Searching for New Particles Beyond the Standard Model by Proton Bremsstrahlung

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- Many proposals for new physics beyond the Standard Model predict novel, weakly interacting, light scalar or vector particles (e.g. Majorons, axions, Kaluza-Klein modes).
- Novel light particles could be responsible, among other things, for solving the strong CP problem in QCD, giving neutrinos their mass, or even explaining the origin of Dark Energy.
- Searches for such light particles will be extremely difficult at the high energy colliders designed to search for new, high mass particles.
- However, these light particles can be readily produced by proton bremsstrahlung! (Complementary to collider & dark matter searches)

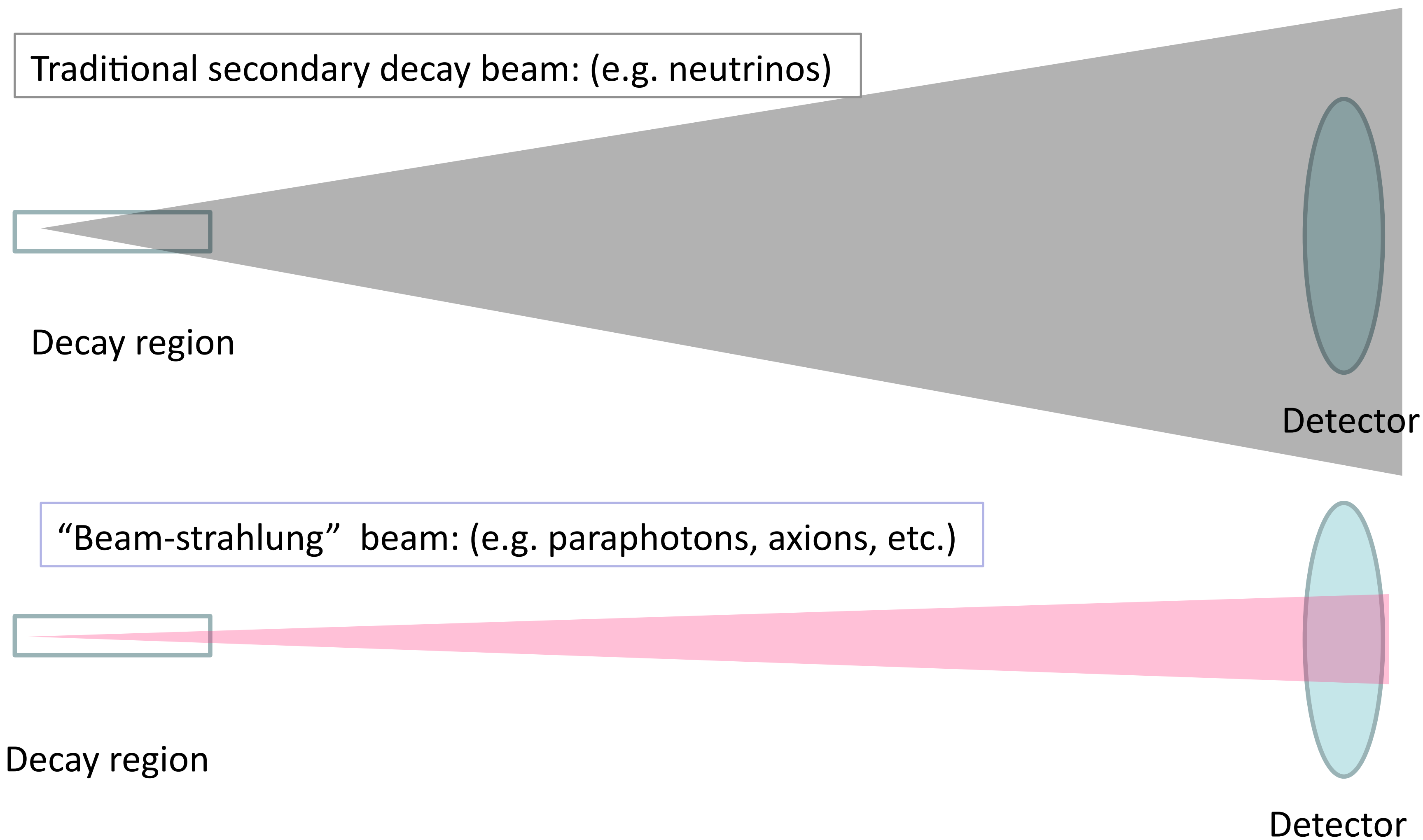
Why are neutrino experiments useful for new particle searches?

- Have a large number of protons on target (>10^{21}!!)

- Usually located a fair distance from the target so that backgrounds from neutrino interactions are low (~$1/r^2$), while the exotic particle flux is collimated and remains constant with r.
  - A spatially large detector contains these collimated events and makes identification easier.
  - Good beam and reconstruction timing (~nsec) allows for searches of heavy particles (> MeV).

- *The "brem-ed" particles will be tightly collimated around the incoming proton beam direction (<~0.5 mrad) and will either decay or scatter in the center of the detector (assuming on-axis beam!)*

Beam-strahlung beam



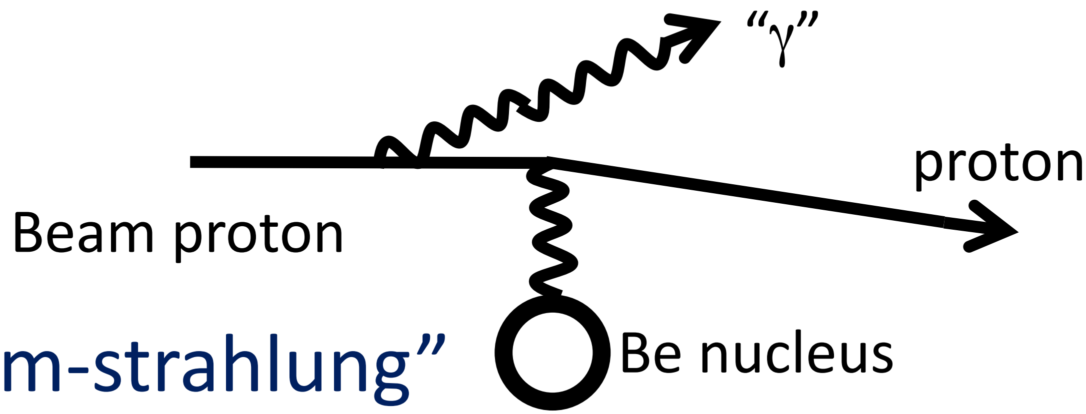
One example: "Paraphoton"[1]

- Gauge boson for a nearly unbroken $U(1)_{B\text{-}L}$ symmetry
- Mass ~10 KeV (to evade bounds from 5th force measurements it needs to be short range)
- Astrophysics does not obviously exclude the light paraphoton because the mass is density dependent (in a supernova the particle becomes much more massive)
- Couples weakly ($g^2/\alpha \sim 10^{-9}$) to a "B-L" charge (for neutral matter this is proportional to number of nucleons)
- Generates an MSW-like potential in matter which affects neutrino oscillations in short baseline expts.
- Antineutrino and neutrino MSW-like effects are very different when caused by paraphotons

[1]A. Nelson and J. Walsh (arXiv:0711.13663)

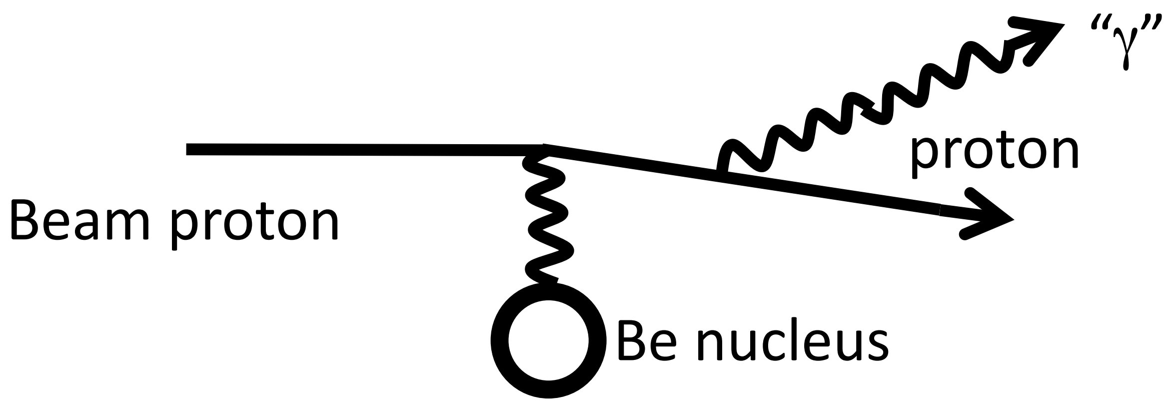
Paraphoton Production via Bremsstrahlung

I



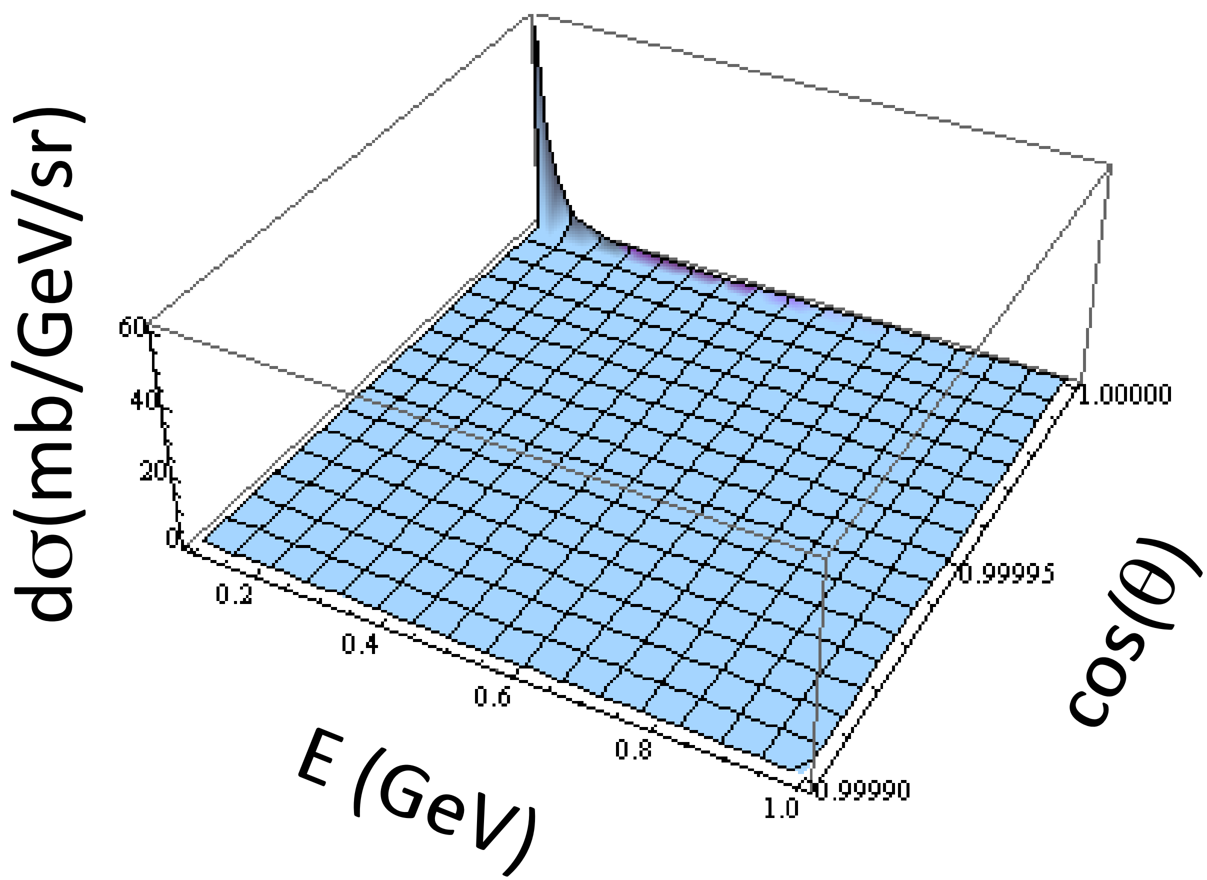
"beam-strahlung"

II



Paraphoton Production Forward Peaked

• “beam-strahlung” cross section is forward peaked along beam direction and peaked at low energy



$g^2 = 10^{-9}\ \alpha_{QED}$

Conclusions

- Neutrino Experiments can search with very high sensitivity for new scalar & vector boson production by proton bremsstrahlung
- These new particles will be produced in the forward directions and can either scatter or decay in the center of the detector
- Project X would provide 10x the current intensity (>2E21 POT per year)!
  - Coupled with a dedicated beam dump to reduce neutrino backgrounds, can make extremely sensitive searches.

Backup

Estimated Rates from the Paraphoton Model of Nelson & Walsh

- Described in arXiv:0711.1363, “Short Baseline Neutrino Oscillations and a New Light Gauge Boson”, Ann Nelson & Jonathan Walsh
- The new light gauge vector boson (“paraphoton”) has a mass of ~10 keV, a lifetime of ~2.5 ns, and a coupling strength of $g^2/e^2 \sim 10^{-9}$
- BR(P –> $\nu\nu$) ~ 100%, BR(P->$\gamma\gamma\gamma$) ~ 10^{-7}
- The paraphotons can be produced by hadronic bremsstrahlung ($1/E_\gamma$) of the incident proton beam (~1%) in the forward direction (<5 mrad). Approximately all paraphotons will pass through the neutrino detector with little attenuation.

Paraphoton Decay In MB

- Assume PID & Fiducial Volume efficiency ~ 50%
- Probability of decay in MB ~ 5m/$\gamma c\tau$ = 5m/25km = 2E-4
- Angle of decay products ~1/γ ~ 0.0001
- #events = (2E20 POT)(1%)(1E-9)(2E-4)(1E-7)(50%) = **0.01 events** in the forward direction

Paraphoton EM Shower In MB

- Assume PID & Fiducial Volume efficiency ~ 50%
- Assume 50 cm radiation length
- Angular resolution ~3 degrees
- Number of radiation lengths in MB ~ 5m/50cm = 10
- #events = (2E20 POT)(1%)(1E-9)(1E-9)(10)(50%) = **10 events** in the forward direction!