ATLAS Status & Recent Highlights

Andreas Hoecker (CERN)

SUSY Workshop, October 19—21, 2011, LBNL-USA

Outline

— Succinct snapshot of ATLAS physics searches

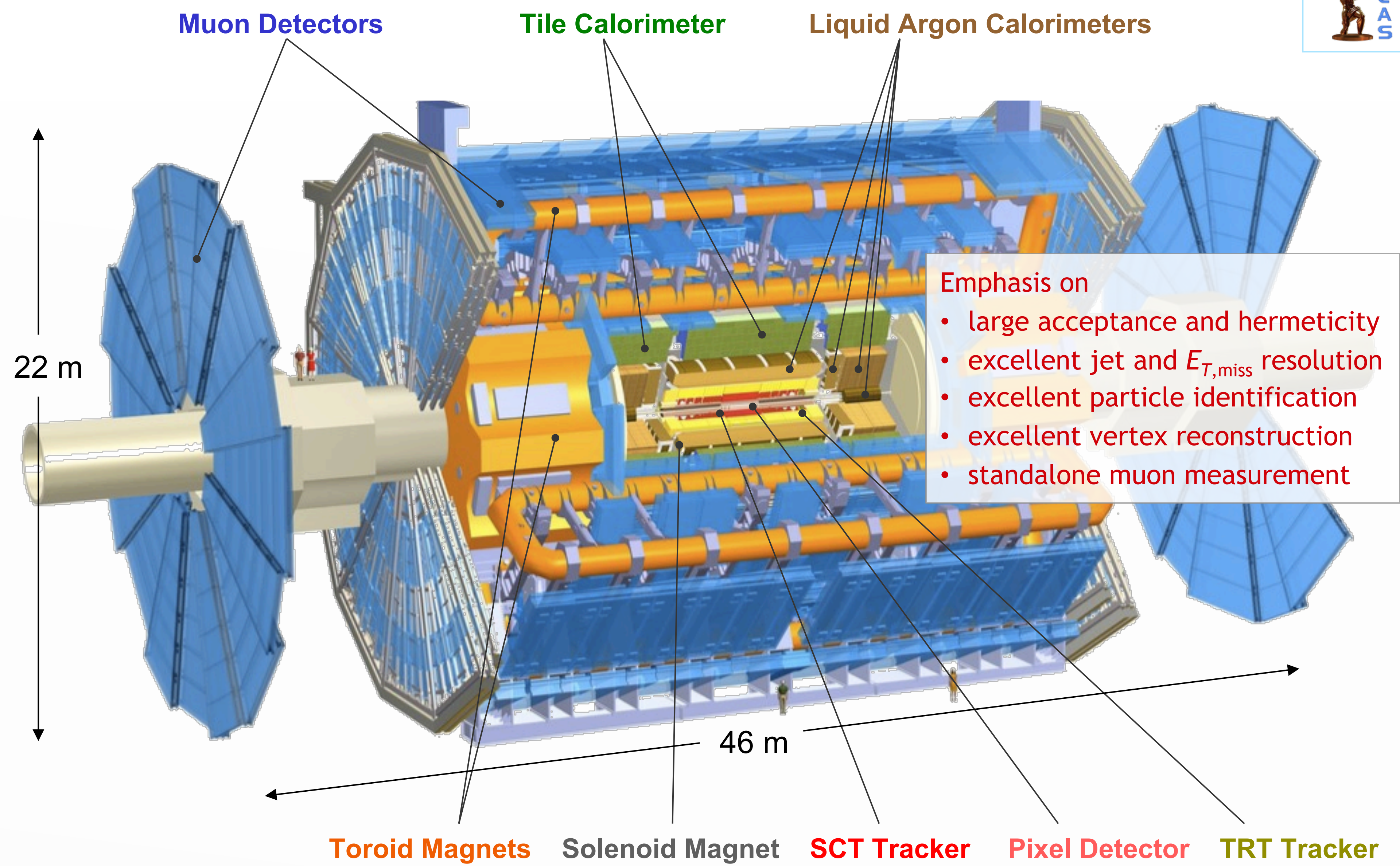
— ATLAS status and running conditions

— ATLAS results with emphasis on performance and Standard Model measurements

Acknowledgment:

This talk builds heavily upon Daniel Froidevaux's brilliant LHCC presentation at the Open Session of the Sep 21 LHCC meeting at CERN:

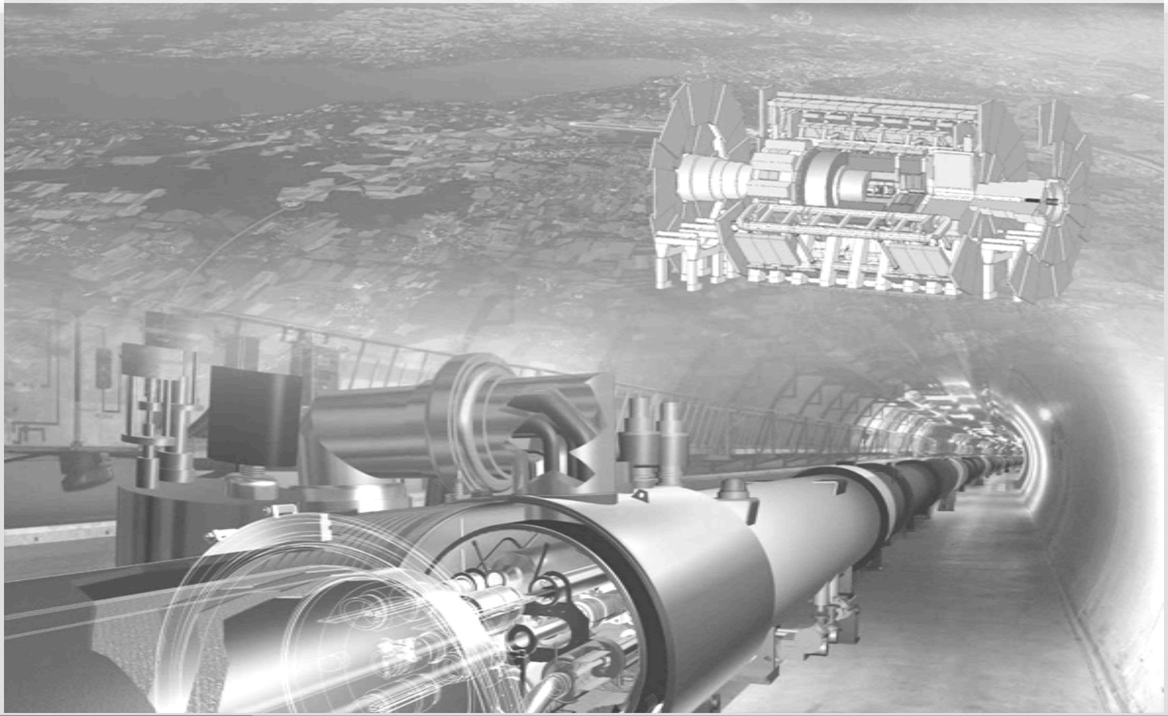
https://indico.cern.ch/conferenceDisplay.py?confId=153317



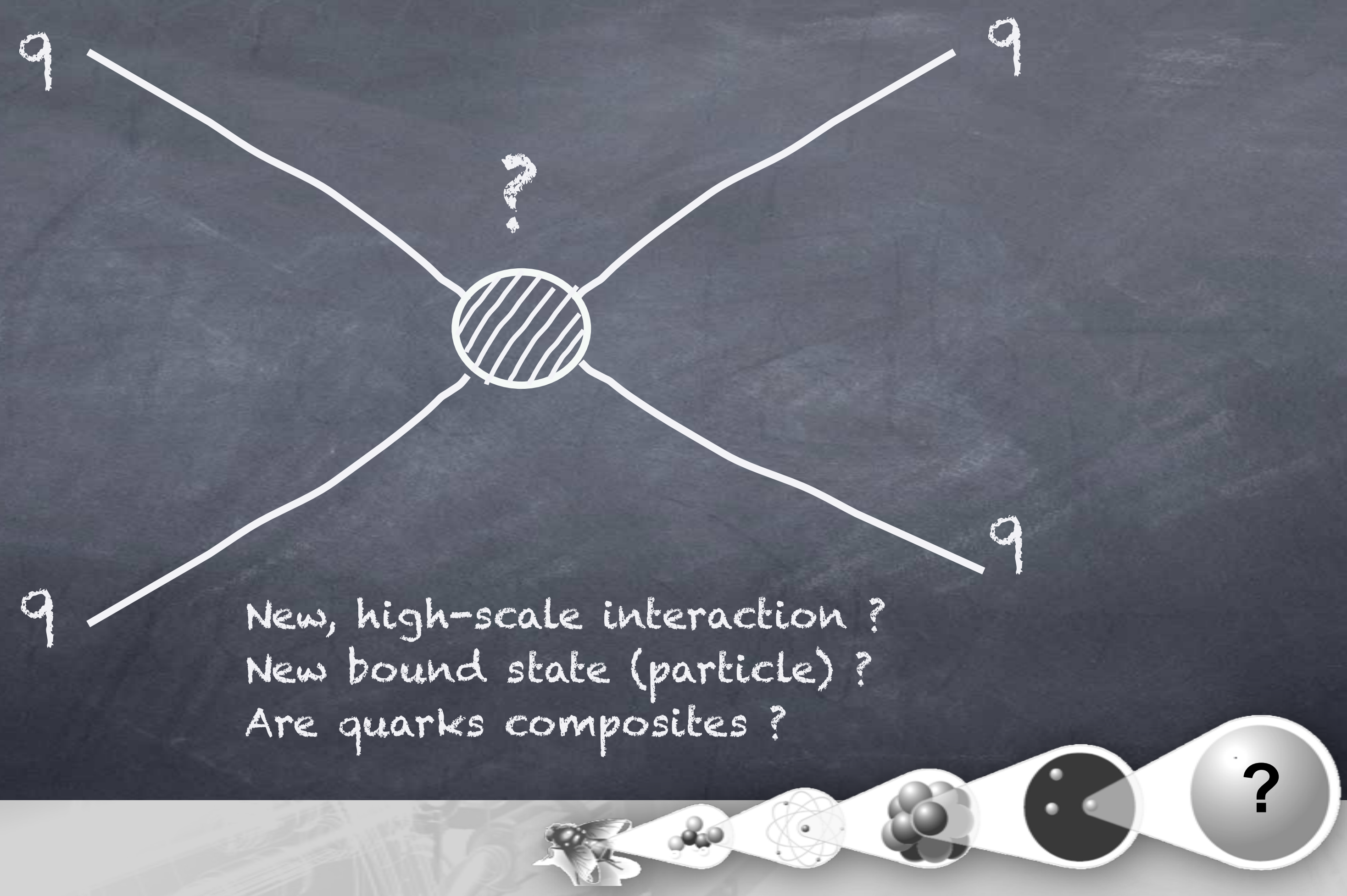
Emphasis on

- large acceptance and hermeticity
- excellent jet and $E_{T,miss}$ resolution
- excellent particle identification
- excellent vertex reconstruction
- standalone muon measurement

Physics at ATLAS — Year Two of the LHC



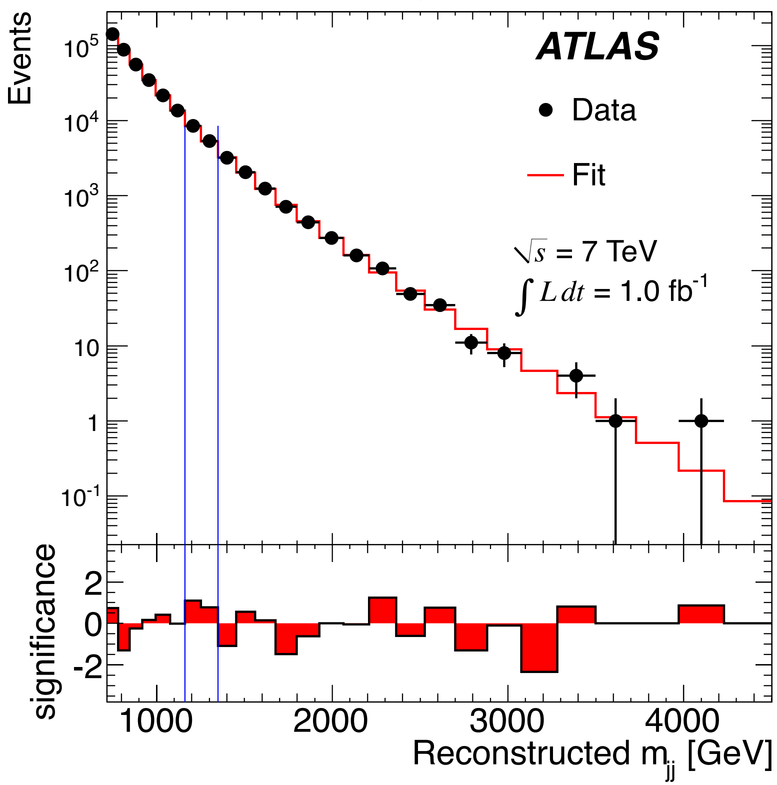
ATLAS mines its data for new physics in events with jets …



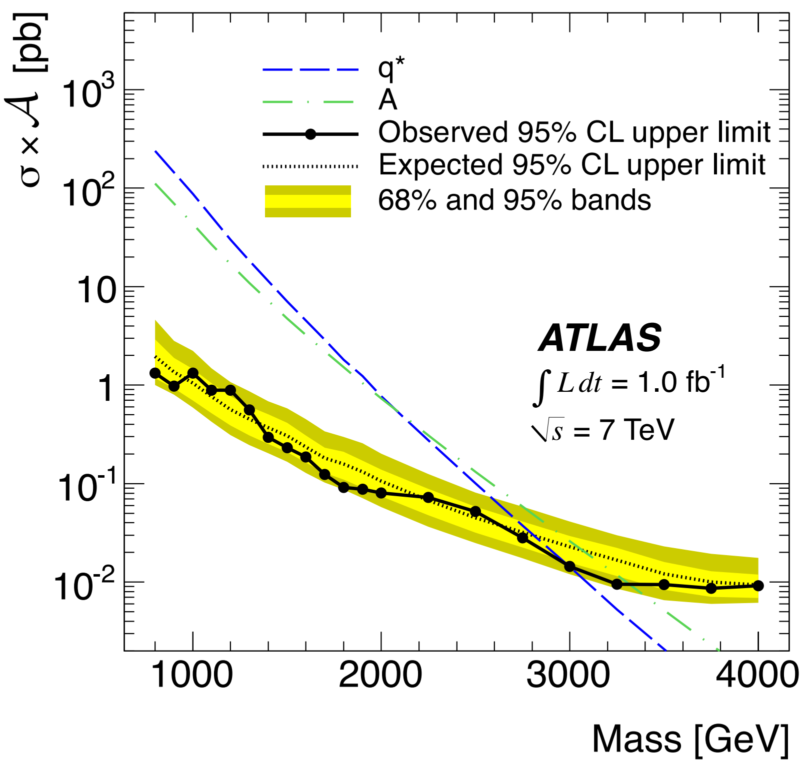
ATLAS mines its data for new physics in events with jets …
… gradually approaching the limits of phase space

ATLAS arXiv:1108.6311

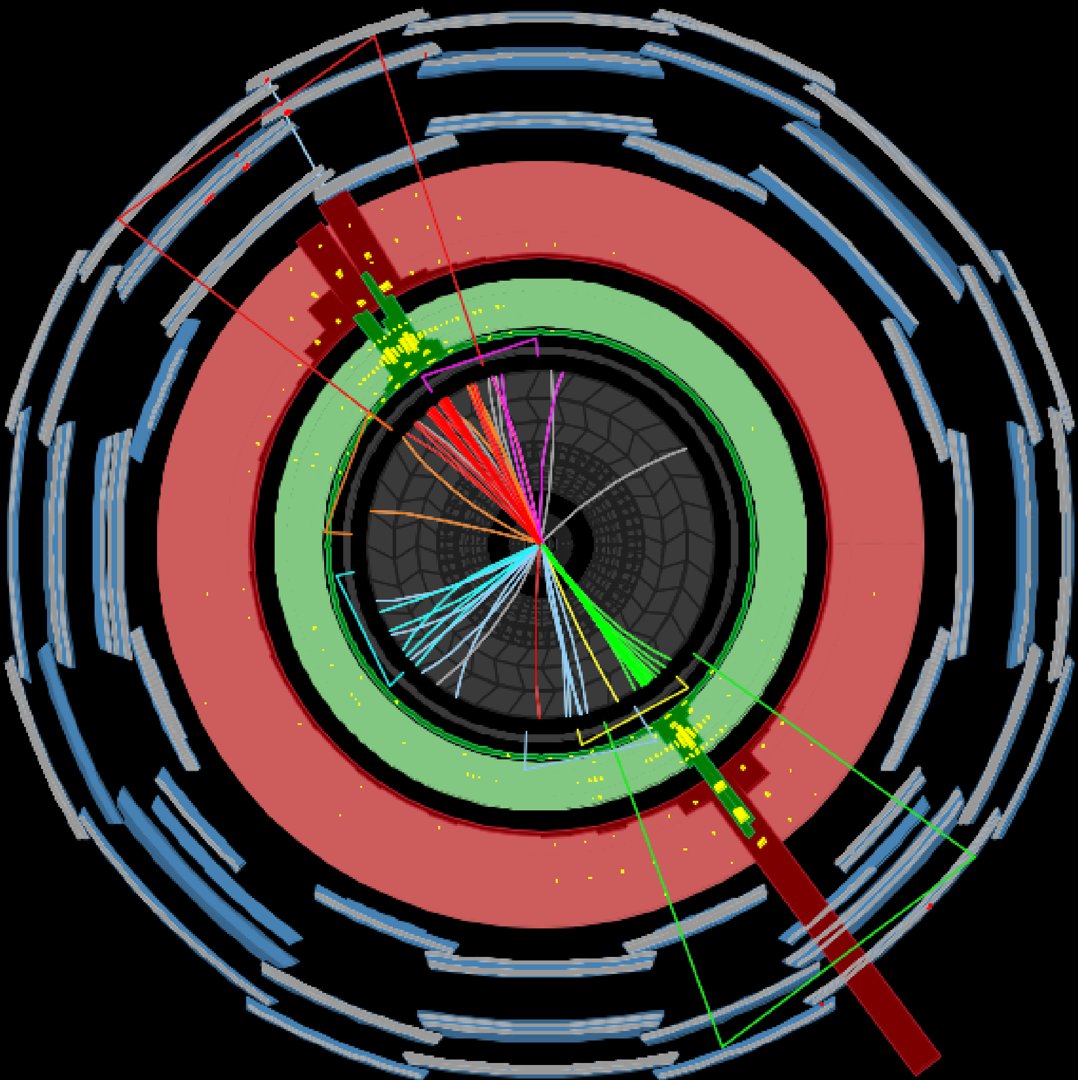
Observed and fitted **dijet mass**



Upper limit on fiducial cross section

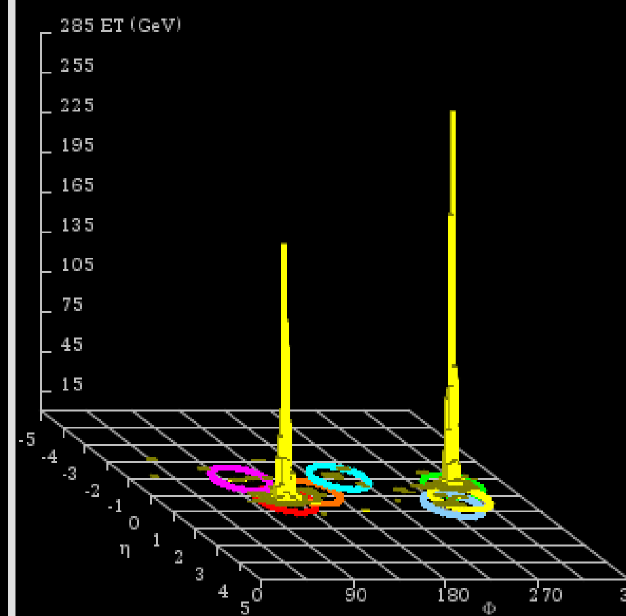


Event with 4.04 TeV dijet invariant mass

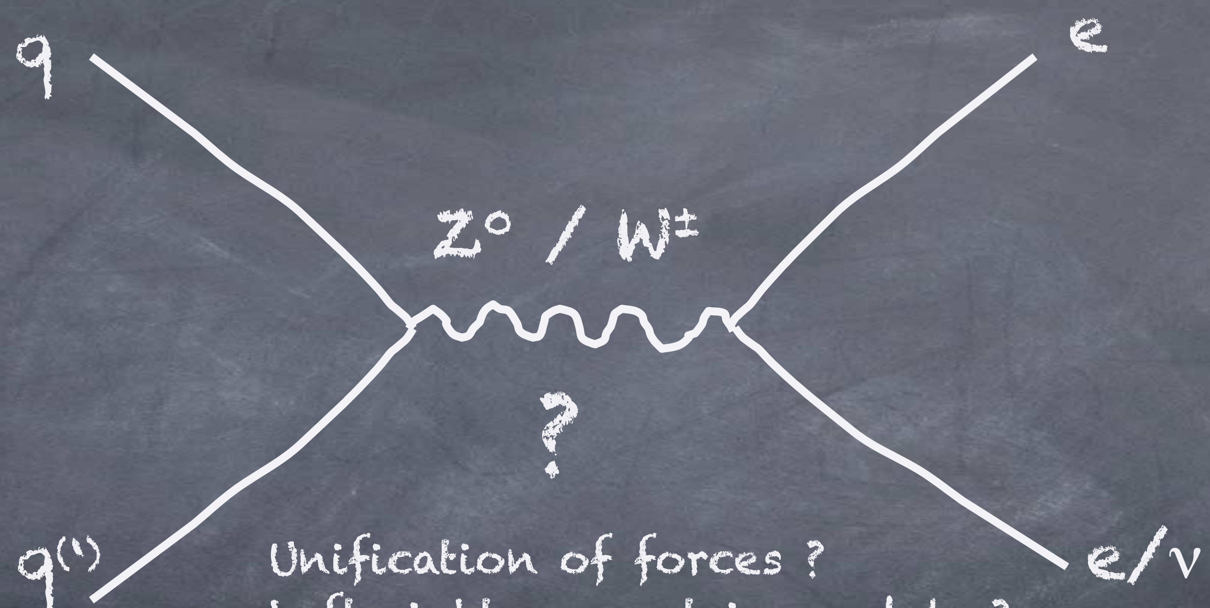


Run Number: 179938, Event Number: 12054480

Date: 2011-04-18 17:57:29 EDT



ATLAS mines its data for new physics in events with leptons …



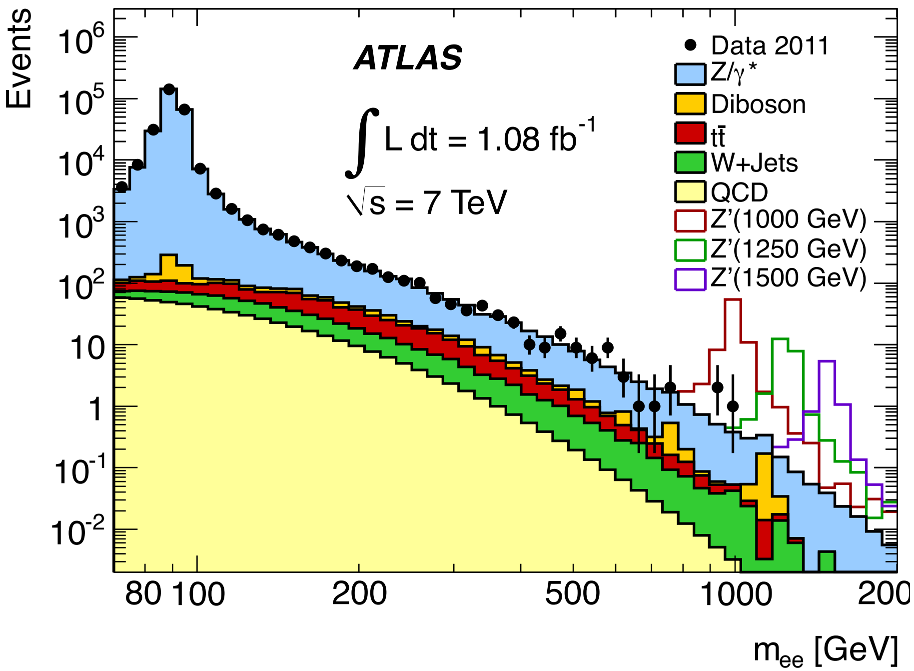
Unification of forces ?
Left-right symmetric models ?
Compact extra dimensions ?
Technicolour ?
Higgs doublet extensions ?

ATLAS mines its data for new physics in events with leptons … … gradually (but not yet!) approaching the limits of phase space

ATLAS arXiv:1108.1582

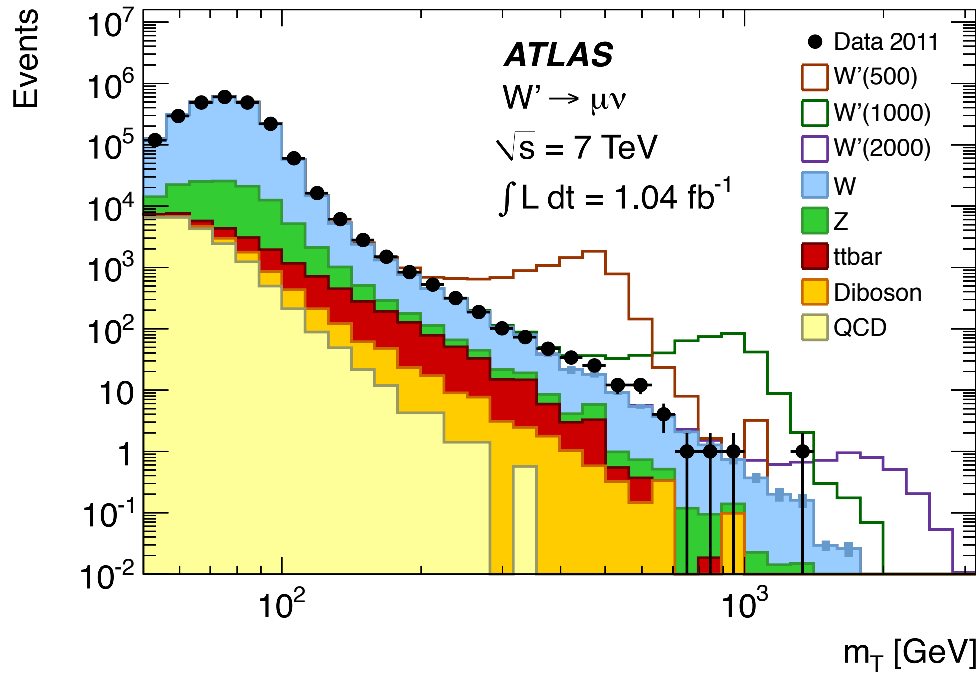
ATLAS arXiv:1108.1316

Observed and predicted **dielectron mass,** search bumps



95% CL lower limit: $m(Z'_{SSM}) > 1.8$ TeV

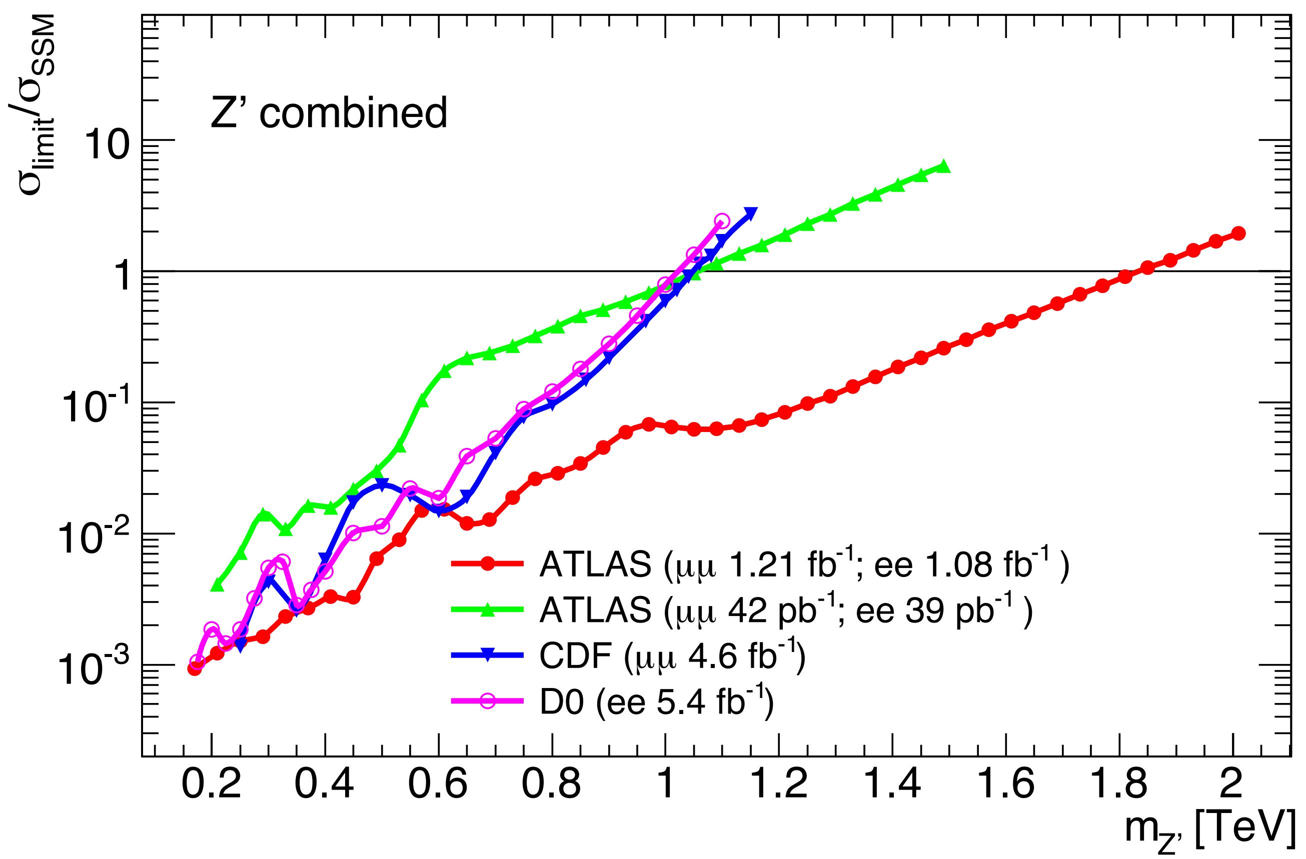
Observed and predicted **transverse mass**



95% lower limit: $m(W'_{SSM}) > 2.1$ TeV

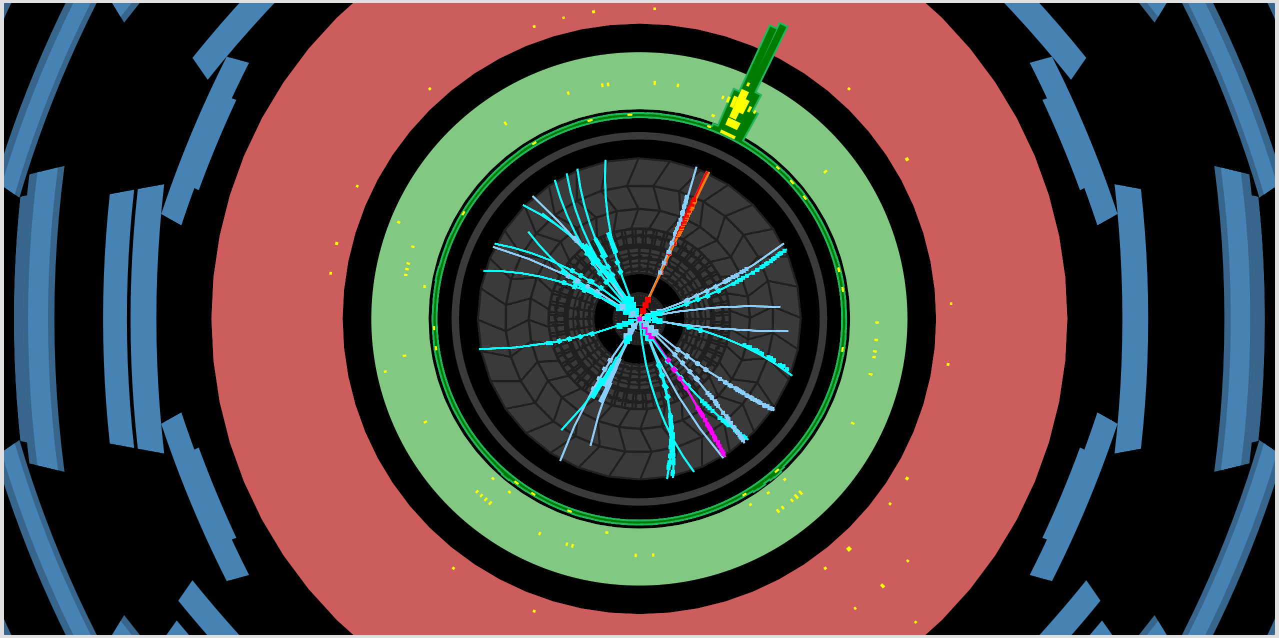
ATLAS mines its data for new physics in events with leptons … … gradually (but not yet!) reaching the limits of phase space

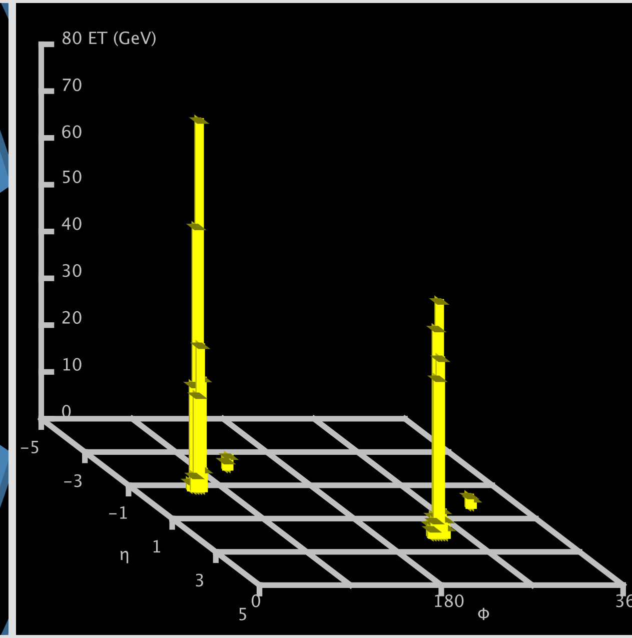
ATLAS arXiv:1108.1582

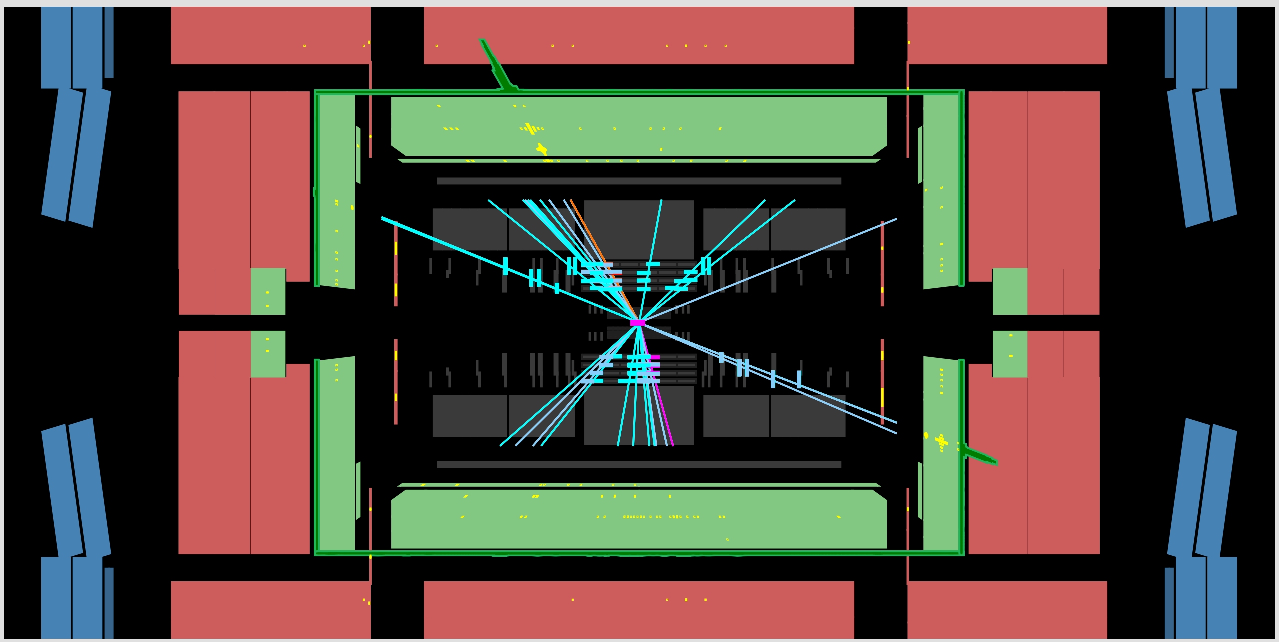


Ratio of observed limit for the *Z'* search using both channels, divided by the SSM Z' cross section times branching fraction

Highest mass dielectron event observed: $m(ee)$ = 993 GeV (only tracks with p_T > 1 GeV are drawn)



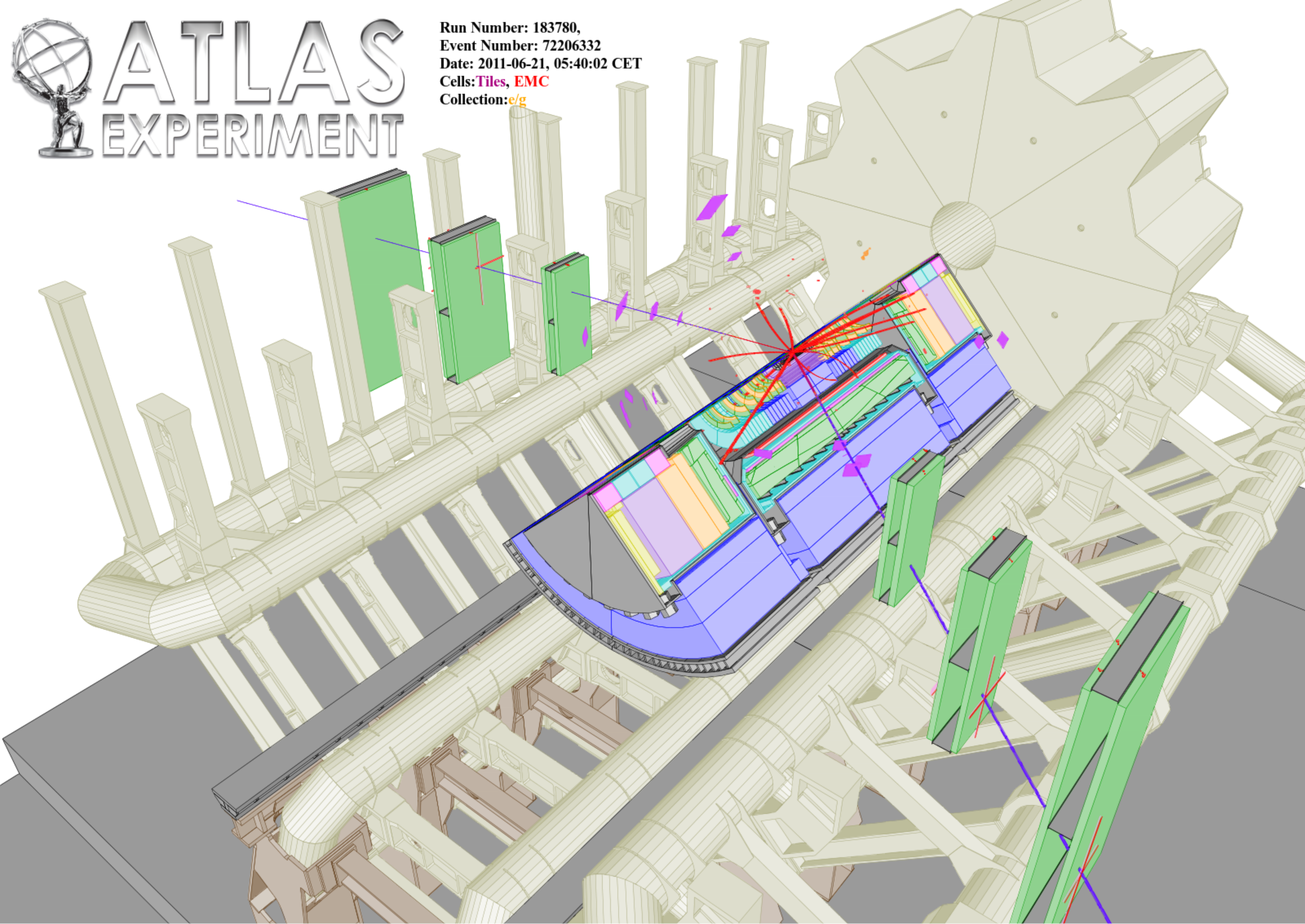




ATLAS EXPERIMENT

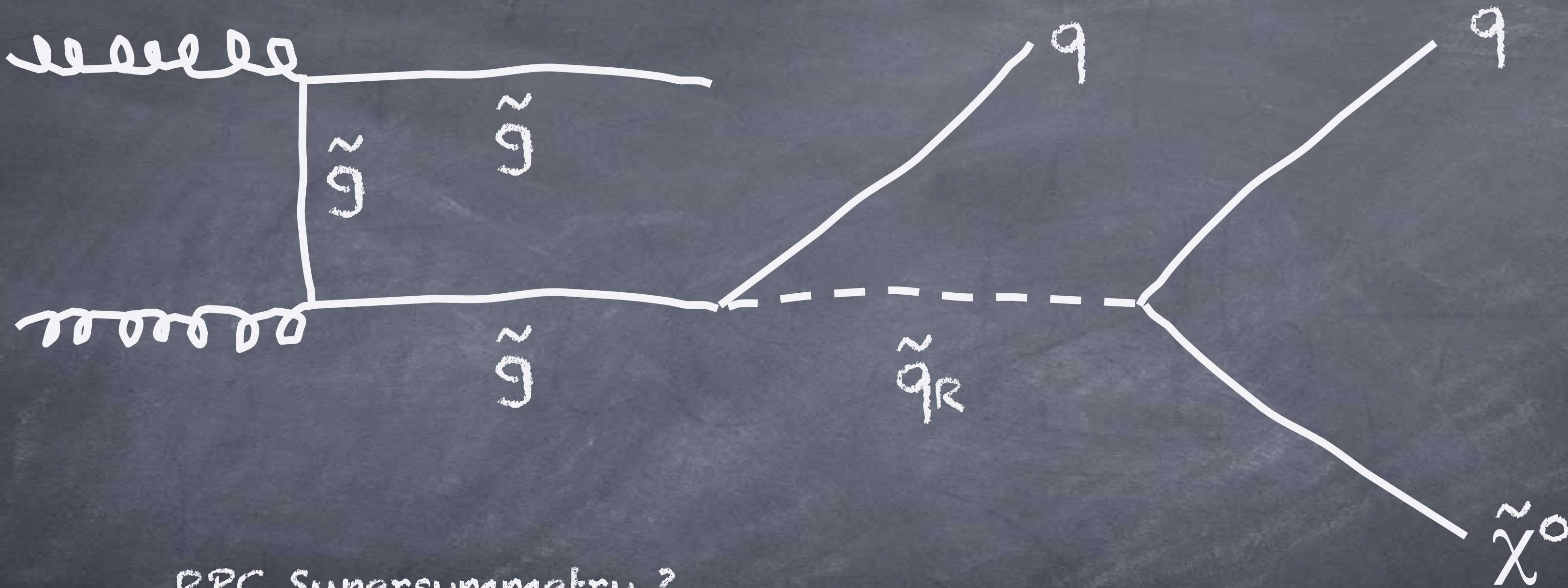
Run Number: 183462, Event Number: 48979599

Date: 2011-06-14 02:48:15 PDT



Highest mass dimuon event observed: $m(\mu\mu)$ = 959 GeV (only tracks with p_T > 0.5 GeV are drawn)

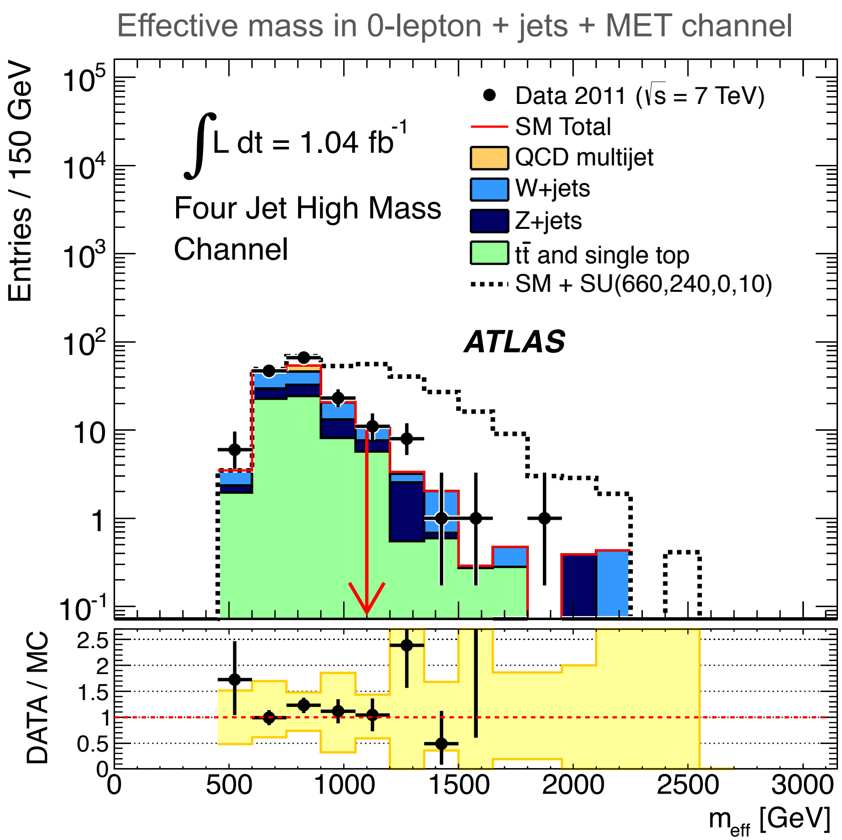
ATLAS mines its data for new physics in events with MET…

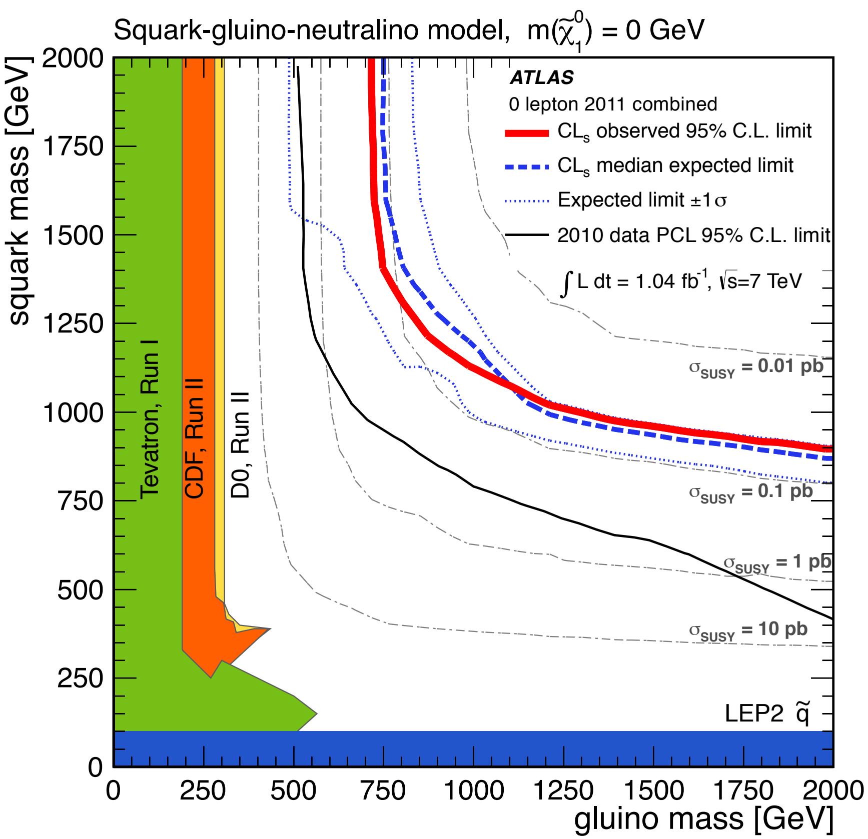


RPC Supersymmetry ?
Universal extra dimensions ?
Any new physics with conserved "new-physics" number ?

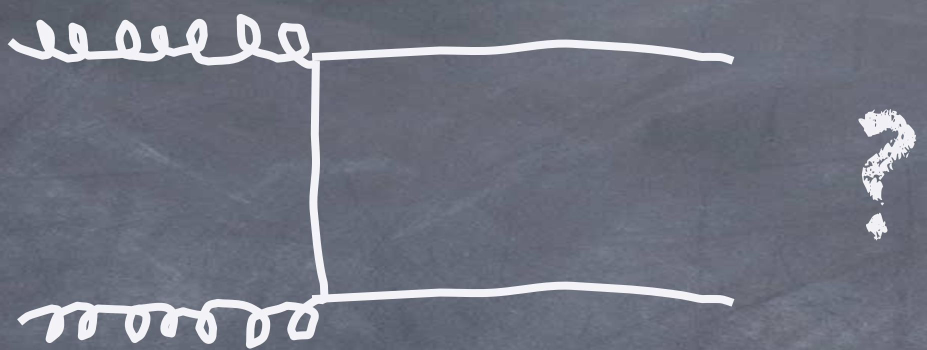
ATLAS mines its data for new physics in events with MET …
… gradually reaching the limits of phase space

ATLAS arXiv:1109.6572

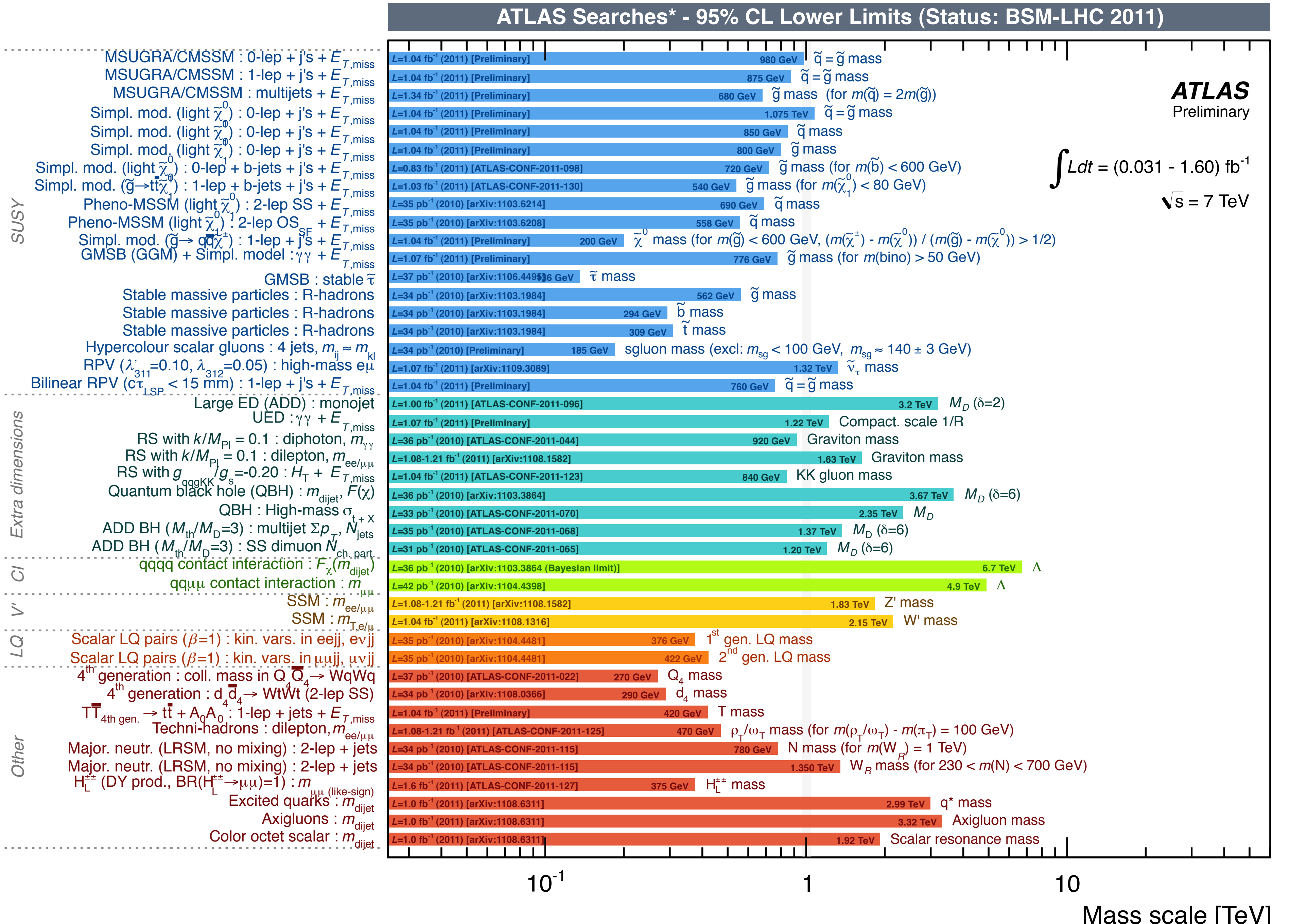




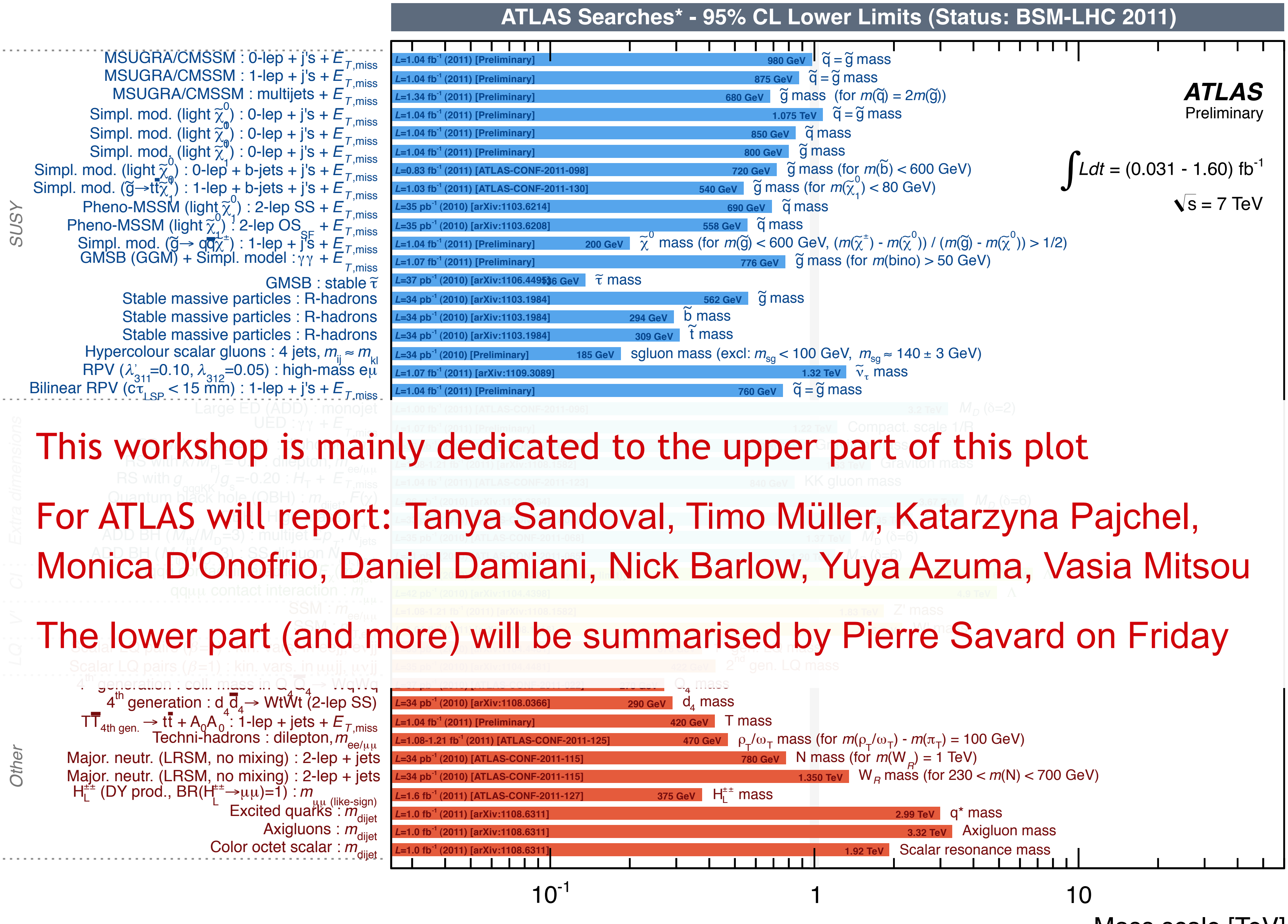
ATLAS mines its data for *any* new physics in its events …



Of course there are many, many more proposed new physics models with various, more or less involved signatures …



*Only a selection of the available results leading to mass limits shown



This workshop is mainly dedicated to the upper part of this plot

For ATLAS will report: Tanya Sandoval, Timo Müller, Katarzyna Pajchel, Monica D'Onofrio, Daniel Damiani, Nick Barlow, Yuya Azuma, Vasia Mitsou

The lower part (and more) will be summarised by Pierre Savard on Friday

*Only a selection of the available results leading to mass limits shown

We haven't found any obvious new physics so far …

Apart from searches for strong new physics signatures …

…we have made wonderful **Standard Model QCD measurements**

…we are looking into **electroweak production**, which involves searches for the diboson production, single top, Higgs boson, but also SUSY processes such as gaugino pair production and others

These searches are difficult and need a well performing and understood (simulated) detector

ATLAS Status and SM Physics

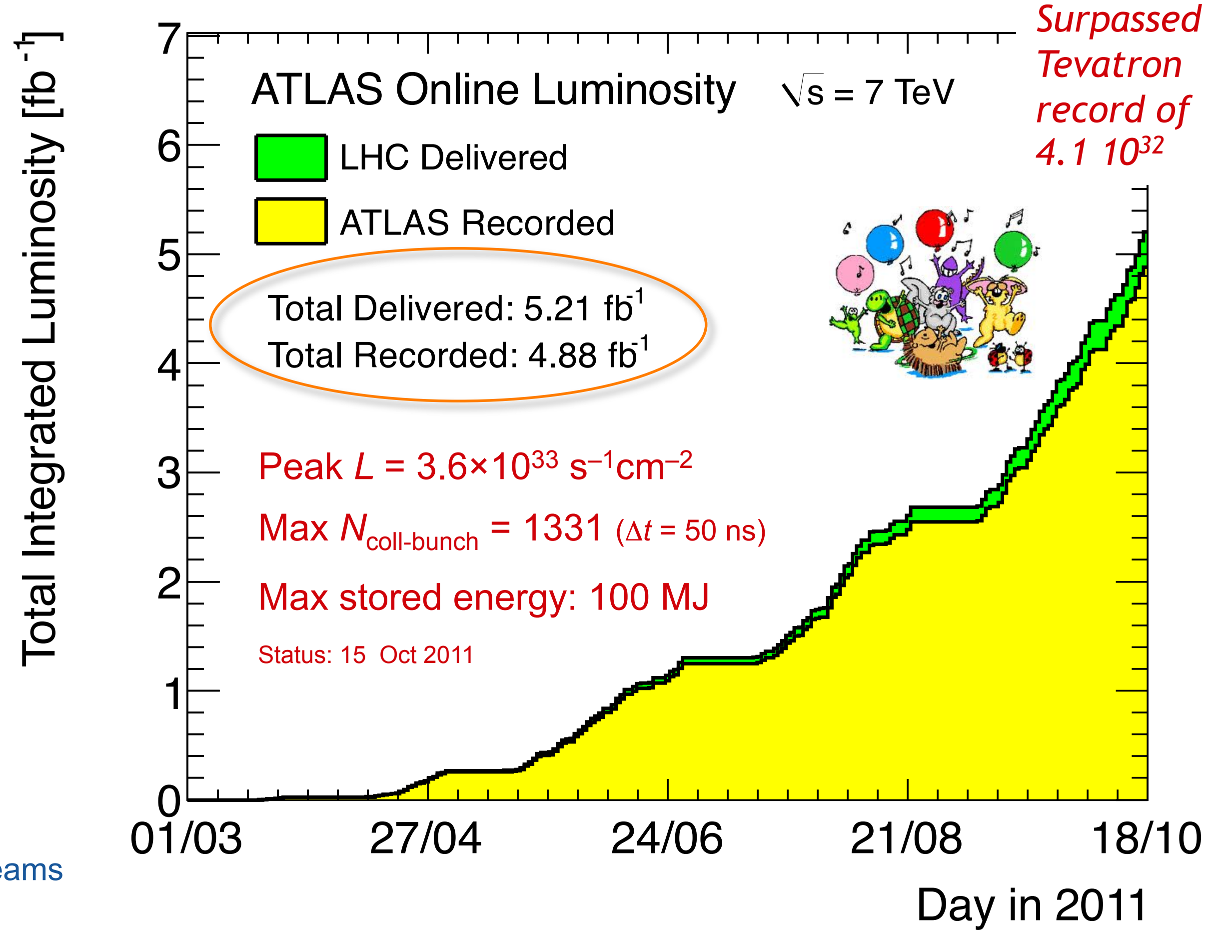
Recorded luminosity in 2010 and 2011

Measured with forward detectors, calibrated with beam separation scans

ATLAS integrated luminosity in 2011

Weekly record: 584 pb^{-1}

In 2010: 0.04 fb^{-1} collected



Surpassed Tevatron record of 4.1 10^{32}

94% data-taking efficiency

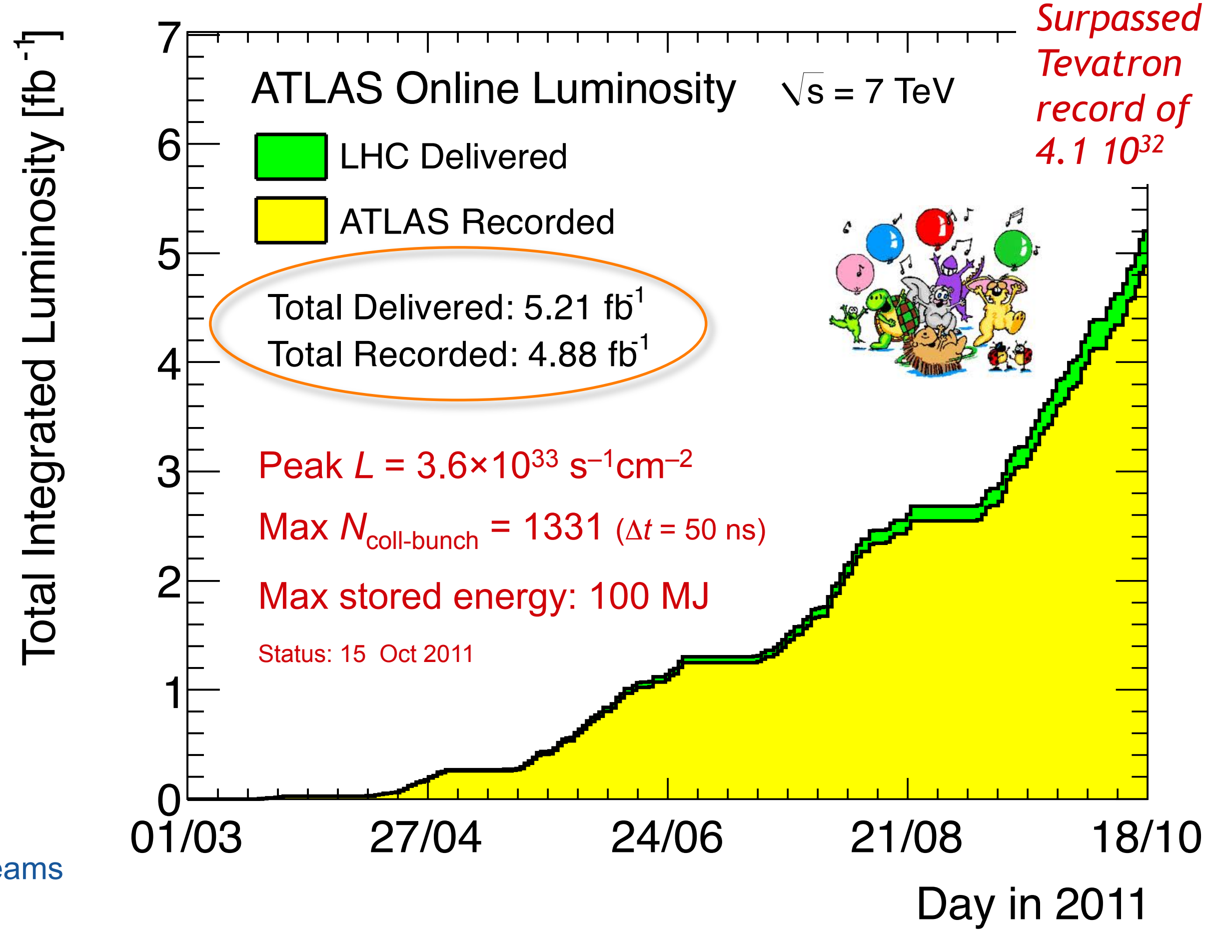
- Lost ~2% at turn-on at start of stable beams
- Lost ~3% due to deadtime

Recorded luminosity in 2010 and 2011

Measured with forward detectors, calibrated with beam separation scans

At $L = 3\times10^{33}\ s^{-1}cm^{-2}$, produce 225 (129) Higgs bosons of 115 (150) GeV mass in ATLAS and CMS per hour

Tevatron @ 115 GeV: 2/h at max luminosity



Surpassed Tevatron record of 4.1 10^{32}

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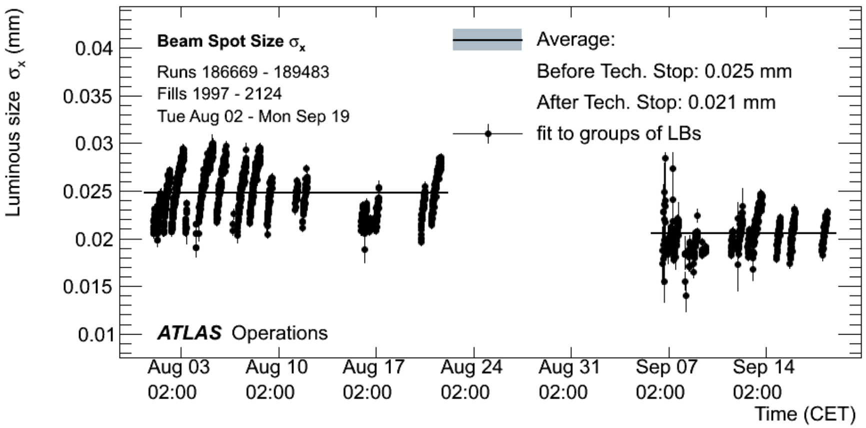
ATLAS Operations

During August technical stop, LHC reduced β* from 1.5 m to 1 m

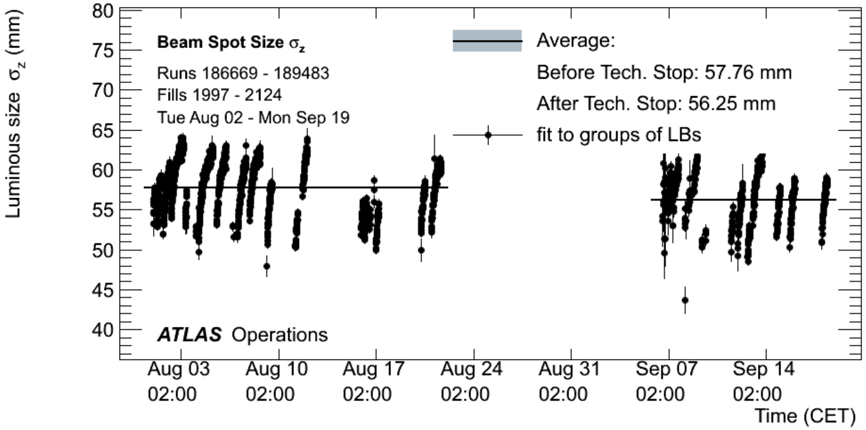
Corresponding linear increase of luminosity (and pileup — see later)

Beamspot reduced as expected:

$<\sigma_x>$ decrease: 25 μm → 21 μm



$<\sigma_z>$ stable: 58 mm → 56 mm



Adjust L1 menu for up to 5×10^{33} (moderate isolation introduced for leptons)

Upgrade readout system and HLT CPU resources to preserve low-p_T triggers

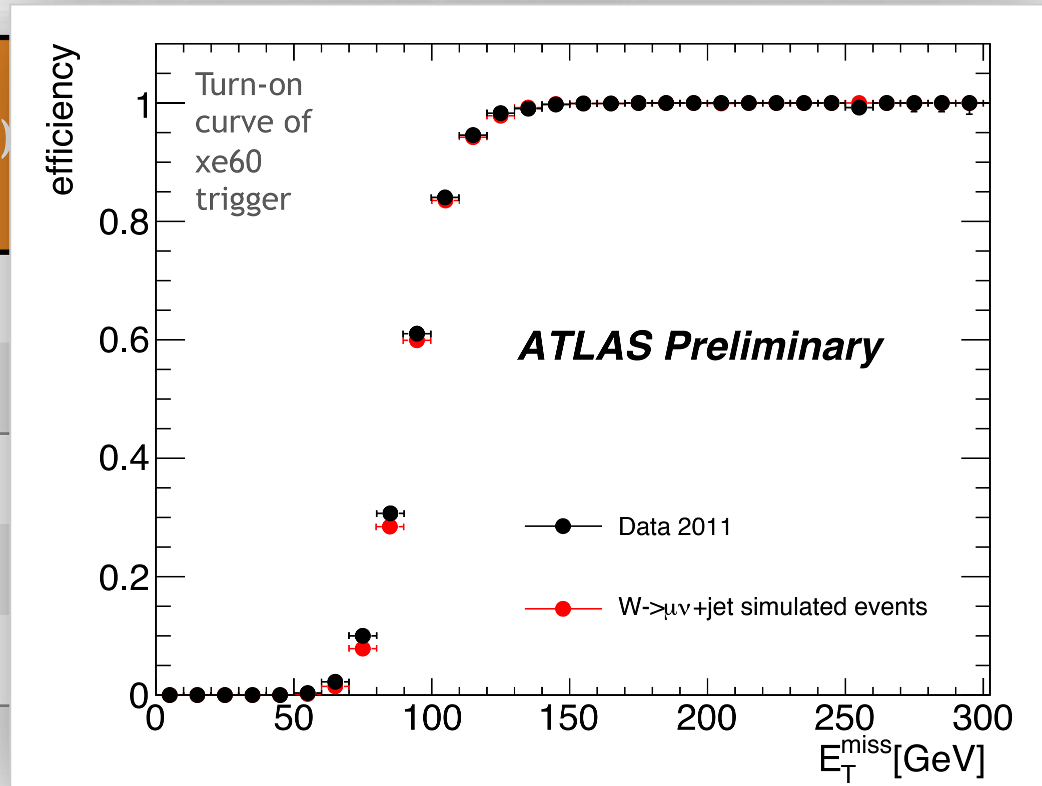
ATLAS Operations – Trigger

Task: preserve physics and perf. analysis → low single lepton thresholds

Trigger objects	Offline Selection (p_T thresholds in GeV)	Trigger Selection (GeV)		L1 Rate (kHz) at 3×10^{33}	EF Rate (Hz) at 3×10^{33}
		L1	EF		
Single leptons	Single muon > 20	11	18	8	100
	Single electron > 25	16	22	9	55
Two leptons	2 muons > 4	11	15, 10	6	5
	2 electrons, > 15	2×10	2×12	2	1.3
	2 tau → had > 45, 30	15, 11	29, 20	7.5	15
Two photons	2 photons > 25	2×12	2×20	3.5	5
MET	MET > 170	50	70	0.6	5
Multi-jets	5 jets, > 55	5×10	5×30	0.2	9
Single jet + MET	Jet p_T > 130 & MET > 140	50 & 35	75 & 55	0.8	18
Total rate (peak)				**55 kHz**	**550 Hz**

ATLAS Operations — Trigger

Task: preserve physics and perf. analysis → low single lepton thresholds

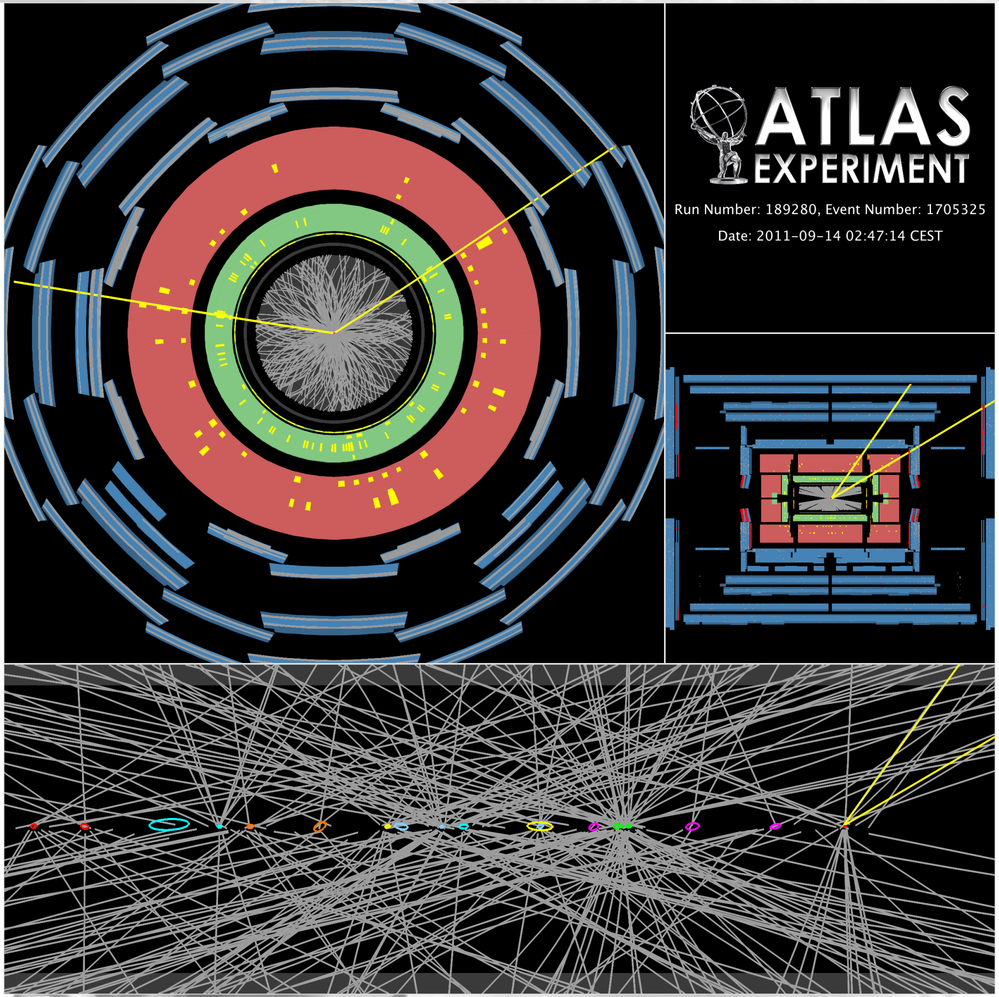


Trigger objects	Offline Selection (p_T thresholds in GeV)				
Single leptons	Single muon > 20				
	Single electron > 25				
Two leptons	2 muons > 4				
	2 electrons, > 15				
	2 tau → had > 45, 30				
Two photons	2 photons > 25				
MET	MET > 170	50	70	0.6	5
Multi-jets	5 jets, > 55	5×10	5×30	0.2	9
Single jet + MET	Jet p_T > 130 & MET > 140	50 & 35	75 & 55	0.8	18
Total rate (peak)				**55 kHz**	**550 Hz**

Pileup

High luminosity comes at a price: probability of parasitic collisions in one bunch crossing (= *pileup*) increases

Peak of up to 22 collisions per crossing reached

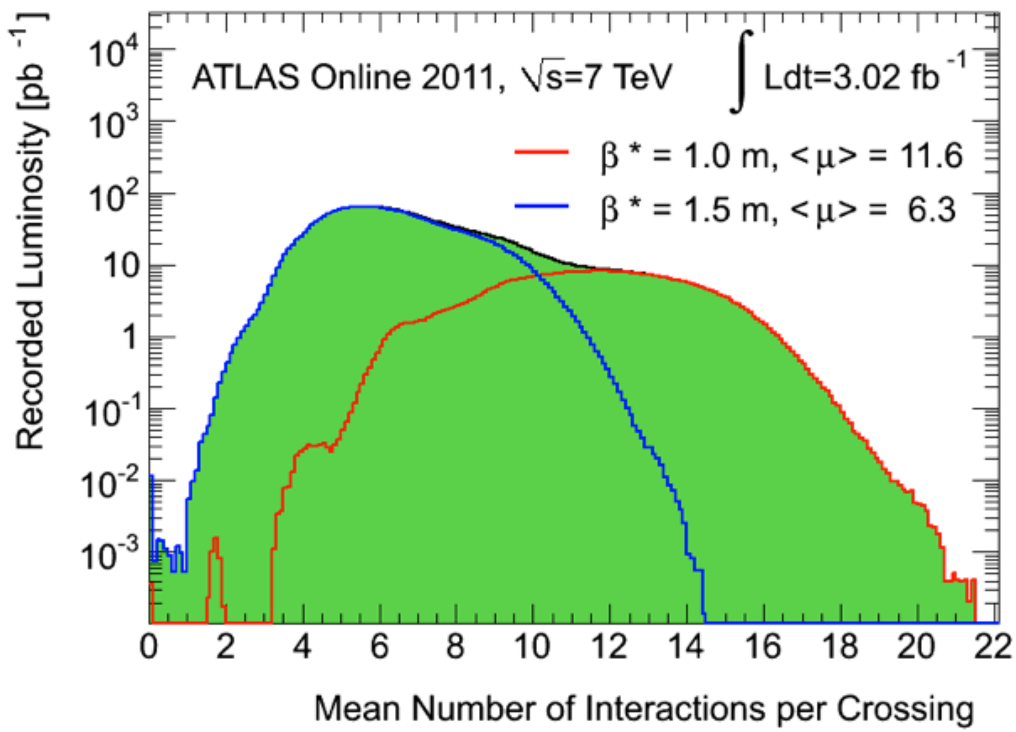


$Z \to \mu\mu$ event in ATLAS with 20 reconstructed vertices

Pileup

Do not expect a significant impact on tracking, nor muons, nor even electrons and photons

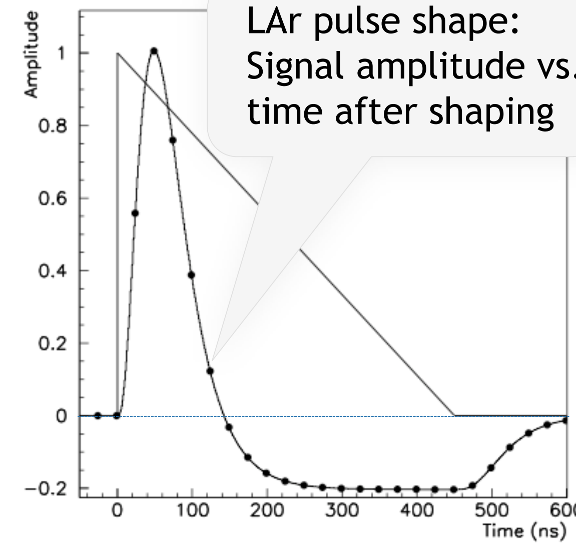
However, sizable impact on jets, MET and tau reconstruction



Impact of Pileup

LAr drift-time is ~500 ns and out-of-time bunches have impact on measurement

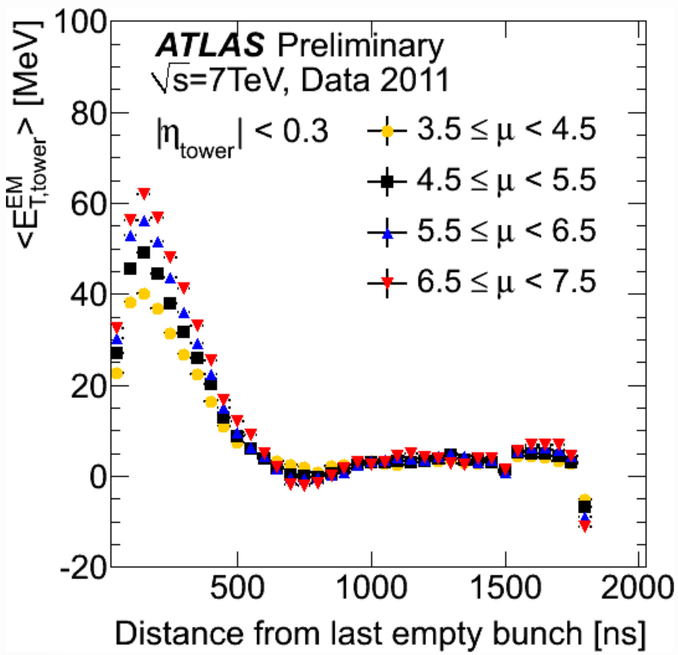
Bipolar pulse shaping designed so that **$\langle E_T \rangle$ ~ 0 for 25 ns bunch-spacing and uniform intensity per BX**

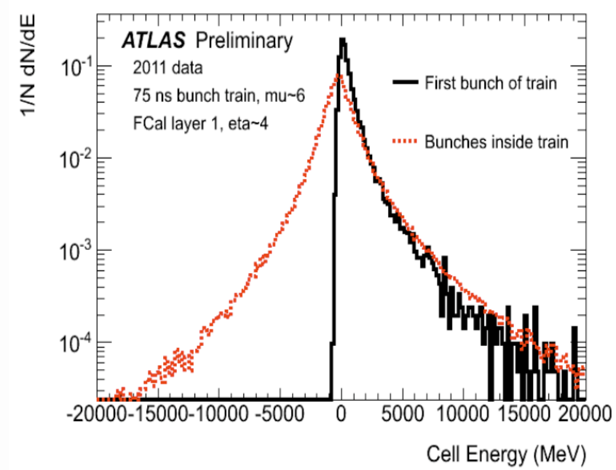


LAr pulse shape: Signal amplitude vs. time after shaping

Optimal performance requires correction per cell type vs. η and luminosity to calibrate $\langle E_T \rangle$ ~ 0

Currently, introduced increased JES error for low-p_T jets (worst: 7% for jets in forward calo)





Quality of ATLAS Data for Physics Analysis

Fraction of good data **after Tier-0 reconstruction:**

Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.8	100	89.0	92.4	94.2	99.7	99.8	99.7	99.8	99.7	99.3	99.0

Data from March 13th to June 29th, 1.3 fb^{-1}

- Data quality close to 100% for all sub-detectors, except for LAr
- Origin of lower data LAr quality is mostly noise bursts (and HV trips)

Fraction of good data **after reprocessing:**

Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.8	100	96.3	98.6	98.9	99.7	99.8	99.8	99.8	99.7	99.3	99.0

- Event-by-event flagging of noise bursts regained 7% of luminosity for physics (now also in Tier-0)

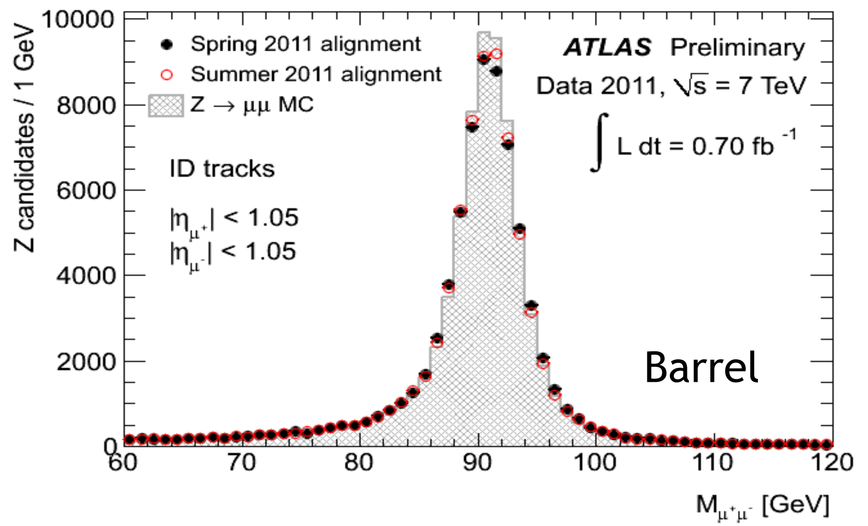
Alignment: Inner Detector

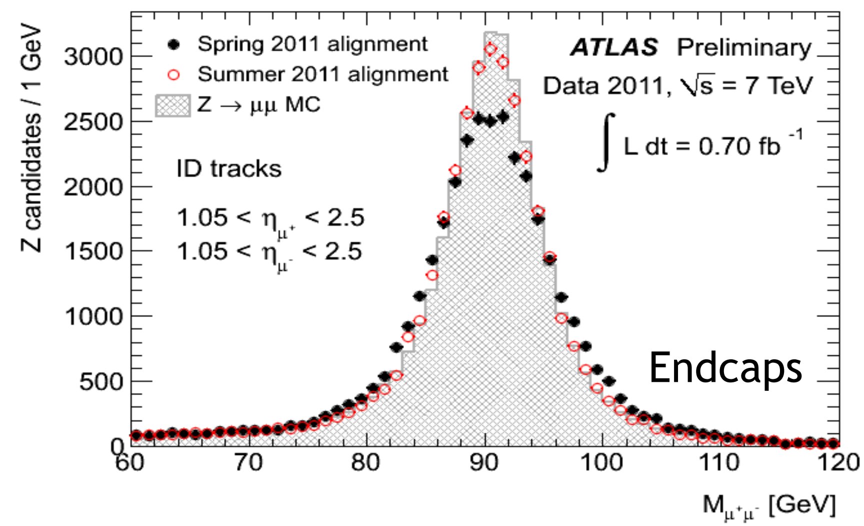
Initial alignment work concentrated on minimising track-to-hit residuals

This is not sufficient for a properly aligned tracking detector → "weak modes"

Require "physics input" to eliminate shadow distortions, eg, *E*/*p* from electrons!

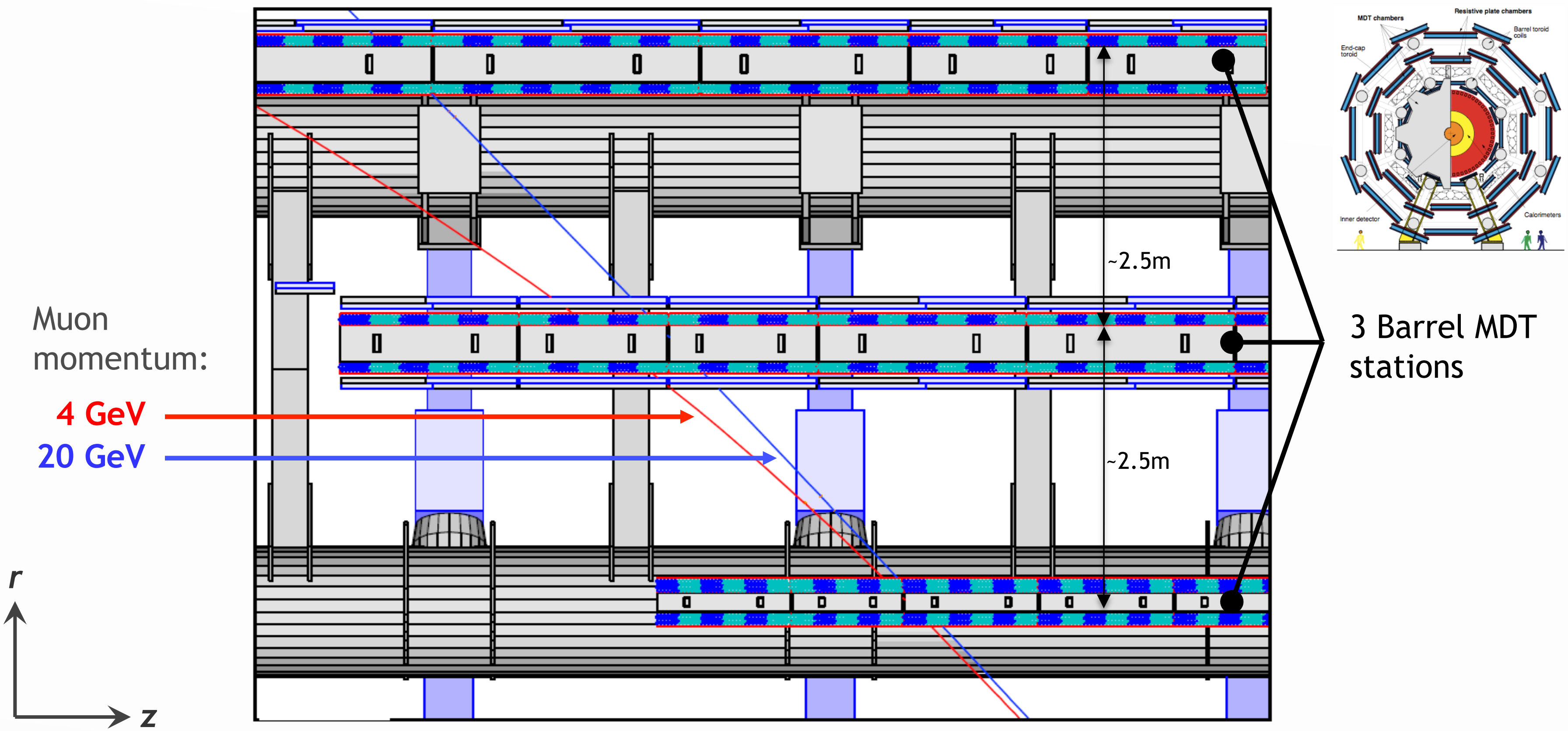
Z to μμ in ID only (250k events)	Ideal (MC)	Deterioration in data using residuals fit only	Add *E*/*p* constraint from e^+ vs e^-
Both μ in barrel ID	1.60	0.98 ± 0.01	**0.71 ± 0.01**
Both μ in same end-cap ID	3.42	3.03 ± 0.03	**1.16 ± 0.01**





Alignment: Muon System

Challenge to achieve in ~ 10’000 m^3 of muon system design stand-alone resolution of 10% at 1 TeV over $|\eta| < 2.7$ (requires sagitta accuracy of 50 μm)



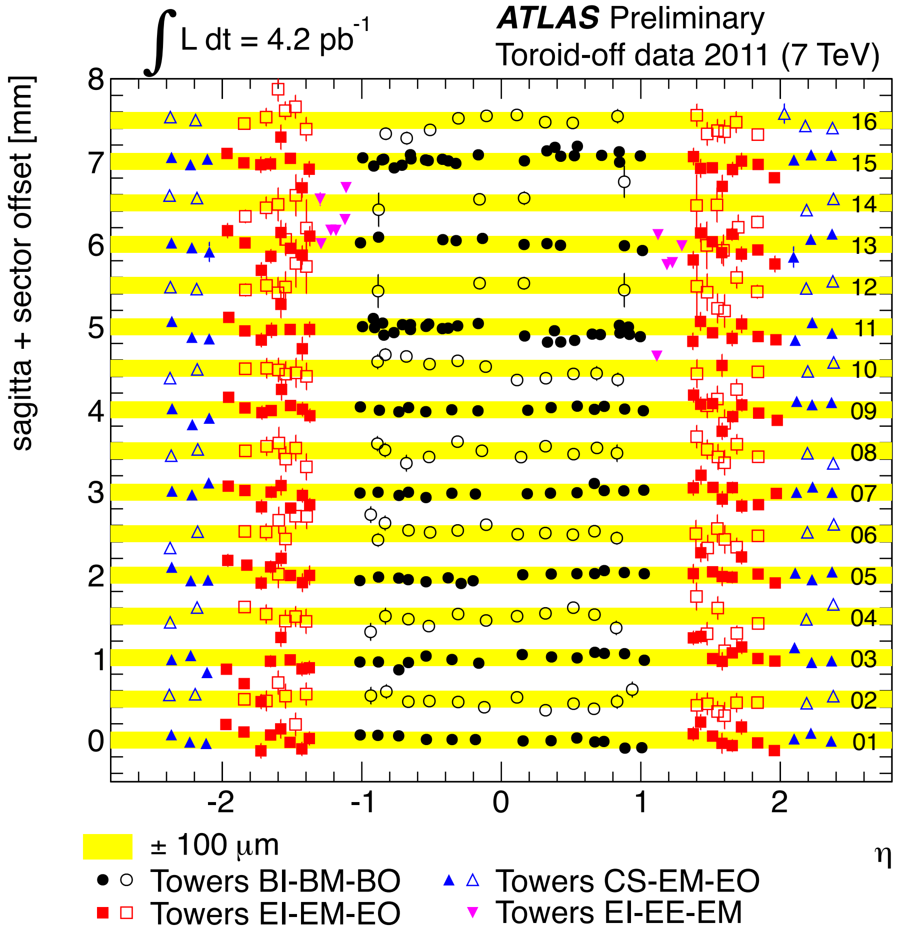
Alignment: Muon System

Challenge to achieve in ~ 10’000 m^3 of muon system design stand-alone resolution of 10% at 1 TeV over |η| < 2.7 (requires sagitta accuracy of 50 μm)

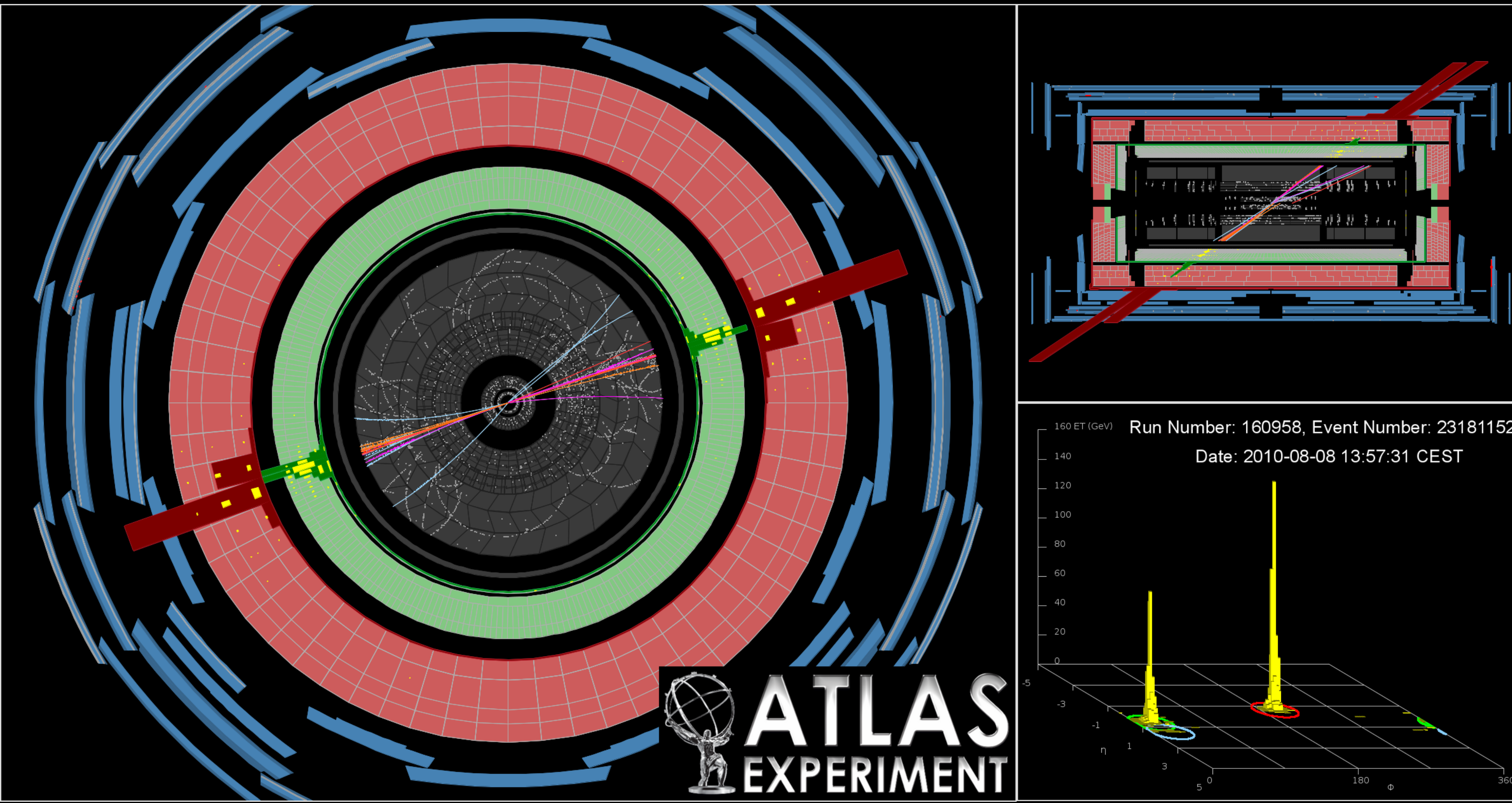
Combination of optical alignment and tracks taken with toroid off and solenoid on (4.2 pb^{-1} in spring 2011) resulted in much improved endcaps, where constraints from cosmics were statistically much weaker than in barrel

Recent reprocessing yielded factor > 2 improvement for CSC chambers at high |η|

All chambers now within < ±100 μm



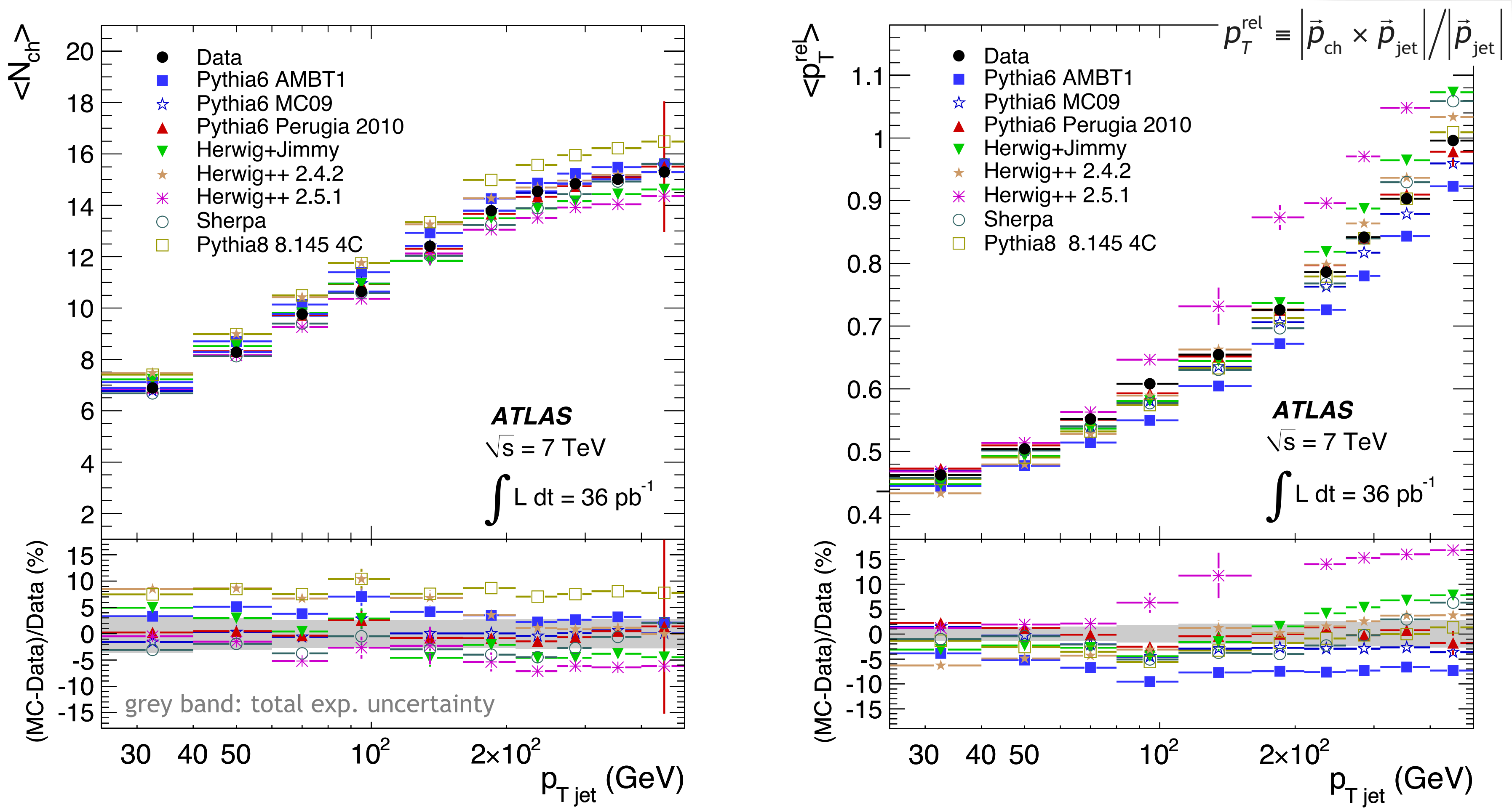
A beautiful dijet event: m(jet-jet) = 1.9 TeV, p_T : 0.9 TeV, 0.8 TeV



Measuring jet fragmentation — towards improving JES

Large HERWIG++ / Pythia discrepancies dominate JES uncertainty at high p_T

ATLAS arXiv:1109.5816



None of current generators or tunes agree well with all the transverse measurements

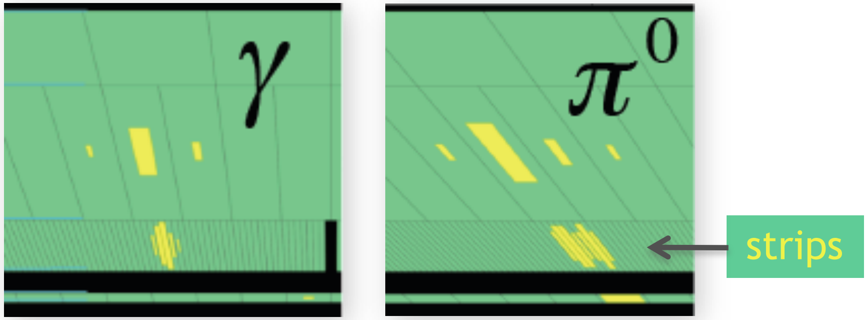
Photon measurements — crucial ingredient to $H \to \gamma\gamma$

Huge hierarchy: jj (~500 μb) → γj (~200 nb) → $\gamma\gamma$ (~30 pb) → $H \to \gamma\gamma$ (~40 fb)

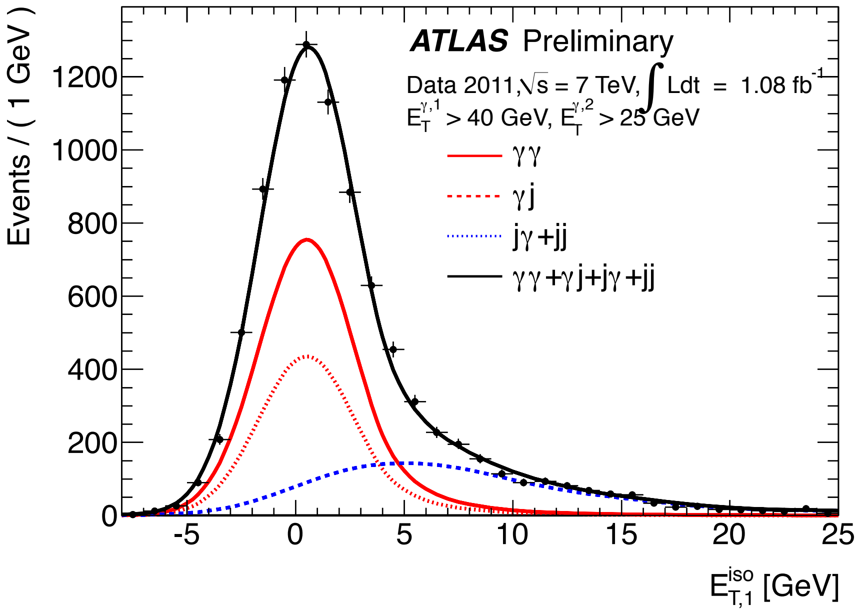
ATLAS arXiv:1108.5895

Background from jets fragmenting into single hard π^0 → fake γ

Determined choice of fine lateral segmentation (4mm strips) of the first layer of ATLAS EM calorimeter



Huge uncertainty in jj and $j\gamma$ cross sections: γ—jet separation must be measured from data



Calorimeter Isolation distributions in data for leading photon

→ *sample purity from template fits*

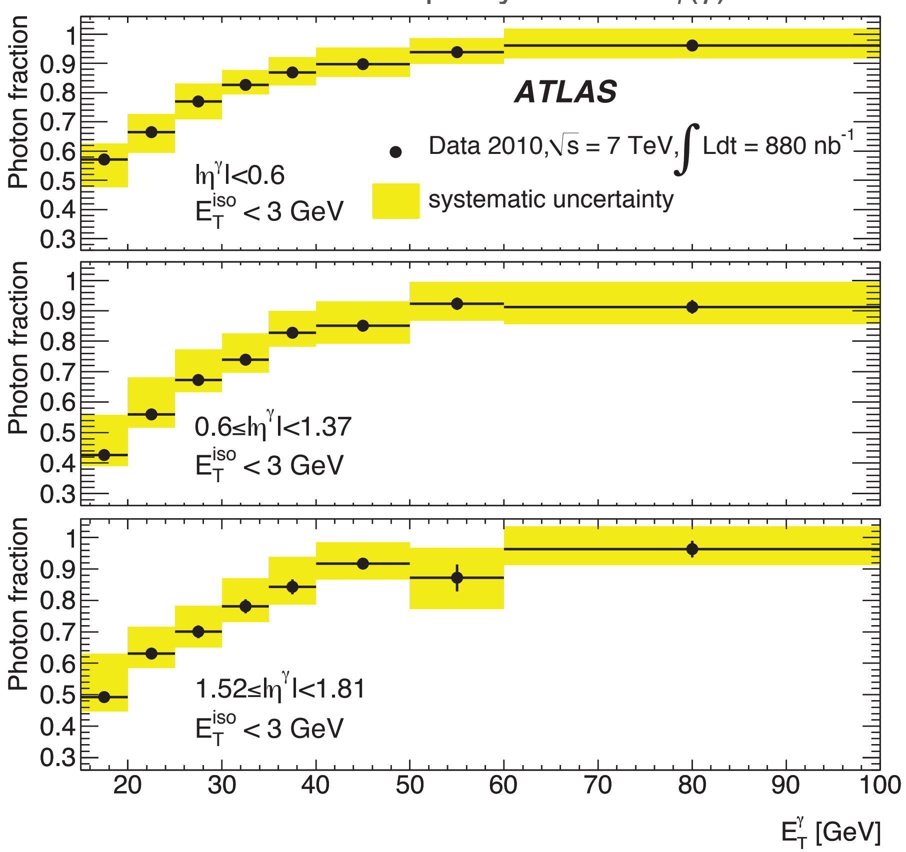
Photon measurements — crucial ingredient to $H \rightarrow \gamma\gamma$

Huge hierarchy: *jj* (~500 μb) → *γj* (~200 nb) → *γγ* (~30 pb) → *H→γγ* (~40 fb)

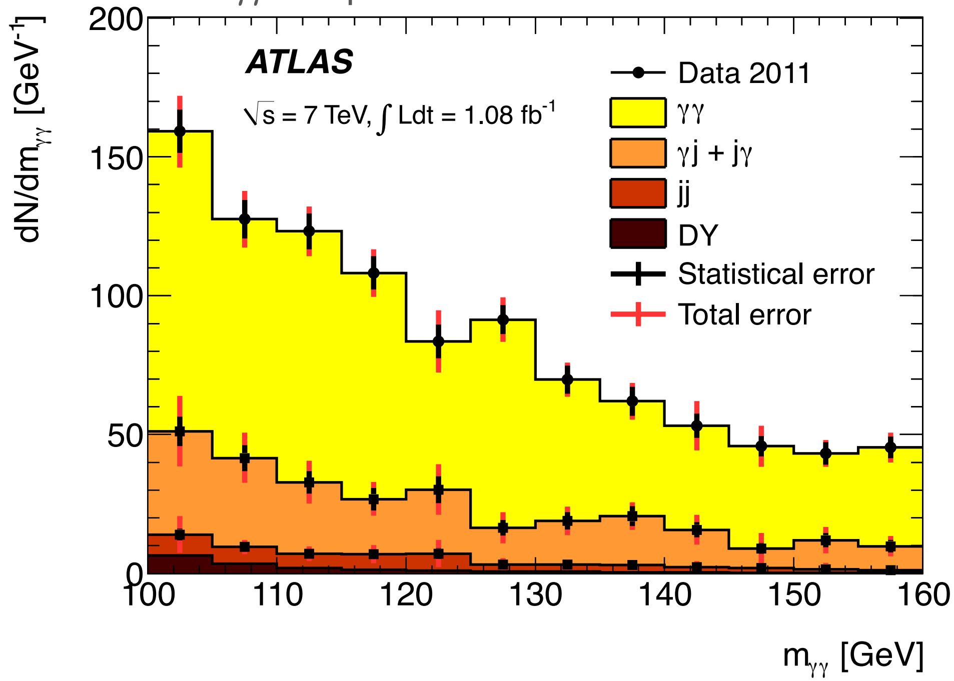
ATLAS arXiv:1012.4389

ATLAS arXiv:1108.5895

Photon identification purity versus $E_T(\gamma)$



$H \rightarrow \gamma\gamma$ sample contributions measured in data



Photon purity versus E_T :

Around 70–80% in $H \rightarrow \gamma\gamma$ range

Above 90% at high E_T

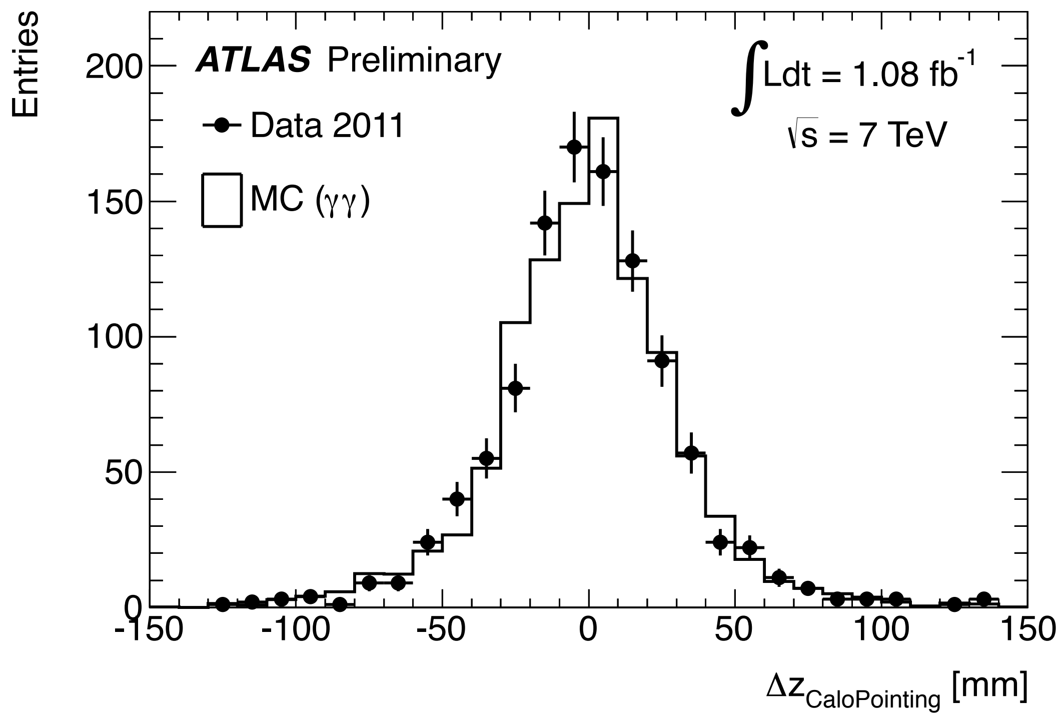
Photon measurements — crucial ingredient to $H \rightarrow \gamma\gamma$

Diphoton mass reconstruction in presence of pileup

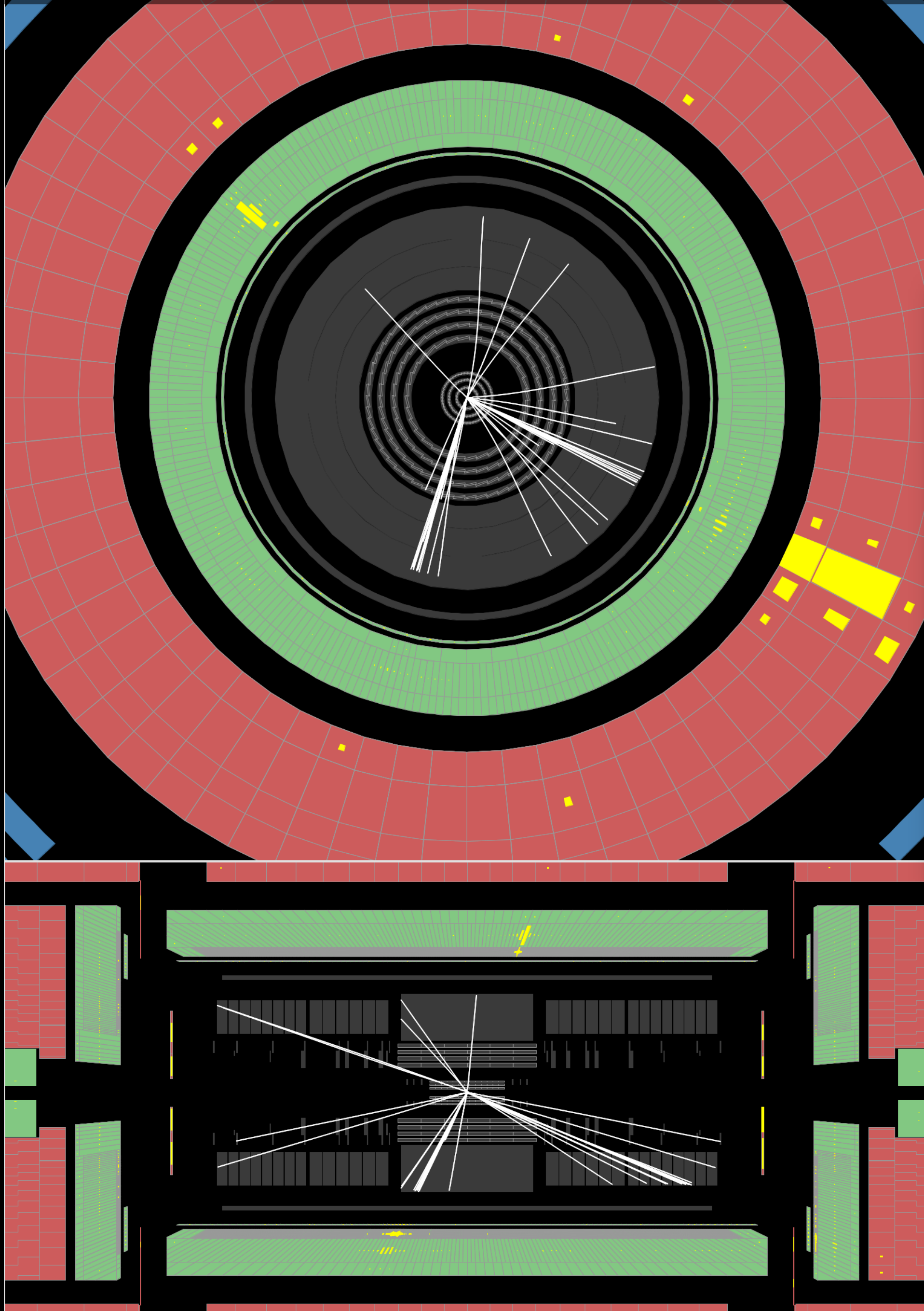
ATLAS arXiv:1108.5895

- Hard scattering vertex not reliably reconstructed in diphoton events in presence of significant pileup
- Use projective geometry of EM calo layers to reconstruct *z* vertex
- Good agreement between data and MC in barrel; ~20% worse in data in endcaps (yet uncorrected 2nd layer modulation)
- 1.6 cm *z* vertex resolution from pointing (5.5 cm vertex spread)
- Negligible impact on $m(\gamma\gamma)$ resolution compared to $E(\gamma)$ measurement

$\Delta z = z(\gamma_1) - z(\gamma_2)$ in diphoton events (unconverted γ's)



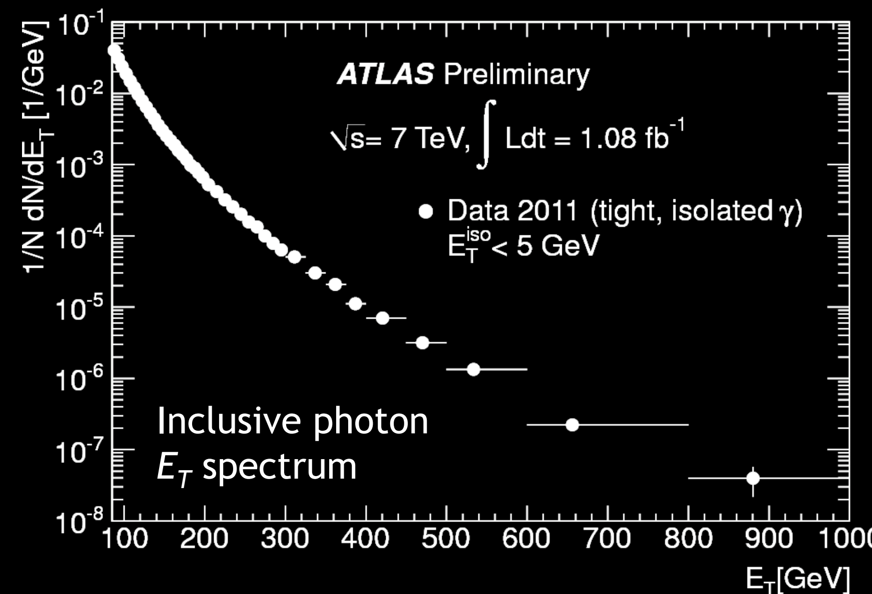
Highest E_T (960 GeV) unconverted photon observed to date

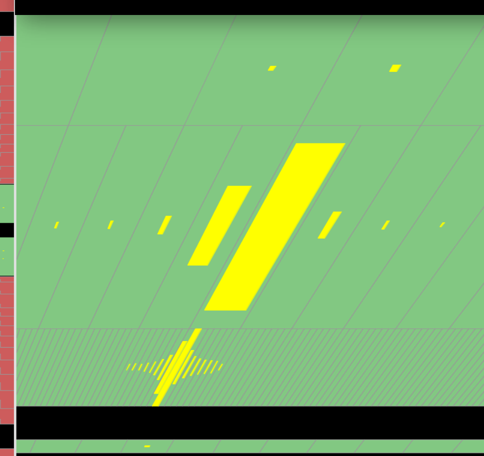


ATLAS EXPERIMENT

Run Number: 183407, Event Number: 15829585

Date: 2011-06-12 15:12:55 CEST





W and *Z* physics: differential measurements

Precision probes of theory, PDFs, MC generators. Backgrounds to searches

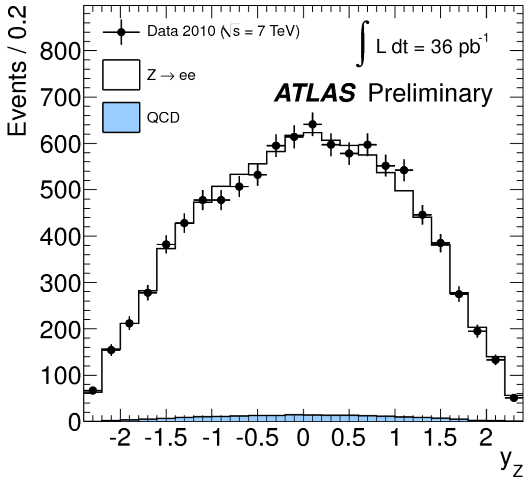
ATLAS arXiv:1109.5141

In 3 fb^{-1}, expect ~20M $W \to l\nu$ decays, 1.7M $Z \to ll$ decays, 0.5M $Z \to ee$ decays with one forward electron $(2.5 < |\eta| < 4.9)$

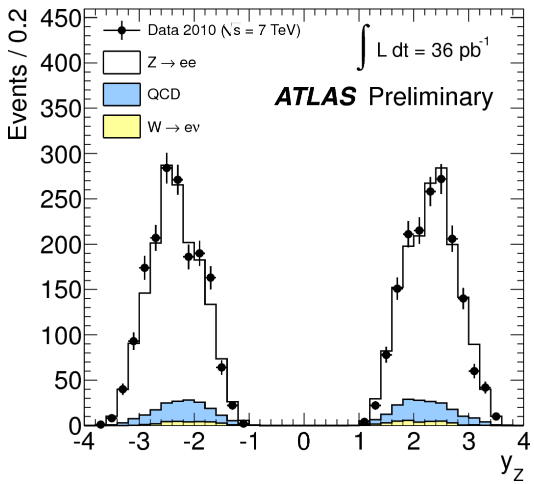
→ allows precision tests of theory

Interesting lessons learned already:

- **NNLO tools** to predict **fiducial cross sections** (FEWZ, DYNNLO) **are powerful** and provide means for more precise comparisons
- Complete set of differential distributions for $W^{\pm}$, and Z will provide **strong constraints on theory and in particular on PDFs**
- Must **decrease experimental systematics** on efficiencies and MET for ratios and luminosity for absolute measurements



Rapidity distribution of 9725 Z ($\to ee$) candidates with two central electrons



3376 Z ($\to ee$) candidates with one forward electrons

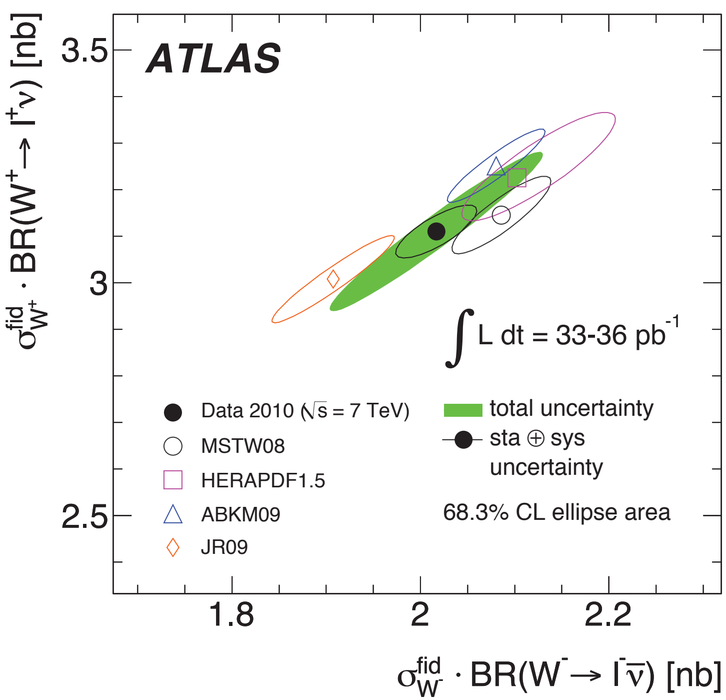
W and *Z* physics: differential measurements

Precision probes of theory, PDFs, MC generators. Backgrounds to searches

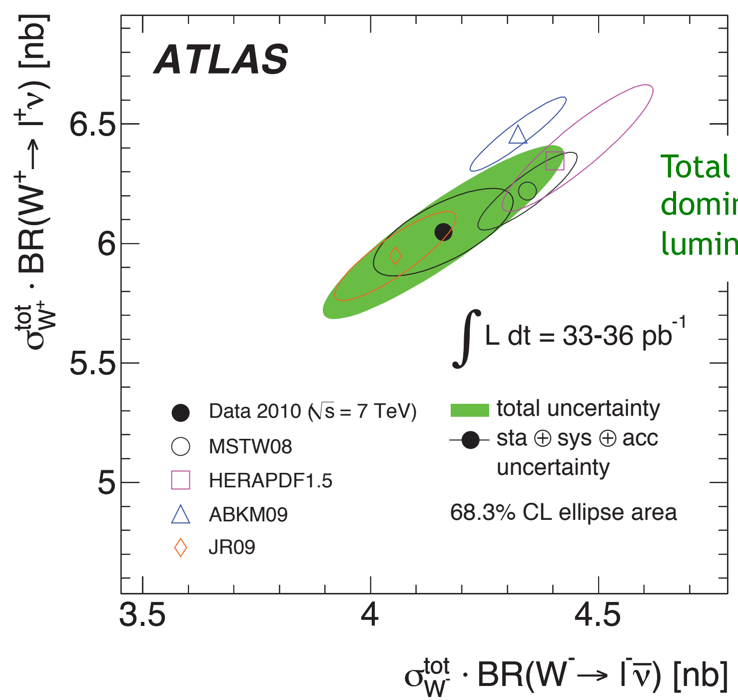
ATLAS arXiv:1109.5141

Fiducial measurements provide already a more precise test of QCD predictions, at least in terms of PDFs, than when they are corrected back to the total cross-sections

Fiducial cross section measurements



Total cross section measurements



Total uncertainty dominated by luminosity error

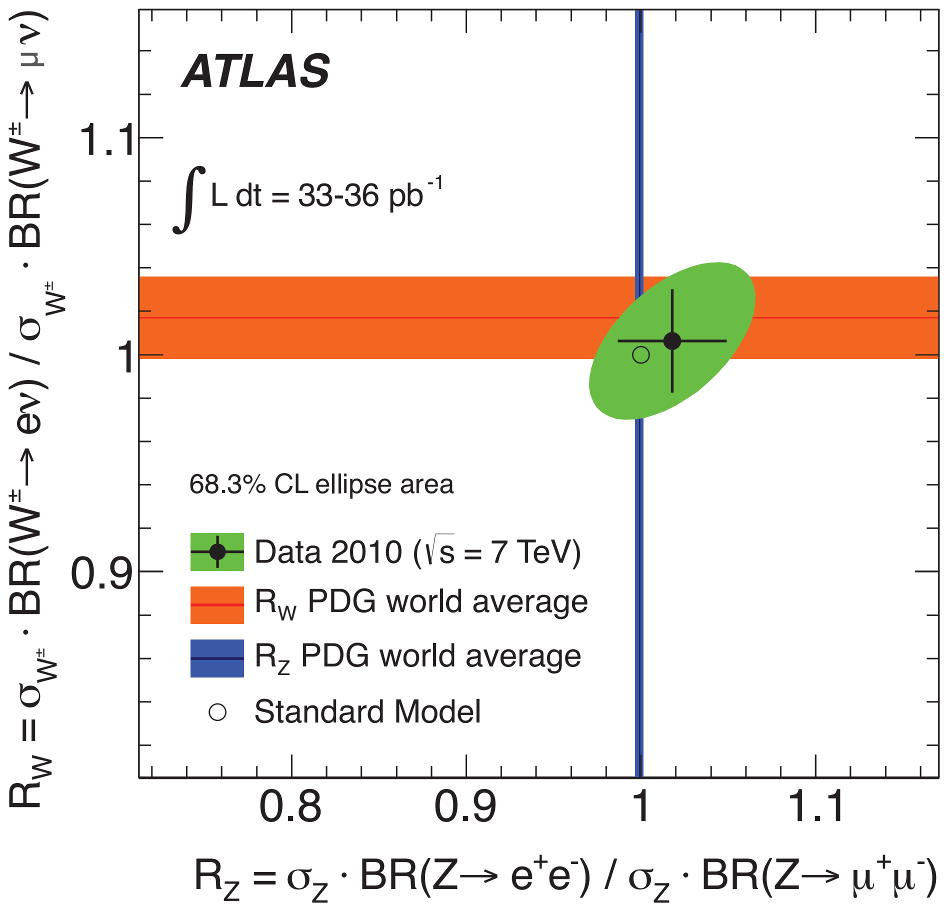
W and *Z* physics: differential measurements

Precision probes of theory, PDFs, MC generators. Backgrounds to searches

ATLAS arXiv:1109.5141

Probe lepton universality with good accuracy (~3%) compared to the PDG world average from LEP and Tevatron for *W* boson.

(An order of magnitude less precise than the weak universality tests from Tau / *Z* decays and weak vector and axial-vector coupling measurements at the *Z* pole.)



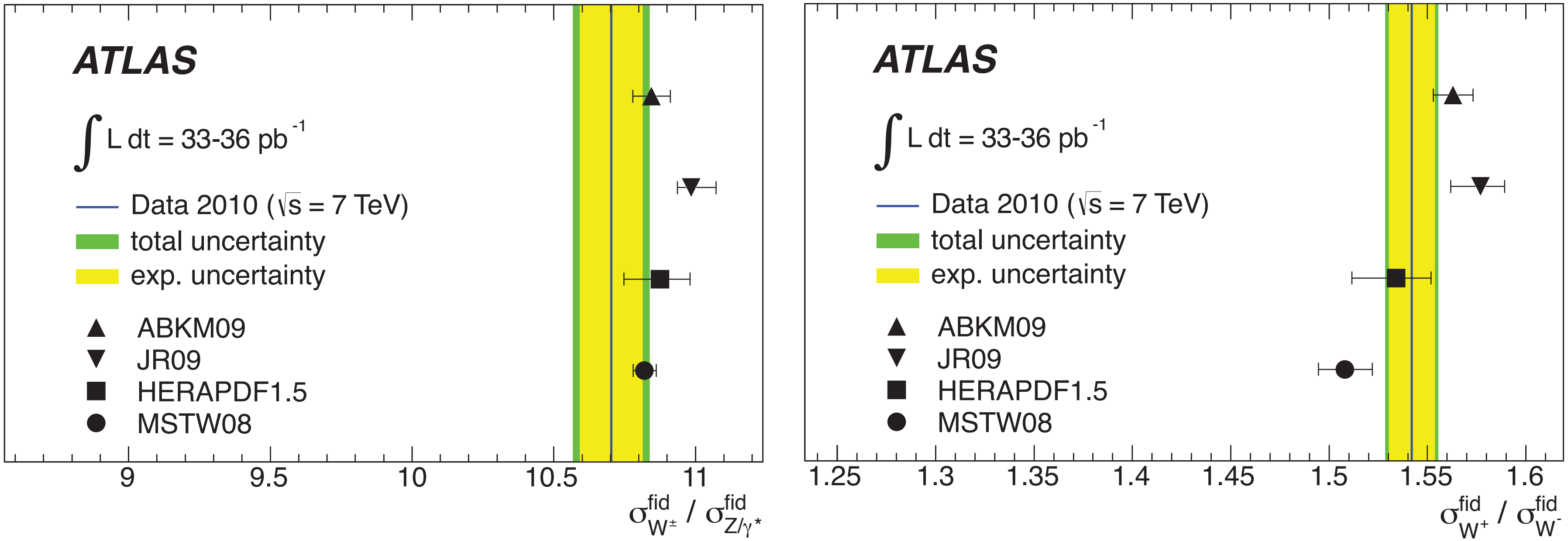
W and *Z* physics: differential measurements

Precision probes of theory, PDFs, MC generators. Backgrounds to searches

ATLAS arXiv:1109.5141

The ratios of *W* to *Z* fiducial cross-sections have perhaps the highest potential for precision measurements in the future

Measured (bands) and predicted (dots) fiducial cross section ratios



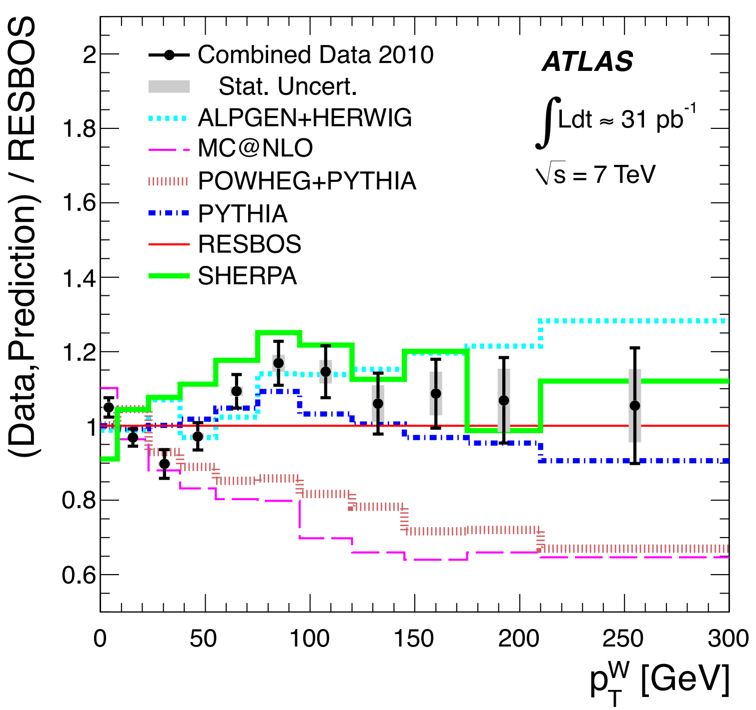
W and Z physics: transverse momentum distributions

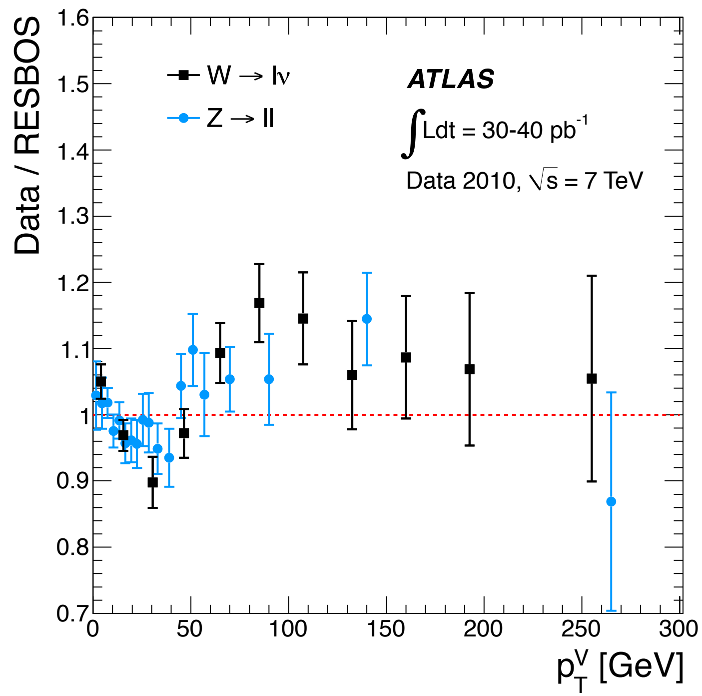
Sensitive to hadronic recoil, important for m_W measurement

ATLAS arXiv:1107.2381, arXiv:1108.6308

Already a quite precise measurement for $p_T(W)$, with the unfolded fiducial distribution showing shape differences wrt. certain models

Hadronic recoil calibrated in terms of data to MC differences using the $Z \to ll$ decays





[$Z \to ll$ and $W \to l\nu$ shapes seem to agree better among themselves than with any model]

W and *Z* physics: production in association with *b*-jets

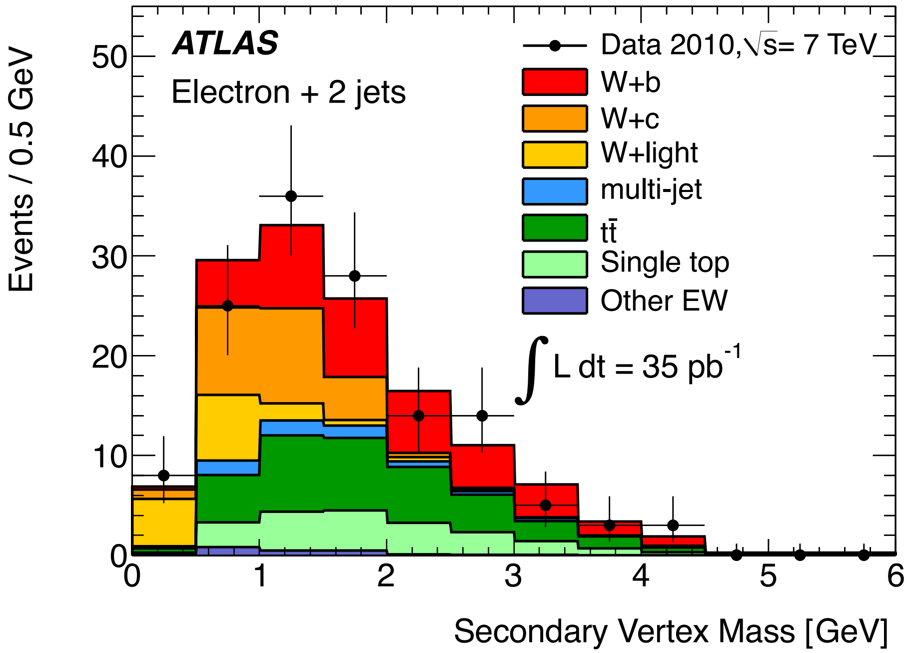
W/*Z* + jets measurements provide stringent test of QCD at hadron colliders

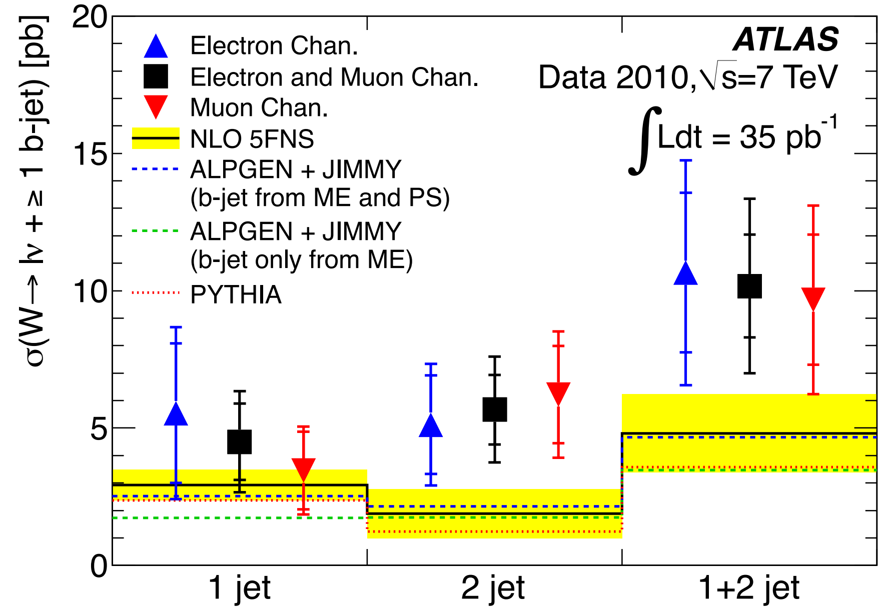
ATLAS arXiv:1109.1403, arXiv:1109.1470

W + *b*-jets measurement by CDF [0909.1505] gave 3σ cross section excess over NLO prediction

Prelude to *W*/*Z* + 2 *b*-jets measurement in view of Higgs-boson searches in the *bb* channel

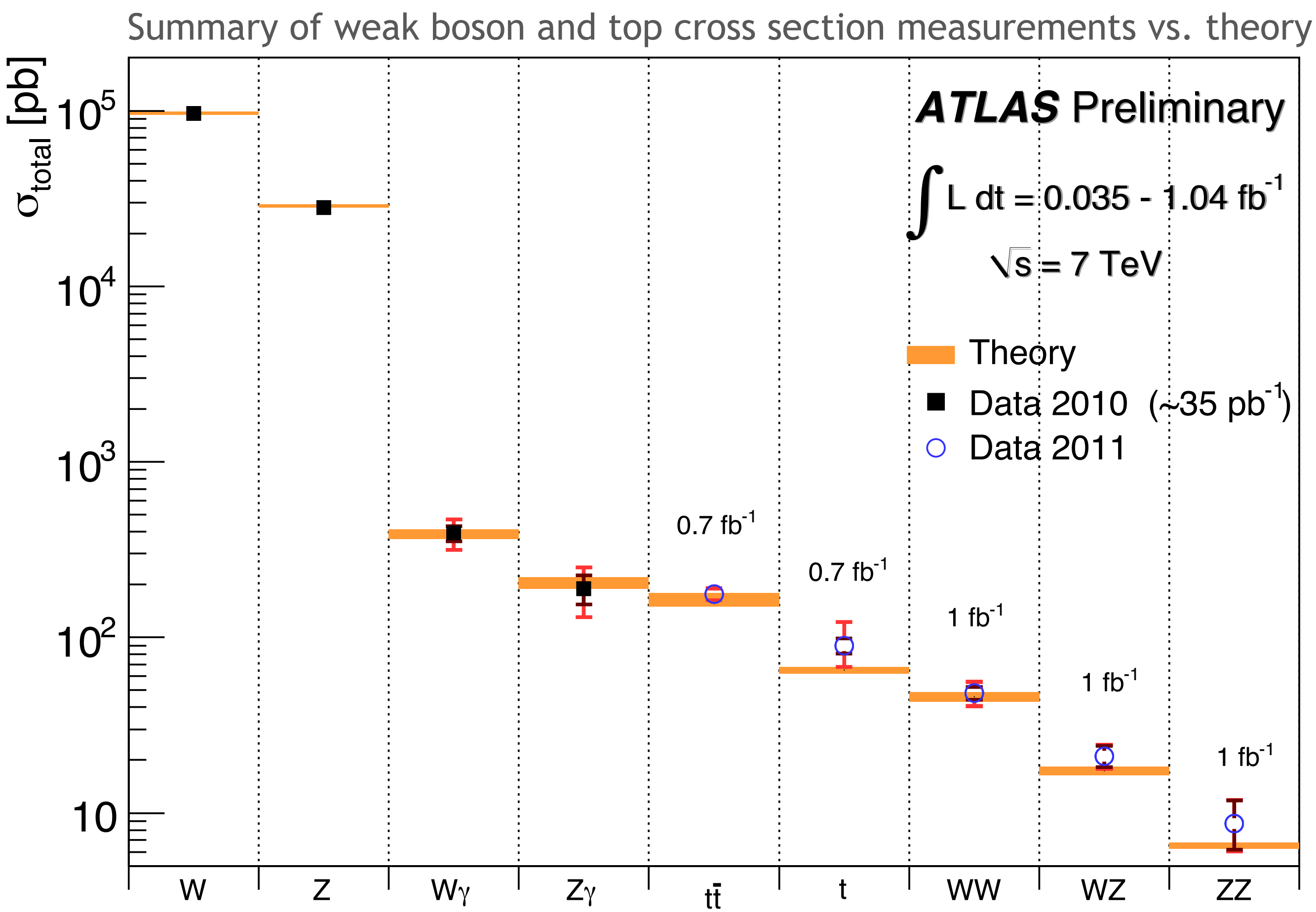
Note that QCD background at LHC much higher than at Tevatron, hampering inclusive searches for low-mass $H \to bb$





Summary of *W*, *Z* and top cross section measurements

Challenging theory over five orders of magnitude



Summary of *W*, *Z* and top cross section measurements

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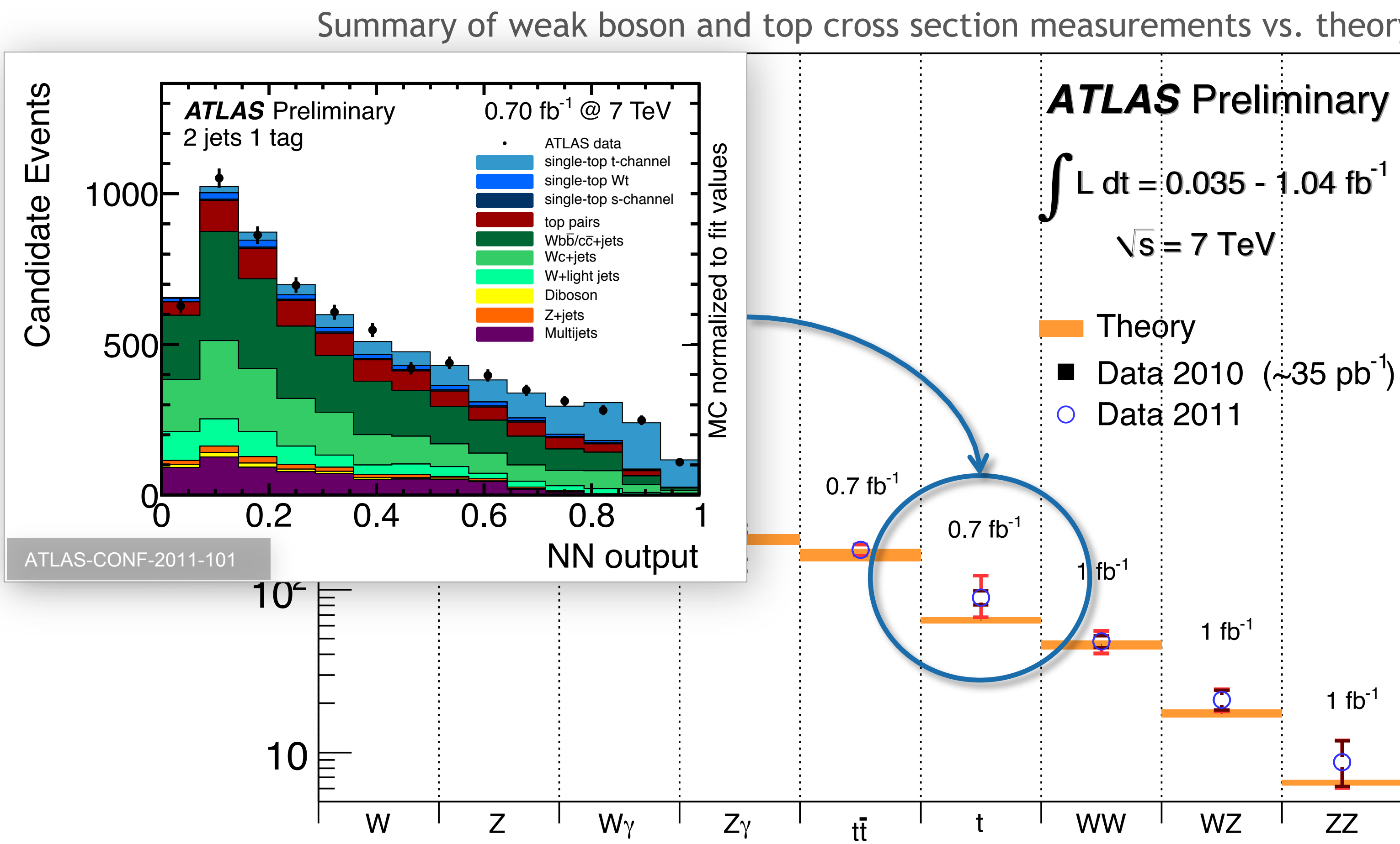
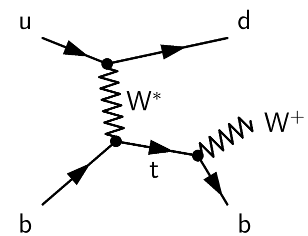


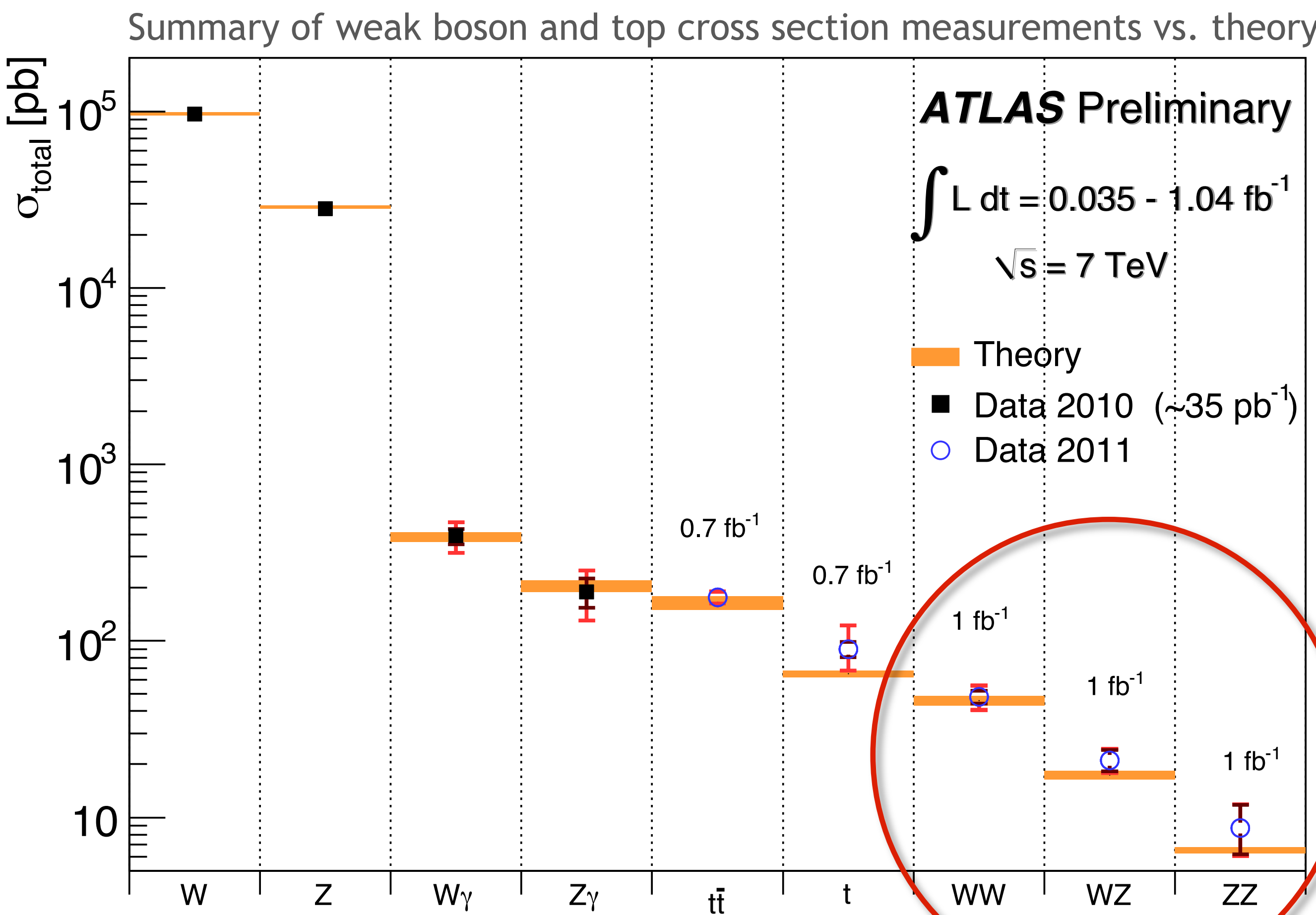


t-channel dominates single-top production

Expected cross sections for t, *Wt*, s chans.: 65, 16, 4.6 pb

Summary of *W*, *Z* and top cross section measurements

Challenging theory over five orders of magnitude

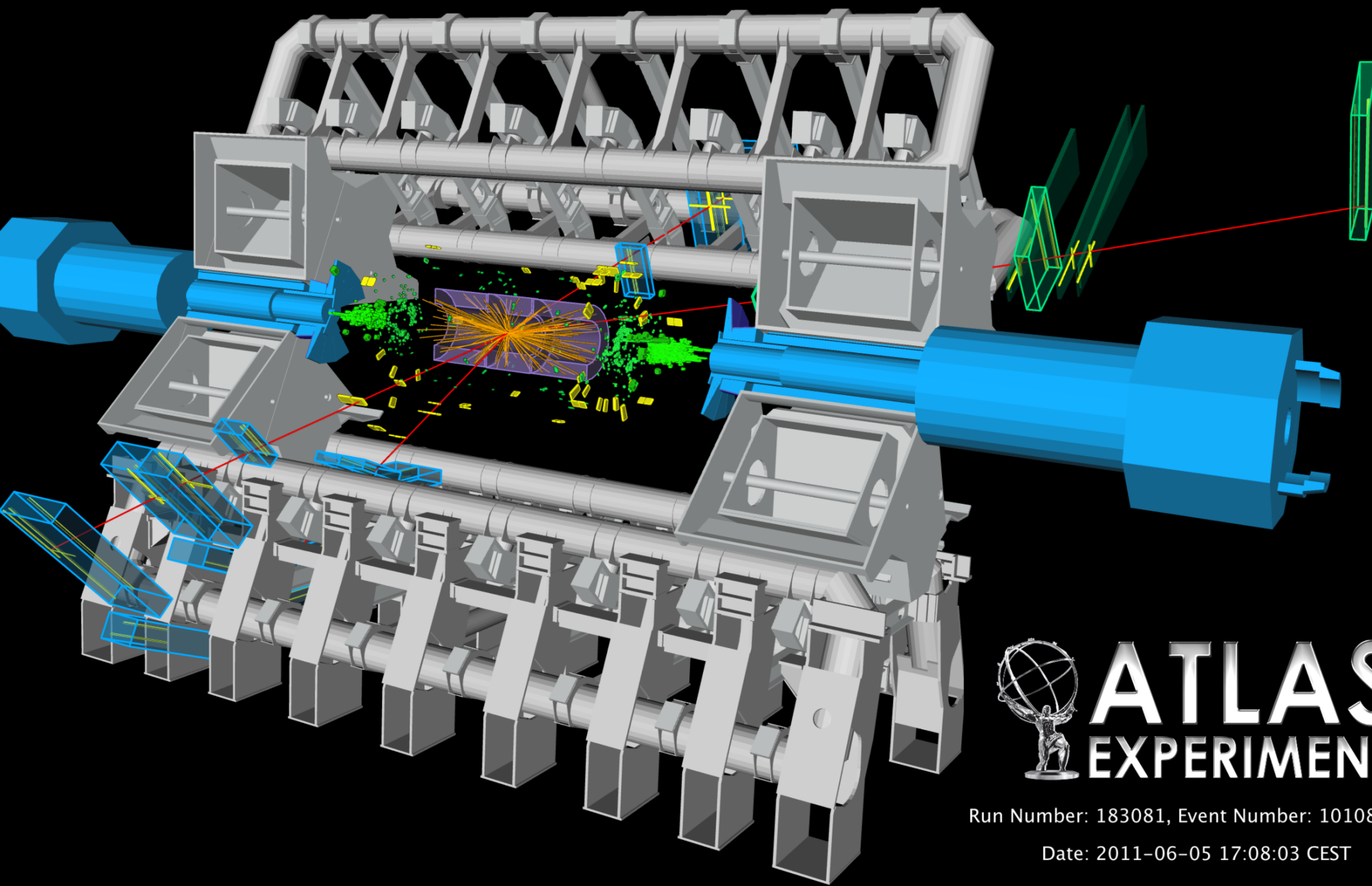


The long road to measuring electroweak symmetry breaking

H(130 GeV) → *WW* 4.9 pb

H(130 GeV) → *ZZ* 0.65 pb

A beautiful 4-muon event



ATLAS EXPERIMENT

Run Number: 183081, Event Number: 10108572

Date: 2011-06-05 17:08:03 CEST

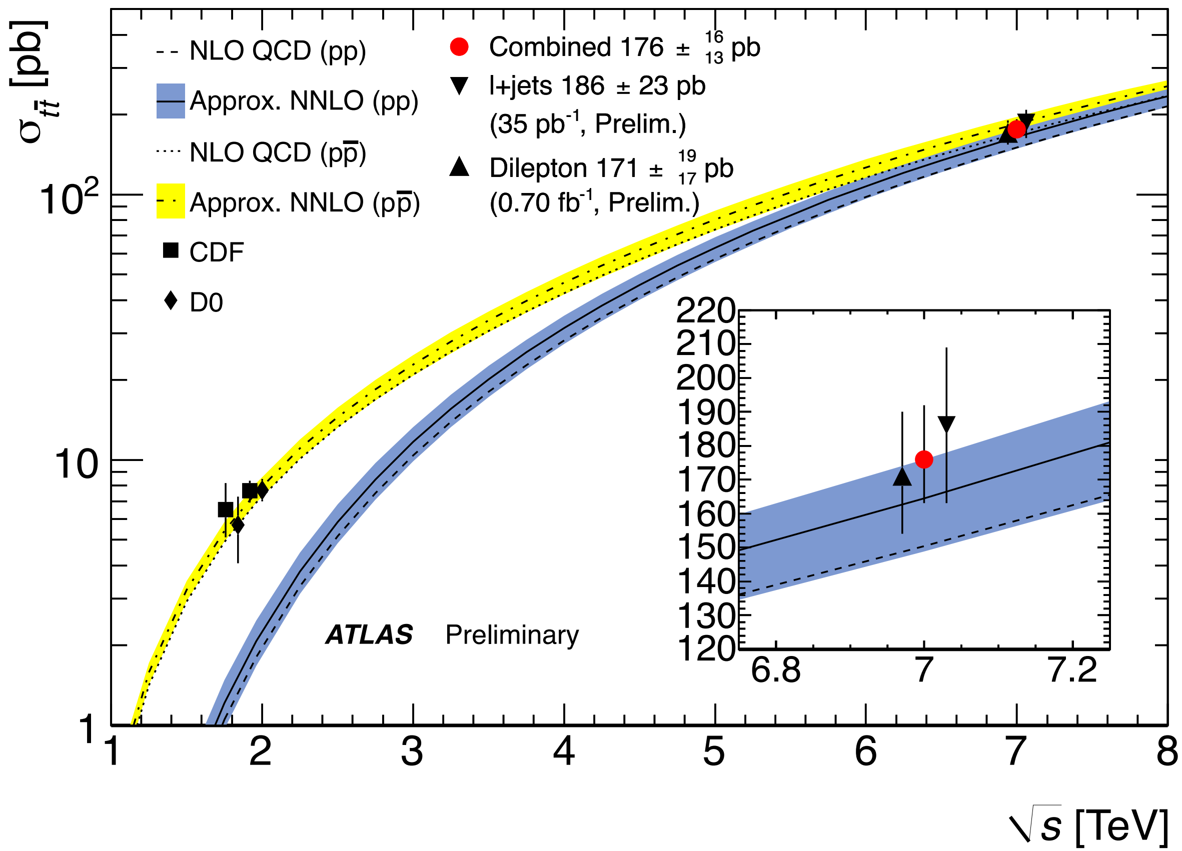
Top physics: top–antitop cross section

Challenge theory also with top measurements

ATLAS-CONF-2011-108

LHC is **top factory**

At 7 TeV CM energy:
~25 times larger cross section than at Tevatron



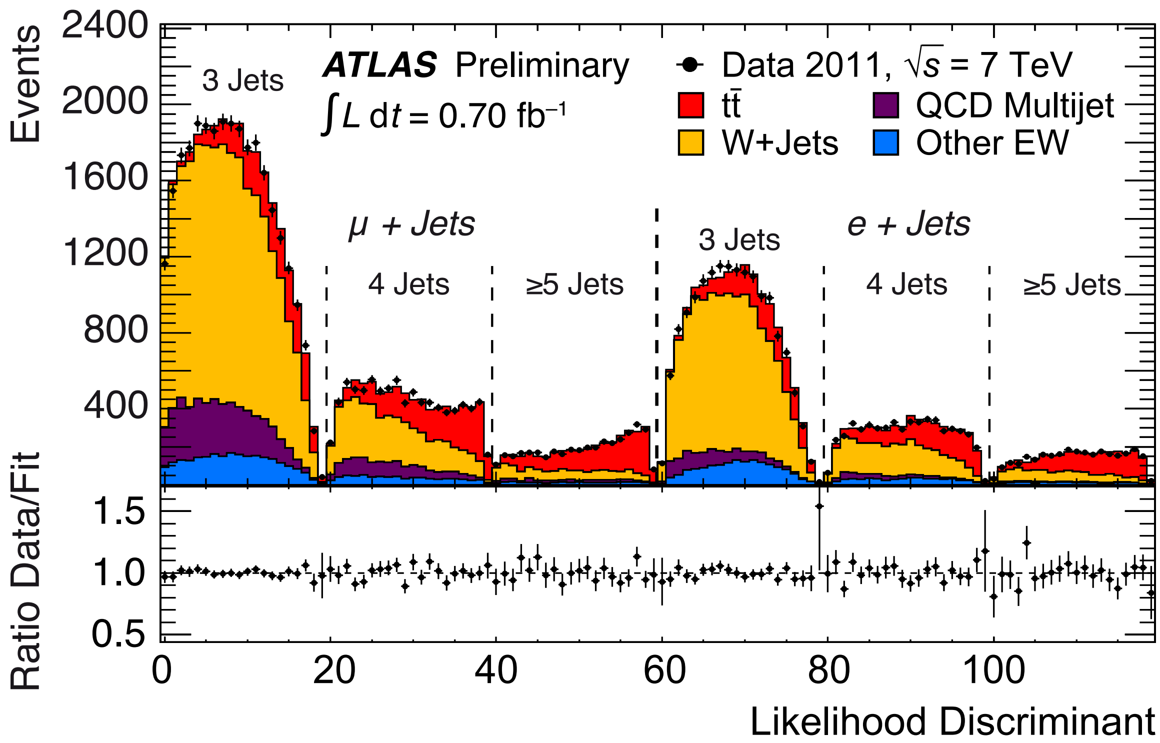
Top physics: top–antitop cross section

Challenge theory also with top measurements

ATLAS-CONF-2011-121

Theory at approximate NNLO: $\sigma(tt) = 165^{+11}_{-16}$ pb — using m_{top} = 172.5 GeV (same value in measurement)

ATLAS lepton + jets result with 0.7 fb^{-1}: $\sigma(tt) = 179.0 \pm 3.9_{stat} \pm 9.0_{syst} \pm 6.6_{lumi}$ pb



Systematic error dominated by signal MC generator, followed by JES and ISR/FSR uncertainties.

Result of combined fit to data in the 3-jet, 4-jet, ≥5-jet bins of the *e* + jets and *μ* + jets channels

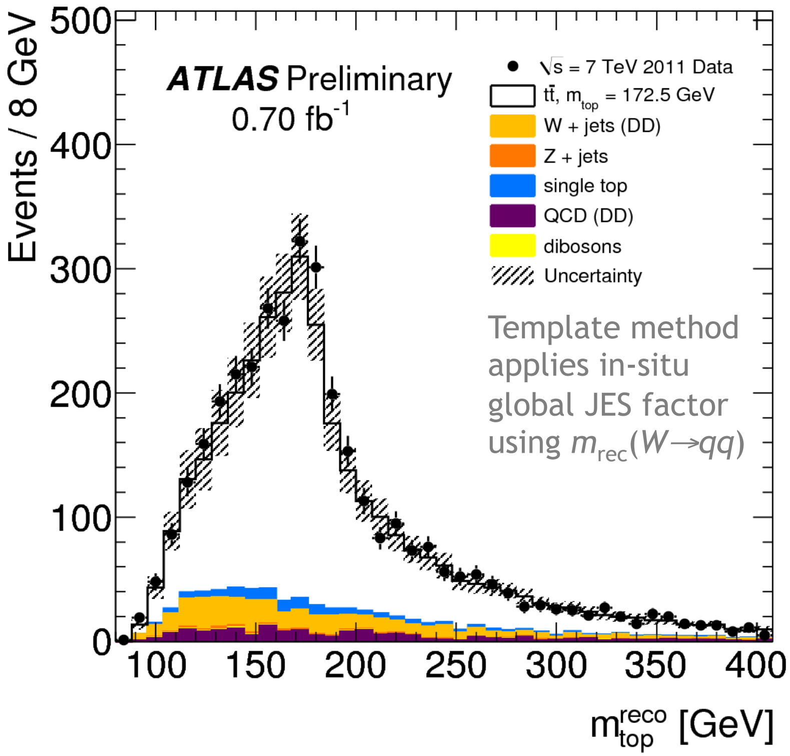
Lower plot shows data/fit ratio

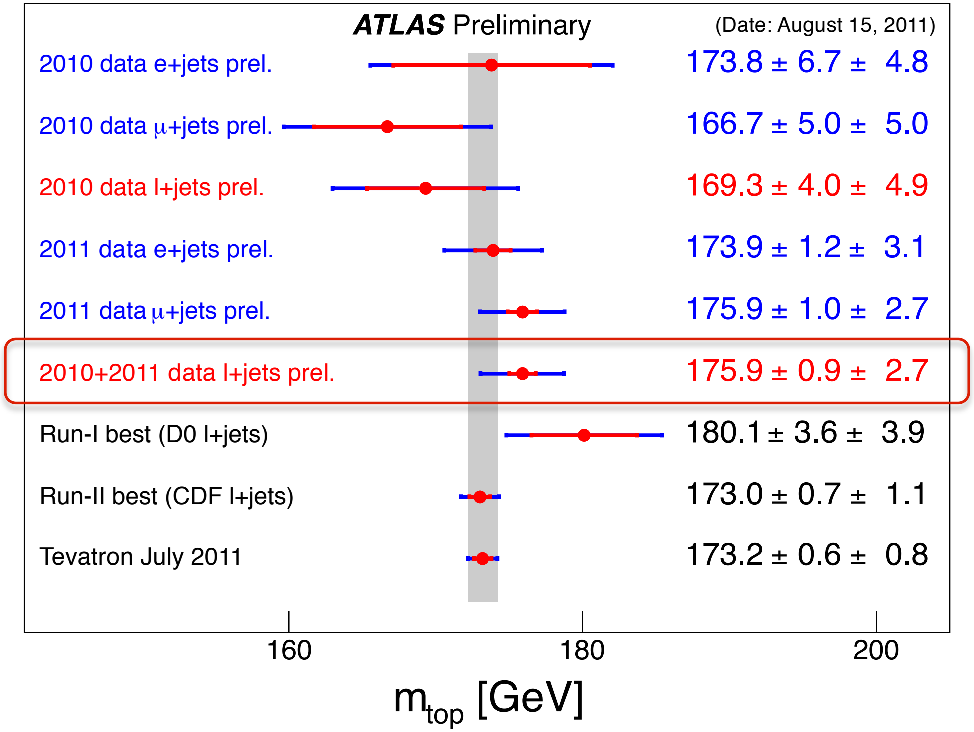
Top physics: top-quark mass

A long-term effort to challenge the Tevatron precision

ATLAS-CONF-2011-120

Measurement of the top-quark mass in lepton+jets channels now accurate to ~1.6% (Tevatron: 0.6% !), demonstrating the quality of the data and the maturity of the analysis





Top physics: *W* polarisation at *W*–*t*–*b* vertex

Complements precision *V*–*A* tests performed at low energies (μ, τ)

ATLAS-CONF-2011-122

Used ~7000 semi-leptonic and ~900 dilepton top–antitop candidates (0.7 fb^{-1}) to measure **helicity fractions**, depending on *W* polarisation, extracted from cosθ* distribution between lepton and reversed *b*-quark in *W* rest frame

Precise NNLO QCD predictions:

F_0 = 0.687 ± 0.005

F_{LH} = 0.311 ± 0.005

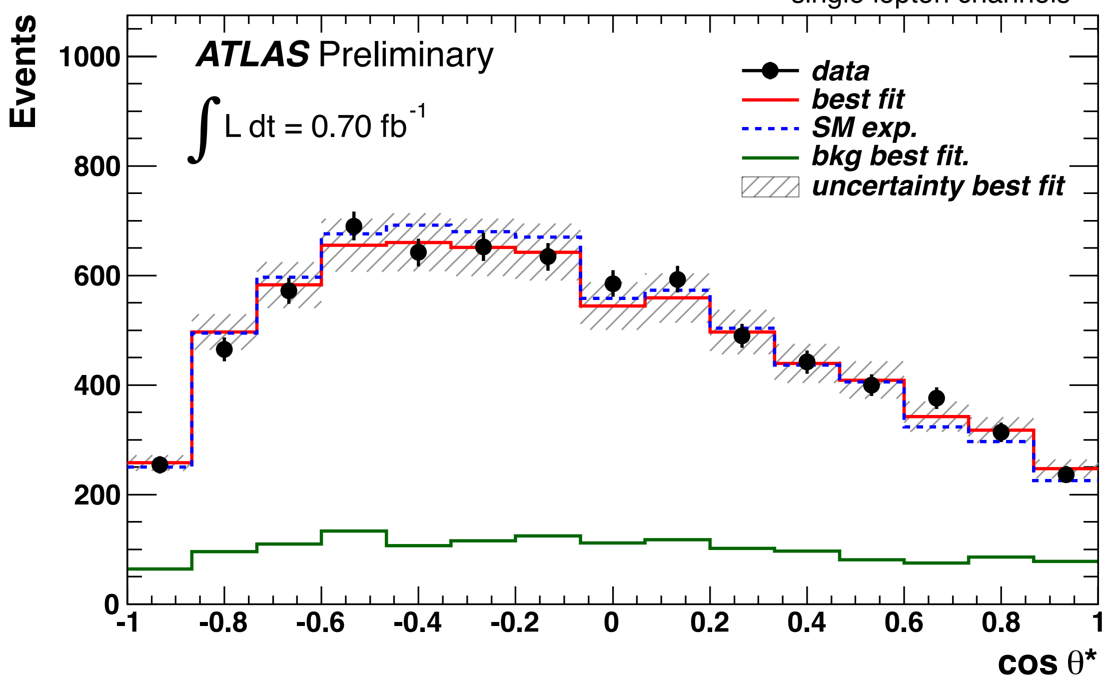
F_{RH} = 0.0017 ± 0.0001

Measurement (combined):

$F_0 = 0.75 \pm 0.08_{stat+syst}$

$F_{LH} = 0.25 \pm 0.08_{stat+syst}$

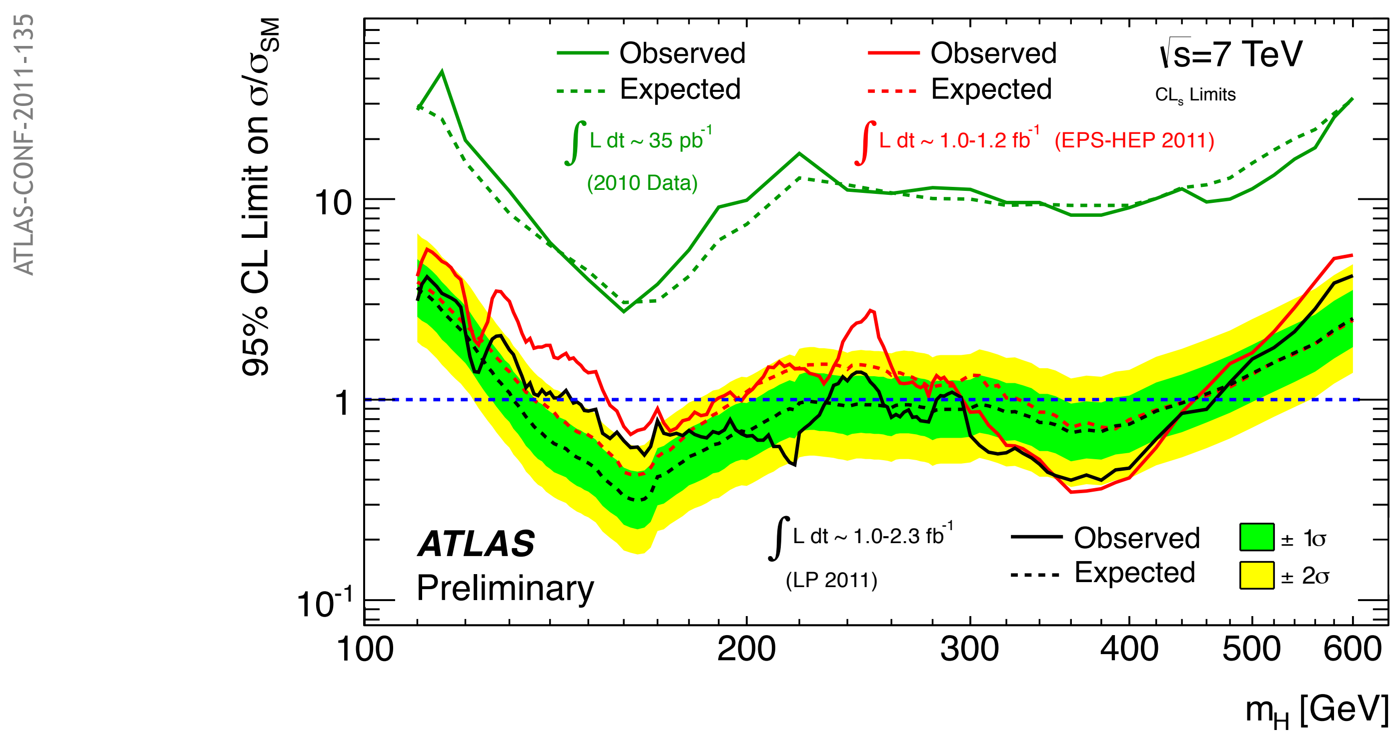
single lepton channels



What did I forget ?

P. Higgs at ATLAS

Gee — Of course !



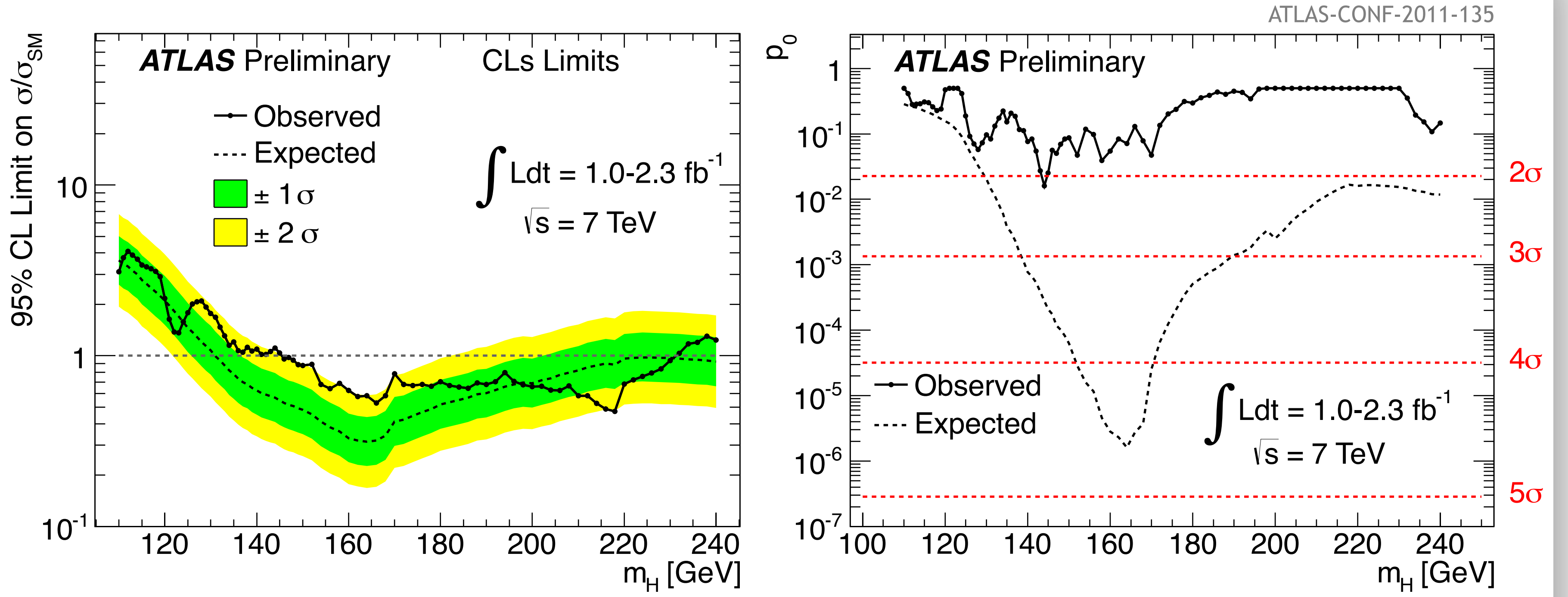
Huge progress in Higgs search over 2011 — many channels commissioned — much more to come !

95% exclusion ranges:
146−232 GeV &
256−282 GeV &
296−466 GeV

120−600 GeV for SM4

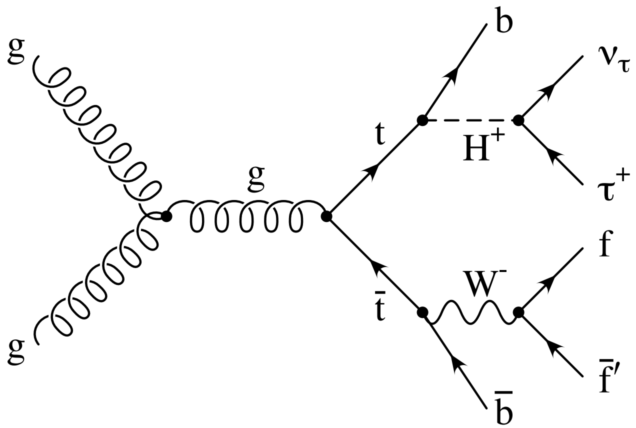
→ ***Talk by Bill Quayle on Friday !***

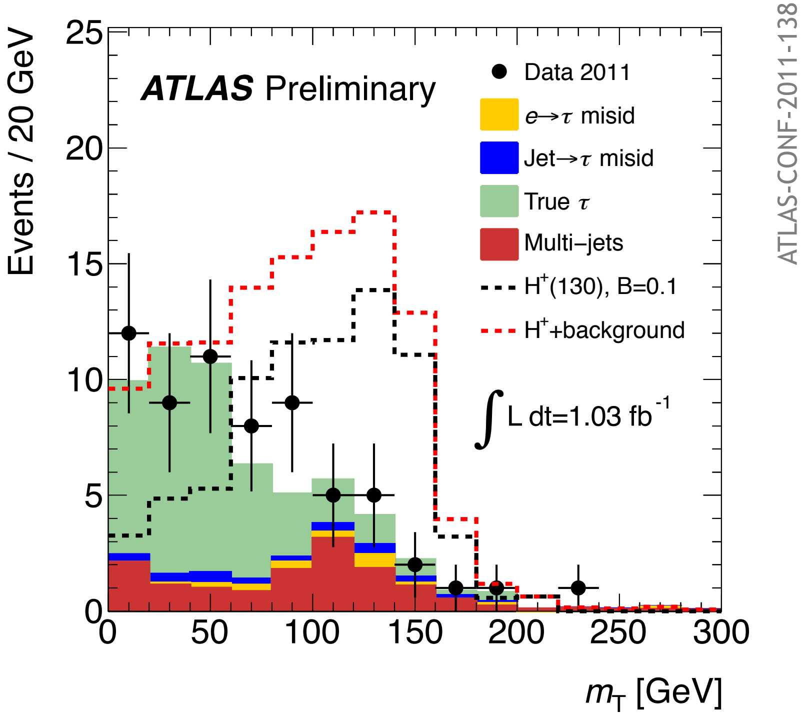
Gee — Of course !



And: BSM — charged Higgs

Search for charged Higgs in τ + jets final state in top–antitop events

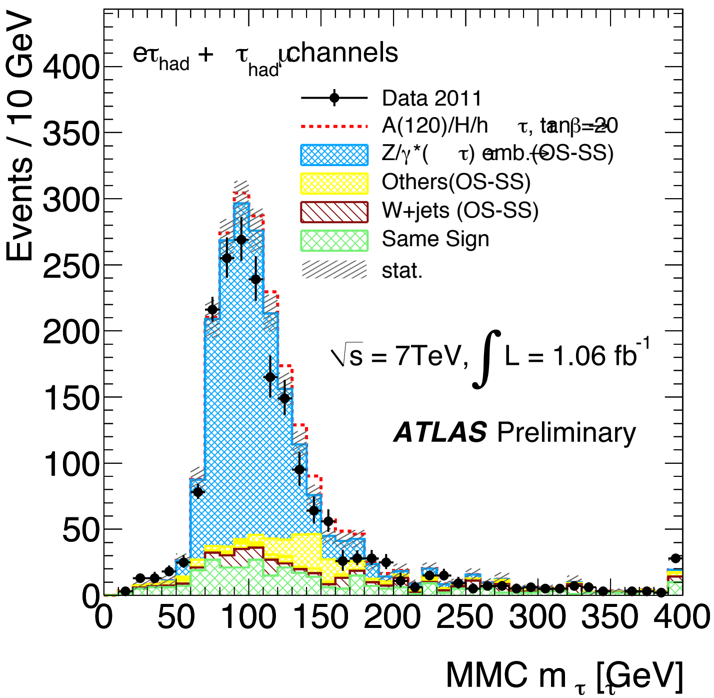


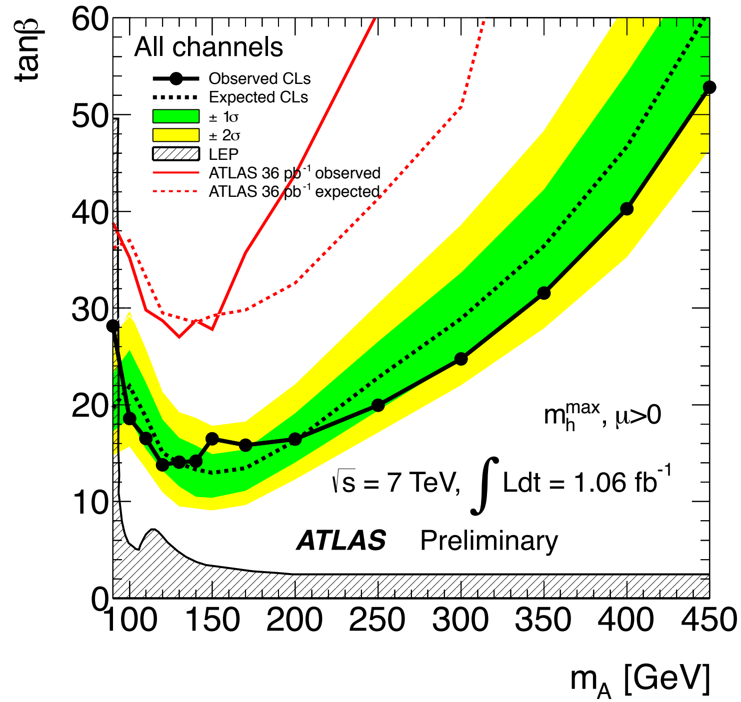


95% exclusion down to $\tan\beta$ ~23 (m_h^{max}, m_{H+} ~ 110 GeV)

→ *Talk by Louise Skinnari on Friday !*

And: BSM — neutral MSSM Higgs





Huge progress also here over 2011 — limits clearly exceed Tevatron sensitivity

Summary

I attempted a (necessarily incomplete) overview of the ATLAS status and recent physics results, after not even two years of data taking at 7 TeV, with a record peak luminosity of 3.6×10^{33}, and after passing 5 fb^{-1} integrated luminosity …

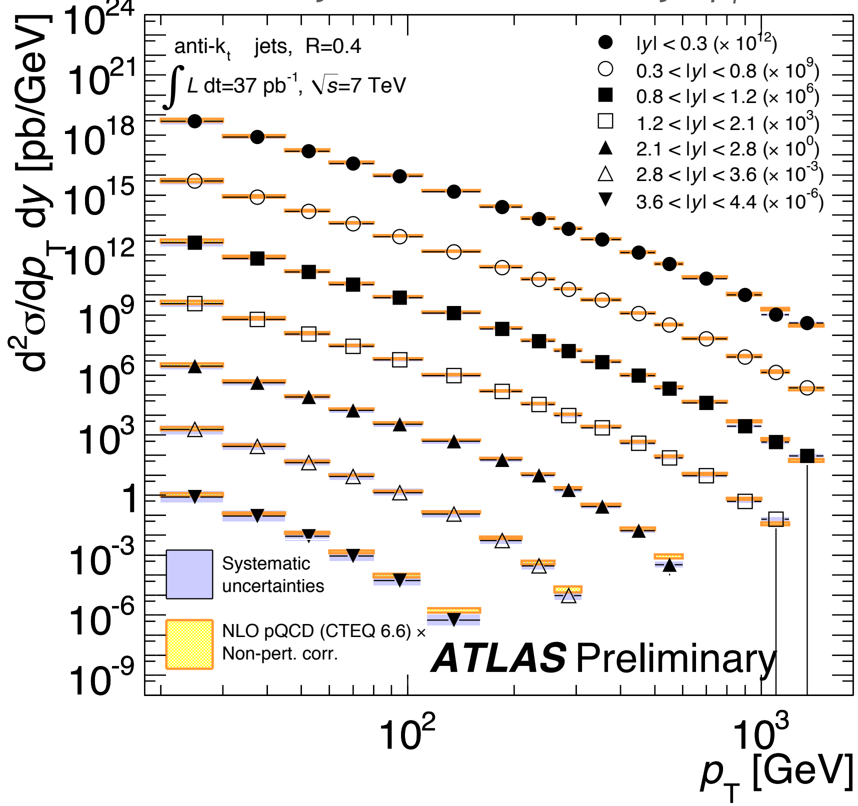
- ATLAS is a happily learning experiment. The accelerator and detector are continuously delivering beautiful data. This together with the emerging state-of-the-art MC tools opens the possibility of doing precision measurements in both the EW and QCD sectors of the SM
- Already the first 36 pb^{-1} 2010 data allowed precise theory tests
- The >5 fb^{-1} 2011 sample (thanks to the LHC team!) provides huge opportunities in all areas of the LHC physics programme. Exploiting it will keep us busy for years, and requires help from our theory colleagues on improved predictions, MC tools, critical discussions and ideas
- ATLAS, as well as the other LHC experiments, has proven to deliver high-quality analyses of its data. We need to work hard to further improve the detector understanding and to cope with the harsher getting LHC conditions
- *New physics was not around the corner. No need for preliminary conclusions. Let's just continue our work and look were we haven't looked so far!*

Extra slides…

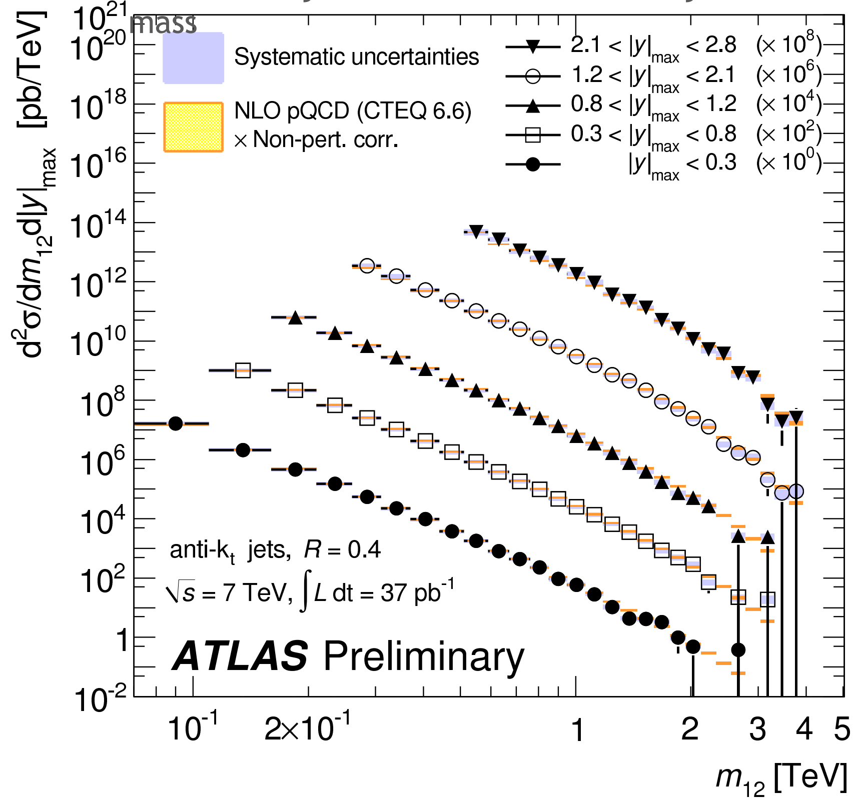
ATLAS and CMS have Measured Inclusive and Exclusive Jet Cross Sections at never Explored Energies

ATLAS-CONF-2011-047

Differential jet cross section versus jet p_T

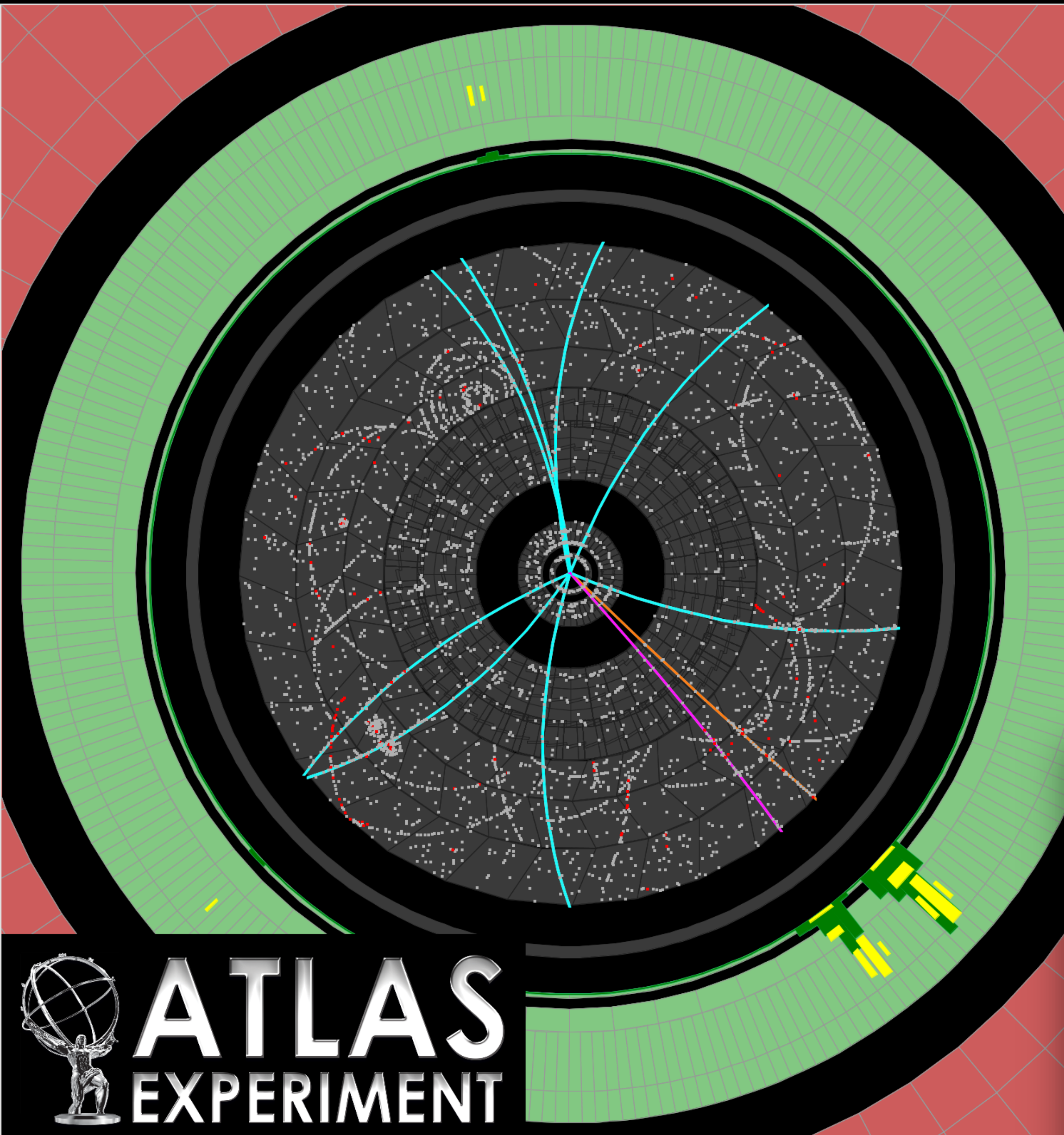


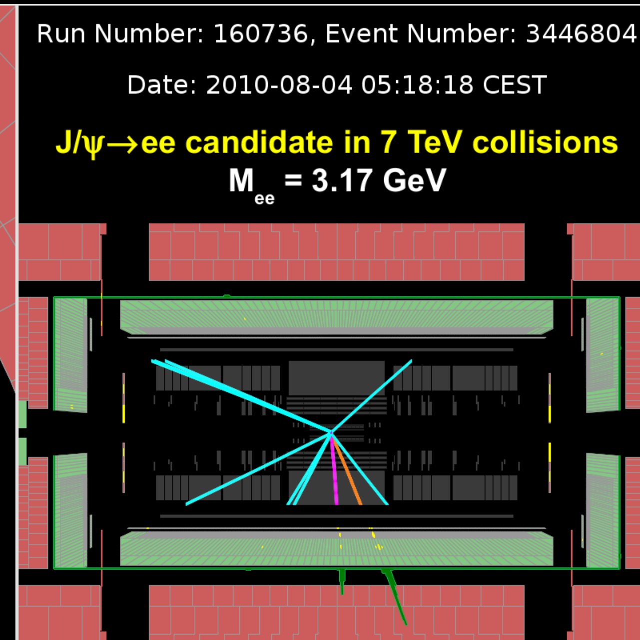
Differential jet cross section versus di-jet mass



Agreement over many orders of magnitude gives confidence for new physics searches

Display of $J/\psi \rightarrow ee$ event





Thanks to TRT, ATLAS has a J/ψ tag-and-probe trigger even at $L = 3 \times 10^{33}$. Crucial to understand low-p_T electrons for, e.g. $H \rightarrow 4e$

$J/\psi \rightarrow ee$ events also important for understanding of EM calo performance (extraction of resolution, intercalibration, etc)

Combining all channels (status: Lepton-Photon 2011)

At high mass also $WW \to llqq$ and $ZZ \to ll\nu\nu$ channels contribute

ATLAS-CONF-2011-135, CMS-PAS-HIG-11-022

Individual results (ATLAS)