Initial Studies into the Design of an Axion Cannon

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Friday, August 3, 2007

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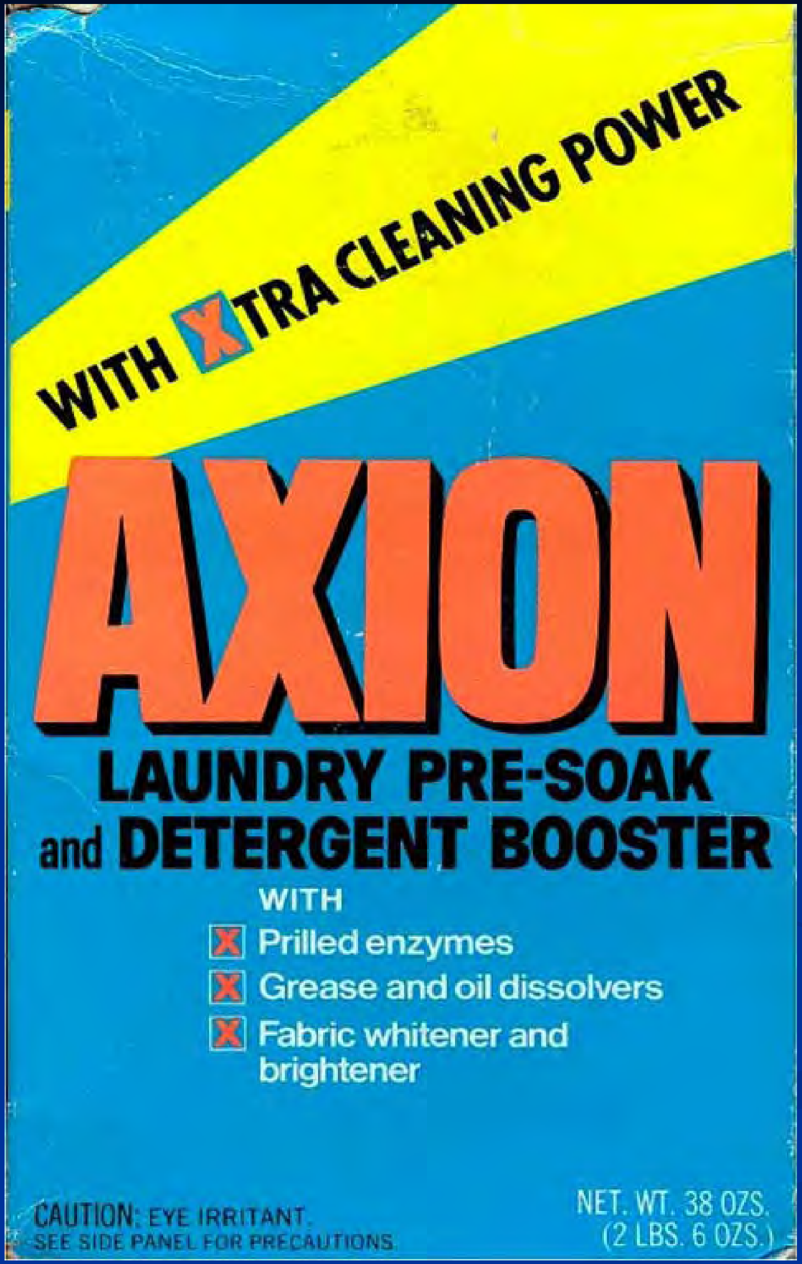
History of Axions

- Strong CP Problem in QCD
  - The small amount of CP violation in QCD is very arbitrary
- Solution: Peccei-Quinn Symmetry
  - The breaking of Peccei-Quinn Symmetry allows for the little CP violation observed
- It also predicts the existence of the axion



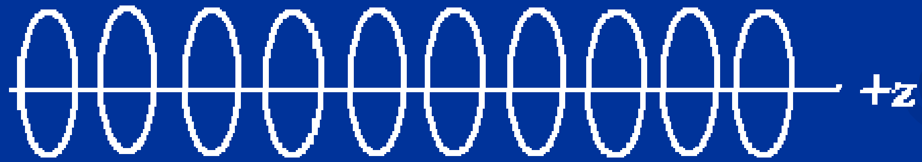
http://particle.physics.ucdavis.edu/Graphics/rotate/images.php

Properties of the Axion

- Charge = 0
- Mass ~ 10^{-3} eV/c^2
  - Electron mass = .511 MeV/c^2
  - Electron Neutrino mass < 2.2 eV/c^2
- In classical electrodynamics $\mathbf{E}\times\mathbf{B}$ is needed in determining the Poynting vector and direction of propagation of EM waves
- With axions $\mathbf{E}\bullet\mathbf{B}$ is part of calculating axion production

The Axion Cannon

- What situation occurs where **E** and **B** are parallel?
- Sending a relativistic electron bunch through a set of current loops (much like a solenoid)

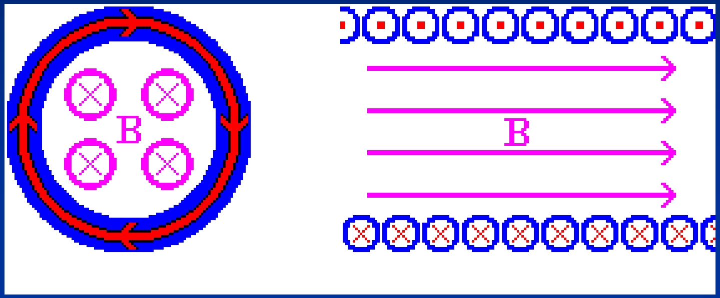


Cartoon of Current Loop Structure

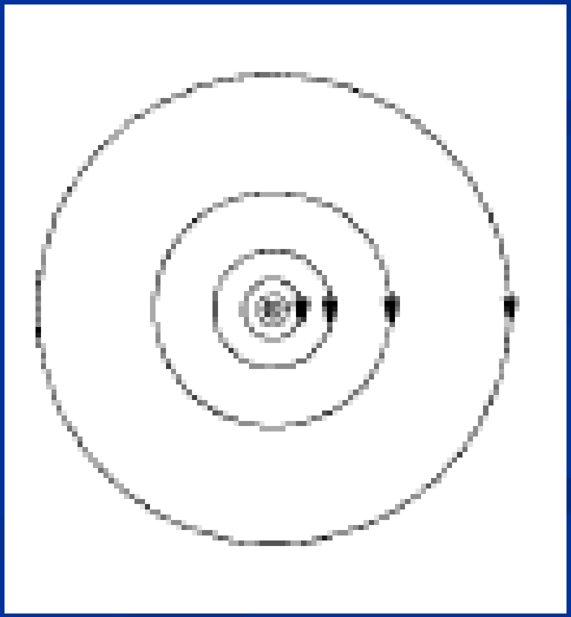
Cartoon of electron bunch

Current Loop Field Diagram

- Magnetic field of a solenoid points along the z-axis
- Electric field point in the phi direction



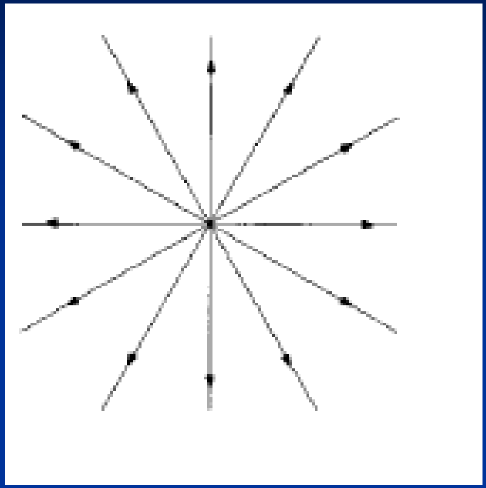
http://www.physics.udel.edu/~watson/phys208/clas0413.html

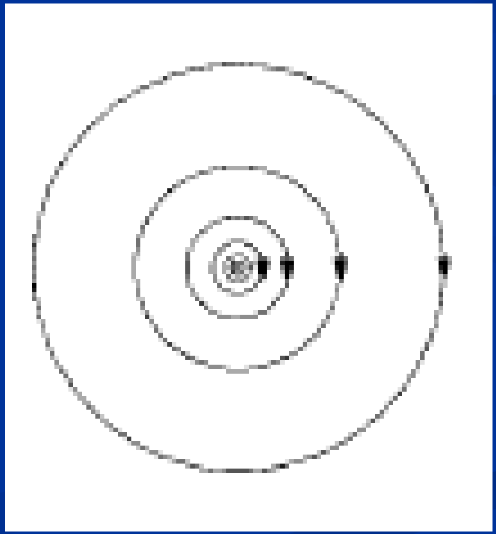


http://scitation.aip.org/journals/doc/AJPIAS-ft/vol_68/iss_2/171_1.html

Electron Bunch Field Diagram

- Electric field of the bunch points inward radially
- Magnetic field point in the phi direction





http://scitation.aip.org/journals/doc/AJPIAS-ft/vol_68/iss_2/171_1.html

Current Loop Specifications

- 1000 loops of infinitely thin, 0 resistance wire were used
- Spacing = 1 mm
- Radius = 5 cm

Electron Bunch Specifications

- A simplified version of the ILC specifications
- Energy = 250 GeV
- Bunch Spacing = 100 m
- Shape: cylinder
  - Bunch Length = 1 mm
  - Bunch Radius = 1 μm
- No. of electrons / bunch = 2×10^{10}

Current Loop Magnetic Field

- The exact solution to the Biot-Savart Law for a current loop is

$$B_0 = \frac{\mu_0 I}{2radius}$$

$$\alpha = r / radius$$

$$\beta = z / radius$$

$$\gamma = z / r$$

$$Q = (1+\alpha)^2 + \beta^2$$

$$k = \sqrt{\frac{4\alpha}{Q}}$$

$$B_z = B_0 \frac{1}{\pi\sqrt{Q}}\left[E(k)\frac{1-\alpha^2-\beta^2}{Q-4\alpha} + K(k)\right]$$

$$B_r = B_0 \frac{\gamma}{\pi\sqrt{Q}}\left[E(k)\frac{1+\alpha^2+\beta^2}{Q-4\alpha} - K(k)\right]$$

K(k) is the complete elliptic integral of the first kind
E(k) is the complete elliptic integral of the second kind

http://www.netdenizen.com/emagnet/offaxis/iloopoffaxis.htm

Current Loop Electric Field

- Electric Field is calculated using Ampère-Maxwell Equation, $\nabla\times\mathbf{B} = \mu_0 \mathbf{J} + \mu_0\varepsilon_0\partial\mathbf{E}/\partial t$
- Solving for **E** yields $\mathbf{E} = \int(c^2\ \nabla\times\mathbf{B}\ -\ \varepsilon_0^{-1}\mathbf{J})dt$

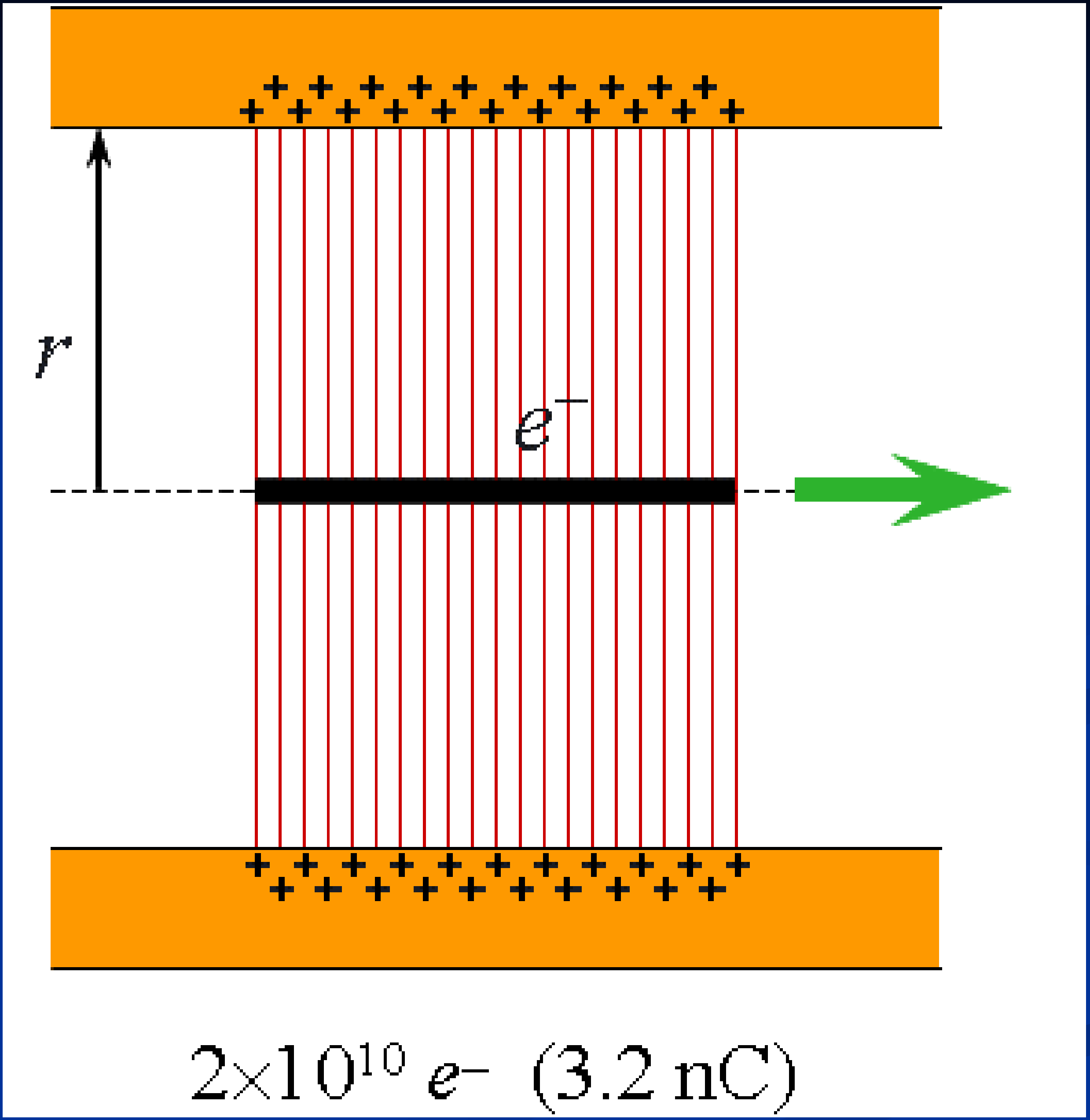
Electron Bunch Field

- In the rest frame, the bunch is ~147 m long
- The bunch can be treated as a infinitely long line of charge from which it is easy to calculate the electric field

$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{r}$$

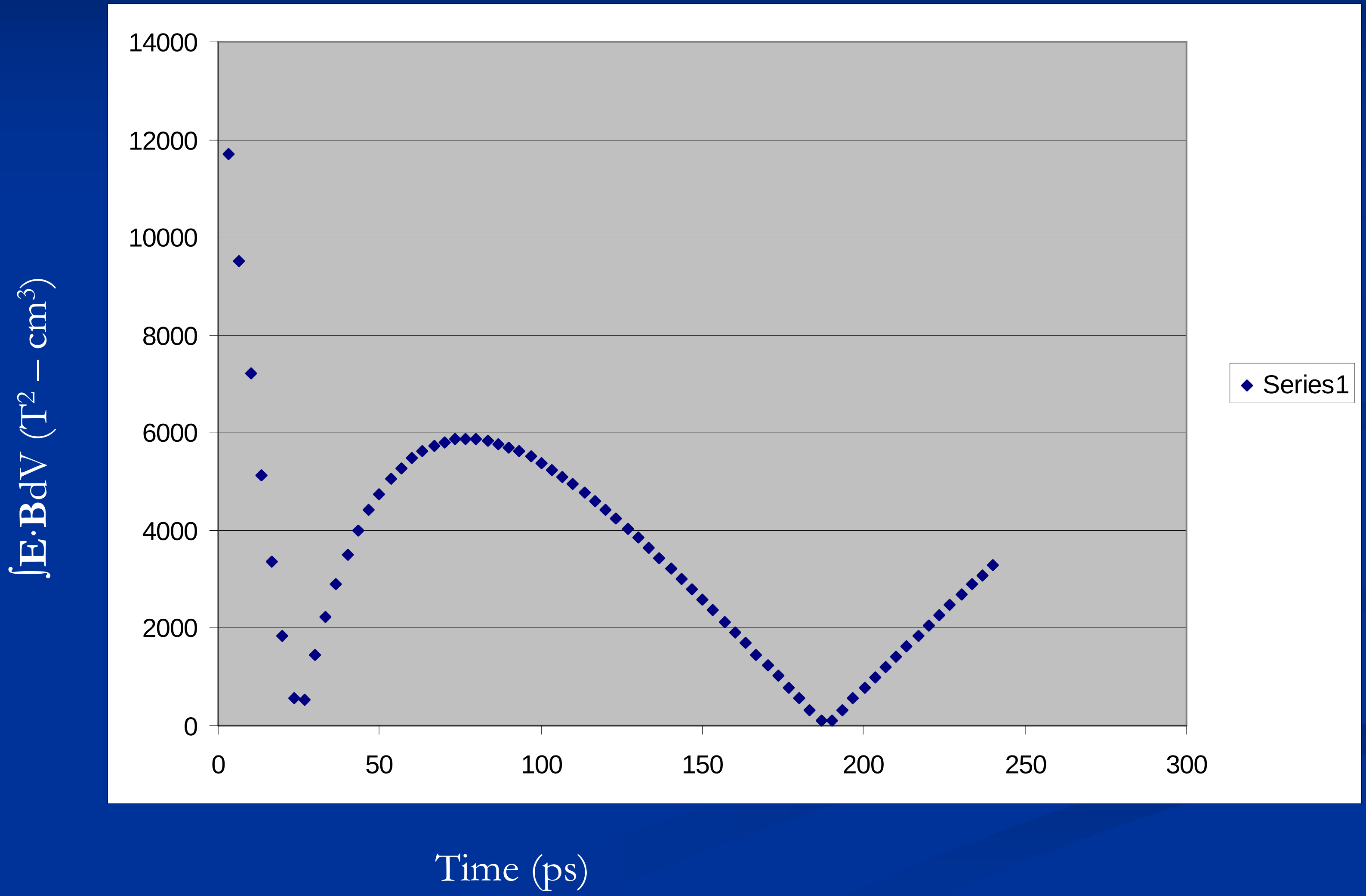
- The field is then increased by a factor of γ for the lab frame
- The magnetic field is simply,

$$\vec{B} = \vec{v} \times \vec{E} / c^2 = \gamma \frac{\mu_0 v \lambda}{2\pi r}\hat{\phi}$$

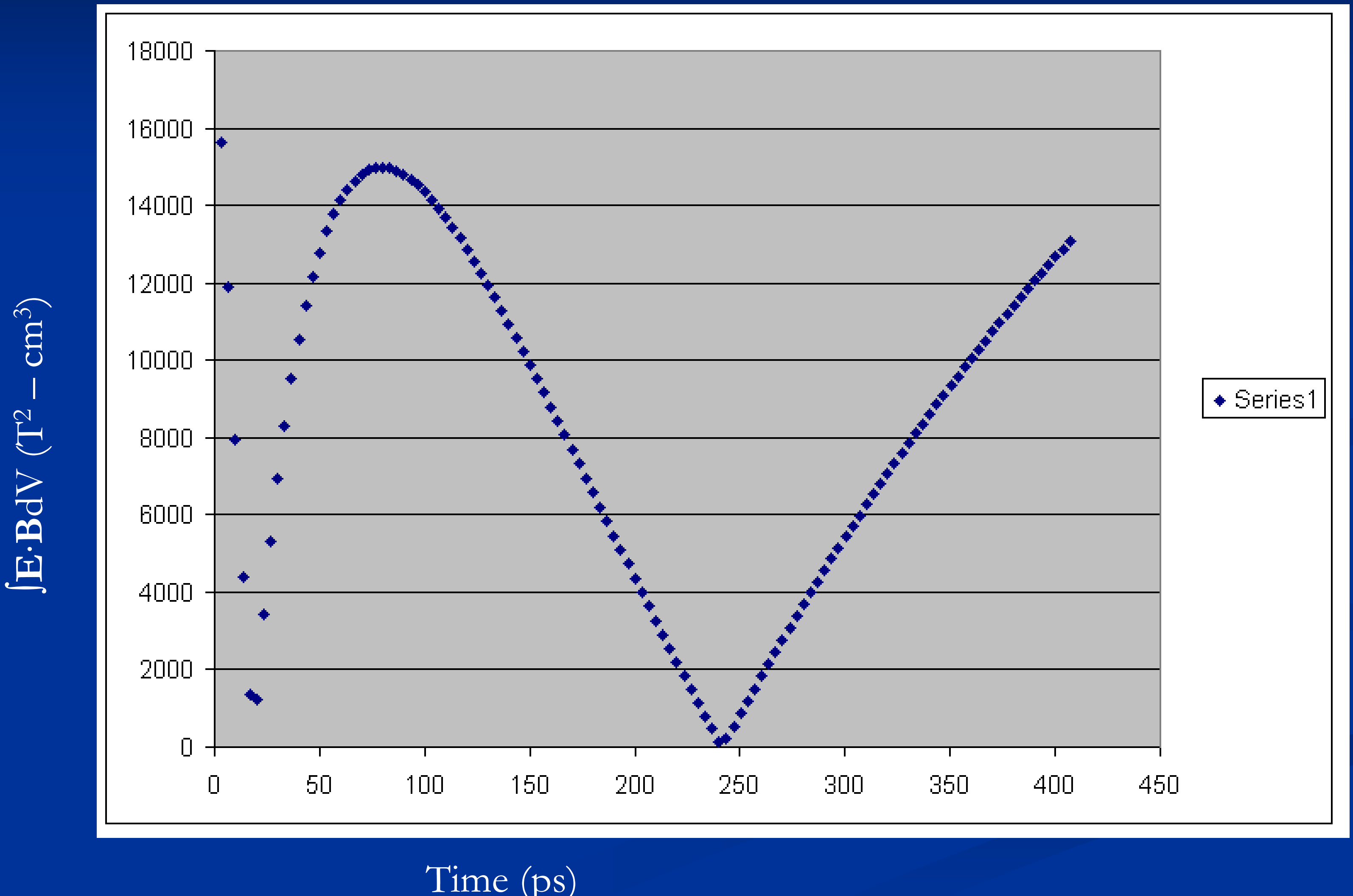


http://www.hep.uiuc.edu/home/g-gollin/talks/2006_05_18_ILC_seminar.ppt

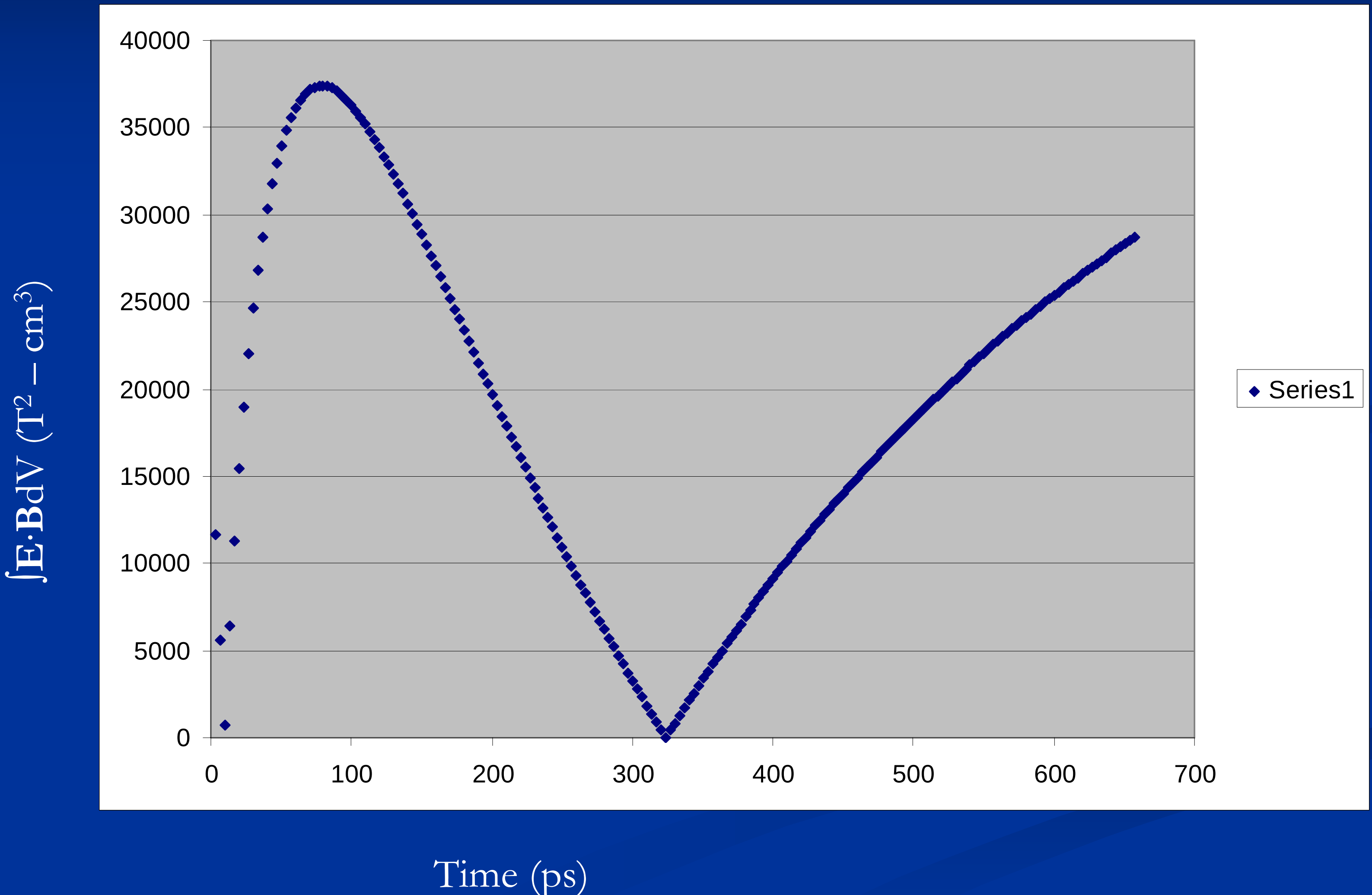
Initial Results – 75 loops



Initial Results – 125 loops



Initial Results – 200 Loops



Special Thanks To…

- George Gollin
- Mike Haney
- Mike Kasten
- Jason Chang
- Perry Chodash
- Michael Davidsaver
- Alex Lang
- Yehan Liu