# Triplet polarimeter study

Michael Dugger*
*Arizona State University*

*Work at ASU is supported by the U.S. National Science Foundation

# Outline

- Triplet production
- Potential detector
- Event generator
- Comparison to previous triplet polarimeter
- Absolute polarization uncertainty for 4 hours of running
- Estimate of accidentals
- Testing a triplet polarimeter

# Triplet production

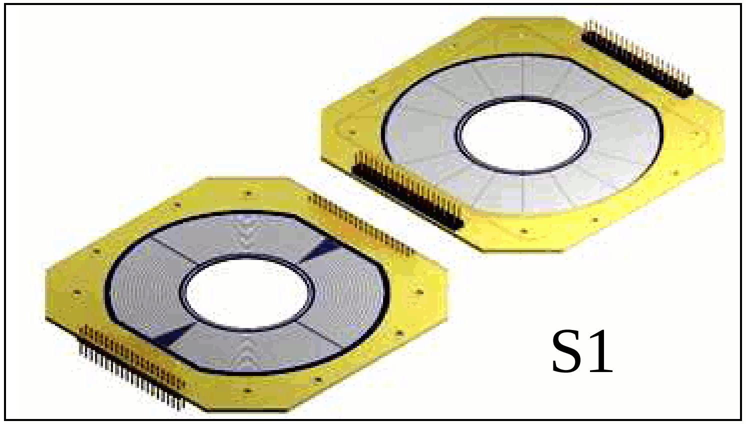
- Pair production off a nucleon: $\gamma$ nucleon $\rightarrow$ nucleon $e^+$ $e^-$.

- For polarized photons $\sigma = \sigma_0[1 + P\Sigma \cos(2\varphi)]$, where $\sigma_0$ is the unpolarized cross section, $P$ is the photon beam polarization and $\Sigma$ is the beam asymmetry

- Triplet production off an electron: $\gamma$ $e^-$ $\rightarrow$ $e_R^-$ $e^+$ $e^-$, where $e_R$ represents the recoil electron

- Any residual momentum in the azimuthal direction of the $e^-$ $e^+$ pair is compensated for by the slow moving recoil electron. This means that the recoil electron is moving perpendicular to the plane containing the produced pair and can attain large polar angles.

# Potential detector

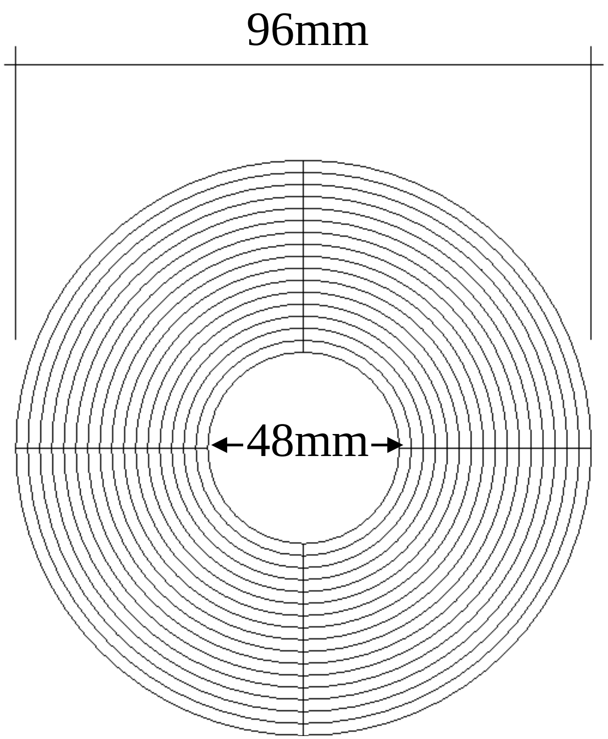



Front:
4 sectors
16 strips/sector

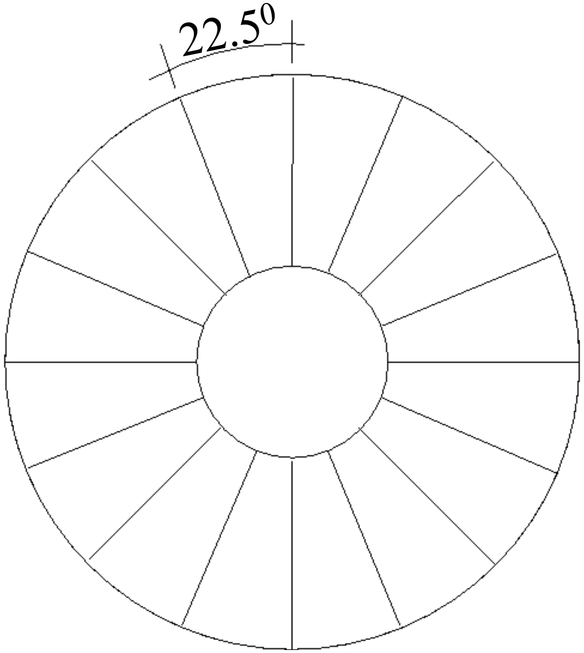
Back:
16 sectors

Cost: $7500
(back stock)

Manufacturer:
Micron
Semiconductor



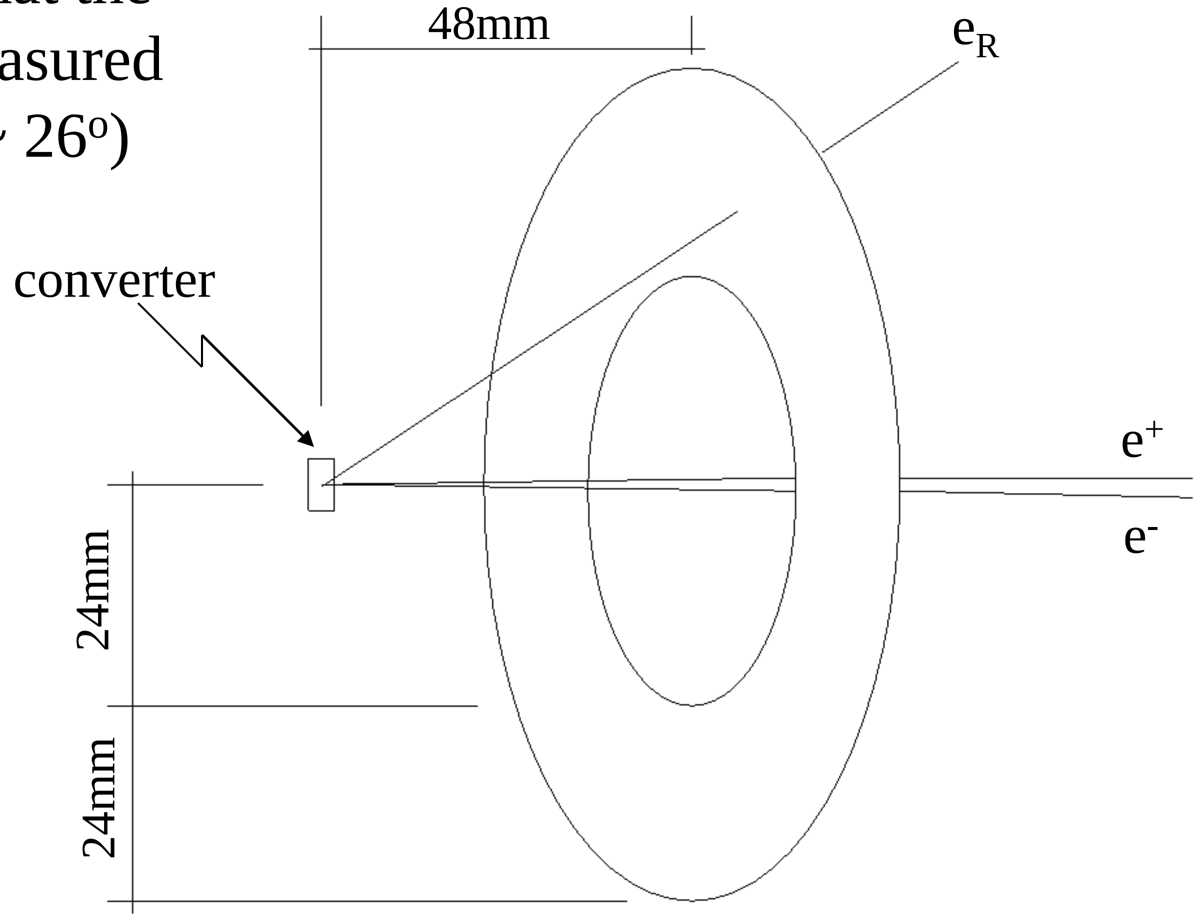

**Front**




**Back**

# Sample geometry

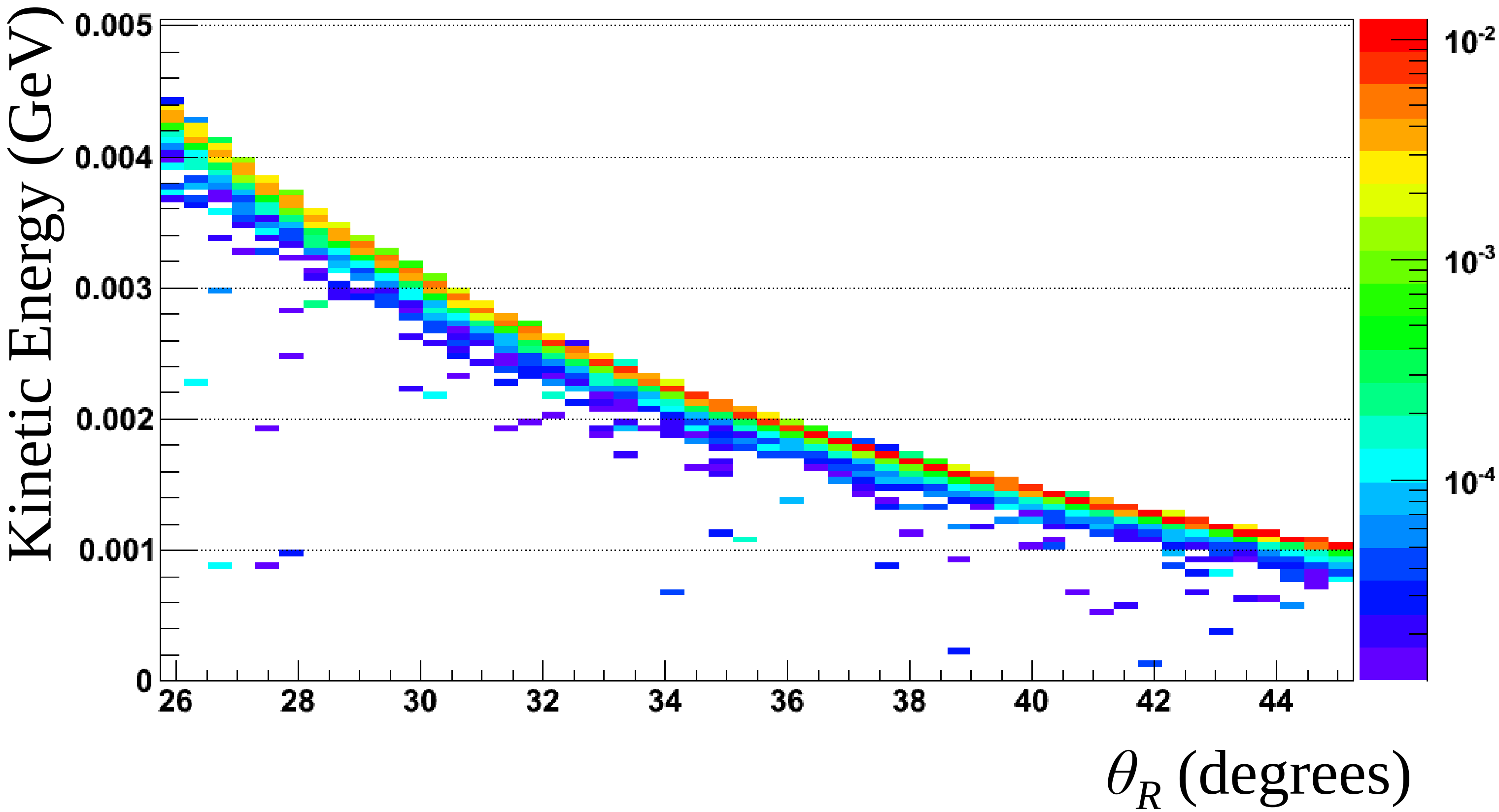
Setting the detector distance from converter such that the largest polar angle measured is 45° (results in $\theta_{min} \sim 26^o$)



# Event generator

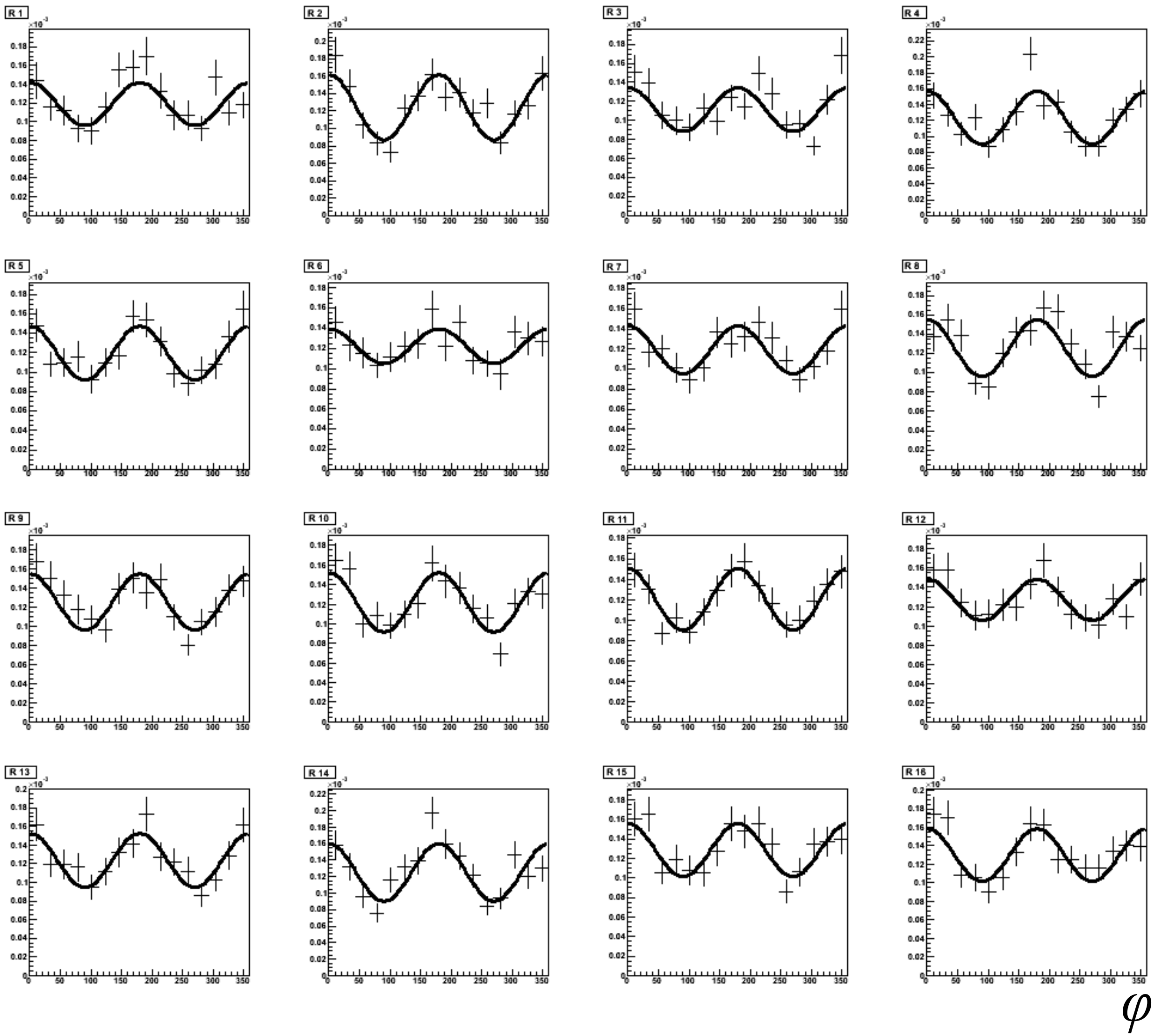
- Richard Jones provided an event generator that calculates QED tree level Feynman diagrams

# kinetic energy of recoil versus polar angle for $26^o < \theta < 45^o$ and $E_\gamma = 9$ GeV



# Triplet asymmetry fits

- 10 million generated events using Richard’s code
- $E_\gamma$ = 9.0 GeV
- Fit each ring separately
- Fit function: $A[1 + B\cos(2\varphi)]$

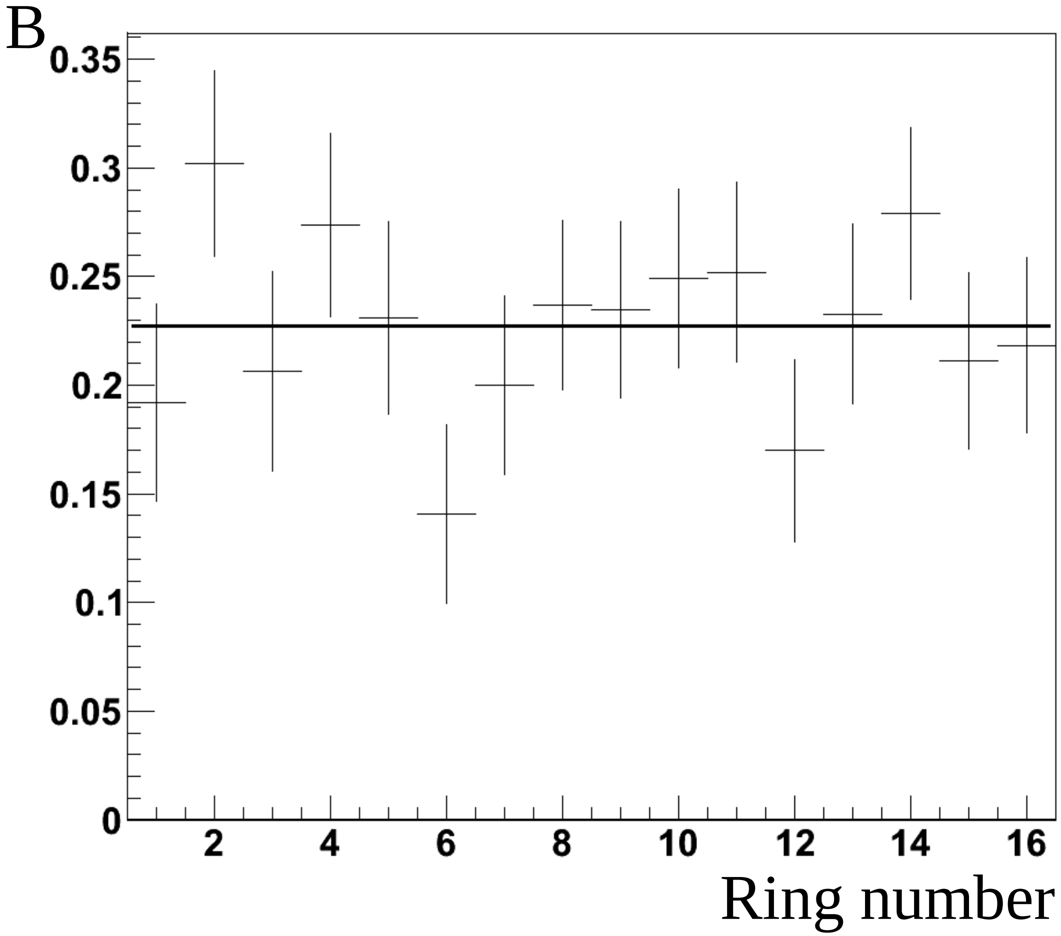


# Triplet asymmetry fit results
# $A[1 + B\cos(2\varphi)]$

• Parameter B from fit

• Results fairly consistent over ring number (inner most ring number = 1)

• Zero order fit:
22.7 ± 0.1



# Comparison of GEANT4 study of triplet polarimeter to previous study

- The SAL detector
- $\delta$-rays
- Pair to triplet ratio
- ASU simulation of SAL
- Could SAL have been modified to work in the Hall-D environment?

# The GW SAL detector

- $E_\gamma$ = 220 to 330 MeV
- 2 mm scintillator converter
- Polarimeter located ~39 cm downstream of converter
- Recoil $\theta$ = 15 to 35 degrees
- Recoil $\varphi$ = 0, 90, 180, 270 degrees with $\Delta\varphi$ = 44 degrees
- Analyzing power at the event generator level = 12%
- Analyzing power from simulation 3-4% (post experiment)
- Measured analyzing power = 2.7%
- Quick check - Can ASU reproduce the GW results?

ARIZONA STATE UNIVERSITY

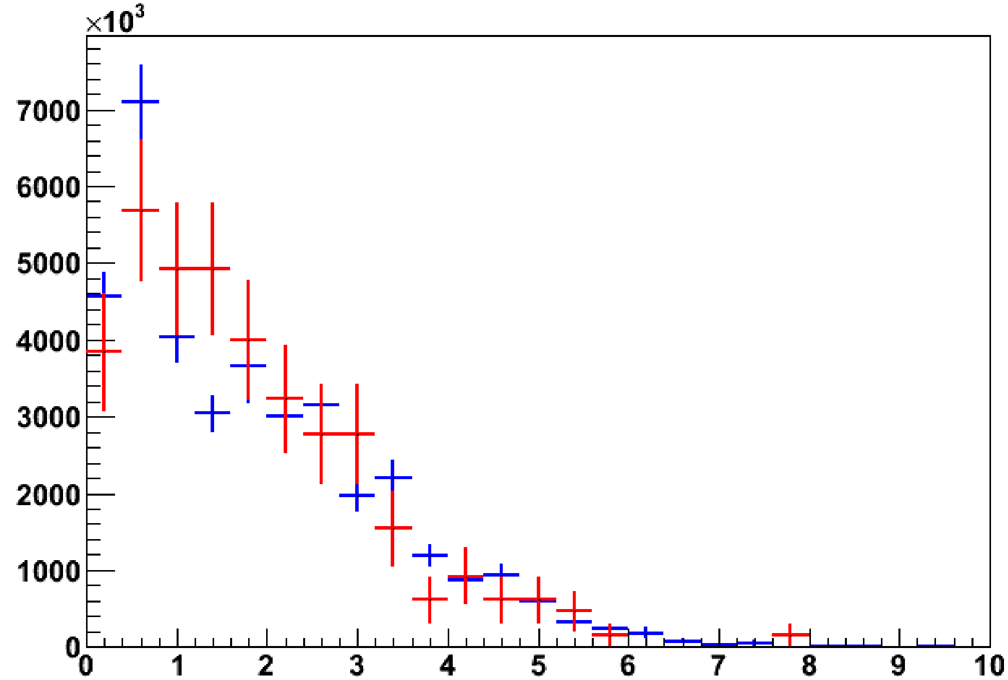
# $\delta$-ray comparison with Iwata 1993 simulation

- $E_\delta$ is $\delta$-ray kinetic energy after traveling through 1 mm of scintillator using Iwata's polar geometry and scintillator widths

- **BLUE**: Current ASU GEANT4 results

- **RED**: Iwata GEANT3 (scaled to GEANT4 results by ratio of signal  integration)

- Shapes of the distributions look similar




$E_\delta$ (MeV)

- ASU simulation $E_\gamma$ = 300 MeV

- Iwata simulation $E_\gamma$ = 250, 365, 450 MeV

Note: ASU simulation did not wrap scintillators

# NIST cross sections for triplet and pair production off carbon

- $\sigma_{pair}/\sigma_{triplet}$:

  5.75 @ 300 MeV

  5.16 @ 9.0 GeV

- Ratio does not vary much over large energy range

# Comparison of ASU MC of SAL detector to GW results

Note: ASU results are for $E_\gamma$ = 300 MeV and GW is of $E_\gamma$ = 220 to 330 MeV

Analyzing power:

- At event generator level: 12.6 ± 0.1 % ASU; ~12% GW (no error reported)
- ASU simulation: 2.65 ± 0.05%
- ASU simulation (30 μm Al wrapped scintillators): 2.8 ± 0.1 %
- GW experiment: 2.7% (no error reported)
- GW simulation: 3-4% (range given with no error reported)

- ASU results are in agreement with the GW results for the SAL detector ☺

# How could the SAL detector be modified to work in Hall-D environment?

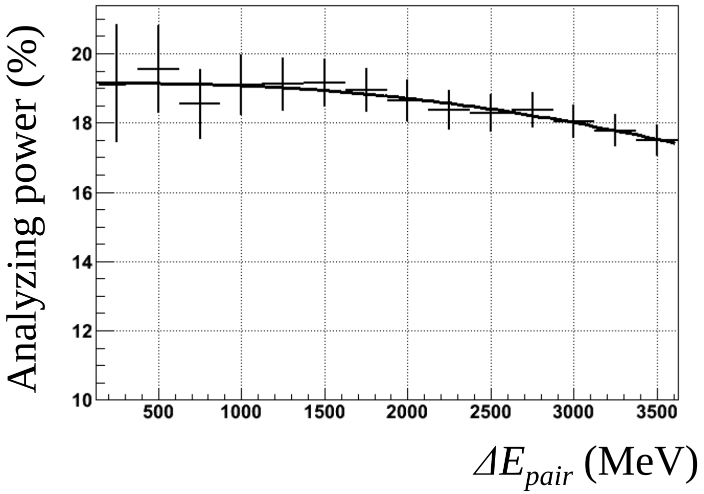
| Air → Vacuum | Converter rad length → $10^{-4}$ | E → 9 GeV | $\Delta E_{\mathrm{pair}} < 1.5$ GeV | Analyzing power |
|---|---|---|---|---|
| | | | | 2.8(1) % |
| X | | | | 6.9(1) % |
| X | X | | | 12.5(2) % |
| X | X | X | | 10.6(2) % |
| X | X | X | X | 17.5(3) % |

# Dependence of analyzing power on $\Delta E_{pair}$ for 16 sector detector

• Same parameters as previous best configuration but now with 16 sectors instead of 4 paddle SAL design

• Analyzing power fairly constant for $\Delta E_{pair}$ < 1750 MeV

• The 16 sector design increases the analyzing power to 19.1 ± 0.7 % from 17.5 ± 0.3 % of the 4 paddle design ($\Delta E_{pair}$ < 1500 MeV)



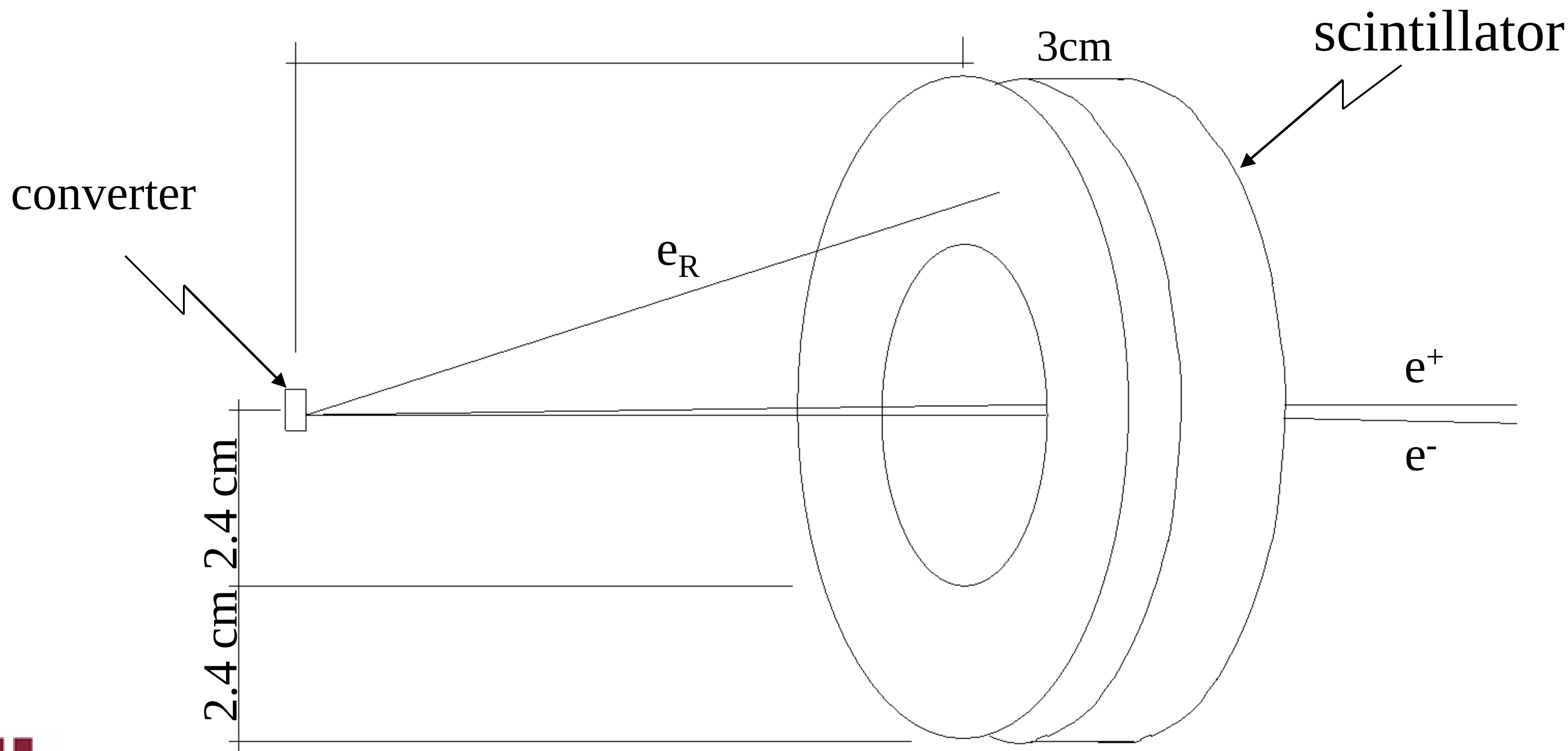
# Recap of modifications that would make SAL type detector work in Hall-D

| Air → Vacuum | Converter rad length → $10^{-4}$ | E → 9 GeV | $\Delta E_{pair}$ < 1.5 GeV | 16 Sector | Analyzing power |
|---|---|---|---|---|---|
| | | | | | 2.8(1) % |
| X | | | | | 6.9(1) % |
| X | X | | | | 12.5(2) % |
| X | X | X | | | 10.6(2) % |
| X | X | X | X | | 17.5(3) % |
| X | X | X | X | X | 19.1(7) % |

# Study of converter thickness, and placement of triplet polarimeter, to the absolute error in polarization measurement

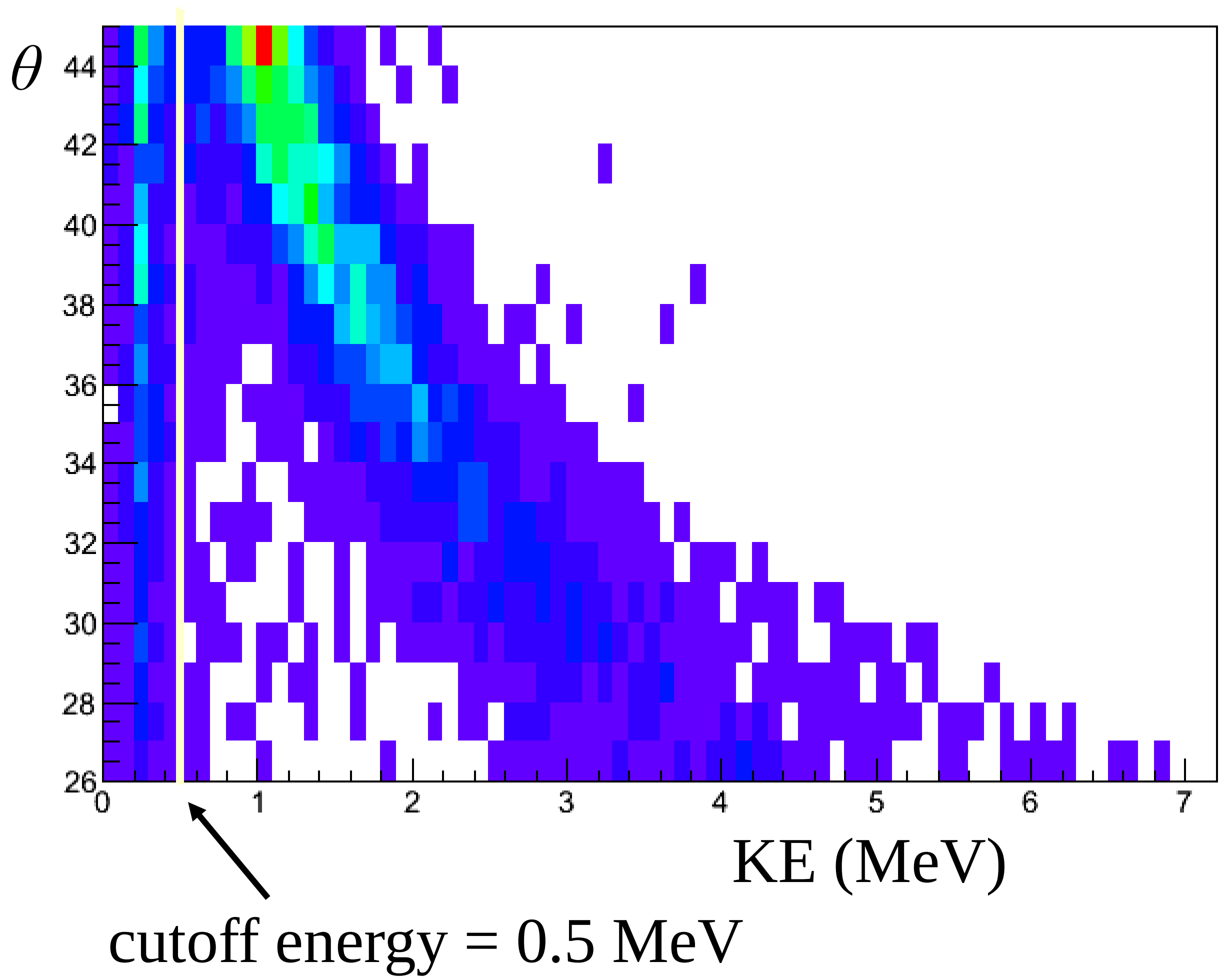
# Detector

- Figure not to scale



# Energy cut

• Cutoff energy of 0.5 MeV won't cut out good recoil-electron events



# NIST cross sections for triplet and pair production off Lithium

- $\sigma_{pair}/\sigma_{triplet}$:

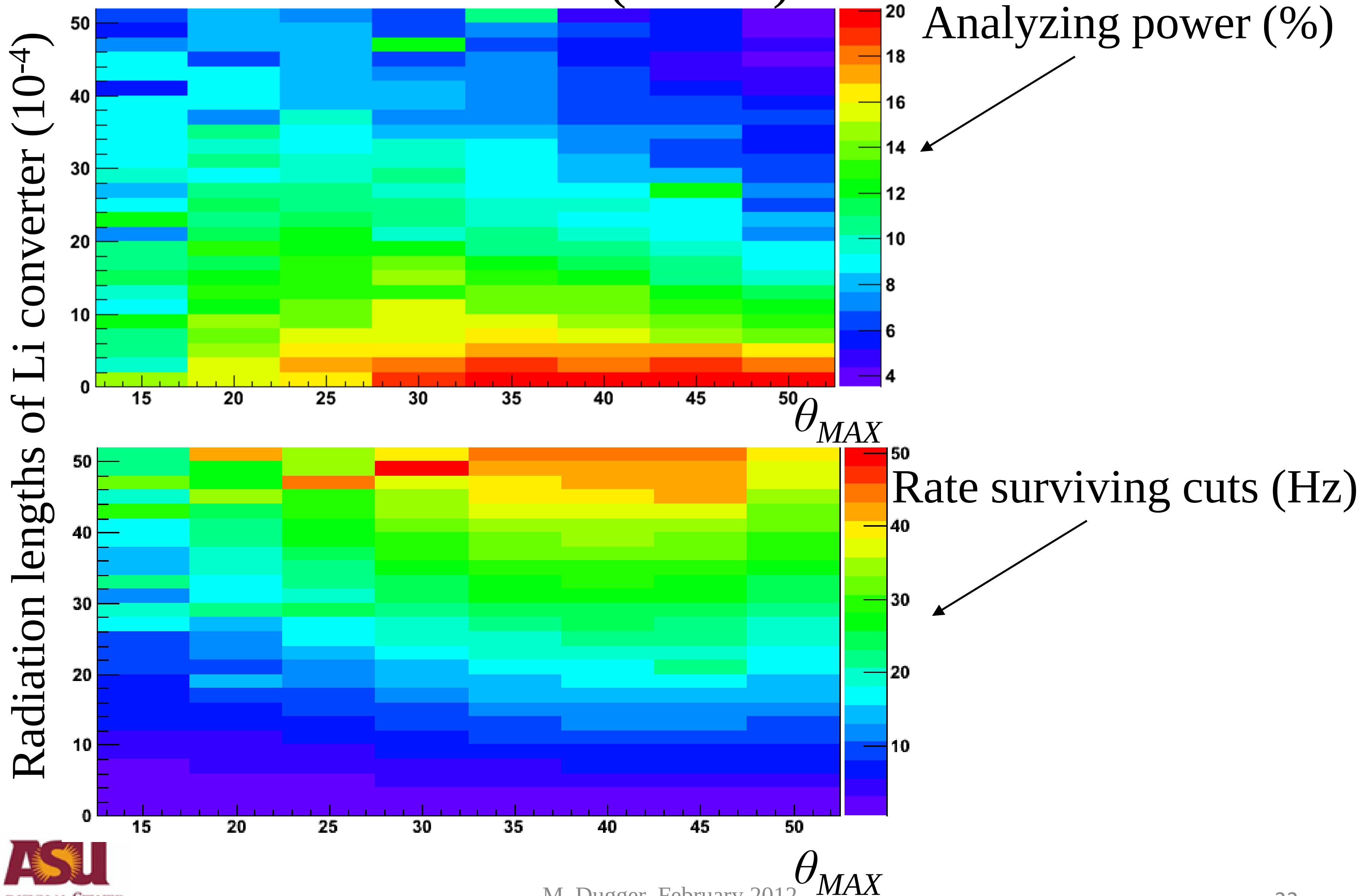
  2.89 @ 300 MeV

  2.49 @ 9.0 GeV

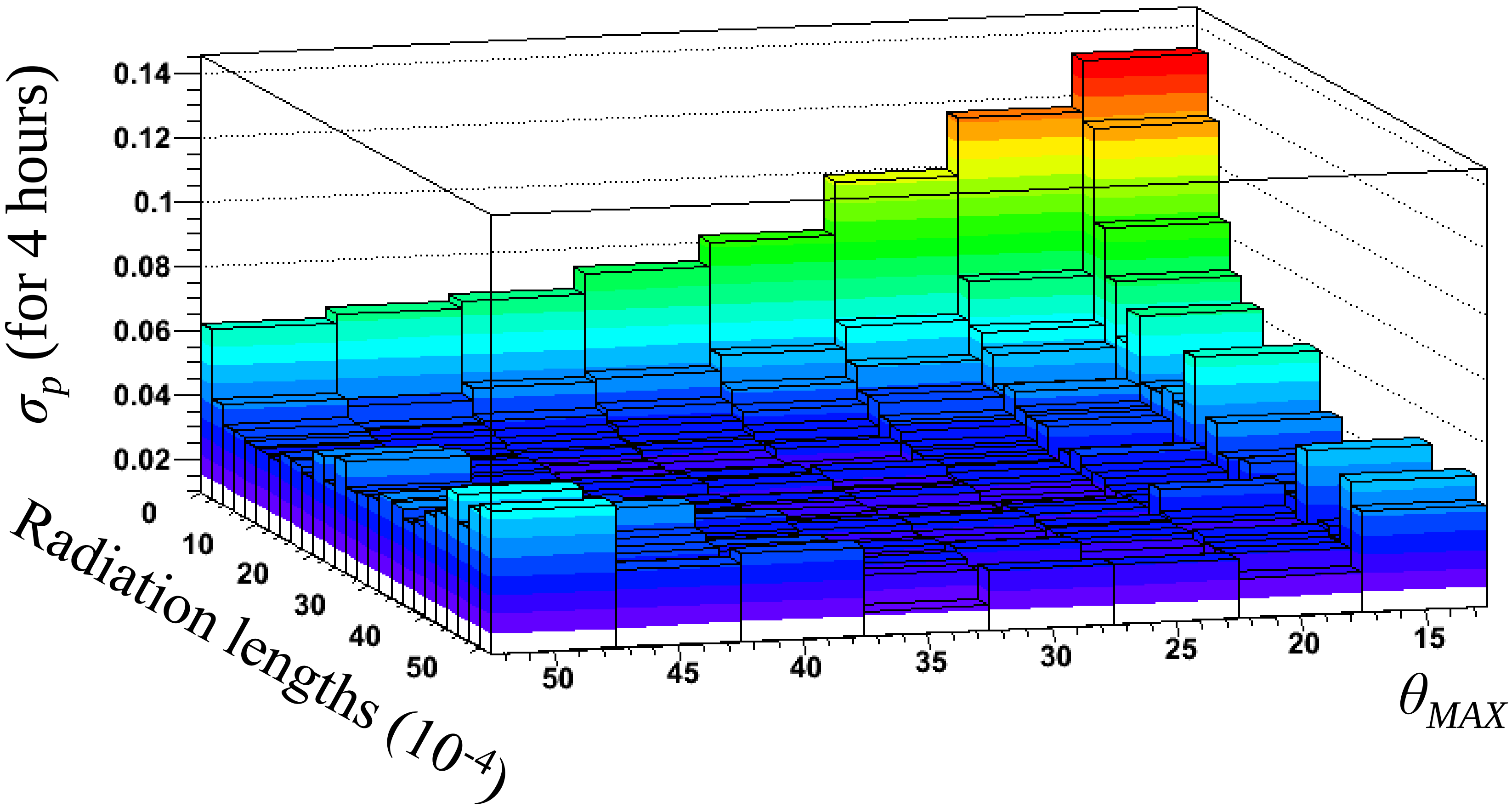
- Ratio more favorable than when using carbon (~5 @ 9GeV)

- Will use lithium converter from here on

# Converter thickness and polarimeter placement study (slide 1)



# Absolute polarization uncertainty in 4 hours of running




Assumed $\frac{\sigma_P}{P} = \sqrt{\frac{1}{N}}\sqrt{\frac{2}{\alpha^2 P^2} - 1}$

where N ≡ Rate * 4 hour,
P ≡ Polarization = 0.4, and
α ≡ analyzing power

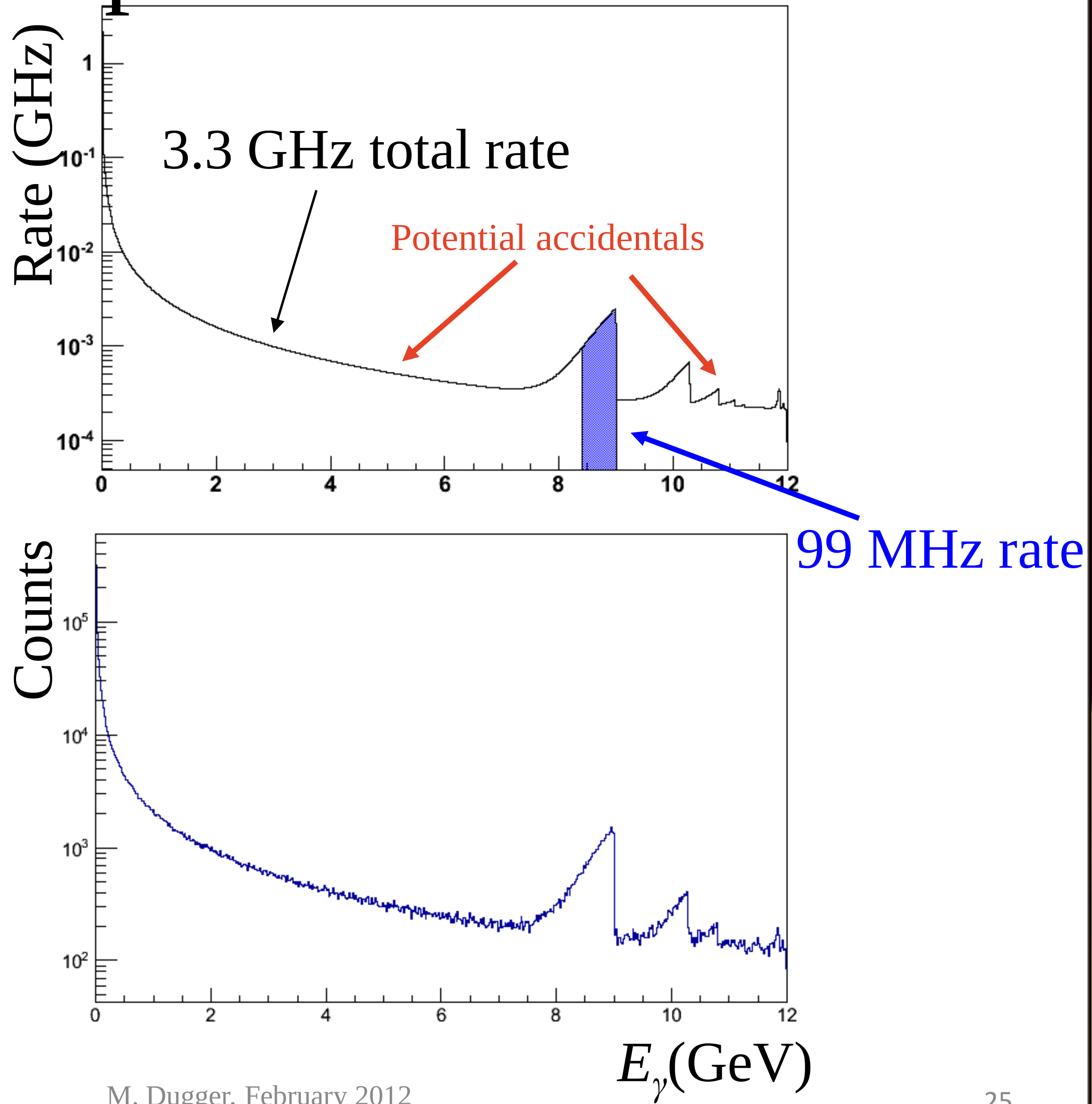
ARIZONA STATE UNIVERSITY

# Estimate of accidentals for the triplet polarimeter

# Collimated photon distribution

- Used Richard's cobrems_root code to create shape of $E_\gamma$ distribution (top panel)

- Used shape of $E_\gamma$ to generate 1 million events (bottom panel) that were fed into the triplet-polarimeter Monte Carlo



# Accidental estimate

- For 1 million events thrown ($N_T$) there were 177 events seen ($N_S$) on the polarimeter

- Assumed a lithium converter of $10^{-3}$ radiation lengths

- Total expected photon rate: $R_\gamma = 3.3$ GHz

- Expected total photon rate seen on device:
$R_S = R_\gamma * (N_S/N_T) = 3.3\text{GHz} * (177/1\text{million}) = 584$ kHz

- Expected number of polarimeter hits for a 20 ns window:
$\langle n_{5ns} \rangle = R_S * 20\text{ns} = 0.012$

- Probability of accidental coincidence between pair spectrometer and polarimeter: $P_{acc} = 1 - P_0(\langle n_{5ns} \rangle) = 1.2$ %

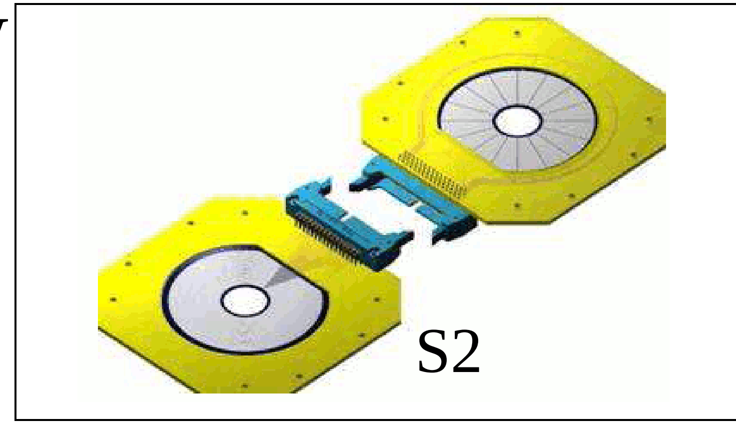
ARIZONA STATE UNIVERSITY

# Testing a triplet polarimeter

# Possibility of testing a device at Mainz

- Ken Livingston suggested trying to test a device similar to the ASU design at Mainz
    - Ken might be able to borrow a ring detector (Micron semiconductor S2 design)
    - Ken already has designed electronics that can read out the ring detector with possibility of timing widow as small as 20 ns
- Need to see if we can put all the pieces together and get permission for a parasitic test run at Mainz

# Potential detector to borrow



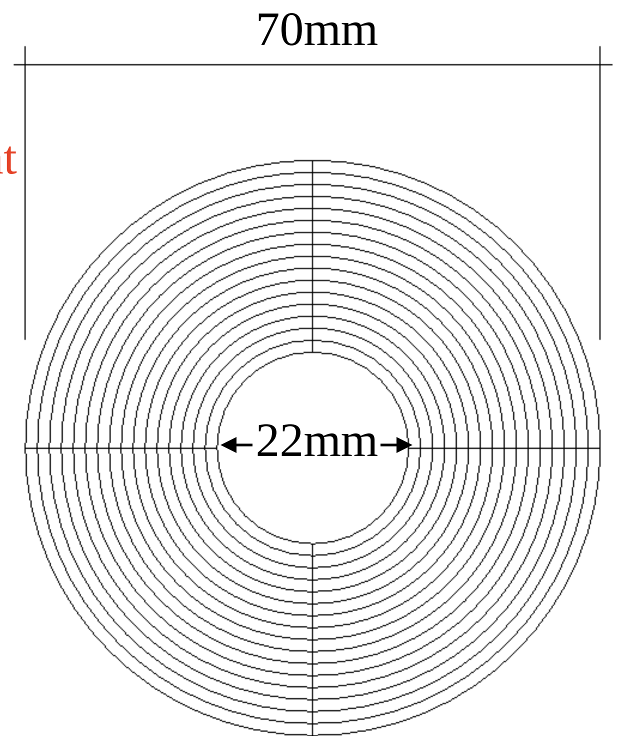

Front:
4 sectors
48 rings/sector

Back:
16 sectors

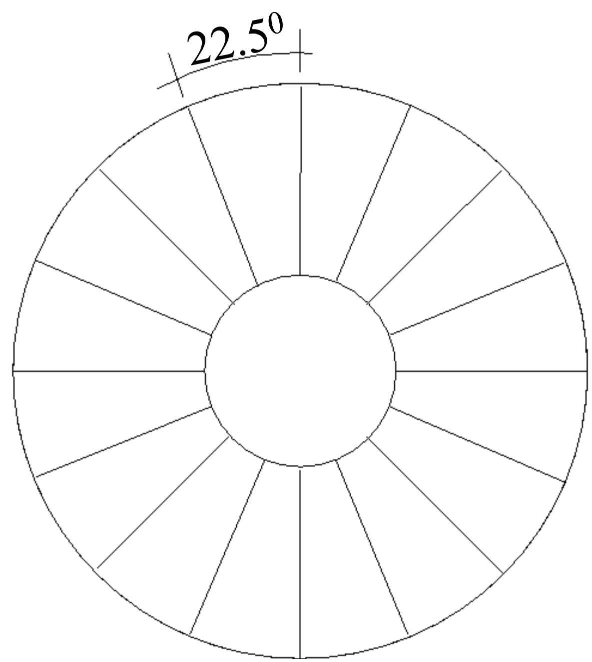
Very similar to current ASU design

Front: 4 sectors
16 rings/sector

Back:
16 sectors




**Front**




**Back**

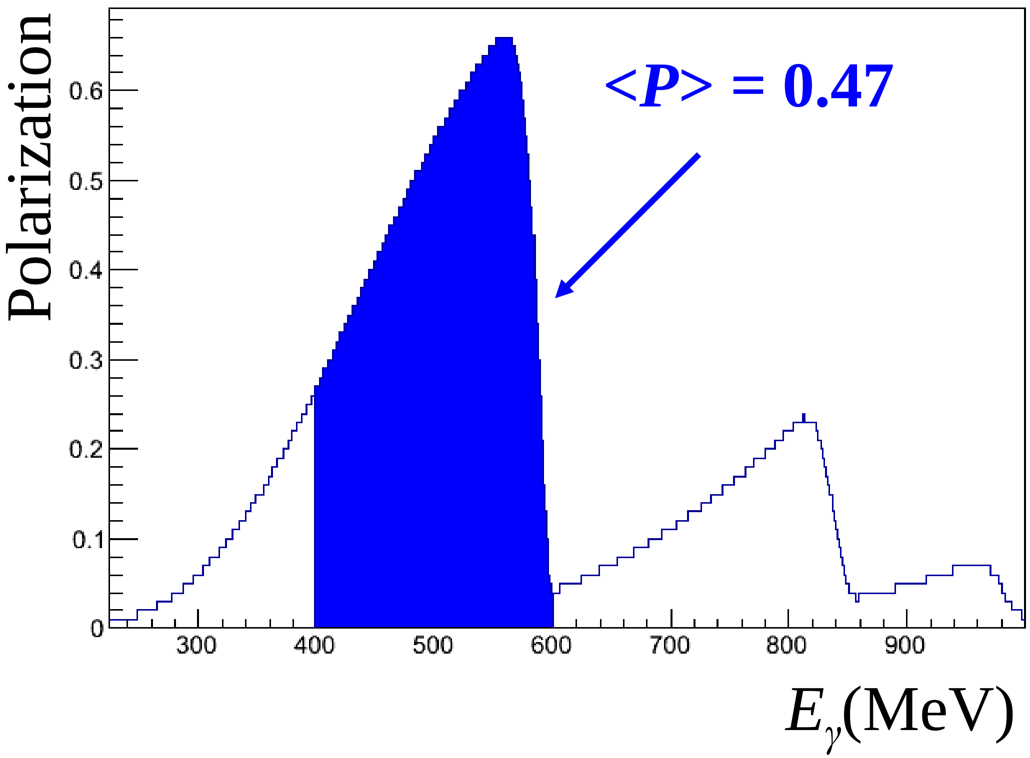
# Expected Mainz photon polarization

- Distribution provided by Ken Livingston

- Electron beam energy = 1500 MeV

- Coherent edge = 600 MeV

- The rest of the slides will assume a 500 MeV photon beam with Polarization = 0.47




- Should be able to use a much finer energy binning than what is shown on the plot, but just simulating a single energy for now

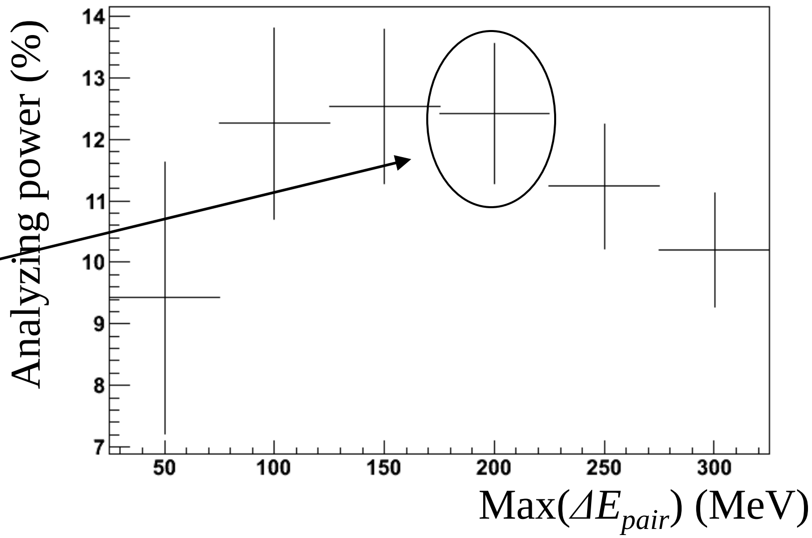
Arizona State University

# Dependence of analyzing power on $\Delta E_{pair}$ for S2 geometry at Mainz photon energy

- Converter is $10^{-3}$ radiation lengths of lithium

- No energy cut

- Symmetric pair definition of $\Delta E_{pair} < 200$ MeV seems reasonable and is used from here on



# Simulation results

- Assumed collimated photon rate (over 200 MeV range) : $4.8\text{x}10^7$ Hz

- Electron rate on device that survive cuts: 9 Hz

- $\Delta t$ = 4 hours

- Analyzing power: 0.136(6)

- Polarization uncertainty: 0.029