AN INTERROGATION METHOD USING LINEARLY POLARIZED PHOTONS

By Jasen Swanson

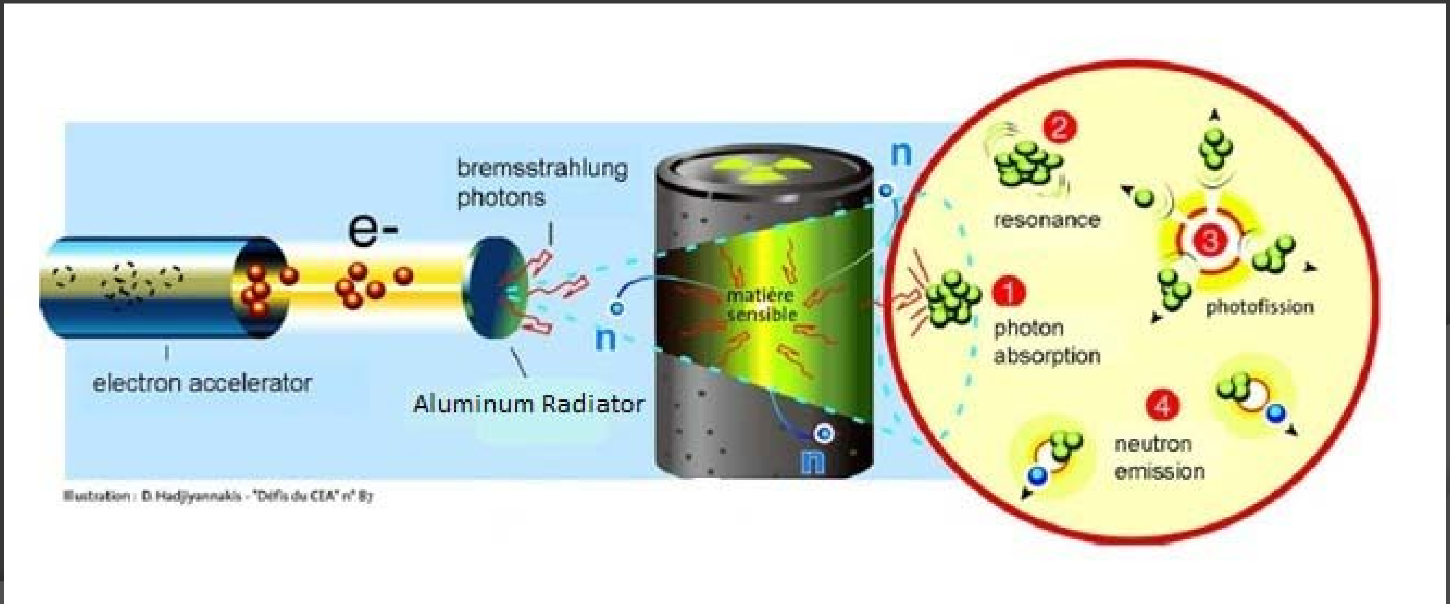
Motivation

- Not everybody likes us
  - Sept. 11, 2001
- To prevent another 9/11 more precautions have to be taken
- 3 ways to smuggle a nuclear weapon to the United States
  - Air
  - Land (rail or truck)
  - Water (cargo ship)
- Billions of dollars of commercial goods pass through these ports into the US each month
  - Impossible to screen every piece of cargo
- Radiation detectors put into place providing a “yes or no” system response
- New techniques need to be investigated

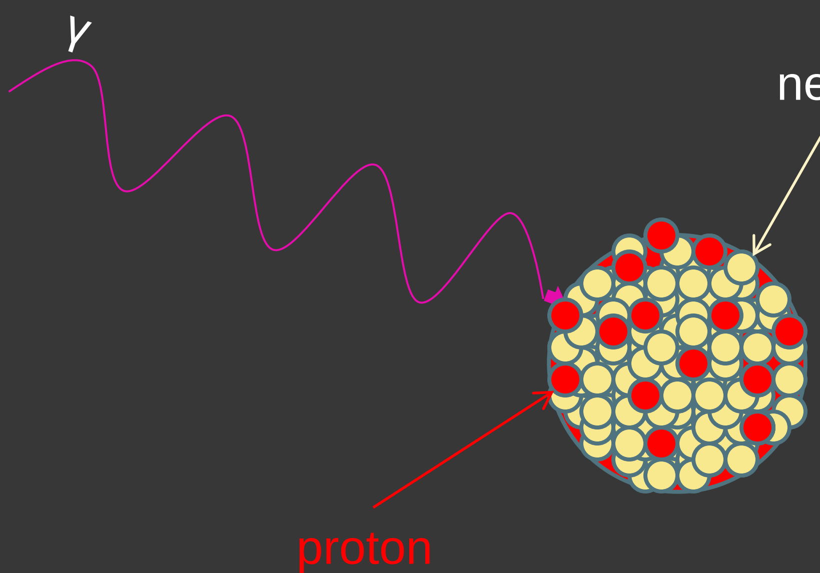
http://www.transtats.bts.gov/Fields.asp?Table_ID=1358

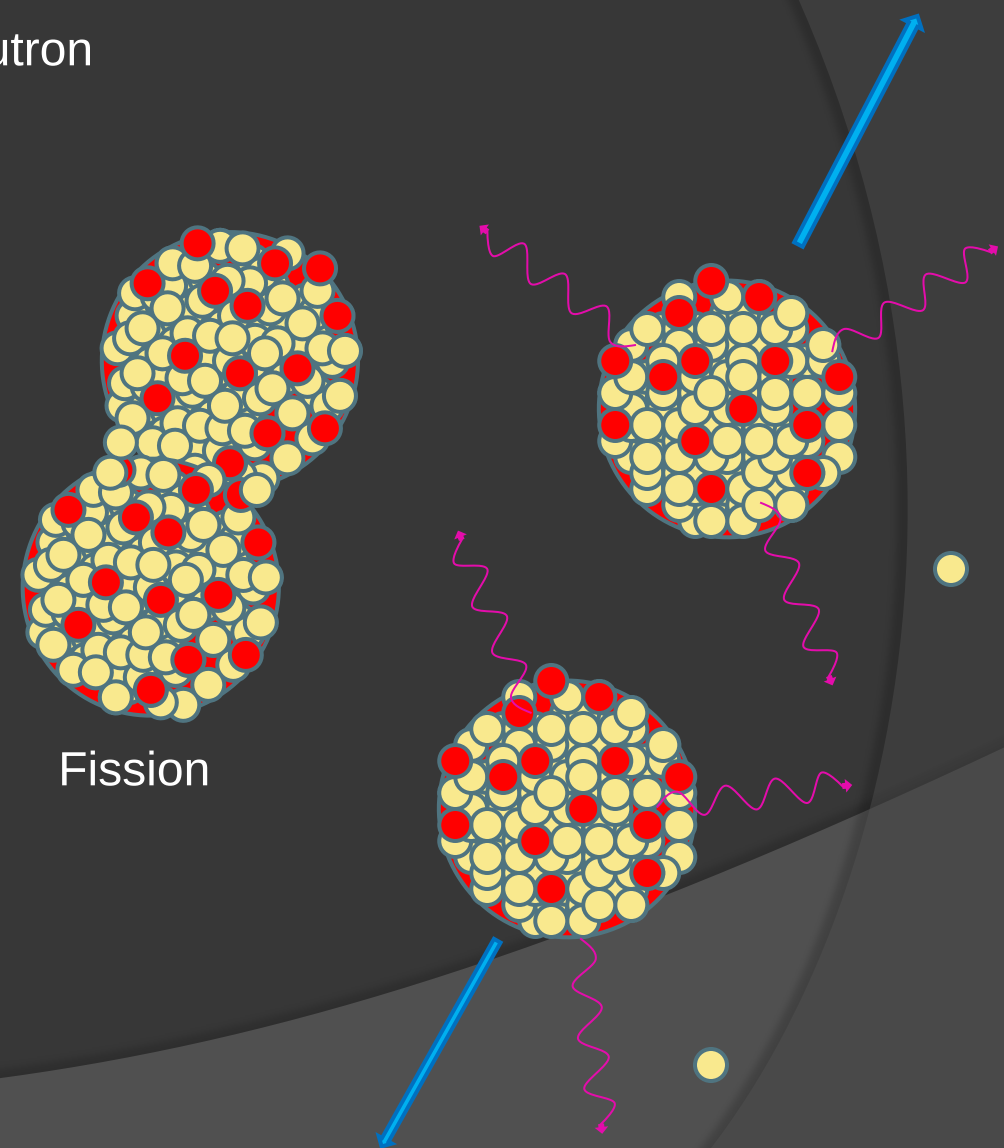
<u>Interrogation Using High Energy Linearly Polarized Photons</u>

- Polarized 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: Nuclear Fission (unpolarized cont..)

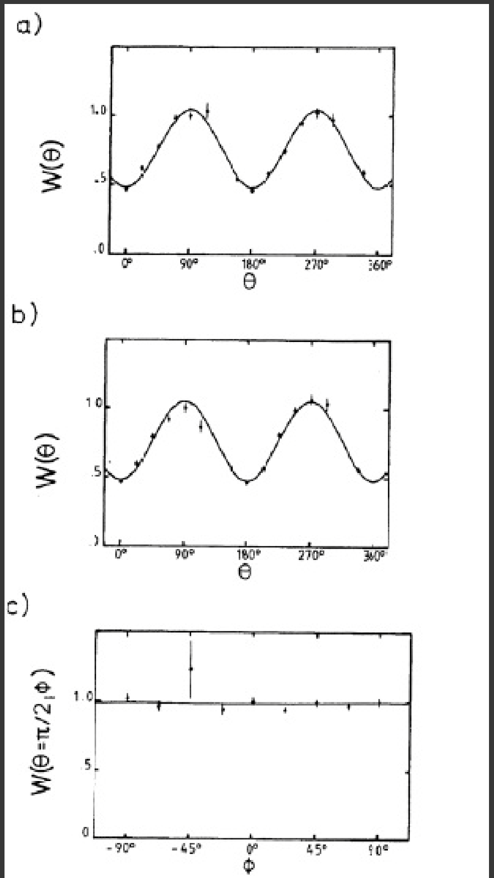


Fig. 5. Fragment angular distribution for unpolarized radiation (E_{RS} = 10 MeV); a) Ring R_H, b) Ring R_V, c) Ring R_φ (Full lines: least squares fits according to (2) and (13) respectively)

- Identical angular distributions measured by detector rings R_h and R_v.
  - Only dependent on polar angle
    - $W(\theta) = a + b \sin^2\theta$
- Isotropic angular distributions in azimuthal angle

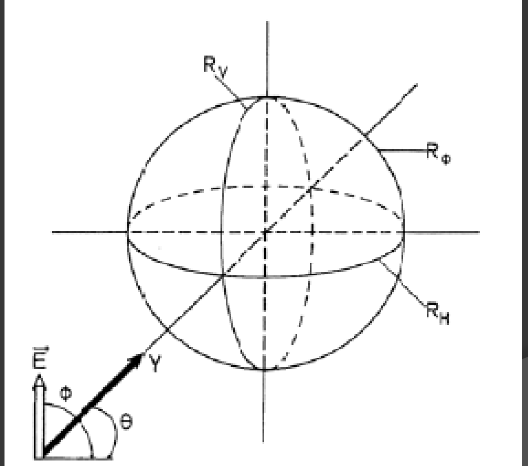


Fig. 4. Detector set up (schematically)

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

Theory: Photofission with linearly 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:
  - $W(\theta, \Phi) = A_0 + A_2(P_2(\cos\theta) +$
    $+ P_\gamma f_2(1,1)\cos 2\Phi \; P^2_2(\cos\theta))$
    - P_γ is the degree of photon polarization
    - $f_2(1,1) = 3\sin^2\theta$
    - 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

- Discuss a technique under development sensitive to azimuthal asymmetries, but eliminates the difficulties of detecting short ranged fission fragments

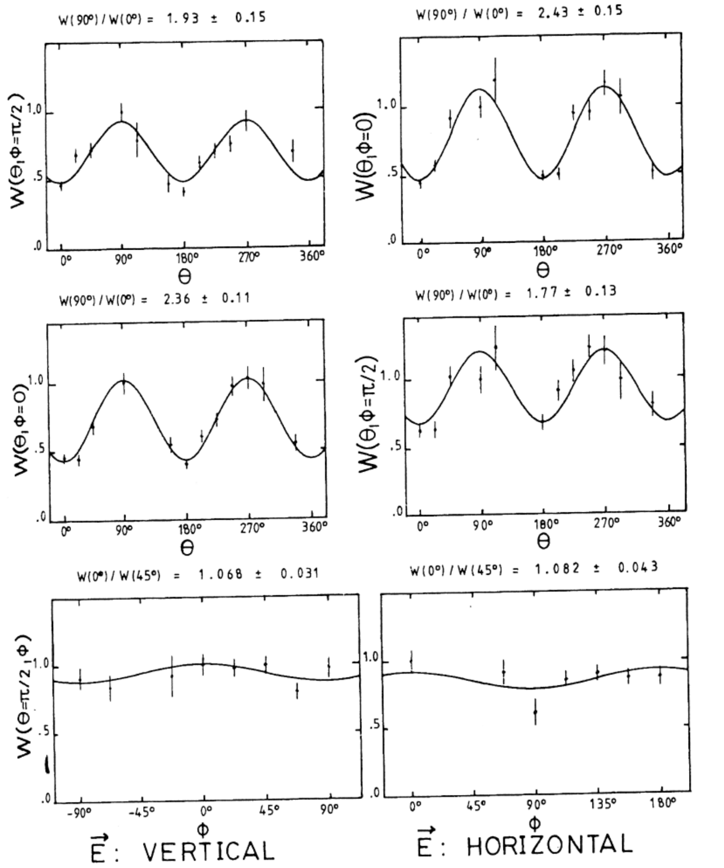
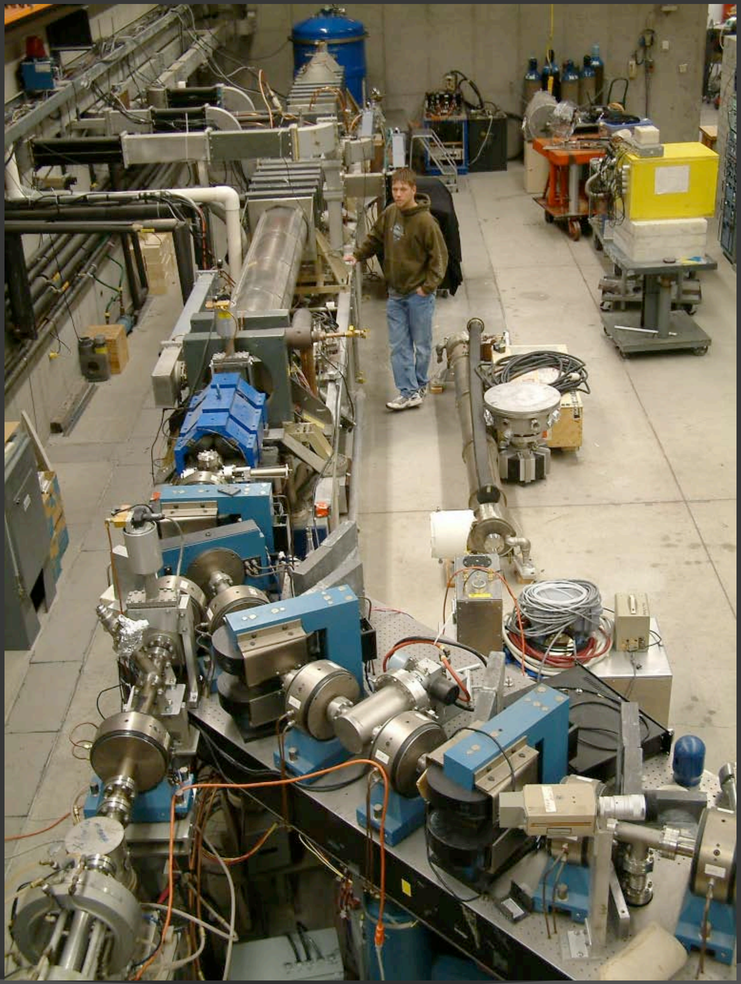


Fig. 6. Fragment angular distribution for linearly polarized radiation ($E_{BS}=10$ MeV) (Full lines: least squares fits according to (2) and (13) respectively)

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

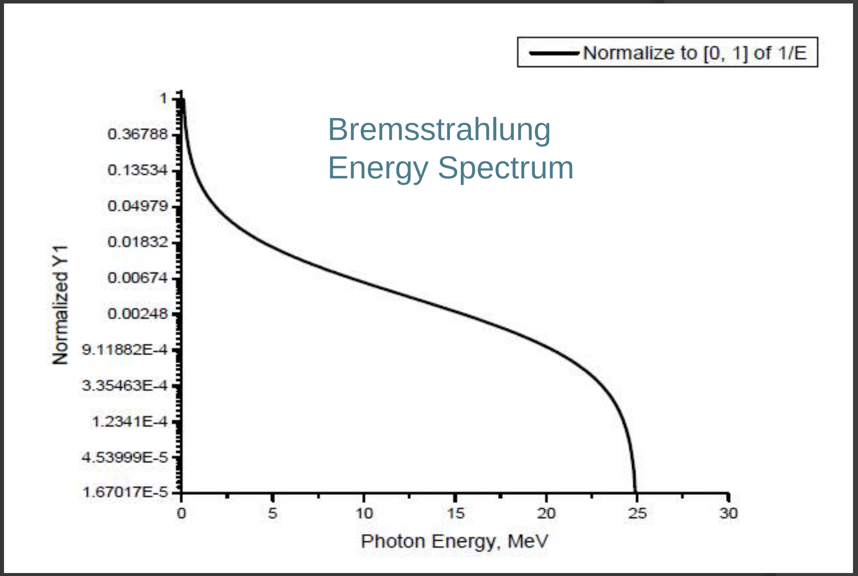
44 MeV Linac at Idaho Accelerator Center

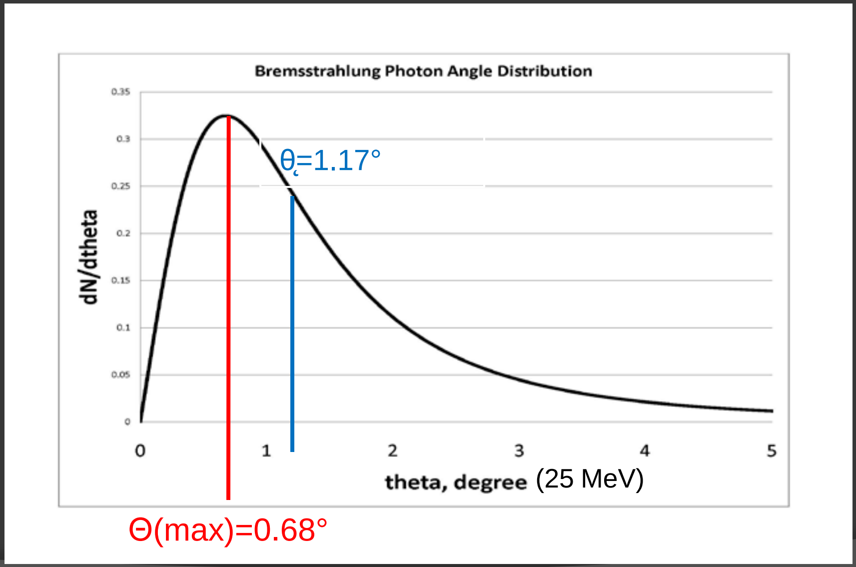


44-MeV Short Pulsed Linac
- 1.3 GHz L-band traveling-wave linac
- 2 ns *pulse width*
- 150 Hz rep rate
-1 nC/pulse (2 ns width)
- 25 MeV

Bremsstrahlung Radiation Characteristics

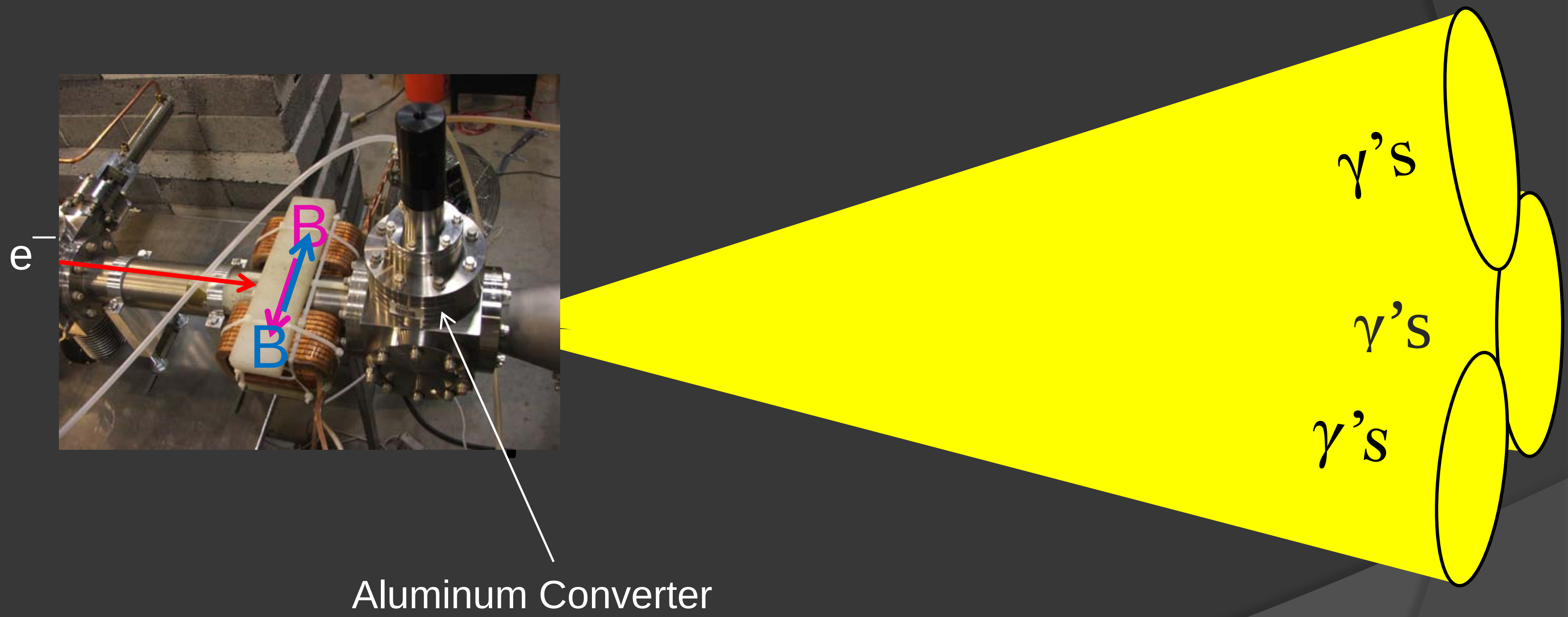
- 25 MeV end point energy



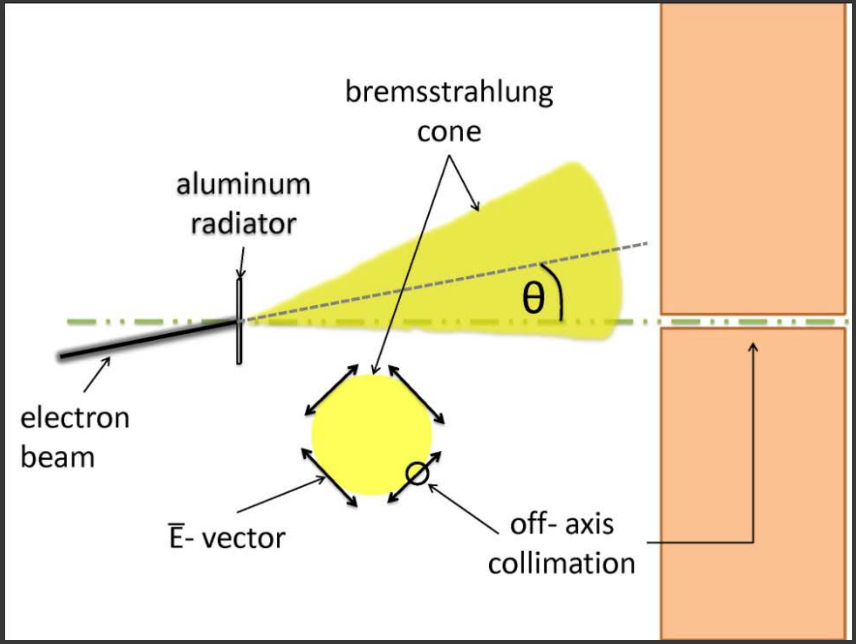


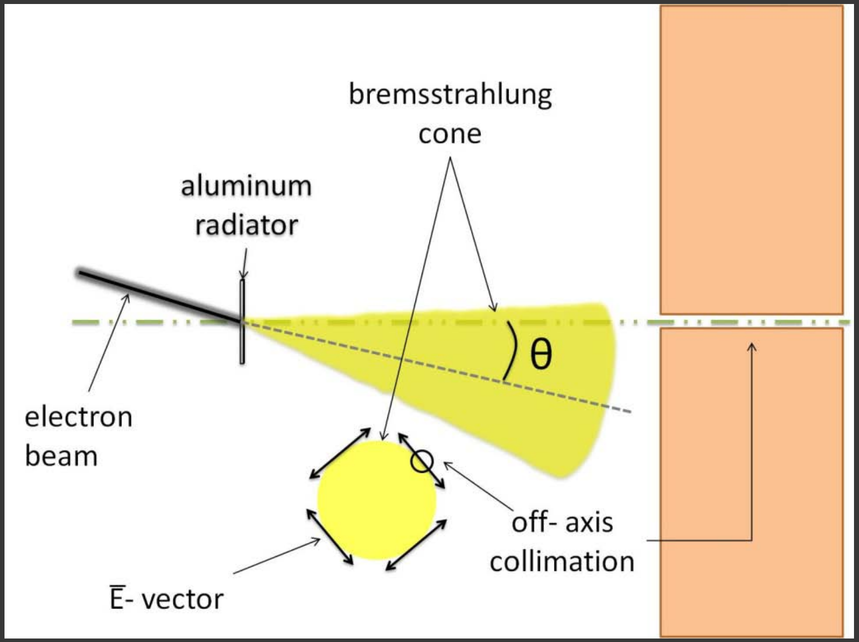
- Highest degree of polarization within the bremsstrahlung cone is at $\theta = m_e c^2 / E_{beam}$

Steering the Beam



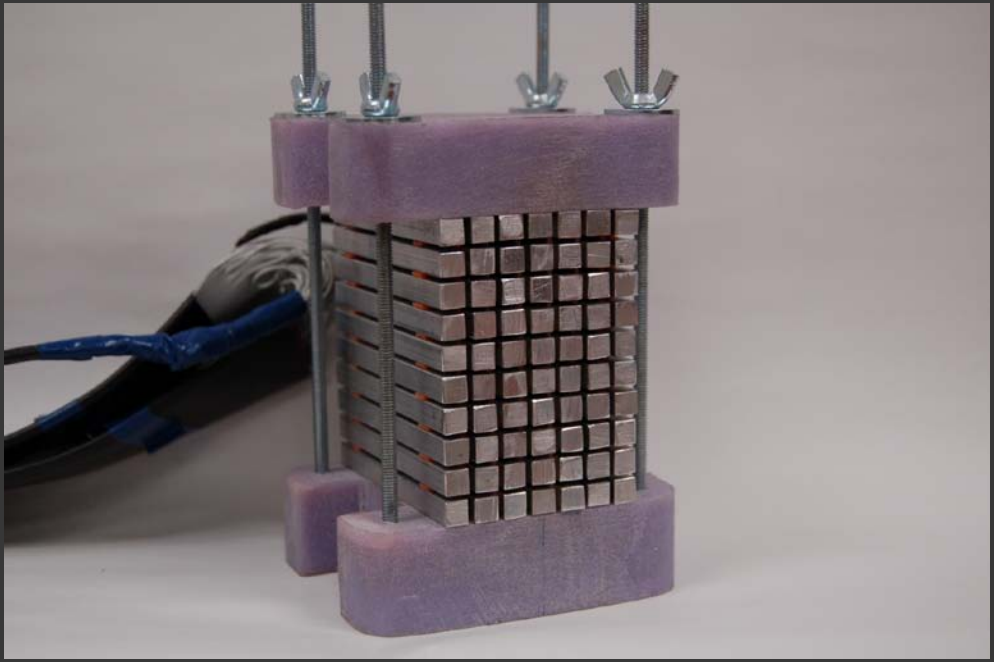
Off-Axis Bremsstrahlung Collimation



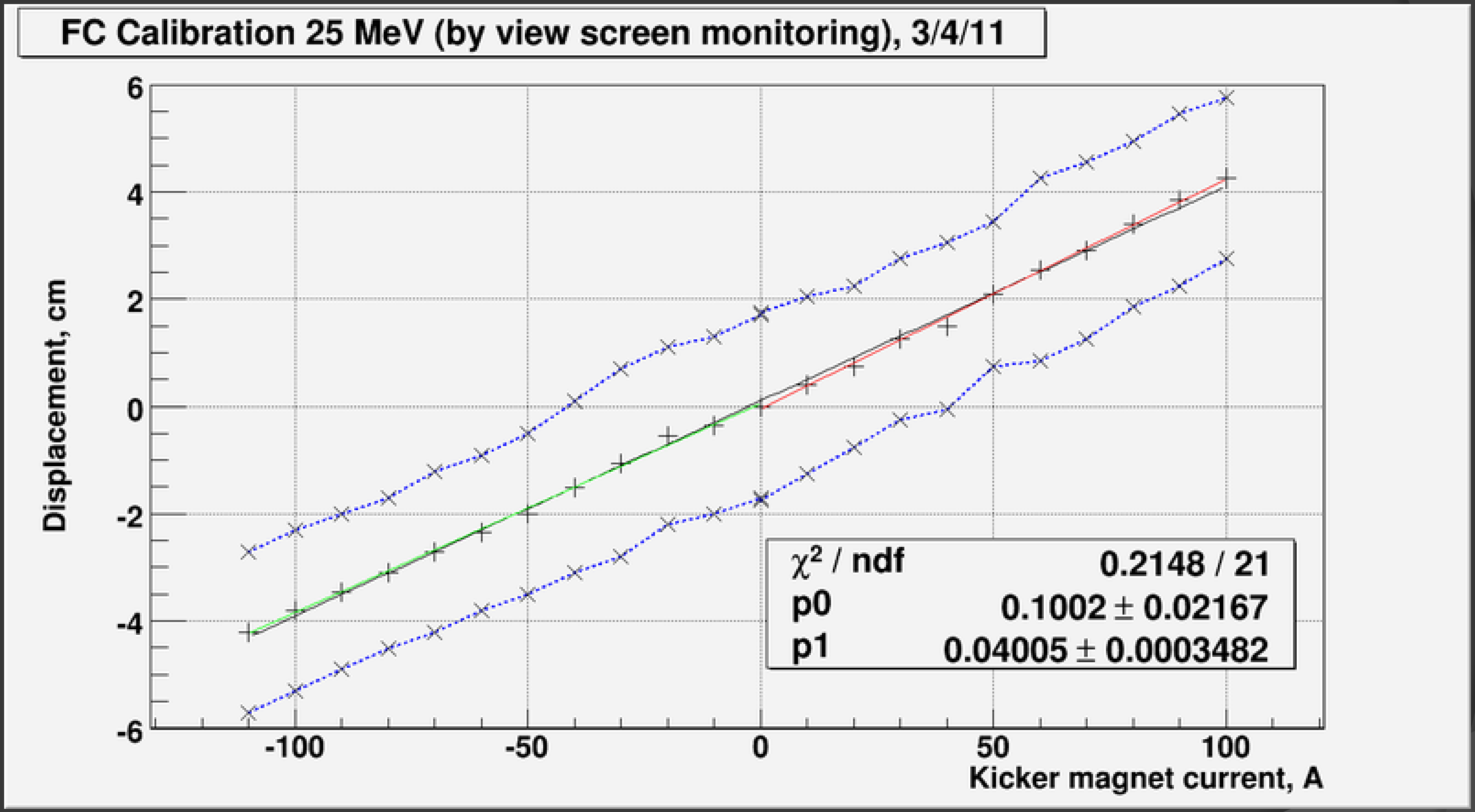


Beam-up **Beam-down**

Beam Position Monitoring



- To optimize polarization, the electron beam needs to be bent such that we collimate at θ_c=1.17° with respect to bremsstrahlung cone center
- Kicker Magnets calibrated to ensure this critical angle is met using a Faraday Cup


FC Calibration 25 MeV (by view screen monitoring), 3/4/11
Displacement, cm
Kicker magnet current, A
6
4
2
0
-2
-4
-6
-100
-50
0
50
100
χ² / ndf 0.2148 / 21
p0 0.1002 ± 0.02167
p1 0.04005 ± 0.0003482

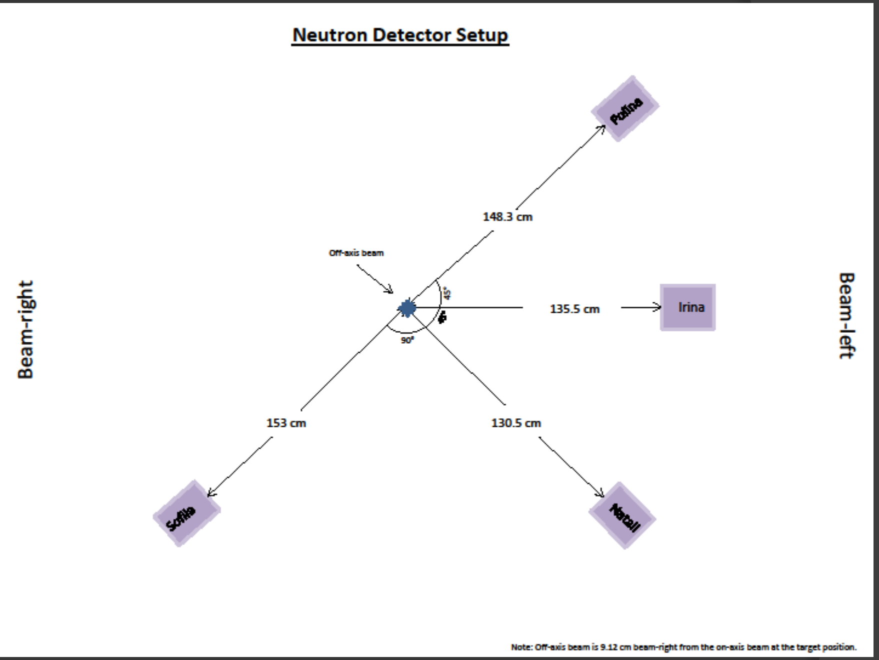
Dumping The Electron Beam

- A 5 kG permanent magnet sweeps all the electrons into a graphite beam dump

- Polarized photons are then sent into the experimental cell

Neutron Detector Setup

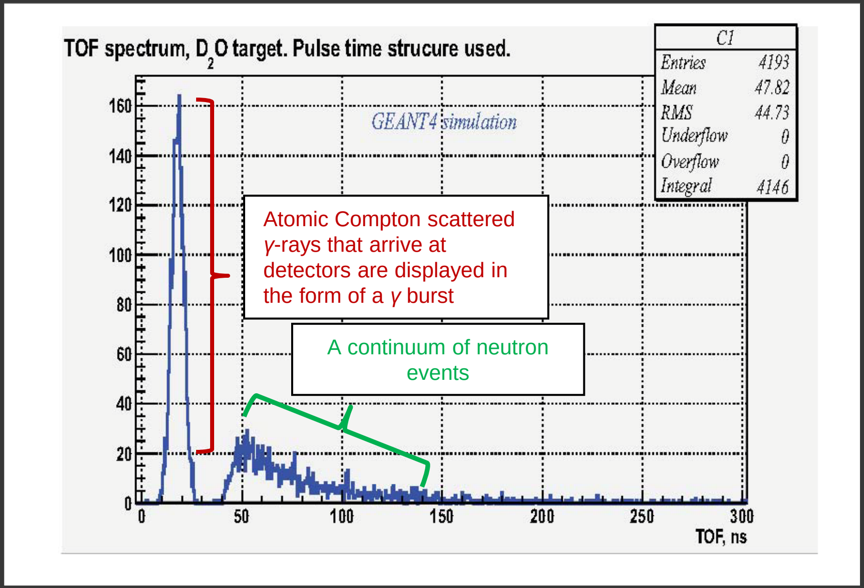
- 4 neutron detectors at set angles for asymmetry measurements
  - Covered in
    - 4 inches lead
    - 4 inches poly

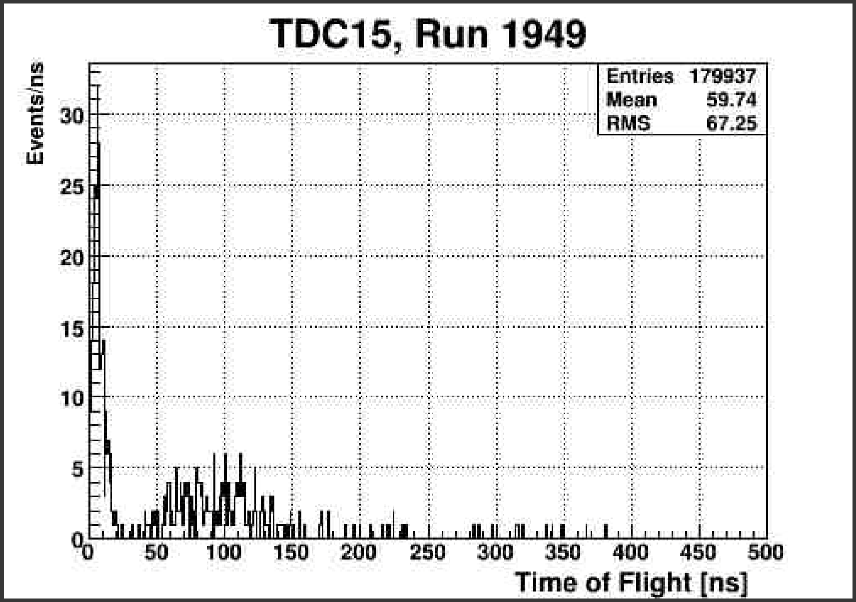


- Target-detector distance 1.5m
- Closed geometry to reduce background

Preliminary Run Results

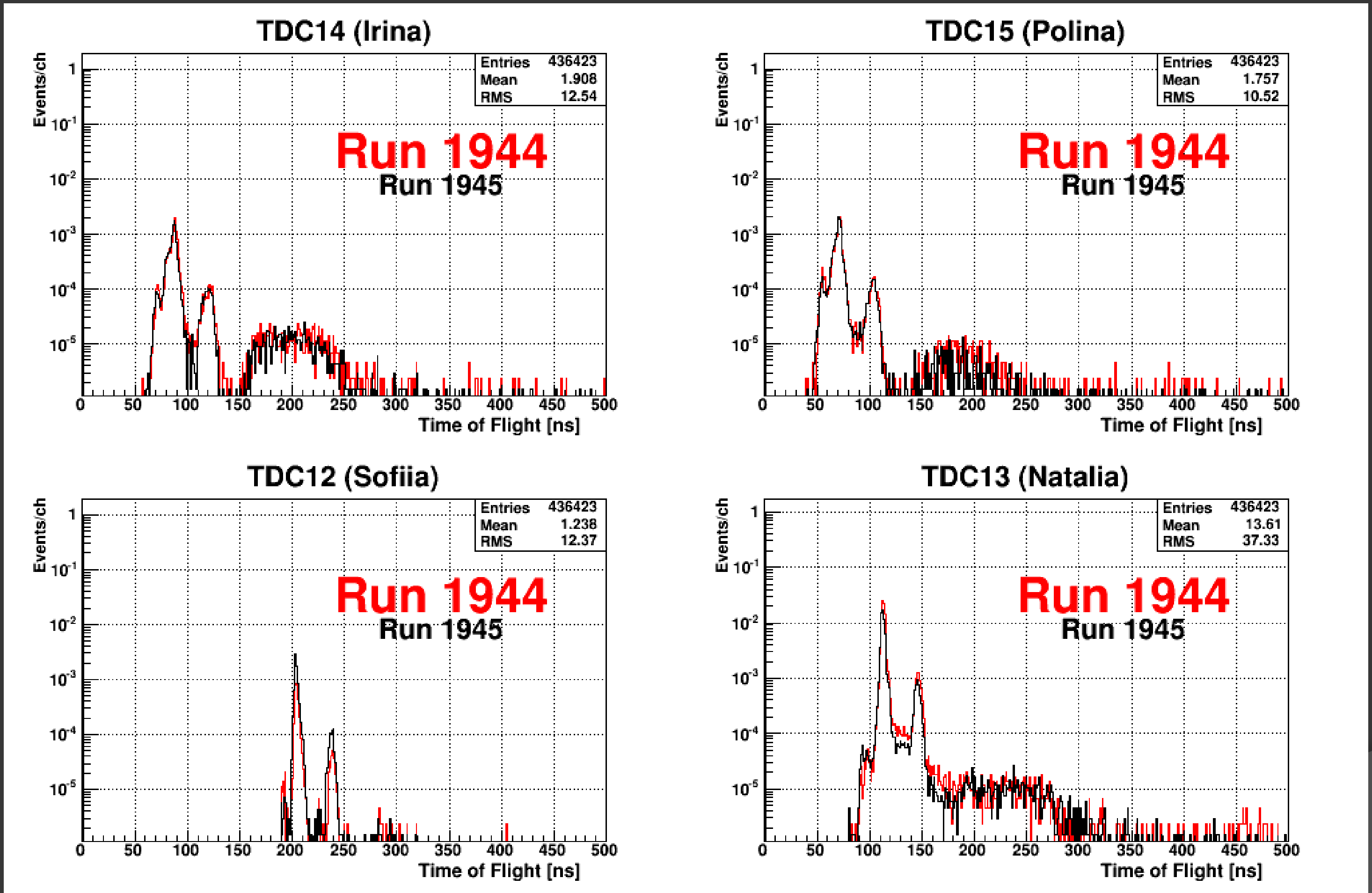
What we simulated..





Experimental data..

Data Analysis: Comparing Polarization States on a D2O Target



Run 1944-beam down
Run 1945-beam up

The Calculations

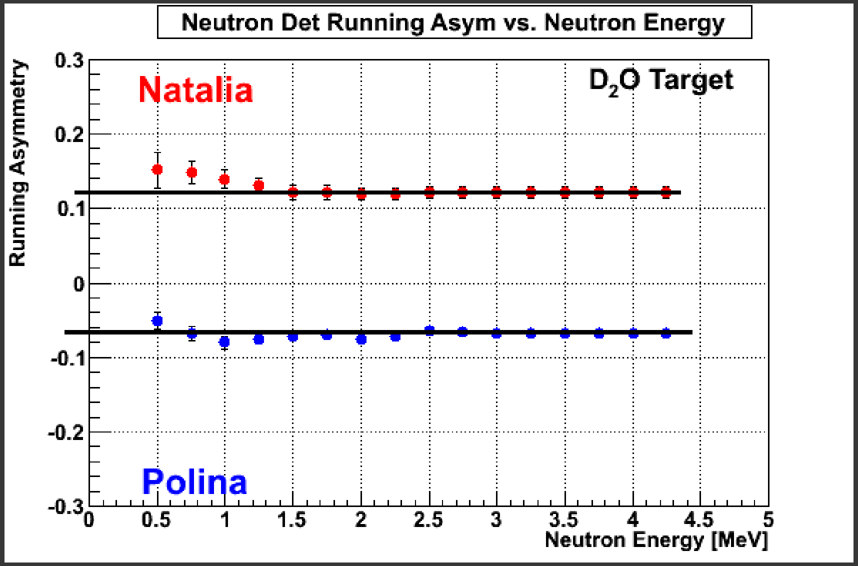
- Compare the two polarization states, beam-up and beam-down
- Normalize neutron counts (in Natalia and Polina) using neutron counts in Irina
- Calculate individual asymmetry for Polina and Natalia

$$\text{Asymmetry} = \frac{\sigma^{+}_{N/P} - \sigma^{-}_{N/P}}{\sigma^{+}_{N/P} + \sigma^{-}_{N/P}}$$

$$\text{where} \quad \sigma^{\pm}_{N/P} = \frac{N^{\pm}_{N/P}}{N^{\pm}_{I}}$$

- Beam polarization = measured asymmetry / theoretical asymmetry

Asymmetry Results



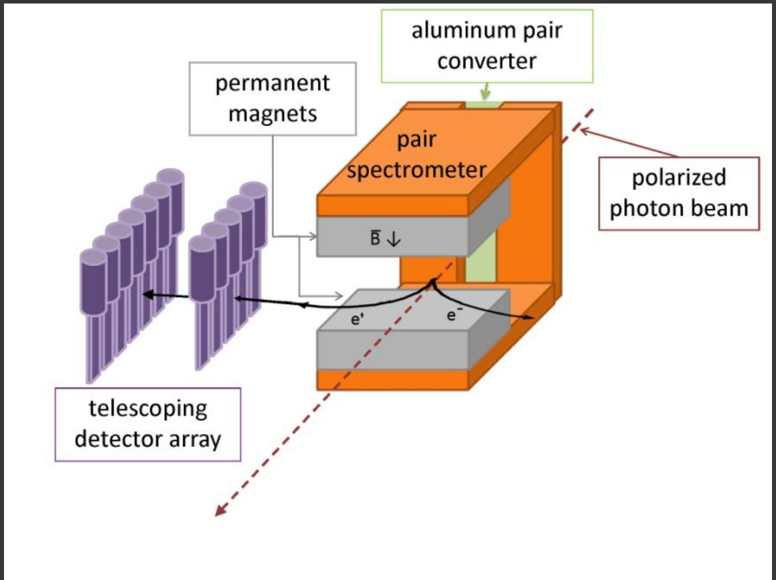
- Both Natalia and Polina give fairly consistent and opposite sign results
- An overall asymmetry of:
  - ~ 11.15% ± 0.7% for Natalia
  - ~ 6.54% ± 0.5% for Polina
- Beam polarization of
  ~8.2% ± 0.6%

Lots of bugs to workout still!

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



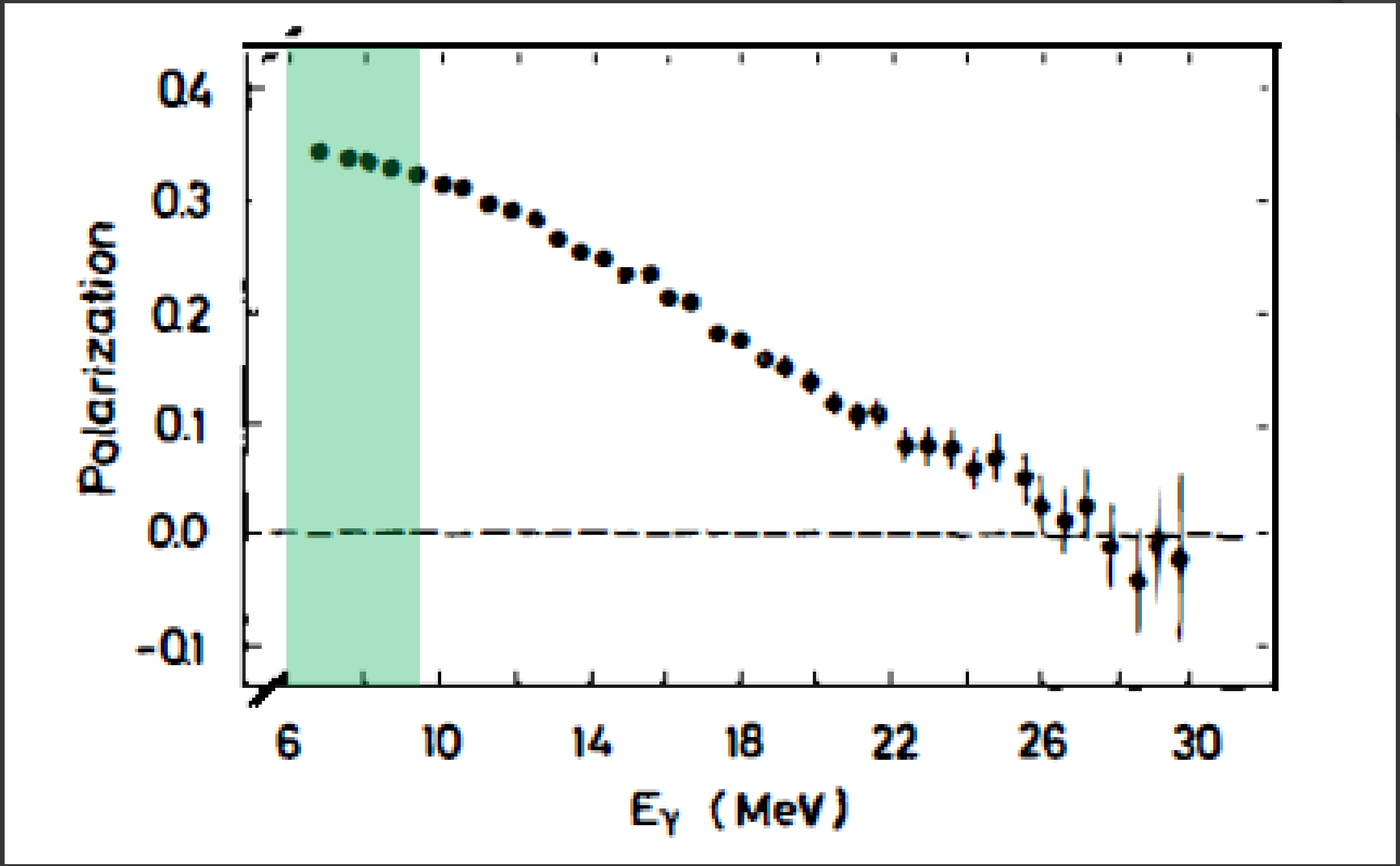
- How it Works
  - γ's pair-produce in Al converter
  - e+/e- trajectories change in B-field
  - detect positrons using telescope detector system
  - normalize detected neutron yield from the target

Conclusion

- 44 MeV beamline at the IAC was modified for the production of linearly polarized photons
- Neutron asymmetries were found using a deuterium target
  - ~ 6.54% ± 0.5% for Polina
  - ~ 11.15% ± 0.7% for Natalia
- Beam polarization was calculated to be

  ~8.2% ± 0.6%
- Further analysis of the data

Thank You!

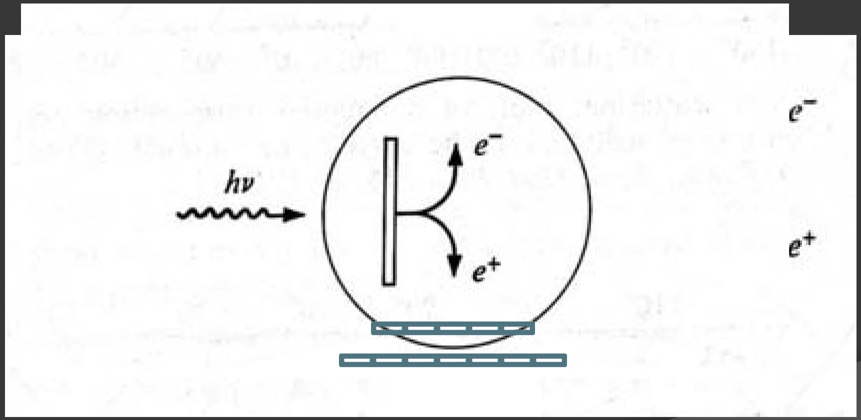


Degree of polarization of off-axis bremsstrahlung as a function of the photon energy (E_e = 30 MeV, θ = 1.4°)

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

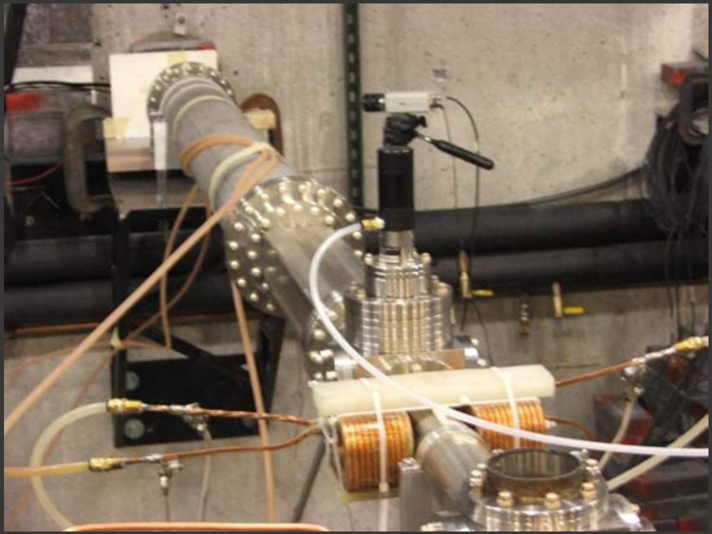
- γ's pair-produce in Al converter
- e+/e- trajectories change in B-field
- Chose to detect positrons using telescope detector system
- Use to normalize detected neutron yield from the target



Background Issues

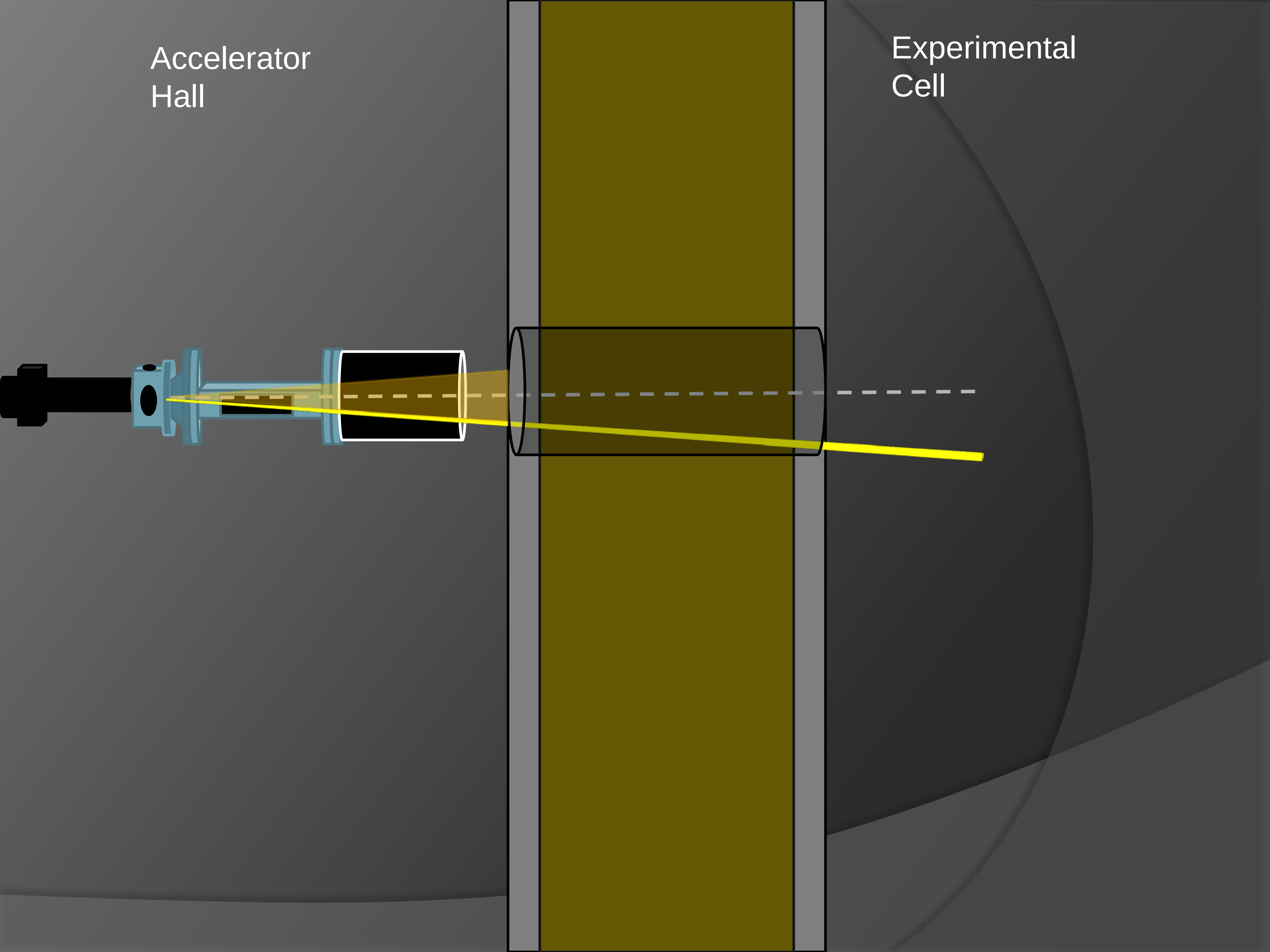
- The cross-section for pair-production in air is about 0.15 barns/atom, which produces 300 pairs per pulse.
  - Al converter produces roughly 3 pairs per pulse.

Try more vacuum…



« upstream vacuum-pipe extension

Downstream vacuum pipe and sweep magnet


Accelerator
Hall
Experimental
Cell

Off-Axis Collimation