Strategies for early physics with ATLAS at the LHC

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Getting ready for first LHC collisions

- **ATLAS has very ambitious performance goals**
  - driven by physics requirements
  - needs time and effort to control the detector at required level
  - final understanding of detector only achievable with LHC collisions

- **Pressure to extract results as soon as possible**
  - competition with other experiments
  - feedback signs of new physics to HEP community for planning

- **Exploit time available before collisions to understand the detector enough to take advantage of the very first data**
  - beam tests
  - detector and computing commissioning
  - preparation of calibration and analysis strategies
Initial conditions

- Assume the ATLAS detector installed
- Assume good knowledge of the detector
  - many years of simulation and (combined) beam test studies
  - commissioning at low and high rates
    - electronics pulser systems
    - cosmic rays: detector timing and alignment
    - first injections (beam gas collisions / beam halo muons): more specialized alignment work

- Expected detector performance at first collisions
  - EM calorimeter response uniformity ~1%
  - Hadronic calorimeter response uniformity 2 to 3%
  - $\gamma/e/\mu$ energy scale 0.5 to 2%
  - Jet energy scale <10%
  - Tracker alignment (in $R_\phi$ plane) 20 to 200 $\mu$m
LHC luminosity profile and physics reach

![LHC luminosity profile and physics reach graph]

- **ADD X-dim@9TeV**
- **SUSY@1TeV**
- **Higgs@200GeV**
- **SUSY@3TeV**
- **Compositeness@40TeV**
- **Z’@6TeV**
- **H(120GeV)\to\gamma\gamma**

**Integrated luminosity (fb⁻¹)**

- **L = 10^{33}**
- **L = 10^{34}**
- **SLHC: L = 10^{35}**

**End of Year**

- **2008**
- **2010**
- **2012**
- **2014**
- **2016**
- **2018**

**Early physics**

- **O(1fb⁻¹)**

M. Lefebvre

Strategies for early physics, NSERC ATLAS Review, 15-16 Dec 2006
LHC PP Cross Section

\[ \sigma_{pp}^{(14\text{TeV})} \]

- 10^{14} inelastic
- 10^{11} b\bar{b}
- 10^{8} QCD jets (\(P_T > 200\text{ GeV})
- 10^{5} W \rightarrow e\nu
- 10^{5} Z \rightarrow e\bar{e}
- 10^{2} \text{Higgs} (m_H = 100\text{ GeV, } 200\text{ GeV, } 800\text{ GeV})

- \tilde{q}\tilde{q} (m_{\tilde{q}} = 1\text{ TeV}) m(\tilde{q}) \approx 1\text{ TeV}

- 1 fb^{-1}

**Assume total pp cross section known to \sim 1\% from the TOTEM experiment**

**Typical cross sections:**

<table>
<thead>
<tr>
<th>Process</th>
<th>(\sigma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(W \rightarrow e\nu)</td>
<td>15 nb</td>
</tr>
<tr>
<td>(Z \rightarrow e\bar{e})</td>
<td>1.5 nb</td>
</tr>
<tr>
<td>(t\bar{t})</td>
<td>800 pb</td>
</tr>
<tr>
<td>(b\bar{b})</td>
<td>500 (\mu b)</td>
</tr>
<tr>
<td>(\tilde{q}\tilde{q}) (m_{\tilde{q}} = 1\text{ TeV})</td>
<td>1 pb</td>
</tr>
<tr>
<td>Higgs (m_H = 0.8\text{ TeV})</td>
<td>1 pb</td>
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</table>
Strategy for first interactions

- **First use of in-situ calibration** *(see Rob McPherson’s talk)*
  - understand and calibrate detector and trigger in-situ using well known physics samples

- **Understand basic SM physics at 14 TeV**
  - first checks of Monte Carlo simulations
  - first look at minimum bias events, jet distributions, parton density functions constraints; W, Z, top cross sections; top mass
  - understand detector signatures

- **The road to discovery**
  - understand SM backgrounds to searches
    - in particular missing $E_T$ distribution
  - focus on robust signatures that could reveal new physics without a complete knowledge of the detector response
    - for example, hunt for mass bumps where more than one sub-detector contribute to the signal
## Analyses in Canada for early physics

<table>
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<th>Topic</th>
<th>Institute</th>
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<td>QCD di-jets</td>
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<td>SM top physics</td>
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<tr>
<td>Hadronic top pair decays</td>
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<td>Anomalous top production</td>
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<td>Inclusive SUSY; fake / instrumental $E_T$</td>
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<td>Two-electron finder for Drell-Yan, $Z'$</td>
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<td>$Z'$ or strong interaction resonance in $\tau$ channel</td>
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<td>Black holes</td>
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<td>Randall-Sundrum graviton search</td>
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<td>Trigger-aware charged Higgs</td>
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<td>QCD event shapes and underlying event</td>
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<tr>
<td>$\tau$/jet separation and fake rate studies</td>
<td>Regina</td>
</tr>
<tr>
<td>$W'$ and $Z'$ studies</td>
<td>Regina</td>
</tr>
</tbody>
</table>
Trigger-aware analyses

- Triggering on interesting events is one of the greatest challenges at a hadron collider
  - All Computer System Commissioning (CSC) studies must be trigger-aware
- Canadian groups lead the efforts to characterize the trigger performance, in particular jet reconstruction

<table>
<thead>
<tr>
<th>Trigger jet slice</th>
<th>Level1: Custom made electronics. Produces regions of interest (RoIs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HLT: RoI algorithms sequence.</td>
</tr>
</tbody>
</table>

Level1: Custom made electronics. Produces regions of interest (RoIs)

L2: 
- **TrigT2CaloJet**: Fast Cone algorithm
- **TrigL2JetHypo**: Et cut

(L2 time budget: 10 ms per event)

EF: 
- **TrigCaloCellMaker**: Data unpacking
- **TrigCaloTowerMaker**: Calorimeter towers
- **TrigJetRec**: Jets Reconstruction
- **TrigJetHypo**: ET cut

(EF time budget: 1s per event)
Event filter jet reconstruction

- Event Filter (EF) jet calibration comparison

\[
\frac{p_T^{\text{trig}}}{p_T^{\text{offline}}}
\]

for di-jet samples and small ROI of 0.4 \times 0.4

for three different offline calibrations
Trigger menus for jets

- For performance studies
  - j20 ; j20kt ; 2j20 ; 3j20; 4j20
  - the 1,2,3,4 thresholds can be tuned simultaneously
  - compare $k_T$ and cone jet algorithms when analysing AOD/ESD

- Low luminosity
  - J160 ; 2J120 ; 3J65 ; 4J50
  - these signatures are available for trigger aware analyses
tau/jet separation studies

- samples used
  - $Z \rightarrow \tau\tau$ and $W \rightarrow \tau\nu$
  - di-jet samples

Athena 12.0.31
Electron ID and fake rate studies

- Electron identification using likelihood
  - distribution of some likelihood variables and the likelihood estimator
  - $0 < |\eta| < 1.3$
Electron ID and fake rate studies

- Likelihood efficiency studies
  - $1.3 < |\eta| < 1.6$

![Fake rate (% vs. efficiency (%)) diagram](image-url)
Missing $E_T$ studies

- Missing $E_T$ is expected to be a key signature for most theories beyond the SM, such as SUSY or extra dimensions
  - in SUSY, Missing $E_T$ is associated to a (new) weakly interacting particle, such as the lightest SUSY particle (LSP)
  - Thorough understanding of missing $E_T$ measurement essential to many studies, in particular missing $E_T$ tails

- SM source of missing $E_T$ must be studied carefully
  - processes involving neutrinos

- Instrumental source of missing $E_T$ can have many causes
  - known holes in the detector acceptance
  - unknown or poorly known material distributions
  - energy miscalibration
  - electronics problems
Missing $E_T$ fake rate studies

- Tools have been developed to study instrumental fake missing $E_T$.
  - Simulated data produced with a number of calorimeter channels turned off or at reduced voltage
    - Control crates, high-voltage lines, readout lines
  - Compare simulated data with and without degraded calorimeter
    - For processes with and without genuine missing $E_T$
  - Learn how to detect such problems
  - Understand the effect on the missing $E_T$ distribution (tails)

- Learn how to correct the calorimeter (and jet) energy

- Use corrections in inclusive searches for missing $E_T$ signal beyond the SM
  - For example SUSY, extra dimensions
Minimum-bias events

- One of the very first measurements
  - Modelling of pileup event crucial for high $p_T$ studies
  - extrapolating from Tevatron to LHC
  - in principle, only requires a few days of data
  - energy dependence of $dN/d\eta$?

PYTHIA favours $\ln^2 s$
PHOJET suggests $\ln s$

charged particle density at $\eta = 0$
Underlying event

- Also one of the very first measurements
  - Modelling of underlying event crucial for high $p_T$ studies
- Look at tracks in the region transverse to jet activity

$$\eta < 2.5$$

$$p_T^{\text{track}} > 1 \text{ GeV}$$

$$|\eta_{\text{track}}| < 2.5$$

Can be used to tune simulations

different UE models can change the reconstructed top mass by up to 5 GeV
QCD event shapes 🇨🇦

- Event shape variables under investigation
  - special event shape variables for pp collision
  - for example: thrust

\[
T_{\perp, g} = \max \sum_{i} \frac{|p_{\perp, i} \cdot \vec{n}_{\perp}|}{\sum_{i} |p_{\perp, i}|}
\]

- Thrust found sensitive to underlying event MC tune
  - potentially, an independent method to tune the MC
Top Quark Production

LHC is a top factory...

\[ \bar{t}t \text{ production} = 833 \text{ pb} \]
\[ \approx 10^6 \bar{t}t \text{ pairs produced for } 1 \text{ fb}^{-1} \]

\[ Wg \text{ fusion} \approx 245 \text{ pb} \]
\[ Wt \text{ production} \approx 60 \text{ pb} \]
\[ W^* \text{ channel} \approx 10 \text{ pb} \]

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Top mass

- Reconstructed top mass, without b-tagging, with 150 pb$^{-1}$
  - aim at extremely simple and robust selection criteria
  - one isolated e or $\mu$ with $p_T > 20$ GeV
  - missing $E_T > 20$ GeV
  - exactly 4 jets
    - $\Delta R = 0.4$
    - $|\eta| < 2.5$
    - $p_T > 40$ GeV
  - cut efficiency $\sim 4.5\%$
  - top mass obtained from the three jets with the max $p_T$ sum
  - systematics limited
    - in 175 GeV
    - out 167 +/- 0.8 GeV
Top mass from the fully hadronic channel

- Try to reconstruct the top mass from ttbar events in the fully hadronic channel (6 jets)
  - NLO: 369 pb
- Attempt without b-jet tagging
  - uses only calorimeter information
  - developing selection criteria
  - kinematic fit on 6 jets
- Background samples have been generated
  - QCD mlutijet
  - W + jets
  - non fully hadronic ttbar
- Preliminary results show that this is difficult to achieve
  - may need to use at least one b-tag
  - may also need to extend analysis using 5 jets
SUSY searches: effective mass

- Emphasis on $R$-parity conserving mSUGRA model
- Plan to perform both inclusive and exclusive searches
  - SM backgrounds include $W/Z$ + jets, QCD multijets, $tt\bar{t}$ and single top
- Inclusive search example: effective mass
  - study of $M_{\text{eff}} = E_T^{\text{miss}} + P_{T1} + P_{T2} + P_{T3} + P_{T4}$

![Graph showing effective mass distribution with points and lines indicating Standard Model and SUSY SU3 models. The graph has a legend indicating points in bulk region with 0.1 fb$^{-1}$ data.]
SUSY searches: dilepton endpoint

- **Exclusive search example: dilepton endpoint**
  - search for the next to lightest SUSY particle (NLSP)
  - decay mode $\tilde{\chi}^0_2 \rightarrow \tilde{\ell}^{\pm} \ell^{\mp} \rightarrow \tilde{\chi}^0_1 \ell^+ \ell^-$
  - look at $M_{ll}$: sharp edge (endpoint) expected

$$M_{ll}^{\text{max}} = M(\tilde{\chi}^0_2) \sqrt{1 - \frac{M^2(\tilde{\ell}_R)}{M^2(\tilde{\chi}^0_2)}} \sqrt{1 - \frac{M^2(\tilde{\chi}^0_1)}{M^2(\tilde{\ell}_R)}}$$

- for SU3, the endpoint is expected at 100.3 GeV
- flavour-subtracted
  - $e^+e^- + \mu^+\mu^- - e^+\mu^- - \mu^+e^-$
  - 2.45 fb$^{-1}$
SUSY searches: anomalous top production

- Physics BSM, such as SUSY, can lead to anomalous (non-SM) top quark production
  - can have different kinematic distributions than SM ttbar or single top
- Inclusive search for top quark production, non assuming SM kinematics, is under way
  - attempting to use hadronic top decays and constrained kinematic fit
    - W and top mass constraints
  - dominant background seems to be SM ttbar where one top decays semi-leptonically
- In some SUSY models anomalous top production can be a potential discovery channel below 1 fb⁻¹.
- Early’ish physics
Z’ and W’ studies

- Many theories predict new gauge bosons
  - backgrounds: ttbar, dijet, W+jets, Z+jets, dibosons, Drell-Yan
- Analyses involve muon and electron performance at very high $p_T (>1$ TeV)... “earlyish” physics.
- Example: $Z' \rightarrow ee$  
  - here normalized for 10 fb$^{-1}$
Comments and Conclusions

- We are aggressively getting ready for first collisions
  - take advantage of our ATLAS detector expertise
  - ATLAS Canada computing in fast progress (see M. Vetterli’s talk)
  - we need to increase our presence at CERN

- Canadian involvement in early physics analyses
  - broad range of interests
    - trigger
    - jets, leptons, missing $E_T$ signatures
    - SM processes
    - first search for evidence of BSM physics
  - integrated in ATLAS working groups
  - strong involvement in CSC notes preparation
  - frequent regional Canadian meetings
Total proton-proton Cross Section

\[
\sigma_{\text{tot}} = \sigma_{\text{elas}} + \sigma_{s.\text{dif}} + \sigma_{d.\text{dif}} + \sigma_{n.\text{dif}}
\]

**Elastic**: both hadrons are not broken up to form new hadrons.

**Diffractive**: one (or both) hadron gets excited to a more massive state with the same quantum numbers which subsequently decays, as in \( p \rightarrow N^* \rightarrow p\pi \).

A double pomeron exchange event is equivalent to a central diffractive event, a special type of **double diffractive** event.
The total cross section for $p\bar{p}$ and $pp$ scattering

\[\sigma_{\text{tot}}(\text{mb})\]

The high energy behaviour follows $(\ln s)^{\gamma}$

- $\gamma = 2.2$ (best fit)
- $+1\sigma$
- $\gamma = 1.0$

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Top mass

- Top mass and the underlying event

Different underlying event models can shift the top mass by up to 5 GeV