# ATLAS @ LHC: status and recent results

**HEP2016**

**Thessaloniki, Greece**

**12 May 2016**

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**University of Victoria / IPP**

**+ CERN**

**(ATLAS Deputy Spokesperson)**

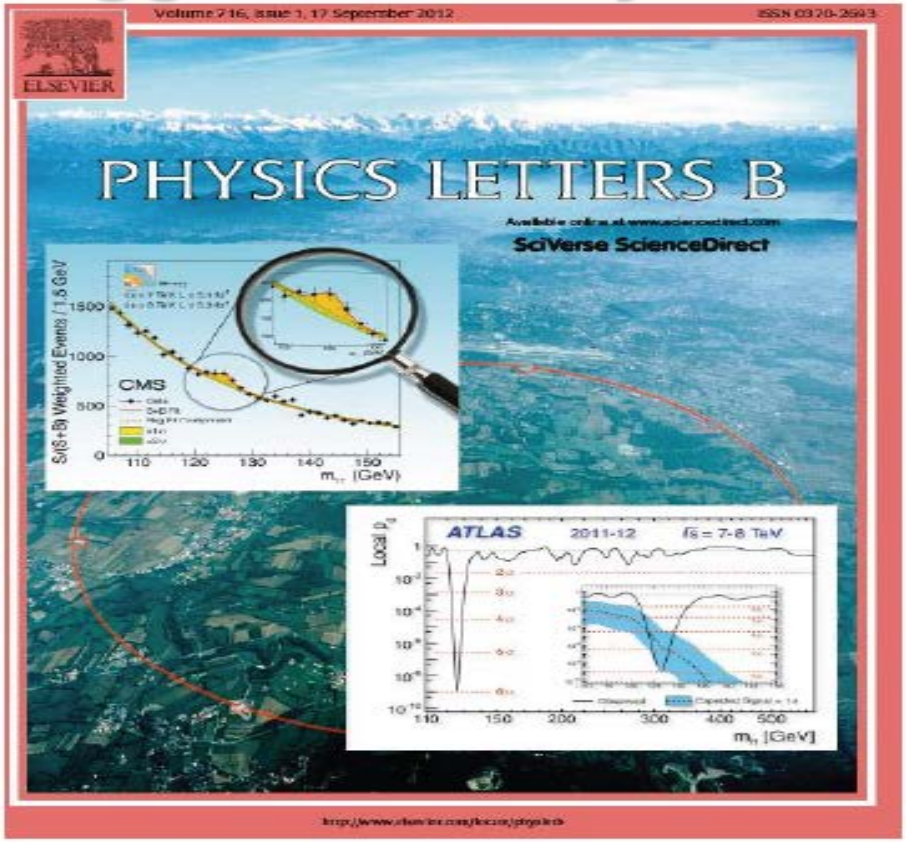
- **LHC Program: reminder**

# LHC: recent history and near future

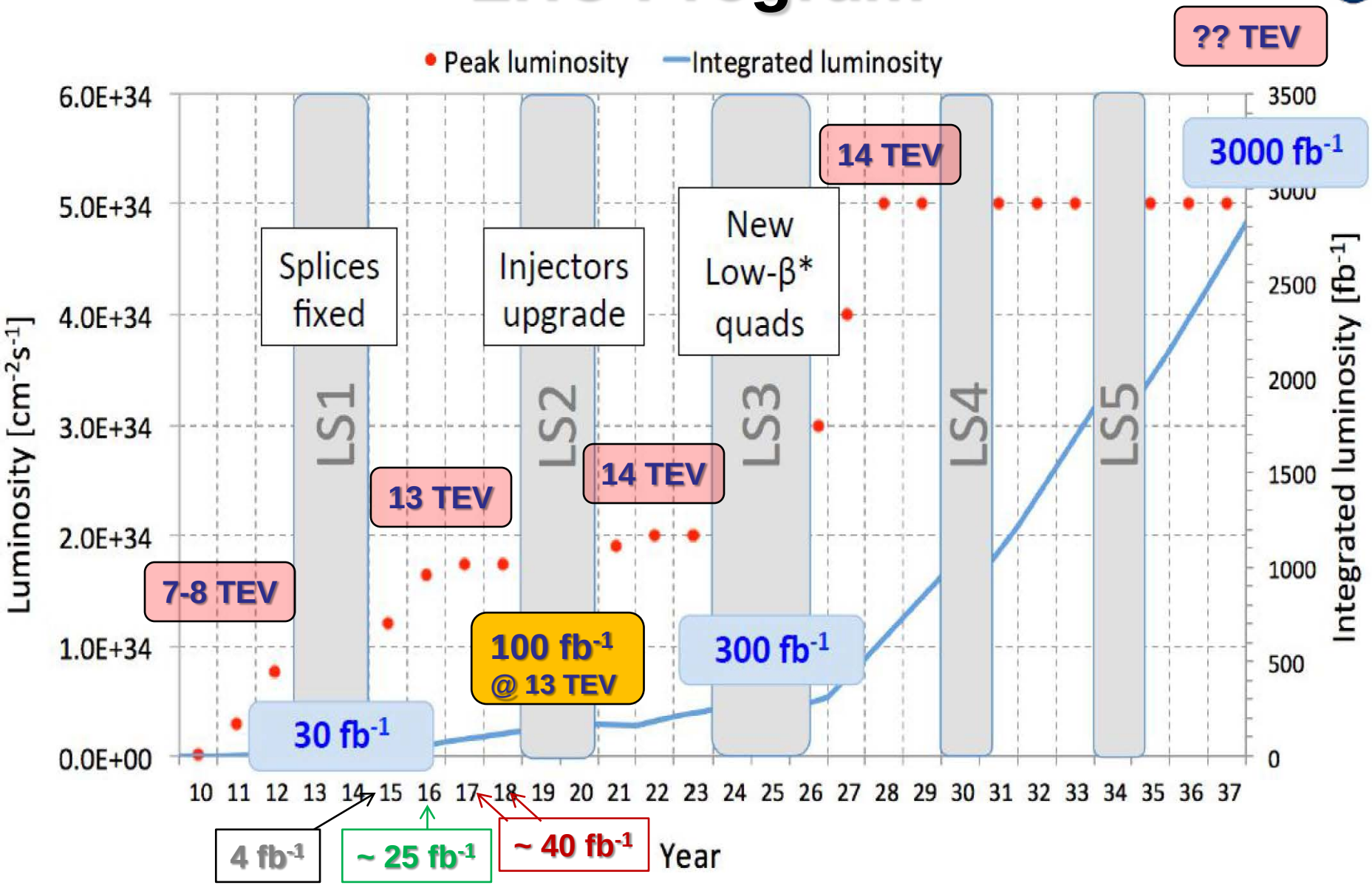
- **LHC Run-1: 2009-2013**
  - $\sqrt{s}$ = 7—8 TeV
- **Now in high-energy phase**
  - $\sqrt{s}$ = 13—14 TeV

# Run-1 Highlight: Higgs discovery

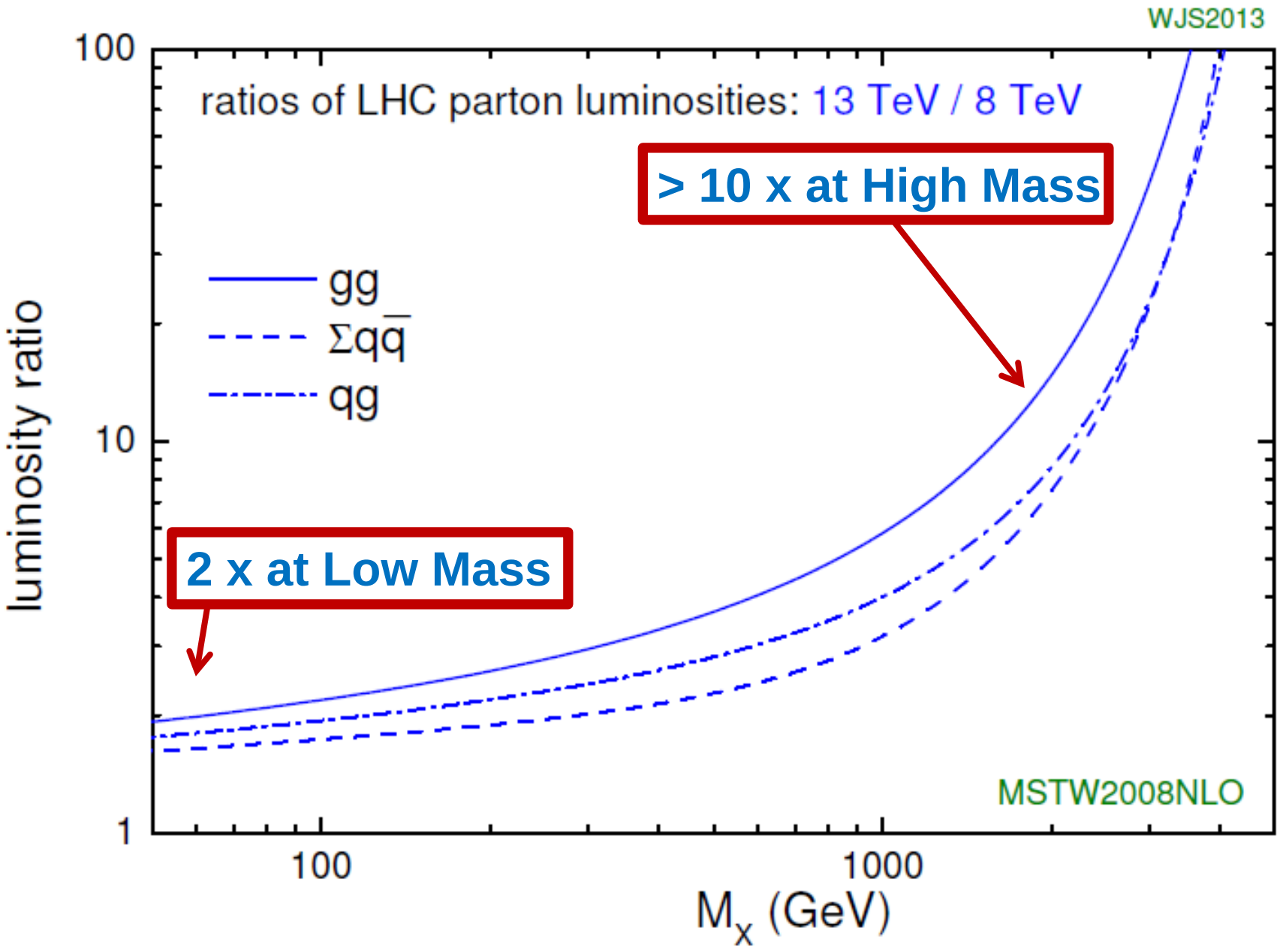
- Higgs-like particle discovery announced July 4th, 2012
  - Phys. Lett. B 716 (2012) 1-29
  - 6013 citations (as of 2016-05-09)
- March 2013: key papers on particle properties
  - new particle declared “a Higgs boson”
- Citation for 2013 Nobel Prize in Physics




# LHC Program


Peak luminosity
Integrated luminosity
?? TEV
14 TEV
3000 fb-1
Splices fixed
Injectors upgrade
New Low-β* quads
LS1
LS2
LS3
LS4
LS5
13 TEV
14 TEV
7-8 TEV
100 fb-1 @ 13 TEV
300 fb-1
30 fb-1
4 fb-1
~ 25 fb-1
~ 40 fb-1
Luminosity [cm-2s-1]
Integrated luminosity [fb-1]
Year
6.0E+34
5.0E+34
4.0E+34
3.0E+34
2.0E+34
1.0E+34
0.0E+00
3500
3000
2500
2000
1500
1000
500
0
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37

# √s = 13 TeV: parton luminosities



# LHC: Discovery Machine

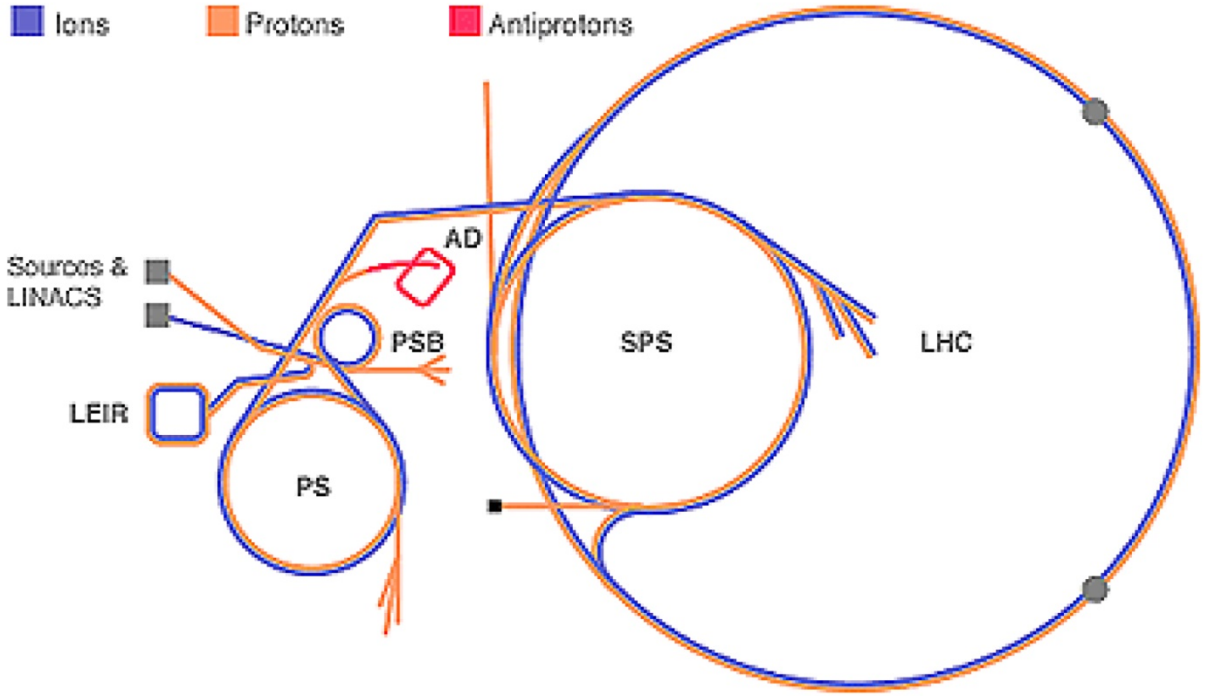
- **For decades we've known of:**
  - **Higgs fine-tuning problem pointing to new EW scale physics**
  - **Dark Matter (WIMP "miracle") suggestive of new EW scale particle**
- **Strong motivation for direct exploration of new physics at the Electroweak Scale with Electroweak Couplings**
  - **Nothing to do with any specific model**

- **If you had a 13 TeV proton-proton collider, how much data would you need for this exploration?**
  - **Answer known for > 30 years: $\mathcal{O}$(100 fb$^{-1}$)**
  - **This is LHC Run-2 & 3, starting now**

- **LHC Status: 2016 turn-on**

# Injectors

- **Booster**
  - **All beams available**
- **PS**
  - **Beam to nTOF, AD, East Area on schedule**
  - **Transfer to SPS for North Area**
- **SPS**
  - **LHC 25 nsec operational**
  - **Beam dump leak may limit trains to 72 (or 144) bunches instead of 288**

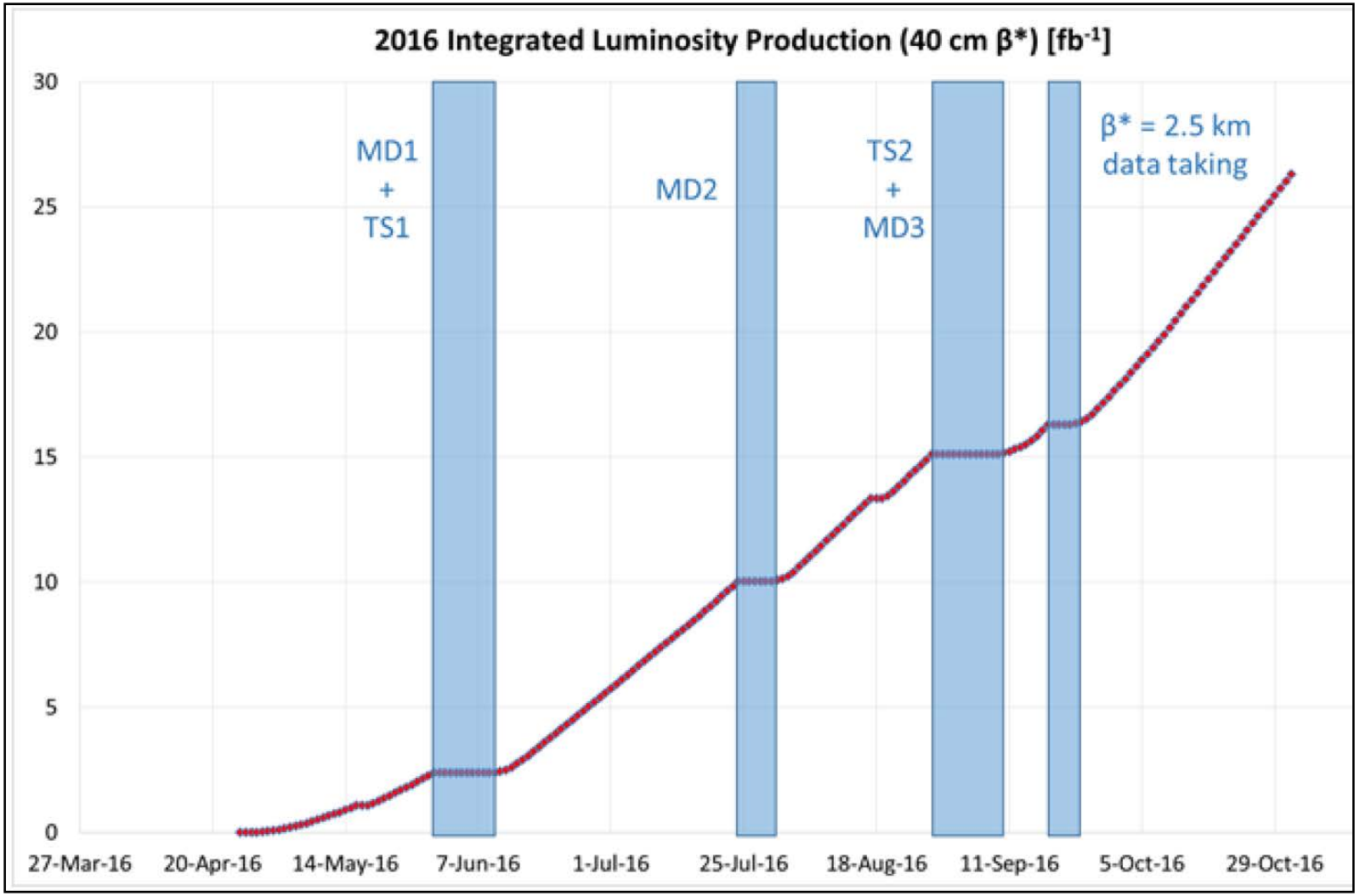


# LHC: 2016 Milestones/Progress

| Date | Description |
|---|---|
| Friday 25 March | First beam, RF capture |
| Saturday 26 March | First ramp to 6.5 TeV beams |
| Sunday 27 March | Squeeze to β* = 40 cm |
| Thursday 31 March | Flat-top and squeeze at 6.5 TeV |
| Wednesday 6 April | Nominal bunches to flat-top |
| Friday 8 April | Nominal bunches in collision |
| Tuesday 12 April | Quiet beams |
| Sunday 17 April | Collision aperture measurements |
| Thursday 21 April | 72 bunch train injections |
| Friday 22 April | FIRST STABLE BEAMS |
| Monday 25 April | LHC Machine scrubbing started |
| Friday 29 April | Fouine … |
| Thursday 5 May | Back in operations |
| Thursday 12 May | 600 bunches |

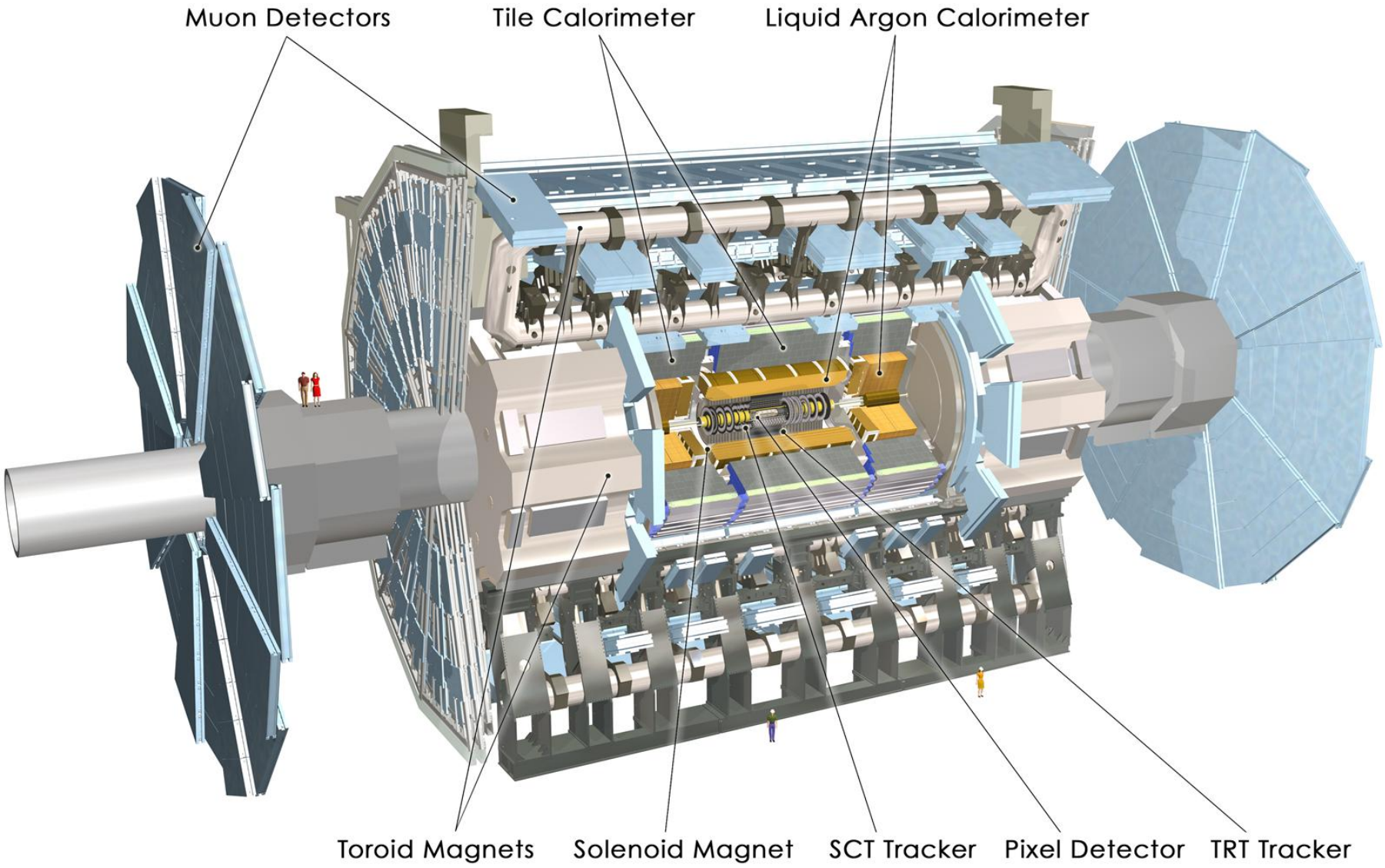
# LHC Goal for 2016

- **Integrated Luminosity: ≈ 25 fb$^{-1}$ at √s = 13 TeV**



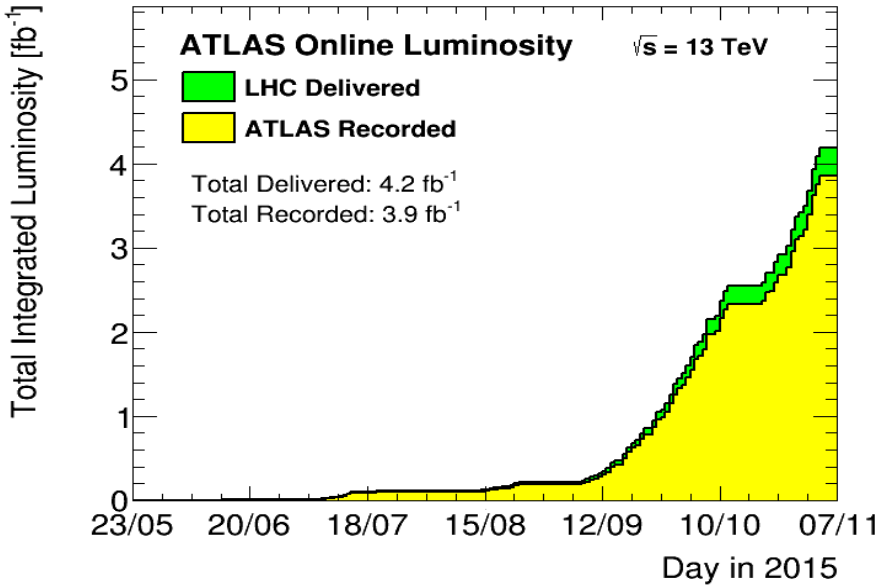
- **ATLAS Status**

# ATLAS Detector

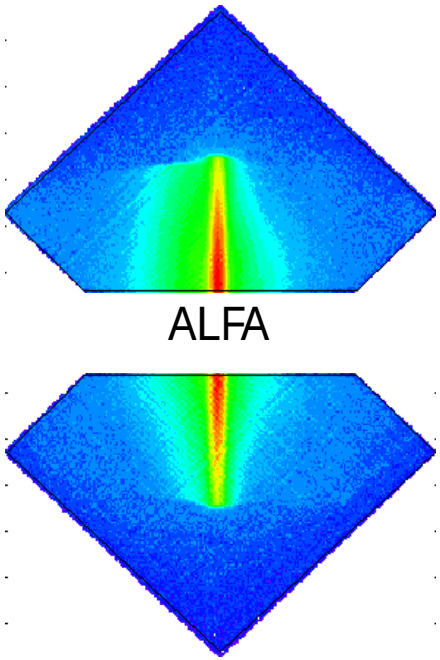


# ATLAS 2015 p-p data √s=13 TeV

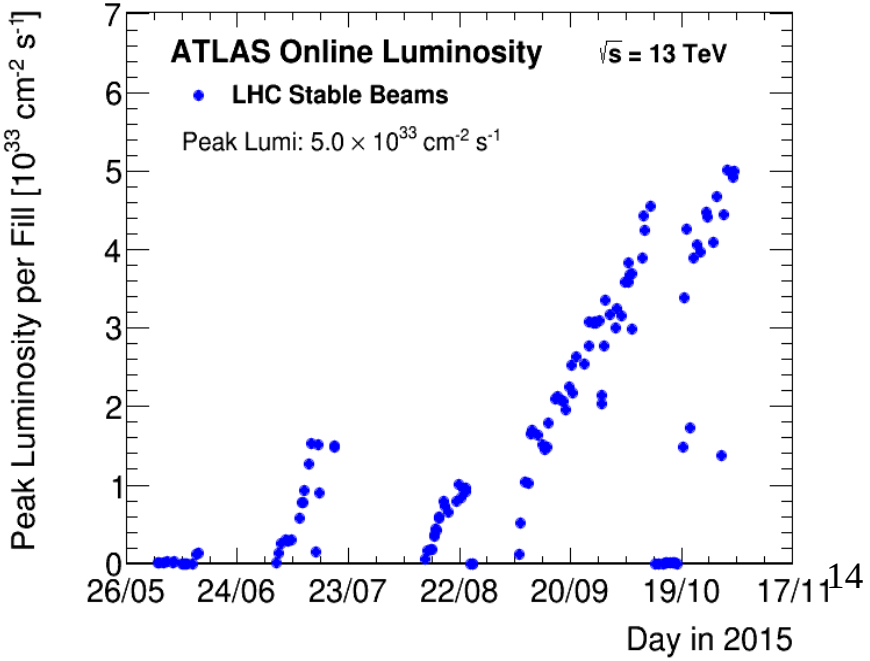
- 4 $fb^{-1}$ delivered at 13 TeV
- ATLAS data-taking efficience 92.0%
  - Was 93.5% in 2012




Special physics run with β* 90m in October (elastics & diffractive)

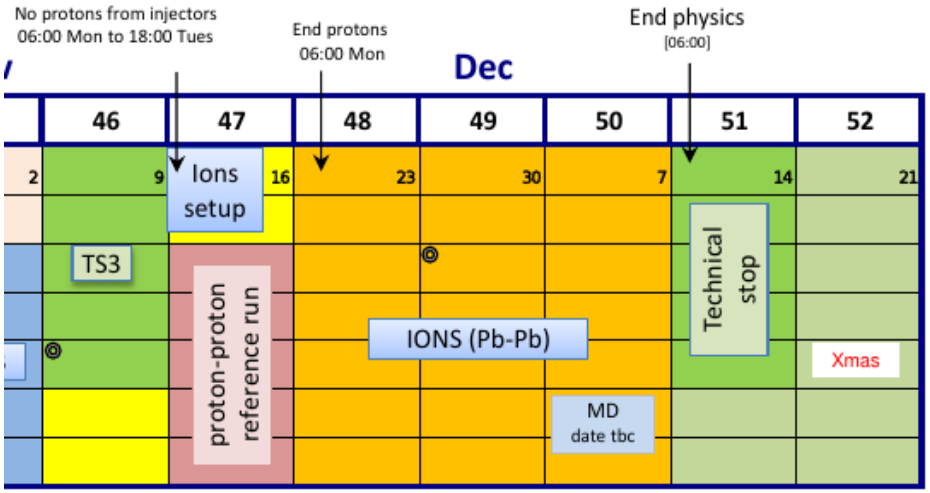


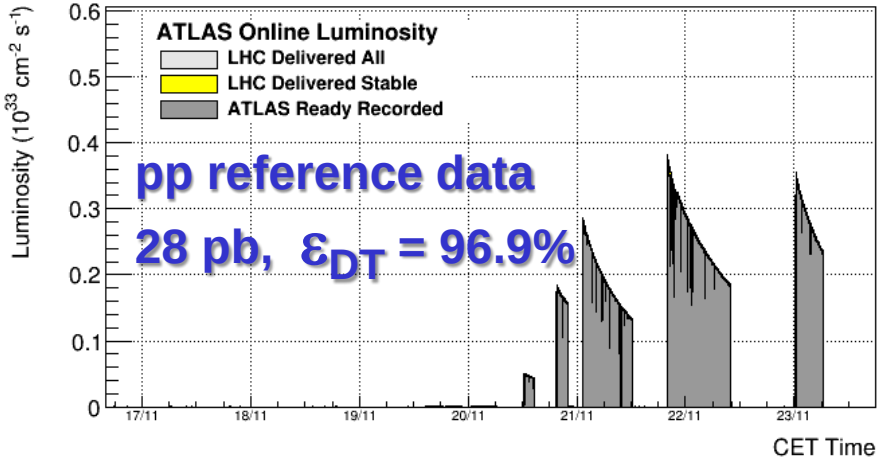

2016-May-12

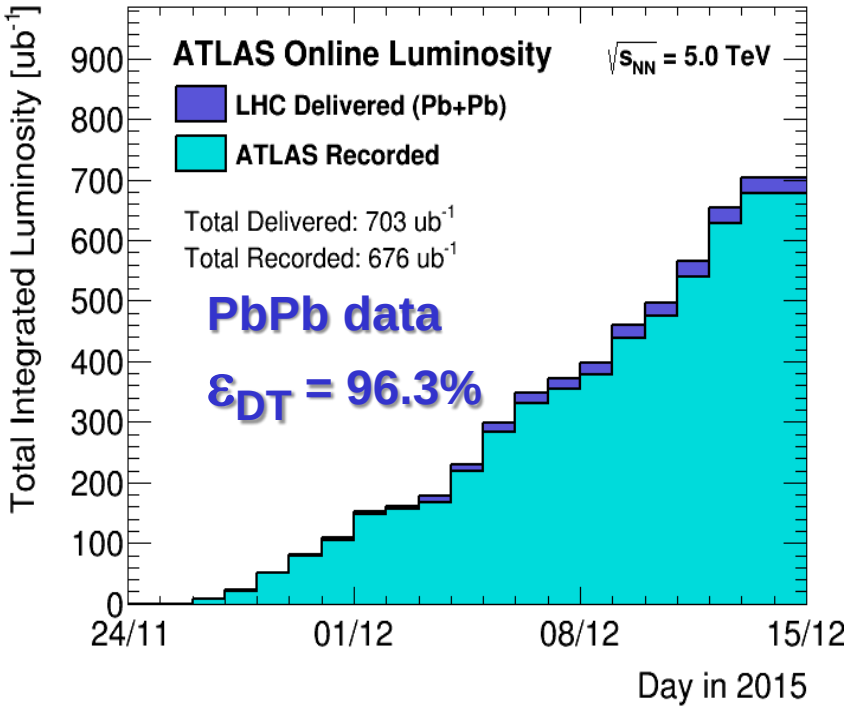


# 2015 Heavy Ion Pb-Pb data

- **Nov-Dec 2015**
  - **5.02 TeV p-p reference data**
  - **$\sqrt{s_{NN}}$ = 5.02 TeV Pb-Pb data**
  - **$\sqrt{s}$ = 1.1 PeV (!)**
  - **Great LHC and ATLAS performance**



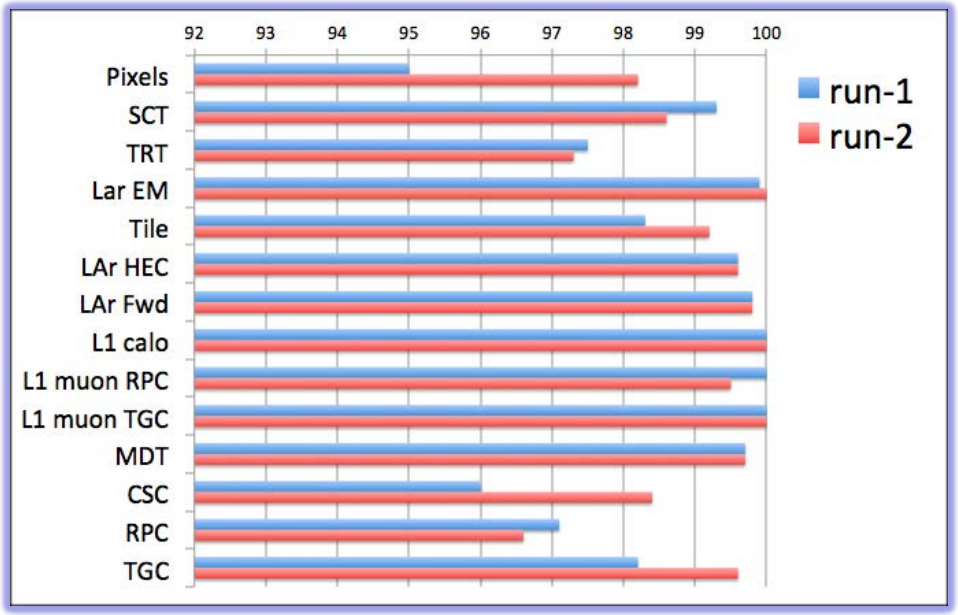




- **2016 Heavy Ion Plan**
  - **p + Pb at both 5 and 8 TeV**

# ATLAS Detector in 2015

- **Mostly smooth operation**
- **Some anomalous currents "Insertable b-layer" (IBL) pixel detector**
  - **Turned off for two fills**
- **Fraction of live channels better than Run-1 (ongoing muon/RPC commissioning)**




## ATLAS pp run: August-November 2015

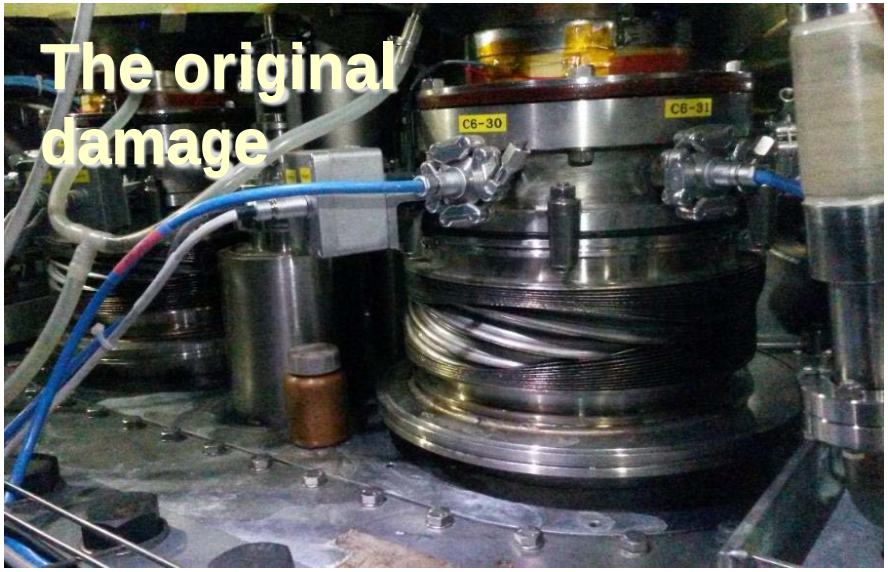
| Inner Tracker | | | Calorimeters | | Muon Spectrometer | | | | Magnets | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pixel | SCT | TRT | LAr | Tile | MDT | RPC | CSC | TGC | Solenoid | Toroid |
| 93.5 | 99.4 | 98.3 | 99.4 | 100 | 100 | 100 | 100 | 100 | 100 | 97.8 |

**All Good for physics:** $3.2 \pm 0.2 \quad fb^{-1}$

Luminosity weighted relative detector uptime and good data quality (DQ) efficiencies (in %) during stable beams in pp collisions with 25ns bunch spacing at $\sqrt{s}$=13 TeV between August-November 2015, corresponding to an integrated luminosity of 3.8 $fb^{-1}$. The lower DQ efficiency in the Pixel detector is due to the IBL being turned off for two runs, corresponding to 0.2 $fb^{-1}$. Analyses that don't rely on the IBL can use those runs and thus use 3.5 $fb^{-1}$ with a corresponding DQ efficiency of 93.4%.

# 2015-2016 Shutdown: Endcap Toroid Bellows Repair

- **Significant damage to bellows on top of ECT-C (Feb 2013) – repair mandatory**
  - **Rapid preparation, execution**
  - **Work completed**
  - **Magnets fully operational**

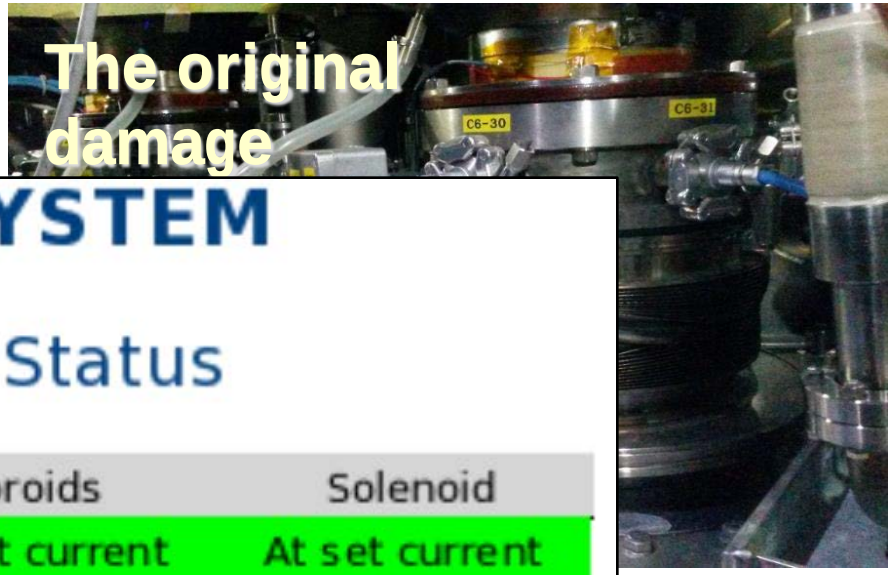





- **Huge Thanks:**
  - **CERN Teams !!!**

# 2015-2016 Shutdown: Endcap Toroid Bellows Repair

- **Significant damage to bellows on top of ECT-C (Feb 201**
  - **F**
  - **V**
  - **M**




## ATLAS MAGNET SYSTEM

### Magnet Status

| Parameter | Toroids | Solenoid |
|---|---|---|
| Magnet status | At set current | At set current |
| Magnet set current [A] | 20397.74 | 7730.00 |
| Magnet actual current [A] | 20399.95 | 7730.02 |
| Power converter voltage [V] | 7.82 | 4.06 |
| Earth leak current [mA] | -1.00 | 0.00 |
| T max Busbar temperature [ | 20.10 | 20.30 |
| T max dump resistor [C] | 19.20 | 19.30 |

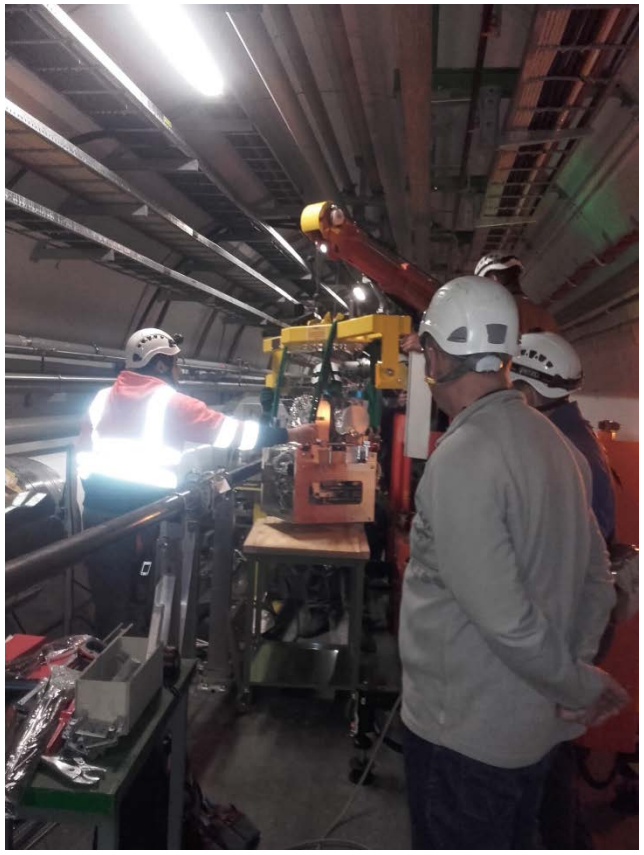
**uge**

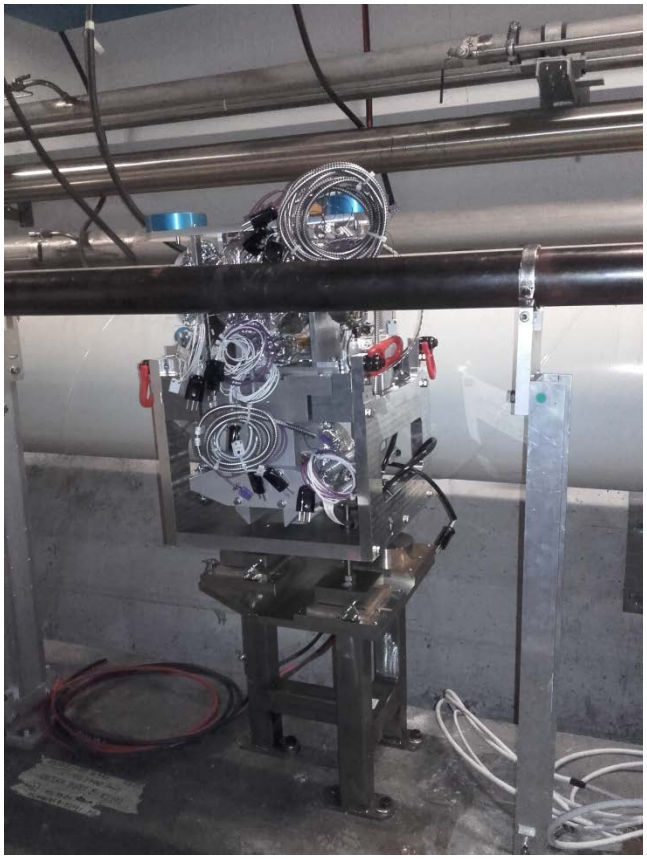
**hanks:**

- **CERN Teams !!!**


# 2015-2016 Shutdown: AFP

- **220m down tunnel from ATLAS: new detector for forward physics:**
  - **ATLAS Forward Protons – AFP**
  - **Roman Pots for first arm installed + cables for both arms**
  - **Completion in 2016/2017 year-end stop**





- **18 Jan 2016**
- **Tremendous progress from AFP team**
- **Huge help from CERN machine group (again!)**

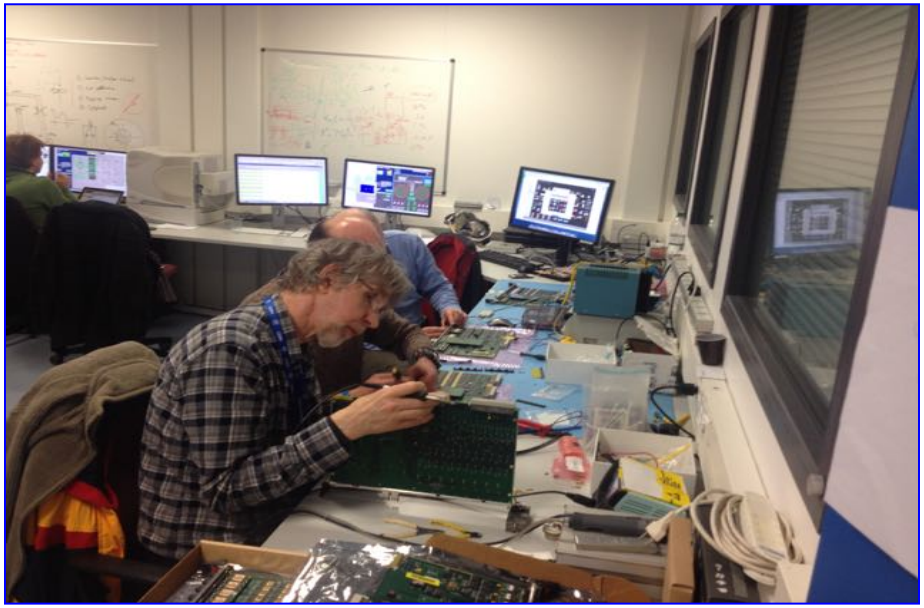
# 2015-2016 Shutdown: ATLAS Pixels

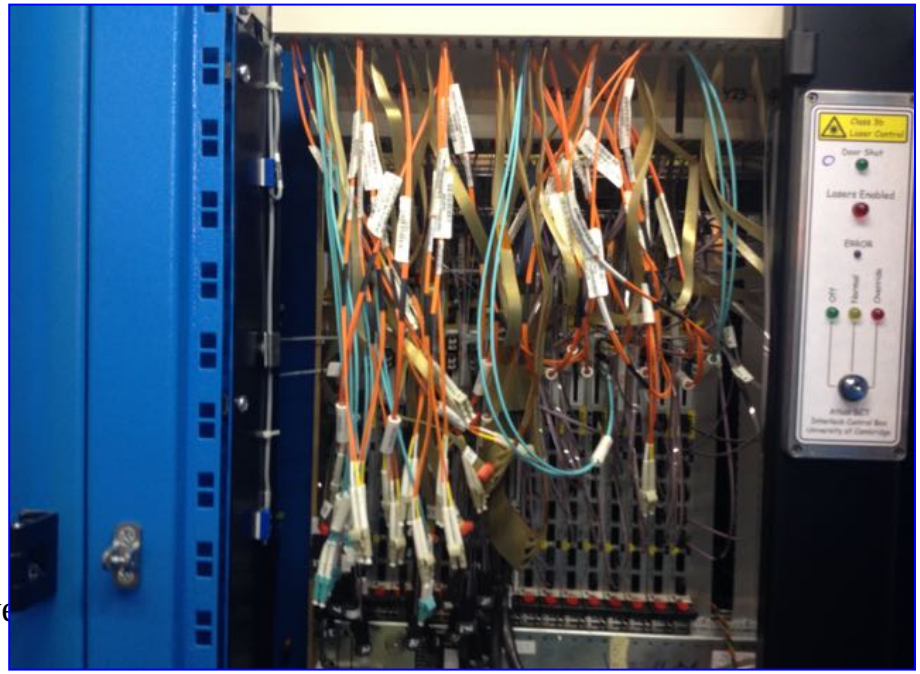
- Readout changed (Layer 2) to copy with higher pileup and luminosity
  - Double bandwidth
- Status
  - IBL, B-Layer and disks: ready
  - Layer 1 with old readout: ready
  - Layer 1 + Layer 2 with new readout: under final optimization

- Remaining Issue:
  - IBL operate at 15 C (or slightly lower) to mitigate radiation-induced current increase
  - Effect should decrease after 1—2 Mrad dose

# 2015-2016 Shutdown: ATLAS SCT

- **Shutdown activities**
  - Mods to 64 back-of-crate cards
  - ROD firmware development increasing robustness
- **SCT status**
  - Ready for beam
  - 98.9% strips active
- **ID General**
  - Cooling reliable and stable
  - Fixed Dew point issue from 2015

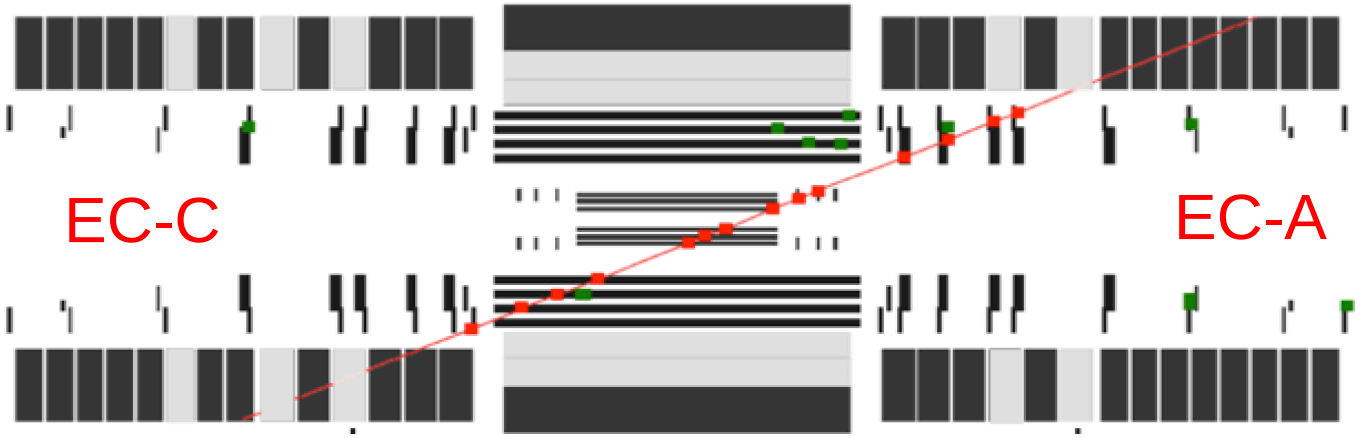




# 2015-2016 Shutdown: ATLAS TRT

- **Will run with 2 barrel and 5 end-cap modules without Xe (leaks)**
  - **Particle ID optimization ⇒ negligible physics impact**
- **Upgraded infrastructure to allow different gas mixtures**
- **DAQ upgraded for higher rates**
- **LV PS cooling upgrades**

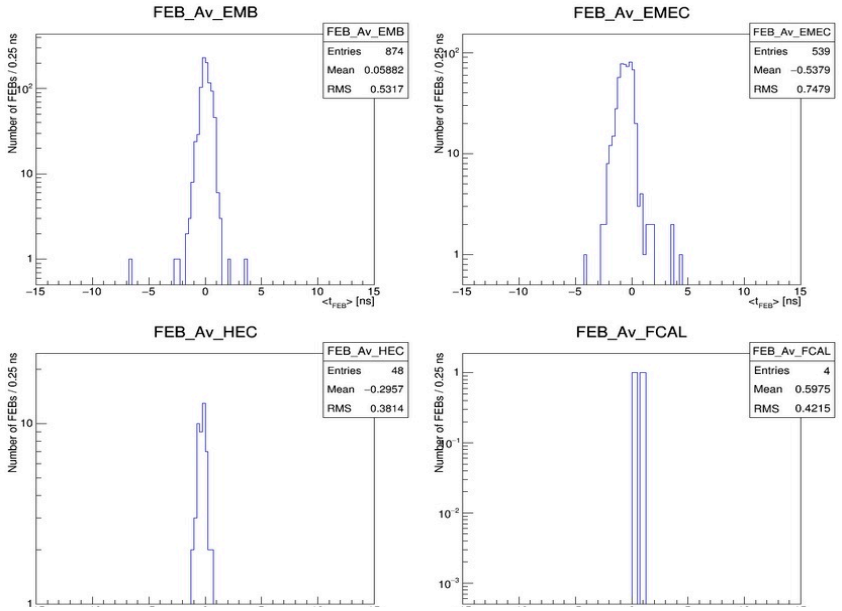
**2016 TRT geometry.**

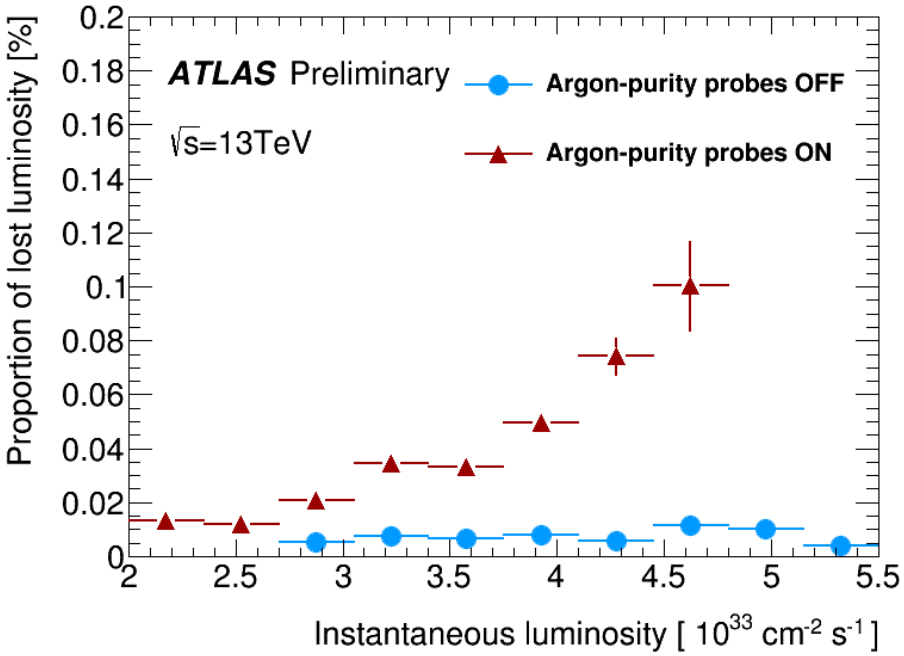



**Black –Xe modules**
**Gray - Ar modules**

# 2015-2016 Shutdown: ATLAS LAr

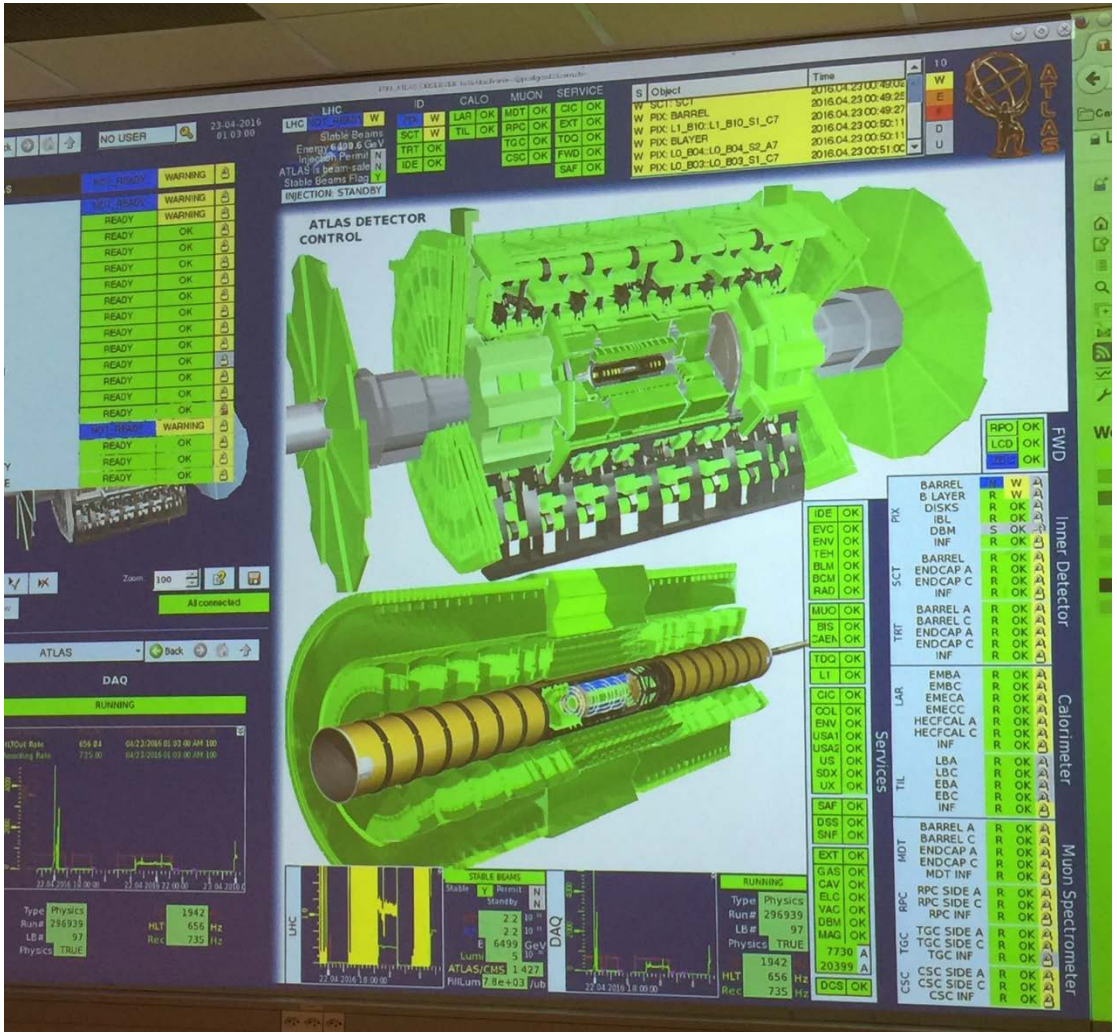
- Repair few front-end boards
- HV module replacement
  - Robustness w.r.t. HV trips
  - Timed-in with “quiet beams”
- Understood longstanding noise bursts
  - LAr purity monitor induced
- Ready for data taking



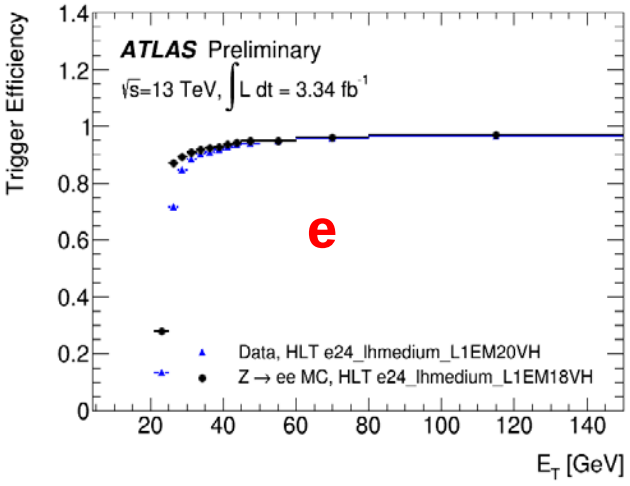
# 2015-2016 Shutdown: ATLAS Muons

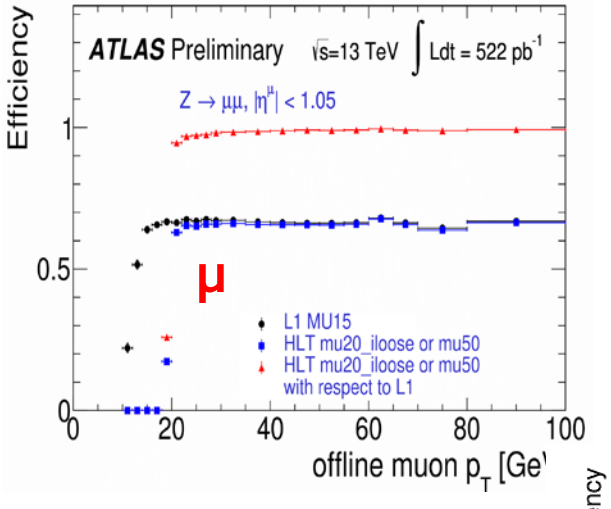
- RPC “feet” trigger fully commissioned
- RPC gas leak repairs ongoing
- TGC: 13 chambers replaced, others recovered
- Ready for stable beams
- Expect 2016 alignment good to 50μm from day 1

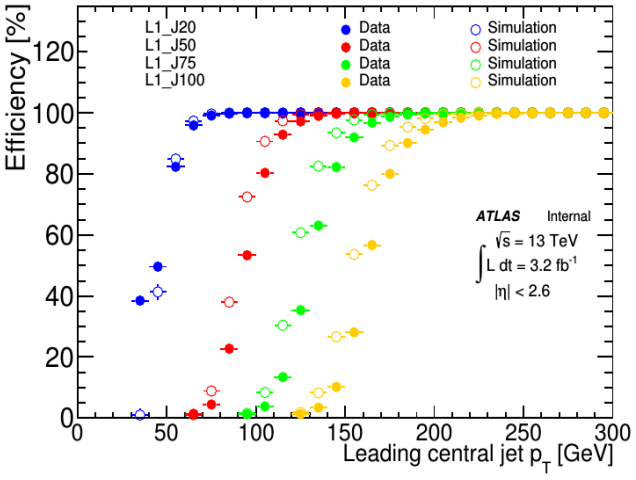


# Trigger Status

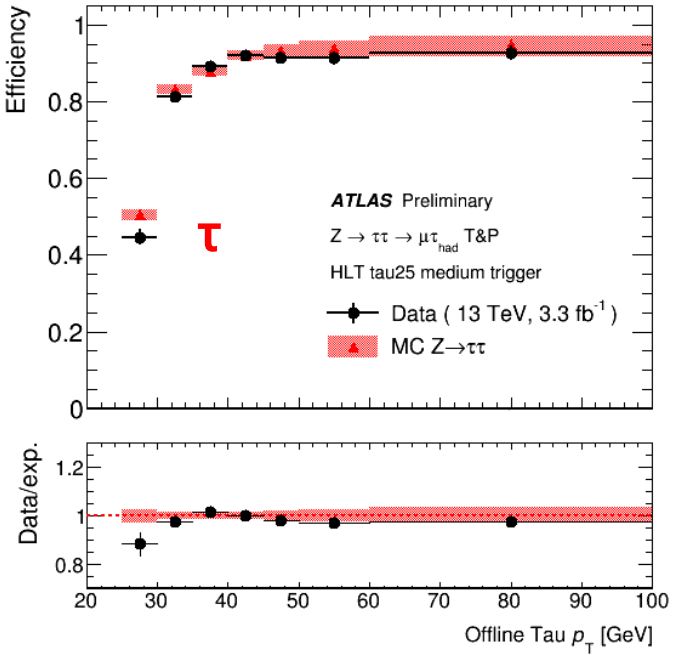
- New L1Calo components and new central trigger processor
- 2015: many efficiency studies and optimization



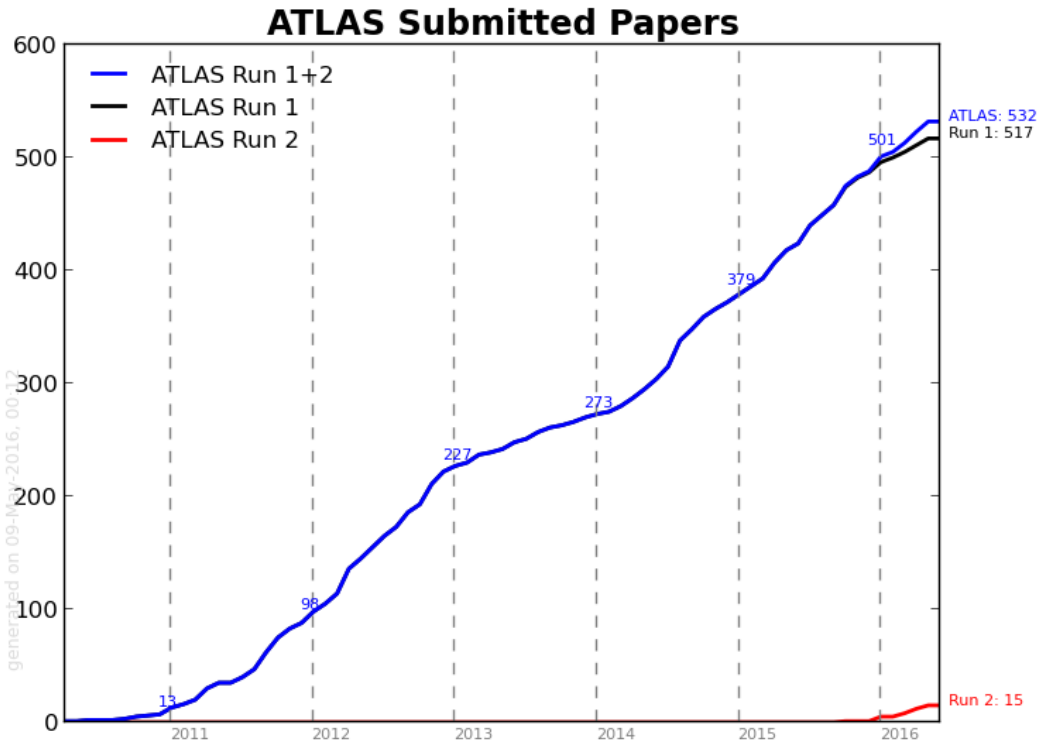




- 2016 Challenges
  - New trigger menu based on new software release (20.7)
  - New L1Calo lookup tables improve $E_T^{Miss}$ and jet resolutions



- **ATLAS Recent Results**

# Collision Data Papers




- **ATLAS submitted our 500th collision-data paper just before end of 2015**

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Submitted to: EPJC

CERN-PH-EP-2015-294
18th December 2015

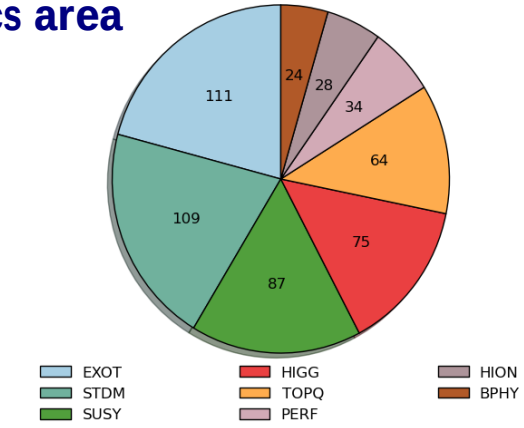
**Collision data paper 500**

**Reconstruction of hadronic decay products of tau leptons with the ATLAS experiment**

The ATLAS Collaboration

**ATLAS - Papers/Lead-group**

**Physics area**




- **15 papers on 2015 data published or submitted**
- **≈ 50 more Run-1 papers in progress**

# Rapid Readiness of 2015 Results

## December 2015 (39)

| Topic | Document type | Short title | Reference and Link | Release conference |
|---|---|---|---|---|
| Tracking performance | Public note | Robustness of neural network clustering in the Pixel Detector | ATL-PHYS-PUB-2015-052 | End of Year Event (15th Dec) |
| Tracking performance | Public plots | Time dependent alignment corrections to IBL distortions | link | End of Year Event (15th Dec) |
| Tracking performance | Public plots | Impact of IBL distortion on impact parameter resolution in MC | link | End of Year Event (15th Dec) |
| Tracking performance | Public plots | Impact of IBL distortion on impact parameter resolution | link | |
| Tracking performance | Public note | Inner Detector tracking performance | ATL-PHYS-PU | |
| Tracking performance | Public note | Inner Detector material studies | ATL-PHYS-PU | |
| Jet and MET performance | Public plots | Large radius jet performance | link | |
| Jet and MET performance | Public plots | In situ JES performance | link | |
| Muon performance | Public plots | Muon and tracking performance | link | |
| Muon performance | Public plots | Muon performance | link | |
| Electron performance | Public plots | Electron efficiency | link | |

| Topic | Document type | Short title | Reference and Link | Release conference |
|---|---|---|---|---|
| Standard Model physics | Paper | Measurement of the ZZ Production Cross Section | arXiv:1512.05314 | End of Year Event (15th Dec) |
| Higgs physics | Conference Note | Higgs 4-lepton cross-section measurement | ATLAS-CONF-2015-059 | End of Year Event (15th Dec) |
| Higgs physics | Conference Note | Higgs 2-photon cross-section measurement | ATLAS-CONF-2015-060 | End of Year Event (15th Dec) |
| Higgs physics | Conference Note | Search for MSSM Higgs decays to tautau | ATLAS-CONF-2015-061 | End of Year Event (15th Dec) |
| Higgs physics | Conference Note | Higgs cross-section combination | ATLAS-CONF-2015-069 | End of Year Event (15th Dec) |
| SUSY | Conference Note | Search for SUSY with events with 0-leptons, jets and MET | ATLAS-CONF-2015-062 | End of Year Event (15th Dec) |
| SUSY | Conference Note | Search for sbottom with two b-jets and MET | ATLAS-CONF-2015-066 | End of Year Event (15th Dec) |
| SUSY | Conference Note | Search for gluino-mediated stop and sbottom with events with b-jets, jets and MET | ATLAS-CONF-2015-067 | End of Year Event (15th Dec) |
| SUSY | Conference Note | Search for SUSY with events with 1-lepton, jets and MET | ATLAS-CONF-2015-076 | End of Year Event (15th Dec) |
| SUSY | Conference Note | Search for SUSY with events with 0-leptons, multijets and MET | ATLAS-CONF-2015-077 | End of Year Event (15th Dec) |
| SUSY | Conference Note | Search for SUSY with events with two same-sign leptons, jets and MET | ATLAS-CONF-2015-078 | End of Year Event (15th Dec) |
| SUSY | Conference Note | Search for SUSY with events with two opposite-sign leptons, jets and MET | ATLAS-CONF-2015-082 | End of Year Event (15th Dec) |
| B-physics and light states | Conference Note | Studies of B+ mass performance | ATLAS-CONF-2015-064 | End of Year Event (15th Dec) |
| Top physics | Conference Note | ttbar+jets cross-section measurement | ATLAS-CONF-2015-065 | End of Year Event (15th Dec) |
| Top physics | Conference Note | t-channel single top cross-section measurement | ATLAS-CONF-2015-079 | End of Year Event (15th Dec) |
| Exotics | Paper | Search for new phenomena with photon+jet events | arXiv:1512.05910 | End of Year Event (15th Dec) |
| Exotics | Conference Note | Search for new physics in the lepton+MET channel (W') | ATLAS-CONF-2015-063 | End of Year Event (15th Dec) |
| | nce Note | Search for diboson resonances in the MET+jet channel | ATLAS-CONF-2015-068 | End of Year Event (15th Dec) |
| | nce Note | Search for new physics in the dilepton channel (Z') | ATLAS-CONF-2015-070 | End of Year Event (15th Dec) |
| | nce Note | Search for diboson resonances in the llqq channel | ATLAS-CONF-2015-071 | End of Year Event (15th Dec) |
| | nce Note | Search for new physics with LFV decays to e+mu | ATLAS-CONF-2015-072 | End of Year Event (15th Dec) |
| | nce Note | Search for diboson resonances in fully hadronic channels | ATLAS-CONF-2015-073 | End of Year Event (15th Dec) |
| | nce Note | Search for diboson resonances in W/Z+Higgs channels | ATLAS-CONF-2015-074 | End of Year Event (15th Dec) |
| | nce Note | Search for diboson resonances in the lnqq channel | ATLAS-CONF-2015-075 | End of Year Event (15th Dec) |
| | nce Note | Search for dark matter in the MET+W/Z channel | ATLAS-CONF-2015-080 | End of Year Event (15th Dec) |
| | nce Note | Search for new physics decaying to two photons | ATLAS-CONF-2015-081 | End of Year Event (15th Dec) |
| | | Search for new physics with multi-jet signatures | arXiv:1512.02586 | End of Year Event (15th Dec) |
| | | Search for new physics in dijet mass and angular distributions | arXiv:1512.01530 | End of Year Event (15th Dec) |

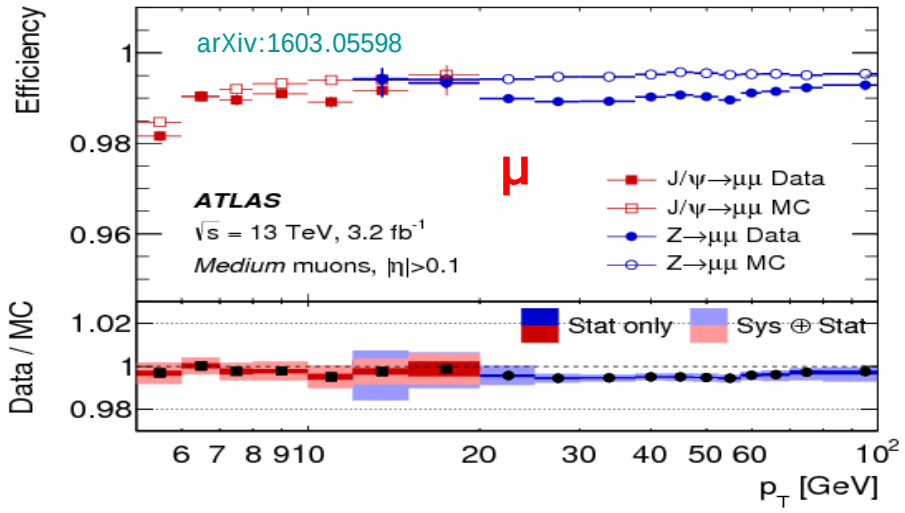
## March 2016 (+22)

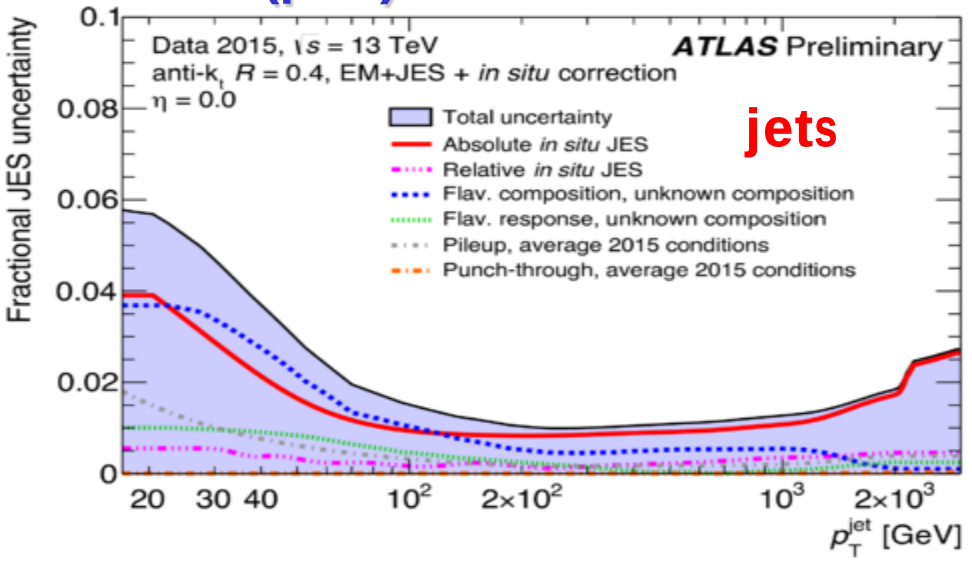
| Topic | Document type | Short title | Reference and Link | Release conference |
|---|---|---|---|---|
| Top physics | Conference Note | ttV cross section at 13 TeV | ATLAS-CONF-2016-003 | Moriond EW |
| Top physics | Conference Note | ttbar cross section in the e+mu channel at 13 TeV | ATLAS-CONF-2016-005 | Moriond EW |
| Higgs physics | Conference Note | HH to bb+2-photons | ATLAS-CONF-2016-004 | Moriond EW |
| Higgs physics | Conference Note | Search for 2-photons + MET | ATLAS-CONF-2016-011 | Moriond EW |
| Higgs physics | Conference Note | Search for H->ZZ->llnn | ATLAS-CONF-2016-012 | Moriond EW |
| Higgs physics | Conference Note | Search for A->Zh | ATLAS-CONF-2016-015 | Moriond EW |
| Higgs physics | Conference Note | Search for H->ZZ->llqq | ATLAS-CONF-2016-016 | Moriond EW |
| SUSY | Conference Note | Direct stop production in the 1-lepton channel | ATLAS-CONF-2016-007 | Moriond EW |
| SUSY | Conference Note | Direct stop production in the 2-lepton channel | ATLAS-CONF-2016-009 | Moriond EW |
| SUSY | Paper | Search for SUSY in the 2 same-sign lepton and 3 lepton channels | arXiv:1602.09058 | Moriond EW |
| SUSY | Paper | Search for SUSY with large jet multiplicities and MET | arXiv:1602.06194 | Moriond EW |
| Exotics | Conference Note | lepton+jets TeV-gravity | ATLAS-CONF-2016-006 | Moriond EW |
| Exotics | Conference Note | Z+gamma resonances | ATLAS-CONF-2016-010 | Moriond |
| Exotics | Conference Note | Search for vector like quarks in lepton+jets | ATLAS-CONF-2016-013 | Moriond |
| Exotics | Conference Note | Search for high mass ttbar resonances | ATLAS-CONF-2016-014 | Moriond |
| Exotics | Conference Note | HH->4b search | ATLAS-CONF-2016-017 | Moriond |
| Exotics | Conference Note | Search for resonances in diphoton events | ATLAS-CONF-2016-018 | Moriond |
| Standard Model physics | Paper | Measurement of charged particle multiplicities | arXiv:1602.01633 | Moriond |

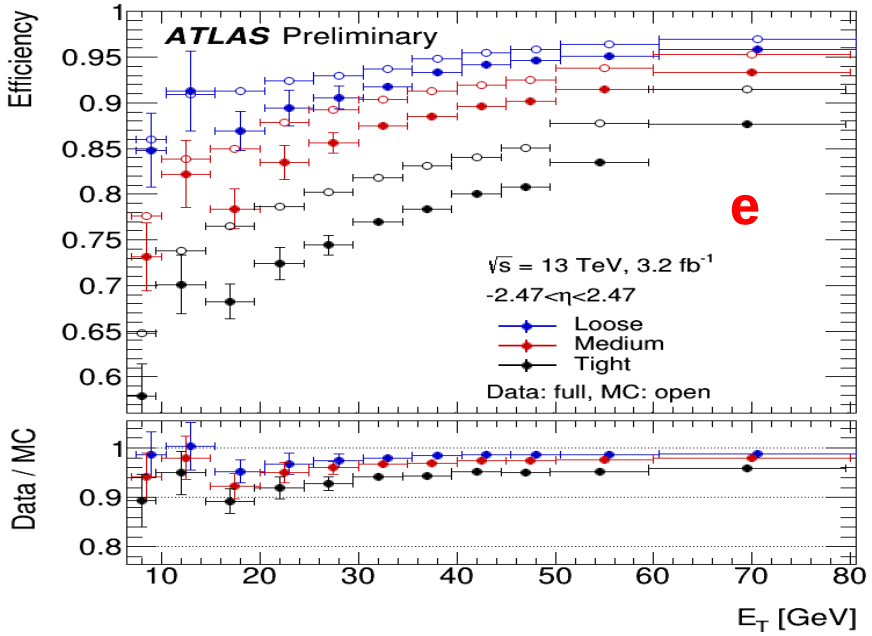
| Topic | Document type | Short title | Reference and Link | Release conference |
|---|---|---|---|---|
| Tracking and vertexing | Public note | Tracking inefficiency in jets | ATL-PHYS-PUB-2016-007 | Moriond EW |
| Jet and MET performance | Conference Note | Large-R jet mass scale and resolution | ATLAS-CONF-2016-008 | Moriond EW |
| Jet and MET performance | Conference Note | b-tagging and large-R jet performance in g->bb | ATLAS-CONF-2016-002 | Moriond EW |
| Muon Combined Performance | Paper | Muon performance in Run 2 | arXiv:1603.05598 | Moriond EW |

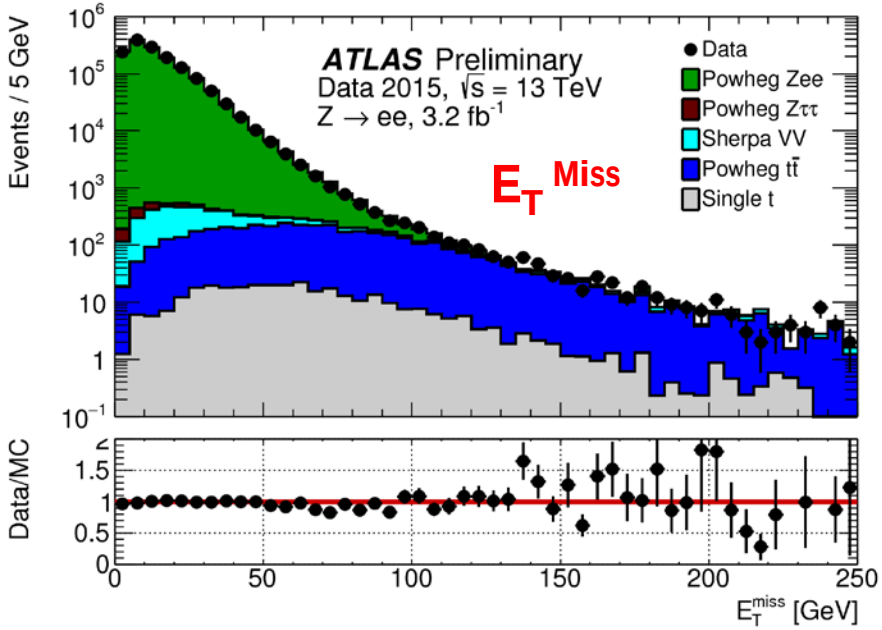
# Physics Performance

- **Fast turn-around from end of data-taking**
- **First 2015 performance paper submitted (μ ID)**

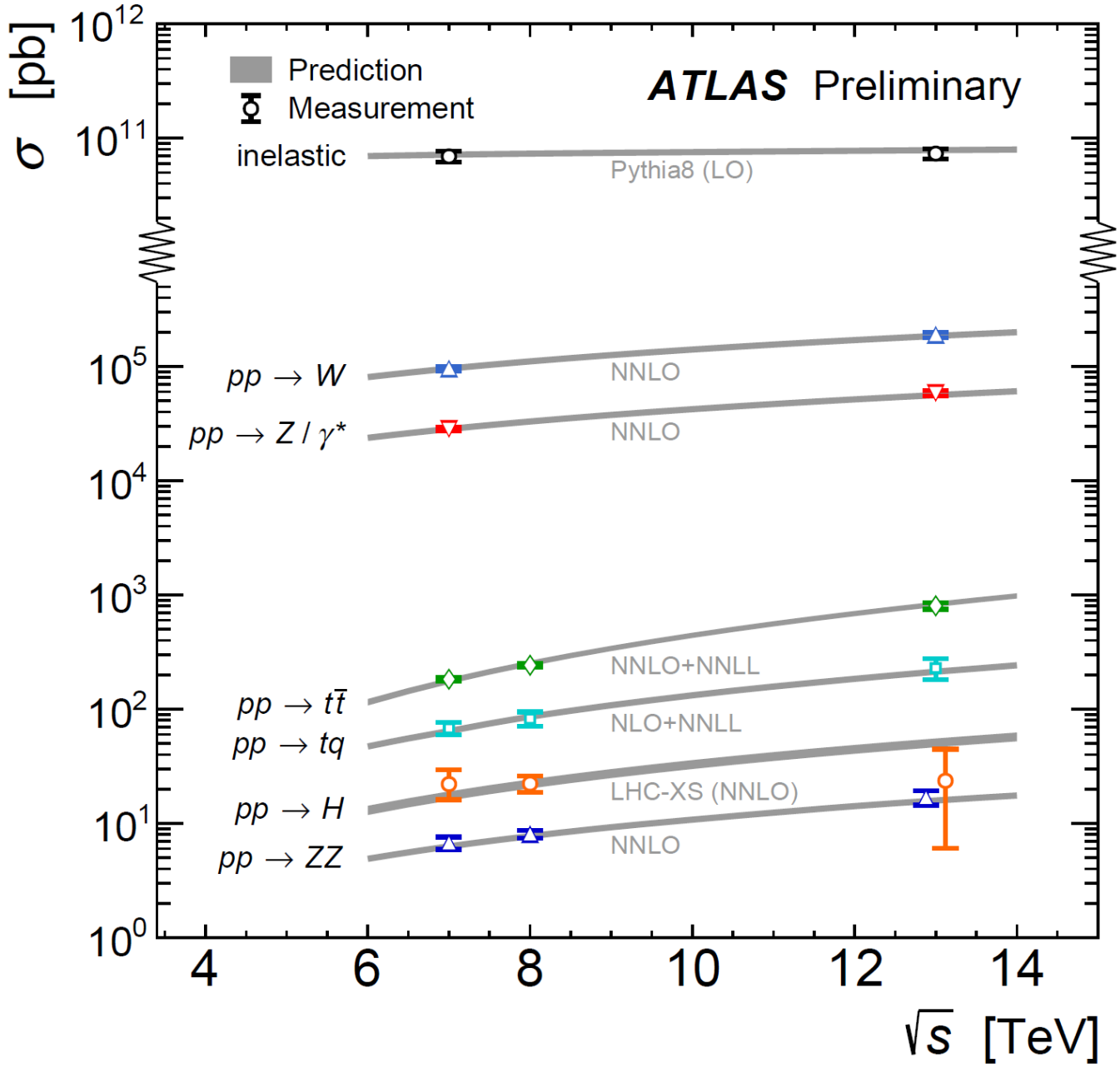


# Inclusive Cross-sections




inelastic
7 TeV, 20 μb$^{-1}$, Nat. Commun. 2, 463 (2011)
13 TeV, 63 μb$^{-1}$, ATLAS-CONF-2015-038

$pp \rightarrow W$
7 TeV, 36 pb$^{-1}$, PRD 85, 072004 (2012)
13 TeV, 81 pb$^{-1}$, arXiv:1603.09222

$pp \rightarrow Z / \gamma^*$
7 TeV, 36 pb$^{-1}$, PRD 85, 072004 (2012)
13 TeV, 81 pb$^{-1}$, arXiv:1603.09222

$pp \rightarrow t\bar{t}$
7 TeV, 4.6 fb$^{-1}$, Eur. Phys. J. C 74:3109 (2014)
8 TeV, 20.3 fb$^{-1}$, Eur. Phys. J. C 74:3109 (2014)
13 TeV, 3.2 fb$^{-1}$, ATLAS-CONF-2016-005

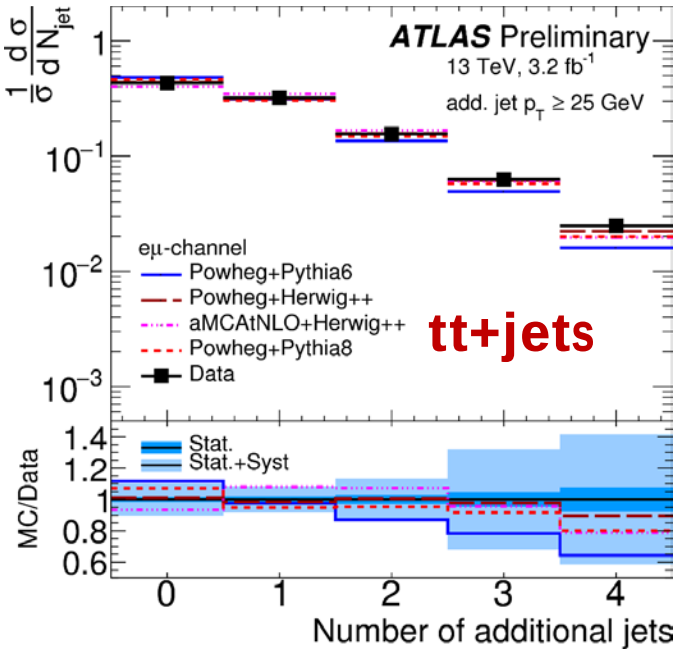
$pp \rightarrow tq$
7 TeV, 4.6 fb$^{-1}$, PRD 90, 112006 (2014)
8 TeV, 20.3 fb$^{-1}$, ATLAS-CONF-2014-007
13 TeV, 3.2 fb$^{-1}$, ATLAS-CONF-2015-079

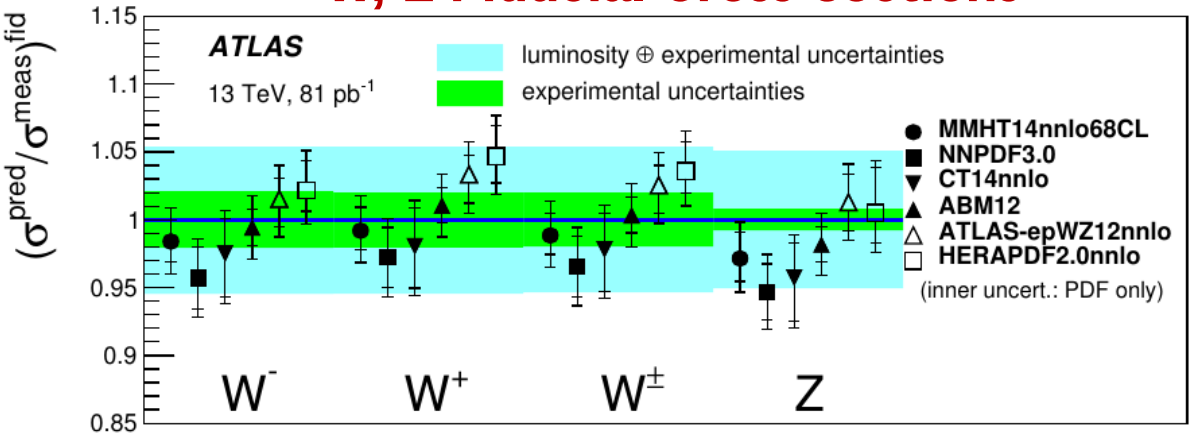
$pp \rightarrow H$
7 TeV, 4.5 fb$^{-1}$, Eur. Phys. J. C76 (2016)
8 TeV, 20.3 fb$^{-1}$, Eur. Phys. J. C76 (2016)
13 TeV, 3.2 fb$^{-1}$, ATLAS-CONF-2015-069

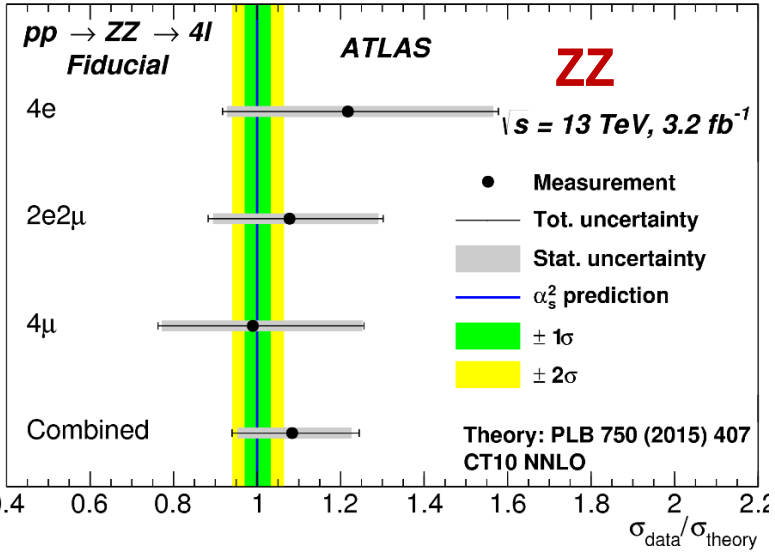
$pp \rightarrow ZZ$
7 TeV, 4.6 fb$^{-1}$, JHEP 03, 128 (2013)
8 TeV, 20.3 fb$^{-1}$, ATLAS-CONF-2013-020
13 TeV, 3.2 fb$^{-1}$, PRL 116, 101801 (2016)

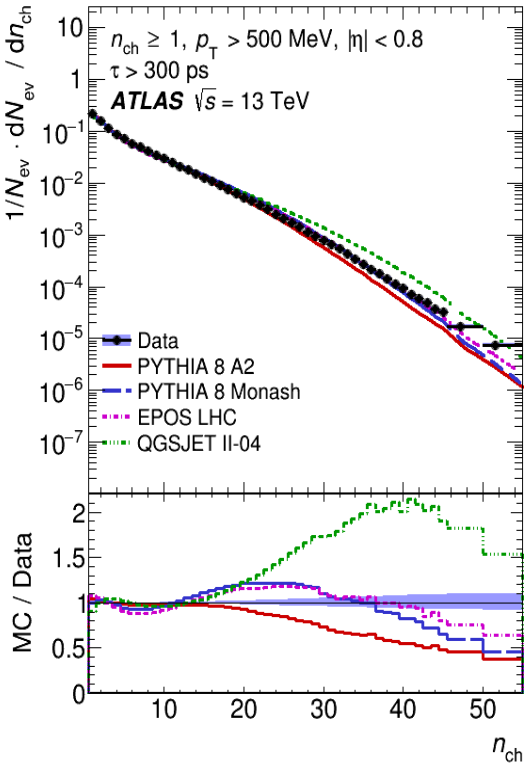
# Measurements at 13 TeV

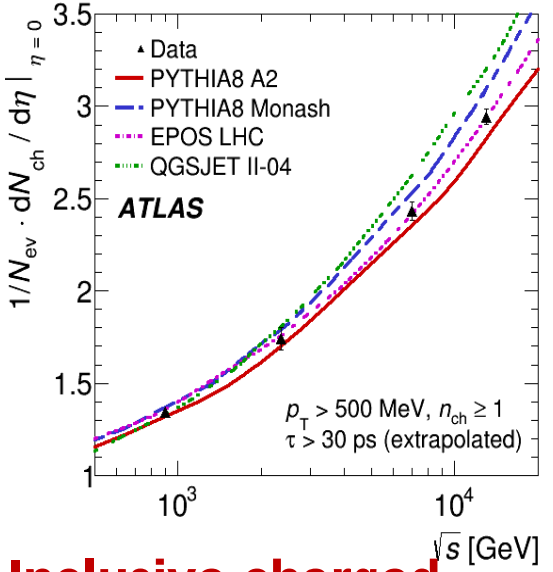
## W, Z Fiducial Cross-Sections



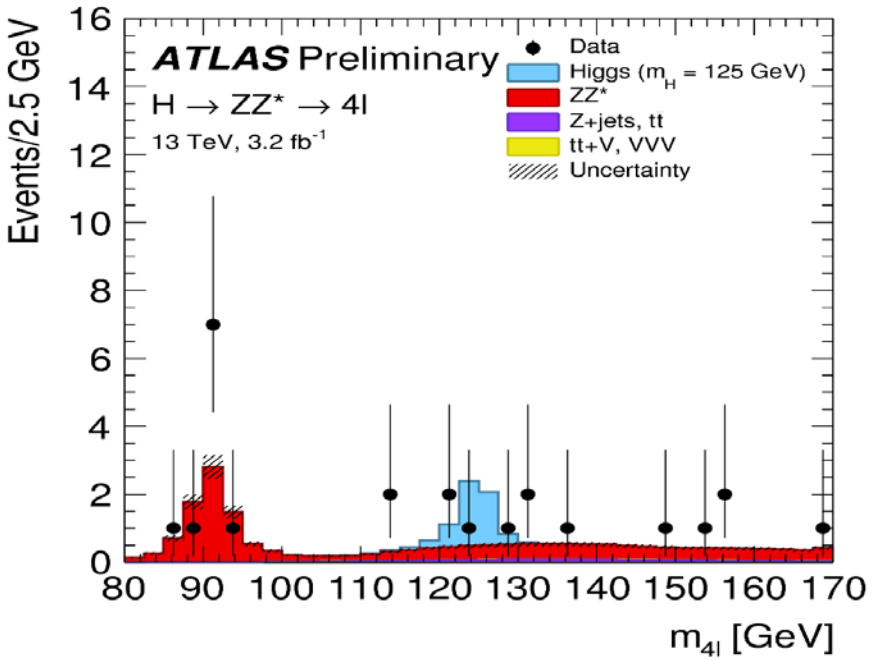



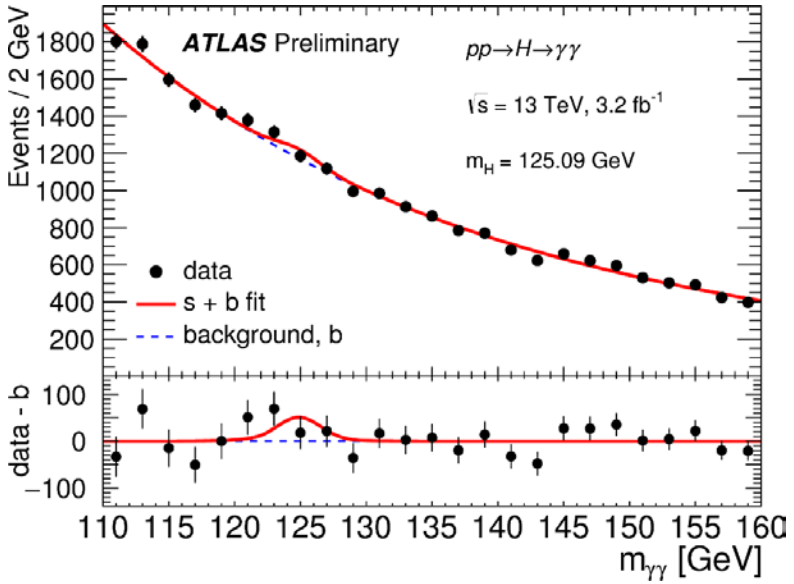



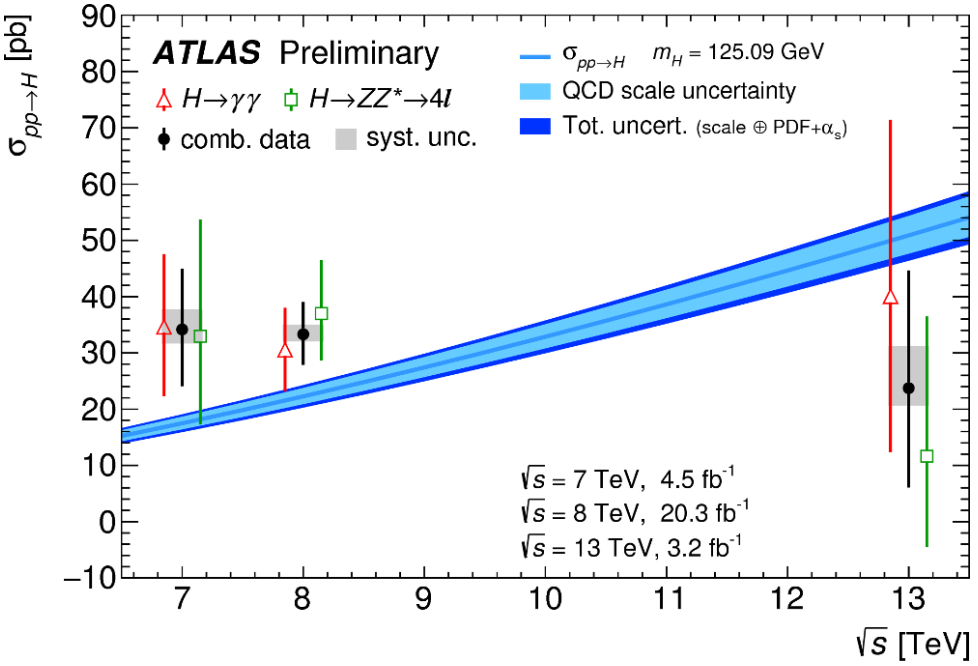

## Inclusive charged particles

# First Look for H(125) at 13 TeV

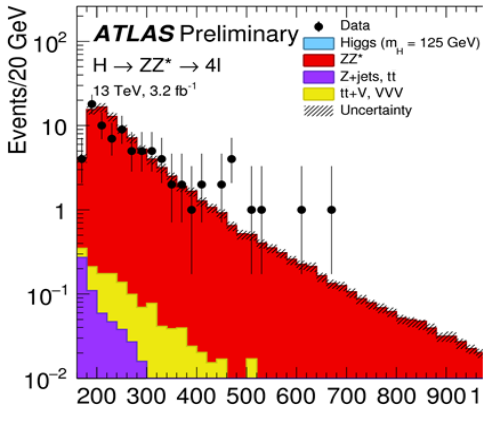


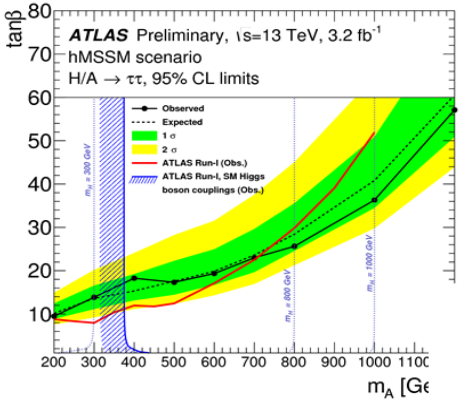



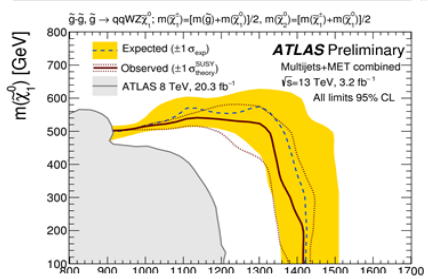

- **Di-photon channel**
  - **Observe 1.5σ, expect 1.9σ**
- **4-lepton channel**
  - **Observe 0.7σ, expect 2.8σ**
- **Combined SM Compatibility**
  - **1.3σ**

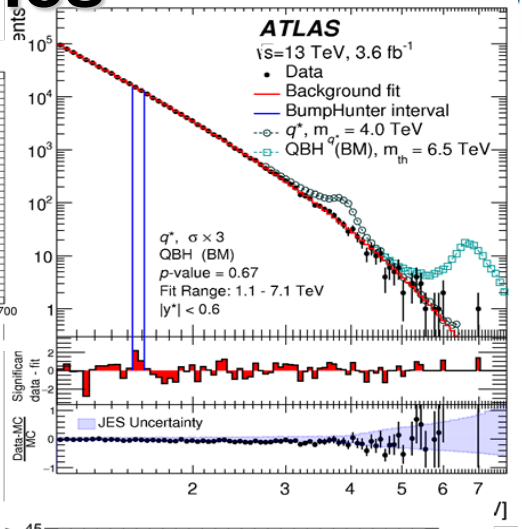


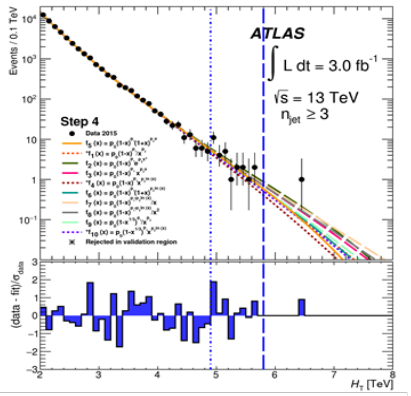
# Many (many, many) Searches

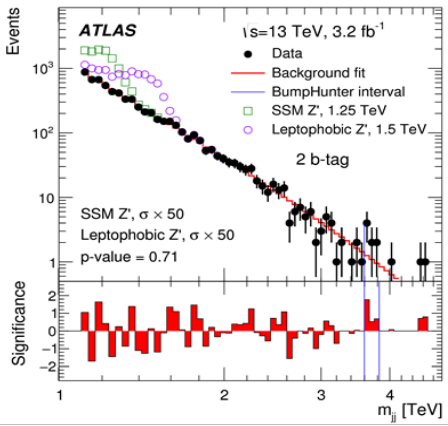


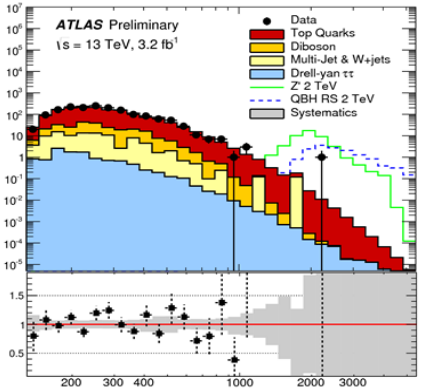



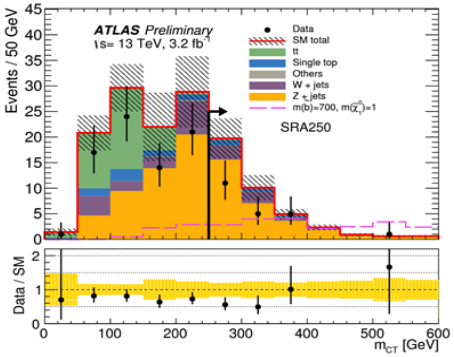



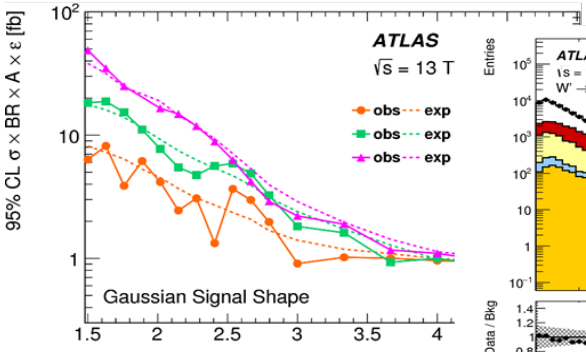



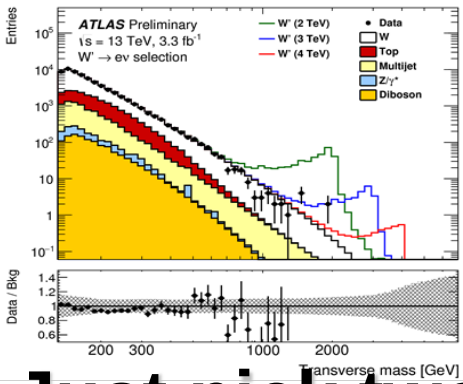



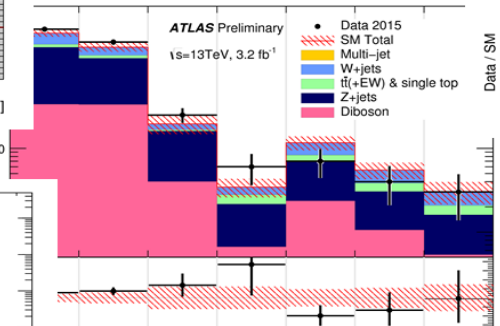



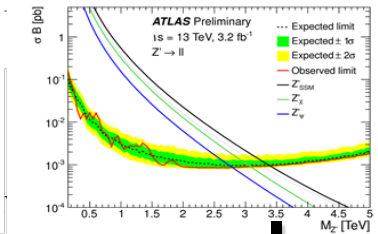



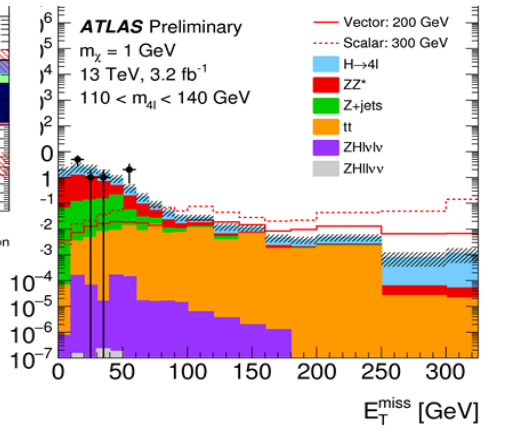



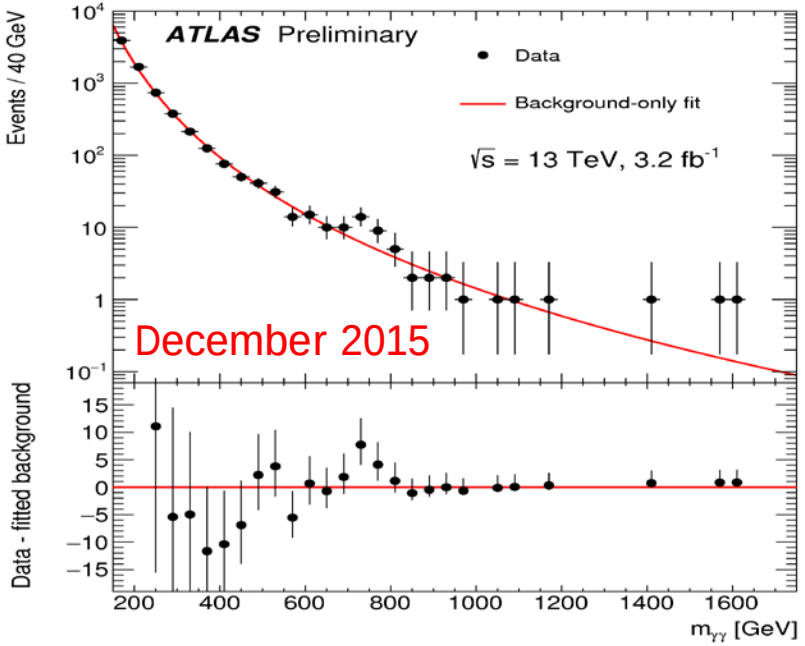



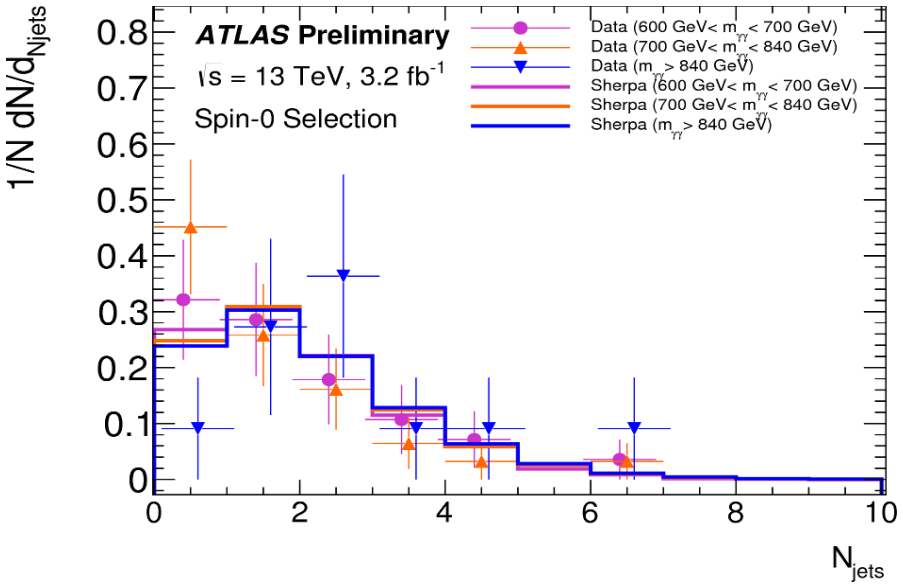

2016-May-12

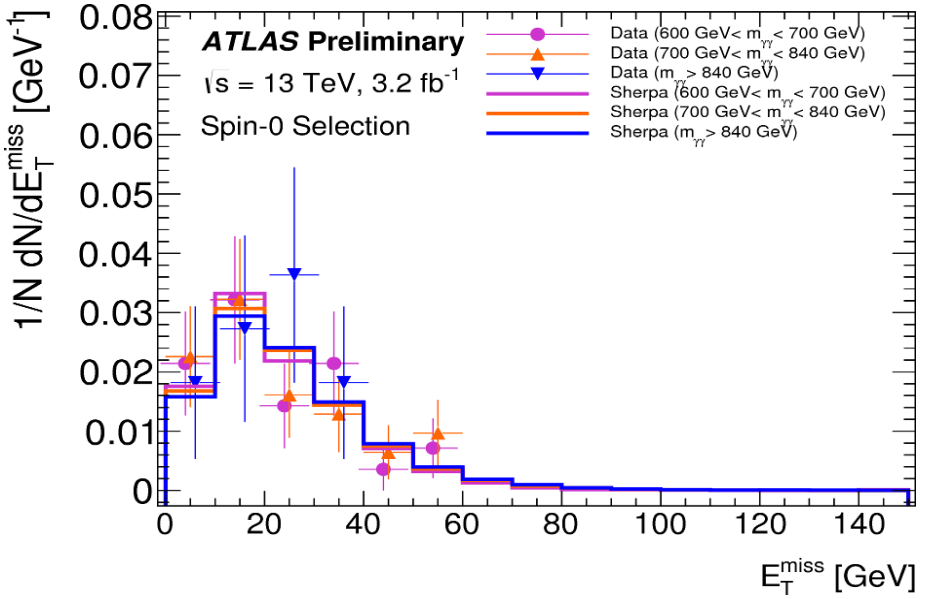
# Just pick two examples …

# Diphoton Resonance Search: Dec 2015

- $X \rightarrow \gamma\gamma$ with $m_X >> m_H$
- December 2015:
  - Scalar (central) selection
  - Modest excess ≈ 750 GeV
    - Local: 3.6σ (narrow)
    - Global: 2.0σ
  - No additional activity



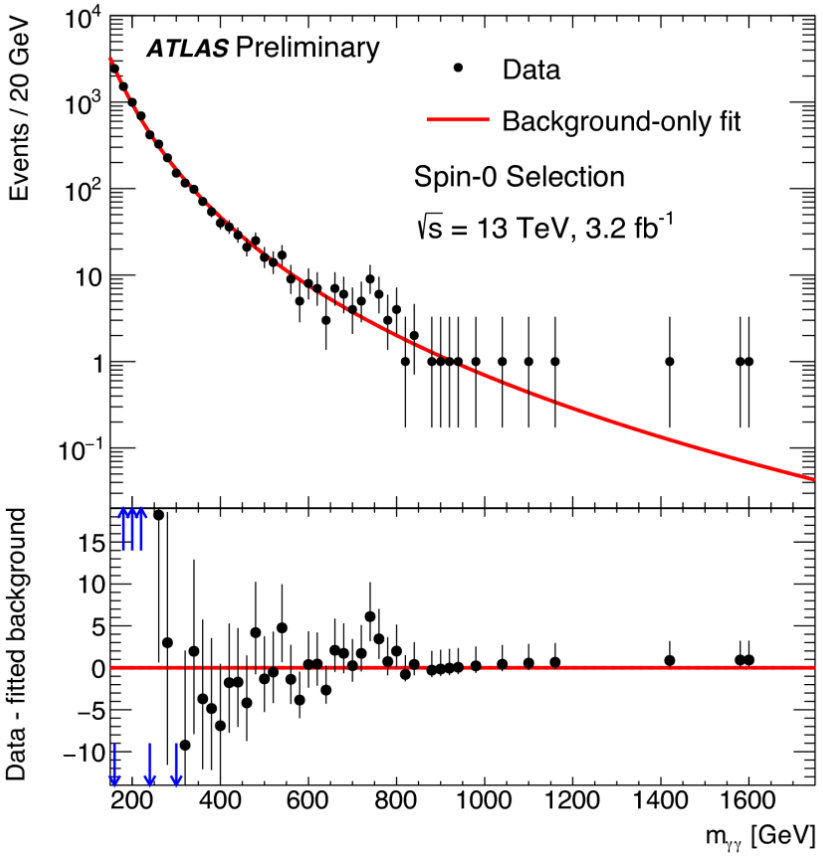



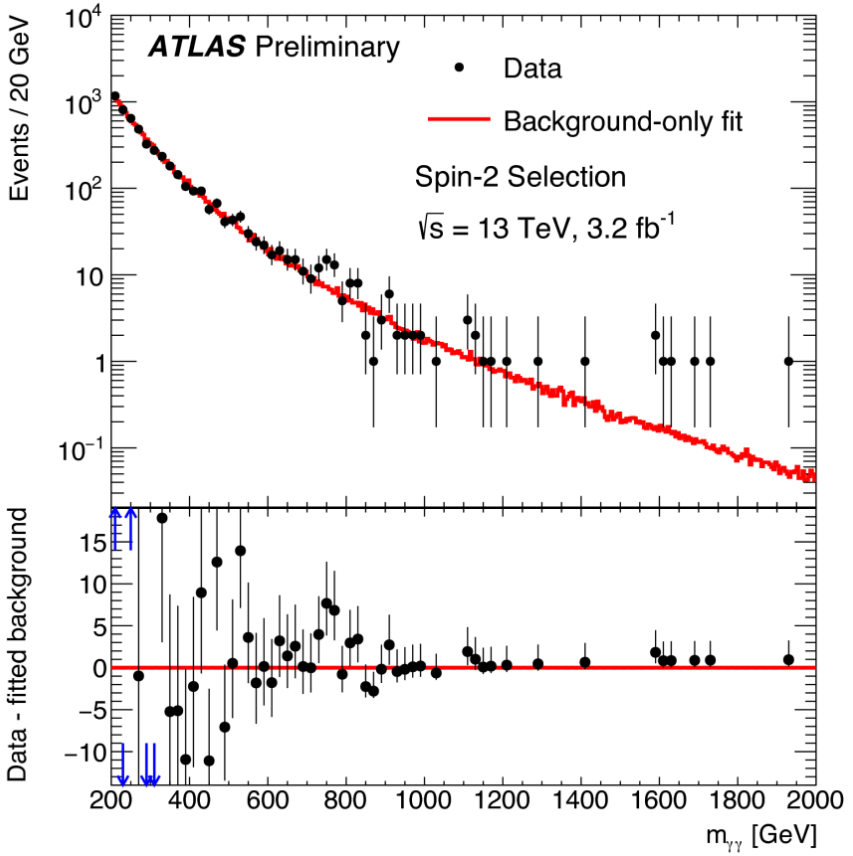
# Diphoton Resonance Search Spring 2016

- **Spring 2016: Spin-2 optimization and non-zero widths**

- **Scalar Search Analysis**
  - **Optimized for spin 0**
- **Selection**
  - **Two isolated photons with large transverse momentum ($p^{\gamma}_T$ / $m_{\gamma\gamma}$ > 0.3, 0.4 for $\gamma_1$, $\gamma_2$)**

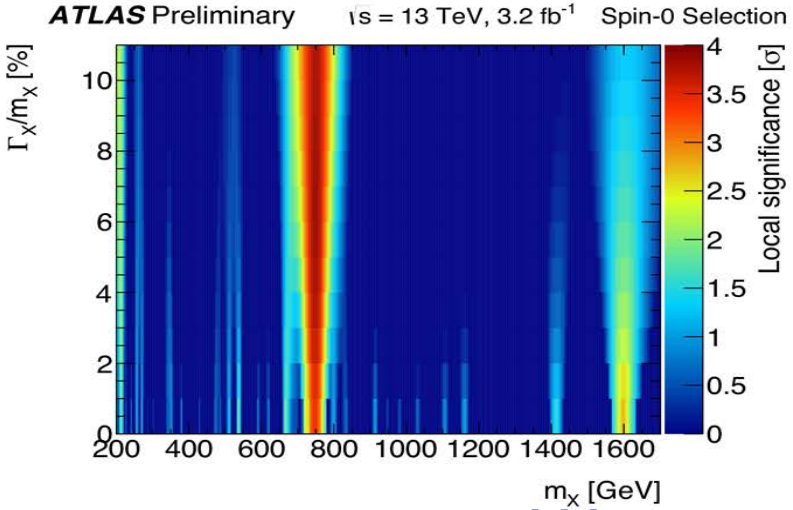
- **Graviton Search Analysis**
  - **Optimized for spin 2**
- **Selection**
  - **Two isolated photons with less transverse momentum ($p^{\gamma}_T$ > 55 GeV for $\gamma_1$, $\gamma_2$)**



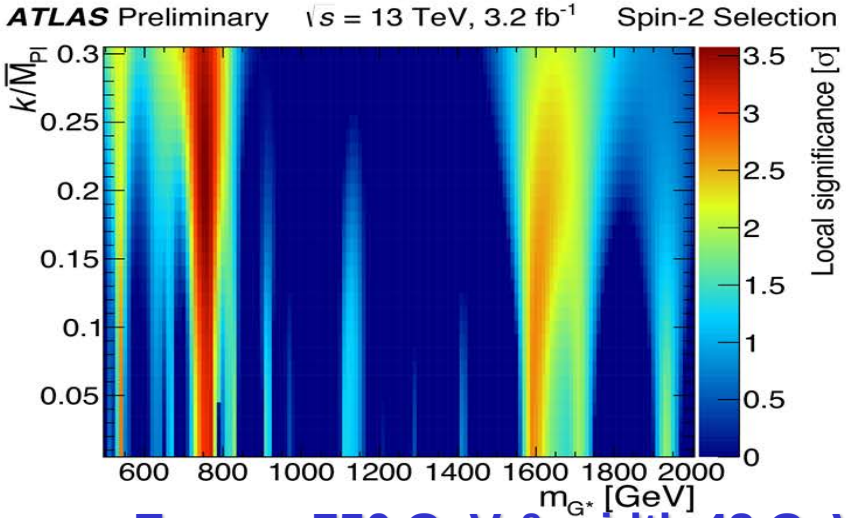



# γγ Resonance: significance

- **13 TeV Spin-0 optimization**

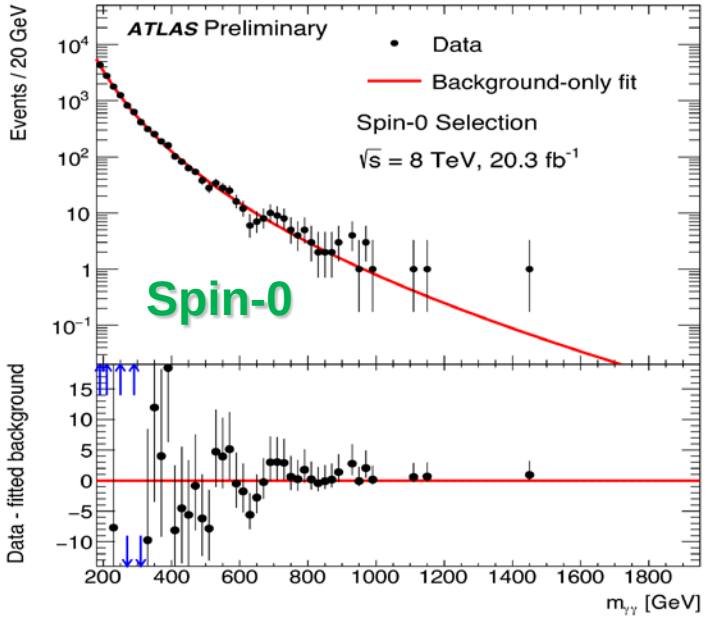


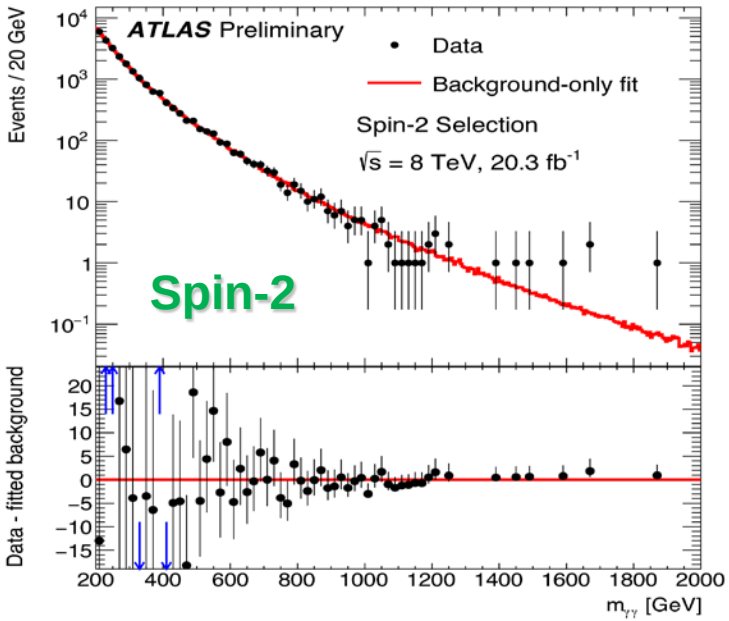

- **13 TeV Spin-2 optimization**




- **Excess 750 GeV & width 45 GeV**
  - **Local: 3.9σ / Global: 2.0σ**
- **Excess 750 GeV & width 48 GeV**
  - **Local: 3.6σ / Global: 1.8σ**

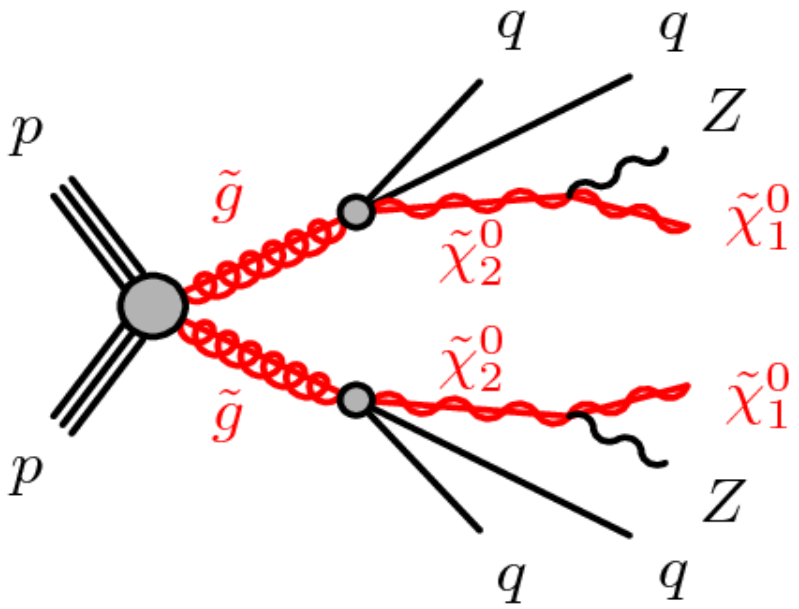
- **8 TeV Updates**

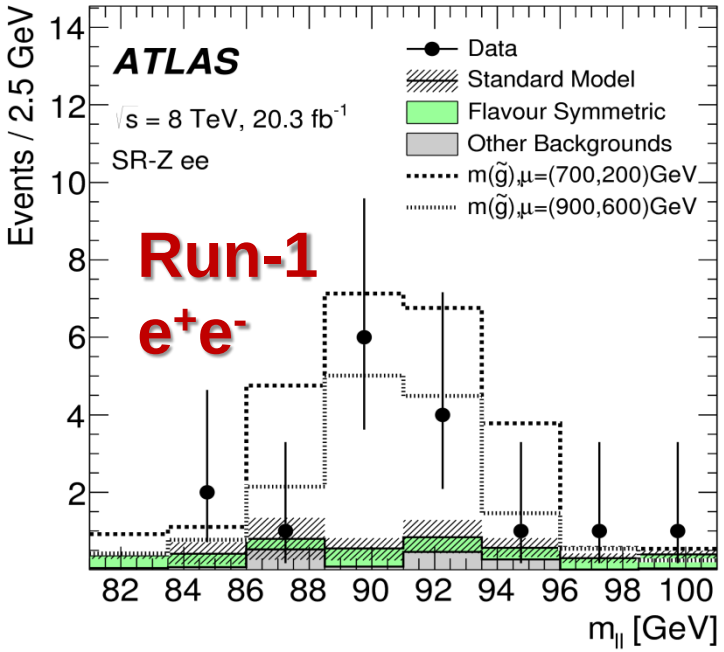


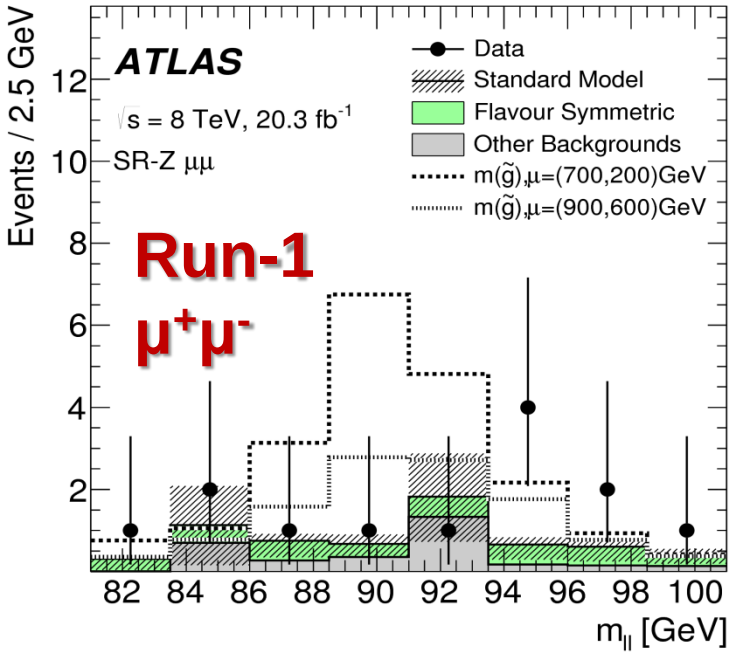



# Z + jets + $E_T^{Miss}$ : Motivation

- **Search for gluino production in events with Z + jets + missing momentum**
  - **$Z \rightarrow e^+ e^-$ or $\mu^+ \mu^-$ with $E_T^{Miss}$**
  - **Run-1: 29 events observed 10.8 ± 2.2 expected**
    - **3σ Excess (mostly in $e^+ e^-$ )**
    - **Analysis to watch for Run-2**

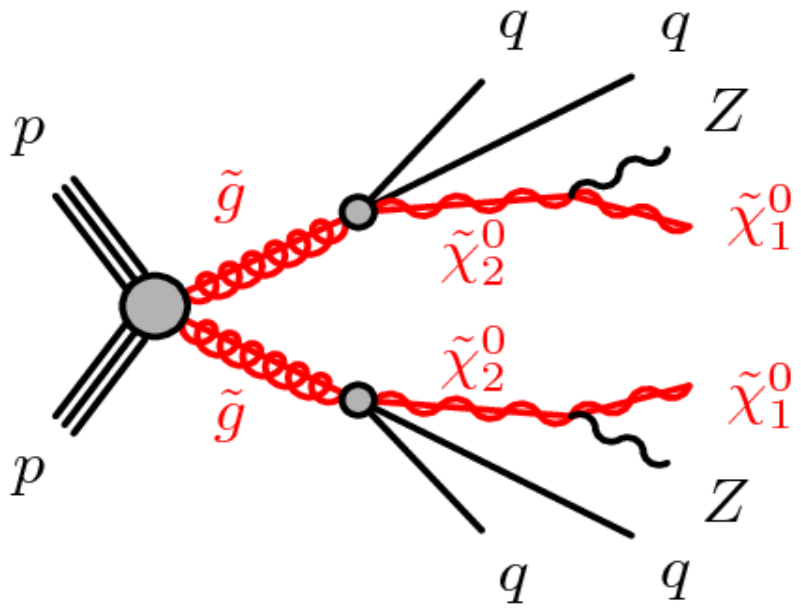


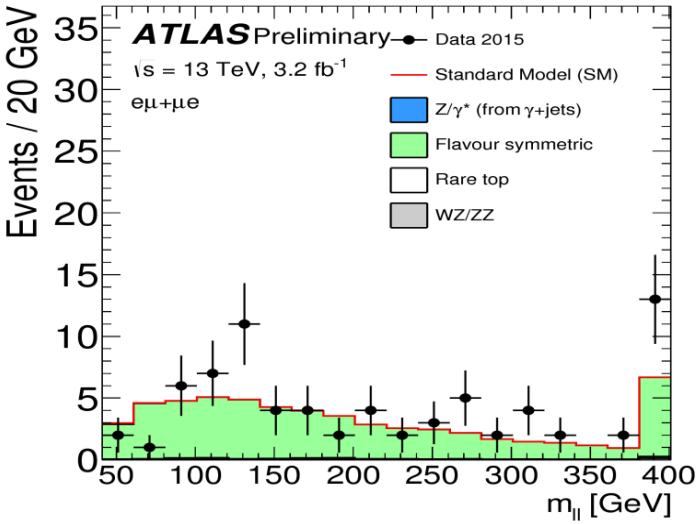
# Z + jets + $E_T^{Miss}$: Analysis

- **Analysis seems ~ simple**
  - **$e^+ e^-$ or $\mu^+\mu^-$ final state**
    - **Provides robust trigger**
  - **Missing momentum $E_T^{Miss}$**
- **Largest backgrounds:**
  - **Top quark pair, WW, WZ**
- **Worrying background**
  - **Z ($\rightarrow e^+ e^-/\mu^+\mu^-$) + jets**
    - **Jets fluctuate to fake $E_T^{Miss}$**
- **Analysis method:**
  - **CR: control regions that exclude signal definition. Use to optimize analysis and estimate backgrounds with data**
  - **VR: validation regions that are "near" signal to check**
  - **SR: final signal region which stays blinded**

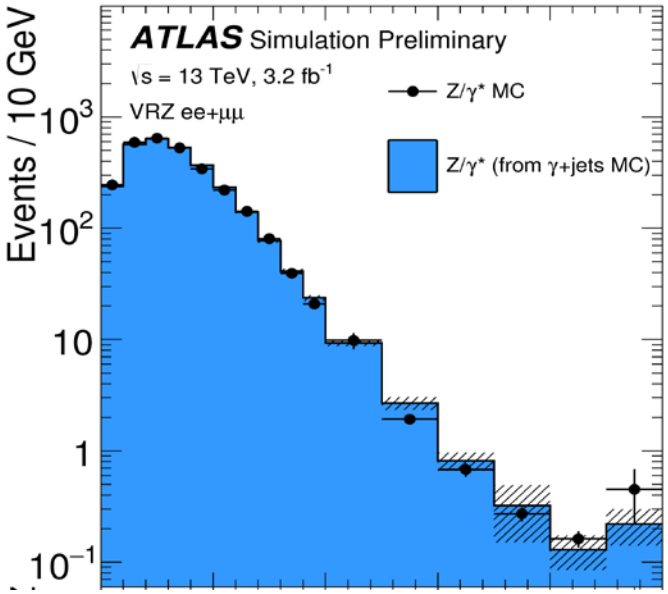


# Z + jets + $E_T^{Miss}$: Backgrounds

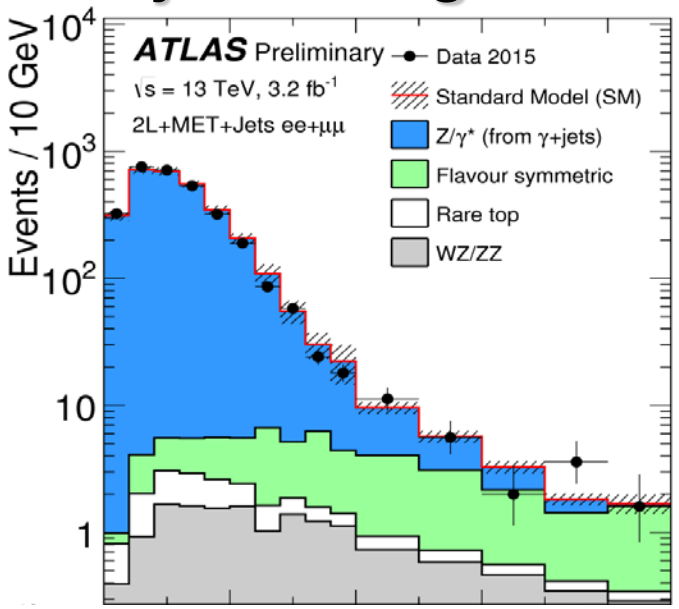
- t tbar → (b $W^+$)(b $W^-$) →jets + ($\ell\,\nu$)($\ell'\nu$)
  - Estimate same flavour ($e^+ e^-$ or $\mu^+\mu^-$) background using different flavour (e μ) Events




- Z (→ $e^+e^-/\mu^+\mu^-$) + jets
  - Use γ + jets data to estimate Z + jets background



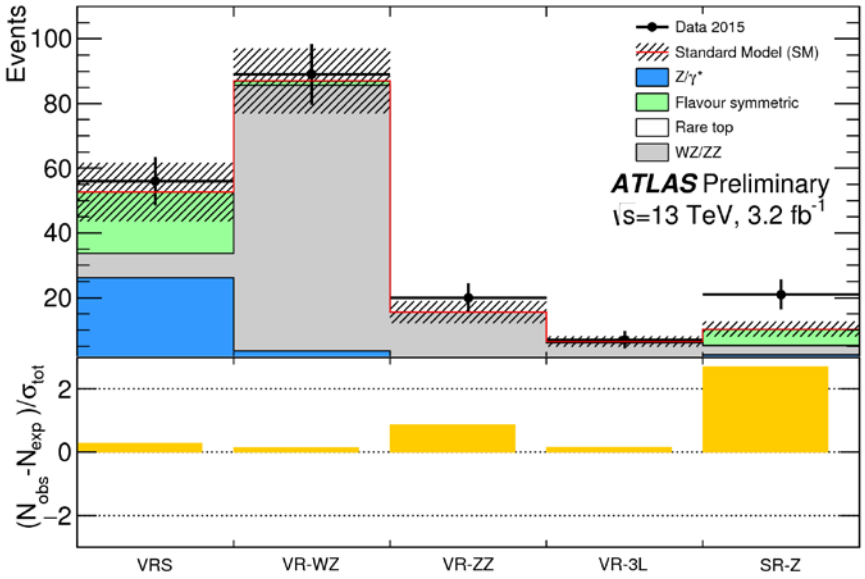

0 $E_T^{Miss}$ 250 GeV




0 $E_T^{Miss}$ 250 GeV

# Z + jets + $E_T^{Miss}$: Results

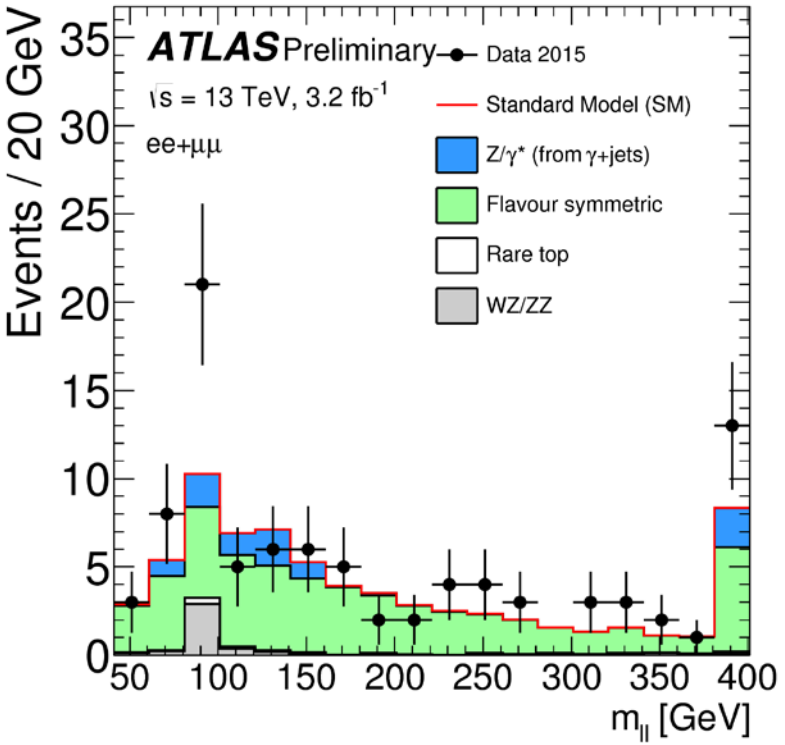
- **Validation and Signal regions**




| | SRZ |
|---|---|
| Observed events | 21 |
| Total expected background events | 10.3 ± 2.3 |
| Flavour symmetric ($t\bar{t}$, $Wt$, $WW$ and $Z \to \tau\tau$) events | 5.1 ± 2.0 |
| $WZ/ZZ$ events | 2.9 ± 0.8 |
| $Z/\gamma^*$ + jets events | 1.9 ± 0.8 |
| Rare top events | 0.4 ± 0.1 |
| $p$-value | 0.013 |
| Significance | 2.2 |
| Observed (Expected) $S^{95}$ | 20.0 ($10.2^{+4.4}_{-3.0}$) |

- **2015 data results with 3.2 fb$^{-1}$**
  - **21 observed,10.8 ± 2.2 expected**
  - **2.2 σ excess with 2015 data**
  - **11 $\mu^+\mu^-$ / 10 $e^+e^-$**
  - **Eagerly await 2016 data**

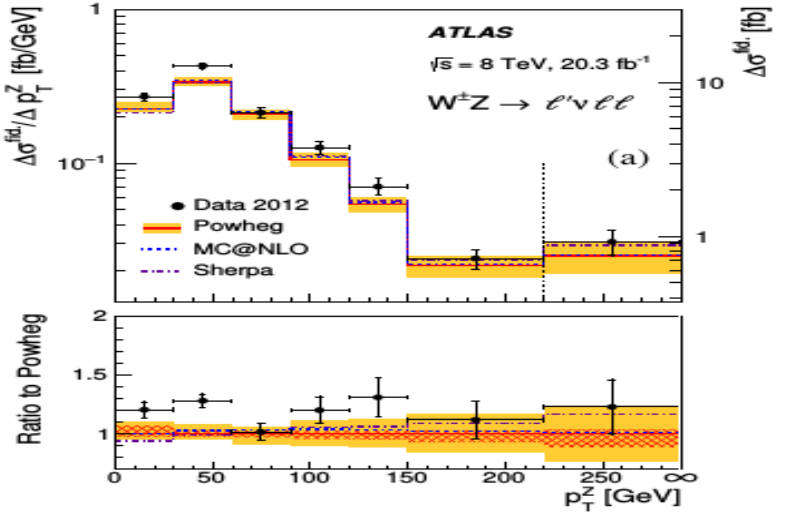
- **Di-lepton invariant mass:**



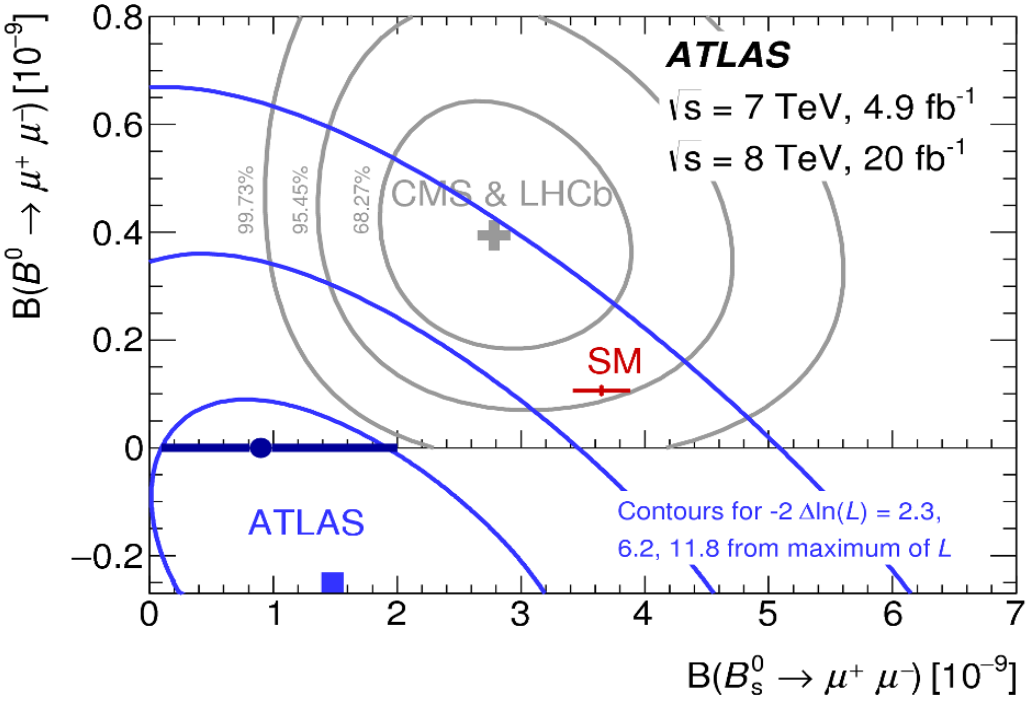
# Selected Run-1 Results

- All Run-1 search papers submitted
- Measurement papers continuing
- Two examples:

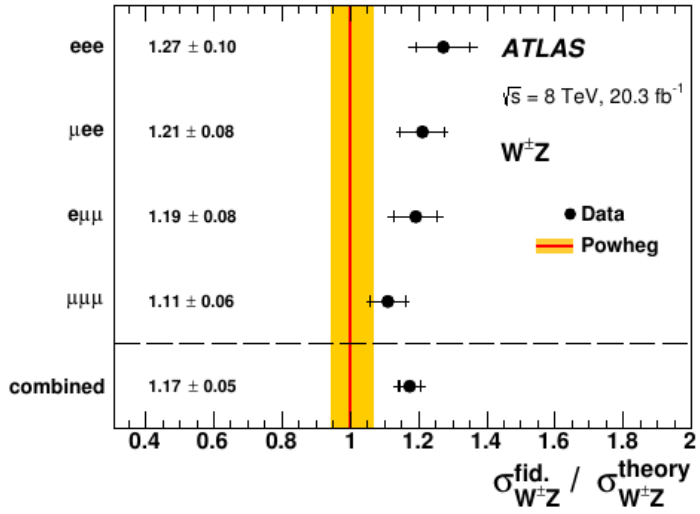
- **WZ production at 8 TeV**




- **Measurement of $B \to \mu^+\mu^-$ decays:**
  - Consistent with SM at 2
  - Also consistent with zero




$\sigma_{FID}(WZ \to \ell\nu\ell\nu\ell) =$
**35.1±0.9(stat)±0.8(sys)±0.8(lumi) fb**
**NLO prediction 30.0±2.1 fb**



- **ATLAS Upgrades**

# ATLAS Upgrade Timelines

2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 .. 2035

## Phase 0 upgrade:

Consolidation, $\sqrt{s}$=13-14 TeV, 25nsec bunch spacing,
$\mathcal{L} \approx 1 \times 10^{34}$ cm$^{-2}$s$^{-1}$ ($\mu \approx 30$)
$\int \mathcal{L} \approx 100$ fb$^{-1}$

- New insertable pixel b-layer (IBL)
- New Al beam pipe
- New pixel services
- New evaporative cooling plant
- Consolidation (calorimeter power supplies)
- Neutron Shielding
- Finish EE muons installation
- Upgrade magnet cryo

## Phase 1 upgrade:

Ultimate luminosity
$\mathcal{L} \approx 2 \times 10^{34}$ cm$^{-2}$s$^{-1}$ ($\mu \approx 60$)
$\int \mathcal{L} \approx 300$ fb$^{-1}$

- New Muon Small Wheel (NSW)
- High Precision Calorimeter Level-1 Trigger
- Fast Track Trigger (FTK)
- Topological Level-1 Trigger Processor
- (New forward diffractive physics detectors AFP)

## Phase 2 upgrade:

$\mathcal{L} \approx 7 \times 10^{34}$ cm$^{-2}$s$^{-1}$ ($\mu \approx 150$)
$\int \mathcal{L} \approx 3000$ fb$^{-1}$

- All new Tracking Inner Detector
- Calorimeter Electronics Upgrades
- Muon system upgrades (big wheels)
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- New forward calorimeters

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- Calorimeter Electronics Upgrades
- Muon system upgrades (big wheels)
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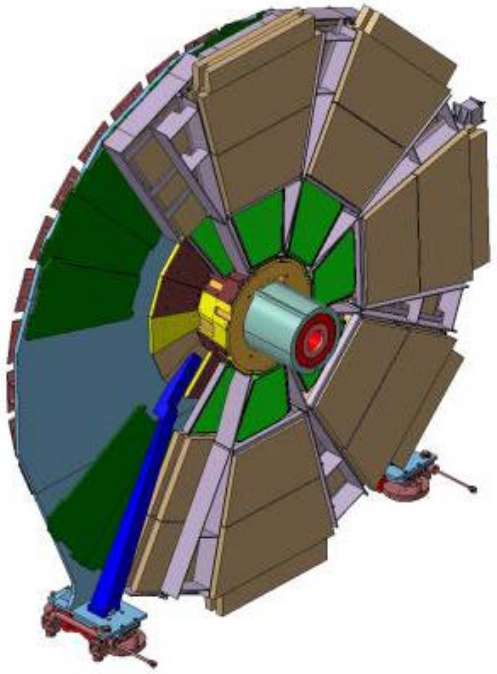
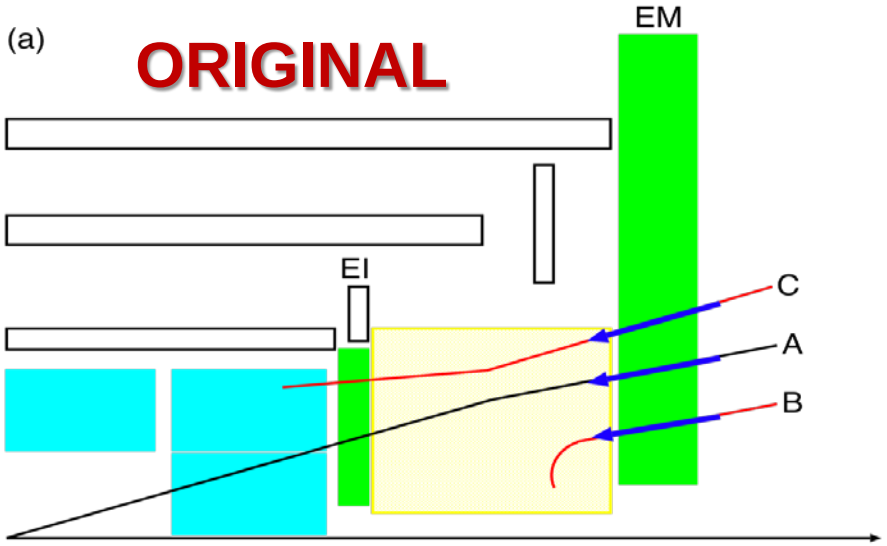
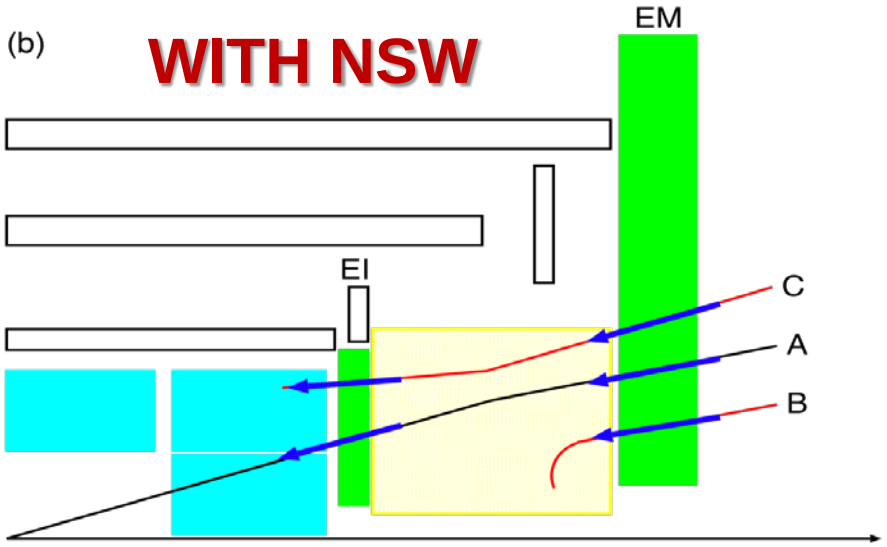
- New forward calorimeters

# Phase-1: New Muon Small Wheel

- Replace muon small wheels with improved granularity / tracking
- Maintain low muon $p_T$ thresholds at highest rates
  - ≈ 1/6 rate for $1.3 < |\eta| < 2.5$ with nominal pT thresholds

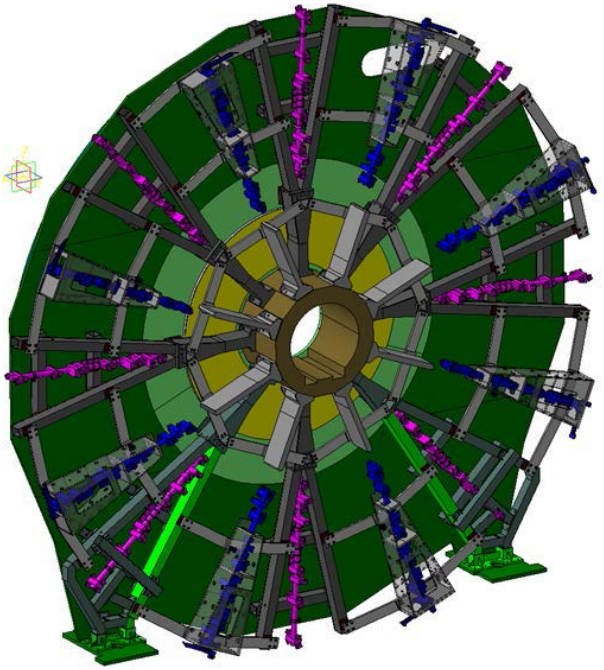


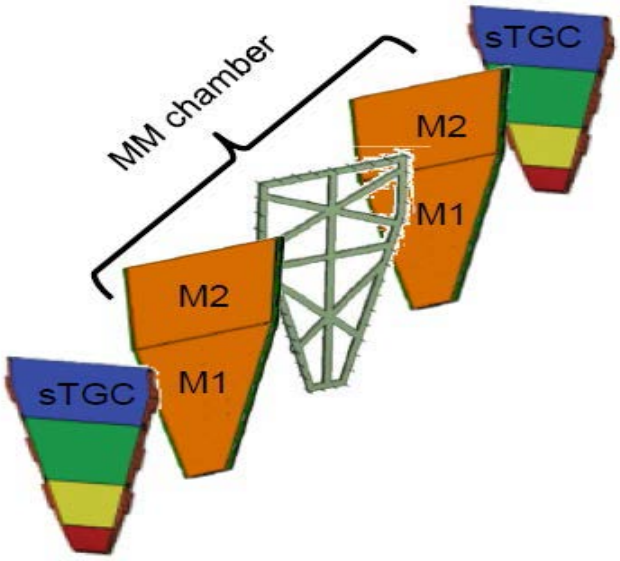


# Phase-1: New Muon Small Wheel

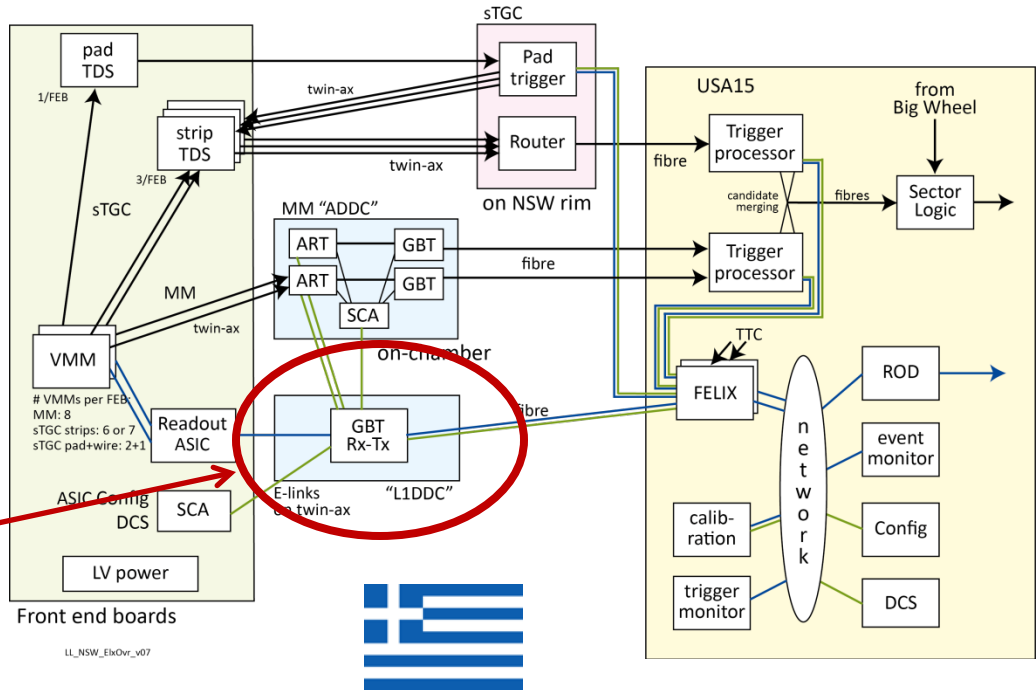
- **Mechanics:**
  - Construction of **New JD** and mechanical Structure (10 Mt Diameter,~100 T)
- **Detectors:**
  - 16x2 Sectors each consisting of **2 MicroMegas (MM)** and **2 sTGC Wedges**
- **Electronics:**
  - **4 Different ASICS** + 5 electronics cards
  - sTGC **Pad Trigger**
  - New **Trigger Processor**

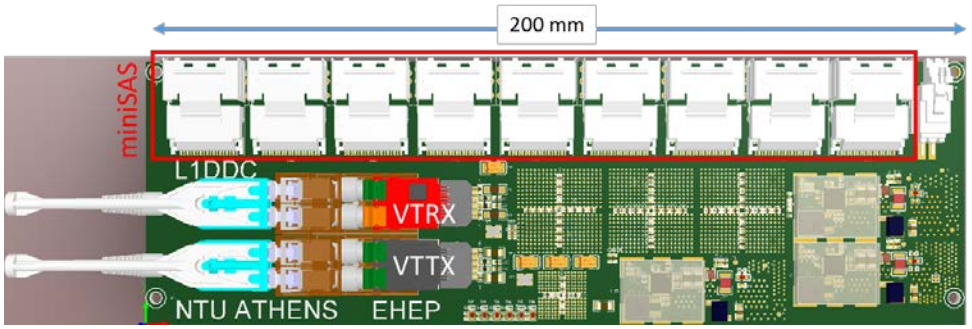




# Greek Participation in the NSW

- **Thessaloniki, NTU Athens & University of Athens:**
  - **major responsibilities for original ATLAS muon chamber construction (BI chambers)**
- **Strong engagement continues for the NSW**
  - **NTUA is in charge of designing, implementing and producing the L1DDC electronics which interfaces the detector front-end cards**
    - **both Micromegas and sTGC**
- **Thessaloniki is responsible for construction of 1 of the 4 Micromegas chamber**
  - **Collaboration with Dubna & CERN**



# Micromegas construction in Thessaloniki

- Quadruplet construction methods developed at CERN by Thessaloniki, Dubna and CERN
- Module-0 prototype nearing completion

**In Parallel**

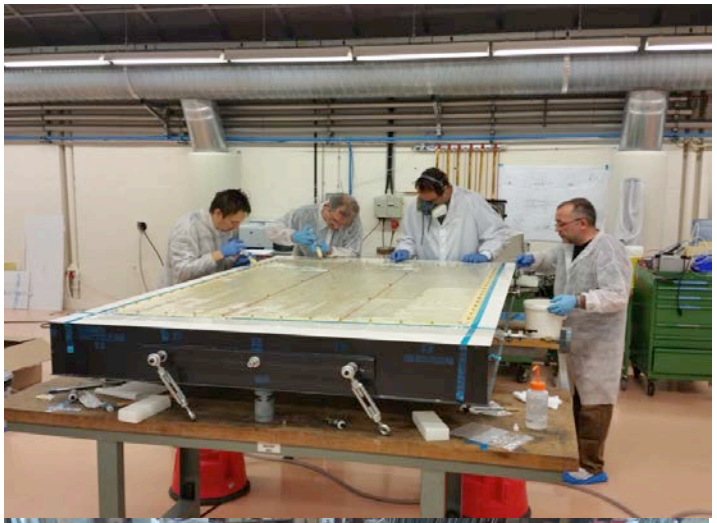
- Clean room in Thessaloniki has been set up
- Mesh stretching tooling and method has been established and is ready for use
- Assembly tooling table is under production

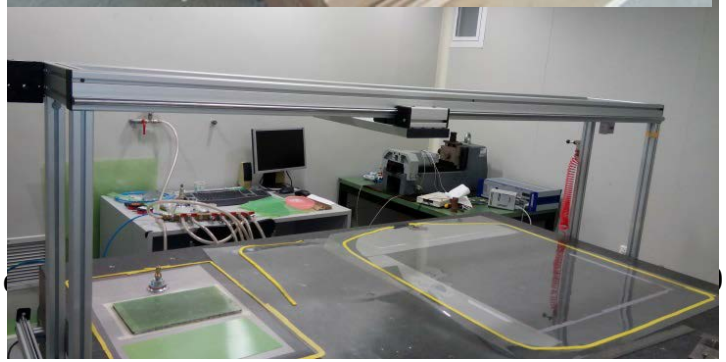
**Next Steps**

- Thessaloniki team will do the chamber production – engineer + physicts + techs + students

- Major and critical activity over the next 2 years, completing ~100 drift panels

- Significant logistics – ATLAS counts on AUTH administration support to have succeed in this critical part of the project !

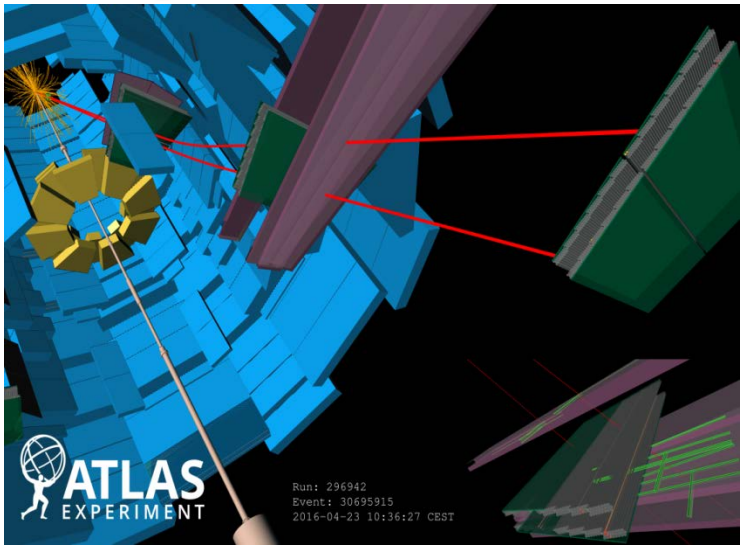


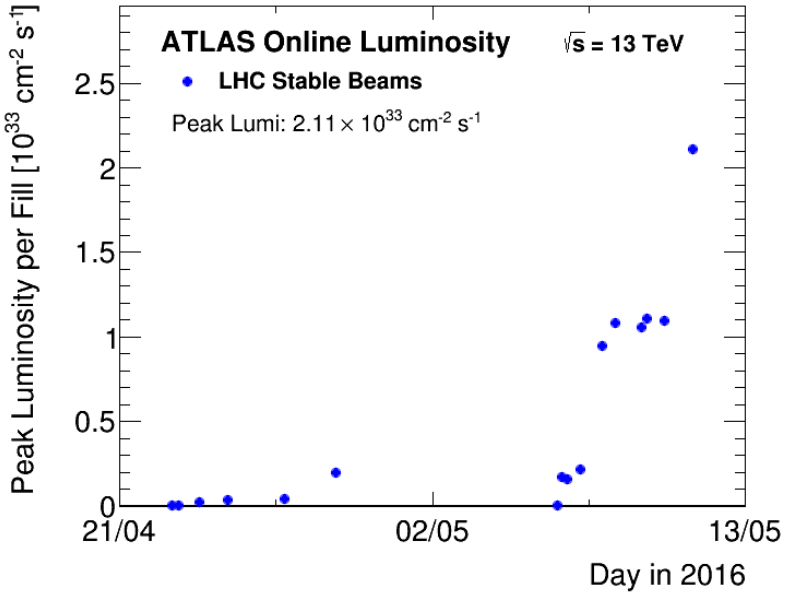


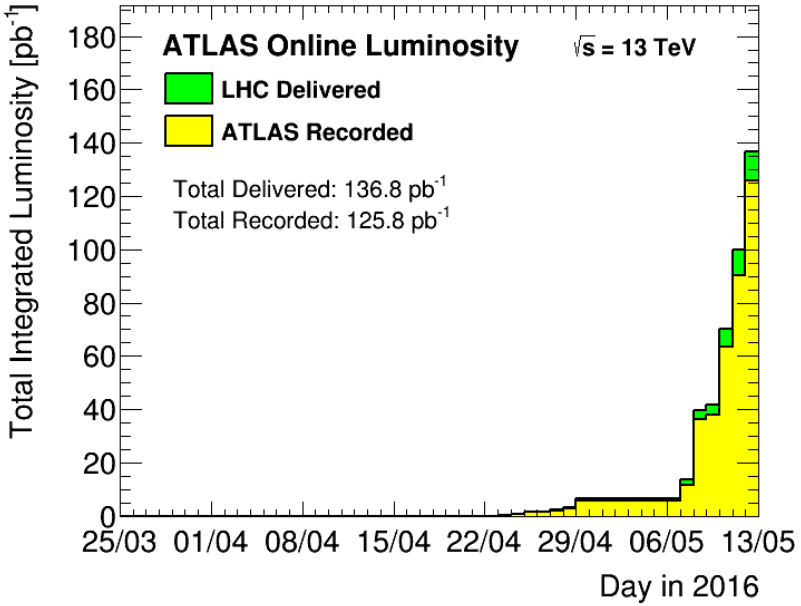
- **Current ATLAS status**

# 2016 Startup

- Running with stable beams
- Moving to intensity ramp
- Expect further “scrubbing”
- 12/05/2016:
  - Intensity ramp now at 600 bunches
  - ATLAS: 0.13 $fb^{-1}$ @ 92% Eff.
- Luminosity ramp continues
  - Eventually > 2000 bunches



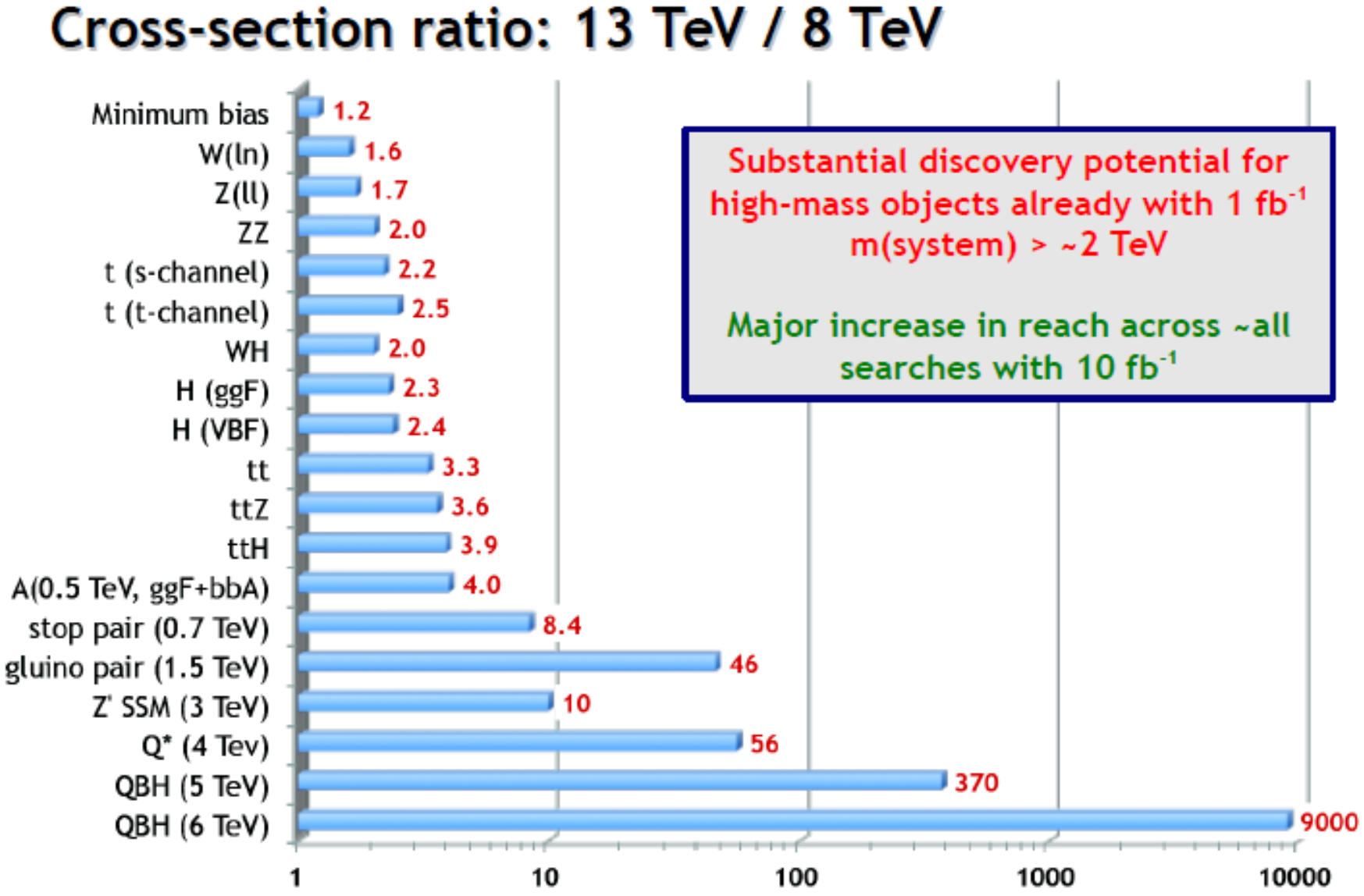
- **Summary**

# Wrap-up

- Huge physics output with 2015 data
- 2016 starting out well.
- Run-2 & Run-3 will see the last large increase in direct energy reach from any project for the foreseeable future
  - Entering into the critical new physics discovery window of the LHC program
- Preparing for precision physics at the TeV-scale @ LHC Run-4 (beyond 2025)
  - ATLAS and LHC upgrades ongoing and ramping
- Intense and fun few years/decades coming up

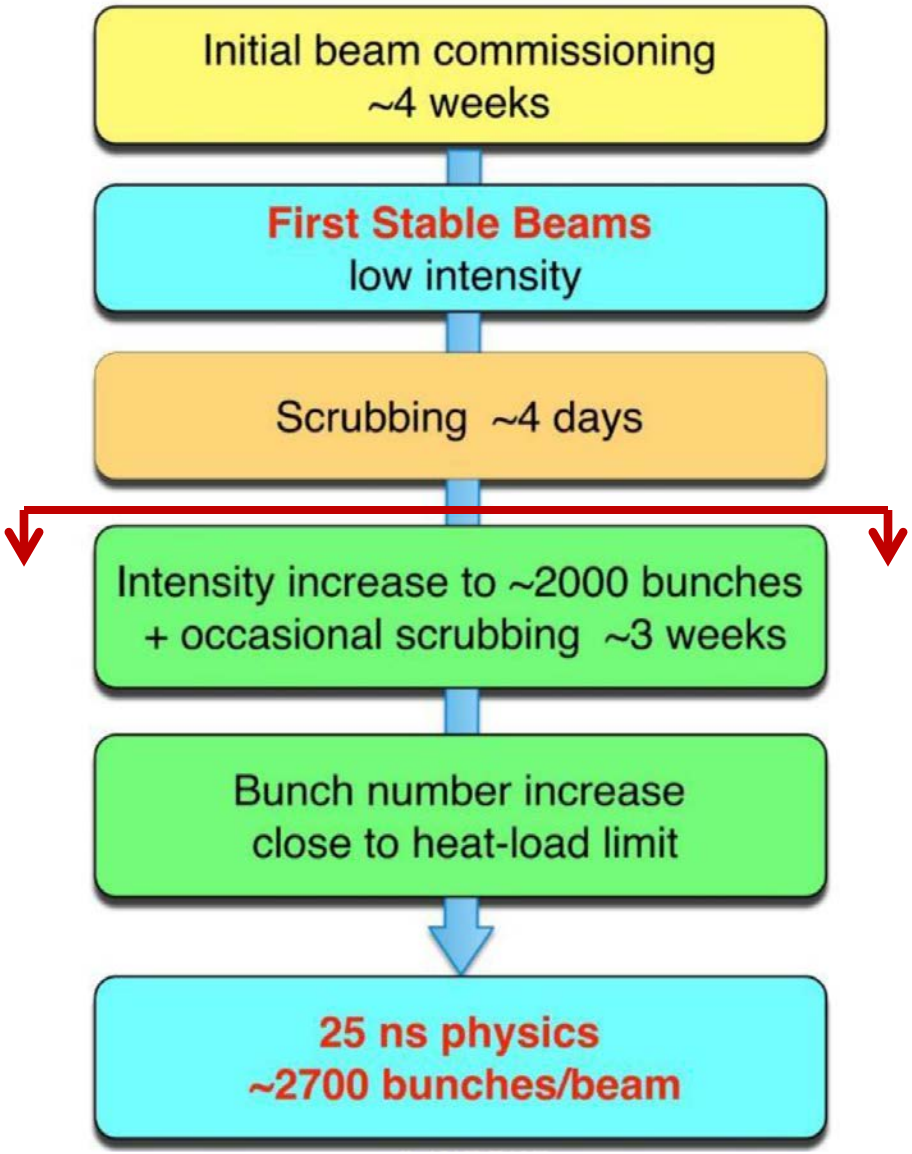
- **Additional Material**

# √s = 13 TeV: cross sections



# Proton-Proton Plans for 2016

- Stable Operations
- Electron Cloud control
- 13 TeV, β* = 40 cm
- 25 nsec bunch separation, 2748 bunches with 228 bunch trains
  - May need to reduce to 72 due to SPS beam dump
- Push availability and efficiency




Argentina
Armenia
Australia
Austria
Azerbaijan
Belarus
Brazil
Canada
Chile
China
Colombia
Czech Republic
Denmark
France
Georgia
Germany
Greece
Israel
Italy
Japan
Morocco
Netherlands
Norway
Poland
Portugal
Romania
Russia
Serbia
Slovakia
Slovenia
South Africa
Spain
Sweden
Switzerland
Taiwan
Turkey
UK
USA
CERN
JINR
ATLAS
Collaboration
July 2010

Adelaide, Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brazil Cluster, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, SMU Dallas, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Edinburgh, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Harvard, Heidelberg, Hiroshima IT, Hong Kong, Indiana, Innsbruck, Iowa SU, Iowa, UC Irvine, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Kyushu, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QM London, RH London, UC London, Louisiana Tech, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, Northern Illinois University, BINP Novosibirsk, NPI Petersburg, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Rome I, Rome II, Rome III, RAL-STFC, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, South Africa Cluster, Stockholm, KTH Stockholm, Stony Brook, Sydney, Sussex, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Tokyo Tech, Toronto, Trento, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, UI Urbana, Valencia, UBC Vancouver, Victoria, Warwick, Waseda, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

| | |
|---|---|
| Colombia | South Africa |
| Czech Republic | Spain |
| Denmark | Sweden |
| France | Switzerland |
| Georgia | Taiwan |
| Germany | Turkey |
| Greece | UK |
| Israel | USA |
| Italy | CERN |
| Japan | JINR |

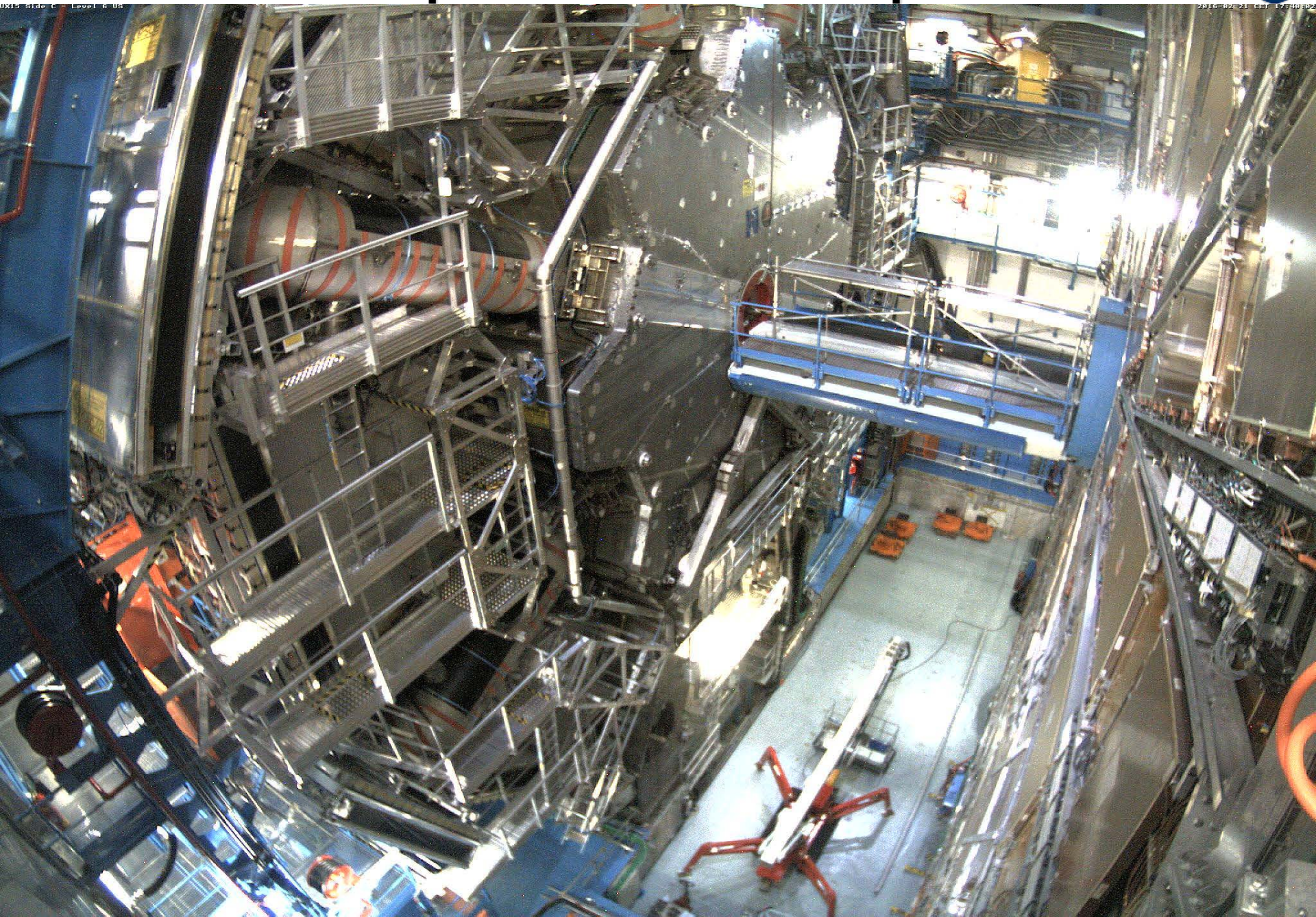
**180 institutions across 38 countries**

**≈ 2900 scientific authors**

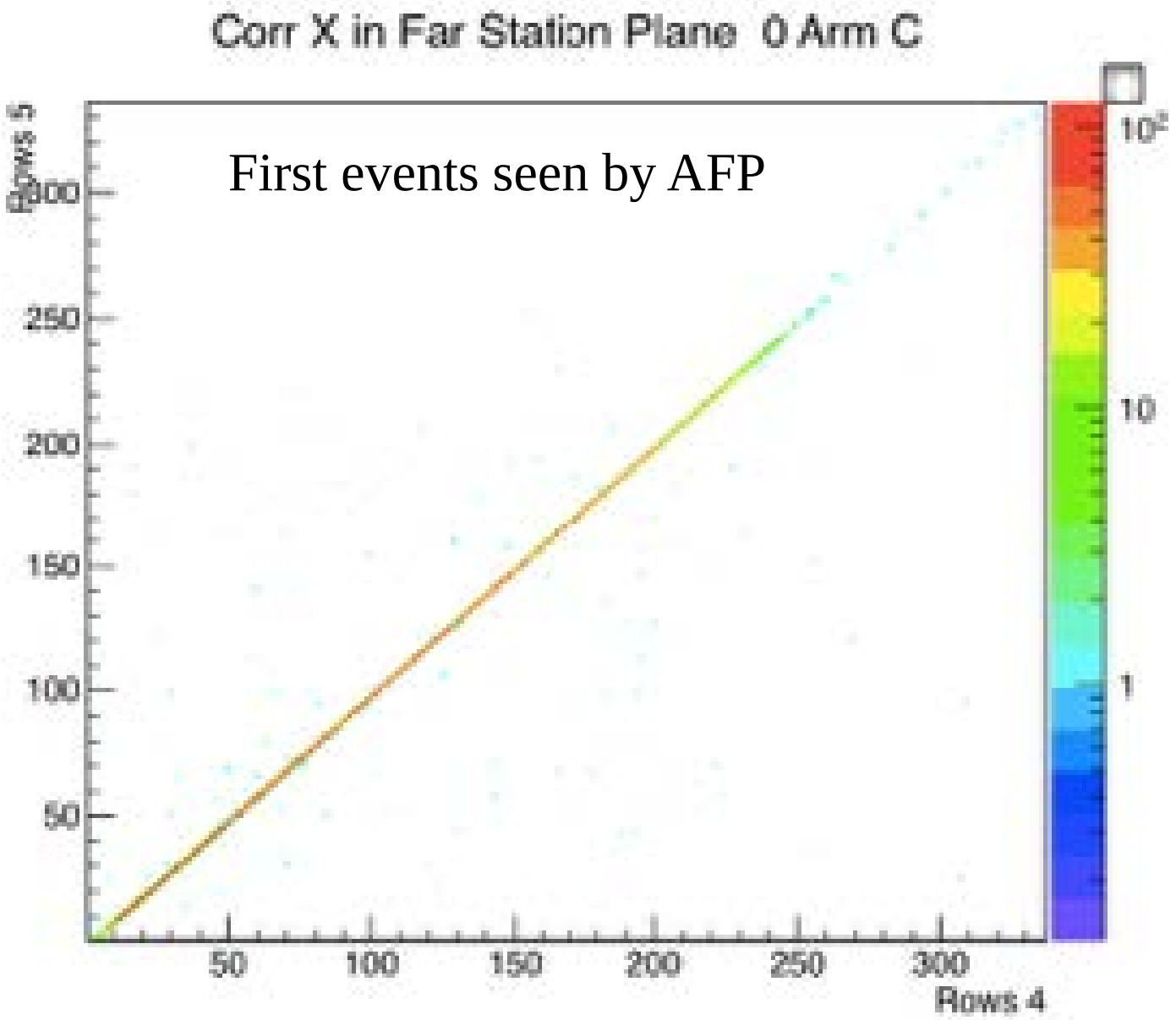
**≈ 1900 with PhD**

**≈ 1000 students**

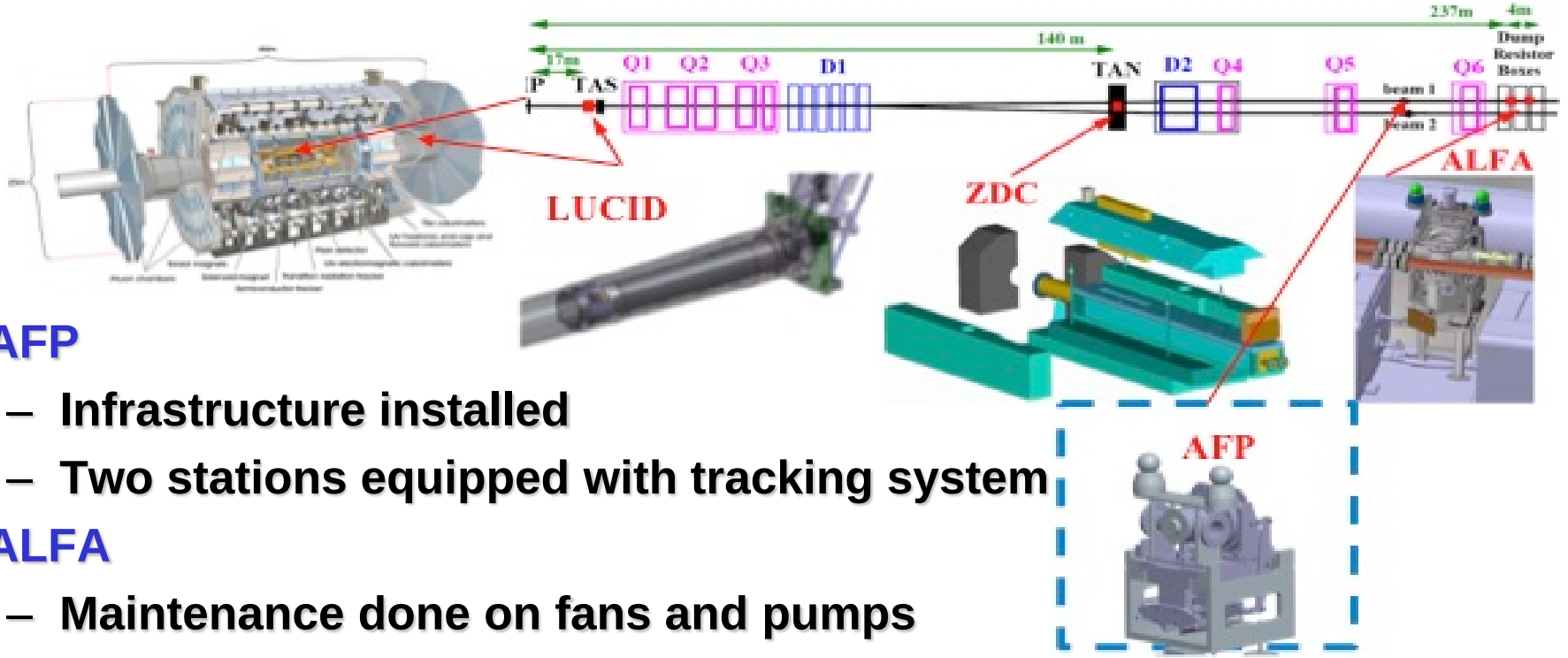
# Endcap toroid C: back in position



# Trackers installed in AFP pots



# 2015-2016 Shutdown: Forward Detectors




- **AFP**
  - Infrastructure installed
  - Two stations equipped with tracking system
- **ALFA**
  - Maintenance done on fans and pumps
  - Noisy electronics changed, DCS/TDAQ upgraded
- **LUCID**
  - 4+4 PMTs replaced with $^{207}$Bi calibrationed PMTs
  - TDAQ upgrades
- **ZDC**
  - Detectors refurbished

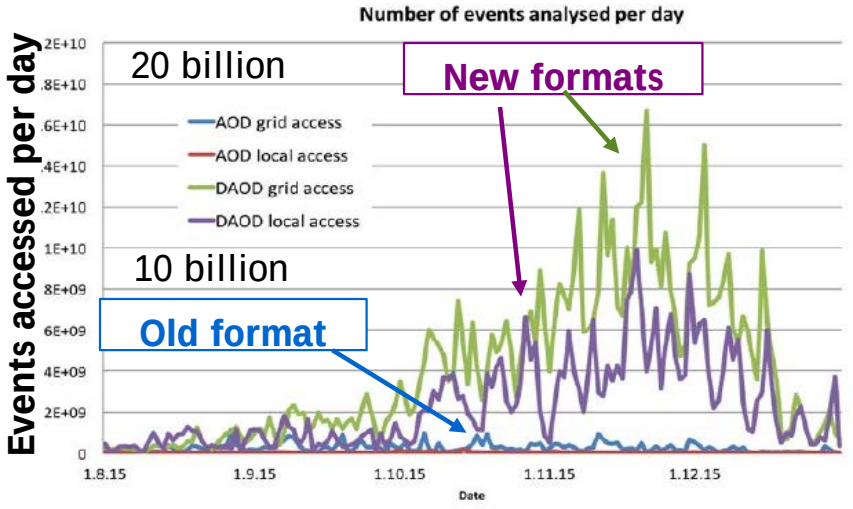
# 2015-2016 Shutdown: TDAQ

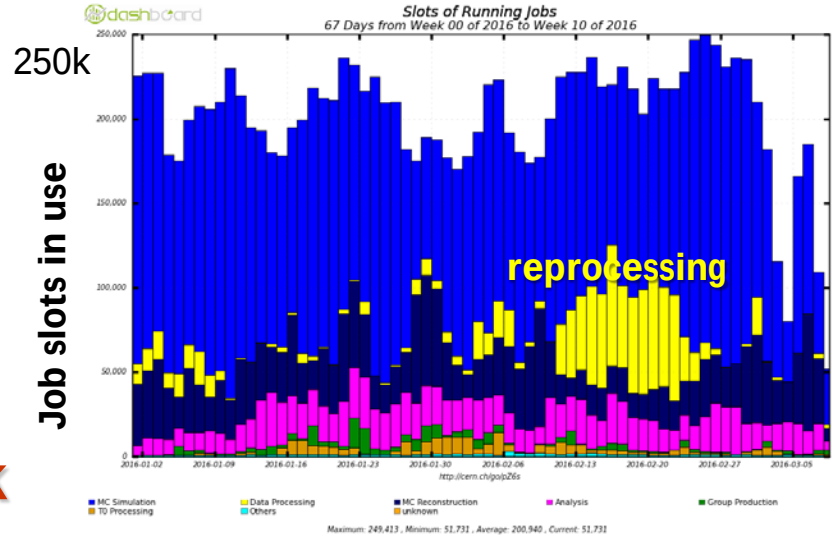
- 168 x 64-bit single-board computers installed
- Hardware-based region-of-interest builders replaced with commodity hardware
- Upgrades for 100 kHz  Level-1
- During 2016 run:
  - Commission Tile-Muon coincidence
  - Increase complexity of new Topological-processor

- TDAQ fully ready for $\sqrt{s}$=13 TeV and $\mathcal{L}=10^{34}cm^{-2}s^{-1}$

# Software and Computing

- **Software releases**
  - **2015: 20.1**
    - **New analysis model**
  - **2016: 20.7**
    - **Also 2015 data/MC reprocessing**
    - **Improve robustness**
  - **2017/2018: 21**
    - **Many improvements for full Run-2 analysis**
    - **Also foundation for fully multithreaded framework**



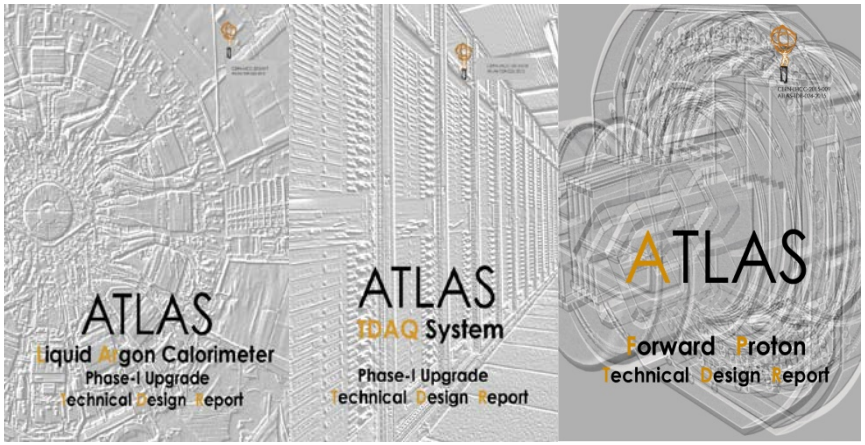



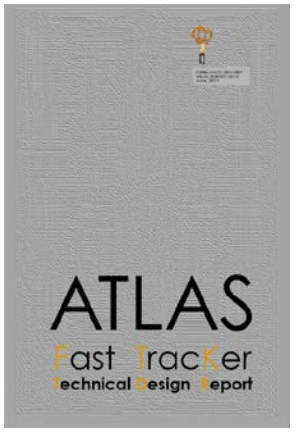
# 2015 Data Papers Already Submitted

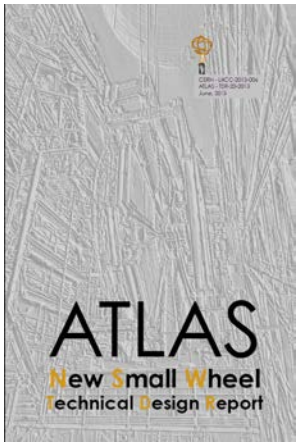
- **Published/accepted**
  - *Observation of long-range elliptic anisotropies in √s=13 and 2.76 TeV pp collisions…*
  - *Search for New Phenomena in Dijet Mass and Angular Distributions…*
  - *Search for strong gravity in multijet final states…*
  - *Measurement of the ZZ Production Cross Section…*
  - *Search for new phenomena with photon+jet events…*
  - *Search for new phenomena in final states with large jet multiplicities and missing transverse momentum…*
  - *Search for supersymmetry … in final states with jets and two same-sign leptons or three leptons…*
- **Submitted**
  - *Charged-particle distributions…*
  - *Muon reconstruction performance…*
  - *Search for resonances in the mass distribution of jet pairs with one or two jets identified as b-jets…*
  - *Measurement of W and Z-boson production cross sections…*
  - *Search for charged Higgs bosons in the $H^{\pm} \rightarrow \tau\nu$ decay channel in fully hadronic final states…*
  - *Search for new phenomena in events with a photon and missing transverse momentum….*
  - *Search for metastable heavy charged particles with large ionisation energy loss…*
- **Additional 2015 data papers in collaboration review**

# Phase-1 Upgrades

- **ATLAS Phase-1 upgrades includes five main projects**
  - **New Muon Small Wheel (NSW)**
  - **LAr Calorimeter Electronics**
  - **Fast Track Trigger (FTK)**
  - **TDAQ Phase-1**
  - **ATLAS Forward Protons (AFP)**



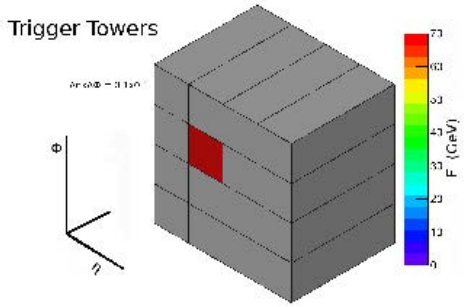



# Phase-1: New Muon Small Wheel

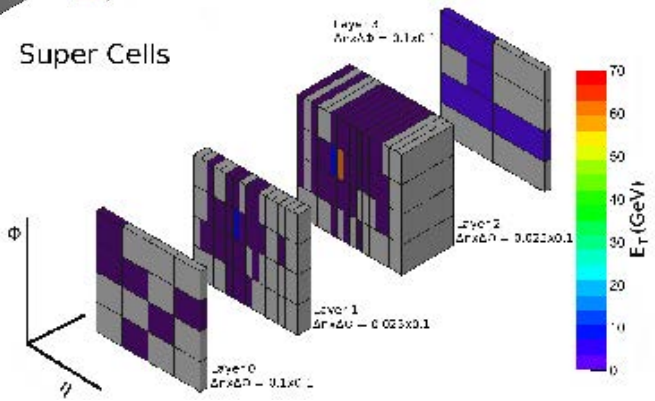
- **Construction:**
  - **Almost all sites active**
  - **First Module 0s being produced**
- **CERN Integration:**
  - **Infrastructure being deployed**
- **3 ASICs expected mid July**
- **Front End boards: ~ 1 year**
- **1 MHz readout:**
  - **Being integrated (significant changes)**
- **Very good progress**

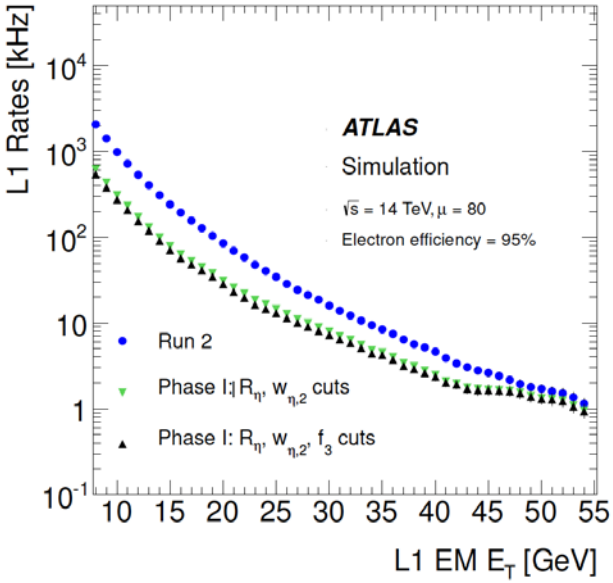
# Phase-1: LAr Electronics

- LAr trigger electronics modified to increase granularity in L1Calo
- Control e/γ trigger rate a high luminosity
  - Many new electronics boards
  - Demonstrator installed for 2015
  - Prototype with final components during 2016



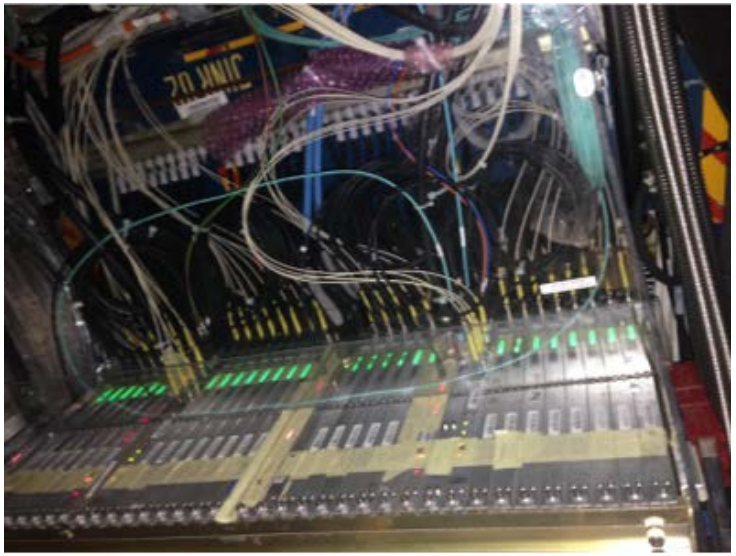

**Simulation 70 GeV e**

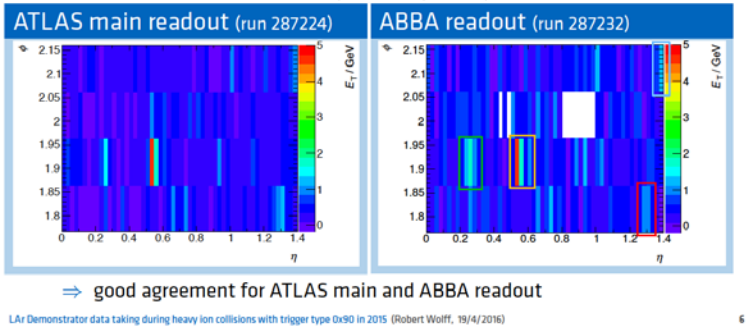


# Phase-1: LAr Electronics

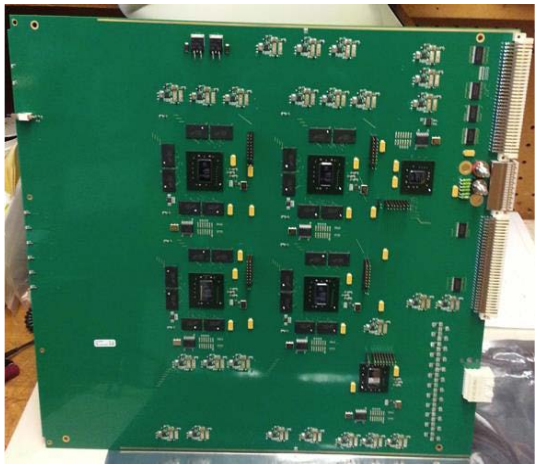
- Upgrade to use offline granularity in L1 trigger
- Demonstrator board used in 2015
- New baseplanes, circuit boards progressing well
- Front-end boards
  - Good preliminary results
  - Might need backup for “LOCx2”
- Back-end boards
  - Successful integration tests
- Front-end – Back-end
  - Integration early 2017

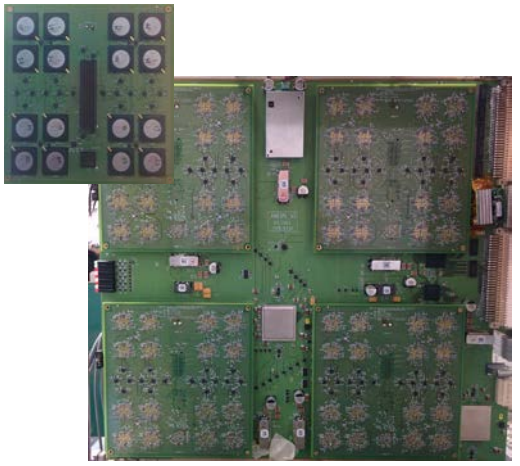




# Phase-1: Fast Track Trigger

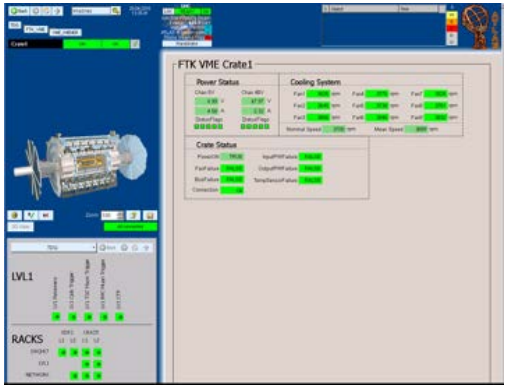
- **FTK performs pattern recognition and track fitting extensively using FPGA and Associative Memories (AM)**
  - **All boards in production except Associative Memory Board (AMB)**
  - **First AM06 ASICS will be delivered shortly and after testing it, AM Boards production will start**
  - **initial installation with enough processing power to cover the barrel for mu<40 around May 2016**
  - **further processing power will be installed staged**

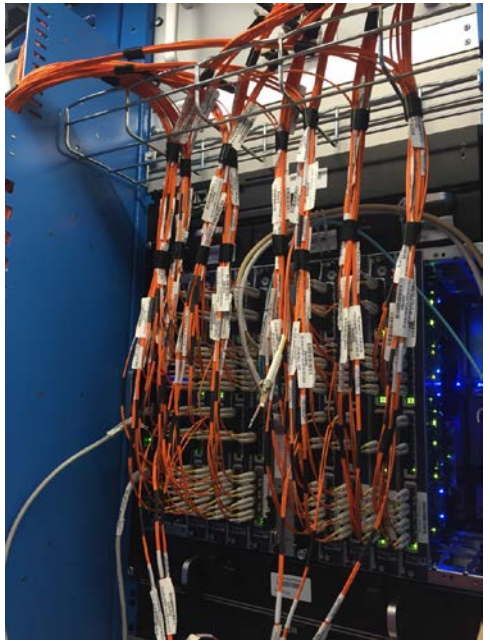


# Phase-1: Fast Track Trigger

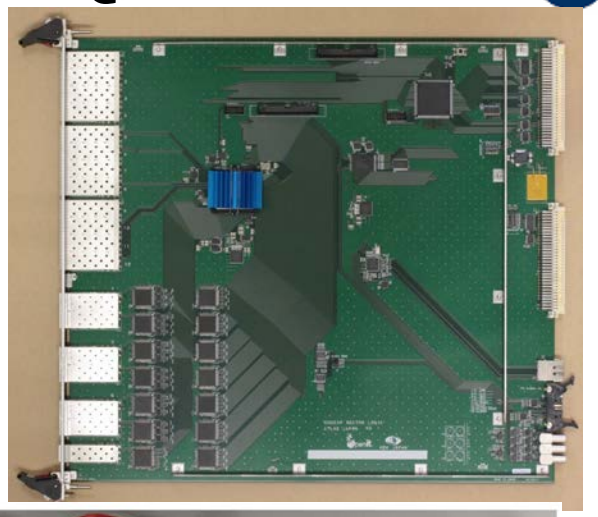
- **Major step ahead**
  - Delivery of “AM06” chip
  - Good yield (83-89%)
- **FTK Barrel**
  - Aim to have all HW at CERN in July
- **FTK Card integration**
  - On-going and time critical
- **P1 Integration**
  - Progressing well

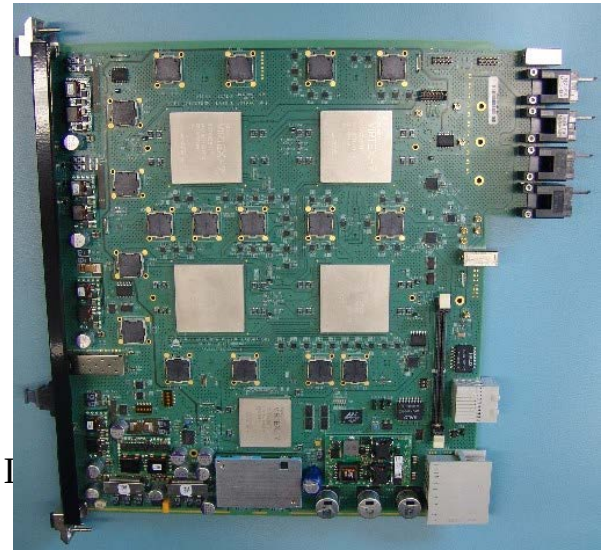


# Phase-1: Trigger-DAQ

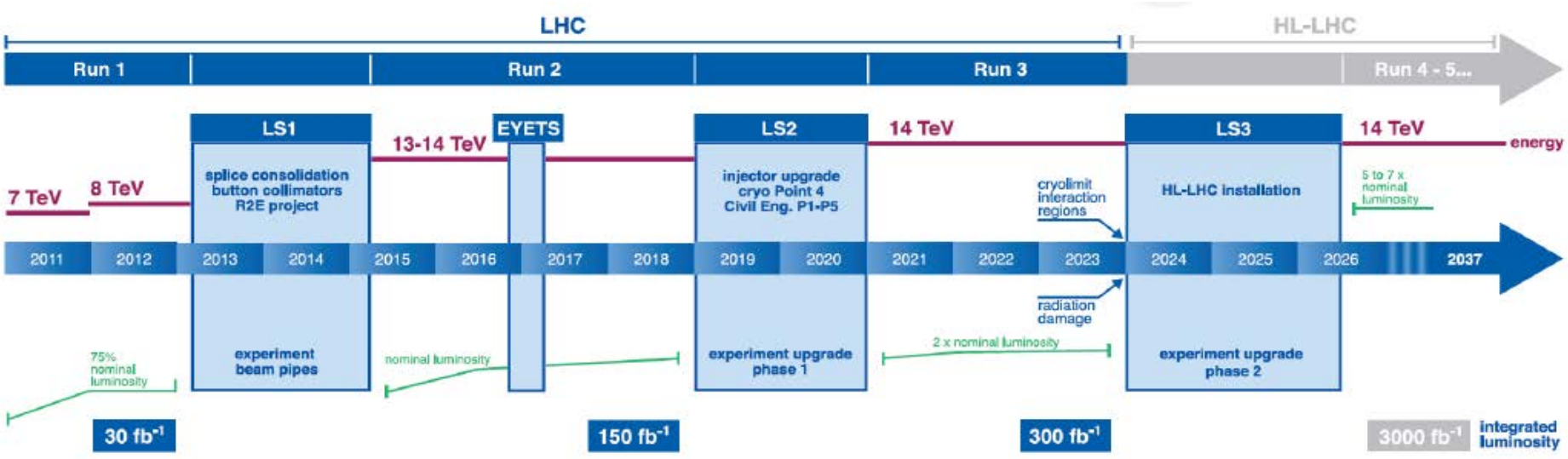
- **L1Muon endcap and barrel progressing**
  - **Many boards delivered and under test**
- **L1Calo**
  - **Prototypes being manufactured**
  - **Readout Driver prototype under test**
- **Link-speed between L1Calo and detectors**
  - **Re-baselined at 11.2 Gb/s**





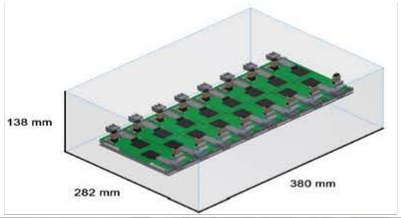
# Phase-2 Upgrades for HL-LHC

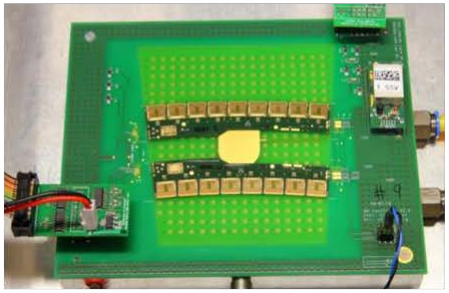
- **Main emphasis in 2016**
  - **R&D continues to establish technical designs**
  - **Initial Design Reviews (IDRs)**
  - **Key decisions on remaining options**
  - **First technical design report (TDR) for the ITk strips**

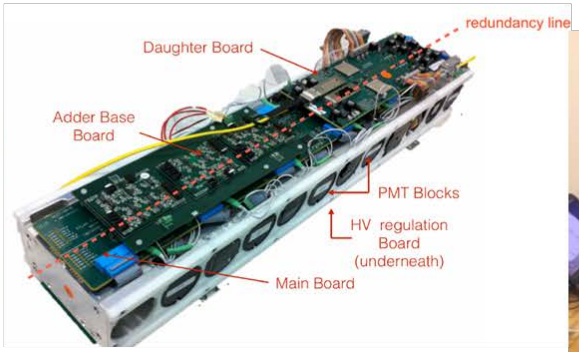


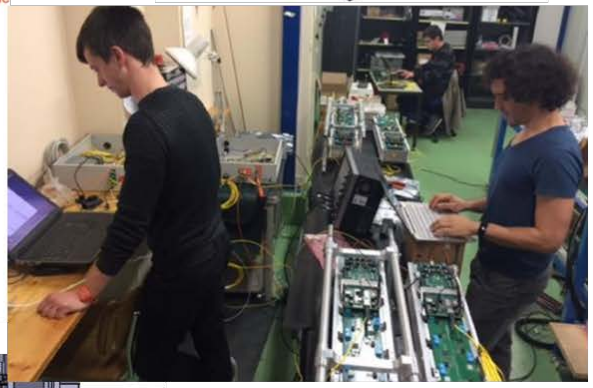
# Ongoing R&D

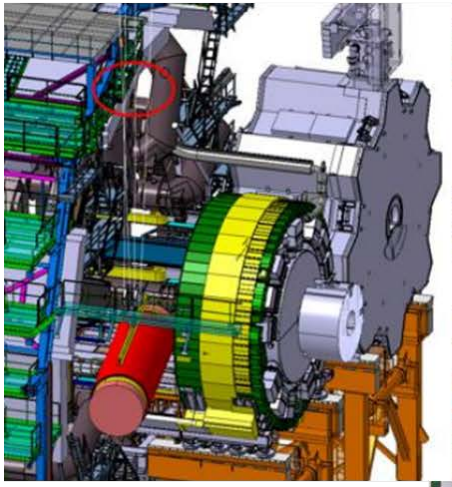
- **Prototyping, design, engineering**
  - **Especially ITk, muons, FCal**

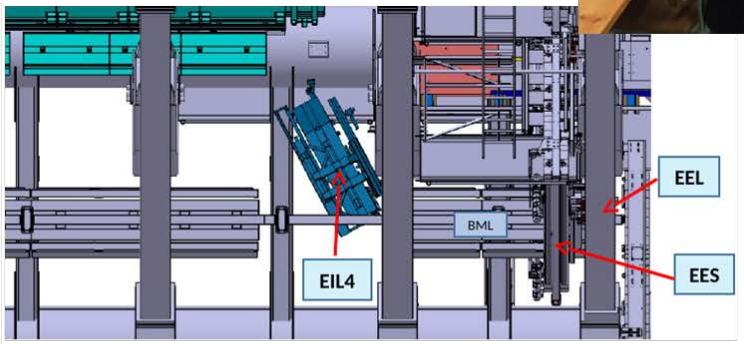


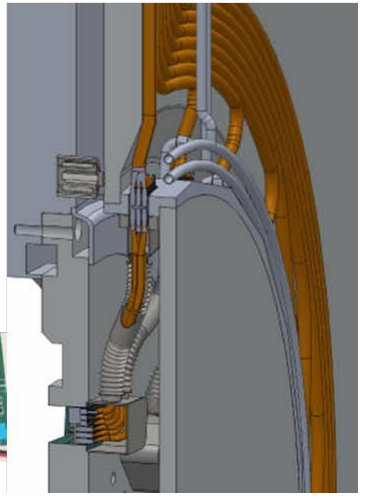









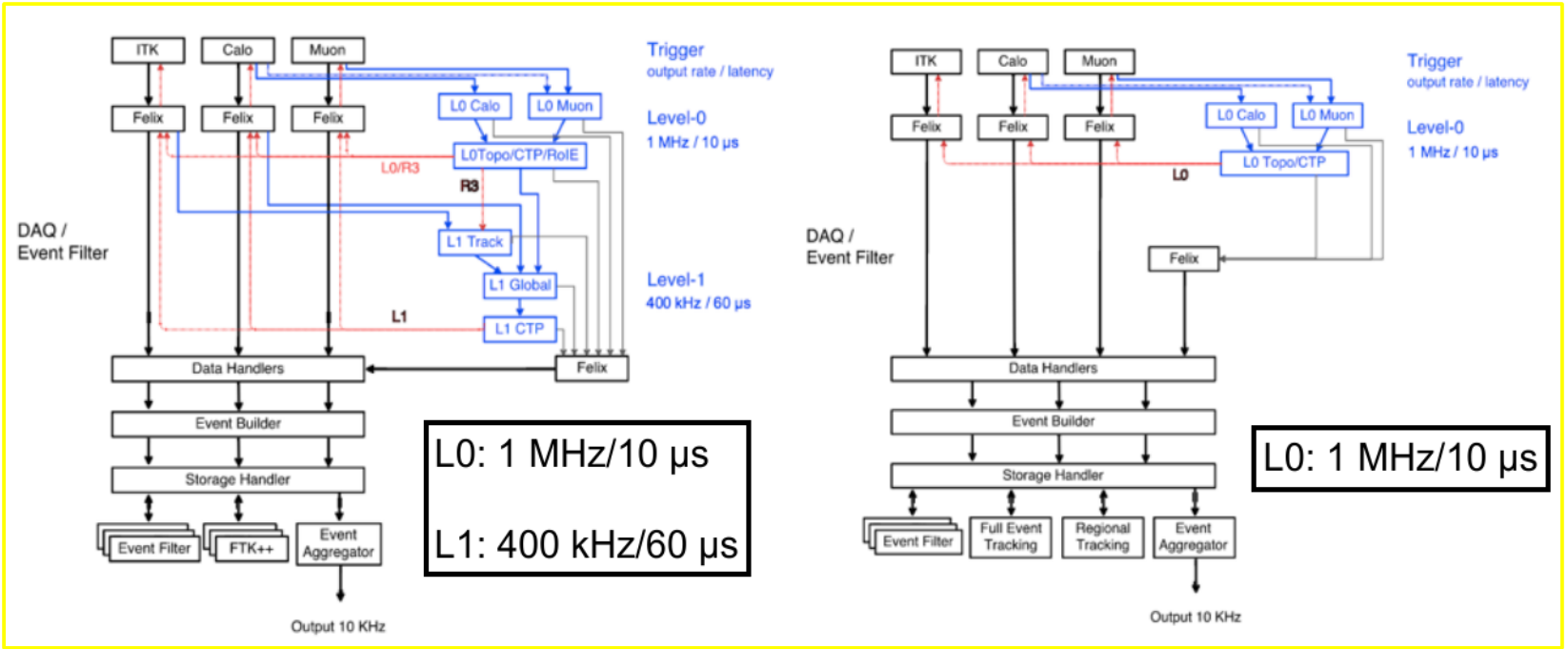
# Reviews

- **Initial Design Review, IDR:**
  - **overall performance and technical requirements**
- **Technical Design Review, TDR:**
  - **Full technical design and contribution breakdown**

| Upgrade PRoject (UPR) | IDR | TDR |
|---|---|---|
| ITk-Strip<br>ITk-Pixel | Q4 2014 | Q4 2016<br>Q4 2017 |
| LAr | Q3 2016 | Q3 2017 |
| TileCal | Q3 2016 | Q3 2017 |
| Muon | Q2 2016 | Q2 2017 |
| TDAQ | Q1-2016 | Q4 2017 |

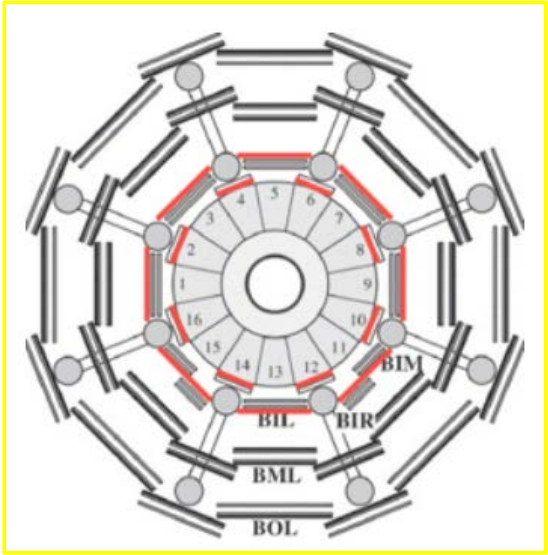
# TDAQ Phase-2 in 2016

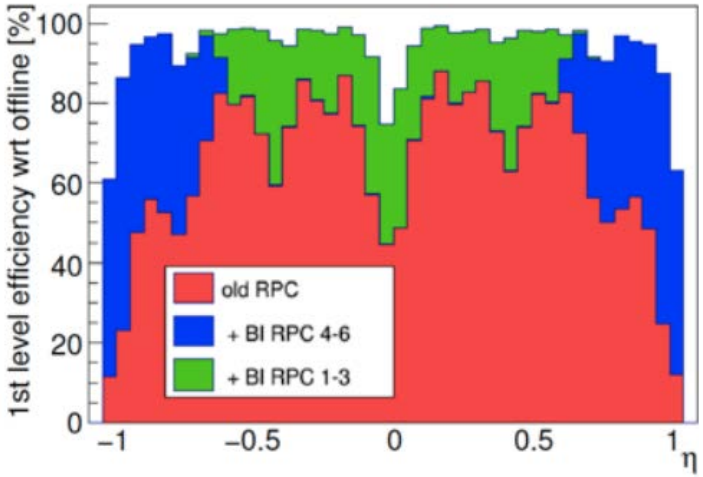
- With muon inner-barrel electronics replacement, a simpler 1 MHz readout architecture would become possible
  - Considering: L0-only scheme
- Decision targeted in summer 2016, after TDAQ IDR review complete
- TDAQ TDR is scheduled at the end of 2017, as late as possible within the constraint to keep all TDRs within 2016/7



# Muon Phase-2 in 2016

- Muon key decisions
  - Scope and details of barrel-inner (BI) region (big potential to improve trigger)
    - Replacement and technology of new detectors
  - Trigger upgrade options, including big-wheel innermost region
  - Review panel is in place, meeting weekly
- Aiming for decision in early summer, to present a single choice in IDR in early autumn
- TDR planned one year after IDR, in June 2017

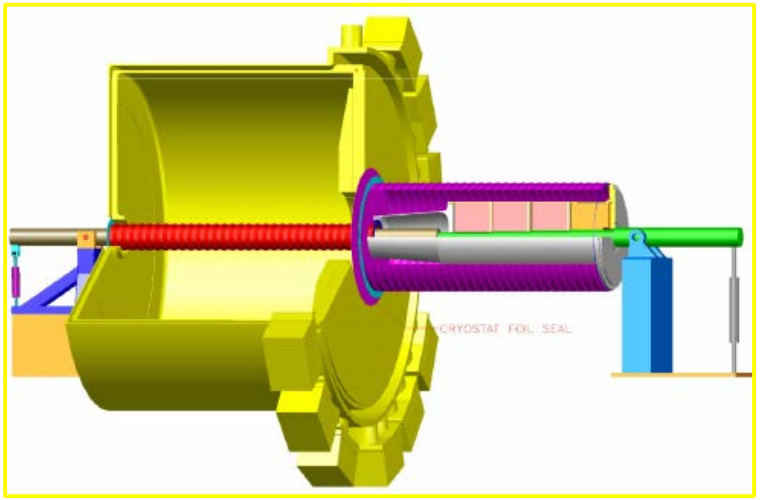


# LAr Phase-2 in 2016

- Largest cost is to replace readout electronics – R&D on-track here without major decision points in 2016

- Key decision: sFCal replacement
  - Risk of FCal during HL-LHC (ion build-up)
  - Risk assessment of replacement
    - ALARA, mechanical risks
  - Performance improvement studies critical



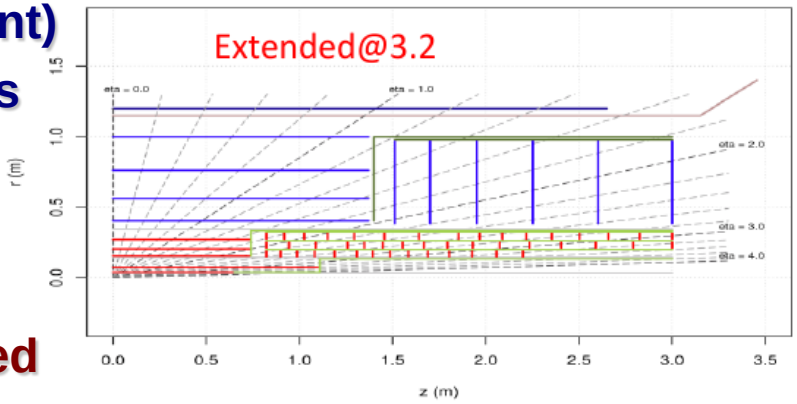

- Targeting June 2016 decision point

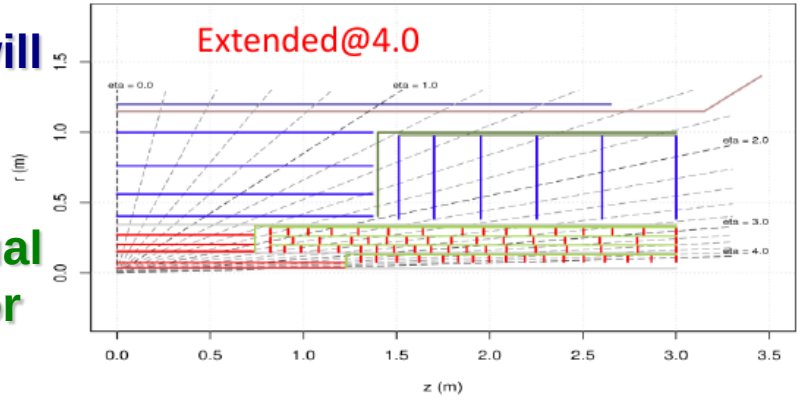
- LAr IDR targeted for autumn 2016, TDR one year later in Sept 2017

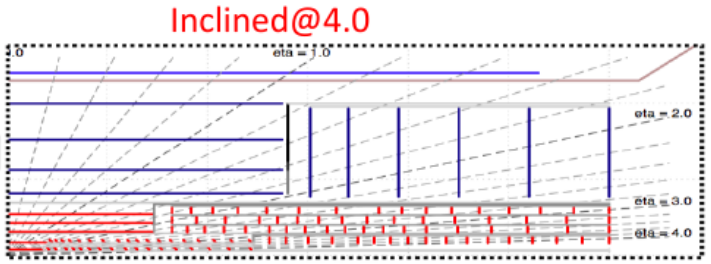
- High-granularity timing detector (HGTD) decision point is under discussion, active R&D programme

# ITk Phase-2 in 2016

- **Layout: beyond LoI layout (Scoping Document)**
  - **Strip baseline has 4 barrel layers and 6 disks**
  - **Pixel barrel, baseline 5 layers**
  - **Main layout optimisation is in pixel forward region, 2<|η|<4**
  - **Decision milestone set to June 2016, required for Strip TDR at end of 2016 and for sFCal decision**
  - **Further refinement of forward pixel layout will follow (for Pixel TDR)**
- **TDR planned in two parts**
  - **First ("Strip TDR") will include full conceptual design of ITk plus much more (TDR level) for strip tracker and other available parts**
  - **Second ("Pixel TDR") will provide TDR-level description of pixels plus remaining items**
- **The two TDRs are targeting December 2016 and December 2017**



- **Long Term LHC?**

# Higher Energy in the LHC Tunnel

- **Working group on pushing LHC energy**
  - **Design: 14 TeV**
  - **Ultimate: 15—16 TeV (max dipole field ≈ 9.5 T)**
  - **Beyond: eg, replace 1/3 of dipoles with 11 T $Nb_3Sn$ magnets**
- **HE-LHC (part of FCC study): ≈ 16 T magnets, √s = 28 TeV**
  - **Can be built at constant CERN budget**