CEPC Workshop

Higgs Hadronic Decay Branch Ratio Measurement in CEPC

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On Behalf of CEPC Physics-Software Study Group

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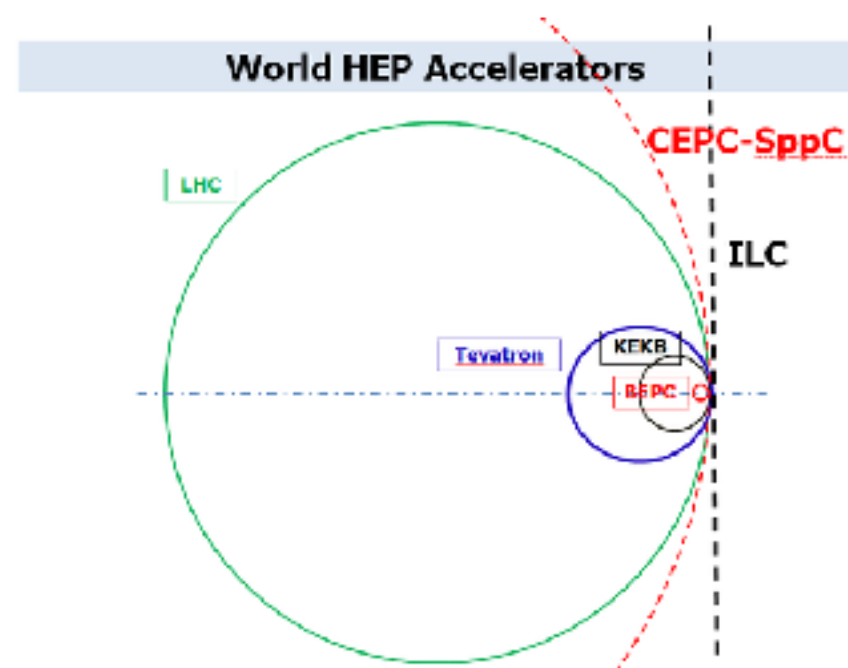
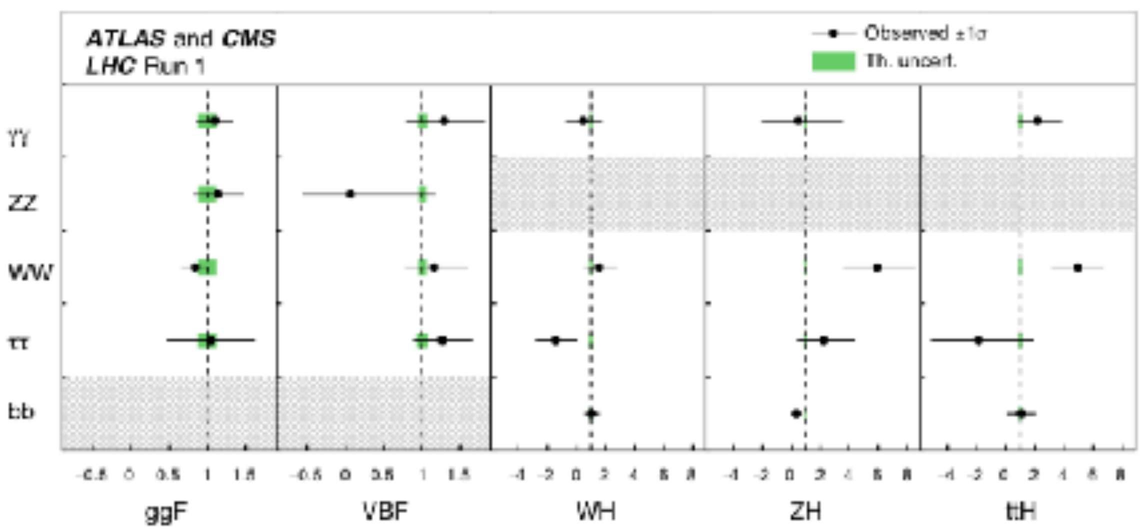


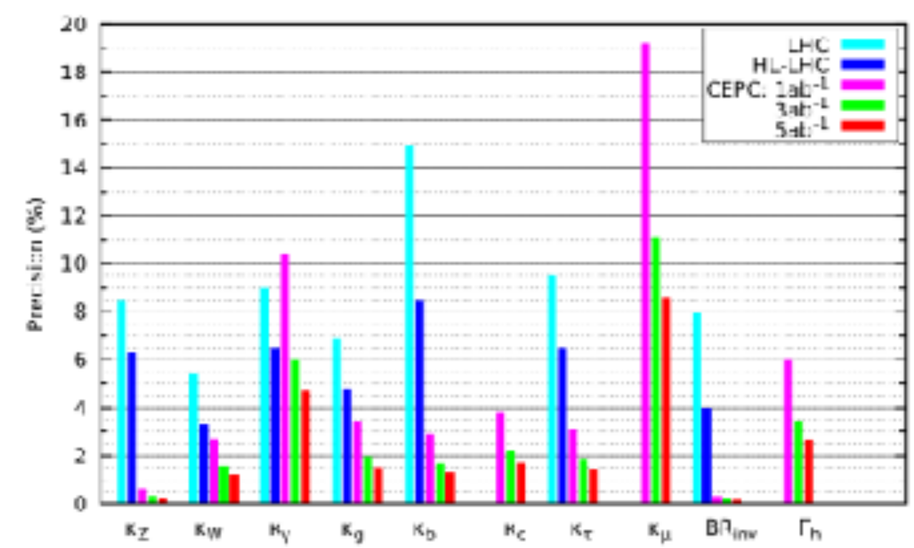
Introduction

Current Result in H->bb



$H \to b\bar{b}$	Tevatron	ATLAS Run 1	CMS Run 1	ATLAS Run 2	CMS Run 2
VH	1.6 ± 0.7	$0.52 \pm 0.32 \pm 0.24$	1.0 ± 0.5	$1.20 \pm 0.24 \pm 0.28$	1.2 ± 0.4
VBF	—	-0.8 ± 2.3	$2.8 \pm 1.4 \pm 0.8$	-3.9 ± 2.8	-3.7 ± 2.7
ttH	—	$1.4 \pm 0.6 \pm 0.8$	0.7 ± 1.9	$2.1 \pm 0.5 \pm 0.9$	$1.19 \pm 0.5 \pm 0.7$
Inclusive	—	—	—	—	2.3 ± 1.7
PDG Comb.	1.6 ± 0.7	0.6 ± 0.4	1.1 ± 0.5	1.2 ± 0.3	1.2 ± 0.4

An improvement of more than
1 order of magnitude in precision at CEPC

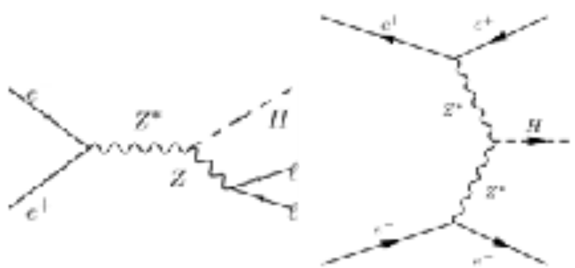
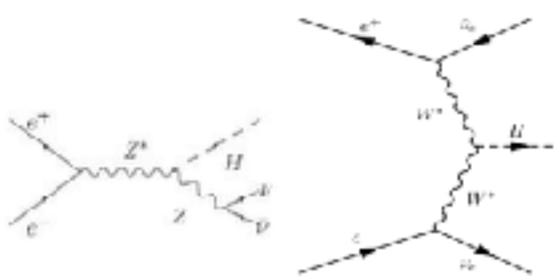
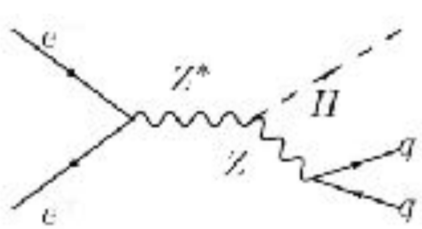


Higgs hadronic decay:
Benchmark channel to understand the performance in tracking, vertex finding, jet clustering and flavor tagging

Review of the Analysis

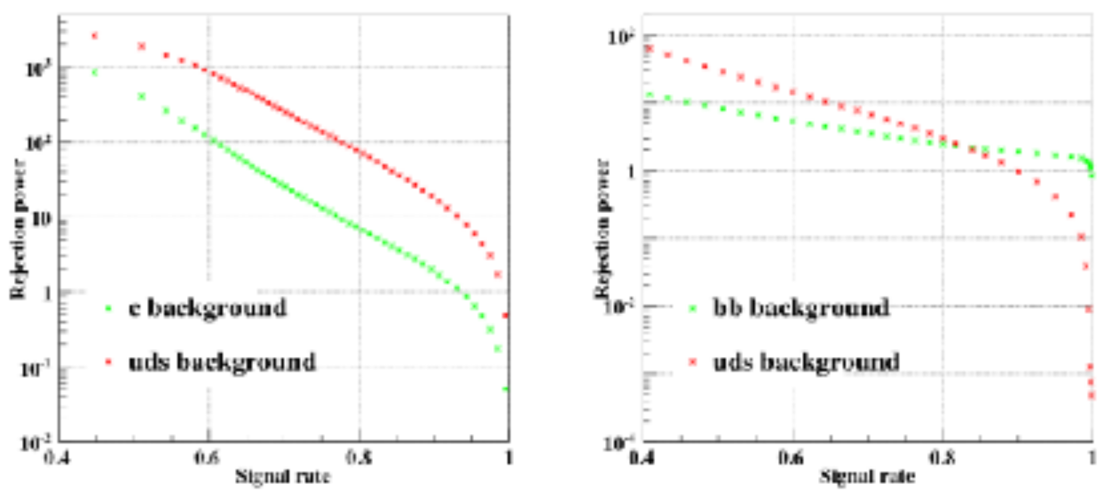
- **2016-2017: H->bb/cc/gg Analysis in qqH/ννH/eeH/μμH**
  - **Demonstrate the capability of flavor tagging and jet clustering in achieving the precision**
  - **Flavor tagging are implemented with template fit method**
  - **Higgs white paper include these results**
- **From summer in 2017, llH channel redone with new method:**
  - **2-D template fit replaced by a 3-D fit**
  - **Systematic uncertainty considered**
  - **Summarize in note, paper draft reviewed**
- **Latest update:**
  - **Redo analysis with 3T samples**
  - **New techniques to improve the performance of analysis**

Event Selection in llH/$\nu\nu$H/qqH

Signal:	Backgrounds:	Preselection:	Flavor Tagging
ZH->ll+jj 	ZZ semi-leptonic($\mu\mu$jj) Single Z-leptonic(eejj)	Lepton Pair Invariant mass Lepton Recoil mass Jets Invariant mass Higgs Polar angle	
ZH->$\nu\nu$+jj 	ZZ semi-leptonic (one Z invisible decay) Single Z semi-leptonic WW/SW semi-leptonic	Missing Energy,p_T Jets invariant/recoil mass Jet Multiplicity(yth-value) Angle between jets MVA applied	Template Fit
ZH->multi-jets 	quark pair production ZZ/WW hadronic	Total Energy Jet Multiplicity Jet Paring(jet invariant mass and angular distribution) MVA applied	

Results of llH/$\nu\nu$H/qqH

Performance of multi-variable based flavor tagging :



(a) (b)

Template Fit:

$$L_{qq} = \frac{qq\ pair}{qq\ pair\ +\ neither\ is\ q} = \frac{x_q^1\, x_q^2}{x_q^1 x_q^2 + (1-x_q^1)(1-x_q^1)}\ (qq = bb, cc)$$

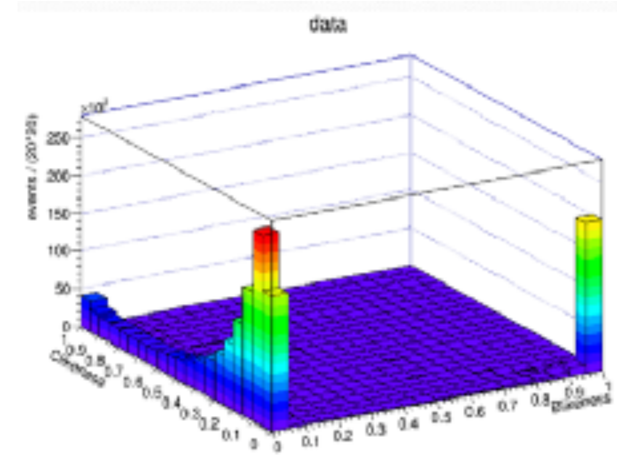


Table 6. Expected relative precision on $\sigma(ZH) \times \mathrm{BR}$ for the $H \to b\bar{b}$, $c\bar{c}$ and gg decays from a CEPC dataset of 5 ab^{-1}.

Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	Comments
$Z \to e^+e^-$	1.3%	14.1%	7.9%	CEPC study
$Z \to \mu^+\mu^-$	1.0%	10.5%	5.4%	CEPC study
$Z \to q\bar{q}$	0.4%	8.1%	5.4%	CEPC study
$Z \to \nu\nu$	0.4%	3.8%	1.6%	CEPC study
Combined	0.3%	3.2%	1.5%	

Results in preCDR:

Decay mode	$\sigma(ZH) \times \mathrm{BR}$	BR
$H \to b\bar{b}$	0.28%	0.57%
$H \to c\bar{c}$	2.2%	2.3%
$H \to gg$	1.6%	1.7%

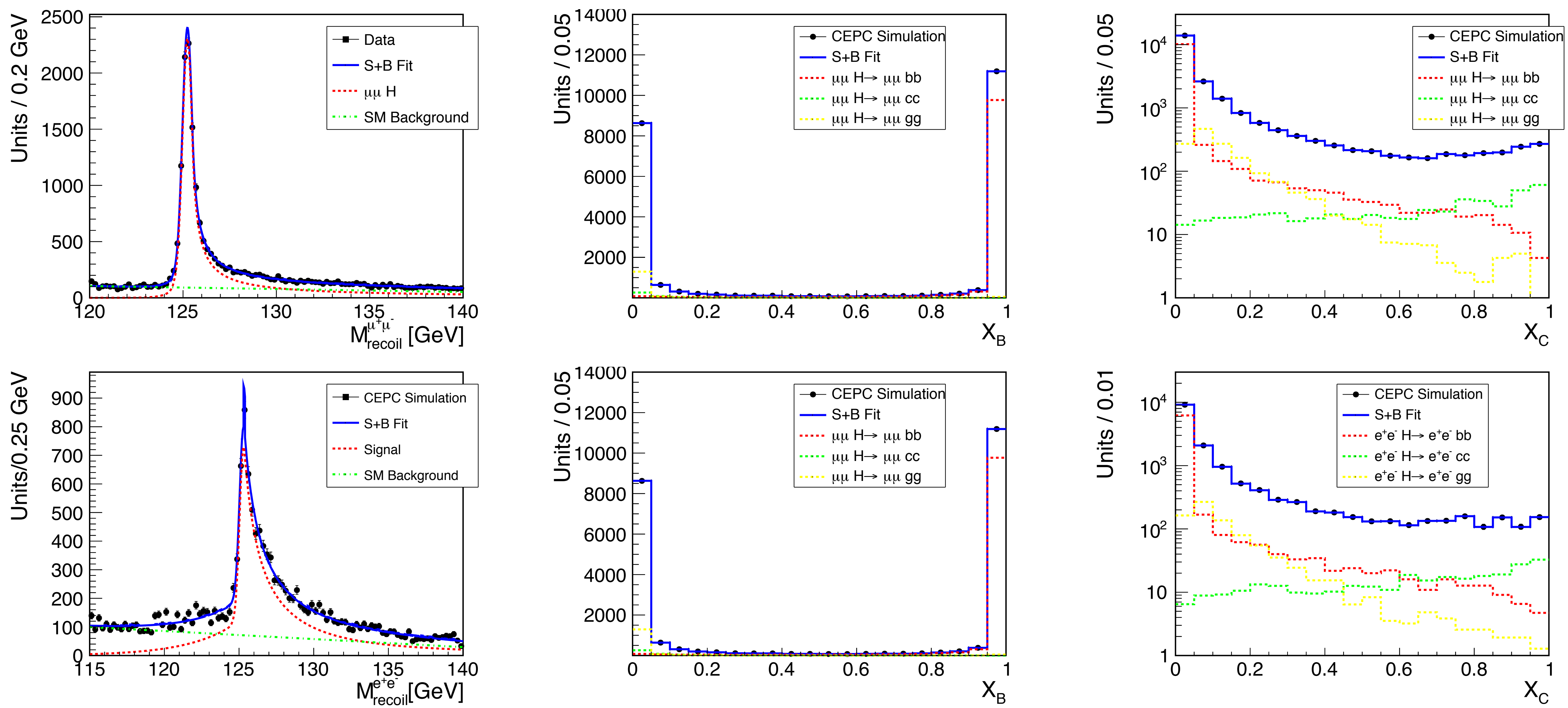
- Consistent with pre-CDR result
- Demonstrate the capability to achieve expected performance

llH Analysis

- Dominant background in llH analysis:
  - $\mu\mu$H channel: ZZ*/Zγ*-> $\mu\mu$qq
  - eeH channel: ee+qq
- Analysis independent of MC prediction of dominant backgrounds:
  - These background have different lepton pair recoil mass spectrum
  - Extract the background yield by including recoil mass spectrum in the fit

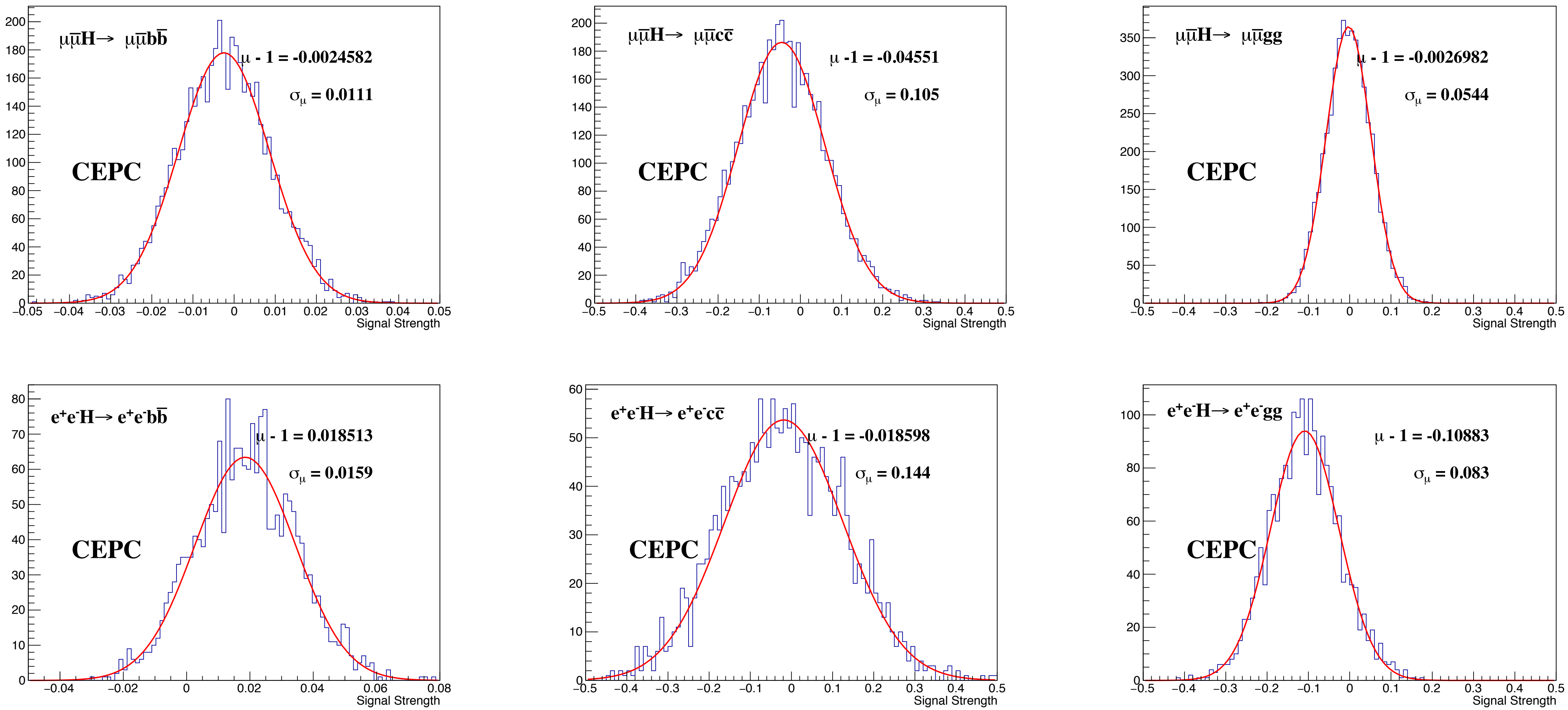
3D Fit

$$PDF^{3D}(X_B, X_C, M_{recoil}) = PDF^{flavor}(X_B, X_C) \times PDF^{recoil\_mass}(M_{recoil})$$



- Recoil mass of signal: Crystal ball + double side exponential
- Recoil mass of background: 1 order Chebychev polynomial
- Background and signal model describe the simulated data well

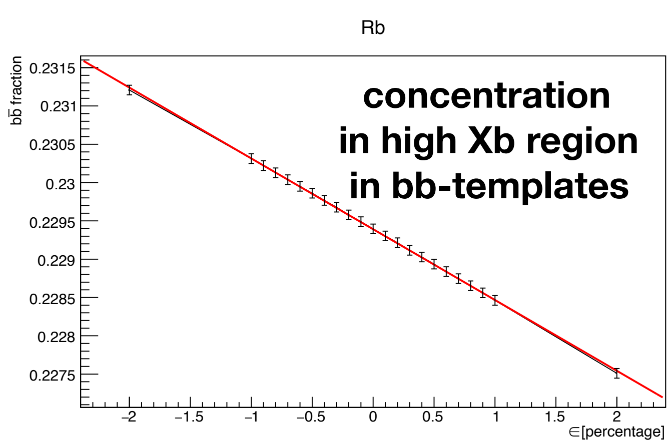
Statistic Uncertainties

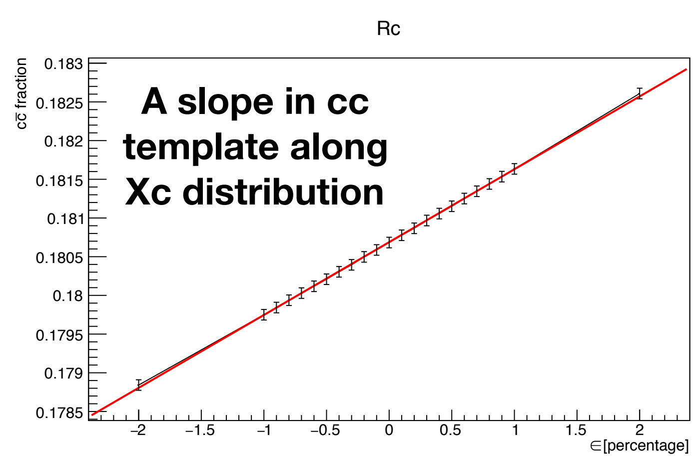


- ToyMC generate data fluctuate according to statistic uncertainty
- Roughly get the same statistic uncertainty as before

Systematic Uncertainty

- Flavor tagging systematic uncertainty directly caused by the bias in templates
- Flavor tagging systematic uncertainty are estimated in the scenario calibration with $\mu\mu$qq
- The precision of calibration are limited by $\mu\mu$qq statistic uncertainty and the knowledge of its flavor components
- Typical bias are considered in each template





Output of flavor fraction linear to typical bias: linearity can be used to extract uncertainty

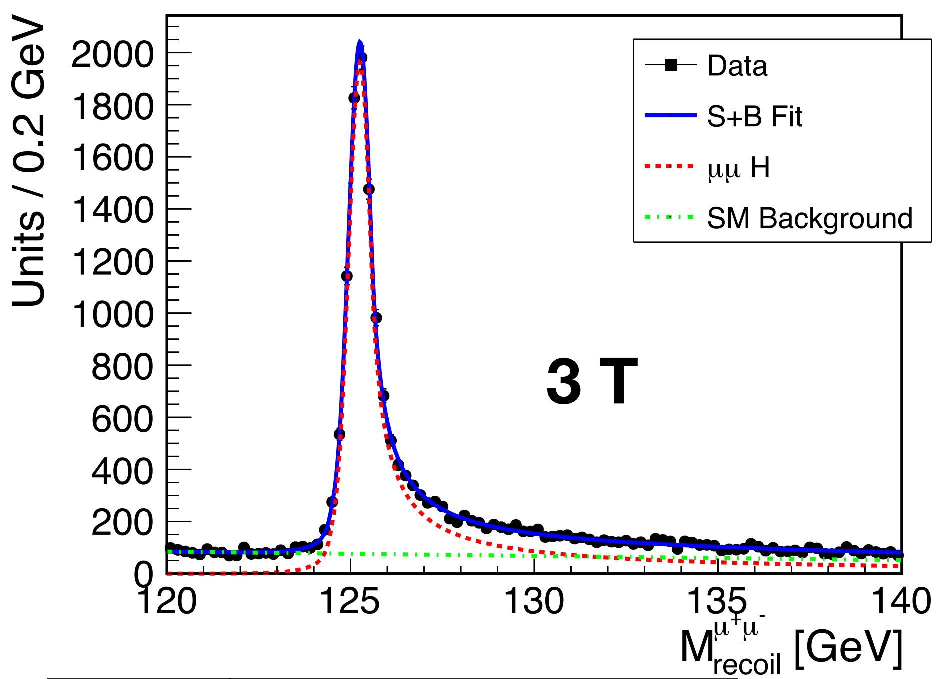
Only a methodology study. Need to be fulfilled with calibration in real data

Systematic uncertainty in llH channel

	$\mu^+\mu^- H$			$e^+e^- H$		
	1.11%	10.5%	5.44%	1.59%	14.4%	8.3%
	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
Fixed Background	-0.17% +0.06%	+4.1% -4.2%	7.6%	-0.17% +0.06%	+4.1% -4.2%	7.6%
Event Selection	+0.68% -0.20%	+0.43% -1.1%	+0.71% -1.7%	+0.68% -0.20%	+0.43% -1.1%	+0.71% -1.7%
Flavor Tagging	0.67%	10.4%	1.1%	0.67%	10.4%	1.1%
Non uniformity	0.016%			0.016%		
Combined	+0.96% -0.72%	+11.2% -11.3%	+7.7% -7.9%	+0.96% -0.72%	+11.2% -11.3%	+7.7% -7.9%

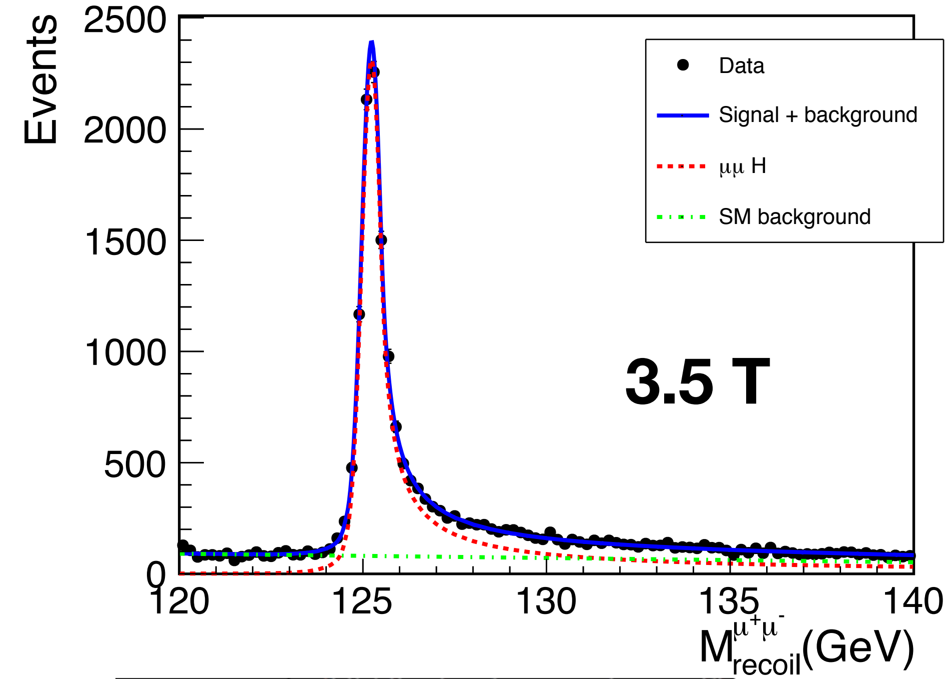
eeH uncertainty extrapolate from mumuH

Analysis with 3T sample



EXT NO.	PARAMETER NAME	VALUE	ERROR	INTERNAL STEP SIZE	INTERNAL VALUE
1	C	2.58443e-02	1.16816e-02	3.22050e-02	-1.81745e+00
2	d	-1.83682e+00	3.15654e-02	4.29202e-04	-1.83780e-01
3	d1	-3.44392e-01	1.92103e-02	6.12454e-03	-3.44392e-01
4	mean	1.25256e+02	6.52233e-03	1.96398e-03	1.74202e-01
5	n	8.17291e-01	3.81682e-02	2.76175e-03	2.61914e-01
6	nHbb	1.09549e+04	1.36900e+02	4.07062e-03	9.55916e-02
7	nHcc	5.41724e+02	6.80616e+01	8.19061e-03	-1.18141e+00
8	nHgg	1.41518e+03	9.82271e+01	1.22154e-02	-4.50060e-01
9	nbkg	8.93584e+00	9.88045e+00	6.48192e-02	-1.48313e+00
10	nzzsl_mu_bb	2.42706e+03	1.04827e+02	8.22363e-03	-3.11516e-01
11	nzzsl_mu_cc	2.08545e+03	7.00836e+01	6.90097e-03	-4.16277e-01
12	nzzsl_mu_uds	7.00000e+03	1.06463e+02	3.51038e-03	-2.96322e-01
13	sigma	3.22645e-01	6.59670e-03	4.57437e-03	-4.58375e-01

True Value:
nHbb: 10806
nHcc: 497
nHgg: 1471.6



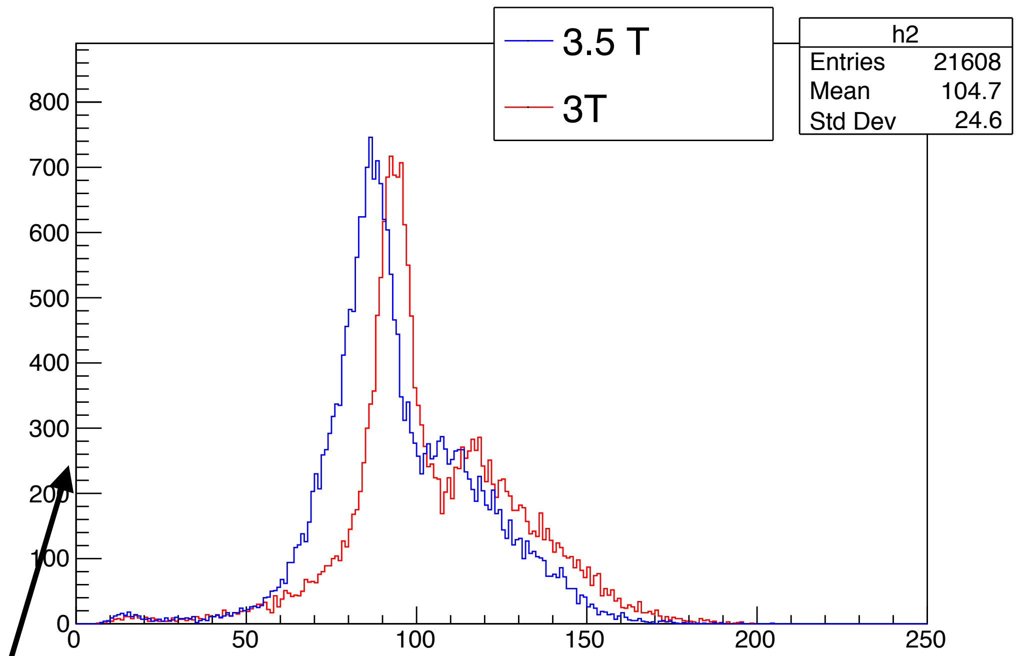
EXT NO.	PARAMETER NAME	VALUE	ERROR	INTERNAL STEP SIZE	INTERNAL VALUE
1	C	1.41257e-02	7.10497e-03	1.01210e-03	-1.19271e+00
2	d	-1.81976e+00	2.04581e-02	7.42820e-05	-1.02154e-01
3	d1	-2.66001e-01	7.94429e-02	3.80145e-04	-2.66061e-01
4	mean	1.25237e+02	5.30034e-03	5.94020e-05	1.52510e-01
5	n	9.26016e-01	2.62238e-02	9.82016e-05	2.88884e-01
6	nHbb	1.12277e+04	1.31890e+02	1.49491e-04	1.23038e-01
7	nHcc	5.15823e+02	5.57565e+01	2.94394e-04	-1.11426e+00
8	nHgg	1.54453e+03	8.43753e+01	4.18167e-04	-3.92464e-01
9	nbkg	5.86001e-01	7.91414e+00	4.45507e-01	-1.57875e+00
			WARNING -	- ABOVE PARAMETER IS AT LIMIT.	
10	nzzsl_mu_bb	1.37309e+03	8.65210e+01	3.87648e-04	-6.52715e-01
11	nzzsl_mu_cc	1.48088e+03	5.98582e+01	2.46184e-04	-6.22211e-01
12	nzzsl_mu_uds	4.38346e+03	8.63575e+01	1.22872e-04	-6.06180e-01
13	sigma	2.68430e-01	5.42687e-05	1.48477e-04	-8.14820e-01

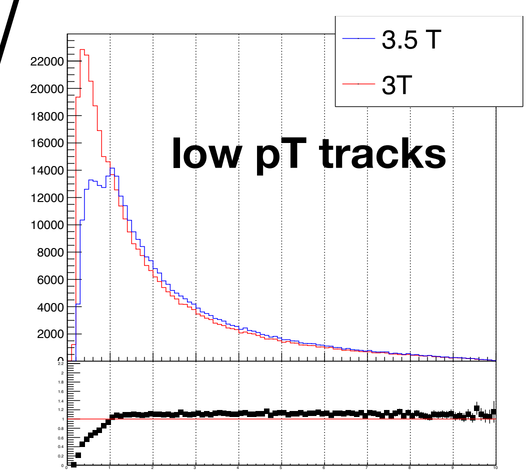
True Value:
nHbb: 11188.2
nHcc: 518.2
nHgg: 1502.4

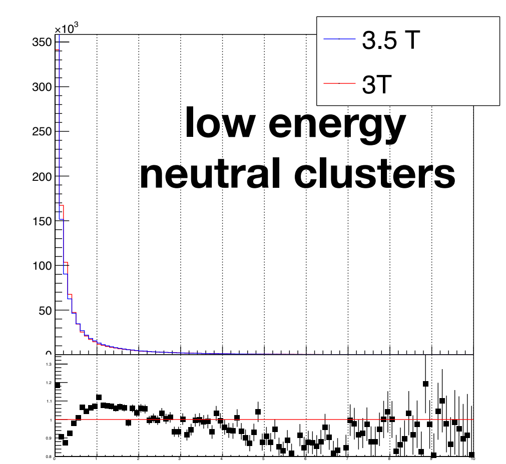
- No obvious change in the fitted results
- The recoil mass spectrum change as expected

3T sample disagreement in soft region

	3T	3.5T	Eff Ratio
Filter	4.5%		
FSClasser	Unknown		
cos θ_Z	68.021%	68.619%	0.9913
cos $\theta_{\mu\mu}$	89.068%	89.052%	1.0002
$M_{\mu\mu}$	88.390%	89.680%	0.9968
M_recoil	44.845%	45.302%	0.9899
2J+Lep_Veto	97.111%	98.397%	0.9869
JetnPFO	99.346%	97.403%	1.0199
cos θ_{JJ}	91.916%	92.420%	0.9945
M_{JJ}	94.528%	85.973%	1.0995
y-value	93.246%	94.013%	0.9918







- It seems the disagreement is from low energy neutral clusters
- Problems in survey, will be cleared soon

Technic development : Convolutional NN in Jets

- We use CNN to separate H->qq and H-> ZZ*/WW*->qqqq

Take image of Energy Distribution

65×65 pixels in detectable region

64 5×5 filters
4×4 pooling

14×14 pixels
64 images

64 5×5 filters
2×2 pooling

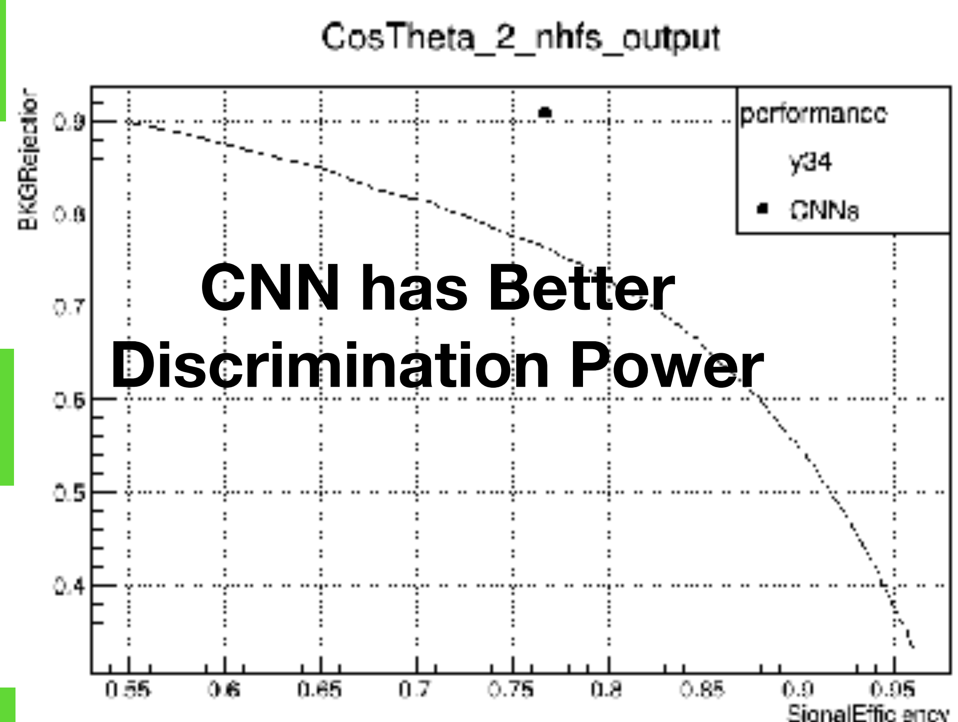
5×5 pixels
64 images

64 5×5 filters
2×2 pooling

64 Single Pixels images

64×128 Condense layer

Logistic Regression to 2 classes



- **CNN provides new to extract character in event with jets**
- **Should be useful need to know the multiplicity of jets: Higgs->qq, QCD measurements etc.**
- **Would like to know other types of character can be extracted: try to use in qqH channel**

Summary

- Study of Higgs hadronic decay measurement in eeH/$\mu\mu$H/$\nu\nu$H/qqH channel are done with full simulation sample, demonstrating the capability to achieve expected performance in CEPC
- eeH/$\mu\mu$H redone with less MC-dependent way, systematic uncertainties studied in terms of methodology
- Precision of measurements with 3 Tesla magnitude in study. No significant change in final results but need to find out the result of disagreement with previous sample
- New analysis technics are studied and it is helpful to the analysis in future.