Experimental constraints on photon-dark energy couplings

Amol Upadhye

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- ARU, J. Steffen, and A. Weltman, 2010
- A. S. Chou, et. al., 2009
- J. H. Steffen, et. al., 2010.
- J. H. Steffen and ARU, 2009

Introduction

- We've known about the cosmic acceleration for over a decade, and the search is on for its cause.
  - cosmological constant Λ (simplest)
  - dark energy (scalar field?)
  - modified gravity/extra dimensions
- Deviations from Λ can take several forms.
  - equation of state $P/\rho = w(z) \neq -1$
  - couplings to known particles
  - variations of fundamental "constants"
- Cosmological and laboratory experiments are complementary.
- I will discuss a laboratory experiment designed to produce, trap, and detect dark energy particles.

Action

$$S = \int d^4x\sqrt{-g}\left[\frac{R}{16\pi G} - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) - \frac{1}{4}e^{\frac{\beta_\gamma\phi}{M_{\rm Pl}}}F_{\mu\nu}F^{\mu\nu} + \mathcal{L}_m(e^{\frac{2\beta_{\rm m}\phi}{M_{\rm Pl}}}g_{\mu\nu}, \psi_{\rm m}^{(i)})\right]$$

ordinary terms

nonlinear potential

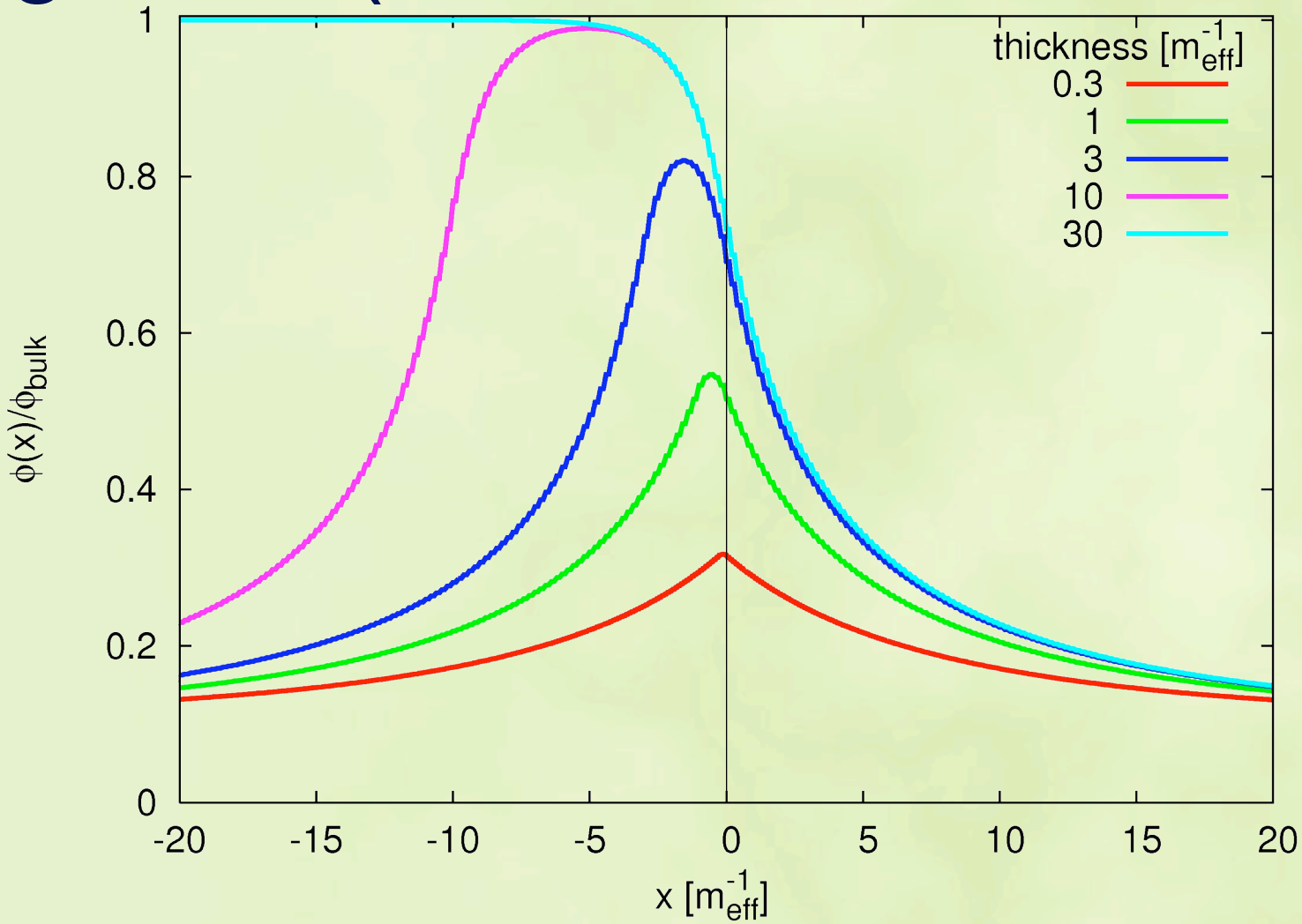
photon coupling

matter coupling

chameleon effect
(mass depends upon environment)
and
thin shell effect
(large sources hidden)

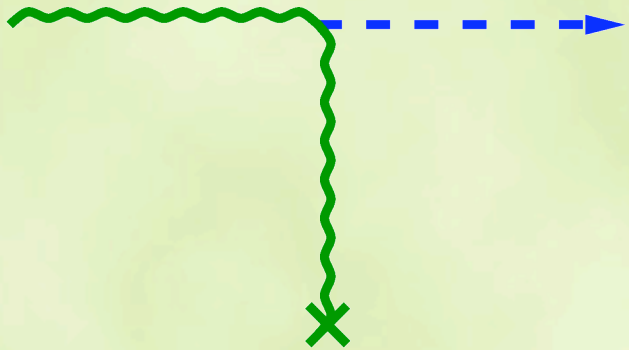
oscillation
between photons
and scalar particles

Nonlinearities suppress field growth (chameleon/thin shell)



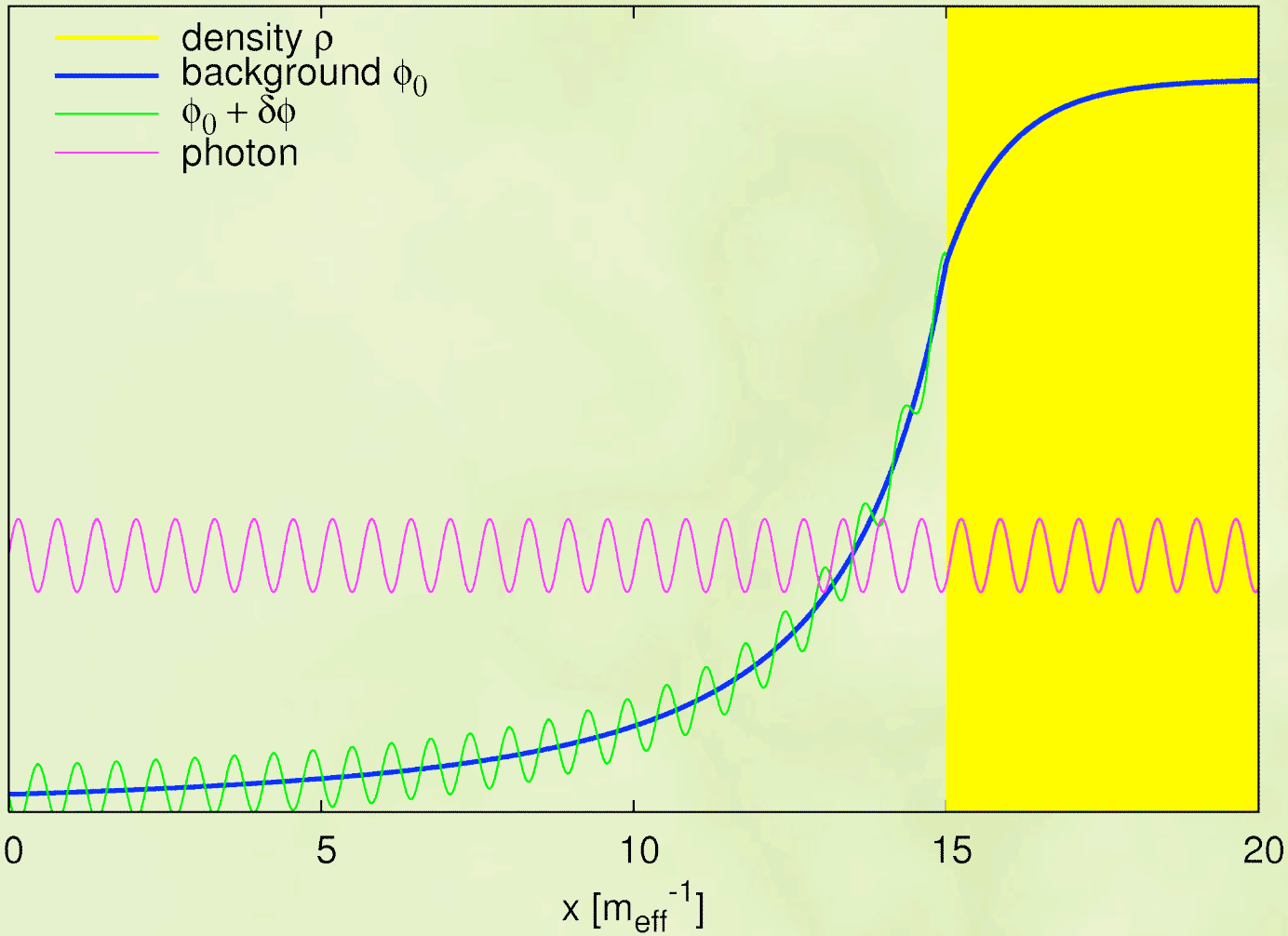
Chameleon-photon oscillation

- γ–––>ϕ conversion
  in background B field (interaction goes as ϕF^2)



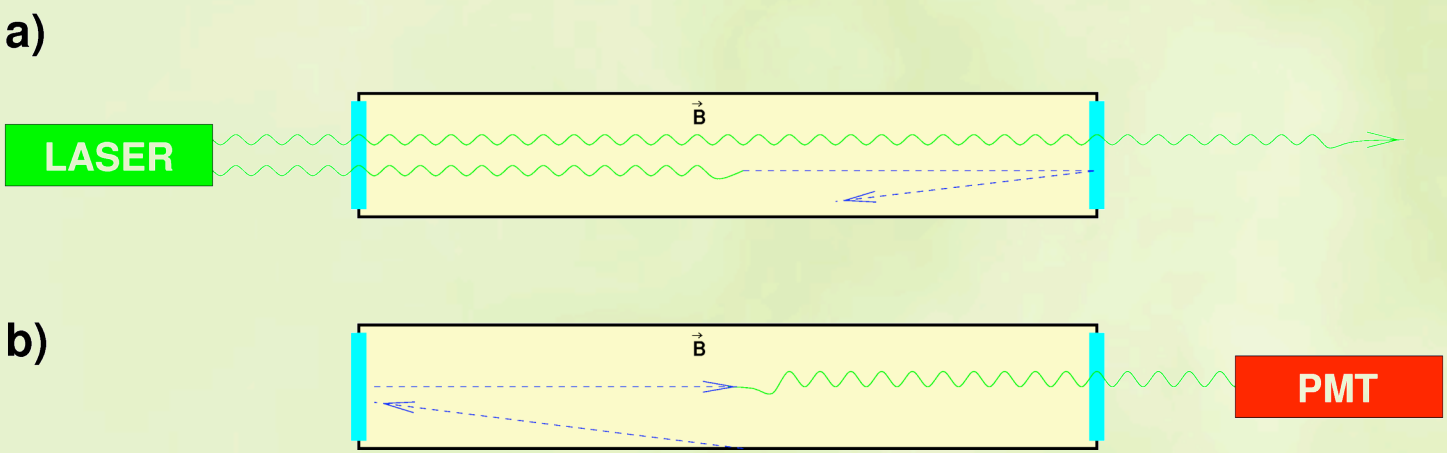
- oscillation probability
  - see Upadhye, Steffen, Weltman 2010
  - massless limit and $\hat{k} \perp \hat{x}$: $\mathcal{P}_{\gamma\leftrightarrow\phi} \approx \frac{\beta_\gamma^2 B_0^2 t^2}{4M_{\rm Pl}^2}$
- conversion rate
  - start with chameleon at time *0*
  - propagate through region with magnetic field
  - measure particle content at time t_M
  - rate of photon production: $\Gamma = \frac{\mathcal{P}_{\gamma\leftrightarrow\phi}(t_{\rm M})}{t_{\rm M}}$

Window acts as a quantum measurement device



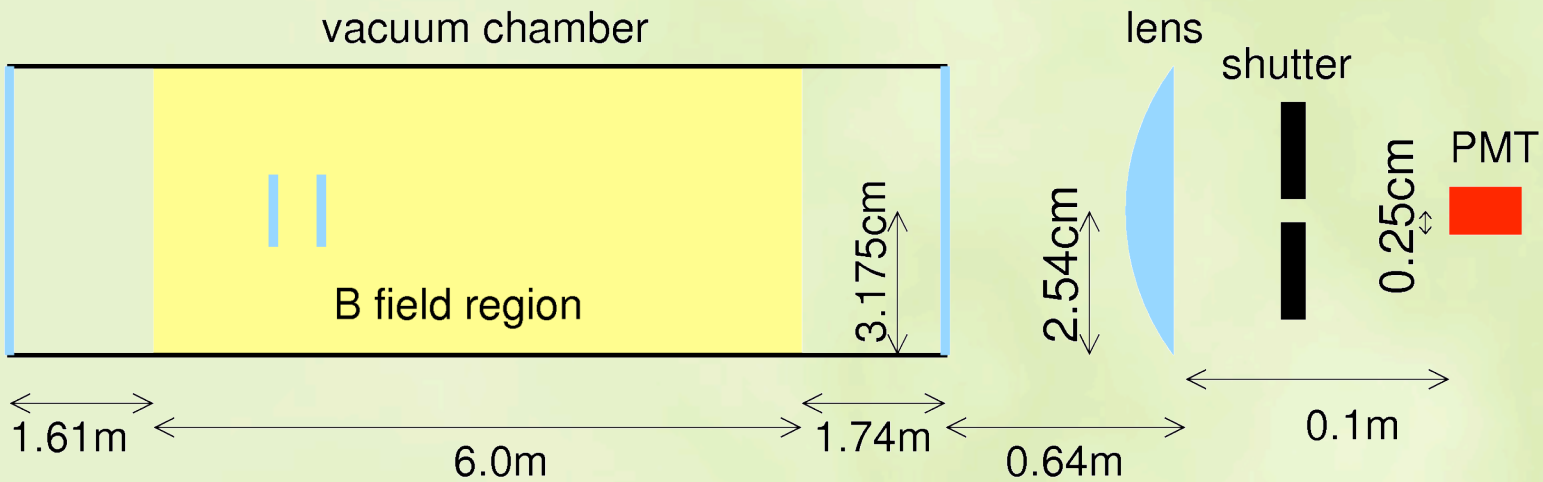
Afterglow experiment

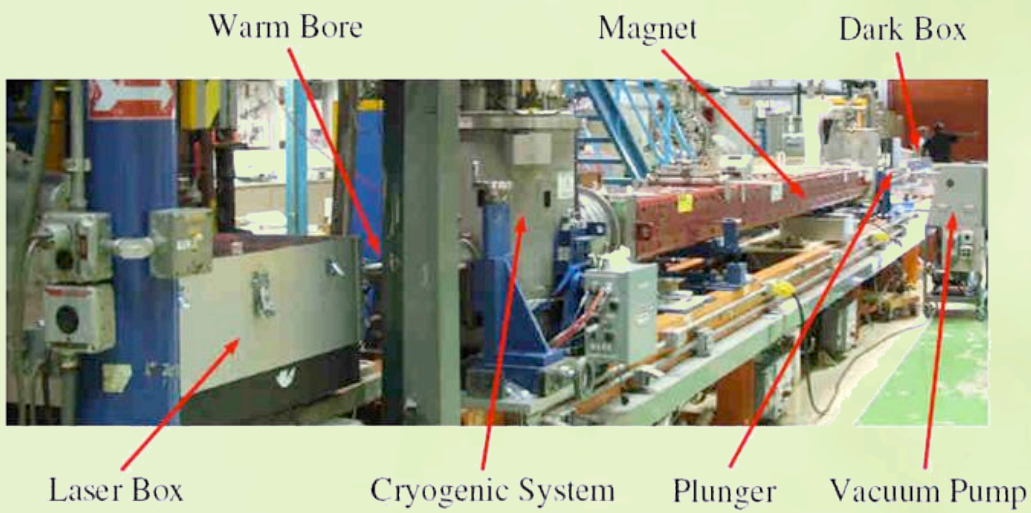
a) production: Stream photons through the magnetic field region via glass windows. Any chameleon particles produced will be trapped in the chamber.



b) afterglow: Turn off the photon source, and wait for chameleon particles to convert back into detectable photons, which will emerge through the windows.

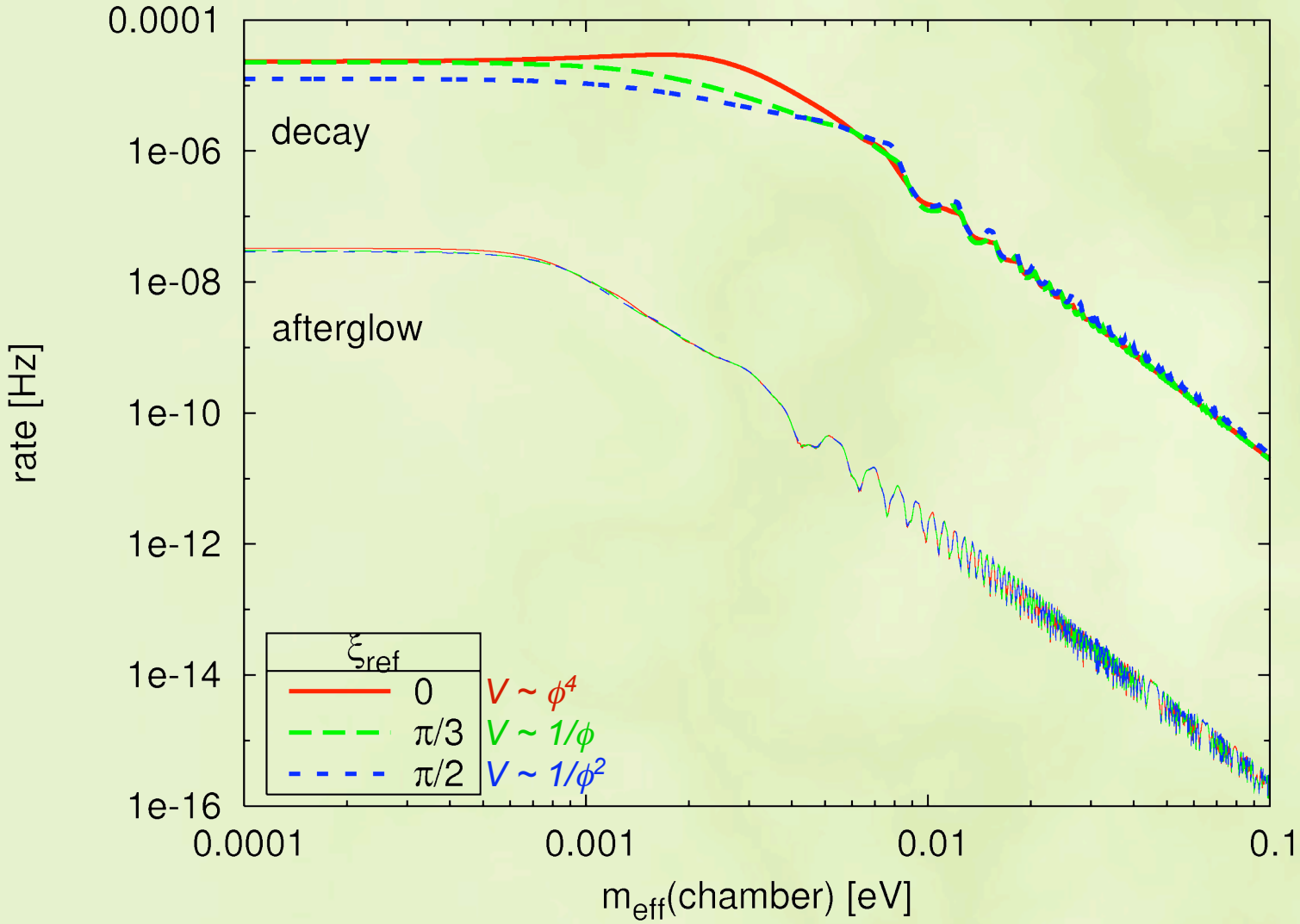
GammeV-CHASE Experiment



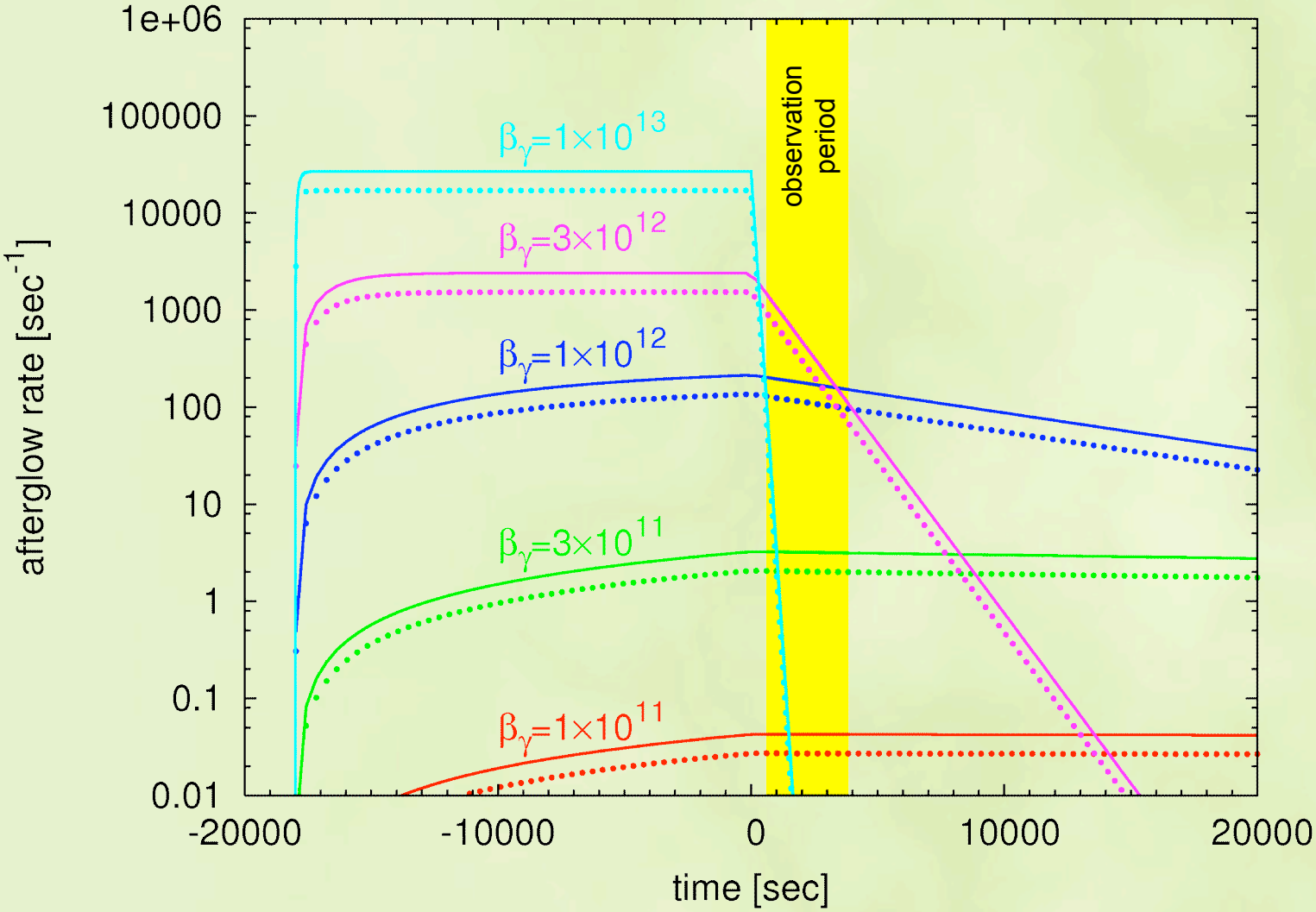


- photon source: frequency-doubled 20 Hz pulsed 3 W Nd:YAG laser
- magnet: 5 T, 6 m Tevatron dipole magnet
- vacuum: 1.6×10^{-9} torr
- detector: Hamamatsu PMT, dark rate 30Hz

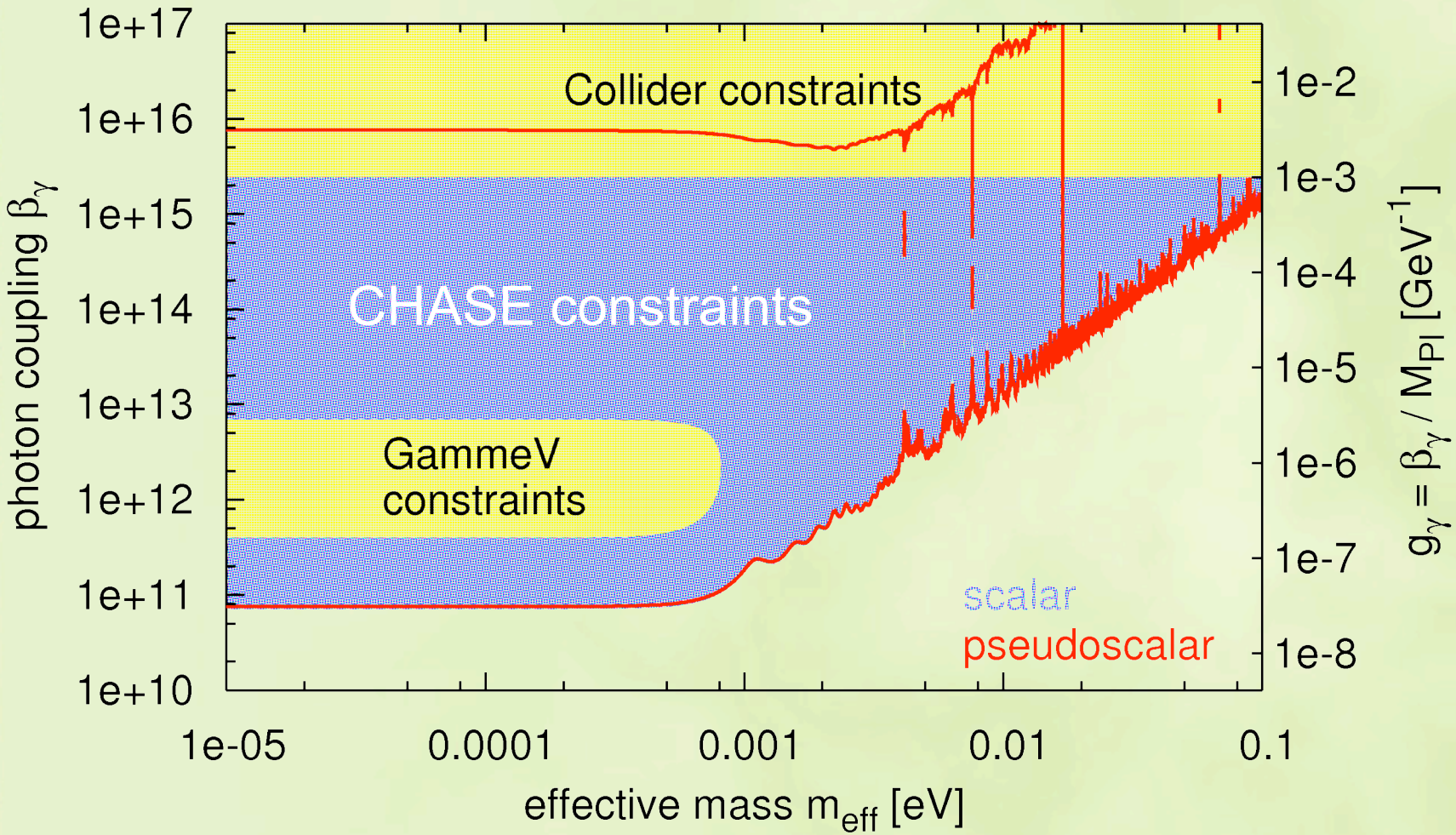
Conversion rate in GammeV



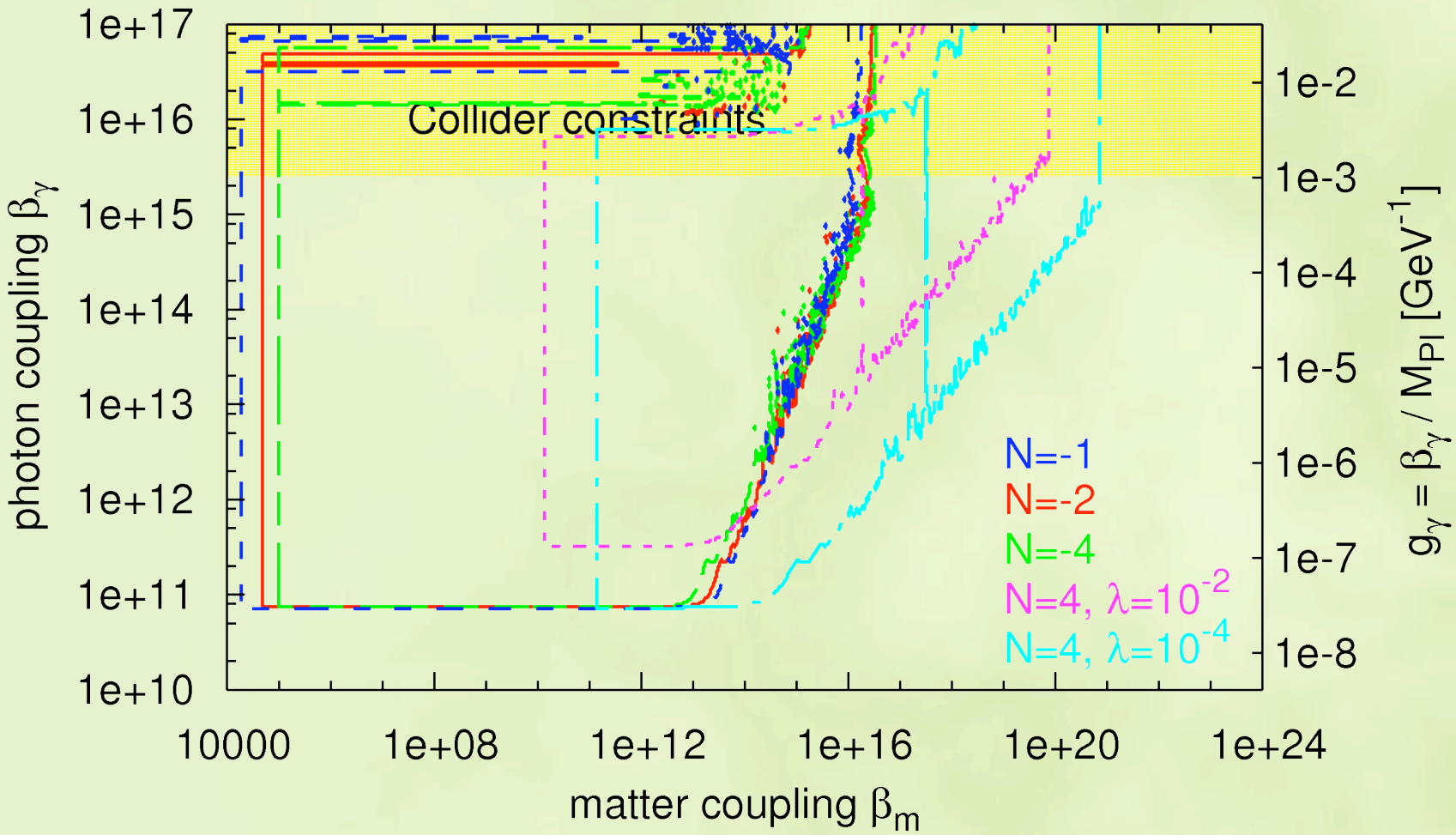
Expected signal



Constraints



Power law dark energy



Conclusions

- Laboratory probes of dark energy are complementary to cosmological probes.
- Photon-coupled chameleon dark energy can be produced and trapped inside a “bottle,” and its afterglow observed.
- The GammeV Experiment was the first afterglow experiment to report constraints on such chameleon theories.
- GammeV-CHASE has probed a much greater region of parameter space, covering the dark energy mass scale and bridging the gap between GammeV and accelerator constraints.