中国科学院高能物理研究所
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Status on Hss

Summary of Hss research groups reports

Outline

- Measurements in mumuH channel
  - Yanping Huang, Xiaotian Ma, Zuofei Wu
- Measurements in nnH channel
  - Haijun Yang, Kun Wang, Yifan Zhu, Xinzhu Wang, Chunxiang Zhu
- Measurements in nnH channel
  - Manqi Ruan, etc
- Scaling behavior
  - Manqi Ruan, Jianfeng Jiang
- Summary of Hss uncertainty
- Existing samples
- Plans

Measurements in mumuH channel

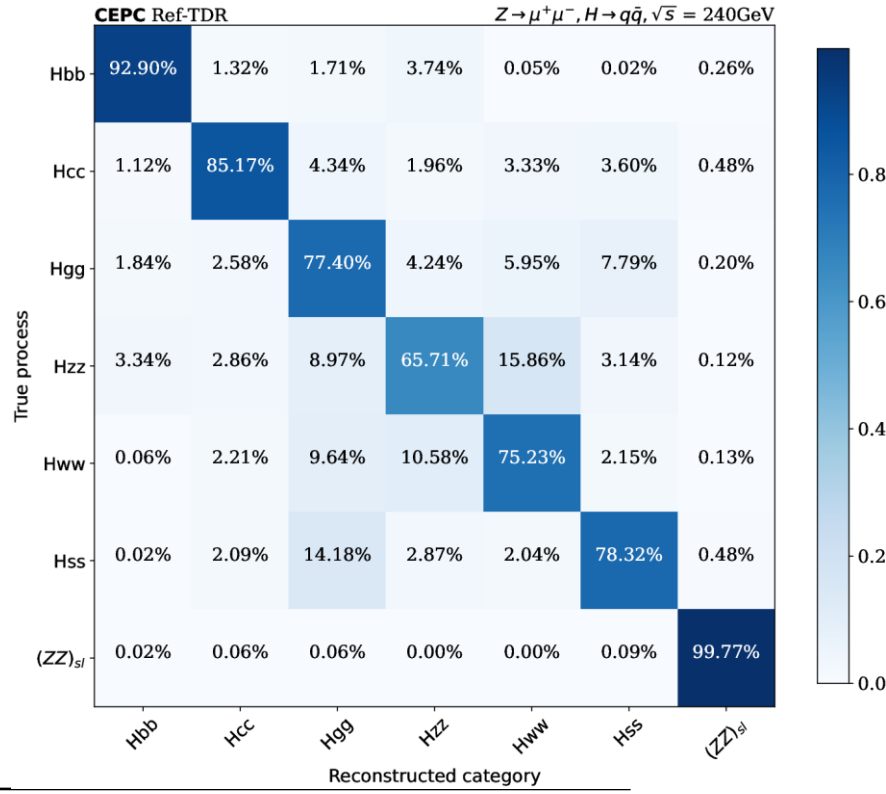
Yanping Huang, Xiaotian Ma, Zuofei Wu

- 300k events generated for each process
  - Using Whizard 1.95 and Pythia6 for the fragmentation and hadronization
  - Signal process: Z decays to a pair of muons and H decays in pairs of $b\bar{b}/c\bar{c}/gg/WW^*/ZZ^*/s\bar{s}$, full simulation generated under Ref-TDR CEPCSW
  - Backgrounds: processes with two-fermion and four-fermion final states, full simulation generated under Ref-TDR CEPCSW
- Apply pre-cuts to select muons from Z and reduce backgrounds
- Apply Particle Transformer at event level using particles info to separate all decay channels simultaneously

Measurements in mumuH channel

Yanping Huang, Xiaotian Ma, Zuofei Wu

- Syst. Unc: To account for detector-related effects, particularly those arising from vertex reconstruction and tracking, the D_0/Z_0 of each track was conservatively smeared by 20% of its error.
- Stat. Unc. for Hss: 97%

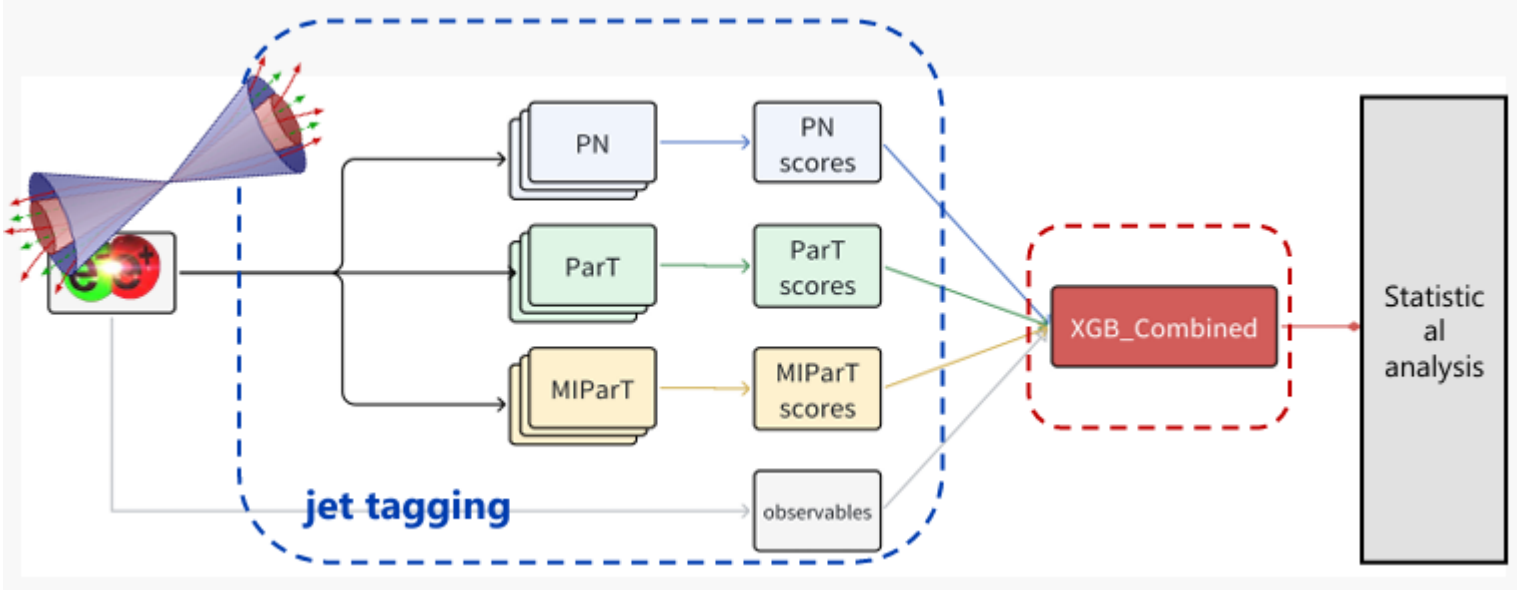


Sig	$H\to b\bar{b}$	$H\to c\bar{c}$	$H\to gg$	$H\to ZZ^*$	$H\to WW^*$	$H\to s\bar{s}$
Branching fraction	57.7%	2.91%	8.57%	2.64%	21.5%	4.4×10^{-4}
Rel. Stat. Un.	0.4%	2.2%	1.3%	7.8%	1.1%	97.2%
Rel. Syst. Un.	0.1%	3.7%	1.8%	4.2%	0.4%	211.7%

Measurements in nnH channel

Haijun Yang, Kun Wang, Yifan Zhu, Xinzhu Wang, Chunxiang Zhu

- 10M Delphes events generated for each process
  - Signal: ee→ZH, Z→$\nu\nu$, H→qq/gg @ 240GeV
  - Backgrounds: Dominated by H→ZZ, 2 fermions and 4 fermions
- Pre-cuts
- Jet-tagging using three networks and then combined by XGB

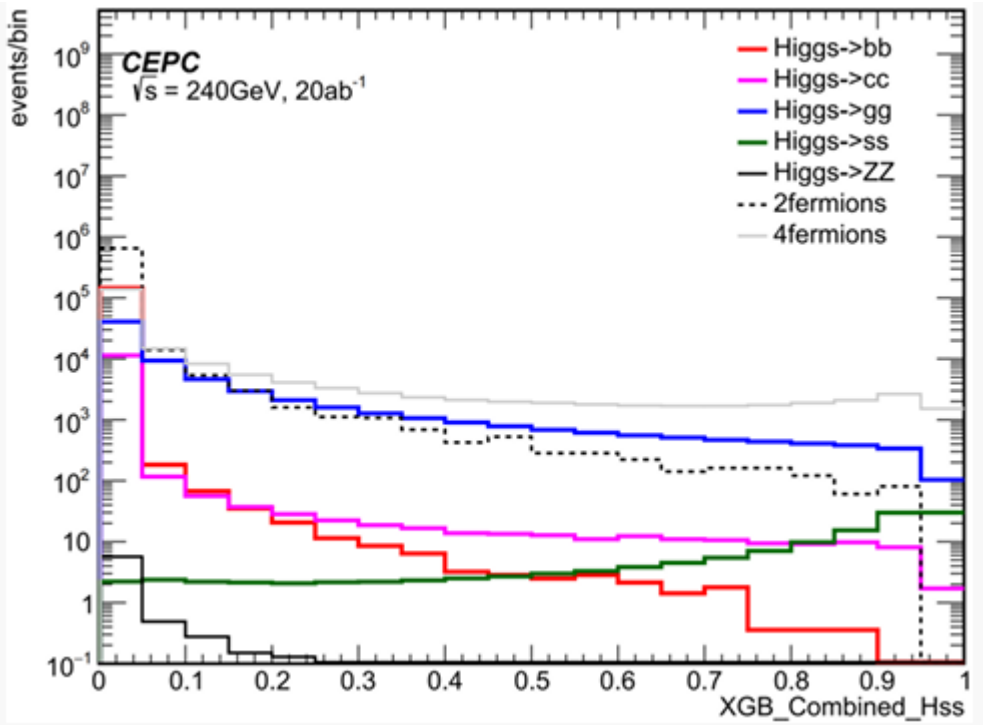


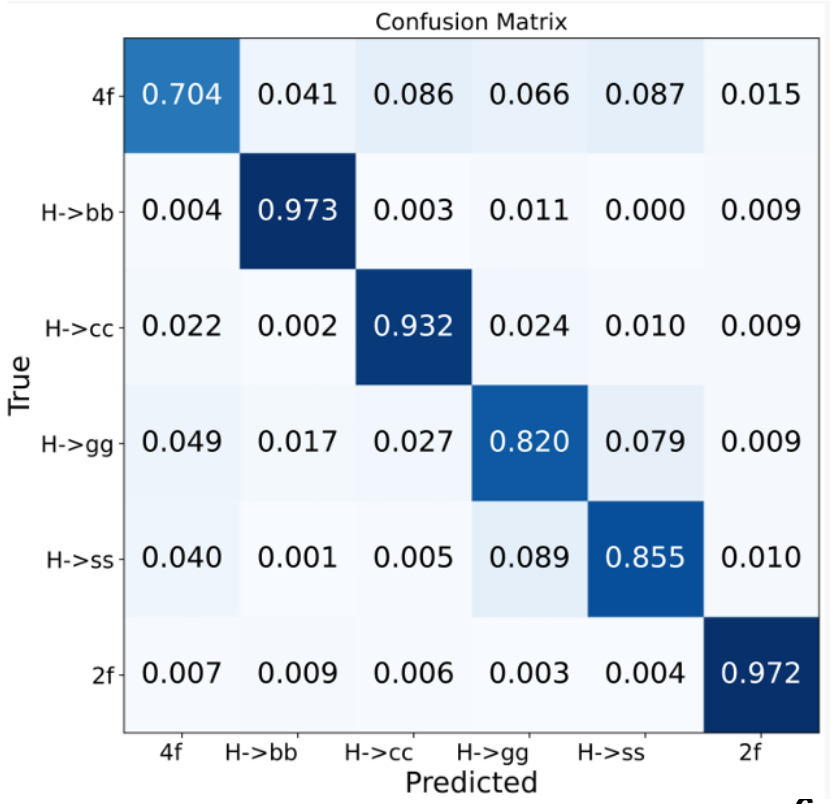
Measurements in nnH channel

Haijun Yang, Kun Wang, Yifan Zhu, Xinzhu Wang, Chunxiang Zhu

- ~1.3σ (statistical only) for H→ss search
- Rel. Unc. ~78%
- chosen at the point of maximum signal significance Z

$$\text{Relative error} = \frac{\sqrt{S+B}}{S}$$





Measurements in nnH channel

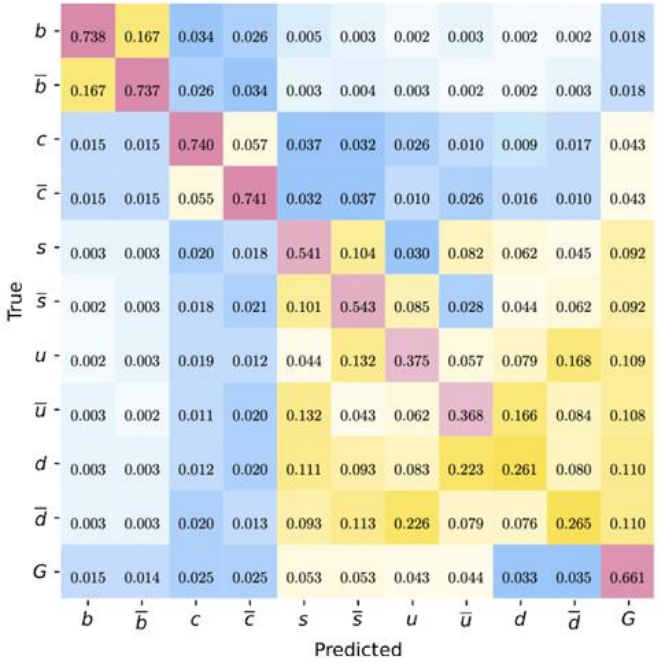
Haijun Yang, Kun Wang, Yifan Zhu, Xinzhu Wang, Chunxiang Zhu

- Challenge in llH(e.g. eeH) which is in process
  - leptons(high E) be incorporated into jet reconstruction
  - Jet mis-including "isolated lepton" pT ~10GeV higher than clean jet
- Network optimization idea
  - Memory
    - Padding issue (solved)
    - Standard attention->FlashAttention memory complexity $O(N^2)$->$O(N)$
  - Representation Learning
    - Mask particles' all features randomly
    - Multi-Class-Attention
    - Implicit ACSI ?

Measurements in nnH channel

Manqi Ruan, etc

- **JOI approach**: Based on ParticleNet; using all reconstructed particles
- Jet origin identification: 11 categories
- CEPC-v4 detector, reconstructed with Arbor + ParticleNet
  - Full Simulated vvH, Higgs to two jets sample
  - All SM bkg
- 1 Million samples each, 60/20/20% for training, validation & test



Upper limit of Hss Signal Strength ~ 3 * SM

PHYSICAL REVIEW LETTERS 132, 221802 (2024)

Measurements in nnH channel

Manqi Ruan, etc

- Holistic approach and Advanced Color Singlet Identification for physics measurements at high energy frontier
  - Hadronization model: Pythia-6.4, Herwig-7.2.2 Pythia-8.313
  - Physics process: ee->nnH, H->bb/cc/gg/uu/dd/ss
  - Higgs only background, dominant by H->gg
  - 1M for each process trained by ParticleNet

$$\text{Relative error} = \frac{\sqrt{S+B}}{S}$$

	$\nu\bar{\nu}H$			
	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$	$H \to s\bar{s}$
cut + BDT	0.26%[21]	3.04%[21]	0.96%[21]	190.00%[19]
holistic	0.14%	0.72%	0.46%	29.34%
holistic with CSI	-	-	-	-
holistic with ideal CSI	-	-	-	-
statistical limit	0.14%	0.61%	0.36%	6.91%

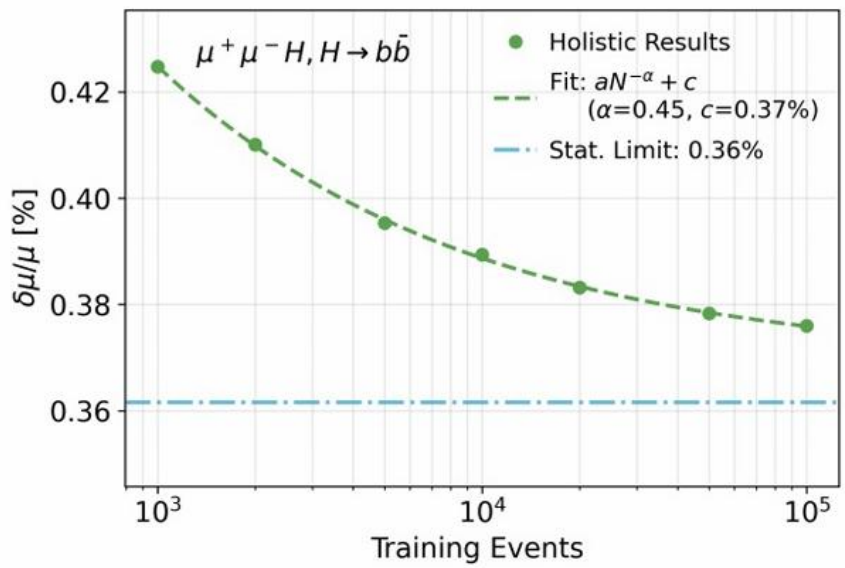
Yongfeng, Yuexin, etc
arXiv:2506.11783

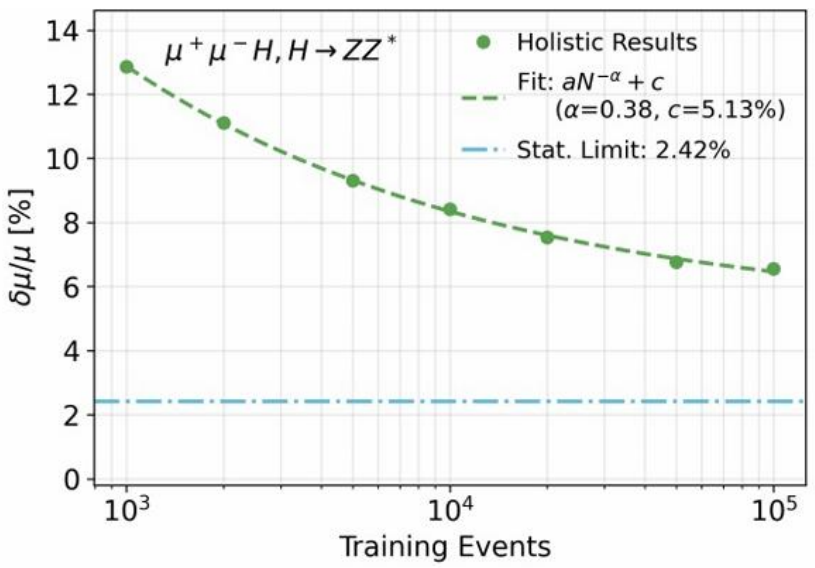
Hss Signal 4-8σ

Scaling behavior

Manqi Ruan, Jianfeng Jiang

- Holistic approach: based on ParticleNet; using all reconstructed particles
- Asymptotic limit
  - Channels: ee -> Z(nunu)H(bb/cc/gg/WW/ZZ) and ee -> ZZ
  - Data size : 10k ~ 1M, generated by Madgraph + pythia8
  - Relative stat. uncertainties improve rapidly with increasing statistics



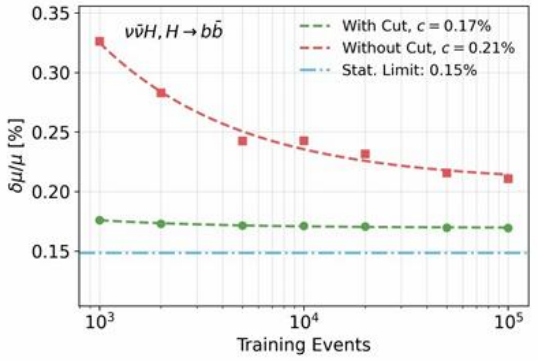


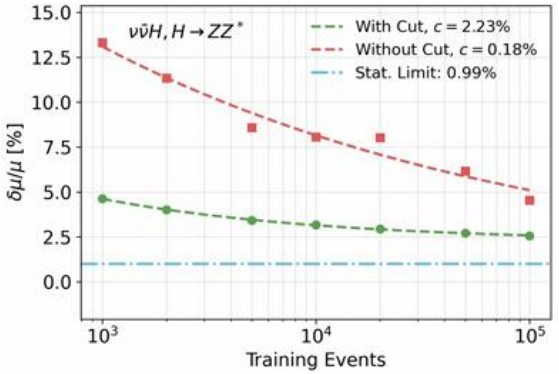
$$y = aN^{-\alpha} + c$$

Scaling behavior

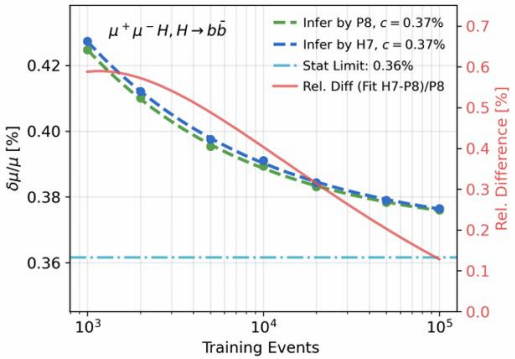
Manqi Ruan, Jianfeng Jiang

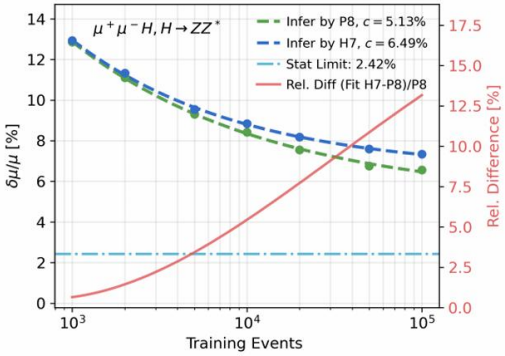
- Pre-cut:
  - Channels: ee>Z(nunu)H(bb/cc/gg/WW/ZZ) and ee> ZZ/WW/qq
  - fast convergence but hits a plateau, with increasing data size, crossing with no cuts'





- Generator Robustness
  - mumuH training with Pythia8
  - Pythia8(green line), Herwig7(blue line)
  - Except ZZ, the rel. differences are less than 4%





Summary of Hss uncertainty

approach	signal process	background process	Stat. Unc./Sig. of Hss
Particle Transformer with particles info at event level	ee->mumuH, H->bb/cc/gg/ss/ZZ/WW	2-fermion background 4-fermion background	97.2%
xgb combined with jet tagging at event level	ee->nnH, H->bb/cc/gg/ss	2-fermion background 4-fermion background H->ZZ, ZZ->nnqq	77.9%/1.3σ
holistic approach	ee->nnH, H->bb/cc/gg/uu/dd/ss	Higgs only	29.3%/4-8σ

Existing samples

240GeV						
Higgs signal						
process	Simulation category	Simulated Nevent	release	Simulation category	Simulated Nevent	release
ee->mumuH, H->bb/cc/gg/ss	full sim	494k/495k/371k/494k	CEPCSW_tdr25.3.5			
ee->mumuH, H->ZZ/WW(full hadronic)	full sim	497k/497k	CEPCSW_tdr25.3.5			
ee->mumuH, H->ZZ/WW	full sim	380k/386k	CEPCSW_tdr25.6.0			
ee->nnH, H->bb/cc/dd/ss/uu/gg	full sim	1M for each channel	CEPCSW_tdr25.3.7	fast sim	10M for each channal	whizard1.95+pythia6
				fast sim	10M for each channal	madgraph3.6.3+pythia8.313
ee->nnH, H->ZZ, ZZ->nnqq				fast sim	10M	whizard1.95+pythia6

2-fermion bkg						
ee	full sim	100k	CEPCSW_tdr25.3.6			
mumu	full sim (filtered)	568k	CEPCSW_tdr25.3.7			
tautau	full sim	100k	CEPCSW_tdr25.3.6			
qq	full sim	500k	CEPCSW_tdr25.3.6	fast sim (filtered)	5M	whizard1.95+pythia6
4-fermion bkg						
ZZ/WW/SZ/SW/mix	full sim	~400k for each sub channel	CEPCSW_tdr25.3.6	fastsim	40M for ee->nnqq	whizard1.95+pythia6
91.2GeV						
ee->ss/uu/dd/cc/bb	full sim	~200k for each channel	CEPCSW2 5.3.7 whizard			
	full sim	~200k for each channel	CEPCSW2 5.3.7 Madgraph5			

For more details: Analysis and samples's summary

Plans

- Get Hss results of combined eeH/mumuH/vvH channels
  - Full sim samples under generating
- Theoretical Uncertainties
- Realistic collision environments
  - BIB