Fermilab's search for Chameleons

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Some Numerology

Dark Energy: $\Lambda^4 = (2\ \text{meV})^4$

$hc \sim 1\text{meV mm}$

$\Delta m^2\ L/E \sim \text{meV}^2\ \text{m/eV}$

Some Numerology

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Add a resonating cavity...

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Power recycle for a factor of 10 to 100

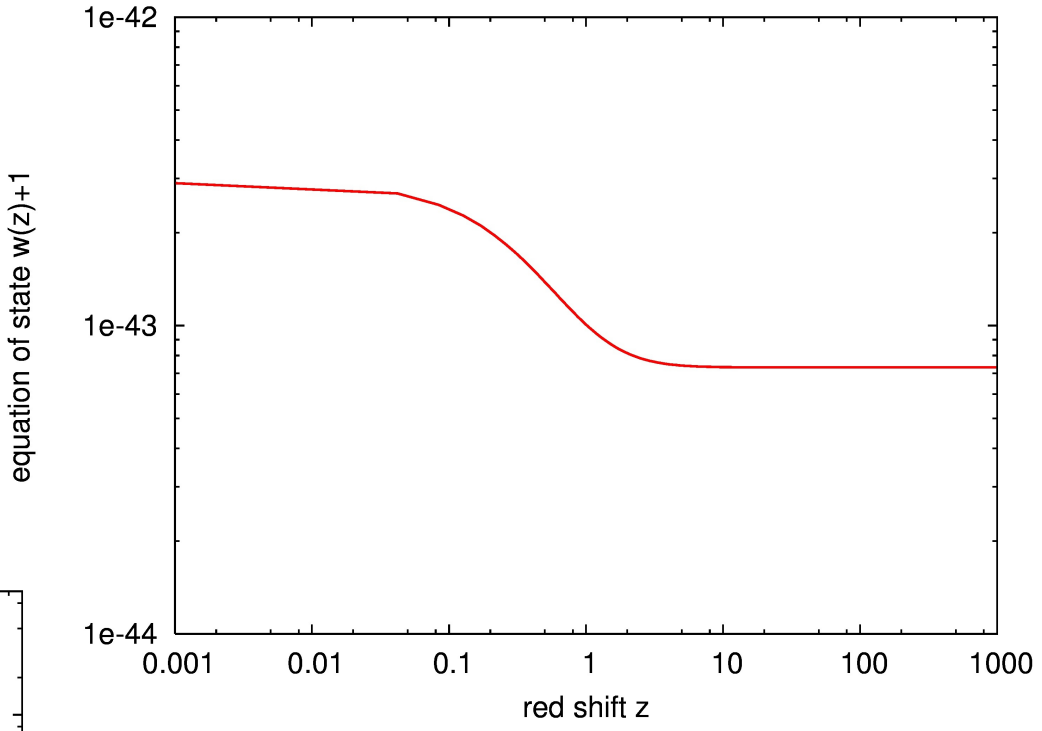
Use an interferometer...

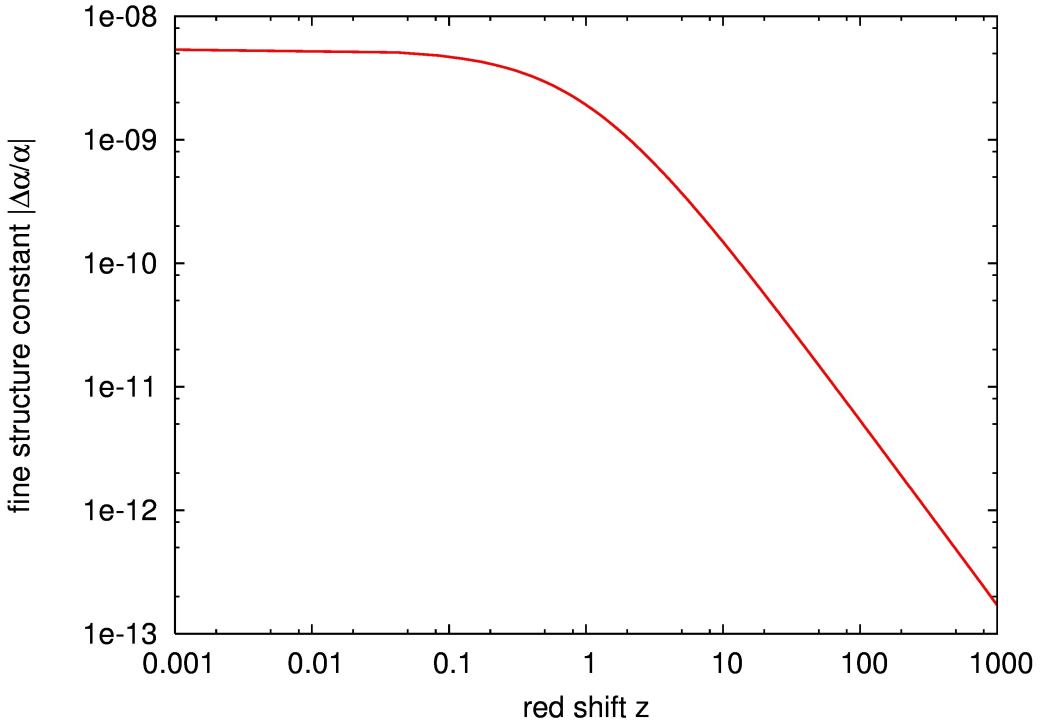
Angular sensitivity ~ 10^{-12} radians

Differential length sensitivity ~ 10^{-19} meters

Chameleon Dark Energy

Equation of state parameter from chameleon dark energy (current limits ~0.1).





Variation in fine structure constant from chameleon dark energy (current limits 1e-6)

Chameleon Dark Energy

We consider potentials of the form

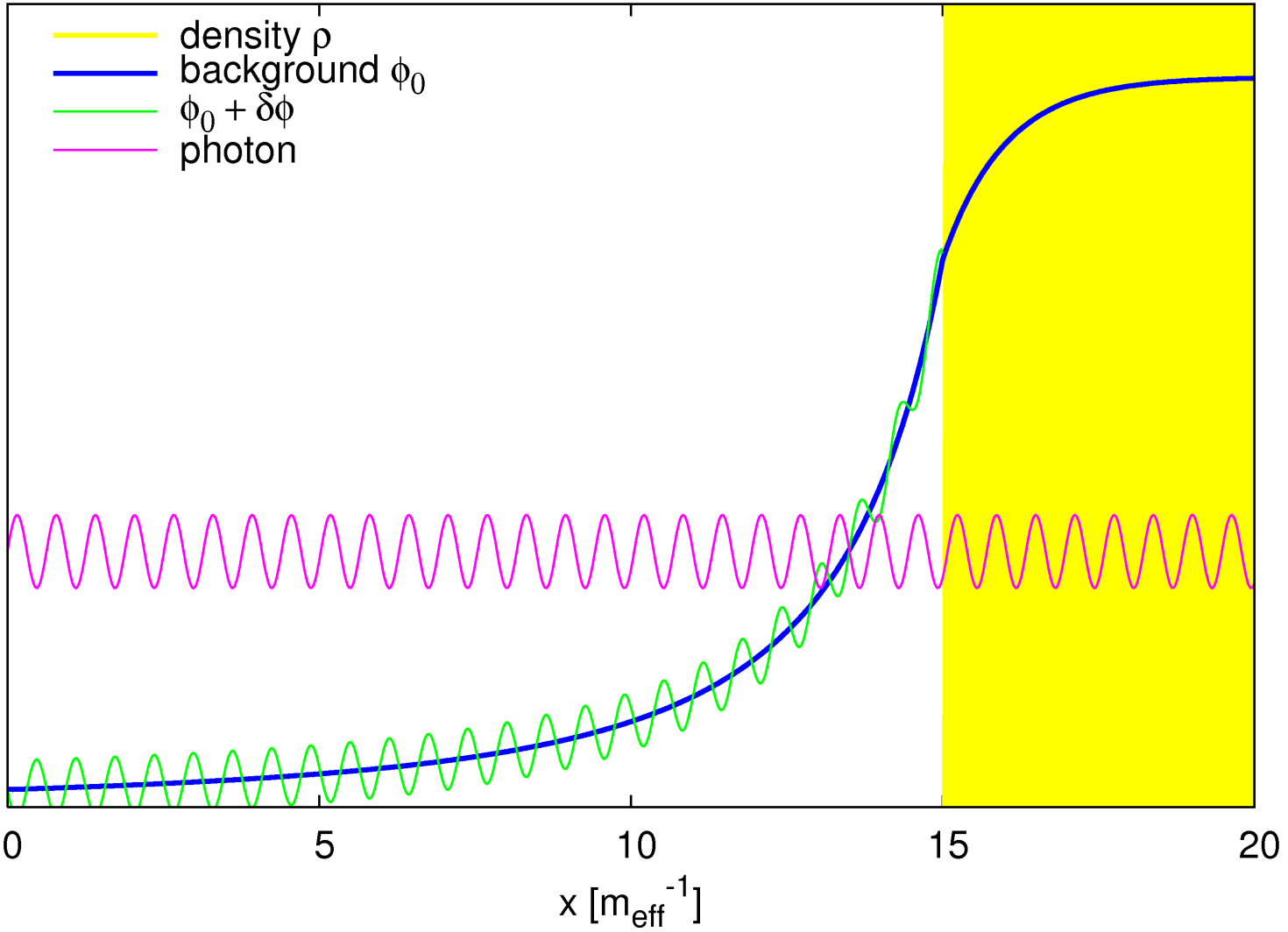
$$V(\phi) = M_\Lambda^4 \exp(\phi^N/M_\Lambda^N) \approx M_\Lambda^4 (1 + \phi^N/M_\Lambda^N)$$

- M_Λ is the dark energy scale, 2.4×10^{-3}eV

In bulk matter density ρ, m_{eff} scales as ρ^η

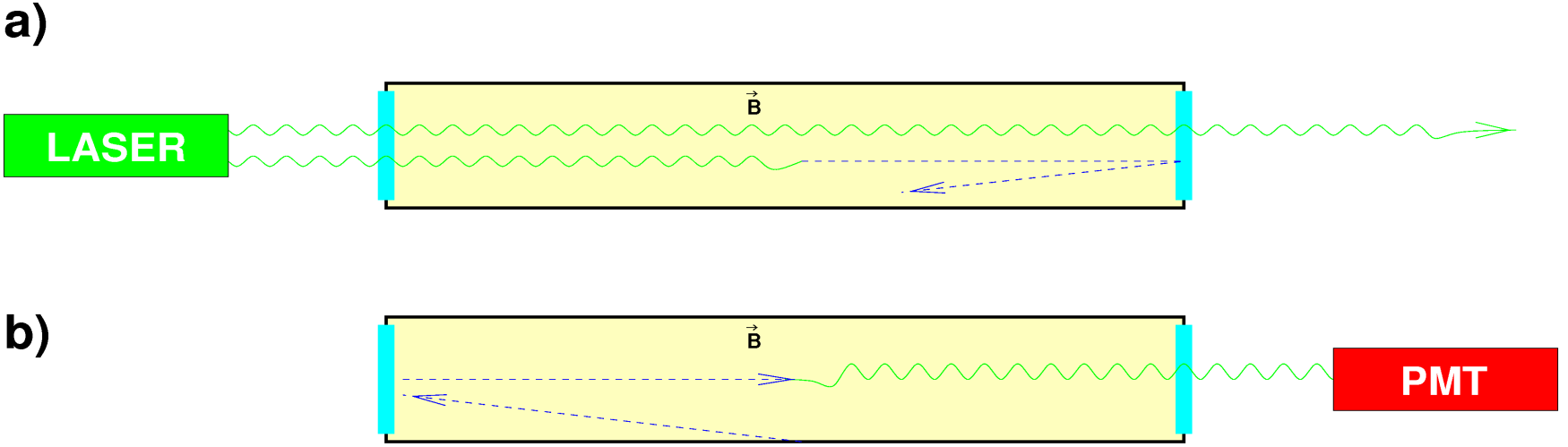
- $\eta=(N-2)/(2N-2)$
- $\eta=1/3$ for ϕ^4 theory, $\eta=3/4$ for $1/\phi$ model

Quantum Measurement: Windows



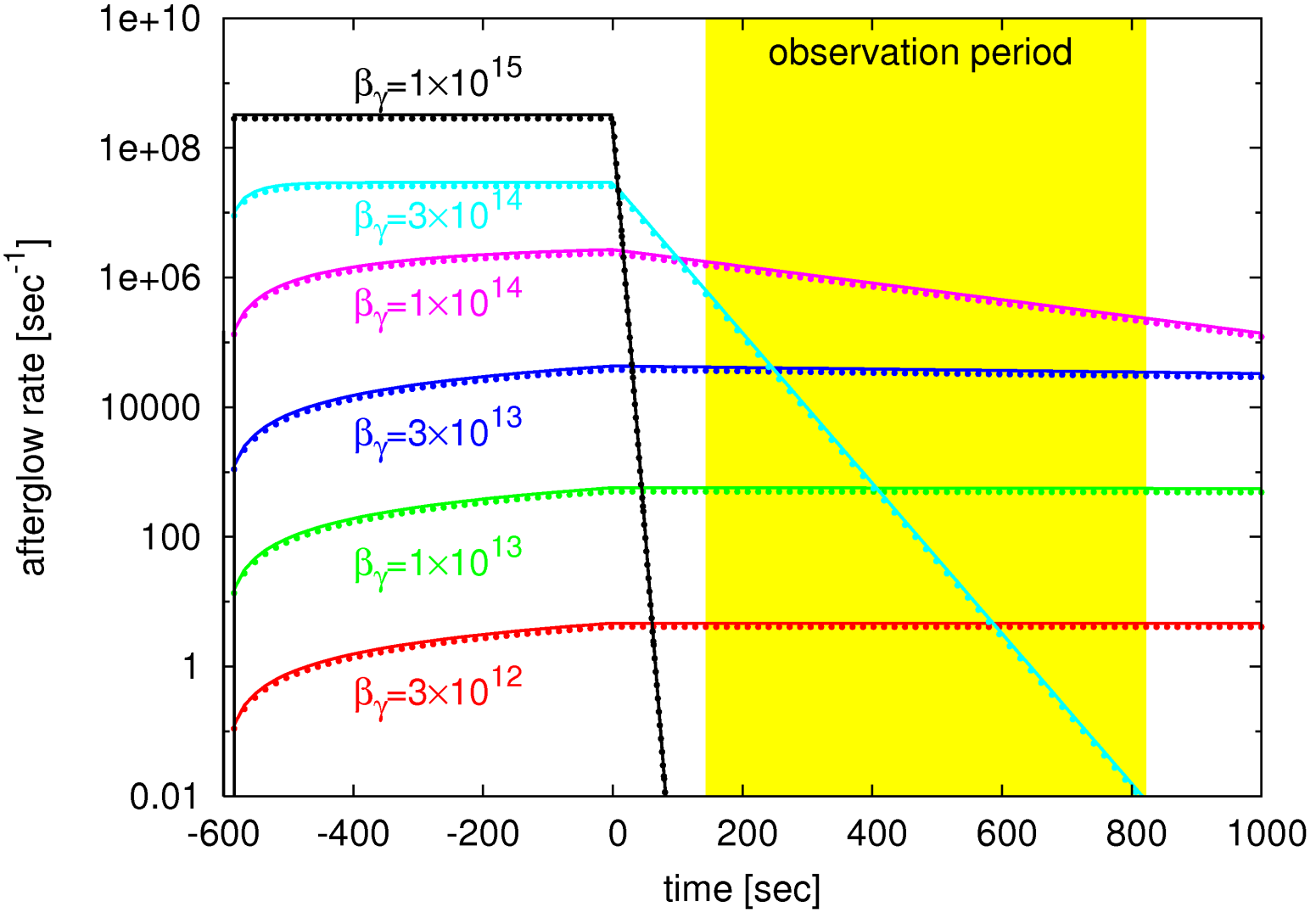
Afterglow experiment

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



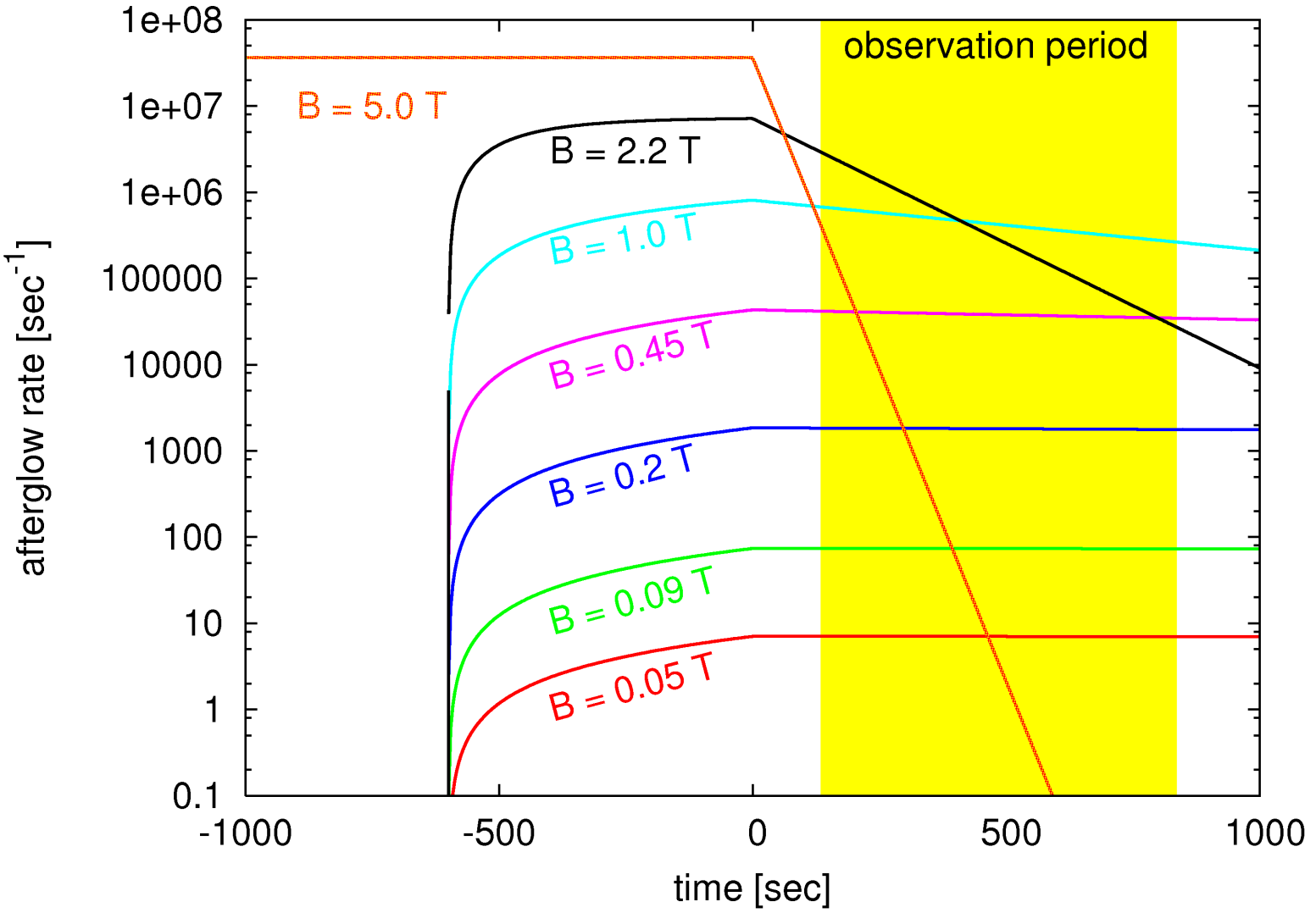
b) afterglow: Turn off the photon source, and wait for chameleon particles to convert back into detectable photons, which emerge through the windows.

Expected signal

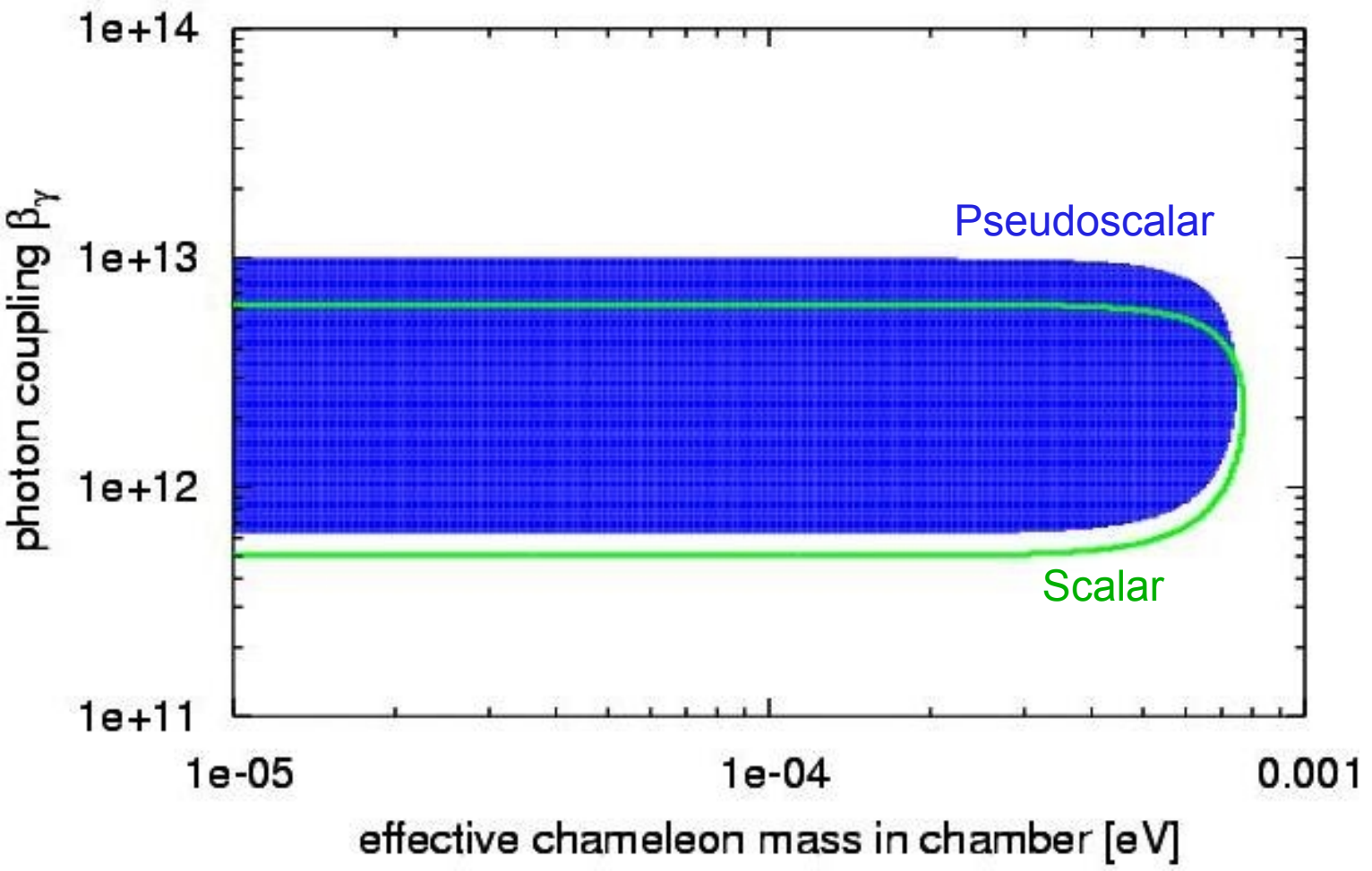


solid lines: m_{eff}=1x10^{-4}eV dotted lines: m_{eff}=5x10^{-4}eV

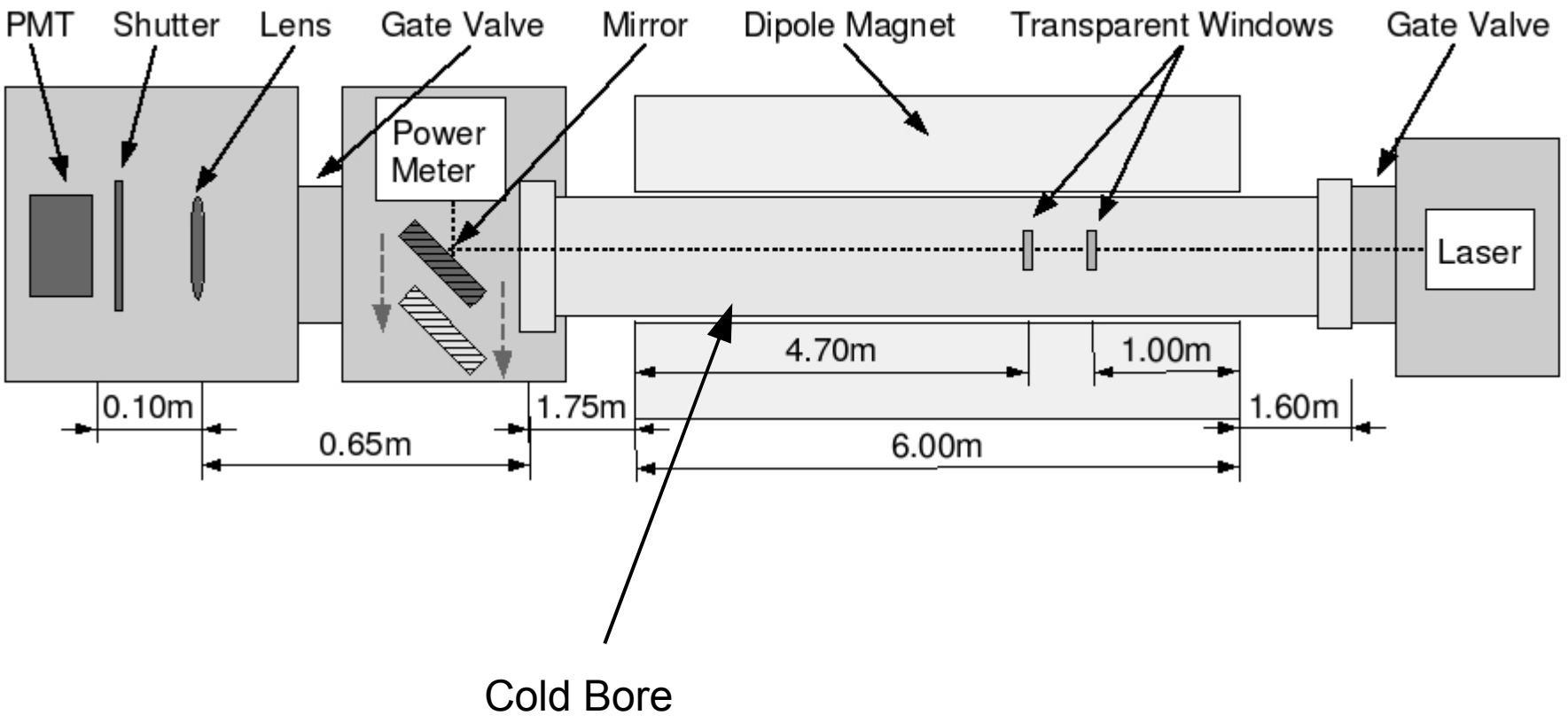
Expected signal



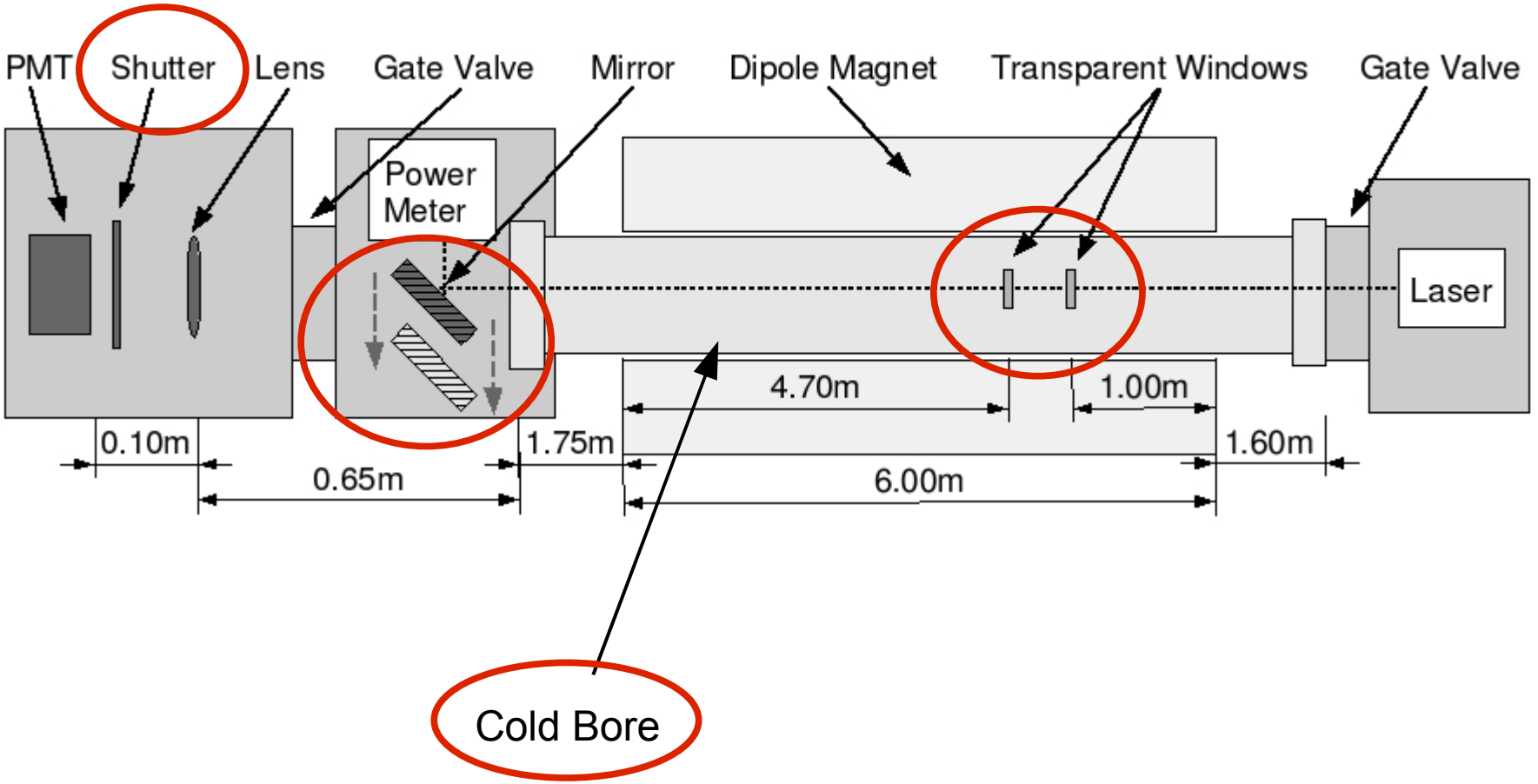
Constraints from GammeV



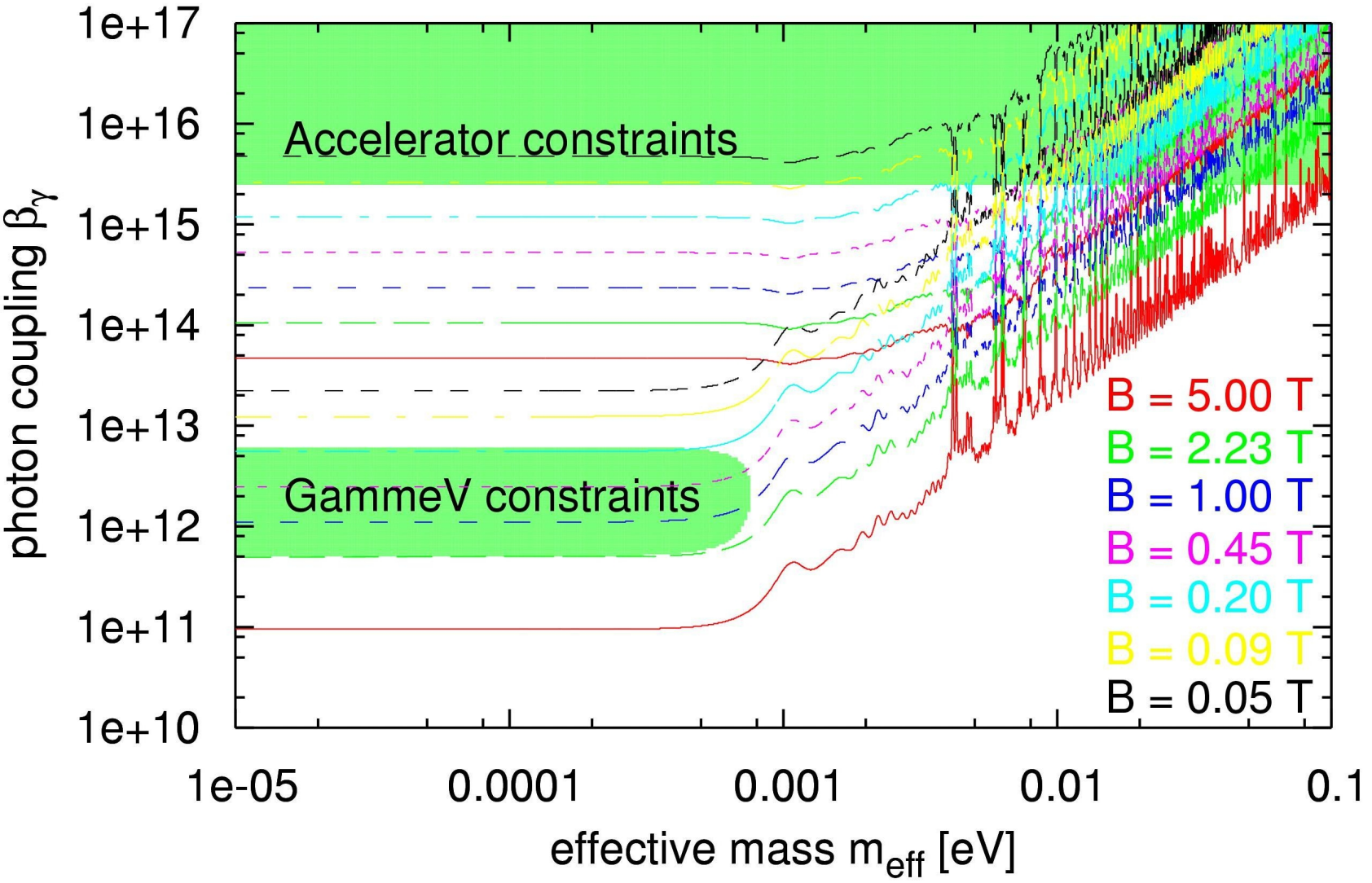
CHASE schematic



CHASE schematic

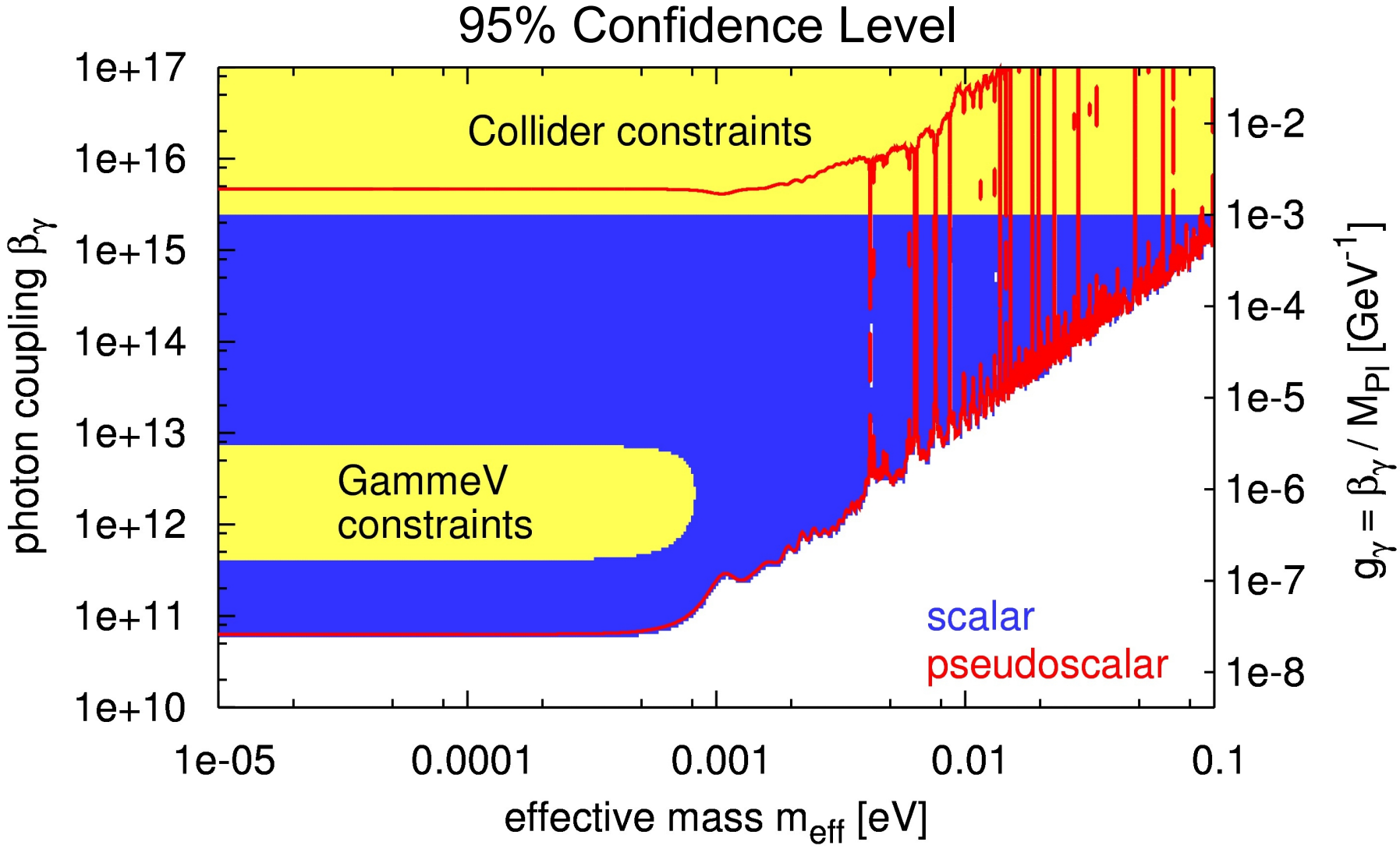


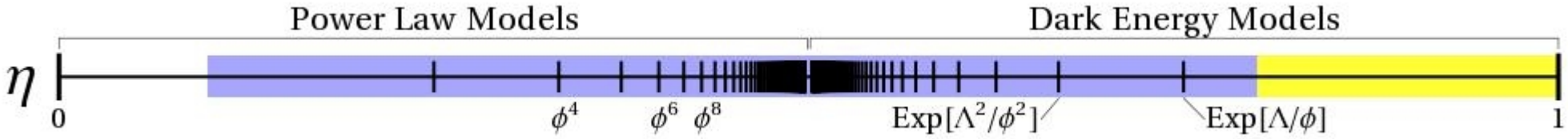
CHASE experimental approach



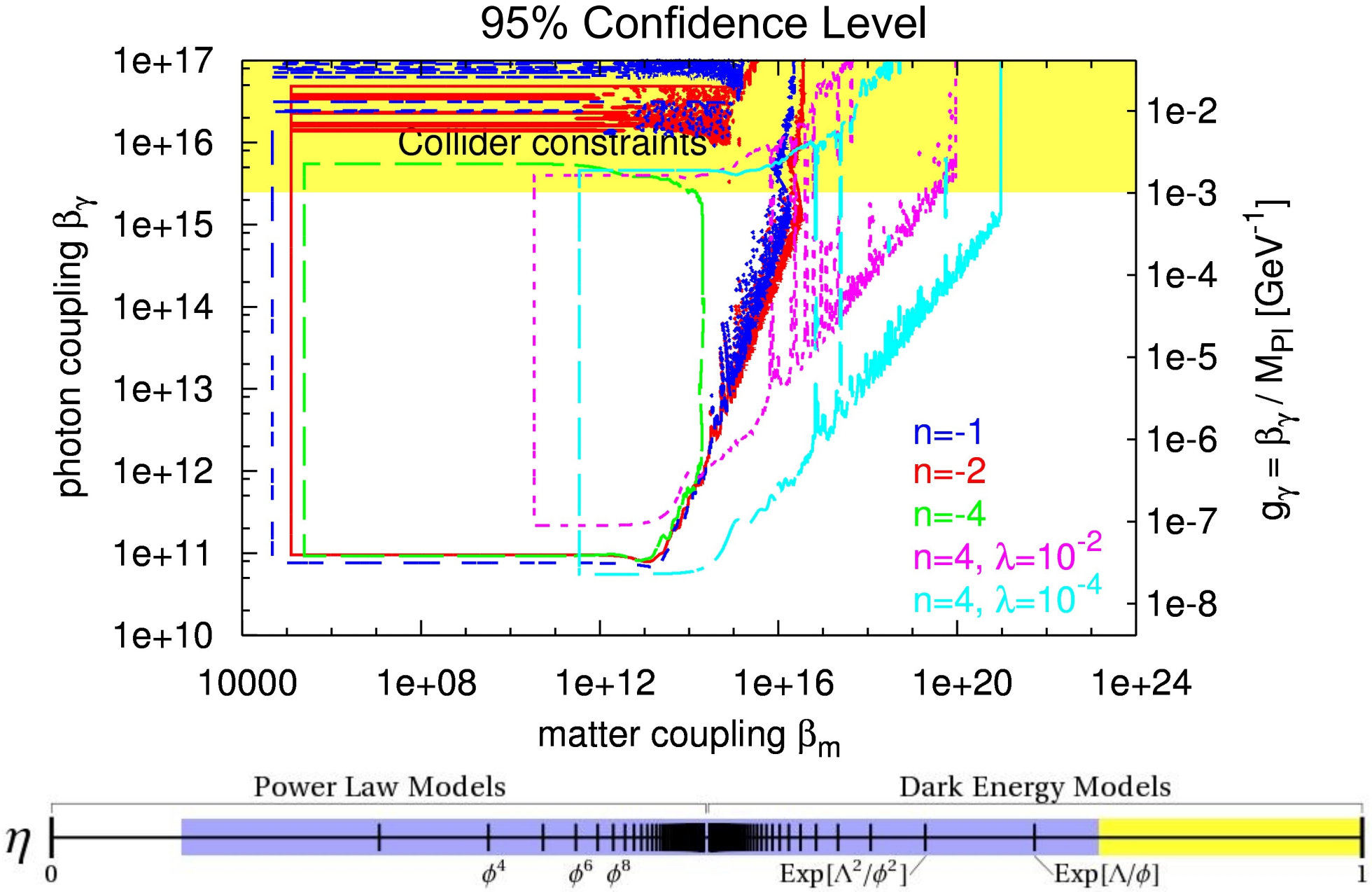
Lowering the magnetic field allows us to probe larger photon couplings and to eliminate some systematic effects.

Constraints from CHASE





Model Dependent Results



Limitations on Future Experiments

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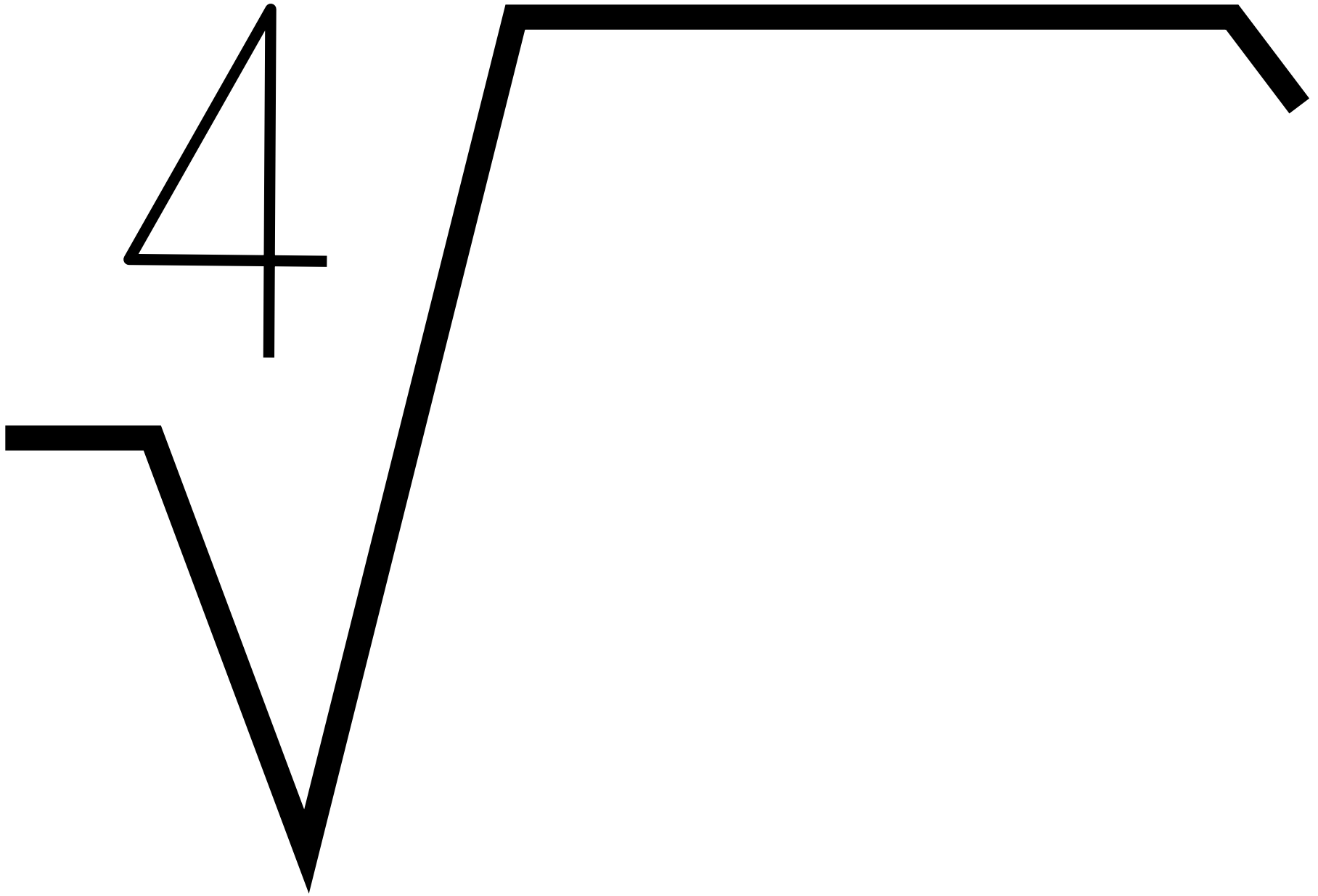

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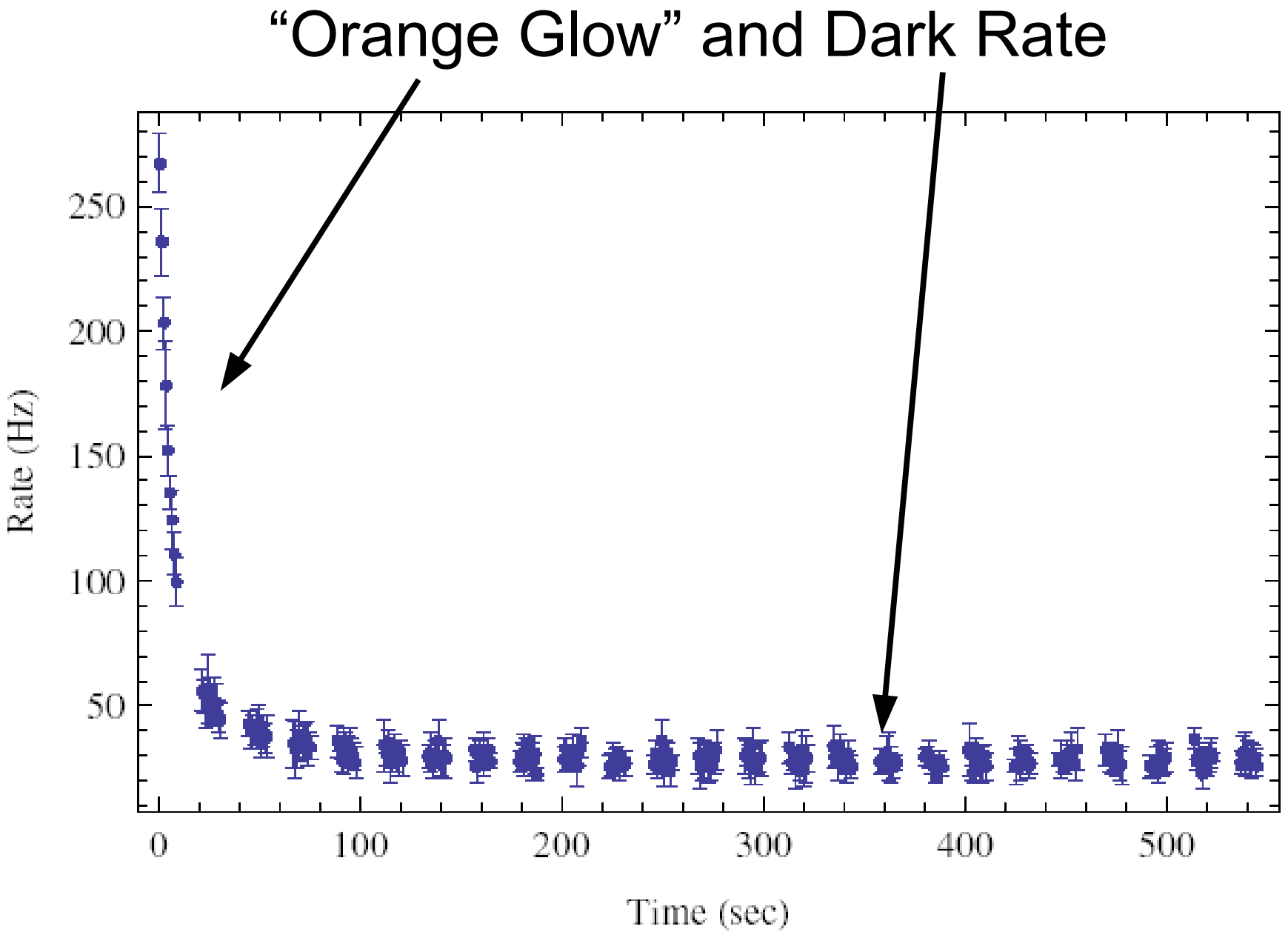
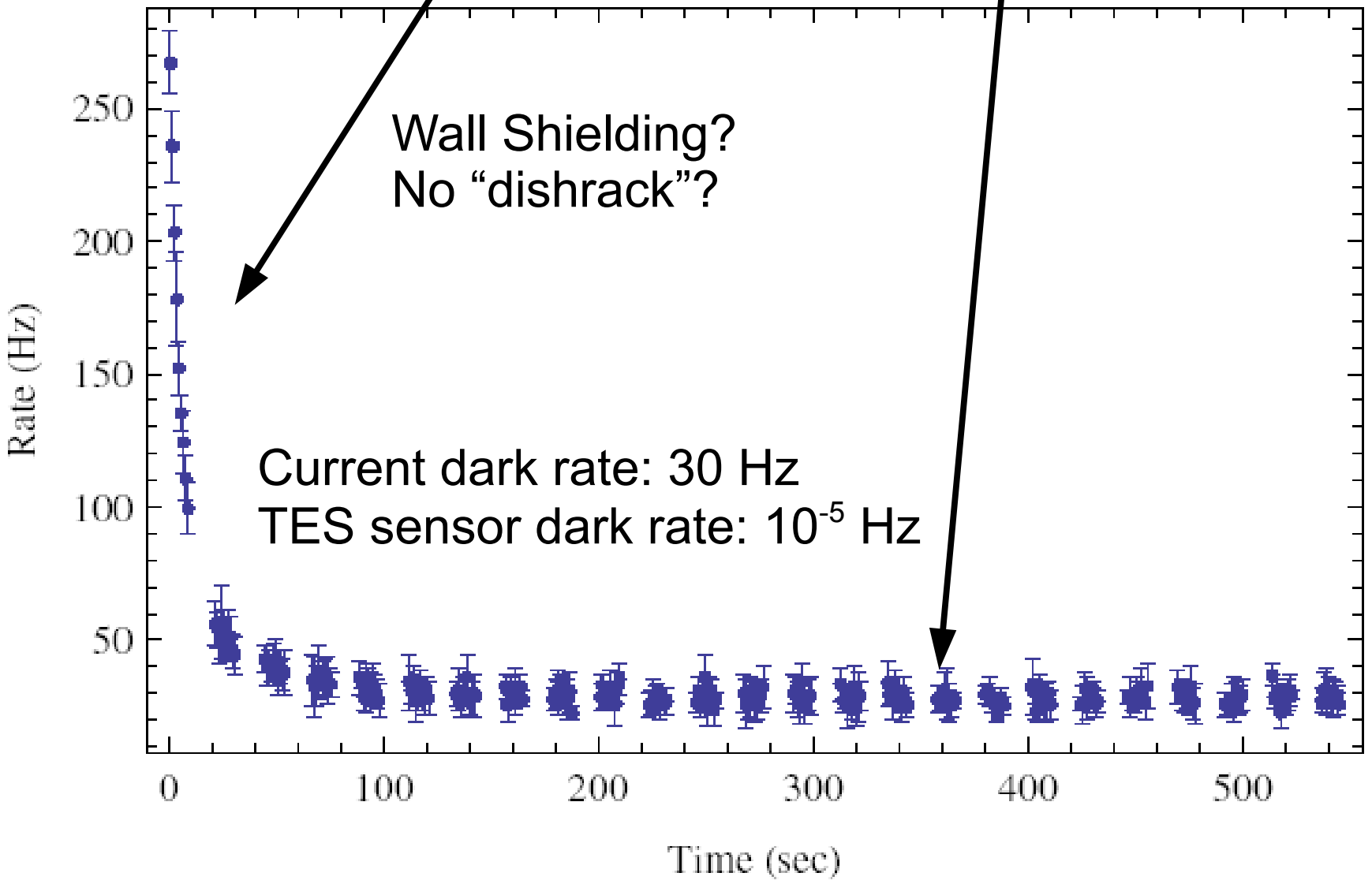


Limitations on Future Experiments

"Orange Glow" and Dark Rate



Limitations on Future Experiments

Effective angular size of the detector ~ 10^{-4}

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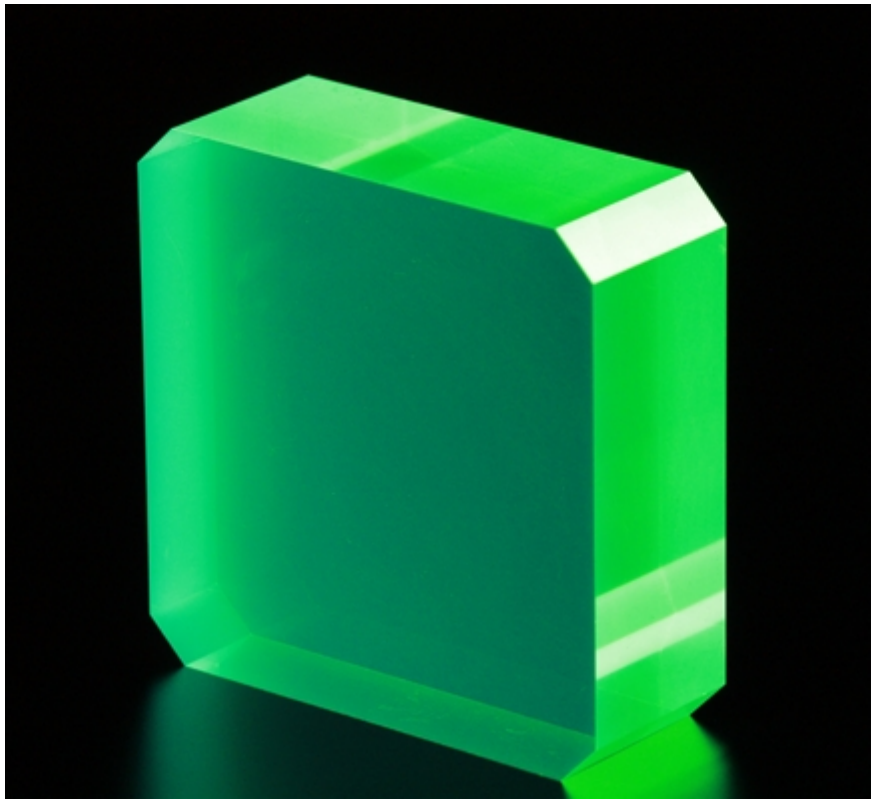
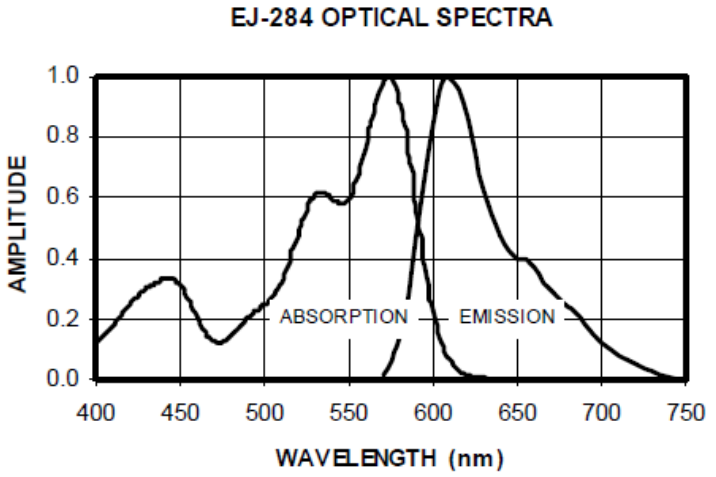
Effective angular size of the detector ~ 4π



Wavelength shifter



Conclusions

- CHASE results exclude chameleon dark energy models over a wide range of photon and matter couplings.
  - For simple models the improvement is five orders of magnitude in photon coupling for matter couplings that span 12 orders of magnitude
  - Sensitive to chameleon effective mass at the dark energy scale and beyond

- CHASE is also sensitive to power-law chameleon models

- Improvements in the detector noise and angular acceptance could give two additional orders of magnitude

How do you hide a scalar field?

$$\nabla^2\phi + m^2\phi = \frac{g}{M_{\rm Pl}}\rho$$

$$K(\rho)\nabla^2\phi + m^2\phi = \frac{g}{M_{\rm Pl}}\rho$$

Vainshtein

$$\nabla^2\phi + m^2\phi = \frac{g(\rho)}{M_{\rm Pl}}\rho$$

symmetron

$$\nabla^2\phi + M^2(\rho)\phi = \frac{g}{M_{\rm Pl}}\rho$$

chameleon

Slides stolen from Justin Khoury

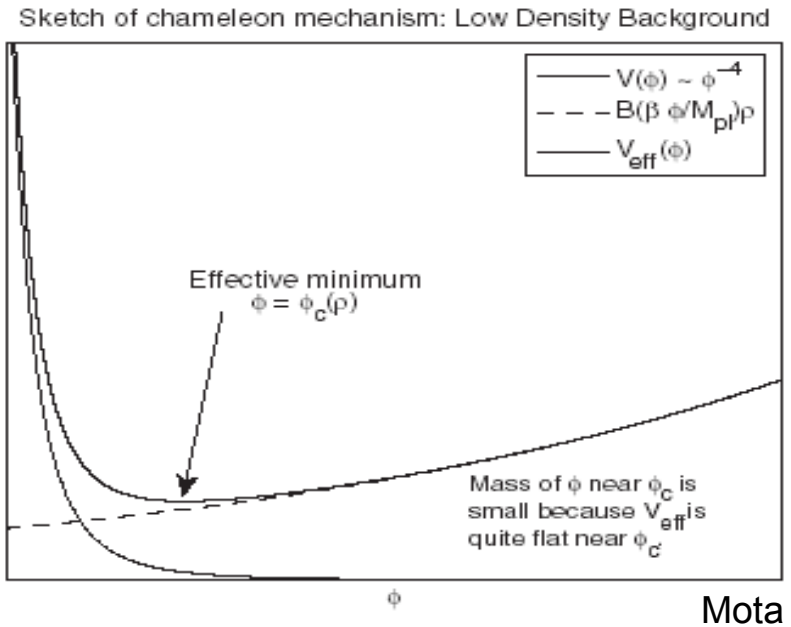
The Chameleon Effect

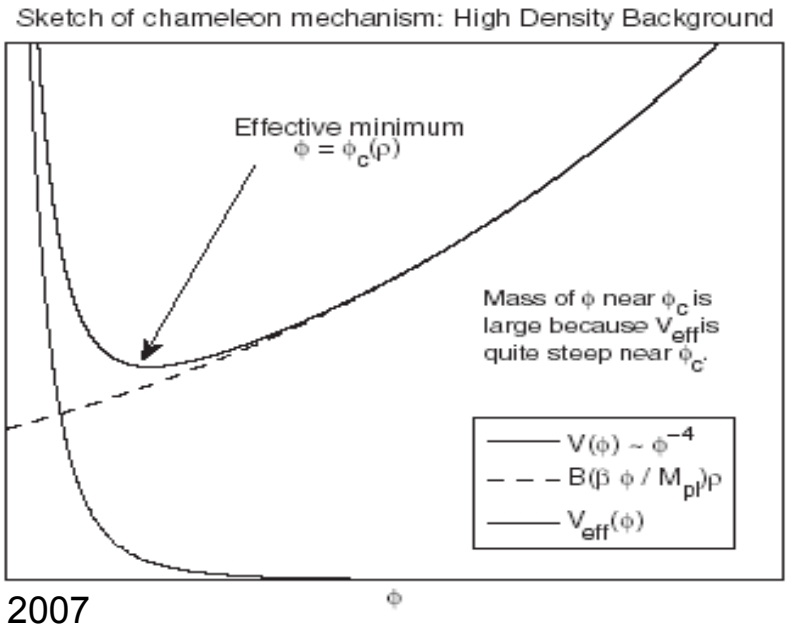
$$S = \int d^4x\sqrt{-g}\left[\frac{R}{16\pi G} - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) - \frac{1}{4}e^{\frac{\beta_\gamma\phi}{M_{\rm Pl}}}F_{\mu\nu}F^{\mu\nu} + \mathcal{L}_m\left(e^{\frac{2\beta_{\rm m}\phi}{M_{\rm Pl}}}g_{\mu\nu}, \psi_{\rm m}^{(i)}\right)\right]$$

chameleon potential

photon coupling

matter coupling





Mota & Shaw 2007