ATLAS EXPERIMENT
http://atlas.ch

MAX-PLANCK-GESELLSCHAFT

ATLAS Project Review

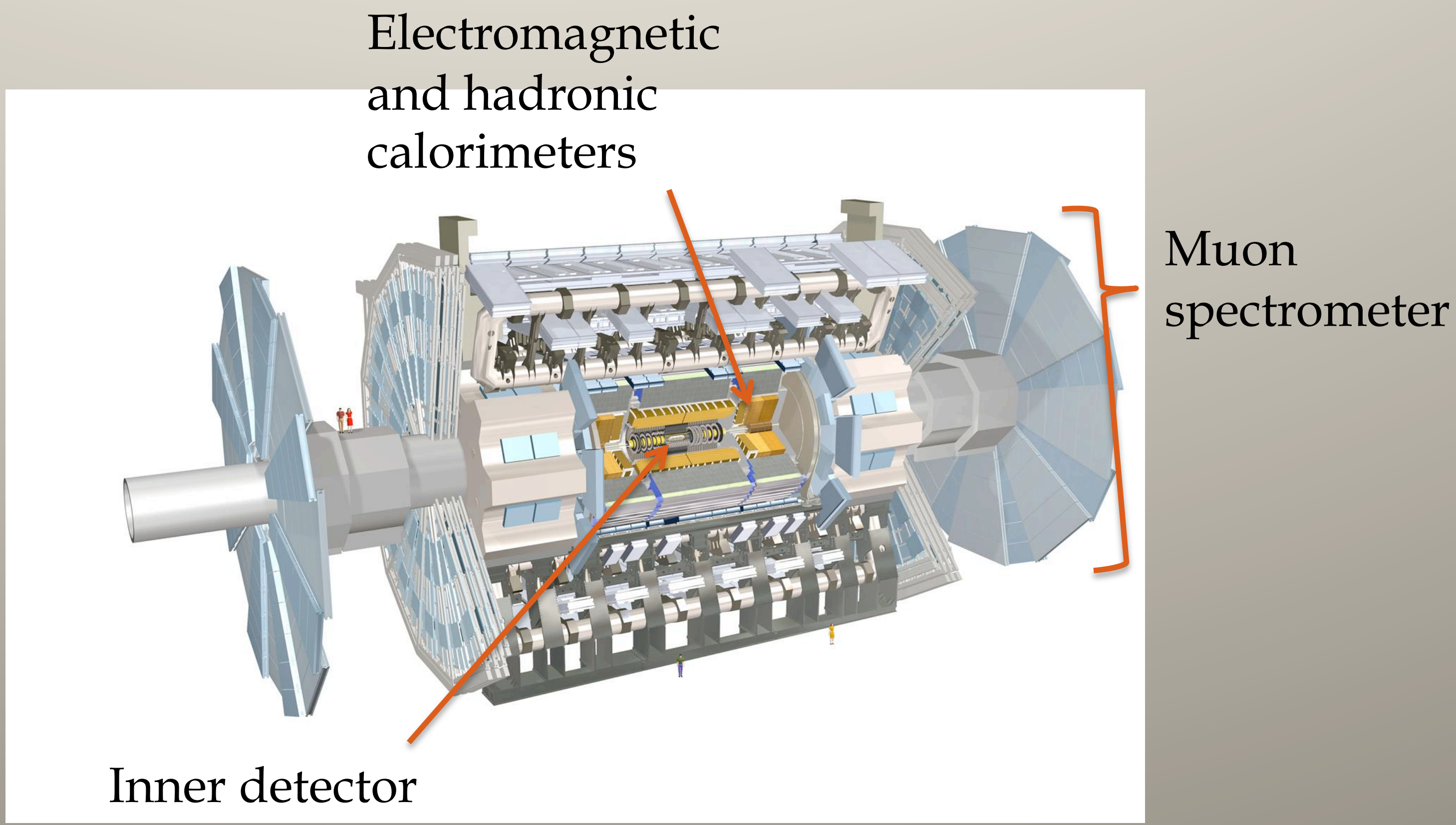
Mike Flowerdew
on behalf of the MPP ATLAS group

Outline

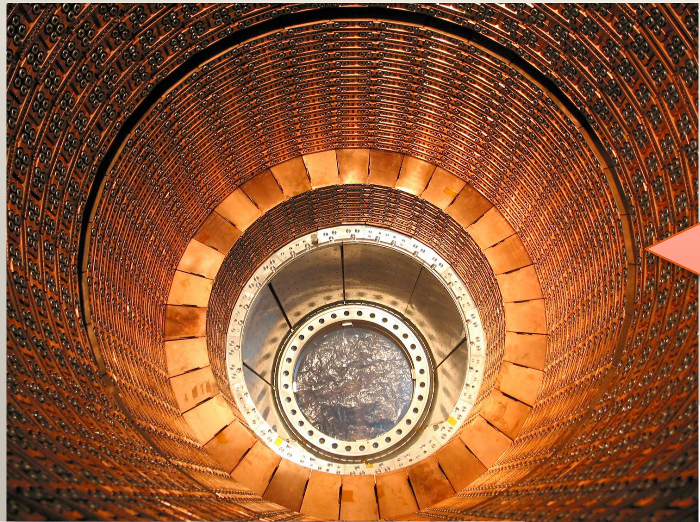
- **ATLAS and the LHC** in 2011
- **Detector monitoring and performance** activities
  - Data Quality and detector operations
  - Muon Spectrometer
  - Hadronic calibration
- **Physics analysis @ MPP**
  - Standard Model physics (including top quark)
  - SM and MSSM Higgs searches
  - Supersymmetry
- **High luminosity upgrade** activities
  - Pixel tracker, hadronic endcap and muon spectrometer
- **Summary and conclusions**

ATLAS

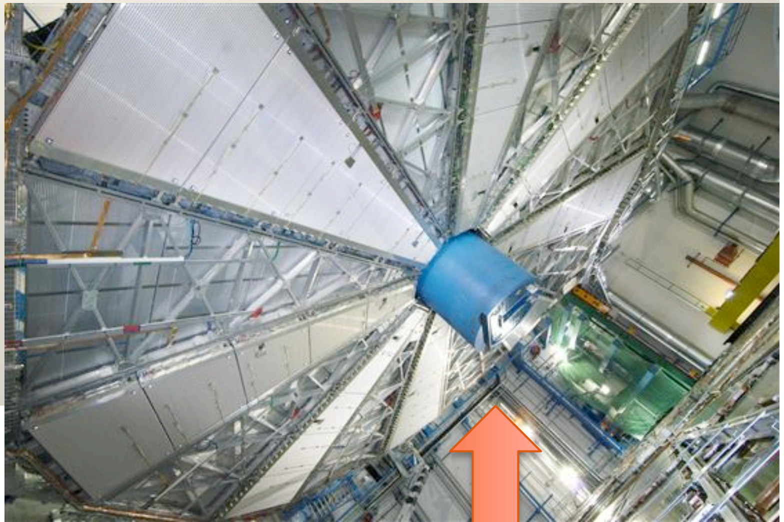
- **Multi-purpose 4π detector design**
  - For jets, b-jets electrons, photons, muons, tau leptons and missing E_T (MET) from proton-proton and heavy ion collisions



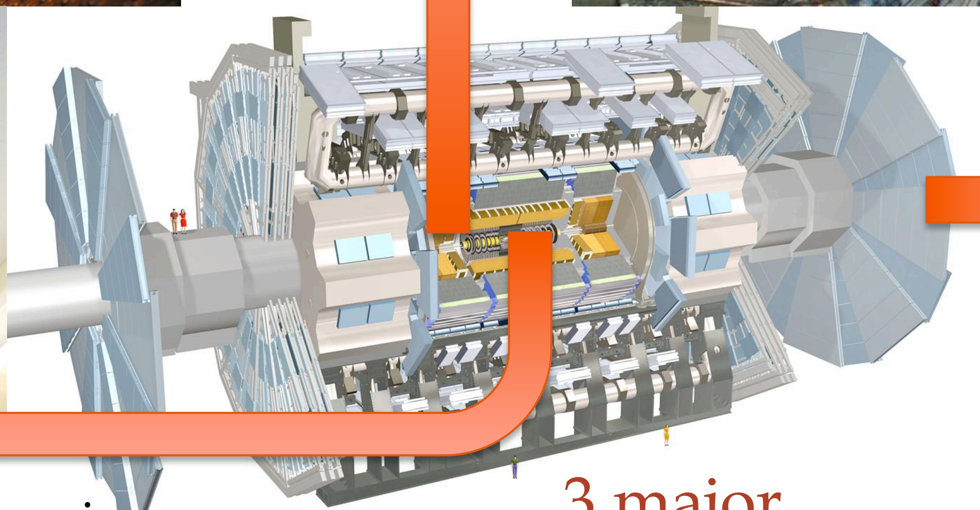
MPP in ATLAS

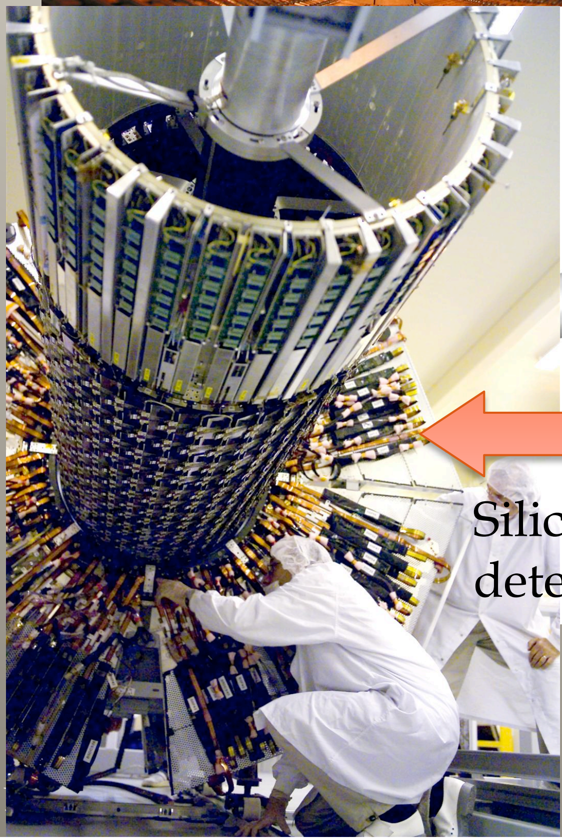


Hadronic
endcap
calorimeter



Muon
spectrometer



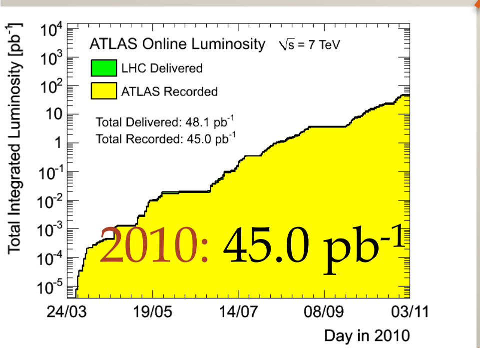


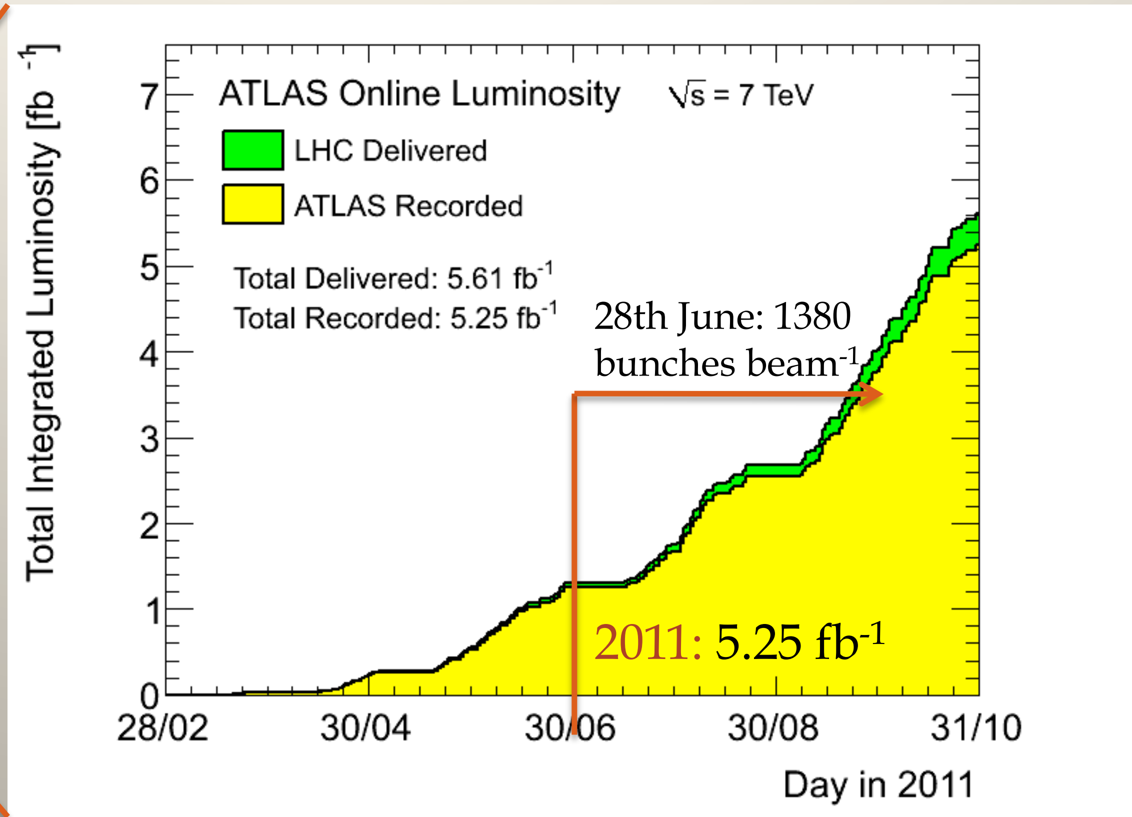
Silicon inner
detector tracker

3 major
subsystems...

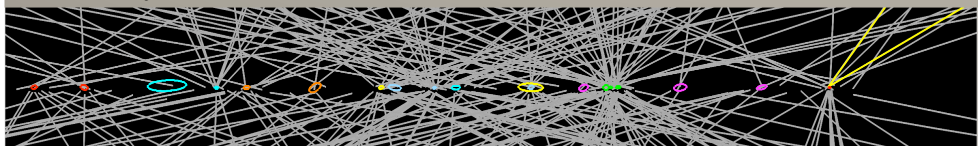
... plus many activities in software,
monitoring, trigger and physics analysis

The LHC in 2011





Typical low β* collision with 20 reconstructed primary vertices



- 2011 was an incredible data-taking year for the LHC
- Instantaneous luminosities up to 3.65×10^{33} cm^{-2} s^{-1}
  - Serious challenges with pile-up
- Also heavy ion collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

The ATLAS MPP group

H Abramovitz, T Barillari, S Bethke, B Bittner, J Bronner, D Capriotti, G Compostella, G Cortiana, J Dubbert, M Flowerdew, C delle Fratte, P Giovannini, M Goblirsch-Kolb, P Haefner, A Jantsch, A Kiryunin, S Kluth, O Kortner, S Kortner, S Kotov, H Kroha, J v. Loeben, A Manfredini, A Macchiolo, S Menke, H-G Moser, M Nagel, R Nisius, H Oberlack, G Pospelov, C Pahl, I Potrap, R Richter, R Sandstrom, D Salihagic, P Schacht, H v. d. Schmitt, P Schwegler, R Seuster, S Stern, S Stonjek, M Vanadia, P Weigell, D Zanzi, V Zhuravlov

Staff/postdocs, students

... plus a **huge** thanks to the MPP technical department!

Coordinating roles in 2011:

Speakers' Committee chair: **Hubert Kroha**
Computing coordinator: **Hans von der Schmitt**
Higgs working group convenor: **Sandra Kortner**
Muon combined performance WG convenor: **Oliver Kortner**

Reconstruction coordinator: **Rolf Seuster** → Software coordinator in 2012
SCT data quality coordinator and Run manager: **Petra Haefner**
Top quark mass subgroup convenor: **Giorgio Cortiana**

EXPERIMENTAL OPERATIONS AND PERFORMANCE

T Barillari, P Haefner,
S Huber, M Nagel,
H Oberlack, S Stern,
M Vanadia

Data Quality and detector operations

- Data Quality describes how well the detector is working, assessed online and offline
  - Originally green / red subdetector flags
  - Now we use **defect monitoring** for additional flexibility

- **All detectors** operating well, with high efficiency
  - Thanks in part to years of design, construction and commissioning efforts, not least by workers at MPP

Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.6	99.2	97.5	99.2	99.5	99.2	99.4	98.8	99.4	99.1	99.8	99.3

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and October 30th (in %), after the summer 2011 reprocessing campaign

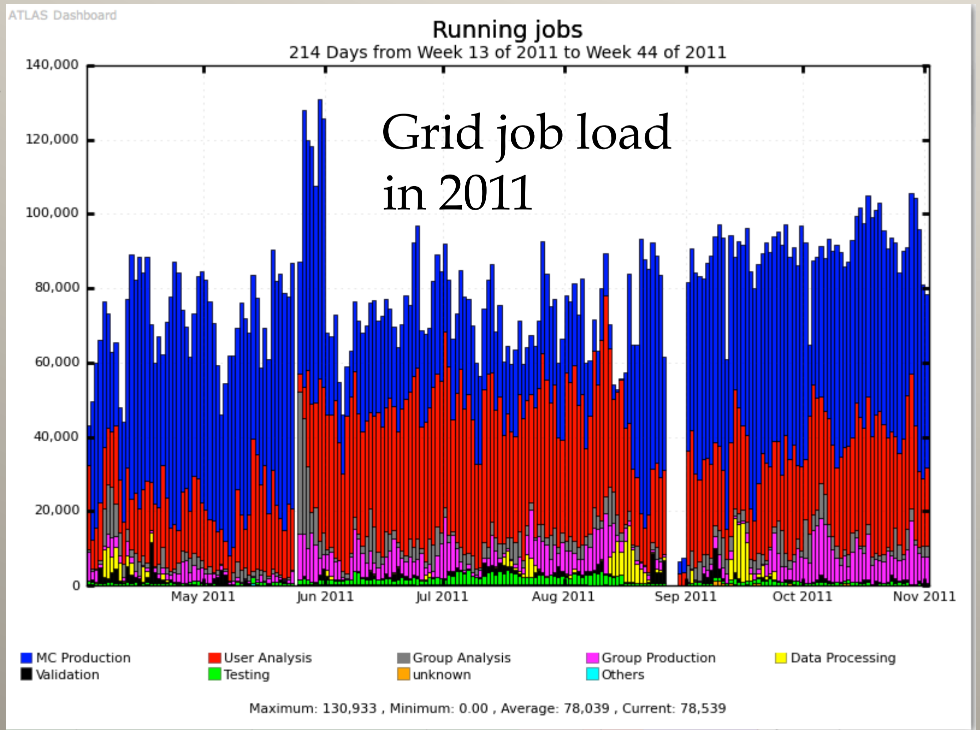
- MPP contributions to DQ of SCT, HEC and MDT
  - SCT Data Quality
  - MDT Data Quality (including for calibration)
  - HEC low voltage hardware/software and local expert coordination

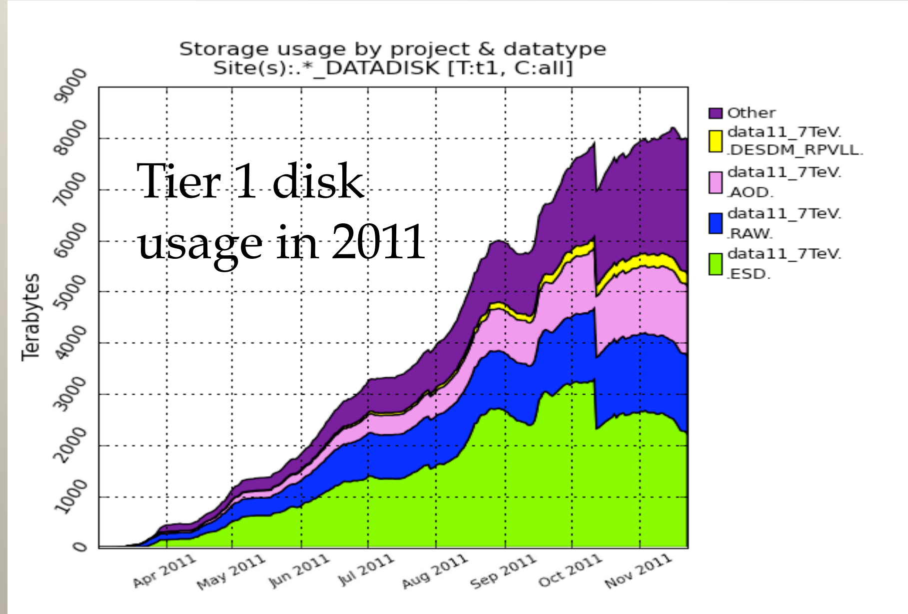
Computing

G Compostella,
S Kluth,
H vd Schmitt,
R Seuster

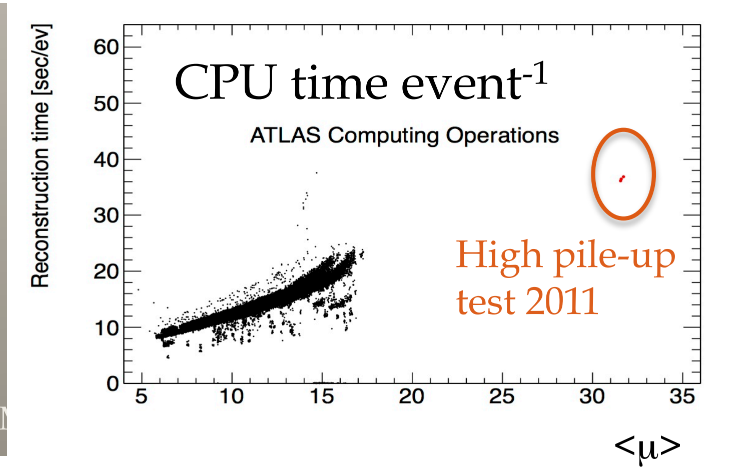
- Tier 0 (CERN): prompt and post-calibration data reconstruction
- Results distributed to Tier 1 and Tier 2 sites
  - Re-reconstruction with new software releases/calibrations; physics analysis
- The Grid has ~ 80k CPU cores and ~20 PB storage

concurrent Grid jobs





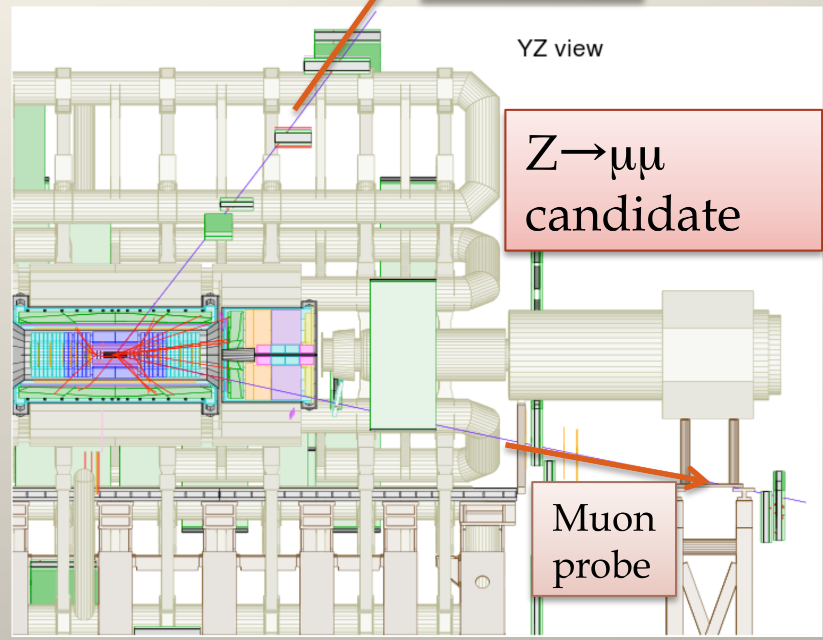
- High pile-up places strain on event reconstruction too
  - Increased software speed and CPUs for 2012



Muon performance

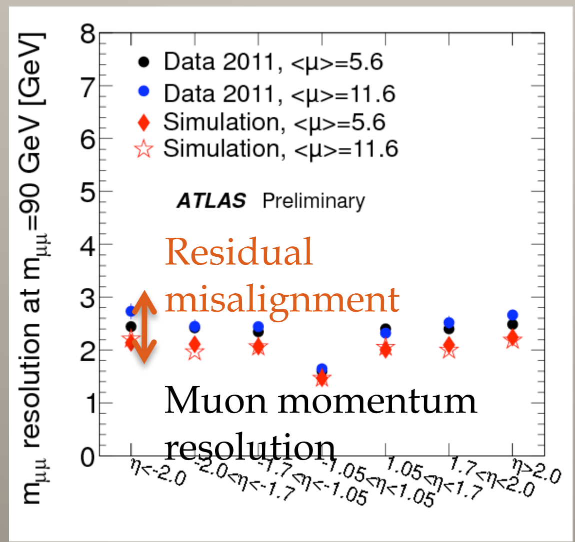
J Bronner, D Capriotti, M Flowerdew,
M Goblirsch-Kolb, A Manfredini,
C Pahl, I Potrap, R Sandström,
S Stern, M Vanadia, O Kortner

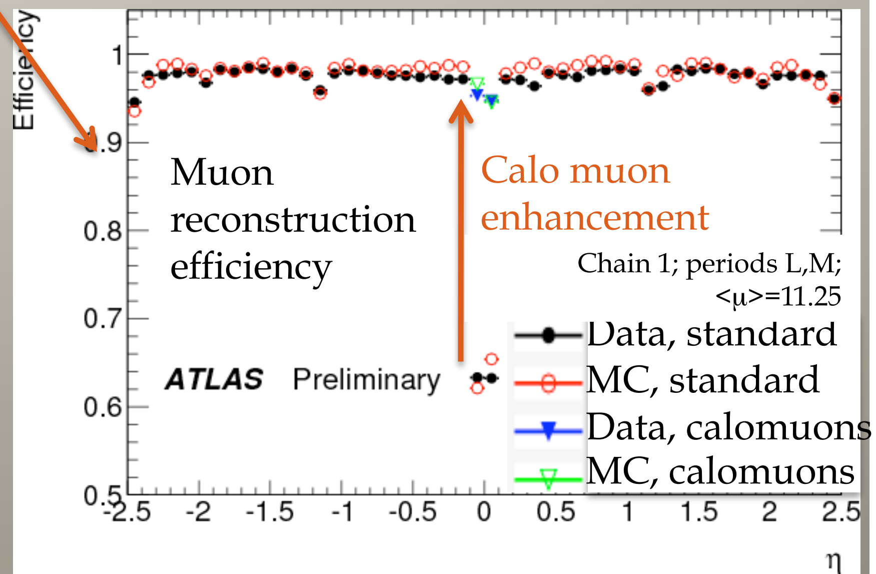
Major MPP contributions



- Muon spectrometer performance measured using Z → μμ decays (tag and probe)
- Reconstruction **efficiency** is high, flat and stable between run periods
  - **Isolation** efficiencies also measured with different pile-up conditions
- Muon **resolution** approaching design value

- Other performance work:
  - Spectrometer **Alignment**
  - Precision chamber **calibration**



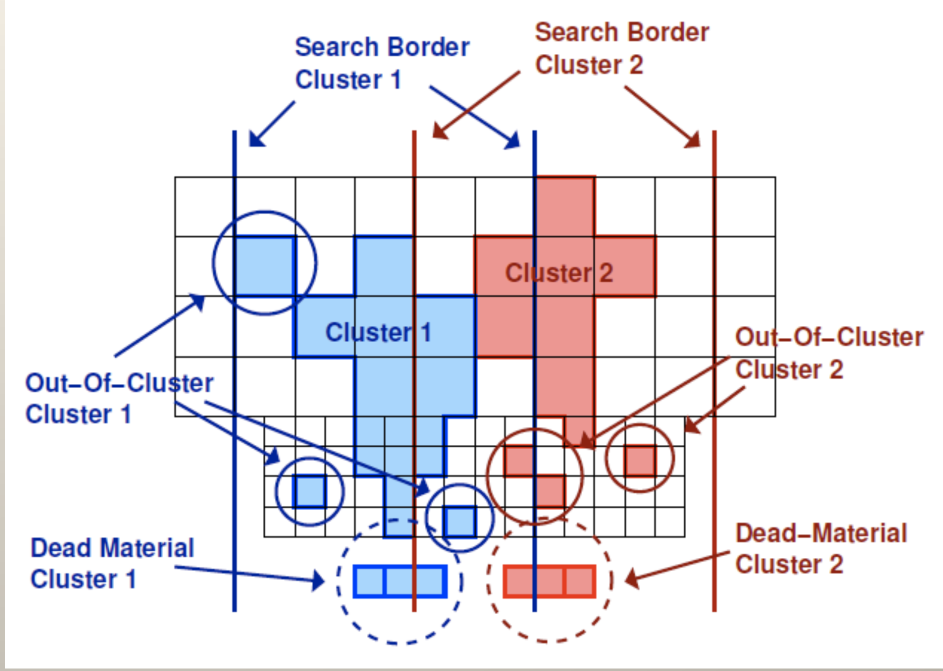


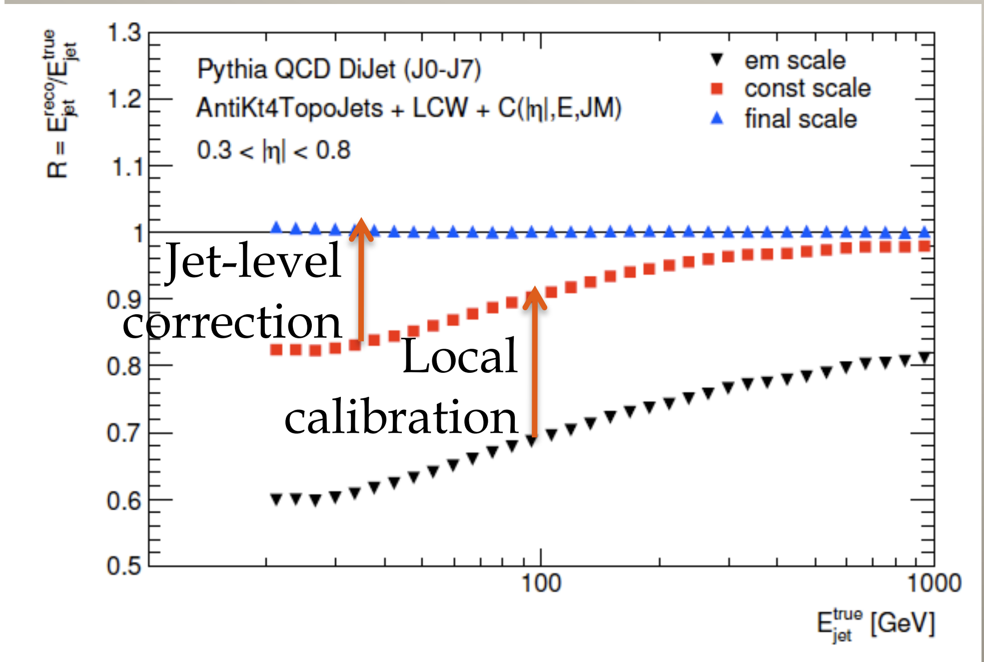
Hadronic calibration

T Barillari, A Jantsch,
A Kiryunin, G Pospelov,
D Salihagic, S Menke

Major MPP contributions

- **Topological clusters** now used as standard for jets in ATLAS
  - 3D energy blobs
  - Stable particle picture of a jet
  - Calibration **stable** with increasing pile-up



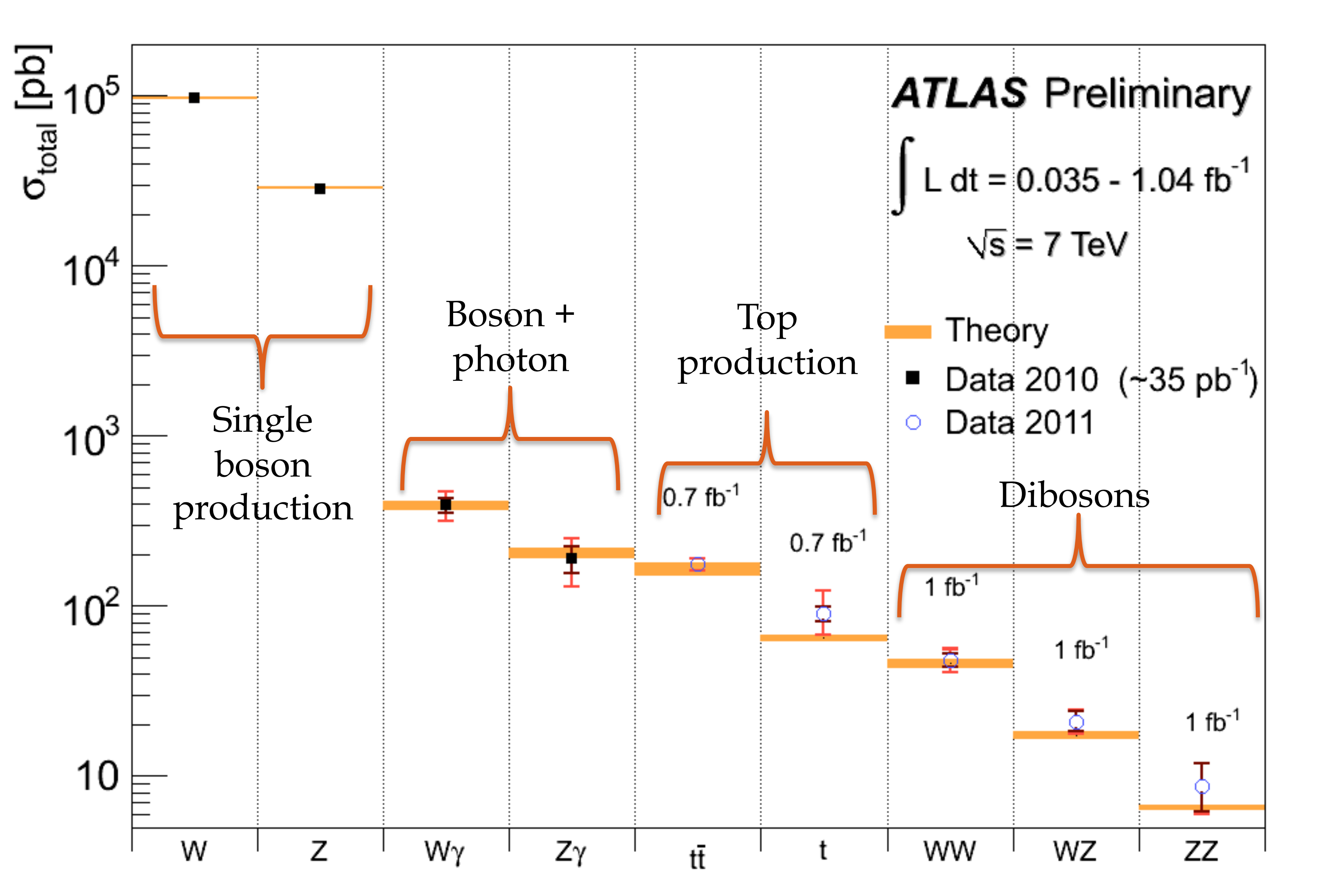


- **Local Hadronic Calibration** now a standard for jets and MET
  - **Modular identification** and calibration of energy deposits

PHYSICS ANALYSIS

For (lots) more information, please visit
https://twiki.cern.ch/twiki/bin/view/AtlasPublic

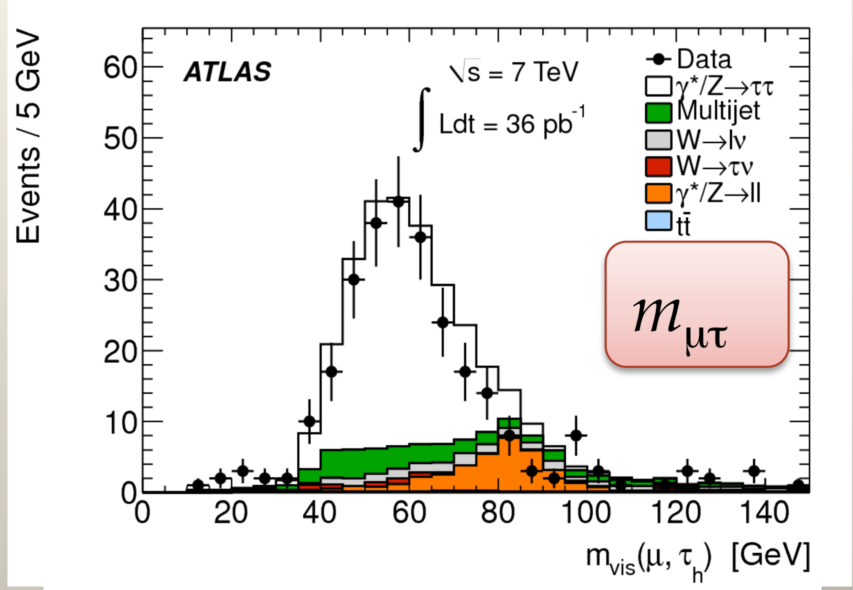
Standard Model overview

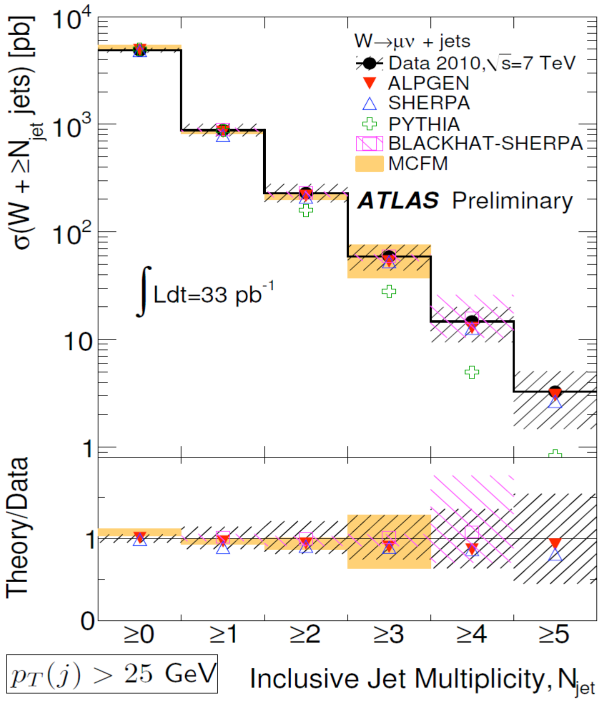


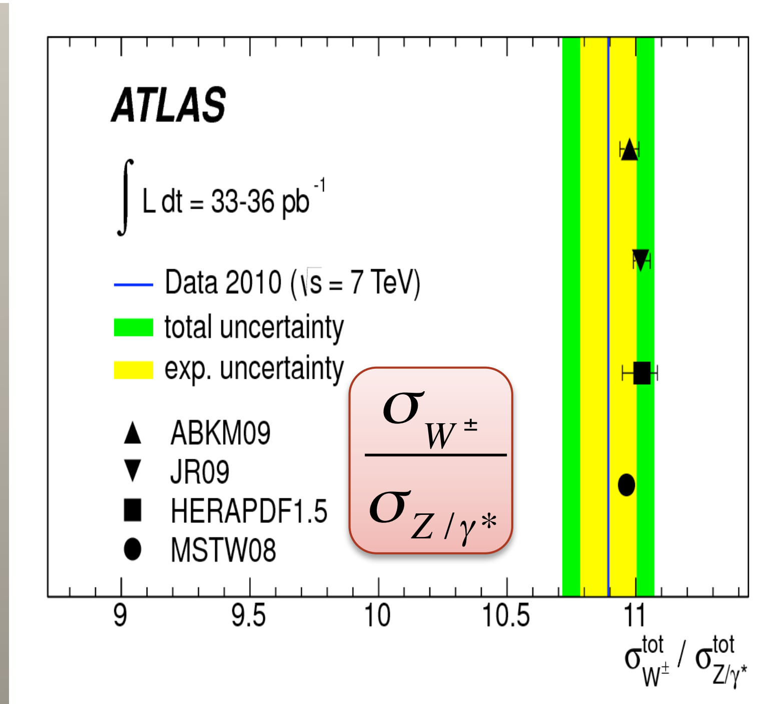
SM electroweak physics

D Capriotti, M Goblirsch-Kolb, M Vanadia, O Kortner, S Kortner, H Kroha

- **Inclusive W and Z** production measured with 2010 and 2011 data
  - Also **W+jets**, W+b and W+c
  - MPP contributions to **muon and tau** channels
  - Demonstrates **detector performance**
  - Tests theoretical **QCD** predictions



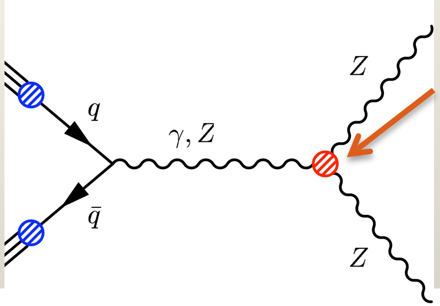




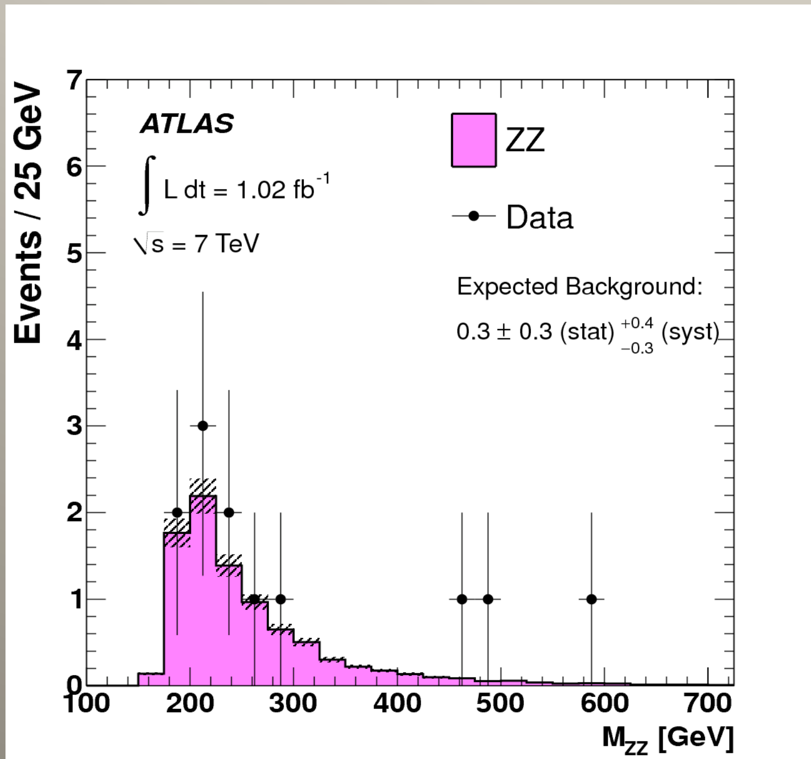
ZZ→4l cross section measurement

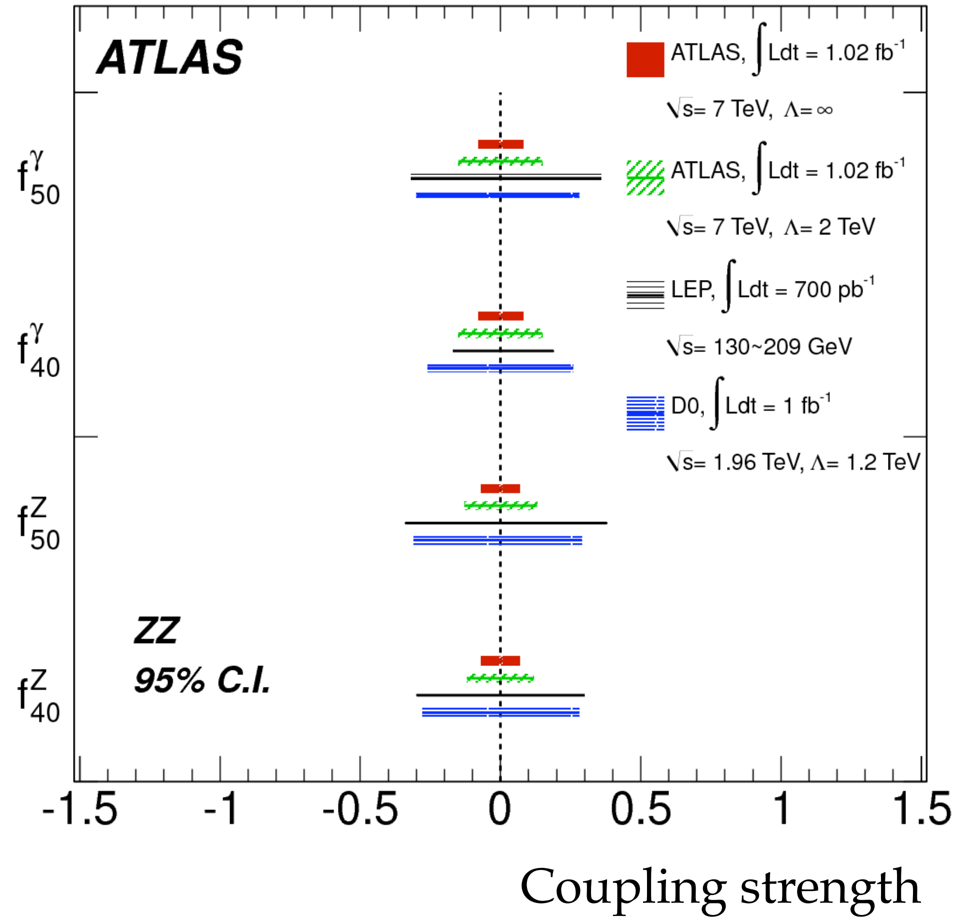
M Goblirsch-Kolb, O Kortner, H Kroha

- 4e, 4μ and 2e2μ final states
- Main **background** to H→ZZ→4l
- Sensitive to anomalous triple gauge couplings
  - **No indications of anomalies** with 1 fb^{-1}



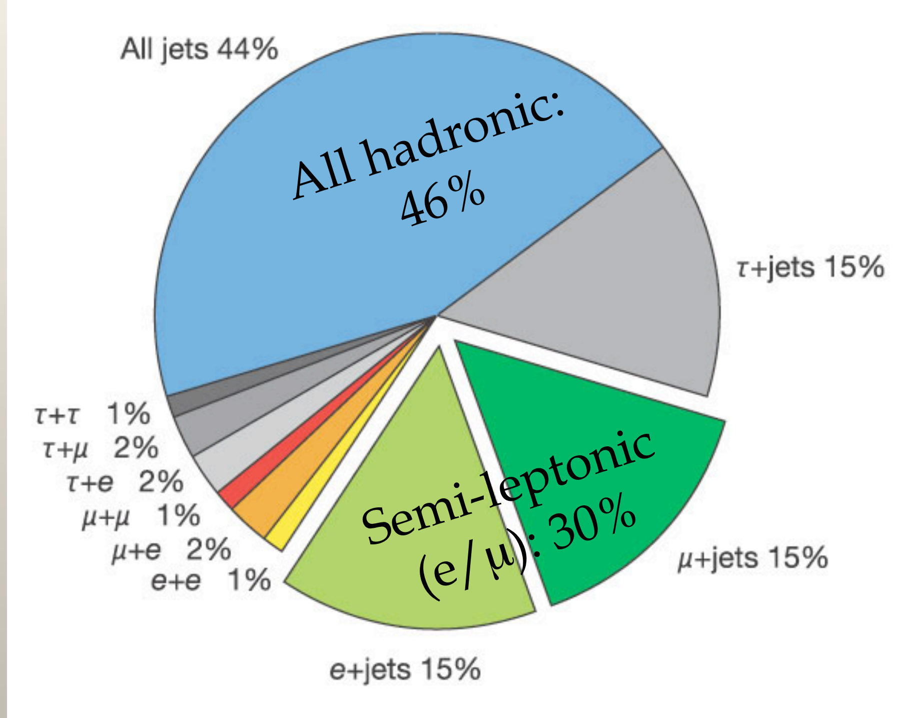
Coupling = 0 in SM @ Leading Order
Non-SM:
f_4^V: CP-violating
f_5^V: CP-conserving

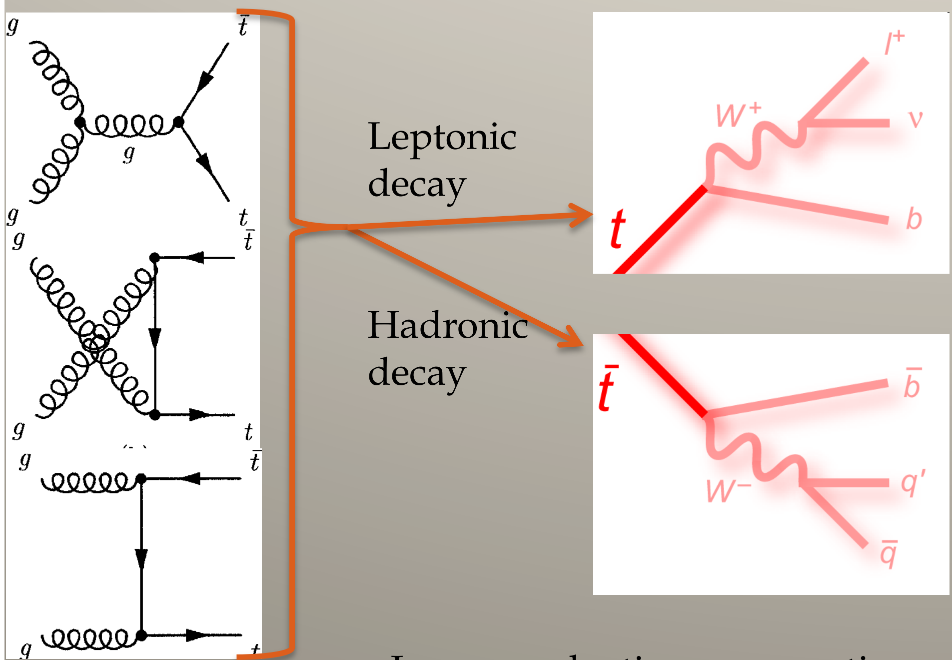




Top quark overview

- The **top quark** plays a central role in LHC physics
  - Mass is a **fundamental parameter** of the Standard Model
  - Unbiased constraint on **Electroweak symmetry breaking**
  - **New physics** coupled to 3rd generation
  - Important **background** to direct searches





- Many measurements made so far by ATLAS
  - Top quark **production**
    - Including single top, resonance and 4th generation searches
  - Different **decay channels**
    - e.g. searches for anomalous decays
  - Top **properties**
    - Mass, charge, polarisation

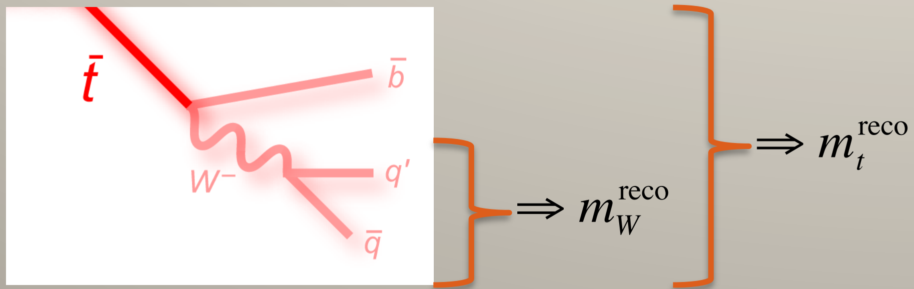
Large production cross section:

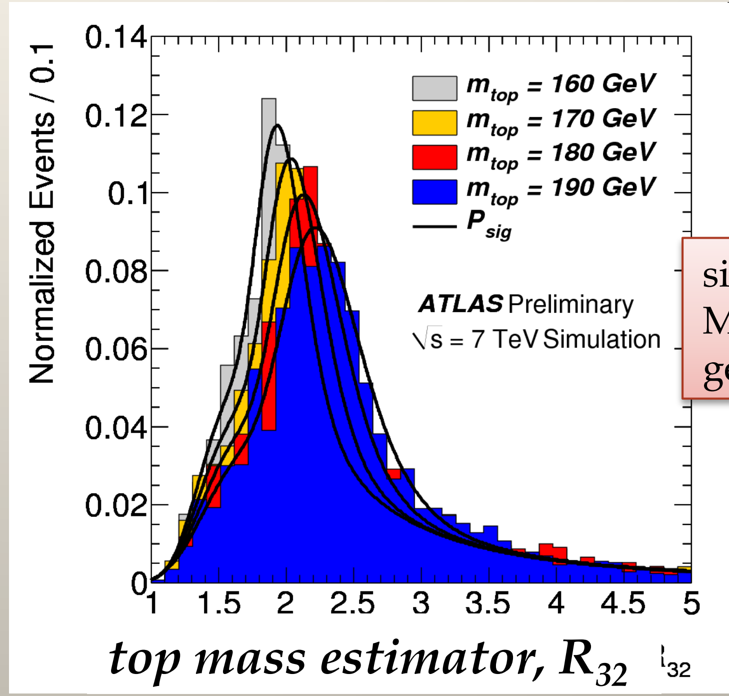
$$\sigma(t\bar{t}) = 171\ \text{pb} \pm 20\ (\text{stat}) \pm 14\ (\text{syst})\ ^{+8}_{-6}\ (\text{lumi})$$ arXiv:1108.3699, submitted to Phys. Lett. B

Top quark mass in the semileptonic channel

G Compostella, G Cortiana, A Jantsch, S Kluth, R Nisius

- Signal and background **templates** fitted to data to extract the top mass
  - Major MPP contribution
- Use reconstructed jets to measure the top mass





signal PDF from MC at different generated m_{top}

- This ratio **minimises systematic uncertainties**, eg from jet energy scale (JES):

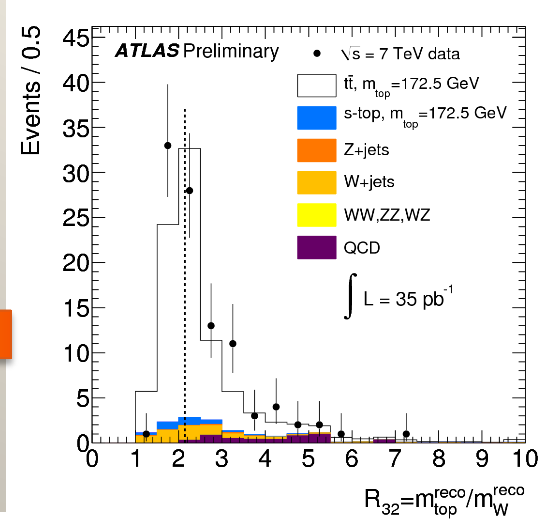
$$R_{32} = \frac{m_t^{reco}}{m_W^{reco}} = \frac{m(\text{jet, jet, bjet})}{m(\text{jet, jet})}$$

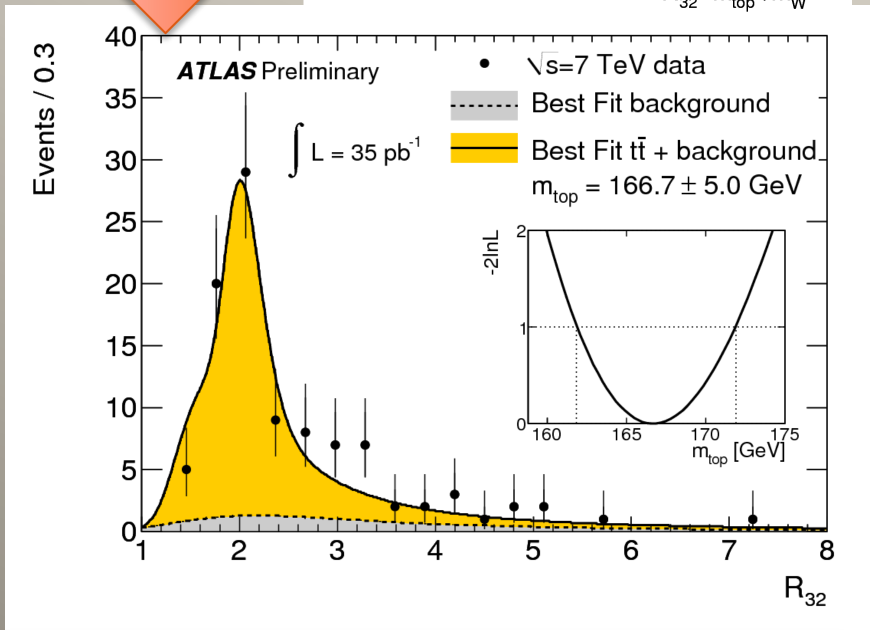
- 3× reduced JES systematic
- Analysis will be improved further:
  - Multi-dimensional templates to constrain b-jet energy scale
  - Improved W/top jet association

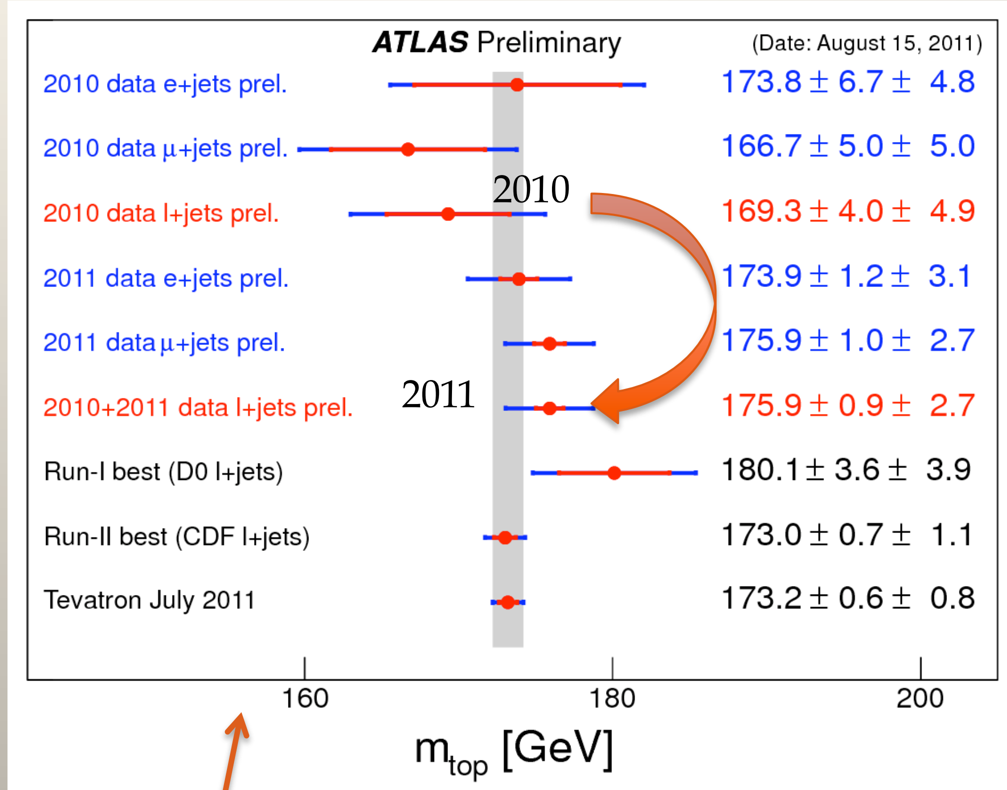
Top mass in the semileptonic channel

μ+jets, 35 pb^{-1}

Template fit







First ATLAS top quark mass result!

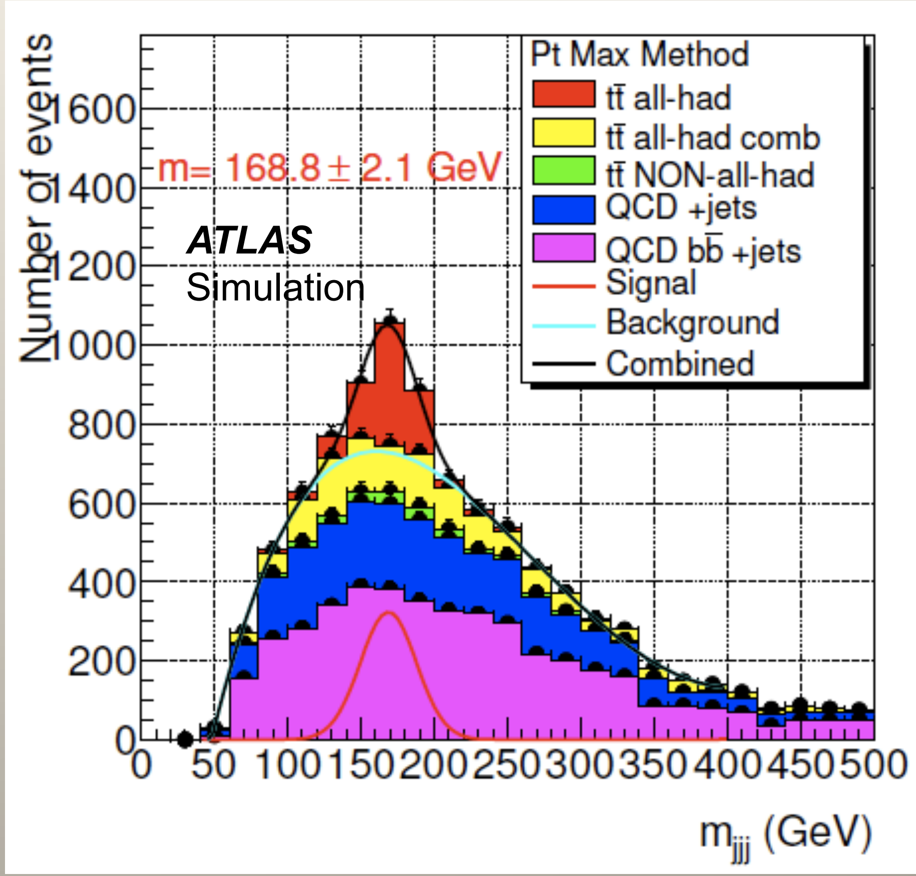
Strong MPP contribution

- Semileptonic top mass summary
  - **Huge improvements** from 2010-2011
  - Already much closer to Tevatron precision

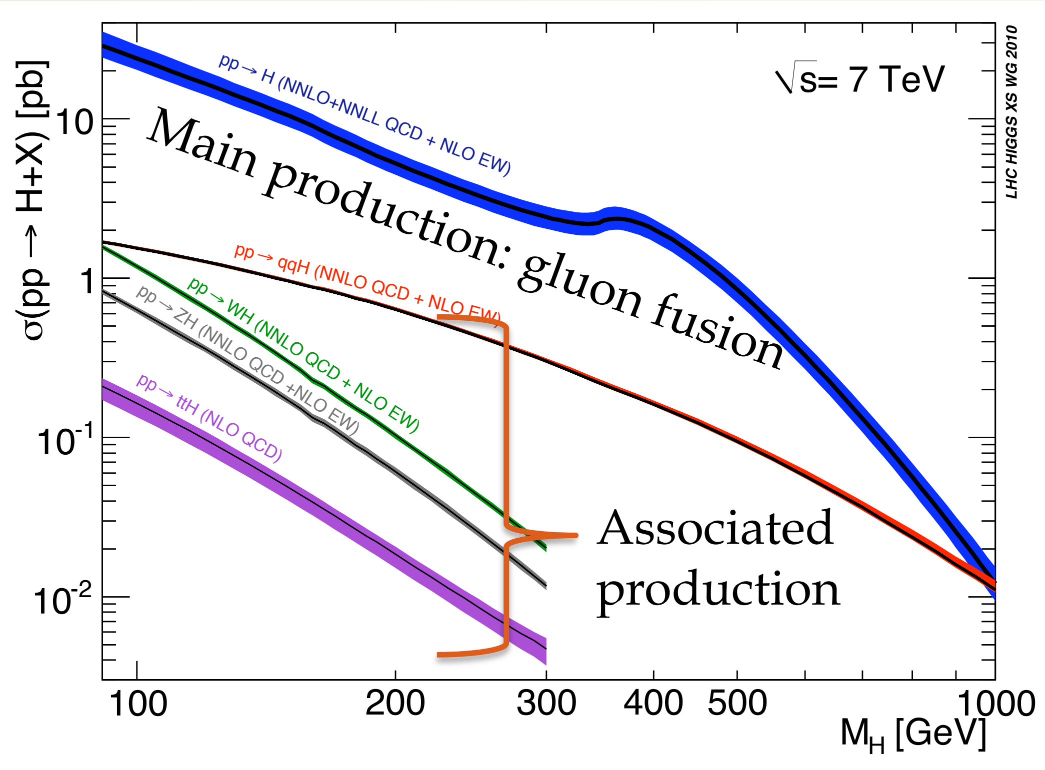
Top quark mass: fully hadronic channel

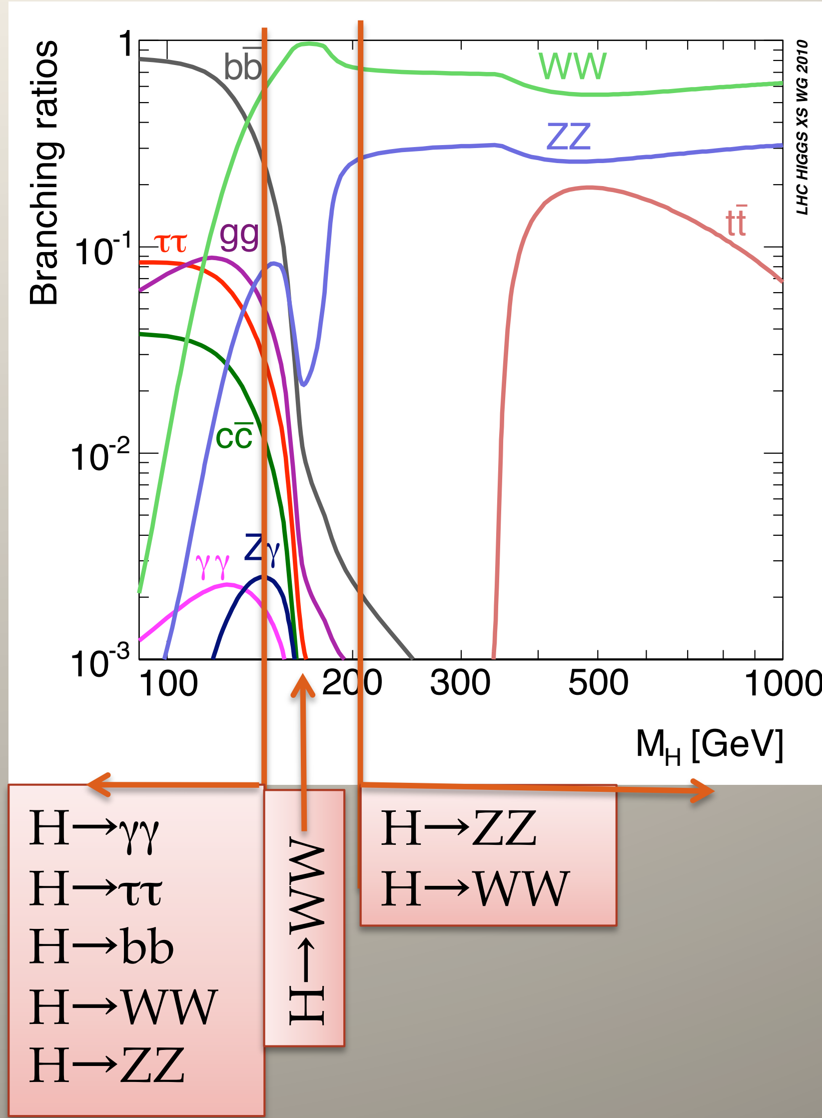
P Giovannini

- The fully hadronic mode is challenging to reconstruct
  - 6 jets, no leptons or MET!
- **MC feasibility study** shows potential for a mass measurement
  - √s = 10 TeV simulation
  - 200 pb^{-1} assumed luminosity
- Gaussian + polynomial fit to tri-jet mass
  - Systematic uncertainty of **7.3 GeV**, dominated by jet energy scale



Standard Model Higgs overview



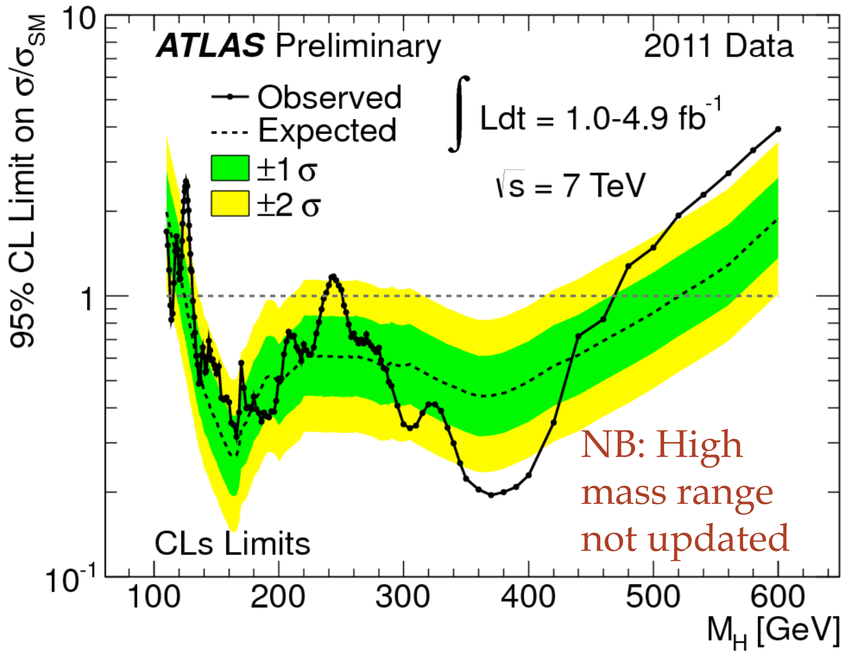


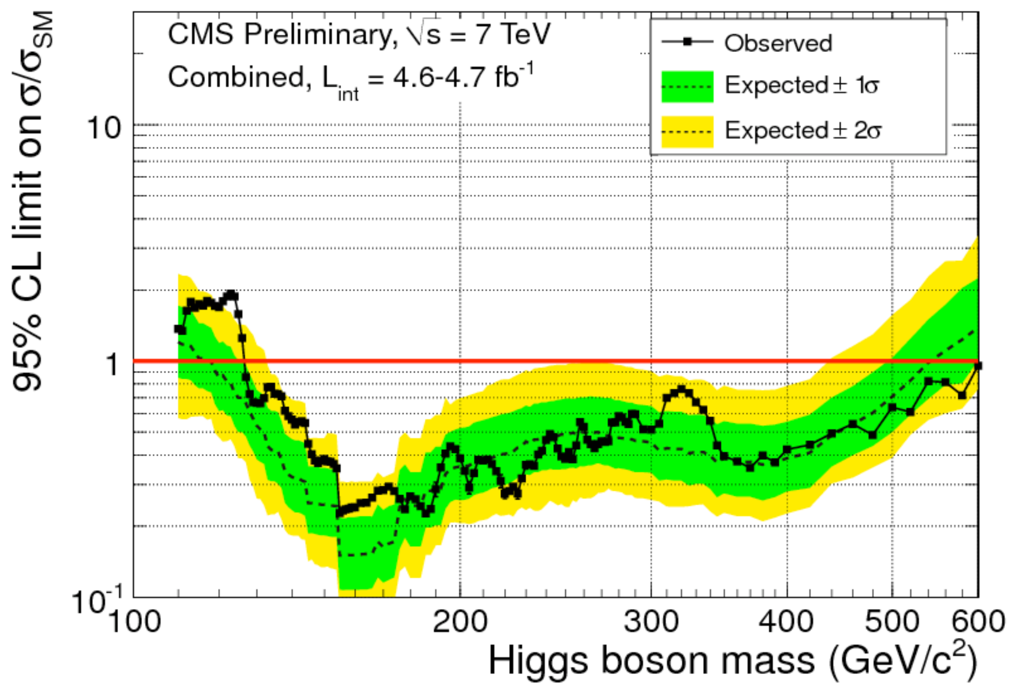
- **Critical part** of the Standard Model
- Significant reach with 5fb^{-1} of LHC data
- **Multi-channel discovery strategy** covers the full mass range

SM Higgs search status

S Kortner

- ATLAS and CMS updates presented at public CERN seminar last Tuesday
  - A **wide mass range excluded**, accompanied by an **excess at low mass**

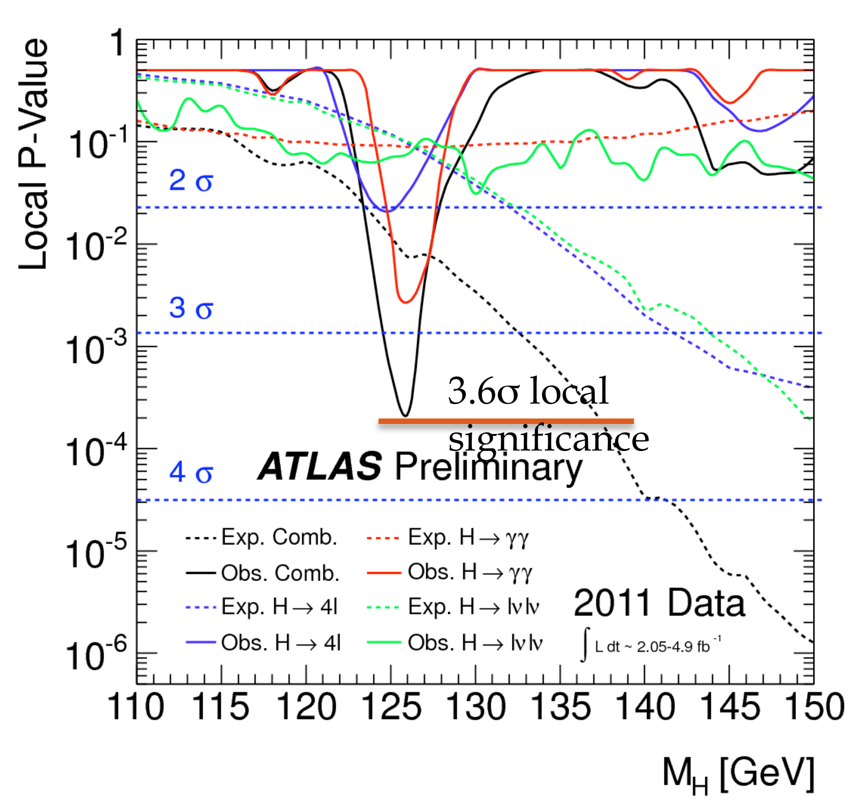




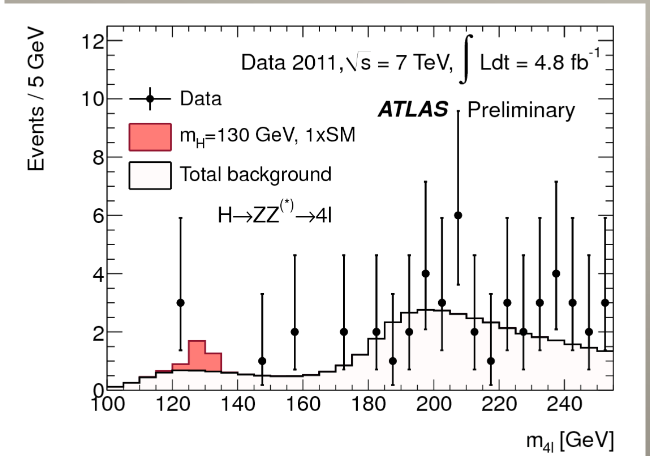
	ATLAS	CMS
Expected	124.6-520 GeV	117-543 GeV
Observed	112.7-115.5, 131-237, 251-453 GeV	127-600 GeV

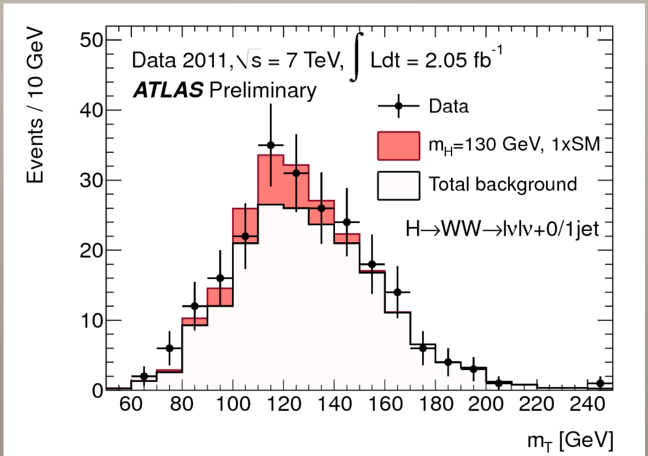
Excluded ranges (95% CL, CL_s prescription)

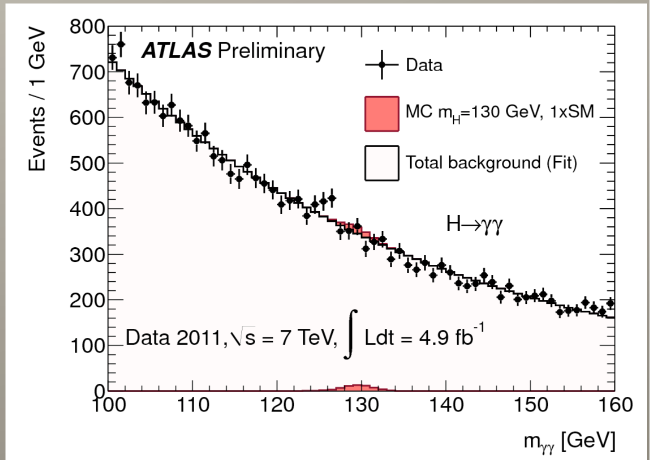
Observed low mass excess



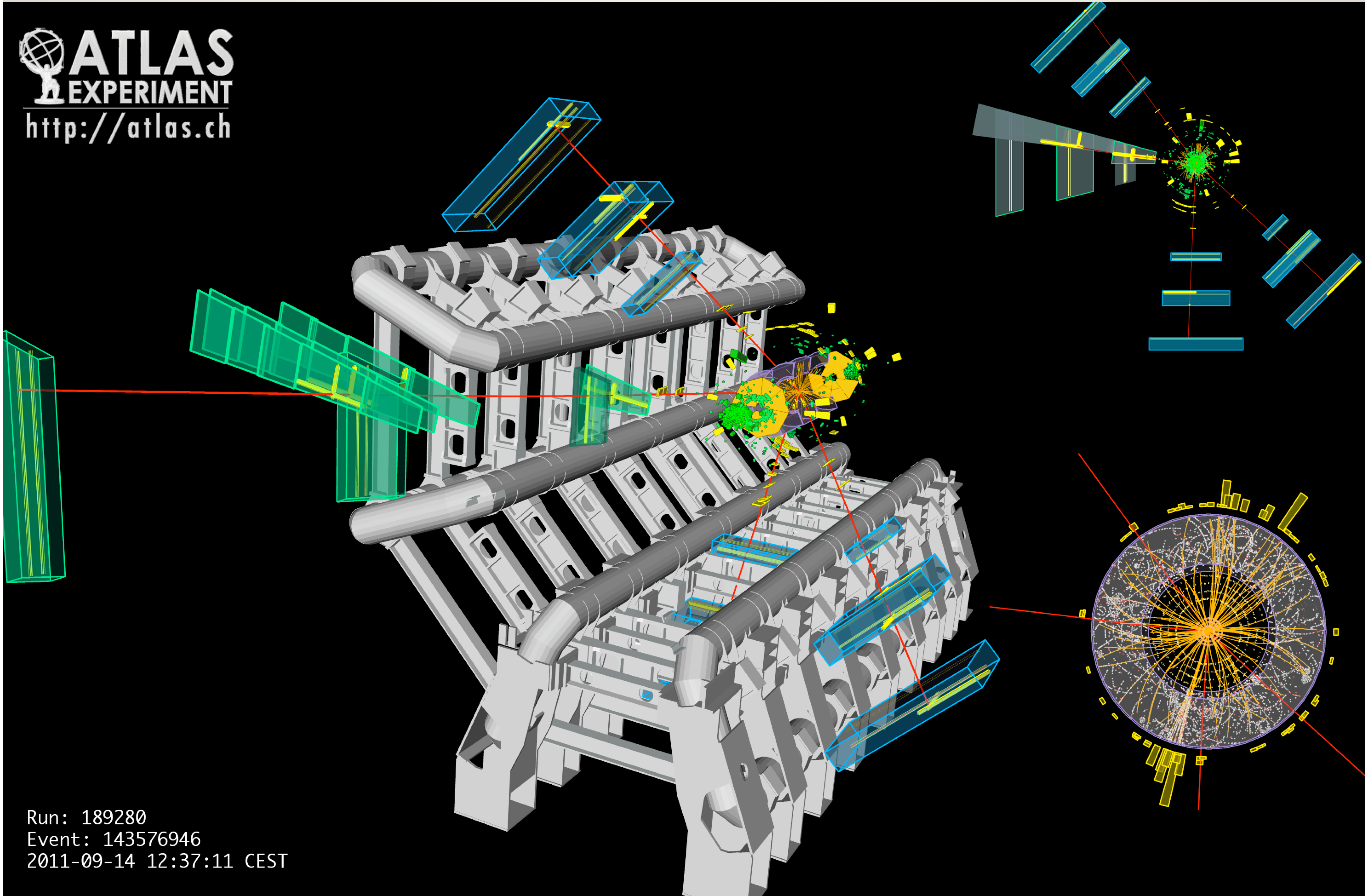
- Multiple channels contribute to an excess observed near 125 GeV
  - Including two with direct MPP involvement
- Significances with look-elsewhere effects (114-145 GeV):
  - **2.5σ** (ATLAS)
  - **1.9σ** (CMS)
- A fluke? Or a new particle?
  - Only more data will tell







4 muon event, m_{ll} = 24.6 GeV and 89.7 GeV, $\mathbf{m_{4l}}$ **= 124.6 GeV**



MPP Higgs activities

Standard Model Higgs searches

- $H \rightarrow WW(*) \rightarrow l\nu\ l\nu$
  – Muon selection, QCD background and analysis developments

J Bronner, S Kortner

- $H \rightarrow WW(*) \rightarrow l\nu\ qq$
  – Background estimation and analysis developments

R Sandström, S Kortner

- $H \rightarrow Z\,Z(*) \rightarrow 4l$
  – Optimisation of the muon selection, increasing acceptance

M Goblirsch-Kolb, O Kortner, H Kroha

- $H \rightarrow \tau_h\ \tau_h$
  – **New analysis** for Moriond 2012
  – Hadronic tau trigger and selection

D Zanzi, S Kortner

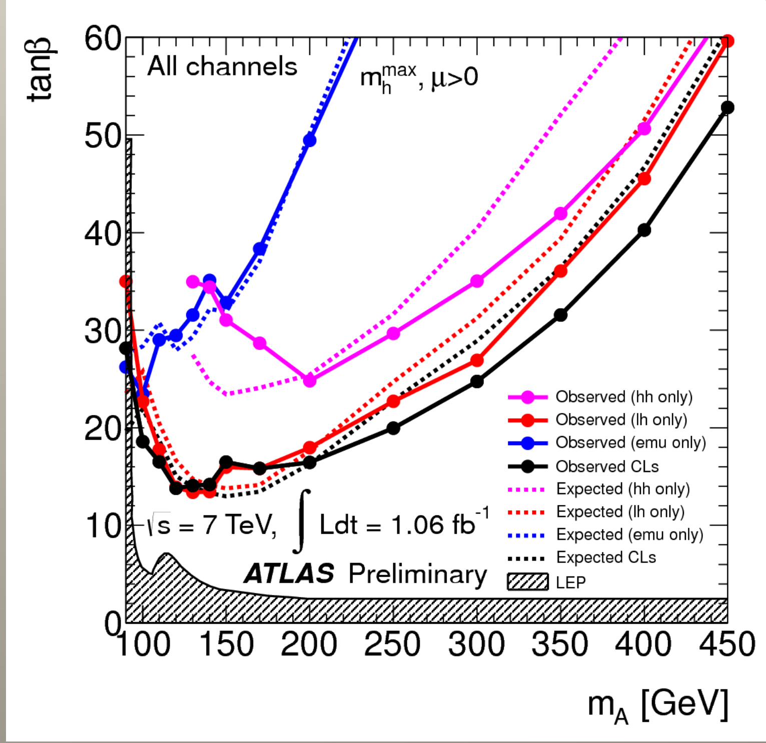
Supersymmetric (MSSM) Higgs searches

A Manfredini, D Zanzi, S Kortner

- $H/A \rightarrow \tau\tau$
  – Analysis optimisation and reconstruction performance

S Stern, S Kortner

- $H/A \rightarrow \mu\mu$
  – **New analysis** for Moriond 2012
  – Full analysis chain



Combination of $H/A \rightarrow \tau\tau$ channels in the MSSM

Supersymmetry overview

A natural extension to the Standard Model

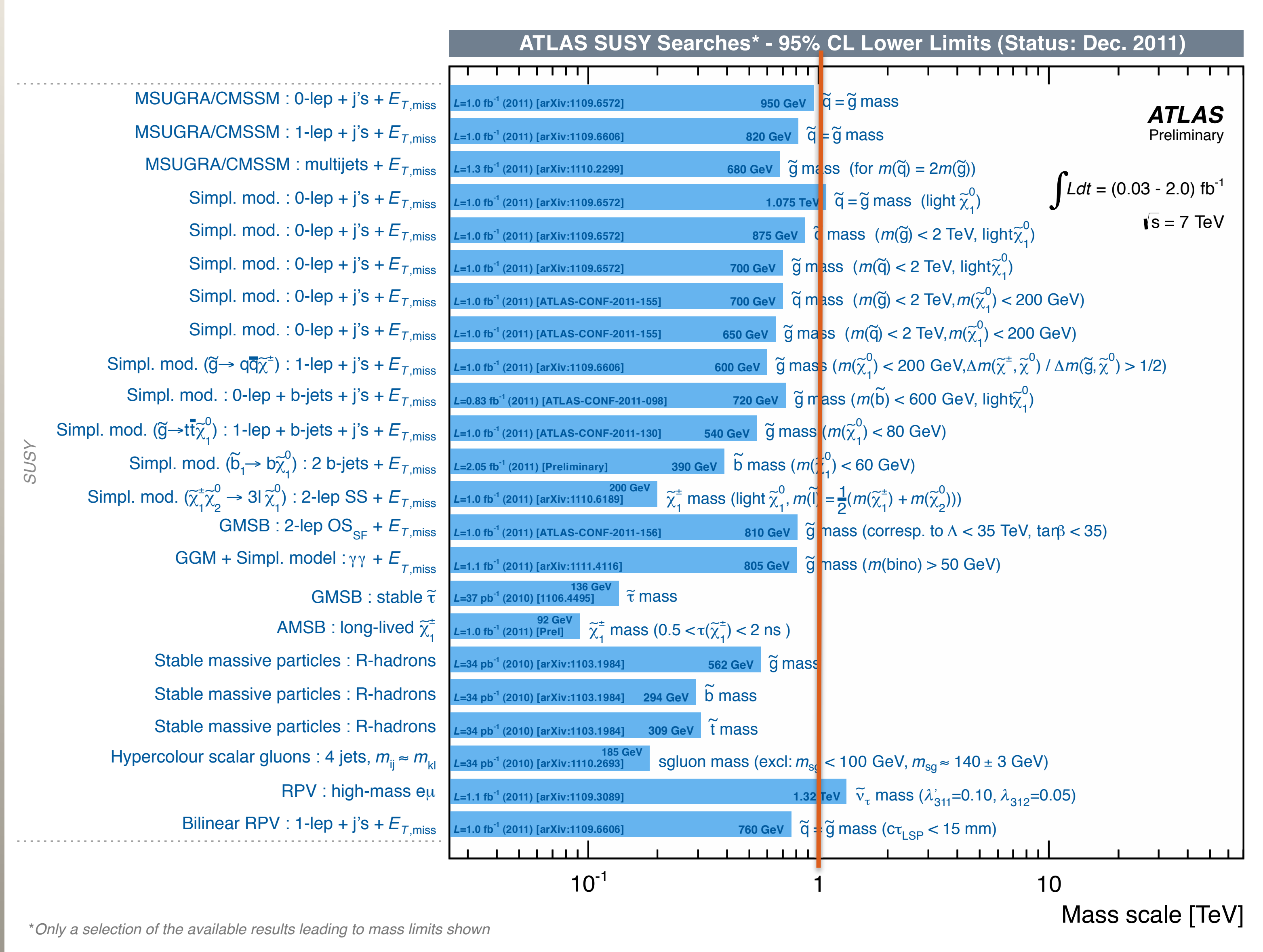
Diverse predictions of final state particles

2011 searches cover many of these:

- 0-2 leptons
- 0-8 jets
- Photons
- b-jets
- Taus
- jj and eμ resonances
- Long-lived particles

Nothing found yet...

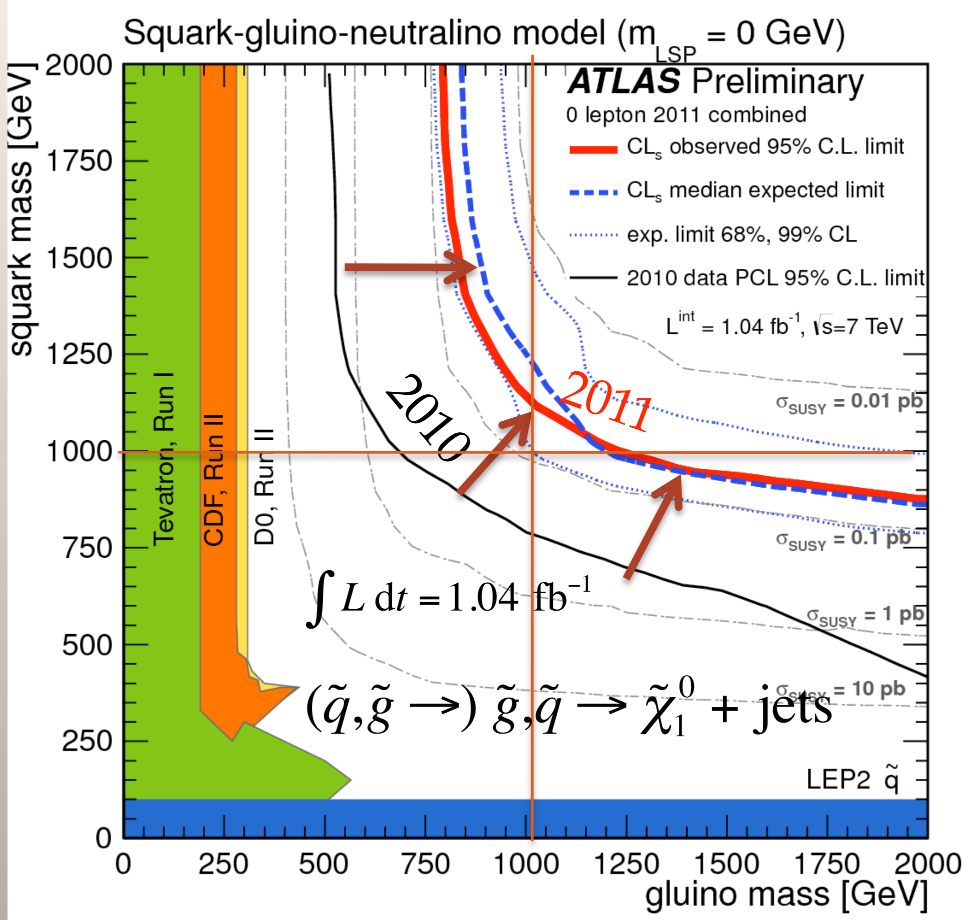
... but much more is planned for 2012!

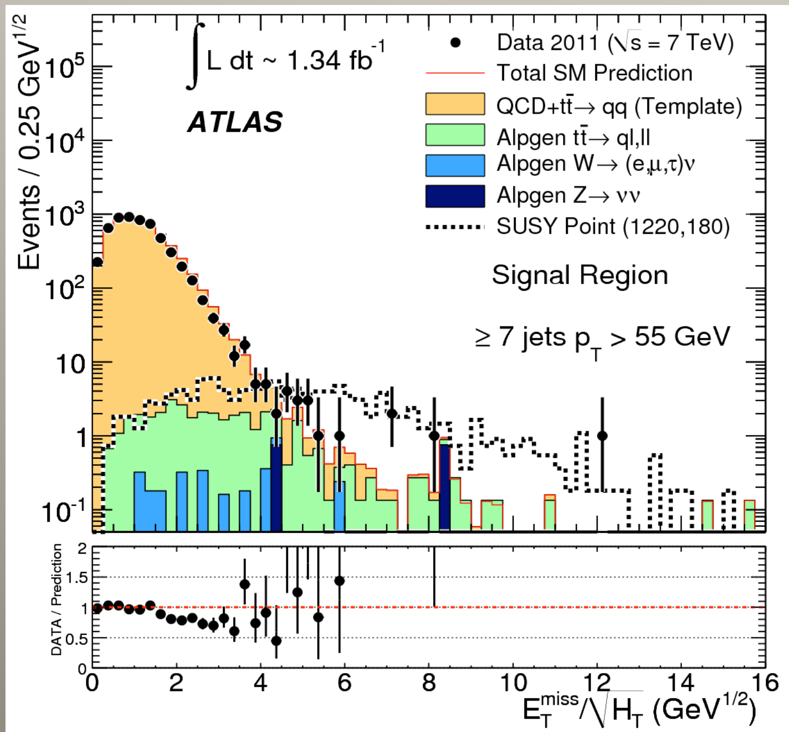


Supersymmetry searches @ MPP

M Flowerdew,
V Zhuravlov,
H Kroha

- MPP contributions in 2010/11 to searches without leptons
  - 2-4 jets + MET
  - 6-8 jets + MET
  - Exclusion limits **at/approaching 1 TeV**





- For 2012, **focus is shifting** to channels requiring more luminosity
  - Direct gaugino (weak) production with 2/3 leptons
  - 4+ lepton final states

Other ATLAS searches

Extra dimensions

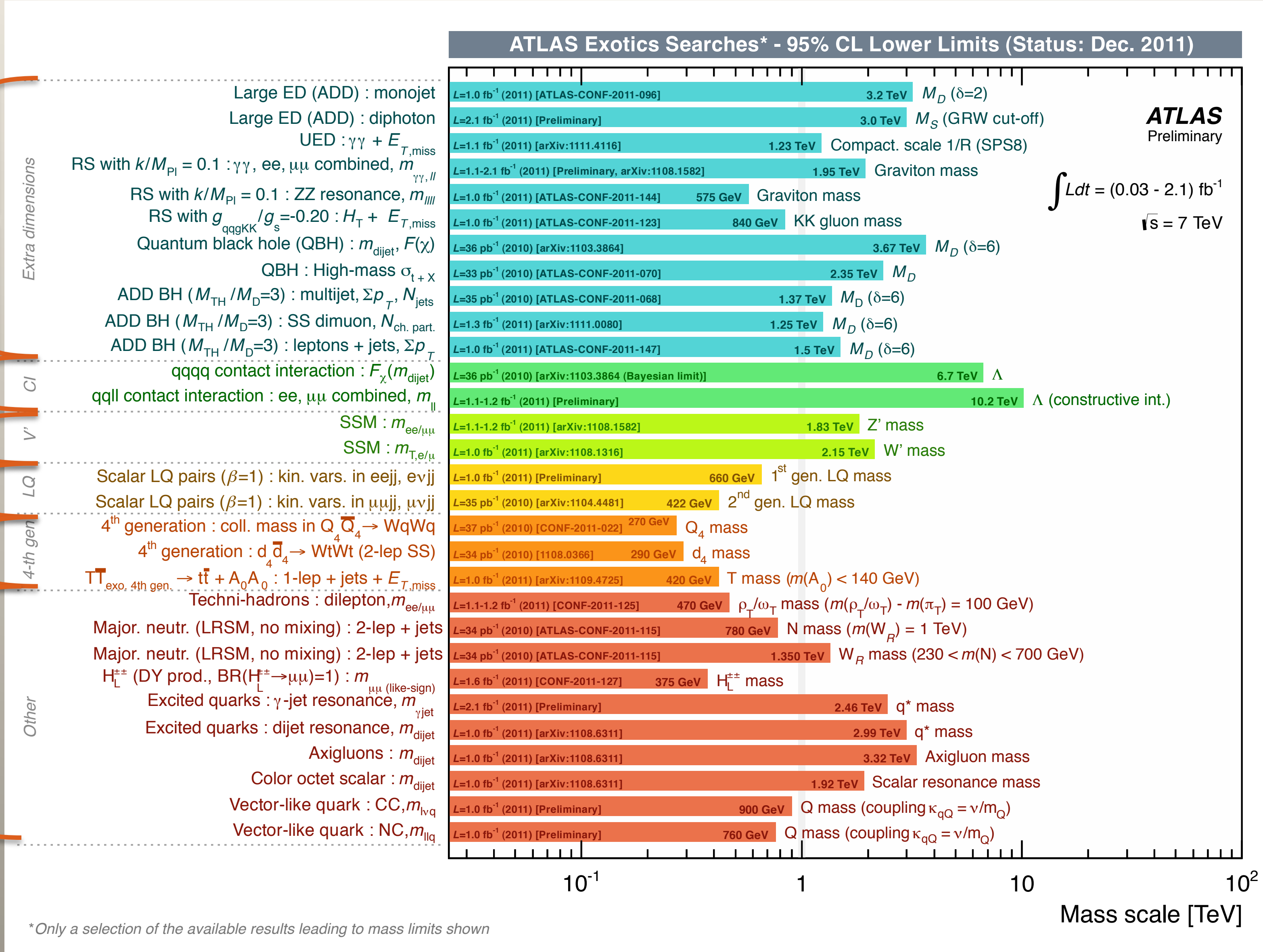
Contact interactions

V′

Leptoquarks

4th generation

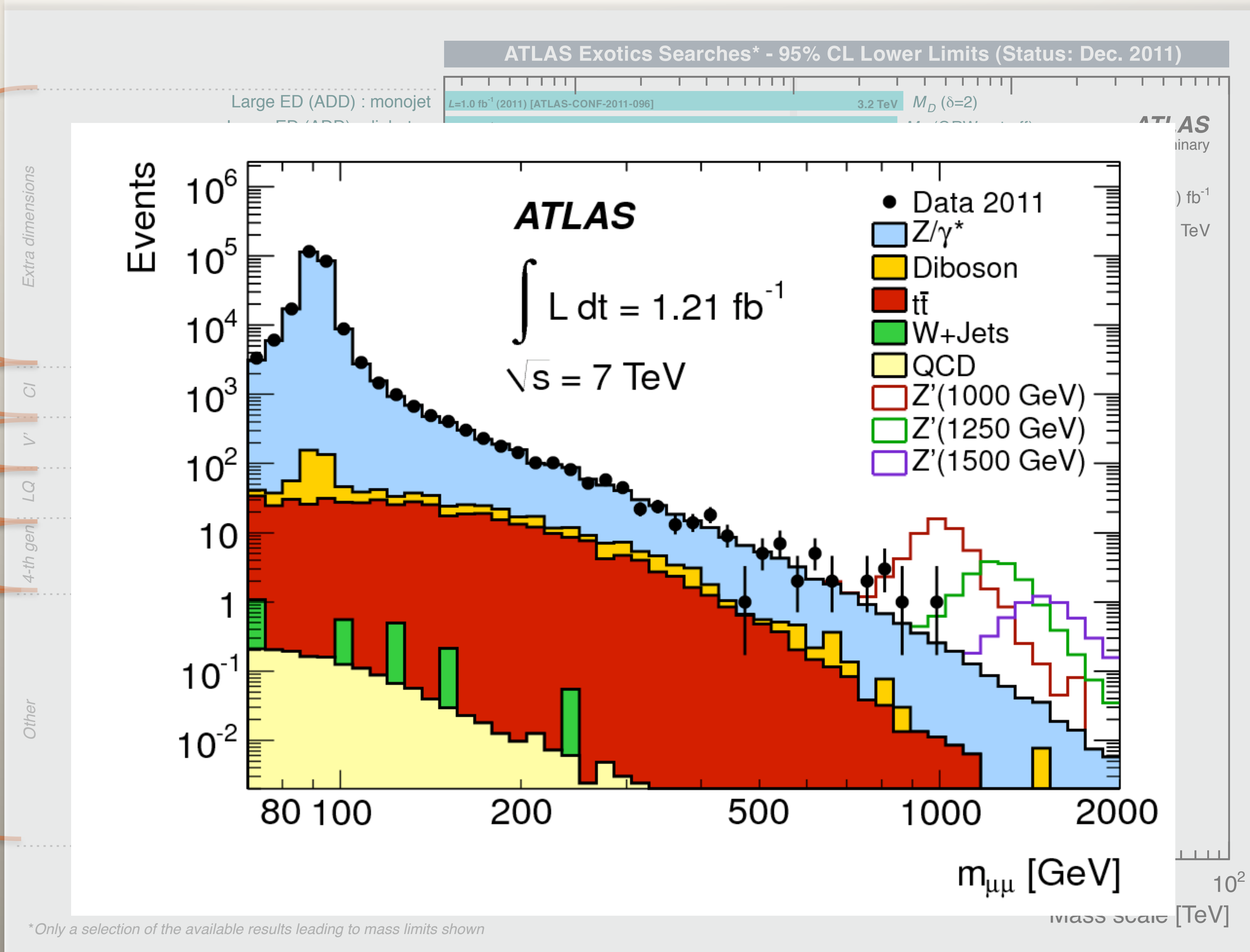
Technicolor, q′, exotic quarks, gluons etc



Other ATLAS searches

I Potrap,
O Kortner,
H Kroha

- Extra dimensions
- Contact interactions
- V′
- Leptoquarks
- 4^{th} generation
- Technicolor, q′, exotic quarks, gluons etc

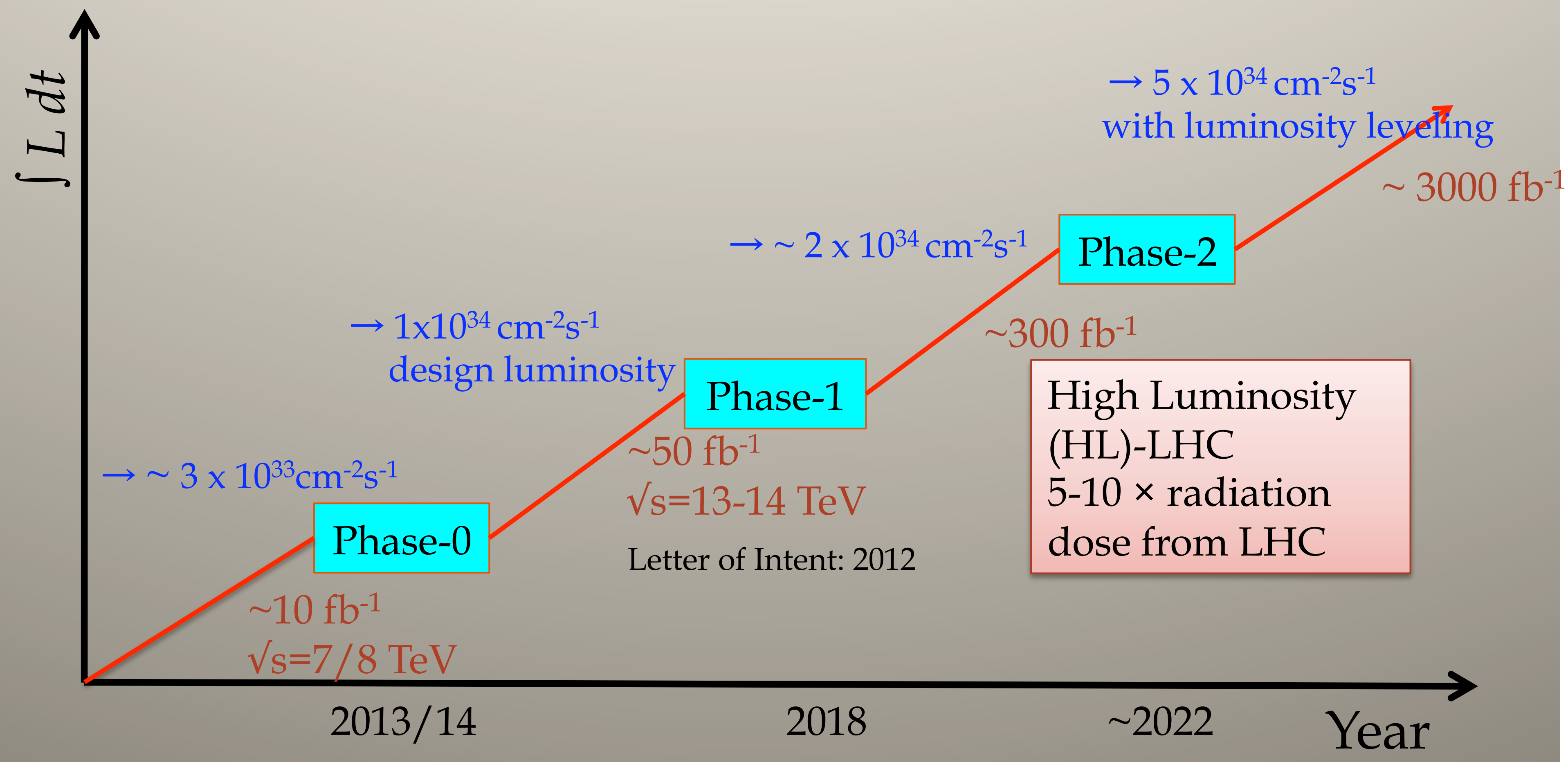


MPP contribution to muon alignment & resolution at high p_T

UPGRADE

The LHC upgrades

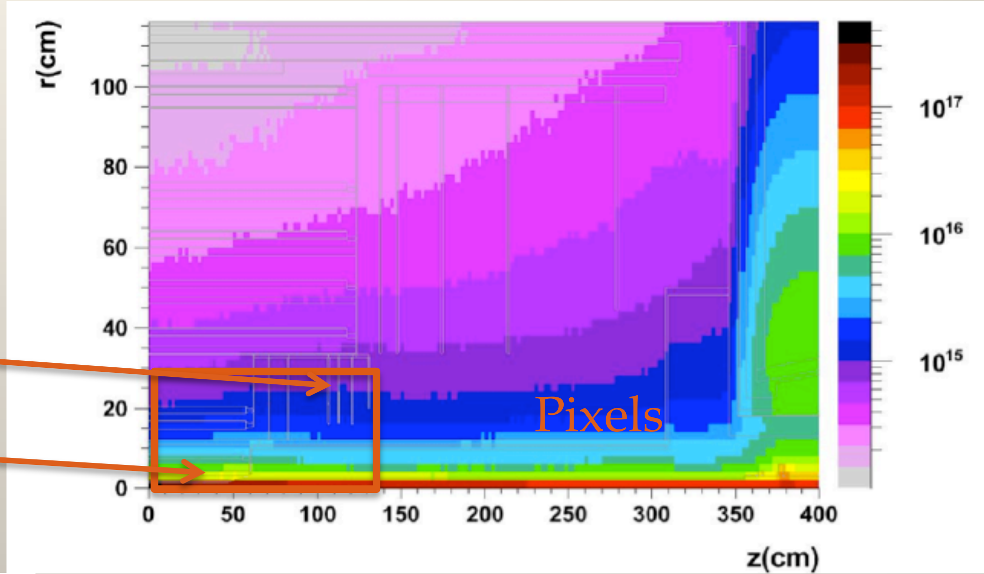
- **Three-phase upgrade plan** for ATLAS
  - **Accelerator upgrades** to provide higher energies and luminosities
  - Gradual **replacement/upgrade** of detector components to cope with ever-increasing radiation and occupancy levels



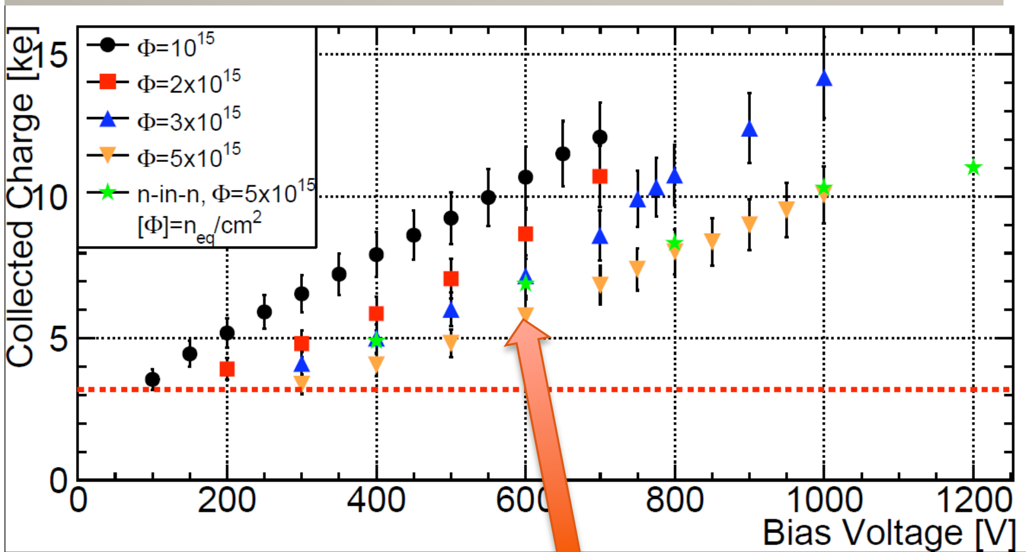
Pixel upgrade

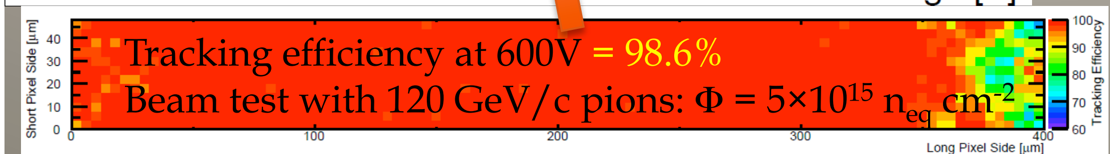
A Macchiolo, P Weigell and the HLL/MPP group

1 MeV equivalent fluence for Phase II tracker



- **Full pixel system replacement**
  - Phase 1 or 2
  - **Outer** layers: **Cost-effective** pixel sensors, area up to 10 m^2
  - **Inner** layer candidate: **Thin** planar pixel sensors, 75-150 μm thick
  - MPP contributions to both



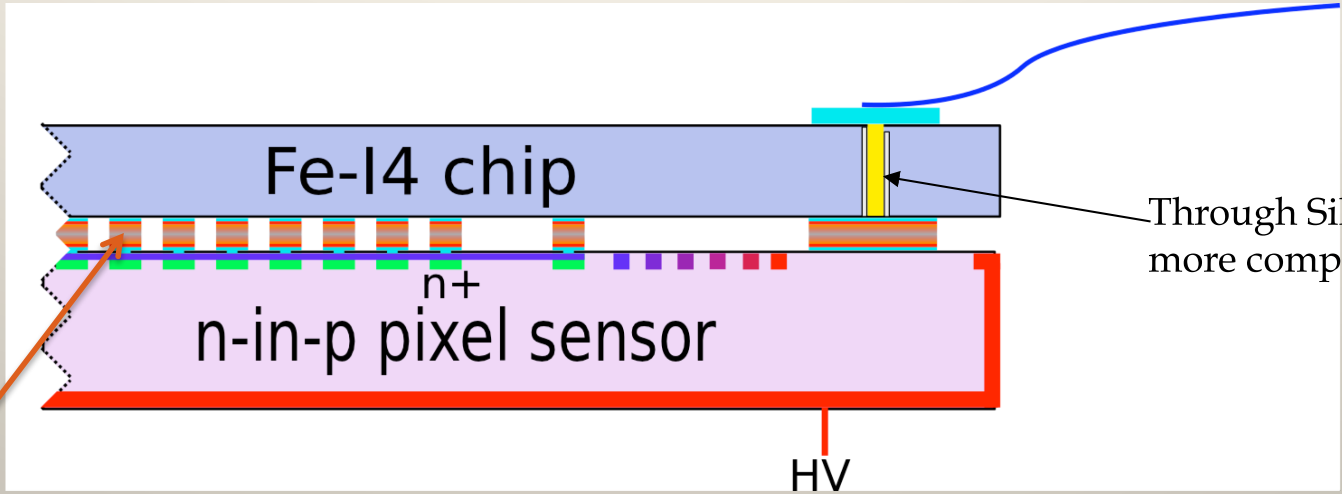


- **Outer layer prototype** pixels, 285 μm thick, produced by CiS
- **Single-sided process** for n-in-p pixels
  - Less expensive than current double-sided process

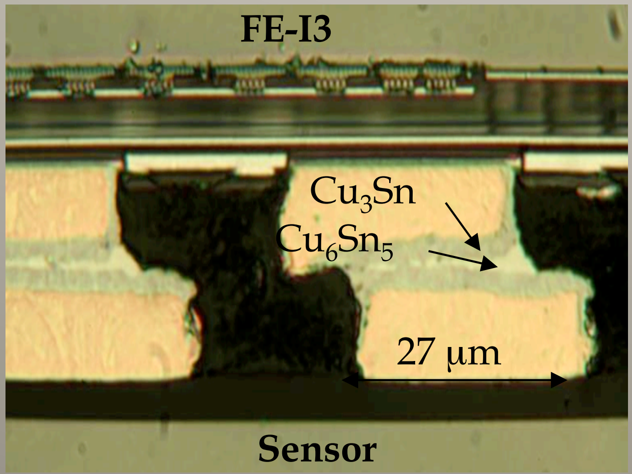
✓Radiation hard up to $\Phi = 5\times10^{15}\ n_{eq}cm^{-2}$

✓HV stability demonstrated up to 1000 V

Inner layer R&D (Vertical Integration Technology)

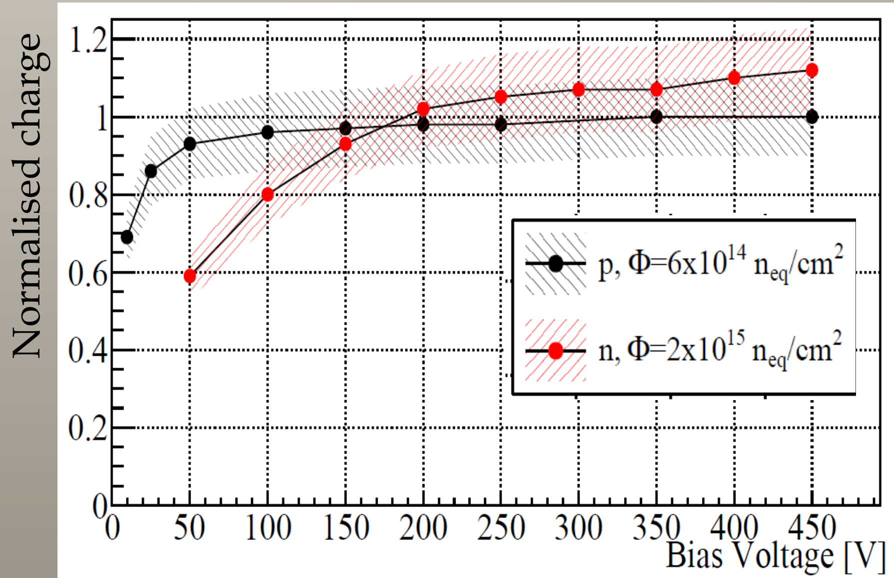


- New soldering technique: **Solid-liquid interdiffusion (SLID)**
  - Improvement on bump-bonding
  - Multiple layer interconnections possible



CuSn soldering (SLID)

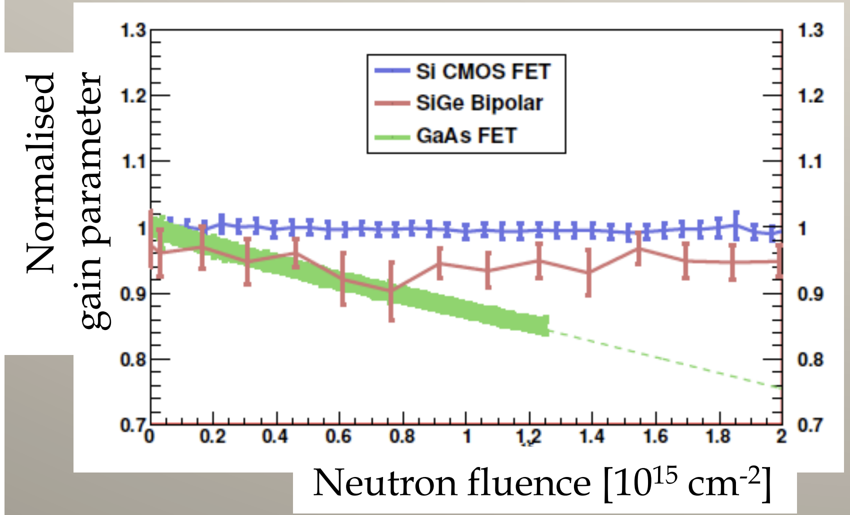
- 5 SLID modules produced at HLL/EMFT
  - Thin (75 μm) n-in-p pixels
  - **Stability under irradiation** demonstrated



T Barillari, A Kiryunin,
H Oberlack, M Nagel,
G Pospelov, P Schacht,
S Menke

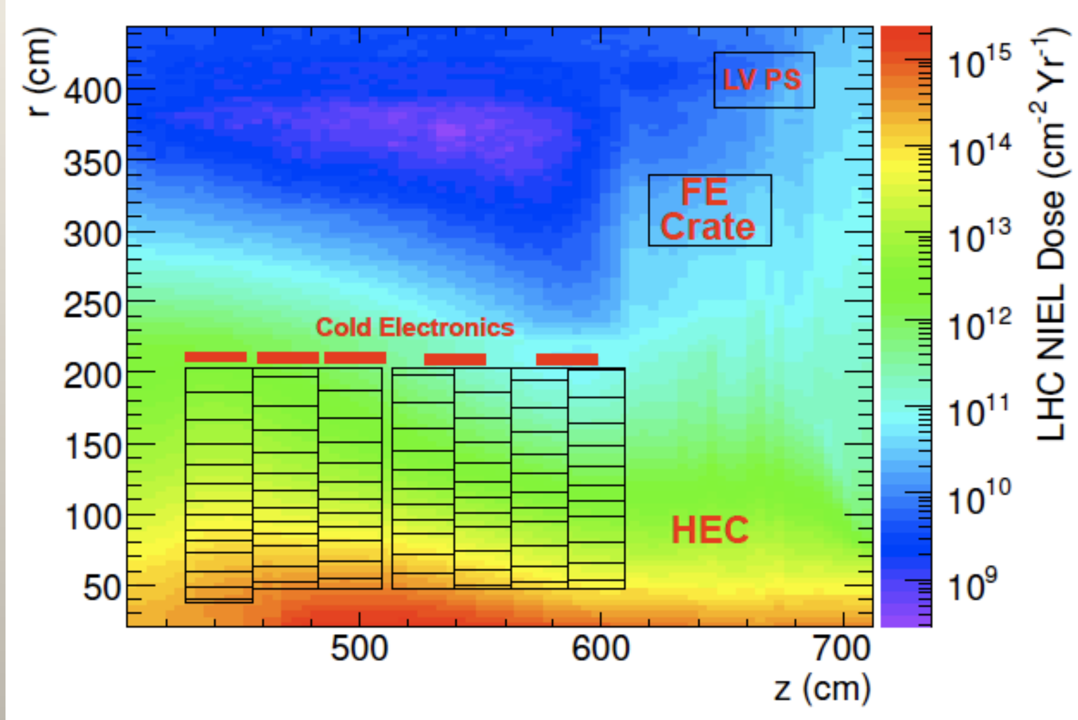
HEC upgrade

- Phase II upgrade:
  - Support electronics need replacing
  - MPP projects



Technology	Neutrons 2×10^{15} n cm^{-2}	Protons 2×10^{14} p cm^{-2}
Si CMOS FET	-1%	-11%
SiGe bipolar	-3%	-10%
GaAs FET	-24%	-21%

Neutron dose for 1 year LHC
HL-LHC ~ 10×LHC + factor 10 safety factor

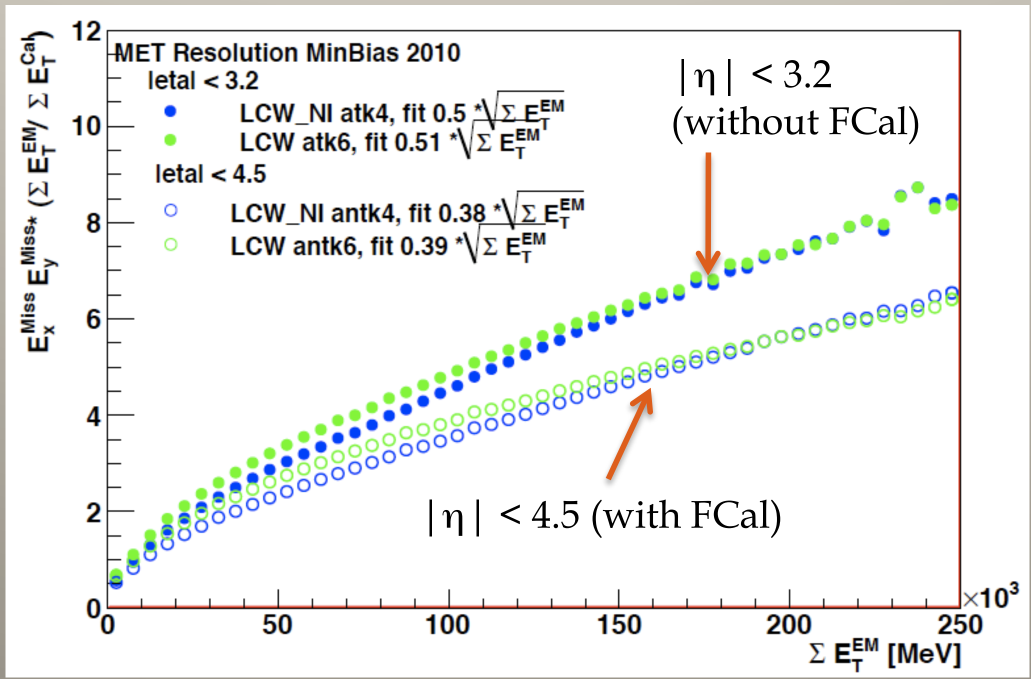


- **Cold electronics**: pre-amplifier technologies under test
  - Si CMOS FETs most promising for performance, availabliliy and price
- **Low voltage power supply** (LV PS) control units: Tests started

High luminosity studies for the upgrade

- **Mini-modules** exposed to test beams at Protvino
  - Three endcap systems (**EMEC, HEC, FCal**)
  - High intensity 50 GeV protons
- HEC operation in HL-LHC demonstrated up to $L = 8.3 \times 10^{34}$ cm^{-2} s^{-1}
  - **HEC and EMEC hardware OK!**

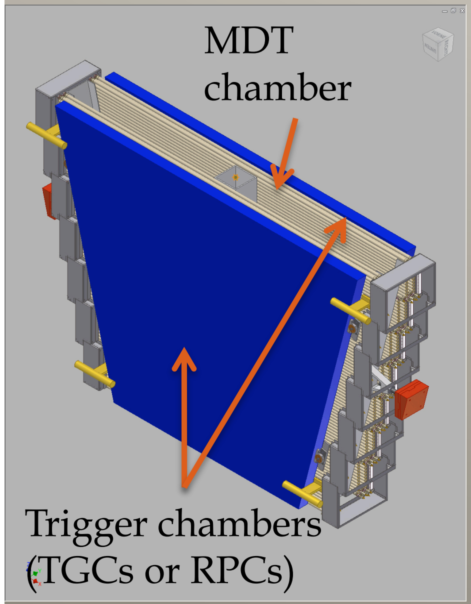
- **FCal** needs smaller gap sizes (250 μm → 100 μm)
  - MET performance degrades with FCal only partially functional
  - Fake MET is a problem at high luminosity!



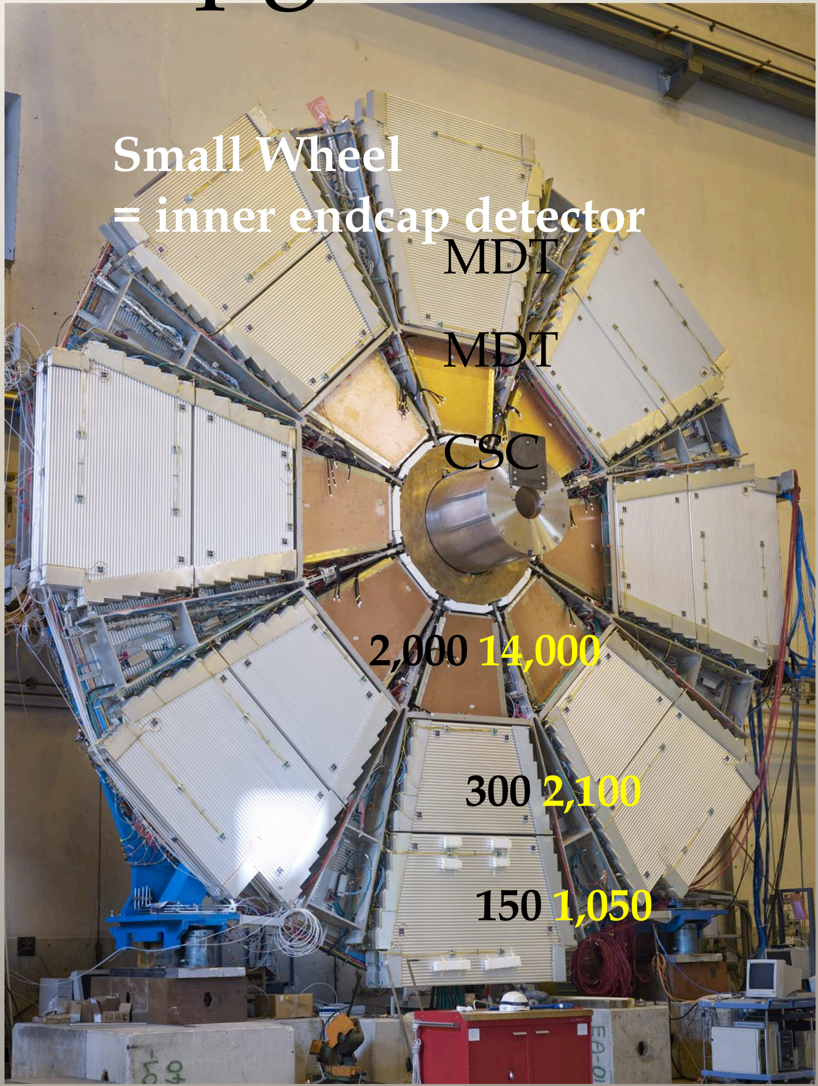
MDT small wheel upgrade

B Bittner, J Dubbert, O Kortner,
S Kortner, A Manfredini,
R Richter, P Schwegler,
D Zanzi, H Kroha

- **Phase I** upgrades to small wheel:
  - Small diameter drift tubes (**sMDTs**)
    - MPP proposal
    - 96 sMDTs to be made in collaboration with other institutes (2013-16)
  - Trigger chambers

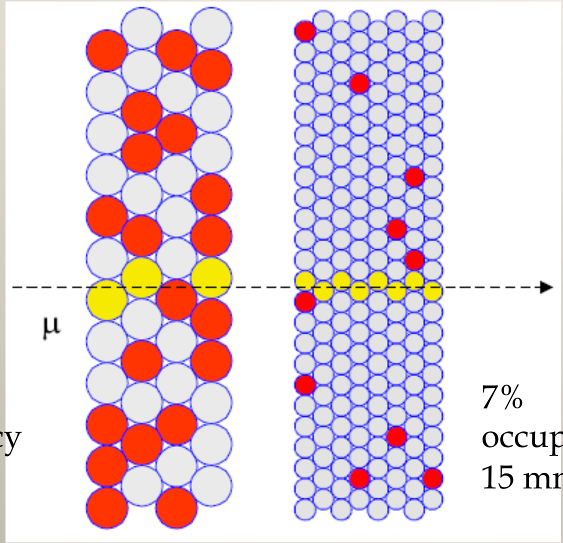


- **Phase II** upgrades:
  - Small wheel trigger upgrade
  - Use (s)MDTs in Level 1 trigger MPP proposal



Background counting rates [Hz cm^{-2}]
at design luminosity and for HL-LHC
Current MDT rate limit: **500 Hz cm^{-2}**

Small MDT prototype tests

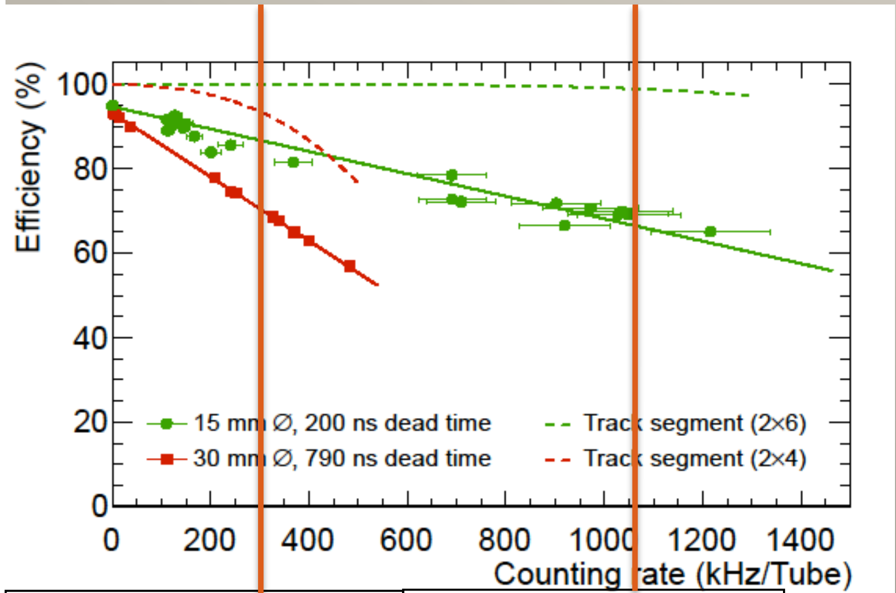


50% occupancy 30 mm ∅

7% occupancy 15 mm ∅

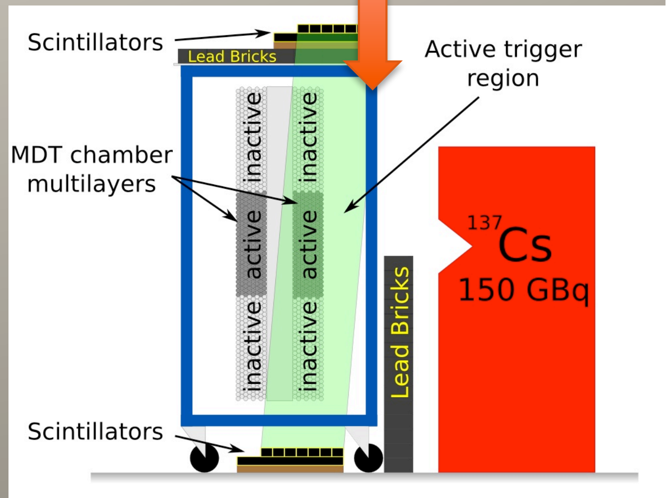
- 30mm → **15 mm diameter drift tubes**
  - Improved **occupancy**, **efficiency** and **resolution** in high luminosity conditions

- **Prototype chamber** built here at MPP
  - Sense wire position accuracy **< 20 μm** achieved
  - Tested at CERN's Gamma Irradiation Facility



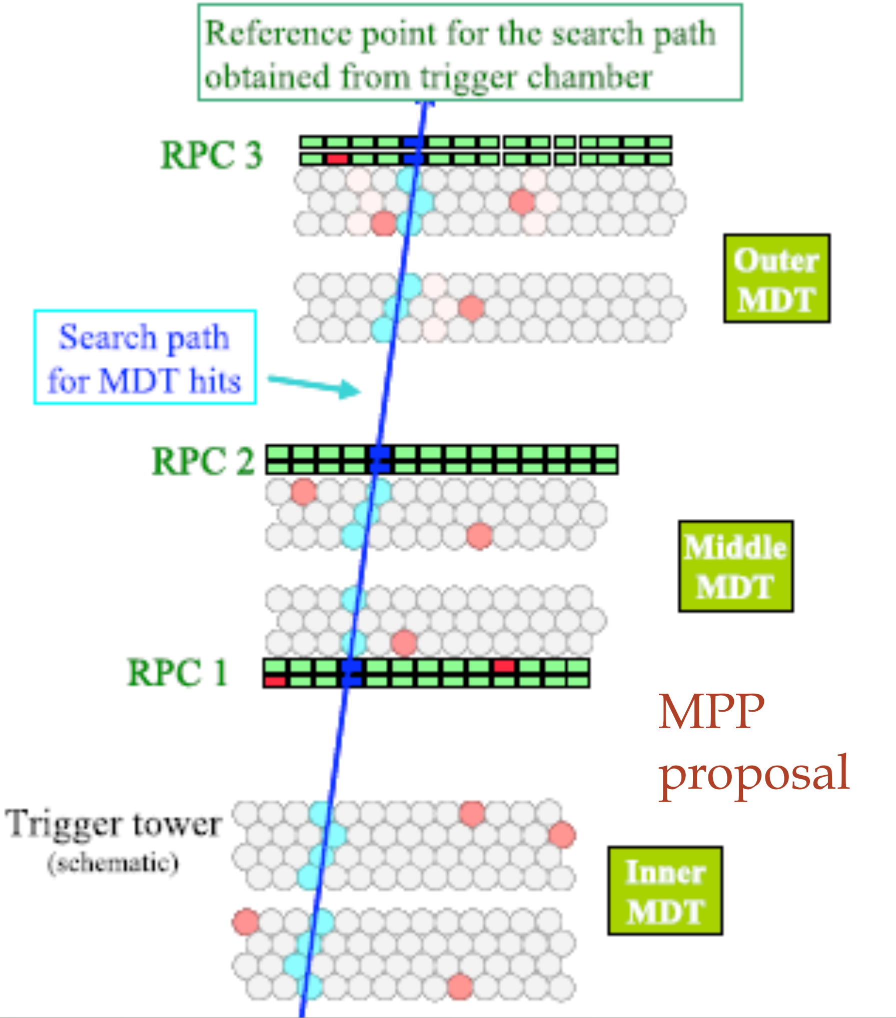
Max. rate for 30 mm ∅ LHC design luminosity

Max. rate for 15 mm ∅ at HL-LHC



Level 1 muon trigger and readout electronics

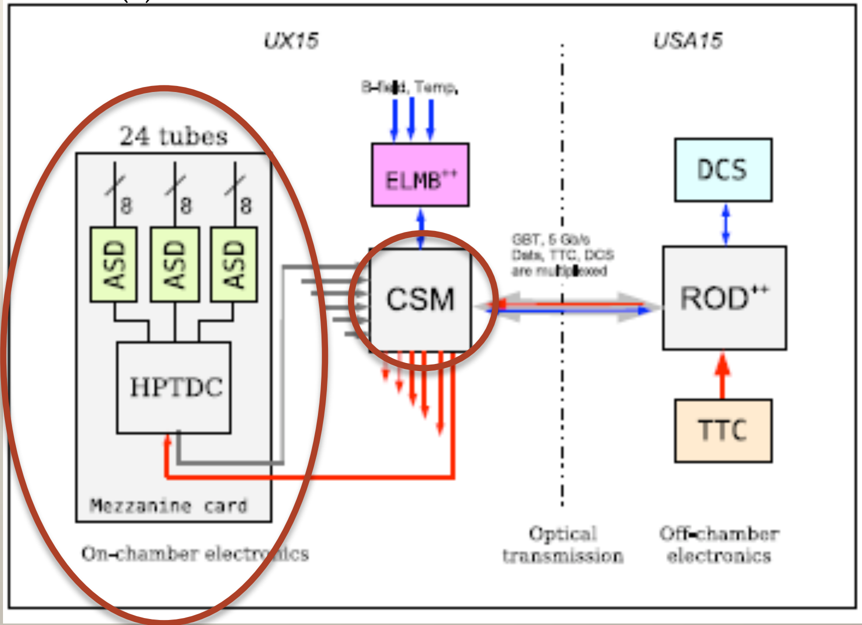
- MDT-based **L1 muon trigger concept**:
  - Fast track segment finder on new front-end boards



MPP proposal

MPP developments

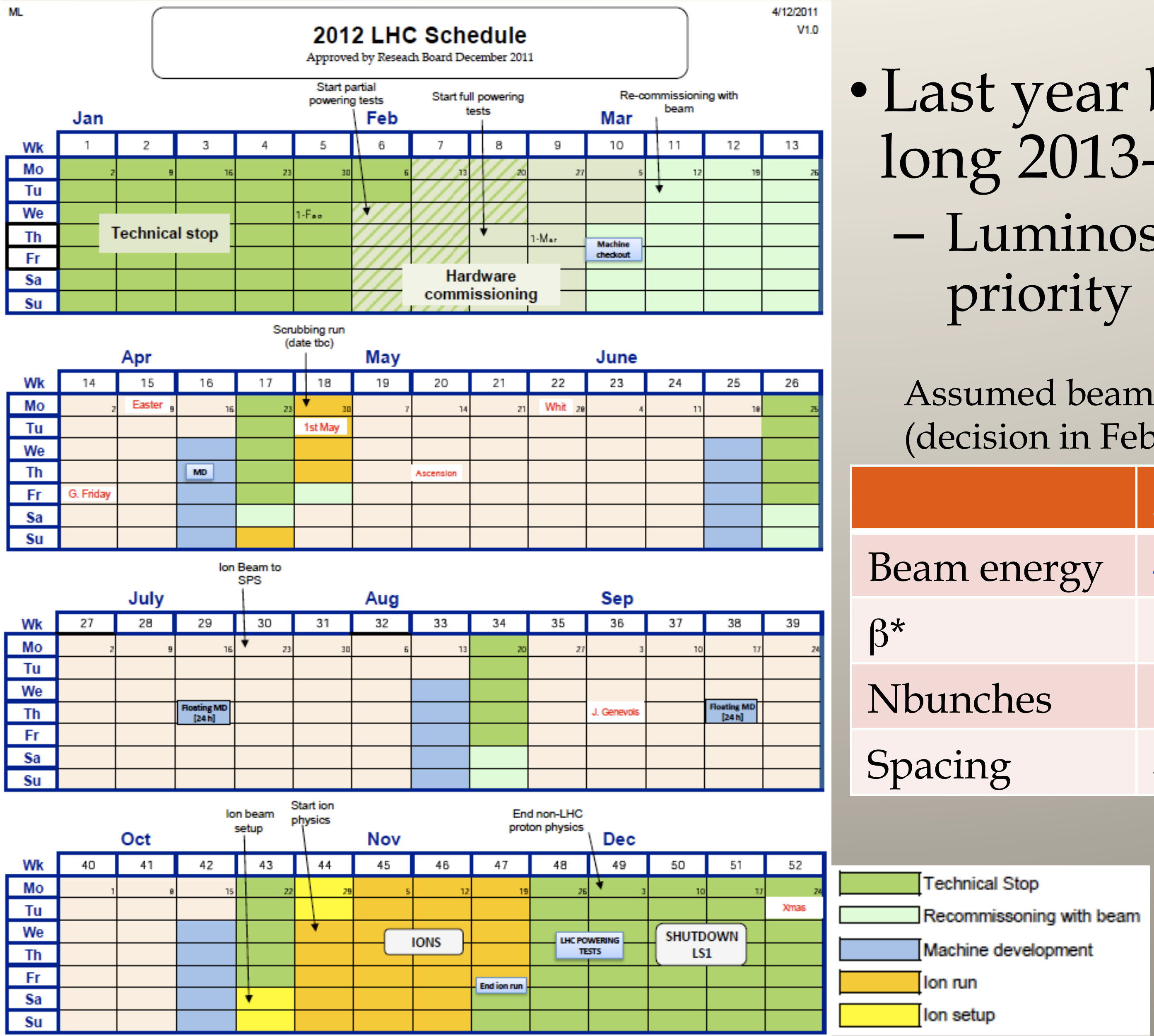
New (s)MDT readout electronics chain



Front-end ASD **chip prototype**

FINAL REMARKS

Machine planning for 2012



- Last year before the long 2013-14 shutdown
  - Luminosity is **the** priority

Assumed beam parameters
(decision in Feb @ Chamonix)

	2012	2011
Beam energy	4 TeV	3.5 TeV
β*	0.7 m	1.0 m
Nbunches	1380	1380
Spacing	50 ns	50 ns

(25 ns tested for the future)

Target lumi: 16 fb^{-1}

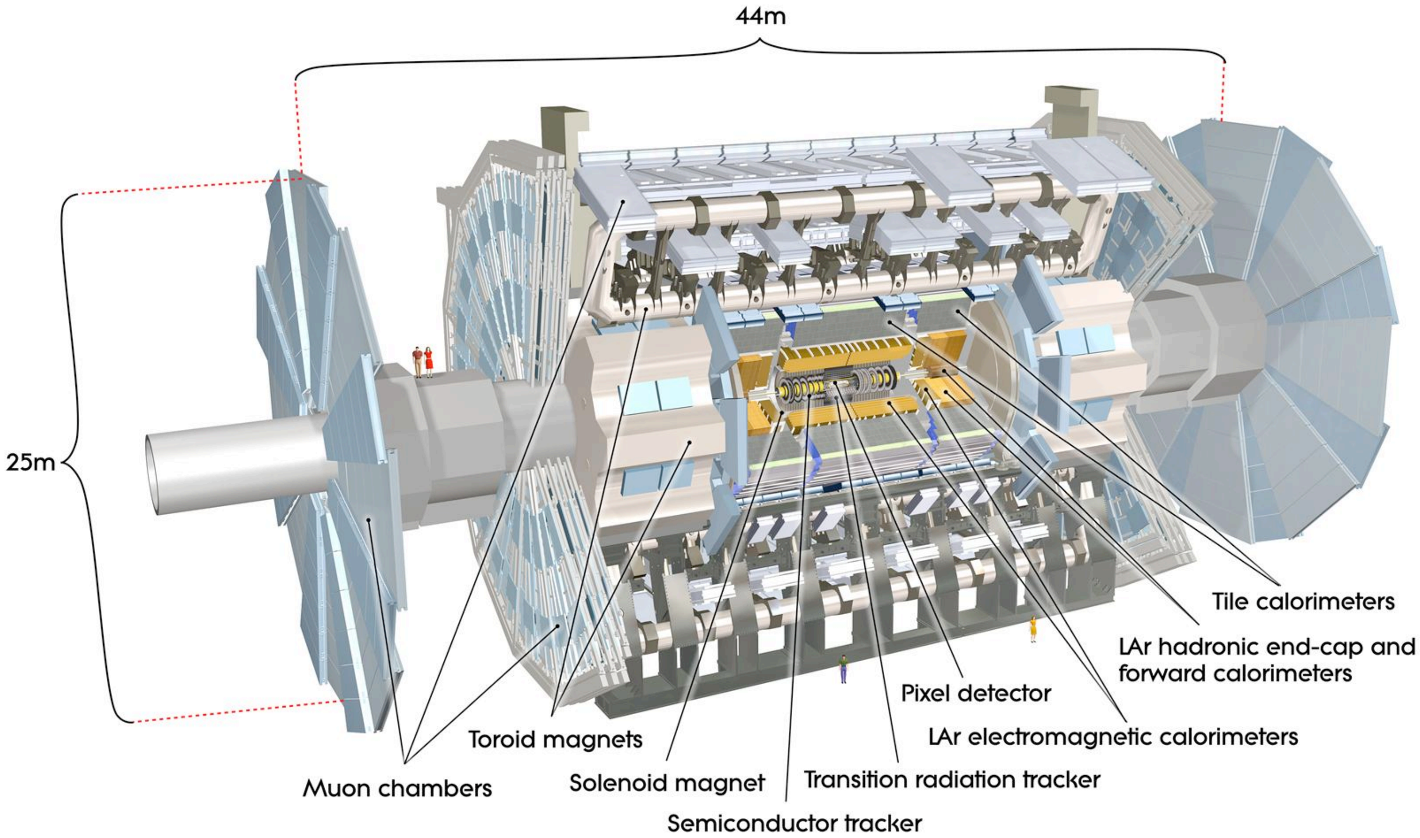
Conclusions

- 2011 has been our [first] **year of luminosity**
  - 0.045 fb^{-1} → 5.2 fb^{-1} recorded on tape
    ... with much more to come!
- Detector performance demonstrated at high and low p_T, with W, Z and top becoming workhorse particles
  - Ultimate **design precision** is being approached
- ATLAS has good reach for **new physics signatures**
  - This could have been the year of SUSY, TeV-scale gravity, dijet/ dilepton resonances ... So far not, but we'll keep looking!
- There are however hints of a **Higgs-like signal**, to be confirmed/refuted in 2012
- **MPP continues to play a central role** in the collaboration
  - Detector operation and performance
  - Physics analysis
  - High luminosity upgrade

Thank you to everyone involved!

BACKUP

ATLAS



General-purpose detector

Nearly 4π coverage

Excellent resolution and identification for **jets**, b-jets **electrons**, photons, **muons**, tau leptons and **missing E_T** (MET)

Inner Detector
- $|\eta| < 2.5$
- Si pixels, SCT (Si strips), TRT
- $\sigma/p_T \sim 3.8\times10^{-4}\, p_T \oplus 0.015$

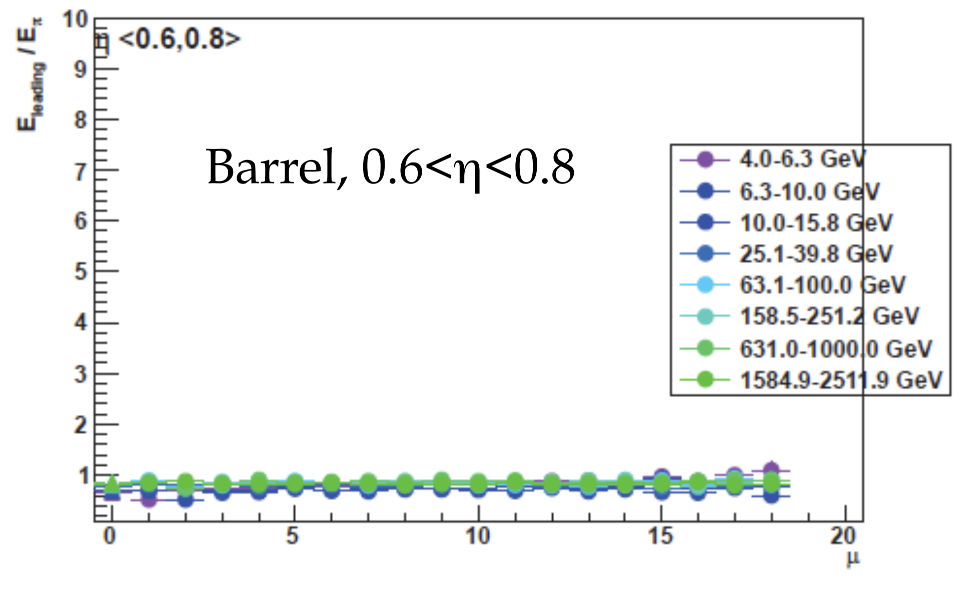
Hadronic calorimeter
- $|\eta| < 4.9$
- Fe+scintillator tiles: $\sigma/E = 50\%/\sqrt{E} \oplus 0.03$
- Cu/W-LAr: $\sigma/E = 90\%/\sqrt{E} \oplus 0.07$

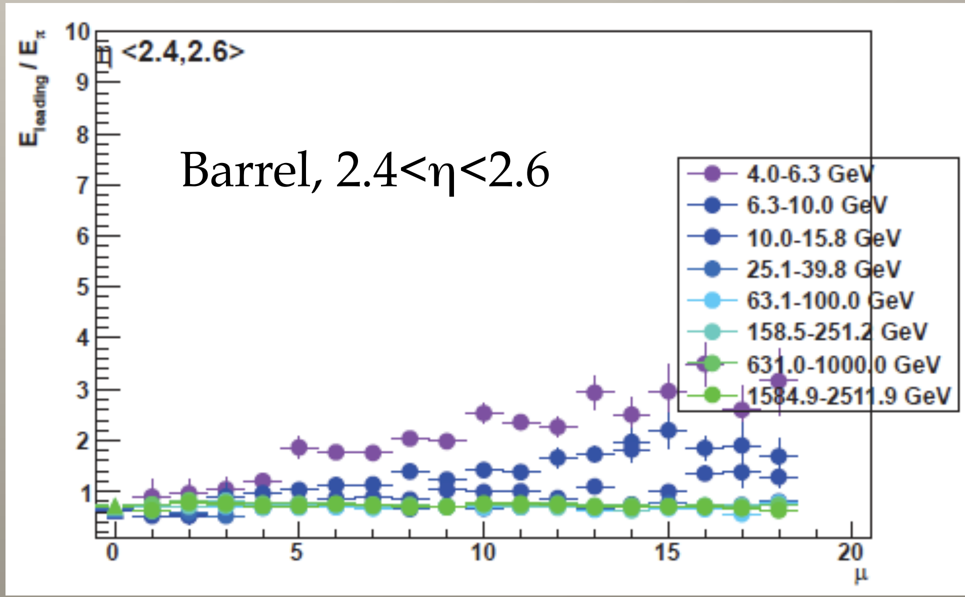
Electromagnetic calorimeter
- $|\eta| < 3.2$
- Pb-LAr with accordion structure
- $\sigma/E \sim 10\%/\sqrt{E}$

Muon spectrometer
- $|\eta| < 2.7$
- Air-cored toroids + gas-based muon chambers
- $\sigma/p_T \sim 10\%$ for $p_T \sim 1$ TeV

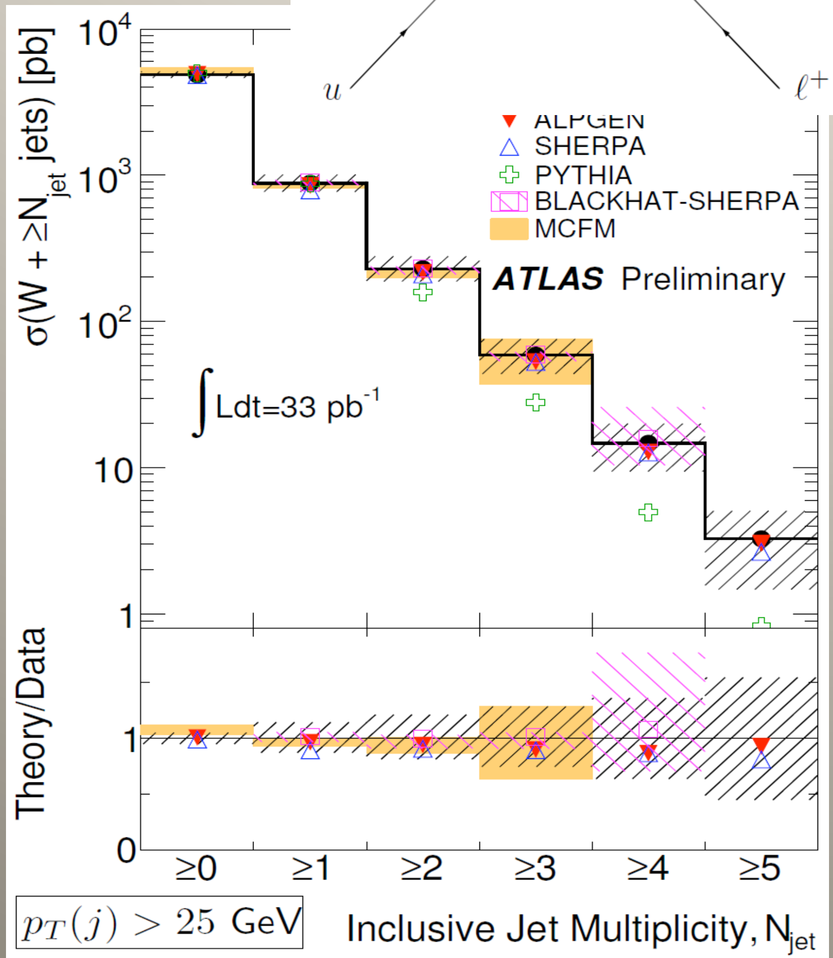
Robustness with pile-up

- In 2011 the expected number of interactions was raised significantly above 1
- Topo clusters remain stable with increasing pileup, despite substantially different cluster properties
  - Thresholds fixed for expectation of <μ>=8
  - E/p shown for simulated pions, with different amounts of pile-up mixed in





Production of W bosons in association with jets



- Motivation: test of QCD and background to many physics processes

$$pp \to t\bar{t} \to (W^+b)(W^-b), \quad pp \to t \to Wb$$

$$pp \to H \to W^+W^- \to 2j + l\nu$$

- Good agreement with multiparton matrix element generators ALPGEN and SHERPA
- In preparation: measurement of W+c
  - Probes s quark parton density

Reducing the jet energy scale uncertainty

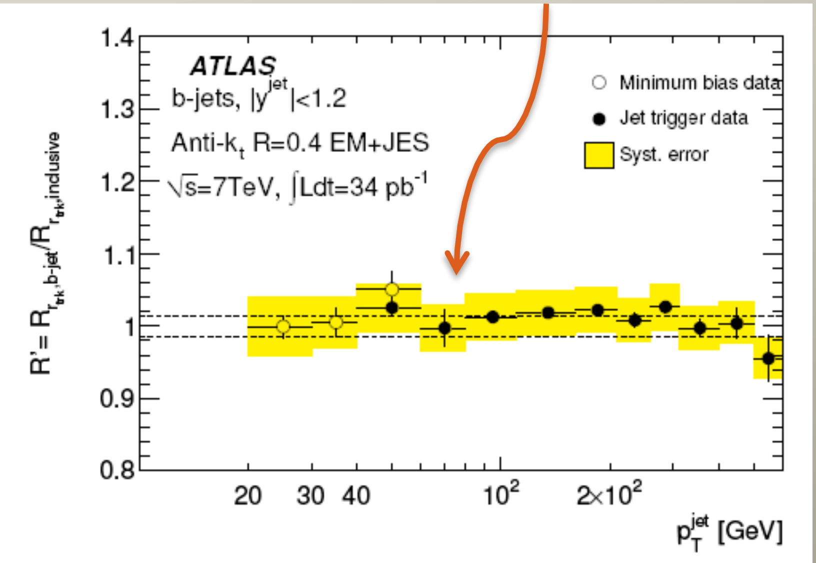
- Current top mass measurements limited by:
  - Jet energy scale (JES)
  - b-jet energy scale (bJES)
  - Initial/final state radiation (ISR/FSR) systematics
- Impact could be reduced with multi-dimensional template fits
  - In-situ determination of global scale factors for light jets (JSF) and b-jets (bJSF)
- Three-dimensional template:
  - Reconstructed top mass (=> m_{top})
  - Reconstructed W mass (=> JSF)
  - R_{lb} (=> bJSF)

$$R_{lb} = \frac{r_{trk}^{light-jet}}{r_{trk}^{b-jet}} = \frac{\left(\frac{p_T^{trk}}{p_T^{calo}}\right)^{light-jet}}{\left(\frac{p_T^{trk}}{p_T^{calo}}\right)^{b-jet}}$$

- bJES uncertainty cross-checked on data

$$r_{trk} = \frac{p_T^{trk}}{p_T^{calo}} \qquad R = \frac{\langle r_{trk}\rangle_{Data}}{\langle r_{trk}\rangle_{MC}}$$

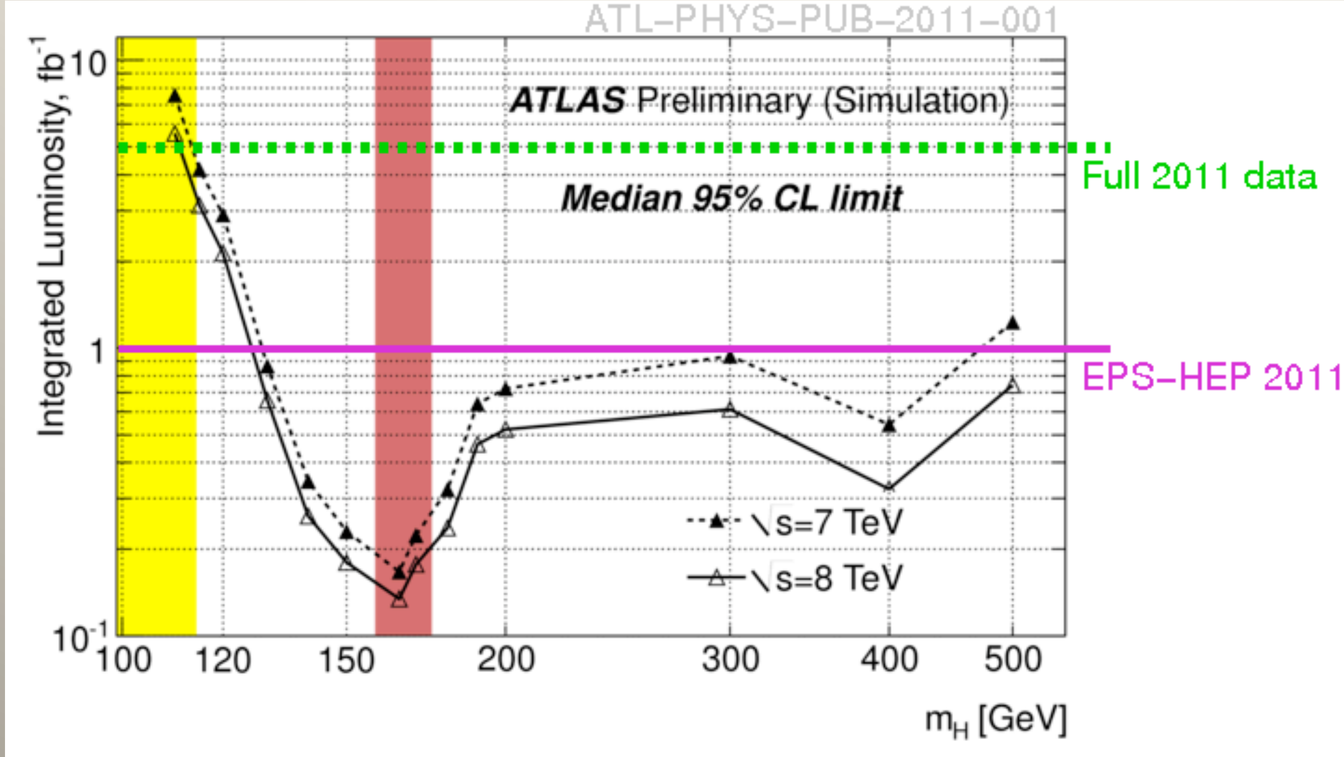
$$R' = \frac{R^{b-jets}}{R^{light-jets}} = \frac{R_{lb}^{MC}}{R_{lb}^{Data}}$$



- Analysis with 5fb^{-1} in preparation
- Also planned: simultaneous l+jets and dileptonic mass fit
  - Dileptonic mass estimators in development

SM Higgs boson: projections

Predictions made at start of data-taking have been met



Projections for ~5 fb-1 (full 2011 data)

- Exclusion possible in the whole mass range
- 3σ evidence possible from m_H ~ 130 GeV

Projection for ~2x5 fb-1 (ATLAS & CMS together)

- 3σ evidence possible for almost entire mass range
- 5σ discovery possible from m_H ~ 130 GeV

The answer is just around the corner