Searches for exotic Dark Matter at ATLAS and CMS

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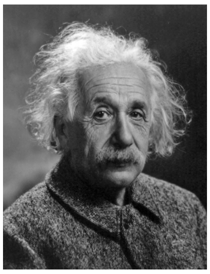

The nature of dark matter is still a mystery. Many direct and indirect search experiments are trying to solve this puzzle. The LHC offers a unique opportunity at the high energy frontier, where dark matter particles or related new particles may be produced and detected. Both the CMS and ATLAS collaborations have carried out comprehensive dark matter search programs, providing critical experiemntal results. In this article, recent exotic dark matter searches in CMS and ATLAS are summarized and a brief outlook is given.

1 Introduction

The nature of DM remains a mystery and there are many Beyond Standard Model (BSM) theories proposed to offer an explanation. LHC [2] offers a unique opportunity to search for Dark Matter (DM) and related new particles at the high energy frontier. ATLAS [4] and CMS [3] are the two general-purpose detectors at the LHC that are capable of searching for new particles using a rich set of signatures. Both experiments have carried out comprehensive sedicated DM search programs, primarily in the following categories:

- Mono-X Signature: DM candidates are produced in association with another detectable Standard Model (SM) physics object (X). The non-interacting DM candidates give rise to a sizable missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$). The detectable physics object can be a jet, photon, Z boson or Higgs boson, etc.

- Resonance Signature: The mediator coupled to DM candidates is produced resonantly, decaying to SM particles to form a peak in the invariant mass spectrum. The SM pariticles can be a pair of jets, leptons or bosons, etc.

- Associated Production with Heavy Flavor Quarks:

- Higgs Portal:

- Supersymmetry Searches:

2 Dedicated search results

2.1 Producing the Hard Copy

The hard copy may be printed using the procedure given below. You should use two files: [a]

`moriond.cls` the style file that provides the higher level LaTeX commands for the proceedings. Don't change these parameters.

`moriond.tex` the main text. You can delete our sample text and replace it with your own contribution to the volume, however we recommend keeping an initial version of the file for reference.

The command for (pdf)LaTeXing is `pdflatex moriond`: do this twice to sort out the cross-referencing.

Page numbers should not appear.

2.2 Headings and Text and Equations

Please preserve the style of the headings, text fonts and line spacing to provide a uniform style for the proceedings volume.

Equations should be centered and numbered consecutively, as in Eq. 1, and the *eqnarray* environment may be used to split equations into several lines, for example in Eq. 3, or to align several equations. An alternative method is given in Eq. 2 for long sets of equations where only one referencing equation number is wanted.

In LaTeX, it is simplest to give the equation a label, as in Eq. 1 where we have used `\label{eq:murnf}` to identify the equation. You can then use the reference `\ref{eq:murnf}` when citing the equation in the text which will avoid the need to manually renumber equations due to later changes. (Look at the source file for some examples of this.)

The same method can be used for referring to sections and subsections.

2.3 Tables

The tables are designed to have a uniform style throughout the proceedings volume. It doesn't matter how you choose to place the inner lines of the table, but we would prefer the border lines to be of the style shown in Table 1. The top and bottom horizontal lines should be single (using `\hline`), and there should be single vertical lines on the perimeter, (using `\begin{tabular}{|...|}`). For the inner lines of the table, it looks better if they are kept to a minimum. We've chosen a more complicated example purely as an illustration of what is possible.

The caption heading for a table should be placed at the top of the table.

2.4 Figures

If you wish to 'embed' an image or photo in the file, you can use the present template as an example. The command `\includegraphics` can take several options, like `draft` (just for testing the positioning of the figure) or `angle` to rotate a figure by a given angle.

The caption heading for a figure should be placed below the figure.

[a] You can get these files from our site at http://moriond.in2p3.fr/proceedings.php.

Table 1: Experimental Data bearing on $\Gamma(K \rightarrow \pi\pi\gamma)$ for the K^0_S, K^0_L and K^- mesons.

	$\Gamma(\pi^-\pi^0)\ s^{-1}$	$\Gamma(\pi^-\pi^0\gamma)\ s^{-1}$	
Process for Decay			
K^-	1.711×10^7	2.22×10^4 (DE 1.46×10^3)	No (IB)-E1 interference seen but data shows excess events relative to IB over $E^*_\gamma = 80$ to $100 MeV$

2.5 *Limitations on the Placement of Tables, Equations and Figures*

Very large figures and tables should be placed on a page by themselves. One can use the instruction `\begin{figure}[p]` or `\begin{table}[p]` to position these, and they will appear on a separate page devoted to figures and tables. We would recommend making any necessary adjustments to the layout of the figures and tables only in the final draft. It is also simplest to sort out line and page breaks in the last stages.

2.6 *Acknowledgments, Appendices, Footnotes and the Bibliography*

If you wish to have acknowledgments to funding bodies etc., these may be placed in a separate section at the end of the text, before the Appendices. This should not be numbered so use `\section*{Acknowledgments}`.

It's preferable to have no appendices in a brief article, but if more than one is necessary then simply copy the `\section*{Appendix}` heading and type in Appendix A, Appendix B etc. between the brackets.

Footnotes are denoted by a letter superscript in the text,[b] and references are denoted by a number superscript.

Bibliography can be generated either manually or through the BibTeX package (which is recommanded). In this sample we have used `\bibitem` to produce the bibliography. Citations in the text use the labels defined in the bibitem declaration, for example, the first paper by Jarlskog [1] is cited using the command `\cite{ja}`.

2.7 *Photograph*

You may want to include a photograph of yourself below the title of your talk. A scanned photo can be directly included using the default command
`\newcommand{\Photo}{\includegraphics[height=35mm]{mypicture}}`
just before the `\begin{document}` line. If you don't want to include your photo, just comment this line by adding the `%` sign at the beginning of the line and uncomment the next one `%\newcommand{\Photo}{}` by removing its `%` sign.

2.8 *Final Manuscript*

All files (.tex, figures and .pdf) should be sent by the **15th of May 2017** by e-mail to **moriond@in2p3.fr**.

[b] Just like this one.

3 Sample Text

The following may be (and has been) described as 'dangerously irrelevant' physics. The Lorentz-invariant phase space integral for a general n-body decay from a particle with momentum P and mass M is given by:

$$I((P-k_i)^2, m_i^2, M) = \frac{1}{(2\pi)^5}\int \frac{d^3k_i}{2\omega_i}\delta^4(P-k_i). \tag{1}$$

The only experiment on $K^\pm \to \pi^\pm\pi^0\gamma$ since 1976 is that of Bolotov *et al.* [?] There are two necessary conditions required for any acceptable parametrization of the quark mixing matrix. The first is that the matrix must be unitary, and the second is that it should contain a CP violating phase δ. In Sec. 2.4 the connection between invariants (of form similar to J) and unitarity relations will be examined further for the more general $n \times n$ case. The reason is that such a matrix is not a faithful representation of the group, i.e. it does not cover all of the parameter space available.

$$\begin{aligned}
\mathbf{K} &= Im[V_{j,\alpha}{V_{j,\alpha+1}}^*{V_{j+1,\alpha}}^*V_{j+1,\alpha+1}] \\
&\quad + Im[V_{k,\alpha+2}{V_{k,\alpha+3}}^*{V_{k+1,\alpha+2}}^*V_{k+1,\alpha+3}] \\
&\quad + Im[V_{j+2,\beta}{V_{j+2,\beta+1}}^*{V_{j+3,\beta}}^*V_{j+3,\beta+1}] \\
&\quad + Im[V_{k+2,\beta+2}{V_{k+2,\beta+3}}^*{V_{k+3,\beta+2}}^*V_{k+3,\beta+3}] \\
\\
\mathbf{M} &= Im[{V_{j,\alpha}}^*V_{j,\alpha+1}V_{j+1,\alpha}{V_{j+1,\alpha+1}}^*] \\
&\quad + Im[V_{k,\alpha+2}{V_{k,\alpha+3}}^*{V_{k+1,\alpha+2}}^*V_{k+1,\alpha+3}] \\
&\quad + Im[{V_{j+2,\beta}}^*V_{j+2,\beta+1}V_{j+3,\beta}{V_{j+3,\beta+1}}^*] \\
&\quad + Im[V_{k+2,\beta+2}{V_{k+2,\beta+3}}^*{V_{k+3,\beta+2}}^*V_{k+3,\beta+3}],
\end{aligned} \tag{2}$$

where $k = j$ or $j+1$ and $\beta = \alpha$ or $\alpha+1$, but if $k = j+1$, then $\beta \neq \alpha+1$ and similarly, if $\beta = \alpha+1$ then $k \neq j+1$.[c] There are only 162 quark mixing matrices using these parameters which are to first order in the phase variable $e^{i\delta}$ as is the case for the Jarlskog parametrizations, and for which J is not identically zero. It should be noted that these are physically identical and form just one true parametrization.

$$\begin{aligned}
T &= Im[V_{11}{V_{12}}^*{V_{21}}^*V_{22}] \\
&\quad +Im[V_{12}{V_{13}}^*{V_{22}}^*V_{23}] \\
&\quad -Im[V_{33}{V_{31}}^*{V_{13}}^*V_{11}].
\end{aligned} \tag{3}$$

Acknowledgments

This is where one places acknowledgments for funding bodies etc. Note that there are no section numbers for the Acknowledgments, Appendix or References.

Appendix

We can insert an appendix here and place equations so that they are given numbers such as Eq. 4.

$$x = y. \tag{4}$$

[c] An example of a matrix which has elements containing the phase variable $e^{i\delta}$ to second order, i.e. elements with a phase variable $e^{2i\delta}$ is given at the end of this section.

Figure 1 – same figure with draft option (left), normal (center) and rotated (right)

References

1. C Jarlskog in *CP Violation*, ed. C Jarlskog (World Scientific, Singapore, 1988).
2. L. Evans and P. Bryant (editors), JINST **3**, S08001 (2008).
3. CMS Collaboration, JINST **3**, S08004 (2008).
4. ATLAS Collaboration, JINST **3**, S08003 (2008).