### BSM THEORY OVERVIEW

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# BSM THEORY OVERVIEW ()RIMPLICATIONS OF THE LHC DATA FOR EXTENSIONS OF THE STANDARD MODEL

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Lots of models out there...

### OVERVIEW

ATLAS SUSY Searches\* - 95% CL Lower Limits (Status: March 2012)

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	MSUGRA/CMSSM : 0-lep + j's + E <sub>T,miss</sub>	L=4.7 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-033]	1.40 TeV q = g mass			
clusive searches	MSUGRA/CMSSM : 1-lep + j's + E <sub>T,miss</sub>	L=4.7 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-041]	1.20 TeV q = g mass	$\int Ldt = (0.03 - 4.7) \text{ fb}^{-1}$		
	MSUGRA/CMSSM : multijets + E <sub>T,miss</sub>	L=4.7 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-037]	850 Gev g mass (large m <sub>0</sub> )	(s = 7 TeV		
	Pheno model : 0-lep + j's + E <sub>T,miss</sub>	L=4.7 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-033]	1.38 TeV q̃ mass (m(g̃) < 2 TeV	(, light $\overline{\chi}_1^0$ ) ATLAS		
	Pheno model : 0-lep + j's + E <sub>T.miss</sub>	L=4.7 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-033]	940 GeV $\tilde{g}$ mass $(m(\tilde{q}) < 2 \text{ TeV}, \text{ ligh})$	t $\bar{\chi}_1^0$ Preliminary		
	Gluino med. $\tilde{\chi}^{\pm}$ ( $\tilde{g} \rightarrow q \bar{q} \tilde{\chi}^{\pm}$ ) : 1-lep + j's + $E_{T,miss}$	L=4.7 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-041]	<b>300 GeV</b> g̃ mass ( <i>m</i> (χ̃ <sup>0</sup> <sub>1</sub> ) < 200 GeV, <i>i</i>	$m(\bar{\chi}^{\pm}) = \frac{1}{2}(m(\bar{\chi}^{0}) + m(\tilde{g}))$		
	GMSB : 2-lep OS <sub>SF</sub> + E <sub>T,miss</sub>	L=1.0 fb <sup>-1</sup> (2011) [ATLAS-CONF-2011-156]	<b>810 GeV</b> g mass (tanβ < 35)	2		
5	GMSB : $1-\tau + j's + E_{T,miss}$	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-005]	920 GeV g̃ mass (tanβ > 20)			
	GMSB : $2-\tau + j's + E_{T,miss}$	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-002]	990 Gev g mass (tanβ > 20)			
	$GGM:\gamma\gamma + E_{T,miss}$	L=1.1 fb <sup>-1</sup> (2011) [1111.4116]	<b>805 GeV</b> $\tilde{g}$ mass $(m(\tilde{\chi}^0) > 50 \text{ GeV})$			
	Gluino med. $\tilde{b}$ ( $\tilde{g} \rightarrow b \bar{b} \chi^0$ ) : 0-lep + b-j's + $E_{T,miss}$	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-003]	soo GeV $\tilde{g}$ mass $(m(\tilde{\chi}_{\star}^{0}) < 300 \text{ GeV})$			
tion	Gluino med. $\tilde{t}$ ( $\tilde{g} \rightarrow t \tilde{t} \chi^0$ ) : 1-lep + b-j's + $E_{T miss}$	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-003]	710 GeV g mass (m(x <sup>0</sup> ) < 150 GeV)			
nera	Gluino med. $\tilde{t}$ ( $\tilde{g} \rightarrow t\bar{t}\chi^0$ ): 2-lep (SS) + j's + $E_{T,miss}$	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-004]	650 GeV g̃ mass (m(χ̃, ) < 210 GeV)			
hird ger	Gluino med. $\tilde{t}$ ( $\tilde{g} \rightarrow t \bar{t} \chi^0$ ) : multi-j's + $E_{T miss}$	L=4.7 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-037]	<b>830 GeV</b> $\tilde{g}$ mass $(m(\bar{\chi}_{*}^{0}) < 200 \text{ GeV})$			
	Direct $\tilde{b}\tilde{b}$ ( $\tilde{b}_{,} \rightarrow b\bar{\chi}^{0}$ ) : 2 b-jets + $E_{T}$ miss	L=2.1 fb <sup>-1</sup> (2011) [1112.3832]	<b>390 GeV</b> $\tilde{b}$ mass $(m(\tilde{\chi}_{-}^{0}) < 60 \text{ GeV})$			
1	Direct tt (GMSB) : Z(→II) + b-jet + E	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-036]	310 GeV T mass (115 < m(x)) < 230 GeV)			
(2)	Direct gaugino $(\tilde{\chi}^{\pm}_{\tau}\tilde{\chi}^{0}_{-} \rightarrow 3   \tilde{\chi}^{0}_{-})$ : 2-lep SS + $E_{T miss}$	L=1.0 fo <sup>-1</sup> (2011) [1110.6189] 170 GeV	$\bar{\chi}_{+}^{\pm}$ mass (( $m(\bar{\chi}_{+}^{0}) < 40$ GeV, $\bar{\chi}_{+}^{0}, m(\bar{\chi}_{+}^{\pm}) = m(\bar{\chi}_{-}^{0}), m(\bar{\mu}_{+})$	$\bar{v}$ ) = $\frac{1}{2}(m(\bar{\chi}_{*}^{0}) + m(\bar{\chi}_{*}^{0})))$		
ă	Direct gaugino $(\tilde{\chi}_{\tau}^{\pm}\tilde{\chi}_{\tau}^{0} \rightarrow 3I \tilde{\chi}_{\tau}^{0})$ : 3-lep + $E_{\tau miss}$	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-023] 2	50 GeV $\overline{\chi}_{\star}^{\pm}$ mass $(m(\overline{\chi}_{\star}^{0}) < 170$ GeV, and as above)	2		
ŝ	AMSB : long-lived $\bar{\chi}^{\pm}_{*}$	L=4.7 fb <sup>-1</sup> (2011) [CF-2012-034]	mass $(1 < \tau(\bar{\chi}_{*}^{\pm}) < 2 \text{ ns}, 90 \text{ GeV limit in } [0.2,90] \text{ ns})$			
ticle	Stable massive particles (SMP) : R-hadrons	L=34 pb <sup>-1</sup> (2010) [1103.1984]	562 GeV g mass			
lag	SMP : R-hadrons	L=34 pb <sup>-1</sup> (2010) [1103.1984]	294 GoV b mass			
ived	SMP : R-hadrons	L=34 pb <sup>-1</sup> (2010) [1103.1984]	309 Gev t mass			
l-gr	SMP : R-hadrons (Pixel det. only)	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-022]	810 GeV g mass			
L0	GMSB : stable ₹	L=37 pb <sup>-1</sup> (2010) [1106.4495] 136 GeV	t mass			
	RPV : high-mass eµ	L=1.1 fb <sup>-1</sup> (2011) [1109.3089]	1.32 TeV V, mass (λ'1++=0.10, λ.	=0.05)		
2PV	Bilinear RPV : 1-lep + j's + ET, miss	L=1.0 fb <sup>-1</sup> (2011) [1109.6606]	760 Gev q = g mass (cτ <sub>1 cp</sub> < 15 mm)			
U,	MSUGRA/CMSSM - BC1 RPV : 4-lepton + ET,miss	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-035]	1.77 TeV g mass			
	Hypercolour scalar gluons : 4 jets, m <sub>i</sub> ≈ m <sub>kl</sub>	L=34 pb <sup>-1</sup> (2010) [1110 2693] 185 Ge	sgluon mass (excl: $m_{aa} < 100$ GeV, $m_{aa} \simeq 140 \pm 3$	3 GeV)		
		10 <sup>-1</sup>	1	10		
Mass scale [TeV]						

\*Only a selection of the available mass limits on new states or phenomena shown

No evidence for SUSY

### OVERVIEW

ATLAS Exotics Searches\* - 95% CL Lower Limits (Status: March 2012)

	Large ED (ADD) : monojet	L=1.0 fb <sup>-1</sup> (2011) [ATLAS-CONF-2011-096]	3.2 TeV M <sub>Ω</sub> (δ=2)	
	Large ED (ADD) : diphoton	L=2.1 fb <sup>-1</sup> (2011) [1112.2194]	3.0 TeV M <sub>S</sub> (GRW cut-	
10	$UED: \gamma\gamma + E_{\tau}$	L=1.1 fb <sup>-1</sup> (2011) [1111.4116]	1.23 TeV Compact. scale 1/R (SPS8	) Preliminary
ons	RS with $k/M_{pl} = 0.1$ : diphoton, $m_{rr}$	L=2.1 fb <sup>-1</sup> (2011) [1112.2194]	1.85 TeV Graviton mass	, , , , , , , , , , , , , , , , , , , ,
nsi	RS with $k/M_{Pl} = 0.1$ : dilepton, $m_{ll}$	L=4.9-5.0 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-007]	2.16 TeV Graviton mass	for more and
BUU	RS with k/M <sub>PI</sub> = 0.1 : ZZ resonance, m <sub>III / III</sub>	L=1.0 fb <sup>-1</sup> (2011) (1203.0718)	845 Gev Graviton mass	$Ldt = (0.04 - 5.0) \text{ fb}^{-1}$
i o	RS with $g /g = -0.20$ : $t\bar{t} \rightarrow l+jets, m$	L=2.1 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-029]	1.03 TeV KK gluon mass	s = 7 TeV
xtr	ADD BH $(M_{TH}^{gggs}M_{D}^{s}=3)$ : multijet, $\Sigma p_{\tau}$ , $N_{iets}^{tt}$	L=35 pb <sup>-1</sup> (2010) [ATLAS-CONF-2011-068]	1.37 TeV M <sub>D</sub> (δ=6)	
ш	ADD BH (M <sub>TH</sub> /M <sub>D</sub> =3) : SS dimuon, N <sub>ch. part.</sub>	L=1.3 fb <sup>-1</sup> (2011) [1111.0080]	1.25 TeV M <sub>D</sub> (δ=6)	
	ADD BH $(M_{TH}/M_{D}=3)$ : leptons + jets, $\Sigma p_{T}$	L=1.0 fb <sup>-1</sup> (2011) [ATLAS-CONF-2011-147]	1.5 TeV M <sub>D</sub> (δ=6)	
	Quantum black hole : dijet, $F_{y}(m_{j})$	L=4.7 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-038]	4.11 TeV M <sub>D</sub> (δ=6)	
	qqqq contact interaction : χ(m)	L=4.8 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-038]	7.8 TeV A	
5	qqll Cl : ee, μμ combined, m	L=1.1-1.2 fb <sup>-1</sup> (2011) [1112.4462]	10.2 TeV	A (constructive int.)
	uutt CI : SS dilepton + jets + E <sub>T,miss</sub>	L=1.0 fb <sup>-1</sup> (2011) [1202.5520]	1.7 TeV A	
٤	SSM Z' : m	L=4.9-5.0 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-007]	2.21 TeV Z' mass	
2	SSM W': m <sub>T.e/µ</sub>	L=1.0 fb <sup>-1</sup> (2011) [1108.1316]	2.15 TeV W' mass	
a	Scalar LQ pairs (β=1) : kin. vars. in eejj, evjj	L=1.0 fb <sup>-*</sup> (2011) [1112.4828]	660 GeV 1 <sup>st</sup> gen. LQ mass	
-	Scalar LQ pairs (β=1) : kin. vars. in μμjj, μvjj	L=1.0 fb <sup>-*</sup> (2011) [Preliminary]	685 Gev 2 <sup>nd</sup> gen. LQ mass	
92	$4^{th}$ generation : $Q_1 \overline{Q}_4 \rightarrow WqWq$	L=1.0 fb <sup>-*</sup> (2011) [1202.3389] 350 GeV	Q <sub>4</sub> mass	
ALC: N	4 <sup>th</sup> generation : u₁ u₄→ WbWb	L=1.0 fb <sup>-*</sup> (2011) [1202.3076] 404 G	ev u <sub>4</sub> mass	
nb	$4^{th}$ generation : $d_1 d_4 \rightarrow WtWt$	L=1.0 fb <sup>-*</sup> (2011) [Preliminary] 48	gev d <sub>4</sub> mass	
θM	New quark b' : b' $\overline{b}' \rightarrow Zb+X, m_{Tb}$	L=2.0 fb <sup>-*</sup> (2011) [Preliminary] 400 G	ev b' mass	
<	$T\overline{T}_{axc, 4th, eec} \rightarrow t\overline{t} + A_0A_0$ : 1-lep + jets + $E_{T, miss}$	L=1.0 fb <sup>-1</sup> (2011) [1109.4725] 420 0	T mass (m(A <sub>n</sub> ) < 140 GeV)	
E.	Excited quarks : y-jet resonance, m	L=2.1 fb <sup>-1</sup> (2011) [1112.3580]	2.46 TeV q* mass	
fol	Excited quarks : dijet resonance, m	L=4.8 fb <sup>-*</sup> (2011) [ATLAS-CONF-2012-038]	3.35 TeV q* mass	
(cit.	Excited electron : e-y resonance, m	L=4.9 fb" (2011) [ATLAS-CONF-2012-023]	2.0 TeV e* mass (Λ = m(e*))	
ŵ	Excited muon : µ-y resonance, m	L=4.8 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-023]	1.9 TeV μ* mass (Λ = m(μ*))	
	Techni-hadrons : dilepton, m <sub>eeluu</sub>	L=1.1-1.2 B" (2011) [ATLAS-CONF-2011-125] 470	GeV $\rho_{T}/\omega_{T}$ mass $(m(\rho_{T}/\omega_{T}) - m(\pi_{T}) = 100 \text{ GeV}$	V)
	Techni-hadrons : WZ resonance (vIII), m	L=1.0 fb <sup>-*</sup> (2011) [Preliminary] 483	<b>3 GeV</b> $p_{T}$ mass $(m(p_{T}) = m(\pi_{T}) + m_{W}, m(a_{T}) = 1$	.1 <i>m</i> (ρ <sub>τ</sub> ))
	Major. neutr. (LRSM, no mixing) : 2-lep + jets	L=2.1 fb <sup>-1</sup> (2011) [Preliminary]	1.5 TeV N mass (m(W <sub>R</sub> ) = 2 TeV	) .
1er	W <sub>R</sub> (LRSM, no mixing) : 2-lep + jets	L=2.1 fb <sup>-1</sup> (2011) [Preliminary]	2.4 TeV W <sub>R</sub> mass (m(N) <	1.4 GeV)
0 <del>1</del>	$H_{L}^{L+}$ (DY prod., BR( $H_{L}^{L+} \rightarrow \mu\mu$ )=1) : SS dimuon, $m_{\mu\mu}$	L=1.6 fb <sup>-1</sup> (2011) [1201.1091] 355 GeV	H <sup>tt</sup> mass	
	Color octet scalar : dijet resonance, m	L=4.8 fb <sup>-1</sup> (2011) [ATLAS-CONF-2012-038]	1.94 TeV Scalar resonance ma	155
	Vector-like quark : CC, mivg	L=1.0 fb <sup>-1</sup> (2011) [1112.5755]	900 GeV Q mass (coupling $\kappa_{qQ} = v/m_Q$ )	
	Vector-like quark : NC, m <sub>Ilq</sub>	L=1.0 fb <sup>-1</sup> (2011) [1112.5755]	760 GeV Q mass (coupling $\kappa_{qQ} = v/m_Q$ )	
		10 <sup>-1</sup>	1 1	0 10 <sup>2</sup>
				Mass scale [TeV]

\*Only a selection of the available mass limits on new states or phenomena shown

No evidence for anything else...

# THE END

OR IS IT?

# NOT ALL MODELS CREATED EQUALLY



# AND WE FOUND SOMETHING\*!



#### WHY HAVEN'T WE FOUND ANYTHING ELSE AND WHERE TO LOOK?

- What are we looking for so far?
  - Physics of EWSB
  - EW naturalness
  - Dark Matter
  - Odd balls

### PHYSICS OF EWSB

Weakly coupled

Strongly coupled

# PHYSICS OF EWSB

#### Weakly coupled



#### Strongly coupled



# EW NATURALNESS AFTER DECADES OF RESEARCH...

Supersymmetry

Extra Dimensions

#### AdS/CFT

Strong Dynamics





How do we put it on trial???

#### DARK MATTER/WIMP MIRACLE

$$\Omega_X \propto \frac{1}{\langle \sigma v \rangle} \sim \frac{m_X^2}{g_X^4}$$

If we have weak scale couplings and masses this works out right

Just one number, maybe we put too much stock in it as far as the LHC goes

# WHERE ARE WE AT?



# WHERE ARE WE AT?



# WHAT'S EXCLUDED?

- ATLAS and CMS have done well at the following things so far:
  - Basic two body final states and close to these...
  - Really blatant oddballs
  - Anything + MET

# BUMPS AND BIG SIGNAL SEARCHES



# BUMPS AND BIG SIGNAL SEARCHES



Nothing here... move along our p-value is big

### OBVIOUS ODDBALLS



- Experiments have looked for SUSY in a variety of different flavors and channels:
  - Jets + MET
  - b jets +MET
  - Ilep+jets +MET
  - OS dileptons +MET
  - SS dileptons + MET
  - diphoton+MET
  - multileptons
  - R-hadrons
  - AMSB

For the most part exclusion is based on MET + (n)m (b)-jets +k leptons



#### • Where do we expect exclusions?



• Not all searches as powerful as they could be (at least at 1/fb)



# REGARDLESS OF SUBTLE DETAILS



# WHAT'S NOT EXCLUDED YET...

- Final states without much MET
- primarily 3rd Generation final states produced from direct production of 3rd generation partners
- Long lived final states
- Odd balls

• All of these ideas may be correlated!

LOW MET

 $\overline{S}$ 

 $\overline{t}$ 



#### Stealth SUSY

Fan, Reece, Ruderman

#### MFV RPV

Csaki, Grossman, Heidenreich



# HAVEN'T DIRECTLY SEARCHED STATES FOR NATURALNESS

• We care about the third generation, top partners in particular for naturalness - don't HAVE to have other things around...



We've been waiting on this search for a long time...

# ATLASTOTHE RESCUE!

Search for Scalar Top Quark Pair Production in Natural Gauge Mediated Supersymmetry Models with the ATLAS Detector in ppCollisions at  $\sqrt{s} = 7$  TeV

# Direct Stop



# ATLAS TO THE RESCUE!

Search for Scalar Top Quark Pair Production in Natural Gauge Mediated Supersymmetry Models with the ATLAS Detector in ppCollisions at  $\sqrt{s} = 7$  TeV

WT#\$%@\*?

)p

$$m_{\tilde{q}_3} = m_{\tilde{u}_3} = -A_t/2; \quad \tan\beta = 10$$



# HAVEN'T DIRECTLY SEARCHED STATES FOR NATURALNESS

• We care about the third generation, top partners in particular for naturalness - don't HAVE to have other things around...



# Not quite there, but we are getting there SOON!

# MODEL BUILDING 3RD

- To avoid constraints we'd like to separate off first two generations from the third
  - Compositeness Csaki, Randall, Terning
  - Flavor Mediation Craig, Mcullough, Thaler
  - Other 3rd generation fun Craig et al. and others in the past

All avoid naturalness for stops, but do we really care? Depends on Higgs sector

### 3RD WITHOUT MET

- Only talked about "SUSY" partners
- Little Higgs, XDs, etc.
- Good Models?

# 3RD WITHOUT MET

#### Exclude Triangles not Points

Wb

- Only talked about "SUSY" partners
- Little Higgs, XDs, etc.
- Good Models? no... BUT
- Can still profess ignorance and look for motivated states
   7t



# IMPLICATIONS FROM HIGGS

- Why do we care about 3rd generation? HIGGS
- We now have something concrete to say if we have found the thing!

#### Higgs at 125 Gev, what does it mean?

Another nail in the coffin for strong coupling?

Not too great for SUSY either, right?

# SUSY AND 125 GEV HIGGS

10

No Mixing







FIG. 6. Higgs mass as a function of  $M_S$ , with  $X_t = 0$ . The green band is the output of FeynHiggs together with its associated uncertainty. The blue line represents 1-loop renormalization group evolution in the Standard Model matched to the MSSM at  $M_S$ . The blue bands give estimates of errors from varying the top mass between 172 and 174 GeV (darker band) and the renormalization scale between  $m_t/2$  and  $2m_t$  12(lighter band).

 $A_t$ 

# SUSY AND 125 GEV HIGGS

- Three options:
  - Maximal Mixing and "light" stops
    - No good high scale models and low scale models have to be at "high" scales
  - SUSY really heavy and tuned Split SUSY
  - SUSY effects Higgs properties (do we care about 3rd gen as much?)

# SUSY AND 125 GEV HIGGS

#### • "Low" scale models = Long lifetimes



Tuned models = Long lifetimes as well! quasi-stable R-hadrons

How much do we care about stops?

# LONG LIFETIMES

- These exist as a whole branch of BSM models without Higgs motivation
- Handful of searches already, but typically tied to obscure models!
- Can give us deep insights!

# HIGGS CORRELATIONS





#### HIGGS CORRELATIONS



Carmi, Falkowski, Kuflik, Volansky + many others

Figure 3: Left: Favored region, 90% CL, in the  $m_{\tilde{t}} - m_h$  plane, derived from the combination of the three search channels, for the one-scalar model described in Sec. 4.1. Right: Constraints for  $m_h = 125$  GeV. The three bands show the  $1\sigma$  allowed regions from Higgs produced via gluon fusion decaying to two photons (ggF  $h \to \gamma\gamma$ , pink), Higgs produced via gluon fusion decaying through two Z-bosons (ggF  $h \to ZZ^*$ , blue), and Higgs produced via vector boson fusion decaying to two photons (VBF  $h \to \gamma\gamma$ , beige). The three curves show the theoretical predictions as a function of  $m_{\tilde{t}}$ : ggF  $h \to \gamma\gamma$  (solid-pink), ggF  $h \to ZZ$  (dashed-blue), and VBF  $h \to \gamma\gamma$  (dotted-beige). The region to the right of the green line at  $m_{\tilde{t}} = 300$  GeV shows the 90% CL experimental (combined) bound.

# HIGGS CORRELATIONS By combining exclusive channels AT THIS EARLY JUNCTURE, we can already make important statements

about BSM physics



# Electroweak Baryogenesis in the MSSM is done!

 $m_h = 125 \,\mathrm{GeV}$ 

# OTHER ODDBALLS?





New Odd Tracks (NOTs) eg:  $X + \bar{X} \sim (3, 1)_0 + (\bar{3}, 1)_0$  $Y + \bar{Y} \sim (1, 1)_{1/9} + (1, 1)_{-1/9}$  $\frac{1}{\Lambda^2} X \bar{d}_R Y^3$ 

Microbarn cross sections without detection!

# BSMTHEORY STATUS



## BSMTHEORY STATUS

#### • No sign of it

# BSMTHEORY STATUS

- No sign of it
- Lots of holes
  - Low MET
  - No MET?

Role of BSM theory now:

Model for explanations

- 3rd gen
   Models for experimentalists
- Long Lifetimes
- Odd balls

Obvious MC implications: SM needs to be better BSM has to be ready for weird things but with accuracy