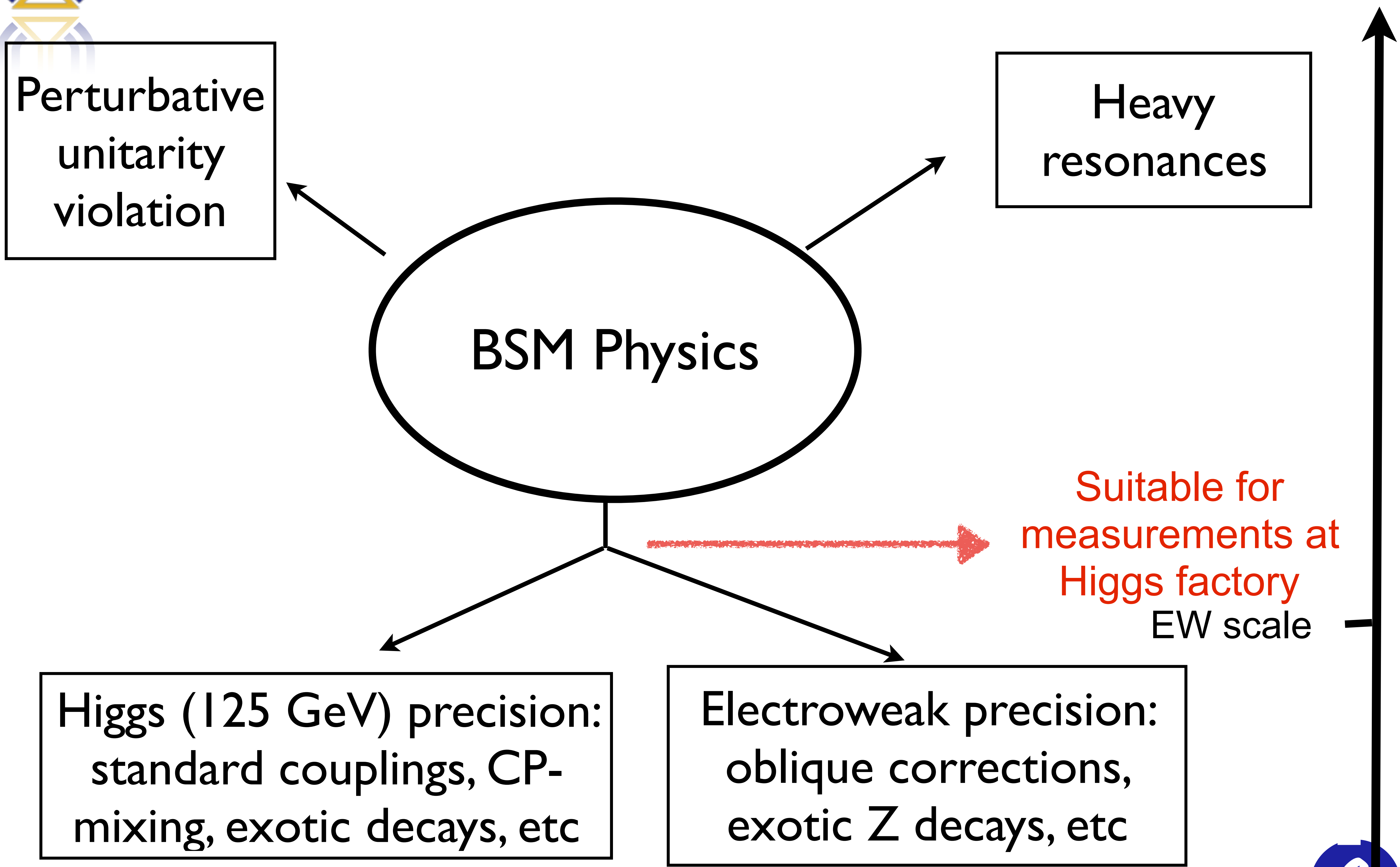
SUMMARY OF PHYSICS AT CEPC

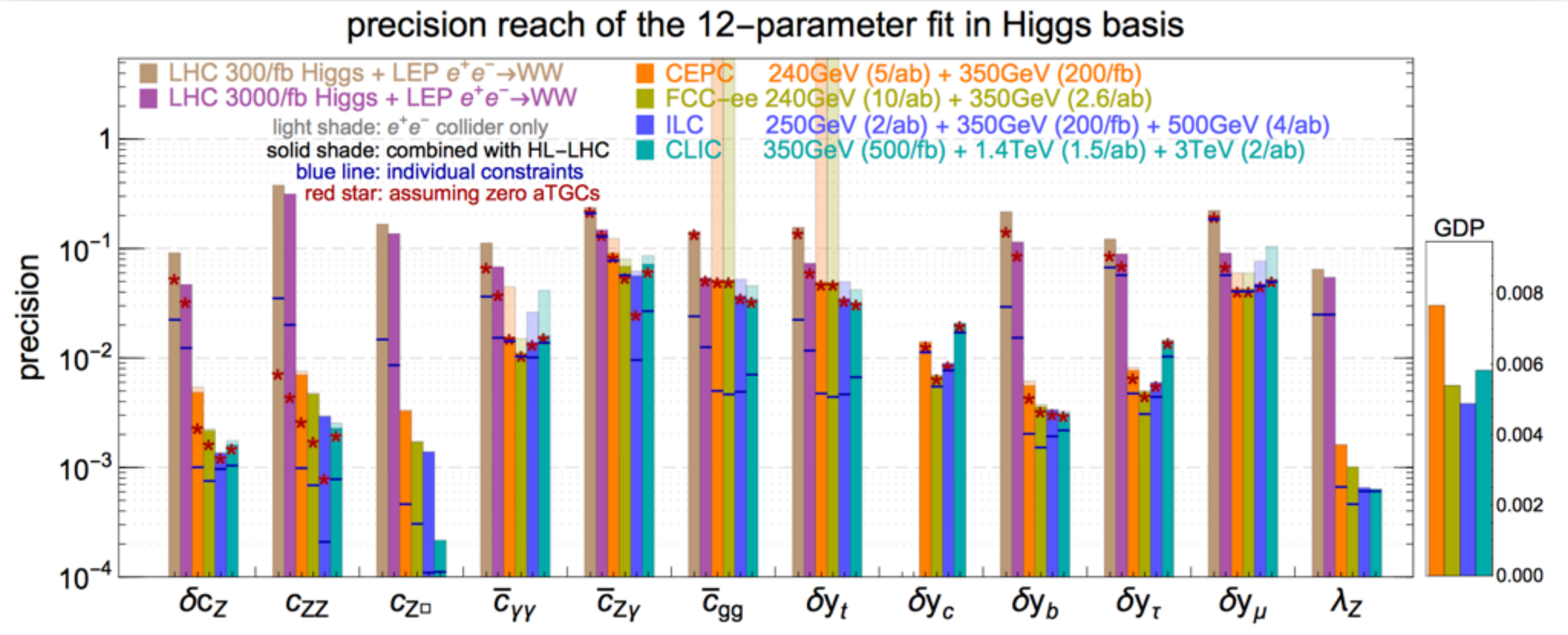
Tao Liu

The Hong Kong University of Science and Technology

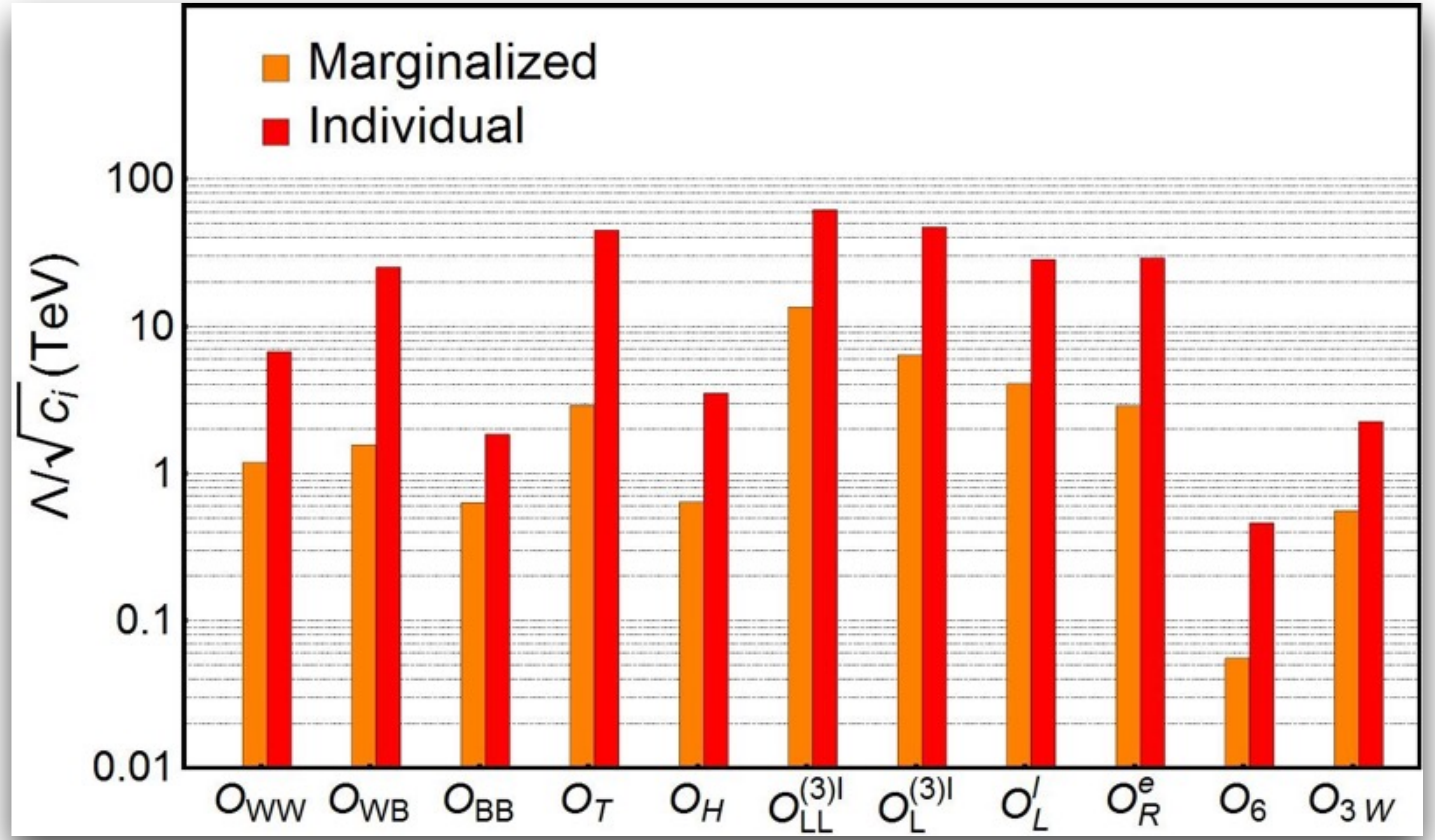
BSM Physics at a Higgs Factory



Higgs EFT

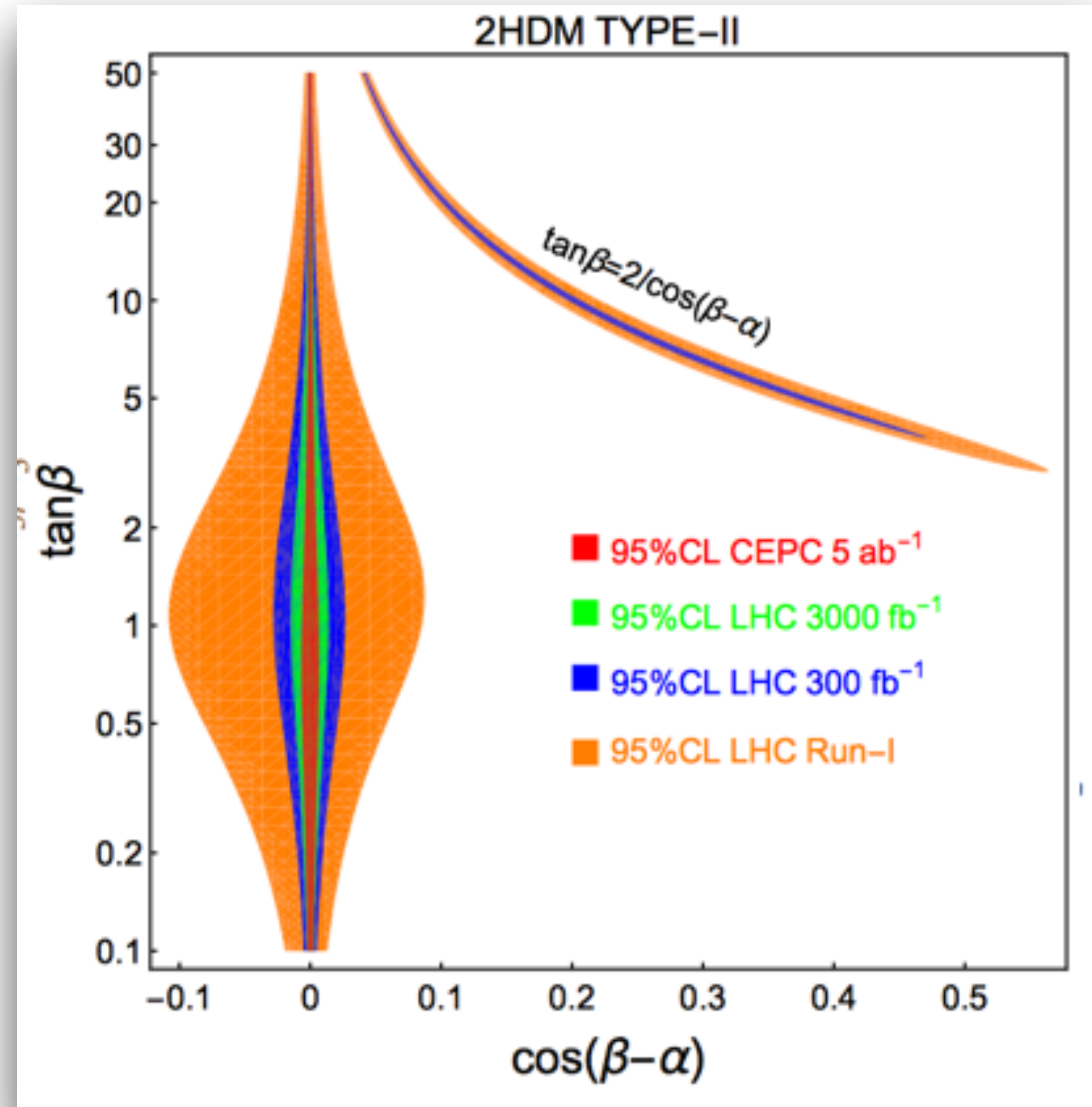

precision reach of the 12−parameter fit in Higgs basis
LHC 300/fb Higgs + LEP e+e−→WW
LHC 3000/fb Higgs + LEP e+e−→WW
light shade: e+e− collider only
solid shade: combined with HL−LHC
blue line: individual constraints
red star: assuming zero aTGCs
CEPC 240GeV (5/ab) + 350GeV (200/fb)
FCC−ee 240GeV (10/ab) + 350GeV (2.6/ab)
ILC 250GeV (2/ab) + 350GeV (200/fb) + 500GeV (4/ab)
CLIC 350GeV (500/fb) + 1.4TeV (1.5/ab) + 3TeV (2/ab)
precision
GDP
δcZ
cZZ
cZ□
c̄γγ
c̄Zγ
c̄gg
δyt
δyc
δyb
δyτ
δyμ
λZ

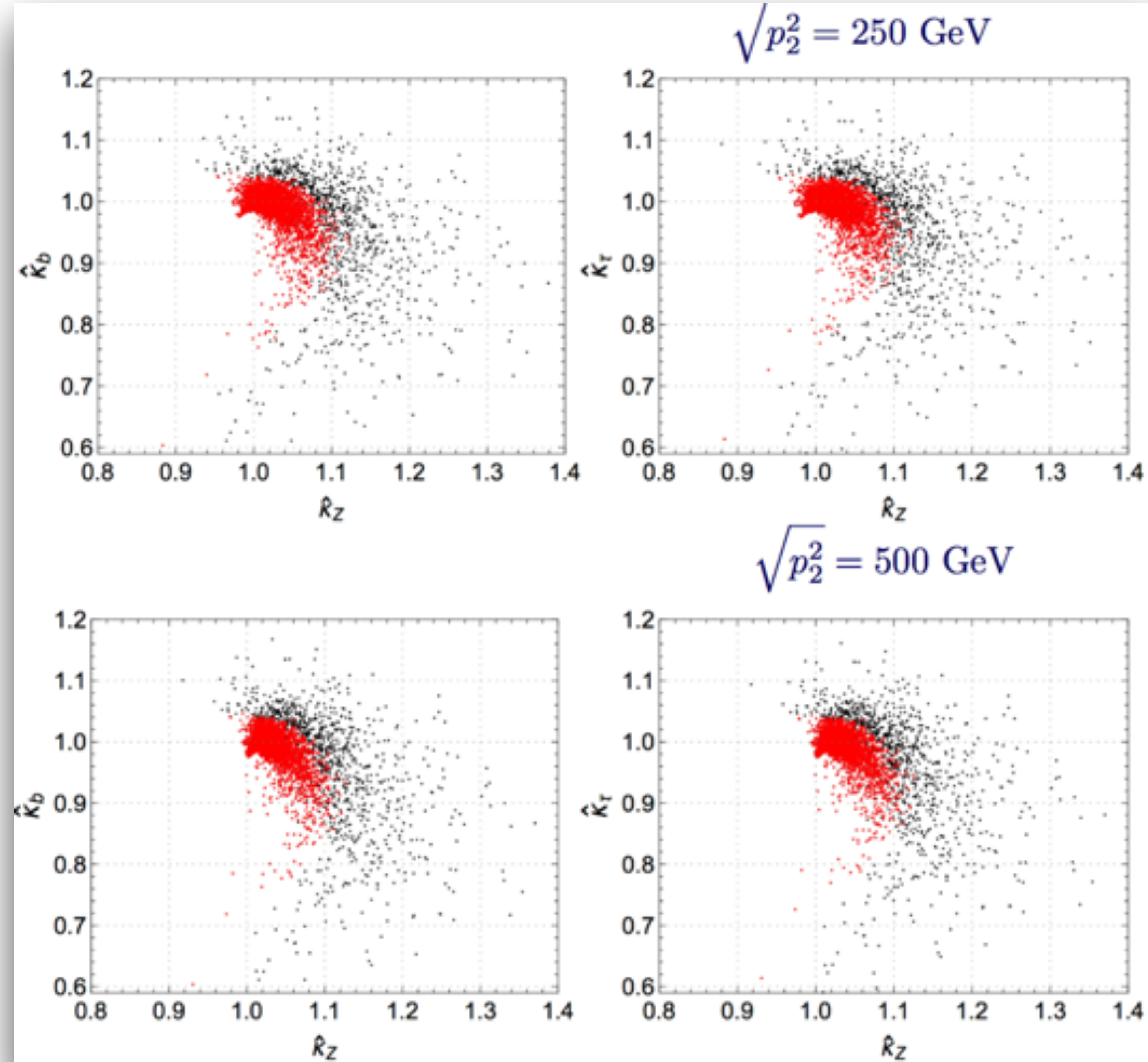
L.-T. Wang


Marginalized
Individual
100
10
1
0.1
0.01
$\Lambda/\sqrt{c_i}$ (TeV)
O_{WW}
O_{WB}
O_{BB}
O_T
O_H
$O_{LL}^{(3)l}$
$O_L^{(3)l}$
O_L^l
O_R^e
O_6
O_{3W}

Perturbative Theories (THDM, GM Model, etc.)

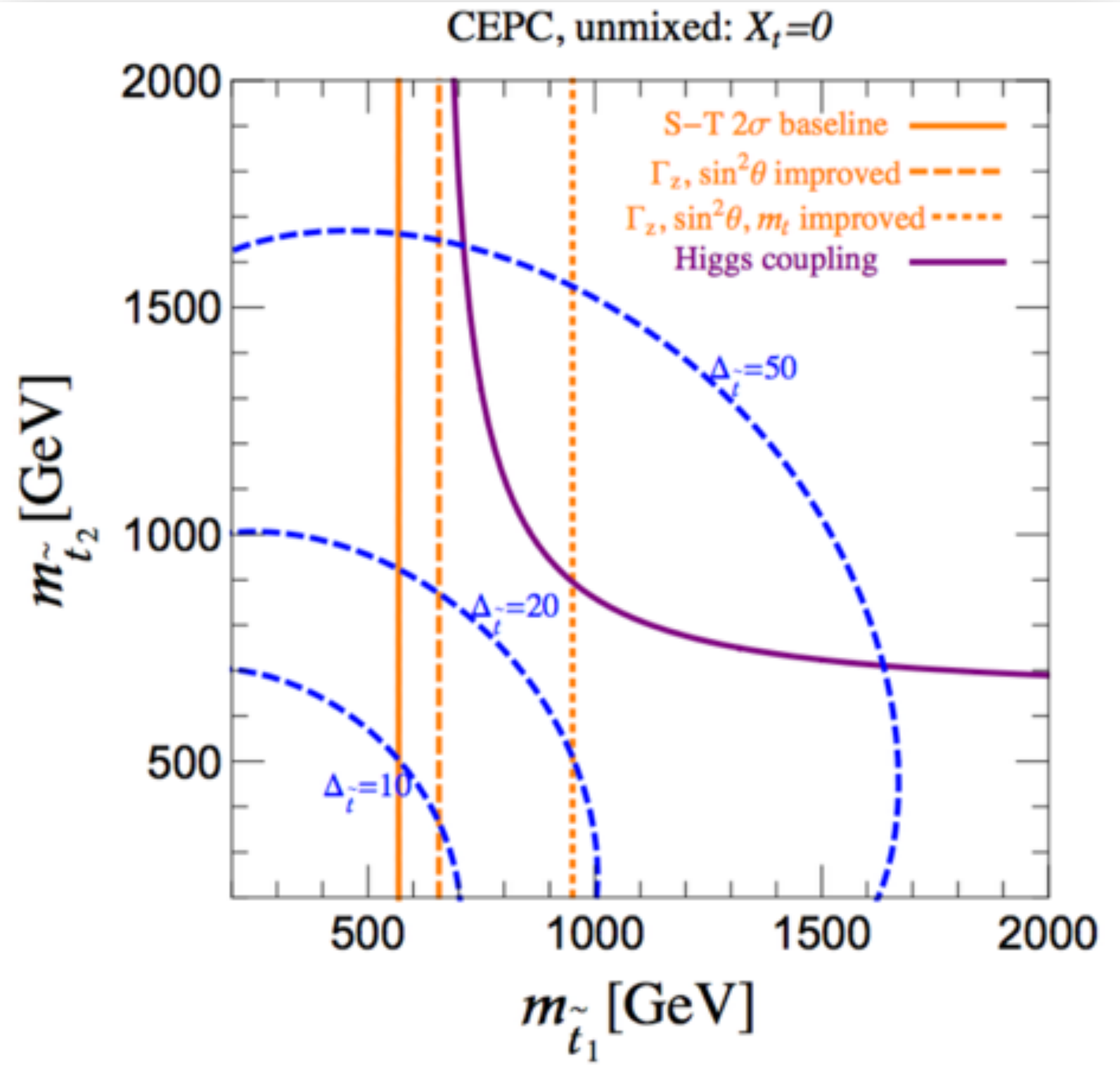
Shufang Su, Cheng-Wei Chiang

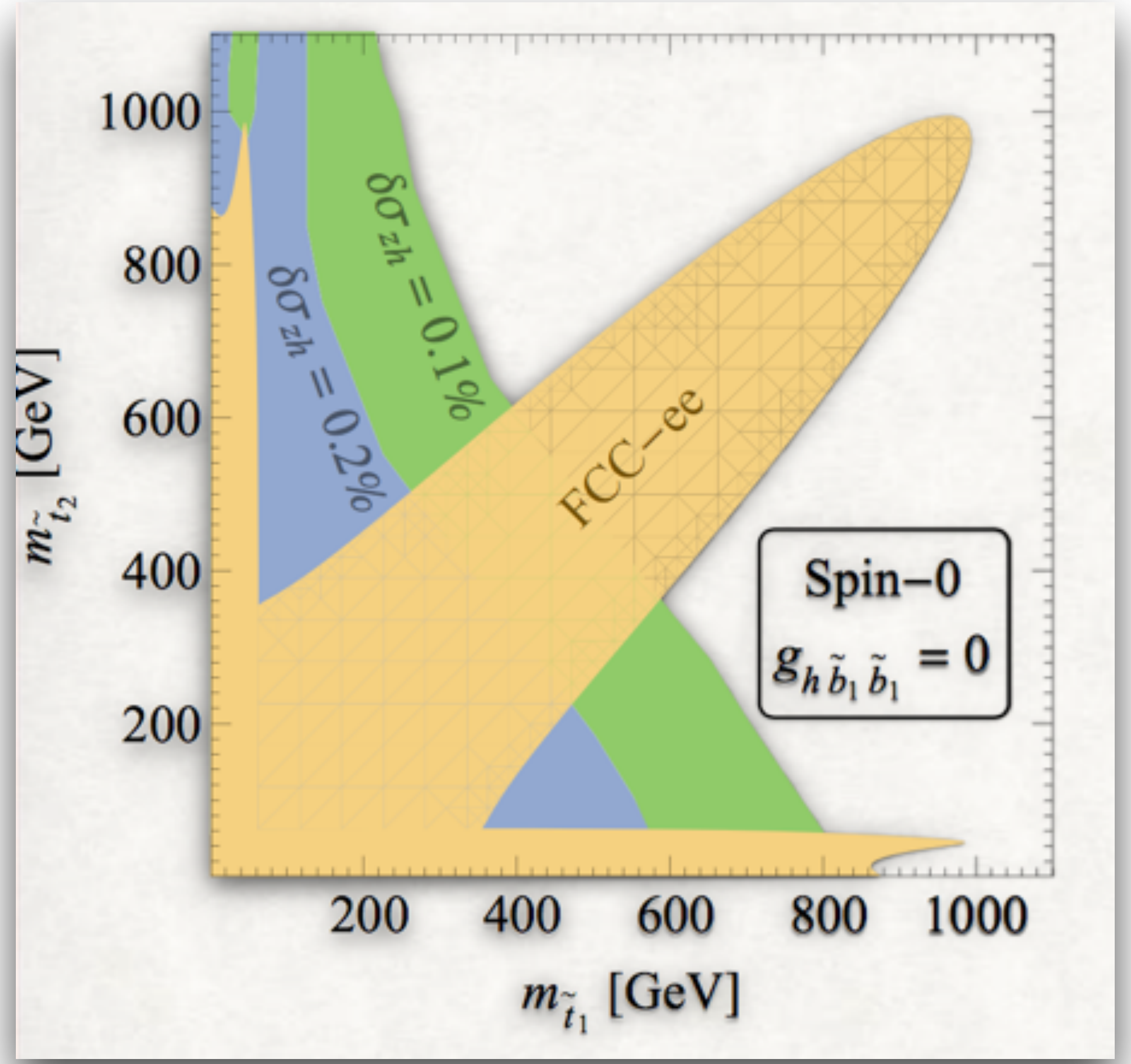




Top-Partners

Matt Reece, H. Ramani

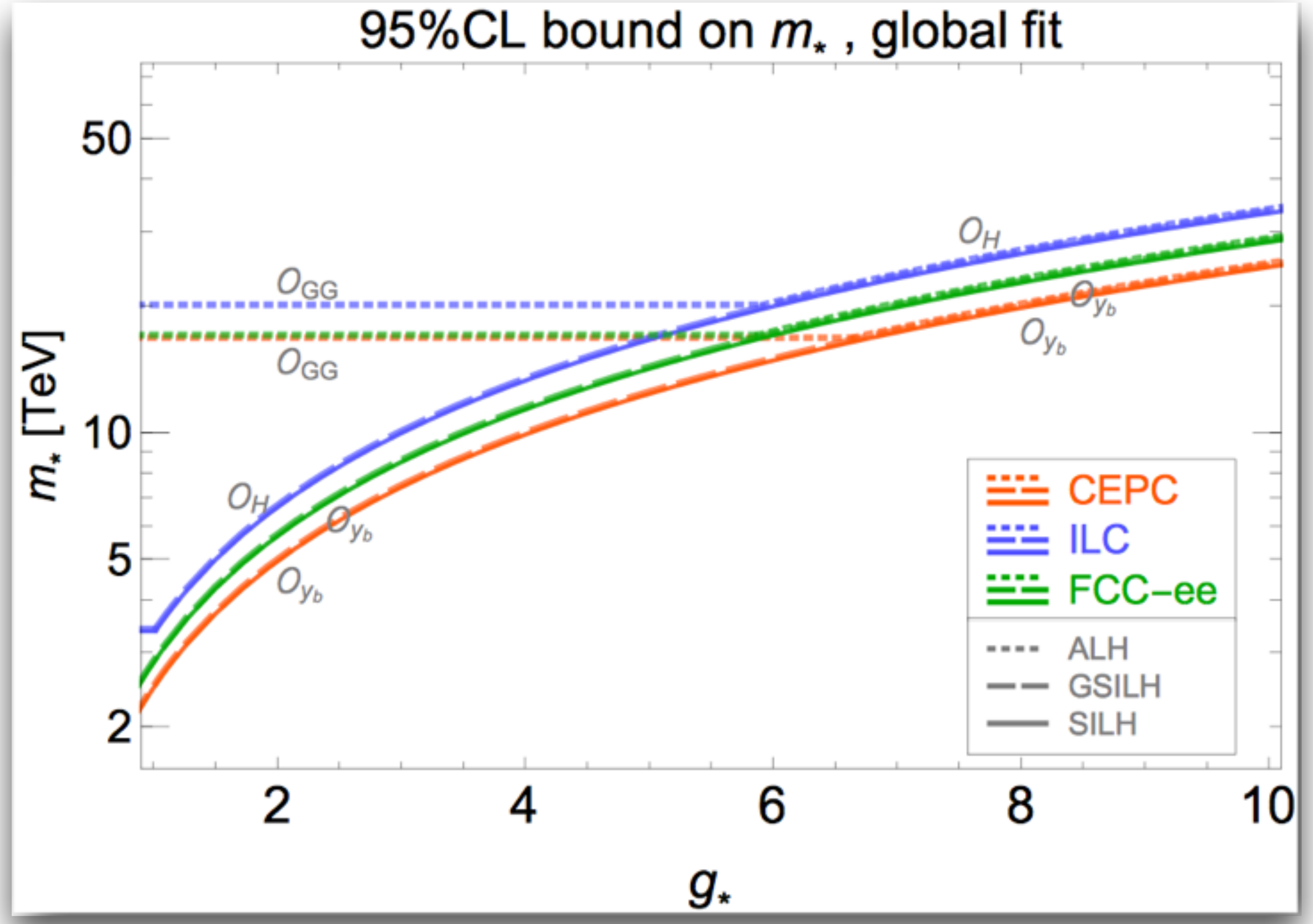




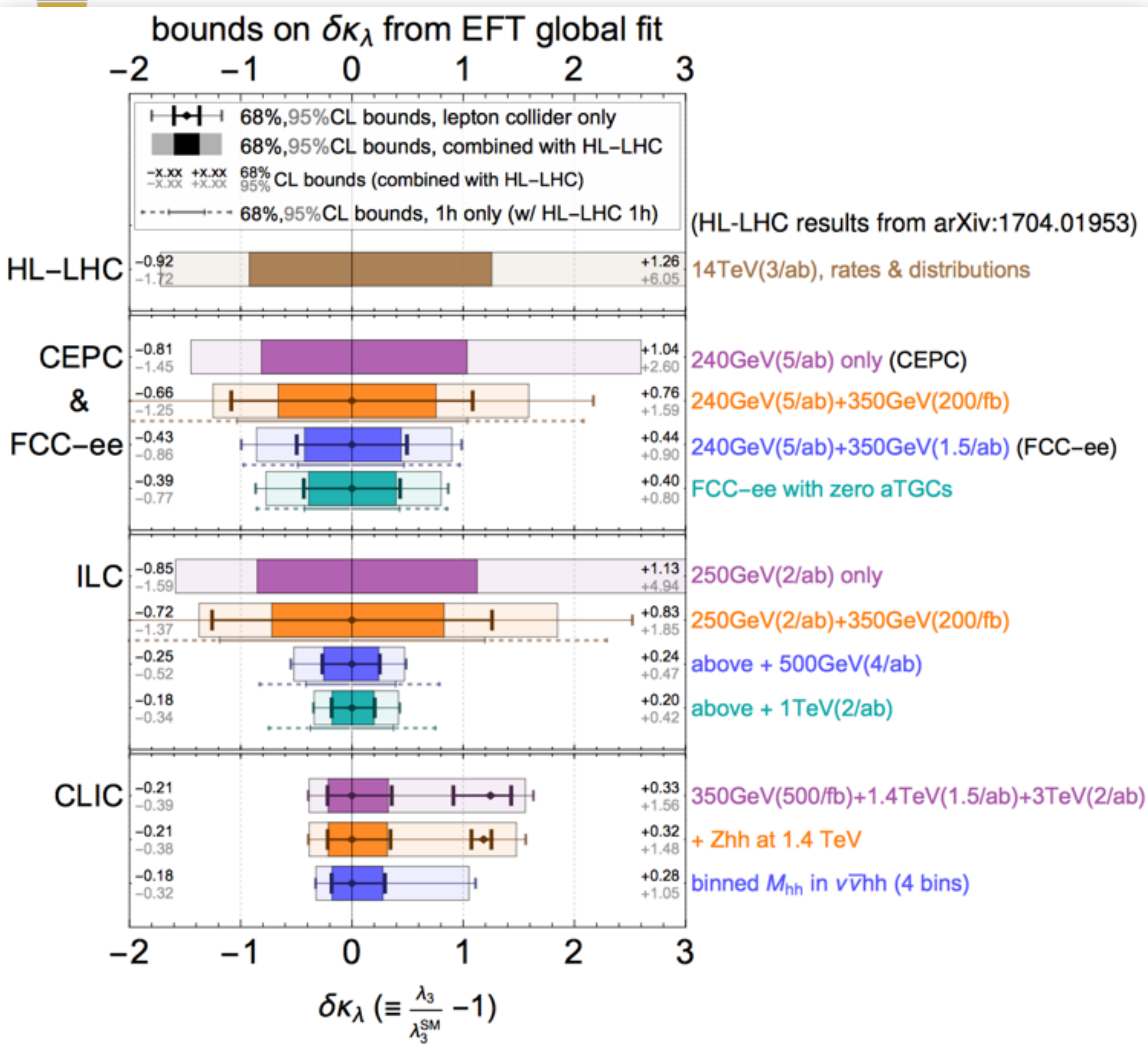
(Also see Wei Su's talk)

Non-perturbative Theories

Shufang Su



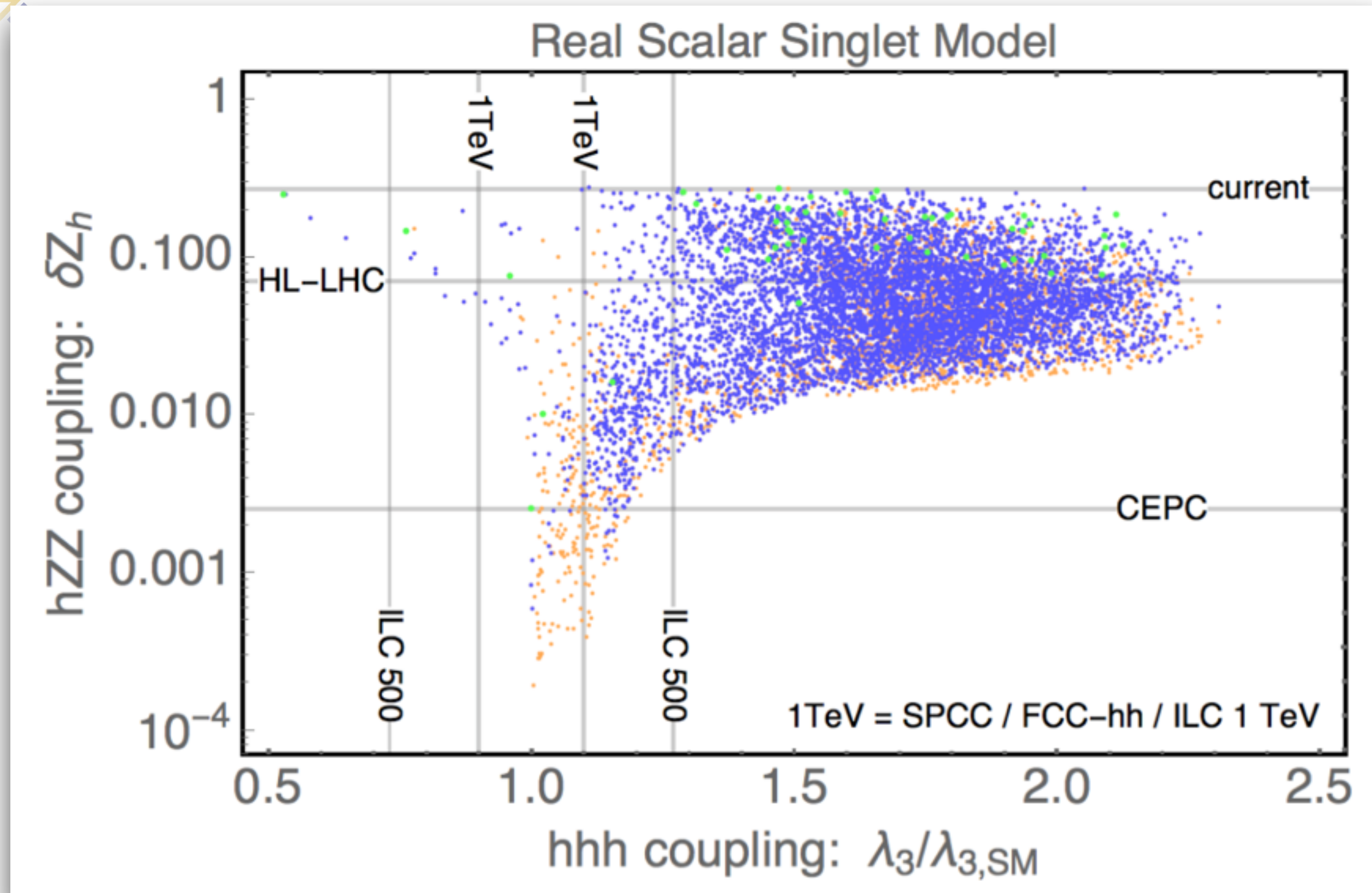
Jiayin Gu



(For discussions on tri-Higgs coupling measurement, also see Sunghoon Jung's talk)

1st-order EW Phase Transition

Andrew Long



arXiv.org > hep-ph > arXiv:1312.4992

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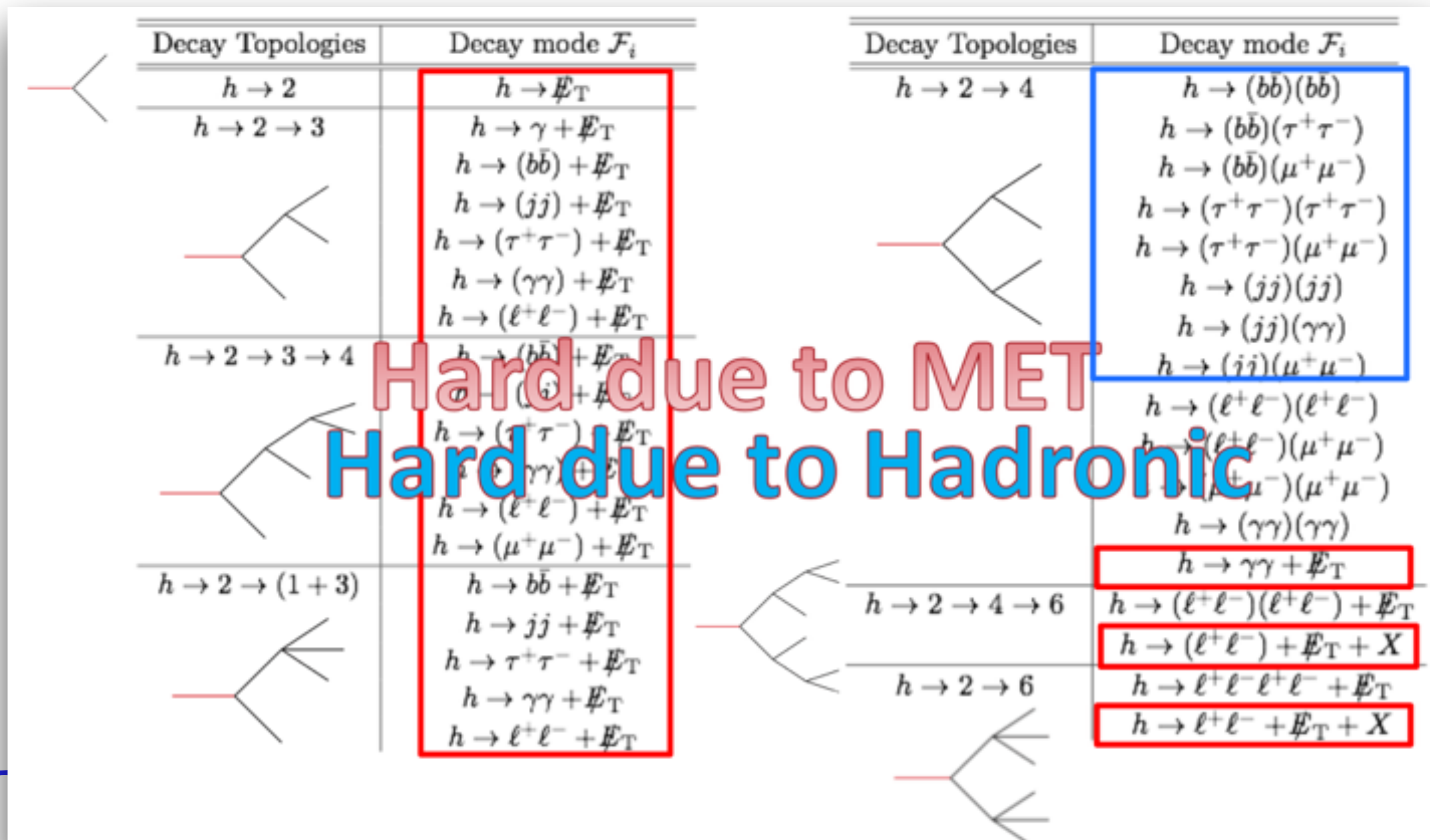
High Energy Physics – Phenomenology

Exotic Decays of the 125 GeV Higgs Boson

David Curtin, Rouven Essig, Stefania Gori, Prerit Jaiswal, Andrey Katz, Tao Liu, Zhen Liu, David McKeen, Jessie Shelton, Matthew Strassler, Ze'ev Surujon, Brock Tweedie, Yi-Ming Zhong

(Submitted on 17 Dec 2013 (v1), last revised 9 Oct 2017 (this version, v6))

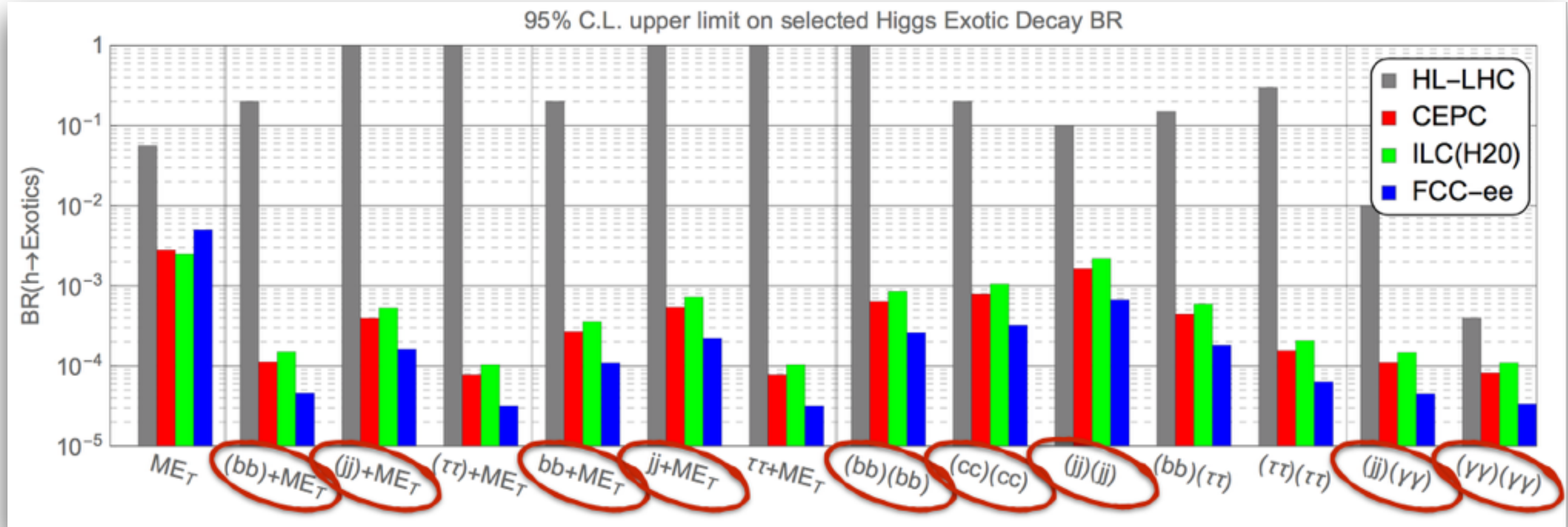


Decay Topologies	Decay mode $\mathcal{F}_i$
$h \to 2$	$h \to \not{E}_T$
$h \to 2 \to 3$	$h \to \gamma + \not{E}_T$
	$h \to (b\bar{b}) + \not{E}_T$
	$h \to (jj) + \not{E}_T$
	$h \to (\tau^+\tau^-) + \not{E}_T$
	$h \to (\gamma\gamma) + \not{E}_T$
	$h \to (\ell^+\ell^-) + \not{E}_T$
$h \to 2 \to 3 \to 4$	$h \to (b\bar{b}) + \not{E}_T$
	$h \to (jj) + \not{E}_T$
	$h \to (\tau^+\tau^-) + \not{E}_T$
	$h \to (\gamma\gamma) + \not{E}_T$
	$h \to (\ell^+\ell^-) + \not{E}_T$
	$h \to (\mu^+\mu^-) + \not{E}_T$
$h \to 2 \to (1+3)$	$h \to b\bar{b} + \not{E}_T$
	$h \to jj + \not{E}_T$
	$h \to \tau^+\tau^- + \not{E}_T$
	$h \to \gamma\gamma + \not{E}_T$
	$h \to \ell^+\ell^- + \not{E}_T$

Decay Topologies	Decay mode $\mathcal{F}_i$
$h \to 2 \to 4$	$h \to (b\bar{b})(b\bar{b})$
	$h \to (b\bar{b})(\tau^+\tau^-)$
	$h \to (b\bar{b})(\mu^+\mu^-)$
	$h \to (\tau^+\tau^-)(\tau^+\tau^-)$
	$h \to (\tau^+\tau^-)(\mu^+\mu^-)$
	$h \to (jj)(jj)$
	$h \to (jj)(\gamma\gamma)$
	$h \to (jj)(\mu^+\mu^-)$
	$h \to (\ell^+\ell^-)(\ell^+\ell^-)$
	$h \to (\ell^+\ell^-)(\mu^+\mu^-)$
	$h \to (\mu^+\mu^-)(\mu^+\mu^-)$
	$h \to (\gamma\gamma)(\gamma\gamma)$
	$h \to \gamma\gamma + \not{E}_T$
$h \to 2 \to 4 \to 6$	$h \to (\ell^+\ell^-)(\ell^+\ell^-) + \not{E}_T$
	$h \to (\ell^+\ell^-) + \not{E}_T + X$
$h \to 2 \to 6$	$h \to \ell^+\ell^-\ell^+\ell^- + \not{E}_T$
	$h \to \ell^+\ell^- + \not{E}_T + X$

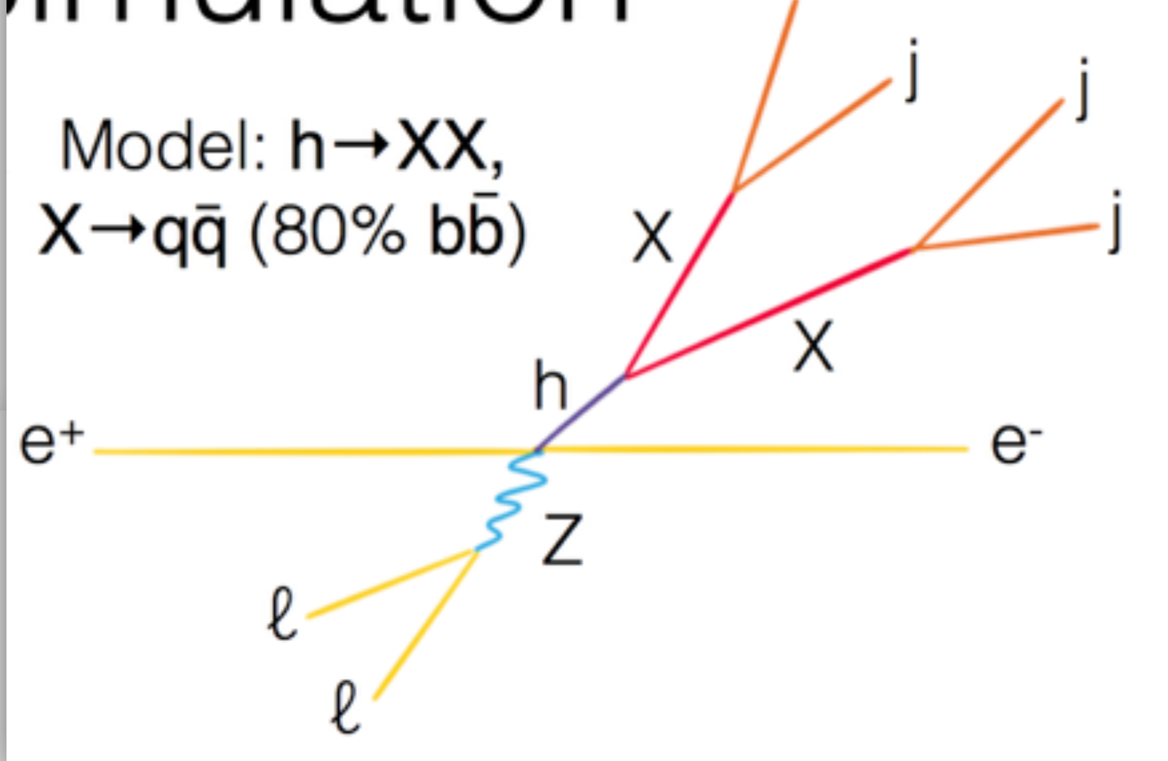
Exotic Higgs Decays

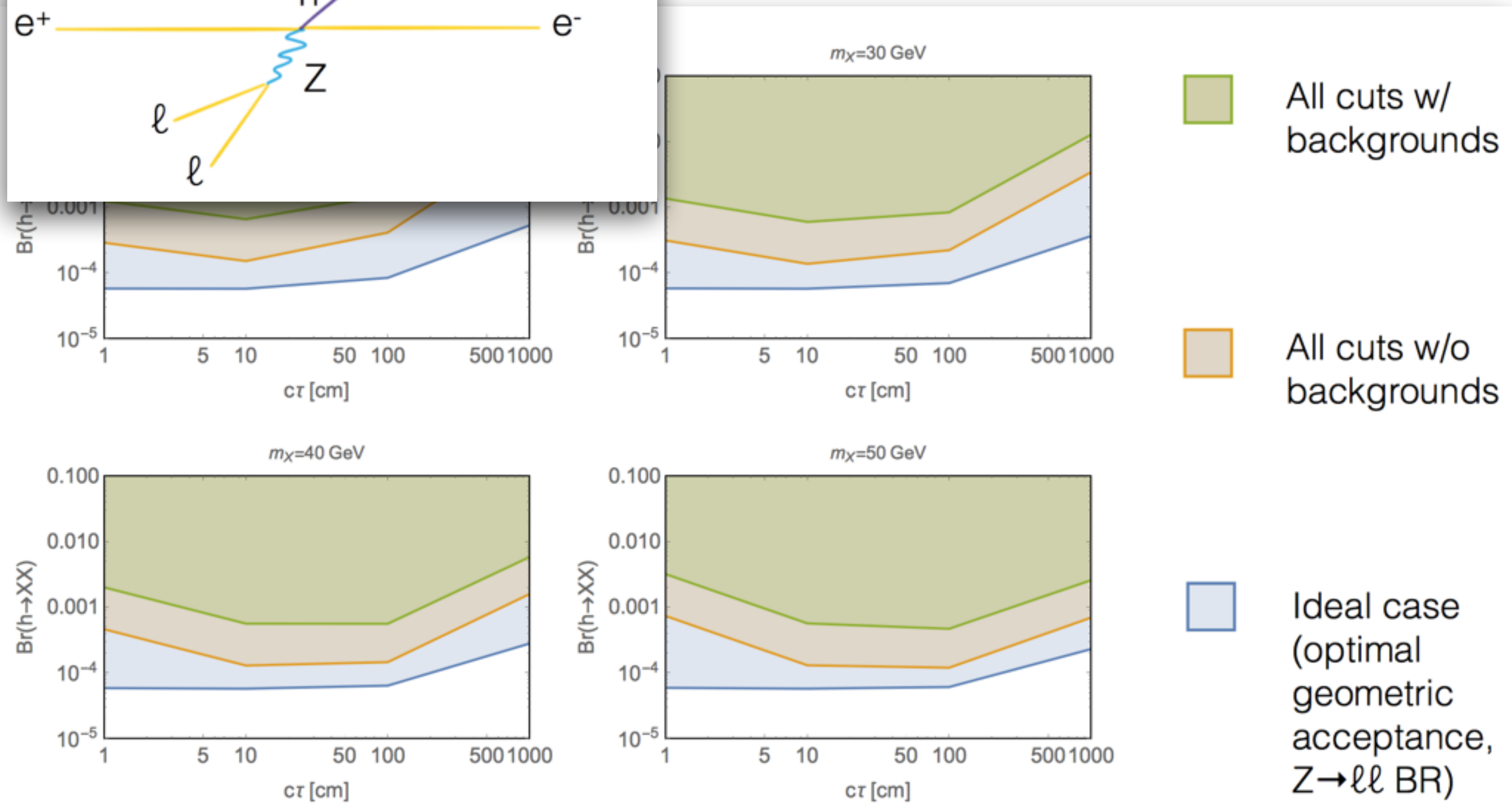
Hao Zhang



tic Higgs Decays

Nathaniel Craig



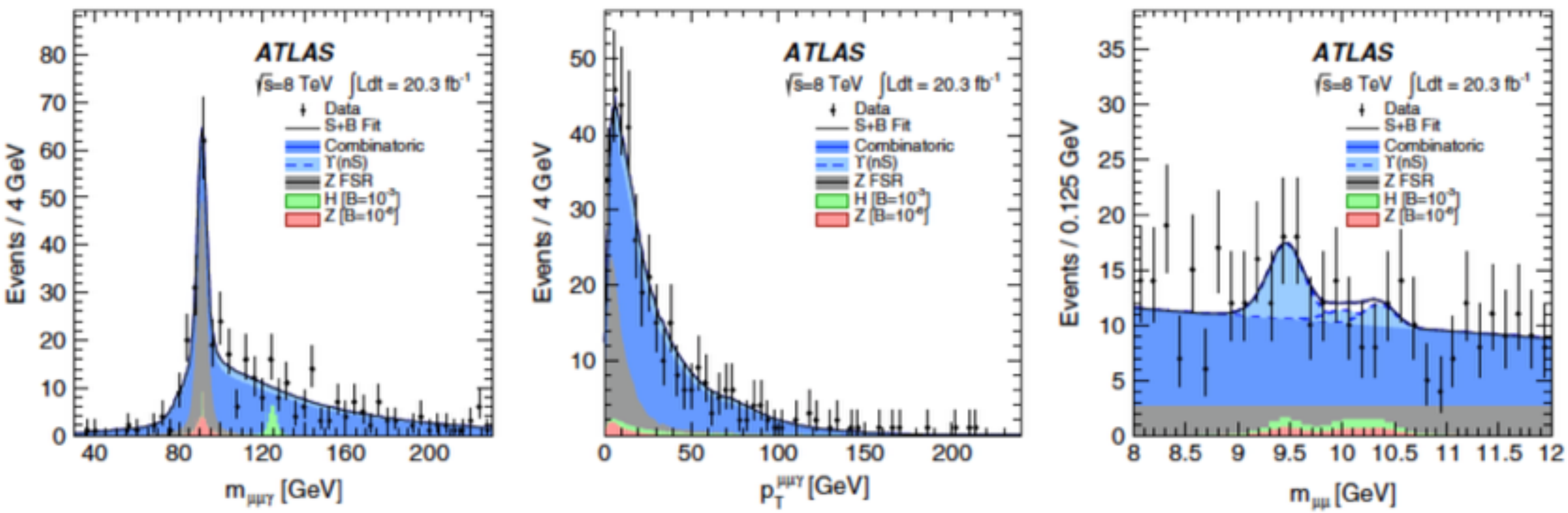


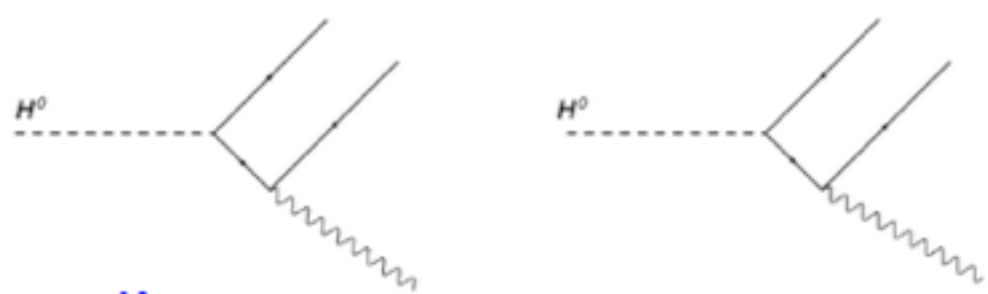
Quarkonium at CEPC

Higgs decays to quarkonium + γ at the LHC

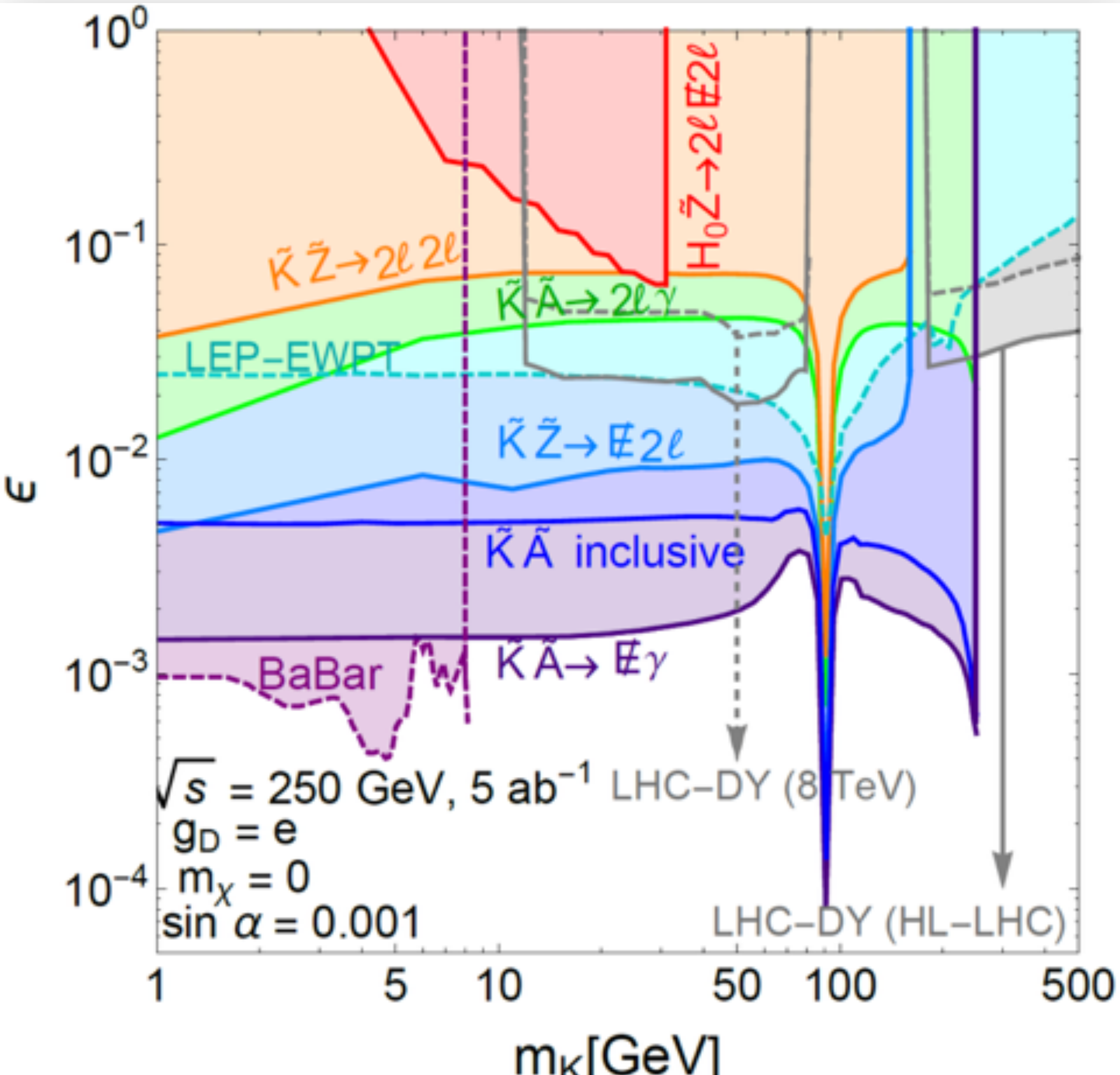
- Υ(n)+ isolated γ :

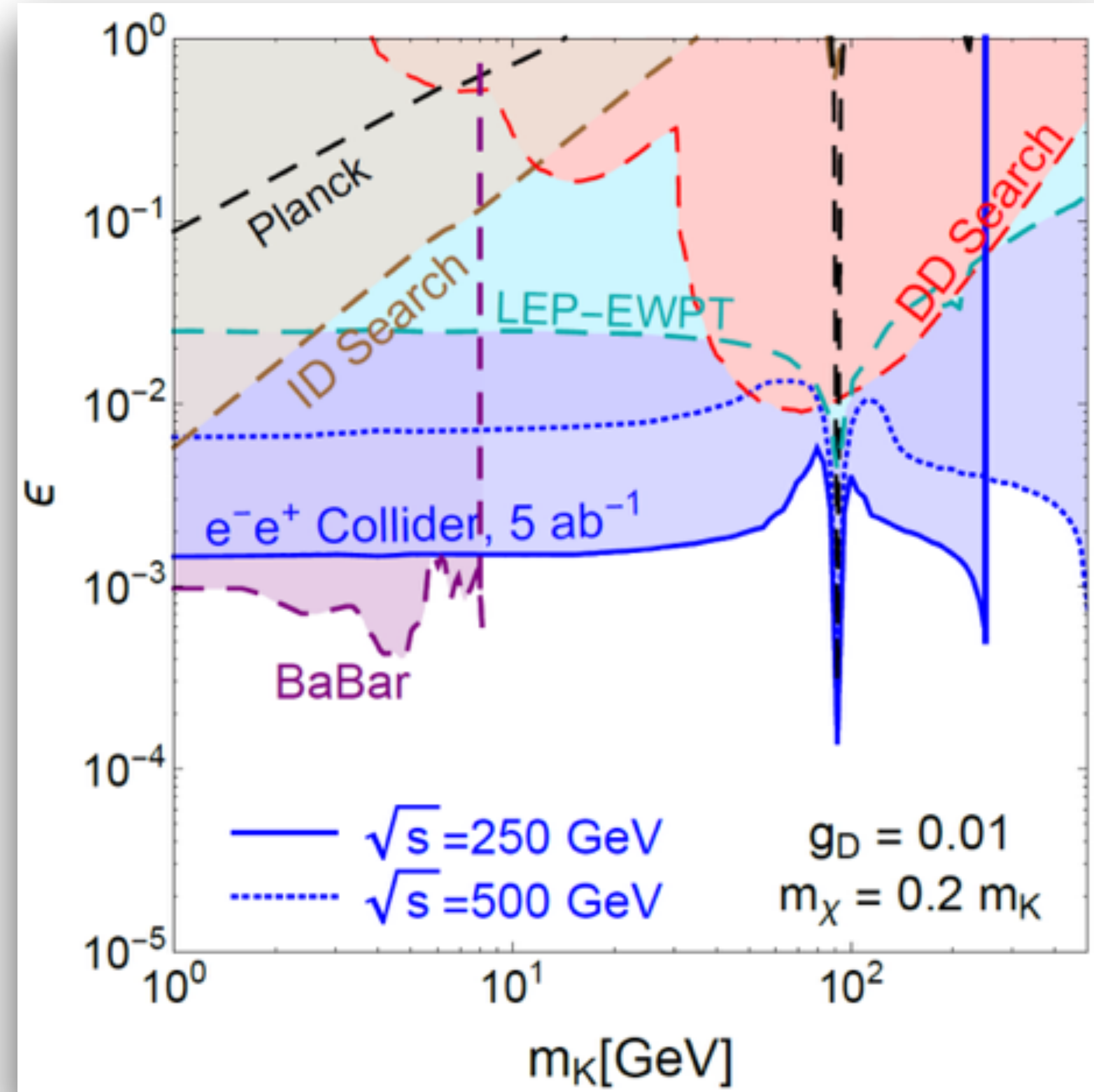
G. Aad et al. PRL114, 121801 (2015)





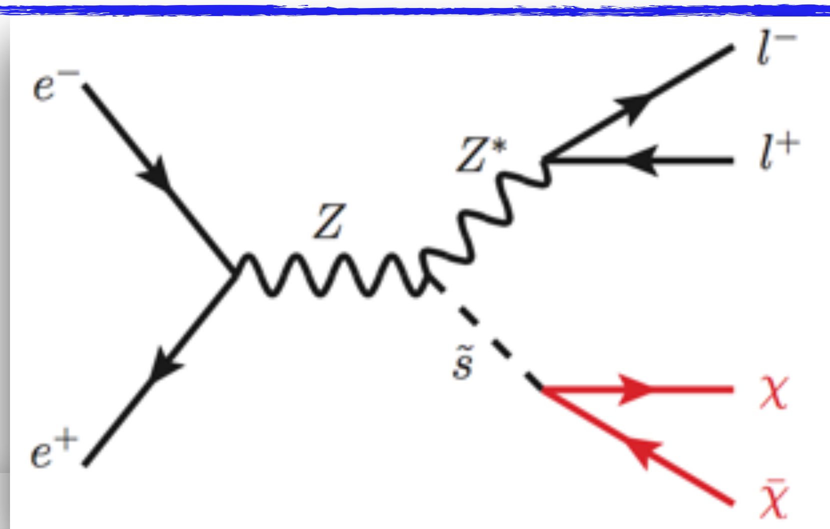
- ✧ Branching ratio
- ✧ Flavor dependence of Higgs couplings
- ✧ NLO calculation for CEPC
- ✧ …

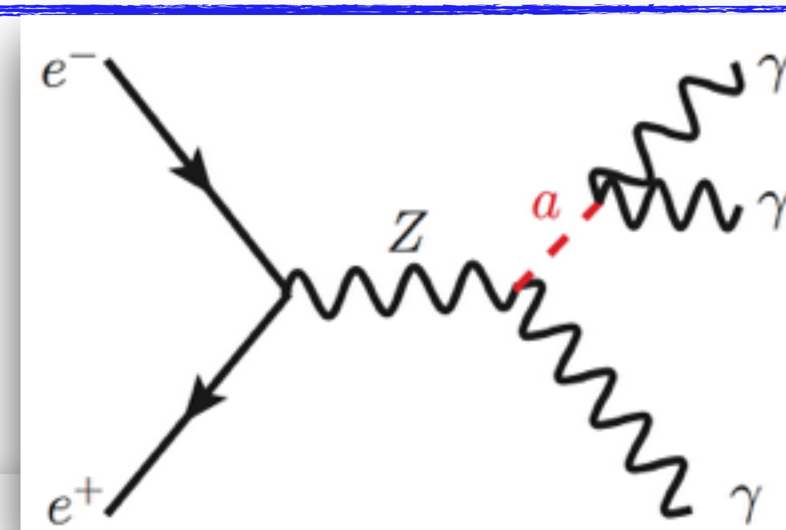

$\tilde{K}\tilde{Z}\to 2\ell\,2\ell$
$H_0\tilde{Z}\to 2\ell\not{E}2\ell$
$\tilde{K}\tilde{A}\to 2\ell\gamma$
LEP-EWPT
$\tilde{K}\tilde{Z}\to\not{E}2\ell$
$\tilde{K}\tilde{A}$ inclusive
BaBar
$\tilde{K}\tilde{A}\to\not{E}\gamma$
$\sqrt{s}$ = 250 GeV, 5 ab^{-1}
LHC-DY (8 TeV)
g_D = e
m_χ = 0
sin α = 0.001
LHC-DY (HL-LHC)
ε
m_K[GeV]

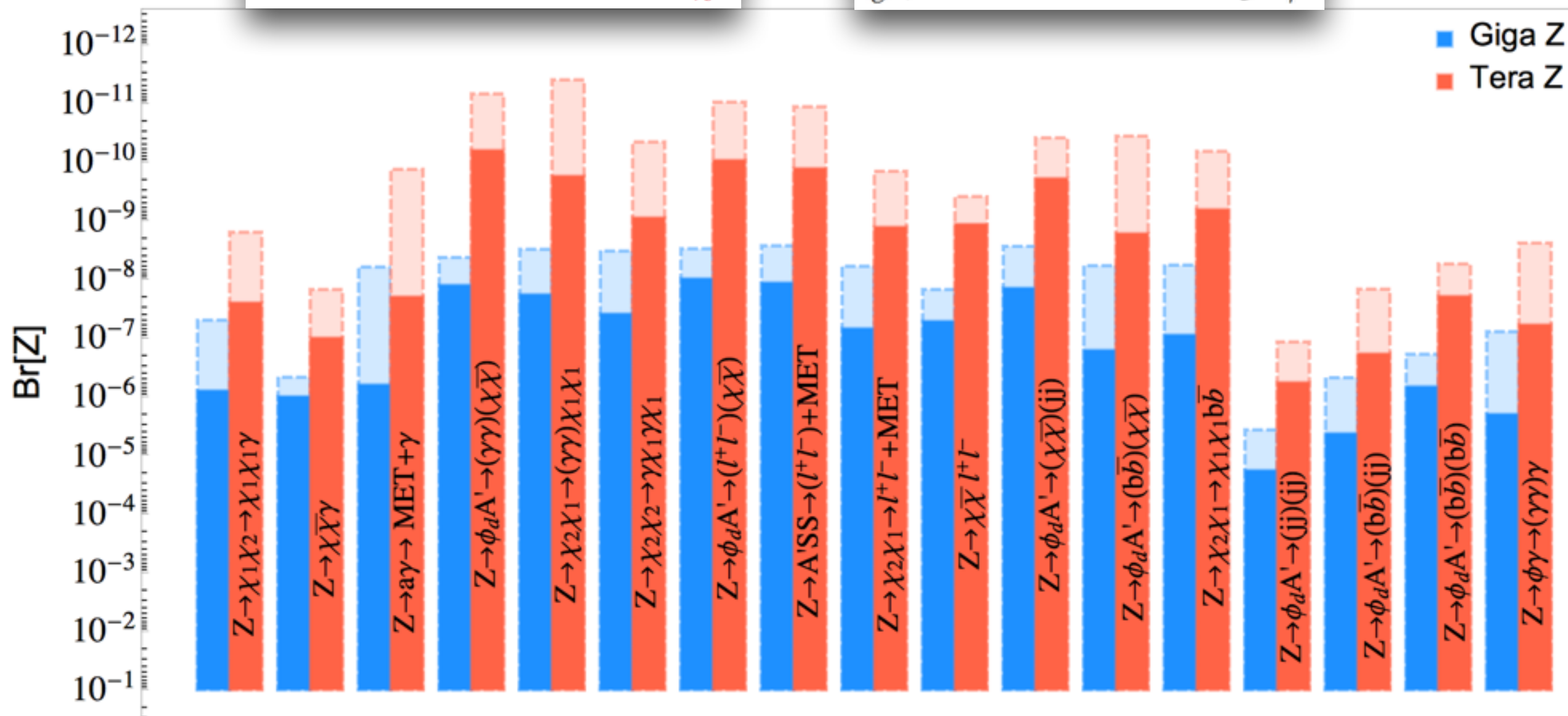

Planck
ID Search
LEP-EWPT
DD Search
e^-e^+ Collider, 5 ab^{-1}
BaBar
$\sqrt{s}$ =250 GeV
$\sqrt{s}$ =500 GeV
g_D = 0.01
m_χ = 0.2 m_K
ε
m_K[GeV]

Jia Liu

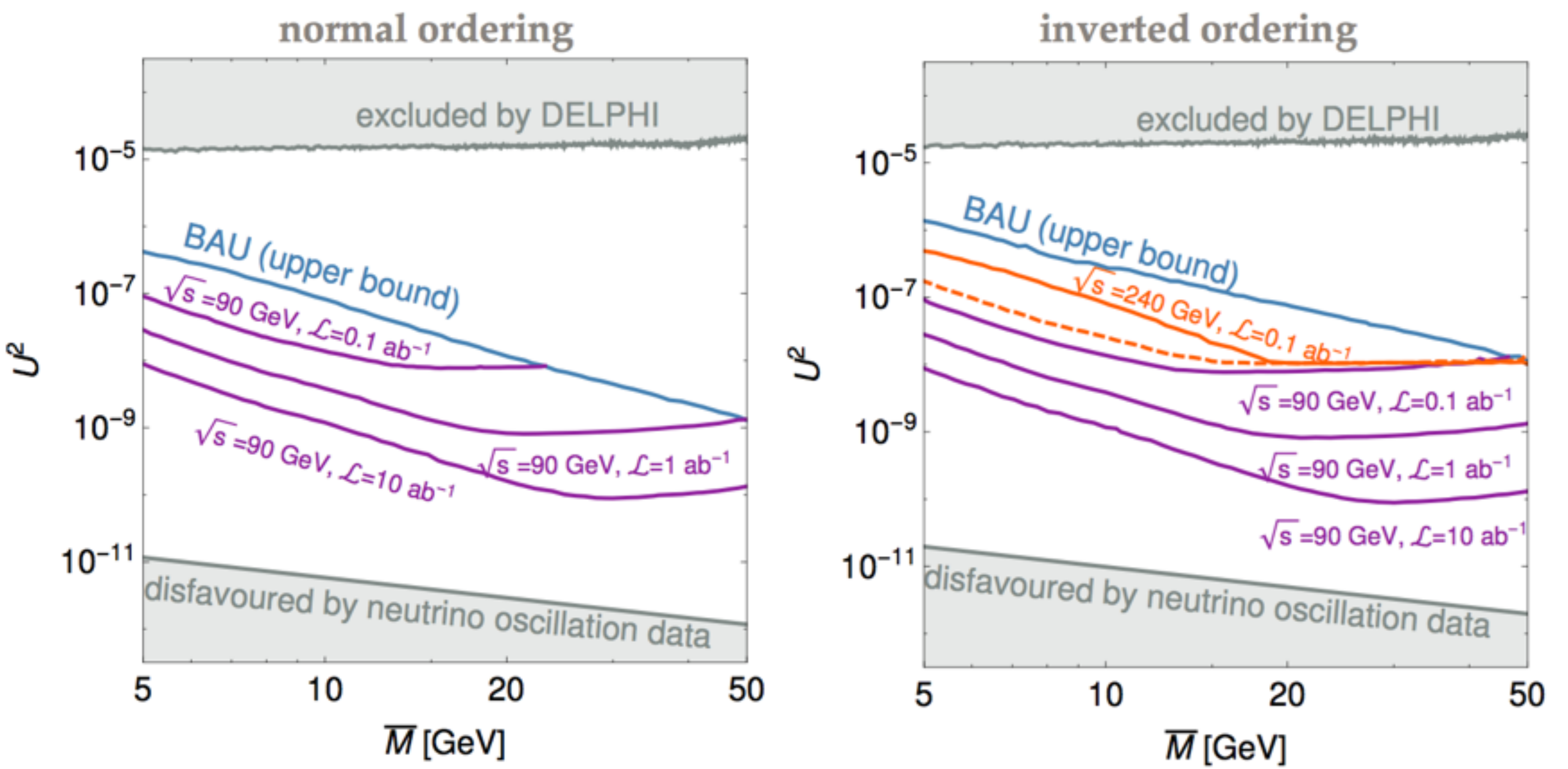
Dark Matter Physics at Z-pole



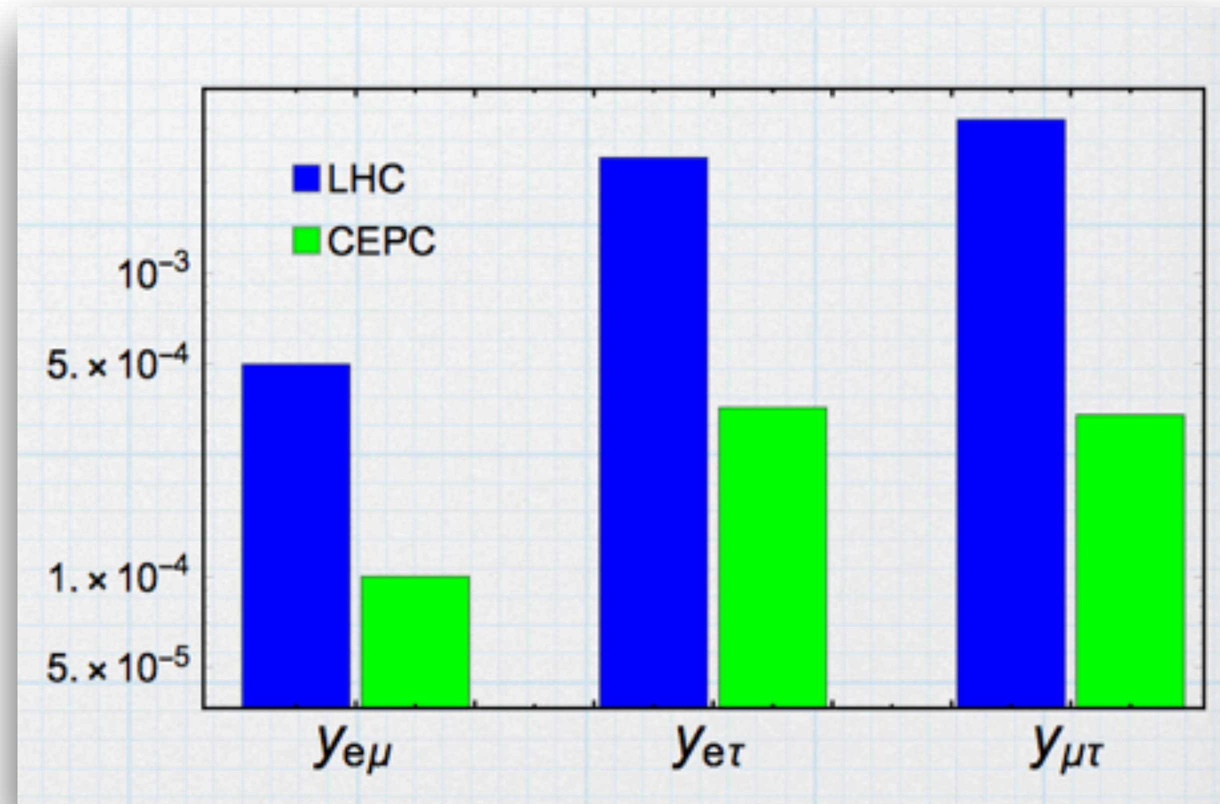


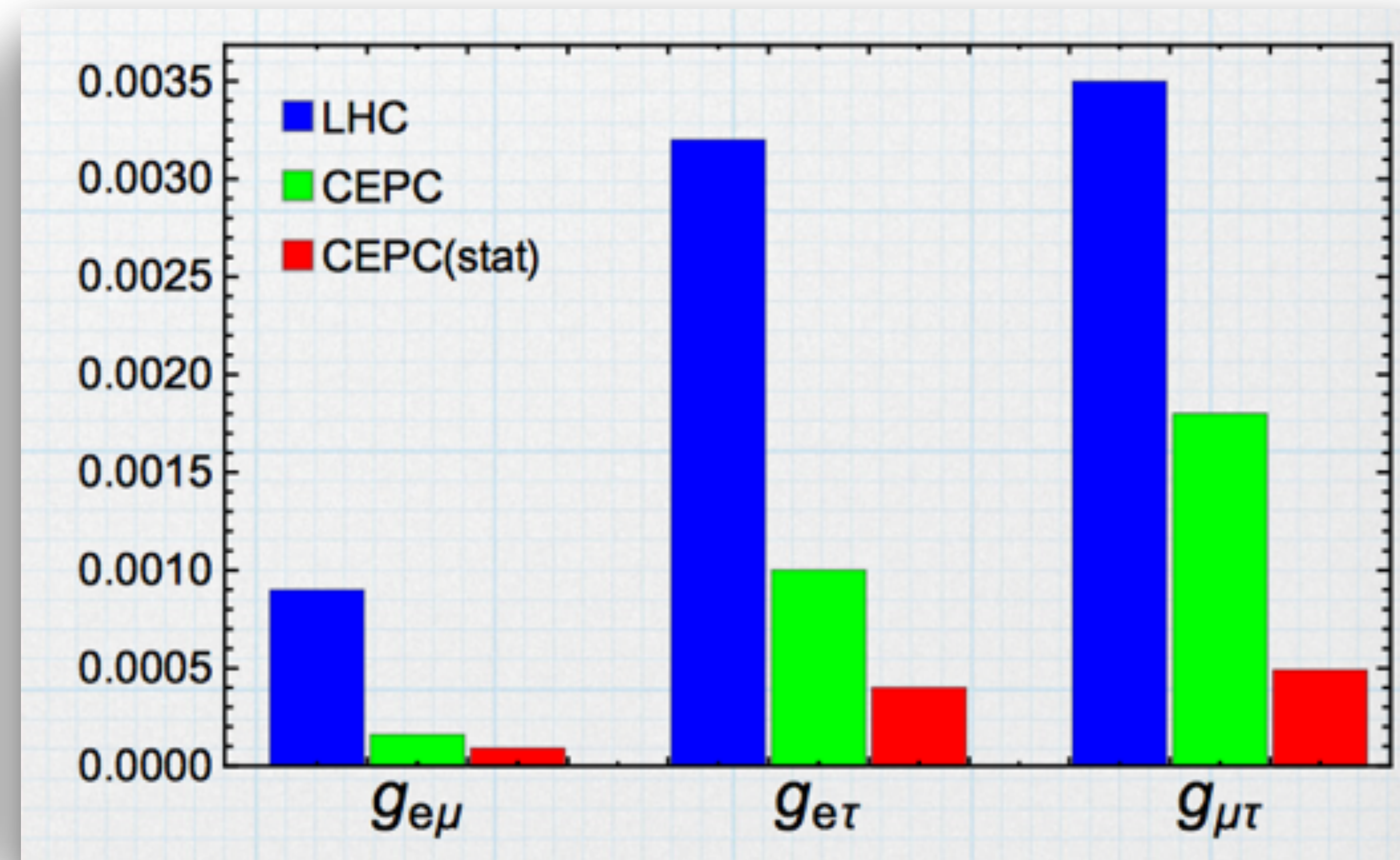


Displaced Vertices at CEPC



FLV Higgs and Z Boson Couplings





Theory Uncertainties at CEPC (Higgs Decay)

Sven Heinemeyer

decay	fut. intr.	fut. para. m_q	para. α_s	para. M_H	FCC-ee/CEPC
$H \to b\bar{b}$	$\sim 0.2\%$	0.6%	$< 0.1\%$	–	$\sim 1.0\%$
$H \to c\bar{c}$	$\sim 0.2\%$	$\sim 1\%$	$< 0.1\%$	–	$\sim 1.7\%$
$H \to \tau^+\tau^-$	$< 0.1\%$	–	–	–	$\sim 1.3\%$
$H \to \mu^+\mu^-$	$< 0.1\%$	–	–	–	$\sim 15\%$
$H \to gg$	$\sim 1\%$		0.5%	–	$\sim 2\%$
$H \to \gamma\gamma$	$< 1\%$	–	–	–	$\sim 3.6\%$
$H \to Z\gamma$	$\sim 1\%$	–	–	$\sim 0.1\%$	
$H \to WW$	$\lesssim 0.4\%$	–	–	$\sim 0.1\%$	$\sim 0.5\%$
$H \to ZZ$	$\lesssim 0.3\%$	–	–	$\sim 0.1\%$	$\sim 0.4\%$
Γ_{tot}	$\sim 0.3\%$	$\sim 0.4\%$	$< 0.1\%$	$< 0.1\%$	$\sim 1\%$

Theory Uncertainties at CEPC (Higgs Strahlung)

Yu Jia

$\sqrt{s}$	schemes	σ_{LO} (fb)	σ_{NLO} (fb)	σ_{NNLO} (fb)	$\sigma^{\mathrm{ISR}}_{\mathrm{LO}}$ (fb)	$\sigma^{\mathrm{ISR}}_{\mathrm{NLO}}$ (fb)	$\sigma^{\mathrm{ISR}}_{\mathrm{NNLO}}$ (fb)
240	$\alpha(0)$	223.14	229.78	232.21	190.72	196.14	198.22
	$\alpha(M_Z^2)$	252.03	228.36	231.28	215.41	194.95	197.44
	G_μ	239.64	232.46	233.29	204.82	198.44	199.15
250	$\alpha(0)$	223.12	229.20	231.63	198.77	204.06	206.22
	$\alpha(M_Z^2)$	252.01	227.67	230.58	224.51	202.72	205.32
	G_μ	239.62	231.82	232.65	213.47	206.40	207.14

Summary for α_s measurement

	Current relative precision (LEP+B fact.)	Future relative precision (CEPC)
Z decay EW fit	expt. $\sim 3\%$ (mostly statistics) theo. $\sim 0.6\%$ (pert. QCD/EW)	expt. $< 0.1\%$ (possible) theo. $\sim 0.3\%$ (N^4LO, almost there)
τ decay	expt. $\sim 0.5\%$ theo. $\sim 2-3\%$ (FOPT v.s. CIPT)	expt. $< 0.2\%$ (possible) theo. $\sim 1\%$ (feasible, N^4LO)
jet rates	expt. $\sim 2\%$ (exp.) theo. $\sim 2\%$ (pert. QCD scale)	expt. $< 1\%$ (possible) theo. $< 1\%$ (feasible, NNLO+NNLL)
event shapes	expt. $\sim 1\%$ theo. $\sim 1-3\%$ (analytic v.s. MC N.P.)	expt. $< 1\%$ (possible) theo. $< 1\%$ (feasible, Q^2, NLO+NLL MC)

Summary: WHIZARD for CEPC Physics

- Universal multi-particle event generator (SM and beyond)
- Accurate e^+e^- beam description
- Parallel computation using MPI and OpenMP
- e^+e- precision studies bear challenges that are not addressed by conventional automated multi-particle simulations

  Work items:
  - SM NLO is as important as QCD NLO, higher orders
  - Accurate description of (almost) collinear photon radiation
  - Precise shape and normalization of thresholds and resonances
  - Electroweak resonances as sources of QCD radiation

http://whizard.hepforge.org

Take-home Questions

Is there any significant physics at CEPC missed?

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How does a future hadron collider complement a Higgs factory like CEPC?

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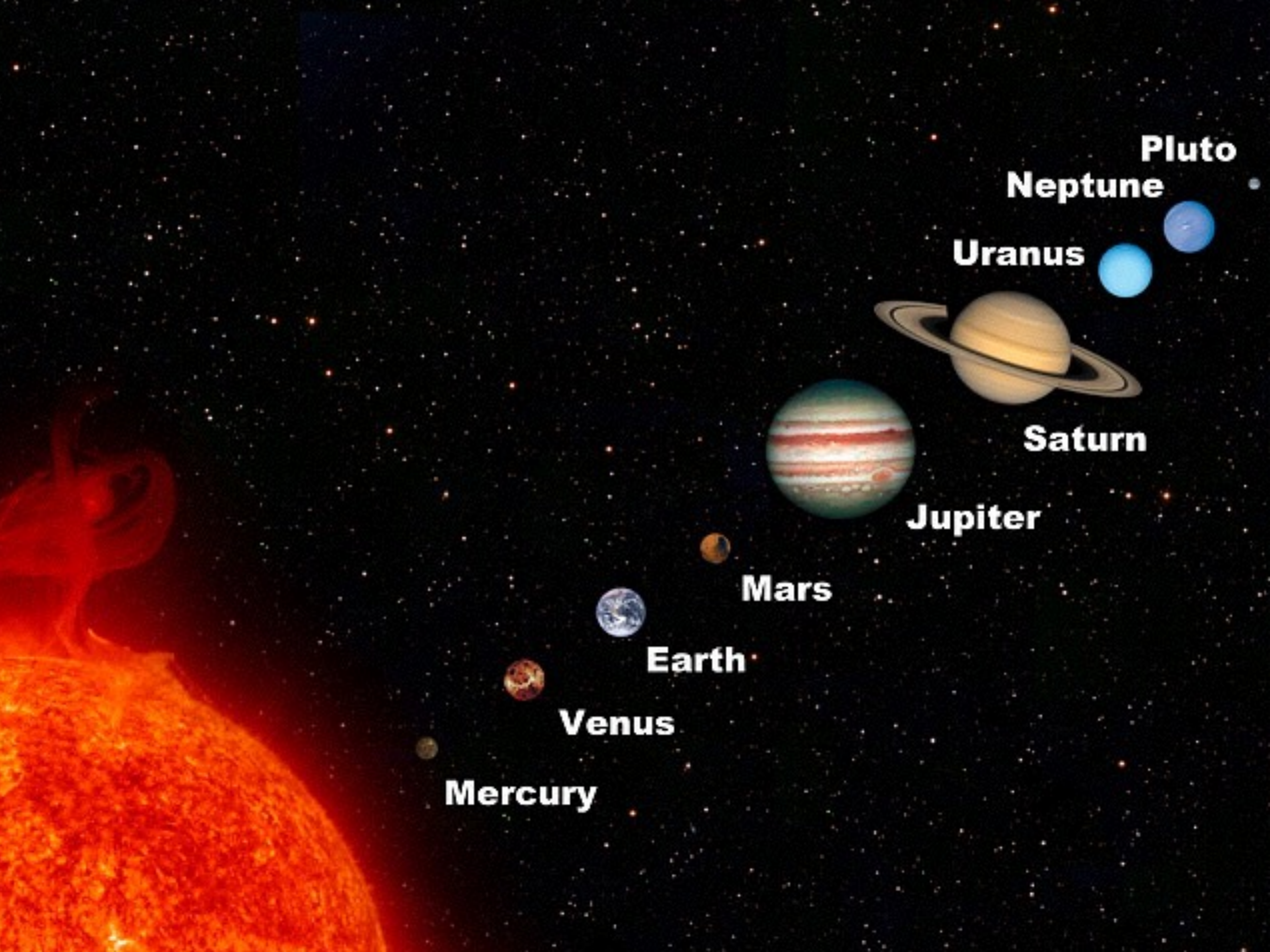
How does a future hadron collider complement a Higgs factory like CEPC?

How will new analysis tools such as deep machine learning influence collider physics?


Pluto
Neptune
Uranus
Saturn
Jupiter
Mars
Earth
Venus
Mercury

Long journey, but exciting ……

Thank you!