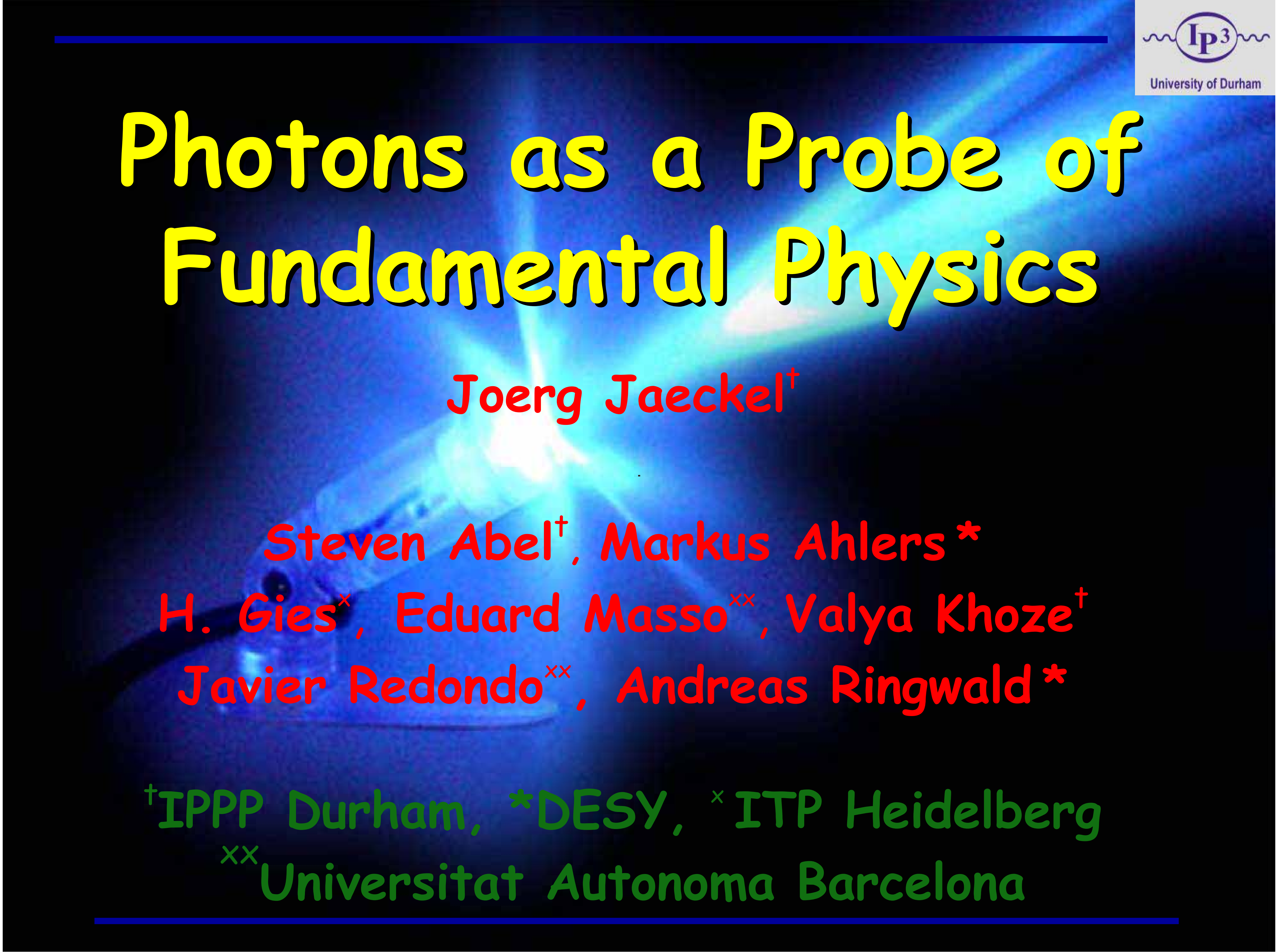
University of Durham



Photons as a Probe of Fundamental Physics

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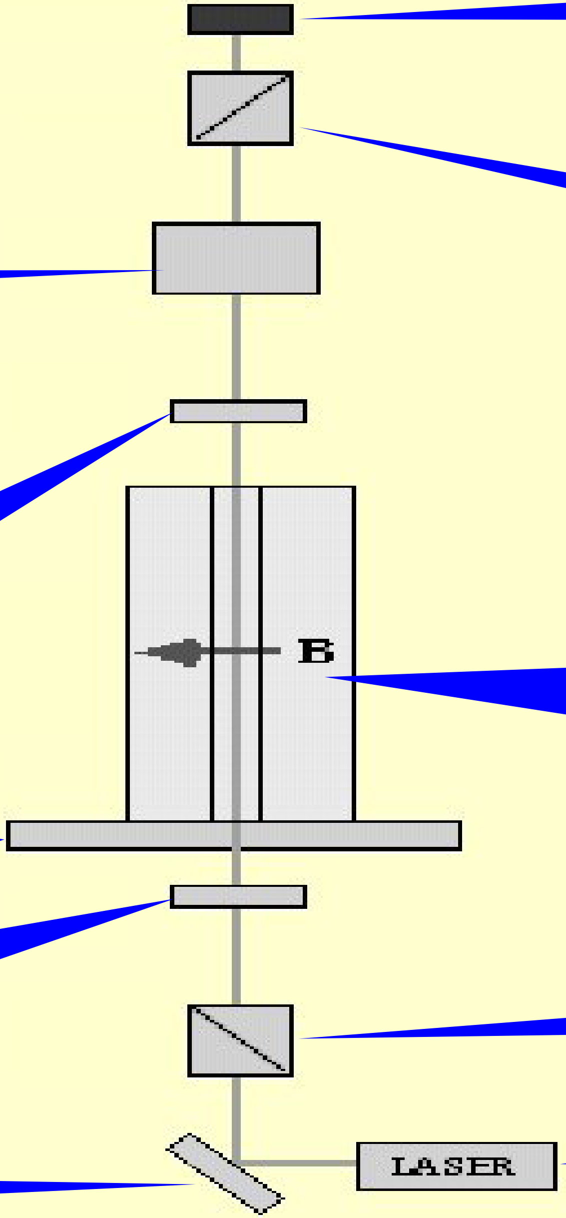
PVLAS:
An unexpected Result

The Experiment



Detector

Analyzer

PEM

Cavity Mirror 1

Magnetic field (rotating)

Turntable

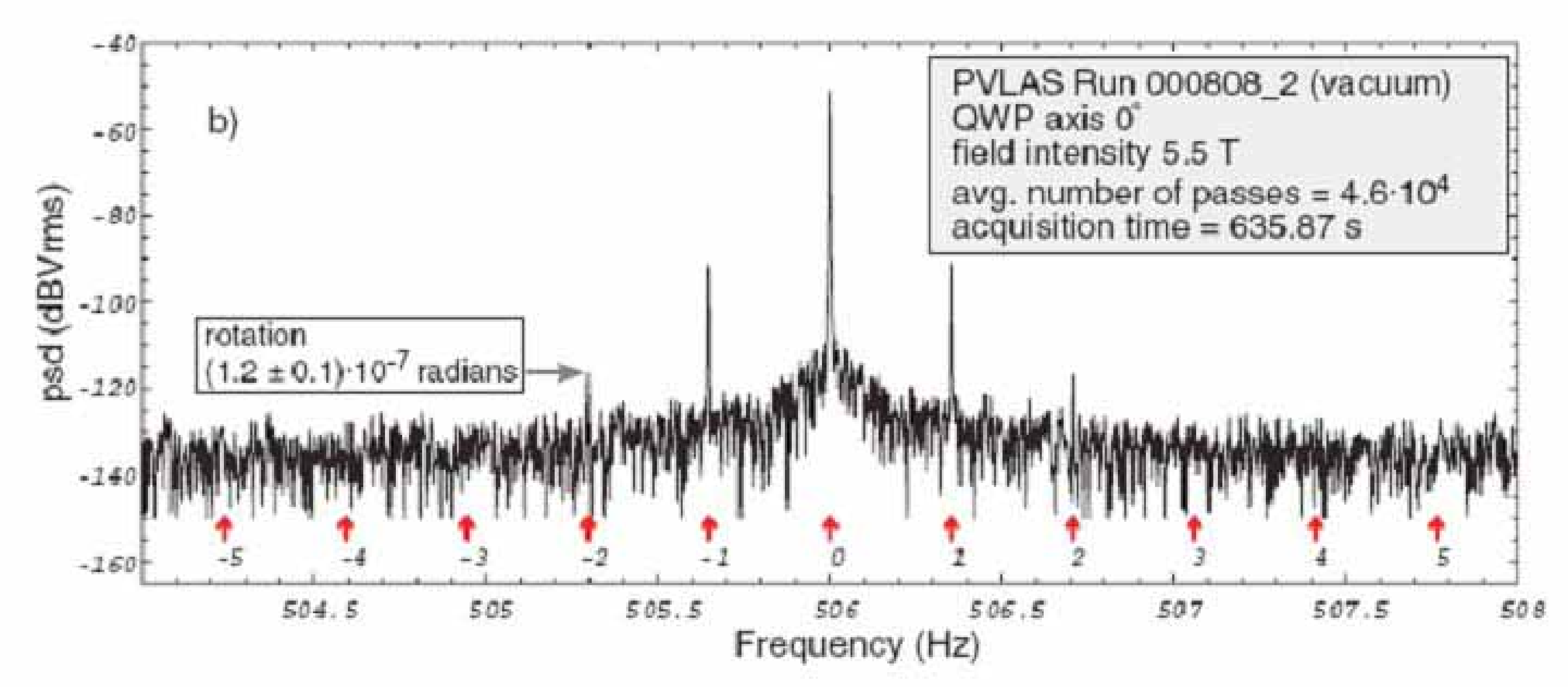
Cavity Mirror 1

Polarizer

Mirror

Laser

Result


PVLAS Run 000808_2 (vacuum)
QWP axis 0°
field intensity 5.5 T
avg. number of passes = $4.6 \cdot 10^4$
acquisition time = 635.87 s

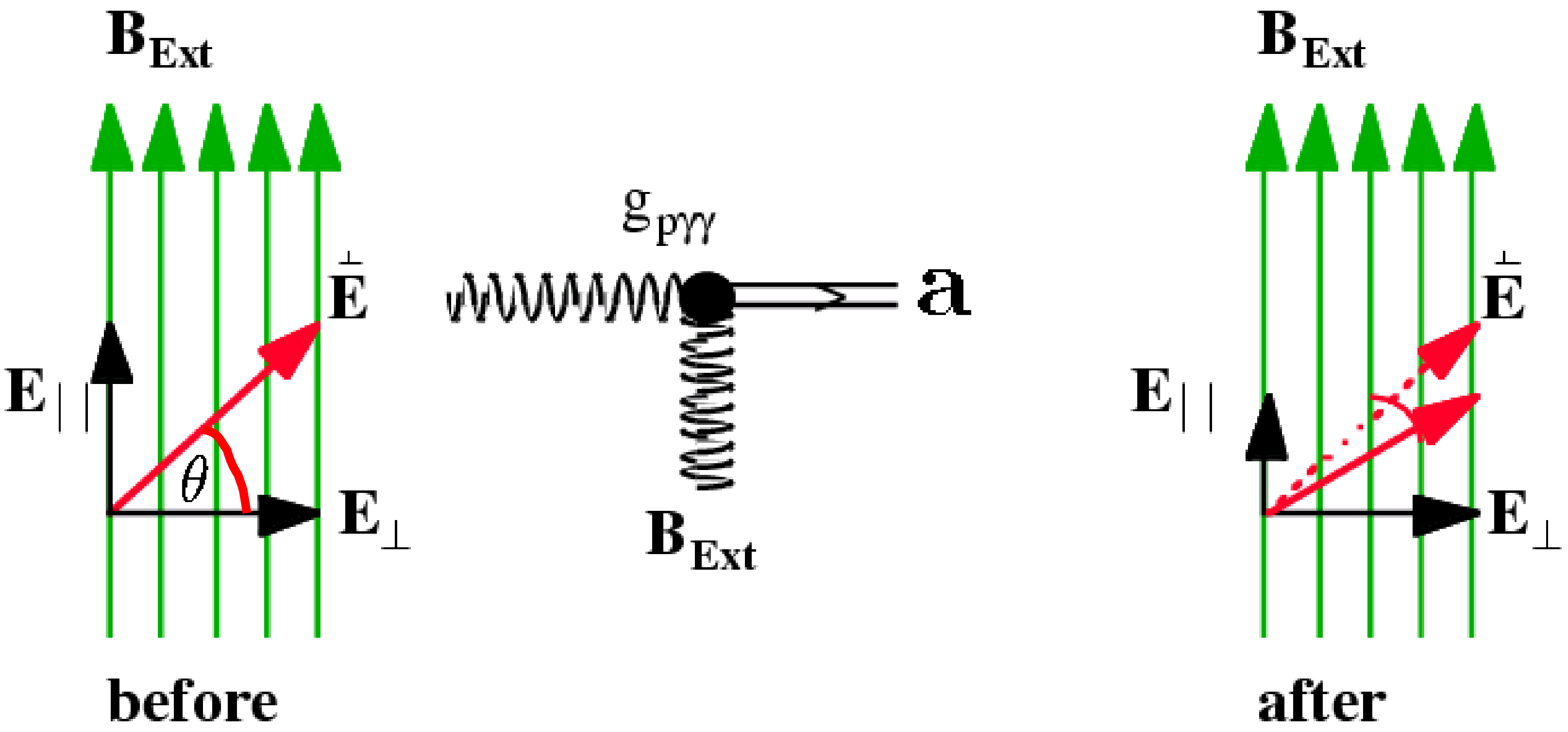
rotation
$(1.2 \pm 0.1) \cdot 10^{-7}$ radians

$$\frac{\text{rotation}}{\text{pass}} = \frac{\epsilon}{N} \sim 10^{-12} rad$$

$$\frac{\text{ellipticity}}{\text{pass}} = \frac{\psi}{N} \sim 10^{-12} rad$$

Dichroism (Rotation)

- Coupling $\mathcal{L} \sim ga\, F^{\mu\nu}\, \tilde{F}_{\mu\nu} \sim ga\vec{E}\cdot\vec{B}$

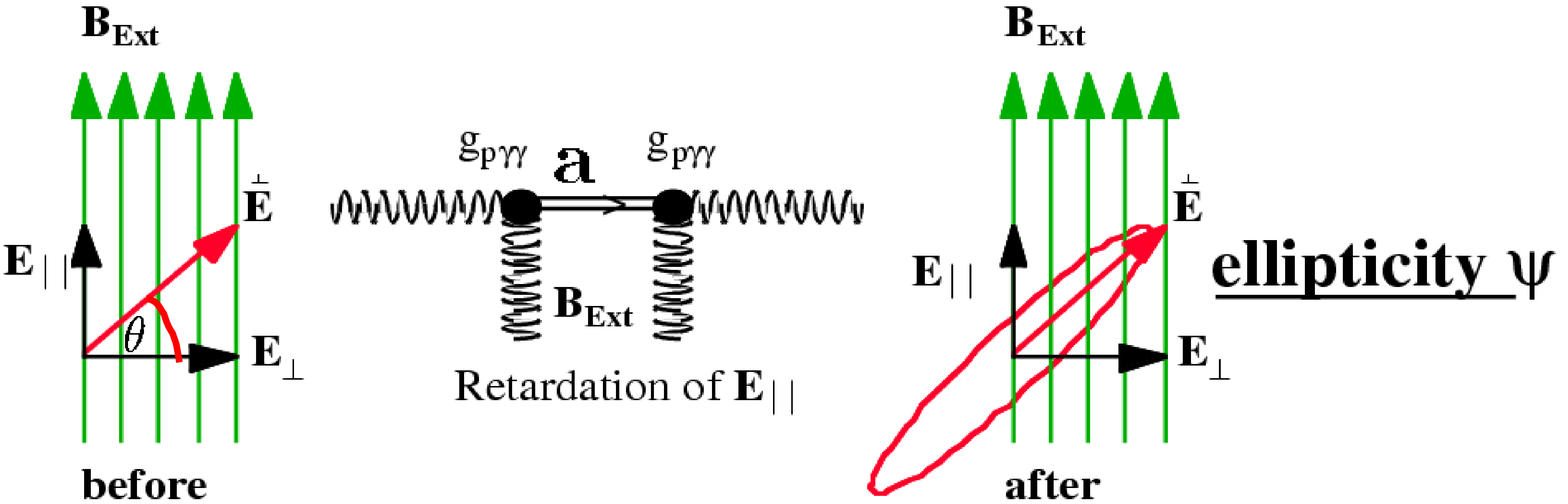


rotation ε

$$\Rightarrow \epsilon \approx -N\left(\frac{gBL}{4}\right)^2 \sin(2\theta)$$

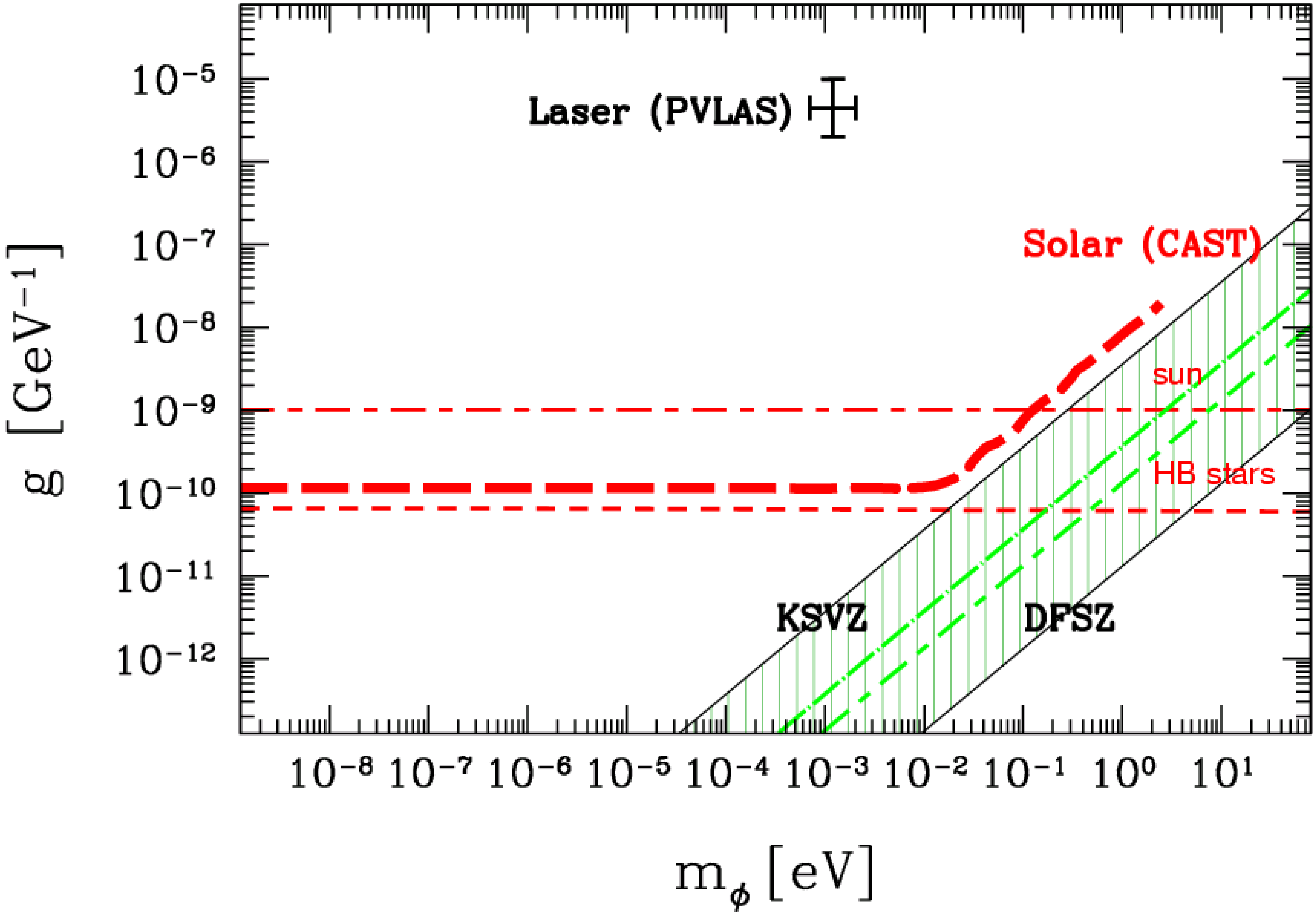
Ellipticity

Virtual ALP production leads to Birefringence



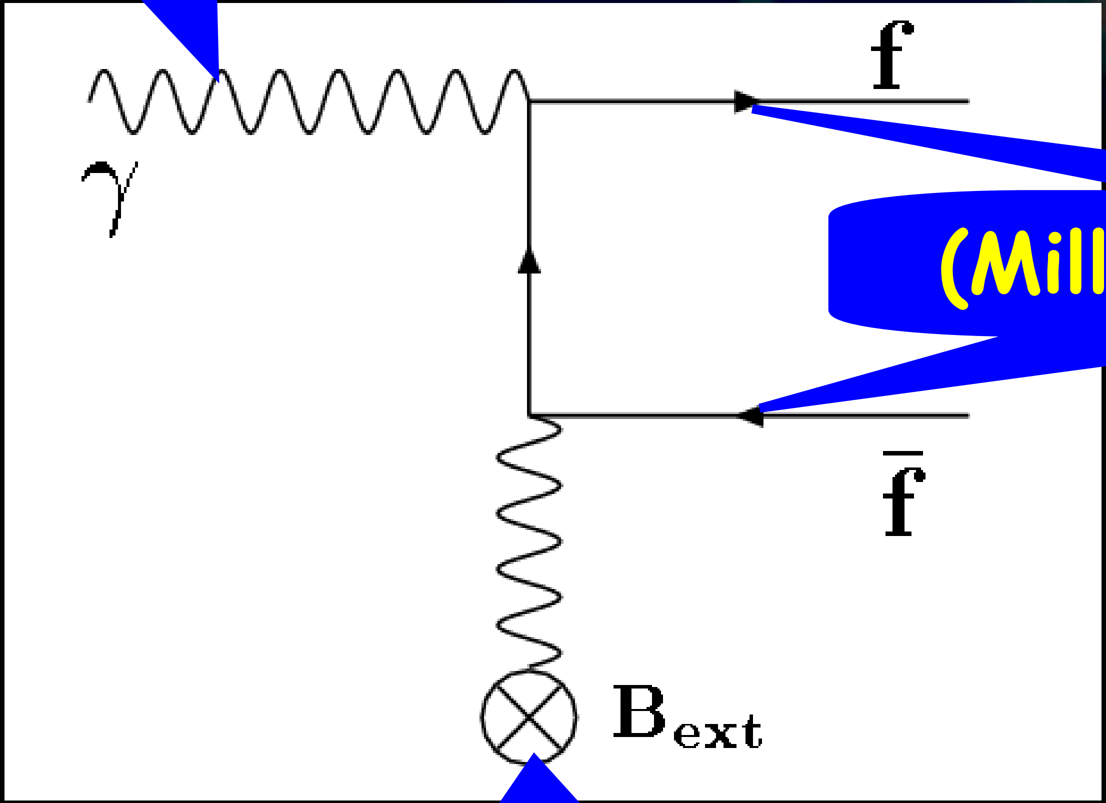
$$\Rightarrow \psi \approx \frac{N}{6}\left(\frac{gBL}{4}\right)^2 \frac{m_a^2 L}{\omega} \sin(2\theta)$$

Problems with the ALP Interpretation



Millicharged Fermions – A possible Explanation

Pairproduction with a Laser



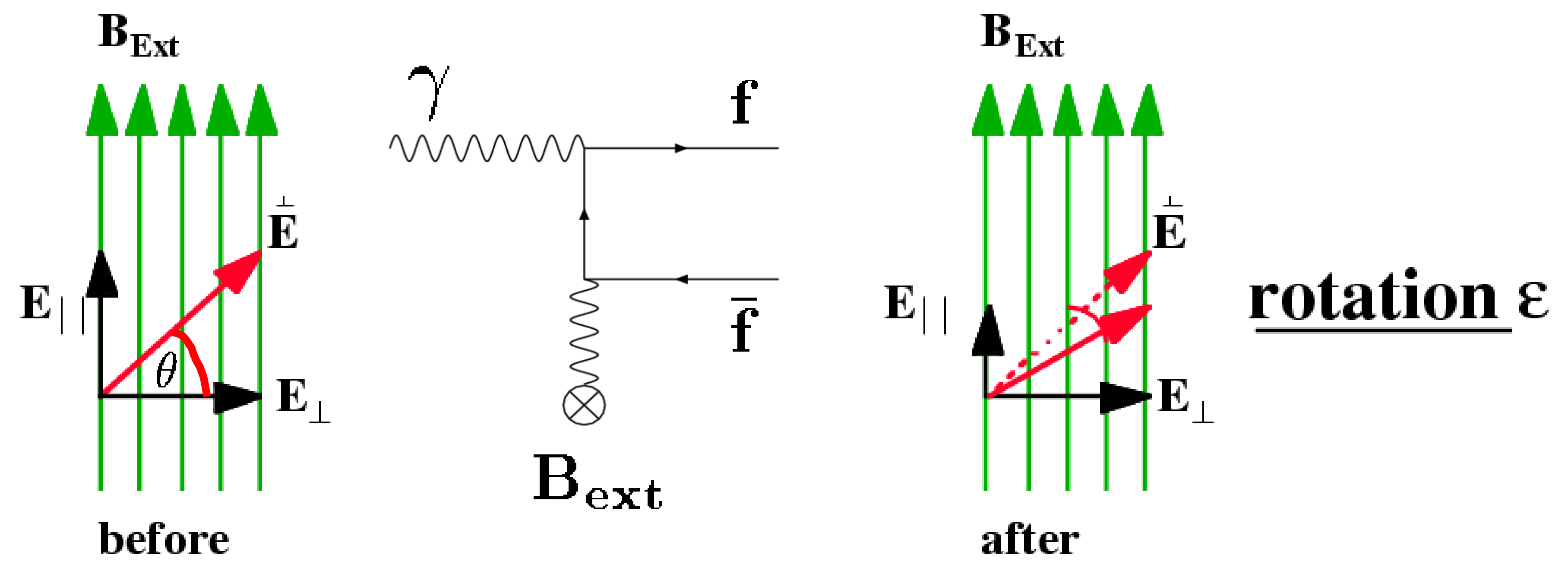
Laserphoton

(Milli-)charged Particles

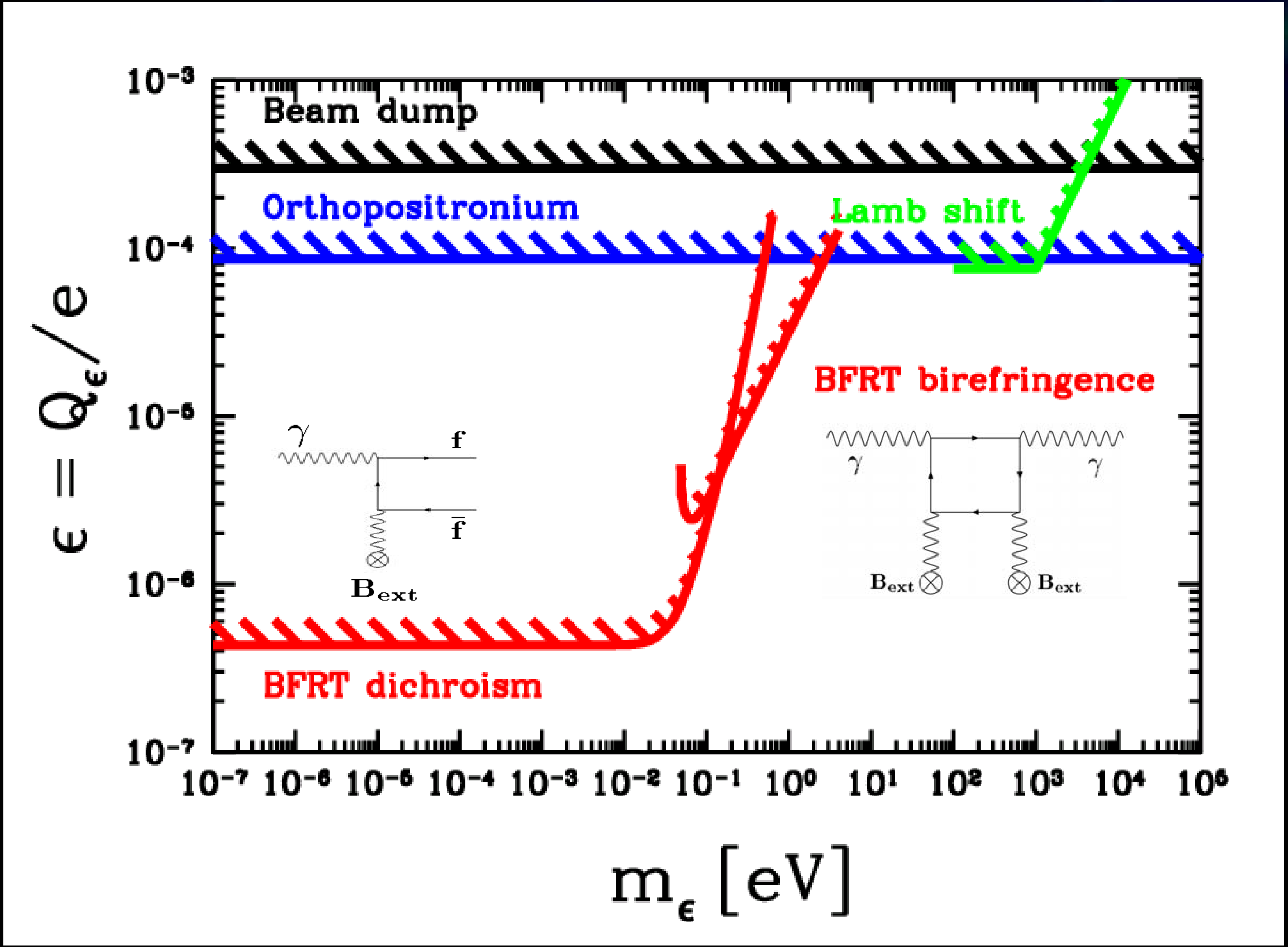
External B-Feld

Dichroism (Rotation)

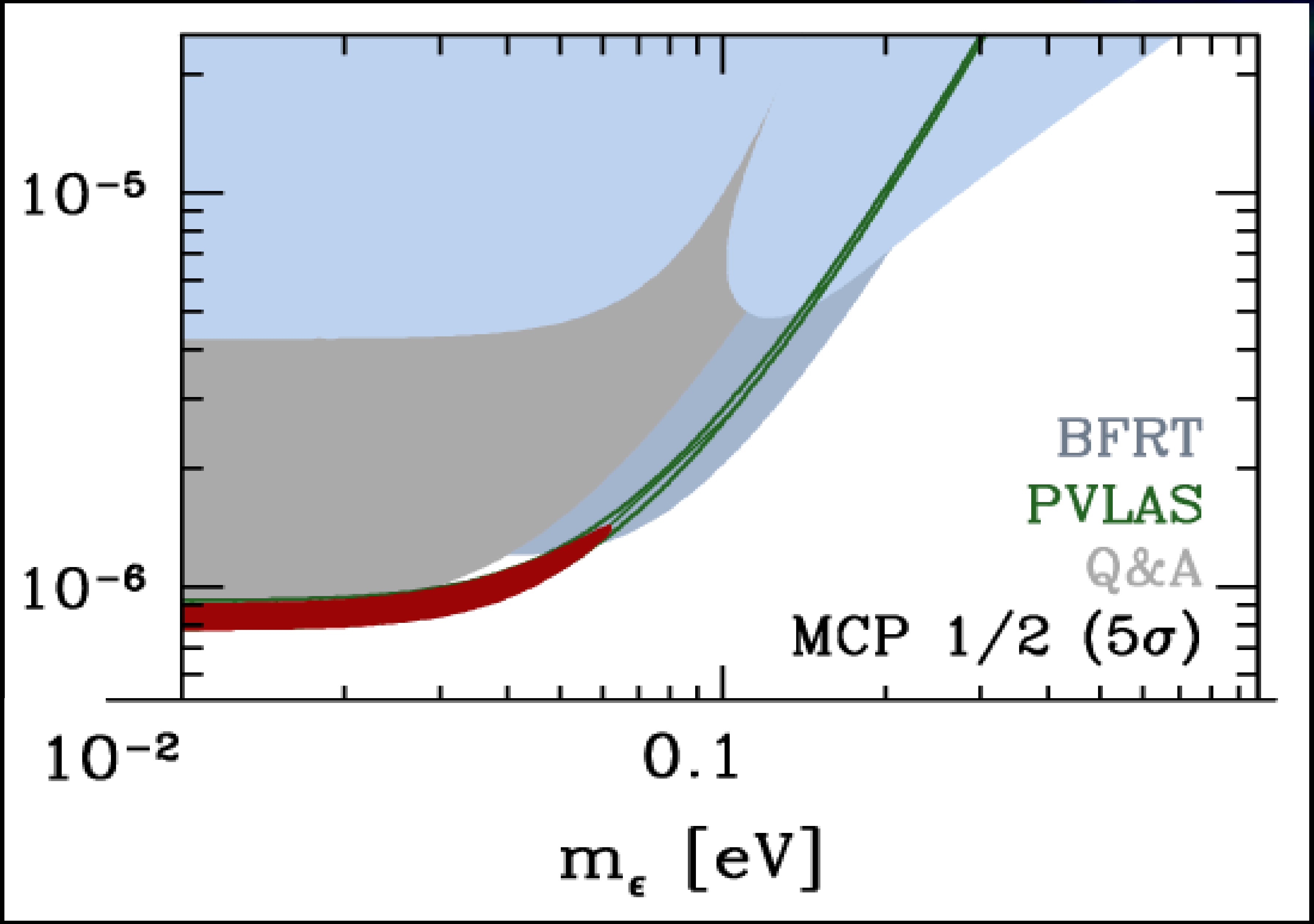
- Pairproduction leads to an „absorption“ of Laser light
- Pairproduction depends on relative orientation of Laser polarization and B-field

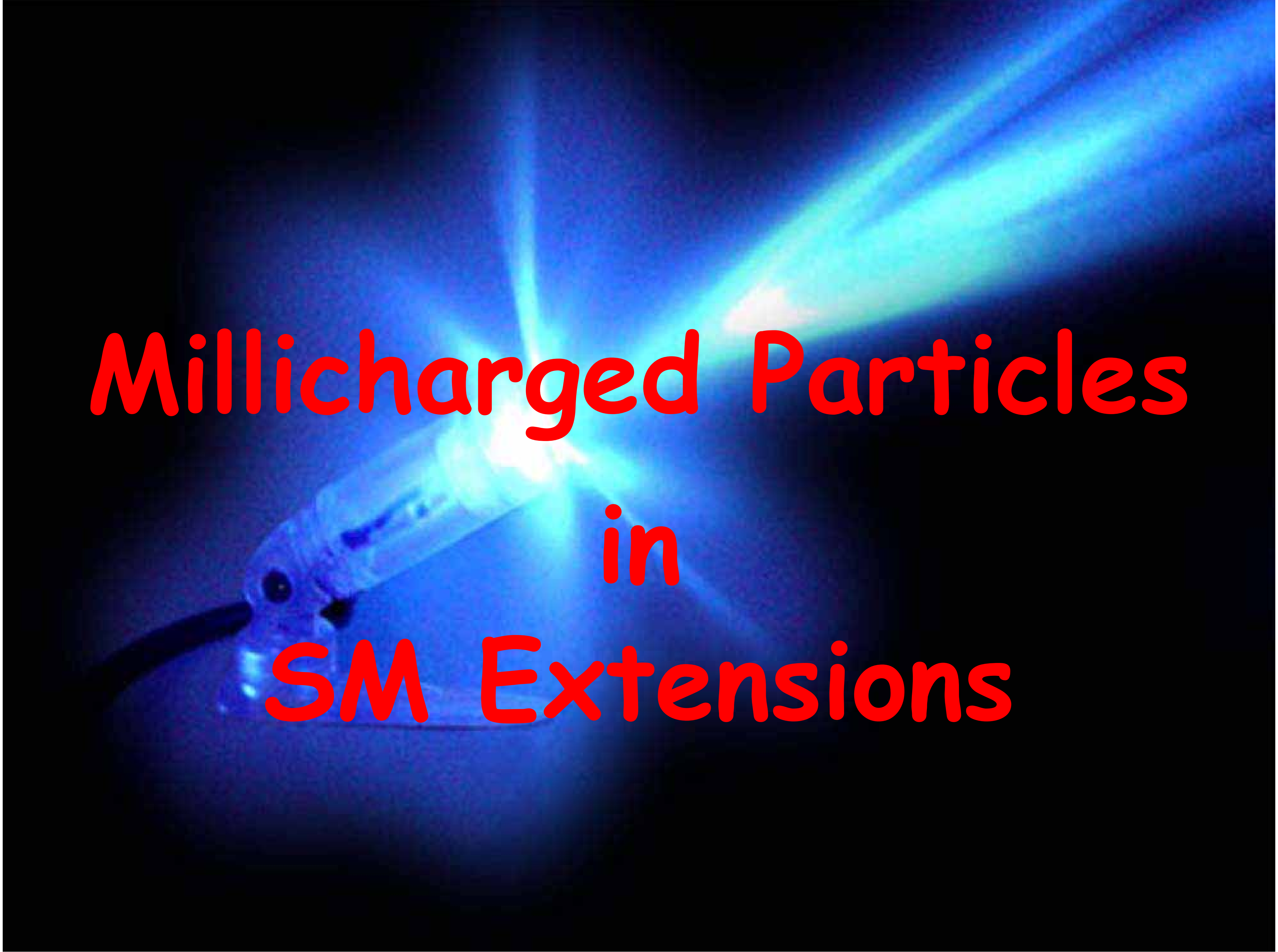


Resulting bounds from BFRT



PVLAS





Millicharged Particles in SM Extensions

Are millicharge particles crazy?

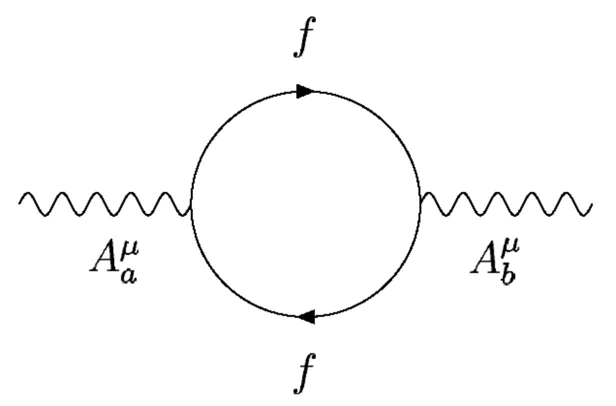
- NO!
- Extensions of Standard Model

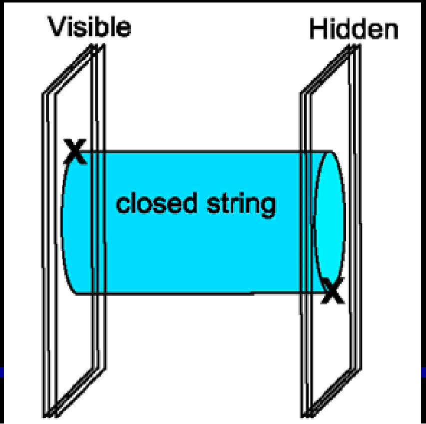
→ Extra U(1)'s

→ **Millicharged particles!**

10^{-6} charge reasonable in such models

+

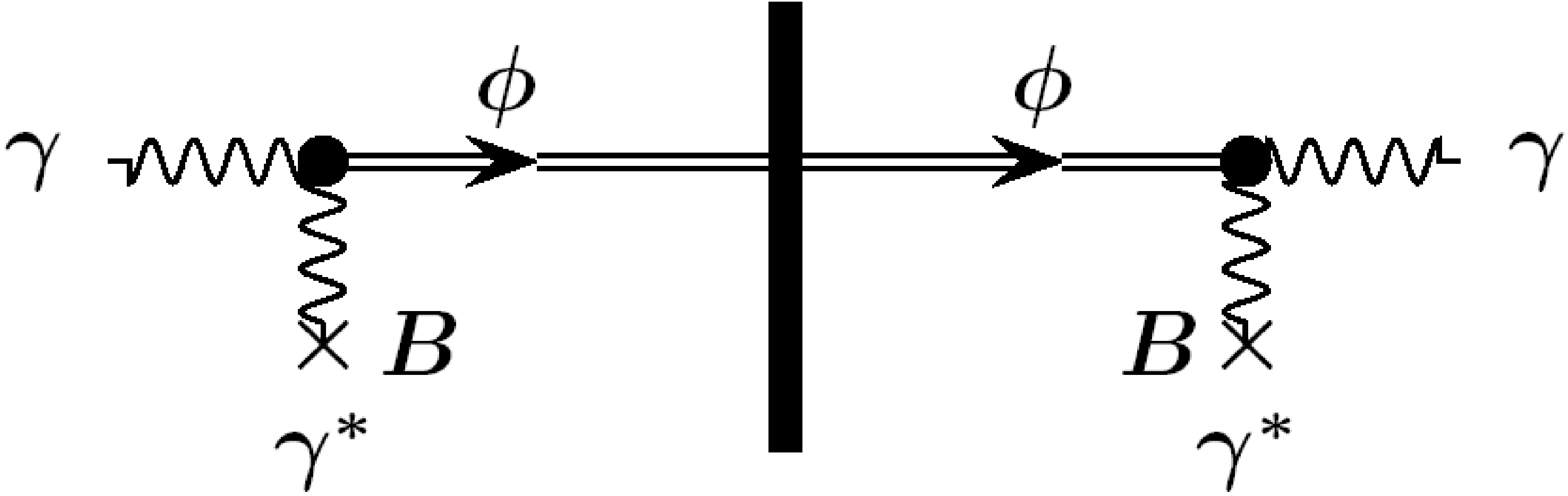




Experimental Tests

Light shining through walls?

“Light shining through a wall”

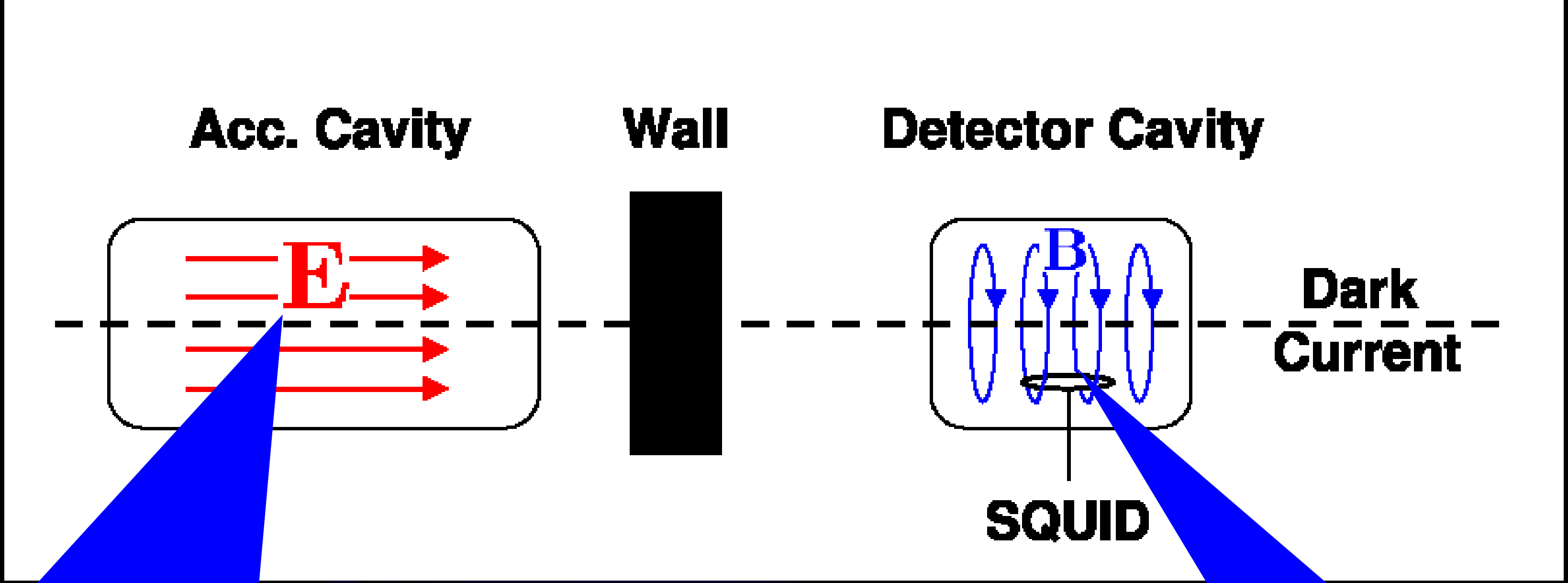


DESY, Jefferson Lab... 2007!!!!

For millicharges particles similar effect possible with and without B-field!

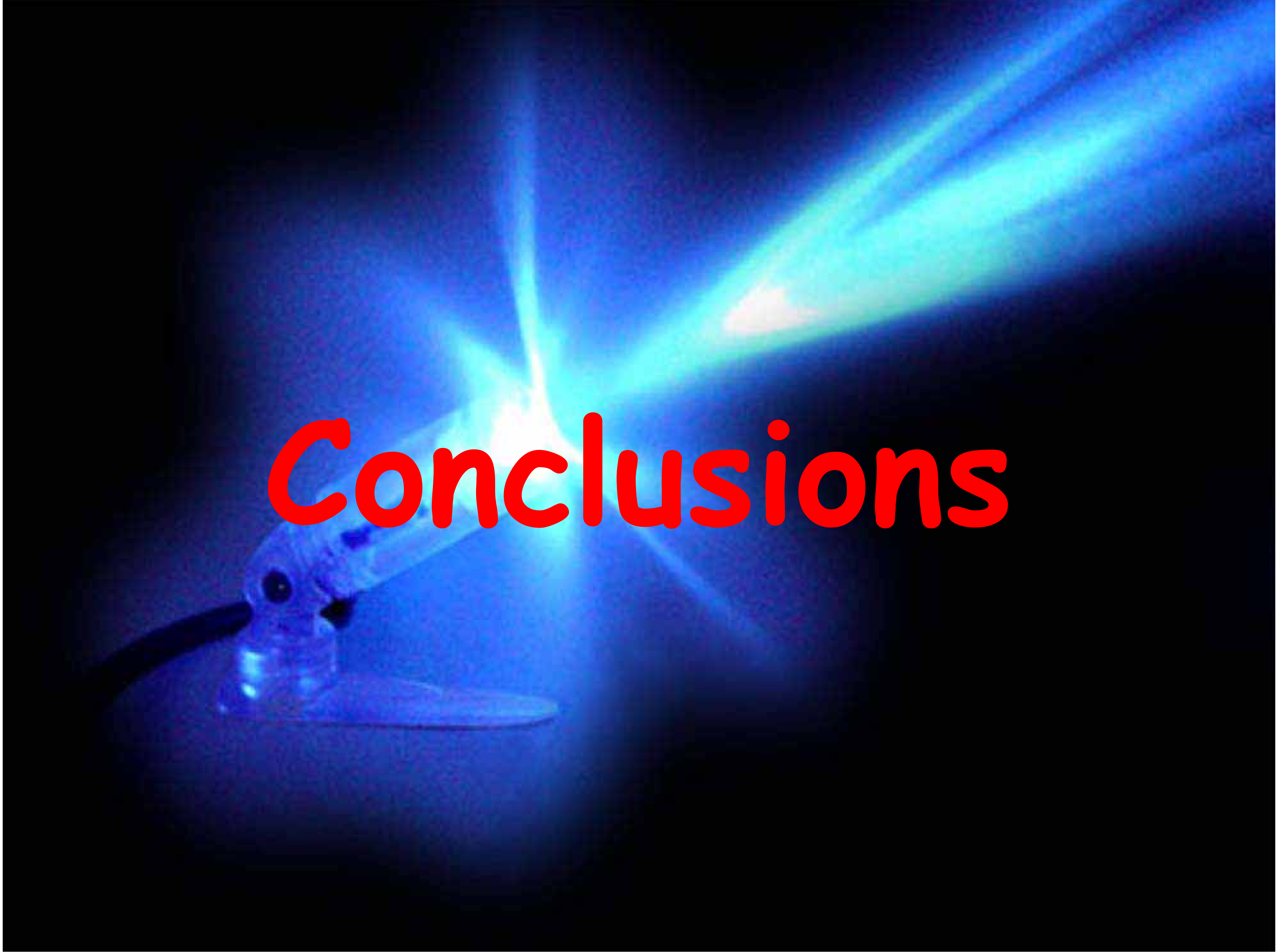
Millicharged particle detection

Dark Current Shining through a Wall!



Millicharged particles produced in the cavity lead to a Dark Current

Dark Current detection



Conclusions

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- New laboratory bounds on light millicharged particles from

  Laser-induced pairproduction in magnetic fields and

  Schwinger Pair production in Acc. Cavities
- The PVLAS observation of a nonvanishing rotation of the polarization of light in a magnetic field may be interpreted as pair production of light millicharged particles
- Millicharged particles are natural in extensions of the Standard Model!

Conclusions

- New laboratory bounds on light millicharged particles from

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- Millicharged particles are natural in extensions of the Standard Model!

→ Low energy experiments with photons may provide deep insights into fundamental Physics

Astrophysical Bounds: Problem

- BBN gives: $\epsilon \lesssim 10^{-9}$
- Astrophysical Bounds yield:

$$\epsilon \lesssim 10^{-14}$$

⇒ **PVLAS interpretation in trouble!**

Can we evade Astrophysical Bounds?

- Yes!
- Need two additional U(1)'s:

  one massless: $m_1 = 0$

  one massive: $m_2 \lesssim 1\,\mathrm{meV}$
- Fermions have to have charge (0,e,-e)

What do we get from String Theory?

- Typically many U(1) → ☺

- Fermions are Bifundamentals

  → (0,e,-e) → ☺

- One massive and one massless U(1) → ☺
- Massscale ~meV for gauge boson?

  → not natural, but not impossible

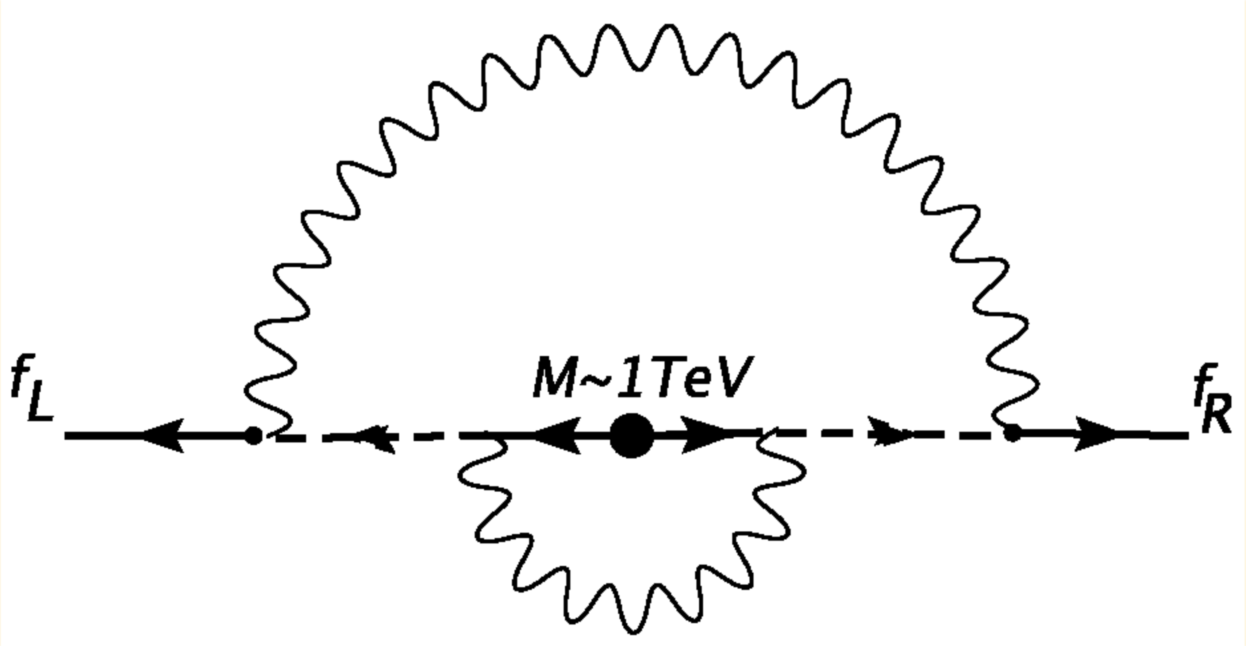
  → 😐

Mysterious mass scale:

$$m_2 \sim \mathrm{meV} \sim \mathrm{m}_\nu \sim \mathrm{m}_{\mathrm{DarkEnergy}}$$

Fermion mass?

- We need $m \sim 0.1\,\mathrm{eV}$
- Hidden sector fermions get a mass at 2-loop



$$m_{\mathrm{hidden}} = \alpha_p^{-4}\frac{M_s^6}{M_P^4\,\mu} \sim \alpha_p^{-4}\frac{M_W^2}{M_P} \sim \mathrm{eV}$$

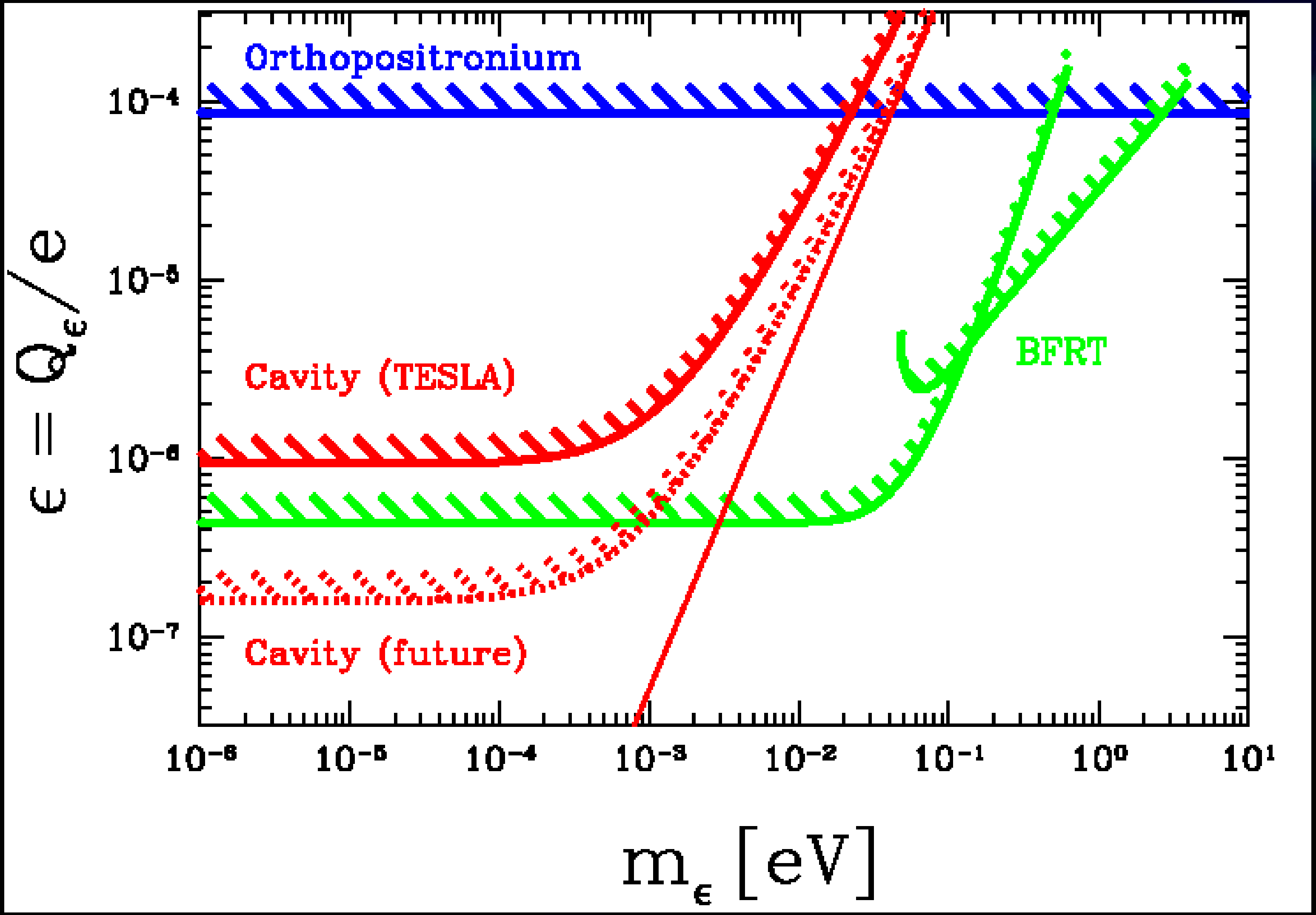
Detection?

- Direct detection difficult ($\sim \epsilon^2$)!
- If many particles are produced we get a

Macroscopic energy loss!

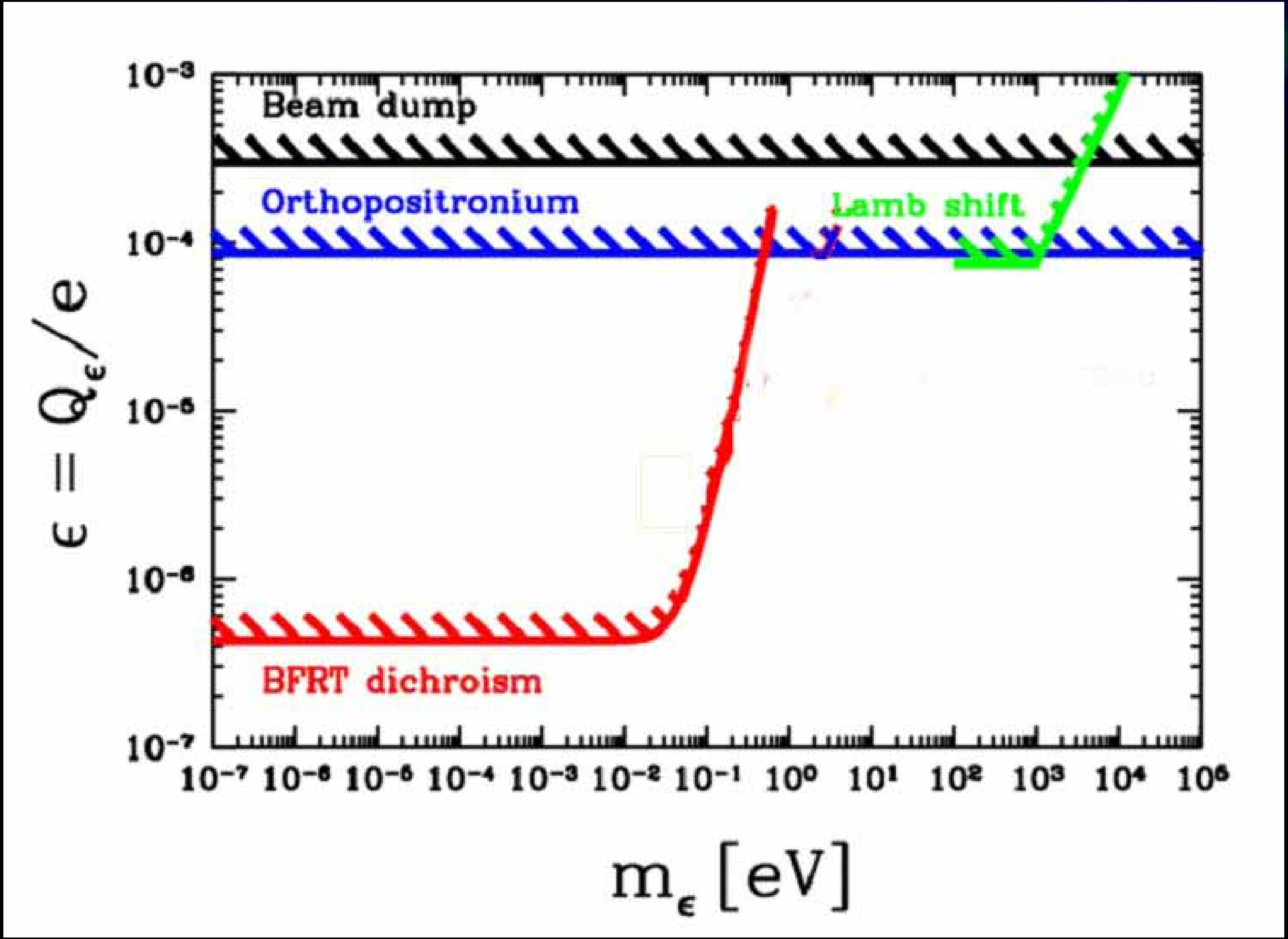
Can be measured

Quite strong bounds!

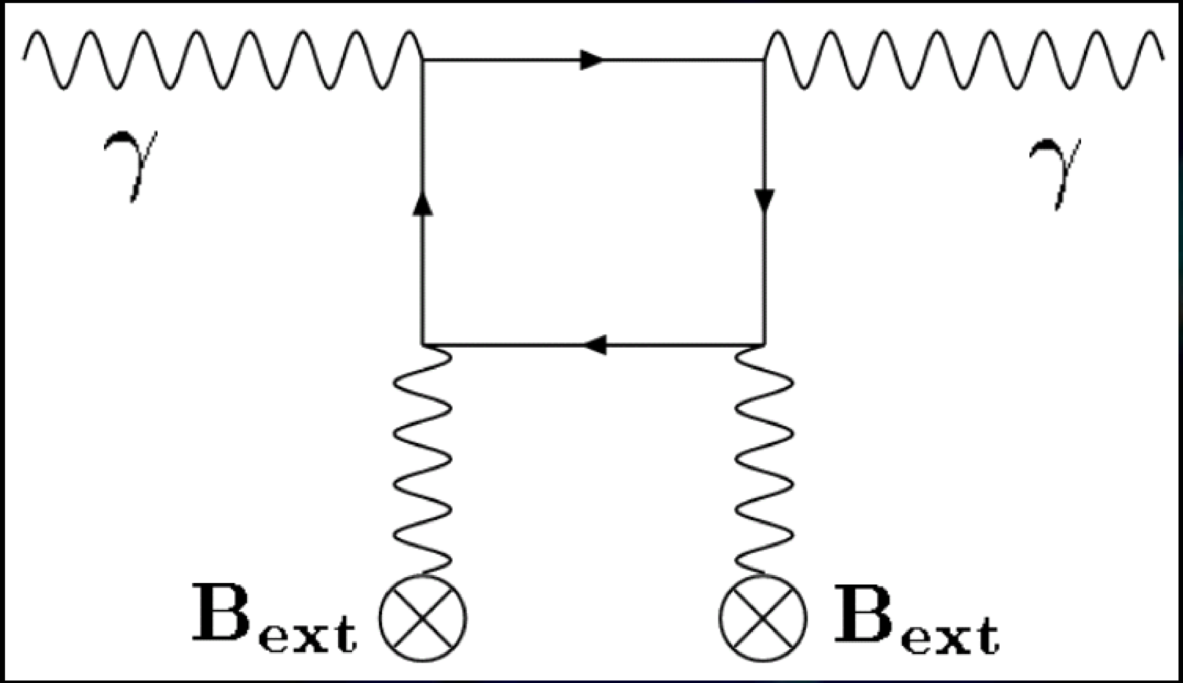


Need stronger E-fields to test PVLAS interpretation!

Result


Beam dump
Orthopositronium
Lamb shift
BFRT dichroism
$\epsilon = Q_\epsilon/e$
m_ϵ [eV]
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5}

Ellipticity (birefringence)



Works also for $\omega < m_\epsilon$!

Results in Phase shift: $\Delta\phi = \omega \ell (n_{||} - n_{\perp})$

Possible systematics

Candidate	Test/Cure	Comment
residual gas	pressure measurement	excluded
mirror coating birefringence/ rotation	direct measurement	excluded
electrical pick-up	measurement without the cavity	excluded
diffusion from magnetised surfaces	pinhole insertion	excluded
polarizer/QWP movement	measurement without the cavity	excluded
residual Faraday rotation (static and modulated)	study freq. locking offset eliminate fringe fields	possible source of birefr/ rotation at Ω_{mag}
yet uknown magnet-polarisation coupling	study freq. locking offset eliminate fringe fields	possible source of birefr/ rotation at Ω_{mag}
beam pointing instability	correlation with measured position signal eliminate fringe fields	possible source of birefringence at Ω_{mag}

Kinetic Mixing - How to get Millicharges

- Two U(1)'s

$$\mathcal{L}_{\rm gauge} = -\frac{1}{4}F^{\mu\nu}_{(a)}F_{(a)\mu\nu} - \frac{1}{4}F^{\mu\nu}_{(b)}F_{(b)\mu\nu} + \frac{\chi}{2}F^{\mu\nu}_{(a)}F_{(b)\mu\nu},$$

„Our" U(1)

„Hidden" U(1)

Mixing

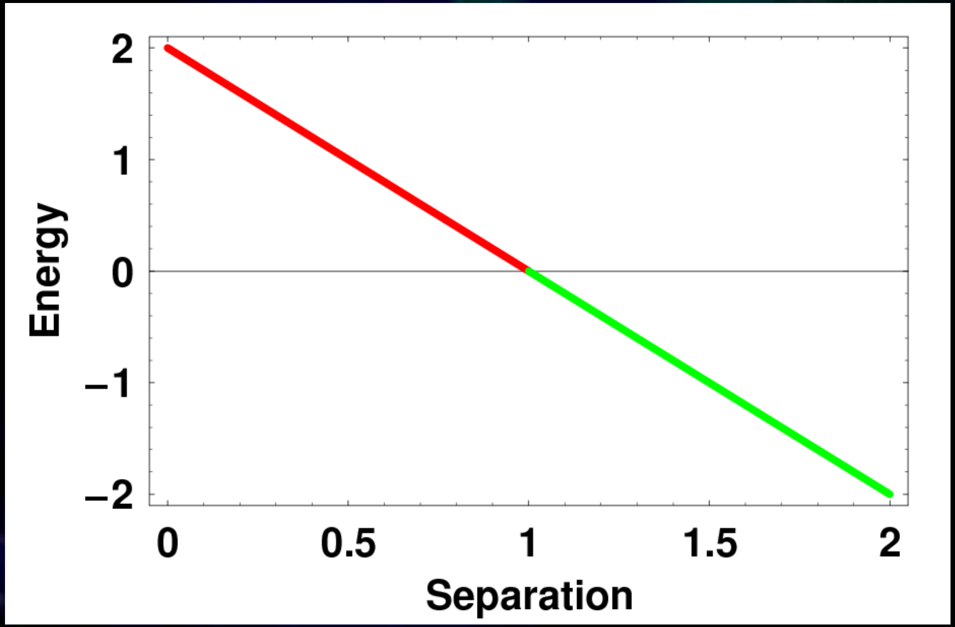
⇒ Diagonalization: $A^{\mu}_{(b)} \rightarrow A^{\mu}_{(b)} + \epsilon A^{\mu}_{(a)} \qquad \epsilon \sim \chi$

⇒ $\bar{\mathrm{f}} A^{\mu}_{(b)} \mathrm{f} \rightarrow \bar{\mathrm{f}} A^{\mu}_{(b)} \mathrm{f} + \epsilon \bar{\mathrm{f}} A^{\mu}_{(a)} \mathrm{f}$

⇒ f carries ϵ electric charge!

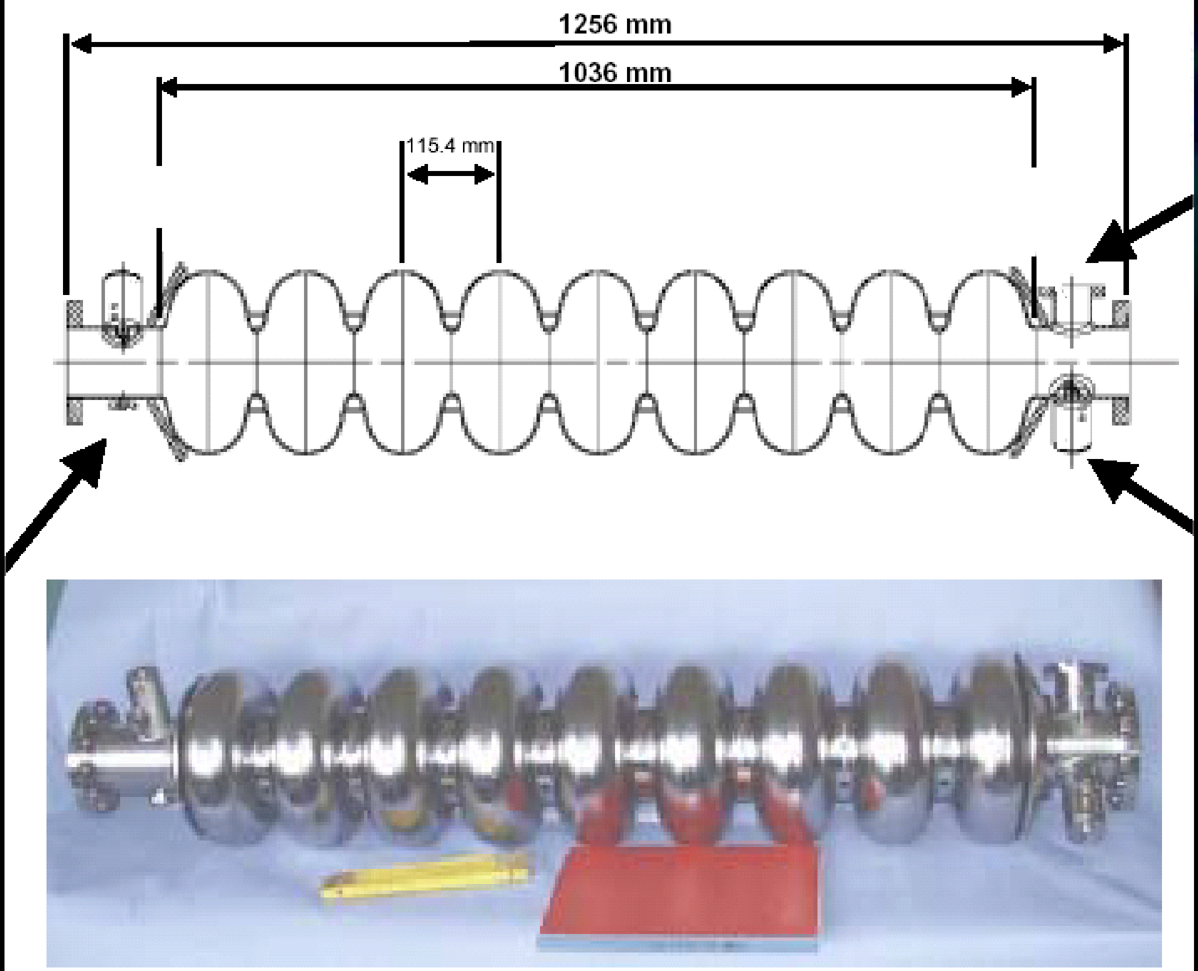
Schwinger Pair Production

- Pair Production works also in a strong electric Field (without Laser)!
- Similar to tunneling:



- An $\mathrm{f}, \bar{\mathrm{f}}$ -pair separated by a distance $d > \frac{2m_\epsilon}{\epsilon e \mathbf{E}}$ has less energy than no particles!

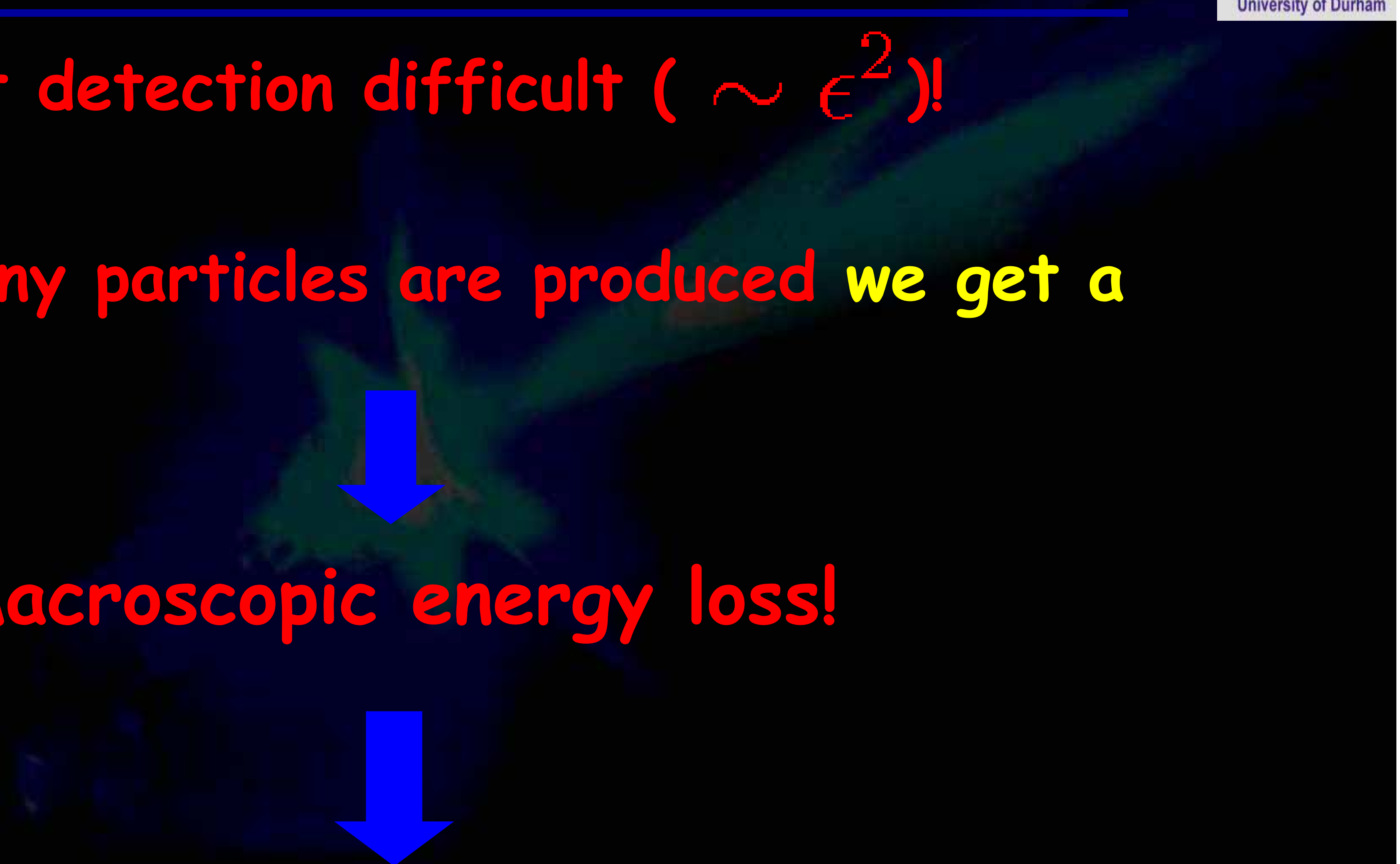
Accelerator cavities



One standard **9-cell TESLA accelerating structure**

$$\mathbf{E} \gtrsim 25\,\mathrm{MV/m}$$

Detection?



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↓

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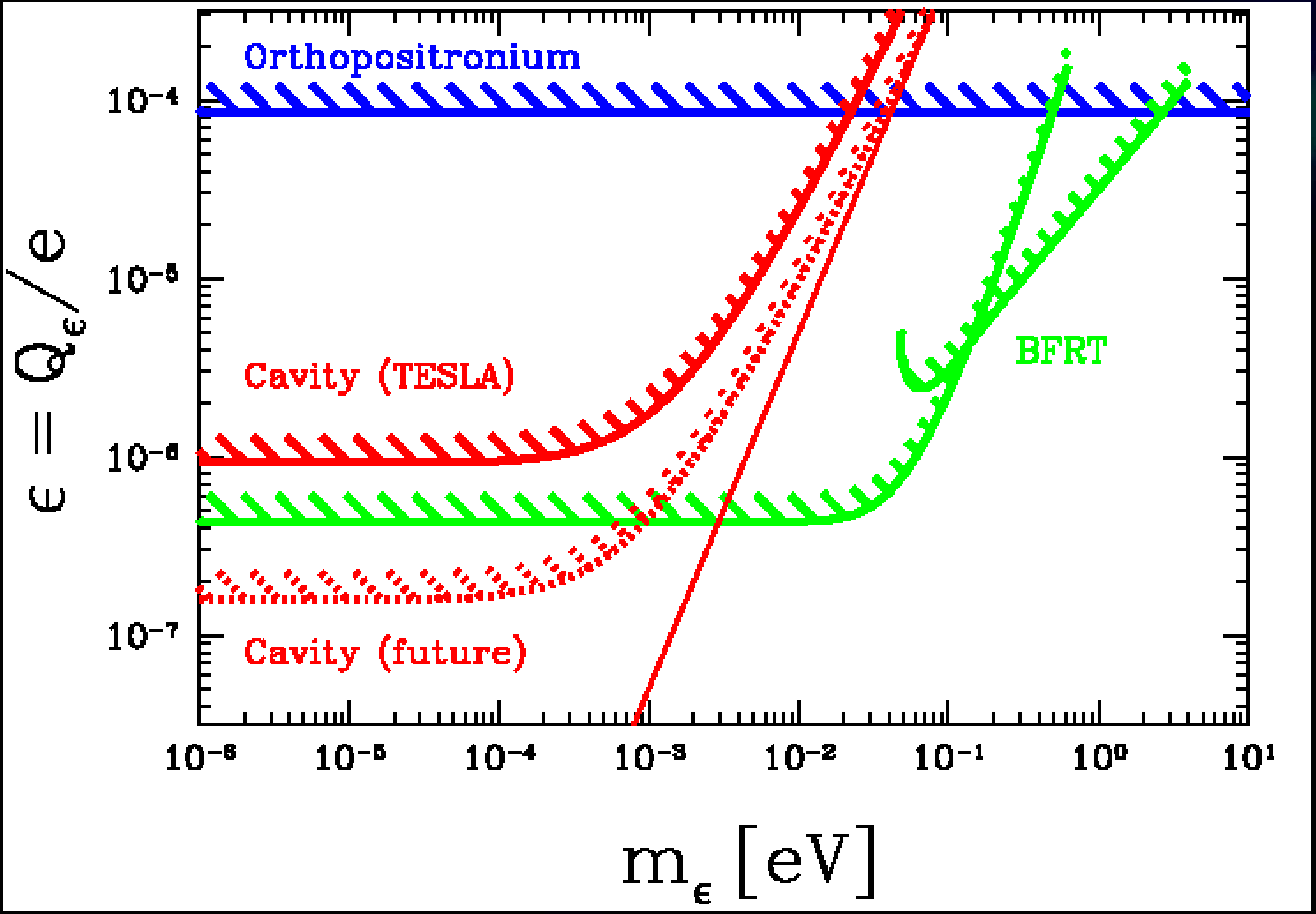
University of Durham



→ Need stronger E-fields to test PVLAS interpretation!