Improving measurement on Higgs-gluon effective coupling

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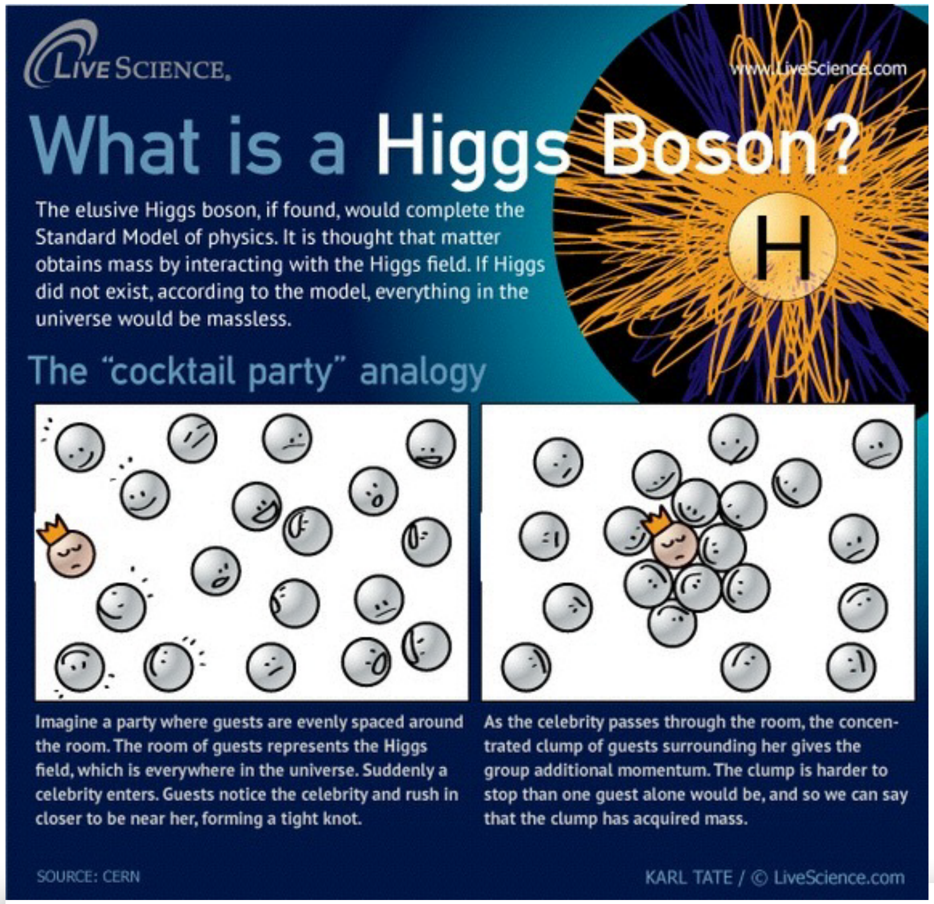
based on PRD98 (2018) no.7, 076010 & arXiv:1901.09391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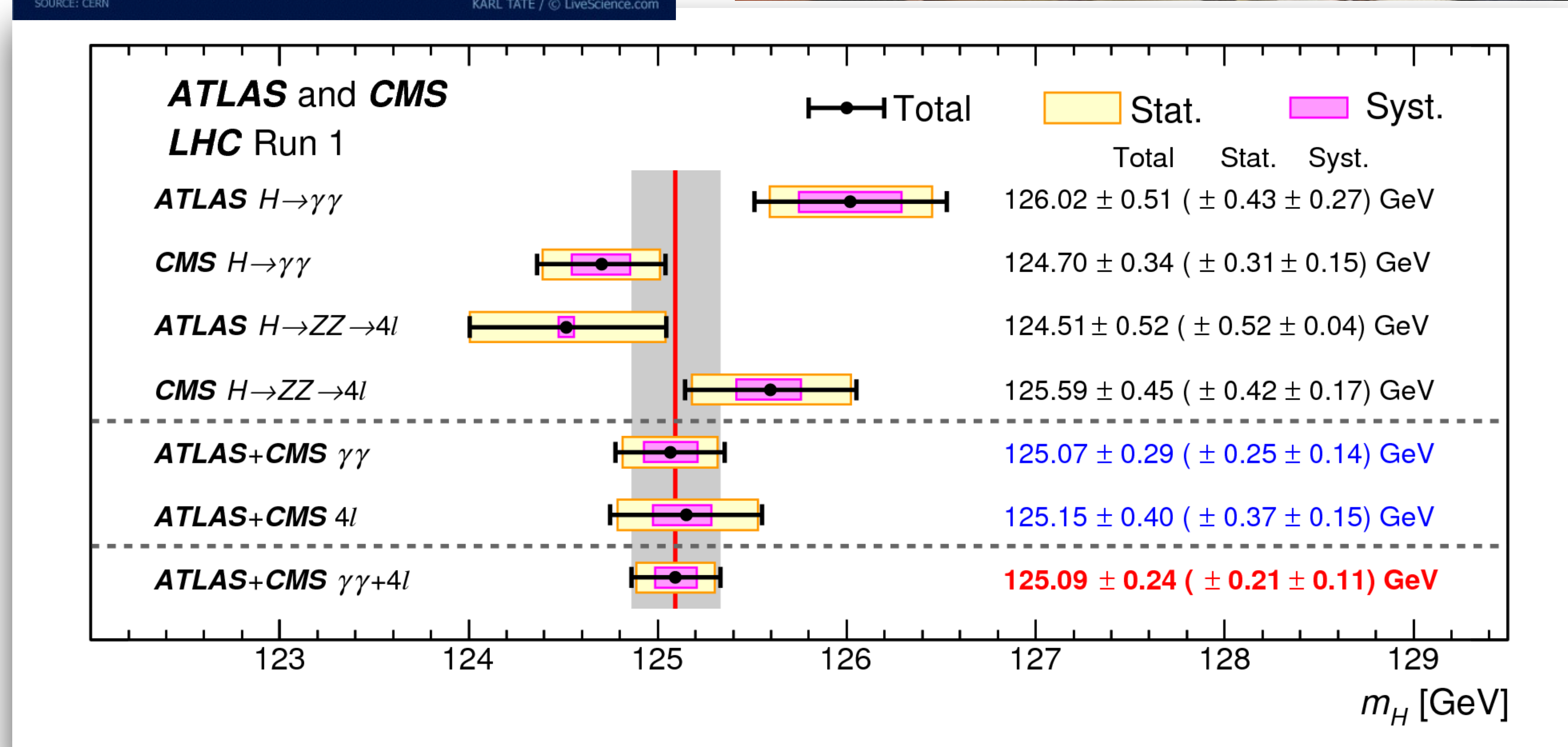
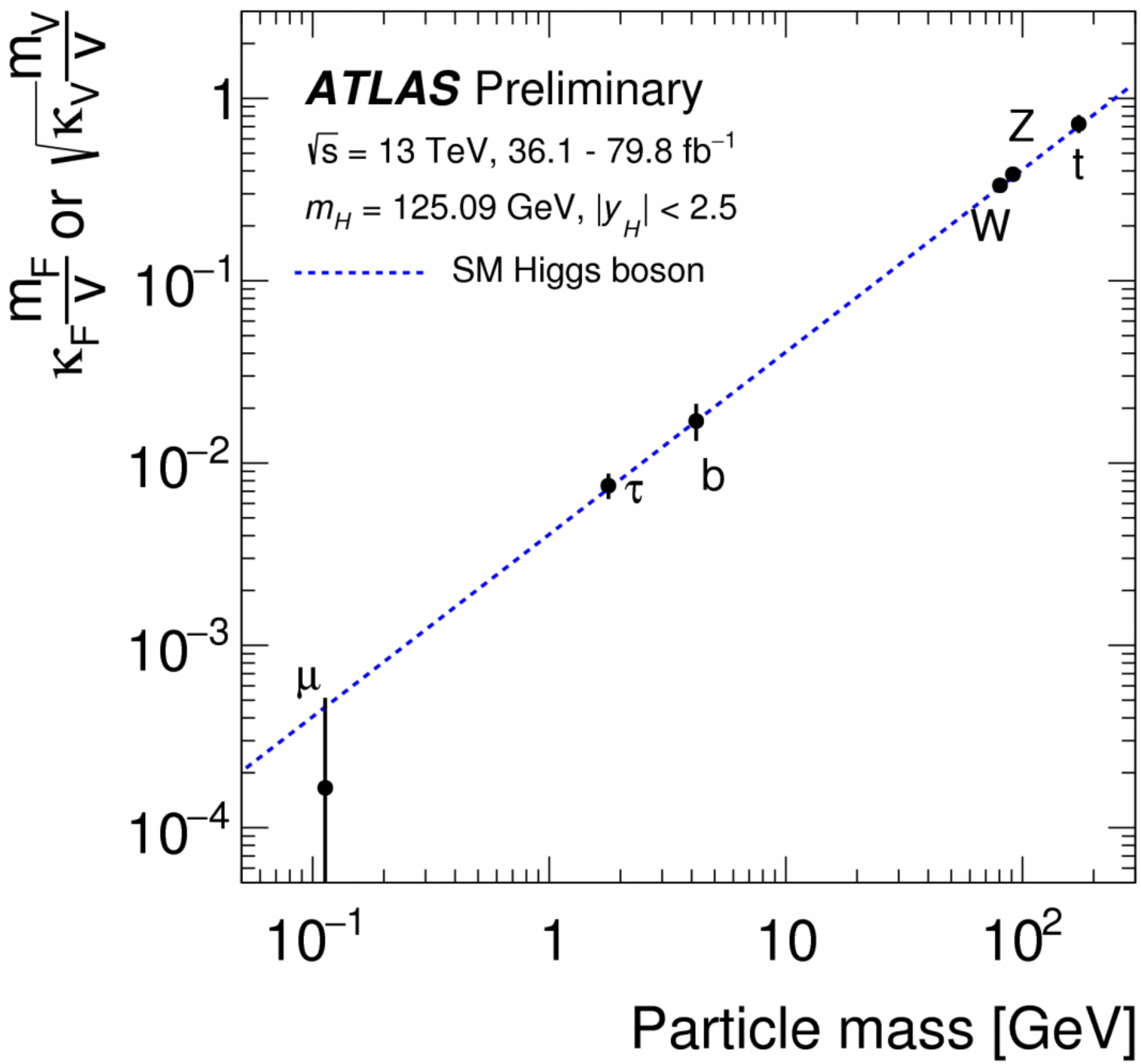
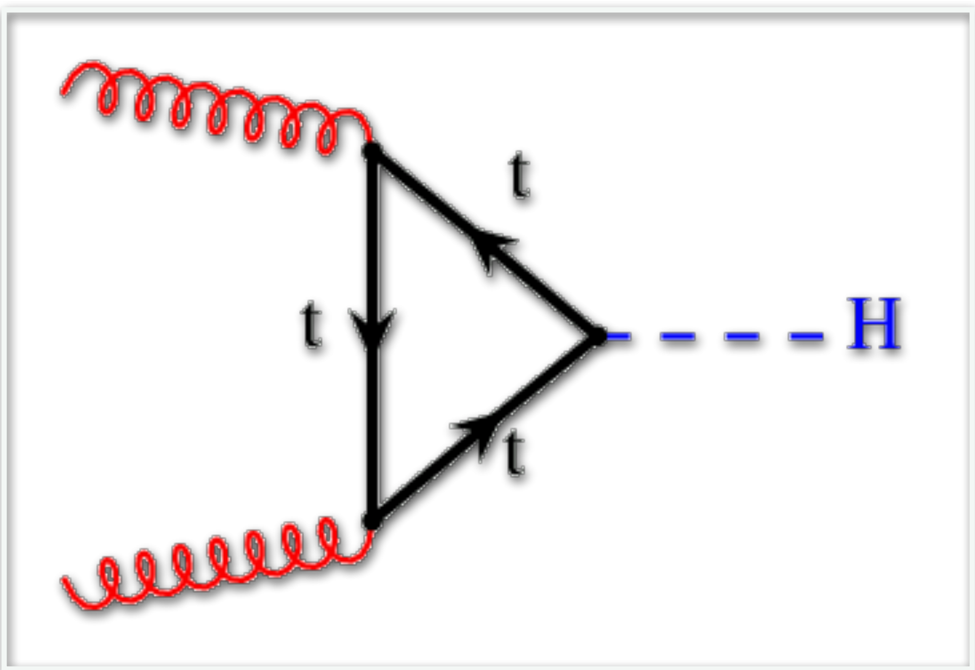
What is a Higgs Boson?
H
The elusive Higgs boson, if found, would complete the Standard Model of physics. It is thought that matter obtains mass by interacting with the Higgs field. If Higgs did not exist, according to the model, everything in the universe would be massless.
The "cocktail party" analogy
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

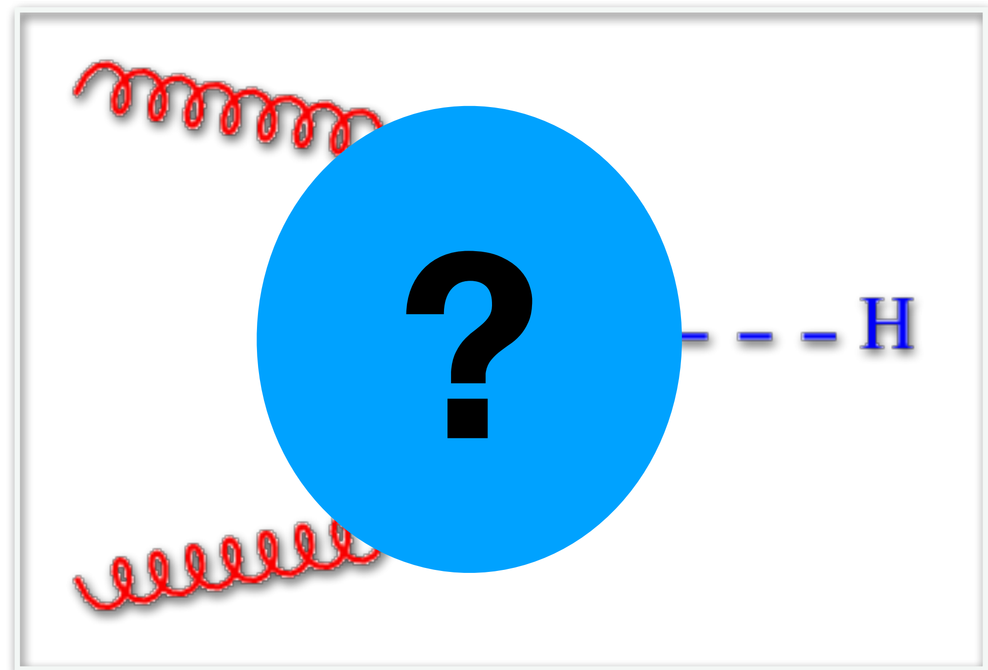

ATLAS and CMS
LHC Run 1
Total
Stat.
Syst.
Total Stat. Syst.
ATLAS $H\rightarrow\gamma\gamma$
126.02 ± 0.51 (± 0.43 ± 0.27) GeV
CMS $H\rightarrow\gamma\gamma$
124.70 ± 0.34 (± 0.31 ± 0.15) GeV
ATLAS $H\rightarrow ZZ\rightarrow 4l$
124.51 ± 0.52 (± 0.52 ± 0.04) GeV
CMS $H\rightarrow ZZ\rightarrow 4l$
125.59 ± 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



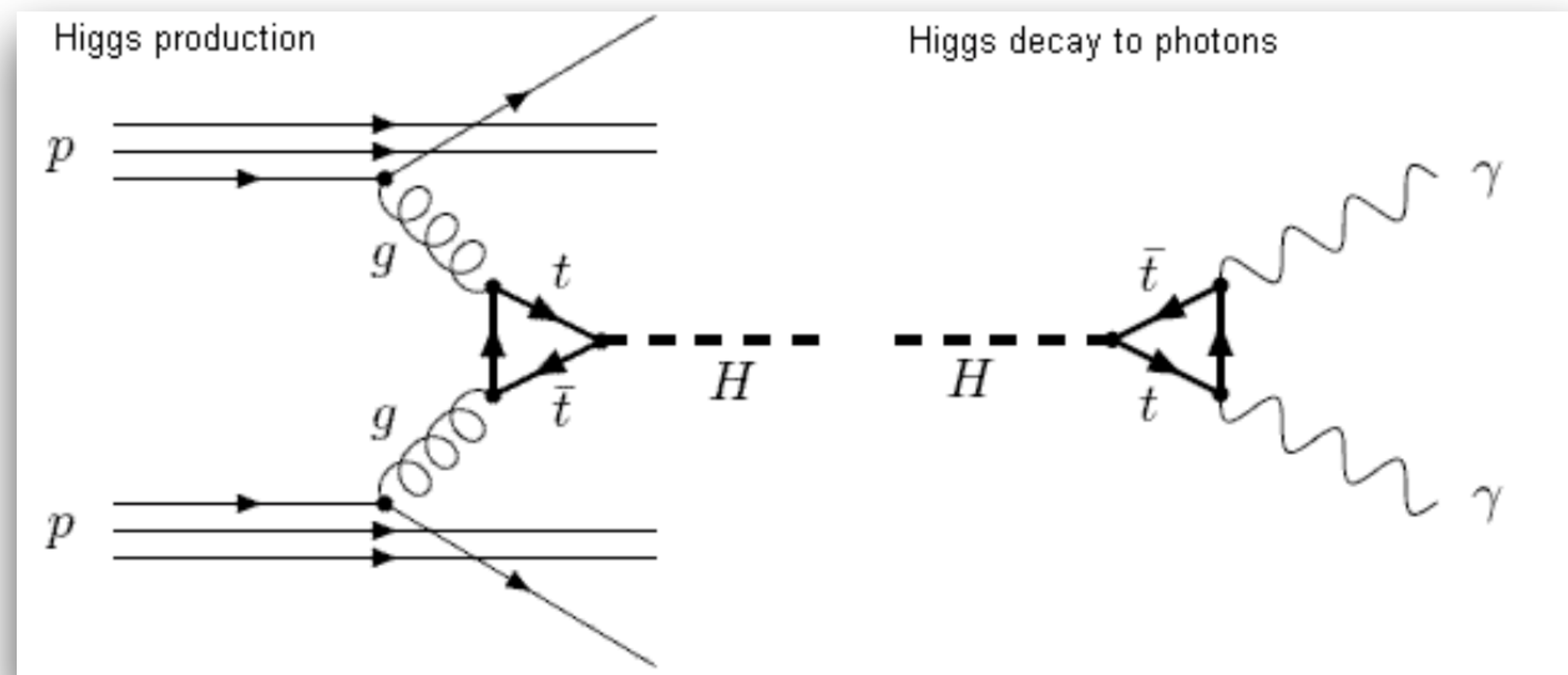


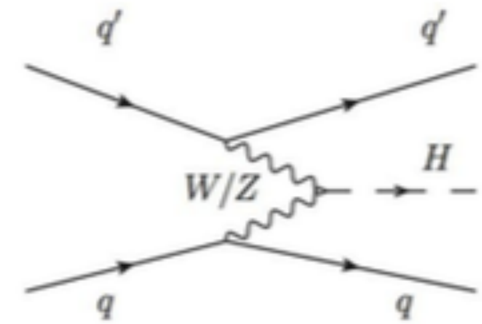
$$\mathcal{L}_{hgg} = \kappa_g c^g_{\rm SM} \frac{\alpha_s}{12\pi v} h G^a_{\mu\nu} G^{a\mu\nu},$$

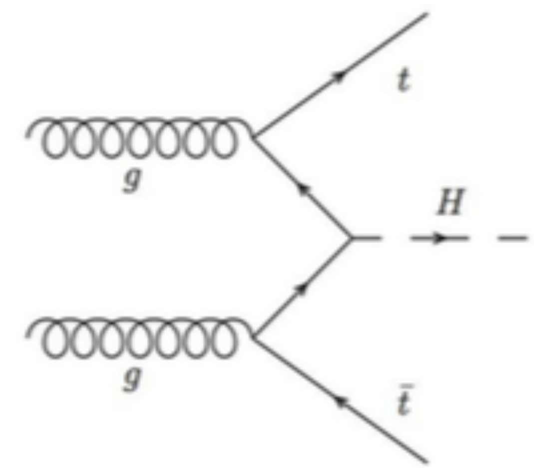
SUSY? Little Higgs? Extra Dimensions? etc.

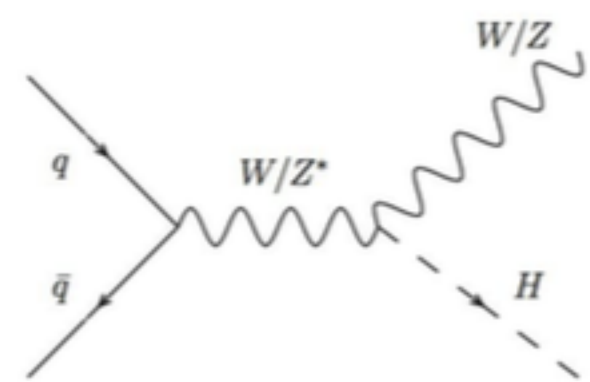
Measurement @ LHC

Different production rate
Different decay BR

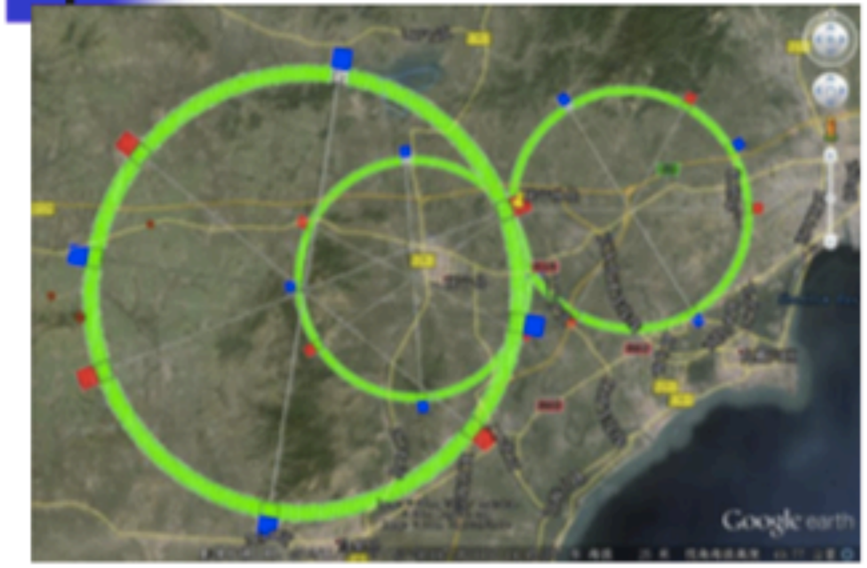




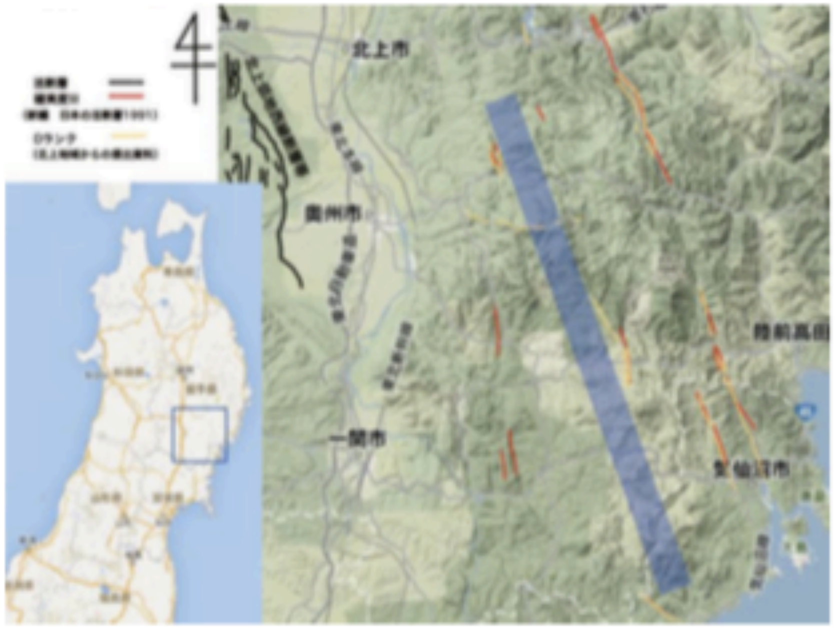




Several Higgs factories under plan



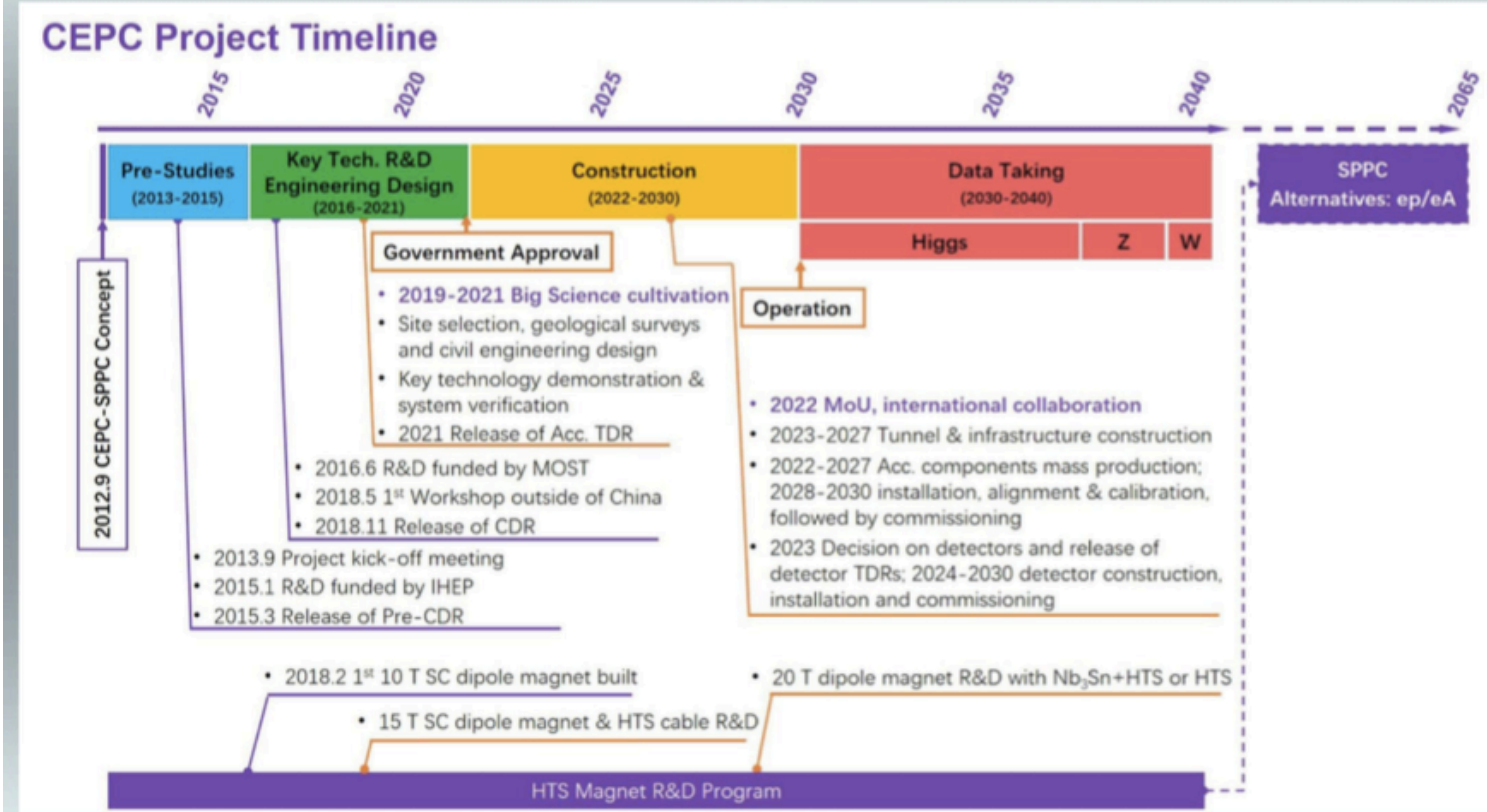
CEPC@90-240 GeV (China)
秦皇岛 or 雄安?



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

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

CEPC timeline

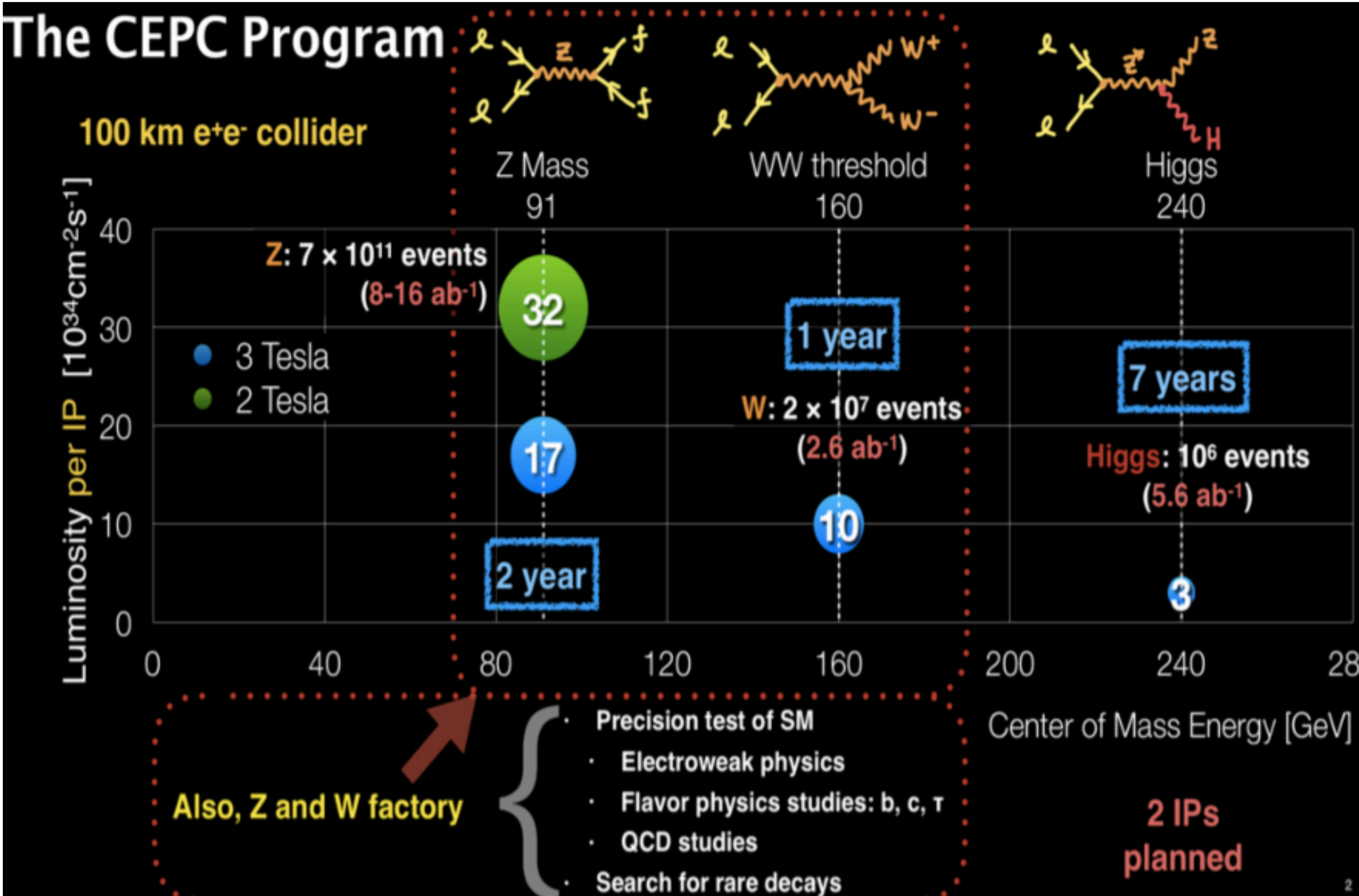


CEPC High Lumi Parameters@Higgs

D. Wang

	Higgs	*W*	*Z (3T)*	*Z (2T)*
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.68	0.33	0.035	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	3.78	8.5	27.7	
Number of particles/bunch N_e (10^{10})	17.0	12.0	8.0	
Bunch number (bunch spacing)	**218 (0.76μs)**	**1568 (0.20μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.8	90.4	461.0	
Synchrotron radiation power /beam (MW)	30	30	16.5	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	0.91			
β function at IP β_x^* / β_y^* (m)	**0.33/0.001**	**0.33/0.001**	**0.2/0.001**	
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	0.89/0.0018	0.395/0.0012	0.13/0.003	0.13/0.00115
Beam size at IP σ_x/σ_y (μm)	17.1/0.042	11.4/0.035	5.1/0.054	5.1/0.034
Beam-beam parameters ξ_x/ξ_y	0.024/0.113	0.012/0.1	0.004/0.053	0.004/0.085
RF voltage V_{RF} (GV)	2.4	0.43	0.082	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.2	2.98	2.42	
Bunch length σ_z (mm)	3.93	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.58	0.77	1.94	
Energy spread (%)	0.19	0.098	0.080	
Energy acceptance requirement (%)	1.7	0.90	0.49	
Energy acceptance by RF (%)	3.0	1.27	1.55	
Photon number due to beamstrahlung	0.104	0.050	0.023	
Beamstruhlung lifetime /quantum lifetime* (min)	30/50	>400		
Lifetime (hour)	0.22	1.2	3.2	2.0
F (hour glass)	0.85	0.92	0.98	
Luminosity/IP *L* ($10^{34}cm^{-2}s^{-1}$)	**5.2**	**14.5**	**23.6**	**37.7**

*include beam-beam simulation and real lattice


The CEPC Program
100 km e+e- collider
Z Mass
91
WW threshold
160
Higgs
240
Luminosity per IP [10^34cm^-2s^-1]
Z: 7 × 10^11 events
(8-16 ab^-1)
32
17
2 year
3 Tesla
2 Tesla
1 year
W: 2 × 10^7 events
(2.6 ab^-1)
10
7 years
Higgs: 10^6 events
(5.6 ab^-1)
3
Center of Mass Energy [GeV]
Also, Z and W factory
Precision test of SM
Electroweak physics
Flavor physics studies: b, c, τ
QCD studies
Search for rare decays
2 IPs
planned
2

Results in CDR (2018.11)

All scaled to 240 GeV, 5.6ab^{-1}

Property	Estimated Precision CEPC-v1		Estimated Precision 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	$\sigma\times$BR	BR	$\sigma\times$BR	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%
$\mathrm{BR}^{\mathrm{BSM}}_{\mathrm{inv}}$	–	< 0.28%	–	< 0.30%

Signal		Precision	Signal		Precision	Signal		Precision
Z	H		Z	H		Z	H	
H->qq			H->WW			H→γγ, Zγ		
ee	bb	1.32%	ee	lvlv	9.52%	μμ+ττ	γγ	23.7%
	cc	13.5%		evqq	4.56%	vv		10.5%
	gg	7.22%		μvqq	3.93%	qq		9.84%
μμ	bb	0.99%	μμ	lvlv	7.29%	vv	Zγ(qqγ)	15.7%
	cc	9.54%		evqq	3.90%	vvH(WW fusion)		
	gg	5.01%		μvqq	3.90%	vv	bb	3.00%
qq	bb	0.46%	vv	qqqq	1.90%	H→μμ		
	cc	11.1%		evqq	4.65%	qq	μμ	17.1%
	gg	3.64%		μvqq	4.14%	ee		
vv	bb	0.39%		lvlv	11.5%	μμ		
	cc	3.83%	qq	qqqq	1.75%	vv		
	gg	1.47%	H->ZZ			H→ττ		
H->Invisible			vv	μμqq	8.26%	ee	ττ	2.75%
qq	ZZ(vvvv)	232%	vv	eeqq	40%	μμ		2.61%
ee		370%	μμ	vvqq	7.32%	qq		0.95%
μμ		245%	ZH bkg contribution		19.4%	vv		2.66%

CEPC团队、国际顾问委员会部分委员和《CEPC概念设计报告》国际评审委员会成员合影 -- 2018年11月14日

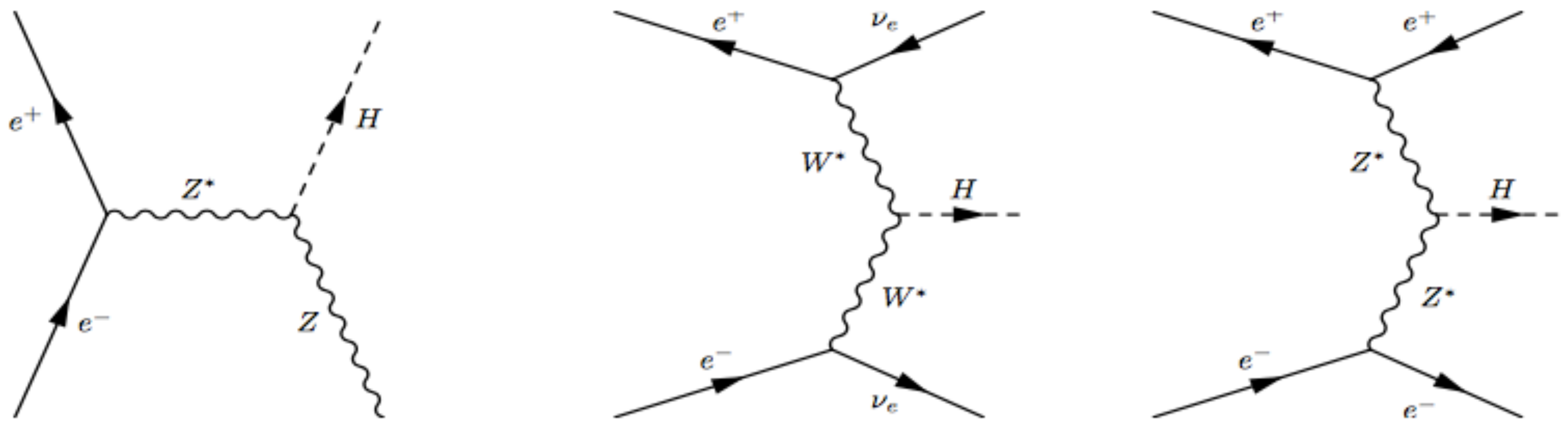
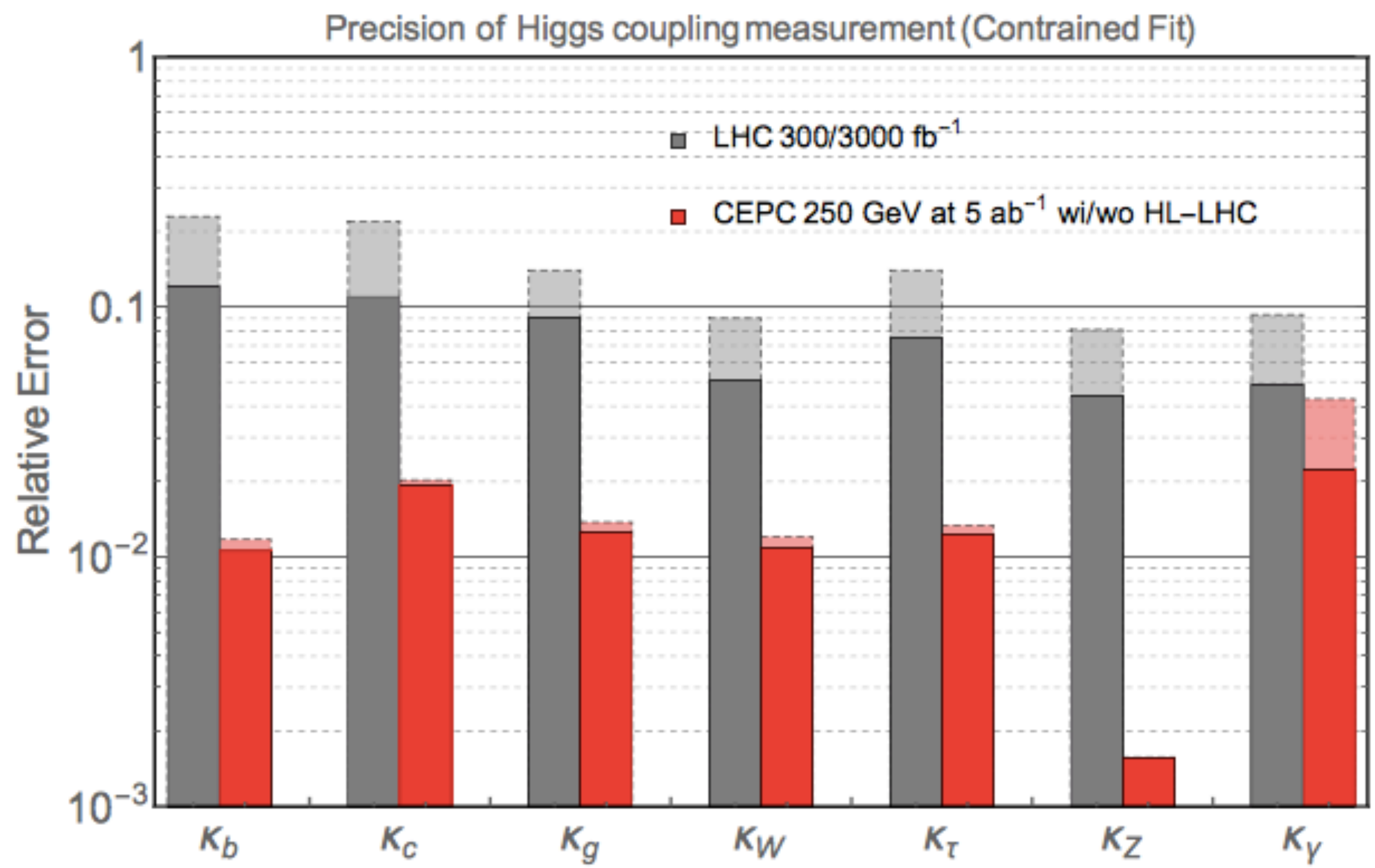


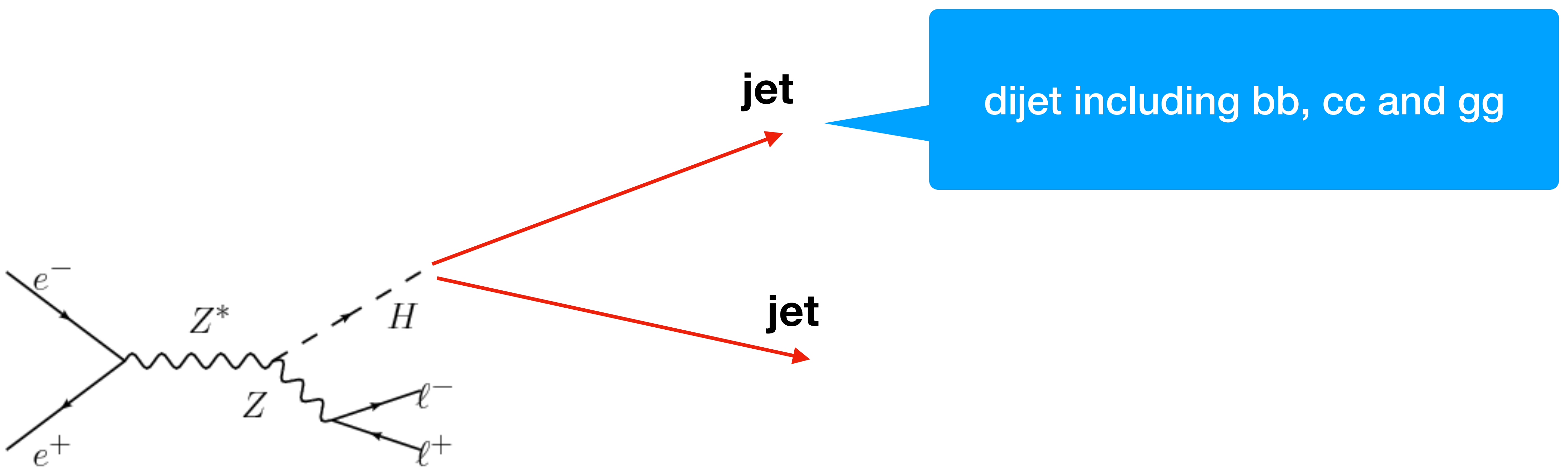
Figure 3.6 Feynman diagrams of the $e^+e^- \to ZH$, $e^+e^- \to \nu\bar{\nu}H$ and $e^+e^- \to e^+e^-H$ processes.



ggH coupling from H->gg

H->gg decay rate is proportional to ggH coupling

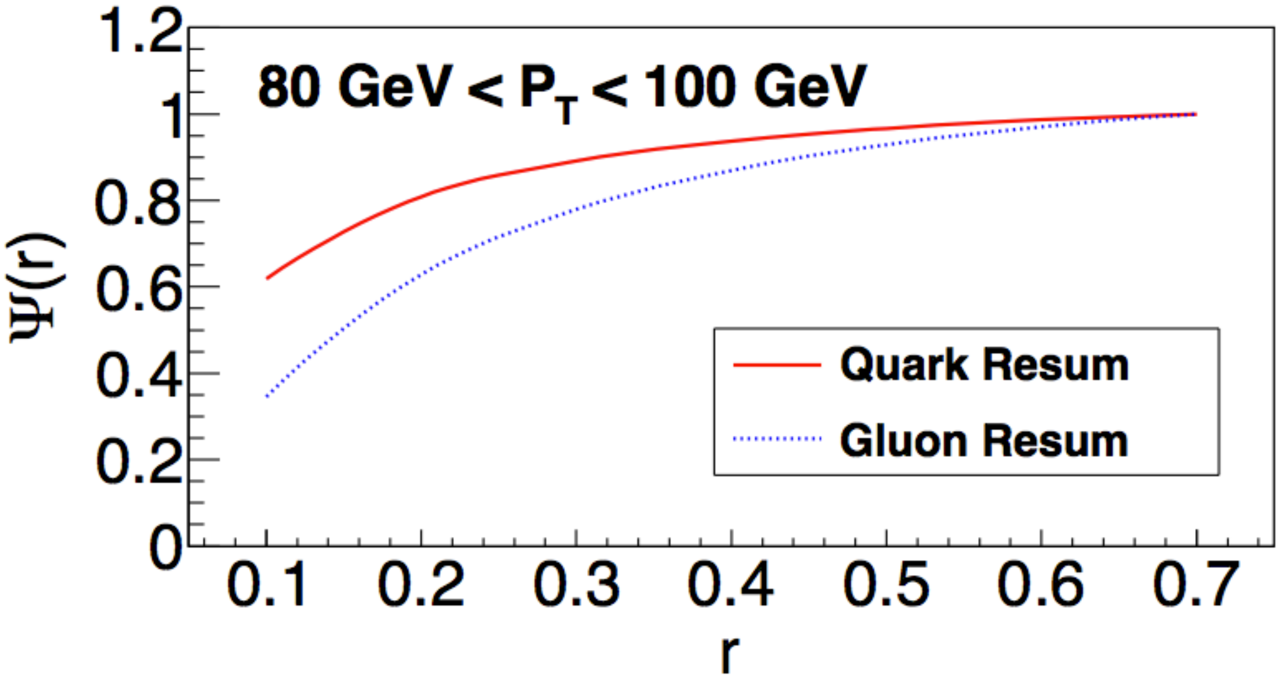
But H->gg is hidden inside H->jj



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

Jet Energy Profile

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



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

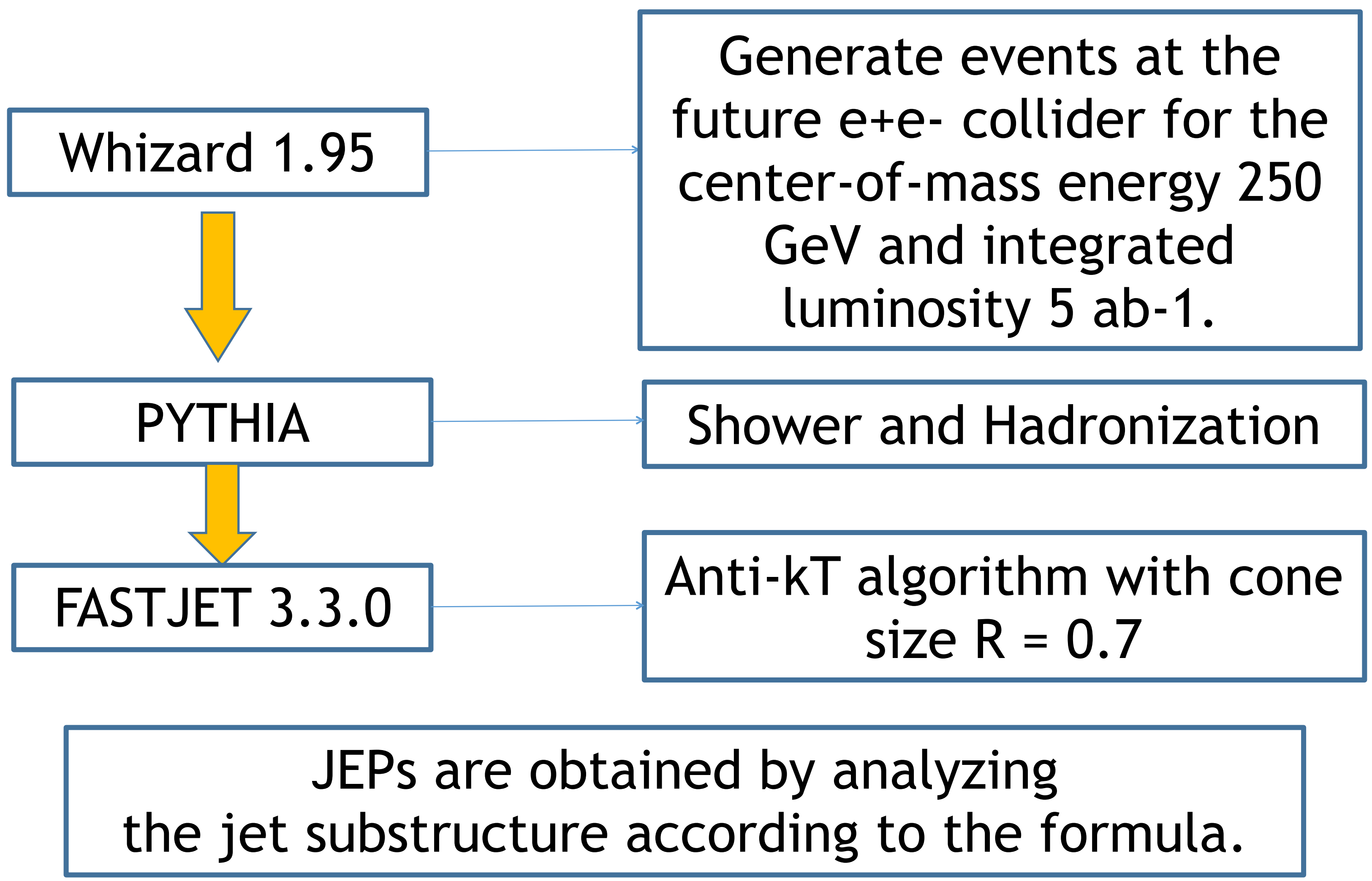
$$Z^N(r) = \frac{\sum_j (\psi_j + b)}{\sum_j^{\rm SM} (\psi_j + b)},$$

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

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

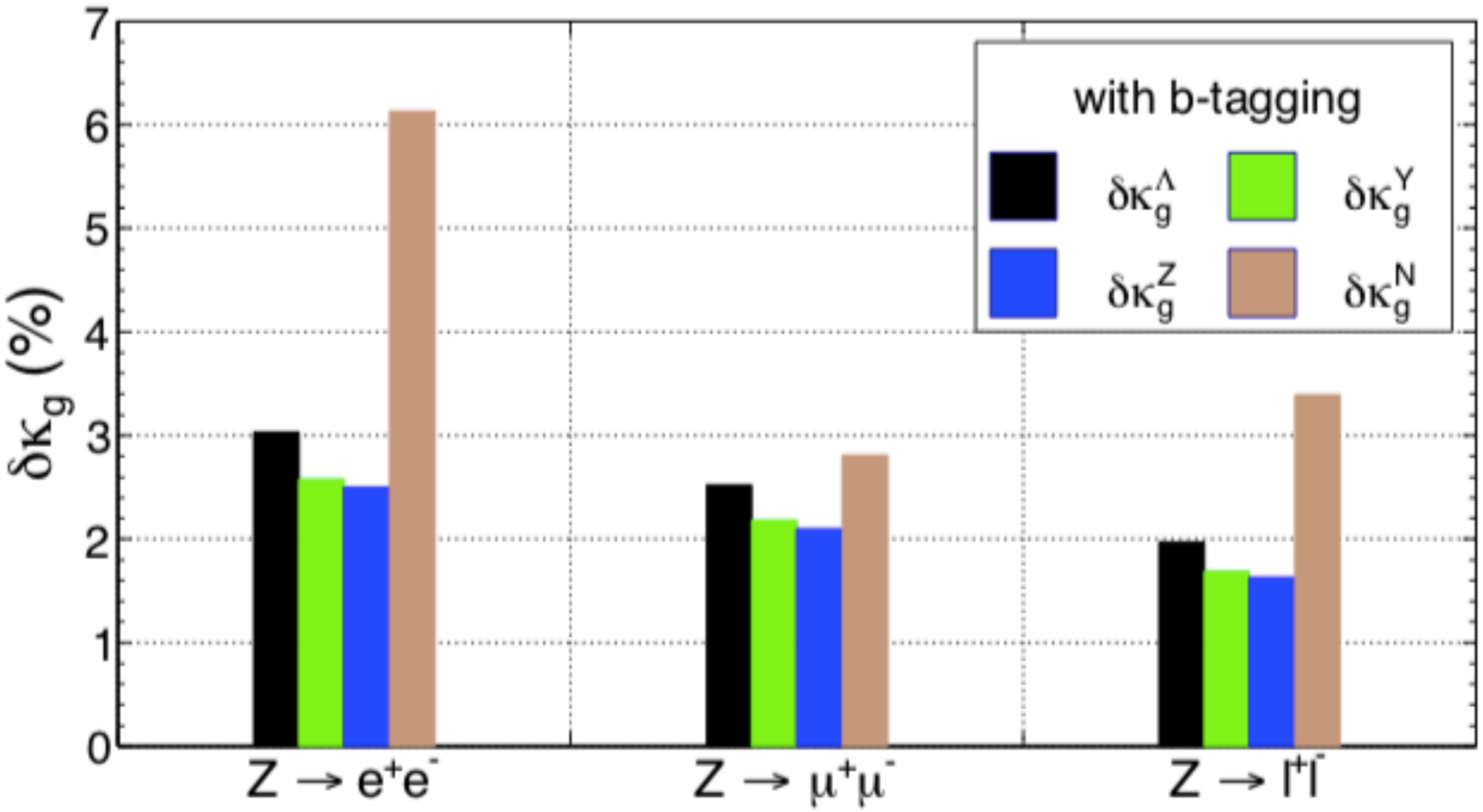
$$b = \frac{\sigma^2(r) + f_{\rm BG}(\psi_q - \psi_{\rm BG})(\psi_g - \psi_{\rm BG})}{f_{\rm q}(\psi_g - \psi_q) + f_{\rm BG}(\psi_g - \psi_{\rm BG})} - \psi_q.$$

MC Simulation



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

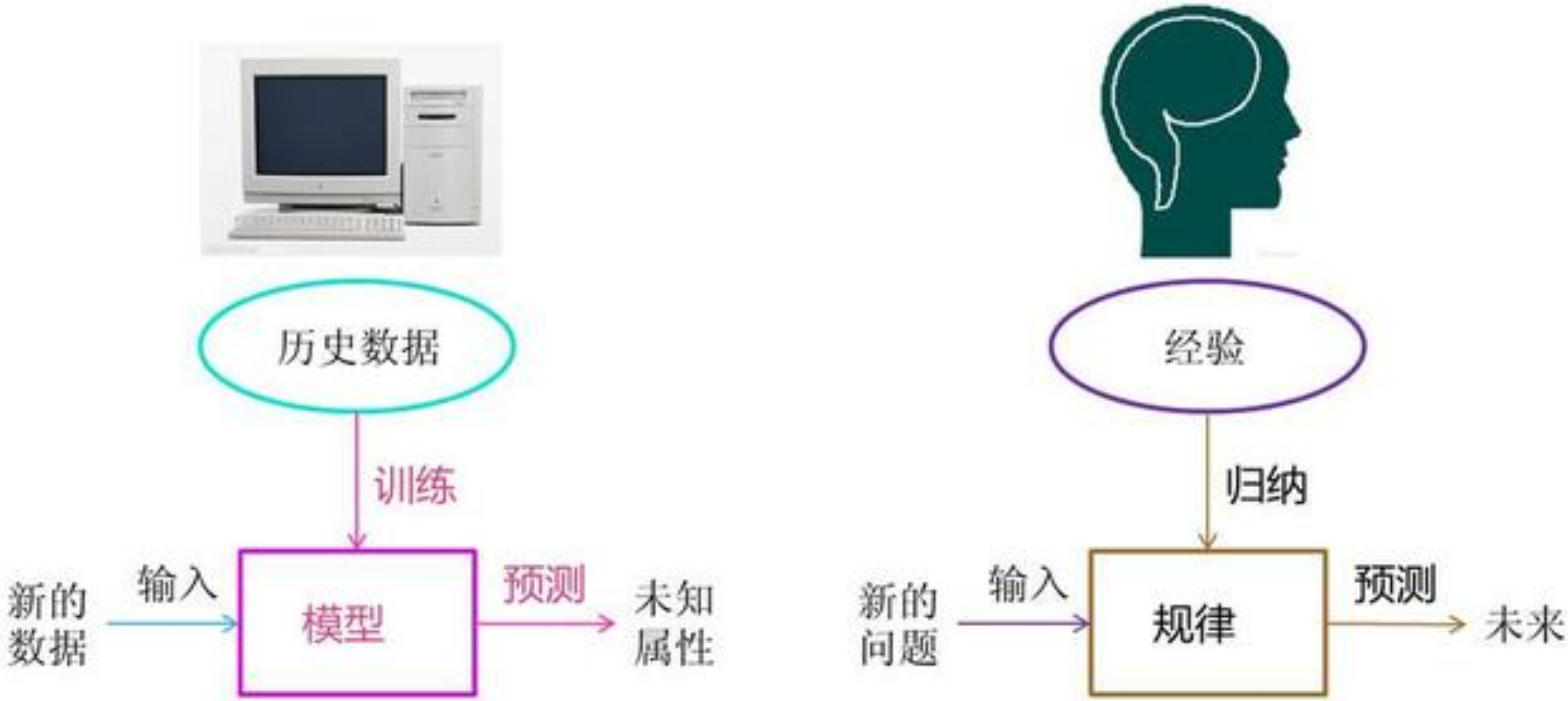
Gexing Li, Zhao Li, Yandong Liu, Yan Wang, and Xiaoran Zhao
Phys. Rev. D **98**, 076010 – Published 17 October 2018



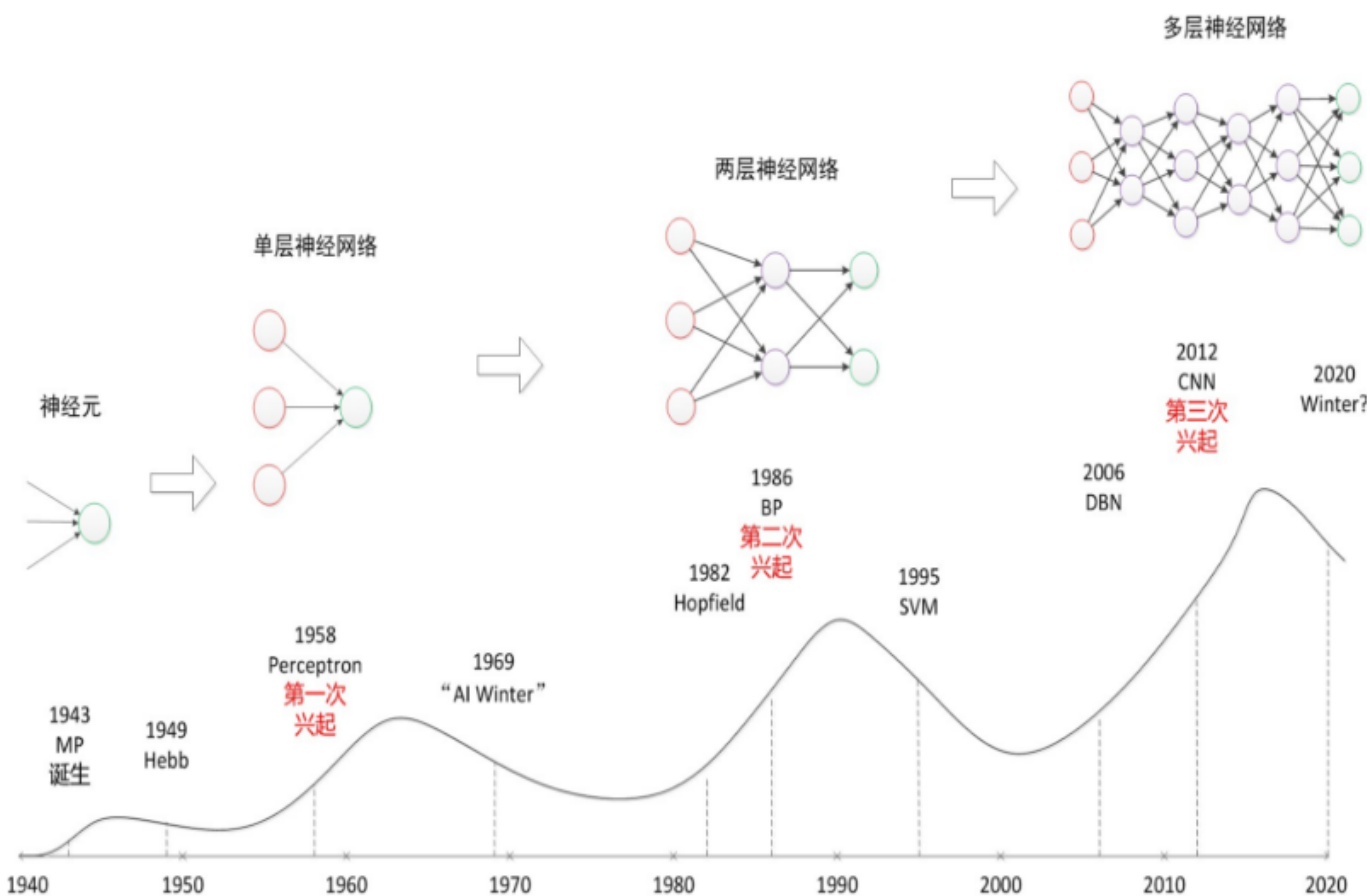
~50% improvement to reach ~1.6%

Machine Learning is widely used in many fields

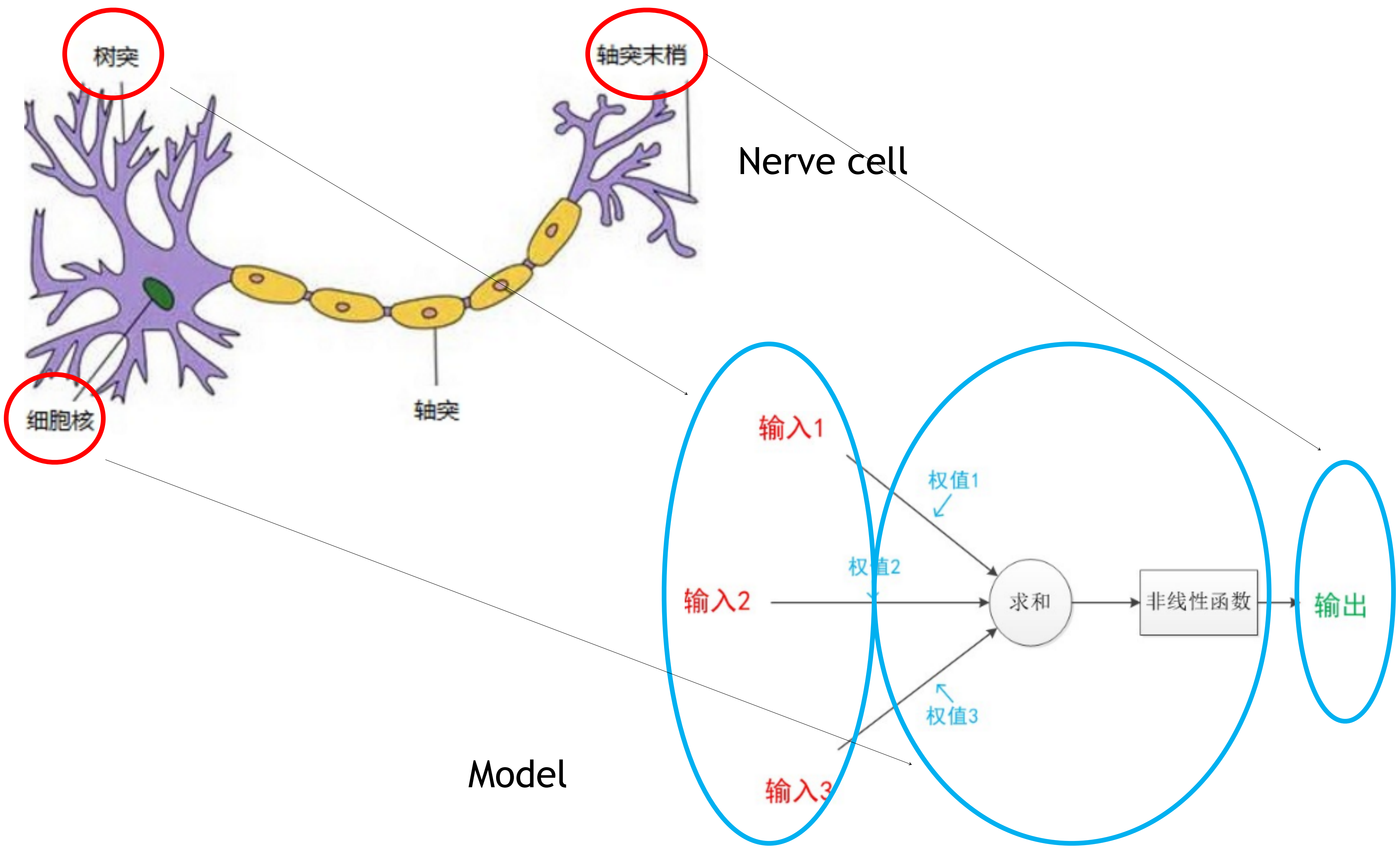
Machine Learning VS. People Learning



History of Machine Learning

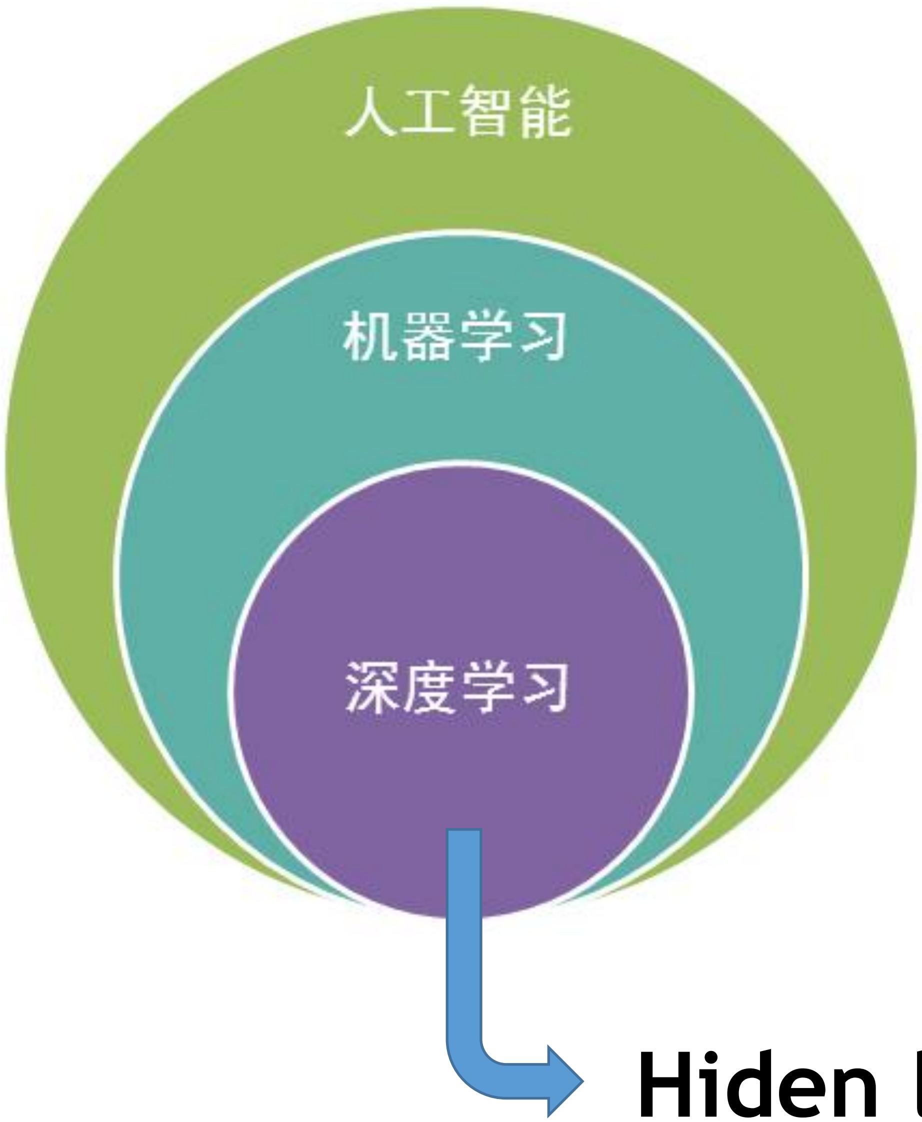


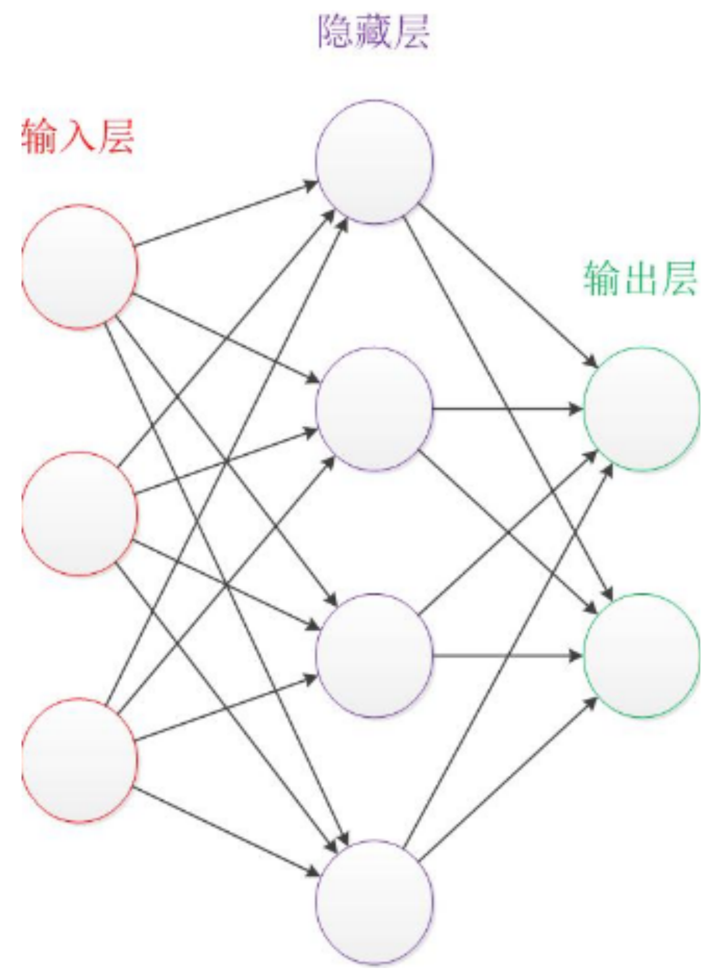
Nerve cell



树突
轴突末梢
细胞核
轴突
Nerve cell
输入1
输入2
输入3
权值1
权值2
权值3
求和
非线性函数
输出
Model

Deep Learning



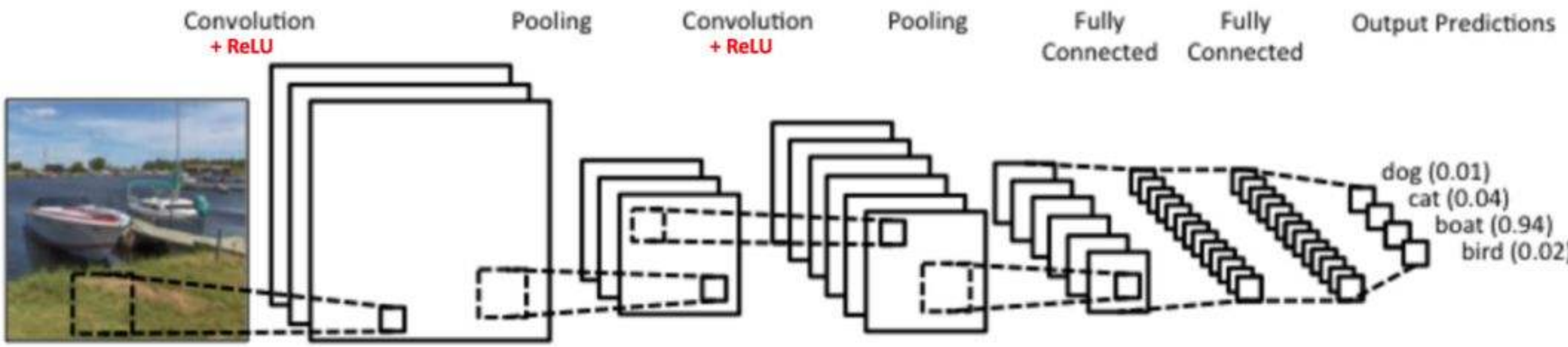


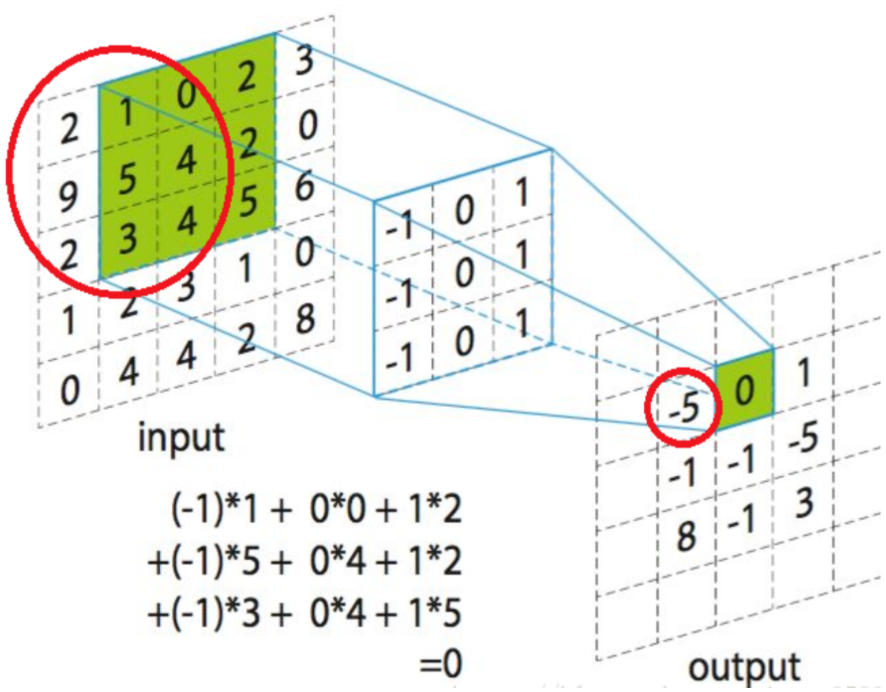
Hiden layer > 2

Deeper networks can achieve more complex linear classifications.

Convolutional Neural Networks (CNNs)

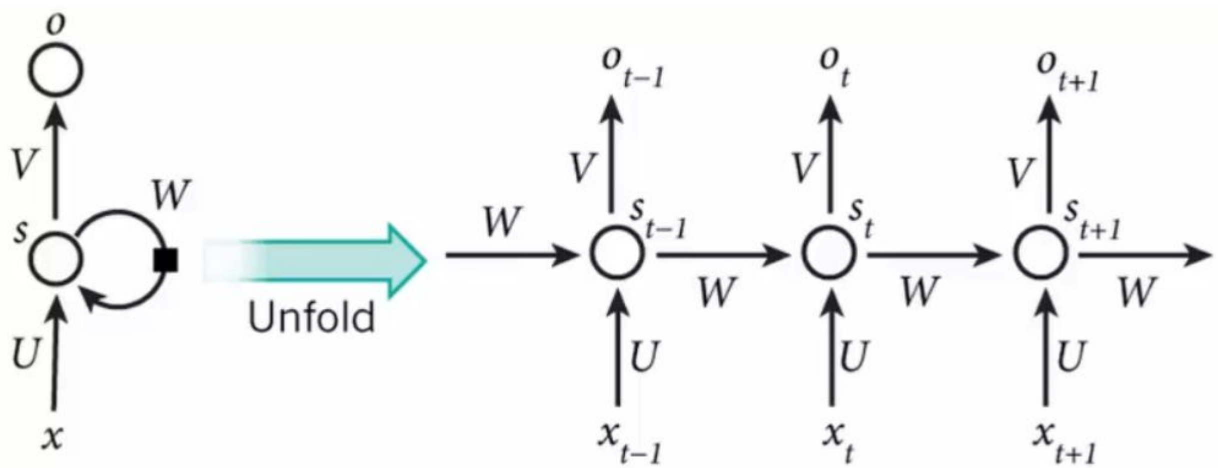
CNNs is one of the most popular algorithms in deep learning. It has powerful ability of image recognition.





CNNs extract the features form images by the convolutional layers.

Recursive neural networks (RecNN)

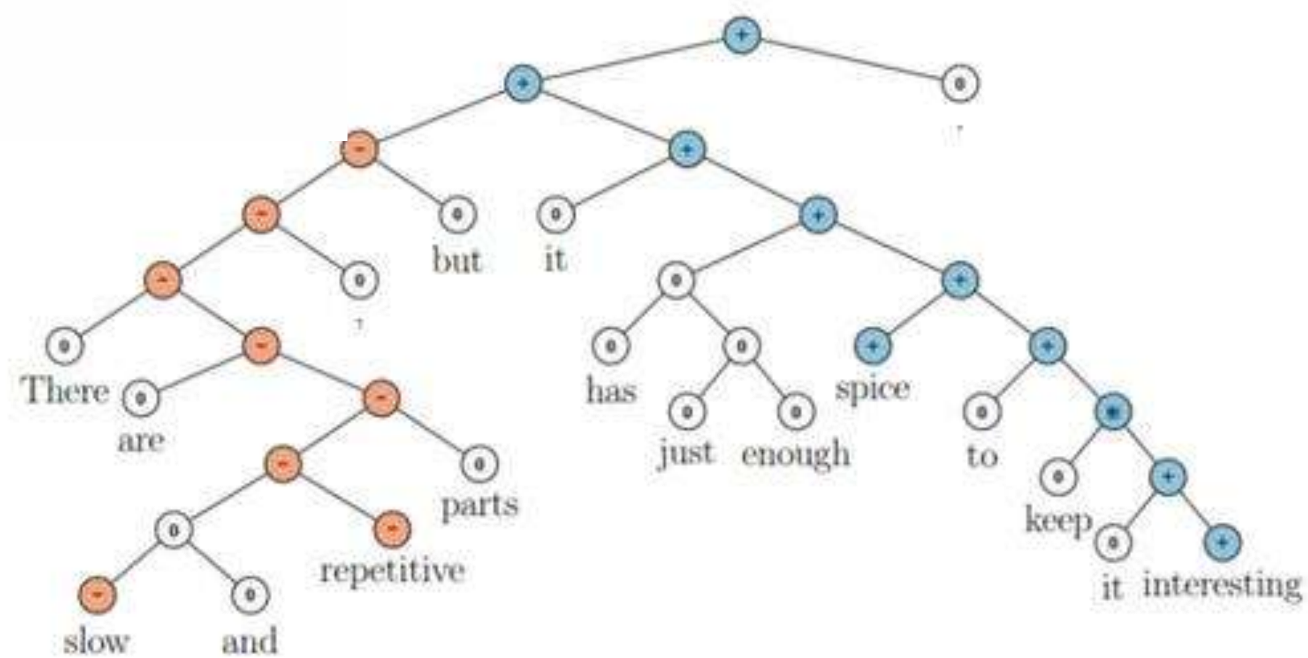


xt表示第t,t=1,2,3...步(step)的输入

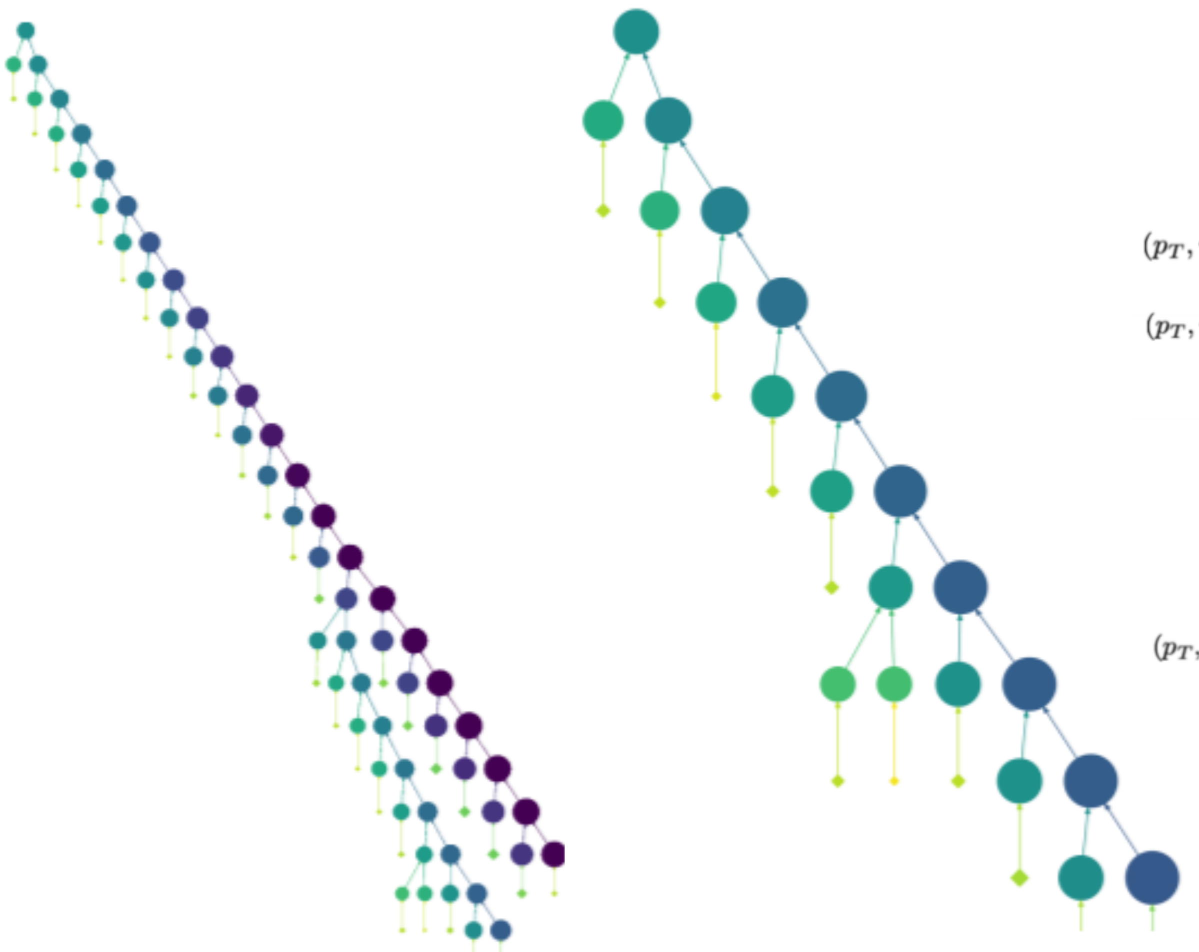
st为隐藏层的第t步的状态，它是网络的记忆单元。

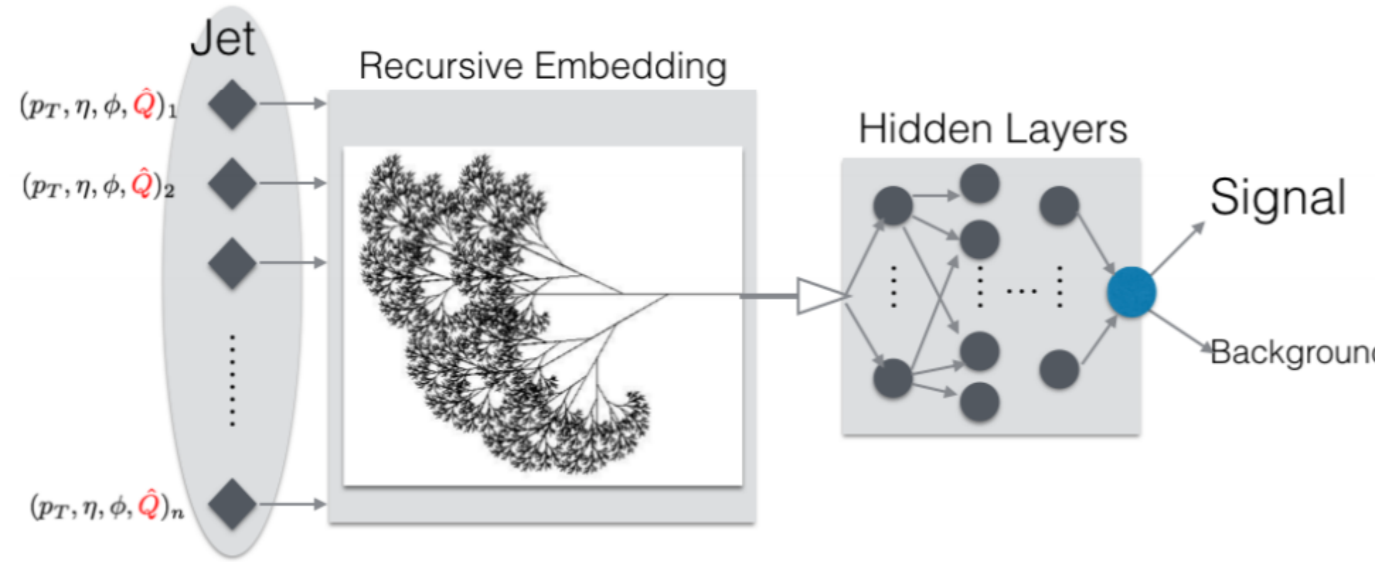
st=f(Uxt+Wst−1)，其中f一般是非线性的激活函数

ot是第t步的输出，如下个单词的向量表示softmax(Vst)



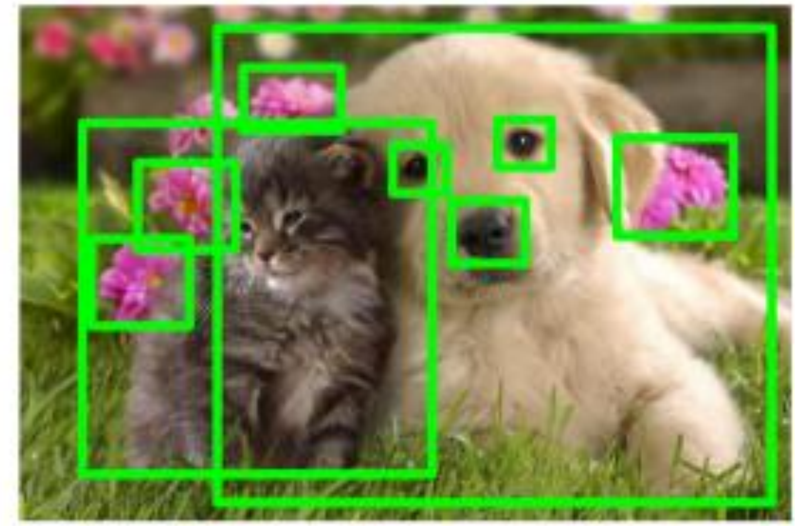
Identification of quark/gluon jets by RecNN





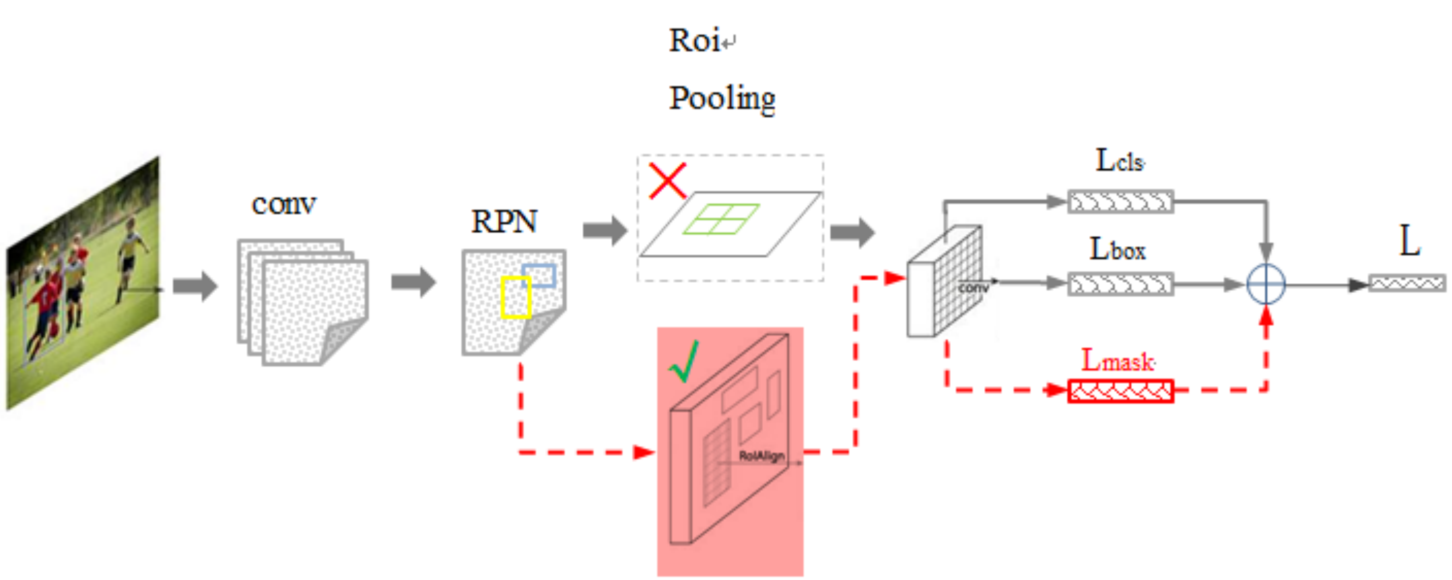
Typical tree structures for 1 TeV gluon jet (left) and quark jet (right)

Object detection: Region-based CNN (RCNN)



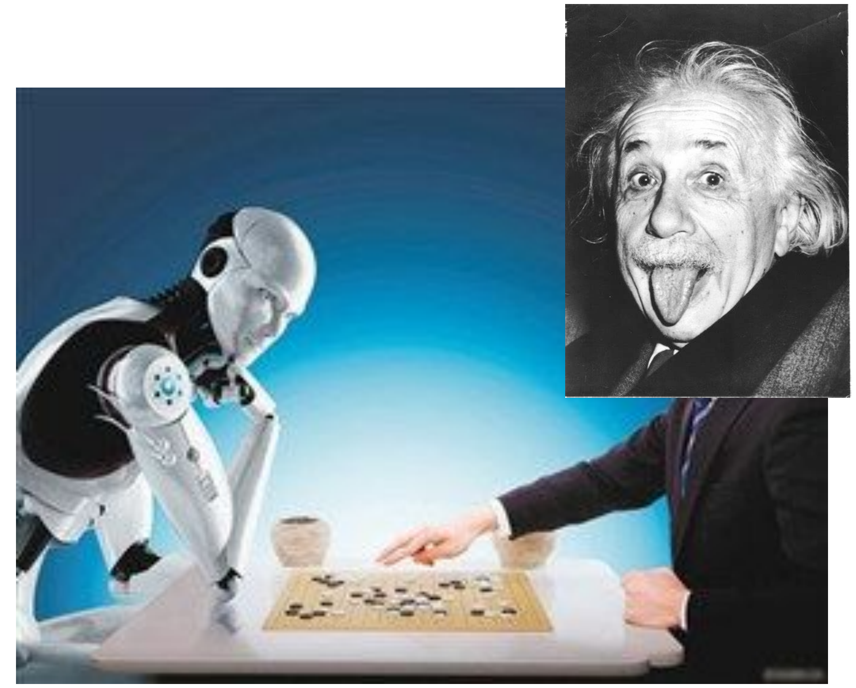
Classification + Localization

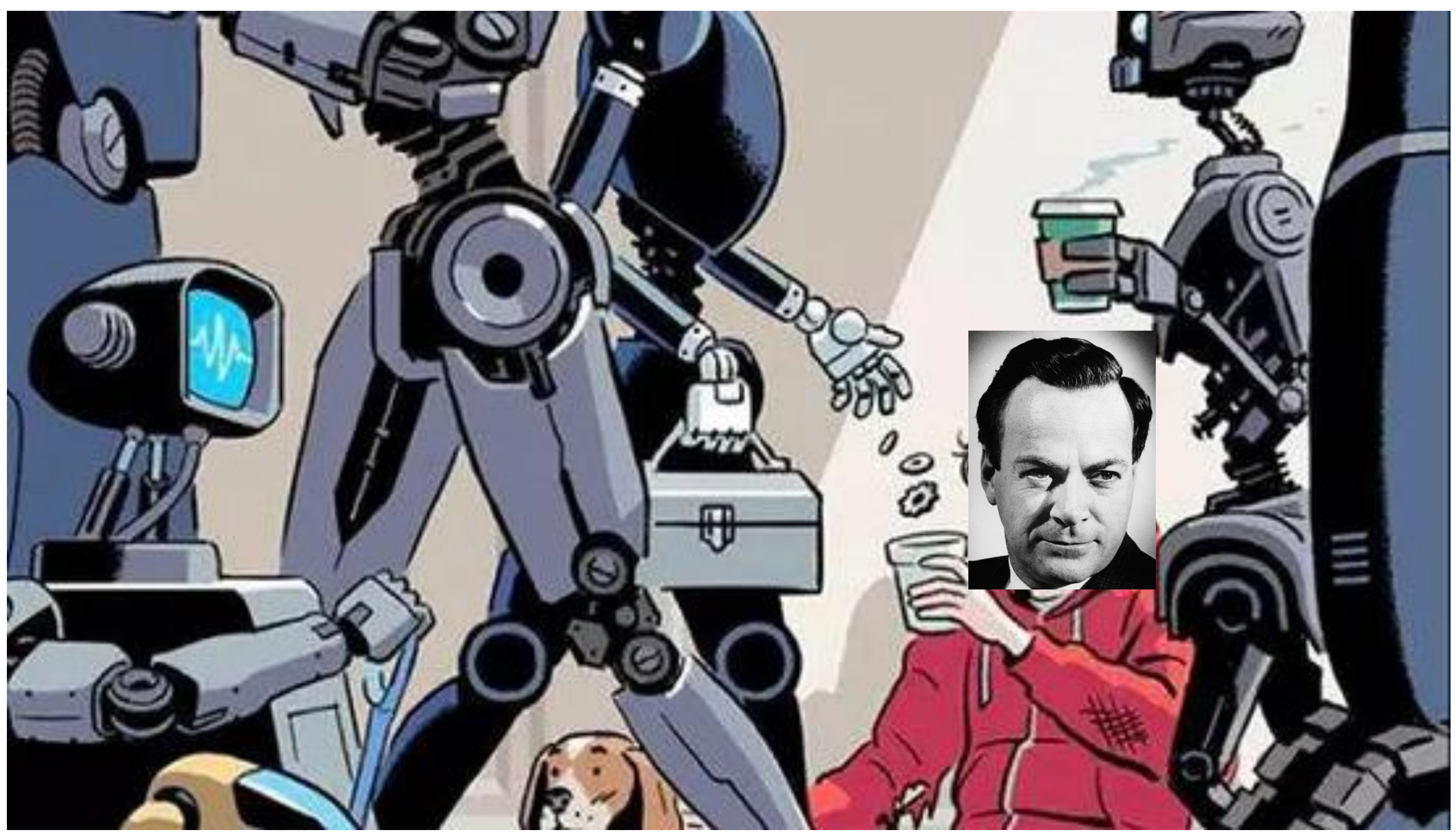
Evolution: **RCNN -> Fast RCNN -> Faster RCNN -> Mask**



Automated jet construction and Classification

Machine Learning @ HEP

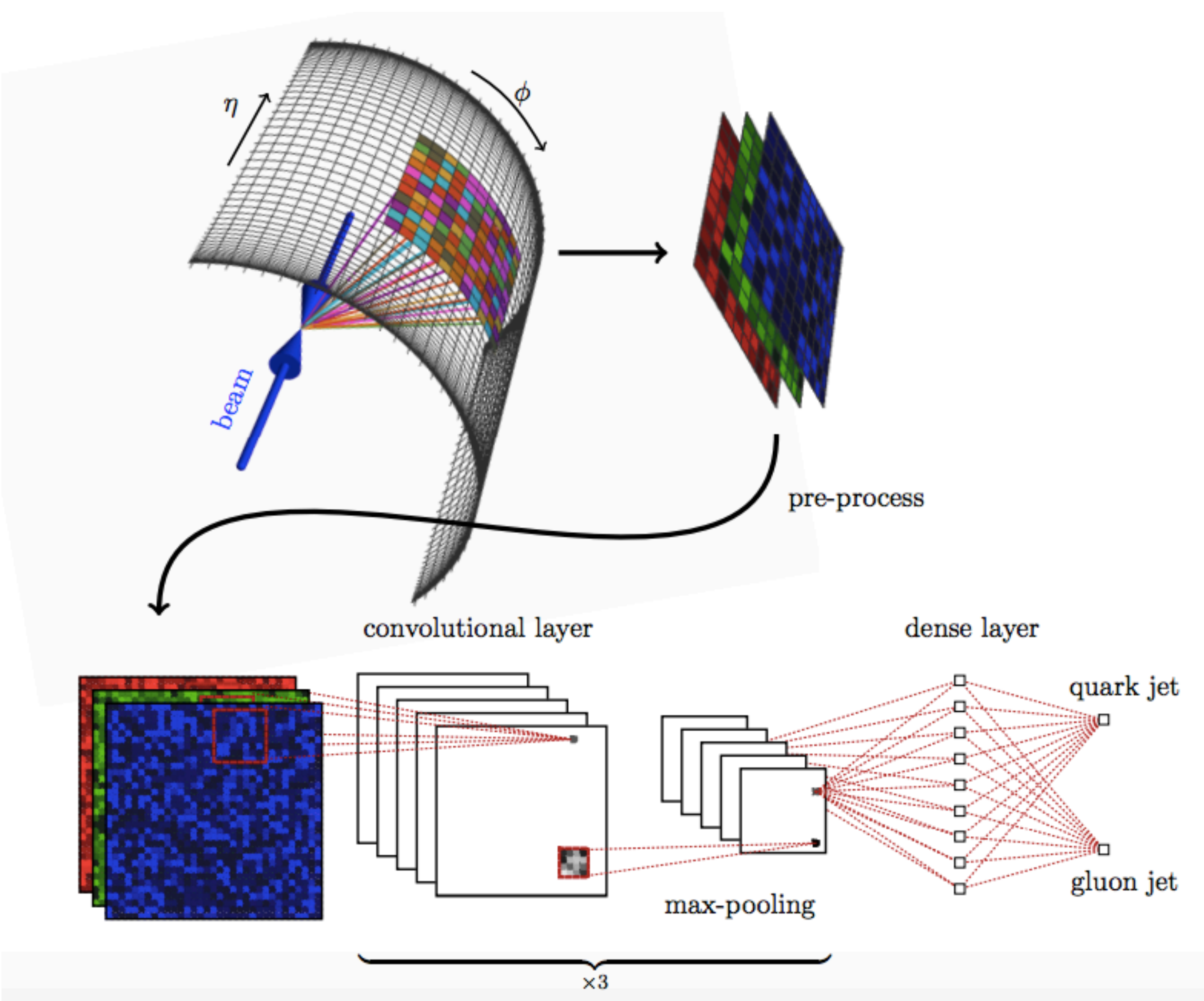




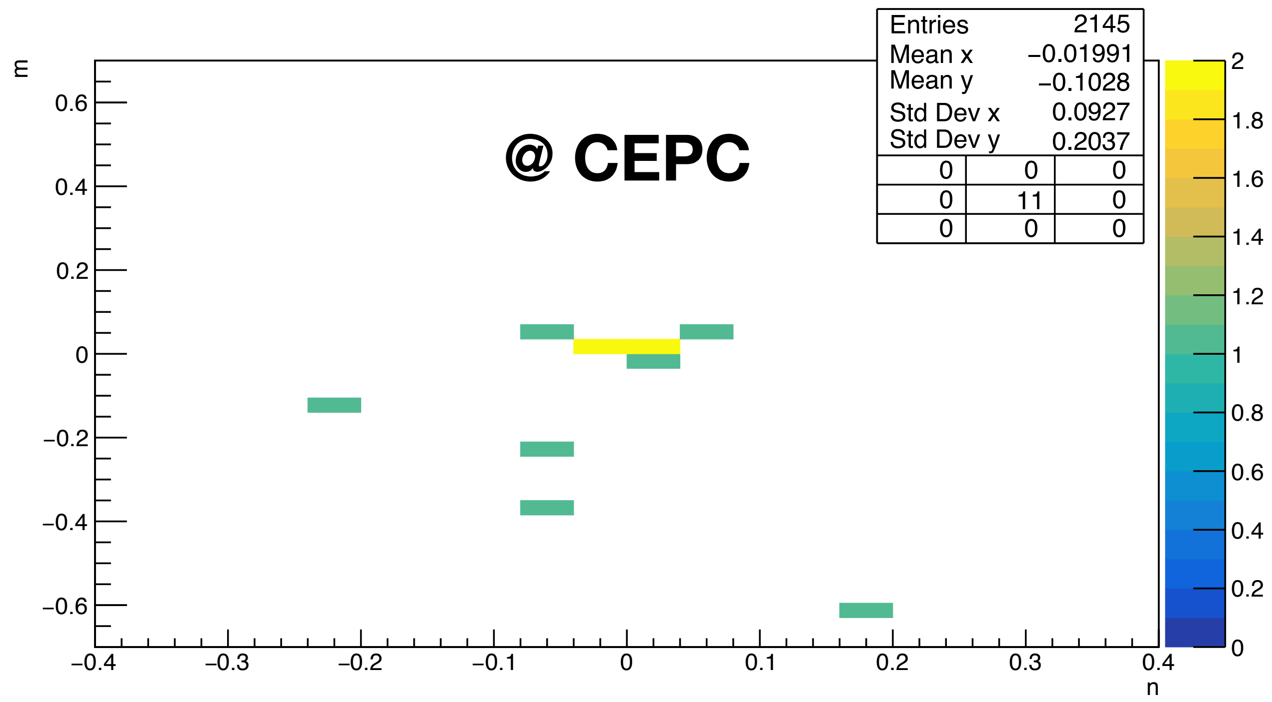
Machine Learning @ HEP

- **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

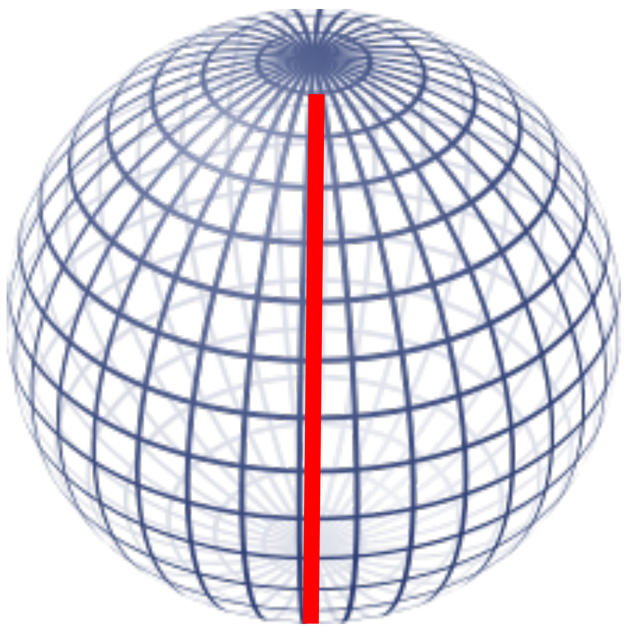


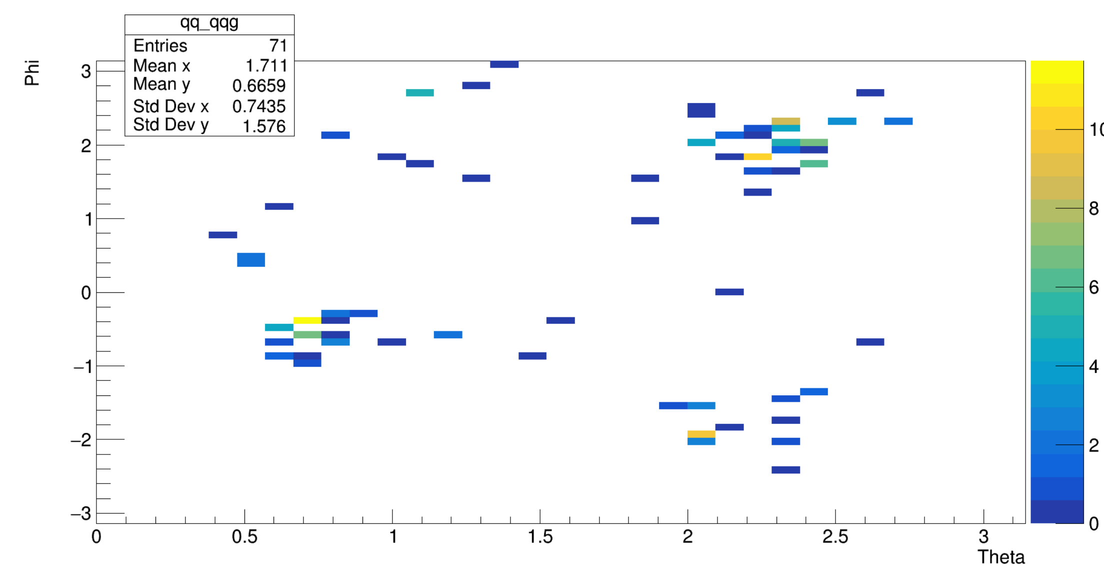
CNN Configuration

```
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



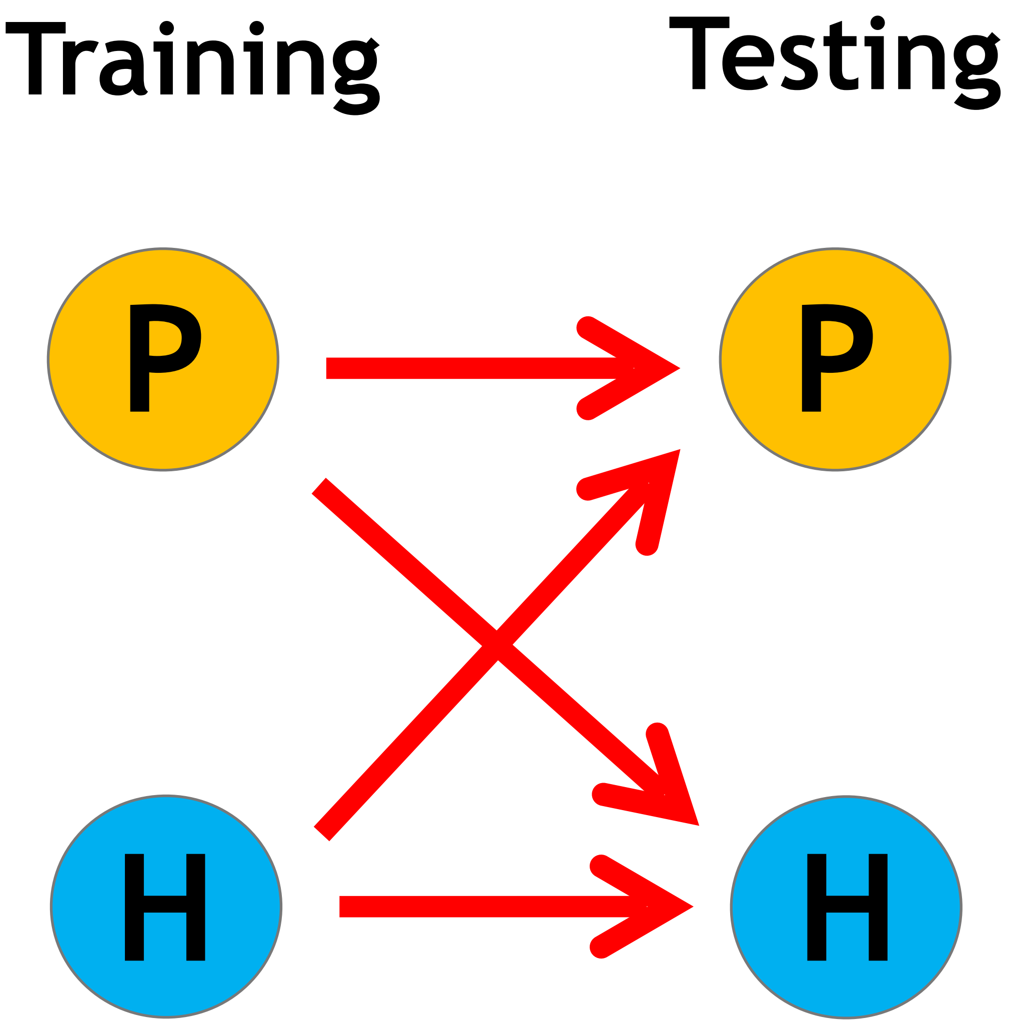


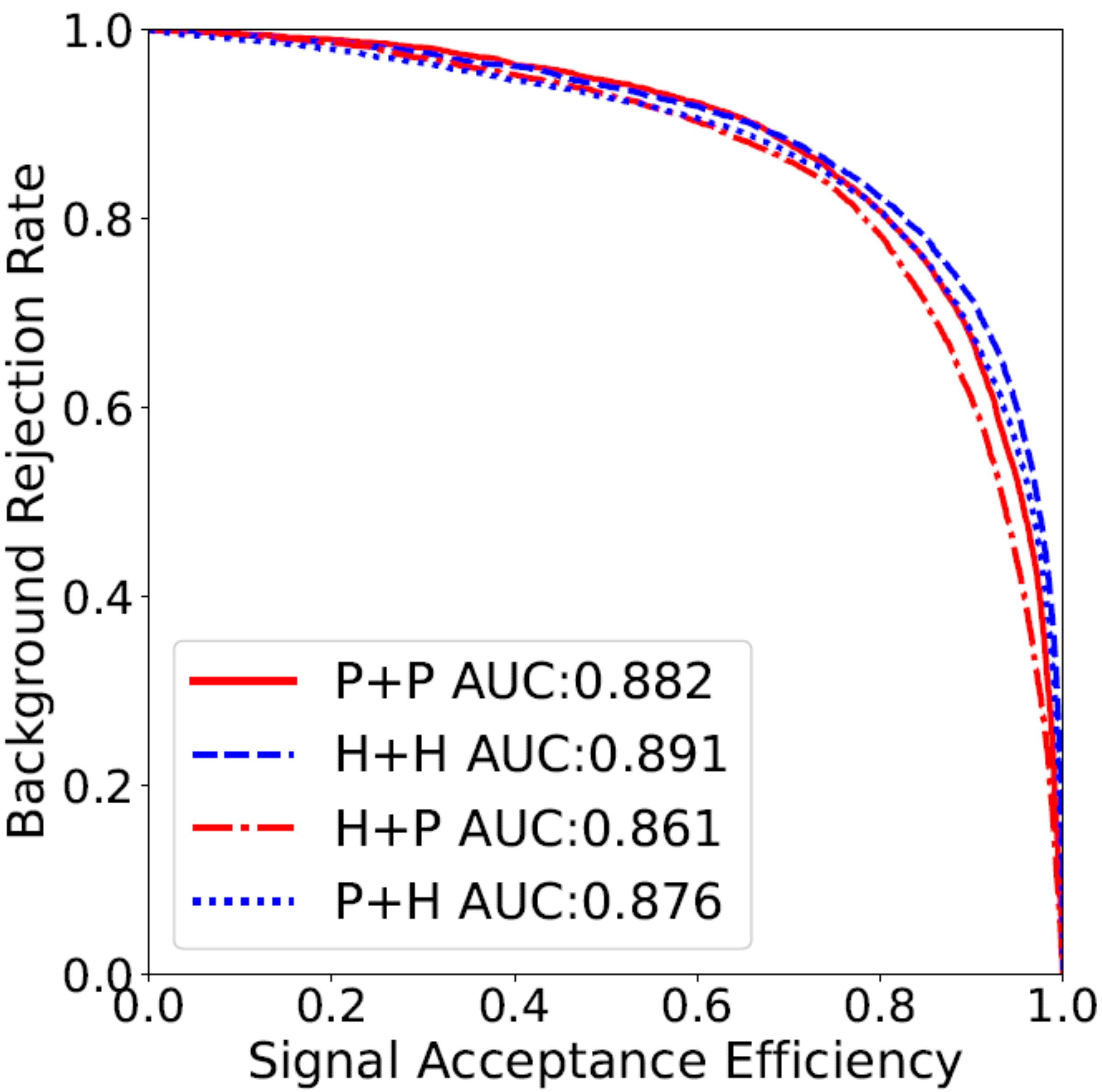
phi symmetry break

Rotate at phi direction

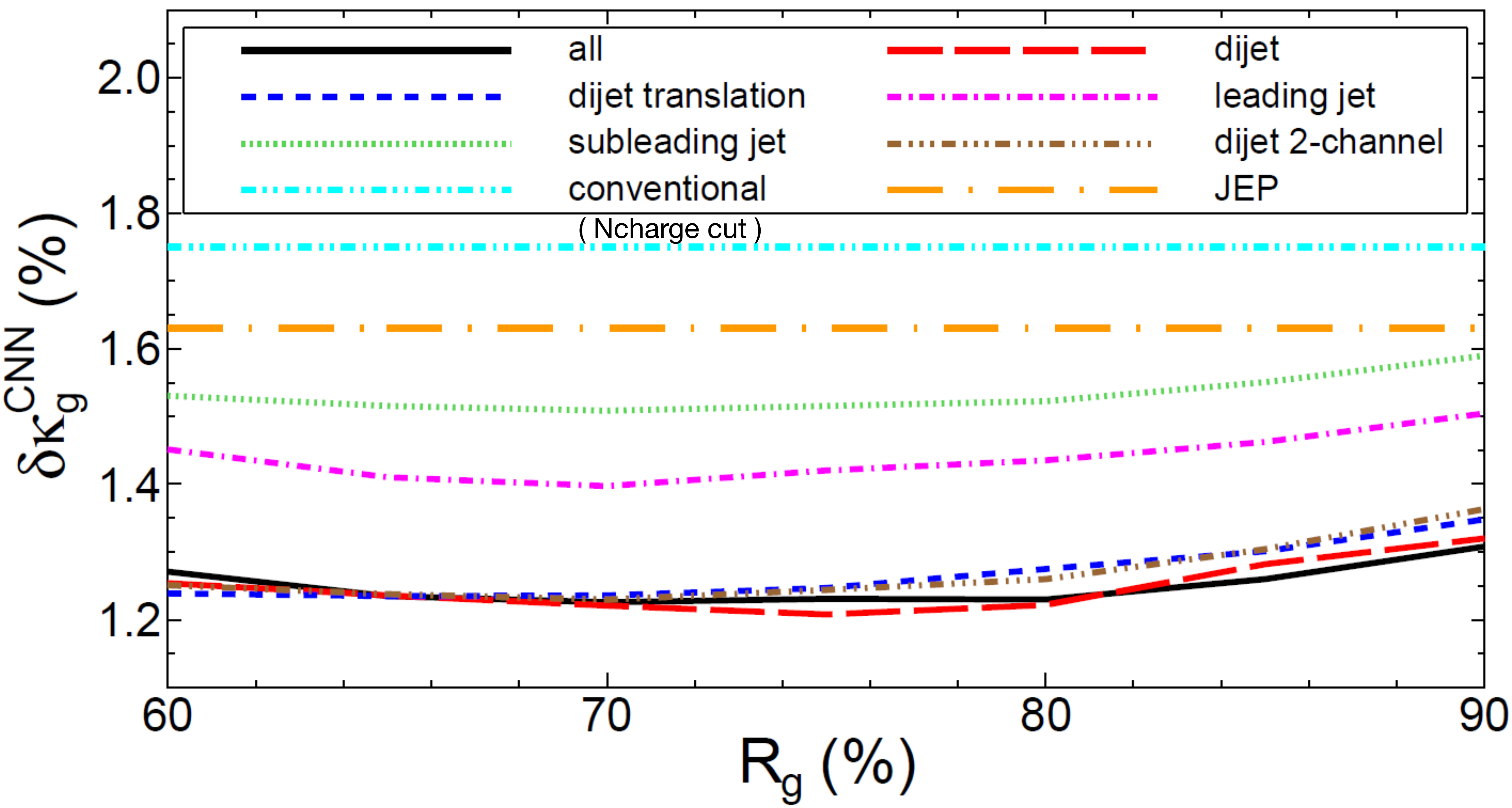
Each rotation turns 13 pixels.
Each image becomes 5 different images.

Performance of CNNs



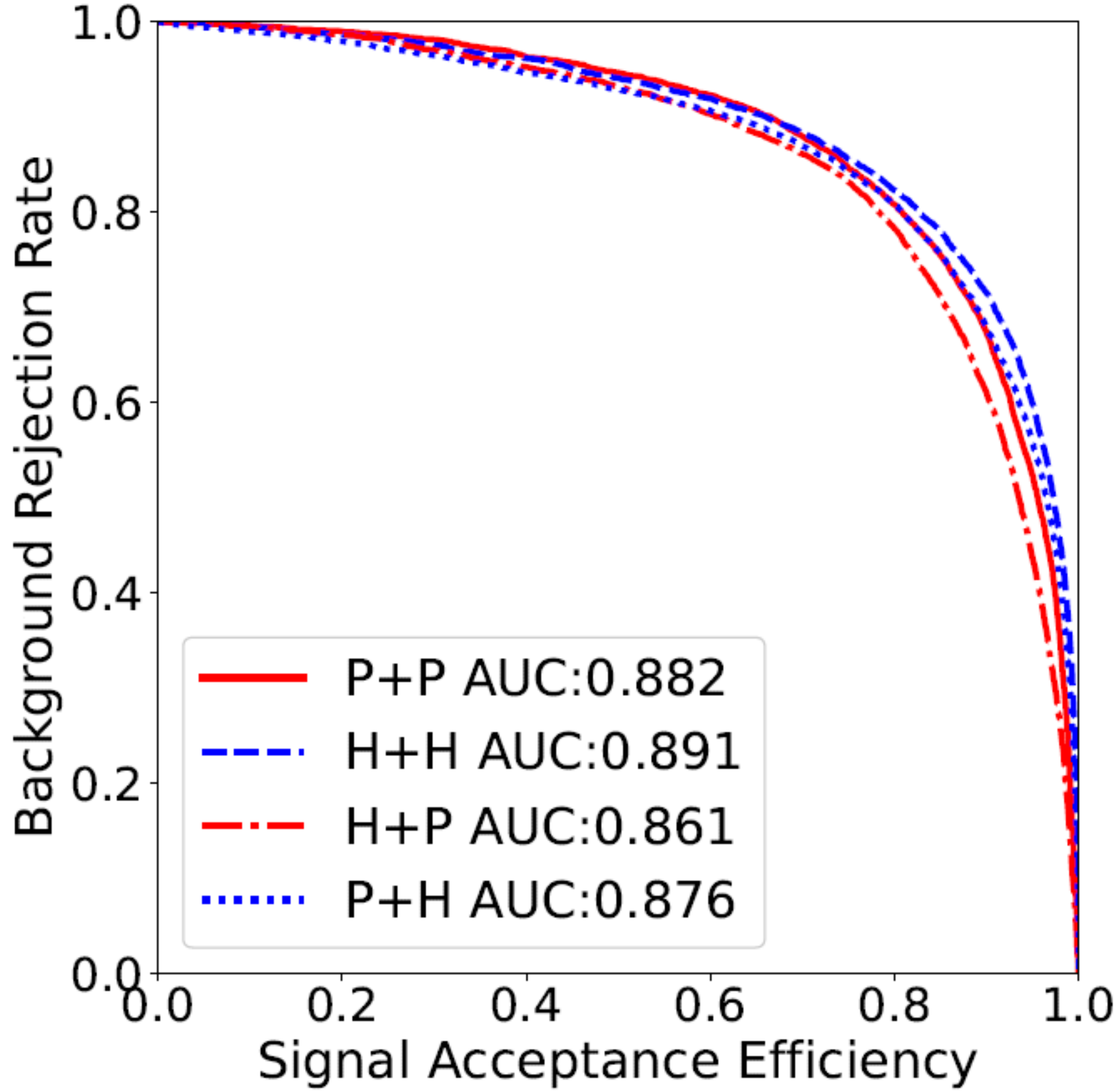


Improvement of CNNs

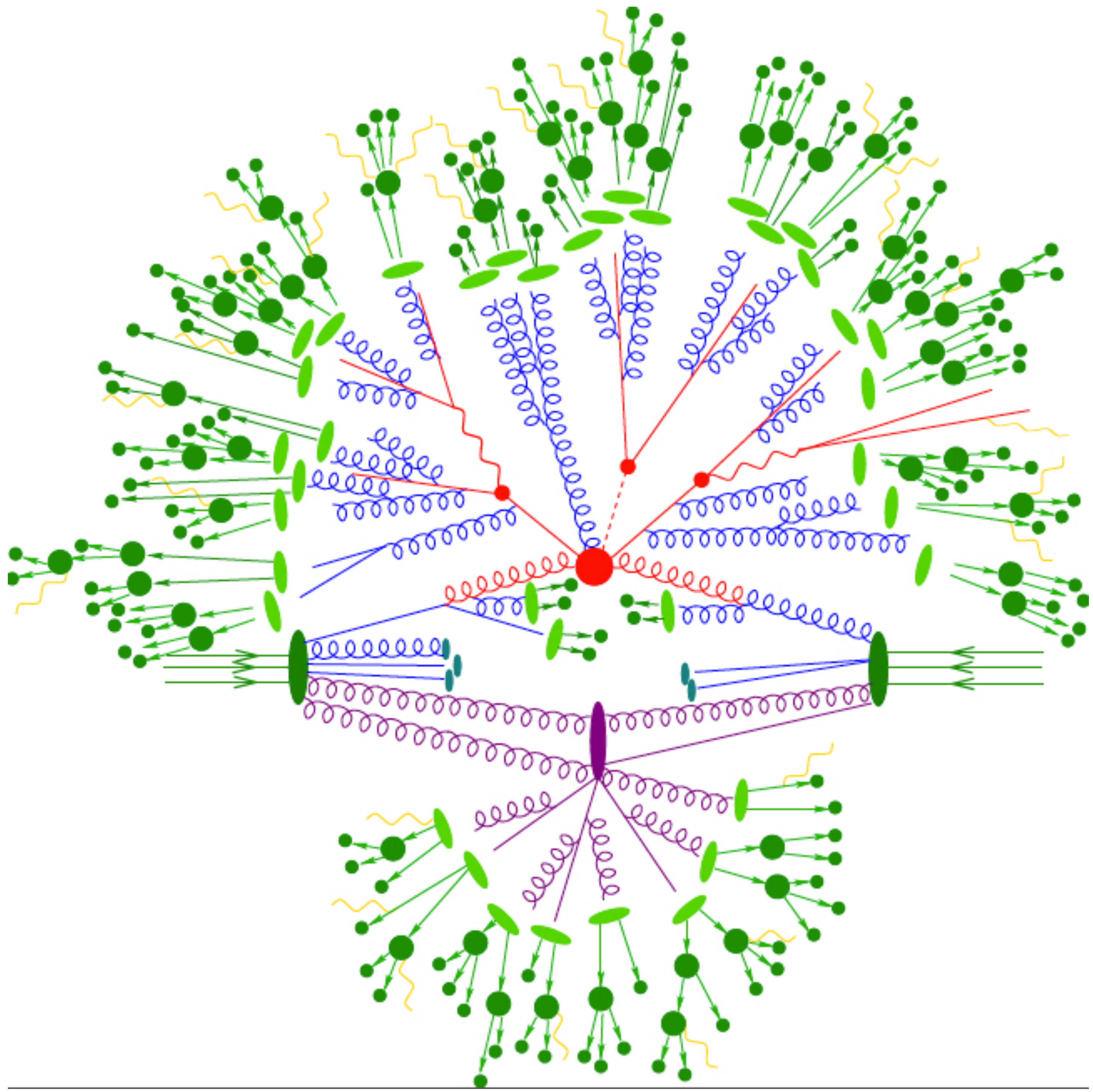


Further ~30% improvements to reach ~1.2%

Revisit AUC comparison between P & H



Does simulation really simulate physics?



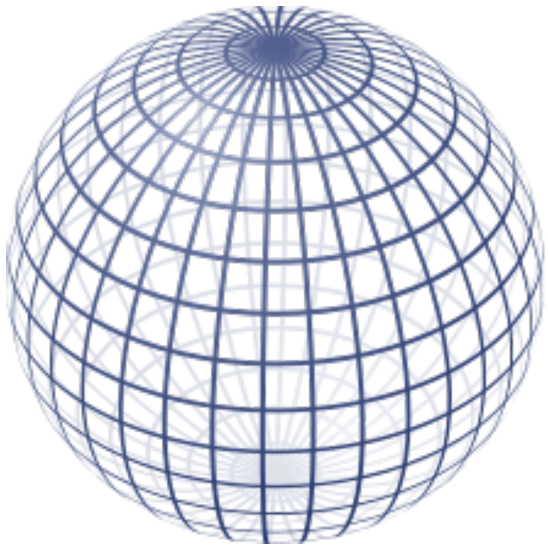
Parton Shower? Hadronization? Underlying events? etc.

Conclusion

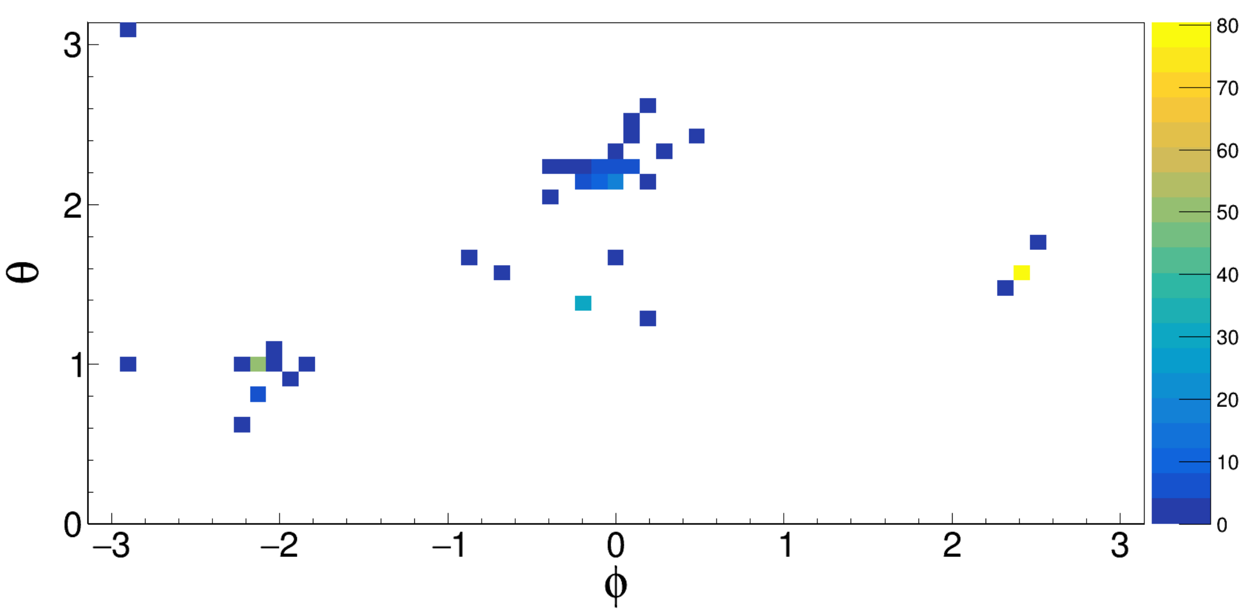
- CEPC can be very precise factory for Higgs investigation.
- Deep learning is full of potential for CEPC physics.
- Maybe deep learning can also help LHC physics.
- However, we should be careful about traps in simulations.

Backup

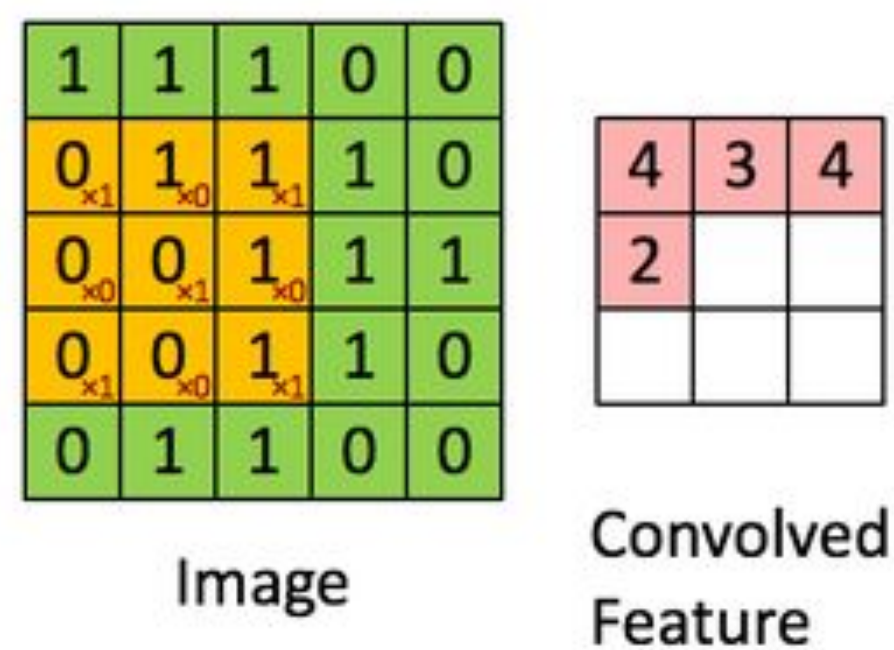
Convolutional Neural Networks (CNNs)

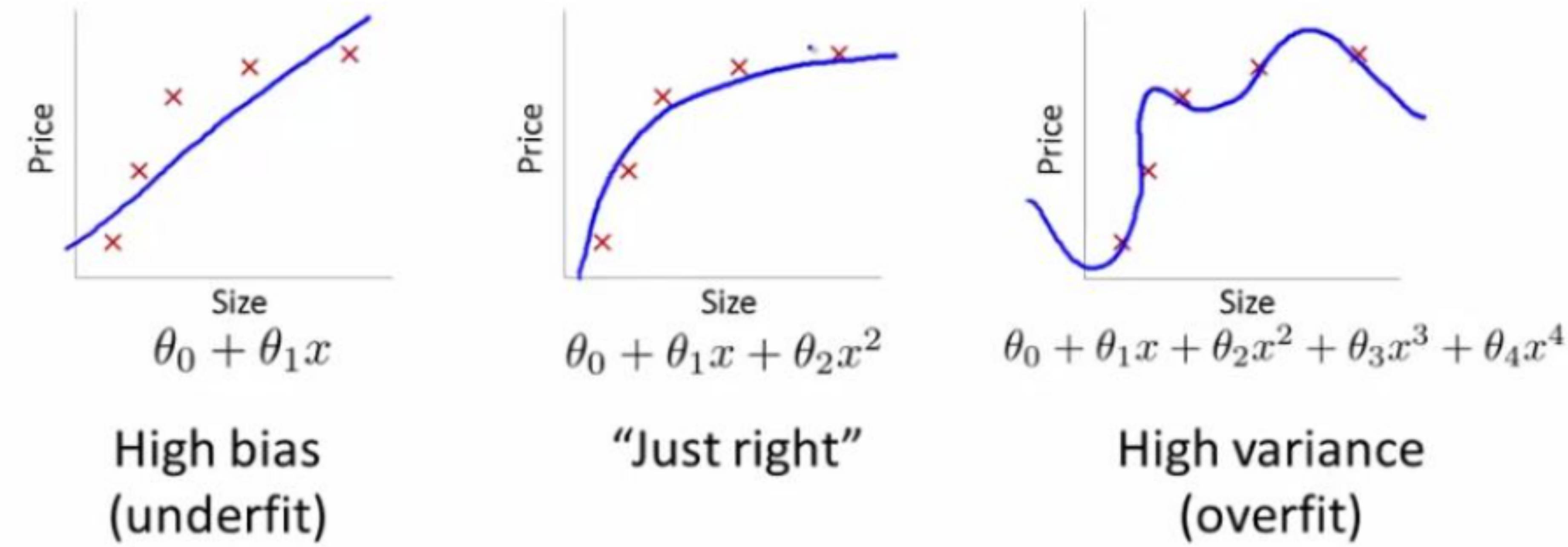


Energy of all the final state stable particles

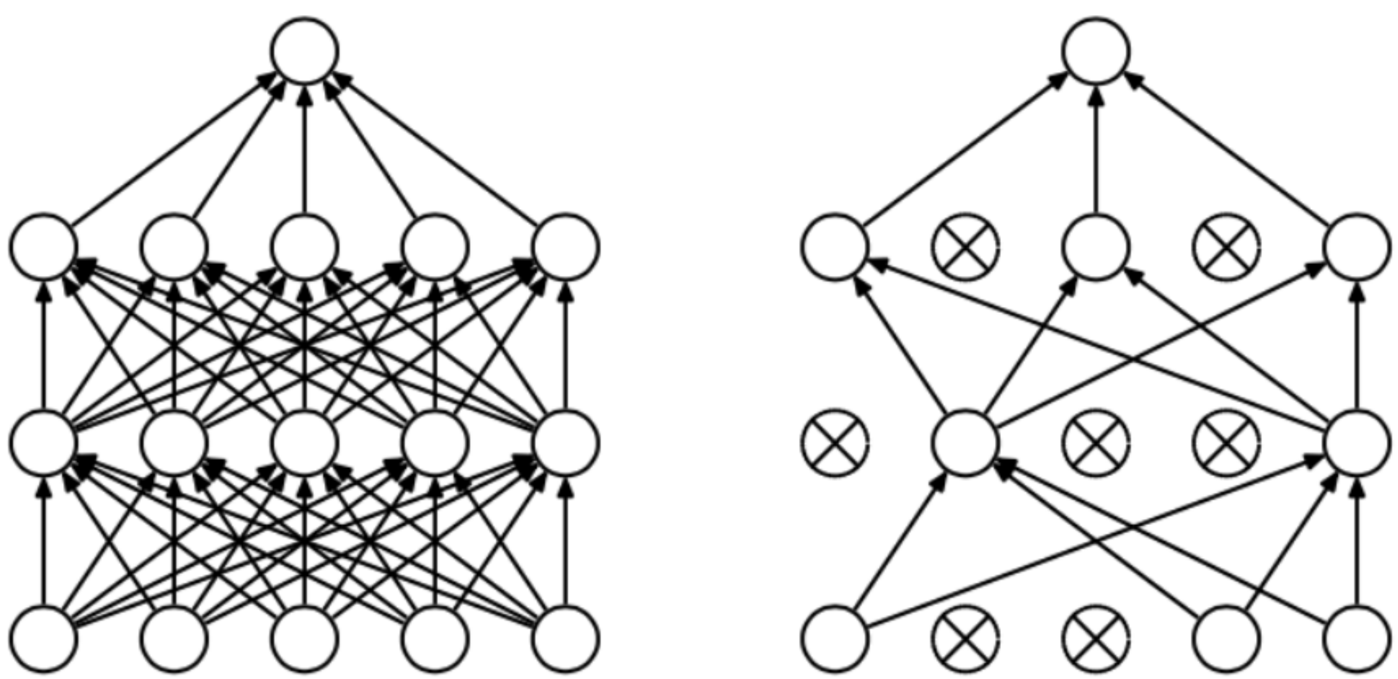


2D image (62*30 pixels)

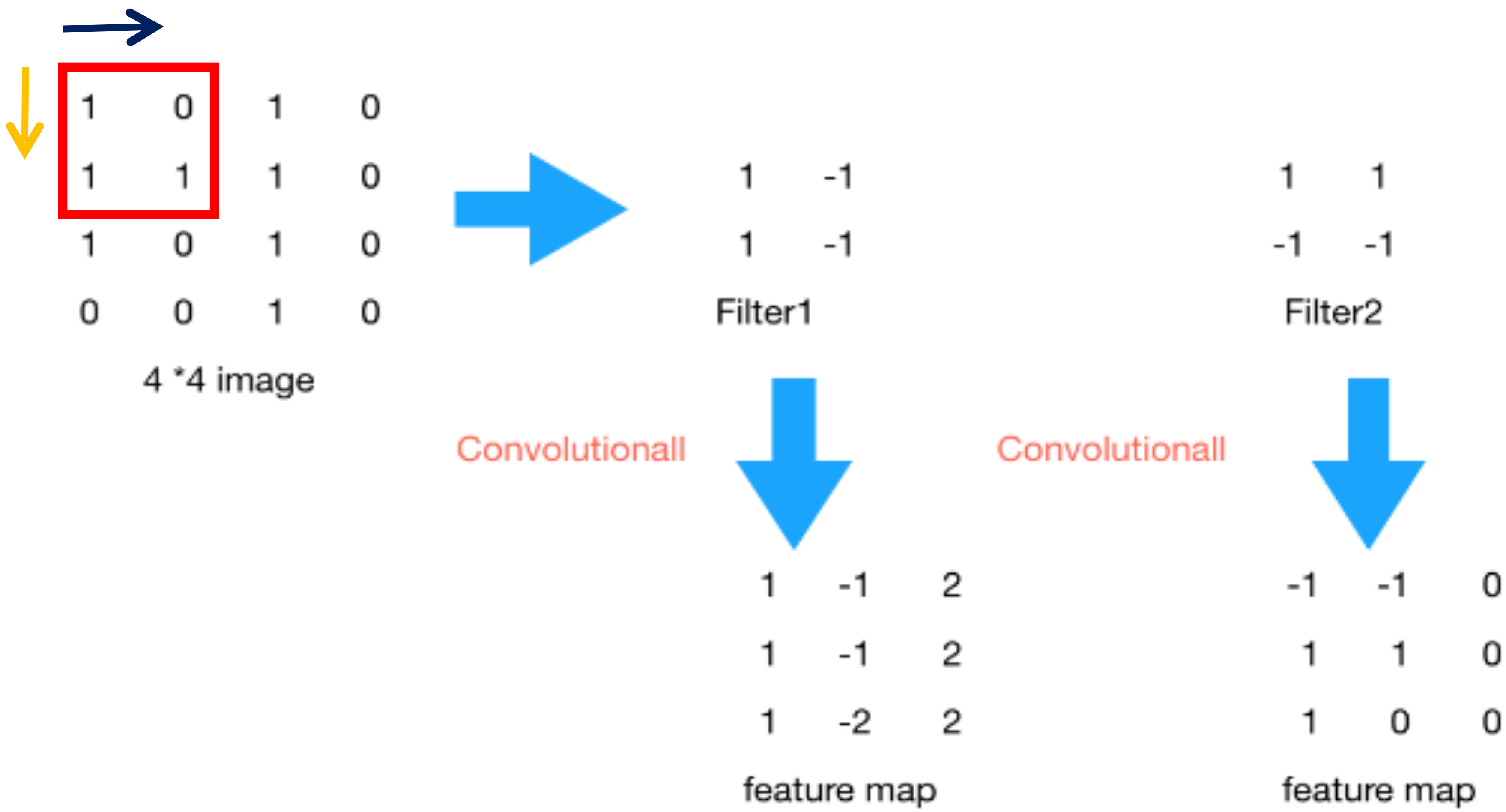




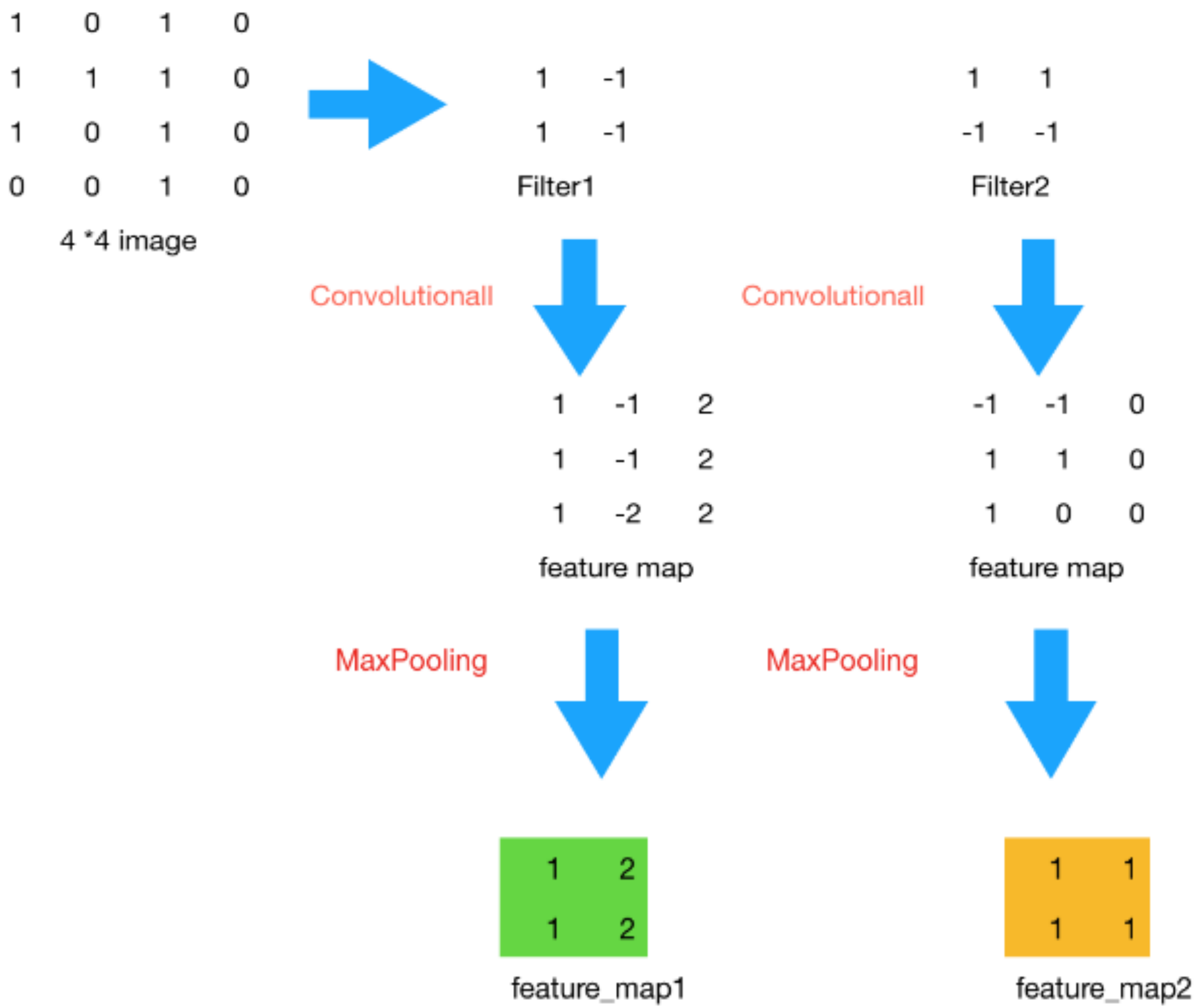
Overfit

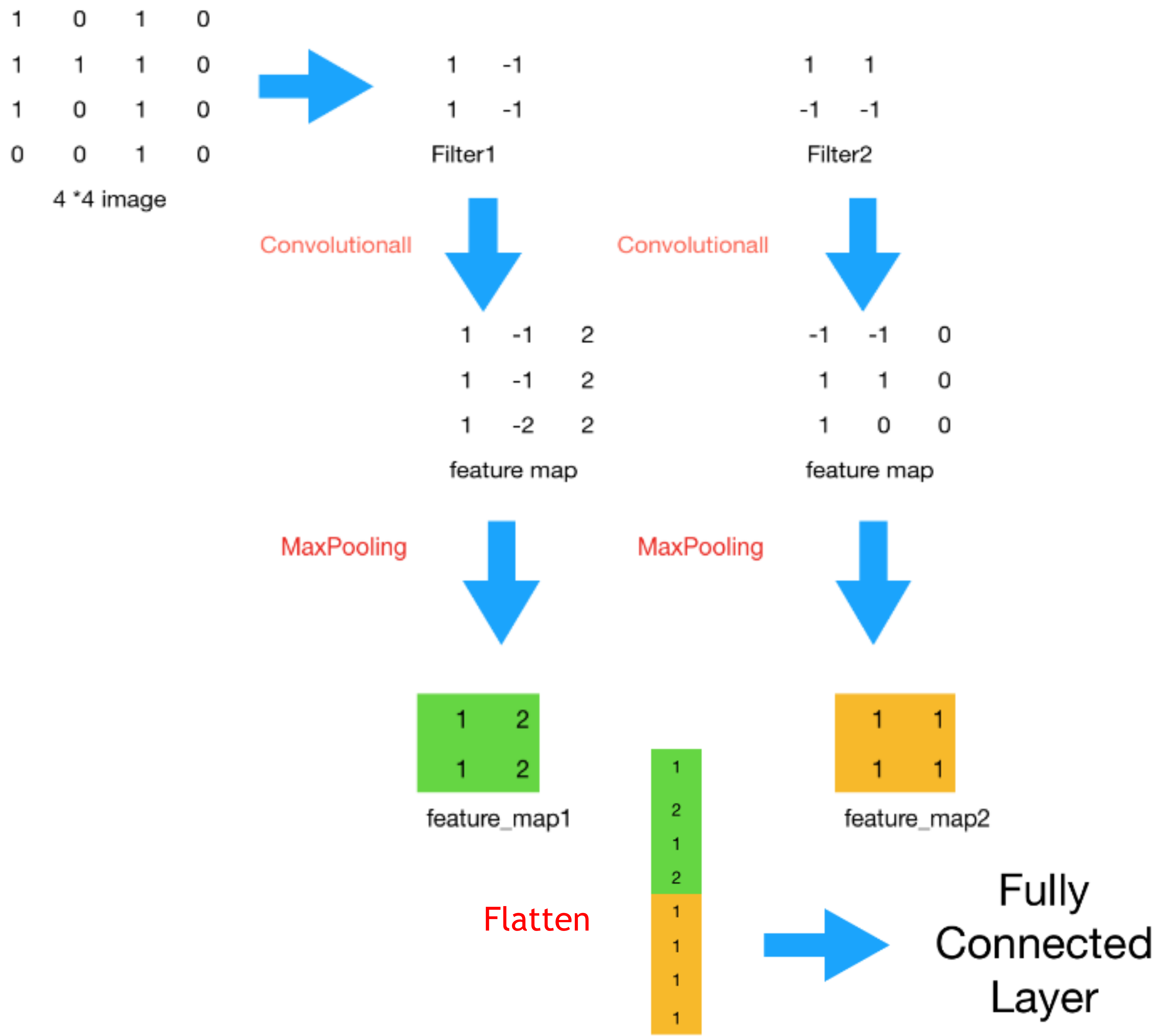


Dropout



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
1
2
1
2
1
1
1
1
Flatten
Fully Connected Layer

Max Pooling