Vision Talk

Joseph Lykken

Outline

- Condensed matter physics in vacuo
- Higgs quo vadis?
- Supersymmetry: aut vincere aut mori
- Naturalness: quem deus vult perdere, dementat prius
- QCD: hic sunt dracones
- Scientia ipsa potentia est

Higgs discovery

The first time that the entire NYT Science section is devoted to a single story

Condensed matter physics in vacuo

Nobel Lecture: Spontaneous symmetry breaking in particle physics: A case of cross fertilization*

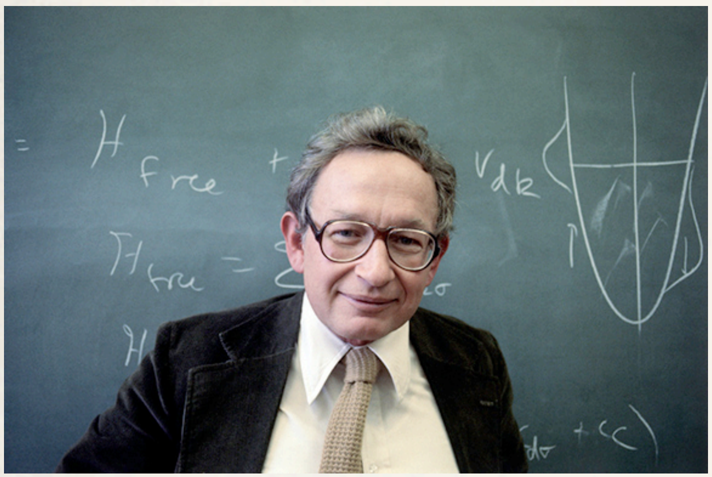
Yoichiro Nambu

Physical system	Broken symmetry
Ferromagnets	Rotational invariance (with respect to spin)
Crystals	Translational and rotational invariance (modulo discrete values)
Superconductors	Local gauge invariance (particle number)

- Apply condensed matter ideas to particle physics
- ***Now the quantum vacuum is "the medium"***

Anderson (1962)

gauge bosons "eat" Goldstone bosons and get mass, just like a photon inside a superconductor

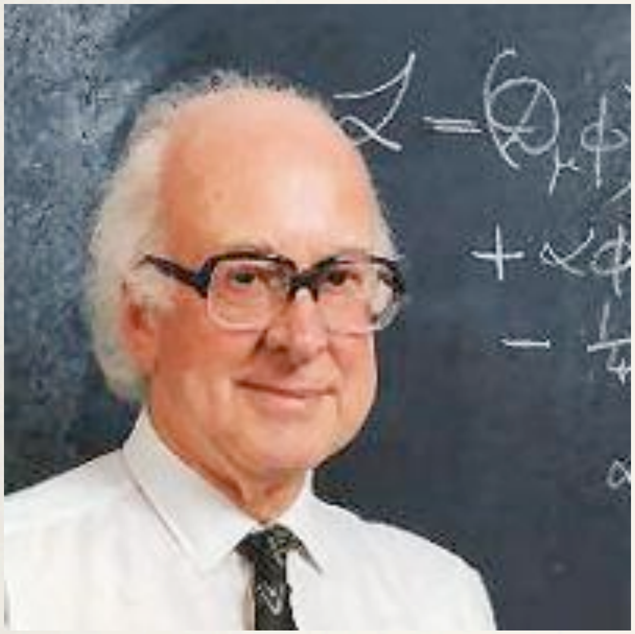


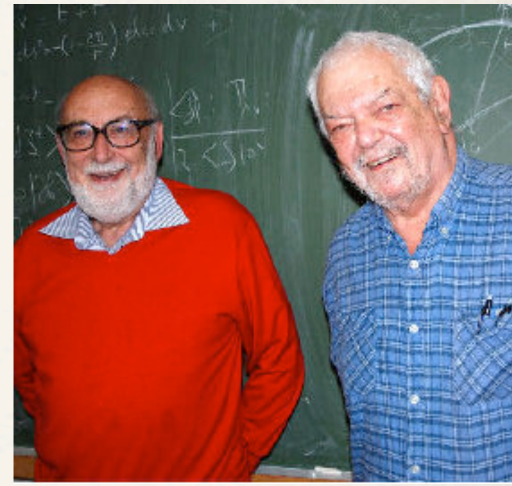
Physical system	Broken symmetry	Goldstone modes
Ferromagnets	Rotational invariance (with respect to spin)	spin waves
Crystals	Translational and rotational invariance (modulo discrete values)	phonons
Superconductors	Local gauge invariance (particle number)	???

> It is likely, then, considering the superconducting analog, that the way is now open for a degenerate-vacuum theory of the Nambu type without any difficulties involving either zero-mass Yang-Mills gauge bosons or zero-mass Goldstone bosons. These two types of bosons seem capable of "canceling each other out" and leaving finite mass bosons only.

Higgs et al (1964)

a fundamental self-sourcing scalar field can cause spontaneous symmetry-breaking in the vacuum and give gauge bosons mass





The purpose of the present note is to report that...the spin-one quanta of some of the gauge fields acquire mass...This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson has drawn attention

the Higgs Mechanism

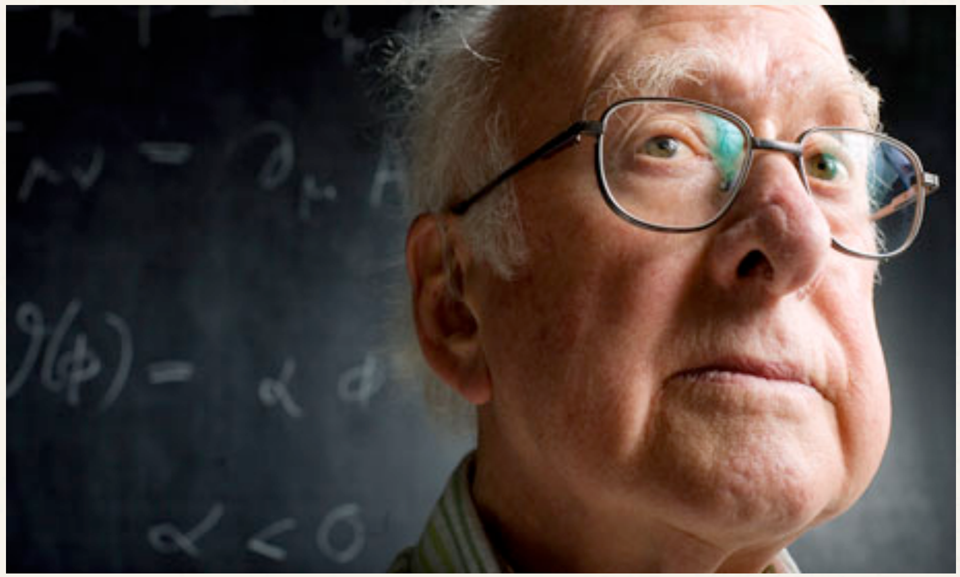
Higgs boson:
not just another particle

- A new **force** has been discovered, the first ever seen* not related to a gauge symmetry.
- Its **mediator** looks a lot like the SM scalar

Talk by Fabio Maltoni at LHCP 2013

- **Fundamental Boson:** **New interaction which is not gauge**
- **Composite Boson:** **New underlying dynamics**

Higgs Quo Vadis?

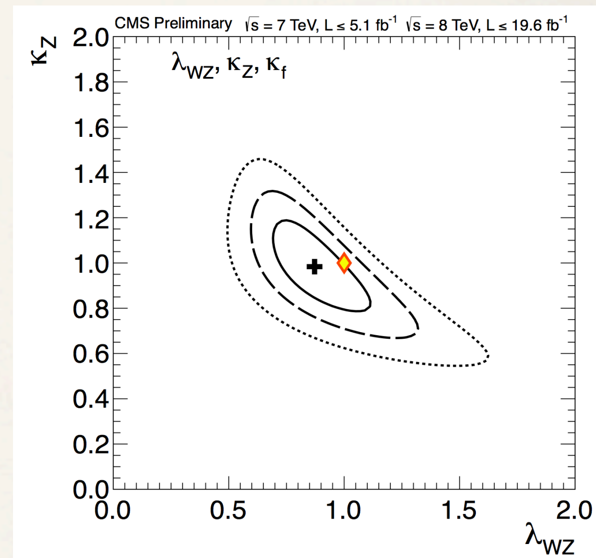


Higgs Imposters

- **First job of the experiments was to rule out Higgs imposters**
- Is it spin 1? [no] or spin 2? [probably not]

Talks by Aurelio Juste, Vivek Sharma

- Is it a pseudoscalar? [no, but could be a CP mixture]
- Does it come from an SU(2) triplet? [no]



CMS: 95% CL interval for λ_{WZ} : [0.62,1.19]

ATLAS: $\lambda_{WZ} = 0.80 \pm 0.15$

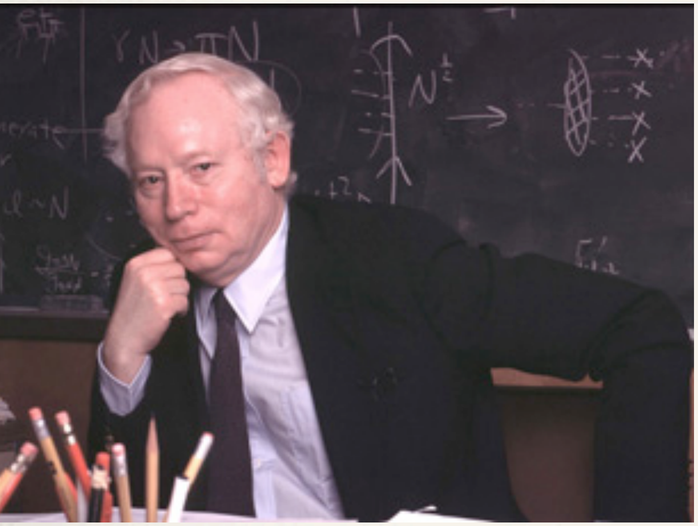
i.e. decays about 8 times more often to WW* than ZZ*, consistent with neutral member of doublet Higgs but not a custodially invariant triplet

Ian Low, JL, Gabe Shaughnessy, arXiv:1207.1093

- Can tune a dilaton imposter or spin 2 imposter to fit data, but ...

Talks by Jay Hubisz and Zakaria Chacko

is it a non-SM Higgs?



- Could be a mixture from more than one Higgs SU(2) doublet, singlets or triplets

  Talk by Mariano Quiros

- Could be a mixture of CP even and CP odd

  Talk by Jure Zupan

- Could have enhanced/suppressed couplings to photons or gluons if there are exotic heavy charged or colored particles Talk by Stefania Gori

- Could decay to exotic particles, e.g. dark matter

- May not couple to quarks and leptons precisely proportional to their masses

- Could be composite, by itself does not unitarize VV scattering

Higgs connections

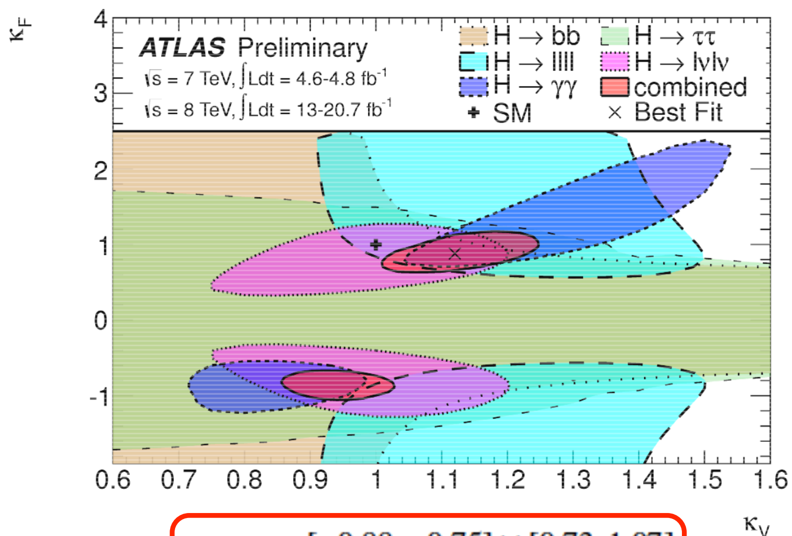
- Is there a Higgs portal to dark matter
- What is the origin of the electroweak scale
- Does the Higgs sector trigger UV instabilities
- Electroweak baryogenesis
- How does the Higgs talk to neutrinos
- Extra credit: is the Higgs related to inflation or dark energy

→ Motivates a multi-decade global experimental effort on all three “frontiers” of HEP

the precision Higgs era has begun

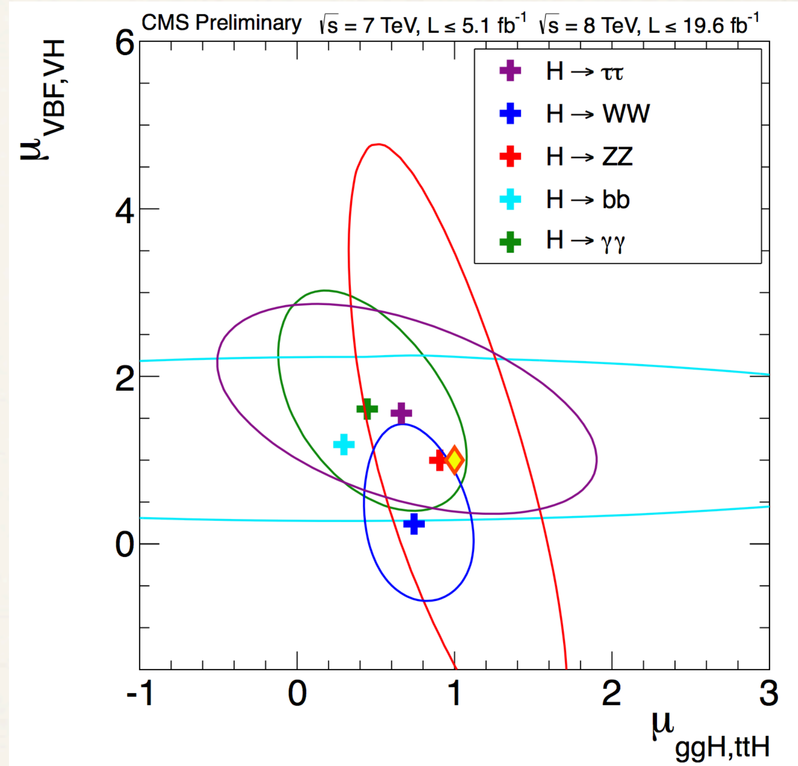
Talks by Aurelio Juste and Vivek Sharma

Assume no BSM contribution to the total Higgs width or the H→γγ loop



$$\kappa_F \in [-0.88, -0.75] \cup [0.73, 1.07]$$
$$\kappa_V \in [0.91, 0.97] \cup [1.05, 1.21]$$

68% CL interval



A simple start is to fit measured Higgs signal strengths to two parameters expressing possible non-SM behavior

precision Higgs studies: model-independent approach

IN A COMPLETE ANALYSIS ALL 59 INDEPENDENT OPERATORS OF Grzadkowski:2010es), INCLUDING 25 FOUR-FERMION OPERATORS, HAVE TO BE CONSIDERED IN ADDITION TO THE SELECTED 34 OPERATORS

Φ^6 and $\Phi^4 D^2$	$\psi^2\Phi^3$	X^3
$\mathcal{O}_\Phi = (\Phi^\dagger\Phi)^3$	$\mathcal{O}_{e\Phi} = (\Phi^\dagger\Phi)(\bar{l}\Gamma_e e\Phi)$	$\mathcal{O}_G = f^{ABC} G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$
[illegible] $\Phi^\dagger\Phi)\Box(\Phi^\dagger\Phi)$	$\mathcal{O}_{u\Phi} = (\Phi^\dagger\Phi)(\bar{q}\Gamma_u u\widetilde{\Phi})$	$\mathcal{O}_{\widetilde{G}} = f^{ABC} \widetilde{G}^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$
[illegible] $^\dagger D^\mu\Phi)^*(\Phi^\dagger D_\mu\Phi)$	$\mathcal{O}_{d\Phi} = (\Phi^\dagger\Phi)(\bar{q}\Gamma_d d\Phi)$	$\mathcal{O}_W = \varepsilon^{IJK} W^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$
		$\mathcal{O}_{\widetilde{W}} = \varepsilon^{IJK} \widetilde{W}^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$
[illegible]	$\psi^2 X\Phi$	$\psi^2\Phi^2 D$
$\mathcal{O}_{\Phi G} = (\Phi^\dagger\Phi) G^A_{\mu\nu} G^{A\mu\nu}$	$\mathcal{O}_{uG} = (\bar{q}\sigma^{\mu\nu}\frac{\lambda^A}{2}\Gamma_u u\widetilde{\Phi}) G^A_{\mu\nu}$	$\mathcal{O}^{(1)}_{\Phi l} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{l}\gamma^\mu l)$
$\mathcal{O}_{\Phi\widetilde{G}} = (\Phi^\dagger\Phi)\widetilde{G}^A_{\mu\nu} G^{A\mu\nu}$	$\mathcal{O}_{dG} = (\bar{q}\sigma^{\mu\nu}\frac{\lambda^A}{2}\Gamma_d d\Phi) G^A_{\mu\nu}$	$\mathcal{O}^{(3)}_{\Phi l} = (\Phi^\dagger i\overleftrightarrow{D}^I_\mu\Phi)(\bar{l}\gamma^\mu\tau^I l)$
$\mathcal{O}_{\Phi W} = (\Phi^\dagger\Phi) W^I_{\mu\nu} W^{I\mu\nu}$	$\mathcal{O}_{eW} = (\bar{l}\sigma^{\mu\nu}\Gamma_e e\tau^I\Phi) W^I_{\mu\nu}$	$\mathcal{O}_{\Phi e} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{e}\gamma^\mu e)$
$\mathcal{O}_{\Phi\widetilde{W}} = (\Phi^\dagger\Phi)\widetilde{W}^I_{\mu\nu} W^{I\mu\nu}$	$\mathcal{O}_{uW} = (\bar{q}\sigma^{\mu\nu}\Gamma_u u\tau^I\widetilde{\Phi}) W^I_{\mu\nu}$	$\mathcal{O}^{(1)}_{\Phi q} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{q}\gamma^\mu q)$
$\mathcal{O}_{\Phi B} = (\Phi^\dagger\Phi) B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{dW} = (\bar{q}\sigma^{\mu\nu}\Gamma_d d\tau^I\Phi) W^I_{\mu\nu}$	$\mathcal{O}^{(3)}_{\Phi q} = (\Phi^\dagger i\overleftrightarrow{D}^I_\mu\Phi)(\bar{q}\gamma^\mu\tau^I q)$
$\mathcal{O}_{\Phi\widetilde{B}} = (\Phi^\dagger\Phi)\widetilde{B}_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{eB} = (\bar{l}\sigma^{\mu\nu}\Gamma_e e\Phi) B_{\mu\nu}$	$\mathcal{O}_{\Phi u} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{u}\gamma^\mu u)$
$\mathcal{O}_{\Phi WB} = (\Phi^\dagger\tau^I\Phi) W^I_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{uB} = (\bar{q}\sigma^{\mu\nu}\Gamma_u u\widetilde{\Phi}) B_{\mu\nu}$	$\mathcal{O}_{\Phi d} = (\Phi^\dagger i\overleftrightarrow{D}_\mu\Phi)(\bar{d}\gamma^\mu d)$
$\mathcal{O}_{\Phi\widetilde{W}B} = (\Phi^\dagger\tau^I\Phi)\widetilde{W}^I_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{dB} = (\bar{q}\sigma^{\mu\nu}\Gamma_d d\Phi) B_{\mu\nu}$	$\mathcal{O}_{\Phi ud} = i(\widetilde{\Phi}^\dagger D_\mu\Phi)(\bar{u}\gamma^\mu\Gamma_{ud} d)$

Talk by Giampiero Passarino

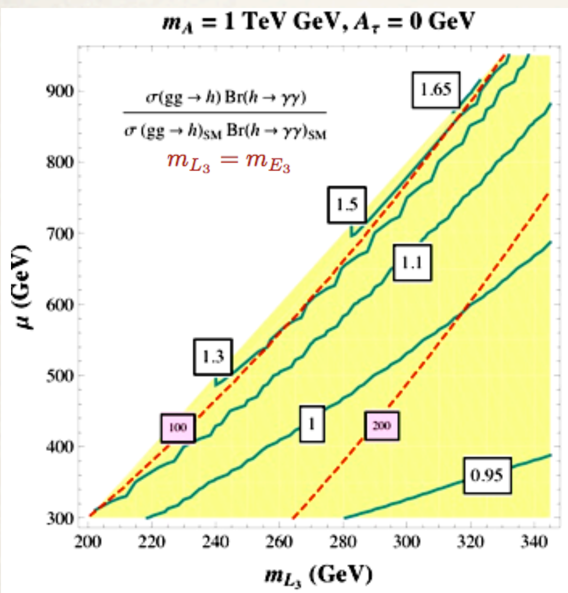
Talk by Jose Ramon Espinosa

THE ART OF CHOOSING A BASIS

Physics is basis-independent, but some bases are more convenient than others and some can mislead you.

what Higgs precision do we need?

- There could be one or more “large” ~10% deviations in Higgs couplings versus the SM
- Many of these would then be detectable at LHC
- Typically this implies other smaller deviations -> ILC
- Large deviations typically imply lighter new particles, within reach of LHC direct detection or perhaps an ILC



Note it is the correlations between deviations that will reveal the underlying physics

Talks by Stefania Gori, Carlos Wagner

EWPO constrain Higgs couplings

Assumption:

Giudice et al;Contino et al;Azatov et al;Contino et al

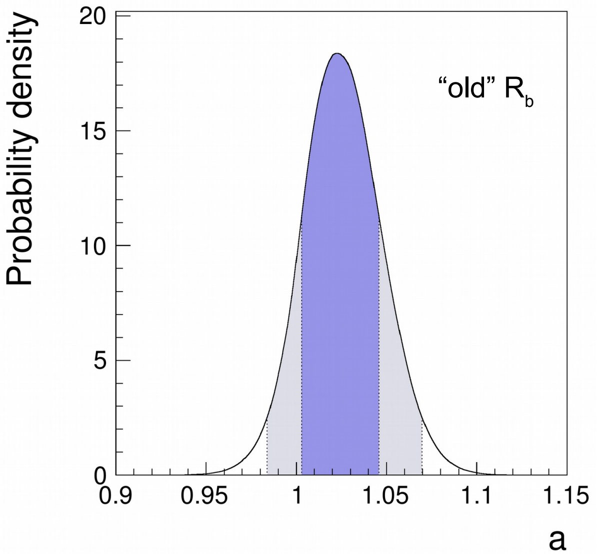
- the main effect in EWPO is due to a possibly modified Higgs coupling a to vectors (GB's):

$$S = \frac{1}{12\pi}(1-a^2)\ln\left(\frac{\Lambda^2}{m_h^2}\right), \quad T = -\frac{3}{16\pi c_W^2}(1-a^2)\ln\left(\frac{\Lambda^2}{m_h^2}\right),$$

LHCP 2013 Barcelona L. Silvestrini 23

$$\Lambda = 4\pi v/\sqrt{|1-a^2|}$$

Talk by Luca Silvestrini at LHCP 2013



See also Falkowski,Riva&Urbano; Contino et al.;Pich et al

Strongly constrains simplest composite Higgs models

Strong bound from EW fit

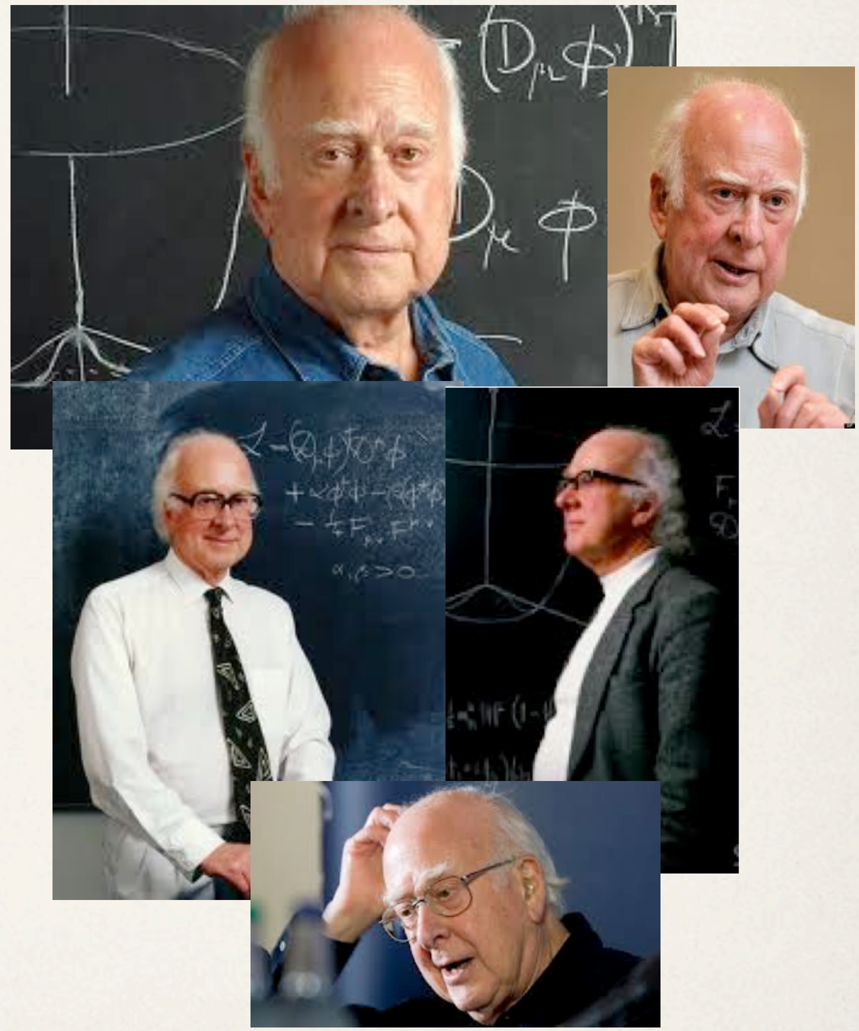
- $a = 1.02 \pm 0.02$
- $a \in [0.98, 1.07]$@95%
- Composite Higgs models typically generate $a < 1$

Falkowski,Rychkov&Urbano

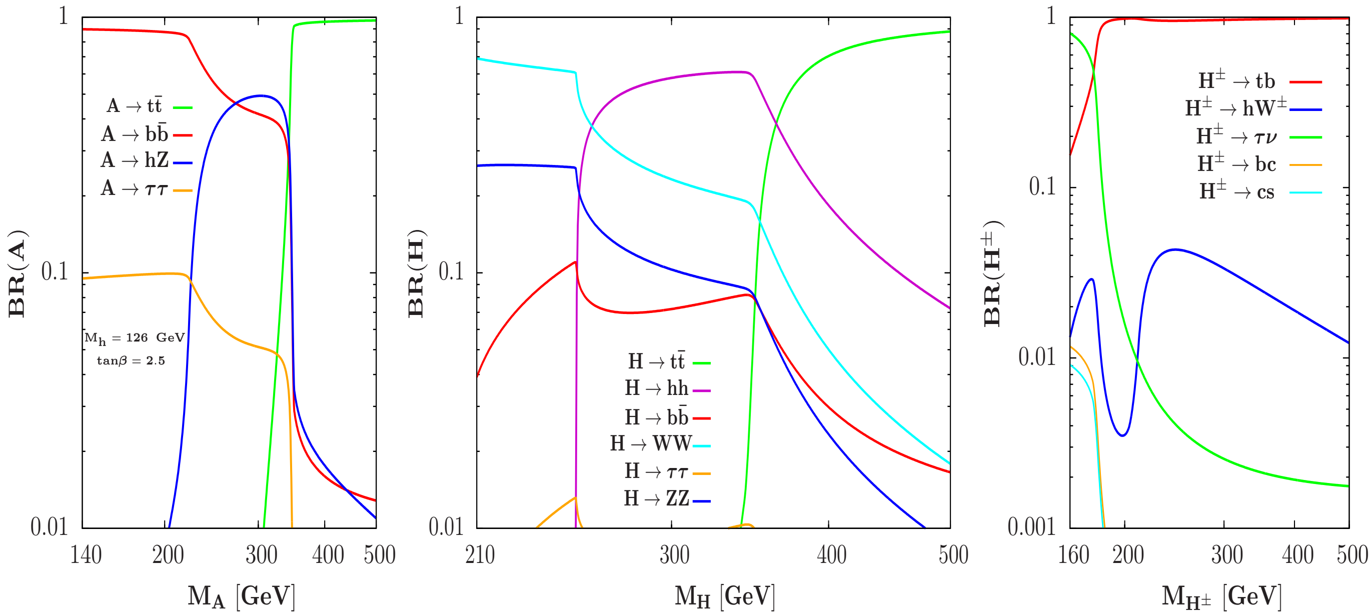
- for $a < 1$, $\Lambda > 15$ TeV
- need additional light states to fix EW fit!

How many more Higgs?

- Finding heavier/lighter Higgs bosons is a major long-term challenge for the LHC
- These searches are just as important and promising as measuring the properties of the Higgs that we have in hand!
- To what extent can we "close the wedge" of heavy Higgs undetectable at LHC?
- How to make sure that we don't miss light exotics?



Heavy Higgs searches



Second Higgs Doublet Decay Topology	Alignment Limit
$H \to WW, ZZ$	–
$H, A \to \gamma\gamma$	✓
$H, A \to \tau\tau, \mu\mu$	✓
$H, A \to tt$	✓
$A \to Zh$	–
$H \to hh$	–
$t \to H^\pm b$	✓

Checkmark = Constant in Alignment Limit
Dash = Vanishes in Alignment Limit

case of Heavy SUSY: A. Djouadi and J. Quevillon, arXiv:1304.1787

Talk by Scott Thomas

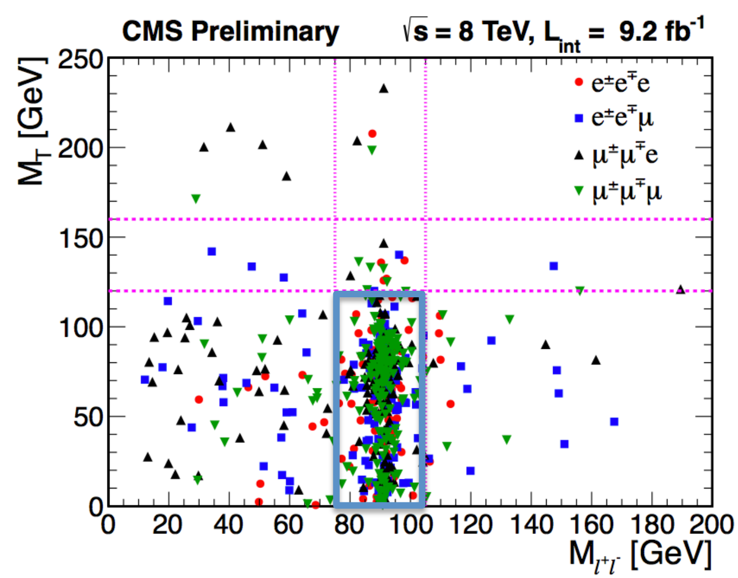
Heavy Higgs searches

- *LHC analyses already slice and dice the data a hundred different ways*
- *But it may be the 101st way that reveals a signal*
- *Need dedicated searches*

Multi-Lepton Search for A->Zh

Tri-Leptons OSSF + Third Lepton

WZ -> 3 Leptons - Dominant Background



$A \to Zh \to (ll)(l\nu jj)$

Lands Right on Top of WZ Background in m_T - m_{ll}

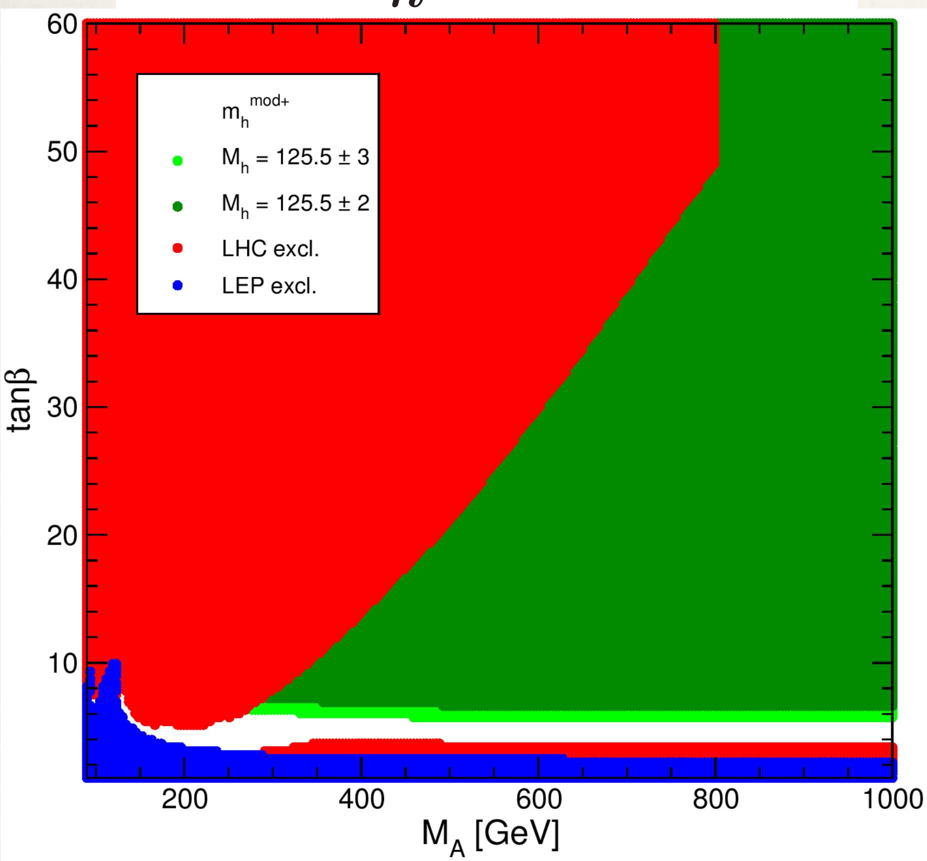
2 Extra Jets

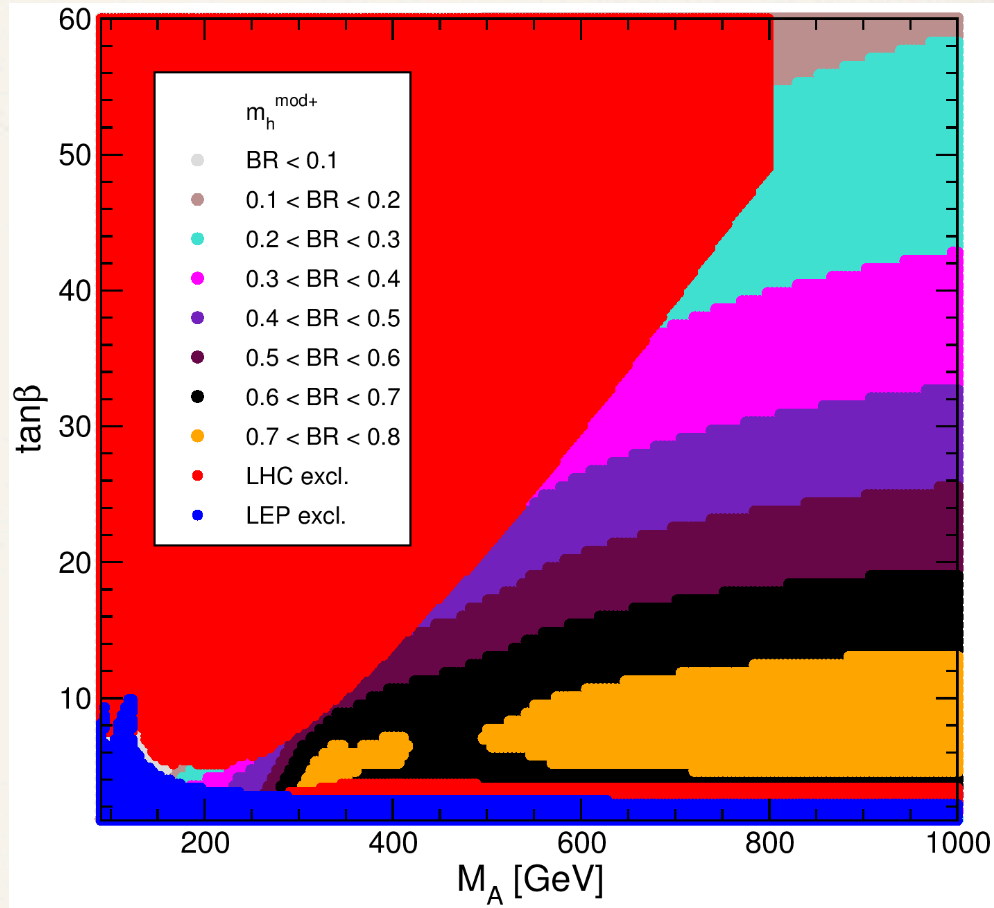
Can Completely Reconstruct Kinematics

Talk by Scott Thomas

Heavy Higgs searches

The m_h^{mod} scenario

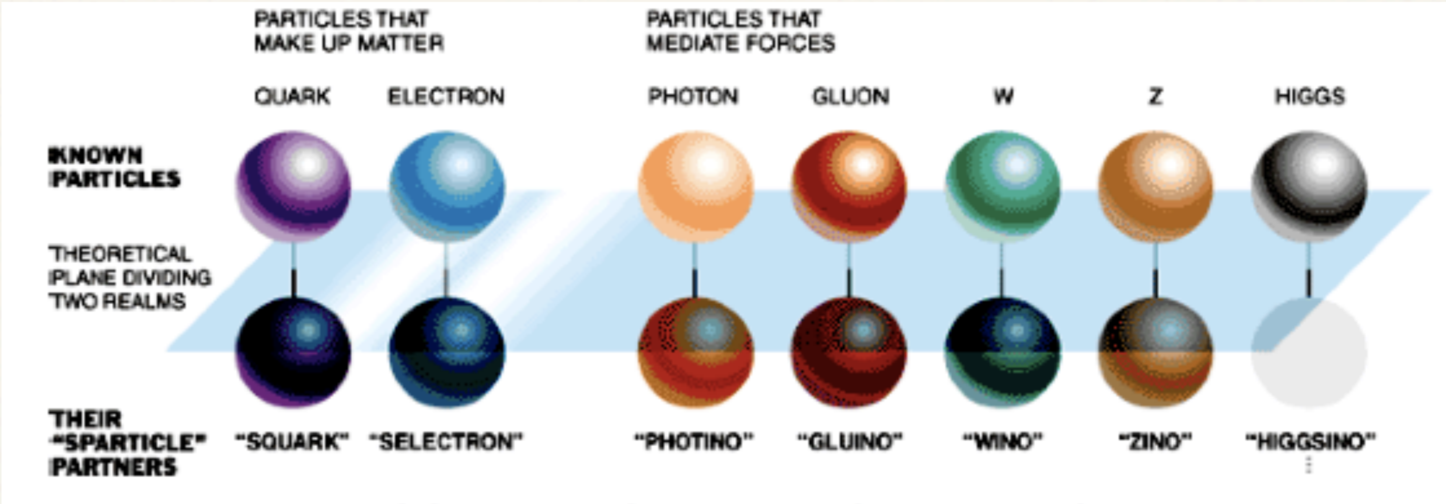




In SUSY, Higgs decays to EWinos may have large BF

Talk by Carlos Wagner

Supersymmetry:
aut vincere aut mori



the canonical BSM paradigm

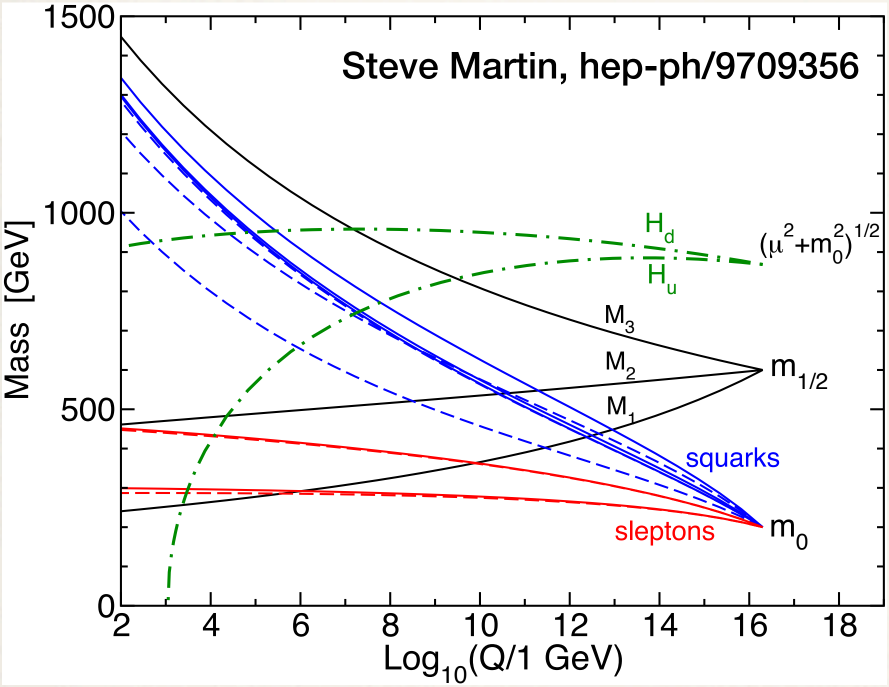
- Natural + ~MFV SUSY at the weak scale
- Neutralino dark matter
- A grand desert populated at the high end by a hidden sector for dynamical SUSY breaking, some heavy Majorana neutrinos, maybe PQ axions, inflatons
- Gauge coupling unification circa 10^{16} GeV accompanied by GUT or stringy unification of matter and gauge forces
- Planck scale stringiness with lots of extra structure to explain flavor etc.

lots of good arguments for this picture

Talks by Gordy Kane, Carlos Wagner and Paul Langacker

the canonical BSM paradigm

the experimental program that goes with this paradigm is pretty clear:



- Find a light fundamental Higgs boson
- Find superpartners, nail down masses, flavor, CP
- Nail down the extended Higgs sector
- Close the circle on dark matter between colliders, DD, ID, and large scale structure
- Nail down the neutrino sector, proton decay, CLFV
- Extrapolate everything to high scales, deduce features of the UV theory (compactification, unification, etc)
- Apply insights to cosmology, dark energy, black holes

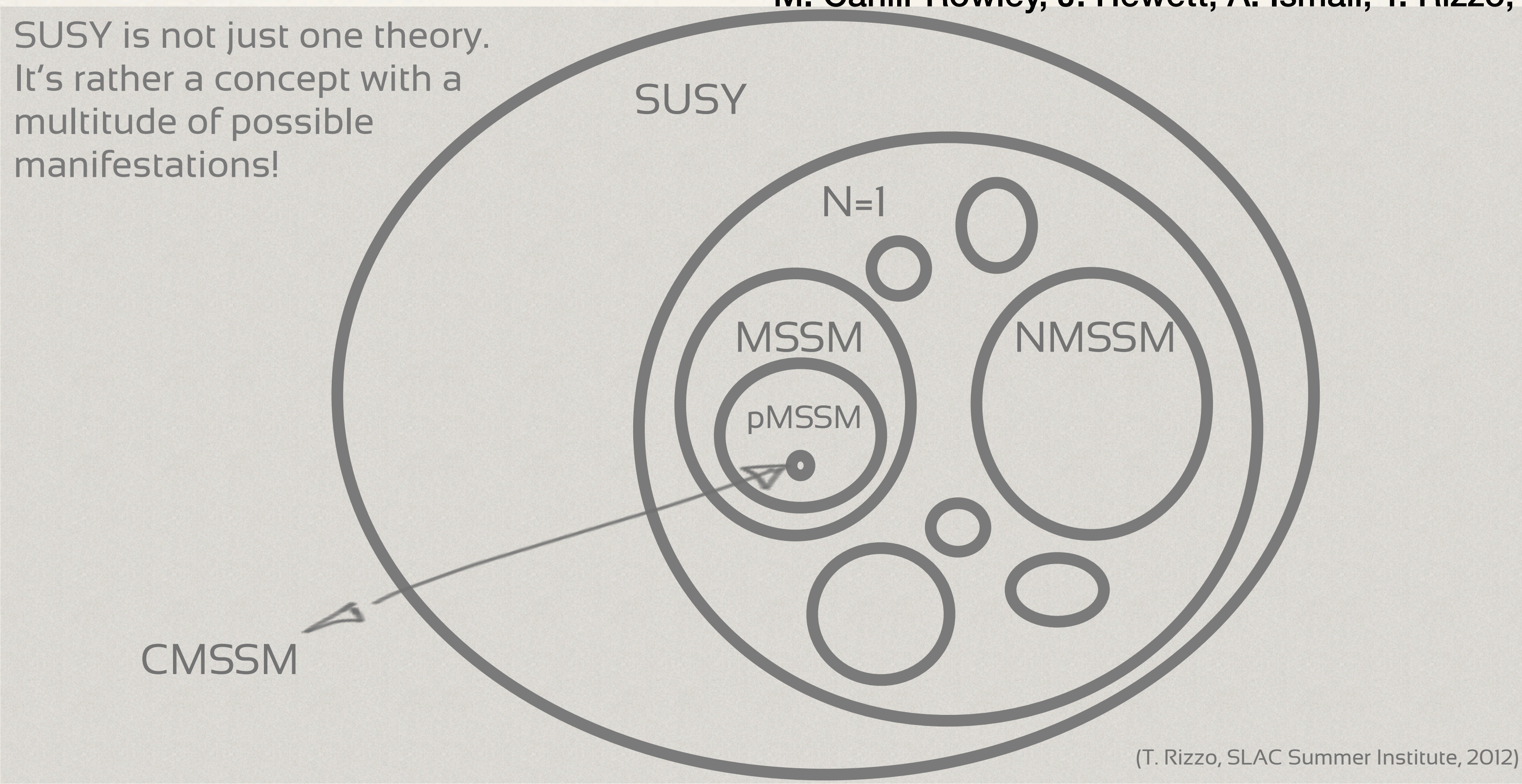
where are the superpartners?

- This canonical paradigm may very well be correct, in which case superpartners will show up at the LHC
- But they haven't yet...
- We knew already that there was a "problem" with SUSY, from no Higgs at LEP and no superpartners at LEP or Tevatron
- The only question is whether it is a "small" problem or a "big" problem

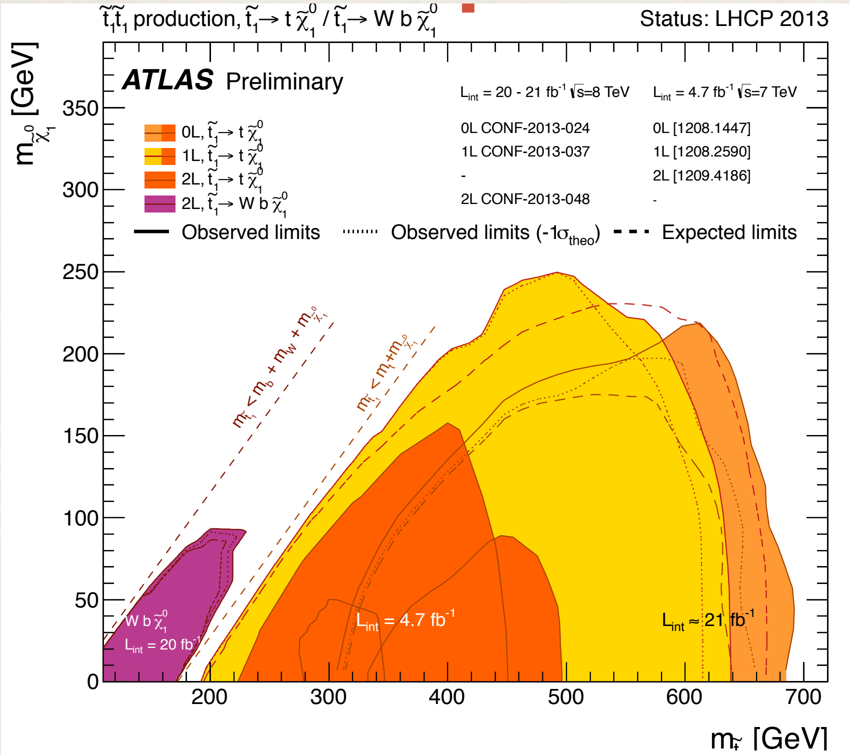
are you getting nervous yet?

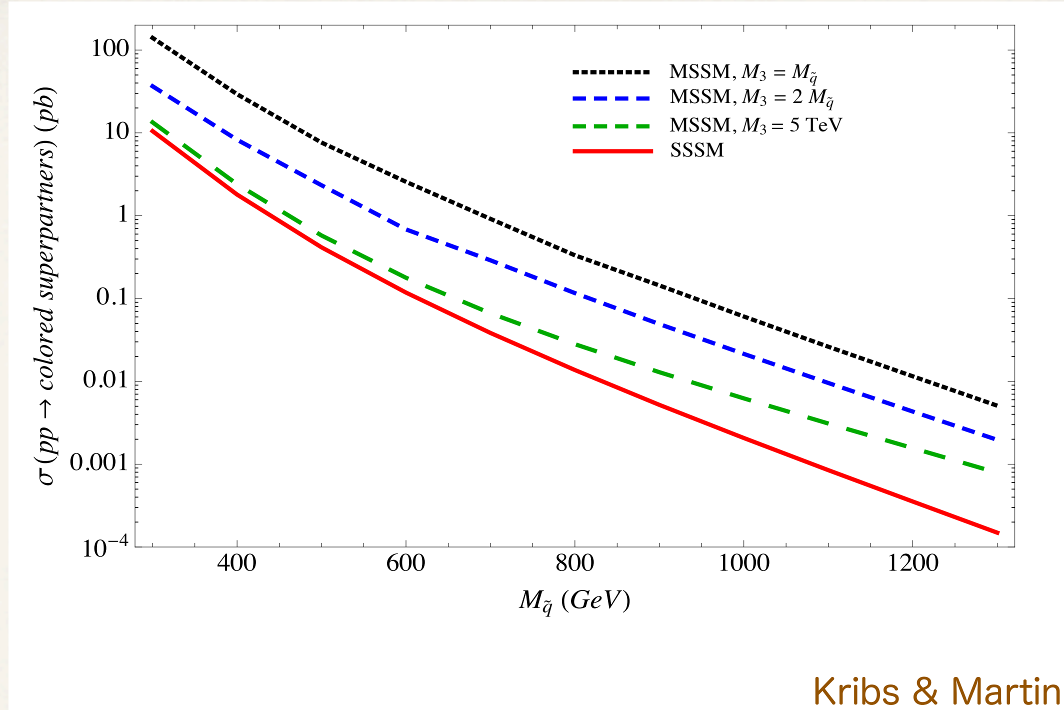
Weak Scale SUSY? : too soon to tell

M. Cahill-Rowley, J. Hewett, A. Ismail, T. Rizzo, arXiv:1211.1981



LHC searches at 7 and 8 TeV have so far excluded about 1/3 of the parameter space of the pMSSM; the full parameter space of relevant SUSY models is not even defined





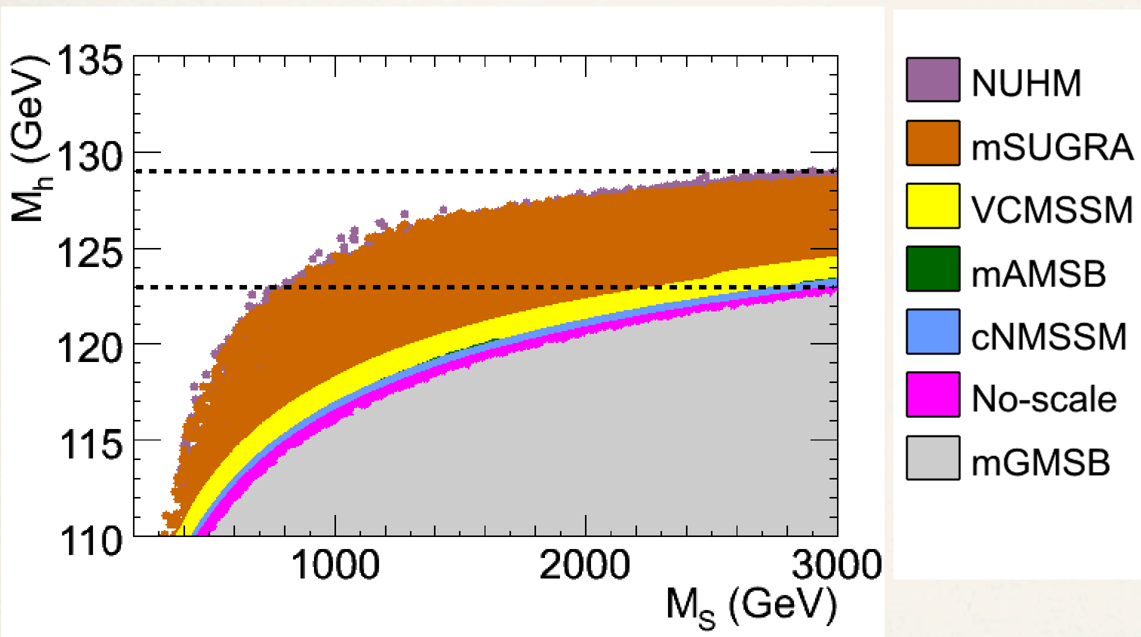
Talk by Graham Kribs

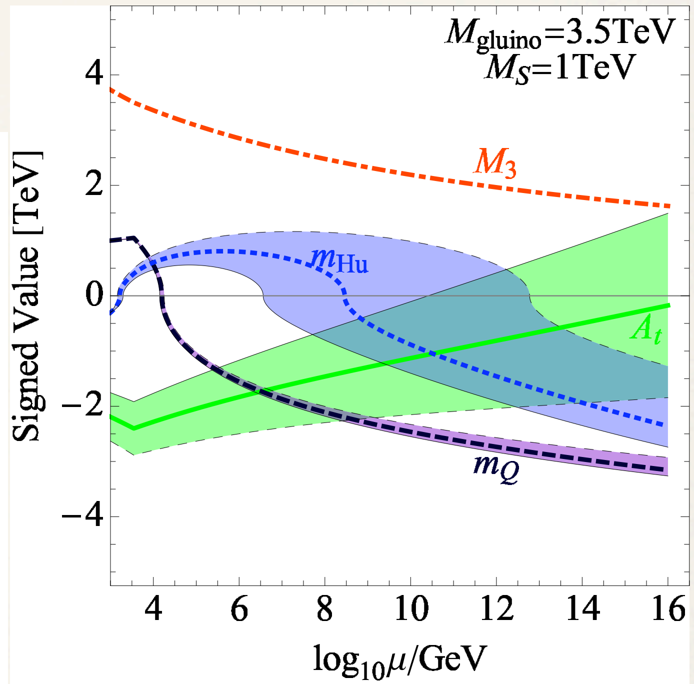
- **Need multiple overlapping analyses even to cover the whole parameter space of Over-Simplified Models; this implies a long campaign to discover or exclude SUSY at the TeV scale**
- **The real SUSY model may have features that suppress the "standard" signatures**

what does a 125 GeV Higgs imply for SUSY?

Even without assumptions about the SUSY-breaking mechanism, the observed Higgs mass tends to pushes some MSSM parameters into the multi-TeV regime. This provides significant tension with naturalness constraints. The tension is exacerbated in specific SUSY breaking models.

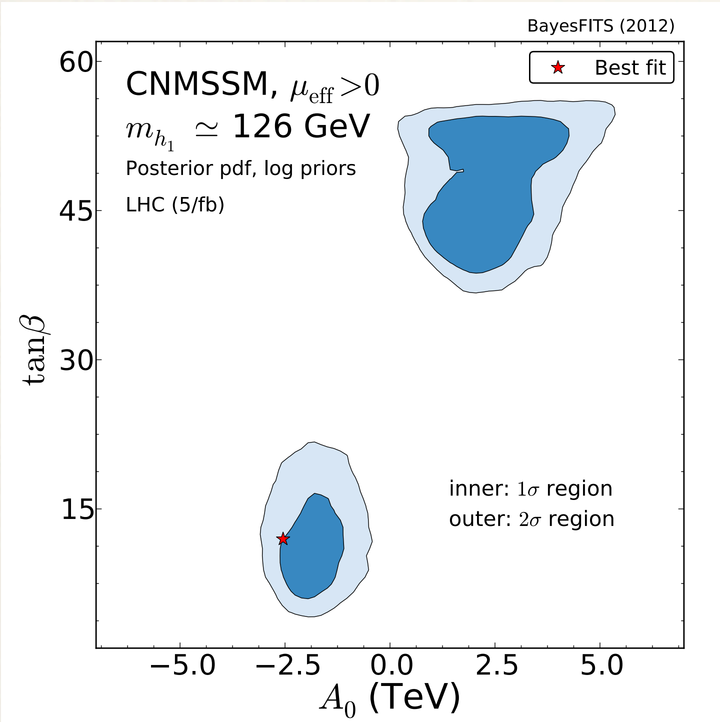
Talk by Howard Haber

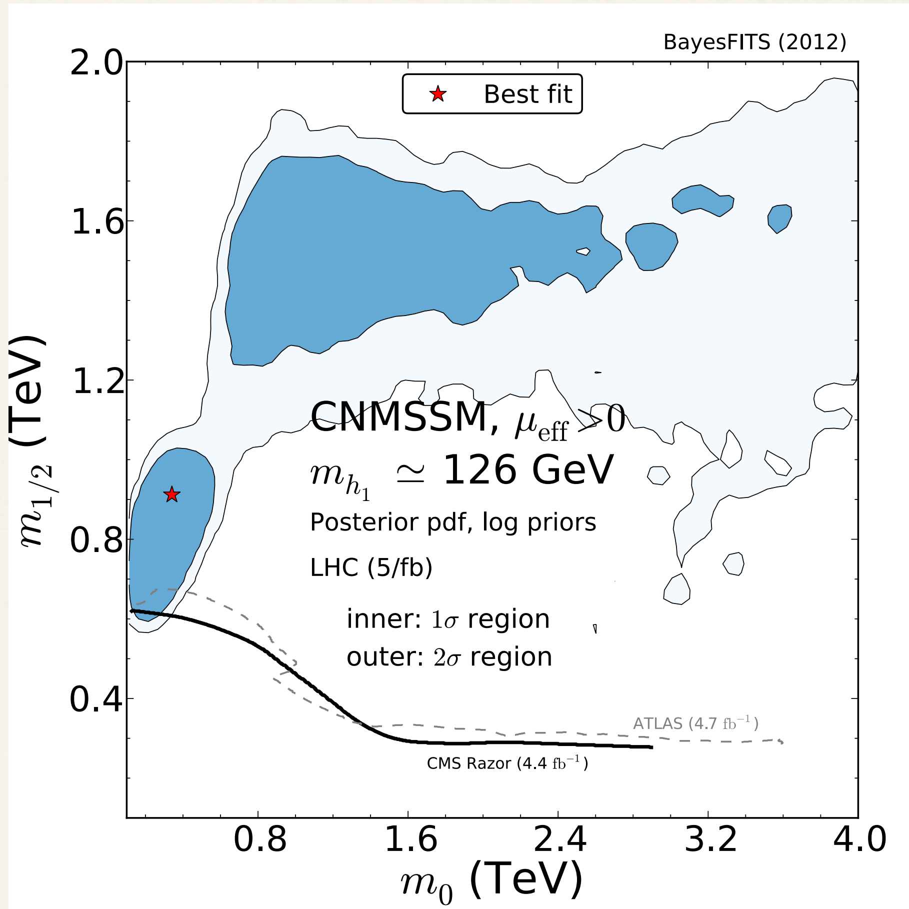




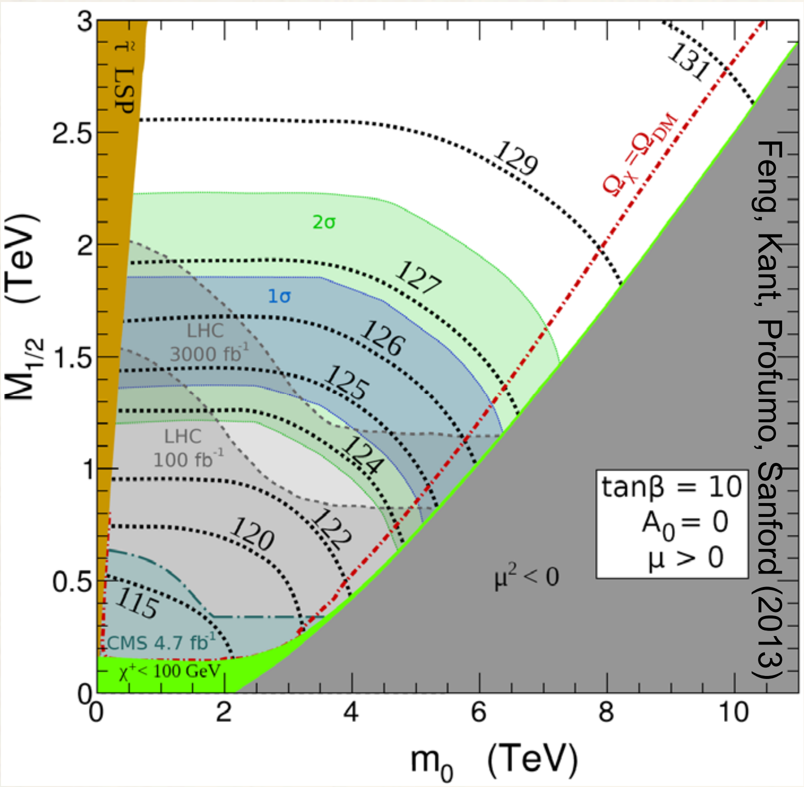
Gauge-Mediated SUSY breaking with $A_t = 0$ at the high scale

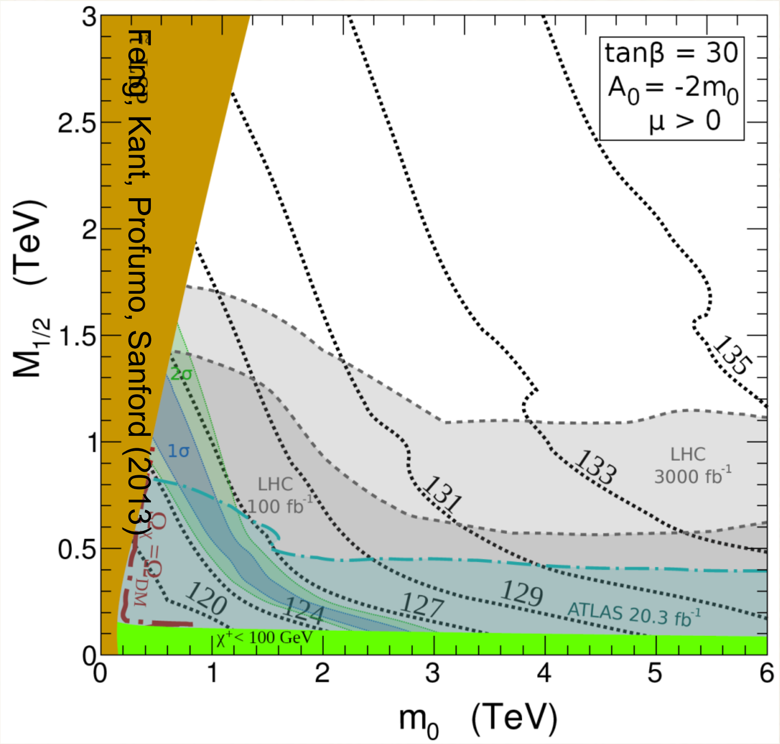
from P. Draper, P. Meade, M. Reece and D. Shih (2012)





Talk by Leszek Roszkowski





Talk by Jonathan Feng

The Naturalness Dogma: caveat emptor

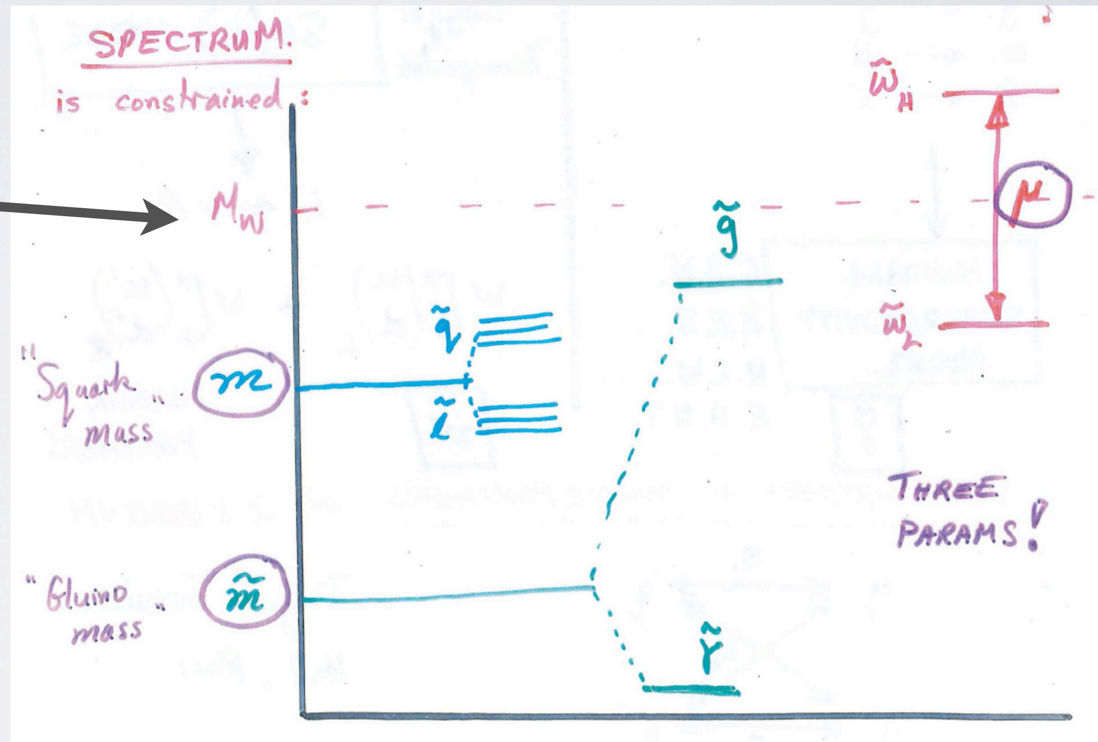
NATURAL SUSY, 1984

From Lawrence Hall's talk at SavasFest

W boson near the top of the spectrum....

1984 was a utopian year for SUSY.

Times have changed!



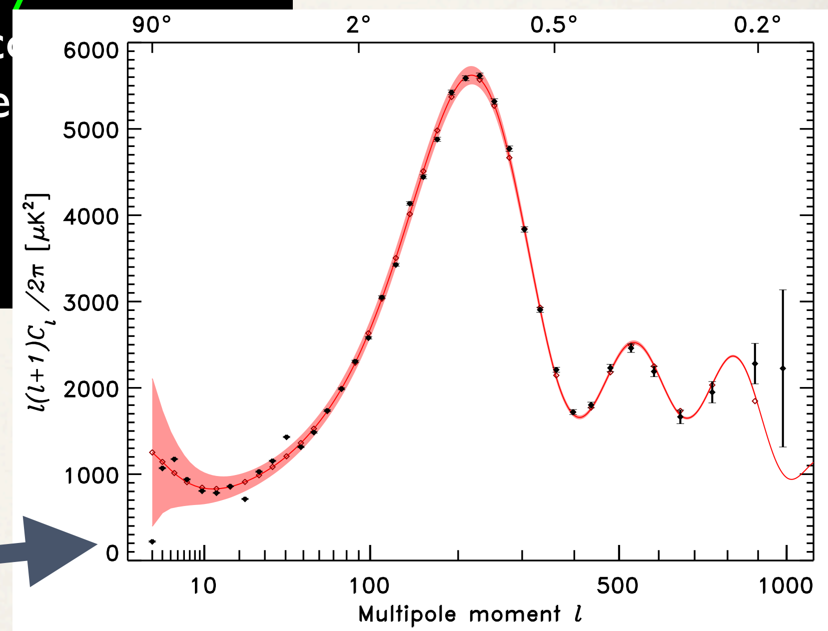
Talk by Matt Reece at LHCP 2013

Moderate tuning doesn't mean your theory is wrong

- Before COBE, upper limit on CMB anisotropy kept getting better and better
- Before 1998, the universe appeared younger than oldest stars
- cosmologists got antsy
- "crisis in standard cosmology"
- it turned out a little "fine-tuned"
  - low quadrupole
  - dark energy

"Big Bang not yet dead but in decline"
Nature 377, 14 (1995)

"Bang! A Big Theory May Be Shot"
A new study of the stars c
the history of the universe
Times, Jan 14 (1991)

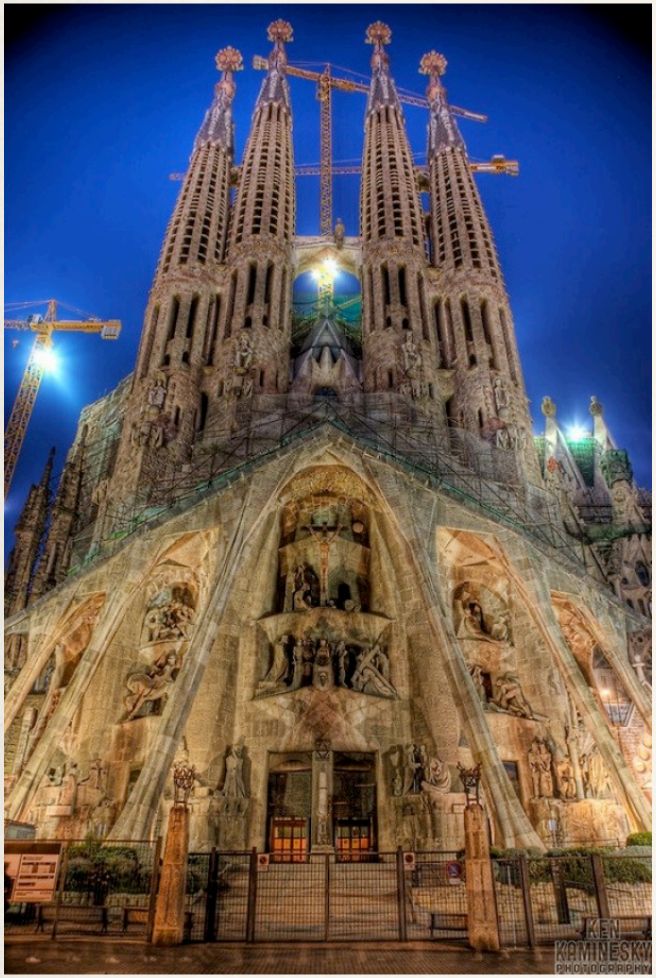


Talk by Hitoshi Murayama at Lepton-Photon 2013

worse than 1% tuning

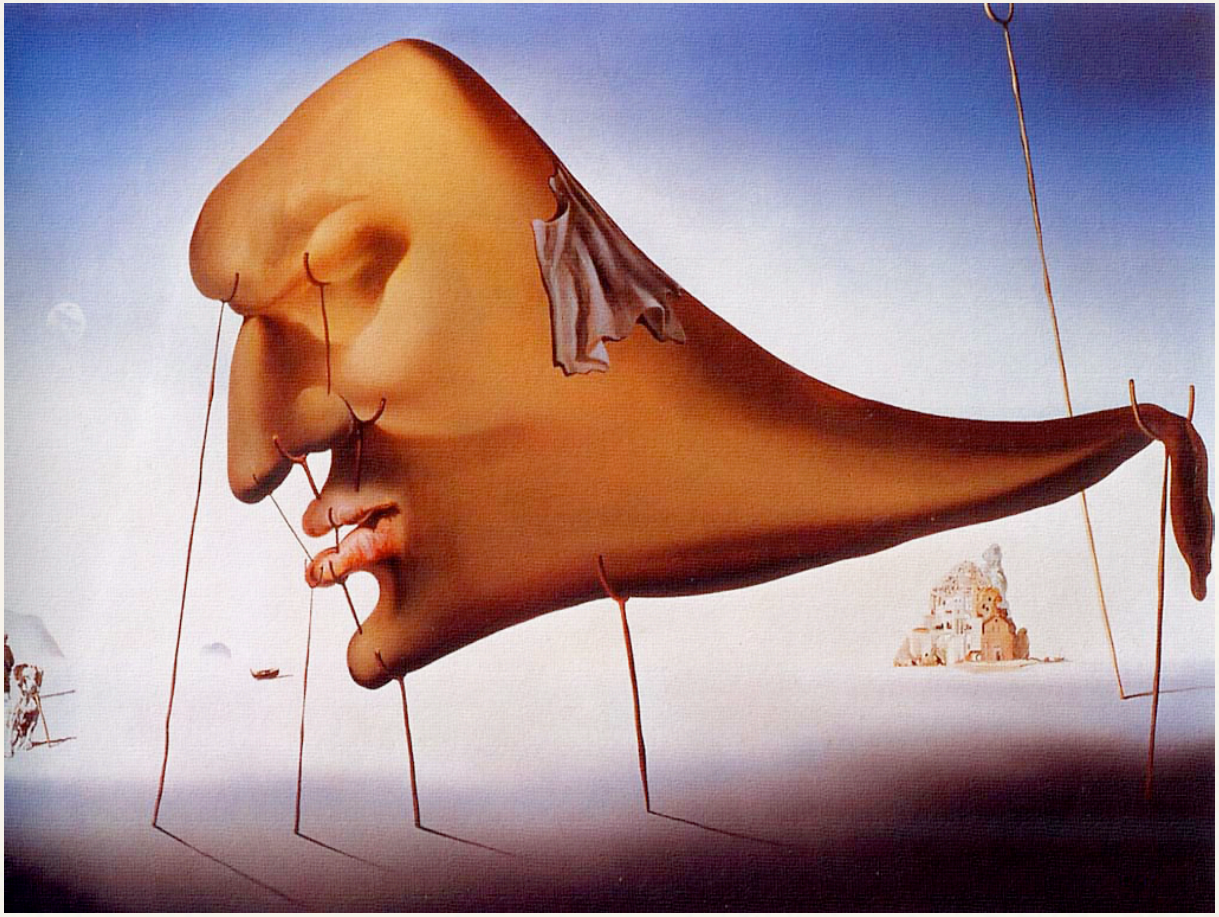
The Naturalness Dogma:

quem deus vult perdere, dementat prius



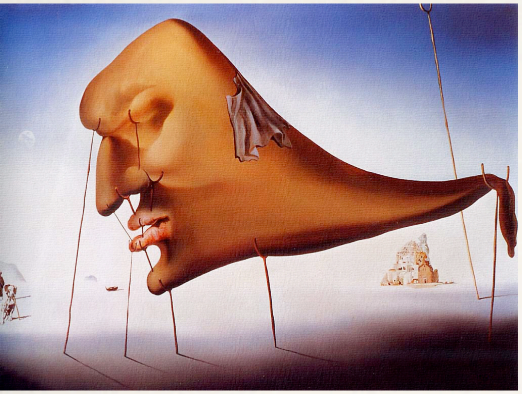
- If superpartners are discovered at LHC, we will figure out what kind of SUSY model we actually have, and shed light on the “small” tuning issues
- Ditto if we find Higgs compositeness etc
- But it is interesting already to question whether the mighty cathedral of BSM built up over 30 years may rest on shaky foundations...

The Naturalness Dogma: how could it be wrong?



Εν οίδα ότι ουδέν οίδα -- Σωκράτης

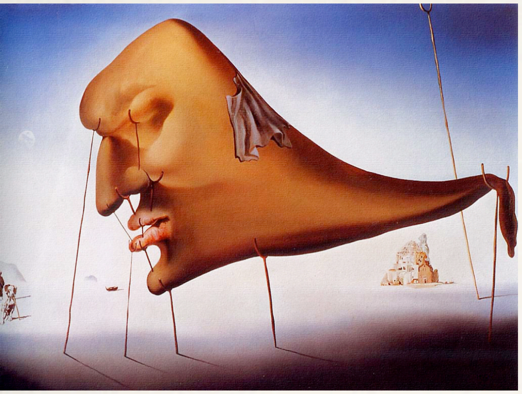
The Naturalness Dogma: how could it be wrong?



Possibility #1:
The Standard Model is (almost) all that there is

- The SM plus some renormalizable TeV scale additions (DM, neutrino see-saw, etc) is all that there is
- Renormalizable theories don't have naturalness problems, because (at the end of the day) they don't have cutoffs
- Usual counterargument is that at least there is a physical cutoff at M_{Planck}, but this is conjecture
- The SM hypercharge coupling has a Landau pole at 10^{27} GeV, but who cares?

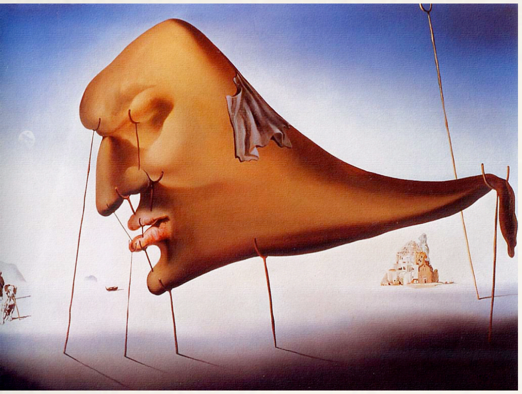
The Naturalness Dogma: how could it be wrong?



Possibility #2:
10 TeV is the ultimate energy scale

- Lots of new BSM physics, but no large hierarchy of mass scales and all tuning issues are “small”
- RS warped extra dims seem to be the most plausible realization of this
- No LHC hints yet, but this is not surprising since we already knew from EWPO and that the exotic states are very heavy

The Naturalness Dogma: how could it be wrong?



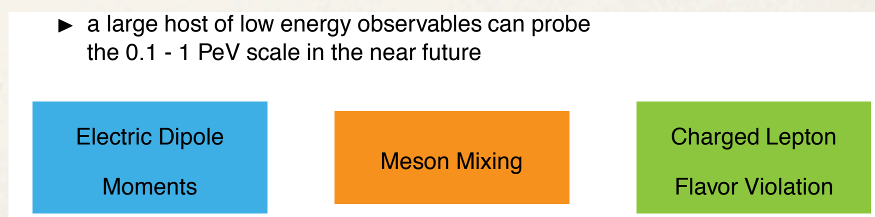
Possibility #3:
It's the Multiverse, Stupid

Από μηχανής Θεός

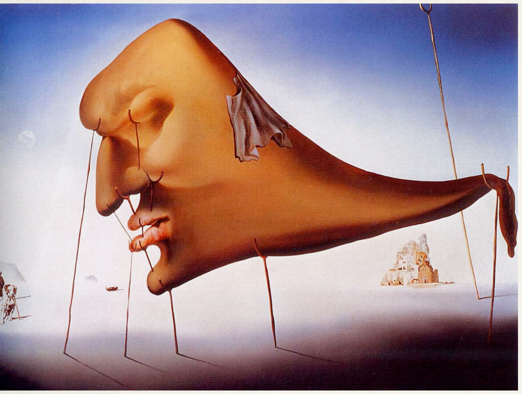
- Because of eternal inflation beyond the Planck scale (or something) there are 10^{500} variations on our universe
- The electroweak scale is hierarchically small for anthropic reasons, or for reasons that have to do with the (unknowable) distribution of universes
- Applied "minimally", leads to semi-split SUSY (or something)
- The latter is probed by a variety of Intensity Frontier experiments

Zeptouniverse

Talks by Wolfgang Altmannshofer, Andrzej Buras



The Naturalness Dogma: how could it be wrong?

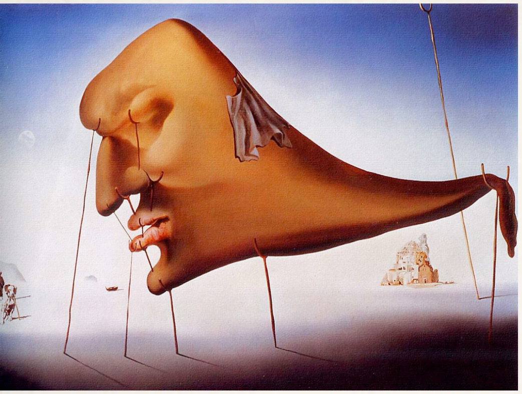


Possibility #4:
Bardeen naturalness

- SM with some TeV additions (dark matter?) has a UV completion with no other intermediate mass scales
- The electroweak scale is generated by dimensional transmutation
- Any other mass dependence of the UV theory is sequestered from the SM beta functions, i.e. no quadratic (or quartic?) sensitivity

W. Bardeen Fermilab-Conf-95-391-T
K. Meissner and H. Nicolai, hep-th/0612165
Iso and Orikasa, Hambye, Hambye and Strumia, etc.

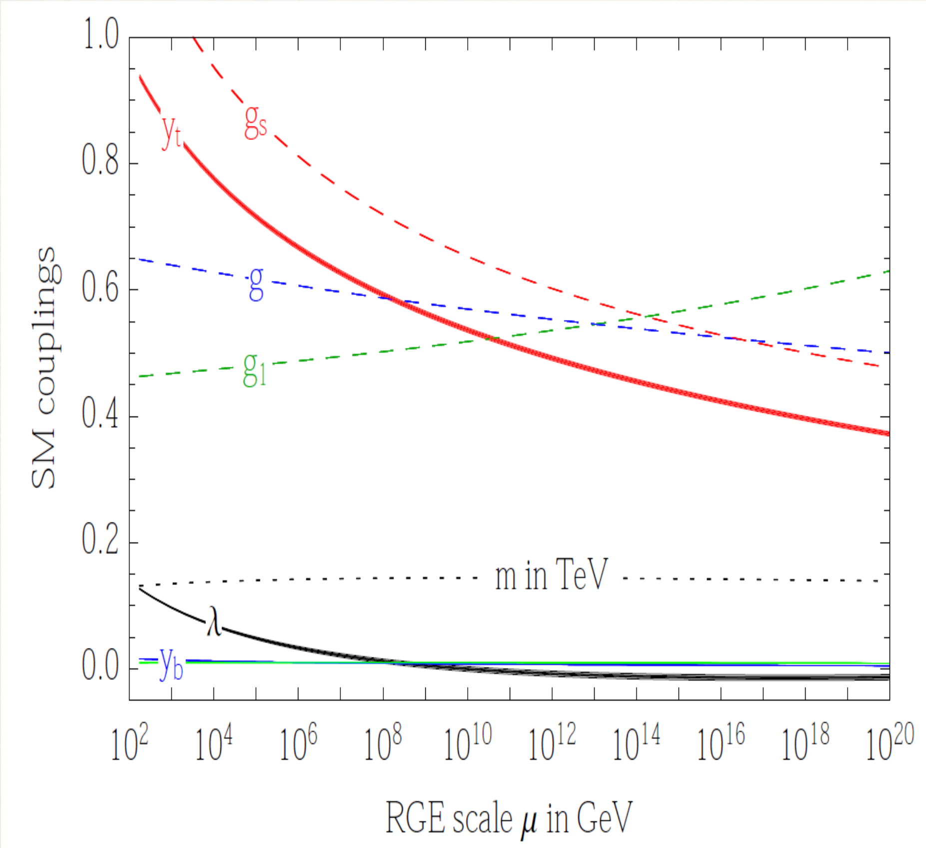
The Naturalness Dogma: how could it be wrong?

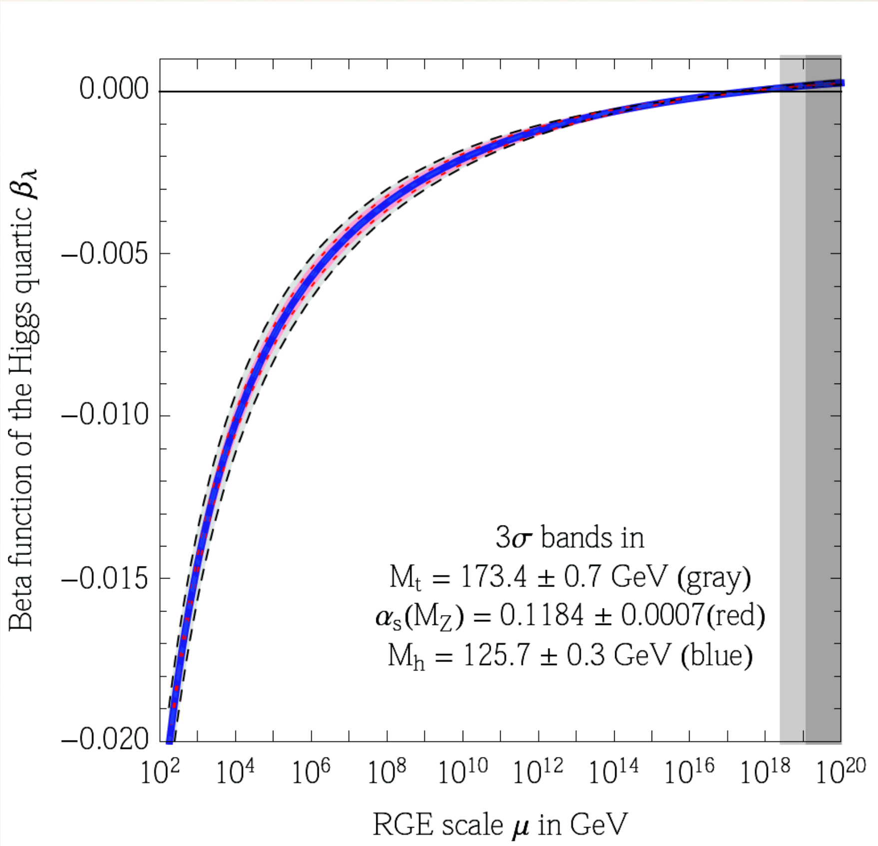


Possibility #4:
Bardeen naturalness

- The QCD scale comes from dimensional transmutation (D. Gross et al)
- In the SM the electroweak scale (tachyonic Higgs mass-squared parameter) is put in by hand. Obviously this is a kluge!
- Need simple additions (SUSY or non-SUSY) to fix this and generate EWSB radiatively
- Having thus explained the known scales and their hierarchy, why would you imagine that Nature sticks in superheavy masses at 10^{16} GeV to screw it up?

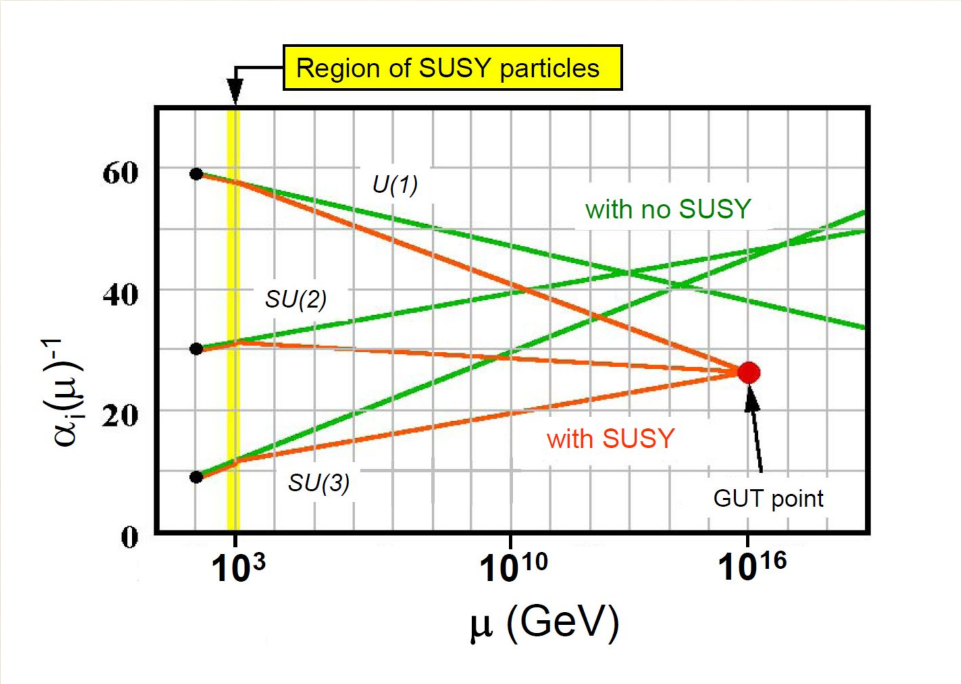
what are these plots trying to tell us?

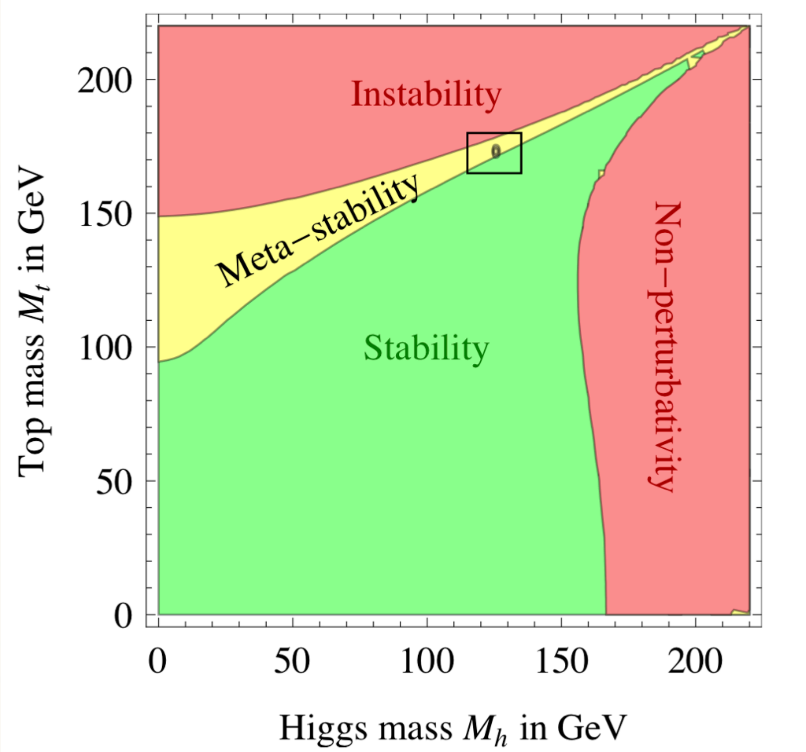




Talk by Giuseppe Degrassi
see also talk by Z. Chacko...

why do we live on the ragged edge of doom?





- Maybe one or both of these is just a coincidence at the few % level
- But dismissing striking features of the data as coincidence has historically not been a winning strategy in science...

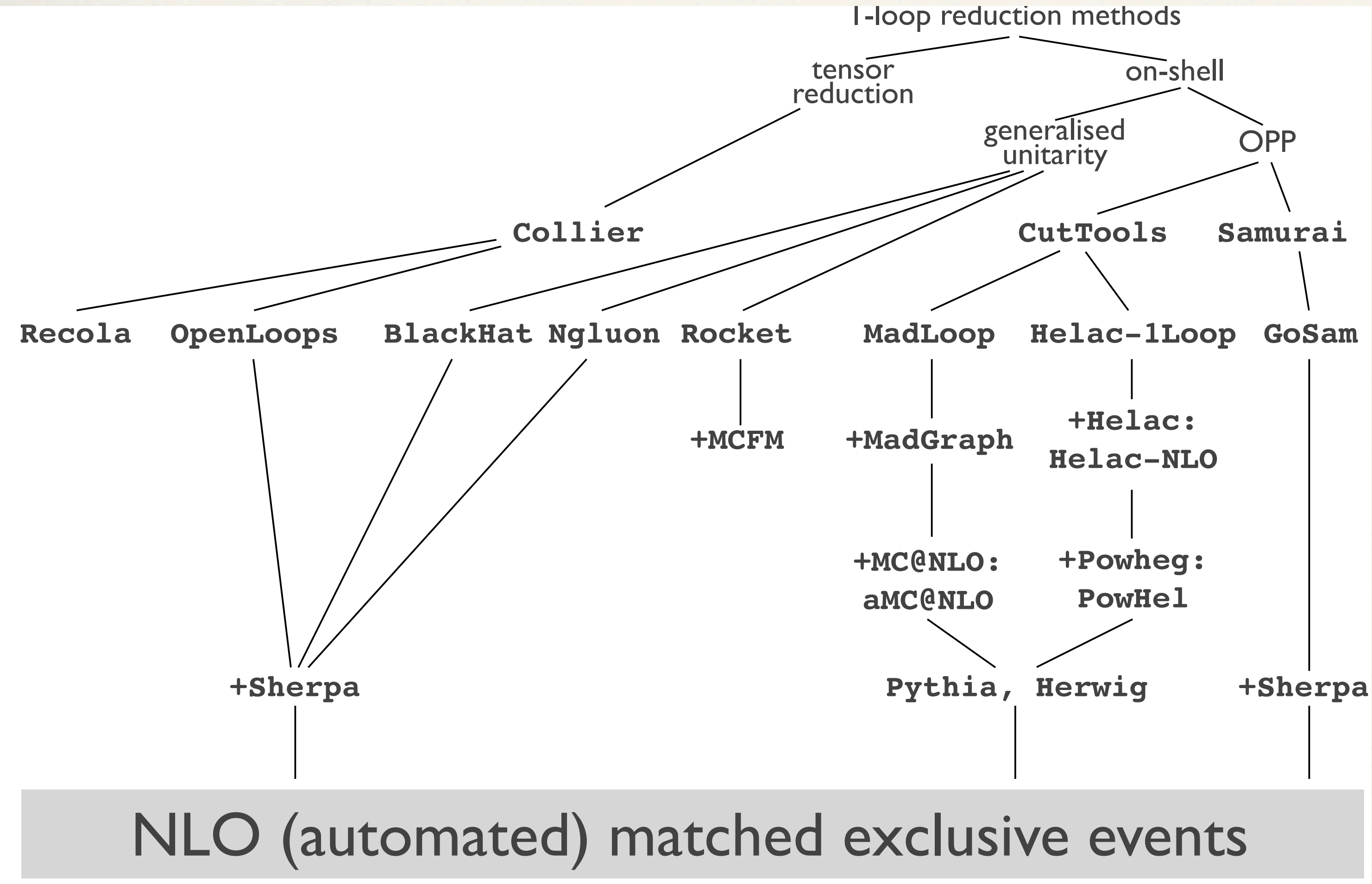
QCD: hic sunt dracones

Just when you thought QCD was becoming tame, LHC data reminds us that QCD is full of surprises and new/old challenges

- ***pQCD for the masses***
- ***parton distributions (need to) grow up***
- ***QCD hydrodynamics***
- ***The revenge of quarkonia?***

pQCD for the masses

Talks by
Barbara Jaeger,
Giulia Zanderighi,
Stefan Weinzierl,
Alexander Mitov,
Thomas Gehrmann,
Uli Haisch



The NLO revolution continues, will be of increasing importance for LHC

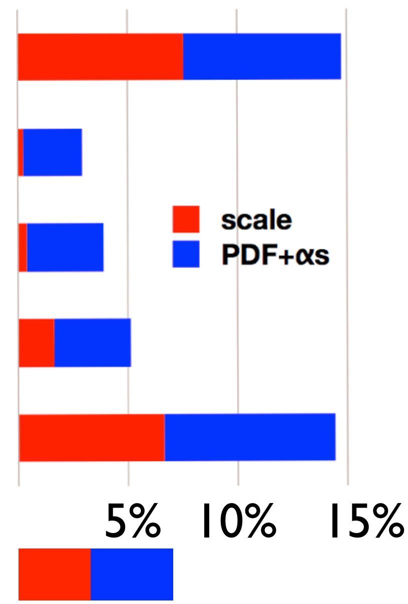
Increasing power of public automated tools for SM and BSM

parton distributions (need to) grow up

Impact of PDFs uncertainties

J. Campbell, ICHEP'12

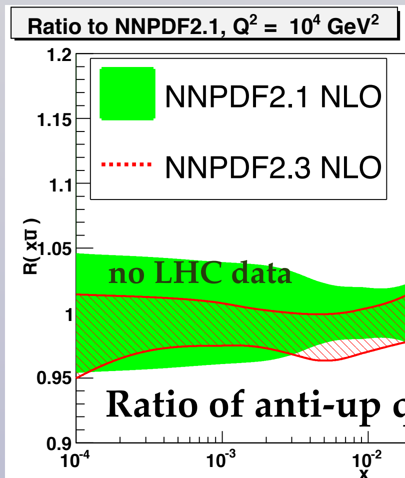
		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
	VBF	1.56 pb	2.9%
NNLO QCD +NLO EW	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%
NNLO QCD	tt	245.8 pb	7%

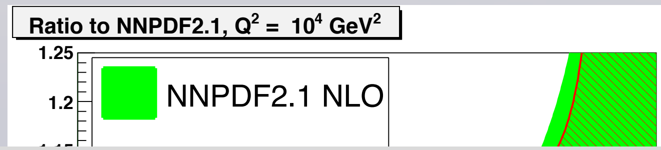


- PDF uncertainties at least comparable to missing higher orders ones

PDFs with LHC data

- A major improvement in PDF sets is **use of LHC data** to constrain quark and gluon PDFs
- **NNPDF2.3** is only publicly available PDF set that includes constrains from **LHC jet and W,Z data**
- Near future goal: PDFs sets based only on **collider data**



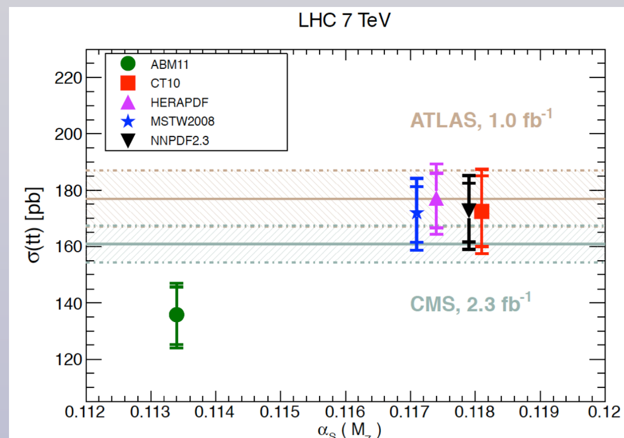


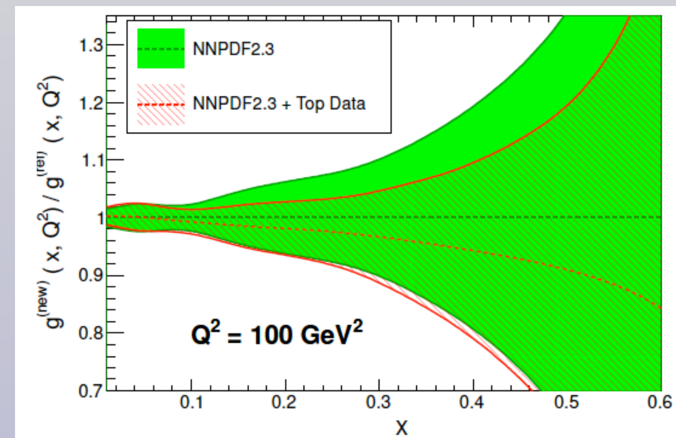
Talk by
Juan Rojo at LHCP 2013

Top quarks as gluon luminometers

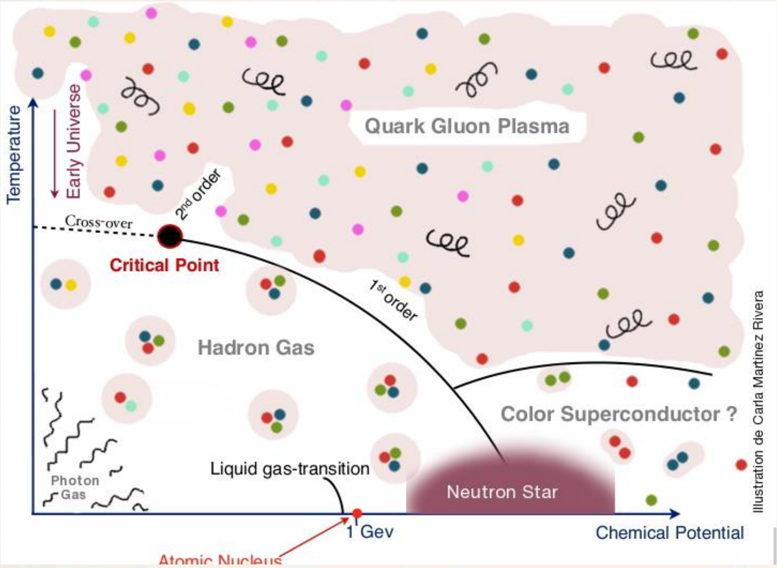
- The recent **NNLO top quark cross section** make top data the **only LHC observable** that is both **directly sensitive to the gluon PDF** and can be included consistently in a **NNLO global analysis**
- The precise 7 and 8 TeV LHC data can be used to **discriminate between PDF sets** and **to reduce the PDF uncertainties on the poorly known large-x gluon**

Czakon, Mangano, Mitov, Rojo, arxiv:1303.7215





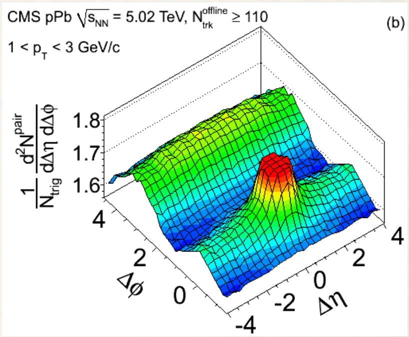
QCD hydrodynamics



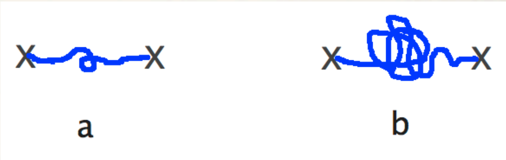
- Heavy ion collisions at LHC produce an excited nonequilibrium strongly-interacting extended state
- It isotropizes extremely rapidly, time scale ~ 1 fermi/c
- Shows flow characteristics of relativistic hydrodynamics
- Quenches jets and melts quarkonia
- This is the Quark Gluon Plasma!

The Golden Age of Heavy Ion physics is now

from strings to QGP to black holes



- At LHC, we see QGP-like features in p-Pb collisions, and even in high multiplicity p-p collisions ("the ridge")!
- An experimental opportunity and a theoretical challenge
- Can we understand the transition from scattering described in terms of gluons and QCD strings, to relativistic hydrodynamics?



E. Shuryak and I. Zahed arXiv:1301.4470

- AdS/CFT duality allows to use perturbed black holes as toy models for strongly-coupled out-of-equilibrium plasmas: how much can we learn from this about QCD?

a quarkonia polarization crisis?

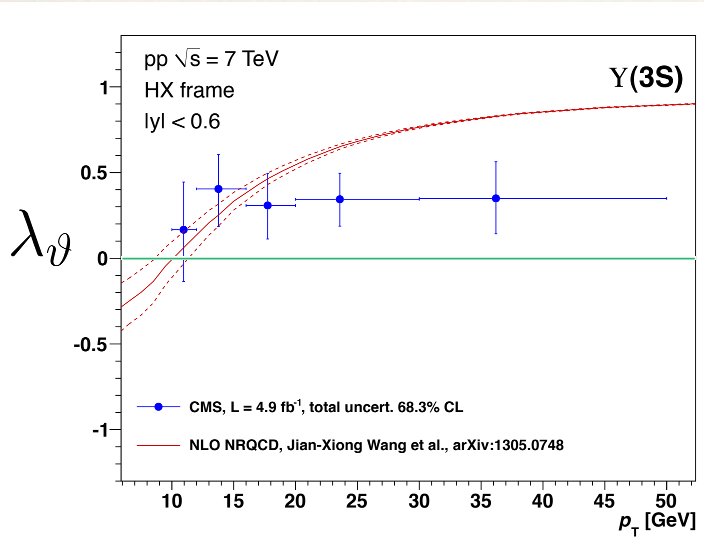
NRQCD factorization [Bodwin Braaten Lepage 95]

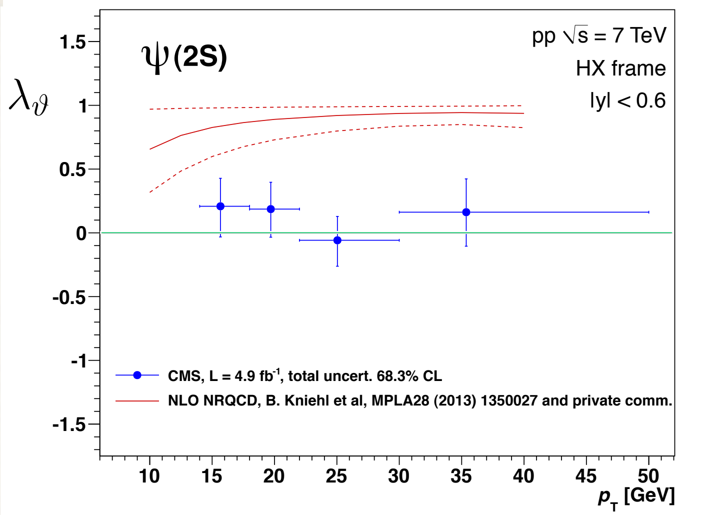
- Rigorous effective field theory
- Based on factorization of soft and hard scales
  (Scale hierarchy: $Mv^2, Mv \ll \Lambda_{QCD} \ll M$)
- Theoretically consistent: no leftover singularities.
- NNLO proof of factorization [Nayak Qiu Sterman 05]
- Can explain hadroproduction at Tevatron.

Talk by Bernd Kniehl

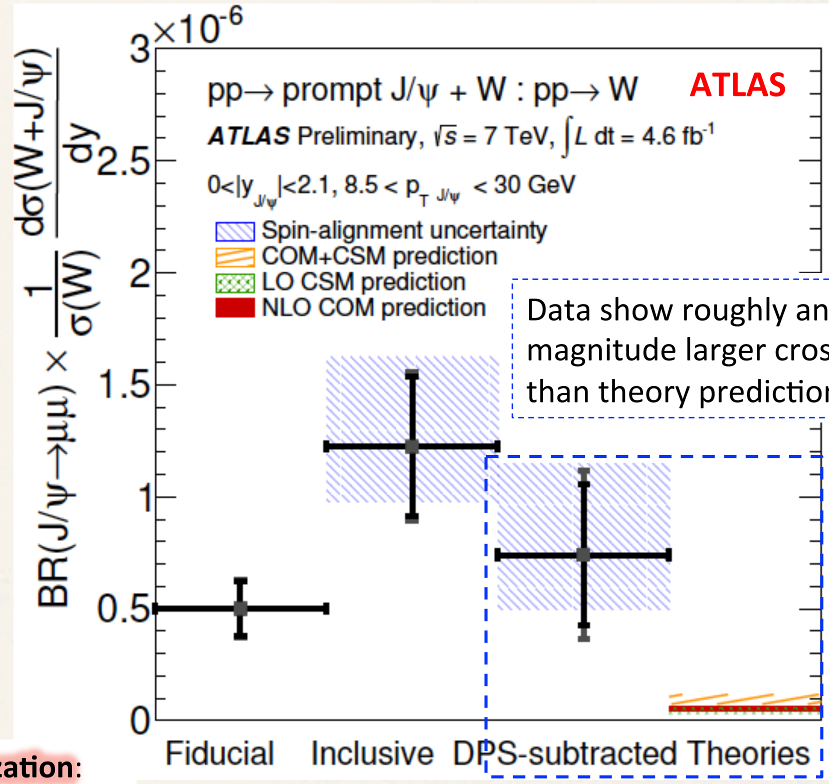
- **NRQCD *is* QCD, in an unambiguous expansion in powers of both α_s and the heavy quark velocity v**
- **However the factorization introduces a number of long distance matrix elements that have to be fit to data (like pdfs)...**
- **And it is assumed that these LDMEs are universal...**
- **And for charmonium and bottomonium, v is not especially small...**

a quarkonia polarization crisis?





"We have been comparing our beautiful data to too many bad theories" -- Carlos Lourenco

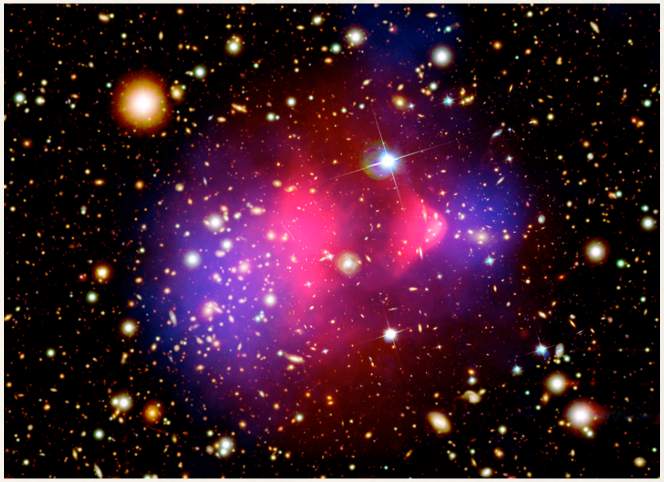


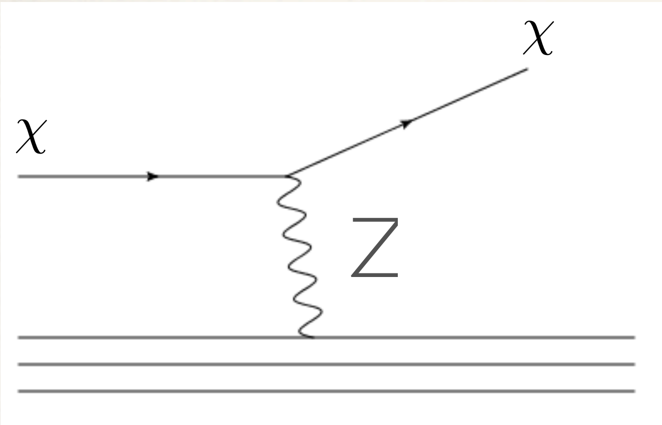
Data show roughly an order of magnitude larger cross section than theory predictions

- **NRQCD factorization**: quarkonia also produced as ***coloured*** *Q*-Qbar pairs *of any possible quantum numbers*

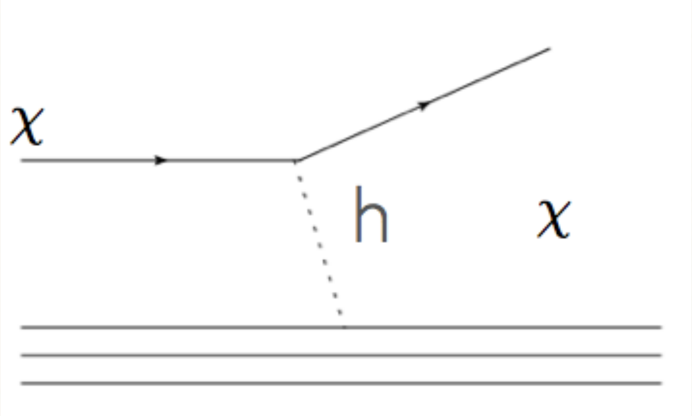
How does dark matter interact with baryonic matter?

via gravity
we know





via the Standard Model
weak interactions?

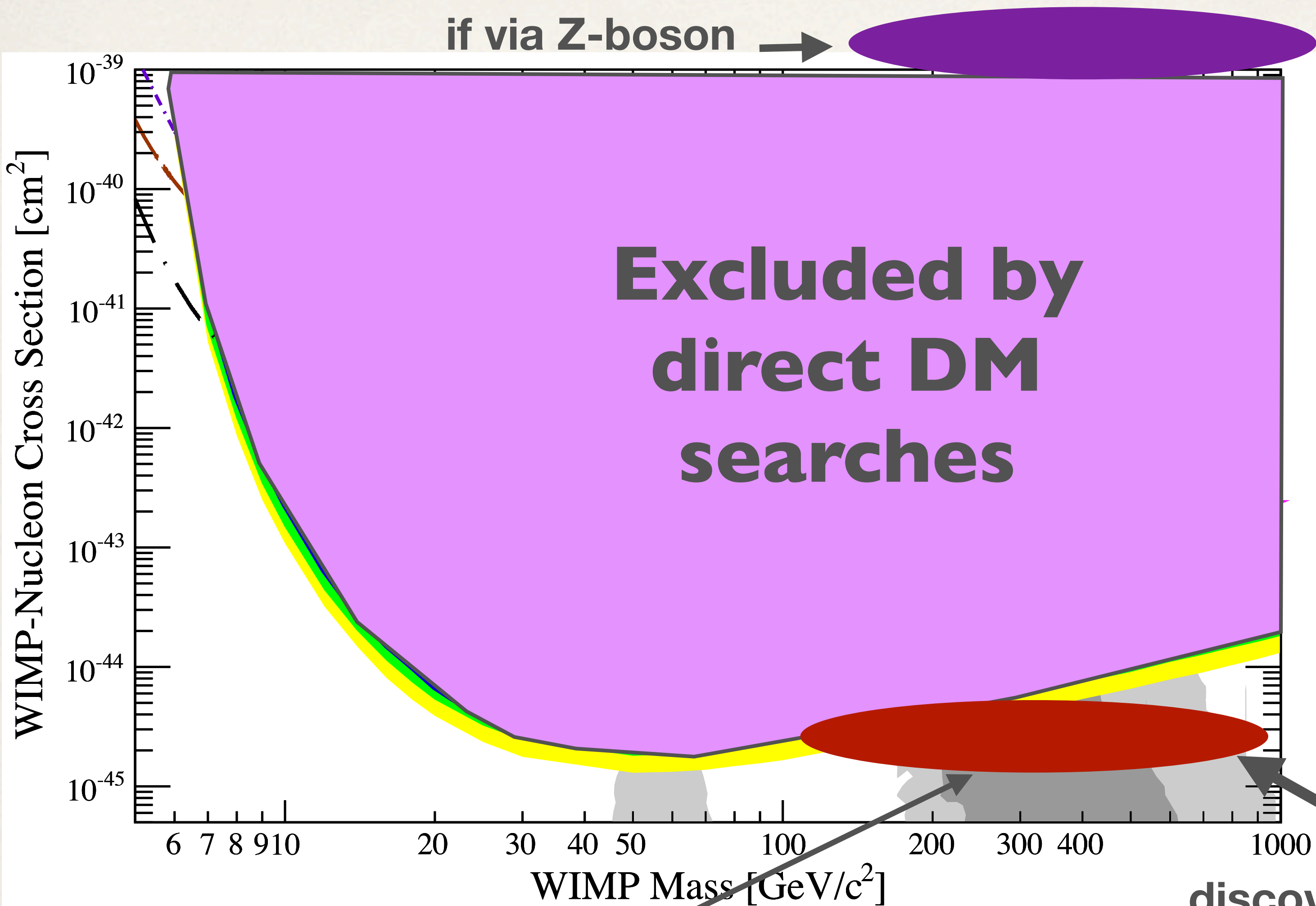


via the Higgs boson?

Direct dark matter detection via the Higgs portal?

if via Z-boson

weak interactions are not weak enough!



see talk by Kathryn Zurek

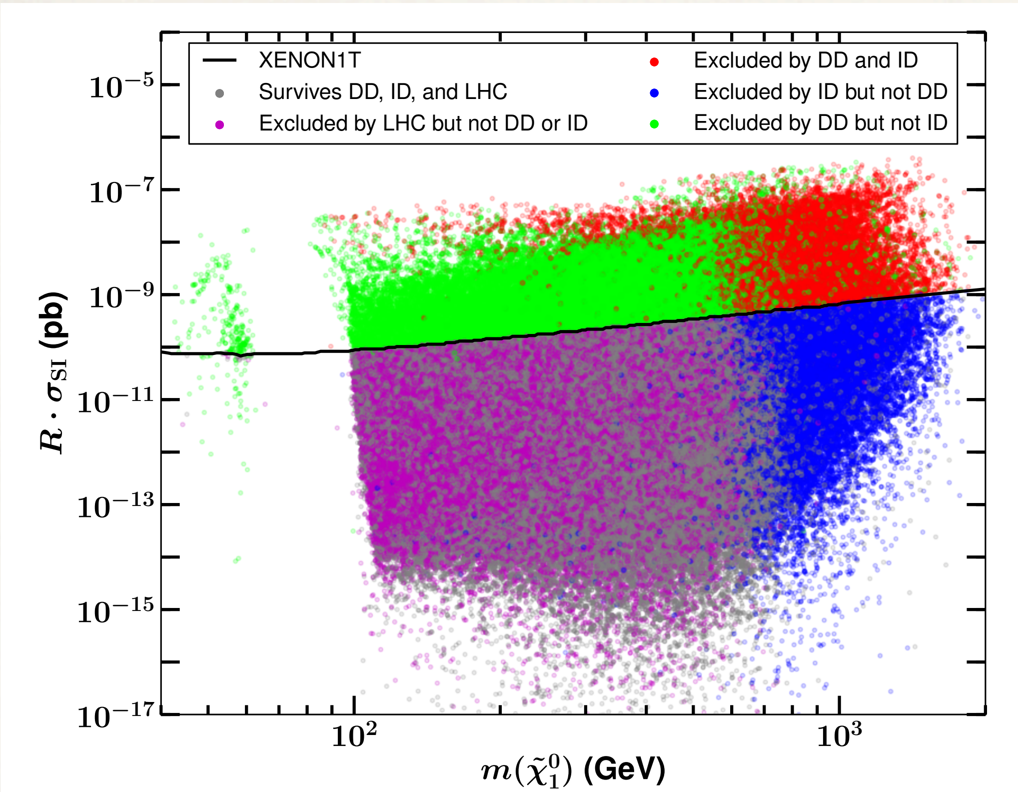
if via 125 GeV Higgs

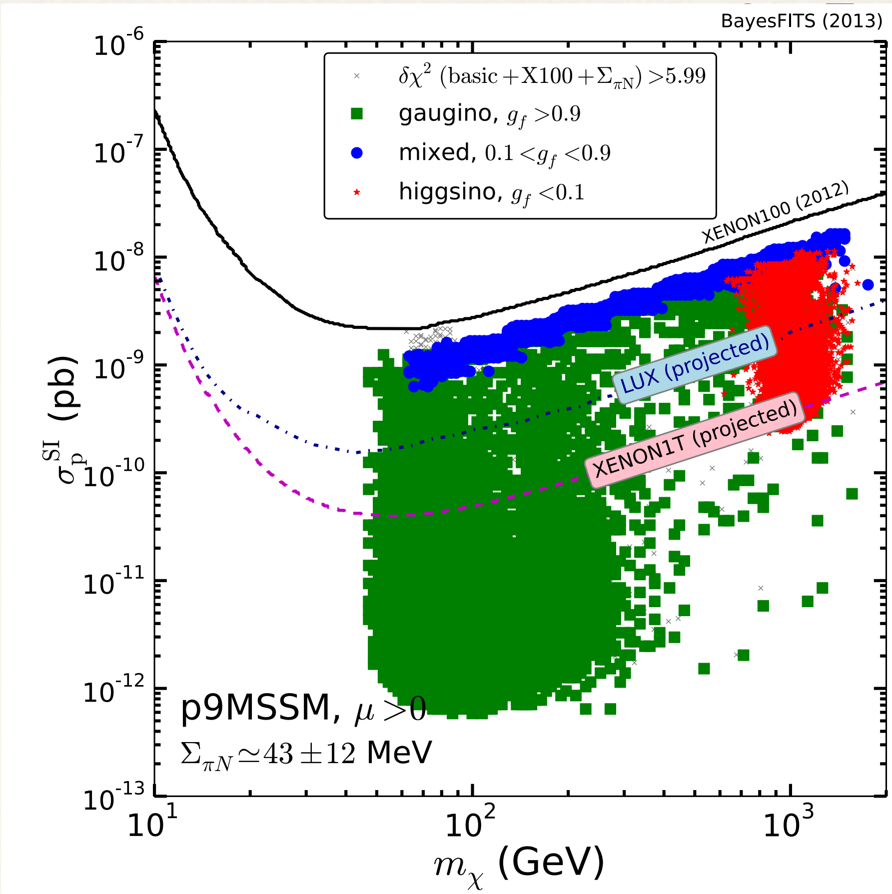
discovery or exclusion in the next few years

If via 500 GeV Higgs

slide adapted from Neal Weiner

Exciting prospects for DM DD





LHC8 actual + projections for XENON1T, CTA

Cahill-Rowley, Cotta, Drlica-Wagner, Funk, Hewett, Ismail, Rizzo, Wood arXiv:1305.6921

Talk by Leszek Roszkowski

What theorists want: scientia ipsa potentia est

Random Theorist: ***"I want CMS to compare your data to this new class of models that I invented yesterday."***

CMS Experimentalist (aka Maurizio Pierini): ***"Yes, and I want a pony."***

Search for new physics in events with same-sign dileptons and b jets in pp collisions at $\sqrt{s} = 8$ TeV

JHEP03(2013)037

The CMS collaboration

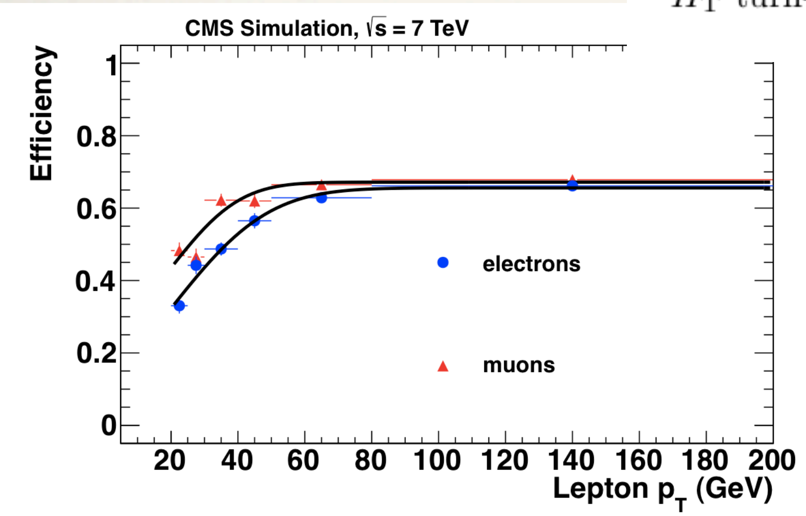
E-mail: cms-publication-committee-chair@cern.ch

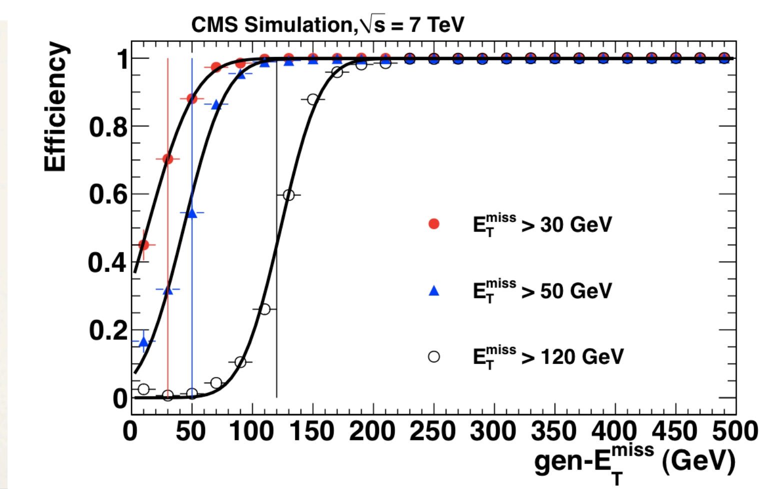
ABSTRACT: A search for new physics is performed using events with isolated same-sign leptons and at least two bottom-quark jets in the final state. Results are based on a sample of proton-proton collisions collected at a center-of-mass energy of 8 TeV with the CMS detector and corresponding to an integrated luminosity of 10.5 fb^{-1}. No excess above the standard model background is observed. Upper limits are set on the
non-standard-model sources and are used to constrain a number o
Information on acceptance and efficiencies is also provided so that t
to confront an even broader class of new physics models.

- **Some LHC analyses provide extra information to allow theorists to recast the limits for their own models with decent accuracy**
- **CMS SS-dilepton SUSY was a pioneer in this**

7 Information for model testing

Our results can be used to confront models of new physics in an approximate way through generator-level studies that compare the expected numbers of events with the upper limits from table 2. The prescription to be used is given in ref. [15], section 7. The $E_{\mathrm{T}}^{\mathrm{miss}}$ and H_{T} turn-on curves in this analysis are the same as those of ref. [15]. However the lepton





- This even works for a sophisticated 2D shape analysis like the Razor
- CMS provides the background model, theorists are expected to generate their own signal MC

See talk by Leszek Roszkowski for successful examples

- This kind of service means a lot of extra work for the ATLAS/CMS analyzers

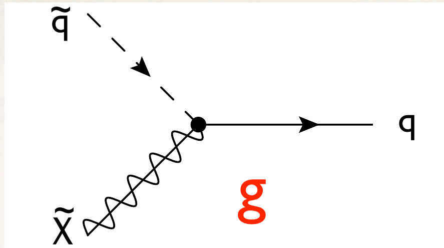
TWiki > CMSPublic Web > Razor-cms > RazorLikelihoodHowTo (22-Mar-2013, MaurizioPierini) Edit Attach PDF

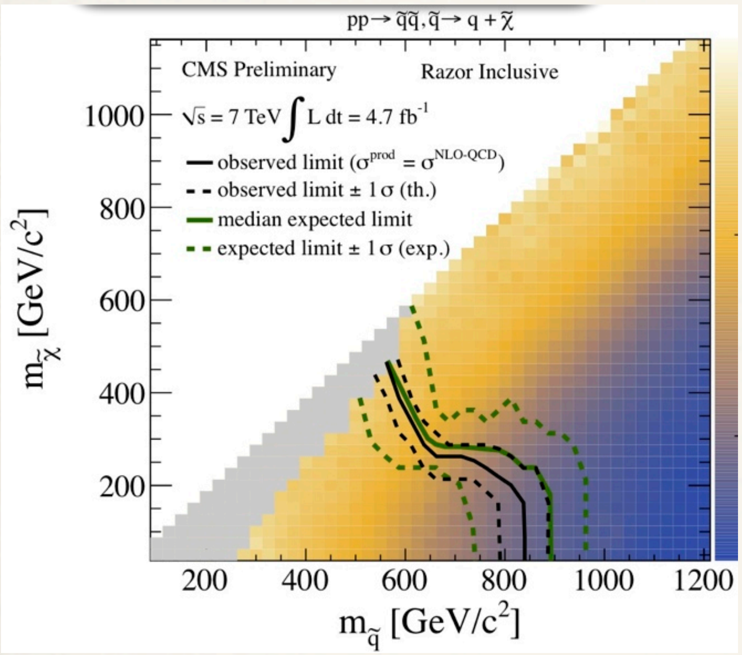
Reproducing The Razor Limit in Your SUSY study

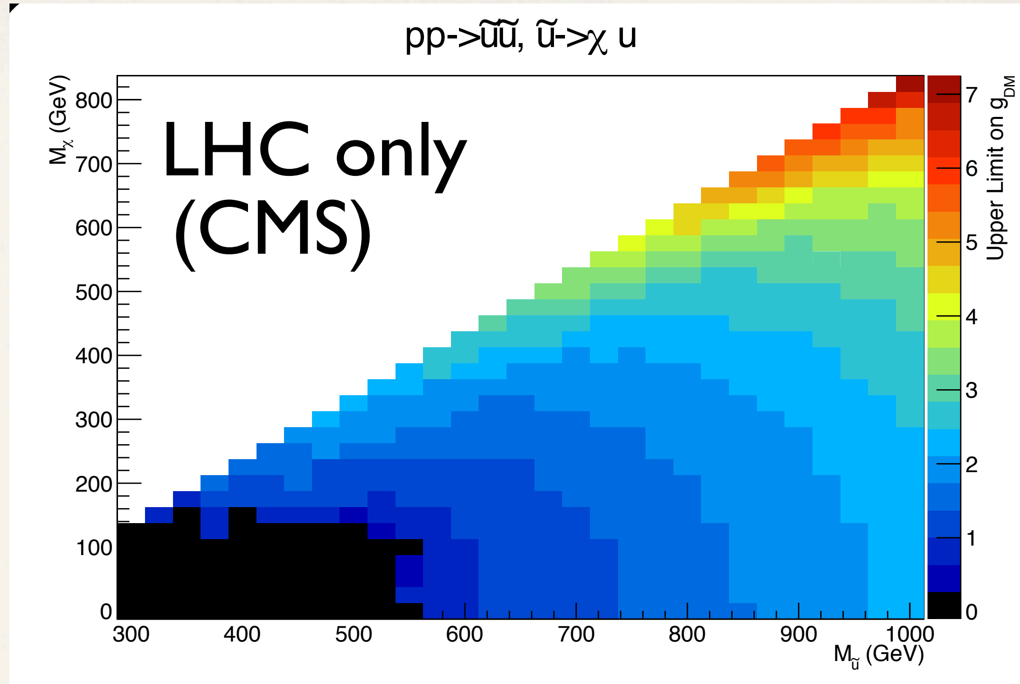
This page guides you through the construction of a binned likelihood which allows you to plug the Razor SUSY constraint in your SUSY pheno study. The page refers to the latest results of the inclusive Razor and inclusive btag Razor analyses, performed on 7TeV CMS data.

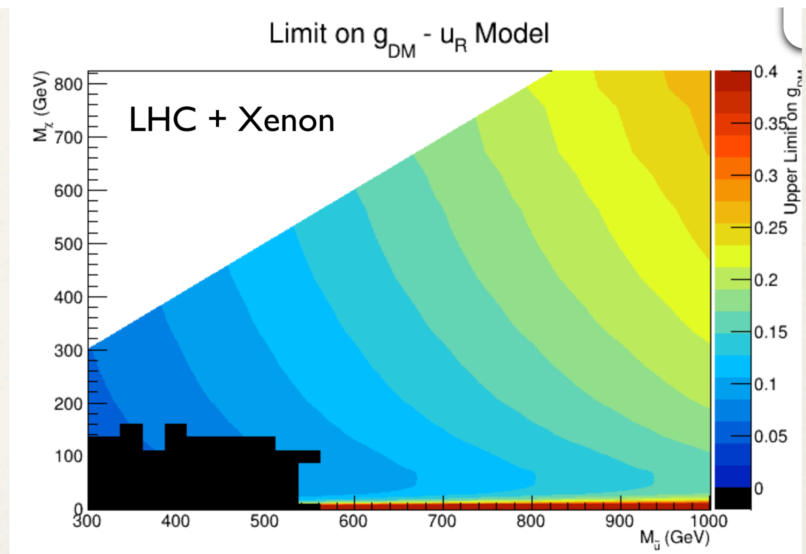
You need to start from an event generator which provides you a sample of simulated SUSY events from 7 TeV pp collisions This twiki page shows how to

1. Account for detector effects in the reconstruction of the main objects used in the analysis (jet, MET, electrons, muons, and btag)
2. Calculate the Razor variables
3. Define the boxes
4. Build a 2D PDF with the binning we provide
5. compute the binned likelihood as a product of Poisson (for the observed yield) and Gaussian (for the background systematic) functions.





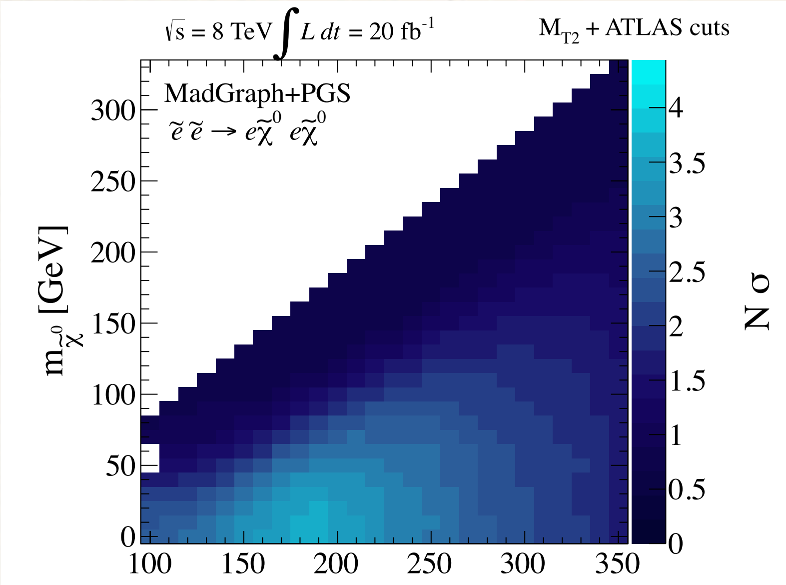


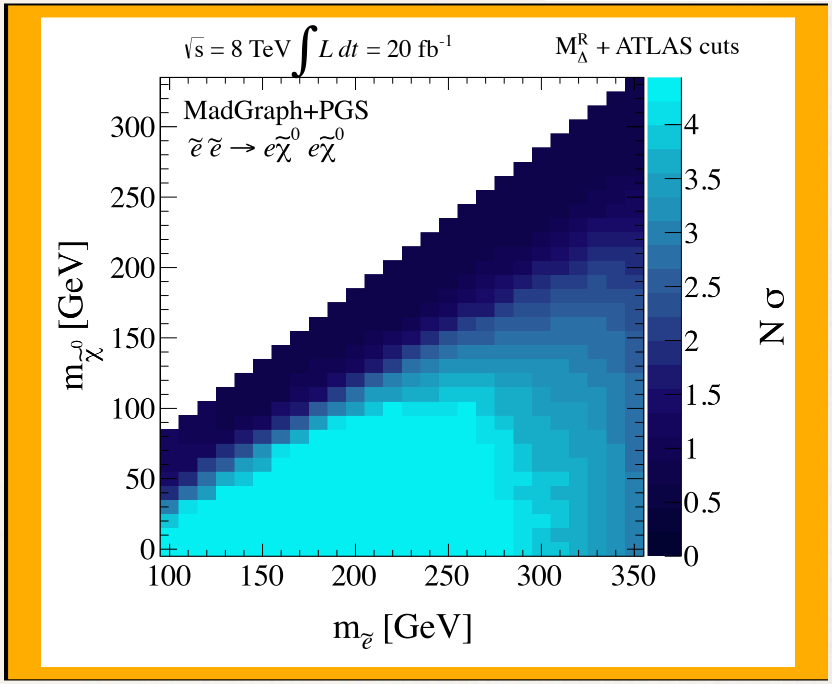


Talk by Tim Tait at Lepton-Photon 2013

- There are also lots of opportunities for theorists to get involved with helping the LHC experiments to find clever ways of improving their sensitivity to various kinds of signals

Super Razor





Talks by Matt Buckley, Scott Thomas, Kaustubh Agashe

ILC on the launchpad

- The Higgs discovery at LHC is a big boost for HEP
- Is it enough to launch a next-generation collider?

Outlook

- The Higgs discovery is only the beginning of a story that will bridge all the frontiers of particle physics
- The LHC/ILC program will be equal parts precision measurements and searches for new particles and phenomena
- Higgs connects to the Intensity Frontier and the Cosmic Frontier as well, where e.g. dark matter may be a game changer in the next few years
- Whether canonical BSM thinking is correct or incorrect, we have entered a New Age

Many Thanks To

- The Conference Organizers: Marcela Carena, Fabio Maltoni, Matthias Neubert, Lian-Tao Wang
- The friendly and helpful KITP staff
- Lars, David, Marty and the other locals for making the KITP a great place
- DOE, NSF and the KITP donors
- The speakers and all the participants