Overview of High Energy Run Opportunities and Challenges

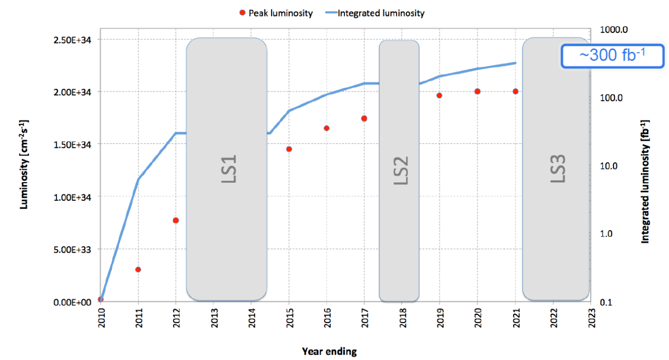
Brian Petersen

THE UNIVERSITY OF MELBOURNE

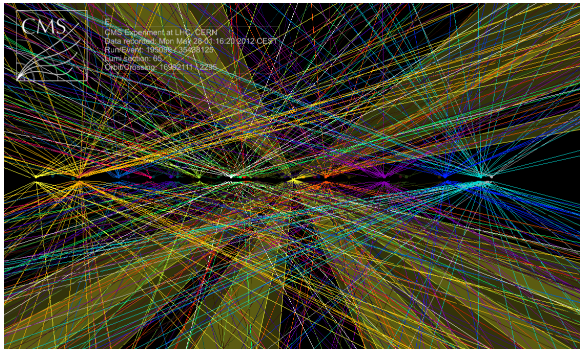
SUSY at the Near Energy Frontier
Wednesday, November 13

Outline

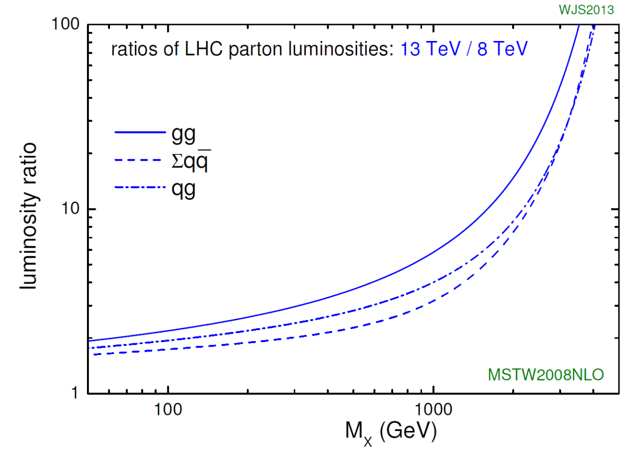
- LHC Prospects and Challenges
  How far can the machine go in luminosity and what are potential limitations



- Run 2 Challenges
  Experimental limitations



- Run 2 Prospects
  What can we expect for 2015



LHC Prospects and Challenges

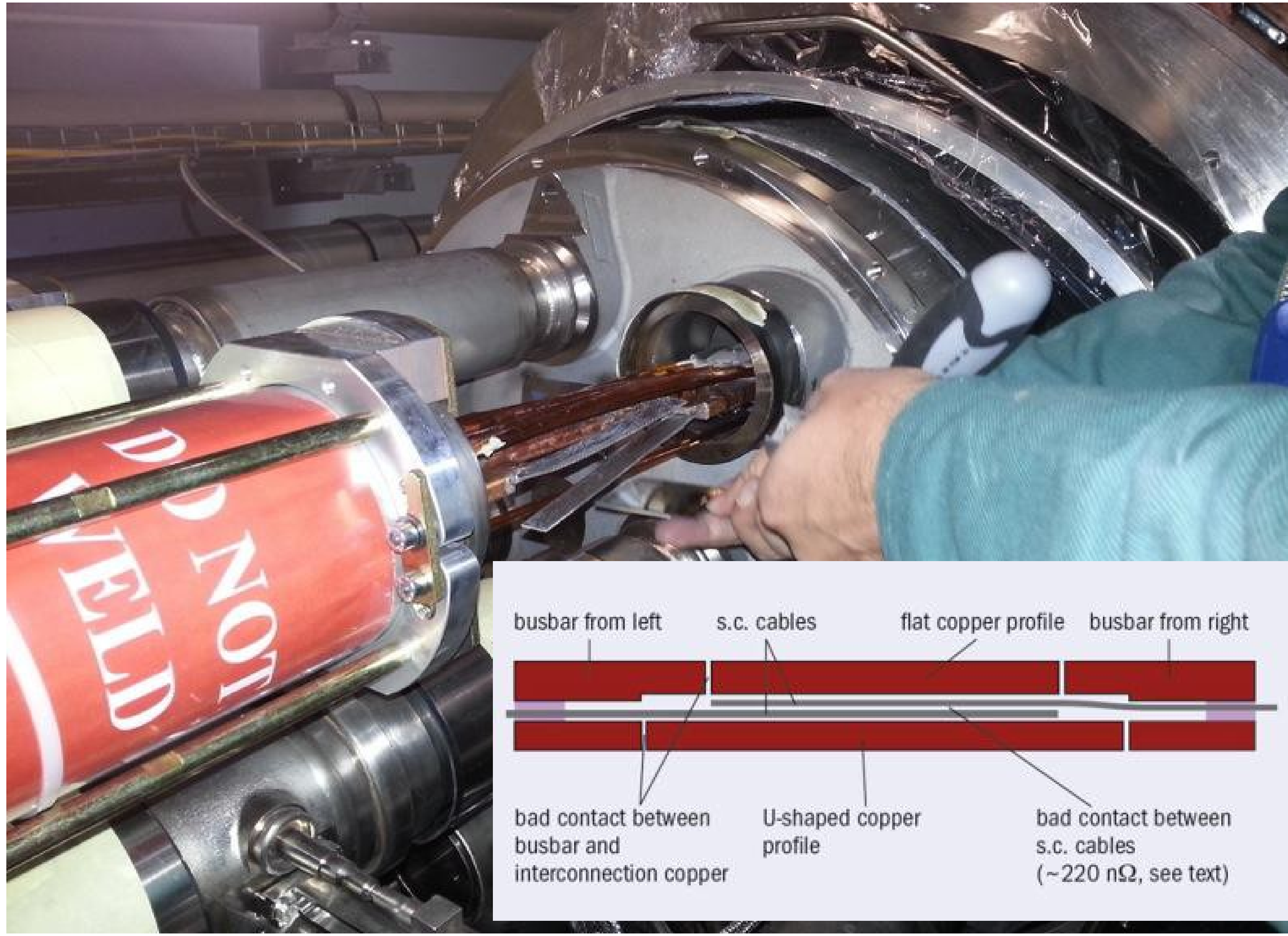
LHC Shutdown Work

Primary task:

Repair magnet interconnects to allow nominal currents in LHC dipole magnets

Consolidating all of the 10170 13kA splices

Need to redoing 30% of all interconnects completely (expected to redo only 15%)



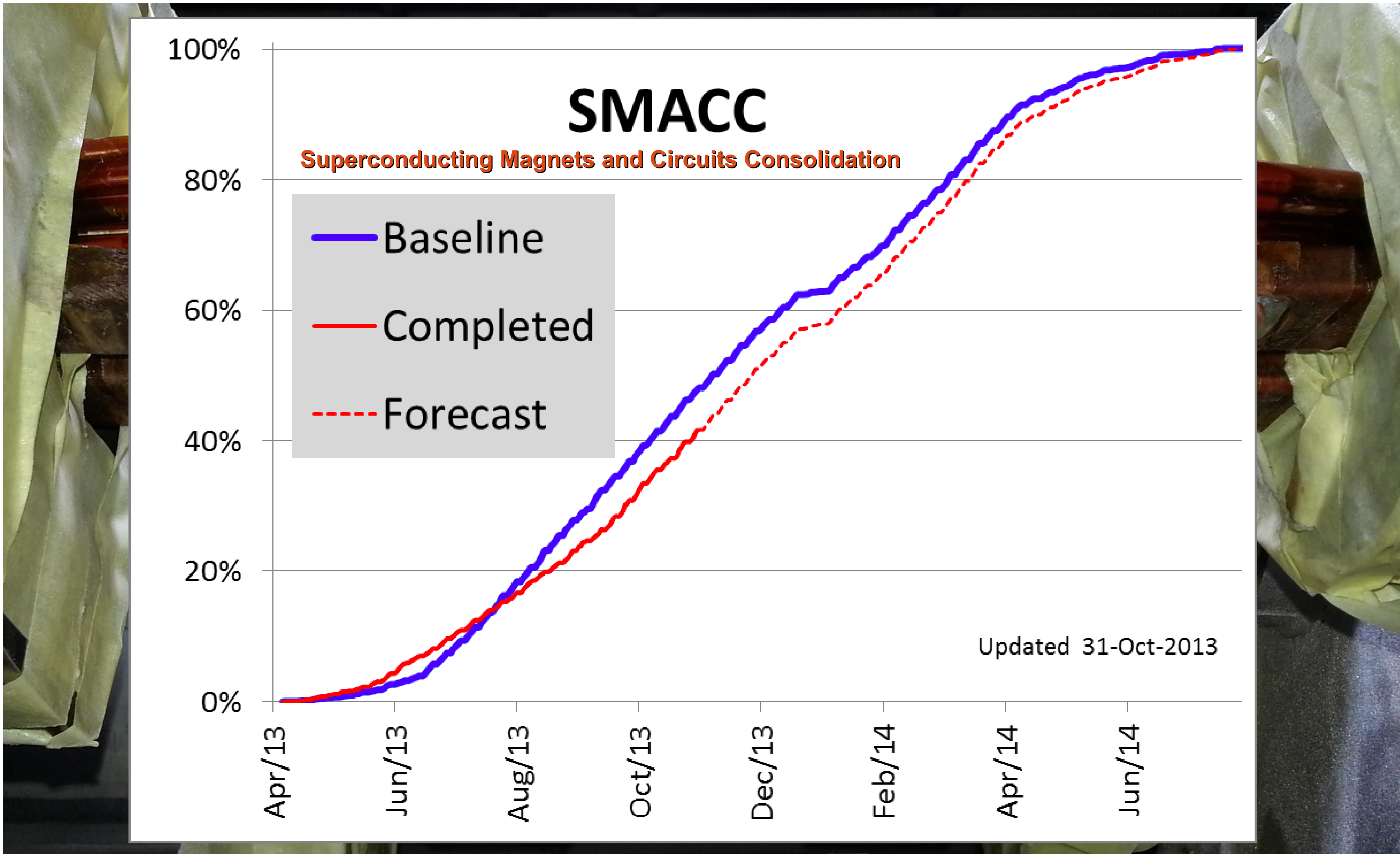
Large consolidation program for the rest of the LHC and the injector complex in shadow of interconnect repairs

Interconnect Consolidation

Shunts to be installed on every interconnect

Interconnect Consolidation

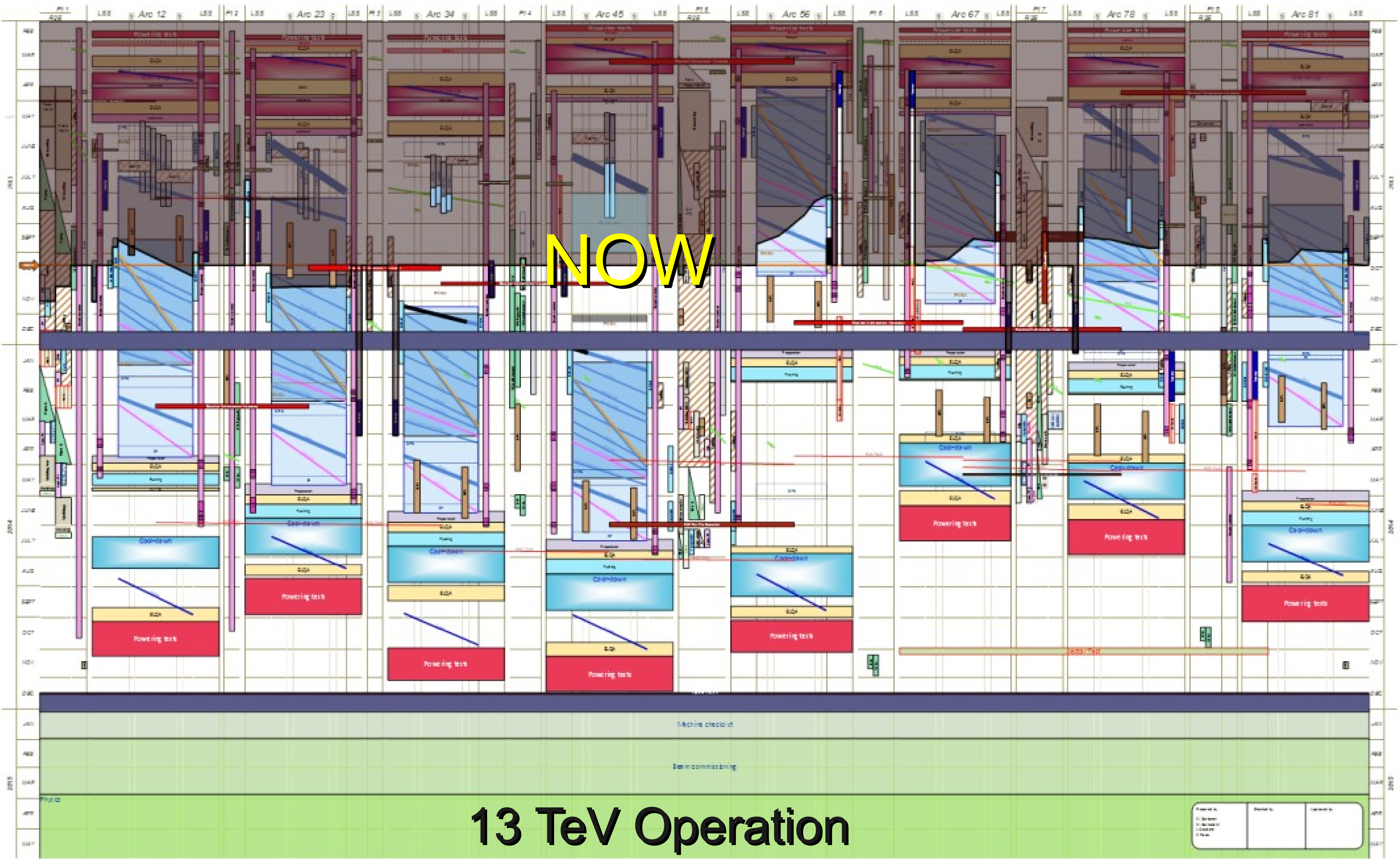
More than 40% done with interconnects



LHC LS1 Schedule Status

On schedule for first beams in January 2015

http://cern.ch/ls1dashboard



Beam Conditions in 2012

	25 ns (design)	50 ns (2012)	25 ns (2012)#
Energy per beam [TeV]	7	**4**	4
Intensity per bunch [$x10^{11}$]	1.15	**1.7**	1.2
Norm. Emittance H&V [μm]	3.75	**1.8**	2.7
Number of bunches	2808	**1380**	N.A. #
β* [m]	0.55	**0.6**	N.A. #
Peak luminosity [$cm^{-2}s^{-1}$]	1×10^{34}	**7.7×10^{33}**	N.A. #

The 25 ns was only used for scrubbing and tests in 2012

Beam Conditions in 2015?

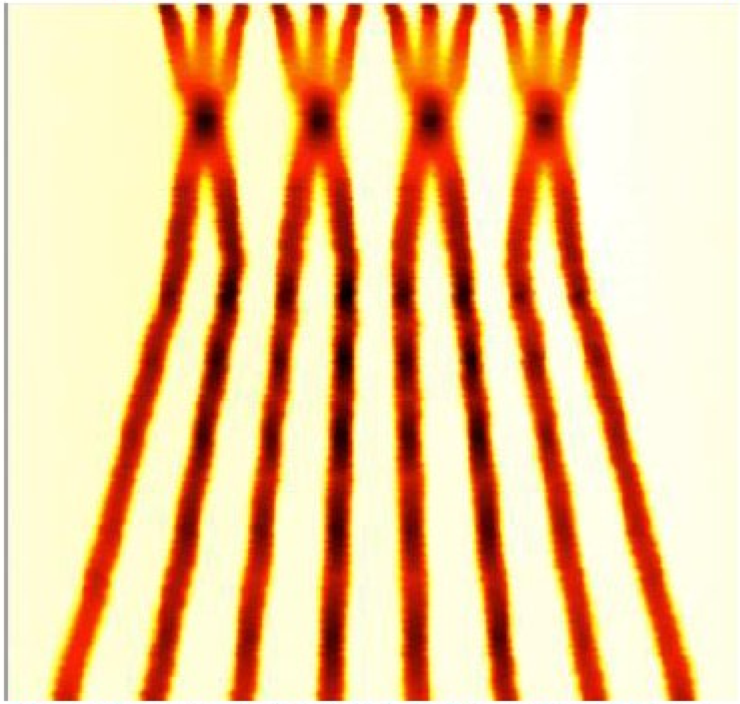
Collision energy

- 13 TeV initially, limited by time for magnet training quenches
- To be raised later depending on experience during 2015

Bunch spacing

- 25 ns to minimize event pileup
- New injector beam production scheme (BCMS) resulting in brighter beams
- 50 ns kept as backup scenario

Batch Compression and Merging and splitting (BCMS)



Courtesy of the LIU-PS project team

Luminosity

- Lower β^* to $\leq$0.5m
- Expected maximum luminosity ~1.6 x 10^{34} $cm^{-2}s^{-1}$ ±20% Limited by inner triplet heat load from collision debris

Potential LHC Performance 2015-

Four main scenarios considered for 2015

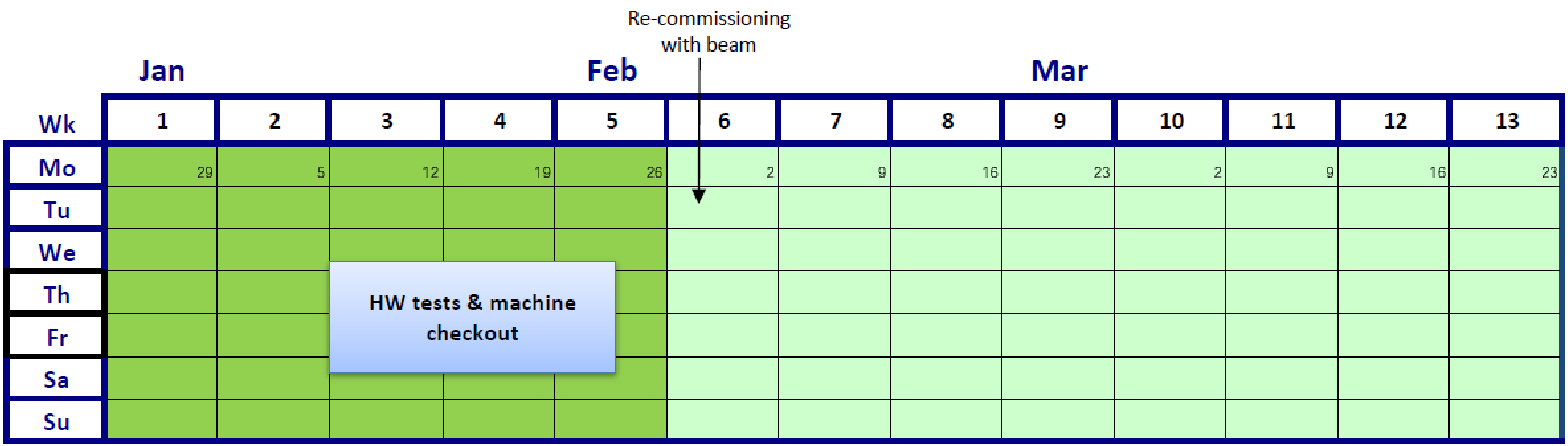
	Number of bunches	Ib LHC [1e11]	Collimat or scenario	Emit LHC (SPS) [um]	Peak Lumi [cm-2s-1]	~Pile-up	Int. Lumi [fb-1]
25 ns	2760	1.15	S1	3.5 (2.8)	9.2e33	21	24
25 ns low emit	***2508***	***1.15***	***S4***	***1.9 (1.4)***	***1.6e34***	***43***	***42***
50 ns	1380	1.6	S1	2.3 (1.7)	1.7e34 levelling 0.9e34	76 levelling 40	~45*
50 ns low emit	1260	1.6	S4	1.6 (1.2)	2.2e34	108	Excluded

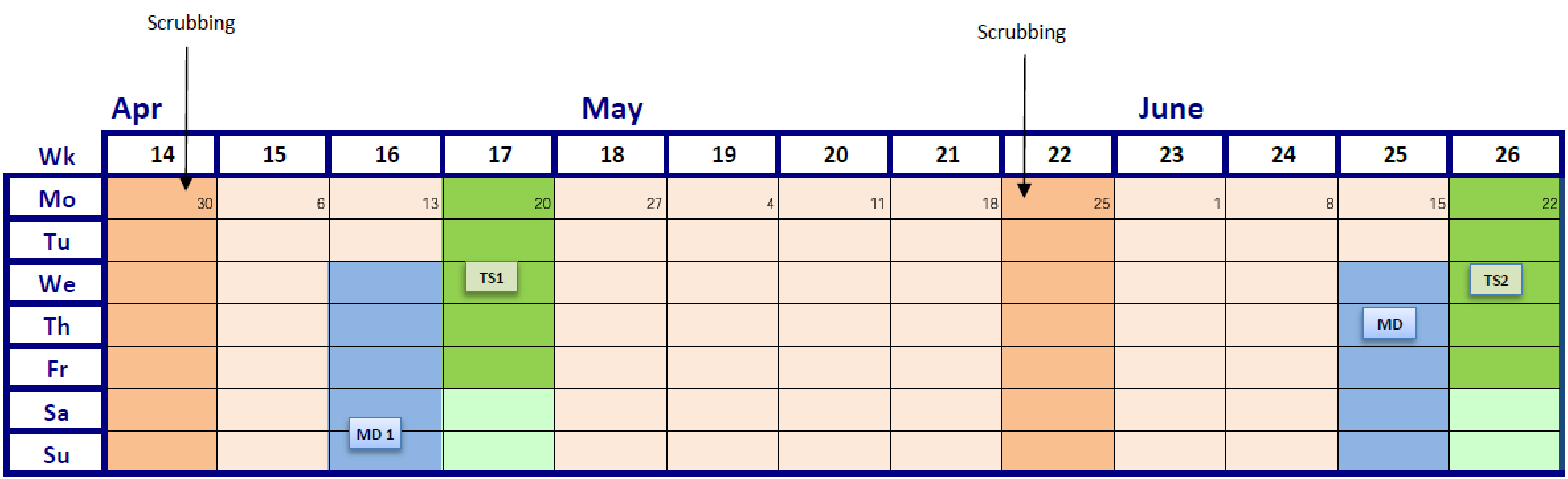
All numbers approximate

* different operational model – caveat - unproven

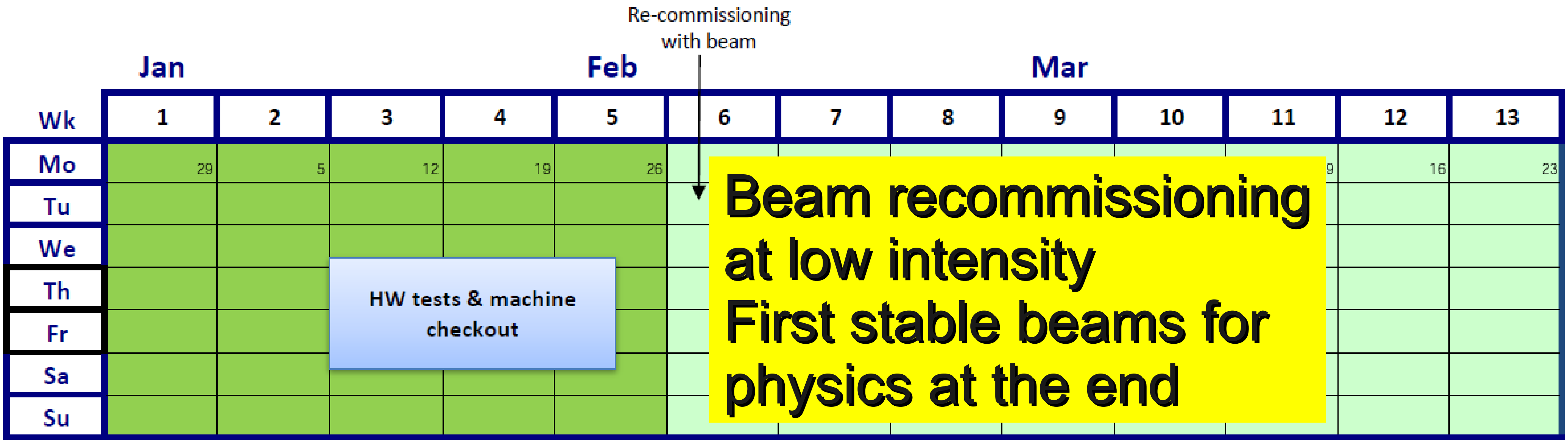
- 6.5 TeV
- 1.1 ns bunch length
- 150 days proton physics, HF = 0.2 ← (effective avg. lumi=20% peak lumi)

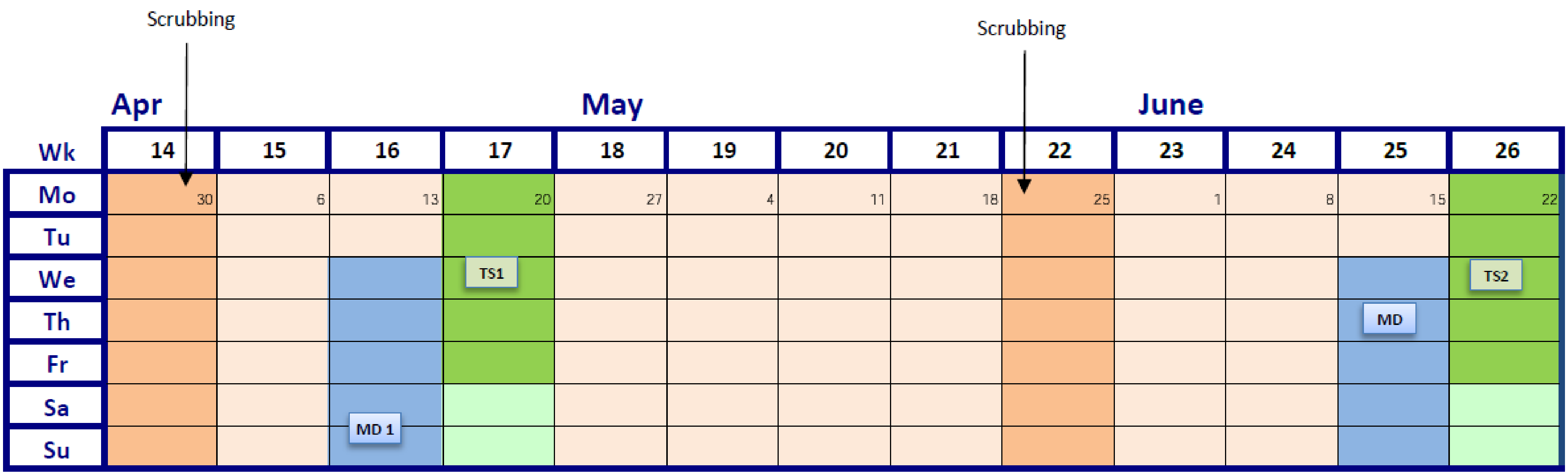
2015 Startup Scenario



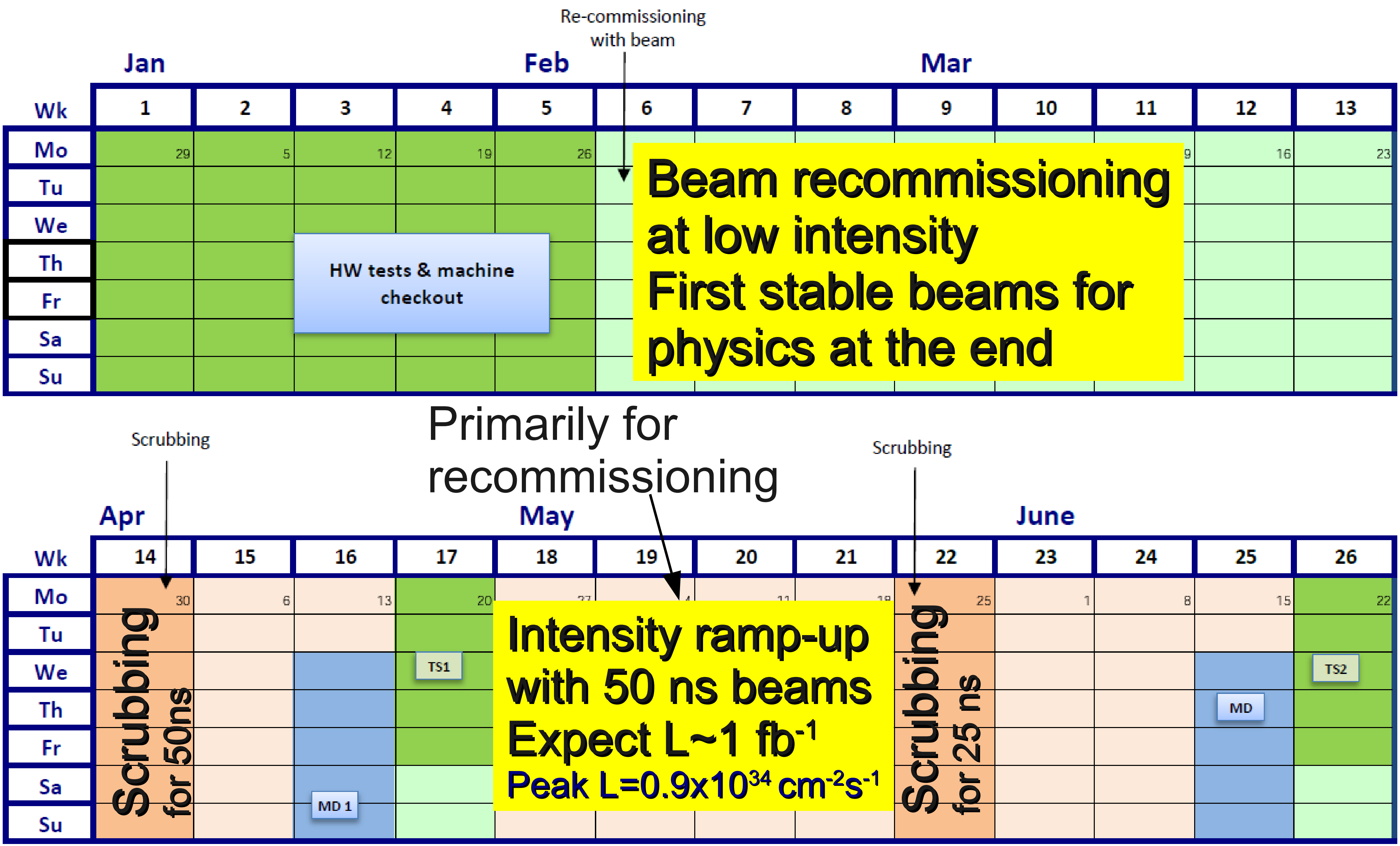


2015 Startup Scenario

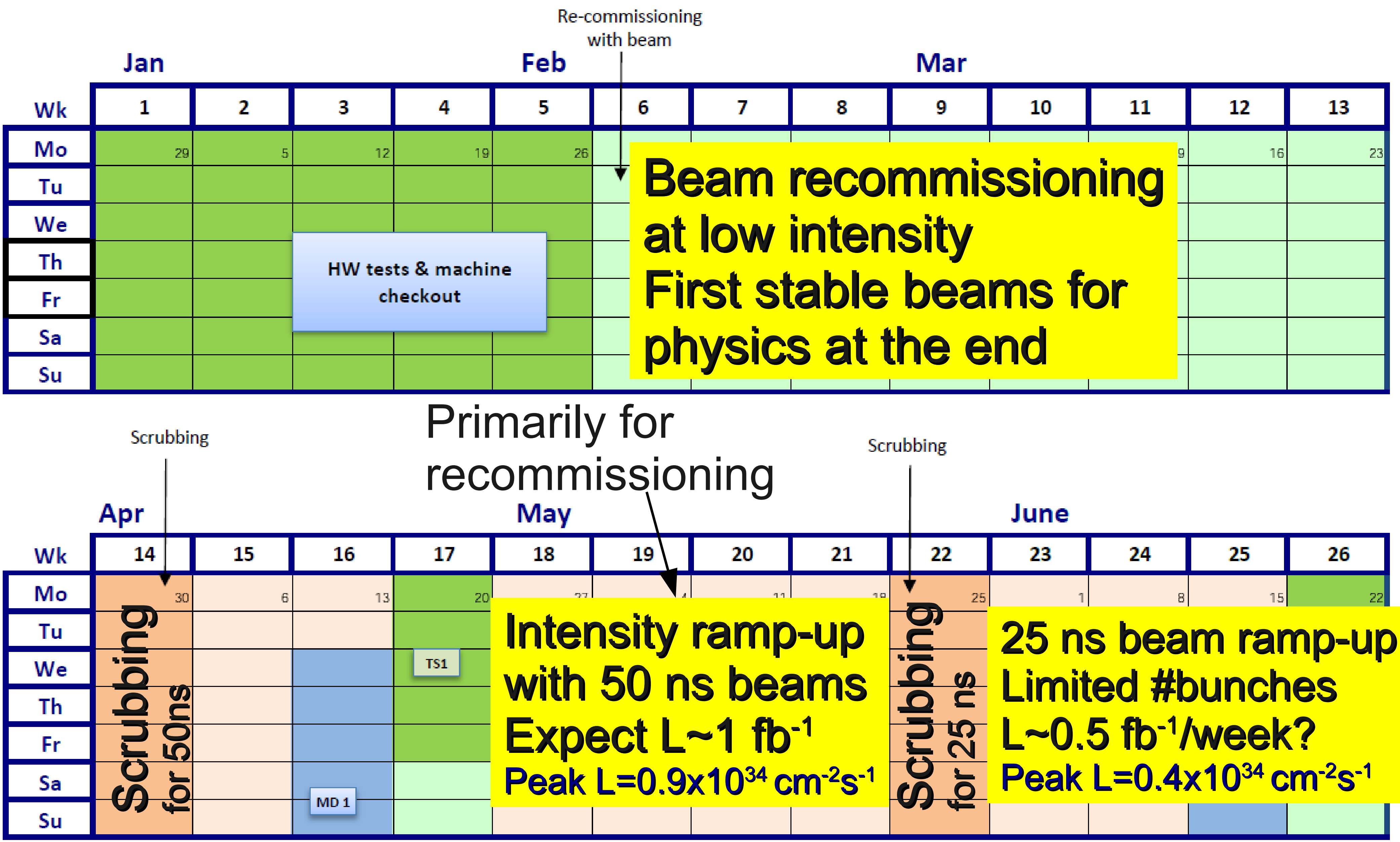




2015 Startup Scenario



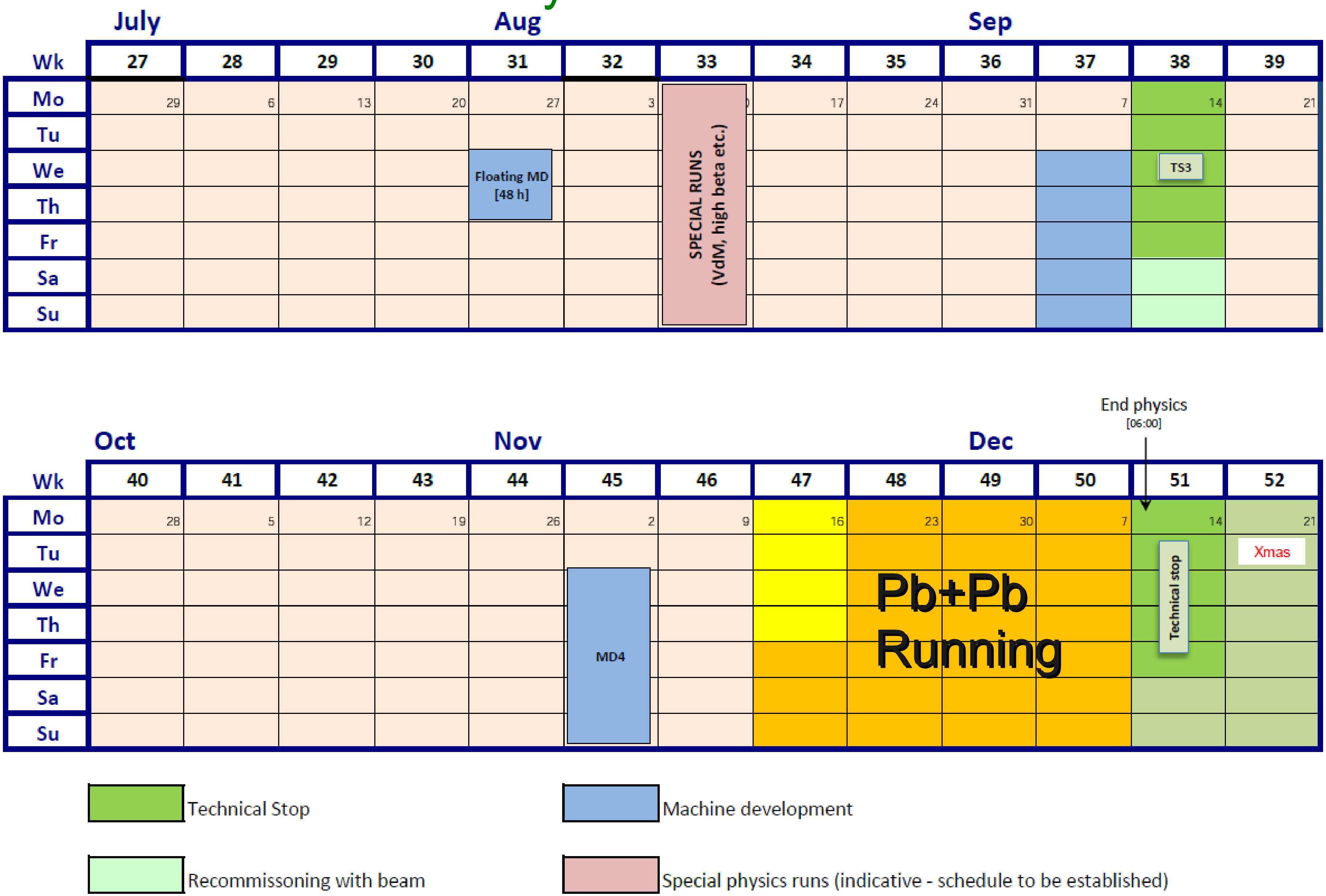
2015 Startup Scenario



Remaining 2015

Continue ramp-up of #bunches over 16 more weeks of p+p

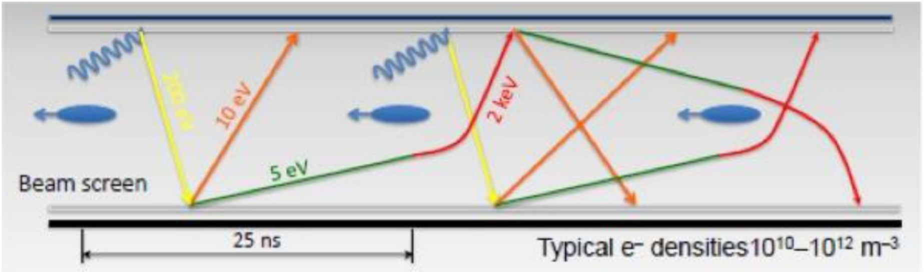
Could have 15-30 fb^{-1} by end of 2015



LHC Luminosity Limitations

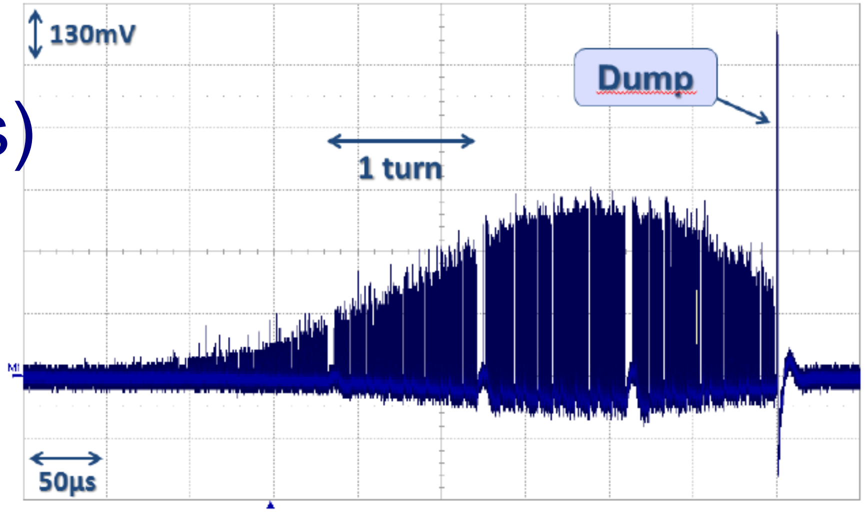
Electron cloud

- Much worse at 25 compared to 50 ns
- Scrubbing will help suppress secondary electron yield
- Will limit length of bunch trains



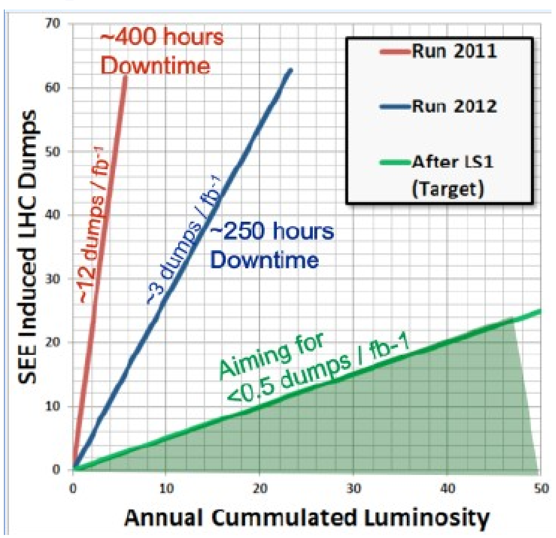
"UFOs" (Unidentified Falling Objects)

- Caused 20 dumps in 2012, but many below-threshold mini-UFOs
- Improvement with time seen, but concern for higher beam-energy

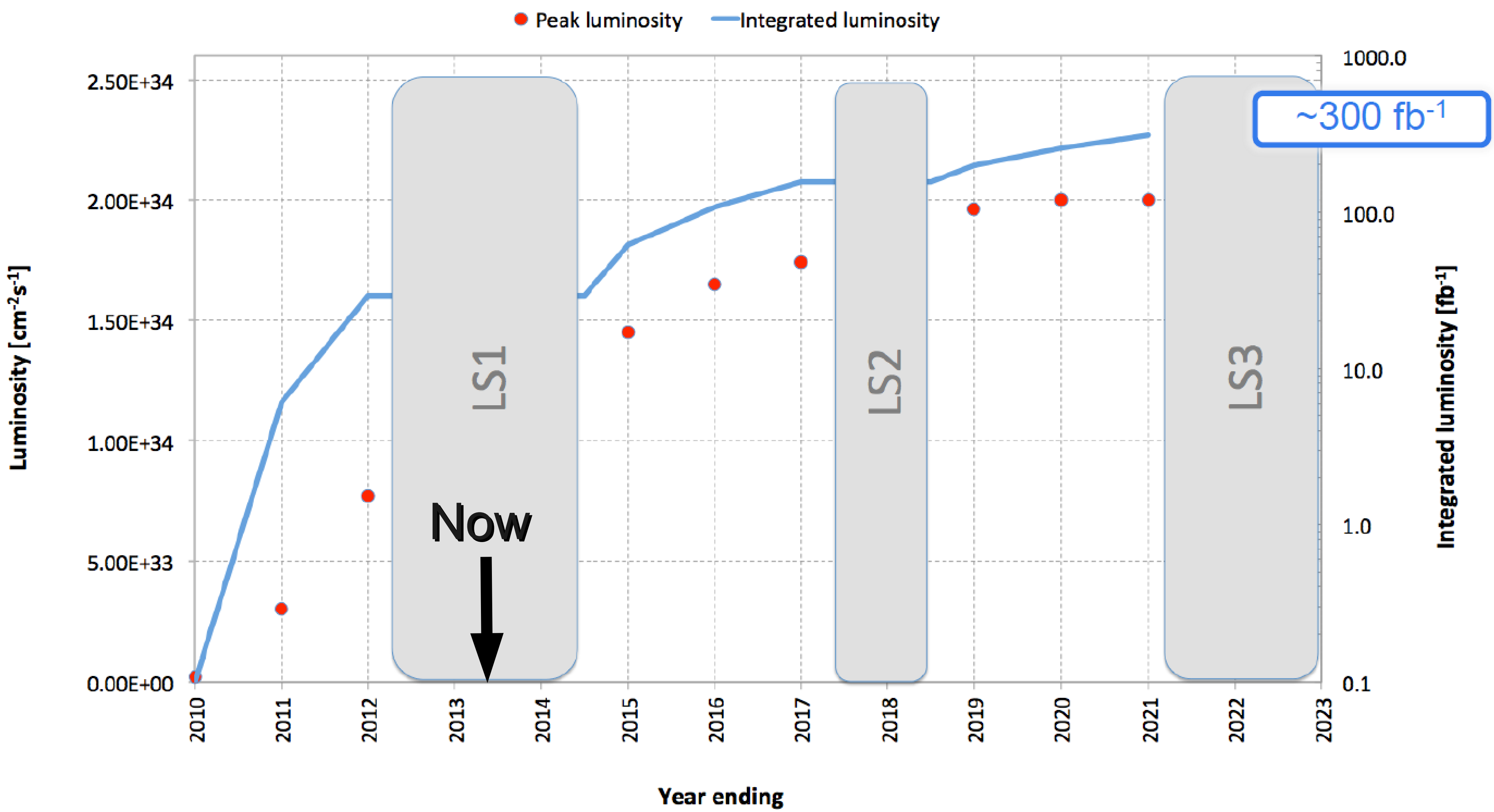


Radiation to electronics

- Single-event upsets causing beam dumps
- Being mitigated with relocation or shielding

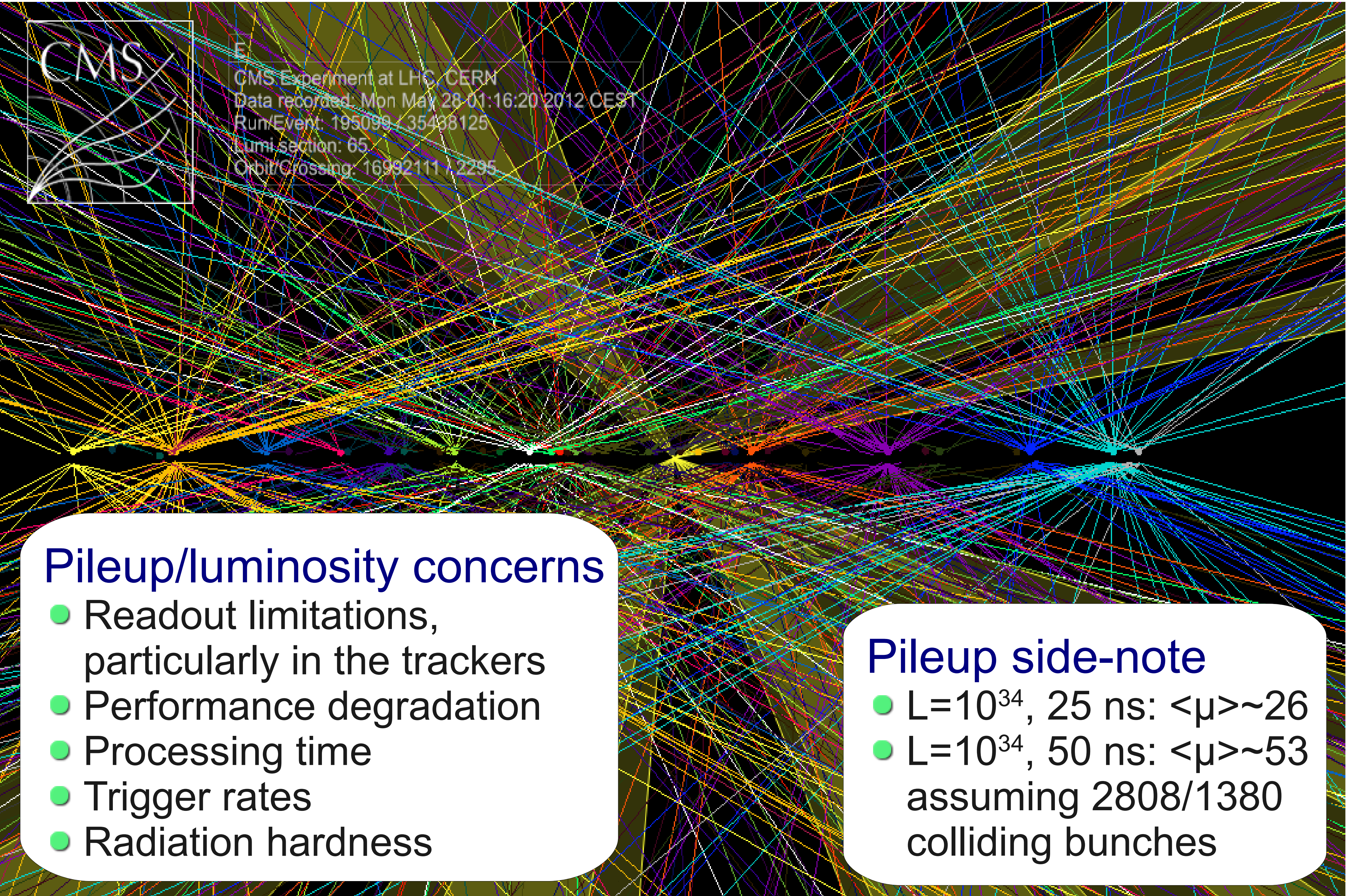


Luminosity Projection for Run 2+3



Run 2 Experimental Challenges

Major Concern: Pileup



Pileup/luminosity concerns

- Readout limitations, particularly in the trackers
- Performance degradation
- Processing time
- Trigger rates
- Radiation hardness

Pileup side-note

- $L=10^{34}$, 25 ns: $\langle\mu\rangle\sim 26$
- $L=10^{34}$, 50 ns: $\langle\mu\rangle\sim 53$

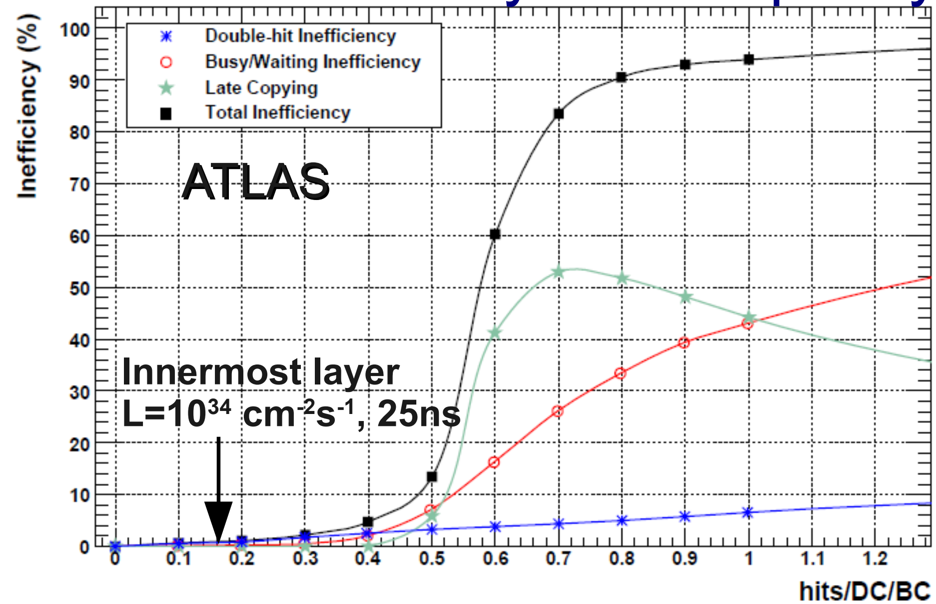
assuming 2808/1380 colliding bunches

Readout Limitations

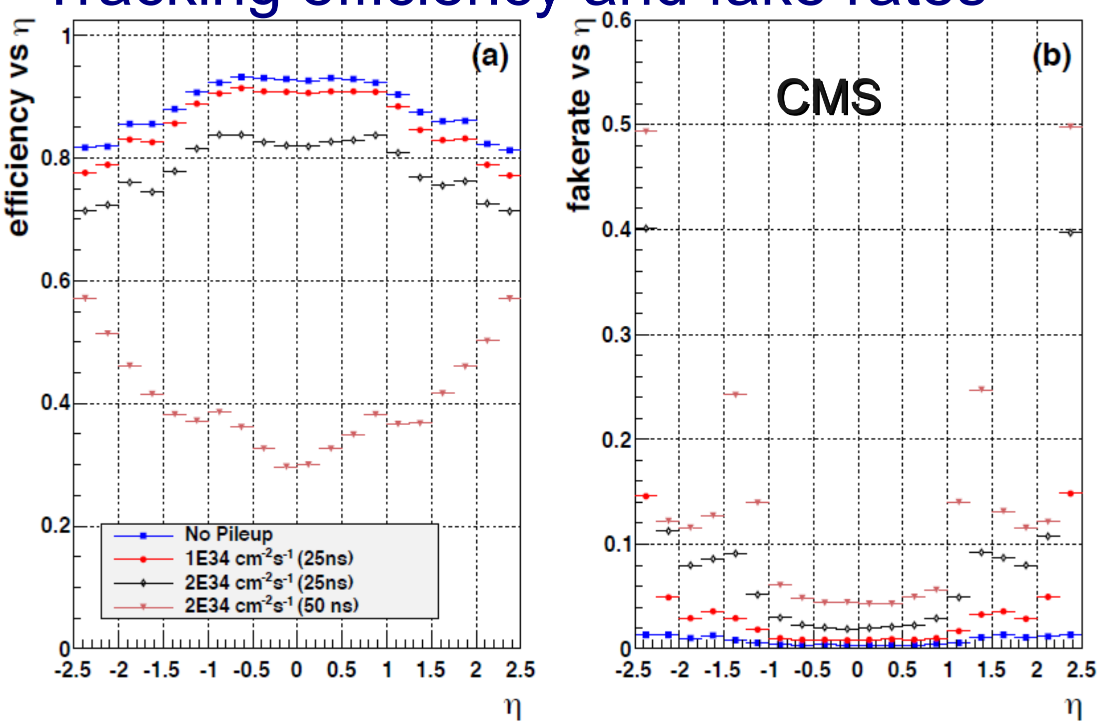
Pileup impact on trackers

- Pixel detectors starts to lose hits as occupancy increases, degrading performance
- ATLAS also have bandwidth limitations in readout of detectors
  – being mitigated with additional readout links during shutdown

Pixel inefficiency vs occupancy



Tracking efficiency and fake rates

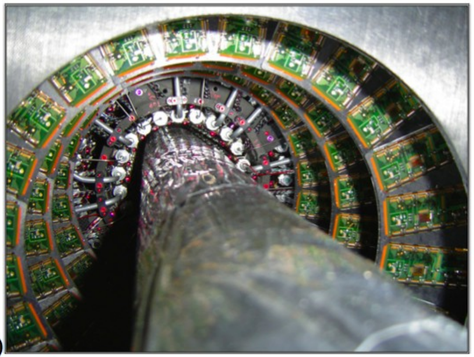
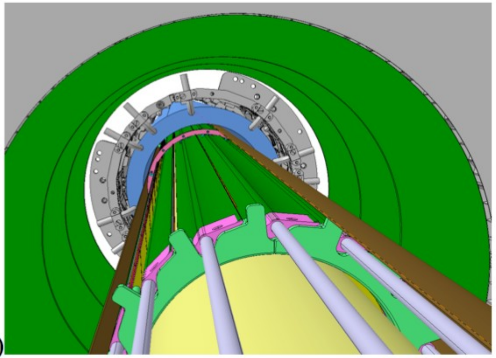


Luminosity limits

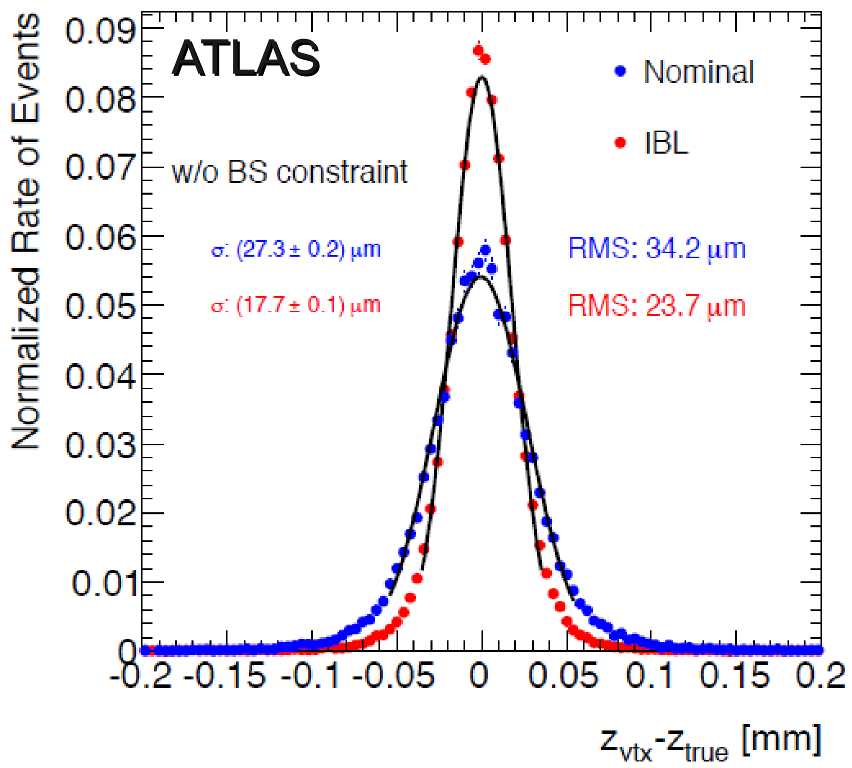
- L~1.6x10^{34} cm^{-2}s^{-1} at 25 ns manageable for ATLAS & CMS
- Neither experiment would currently be able to handle L~2x10^{34} cm^{-2}s^{-1} at 50 ns
  – LHC would need to level at lower luminosity

4th ATLAS Pixel Layer (IBL)

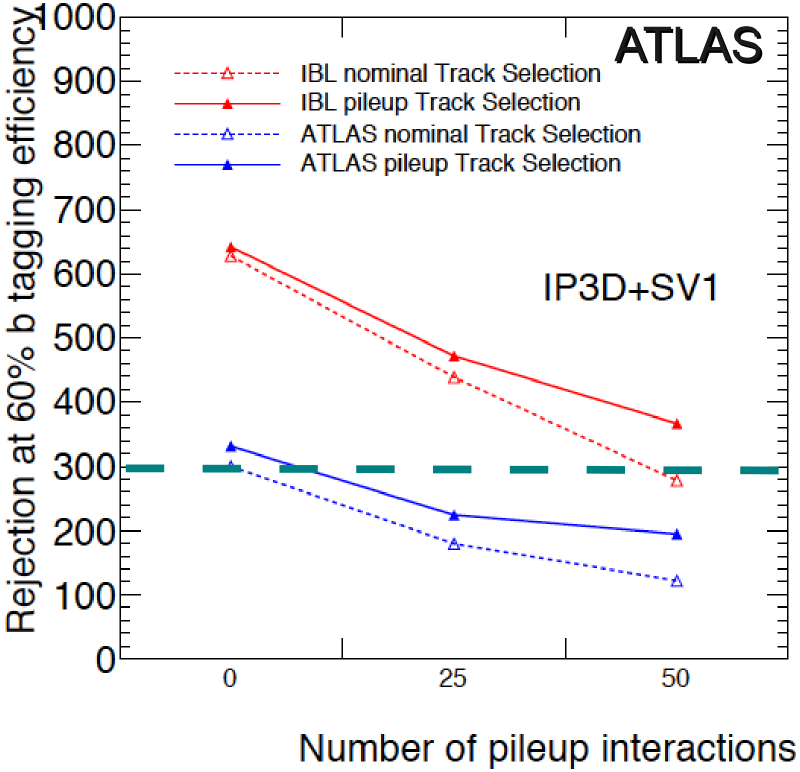
- New pixel layer around smaller beampipe (r=3.3cm) being installed in ATLAS during LS1
- Improves impact resolution and vertexing considerably, compensating for performance loss from high pileup

(a) 
(b) 

Vertexing resolution in z

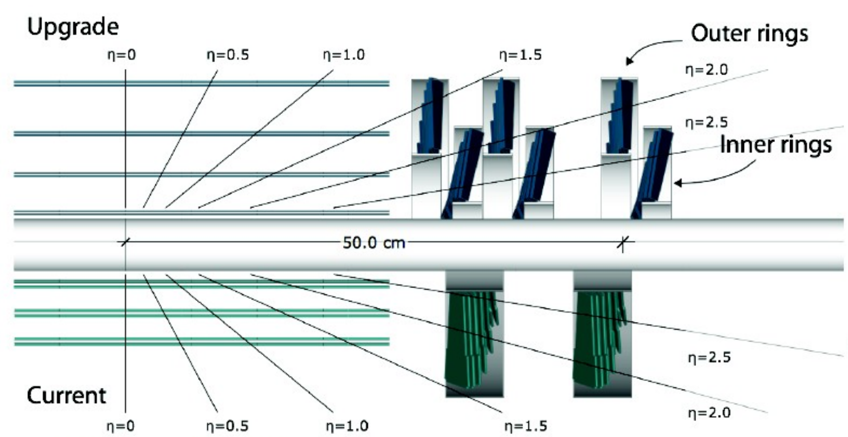


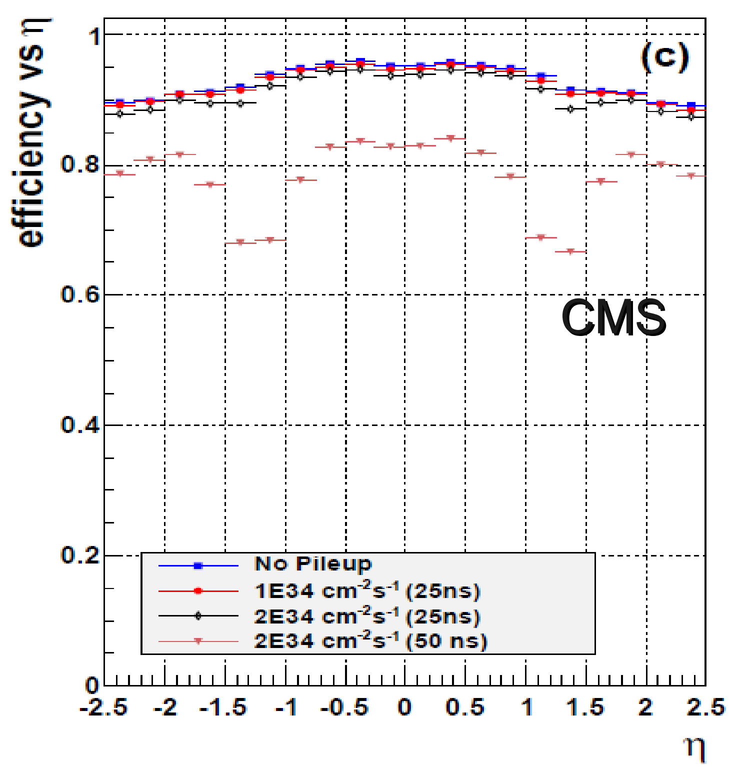
B-tagging rejection power

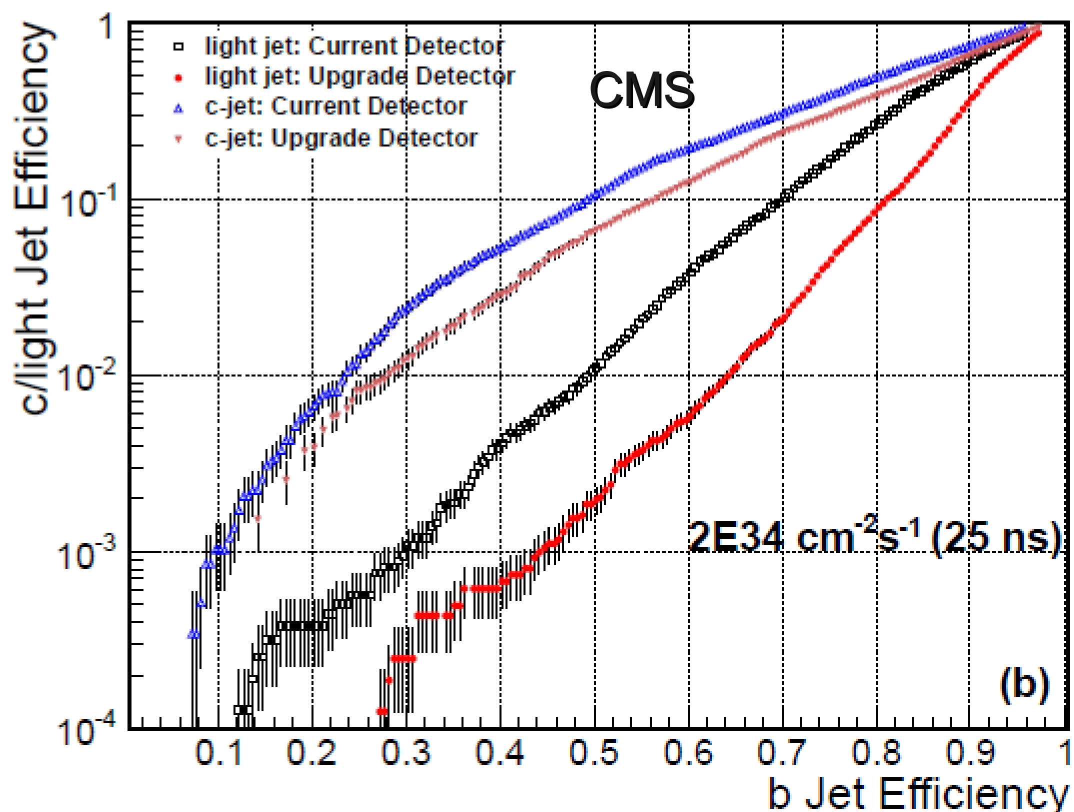


New CMS Pixel Detector

- CMS constructing new 4-layer pixel detector
- Higher occupancy capability, lower material and closer to beam for better impact resolution
- Can handle higher pileup and radiation levels
- Ready for installation by end of 2016

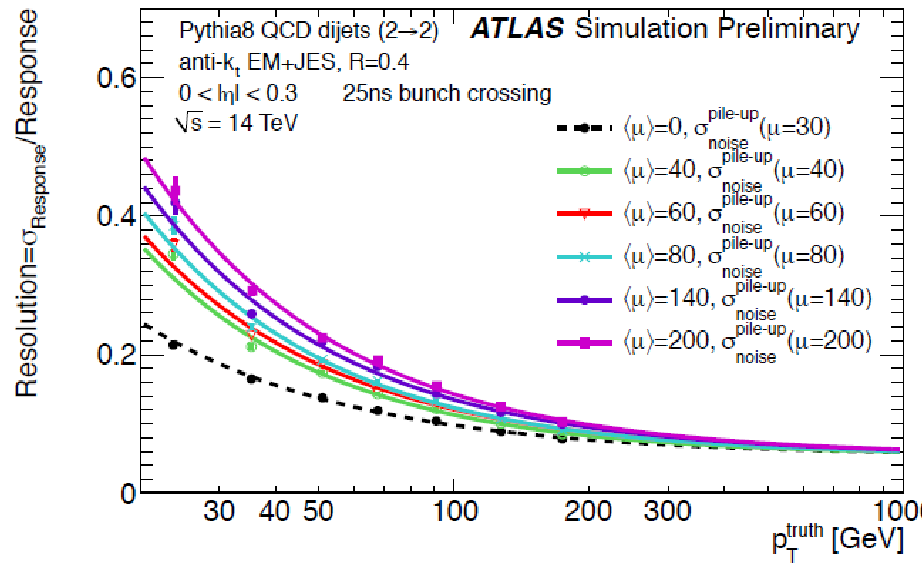




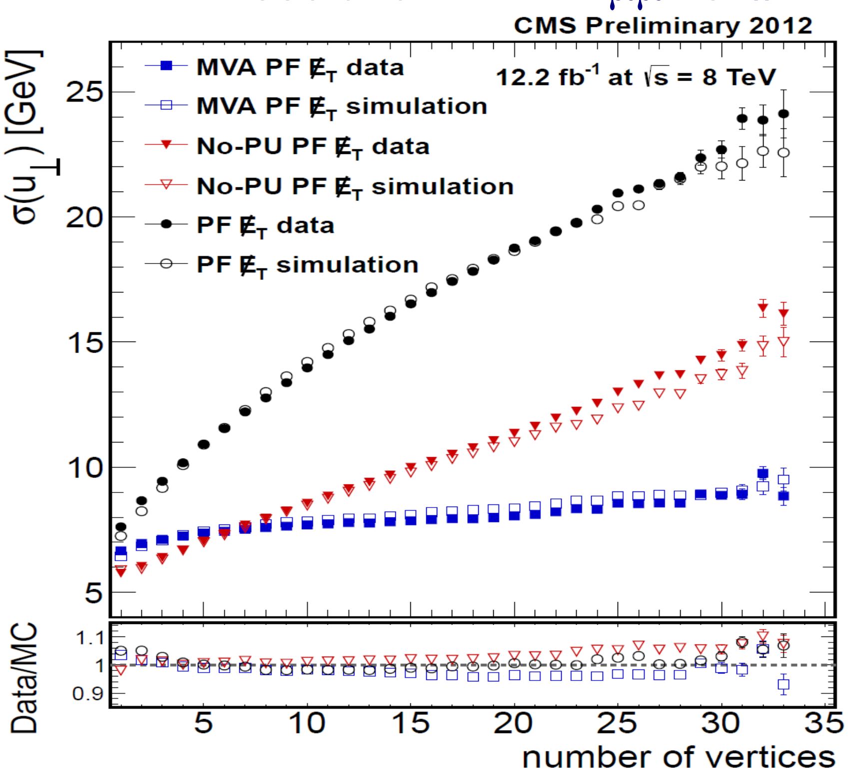


More on Performance vs Pileup

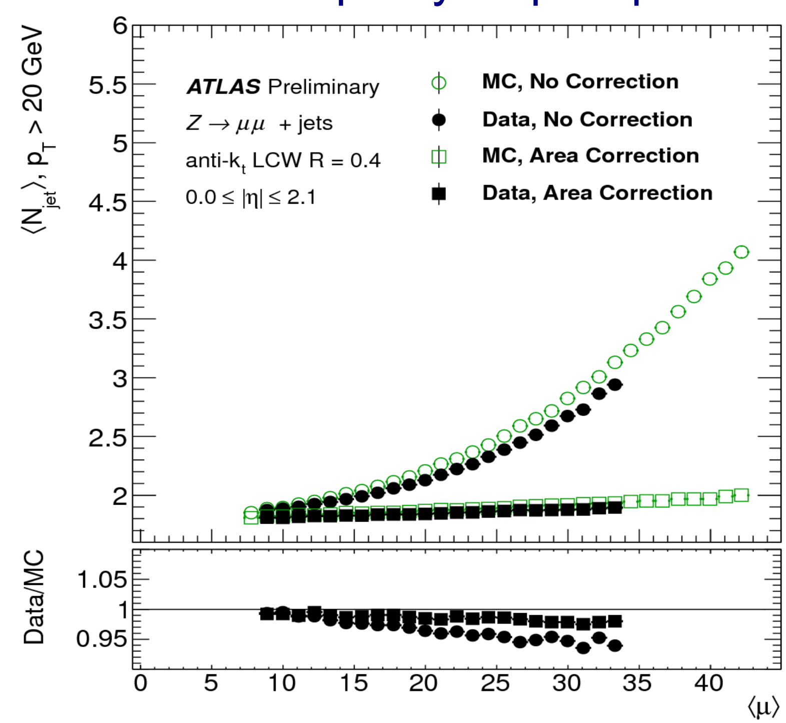
- Pileup degrades calorimeter performance as well
- Particularly affects low-p_T jets and missing E_T
- Can largely compensate with various pileup suppression methods
  - – relies mostly on tracking



MET Resolution in Z → μμ vs #vtx



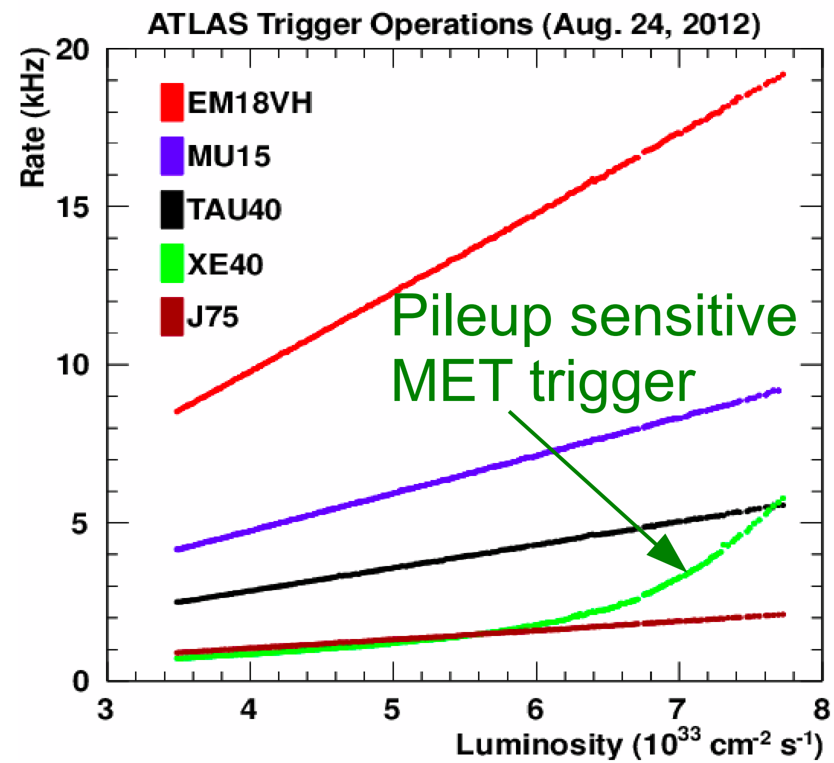
Jet multiplicity vs pileup



Triggering in 2015

Challenge for trigger in 2015

- Background rates typically increase by factor 2-3 due to increase in √s
- Rates increase linearly with luminosity or worse due to pileup
- Higher (35%) fake muon rate in ATLAS when running with 25ns bunch spacing – due to out-of-time low-p_T protons
- HLT processing time increases with pileup as well



Real W/Z leptons (arXiv:1006.3766)

W inclusive	200 Hz
W w/ lepton	80 Hz
($\eta < 2.5$ and $p_T > 30$ GeV)	
Z inclusive	23 Hz
Z w/ lepton	8 Hz
(both lepton $\eta < 2.5$ and $p_T > 20$ GeV)	
Real leptons per flavor	$\approx$ 100 Hz at 1e34

Bandwidth will be limiting

- Will need to prioritize physics
- Even keeping all EW leptons expensive in bandwidth
- Both experiments targeting 1kHz averge trigger rate
- Challenging for offline computing (CPU & storage)

Some Possible Triggers in 2015

2015 trigger menus

- Actual trigger selection for Run 2 still being developed
- Example triggers relevant for SUSY under consideration (at least by ATLAS)
- These will of course change during the next year based on feedback from physics groups

Trigger	2012 Threshold	2015 Threshold?
Single muon	24 GeV	25 GeV
Single electron	24 GeV	28 GeV
lepton+MET	24,40 GeV	24,60 GeV
Di-muon	2x13 or 18+8 GeV	2x14 or 20+8 GeV
Di-electron	2x14 GeV	2x17 GeV
Tri-muon	3x4 or 18+2x4 GeV	3x6 or 20+2x4 GeV
Single jet	360 GeV	450 GeV
Multi jet	5x55 GeV	6x50 GeV w. $\|\eta\|<2.5$
MET	80 GeV	100 GeV

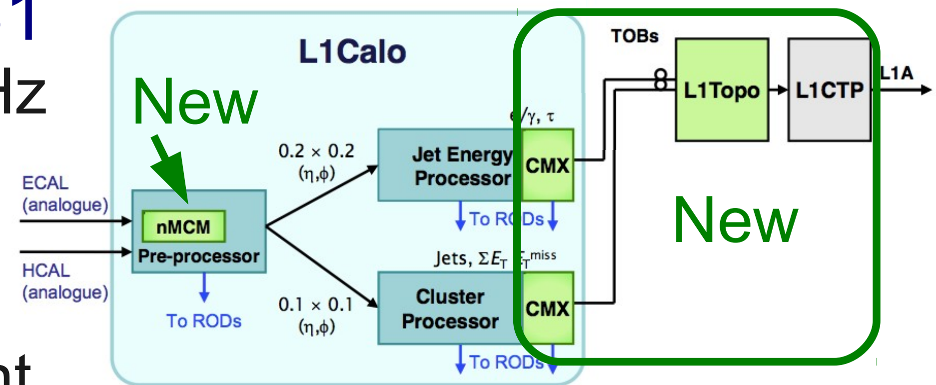
...

Note offline thresholds are 1-3 GeV higher for leptons and 50-70 GeV higher for MET

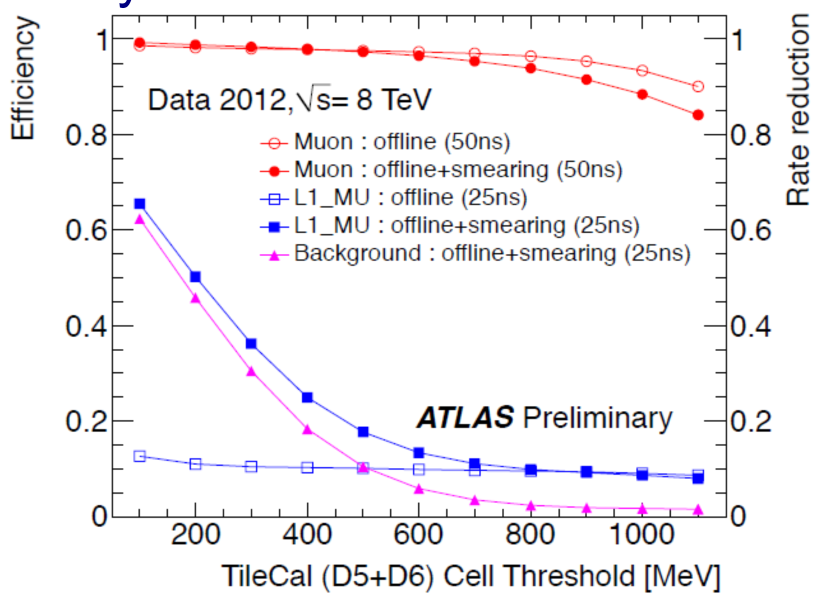
ATLAS Trigger Evolution

New L1 features installed in LS1

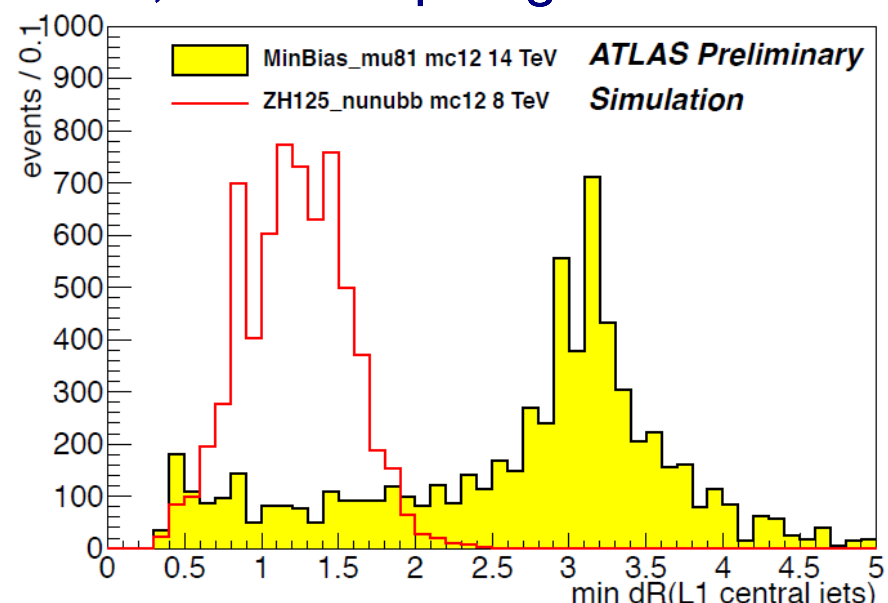
- Increase in peak L1 rate to 100 kHz
- Topological trigger to select on combined L1 quantities (opening angle, mass, ...)
- Additional coincidence requirement in endcap to reduce fake muon rate (using inner muon chamber and outer hadronic calorimeter)



Efficiency of muon-tilecal coincidence



ZH, H→bb topological selection

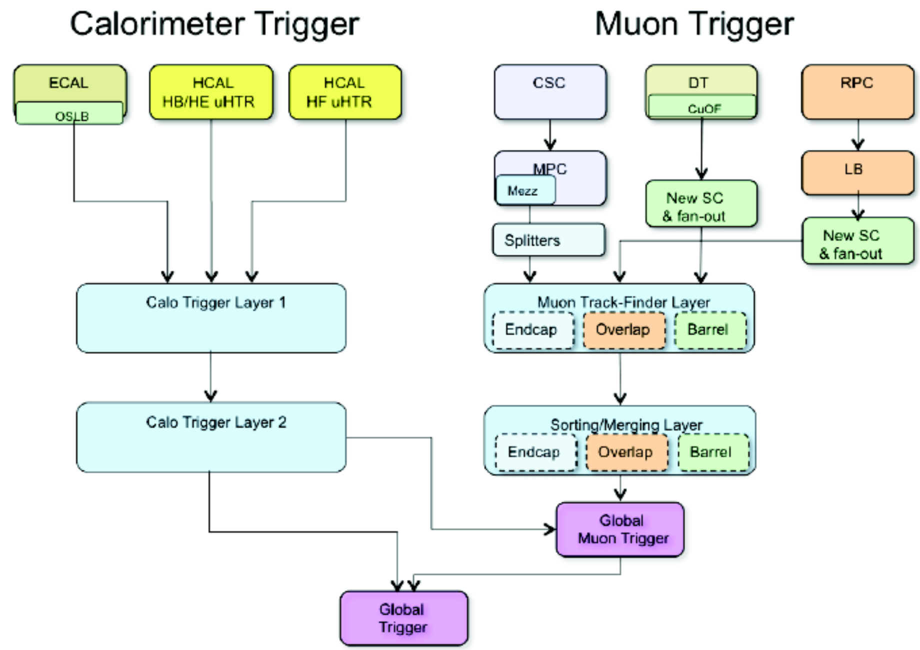


Will need some time for commissioning, but expected to be available for most of 2015 run

CMS Trigger Upgrade

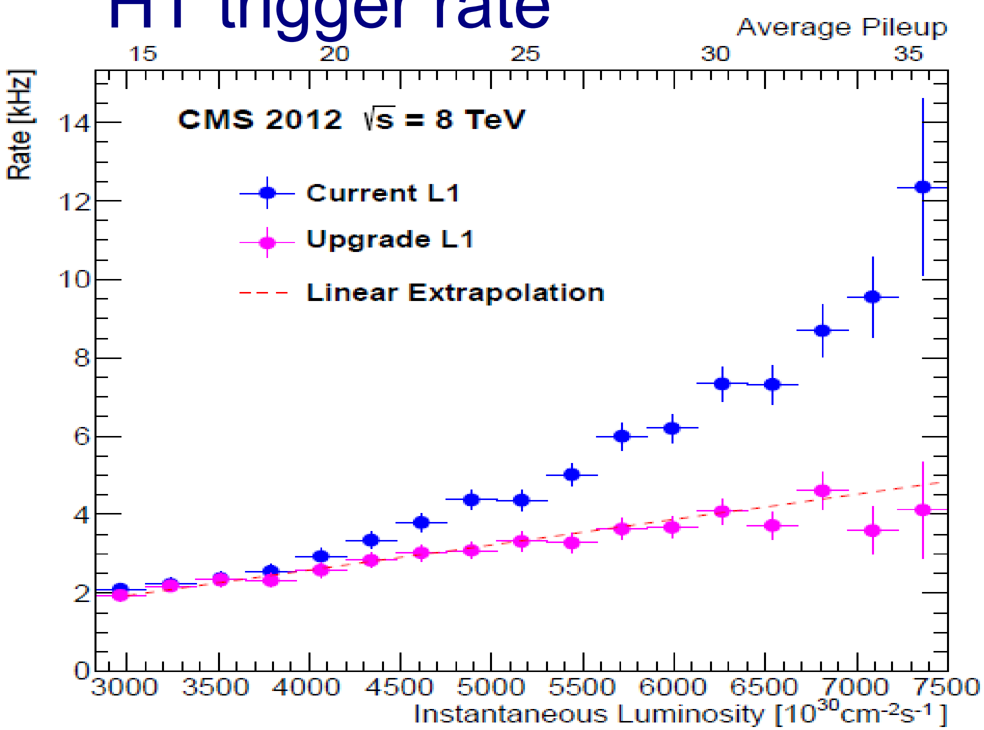
Complete upgrade of L1

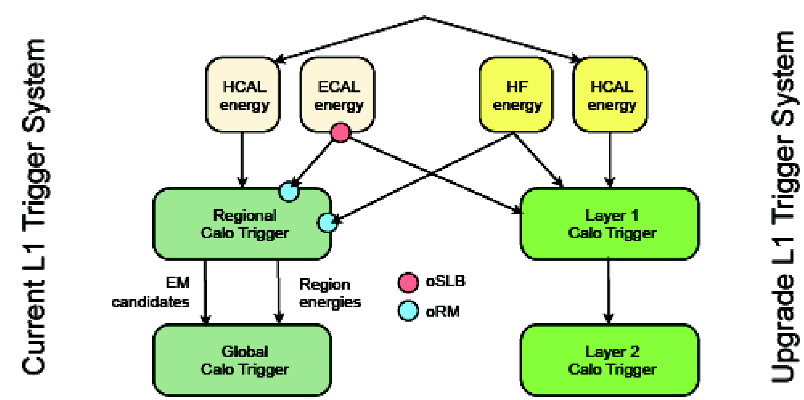
- Modern FPGAs everywhere
- Allowing advanced algorithms for pileup mitigation, isolation and topological selections
- In parallel with legacy system in 2015 for commissioning
- Ready for physics in 2016



Level 1 Trigger Upgrade

HT trigger rate





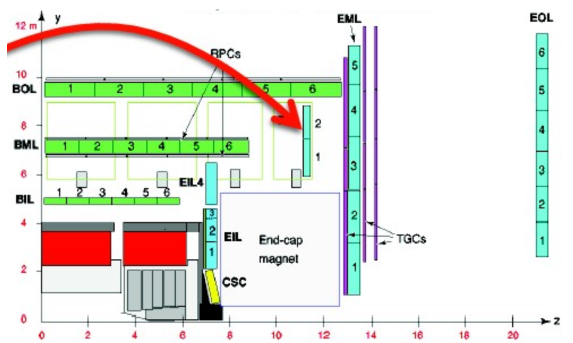
Optical splitting for parallel commissioning, calorimeter trigger

Detector Consolidation

Also extensive consolidation effort for both ATLAS and CMS

ATLAS

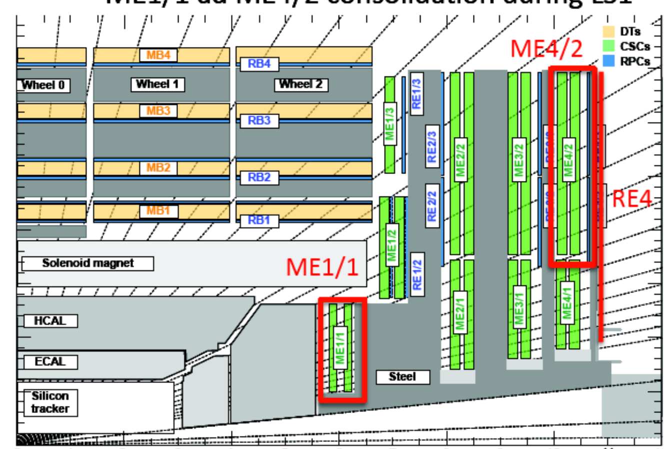
- New pixel+SCT cooling system
- New pixel service panels
  Recovers bad channels and adds additional bandwidth
- New calorimeter power-supplies (less trips, lower noise)
- Magnet cryogenics
- Extra muon chambers at $1<\eta<1.3$
  Completes muon system



CMS

- Cold (-20ºC) tracker to reduce radiation damage
- New photo-detectors in parts of HCAL to reduce beam-background and for B-field operation
- Completion of muon endcap

ME1/1 ad ME4/2 consolidation during LS1



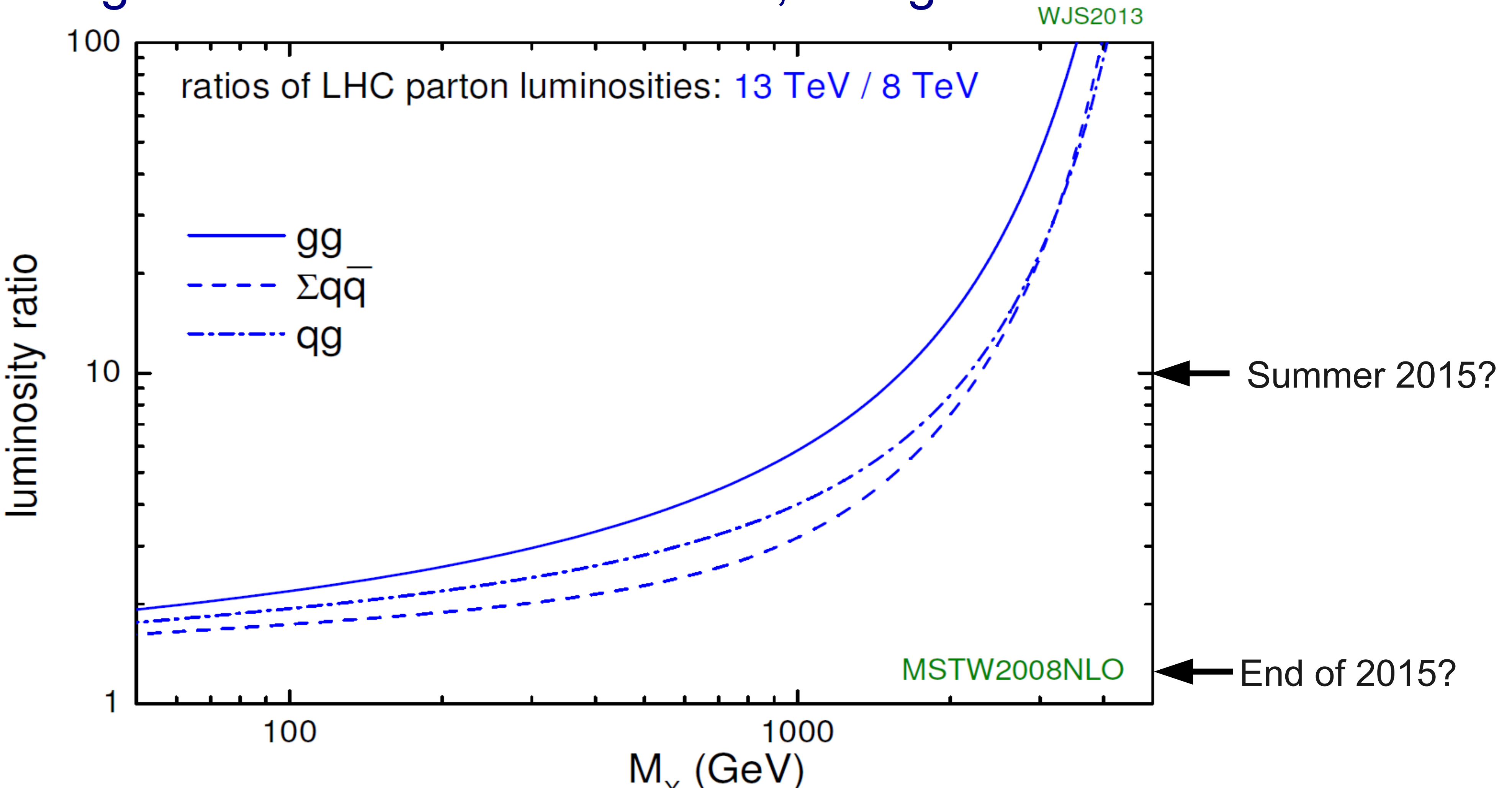
Will test carefully during shutdown, but will require beam-time for commissioning as well

Example: ATLAS toroid-off data for muon alignment

(Early) Physics Opportunities in 2015

Projecting to 2015, 13 TeV

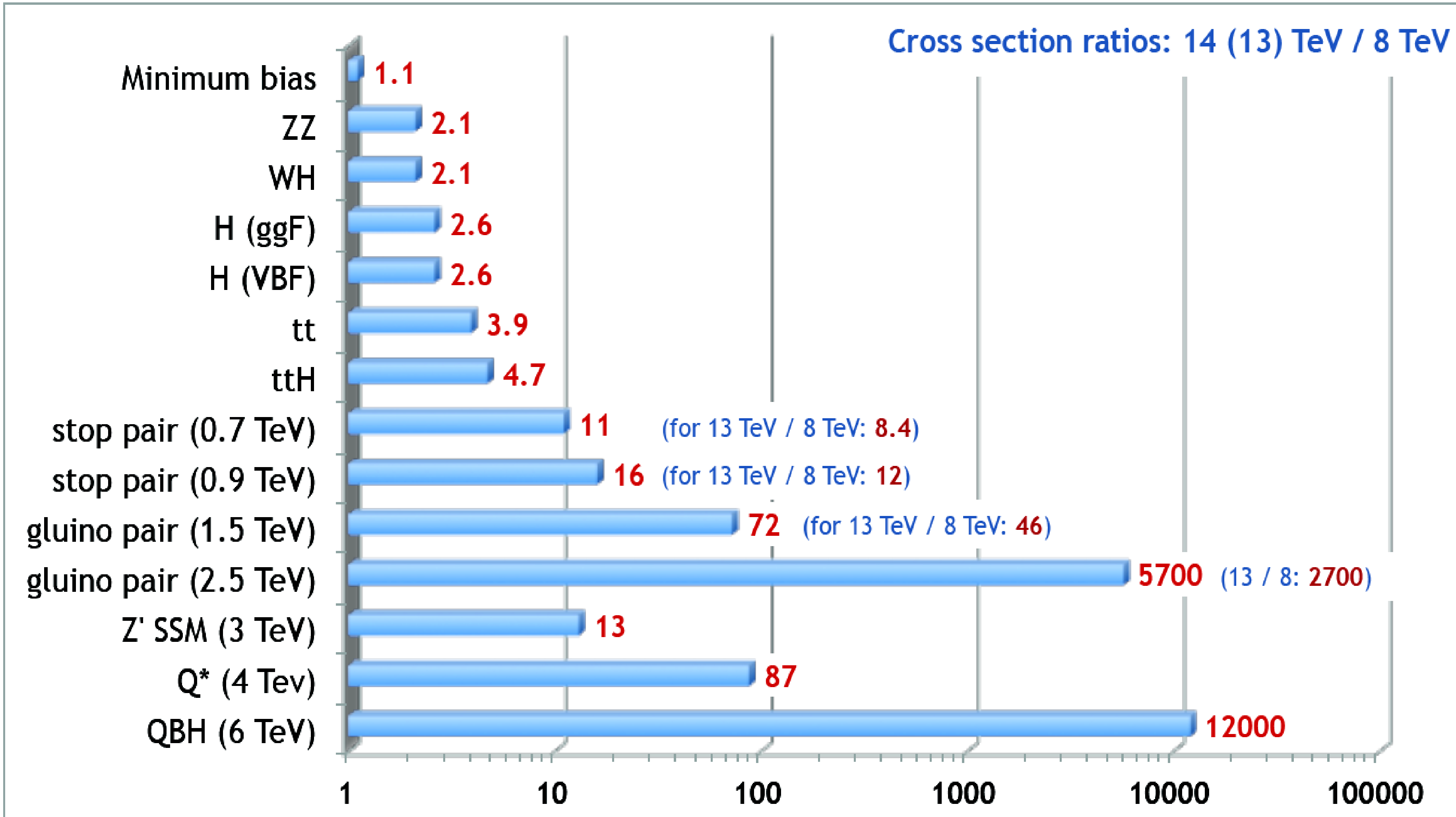
Physics reach, largely driven by increase in partonic luminosities
Backgrounds will increase as well, though



Note: almost all recent physics projection are for 300/3000 fb^{-1} cannot give accurate estimates of 2015 sensitivity

Cross-section Ratios

Very little luminosity needed to exceed
Run-1 sensitivity for heavy particles

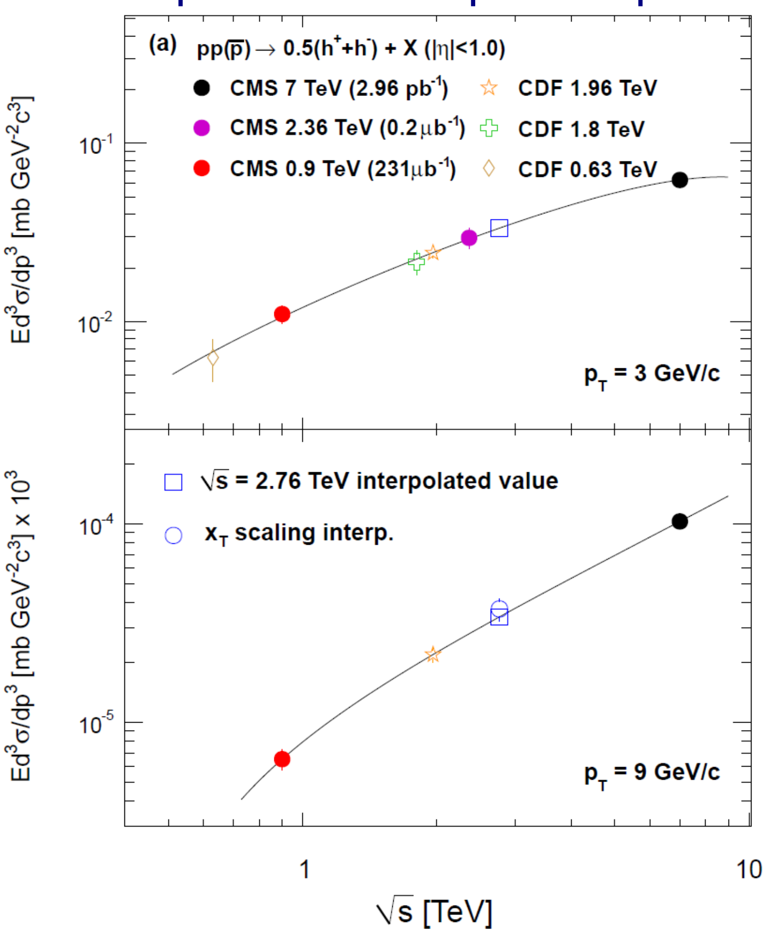


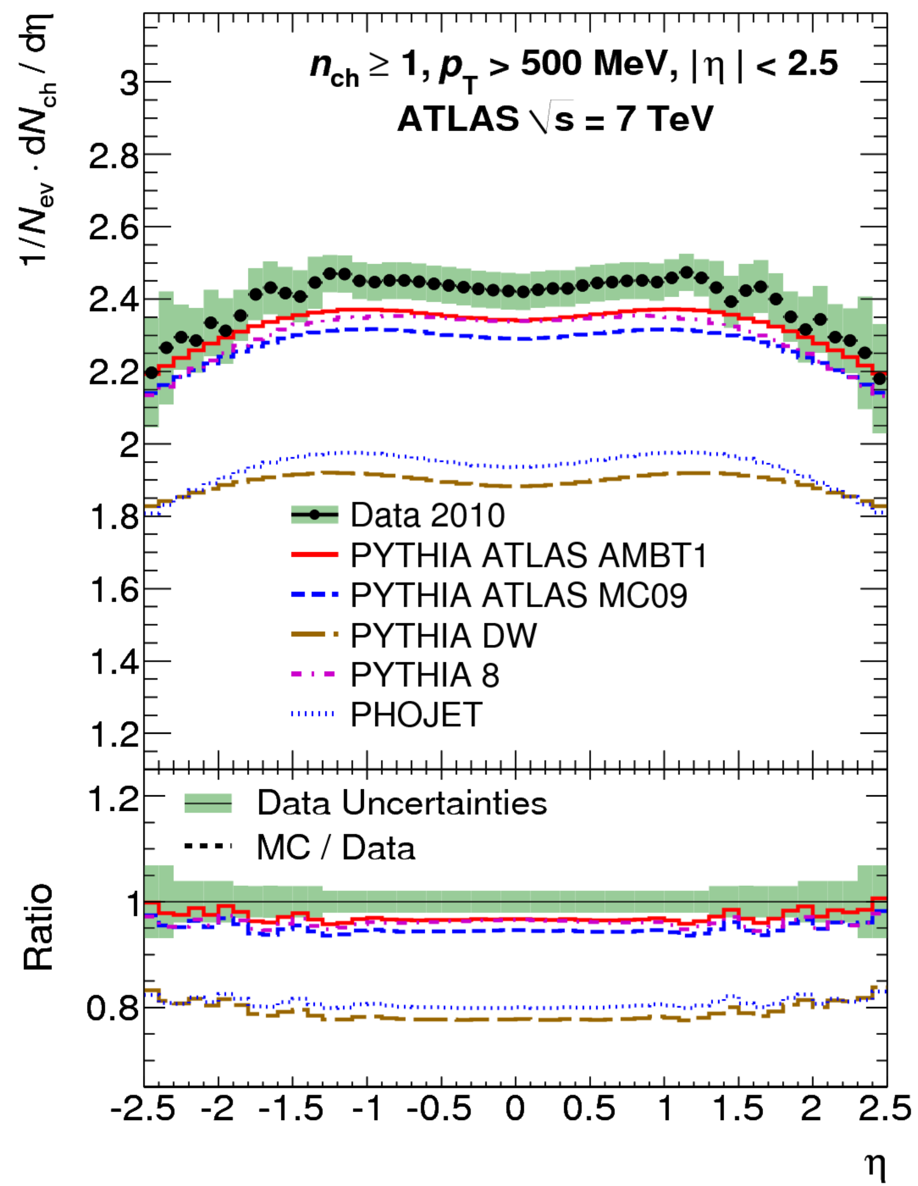
Basic Measurements Required

Will need basic measurements like charge multiplicity

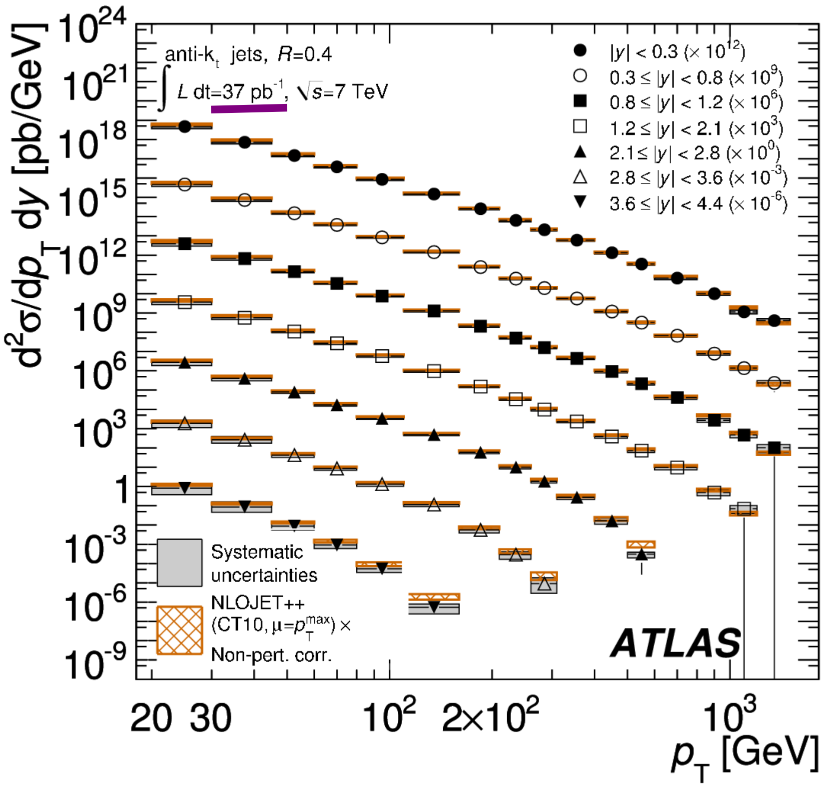
- At least to validate pileup simulation at 13 TeV
- Large samples of low-pileup minbias will be recorded in a few early fills

√s dependence for particle production





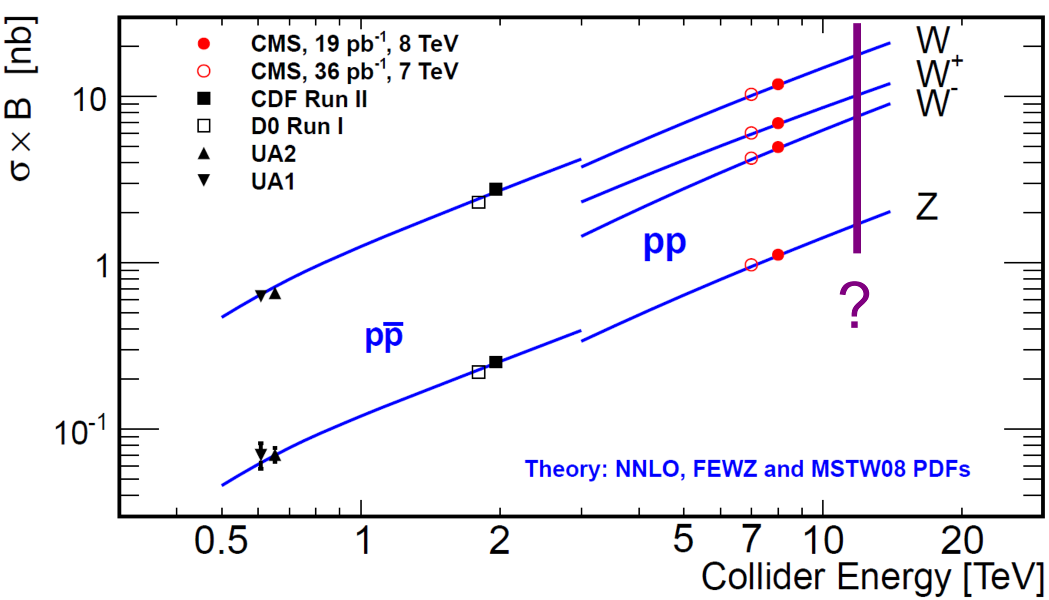
Standard Model Prospects

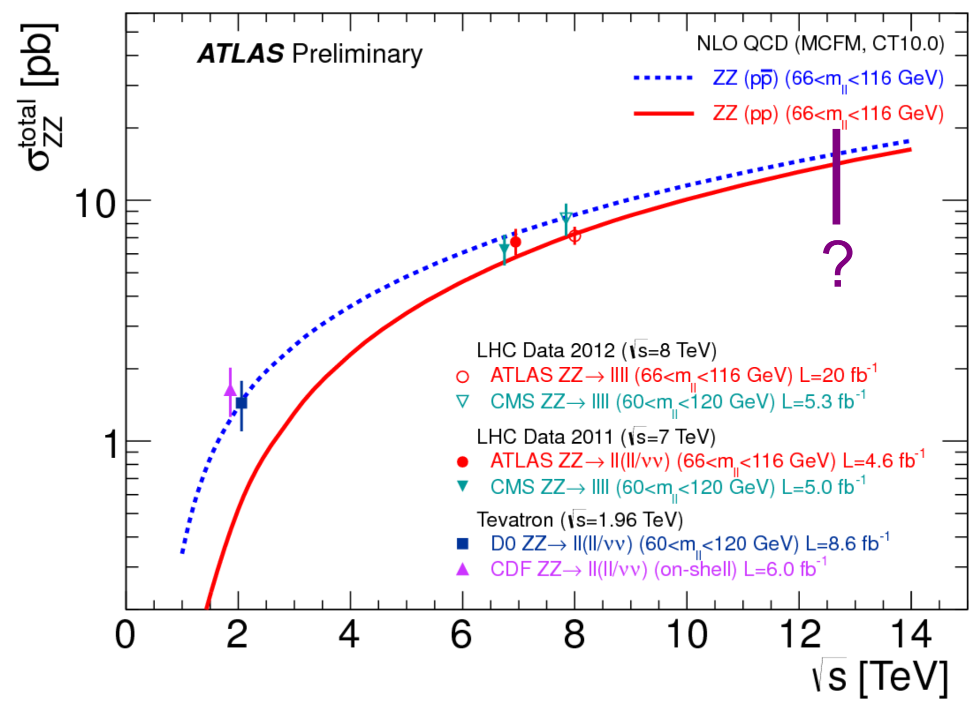


Basic jet and γ/W/Z boson can be done with little data

- Check of our understanding of high-energy physics processes

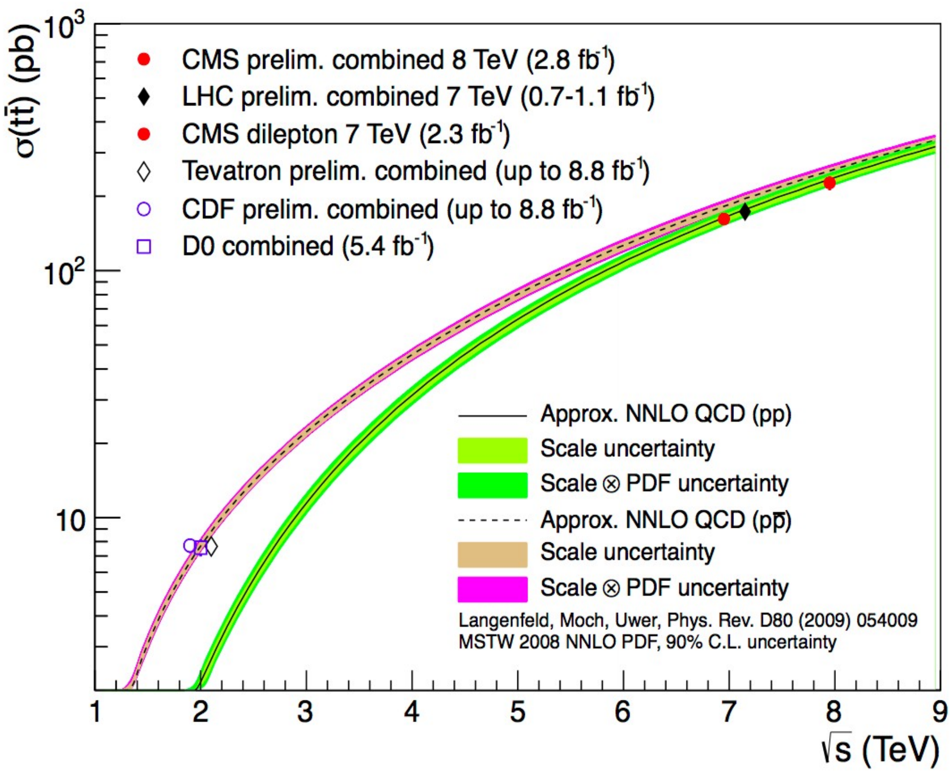
Diboson processes will need more data, but ZZ and γγ could be quick

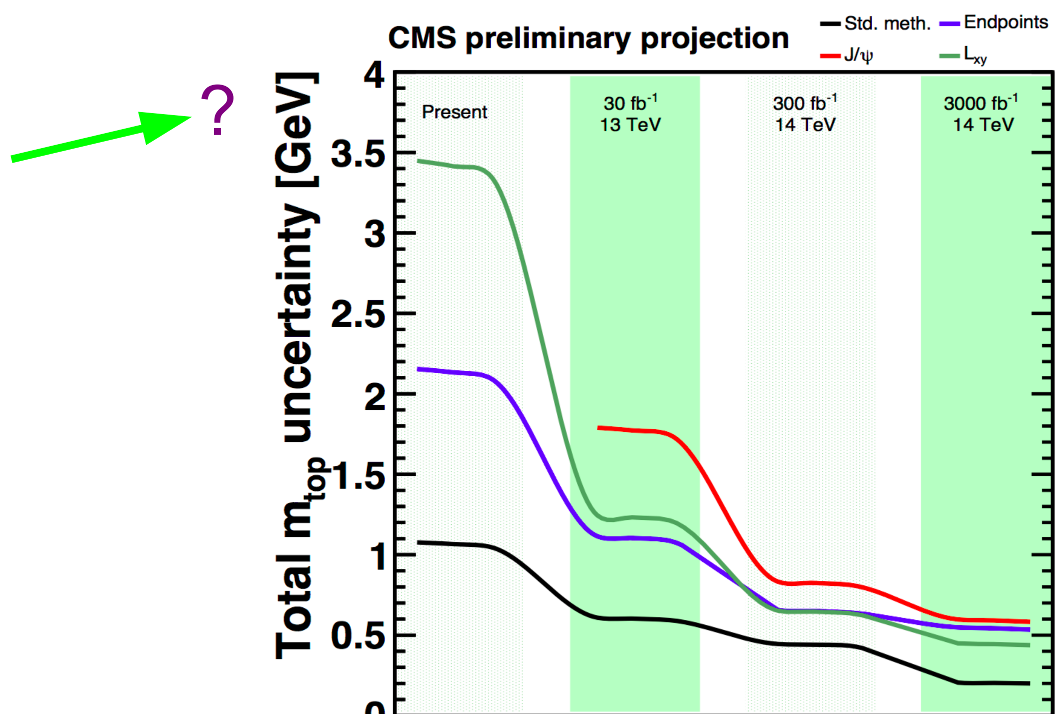




Top Physics Prospects

Similarly $t\bar{t}$ cross section does not need much data
With full 2015 dataset, can expect significant improvement in top mass, though analysis might take time





Cross section ratios 14 TeV/8 TeV: tt = 3.9, $t_{\text{s-chan}}$ = 2.1, $t_{\text{t-chan}}$ = 2.8, tW = 3.8

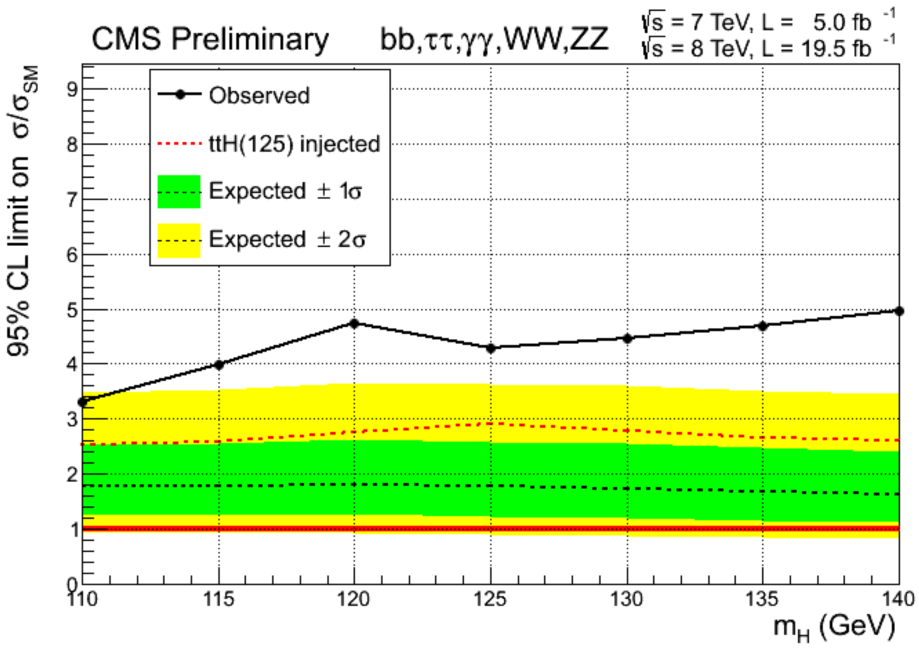
Higgs Boson Prospects

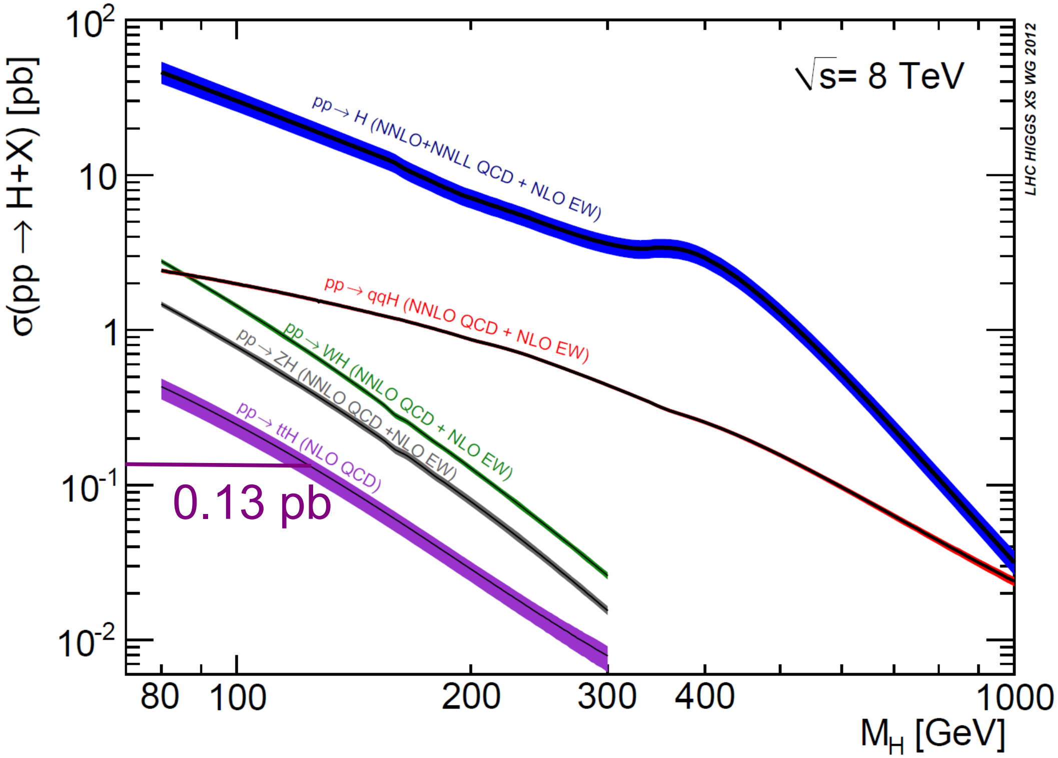
Significant increase in σ(H)

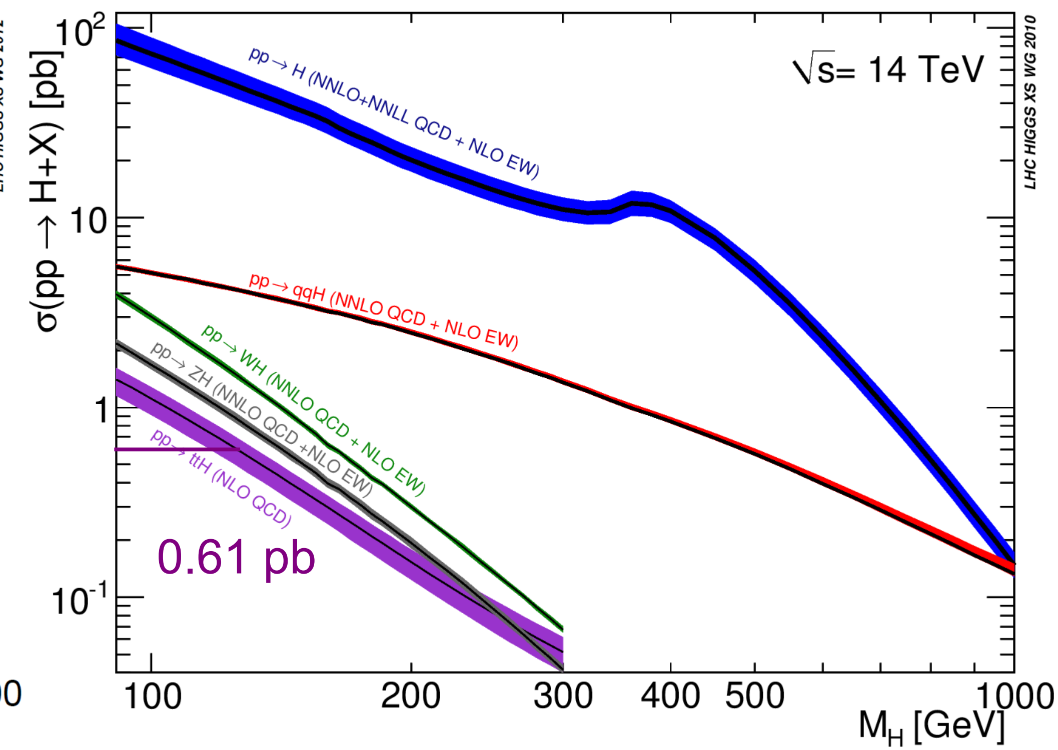
- Can “rediscover” Higgs early on
- With full 2015, measurements of Higgs properties will be beyond Run 1

Large opportunity in ttH channel

- ~4.5 times higher cross-section
- Could have significant signal with full 2015 dataset



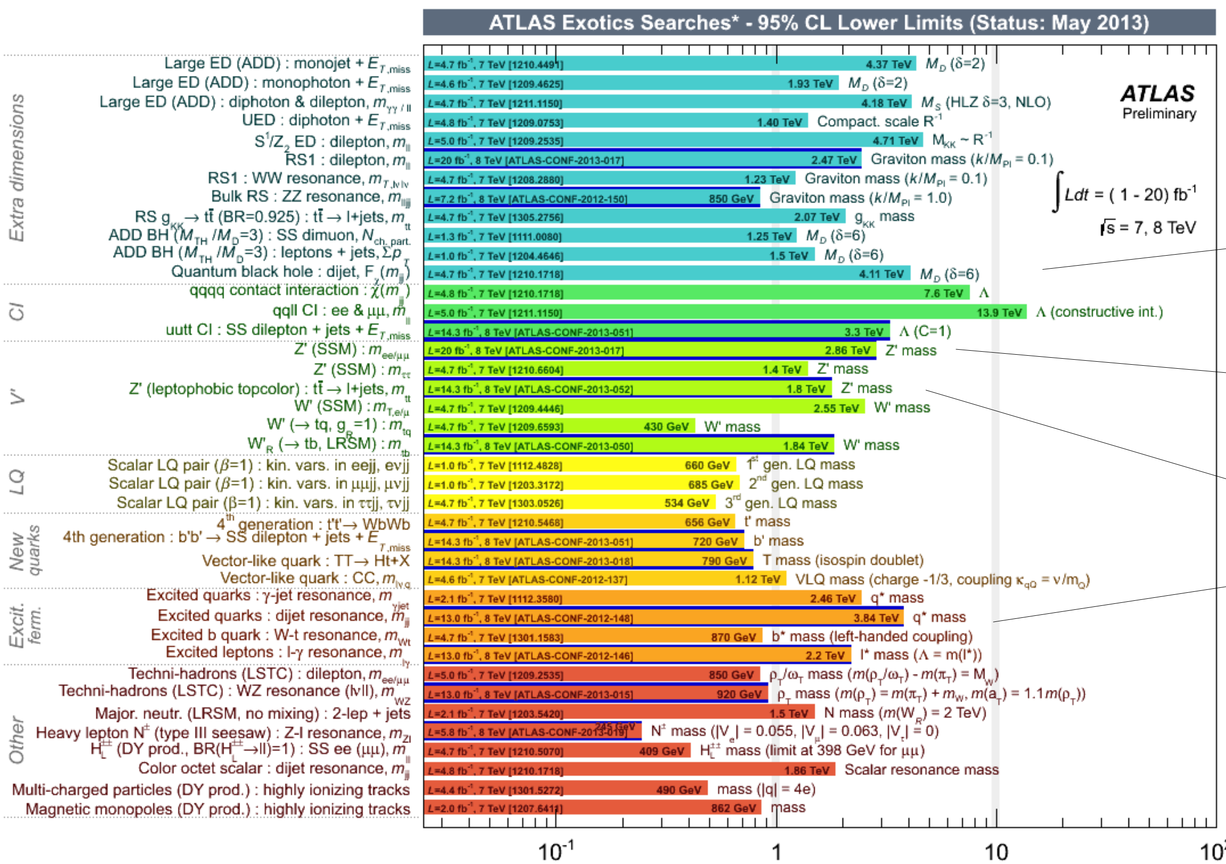




Exotica Prospects

Largest potential for early discoveries due to the large increase in heavy object cross sections predicted by BSM models

- Includes some of the “easy” first-data searches like di-jets and di-leptons

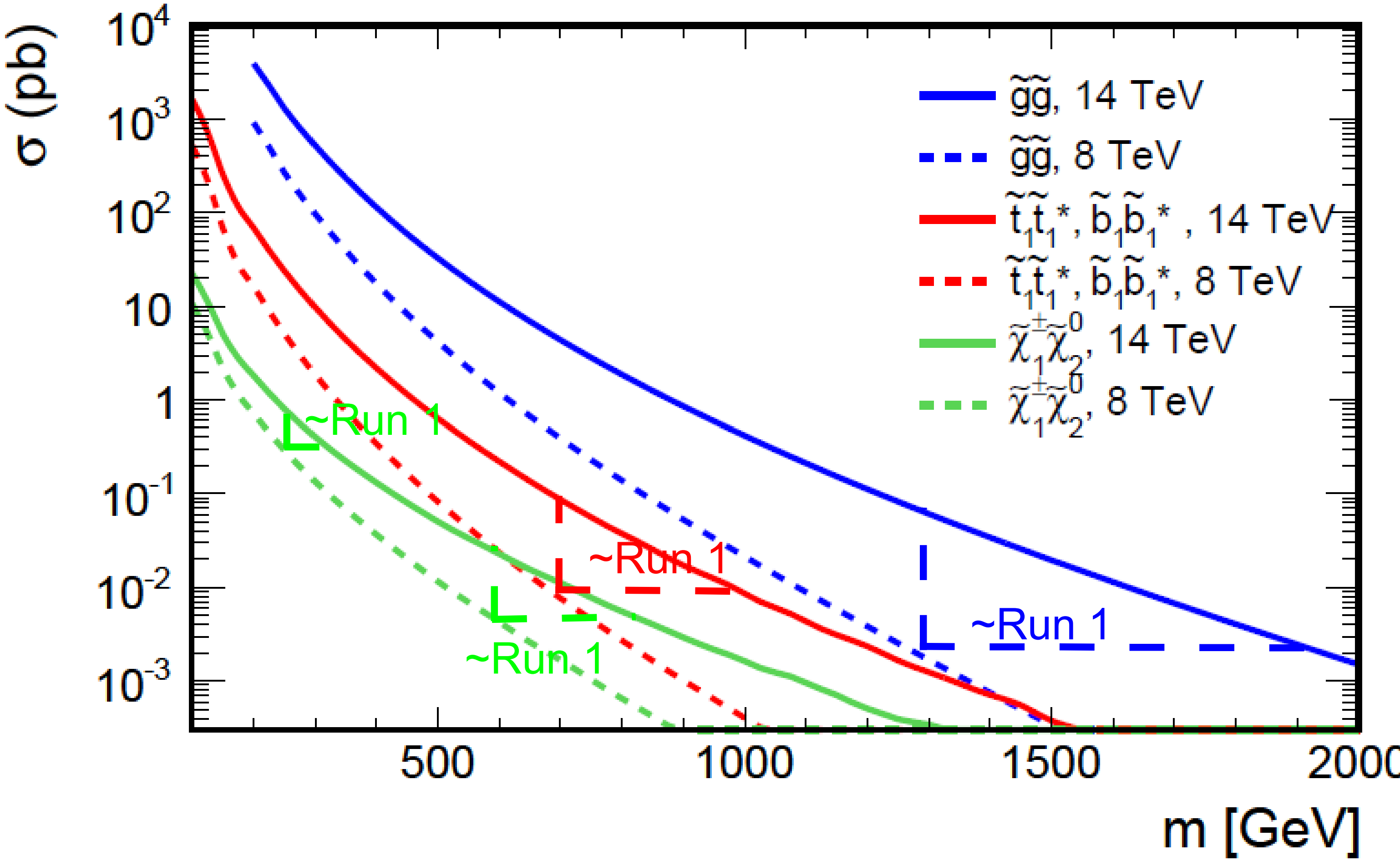


*Only a selection of the available mass limits on new states or phenomena shown

New state	Mass (TeV)	Cross-section ratio: 13/8	Cross-section ratio: 14/8
QBH (dijet search)	**4**	**70**	**105**
	5	400	700
	6	6000	12000
Z’ (SSM)	**3**	**9.4**	**13**
	4	7.2	11
Z’ (TC →*tt*)	**2**	**6.3**	**7.8**
q* (dijet search)	**4**	**56**	**87**
	5	150	270
	6	160	320

Supersymmetry Prospects

Significant increases in cross-section for supersymmetry processes as well
Expect inclusive searches for q,g to pass Run-1 sensitivity after few fb^{-1}



Keep in mind:

"Past performance may not be indicative of future results"

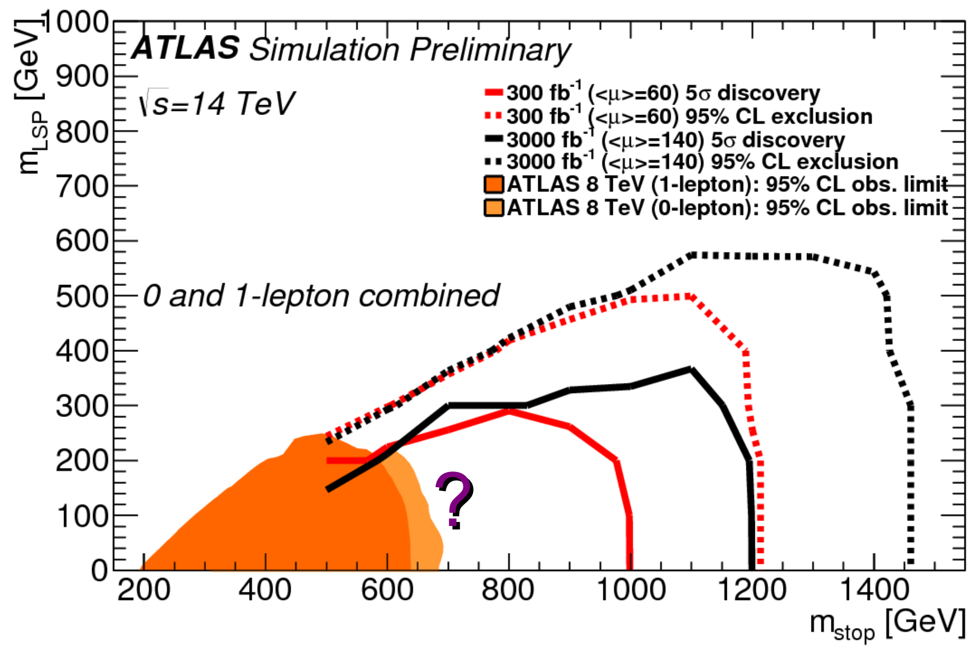
The main backgrounds will also increase with beam-energy

Summary

Summary

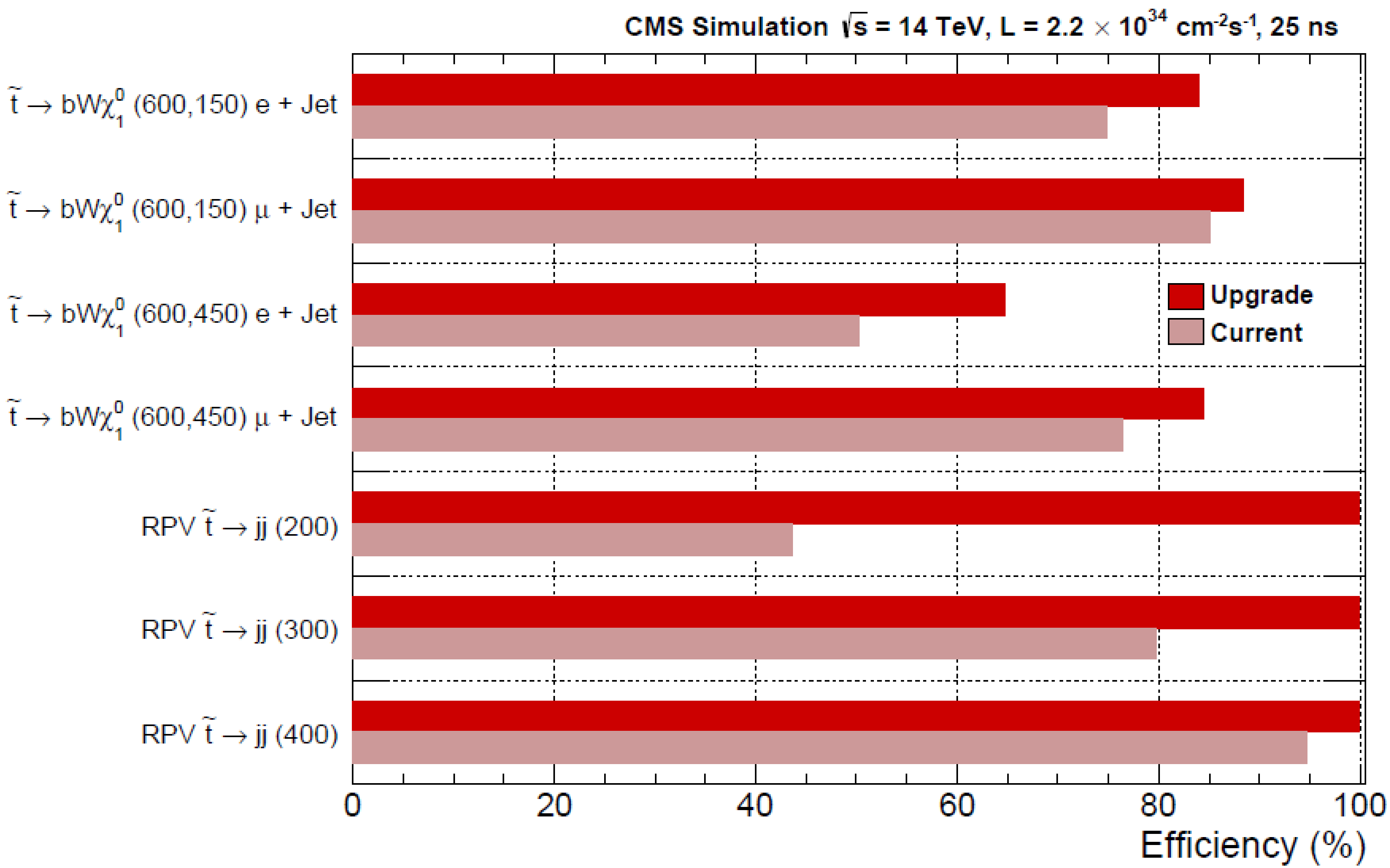
- LHC consolidation for 13+ TeV well underway
  Can expect 1-2 (15-30) fb^{-1} by summer (end) of 2015
- Experiments require 25ns bunch spacing beams to fully cope with potential peak luminosity pileup
- High mass searches will quickly rival/exceed Run 1
- Higgs Boson measurement will likely go beyond Run 1 with the first years data

Excellent prospects for the next exciting discovery in 2015



Backup

Improvements from CMS L1 Upgrade



Improvements from CMS L1 Upgrade