Probing highly collimated photon-jets with deep learning

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arXiv:2203.16703

第十六届TeV工作组学术研讨会
暨邝宇平院士学术思想研讨会

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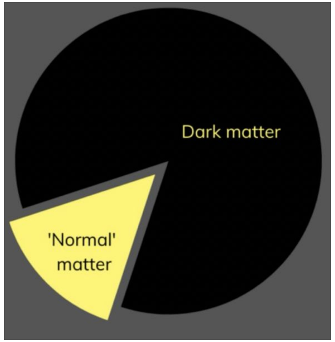
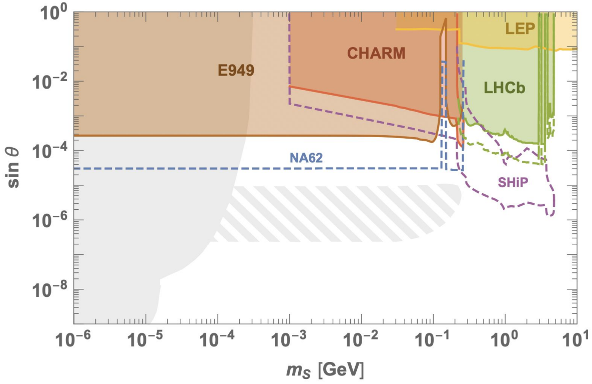


1. The mediator in sub-GeV DM models :

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\bar{\chi}(i\partial\!\!\!/ - m_\chi)\chi + \frac{1}{2}(\partial\Phi)^2 - \frac{c_s}{2}\Phi\bar{\chi}\chi - \frac{c_p}{2}\Phi\bar{\chi}i\gamma_5\chi - V(\Phi, H),$$

$\boxed{Z_2 \text{ symmetry}}$



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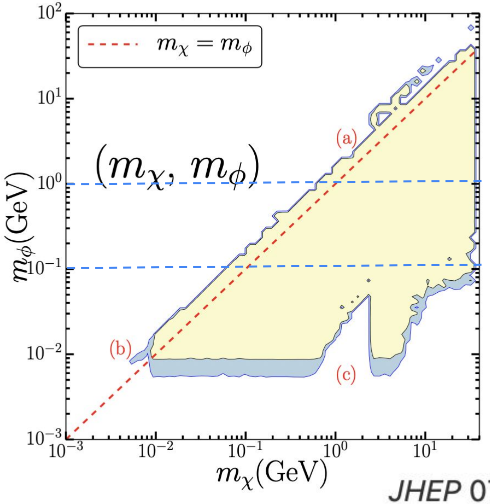

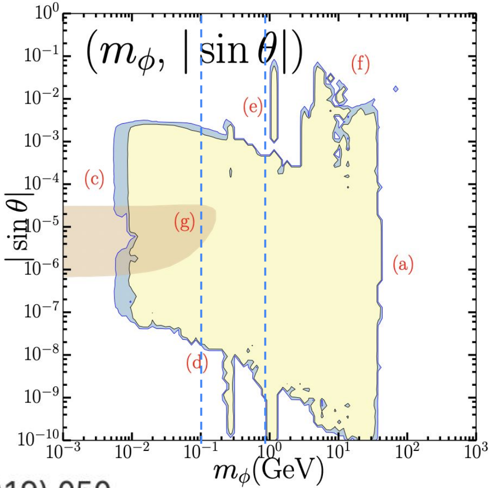

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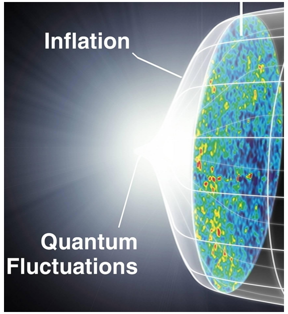
Many extensions of the SM predict the existence of ALPs and/or dark Higgs in the sub-GeV scale.

2. Light inflaton models :

$$V(X,\Phi) = \frac{\beta}{4}X^4 - \frac{1}{2}\mu_X^2 X^2 - \mu_\Phi^2 \Phi^\dagger\Phi + \lambda\left(\Phi^\dagger\Phi + \frac{\alpha}{\lambda}X^2\right)^2.$$



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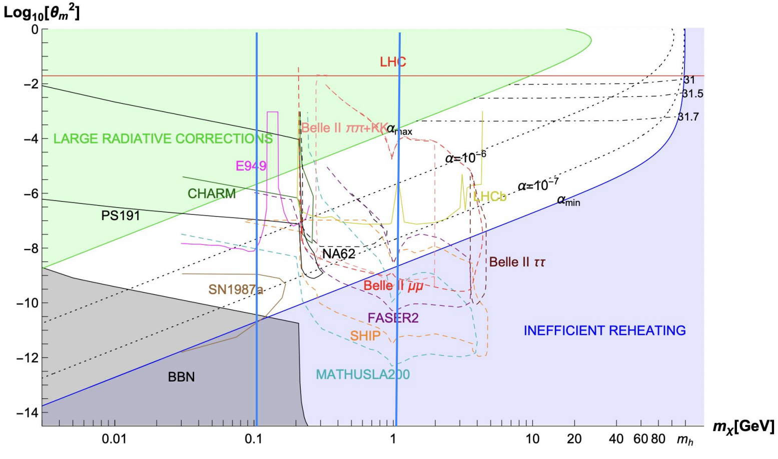
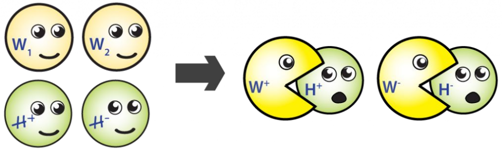
etc …



(a) $\beta = 10^{-9}$

3. The dark Higgs mechanism to provide the dark photon mass

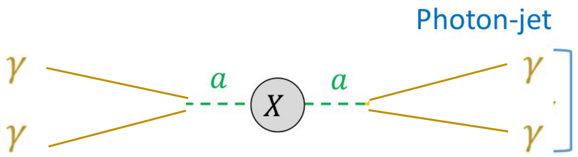


What is highly collimated photon-jets ?

1. Definition of "**photon-jet**" : Grouping of collimated photons
2. How to generate photon-jet ?

(1) Cascade decay : heavy resonance (X) → light resonances (a) → photons

(2) Boosted light resonances (a) decaying into photons leads to a photon-jet

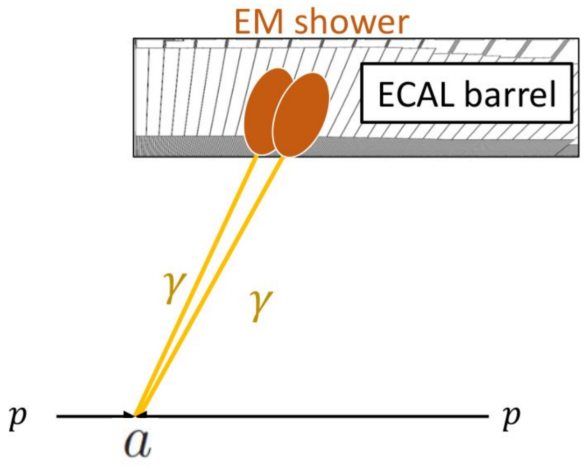


For $m_X = 125$ GeV and sub-GeV m_a, a photon-jet leads to one EM cluster

E.g. for $X \to aa \to 4\gamma$,

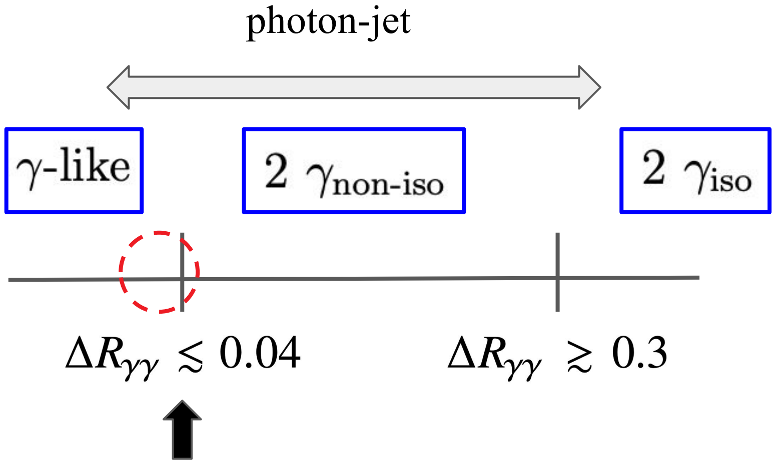
$$\Delta R_{\gamma\gamma} \sim 4 \cdot \frac{m_a}{m_X} = 0.015 \text{ - } 0.035$$

($\because \Delta R_{\gamma\gamma} \sim \frac{2}{\gamma_a}$, where γ_a : Lorentz factor of a)



Y.Kano

Two isolated photons, OR a photon jet, OR a single photon-like ?



ATLAS existing triggers

cannot distinguish them !

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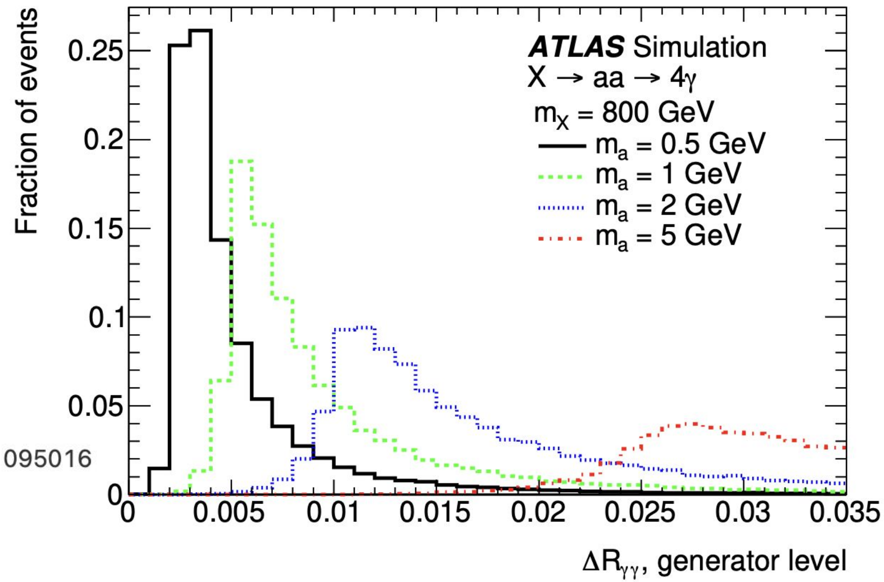
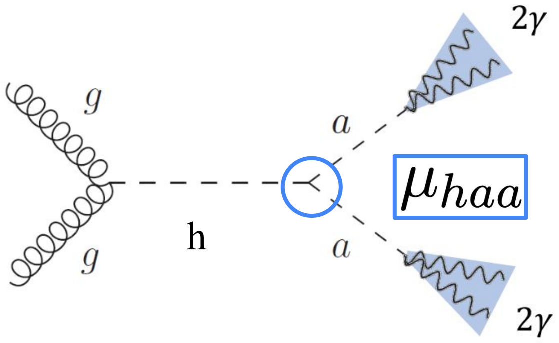
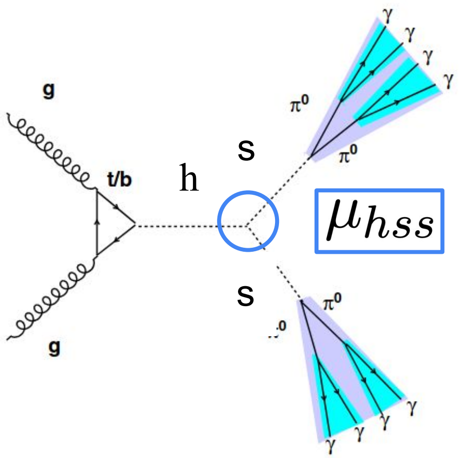


Topology of signal signatures

Photon-jet with 2 photons



Photon-jet with 4 photons



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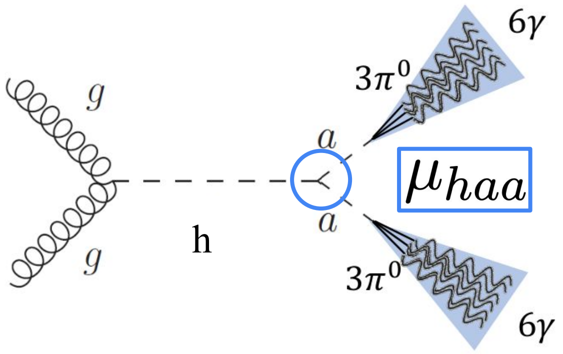
Photon-jet with 6 photons



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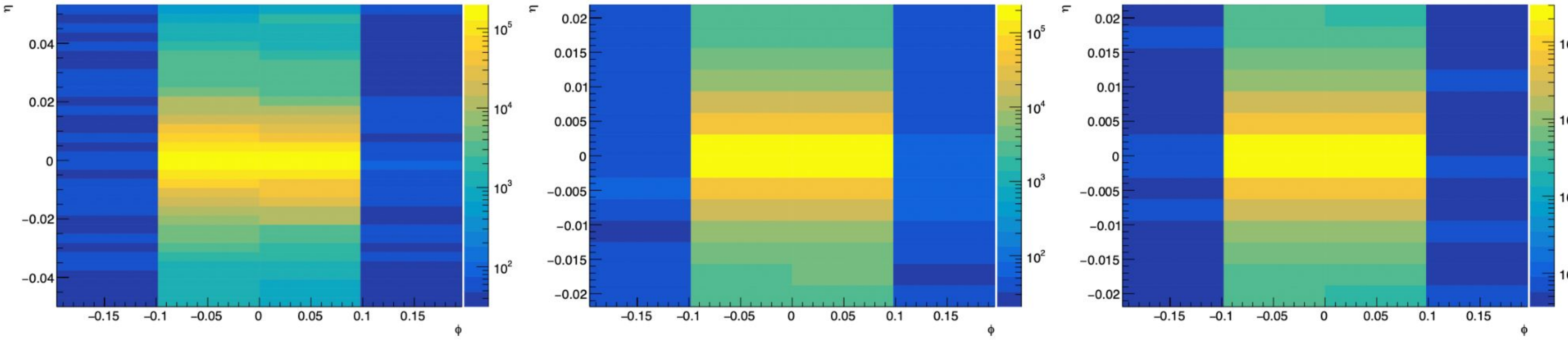
Photon-jet Identification with Deep Learning

ATLAS-like ECAL with EM showers simulated using GEANT4

100,000 events
for each sample

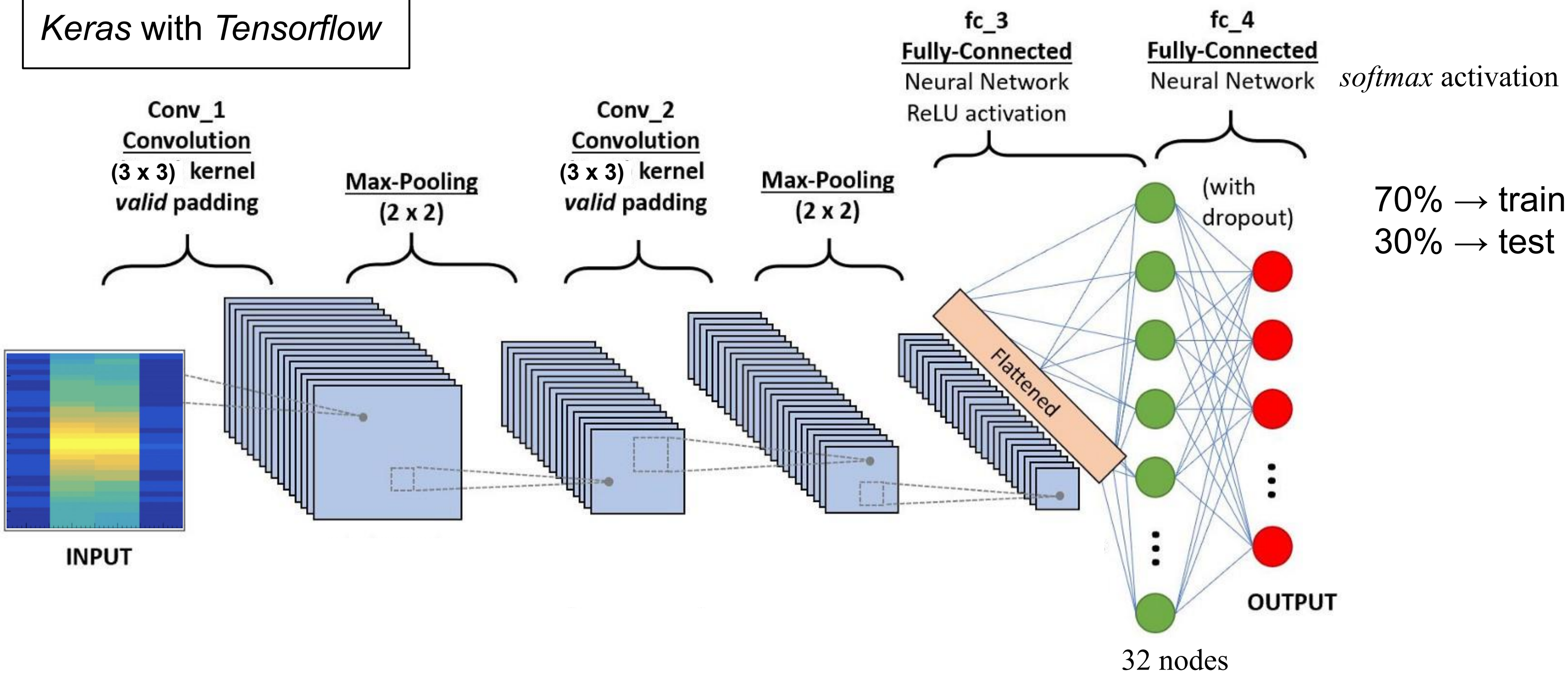
The deposited energy per cell at the 1st layer of the ECAL in the range of [40, 250] GeV :



(a) $a \to \gamma\gamma \ (m_a = 1 \text{ GeV})$ (b) γ (c) π^0

Convolutional Neural Networks (CNN)

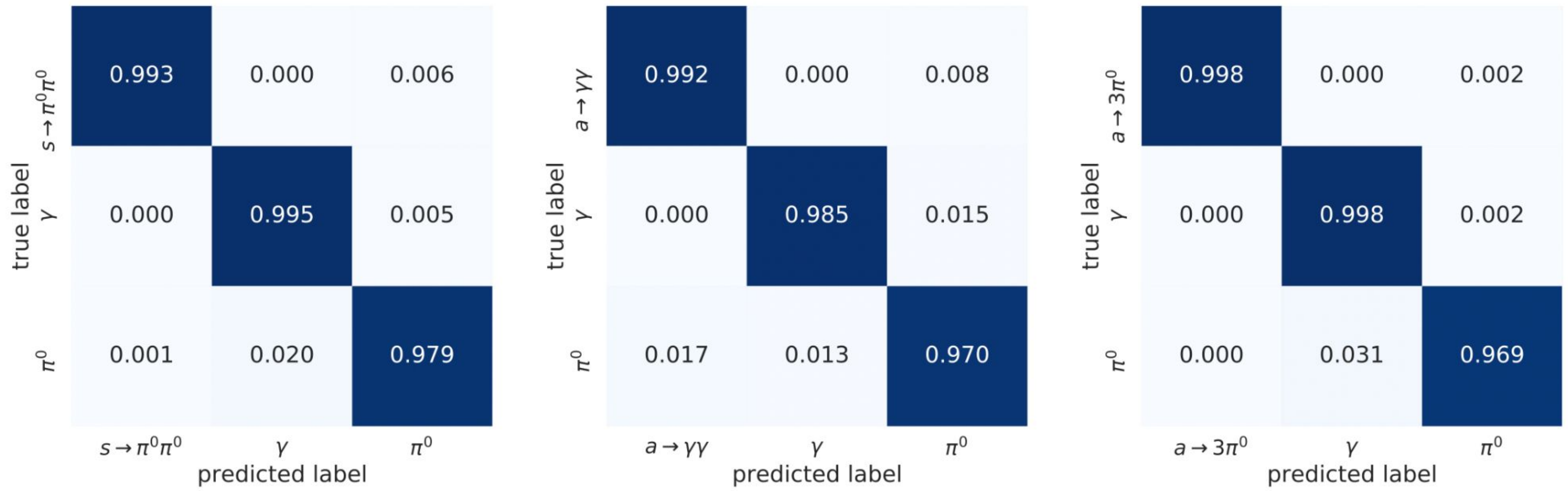
Keras with *Tensorflow*



70% → training
30% → test

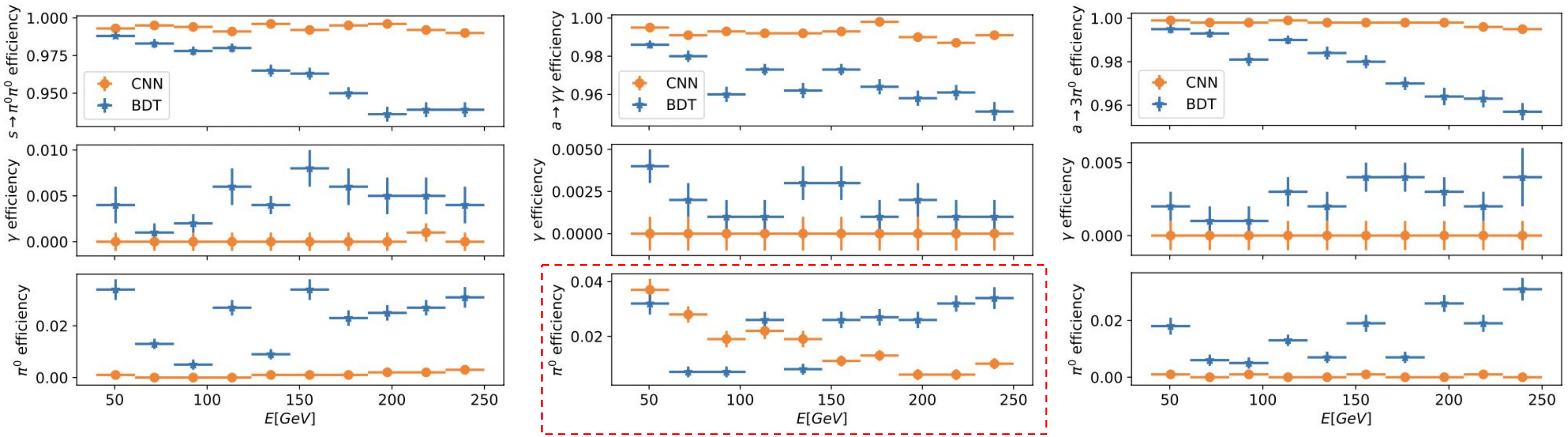
Convolutional Neural Networks (CNN)

The normalized confusion matrix



(a) $s \to \pi^0\pi^0$ (b) $a \to \gamma\gamma$ (c) $a \to \pi^0\pi^0\pi^0$

Comparison of performance between CNN and BDT



(a) $s \to \pi^0\pi^0$ (b) $a \to \gamma\gamma$ (c) $a \to \pi^0\pi^0\pi^0$

Shower shape variables : *Eur.Phys.J.C* 79 (2019) 3, 205

Gradient Boosted Decision Trees (BDT)

$$R_{\mathrm{had}_1},\ R_{\mathrm{had}},\ R_\eta,\ \omega_{\eta 2},\ R_\phi,\ \omega_{s\,3},\ \omega_{s\,\mathrm{tot}},\ f_{\mathrm{side}},\ \Delta E_s,\ E_{\mathrm{ratio}},\ f_1.$$

Contents

Simulation :

Feynrules : generate the UFO model files

↓

MadGraph5 : generate the signal and background events

↓

PYTHIA 8 : parton showering and hadronization

↓

GEANT4 : ATLAS-like ECAL

(1) Two photon-jet candidates with

$$\Delta R_J < 0.25,\ \log\theta_J < -0.8 \text{ and } N_{track} = 0$$

(2) The photon-jets are required to be isolated from nearby charged tracks within $\Delta R < 0.2$

(3) Two photon-jets are required to be boosted

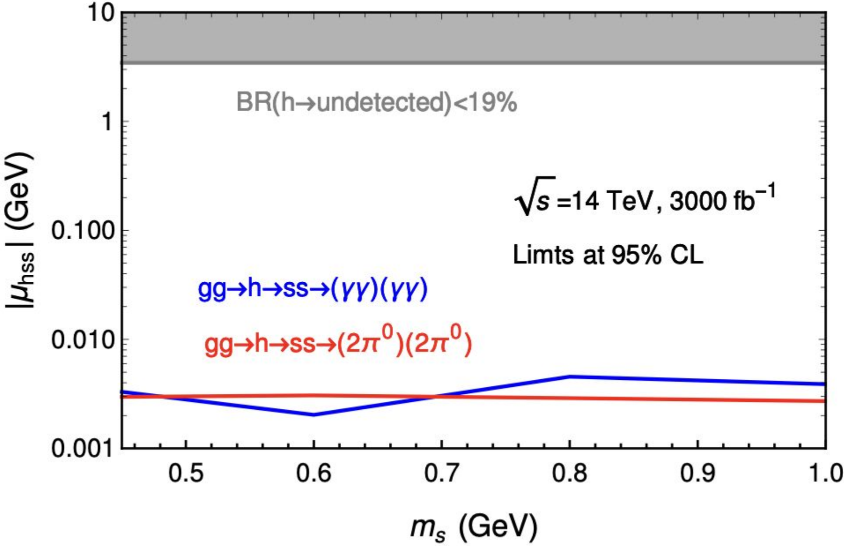
$$P_T(J_{1,2}) > 40 \text{ GeV and } |\eta| < 2.5$$

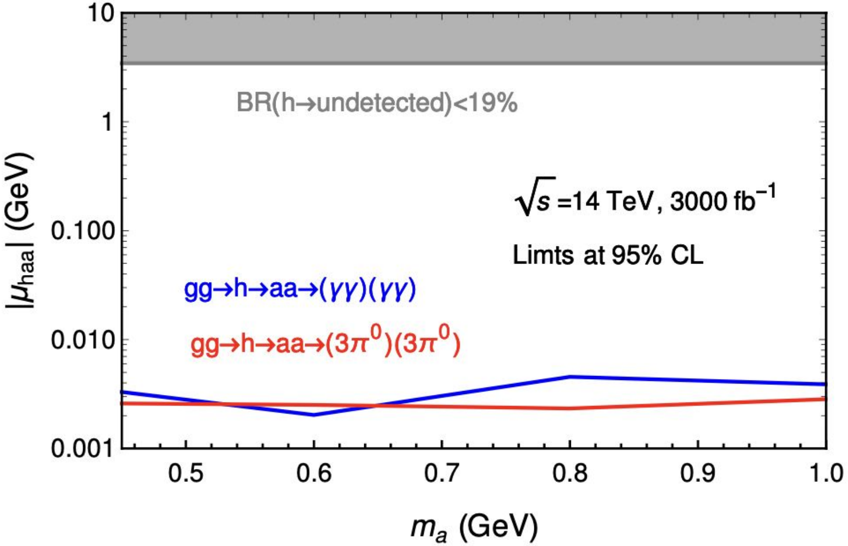
(4) The following selections are applied to further suppress the SM backgrounds

$$P_T(J_1) > 0.4 M_{J_1 J_2},\ \ P_T(J_2) > 0.3 M_{J_1 J_2}$$

$$120 < M_{J_1 J_2} < 130 \text{ GeV},$$

Physics Sensitivity





The branching ratio for each channel, i.e. s/a → γγ, s → π0 π0 and a → π0 π0 π0 is assumed to be 1 in a model-independent way.

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2. Photon-jet Identification with Deep Learning
3. Physics Sensitivity
4. **Conclusions**

Conclusions

1. The results show that the CNN is a promising tool to separate the photon-jet signatures from SM backgrounds such as the single photon and $\pi 0$ from QCD jets.

2. For photon-jet with energy above 150 GeV, CNN shows profound improvement with respect to BDT based on shower shape variables.

3. The future bounds at HL-LHC can be much stronger than the existing constraint BR($h \rightarrow$ undetected) $< 19\%$.

Thank you
for your attention