Recent results from ATLAS

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KEK Physics Seminar
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LHC

● Proton-proton collider with c.m.s. energy $\rightarrow$ 14 TeV
  -- c.m.s. energy of elementary parton-parton collision
  \[ \sqrt{s_{\text{eff}}} (q - q) \approx O(1) \text{ TeV} \]

➡ The real explorer for “TeV scale” physics
  -- Origin of EW symmetry breaking; SM Higgs
  -- New physics (necessary to stabilize EW scale);
    SUSY, Extra Dimension, etc…
  * which can bring good dark matter candidates

ATLAS

● General purpose detector, covering $\sim 4\pi$ solid angle
  -- Detection capability to Higgs with mass covered seamlessly up to $\sim 1$ TeV
● Inner detector: combination of silicon strip / pixel detector and straw tube tracker (2 T by solenoid).
● Calorimeter: LAr for EM and had (endcap), scintillator tiles for had (barrel)
● Muon spectrometer: stand-alone measurement by using Toroid magnet
LHC and ATLAS Operations in 2009, 2010

- Year 2009: $\sqrt{s}=0.9, 2.36$ TeV : $\sim 12\, \mu\text{b}^{-1}$
- Year 2010: $\sqrt{s}=7$ TeV
  $\sim 45\, \text{pb}^{-1}$ collected by ATLAS

- $\sim 92\%$ data-taking efficiency
- $\sim 97$-100% detector elements were in operation

► Today’s talk:
-- Full data set ($\sim 40\, \text{pb}^{-1}$) allows ATLAS to produce a large variety of physics results
LHC and ATLAS Operations in 2011

- Delivered luminosity: 1.0 fb\(^{-1}\)
- ATLAS ready recorded: 0.95 fb\(^{-1}\)
- Data taking efficiency > 95%

Now LHC is not only highest-energy, but also highest-luminosity hadron collider! (At \(10^{33}\) cm\(^{-2}\)s\(^{-1}\), 1 SM Higgs with 150 GeV mass is produced every 83 seconds)

- Max inst. luminosity: \(1.26 \times 10^{33}\) cm\(^{-2}\) s\(^{-1}\)

Today’s talk also includes:
-- Some hot results using up to \(~200\) pb\(^{-1}\) (New at PLHC2011, 6-11/June)
Challenging days for Trigger

- Event trigger rate has to be reduced from 40 MHz down to ~200 Hz → 1/500000 rejection necessary
- Under high pile-up (average 6 interactions (max 8-12) per crossing in 2011) environment
- Pipelined, dead-time free, 3-levels trigger
  -- Typical deadtime 2-3% in 2011 runs
  -- Dynamic changes to trigger settings during a run w/o stop/start
  -- Stopless removal/recovery of detector r/o elements
- Need to cover the wide and rich physics potentials comprehensively
  -- Various kinds of trigger logic (“chain”)
    e.g. inclusive, exclusive, combination…
  -- Typically, few hundred trigger logics are deployed at any time.

11 vertices with 1 Z → μμ

The trigger system has been successfully operating in a wide range of conditions: 10^{27} to over 10^{33} cm^{-2}s^{-1} (6 orders!)
Standard Model Physics

- Hard QCD
- Electro-weak
- Top
Jets @ LHC

- QCD validation at unexplored kinematic phase space
  -- We are seeing $p_T \geq 1$ TeV and di-jets with $M_{jj} \geq 3$ TeV!
Inclusive jet cross sections

- Anti-$k_T$, $R=0.6$ (Measurement with $R=0.4$ was also made):
  - $p_T(jet)>20$ GeV to 1.5 TeV
  - $|y_{jet}|$ up to 4.4

- Data are consistent with NLO pQCD prediction with non-pert. corr
- Some differences observed at high $p_T$ and large $|y|$
**EW bosons @ LHC**

- SM “candles” provide:
  -- QCD validation, with sensitivity to quark’s parton density functions (PDFs)
  -- Important in-situ calibration method

- Z: Event selection
  -- $p_T$ (lepton) > 20 GeV
  -- Oppositely charged pair

- Di-muon invariant mass
  -- $M_{\mu\mu}$ spanned to ~3 orders, several familiar resonances

- W: Event selection
  -- Isolated $p_T$ (lepton) > 20 GeV
  -- $E_T^{\text{miss}}$ > 25 GeV
  -- $m_T > 40$ GeV

\[
\sigma = \sum_{i,j} \int dx_i dx_j [f_i(x_i) f_j(x_j) \Delta \sigma(q_i q_j \rightarrow X; x_i, x_j)]
\]

\[
\begin{align*}
\overline{u}d & \rightarrow W^+ \\
\overline{d}u & \rightarrow W^-
\end{align*}
\]
W/Z-production cross section

- Ratio of W to Z cross sections:
  $\sigma(W)/\sigma(Z/\gamma^*)$

- In the cross section ratio, both exp/theory uncertainties partially cancel
  -- Exp: luminosity, theory: PDF

- Measured cross sections are in agreement with theoretical predictions based on NNLO QCD

- Started to constraint PDFs!
**EW bosons + Jets**

- **W+nJets cross section**
  - A powerful test of QCD
  - Often becomes irreducible/main backgrounds for top, Higgs, SUSY, new physics searches, etc.
  - Mandatory to understand with real data

- **Z+nJets cross section**
  - Measured cross sections are in agreement both with Multi-parton ME + PS MC models (ALPGEN, SHERPA) and also NLO calculations (MCFM, BLACKHAT-SHEPA)

- See ATLAS-CONF-2011-042
Top

- Rich physics programs

- Experimentally:
  Measurement of top quarks requires understanding of full detector performance
    -- Lepton identification
    -- $E_T^{\text{miss}}$
    -- multi-jets
    -- b-tagging
  and also, understanding of QCD backgrounds (W/Z+nJets etc.)
**σ(ttbar) [1-lepton mode]**

- **Br=33%** : “Golden” channel
- **Event Selection**
  - $p_T > 20$ GeV, $|\eta|<2.5$
  - $E_T^{\text{miss}} > 20$ (35) GeV (for e)
  - $m_T(W) > 60-E_T^{\text{miss}}$ (25) GeV (for e)
  - $\geq 1$ jets of $p_T^{\text{jet}} > 25$ GeV, $|\eta^{\text{jet}}| < 2.5$

- **W/ b-tagging**
  - Impact parameter based and secondary vertex based
  - Multivariate discriminant
    - $W_{JP}$, $|\eta|$, aplanarity, $H_{T,3p}$

- **W/o b-tagging**
  - Multivariable discriminant
    - $|\eta|$, $|Q|$, aplanarity

\[\sigma = 171 \pm 17^{+20}_{-17} (\text{stat}) + 6 (\text{lumi}) \, \text{pb}\]
\[\sigma = 186 \pm 10^{+21}_{-19} (\text{stat}) + 6^{+13}_{-13} (\text{lumi}) \, \text{pb}\]
\[ \sigma(\text{ttbar}) \text{ [2-lepton mode]} \]

- Br=6\% : “High purity” channel \(\rightarrow\) “Counting” taking advantage of high purity
- Event Selection
  - 2 opposite sign leptons with \(p_T > 20 \text{ GeV, } |\eta| < 2.5\)
  - \(E_T^{\text{miss}} > 40 \text{ GeV}\)
  - \(\geq 2 \text{ jets of } p_T^{\text{jet}} > 20 \text{ GeV, } |\eta^{\text{jet}}| < 2.5\)
  - \(H_T = \Sigma p_T^{l} + \Sigma p_T^{\text{jet}} > 130 \text{ GeV}\)
  - \(|M_{ll} - M_Z| > 10 \text{ GeV}\)

\[ \sigma = 173 \pm 22(\text{stat})^{+18}_{-16}(\text{syst})^{+8}_{-7}(\text{lumi}) \text{ pb} \quad \sigma = 176 \pm 22(\text{stat}) \pm 22(\text{syst}) \pm 6(\text{lumi}) \text{ pb} \]
Summary of $\sigma$(ttbar)

$\sigma = 180 \pm 9 \text{(stat)} \pm 15 \text{(syst)} \pm 6 \text{(lumi)} \text{pb}$

- 10% precision already with $L = \sim 35 \text{ pb}^{-1}$
Top mass

- Main result: template fit to $R_{32}$

$$R_{32} = \frac{m_{\text{top}}^{\text{reco}}}{m_{W}^{\text{reco}}} = \frac{m_{jjb}}{m_{jj}}$$

- $m_{\text{top}}$: three jets with highest vector sum $p_T$
- $m_{W}$: non b-tagged jets/smaller $dR$ in top rest frame ($60 < m_{W} < 100$ GeV)

$$m_{\text{top}} = 169.3 \pm 4.0(\text{stat}) \pm 4.9(\text{syst})\text{GeV}$$

- Dominant syst: ISR/FSR, JES

- Template fit to $m_{\text{top}}$ (by kine. fit)

- Dominant syst: JES (larger),

$\Rightarrow$ Simultaneous fit to JES and $m_{\text{top}}$

- 3.7 % precision already with $L = 35$ pb$^{-1}$ (expects $\delta m_{\text{top}} \sim 1$ GeV with 1 fb$^{-1}$)
Di-boson

- Sensitivity to Triple Gauge Boson Coupling (TGC)
- Irreducible backgrounds to Higgs, Susy searches, e.g. $H \rightarrow WW, ZZ$
2011 data (205 pb⁻¹)

Di-boson production [WZ, WW]

- 2 opposite sign leptons with $p_T > 20$ GeV
- $|M_{ll} - M_Z| < 10$ GeV
- $E_{\text{miss}, T} > 40$ GeV
- 3rd lepton $p_T > 20$ GeV

$\sigma(WZ)$

- 2 opposite sign leptons with $p_T > 20$ GeV
- 0 jet of $p_T > 20$ GeV
- $|M_{ll} - M_Z| > 10$ GeV
- $E_{\text{miss}, T, \text{rel}} > 40$ GeV

$\sigma(WW)$

- 2 opposite sign leptons with $p_T > 20$ GeV
- 3rd lepton $p_T > 20$ GeV
- $|M_{ll} - M_Z| < 10$ GeV
- $E_{\text{miss}, T} > 40$ GeV

\[ \sigma = 18^{+7}_{-6}(\text{stat}) \pm 3(\text{syst}) \pm 1(\text{lumi}) \text{pb} \]

\[ \sigma = 41^{+20}_{-16}(\text{stat}) \pm 5(\text{syst}) \pm 1(\text{lumi}) \text{pb} \]

- Started to observe di-bosons
  (For $Z\gamma$, $W\gamma$: see arXiv:1106.1592)
Summary of EW, top cross sections

- Observation of t-channel single top production (ATLAS-CONF-2011-088)
Higgs searches: the last missing in SM
2011 data
(209 pb⁻¹)

$\text{H} \rightarrow \gamma\gamma$

- Despite low BR, significant due to excellent $\gamma$ resolution
- Event Selection: 2 isolated $\gamma$ with $p_T \gamma > 40$ (25) GeV
- Backgrounds
  -- Loosened $\gamma$-id.
    to normalize bkgd from jets
  -- “double-sideband”

- New vertex reconstruction by using photon direction at LAr
  -- Cope with 2011 high pileup condition

- Limit down on $4.2 \times \text{SM}$
- World best limit for $\text{H} \rightarrow \gamma\gamma$
H$\rightarrow$WW [$\rightarrow$lvlv]

- Unlike most other channels, full mass reconstruction not possible
- Event Selection: exploit differences in angular distributions (due to spin correl.) + dedicated selection for H+0,1,2 jets
  - 2 opposite charge leptons with $p_T > 20$ (15) GeV
  - $E_{T\text{miss}} > 40$ GeV, $|M_{ll} - M_Z| > 10$ GeV
  - $\Delta\phi(ll) < 1.3$ (1.8) for $m_H < 170$ (> 170) GeV
- Backgrounds: estimated from control sample
  - W+jets: loosing lepton id
  - ttbar: altered jet cuts, b-tag
  - Di-boson: altered $M_{ll}$ and $\Delta\phi(ll)$

- Limit down on $1.2 \times SM$
- Approaching Tevatron excluded region
One of the best channels for intermediate and high masses

Possible to estimate $P_{Z\nu}$ and $M_{WW}$ by solving $M_W = M_{\nu^\nu}$

Event Selection:

- 1 leptons with $p_T^{l} > 30 \text{ GeV}$
- veto 2$^\text{nd}$ with $p_T^{l} > 20 \text{ GeV}$
- $E_T^{\text{miss}} > 40 \text{ GeV}$
- 2 or 3 jets with $p_T^{\text{jet}} > 30 \text{ GeV}$, $|\eta^{\text{jet}}| < 4.5$
- Veto bjet (against ttbar)

Background normalization from fit
- Cross-checked using an anti-isolated lepton sample

Excluded $11.2 \times \text{ SM}$ for $m_H = 400 \text{ GeV}$
$H \rightarrow ZZ \rightarrow llqq, llvv$

- **$llvv$**
  - $E_{\text{miss}} > 66$ GeV
  - Veto bjet
  - $76 < M_{ll} < 106$ GeV

  Final discriminant
  \[ m_T \]

- **$llqq$**
  - $E_{\text{miss}} < 50$ GeV
  - $70 < |M_{jj}| < 105$ GeV
  - $76 < M_{ll} < 106$ GeV

  Final discriminant
  \[ m_{lljj} \]

ATLAS Preliminary

ATLAS Preliminary

- Observed (PCL)
- Expected (PCL)
- $H \rightarrow ZZ \rightarrow llvv$
- $\int L dt=35 \text{ pb}^{-1}, \sqrt{s}=7$ TeV

- $95\%$ C.L. limit on $\sigma \rho_{SM}^2$

- Most sensitive channel in 200-400 GeV
- Excluded $10.5 \times \text{SM}$ for $m_H=300$ GeV

ATLAS Preliminary

- Observed (PCL)
- Expected (PCL)
- $H \rightarrow ZZ \rightarrow llqq$
- $\int L dt=35 \text{ pb}^{-1}, \sqrt{s}=7$ TeV

- $95\%$ C.L. limit on $\sigma \rho_{SM}^2$

- Good sensitivity in 200-600 GeV

ATLAS-CONF-2011-026
Exclusion limits

1. Individual channels

2. Combination

3. SM4

Atlas approaching SM ($x1.6$ SM) Tevatron excl. limit

SM4 excluded for $m_H : 140-185$ GeV

M. Escalier, PLHC 11/June

arXiv:1106.2748
Higgs prospects with $\sim 1 \text{ fb}^{-1}$

- SM Higgs
  -- Conservative analysis scenario (cut based, robust systematic error estimates)

- Observation sensitivity (median)
- $95\%$ CL exclusion

$\rightarrow$ $3\sigma$ observation: $139 < m_h < 180$ GeV
($\sim 50\%$ chance to $3\sigma : 200 < m_h < 430$ GeV)

$\rightarrow$ Exclusion: $129 < m_h < 460$ GeV
($\sim 1 \text{ fb}^{-1} @ 7$ TeV)

- Reminder: $1 \text{ fb}^{-1} = \text{already we have in our hand.}$
  $\rightarrow$ Now, no surprise if we see surprise in our data
SUSY searches

S. Heinemeyer, Feb/2011
“Prediction for LHC” (fit on EW, B rare, g-2)
SUSY searches @ LHC

- SUSY @ LHC
  -- Gluino/squark pair can be produced ‘strongly’
     via t-channel exchange → large production cross section
  -- Cascade decays to lighter ones → multi-jet, (lepton)
  -- LSP (if Rp conserved) → $E_T^{\text{miss}}$
  ➔ Event topology: Multi-jets + $E_T^{\text{miss}}$ + (X)  X=e, μ, τ,γ, b…

- Model-independent inclusive search based on event topology
  -- (0, 1…) lepton + (1, ≥2, ≥3, ≥4…) jets + $E_T^{\text{miss}}$ + (b-jet)…

<table>
<thead>
<tr>
<th>Channel</th>
<th>Signature</th>
<th>Main backgrounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 leptons + jets + $E_T^{\text{miss}}$</td>
<td>$\geq 2$–$4$ jets, large $E_T^{\text{miss}}$, $m_{\text{eff}}$ (*)</td>
<td>$W / Z$ + jets, top, QCD</td>
</tr>
<tr>
<td>1 lepton + jets + $E_T^{\text{miss}}$</td>
<td>$\geq 3$ jets, large $E_T^{\text{miss}}$, $m_{\text{eff}}$, $m_T$</td>
<td>top, $W / Z$ + jets</td>
</tr>
<tr>
<td>2 leptons (SS / OS) + jets + $E_T^{\text{miss}}$ (also “flavour subtraction” OS analysis)</td>
<td>large $E_T^{\text{miss}}$</td>
<td>SS: Fakes, diboson; OS: top, $Z +$ jets, also cosmics ($\mu\mu$)</td>
</tr>
<tr>
<td>$\geq 3$ leptons + jets + $E_T^{\text{miss}}$</td>
<td>$\geq 2$ jets, $E_T^{\text{miss}}$, $m_{H^\pm}$ ≠ $m_Z$</td>
<td>top, $Z +$ jets</td>
</tr>
<tr>
<td>(***) 0(1) lepton + b-jets + $E_T^{\text{miss}}$</td>
<td>$\geq 3$ jets, $E_T^{\text{miss}}$, $m_{\text{eff}}$, $(m_T)$</td>
<td>top, $W / Z$ + jets</td>
</tr>
<tr>
<td>2 photons + $E_T^{\text{miss}}$</td>
<td>$E_T^{\text{miss}}$</td>
<td>QCD, top, $W(\gamma)$ + jets</td>
</tr>
</tbody>
</table>

Incomplete list

(*) $m_{\text{eff}} = E_T^{\text{miss}} + \Sigma p_T\text{jets}$

(***) Large mixing scenario can give light sbottom, stop with: $\tilde{g} \rightarrow \tilde{b}b$, $\tilde{t} \rightarrow \tilde{t}t$

A. Hoecker
Planck 2011
**Jets + mE_T [0-lepton]**

- **Signal region**
  - $E_T^{\text{miss}} > 130$ GeV
  - $\Delta\phi(\text{jet}, E_T^{\text{miss}}) > 0.4$
  - $E_T^{\text{miss}} / M_{\text{eff}} > 0.3$ (0.25 for nJet $\geq 3$)
  - $p_T^{\text{jet}} > 130$ (40) GeV (for sub-leading)

- **Final discriminant cut:**
  - $M_{\text{eff}} > 1000$ GeV

- **Background estimation**
  - $Z+$jets (irreducible, $Z\rightarrow\nu\nu$)
  - $W+$jets
  - $T$op ($tt \rightarrow b\bar{b}\tau vqq$)
    - Control regions + Transfer factors (TFs) from MC
  - QCD multi-Jets ($E_T^{\text{miss}}$ by miss reconstruction)
    - Control region (Δφ inverted)
    - TFs data-driven
• In MSUGRA/CMSSM, 
  \( m(\tilde{g}) = m(\tilde{q}) < 950 \text{ GeV} \) and \( m_{1/2} < 455 \text{ GeV} \) are excluded.

• Cutting into a new territory of SUSY parameter spaces
Jets + \text{mE}_T \text{[1-lepton]}

- **Signal region**
  - $p_T > 25 \ (20) \text{ GeV}$ for e ($\mu$)
  - $E_T^{\text{miss}} > 125 \text{ GeV}$
  - $m_T > 100 \text{ GeV}$
  - $E_T^{\text{miss}} / M_{\text{eff}} > 0.25$

- **Final discriminant cut**
  - $M_{\text{eff}} > 500 \text{ GeV}$

- **Background estimation**
  - W+jets
  - Top
    - Control regions + Transfer factors (TFs) from MC
  - QCD multi-Jets ($E_T^{\text{miss}}$ by miss reconstruction)
    - Control region
    - TFs data-driven
Jets + $m_{E_T}$ [1-lepton]

$\mu_{1/2}$ vs $m_0$

2011 data (165 pb$^{-1}$)  
New @ LHCC 14/6
**Benchmark: R-parity violating SUSY**

\[ \bar{d}d \xrightarrow{\lambda'_{311}} \tilde{\nu}_\tau \xrightarrow{\lambda'_{321}} e^\pm \mu^\mp \]

- Very clean signals: isolated, \( p_T \) > 20 GeV

- \( m(\tilde{\nu}_\tau) < 750 \text{GeV} \) for \( (\lambda'_{311}=0.11, \lambda'_{312}=0.07) \) excluded
MSSM A/H/h → ττ

- e/μ + τ_{had}

Event Selection:
- 1 isolated e/μ with p_T > 20 GeV
- 1 had τ, charge opposite to e/μ
- E_T^{miss} > 20 GeV
- m_T < 30 GeV

Background estimation:
- Z(→ττ)+jets: embedding technique
- W+jets: control sample + OS/SS

Excluded:
m_A = 110-150 GeV (tanβ = 23)
Other BSM searches
Resonance search in $M(\text{lep-lep})$

- Sequential Standard Model (SSM)
  -- $Z'$: same coupling to fermion as $Z$

$\Rightarrow M(Z') < 1.408$ TeV excluded.
Resonance search in $M(\text{lep-mE}_T)$

**Benchmark: $W'$**
- Sequential Standard Model (SSM)
  - $W'$: same coupling to fermion as $W$

$\Rightarrow M(W') < 1.70 \text{ TeV excluded.}$
Resonance search in M(jet-jet)

- Benchmark: Excited Quark

- Fit with smooth function
  \[ \frac{dN}{dx} = p_1 (1-x)^{p_2} x^{p_3 + p_4 \ln x} + \text{BumpHunter} \]

- Excluded q* mass range: \( 0.80 < m_{q^*} < 2.49 \text{ TeV} \)

\[ \sqrt{s} = 7 \text{ TeV}, \int L \, dt = 163 \text{ pb}^{-1} \]

Expected 95% CL upper limit:

- Observed 95% CL upper limit
- 68% and 95% bands

ATLAS Preliminary

\[ \int L \, dt = 163 \text{ pb}^{-1} \]

\[ \sqrt{s} = 7 \text{ TeV} \]
### SUMMARY OF MASS LIMITS

*Several table entries: to be updated if approved*

<table>
<thead>
<tr>
<th>Channel</th>
<th>Particle</th>
<th>Limits [TeV]</th>
<th>Channel</th>
<th>Model/particles</th>
<th>Limits [TeV]</th>
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<tbody>
<tr>
<td>jet+MET+X</td>
<td>mSUGRA g, q</td>
<td>0.950* if m(g)=m(q)</td>
<td>Lep+jets+MET</td>
<td>1st gen. LQ(β=1)</td>
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<td>bjets+MET</td>
<td>gluino</td>
<td>0.590* if m(b)&lt;m(g)</td>
<td>2nd gen. LQ(β=1)</td>
<td>0.422*</td>
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<td>Long lived particles</td>
<td>gluino</td>
<td>0.562-0.584*</td>
<td>γγ+MET</td>
<td>UED(1/R)</td>
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<td>stop</td>
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<td>Gluino (GGM)</td>
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<td>di-jets</td>
<td>Excited quarks</td>
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<td>axigluons</td>
<td>2.67*</td>
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<td>di-leptons</td>
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<td>Lep+MET</td>
<td>SSM W'</td>
<td>1.70</td>
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</tbody>
</table>

* World’s best limit

2010 data already allowed us to set better limits than Tevatron/LEP searches in most channels

50-100 times more data expected by the end of 2011!
Summary and future plan

- LHC is the explorer of the highest energy frontier, no substitute to it. Given the highest energy, search regions for new physics are being significantly extended

- Running plan:
  -- 2011-12: Physics run @ 7 TeV
    * Max inst. Luminosity may increase up to $5 \times 10^{33}$ cm$^{-2}$s$^{-1}$
    * May add a few fb$^{-1}$ more already in 2011
  -- 2014 mid: Physics run @ 14 TeV

- KEK physics seminar on 26/July (c.f. “EPS-HEP 2011” 21-27/July)
  ATLAS results report by Soshi Tsuno (KEK)
    -- Most probably, many updates with several 100 pb$^{-1}$ or even O(1 fb$^{-1}$)
      Stay tuned!