ATLAS Overview and main results

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for the ATLAS Collaboration

XI LISHEP High Energy Physics in the near Future

Rio de Janeiro, March 17th – March 24th, 2013

Outline

- PHYSICS PROGRAM AT THE LHC
  - test the Standard Model, hopefully find "physics beyond SM"
  - find clues to the EWK symmetry breaking - Higgs(ses)?

- what has and what has NOT changed after a Higgs-like boson at ~125 GeV was found by ATLAS and CMS in 2012?

- ATLAS – exploratory experiment with multipurpose detector to study pp collisions at LHC at highest energies possible:
  7 TeV in 2011, 8 TeV in 2012, ~13 TeV from April 2015…

- Selected ATLAS results (a summary, see other ATLAS talks at this conference for more details)

- FUTURE plans?

Standard Model (~1975)

Standard Model is a gauge theory based on the following "internal" symmetries:

$$SU(3)_c \times SU(2)_I \times U(1)_Y$$

The SU(3) is an unbroken symmetry, it gives Quantum Chromo-Dynamics (QCD), a quantum theory of strong interactions, whose carriers (gluons) are massless, couple to color (strong force charge)

SU(2) × U(1) (quantum theory of electroweak interactions) is spontaneously broken by the Brout-Englert-Higgs mechanism; which gives mass to electroweak bosons (massive W^+, W^-, Z^o and a massless photon) and all fermions

In the Minimal Standard Model, the Higgs sector is the simplest possible: contains one weak isospin doublet of complex Higgs fields, which after giving masses to W^+, W^-, Z^o leaves a single neutral scalar Higgs particle which should be observed

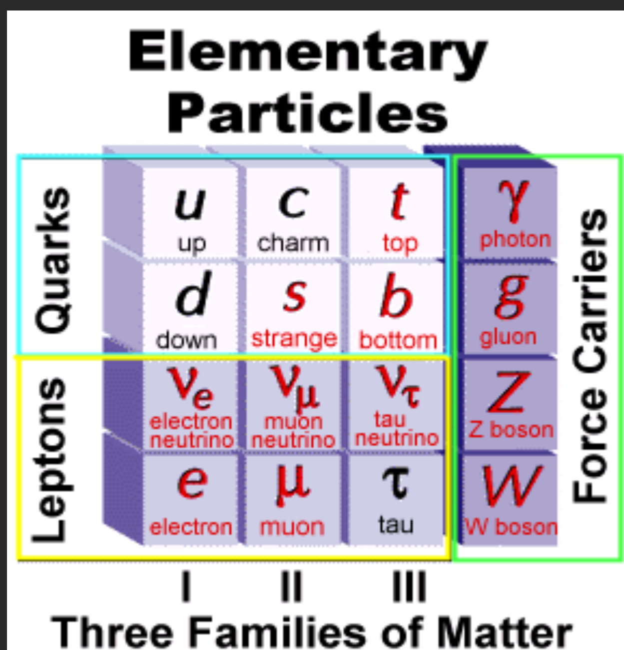
Minimal Standard Model

Matter is build of fermions - quarks and leptons, three families of each, with corresponding antiparticles; quarks come in three colors, leptons are color singlets, do not couple to gluons

Bosons are carriers of interactions: 8 massless gluons, 3 heavy weak bosons (W,Z) and 1 massless photon

A neutral scalar Higgs field permeates the Universe and is (in some way) responsible for masses of other particles (they originate from couplings to Higgs field)

SINGLE NEUTRAL HIGGS SCALAR - THE ONLY PARTICLE MISSING IN MSM

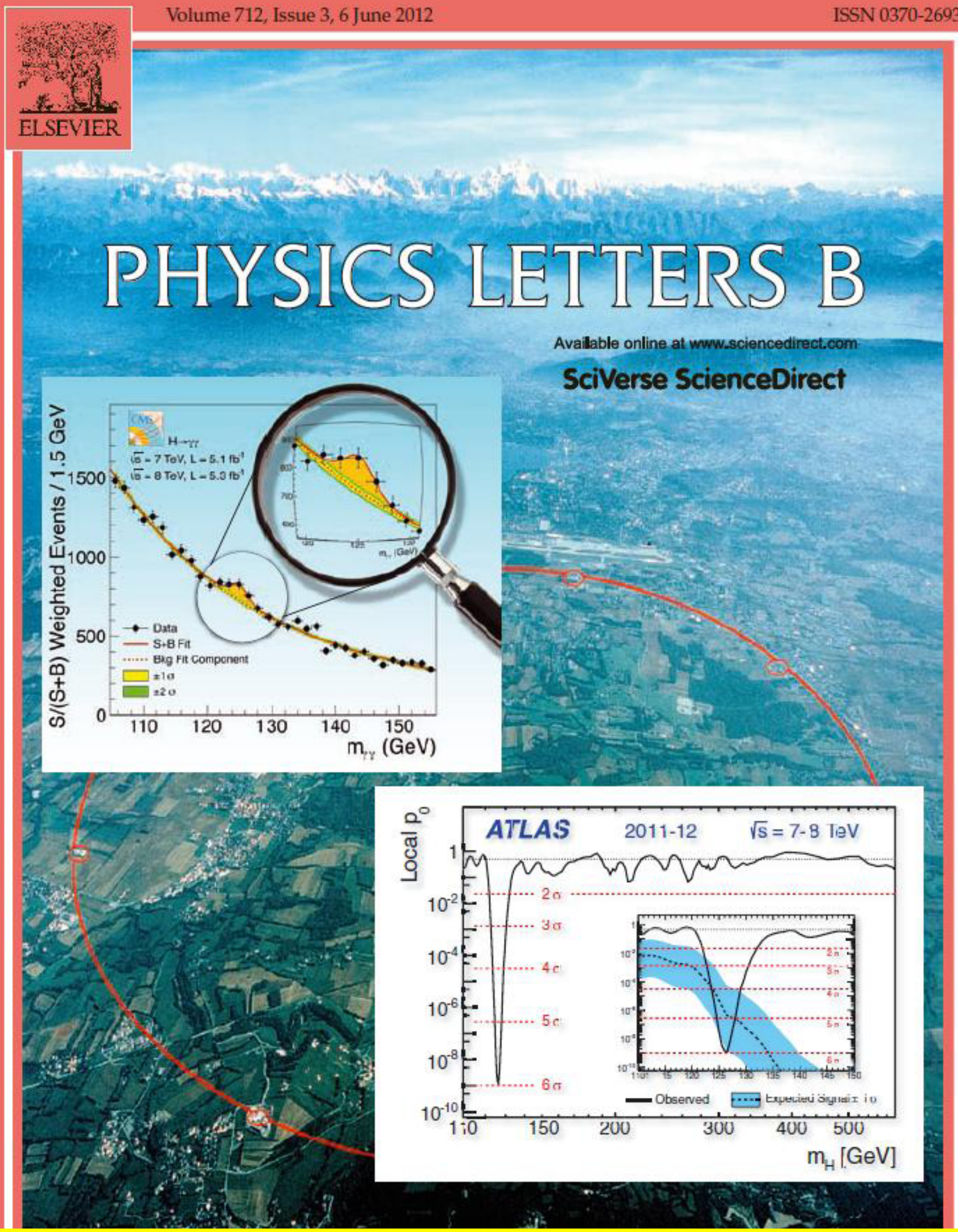


26 parameters NOT predicted by SM:

- masses of 6 quarks
- masses of 6 leptons
- coupling constants of SU(3), SU(2) and U(1)
- Higgs mass and vacuum expectation value
- Cabibbo-Kobayashi-Maskawa quark mixing angles and complex phase
- Maki-Nakagawa-Sakata lepton mixing matrix angles and complex phase
- QCD phase Θ

ALL MUST BE MEASURED !!!

4 July 2012: new boson announcement !!



Great day for the 20+ years' project !!!

"Always the last place you look!"

CERN-PH-EP-2012-218

Submitted to: Physics Letters B

Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC

The ATLAS Collaboration

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

IS THIS THE MSM BOSON ???

Fantastic, but…many questions, some new and many old:

i) is this the Minimal Standard Model boson?? answering this question will take time and many precision measurements - with the Higgs mass known, all SM couplings can now be calculated

ii) there remain MANY unsolved problems in SM – still plenty to understand and search for

(personally, I think it would be much more interesting if Higgs boson were not there…or if the new-found particle is NOT a Minimal Standard Model boson)

STANDARD MODEL – MANY OUTSTANDING QUESTIONS

- why so many (26) free parameters: all masses, all couplings, all mixing angles and CP- violating phases

- why 6 quarks and 6 leptons - is there an additional symmetry?

- why quarks and and leptons come in three pairs (generations)?

- why is CP not an exact symmetry (or why are laws of physics not symmetrical between matter and antimatter?) perhaps related to why is our Universe matter-dominated?

- what is Dark Matter which seem to be 5 times more prevalent in the Universe than ordinary matter (21% vs 4%)?

- HOW TO INCLUDE GRAVITY ???

- **Standard Model just a low-energy approximation…**

SM problems: spontaneous breaking of the electroweak symmetry by Higgs mechanism

Difficulties with the elementary Higgs sector : quantum corrections to scalar particle (Higgs) exhibit quadratic dependence on scale Λ, making Higgs mass VERY sensitive to the scale of the NEW physics => fine tuning problem (or a gauge hierarchy problem). This fine tuning has to be performed for each order of perturbation theory - this is a very unpleasant feature of MSM

The original problem of how to give masses to weak gauge bosons in a gauge invariant way was only partially solved by the Higgs mechanism, and the problem was transferred to a new level, where the new puzzle is how to keep Higgs mass stable against large quantum corrections from the higher energy scales

A method of controlling Higgs mass divergence other than fine tuning of parameters would be very welcomed

supersymmetry - the most elegant solution?

Supersymmetry is a space-time symmetry which introduces a fermionic partner to every boson and vice-versa, identical in all quantum numbers; divergencies would cancel without any fine tuning and in all orders of perturbation theory !!

If supersymmetry were real, it must be somehow broken as we have not yet observed superparticles. while still keeping the ability to solve the gauge hierarchy problem. Not easy, depends on the scale at which SUSY is broken, and on how it is broken. To some extent it remains still an open question

SUSY provides a natural explanation for "dark matter"

Local supersymmetry could also be a viable theory of gravity - supergravity.

gauge theories and extra dimensions

- Gauge theories can be understood best in the mathematical picture - a gauge potential (e.g. 4-vector potential of electrodynamics, or Yang-Mills potentials for Electroweak Theory) is a connection in a fibre bundle, a state-space described by a given gauge group: U(1) of EM, SU(2) of Yang-Mills theory, superimposed on space-time. The curvature of the connection is the gauge field (e.g the field strength tensor $F_{\mu\nu}$ of electrodynamics).
- It is a geometrical picture, very similar to Einstein's gravity, except the distortion measured by curvature is not taking place in the geometry of space-time but in the geometry of the more-dimensional "total space", imposed over space-time.
- Gauge (phase) transformations are analogous to co-ordinate transformations in Riemannian geometry of Einstein's General Relativity
- We may be living in a world which is more than just 4 dimensional (11??), except we don't "see" beyond the familiar 4 space-time dimensions (see my additional slides)

BEYOND STARDARD MODEL??

- SUPERSYMMETRY
- GRAND UNIFIED THEORIES based on larger symmetry groups, e.g. SU(5), SO(10), E_8, Monster group…
- new models, extensions of Kaluza-Klein theory, string theory, superstring theory, branes, M-theory, quantum gravity?
- TECHNICOLOR ??

- finding Higgs does not solve SM problems
- EXPERIMENTAL DATA NEEDED BADLY!!

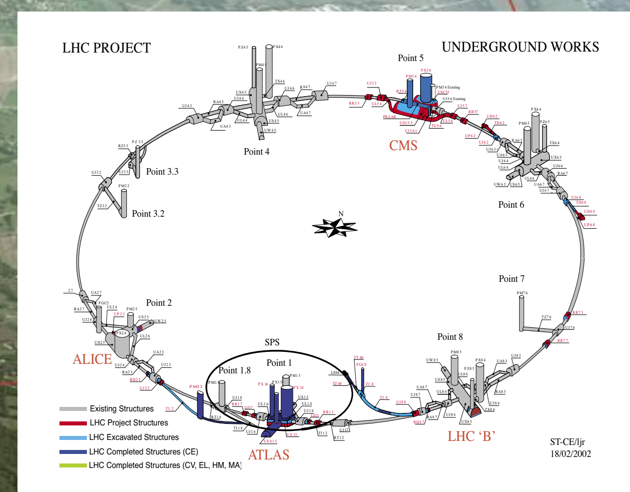
Large Hadron Collider at CERN

European Centre for Particle Physics, Geneva, Switzerland

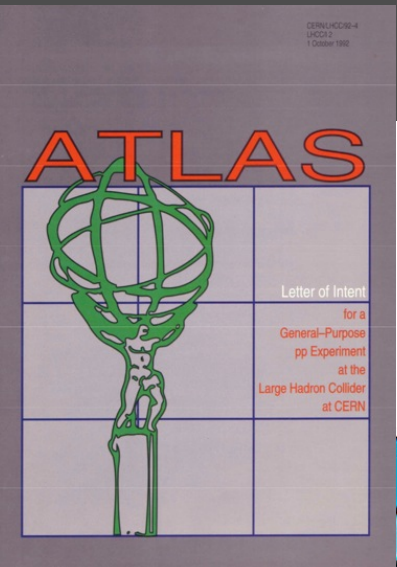
Superconducting Proton Accelerator and Collider
installed in a 27km circumference underground tunnel (tunnel cross-section diameter 4m) at CERN
Tunnel was built for LEP collider in 1985
First operation in Fall 2008

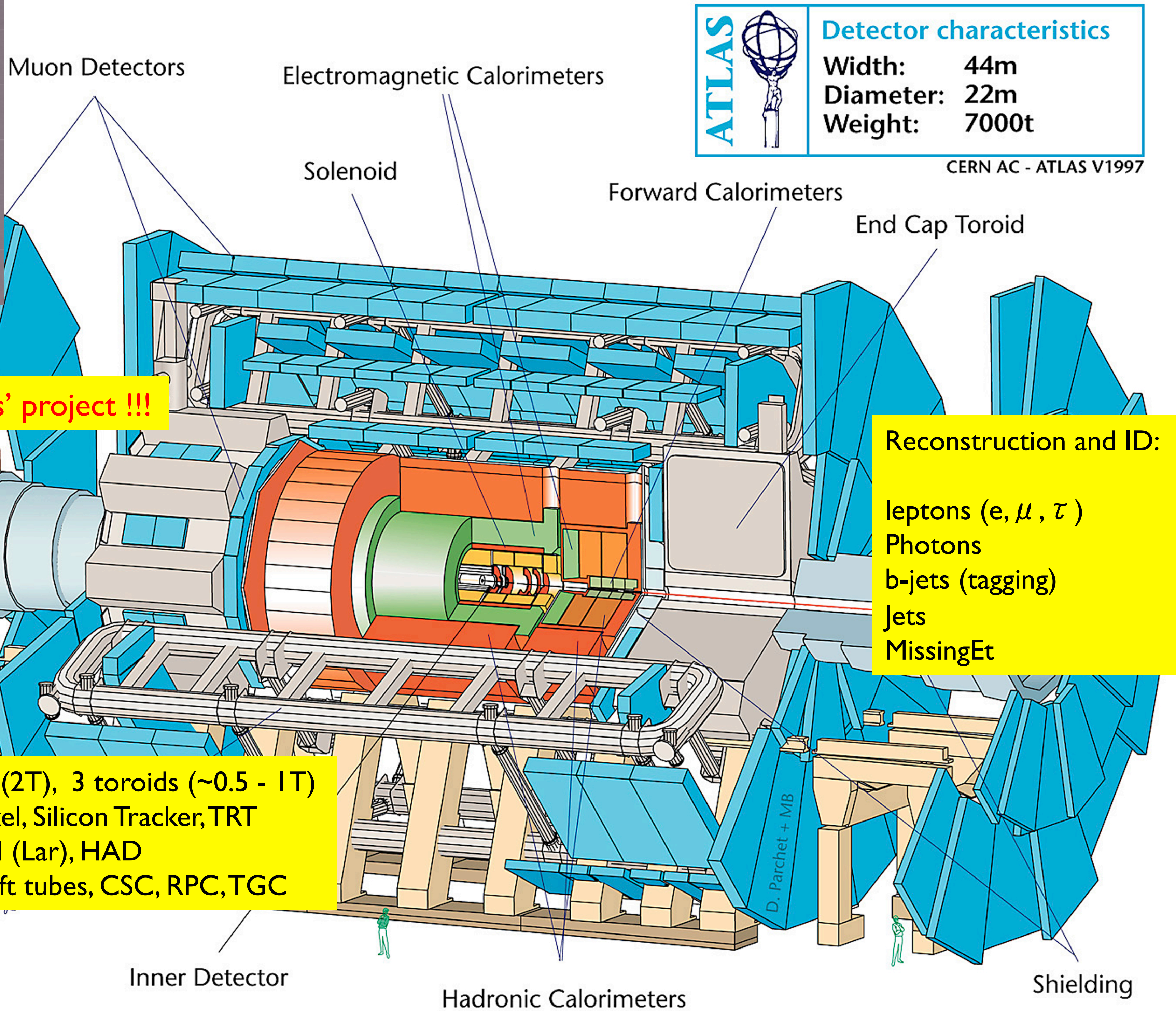
1984 : First studies for a high-energy pp collider in the LEP tunnel
1993 : cancellation of SSC
1994 : LHC approved by the CERN Council
1994 : top-quark discovered at the Tevatron
1996 : start of construction of LHC machine and experiments
2000 : closing of LEP2
2003 : Start of LHC machine and experiments installation
2009 : 23 November: first LHC collisions ($\sqrt{s}$ = 900 GeV)
2010 : 30 March: first collisions at $\sqrt{s}$ = 7 TeV
beginning of a long physics programme
2011 : hints of a new particle of mass ~125 GeV
2012 : 1st May: first collisions at $\sqrt{s}$ = 8 TeV

2012 : 4th July: discovery of a Higgs-like boson announced



ATLAS DETECTOR AT LHC





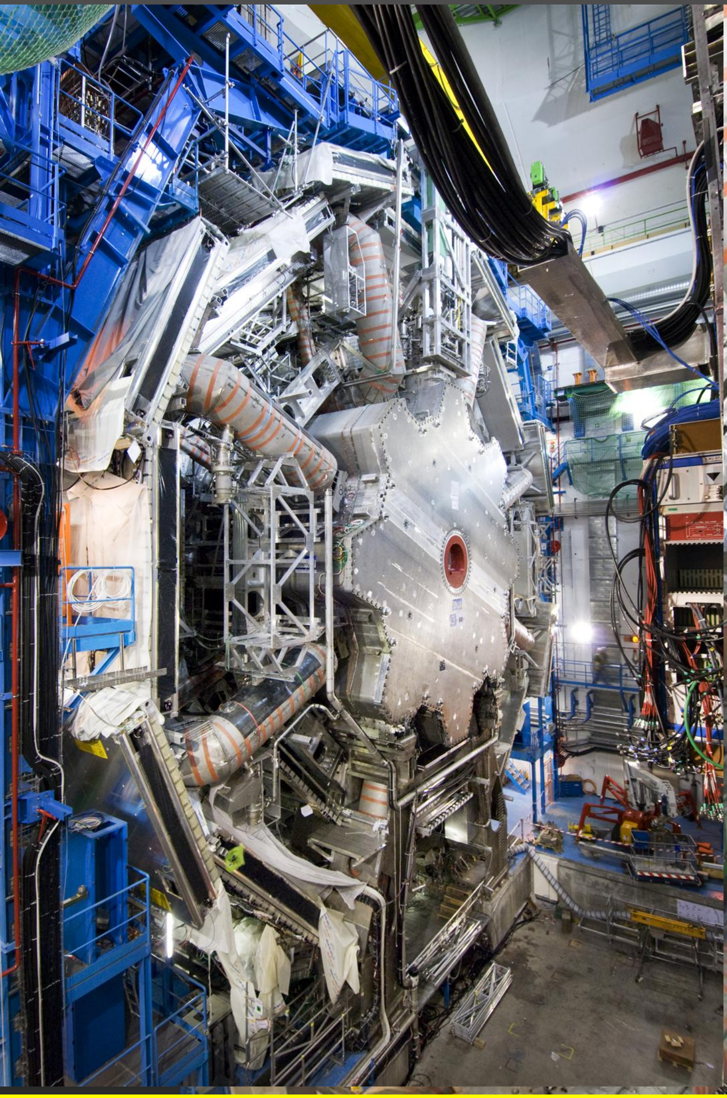
more than 20 years' project !!!

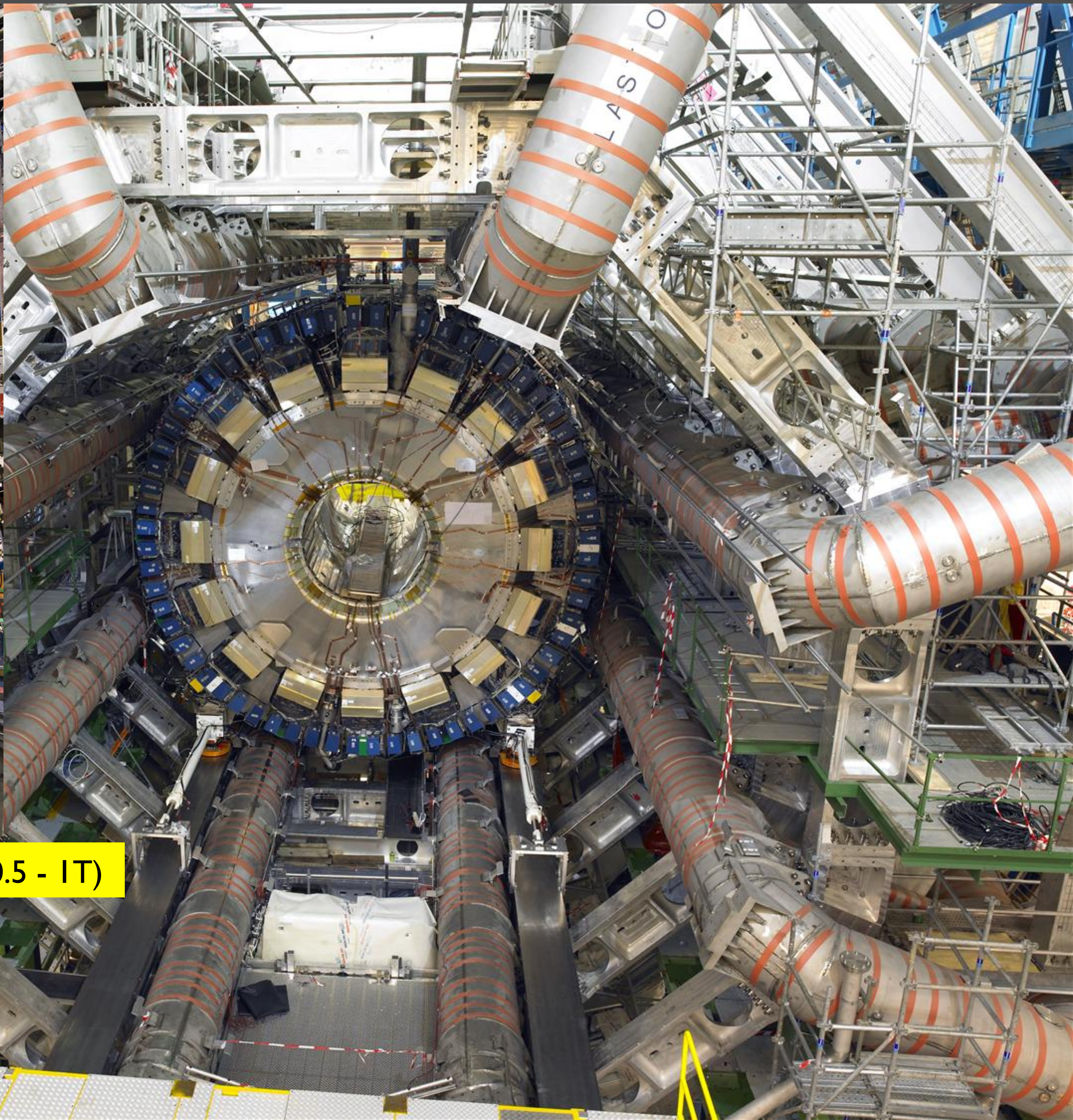
Reconstruction and ID:

leptons (e, μ , τ)
Photons
b-jets (tagging)
Jets
MissingEt

Magnets: solenoid (2T), 3 toroids (~0.5 - 1T)
Tracking: Pixel, Silicon Tracker, TRT
Calorimeter: EM (Lar), HAD
Muons: drift tubes, CSC, RPC, TGC

ATLAS DETECTOR AT LHC

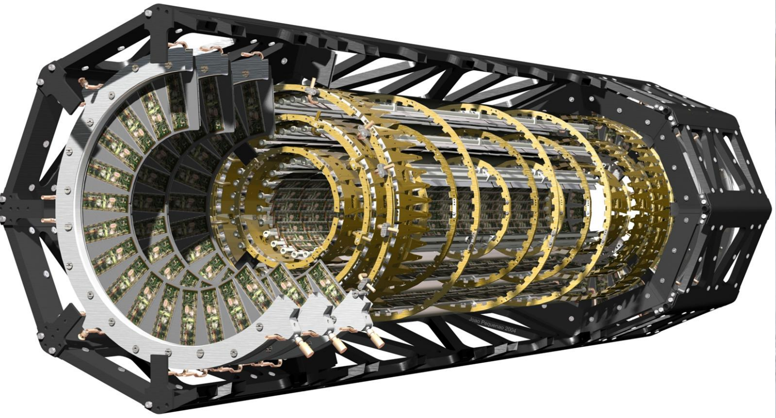


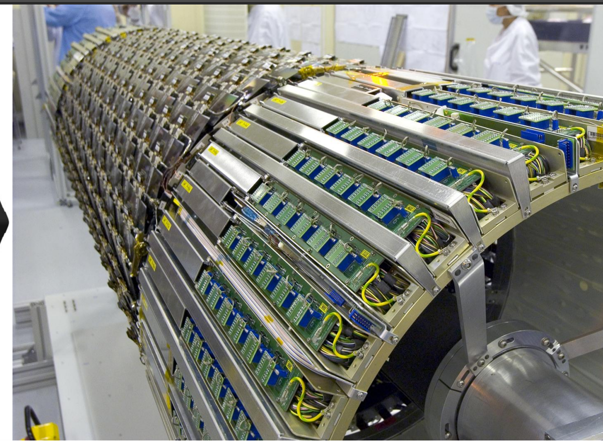


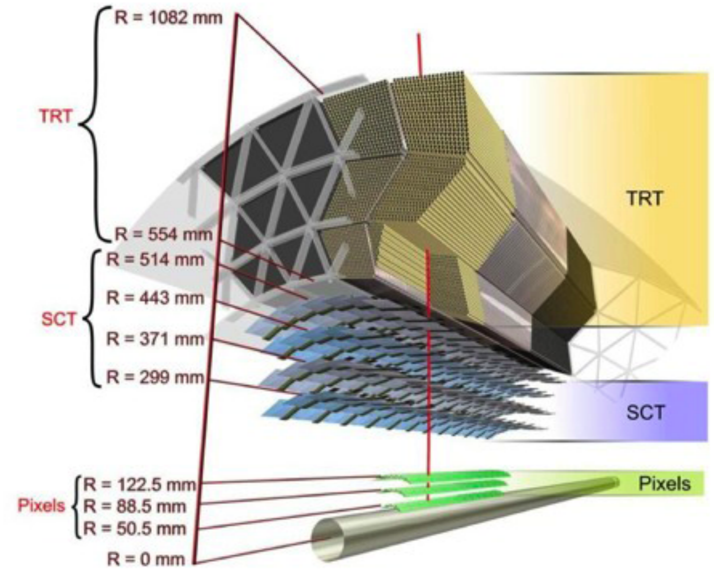
Magnets: solenoid (2T), 3 toroids (~0.5 - 1T)

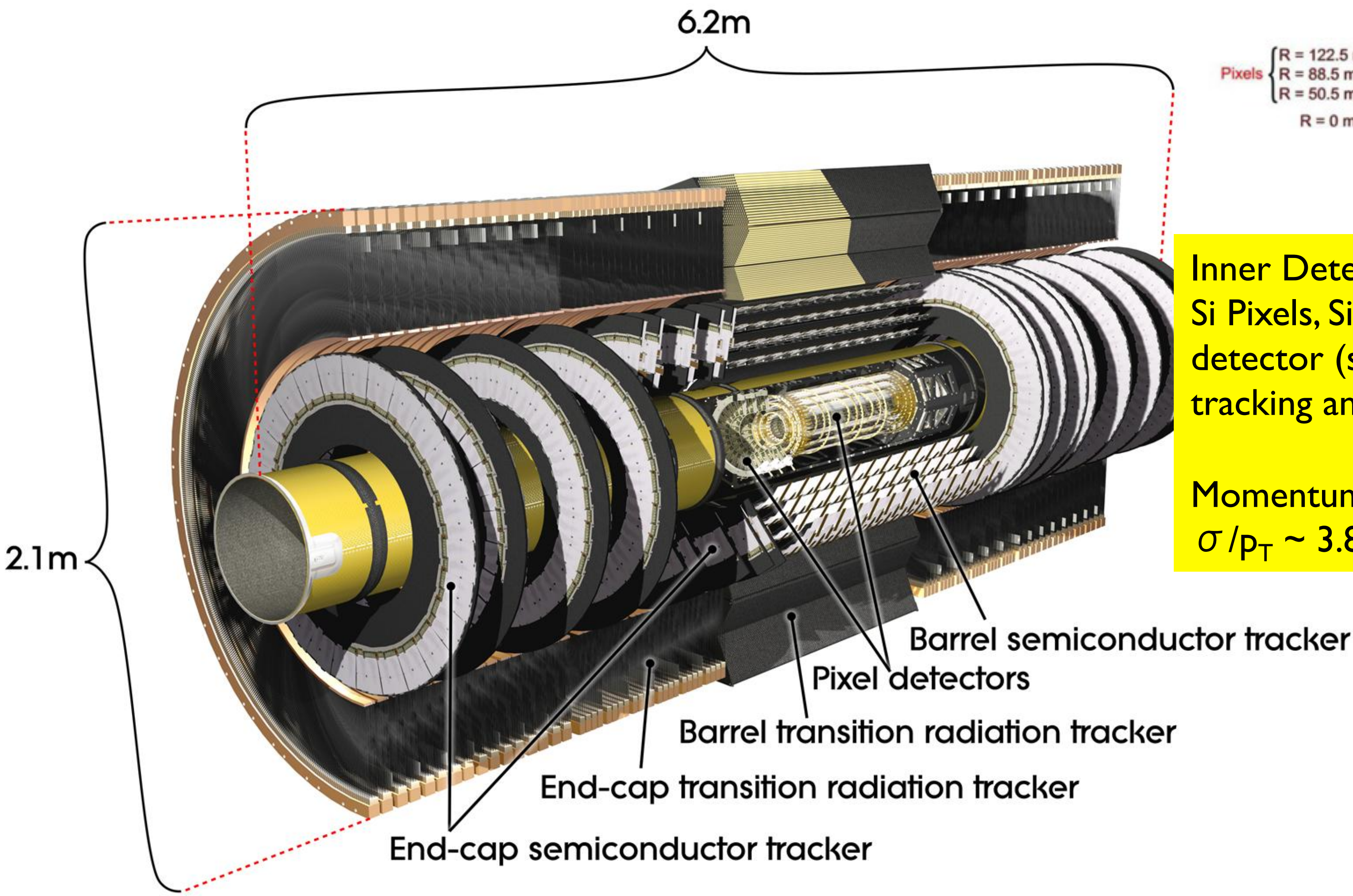
ATLAS EXPERIMENT
http://atlas.ch

ATLAS TRACKING DETECTORS





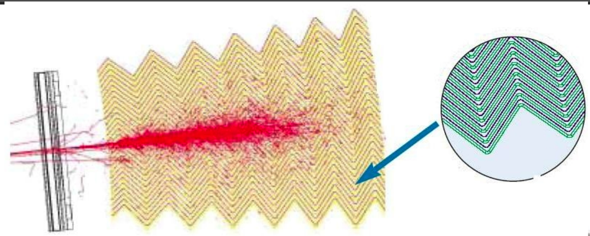


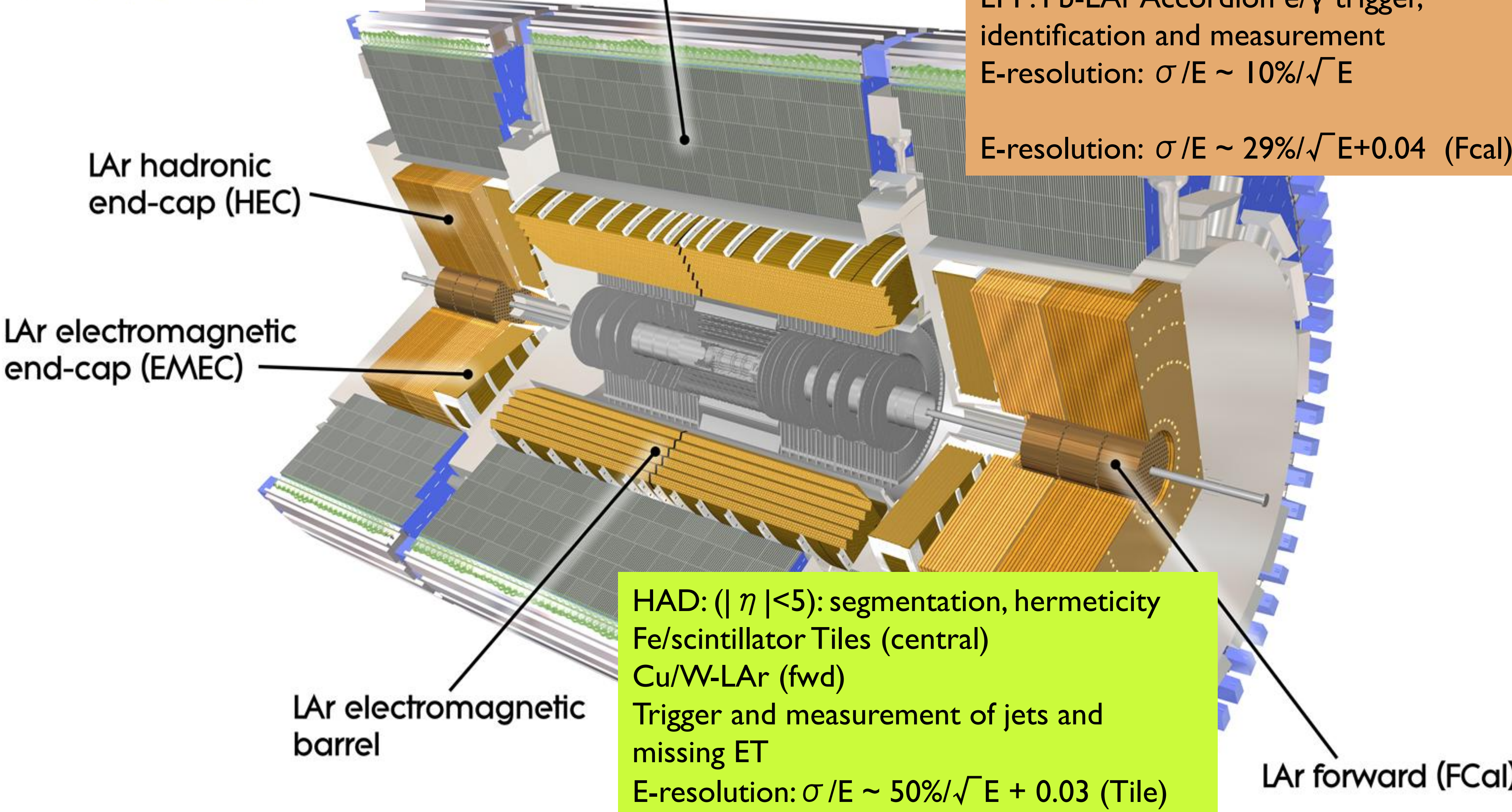


Inner Detector ($|\eta|<2.5$, solenoid B=2T): Si Pixels, Si strips, Transition Radiation detector (straws) – particle ID, precise tracking and vertexing, e/π separation

Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T\,(\mathrm{GeV}) + 0.015$

ATLAS CALORIMETERS





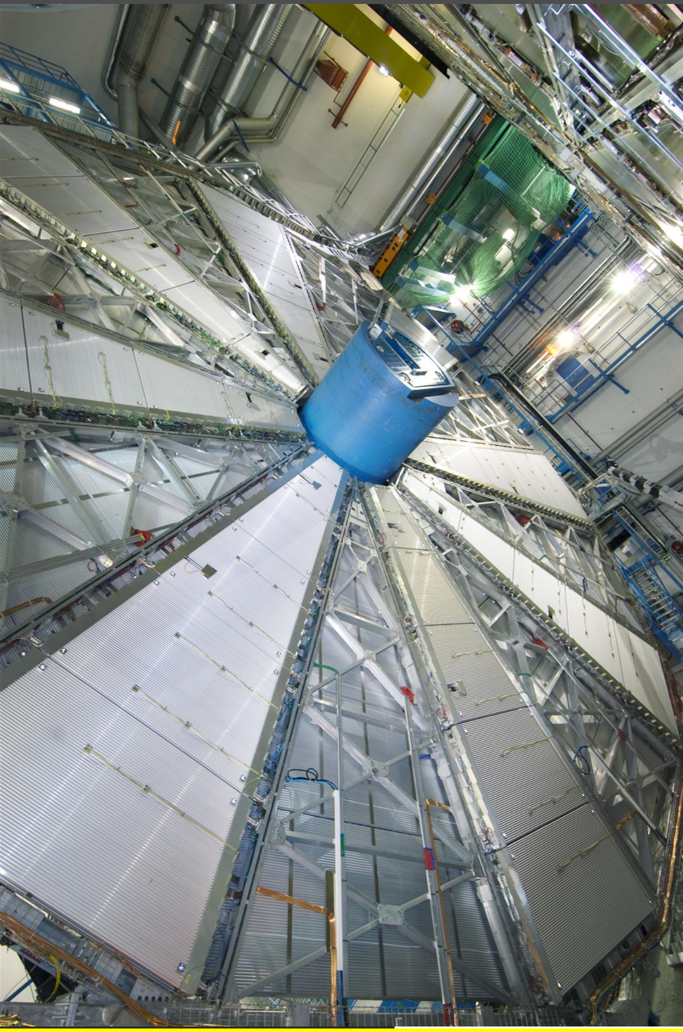
EM : Pb-LAr Accordion e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

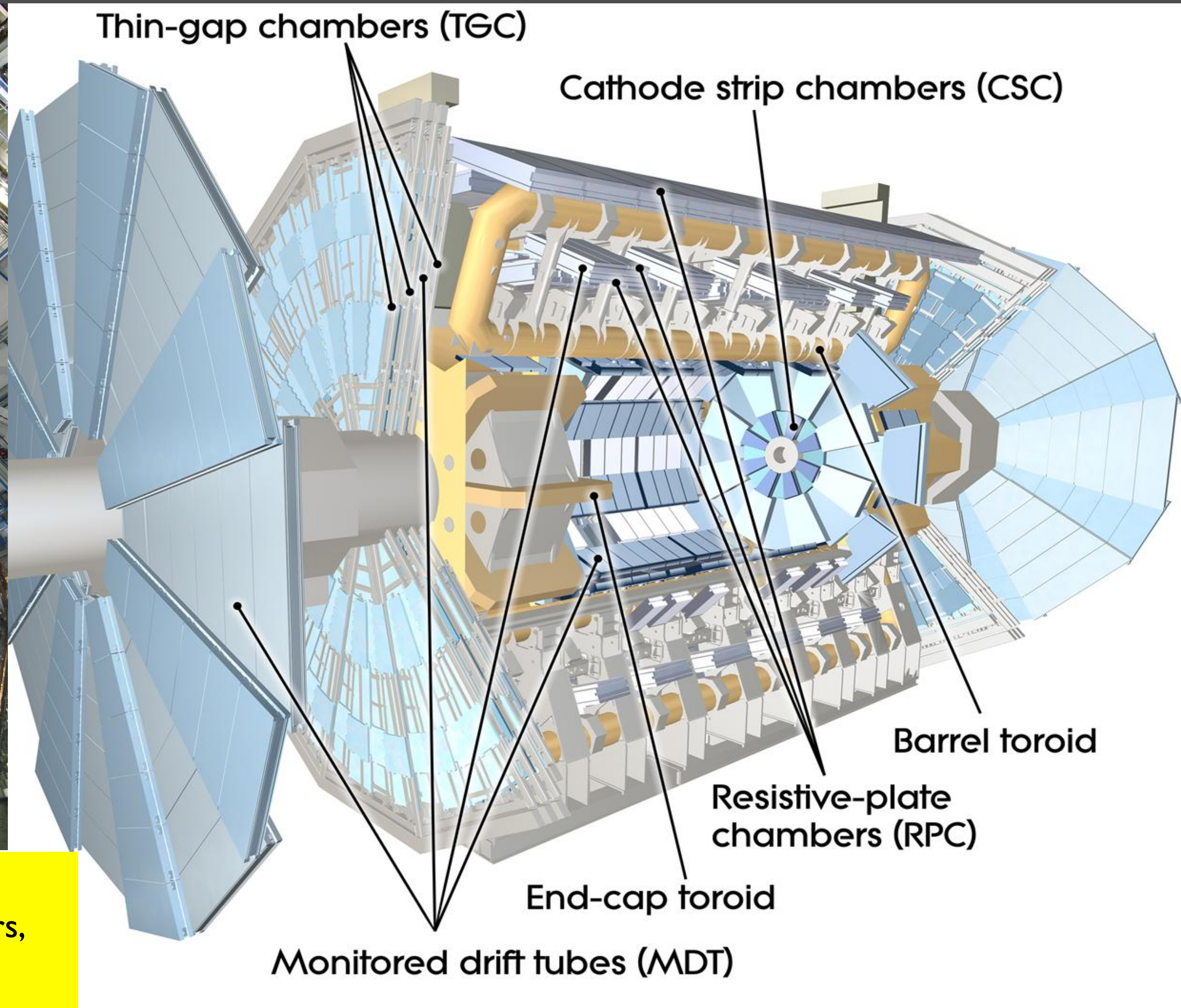
E-resolution: $\sigma/E \sim 29\%/\sqrt{E}+0.04$ (Fcal)

HAD: ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central)
Cu/W-LAr (fwd)
Trigger and measurement of jets and missing ET
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} + 0.03$ (Tile)

E-resolution: $\sigma/E \sim 95\%/\sqrt{E} + 0.08$ (FCal)

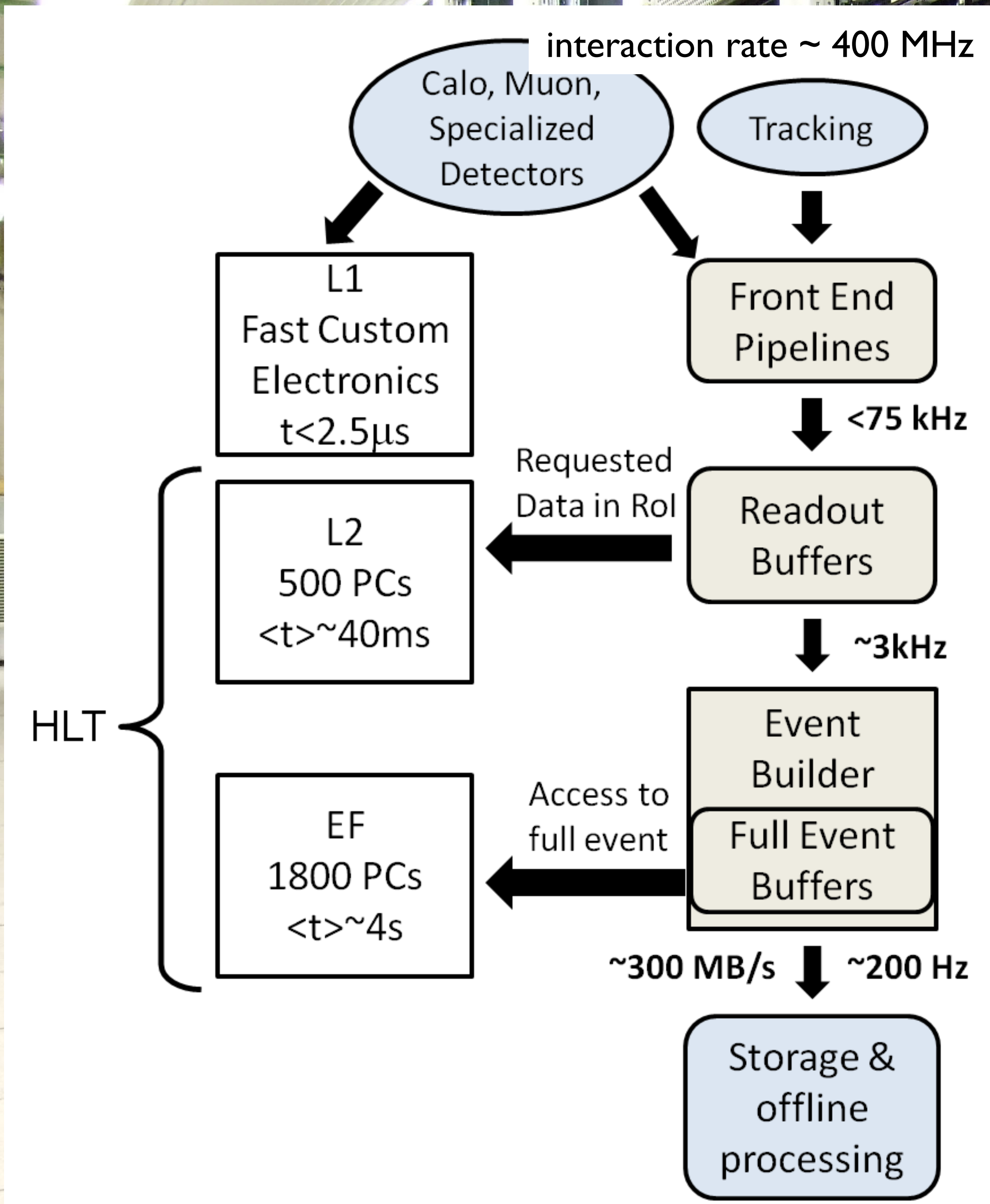
ATLAS MUON SPECTROMETER





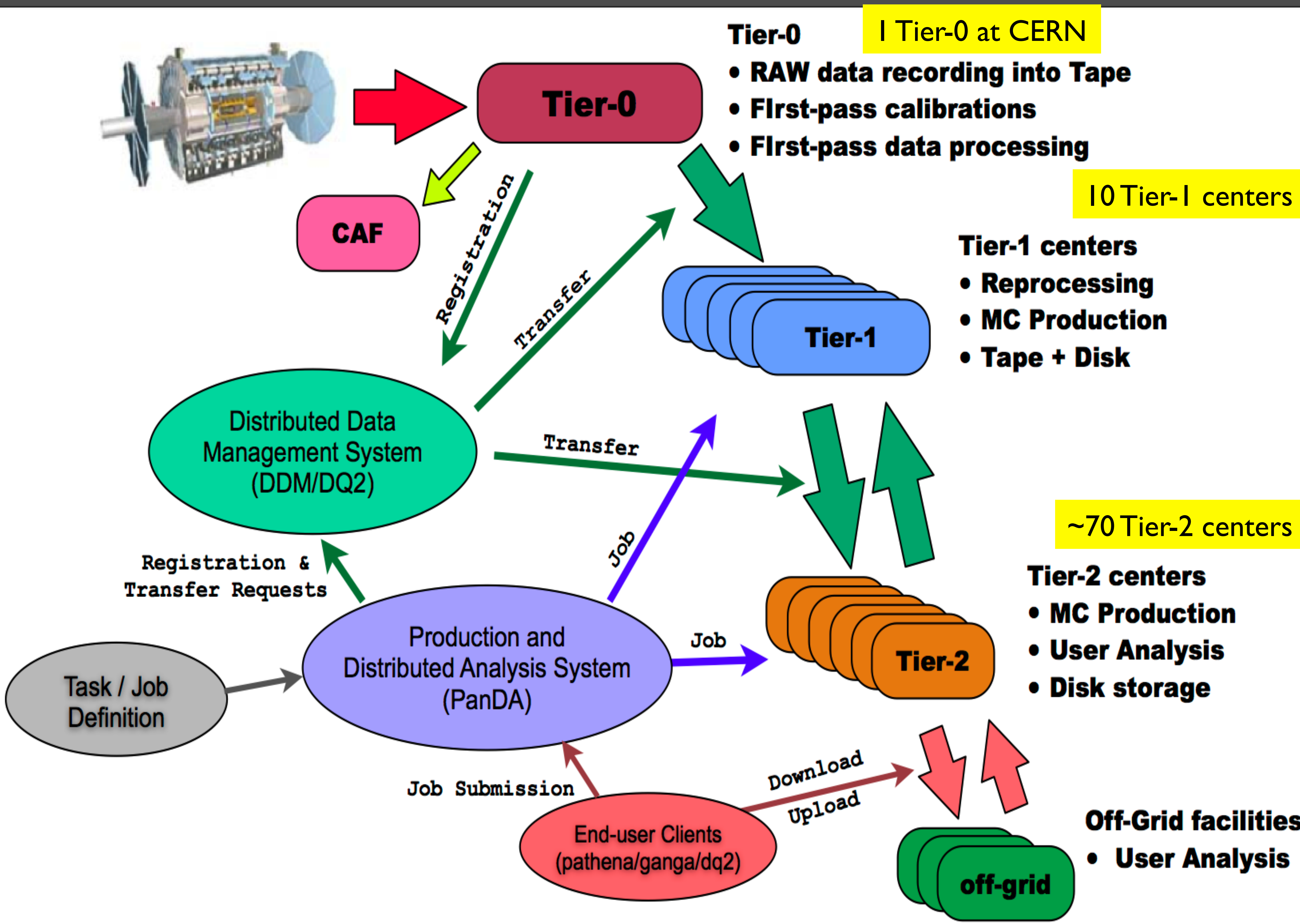
Muon coverage (| η |<2.7) : 3 air-core toroids with gas-based muon chambers, measurement (CSC, MDT) with momentum resolution
< 10% up to Eμ ~ 1 TeV
Trigger (TGC, RPC)

ATLAS TRIGGER AND DATA ACQUISITION SYSTEM



Number of nodes:	2000
Number of computing cores:	17000
Cooling power:	800 kW
Peak Event Building Bandwidth:	10 GB/s
Peak Storage Bandwidth:	1.6 GB/s
Amount of data in 2012:	6 PB

ATLAS COMPUTING



ATLAS COLLABORATION

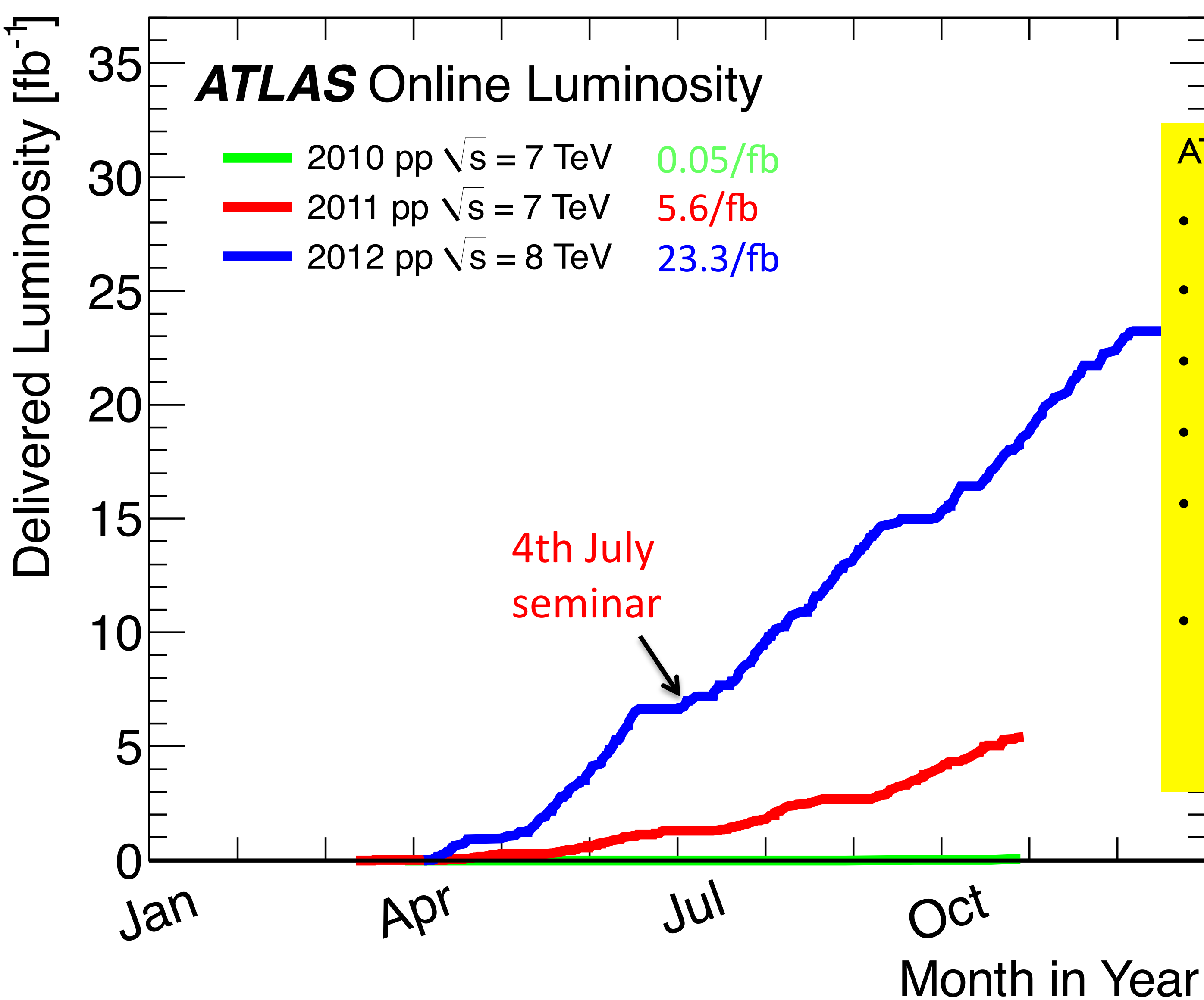
ATLAS RESULTS ARE A TRULY COLLABORATIVE EFFORT OF MANY THOUSANDS OF PEOPLE, PHYSICISTS, ENGINEERS, PROGRAMMERS, TECHNICIANS AND STUDENTS….

AND MANY FUNDING AGENCIES INVOLVED!!

~3000 physicists
48 countries
177 universities
~1000 students

+ engineers
+ technicians
+ computer scientists

delivered luminosity– fantastic LHC performance

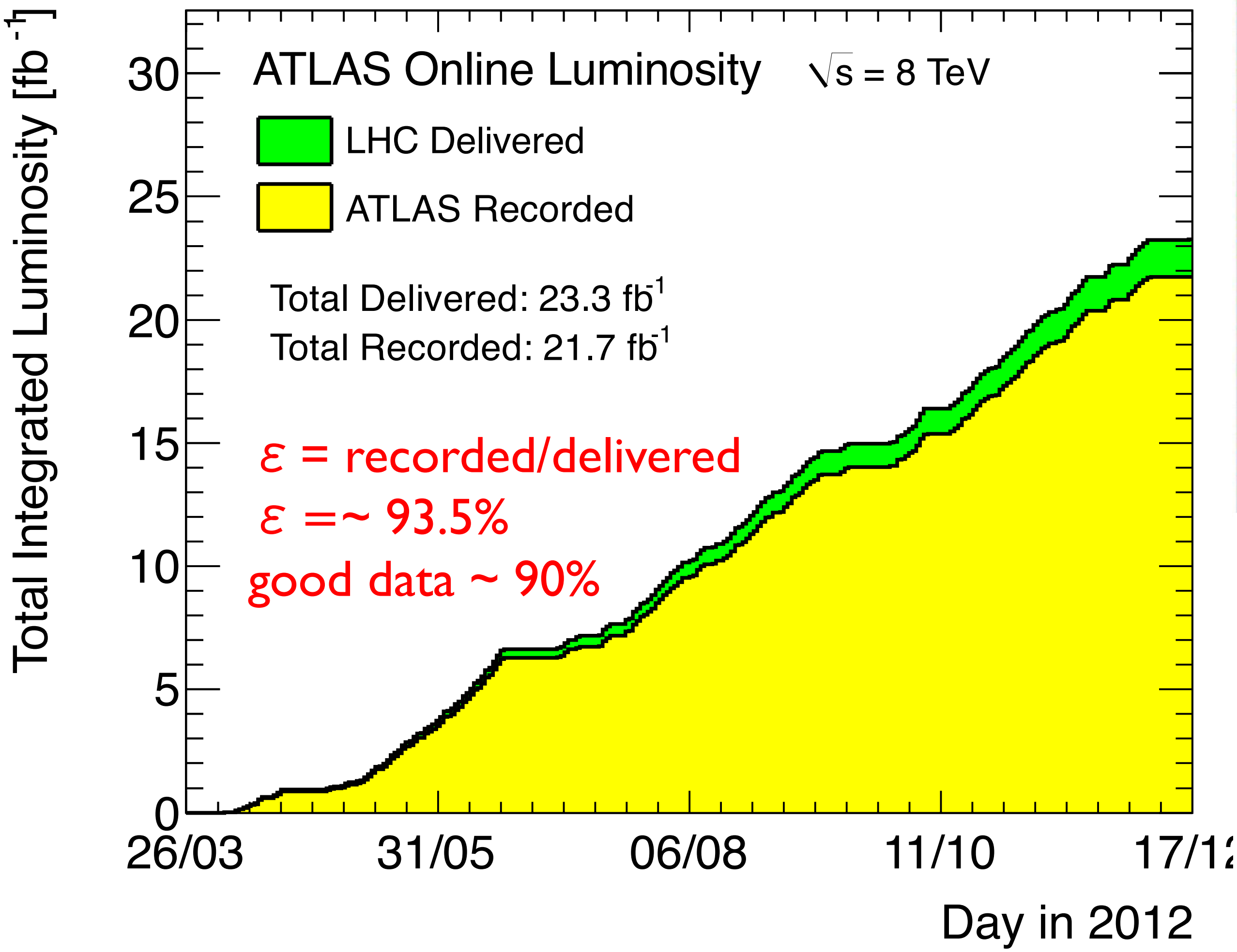


ATLAS integrated luminosity in 2012

- Peak $L = 7.7\times10^{33}\ s^{-1}cm^{-2}$ (Aug)
- Max L/fill: 237 pb^{-1} (June)
- Weekly record: 1350 pb^{-1} (June)
- Longest stable beams: 22.8 h (July)
- Fastest turn-around between stable beams: 2.1 h (April)
- Best weekly data-taking efficiency: 92 h (55%) (July)

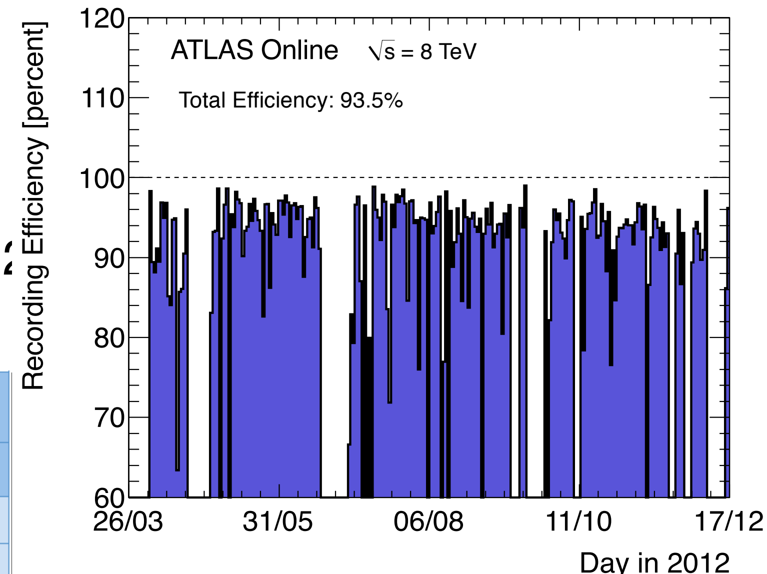
Luminosity: measured with forward detectors, calibrated with beam separation scans
Current uncertainty: 3.6%

detector operation efficiency, data quality



Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	100%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	96.0%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	98.2%

≥ 95% for all systems

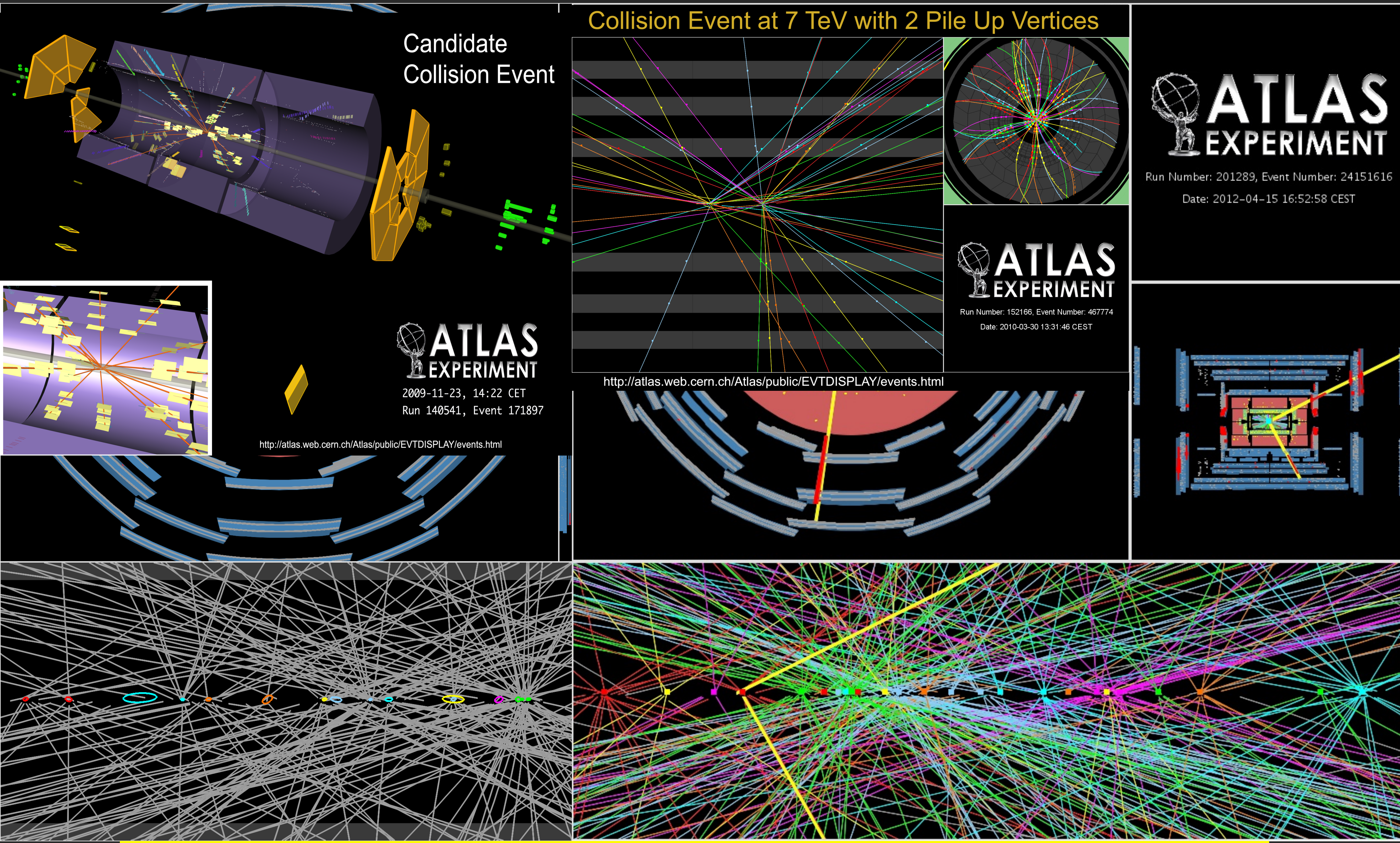


ATLAS p-p run: April-Sept. 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.3	99.5	97.0	99.6	99.9	99.8	99.9	99.9	99.7	99.2
All good for physics: 93.7%										

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and September 17th (in %) – corresponding to 14.0 fb^{-1} of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future.

ATLAS EXPERIMENT http://atlas.ch

pileup – a difficulty in 2012 8 TeV running



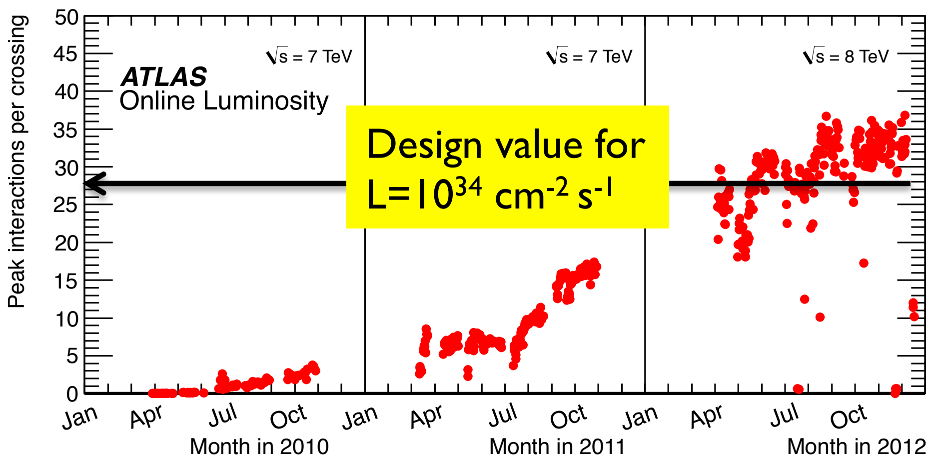
Z candidate events 2012 data, 20 (left) and 25 (right) reconstructed vertices

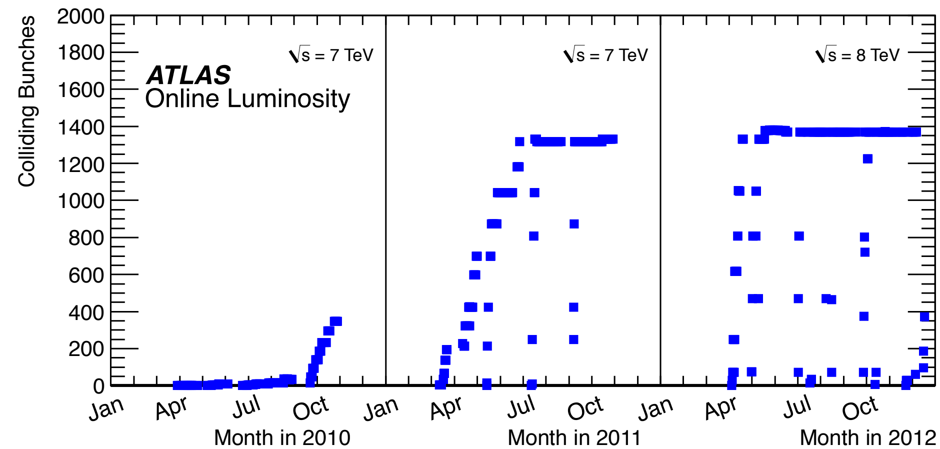
pileup

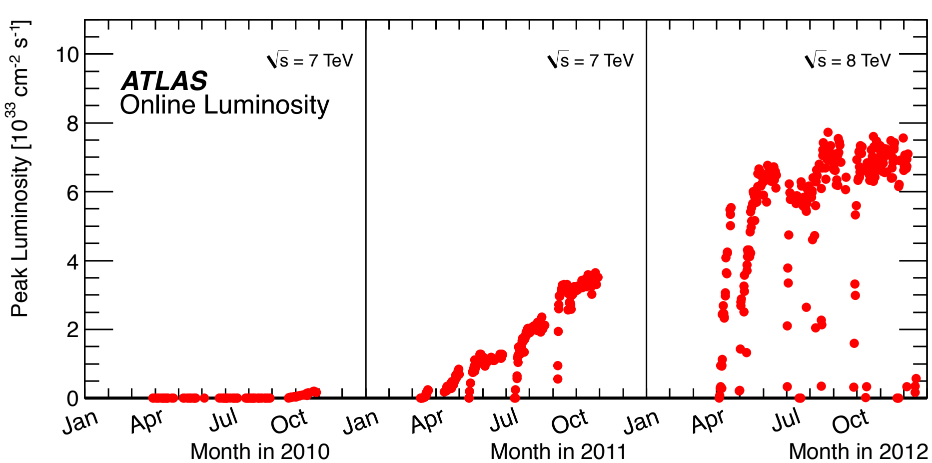
Running with 50 ns bunch spacing (rather than 25 ns) results in 2x larger pile-up for the same luminosity – lots of effort devoted to prepare for 2012 running - trigger and off-line algorithms which are pile-up “robust” needed to be developed. In general:

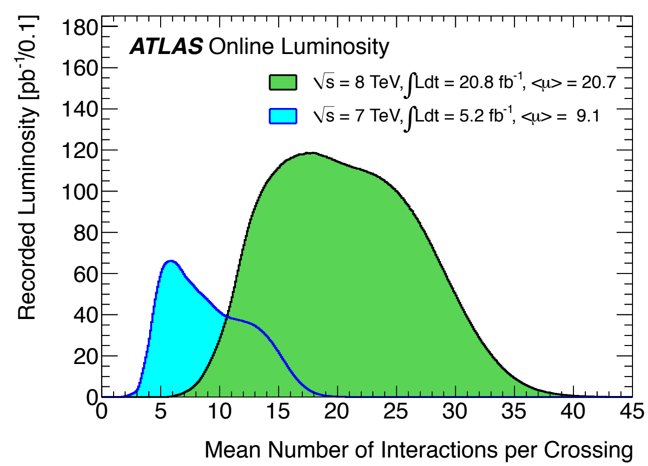
> sizable impact on jets, E_T^{miss} and tau reconstruction as well as on trigger rates and computing,
>
> no significant impact on tracking, muons, electrons and photons

Improved modeling of in-time and out-of-time pile-up in MC simulations
Computing challenges due to 2x higher trigger rates and large event sizes (10-50 sec/event for μ = 5−50



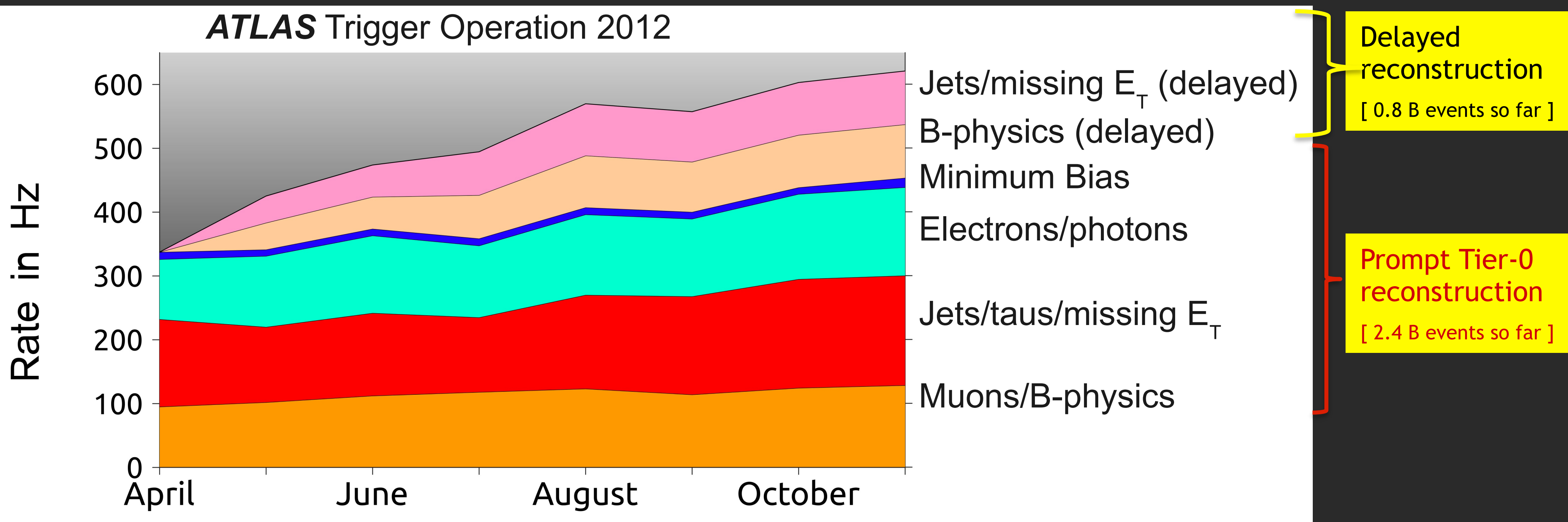






Baseline menu designed for $L = 8 \times 10^{33}\ cm^{-2}s^{-1}$ and mostly unchanged during 2012 run

Average trigger table during Stable Beams:



Average rate of 400 Hz over 2012 run for prompt trigger streams
(~1700 stable beam hours)

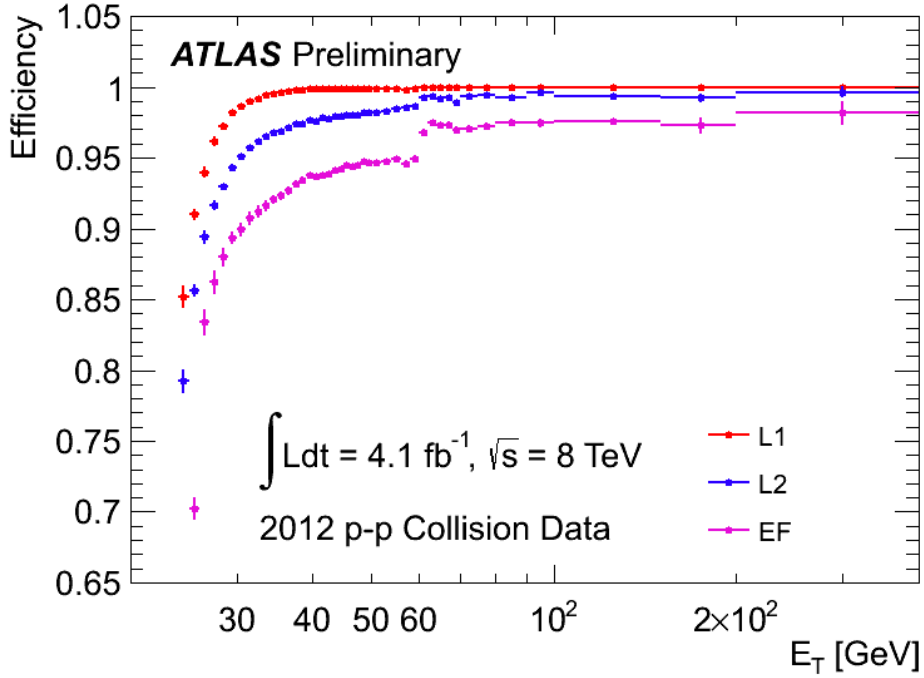
(from A. Hoecker slides – ATLAS Status Report – LHCC, Dec 5, 2012

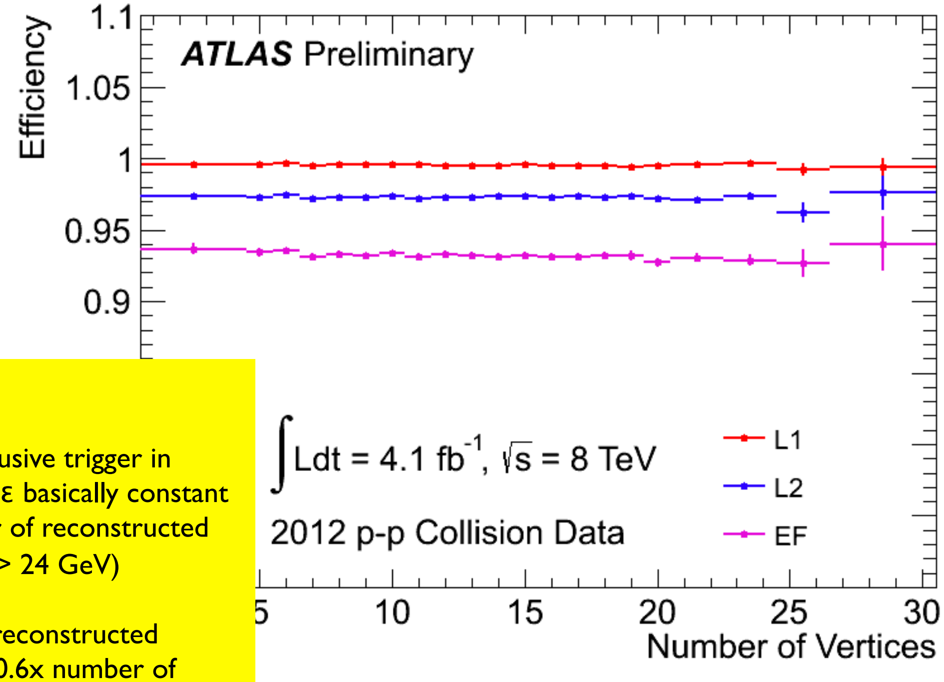
primary triggers in 2012

Signature	Offline selection	Trigger selection L1	Trigger selection EF	L1 Peak (kHz) $L_{peak} = 7\times10^{33}$	EF Ave (Hz) $L_{ave} = 5\times10^{33}$
Single leptons	Single muon p_T > 25 GeV	15 GeV	24 GeV	**8**	**45**
	Single electron p_T > 25 GeV	18 GeV	24 GeV	**17**	**70**
Two leptons	2 muons p_T > 6 GeV	2 × 6(4_{EOF}) GeV (also 2mu4 barrel only)	2 × 6 GeV	**3**	**2**
	2 muons p_T >15 GeV 2 muons p_T > 20,10 GeV	2 × 10 GeV 15 GeV	2 × 13 GeV 18,8 GeV	**1** **8**	**5** **8**
	2 electrons, each p_T > 15 GeV	2 × 10 GeV	2×12 GeV	**6**	**8**
	2 taus p_T > 45, 30 GeV	15,11 GeV	29,20 GeV	**12**	**12**
Two photons	2 photons, each p_T > 25 GeV 2 loose photons, p_T > 40,30 GeV	2 × 10 GeV 12,16 GeV	2 × 20 GeV 35, 25 GeV	**6** **6**	**10** **7**
Single jet	Jet p_T > 360 GeV	75 GeV	360 GeV	**2**	**5**
E_T^{miss}	E_T^{miss} > 120 GeV	40 GeV	80 GeV	**2**	**17**
Multi-jets	5 jets, each p_T > 60 GeV 6 jets, each p_T > 50 GeV	4×15 GeV	5 × 55 GeV 6 × 45 GeV	**1**	**8**
b-jets	*b* + 3 other jets p_T > 45 GeV	4 × 15 GeV	4 × 45 GeV + *b*-tag	**1**	**4**
TOTAL				**< 75**	**~ 400 (ave)**

(from A. Hoecker slides – ATLAS Status Report – LHCC, Dec 5, 2012)

ATLAS TRIGGER AND DATA ACQUISITION

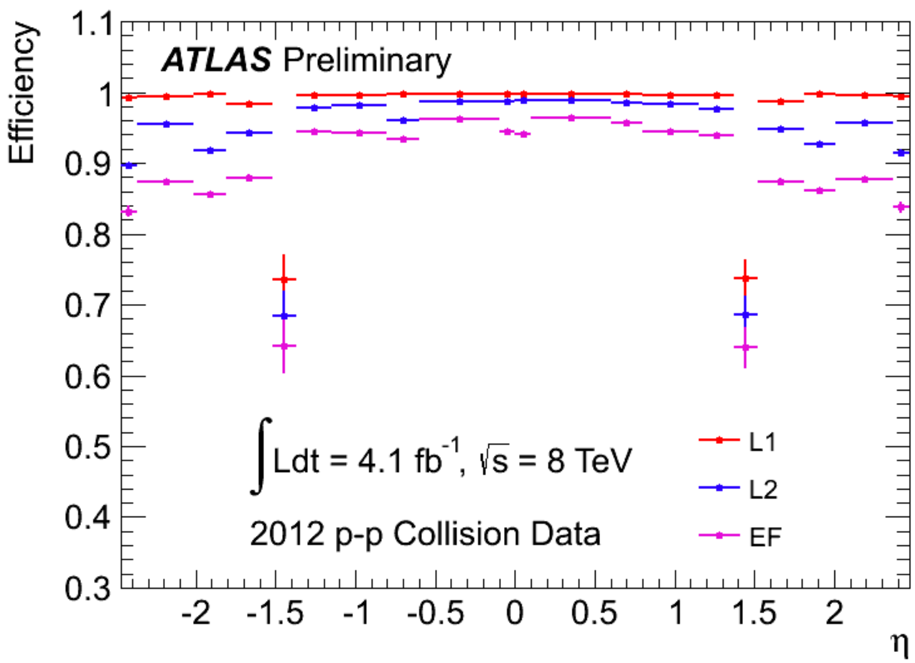


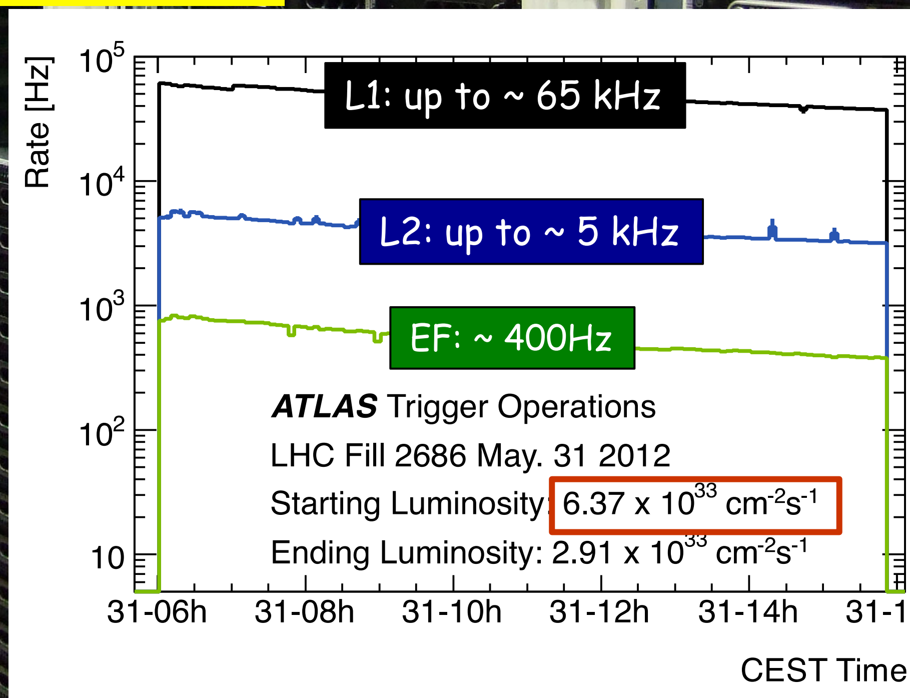


example:

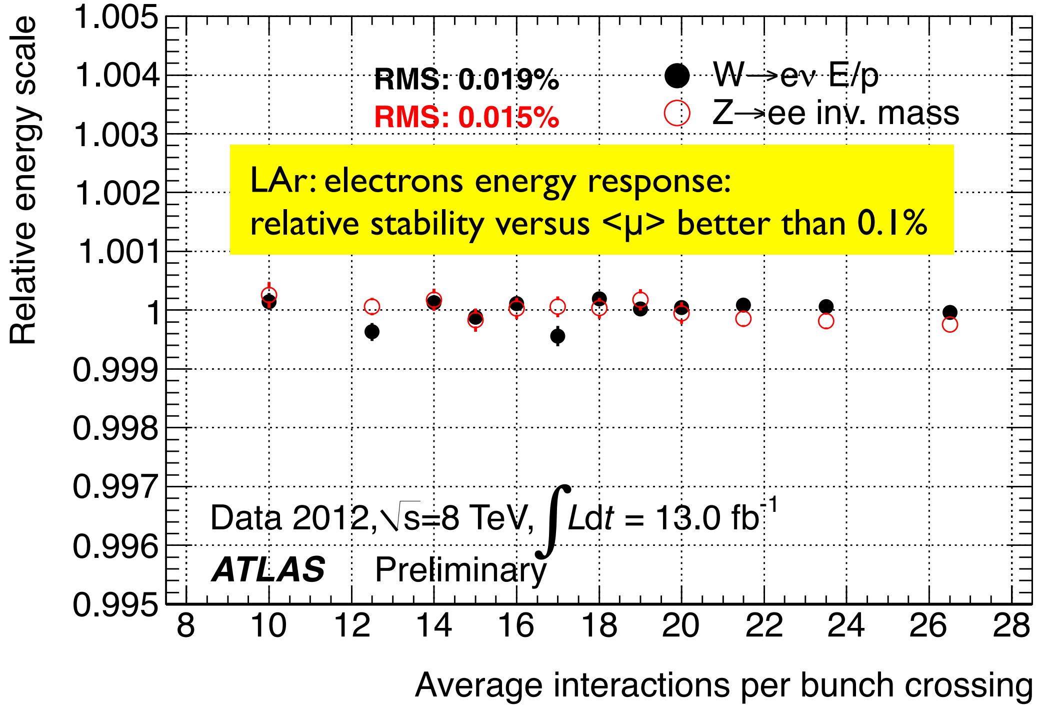
electron inclusive trigger in 2012 data - ε basically constant with number of reconstructed vertices (E_T > 24 GeV)

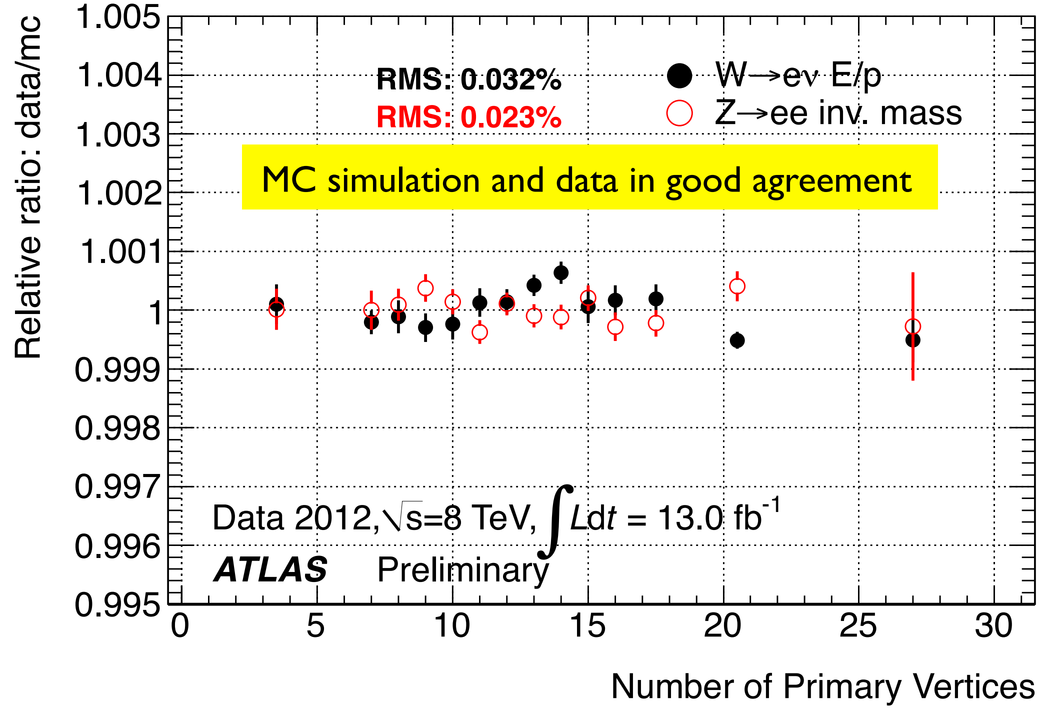
(number of reconstructed vertices is ~0.6x number of interactions per crossing)

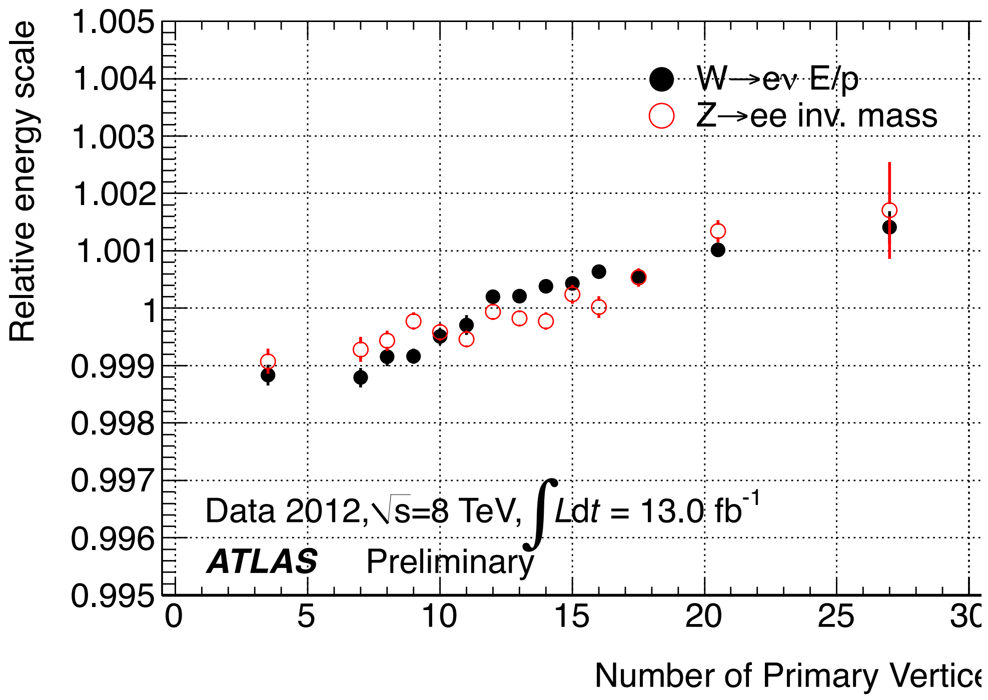


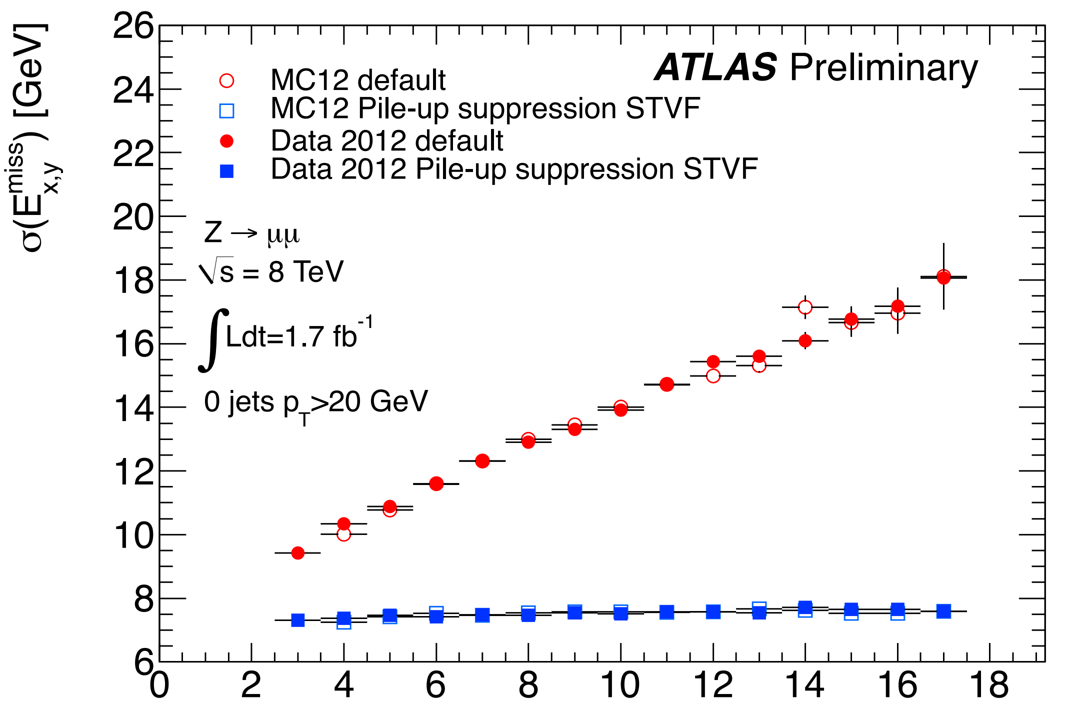


STABILITY WITH RESPECT TO PILEUP









ATLAS – MAIN RESULTS

- precision measurements and tests of Standard Model

  WW, WZ, ZZ, Wγ, Zγ, $\gamma\gamma$ …. tt, single top
  most important background to most Higgs and new physics searches

  QCD studies……

  WELL UNDERWAY…

- searches for physics "BEYOND the STANDARD MODEL"

  SO FAR, NOTHING:(

- Higgs search: new boson at ~125 GeV !!

  just one? two? spin-parity? Is this the MSM boson?

ATLAS – MAIN RESULTS

for more details see talks at this conference by:

Nicola Orlando – “QCD”

Marilyn Marx – “Electroweak and Top results”

Carsten Hensel – “SUSY searches with the ATLAS detector”

Elisa Pueschel – “Exotics”

Sofia Maria Consonni – “Higgs search at ATLAS”

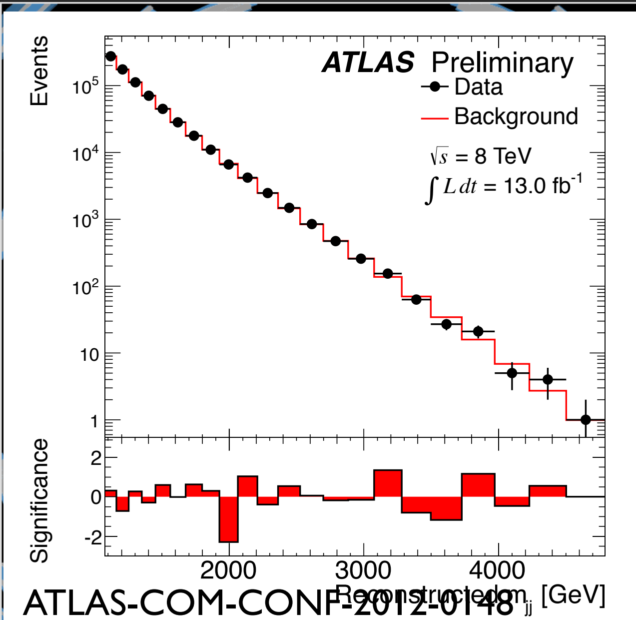
Theodore Todorov - “ATLAS-Upgrade”

Edson Carquin - “Forward Physics”

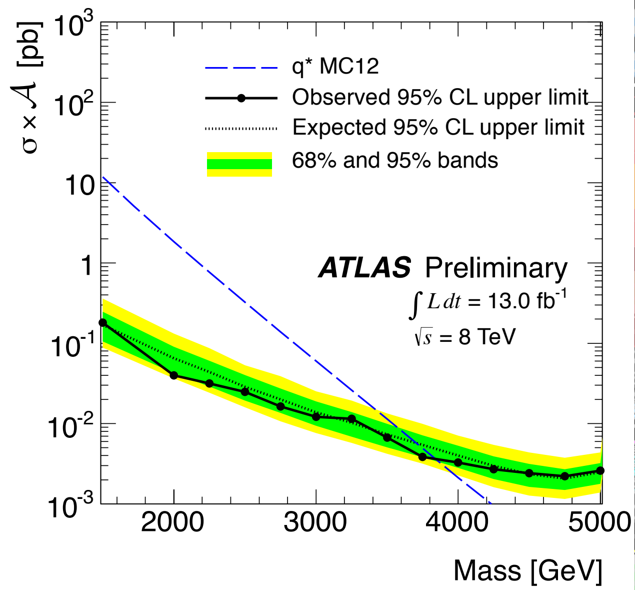
Marisilvia Donadelli – “Heavy Ion results”

QCD jet studies

QCD: two central high-p_T jets with an invariant mass of 4.69 TeV (2012 – 8 TeV running)

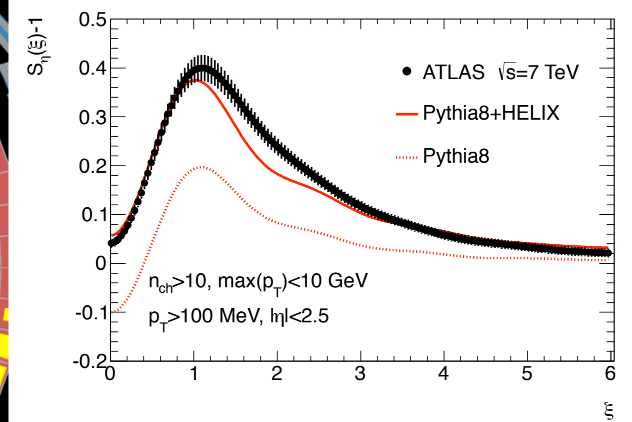


ATLAS-COM-CONF-2012-0148



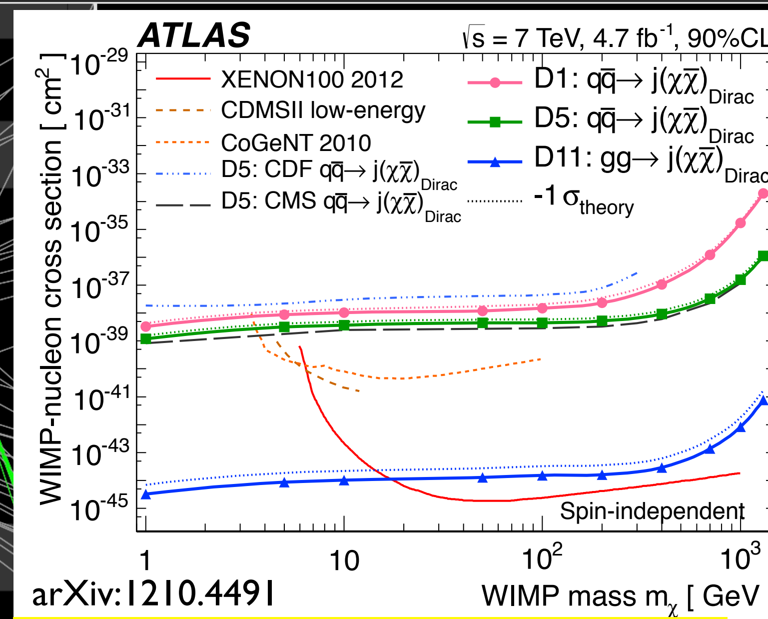
M(q*) > 3.84 TeV @95 CL

Phys.Rev.D86,034001(2012)



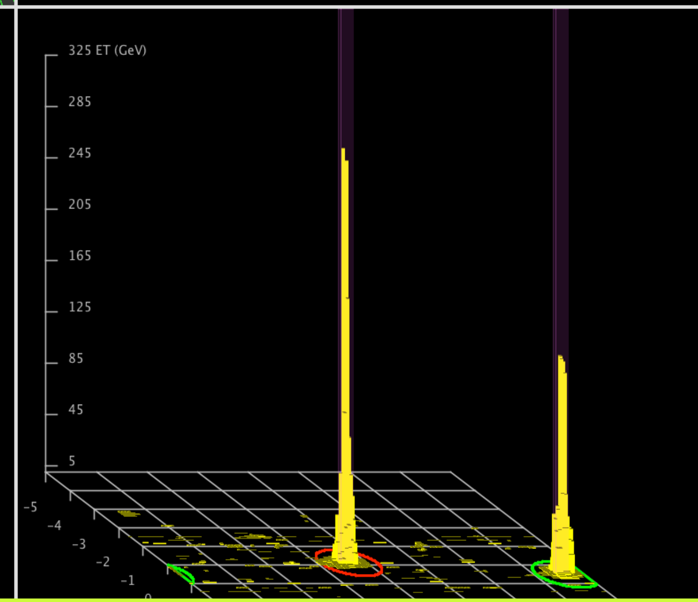
Evidence for helix structure of QCD string – should lead to improved description of fragmentation models – will benefit ALL analyses

Understanding of QCD effects is essential for all precision measurements



arXiv:1210.4491

Monojet analysis – limits on WIMP



- for details and other results see Nicola Orlando’s talk

top studies

Top is heaviest particle in the SM, and it may be playing a special role in EW symmetry breaking.

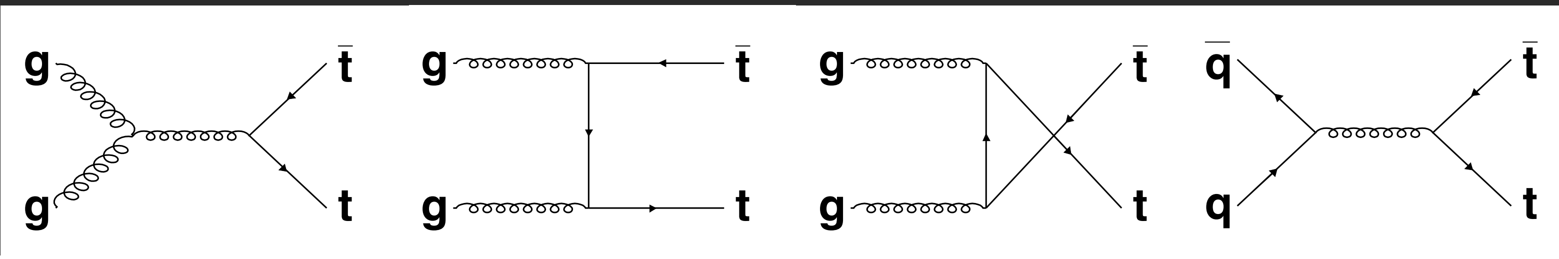
Most physics beyond the SM will show up as excess of events above the SM including 6 quarks –

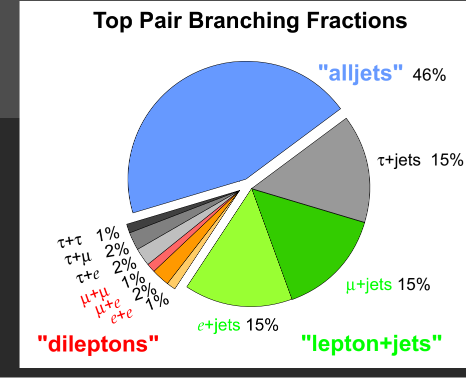
TOP PRODUCTION HAS TO BE UNDERSTOOD REALLY WELL AS IT IS THE MOST IMPORTANT BACKGROUND FOR MANY OF "NEW PHYSICS" SIGNATURES

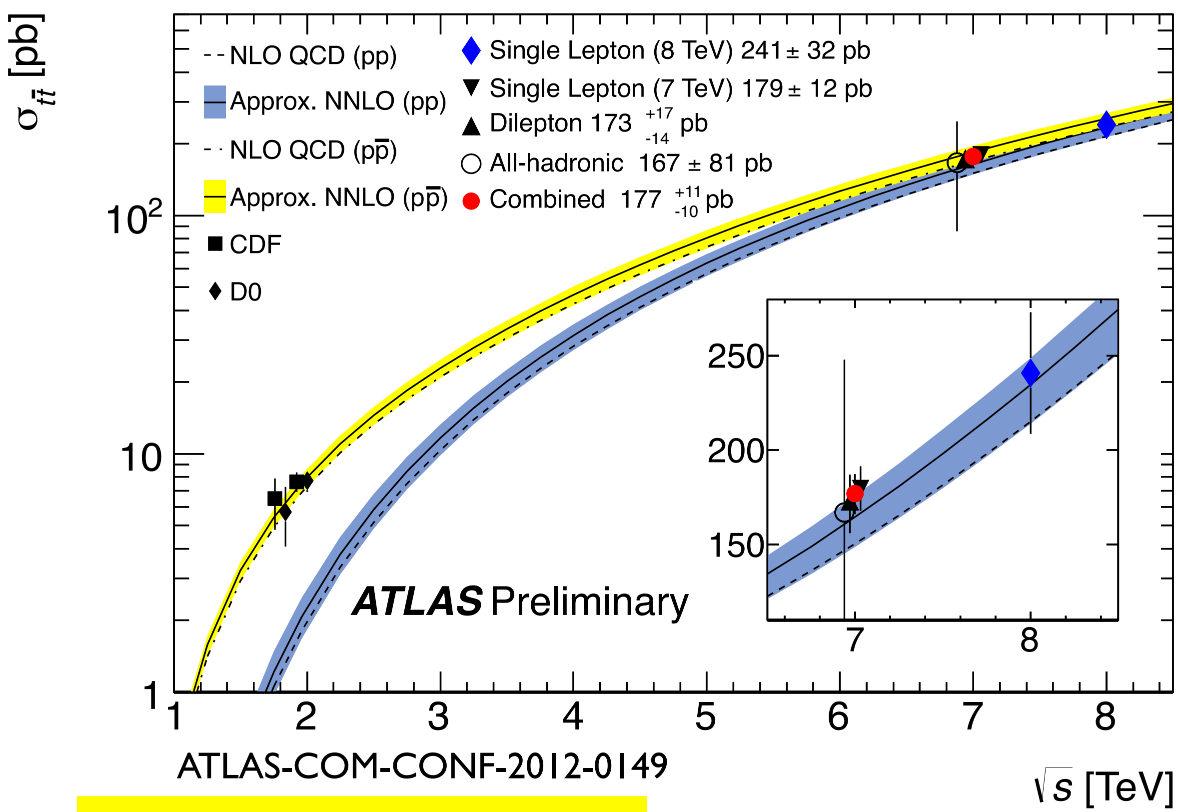
Top studies may be the best testing ground for NLO and NNLO calculations

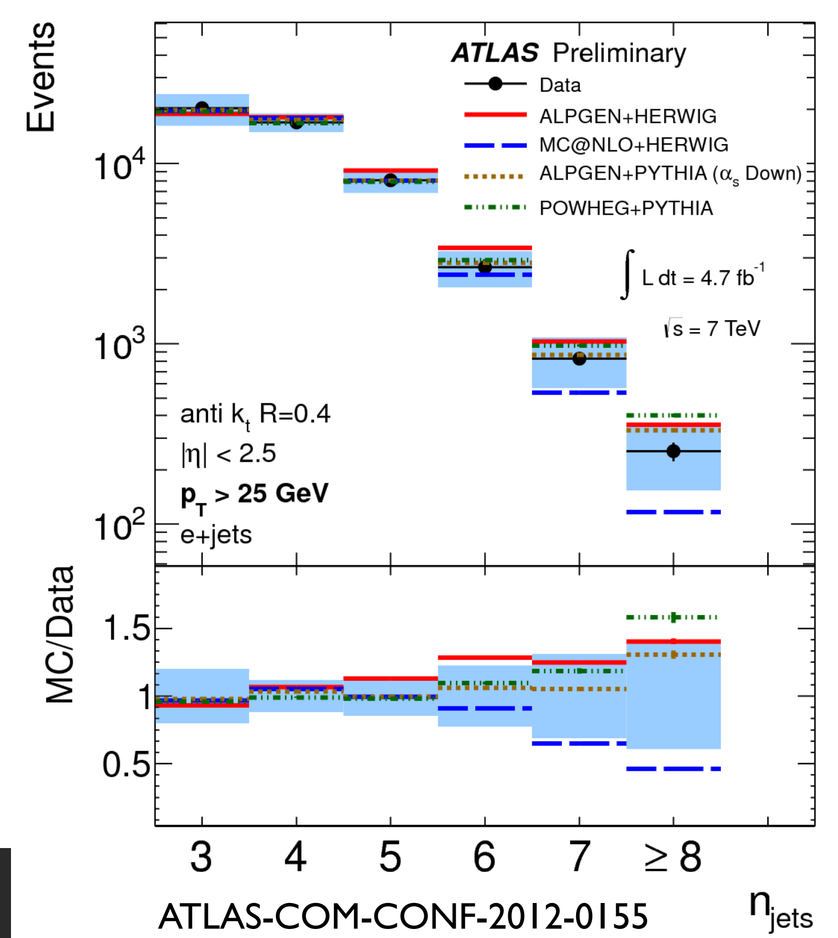
(recently lots of progress - Czakon and Mitov finished qq and qg NNLO -arXiv:1210.6832, gg – soon, may explain the ttbar charge asymmetry puzzle)

top studies





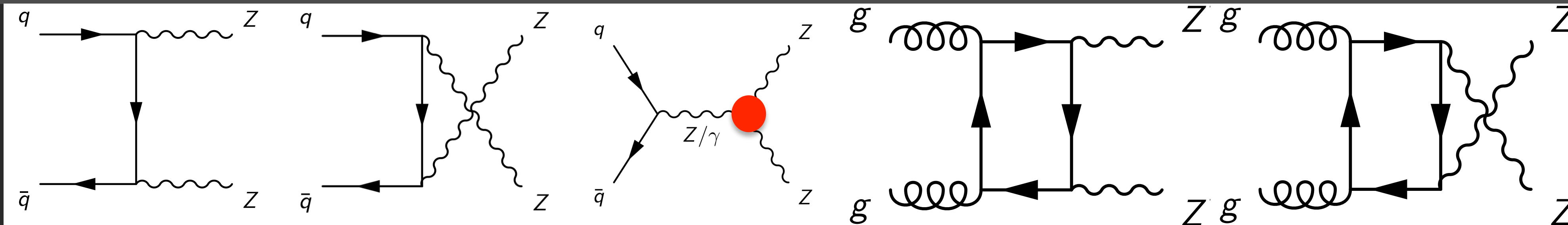


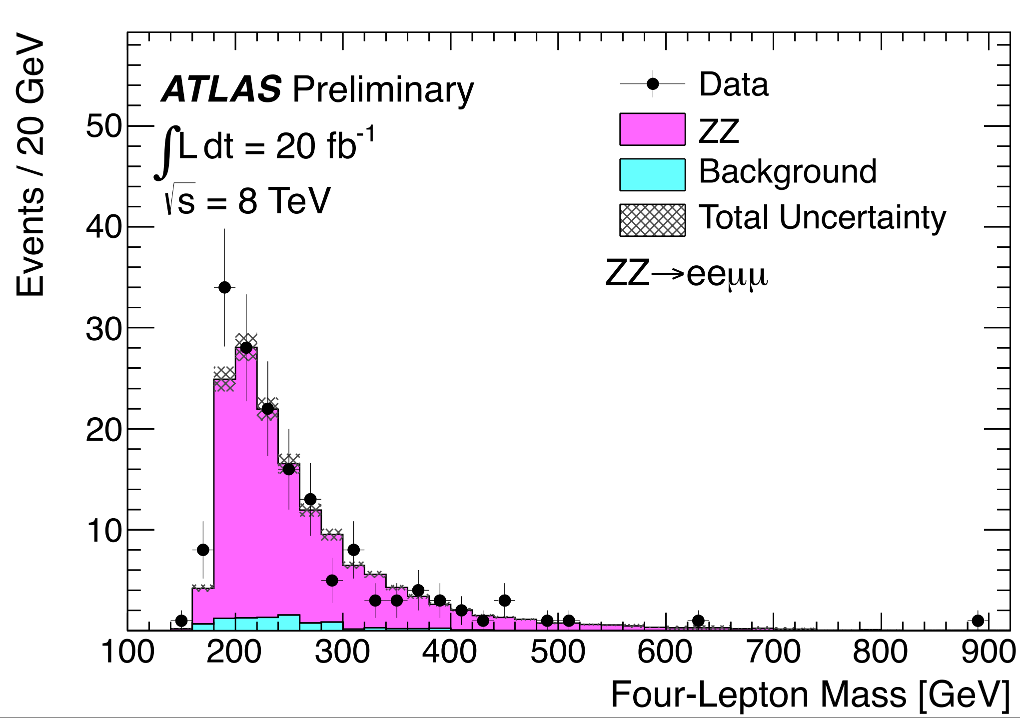


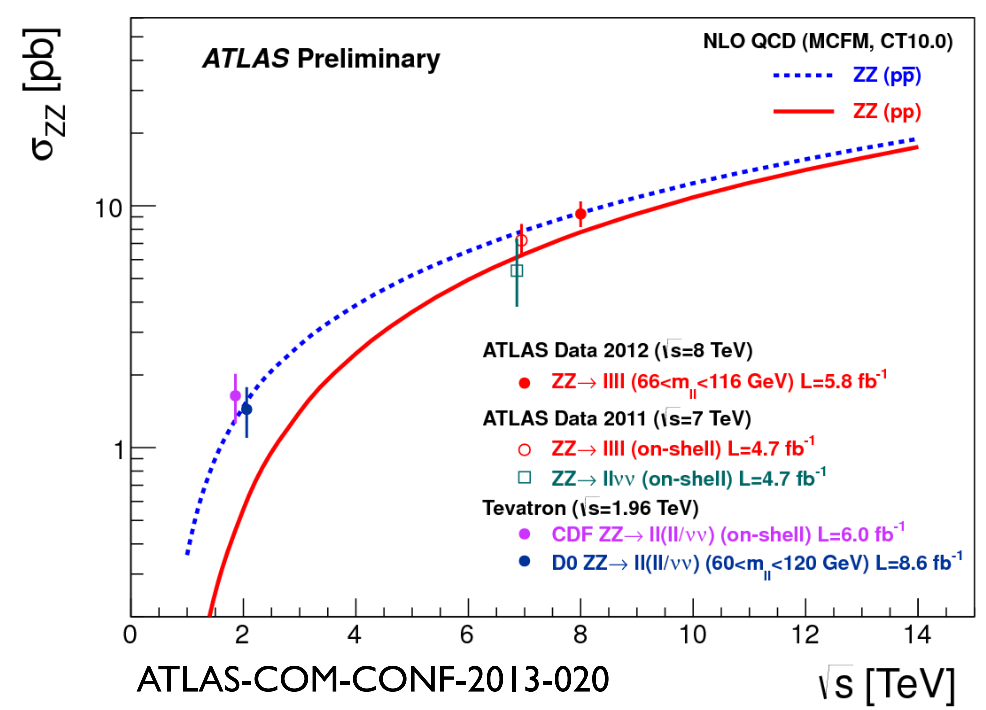
7 TeV: σ = 177+11-10 pb
8 TeV: σ = 241±32 pb

Top quark in addition to being of fundamental importance on their own, provide opportunity to test QCD calculations and improve tuning of MC – essential for all analyses

ZZ studies





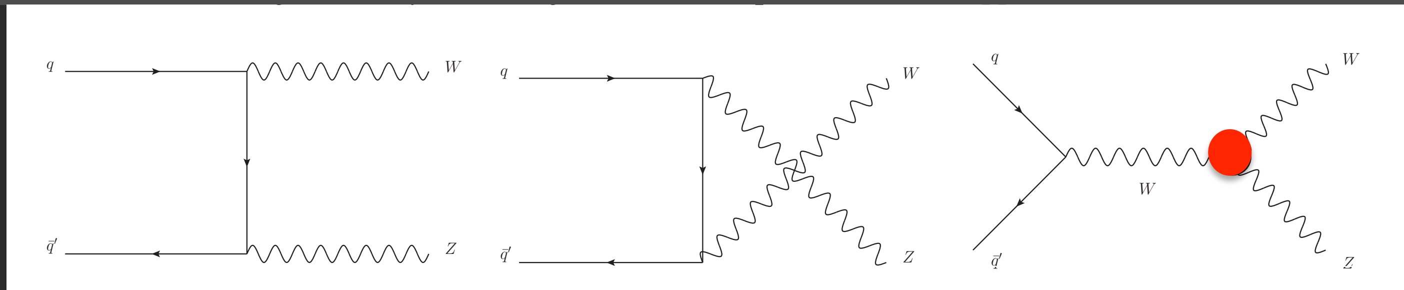


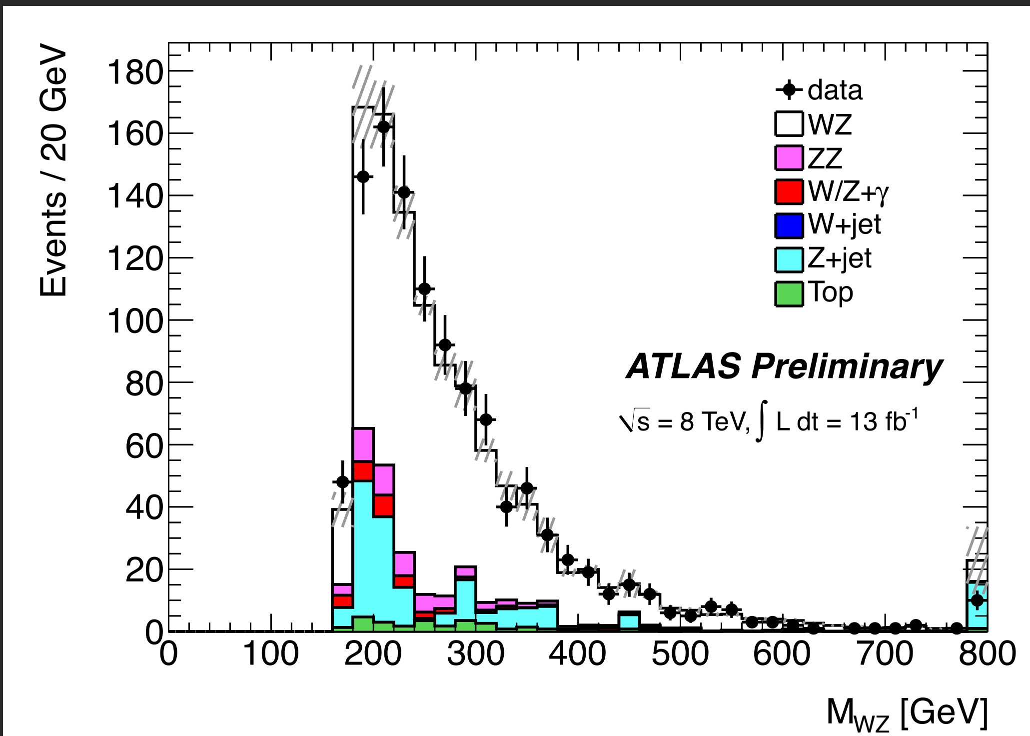
$\sigma(ZZ) = 7.1{+0.5}{-0.4}$ (stat) ± 0.3 (syst) ± 0.2 (lumi) pb

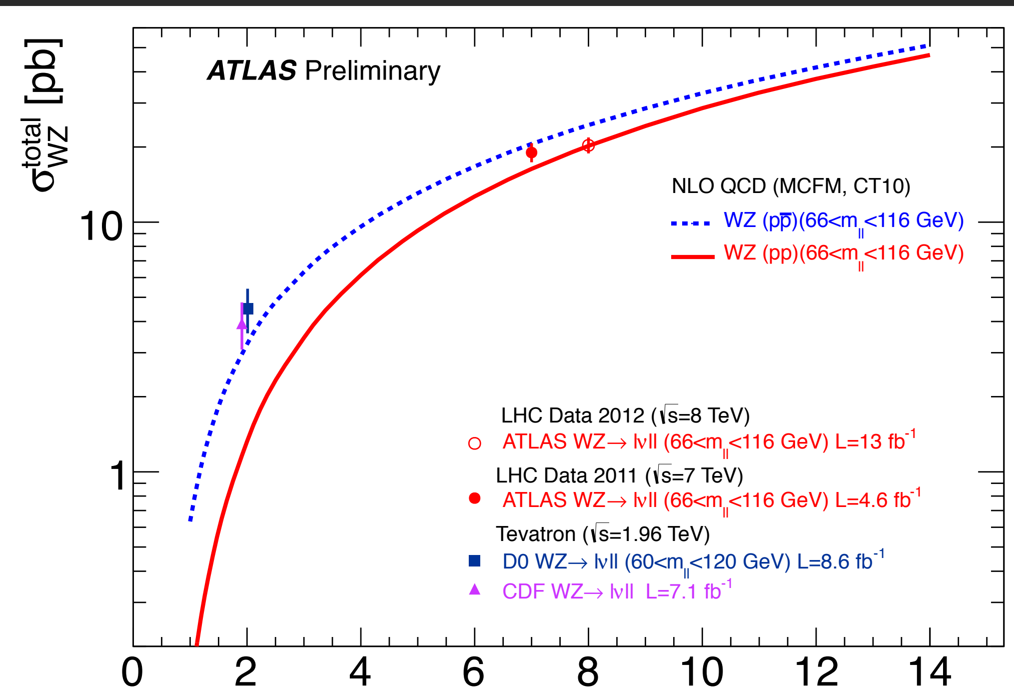
Tests of NLO SM calculations, good agreement.

Deviations could indicate physics beyond SM; neutral triple-gauge-couplings zero in SM

WZ studies







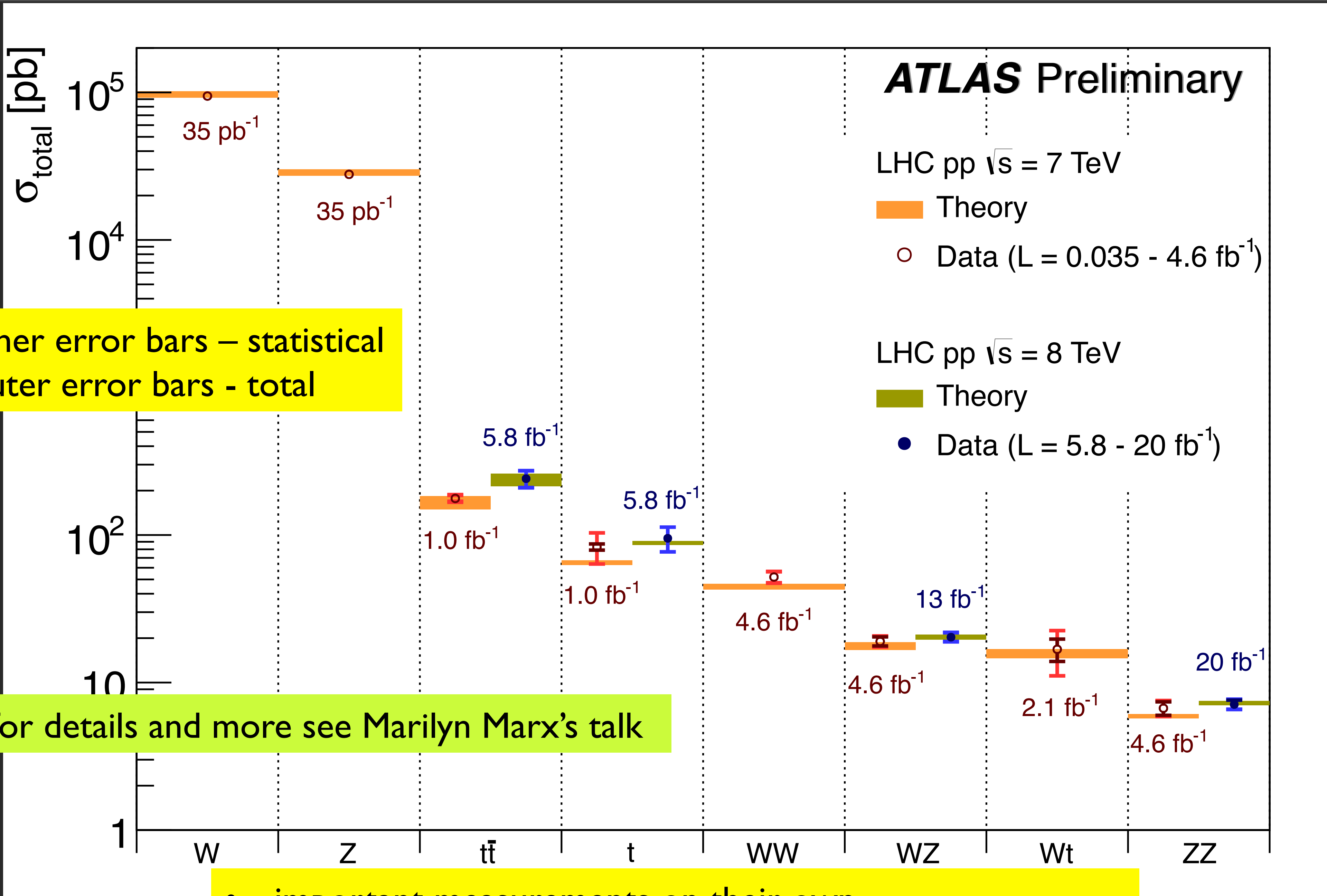
ATLAS-COM-CONF-2013-021

σ(WZ) =20.3+0.8-0.7(stat)+1.2-1.1(syst)+0.7-0.6(lumi)

Tests of NLO SM calculations, good agreement.

Deviations could indicate physics beyond SM; triple-gauge-couplings;

status of ATLAS electroweak and top measurements



inner error bars – statistical
outer error bars - total

- for details and more see Marilyn Marx's talk

- important measurements on their own
- but, most also irreducible background to Higgs searches

SUSY:

SUSY particles are expected to be produced strongly in pairs, and their decay chains invariably include a LSP, usually neutral. The typical signatures are final states with variable number of jets, also multi-leptons, same-sign leptons - almost always with large MET. Large mixing in 3rd generation of SUSY sfermions is expected, with at least one of the top squarks expected to be light.

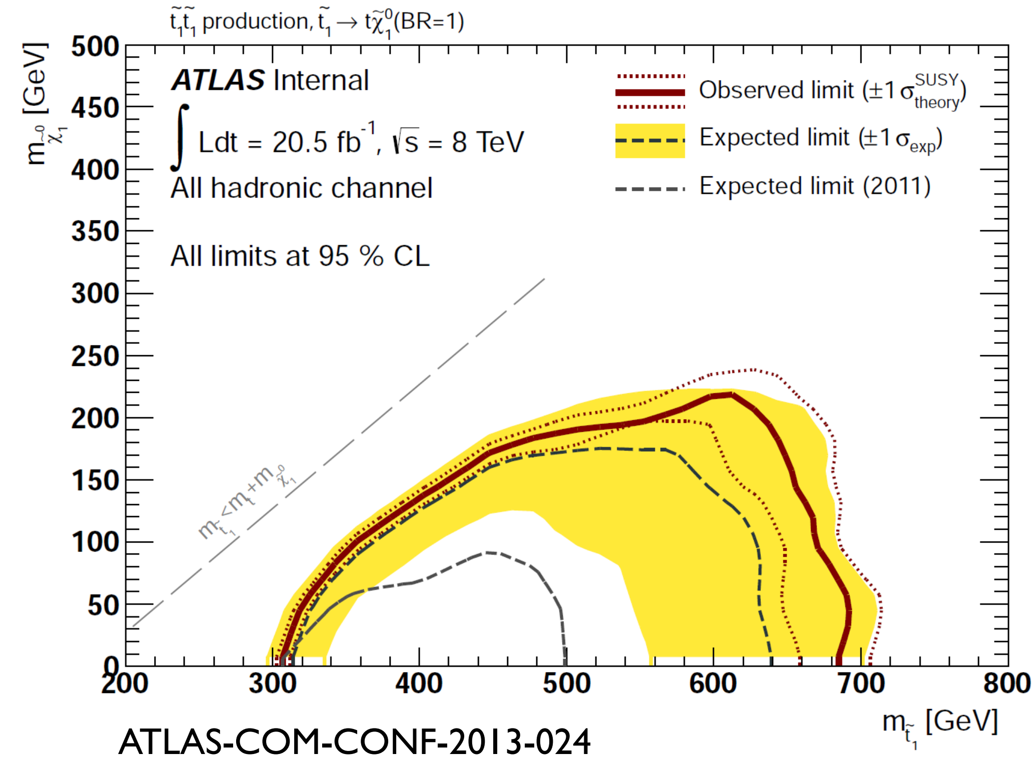
The Minimal Supersymmetric SM is difficult to reconcile with M_H=125 GeV, as it predicts a smaller mass for its lightest neutral Higgs, h. Large part of MSSM parameter space is excluded.

In the NMSSM, a singlet chiral superfield added to MSSM allows to alleviate the μ and the lightest Higgs mass (H_1) problem. The model has 7 physical Higgses (MSSM has 5).

Many searches for physics beyond SM look for SUSY particles.

I'll show a few latest results
- for details and more see Carsten Hensel's talk

SUSY: stop searches



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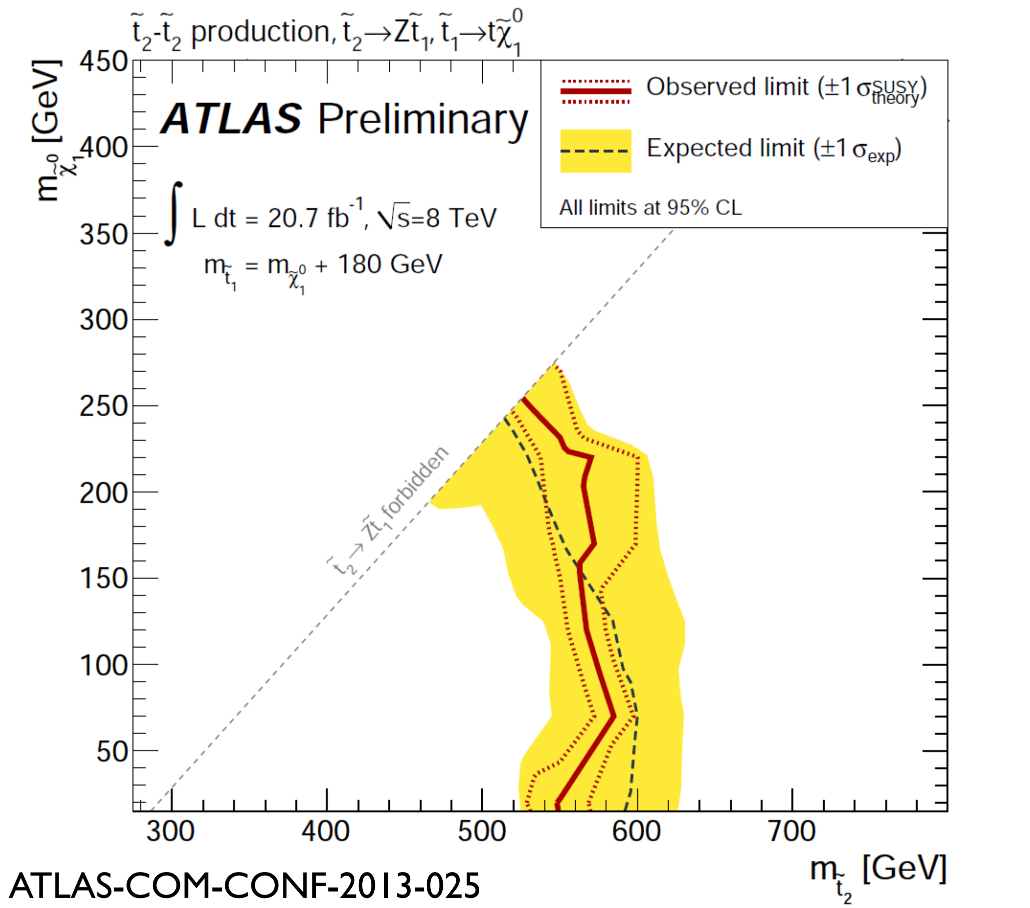


ATLAS-COM-CONF-2013-025

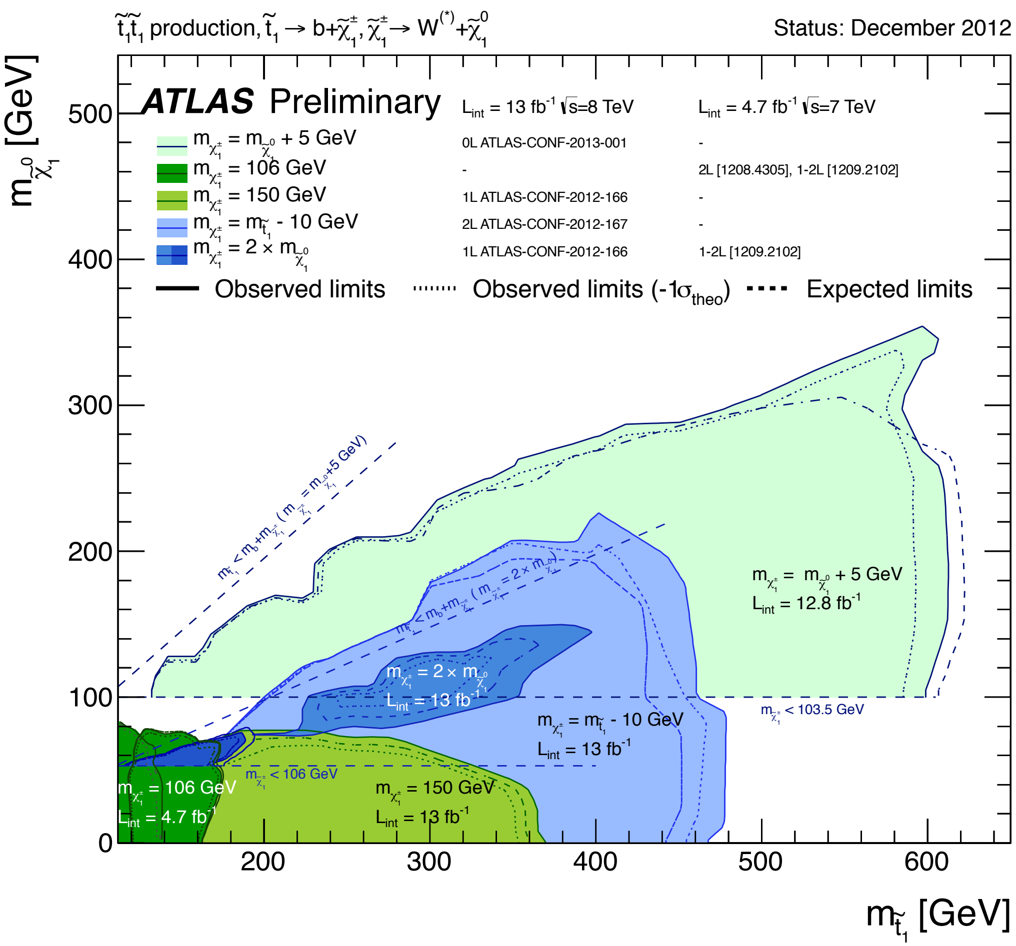
stop pair –> t+LSP+t+LSP(MET) final state (both top quark decay hadronically – jets)

320 GeV > M(stop) > 660 GeV for massless LSP

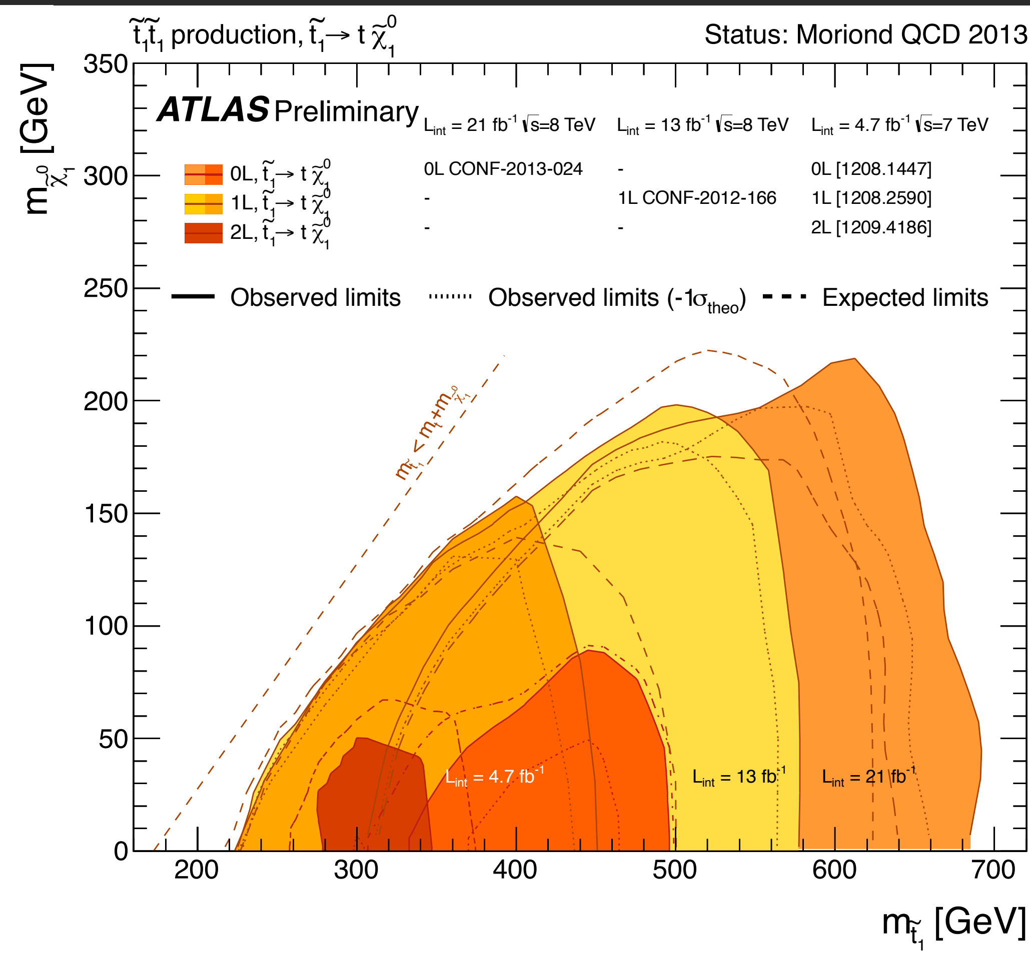
400 GeV > M(stop) > 620 GeV forM(LSP)=150GeV (95% CL)

stop pair –> Z+b+LSP(MET) final state (˜t2 –> Z˜t1 decay chain)

SUSY: stop searches



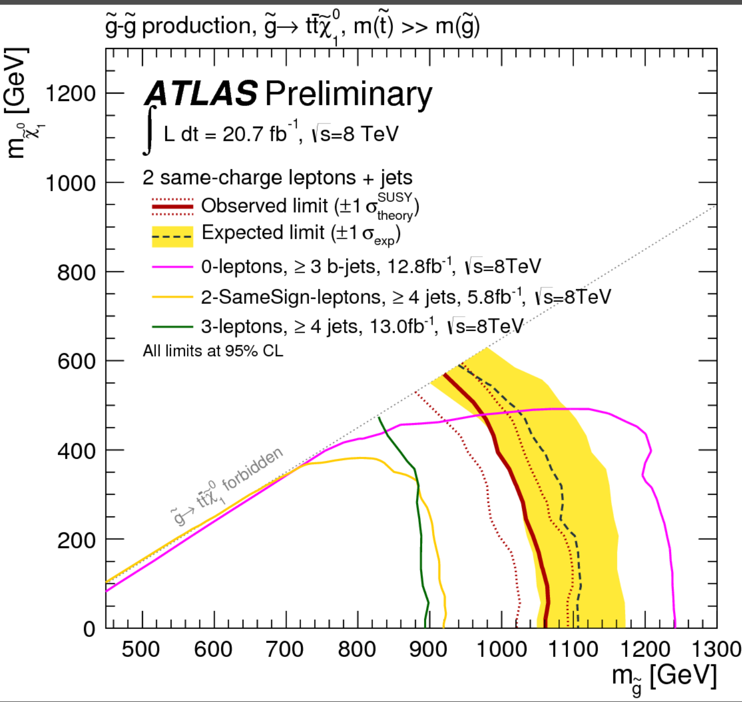
stop pair –> b+W*+LSP

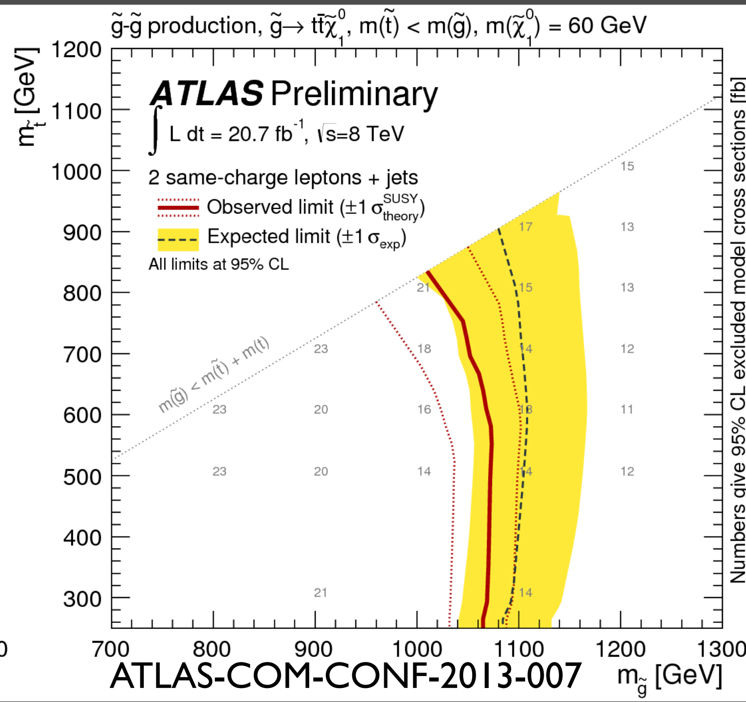


stop pair –> top+LSP

Exclusion limits at 95% CL are shown in the $\tilde{t}_1$ - $\tilde{\chi}^0_1$ mass plane.
These plots overlay contours belong to different stop decay channels, different sparticle mass hierarchies, and simplified decay scenarios – one should be careful when interpreting

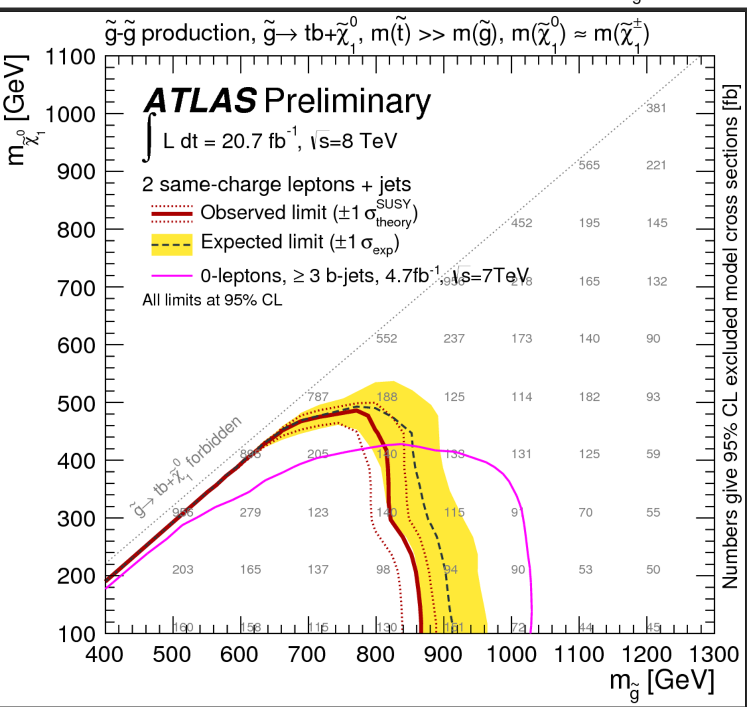
SUSY: stop searches

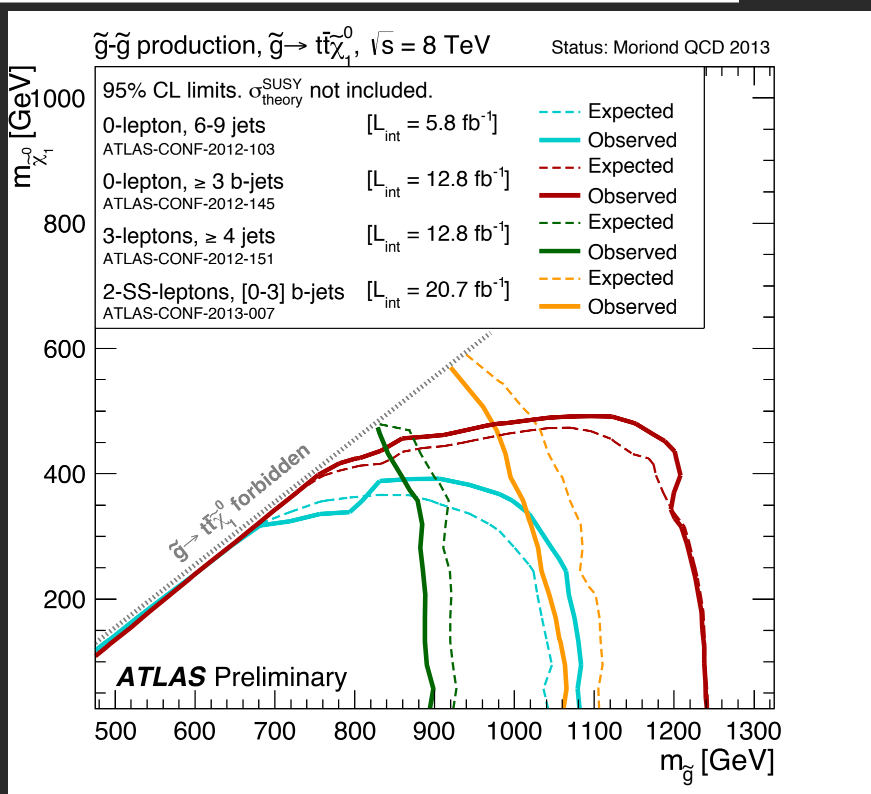




gluino mediated stop production:

same-sign dileptons, jets, varying number of b-jets

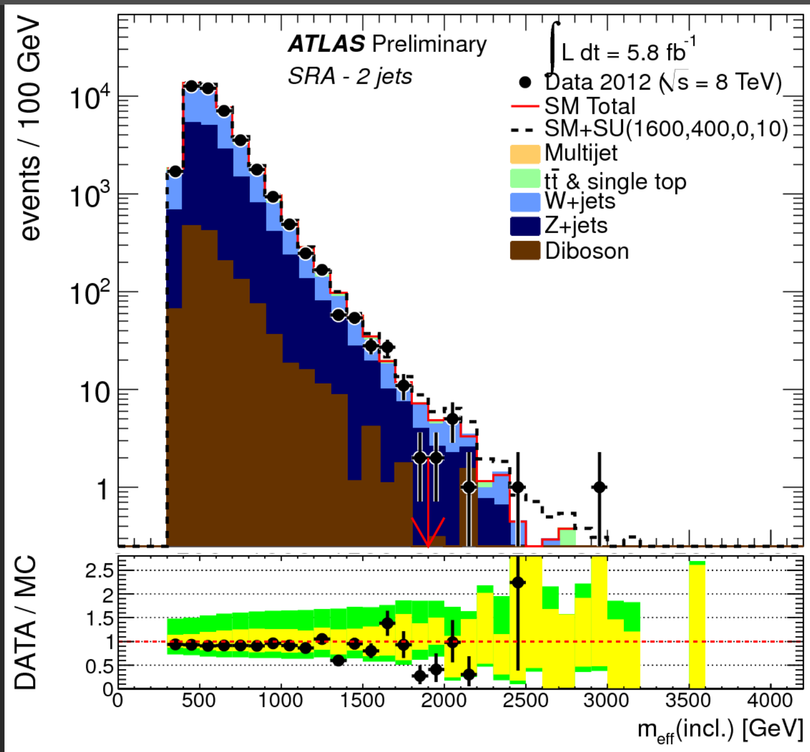


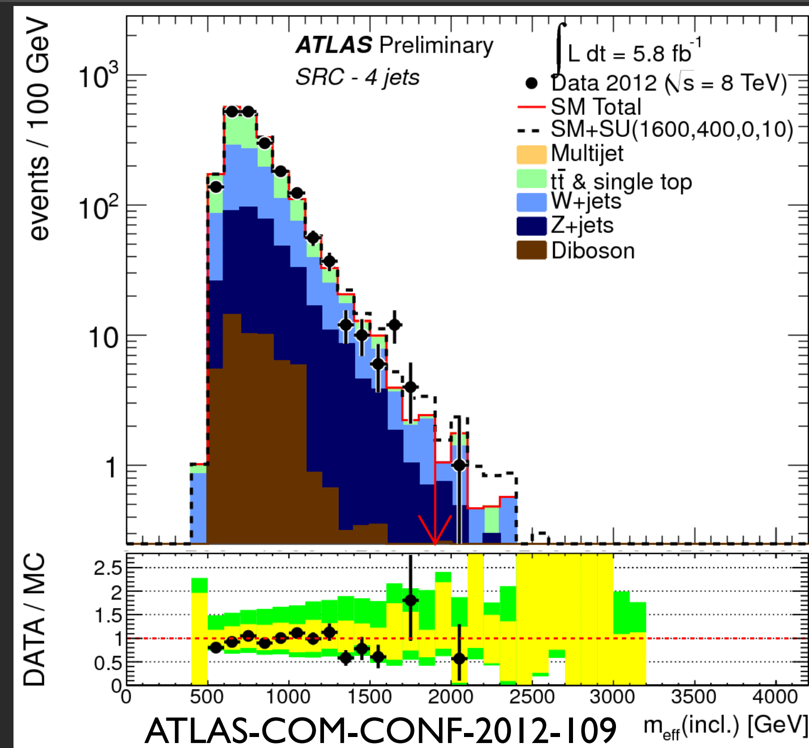


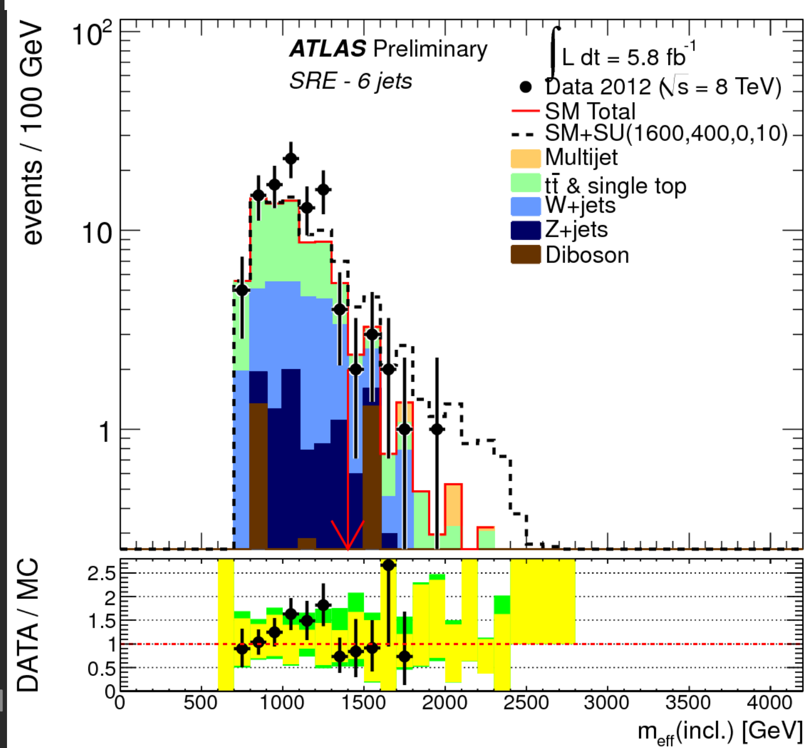
summary plot: gluino mediated stop production

0 leptons
3 leptons
2 same-sign leptons

SUSY searches –squarks and gluinos







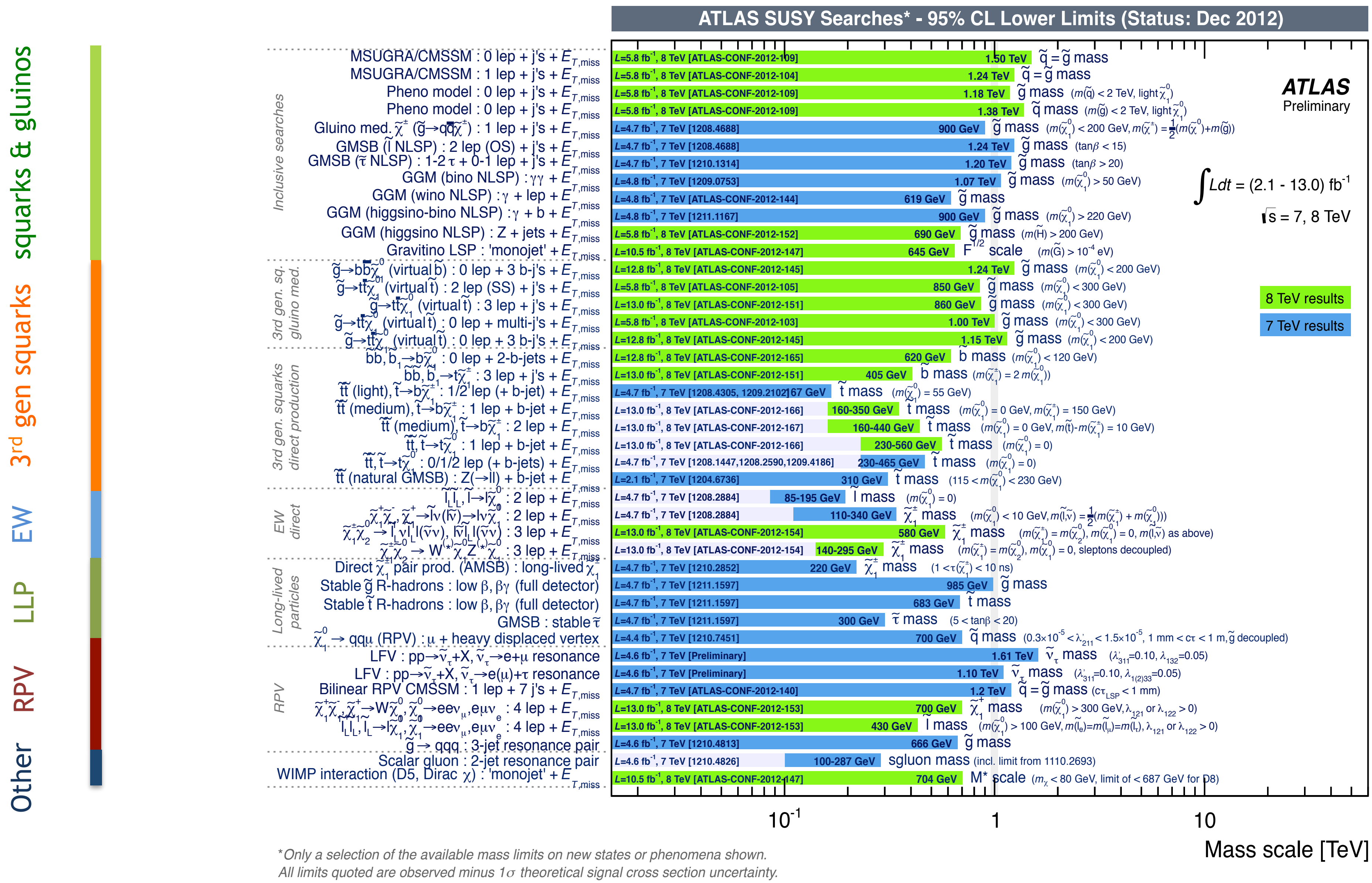
squarks and gluinos, strongly produced
1st and 2nd generation

2 jets + MET
4 jets + MET
6 jets + MET

model dependent limits (~TeV scale)

SUSY searches

"natural" SUSY, R-parity violating, and searches for long-lived particles



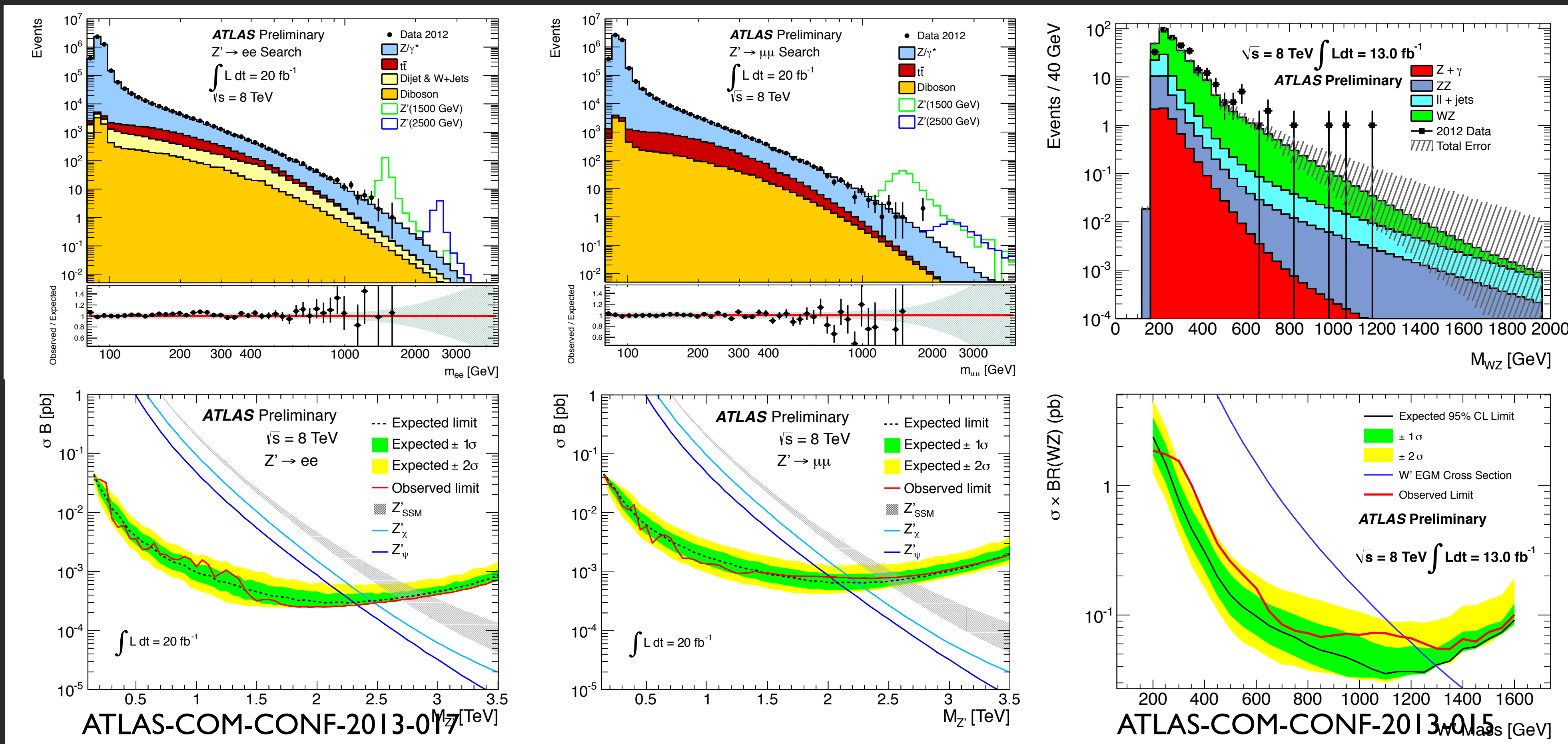
(from A. Hoecker slides – ATLAS Status Report – LHCC, Dec 5, 2012)

ATLAS-COM-CONF-2013-026

ATLAS-COM-CONF-2013-028

exotic: ee, μμ,WZ

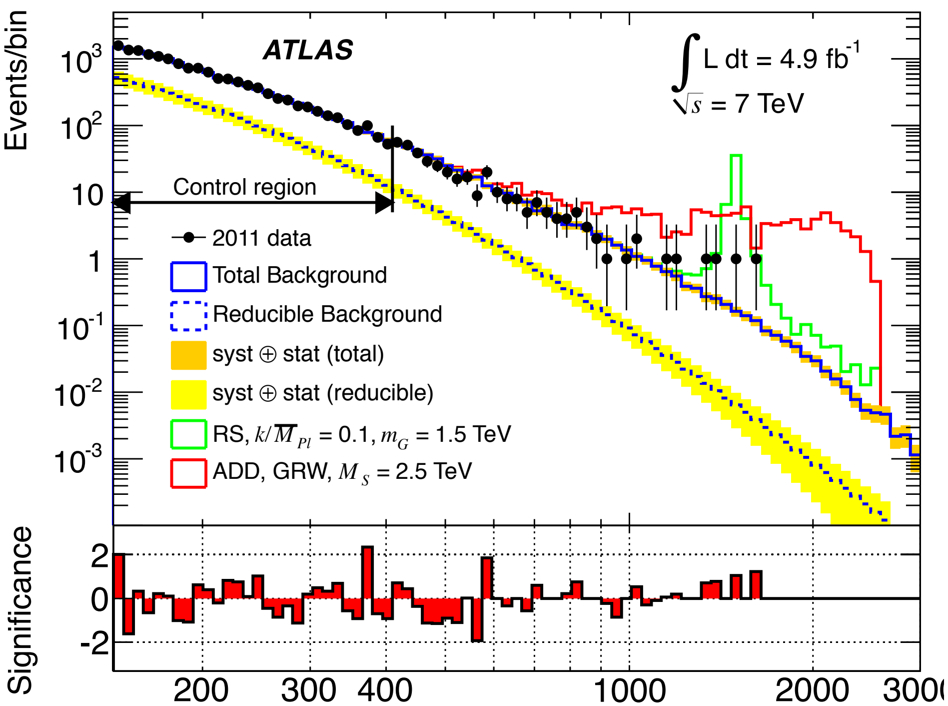
Searched for resonanses (new bosons?) in invariant mass spectra of dileptons, WZ



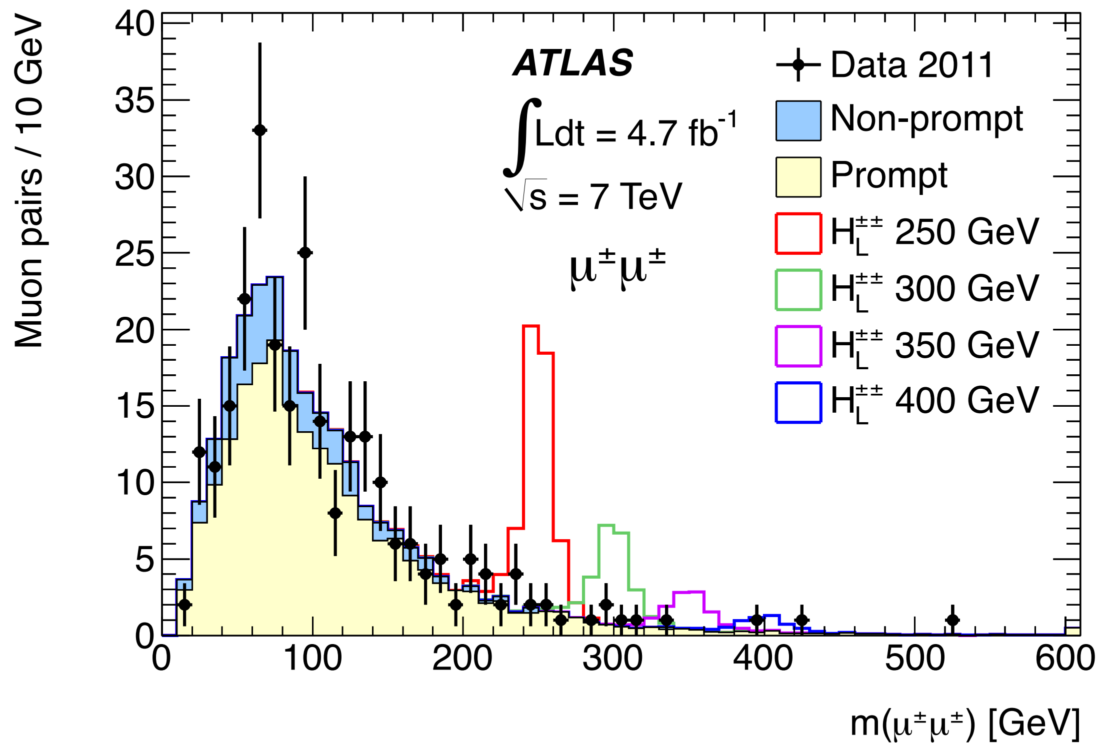
Limits (95% CL): M(Z') > 2.79 TeV (ee); M(Z') > 2.48 TeV (μμ); M(Z') > 2.86 TeV (combined)
M(W')> 1.18 TeV

exotic: $\mu^{\pm}\mu^{\pm}$ and $\gamma\gamma$ searches

Prompt photons or like-sign leptons is one of the most powerful signatures for new physics



arXiv:1210.8389



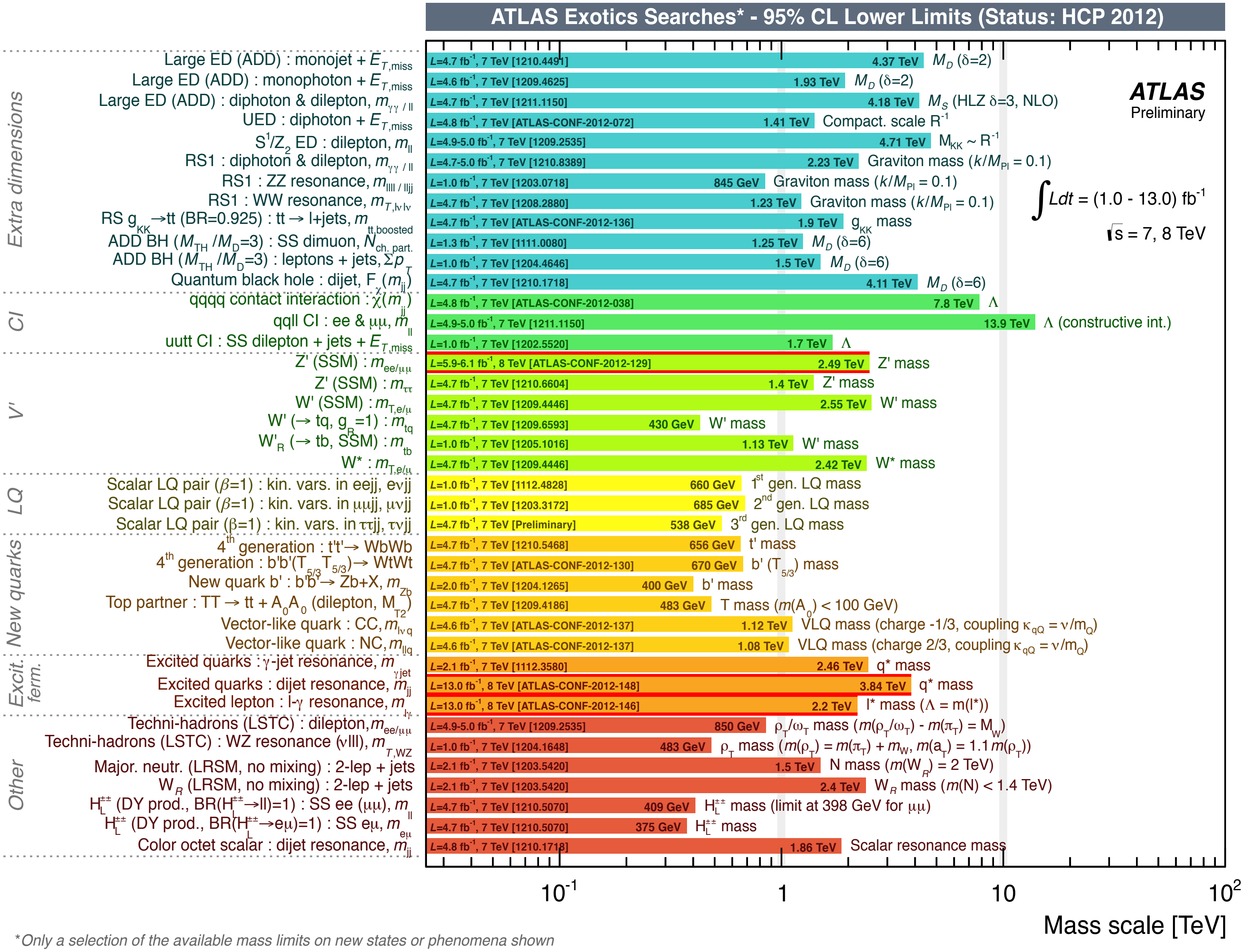
Randall-Sundrum graviton with strong coupling to SM particles would decay to a photon pair

$M(G) > 2.06$ TeV ($k/M_{Pl}=0.1$)

Doubly charged Higgs would show up as a narrow like-sign resonance

- for details and more see Elisa Pueschel's talk

searches for new physics
specific models and model independent studies



Exotics Models:

Extra dimensions:
- RS KK Graviton (dibosons, dileptons, diphotons)
- RS KK gluons (top antitop)
- ADD (monojets, monophotons, dileptons, diphotons)
- KK Z/gamma boosns (dileptons)

Grand Unification symmetries
- (dielectons, dimuons, ditaus)
- Leptophobic topcolor Z' boson (dilepton ttbar, l+j, all had)

S8- color octet scalars (dijets)
String resonance (dijets,)
Benchmark Sequential SM Z',W'
W' (lepton+MET, dijets, tb)
W* (lepton+MET, dijets)
Quantum Black Holes (dijet)
Black Holes (l+jets, same sign leptons)
Technihadrons (dileptons, dibosons)
Dark Matter
- WIMPs (Monojet, monophotons)

Excited fermions
- q*, Excited quarks (dijets, photon+jet)
- l*, excited leptons (dileptons+photon)

Leptoquarks (1st, 2nd, 3rd generations)
Higgs -> hidden sector
- (displaced vertices, lepton jets)

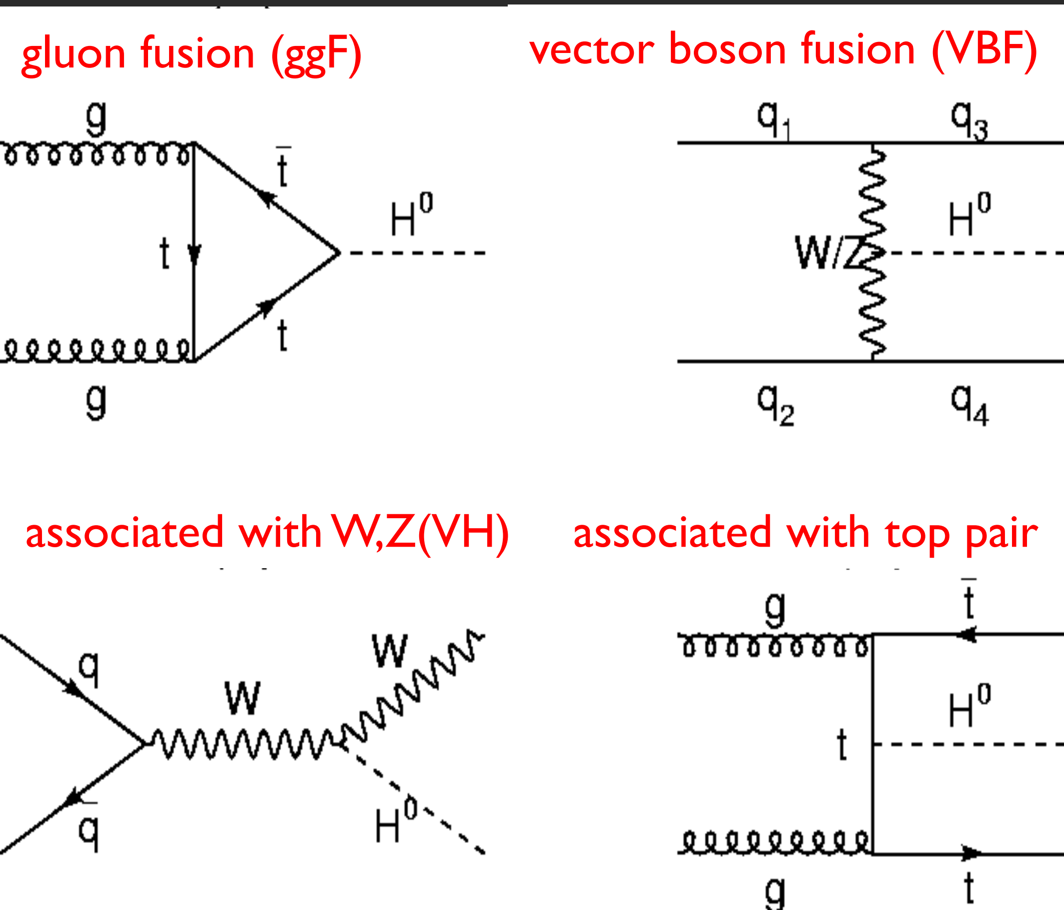
Contact Interaction
- llqq CI
- 4q CI (dijets)

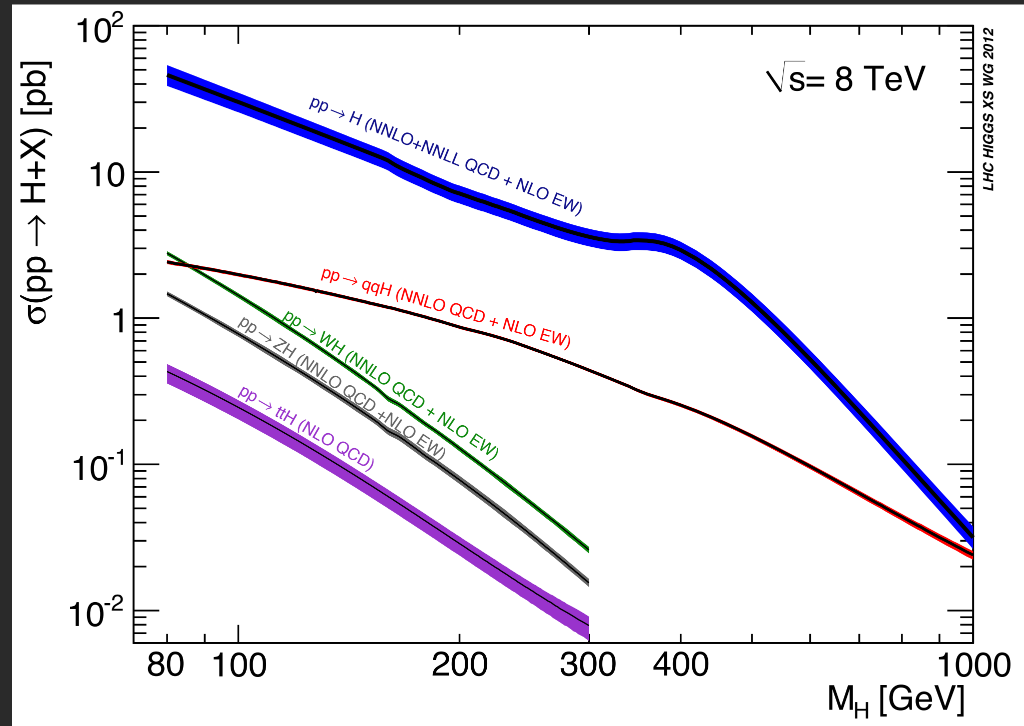
Doubly charged Higgs (
- multi leptons, same sign leptons)

4th generation
- t'->Wb, t'->ht, b'-Zb, b'->Wt
- (dileptons, same sign leptons, l+J)

VLQ-Vector Like quarks
Magnetic Monopoles (and HIP)
Heavy Majorana neutrino and RH W

MSM Higgs search and properties





gluon fusion – largest cross sections, but also large backgrounds

associated production – smaller but cleaner

VBF – even smaller but may help to improve sensitivity

Higgs cross section higher ~1.3x at 8 TeV

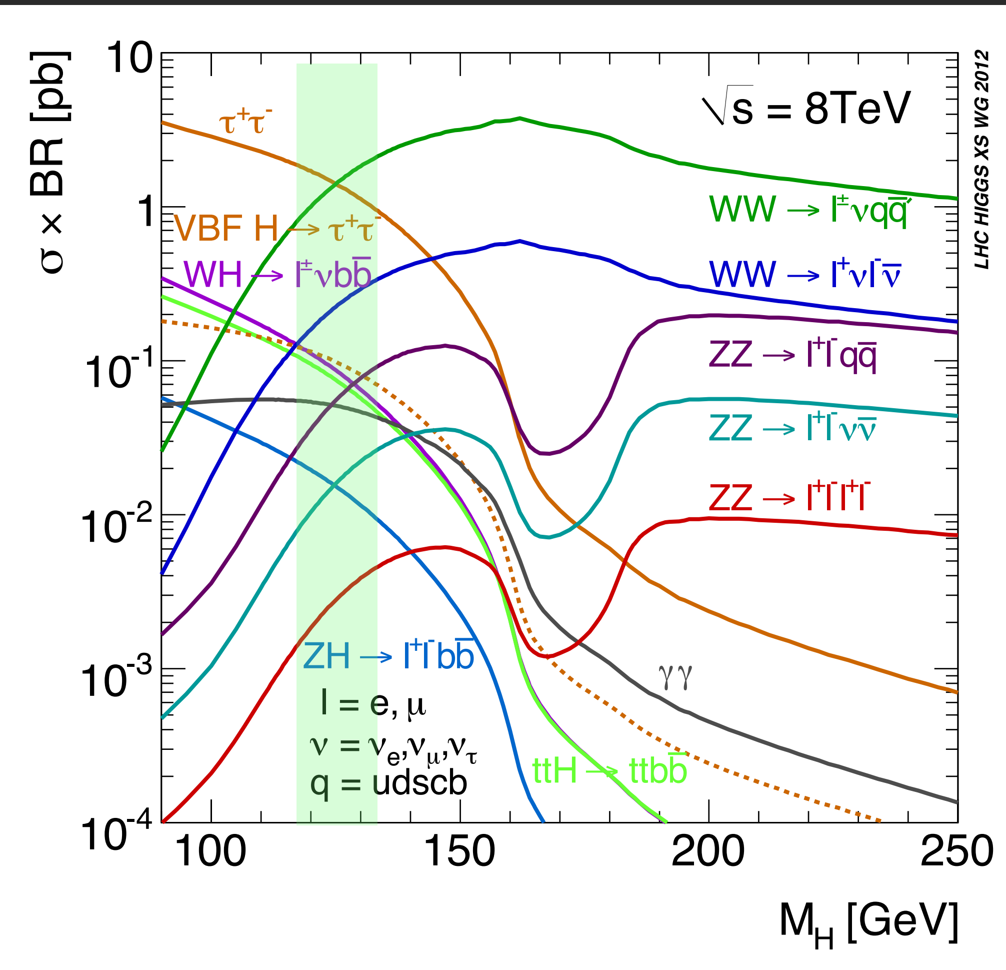
irreducible backgrounds (γγ, WW, WZ, ZZ) also higher, but a bit less

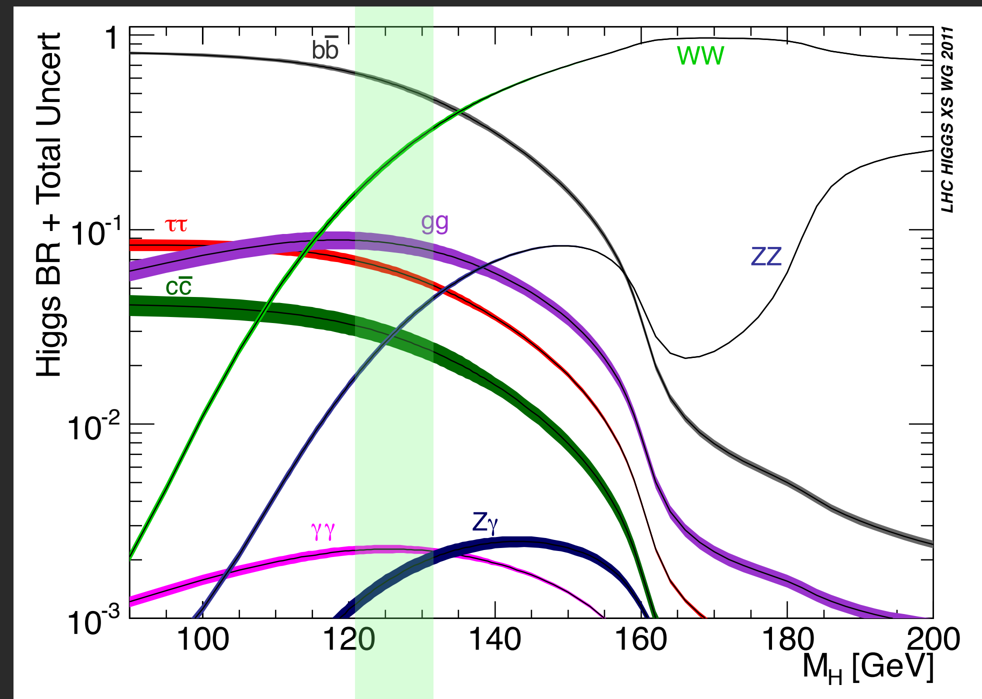
reducible backgrounds (top, Zbb) higher even a bit more

increase in sensitivity at 8 TeV
–> 1.1x - 1.15x

See talk by Sofia Maria Consonni for details

MSM Higgs search and properties





By some strange coincidence, M_H= 125 GeV is one of the best places to find Higgs and study its properties (from the experimental point of view) – many channels with relatively large branching fractions !

Most sensitive channels for 120 < M_H < 130 GeV:

H −>ZZ*−>4l,
H−> $\gamma\ \gamma$
H−>WW*−>l ν l ν
H−> $\tau\ \tau$
W/ZH−>W/Z bb

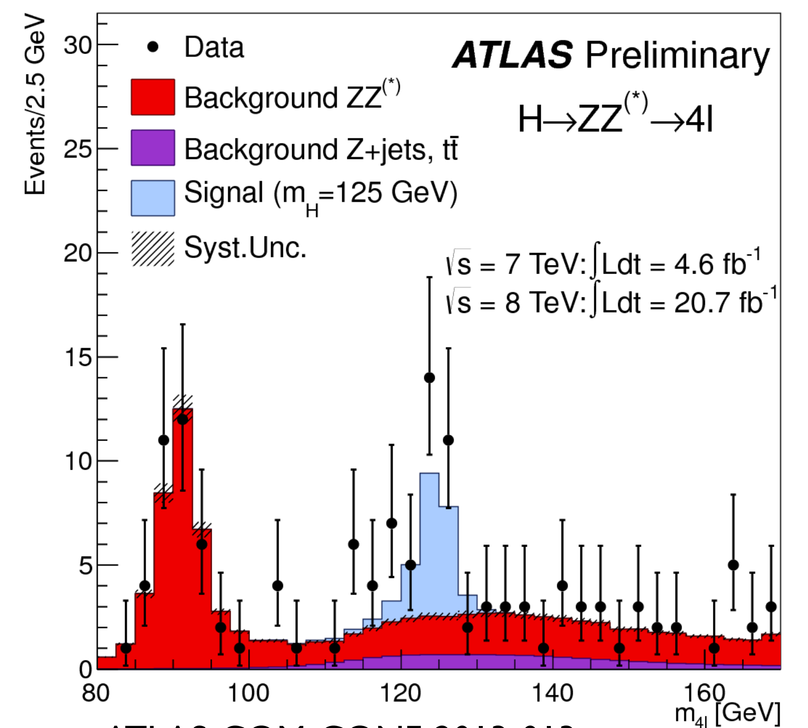
MSM Higgs search and properties

M_{4l} = 124.3+0.6-0.5(stat) +0.5-0.3(syst) GeV

$M_{\gamma\gamma}$ = 126.8±0.2(stat) ±0.7(syst) GeV

M_H = 125.5±0.2(stat) +0.5-0.6(syst) GeV
(4l + γγ)

ΔM = 2.3+0.6-0.7(stat) ±0.6(syst) GeV



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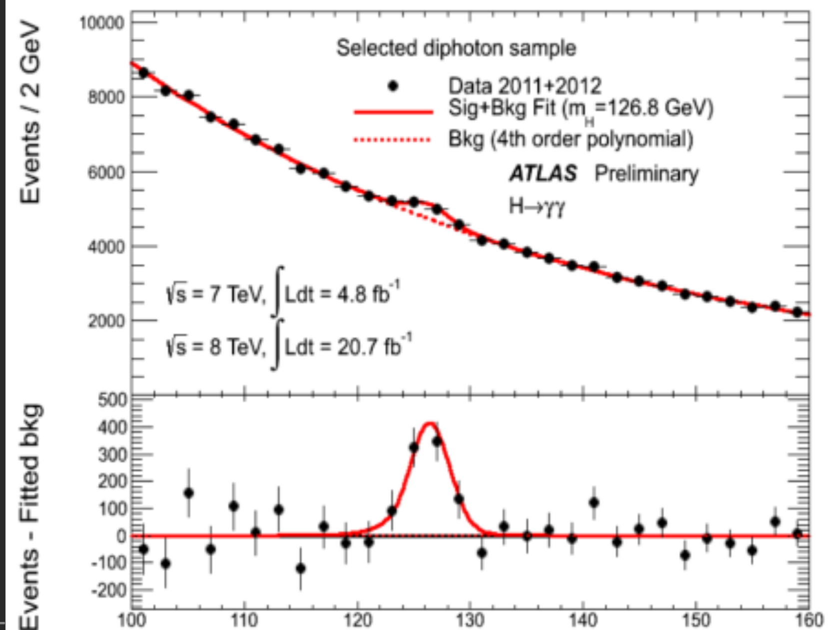

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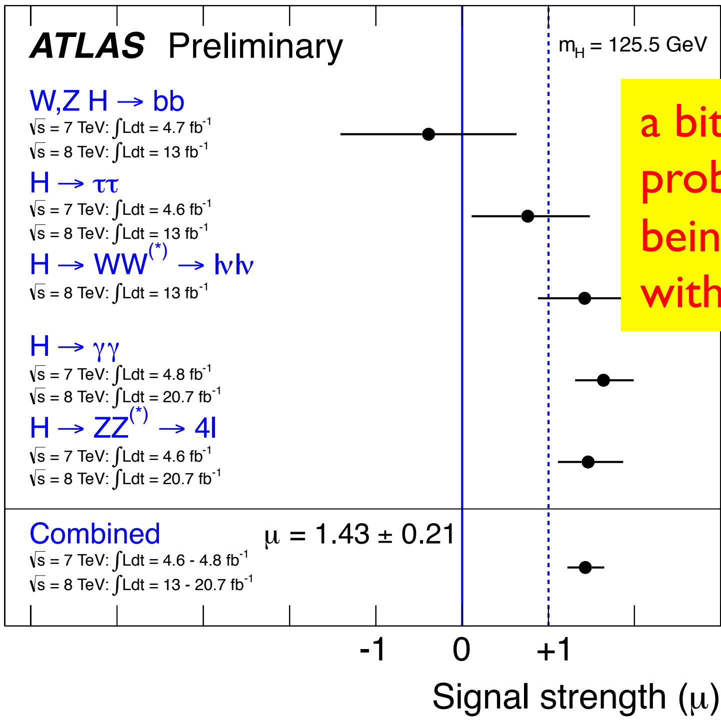
MSM Higgs search and properties

Higgs Boson Decay	μ (m_H=125.5 GeV)
$VH \to Vbb$	-0.4 ± 1.0
$H \to \tau\tau$	0.8 ± 0.7
$H \to WW^{(*)}$	1.0 ± 0.3
$H \to \gamma\gamma$	1.6 ± 0.3
$H \to ZZ^{(*)}$	1.5 ± 0.4
Combined	1.30 ± 0.20



a bit high, probability of being compatible with SM ~9%

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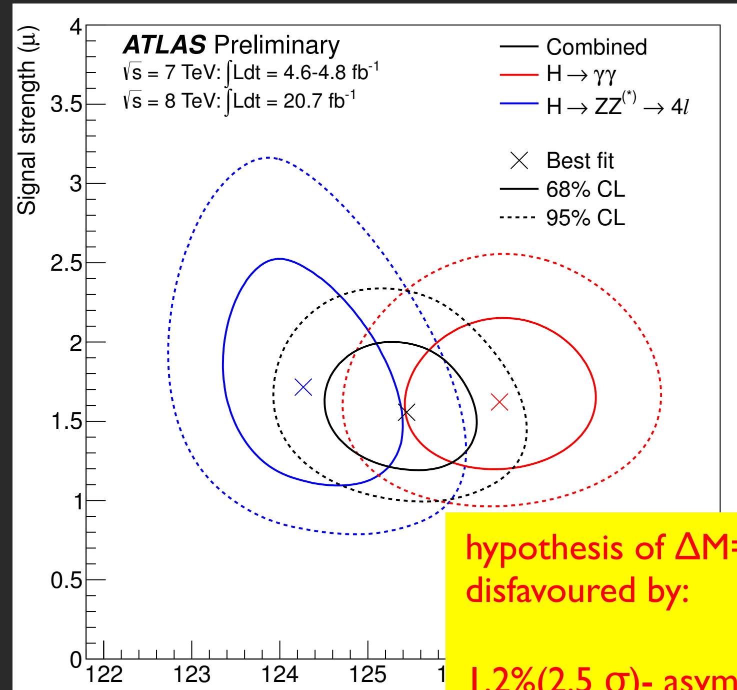
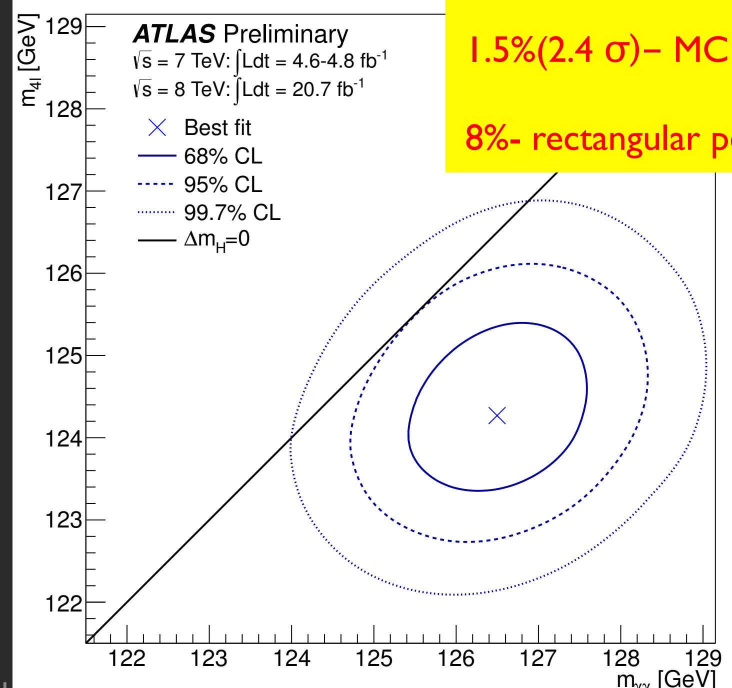


hypothesis of $\Delta M=0$ disfavoured by:

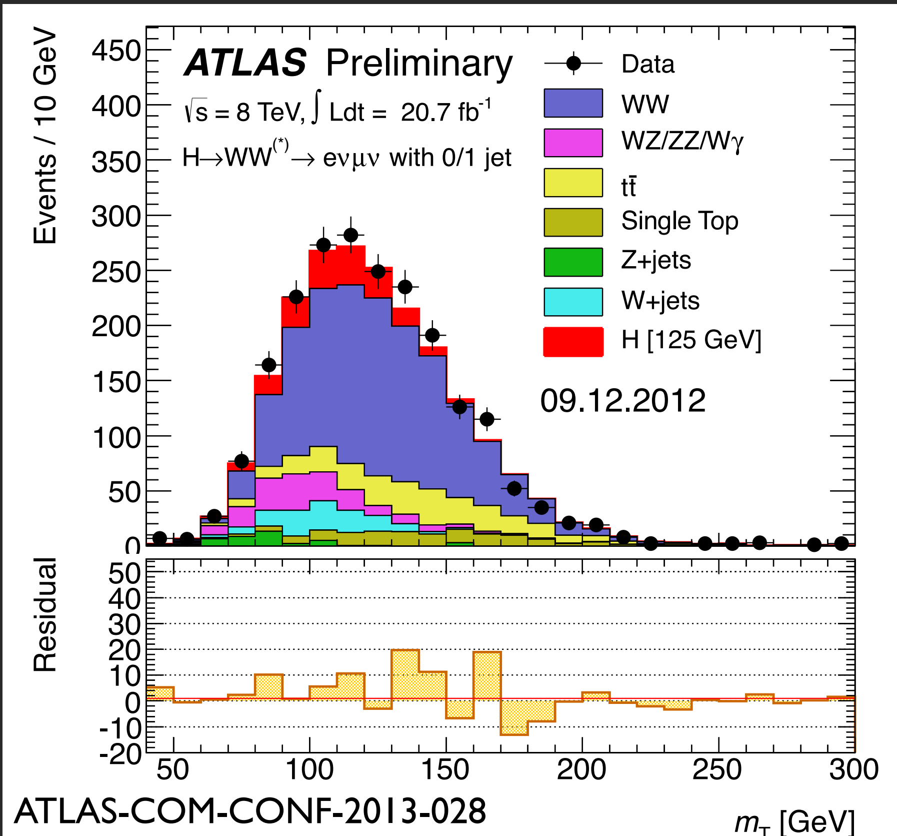
1.2%(2.5 σ)- asymptotic assumption

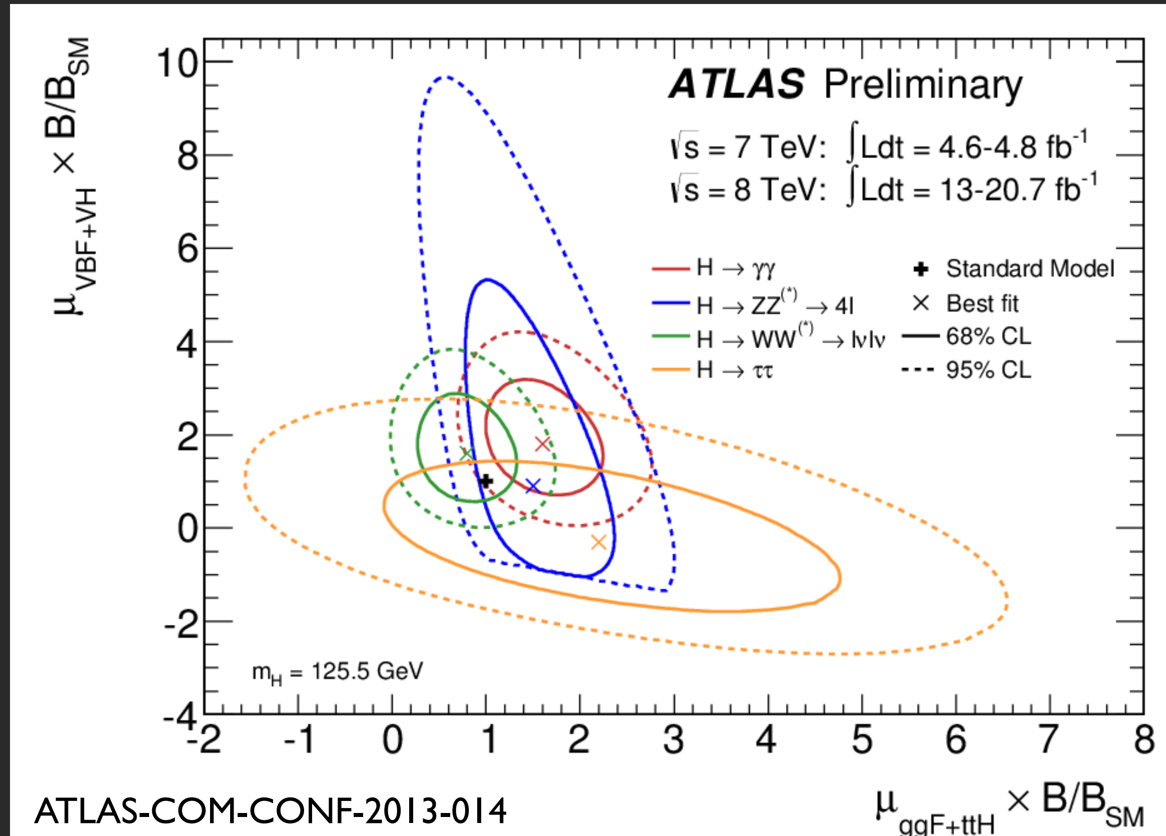
1.5%(2.4 σ)– MC ensembles;

8%- rectangular pdfs



MSM Higgs search and properties





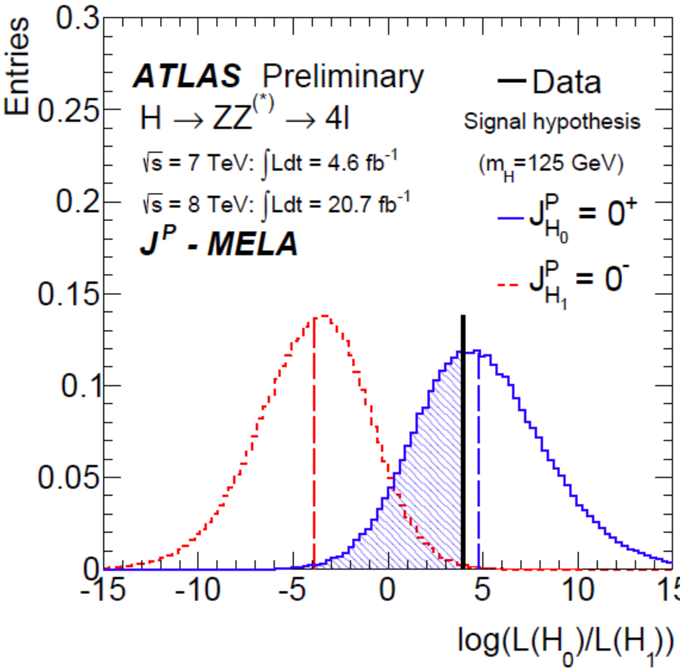
Evidence for VBF (~3.1σ)
Measurements of relative production rates very important for establishing properties of a new boson

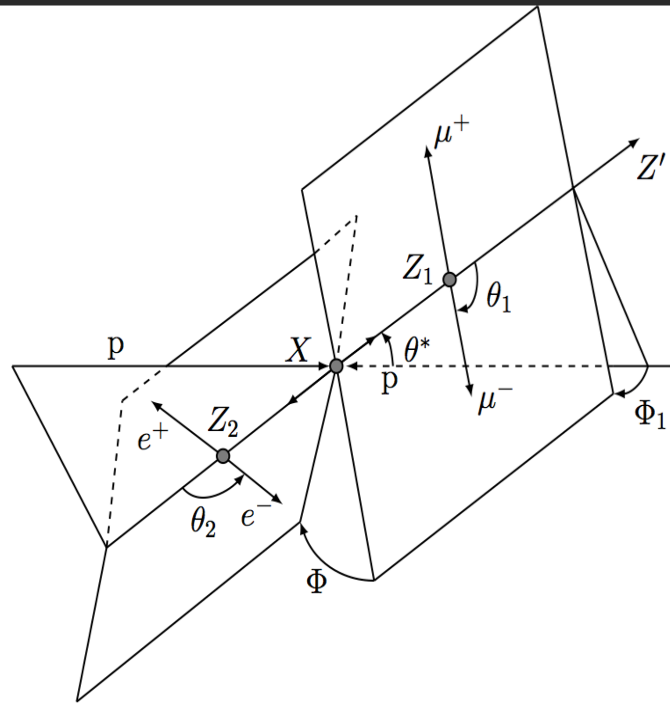
With the M_H known, all couplings can be calcutated within SM –> is this a SM Higgs or not?

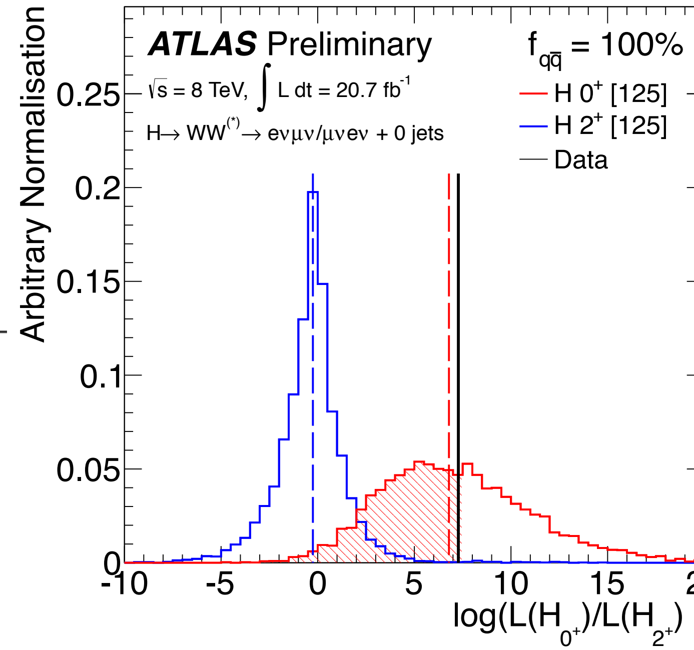
Expected for M_H=125 GeV at 8 TeV

ggF 19.5 pb fermion couplings (γγ, ZZ, WW*)
VBF 1.6 pb boson couplings (γγ, ZZ, WW* >=2 jets)
VH 1.1 pb boson couplings (γγ, ZZ, WW* +W,Z)
ttH 0.1 pb fermions couplings

MSM Higgs search and properties







spin-parity compatible with $J^{CP} = 0^+$ (as in Minimal Standard Model)

H−> $\gamma\ \gamma$: spin 2 excluded at 2.8 σ (100% gg)
(spin 1 excluded, as well, of course)
H−>4l : spin 0^- excluded at >2 σ, spin 2 excluded at 1.5- 3 σ (0-100% gg)
H−>WW*: spin 2 excluded at 95-99% C.L (depending on %gg)

near Future – present LHC schedule

see talk by T. Todorov

2009		✧ LHC startup, $\sqrt{s}$ = 900 GeV
2010–2012		$\sqrt{s}$=7~8 TeV, L=6x10^{33} cm^{-2} s^{-1}, bunch spacing 50 ns
2013–2014	LS1	Go to design energy, nominal luminosity (Phase-0)
2015–2017		$\sqrt{s}$=13~14 TeV, L~1x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns
2018	LS2	Injector and LHC Phase-1 upgrade to full design luminosity
2019–2021		$\sqrt{s}$=14 TeV, L~2x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns
2022	LS3	HL-LHC Phase-2 upgrade, IR, crab cavities?
2023 … 2030?		$\sqrt{s}$=14 TeV, L=5x10^{34} cm^{-2} s^{-1}, luminosity levelling

~20-25 fb^{-1}

new Pixel B-layer

~75-100 fb^{-1}

NSW, FTK LVL1 trigger

~350 fb^{-1}

new tracker

~3000 fb^{-1}

Higgs boson properties

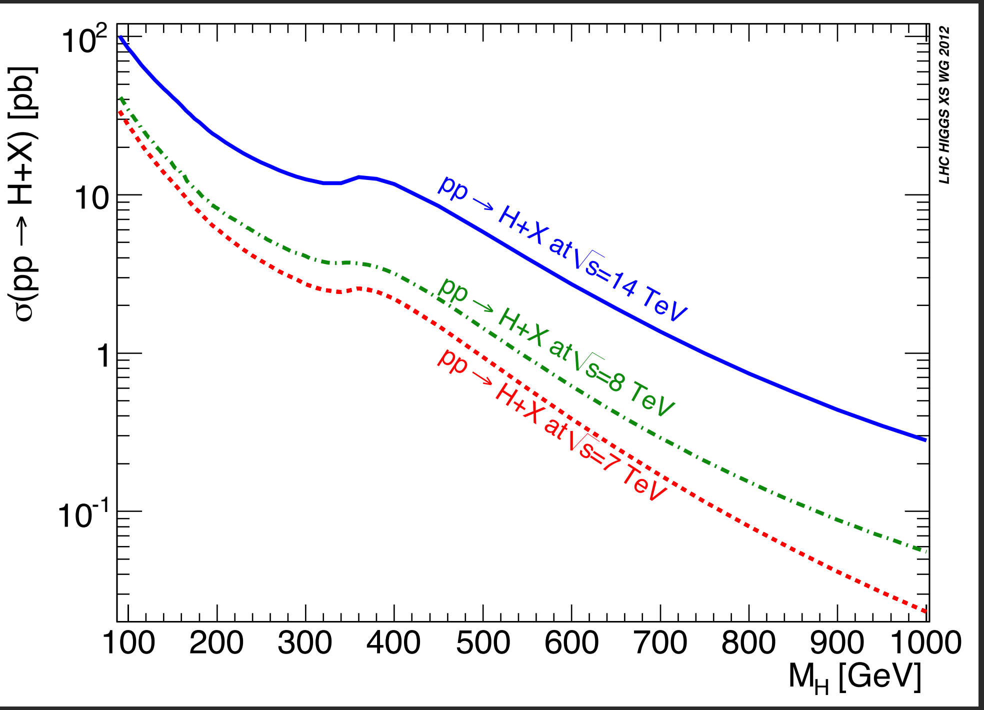
With the KNOWN mass of a new boson, the MSM couplings are calculable, and will be compared with the data

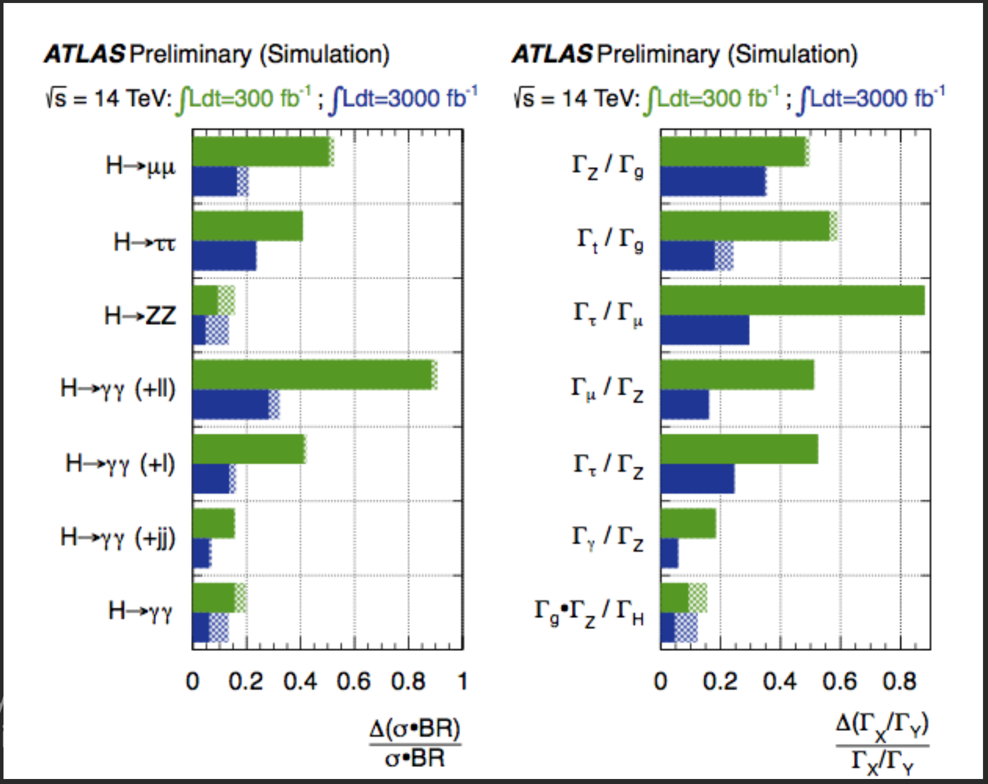
With ~300/fb- after Phase-I upgrade - the ratios of couplings will be known to within 30-50%

Spin and parity will be known with ~5σ level

HHH couplings – maybe with 3000/fb

HHHH – perhaps not at LHC





NEW PHYSICS ? FUTURE?

Of course, with the energy increase from 8 TeV to ~13 TeV, in addition to Higgs boson(s) studies, there will be another round of comprehensive searches for NMSSM and other "new physics".

This is what the physics goal of the LHC program is – to EXPLORE the new, previously unreachable, energies, and – in turn – new regions of phase space and model parameter spaces.

NEW PHYSICS ? FUTURE?

Finding the new boson is a great physics result, however, if it just looks like the minimal Standard Model Higgs boson – the simplest possible realization of the electroweak symmetry breaking – it will leave many unanswered questions – the fine tuning (gauge hierarchy problem) will still be with us

It is possible that with an increase of the pp collision energy from 8 TeV to 13 TeV we'll cross a threshold above which we'll observe new particles, too heavy to have been produced so far. This would be REALLY GREAT !

If not, then perhaps we'll have to turn our attention to precise measurements of the branching fractions and properties of the Higgs boson, either at LHC, or at a new e^+e^- collider, a "cleaner" environment in which to study the MSM Higgs boson

additional slides

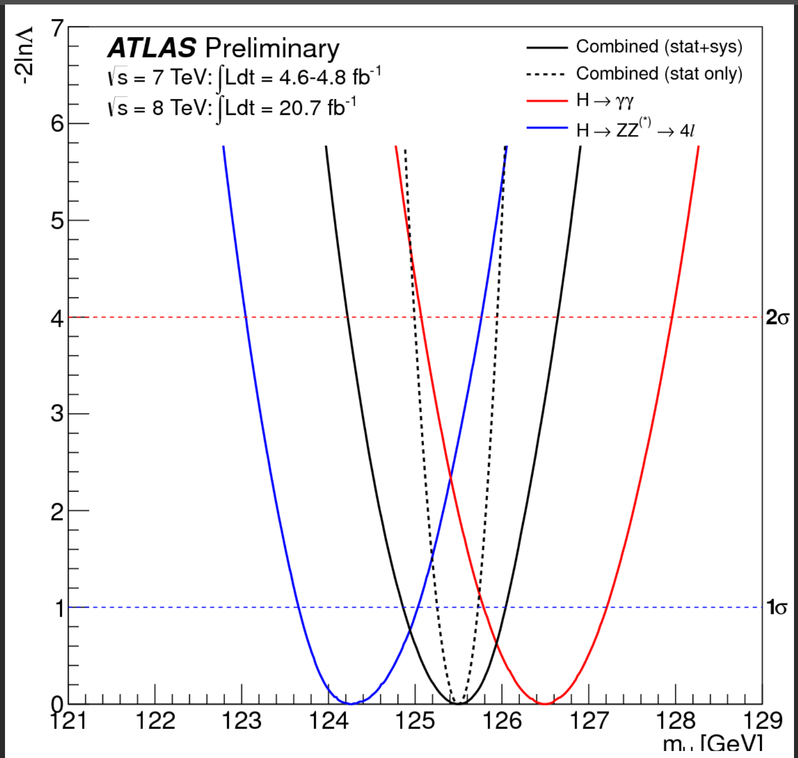
MSM Higgs search and properties

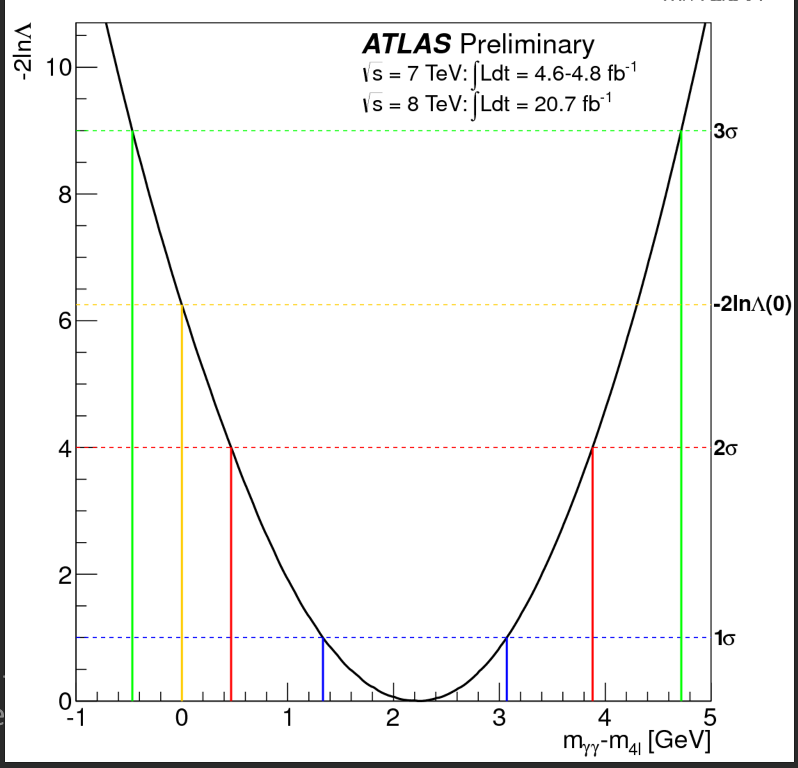
M_{4l} = 124.3+0.6-0.5(stat)
+0.5-0.3(syst) GeV

$M_{\gamma\gamma}$ = 126.8±0.2(stat)
±0.7(syst) GeV

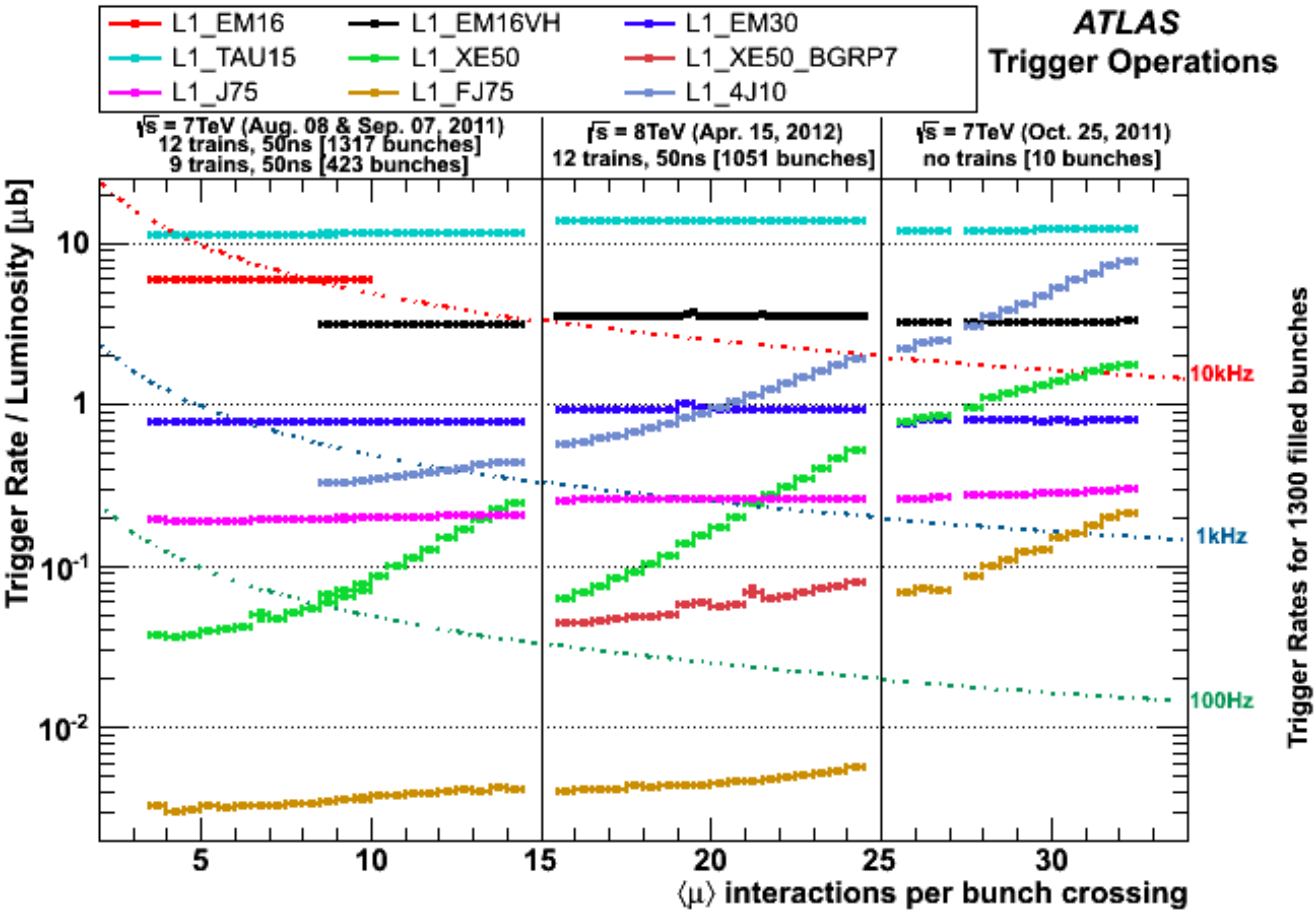
M_H = 125.5±0.2(stat)
(4l + γγ) +0.5-0.6(syst) GeV

ΔM = 2.3+0.6-0.7(stat)
±0.6(syst) GeV

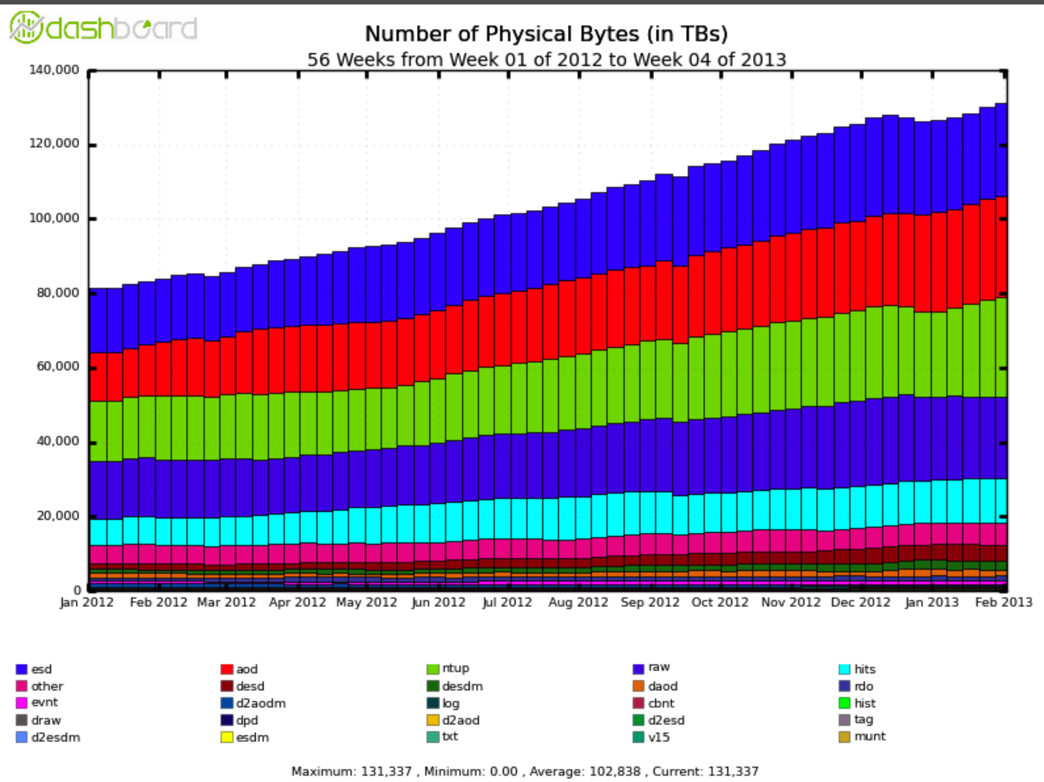


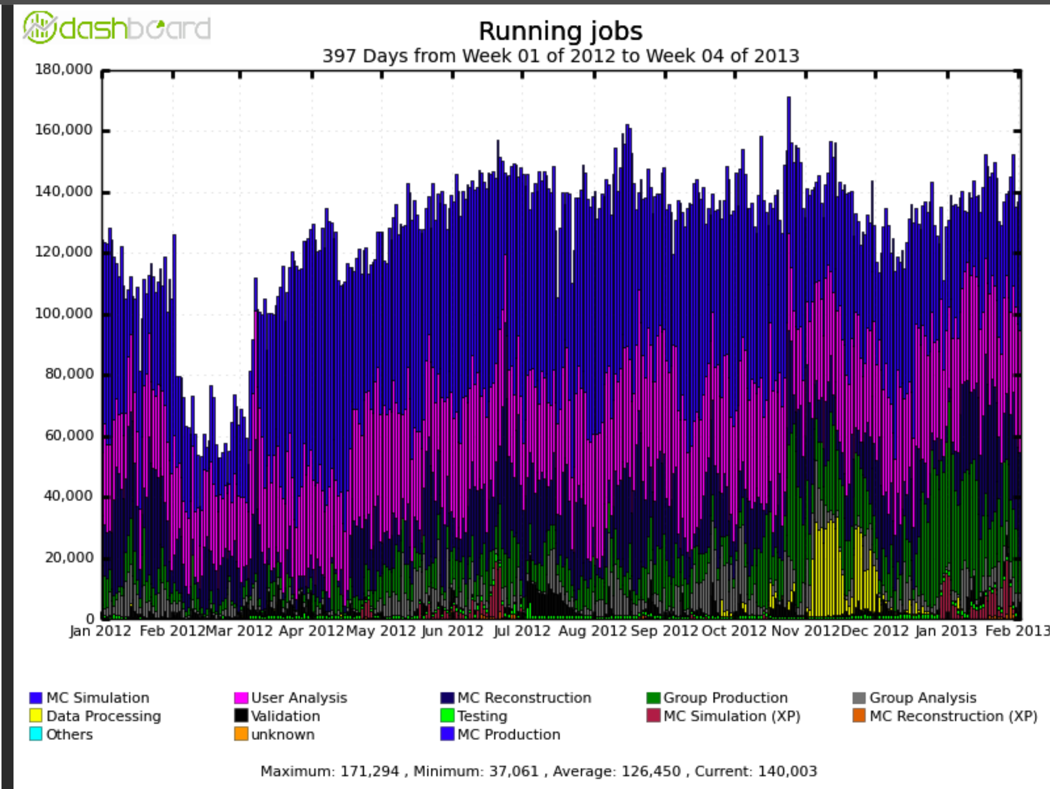


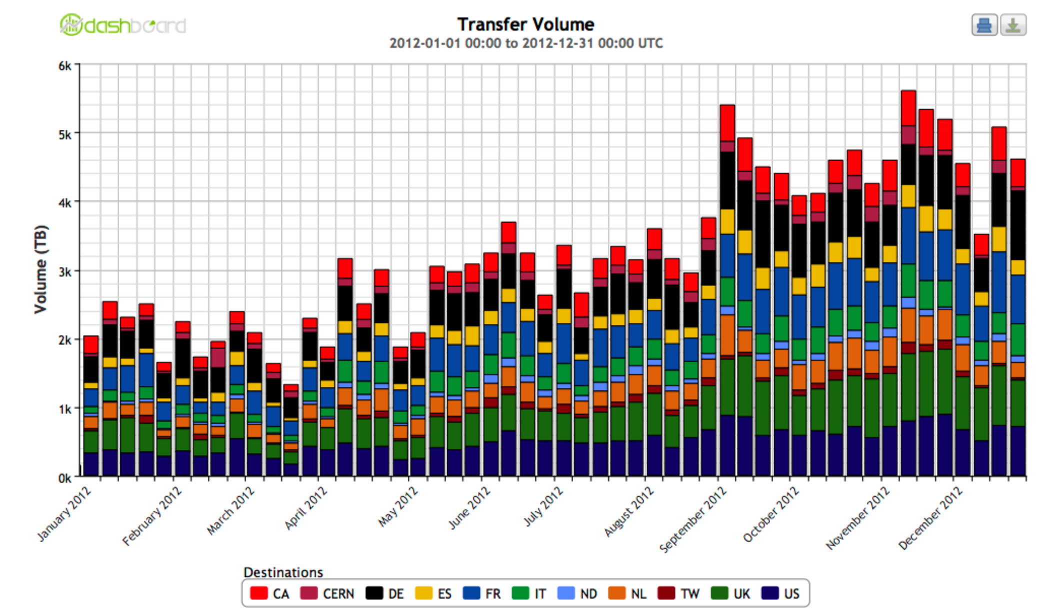
ATLAS TRIGGER AND DATA ACQUISITION



ATLAS COMPUTING/RECONSTRUCTION/ MonteCarlo….

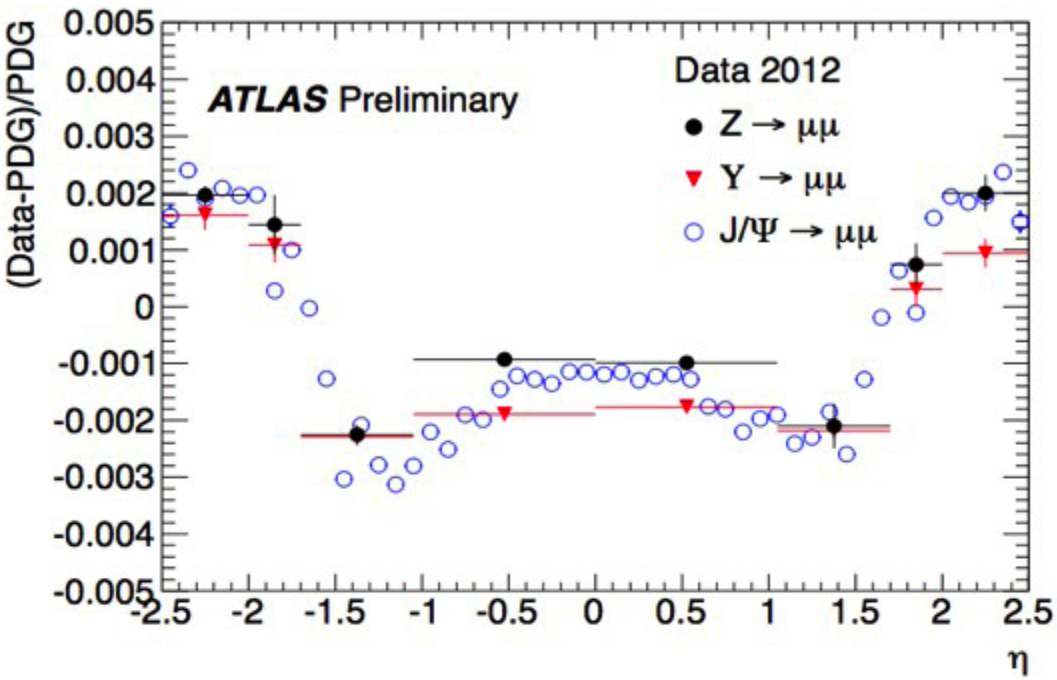






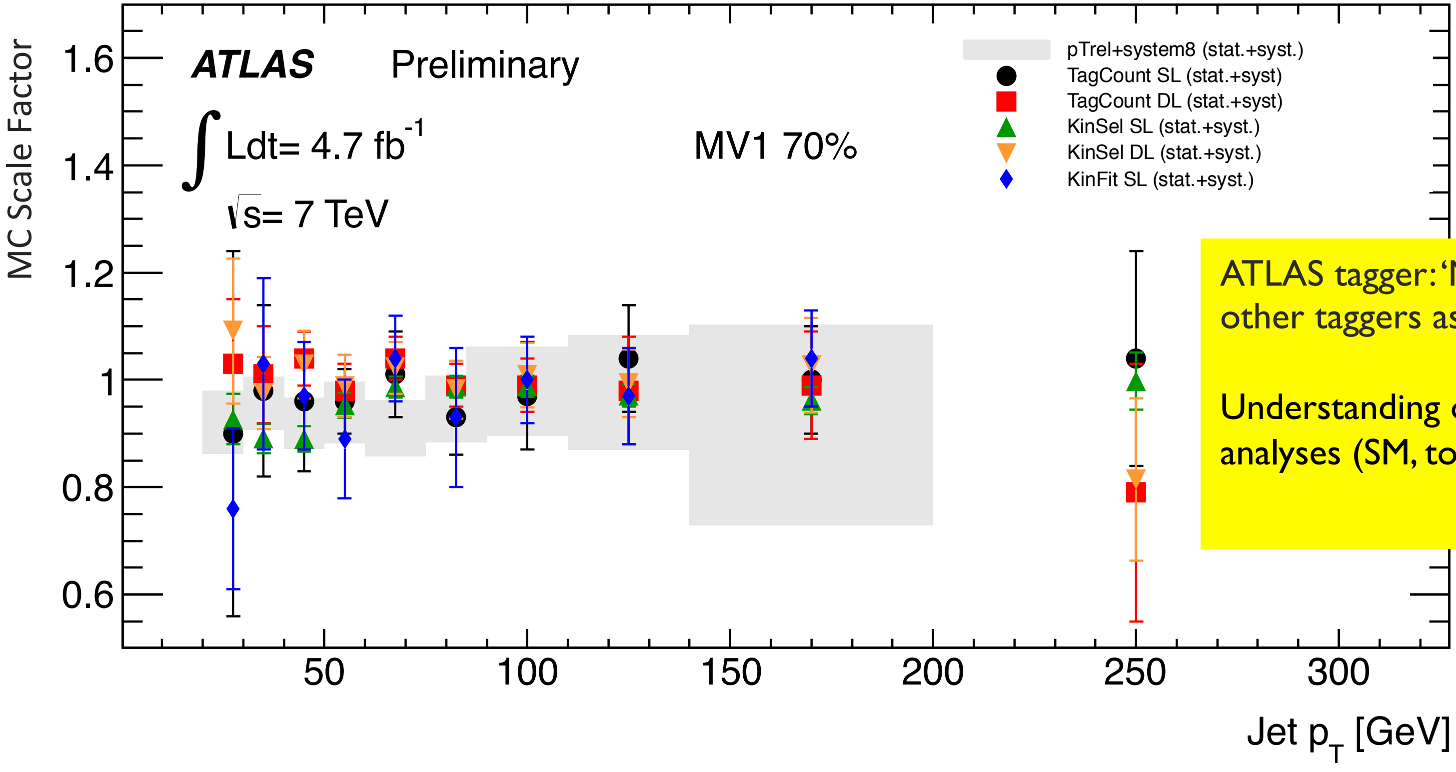
- Massive production of 8 TeV Mont Carlo samples
- effective and flexible Computing Model and Operation Team
- Reprocessing of 2012 data (~2 B events !)
- Tier-0 at CERN (6000 CPUs)
- 10 Tier-1
- ~70 Tier-2 federations

PERFORMANCE/ MUONS AND b–TAGGING



mass resolution for multimuon final states

ATLAS-CONF-2012-097



ATLAS tagger: 'MV1' neural network using other taggers as input

Understanding of *b*-tagging efficiencies crucial for many analyses (SM, top, *H* –> *bb, new physics searches*)

gauge theories and extra dimensions

- Geometrical picture (from ~1970: Attiyah, Singer, Donaldson, Witten, Bott…). In the mathematical language of fibre bundles, a gauge potential (e.g. 4-vector potential of electrodynamics, or Yang-Mills potentials for Electroweak Theory) is a connection in a fibre bundle, an abstract state-space of internal structure, described by a given gauge group: U(1) of EM, SU(2) of Yang-Mills theory, superimposed on space-time. The curvature of the connection is the gauge field (e.g the field strength tensor $F_{\mu\nu}$ of electrodynamics).

- It is a geometrical picture, very similar to Einstein's gravity, except the distortion measured by curvature is not taking place in the geometry of space-time but in the geometry of the more-dimensional and "total space", imposed over space-time.

- Gauge (phase) transformations are analogous to co-ordinate transformations in Riemannian geometry of Einstein's GR (Hilbert derived Einstein's equations from a postulate that action is invariant under general co-ordinate transformation)

- Fiber bundles provide a geometrical picture of all interactions; some physicists and mathematicians think that fiber bundles will have to be part of any future progress in particle physics

- The remaining problem is to quantize gravity….but lots of progress here, too

gauge theories and extra dimensions

- 1918 Weyl's theory of gravitation and electricity, he introduced term gauge invariance; unification was unsuccessful; however, his idea applied to quantum mechanic became what we now call gauge theories (complex scale factor rather than real)

- 1921 Kaluza and Klein suggested that gravitation and electromagnetic interactions can be unified in a theory of gravity in 5-dimensional Riemannian geometry; not much support, mainly because it was introducing new dimension (Ockham's razor principle)

- In 1980 Scherk, Schwartz and Cremmer revived interest in Kaluza-Klein theories. They advocated that the extra dimensions should be regarded as physical, not abstract, just like the four dimensions that we are aware of.

- Cremmer and Scherk suggested that the difference between the four observed and the unobserved dimensions has its origin in a process of "spontaneous compactification" of the extra dimensions.

gauge theories and extra dimensions

- 1981 Witten noticed a remarkable fact (could be a concidence): the minimum number of dimensions for a manifold with SU(3)xSU(2)xU(1) symmetry is 7, so to construct a Kaluza-Klein theory in which those symmetries arise as components of gravity in more than 4 dimensions, one must have at least 11 dimensions. At the same time, 11 is probably the maximum number of dimensions for supergravity.

- 1984 Green and Schwartz: proved consistency of string theories only in 26 dimensions (bosonic) and 10 (supersymmetric)

- 1990 Sen, Duff, Witten: M-theory - in 11 dimensions, unites all types of 10 dimensional superstring theories

We may be living in a world which is more than just 4 dimensional, except we don't "see" beyond the familiar 4 space-time dimensions