Acceptance Studies for Dark Sectors

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Introduction

HPS is optimized for sensitivity to dark photons decaying into electrons

It is important to keep in mind that dark sectors may be more complicated than the Arkani-Hamed & friends model

- Hidden valley scenarios in general (esp if no new physics at LHC Run2)

In this talk:

- Assume dark photon decays into pairs of $W'$, which in turn decay into electron pairs. Very different kinematics, plus $W'$ can be long-lived.
- Test acceptance of different detector configurations to different lifetimes / masses / etc ($M_{A'}$, $M_{W'}$, $c\tau$, $E_{\text{beam}}$, B grid)

Toy simulation:

- Tracker layers (0 to 90 cm) in magnetic field, no field between 90 cm and ECAL
- Propagate electrons as helixes through magnetic field
- Count “hits” on the tracks

Only mess with the tracker so far

- Larger ECAL may help, but here treat it as mainly a trigger device
A' → W' W' → 4e

Compared to A' search, we have extra $\alpha^2$ working in our favor since the “physics” background is now order $\alpha^4$, plus 3 mass peaks instead of one.

The main issue is efficiency:
- For 300 MeV and $\varepsilon=10^{-6}$ one gets $N \sim \left( \frac{N_e}{1C} \right) \tilde{\chi} \left( \frac{T}{0.1} \right) \left( \frac{\varepsilon}{10^{-4}} \right)^2 \left( \frac{100 \text{ MeV}}{m_{A'}} \right)^2$
Sources of inefficiency

- Large angle tracks are softer (mostly for large $m(A')/E_{beam}$)
- Heavily boosted tracks (mostly for small $m(A')/E_{beam}$)
- Large lifetimes
“HPS”-like geometry

Note how the angular acceptance in vertical is much smaller than horizontal.
Trying to equalize the large angle acceptance
\sim 2 \times \text{the silicon area}
Same as 1, but close the gap near the “sheet of death” by a factor of 2
• May not be feasible, but great diagnostics that tells you where you looses the particles
Enhance the large angle acceptance

~ 5 times the silicon area
Acceptance

Need to cut on number of hits on the track

Three configurations

- 4 tracks with $\geq 4$ hits, 2 out of them with $\geq 5$
- 4 tracks with $\geq 4$ hits
- 4 tracks with $\geq 3$ hits, 3 out of them with $\geq 4$

Two trigger conditions

- no trigger 😊
- $\geq 2$ clusters with $E/E_{\text{beam}} > 0.08$ and total ECAL energy $> 0.3 E_{\text{beam}}$
Example Acceptances: HPS-like

$M_{A'} = 0.2 \text{ GeV}$
$M_{W'} = 0.08 \text{ GeV}$
$E_{\text{beam}} = 2.2 \text{ GeV}$

Red: $c\tau = 0$

Blue: $c\tau = 2\text{cm}$

Purple: $c\tau = 4\text{cm}$

Have to accept shorter tracks for long-lived $W'$
Example Geometry vs $E_{\text{beam}}$

Red: 2.2 GeV, Blue: 3.3 GeV, Purple: 4.4 GeV
Example Geometry Impact

- For small mass it’s important to go closer to the beam
- For large mass it’s important to have wide angles
Note that the most favorable $E_{\text{beam}}$ is different for prompt and long-lived.
Lifetime vs. Geometry

\[ M_{A'} = 0.2 \text{ GeV} \]
\[ M_{W'} = 0.08 \text{ GeV} \]
\[ E_{\text{beam}} = 2.2 \text{ GeV} \]
Lifetime vs. Geometry

\[ M_{A'} = 0.2 \text{ GeV} \]
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Larger trackers especially useful for long-lived scenarios

\[ M_{A'} = 0.2 \text{ GeV} \]
\[ M_{W'} = 0.08 \text{ GeV} \]
\[ E_{\text{beam}} = 4.4 \text{ GeV} \]
Not BG-free possibilities

- Fully detect one of the W’ and one track from the other
  - Estimates show extra factors of 2 in eff

- Detect just one of the W’
  - Works also when A’ → W’ + MET
  - Large background from tridents – will have to rely on the transverse kick of the W’
    - Need to have a realistic BG simulation
    - Trigger becomes a problem?

- Need to understand ultimate B-factories reach for topologies like this
Summary

We started making steps towards fixed target study of more complex hidden sectors.

The main problem seems to be the acceptance.

Depending on the masses and lifetimes:
- Doubling tracker area results in a factor of 2-3 in efficiency.
- Going to 5x the area gives ~5 times improvement.
  (note that the HPS silicon area is very small).

For the chosen topology, requiring trigger in ECAL cost about factor of 2 in acceptance.
  One can think about alternative ways to trigger.

Just starting up, need BG and more topologies / options to consider.