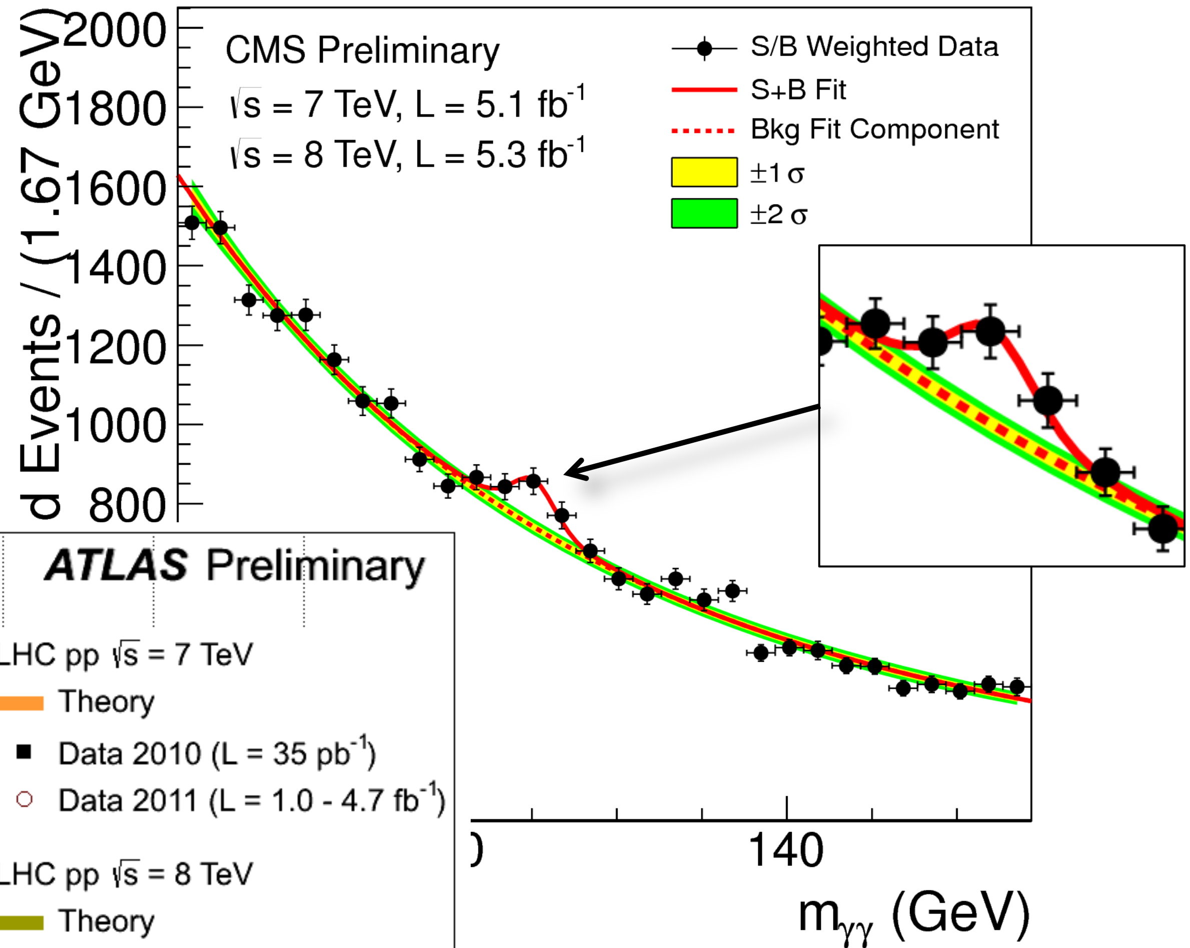
Coloron Models and LHC Phenomenology

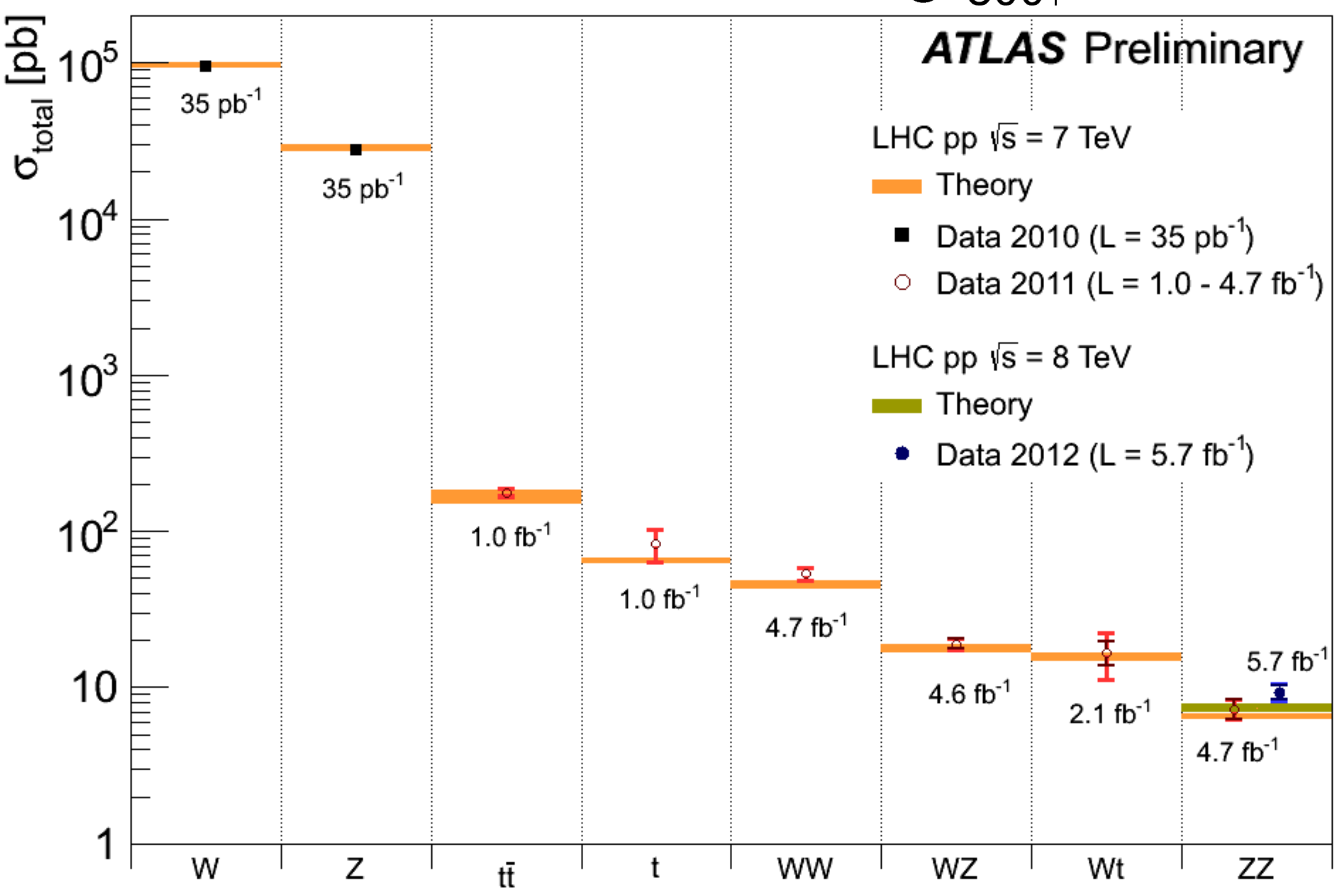
Elizabeth H. Simmons
Michigan State University

- New Strong Dynamics
- Models
- LHC Phenomenology
- Other Phenomenology
- Conclusions ... Outlook

LHC's rediscovery and new particle

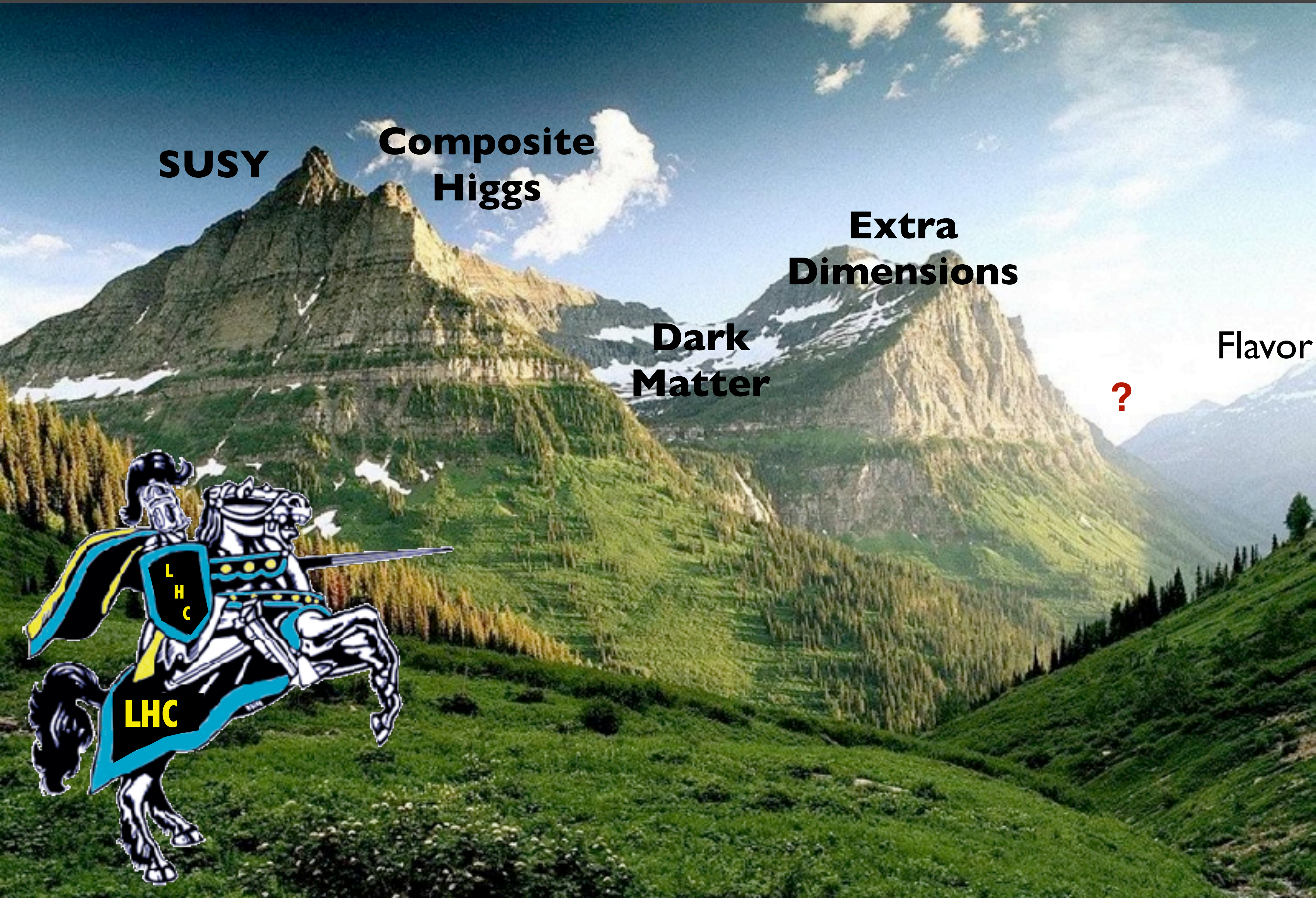
After years of work pay off ...





What's next?

A Quest in The BSM Landscape



New Strong Dynamics

new colored gauge bosons

Classic Axigluon: P. H. Frampton and S. L. Glashow, Phys. Lett. B 190, 157 (1987).

Topgluon: C. T. Hill, Phys. Lett. B 266, 419 (1991).

Flavor-universal Coloron: R.S. Chivukula, A.G. Cohen, & E.H. Simmons, Phys. Lett. B 380, 92 (1996).

Chiral Color with $g_L \neq g_R$: M.V. Martynov and A. D. Smirnov, Mod. Phys. Lett. A 24, 1897 (2009).

New Axigluon: P. H. Frampton, J. Shu, and K. Wang, Phys. Lett. B 683, 294 (2010).

hot topic: possible effects on A^t_{FB}

L. M. Sehgal and M. Wanninger, Phys. Lett. B 200, 211 (1988).

D. Choudhury, R.M. Godbole, R. K. Singh, and K. Wagh, Phys. Lett. B 657, 69 (2007).

P. Ferrario and G. Rodrigo, J. High Energy Phys. 02 (2010) 051.

M.V. Martynov and A. D. Smirnov, arXiv:1006.4246.

Q. H. Cao, D. McKeen, J. L. Rosner, G. Shaughnessy, and C. E. M. Wagner, Phys. Rev. D 81, 114004 (2010).

P. Ferrario and G. Rodrigo, Proc. XVIII Int'l Workshop on Deep-Inelastic Scattering, April 19 -23, 2010, Firenze.

R.S. Chivukula, E.H. Simmons, and C.-P. Yuan, Phys. Rev. D82 (2010).

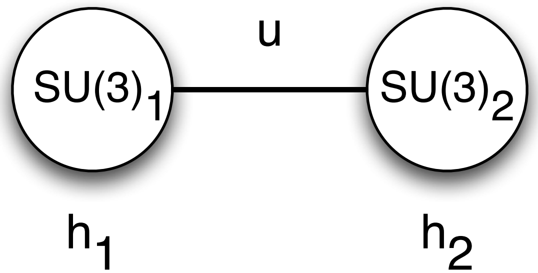
G. Rodrigo and P. Ferrario, 3rd Int'l Workshop on Top Quark Physics, Brugges, Belgium, 31 May to 4 Jun 2010.

G. Rodrigo and P. Ferrario arXiv:1007.4328 [hep-ph]

...

Models

Coloron Models: Gauge Sector



$SU(3)_1 \times SU(3)_2$ color sector with $M^2 = \frac{u^2}{4}\begin{pmatrix} h_1^2 & -h_1 h_2 \\ -h_1 h_2 & h_2^2 \end{pmatrix}$

unbroken subgroup: $SU(3)_{1+2} = SU(3)_{QCD}$

$$h_1 = \frac{g_s}{\cos\theta} \qquad h_2 = \frac{g_s}{\sin\theta}$$

gluon state: $G^A_\mu = \cos\theta\, A^A_{1\mu} + \sin\theta\, A^A_{2\mu}$

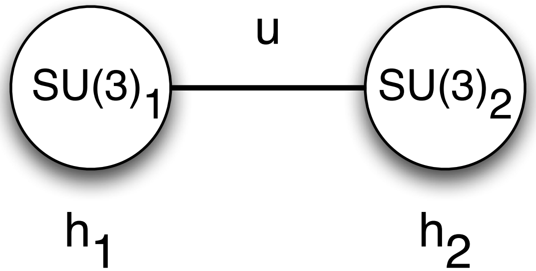
couples to: $g_S J^\mu_G \equiv g_S (J^\mu_1 + J^\mu_2)$

coloron state: $C^A_\mu = -\sin\theta\, A^A_{1\mu} + \cos\theta\, A^A_{2\mu}$ $\qquad M_C = \frac{u}{\sqrt{2}}\sqrt{h_1^2 + h_2^2}$

couples to: $g_S J^\mu_C \equiv g_S(-J^\mu_1 \tan\theta + J^\mu_2 \cot\theta)$

low-energy current-current interaction: $\mathcal{L}^2_{FF} = -\frac{g_S^2}{2M_C^2} J^\mu_C J_{C\,\mu}$

Coloron Models: Quark Charges



$$g_S J^\mu_G \equiv g_S(J^\mu_1 + J^\mu_2)$$

$$g_S J^\mu_C \equiv g_S(-J^\mu_1 \tan\theta + J^\mu_2 \cot\theta)$$

low-energy current-current interaction: $\mathcal{L}^2_{FF} = -\frac{g_S^2}{2M_C^2} J^\mu_C J_{C\,\mu}$

Depending on how quarks transform under $SU(3)_1$ x $SU(3)_2$ the presence of colorons may impact

- LHC dijet mass distribution (or angular distribution)
- kinematic distributions of tt or bb final states
- asymmetry in top-quark production: A^t_{FB}
- FCNC processes: $K\bar{K}, D\bar{D}, B\bar{B}$ mixing, $b \to s\gamma$
- precision EW observables: delta-rho, R_b

Patterns of Quark Charges

SU(3)$_1$	SU(3)$_2$	model	pheno.
	$(t,b)_L$ q_L t_R,b_R q_R	**coloron**	dijet
q_R	$(t,b)_L$ q_L t_R,b_R		
t_R,b_R	$(t,b)_L$ q_L q_R		
q_L	$(t,b)_L$ t_R,b_R q_R		
q_L t_R,b_R	$(t,b)_L$ q_R	**new axigluon**	dijet, A^t_{FB}
q_L q_R	$(t,b)_L$ t_R,b_R	**topgluon**	dijet, tt, bb, FCNC, R_b
t_R,b_R q_R	$(t,b)_L$ q_L	**classic axigluon**	dijet, A^t_{FB}
q_L t_R,b_R q_R	$(t,b)_L$		

q = u,d,c,s

A Toy Topgluon Model

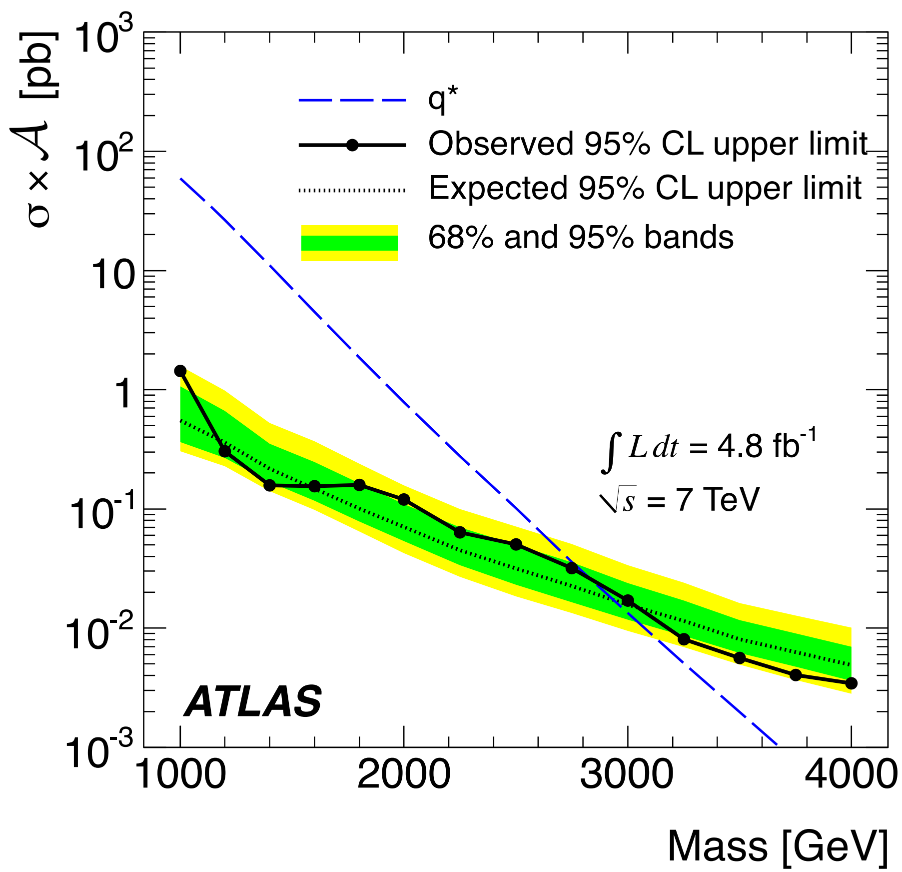
particles		$SU(3)_1$	$SU(3)_2$	$SU(2)_W$
3rd generation quarks	$(t,b)_L$	3	1	**2**
	t_R, b_R	3	1	1
light quarks	$(u,d)_L$ $(c,s)_L$	1	3	2
	u_R, d_R c_R, s_R	1	3	1
vector quarks	Q_L, Q_R	3	1	**2**
light scalar	□□ $\boldsymbol{\varphi}$	1	1	**2**
heavy scalar	$\boldsymbol{\Phi}$	3	3*	1

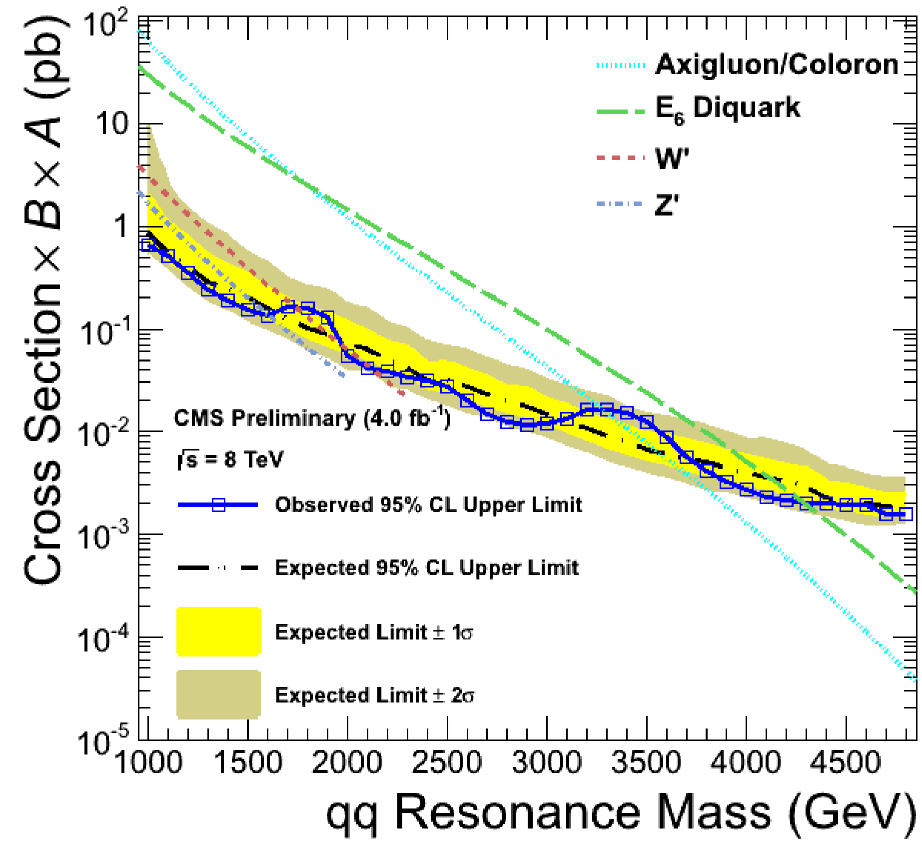
R.S. Chivukula, EHS, N. Vignaroli (2012) in preparation

LHC Phenomenology

LHC Limits on Colorons

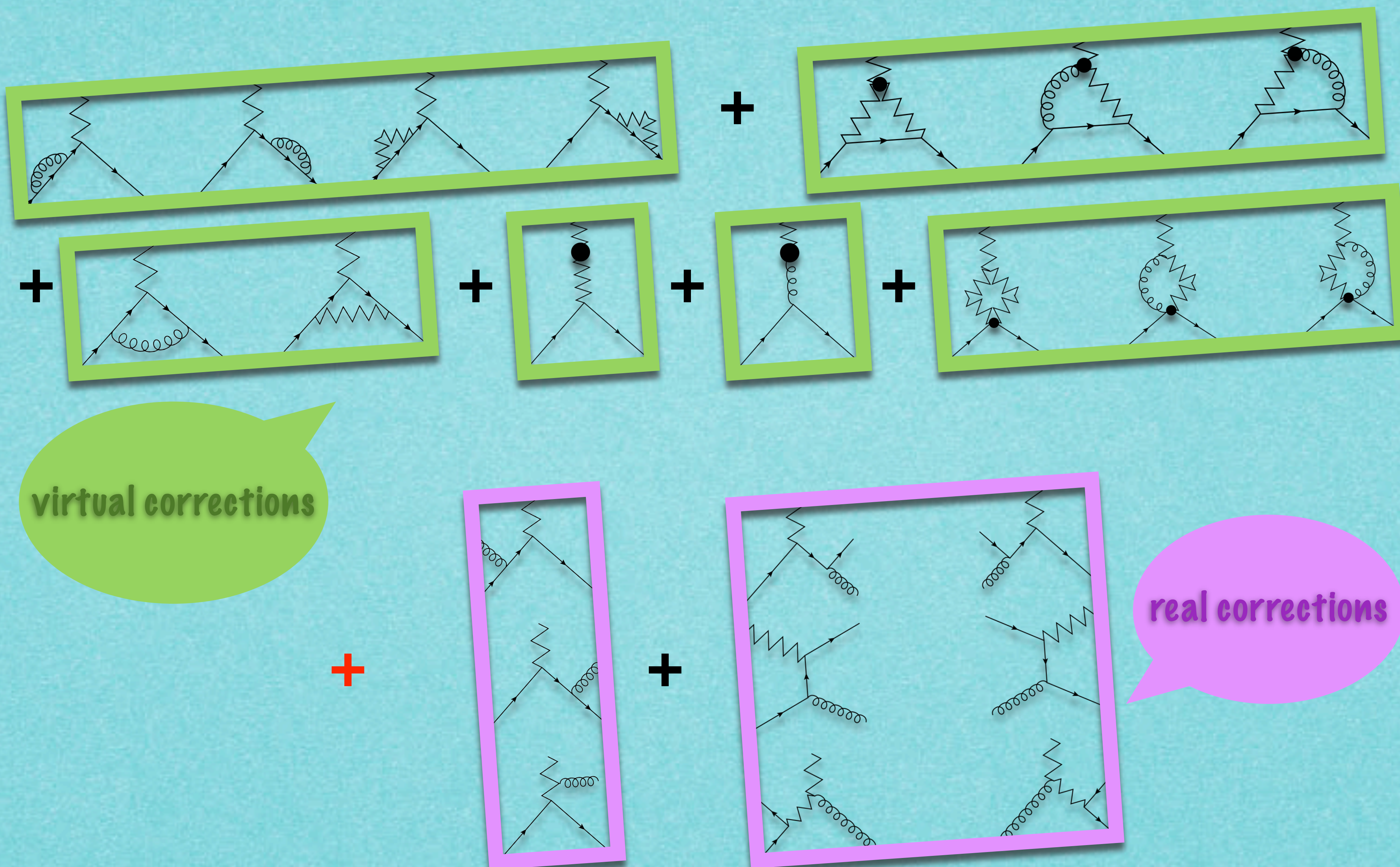
- LHC searches for colorons in dijet constrain $M_C > 3.5$ TeV





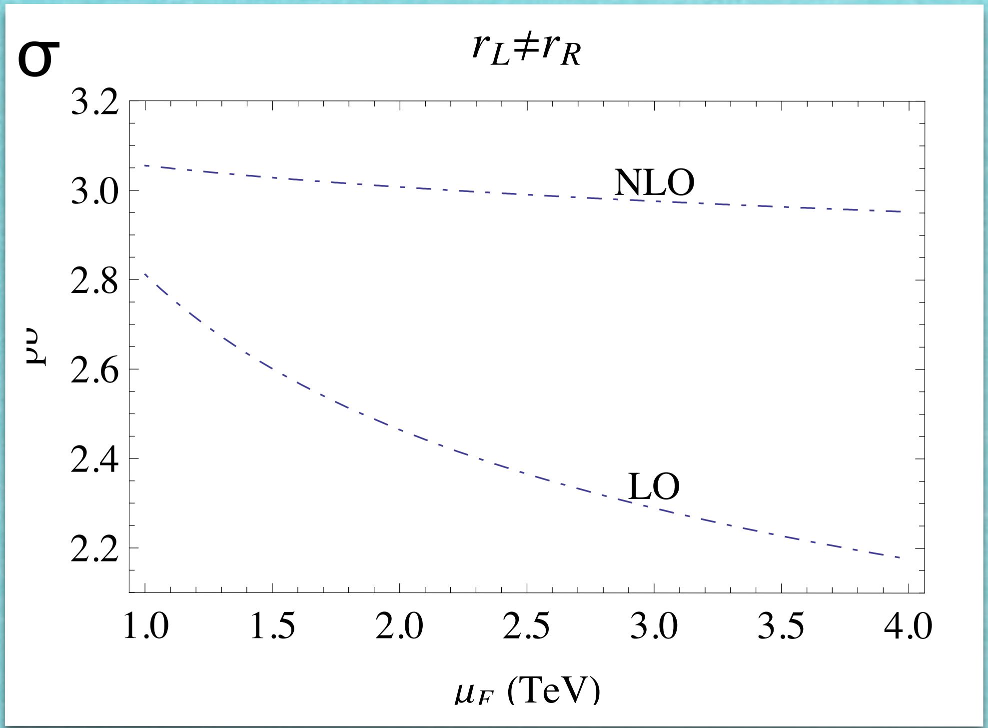
- But these calculations have treated the colorons only at LO and QCD to NLO (or beyond) ... we can do better!

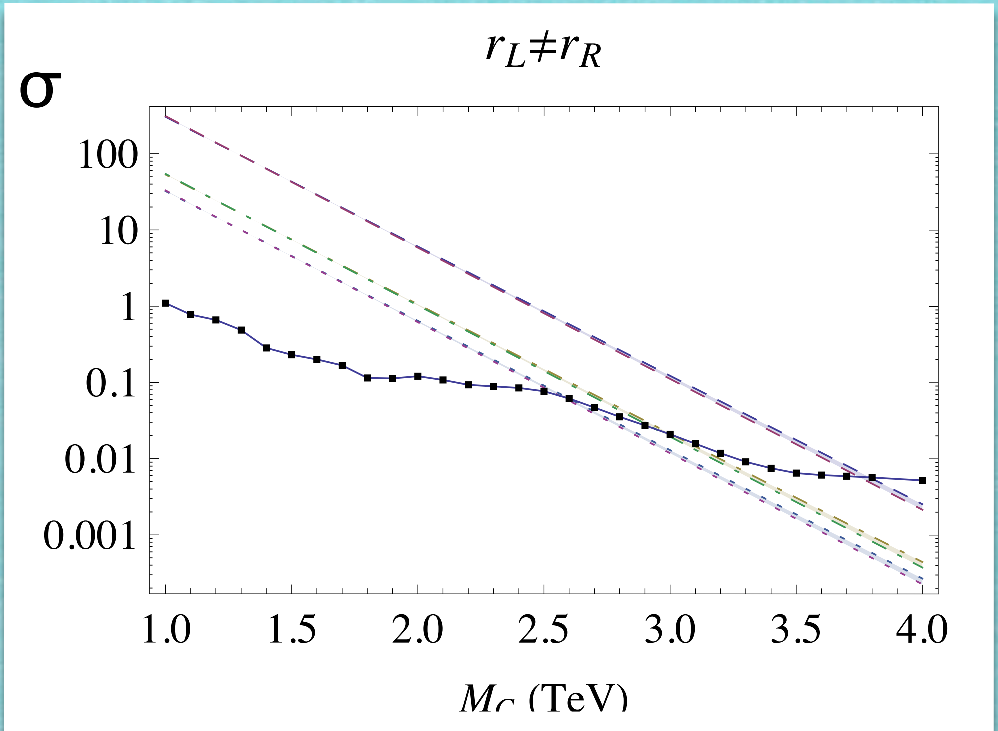
Colorons at NLO



R.S.Chivukula, A.Farzinnia, R.Foadi, EHS arXiv:1111.7261

Impact of NLO Corrections

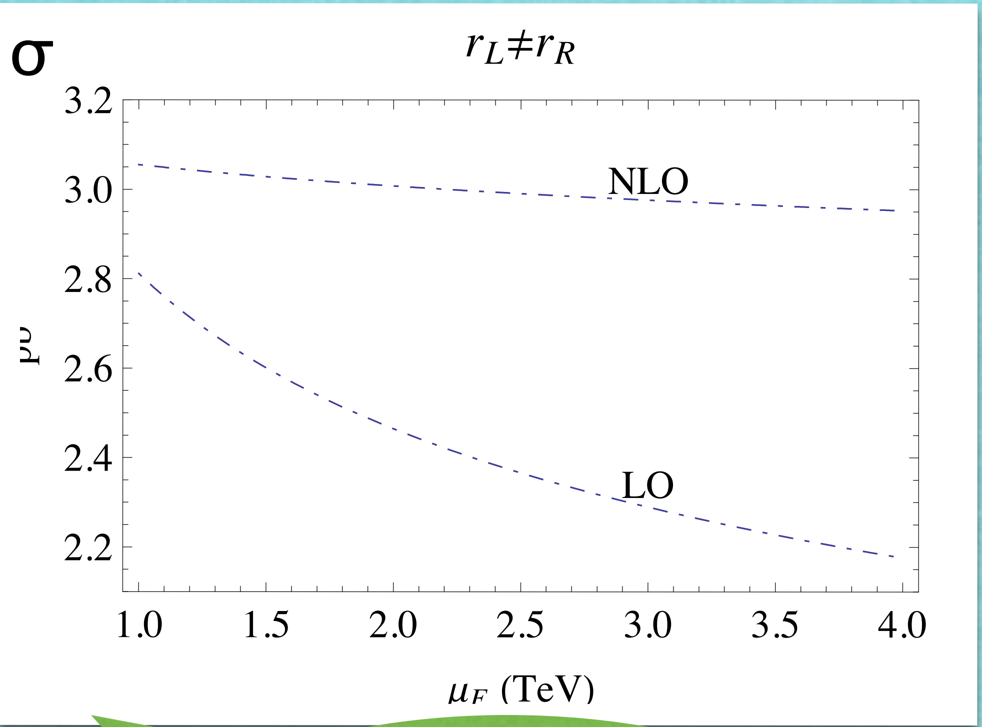


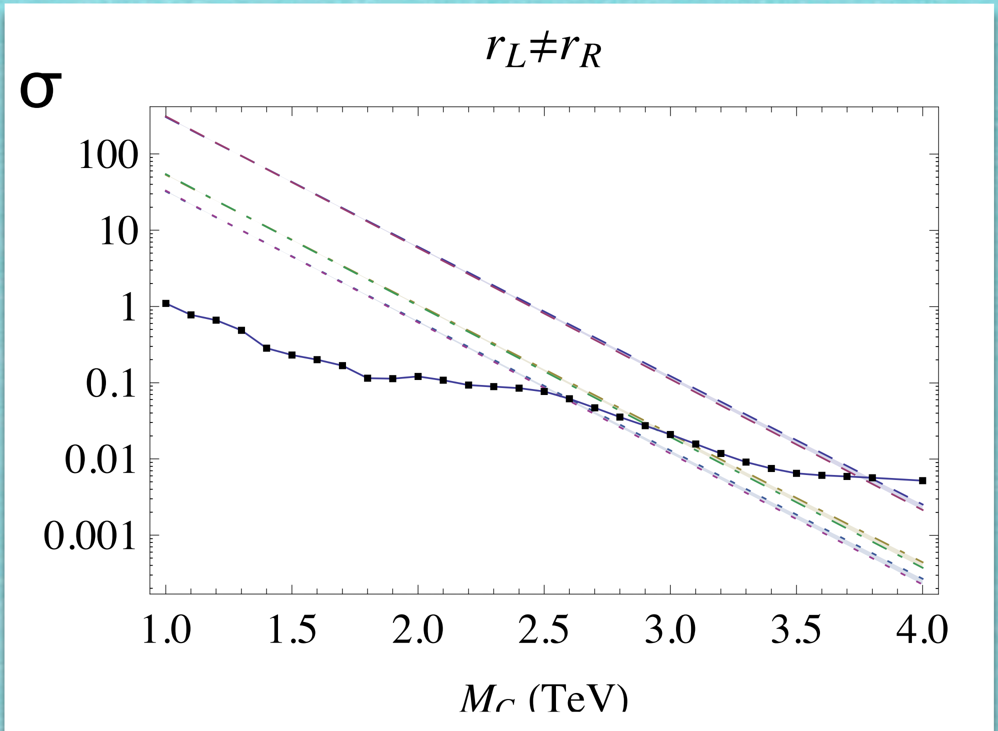


- K-factor: $\sigma_{NLO}/\sigma_{LO} \sim 30\%$
- 30% of produced colorons have p_T > 200 GeV!

RSC, Farzinnia, Foadi, EHS arXiv:1111.7261

Impact of NLO Corrections





scale dependence
at LO: 30%
at NLO: 2%

- K-factor: $\sigma_{NLO}/\sigma_{LO} \sim 30\%$
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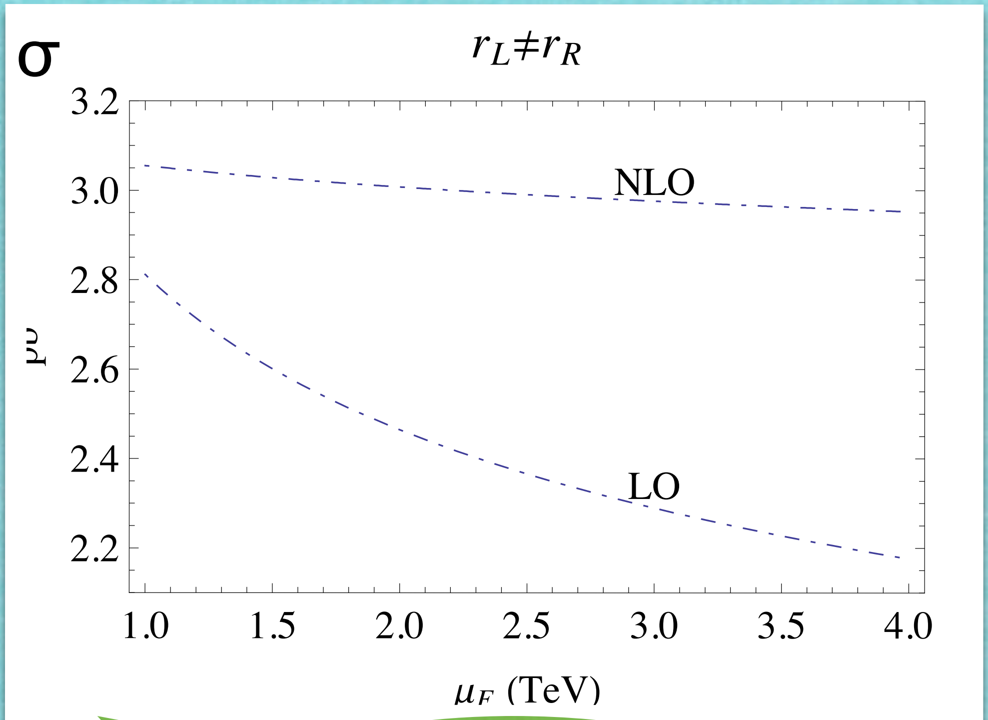
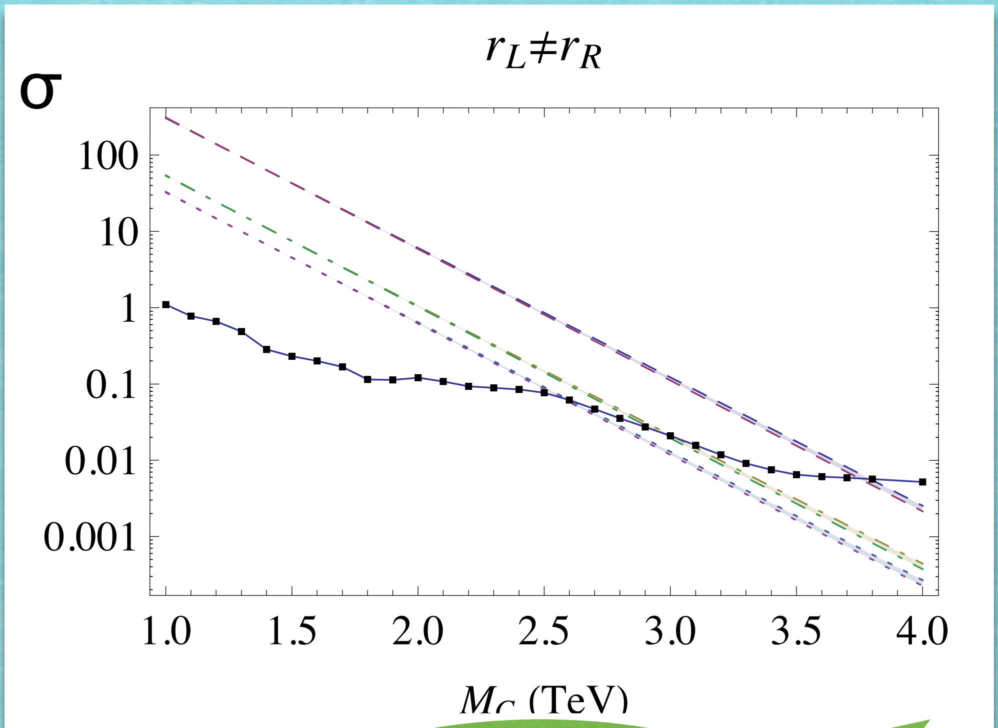
RSC, Farzinnia, Foadi, EHS arXiv:1111.7261

Impact of NLO Corrections





scale dependence
at LO: 30%
at NLO: 2%

Axigluon
mass limit from CMS
stronger when NLO
included

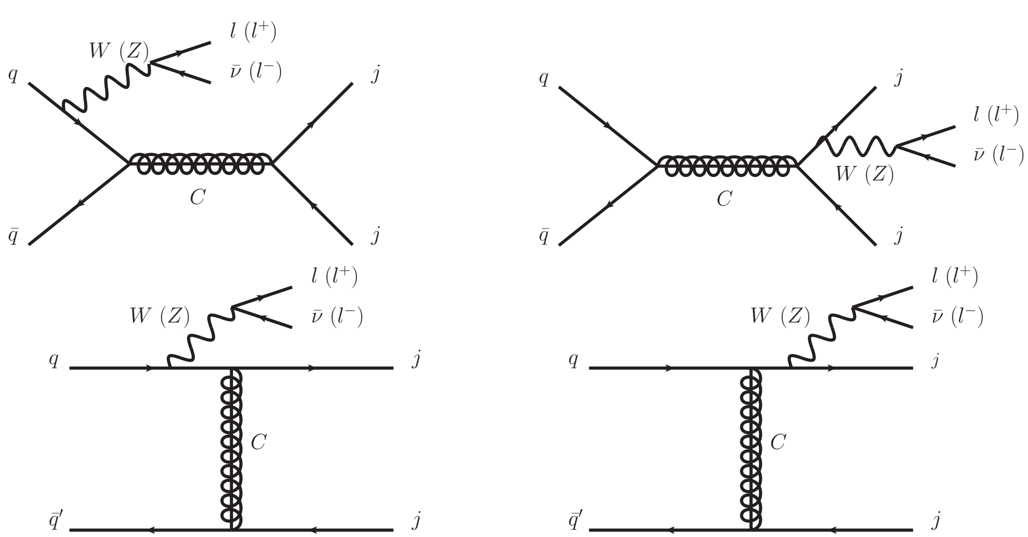
- K-factor: $\sigma_{NLO}/\sigma_{LO} \sim 30\%$
- 30% of produced colorons have p_T > 200 GeV!

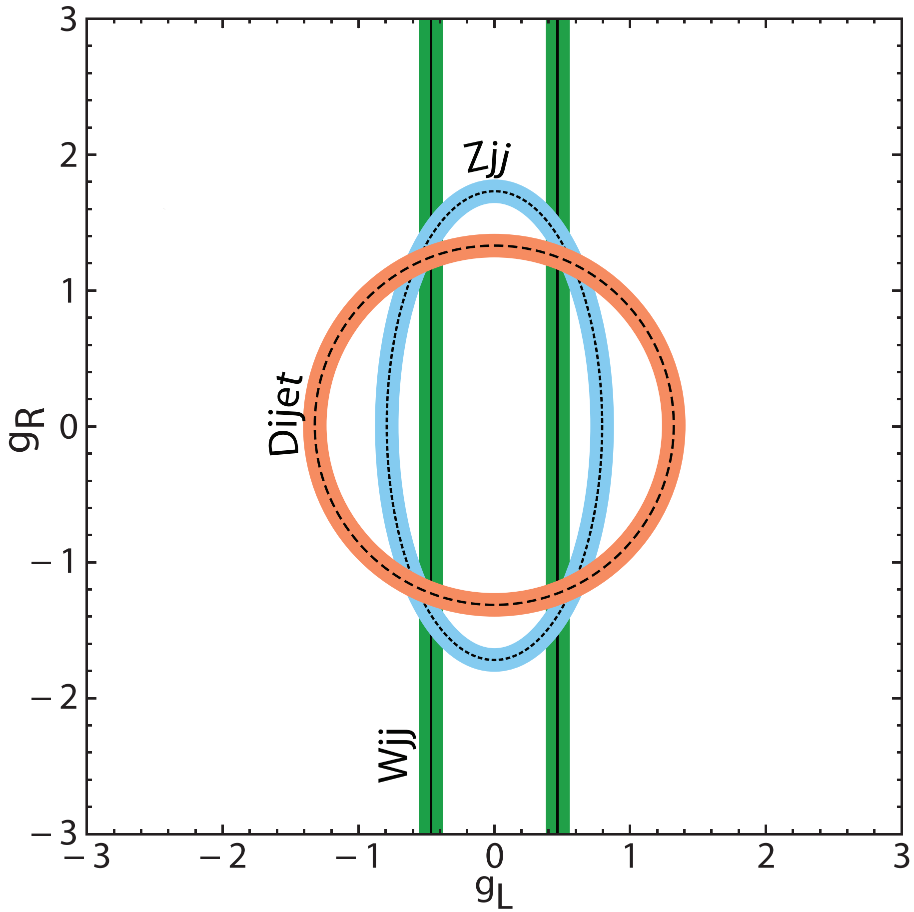
RSC, Farzinnia, Foadi, EHS arXiv:1111.7261

New Mode: W+C^A probes Chiral Couplings

Different production modes probe several combinations of the coloron's couplings to RH and LH fermions:

$$pp \to C^a + W[Z] \to jj\ell\nu[\ell\ell]$$

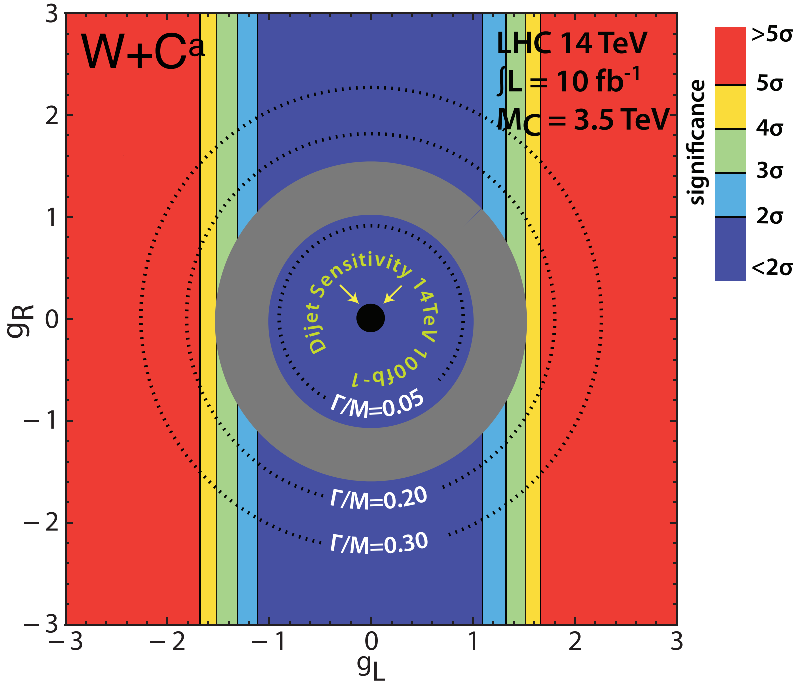


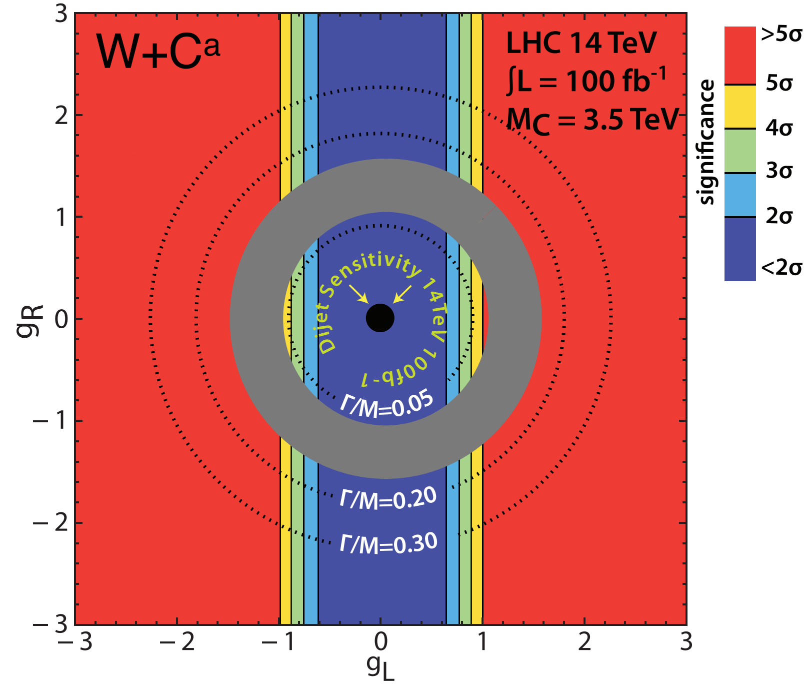


A. Atre, R.S.Chivukula, P. Ittisamai, EHS arXiv:1206.1661

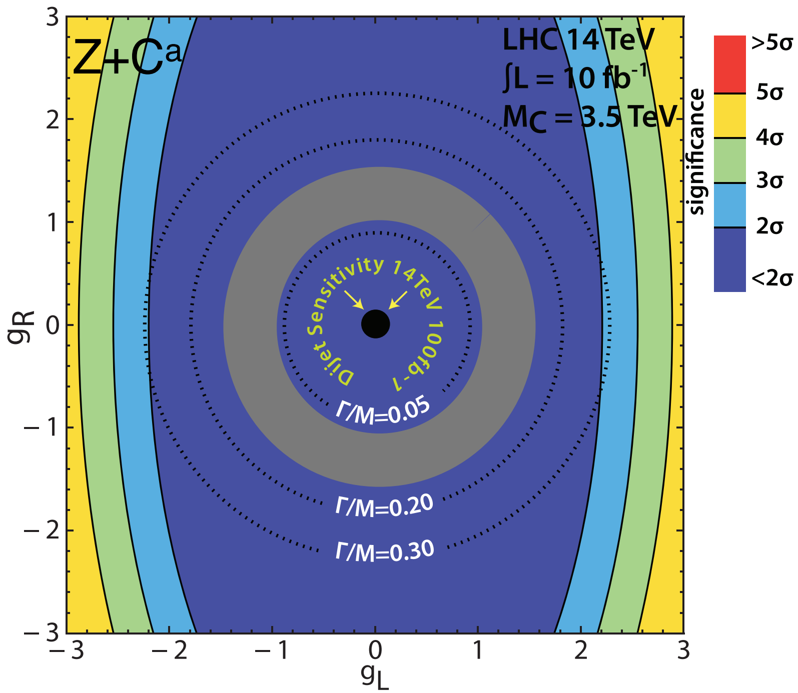
W+C^A: Heat Map of Significance

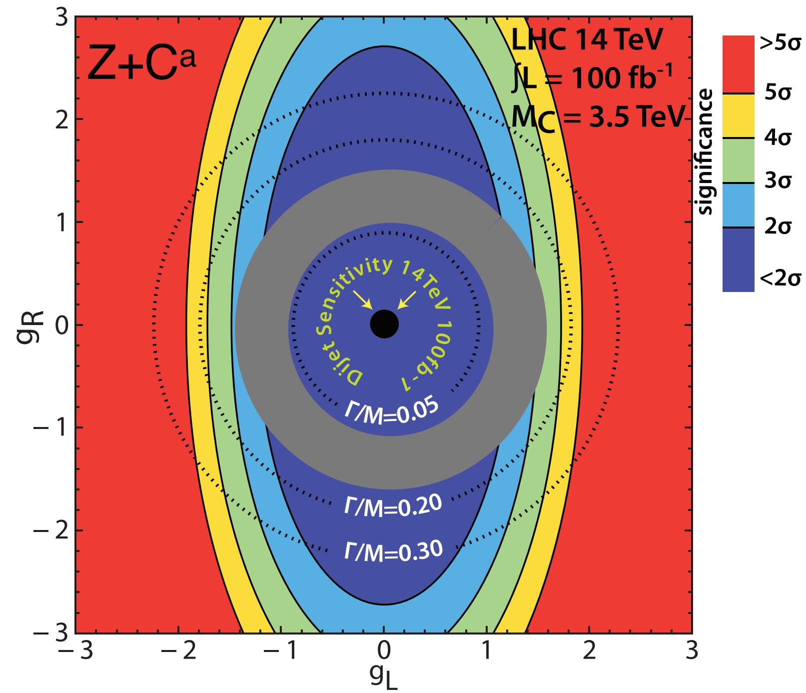
all of these heat maps are for M_c = 3.5 TeV at **14 TeV LHC**



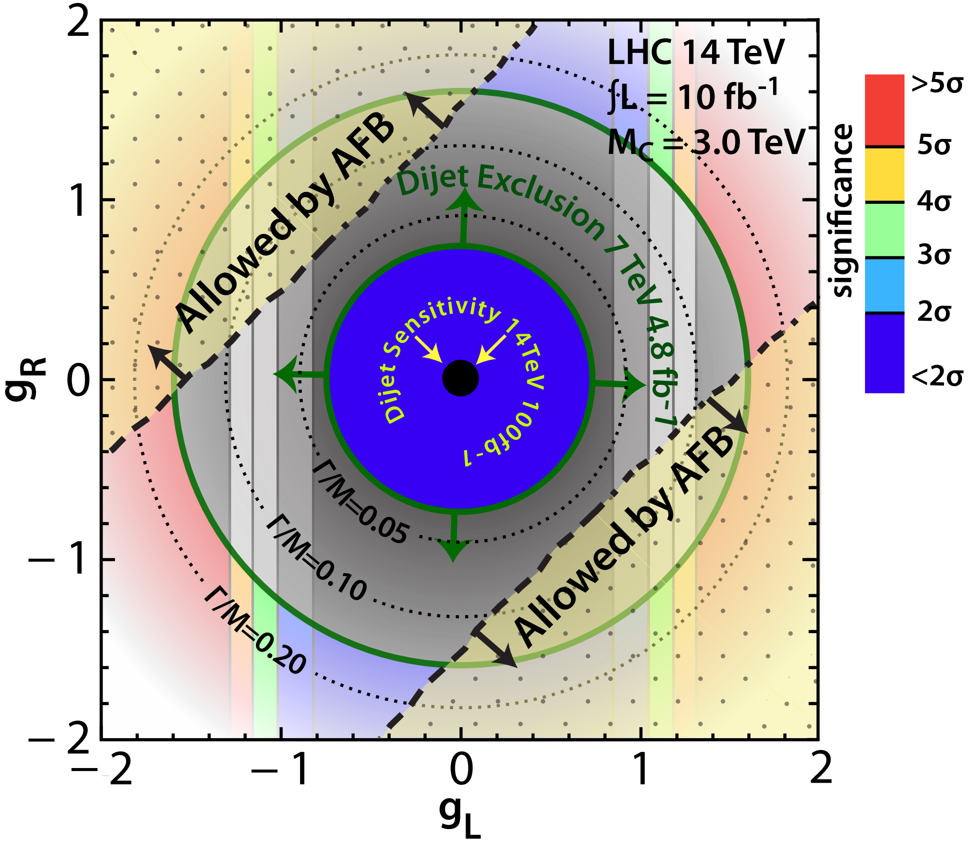


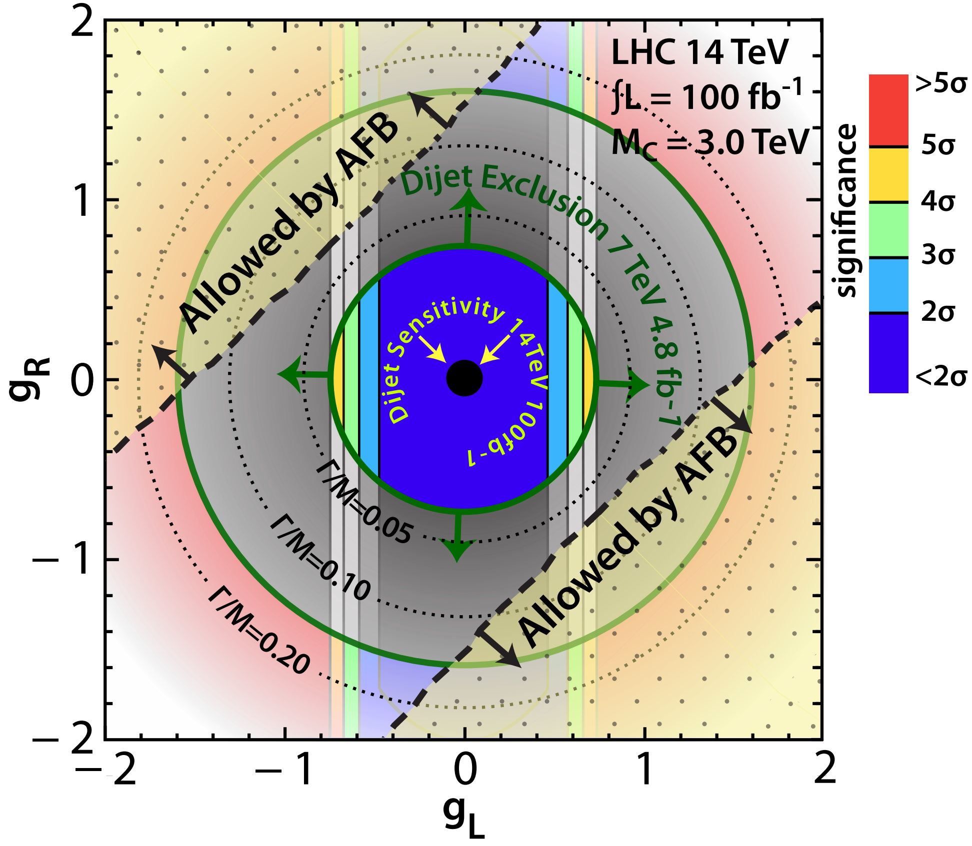
grey ring is excluded by 7 TeV LHC dijet searches with 5 fb^{-1} of data





W+C^A: Heat Map and AFB range

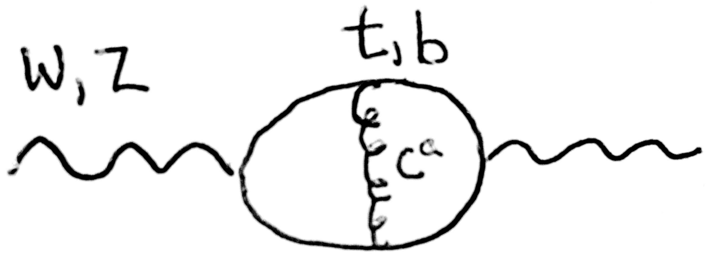




Other Phenomenology

Precision EW Tests

- Coloron exchange does impact $\Delta\rho$ at one-loop



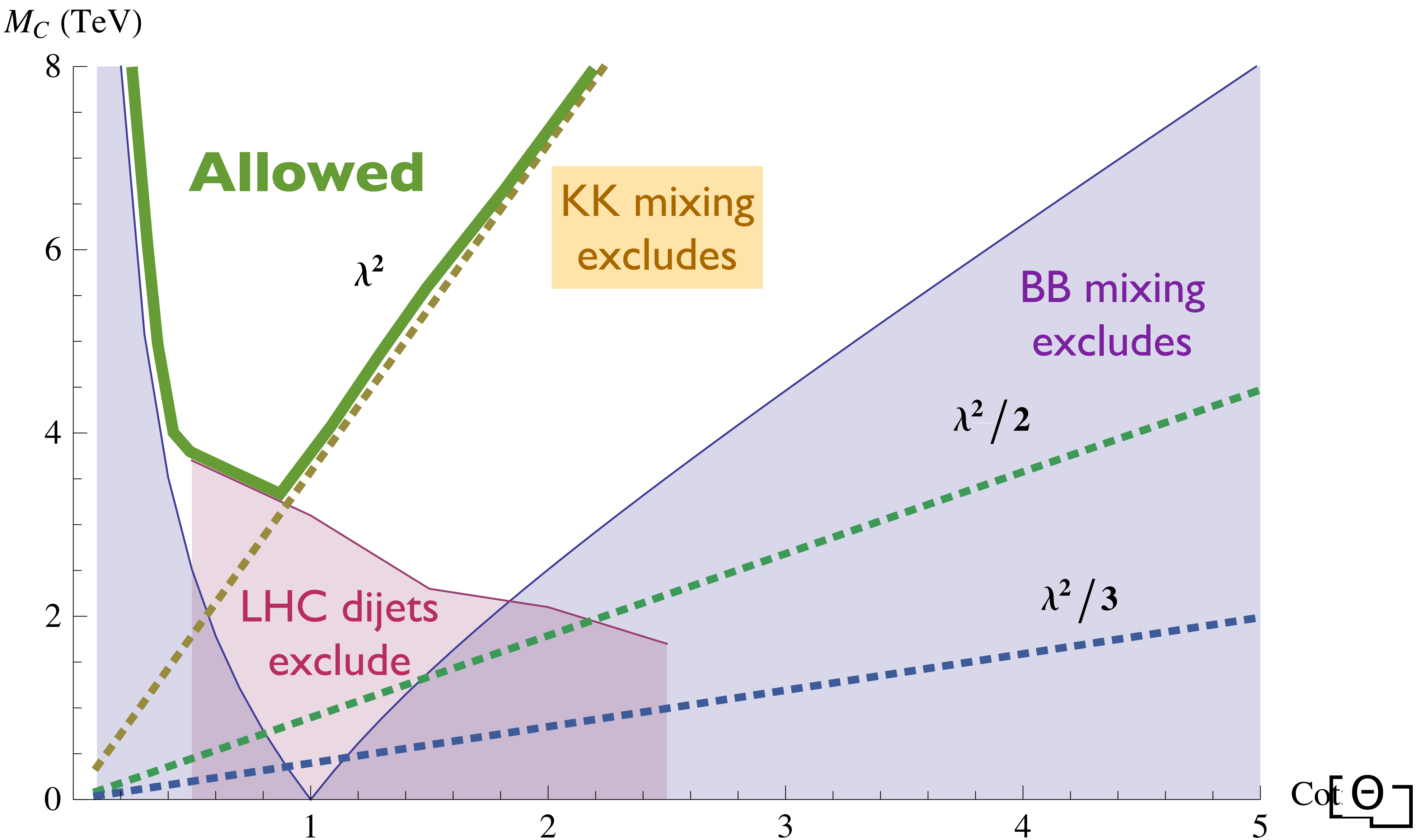
but since

$$\Delta\rho_c \sim \frac{m_t^4}{M_W^2 M_C^2} \ln\left[\frac{M_c^2}{m_t^2}\right]$$

the size of the effect is small

- Likewise, coloron exchange across the $Zb\bar{b}$ vertex yields effects proportional to m_b^2 which are negligible

FCNC Limits on Our Toy Model



R.S. Chivukula, EHS, N. Vignaroli (2012) in preparation

Coloron Conclusions

Conclusions

Physics beyond the SM may lurk in the strong interactions

LHC can discover and study colorons,

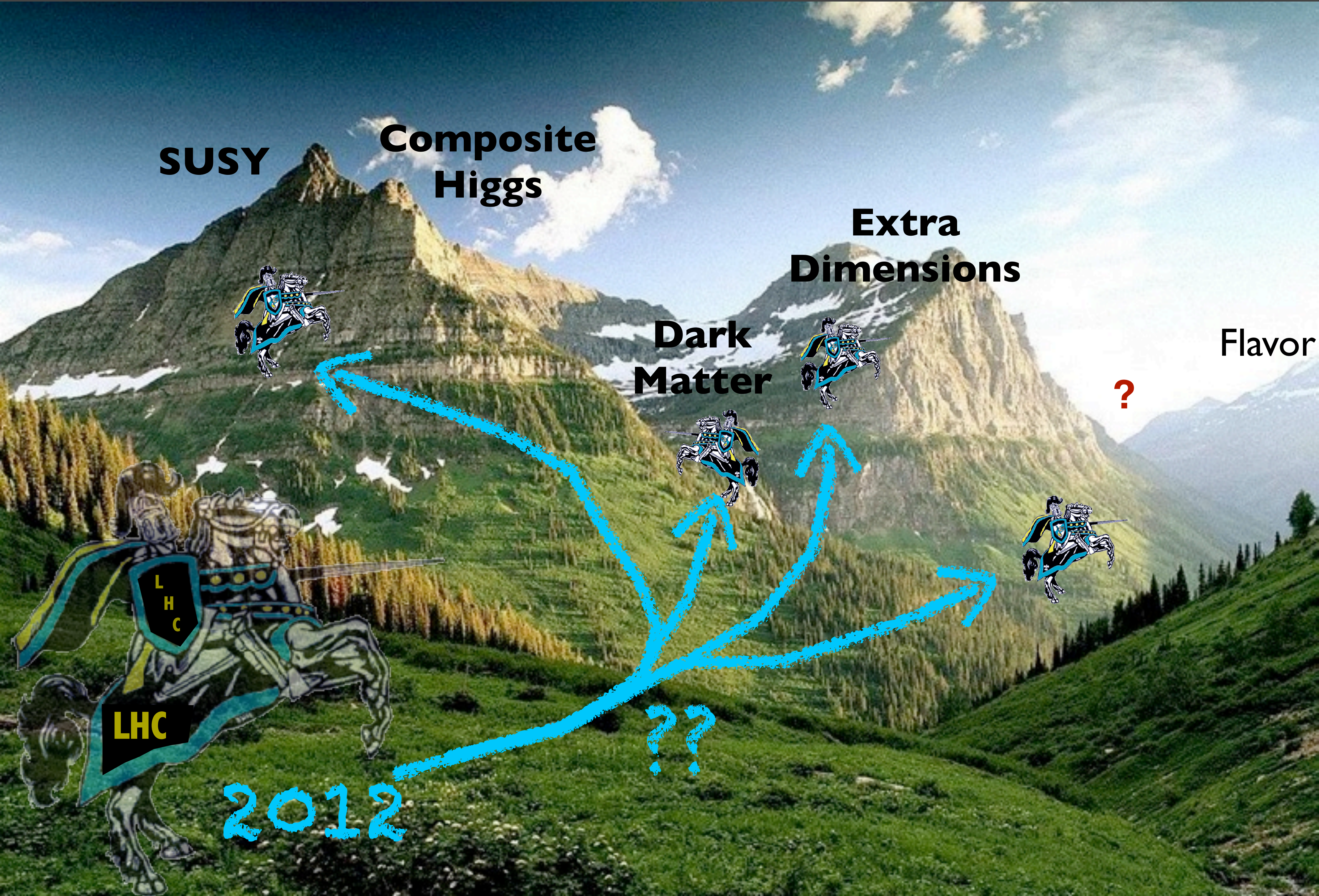
- incorporate NLO results for the coloron K-factor and p_T distribution into dijet searches
- use associated W+ C^a production to probe the coloron's couplings.

Additional coloron effects?

- FCNC: yes, if couplings are flavor non-universal
- precision EW: negligible in $\Delta\rho$, $Zb\bar{b}$
- top-quark asymmetry: for some coupling values

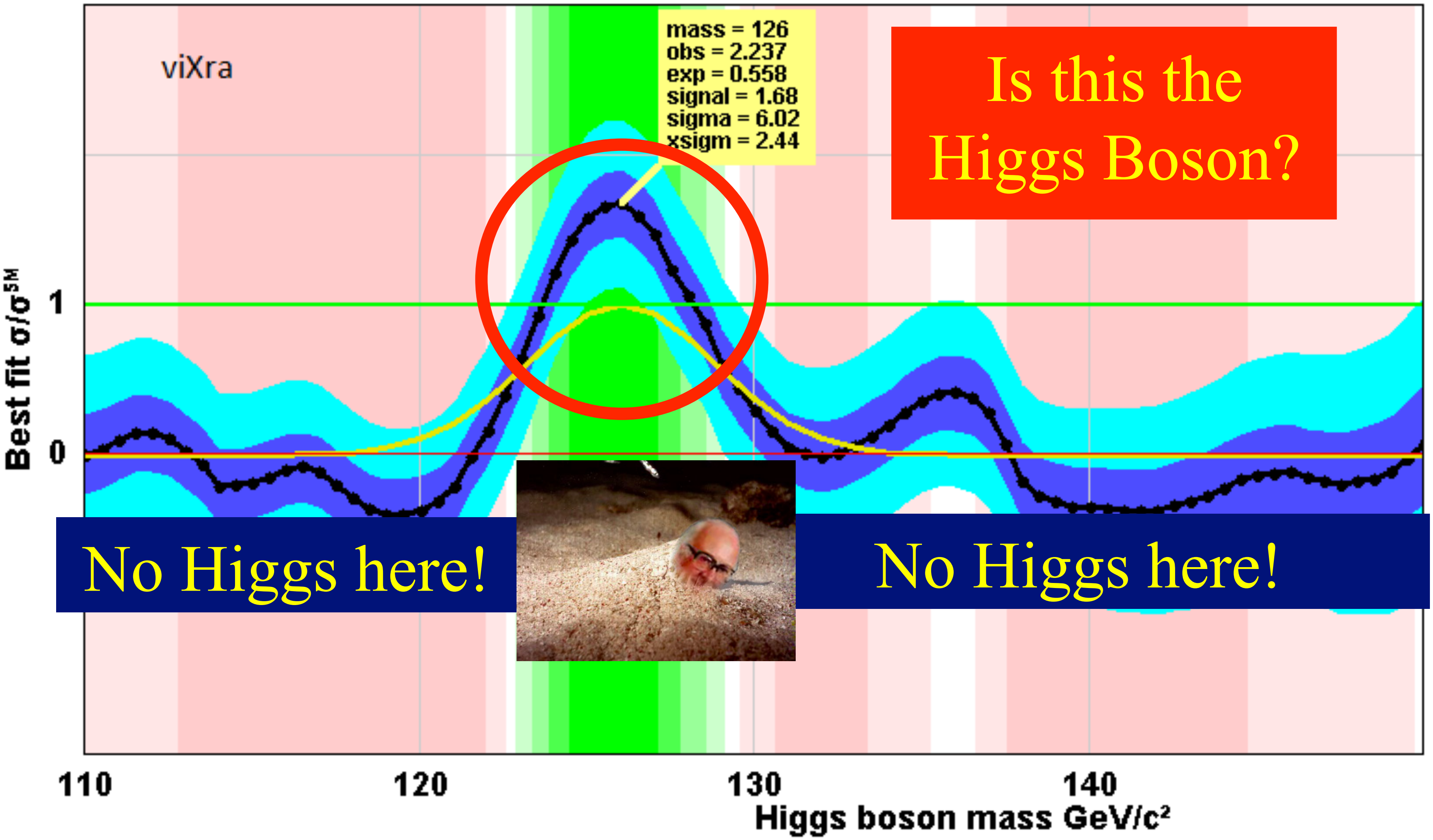
Outlook and Conference Conclusions

The Quest Continues...



The July 4th discovery prompts QUESTIONS:

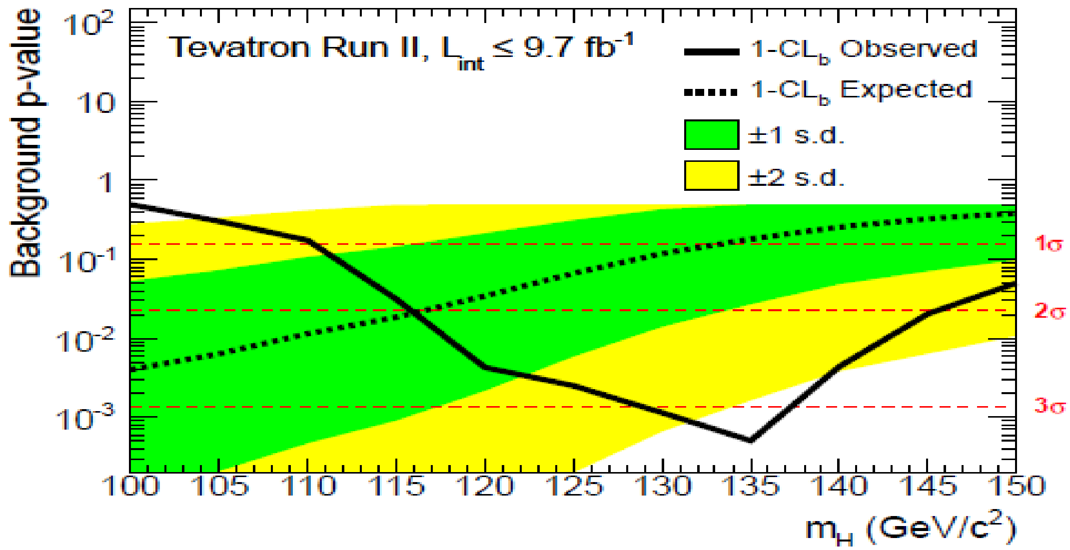
Unofficial Combination of Higgs Search Data from July 4th



Quantifying H→bb Excess:

•Calculating local p-value distribution for background-only hypothesis.

•Local p-value=3.3σ at 135GeV gives global p-value=3.1σ with LEE factor 2.



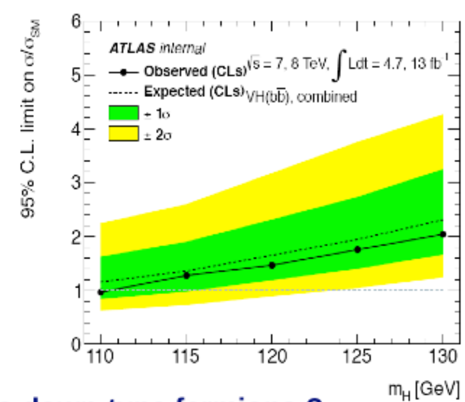
FNAL sees evidence of Higgs in bb;

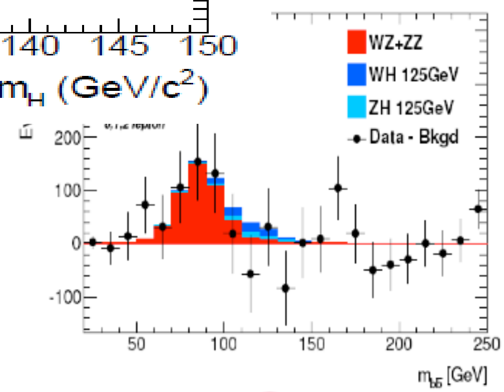
ATLAS sees a bit less than expected in Vbb

Statistical results

A SM Higgs in bbar decay is excluded for 1-2xSM rate.

The fitted signal strength
μ = -0.4±1.0

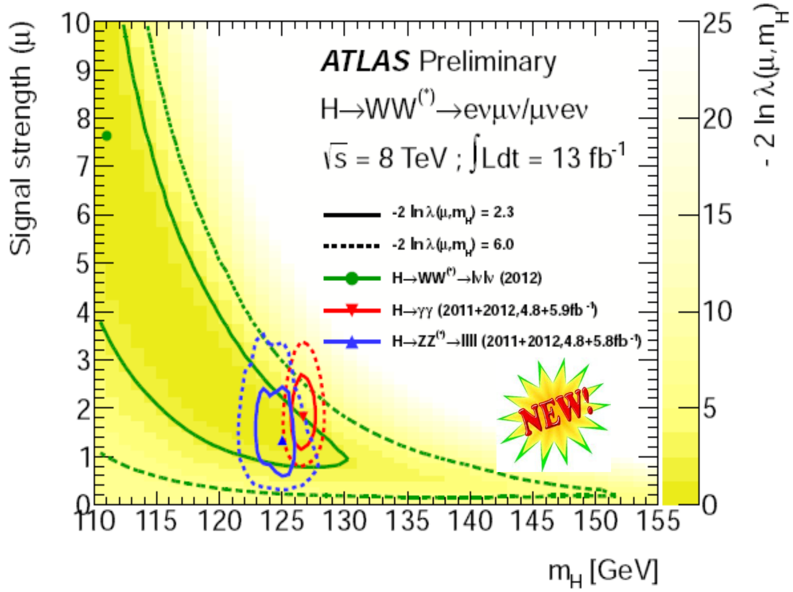


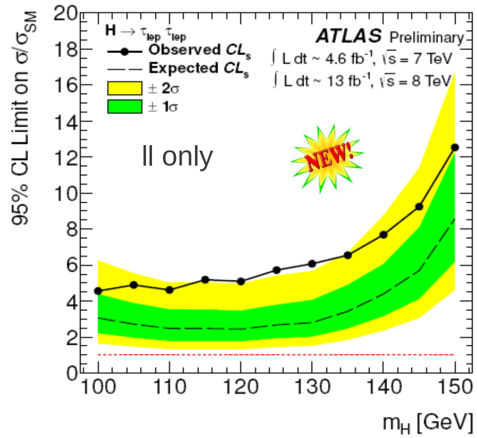


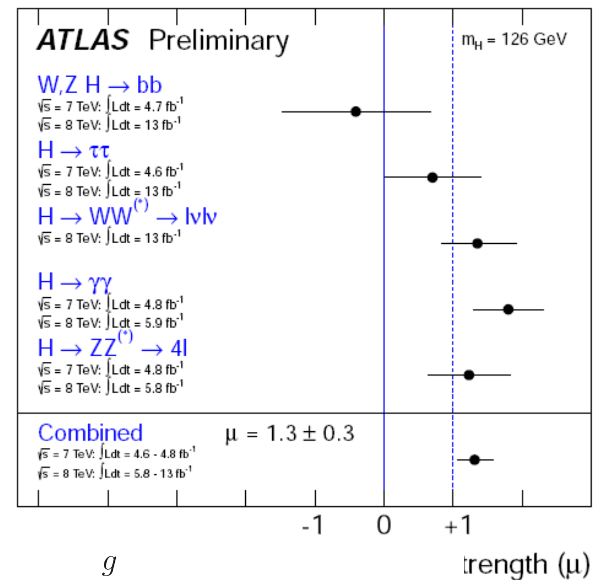
To validate the bbar decays of diboson background, subtract all other background from data except diboson – we have confidence in signal modeling

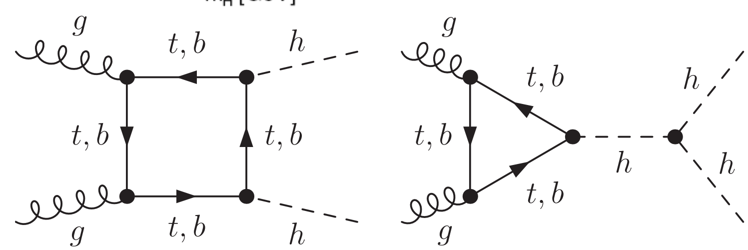
Is H->bb SM-Like?

Does Higgs couple less to down-type fermions ?

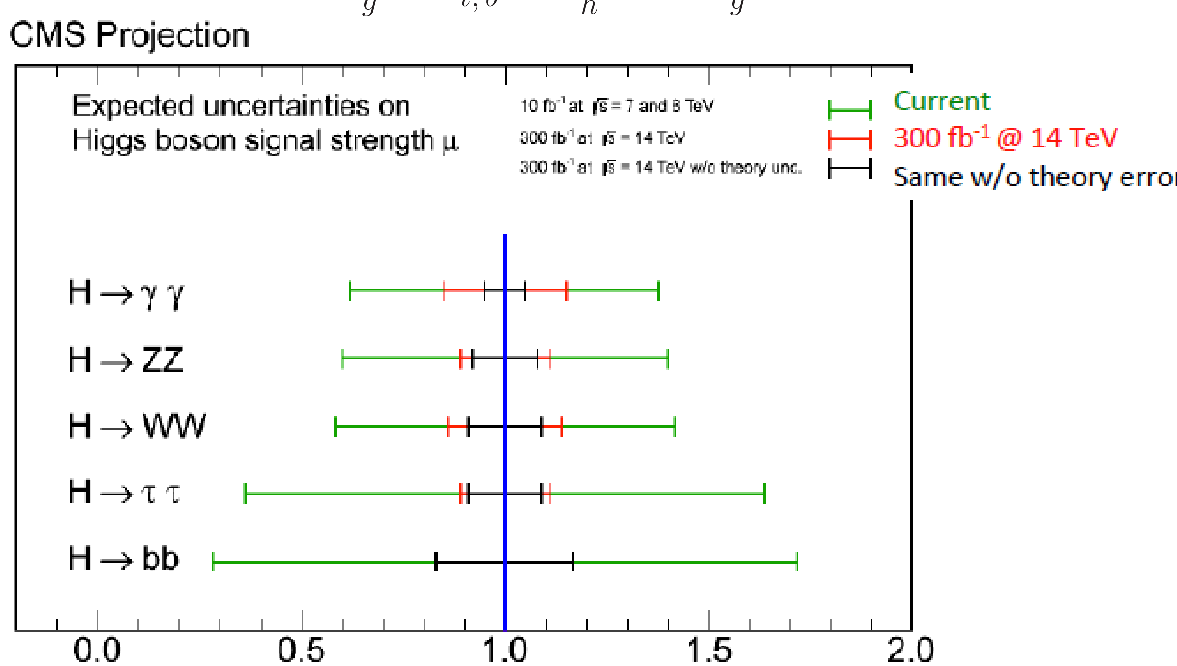








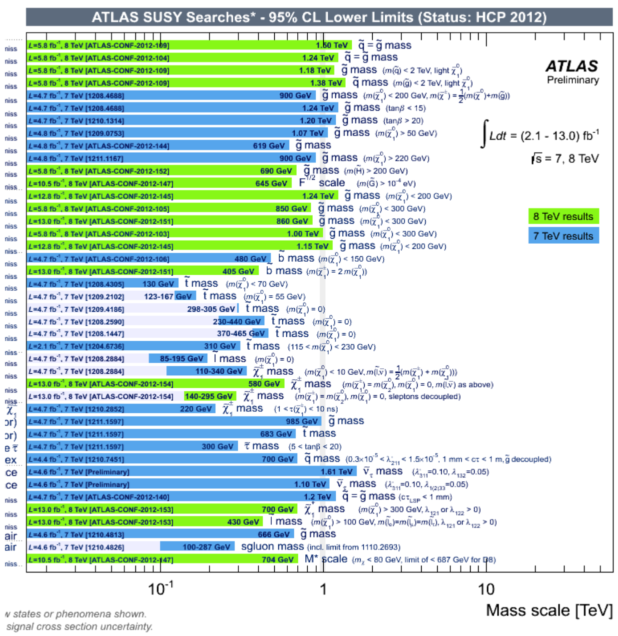
Results rolling in ... what will further precision reveal?



Is the New Boson THE HIGGS Boson?

Symmetry Magazine, Oct 30, 2012

Summary for SUSY NEW!



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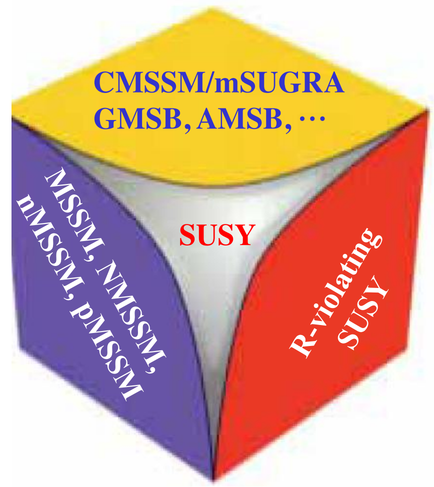
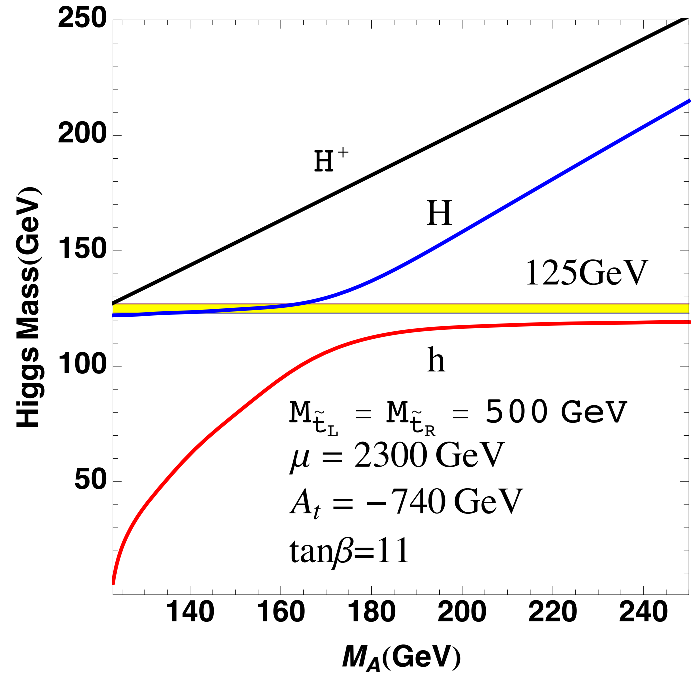
SUSY?





Exploring LHC reach for the electroweak sector of MSSM
gauginos, Higgsinos with the help of the Higgs boson

C.L. & Z.-h. Zhao, arXiv: 1205.3849 (hep-ph)

θ_{13} and m_h from high scale SUSY

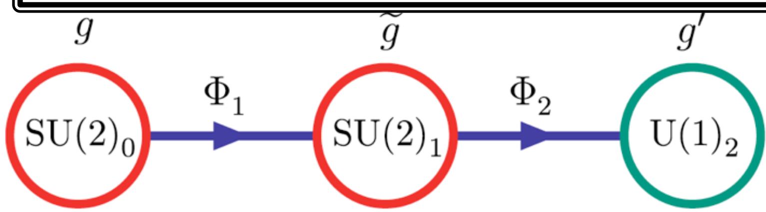
basic idea: SUSY is for fermion mass

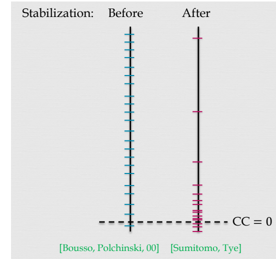
not for gauge hierarchy

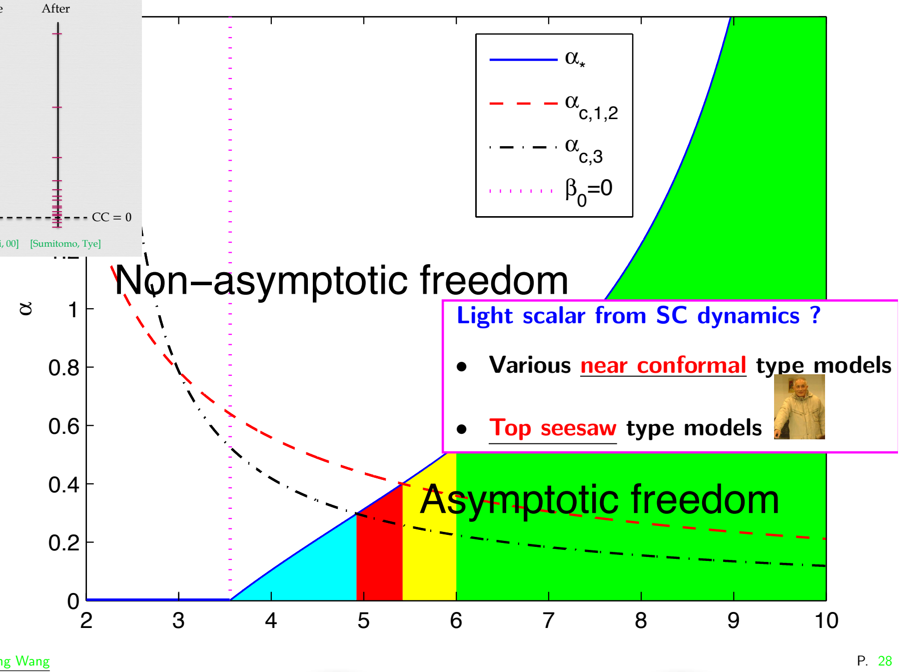
?

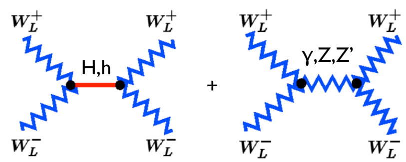
- Now that both Higgs boson mass and spontaneous CPV arise from spontaneous symmetry breaking, is there any connection between spontaneous CPV and the Higgs boson mass?

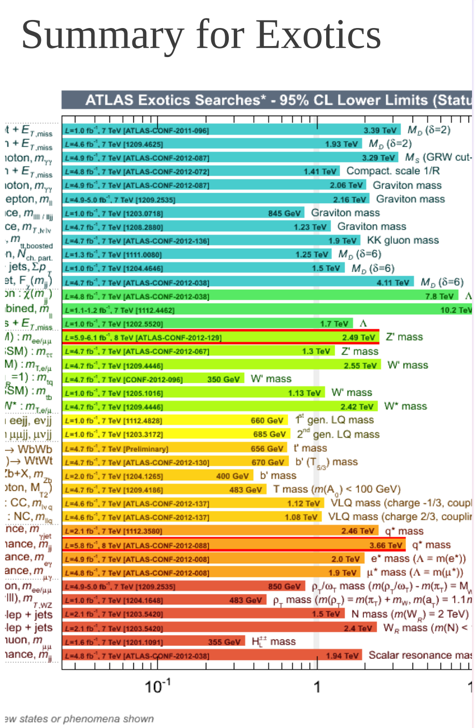
More phenomena to find?

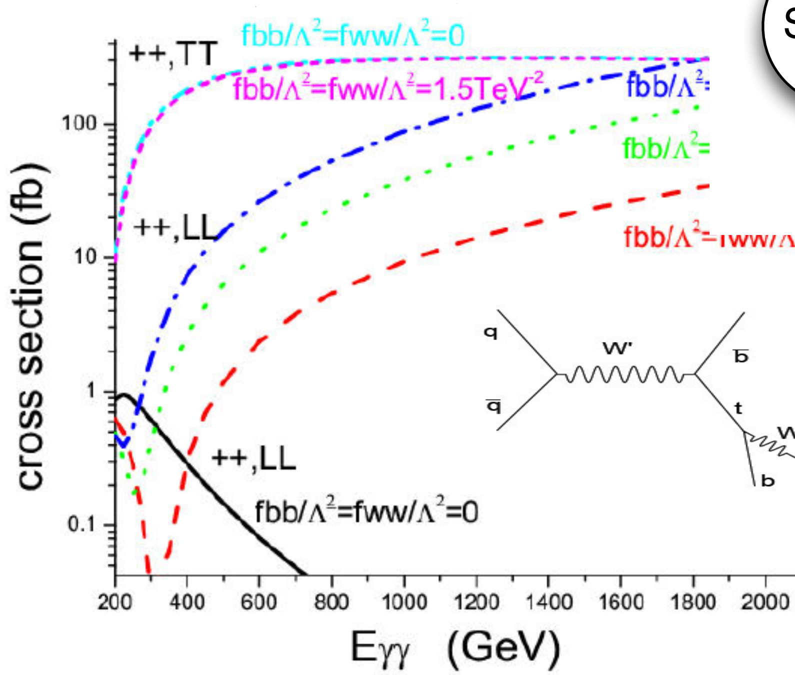


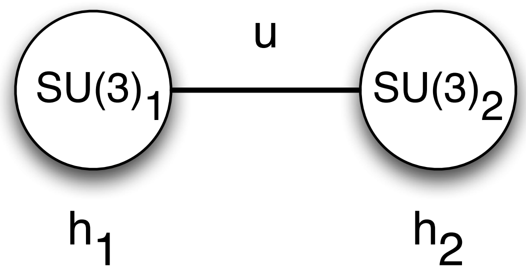


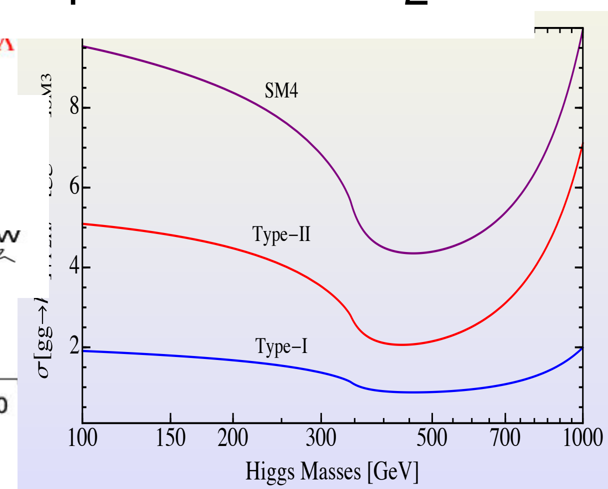






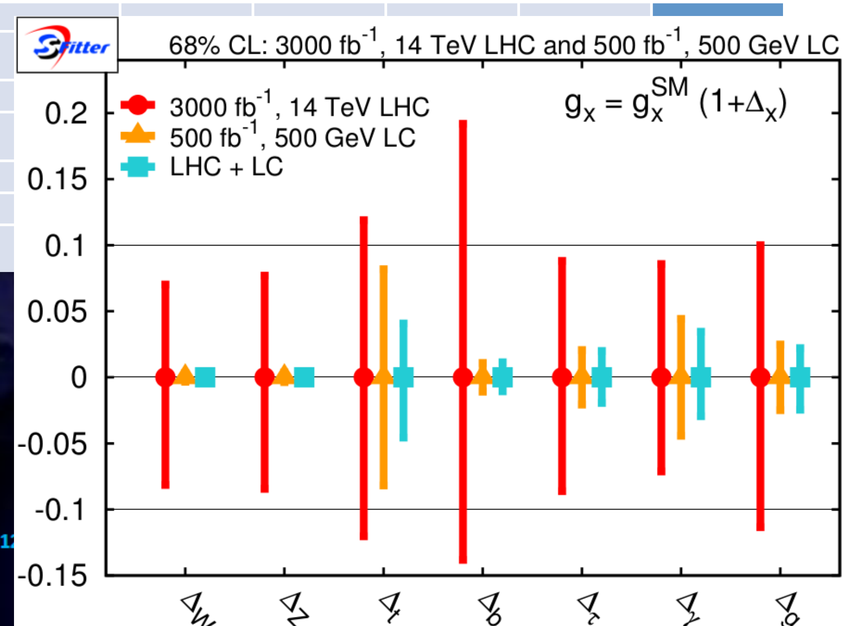




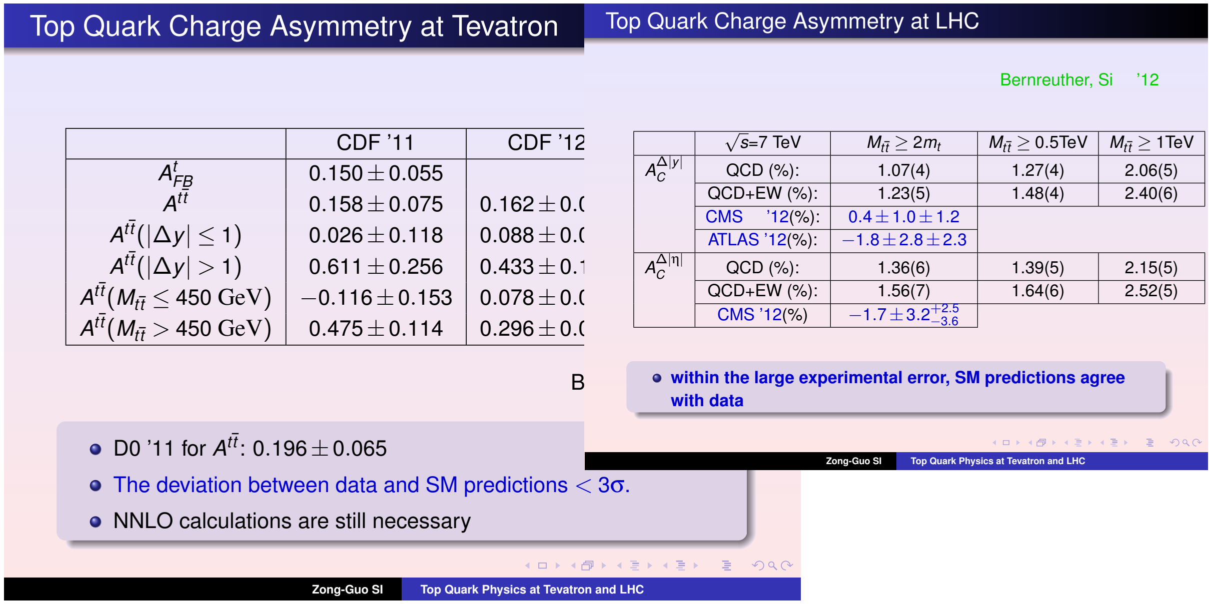


Future Higgs Factories?

	ILC	CLIC	SLC	NLC	LEP3	TLEP	Super-TRISTAN	Fermilab Site-filler	IHEP Ring	LBL/SLAC Ring	Muon Collider	γγ Collider
E_{cm} (GeV)												
L (10^{34} $cm^{-2}s^{-1}$)												
Length (km)												
Bending ρ (km)												
I_{beam} (mA)												
P_{beam} (MW)												
ΔE_{synch} (GeV/turn)												

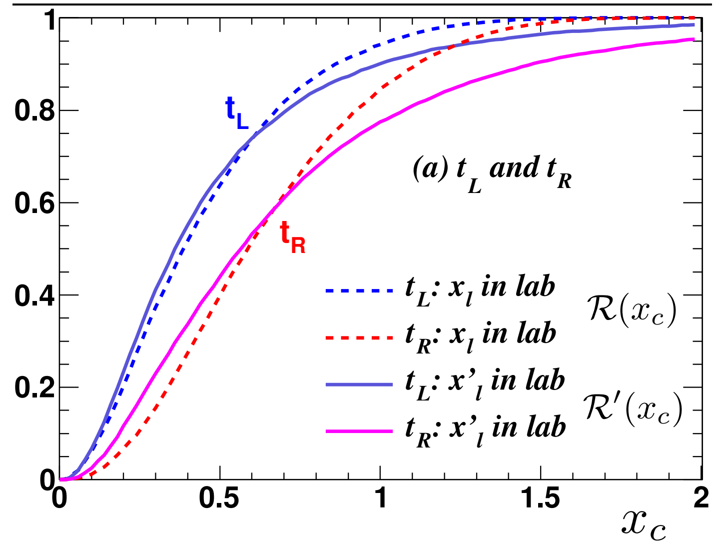


Top still holds mysteries:

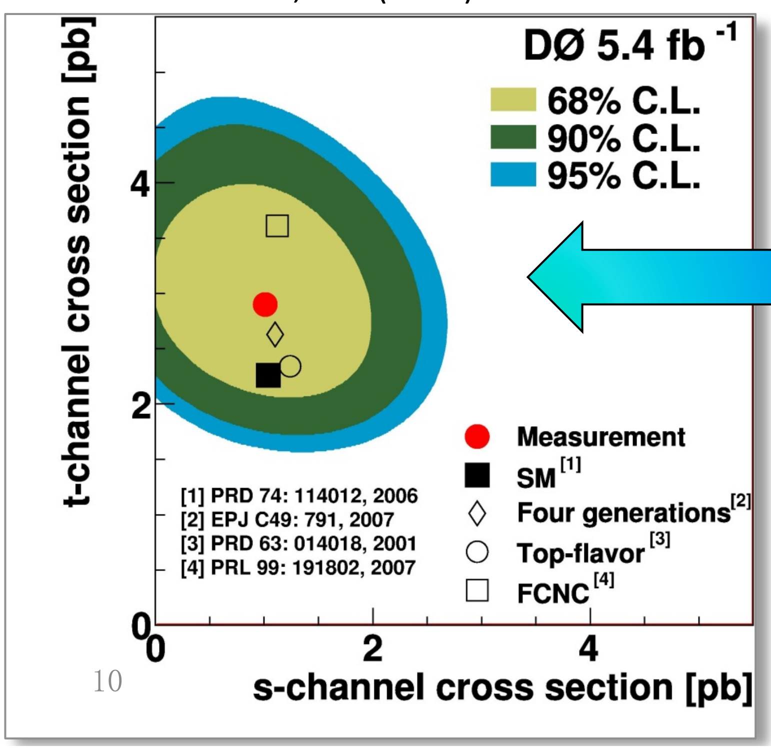


	CDF '11	CDF '12
A^t_{FB}	0.150 ± 0.055	
$A^{t\bar{t}}$	0.158 ± 0.075	$0.162 \pm 0.($
$A^{t\bar{t}}(\lvert\Delta y\rvert \le 1)$	0.026 ± 0.118	$0.088 \pm 0.($
$A^{t\bar{t}}(\lvert\Delta y\rvert > 1)$	0.611 ± 0.256	0.433 ± 0.1
$A^{t\bar{t}}(M_{t\bar{t}} \le 450\ \mathrm{GeV})$	-0.116 ± 0.153	$0.078 \pm 0.($
$A^{t\bar{t}}(M_{t\bar{t}} > 450\ \mathrm{GeV})$	0.475 ± 0.114	$0.296 \pm 0.($

	$\sqrt{s}$=7 TeV	$M_{t\bar{t}} \ge 2m_t$	$M_{t\bar{t}} \ge 0.5$TeV	$M_{t\bar{t}} \ge 1$TeV
$A_C^{\Delta\lvert y\rvert}$	QCD (%):	1.07(4)	1.27(4)	2.06(5)
	QCD+EW (%):	1.23(5)	1.48(4)	2.40(6)
	CMS '12(%):	$0.4 \pm 1.0 \pm 1.2$		
	ATLAS '12(%):	$-1.8 \pm 2.8 \pm 2.3$		
$A_C^{\Delta\lvert\eta\rvert}$	QCD (%):	1.36(6)	1.39(5)	2.15(5)
	QCD+EW (%):	1.56(7)	1.64(6)	2.52(5)
	CMS '12(%)	$-1.7 \pm 3.2^{+2.5}_{-3.6}$		

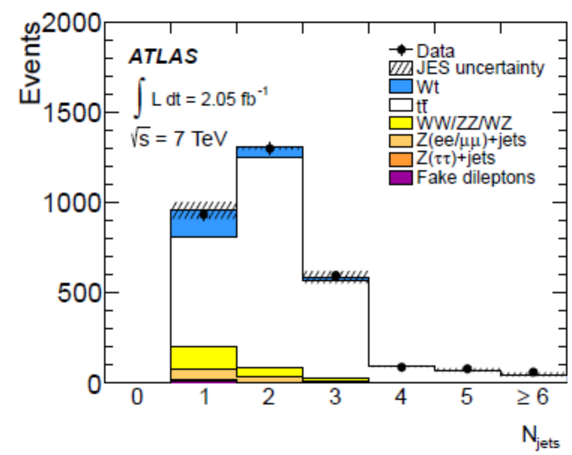


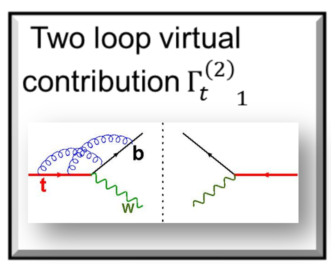
PLB 705 , 313 (2011)

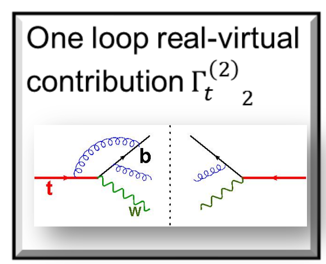


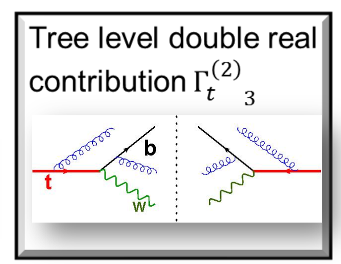
Single Top Quark Cross Section

Sensitivity to new physics!



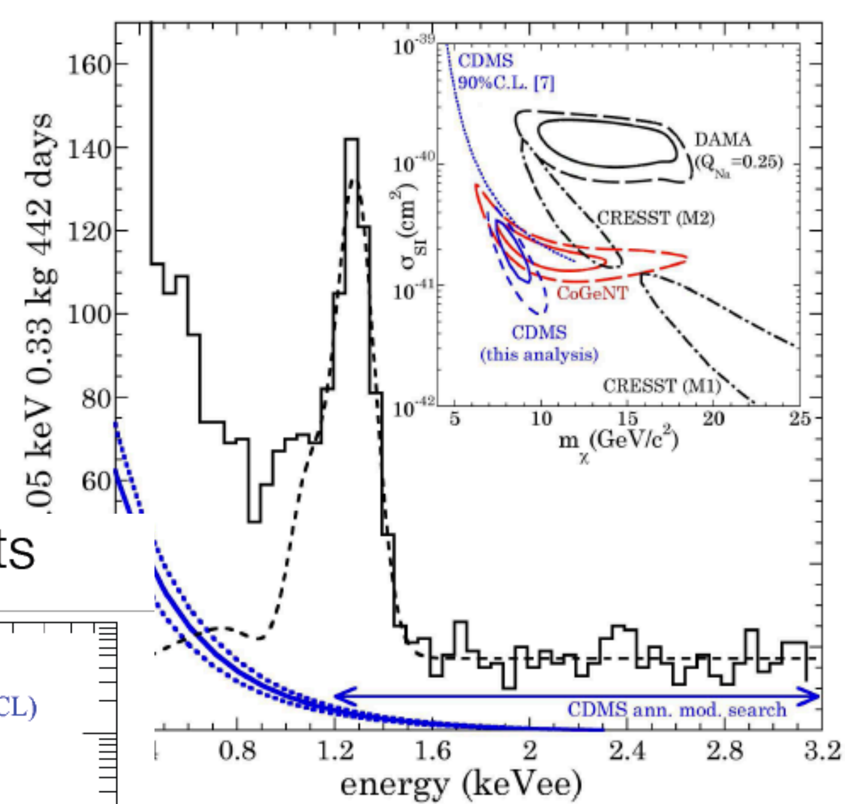




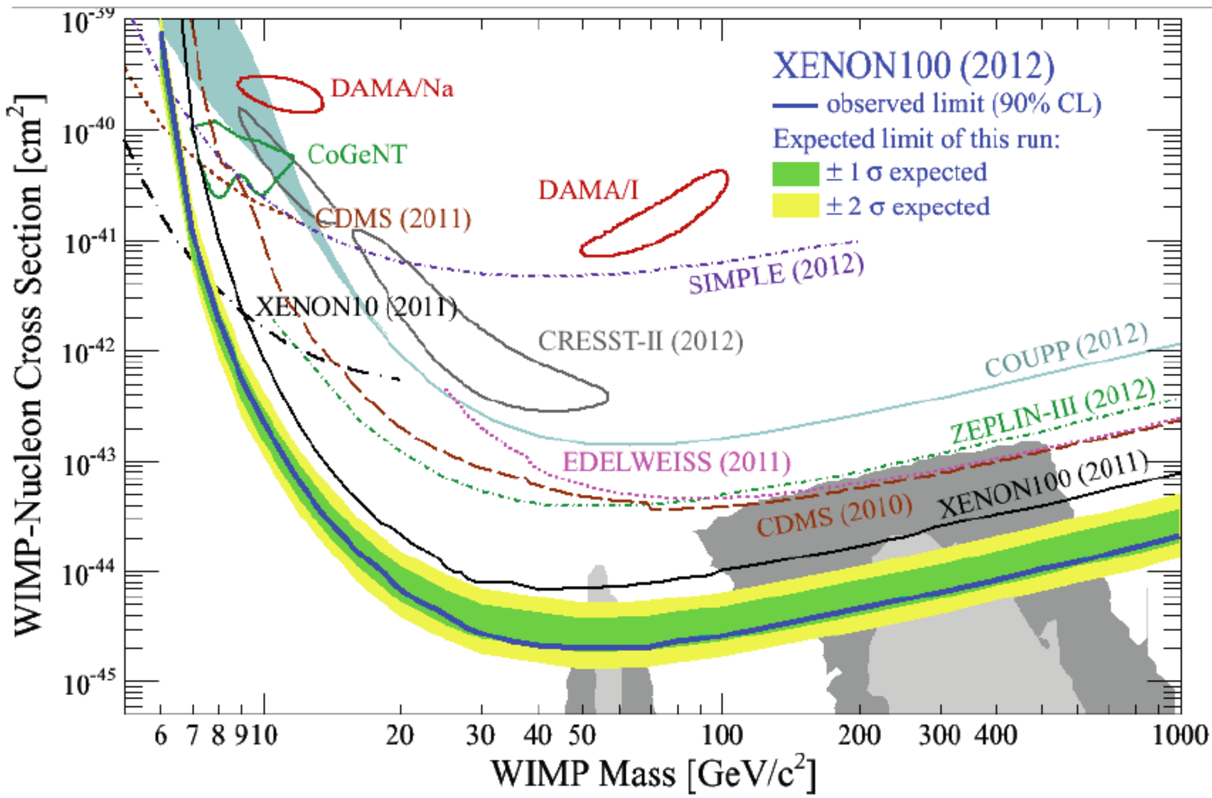


DM data exhibits tension

Xenon100
vs
DAMA, CoGeNT,
CRESST, CDMS

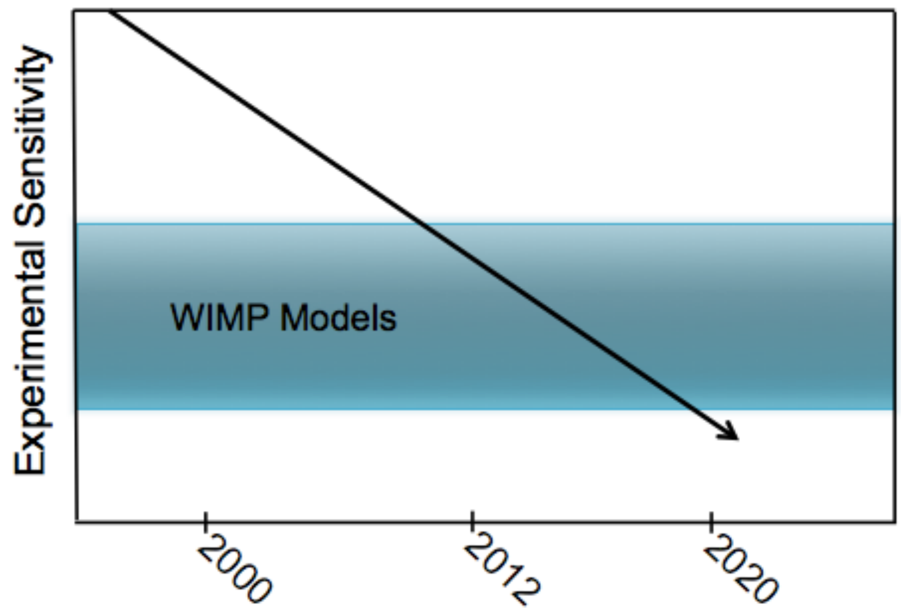


XENON100: New Spin-Independent Results



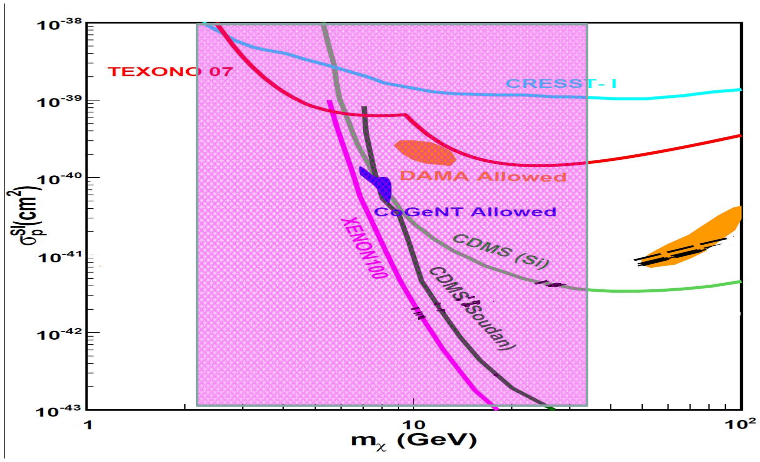
Upper Limit (90% C.L.) is 2 x 10^{-45} cm^2 for 55 GeV/c^2 WIMP

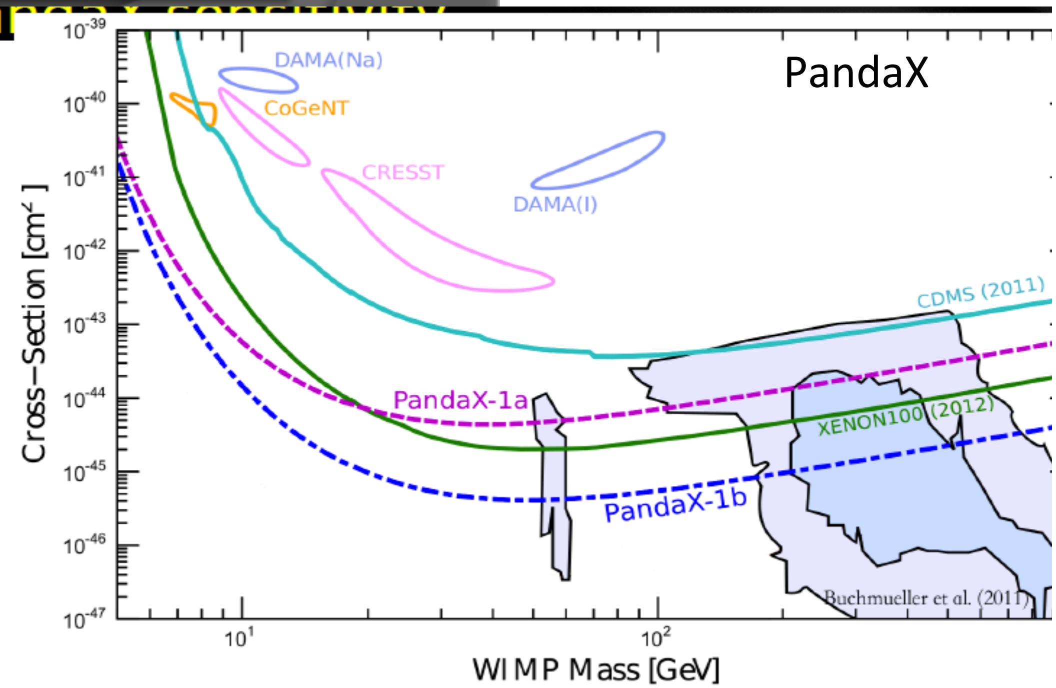
If DAMA,
CoGeNT,
CRESST,
CDMS
agree...on
what?



Will direct detection eliminate all WIMPS?

CDEX physics goals



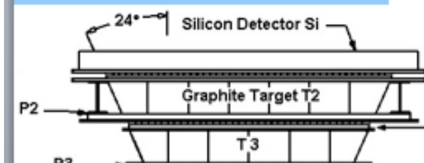


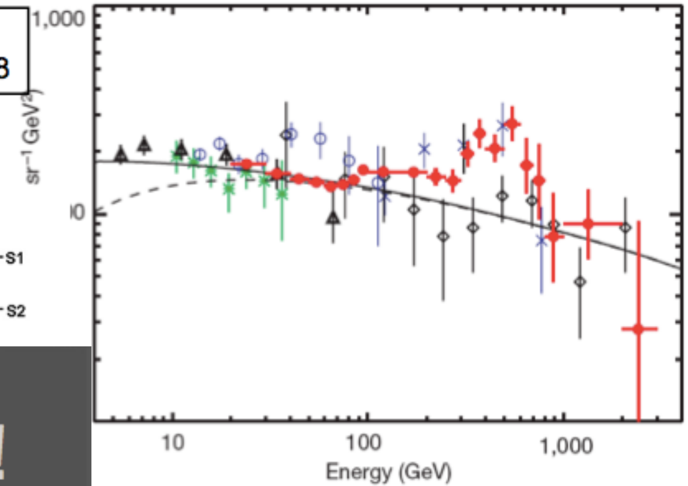
CJPL

Real?

Bump at the electron/positron spectrum

Chang et al.
Nature456, 362 2008

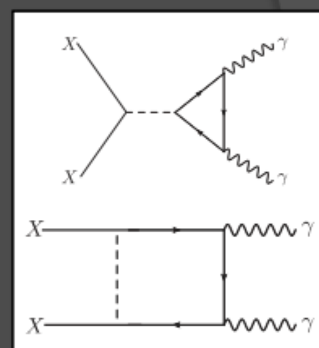


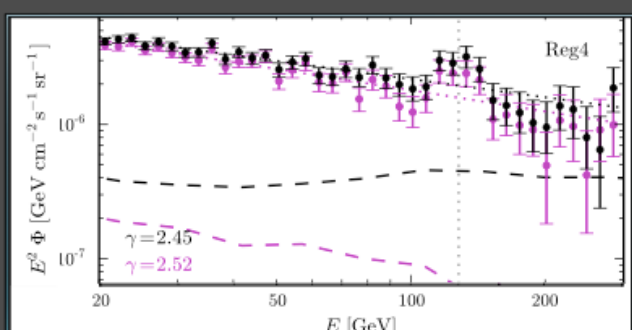


TIC results showing agreement with previous data at lower
with the imaging calorimeter PPB-BETS at higher energy. The
rential energy spectrum measured by ATIC (scaled by E^3) at the
mosphere (red filled circles) is compared with previous
from the Alpha Magnetic Spectrometer AMS (green stars)[31],
black triangles)[30], BETS (open blue circles)[32], PPB-BETS (blue
d emulsion chambers (black open diamonds)[4,8,9], with one
ainties. The GALPROP code calculates a power-law spectral

A Gamma-Ray Line at 130 GeV?!

- Recently, evidence for a monoenergetic (up to resolution) gamma-ray line from the Inner Galaxy has been identified within Fermi's data (at 3.3σ, after LEE)
- Such a single has long been considered a "smoking gun" of dark matter annihilations, provided through loop-level diagrams
- Morphology of the signal is well fit to a that predicted from a cusped dark matter distribution, with a cross section of σv ~ 2 x 10^{-27} cm^3/s



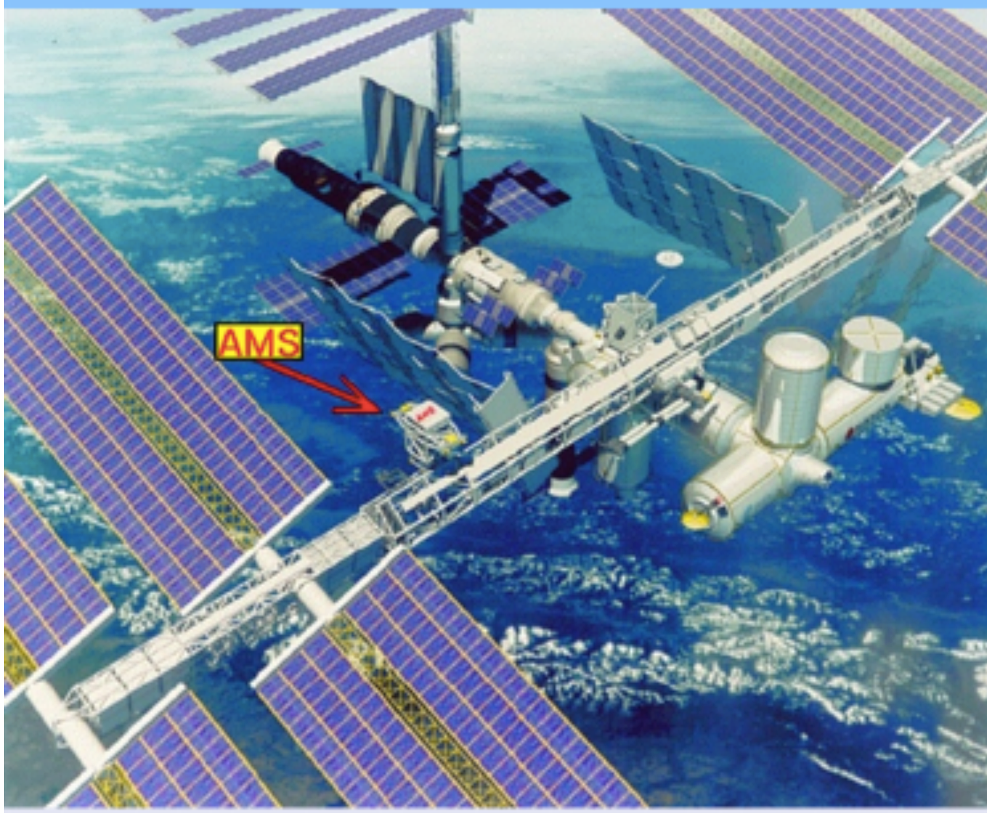


C. Weniger, arXiv:1204.2797

But is it real?

If so,
what do
they
imply?

AMS02



Y.P. Kuang's contribution to BES: heavy quarkonium transitions and decays:

(1) Hadronic transition – QCD multipole expansion
(2) Coupled channel effect
(3) 2S-1D mixing for $\psi(3770)$ –non-DDbar decays
(4) improved potential model for charmonium decays

- In fact, Prof. Kuang is the main player in early days of BES for charmonium physics
- Theoretical support for the study at BES on charmonium transitions
- BESIII yellow book on hadronic transitions of charmonium
- Proposed the study of $\chi_{c1} \rightarrow \eta_c \pi\pi$ at BESIII
- Many other suggestions to BESIII…

Not in question: Prof. Kuang's impact

MSU, Tsinghua, and Prof. Kuang

- C.-P. Yuan met Prof. Kuang at CCAST Workshop, Beijing in 1993.
- E. Simmons invited by Prof. Kuang to speak at ITP in Beijing in 1995.
- NSF USA-China International Program, Qing Wang and Yi Liao visited MSU, Carl Schmidt visited Tsinghua U, 1997-99.
- Hong-Jian He was a postdoc at MSU, 1997-2000.
- Chivukula, Dicus, & He on unitarity, 2001.
- Kuang et. al., LHC signature paper 2007...

PHYSICAL REVIEW D **85**, 114010 (2012)

Testing the anomalous color-electric dipole moment of the c quark from $\psi' \to J/\psi + \pi^+ + \pi^-$ at the Beijing Spectrometer

Yu-Ping Kuang,[1,*] Jian-Ping Ma,[2,†] Otto Nachtmann,[3,‡] Wan-Peng Xie,[1,§] and Hui-Huo Zheng[1,4,∥]
[1]Center for High Energy Physics and Department of Physics, Tsinghua University, Beijing, 100084, China
[2]Institute of Theoretical Physics, Academia Sinica, Beijing, 100190, China
[3]Institut für Theoretische Physik, Philosophenweg 16, 69120, Heidelberg, Germany
[4]Department of Physics, University of Illinois at Urbana-Champaign, 1110 West Green Street, Urbana, Illinois 61801-3080, USA

清華大學 Tsinghua University

7th Workshop on TeV Physics–In honor of Prof Yu-Ping Kuan

PHYSICAL REVIEW D, VOLUME 61, 054011

Derivation of the effective chiral Lagrangian for pseudoscalar mesons from QCD

Qing Wang,[1,2] Yu-Ping Kuang,[2,1] Xue-Lei Wang,[1,3] and Ming Xiao[1]
[1]Department of Physics, Tsinghua University, Beijing 100084, China*
[2]China Center of Advanced Science and Technology (World Laboratory), P.O. Box 8730, Beijing 100080, China
[3]Department of Physics, Henan Normal University, Xinxiang 453002, China

清華大學 Tsinghua University

7th Workshop on TeV Physics–In honor of Prof Yu-Ping Kuang

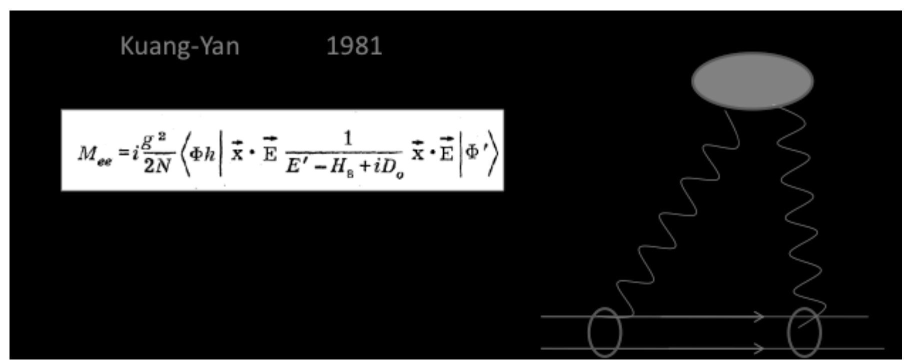
PHYSICAL REVIEW D **66**, 014019 (2002)

Calculation of the chiral Lagrangian coefficients from the underlying theory of QCD: A simple approach

Hua Yang,[2,4] Qing Wang,[1,2,3] Yu-Ping Kuang,[1,2,3] and Qin Lu[2]
[1]CCAST (World Laboratory), P.O. Box 8730, Beijing 100080, China
[2]Department of Physics, Tsinghua University, Beijing 100084, China*
[3]Institute of Theoretical Physics, Academia Sinica, Beijing 100080, China
[4]Institute of Electronic Technology, Information Engineering University, Zhengzhou 450004, Henan, China

Sensitivity to measure the anomalous gauge couplings of the Higgs boson via W^+W^+ scattering at the CERN LHC

Inspired by Prof. Kuang (邝宇平院士)



Prof. Kuang is co-author of the ILC TDRs

2006 Yunjin Temple

I am very proud of being a student of Prof. Kuang !

Happy Birthday !

Happy birthday,
Prof. Kuang.
I learned a lot from you since 1986.
Thanks

生日快乐!

Monday, November 12, 12

Happy 80th Birthday to Prof. Kuang!

This workshop's questions are a birthday present for you!

Figure 1: Ithaca 1980, Niagara Falls

Happy Birthday to
Professor Kuang !

恭贺邝宇平院士八十华诞

Happy Birthday, Professor Kuang!