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Dark Photon Search simulation using New proposed FoCAL Detector

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Abstract: In number of proposed DARK sector models, Dark-photons ($\bar{\gamma}$) are hypothetical constituents. In these, we can consider those models which are experimentally verifiable. Among them Dark U $(1)_F$ models predicts that Higgs boson couples to a Photon and a Dark Photon ($H\rightarrow\gamma\bar{\gamma}$)with a branching fraction of 0.5%at LHC energies. These Dark Photons do not give any signals in the detectors, as they are not detectable. Therefore at LHC, one plausible signal of these events is a monochromatic photon with E_γ is (m_H /2) and missing energy of equivalent amount. We have implemented Forward EM Calorimeter (FoCAL) in ALICE detector at LHC using GEANT code in AliRoot Frame work [1]. FoCAL will be utilized to detect the isolated Photons (γ) and various other ALICE detector components will be utilized to detect Missing Transverse Energy, to detect Dark Photons.

Keywords: Dark Photons, LHC, Forward EM Calorimeter (FoCAL), ALICE Detector, GEANT, AliRoot Framework.

1. Introduction

Dark matter (DM) is expected to be 5 times more abundant in the Universe than ordinary baryonic matter [2], and DM properties are not known yet. It is plausible that the dark sector, which is weakly coupled to the standard model (SM), possesses rich internal structure and interactions. Among the most popular scenarios is the idea that the dark sector contains light or mass less gauge bosons [3] that mediate long-range forces between dark particles. The existence of properties of dark matter is inferred from its gravitational effects on visible matter. DM is not detected till now and is still a greatest mystery in modern Physics .Rotation curve of spiral galaxies implying the presence of dark matter. If we look for Mass-Energy of the known universe which formed after Big Bang, is about 4.9% of baryonic matter. And about 26.8% is Dark Matter, which is about 5 times more than

ordinary matter. Dark Matter does not absorb or radiate light or any other Electromagnetic radiation. Higgs boson couples to a Photon and a Dark Photon ($H \rightarrow \gamma\bar{\gamma}$) with a branching fraction of 0.5% at LHC energies. This channel gives rise to $E\gamma$ is ($m_H/2$) and missing energy of equivalent amount [4]. The E in this case will be more than twice the photon energy in the rare standard-model decay ($H \rightarrow \gamma Z \rightarrow \gamma\nu\bar{\nu}$).

Monophoton plus $\not{E}$ signatures have been used by the LHC experiments to search for NP scenarios such as extra dimensions, super symmetry, DM pair production [5]. A resonant mono photon plus $\not{E}$ signature occurs in the SM rare Higgs decays ($H \rightarrow Z\gamma \rightarrow \gamma\nu\bar{\nu}$) with a energy of about 30 GeV, which is much lower than of (m_H /2) photon energy in ($H \rightarrow \gamma\bar{\gamma}$) . We proceeded in the following way to test the possibility of such DM photon detection. We require measuring a 63 GeV Gamma in our FoCAL Detector. Below we have discussed construction and resolution of our proposed FoCAL detector and also analysis strategy.

2. Forward Calorimeter (FoCAL)

Calorimeters are most useful detectors which allow us to explore new physics in the energy range from eV to more than 10^{20} eV. Till now there is no calorimeter in Alice in the forward direction. The proposal is to put a calorimeter (i.e.) FoCAL (Forward Calorimeter) in Alice at $2.4 \leq \eta \leq 4.0$. The ALICE experiment at the LHC is dedicated for the heavy-ion collisions to exploit the unique physics potential of high energy PP & heavy-ion collisions at LHC energies. Forward Calorimeter (FoCAL) is a sampling EMCAL. It is one of the upgrade plans for the ALICE experiment. FoCAL intends to locate at z =366 cm from Interaction Point. FoCAL detector will do electromagnetic measurements such as photons and π^0, jet measurements and their correlations with respect to the central rapidity region. This High precision photon measurement capability of FoCAL gives us leverage to search for Dark Photon. FoCAL also allows us to study the Parton distributions and high gluon density (Color Glass Condensate) in proton and nuclei at small-x region, which is the key to understand the early thermalization of the hot and dense medium.

The FoCAL design consists of the following parts [6]:

- 40 layers of (W Scintillator)
- Super Modules
- Unit Module

The FoCAL is sampling type calorimeter in which tungsten follows Polystyrene scintillator for all the 40 layers. The tungsten is used as the converter material because of space restriction in the forward region. The Polystrene scintillator gives the better position resolution. Each Polystyrene pad detector is 0.3 mm thick; also tungsten (W) absorber is 0.3mm thick. It has 21 X0 depth and 3 longitudinal segments. The total radiation length of 21 X0 of the modules provides the full energy absorption of the electromagnetic particles up to very high energies.

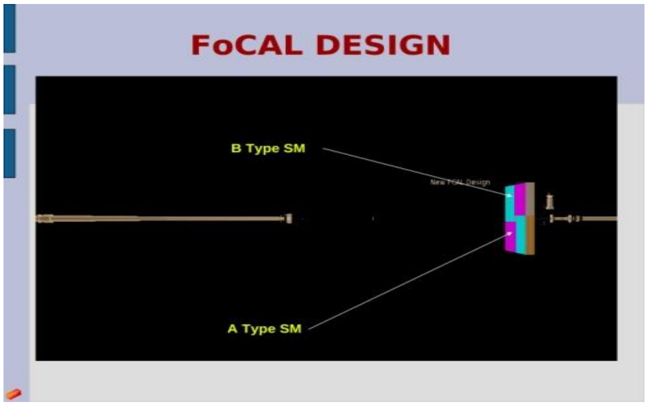

Fig1: An array of 72× 60 cells in A- type super module.

Each layer consists of two types of super modules A − type and B − type. Each type of super module has unit modules distributed in a matrix of specific rows and columns. A − type super module has 30 unit modules distributed in 6 Col × 5 Row while B – type super module has 30 unit module distribute in 5 Col × 6 Row as shown in fig1.

One unit module is 12cm × 12cm giving a total of 144 cells. Thus one cell is a square cell of 1cm × 1cm dimensions. Each unit module has 12 strips arranged in 12 rows. The pair of each A-type and B-type super module is adjusted in such a manner that the center of each layer remains unallocated by any cell as shown in figure 2.

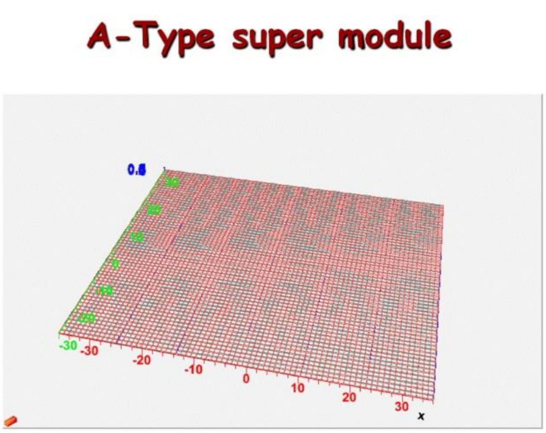

Fig 2: An array of 72 × 60 cells in A- type super module

To test the FoCAL Geometry, we have put a 200 GeV Photon on to FoCAL detector, to see the response. The EM shower has expanded into the detector to various layers. We have summed up the total Energy deposited in each FoCAL Layer and plotted. In the fig 3, one can see that the energy distribution has a nice peak at 18th layer and Energy deposition almost runs up to 36th Layer. It shows that the FoCAL is capable of measuring Photons upto200 GeV and above.

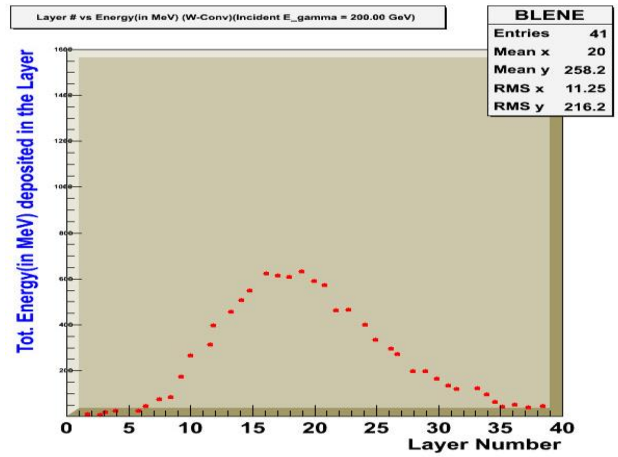

Fig 3- Energy Deposition in various Layers of FoCAL

3. Energy Response of FoCAL for Photons

A full simulation study of the basic characteristics of the FoCAL such as deposited energy distributions, linearity response and relative energy resolutions have been performed. In Calorimeters the Energy response is normally seen as linear and the energy resolution is the most important parameter of the Calorimeter. The absolute energy deposited in each layer must be determined sufficiently well over the entire dynamic range to satisfy minimum requirements for all measurement parameters. The linearity of energy calorimeter response or energy calibration is calculated as described below. This is required for proper reconstruction of particles (photon, electron and pion etc.) of various energies.

One can see for photon energies from 1 GeV to 200 GeV, we have plotted response of the deposited energy “E_{dep}” verses incident Photon energy. From the fig 4, one can see a very linear response of “E_{dep}” and a proportional constant of 50.31 ± 0.2989 are obtained from the linear fit using formula.

y [0] = [p0 + p1 * x (0)].

Where p0 is the y-intercept, p1 is the slope or gradient of line.

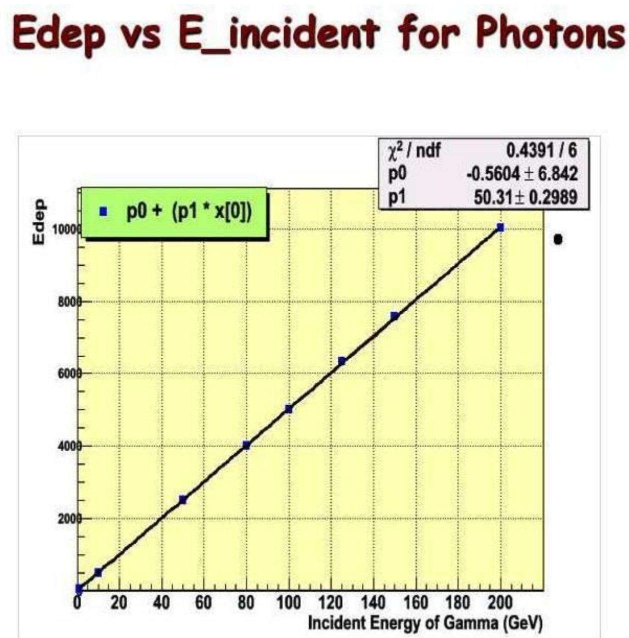

Fig 4- Energy response of Photon 1-200 GeV.

Similarly Electron energy from 1 GeV to 200 GeV is plotted which gave us almost similar proportional constant 50.41 ± 0.264 from the fit for Electrons, showing that the response of FoCAL is as desired for various energies of various particles.

As discussed above the "Edep" response for photons over the energy range 1 - 200 GeV was found to be very linear and also found to be better than 2%. And also similar result was found for electrons. Now looking into the Relative energy resolution of the FoCAL for Photon's as shown in the (Fig.5), where we measured the resolution ($\sigma(E)/E$) =14.18±.1% with tungsten as absorber.

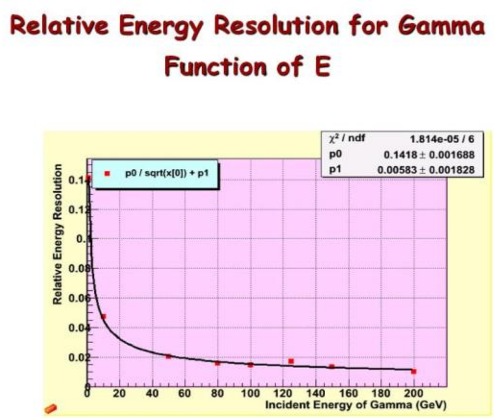

Fig 5- Relative Energy Resolutions of Photons 1-200 GeV.

Similarly in the case of electrons the energy resolution is found to be resolution ($\sigma(E)/E$) = 14.67±.1% which is good.

The energy resolution is found to be ($\sigma(E)/E$) = 14.76±.2 % for π^0 ^{s} as incident particles. The energy resolutions are better when we compared our results with Calorimeters with pb absorbers from other experiments.

It is observed that the energy resolution is better for tungsten absorber of FoCAL in comparison to lead absorbers of other detectors as shown in Table 1. Due to our choice of Tungsten absorber, we can measure Photons with much accuracy and it is the main requirement of our analysis.

4. Analysis Strategies for Dark Photon Identification.

For detecting DM, our analysis requires mono photon plus $\not{E}$ (missing Energy) signature at LHC. Looking for events with a single photon and missing energy, with no jets or leptons, and cutting around the expected maximum of the MT and P_T distributions. These peaks could be relatively easy to pinpoint on top of the continuous relevant backgrounds. Now we formulate the criteria for event selection as follows:

One isolated photon with 50 GeV < P_T < 63 GeV.

- Missing transverse momentum with $\not{E}_T$ > 50 GeV.
- Transverse mass in 100 GeV < MT < 126 GeV.
- No isolated jets or leptons.

Table I: Comparing Energy Resolution

S. No	Experiment	Energy Resolution	Particles	Absorber
1.	FoCAL	$\sigma(E)/E = 14.2\% / \sqrt{E} \oplus 0.3\%$	γ' s	Tungsten
2.	FoCAL	$\sigma(E)/E = 14.7\% / \sqrt{E} \oplus 0.2\%$	electrons	Tungsten
3.	EEMC STAR	$\sigma(E)/E = 15.6\% / \sqrt{E} \oplus 0.8\%$	γ' s	Stainless Steel/Lead
4.	JLC	$\sigma(E)/E = 23.9\% / \sqrt{E} \oplus 0.8\%$	electrons	Lead
5.	ZEUS EPC	$\sigma(E)/E = 32\% / \sqrt{E} \oplus 5\%$	electrons	Lead

The above selection ensures to get the

decayed normal Photon from ($H\rightarrow \gamma\bar{\gamma}$) decay. The signature of Dark Photon will be equal amount of Missing Energy. But there are some other similar events also possess similar Missing Energy criteria. They will form as back ground events, which needed to be identified and isolated, to realize our signal for Dark matter candidates. The most relevant background events[4] are given as follows:

1. ($pp \rightarrow \gamma j$) where large apparent $\not{E}_T$ is created by a combination of real $\not{E}_T$ from neutrinos in heavy quark decays and mismeasured jet energy.
2. ($H\rightarrow \gamma Z \rightarrow \gamma \bar{\nu}$) (irreducible background);
3. ($H\rightarrow jZ\rightarrow j\nu\bar{\nu}$) where the jet is misidenfied as a photon;
4. ($pp\rightarrow W\rightarrow e\nu$) where the electron (positron) is misidenfied as a photon;
5. ($pp\rightarrow \gamma W\rightarrow \gamma l\nu$) where the lepton is missed;
6. ($pp \rightarrow \gamma\gamma$) where one of the photons is missed.

After identifying the back ground events, we can identify the DM signal events. For doing our proposed Dark Photon analysis we require to understand and measure Missing Energy $\not{E}$. For this we use the procedure adopted by CMS [7]. The procedure adopted by CMS is as follow
The missing Transverse Energy (E_T) is determined in the recent versions of the CMS software framework, CMSSW, from the transverse vector sum over uncorrected energy deposits in projective Calorimeter Towers.

$$\not{E}_T = \sum_n^X (E_n \, Sin\, \theta_n Cos\sqrt{n}\ \hat{\imath} + \ E_n Sin\theta_n Sin\sqrt{n}\ \hat{\jmath}) \quad (1)$$

$$\not{E}_T = \not{E}_x \,\hat{\imath} + \not{E}_y \,\hat{\jmath} \quad (2)$$

Where the index n runs over all calorimeter input objects (eg. energy deposits in towers, reconstructed hits, or generator-level particle energies). Here î, ĵ are the unit vectors in the direction of the x and y axis of the CMS right-handed coordinate system, where z is pointing in the direction of the beam, and x is horizontal. Note that in the absence of $\not{E}_T$ from physics sources in the event, $\not{E}_x$ and $\not{E}_y$ are expected to be distributed as Gaussians with a mean of zero and a standard deviation of Ǫ.
The Scalar Transverse Energy ($*E_T$), or total visible E_T in the event is defined as the scalar sum:

$$*E_T = \sum_n^X (E_n \, Sin\theta_n) \quad (3)$$

Where index n runs over the same input objects as for $\not{E}_T$ using the above procedure and other details as given in the reference[7], we can measure Missing Energy $\not{E}$. For measuring $\not{E}$ we use all other detector components of ALICE detector.

5. Conclusions

The geometrical implementation of the new design of the FoCAL in ALICE framework was done successfully. A full simulation study of the basic characteristics of the FoCAL such as deposited energy distributions, linearity response and relative energy resolutions have been performed. Using the above analysis procedure given in section 4, we can find Dark Photon, which is a Dark Matter candidate. This measurement is one of the most required results of Physics beyond Standard model of particle physics.

6. Acknowledgement

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