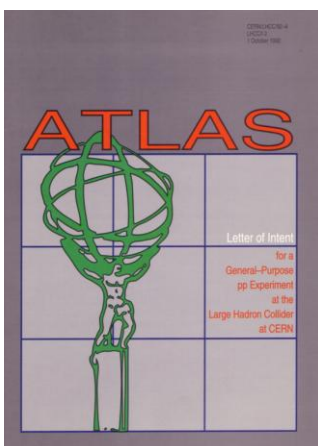
Status and Recent Results of the ATLAS Experiment

A.Cheplakov (JINR, Dubna)
on behalf of the ATLAS Collaboration

- ATLAS detector overview
- Highlights of recent results
  - Standard Model study (and beyond)
  - Heavy Ion physics
  - A new (Higgs?) boson discovery
- ATLAS future – upgrade program



October 1992

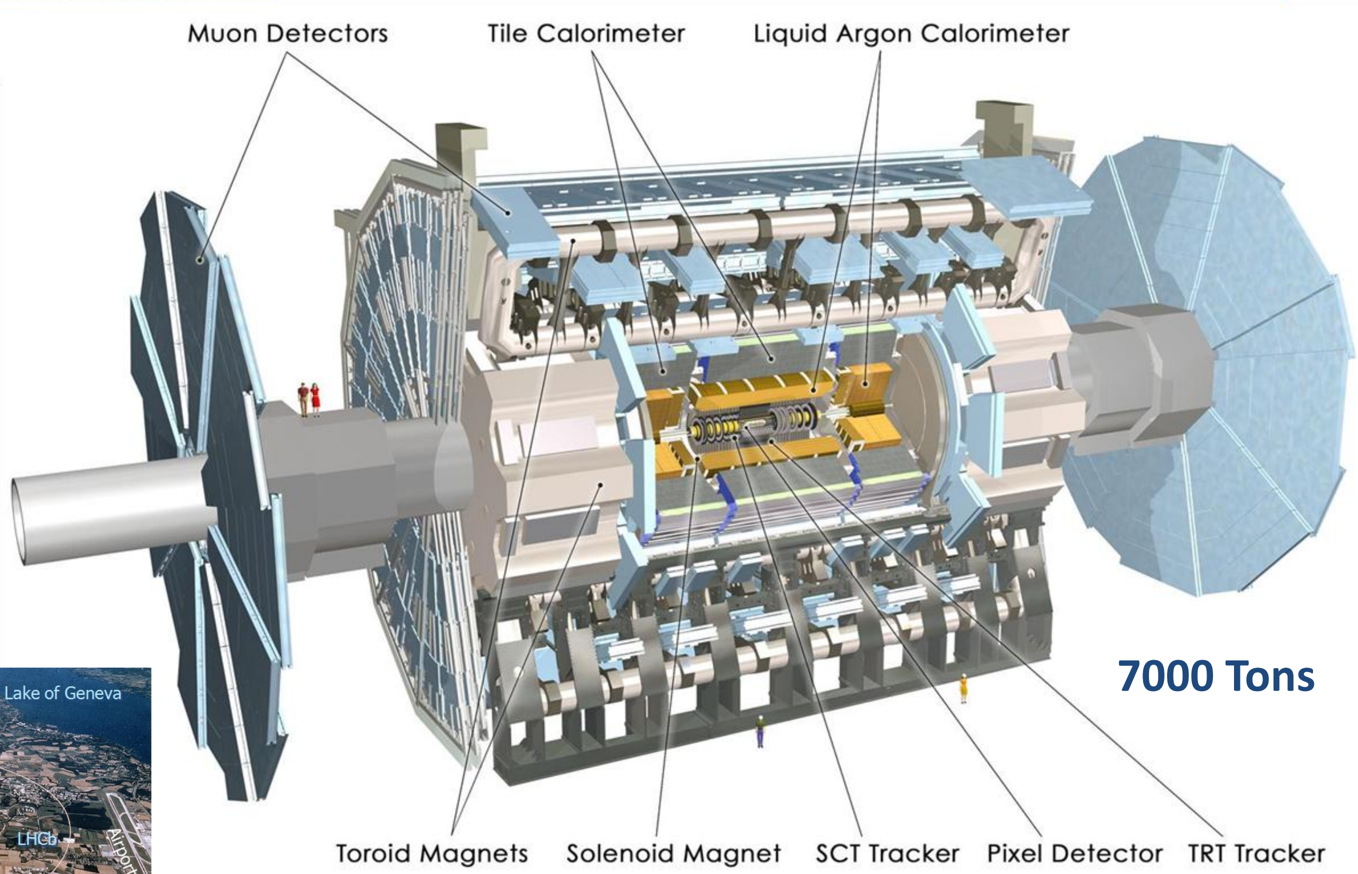
… 20 years since the ATLAS Letter of Intent

We are:
38 nations
174 Institutions
3000 individuals

ATLAS Detector

ATLAS superimposed to
the 5 floors of building 40

45 m

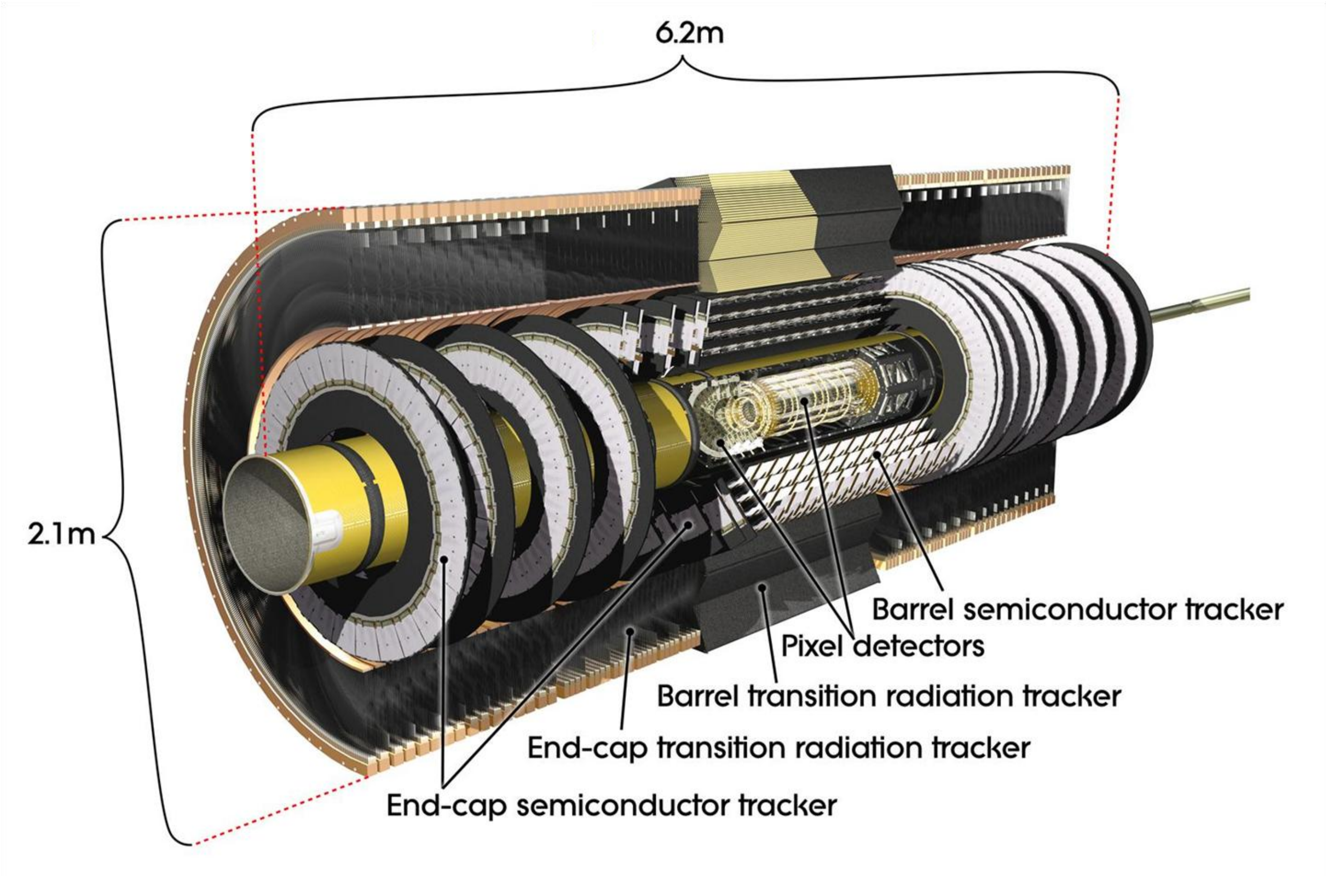


+ forward detectors

25 m

7000 Tons

ATLAS Inner Tracking Detector (ID)



Si Pixels:
80M channels ;
3 layers and 3 disks ;
σ = 10 µm [rϕ]

Si strips (SCT):
6M channels;
4 layers and 9 disks ;
σ = 17 µm [rϕ]

Transition RadiationTracker (TRT):
350k channels ;
σ =120 µm/straw

<#hits> in barrel
~ 3/8/30 in Pixel/SCT/TRT

Precise tracking and vertexing, e/π separation;
coverage: **$|\eta|<2.5$** B (solenoid) = 2T
$0.5X_0$ at $\eta=0$; $1.1\ X_0$ at $\eta=1.8$

$\sigma/p_T = 0.038\%\ p_T(\mathrm{GeV}) \oplus 1.5\%$
(3.8% p_T= 100GeV ; <2% p_T<35GeV)

Impact parameter resolution (0.25<|η|<0.5)
$(\sigma_{d0}) = 10\ \mu m \oplus 140\ \mu m\ /\ p_T$ [GeV/c]

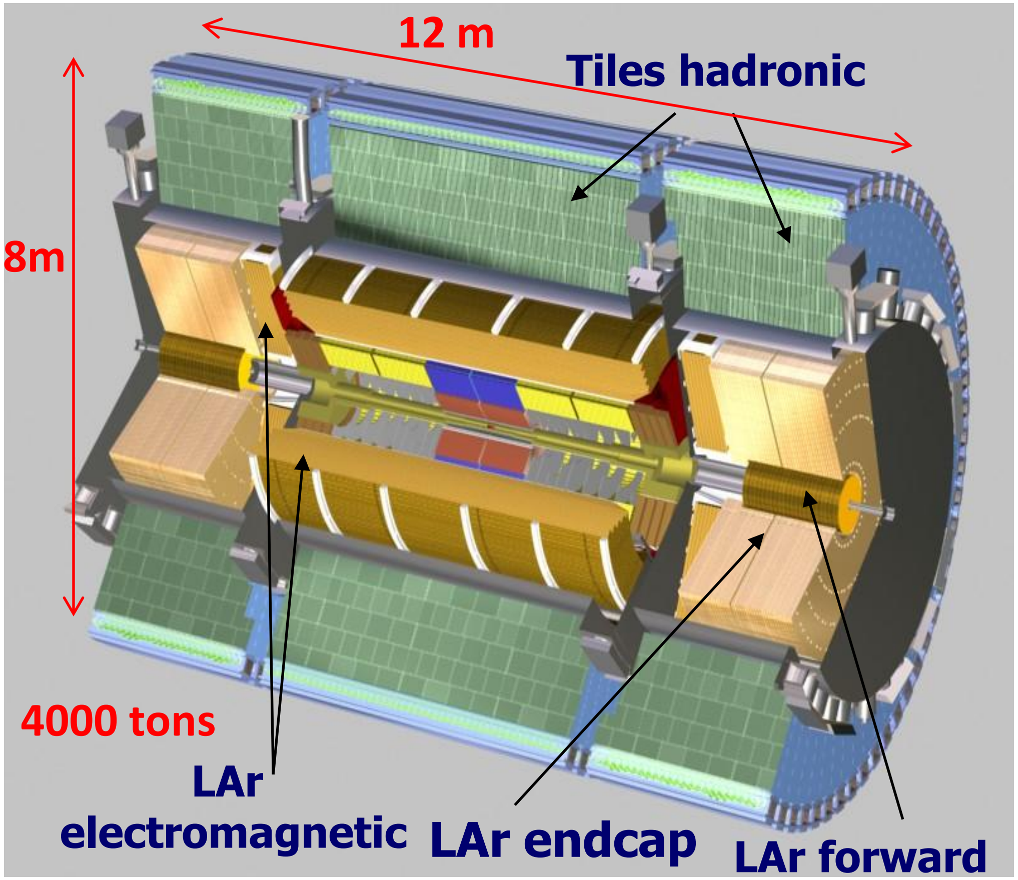
ATLAS Calorimeters

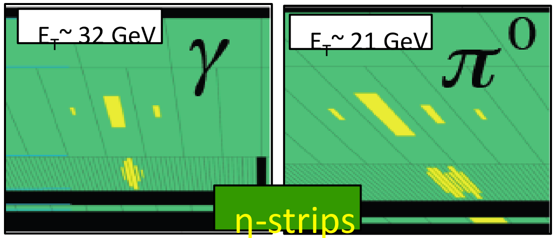
LAr-Pb EM calorimeter) (|η|<3.2) :
e/γ trigger, identification; measurement
$\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
Granularity: **0.025x0.025** ; $22X_0$
3 longitudinal layers + presampler (|η|<1.8)
180×10^3 channels

Hadronic calorimeter (|η|<4.9) :
Trigger; measure jets; $E_{T,miss}$:
$\sigma/E \sim 50\text{-}60\%/\sqrt{E} \oplus 3\%$ central
$\sigma/E \sim 90\%/\sqrt{E} \oplus 7\%$ in fwd
$\sigma(E_{T,miss})/\Sigma E_T \approx 55\ \%$

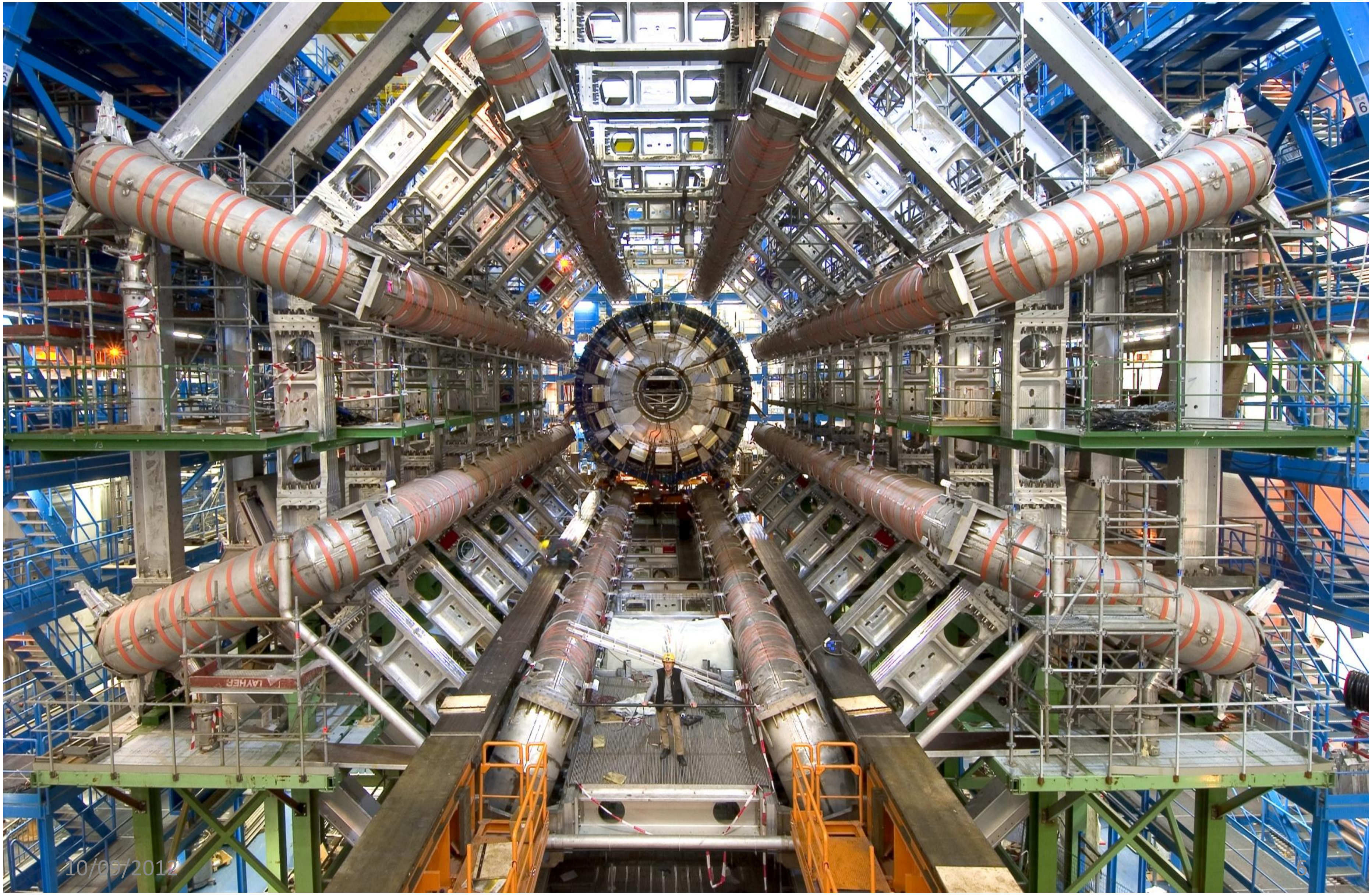
Tiles: |η|<1.7; Fe/scintilators
HEC: 3.2 <|η|<1.5; Cu-LAr
FCAL: 3.1<|η|<4.9; Cu/W-LAr

Thickness: 10λ at |η|=0
Granularity: Δη×Δϕ : 0.1x0.1 up to |η|<2.5
Segmentation: 3-4 longitudinal layers
20×10^3 channels





Muon Spectrometer during the assembly



Muon Spectrometer

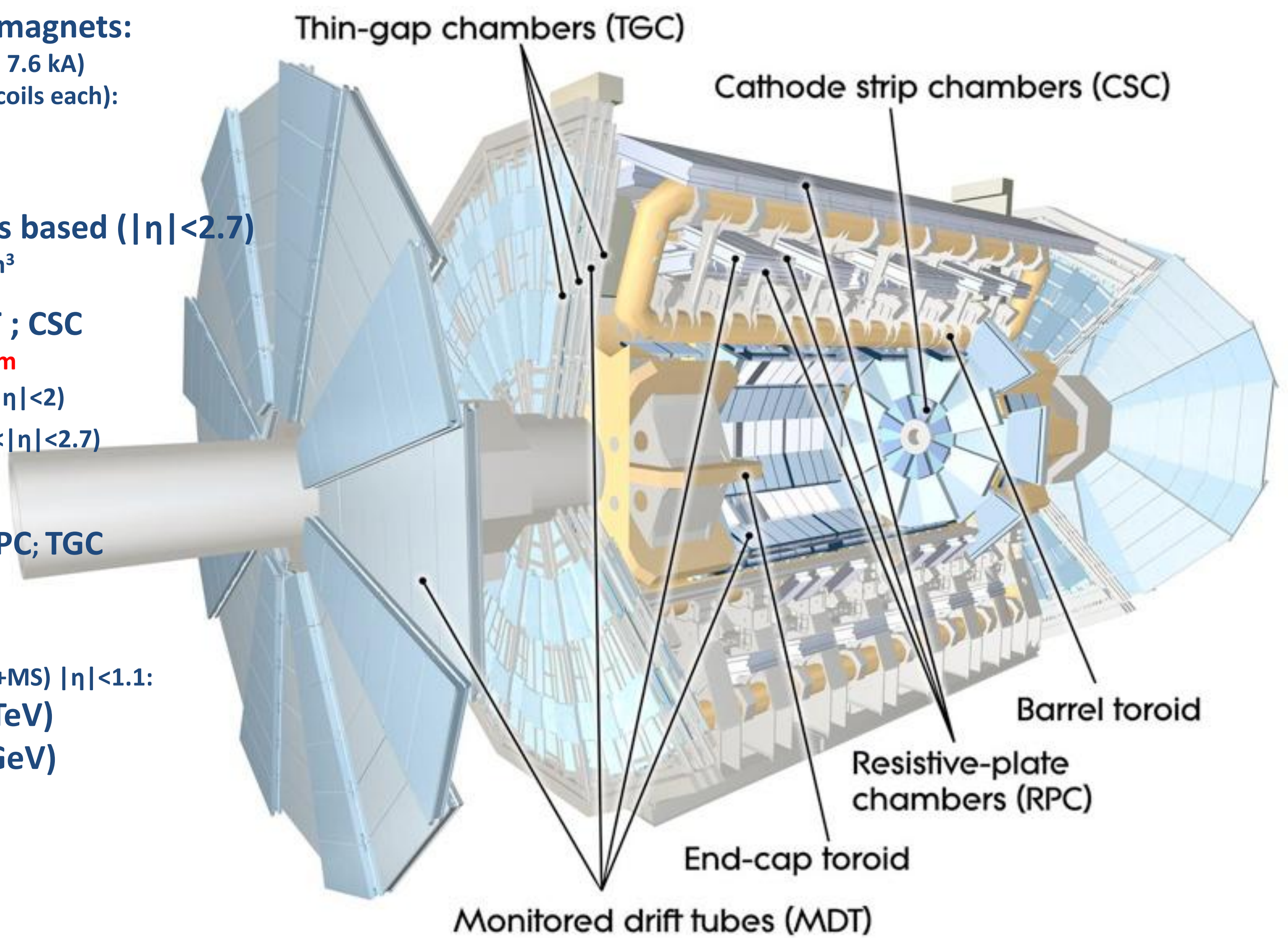
4 Superconducting magnets:
- **Solenoid** around ID (**B=2T**; 7.6 kA)
- **3 Air core Toroids** (with 8 coils each): 20kA, B_{toroid} ~0.5-1T

4 chambers types gas based (|η|<2.7)
1.1×10^6 channels ; 12000 m^3

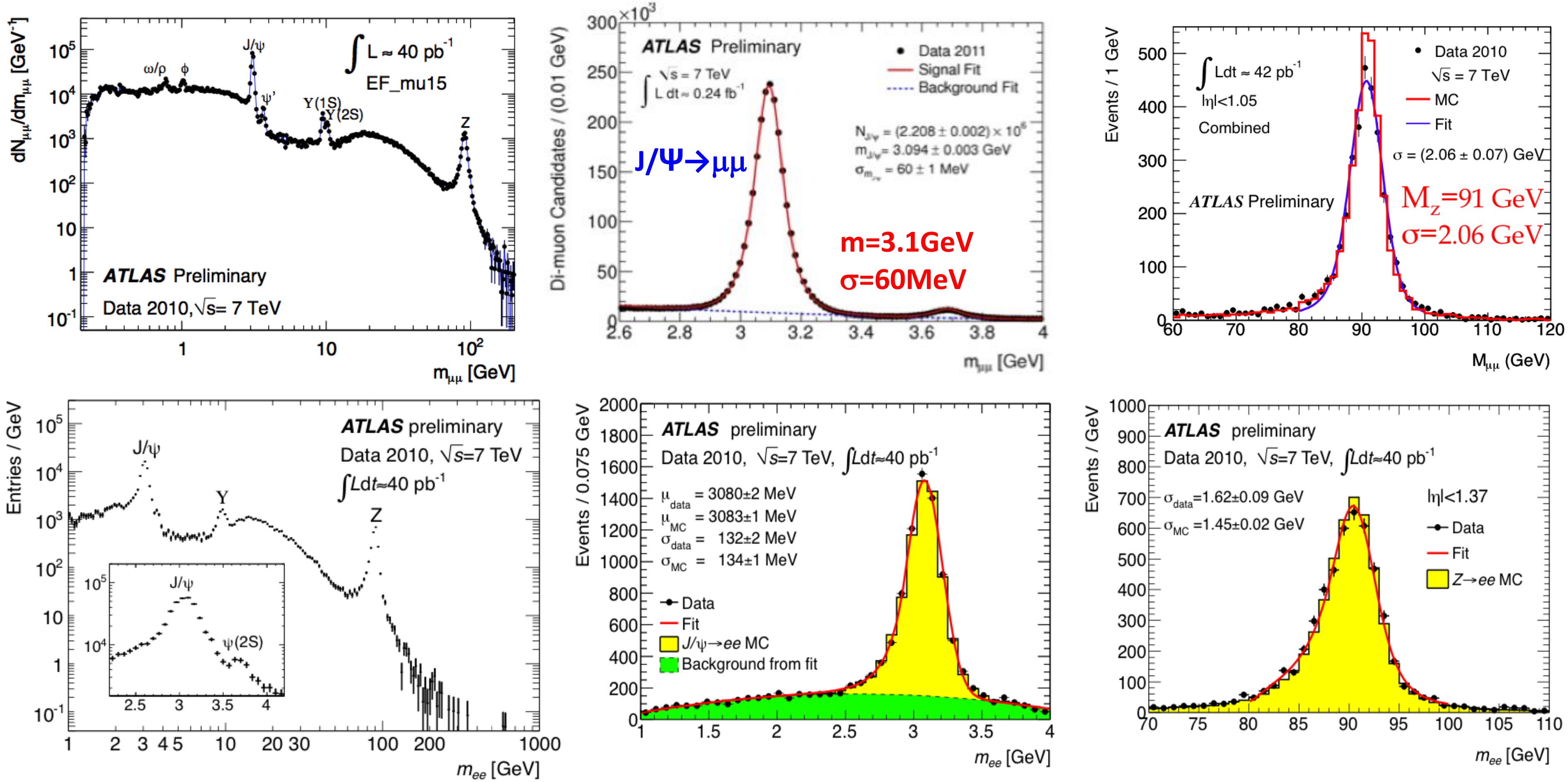
Precision chambers : **MDT ; CSC**
Alignment accuracy: ~ 30μm
MDT resolution = 80μm (|η|<2)
CSC resolution =60μm (2<|η|<2.7)

Trigger chambers (LVL1): **RPC; TGC**

Momentum resolution (ID+MS) |η|<1.1:
σ_{pT}/p_T ~10% (p_T ~ 1 TeV)
σ_{pT}/p_T ~2% (p_T =50 GeV)



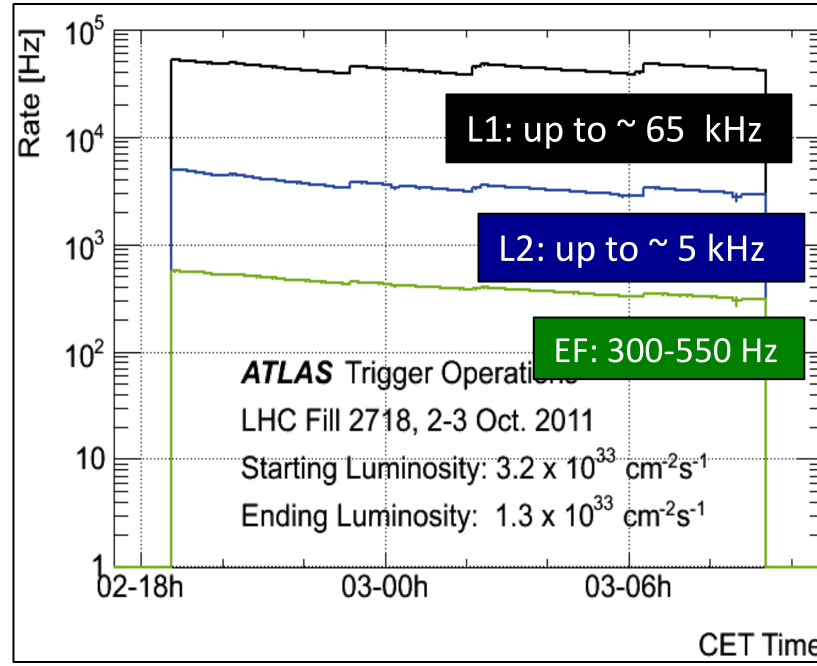
ATLAS performance for physics



- Perfect agreement with Monte-Carlo simulation
- Check detector performance with known resonance particles (ω, ρ, ϕ, J/Ψ, Y, Z,…)
- Excellent mass resolution, close to design: (2.2 % at 91 GeV, 1.9% at ~3 GeV)
- Linear response , absolute momentum scale known to ~ 0.2%

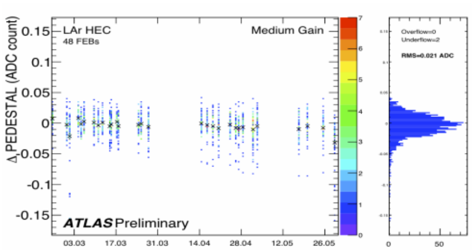
ATLAS operation

Subdetector	# channels	Operational fraction
Pixels	80 M	96.8%
SCT Silicon Strips	6.3 M	99.1%
Transition Radiation Tracker (TRT)	350 k	97.5%
LAr EM Calorimeter	170 k	99.8%
Tile calorimeter	9800	96.2%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	97.7%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.1%
Total	**88M**	**>96%**



Running smoothly:

- **~95%** data taking efficiency,
- high & stable recorded physics rate
- e.g. LAr HEC pedestal stability:



rms~0.021ADC

GRID resources are in intensive use:

- reconstruction at Tier0 in **~2 days**,
- data available for the analysis on GRID in **~1 week**
- up to 150k simultaneous jobs running in parallel (analysis & simulation)

Phenomenal LHC performance

Good start in 2010: ATLAS recorded 45 pb^{-1} at 7 TeV

Perfection in 2011: 5.25 fb^{-1} at 7 TeV

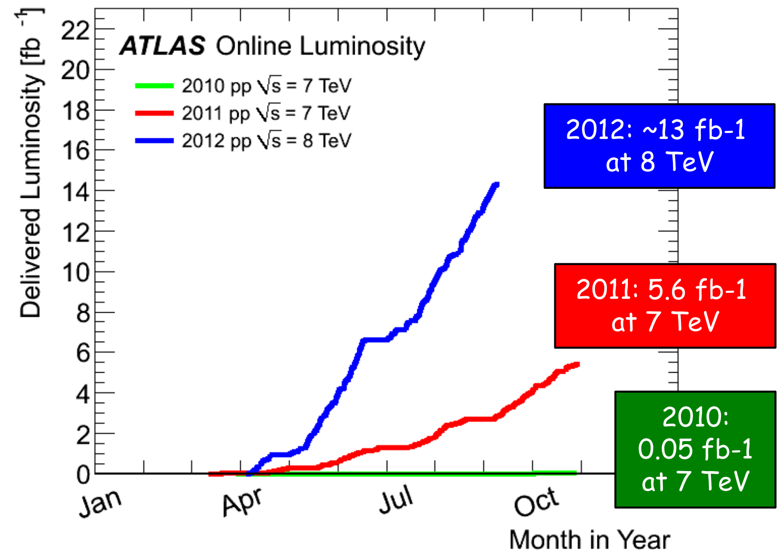
Outstanding in 2012: so far 13.4 fb^{-1} at 8 TeV

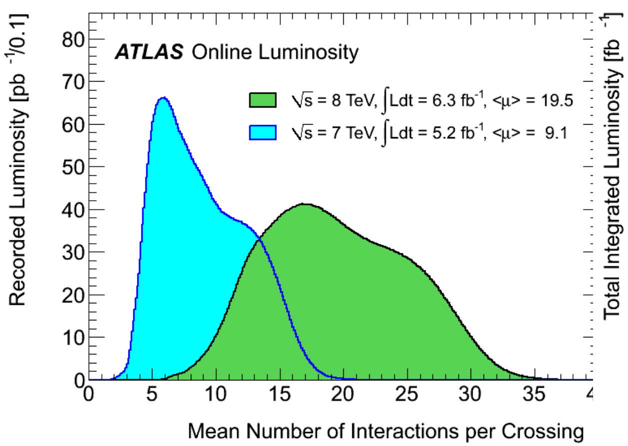
Bunch intensity: $1.5x10^{+11}$ ppb

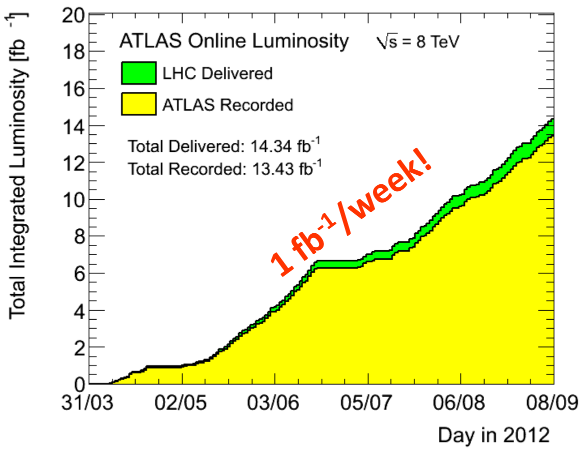
Peak Luminosity: $7.73x10^{+33}$ cm^{-2} s^{-1}, may reach ~$9 \cdot 10^{+33}$!

Best week #24: 1.3fb^{-1} recorded

>50% of time in stable beam







LHC in 2012:

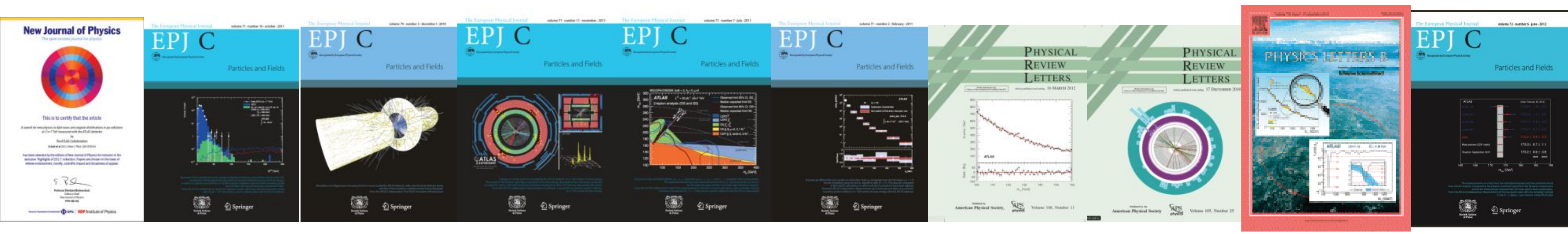
- ✓ Stick with 50ns bunch spacing 1380 bunches, push the bunch intensity
  - ➢ ~40 events/crossing
- ✓ Proton beam energy 3.5 TeV → 4 TeV (+15% in Luminosity)
  - ➢ Check for risk from the splices
- ✓ Reduced β^*=0.6m in CMS and ATLAS (+60% in Luminosity)

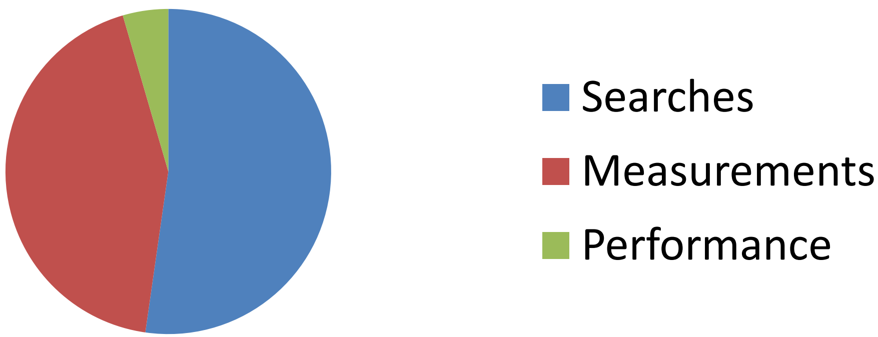
Hope for 15fb^{-1} by Sep 17 and 20fb^{-1} @ 8TeV before a long shutdown in 2013

ATLAS results

ATLAS EXPERIMENT - Public Results

available at https://twiki.cern.ch/twiki/bin/view/AtlasPublic





Physics Groups:

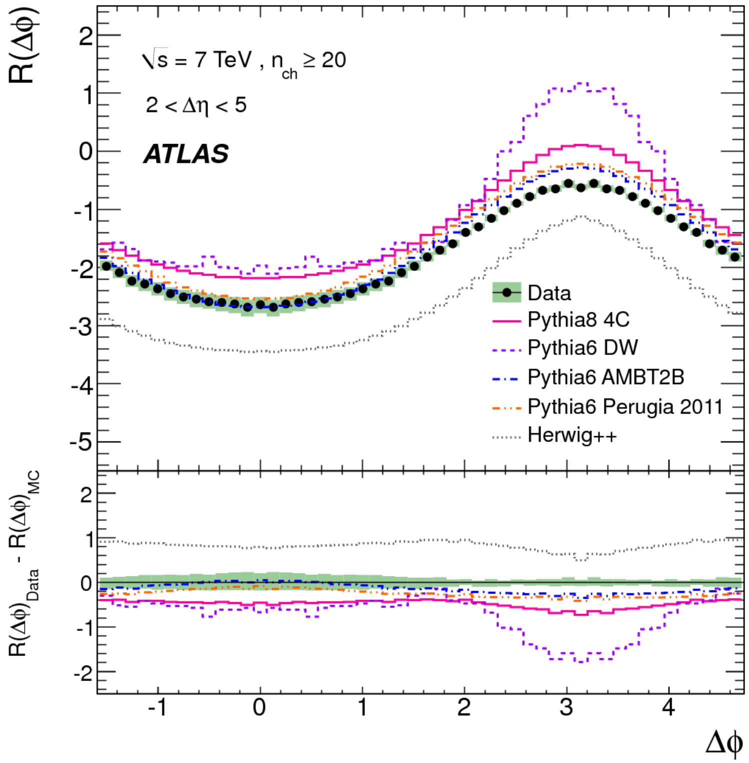
- Standard Model — **Soft QCD, Jets, W/Z, Direct γ, EW**
- B Physics
- Top Physics
- Higgs
- Supersymmetry
- Exotics
- Heavy Ions
- Monte Carlo

Last week:
Papers on collision data submitted: 186(+30),
CONF-notes: 386,
average ~2 papers/week this year

Soft QCD results

Two-particle angular correlations:

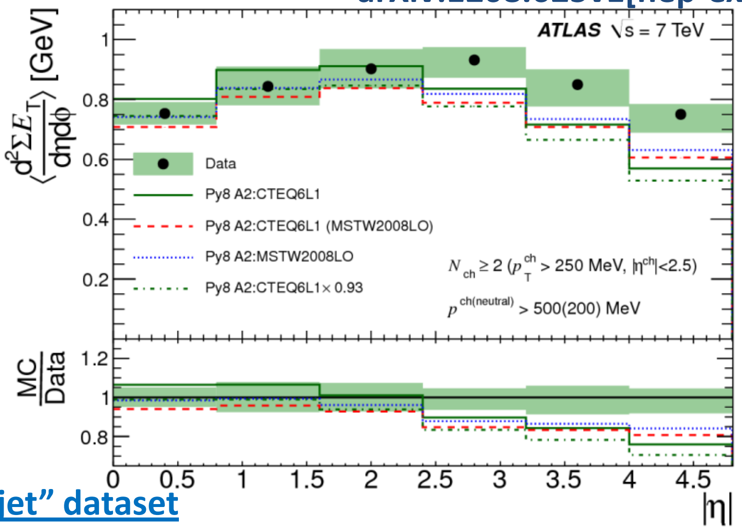
JHEP 1205(2012)157



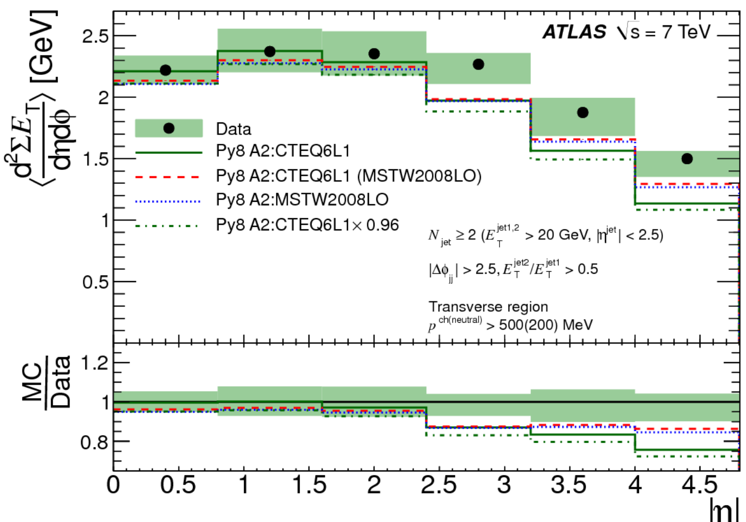
None of the models provide a good quantitative description of the strength of the correlations. The changes required may go beyond their re-tuning.

Total transverse energy:

"inclusive" dataset **arXiv:1208.625v1[hep-ex]**

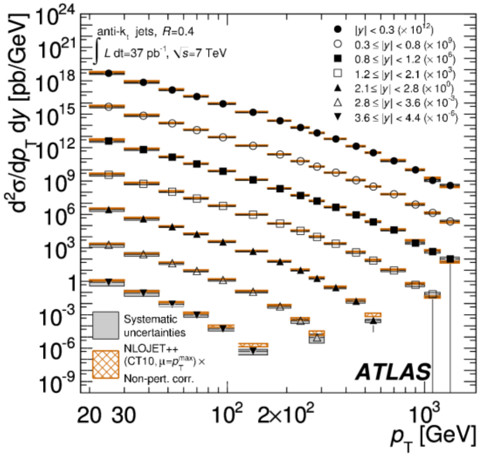


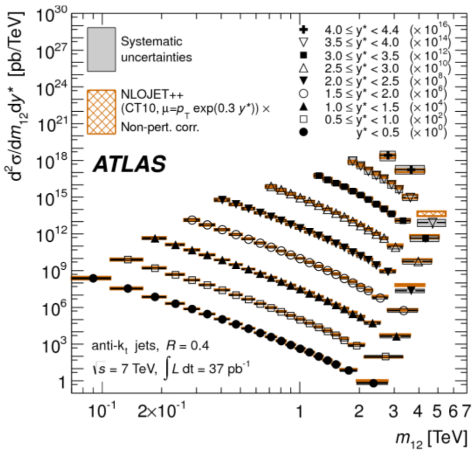
"di-jet" dataset



MC models tend to underestimate the amount of transverse energy at high |η|

Jet Physics





properties of jets with high p_T:

Jet mass - $M^2 = \left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p}_i\right)^2$ **Jet width** - $W = \frac{\sum_i \Delta R^i\, p_T^i}{\sum_i p_T^i}$

Eccentricity, ε – jet profile deviation from the perfect circle (PCA)

$$\mathcal{E} = 1 - \frac{v_{\min}}{v_{\max}}$$

Planar flow, P - jet's energy spread over the plane across the face of the jet (evenly/linearly)

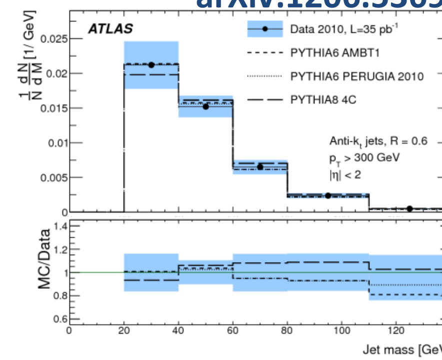
$$P = 4 \times \frac{\det(I_E)}{\mathrm{Tr}(I_E)^2}$$

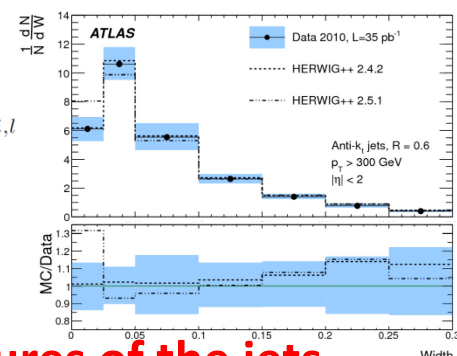
$$I_E^{kl} = \frac{1}{M} \sum_i \frac{1}{E_i} p_{i,k} p_{i,l}$$

Angularity, τ_a – degree of symmetry in the energy flow inside a jet (a= -2)

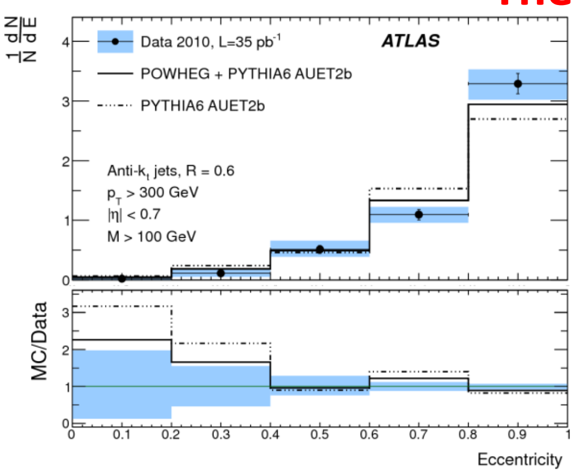
$$\tau_a \simeq \frac{2^{(a-1)}}{M} \sum_i E_i \theta_i^{(2-a)}$$

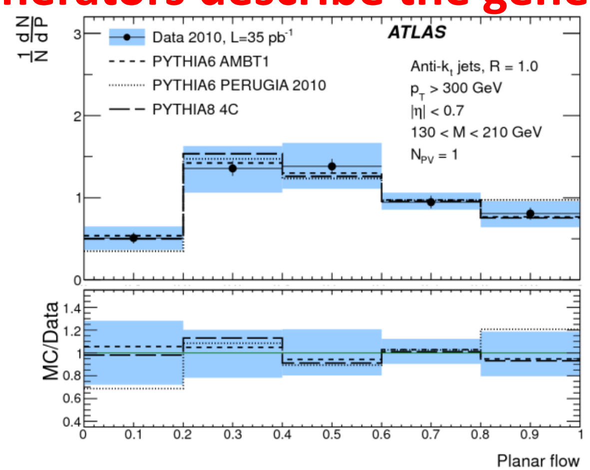
arXiv:1206.5369

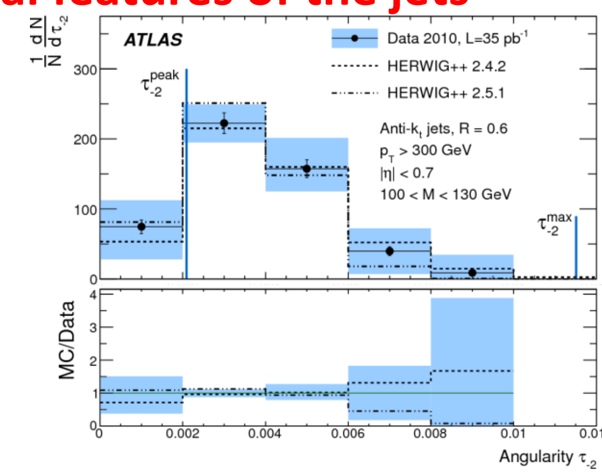




The generators describe the general features of the jets

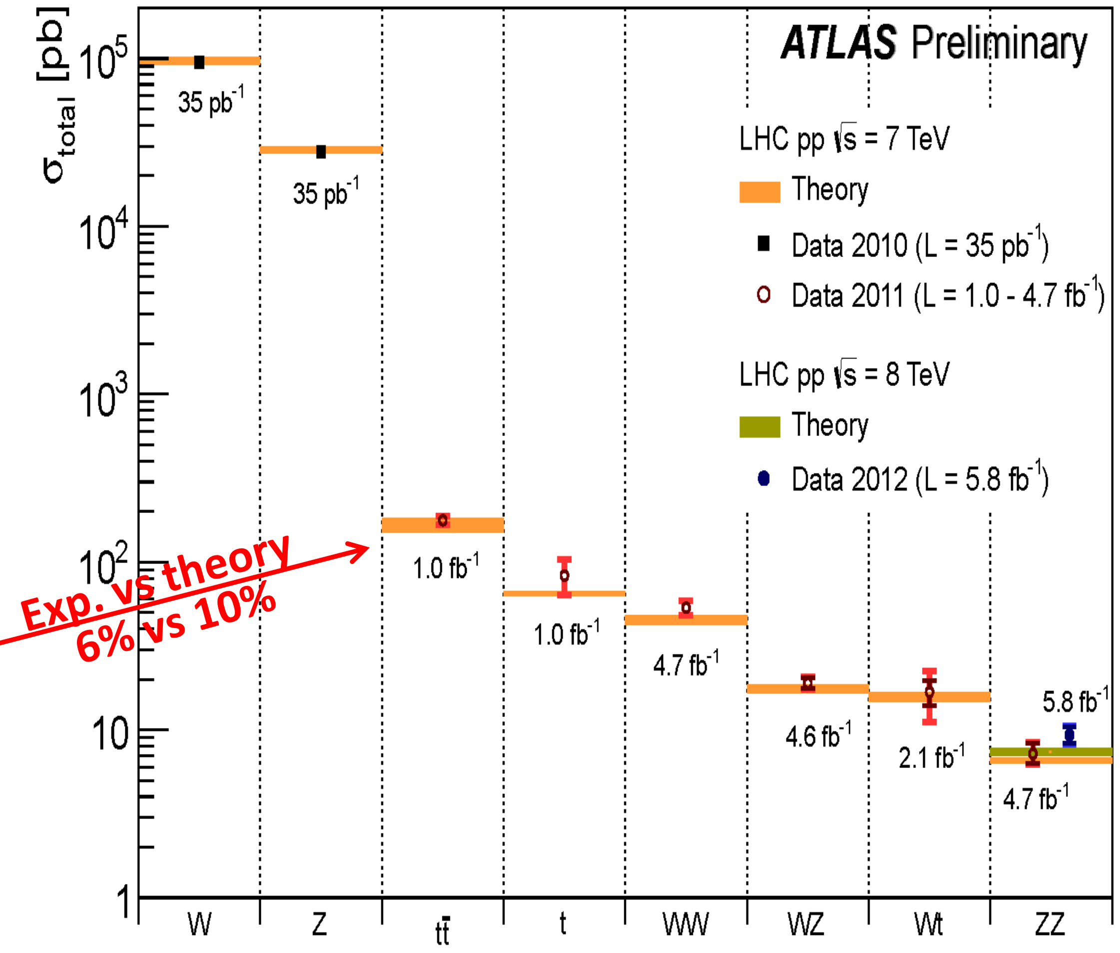




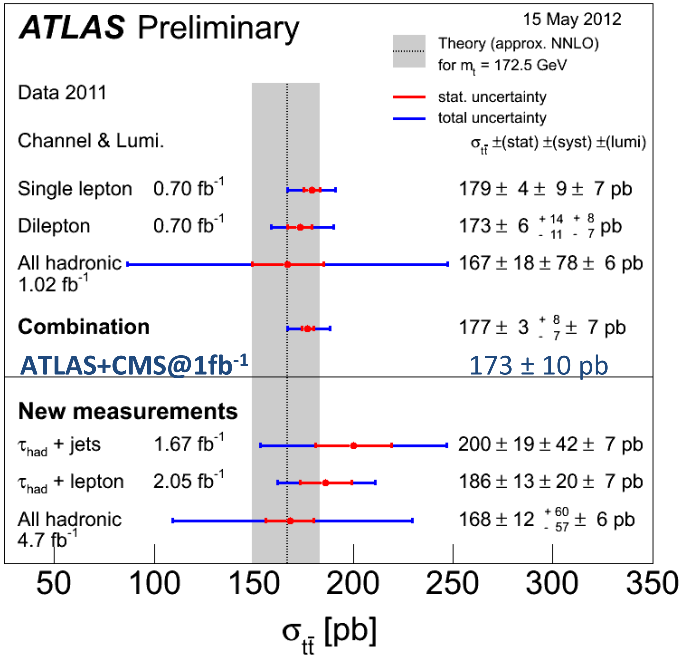


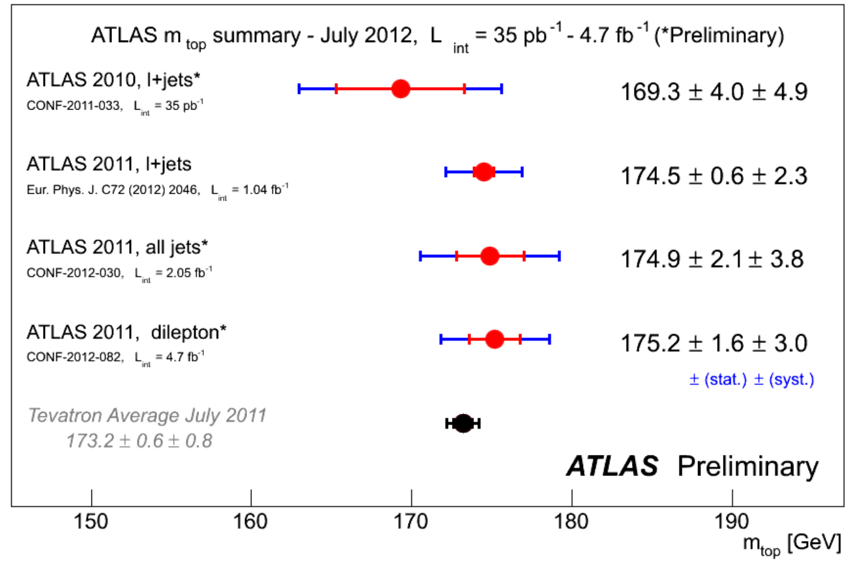
Summary for Standard Model processes

- **Measurements of Standard Model processes going well – no surprises so far (NLO or higher)**
- **Good foundation for searches (backgrounds for Higgs)**
- **A general approach:**
  discovery through precision measurements (e.g. ttbar)

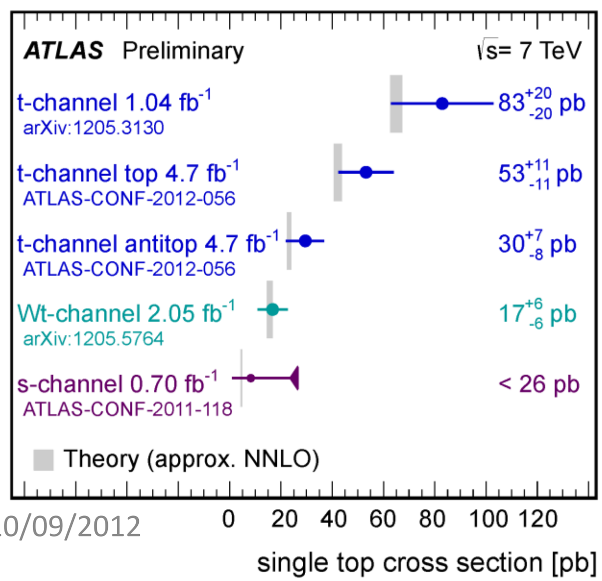


Top quark study examples





ATLAS+CMS: $m_{top} = 173.3 \pm 0.5\ (\mathrm{stat}) \pm 1.3\ (\mathrm{syst})\ \mathrm{GeV}$



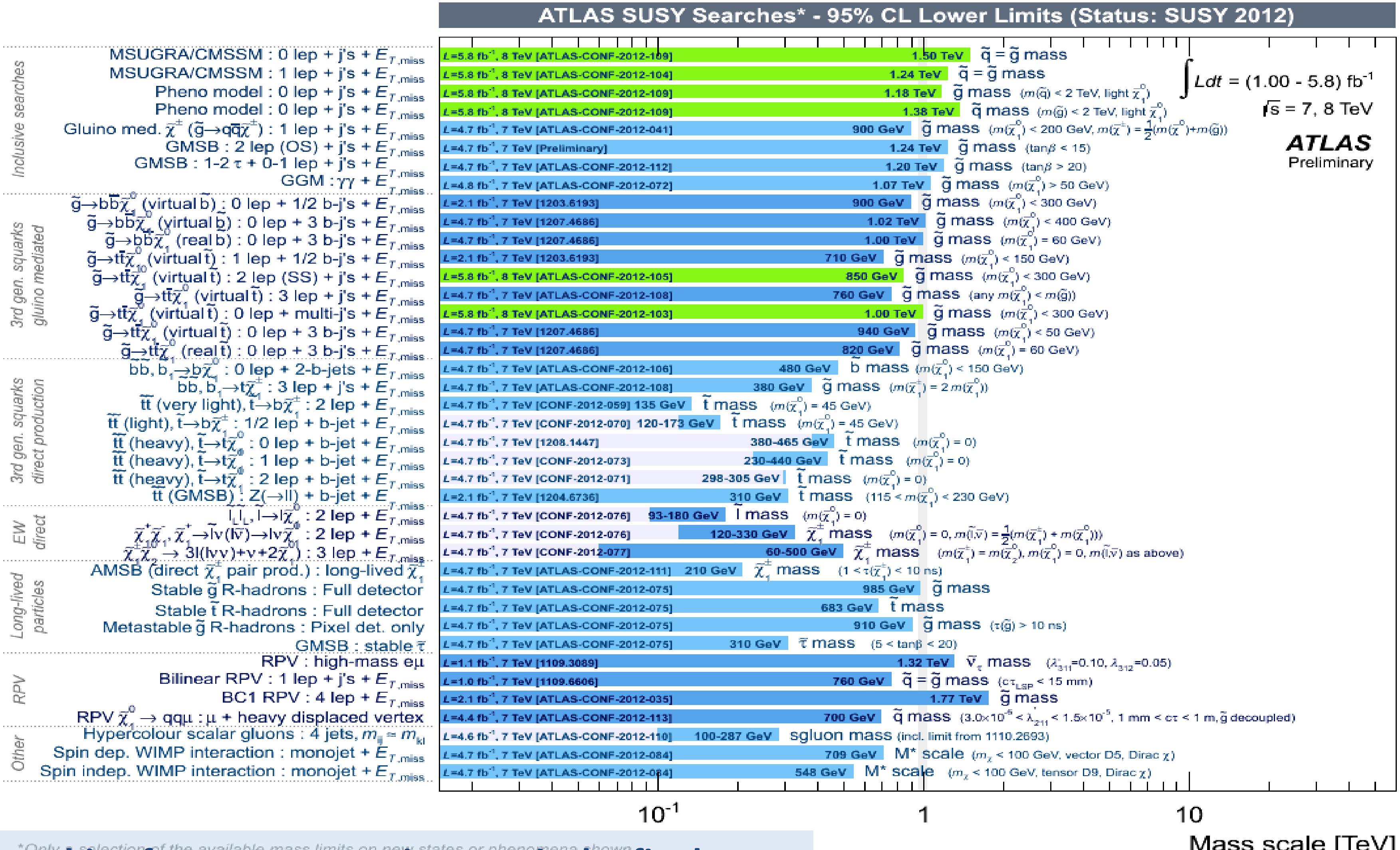
Perspective:

in 2011 (5fb^{-1}), almost one million top pairs were produced and over half billion W bosons

More results being prepared for TOP-2012 (Sept 16):

cross-sections, charge asymmetry, W-polarisation,
ttZ production, ttbar resonances, etc. including 8 TeV data

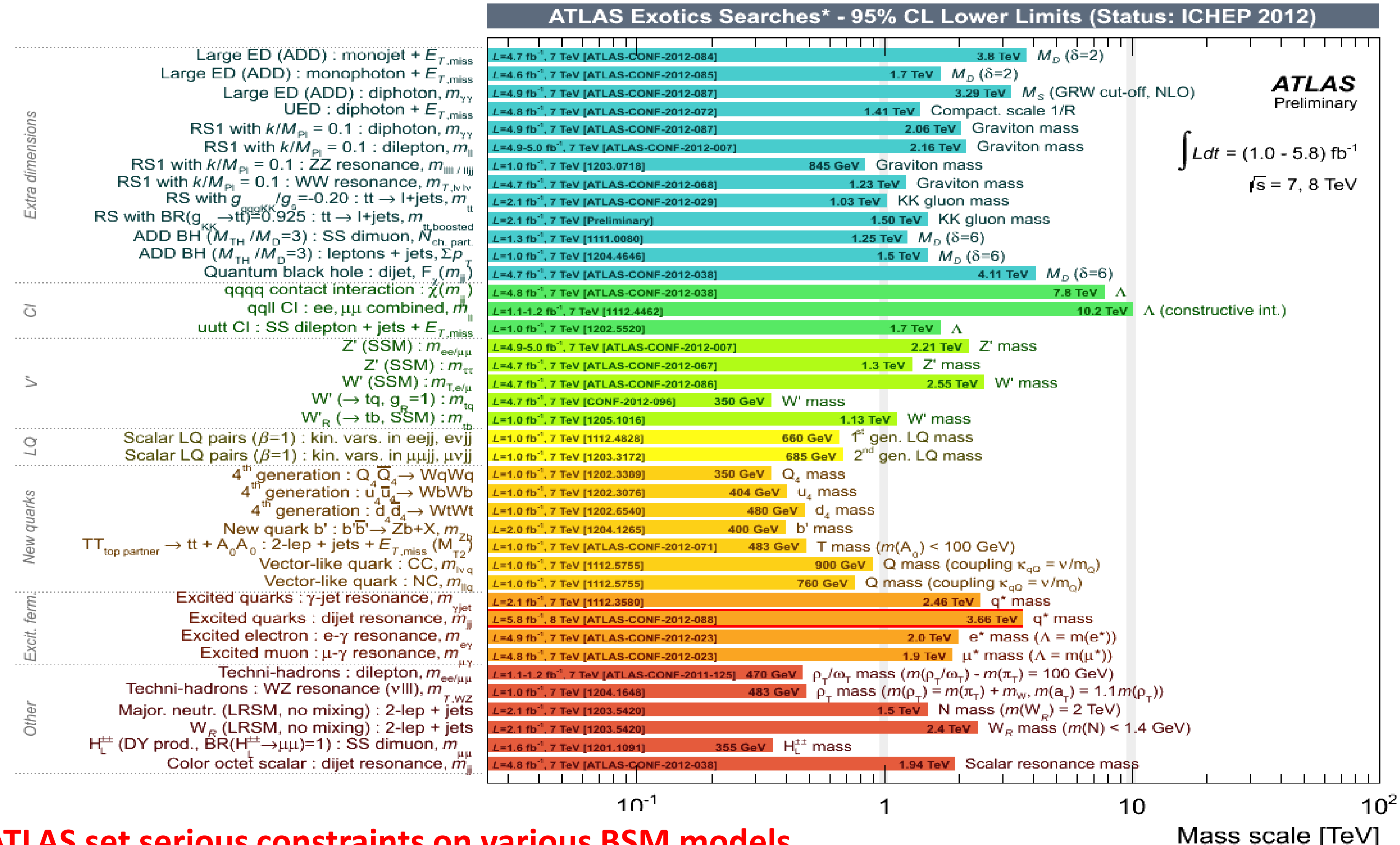
ATLAS limits for SUSY searches



…searching for event excess in a particular final state

…searching for bump in an invariant mass spectrum

Representative selection of other BSM searches



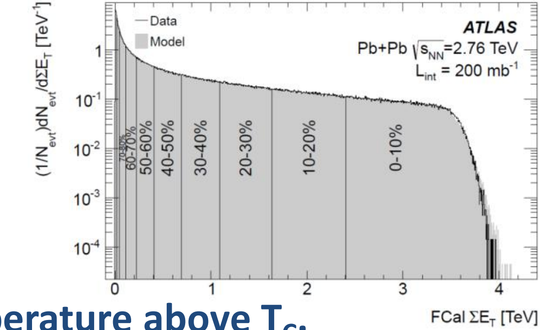
ATLAS set serious constraints on various BSM models

Ian Hinchliff: "Your model may not be on the list yet… Your time will come"

Heavy Ion program

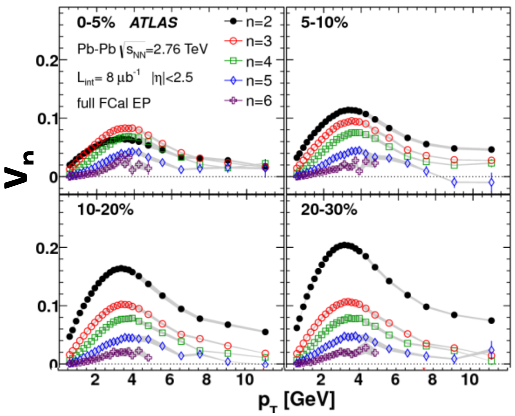
Probing the QGP in Pb+Pb at $\sqrt{s_{NN}}$=2.76 TeV (9μb^{-1} + 160μb^{-1}):

- **pressure-driven collective expansion as well as attenuations (“quenches”) of high-p_T quarks and gluons not achievable in hadronic system;**
- **final state multiplicity consistent with initial state gluon production at temperature above T_C.**



Recent observations:

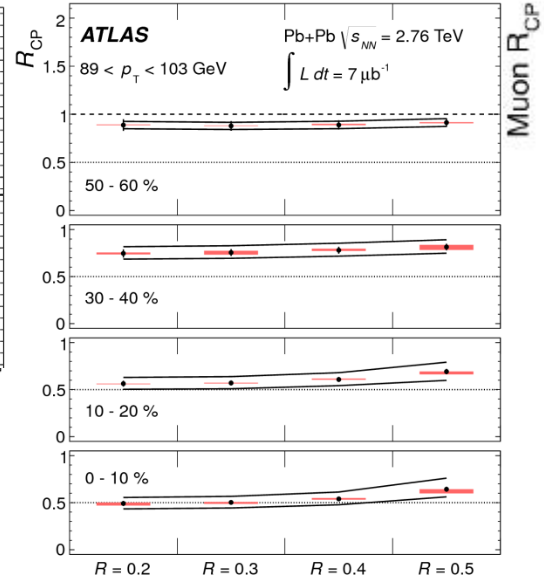
Azimuthal anizotropy



- significant harmonic flow coefficients v_n (n>2)
- v3>v2 (0-5%)

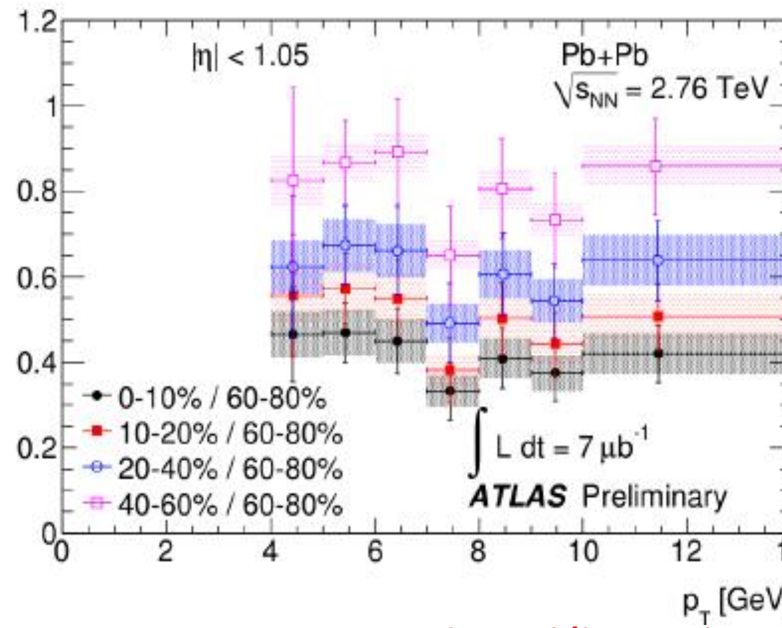
$$E\frac{d^3N}{dp^3} = \frac{d^2N}{2\pi p_T dp_T d\eta}\left(1 + 2\sum_{n=1}^{\infty} v_n(p_T,\eta)\cos n\left(\phi - \Phi_n\right)\right)$$

Jet suppression



- suppression factor of ~2 in central collisions

Heavy flavour suppression



- factor of ~2 suppression in (0-10%)/(60-80%)

ATLAS will focus on:

- using high-p_T jets, dijets and multi-jet final states, and b-jets
- precision measurements with γ-jet and Z-jet pairs
- use quarkonia – Υ(1S), Υ(2S), Υ(3S) to study Debye screening

- study of Cold Nuclear Matter effects & low-x with p+Pb

2013: 30 nb^{-1} (pilot run this week)

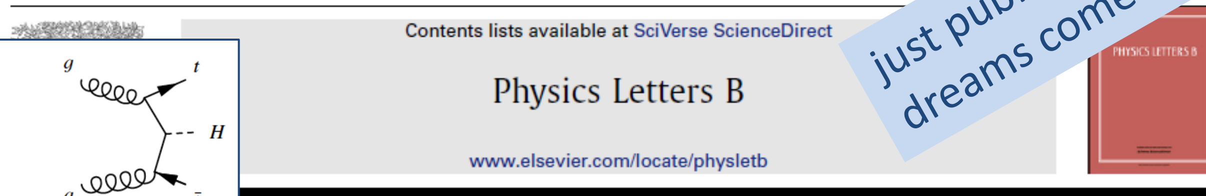
- high precision Pb+Pb

2015-16: ~400μb^{-1} at $\sqrt{s_{NN}}$=5.5 TeV

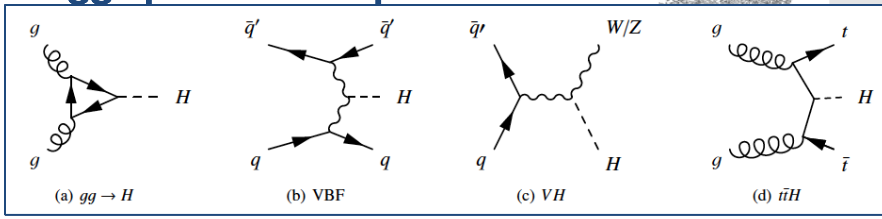
Higgs boson hunting

Physics Letters B 716 (2012) 1-29

just published - the dreams come true!



Higgs production processes:



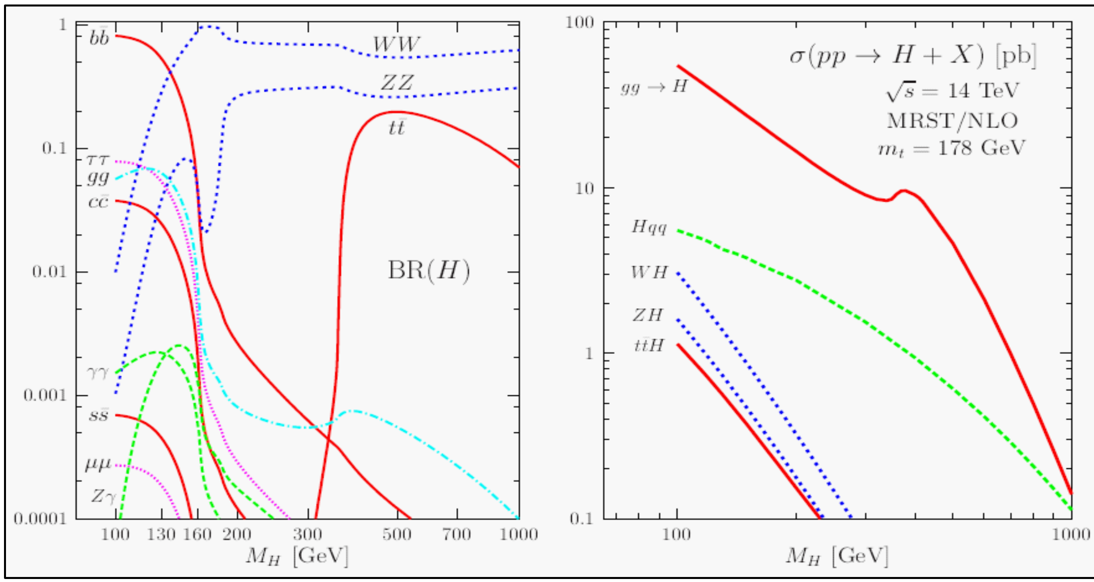
Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

AS colleagues who did not live to see the full impact and significance of their

T R A C T

h for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at C is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} ed at $\sqrt{s}=7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s}=8$ TeV in 2012. Individual searches in the channels $Z^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously ed results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from ed analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for duction of a neutral boson with a measured mass of 126.0±0.4 (stat)±0.4 (sys) GeV is presented. bservation, which has a significance of 5.9 standard deviations, corresponding to a background tion probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model boson.

BR & σ:



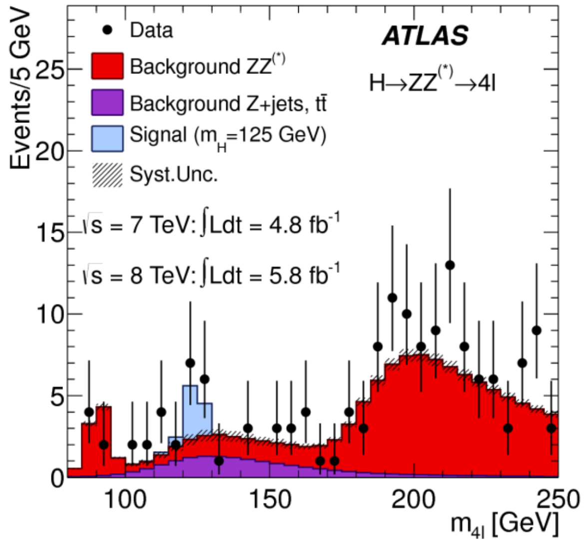
σ_{tot}= 17.5 (22.3) pb at 7 (8) TeV

m = 126.0 ± 0.4 (stat) ± 0.4 (syst) GeV

The channels involved:

H→ γγ,	H→ ττ	H→ ZZ → llqq
H→ ZZ(*) → 4l	W/ZH→bb	H→ ZZ → llνν
H→ WW(*) → lνlν	H→ WW → lνqq	

Two most sensitive channels – 4ℓ and γγ



4ℓ: σ·BR=2.2(2.8) fb @ 7(8) TeV
Backgrounds: ZZ(*), ttbar, Z+jets

Event selection – single & dilepton triggers
Lepton candidates (isolated):
- **muons – ID+MS, $p_T > 7$ GeV, $|\eta|<2.47$**
- **electrons – ID+LArEM, $p_T > 6$ GeV, $|\eta|<2.7$**

Mass-window cut for m_{34} ($m_{min}<m_{34}<115$ GeV)

Combined signal reconstruction and event selection efficiencies: 15%(4e) - 37%(4μ)

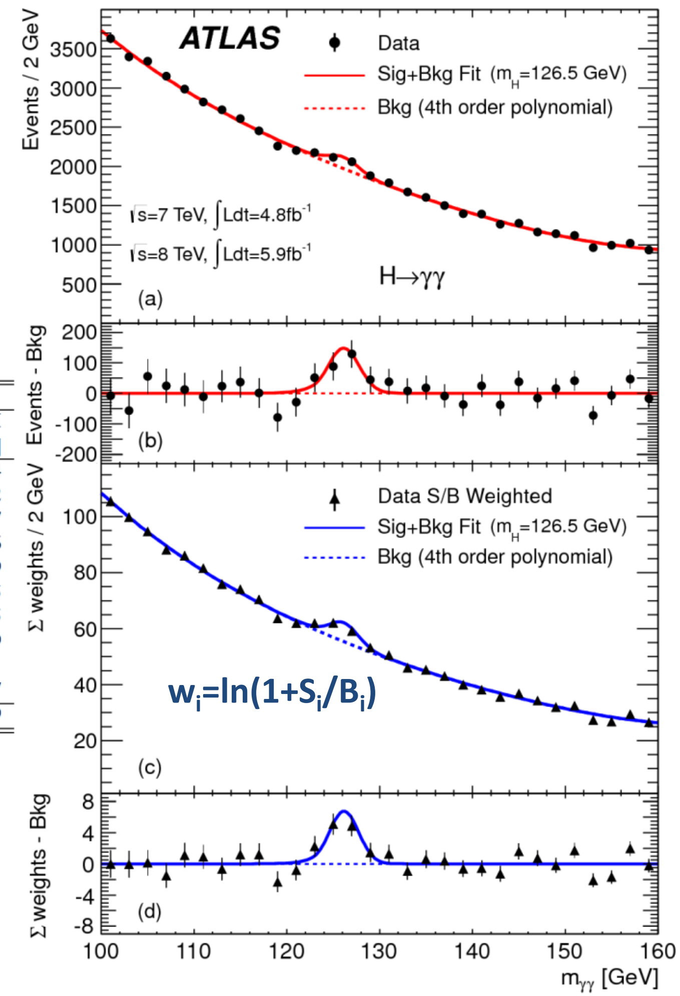
	Signal	$ZZ^{(*)}$	$Z+\text{jets}, t\bar{t}$	Observed
4μ	2.09±0.30	1.12±0.05	0.13±0.04	6
$2e2\mu/2\mu2e$	2.29± 0.33	0.80±0.05	1.27±0.19	5
$4e$	0.90±0.14	0.44±0.04	1.09±0.20	2

γγ: σ·BR=39(50) fb @ 7(8) TeV
Backgrounds: QCD-γγ, γ+j, j+j, D-Y

Event selection – diphoton trigger
Photon candidates (isolated):
- **E_T> 40/30 GeV , $|\eta|<2.37$**
- **LArEM shower shapes**

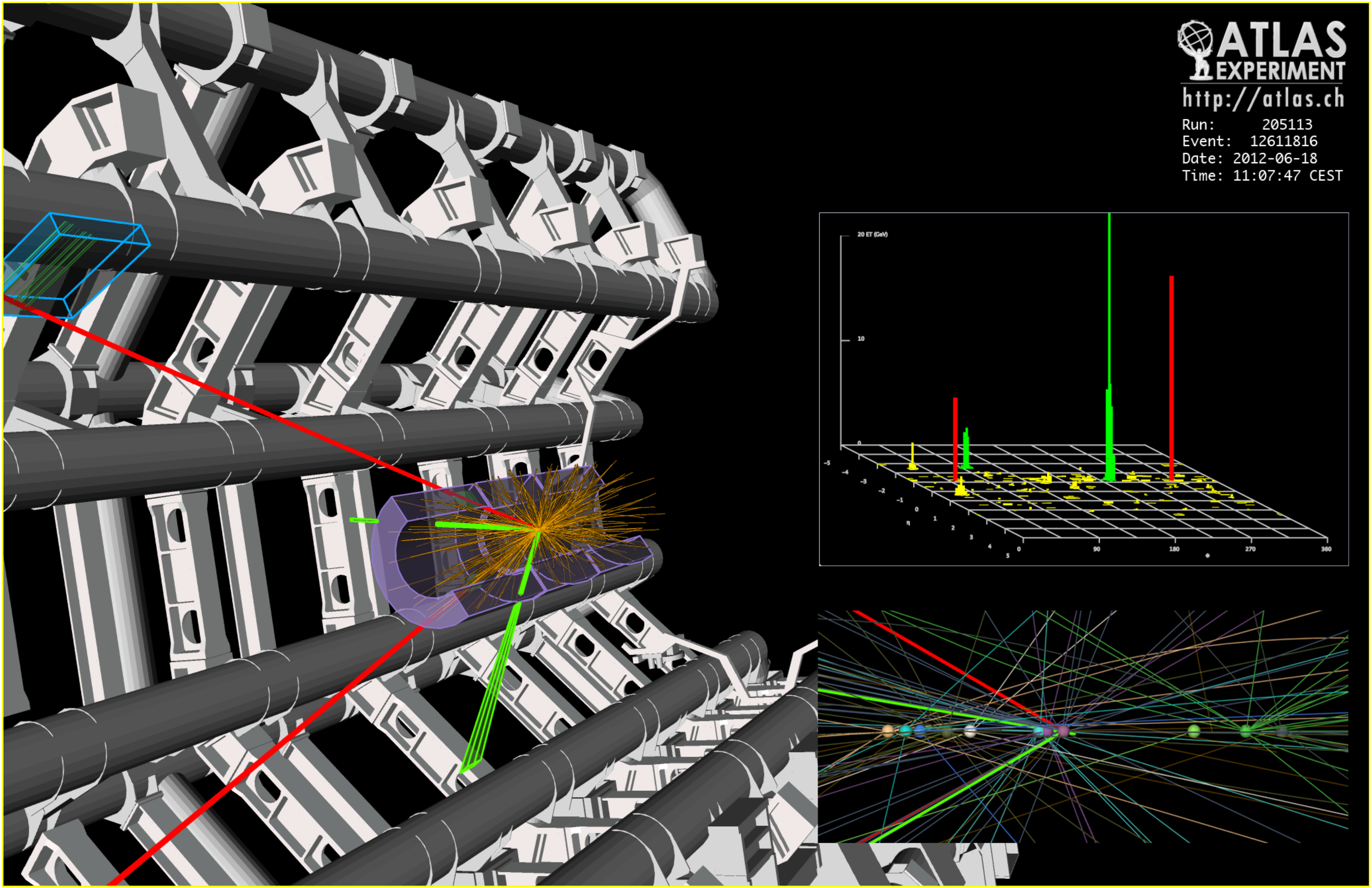
VBF (2 extra jets) + 9 event categories:

$\sqrt{s}$	7 TeV		8 TeV		
$\sigma \times B(H \to \gamma\gamma)$ [fb]		39		50	FWHM
Category	N_D	N_S	N_D	N_S	[GeV]
Unconv. central, low p_{Tt}	2054	10.5	2945	14.2	3.4
Unconv. central, high p_{Tt}	97	1.5	173	2.5	3.2
Unconv. rest, low p_{Tt}	7129	21.6	12136	30.9	3.7
Unconv. rest, high p_{Tt}	444	2.8	785	5.2	3.6
Conv. central, low p_{Tt}	1493	6.7	2015	8.9	3.9
Conv. central, high p_{Tt}	77	1.0	113	1.6	3.5
Conv. rest, low p_{Tt}	8313	21.1	11099	26.9	4.5
Conv. rest, high p_{Tt}	501	2.7	706	4.5	3.9
Conv. transition	3591	9.5	5140	12.8	6.1
2-jet	89	2.2	139	3.0	3.7
All categories (inclusive)	23788	79.6	35251	110.5	3.9



H→ZZ$^{(*)}$→2e2μ candidate with $m_{2e2\mu}$= 123.9 GeV

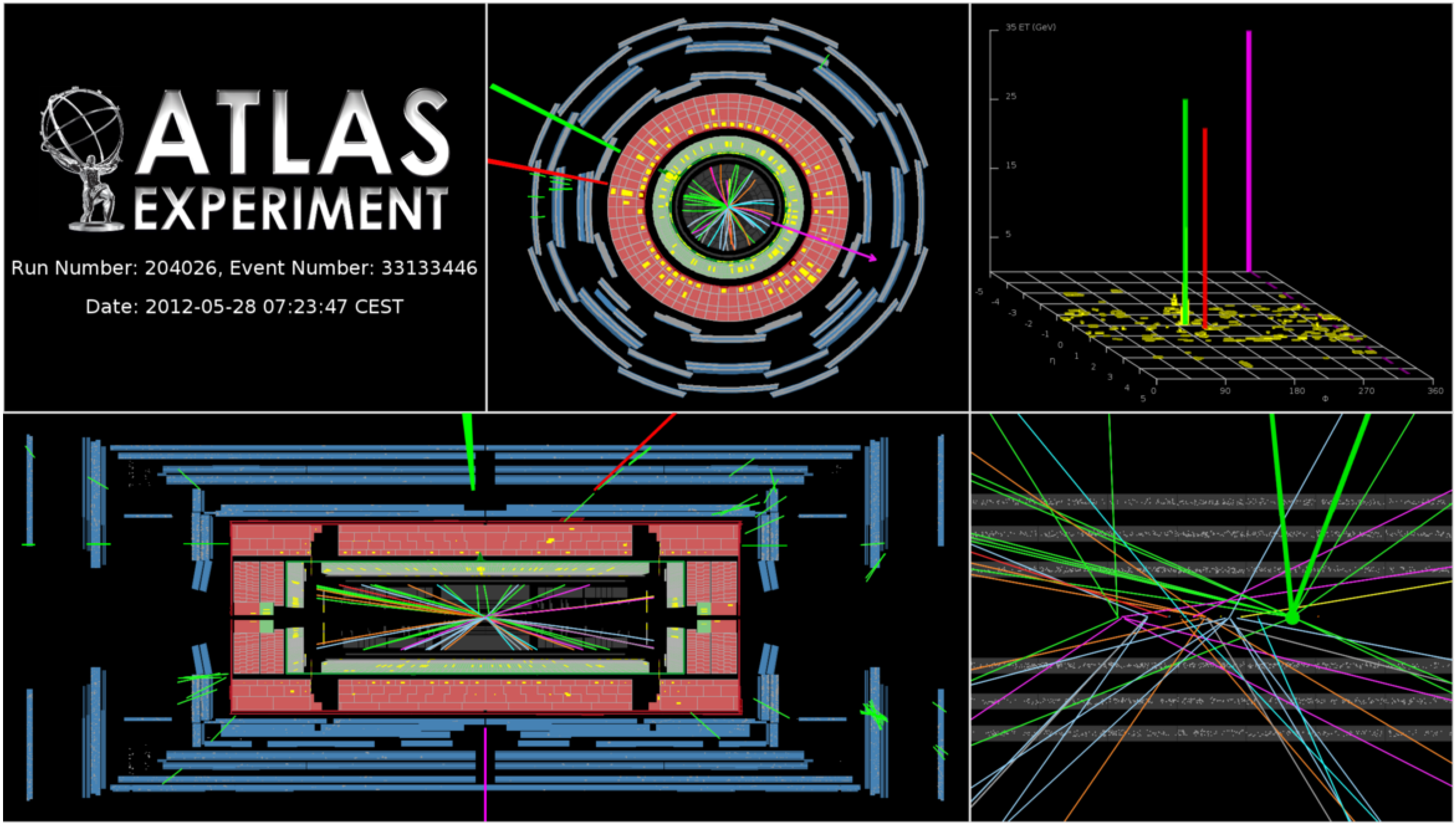
p_T (e,e,μ,μ)= 18.7, 76, 19.6, 7.9 GeV,   m (e^+e^-)= 87.9 GeV, m($\mu^+\mu^-$) =19.6 GeV
12 reconstructed vertices



H→WW(*)→eν μν candidate

$p_{T,e}$ =33 GeV, $p_{T,\mu}$ = 29 GeV, E_{tmiss} = 35 GeV and m_T = 94 GeV

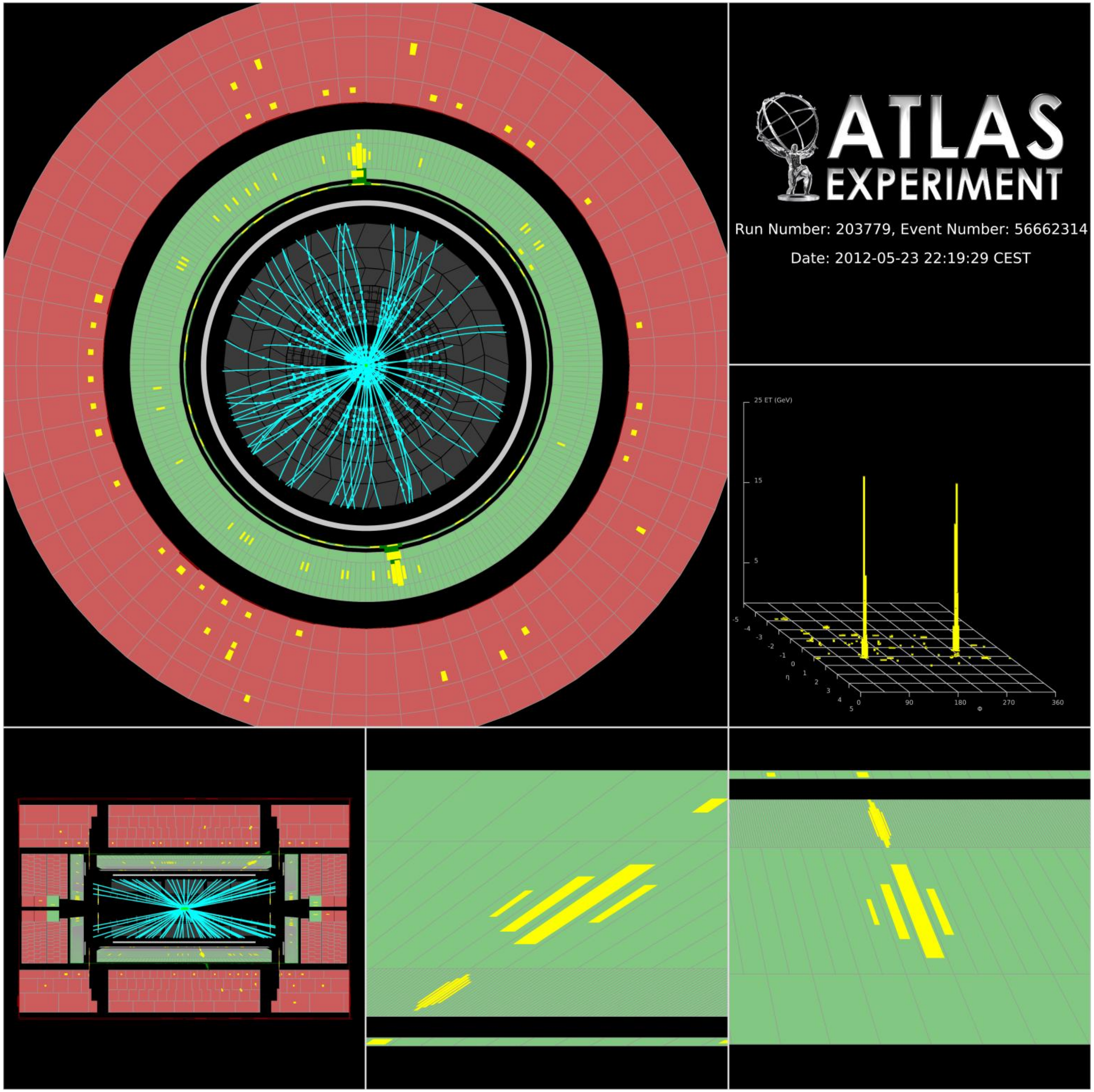
ATLAS-CONF-2012-098



H→γγ candidate with $m_{\gamma\gamma}$= 126.9 GeV

ATLAS-CONF-2012-091

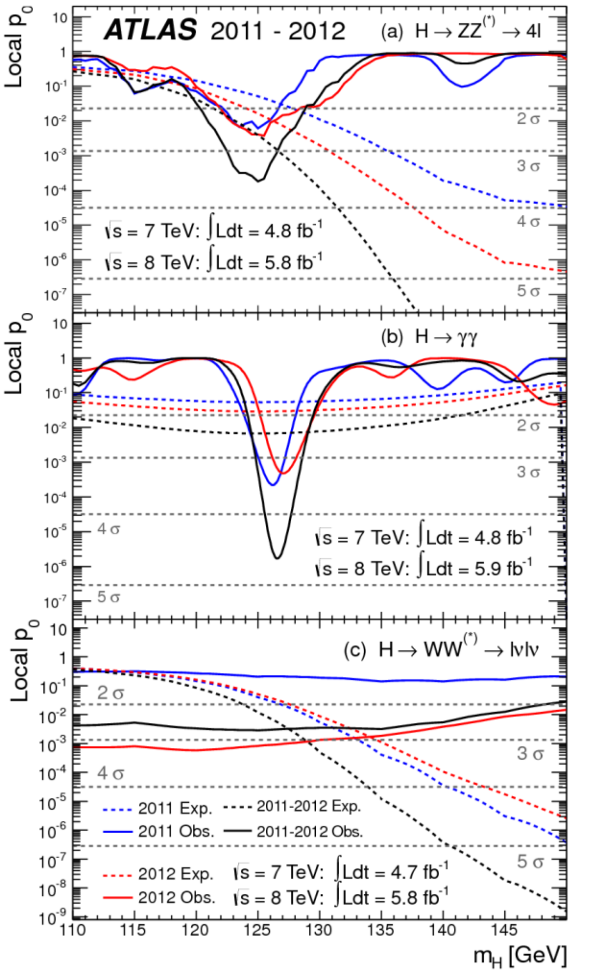
$E_{T,\gamma 1}$ = 62.2 GeV, $\eta_{\gamma 1}$= 0.39
$E_{T,\gamma 2}$ = 55.5 GeV, $\eta_{\gamma 2}$= 1.18



Summary of individual channels entering the combination

To enhance the search sensitivity, the decay modes are subdivided into sub-channels with different signal and background contributions and different systematics:

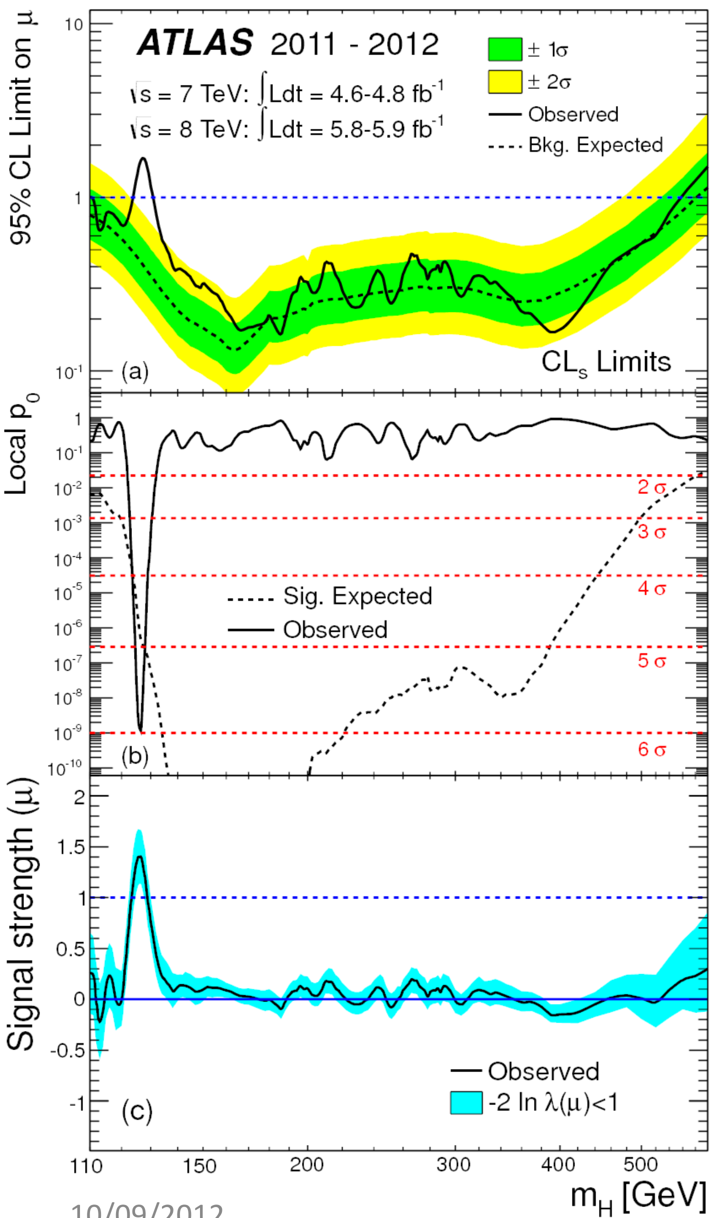
Higgs Boson Decay	Subsequent Decay	Sub-Channels	m_H Range [GeV]	$\int L\,dt$ [fb^{-1}]
		2011 $\sqrt{s}=7$ TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110–600	4.8
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes$ {low, high pile-up}	200–280–600	4.7
	$\ell\ell q\bar{q}$	{b-tagged, untagged}	200–300–600	4.7
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	110–150	4.8
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu/\mu e, \mu\mu\} \otimes$ {0-jet, 1-jet, 2-jet} $\otimes$ {low, high pile-up}	110–200–300–600	4.7
	$\ell\nu q q'$	$\{e, \mu\} \otimes$ {0-jet, 1-jet, 2-jet}	300–600	4.7
$H \to \tau\tau$	$\tau_{\rm lep}\tau_{\rm lep}$	$\{e\mu\} \otimes$ {0-jet} $\oplus \{\ell\ell\} \otimes$ {1-jet, 2-jet, VH}	110–150	4.7
	$\tau_{\rm lep}\tau_{\rm had}$	$\{e, \mu\} \otimes$ {0-jet} $\otimes \{E_T^{\rm miss} < 20$ GeV, $E_T^{\rm miss} \geq 20$ GeV$\}$ $\oplus \{e, \mu\} \otimes$ {1-jet} $\oplus \{\ell\} \otimes$ {2-jet}	110–150	4.7
	$\tau_{\rm had}\tau_{\rm had}$	{1-jet}	110–150	4.7
$VH \to Vbb$	$Z \to \nu\nu$	$E_T^{\rm miss} \in \{120-160, 160-200, \geq 200$ GeV$\}$	110–130	4.6
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110–130	4.7
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110–130	4.7
		2012 $\sqrt{s}=8$ TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110–600	5.8
$H \to \gamma\gamma$	–	10 categories $\{p_{Tt} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	110–150	5.9
$H \to WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes$ {0-jet, 1-jet, 2-jet}	110–200	5.8

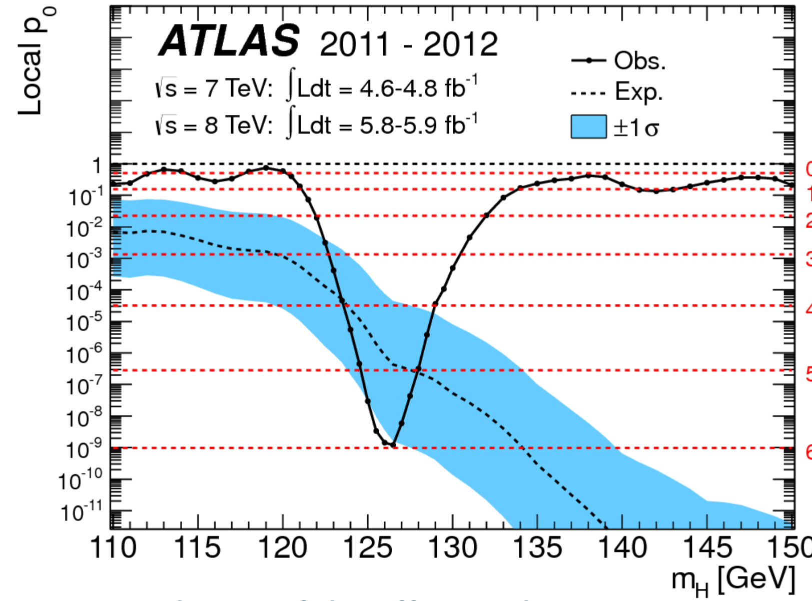


The parameter of interest is the global signal strength factor μ, which acts as a scale factor on the total number of SM Higgs events: μ=0 – backgr. only hypothesis, μ=1 – SM Higgs in addition to background. Hypothesized values of signal strength were tested based on the profile likelihood ratio (G.Cowan et al, 2011)

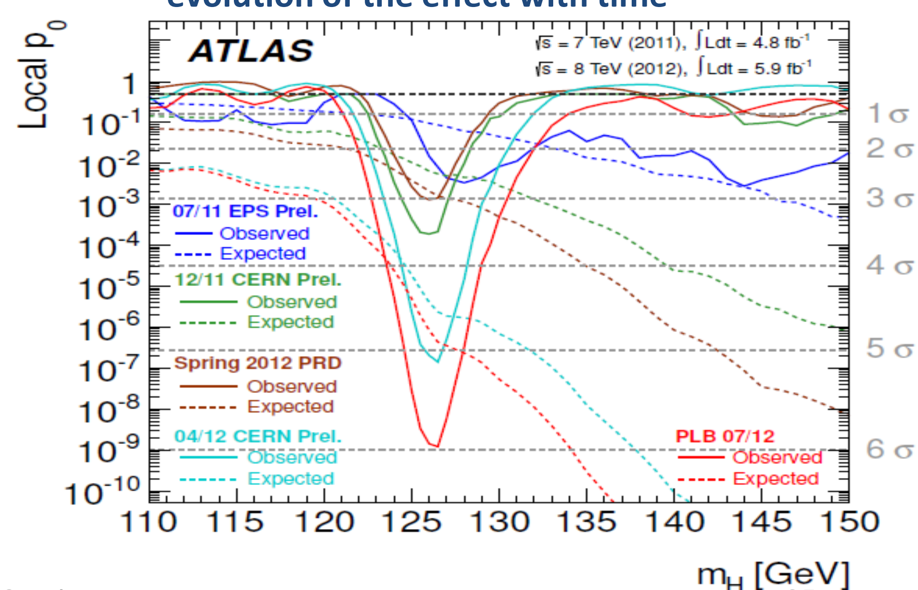
p_0 – probability of the background fluctuation (excess significance)

Combined search results





evolution of the effect with time



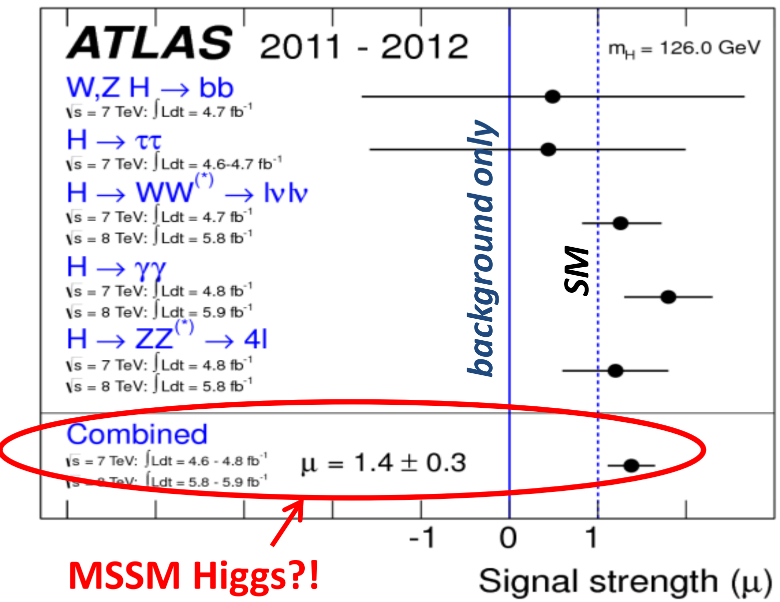
ATLAS upgrade motivation

The European Strategy for Particle Physics - Krakow, 10-12 September 2012

ATLAS is interested in two domains of LHC upgrade:

- a luminosity upgrade (HL-LHC), with instantaneous luminosity up to $L \sim 5\times10^{34}$ cm^{-2} s^{-1}

- an energy upgrade (HE-LHC), with a center of mass energy $\sqrt{s}$ = 30 TeV



Once the Higgs-like boson is discovered we will measure the physics properties of this object:

- its mass,

- set an upper limit to its width,

- measure the couplings to W and Z, and to fermions.

With integrated luminosities as large as 300fb^{-1} at $\sqrt{s}$~13 TeV:

- accurate measurements of couplings,

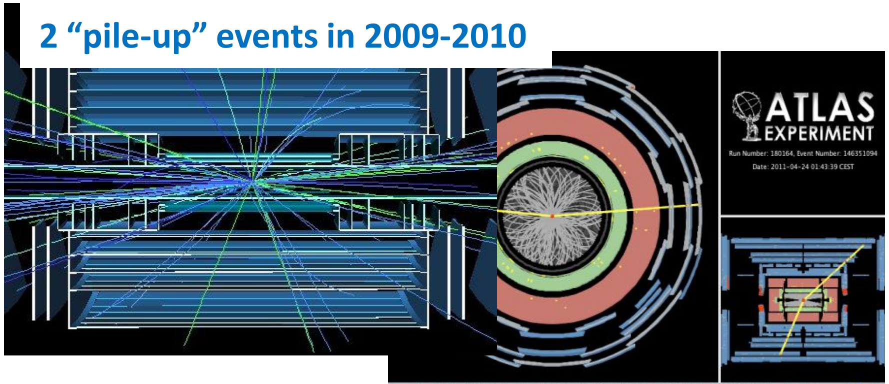
- rare decays of Higgs boson, such as H→μμ and H→Zγ ,

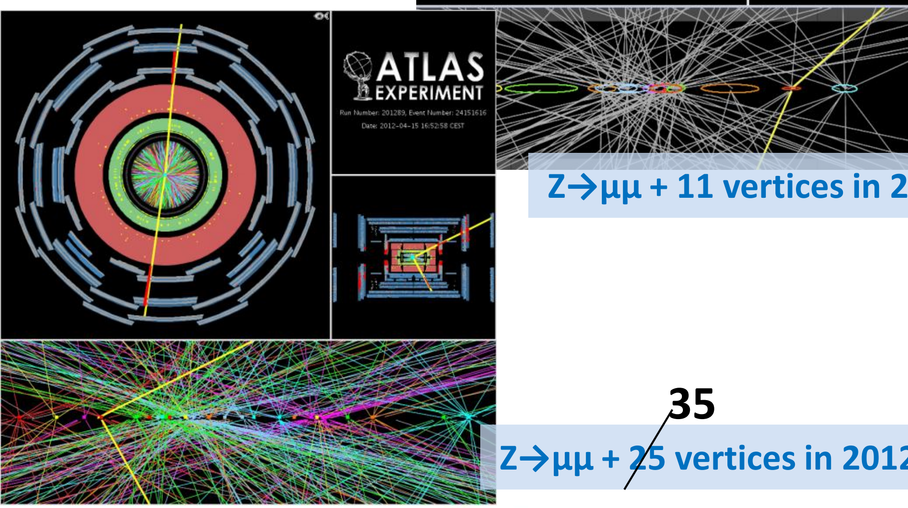
- study of the VV scattering (V=W,Z)

ATLAS will continue the search for new phenomena or new particles that are predicted by alternative models and theories.

Upgrade schedule

2 “pile-up” events in 2009-2010

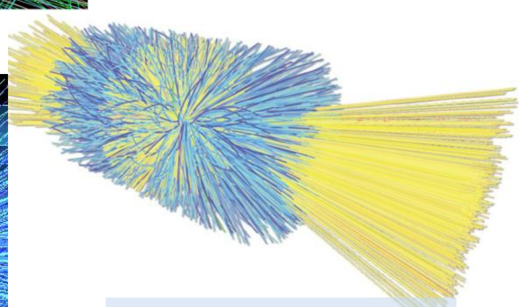


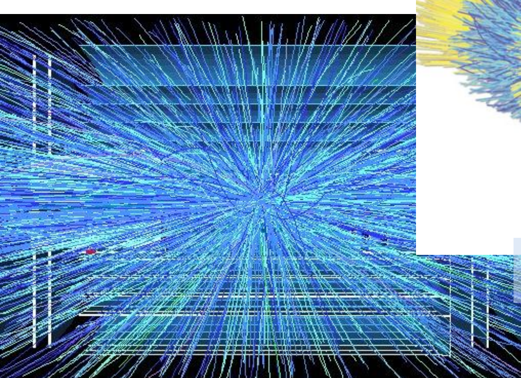


Z→μμ + 11 vertices in 2011

Z→μμ + 25 vertices in 2012

35



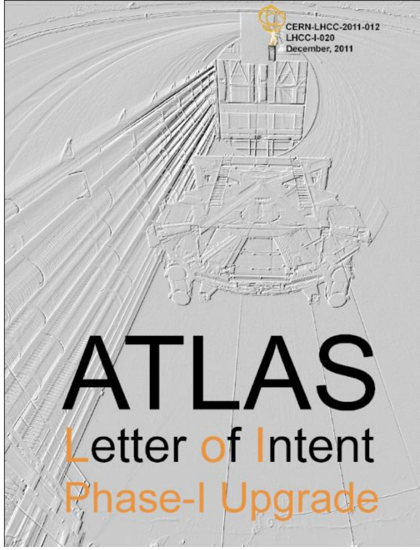


200 vertices in 2022

Expected Luminosities LHC → HL-LHC

		∫Ldt
2009	LHC startup, √ s = 900 GeV	
2010–2012	√s=7~8 TeV, L=6x10^{33} cm^{-2} s^{-1} , 50ns	~20 fb^{-1}
2013	Go to design energy, nominal luminosity	
2014–2017	√s=13~14 TeV, L~1x10^{34} cm-2 s-1, 25ns	~100 fb^{-1}
2018	LHC Phase-1 upgrade to full design luminosity	
2019–2021	√s=14 TeV, L~2x10^{34} cm^{-2} s^{-1}, 25ns	~300 fb^{-1}
2022	HL-LHC Phase-2 upgrade	
2023 … 2030?	√s=14 TeV, L=5x10^{34} cm^{-2} s^{-1}, luminosity leveling	~3000 fb^{-1}

ATLAS upgrades



ATLAS Letter of Intent for Phase-I Upgrade as been published early this year in CERN-LHCC-2011-012:
https://cdsweb.cern.ch/record/1402470/files/LHCC-I-020.pdf

32.62 MCHF
the total Core cost

Muon system – a new tracking and trigger device in the inner layer of the forward spectrometer, that will not only provide a sharper trigger threshold, but also greatly improve the tracking performance under the higher backgrounds expected with the LHC upgrades (e.g. 60 kHz for L1MU20 trigger @ 14TeV @ $3\cdot10^{34}cm^{-2}s^{-1}$).

- Baseline (approved) solution: equip the Small Wheels with sTGC & MicroMegas chambers
- MAMMA's R&D is ongoing at CERN (successful test-beam in June'2012)

Calorimeters – a new trigger read-out boards will be implemented in the electromagnetic and forward calorimeters to exploit the longitudinal sampling of the calorimeter as well as including a higher trigger granularity comparable to that presently available in the full calorimeter read-out, which will lead to an improvement in rejecting fake electron triggers (e.g. 80 kHz - the rate for single isolated EM clusters above 23 GeV, projected to $2\cdot10^{34}cm^{-2}s^{-1}$).

Also,
- additional ATLAS Forward Proton (**AFP**) detector at the distance of ~200m
- Fast TracKing trigger (**FTK**) – a pipeline electronics system for the fast track processing in Si-detectors at L1-level
- Trigger/DAQ upgrades, etc.

ATLAS LoI for Phase II should be ready by the end of 2012

Conclusions

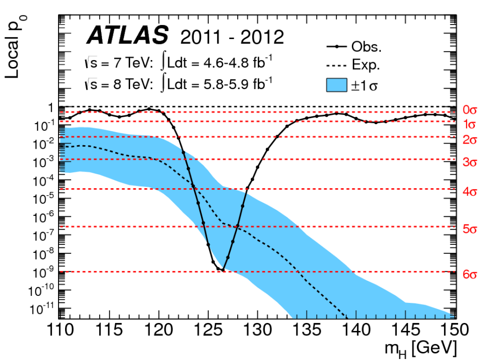
- **2012 is another exciting year for the LHC machine and the experiments**

- **the SM Higgs boson is excluded at 95% CL in a wide mass range of 111 GeV – 559 GeV, except for a narrow window around 126 GeV**

- **very reliable candidate for the Higgs boson is observed by the ATLAS and the CMS Collaborations (well above 5σ “discovery threshold”) - but hunting is not over yet!**

- **the strategy of the future analyses and detector development is shaping up**

- **more news inevitably to come, stay tuned**



V.Rubakov: “A particle physics becomes the experimental science [again]”

– what a great time!

Hurry up - the trophies are available now at the ATLAS secretariat…