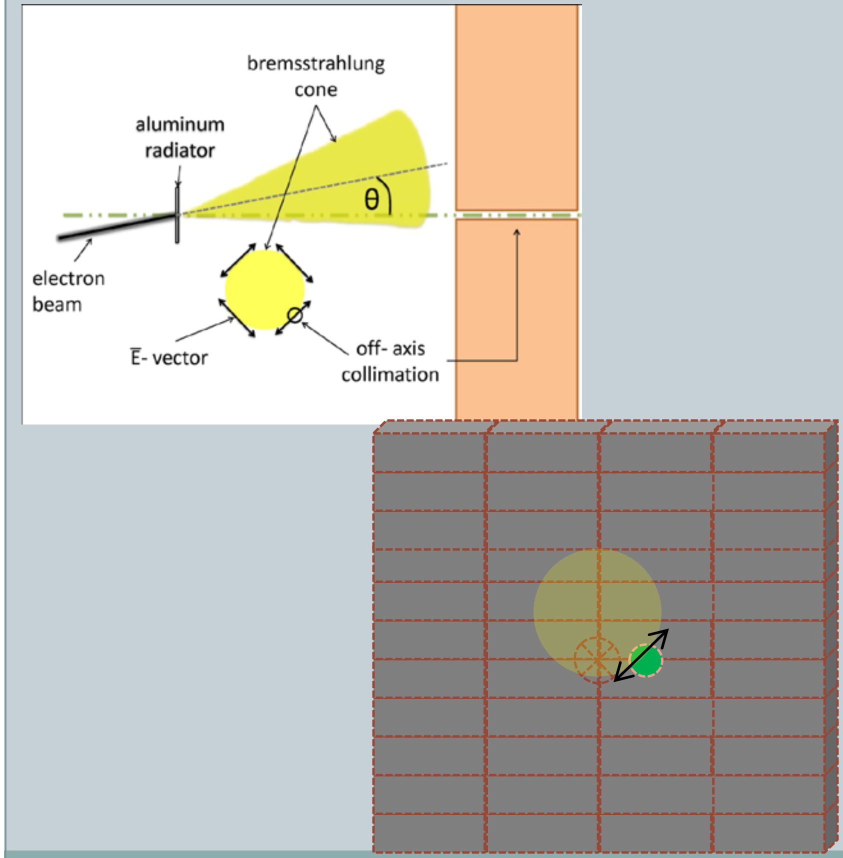




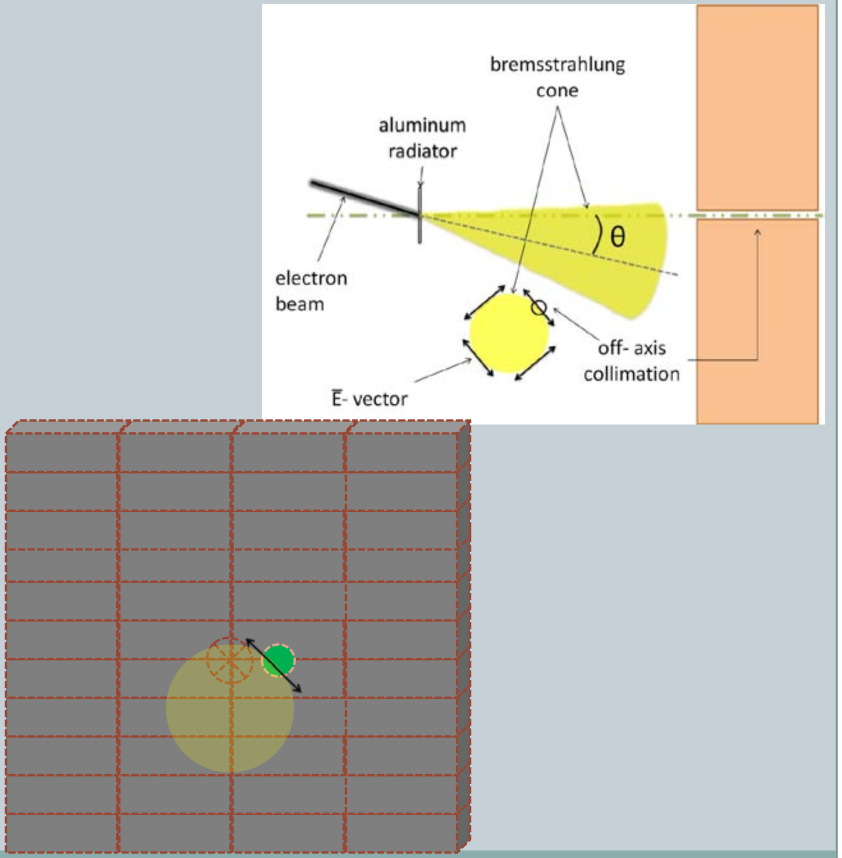


Off-Axis Bremsstrahlung Collimation

Beam-up



Beam-down

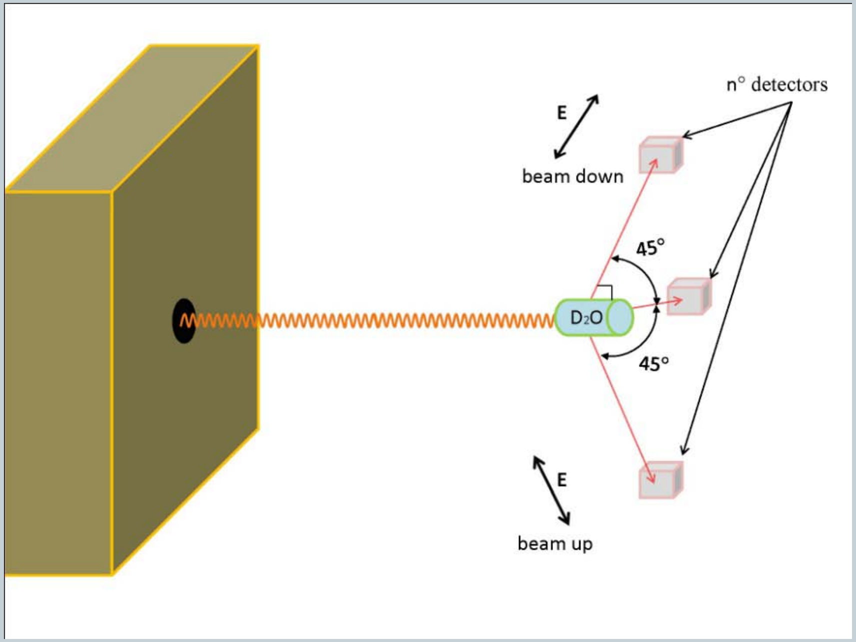


Neutron Detector Setup

The Detectors

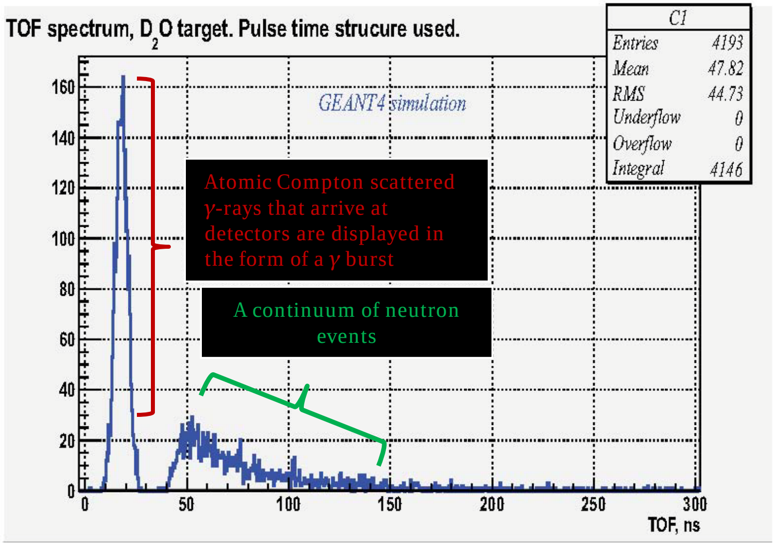
- 3 plastic scintillator neutron detectors placed at 90° to beam
  - 45° and -45° from horizontal plane for neutron yield measurements
  - 0° from horizontal plane for neutron yield normalizing
- Target-detector distance 1.5m
- Closed geometry to reduce background
  - Covered in
    - 4 inches lead
    - 4 inches poly

The Setup

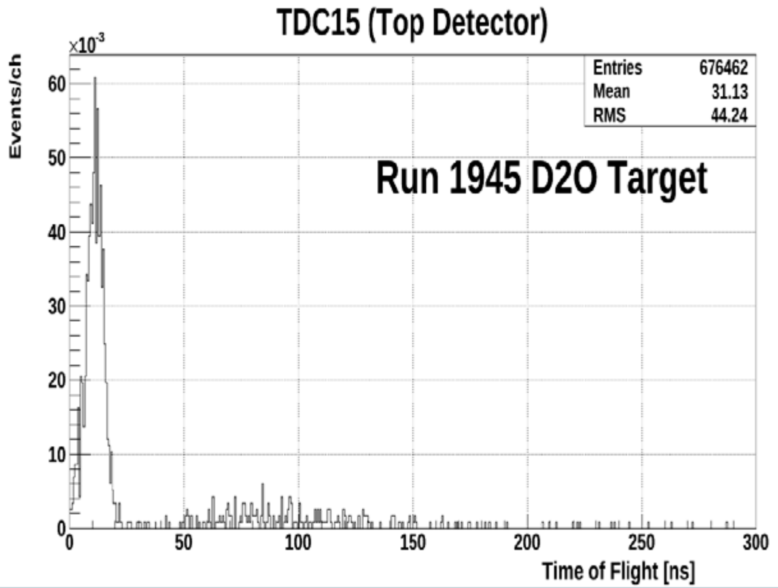


Preliminary Run Results

What we simulated..

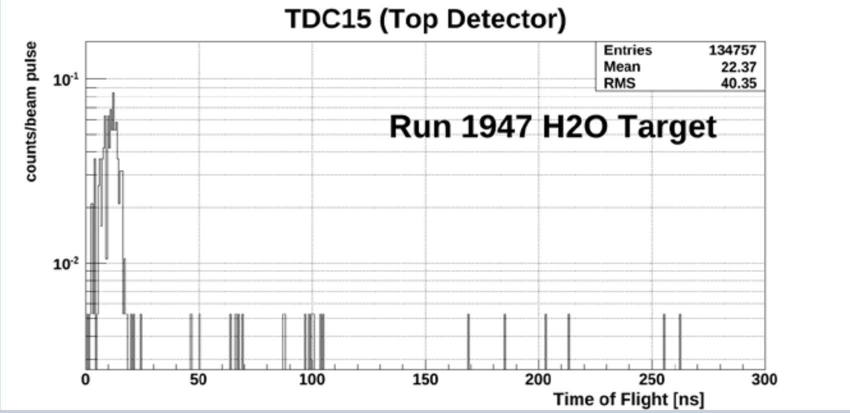


Experimental data..

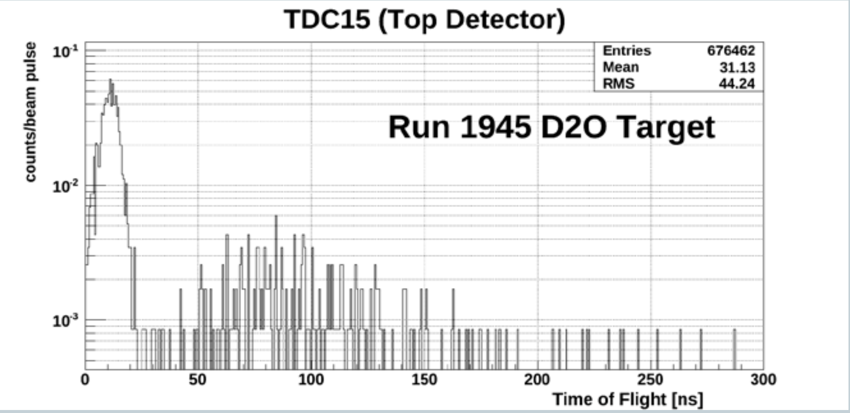


Preliminary Run Results cont.

H2O Physics Target



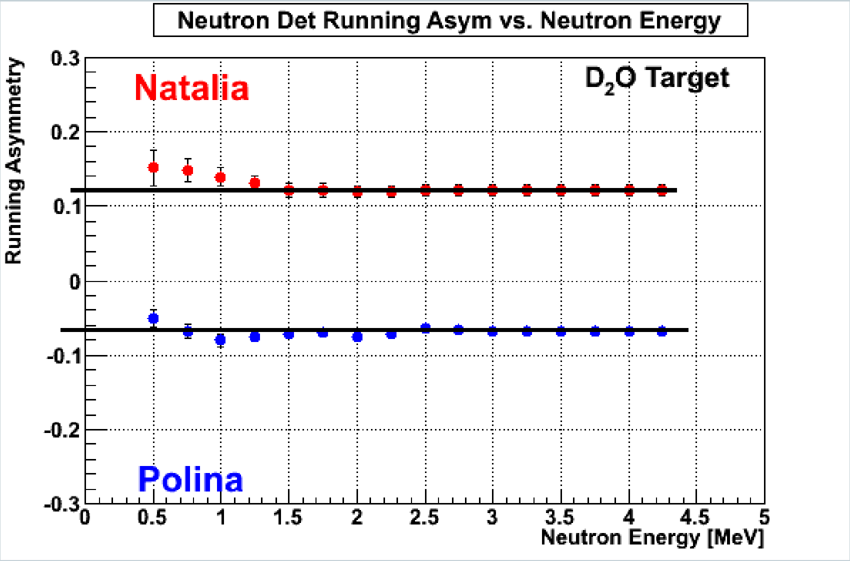
D2O Physics Target



The Asymmetry Calculation

- Compare the two polarization states, beam-up and beam-down
- Normalize neutron yield rates in top and bottom detector using neutron counts in the middle detector
- Calculate individual asymmetry for the top and bottom det.
- Asymmetry = $\dfrac{\sigma^{beamup} - \sigma^{beamdown}}{\sigma^{beamup} + \sigma^{beamdown}}$
  - where σ = neutron yield / neutron normalization factor

Preliminary Run Asymmetry Results



- Both bottom and top detector give fairly consistent and opposite sign results
- An overall asymmetry of:
  - ~ 11.15% ± 0.7% for bottom detector
  - ~ 6.54% ± 0.5% for top detector

Conclusion

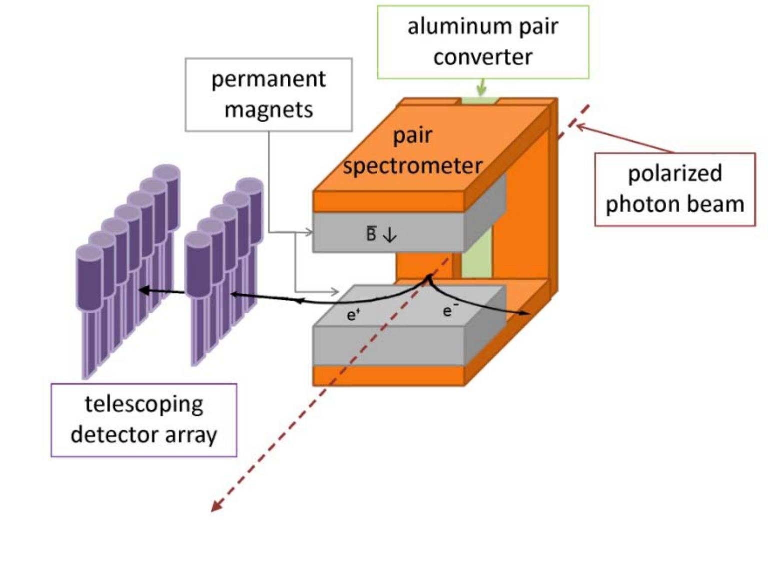
- Developing a signature for actinides for nuclear safeguards and homeland security applications
- Neutron asymmetries were found using a deuterium target
  - ~ 6.54% ± 0.5% for top detector
  - ~ 11.15% ± 0.7% for bottom detector
- Need to perform a systematic study using a variety of targets to determine the possibility of neutron rate ratios arising from other mechanisms causing false positives

Thank You!

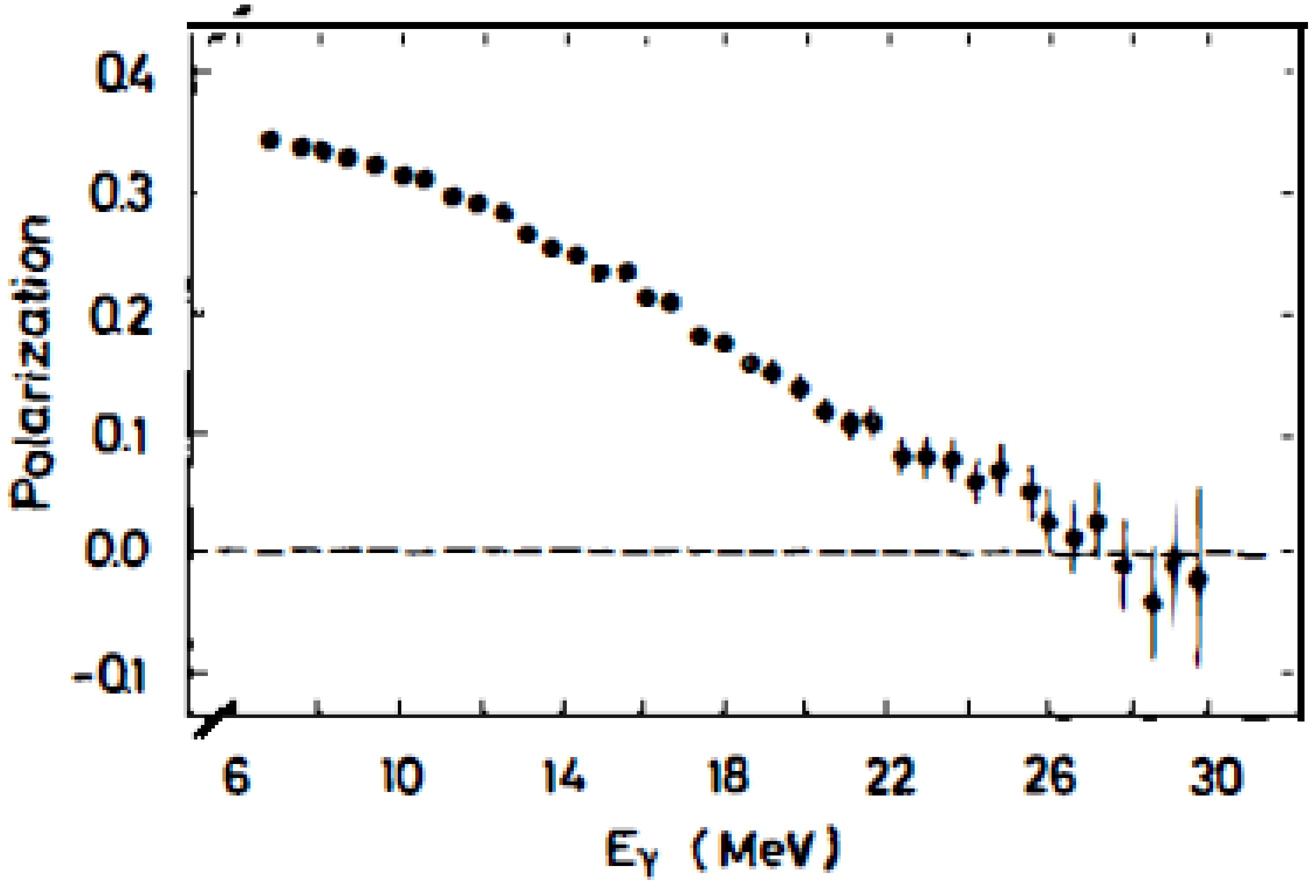
Future Work

- Further analyze the data
  - Where are the extra gamma peaks from?
- Re-run using a smaller radiator
  - Improve the quality of the photon beam
    - Less background
    - Less electron multiple scattering
- Remove lead in front of the neutron detectors
  - Increase gamma flash from target
- Better normalization technique...

New Photon Flux Monitor



- How it Works
  - γ's pair-produce in Al converter
  - e+/e- trajectories change in B-field
  - detect positrons using telescope detector system
  - normalize detected neutron yield from the target

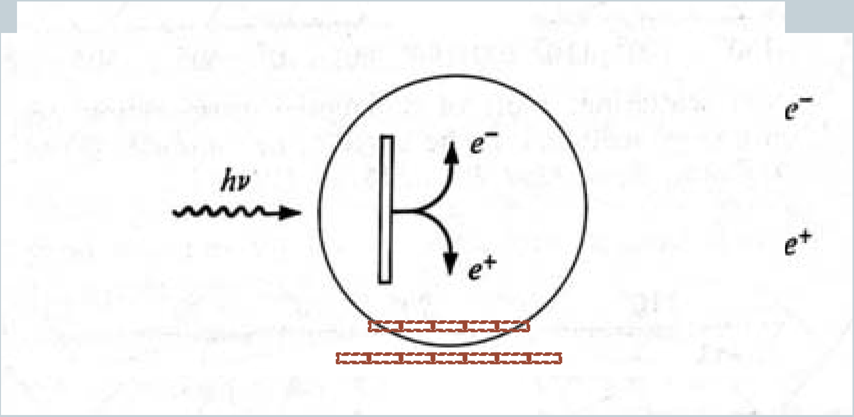


Degree of polarization of off-axis bremsstrahlung as a function of the photon energy (E_e = 30 MeV, θ = 1.4°)

C.F. Wienhard, K., Schneider, R. K. M., Ackermann, K., Bangert, K., Berg, U. E. P. Phys. Rev. C 24: 1363--66 (1981)

How it Works

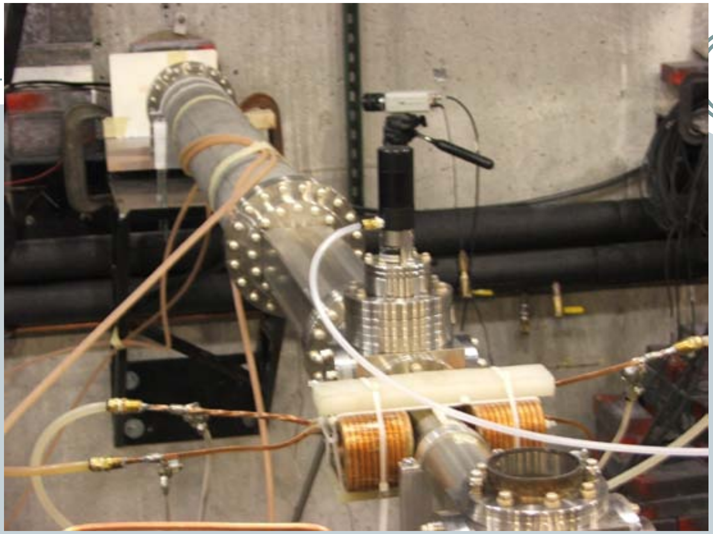
- γ's pair-produce in Al converter
- e+/e- trajectories change in B-field
- Chose to detect positrons using telescope detector system
- Use to normalize detected neutron yield from the target



Background Issues

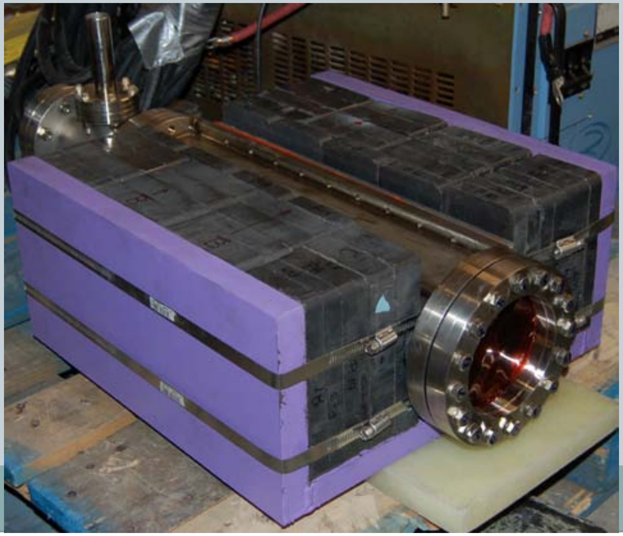
- The cross-section for pair-production in air is about 0.15 barns/atom, which produces 300 pairs per pulse.
  - Al converter produces roughly 3 pairs per pulse.

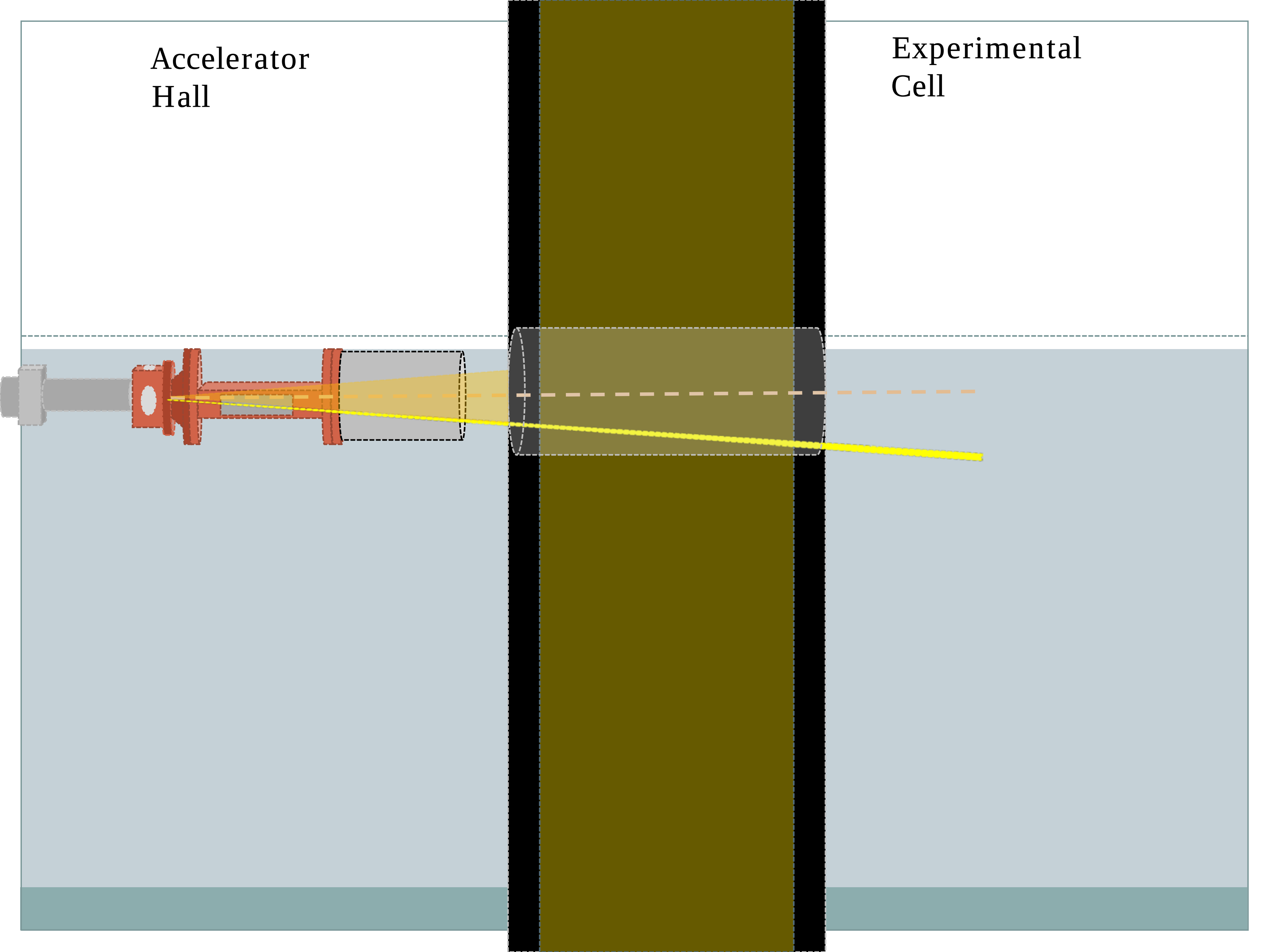
Try more vacuum…



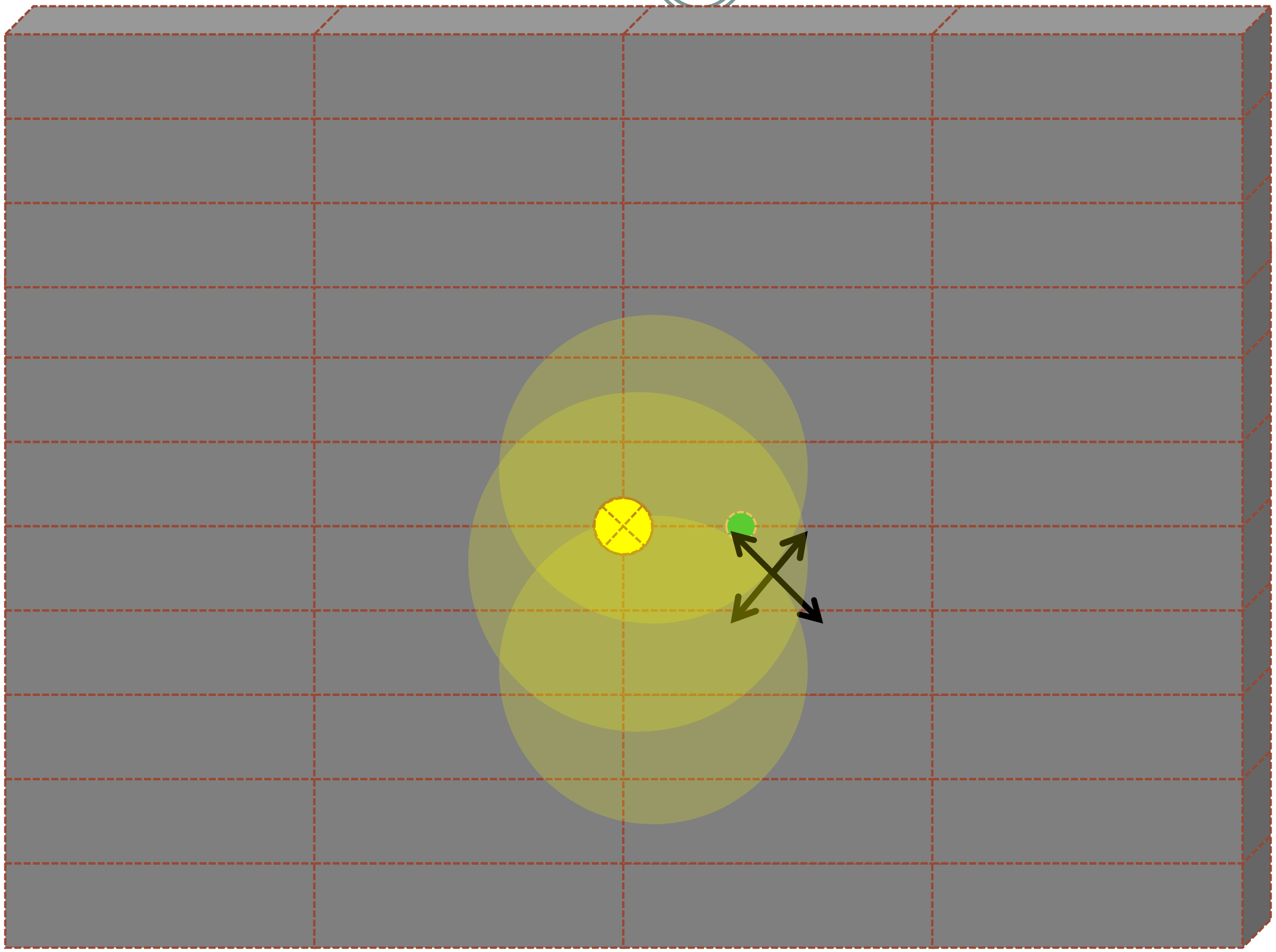
« upstream vacuum-pipe extension

Downstream vacuum pipe and sweep magnet

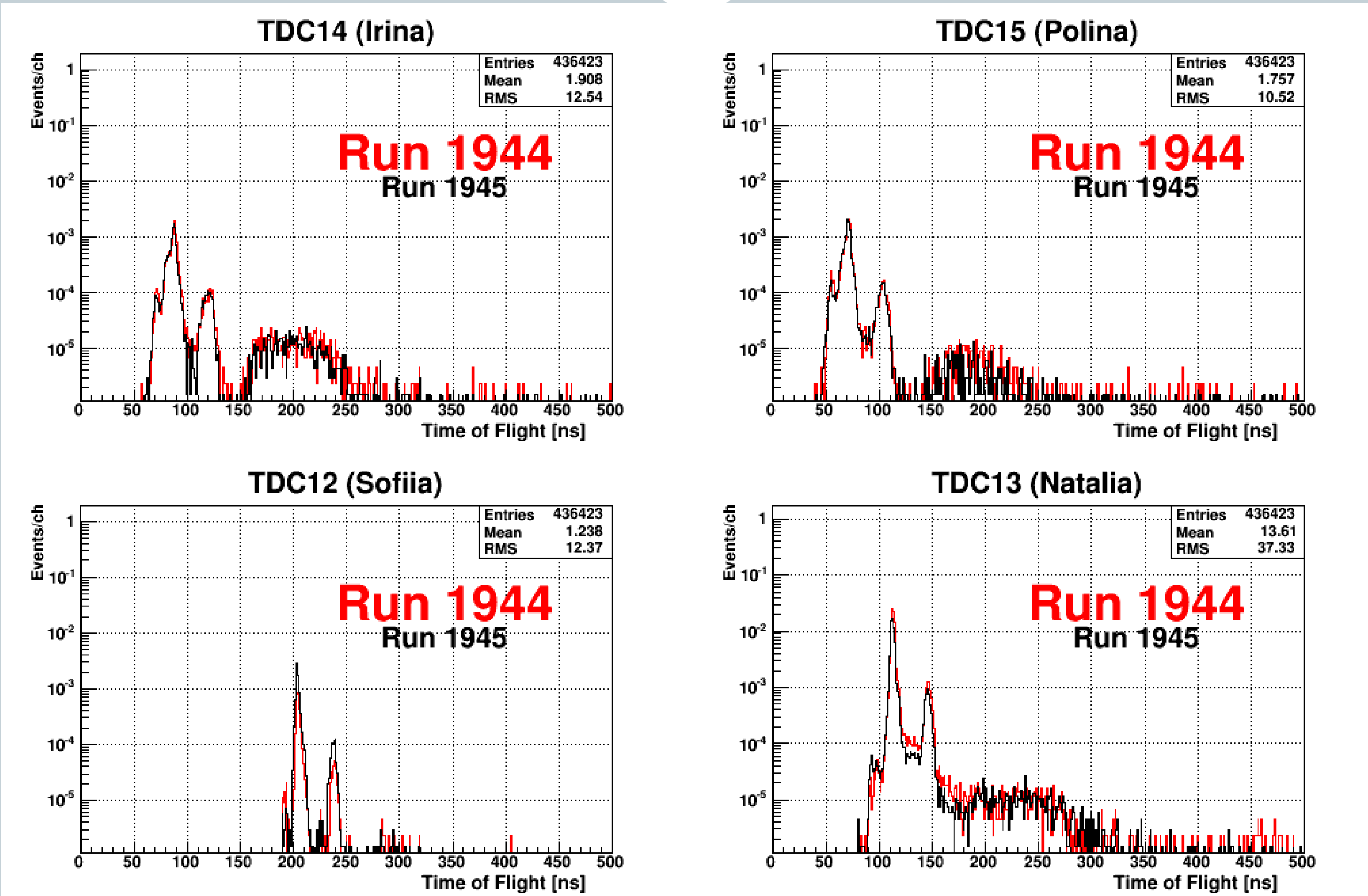



Accelerator Hall
Experimental Cell

Off-Axis Collimation



Data Analysis: Comparing Polarization States on a D2O Target



Run 1944-beam down   Run 1945-beam up