MC tools
Working Group's Report

Qishu Yan (UCAS)
coordinator: J.X. Wang/QY

CFHEP Kickoff Meeting, 25/Feb. /2014, Beijing

Outline

- 1. Introduction
- 2. Status
- 3. Works for 100 collision ongoing
  - 3.1 Higgs pair production and trilinear Higgs coupling measurements
  - 3.2 Heavy B' search
  - 3.3 Anomalous couplings measurements
- 4. Future plans
- 5. Summary

CEPC: Circular Electron-positron and Proton-proton Collider

1. Introduction

1 Tools make our life easy

2 MC tools have been proved to be vital for the success of collisions

3 It is indispensable for CEPC/100 TeV collisions

MC tools are supposed to make physics study easy, both for theorists and experimentalists.

FHC.1.5 Theoretical tools for the study of 100 TeV collisions

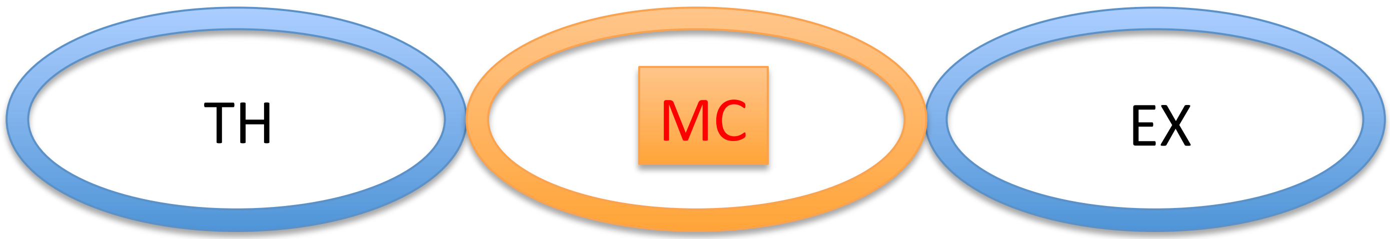
FHC.1.5.1 PDFs

FHC.1.5.2 MC generators

FHC.1.5.3 N^nLO calculations

FHC.1.5.4 EW corrections

From M.L.Magano's slide



1. To make MC generators is a theoretical work.
2. MC generators can provide the most comprehensive information which are needed by experimental groups (cross sections, differential distributions, angular correlations, etc).

MC tools can develop proposed physics study into CDR/TDR stages.
We need to work side by side with our theorists and experimentalists.

2. Status

Affiliations[12]	Core Members[22]
CMS, Zhejiang University	B. Feng
Hangzhou University	Q.J. Xu[F]
He-Bei University	T.F. Feng, S.M. Zhao
Hua-Zhong Normal University	X.Q. Li
TH division, IHEP,CAS	J.X. Wang, B. Gong, Y. Feng, Z. Li
PEKING UNIVERSITY	Q. LI, H.S. SHAO[CERN]
Shan-Dong University	Z.G. Si, S.Y. Li, S.S. Bao, H.L. Li
UCAS	QY, X.R. ZHAO
USTC	L. Guo, R.Y. Zhang, W.G. Ma
ZhengZhou University	G.L. Liu[F]
ZhongShan University	H.H. Zhang
ShangHai Jiaotong University	J.H. Zhang

Roles	Core Members[22]
Amplitude Computations(TH)	B. Feng
Physics Study	Q.J. Xu[F]
H/W/Z, QCD/EW corrections	T.F. Feng, S.M. Zhao
H/W/Z, QCD/EW corrections	X.Q. Li
FDC and ME generators	J.X. Wang, B. Gong, Y. Feng, Z. Li
TOOLKITS DEVELOPMENT	Q. LI, H.S. SHAO
QCD cor./Showering/Matching	Z.G. Si, S.Y. Li, S.S. Bao, H.L. Li
TOOLKITS & Physics Study	QY, X.R. ZHAO
TOOLKITS & Physics Study	L. Guo, R.Y. Zhang, W.G. Ma
Physics Study	G.L. Liu[F]
Physics Study	H.H. Zhang
Amplitude Computations(TH)	J.H. Zhang

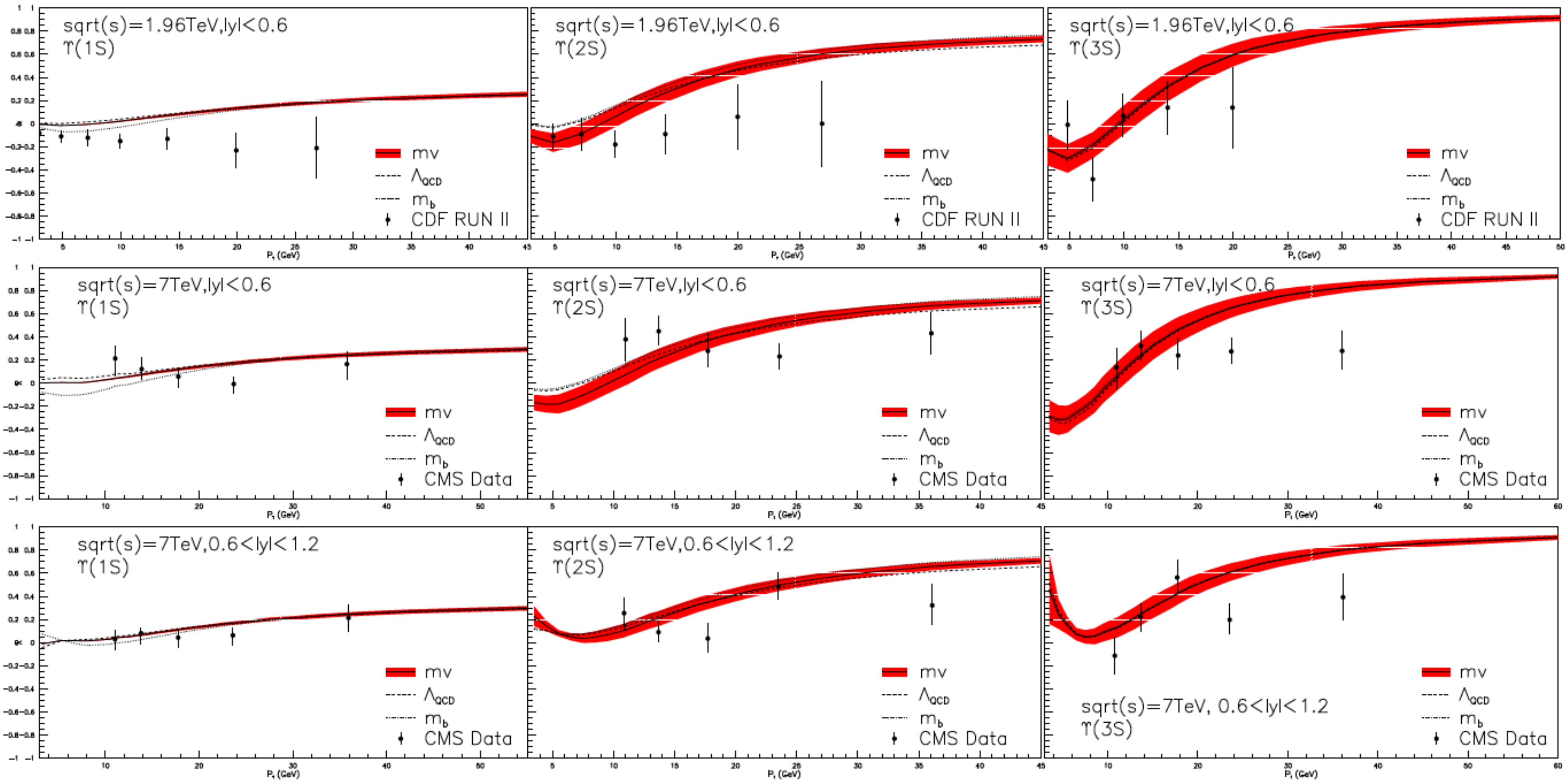
2. Status

FDC is the only existed general ME MCtools of regional community, has been used@BES. Now it had evolved into FDC@Loop.

- The loop amplitude can be obtained analytically.
- The results has been demonstrated to work for low energy physics processes (quarkonium production at ECs and HCs)
- FDC@Loop for high energy processes need some works, i.e. a systematic IR subtraction, the matching/merging at NLO, etc. [In principle, no insurmountable obstacles]

From J.X. Wang & B.Gong (IHEP,CAS)

2. Status



PRL 112, 032001, 2014, by Bin Gong, Lu-Ping Wan, Jian-Xiong Wang and Hong-Fei Zhang

Figure: Polarization parameter λ of prompt $\Upsilon(1S, 2S, 3S)$ hadroproduction in helicity frame

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From J.X. Wang & B.Gong (IHEP,CAS)

2. Status

Sophie: A General ME Generator Created By Zhao Li (IHEP,CAS)

Under development but quite promising

Ambitions:

- High precision: Fixed order calculation for LO, NLO, NNLO, etc.
- Fast: LO (seconds), NLO (minutes), NNLO (hours),... Fully utilizing the computing potential of GPU to handle loop integrals
- Efficient: Fully utilizing the analytic method for helicity amplitudes of spinors
- Flexible for New Physics: Using the UFO model files

From Z. Li (IHEP,CAS)

3. Works for 100 collision ongoing

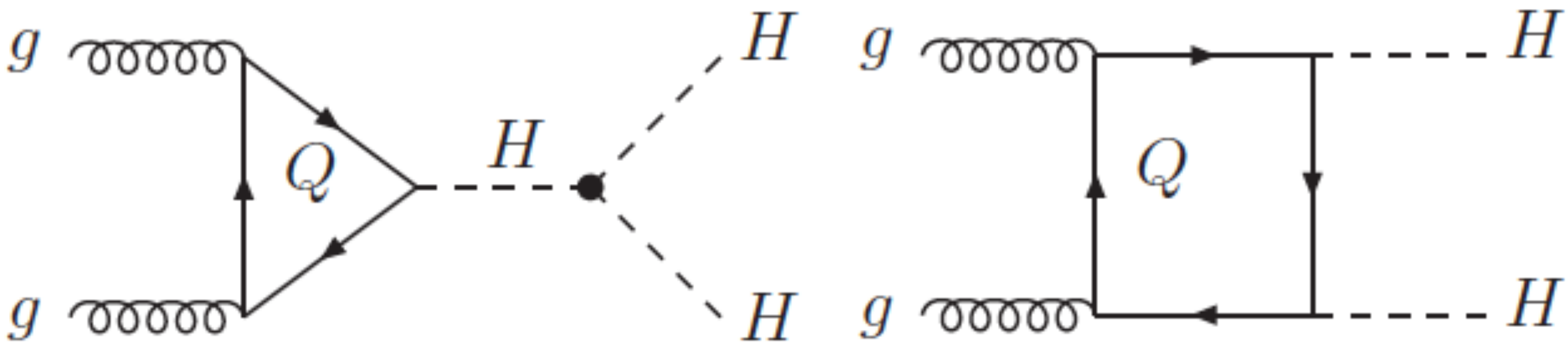
3.1 Connections to trilinear Higgs couplings measurement

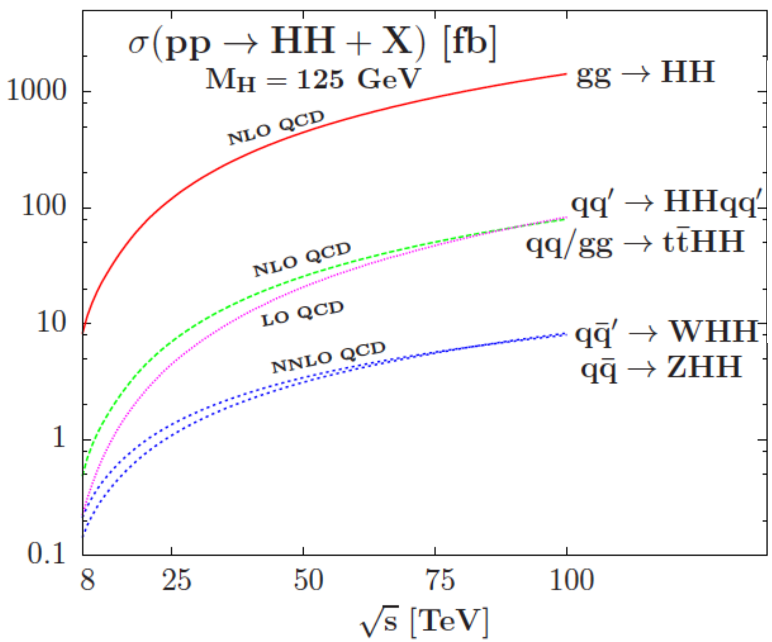
$$V = \frac{1}{2} m_h^2 h^2 + \lambda_3 \, v \, h^3 + \frac{1}{4} \lambda_4 \, h^4$$

$$m_h = 125\text{GeV}$$

Is it the standard model Higgs?
Let's measure them.

3.1 Connections to trilinear Higgs couplings measurement



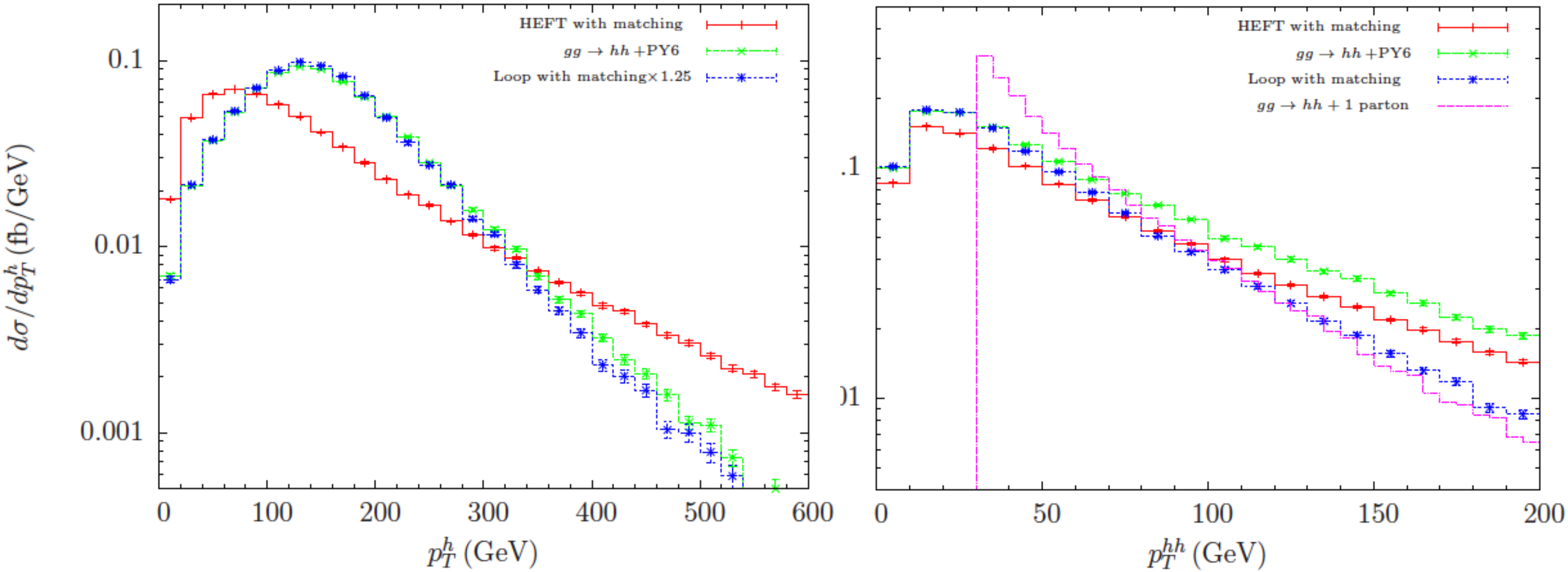


$\sqrt{s}$ [TeV]	$\sigma^{\rm NLO}_{qq'HH}$ [fb]	Scale [%]		PDF [%]		PDF+α_s [%]		Total [%]	
8	0.49	+2.3	−2.0	+5.2	−4.4	+6.7	−4.4	+9.0	−6.4
14	2.01	+1.7	−1.1	+4.6	−4.1	+5.9	−4.1	+7.6	−5.1
33	12.05	+0.9	−0.5	+4.0	−3.7	+5.2	−3.7	+6.1	−4.2
100	79.55	+1.0	−0.9	+3.5	−3.2	+5.2	−3.2	+6.2	−4.1

Nice theoretical works. But…
J. Baglio, et.al. 1212.5581

D.Y. Shao, C.S. Li, H.T. Li, J. Wang, 1301.1245

3.1 Connections to trilinear Higgs couplings measurement



A MC generator for multiHiggs production starts to work

The first fully exclusive accurate prediction for Higgs pair production plus one jet With MLM matching

Qiang Li(PKU), QY, Xiao-Ran Zhao(UCAS), 1312.3830, accepted by PRD.

3.1 Feasibility study@HC

signal: $pp \to hh \to$ w ww*w$^* \to 2j3\ell +$ MET

	Before	Cut 1	Cut 2	Cut 3	Cut 4
signal	71.3634	9.22015	6.59398	4.78135	3.24831
ttw	12771.3	759.15	427.045	89.3584	23.8853
zw	867414	114.272	59.6232	13.4169	3.98163
www	3634.44	148.685	90.5845	13.1526	2.73745
hw	2956.61	99.7478	55.1647	19.1807	6.51472
$\frac{S}{\sqrt{B}}$	0.07578	0.27527	0.26220	0.411347	0.53316

- Cut 1:enlarge Z reconstruct cut: m(e^+, e^-) and m(μ^+, μ^-) are not in [50,120]
- Cut 2:New W reconstruct method: iterate all jets, to find two jets that make mass(h1)+mass(h2) smallest.
- Cut 3:h1 and h2 mass cut
- Cut 4:TMVA

Higgs pair signal search @LHC 14TeV, ongoing works

Qiang Li(PKU), QY, Xiao-Ran Zhao(UCAS)

From M.L. Mangano's talk, 16/Dec/2013, Beijing

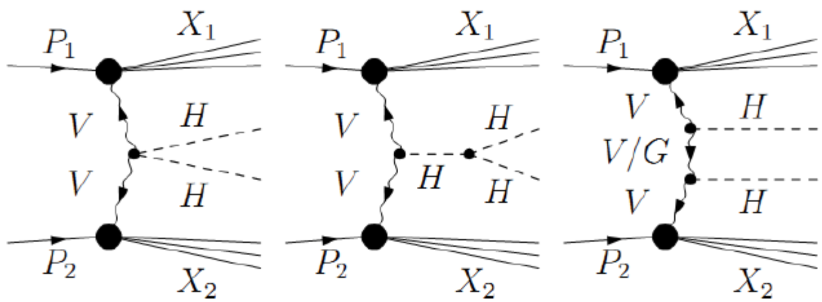
NLO rates **R(E)** = σ(E TeV)/σ(14 TeV)

	σ(14 TeV)	R(33)	R(40)	R(60)	R(80)	R(100)
ggH	50.4 pb	3.5	4.6	7.8	11.2	14.7
VBF	4.40 pb	3.8	5.2	9.3	13.6	18.6
WH	1.63 pb	2.9	3.6	5.7	7.7	9.7
ZH	0.90 pb	3.3	4.2	6.8	9.6	12.5
ttH	0.62 pb	7.3	11	24	41	61
HH	33.8 fb	6.1	8.8	18	29	42
ttW	**0.5 pb**	**3.7**	**4.9**	**8.4**	**12.1**	**15**
ZW[dc]	12 pb	3.0	3.8	6.1	8.7	11.1
tttt	5.3 fb	18.1	32.1	97.7	199.9	345.3
ttww	8.6 fb	9.1	14.2	35.3	64	102

A gain in significance for hh is obvious!

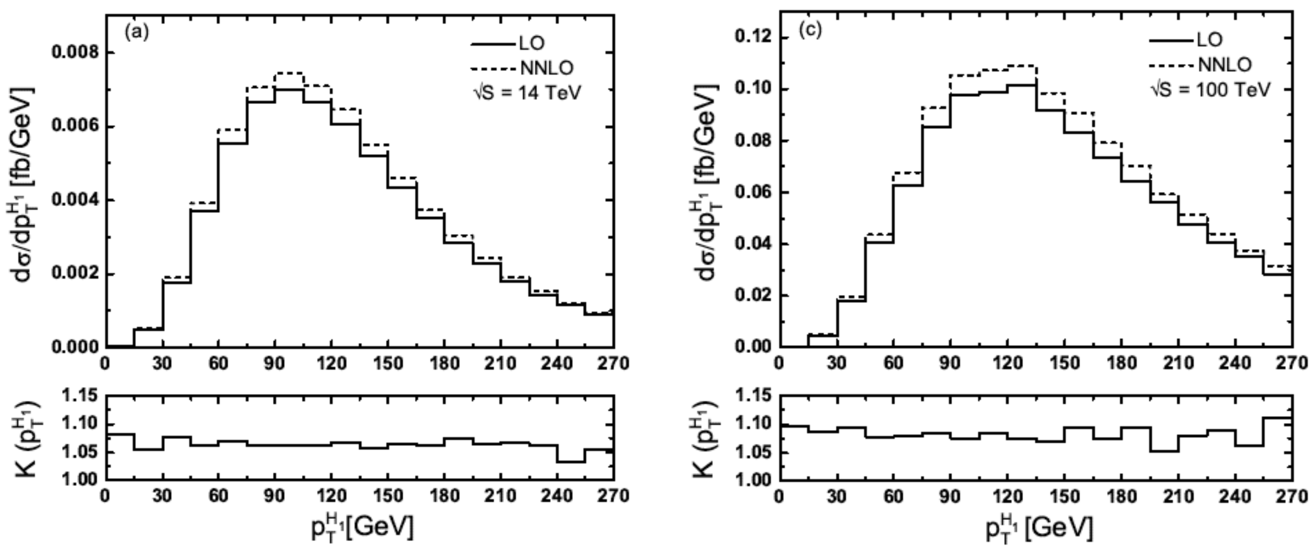
More detailed analysis extended for 100 TeV is ongoing

3.1 A toolkit for VBF@NNLO



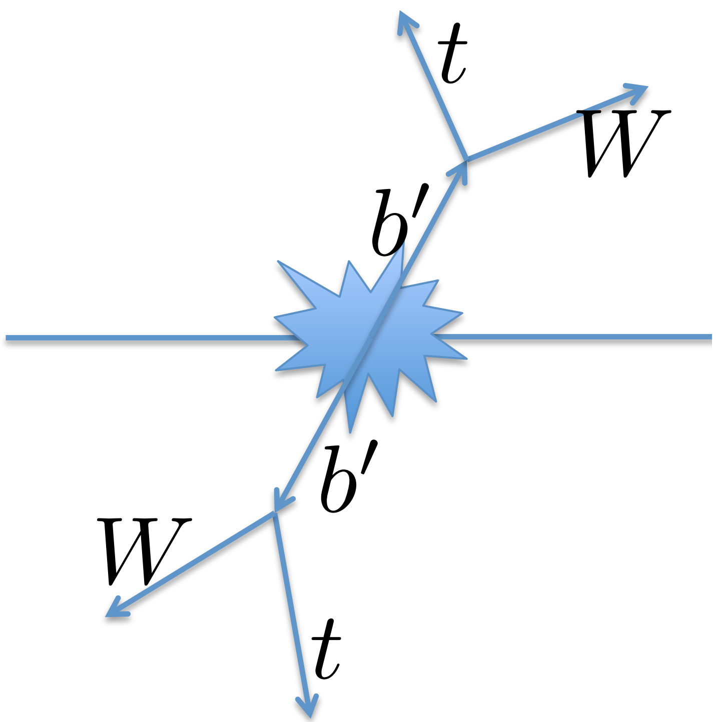
VBF@NNLO

$\sqrt{S}$ TeV	LO [fb]	NLO [fb]	NNLO [fb]
14	$0.977^{+0.192}_{-0.145}$	$1.034^{+0}_{-0.037}$	$1.041^{+0.016}_{-0.006}$
33	$4.614^{+0.159}_{-0.231}$	$4.951^{+0.139}_{-0.202}$	$4.961^{+0.196}_{-0.058}$
100	$18.28^{+1.54}_{-2.50}$	$19.77^{+1.44}_{-1.18}$	$19.75^{+1.36}_{-0.46}$



L.S. Ling, R.Y. Zhang, W.G. Ma, L. Guo, W.H. Li, X.Z. Li [USTC]; 1401.7754

3.2 Connections to BSM



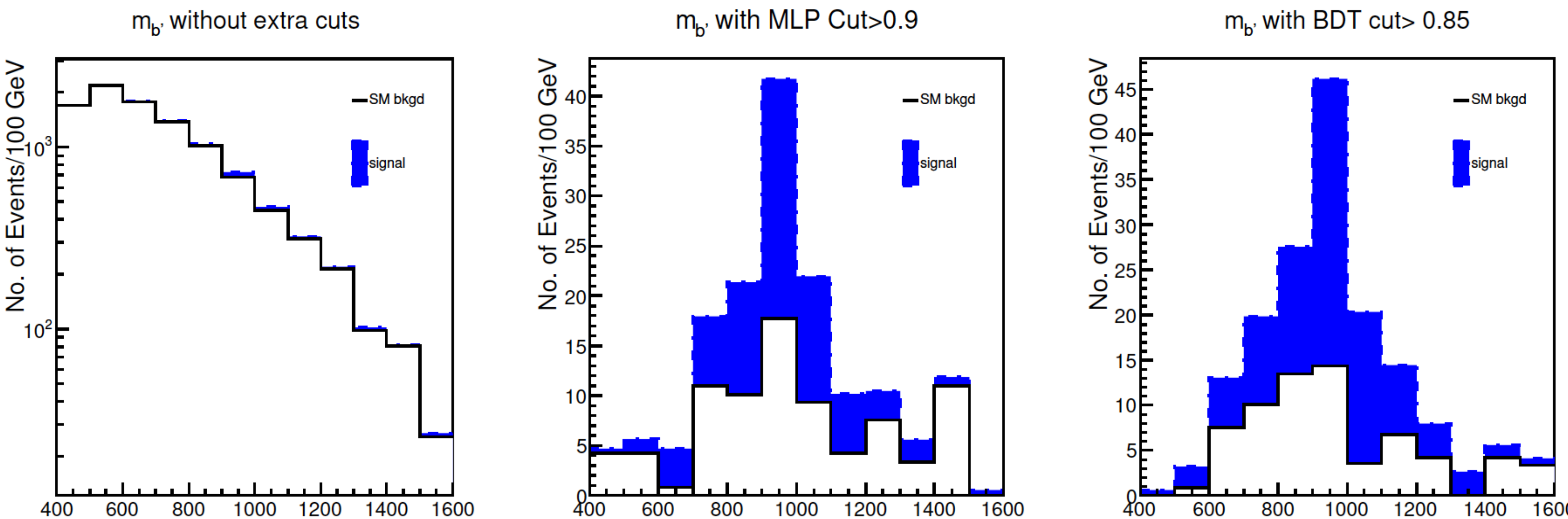
$$p\,p \to b'\;b' \to t\,\bar{t}\,W^+\,W^-$$

$b'\bar{b}'$	$4\ell\,\not{E}\,2j$	$3\ell\,\not{E}\,4j$	$2\ell\,\not{E}\,6j$	$\ell\,\not{E}\,8j$	10 j
Br. $\times 100$ $(\ell = e, \mu, \tau)$	1.0	9.1	28.5	39.3	20.4
Br. $\times 100$ $(\ell = e, \mu)$	0.2	2.4	12.8	26.2	20.4

Hadronic channel is usually challenging due to huge SM background and high combinatorics

Taggers for boosted object could play a role to distinguish signal and background if b' is heavy.

3.2 Connections to BSM



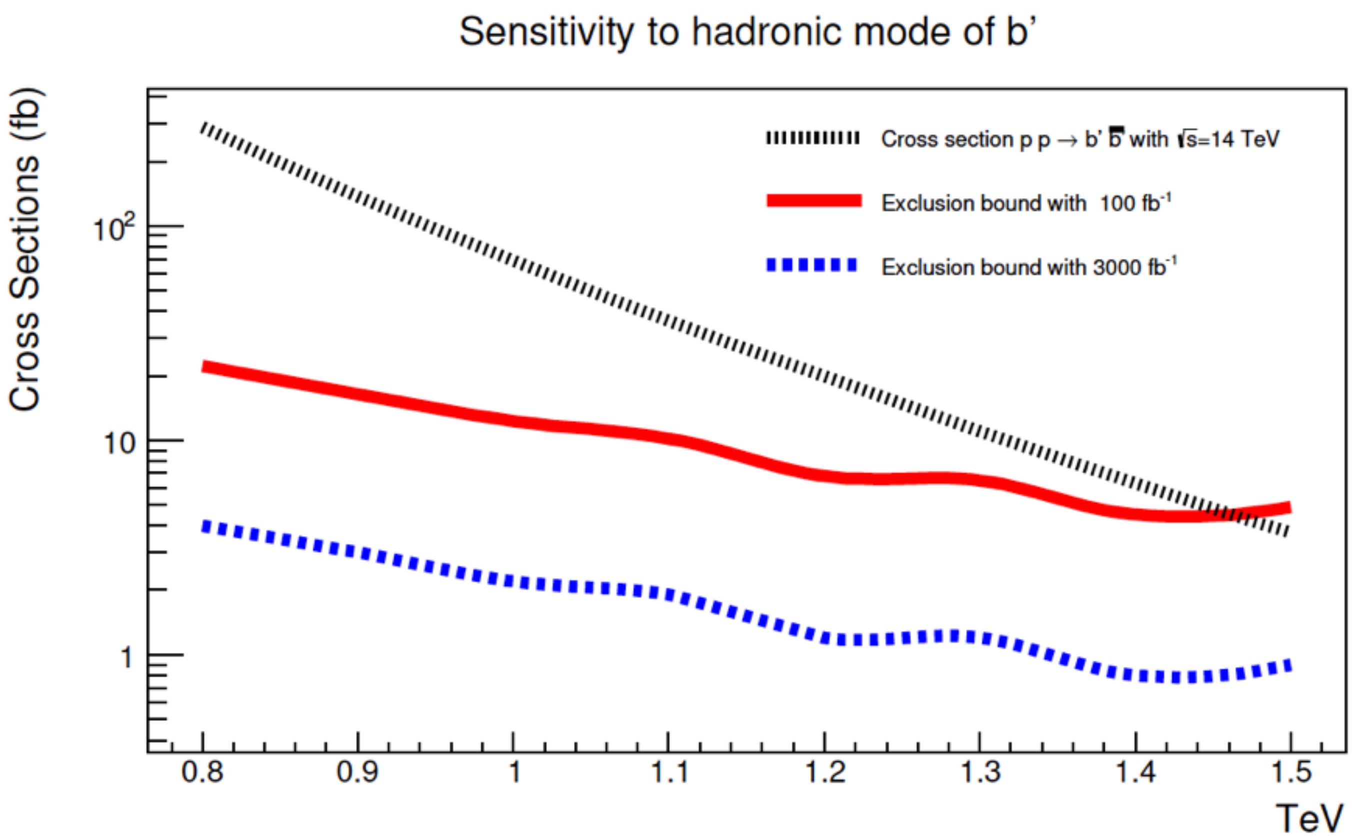
$H_T \geq 1.5\,\text{TeV},$
$n_{tagged} \geq 2$

A show case with $m_b' = 1\text{TeV}$

B' signal search @LHC 14TeV with HEPtop and W taggers

Ji Jiang(ZZU),S. Yang(DLU), QY, Xiao-Ran Zhao(UCAS)

3.2 Connections to BSM

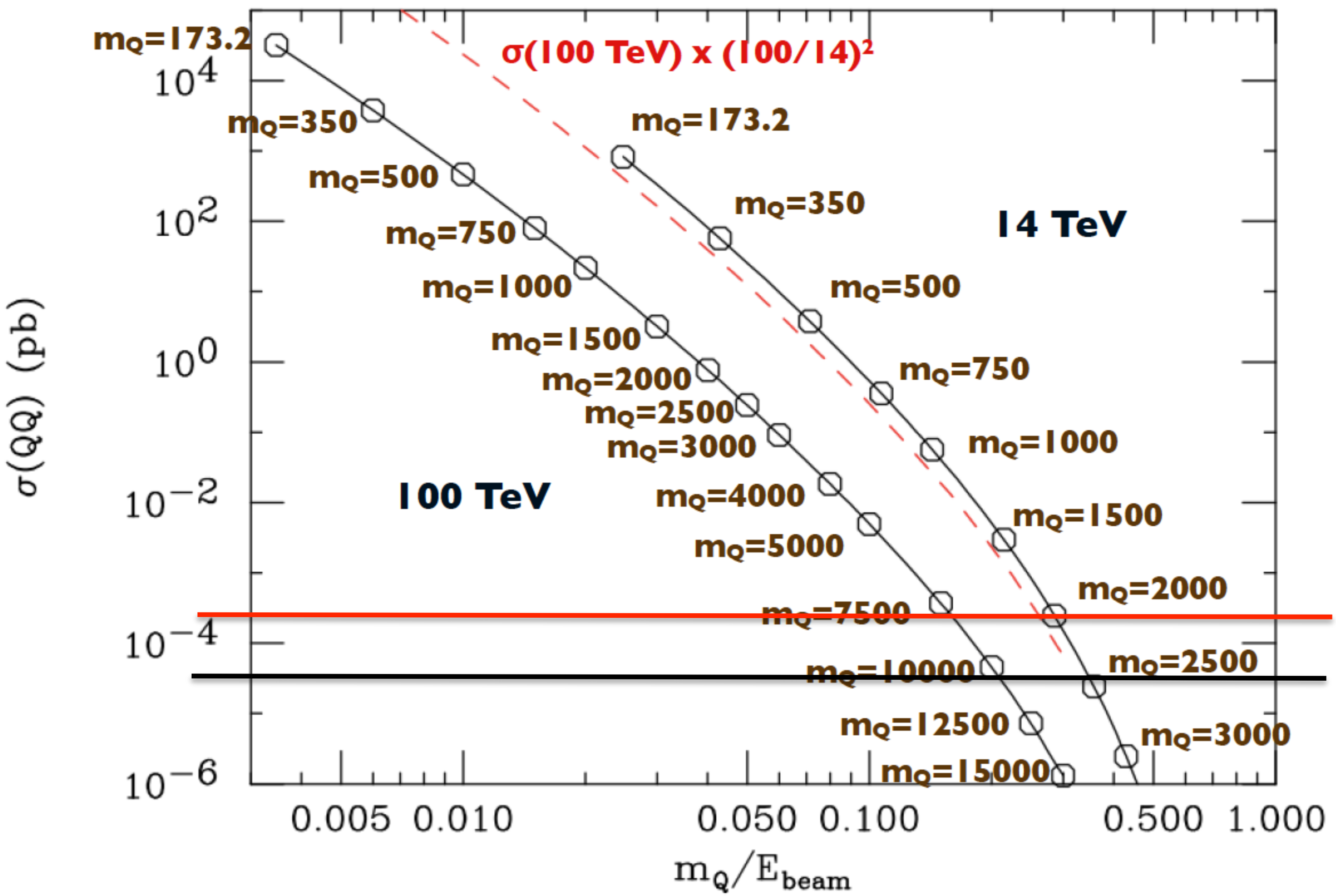


2 TeV b' might be reachable.

B' signal search @LHC 14TeV with top and w taggers ongoing works

Ji Jiang(ZZU),S. Yang(DLU), QY, Xiao-Ran Zhao(UCAS)

3.2 Connections to BSM



8 TeV b' might be reachable for 100 TeV

Even if hadronic mode is considered

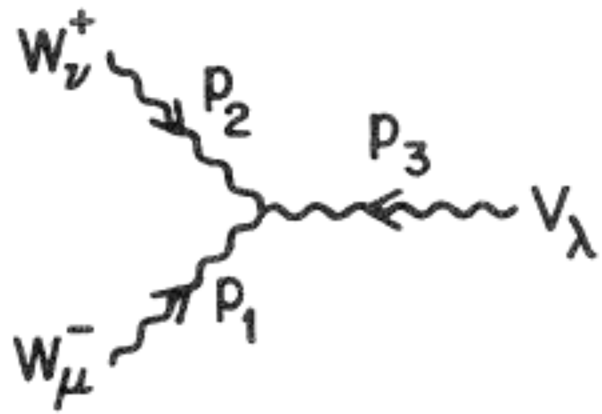
Work ongoing

Further analysis is needed.

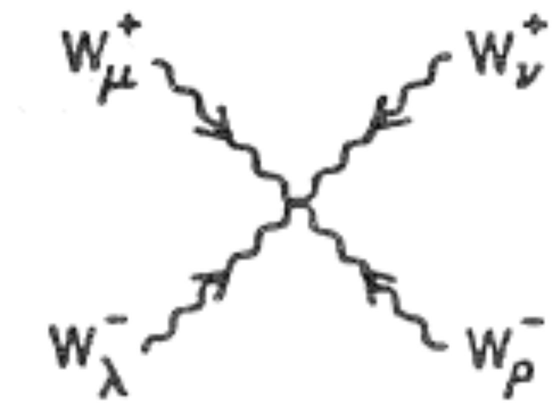
3.3 aQGC measurements

$$\mathcal{L} = -\frac{1}{4} W^a_{\mu\nu} W^{\mu\nu,a} \quad SU_L(2)$$

$$W^a_{\mu\nu} = \partial_\mu W^a_\nu - \partial_\nu W^a_\mu + f^{abc} W^b_\mu W^c_\nu$$

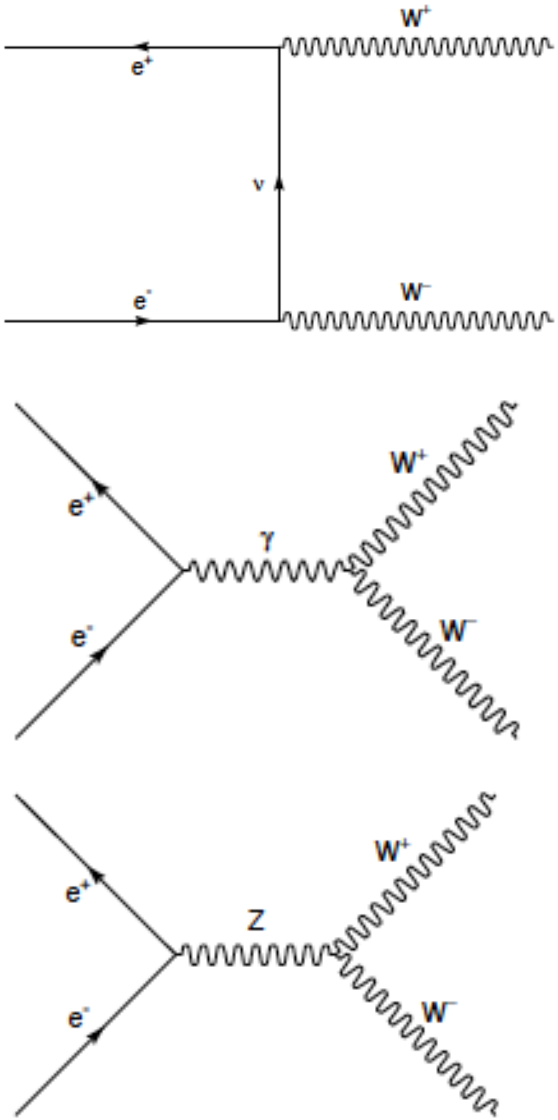


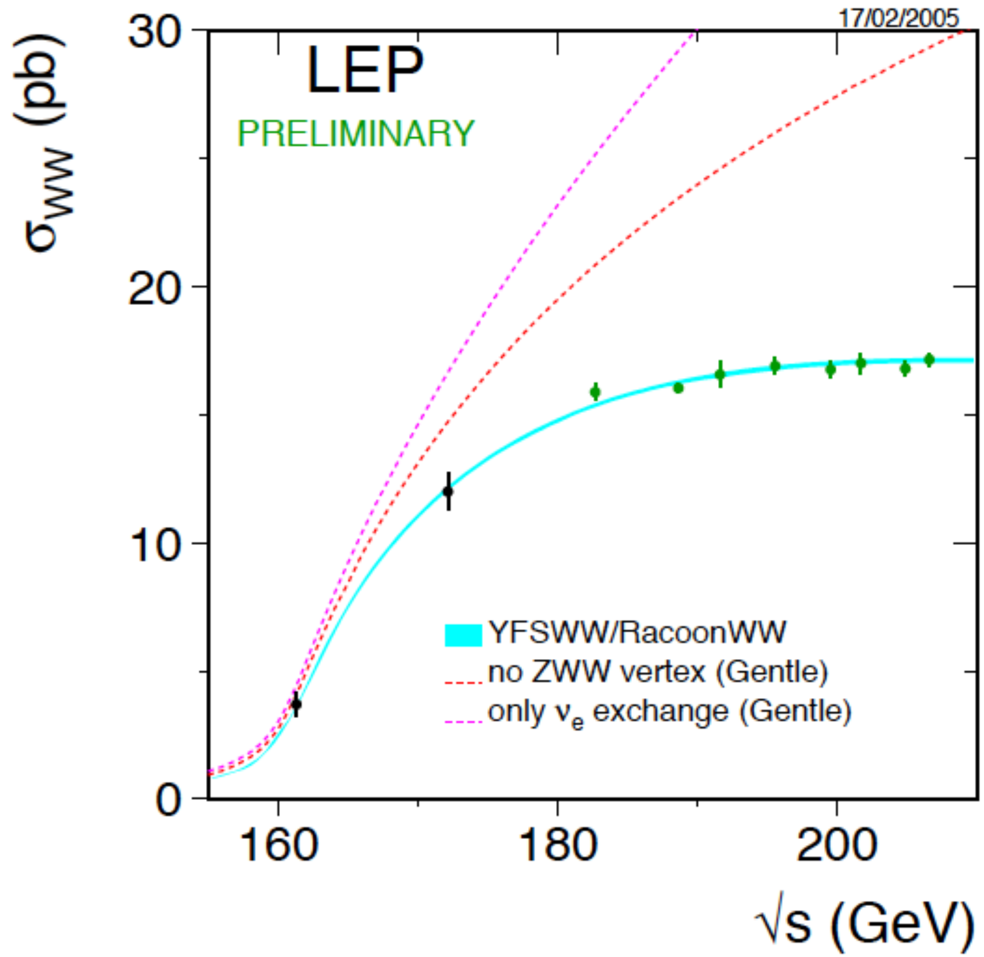
Triple Gauge Couplings



Quartic Gauge Couplings

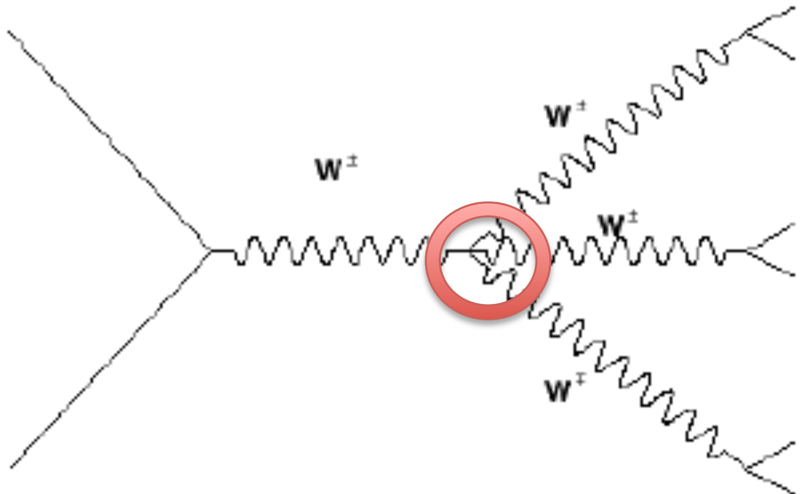
3.3 aQGC measurements





NonAbelian triple Gauge structure has been tested and confirmed!

3.3 aQGC measurements



$$pp \rightarrow \mathrm{W\ W\ W}$$

(b) With (anomalous) QGC

LHC is a good place to test QGC of NonAbelian structure of SU(2)xU(1)!

3.3 aQGC measurements

S1 means only mZ with cut, s2 means same sign same flavor $e^-\mu^+\mu^+$

Processes	Cross section[fb]	Events					
		cut-based					
		Pileup 0		Pileup 50		Pileup 140	
		s1	s2	s1	s2	s1	s2
WWW	2.169	20.96	6.290	19.95	5.821	17.89	5.179
WZ	411.6	421.2	6.86	428.6	6.722	397.6	6.586
$tt\bar{W}$	9,884	33.39	10.34	38.23	11.52	38.76	11.88
ZZ	272.8	40.37	1.091	98.75	1.636	106.9	2.728
$t\bar{t}Z$	6.345	10.82	2.779	12.57	3.464	13.25	3.603
WWZ	0.8487	3.734	1.037	3.734	1.011	3.54	0.9488
significance		0.9220	1.281	0.8223	1.137	0.7512	0.9891

Table 2. Cut flow at the LHC with $\sqrt{s} = 14$ TeV and integrated luminosity of $100\,\mathrm{fb}^{-1}$.

Feasibility study@LHC for aQGC via tri-lepton channel
Pileup mitigates the significance to a certain degree.

Y. Wen, D.N.Yang, QY, Q. Li, Y. Mao

3.3 aQGC measurement

lv+4j @8TeV LHC 20fb-1

cut method	no PileUp, 0.099 sigma,	PileUp 20, 0.085 sigma,
BDT	no PileUp, 0.14sigma,	PileUp 20, 0.11sigma

lv+l'v+2j (OS OF) @8TeV LHC 20fb-1

cut method	no PileUp, 0.21 sigma,	PileUp 20, 0.16 sigma,
BDT	no PileUp, 0.26sigma,	PileUp 20, 0.20sigma

llvv+2J (SS) @8TeV LHC 20fb-1

cut method	no PileUp, 0.81 sigma,	PileUp 20, 0.69 sigma,
BDT	no PileUp, 0.90sigma,	PileUp 20, 0.79sigma

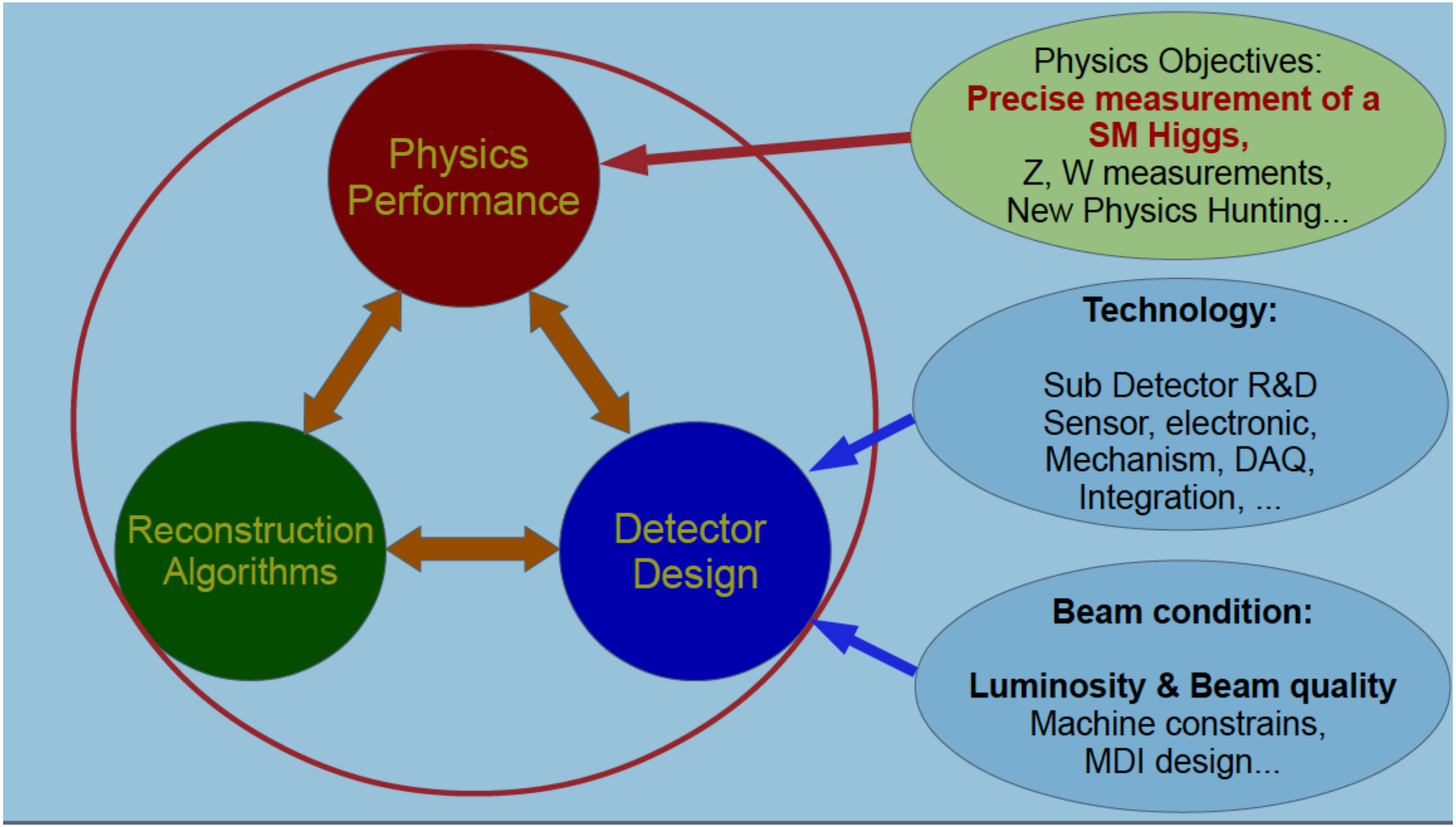
llvv+2J (SS) @14TeV LHC 100fb-1

cut method	no PileUp, 1.55 sigma,	PileUp 20, 1.12 sigma,
BDT	no PileUp, 1.76sigma,	PileUp 20, 1.51sigma

Feasibility study@LHC on SM WWW measurement via Semi-/dileptonic channels aQGC sensitivities and Extension to 100 TeV collision is ongoing

H.L. Qu, Y.W. Wen, D.N. Yang, QY, Q. Li, Y.J. Mao

4. Future plans



From Manqi Ruan(IHEP,CAS)

4. Future plans

A tentative experiment wishlist for CEPC:

1. To understand the theoretical error bars in Higgs branching ratio @CEPC.

2. To understand the prediction of SM beyond tree/1-loop level @CEPC: To interpret the possible observed derivations.

3. New Physics landscape & typical benchmark models: To what extent we can rule out/discover new physics @CEPC.

4. Investigating into a no-lose search program for new physics @CEPC.

High accurate MC tools are needed for serious physics analysis.

Provided by Manqi Ruan(IHEP,CAS)

An accurate MC Event generator for Linear Collider

for Both SM and NP

1. e+e− → Z (→ l+l−) NLO EWK + QED Shower
2. e+e− → ZA, ZZ, ZH, NLO EWK + QED Shower

3. e+e− → bbar, ttbar NLO EWK + QED Shower
   e+e− → bbar, ttbar NLO QCD + QCD Shower

4. e+e− → Z, ZA, ZAA matching, comparing with 1, 2
   urgently needed for $ZH \to ZAA$

5. e+e− → Z NNLO EWK, Z→ l+l− NNLO EWK
6. e+e− → Z → f+f− NNLO QCD

7. AA → HH, ZZ NLO (2 loop)

Grace@Loop, FDC@Loop, Gosam, **Sophie** can be our options.

8. New physics: e.g. effective anomalous operators

9. $e^+e^- \to VVV(W^+W^-Z/\gamma, ZZ\gamma, \cdots)$

A more pragmatic list provided by Qiang Li (PKU)

4. Physics projects for 100 TeV

1 The triple and quartic gauge couplings measurements.

2 The triple and quartic couplings measurements of Higgs Potential.

3 A no-lose search for new particles, say extra neutral Higgs boson, charged Higgs boson, heavy t'/b' search, W'/Z' etc.

4 SUSY searches, signals of sparticles, say DM, stops and gluinos.

Physics target determines what kind of MC tools we need.

4. Long-term Activities

- Implement novel amplitude methods into ME generators
  B. Feng, and J.-X.'s group, Z. Li
- Further develop Sophie and make it work for physics, say $pp \to hh + 2\text{jets}@2$ loop and perform matching@NLO.
  J. Shu, Zhao Li, Q. Li, QY, X.R. Zhao
- Develop MCtools for high energy e^+e^- collisions by taking into account ISR/FSR of EW radiation and Matching
  Zhao Li, Q. Li, QY, X.R. Zhao
- Develop MCtools for hadron colliders, systematically handle IR divergences, perform matching/merging at high order
  Z.G. Si, Q. Li, Jian-Xiong's group
- Provide the interface of Sophie and FDC@Loop to UFO, etc.
  Z. Li, Jian-Xiong's group
- Strengthen connections with other MCtools development groups, like Madgraph, Sherpa, Blackhat, grace, etc.

Synergy of theorists and MC developers is needed.
The interface of CFHEP can help regional MC tool development.

5. Summary

1. Tree-level and few body MC generator tools have grown into their maturity.
2. Regional working group may march into high precision frontier [multiloop and multileg] for well-motivated physics study.
3. CEPC/100 TeV collision [**precision and energy frontier**] offers a unique opportunity [challenge] for regional computing working group.

Thanks

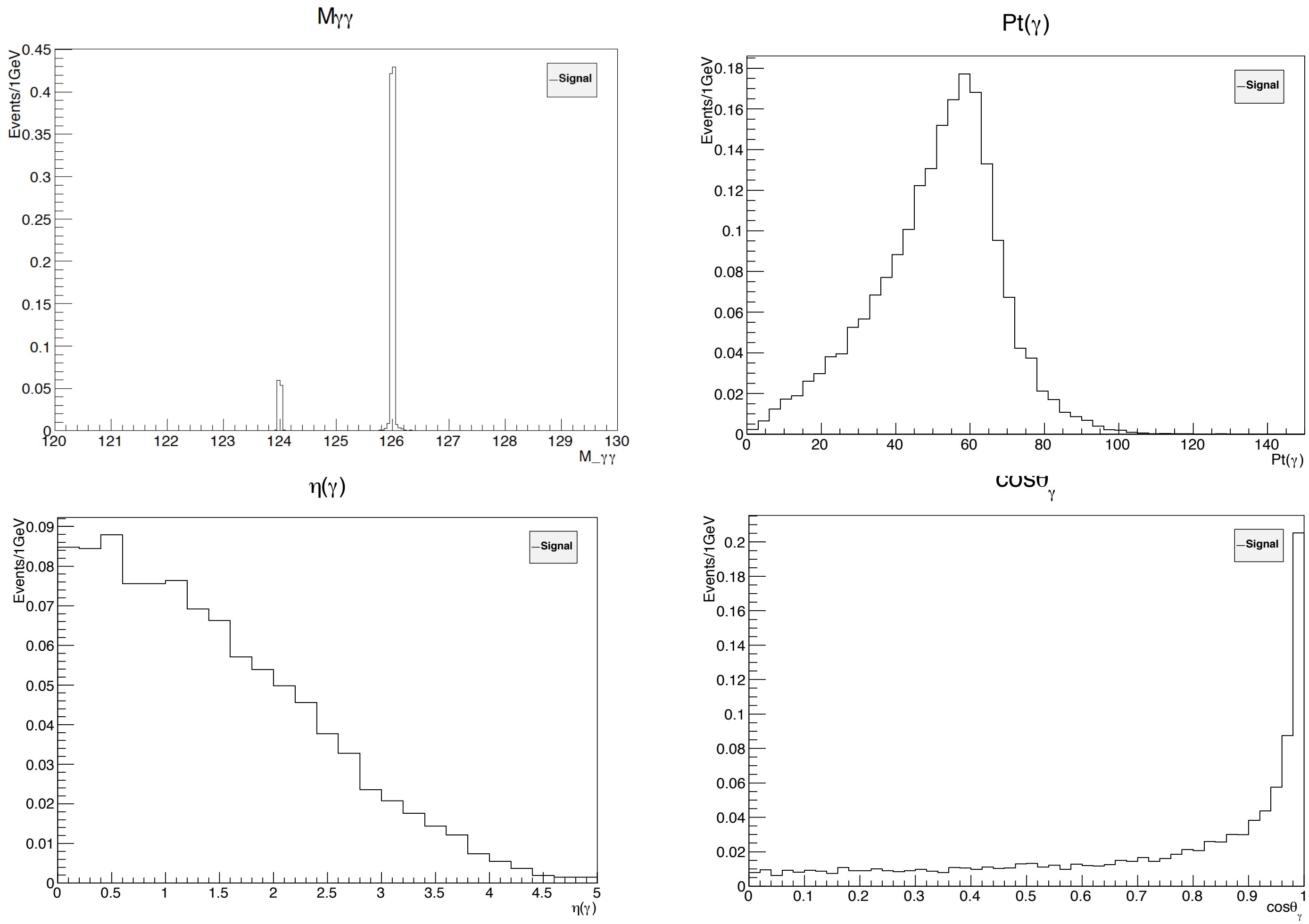
Disclaimers

1. Not a MC package developer, I confine to provide a point of view of users with physics studies.

2. My report is neither complete nor logically self-contained. Please feel free to comment.

Your opinions might greatly help our works!

2.3 A tool small but useful



hH
hA
aA

A MC toolkit for the interference study of g g -> gamma gamma with multiple resonances in the NMSSM

G. M. Chen, Q. Li, QY, X.R. Zhao (ongoing)