Report from the Energy Frontier Hadron Collider Detector R&D

Hal Evans Indiana University

Joint CPAD and Instrumentation Frontier Workshop
Boulder, CO
17 – 19 April, 2013

Outline

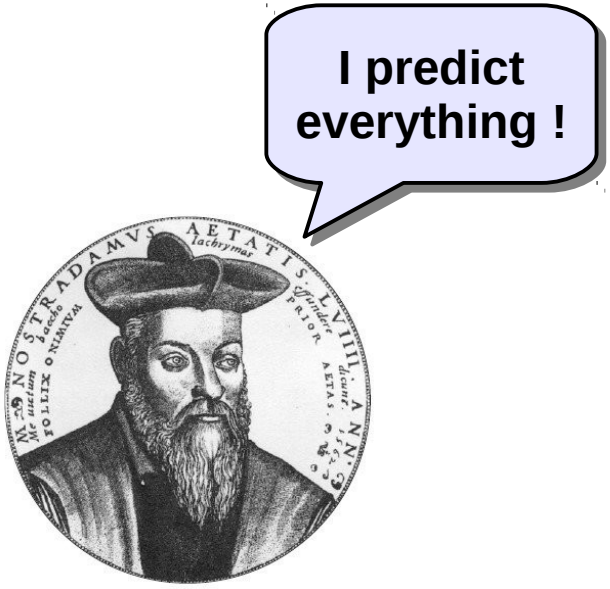
1) **State of Knowledge at the Energy Frontier**
   - Higgs, SUSY, Exotica, etc....

2) **Physics Goals for the next two decades**
   - Plans and Projections for ATLAS and CMS

3) **Hadron Collider Evolution**
   - LHC Upgrades

4) **Detector Challenges to meet those Goals**
   - ATLAS and CMS upgrade strategies

5) **Ongoing R&D Summary**
   - Emphasis on US involvement
   - Many efforts here – no time for details



the Nostradamus seal of approval

Acknowledgments & Information

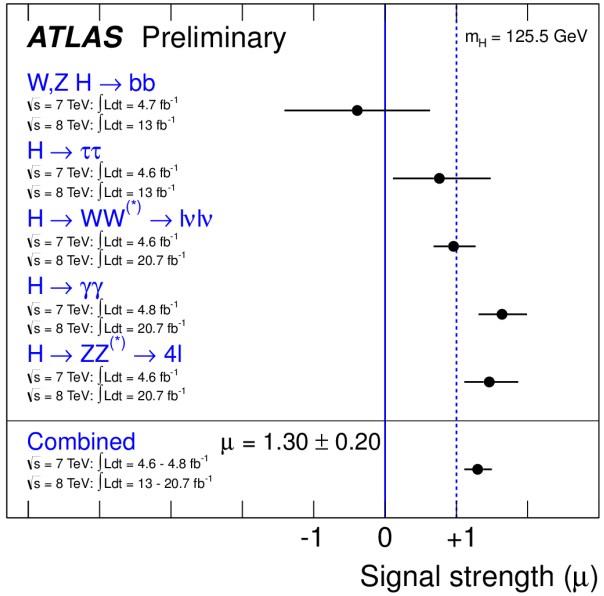
Special Thanks To

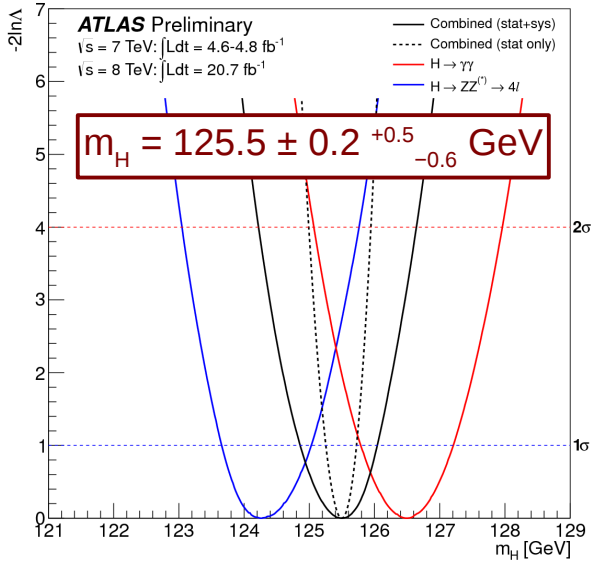
- Daniela Bortoletto, Abe Seiden

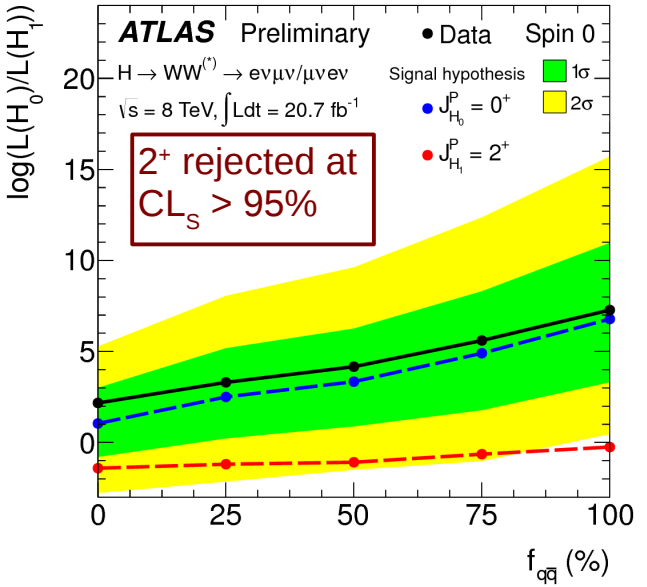
More Information

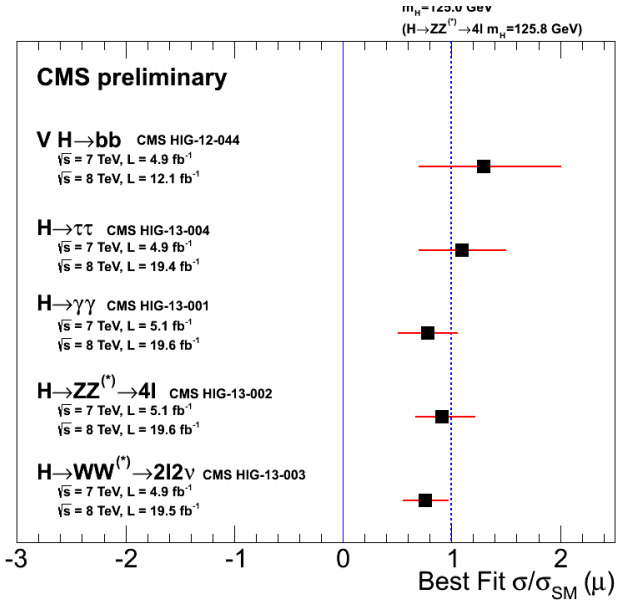
- ATLAS
  - physics documents https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - Phase-1 LOI CERN-LHCC-2011-012
  - Phase-2 LOI CERN-LHCC-2012-022
- CMS
  - physics documents http://cms.web.cern.ch/news/cms-physics-results
  - Phase-1 HCAL TDR CERN-LHCC-2012-015
  - Phase-1 Pixels TDR CERN-LHCC-2012-016
- General
  - HEPAP Facilities Report http://science.energy.gov/hep/hepap/reports/
  - European Strategy homepage

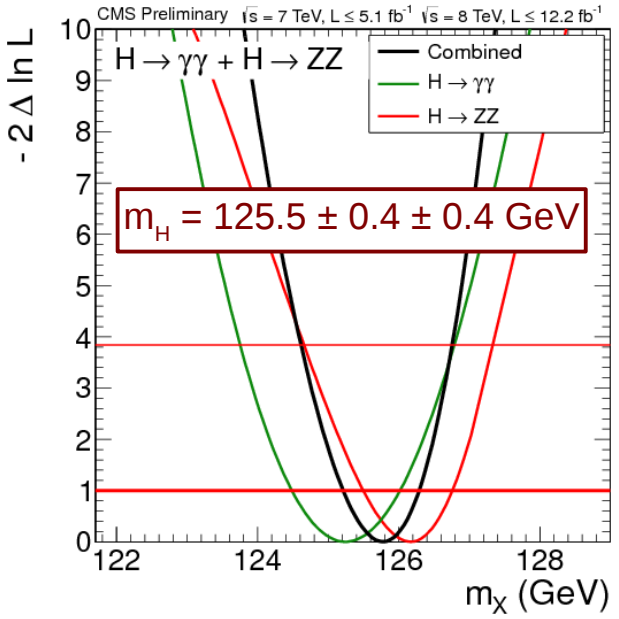
The Higgs (or something like it)

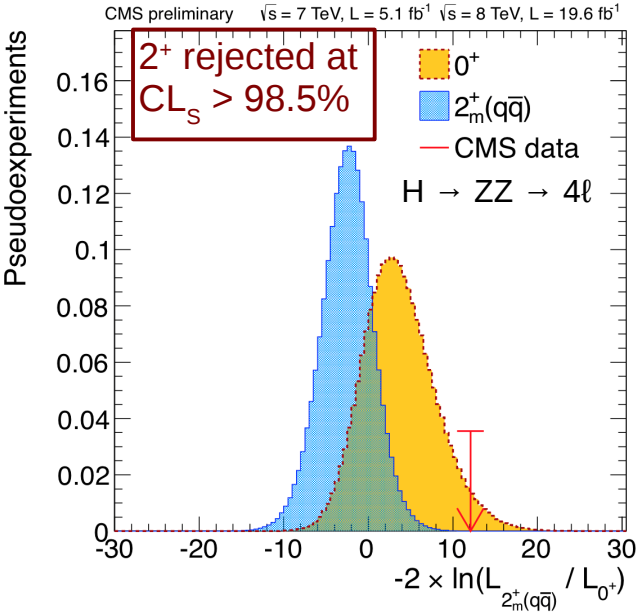




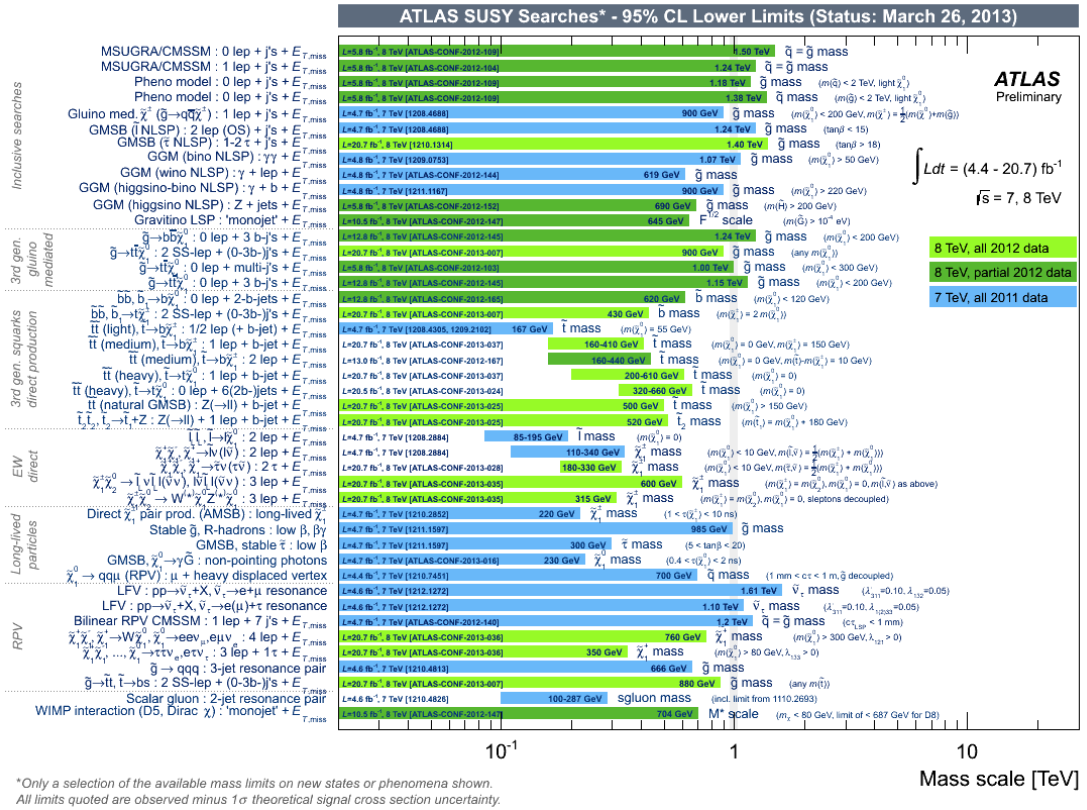


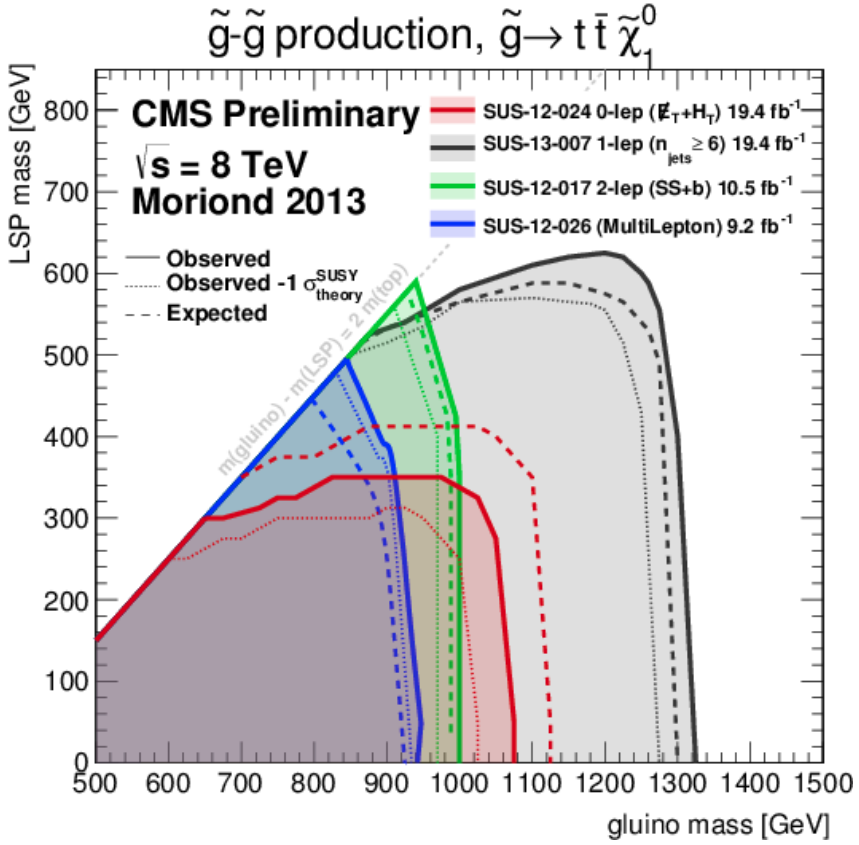






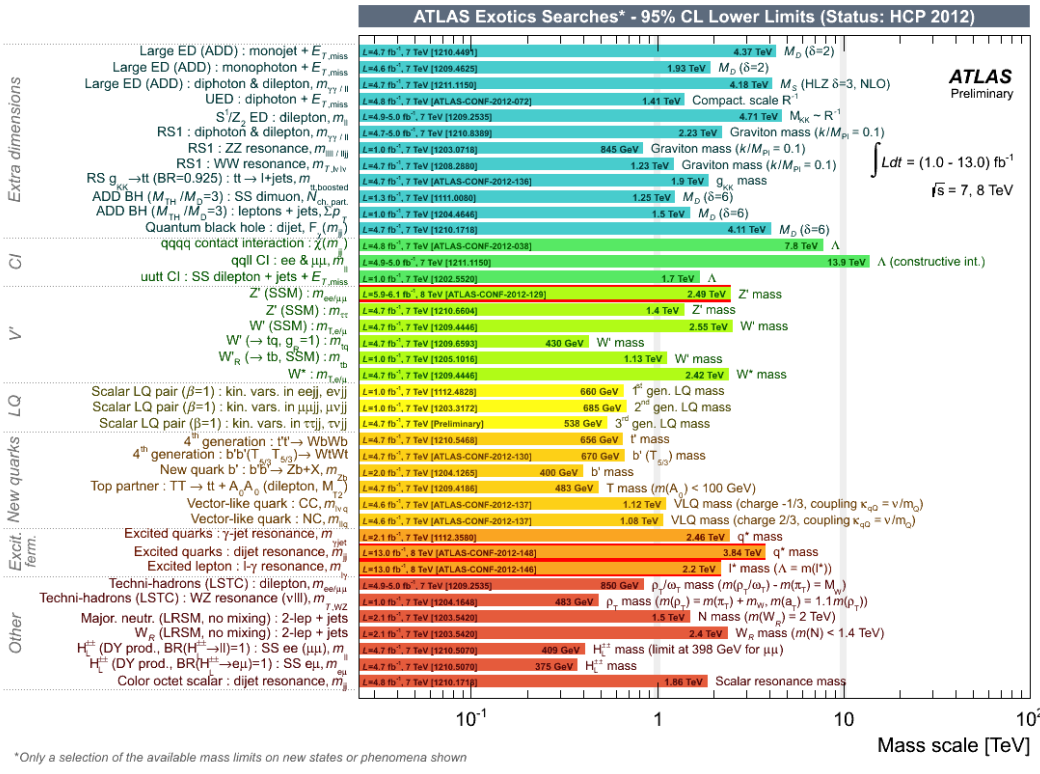
Still Seeking SUSY



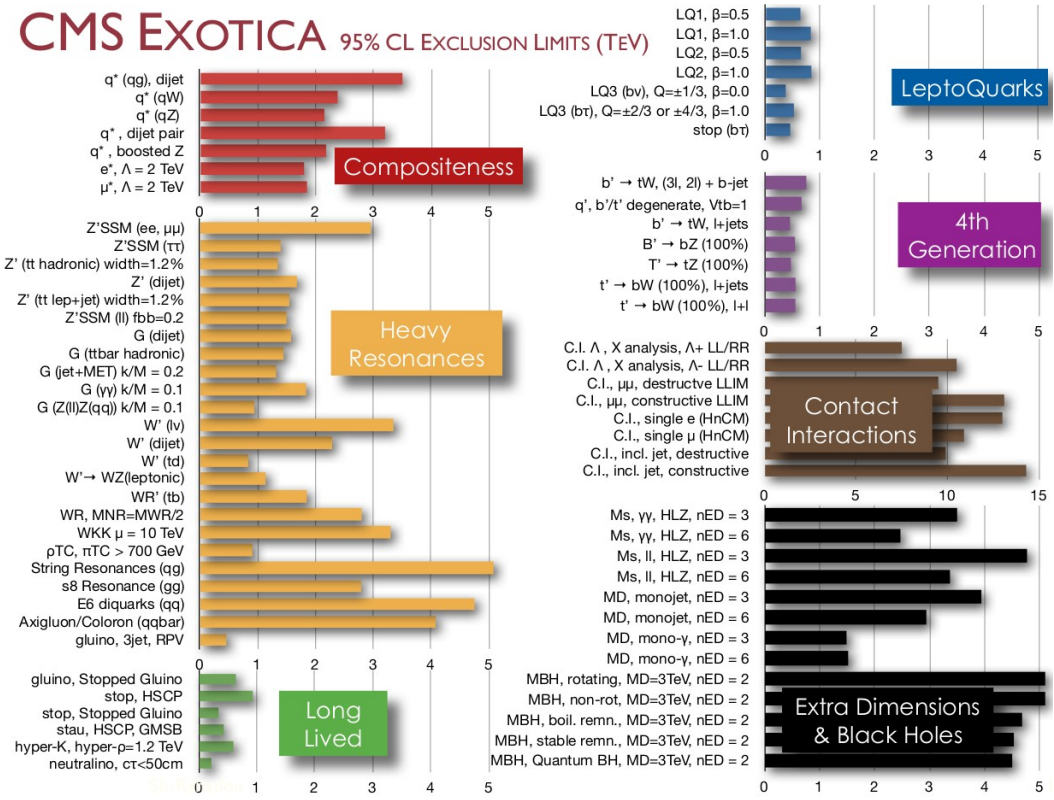


Strongly Produced	$\tilde{q}, \tilde{g}$	**> 1 TeV**
Weakly Produced	$\tilde{\chi}_i^0, \tilde{\chi}_i^{\pm}$	**> 200 – 300+ TeV**

Other Searches



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

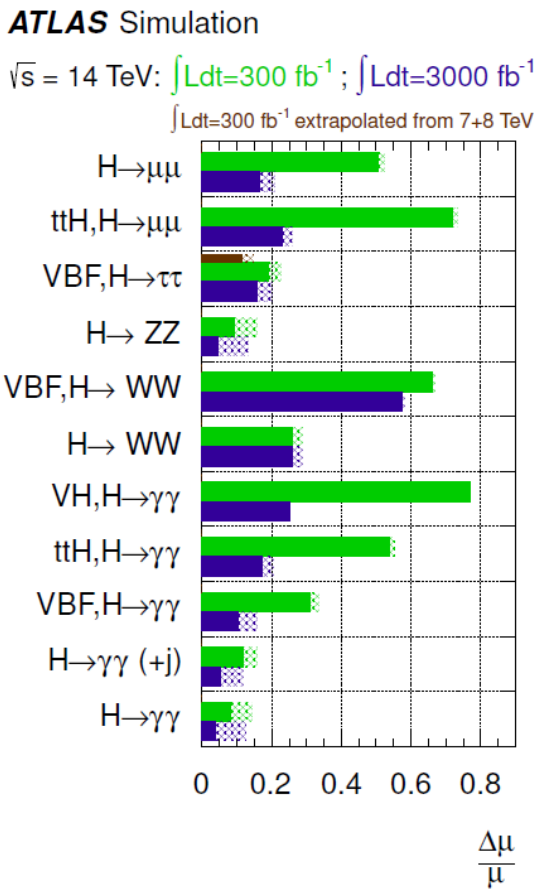


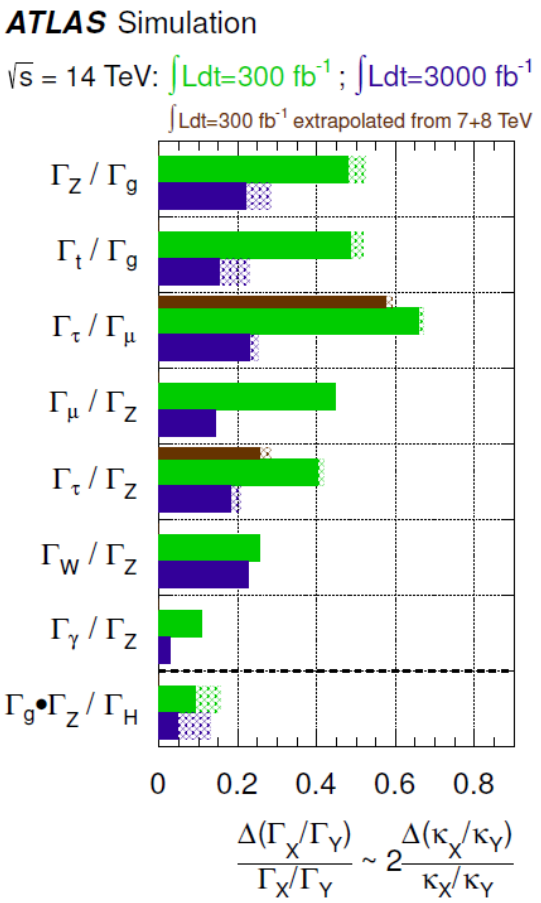
No Hints Yet !

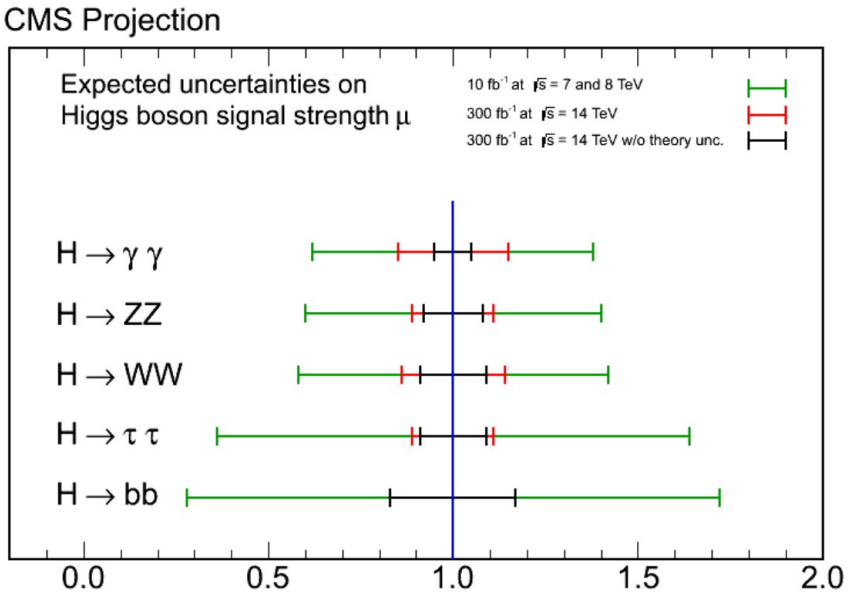
Goals & Projections: Higgs

Measure the Properties of the newly-discovered Boson

- couplings, partial width ratios, spin
- Higgs self-coupling under study: 3σ/exp possible



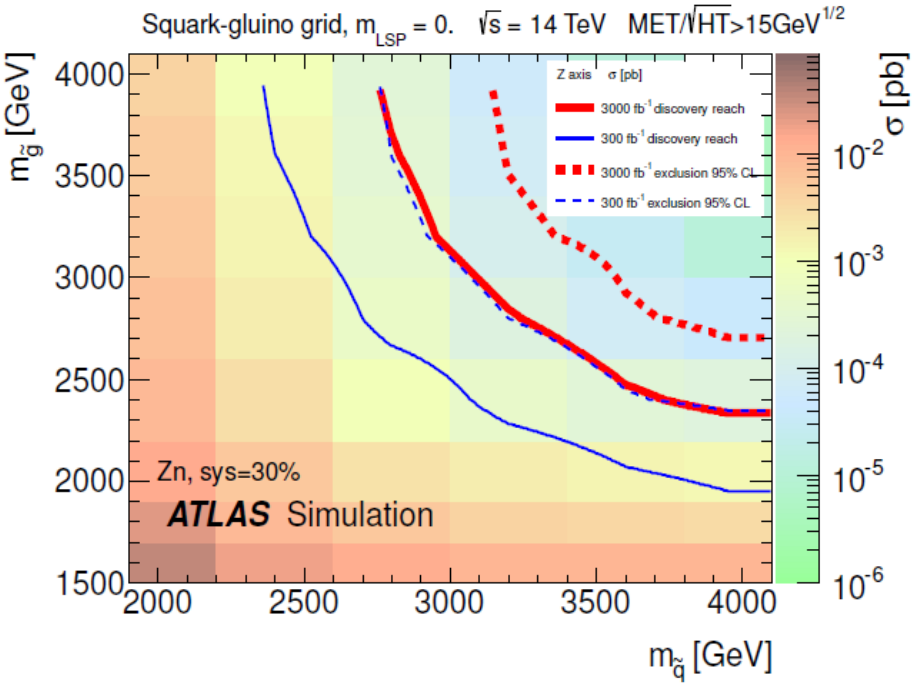


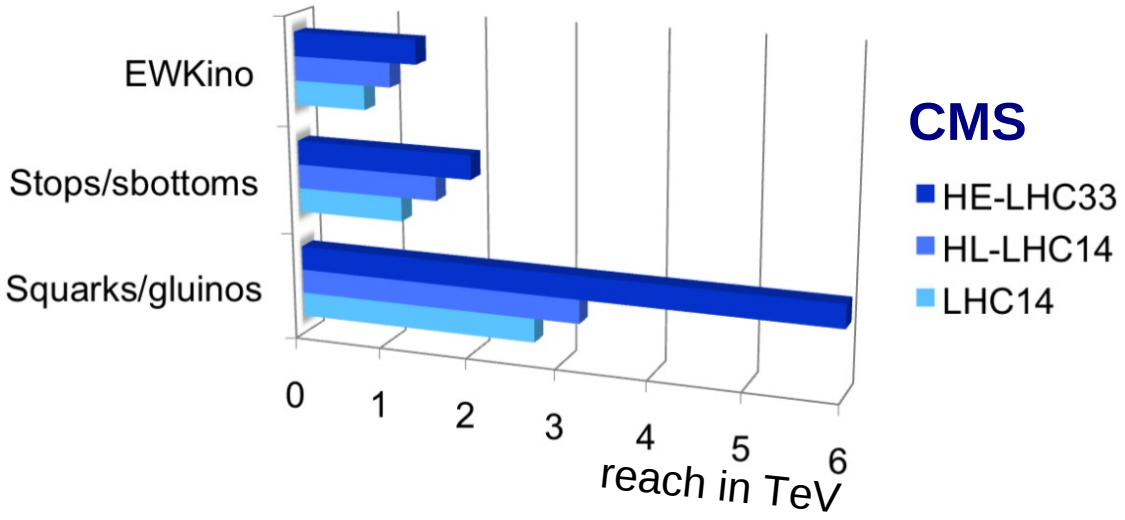


Goals & Projections: SUSY, etc.

Continue Searches for New Particles/Deviations from the SM

- **LHC will remain the energy frontier of the Energy Frontier**





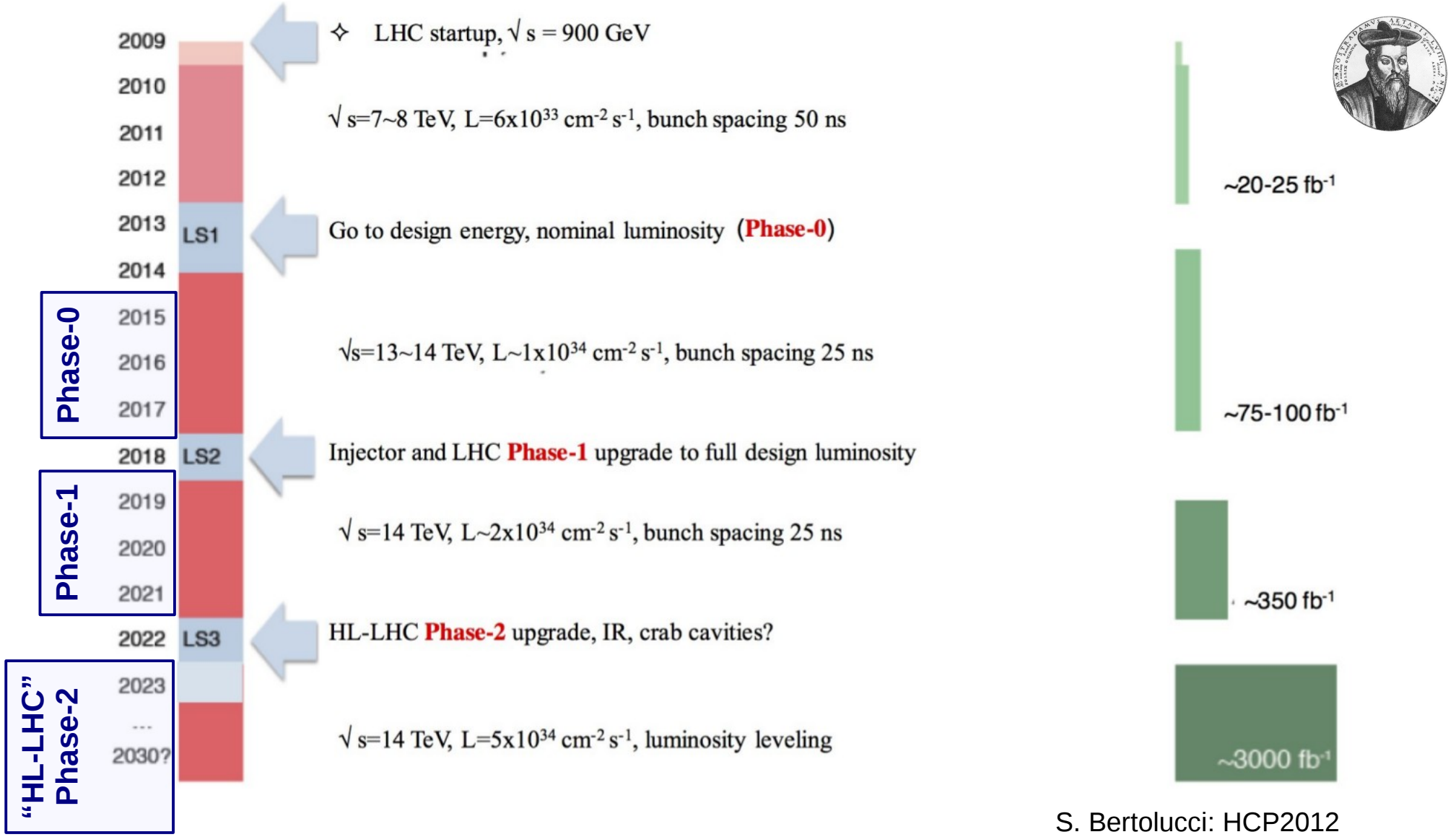
ATLAS: Weak Boson Scattering

Res. Mass	Coupling	300 fb^{-1}	3000 fb^{-1}
500	g = 1.0	2.4σ	7.5σ
1 TeV	g = 1.75	1.7σ	5.5σ
1 TeV	g = 2.5	3.0σ	9.4σ

CMS: Lepto-Quarks (ℓℓjj)

M Reach	LHC	3000 fb^{-1}	33 TeV
Low S/B	1.6 TeV	1.8 TeV	2.5 TeV
High S/B	1.7 TeV	2.3 TeV	3.5 TeV

LHC Roadmap (tentative)



S. Bertolucci: HCP2012

Accelerator Evolution

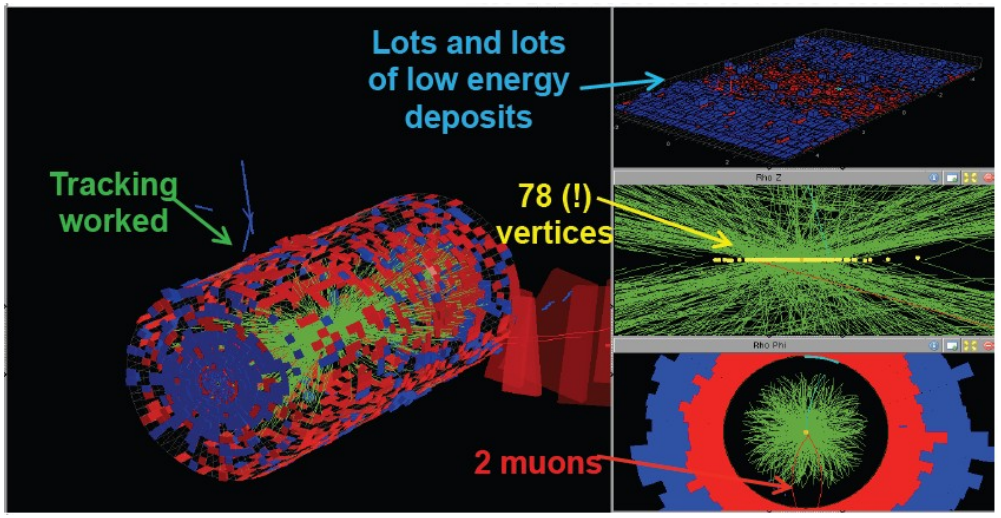
Parameter	Tevatron Run 2	LHC 2012	Phase-0	Phase-1	Phase-2	HE-LHC
√s	1.96 TeV	8 TeV	13–14 TeV	14 TeV	14 TeV	33 TeV
ε_n	7–11 μm	2.2 μm	1.4 μm	2.5 μm	2.5 μm	2.59 μm
β*	0.28 m	0.6 m	0.4 m	0.3 m	0.15 m	0.6 m
crossing angle	0	290 μrad	300 μrad	~450 μrad	590 μrad	188 μrad
bunch length	30 cm	9 cm	7.55 cm	7.55 cm	7.55 cm	6.5 cm
N_p / bunch	2.9×10^{11} / 8×10^{10}	1.6×10^{11}	1.15×10^{11}	2.0×10^{11}	2.0×10^{11}	1.3×10^{11}
spacing	396 ns	50 ns	25 ns	25 ns	25 ns	50 ns
luminosity	4.3×10^{32} $cm^{-2}s^{-1}$	0.76×10^{34}	2.0×10^{34}	$2–3\times10^{34}$	$5–7\times10^{34}$ (levelled)	2×10^{34}
pileup	2	35	48	>80	140	76
int. lumi.	12 fb^{-1}	22 fb^{-1}	75 fb^{-1}	350 fb^{-1}	3000 fb^{-1}	300 fb^{-1}

Challenges for the Detectors

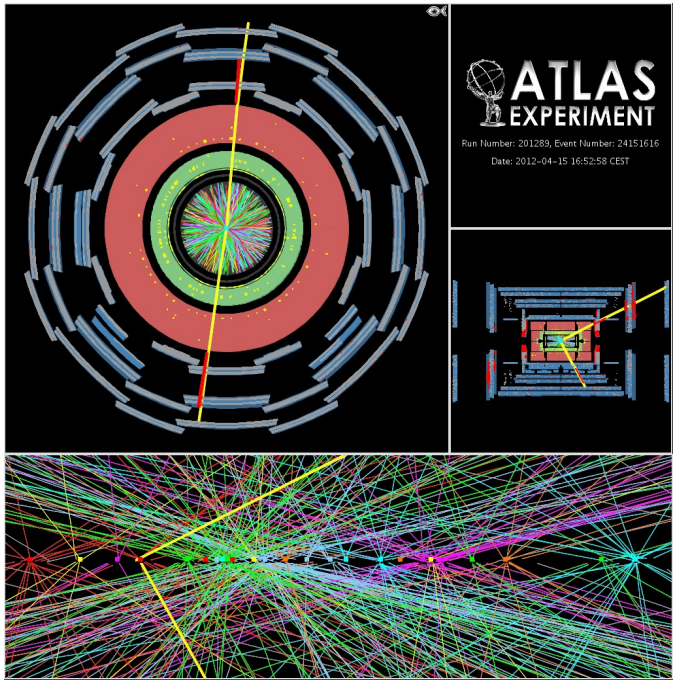
1. Instantaneous Luminosity

- event complexity
- data volume

CMS: Z→μμ with 78 vertices



ATLAS: Z→μμ with 25 vertices



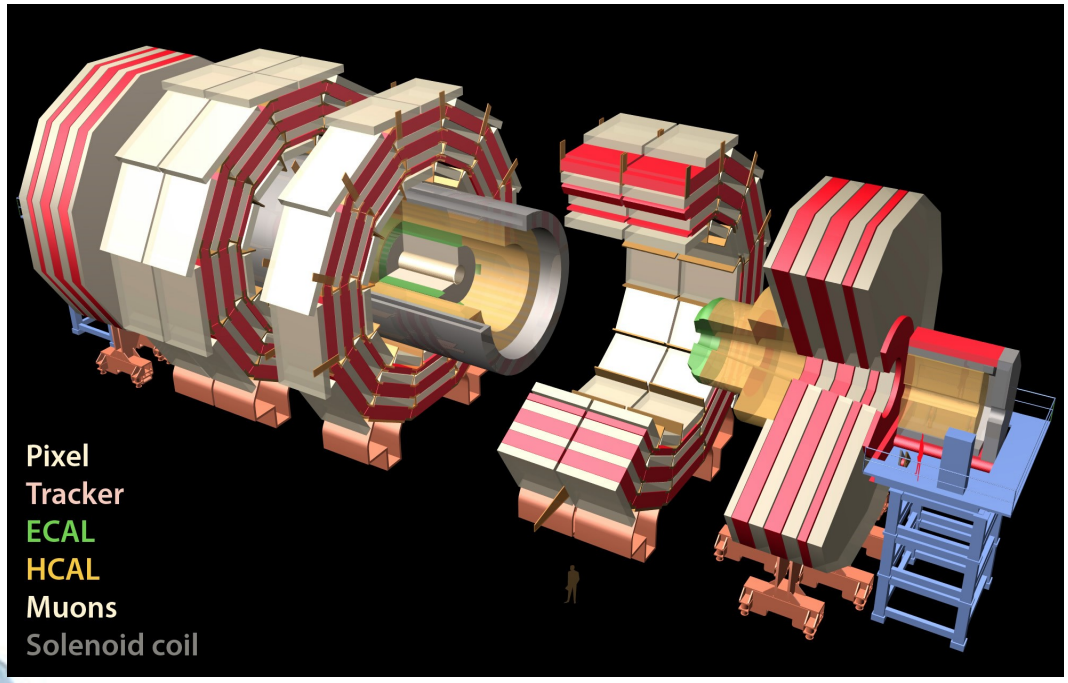
2. Integrated Luminosity

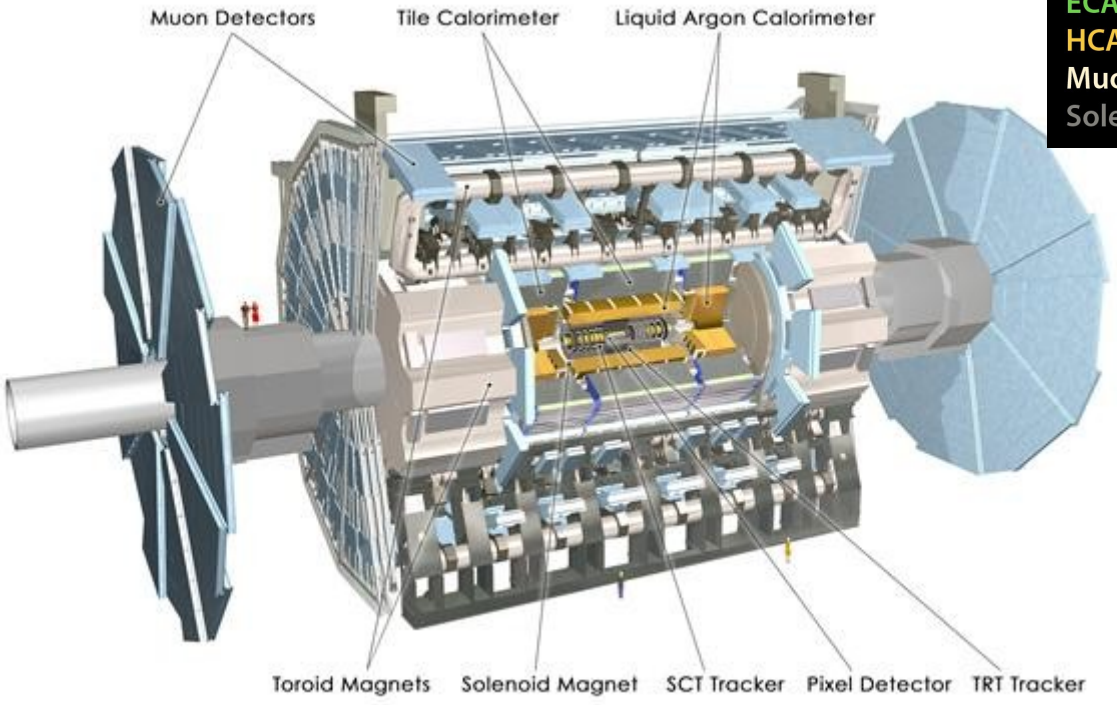
- radiation damage

3. Component Activation

- constraints on detector manipulation

Current ATLAS & CMS Detectors

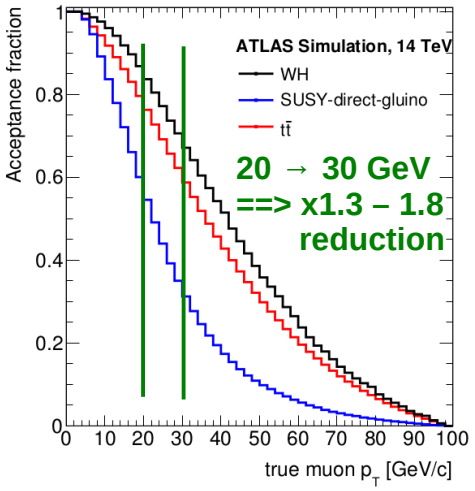




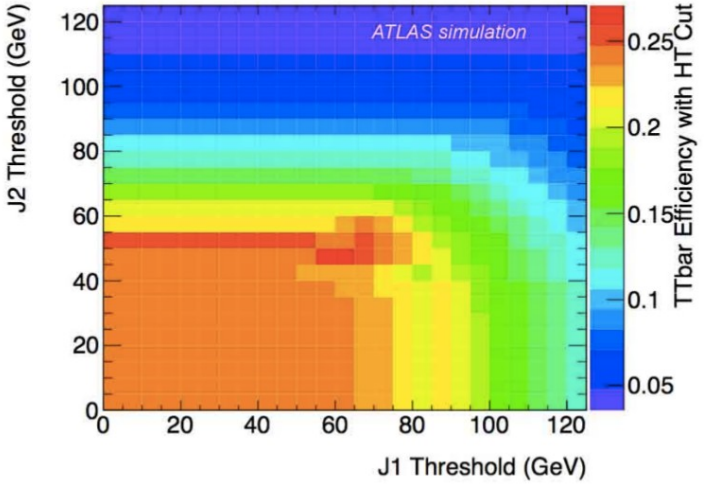
Object Reconstruction

Example Channels	Objects Required
W, Z, $t\bar{t}$	• single e,μ triggers with p_T ~ 20 GeV • di-jet triggers in the 60–80 GeV range
$HH \rightarrow b\bar{b}\gamma\gamma$ & $t\bar{t}H, H\rightarrow\gamma\gamma$	• photons with E_T ~ 25 GeV • retain/improve current b-ID performance
VBF, H → ττ	• retain/improve τ-ID performance
VBF: H→γγ & H→WW	• retain forward jet capabilities
squarks, gluions, stops	• missing Energy + b-ID

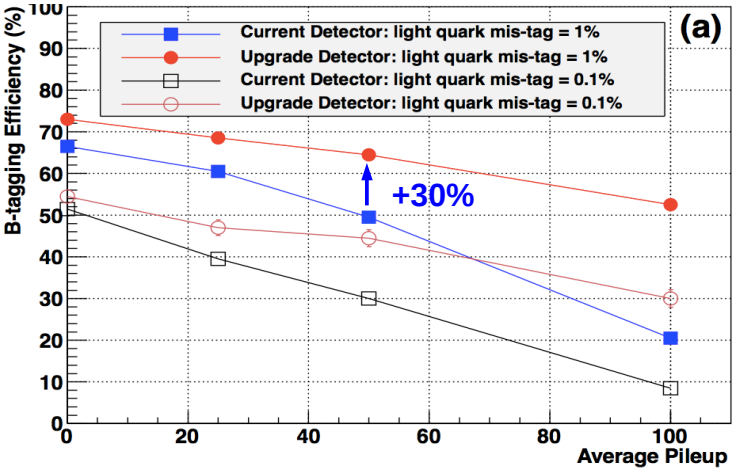
ATLAS: μ Thresholds



ATLAS: jj Trigger Thresholds $(t\bar{t})$



CMS: Phase-1 b-tag improvements



ATLAS & CMS Upgrade Overview

Phase	ATLAS Upgrades	CMS Upgrades
Phase 0	• new insertable b-layer pixels (IBL) + services • new Al beam pipe • new low voltage power supplies for calorimeters • finish installation of EE muon chambers (staged) • topological triggering at Level-1 • dataflow improvements (merge L2/EF/EB) • new evaporative cooling plant • added neutron shielding	• new beam pipe (necessary for pixel repl. 2016/17) • complete muon coverage (4th endcap layer) • barrel drift tube electronics • replace HCAL forward photo-detectors (new PMTs) • replace outer HCAL photo-detectors (SiPMs) • Level-1 trigger upgrade • DAQ improvements
Phase 1	• new Small Wheel (nSW) for forward muon system • higher granularity calo information to Level-1 • fast tracking trigger (FTK) at Level-2 • expanded topological capabilities at Level-1	• pixel detector replacement (2016/17) • HCAL electronics/granularity upgrade • complete Level-1 trigger upgrade
Phase 2 (tentative)	• complete tracker replacement (all silicon) • calorimeter electronics upgrade (fully digital) • muon system/electronics upgrades • forward calorimeter upgrade/replacement • track trigger at Level-1 • overhaul of trigger architecture	• complete tracker replacement • forward region: tracking, calorimeters, muons • track trigger at Level-1 • further trigger upgrades
note: lots of standard maintenance and improvements at each phase		

Phase 0: **all projects now in production**

Phase 1: **R&D well advanced for most projects**

Phase 2: **R&D started for many projects**

Summary of Main US R&D Efforts in the following slides

(some) Joint ATLAS–CMS R&D

Common CERN RD Projects

- RD42 Diamond Detectors http://rd42.web.cern.ch/rd42/
- RD50 Silicon Detectors http://rd50.web.cern.ch/rd50/
- New 65 nm Chip Design 27 Nov, 2012 meeting

Versatile Link Project

- rad-hard, bi-directional optical link at ~5 Gbs
- https://espace.cern.ch/project-versatile-link/public/default.aspx

QIE10: Charge Integrating ADC with TDC

- studying adapting Fermilab design for ATLAS TileCal and CMS HCAL

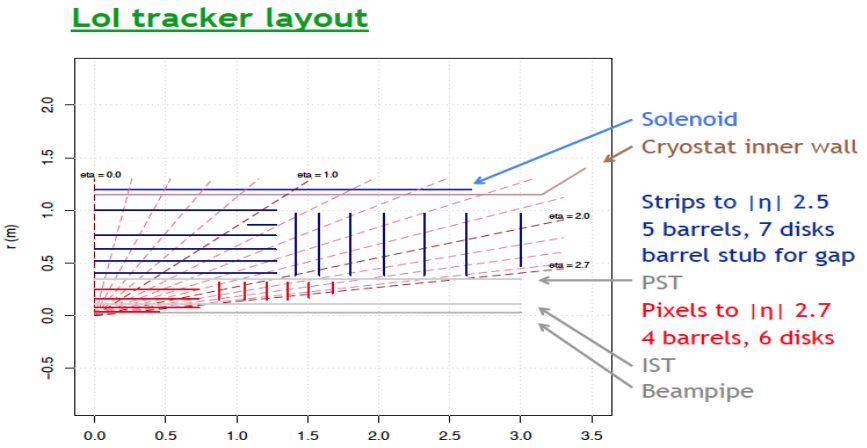
Many other Joint Efforts

- xTCA, Power, ...

ATLAS-specific R&D

Tracking

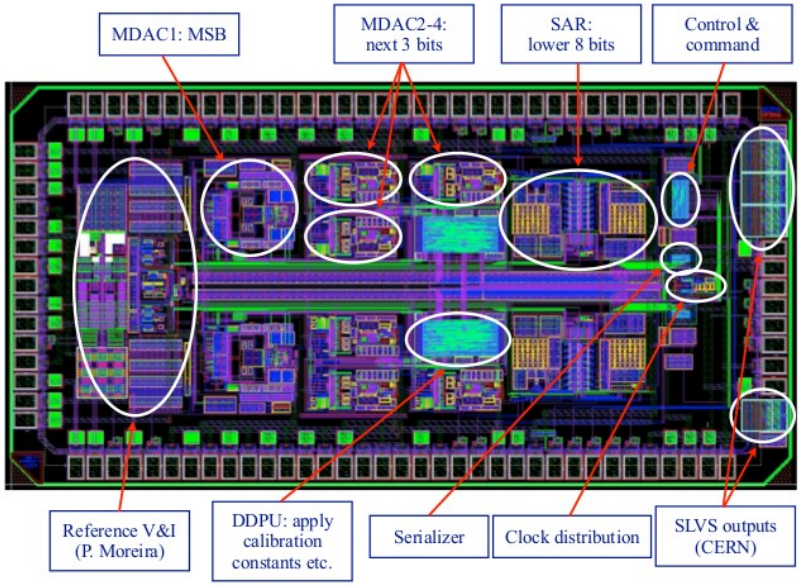
- Pixels: large wafers, edge reduction, rad hardness, electronics, optical transmission
- Strips: mechanics, cooling, powering, electronics, DAQ



Calorimetry

- rad-hard ADC (Phase 1) for Liquid Argon
- QIE ASIC for TileCal
- detector development for Forward Calorimetry

Nevis12: dual 12-bit ADC



Trigger

- Level-1 Track Trigger

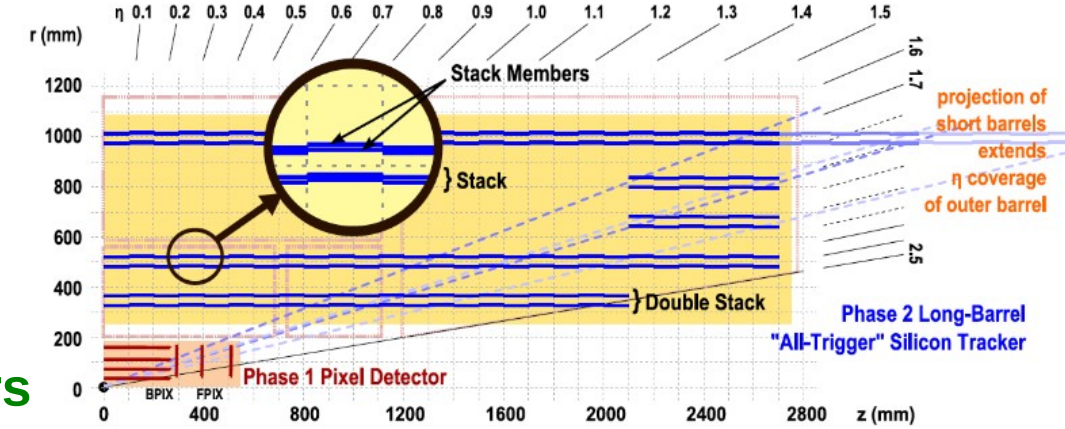
Timeline

- Ph-1 TDRs: summer-fall 2013

CMS-specific R&D

Tracker

- rad-hard sensors/electronics, cooling, DC-DC powering

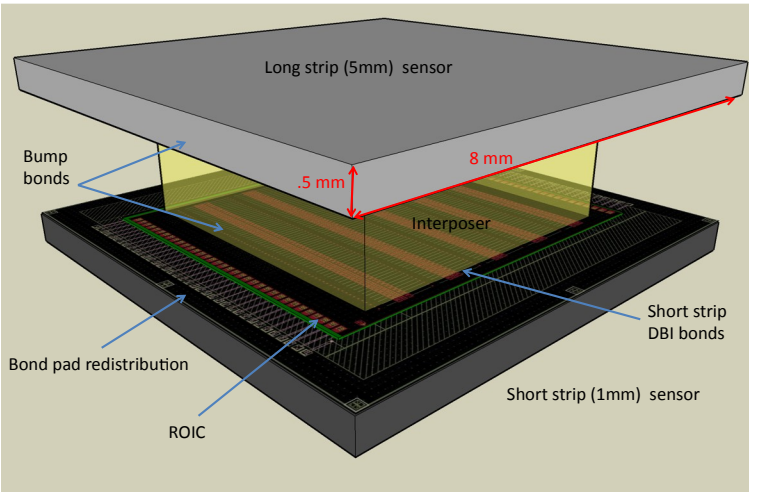


Forward Calorimetry

- rad-hard crystals/ceramics, fibers
- GaAs photosensors
- readout schemes

Trigger

- Level-1 Track Trigger



Timeline

- Ph-2 Technical Proposal: 2014
- TDRs: ~2016

Conclusions

Strong Physics Case for LHC Upgrade Program

- continued studies of Higgs-like particle
- direct detection of new particles at highest mass scales

Accelerator Plan can provide data to meet our goals

- 350 fb^{-1} $L \rightarrow 2\times10^{34}\ cm^{-2}s^{-1}$ by ~2021 (Phase 1)
- 3000 fb^{-1} $L \sim 5\times10^{34}\ cm^{-2}s^{-1}$ (levelled) by ~2030 (Phase 2)

ATLAS and CMS upgrades to deal with this data

- event pileup, radiation damage, activation
- Phase 1: projects well-defined, moving into construction phase
- Phase 2: R&D needed in many areas
  - > rad hard detectors & electronics; data transmission; powering;...
  - > a lot of ongoing effort in the US