Report from Theory: Pre-cdr Status
---Mainly based on parallel talks

朱守华(Shou-hua Zhu)
北京大学（Peking University）

2014/9/13

致歉(sorry)

I am sorry if your favorite part is not mentioned in this status report.

感谢(Acknowledgement)

- 物理想法(idea)
- 写作(writing)
- 讨论(discussion)
- 建议(suggestion)
- 批评(criticism)
- 攻击(attack)

CEPC/SPPC definition

- CEPC (~240GeV Circular Electron-Positron Collider)

- SPPC (50-100 TeV Super Proton-Proton Collider)

Content

- Theory Activities
- Motivations for CEPC/SPPC
- Pre-cdr for each sub-group & main physics ideas
- Summary

Content

- Theory Activities
- Motivations for CEPC/SPPC
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8 working groups

1. SM tests (conveners: Qing-hong Cao/Li-lin Yang/Zhao Li/Chong Sheng Li)
2. Higgs Physics (Hong-jian He/Shou-hua Zhu/Tao Liu)
3. BSM: SUSY(Tianjun Li/Jin-min Yang)
4. BSM: Non-SUSY(Qi-shu Yan/Jing Shu/Wen-Gan Ma/Yi Liao/Wei Liao)
5. Flavor Physics(Cai-Dian Lu/Zong-Guo Si)
6. TeV Cosmology(Xiao-jun Bi/Yu-Feng Zhou)
7. Heavy Ion(Xin-nian Wang/Qun Wang)
8. MC tools(Qi-shu Yan/Jian-Xiong Wang)

Brief History (1)

- 2012/11/7, the theory working group formed
- 2012/12/20, first group meeting at Tsinghua U
- 2013/8/25, small scale meeting at Dalian (TeV working group workshop)
- 2013/9/14, Kick-off meeting, adding “flavor” and “TeV cosmology” working groups
- 2013/11, second group meeting at Peking U
- 2013/12/16, preliminary report
- 2014/1, adding “heavy ion” working group
- 2014/2/24-25, 1^{st} CFHEP symposium

Brief history (2)

- 2014/5/19, TeV Working group Workshop, Guangzhou, open discussion on CEPC/SPPC, and round-table meeting for pre-cdr
- 2014/6/15, Mini-workshop on LHC physics, Xi-an, round-table meeting for pre-cdr
- 2014/8, 2st CFHEP symposium
- 2014/9, 4th CEPC workshop, Shanghai

Status of Pre-cdr

- Framework fixed: Executive summary+ subgroup reports, 50-70 pages
- International
- Keeping updating each part

Activities in Shanghai Meeting

- Went through Pre-cdr each part one-by-one
- Almost fixed the contents
- How to merge the contents into a coherent whole
- Timeline for pre-cdr

Content

Motivation(I): Test new type interactions

1. Well-tested gauge interactions (strong, electroweak can be excellently descried)

2. Yukawa interaction (New type interaction, fermion mass generationflavor problem…)

3. Higgs self-interaction-h^3 and h^4 couplings (Higgs mass generation, order of electroweak phase transition…)

Motivation(II): Observations

- **Dark matter (DM candidate, new symmetry…)**
- **Baryon Asymmetry(Higgs self-interaction, CP-Violation…)**
- **Inflation (Higgs related?)**
- **…**

Motivation(III): Theoretical

- **Too many parameters in SM (origin of electro-weak symmetry breaking, CPV, flavor…)**
- **Naturalness (new strong interaction, supersymmetry, extra-dimension…)**
- **+gravity (insight into space-time and quantum theory)**
- **…**

Motivation(IV): Common sense

1. New physics object --- scalar particle (Small Apple of particle physics): Need to measure its properties

2. Go to higher energy and smaller distance: Is this single reason enough?

Content

Theory Activities

Motivations for CEPC/SPPC

Pre-cdr for each sub-group & main physics ideas

Summary

Executive summary

p1 by Nima

The discovery of the Higgs boson at the Large Hadron Collider (LHC) completed our understanding of 20th century physics. Fundamental physics now finds itself at one of the most exciting crossroads in its history. The central questions today are the most profound ones that have been posed in decades, related to the ultimate origins of the elementary particles and of space-time itself. Many of these questions are intimately connected with the Higgs particle, which is unlike any elementary particle we have seen before, appearing to be far more point-like than naturally expected on theoretical grounds.

Major new input from experiments is needed for progress. The future of fundamental physics on the 20-50 year timescale hinges on starting a huge new accelerator complex that can take us at least one order of magnitude beyond the ultimate reach of the LHC.

A remarkable proposal from China is to house a huge new accelerator in an approximately 100 km circular tunnel. In the first stage, the machine would collide electrons and positrons, thereby producing millions of Higgs particles and measuring its properties to fantastic sub-percent level precision, providing vital clues to its microscopic structure. In the second stage, the machine would collide protons at energies almost 10 times more powerful than the LHC. This will allow us to hunt for new fundamental particles 10 times heavier than we can possibly produce with the LHC, and new particles the LHC may produce in small numbers will be produced with a 1000 times higher rate, giving us a powerful window into the quantum-mechanical vacuum of our universe with 100 times greater sensitivity than ever before.

It would be a boon for physics to actively engage the ocean of Chinese talent into the field. The scientific and engineering challenges involved in building the machine would be a major stimulus to the development of Chinese science and technology- work in this subject is the ideal training ground for learning to attack difficult, long-term problems in technical fields, fostering skills sure to be of paramount importance in the coming decades. At the same time, thousands of the world's most talented physicists and engineers would flock to China to enthusiastically join in the effort.

Over the centuries, the quest to understand the laws of Nature at the deepest level has been one of the noblest and most consequential aspirations of humanity. By building this "Great Collider", China will catapult into global leadership of fundamental physics in the 21st century.

…In the first stage… measuring its (Higgs particles) microscopic structure. In the second stage…hunt for new fundamental particles 10 times heavier than we can possibly produce with the LHC, and new particles the LHC may produce in small numbers will be produced with a 1000 times higher rate…

Higgs subgroup

Current Higgs Report (v.8)

Preliminary

Welcome more inputs and more contributors + authors !

Higgs Physics at the CEPC-SPPC (for Pre-CDR)

Ning Chen,[a] Hong-Jian He,[a,b,*] Tao Liu,[c,*] Zuo-Wei Liu,[a,] Felix Yu,[d,e,] Shou-Hua Zhu,[b,f,*] & other members (*add*)

[a] *Institute of Modern Physics and Center for High Energy Physics, Tsinghua University, Beijing, 100084, China*

[b] *Center for High Energy Physics, Peking University, Beijing 100871, China*

[c] *Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong*

[d] *Theoretical Physics Department, Fermi National Accelerator Laboratory, P. O. Box 500, Batavia, IL 60510, USA*

[e] *PRISMA Cluster of Excellence and Mainz Institute for Theoretical Physics, Johannes Gutenberg University, 55099 Mainz, Germany*

[f] *Institute of Theoretical Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China*

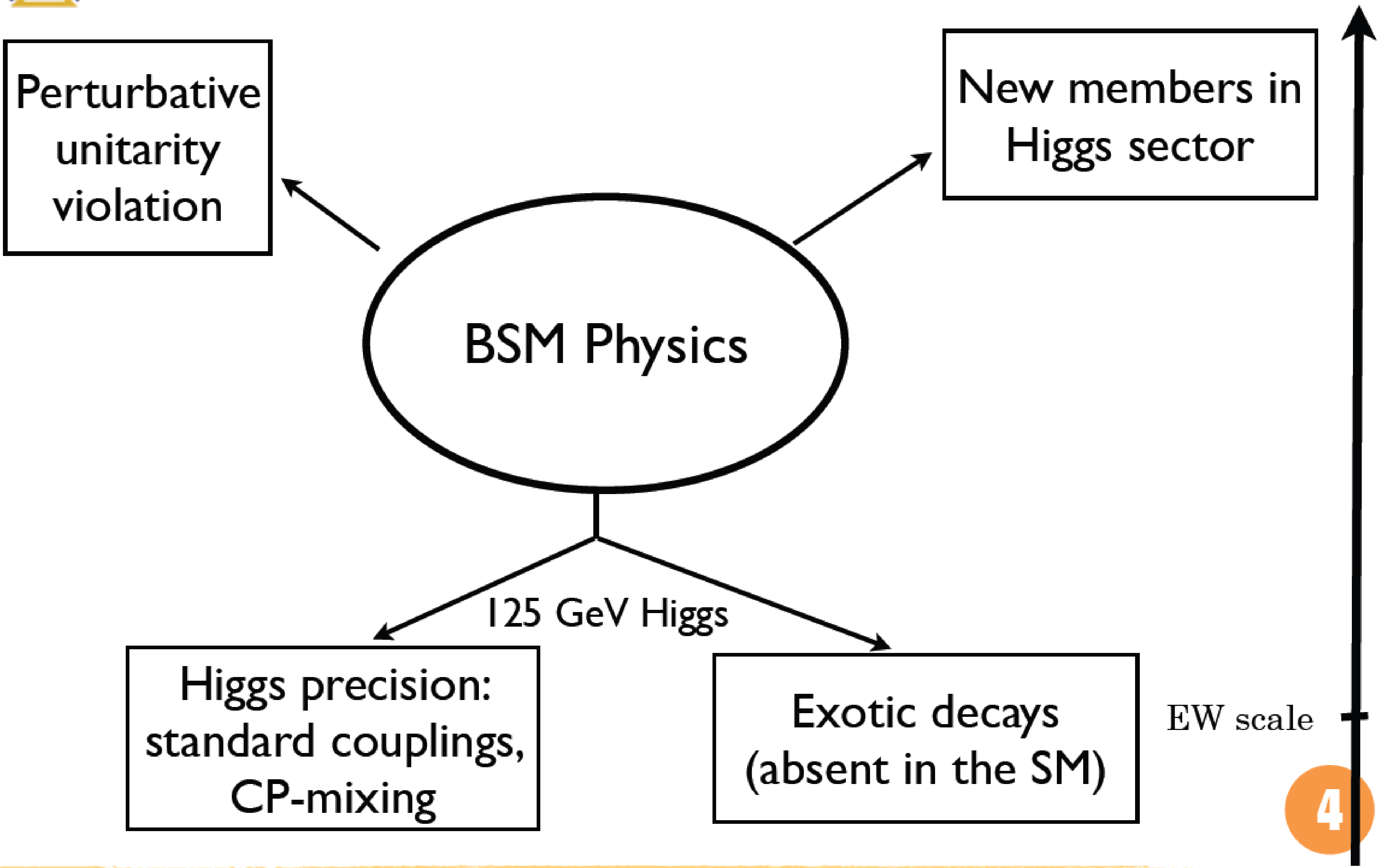
[*] *Conveners*

Abstract:

In this report, we survey Higgs physics in the SM and beyond, review the current measurements of Higgs physics at the LHC, and present the potential studies of Higgs physics at the Circular Electron-Positron Collider (CEPC) and Super Proton-Proton Collider (SPPC).

Contents

Implications for Higgs Collider Phenomenology



Sensitivities of Testing Higgs Couplings at LHC(300/fb), HL-LHC(3/ab), CEPC(1, 3,10/ab)

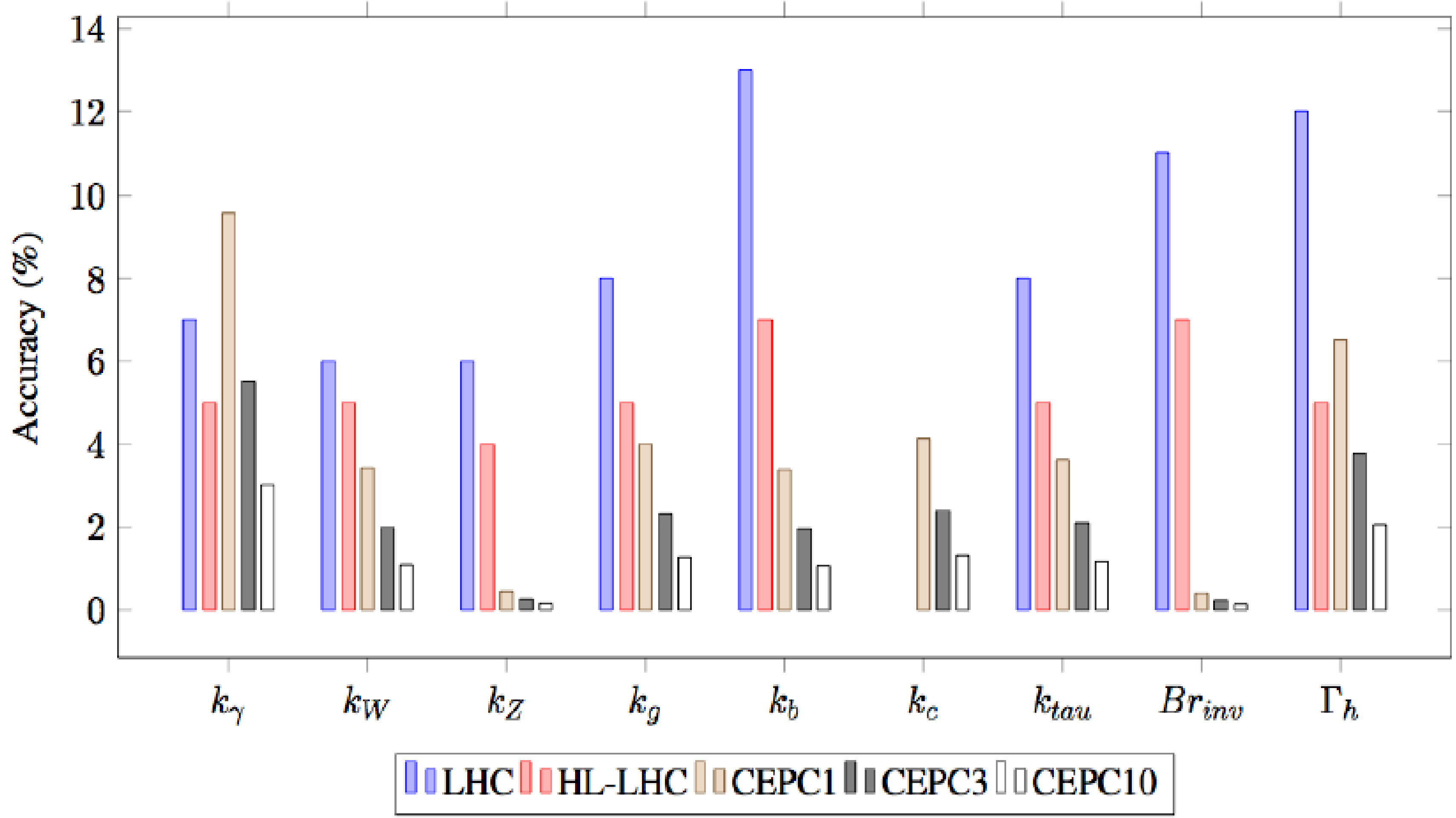


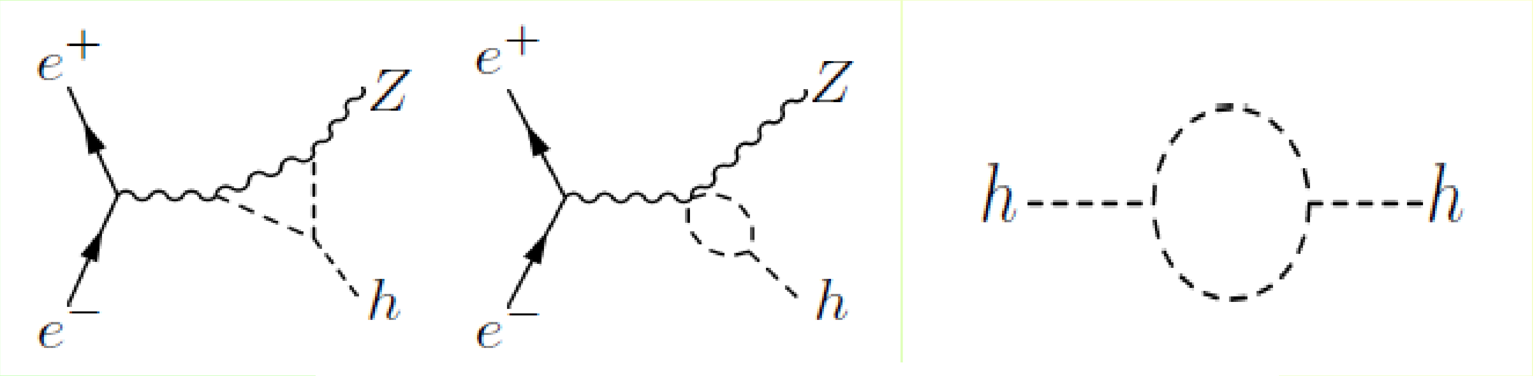
Figure 7. Estimated accuracies of measuring Higgs couplings at the LHC, HL-ILC, and the CEPC

Theory Predictions for Modifications

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$< 1.5\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

Table 3-1. *Generic size of Higgs coupling modifications from the Standard Model values in classes of new physics models: mixing of the Higgs boson with a singlet boson, the two-Higgs Doublet Model, the Minimal Supersymmetric Standard Model, models with a composite Higgs boson, and models with a heavy vectorlike top quark partner. For these estimates, all new particles are taken to have $M \sim 1$ TeV and mixing angles are constrained to satisfy precision electroweak fits.*

Can Circular e^-e^+ (240) Probe h^3 Coupling?



$$\delta_\sigma = \frac{\sigma_{\delta_{h\neq0}}(e^+e^- \to hZ)}{\sigma_{\Delta_h=0}(e^+e^- \to hZ)} - 1 = 2\Delta_Z + 0.014\Delta_h.$$

Colliders	CEPC(1ab^{-1})	CEPC(3ab^{-1})	CEPC(10ab^{-1})
$\delta_\sigma(1\sigma)$	1.0%	0.6%	0.3%
$\Delta_h(1\sigma)$	71%	41%	21%

Table 4. The accuracy in measuring $|\Delta_h|$ at the CEPC.

- **Recall: HL-LHC probes h^3 to 50%. ILC500 probes h^3 to 83%.**

Probing Higgs CPV Couplings at CEPC

Colliders	LHC	HL-LHC	CEPC(1ab^{-1})	CEPC(3ab^{-1})	CEPC(10ab^{-1})
Accuracy(1σ)	25°	8.0°	5.5°	3.2°	1.7°

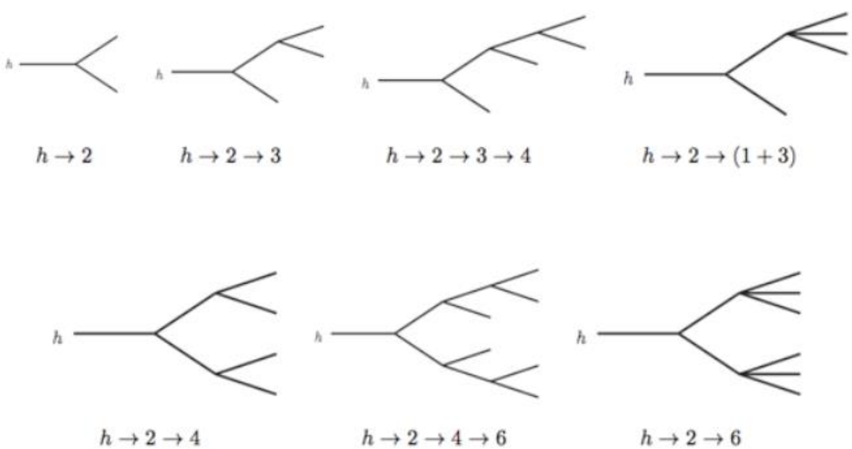
Table 6. The accuracy in measuring Δ, the CPV phase in Higgs coupling with $\tau^+\tau^-$, at the 14 TeV LHC, HL-LHC and the CEPC. Here 70% τ_h efficiency is assumed for the LHC and the HL-LHC.

Colliders	LHC	HL-LHC	$e^+e^-(0.25ab^{-1})$	Target (theory)
VVh	4×10^{-4}	1.2×10^{-4}	7×10^{-4}	$< 10^{-5}$

H(125) exotic decay

(2) Many Topologies

- If the initial exotic decay of the 125 GeV Higgs is 2-body, there are many possibilities
- Collider signature can be classified into three cases: purely invisible, semi-invisible and visible



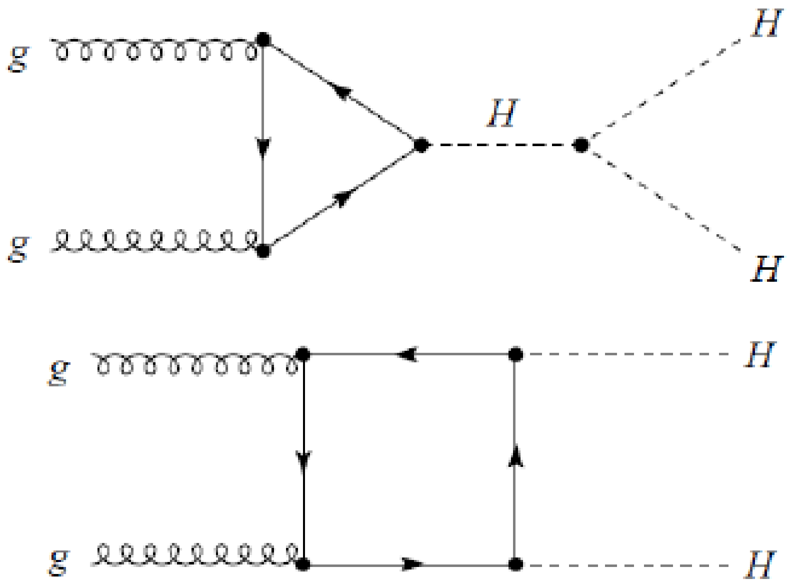
$h \to$ MET	$h \to Z_D Z_D \to 4l$
$h \to 4b$	$h \to \gamma$+MET
$h \to 2b2\tau$	$h \to 2\gamma$+MET
$h \to 2b2\mu$	$h \to 4l$+MET
$h \to 4\tau$, $2\tau 2\mu$	$h \to 2l$+MET
$h \to 4j$	$h \to$ one lepton jet
$h \to 2\gamma 2j$	$h \to$ two lepton jets
$h \to 4\gamma$	$h \to bb$+MET
$h \to ZZ_D \to 4l$	$h \to \tau\tau$+MET

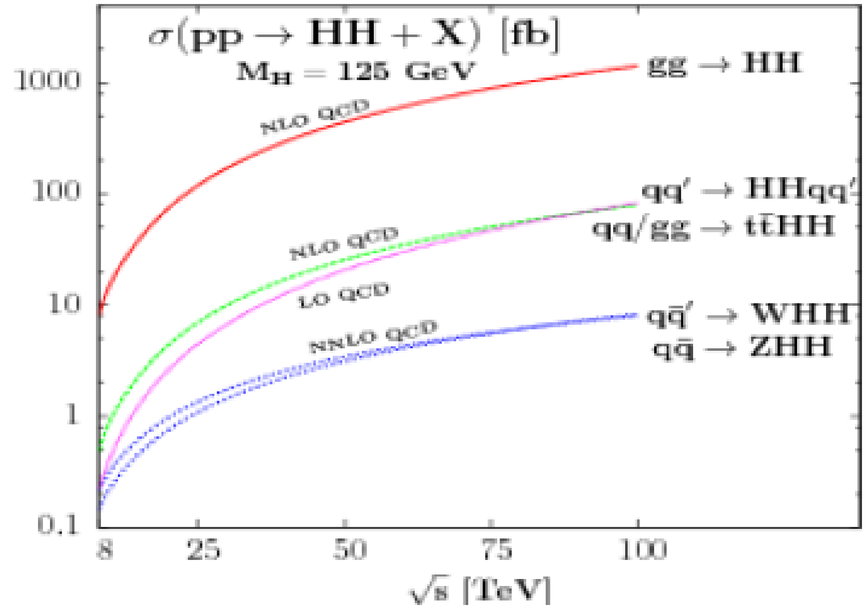
SPPC

NLO rates $\mathbf{R(E)} = \sigma(E\ \text{TeV})/\sigma(14\ \text{TeV})$

	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

Testing Higgs Self-Couplings
LHC(14TeV) vs pp(50-100TeV)





pp → hh + X → bbγγ

- LHC(14TeV, 3/ab) probe h^3 coupling with 50% accuracy.
- pp(100TeV, 3/ab) probe h^3 coupling with 8% accuracy.

W. Yao, Snowmass-2013 (arXiv:1308.6302)

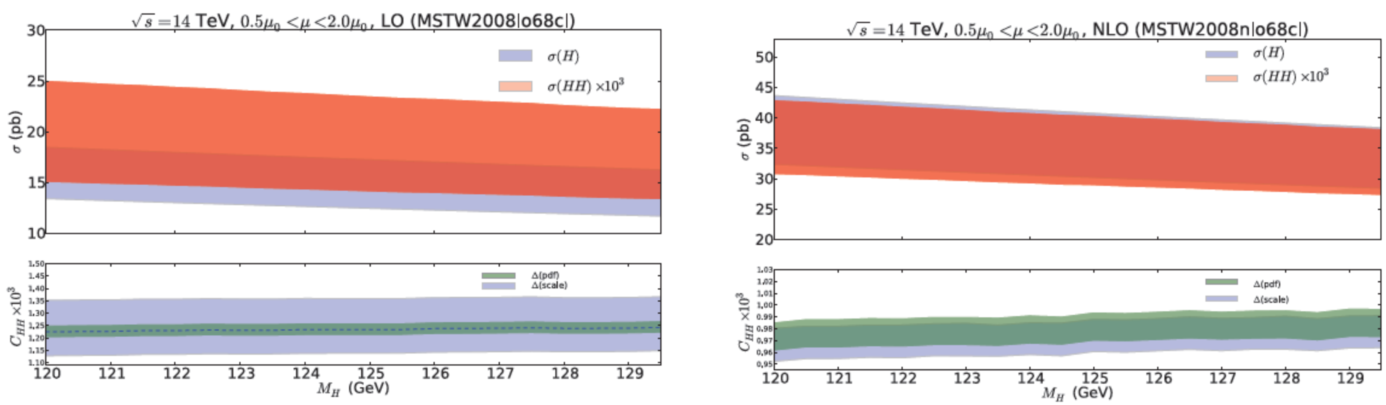
SPPC对于Higgs自耦合的测量

Higgs Self-coupling

Li Lin Yang

$$C_{HH} = \frac{\sigma(pp \to HH)}{\sigma(pp \to H)}$$

$\frac{2}{1}$ method



14TeV $y_t = y_t^{\mathrm{SM}}$

Channel	600 fb^{-1} (2σ)	600 fb^{-1} (1σ)	3000 fb^{-1} (2σ)	3000 fb^{-1} (1σ)
$b\bar{b}\tau^+\tau^-$	(0.22, 4.70)	(0.57, 1.64)	(0.42, 2.13)	(0.69, 1.40)
$b\bar{b}W^+W^-$	(0.04, 4.88)	(0.46, 1.95)	(0.36, 4.56)	(0.65, 1.46)
$b\bar{b}\gamma\gamma$	(−0.56, 5.48)	(0.09, 4.83)	(0.08, 4.84)	(0.48, 1.87)

To achieve same sensitivity

L/3.4 (50TeV)

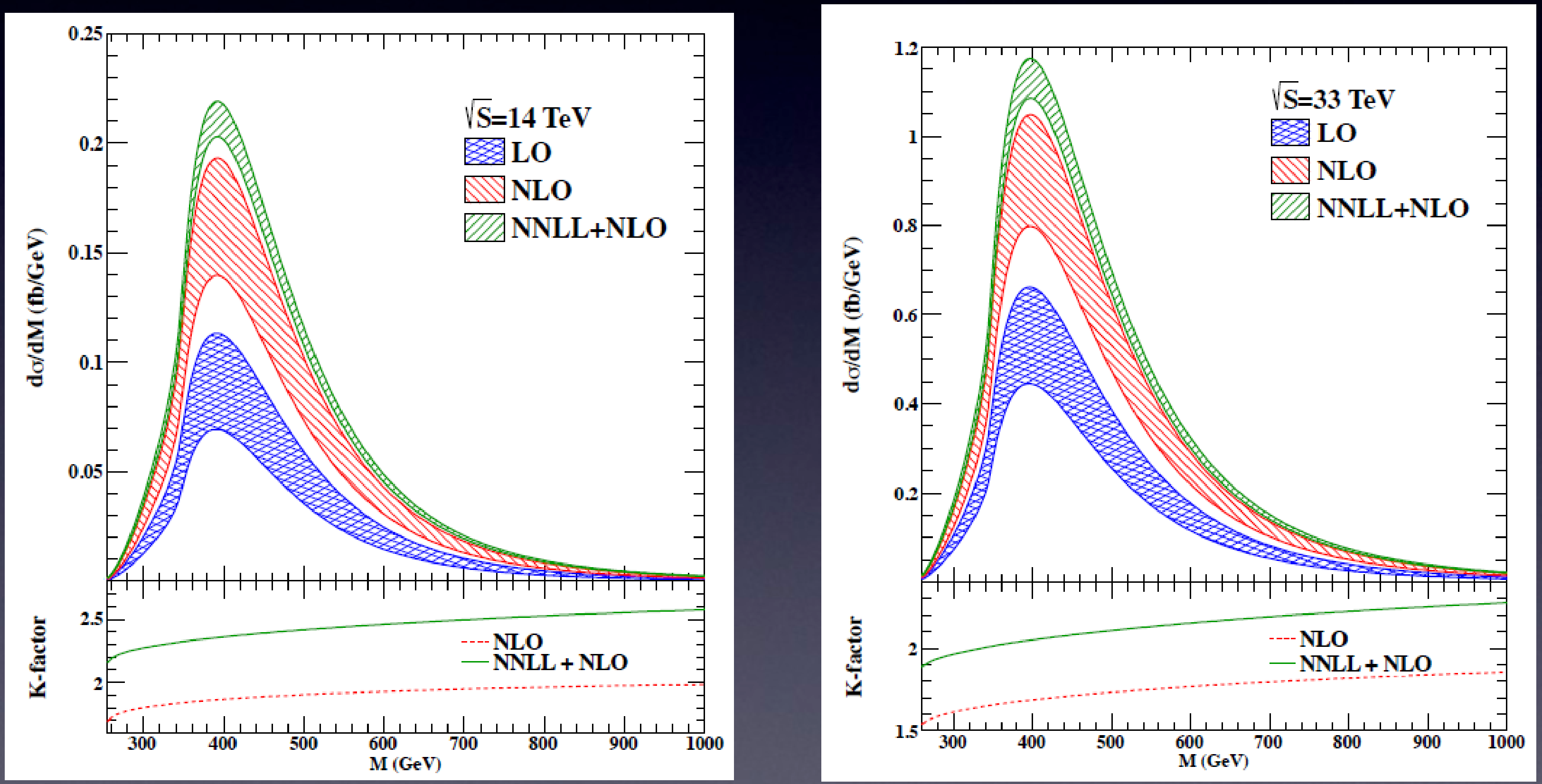
L/5.8 (100TeV)

Higgs Self-coupling

Threshold resummation effects at the NNLL

Ding Yu Shao, Chong Sheng Li, Hai Tao Li, Jian Wang, JHEP07(2013)169

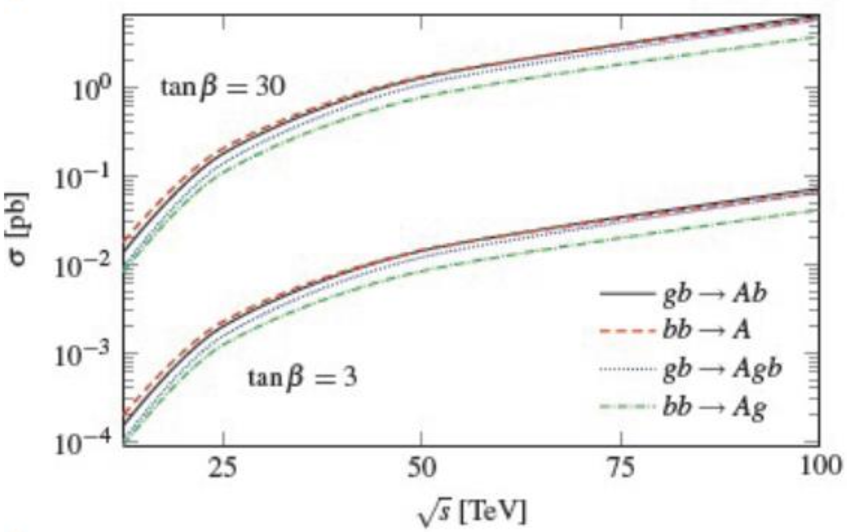
Also see 1401.1101

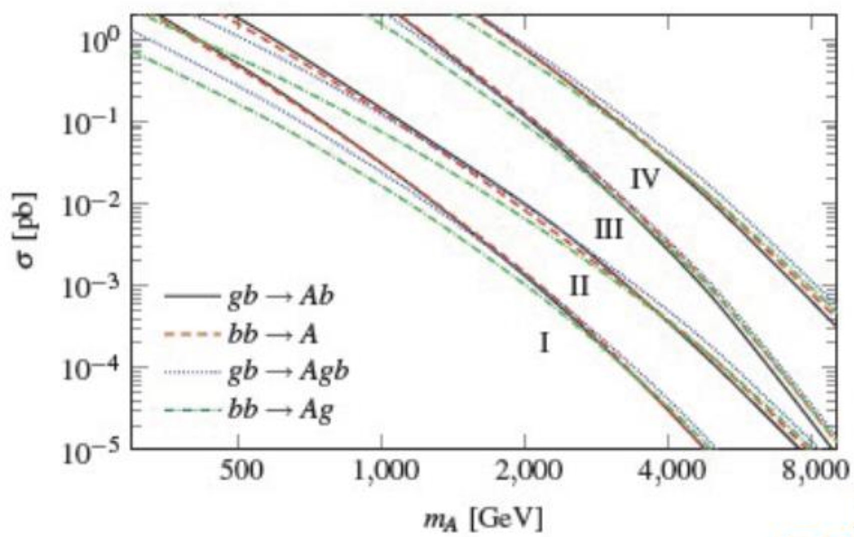


Scale Error ~ 8%, PDF + alphas Error ~10%

SPPC & extra Higgs bosons

- Can be electrically neutral, singly charged, doubly charged. The SPPC can play a role in performing searches over larger possible mass range!
- Using the MSSM as an example, the production cross section of the CP-odd Higgs boson is enhanced by roughly two orders at the SPPC, compared with the LHC.

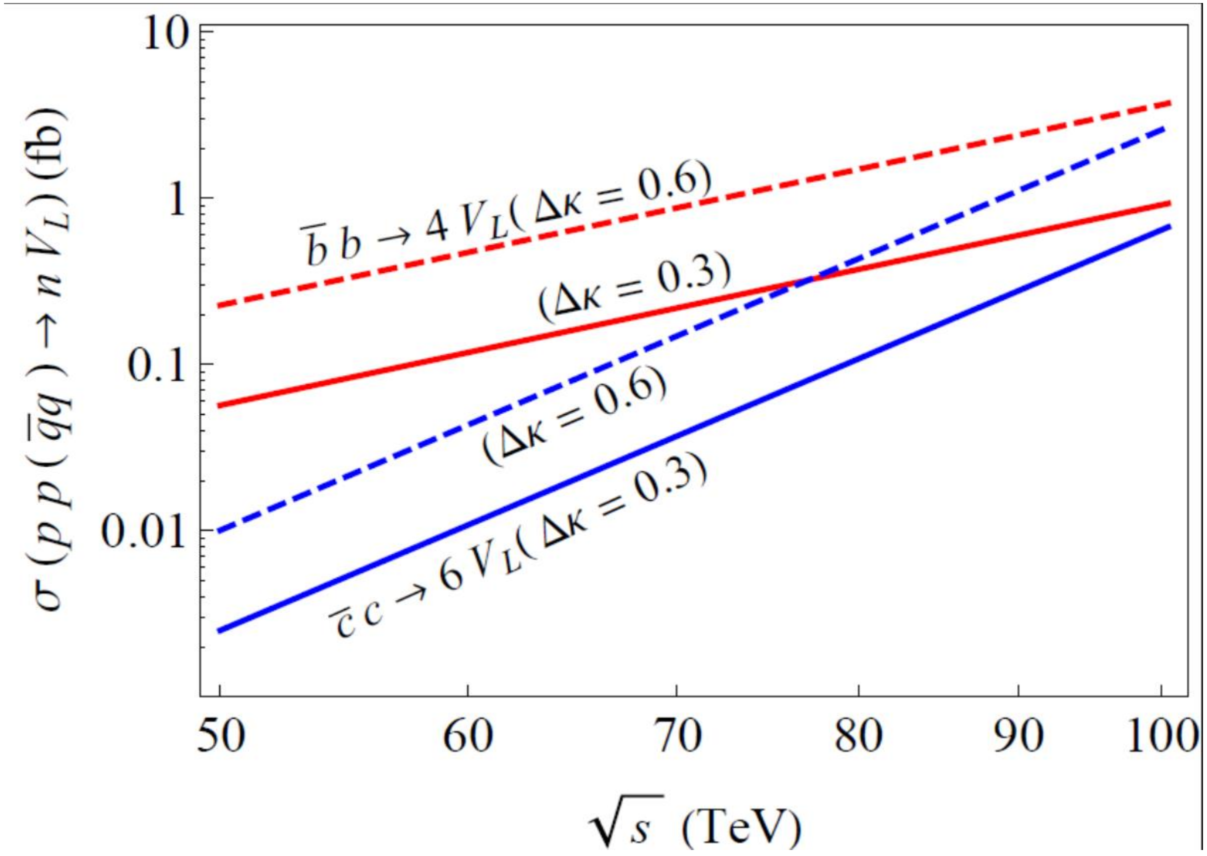




Hajar, Liu

Flavor scale： Next scale？

- $\mathbf{Y_f = \frac{\sqrt{2}}{v} M_f(1 + \Delta\kappa_f)}$



J. Ren & HJH

SM subgroup

Standard Model Physics

Qing-Hong Cao,[a] Chong Sheng Li,[a] Zhao Li,[b] Li Lin Yang,[a] C.-P. Yuan[c]

[a] *School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China*

[b] *Institute of High Energy Physics, Chinese Academy of Science, Beijing 100049, China*

[c] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA*

$A_{FB}(b)$ and $R(b)$

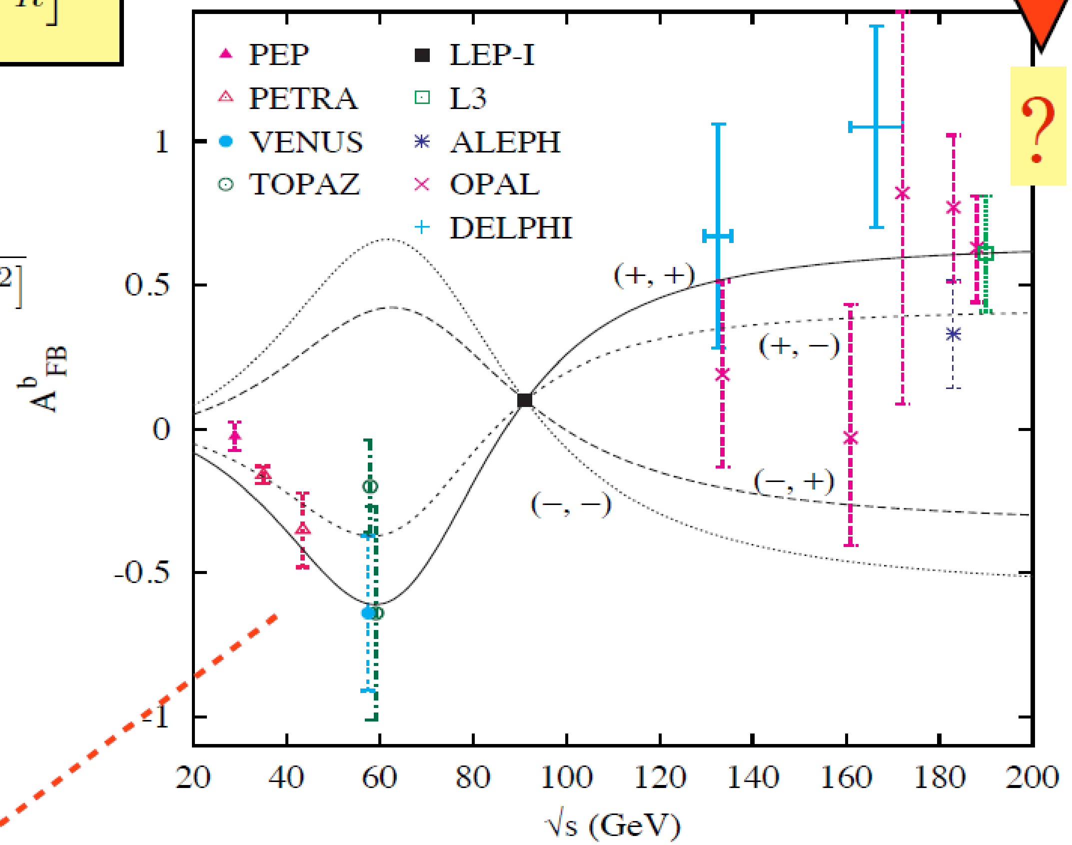
CEPC

$$\mathcal{L}_{Zb\bar{b}} = \frac{-e}{s_W c_W} Z_\mu \bar{b}\gamma^\mu \left[\bar{g}_L^b P_L + \bar{g}_R^b P_R\right] b$$

$$R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{hadrons})} \simeq \frac{(\bar{g}_L^b)^2 + (\bar{g}_R^b)^2}{\sum_q \left[(\bar{g}_L^q)^2 + (\bar{g}_R^q)^2\right]}$$

$$A_{FB}^b|_{\sqrt{s}\simeq m_Z} = \frac{3}{4} A_\ell\, A_b$$

$$A_b \simeq \frac{(\bar{g}_L^b)^2 - (\bar{g}_R^b)^2}{(\bar{g}_L^b)^2 + (\bar{g}_R^b)^2}$$



+

$$(\bar{g}_L^b, \bar{g}_R^b) \approx (\pm 0.992 g_L^b(SM), \pm 1.26 g_R^b(SM))$$

Massless limit: Top PDF

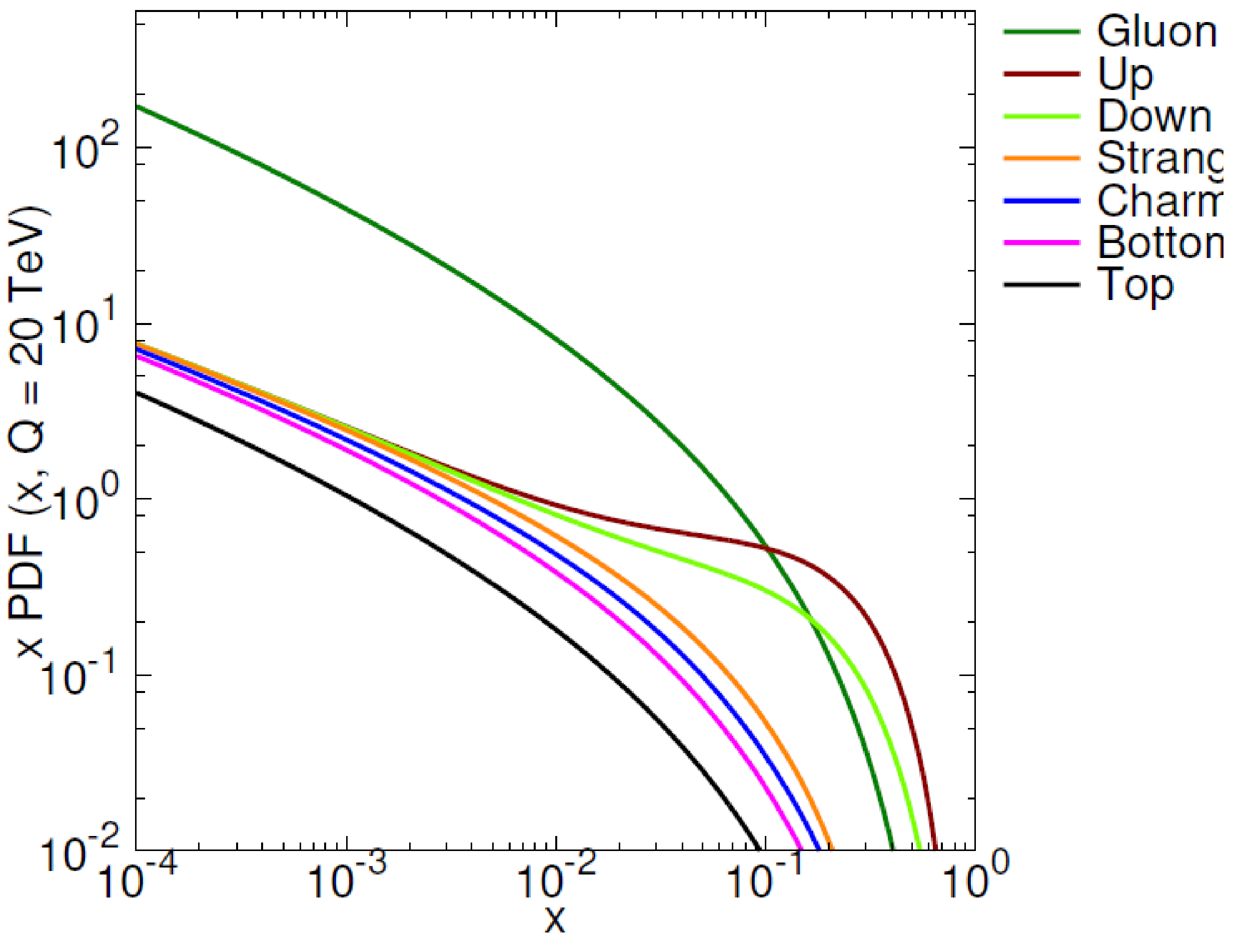


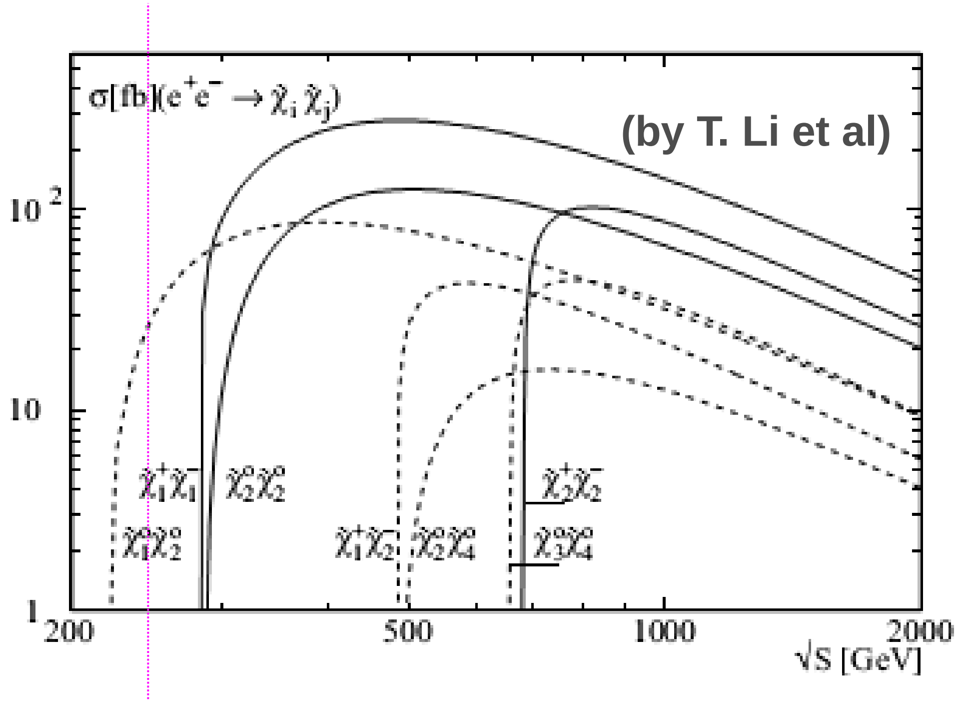
Figure 2. The CTEQ PDF values including the top quark PDF.

BSM: SUSY

Contents

3.3 Probe SUSY at Higgs factory

Direct production of sparticles:



For an e^+e^- Higgs factory (250 GeV) :

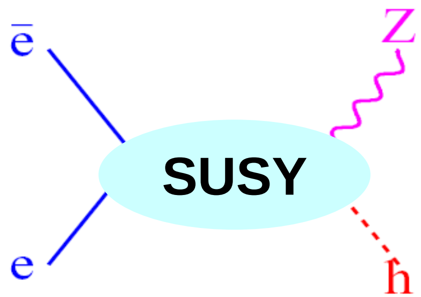
Direct search of SUSY is limited

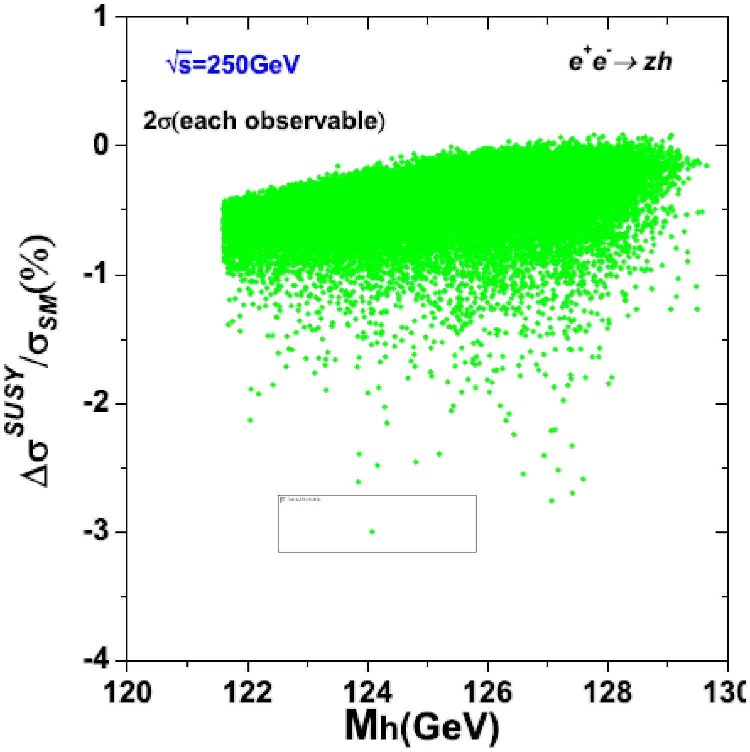
We may look for quantum effects of SUSY

Higgs production at e^+e^- Higgs factory (250 GeV)

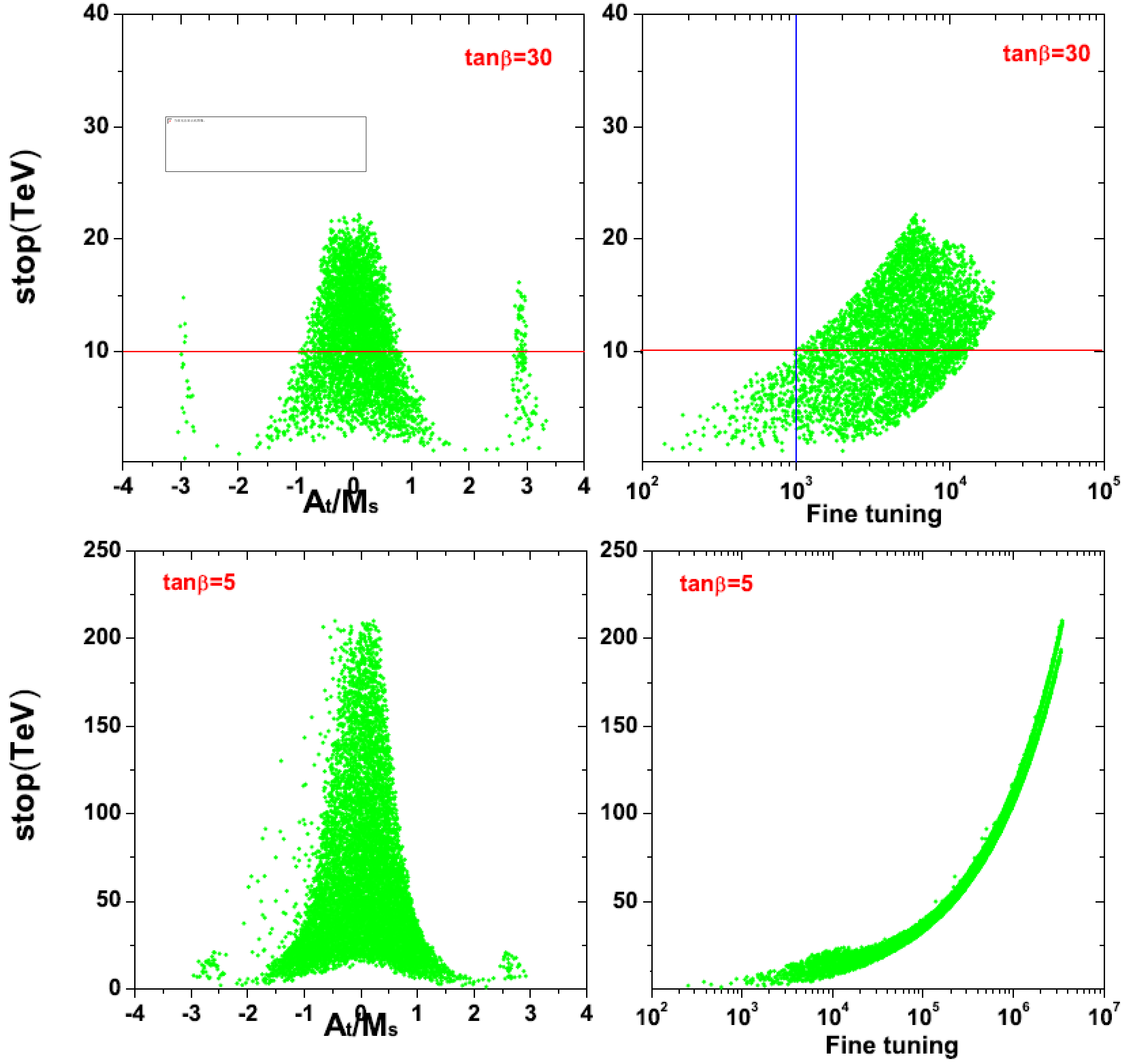
can sizably differ from SM:

Han, Wu, Wu,JMY,
work in progress





Finally, can a 100 TeV pp collider find SUSY particles ?



Conclusion for SUSY

Confronted with LHC Higgs data:

- Some SUSY models are healthy
- Some SUSY models need repairing

Probe SUSY at LHC:

- Looking for sparticles (like stop)
- Higgs pair production
- Higgs decays to Z-photon vs diphoton
- Higgs decays to dark matter
- Higgs decays to goldstini
- Top decay t -> ch

Probe SUSY at Higgs factory (via Higgs couplings or quantum effects):

$e^+e^- \to zh$ $\quad e^+e^- \to H\gamma$ $\quad \gamma\gamma \to h \to b\bar{b}$

BSM: Non-SUSY

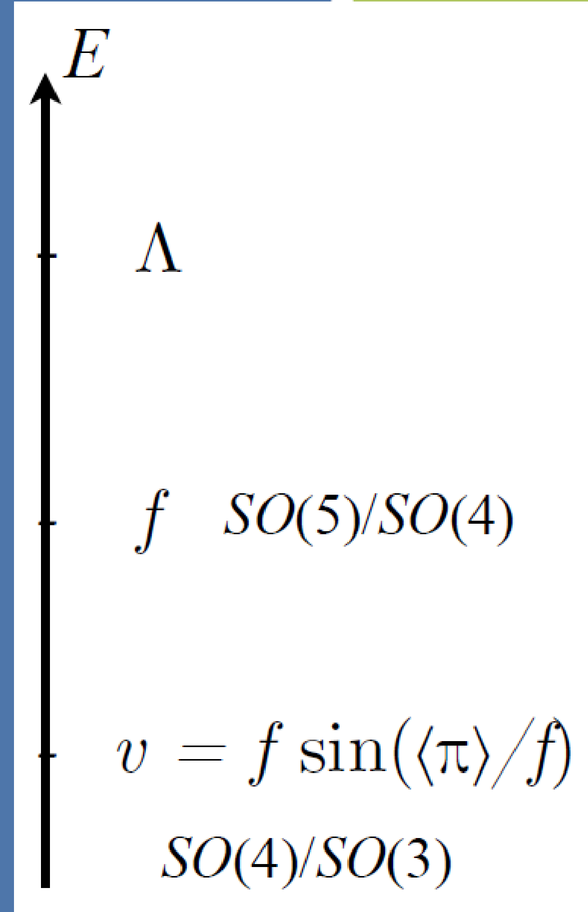
Contents

By saying moose, I mean what ever models with extended symmetries that are global, local or even emergent

Moose Models

- 4D Composite Higgs
- Little Higgs (with collective symmetry breaking)
- RS with gauge Higgs unification (deconstructed)

Higgs as a pNGB from G/H:
Higgs properties based on G/H



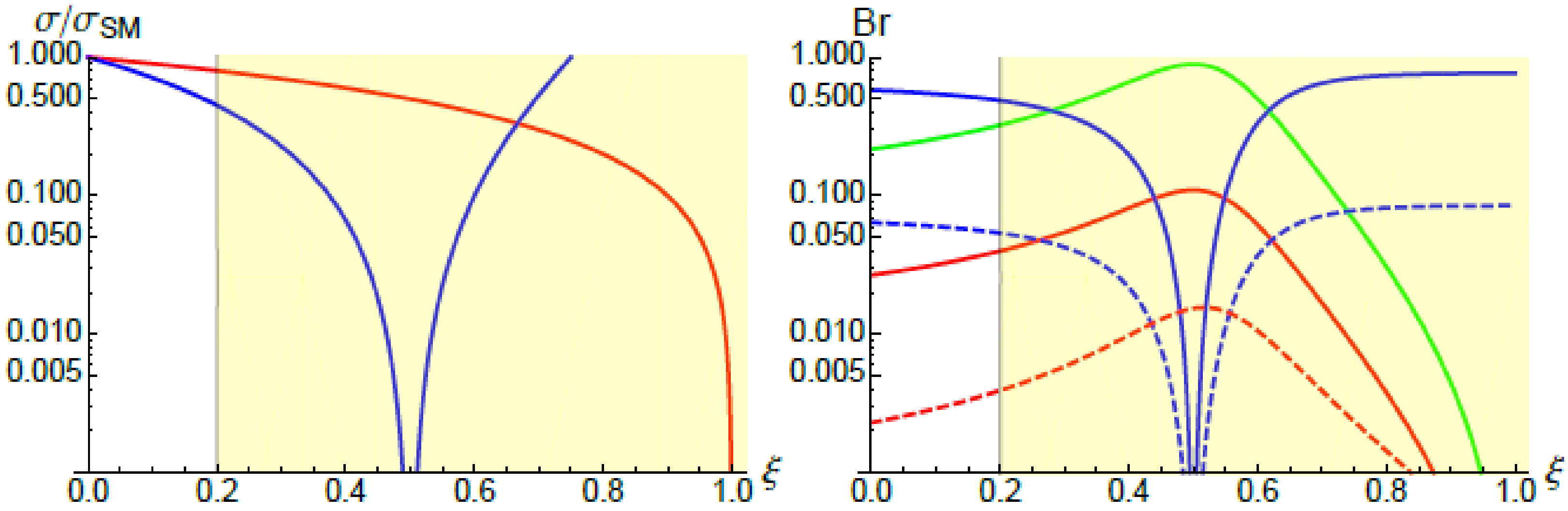
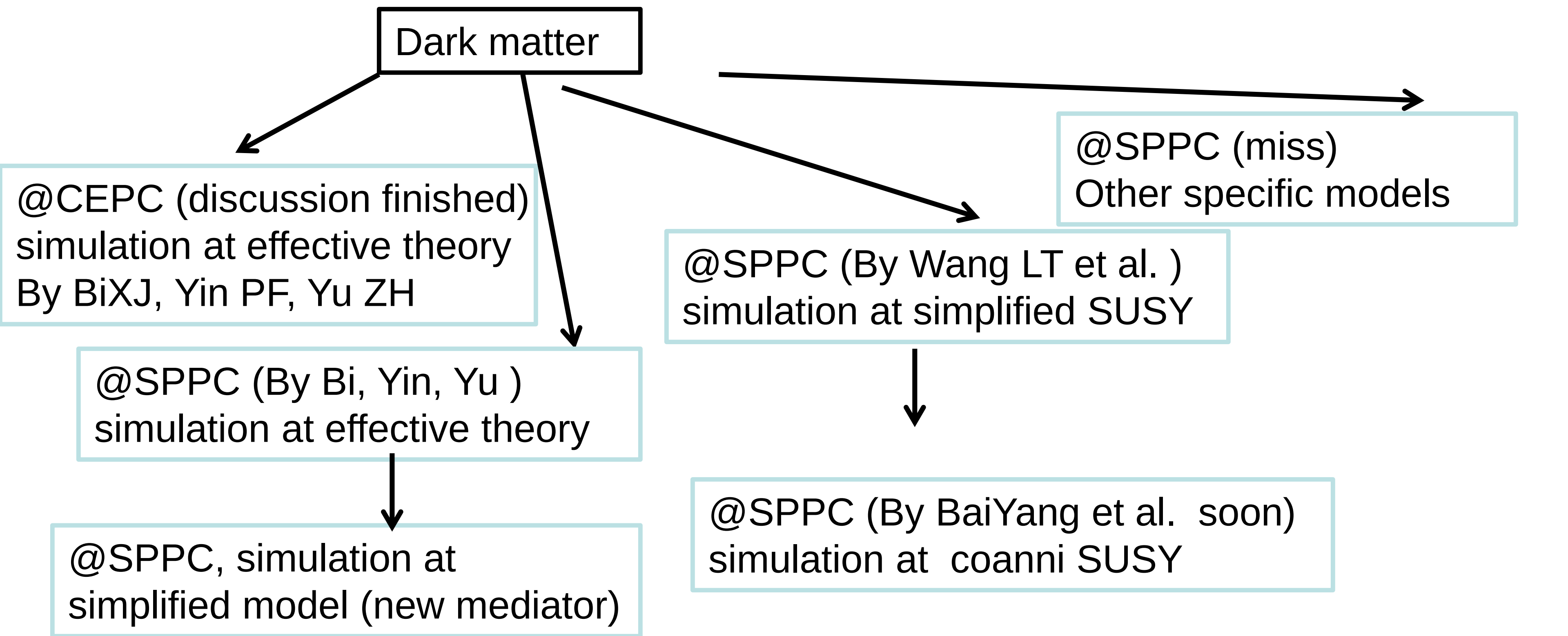


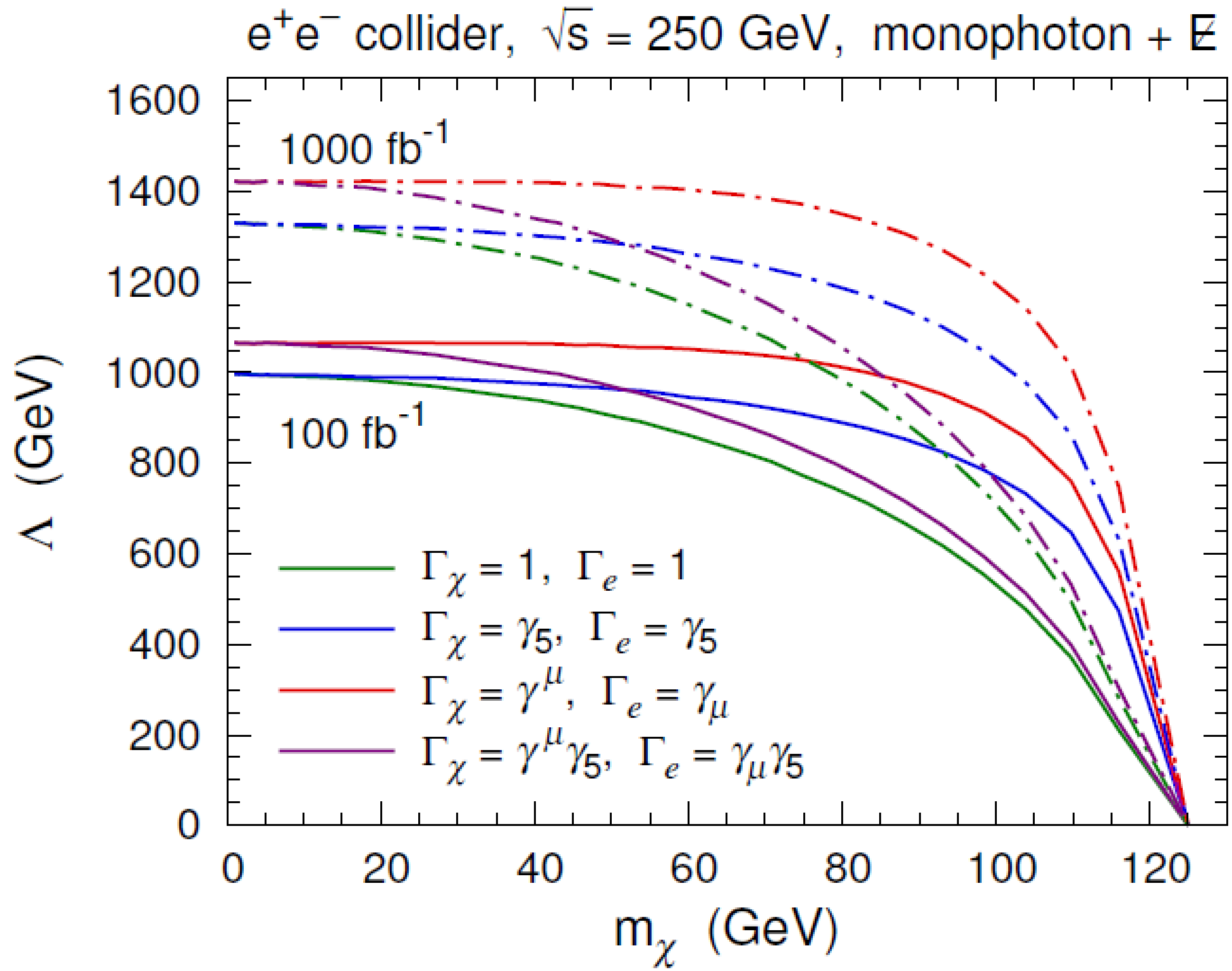
Figure 1. Left panel: The production rate ratio between the composite Higgs and the SM Higgs. The red line stands for weak boson fusion and associate production channel while the blue line stands for the gluon fusion channel. The yellow region $\xi > 0.2$ are not preferred by the electroweak precision test. Right panel: The decay branching ratio for 125 GeV composite Higgs in MCHM5. The red solid, green solid, blue solid, blue dashed and red dashed lines stand for ZZ, WW, $b\bar{b}$, $\tau\bar{\tau}$ and $\gamma\gamma$ decay channels.

TeV cosmology

Contents

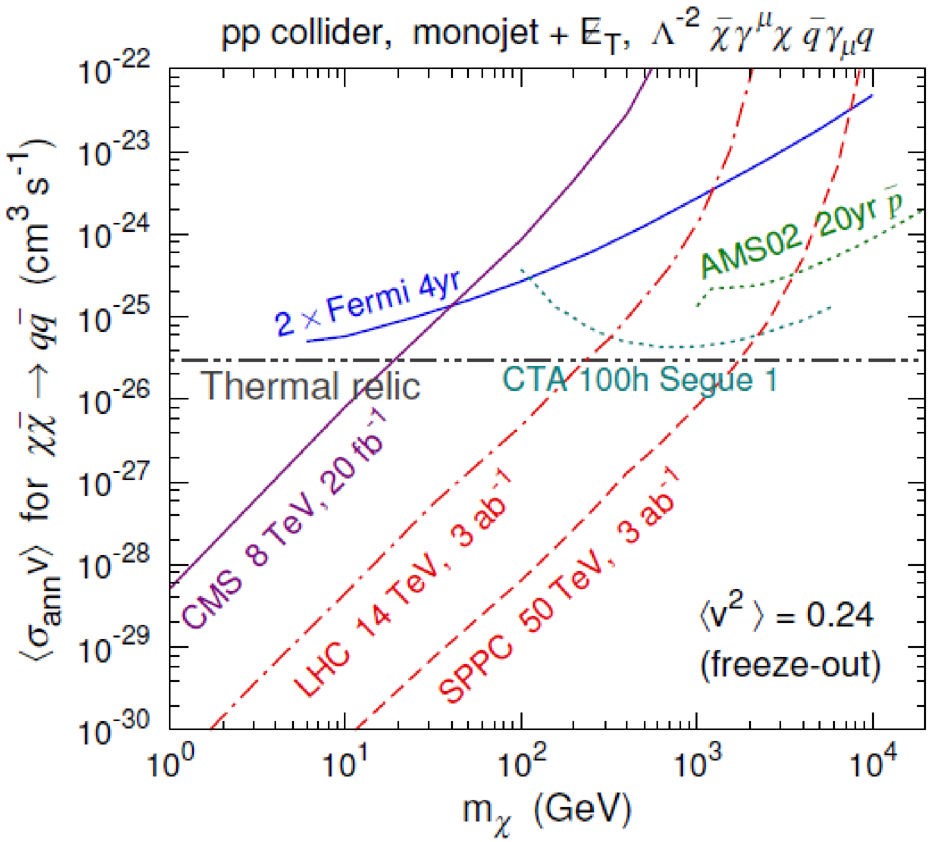

Dark matter
@CEPC (discussion finished)
simulation at effective theory
By BiXJ, Yin PF, Yu ZH
@SPPC (By Bi, Yin, Yu)
simulation at effective theory
@SPPC, simulation at
simplified model (new mediator)
@SPPC (By Wang LT et al.)
simulation at simplified SUSY
@SPPC (By BaiYang et al. soon)
simulation at coanni SUSY
@SPPC (miss)
Other specific models

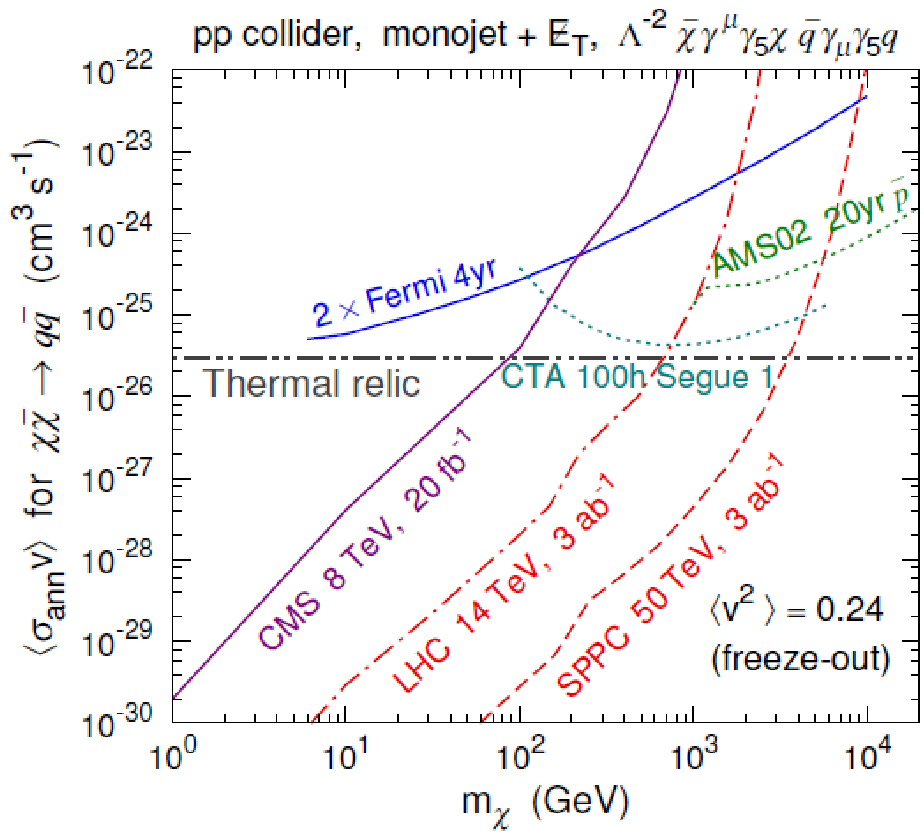
Constraints on the 4-fermion operators @CEPC

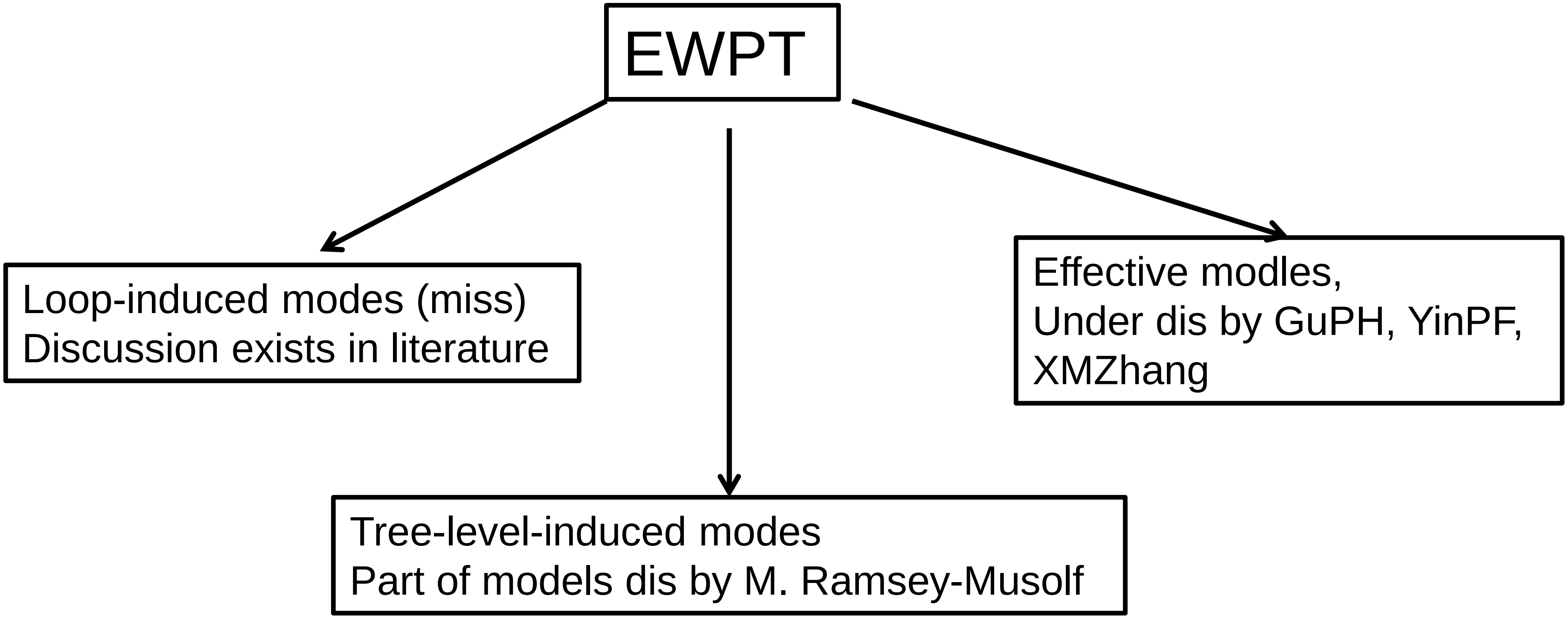


Simulation of LHC and SPPC (@50TeV)

Comparison with the indirect detection by Fermi, CTA and AMS-02 (20yrs)





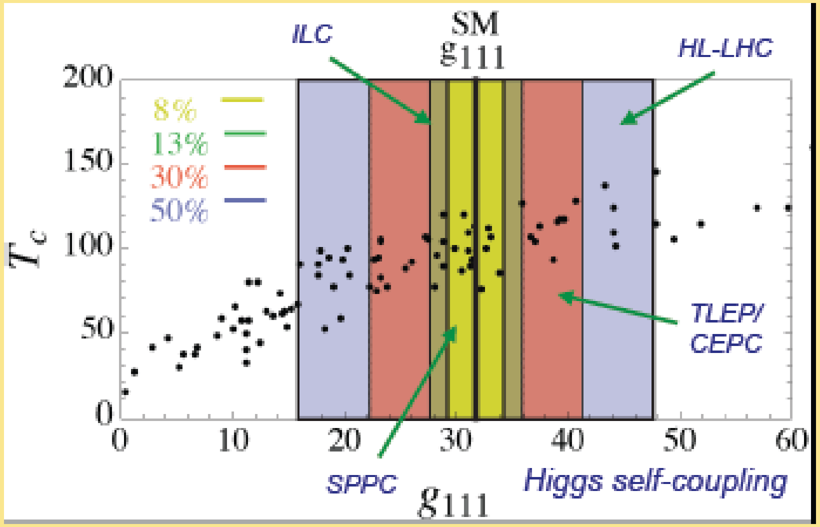

EWPT
Loop-induced modes (miss)
Discussion exists in literature
Effective modles,
Under dis by GuPH, YinPF,
XMZhang
Tree-level-induced modes
Part of models dis by M. Ramsey-Musolf

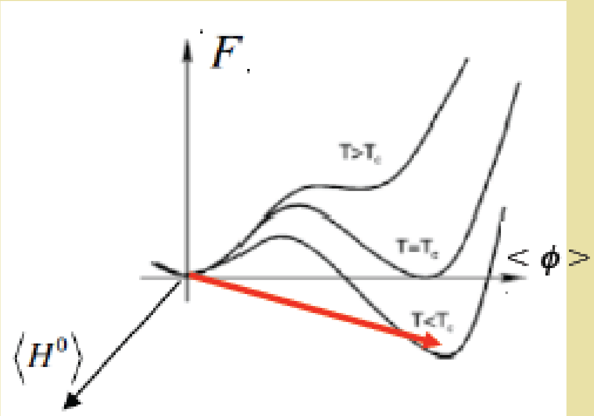
EWPT & Singlets: Higgs Self-Coupling

$$V(H,\phi) \supset a_1 H^\dagger \phi H + \frac{a_2}{2} H^\dagger H \phi^\dagger \phi$$

Tree-level barrier

Modify T_C





- Tree-level barrier
- Possible lower T_C : better for baryogenesis

  - Black points: strong 1st order EWPT
  - Colored bands: prospective precision

Thanks: P. Winslow

1407.5342

Flavor Physics

Heavy Flavor Physics: B Sector

Ying Li,[a] Chao-Feng Liu,[b] Cai-Dian Lü,[b] Wei Wang,[c] Zhen-Jun Xiao,[d] Guo-Huai Zhu[e]

Contents

Flavor Physics @ CEPC

Honestly, there is little space left after LHC-b (Large Background) and Super-b ("Low" Energy) for studying Beauty-Physics and Charm Physics.

However, there are some advantages over LHC-b and Super-b.

$$e^+ + e^- \rightarrow f + \bar{f}$$

- At CEPC, the produced b quark and anti-b quark are flying in the center of the mass. So, it is convenient to measure some time-dependent observables, for example, the time-dependence CP violation of the hadronic B meson decays.

$$L = 2.6 \times 10^{34}\ cm^{-2}\ s^{-1}$$

Cross Section	$\sqrt{s} = m_Z$		$\sqrt{s} = 240\text{GeV}$	
Tau	1474 pb	1.2×10^9	4.3pb	3.5×10^7
Charm Pair	5237 pb	4.3×10^9	10.7pb	9.5×10^7
Beauty Pair	6549 pb	5.4×10^9	10.8pb	9.6×10^7

LHC-b(b-pair+X)	89.6$\times 10^6$ Pb	5.8×10^{11}	$4.0 \times 10^{32}\ cm^{-2}\ s^{-1}$
Super-b (b-pair)	1100pb	1.4×10^{10}	$8.0 \times 10^{35}\ cm^{-2}\ s^{-1}$

TOPICS

- **Crosscheck the results from LHC-b and Super-b**
- **Exotics: X Y Z particles, especially their bb-bar partners**
- **Heavy baryon: Λ_b**
- **Heavy quark decays with DM or missing energy**
- **Bs physics, Bc physics**
- **τ physics: $\tau \to \mu\gamma, \tau \to e\gamma$?**
- **Search for rare decays that sensitive to the effect of NP**
- **Characterize the new particles if they could be detected at some machines**

Heavy Ion Physics

I. GLOBAL PROPERTIES

A. Multiplicity

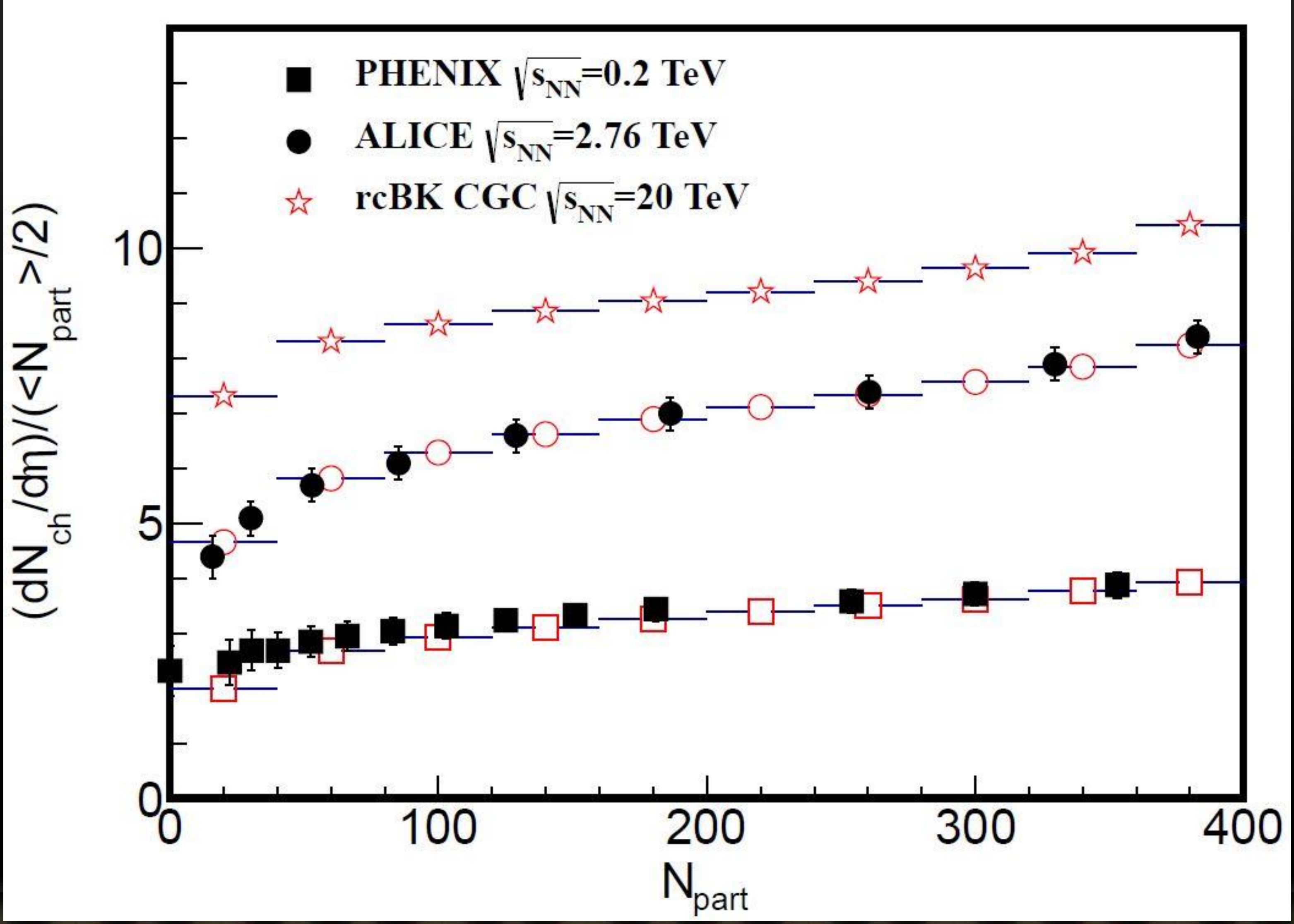
B. Collective flow

II. HARD PROBES AND JET QUENCHING

III. TRANSPORT PROPERTIES

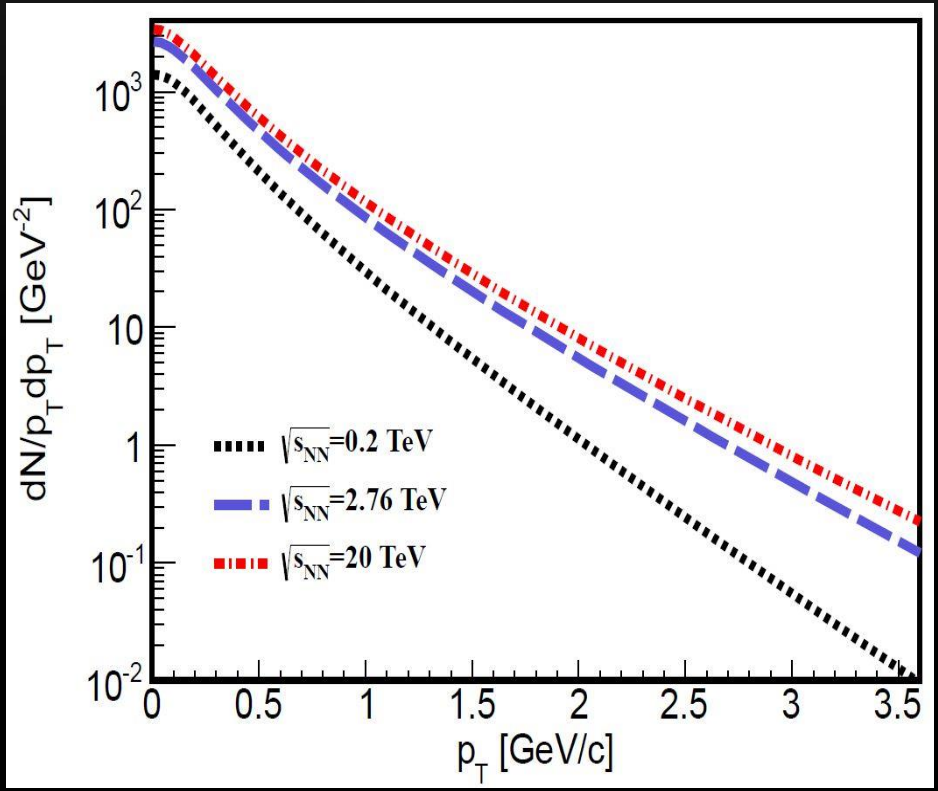
IV. HEAVY QUARKS

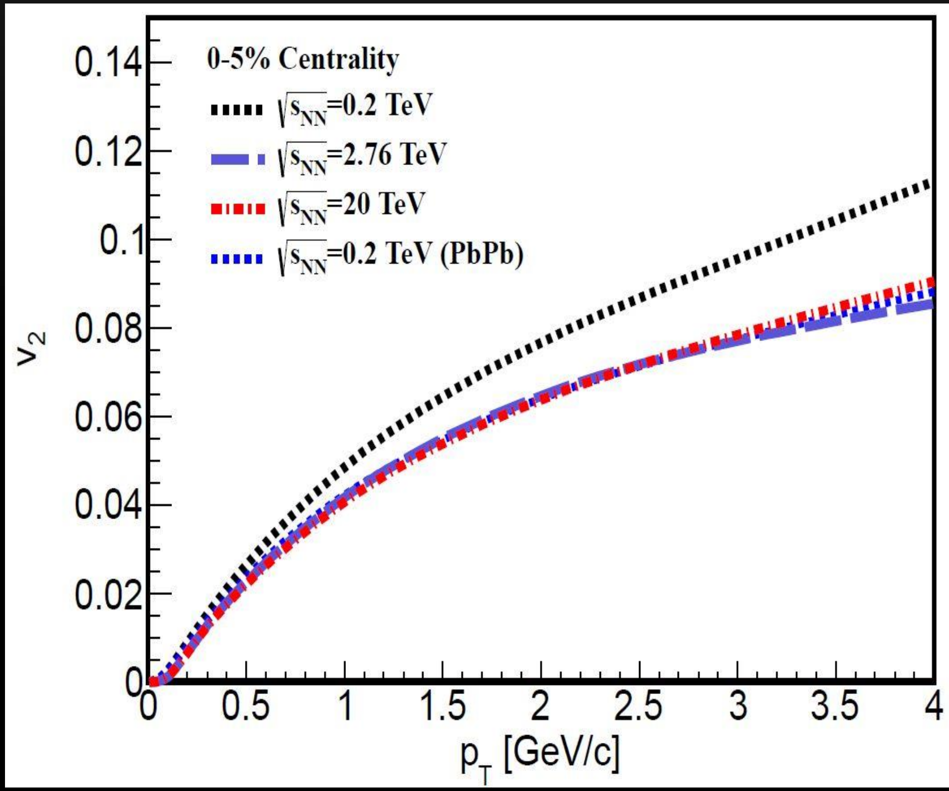
Centrality dependence



Hadron spectra and elliptic flow

- τ_0=0.4fm/c, T_{dec}=120MeV; Equation of State (EOS) given by Lattice QCD s95p-PCE-v0.





MC tools

Pre-CDR: Monte Carlo Tools for future collider projects

Tongguang Cheng, Sergei Chekanov,Bo Feng, Bin Gong,Jiayin Gu,Tao Han,Gang Li,Liang Li,Qiang Li,Zhao Li, Meenakshi Narain,Sanjay Padhi,Meade Patrick,Jimmy Proudfoot, Huilin Qu,Manqi Ruan,Dayong Wang,Jian-Xiong Wang,Kechen Wang, Liantao Wang,Yiwen Wen,Yongcheng Wu,Keping Xie,Qin-Jun Xu, Qi-Shu Yan,Daneng Yang, Gao Yu,Bin Zhang,Jian-Hui Zhang, Xiao-Ran Zhao, Zhijie Zhao

Contents

Motivations for our efforts

- As end users, you will not be able to know details of generators (you are unable to custom them).
- Current MC tools are not so powerful as you thought, new colliders bring new difficulties. (Gluon Fusion; QED matching; Multi-V emission; beam energy loss)
- Future high energy physics needs more powerful MC generators (two and even higher loops/more than 10 legs)
- We are not too far away, but will never catch up if we stop.

Our aims

At the early stage of CEPC, to provide important information for detector designs; to explore the event shape of the SM; to explore the physics potential at future colliders

To develop High Precision MC toolkits and general purposed MC generators for data analysis

To train regional users and foster next generation of MC authors; to strength connections with the other MC working groups in the world

Multi-Higgs Box

(Q. S. Yan, X. R. Zhao, Z. J. Zhao, Q. Li,)

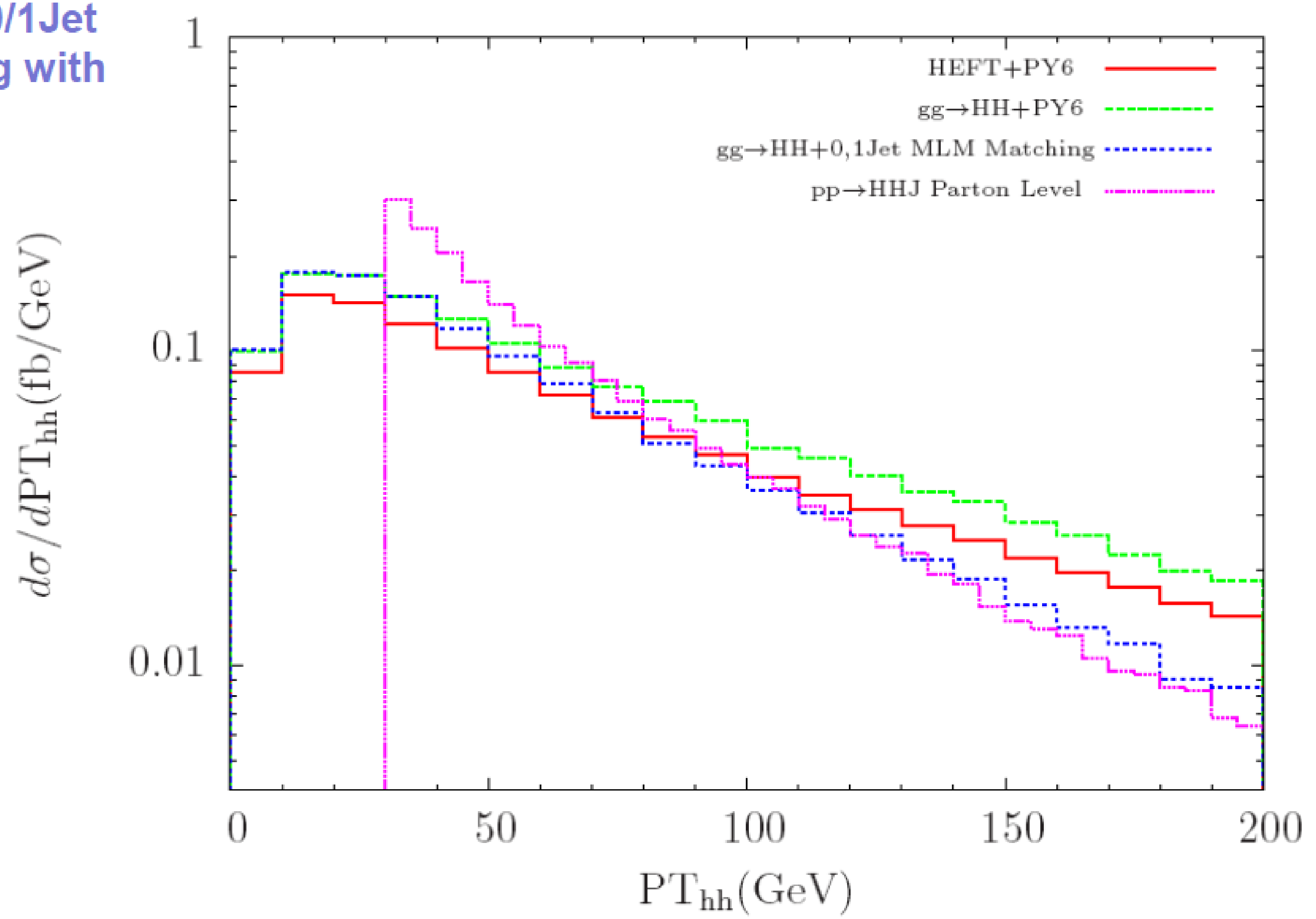
Di- and Tri- Higgs productions are crucial for Higgs self-coupling measurement; However, in current MC tool, Gluon-Fusion processes are not supported well

We are preparing a Multi-Higgs Box:

- Include Di- and Tri- Higgs GF and VBF and V-associated production process, able to generate LHE events;
- Make it Suitable for BSM: 2HDM, Composite Higgs…;
- Implement HH+1Jet and the 0/1Jet matching;
- Implement VBF HH NLO PS matching;
- Perform Physics studies

Matched predictions for Higgs pair production
Q.Li, Qi-Shu Yan, Xiaoran Zhao Phys. Rev. D 89, 033015 (2014)

GF HH+0/1Jet matching with Pythia



Content

Summary

- Great effects have been put on pre-cdr
- Many physics ideas are motivated which can be studied at CEPC/SPPC
- Each part of draft for precdr are almost ready
- However more effects are required to merge all draft into a coherent form
- Need to act right now!

Thanks for your attention!