Improving measurement on Higgs-gluon effective coupling

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Mini-workshop on precision physics and future colliders
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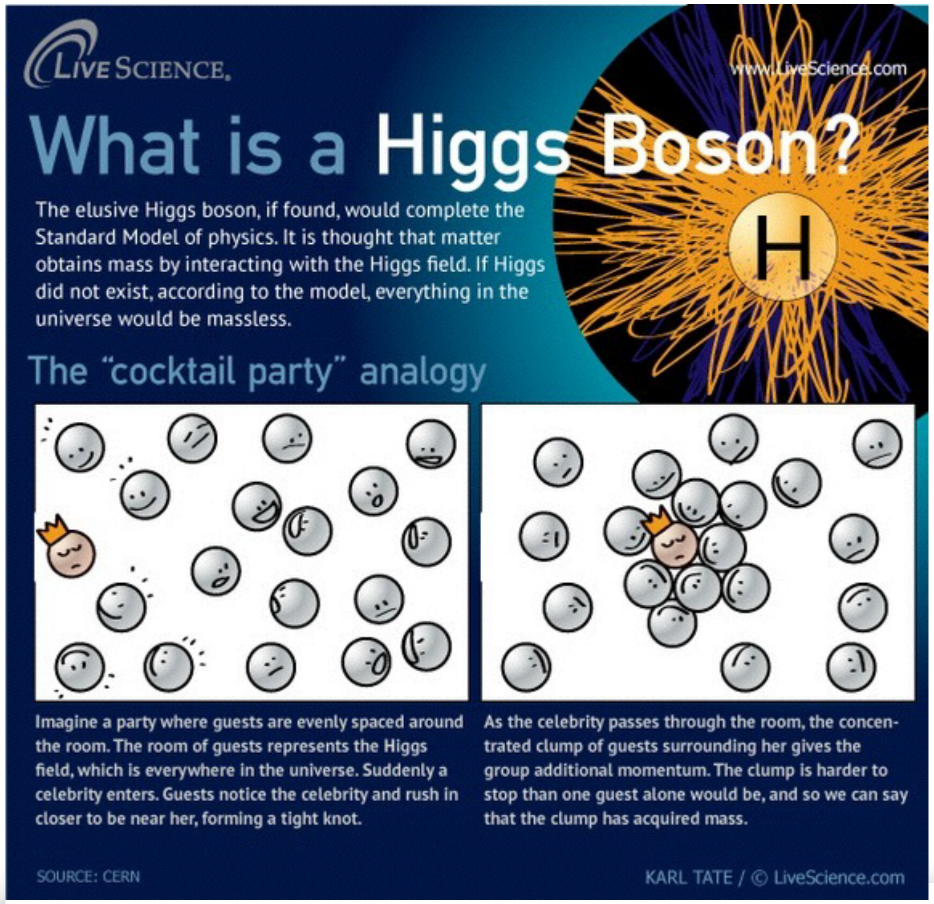
物理理論
THEORETICAL PHYSICS DIVISION

based on PRD98 (2018) no.7, 076010 & arXiv:1901.09391



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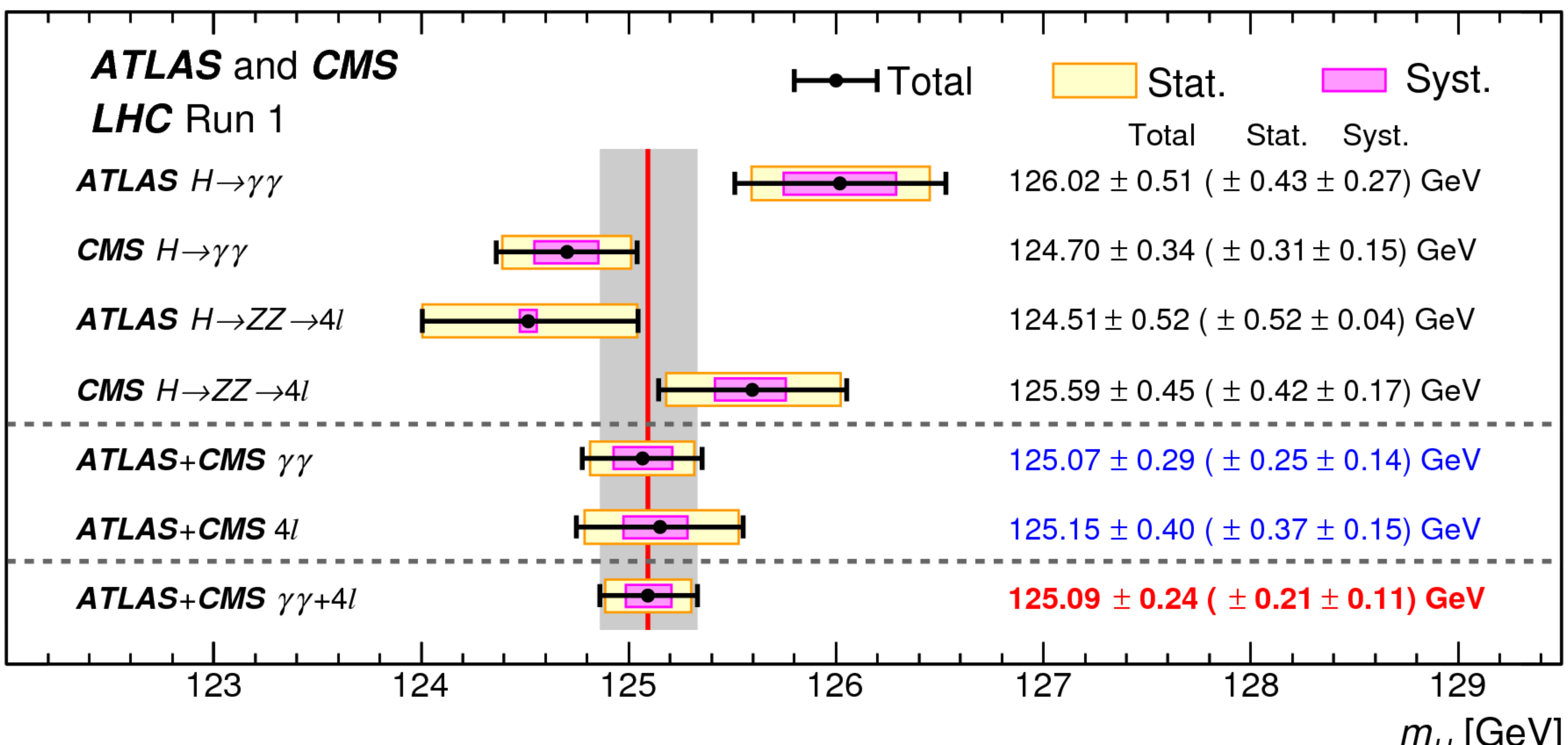
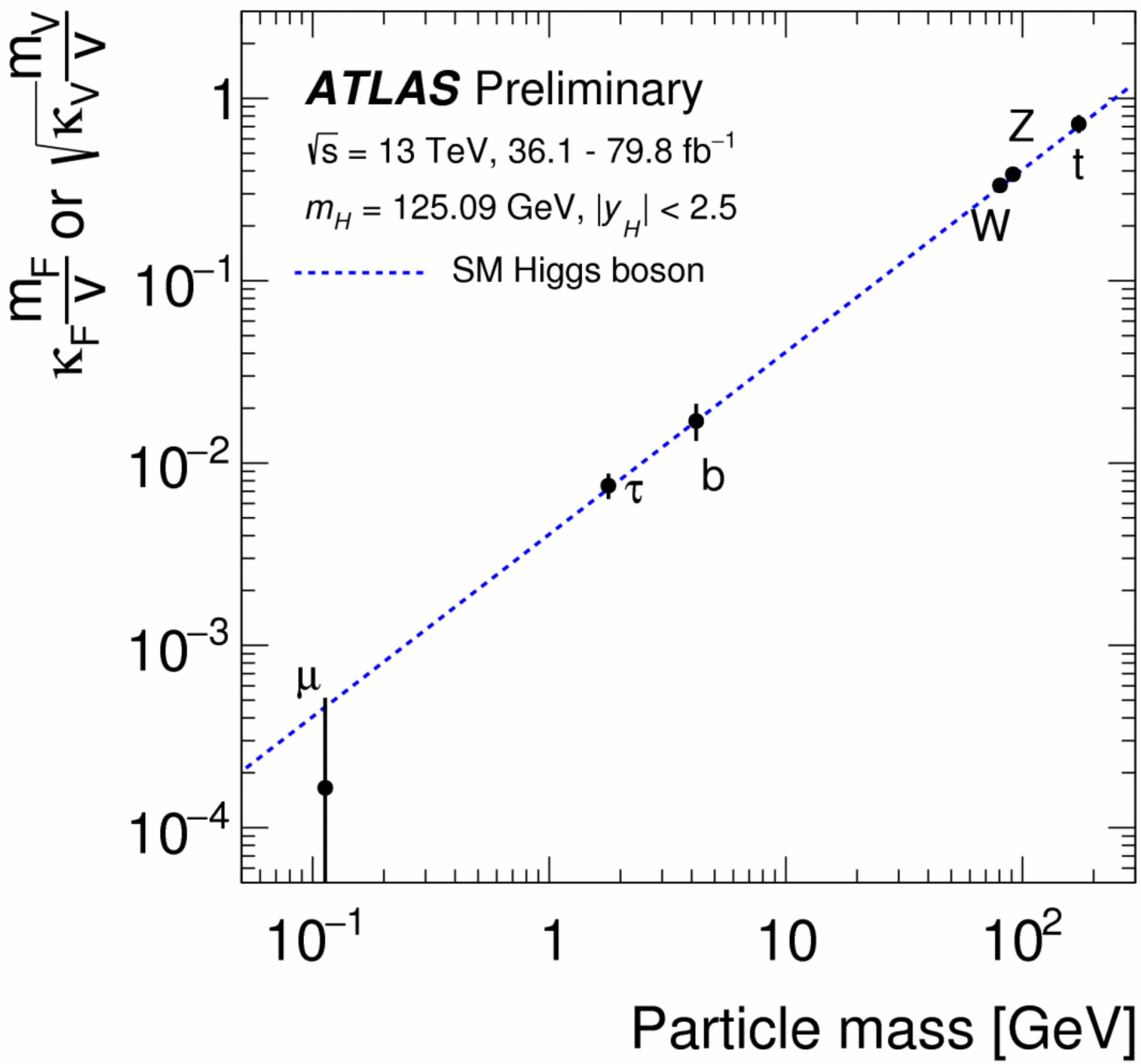
What is a Higgs Boson?
H
The elusive Higgs boson, if found, would complete the Standard Model of physics. It is thought that matter obtains mass by interacting with the Higgs field. If Higgs did not exist, according to the model, everything in the universe would be massless.
The "cocktail party" analogy
Imagine a party where guests are evenly spaced around the room. The room of guests represents the Higgs field, which is everywhere in the universe. Suddenly a celebrity enters. Guests notice the celebrity and rush in closer to be near her, forming a tight knot.
As the celebrity passes through the room, the concentrated clump of guests surrounding her gives the group additional momentum. The clump is harder to stop than one guest alone would be, and so we can say that the clump has acquired mass.
SOURCE: CERN
KARL TATE / © LiveScience.com

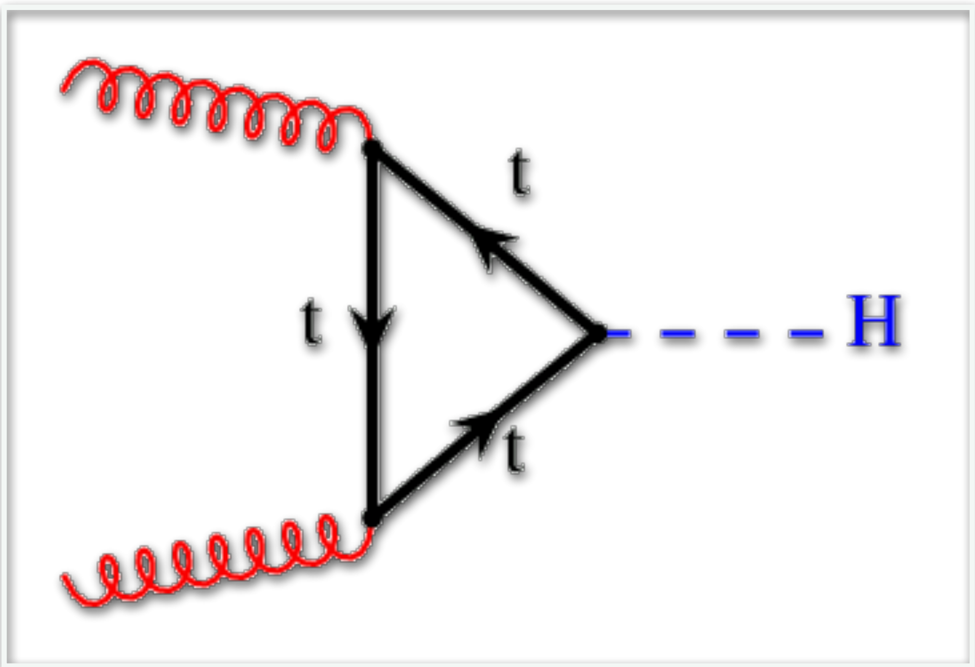


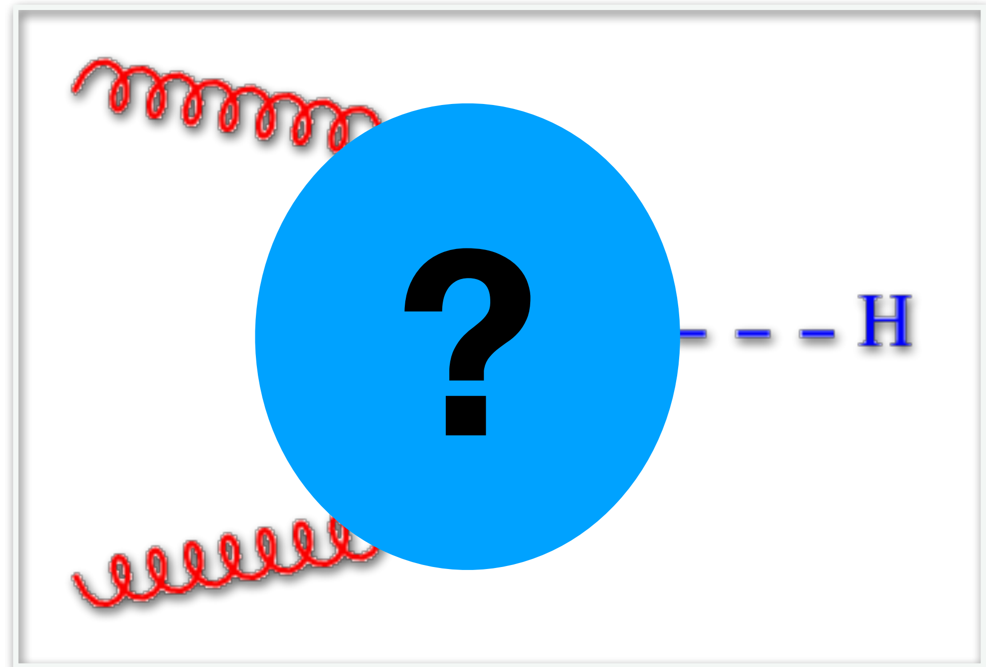
ATLAS and CMS
LHC Run 1
Total
Stat.
Syst.
Total Stat. Syst.
ATLAS $H\rightarrow\gamma\gamma$
126.02 ± 0.51 (± 0.43 ± 0.27) GeV
CMS $H\rightarrow\gamma\gamma$
124.70 ± 0.34 (± 0.31 ± 0.15) GeV
ATLAS $H\rightarrow ZZ\rightarrow 4l$
124.51 ± 0.52 (± 0.52 ± 0.04) GeV
CMS $H\rightarrow ZZ\rightarrow 4l$
125.59 ± 0.45 (± 0.42 ± 0.17) GeV
ATLAS+CMS $\gamma\gamma$
125.07 ± 0.29 (± 0.25 ± 0.14) GeV
ATLAS+CMS $4l$
125.15 ± 0.40 (± 0.37 ± 0.15) GeV
ATLAS+CMS $\gamma\gamma+4l$
125.09 ± 0.24 (± 0.21 ± 0.11) GeV
123
124
125
126
127
128
129
m_H [GeV]

Higgs Properties, i.e. couplings/interactions



Direct or Indirect modification



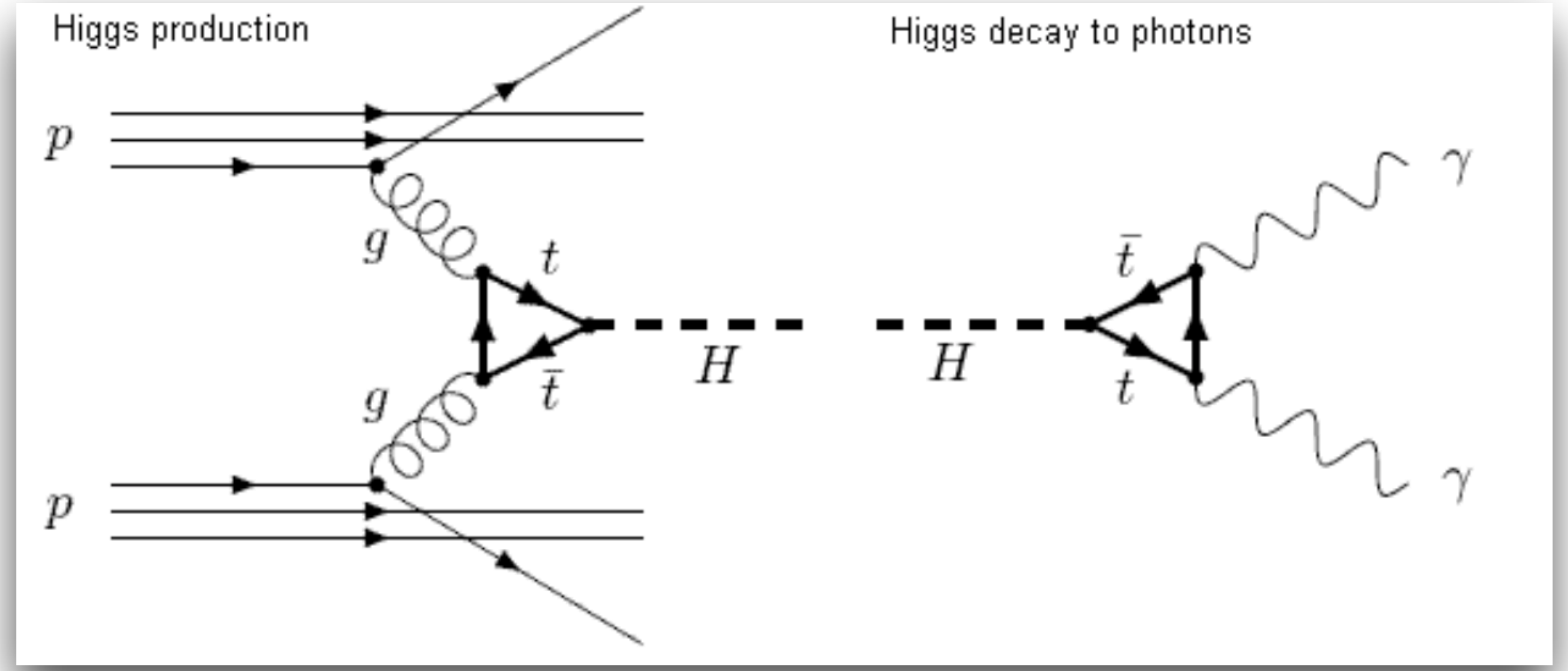


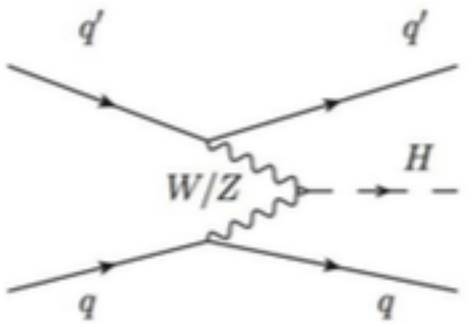
$$\mathcal{L}_{hgg} = \kappa_g c^g_{\mathrm{SM}} \frac{\alpha_s}{12\pi v} h G^a_{\mu\nu} G^{a\mu\nu},$$

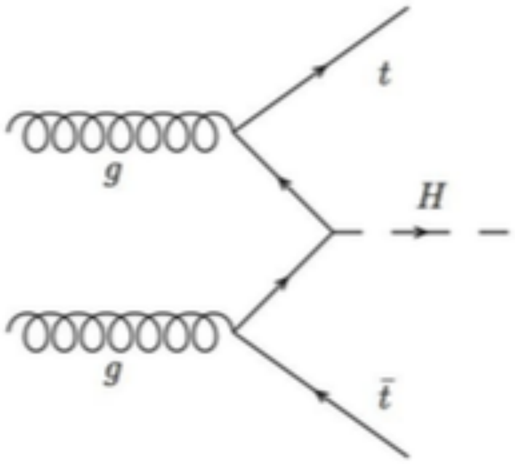
SUSY? Little Higgs? Extra Dimensions? etc.

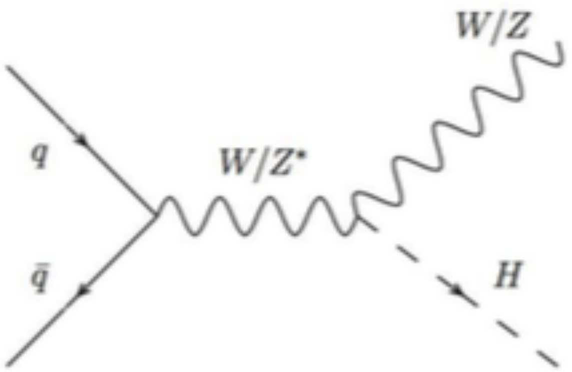
Measurement @ LHC

Different production rate
Different decay BR

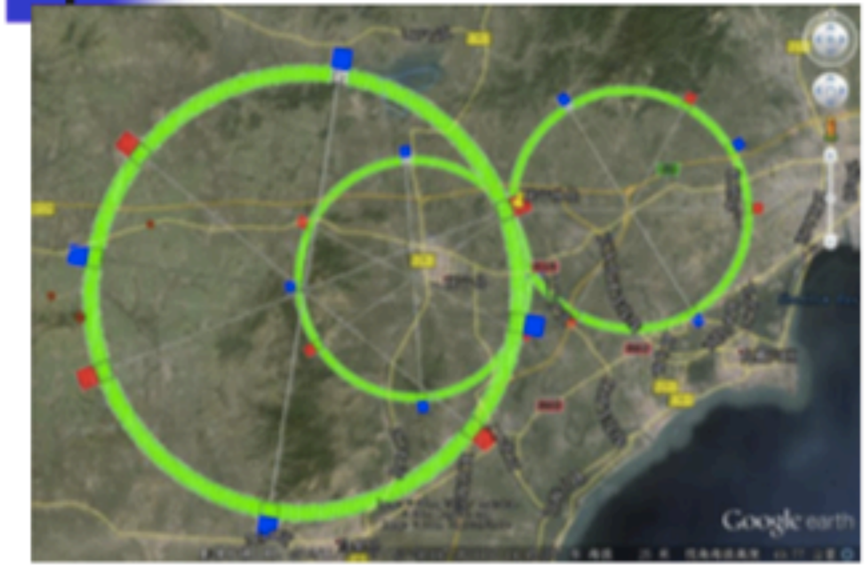




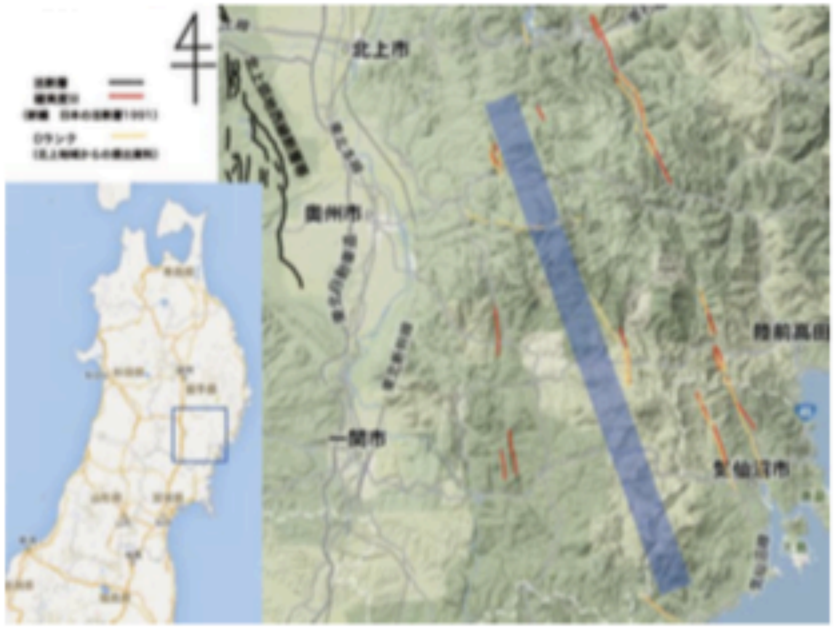




Several Higgs factories under plan



CEPC@90-240 GeV (China)
秦皇岛 or 雄安?



ILC@500,350,250 GeV (Japan)
Kitakami Candidate Site

FCC-ee @ 90-400 GeV (Geneva, EU)

Results in CDR (2018.11)

All scaled to 240 GeV，5.6ab^{-1}

Property	Estimated Precision CEPC-v1	CEPC-v4
m_H	5.9 MeV	5.9 MeV
Γ_H	2.7%	2.8%
$\sigma(ZH)$	0.5%	0.5%
$\sigma(\nu\bar{\nu}H)$	3.0%	3.2%

Decay mode	CEPC-v1 $\sigma\times$BR	CEPC-v1 BR	CEPC-v4 $\sigma\times$BR	CEPC-v4 BR
$H\to b\bar{b}$	0.26%	0.56%	0.27%	0.56%
$H\to c\bar{c}$	3.1%	3.1%	3.3%	3.3%
$H\to gg$	1.2%	1.3%	1.3%	1.4%
$H\to WW^*$	0.9%	1.1%	1.0%	1.1%
$H\to ZZ^*$	4.9%	5.0%	5.1%	5.1%
$H\to\gamma\gamma$	6.2%	6.2%	6.8%	6.9%
$H\to Z\gamma$	13%	13%	16%	16%
$H\to\tau^+\tau^-$	0.8%	0.9%	0.8%	1.0%
$H\to\mu^+\mu^-$	16%	16%	17%	17%
$\mathrm{BR}_{\mathrm{inv}}^{\mathrm{BSM}}$	–	< 0.28%	–	< 0.30%

Signal Z	Signal H	Precision
H->qq		
ee	bb	1.32%
ee	cc	13.5%
ee	gg	7.22%
μμ	bb	0.99%
μμ	cc	9.54%
μμ	gg	5.01%
qq	bb	0.46%
qq	cc	11.1%
qq	gg	3.64%
νν	bb	0.39%
νν	cc	3.83%
νν	gg	1.47%
H->Invisible		
qq	ZZ(νννν)	232%
ee	ZZ(νννν)	370%
μμ	ZZ(νννν)	245%

Signal Z	Signal H	Precision
H->WW		
ee	lνlν	9.52%
ee	eνqq	4.56%
ee	μνqq	3.93%
μμ	lνlν	7.29%
μμ	eνqq	3.90%
μμ	μνqq	3.90%
νν	qqqq	1.90%
νν	eνqq	4.65%
νν	μνqq	4.14%
νν	lνlν	11.5%
qq	qqqq	1.75%
H->ZZ		
νν	μμqq	8.26%
νν	eeqq	40%
μμ	ννqq	7.32%
ZH bkg contribution		19.4%

Signal Z	Signal H	Precision
H→γγ, Zγ		
μμ+ττ	γγ	23.7%
νν	γγ	10.5%
qq	γγ	9.84%
νν	Zγ(qqγ)	15.7%
ννH(WW fusion)		
νν	bb	3.00%
H→μμ		
qq, ee, μμ, νν	μμ	17.1%
H→ττ		
ee	ττ	2.75%
μμ	ττ	2.61%
qq	ττ	0.95%
νν	ττ	2.66%

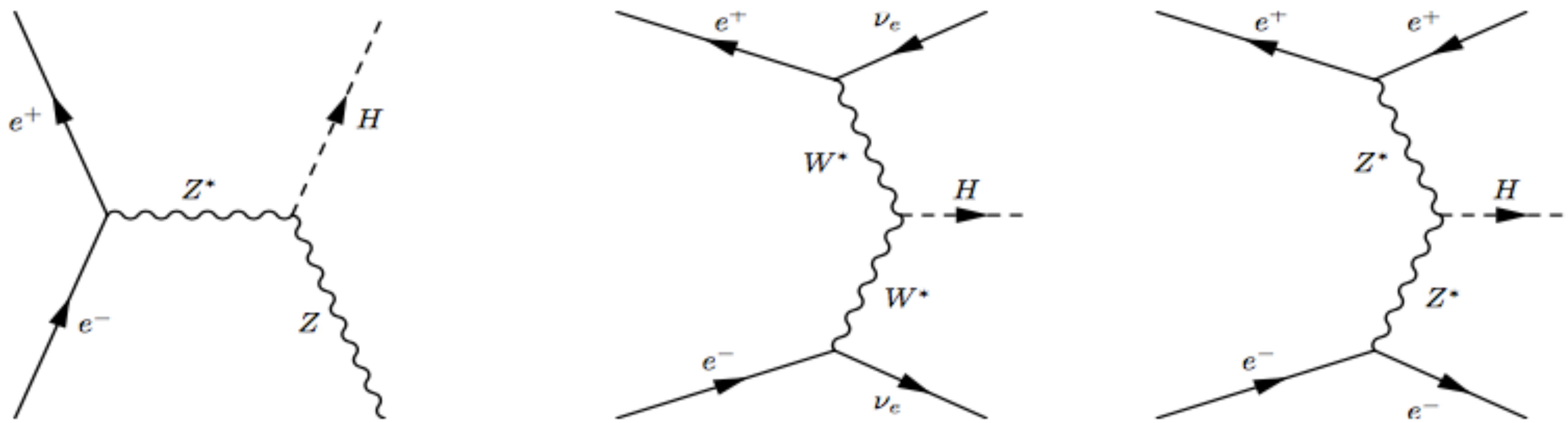
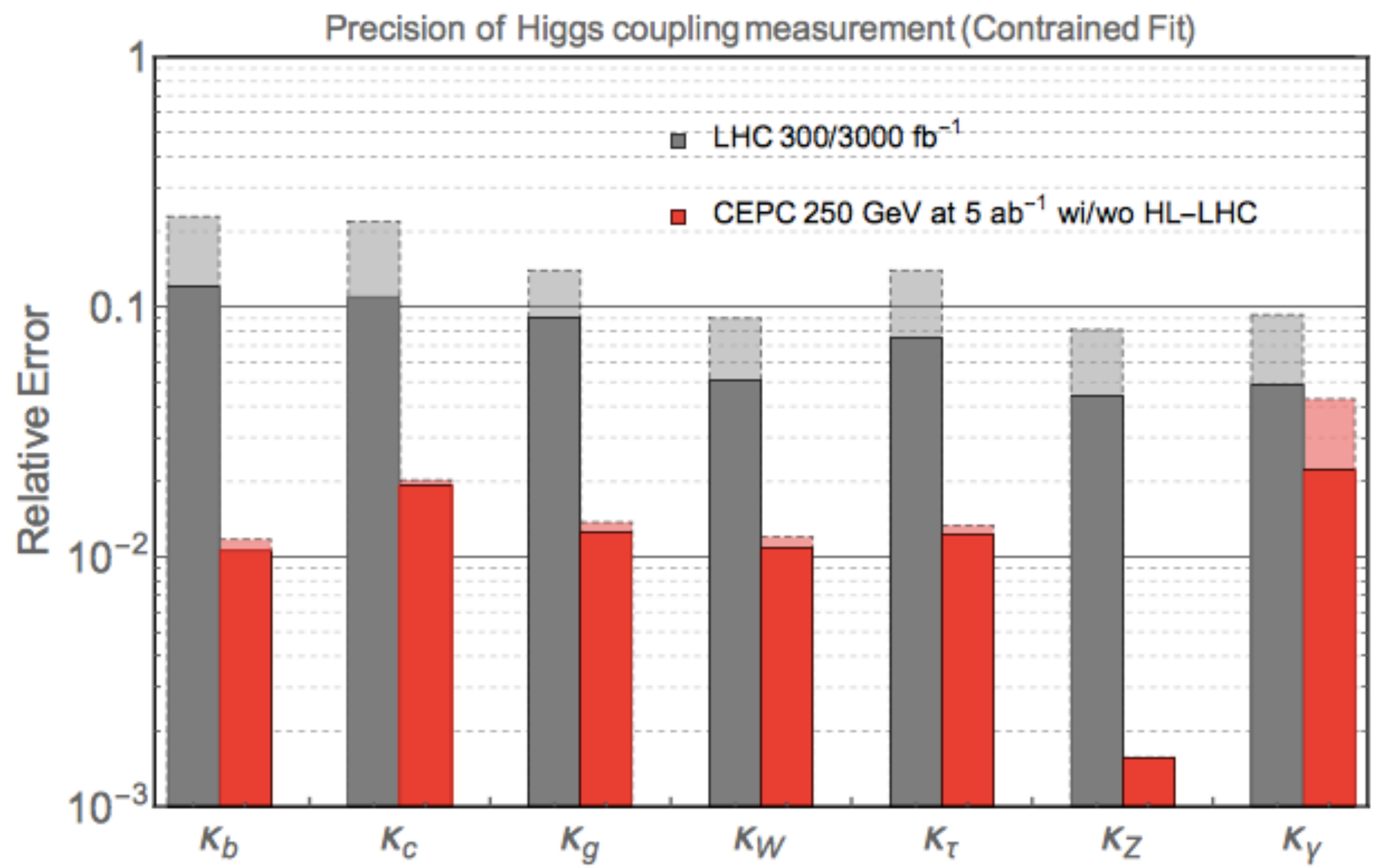


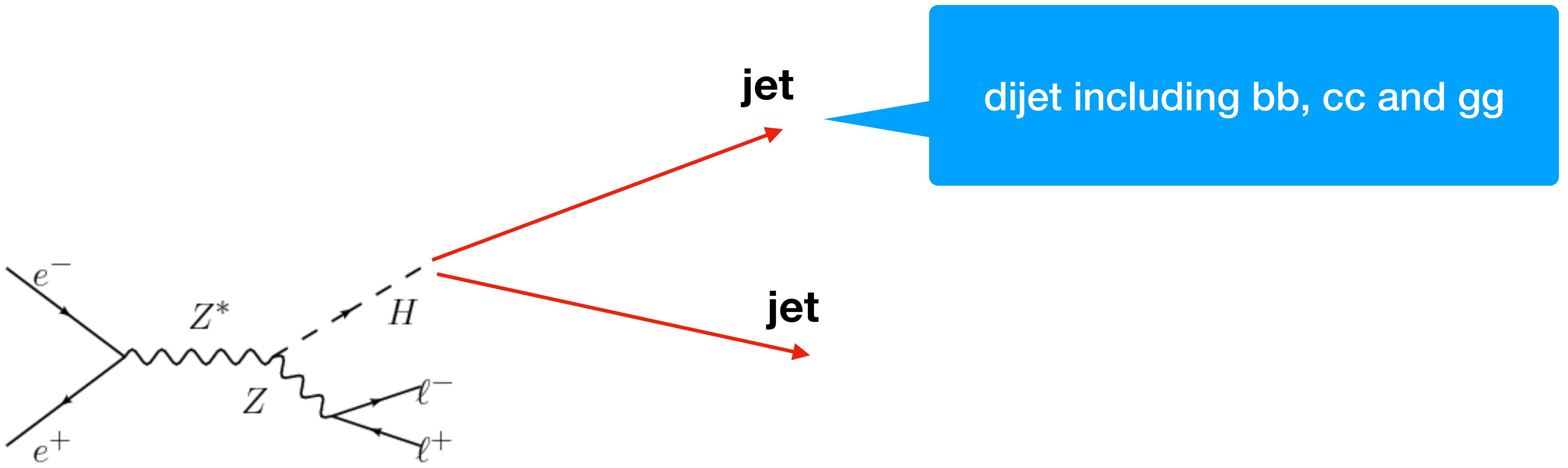
Figure 3.6 Feynman diagrams of the $e^+e^- \to ZH$, $e^+e^- \to \nu\bar{\nu}H$ and $e^+e^- \to e^+e^-H$ processes.



ggH coupling from H->gg

H->gg decay rate is proportional to ggH coupling

But H->gg is hidden inside H->jj

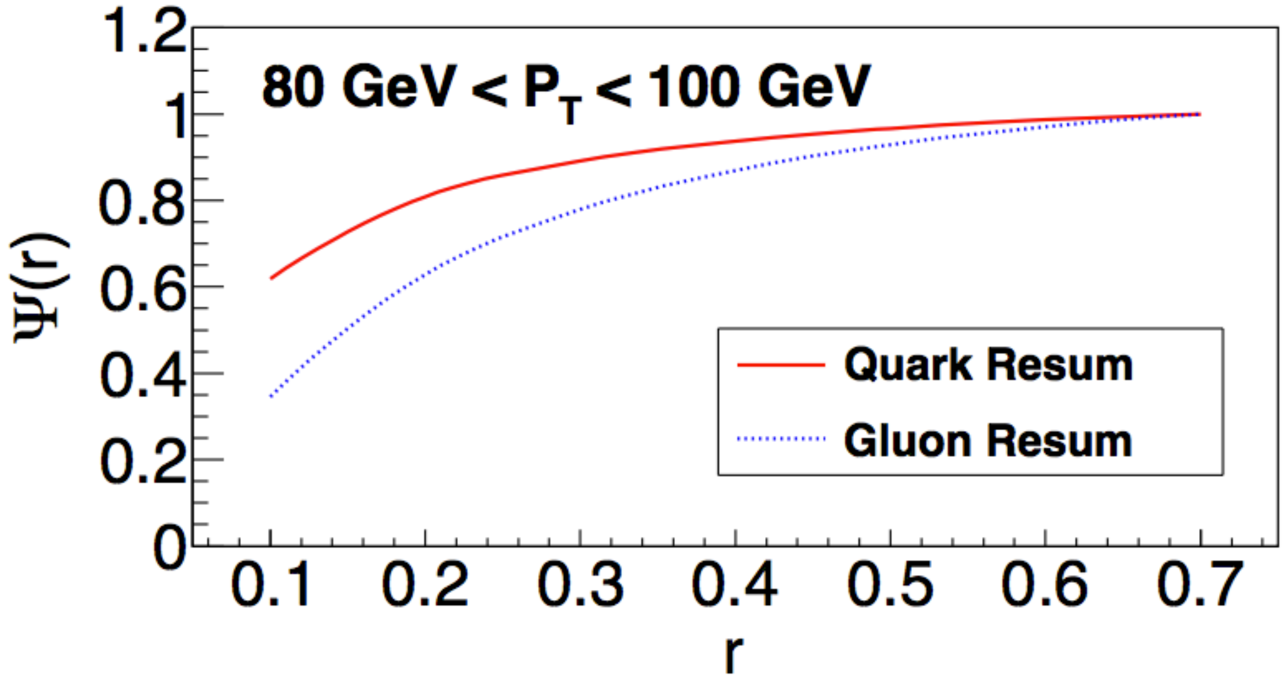


$gg(8.18\%)$, $c\bar{c}(2.884\%)$ and $b\bar{b}(58.09\%)$

Jet Energy Profile

$$\psi(r) = \frac{1}{N_j}\sum_j \psi_j(r) = \frac{1}{N_j}\sum_j \frac{\sum\limits_{r_i<r} p_{\mathrm{T},i}(r_i)}{\sum\limits_{r_i<R} p_{\mathrm{T},i}(r_i)},$$

Shape of JEP reflects the relative ratio between quark and gluon!



$$\Psi(r) = \frac{N_q\Psi_q(r) + N_g\Psi_g(r)}{N_q + N_g}$$

H->bb is well measured.
&
Assume Hbb Yukawa is true.

Optimized uncertainty of effective coupling

$$Z^N(r) = \frac{\sum_j (\psi_j + b)}{\sum_j^{\mathrm{SM}} (\psi_j + b)},$$

$$\delta\kappa_g^Z = \delta\kappa_g^N \Big[\left(\frac{\sigma(r)}{\psi_g + b} \right)^2 + f_g + f_q \left(\frac{\psi_q + b}{\psi_g + b} \right)^2 + f_{\mathrm{BG}} \left(\frac{\psi_{\mathrm{BG}} + b}{\psi_g + b} \right)^2 \Big]^{1/2}.$$

Minimization $\Rightarrow$ $$\frac{\partial \delta\kappa_g^Z}{\partial b} = 0,$$

$$b = \frac{\sigma^2(r) + f_{\mathrm{BG}}(\psi_q - \psi_{\mathrm{BG}})(\psi_g - \psi_{\mathrm{BG}})}{f_{\mathrm{q}}(\psi_g - \psi_q) + f_{\mathrm{BG}}(\psi_g - \psi_{\mathrm{BG}})} - \psi_q.$$

MC Simulation

Whizard 1.95 → Generate events at the future e+e- collider for the center-of-mass energy 250 GeV and integrated luminosity 5 ab-1.

↓

PYTHIA → Shower and Hadronization

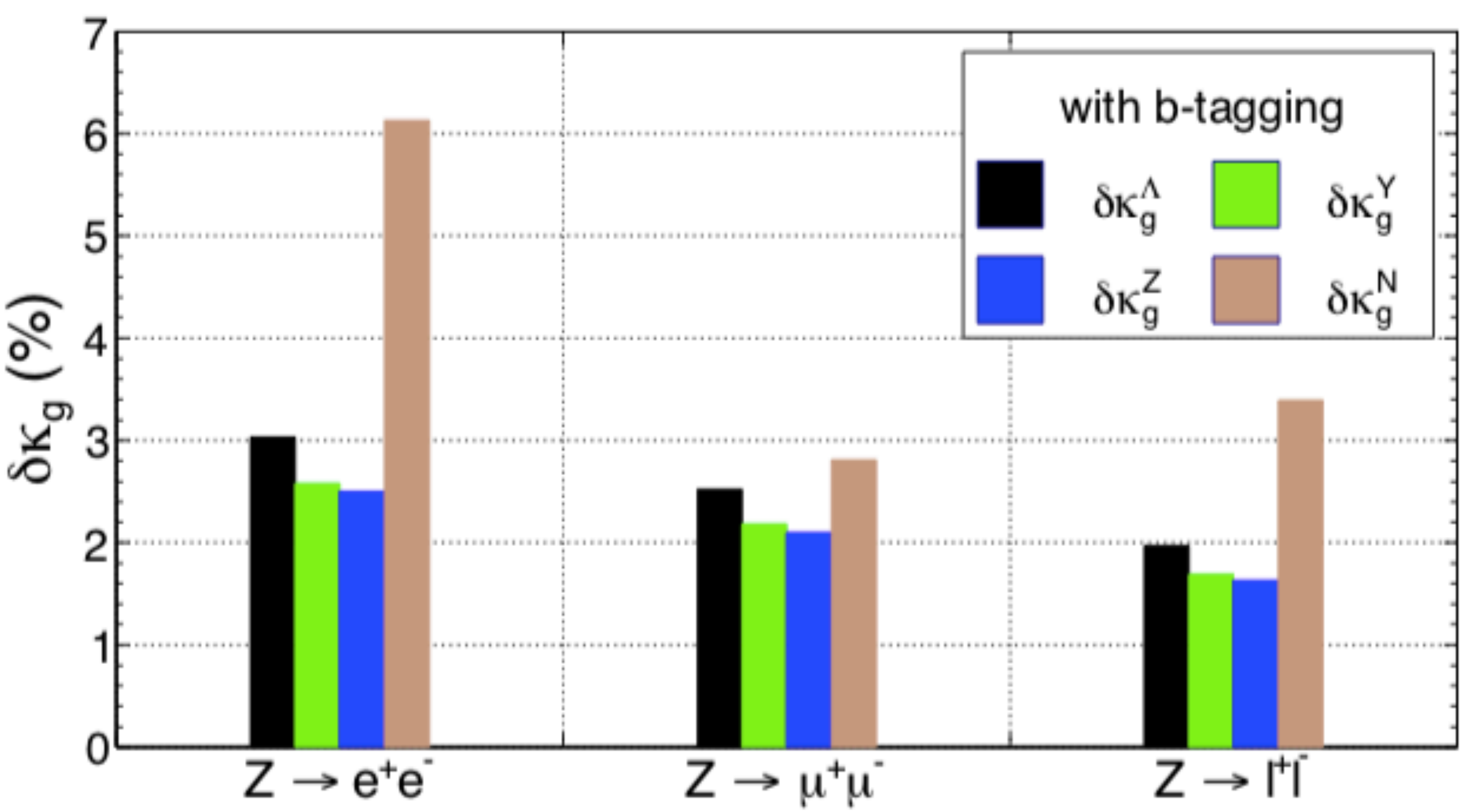
↓

FASTJET 3.3.0 → Anti-kT algorithm with cone size R = 0.7

JEPs are obtained by analyzing
the jet substructure according to the formula.

Probing the Higgs boson-gluon coupling via the jet energy profile at e^+e^- colliders

Gexing Li, Zhao Li, Yandong Liu, Yan Wang, and Xiaoran Zhao
Phys. Rev. D **98**, 076010 – Published 17 October 2018

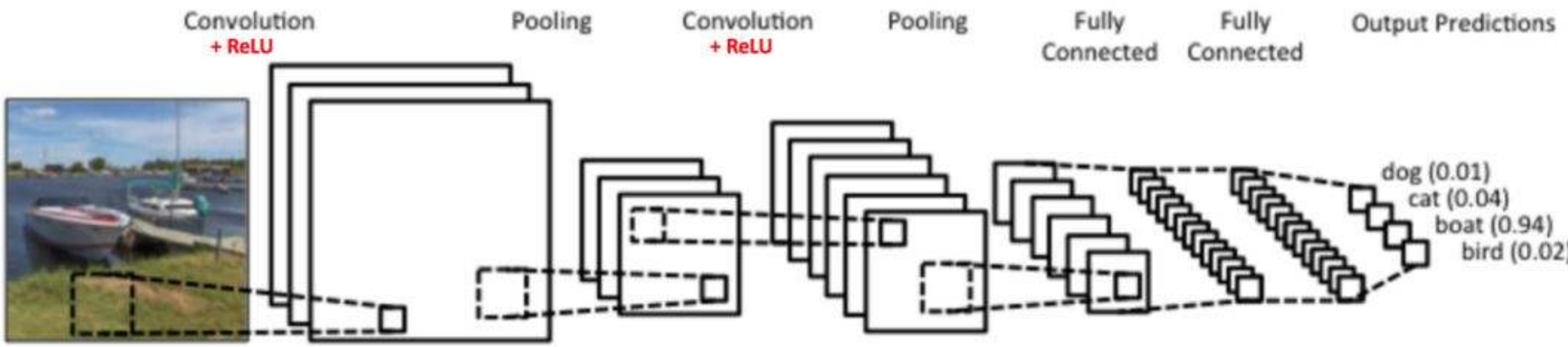


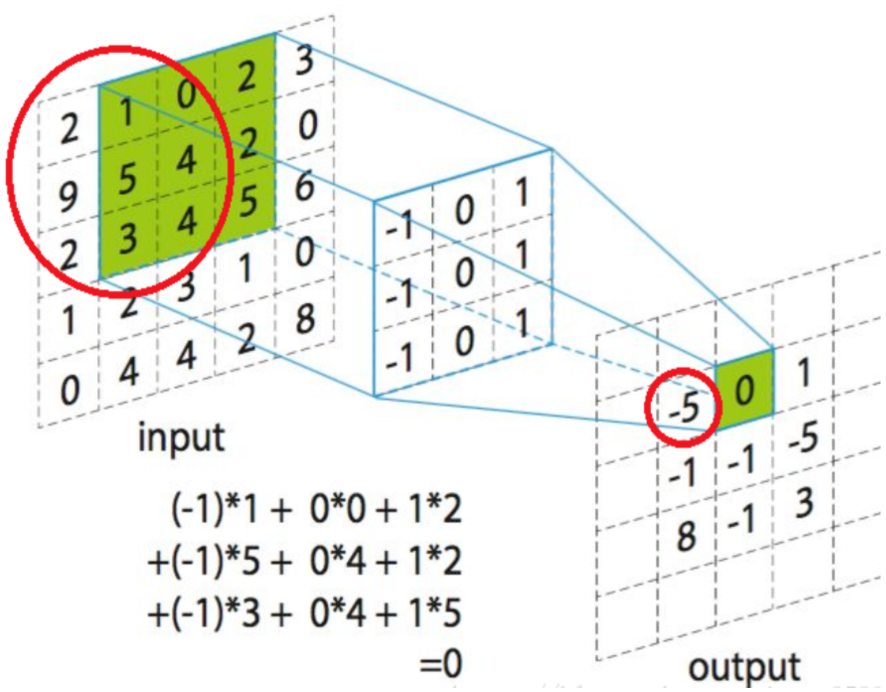
~50% improvement to reach ~1.6%

Machine Learning is widely used in many fields

Convolutional Neural Networks (CNNs)

CNNs is one of the most popular algorithms in deep learning. It has powerful ability of image recognition.



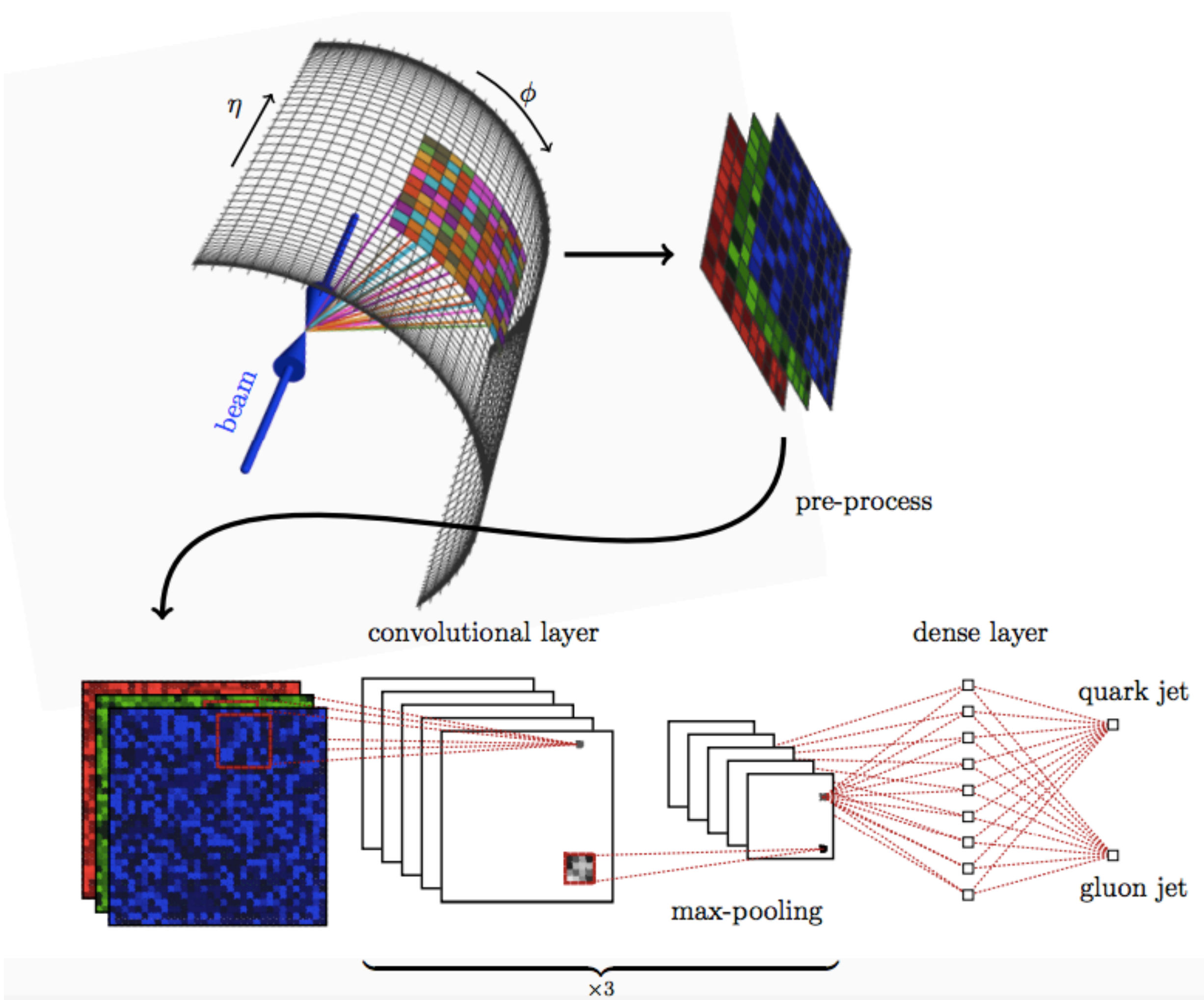


CNNs extract the features form images by the convolutional layers.

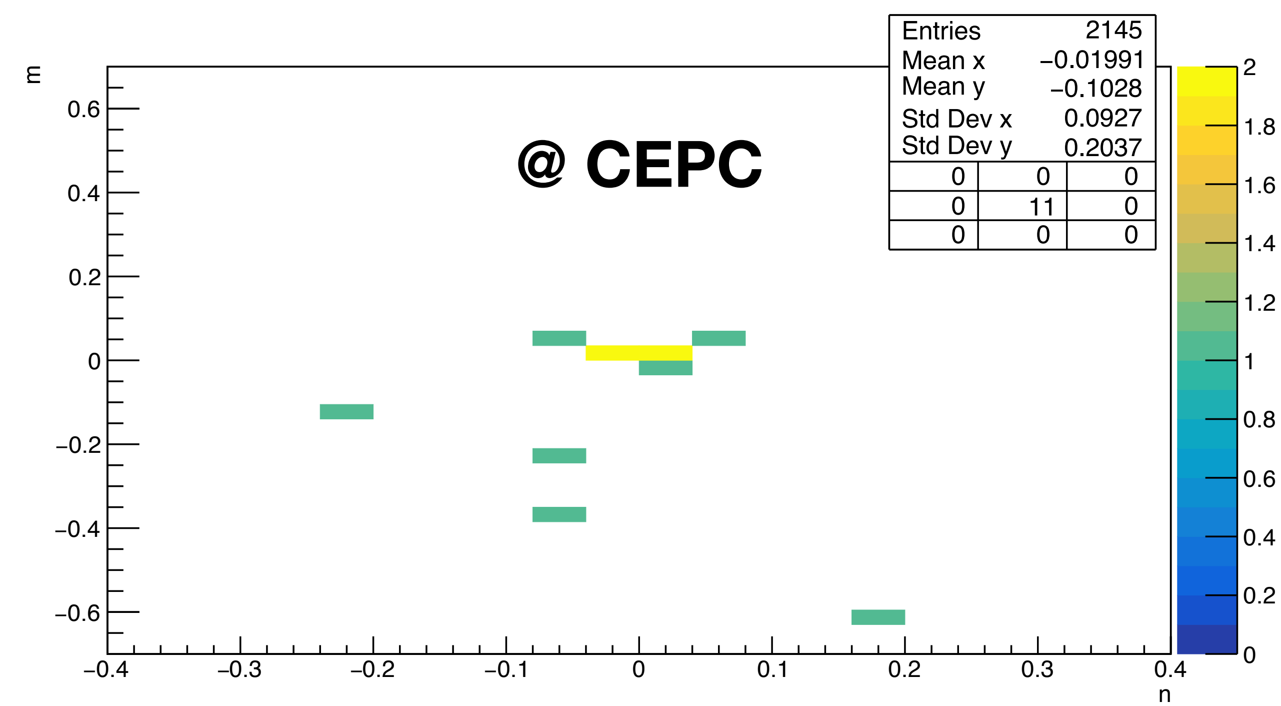
Machine Learning @ HEP

- **Higgs boson tagging** *PLB 322 (1994) 219-223*
- **boosted W boson tagging** *JHEP1502 (2015) 118*
- **boosted top tagging** *JHEP 1507 (2015) 086*
- **single merged jet tagging** *PRD 93 (2016) 094034*
- **heavy-light quark discrimination** *PRD 94 (2016) 112002*
- **quark-gluon discrimination** *PRL 65 (1990) 1321-1324*
- **scan parameter space in the BSM** *arXiv:1708.06615*
- *…*

CNN for effective coupling measurement



Images of not-only-jet-but-whole-event

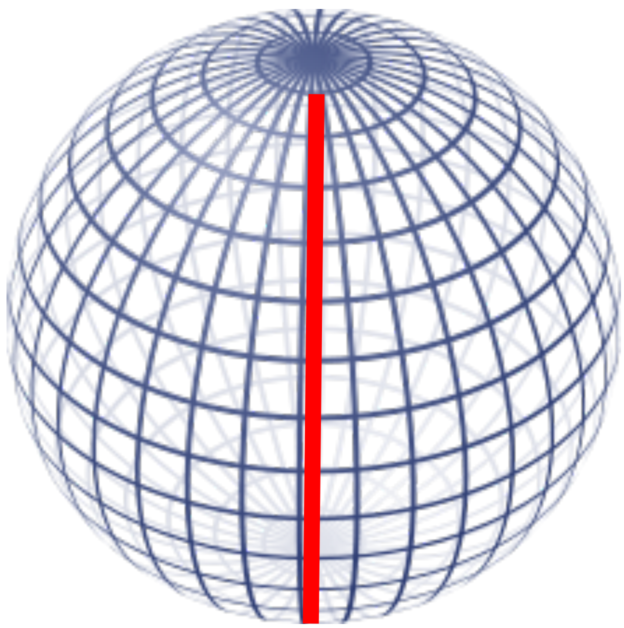


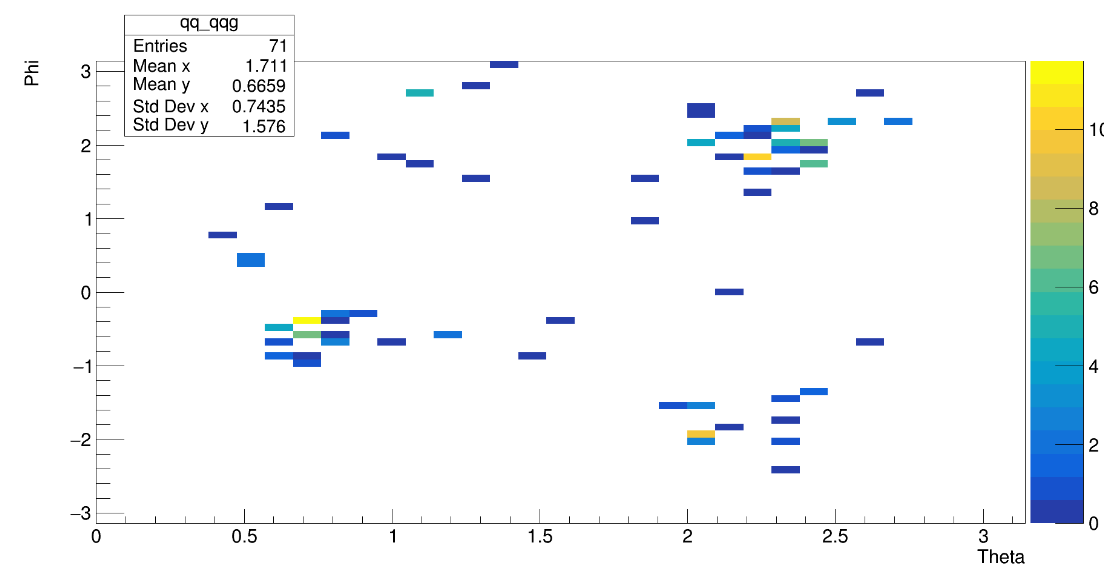
CNN Configuration

```
nb_filters=64
batch_size=128
nb_epoch=50

model=Sequential()
model.add(Conv2D(nb_filters,(3,3),padding='valid',kernel_initializer="random_normal",input_shape=(33,65,1)))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2,2),strides=2))
model.add(Dropout(0.5))

model.add(Conv2D(nb_filters,(3,3),padding='valid',kernel_initializer="random_normal"))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2,2),strides=2))
model.add(Dropout(0.5))

model.add(Conv2D(nb_filters,(3,3),padding='valid',kernel_initializer="random_normal"))
model.add(Activation('relu'))
model.add(MaxPooling2D(pool_size=(2,2),strides=2))
model.add(Flatten())
model.add(Dense(128))
model.add(Activation('relu'))
model.add(Dropout(0.5))

model.add(Dense(1))
model.add(Activation('sigmoid'))

adam = Adam(lr=0.0005, beta_1=0.9, beta_2=0.999, epsilon=1e-08)
model.compile(loss='binary_crossentropy',optimizer = adam, metrics=['accuracy'])
early_stopping = EarlyStopping(monitor='val_loss', patience=3, verbose=0, mode='auto')
```

https://github.com/zhaoli-IHEP/Higgs-ML

Recover symmetry via rotation



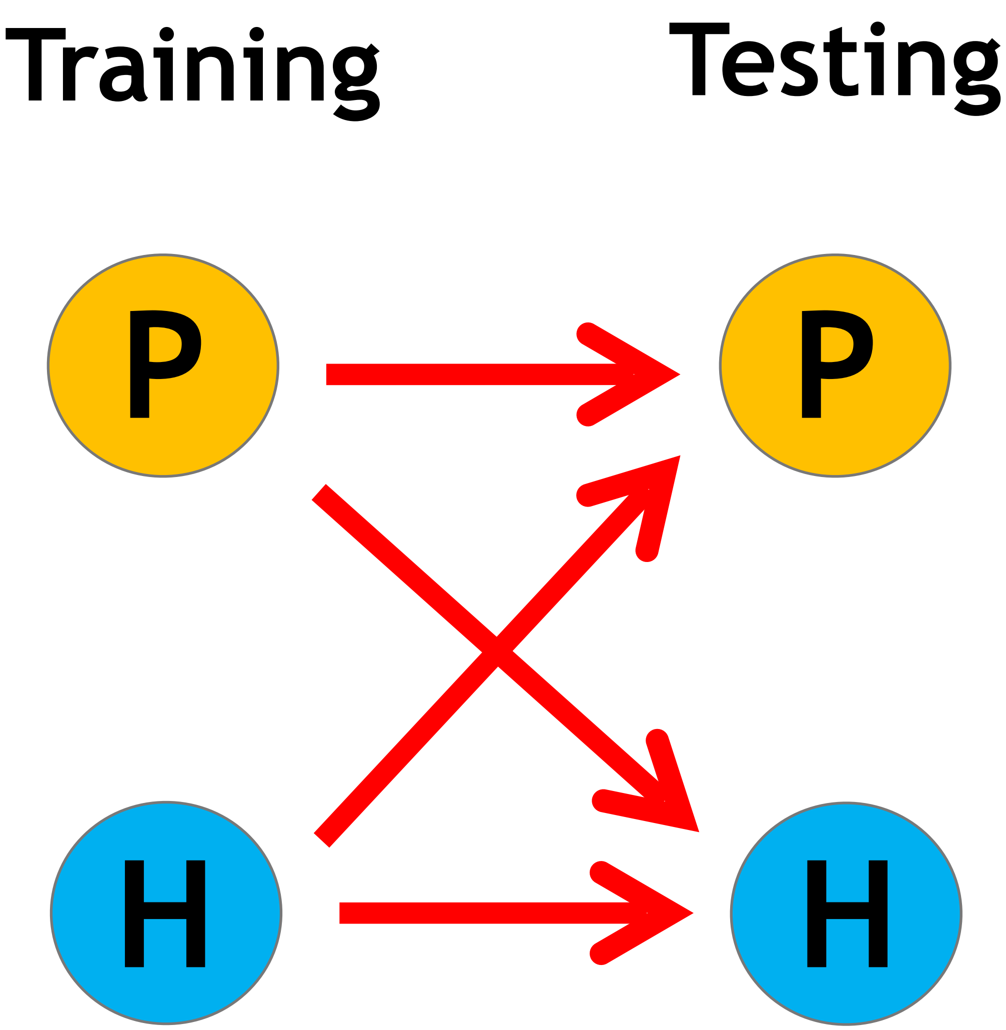


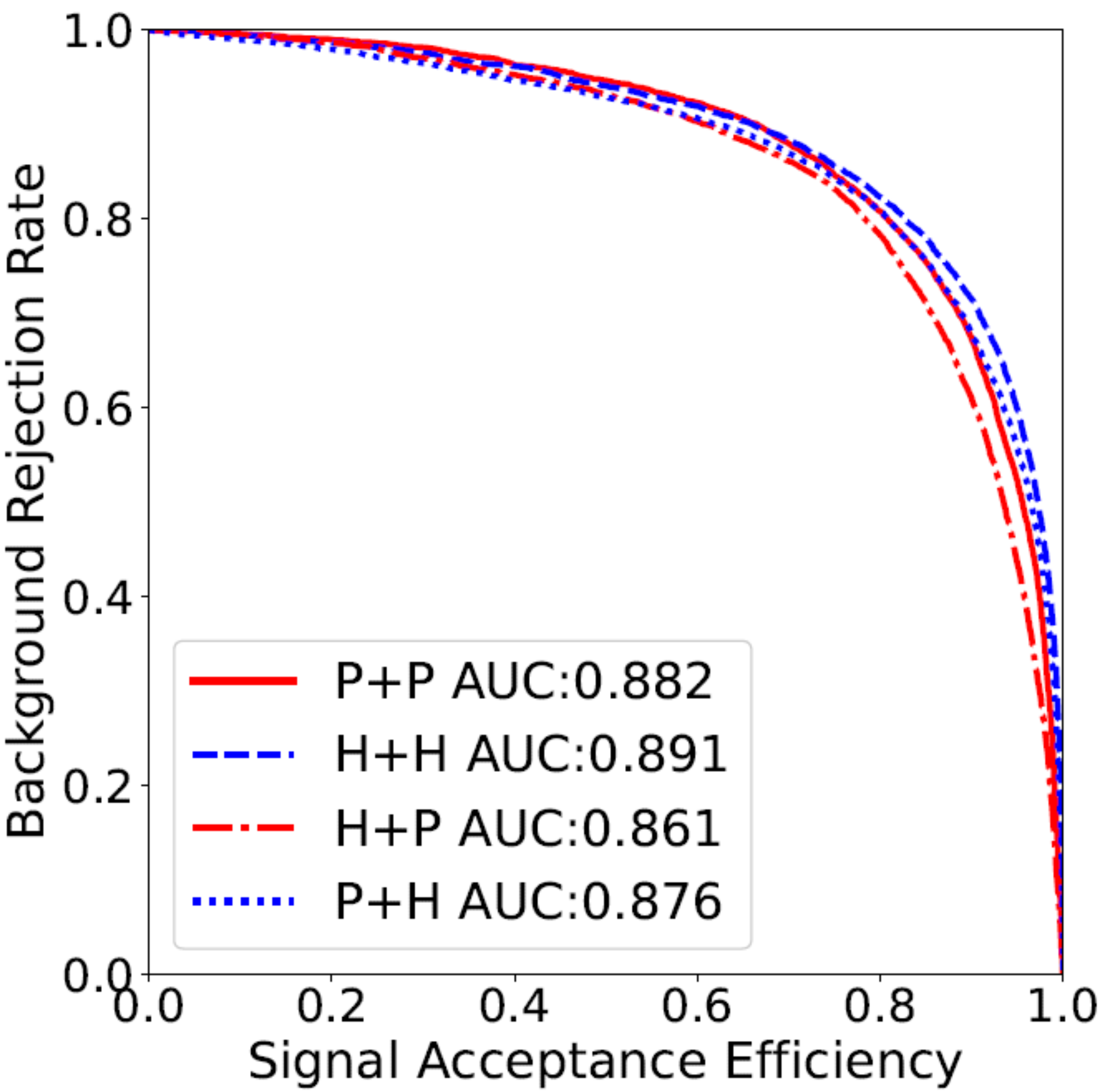
phi symmetry break

Rotate at phi direction

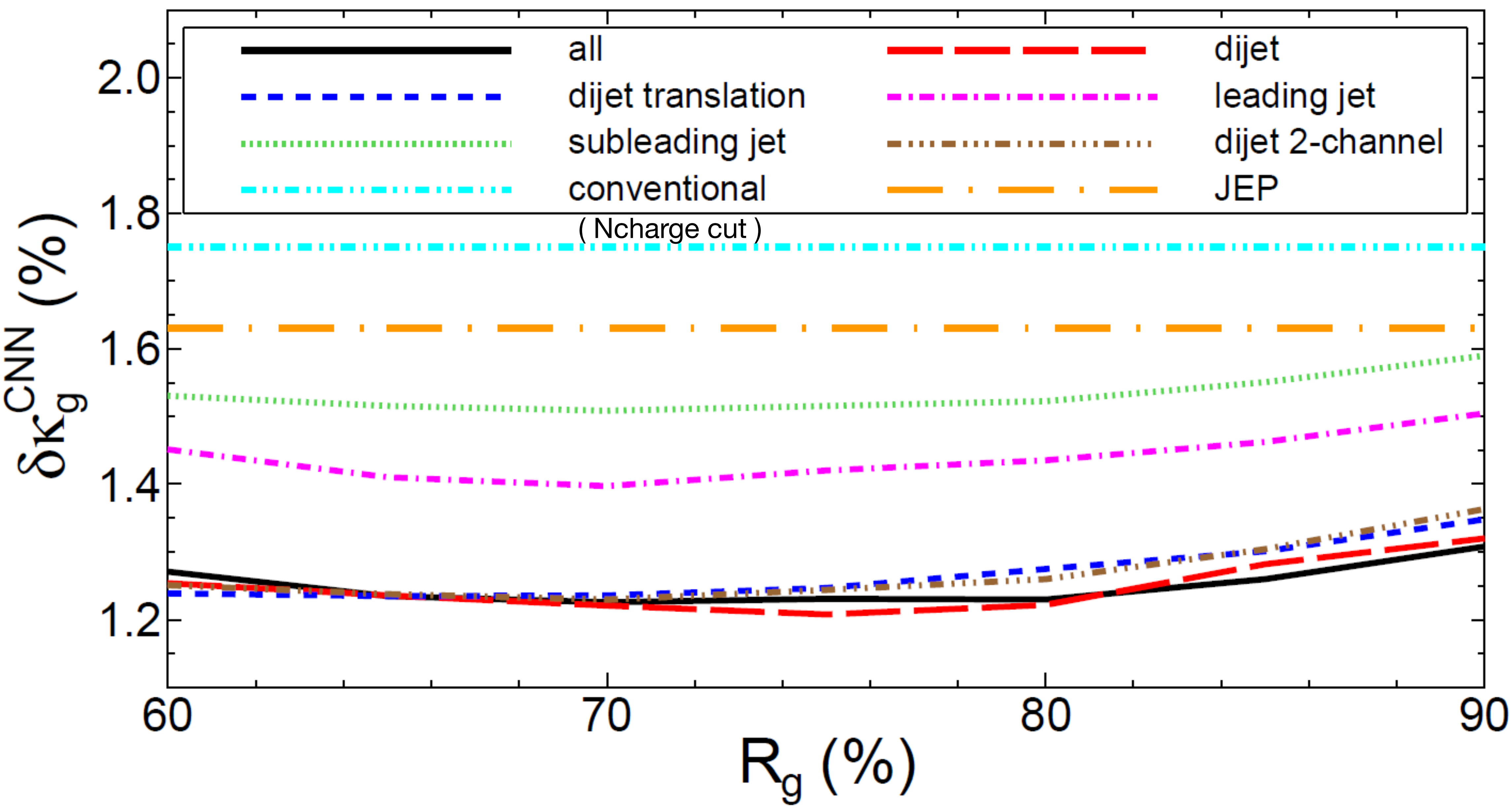
Each rotation turns 13 pixels.
Each image becomes 5 different images.

Performance of CNNs



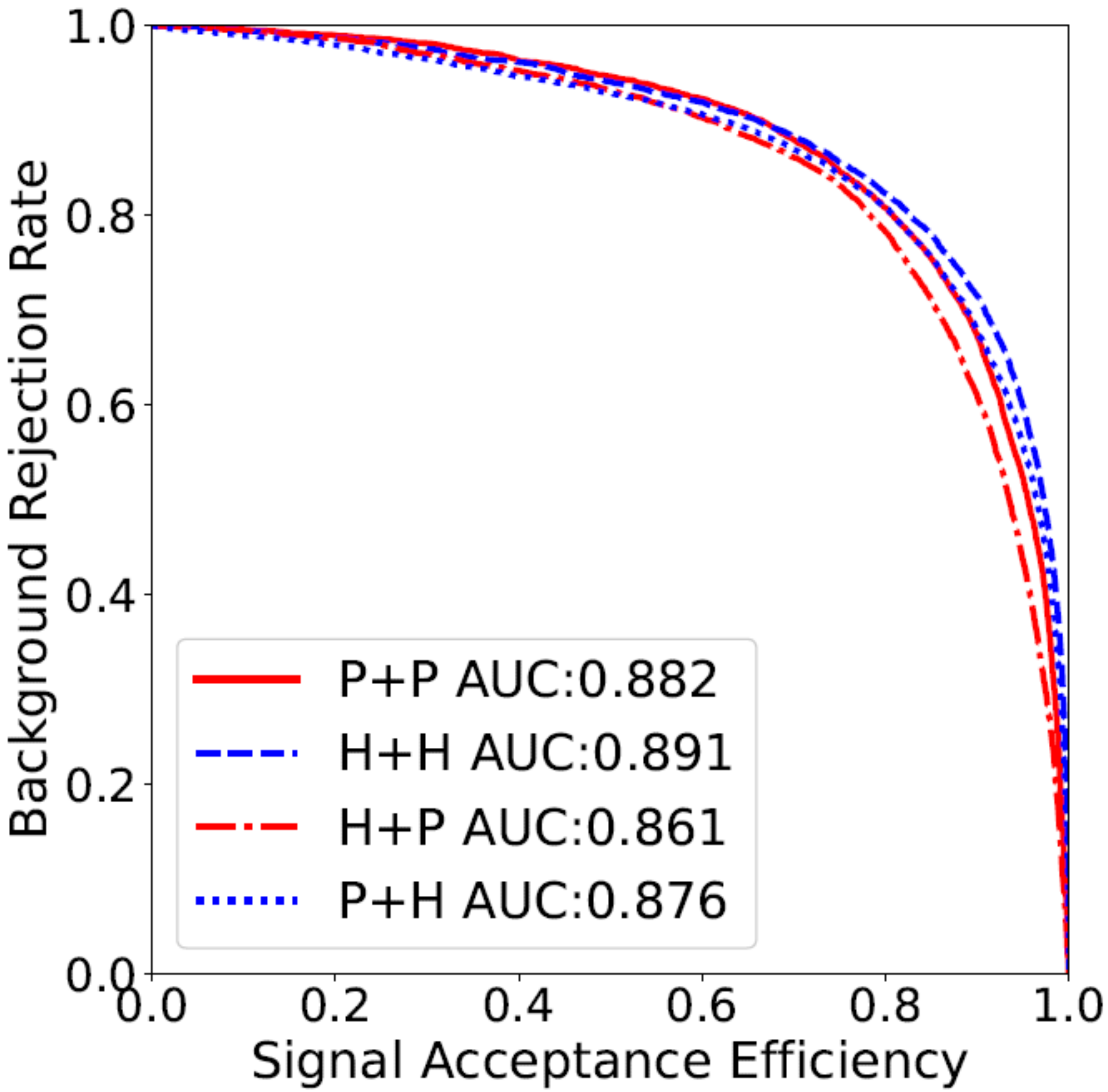


Improvement of CNNs

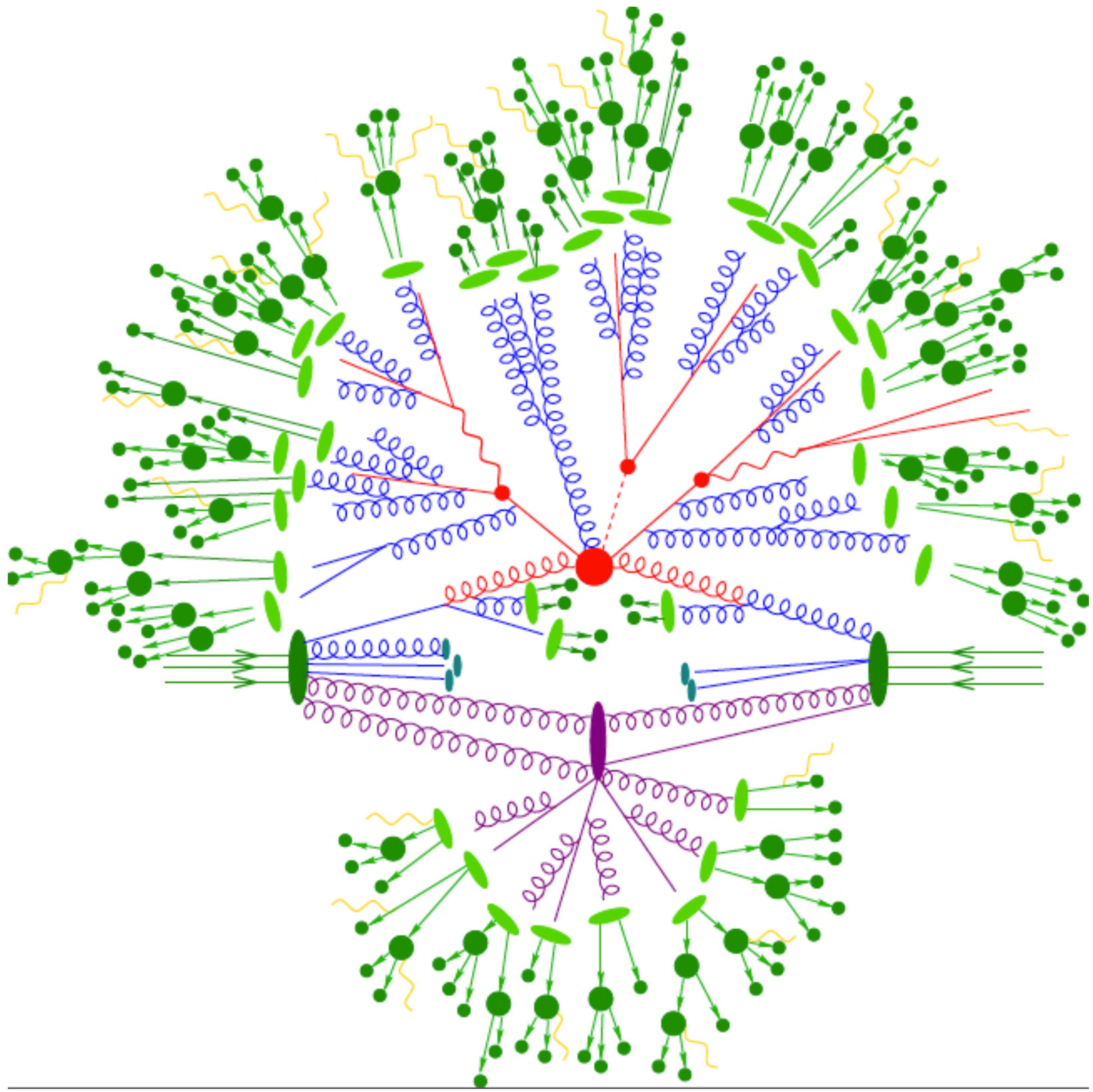


Further ~30% improvements to reach ~1.2%

Revisit AUC comparison between P & H



Does simulation really simulate physics?



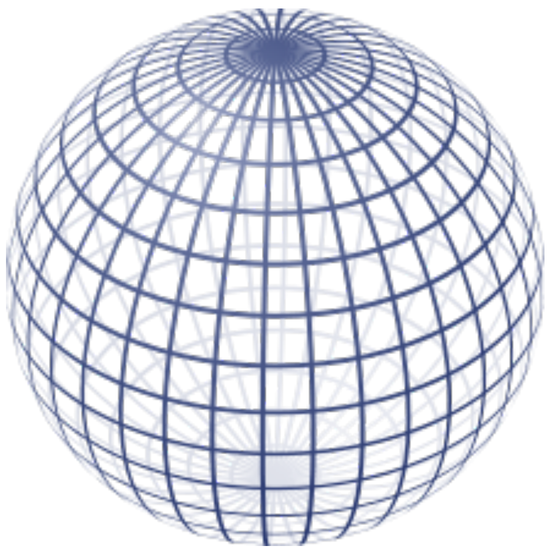
Parton Shower? Hadronization? Underlying events? etc.

Conclusion

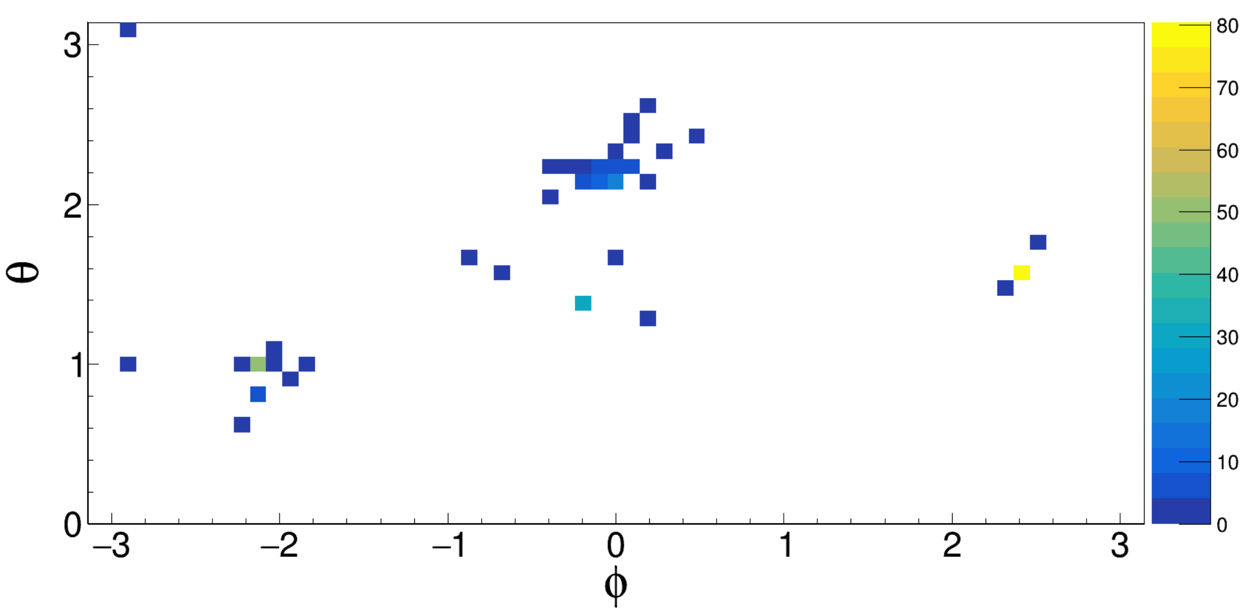
- CEPC can be very precise factory for Higgs investigation.
- Deep learning is full of potential for CEPC physics.
- Maybe deep learning can also help LHC physics.
- However, we should be careful about traps in simulations.

Backup

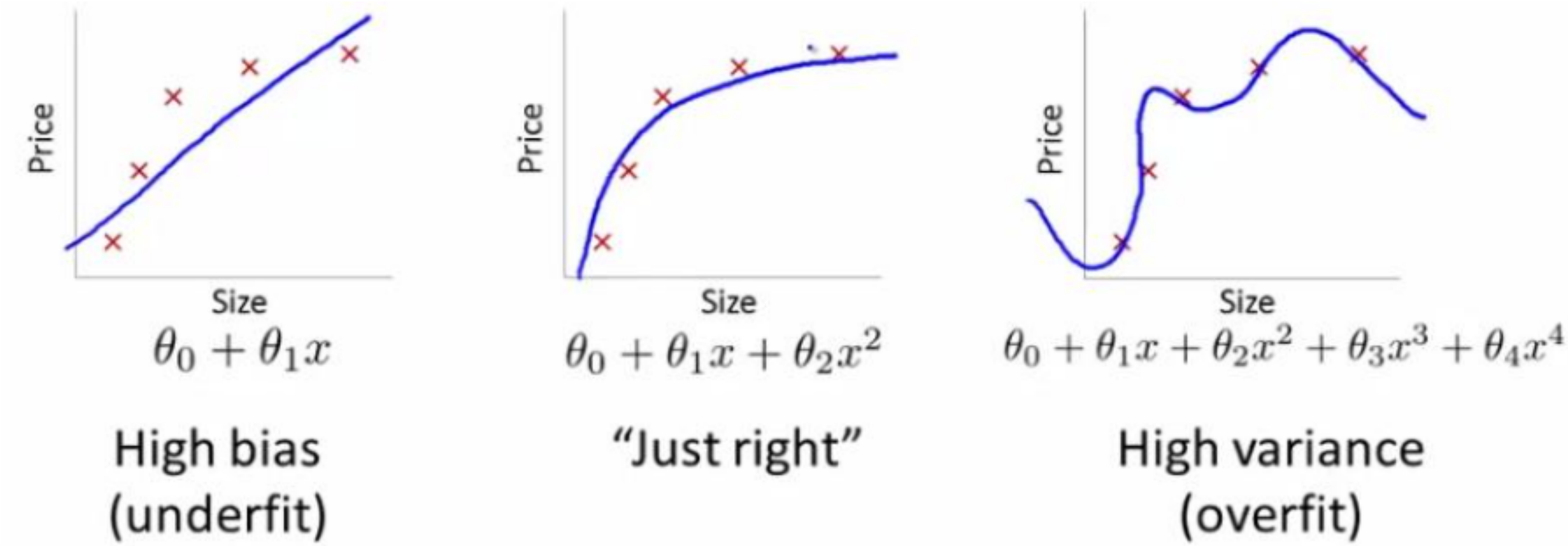
Convolutional Neural Networks (CNNs)



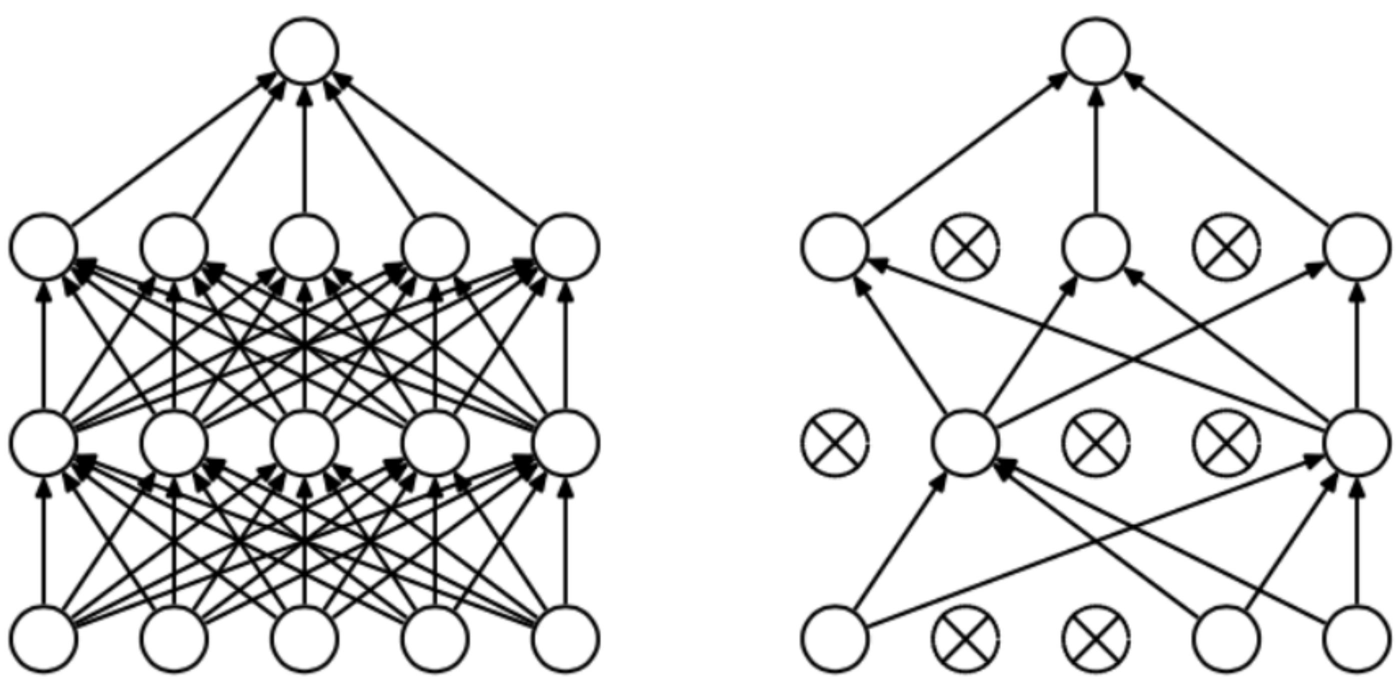
Energy of all the final state stable particles



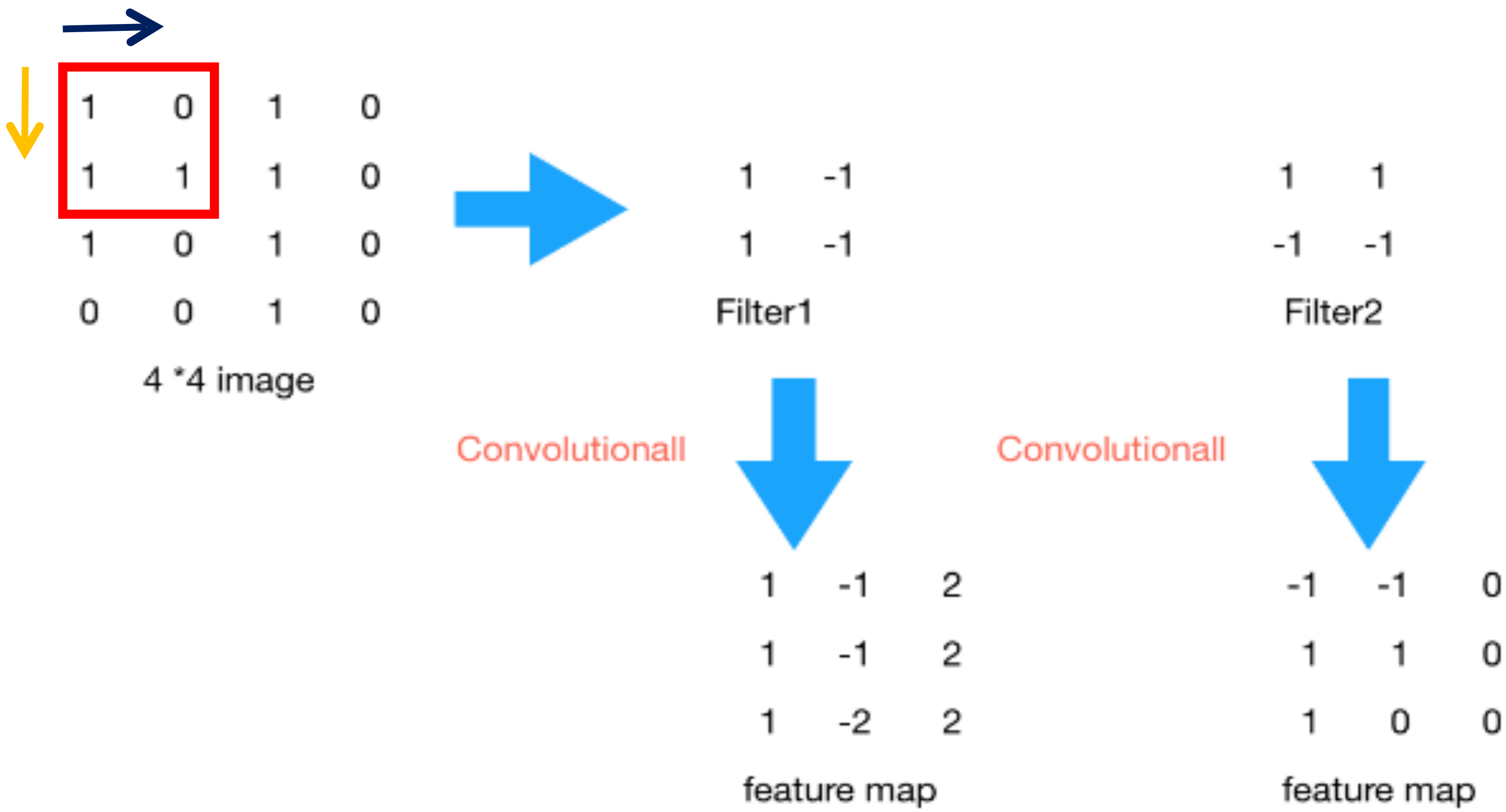
2D image (62*30 pixels)

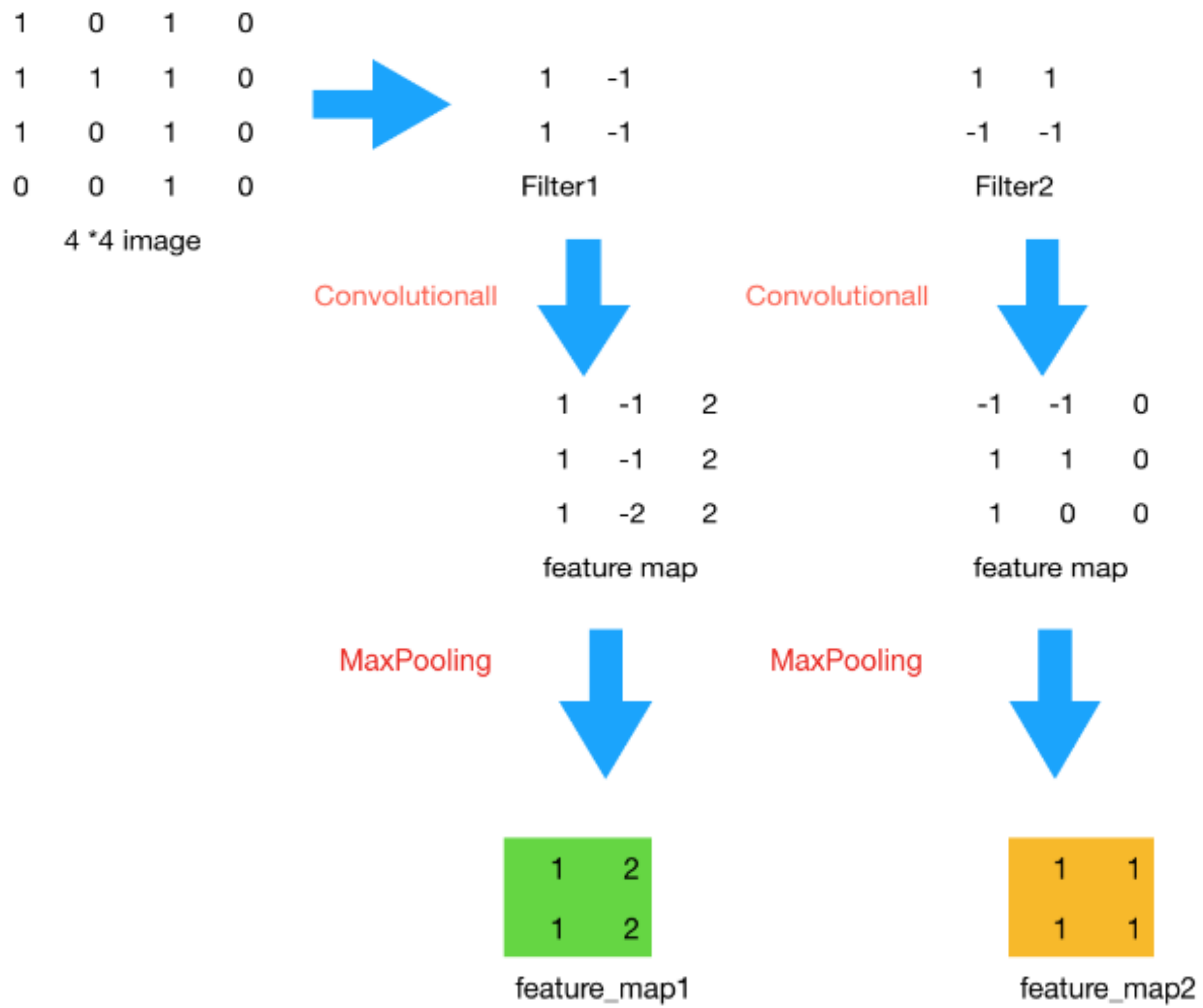


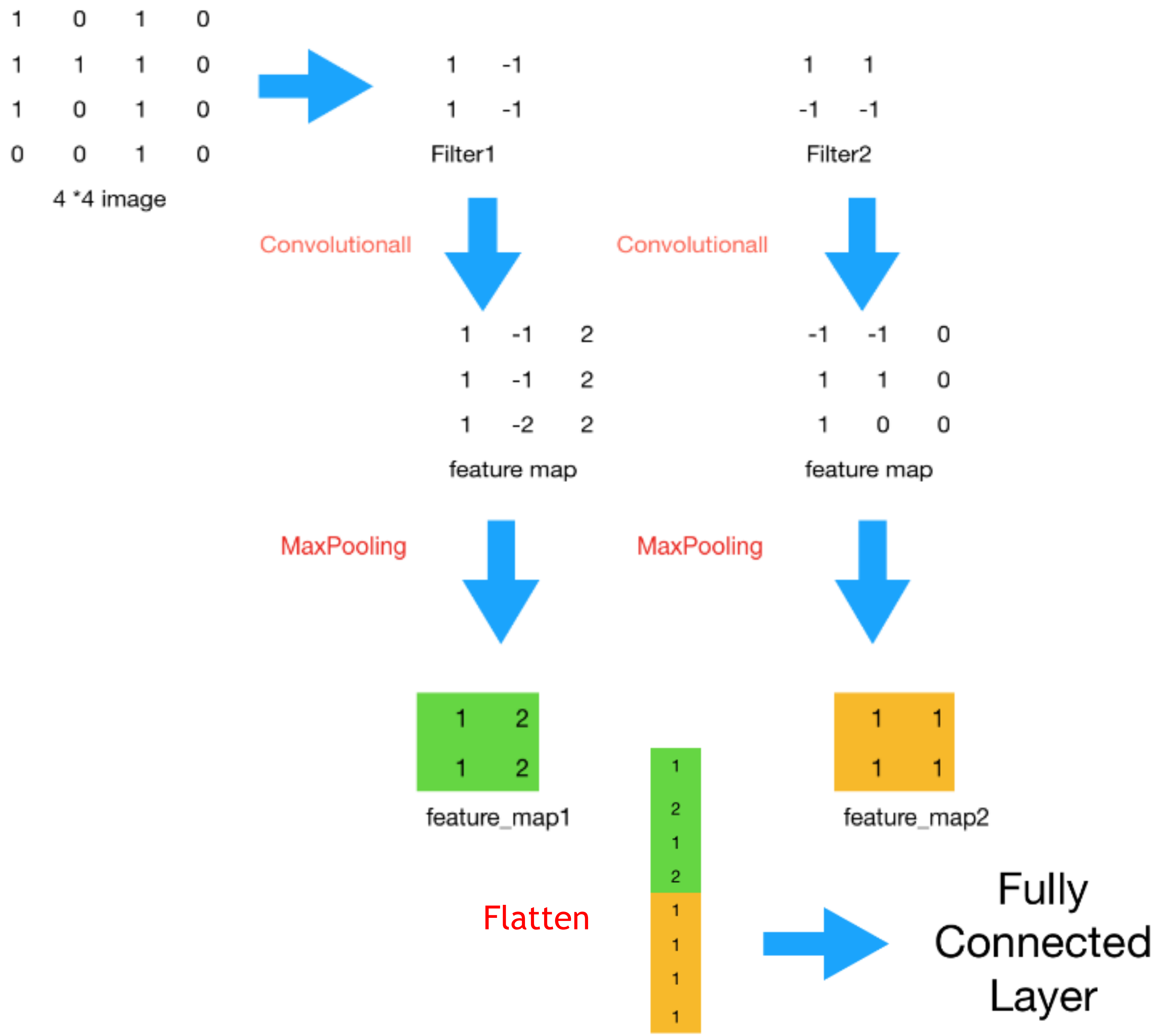
Overfit



Dropout


1 0 1 0
1 1 1 0
1 0 1 0
0 0 1 0
4 *4 image
1 -1
1 -1
Filter1
1 1
-1 -1
Filter2
Convolutionall
Convolutionall
1 -1 2
1 -1 2
1 -2 2
feature map
-1 -1 0
1 1 0
1 0 0
feature map


1 0 1 0
1 1 1 0
1 0 1 0
0 0 1 0
4 *4 image
1 -1
1 -1
Filter1
1 1
-1 -1
Filter2
Convolutionall
Convolutionall
1 -1 2
1 -1 2
1 -2 2
feature map
-1 -1 0
1 1 0
1 0 0
feature map
MaxPooling
MaxPooling
1 2
1 2
feature_map1
1 1
1 1
feature_map2



1 0 1 0
1 1 1 0
1 0 1 0
0 0 1 0
4 *4 image
1 -1
1 -1
Filter1
1 1
-1 -1
Filter2
Convolutionall
Convolutionall
1 -1 2
1 -1 2
1 -2 2
feature map
-1 -1 0
1 1 0
1 0 0
feature map
MaxPooling
MaxPooling
1 2
1 2
feature_map1
1 1
1 1
feature_map2
Flatten
1
2
1
2
1
1
1
1
Fully Connected Layer

Max Pooling