Theory Summary & Prospects

Some 2014 Anniversaries

- 150: Maxwell unified electromagnetic interactions
- 100: WW1 started
- 70: D-Day
- 65: Feyman diagrams, π^0 to $\gamma\gamma$ decay calculated by Steinberger
- 60: Higgs got his PhD, CERN founded, Fermi extrapolation
- 50: quarks, Ω-, CPV, charm, colour, EWSB,
- 50: CMB, Bell's theorem, Beatles invade US, civil rights
- 40: J/ψ discovered
- 35: Discovery of the gluon
- 30: First LHC workshop, SUSY ~~discovered~~ at CERN p-pbar
- 25: World-Wide Web, downfall of (much of) communism
- 20: Approval of LHC
- 0: ~~Quantum gravitational radiation~~ ?

Tests of SM

Top physics

- Mass, A_{FB}, …?

Producing new particles

- e.g., Higgs

Possible signals

- e.g., boosted jets

Backgrounds

- e.g., pile-up

The basis for everything at the LHC

Boughezal, Ubiali, …

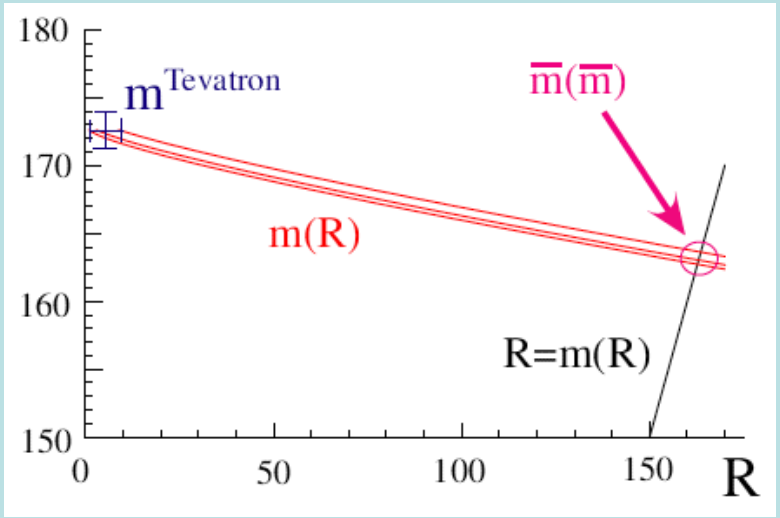
Hard QCD (1): Top

- Basic parameter of SM; stability of EW vacuum?
- Experimental world average:

  $m_t = 173.34 \pm 0.76$ GeV
- Monte Carlo mass!
- MC mass ➔pole mass?

  ± 0.7 GeV (MC ➔running mass)

  + 0.5 GeV (running mass ➔pole mass)



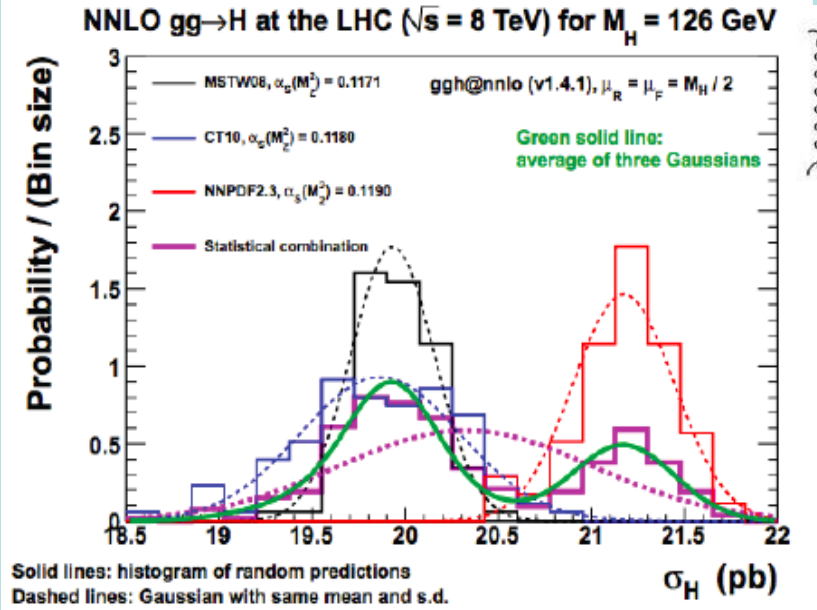
Moch

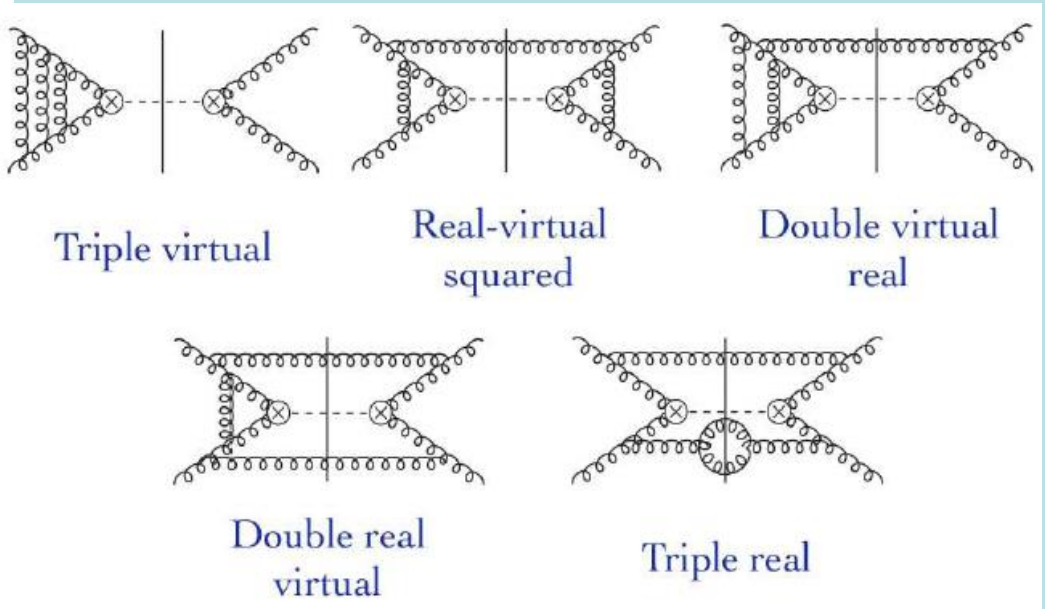
- New measurements:

CMS: 172.2±0.7 GeV, D0: 174.98±0.58±0.49

Hard QCD (2): Higgs

- Many perturbative QCD calculations to NNLO
- E.g., gg to H: agreement unsatisfactory

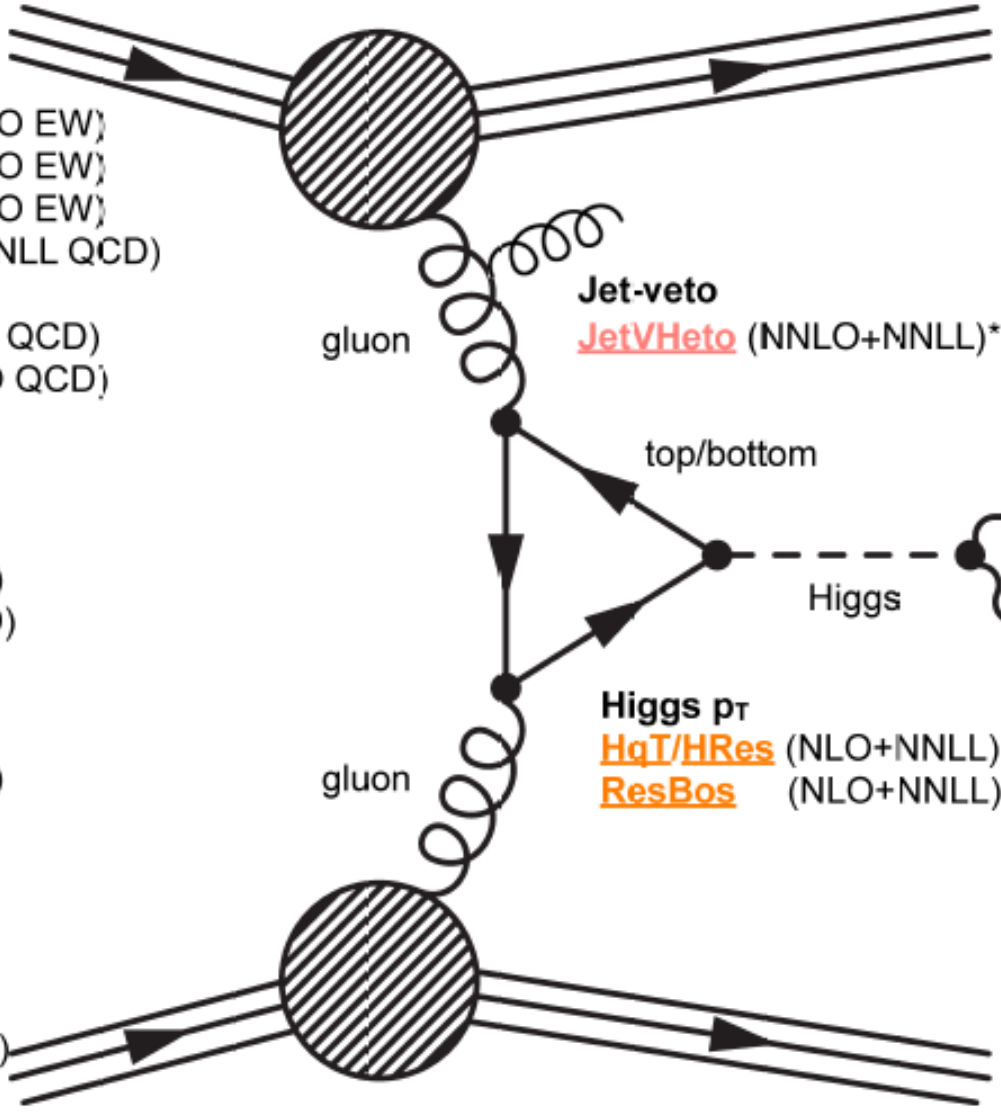




- Progress towards NNNLO calculation

Dittmaier, Neubert

Tools for Higgs Physics



Cross Section

ggF
HIGLU (NNLO QCD+NLO EW)
iHixs (NNLO QCD+NLO EW)
FeHiPro (NNLO QCD+NLO EW)
HNNLO, HRes (NNLO+NNLL QCD)
SusHi (NNLO QCD)
RGHiggs (NNLO+NNNLL QCD)
ggHiggs (approx. NNNLO QCD)

VBF
VV2H (NLO QCD)
VBFNLO (NLO QCD)
HAWK (NLO QCD+EW)
VBF@NNLO (NNLO QCD)

WH/ZH
V2HV (NLO QCD)
HAWK (NLO QCD+EW)
VH@NNLO (NNLO)

ttH
HQQ (LO QCD)

bbH
bbh@NNLO (NNLO QCD)

HH
HPAIR (NLO QCD)

+ private codes.

NLO MC
POWHEG MiNLO
MadGrapn5_aMC@NLO
SHERPA MEPS@NLO

LO MC
gg2VV

NLO ME
MCFM, MG5_aMC@NLO

Higgs Properties
MELA/JHU, MEKD
MG5_aMC@NLO (HC)

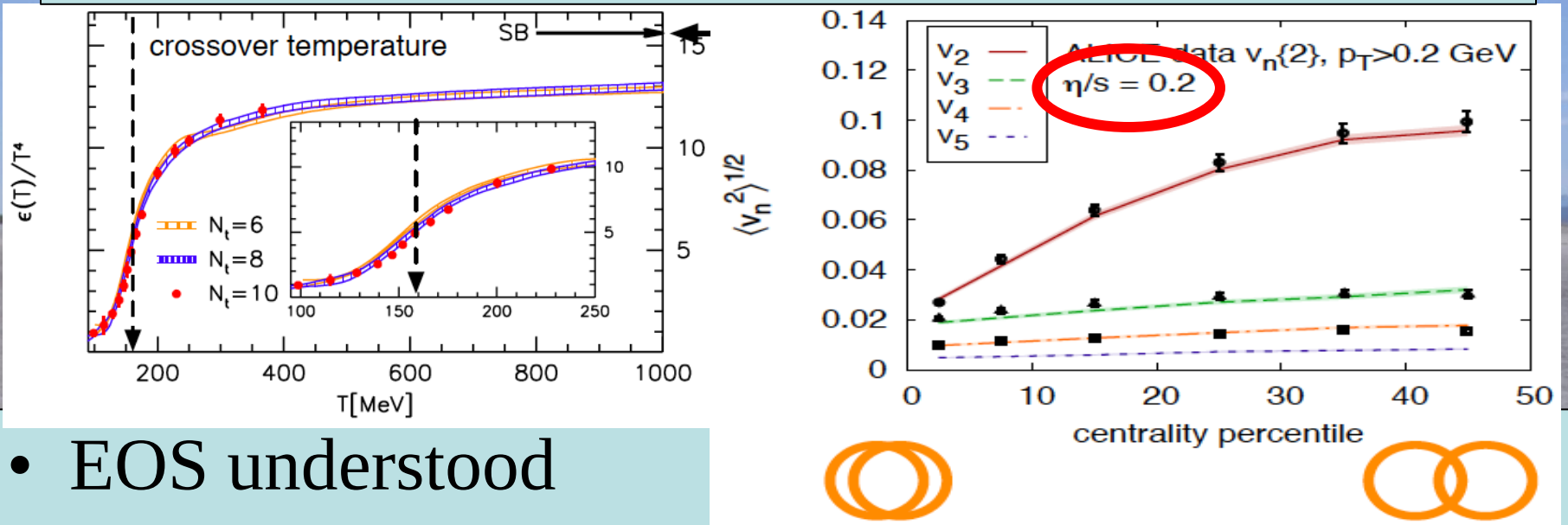
MSSM/2HDM
FeynHiggs, CPSuperH
SusHi+2HDMC
HIGLU+HDECAY

PDF: MSTW, CTEQ, NNPDF, etc.
LHAPDF, HOPPET, APFEL

Dittmaier

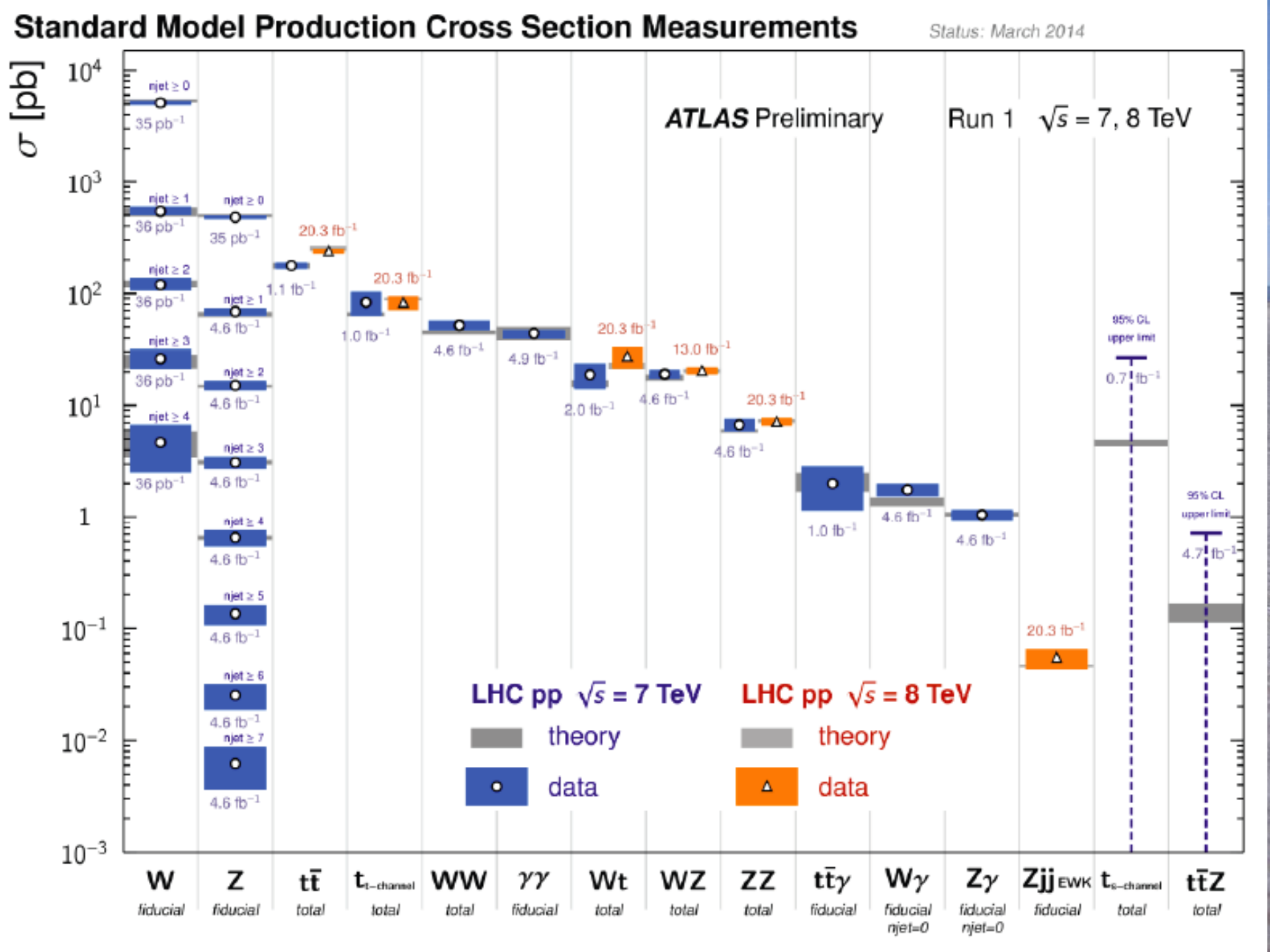
Teaney, Li, Kalweit, Scomparin, Cole

Heavy-Ion Collisions



- EOS understood
- Near-perfect fluid (string, holography, AdS/CFT)
- Evidence for collective phenomena in p-Pb
- Transverse shape of proton?

- Energy ‘splashes’ to large angles in jet quenching
- Screening (J/ψ, ϒ), regeneration (J/ψ)


Standard Model Production Cross Section Measurements
Status: March 2014
ATLAS Preliminary
Run 1 $\sqrt{s}$ = 7, 8 TeV
σ [pb]
10^4
10^3
10^2
10^1
1
10^{-1}
10^{-2}
10^{-3}
njet ≥ 0
35 pb^{-1}
njet ≥ 1
36 pb^{-1}
njet ≥ 2
36 pb^{-1}
njet ≥ 3
36 pb^{-1}
njet ≥ 4
36 pb^{-1}
njet ≥ 0
35 pb^{-1}
njet ≥ 1
4.6 fb^{-1}
njet ≥ 2
4.6 fb^{-1}
njet ≥ 3
4.6 fb^{-1}
njet ≥ 4
4.6 fb^{-1}
njet ≥ 5
4.6 fb^{-1}
njet ≥ 6
4.6 fb^{-1}
njet ≥ 7
4.6 fb^{-1}
20.3 fb^{-1}
1.1 fb^{-1}
20.3 fb^{-1}
1.0 fb^{-1}
4.6 fb^{-1}
4.9 fb^{-1}
20.3 fb^{-1}
2.0 fb^{-1}
13.0 fb^{-1}
4.6 fb^{-1}
20.3 fb^{-1}
4.6 fb^{-1}
1.0 fb^{-1}
4.6 fb^{-1}
4.6 fb^{-1}
20.3 fb^{-1}
95% CL upper limit
0.7 fb^{-1}
95% CL upper limit
4.7 fb^{-1}
LHC pp $\sqrt{s}$ = 7 TeV
theory
data
LHC pp $\sqrt{s}$ = 8 TeV
theory
data
W fiducial
Z fiducial
$t\bar{t}$ total
$t_{t-channel}$ total
WW total
$\gamma\gamma$ fiducial
Wt total
WZ total
ZZ total
$t\bar{t}\gamma$ fiducial
$W\gamma$ fiducial njet=0
$Z\gamma$ fiducial njet=0
Zjj EWK fiducial
$t_{s-channel}$ total
$t\bar{t}Z$ total

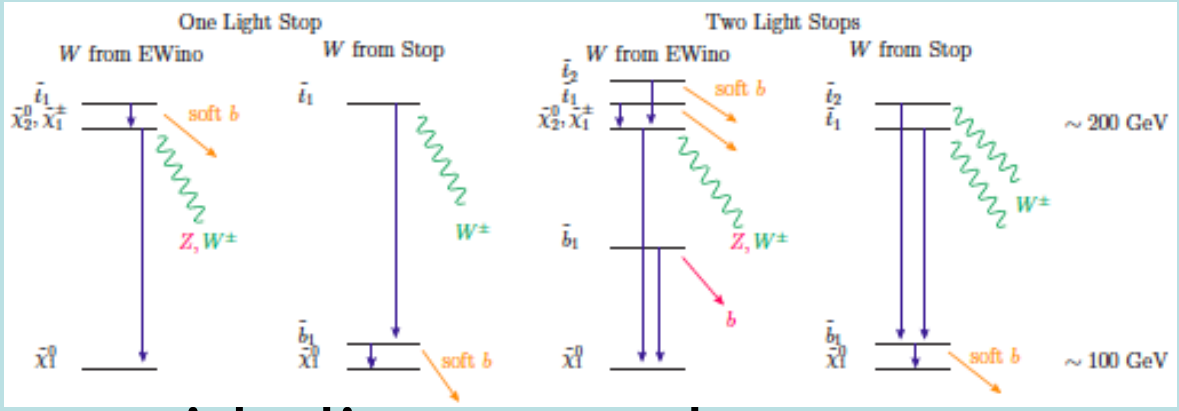
Excess in W^+W^- Production?

Hallon

- CMS: $69.9 \pm 2.8 \pm 5.6 \pm 3.1$ pb @ 8 TeV:
  - Cf, TH: $57.3^{+2.3}_{-1.6}$ pb
- ATLAS: $51.9 \pm 2.0 \pm 3.9 \pm 2.0$ pb @ 7 TeV:
  - Cf, TH: $44.7^{+2.1}_{-1.9}$ pb

Curtin, Meade, Tien: arXiv:1406.0848;
Kim, Rolbiecki, Sakurai, Tattersall: arXiv:1406.0858

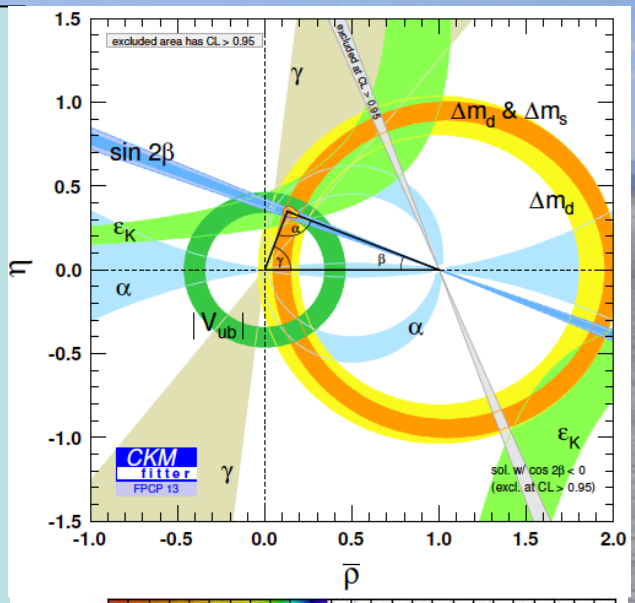
- 'Stop' ambulance-chasing: scenarios with:
  - Light stop(s)
  - Wino
  - Bino

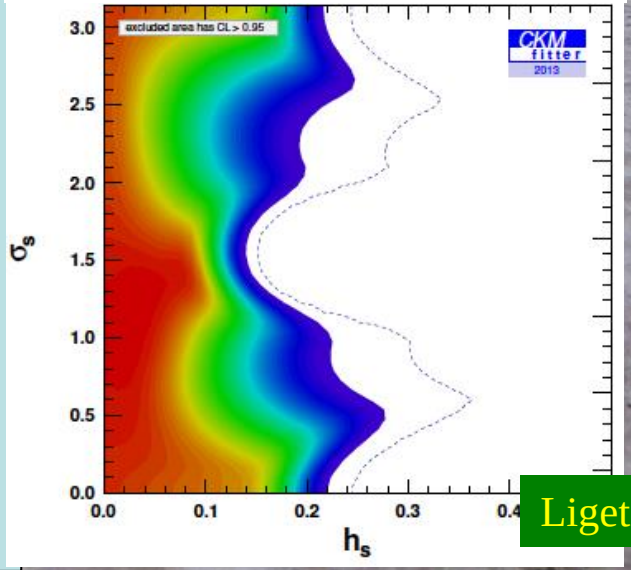


- Check consistency with direct searches

Flavour Physics

- CKM picture works very well
- Many successful predictions:
  - Many modes of CPV
  - In K^0, B^0, $B^{\pm}$, B_s systems
  - No sign of CPV in charm ☹
- Also rare decays: $B_{s,d}$ ➔ $\mu^+\mu^-$
- Could still be substantial BSM contribution
- Does new TeV physics copy CKM? Squarks non-





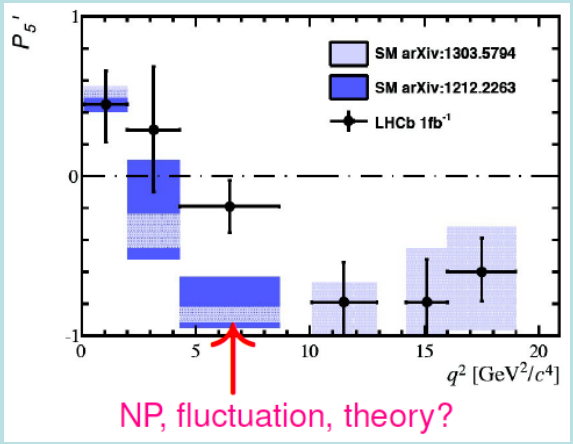
Ligeti

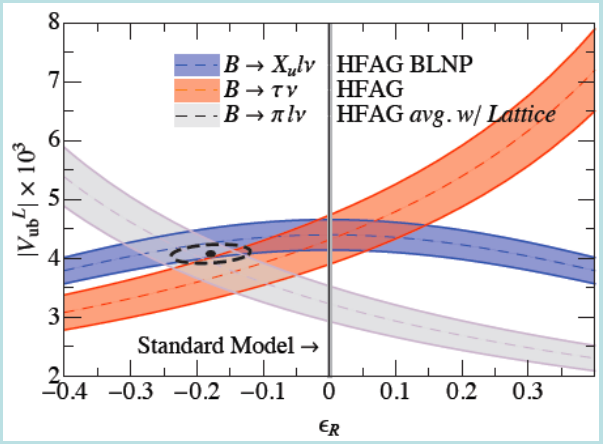
Flavour Puzzles

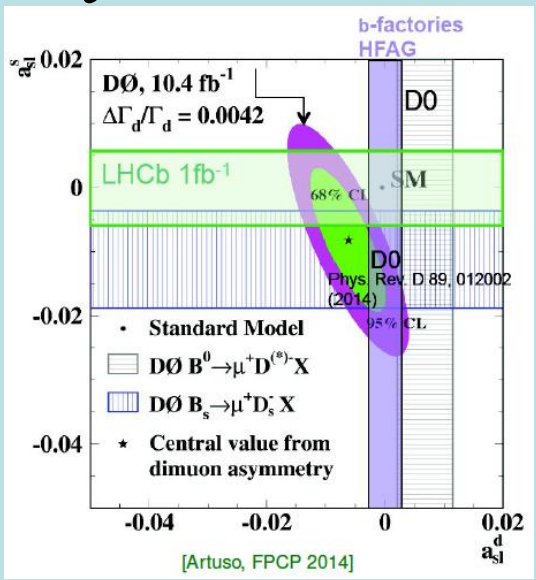
- CP asymmetries in D to Kπ?

$$A_{K^+\pi^0} - A_{K^+\pi^-} = 0.122 \pm 0.022$$

- B^0 to K^{*0} μ^+ μ^- angular distribution: P_5' anomaly (3.7σ, 0.5% with LEE): explicable by Z'?





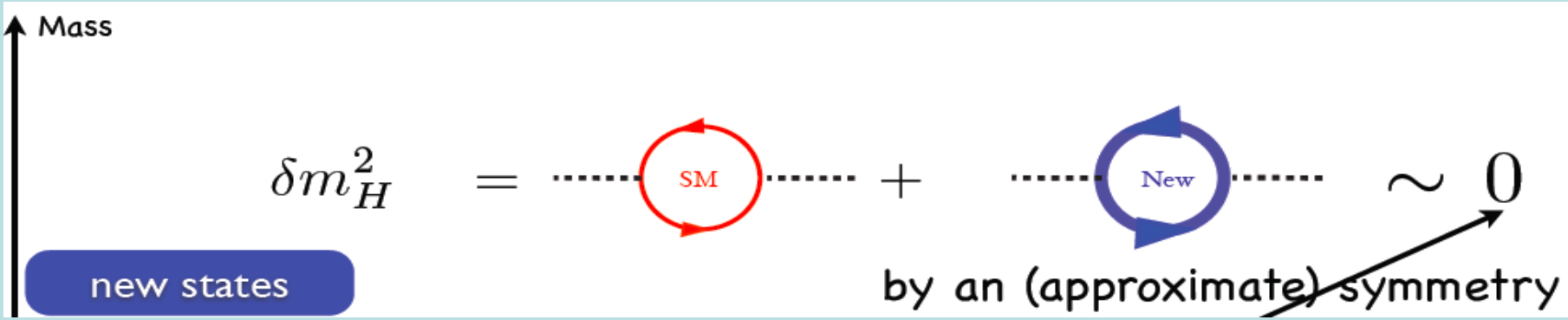


- V_{ub}: leakage to vector-like q?
- Dimuon asymmetry at TeVatron?

Ligeti

SM Measurements

- **Flavour, electroweak and Higgs measurements complement searches for New Physics**
- From LEP paradox to LHC paradox
  - Light Higgs + nothing else?
  - If something light, why no indirect evidence?
- If nothing light, is light Higgs unnatural?



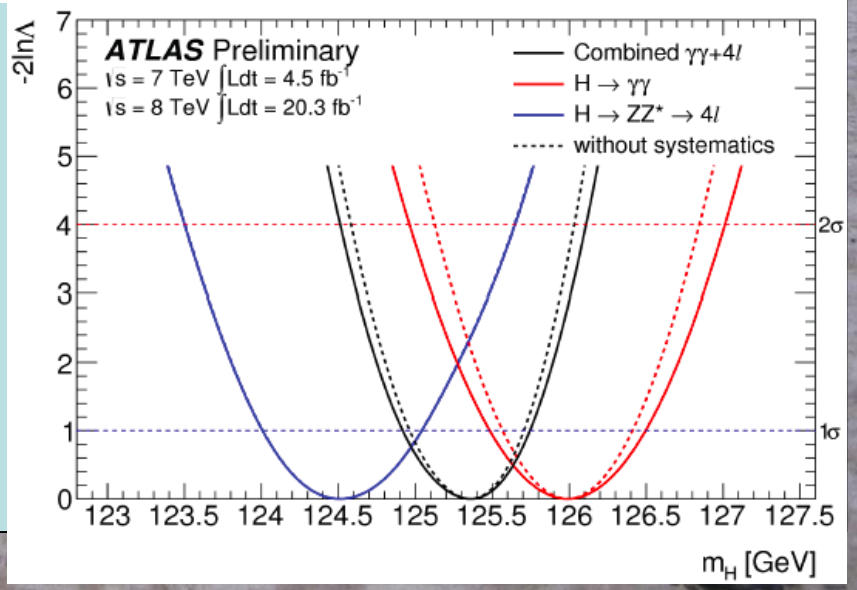
Higgs Mass

- Updates from ATLAS and CMS:
  - CMS: 125.6 ± 0.4 ± 0.2 GeV from ZZ*
  - ATLAS:

$H \to \gamma\gamma$	$125.98 \pm 0.42\,(\text{stat}) \pm 0.28\,(\text{sys}) = 125.98 \pm 0.50$
$H \to ZZ^* \to 4\ell$	$124.51 \pm 0.52\,(\text{stat}) \pm 0.04\,(\text{sys}) = 124.51 \pm 0.52$
Combined	$125.36 \pm 0.37\,(\text{stat}) \pm 0.18\,(\text{sys}) = 125.36 \pm 0.41$

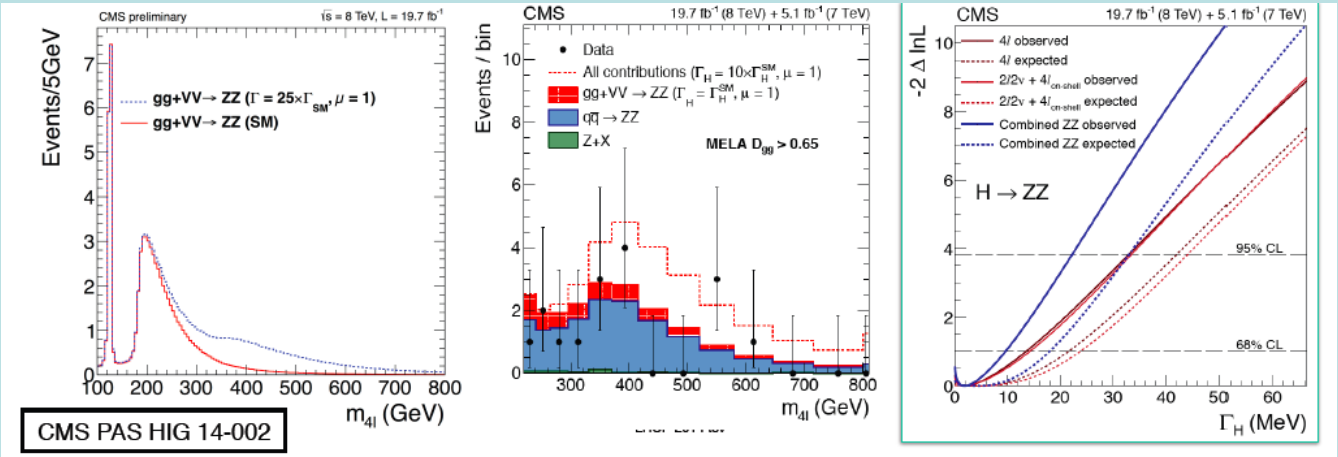
$$\Delta m_H = 1.47 \pm 0.67\,(\text{stat}) \pm 0.28\,(\text{sys})\ \text{GeV} = 1.47 \pm 0.72\ \text{GeV}$$

- 2-σ!
- Basic parameter of SM:
  - Measure it!
- **Crucial for stability of electroweak vacuum**



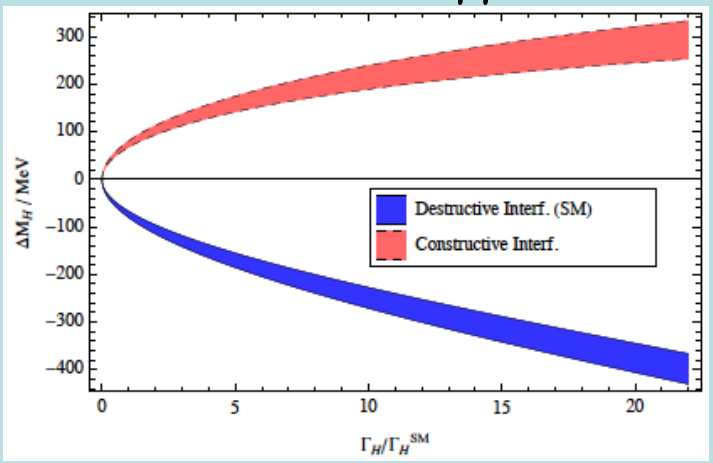
Measuring Γ_H @ LHC?

- Constraint from off-shell H* ➔ZZ: Γ_H < 22 MeV

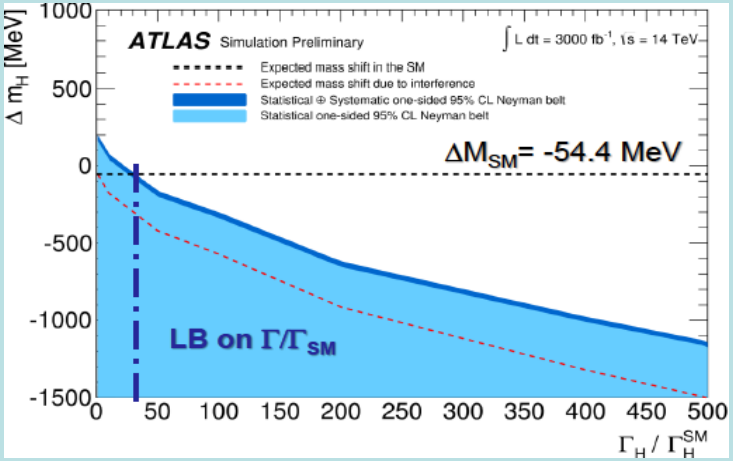


– But: Sensitive to BSM e.g., dim-6

- Apparent $m_{\gamma\gamma} \neq m_{ZZ^*}$ due to interference with QCD



Tough!



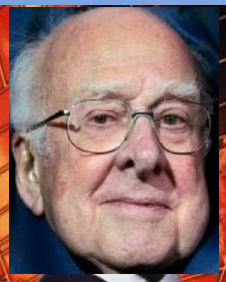
No BSM? Beware Historical Hubris

- ***"So many centuries after the Creation, it is unlikely that anyone could find hitherto unknown lands of any value"* - Spanish Royal Commission, rejecting Christopher Columbus proposal to sail west, < 1492**
- *"The more important fundamental laws and facts of physical science have all been discovered"* – Albert Michelson, 1894
- *"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement"* - Lord Kelvin, 1900
- *"Is the End in Sight for Theoretical Physics?"* – Stephen Hawking, 1980

Theoretical Confusion

- High mortality rate among theories
- (M_H, M_t) close to stability bound
- Split SUSY? High-scale SUSY?
- Modify/abandon naturalness? Does Nature care?
- String landscape?
- SUSY anywhere better than nowhere
- SUSY could not explain the hierarchy
- **New ideas needed!**

"In ~~football as in watchmaking~~, talent and elegance mean nothing without rigour and precision."
particle theory
[Lionel Messi]



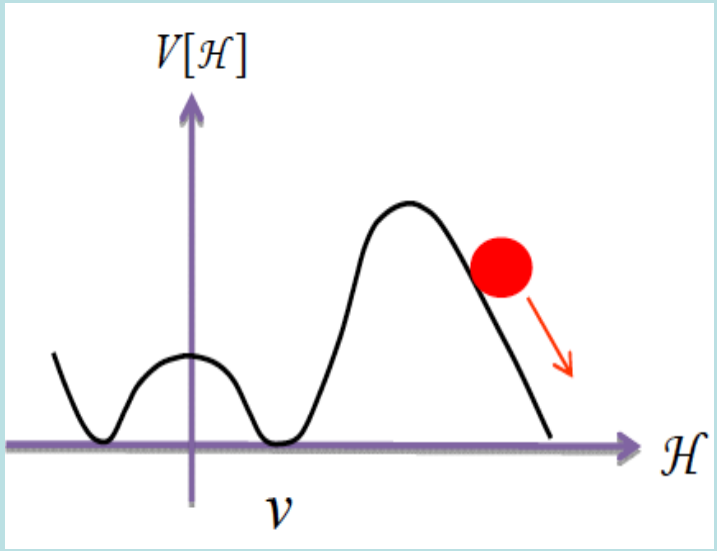
Gianotti

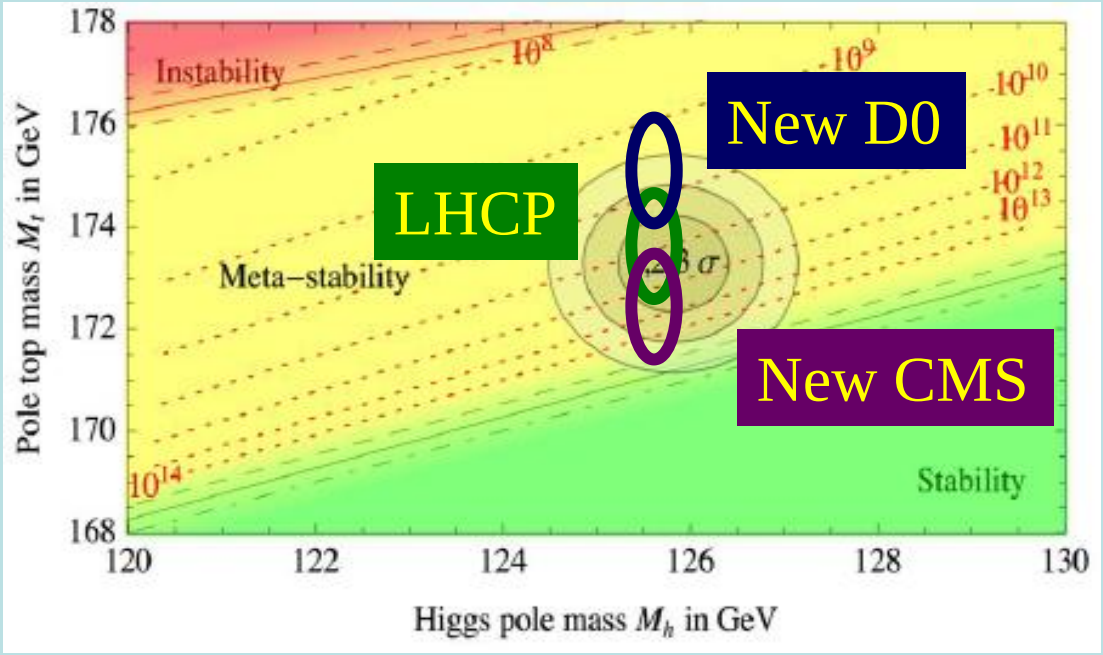
- « Empty » space is unstable
- Dark matter
- Origin of matter
- Masses of neutrinos
- Why is weak force so strong?
- Inflation
- Quantum gravity
- …

The *Standard Model* Is Not *Enough*

Vacuum Instability in the Standard Model

- Very sensitive to m_t as well as M_H





- Instability scale: Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio & Strumia, arXiv:1307.3536

$$\log_{10}\frac{\Lambda_I}{\text{GeV}} = 11.3 + 1.0\left(\frac{M_h}{\text{GeV}} - 125.66\right) - 1.2\left(\frac{M_t}{\text{GeV}} - 173.10\right) + 0.4\,\frac{\alpha_3(M_Z) - 0.1184}{0.0007}$$

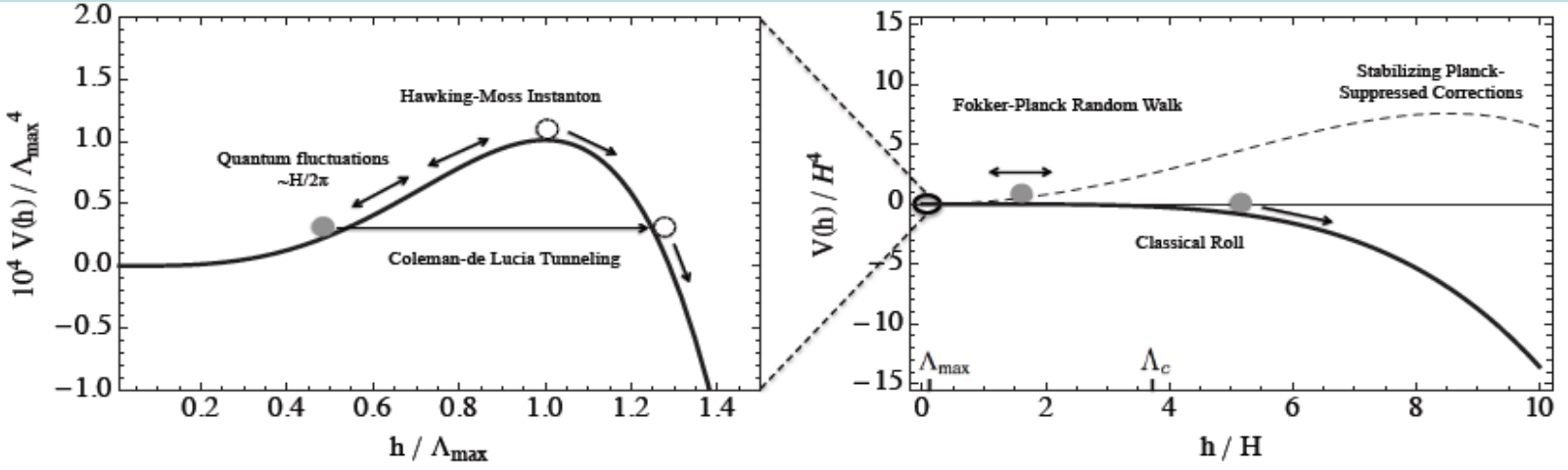
- **m_t = 173.8 ± 1 GeV ➔ $\log_{10}(\Lambda/\text{GeV})$ = 10.3 ± 1.3**

Kosowsky

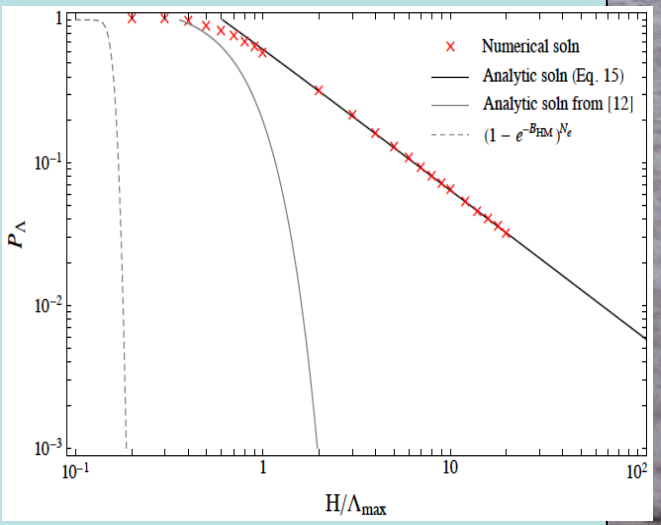
Instability during Inflation?

Hook, Kearns, Shakya & Zurek: arXiv:1404.5953

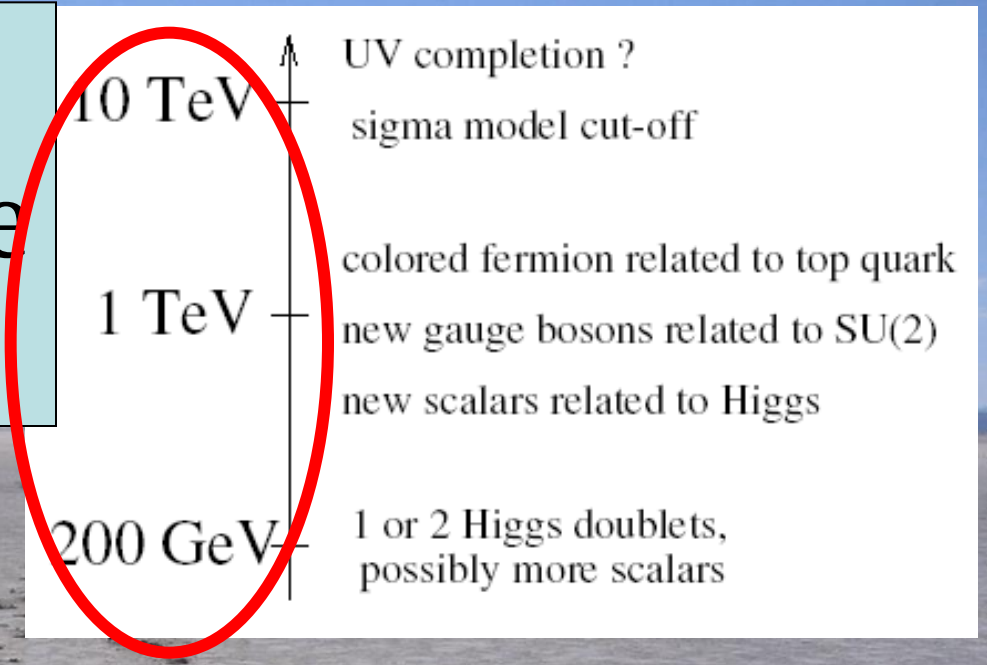
- Do quantum fluctuations drive us over the hill?



- Then Fokker-Planck evolution
- Do AdS regions eat us?
  - Disaster if so
  - If not, OK if more inflation
- Cure with non-ren'ble operator?

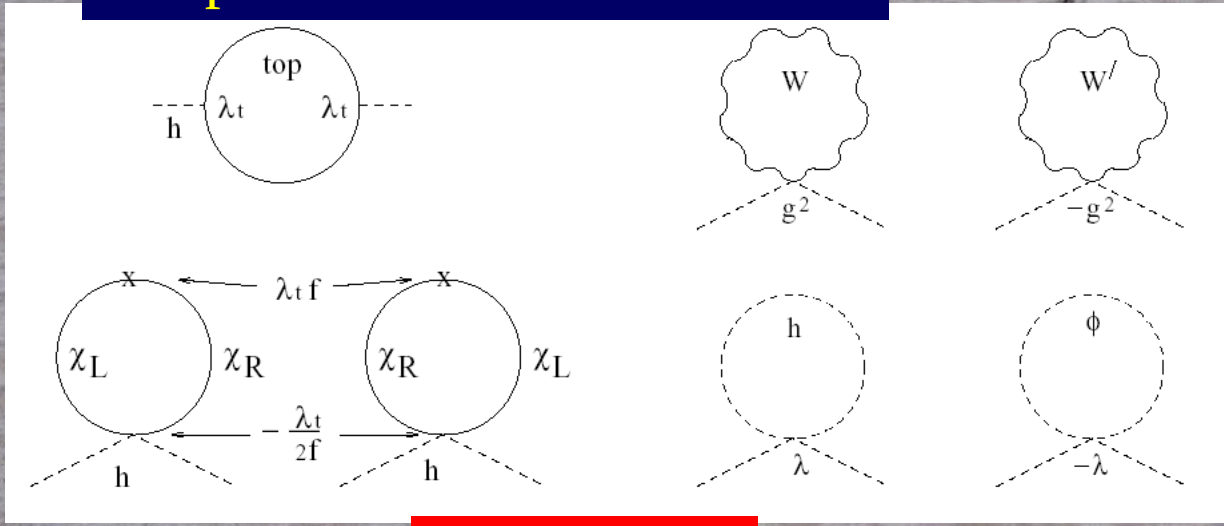


Higgs as a Pseudo-Goldstone Boson?

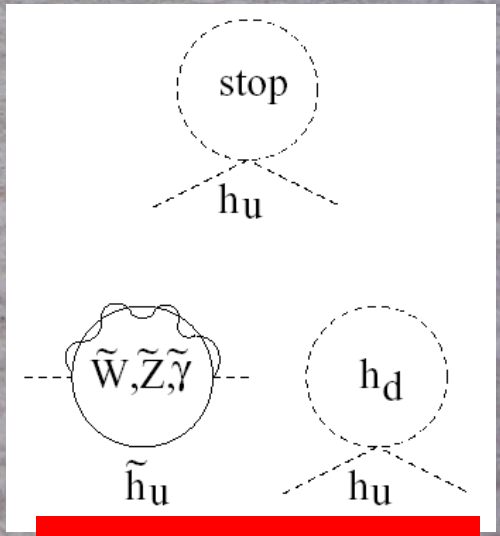


'Little Higgs' models
(breakdown of larger symmetry)

Loop cancellation mechanism



Little Higgs

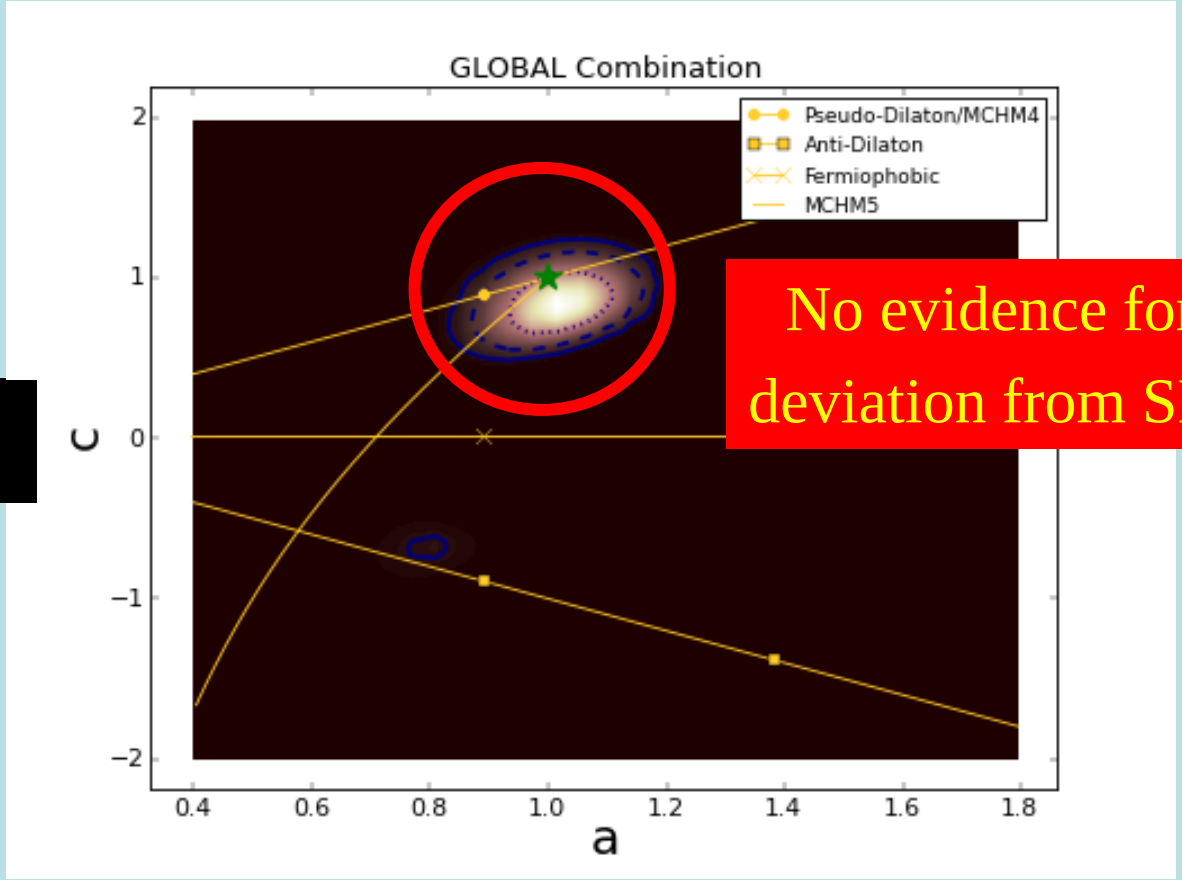


Supersymmetry

Global Analysis of Higgs-like Models

- Rescale couplings: to bosons by a, to fermions by c

Global



No evidence for deviation from SM

Muehlleitner

- Standard Model: $a = c = 1$

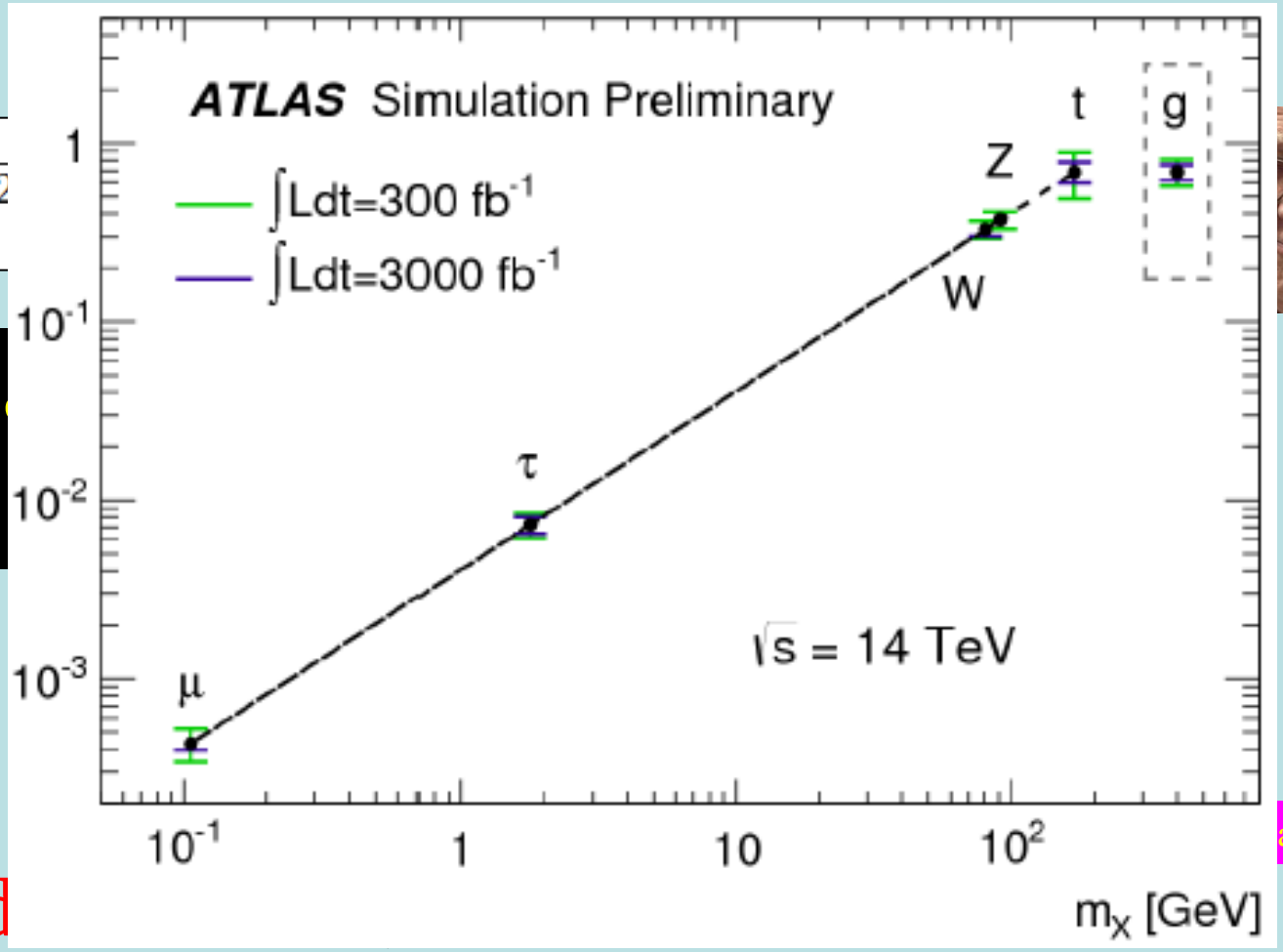
JE & Tevong You, arXiv:1303.3879

It Walks and Quacks like a Higgs

- Do couplings scale ~ mass? With scale = v?

$\lambda_f = \sqrt{2}$

Glob… fit



arXiv:1303.3879

- **Red…**

BSM via Higher-Dimensional Operators

- SM Higgs + corrections due to BSM

Muehlleitner

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \tilde{\varphi})$
Q_W	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu \varphi\right)^* \left(\varphi^\dagger D_\mu \varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\tilde{W}}$	$\epsilon^{IJK} \tilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D_\mu}\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\tilde{G}}$	$\varphi^\dagger\varphi\, \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D_\mu^I}\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\tilde{\varphi} G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D_\mu}\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\tilde{W}}$	$\varphi^\dagger\varphi \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \tilde{\varphi} W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D_\mu}\varphi)(\bar{q}_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tilde{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D_\mu^I}\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\tilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r)\varphi G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D_\mu}\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D_\mu}\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\tilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\tilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

$(LL)(LL)$		$(RR)(RR)$		$(LL)(RR)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_t^j)$	Q_{duq}	$\epsilon^{\alpha\beta\gamma} e_{jk} \left[(d_p^\alpha)^T C u_r^\beta\right] \left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \epsilon_{jk} (\bar{q}_s^k d_t)$	Q_{qqu}	$\epsilon^{\alpha\beta\gamma} e_{jk} \left[(q_p^{\alpha j})^T C q_r^{\beta k}\right] \left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r) \epsilon_{jk} (\bar{q}_s^k T^A d_t)$	$Q_{qqq}^{(1)}$	$\epsilon^{\alpha\beta\gamma} e_{jk} e_{mn} \left[(q_p^{\alpha j})^T C q_r^{\beta k}\right] \left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r) \epsilon_{jk} (\bar{q}_s^k u_t)$	$Q_{qqq}^{(3)}$	$\epsilon^{\alpha\beta\gamma} (\tau^I \epsilon)_{jk} (\tau^I \epsilon)_{mn} \left[(q_p^{\alpha j})^T C q_r^{\beta k}\right] \left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r) \epsilon_{jk} (\bar{q}_s^k \sigma^{\mu\nu} u_t)$	Q_{duu}	$\epsilon^{\alpha\beta\gamma} \left[(d_p^\alpha)^T C u_r^\beta\right] \left[(u_s^\gamma)^T C e_t\right]$

- E.g., analysis of Higgs constraints

$$\Delta\mathcal{L}_{\text{input}} = \frac{c_T}{v^2}\mathcal{O}_T + \frac{c_V^+}{m_W^2}\left(\mathcal{O}_W + \mathcal{O}_B\right) + \frac{c_{LL}^{(3)\,l}}{v^2}\mathcal{O}_{LL}^{(3)\,l}$$

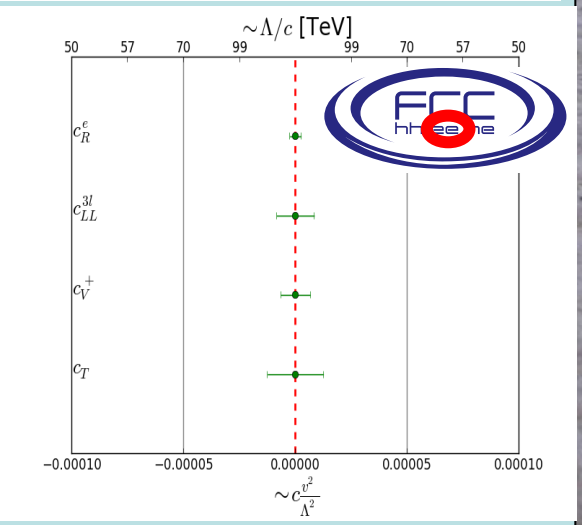
$$\mathcal{O}_R^e = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R\gamma^\mu e_R)$$

$$\mathcal{O}_{LL}^{(3)\,l} = (\bar{L}_L\sigma^a\gamma^\mu L_L)\,(\bar{L}_L\sigma^a\gamma_\mu L_L)$$

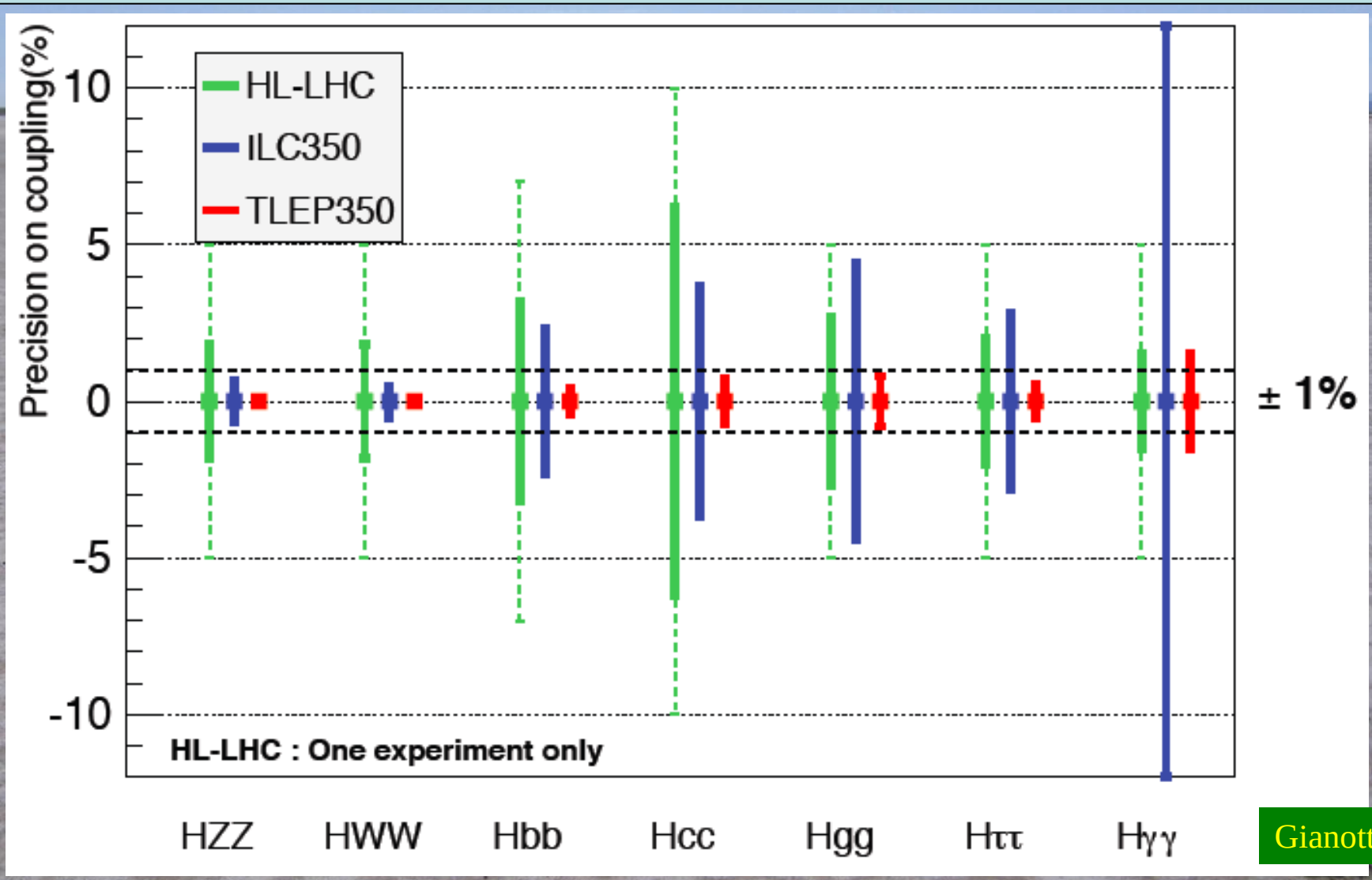
$$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger\sigma^a \overleftrightarrow{D}^\mu H\right) D^\nu W_{\mu\nu}^a$$

$$\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right)\partial^\nu B_{\mu\nu}$$

$$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$$



Possible Future Higgs Measurements



What else is there?

Supersymmetry

- Successful prediction for Higgs mass
  - Should be < 130 GeV in simple models
- Successful predictions for Higgs couplings
  - Should be within few % of SM values
- Could explain the dark matter
- Naturalness, GUTs, string, … (???)

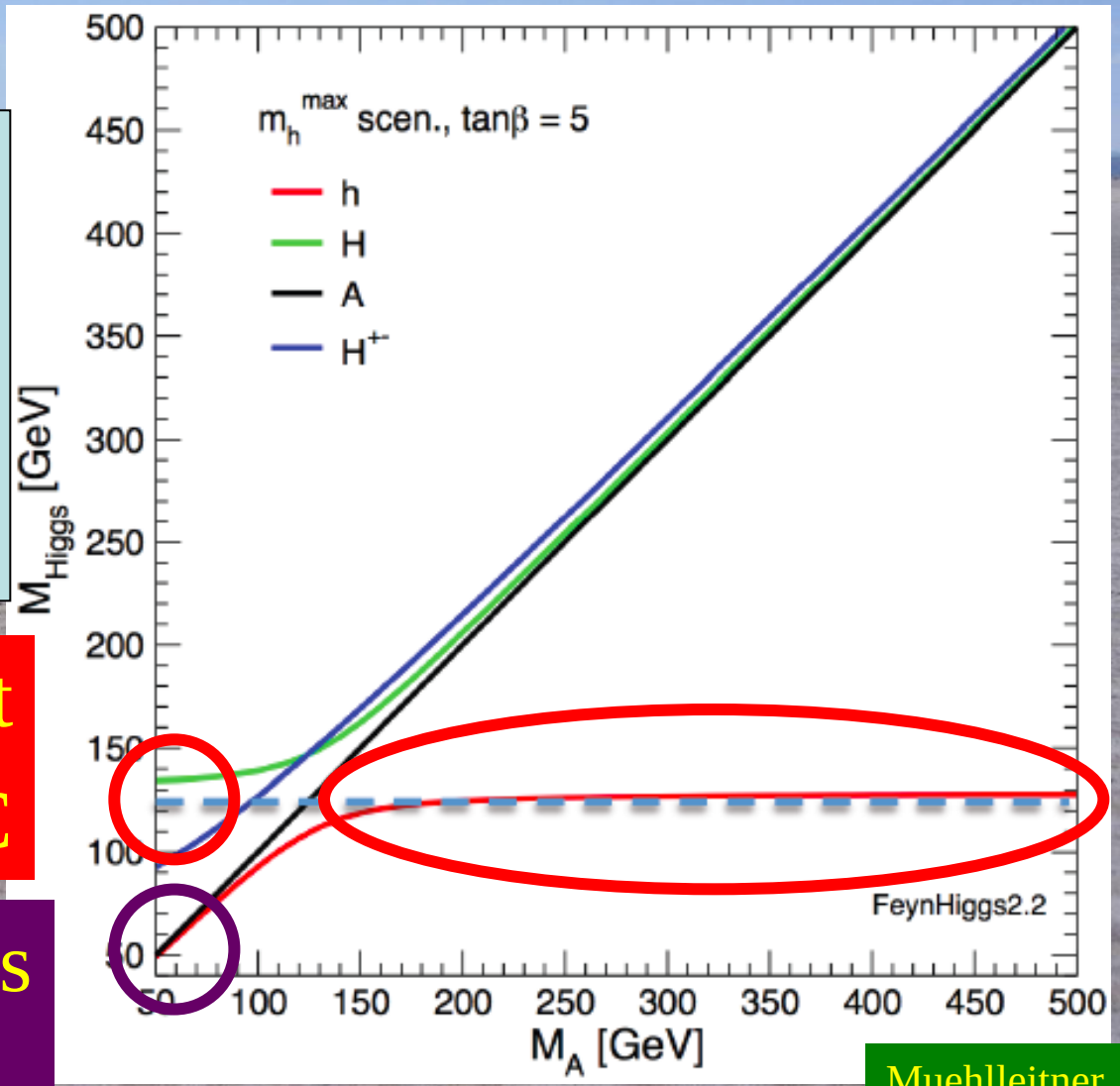
MSSM Higgs Masses & Couplings

Lightest Higgs mass up to ~ 130 GeV

Heavy Higgs masses quite close

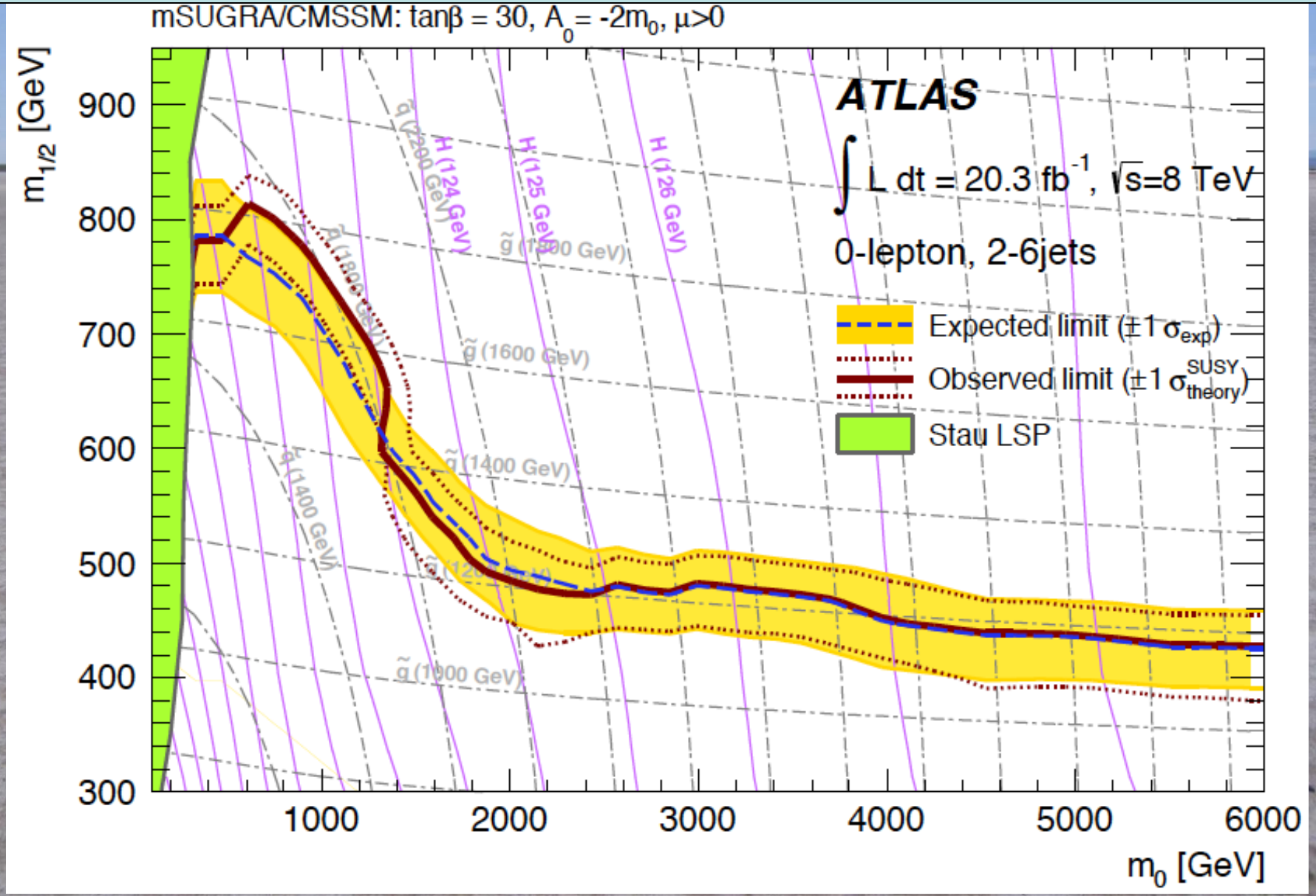
Consistent With LHC

Is a lighter Higgs still waiting?



Muehlleitner

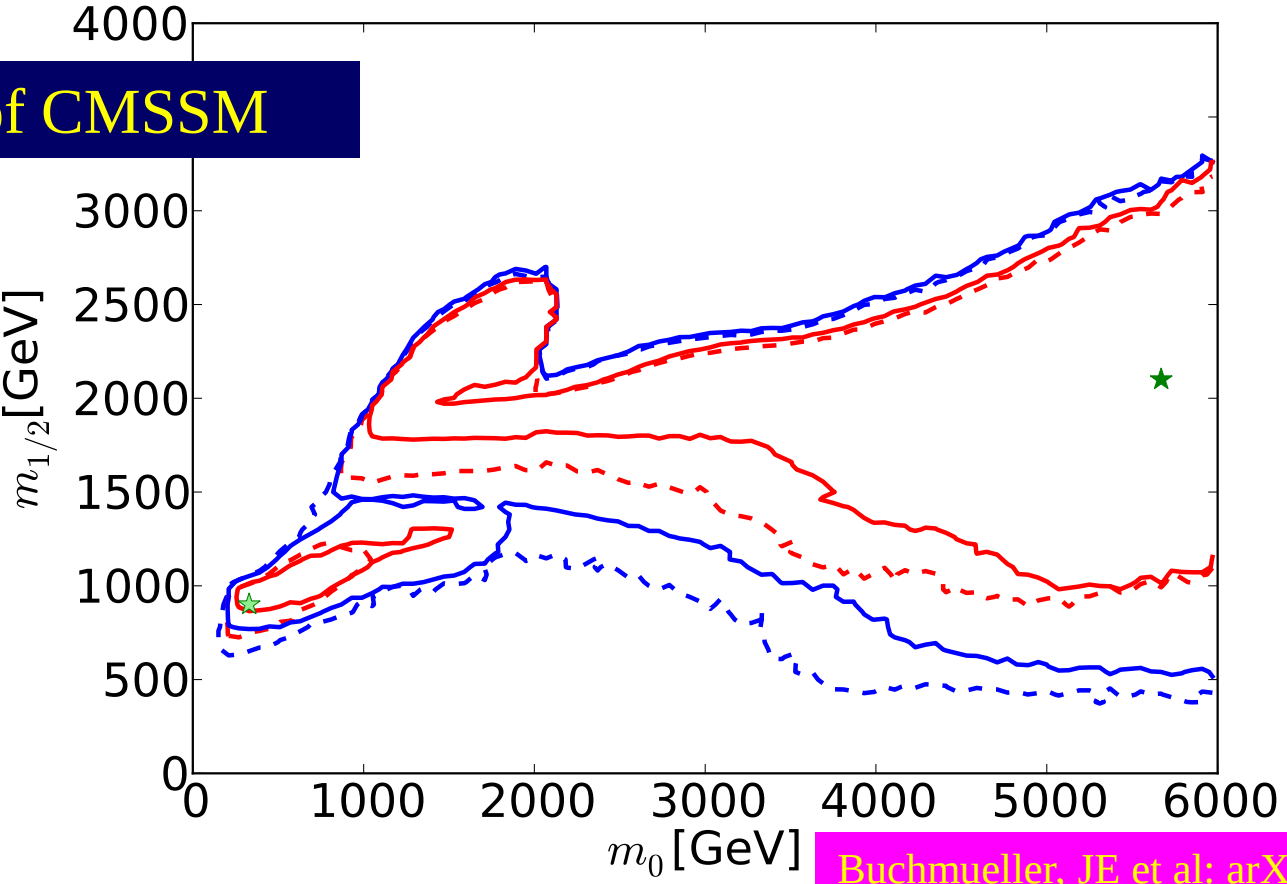
CMSSM Search @ 8 TeV



Post-LHC, Post-XENON100

2012 ATLAS + CMS with 20/fb of LHC Data

Scan of CMSSM

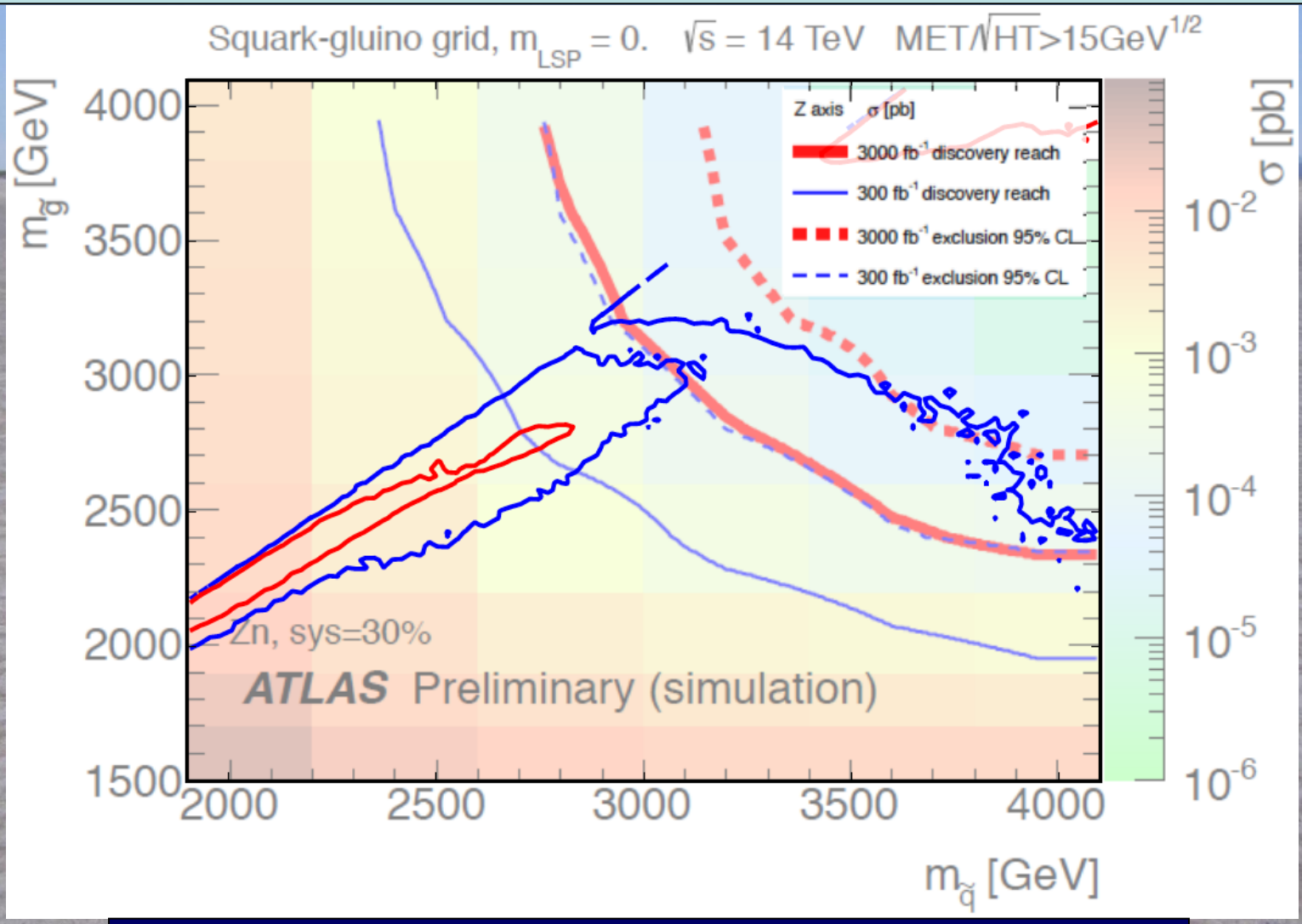


Buchmueller, JE et al: arXiv:1312.5250

Red and blue curves represent $\Delta\chi^2$ from global minimum, located at ★

p-value of simple models ~ 5% (also SM)

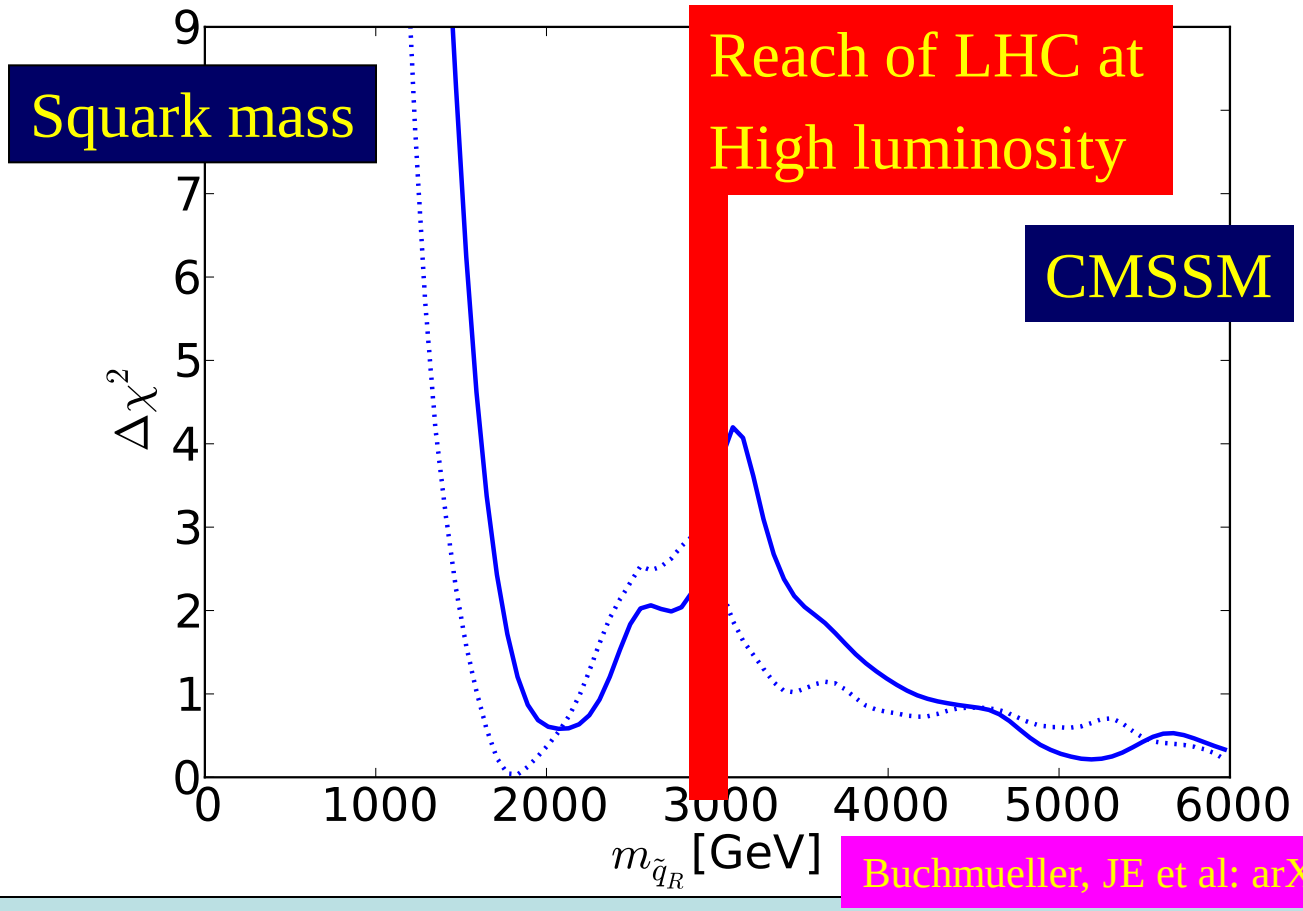
LHC Reach for Supersymmetry



Confronted with likelihood analysis of CMSSM

Post-LHC, Post-XENON100

2012 ATLAS + CMS with 20/fb of LHC Data



Buchmueller, JE et al: arXiv:1312.5250

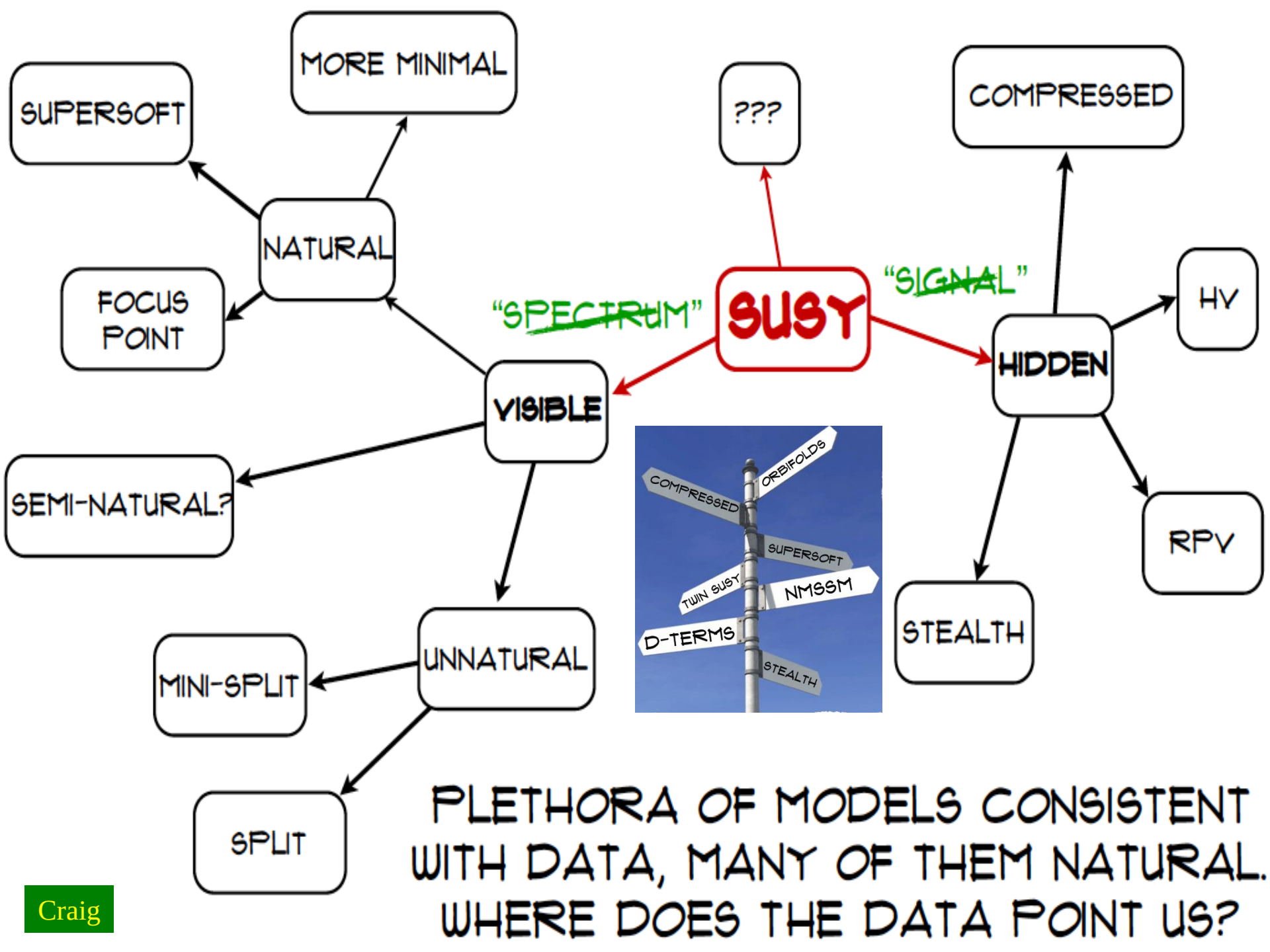
Favoured values of squark mass also significantly above pre-LHC, > 1.6 TeV

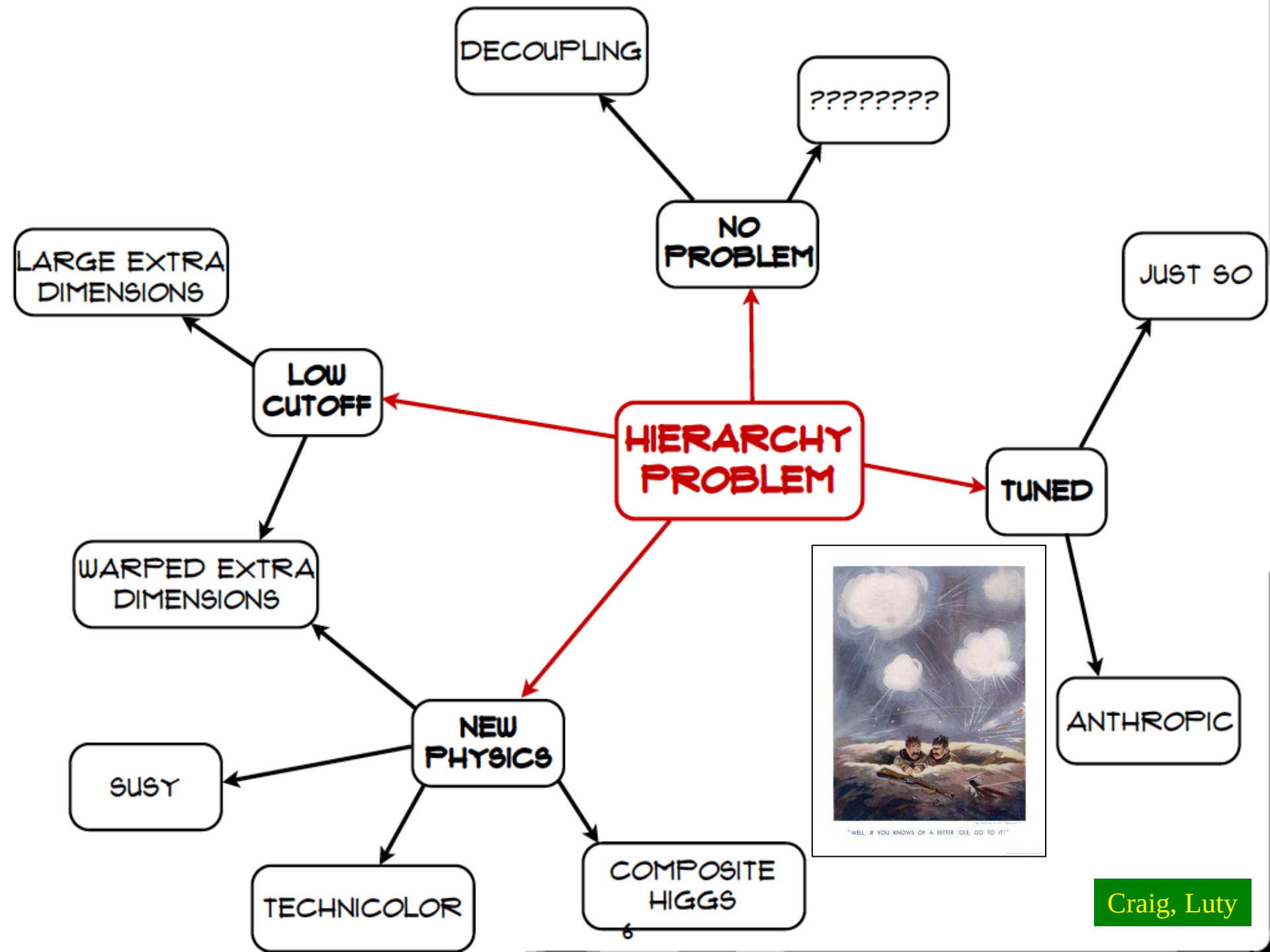
If you Know of a Better Hole, go to it

"WELL, IF YOU KNOWS OF A BETTER 'OLE, GO TO IT!"

- The hierarchy problem is more pressing than ever
- SUSY is increasingly the best solution we have
- We have an evolving sense of what SUSY models do not work
- But SUSY is a framework, not a model, and contains multitudes
- This points us in new directions; many novel possibilities for SUSY remain

Craig


MORE MINIMAL
SUPERSOFT
???
COMPRESSED
NATURAL
FOCUS POINT
"SPECTRUM"
SUSY
"SIGNAL"
HV
HIDDEN
VISIBLE
SEMI-NATURAL?
ORBIFOLDS
COMPRESSED
SUPERSOFT
TWIN SUSY
NMSSM
D-TERMS
STEALTH
RPV
STEALTH
UNNATURAL
MINI-SPLIT
SPLIT
PLETHORA OF MODELS CONSISTENT WITH DATA, MANY OF THEM NATURAL. WHERE DOES THE DATA POINT US?
Craig


DECOUPLING
????????
NO PROBLEM
LARGE EXTRA DIMENSIONS
LOW CUTOFF
HIERARCHY PROBLEM
JUST SO
TUNED
WARPED EXTRA DIMENSIONS
NEW PHYSICS
ANTHROPIC
SUSY
TECHNICOLOR
COMPOSITE HIGGS
"WELL, IF YOU KNOWS OF A BETTER 'OLE, GO TO IT!"
Craig, Luty

Proton-Proton Colliders: Luminosity and Energy

- Future runs of the LHC:
  - Run 2: 30/fb @ 13/14 TeV
  - Run 3: 300/fb @ 14 TeV
- HL-LHC: 3000/fb @ 14 TeV?

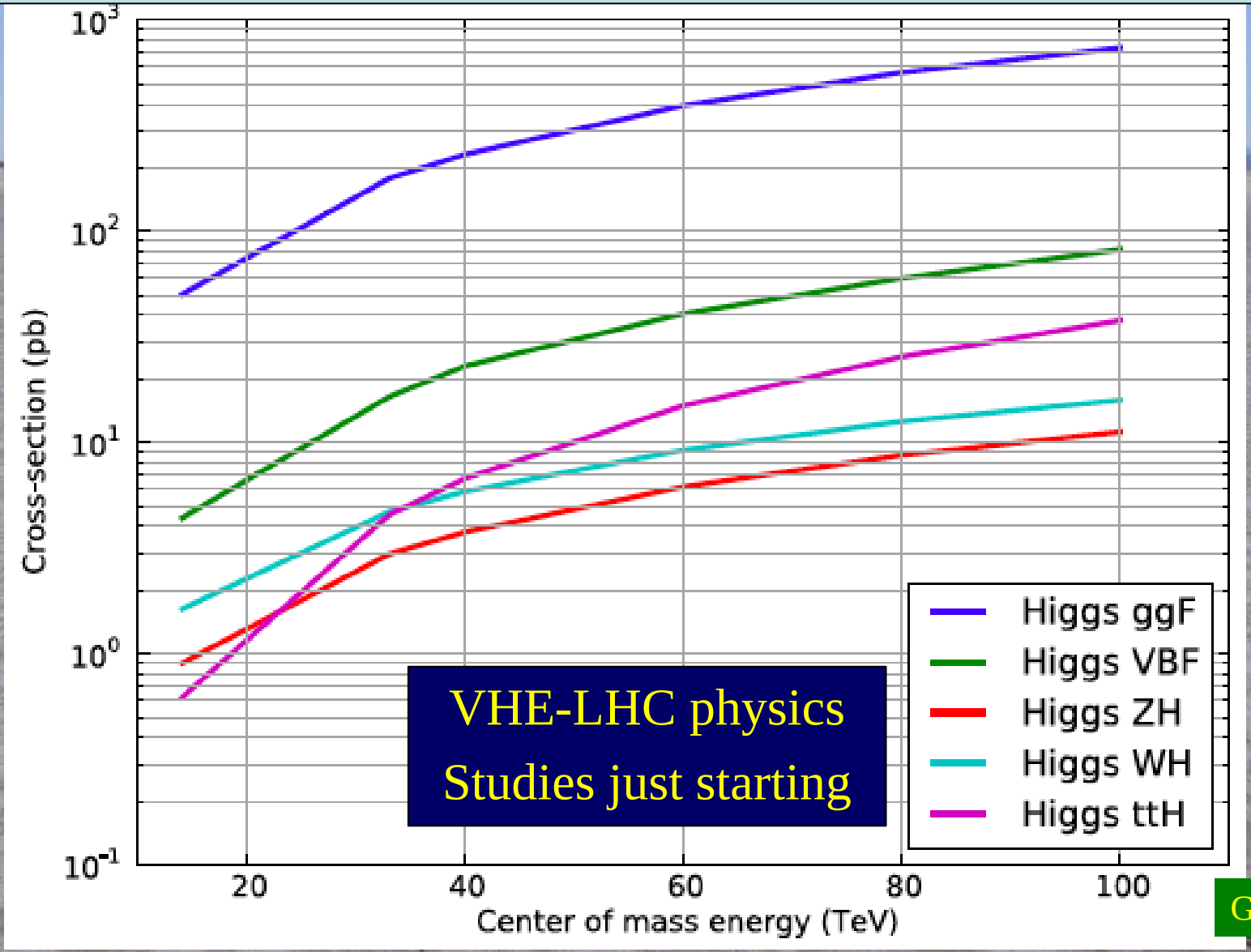
  (proposed in CERN's medium-term plan)
- HE-LHC: 3000/fb @ 33 TeV??

  (high-field magnets in the LHC tunnel)
- VHE-LHC: 3000/fb @ 100 TeV??

  (high-field magnets in 80/100 km tunnel)

Gianotti

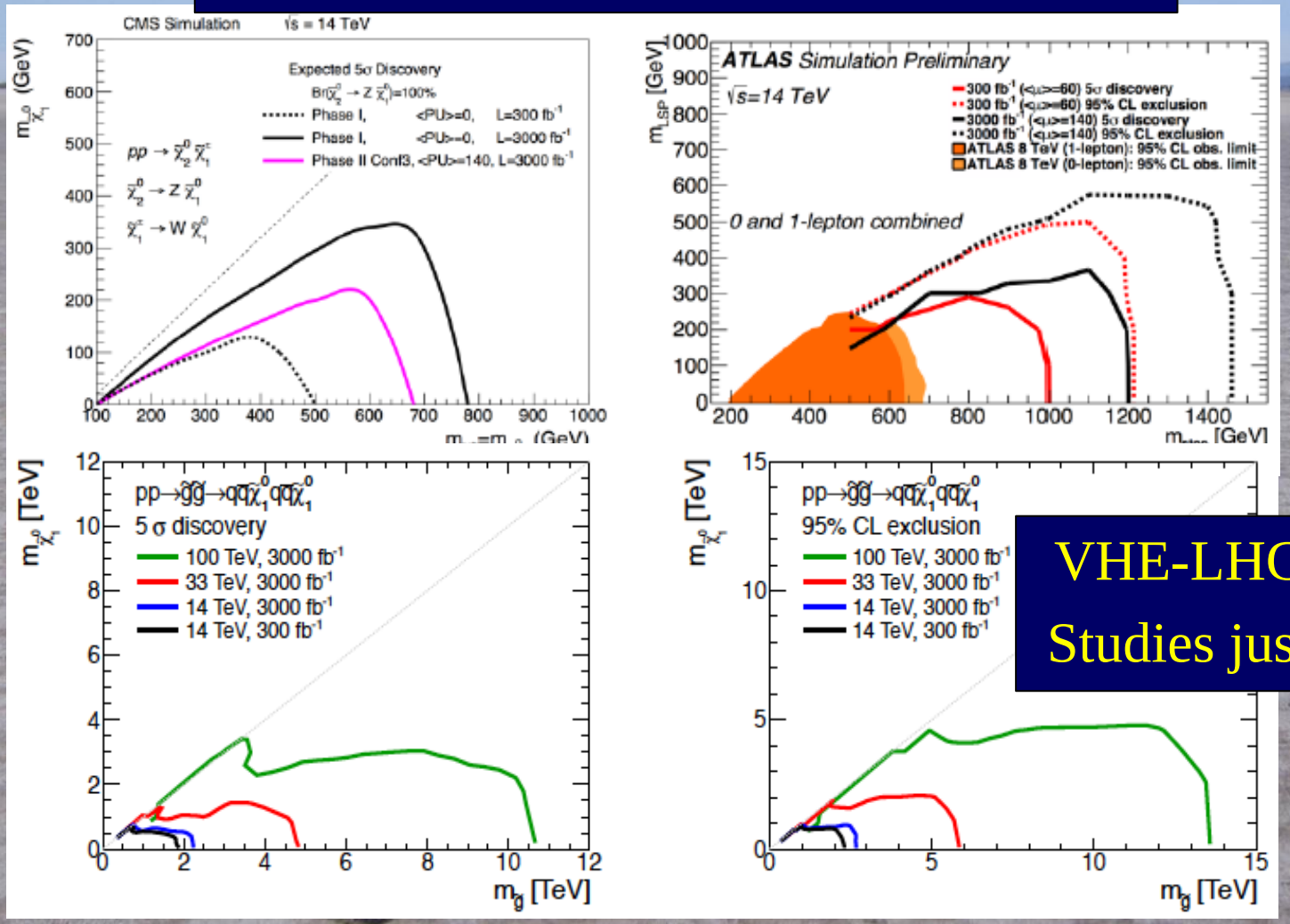
Higgs Cross-Sections @ HE/VHE-LHC



Gianotti

Reaches for Sparticles

@ LHC, HE-LHC, VHE-LHC



VHE-LHC physics
Studies just starting

Gianotti

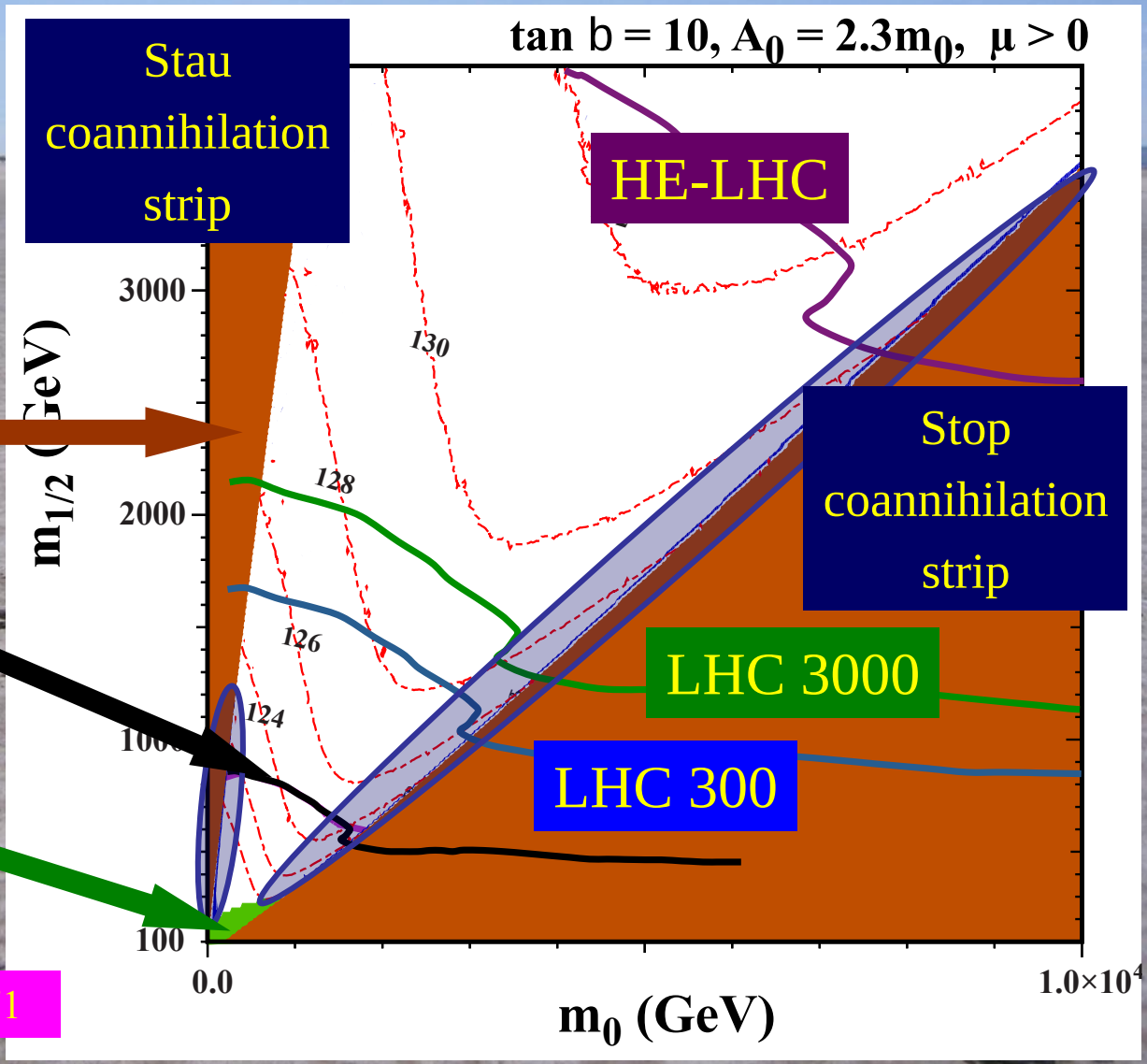
Where May CMSSM be Hiding?

Relic density constraint, assuming neutralino LSP

Excluded because stau or stop LSP

Excluded by ATLAS Jest + MET search

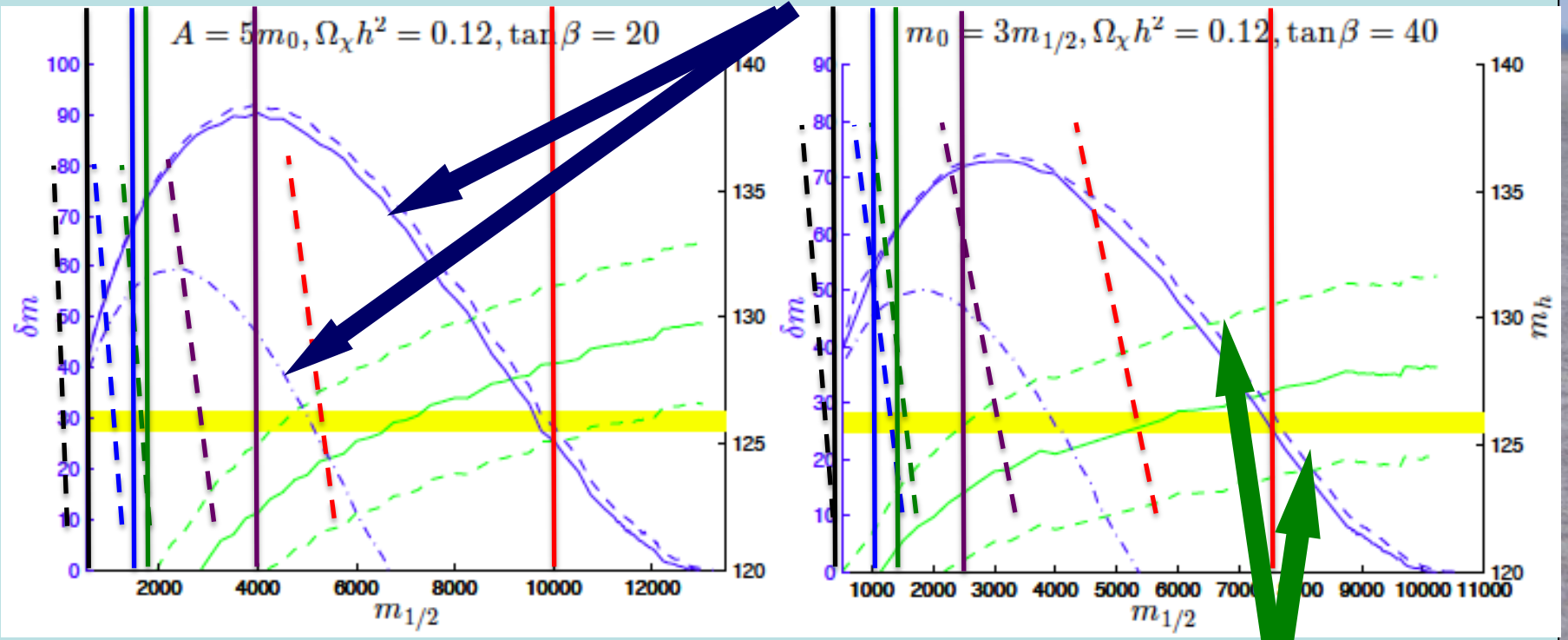
Excluded by $b \rightarrow s\,\gamma$, $B_s \rightarrow \mu^+\mu^-$



JE, Olive & Zheng: arXiv:1404.5571

Exploring the **Stop Coannihilation Strip**

- Extended by Sommerfeld effects on annihilations



Current limits | LHC 300 (monojets), MET | LHC 3000 (monojets), MET

(monojets), MET | HE-LHC (monojets), MET | 100 TeV (monojets), MET

JE, Olive & Zheng: arXiv:1404.5571

Standard Model Particles:
Years from Proposal to Discovery