Deep Learning in High Energy Physics

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Based on 1904.08549 and upcoming articles

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POSTECH

Introduction

- In the high energy physics (HEP), signal is not alone and has a lot of background around it. Thus it is very important to reduce background.
- There are several ways to reduce background. Most of them are based on cut analysis using physical variables.
- People are trying to use all information from data now.
- How can we handle all information?

Introduction

Very small signal portion!

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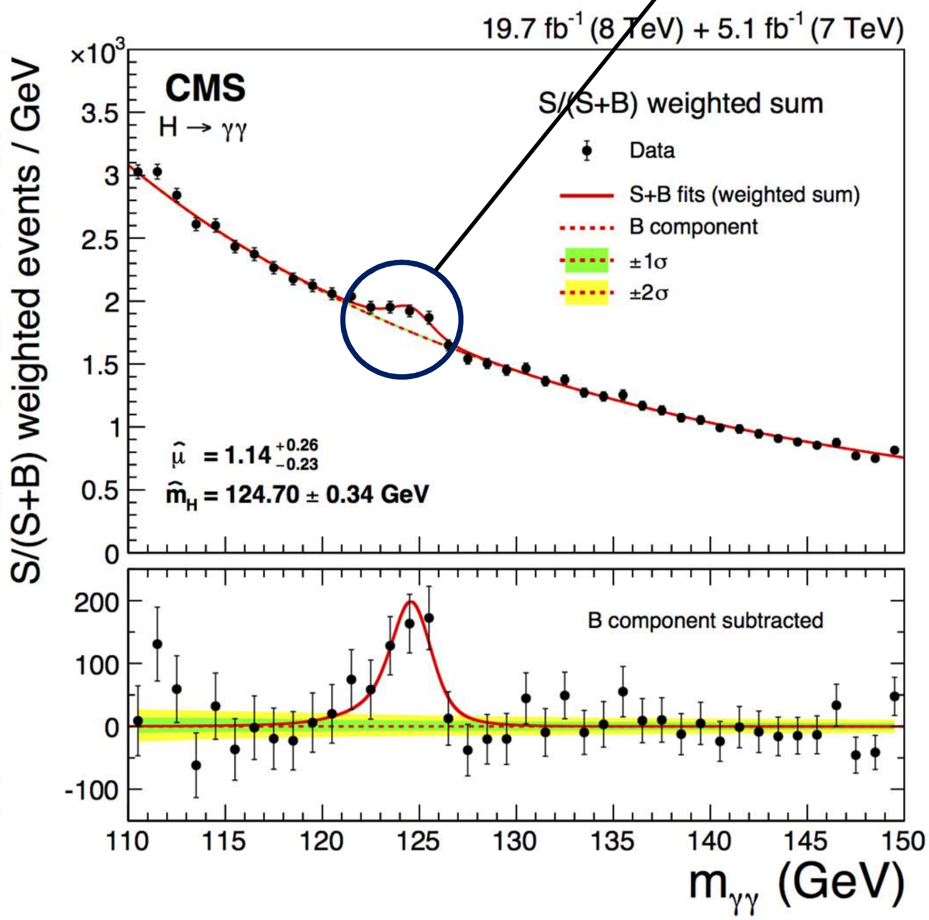
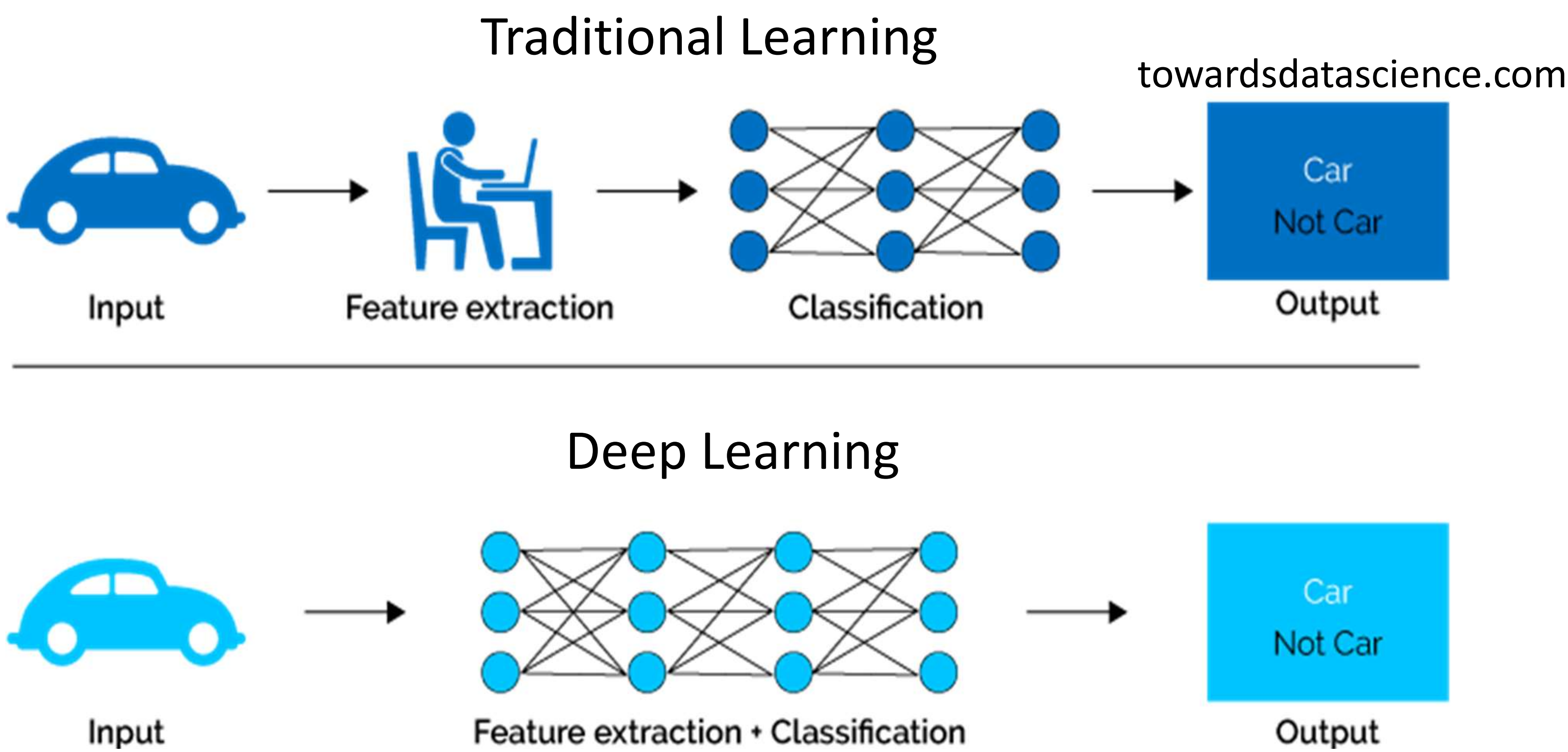
- How ca



The Solution : Deep Learning

- Deep learning (DL) can be one of the best solution.
- Main difference is use of feature extraction.



The Solution : Deep Learning

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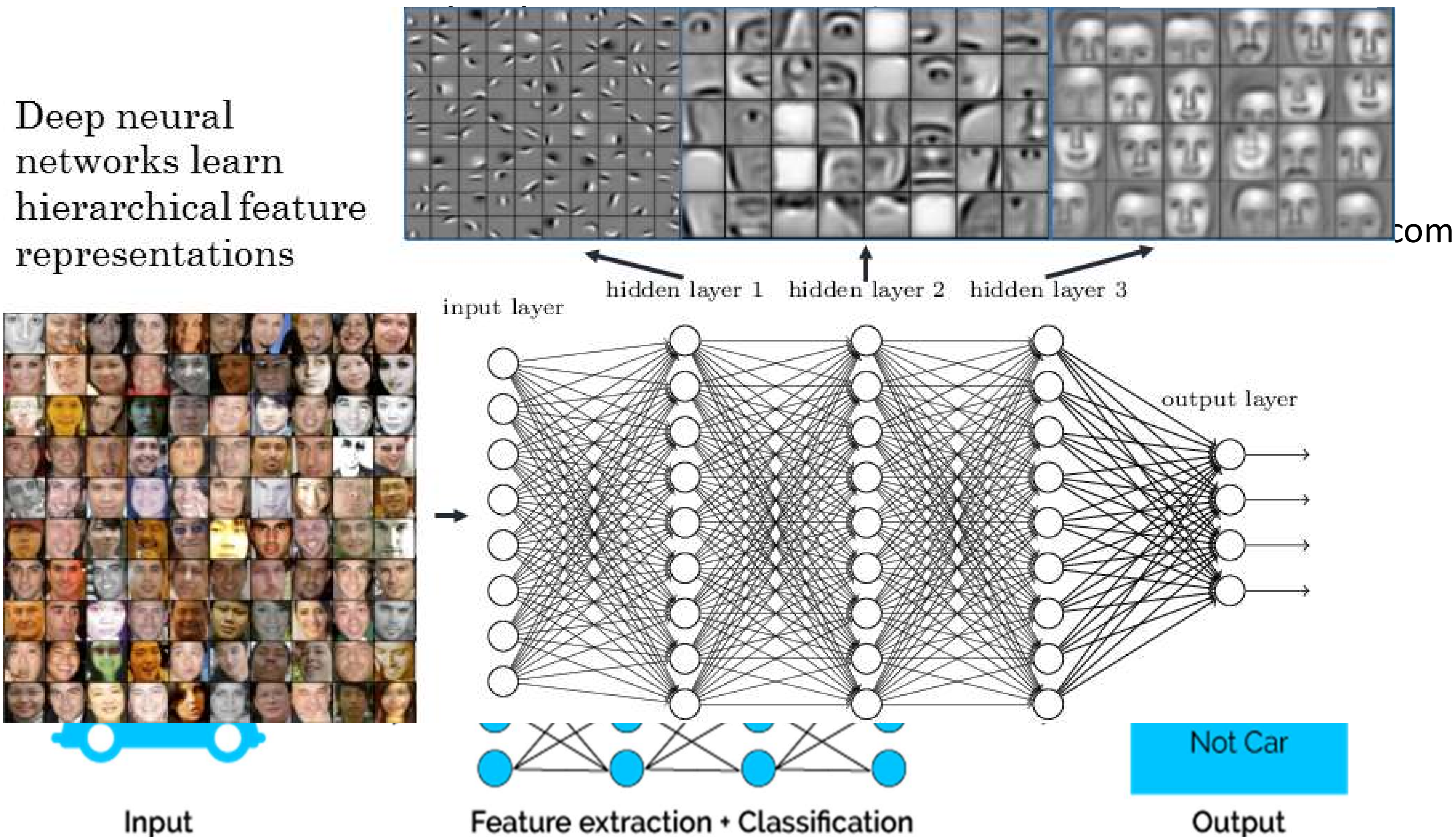
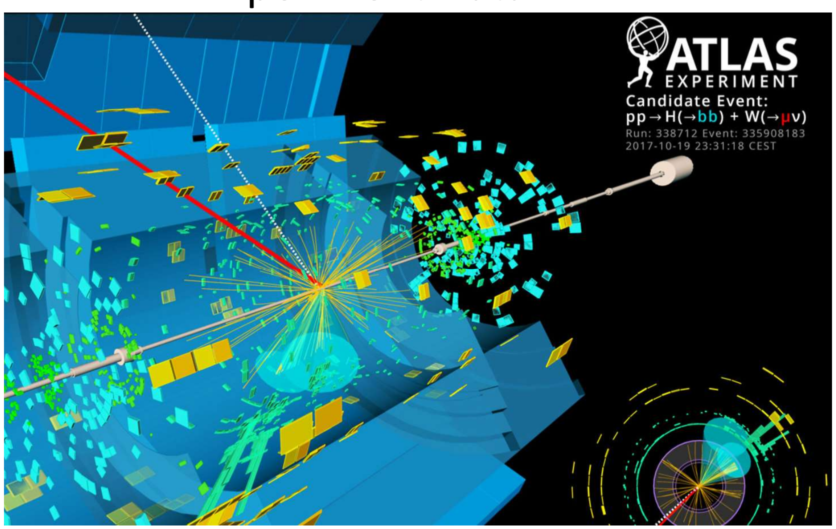
Deep neural networks learn hierarchical feature representations



The Solution : Deep Learning

- Deep learning allows you to use all physics information from data.
- One of the successful approach is making LHC data as (jet) image and feed them to deep learning.

Experiment Data



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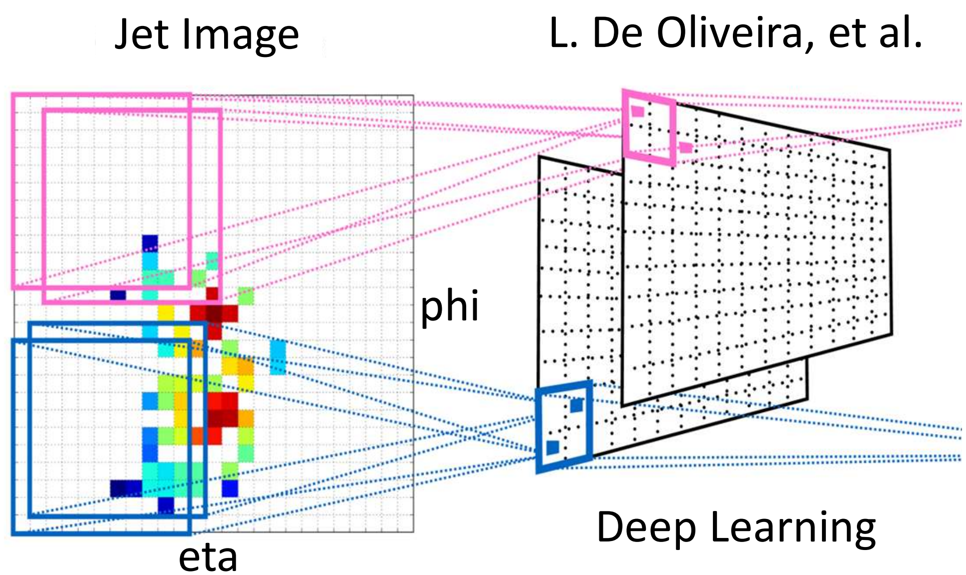
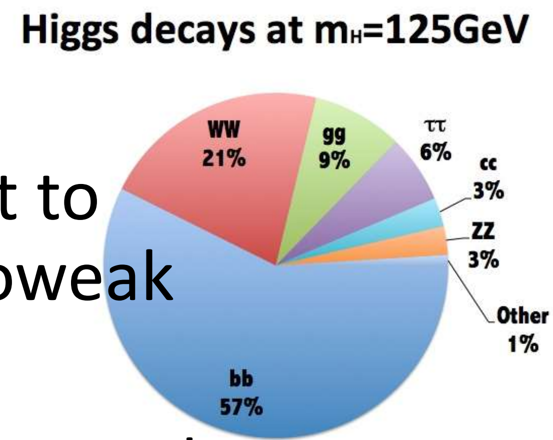
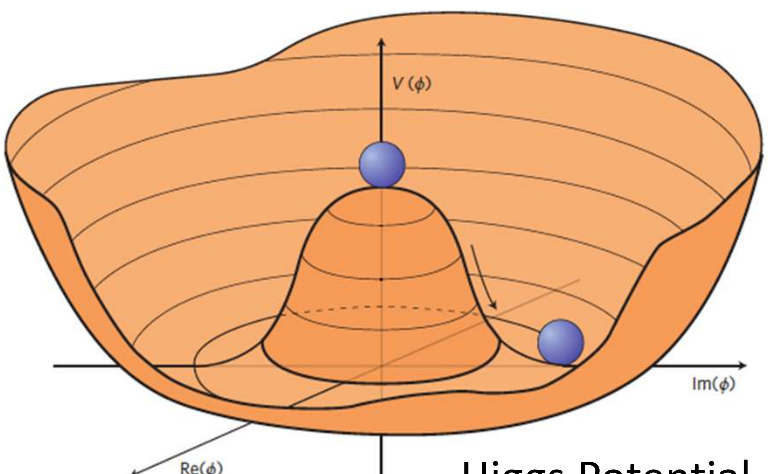
JHEP07(2016) 069
L. De Oliveira, et al.



Applications on LHC : Higgs Pair Production



- Higgs pair production is very important to understand Higgs potential and electroweak symmetry breaking of SM.
- Because major decay processes of Higgs are b quarks pair and W boson pair, it suffers from enormous QCD background.



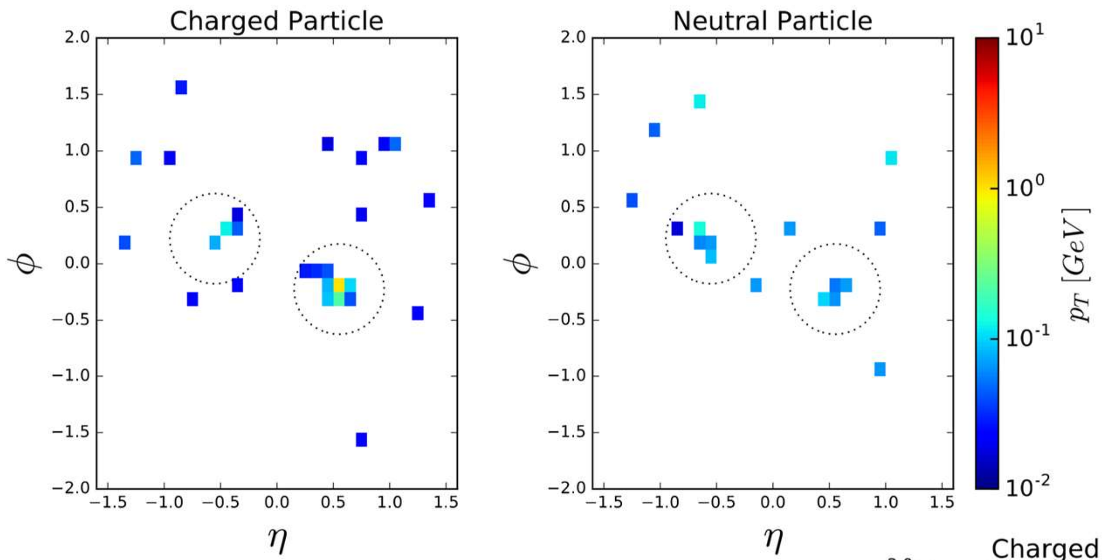
- Higgs Potential

ATL-PHYS-PUB-2017-001 CMS-FTR-15-002-PAS $3\ \mathrm{ab}^{-1}(14\ \mathrm{TeV})$

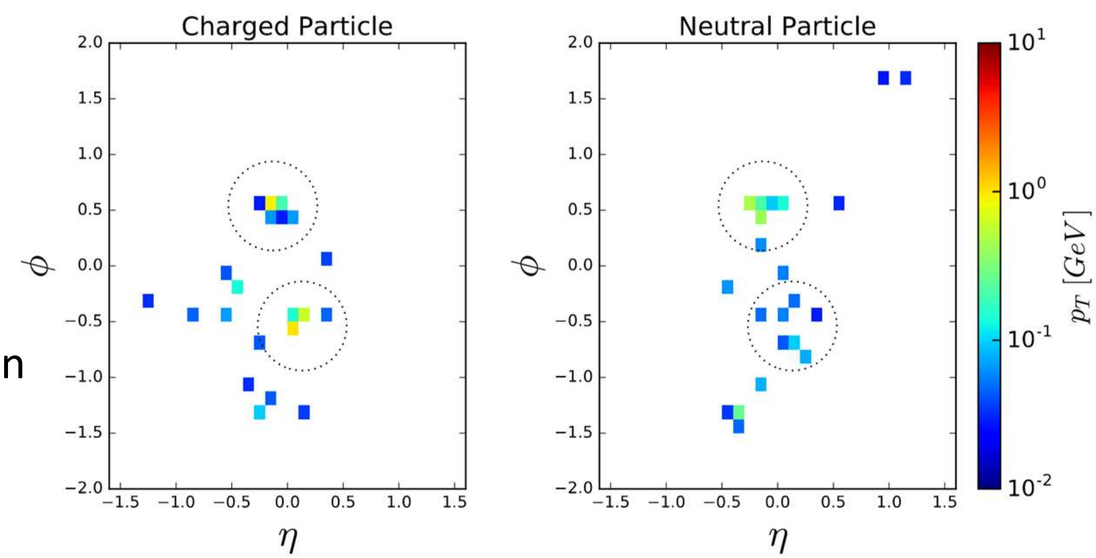
		$N(hh)_{SM}$	N_{BKG}	$S/\sqrt{B}$
ATLAS	$bb\gamma\gamma$	8.4	47.1	1.2
CMS	$bb\gamma\gamma$	9	26.9	1.7
	$bb\tau\tau$ (fully-hadronic)	4.9	30.3	0.89
	$bb\tau\tau$ (semi-leptonic)	6.1	122	0.55
	$bbWW^*$ (di-leptonic)	37.1	3875	0.60

Applications on LHC : Higgs Pair Production

Jet image of signal and background



- Higgs pair production
(h h > b b~ w- w+)



- Top pair production
(t t~ > b b~ w- w+)

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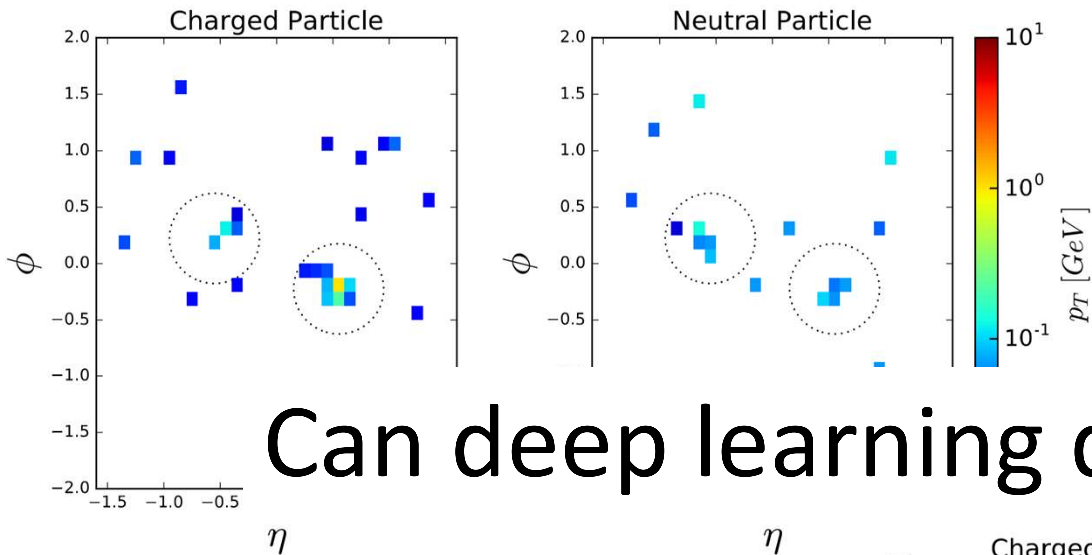
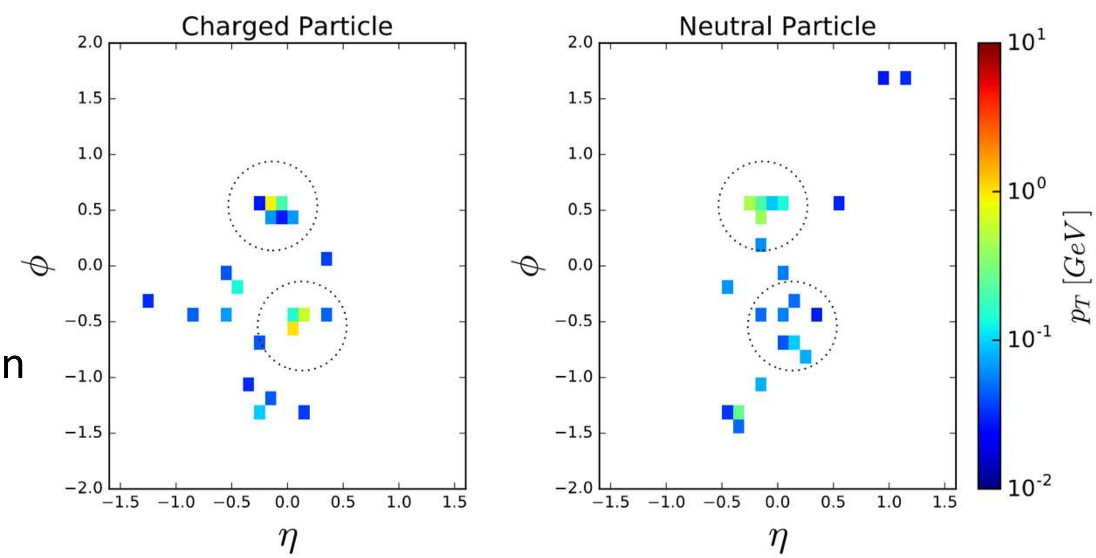
Applications on LHC : Higgs Pair Production



Jet image of signal and background

Can deep learning distinguish this?

- Top pair production (t t~ > b b~ w- w+)



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Note : Data Limitation

- Unfortunately, deep learning performance highly depends on the number of data to learn.
- In high energy physics, it is very difficult to generate a lot of data.
- We can enhance DL performance as follows:
  - By using featured variables,
  - By utilizing optimized DL architecture.

Use of Featured Variables

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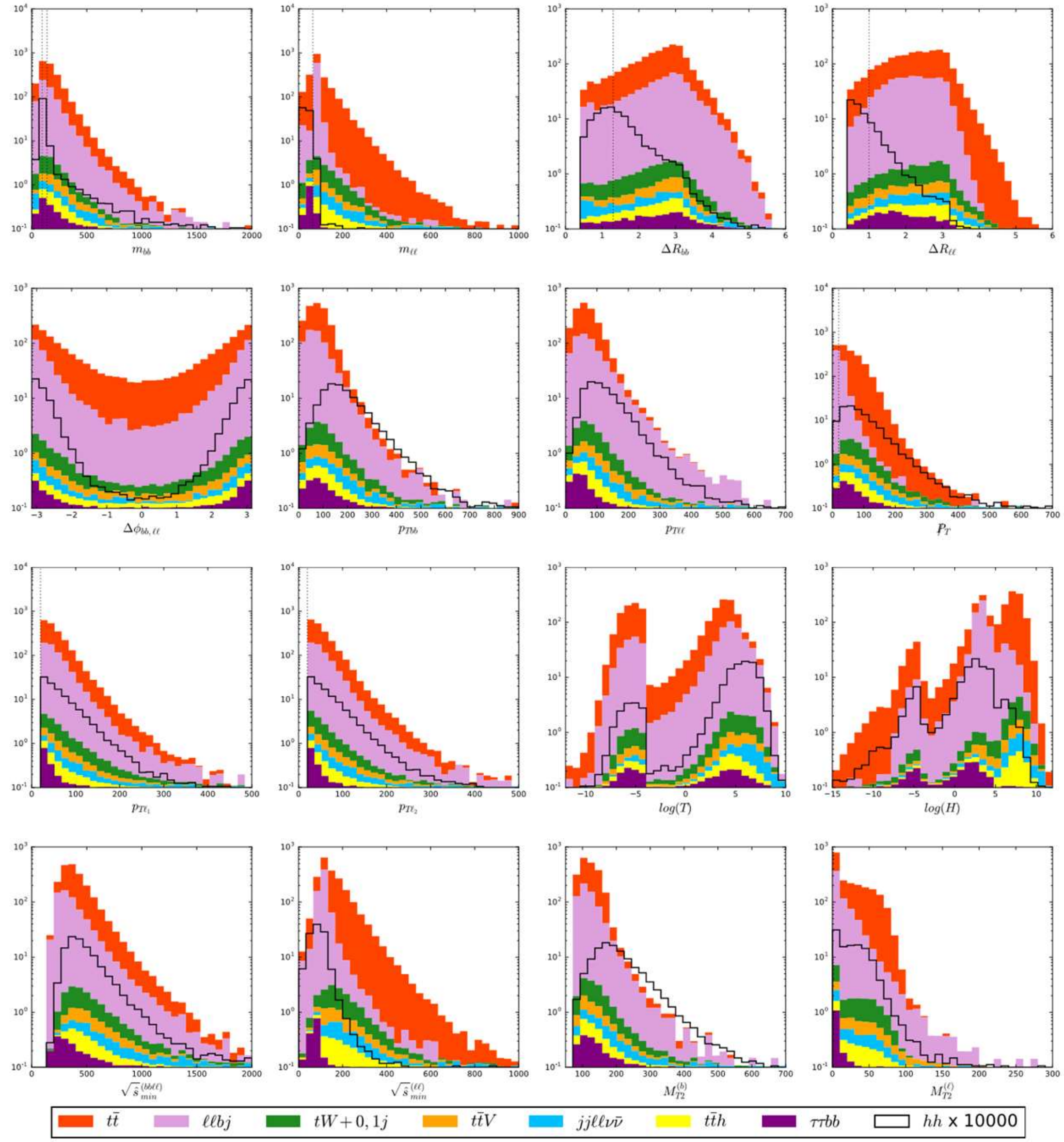
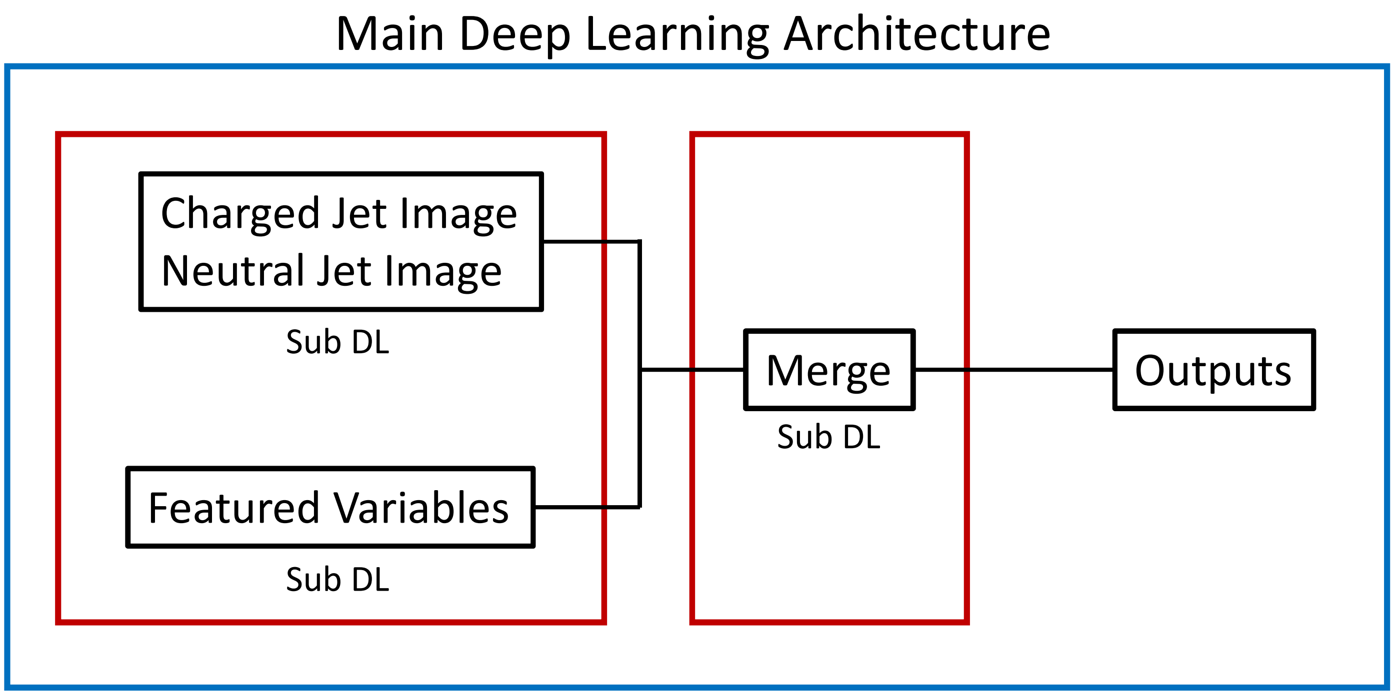
- We can extract good physical variables from data.
- Its effect is similar to reducing dimensions.



Use of Featured Variables

- We can use jet image and featured variables simultaneously :



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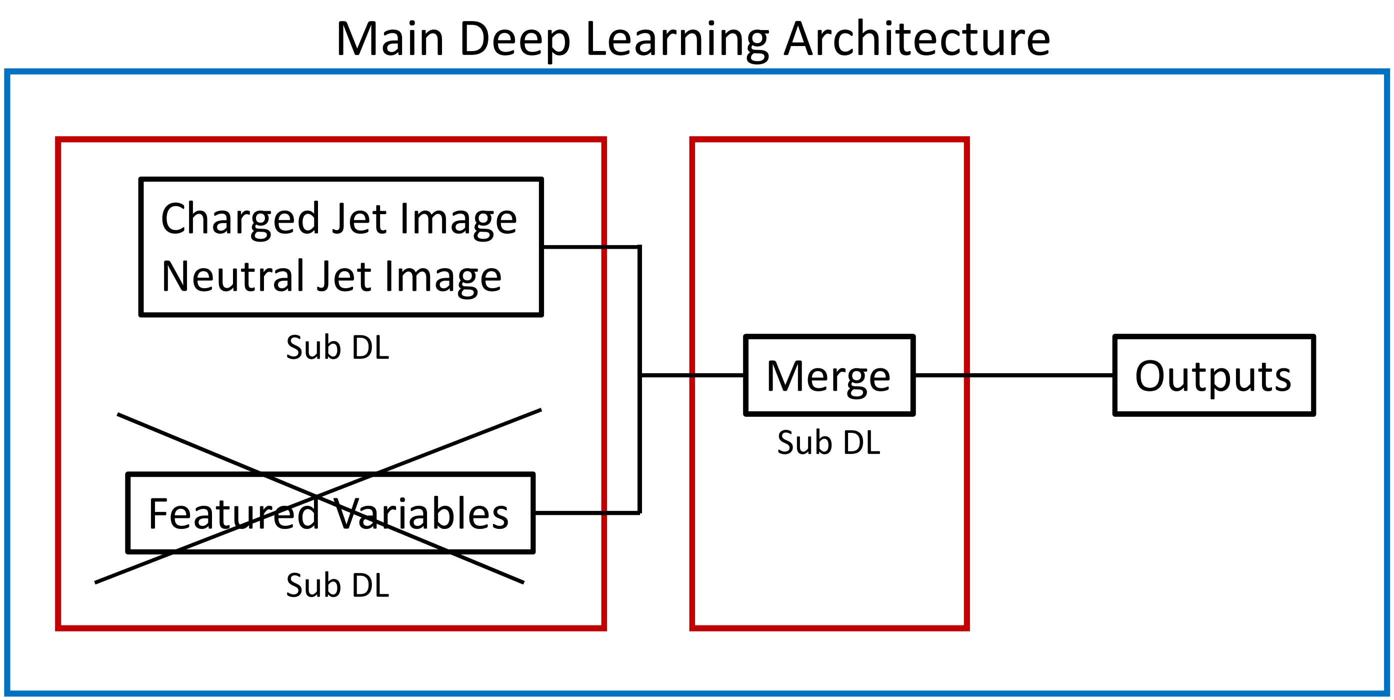

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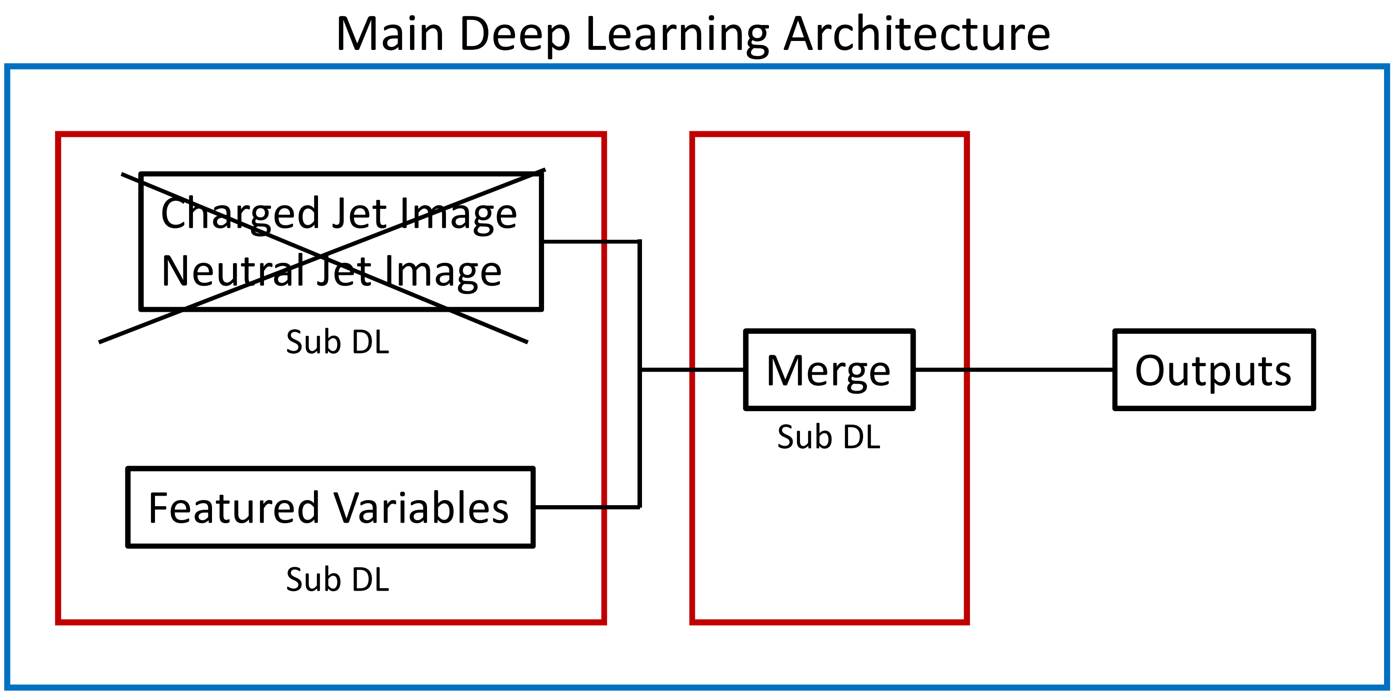
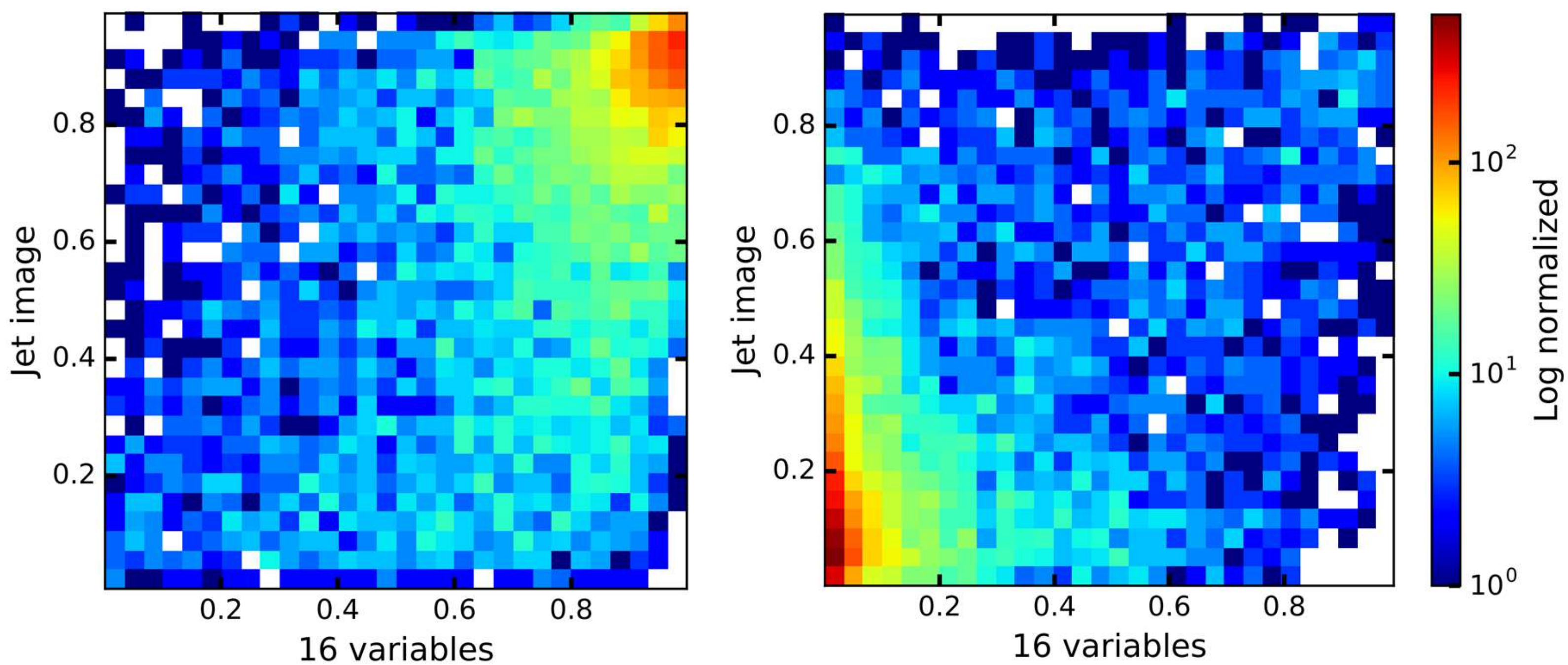


Use of Featured Variables

- The correlation between jet image only DL and featured variables only DL clearly shows that there is uncorrelated information!



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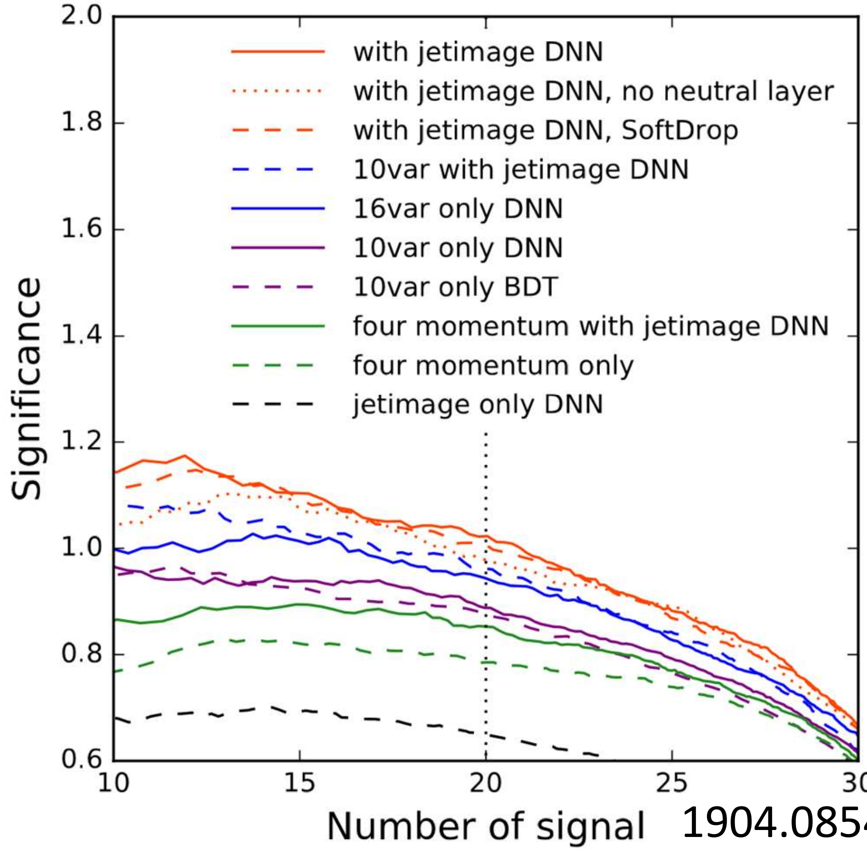
Signal

Background

Use of Featured Variables

- Then deep learning can distinguish signal and background with better performance.

- Signal and (all) background discrimination performance of Higgs pair production with tight cut



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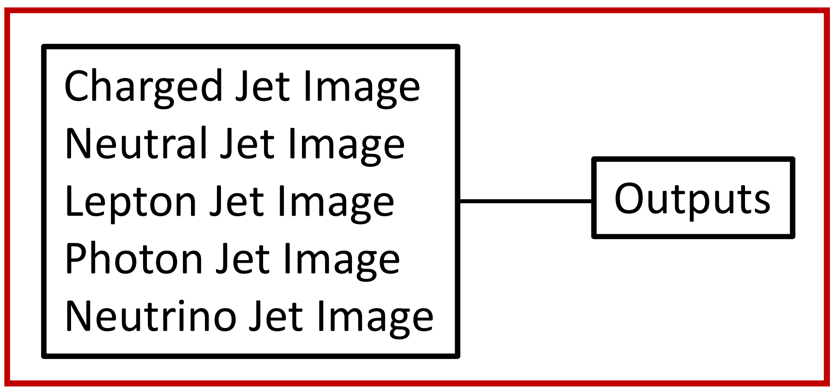
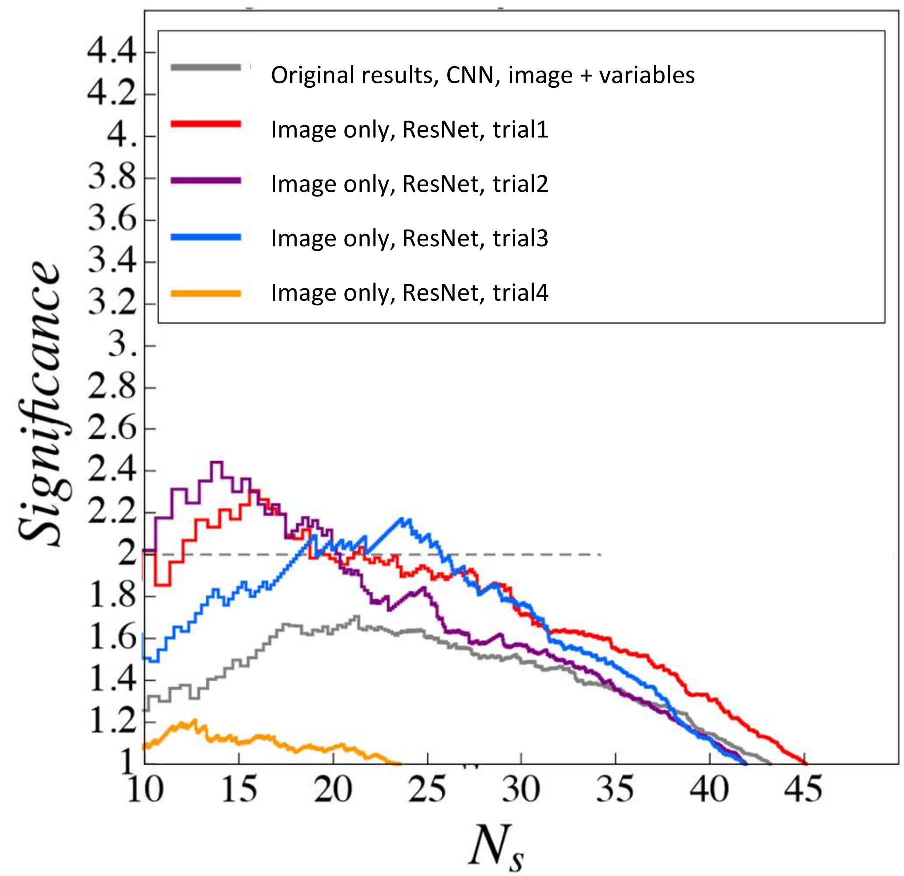
Optimized Deep Learning Architecture

- Appropriate deep learning algorithm can also give us overwhelming performance without featured variables.

Main Deep Learning Architecture



- Preliminary, signal and background (ttbar only) discrimination performance with loose cut



Conclusion

- It is very hard to obtain best performance using traditional analysis method in the HEP.
- Deep learning can be the breakthrough.
- It is showing outstanding performance in various high energy physics problems.

Thanks

Back Up

Higgsness, Topness

- Higgsness and Topness examine how many specific kinematic resembles Higgs or Top quarks.
- We can use momentum which minimize Higgsness or Topness as neutrino momentum.

Higgsness

$$H \equiv \min\left[\frac{\left(m^2_{\ell^+\ell^-\nu\bar{\nu}} - m_h^2\right)^2}{\sigma^4_{h_\ell}} + \frac{\left(m^2_{\nu\bar{\nu}} - m^2_{\nu\bar{\nu},peak}\right)^2}{\sigma^4_{\nu}}\right.$$
$$+min\left(\frac{\left(m^2_{\ell^+\nu} - m_W^2\right)^2}{\sigma^4_W} + \frac{\left(m^2_{\ell^-\bar{\nu}} - m^2_{W^*,peak}\right)^2}{\sigma^4_{W_*}},\right.$$
$$\left.\left.\frac{\left(m^2_{\ell^-\bar{\nu}} - m_W^2\right)^2}{\sigma^4_W} + \frac{\left(m^2_{\ell^+\nu} - m^2_{W^*,peak}\right)^2}{\sigma^4_{W_*}}\right)\right],$$

Topness

$$T \equiv min\left(\chi^2_{12}, \chi^2_{21}\right).$$

$$\chi^2_{ij} \equiv \min_{\vec{p}_T = \vec{p}_{\nu T} + \vec{p}_{\bar{\nu} T}}\left[\frac{\left(m^2_{b_i\ell^+\nu} - m_t^2\right)^2}{\sigma_t^4} + \frac{\left(m^2_{\ell^+\nu} - m_W^2\right)^2}{\sigma_W^4}\right.$$
$$\left.+\frac{\left(m^2_{b_j\ell^-\bar{\nu}} - m_t^2\right)^2}{\sigma_t^4} + \frac{\left(m^2_{\ell^-\bar{\nu}} - m_W^2\right)^2}{\sigma_W^4}\right],$$

ResNet

- Residual network (ResNet) uses operation jumping which prevents gradient vanishing problem.