Detector considerations for DarkLight

Peter Fisher
Riccardo Alarcon, Purinima Balakrishnan, Ray Cowan, Aiden Kelleher

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Primary requirements:

- Reconstruct all final state particles in $e^- + p \rightarrow e^- + p + e^+ + e^-$
- Measure invariant mass of e^+e^- pair with better than 1 MeV resolution.
- Operate in 1 MW electron beam
- Acquire 1/ab per month

Detector layout

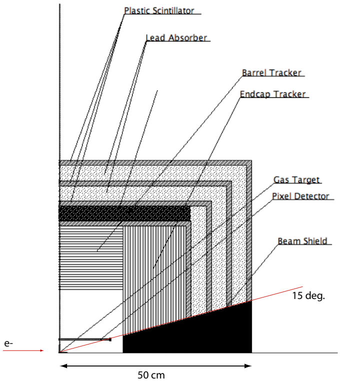


Figure: Detector quadrant.

- Gas target with 10^{19}cm^2 thickness
- Be beampipe
- Pixel detector at 5 cm radius
- 25 layer open cell drift chamber with 100 μm resolution
- Scintillator/lead sandwich trigger
- Toroidal magnet

Toroidal Magnet

- $\int \vec{B}_{\perp} \cdot d\vec{l} = 0.5$ T-m
- Normal copper conductor requires ~ 500 cm^2 of conductor
- Use of LN_2 cooled copper (80 K) reduces requirement to 50 cm ^{2}
- 13% loss of acceptance for single track, geometric acceptance of 66% for three track events

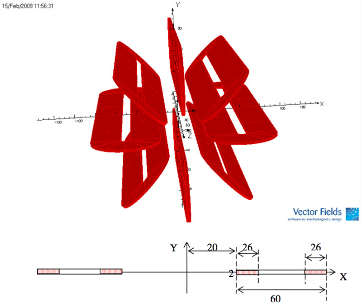
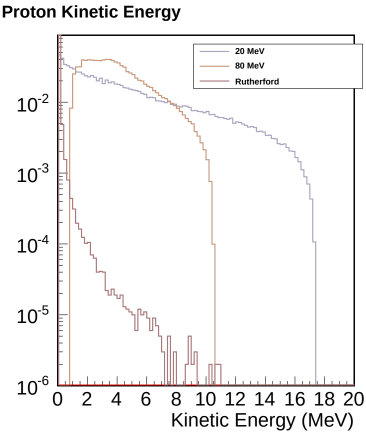


Figure: Eight coil toroidal magnet. Upper panel shows perspective drawing, lower shows cross section.

Proton detector



- Pixel detector 5 cm from target to give space point and energy for recoil proton. Use vertex from leptons to determine proton momentum
- 50 μ pixel size, covers 15^o to 180^o
- dE=140 keV for leptons
- Timing and occupancy will be challenging

Tracking

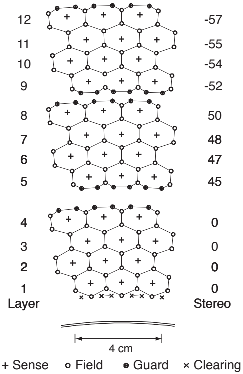
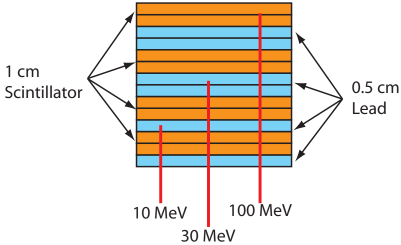


Figure: BaBar drift chamber cell layout. The nominal cell size was 12×16 mm.

- 25 layers, 25-50 cm from target, 15^o to 180^o
- Open cell geometry, 1 cm cell size
- Helium based gas, He:C_4H_{10}, 80:20, $X_o = 800$m
- For $\sigma \sim 100\mu$ and $\int \vec{B}_\perp \cdot d\vec{l} = 0.5$ T-m, can tolerate 0.01 X_o before MS dominates position resolution

Trigger scintillator



- Provide first level trigger based on three leptons, does not aim to measure energy
- $dE/dx = 12$ MeV/cm at 10 MeV
  $dE/dx = 16$ MeV/cm at 100 MeV
- PMT timing of 100 ps given few cm position, timing
- Covers entire solid angle

Design requirements

- Tracker thickness 1% of X_o
- Bending power $\int \vec{B}_\perp \cdot d\vec{l} = 0.5$ T-m

These give

- Angular resolution $\sigma_\theta = 130\mathrm{mrad}/(p/10\mathrm{MeV})$
- Momentum resolution $\sigma_p = 0.01p/(100\mathrm{MeV})$

Mass resoluion

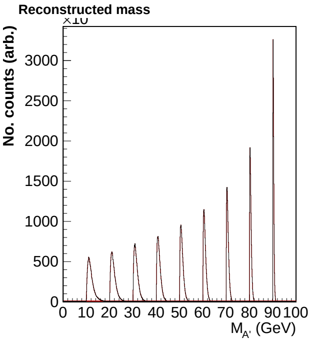


Figure: Sampled invariant mass distribution for $m_{A'}$=10-90 MeV.

- $m_{A'} = \sqrt{E_1 E_2 (1 - \cos\theta)}$
- Sample from momentum and angular resolution functions
- Determine RMS of the invariant mass distribution

Mass resolution

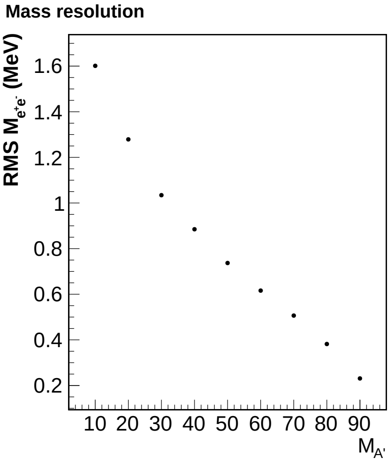
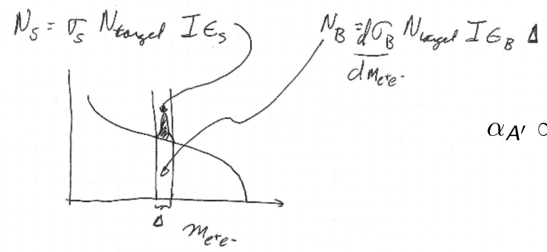


Figure: RMS as a function of $m_{A'}$.

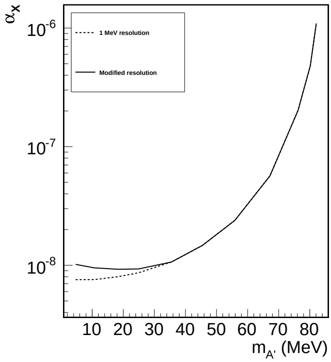
Sensitivity to $\alpha_{A'}$



$$\sigma_s \propto \alpha_{A'}$$

$$\alpha_{A'} \propto \sqrt{\frac{\Delta}{NI(\epsilon_s^2/\epsilon_B)}}$$

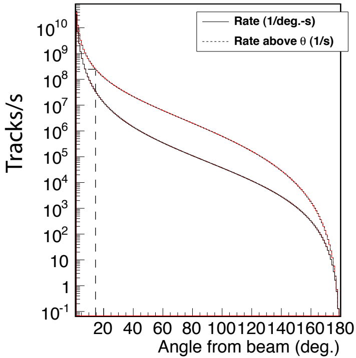
Sensitivity



Below $m_{A'}$, the resolution is above 1 MeV and we can use the $\alpha_{A'} \propto \sqrt{\Delta}$ scaling to estimate the change in sensitivity.

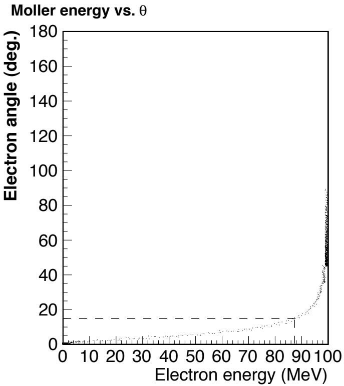
Assumes $\epsilon_S = \epsilon_B$. May be able to do better; see Thaler et al. for discussion of matrix element method.

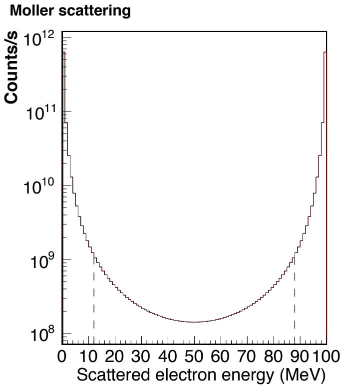
Rutherford Scattering



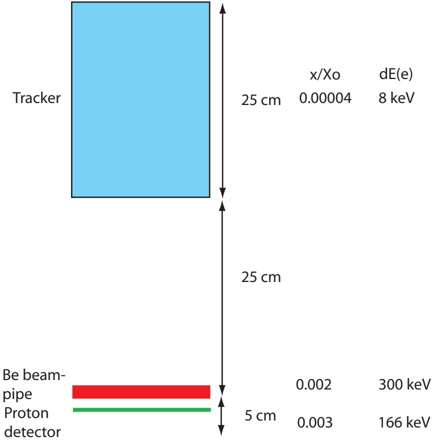
Rutherford rate for singles above nominal 15^o is about 250 MHz at nominal luminosity.

Moller Scattering





Radiation Length



Summary

A first assessment of the DarkLight detector does not show any show stoppers. There are significant challenges

- The scattered electron singles rates exceed 1 GHz. A multiple level trigger will be required.
- Need to be very careful with material to keep below 1% X_o
- Proton detector needs ot be thought through carefully