ハドロンコライダーによる エネルギーフロンティアの物理

–LHCの現状とSMの物理–

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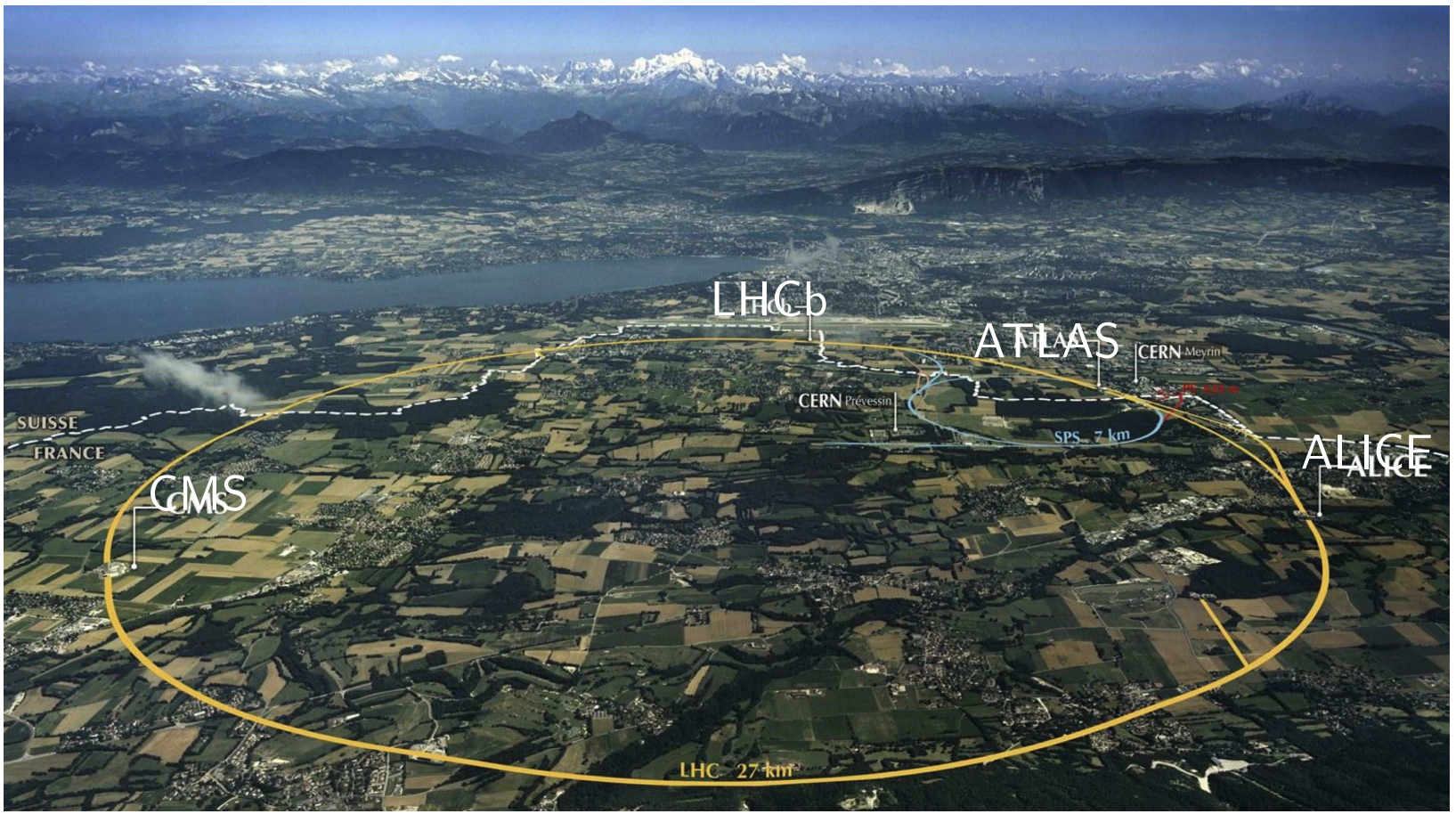
- LHC
- ATLAS detector and performance
- Standard Model measurements
- Summary

biased to ATLAS results

Large Hadron Collider at CERN

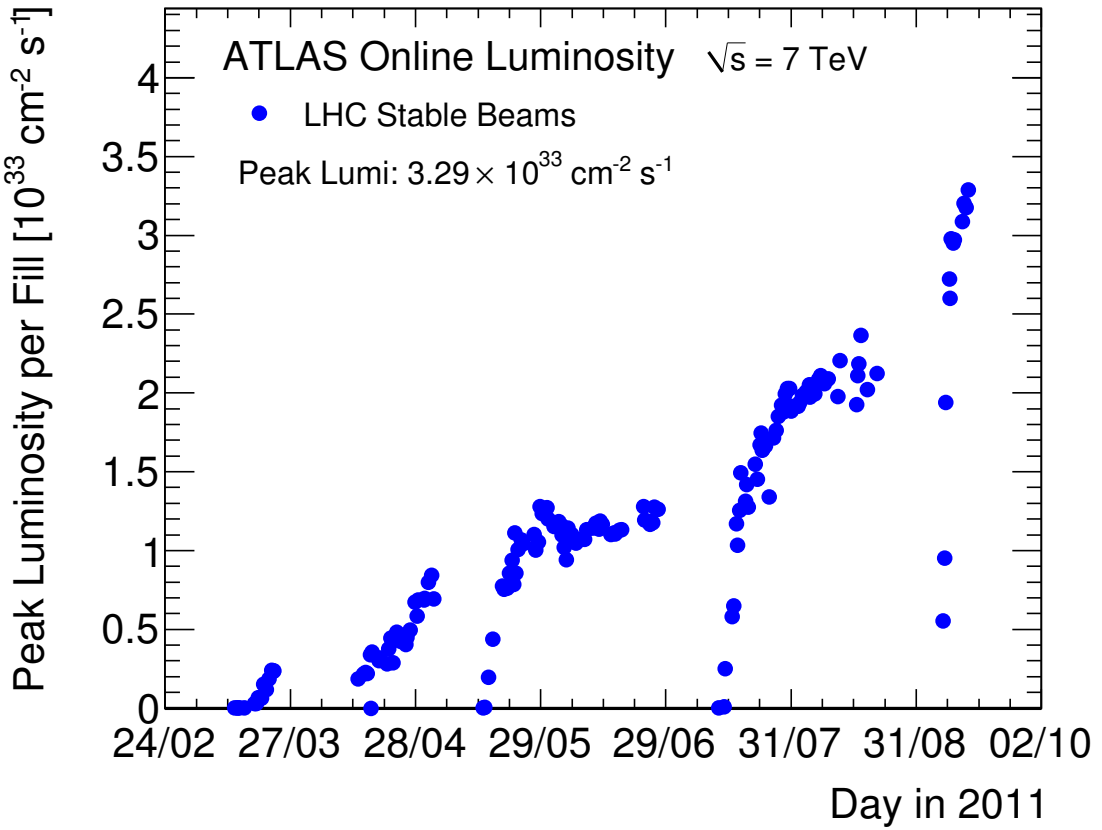
- The largest accelerator with the highest energy
  - circumference 26.7 km
  - proton-proton collisions at 7 TeV CMS energy



Large Hadron Collider
2011 Instantaneous luminosity

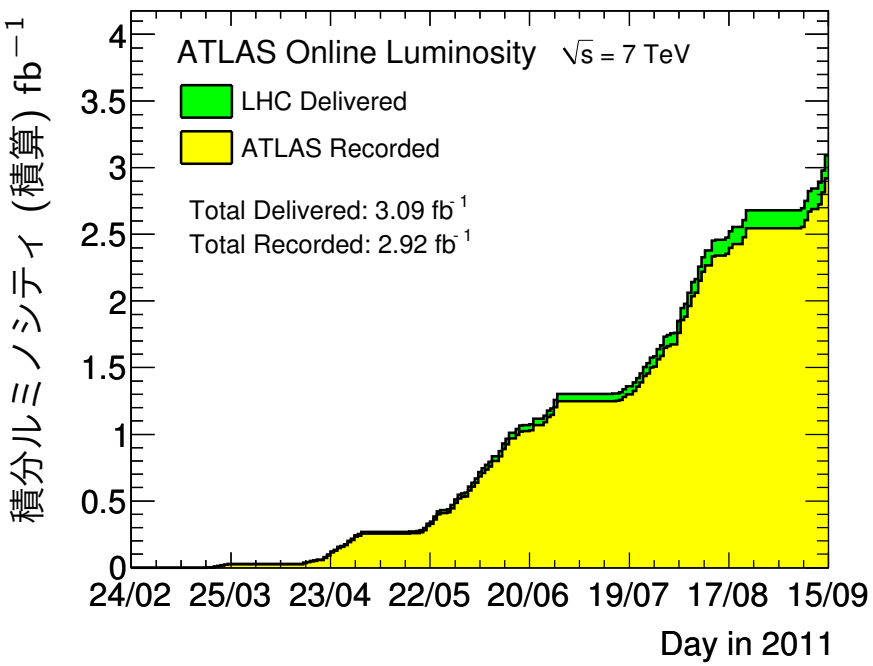
$$\mathcal{L} \propto \frac{n_b N_{bunch1} N_{bunch2}}{\beta^* \epsilon_n}$$

- Physics runs re-established with 75 ns bunch spacing then switched to 50 ns
- Increased number of bunches to 1380 by end of June
- Reduced ϵ_n from [2.5 - 3.0] μm to 2.0 μm in July - August
- Reduced β^* from 1.5 m to 1 m in September



Large Hadron Collider
2011 Integrated luminosity

- 1 fb^{-1} of data recorded by 17 June
- by today ...
  - 3.09 fb^{-1} delivered
  - 2.92 fb^{-1} recorded by ATLAS
  - best in a day: 116.56 pb^{-1}
  - best in 7 days: 499.45 pb^{-1}

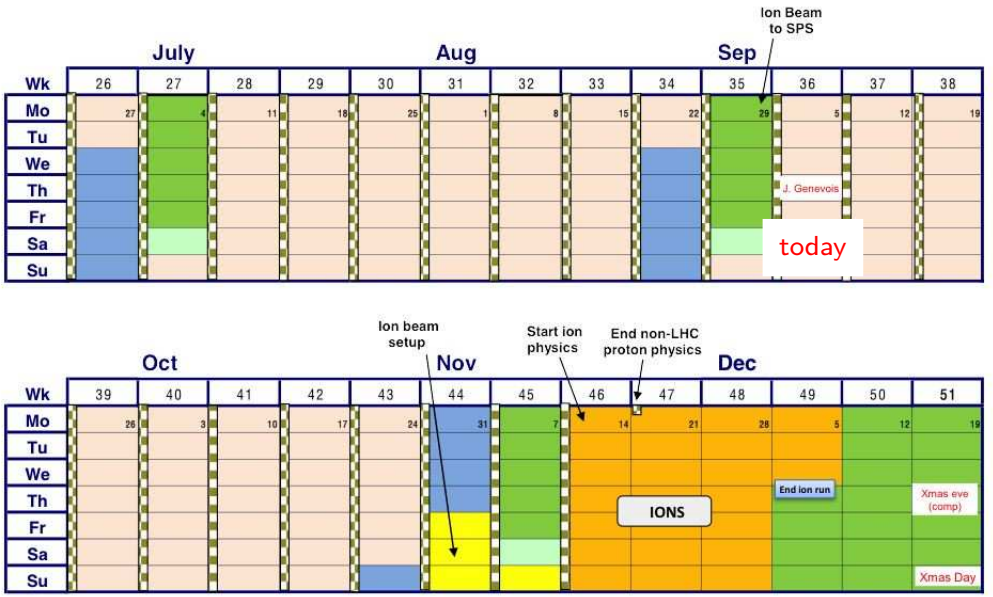


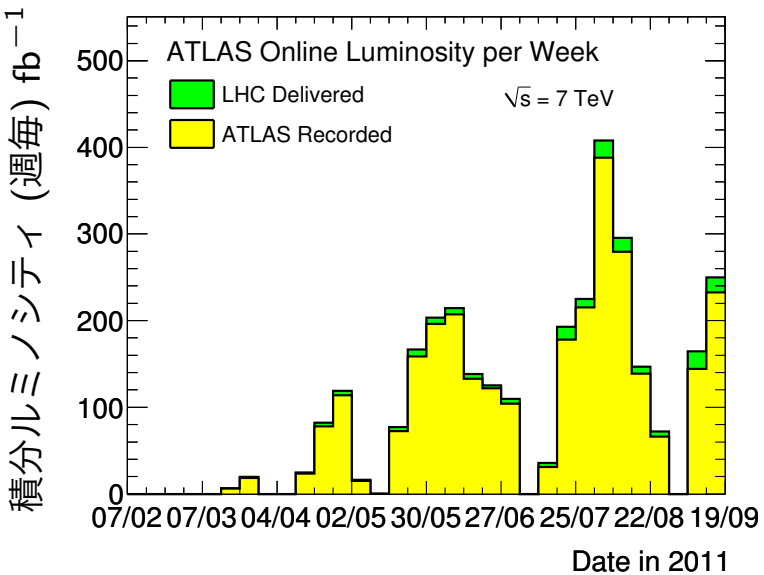
parameter	2011	design
beam energy [TeV]	3.5	7
bunch spacing [ns]	50	25
number of bunches	1380	2808
ϵ_n [μm]	2.0	3.75
β^* [m]	1.0	0.55
bunch intensity [10^{11}]	1.2	1.15
peak luminosity [$cm^{-2}s^{-1}$]	3.29 x 10^{33}	1 x 10^{34}
stored energy [MJ]	~100	362

Large Hadron Collider
2011 Operational problems

- SEU (single event upset)
  - Radiation induced malfunction of QPS, Cryogenics, Collimators, Power Converters...
  - Dependent on total intensity and luminosity
  - Relocation of electronics and additional shielding planned in Christmas technical stop. In the meantime - victim of our own success

Large Hadron Collider
2011 Schedule





- ~40 days left for *pp* runs in 2011

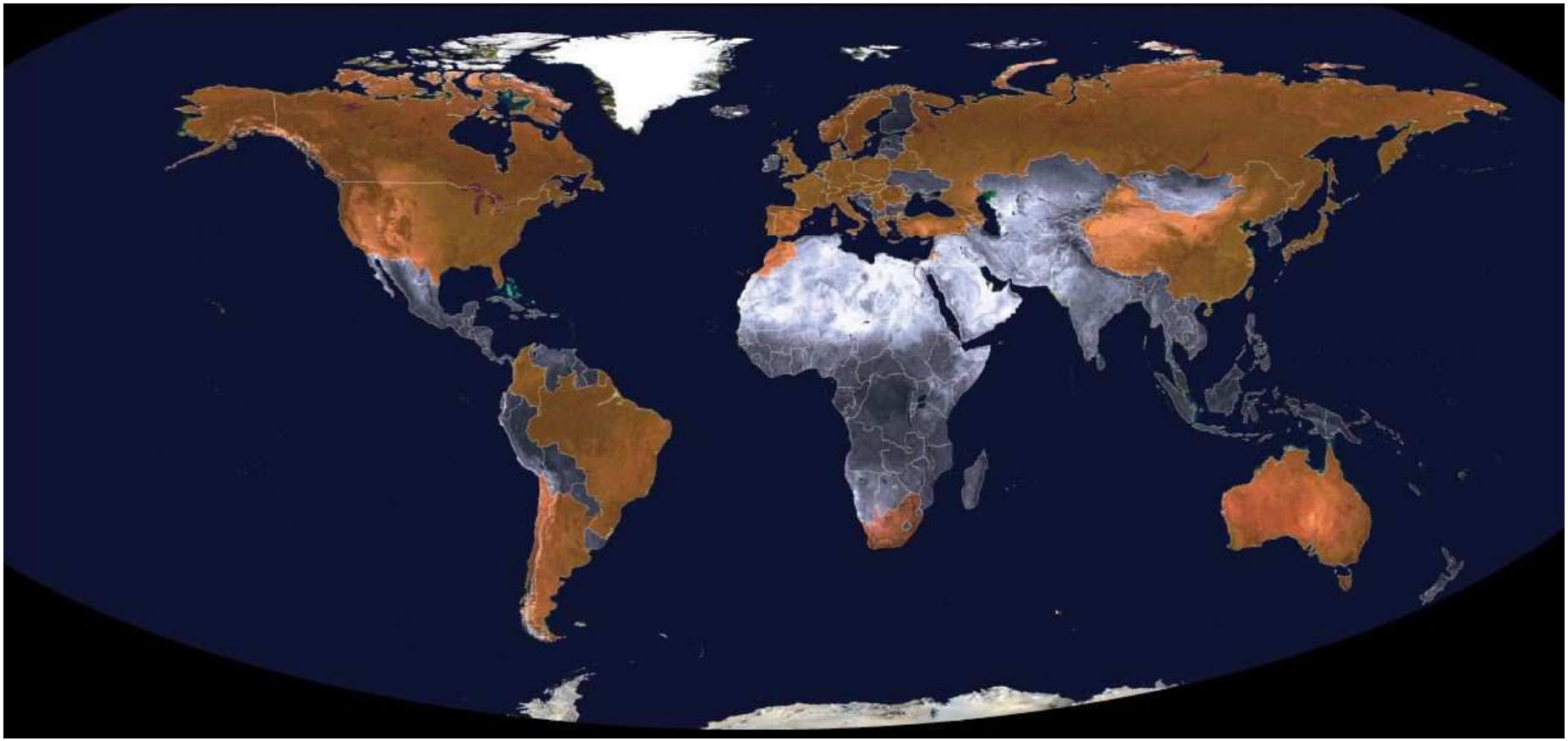
$$\mathcal{L} \propto \frac{n_b N_{bunch1} N_{bunch2}}{\beta^* \epsilon_n}$$

- Increase bunch intensity up to 1.55 x 10^{11} (maximum) [$\mathcal{L}$ x 1.7]
- Christmas stop
- Chamonix workshop (6-10 Feb.) to decide run plan in 2012

✓テラスケールの物理を探るLHC加速器は順調に動いています
次はATLAS検出器とその性能について

ATLAS collaboration

- 38 Countries
- 174 Institutions
- 3000 Scientists (1000 Students)



- $\sim$ 150 participants from Japan ($\sim$ 80 students)

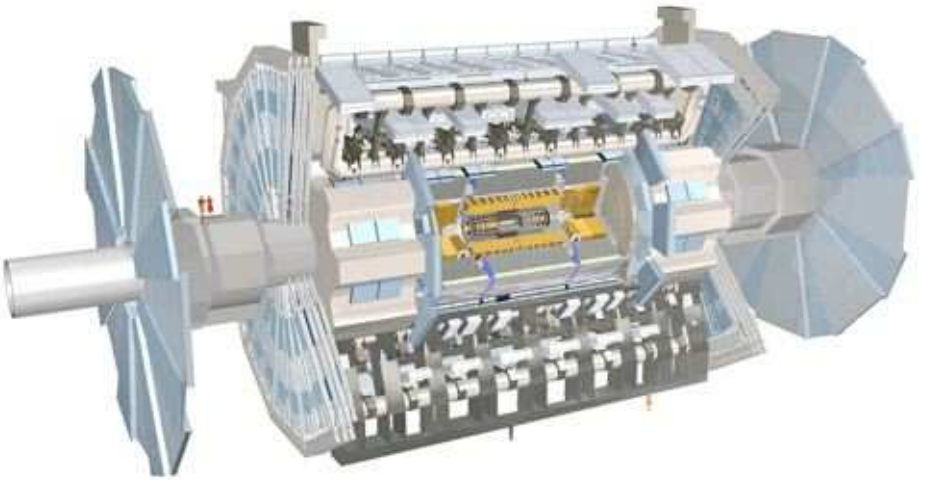
Hiroshima IT, KEK, Kobe, Kyoto, Kyoto UE, Nagasaki IAS, Nagoya, Okayama, Osaka, Shinshu, Tokyo ICEPP, Tokyo MU, Tokyo Tech, Tsukuba, Waseda, (Kyushu)

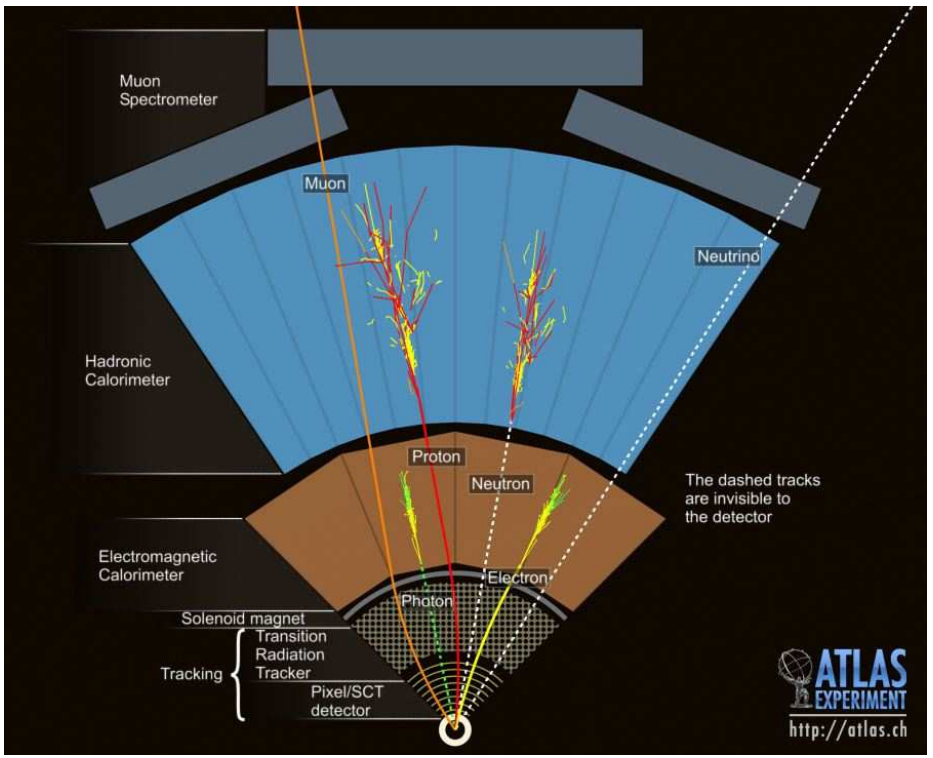
ATLAS

Detector: Exploring a new territory with a precision instrument is the key to discovery

- Length: ∼45 m
- Diameter: ∼22 m
- Weight: ∼7,000 tons

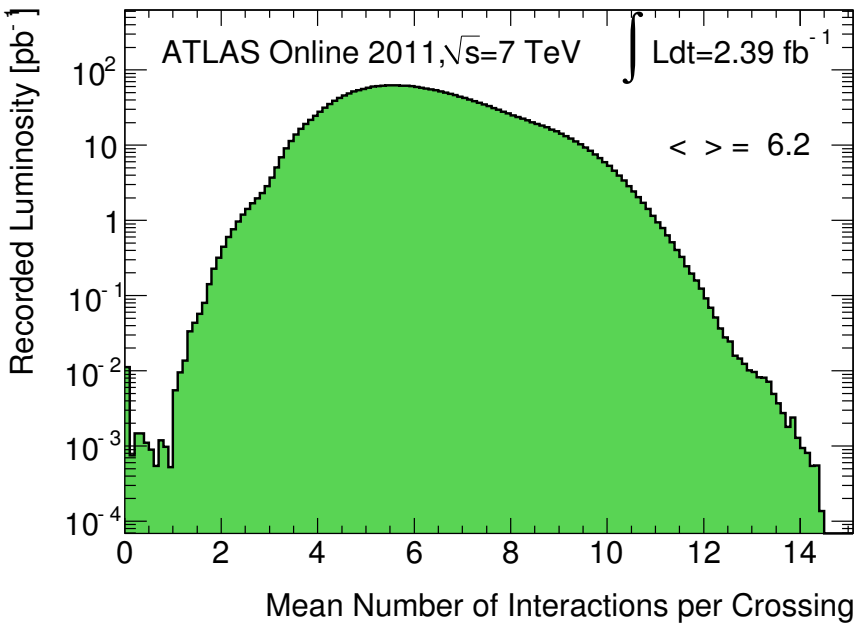
- 2 T solenoid[a] and air-core toroids
- Tracker:$|\eta|$ <2.5 [$0.05 \times p_T \oplus 1\%$]
  - silicon tracker (pixel + strip)
  - transition radiation tracker
- Calorimeter:$|\eta|$ <4.9
  - EM: lead/LAr [$10/\sqrt{E} \oplus 0.7\%$]
  - hadron: Fe/scint., copper/LAr [$50/\sqrt{E} \oplus 3\%$]
- Muon system:$|\eta|$ <2.7 [13% at 1 TeV]
  - drift tube, cathode strip chamber
  - thin-gap chamber, resistive plate chamber



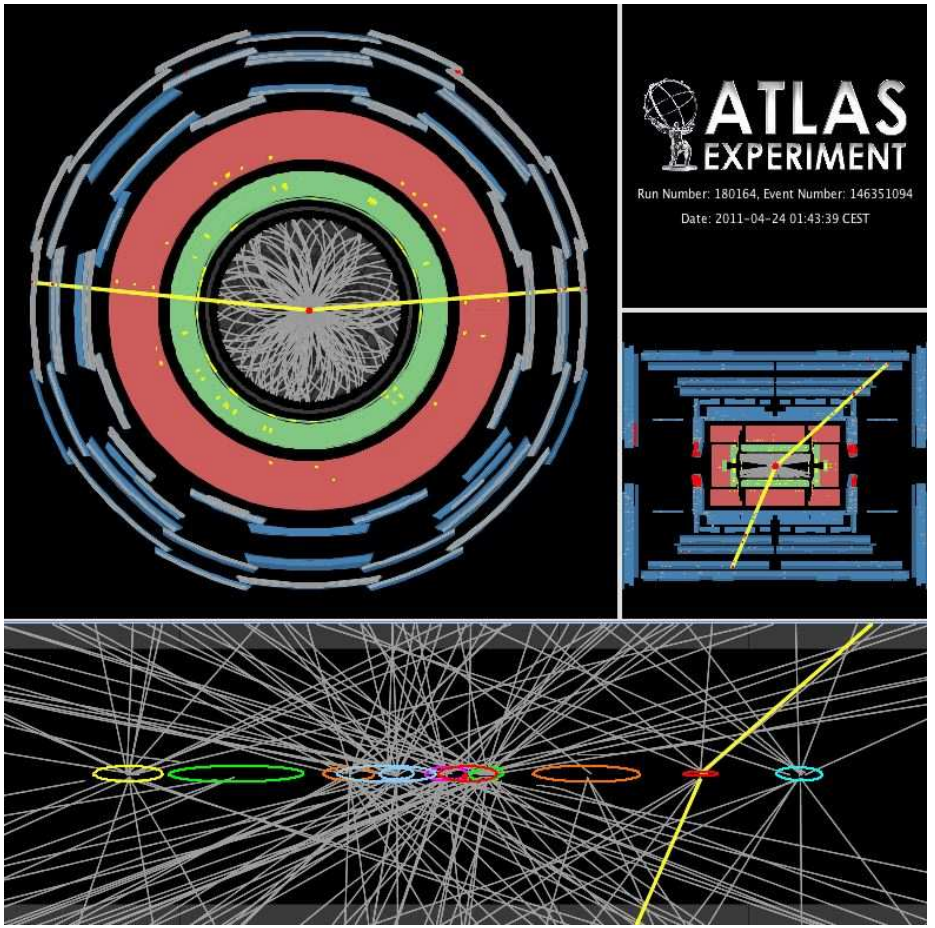


[a] major contribution from Japan

Event pile-up in 2011



- distribution of $< \mu >$ in simulation re-weighted to reproduce data

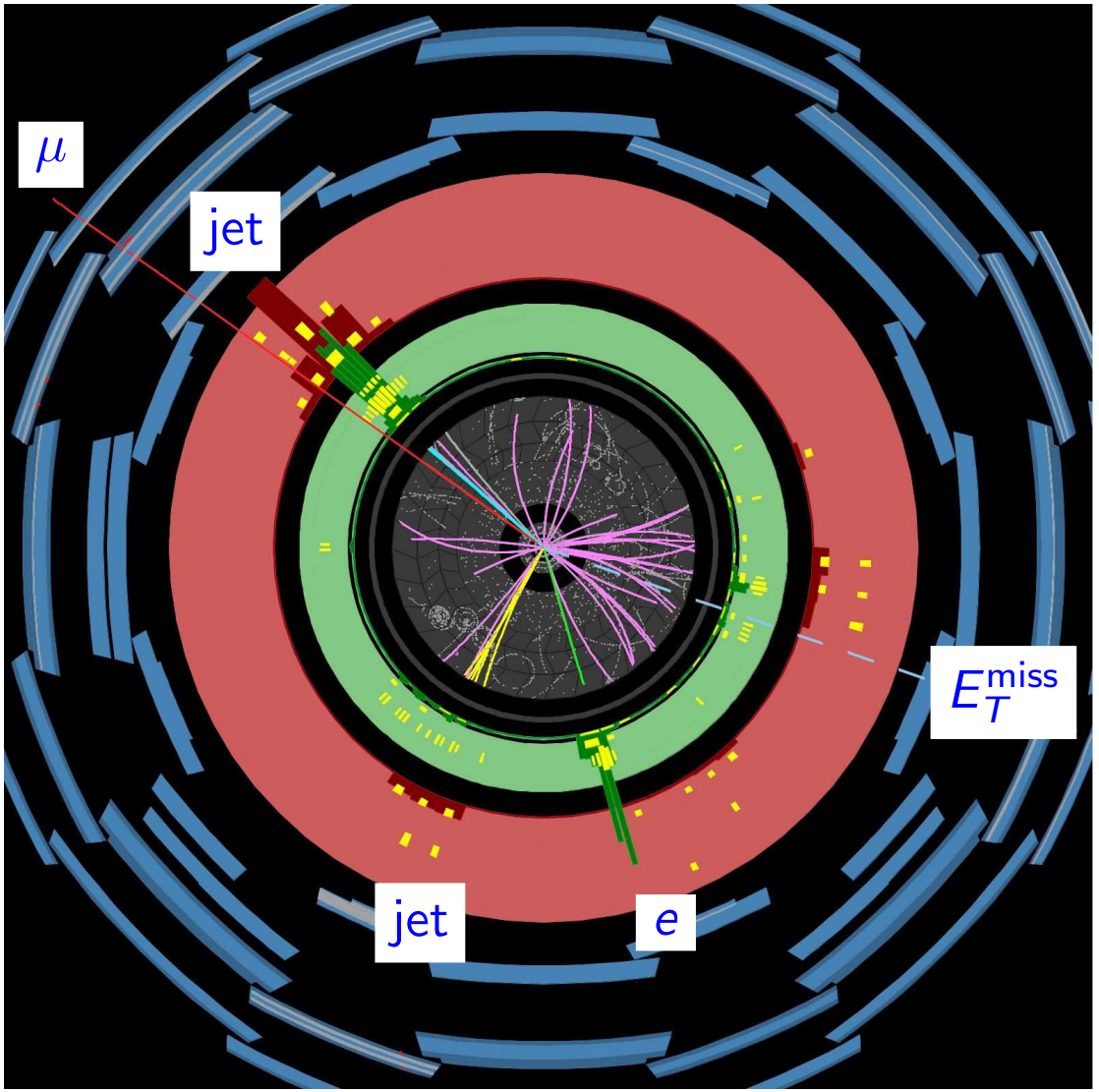


$Z \rightarrow \mu\mu$ event with 11 primary vertices

- need to study effects on
  - vertexing, lepton isolation, jet energy scale, E_T^{miss}, CPU time/event size

Detector performance

- *Luminosity measurement*
- *Object reconstruction*
  - e/μ
  - jet
  - neutrino – E_T^{miss}

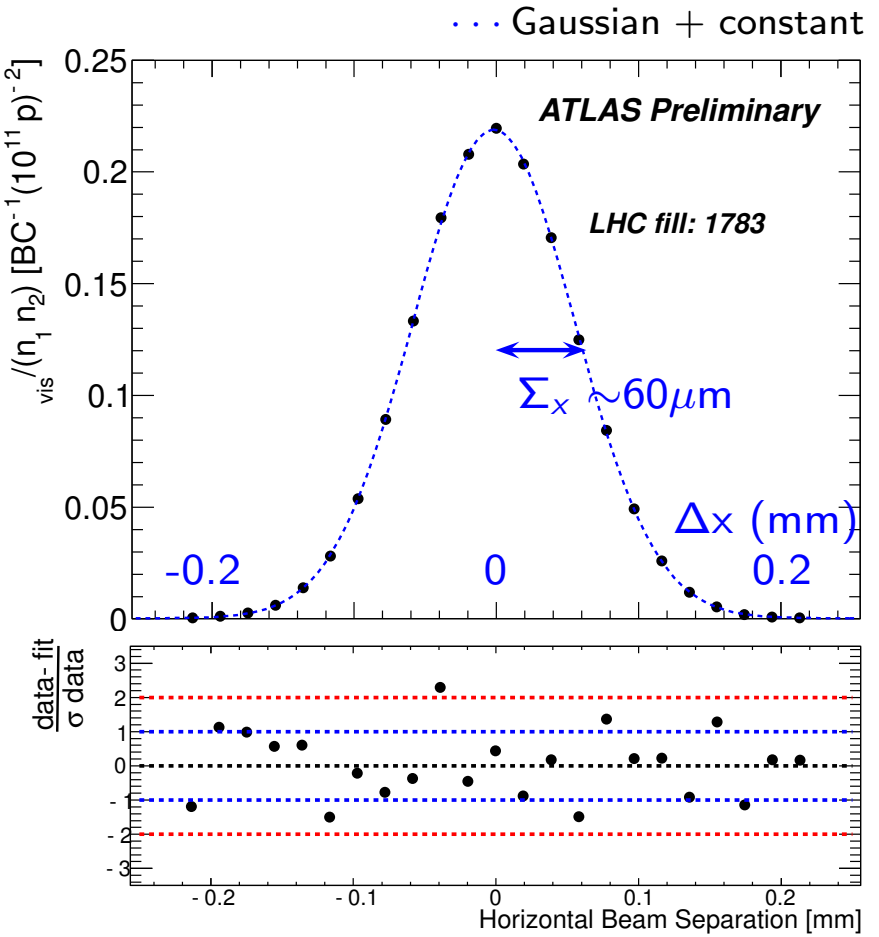


Luminosity measurement
ATLAS

$$\mathcal{L} = n_b f_{\mathrm{LHC}} \frac{\mu_{\mathrm{vis.}}}{\sigma_{\mathrm{vis.}}} = n_b f_{\mathrm{LHC}} \frac{N_1 N_2}{2\pi \Sigma_x \Sigma_y}$$

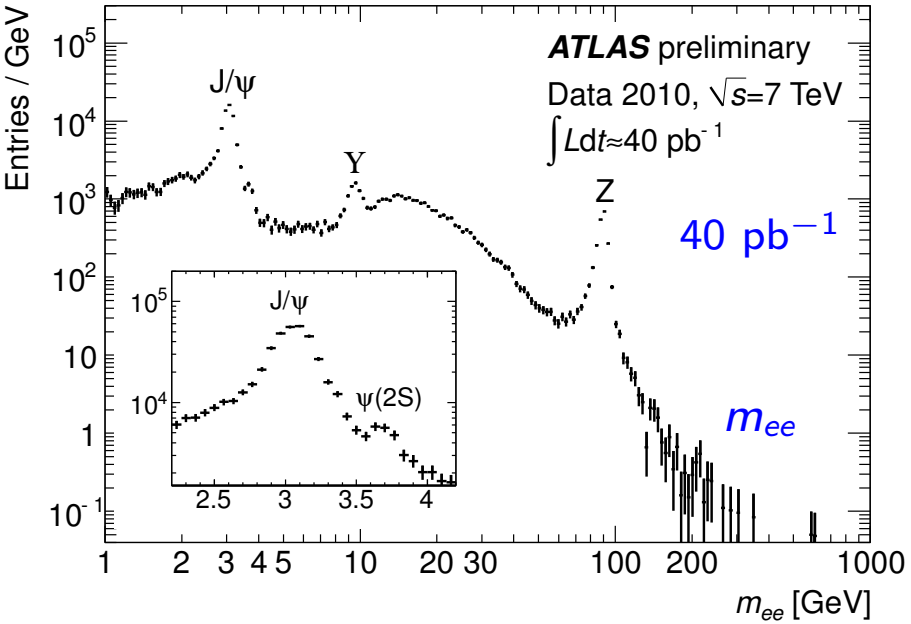
n_b: number of colliding bunch pairs
f_{LHC}: LHC revolution frequency = 11245.5 Hz
$\mu_{\mathrm{vis.}}$: measured from detector rates
$\sigma_{\mathrm{vis.}} = \epsilon \sigma_{\mathrm{inel.}}$
N_1, N_2: number of protons in bunch
Σ_x, Σ_y: profiles of the colliding beams

- van der Meer scan for $\sigma_{\mathrm{vis.}}$
- $N_{1,2}$ from
  - DC Current Transformer (CT): total current
  - Fast Beam CT: fraction of current in each bunch
- $\Sigma_{x,y}$ from van der Meer scans
- $\mu_{\mathrm{vis.}}$ by LUCID, BCM, Calorimeter
- 2011 $\mathcal{L}$ uncertainty: $\pm$ 3.7%
  - $N_{1,2}$ measurement: $\pm$ 3.0%

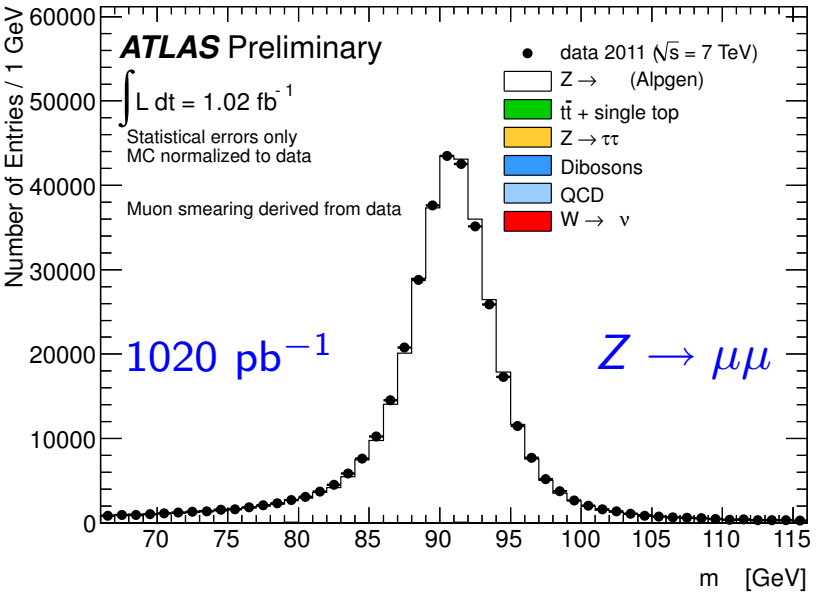


Lepton performance

- Re-discovery of known resonances in 2010
  - J/ψ, Υ, Z

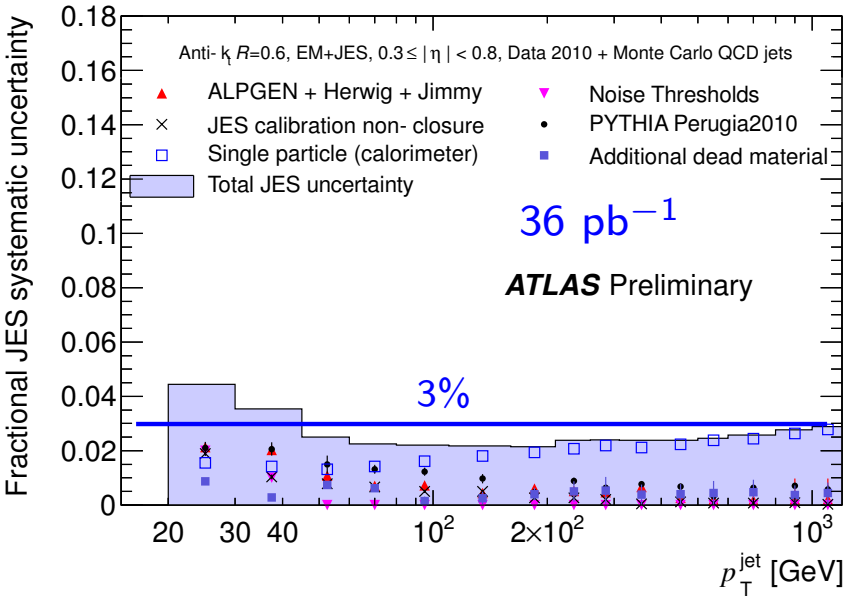


- performance study with $Z \rightarrow ll$
  - $\sigma(m_Z) \sim 1.8/2.5$ GeV for e/μ
  - efficiency with high precision: $\sigma(\epsilon) \sim \pm$ 1%
  - electron energy scale with high-precision: 0.3–1.6% in $|\eta| <$2.47
  - $\sigma(p_T)/p_T =$ 13% at 1 TeV in barrel region



Jet/missing E_T performance

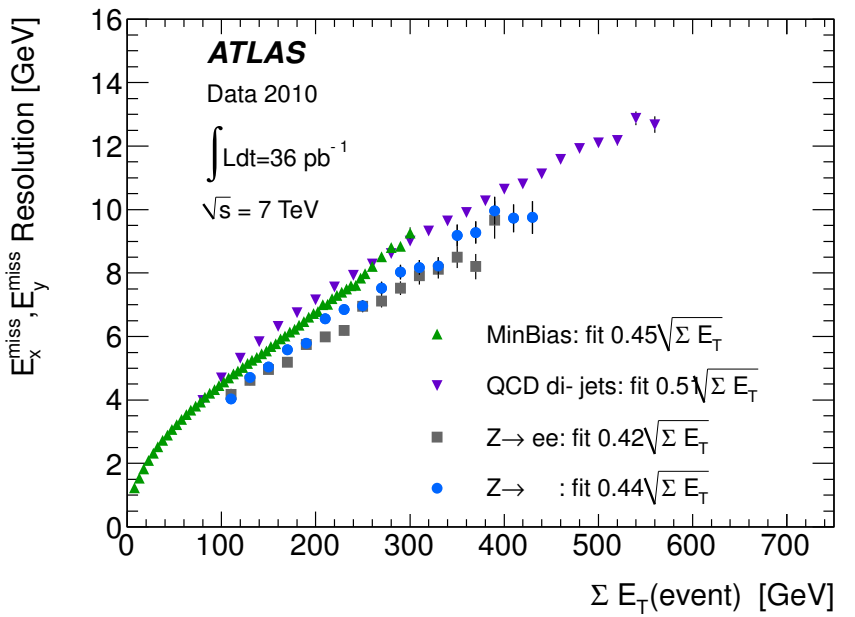
- Jets reconstructed by anti-k_T algorithm
- Jet Energy Scale uncertainty
  - $\sim$ 3% in $|\eta| < 0.8$ (central)
- Additional uncertainty due to pile-up
  - $20 < p_T^{jet} < 50$ GeV: 5% in central
  - $50 < p_T^{jet} < 100$ GeV: 2% in central



- E_T^{miss} resolution with $Z \rightarrow ll$, QCD di-jets, minimum bias (MB)
- Fit resolution curve with $\sigma = k\sqrt{E_T}$

	k(data)	k(MC)
$Z \rightarrow ee$	0.42	0.42
QCD di-jets	0.51	0.50
MB	0.45	0.48

  - MB difference: probably due to imperfect modelling of soft particle activity



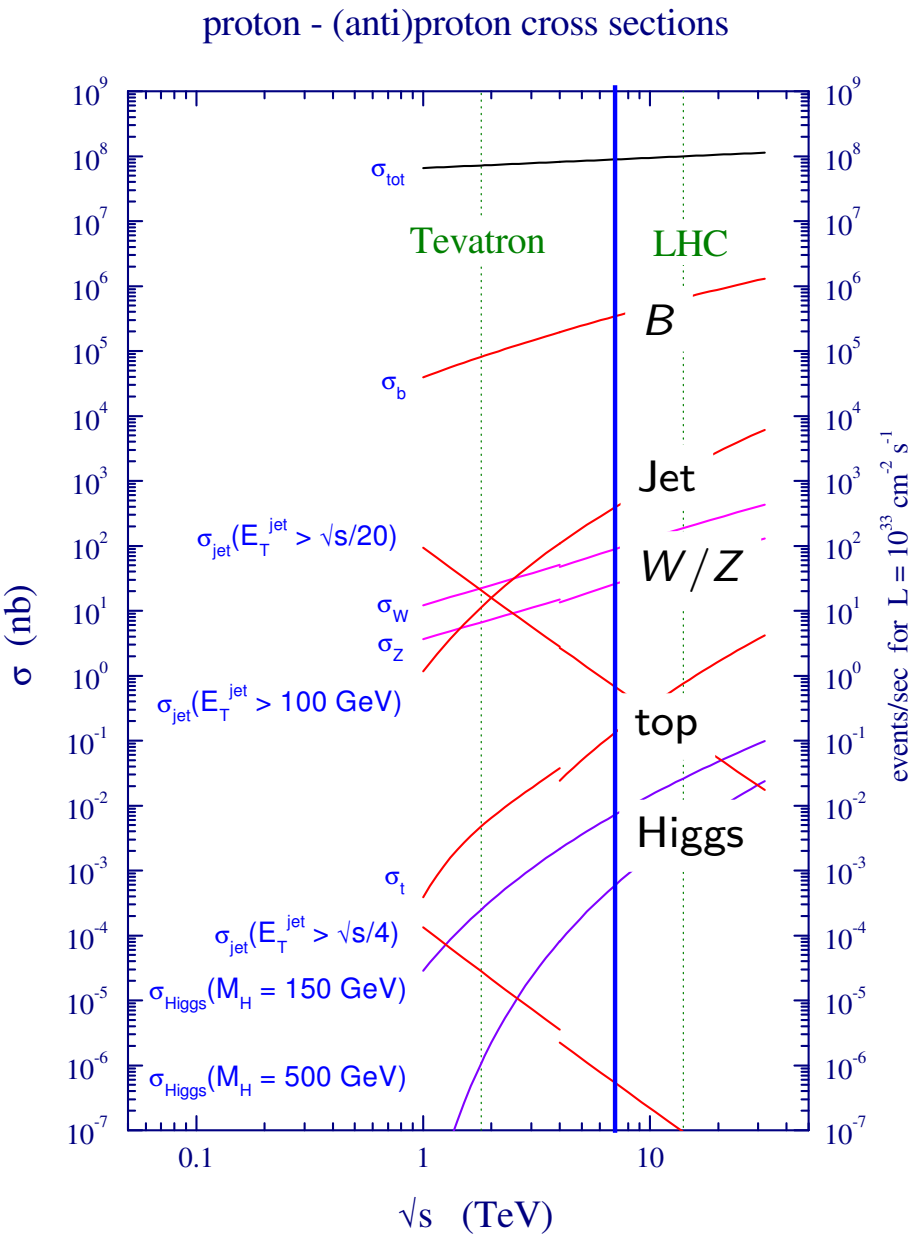
✓テラスケールの物理を探るLHC加速器は順調に動いています

✓検出器も順調に稼働しており、性能評価も進んでいます

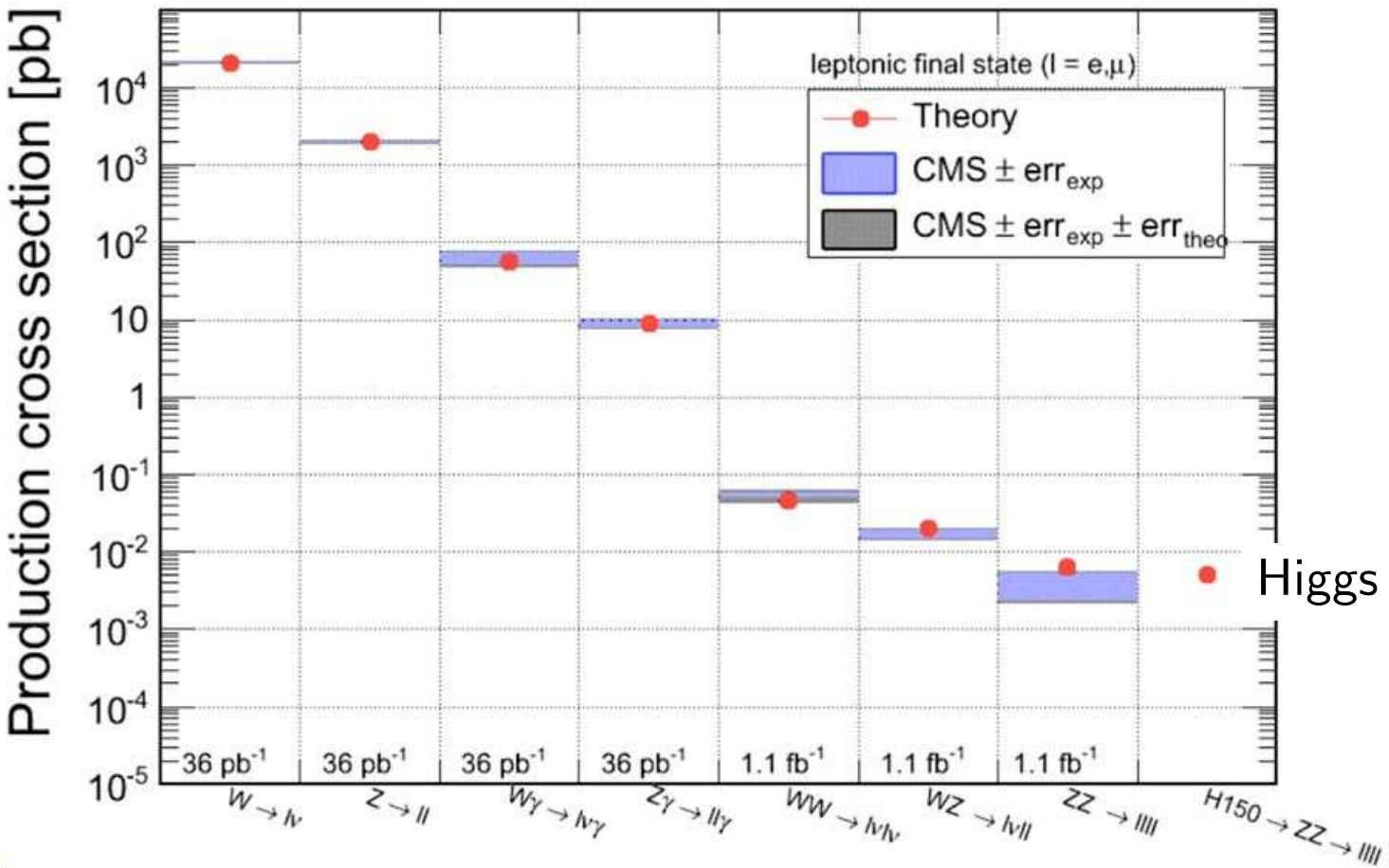
次は標準模型の測定について

Physics programme

- 発見 = 測定結果 − 標準模型
- $L = 10^{33}$ cm^{-2}s^{-1} に於いて
  - Heavy flavours: $\sim$ 100 kHz
  - Jets ($p_T = 250$ GeV): $\sim$ 100 Hz
  - $W \to l\nu$: $\sim$ 10 Hz
  - $t\bar{t}$: $\sim$ 0.1 Hz
- ex. Higgs 粒子探索には $<1/10^{10}$ のselection が必要
  - Background の理解が重要

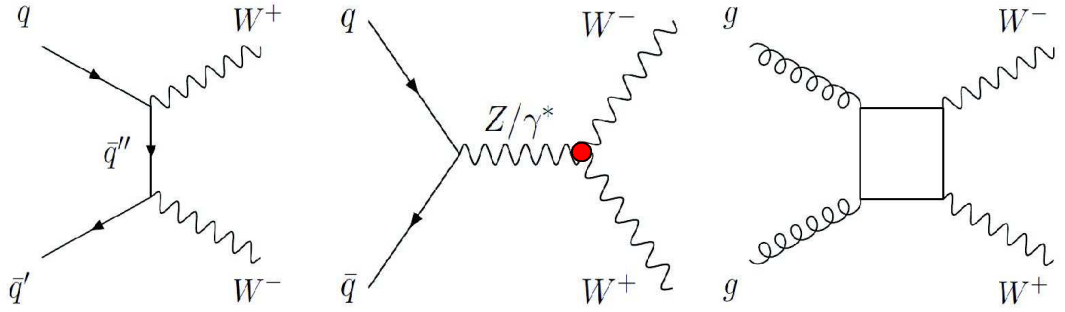


Electroweak boson productions



- $WW/WZ/ZZ$ production
  - the last step before Higgs search
  - study of triple gauge boson couplings (TGC)
- Background to searches: $H \to WW$, $H \to ZZ$

$WW \to l\nu l\nu$

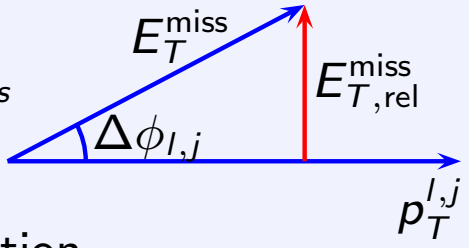


- sensitive to triple gauge boson coupling
- important background to $H \to WW$

event selection / background rejection

Drell-Yan: fake-E_T^{miss}

- Z-mass veto
- require large relative-E_T^{miss}



W + jets: fake-lepton

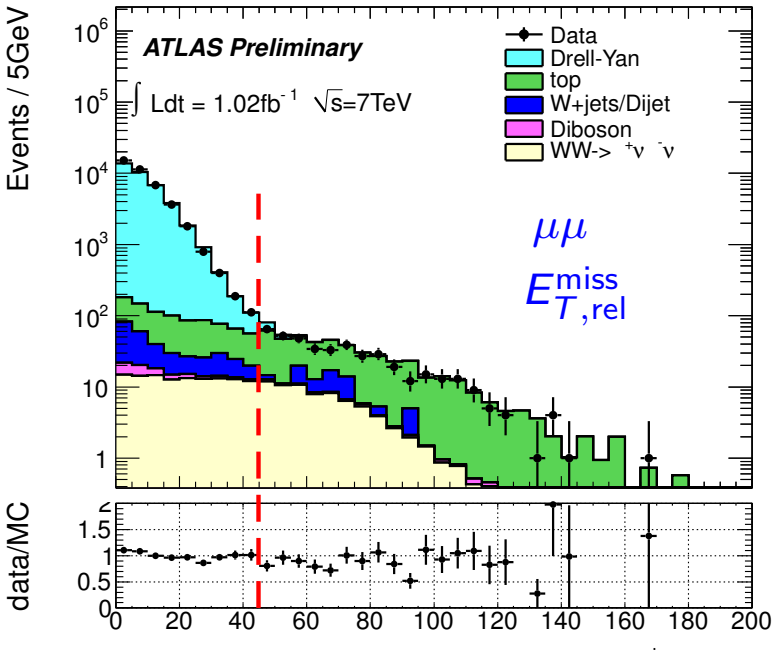
- lepton isolation/identification

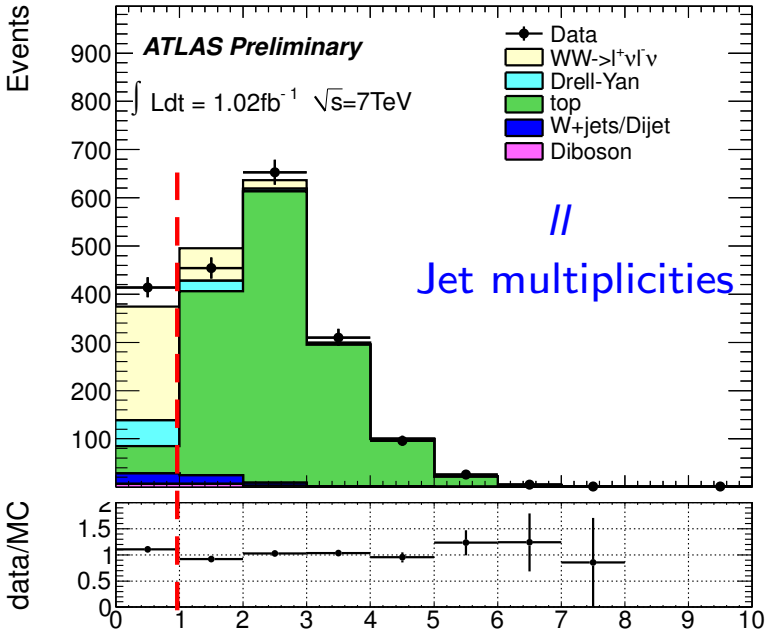
top: WW with two b-jets

- jet veto

Other diboson: WZ, ZZ

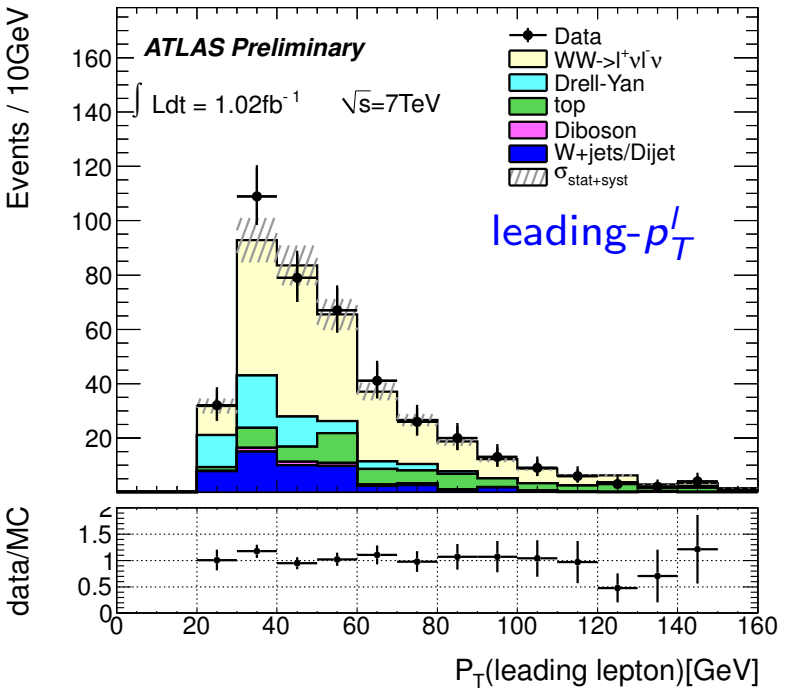
- no third lepton





$WW \to l\nu l\nu$

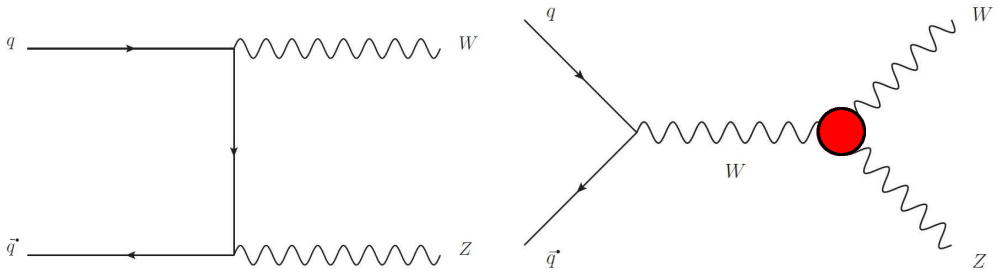
- kinematic distributions after selections $\to$
- reasonable agreement between data and predictions



	events
Signal (MC)	$232.4 \pm 0.9 \pm 21.5$
top (data)	$58.6 \pm 2.1 \pm 22.3$
W + jets (data)	$50.5 \pm 4.8 \pm 14.7$
Drell-Yan (MC/data)	$54.0 \pm 3.7 \pm 4.5$
other diboson (MC)	$6.8 \pm 0.4 \pm 0.8$
total background	$169.8 \pm 6.4 \pm 27.1$
$S/\sqrt{B}$	17.8
observed events	414

- $\sigma = 48.2 \pm 4.0$ (stat.) ± 6.4 (syst.) ± 1.8 (lumi.) pb
- Systematic uncertainty dominated by data driven background estimation
- NLO prediction: 46 ± 3 pb
- measurement in agreement with prediction

$WZ \to l\nu ll$

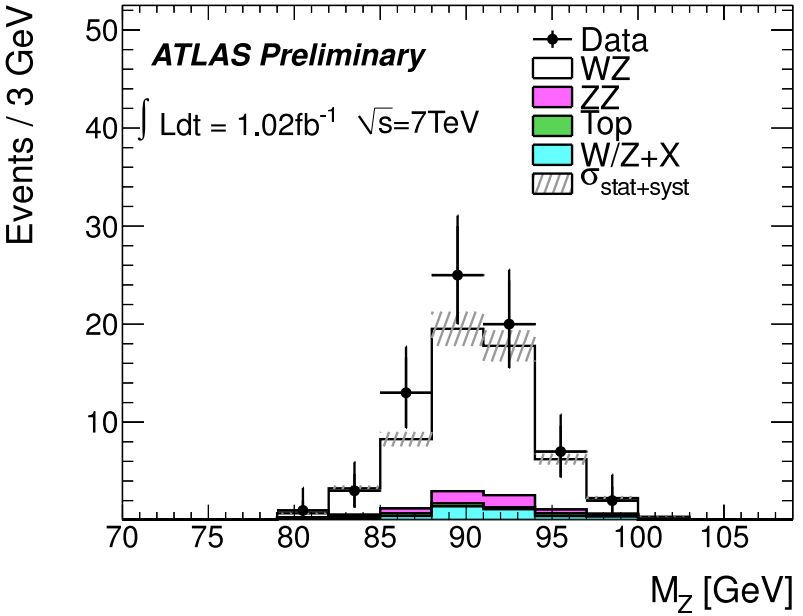


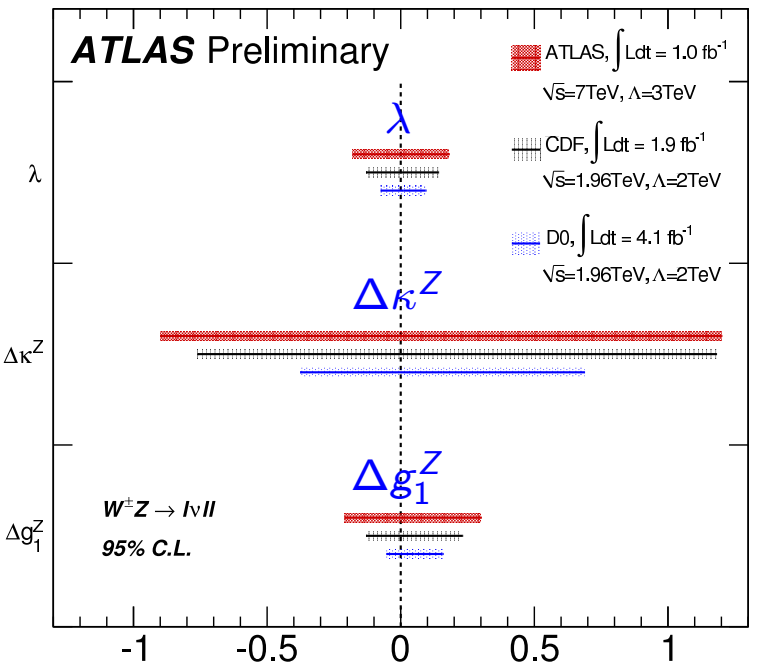
- Three leptons and $E_T^{\text{miss}} > 25$ GeV
- $|m_{ll} - m_Z| < 10$ GeV, $m_T(W) > 20$ GeV

	events
Signal (MC)	$49.1 \pm 0.4 \pm 3.02$
total background	$10.5 \pm 0.8\ ^{+2.9}_{-2.1}$
$S/\sqrt{B}$	15
observed events	71

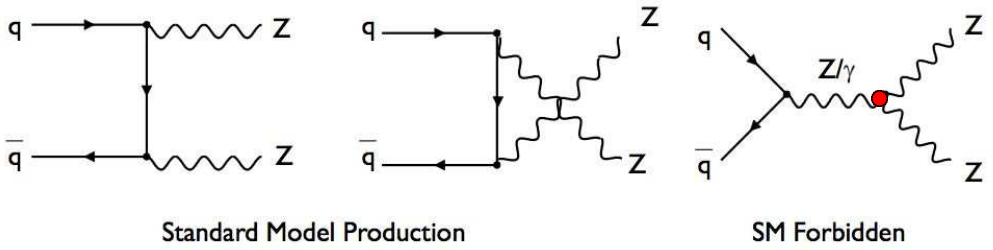
$\sigma = 21.1^{+3.1}_{-2.8}\ (\text{stat.}) \pm 1.2\ (\text{syst.})^{+0.9}_{-0.8}\ (\text{lumi.})$ pb

- NLO prediction: $17.2^{+1.2}_{-0.8}$ pb
- measurement in agreement with prediction
- limits on anomalous TGC have been derived
- comparable to Tevatron limit with 1 fb^{-1}





$ZZ \to llll$



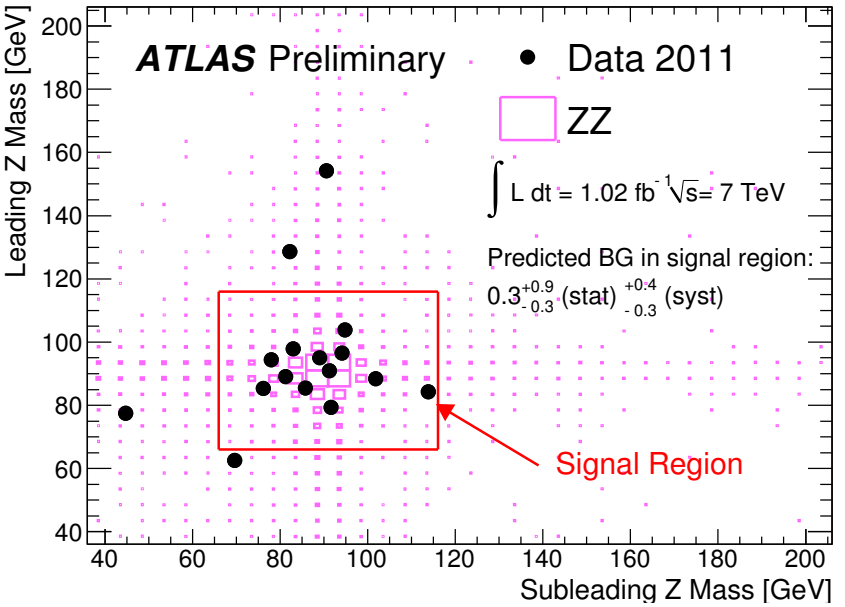
Standard Model Production | SM Forbidden

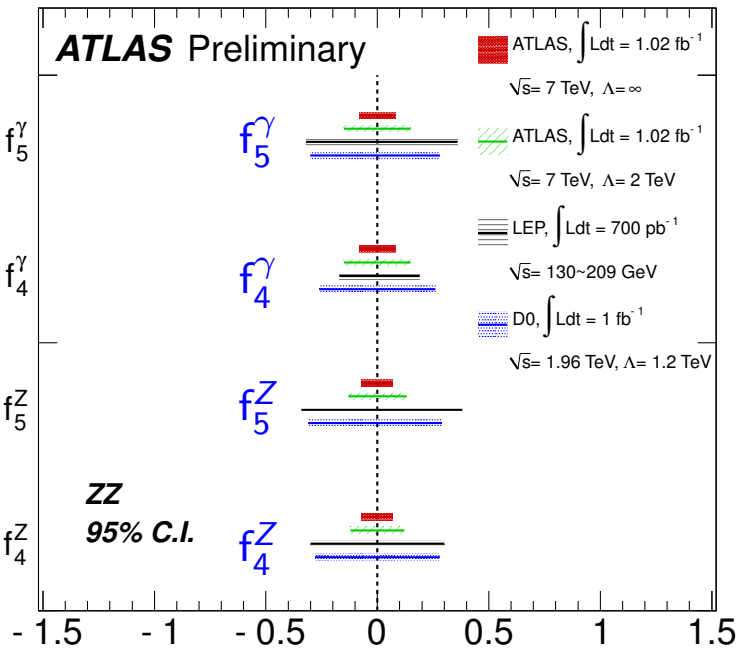
- Four leptons ($eeee/ee\mu\mu/\mu\mu\mu\mu$)
- Two Z with $|m_{ll} - m_Z| < 25$ GeV

	events
Signal (MC)	$9.1 \pm 0.1 \pm 0.3$
total background	$0.3\ ^{+0.9+0.4}_{-0.3-0.3}$
$S/\sqrt{B}$	16
observed events	12

$\sigma = 8.4^{+2.7}_{-2.3}\ (\text{stat.})^{+0.4}_{-0.7}\ (\text{syst.}) \pm 0.3\ (\text{lumi.})$ pb

- NLO prediction: $6.5^{+0.3}_{-0.2}$ pb
- measurement in agreement with prediction
- limits on anomalous neutral TGC have been derived
- competitive to LEP/Tevatron limits with 1 fb^{-1}

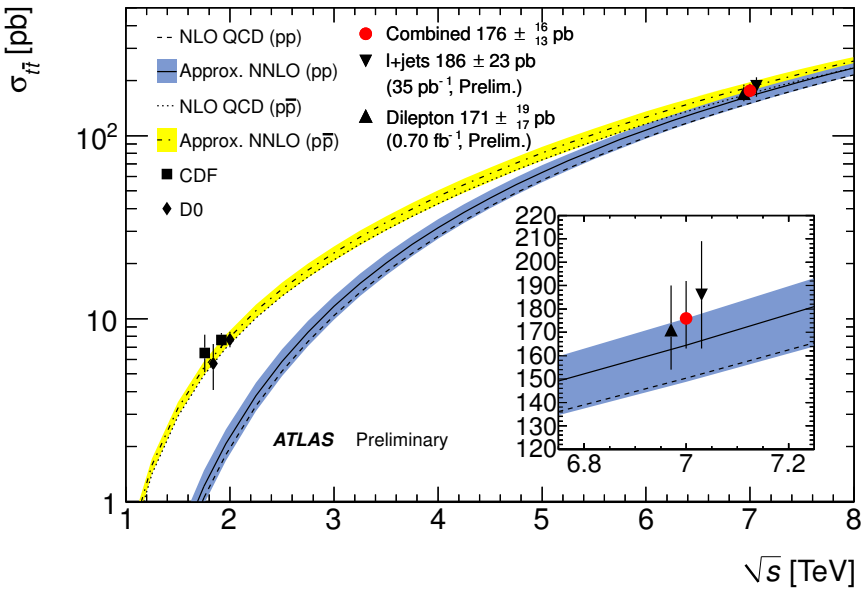




top

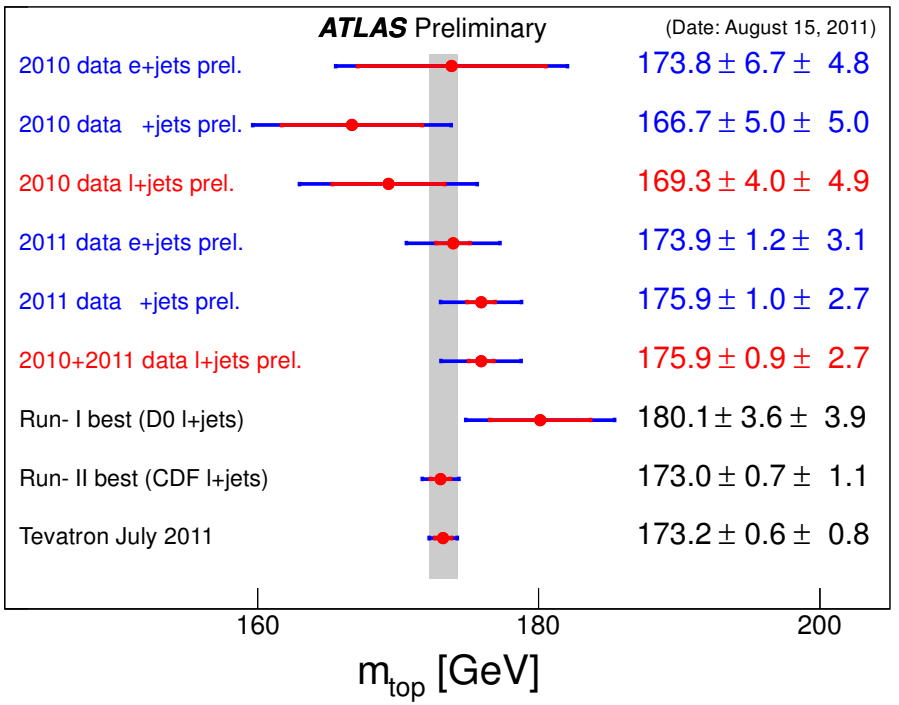
- combined cross-sections measured in di-lepton and lepton-jets channels

σ: 176 $\pm$ 5 (stat.) $^{+13}_{-10}$ (syst.) $\pm$ 7(lumi.) pb



- precision of combined results (∼10%) already close to theoretical one

- m_{top} determined with template fit using lepton-jets channel by combining 2010 and 2011 data

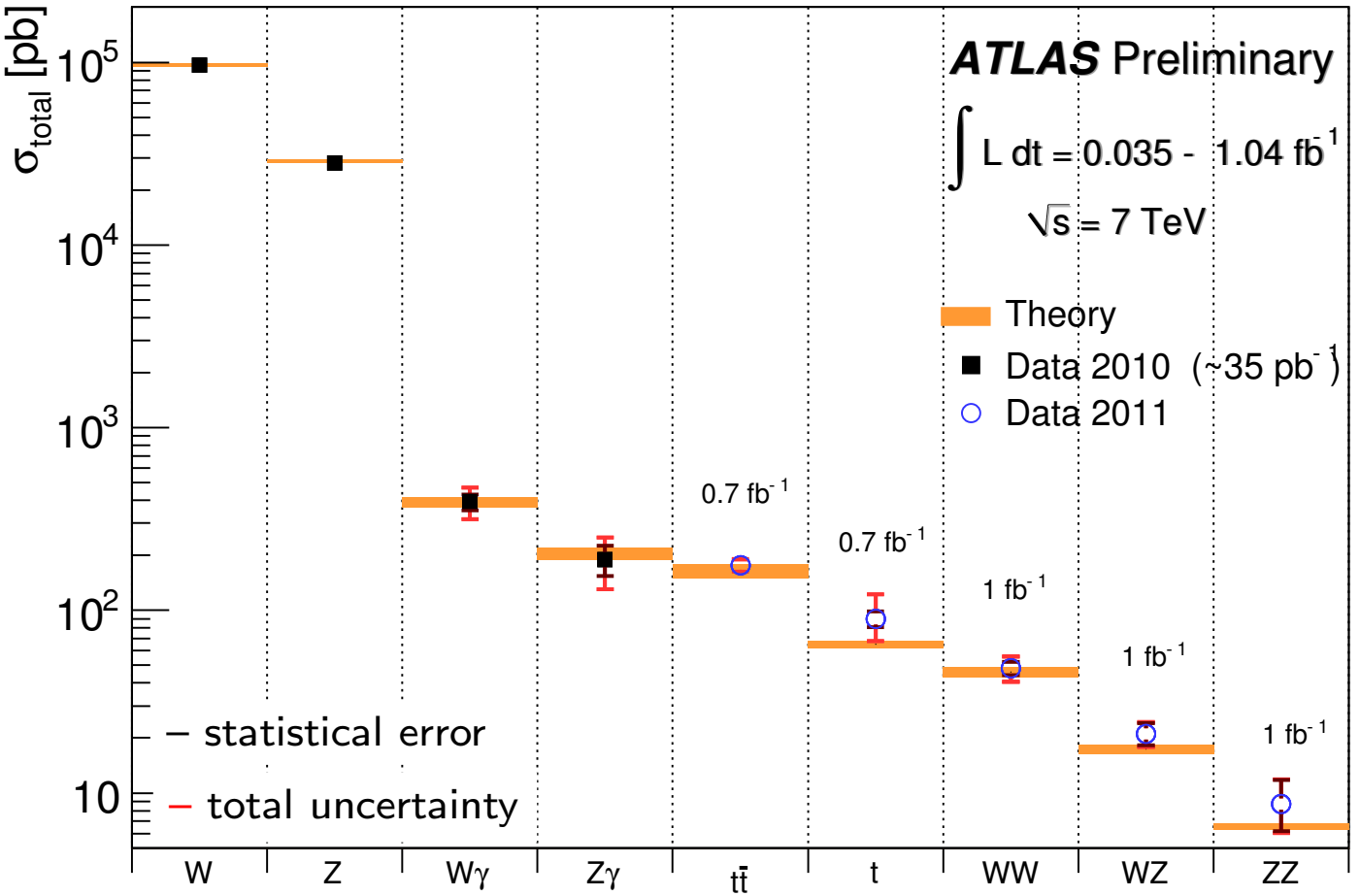


- m_{top}: 175.9 $\pm$ 0.9 (stat) $\pm$ 2.7 (syst)
- Tevatron: 173.2 $\pm$ 0.6 (stat) $\pm$ 0.8 (syst)

Standard Model cross-section measurements

current status – ATLAS

measured/predicted cross-sections of SM processes
in agreement



"Yesterday's signal is today's control sample and tomorrow's background"

- probing heavy di-boson productions, the last step before Higgs

Summary

- LHC is performing well
  - peak and integrated luminosity increasing rapidly
  - delivered 3.09 fb^{-1}, 6 weeks of pp runs left in 2011
- ATLAS detector is performing well
  - high data taking efficiency with high operational fraction of detector
  - recorded 2.92 fb^{-1}
  - understanding of detector and reconstruction performance is progressing
- Standard Model processes re-discovered up to di-boson processes ($WW/WZ/ZZ$)
  - the last step before Higgs searches
  - measurements in agrement with predictions
  - precision of measurements quickly catching up to Tevatron results
- Necessary and successfull step before discoveries
  - discovery = measurements – standard model