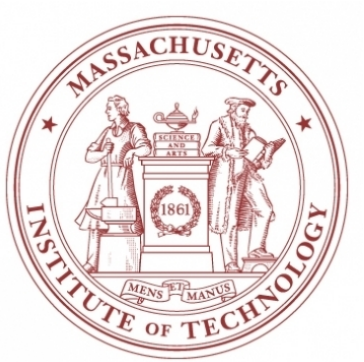
Searching for Physics Beyond the Standard Model at GlueX

Justin Stevens & Mike Williams

Department of Physics

Massachusetts Institute of Technology



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Searching for BSM Particles

There are two main ways of observing particles:

- producing them and observing their decay products (direct);
- observing their (virtual) effects on lower-energy observables (indirect).

As an analogy, consider the two ways of observing a planet:

- observing light reflected off the planet with a telescope (direct);
- observing its parent star wobbling (indirect).

Just like we can observe stars without access to telescopes powerful enough to observe them directly; we can observe/study particles that are too heavy to produce directly (of course, BSM particles might also be light!)

Bottom line: GlueX can search for light and heavy BSM particles.

Light or Heavy?

Heavy

Just about every BSM theory postulates the existence of new heavy particles so let's just accept that searches for their effects are *interesting* (even though the SM might be stable up to the Planck scale making heavy BSM unnecessary; see, *e.g.*, arxiv:0912.0208).

Light

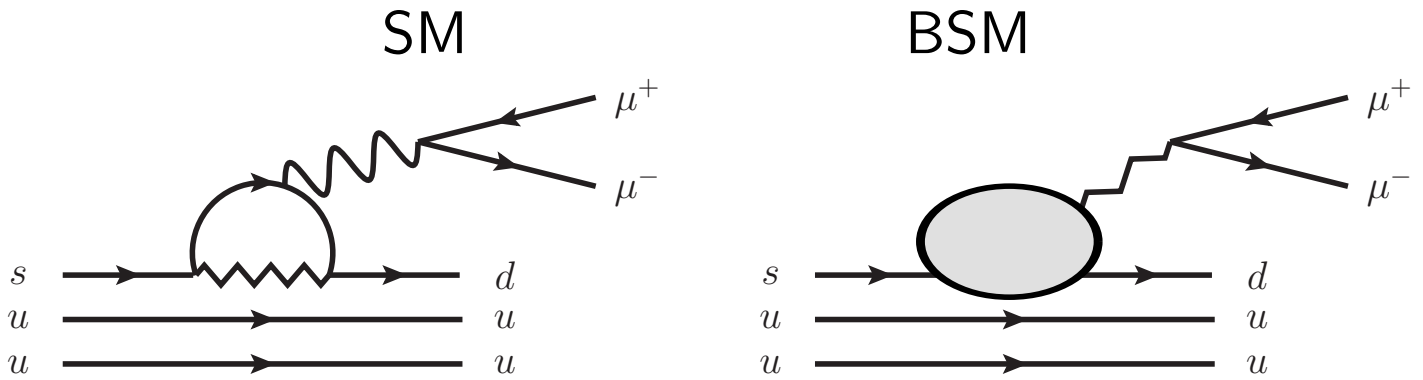
In many theories new light particles appear as a consequence of some broken symmetry. Beyond this, there is some evidence suggesting dark matter may have a light X boson: PAMELA & Fermi both observe a e^+/e^- excess at high energies in cosmic rays; no $\bar{p}/p$ excess is observed.

The easiest way to explain e^+/e^- excess but no $\bar{p}/p$ is $m_X < 2m_p$. Depending on m_X, $X \to \mu^+\mu^-, \pi^+\pi^-, K^+K^-$ may also be allowed.

So, we should look for light bosons decaying to leptons.

$\Sigma^+ \to p\mu^+\mu^-$

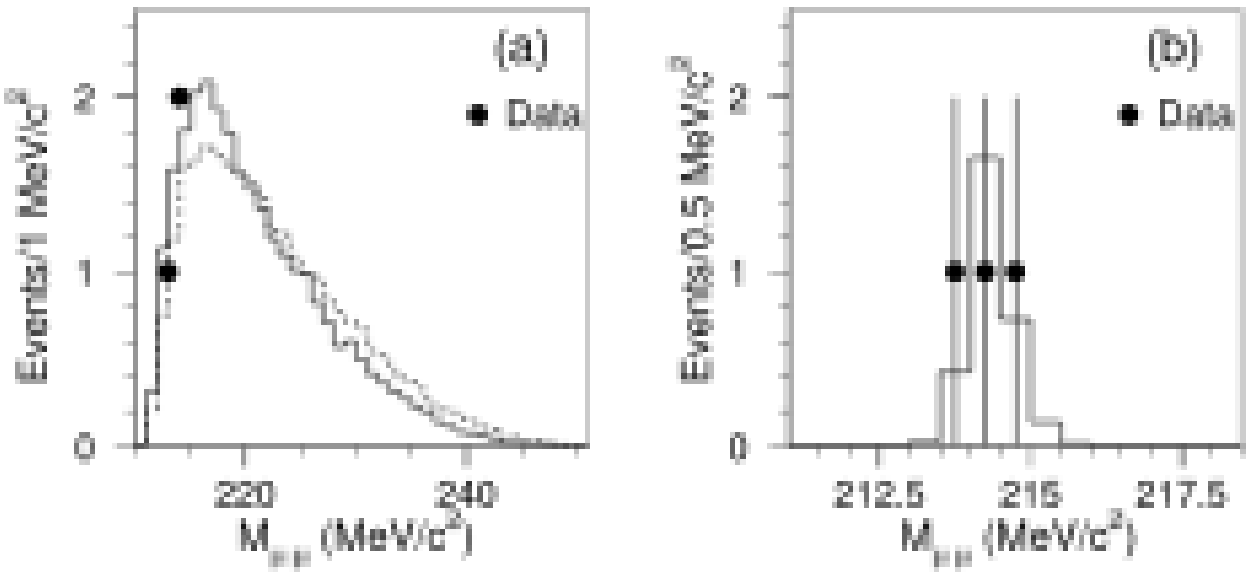
In the SM, $\Sigma^+ \to p\mu^+\mu^-$ is a penguin decay with a predicted branching ratio $\mathcal{O}(10^{-8})$.



BSM physics can enter either as a heavy virtual particle in the loop or as a FCNC mediated by a light boson that decays to $\mu^+\mu^-$.

HyperCP Anomaly

In 2005, HyperCP found the first evidence for $\Sigma^+ \to p\mu^+\mu^-$ [arXiv:hep-ex/0501014]. They observed 3 events (with no BKGD) yielding $\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = (8.6^{+6.6}_{-5.4} \pm 5.5) \times 10^{-8}$.



The interesting thing though is that $m_{\mu\mu}$ is not consistent with the SM expectation but rather $m_X = 214.3 \pm 0.5$ MeV.

HyperCP Anomaly

Of course, it's only 3 events but this paper has been cited close to 100 times. What we know about X (if it's real):

- It can't be a scalar or vector otherwise it would've been observed in $K \to \pi X$ decays. If it's a pseudoscalar it would show up in $K \to \pi\pi X$ decays but at a level low enough to have avoided existing searches.
- It's $c\tau \leq 1$ cm (otherwise HyperCP wouldn't have seen it).

Why so much interest? Well, anamolies are rare these days and theorists need something to do. Also, this makes 3 anamolies involving muons: (1) HyperCP; (2) $(g-2)_\mu$ and (3) r_p in H_μ ... and, of course, the e^+/e^- excess in cosmic rays makes 4 involving leptons.

GlueX?

Some key (but rough) GlueX numbers for $\Sigma^+ \to p\mu^+\mu^-$:

- The Σ^+ production rate is about 800 Hz under high-intensity (HIT) conditions. Assuming 270 days of running at 70% efficiency that's 1.4×10^{10} Σ^+ produced in a nominal year at GlueX.
- $\epsilon_{\mathrm{reco}} \sim 60\%$.
- $\epsilon_{\mathrm{trig\cdot sel}} \sim 50\%$.
- $N(\Sigma^+ \to p\mu^+\mu^-) \sim 300/\mathrm{yr}$.

So, if HyperCP is *right* we might see something interesting in year one. Either way, we will confirm/deny this anamoly after one HIT year.

If we do find evidence for a light X, then we'd even have enough stats to say something about its J^P.

$\Sigma^+ \to p\mu^+\mu^-$ & Friends

If an X particle is contributing to this decay, where else can we look for it?

- $\Sigma^+ \to pe^+e^-$: Various models for the X predict vary different things here. In some models, $\mathcal{B}(X \to \mu^+\mu^-) \gg \mathcal{B}(X \to e^+e^-)$, while in others they are $\approx$.
- $\Lambda \to ne^+e^-$ (the $\mu^+\mu^-$ decay is kinematically forbidden).
- $K_S \to \pi^+\pi^- X$, $X \to \mu^+\mu^-, e^+e^-, \gamma\gamma$: These $\mathcal{B}$'s are expected to be $10^{-11} - 10^{-8}$ (more on K_S decays on the next slide).

I've omitted decays with ≤ 1 charged track since we would not be able to cut on a displaced vertex. It may be possible though to do some of these, *e.g.*, $\Sigma^+ \to p\gamma\gamma$, with enough statistics using exclusive reactions.

GlueX as K_S Factory

GlueX will also be a K_S factory producing them at roughly 6 kHz; that's 10^{11} produced per nominal HIT year!

Some Interesting K_S Decays

N.b., $\ell = e, \mu$; yields are for HIT years using GlueX MC efficiencies and assuming $\epsilon_{\text{trig·sel}} \sim 50\%$.

- $K_S \to \pi^+\pi^- X, X \to \ell^+\ell^-, \gamma\gamma$: Expect $\mathcal{O}(1 - 1000)$/HIT yr. The 4-body decay $\mathcal{B}_{ee} = (4.79 \pm 0.15) \times 10^{-5}$ making it the dominant *background*.
- $K_S \to \pi^0\ell\ell$: $\mathcal{B}_{\text{PDG}} = (3.0^{+1.5}_{-1.2} \times 10^{-9})_{ee}, (2.9^{+1.5}_{-1.2} \times 10^{-9})_{\mu\mu}$ (from 7, 6 events). Can look for X but also better measurement needed of SM $\mathcal{B}$ as utility measurement for BSM searches in $K_L \to \pi^0\ell^+\ell^-$. Expect ~ 90/HIT yr; we will make the World's best measurements quickly.

GlueX as K_S Factory

- $K_S \to \ell\ell$: $\mathcal{B}_{\rm PDG} < (9 \times 10^{-9})_{ee}, < (3.2 \times 10^{-7})_{\mu\mu}$; $\mathcal{B}_{\rm SM} \sim 2 \times 10^{-14}_{ee}, 5 \times 10^{-12}_{\mu\mu}$. Very sensitive to BSM; limits close to $\sim 10^{-11}$ would put stringent constraints on many BSM models. $K_S \to \mu\mu$ requires a muon system (would be a fairly high-profile measurement).
- $K_S \to \pi^+\pi^-\pi^0$: $\mathcal{B}_{\rm PDG} = 3.5^{+1.1}_{-0.9} \times 10^{-7}$. GlueX will have $\sim$ 10k events/HIT yr. I have never seen any theory papers on this decay but we'd have enough events to look for CPV in the Dalitz plot (see MW, PRD 84, 054015 (2011)). That would be interesting. I will probably look into writing a paper on this.
- $K_S \to \ell\ell\gamma$: No measurements yet. Highly suppressed in SM so BSM could be visible: $\mathcal{B}_{\rm SM} \sim (3 \times 10^{-8})_{ee}, (7 \times 10^{-10})_{\mu\mu} \to 900, 20$ events/HIT yr (μ decay need μ/π separation).
- *Etc.*, too many to list them all here.

More BSM Physics at GlueX

More Tests of SUSY/DM

There are a number of other possible decays to look for. We are looking into this to see: (a) which decays we can make the World's best measurements of at GlueX and (b) which decays are interesting for BSM physics searches.

Purely Speculative Searches

- BSM should couple weakly; thus, produce displaced vertices. So, displaced vertices are where we'll look (excluding detector material of course). Can look for peaks of non $K_S, \Lambda, \Sigma, \ldots$ masses.
- LFV: Take any decays above (or other decays) and make the ℓ's different flavors; *i.e.*, look for $e^-\mu^+X$ instead of e^-e^+X.
- LNV: Look for $\mu^+\mu^+X^-$ final states.
- *Etc.*, too many to list them all here but you get the point.

What GlueX Needs

Trigger

Many of these decays can be measured "as is" provided we record them. The key is to be able to trigger as generically as possible on interesting BSM decays. Displaced vertices should be easy enough to trigger on.

Muon PID

For a number of these the kinematic separation of pion and muon decay modes isn't enough to overcome the many orders of magnitude difference in the $\mathcal{B}$'s. A forward muon system should do it for most of these (and be fairly cheap and easy to build). We will look into other options as well.

Kaon ID

About 50% of Σ^+, Λ, K_S also have a $K^\pm$ in the event. If we can identify these we can clean things up (even in inclusive measurements).

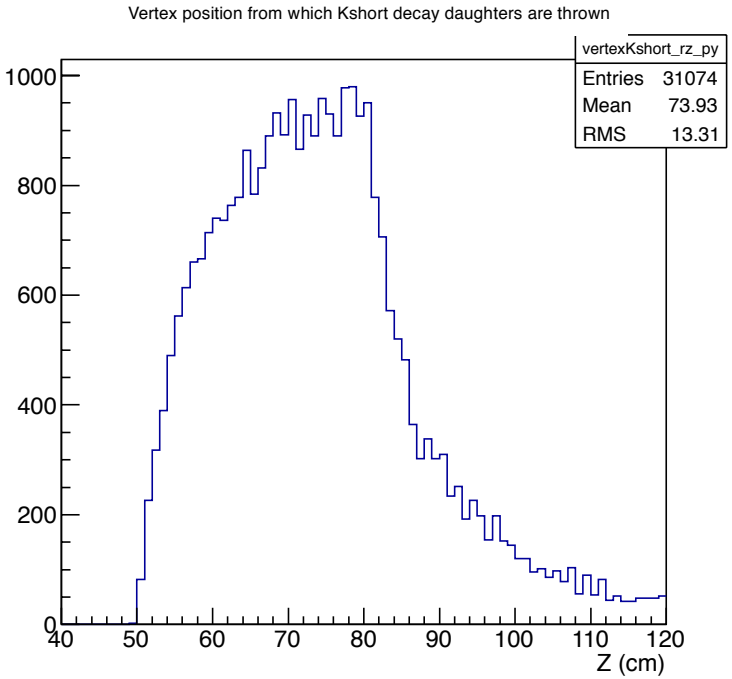
More Luminosity

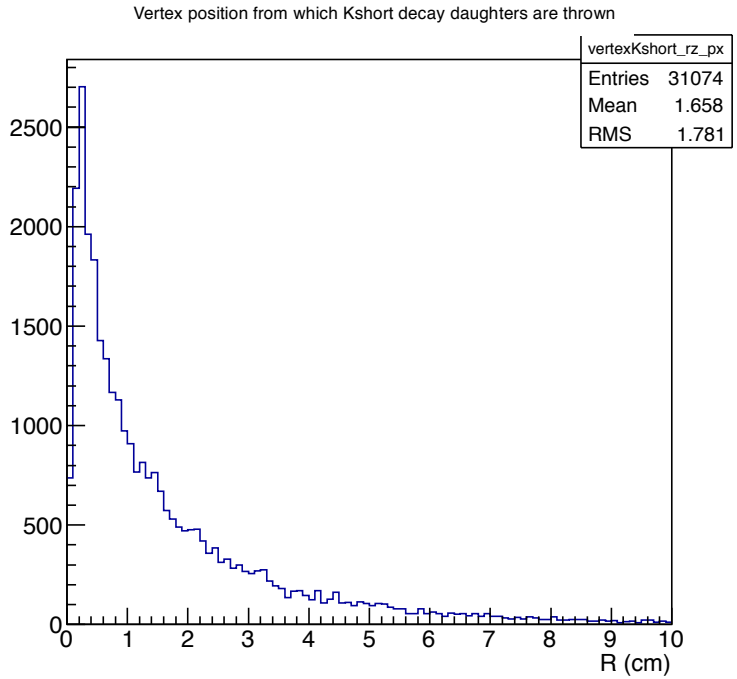
If we find something interesting we could do a special run designed to maximize the high-energy photon luminosity.

Summary

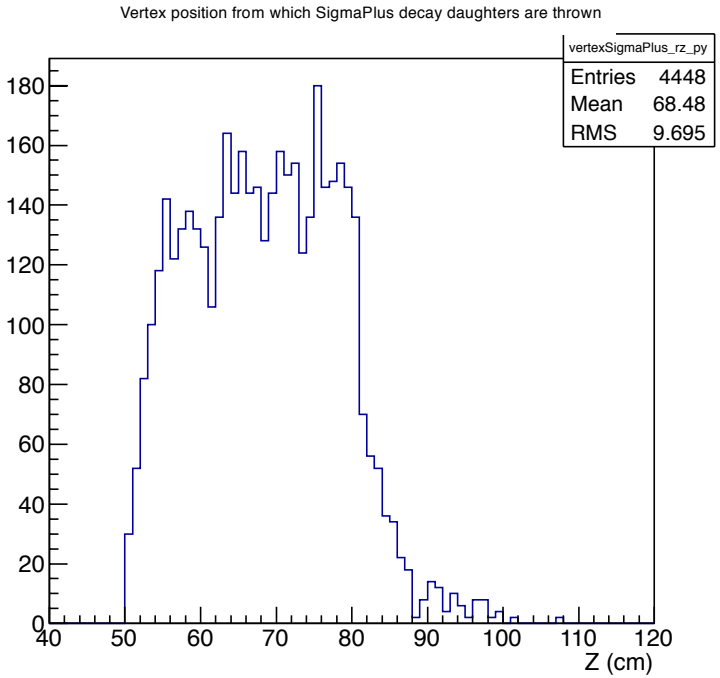
- GlueX will be a hyperon and K_S factory with yields expected to be $10^{10} - 10^{11}$/HIT yr. This will allow us to make the World's best measurements of many flavor-changing rare decays.
- BSM may be light enough for us to produce it at JLab and observe it GlueX.
- $\Sigma^+ \to p\mu^+\mu^-$ is a *no brainer* but there are many other places to look. I will look into the theory side to try and paint a clearer picture of where all we should be looking.
- We will need to design a high-level trigger for displaced vertices (should be doable). A muon system (or other muon PID) would expand our BSM potential.

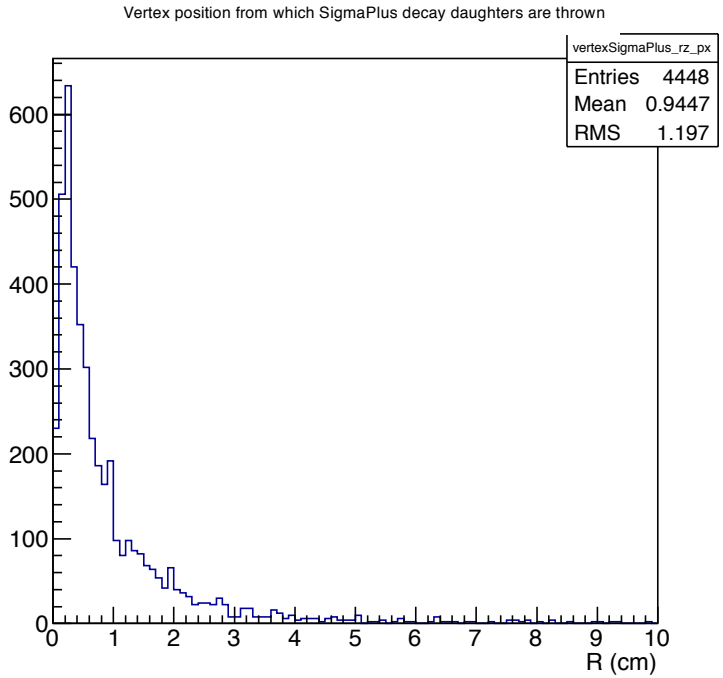
Back Up: K_S Vertices





Back Up: Σ^+ Vertices





Back Up: Λ Vertices