



# Status and Plans for the ATLAS Experiment

- Brief review of 7 & 8 TeV results
- Improvements to ATLAS for 13 TeV running
- Physics prospects for Run II
- Ultimate goals for ATLAS at the HL-LHC

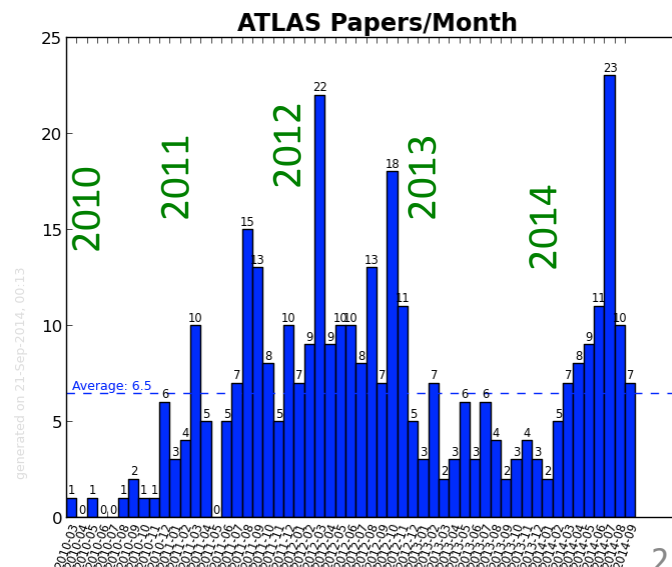
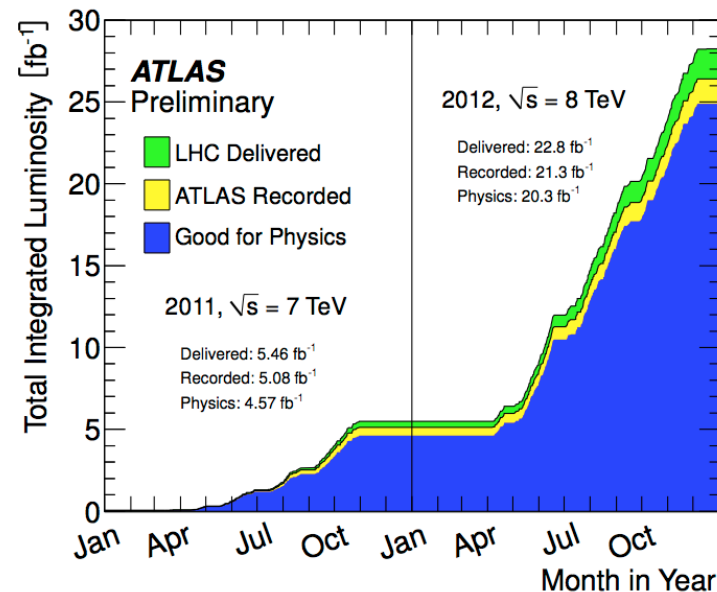
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University of Toronto  
Miami2014



# Run I in a Nutshell



- ATLAS recorded  $\sim$ all collisions
- 90% end up in physics papers
  - 0.05 fb<sup>-1</sup> (7 TeV, 2010)
  - 4.6 fb<sup>-1</sup> (7 TeV, 2011)
  - 20.6 fb (8 TeV, 2012)
- Publications
  - 350 papers published (100+ in prep)
  - 600 conference notes
  - 660 conference talks (+ this one)





# The ATLAS/LHC Physics program



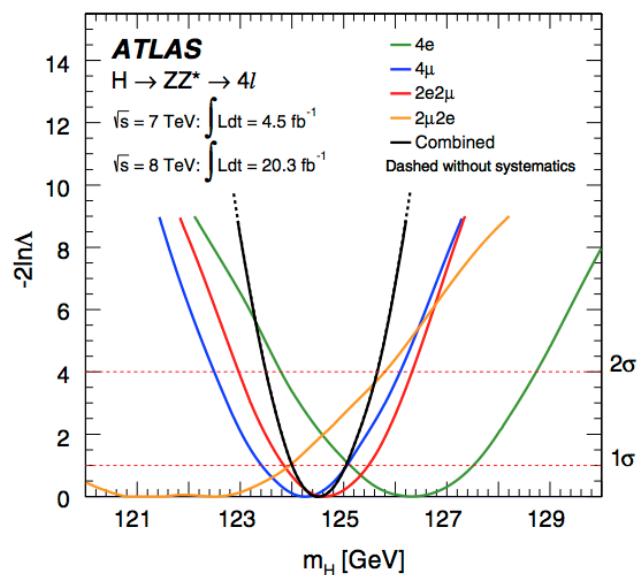
- Understand the Higgs Boson
  - Mass, CP, Standard Model couplings, ...
- Measure the properties of  $t$ ,  $W$  and  $Z$ 
  - They couple most strongly to the Higgs
- Search for new TeV-scale particles
  - What is the importance of this scale to SM?
- Find/understand any Standard Model anomalies



# The Higgs Boson



- We hoped for discovery – and got more
  - Higgs mass  $\sim 125$  GeV – as predicted (sigh..)
  - Higgs mass =  $(125.4 \pm 0.4 \pm 0.2)$  GeV (precise!)
  - Spin-parity properties consistent with  $0^+$  ...



Currently 40 candidates/channel

Run II expect  $\sim 500$ /channel





# Higgs Couplings

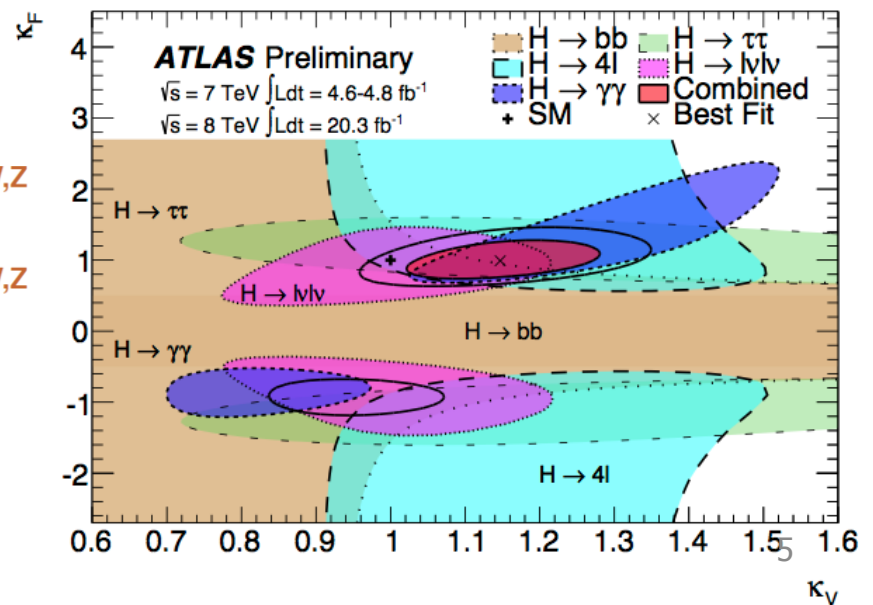
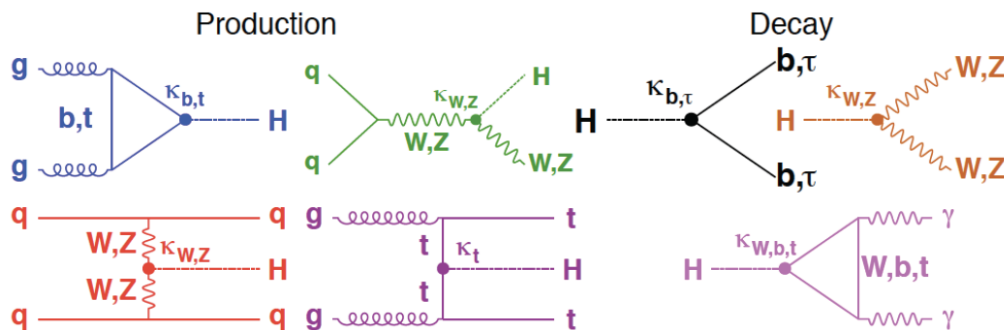
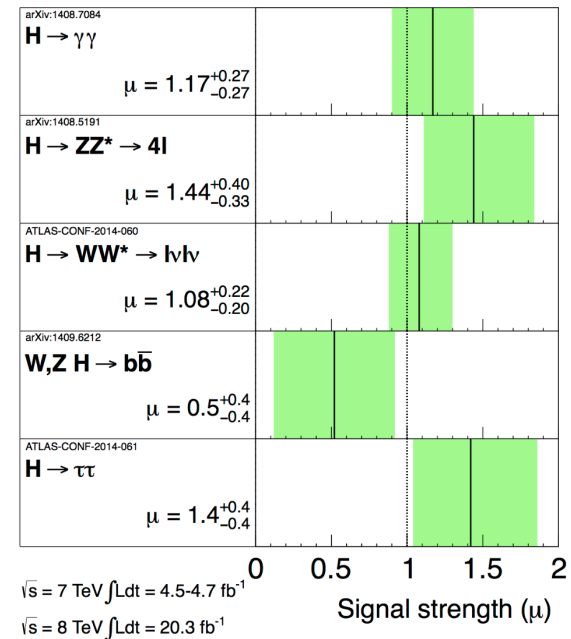
- Higgs couplings falling into place
  - Model dependent ratios to the SM
  - Model independent global fits
- Reduce assumptions as get more data

ATLAS Preliminary

$m_H = 125.36 \text{ GeV}$

Total uncertainty

$\pm 1\sigma$  on  $\mu$

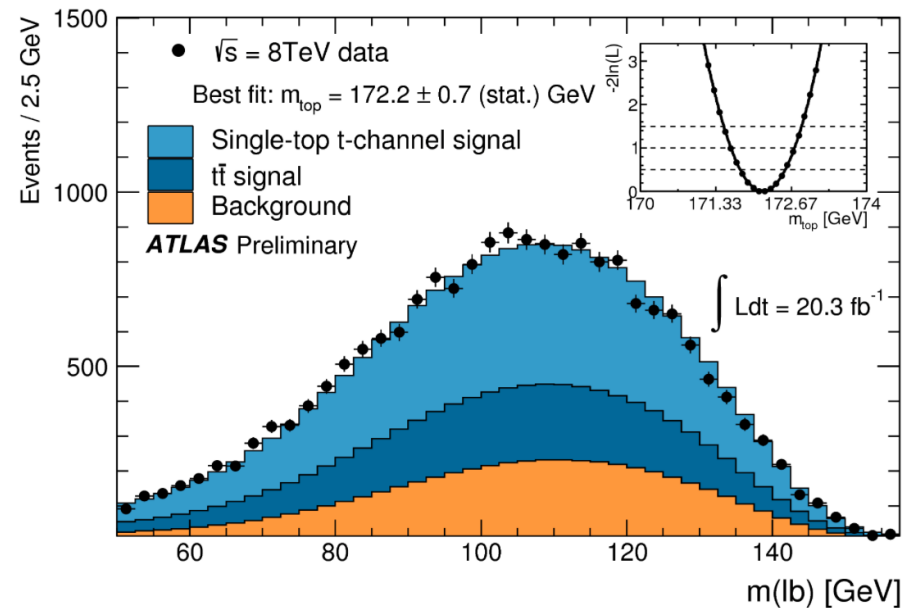
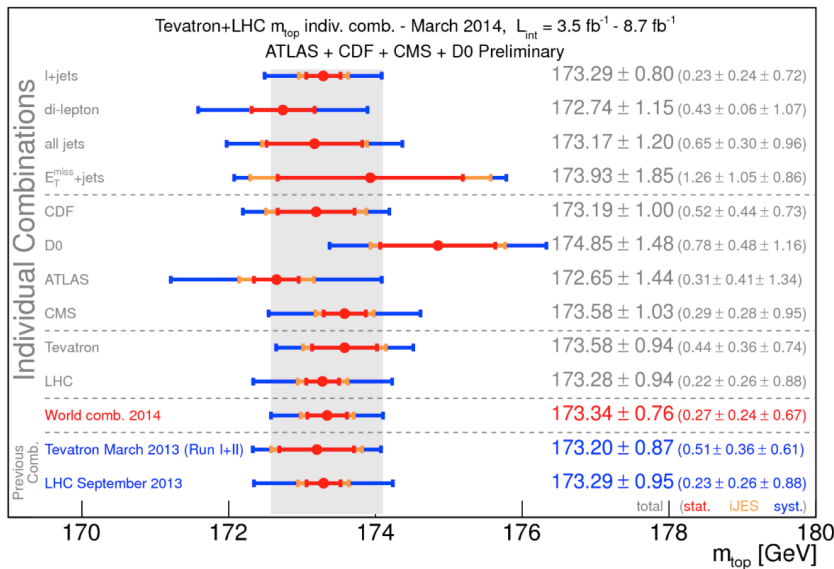




# The Top Quark



- The LHC is the 'real' top factory
  - Production cross-sections teaching us about proton structure
- Top quark mass still an important SM ingredient even with  $m_H$ 
  - Tour de force: measuring top mass in single-top final state
  - Systematics dominate, but also th. (pole vs. QCD mass:  $\Delta \sim 0.3$  GeV)



ATL-CONF-2014-008

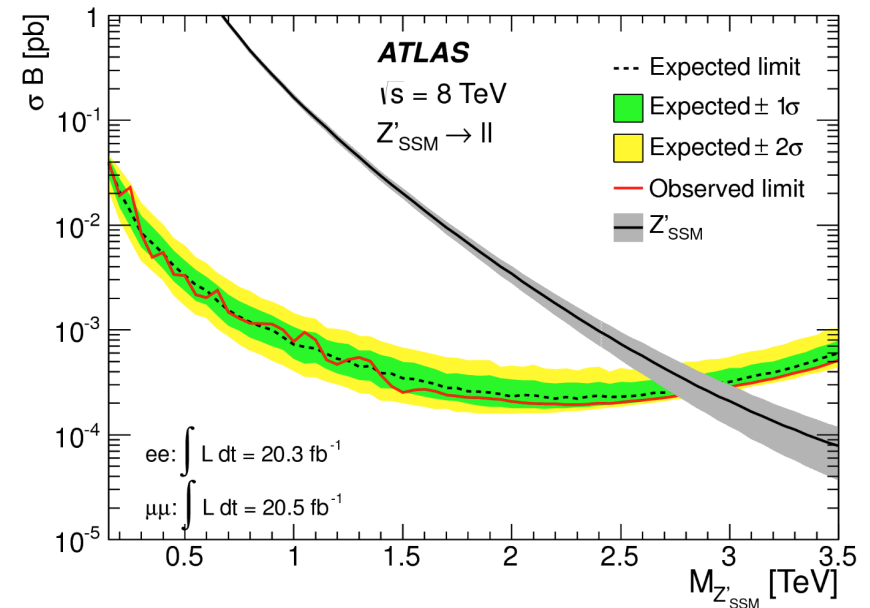
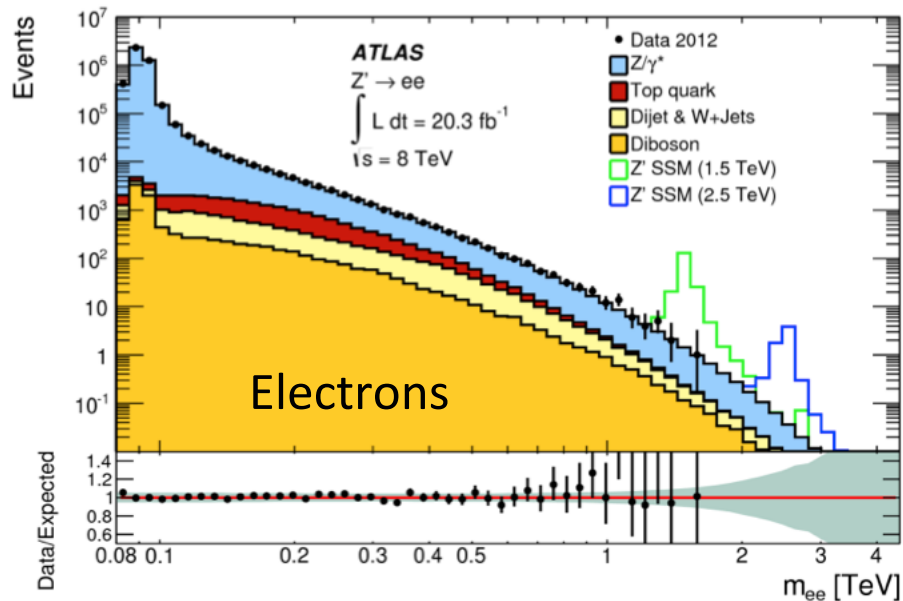
ATL-CONF-2014-055



# Z' Searches



- **Electrons:**  $E_T > 40,30$  GeV ( $|\eta| < 1.37, 1.52 < |\eta| < 2.47$ )
  - Acceptance \*  $\epsilon_{ID} = 72\%$
- **Muons:**  $E_T > 25,25$  GeV ( $|\eta| < 1, 1.3 < |\eta| < 2$ )
  - Acceptance \*  $\epsilon_{reco} = 46\%$



Phys Rev D 90 052005 (2014)

$m_{Z'} > 2.9 \text{ TeV}$   
(also  $m_{W'} > 3.2 \text{ TeV}$ )



# Many Other Exotics Searches



## ATLAS Exotics Searches\* - 95% CL Exclusion

Status: ICHEP 2014

ATLAS Preliminary

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

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

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

Mass scale [TeV]



# Summary of Supersymmetry Searches

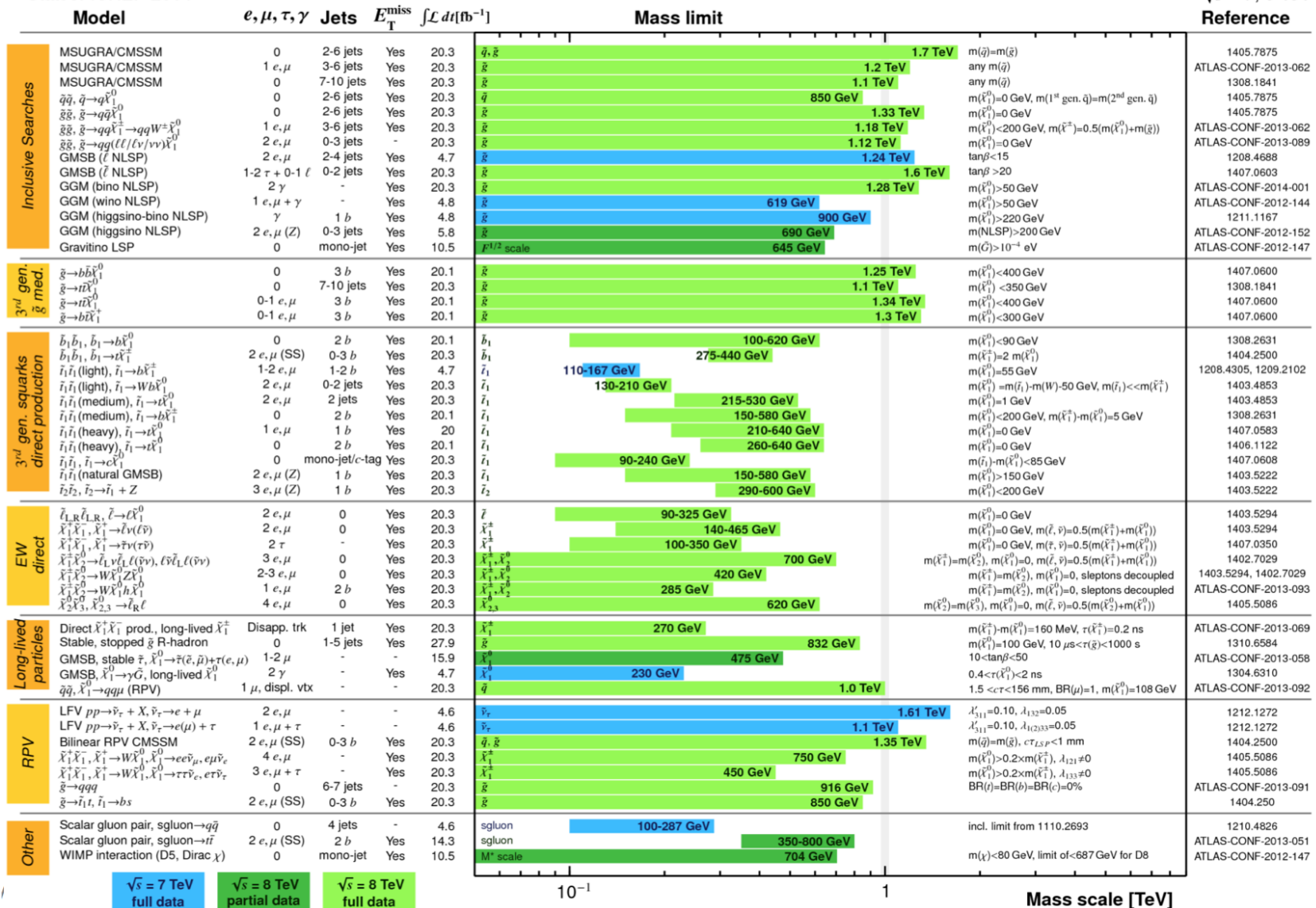


## ATLAS SUSY Searches\* - 95% CL Lower Limits

Status: ICHEP 2014

ATLAS Preliminary

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



\*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus  $1\sigma$  theoretical signal cross section uncertainty.

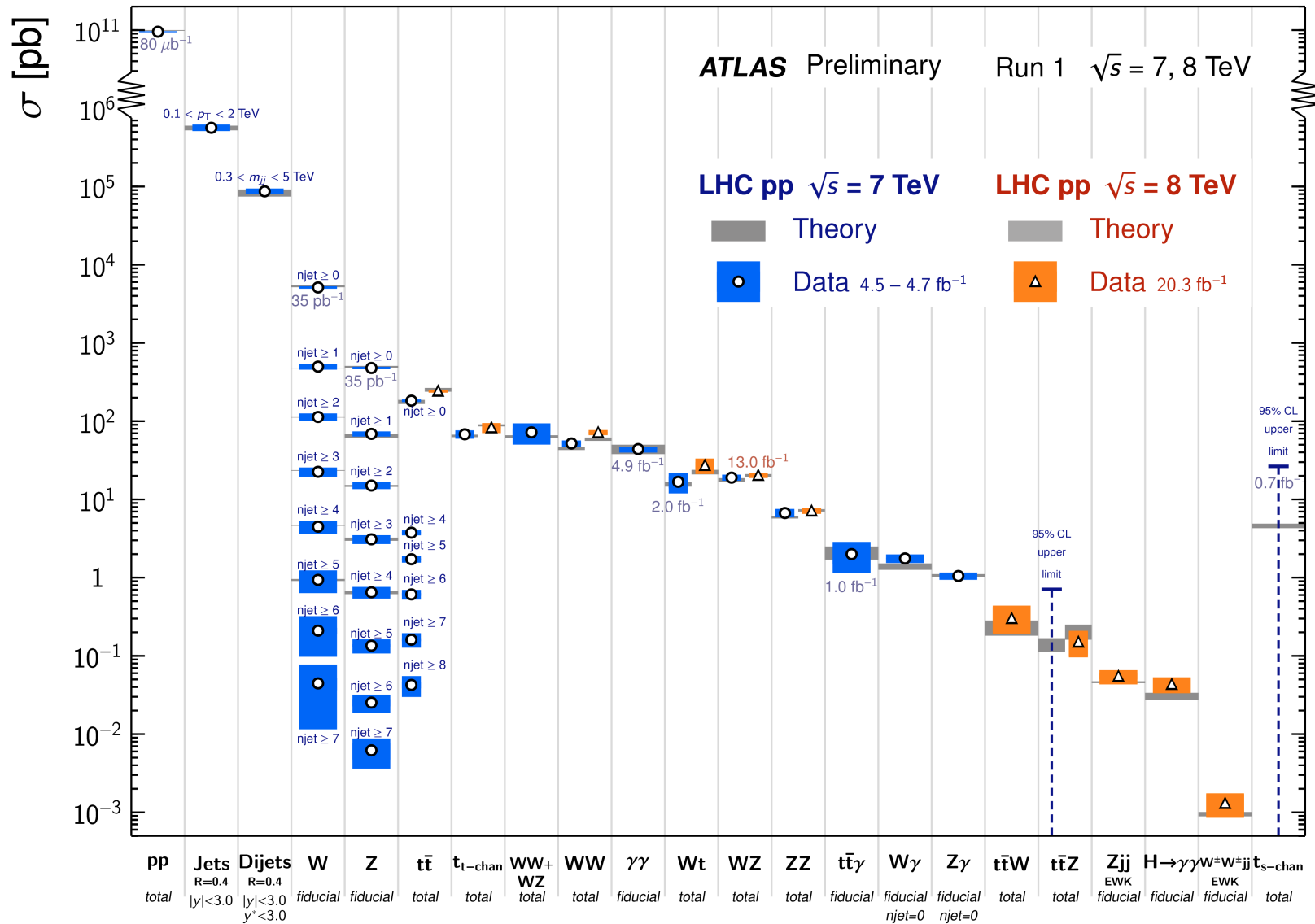


# Not Least: Understand All Accessible SM Processes



## Standard Model Production Cross Section Measurements

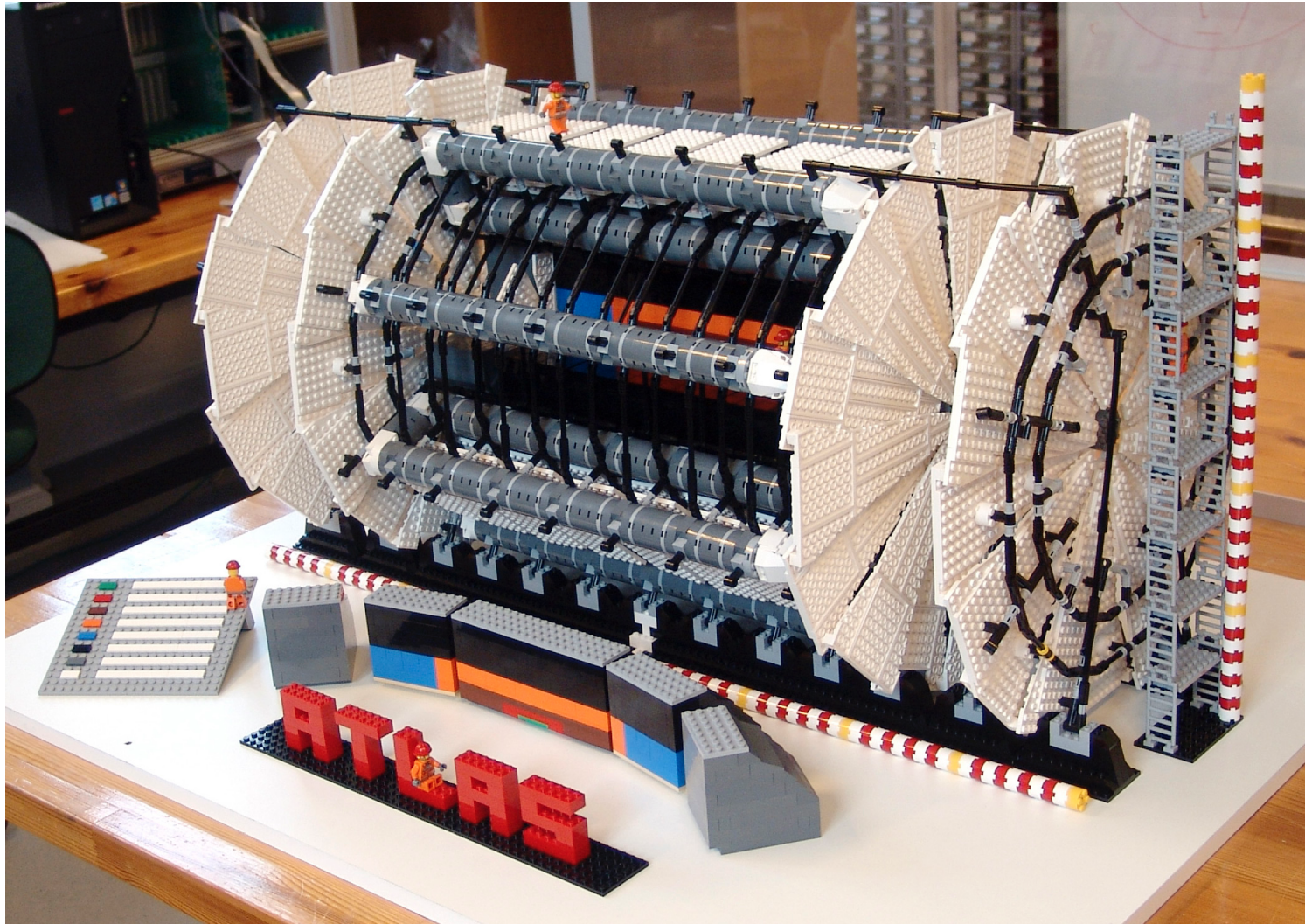
Status: July 2014







# Preparing ATLAS for the Future



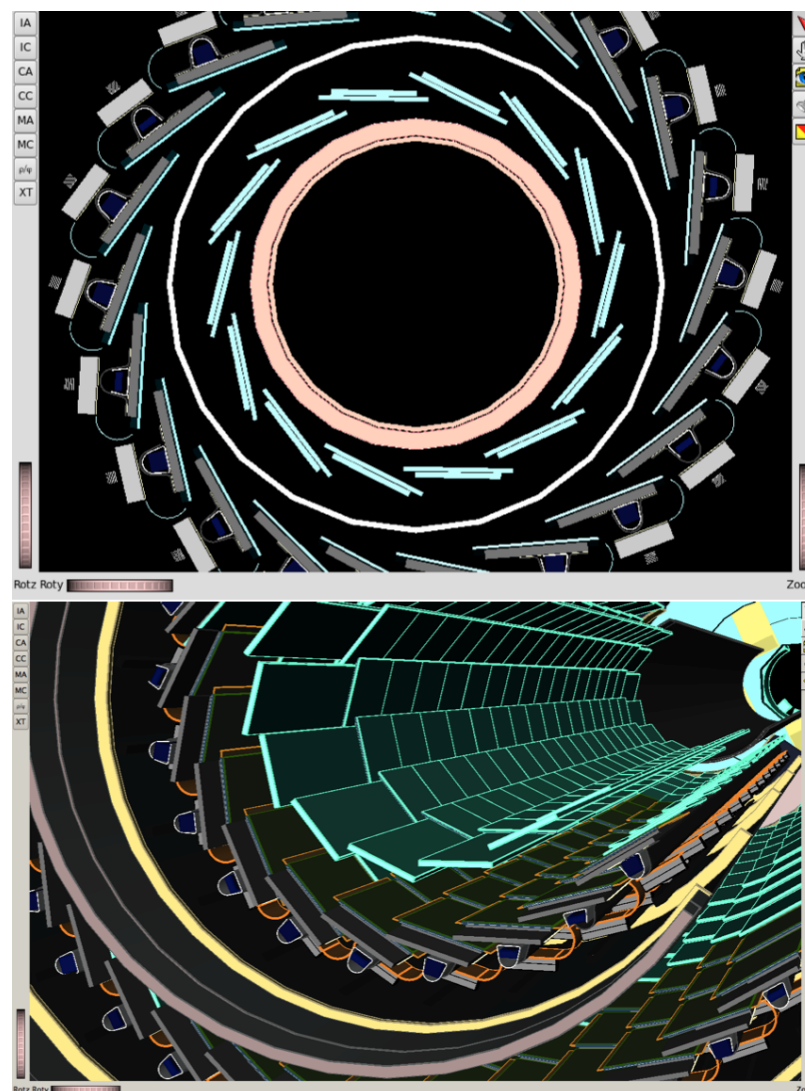
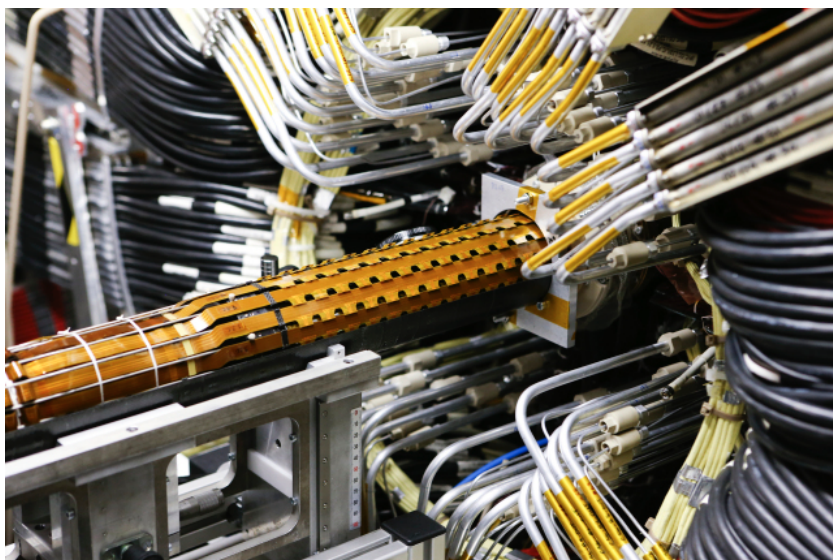




# The ATLAS Insertible *B* Layer (IBL)



- Additional layer of pixels
- Built/installed during 2013-14
- Improved radiation tolerance
  - Will survive to  $300 \text{ fb}^{-1}$



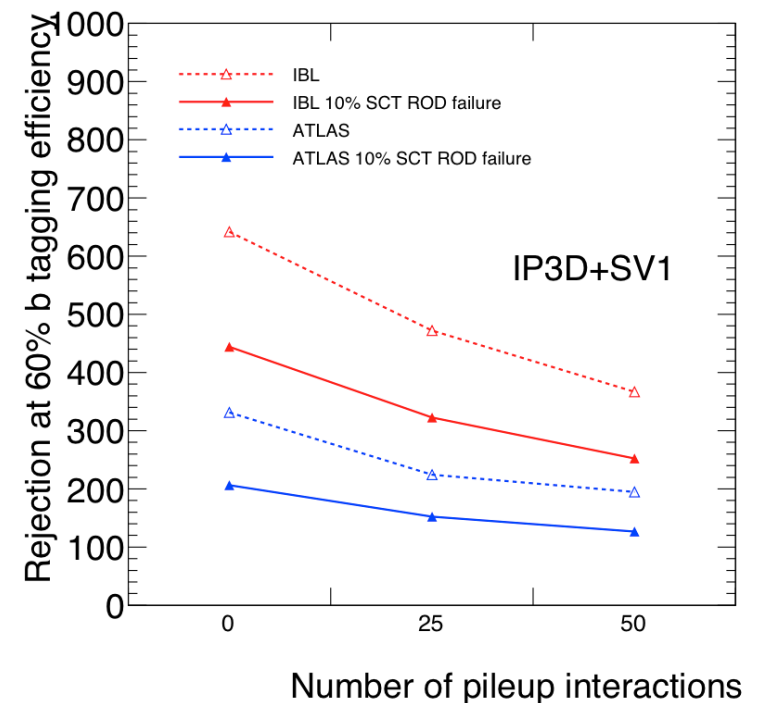




# The ATLAS Insertible *B* Layer (IBL)



- IBL mission:
  - Improved impact parameters
  - Insurance against radiation damage in original pixel layers
  - More robust *B* tagging especially if remainder of tracking suffers
    - Failure of SCT/Pixel module gp.
    - High pileup  $\rightarrow$  TRT saturation

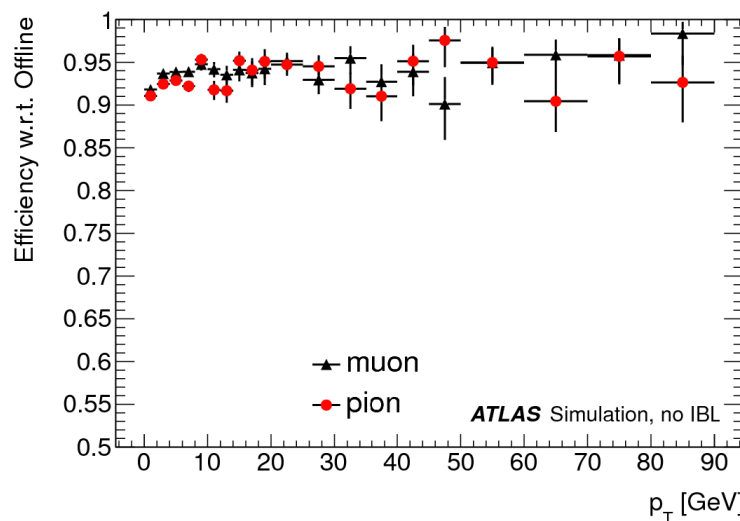
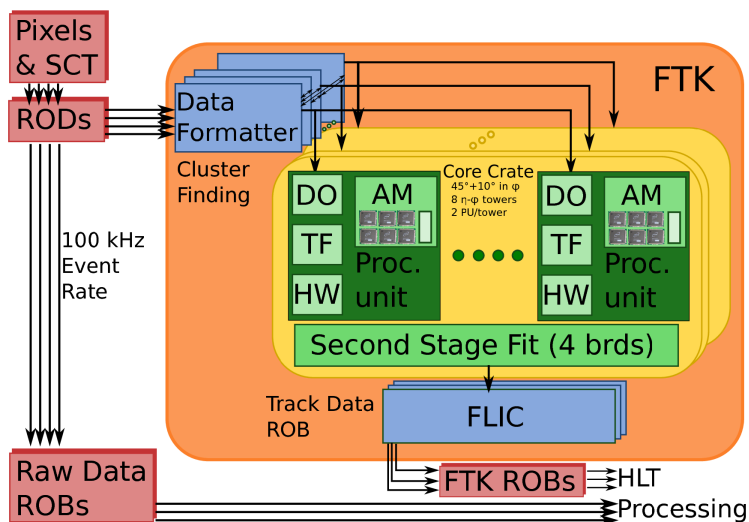


- Installed with  $> 99.9\%$  live channels
- Routinely readout in cosmic ray running



# Fast Track Trigger (FTK)

- As luminosity increases, trigger must become more selective
- Push global tracking to Level 1 (100 kHz and  $< 100\mu\text{s}$ )
  - Requires dedicated hardware track finder (FTK)
  - Receives all SCT/pixel hits
  - Computes helix parameters (lookup tables in associative memory)
  - Provides full track fit for electron, muon (other?) trigger decisions
- Implementation already well underway
  - Key to maintaining single lepton  $p_T$  thresholds
  - Does not require shutdown or (further) detector modifications





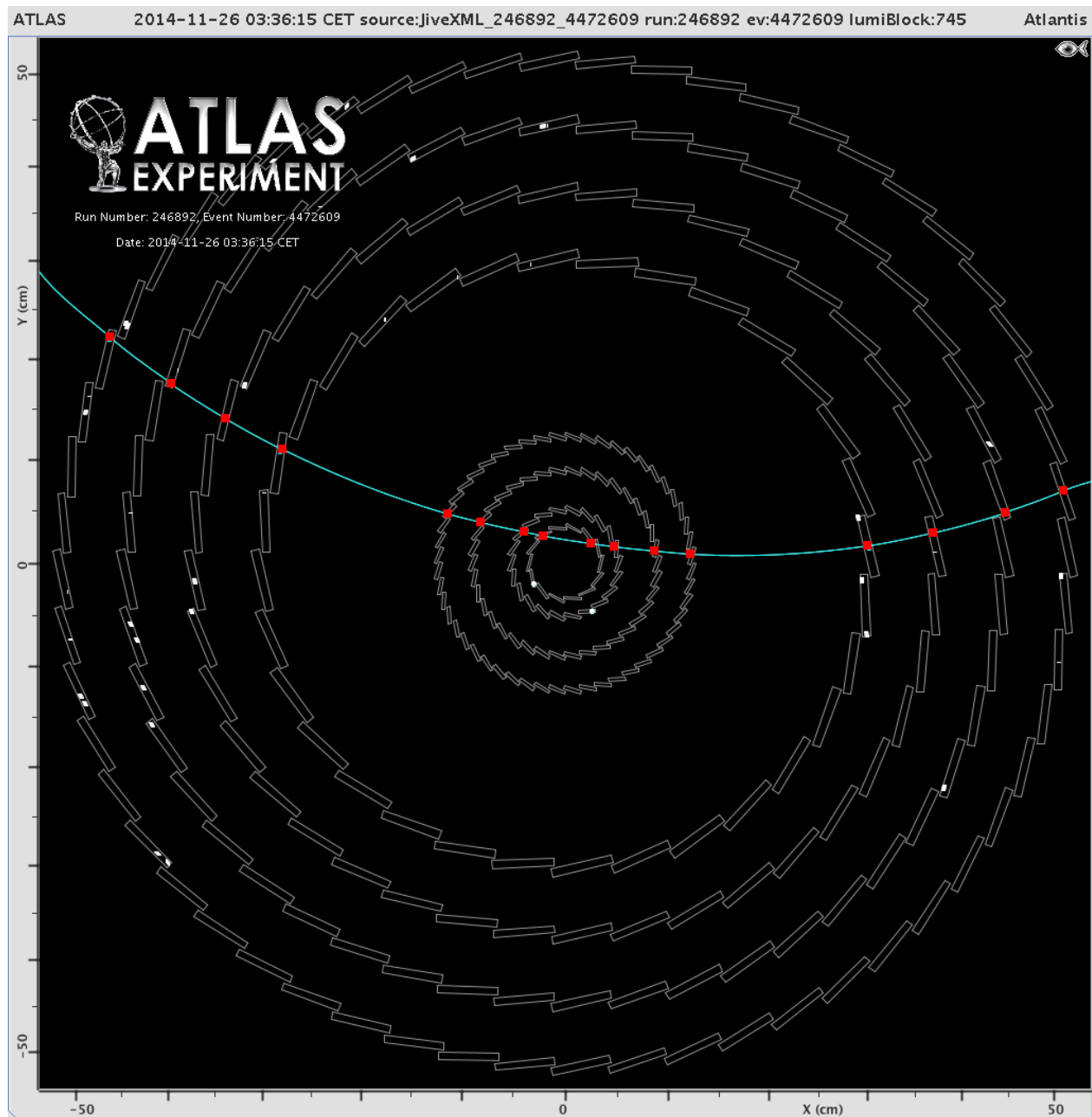
# Milestone Commissioning Weeks



	M1	M2	M3	M4	M5	M6	<b>M7 - Cosmic Run Nov 24<sup>th</sup> - Dec 8<sup>th</sup></b>
	Feb 17– Feb 23	Mar 31– Apr 4	May 19– May 23	Jul 7– Jul 11	Sep 8– Sep 12	Oct 13– Oct 17	Full Shiftcrew; all detectors; B field ON from Dec 1st.
PIX				X <sup>1</sup>	X <sup>2</sup>		<sup>1</sup> TDAQ integration, using simulated events <sup>2</sup> detector cooled to nominal operating temperature
IBL				X	X <sup>2</sup>		<sup>2</sup> All staves in M6
SCT				X	X <sup>2</sup>		<sup>2</sup> Barrel + Endcap in M6
TRT		X					
LAR				X			
TIL				X			
MBTS				X			Both sides in M5
L1Calo	X			X	X	X <sup>2</sup>	<sup>2</sup> L1Topo trigger commissioned fully in trigger system
CSC	X				X	X	
MDT	X						
RPC		X <sup>1</sup>	X <sup>1</sup>				<sup>1</sup> TDAQ integration. HV for ~ 1 sector
TGC	X					X <sup>2</sup>	<sup>2</sup> Out for chamber replacements
BCM		X					
ALFA						X	
LUCID							
Lumi					X		



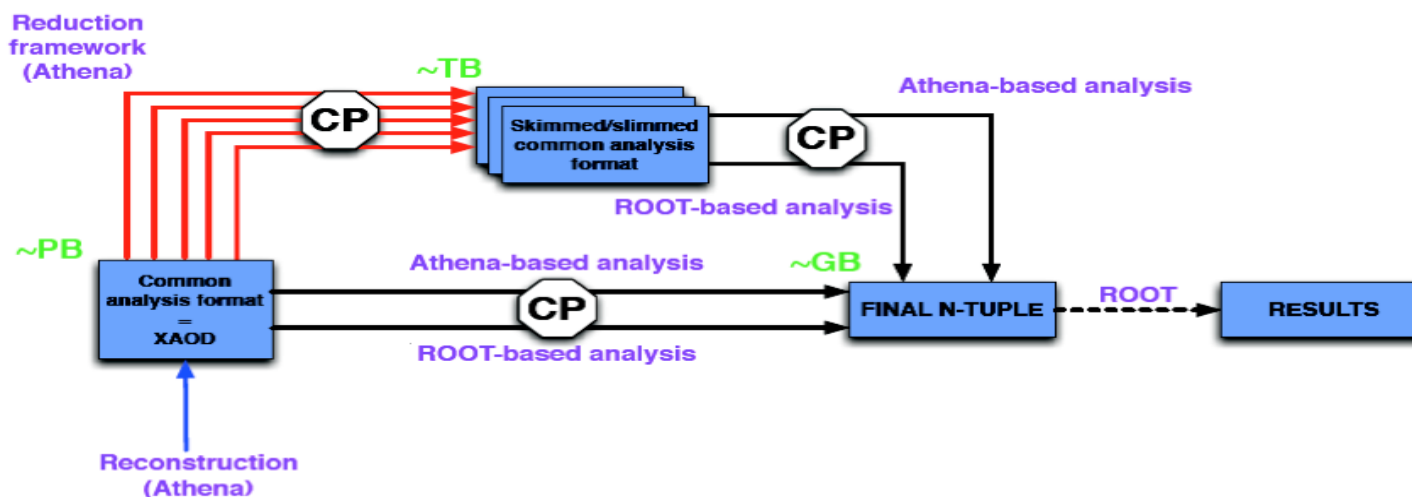
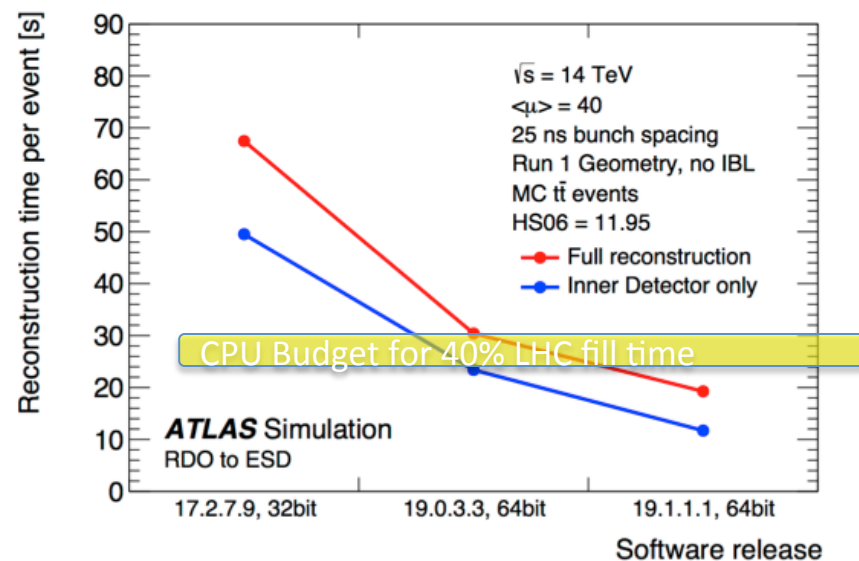
# Cosmic Track Reconstructed with IBL





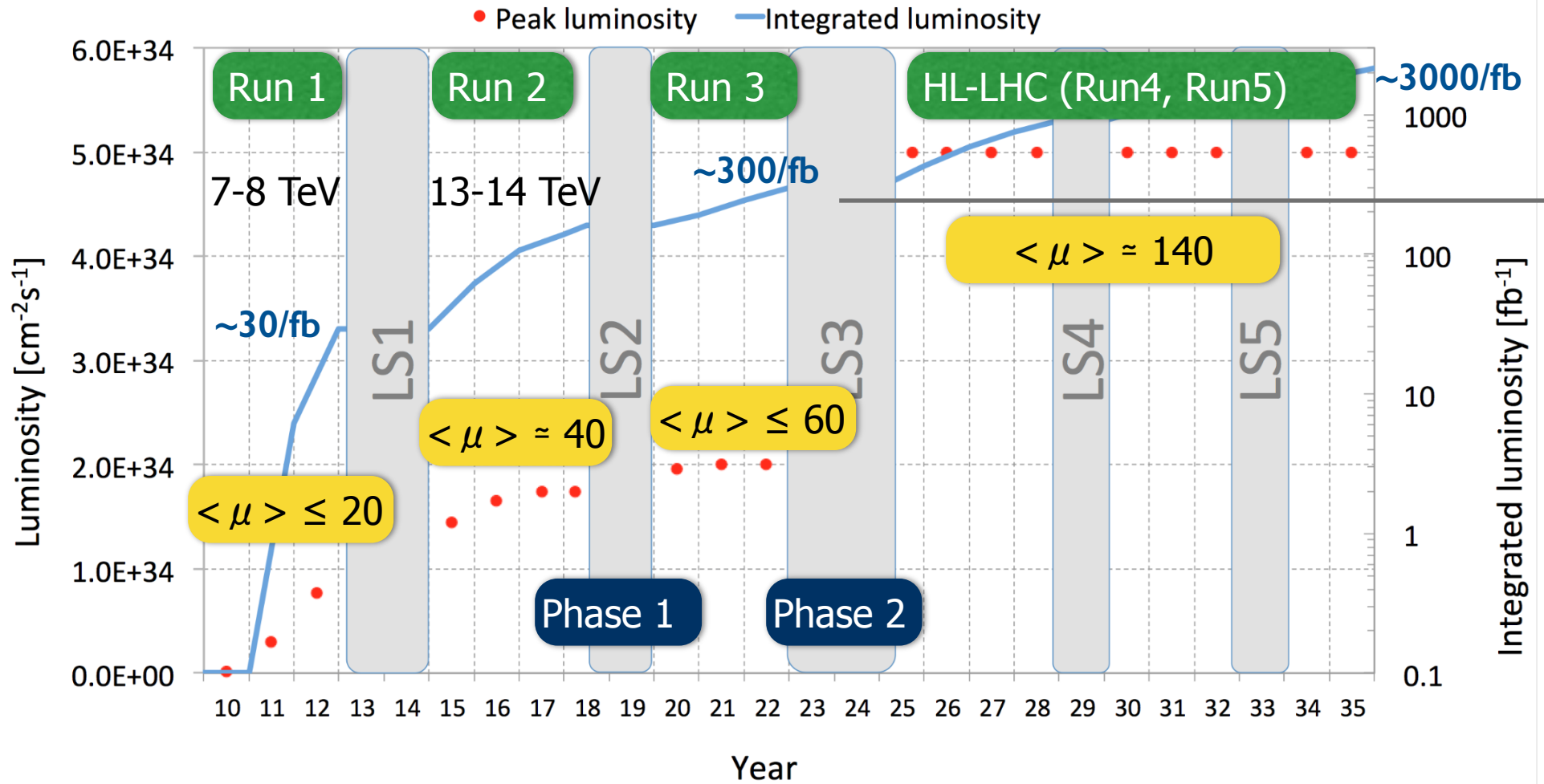
# Computing, Software and Analysis

- Physics algorithm and mathematical fitting changes
  - Factors of 3+ improved speed
  - Robustness against pileup
- Root readable mini-DSTs
- Reducing disk usage
  - Computing may limit analysis





# LHC Operating Parameters





# Jet Reconstruction Improvements

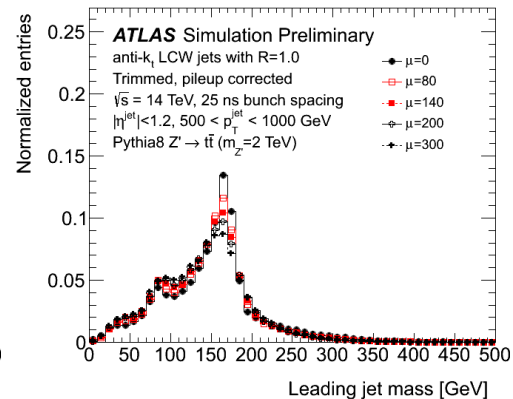
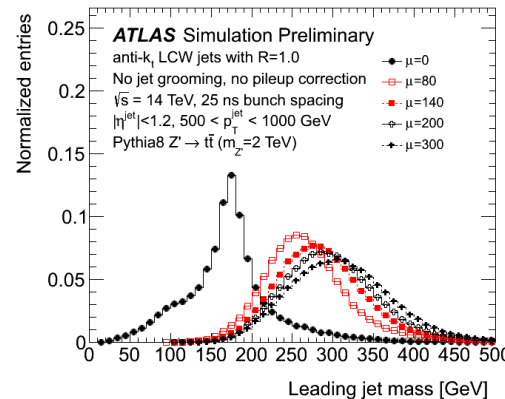
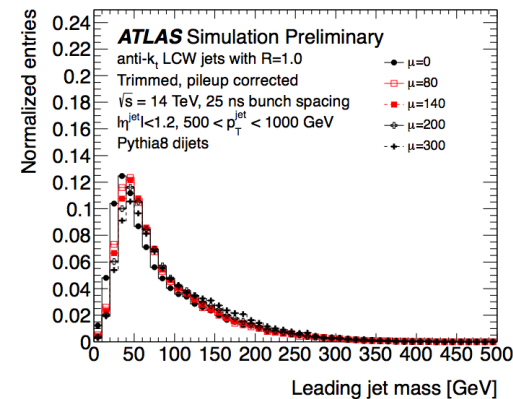
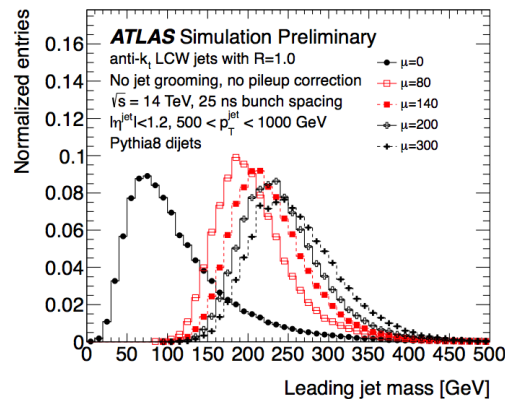
- Discriminate jets from hard-scatter and pile-up
  - Use tracking to remove jets from different primary collision points
  - Energy corrections restore scale and improve jet resolution

QCD background

$$Z' \rightarrow t\bar{t}$$

Uncorrected

Corrected

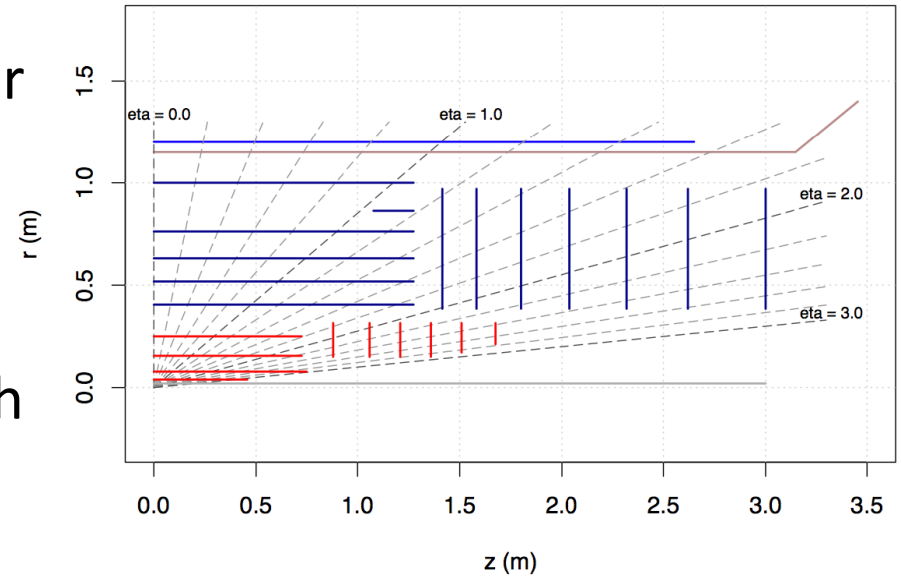




# The ATLAS Inner Tracker upgrade

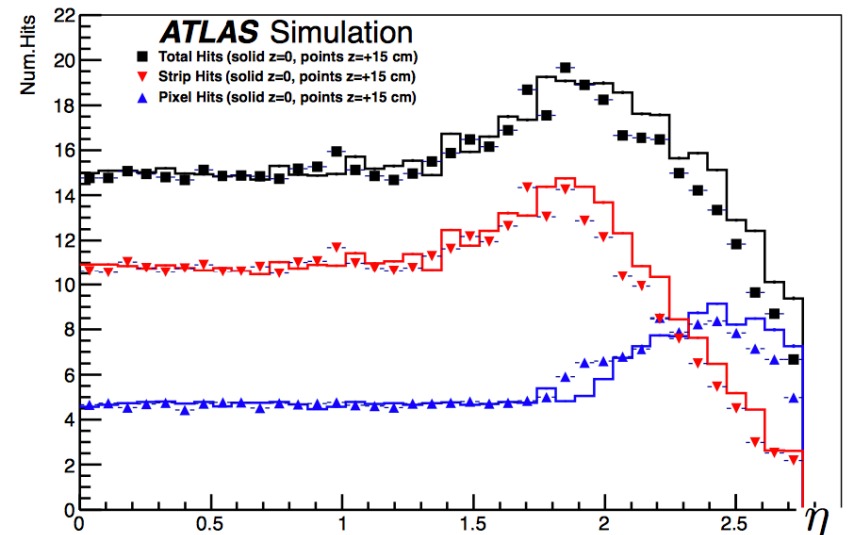


- For HL-LHC replace full inner tracker
  - Design uses all solid-state sensors
    - 4 barrels of pixels
    - 6 barrels of strips
  - Full coverage to  $|\eta| < 2.5$
- Maintain tracking performance with increased pileup



Track parameter $ \eta  < 0.5$	Existing ID with IBL no pile-up $\sigma_x(\infty)$	Phase-II tracker 200 events pile-up $\sigma_x(\infty)$
Inverse transverse momentum ( $q/p_T$ ) [TeV]	0.3	0.2
Transverse impact parameter ( $d_0$ ) [ $\mu\text{m}$ ]	8	8
Longitudinal impact parameter ( $z_0$ ) [ $\mu\text{m}$ ]	65	50

- Will take 7-8 years to build
  - Start soon if needed for 2023 installation



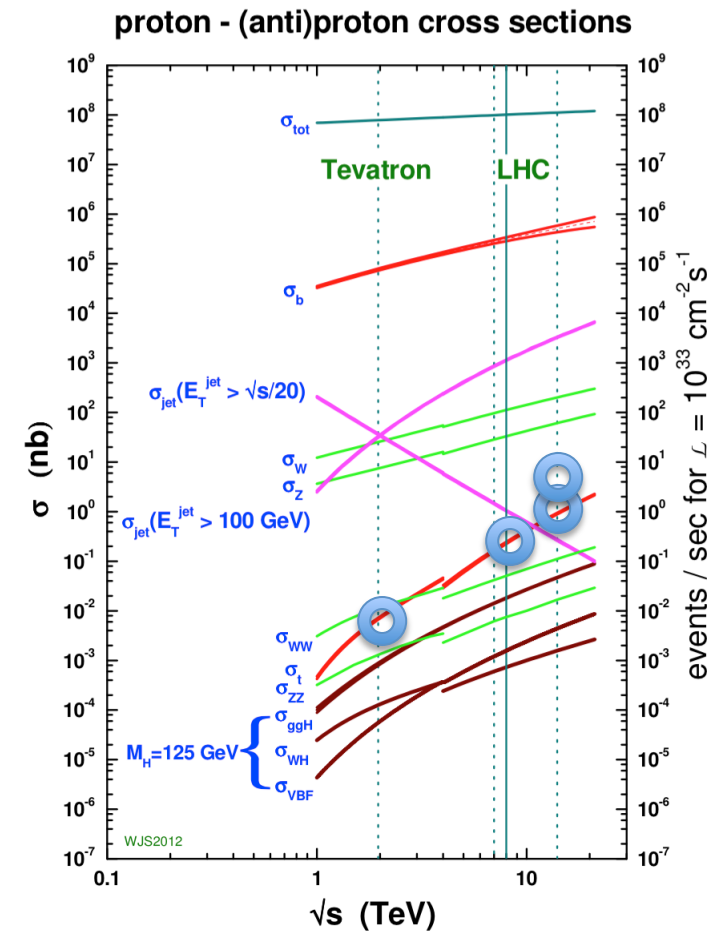




# Physics Reach for Run-II and Beyond



- Energy increase:
  - Tevatron  $\rightarrow$  LHC-I:  $\Delta \sqrt{s} = 6 \text{ TeV}$
  - LHC-I  $\rightarrow$  LHC-II:  $\Delta \sqrt{s} = 5-6 \text{ TeV}$
- Luminosity increase:
  - Tevatron  $\rightarrow$  LHC-I:  $\times 10$  (to  $7 \times 10^{33}$ )
  - LHC-I  $\rightarrow$  LHC-II:  $\times 2$  (to  $1.5 \times 10^{34}$ )
- LHC-I  $\rightarrow$  LHC-II bigger jump than LHC-III
- From:
  - $1 t\bar{t}$  events/s at Tevatron
  - $2 t\bar{t}$  events/s at LHC-I
  - $13 t\bar{t}$  events/s at LHC-II
  - $40 t\bar{t}$  events/s at LHC-III

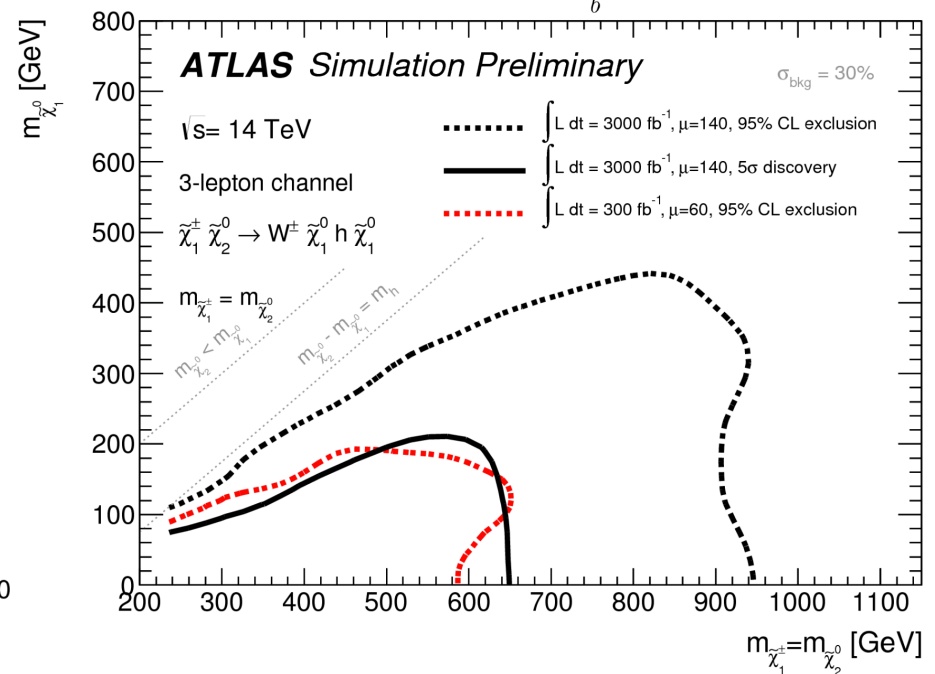
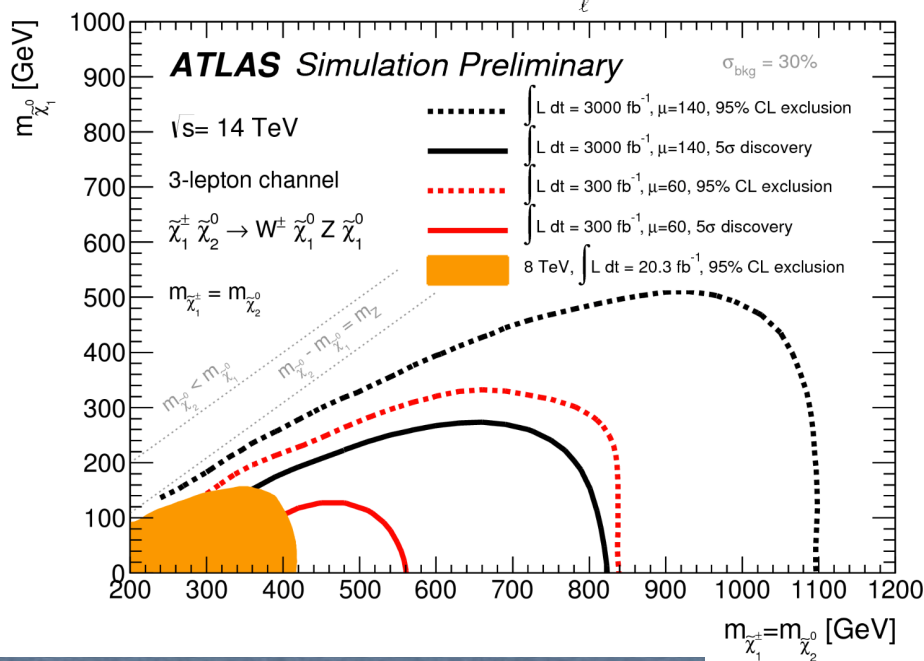
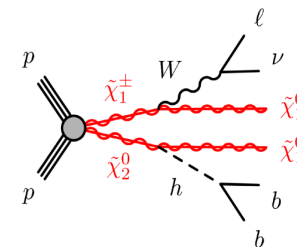
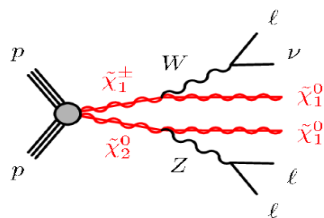




# Electroweak SUSY at Run II and HL-LHC



- Strongly produced SUSY has all but priced itself out of the market
- Neutralinos could still explain the naturalness of the TeV scale
- Run II ++ will cover the remaining phase space





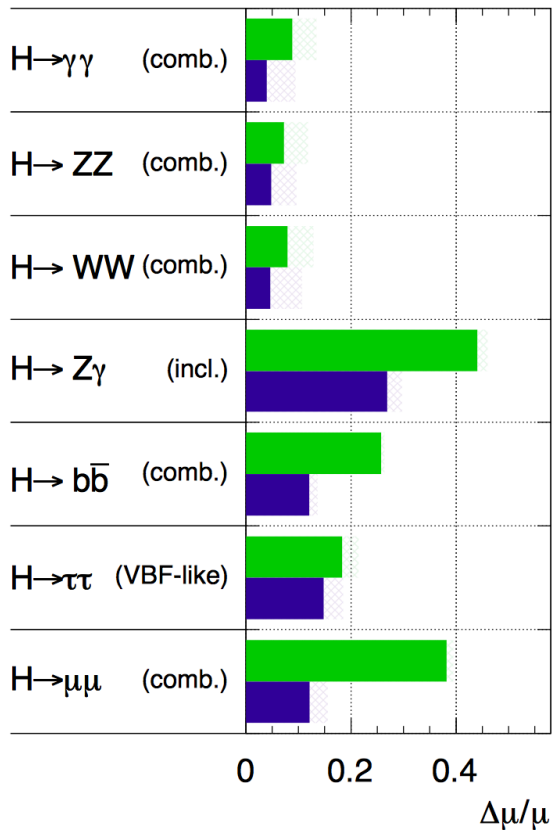
# Prospects for Higgs Coupling Improvements



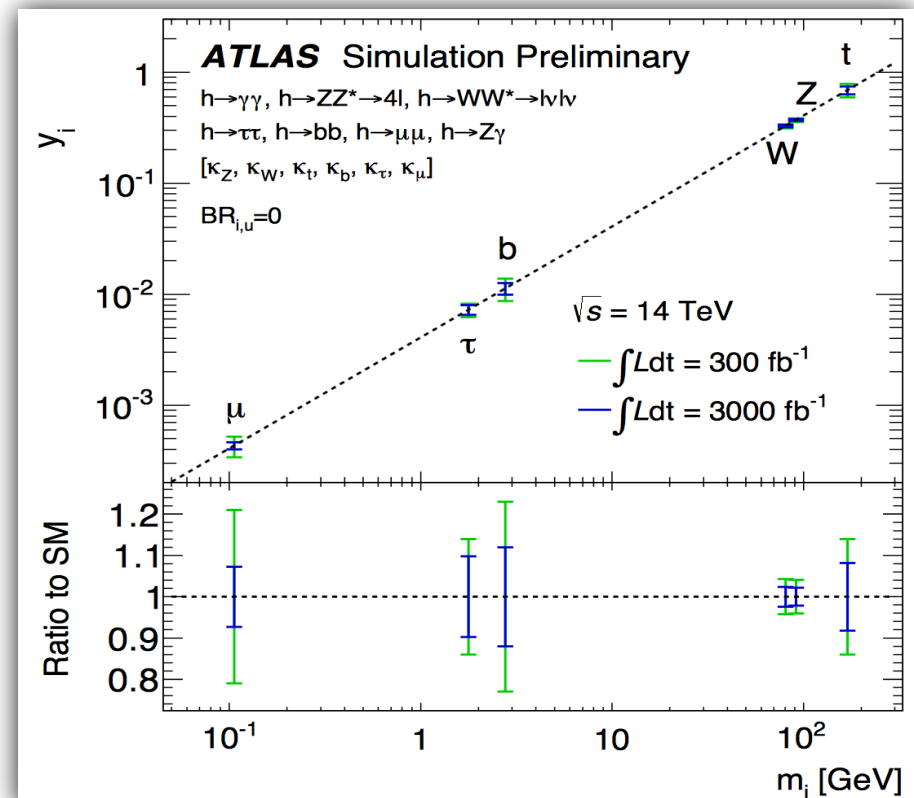
- Pin down SM couplings or reveal anomalies

**ATLAS Simulation Preliminary**

$\sqrt{s} = 14$  TeV:  $\int L dt = 300 \text{ fb}^{-1}$ ;  $\int L dt = 3000 \text{ fb}^{-1}$



$$\frac{\sigma \cdot B(gg \rightarrow H \rightarrow \gamma\gamma)}{\sigma_{\text{SM}}(gg \rightarrow H) \cdot B_{\text{SM}}(H \rightarrow \gamma\gamma)} = \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

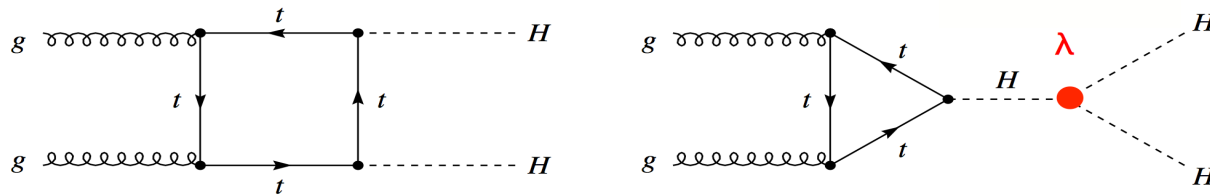




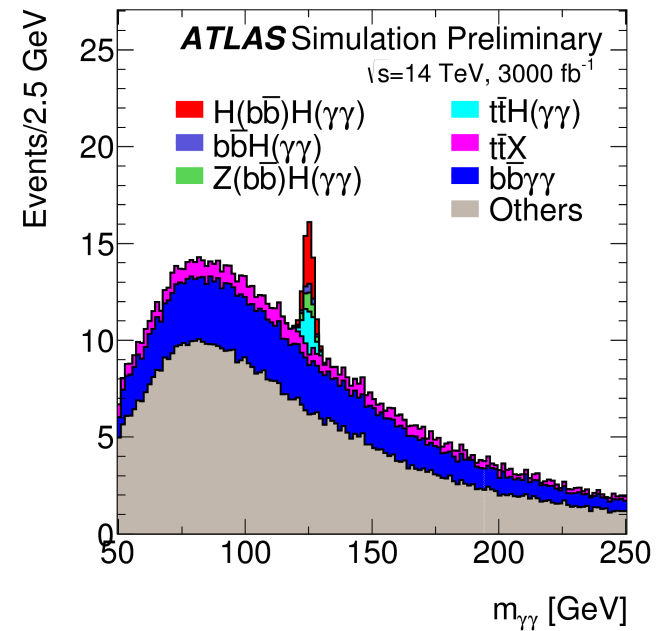
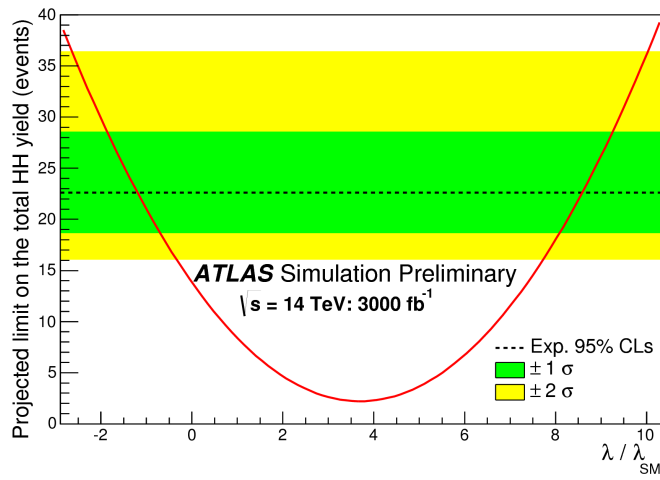
# Higgs Pair Production



- Ultimate test of the Higgs potential (self-coupling)
  - Cancellation between box and triangle diagram doesn't help



- Simulation shows that it might not be hopeless
- Very challenging even for ILC





# Summary

- ATLAS and the LHC have exceeded expectations during run I
- We have improved the experiment during LS1
  - Detector refurbishments and important additions
  - Building on physics algorithm data processing lessons from Run I
- Expect factor of **two** in energy reach soon (end of 2015?)
- Ultimately factor of 10 in reach (lumi\*energy) from Run II
- Further factor of 2-5 by the end of LHC era (2030++)

Next target not so clearly spelled out

But if it is there we will hit it...

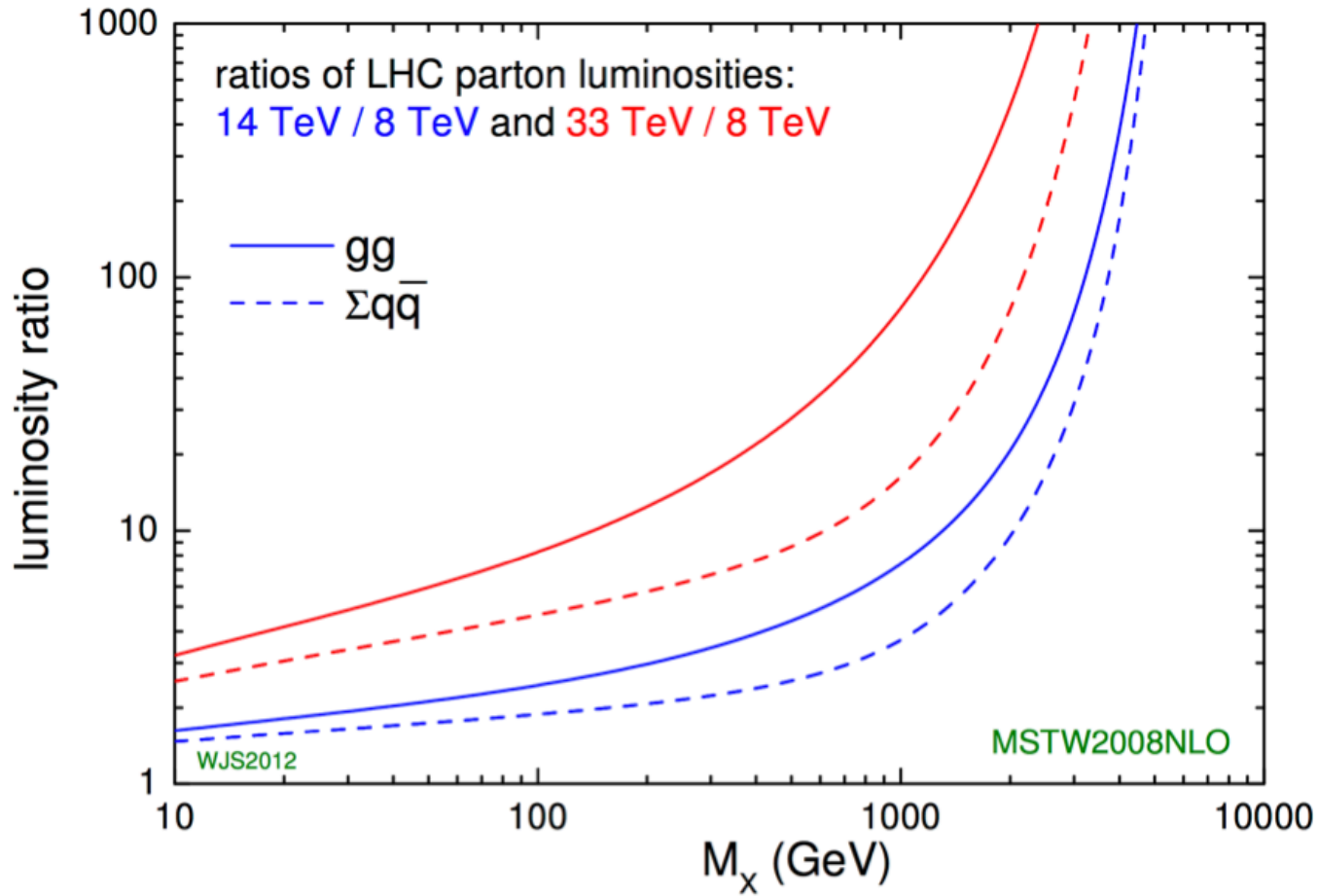


# Backup





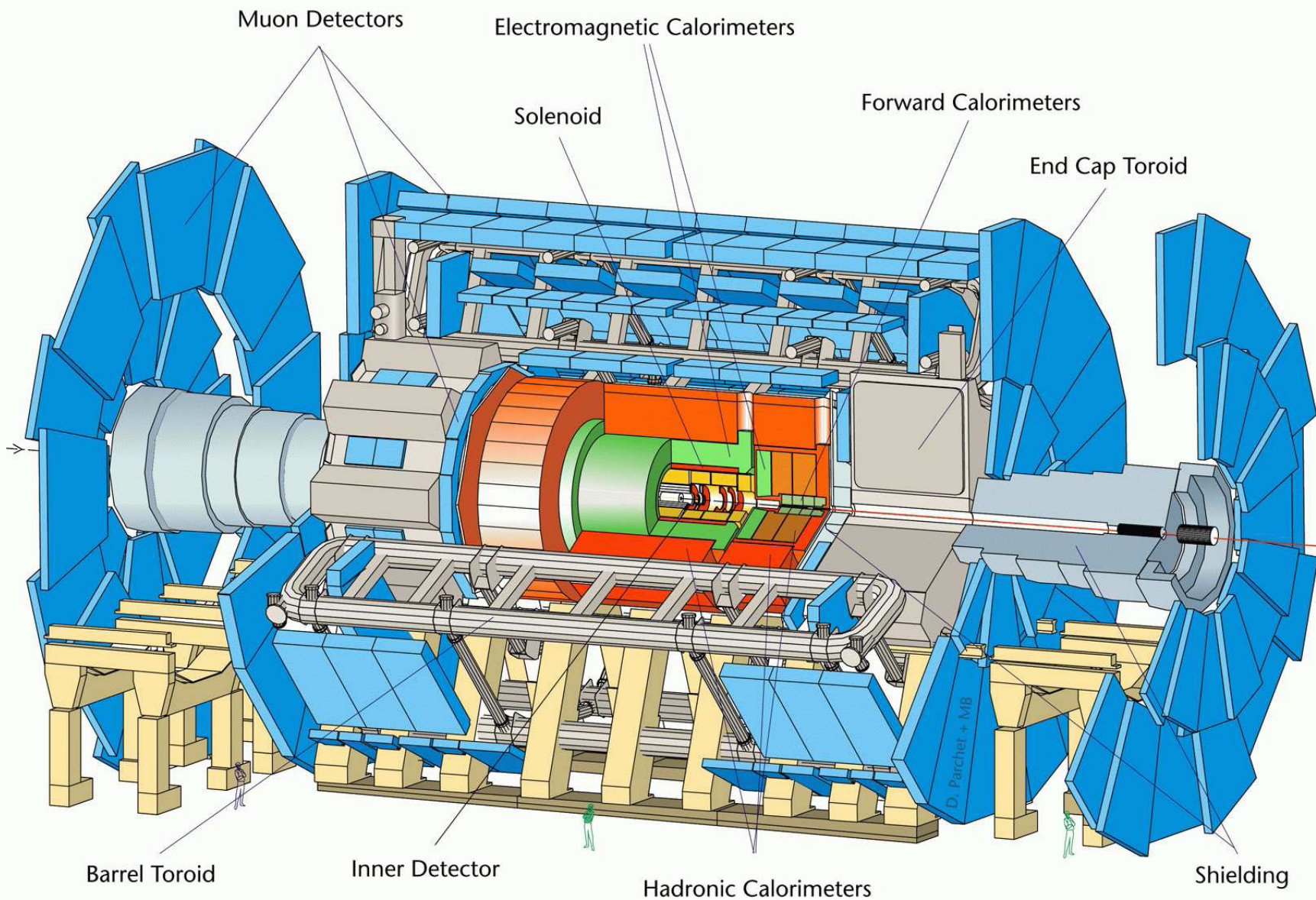
# Parton Luminosity Scaling







# The ATLAS Detector



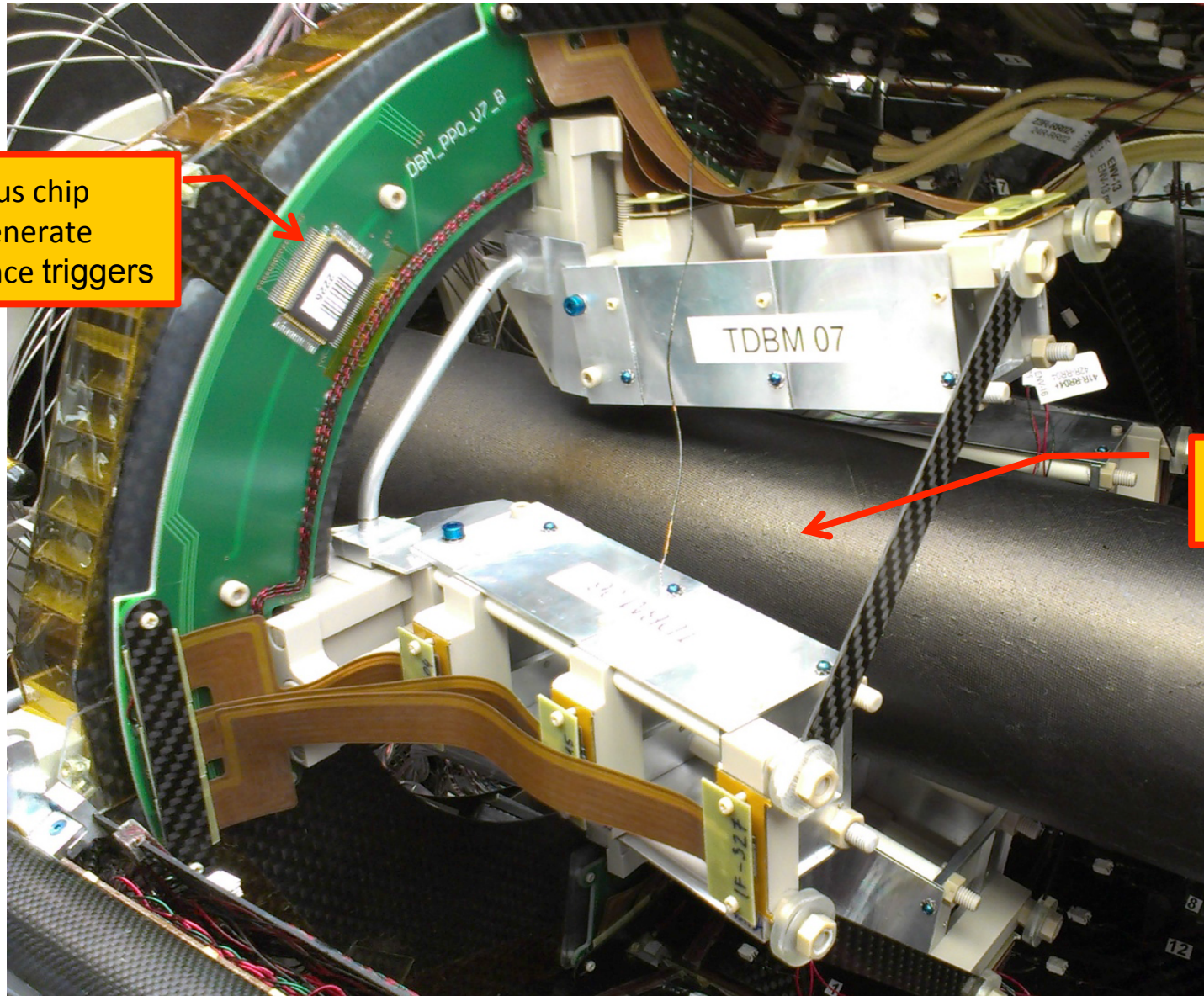




# The ATLAS Diamond Beam Monitor



Hitbus chip  
to generate  
coincidence triggers



IBL  
Insertion tube