Using a Liquid Xenon Positron Target

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ABSTRACT

Usage: Secondary publications and information retrieval purposes.

Structure: You may use the `description` environment to structure your abstract; use the optional argument of the `\item` command to give the category of each item.

I. OUTLINE

- Introduction
  - What is the problem that we are trying to solve?
  - What are the issues with "traditional" positron targets?
  - What approaches have been tried already?
  - How many positrons-per-second are needed for Linear Collider applications?
  - Introduction is basically a literature survey/review.
- Comparing Positron production in Xenon vs W or Ta
  - This is where the GEANT simulations go.
  - How thick/dense does Xenon need to be to match positron production in W or Ta?
- Cryo-cooled Xenon gas jets
  - Does this exist?
  - Describe work with liquid Xenon and work with cryo-cooled gas jets at SLAC.
  - Vacuum challenges?
- Conclusion
  - Describe next steps. How would we actually build/implement this?

II. INTRODUCTION

A common scheme for producing positrons is by colliding high energy electrons into a high-Z target. The collision between an electron beam and a solid target generates an electromagnetic particle shower, in which positrons are produced. Because the collision is such high energy, a great deal of energy is deposited in the target in the form of thermal energy. As a result, solid targets tend to degrade over time []. Since positron yield increases as a function of radiation length [], a thicker the target implies a greater positron yield, but that also implies a greater energy will deposited into the target, leading to a quicker degredation of the target.

There are various methods for increasing the life span of solid targets, such as using a cooling system [] and rotating the target so that the beam doesn't hit the same spot of the target every pulse [].

Previous experiments have been carried out to explore alternatives to using solid targets, such as using liquid Mercury (Hg), but the apparent hazards that Hg presents are too dangerous to implement in any efficient manner. Other approaches include...

For typical Linear Collider applications, around *** e^+ per second need to be produced [].

In this paper, we explore the possibility of using a liquid Xenon (Xe) target to produce positrons.

III. SIMULATION RESULTS

A. Comparing Liquid Xe and Ta Targets

Comparison study between Tantalum (Ta) and liquid Xe because we have a reference study on Ta []. We used GEANT4 to simulate the collision between 10 GeV e^- and a target. We compare the results of using a Ta target and a liquid Xe target.

See Table I for parameters used in the simulation.

Material	Z	Density [$g \cdot cm^{-3}$]	Radiation Length [cm]
Tantalum (Ta)	73	16.654	0.4094
Liquid Xe (Xe)	54	2.953	2.872

TABLE I: Parameters used in GEANT4 simulation when comparing targets.

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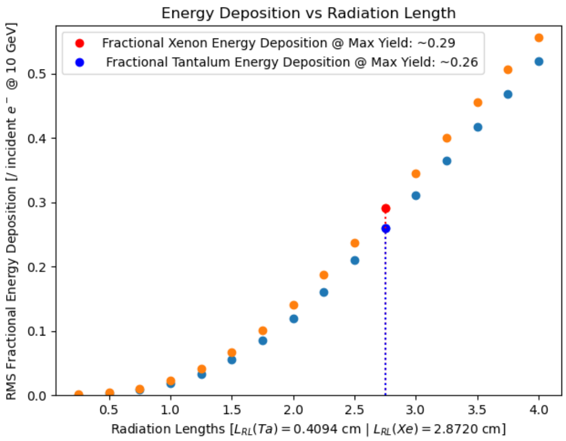
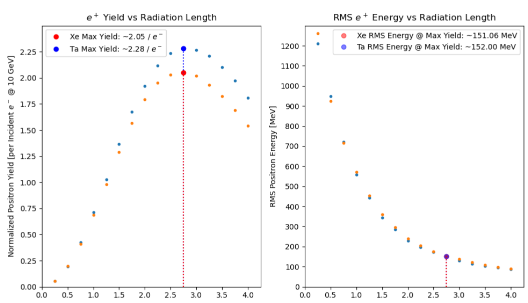
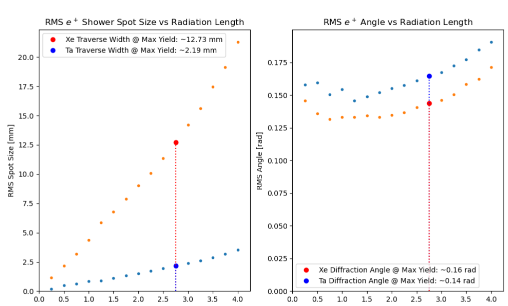


FIG. 1: Energy deposition in Ta and liquid Xe targets per incident electron at 10 GeV.

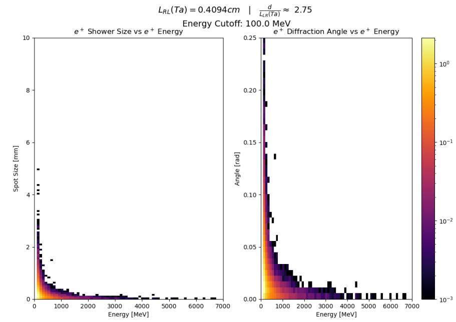


(a) Positron yield per incident electron at 10 GeV.

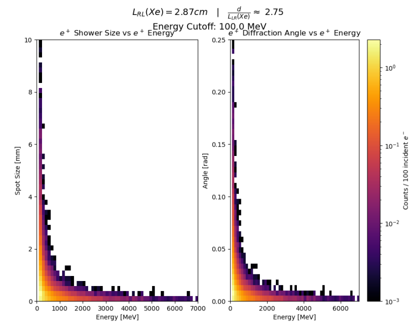


(b) Positron spot size and diffraction angle at the exit of the target.

FIG. 2



(a) Tantalum target.



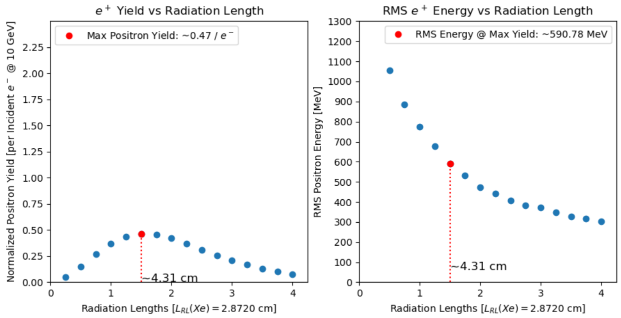
(b) Liquid Xenon target.

FIG. 3: Traverse width and angular diffraction of positrons as a function of their energy upon production. Data is shown for widths of 2.75 radiation lengths (max e^+ yield).

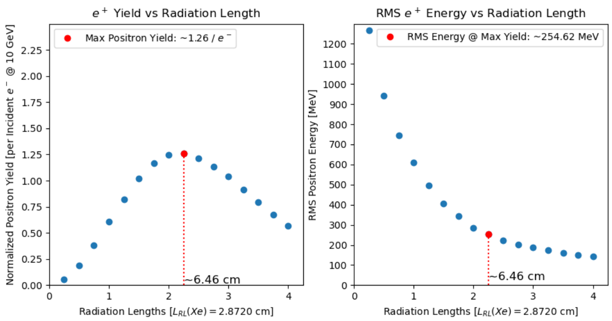
As seen in Figure 2a, the max positron yield for both Ta and liquid Xe occurs at around 2.75 radiation lengths.

B. Setting a Cutoff Energy and Traverse Width

Although the max yield for liquid Xenon is on par with that of the Tantalum target, according to Figures 2b and 3, the physical spread of positrons produced from the liquid Xenon target is much larger than that of the Tantalum target. As a result, only a small fraction of the positrons that exit the target will have the correct parameters to make it down the rest of the accelerator. In order to accurately assess the plausibility of using a liquid Xenon positron target, we set cutoffs for the traverse width of positrons created during the collision.

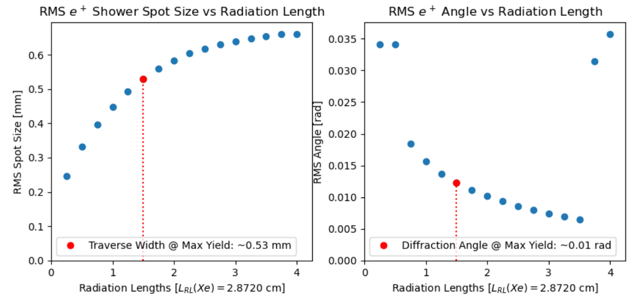


(a) 1 mm cutoff

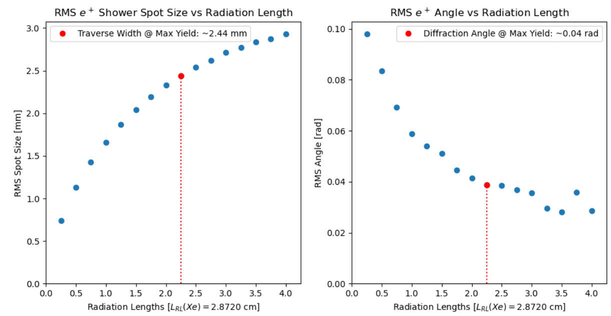


(b) 5 mm cutoff

FIG. 4: Positron yield and energy using a liquid Xenon target with a 1 mm cutoff and 5 mm traverse width cutoff.



(a) 1 mm cutoff



(b) 5 mm cutoff

FIG. 5: Positron spot size and angular diffraction using a liquid Xenon target with a 1 mm cutoff and 5 mm traverse width cutoff.

IV. CRYO-COOLED XENON GAS JETS/LIQUID XENON

Below is a basic schematic of how the liquid Xenon chamber will interact with the beam.

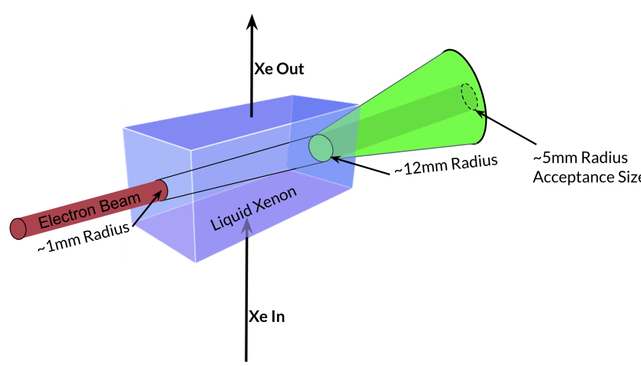


FIG. 6: Schematic of liquid Xenon setup

A. Calculating the Liquid Xenon Flow Rate

To calculate the flow rate of the liquid Xenon, we first calculate preliminary values using the information given in the table below.

Quantity	Symbol	Value	Units
Molar Mass	M	131.293	u
Heat of Vaporization	ΔH	12.636	kJ·mol^{-1}
Radiation Length	$\mathrm{L_{RL}}$	2.872	cm
Target Width	$\frac{\mathrm{d}}{\mathrm{L_{RL}}}$	2.25	$\mathrm{L_{RL}}$
Energy Deposition per e$^-$	$\mathrm{E_{dep}}$	.66581	GeV
Beam Rep Rate	f	10.0	Hz
Beam Charge	q	2.0	nC
Target Density	ρ	2.953	g · cm^{-3}
Calculated Quantities			
Number of e$^-$	n	1.248×10^{10}	
Energy Deposit per Bunch	ε	1.33162	J
Heat of Vap. per Volume	$\Delta\mathrm{H_{vol}}$	284.205	J·cm^{-3}
Flow Rate	Q	4.685×10^{-2}	cm^3 · s^{-1}

TABLE II: Important parameters associated with liquid Xenon target.

We first convert the heat of vaporization to units of Joules per unit volume (J·cm^{-3}), which is given by Eq. (1a). We then calculate the number of electrons per beam bunch (SLAC), by comparing the total charge of the beam bunch to the charge of an electron ($e \approx 1.602 \times 10^{-10}$ nC), as follows from Eq. (1b). From this, we calculate the total energy deposited in the liquid Xenon target, as seen in Eq. (1c).

$$\Delta\mathrm{H_{vol}} = \frac{\Delta\mathrm{H} \cdot \rho}{\mathrm{M}}, \tag{1a}$$

$$n = \frac{q}{e}, \tag{1b}$$

$$\varepsilon = n \cdot E_{\mathrm{dep}}. \tag{1c}$$

Now we have everything we need in order to calculate the flow rate of liquid Xenon required to replace the vaporized Xenon due to the energy deposited by the beam,

$$Q = \frac{\varepsilon \cdot f}{\Delta\mathrm{H_{vol}}}. \tag{2}$$

B. Using Beryllium Windows to the Target Chamber

We explore using Beryllium windows for the beam to enter the target chamber. Below is a table of useful information about Beryllium.

Table??

We can calculate the max yield and strain of Beryllium windows based on a piece of Beryllium that is ***Dimensions??***

Equations??

V. CONCLUSION

A. Design of Liquid Xenon Chamber

Here we explore how one could design a chamber for the liquid Xenon target.

Source code and sample data for GEANT4 simulations can be found at `https://github.com/MaxVarverakis/LiquidXenonSims.git`.

ACKNOWLEDGMENTS

We wish to acknowledge the support of the author community in using REVTEX, offering suggestions and encouragement, testing new versions, ...

Appendix A: Appendixes

To start the appendixes, use the `\appendix` command. This signals that all following section commands refer to appendixes instead of regular sections. Therefore, the `\appendix` command should be used only once—to setup the section commands to act as appendixes. Thereafter normal section commands are used. The heading for a section can be left empty. For example,

```
\appendix
\section{}
```

will produce an appendix heading that says "APPENDIX A" and

```
\appendix
\section{Background}
```

will produce an appendix heading that says "APPENDIX A: BACKGROUND" (note that the colon is set automatically).

If there is only one appendix, then the letter "A" should not appear. This is suppressed by using the star version of the appendix command (`\appendix*` in the place of `\appendix`).

Appendix B: A little more on appendixes

Observe that this appendix was started by using

```
\section{A little more on appendixes}
```

Note the equation number in an appendix:

$$E = mc^2. \tag{B1}$$

1. A subsection in an appendix

You can use a subsection or subsubsection in an appendix. Note the numbering: we are now in Appendix B 1.

Note the equation numbers in this appendix, produced with the subequations environment:

$$E = mc, \tag{B2a}$$
$$E = mc^2, \tag{B2b}$$
$$E \gtrsim mc^3. \tag{B2c}$$

They turn out to be Eqs. (B2a), (B2b), and (B2c).