The single electron project

S. White, BNL Physics

Oct. 6, ATF User’s Meeting

- A unique feature of ATF beam is 3 picosec bunch length (streak camera)
- Could this be exploited to evaluate fast timing detectors?
- We present a method to produce a compact secondary beam.
  - ~1 electron/pulse
  - Initial use to develop fast timing detectors
representing work of:
V.Yakimenko, M.Fedurin, T.Tsang, M.Chiu, M.Diwan,
G.Atoian(BNL)
K.McDonald(Princeton)

correspondents:
H.Frisch, J.Va’vra, K.Goulianos, D.Acker, I.Mousienko,
P.Vaska, M.Suyama
Why is a 100 MeV, single electron, 3 picosecond beam interesting?

Deep diffused avalanche photodiode

650 picosecond risetime (β’s)

“A 10 picosecond time of flight detector using APD’s”, SNW et al.
100 years of subatomic Structure

• Rutherford, Geiger, Marsden (1909)
  – Atom’s 100\textsuperscript{th} Birthday!
  – Rutherford’s teacher, JJ Thomson, discovered electron 10 years earlier

• “counter experiment”
  – Beam of 5 MegaVolt $\alpha$ particles from Radium C decay

• Use Rutherford scattering for a “1 step” secondary beam
Question: with an incident beam of $10^9$ 60-80 MeV electrons, a ~1 mm target (Al or Be), how many are scattered @90 degrees into a ~1cm$^2$ detector 30 cm away?

Answer: ~1 !

• calculations presented in: “LBNE energy calibration using a 100 MeV electron accelerator”-SNW& Vitaly Yakimenko

http://arxiv.org/abs/1004.3068

• small accelerators previously used for calibration. ie:
  • Super K made good use of a 5-16 MeV medical accelerator -Mitsubishi ML-15MIII. They used a conventional secondary beam design (requires space)
Background issues

• It would be almost impossible to calculate, from first principles, detector backgrounds from scraping, etc to the level of ~1 counts/pulse

• Vitaly’s intuition was that such backgrounds are low at ATF

• the bee:

• Our approach has been to focus entirely on APD based devices. This makes it easy to analyze backgrounds since rates and energy deposition depend primarily on area and effective depth.
Wide angle electron scattering

Approximations to Hofstadter's form:

\[
\begin{align*}
\text{Rutherford}[\theta, Z, \text{EeMeV}] & := \frac{1}{4} (Z \alpha_{\text{EM}})^2 \frac{\hbar c l^2}{\text{EeMeV}^2} \csc^4 \frac{\theta}{2} \\
\text{Mott}[\theta, Z, \text{EeMeV}] & := \text{Rutherford}[\theta, Z, \text{EeMeV}] \ast \\
\cos^2 \frac{\theta}{2} \left( 1 + \frac{\pi Z \alpha_{\text{EM}} \sin \frac{\theta}{2} \ast (1 - \sin \frac{\theta}{2})}{\cos^2 \frac{\theta}{2}} \right) \\
Q[\theta, \text{EeMeV}] & := \frac{2 \ast \text{EeMeV}}{\hbar c} \sin \frac{\theta}{2} \\
\rho[r, a] & := \frac{1}{8 \pi (a)^3} \exp[-r/a] \\
\text{FormFactor}[\theta, a, \text{EeMeV}] & := 4 \pi \int_0^\infty r \rho(r, a) \sin(r Q(\theta, \text{EeMeV})) dr \\
\text{Hofstadter}[\theta, Z, \text{EeMeV}, a] & := \text{Mott}[\theta, Z, \text{EeMeV}] \ast \text{FormFactor}[\theta, a, \text{EeMeV}]^2
\end{align*}
\]
this calculation

Hofstadter

electron Scattering on Au

Scattering form
- Rutherford
- Mott
- Hofstadter

Cross Section vs. Scattering angle

Sunday, December 5, 2010
\( t_{90} = \text{Table}[.5 \left( \frac{\text{Foils}[[i, 3]]}{M_p \times \text{Foils}[[i, 2]]} \right) \times \text{Correction}[[i]] \times \text{Flux} \times d\Omega \times \text{Hofstadter}[90 \times \text{Degree}, \text{Foils}[[i, 1]], 62, \text{Foils}[[i, 6]]]], \{i, 4\}] \);

<table>
<thead>
<tr>
<th>Beamline Angle</th>
<th>Beryllium</th>
<th>Polystyrene</th>
<th>Aluminum</th>
<th>Gold</th>
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<tbody>
<tr>
<td>45°</td>
<td>0.00507424</td>
<td>0.00619767</td>
<td>0.00108573</td>
<td>0.0000493743</td>
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<tr>
<td>60°</td>
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<td>0.0219929</td>
<td>0.00417395</td>
<td>0.000283</td>
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<tr>
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<td>0.123976</td>
<td>0.15564</td>
<td>0.0354221</td>
<td>0.0050626</td>
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</tbody>
</table>
the beamline
Initial tests (Al)

“target out” background well below scattered rate
“target in” rate ~10*
Calculation
signal has v=c
1 X0 not effective
concluded few MeV gamma
AI is very messy!

Beryllium is excellent!

we now have a backlog of high quality data, with different timing detectors, absorbers and distance to target. Requires ~1 week analysis to make suitable for publication.
In next talk we request: 3 days beam studies, 10 days detector R&D beam time

Our collaboration will provide:

- complete characterization of secondary beam (optimize “target out” background rates)
- currently data quality depend on resident ATF accelerator expertise in beam tuning -> codify procedure for beam setup
- “oscilloscope-based” data acquisition system initially slow and best understood scope was 500 MHz one
- make permanent installation based on ~$1000, 4-channel scope on a chip (DRS4 evaluated by us on loan from Frisch). Also higher performance chips in development (u.Chicago, Hawaii, Orsay, Saclay) - we will provide this.
- high daq rate and fast online feedback
Addendum (slides related to a proposal for use of this design in an accelerator to calibrate LBNE)
Interesting features for calibration

![Graph 1: Carbon 117 MeV 60°](image1.png)

![Graph 2: Extending calibration to 1 GeV](image2.png)

![Graph 3: Resolution broadened detector response (MeV)](image3.png)
“Turn-key” proposal to LBNE

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
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<tr>
<td>RF operating frequency</td>
<td>2856 MHz</td>
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<tr>
<td>RF pulse flat-top duration</td>
<td>3 μs</td>
</tr>
<tr>
<td>Max. RF input power</td>
<td>10 MW</td>
</tr>
<tr>
<td>Max. accelerating gradient</td>
<td>100 MV/m</td>
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<tr>
<td>Max. beam energy at gun output</td>
<td>4.5 MeV</td>
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<tr>
<td>Bunch charge</td>
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<tr>
<td>Repetition rate</td>
<td>10 Hz</td>
</tr>
</tbody>
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<td>Max. RF input power</td>
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<tr>
<td>Max. accelerating gradient</td>
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<td>Max. energy gain per section</td>
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</tr>
<tr>
<td>Repetition rate</td>
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</tr>
</tbody>
</table>

The approximate breakdown of the total cost is as follows:

- Photoinjector gun system: $440,000
- Photocathode drive laser system: $481,000
- 100 MeV linear accelerator system: $628,000
- RF power system: $1,244,000
- Installation and commissioning support: $129,000