Linearly polarised photons and determining the polarisation degree

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Outline

1. Motivation
2. Generation of Coherent Bremsstrahlung
3. Coherent Bremsstrahlung Fit
4. Nuclear Physics Reaction
5. Pair and Triplet Production
6. Triplet Polarimeter - GlueX
7. Prototype Pair Polarimeter
8. Coherent Bremsstrahlung of the Future
Motivation - $N^*$ programme

$N^*$ programme reliant on linear polarisation.

<table>
<thead>
<tr>
<th>Beam</th>
<th>Target</th>
<th>Recoil</th>
<th>Target + Recoil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x y z</td>
<td>$x' y' z'$</td>
<td>$x' x' z' z'$</td>
</tr>
<tr>
<td>Unpol</td>
<td>$\sigma_0$</td>
<td>$T$</td>
<td>$P$</td>
</tr>
<tr>
<td>Linear</td>
<td>$\Sigma$</td>
<td>$H P G$</td>
<td>$O_{x'} T O_{z'}$</td>
</tr>
<tr>
<td>Circular</td>
<td>$F E$</td>
<td>$C_{x'} C_{z'}$</td>
<td>$T_{x'} L_{x'} T_{z'} L_{z'}$</td>
</tr>
<tr>
<td>Experiment</td>
<td>Reaction</td>
<td>Obs</td>
<td>Energy</td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
<td>-----</td>
<td>--------------</td>
</tr>
<tr>
<td>Yerevan</td>
<td>$p\gamma \rightarrow p\pi^0$</td>
<td>$\Sigma$</td>
<td>$0.5 \rightarrow 1.1\text{GeV}$</td>
</tr>
<tr>
<td>Max III</td>
<td>$^{12}C, (p)^{11}B$</td>
<td>$\Sigma$</td>
<td>$40 \rightarrow 50\text{MeV}$</td>
</tr>
<tr>
<td>Clas</td>
<td>$p\gamma \rightarrow p\pi^0$</td>
<td>$\Sigma$</td>
<td>$1.1 \rightarrow 1.8\text{GeV}$</td>
</tr>
<tr>
<td>CBELSA</td>
<td>$p\gamma \rightarrow p\pi^0$</td>
<td>$G$</td>
<td>$0.6 \rightarrow 1.3\text{GeV}$</td>
</tr>
<tr>
<td>A2</td>
<td>$p\gamma \rightarrow p\pi^0$</td>
<td>$\Sigma$</td>
<td>$320 \rightarrow 650\text{MeV}$</td>
</tr>
<tr>
<td>GlueX</td>
<td>$p\gamma \rightarrow p\pi^0$</td>
<td>$\Sigma$</td>
<td>$8.1 \rightarrow 9.0\text{GeV}$</td>
</tr>
</tbody>
</table>
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Generation of Coherent Bremsstrahlung

\[ \gamma = E_0 - E_1 \]

Generated using diamond radiator.
Cover full range beam energy.
Understood but complex polarisation energy dependence.
Generation of Coherent Bremsstrahlung

\[ E_\gamma = E_0 - E_1 \]

Generated using diamond radiator.
Cover full range beam energy.
Understood but complex polarisation energy dependence.

[022,044...] primary contributions.
Other vectors angled to not overlap with region.
http://nuclear.gla.ac.uk/ kl/GlueX/cbrems scans/scan.gif
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Coherent Bremsstrahlung Fit

Currently widely used in most labs.

**Pros:**
Information provided by the photon tagger.
Polarisation over whole tagged photon energy range.

**Cons:**
Very sensitive to orientation of diamond lattice.
Indirect measurement.
Requires runs with amorphous radiator.
Parameters can vary with the same $\chi^2$; giving an uncertainty on the polarisation of about 5%.
Coherent Bremsstrahlung Fit

Currently widely used in most labs.

**Analytic Bremsstrahlung Calculation (anb)**

![Graph showing photon energy (MeV) vs. enhancement and polarization.](image)

**Input Parameters**
- beam energy (MeV)
- energy spread (MeV)
- goni. h (mrad)
- goni. v (mrad)
- goni. a (deg)
- x beam Spot Size (mm)
- y beam Spot Size (mm)
- x beam divergence (mrad)
- y beam divergence (mrad)
- radiator thickness [mm]
- collimator distance [mm]
- collimator length [mm]
- collimator radius [mm]
- incoherence type
- no of lattice vecs
- Z of Crystal (Brili)
- Z of Amorphous (Ni:30)

[Load Data] [Clear] [RUN]
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Examples:
Coherent $\pi^0$ production off spin 0 nucleus ($^4$He, $^{12}$C, $^{208}$Pb)
$\rho$ meson production.
$\pi^0$ production.

Pros:
Can use standard experimental detectors.
Direct continuous post collimation measurement.

Cons:
Precise measurement previously made.
Inherit systematic uncertainty.
Essential to confidently separate background channels.
Only valid for specific targets or secondary target needs to be added.
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Pros:
Electromagnetic processes described precisely by theory.
Direct continuous post collimation measurement.
No significant background reactions.

Cons:
Low count rates.
Requires designated additional detector.
Lower energy coverage


**Pair Production**

Photon Conversion in nuclear field.

\[ \gamma + N \rightarrow e^+ + e^- + N \]

Higher reaction cross section.
Lower analysing power.

**Triplet Production**

Photon Conversion in electron field.

\[ \gamma + e_{atomic} \rightarrow e^+ + e^- + e_{recoil} \]

Lower reaction cross section.
Higher analysing power.
Pair and Triplet Production

Pair Production
Photon Conversion in nuclear field.
\[ \gamma + N \rightarrow e^+ + e^- + N \]
Higher reaction cross section. Lower analysing power.

Triplet Production
Photon Conversion in electron field.
\[ \gamma + e^-_{atomic} \rightarrow e^+ + e^- + e^-_{recoil} \]
Lower reaction cross section. Higher analysing power.

[M. Dugger et. al. NIM 867 (2017)]
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Systematic uncertainty estimated at 1.5%
Accumulate over beamtime to get enough statistics for binning polarisation by photon energy.
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\[ \gamma + N \rightarrow e^+ + e^- + N \]

0.1 \(\rightarrow\) 1.5 GeV tagged photon beam.

Pairs converted in Tantalum foil.

Separated from beamspot by dipole field.

Two Timepix3 detectors.

Scintillation detectors form trigger.

Expected systematic error of \(<2\%.

20 minutes of running under Mainz conditions.
Prototype Pair Polarimeter
Location of the pair polarimeter for tests.
Polarisation Extraction

0→0.25→0.5→0.75→1 degree of polarisation
Linear regression of histogram bins contents.

Fit line to the change in histogram bin fraction with polarisation. Less than 0.5% error, would improve additional simulations.
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Coherent Bremsstrahlung of the Future

Running at Bonn, Mainz and J-Lab for now
Speculative facilities:

- DAΦNE
- ILC (International Linear Collider) - 125 GeV real photons

Figure 3.1. Schematic layout of the ILC, indicating all the major subsystems (not to scale). From TDR Executive Summary (https://arxiv.org/pdf/1306.6327.pdf)
Current methods for determining the degree of polarisation are no longer good enough.

GlueX has proved the effectiveness of a polarimeter.

A pair polarimeter would increase allow measurements at Mainz rates.
END