International Workshop
"Quantum Particles and Fields - 4"
Zagulba Settlement
19th - 25th September 2005
Baku
Azerbaijan

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CERN
On behalf of the ATLAS collaboration
Given the time at disposal, it is impossible to cover in detail all the topics that ATLAS will be able to explore.

Mine will be a (partial) selection of main highlights.

It will be focused on what is achievable in the early years (including detector commissioning) with a hint to what might come later.
Outline

- The Reasons
- ATLAS at LHC: Status and challenges (now)
- Commissioning: living up to expectations and face reality (soon)
- Future Physics: succeeding with what one has (later)
- Conclusions
The Reasons
The SM is a great success.

...But there is need to go beyond

- No explanation for its 19 independent parameters
- Gravity is missing (2 more parameters = $G_N$, cosmological constant)
- Cosmology is incomplete: inflation, baryon asymmetry, universe energy content
- First physics beyond the SM: neutrinos have mass (18 more par.)
1) Mass i.e., how is symmetry broken?

- $M_W, M_Z \neq 0 \Leftrightarrow$ there exists a field breaking gauge symmetry in SM vacuum
- Elementary: Higgs particle
- Composite: quark condensate
- $M_H$: only free parameter with upper limit: $\sim 800$ GeV

**Exp Status**
- LEP direct search: $M_H > 114.4$ GeV
- LEP+Tevatron fit: $M_H = 129^{+74}_{-49}$ GeV

**Search on allowed $M_H$ range = explore TeV scale**
2) Hierarchy and Unification

- Why is coulomb\( (e^2) >> \text{gravity}(G) \)? I.e. why \( M_{\text{Planck}} >> M_w \)?
- Do forces eventually unify? At what scale?

EXTRA DIMENSIONS

SUSY

Conserve R parity → Pair-Produced Sparticles:

TeV scale is lower bound
3&4) Flavour and Universe content

What are the reasons for particles families and their behaviour?

- Why so many types of quarks and leptons (i.e. different masses)?
- Why do their weak interactions mix with different strengths i.e. mass eigenstates ≠ weak eigenstates?
- How is this connected to CP violation i.e. the matter-antimatter imbalance in the universe?
- Is there any additional substructure (compositeness?)

What is the universe made of?

- Baryons ~5%
- Dark matter ~ 25%
- Dark energy ~ 70%

Observing relative energy density content in universe

Dark energy spread over space, slowly-varying in time

Rotational velocity inside galaxies+

Particles families and their behaviour:

- Why so many types of quarks and leptons (i.e. different masses)?
- Why do their weak interactions mix with different strengths i.e. mass eigenstates ≠ weak eigenstates?
- How is this connected to CP violation i.e. the matter-antimatter imbalance in the universe?
- Is there any additional substructure (compositeness?)

Search for weakly interacting particle with M=10-1000 GeV → SUSY (neutralino)?

Pointing at TeV scale again
A new tool is required: the LHC

- Explore TeV energy scale: high mass and rare signatures → increase collision energy

- Use pp collisions. Proton is composite → \( \sigma(pp) = \sum_{1,2} \int_{x_{low}}^{1} F_1 F_2 \sigma(1,2) \, dx_1 dx_2 \) (\( x_{low} = m_2/E_{cm} \))
  - point-like \( \sigma \sim 1/s \)
  - proton structure functions increase very rapidly at low \( x \)

- Significant increase of \( \sigma \) with energy: \( \sigma(pp) \propto C (\log(E_{cm}))^2 \)

Energy and Lumi req. ("back of envelope"): use \( H \rightarrow ZZ \rightarrow \text{leptons} \) (\( m_H \sim 1 \text{ TeV} \))

- \( E_W \sim 500 \text{ GeV} \rightarrow E_{\text{quark}} \sim 1 \text{ TeV} \rightarrow E_{\text{proton}} \sim 6 \text{ TeV} \)
- \( E_{cm} \sim 12 \text{ TeV} \)

Lumi = \( (\#\text{ev}) / (\sigma \cdot \text{BR} \cdot \text{time}) \)

- \( \sigma(pp \rightarrow H) \sim 0.1 \text{ pb} \)
- \( \text{BR}(H \rightarrow ZZ) \sim 0.1 \)
- \( \text{BR}(ZZ \rightarrow \text{lep}) \sim 10^{-3} \)

To get 10 events in 1 year \( \rightarrow L \sim 10^{34} \text{ cm}^{-2}\text{s}^{-1} \)
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LHCLHC

- 1000/1650 main magnets delivered
- ~100 dipoles installed
- Installation: cryogenics service line + magnets are “critical to maintain the schedule” (L. Evans 12/09/05)

Schedule = Start colliding protons in Summer 2007

Operation with Heavy ions at 2.7 TeV /nucleon

### Parameters

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Max energy</td>
<td>7 TeV (~7 x Tevatron)</td>
</tr>
<tr>
<td>Circumference</td>
<td>26,659 m</td>
</tr>
<tr>
<td>Protons per bunch</td>
<td>$1.1 \times 10^{11}$</td>
</tr>
<tr>
<td>Filled bunches</td>
<td>2808 / 3564</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>24.95 ns</td>
</tr>
<tr>
<td>Lumi</td>
<td>$10^{34}$ cm$^{-2}$ s$^{-1}$ ($ &gt;100 \times$ Tevatron)</td>
</tr>
<tr>
<td>Superconducting Dipoles</td>
<td>1232 (15m long at 1.9 K, $B=8.33$ T);</td>
</tr>
<tr>
<td>$E_{\text{beam,Stored}}$</td>
<td>350 MJ (200 x Tevatron)</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>24.95</td>
</tr>
</tbody>
</table>

Facing the challenge: A Toroidal Apparatus at the Large Hadron Collider
Detecting “interesting” physics at LHC

Aim: Operate at high Luminosity with detecting as many “signatures” as possible

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Trigger</th>
<th>Electromagnetic Calorimetry</th>
<th>Combined electromagnetic and hadronic calorimetry</th>
<th>Inner Tracker</th>
<th>Muon detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cope with $10^9$ events/s</td>
<td>Pipelined with reduction factor of $10^7$</td>
<td>$</td>
<td>\eta</td>
<td>&lt;3$: $\sigma(E)/E \sim 10% / \sqrt{E} \oplus 0.7%$</td>
<td>$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$e/\gamma$ identification</td>
<td>Jets and $E_T^{miss}$ Hermetic coverage Forward jet tag</td>
<td>Tracking high $p_T$ lepton, tau ID, btag</td>
<td>standalone, at highest Lumi</td>
</tr>
</tbody>
</table>

Fine granularity to separate signal from 20 events pile-up in same bunch crossing
Fast electronics to minimize pile-up of events from different bunch crossings $\rightarrow 25-50$ns
Radiation hard electronics: fluence up to $10^{16}$n/cm$^2$/year $\sim 10^5$ Gray/year ($1$Gray$=1$J/Kg)
ATLAS: the concept

High multiplicity environment $\rightarrow$ Absorb/measure all hadrons and measure leftover muons (cylindrical symmetry around beam; $\theta$=polar, $\phi$=azimuthal).

**Inner tracker and calorimetry decoupled from muon system**

- **Parameter choices: some examples**
  - For $p_T > 20$ GeV, $dp_T/p_T \sim p_T/B(\text{Tesla})L^2(m^2)$ $\rightarrow$ large $B$ and volumes minimize uncertainty at high $p_T$. $B$ in Inner Det $\sim 2T$, $B$ in $\mu$ spectrometer up to 3.9 T $\rightarrow$ high currents $\rightarrow$ superconducting coils
  - $\lambda(\text{Fe}) \sim 17.6$ cm. Need $\sim 10$ (14) int length before barrel (forward) muon chambers: need $\sim 9.5 \lambda$ for calo $\rightarrow$ $\sim 1.7$ m of iron (TileCal is $\sim 82\%$ iron/18% scint)
  - $\eta = -\ln(\text{tg}(\theta/2))$: a) precision physics coverage ($\mu$, e): $|\eta|<2.2$; b) good $E_{T_{\text{miss}}}$ resolution $\rightarrow$ $|\eta|<5$ coverage $\rightarrow$ detectors up to about 1$^\circ$ from beam axis!

- **2 magnet systems** (solenoidal, toroidal) $\rightarrow$ uniform bending for muon. High res, large-acceptance standalone muon spectrometer
ATLAS as expected...

- Muon Spectrometer
  - Height: ~22m

- EM Calo
  - Tile Had Calo
  - Had EndCap
  - Forward Cal

- Toroid Magnets
  - Inner detectors

- 2T Solenoid

- Mass: ~7000 tons

- ~10^8 channels
- ~3000 km of cables
26th Oct. 04: 1st coil is lowered

Dec. 04 Barrel EM + Had calorimeters installed

25th August 05: final 8th coil is lowered in place!

SCT barrel completed! (4th segment left Oxford on 24th Aug 05)
**Atlas Today (2)**

- Autumn 2005: move calorimeters to “z=0” (final position)
- Currently Commissioning FE (cosmics) and services (for Calo and ID)
- Muon chambers being installed
- Dec05: TileEBC to the pit
- Dec05-Spring 06: Install Barrel services, cool down LAr, Muon Barrel assembly and connection of End-Cap Calo

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**Short term plans**

- Magnet Toroids
- Barrel Tile and Lar Calorimetry
The ATLAS 2004 Combined Test beam
CERN - May-Nov 2004

- The Reasons
- Atlas at LHC
- Commission
- Future
- Physics
- Conclusions

**First experience with**

- Inner Detector alignment
- ID/Calo Alignment
- ID/Calo track matching
- ID/Calo combined reconstruction
- ID/Muon combined reconstruction

**90 million events collected**

- 4.6 TBytes of Data
- Beams:
  - $e^{\pm}, \pi^{\pm}$ 1 → 250 GeV
  - $\mu^{\pm}, \pi^{\pm}$ p up to 350 GeV
  - $\gamma$ ~30 GeV
- B from 0 to 1.4 T

**For the first time**, all ATLAS sub-detectors operated together with:
- “final electronics”
- Common DAQ
- Slow control
- Common ATLAS software to analyse data

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Photon conversion in Inner detectors: Matching tracks to clusters

Pion beam in calorimeters, \( E = 180 \text{ GeV}, \eta = 0.35 \)
Commissioning and early physics: the stepping stone towards physics

i.e.

learning to walk before running
The plan: four stages

1. The Reasons
2. Atlas at LHC
3. Commission
4. Future Physics
5. Conclusions

Gaining confidence: measure basic cross sections and bkg to searches (final commissioning/early physics)

Search for new physics

One beam commissioning: beam gas + beam halo

Commissioning with first collisions

Commissioning with cosmics

Top, W, Z, SM @ 14 TeV, Min bias, B Physics

SM measurements will continue beyond commissioning for refinement/consistency
Commissioning with cosmics

Goals

- Build experience with final detector
- Check stability
- Integrate subdetectors, Commission common systems, trigger-DAQ, exercise offline software
- Understand bkg to rare events

Strategy and schedule

- From Sept 05 – July 2007
- Commission individual sub-detectors first, then add the rest
- Now: Hadronic Tile Calorimeter
- End ’05: add section of muon system
- Spring ’06: Add LAr Electromagnetic Calorimeter
- Spring ’07: global ATLAS cosmic run

~5 million cosmic muons enter the ATLAS cavern in 15 minutes.
Commissioning with single beam
(schedule: ~2 months after spring 2007)

Beam-gas

Estimated vacuum ~3 \times 10^{-8} \text{Torr}

7 TeV protons on p,H,C,O..

Vertices uniformly distributed over ±23m

- ~2500 interactions/m/s (rate ~115 kHz)

Goals: boosted min bias events

→ Use to check trigger backgrounds, alignment for endcap ID and forward muons(?)

Beam halo

- Low \pT particles from LHC
- Total muon rate: ~105 kHz
  - \(E_\mu > 10 \text{ GeV}\) ~16 kHz
  - \(E_\mu > 100 \text{ GeV}\) ~1 kHz
  - \(E_\mu > 1 \text{ TeV}\) ~10 Hz

Goals: Use to check dead channels, initial alignment, inter-calibration
Commissioning with first collisions

**Goal:** Understand trigger and initial detector with real events

<table>
<thead>
<tr>
<th>Sub-det</th>
<th>Expected on day 1</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECAL uniformity e/γ en scale</td>
<td>1% 1-2%(?)</td>
<td>Min Bias, Z→ e⁺e⁻</td>
</tr>
<tr>
<td>ECAL uniformity e/γ en scale</td>
<td></td>
<td>Z→ e⁺e⁻</td>
</tr>
<tr>
<td>HCAL uniformity jet scale</td>
<td>2-3% &lt;10%</td>
<td>Single pions, QCD jets</td>
</tr>
<tr>
<td>HCAL uniformity jet scale</td>
<td></td>
<td>Z/γ (→ ll) +1j; W→ jj in t̅t̅</td>
</tr>
<tr>
<td>Tracker Alignment</td>
<td>20-500 μm in Rφ</td>
<td>Z→ μ⁺μ⁻</td>
</tr>
</tbody>
</table>

**Strategy:**

- Z/γ+jets for inter-calibration (cracks and DM)
- E/p for single hadrons: mainly from tau decays

**Reduced acceptance for** Transition Radiation Tracker (TRT) over |η|<2 (instead of 2.4)
- Deferrals of HLT/DAQ processors → LVL1 output rate limited to 35KHz (instead of 75KHz)
- Impact on physics: significant, but not excessive. Main loss in reduced B-Physics program (muon p⁰ threshold ~6 GeV → ~14-20 GeV)

**Initial Detector**

- The Reasons
- Atlas at LHC
- Commission
- Future
- Physics
- Conclusions
Gaining confidence: minimum bias

- Example of “very early” physics: only need a few thousands interactions
  - “Soft” part of pp interactions not described by PQCD → Worthy of study on their own: provide insight into structure of proton
  - Unavoidable background to all physics channels

- Measure typical quantities using full ATLAS chain:
  - $dN_{ch}/d\eta$
  - $dN_{ch}/dp_T$

- Large uncertainty track densities!

Multiple interaction model in PHOJET predicts a $\ln(s)$ rise in energy dependence. PYTHIA suggests a rise dominated by the $\ln^2(s)$ term.

Plan to Install dedicated minimum bias scintillator trigger in ATLAS.
The Expected Physics Reach: where do we go from here?
The Program

- What we need: commissioned detector
- What we can search: vast number of things
- What do we start with?: a) things to give us confidence (SM) b) things that are "easy" to find
- What do we continue with?: c) unexplored avenues (even more if simple ones fail) d) harder and more exotic things
- Order is logical one, some steps after a) can/should go in parallel
What we can study

Nature of Symmetry Breaking
- Strongly interacting Ws
- Technicolour
- Higgs Mechanisms
- SM Higgs
- Hierarchy problem
- Extra Dimensions
- Black Holes
- Exotics
- New Heavy Bosons
- SUSY
- Universe energy content
- Flavour and CP violation
- New Heavy Bosons
- QCD phen:
  - Jets xsec
- Standard model
- W
- Top
- Z
- Min bias
- B Physics
- Astroparticle
- Heavy ions
- Consider one example for highlight
- Gaining confidence (final commissioning)
- Searching for New physics
- The Reasons
  - ATLAS at LHC
  - Commission
  - Future Physics
  - Conclusions

Add stuff from PDG...

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ATLAS: doing physics with the trigger

<table>
<thead>
<tr>
<th>Process</th>
<th>Ns$^{-1}$ (L=10$^{33}$ cm$^{-2}$s$^{-1}$)</th>
<th>Events/year ($\mathcal{L} = 10$ fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Bias (inelastic)</td>
<td>10$^9$</td>
<td>$\sim$10$^{16}$</td>
</tr>
<tr>
<td>Inclusive jets p$_T &gt; 200$ GeV</td>
<td>100</td>
<td>$\sim$10$^9$</td>
</tr>
<tr>
<td>W $\rightarrow$ ev</td>
<td>15</td>
<td>$\sim$10$^8$</td>
</tr>
<tr>
<td>Z $\rightarrow$ e$^+$ e$^-$</td>
<td>1.5</td>
<td>$\sim$10$^7$</td>
</tr>
<tr>
<td>tt</td>
<td>$\sim$1</td>
<td>$\sim$10$^7$</td>
</tr>
<tr>
<td>bb</td>
<td>$\sim$10$^6$</td>
<td>$\sim$10$^{12}$ - 10$^{13}$</td>
</tr>
<tr>
<td>H (m$_H$~130GeV)</td>
<td>0.02</td>
<td>10$^5$</td>
</tr>
<tr>
<td>gg</td>
<td>0.001</td>
<td>10$^4$</td>
</tr>
<tr>
<td>Di-bosons</td>
<td>10$^{-3}$</td>
<td>$\sim$10$^4$</td>
</tr>
</tbody>
</table>

LHC is a factory for SM processes: QCD, heavy flavours (top, bottom), gauge bosons (W, Z)

Statistics: Throw out 99.9995% of events (record 200 Hz out of 40 MHz) and still have enough for precision measurements! Need to understand trigger efficiencies, detector (→ syst.)
Gaining confidence: Top Physics

Selection:

- Missing $E_T > 20$ GeV
- 1 lepton $P_T > 20$ GeV
- 4 jets $P_T > 40$ GeV

Selection efficiency = 5.3%
Trigger efficiency not accounted for yet

Reconstruction

**Hadronic top:**
Three jets with highest vector-sum $P_T$ as the decay products of the top

**W boson:**
Two jets with highest momentum in reconstructed $jjj$ C.M. frame.

$\sigma_{tt}^{(tot)} = 825$ pb
$BR(e,\mu+\text{jets}) \sim 30\%$

$1500 \, tt \rightarrow bW(l\nu)bW(jj)/\text{day at low } L (=10^{33}\text{cm}^{-2}\text{s}^{-1})$

Assume no $b$-tag!

$\sim 850$ events/hour
Gaining confidence: Using "purer" Top samples

- **Top peak clearly visible after 1 week of LHC data**
  - Ask for: $70 < M(jj) < 90$ GeV
  - $m(t)$: $S/B = 1.77$
  - $m(t)$: $S/B = 1.36$
  - Initial Use of Top
    - Check top mass (to ~7 GeV)
      - If b-jet en scale known to 10%
    - Check jet energy scale using $M_W$ (and $M_{top}$)
    - Gold plated sample for b-tagging commissioning
    - Initial check on $tt$ cross section (bkg to many searches)
      - luminosity meas. limits precision to 10%

**Final goal:** $\Delta M_{top} \sim 2$ GeV if jet en. scale known to 1%
Mass: SM Higgs around LEP limit

- Begin with counting experiment: signal out of bkg in mass dist.
- Significance = $\frac{\text{#signal}}{\sqrt{\text{#background}}}$
- Careful!: usually using LO predictions for signal (NLO increase) “conservative”
- If $M_H \sim$ LEP lower limit ($\sim 115-125$ GeV), discovery is difficult; need to combine three complementary channels

- Extract signal from irreducible $\gamma\gamma$ and QCD di-jet fakes
- Need 1% resolution on $M_H$: excellent $\gamma/e/\pi^0$ separation

$H \rightarrow \gamma\gamma$

$\sigma \times \text{BR} \approx 1.2 \text{pb}$

$ttH \rightarrow ttbb \rightarrow 6j+l\nu$

$\sigma \times \text{BR} \approx 0.3 \text{pb}$

$H \rightarrow \tau\tau$

$\sigma \times \text{BR} \approx 0.36 \text{pb}$

- Complementary to $H_{\gamma\gamma}$
- 6jets(4b) $\rightarrow$ b-tagging is crucial to reduce ttjb and ttjj bkgs
- Irreducible ttbb

- Need efficient jet-rec over $|\eta|<5$ to tag forward jets + Veto additional central jets
- Missing $E_T$ rec.: crucial
Mass: SM Higgs around LEP limit

$M_H = 120 \text{ GeV} - L_{int} = 30 \text{ fb}^{-1}$

**H → γγ**

- Signal and BKG at NLO
- Get isolated photons
- Bkg from sidebands
- S/√B ~ 3.9
  - may improve by requiring 1 additional jet

**H → ττ**

- Tag forward ($\Delta \eta > 4.4$)
- jets and veto additional central jets → large bkg reduction
- $M(ττ)$: only from $E_T^{miss}$ and $τ$ decays
- Need control over bkg normalization and shape

- Including realistic b-tagging
- Use likelihood for jet pairing

**H → γγ + 1j**

**ttH → ttbb**

- S/√B ~ 3.6

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The first good year of data taking at low luminosity (~ first good 10 fb⁻¹) can still deliver the SM Higgs, but discovery is more difficult close to the LEP limit.
Hierarchy: SUSY

- SUSY: fermion-boson symmetry $\rightarrow$ all SM particles have SUSY partners with $\Delta\text{spin}=1/2$
- No evidence for $m(\text{SM})=m(\text{SUSY})$ $\rightarrow$ models for SUSY breaking (MSUGRA, GMSB, AMSB)
- $R$ parity (no proton decay) $\rightarrow$ SUSY particles pair-produced and decay to stable lightest SUSY particle

**Strategy**
- Inclusive searches to extract SUSY excess from bkg
  
  Use
  
  $M_{\text{eff}}=E_T^{\text{miss}} + \sum_{i=1}^{4} p_T(\text{jet})$ (GeV)

  Measure kin. edges in chain decays to determine SUSY masses and parameters

**Event topology:**
- Large missing ET
- Large multiplicity of High $p_T$ jets
- Possibly leptons

**MSUSY correlated with $M_{\text{Eff}}$!**

Nutshell SUSY

Copious gluino/squark production then cascade decay to stable lightest SUSY particle

(Edward as example)
Hierarchy: SUSY Inclusive searches

Build $M_{\text{Eff}}$ distributions ($P_T(jet)>20$ GeV)

- No leptons in final state
- Better estimate of high pt jets bkg by matching parton shower and matrix element description
- SUSY slope similar to SM bkg $\rightarrow$ careful bkg estimation is required

- One lepton in final state
  - Very promising for clean discovery
  - Top is dominant bkg: more under control

Estimate SM Bkg from data.
Normalize MC to low $E_T^{\text{miss}}$ and extrapolate to high $E_T^{\text{miss}}$
Ultimate performance example: Higgs parameters

- Higgs Mass can be measured with good resolution for all $m_H(10\% \text{ for })$

- Non SM spin/CP (0/1) hypothesis can be ruled out with 100fb for $m_H > 230$ GeV

- Coupling constants could be measured combining all available signals with a precision of 10-50% with 300 fb$^{-1}$ of data

- Higgs self coupling might be accessible at an upgraded SLHC
Conclusions

- ATLAS is a multi-purpose detector well poised to take advantage of the wealth of physics at LHC
- Installation for both ATLAS and LHC is progressing well
- Commissioning activity will be essential to
  - understand the detector
  - mark the smooth transition to measuring the SM @ $\sqrt{s}=14$ TeV
  - solid starting point to search for new physics
- ATLAS is well equipped to search for physics beyond the SM, even in difficult areas
- The scientific community is eager to test its view of the universe and discover more about it. 2007 is not far away!
Back-up Slides
Control Large beam current (0.53A) in superconducting environment (T~2K) to avoid magnet quench from beam losses

Reach high luminosity: curb beam-beam and collective instability losses; stabilize beam against non-linear effects of magnetic forces

Flexibility for further upgrades

Deal with 10GJ stored in magnets,

Max. energy: 7 TeV (~7 X Tevatron)

1.1 · 10^{11} protons per bunch

Filled bunches: 2808 / 3564

Bunch spacing: 24.95 ns

Lumi: 10^{34} \text{ cm}^{-2} \text{ s}^{-1} (>100 \times \text{Tevatron})

1232 superconducting dipoles (15m long at 1.9 K, B=8.33 T);

Circumference: 26.659m

E_{\text{beam(Stored)}}=350 \text{ MJ} (200 \times \text{Tevatron})

Operation with Heavy ions at 2.7 TeV /nucleon

1000/1650 main magnets delivered

~100 dipoles installed

Installation: cryogenics service line + magnets are "critical to maintain the schedule" (L.Evans 12/09/05)
LHC: more basics and facts

- 100 GeV electrons loses 2.9 GeV
- \( dE(\text{turn}) = \frac{2\pi}{x} \times P_{\text{circ}} \)
- A 500 GeV electron will lose all its energy after going along ~27% of LEP

# Particles used: Protons and heavy ions (Lead, full stripped 82+)
# Circumference: 26,659 m.
# Injector: SPS
# Injected beam energy: 450 GeV (protons)
# Nominal beam energy in physics: 7 TeV (protons)
# Magnetic field at 7 TeV: 8.33 Tesla
# Operating temperature: 1.9 K
# Number of magnets: ~9300
# Number of main dipoles: 1232
# Number of quadrupoles: ~858
# Number of correcting magnets: ~6208
# Number of RF cavities: 8 per beam; Field strength at top energy ~5.5 MV/m
# RF frequency: 400.8 MHz
# Revolution frequency: 11.2455 kHz.
# Power consumption: ~120 MW
# Gradient of the tunnel: 1.4%
# Difference between highest and lowest points: 122 m.

LHC Statistics

Main dipoles: 1232
Main quadrupoles: 430
Total main magnets: ~1650
Conclusions

**Main objectives:**
- terminate installation in February 2007
- first collisions in summer 2007

- The industrial production of standard components is compatible with this objective.
- The ramping up of QRL activities and magnet installation is critical to maintain this schedule.
- Additional actions have been implemented to ensure proper QRL production and installation rates.
- The installation and interconnection of cryomagnets have started in the tunnel.
- The commissioning of technical systems will take place in two adjacent sectors in parallel.

**Main next actions:**
- partial test of sector 7-8 in autumn 2005
- commissioning test of the two first sectors (7-8 and 8-1) in summer 2006
- find external collaborators to help with commissioning.
Inclusive Selection Signatures

- To select an extremely broad spectrum of “expected” and “unexpected” Physics signals (hopefully!).
- The selection of Physics signals requires the identification of objects that can be distinguished from the high particle density environment.

<table>
<thead>
<tr>
<th>Object</th>
<th>Examples of physics coverage</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrons</td>
<td>Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W/Z, top</td>
<td>(e^{25i}, 2e^{15i})</td>
</tr>
<tr>
<td>Photons</td>
<td>Higgs (SM, MSSM), extra dimensions, SUSY</td>
<td>(\gamma^{60i}, 2\gamma^{20i})</td>
</tr>
<tr>
<td>Muons</td>
<td>Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W/Z, top</td>
<td>(\mu^{20i}, 2\mu^{10})</td>
</tr>
<tr>
<td>Jets</td>
<td>SUSY, compositeness, resonances</td>
<td>(j^{360}, 3j^{150}, 4j^{100})</td>
</tr>
<tr>
<td>Jet+missing (E_T)</td>
<td>SUSY, leptoquarks, “large” extra dimensions</td>
<td>(j^{60} + \times^{E60})</td>
</tr>
<tr>
<td>Tau+missing (E_T)</td>
<td>Extended Higgs models (e.g. MSSM), SUSY</td>
<td>(\tau^{30} + \times^{E40})</td>
</tr>
</tbody>
</table>

**Also inclusive missing\(E_T\), Sum\(E_T\), Sum\(E_T\)_jet & many prescaled and mixed triggers**

The list must be non-biasing, flexible, include some redundancy, extendable, to account for the “unexpected”.

7th June 2005  M. Bosman IFAE Barcelona  F. Spanò
ATLAS Calorimetry

- **EM LAr-Pb**
  - Barrel (EMB): $|\eta| < 1.5$
  - EndCap (EMEC): $1.4 < |\eta| < 3.2$

- **Hadron Calorimeters**
  - Barrel (Tile) Scintill.-Steel: $|\eta| < 1.7$
  - End-Cap (HEC): LAr-Cu $1.5 < |\eta| < 3.2$

- **Forward Calorimeter**
  - $3.2 < |\eta| < 5.0$
  - Fcal1: LAr-Cu
  - Fcal2&3: LAr-W

Variety of materials, techniques, granularity, different performances
Need coherent view!
Physics challenges at the LHC

- Interactions every 25 ns ...
  - In 25 ns particles travel 7.5 m

- Cable length \( \sim100 \) metres ...
- In 25 ns signals travel 5 m

D. Froidevaux, TRDs for the Third Millennium, Ostuni, 08/09/2005
ATLAS Three Level Trigger Architecture

- **Level 1 Trigger**
  - Interaction rate: ~1 GHz
  - Bunch crossing rate: 40 MHz
  - Region of Interest: < 75 (100) kHz
  - LVL1 decision made with calorimeter data with relatively coarse granularity and muon trigger chambers data.
  - Buffering on detector

- **Level 2 Trigger**
  - ~2 kHz
  - Buffering in ROBs
  - LVL2 uses Region of Interest data (ca. 2%)
  - Combines information from all detectors
  - Performs fast rejection.
  - Buffering in ROBs

- **Event Filter**
  - ~200 Hz
  - Buffering in EB & EF
  - EventFilter refines the selection
  - Can perform event reconstruction at full granularity
  - Using latest alignment and calibration data.

**Event Recording**

---

2.5 μs

~10 ms

~ sec.
CTB04 - Summary of alignment & calibration

- Alignment corrections for the complete Pixel+SCT+TRT slice available in Athena from database
  - Alignment accuracy of corrections obtained with $B=0$ better than $10(80)$ $\mu$m for Si(TRT)
  - Residual distributions comparable to MC
- LAr calibration constants available in Athena from database
  - Harder environment than ATLAS: temperature problems, many timing changes etc.
  - Electronic calibration well understood (OFC)
  - Started “high level” calibration (cluster corrections etc.)
- MS alignment corrections available in Athena from database
  - Accuracy of relative alignment for both barrel and endcap obtained from optical systems $\sim 20\mu$m
  - For absolute alignment (optical systems) sagitta mean value of $350$ $\mu$m for barrel and $150$ $\mu$m for endcap
  - Reconstruction of tracks allows backtracking to Inner Detector with rms of $44$mm (over $40$m)
Fit function: $\sigma/E = a/\sqrt{E} + b$

For extended barrel (1997) geometry was different

<table>
<thead>
<tr>
<th>$\eta$</th>
<th>2004 Combined TB</th>
<th>1997 and 1998 standalone TB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a$ [%] GeV$^{1/2}$</td>
<td>$b$ [%]</td>
</tr>
<tr>
<td>0.25</td>
<td>54 ± 1</td>
<td>5.9 ± 0.1</td>
</tr>
<tr>
<td>0.35</td>
<td>57 ± 1</td>
<td>5.6 ± 0.1</td>
</tr>
<tr>
<td>0.45</td>
<td>54 ± 1</td>
<td>5.4 ± 0.1</td>
</tr>
<tr>
<td>0.55</td>
<td>50 ± 2</td>
<td>5.3 ± 0.1</td>
</tr>
<tr>
<td>1.1</td>
<td>43 ± 5</td>
<td>5.0 ± 0.4</td>
</tr>
<tr>
<td>1.2</td>
<td>52 ± 6</td>
<td>5.4 ± 0.5</td>
</tr>
</tbody>
</table>
Top Physics: Check combinatoric bkg using MC@NLO signal Monte Carlo

$m(t)$

Definition
Subset of events where chosen 3-jet combination does not line up with top quark (using MC truth information)

Empirical background shape describes combinatoric background well under peak
Strong $t\bar{t}$ pair production

$\sigma_{tt}(th)=825\pm150$ pb

NNLO-NNNLL: Kidonakis, Vogt, PRD 68 (03) 114014

This means 8 millions $t\bar{t}$ pairs/year (1 pair/second) at low luminosity!
Top Quark decay

SM: by far dominant $t \rightarrow bW$

$$\Gamma(t \rightarrow bW) \approx 0.807 \times \frac{G_F m_t^3}{8\pi \sqrt{2}} = 1.42\text{GeV}$$

$$|V_{tb}|^2 \approx \frac{3}{2} \times 1.42 \text{GeV}$$

$\tau_{\text{top}} \approx 5 \times 10^{-25}\text{sec} << \tau_{\text{hadr}} (10^{-23}\text{sec})$

Top decays before hadronization !!!

- No tt-bar bound states (gluon exchange)
- W helicity from SM V-A (no depolarization)

- Dilepton channels (ee, e\(\mu\), \(\mu\mu\))
- Lepton + jets ch. (e+jets, \(\mu\)+jets)
- All hadronic channel
Top Physics: Overview of fit results

<table>
<thead>
<tr>
<th></th>
<th>(M_{\text{top}}) (GeV)</th>
<th>Resolution (GeV)</th>
<th>(\sigma(N)) stat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signal only</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truth jets</td>
<td>171.1 ± 0.4</td>
<td>7.0 ± 0.2</td>
<td>6.0%</td>
</tr>
<tr>
<td>Full simulation</td>
<td>162.7 ± 0.6</td>
<td>15.8 ± 0.6</td>
<td>6.3%</td>
</tr>
<tr>
<td><strong>Adding W+jet background:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>164.1 ± 1.0</td>
<td>17.0 ± 1.5</td>
<td>10%</td>
</tr>
<tr>
<td>100%</td>
<td>165.9 ± 1.4</td>
<td>19.8 ± 2.8</td>
<td>17%</td>
</tr>
<tr>
<td><strong>100% background plus cut on m(W)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hadronic (M_W)= 80.4±10 GeV</td>
<td>160.0 ± 1.0</td>
<td>15.4 ± 1.2</td>
<td>8.3%</td>
</tr>
</tbody>
</table>
Gaining confidence: Top Physics Masses + W+4jets background

Observe both top and hadronic W peaks!
No b-tag assumed!

\[ m(t) \]
\[ m(W) \]

\[ \text{Number of events / 5.1 GeV} \]

\[ \text{S/B = 0.45} \]
\[ \text{S/B = 0.27} \]

\[ \text{W+jets and MC@NLO signal} \]

\[ \text{Top mass (GeV)} \]
\[ \text{W mass (GeV)} \]

\[ \text{Background} = \text{W+jets events (large, with large uncertainty) and improperly reconstructed t\bar{t}bar events} \]

\[ \text{Use peak position } M(W) \text{ for light jet energy calibration} \]

19th Sept. 2005 ATLAS Physics Potential - QPF 4 - Baku

F. Spanò
Effect of a mis-calibration of jet energy dominant systematics

Several methods to calibrate. Simplest one:

\[ R \equiv \frac{M_W^{PDG}}{M_W} = \sqrt{\alpha_1 \alpha_2} \quad \text{with} \quad \alpha_i = \frac{E_{i \text{part}}}{E_{i \text{jet}}} \]

- compute \( R \) for \( k \) bins in \( E \)
- \( \alpha_k = \langle \alpha_j \alpha_j \rangle \)
- apply \( \alpha_k \) factors on \( R \) and recompute \( R \) \( n \) times \( \Rightarrow \)

\[ \alpha_k^{\text{True}} = \prod_{n} \alpha_k^n \]
Higgs production and decay in a nutshell

- \( gg \rightarrow H \): dominant production, large QCD corrections, H often produced associated with a “hard” jet (\( ZZ^* \), \( WW^* \), \( \gamma \gamma \) decays)
- \( qq \rightarrow Hqq \) (\( WW \), \( ZZ \) fusion “VBF”). Specific signature allowing better background rejection (\( \tau \tau \), \( WW^* \), \( \gamma \gamma \) decays)
- \( ttH \) production: Lepton from top allows to trigger (\( bb \) decay, also \( \tau \tau \), \( WW^* \) for coupling measurements, \( \gamma \gamma \) at high lumi.) *(Eilam’s talk)*
Central analysis issues have been covered with DC1 and are being re-assessed with DC2/Rome production:

- **Photon calibration** (energy scale and resolution)
  - Separation of converted and unconverted photons

- **Photon angle correction**
  - Photon angle with help of calorimeter pointing and tracking vertex

- **Photon ID**
  - Achieve best rejection against jets
    - Photon/$\pi^0$ rejection
Inclusive $H \rightarrow \gamma \gamma$ to NLO

- NLO QCD corrections
  - Higgs production via MC@NLO generator
  - Higgs decay via HDecay program
  - Used QCD NLO corrections to background $pp \rightarrow \gamma \gamma + X$
  - Signal significance possibly further enhanced by 40%.

- $H \rightarrow \gamma \gamma$ may be a discovery channel on its own for 10 fb$^{-1}$

M.Cobal
Summary
ATLAS PHYS WOrkshop

TDR-like analysis with NLO $\sigma$
QCD NLO Corrections to Signal

- **Main production mechanism:** $gg \rightarrow H$
  - NLO corrections calculated by M. Spira et al.
  - Use MC@NLO as a MC generator
    - Implements NLO diagrams. Higgs $P_T$ description to LO. Re-summation effects well modeled

- **Second dominant process:** VBF $H$
  - NLO corrections first calculated by T. Han, G. Valencia, S. Willenbrock PRL69 (1991)
  - VBF $H$ not implemented in MC@NLO yet
    - Use Pythia and scale cross-section by 1.1

- **NLO QCD corrections to** $H \rightarrow \gamma \gamma$
  - Use $H$Decay (M. Spira)
**ttH, H→bb, DC1 Based Full Simulation**

- **Signal:** ttH(120) → lνb jjb bb (0.52 pb, H→bb 70%), 20k events
- **Background:** ttjj (474 pb), 100k (filtered)~250K events ~ 0.5fb⁻¹!

**CBNT Analysis**
- using “realistic” b-tagging performance and selection/rejection efficiencies of signal/background (SV2 method)

→ **b-tag session this afternoon**

![Graphs showing jet rejection vs. jet efficiency and SV2 jet weight with b and light jets distinguished.](image)

Eilam Gross
ATLAS Phys Workshop Rome

*S. Correard, CPPM*
Use likelihood to find the jet best pairing, do not cut on likelihood, but replace it with a cut on the sum of weights of four b quarks.
Light Higgs Search: $ttH \rightarrow ttbb$

- Complementary to $H \rightarrow \gamma\gamma$
- Fully reconstructed final state (except $\nu$)
- Requires good $b$-tagging
  - $\epsilon_b \approx 60\%$, $R_{uds} \approx 100\%$
- Backgrounds:
  - Combinatorial from signal
  - Irreducible $ttbb$ ($ttjb$, $ttjj$)
- Signal significance ($5\sigma$):
  - $m_H < 120$ GeV needs $100$ fb$^{-1}$
  - $m_H < 130$ GeV needs $300$ fb$^{-1}$

$\sigma \times BR \approx 300$ fb

Events / 16 GeV

ATLAS (1999)
$m_H = 120$ GeV/$c^2$
$100$ fb$^{-1}$
### Summary $ttH \rightarrow ttbb$

**Low Luminosity** 30 fb$^{-1}$

<table>
<thead>
<tr>
<th></th>
<th>TDR</th>
<th>Likelihood</th>
<th>Likelihood</th>
<th>AOD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FAST</td>
<td>FAST</td>
<td>FULL</td>
<td>A.W.</td>
</tr>
<tr>
<td>$ttH$ (120)</td>
<td>28</td>
<td>45.6</td>
<td>51.4</td>
<td>53</td>
</tr>
<tr>
<td>$ttbb$</td>
<td>148.4</td>
<td>187</td>
<td>86.1</td>
<td></td>
</tr>
<tr>
<td>$ttjj$</td>
<td>44.7</td>
<td>63</td>
<td>&lt;45</td>
<td>63</td>
</tr>
<tr>
<td>signific</td>
<td>2.0</td>
<td>2.9</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>Signific (inc syst)</td>
<td>1.3</td>
<td>2.0</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>$1/(S/B)$</td>
<td>6.8</td>
<td>7.7</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>$\Delta_{\text{syst}}$</td>
<td>*7.6%</td>
<td>*6.1%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Eilam Gross
ATLAS Phys Workshop
Rome

19th Sept. 2005
ATLAS Physics Potential - QPF 4 - Baku
F. Spanò
**Experimental Issues**

**Forward Tagging Jets:**
- Difficult Forward Region
- Jet Calibration

**Central Jet Veto:**
- Sensitive to pileup
  - +Multiple Interactions
  - +Electronic Noise
  - +PileUp

**Electron Identification:**

**Hadronic Tau Identification:**

**Muon Identification:**

**ET Miss:**
- Central to Tau Reconstruction
- Reconstructed Higgs Mass
- Dominant Experimental Issue
Collinear Approximation & Central Jet Veto

Mass Reconstruction:

- Observe missing transverse momentum and visible Tau-decay products
- Assume Tau decay products collinear with original Tau
- Solve 2 linear equations for the neutrinos
- Taus can be reconstructed
- Higgs can be reconstructed

\[
\begin{align*}
  x_{\tau h} &= \frac{h_x l_y - h_y l_x}{h_x l_y + p_x l_y - h_y l_x - p_y l_x} \\
  x_{\tau l} &= \frac{h_x l_y - h_y l_x}{h_x l_y - p_x l_y - h_y l_x + p_y l_x}
\end{align*}
\]

Central Jet Veto:

Because the signal is an electroweak process, we expect depleted jet activity in the central region \( \Rightarrow \text{Veto on central jets} \)

Local Hadron Calibration Strategy

- Disentangle and factorize different effects
  - Discriminate em and had deposits
  - Local energy scale to separate separate signal calibration from acceptance/hardware corrections (dead material, containment...)
- Connect local energy “blobs” at Test Beam with those in jets: aim at extracting normalization from single particles
  - From clusters: perform particle ID, build jets; apply final corrections (ID, jet algorithm dependent)

Important Features

- Equalize detectors' response to energy deposited by electrons: common scale for Test Beam/ATLAS/DATA/MC
- Noise suppression
- Topological correlations to build energy blobs i.e. localize energy deposit
- Classification in e.m., had based on cluster shape
- Signal Weighting: calibrate local energy depositions of had. clusters to compensate for e/π

Final Physics Calibration/Reconstruction

Specific Weighting to calibrate Cluster

Cluster Formation and Classification

Local Signal Definition

Noise Suppression

Electronic Calibration and EM scale

F. Spanò

ATLAS Physics Potential - QPF 4 - Baku

19th Sept. 2005
Matching parton shower and matrix element

Parton Shower is the good model in the collinear region, but PS has some problem in the high $P_T$ region.

$P_T$ distributions of the additional jets for

3rd and 4th jets in multijet (QCD) were also estimated with PS in the previous study. They have the same problem. $\rightarrow P_T$ of jets were underestimated in the previous.

Hard jet is not emitted in Parton Shower. (It is famous problem.)
SM background to SUSY

[1–2] Production with Matrix Elements

◆ **ALPGEN(V1.33)** is used to produce $W+N$jets, $Z+N$jets and $tt+N$jets. $P_T>20$GeV and $R_{ij}>0.7$ are required to remove collinear and soft divergence. ($N<=6$ for $W/Z$, $N<=3$ for top are produced)

◆ Collinear and soft kinematic regions are covered by the Parton Shower (PYTHIA). ME–PS matching is performed with MLM method. About 60% of generated events are rejected $\rightarrow$ corresponding to Sudakov factor

◆ **ATLFAST** is used for the Detector Simulation (Fast Simulation: ATHENA9.0.2)

Fake $E_T^{miss}$ is important to estimate the Multijet (QCD) background. Detail study using the full simulation with realistic experimental condition is necessary to estimate Fake $E_T^{miss}$. Non-Gaussian tail of $E_T^{miss}$, material effect, imperfect calibration in the first year, and the noise effect should be carefully parametrised for the Fast simulation. (otherwise we can not estimate Multijet)
SUSY parameter space

- Various ways to create some order in the chaos of multi-parameter space
  - Unified boson ($m_0$) and fermion ($m_{1/2}$) masses at GUT scale as in mSUGRA models:
    - Only 4 free parameters remain: $m_0, m_{1/2}, \tan \beta, A_0, \text{sign } \mu = \pm$
- Select several mSUGRA points
  - Consistent with WMAP data for cold dark matter
  - Don't believe mSUGRA, but use it to suggest interesting possible particle spectra
  - Typically $\sigma > 1 \text{ pb}$, so early discovery physics
- Analyze each of these points
  - E.g. point SU1:

$m_0 = 70 \text{ GeV}$, $m_{1/2} = 350 \text{ GeV}$, $A_0 = 0$, $\tan \beta = 10$, $\text{sign } \mu = \pm$

$m(\tilde{q}_L) - M(\tilde{t}_L) = 8.5 \text{ GeV}$, $M(\tilde{t}_R) - M(\tilde{t}_L) = 17 \text{ GeV}$

$m(\tilde{g}_R) - M(t_2) = 6.6 \text{ GeV}$, $M(t_1) - M(\tilde{g}_R) = 9.5 \text{ GeV}$
SUSY: Top background from data

- Obtain the $E_T^{\text{miss}}$ distribution from data using top events
  - By fixing the top mass in the leptonic channel, predict $E_T^{\text{miss}}$
  - Select top without b-tagging
- $E_T^{\text{miss}}$ for top signal minus sideband
  - Reduce combinatorical background
  - Normalise at low $E_T^{\text{miss}}$, where SuSy signals are small

- Add SUSY
  - Repeat procedure with SuSy signal included
  - $E_T^{\text{miss}}$ distribution from data
  - Clear excess from SuSy at high $E_T^{\text{miss}}$ observed: method works!

D. Tovey
ATLAS Physics Workshop
Rome

ATLAS Preliminary

ATLAS Preliminary
T1 + SuSy
Extra Dimensions

Phenomenology at Tevatron collider:

- Direct production of graviton/Kaluza Klein excitations (a whole tower of particles...)

- Indirect effect (i.e. modification of spectra/cross section)

- CDF and D0 searched for modification of $ee, \mu\mu, \gamma\gamma$ production
  - Interpreted in both LED and RS models

- D0 also searched for effects of TeV$^{-1}$ ED in its ee data

- Searches for excess of missing energy in jet events could be interpreted within the ED framework
  - CDF performed a search in 70 pb$^{-1}$ which has not been updated to the current dataset
SUSY is strongly constrained by cosmology – WMAP

- New allowed region \(0.094 \leq \Omega \chi h^2 \leq 0.129\)
- \(\Omega \chi h^2 \sim m_\chi n_\chi\) (relic density) implies lighter neutralino

Can we find SUSY?

Region Disfavoured by BR \((b \to s \gamma)\)
\[= (3.2 \pm 0.5) \times 10^{-4}\] (CLEO, BELLE)

Favoured by \((g_\mu -2)\) at 2\(\sigma\)

Old constraints
\[0.1 \leq \Omega \chi h^2 \leq 0.2\]
SUSY mass scale from inclusive analysis

Inclusive variable:

\[ M_{\text{eff}} \equiv \sum_{i} |p_{T(i)}| + E_{T}^{\text{miss}} \]

\( p_{T(i)} \equiv \text{transverse momentum of jet } i \)

\( M_{\text{eff}} \) distribution for SUSY signal shows a peak.

Define SUSY scale:

\[ M_{\text{eff}}^{\text{susy}} = \left( M_{\text{susy}} - \frac{M_{\text{eff}}^{2}}{M_{\text{susy}}} \right), \text{ with } M_{\text{susy}} \equiv \frac{\Sigma_{i} M_{i} \sigma_{i}}{\Sigma_{i} \sigma_{i}} \]

Test the correlation of \( M_{\text{eff}} \) with \( M_{\text{eff}}^{\text{susy}} \) on a random set of models: mSUGRA and MSSM

Excellent correlation in mSUGRA, acceptable for MSSM

Mass scale to \( \sim 10\% \) (100 fb\(^{-1}\))
SUSY full discovery potential for ATLAS (MSUGRA)

- ATLAS reach in SUSY
Measuring Higgs boson Spin and CP

- Spin 1 discarded if H → γγ or gg → H are observed.
- Verification of J=0, CP=1: compare angular distributions for different J, CP hypothesis, for H → ZZ → 4leptons.
- For m_H > 250 GeV: R can unambiguously separate the hypothesis, for 100 fb⁻¹.

\[ G(\theta) = T \left( 1 + \cos^2 \theta \right) + L \sin^2 \theta \]
\[ R = \frac{L - T}{L + T} \]

P. Conde Muñó, HEP 2005, Lisbon, 21st July