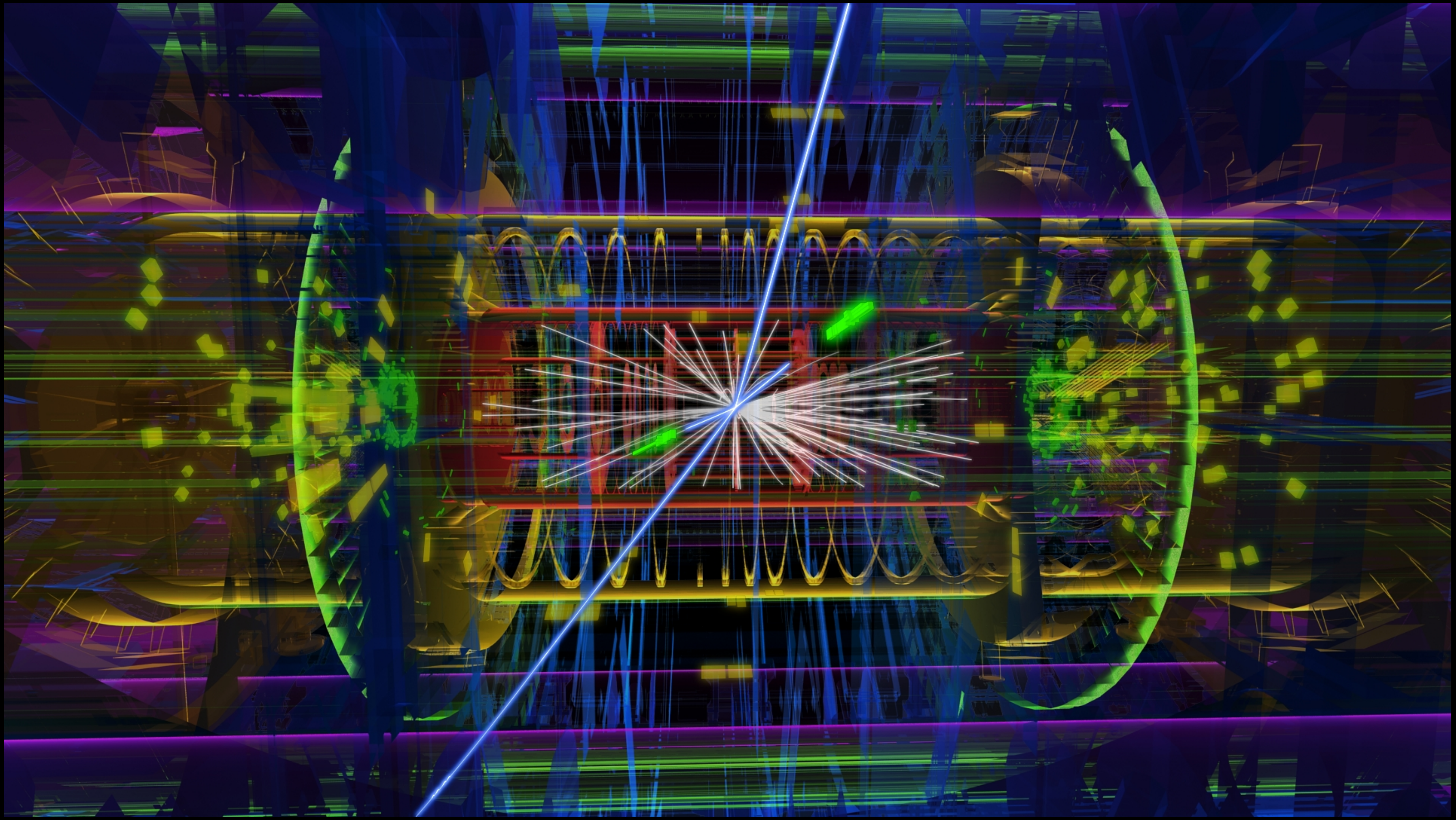
Searching for New Physics at the LHC: Run 2 Status and Prospects

Marjorie Shapiro

University of California, Berkeley and Lawrence Berkeley National Laboratory



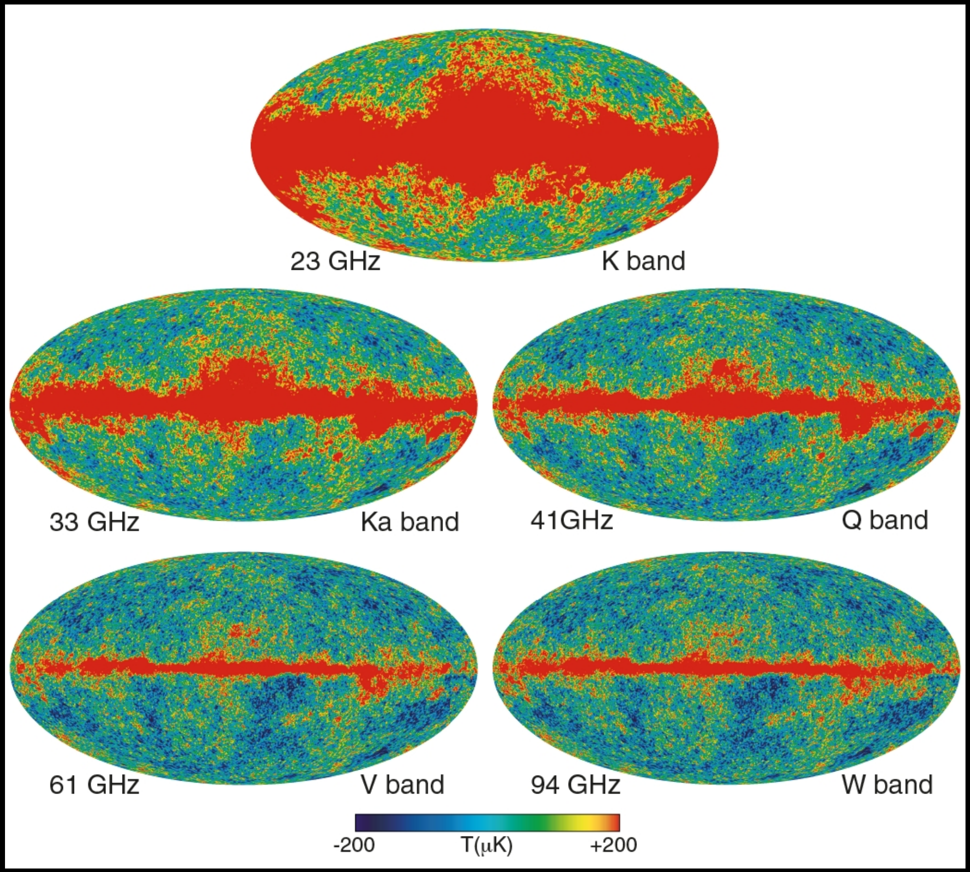
University of Toronto, March 2015

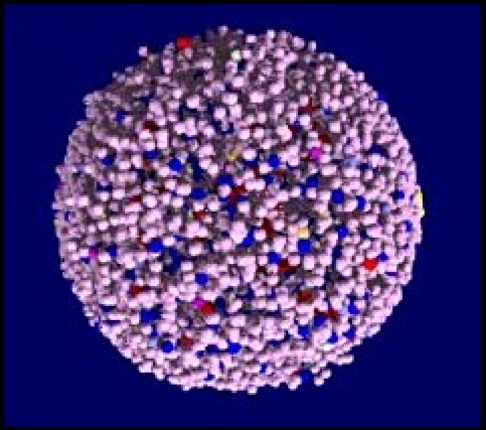
Searching for New Physics at the LHC: Run 2 Status and Prospects

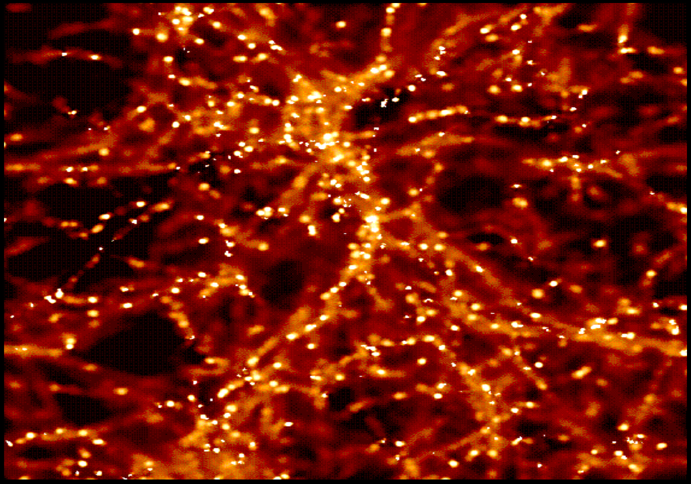
- Introduction
- Run-1 (2009-2013)
- Future Plans
- Conclusions

Thanks to Beate Heinemann whom I have borrowed material from

The Universe is a Laboratory



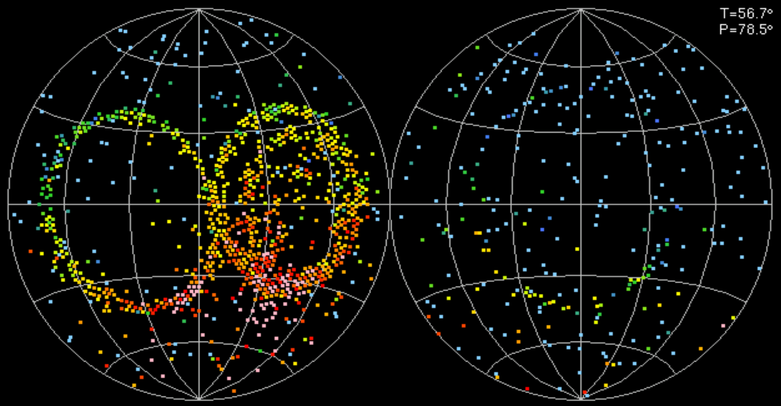


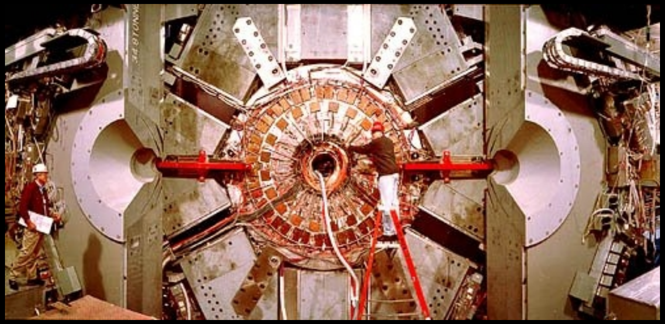


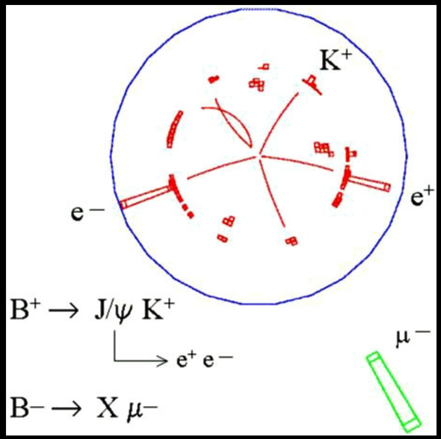
Pictures of the early Universe

But Laboratory Measurements Can Also Tell Us About the Universe

Neutrino interaction from SuperKamioKande (from sun)

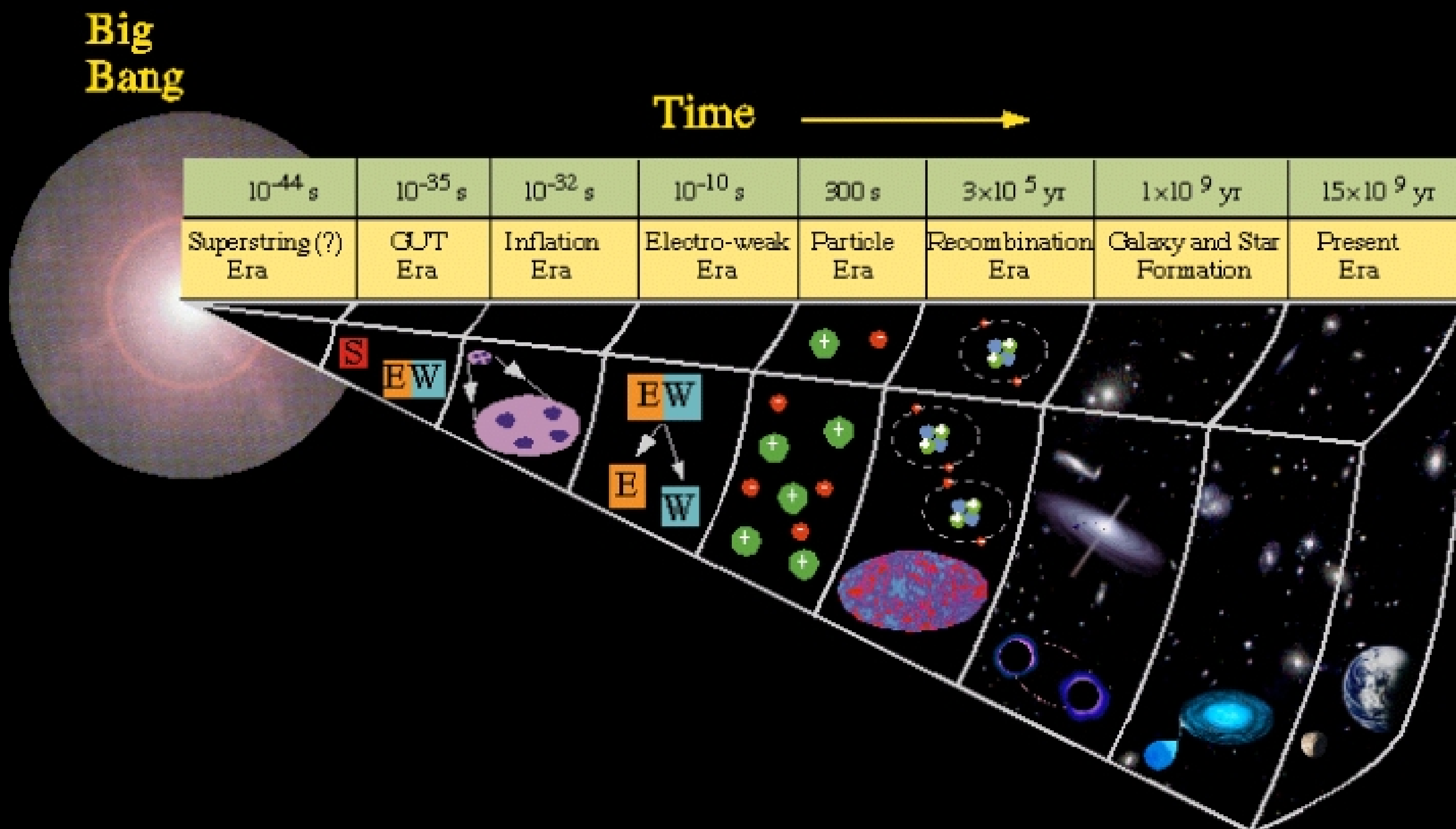






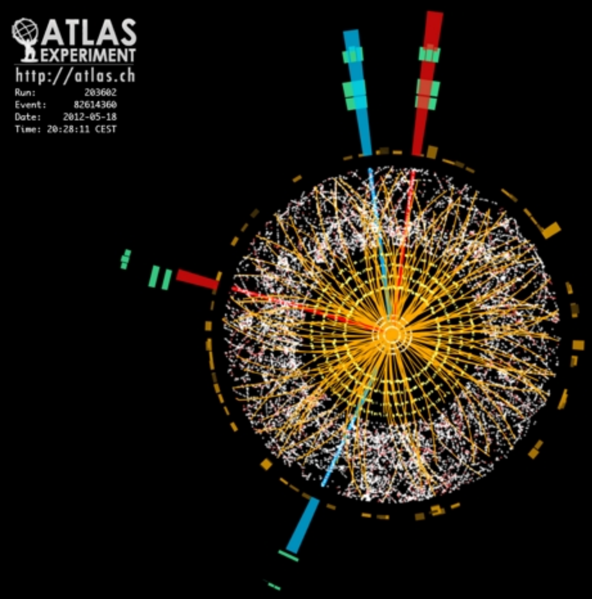
Matter-antimatter asymmetry from Babar (accelerator based)

Description of Early Universe Requires Knowledge of Particles and Interactions that Existed



LHC Plays Especially Critical Role

- Highest Achievable Energy:
  - Reproduce conditions of early Universe

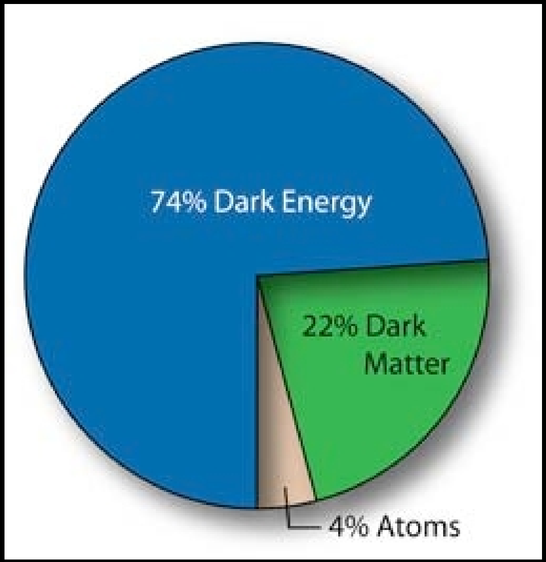


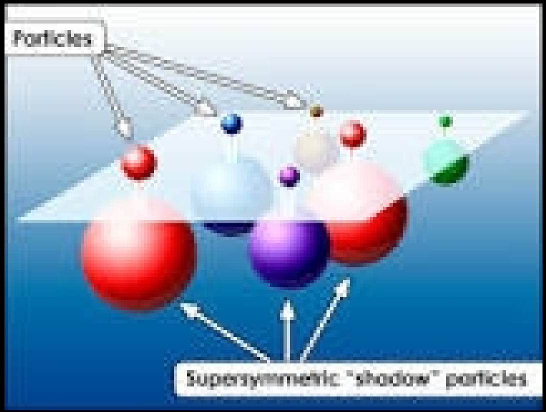
- Tev energy scale:
  - Where fundamental particles obtain their mass

- Many theories, but need data to distinguish between them

What Might We Find at the LHC?

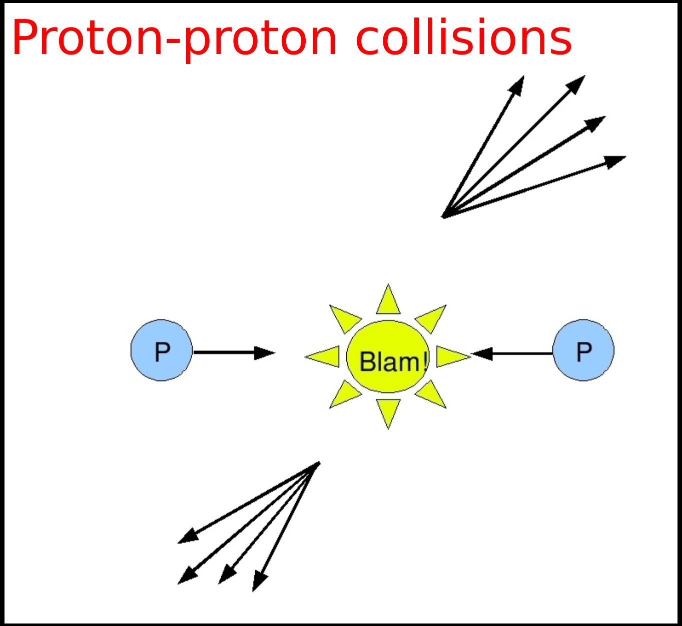
- Answers to very fundamental and simple questions:
  - **What is Dark Matter?**
    - Supersymmetry?
    - Other weakly interacting particles?
  - **Why is gravity so weak?**
    - Supersymmetric particles?,
    - Extra spatial dimensions?
  - **Why do particles have mass?**
    - A single Higgs boson?
    - More complicated Higgs sector?
  - **The unexpected …**





The Large Hadron Collider (LHC)

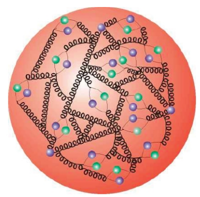
Some Facts About the LHC

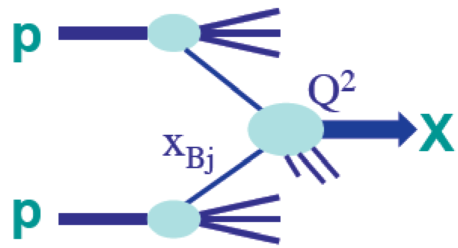


- Circumference: 26.7 km
- Magnet operating temperature: 1.9K
- Number of magnets: 9594 (1232 dipoles)
- Number of proton bunches per beam: 2808
- Number of turns per second: 11,245
- Number of collisions per sec: 600 million

The Physics of Proton Collisions

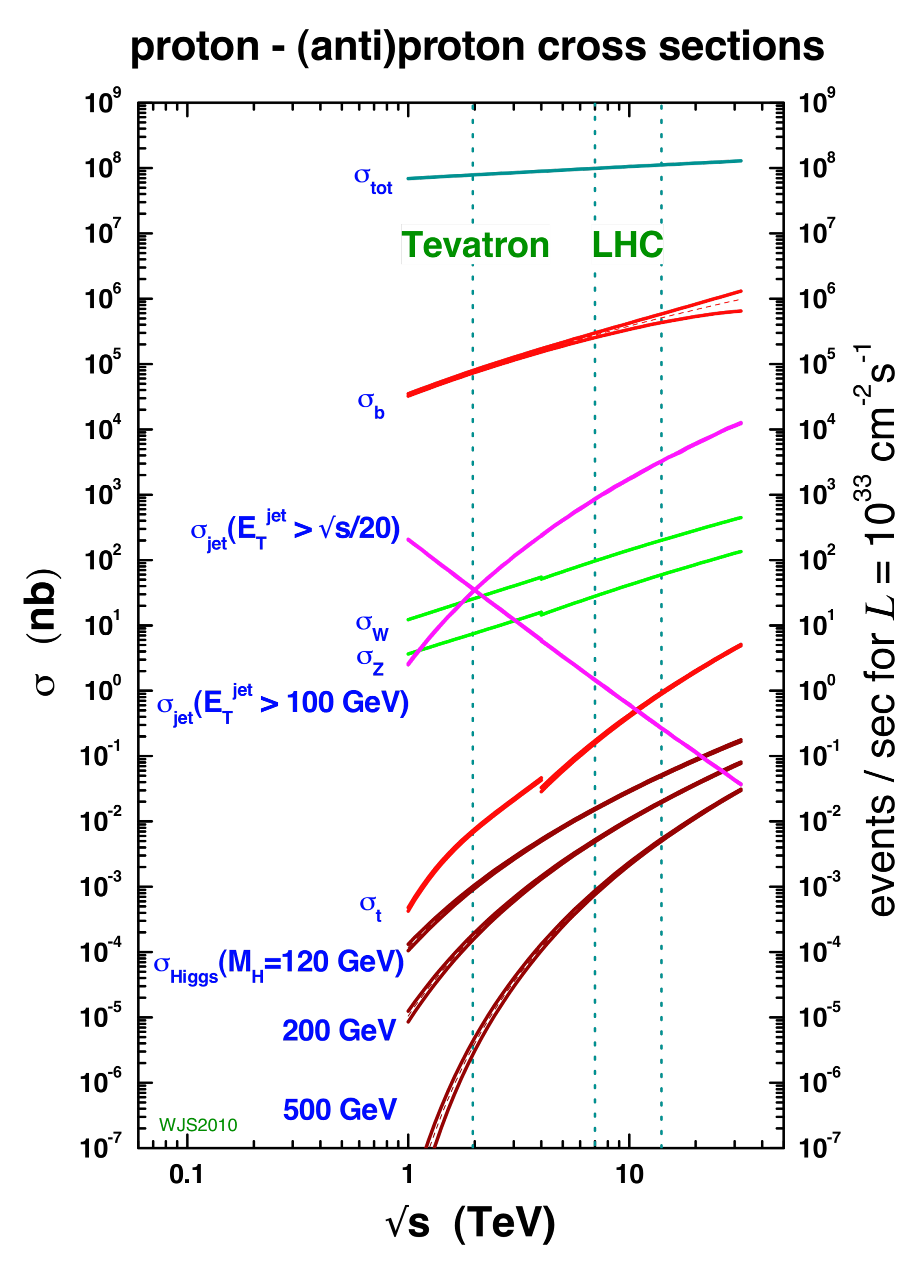
$$M_X = \sqrt{x_1 \cdot x_2 \cdot s}$$





- Protons are made of partons (quarks and gluons)
  - Energy in hard scatter depends on x_1, x_2=fraction of protons' momenta carried by scattered partons
- Like Rutherford, identify high energy scatters by looking at large angles
  - Large transverse momentum (p_T)
- Highest energy collisions rare
  - Requires high intensity beams (large luminosity)

Physics Processes at Hadron Colliders



process	Rate at L_{peak} (Hz)
any interactions	10^9
Bottom quarks	10^6
Jets with p_T>100 GeV	10^4
W bosons	10^3
Z bosons	10^2
Top quarks	1
Higgs (M=125 GeV)	0.1
H->γγ (M=125 GeV)	2×10^{-4}

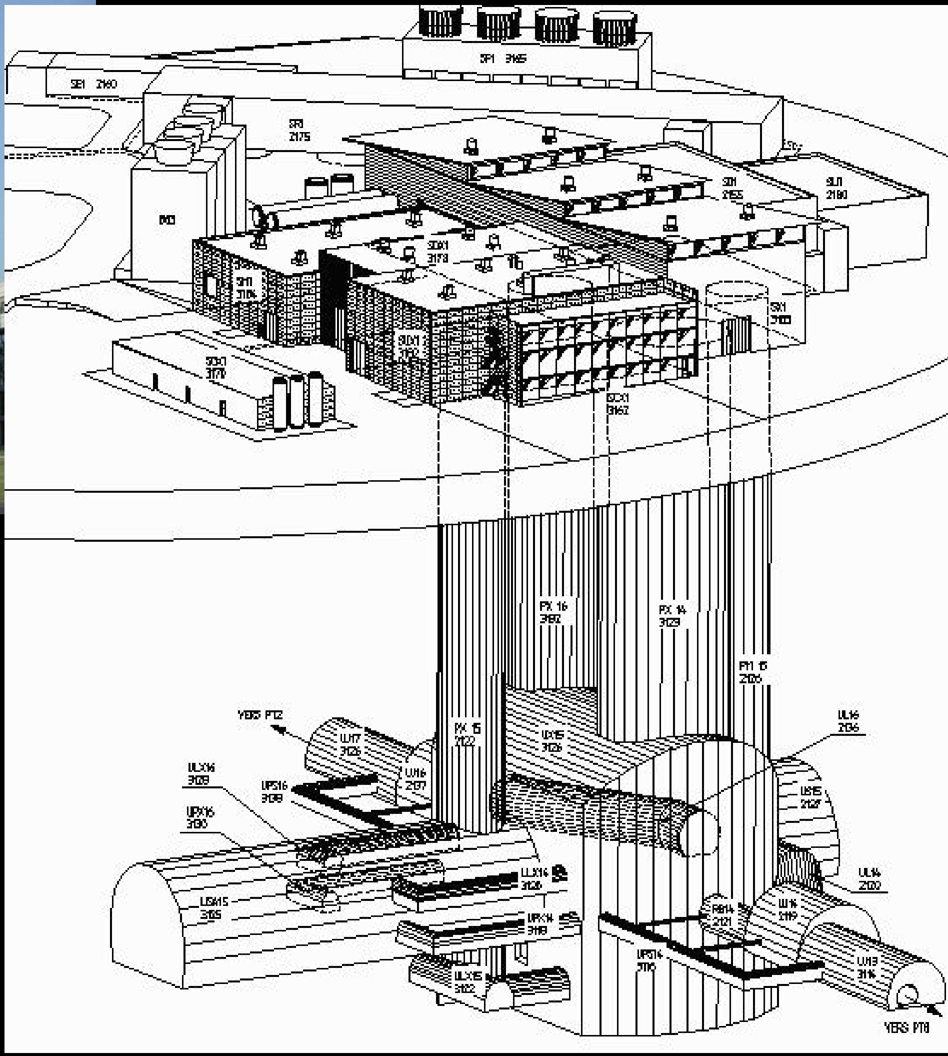
Physics program requires ability to study processes with rates that vary by >13 orders of magnitude!

Detectors for the LHC

- Two big general-purpose detectors
  - ATLAS and CMS
  - Similar goals, different design trade-offs
- One detector optimized to study B-hadron decays
  - LHCb
- One detector optimized to study Heavy Ion collisions
  - Alice

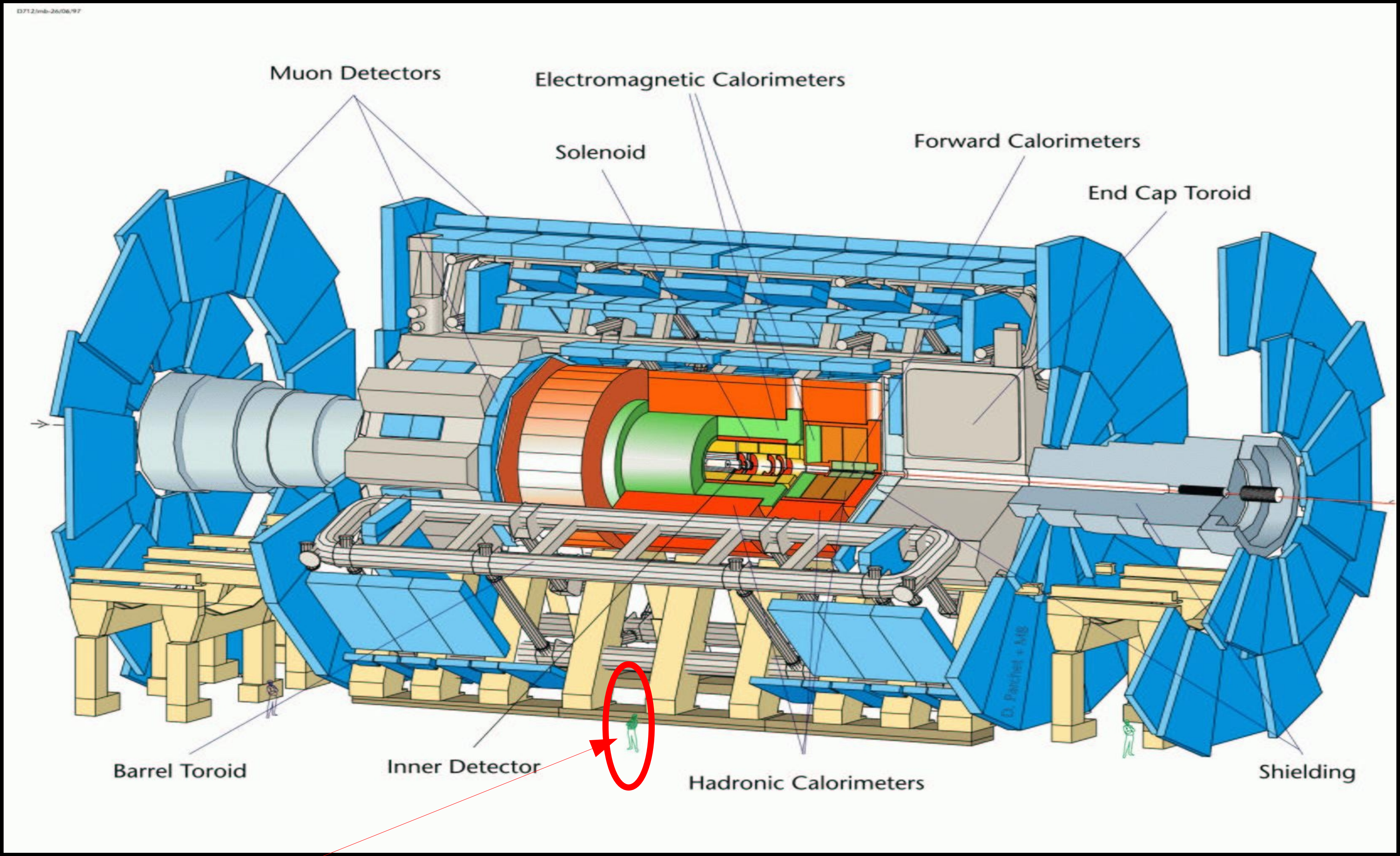
I will concentrate on ATLAS (my experiment and Toronto's)

ATLAS is BIG!



Superimpose ATLAS detector on 5 story LHC office building for scale

ATLAS is Complex!

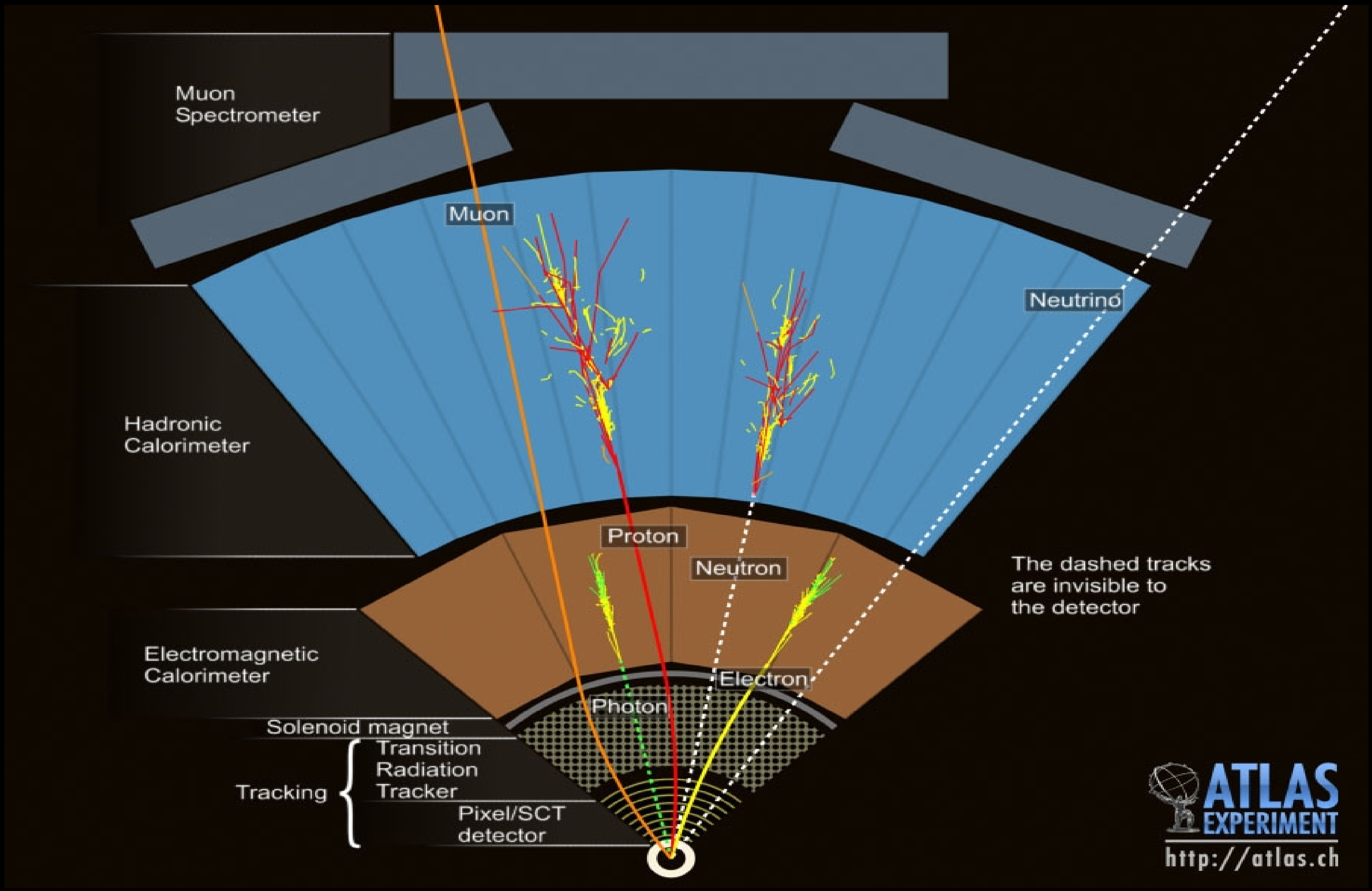


Standard person

ATLAS Built and Operated by a Large International Team

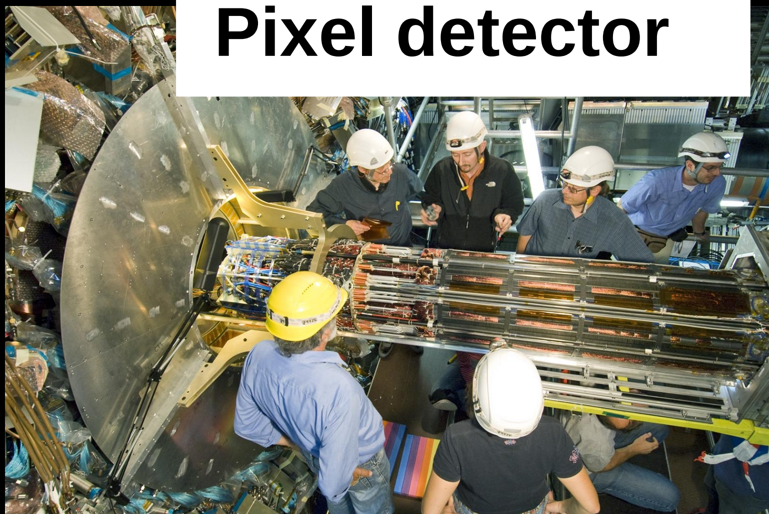
Worldwide collaboration of over 2000 physicists and engineers

A Schematic View of How it Works



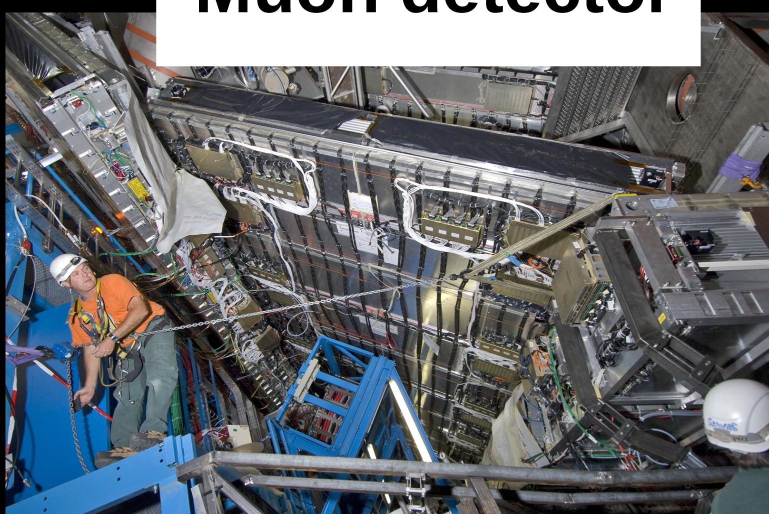
Some Pictures of ATLAS Components

Pixel detector

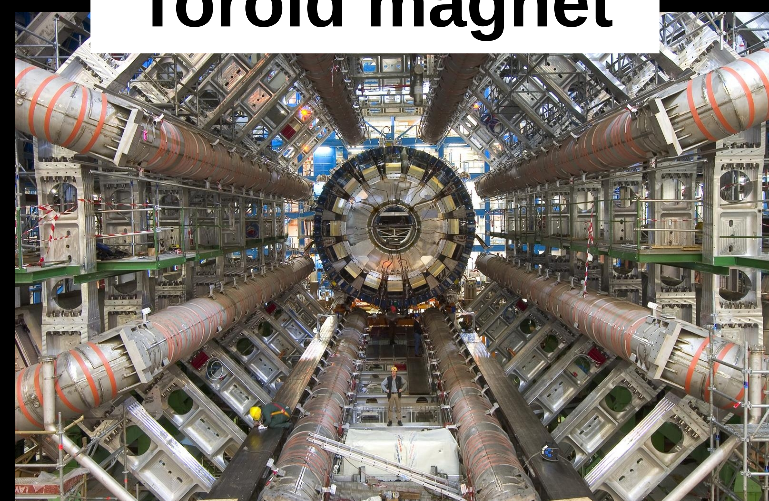


Calorimeter

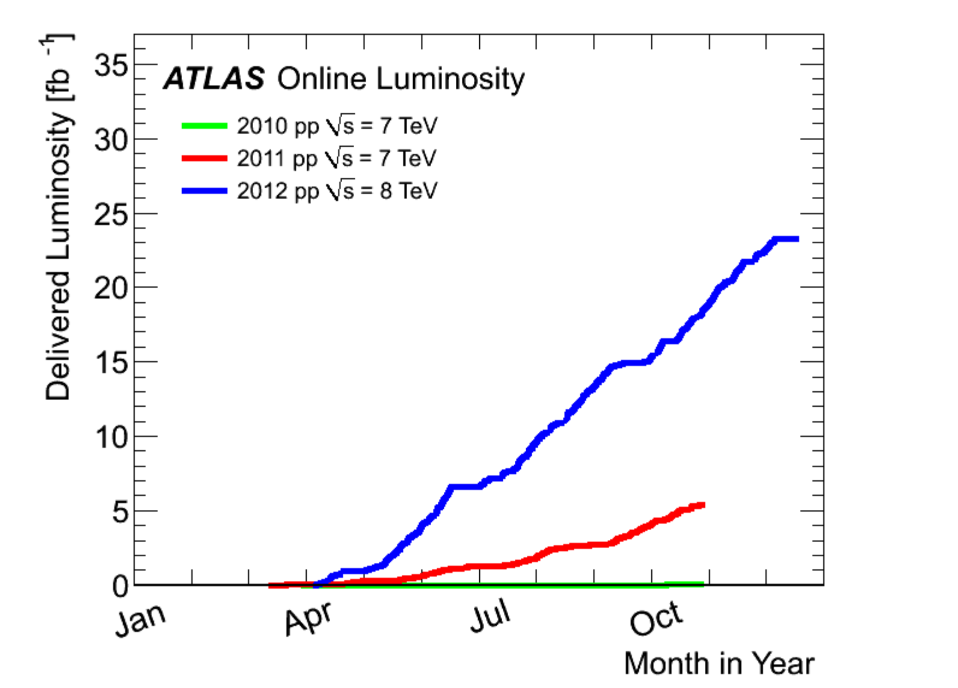
Muon detector



Toroid magnet

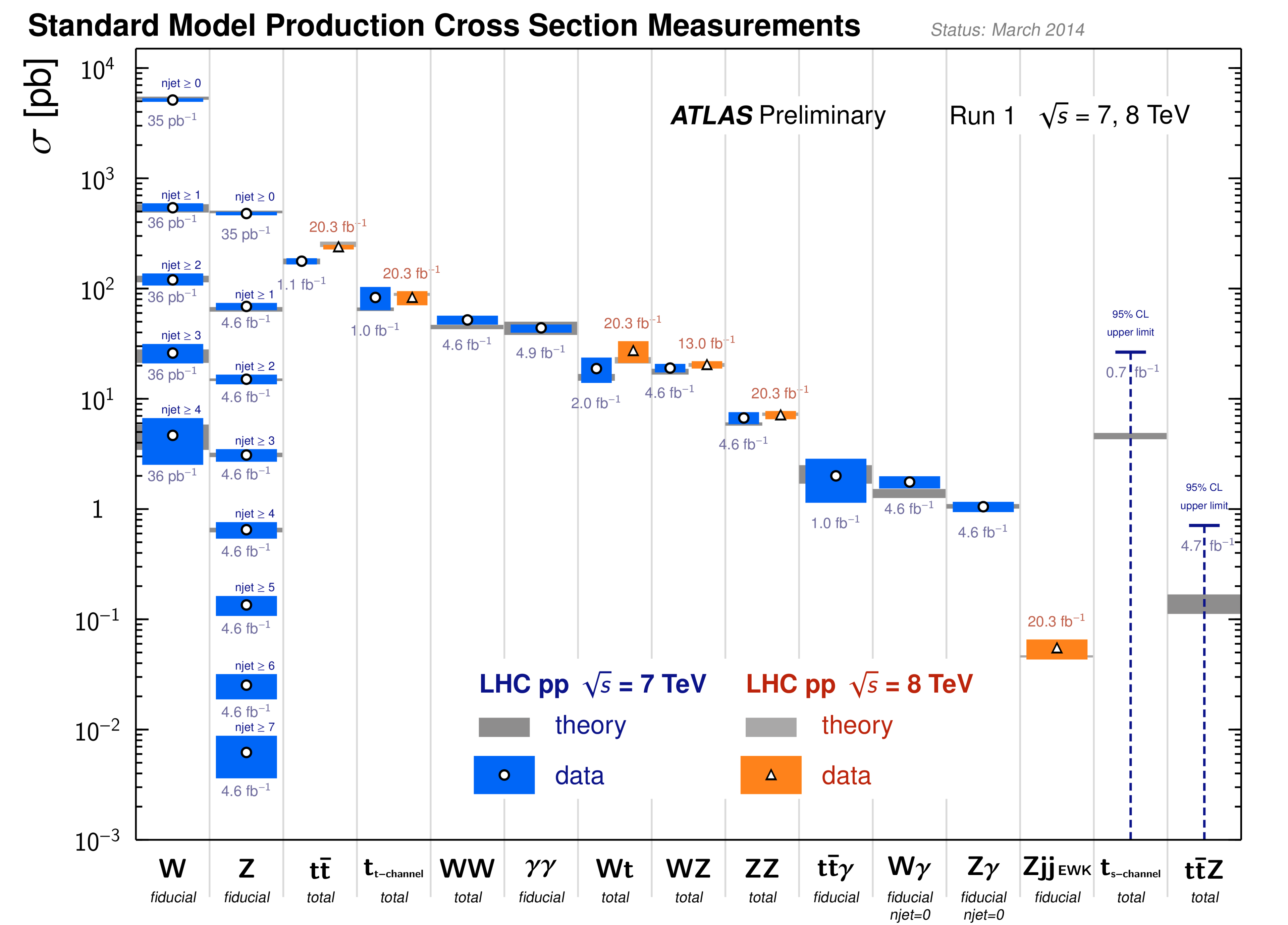


LHC Data Taking: 2010-2012



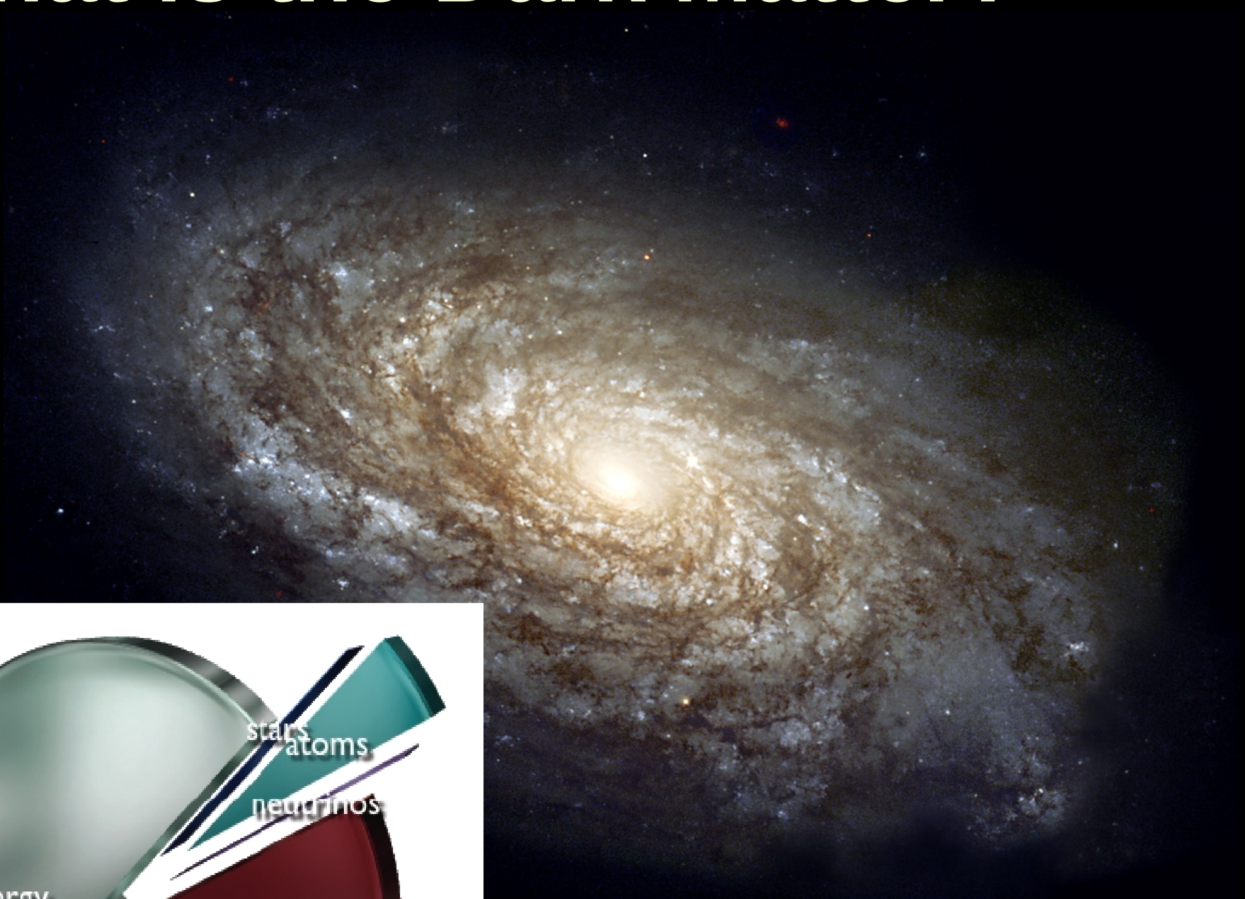
- **Integrated L: 28 fb^{-1}**
  - **2010-11: 7 TeV**
  - **2012 : 8 TeV**
- **Peak L: 7.7x10^{33} cm^{-2}s^{-1}**
  - **20 million events/second**
  - **Write to disk: ~400 events/s**
- **Data Volume**
  - **4x10^{9} events/year**

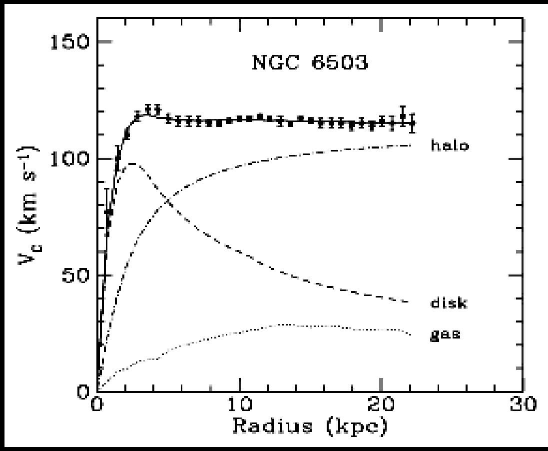
Tremendous success for LHC and for the experiments
Over 300 papers from each of CMS and ATLAS

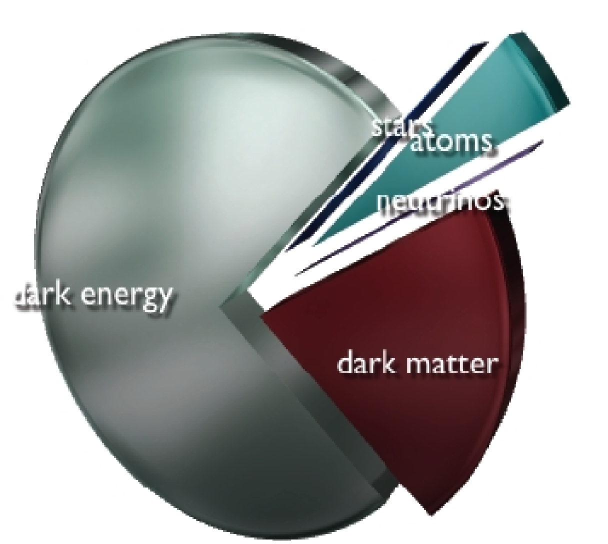

Standard Model Production Cross Section Measurements
Status: March 2014
σ [pb]
ATLAS Preliminary
Run 1 √s = 7, 8 TeV
njet ≥ 0
35 pb⁻¹
njet ≥ 1
36 pb⁻¹
njet ≥ 2
36 pb⁻¹
njet ≥ 3
36 pb⁻¹
njet ≥ 4
36 pb⁻¹
njet ≥ 0
35 pb⁻¹
njet ≥ 1
4.6 fb⁻¹
njet ≥ 2
4.6 fb⁻¹
njet ≥ 3
4.6 fb⁻¹
njet ≥ 4
4.6 fb⁻¹
njet ≥ 5
4.6 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 √s = 7 TeV
theory
data
LHC pp √s = 8 TeV
theory
data
W fiducial
Z fiducial
tt̄ total
t t-channel total
WW total
γγ fiducial
Wt total
WZ total
ZZ total
tt̄γ fiducial
Wγ fiducial njet=0
Zγ fiducial njet=0
Zjj EWK fiducial
t s-channel total
tt̄Z total
10⁴
10³
10²
10¹
1
10⁻¹
10⁻²
10⁻³

Searching for Dark Matter

What is the Dark Matter?





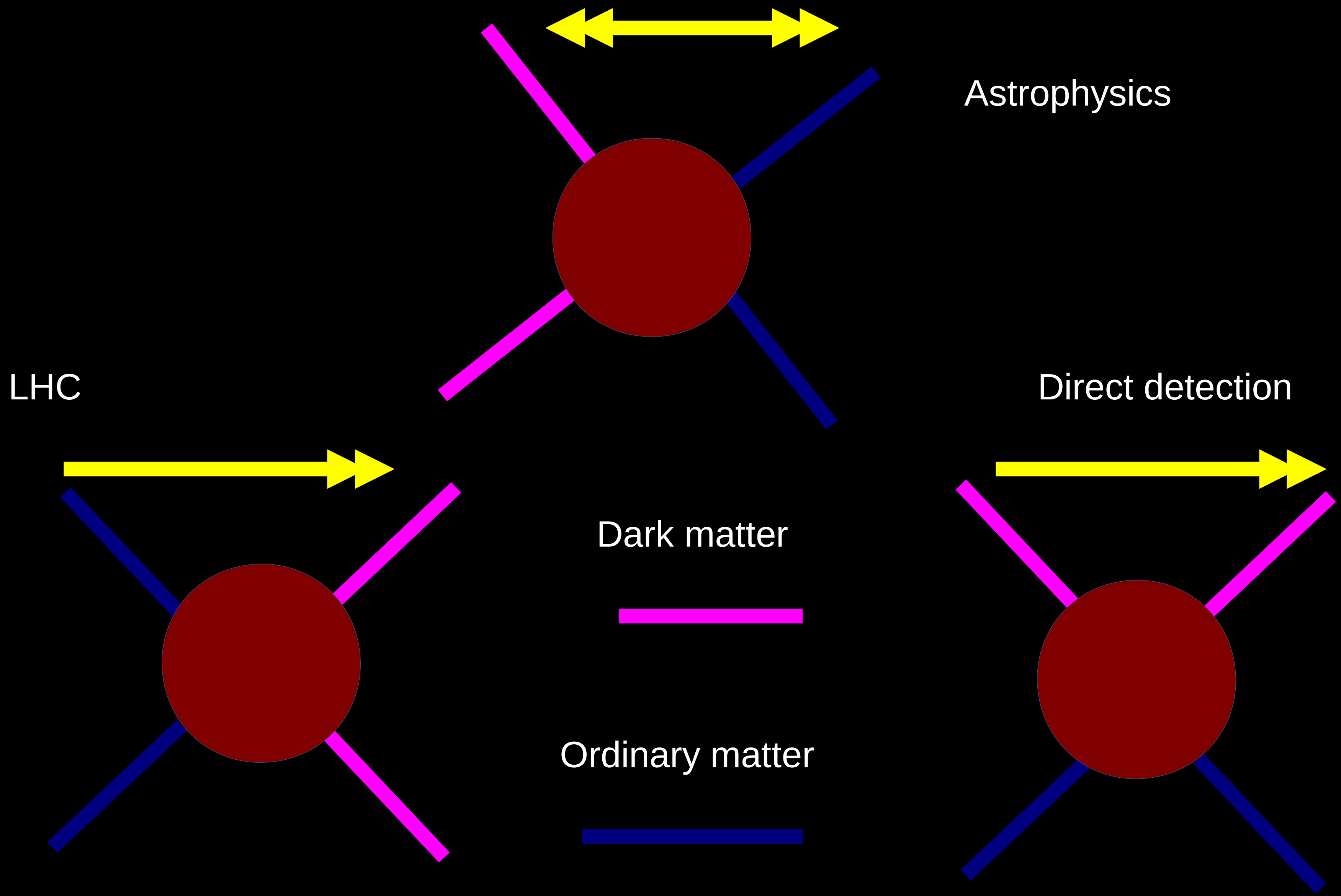


$$\frac{\text{matter}}{\text{all atoms}} = 5.70^{+0.39}_{-0.61}$$

Standard Model only accounts for ~20% of the matter of the Universe:

Many theories predict production of dark matter particles at the LHC

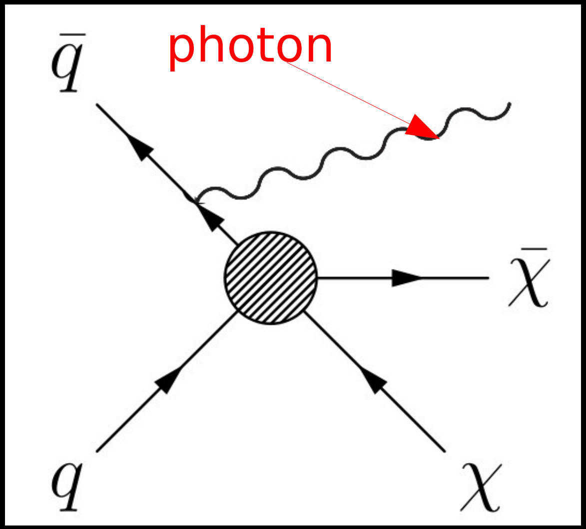
Different Approaches to Dark Matter Detection

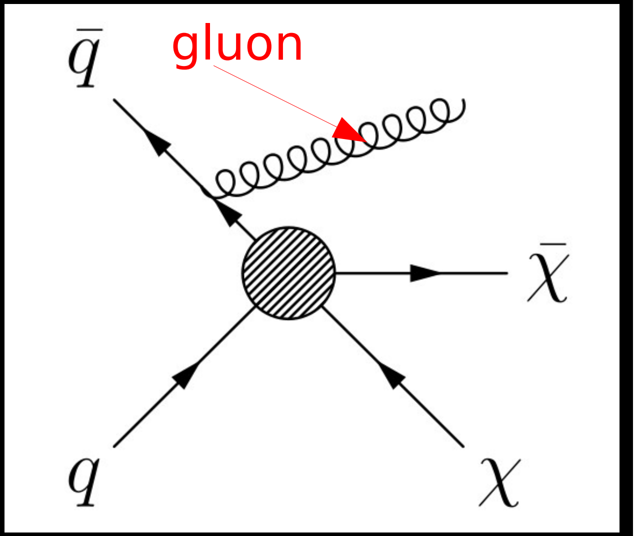


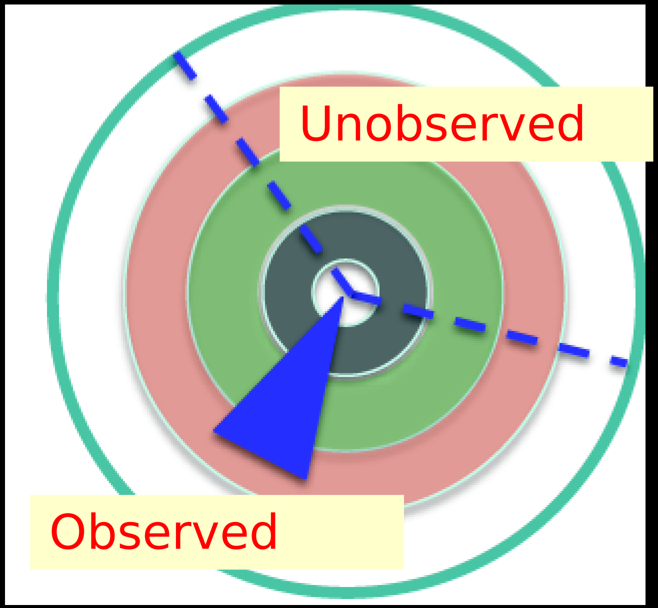
Searches for DM at the LHC:

- Comparison of experimental reach between direct detection and LHC only possible within context of a DM model
- If DM seen, use of direct and LHC measurements together powerful tool to distinguish among models
- At LHC, two basic search strategies:
  - Generic approach:
    - Look for DM recoiling against know particles
    - Characterize reach in terms on DM mass and interaction strength
  - Search within context of specific model
    - More on this when we discuss SUSY

The Generic Approach

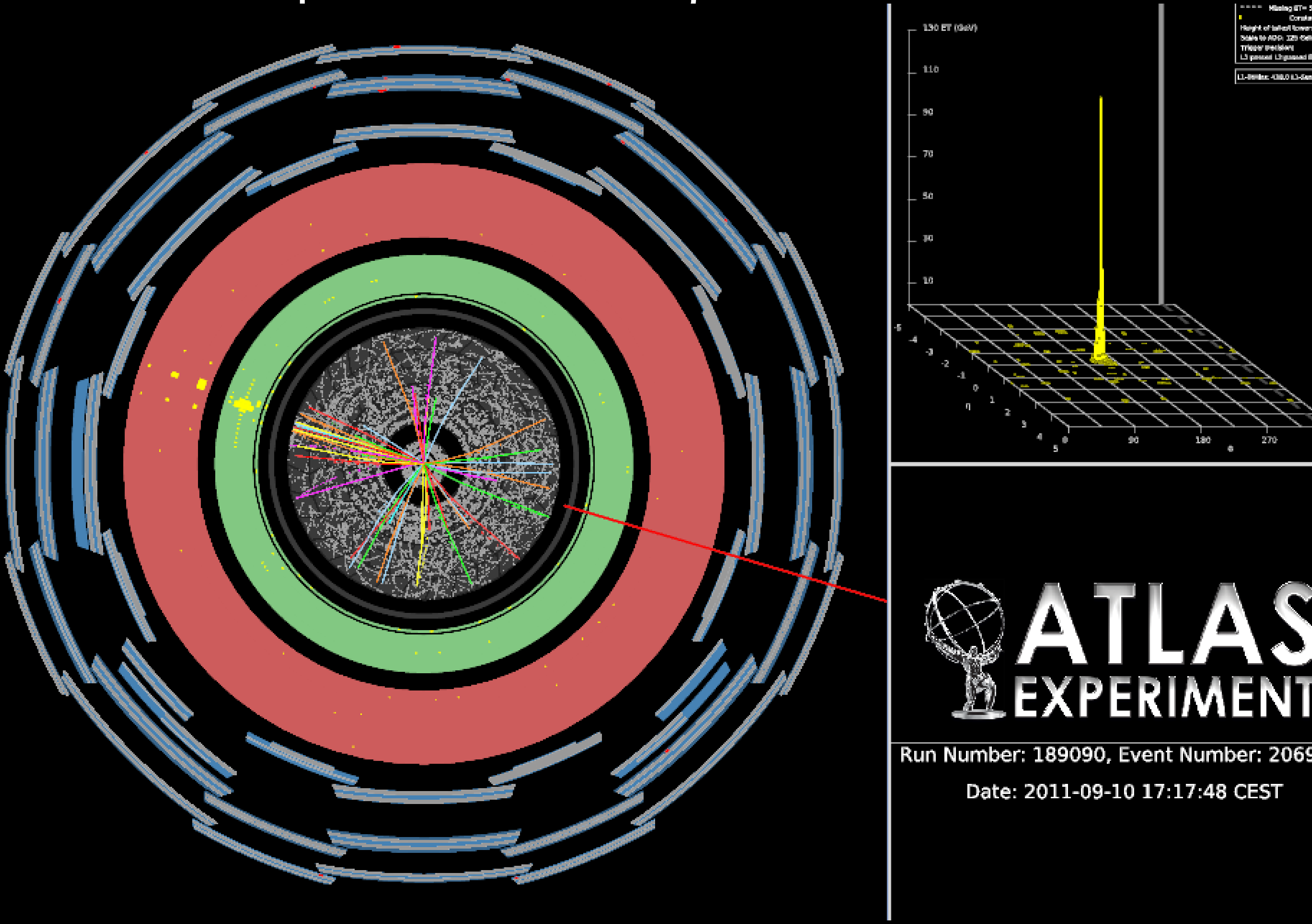




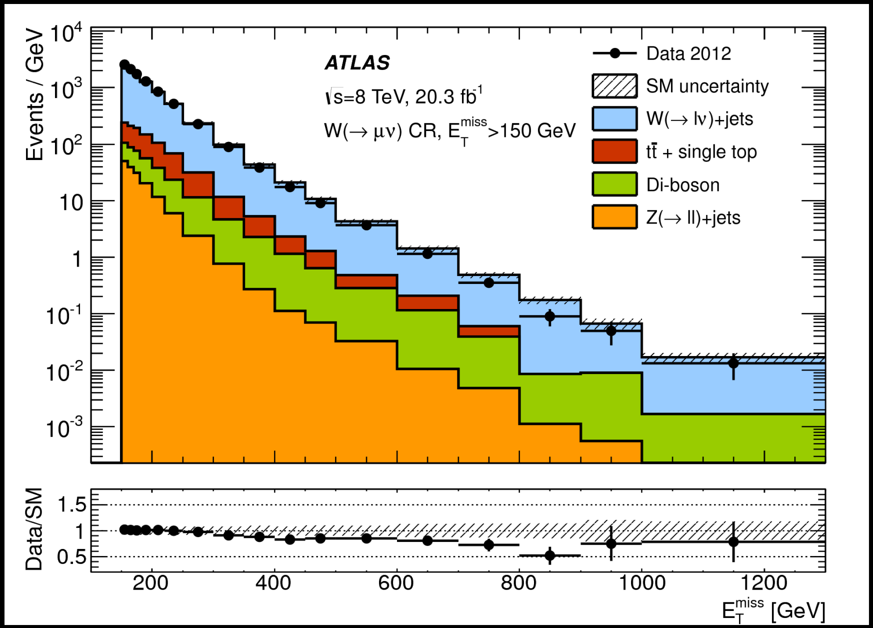


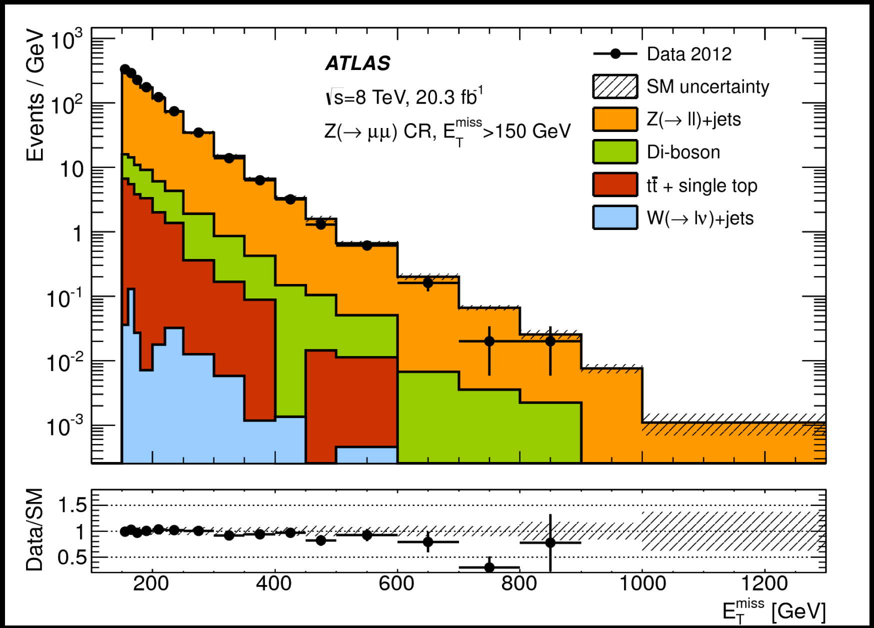
- Apparent momentum imbalance since DM particles escape detector without interacting ("missing E_T")
- Method requires high accuracy in estimating missing E_T background from SM processes

An Example of a “Monojet” Event



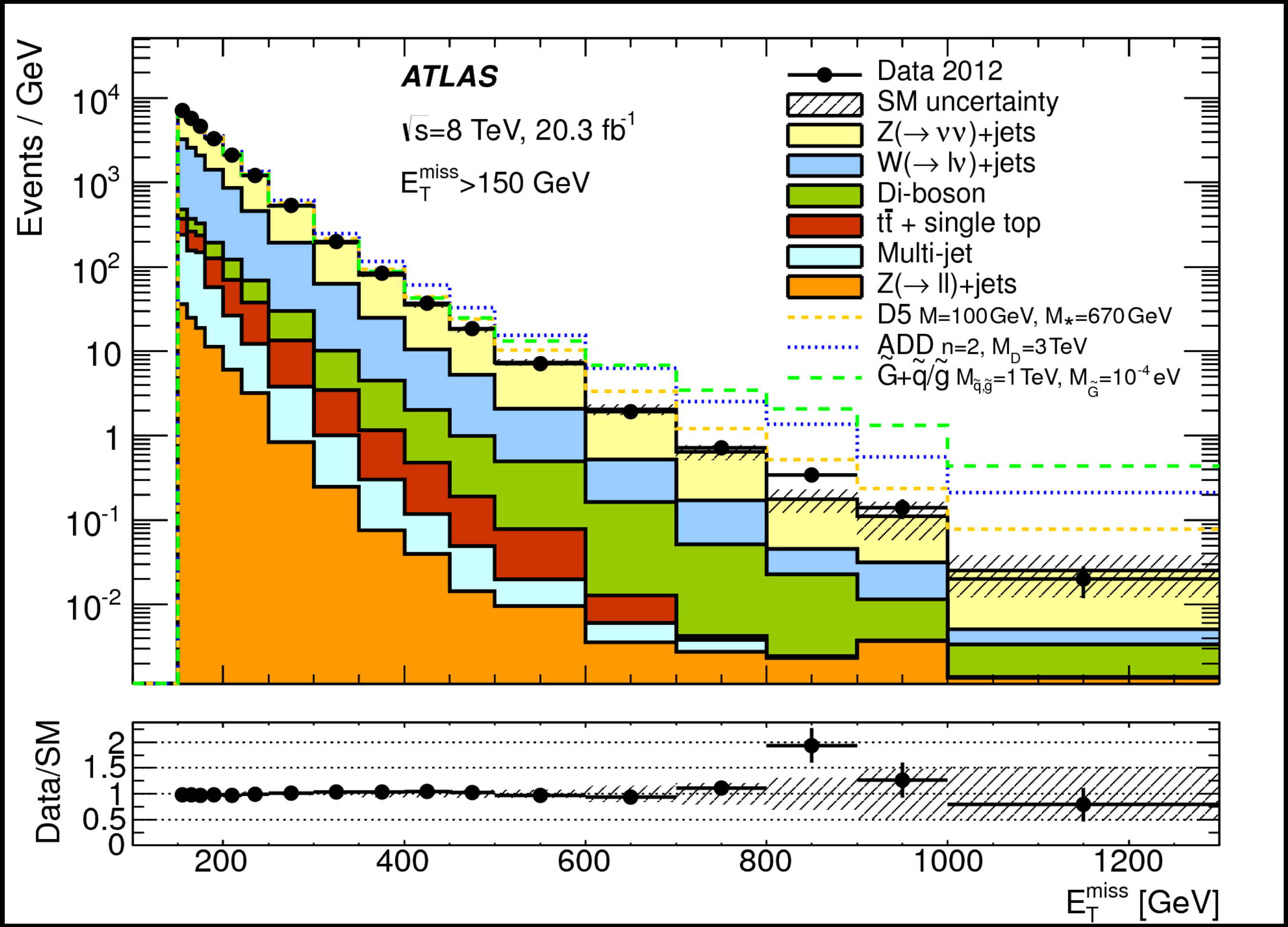
Determination of Background Rates





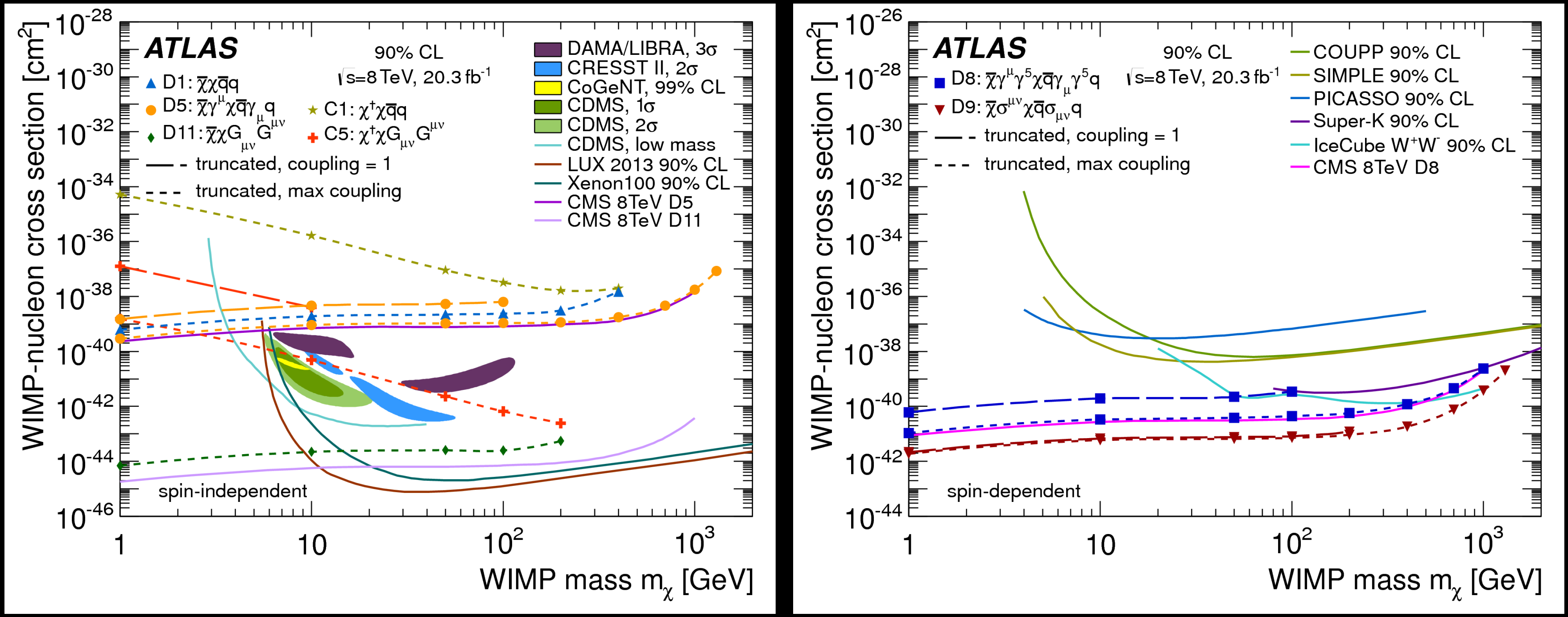
- Most important Physics backgrounds:
  - $Z\to\nu\nu$ and $W\to\mu\nu$ (μ unobserved)
- Measure backgrounds using:
  - $Z\to\mu\mu$ and $W\to\mu\nu$

Results of the Dark Matter Search at 8 TeV



- Excellent description of background rate
- No evidence of DM signal

Interpreting the Measurement



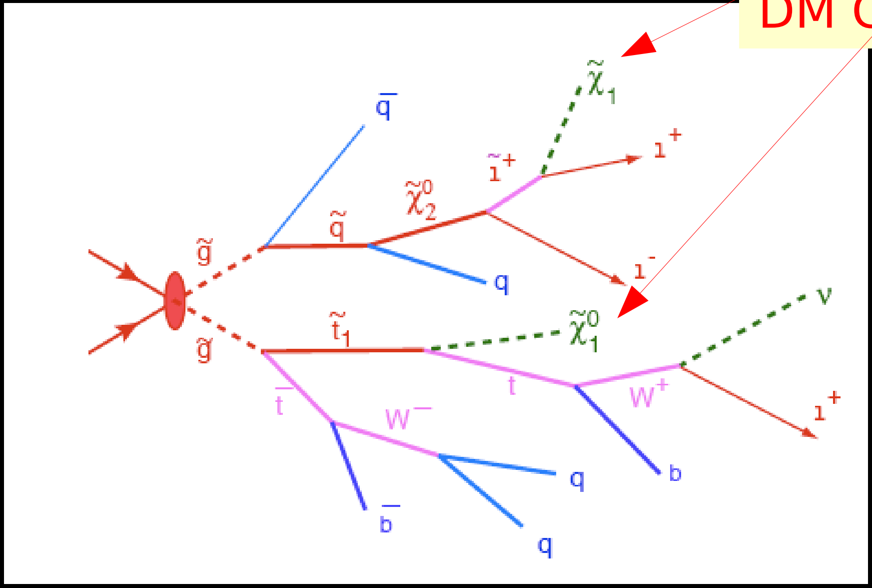
- Limits provided assuming form for operator mediating DM interaction
- Same data result can be used to place limits on other models
  - Extra dimensions
  - SUSY

Supersymmetry

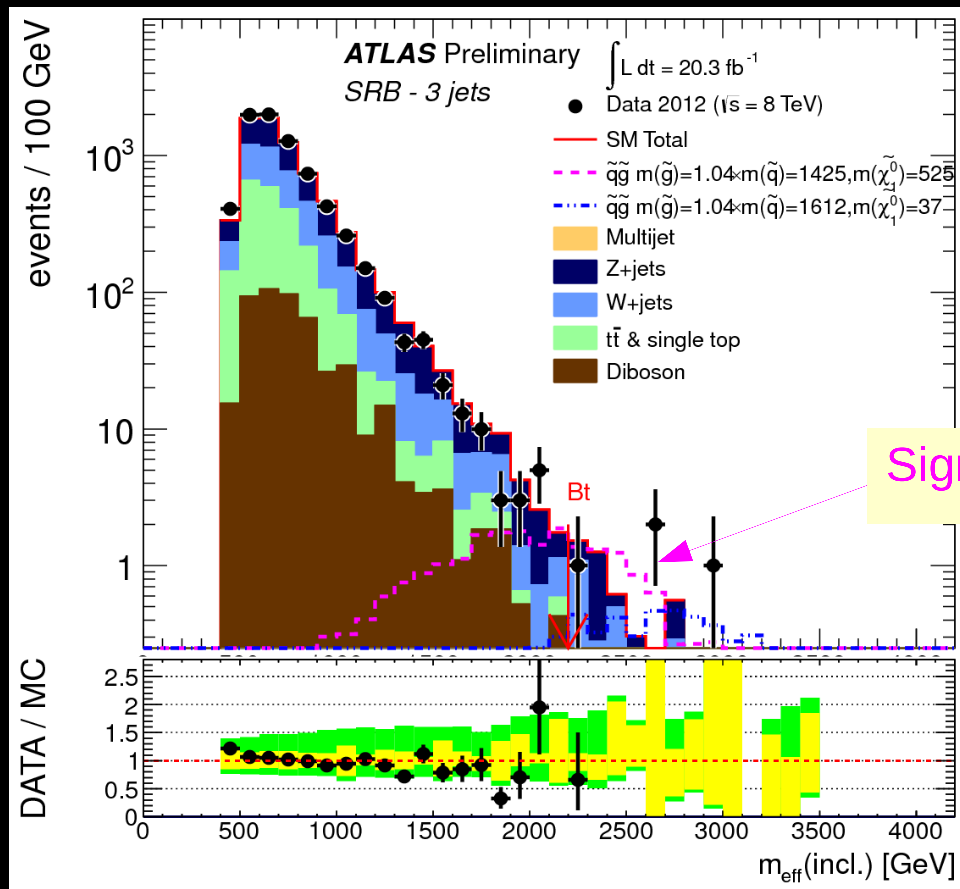
SUSY and Dark Matter

- Supersymmetry models provide DM candidates
  - R parity conservation: Lightest SUSY particle (LSP) stable
  - To be DM candidate must be neutral and weakly interacting
- SUSY also has strongly interacting heavier particles
  - These can be produced with significant cross sections
  - Cascade decays to the LSP

DM Candidate



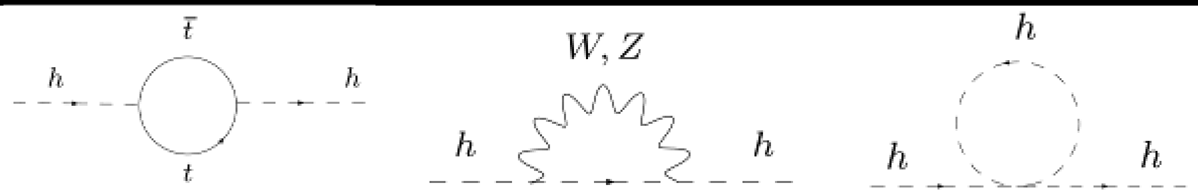
An Example SUSY Search



Signal would appear here

No evidence of signal

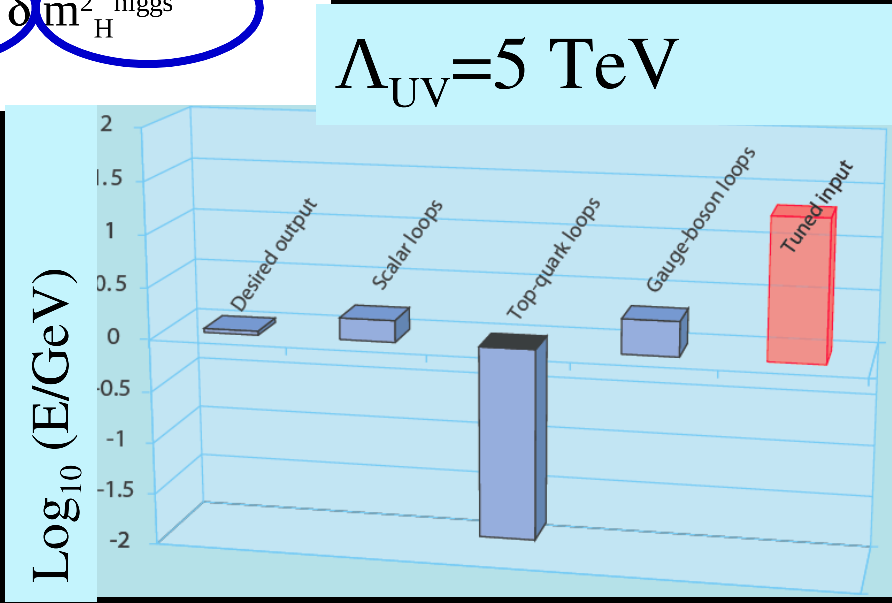
Another Argument for SUSY: The Hierarchy Problem



$$m^2_H \approx (200\ \mathrm{GeV})^2 = m^2_H{}^{\mathrm{tree}} + \delta m^2_H{}^{\mathrm{top}} + \delta m^2_H{}^{\mathrm{gauge}} + \delta m^2_H{}^{\mathrm{higgs}}$$

- Free parameter m_H^{tree} “fine-tuned” to cancel huge corrections

$$\Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}[\Lambda_{UV}^2 + \ldots].$$



- Can be solved by new physics at the TeV scale

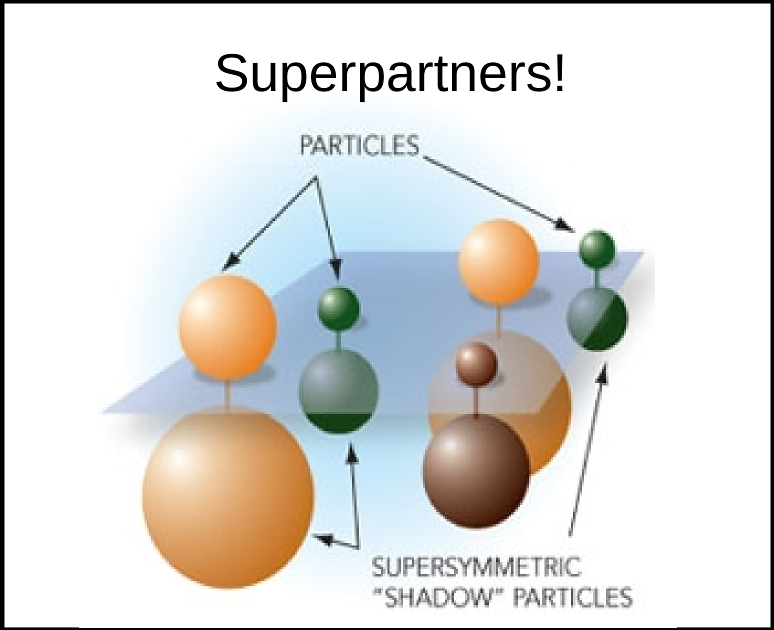
How does SUSY Help?

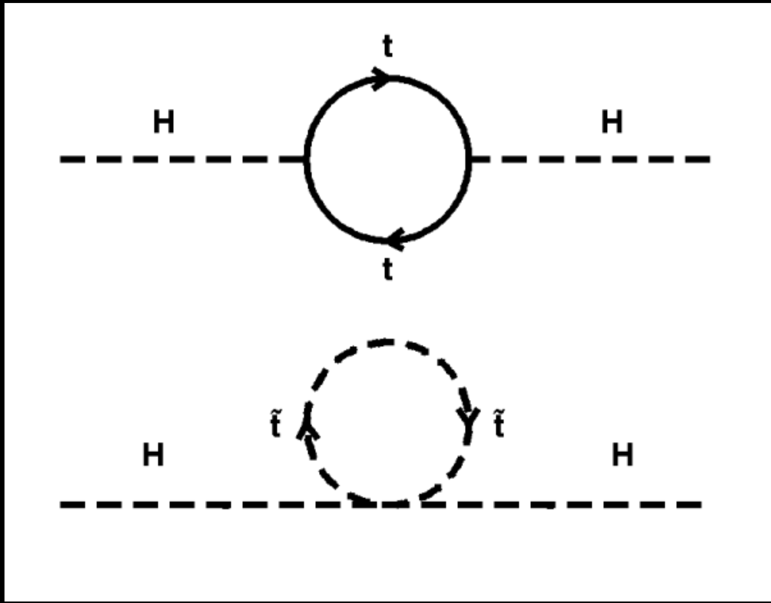
- "Supersymmetric" particles
  - Each SM particle has a partner with different spin, e.g.:

SM	spin	SUSY	spin
electron	1/2	selectron	0
top	1/2	stop	0
gluon	1	gluino	**1/2**

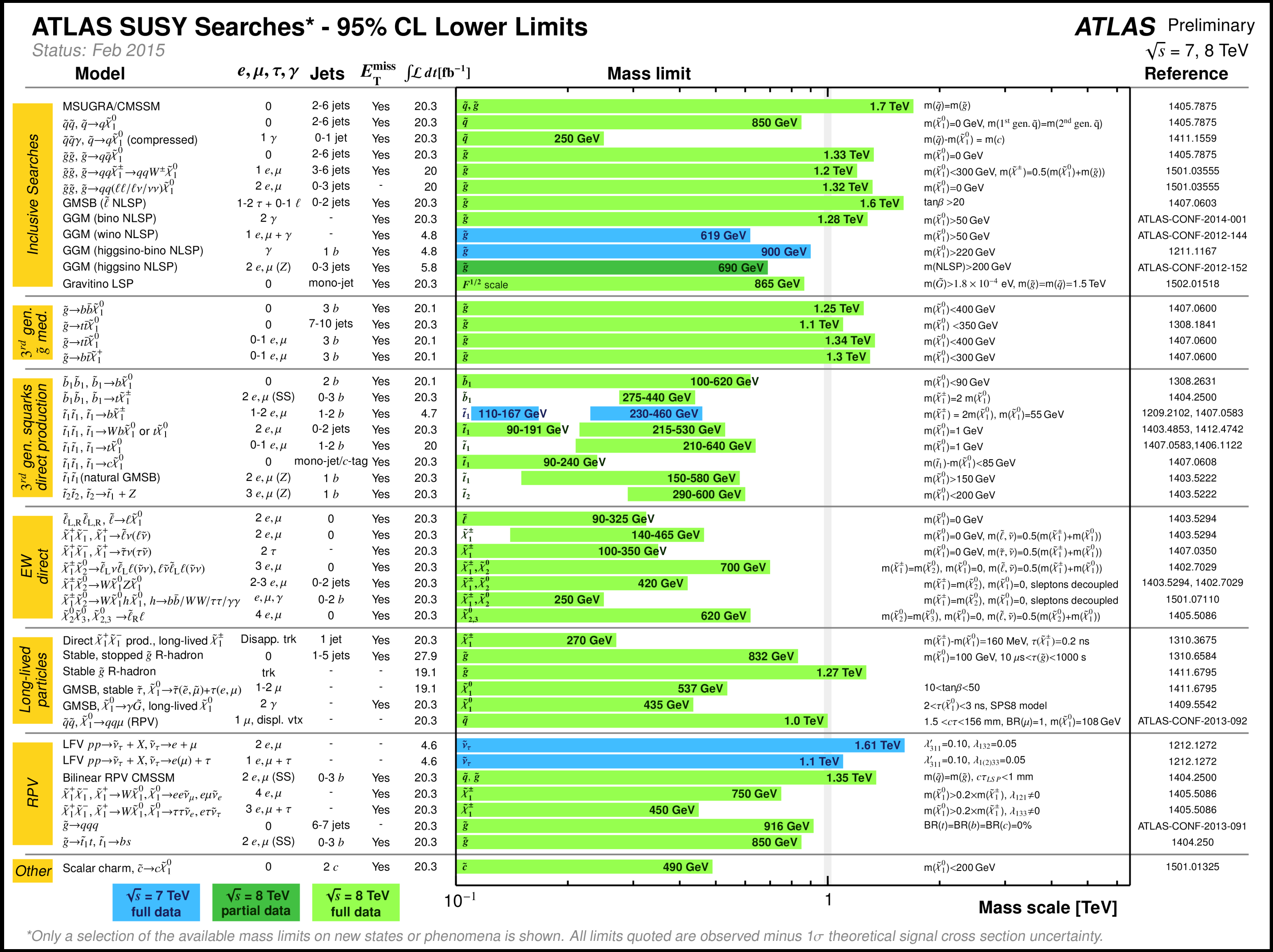
  - SUSY loops cancel SM loops
    - Size of loops naturally the same IF particle masses similar

    => SUSY particles should be found at the LHC
  - No (or little) tuned ad-hoc parameters needed





Current SUSY Search Limits from ATLAS



Note: Many non-SUSY Searches (no new physics so far)

ATLAS Exotics Searches* - 95% CL Exclusion

Status: ICHEP 2014

ATLAS Preliminary

$\int \mathcal{L}\, dt = (1.0 - 20.3)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt [\mathrm{fb}^{-1}]$	Mass limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	1-2 j	Yes	4.7	M_D 4.37 TeV	$n = 2$	1210.4491
	ADD non-resonant $\ell\ell$	$2e, \mu$	–	–	20.3	M_S 5.2 TeV	$n = 3$ HLZ	ATLAS-CONF-2014-030
	ADD QBH $\to \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	20.3	M_{th} 5.82 TeV	$n = 6$	to be submitted to PRD
	ADD BH high N_{trk}	2 μ (SS)	–	–	20.3	M_{th} 5.7 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	20.3	M_{th} 6.2 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1405.4254
	RS1 $G_{KK} \to \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \to WW \to \ell\nu\ell\nu$	2 e, μ	–	Yes	4.7	G_{KK} mass 1.23 TeV	$k/\overline{M}_{Pl} = 0.1$	1208.2880
	Bulk RS $G_{KK} \to ZZ \to \ell\ell qq$	2 e, μ	2 j / 1 J	–	20.3	G_{KK} mass 730 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-039
	Bulk RS $G_{KK} \to HH \to b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK} \to t\bar{t}$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	14.3	g_{KK} mass 2.0 TeV	BR = 0.925	ATLAS-CONF-2013-052
	S^1/Z_2 ED	2 e, μ	–	–	5.0	$M_{KK} \approx R^{-1}$ 4.71 TeV		1209.2535
	UED	2 γ	–	Yes	4.8	Compact. scale R^{-1} 1.41 TeV		ATLAS-CONF-2012-072
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	20.3	Z' mass 2.9 TeV		1405.4123
	SSM $Z' \to \tau\tau$	2 τ	–	–	19.5	Z' mass 1.9 TeV		ATLAS-CONF-2013-066
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	20.3	W' mass 3.28 TeV		ATLAS-CONF-2014-017
	EGM $W' \to WZ \to \ell\nu\, \ell'\ell'$	3 e, μ	–	Yes	20.3	W' mass 1.52 TeV		1406.4456
	EGM $W' \to WZ \to qq\ell\ell$	2 e, μ	2 j / 1 J	–	20.3	W' mass 1.59 TeV		ATLAS-CONF-2014-039
	LRSM $W'_R \to t\bar{b}$	1 e, μ	2 b, 0-1 j	Yes	14.3	W' mass 1.84 TeV		ATLAS-CONF-2013-050
	LRSM $W'_R \to t\bar{b}$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.77 TeV		to be submitted to EPJC
CI	CI $qqqq$	–	2 j	–	4.8	Λ 7.6 TeV	$\eta = +1$	1210.1718
	CI $qq\ell\ell$	2 e, μ	–	–	20.3	Λ 21.6 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2014-030
	CI $uutt$	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	Λ 3.3 TeV	$\lvert C \rvert = 1$	ATLAS-CONF-2013-051
DM	EFT D5 operator (Dirac)	0 e, μ	1-2 j	Yes	10.5	M_* 731 GeV	at 90% CL for $m(\chi) < 80$ GeV	ATLAS-CONF-2012-147
	EFT D9 operator (Dirac)	0 e, μ	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	1 e, μ, 1 τ	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	Vector-like quark $TT \to Ht + X$	1 e, μ	≥ 2 b, ≥ 4 j	Yes	14.3	T mass 790 GeV	T in (T,B) doublet	ATLAS-CONF-2013-018
	Vector-like quark $TT \to Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	14.3	T mass 670 GeV	isospin singlet	ATLAS-CONF-2013-060
	Vector-like quark $TT \to Zt + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	T mass 735 GeV	T in (T,B) doublet	ATLAS-CONF-2014-036
	Vector-like quark $BB \to Zb + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	ATLAS-CONF-2014-036
	Vector-like quark $BB \to Wt + X$	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	B mass 720 GeV	B in (T,B) doublet	ATLAS-CONF-2013-051
Excited fermions	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	20.3	q^* mass 3.5 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1309.3230
	Excited quark $q^* \to qg$	–	2 j	–	20.3	q^* mass 4.09 TeV	only u^* and d^*, $\Lambda = m(q^*)$	to be submitted to PRD
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \to \ell\gamma$	2 e, μ, 1 γ	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
Other	LSTC $a_T \to W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		to be submitted to PLB
	LRSM Majorana ν	2 e, μ	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Type III Seesaw	2 e, μ	–	–	5.8	$N^\pm$ mass 245 GeV	$\lvert V_e \rvert$=0.055, $\lvert V_\mu \rvert$=0.063, $\lvert V_\tau \rvert$=0	ATLAS-CONF-2013-019
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2 e, μ (SS)	–	–	4.7	$H^{\pm\pm}$ mass 409 GeV	DY production, BR($H^{\pm\pm} \to \ell\ell$)=1	1210.5070
	Multi-charged particles	–	–	–	4.4	multi-charged particle mass 490 GeV	DY production, $\lvert q \rvert = 4e$	1301.5272
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g \rvert = 1 g_D$	1207.6411

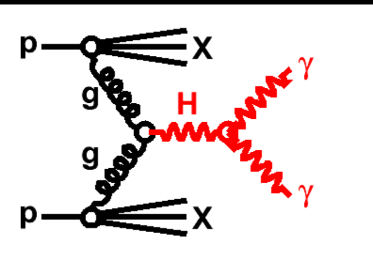
$\sqrt{s}$ = 7 TeV $\sqrt{s}$ = 8 TeV

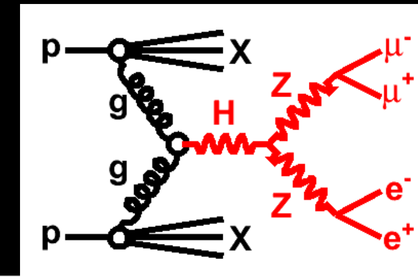
10^{-1} 1 10 **Mass scale [TeV]**

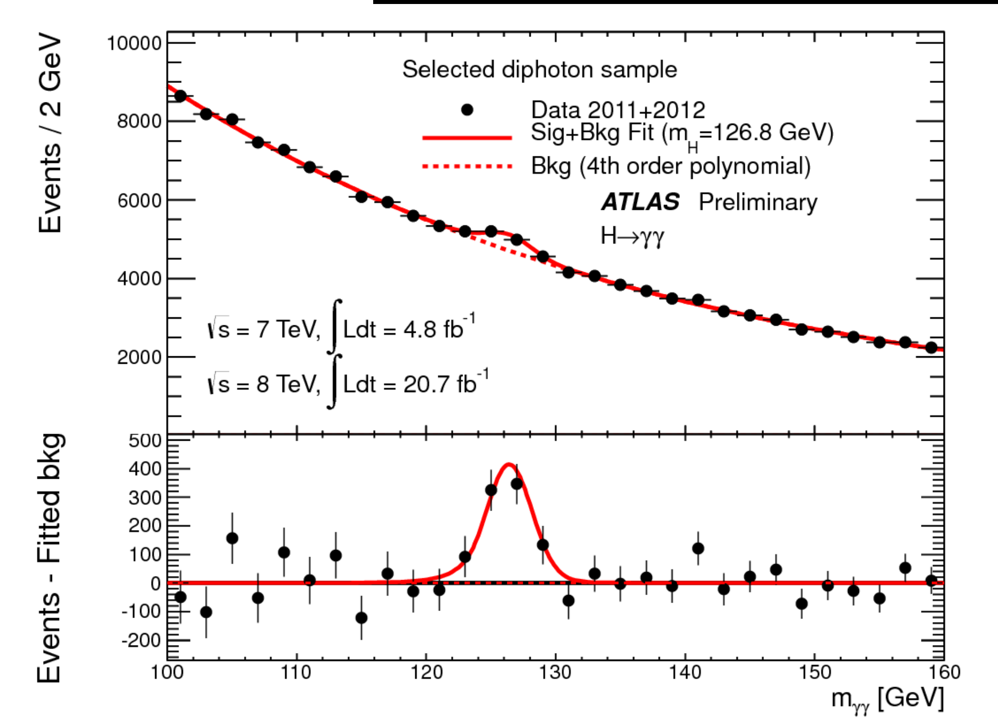
*Only a selection of the available mass limits on new states or phenomena is shown.

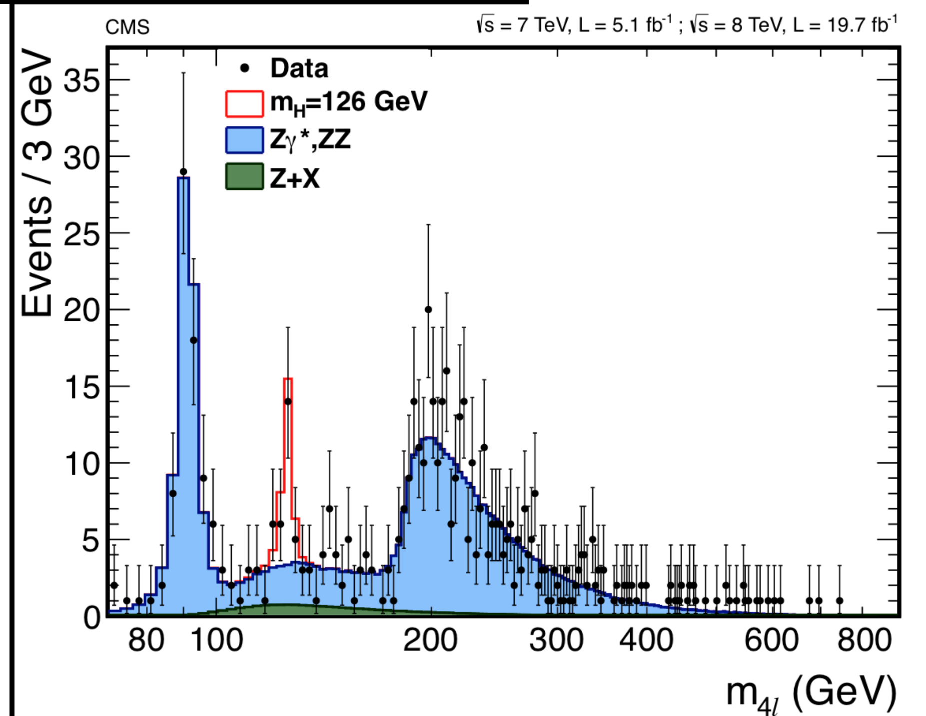
The Higgs Boson

Higgs Boson Discovery



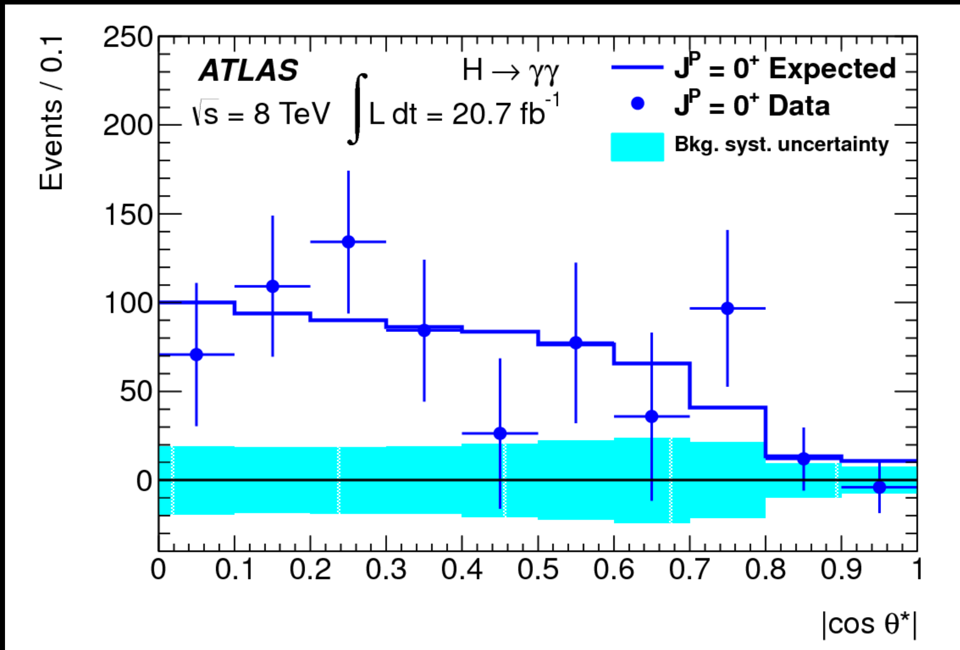


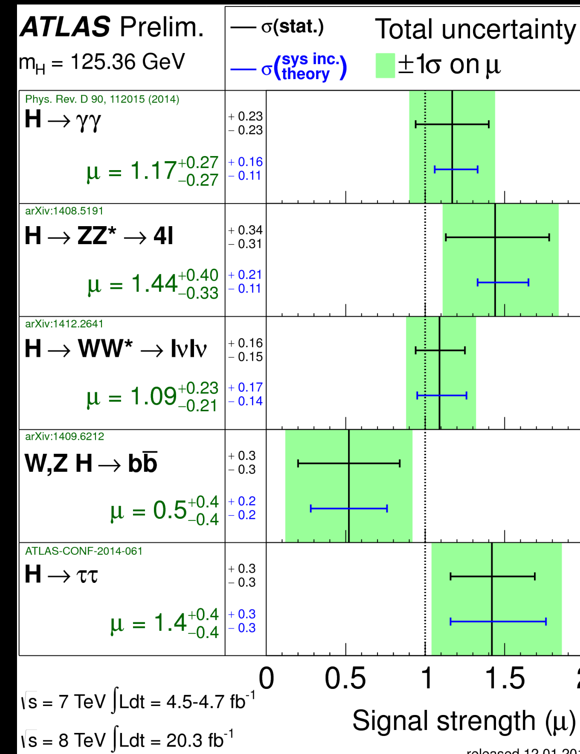




- Both ATLAS and CMS see narrow peak at ~125 GeV in two different decay channels
- Significant signals in two additional channels

Is it the Standard Model Higgs boson?





- spin and parity consistent with 0+
- Decay rates consistent with SM prediction
  - Within current uncertainties of 20-50%
- But: many BSM models include Higgs-like particles
  - Eg, SUSY has multiple higgs

Need for precision measurements to determine nature of Higgs

Summary of Run-1

- LHC machine and detector worked very well!
  - Machine ran at ~half the design energy
- >600 papers published in the past 5 years
  - Surprise #1: Found a new particle!!
    - The only fundamental scalar in Nature (so far)
    - Plays critical role in Standard Model
    - >2500 citations of observation paper per experiment
  - Surprise #2: No other new particles found!
    - No evidence for DM candidate
    - No sign of Supersymmetry or any other new physics yet
    - Intense dialogue between theorists and experimentalists
      - >1000's of citations for SUSY search papers

LHC Roadmap

Run 1: $\sqrt{s}$=7-8 TeV, $\int Ldt$=25 fb^{-1}, pileup $\mu\approx 20$

LS1: phase 0 upgrade

Run 2: $\sqrt{s}\approx 13$ TeV, $\int Ldt\approx 120$ fb^{-1}, $\mu\approx 43$

LS2: phase 1 upgrade

Run 3: $\sqrt{s}\approx 14$ TeV, $\int Ldt\approx 350$ fb^{-1}, μ=50-80

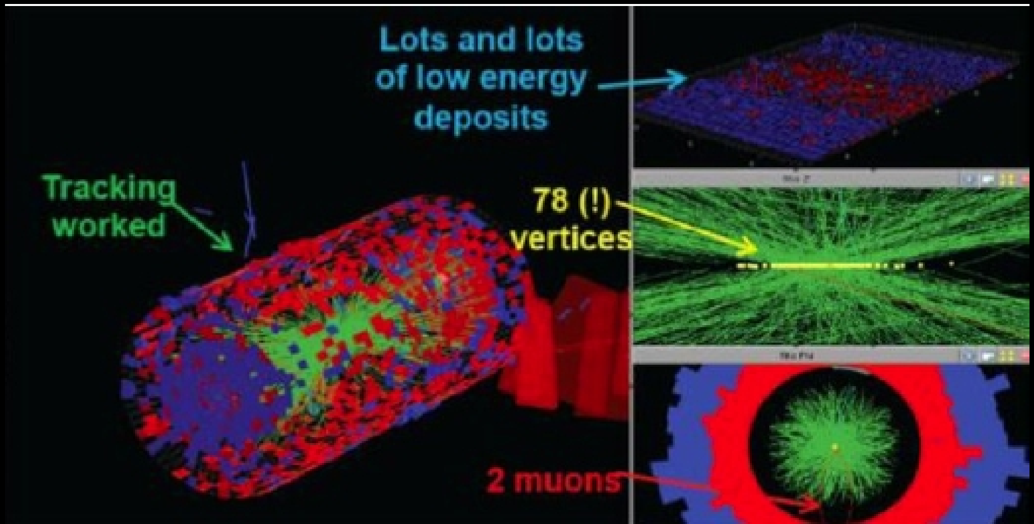
LS3: phase 2 upgrade

HL-LHC: $\sqrt{s}\approx 14$ TeV, $\int Ldt\approx 3000$ fb^{-1}, $\mu\approx 140$-200

(updated by CERN: Dec. 2nd 2013)

Detector Upgrades

- Detectors need to be upgraded to cope with higher luminosity:
  - Improve trigger capabilities
    - better discriminate the desired signal events from background as early as possible in trigger decision
  - Upgrade and/or replace detectors if they:
    - Cannot handle higher rate due to bandwidth limitations
    - Suffer from radiation damage making them less efficient



Detector Upgrades: Phase-0, Phase-I and Phase-II

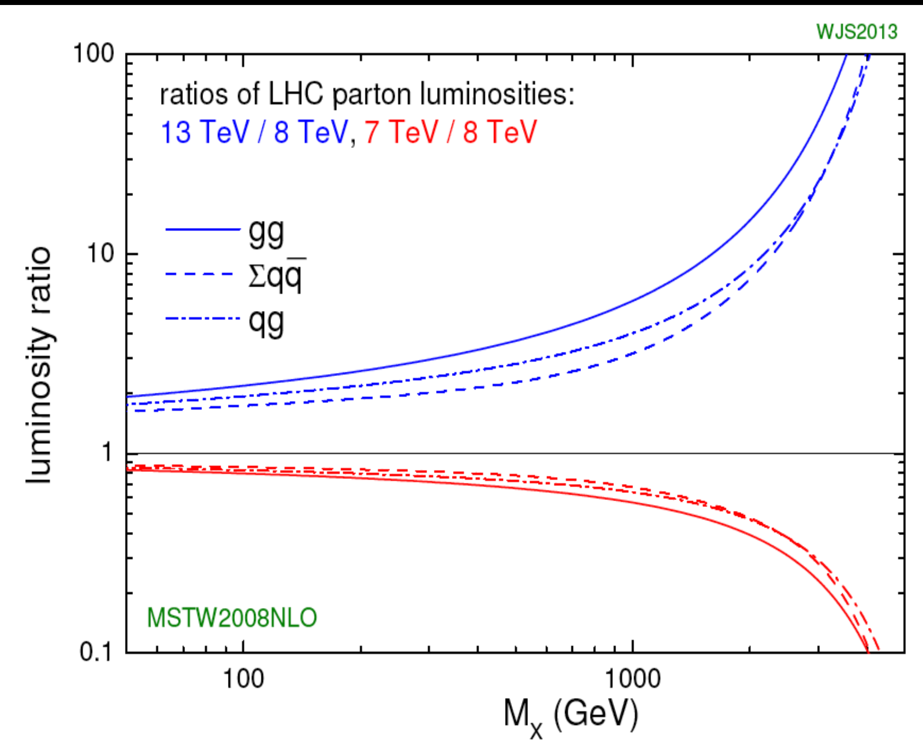
ATLAS

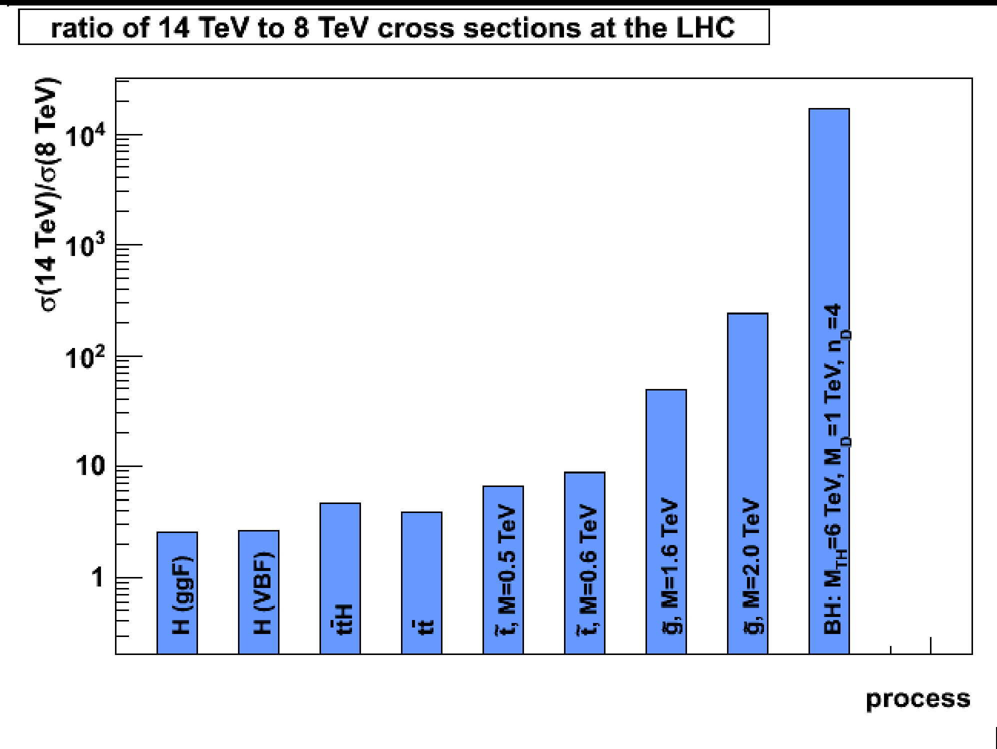
- Phase-0 (now)
  - 4th Si Pixel layer (IBL)
  - Complete muon coverage
  - Repairs (TRT, LAr and Tile)
  - New beampipe and infrastructure updates
- Phase-I (~2018)
  - Fast Track Trigger (FTK)
  - Muon New Small Wheel (NSW)
  - LAr cal. electronics
- Phase-II (~2022)
  - New pixel and strip tracker
  - Calorimeter
  - Muon system
  - Trigger system
  - Computing
  -

CMS

- Phase-0 (now)
  - Complete muon coverage
  - Colder tracker
  - Photodetectors in HCAL
  - New beampipe and infrastructure updates
- Phase-I (~2018)
  - New Si pixel tracker
  - L1 trigger upgrade
  - HCAL electronics
- Phase-II (~2022)
  - New pixel and strip tracker
  - Calorimeter
  - Muon system
  - Trigger system
  - Computing
  -

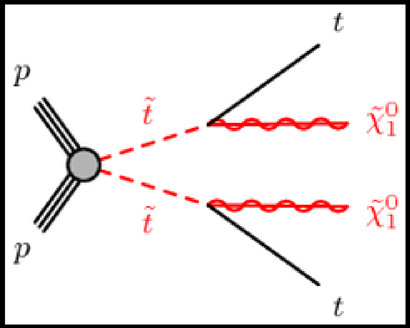
Run-2 Physics Cross Sections

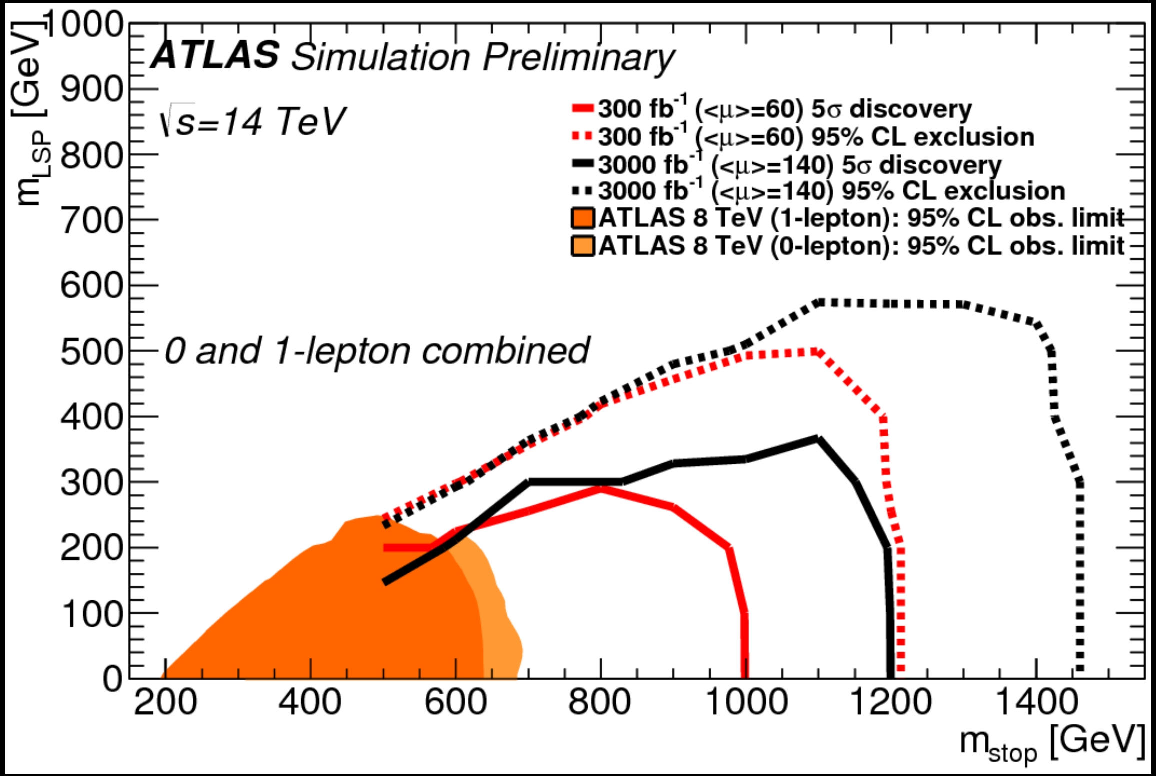




- Increase in cross section by factor ~10 for M~2 TeV
- With a few fb^{-1} discovery of TeV scale particles possible
  - Expect 10 fb^{-1} by end of this year

Future Prospects for SUSY Discovery





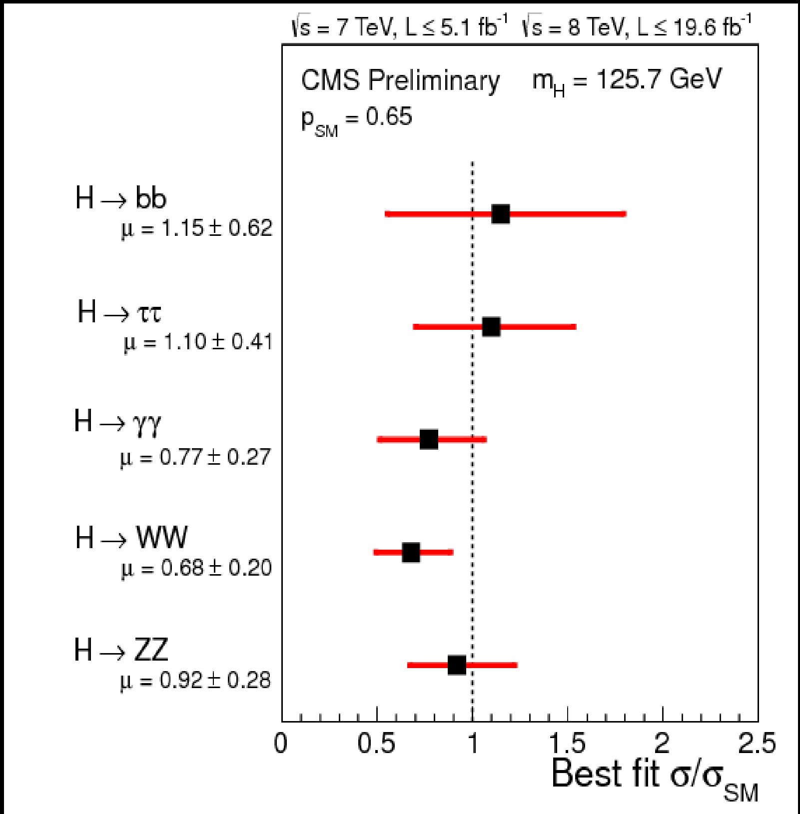
- Run 2 at LHC will approximately double mass reach compared to Run 1
- Significant further increase with 3000 fb^{-1}
- Similar improvements of reach for DM (model dependent)

Higgs Boson Coupling Measurements

Higgs Snowmass report (arXiv:1310.8361)
Deviation from SM due to particles with M=1 TeV

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim -.4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

Current Results on signal strength compared to SM



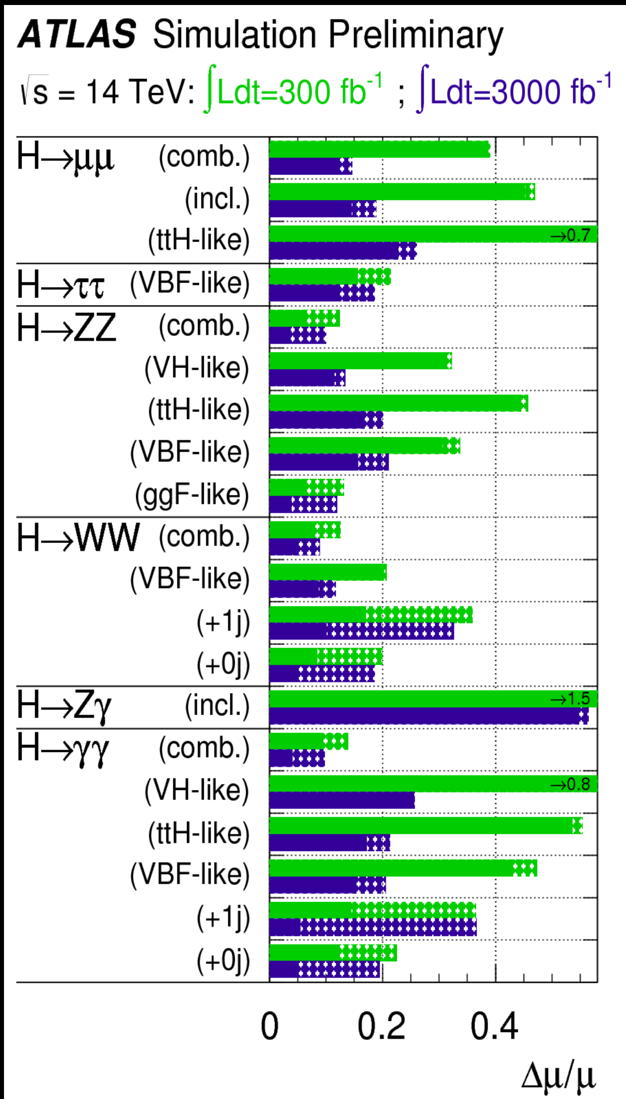
Observable number of Higgs events/exp

	Run-1	HL-LHC
H→4leptons	20	4,000
H→γγ	350	130,000
VBF H→ττ	50	20,000

Higgs studies have only just begun:

- Current precision on about 20-50%
- Need ~3% precision on couplings to probe TeV scale particles
- HL-LHC will increase Higgs dataset dramatically

Future Higgs Boson Coupling Measurements



CMS projections for coupling precision (arXiv:1307.7135)

L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$	BR_{SM}
300	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15]	[6, 8]	[41, 41]	[23, 23]	[14, 18]
3000	[2, 5]	[2, 5]	[2, 4]	[3, 5]	[4, 7]	[7, 10]	[2, 5]	[10, 12]	[8, 8]	[7, 11]

- Future LHC runs will enable precision Higgs physics
  - Couplings measured with 2-8% precision
  - Access to rare decays
    - E.g. how does it couple to muons?

Conclusions I: The Past

- The LHC worked fantastically well
  - after >20 years of design and construction
- Found a new particle consistent with the Higgs boson
  - Program of property measurements is starting
    - With current precision fully consistent with SM Higgs boson
- No other new particles found yet

Conclusions II: The Future

- This was just the beginning!!!
  - High energy running starting this month ($\sqrt{s} \approx 13$ TeV)
  - Increase luminosity by factor ~15 by 2022
    - … and another factor 10 by 2030
    - Major detector upgrade program under way
  - Will probe
    - SUSY, DM and exotics for masses in the multi-TeV range
    - Higgs couplings with 2-8% precision
- LHC has great chance of finding new physics
  - Have worked on completing the SM for >40 years...
    - The Higgs boson has completed the picture

What will we find?