Physics @LHC.CEPC.SPPC

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北京大学（Peking University）
2014/5/17

TeV Workshop, Guangzhou 2014

羊城晚报(1980年1月)

- 广州粒子物理理论讨论会开幕

广州粒子物理理论讲座会5日在从化温泉宾馆陶然厅开幕。世界著名的美籍物理学家杨振宁 、李政道教授参加了这次重要的学术讨论会。这次学术讲座会是由中国科学院协助召开的。它的主要任务是介绍粒子物理理论研究工作的最新进展，包括强子结构规范场理论、最子色动力学、强作用的现象性理论、引力理论、大统一理论、新粒子理论等，同时探讨一些新的研究课题，以加强联系，互相交流，进一步提高我国粒子理论研究的水平.

<科学文化评论>，2011，第8卷第4期，45-65
丁兆君

- 题目：华裔物理界的一次盛会

  1980年广州粒子物理理论讨论会的召开及其意义与影响

- ……广州粒子物理理论讨论会是我国粒子物理发展史上的一个转折点……

CEPC/SPPC定义

- CEPC(Circular Electron-Positron Collider) 240GeV质心能量的正负电子环形对撞机

- SPPC (Super Proton-Proton Collider) 50-70 TeV质心能量的质子质子对撞机

内容

CEPC/SPPC的物理目标（为什么要建CEPC/SPPC？）

CEPC/SPPC理论工作组的进展汇报（主要取自1st CFHEP会议报告）

结论与展望

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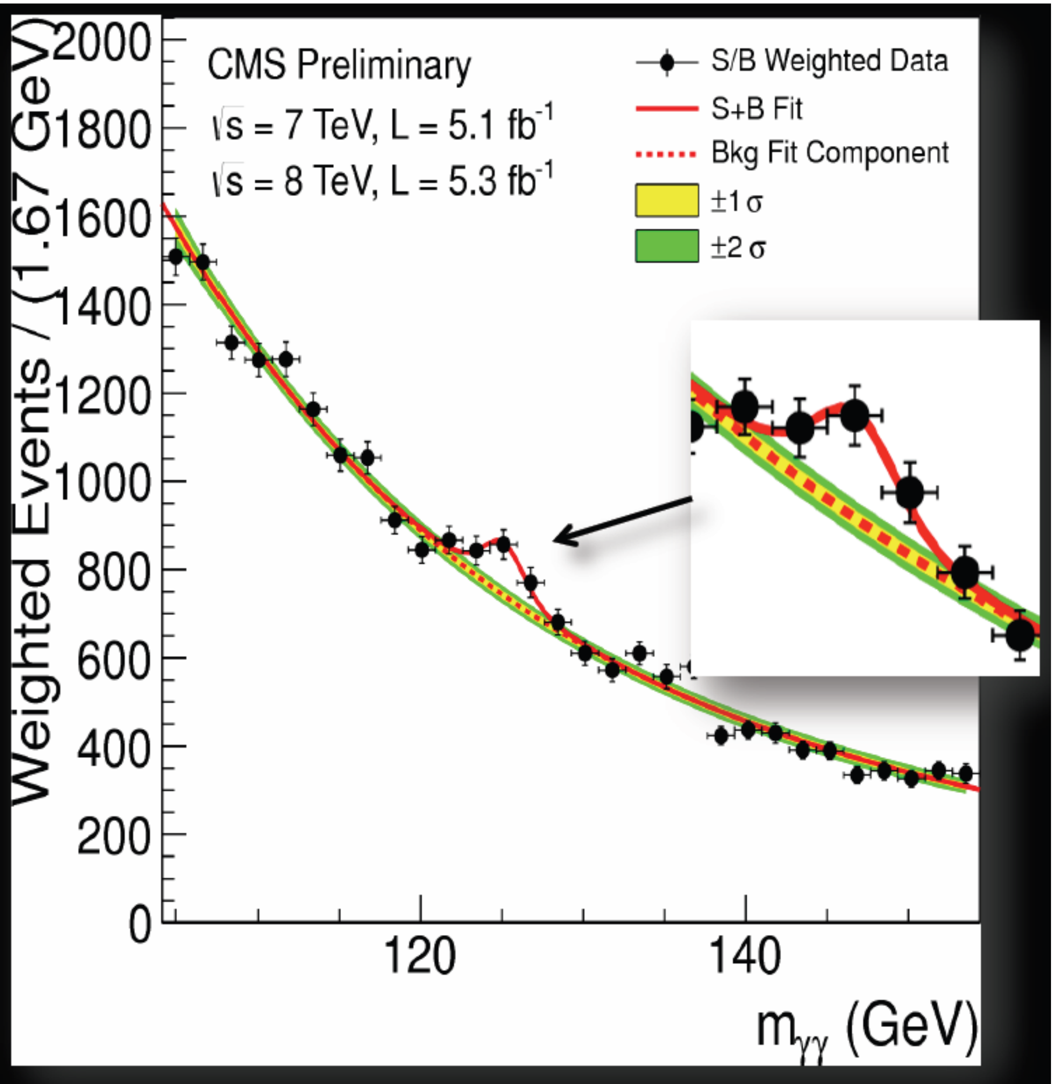
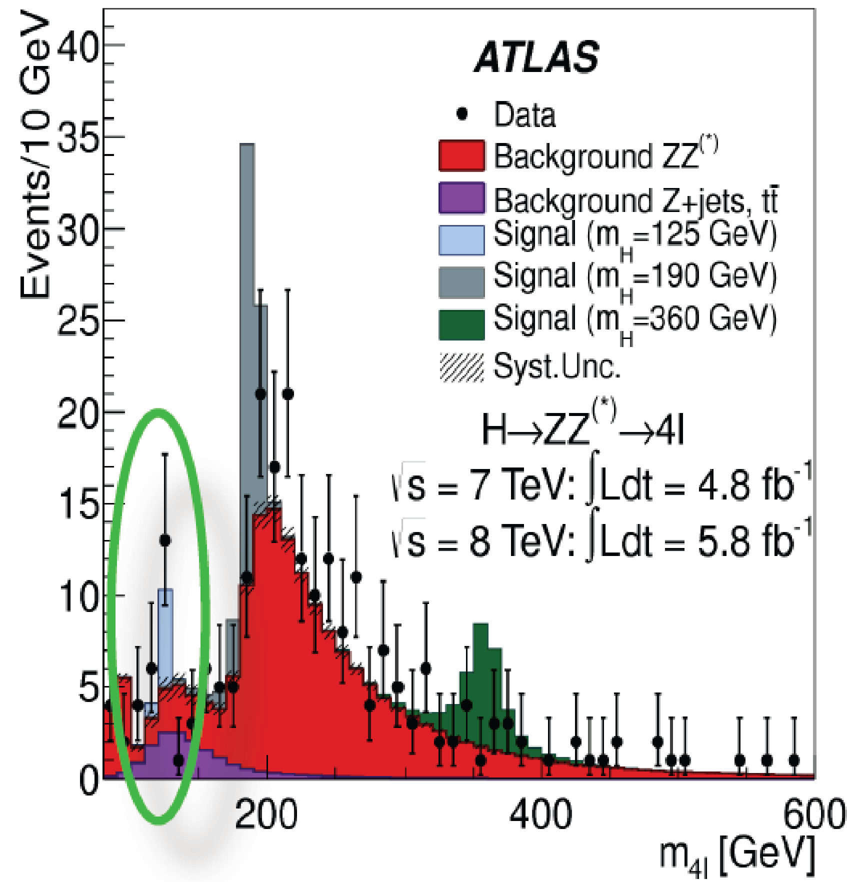
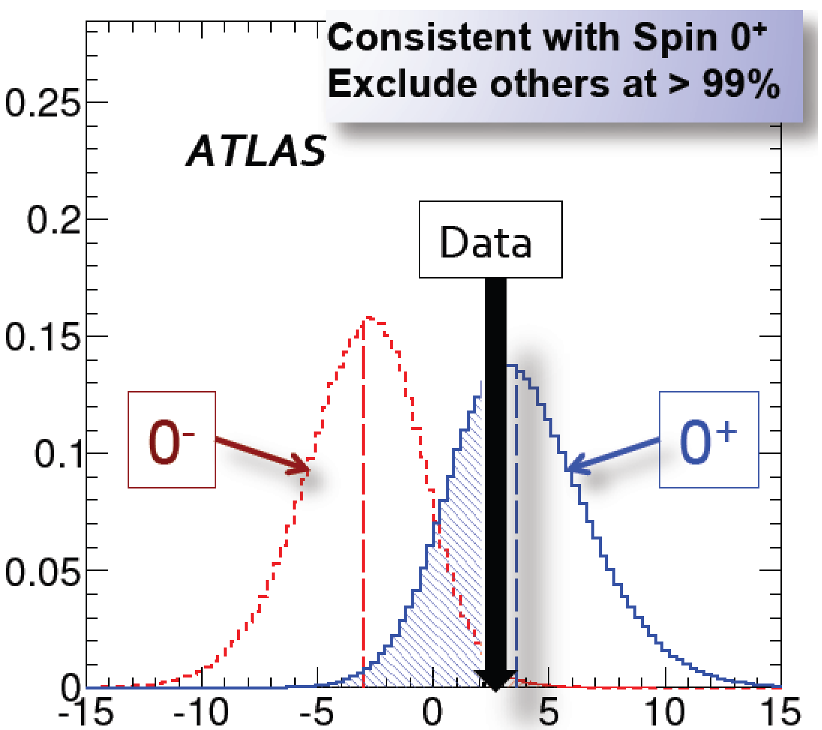
2012年7月4日
X(125):新的共振态

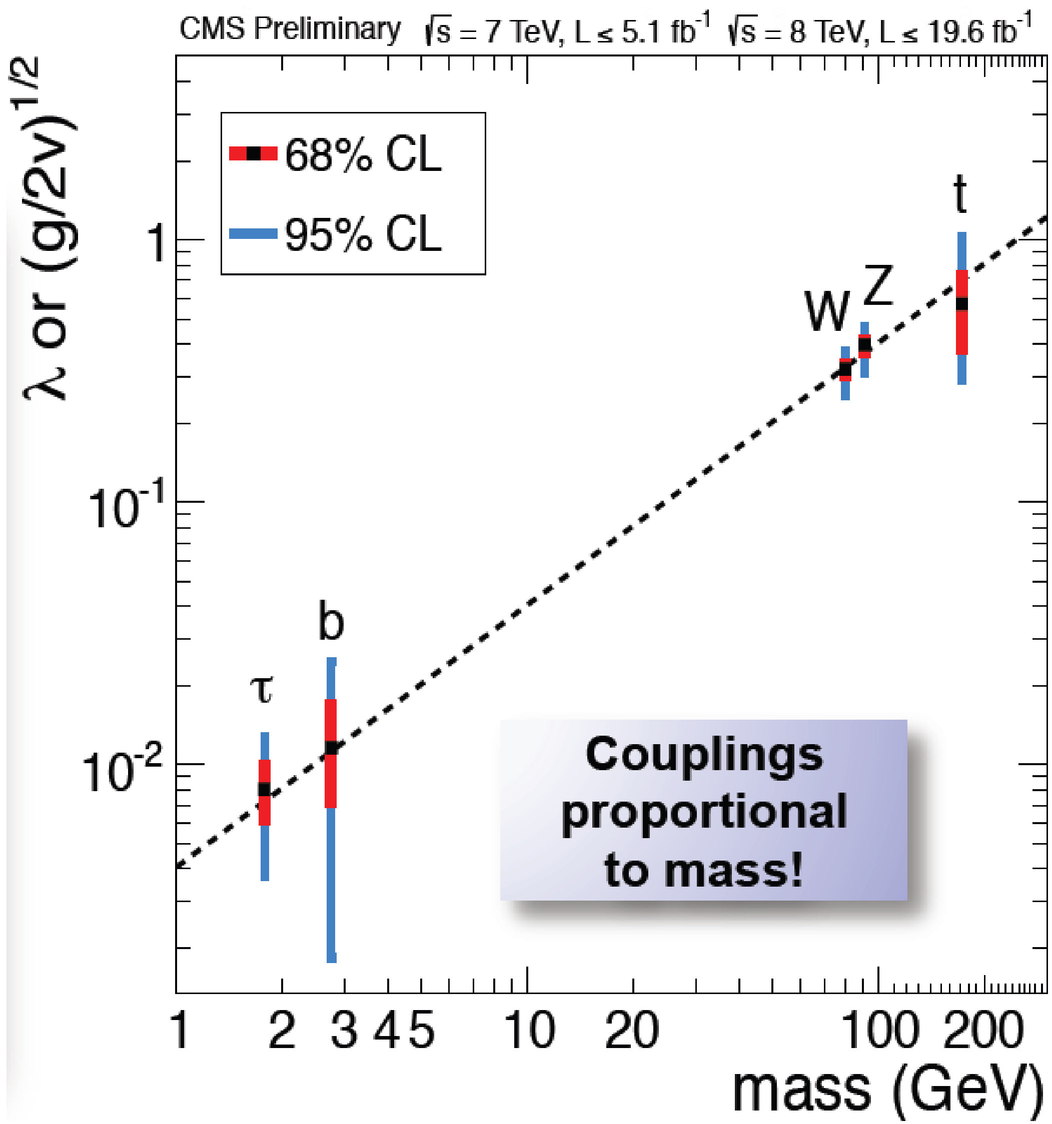




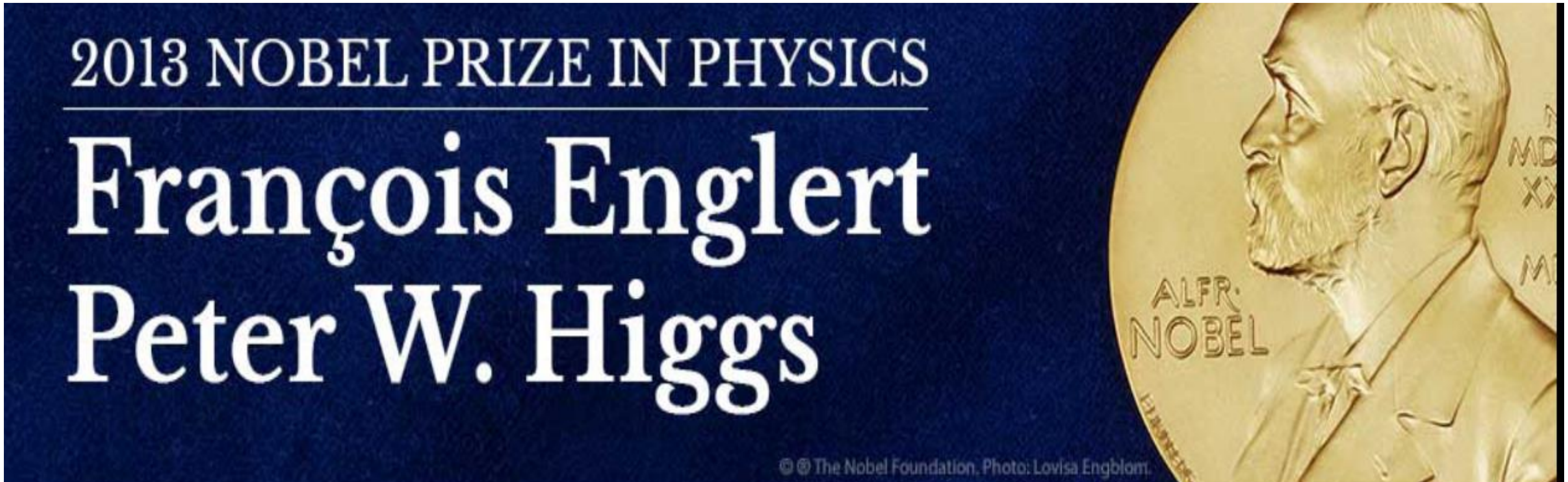
随后分析了更多数据
与Higgs粒子的预期相符



即使H含有0⁻成分，其贡献被压低：被看到的事例主要来自0⁺组分



H(125):新的物理研究对象



8 October 2013

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2013 to François Englert and Peter Higgs

"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"

H(125)与其他标量粒子不同

- H(125)粒子的存在，使得人们第一次得到一个自洽的理论，它可以适用到非常高的能量（指数增长）
- 所以对于H(125)粒子性质的研究，将可能揭示它背后的更深层次的物理（超对称？新的相互作用与新的对称性？额外的时空维度……）

清晰的CEPC物理主要目标

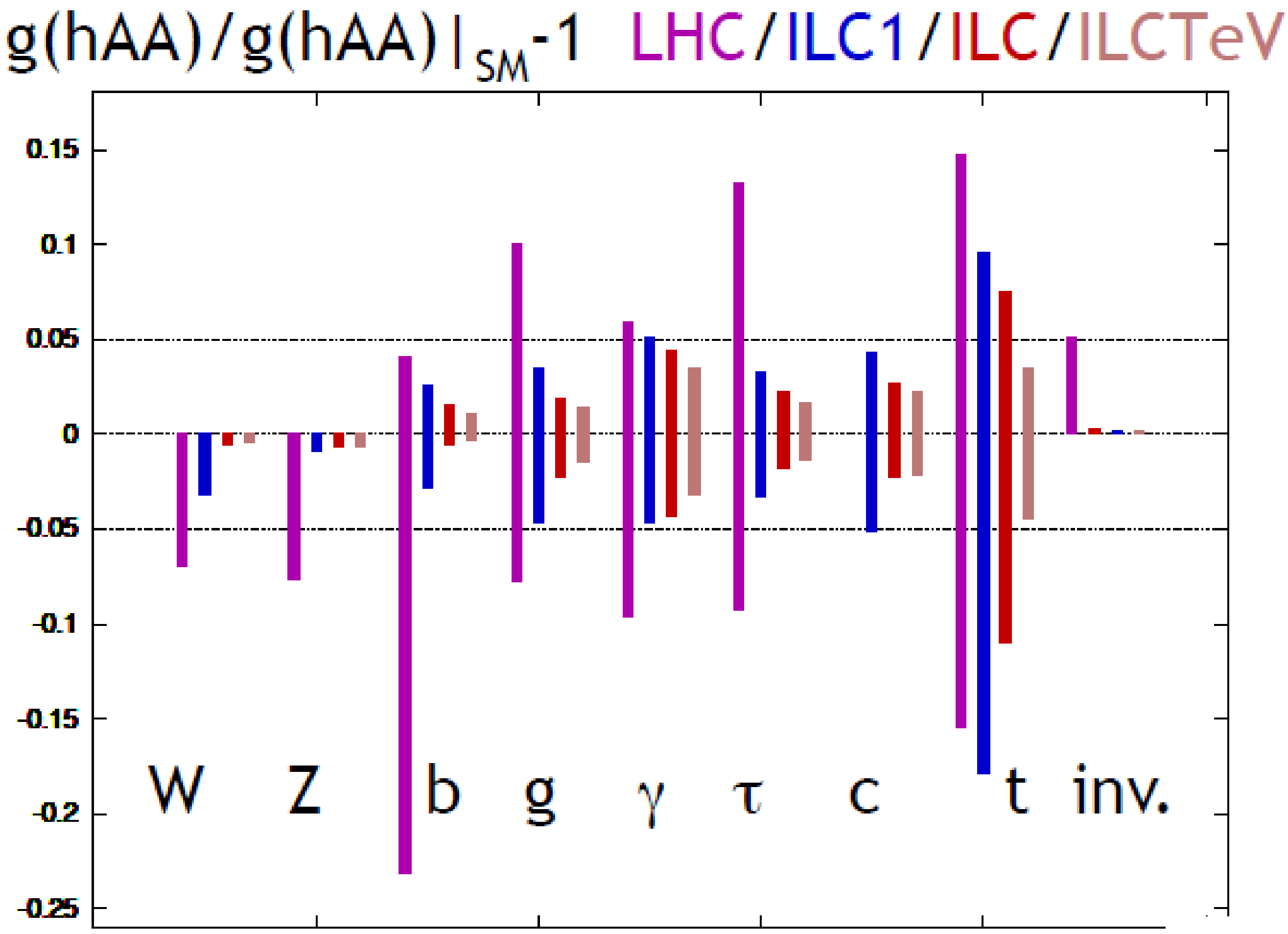
- H(125) 是否为标准模型的Higgs？ 通过精确测量它的性质，如质量，自旋，CP性质，与费米子、规范玻色子的耦合，自身的耦合等等
- 新物理是否存在? 通过

（1）比较H(125)与标准模型预言的性质是否相符

（2）H(125)是否有新的非标准模型衰变道(存在轻的新粒子)

（3）发现其他质量不太高的新粒子等

CEPC(ILC1)精确测量Higgs耦合与LHC对比



ILC at 250 GeV

LHC-14 TeV (300 fb^{-1} with one detector)

(with $\mathcal{L}$ = 250 fb^{-1})

精确测量Higgs质量的意义

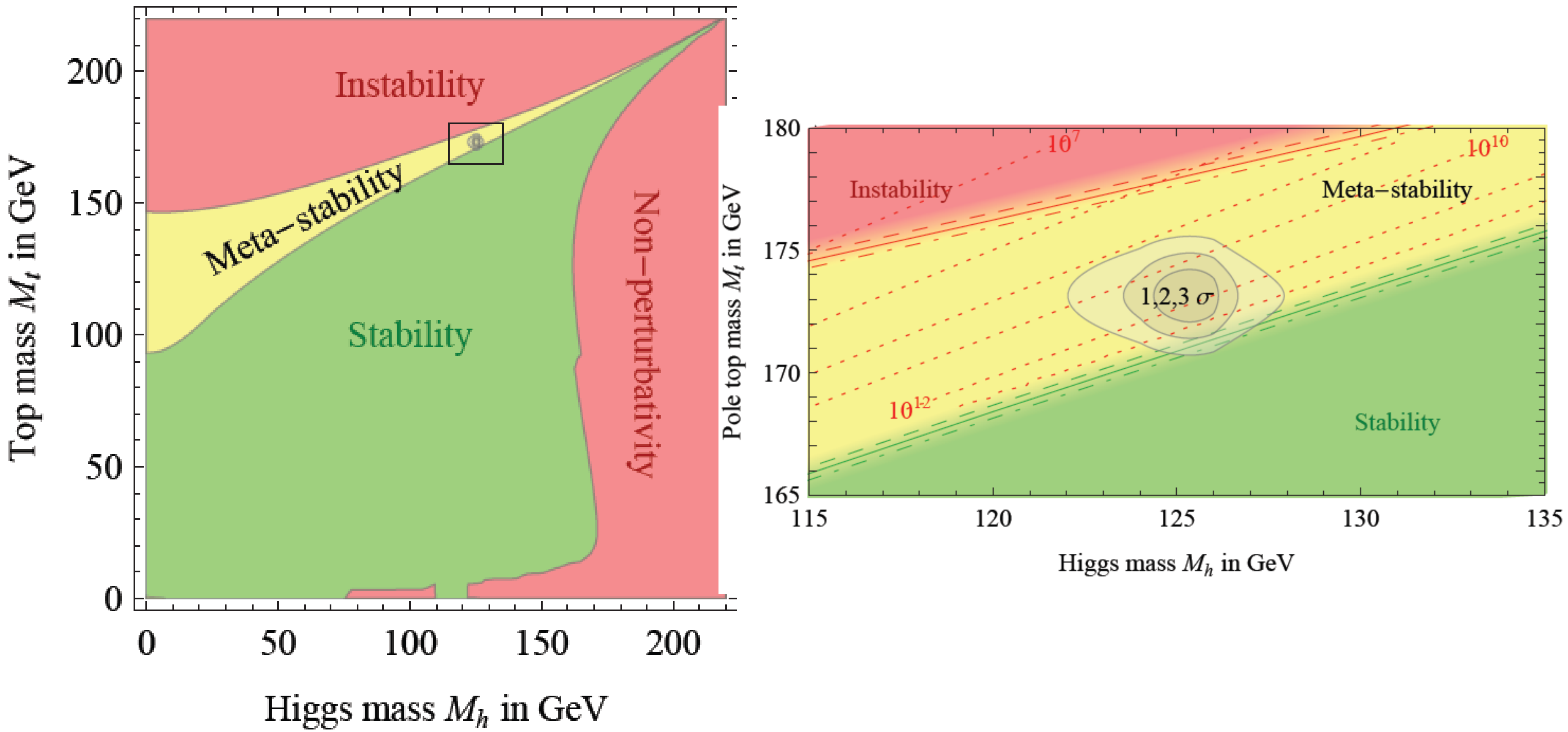


Figure 32. Left: Regions of absolute stability, meta-stability and instability of the SM vacuum in the plane of m_t and m_h. Right: Zoom in the region preferred experimental range of m_h and m_t. The gray areas denote the allowed region at 1, 2 and 3σ [138].

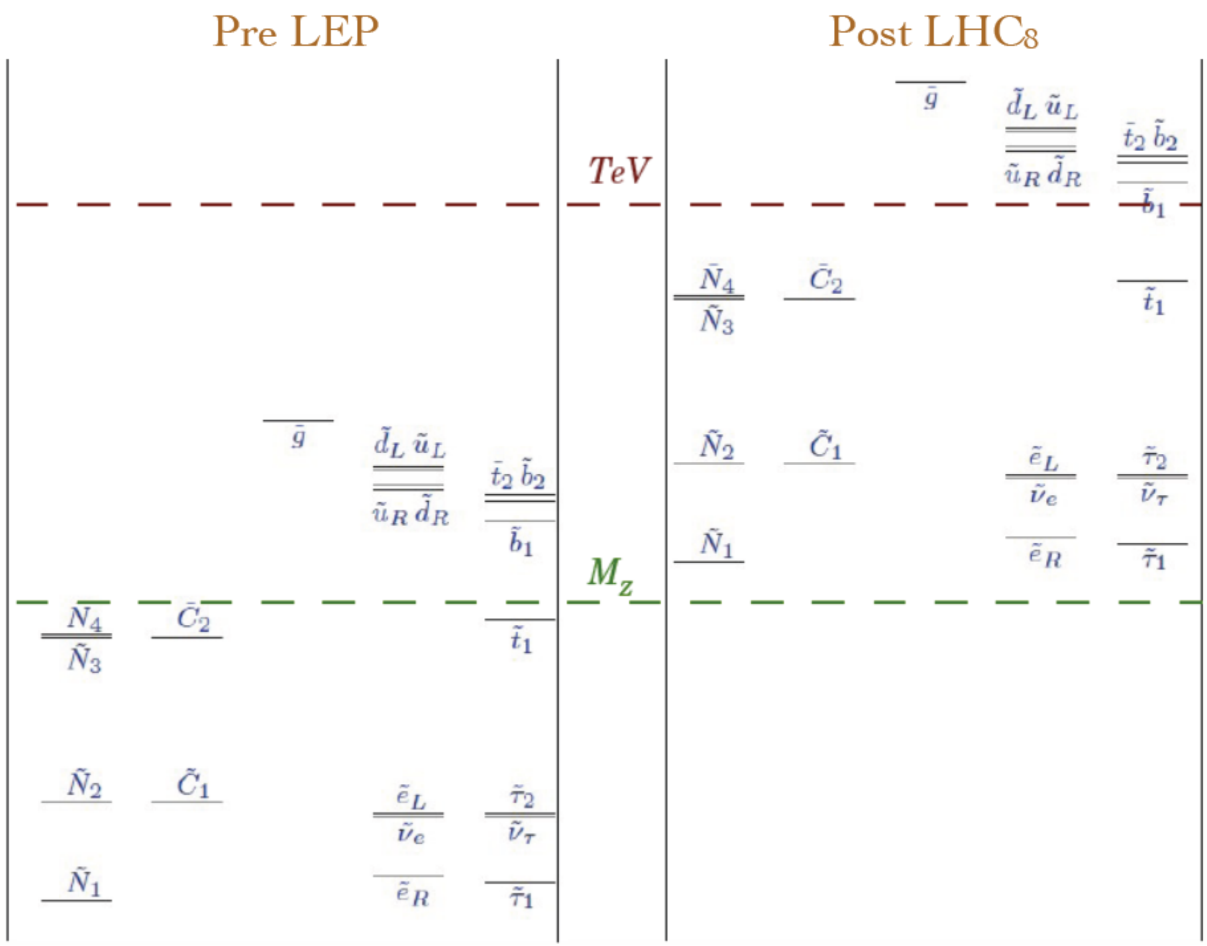
为什么需要SPPC？

- 理由1：质子能量从LHC的1/4TeV~1/7TeV到1/25TeV~1/35TeV,空间分辨率提高4-5倍，是人类可控设备中，分辨率最高的仪器！有可能直接探测新物理！
- 理由2：自然性！
- 理由3：暗物质！
- 理由4：如何解释物质为主的宇宙？
- 理由5：味物理
- ……

自然性：超对称？

The Hard Facts

Savas Dimopoulos



The connection with the hierarchy problem is diminished

Is Weak Scale Natural?

HUGE STAKES

Not just this or that particle — deep, structural issue in QFT

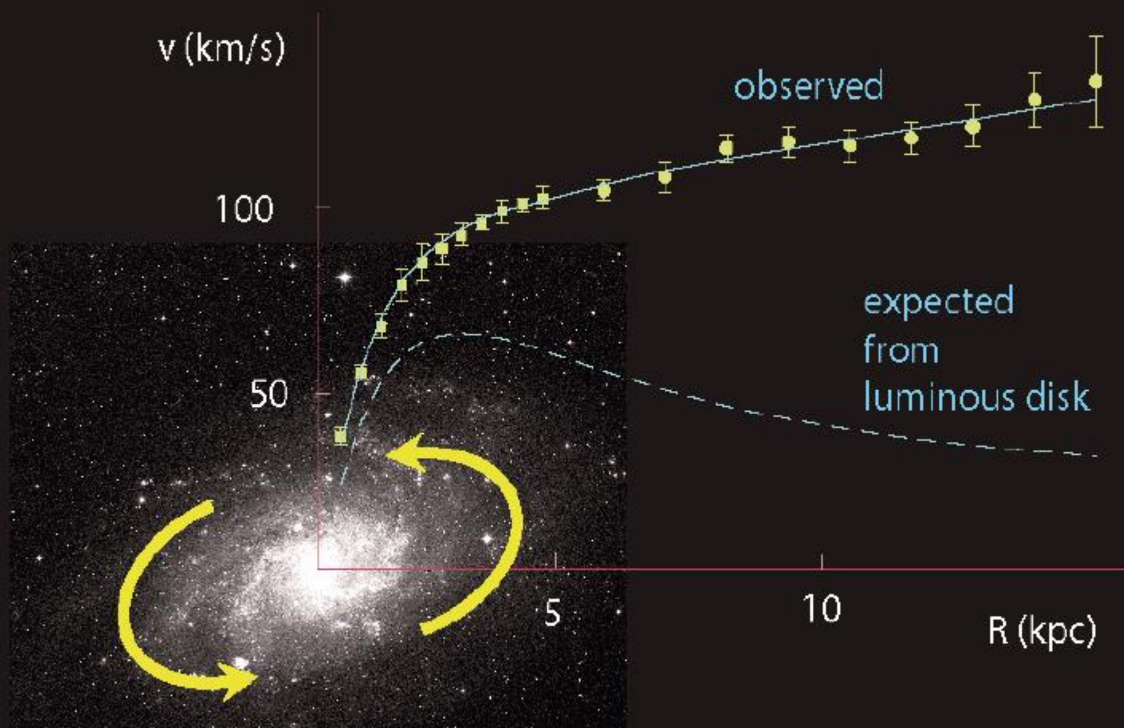
N. Arkani-Hamed

Is weak scale natural?

- EW and strong scalar sectors can mix!
- Although the custodial SU(2)L $\times$ SU(2)R, and the gauged SU(2)L $\times$U(1) symmetry for the whole model remains intact, the mixing breaks the relative chiral symmetry between the two sectors. The mixing should be calculable from light quark masses as a quantum correction.

  N. Toernqvist, hep-ph/0504204
- What if more scalar sectors?

Cosmological Connection - Dark Matter



M33 rotation curve

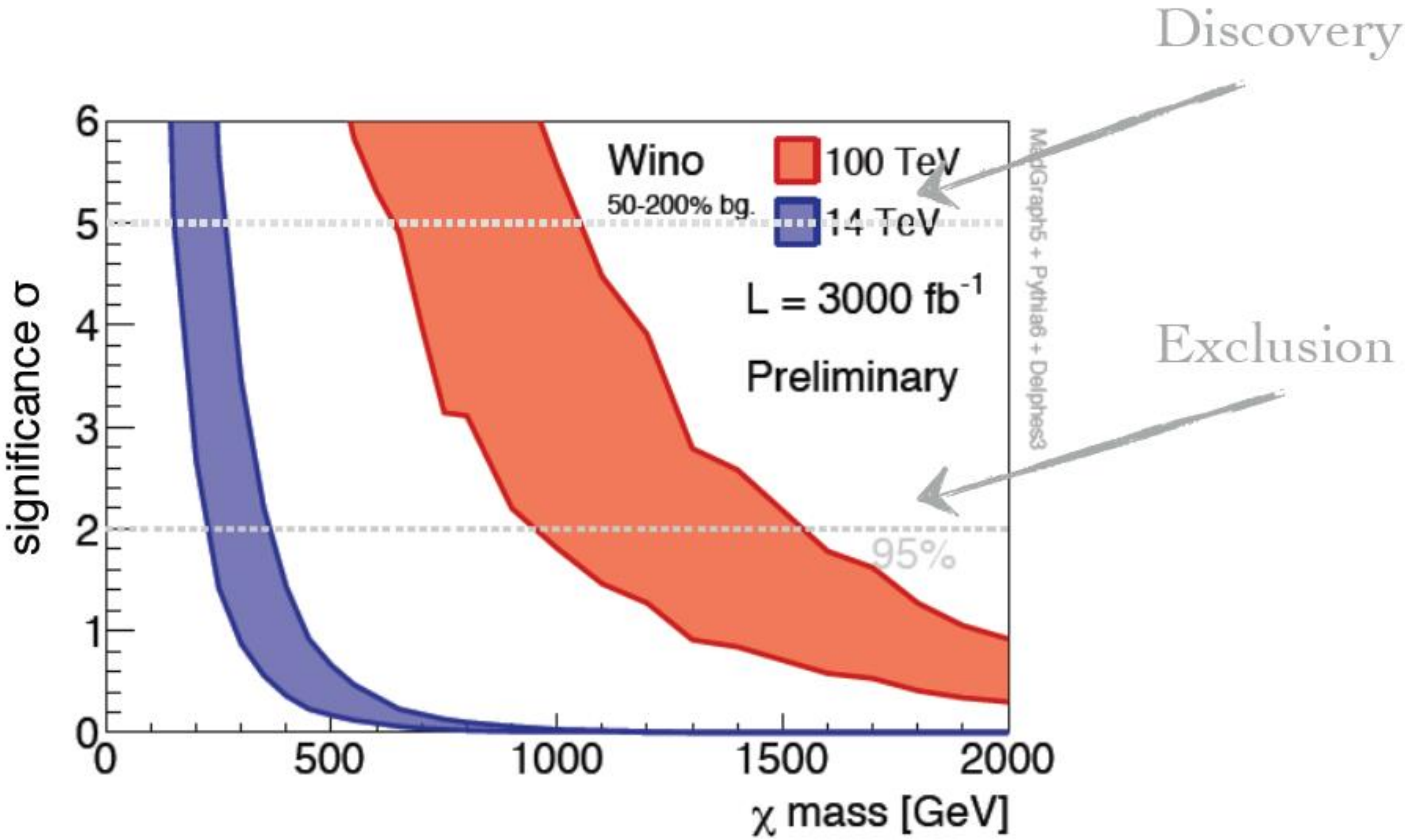
In the 1970's Vera Rubin measured rotation curves of many galaxies to high precision

Vera Rubin

暗物质

- 标准模型不包含冷暗物质
- 冷暗物质如果参与弱作用，可以自然的解释需要的暗物质丰度
- 暗物质的加速器探测至关重要，对于确认它存在至关重要，并可以研究暗物质的相互作用性质

Wino reach at 100 TeV



Talk given by Lian-Tao Wang

TeV Workshop, Guangzhou 2014

Higgs与CP破坏

Zhu, arXiv:1211.2370

- 标准模型不能够解释宇宙中物质不对称性
- H（125）质量较轻(与可能的新物理能量标度相比)，Higgs质量也可能预示着它与CP自发破缺有关(在CP严格守恒下Higgs质量为0)
- Higgs可能为CP的混合态，而且可能有其他较重的Higgs
- 需要CEPC/SPPC检验整个图像！

味物理标度：下一个标度？

Origins of Fermion Mass

- If new physics enters the generation of fermion mass, then Yukawa couplings will be modified

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

Dicus & He, arXiv:hep-ph/0409131

$\xi_1\xi_2$	$V_L V_L$	$t\bar{t}$	$b\bar{b}$	$c\bar{c}$	$s\bar{s}$	$d\bar{d}$	$u\bar{u}$	$\tau^-\tau^+$	$\mu^-\mu^+$	e^-e^+	$\nu_L\nu_L$
Mass (GeV)	80.4	178	4.85	1.65	0.105	0.006	0.003	1.777	0.106	5.11×10^{-4}	5×10^{-11}
n_s	2	2	4	6	8	10	10	6	8	12	22
$E^{\star(\min)}_{2\to n}$ (TeV)	1.2	3.49	23.4	30.8	52.1	77.4	83.6	33.9	56.3	107	158
$E^{\star}_{2\to 2}$ (TeV)	1.2	3.49	128	377	6×10^3	10^5	2×10^5	606	10^4	2×10^6	1.1×10^{13}

- 2-> n scattering put upper bounds on scales of mass generations of the last two generation of quarks and leptons within 3.5-56 TeV and the third one within 77-107 TeV

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结论与展望

8个工作小组

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)

历史

- 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, 1st CFHEP symposium

Physics at Circular Electron-Positron Collider (CEPC) and Super Proton-Proton Collider (SPPC)

Shou-Shan Bao,[a] Xiao-jun Bi,[b] Jun-Jie Cao,[c] Qing-hong Cao,[d,e] Ning Chen,[f] Bo Feng,[g] Lei Guo,[h] Hong-Jian He (convenor),[f] Chong Sheng Li,[d,e] Hong-Lei Li,[i] Tianjun Li,[j] Ying Li,[k] Zhao Li,[b] Wei Liao,[l] Yi Liao,[m] Chun Liu[j] Ji-Yuan Liu,[n] Tao Liu,[o] Cai-dian Lu,[b] Ming-xin Luo,[g] Wen-gan Ma,[h] Cong-Feng Qiao,[p] Hua-sheng Shao,[d] Jing Shu,[j] Zong-Guo Si,[a] Jian-Xiong Wang,[b] Kai Wang,[g] Xiao-Hong Wu,[l] Qi-shu Yan,[p] Jinmin Yang,[j] Li-lin Yang,[d,e] Shuo Yang,[q] Peng-fei Yin,[b] Chong-Xing Yue,[r] Ren-you Zhang,[h] Xin-min Zhang,[b] Yu-Feng Zhou,[j] Guo-huai Zhu,[g] Shou-hua Zhu (convenor),[d,e] more authors to be added[xxx]

~40 authors, more to be added

~200 pages

Higgs Physics at the CEPC-SPPC

Tao Liu

Hong Kong University of Science and Technology

Higgs Portal into New Physics

- If new physics (NP) manifests itself as SM singlet operators, the 125 GeV Higgs is one of the two fields in the SM which may couple with it via renormalizable couplings [Patt and Wilczek, arXiv:[hep-ph/0605188]]

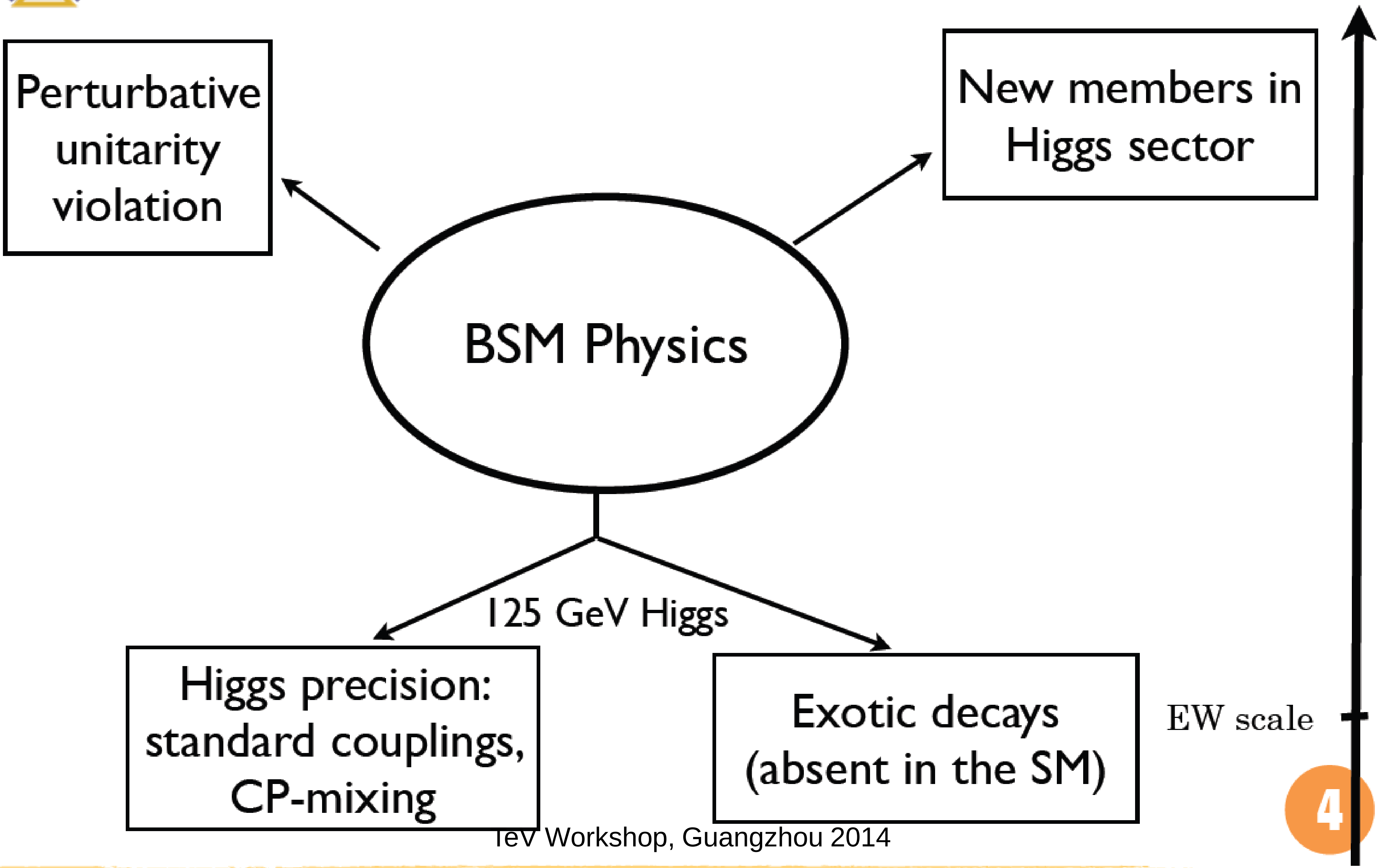
$$\mathcal{L} \supset \lambda H^\dagger H \mathcal{O}_{\rm NP}$$

Lorentz invariant gauge singlet

- If NP serves as a mechanism for stabilizing the 125 GeV Higgs mass (e.g., SUSY), then the Higgs needs to couple with the NP directly

- Both types of couplings can have significant implications for Higgs collider phenomenology.

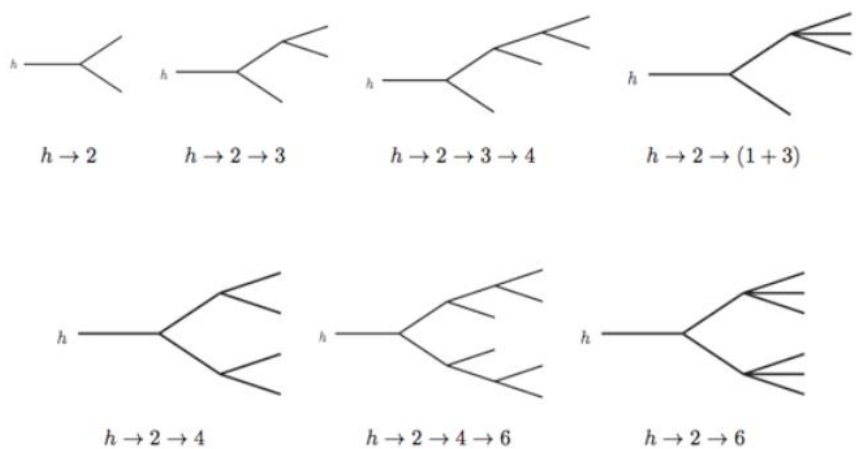
Implications for Higgs Collider Phenomenology



H(125)非标准模型衰变道

(2) Many Topologies

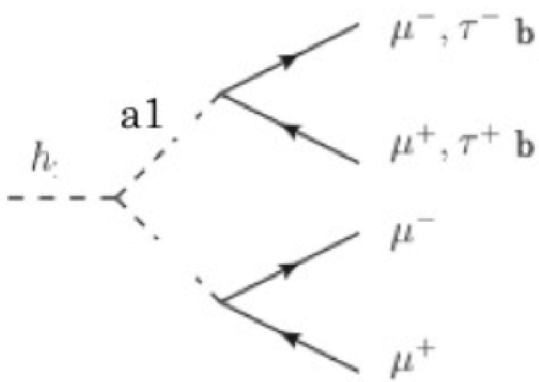
- If the initial exotic decay of the 125 GeV Higgs is 2-body, there are many possibilities
- Collider signature can be classified into three cases: purely invisible, semi-invisible and visible

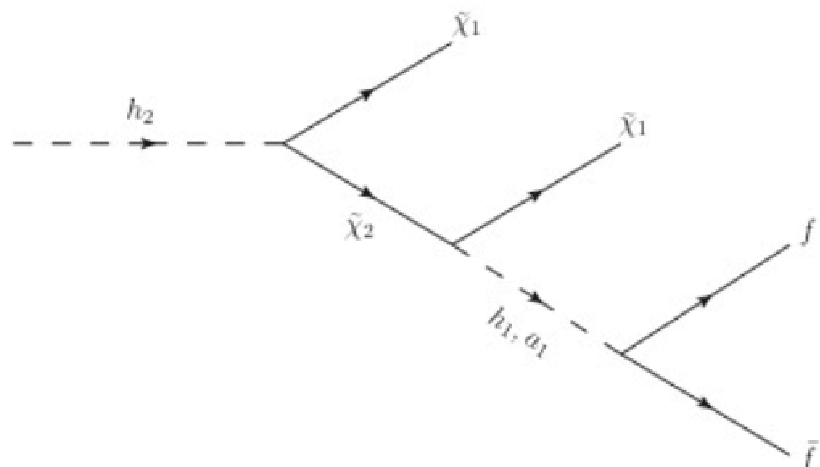


$h \to$ MET
$h \to 4b$
$h \to 2b2\tau$
$h \to 2b2\mu$
$h \to 4\tau, 2\tau2\mu$
$h \to 4j$
$h \to 2\gamma 2j$
$h \to 4\gamma$
$h \to ZZ_D \to 4l$
$h \to Z_D Z_D \to 4l$
$h \to \gamma$+MET
$h \to 2\gamma$+MET
$h \to 4l$+MET
$h \to 2l$+MET
$h \to$ one lepton je
$h \to$ two lepton je
$h \to bb$+MET
$h \to \tau\tau$+MET

(3) Good Motivation in Theory

- SM+S, 2HDM+S
  - gives h -> 2a -> 2f 2f'
  - include R-symmetry limit of the NMSSM
- SM + one or two fermions
  - gives h -> invisible or semi-visible
  - included PQ-limit of the NMSSM
- SM + dark vector boson





[Dobrescu et al., Phys. Rev. D 63 (2001); Dermisek, Gunion, Phys. Rev. Lett. 95 (2005)]

[Draper, TL, Wagner, Wang and Zhang, Phys. Rev. Lett. 106 (2011); J. Huang, TL, L.T.Wang and F. Yu, arXiv: 1309.6633]

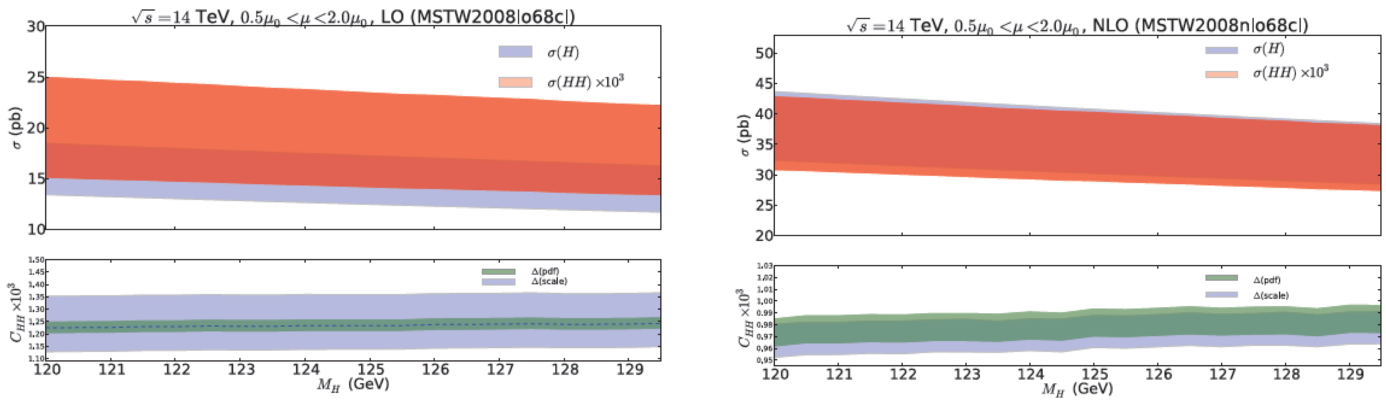
SPPC对于Higgs自耦合的测量

Higgs Self-coupling

Li Lin Yang

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

$\frac{2}{1}$ method



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

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)	[illegible]	[illegible]	(0.48, 1.87)

To achieve same sensitivity

L/3.4 (50TeV)

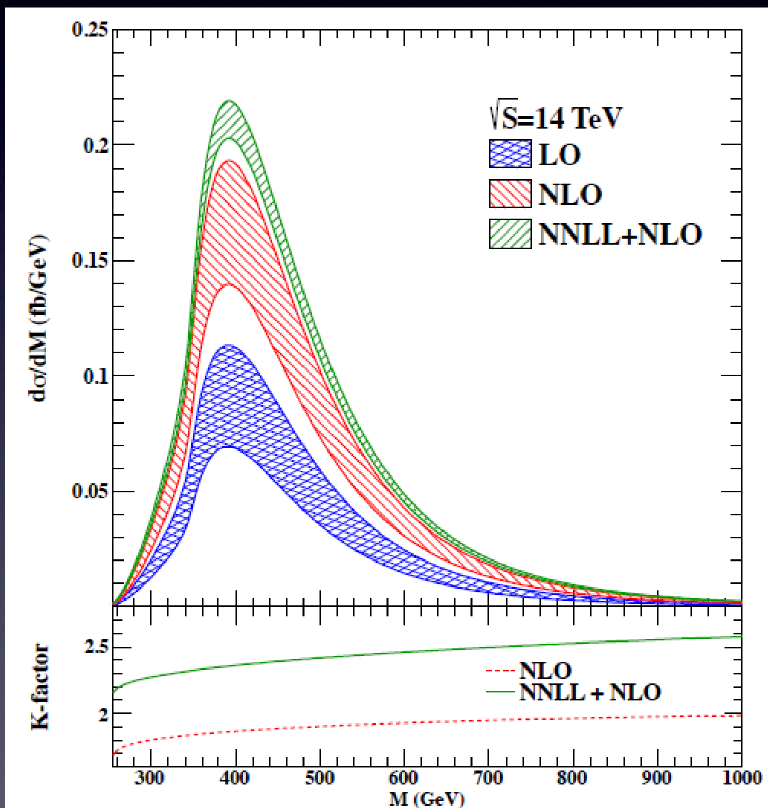
L/5.8 (100TeV)

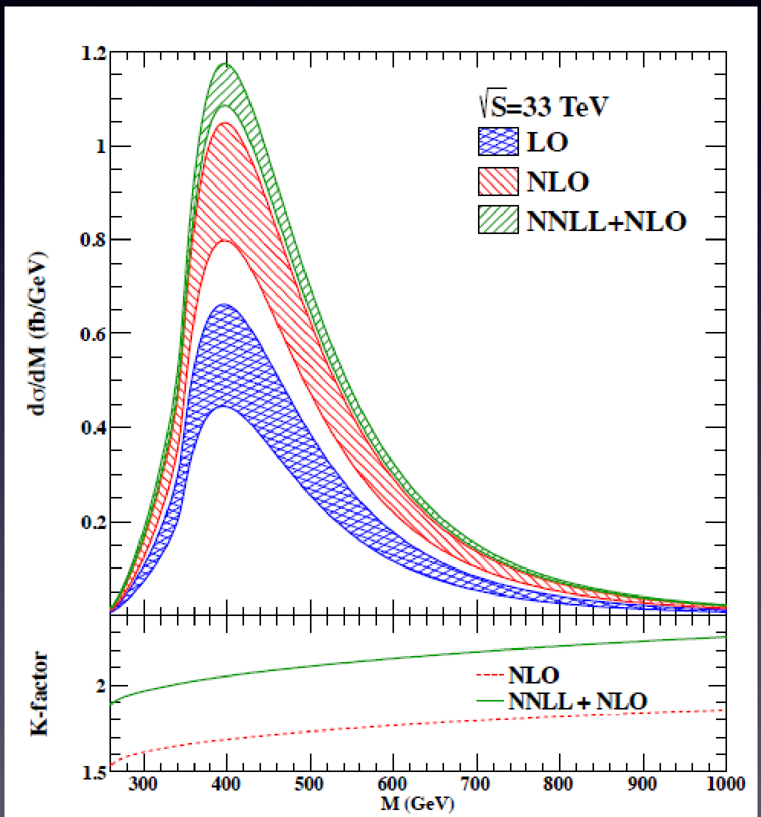
Higgs Self-coupling

Threshold resummation effects at the NNLL

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

Also see 1401.1101

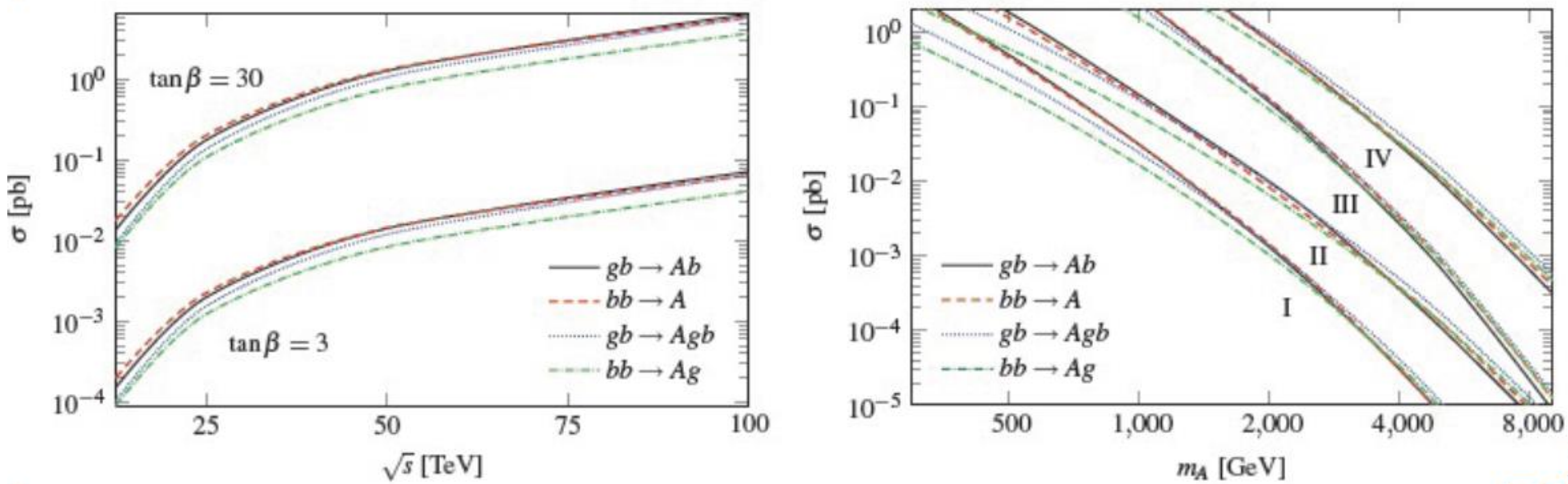




Scale Error ~8%, PDF+alphas Error ~10%

SPPC发现其他非标准Higgs粒子

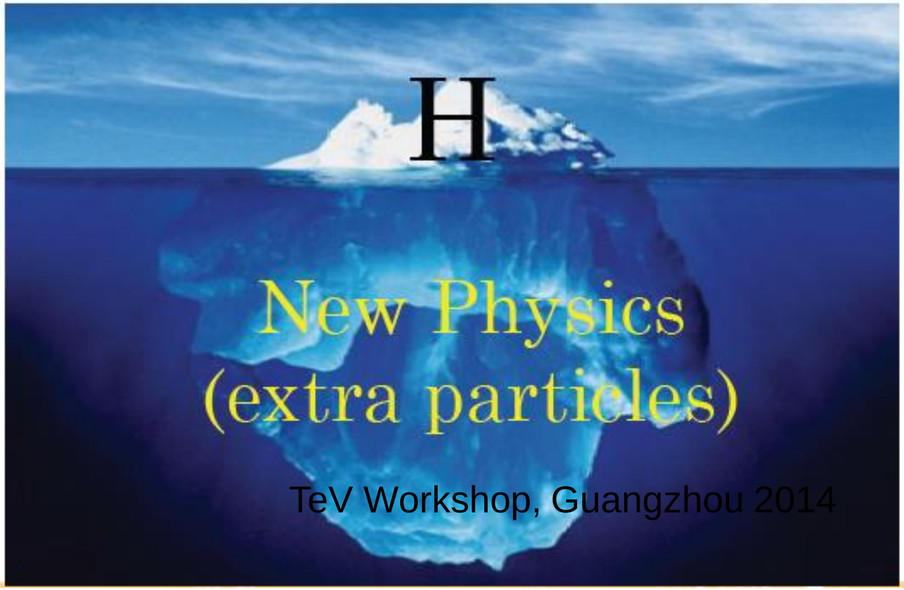
- Can be electrically neutral, singly charged, doubly charged. The SPPC can play a role in performing searches over larger possible mass range!
- Using the MSSM as an example, the production cross section of the CP-odd Higgs boson is enhanced by roughly two orders at the SPPC, compared with the LHC.



Hajar, Liu

Questions to Address

- CP properties of the 125 GeV Higgs: systematic asses potential for their measuring at the ILC
- Exotic decay of 125 GeV Higgs: systematic assess potential for discovery at the ILC
- Higgs unitarity: assess potential for probing it at the SPPC
- Nonstandard Higgs boson: new search strategies, CP-violation



First CFHEP Symposium on Circular Collider Physics

Standard Model Tests

Qing-Hong Cao

Peking University

On behalf of the SM Working Group

Chong Sheng Li Zhao Li Li Lin Yang

Untested Aspects of the SM

Higgs electroweak couplings

See Higgs Working-Group's report

Higgs boson self-coupling

Boosted object techniques

Triple-gauge-coupling / Quartic-gauge-coupling

Dim-6 and Dim-8 operators in linear realization

Weak interaction of the 3rd generation quarks

Fully understanding top- and bottom-quark chirality structure of couplings, $V_{tb}=1$? ...

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

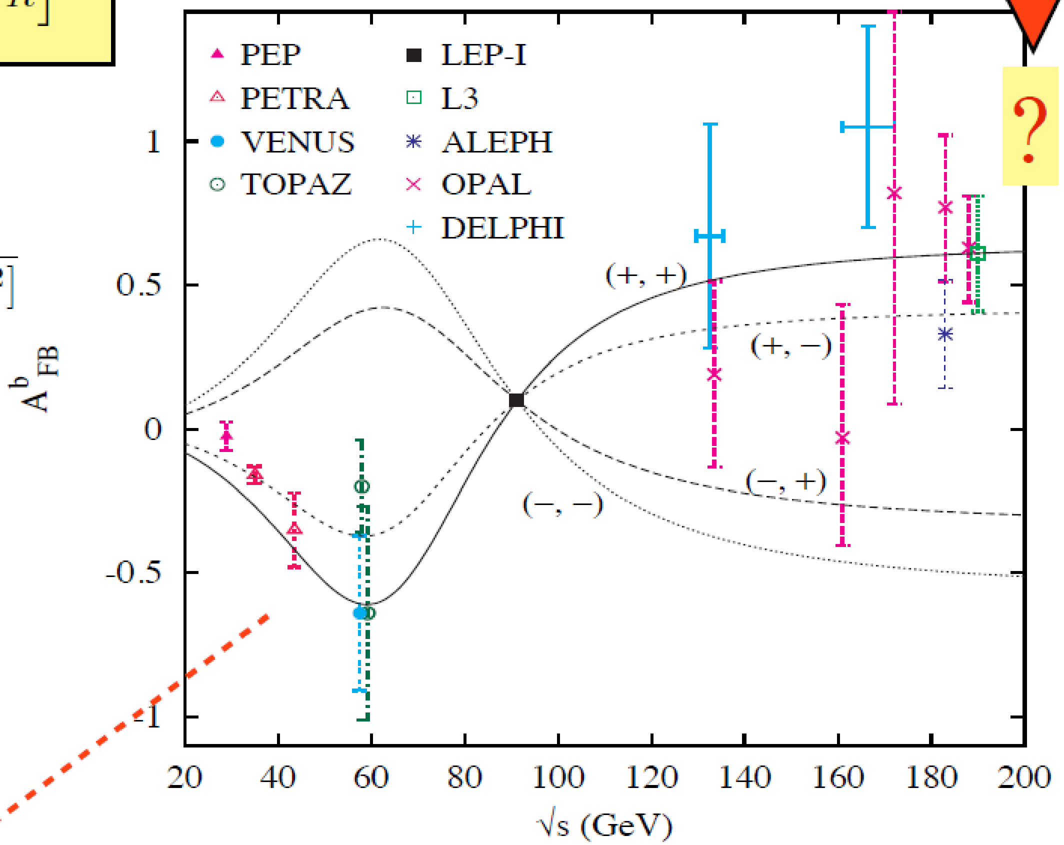
CEPC

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

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

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

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



+

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

SUSY: Status and Future Probe

Jin Min Yang

(ITP, Beijing)

1st CFHEP Symposium on CCP

2014.2.25

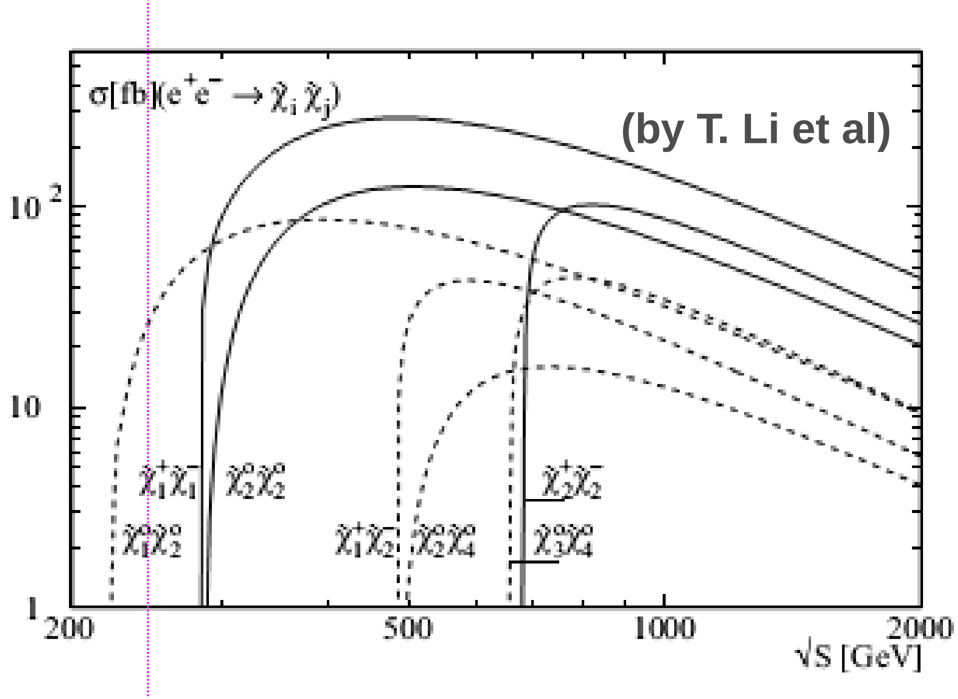
Model Ranking

Savas Dimopoulos

Model	Grade
MSSM	D–
NMSSM	D
Natural SUSY	C
R-parity breaking	C
Colorless Top Partners	C
Split SUSY	B

3.3 Probe SUSY at Higgs factory

Direct production of sparticles:



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

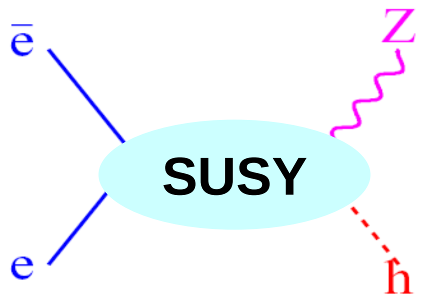
Direct search of SUSY is limited

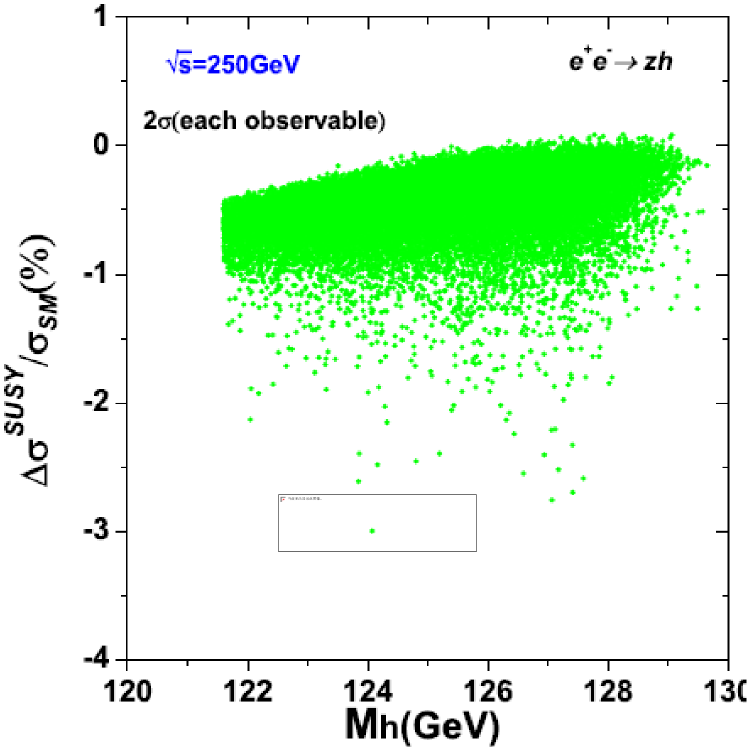
We may look for quantum effects of SUSY

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

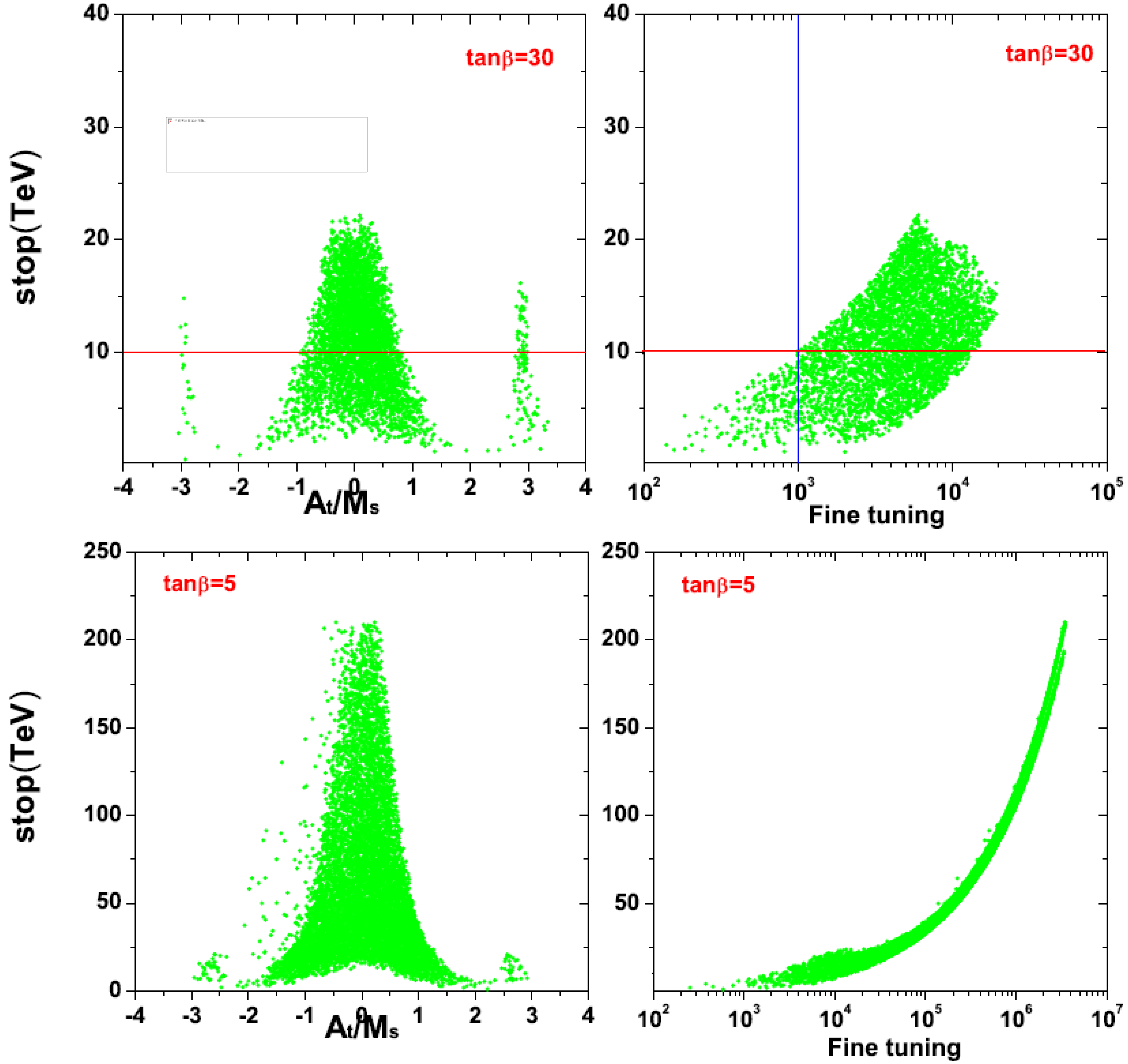
can sizably differ from SM:

Han, Wu, Wu,JMY,
work in progress





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



4 Conclusion

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):

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

Non-SUSY theories in CEPC & SppC

Jing Shu

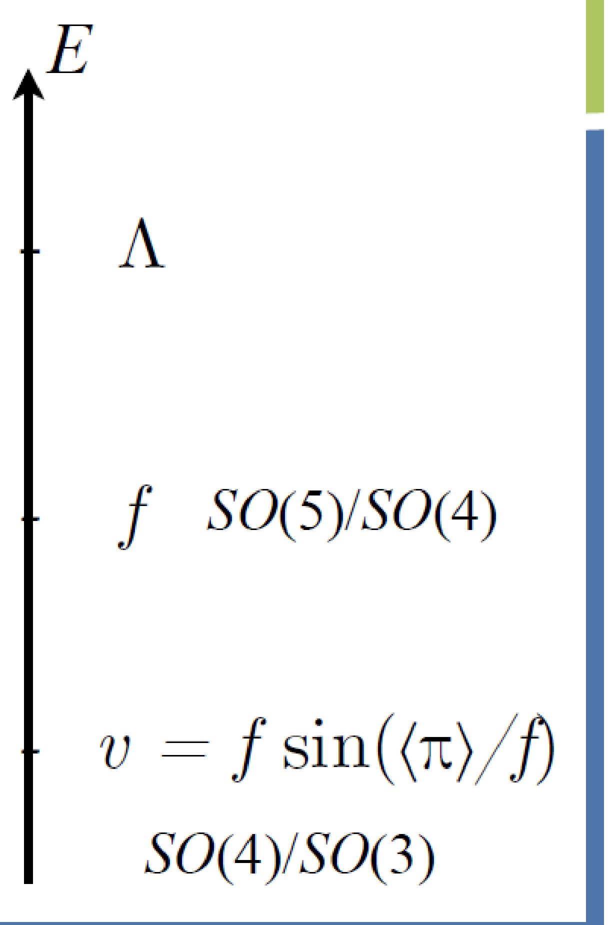
ITP

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



Neutrino Physics at Colliders

Yi Liao

Nankai Univ

Special thanks to Dr. Ji-Yuan Liu for collaboration and help

Summary and outlook

- Great progress in measurements on neutrino parameters, including the oscillation data, cosmological observations, and other low-energy experiments, is very helpful for us to do realistic collider phenomenology.
- Conventional seesaw models have been fully studied in the literature except for type III. Type I has been done for *effective case*.
- There are a variety of models beyond conventional seesaws, some of which have been studied and some are being considered. An open but challenging task is how to distinguish them at colliders.
- Neutrino phys at lepton colliders has been less intensively studied because of limited achievable energy for heavy particles, while study at very high energy colliders has just started.

Working group report
-- cosmology

Bi XJ, Chen SL, Gu PH, Shu J, Yin PF, Yu ZH, Zhang XM, Zhou YF
(more are welcome)

IHEP

2014-2-25

Summary

- DM search at CEPC has little advantage.
- Study on DM @ SPPC is preliminary. More study (SUSYs, minimal …) is in progress

- EW baryogenesis is testable at the CEPC. Works are under way.

Top Quark Physics

Zong-Guo SI

School of Physics, Shandong University

25 Feb. 2014

CFHEP Kickoff Meeting, IHEP, Beijing

Tera-Top

Top Quark Physics: Outline

- Properties of Top Quark
- Top Quark Decay
- Cross Section for Hadronic $t\bar{t}$ Production
- Charge Asymmetry in Hadronic $t\bar{t}$ Production
- Top Quark Spin Effects in Hadronic $t\bar{t}$ Production
- Top Quark Spin and Top Quark Coupling
  - Top Quark Spin and Anomalous Top Quark Coupling
  - Top Quark Spin and W' Chiral Coupling

Some topics of Flavor physics

Zhen-Jun Xiao

Nanjing Normal University, Nanjing, P.R. China

1st CFHEP Symposium on CCP, Feb.24-25, 2014, China

5、Summary and outlooks

- After the discovery of the Higgs, what shall we do next !

  Flavor physics confronts the searches for NP ?
- During past 30 years, the flavor physics got great success, leads to the Nobel prize of 2008.
- SM is OK, we see some deviations or puzzles, but no solid evidence for NP beyond the SM。
- Many people believe the existence of the NP, how to find it?
- High precision th. Predictions and exp. Measurements are the key points to increase the sensitivity of NP.
- The new particles in NP could contribute in loops, which can be detected in LHCb, super-B or other high precision experiments!
- In China, the HEP community has done very good jobs in Flavor Physics, we should and can contribute a lot in searching for NP in the following years!

Higgs Precision Measurements and Flavor Physics: A Supersymmetric Example

Review for "Chinese Science Bulletin" and CEPC+SPPC Proposal

Kai Wang and Guohuai Zhu

Zhejiang Institute of Modern Physics and Department of Physics,

Zhejiang University, Hangzhou, Zhejiang 310027, CHINA

Rare decays in flavor physics often suffer from Helicity suppress and Loop suppress. Helicity flip is a direct consequence of chiral $U(3)$ symmetry breaking and electroweak symmetry breaking. The identical feature is also shared by the mass generation of SM fermions. In this review, we use MSSM as an example to illustrate an explicit connection between bottom Yukawa coupling and rare decay process of $b \to s\gamma$. We take a symmetry

arXiv:1312.4010

MC tools
Working Group's Report

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

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

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.

CFHEP Symposium, Beijing, Feb. 24-25, 2014

Properties of the hottest matter at a future high-energy collider

Xin-Nian Wang
王新年
Central China Normal University
Lawrence Berkeley National Laboratory

BERKELEY LAB

Conclusions

- A future circular collider will provide great physics opportunities for the study of hot matter at extremely high temperature
- At T ~ 700 MeV, it might approach the perturbative regime of a weakly interacting QGP

Hadron Spectroscopy from Strangeness to charm and beauty

Bing-Song Zou
Institute of Theoretical Physics and
Institute of High Energy Physics, CAS, Beijing

TeV Workshop, Guangzhou 2014

4. Prospects at CCP

- CCP – Circular Collider of Particles (e^+e^-, pp, ep, …)
- For hadron spectroscopy at CCP, high priority:

  XYZ mesons with hidden $c\bar{c}$ or $b\bar{b}$ @super c-b

  Ω^* baryons @super c

  Superheavy N^*&Λ^* with hidden $c\bar{c}$ or $b\bar{b}$ @ ep, pp

- XYZ production from $\gamma^*\gamma^*$, $\mathfrak{P}\mathfrak{P}$, $\gamma^*\mathfrak{P}$ by (e^+e^-, pp, ep)

  → XYZ&$\mathfrak{P}$ structure, $q\bar{q}$ production mechanisms

内容

- CEPC/SPPC的物理目标（为什么要建CEPC/SPPC？）
- CEPC/SPPC理论工作组的进展汇报（主要取自1st CFHEP会议报告）
- 结论与展望

结论与展望

- H(125)的发现使得人们得到一个自洽的理论：标准模型
- 标准模型很成功，但超出标准模型物理有很好的动机，如自然性考虑，暗物质，物质与反物质不对称性（CPV的来源），味物理等等。

结论与展望（续）

- 精确测量H(125)的性质是CEPC自然的物理目标，可以达到比LHC更高的测量精度。
- H(125)的非标准的衰变模式的寻找（存在非标准模型的新粒子）以及耦合可能与标准模型的偏离将提供新物理的信息。
- 澄清超出标准模型图像往往需要高能量的SPPC。
- SPPC将是人类可控分辨率最高的仪器！其直接发现新物理的能力远大于LHC。

谢谢！

但是……

N. Arkani-Hamed

* Higgs + nothing else @ 100 TeV

$\Rightarrow \sim 10^{-4}$ tuning!

* Never seen this level of tuning in particle physics – NEW.

CAN'T SHRUG SHOULDERS

N. Arkani-Hamed

* It's the <u>OBVIOUS</u> <u>FUTURE</u>

* BIG machines
  BIG physics ideas

Lifeblood of The Field

Backup: ILC250与TLEP240定义

Collider	ILC 250	TLEP 240
$\mathcal{L}_{\rm tot}$ (fb^{-1})	250	10^4
Higgs bosons from Higgs-strahlung	7×10^4	2×10^6
Higgs bosons from WW fusion	3×10^3	5×10^4

Table 11. Integrated luminosity and number of Higgs bosons produced at ILC-250 GeV (with beam polarizations of $P(e^+, e^-) = (0.3, -0.8)$) and TLEP-240 GeV (with four IPs).

	ILC	LEP3 (2)	LEP3 (4)	TLEP (2)	LHC (300)	HL-LHC
σ_{hZ}	3%	1.9%	1.3%	0.7%	–	–
$\sigma_{\mathrm{hZ}} \times \mathrm{Br}(\mathrm{h} \to \mathrm{b\bar{b}})$	1%	0.8%	0.5%	0.2%	–	–
$\sigma_{\mathrm{hZ}} \times \mathrm{Br}(\mathrm{h} \to \tau^+\tau^-)$	6%	3.0%	2.2%	1.3%	–	–
$\sigma_{\mathrm{hZ}} \times \mathrm{BR}(\mathrm{H} \to W^+W^-)$	8%	3.6%	2.5%	1.6%	–	–
$\sigma_{\mathrm{hZ}} \times \mathrm{BR}(\mathrm{H} \to \gamma\gamma)$	?	9.5%	6.6%	4.2%	–	–
$\sigma_{\mathrm{hZ}} \times \mathrm{BR}(\mathrm{H} \to \mu^+\mu^-)$	–	–	28%	17%	–	–
$\sigma_{\mathrm{hZ}} \times \mathrm{BR}(\mathrm{H} \to \mathrm{invisible})$	?	1%	0.7%	0.4%	–	–
g_{hZZ}	1.5%	0.9%	0.6%	0.3%	13%/5.7%	4.5%
g_{hbb}	1.6%	1.0%	0.7%	0.4%	21%/14.5%	11%
$g_{h\tau\tau}$	3%	2.0%	1.5%	0.6%	13%/8.5%	5.4%
g_{hcc}	4%	?	?	0.9%	?/?	?
g_{hWW}	4%	2.2%	1.5%	0.9%	11%/5.7%	4.5%
$g_{h\gamma\gamma}$	?	4.9%	3.4%	2.2%	?/6.5%	5.4%
$g_{h\mu\mu}$	–	–	14%	9%	?	?
g_{htt}	–	–	–	–	14%	8%
M_h (MeV/c^2)	50	37	26	11	100	100

Table 15. The precision (or 95% C.L. sensitivity for the invisible decay) on the Higgs boson cross subsections and couplings obtained from studies of the Higgsstrahlung process, with five years of running at the ILC, at LEP3 with CMS and ATLAS, and at LEP3 with two additional detectors of similar performance. The numbers for the ILC were obtained with $m_{\mathrm{H}} = 120\,\mathrm{GeV}/c^2$, $\sqrt{s} = 250\,\mathrm{GeV}$, and leading-order cross subsections, while those for LEP3 were conservatively obtained with $m_{\mathrm{H}} = 125\,\mathrm{GeV}/c^2$, $\sqrt{s} = 240\,\mathrm{GeV}$, and next-to-next-to-leading-order cross subsection. The number from TLEP assume two detectors with performance similar to those developed for ILC. The LEP3 missing couplings will be added in a forthcoming update of this note. For completeness, the LHC sensitivity with 300 and 3000 fb^{-1} at 13 TeV is also given. For 300 fb^{-1}, the model-independent projections from SFITTER and the simplified-model projection from CMS are shown, while only the latter is available HL-LHC. The precision on the Higgs boson mass is indicated in the last row of the table.

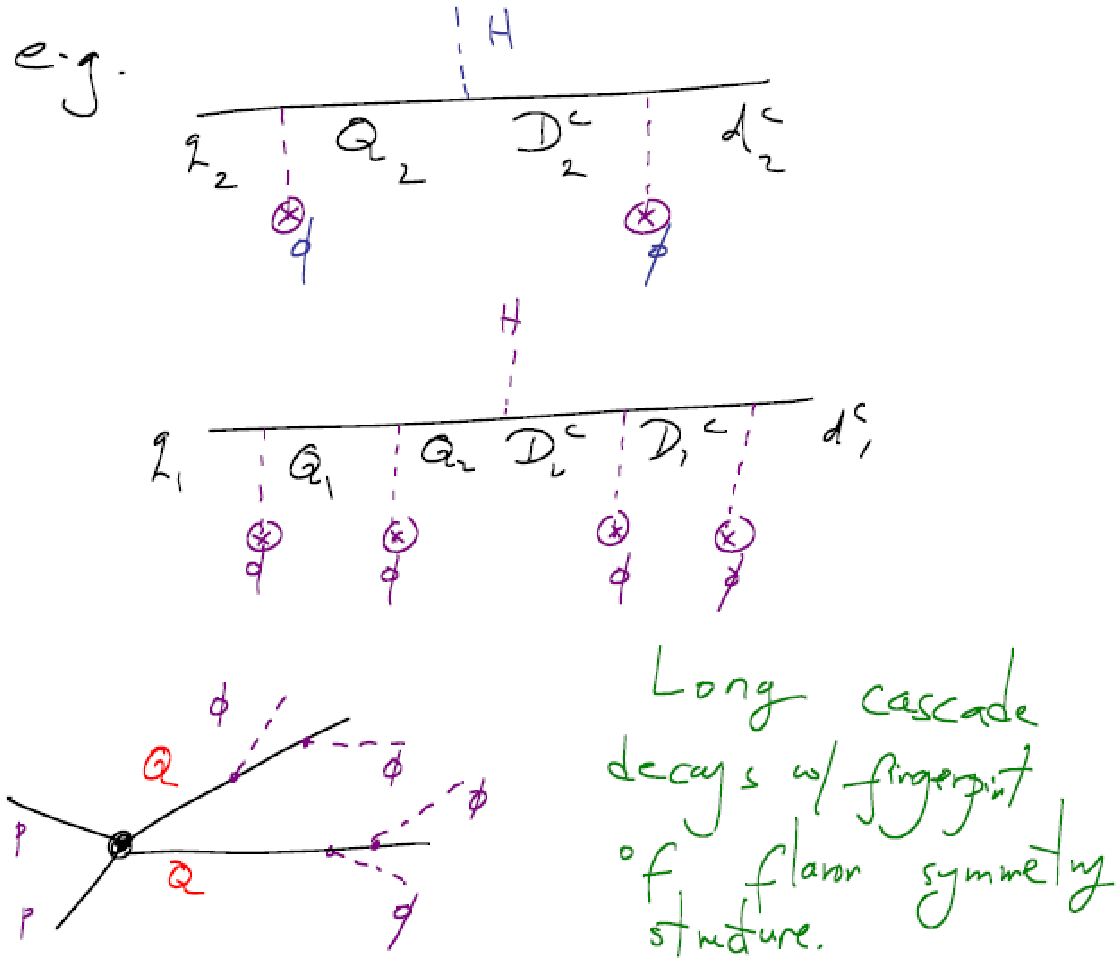
精确测量

* Circular e^+e^- machine
Higgs Factory plays very important, complementary role

Looking for $\frac{h^\dagger h \, (h Q b^c)}{\Lambda^2}$, $\frac{(h^\dagger D_\mu h)^2}{\Lambda^2}$, ...

* Tera-Z particularly exciting + powerful probe!

味物理


e.g.
H
q_2 Q_2 D_2^c d_2^c
ϕ ϕ
H
q_1 Q_1 Q_2 D_2^c D_1^c d_1^c
ϕ ϕ ϕ ϕ
p p Q Q ϕ ϕ ϕ ϕ
Long cascade decays w/ fingerprint of flavor symmetry structure.