QCD and Electroweak Physics at the LHC

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Today's Menu

- Tevatron Appetizer
- QCD for a Starter
- EWK Boson Platter
- Dibosonic Dessert
- Outlook

Concentrated on a selection of recent results for LHC start-up, apologies for unavoidable omissions. Complete references can be found here:

**ATLAS public results web page:**
https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults

**CMS public results web page:**
https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

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From a WW Workshop in 2001
Tevatron Appetizer

Inclusive Jet Cross Sections

W Mass

Precision Measurements that take a lot of work to accomplish!

JES uncertainty: 2-3% D0, 3-4% CDF

See yesterdays talk by Rainer Wallny!
**The ATLAS Detector**

**Inner Detector (ID) tracker:**
- Si pixel and strip + transition rad. tracker
- $\sigma(d_{0}) = 15\mu m@20GeV$
- $\sigma/p_T = 0.05\%p_T \pm 1\%$

**Calorimeter**
- Liquid Ar EM Cal, Tile Had.Cal
- EM: $\sigma_E/E = 10%/\sqrt{E} \pm 0.7\%$
- Had: $\sigma_E/E = 50%/\sqrt{E} \pm 3\%$

**Muon spectrometer**
- Drift tubes, cathode strips: precision tracking +
- RPC, TGC: triggering
- $\sigma/p_T = 2-7\%$

**Magnets**
- Solenoid (ID) $\rightarrow$ 2T
- Air toroids (muon) $\rightarrow$ up to 4T

**Full coverage for $|\eta|<2.5$, calorimeter up to $|\eta|<5$**

See also JINST 3 2008 S08003

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The CMS Detector

Inner detector (tracker):
- Si pixel & strip tracker
- $\sigma/p_T \approx 1-2\%$ ($\mu$ at 100 GeV)

Calorimeter:
- PbWO4 crystal ECAL, brass/scintillator HCAL
- ELM: $\sigma_E/E = 2.8\% / \sqrt{E} + 0.3\%$
- HAD: $\sigma_E/E = 100\% / \sqrt{E} + 5\%$

Muon system:
- Drift tubes, cathode strips, resistive plate chambers
- $\sigma/p \approx 10 - 50\%$ (muon alone)
- $\approx 0.7 - 20\%$ (with tracker)

Magnet:
- Solenoid $\rightarrow 3.8T$

See also:
PTDR I LHCC-2006-001, JINST 3 2008 S08003
QCD/EWK at LHC Start-up

7 TeV, but still high enough rates left ...

- **Startup with SM Reactions:**
  - Not much statistically limited
  - First measurements at multi TeV energy scale
  - Re-establishment of Standard Model, i.e. test extrapolations from Tevatron energies
  - Background to be understood for almost everything
  - Physics commissioning of CMS
  - Be prepared for surprises ...

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**Assuming L = 10^{32} cm^{-2} s^{-1}**

- **MinBias**
  - 1/trigger prescale

- **Jet**
  - \( \sigma_{\text{jet}}(E_{T,\text{jet}} > 100\text{GeV}) \)
  - 40/sec

- **W, Z**
  - \( \sigma_{W}, \sigma_{Z} \)
  - 10/sec, 3/sec

- **Top**
  - \( \sigma_{tt}(E_{T,\text{jet}} > 350\text{GeV}) \)
  - 3/min

- **Higgs**
  - \( \sigma_{\text{Higgs}}(M_{H} = 150\text{ GeV}) \)
  - \( \sigma_{\text{Higgs}}(M_{H} = 500\text{ GeV}) \)

- **Trigger Rates**
  - 36/h

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Check MC with MinBias

Model expectations for charged particles at \(|\eta| = 0\) vs. \(\sqrt{s}\):

- Pythia: \(\sim \ln^2(s)\)
- Phojet: \(\sim \ln(s)\)

Data?

Need good tunes with LHC data!

ATLAS

\begin{tabular}{|c|c|c|}
\hline
Process & Cross-section (mb) & \\
\hline
non-diff. & 69 & 55 \\
single diff. & 11 & 14 \\
double diff. & 4 & 10 \\
central diff. & 1 & 1 \\
total inelastic & 85 & 79 \\
elastic & 35 & 23 \\
total & 120 & 102 \\
\hline
\end{tabular}
Strategy (used by Phobos at RHIC):

- **No tracking**, just hit counting in the pixel layers
- Cluster size to estimate z vertex
- Systematic uncertainty expected below 10%

Simulation result from CMS:

- Charged particle pseudo-rapidity distribution
- Pythia tune DWT

CMS Preliminary simulation

Assumes trigger efficiencies:

- SD 60%
- DD 70%
- ND 99%

CMS PAS QCD-08-004

CMS PAS QCD-07-001
Measurement possibility:
- Charged particle and $p_T$ sum densities in transverse region of leading jet of charged particles

The Underlying Event is everything but the hard scatter.
The Underlying Event

Charged particle density in transverse plane vs. leading charged jet $p_T$

Extrapolation to LHC from CDF data

Comparison of different Pythia tunes

Tracks:

$\rho T > 900\text{MeV}$

$|\eta| < 2$

Different Pythia tunes

Statistics as for 100/pb
The Underlying Event

Increase sensitivity with tracks from $p_T > 0.5$ GeV instead of $> 0.9$ GeV

Decrease systematic effects with ratio, but with similar systematic $→ 0.9 / 1.5$

CMS PAS QCD-07-003

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Jet Algorithms at LHC

In use lately:

- ICone-PR: R = 0.5
  (CL unsafe, CMS)
- ICone-SM: R = 0.4, 0.7
  (IR unsafe, ATLAS)
- $k_T$: R = 0.4, 0.6
  (ATLAS & CMS)
- SISCone: R = 0.5, 0.7
  (CMS)
- Anti-$k_T$: R = 0.5, ?
  (recently adopted by both, ATLAS & CMS)
- Cambridge/Aachen
  used in jet substructure, for example in boosted top

General interest to work with all these 4

Fast $k_T$, Cacciari/Salam, PLB641, 2006
SISCone, Salam/Soyez, JHEP05, 2007
anti-$k_T$, Cacciari et al., JHEP04, 2008
Jet Measurements

All jets in the event satisfying the selection criteria

$$\frac{d^2 \sigma}{d p_T dy} = \frac{N_{jets}}{\epsilon \cdot L \cdot \Delta p_T \cdot \Delta y} \times C_{unsm}$$

- Jet Efficiency
- Event Efficiency

Bins of corrected Jet Pt and Jet rapidity

The JES dominates the total uncertainty of the measurement

Unsmearing correction (due to the finite detector Pt resolution)
Jet Analysis Uncertainties

- **Theoretical Uncertainties** (~ in order of importance):
  - PDF Uncertainty
  - pQCD (Scale) Uncertainty
  - Non-perturbative Corrections
  - PDF Parameterization
  - Electroweak Corrections
  - Knowledge of $\alpha_s(M_Z)$
  - ...

- **Experimental Uncertainties** (~ in order of importance):
  - Jet Energy Scale (JES)
  - Noise Treatment
  - Pile-Up Treatment
  - Luminosity
  - Jet Energy Resolution (JER)
  - Trigger Efficiencies
  - Resolution in Rapidity
  - Resolution in Azimuth
  - Non-Collision Background
  - ...

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Jet Analysis Examples

Important especially at start-up:

- Underlying Event

Examples for jet analyses at high transverse momenta:

- Inclusive jet $p_T$ or dijet mass cross sections
  - Most complicated, require all uncertainties to be under control!

- Incl. jet or 3-jet cross section ratios, dijet mass cross section ratios in rapidity
  - Reduced sensitivity to JES, not dependent on luminosity

- Dijet azimuthal decorrelation, normalized dijet $\chi = \exp(|y_1 - y_2|)$ distr.
  - Less sensitive to JES, not dependent on luminosity

- Event shapes

- Jet shapes
**Inclusive Jets at the LHC**

$k_T, D=0.6, 10$ TeV

*Comparison with Contact Interactions*

- Tevatron limit $\sim 600$ GeV
- CMS preliminary
  - $k_T D = 0.6$
  - $\sqrt{s} = 10$ TeV
  - $\int L dt = 10$ pb$^{-1}$
  - $|y| < 0.55$

LHC reach $> 2 \times 600$ GeV with 10/pb at 10 TeV

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Uncertainties at Start-up

$k_T$, D=0.6, 10 TeV

Experimental Uncertainties

Comparison Exp. - Theory

CMS preliminary $k_T$ D = 0.6, $|y| < 0.55$, $\sqrt{s} = 10$ TeV

Rough estimate:
JES 6%
JES 3%
(years later ...)

CMS PAS QCD-08-001
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Non-perturbative Corrections

To compare with data correct NLO for:
- Multiple Parton Interactions (MPI)
- Hadronization & Decays (Lund, Cluster)

Compared different tuned MC:
- Pythia Tune D6T
- Herwig++

Theoretical Uncertainties

Take correction as average and half the spread as uncertainty.
Possible improvements:
1) Better MC Tunes with LHC data!
2) Full NLO event generator for QCD jets

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"The data are compared with QCD predictions for various sets of parton distribution functions. The cross section for jets with $E_T > 200$ GeV is significantly higher than current predictions based on $O(\alpha_S^3)$ perturbative QCD calculations. ..."

**Today:**

**Much better estimates of PDF uncertainties**

But beware ...

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**CDF 1996**

**Explained by change in gluon density which then can be constrained by jets!**


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**RADCOR 2009**
**Dijet Azimuthal Decorrelation**

**Dijets in pp collisions:**

$\Delta \phi \text{ dijet} = \pi \rightarrow$

Exactly two jets, no further radiation

$\Delta \phi \text{ dijet} \text{ small deviations from } \pi \rightarrow$

Additional soft radiation outside the jets

$\Delta \phi \text{ dijet as small as } 2\pi/3 \rightarrow$

One additional high-pT jet

$\Delta \phi \text{ dijet small } \rightarrow \text{ no limit } \rightarrow$

Multiple additional hard jets in the event

*hep-ex/0409040*

PRL 94, 221801 (2005)
Dijet Azimuthal Decorrelation

Dijets in pp collisions:

Angular measurement →
Reduced sensitivity to jet energy scale

Normalized →
No dependence on luminosity uncertainty

Also look into:

\[ \chi = \exp(|\eta_1 - \eta_2|) = \frac{1 + |\cos(\hat{\theta})|}{1 - |\cos(\hat{\theta})|} \]

Allows to look for deviations from QCD like scattering due to new physics (extra dimensions, ...)

Evaluation of systematics in progress ...

CMS PAS QCD-09-003
**Event Shapes**

**Definition:**
Transverse global Thrust
\(k_T\) jets, \(E_{T,i} > 80\) GeV, \(E_{T,\text{all}} > 60\) GeV

\[ T_{\perp,g} = \max_{\vec{n}_T} \frac{\sum_i |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_i p_{\perp,i}} \]

Similar as Event Shapes in \(e^+e^-\) and ep

- In praxis, need to restrict rapidity range: \(|\eta| < 1.3\) → Transverse central Thrust
- Less sensitive to JES & JER uncertainty
- No luminosity uncertainty
- Useful for MC tuning

CMS PAS QCD-08-003

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Jet Substructure

CDF like: Integrated jet shape

Calorimeter jets, $\sqrt{s} = 14$ TeV

New: $2^{nd}$ radial moment of jet profile

$$\langle \delta R^2_{jet} \rangle (p_T) = \frac{\sum_{i \in \text{jet}} \Delta R^2(i, jet) \cdot p_T^i}{\sum_{i \in \text{jet}} p_T^i}$$

Track jets, $\sqrt{s} = 10$ TeV

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W/Z Measurements

Uncertainties:

- $\Delta N$: Purely statistics; improves with integrated luminosity
- $\Delta B$, $\Delta A$, $\Delta \varepsilon$: Exp. & theor.; improves over time with better understanding
  - Background, acceptance & efficiency estimations, i.a. using MC detector simulations
- $\Delta L$: Luminosity uncertainty; improves with better understanding of LHC beam parameters and luminosity monitors
**W/Z Event Selections**

**ATLAS**

**Electron channels:**
- $W \rightarrow e\nu$: $E_{T,e} > 25$ GeV
  - $|\eta_e| < 2.4$
- MET > 25 GeV
- $M_T > 40$ GeV
- Veto 2nd e from Z
- $Z \rightarrow e\nu$: $E_{T,e} > 15$ GeV
  - $|\eta_e| < 2.4$

**Muon channels:**
- $W \rightarrow \mu\nu$: $p_{T,\mu} > 25$ GeV
  - $|\eta_\mu| < 2.5$
- MET > 25 GeV
- $M_T > 40$ GeV
- Veto 2nd $\mu$ from Z
- $Z \rightarrow \mu\mu$: $p_{T,\mu} > 15$ GeV
  - $|\eta_\mu| < 2.5$
  - $|M_{\mu\mu} - M_Z| < 20$ GeV

**CMS**

**Electron channels:**
- $W \rightarrow e\nu$: $E_{T,e} > 30$ GeV
  - $|\eta_e| < 2.5$
- MET > 30 GeV
- $M_T > 40$ GeV
- Veto 2nd e from Z
- $Z \rightarrow e\nu$: $E_{T,e} > 20$ GeV
  - $|\eta_e| < 2.5$

**Muon channels:**
- $W \rightarrow \mu\nu$: $p_{T,\mu} > 25$ GeV
  - $|\eta_\mu| < 2.0$
  - $M_T > 50$ GeV
- Veto 2nd $\mu$ from Z
- $Z \rightarrow \mu\mu$: $p_{T,\mu} > 20$ GeV
  - $|\eta_\mu| < 2.0$
  - $60 < M_{\mu\mu} < 120$ GeV

**Lepton isolation:** Radii in ($\eta, \Phi$) of 0.3 to 0.5 are imposed

**Lepton ID:** Criteria might be looser for $\mu$ compared to $e$ and for $Z \rightarrow ll$ compared to $W \rightarrow lv$

**Lepton Pairs:** Opposite charges required
# Inclusive W/Z Measurements

$E_{\text{cm}} = 14$ TeV

$N = \frac{N - B}{L A \varepsilon}$

<table>
<thead>
<tr>
<th>Process</th>
<th>$N \times 10^4$</th>
<th>$B \times 10^4$</th>
<th>$A \times \varepsilon$</th>
<th>$\delta A / A$</th>
<th>$\delta \varepsilon / \varepsilon$</th>
<th>$\sigma$ (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W \rightarrow e\nu$</td>
<td>22.67 ± 0.04</td>
<td>0.61 ± 0.92</td>
<td>0.215</td>
<td>0.023</td>
<td>0.02</td>
<td>20520 ± 40 ± 1060</td>
</tr>
<tr>
<td>$W \rightarrow \mu\nu$</td>
<td>30.04 ± 0.05</td>
<td>2.01 ± 0.12</td>
<td>0.273</td>
<td>0.023</td>
<td>0.02</td>
<td>20530 ± 40 ± 630</td>
</tr>
<tr>
<td>$Z \rightarrow ee$</td>
<td>2.71 ± 0.02</td>
<td>0.23 ± 0.04</td>
<td>0.246</td>
<td>0.023</td>
<td>0.03</td>
<td>2016 ± 16 ± 83</td>
</tr>
<tr>
<td>$Z \rightarrow \mu\mu$</td>
<td>2.57 ± 0.02</td>
<td>0.010 ± 0.002</td>
<td>0.254</td>
<td>0.023</td>
<td>0.03</td>
<td>2016 ± 16 ± 76</td>
</tr>
</tbody>
</table>

$L_{\text{int}} = 50/pb$ Signal Background Acc. & Eff.

$W: \sim 5\%$ Precision

$Z: \sim 3\%$ Precision

Without Luminosity uncertainty!

$L_{\text{int}} = 1/fb$

<table>
<thead>
<tr>
<th>Process</th>
<th>$N \times 10^5$</th>
<th>$B \times 10^5$</th>
<th>$A \times \varepsilon$</th>
<th>$\delta A / A$</th>
<th>$\delta \varepsilon / \varepsilon$</th>
<th>$\sigma$ (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W \rightarrow e\nu$</td>
<td>45.34 ± 0.02</td>
<td>1.22 ± 0.41</td>
<td>0.215</td>
<td>0.023</td>
<td>0.004</td>
<td>20520 ± 9 ± 516</td>
</tr>
<tr>
<td>$W \rightarrow \mu\nu$</td>
<td>60.08 ± 0.02</td>
<td>4.02 ± 0.05</td>
<td>0.273</td>
<td>0.023</td>
<td>0.004</td>
<td>20535 ± 7 ± 480</td>
</tr>
<tr>
<td>$Z \rightarrow ee$</td>
<td>5.42 ± 0.01</td>
<td>0.46 ± 0.02</td>
<td>0.246</td>
<td>0.023</td>
<td>0.007</td>
<td>2016 ± 4 ± 49</td>
</tr>
<tr>
<td>$Z \rightarrow \mu\mu$</td>
<td>5.14 ± 0.01</td>
<td>0.02 ± 0.001</td>
<td>0.254</td>
<td>0.023</td>
<td>0.007</td>
<td>2016 ± 4 ± 49</td>
</tr>
</tbody>
</table>

$W/Z: 1-2\%$ with 1/fb

Example from CMS, 10 TeV, 10/pb:

$W \rightarrow e\nu: <2\%$ stat., 4% syst.

$Z \rightarrow ee: <2\%$ stat., 2.4% syst.

Theory: $< 1\%$

Example from CMS, 10 TeV, 10/pb:

$W \rightarrow e\nu: <2\%$ stat., 4% syst.

$Z \rightarrow ee: <2\%$ stat., 2.4% syst.
W/Z Mass Distributions

Dominant background to $W\rightarrow e\nu$: $W\rightarrow \tau\nu$
Dominant background to $W\rightarrow \mu\nu$: $Z\rightarrow \mu\mu$ & $W\rightarrow \tau\nu$
Very clean process: $Z\rightarrow ee$

$Z\rightarrow ee$ mass, 10 TeV, 10/pb

$W\rightarrow e\nu$, $W\rightarrow \mu\nu$ transverse mass, 14 TeV, 50/pb
Z Differential Distributions

Z→ee, 14 TeV, 200/pb

Z→ee Channel

Z→ee, 10 TeV, 100/pb

Example from ATLAS for Z rap. and p_T distributions;

- statistical precision shown
- improve MC tuning & PDF knowledge
- reduce acceptance uncertainties in inclusive W/Z

Stat. uncertainty significant in Distributions with only 100/pb @ 10 TeV
**W/Z Asymmetries**

**FB-Asymmetry Z/γ*→eeX, 14 TeV, 100/fb**

**W Charge Asymmetry W→μνX, 10 TeV, 10/pb**

**ATLAS projection for the weak mixing angle:**
Exploits electron measurement in forward calos (2.5<|η|<4.9)
Needs 100/fb!

\[ \Delta \sin^2 \theta_{\text{eff}} = (1.5 \text{ (stat.)} \pm 0.3 \text{ (exp.)} \pm 2.4 \text{ (PDF)}) \cdot 10^{-4} \]

ATLAS, CERN-OPEN-2008-020

**CMS: Can constrain PDFs starting with only 50/pb**

CMS PAS EWK-09-003
A Word on the W Mass

$W \rightarrow e\nu$, $W \rightarrow \mu\nu$ transverse mass & lepton $p_T$, 14 TeV, 15/pb

<table>
<thead>
<tr>
<th>Method</th>
<th>$p_T(e)$ [MeV]</th>
<th>$p_T(\mu)$ [MeV]</th>
<th>$M_T(e)$ [MeV]</th>
<th>$M_T(\mu)$ [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta m_W$ (stat)</td>
<td>120</td>
<td>106</td>
<td>61</td>
<td>57</td>
</tr>
<tr>
<td>$\delta m_W$ ($\alpha_E$)</td>
<td>110</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>$\delta m_W$ ($\sigma_E$)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>$\delta m_W$ (tails)</td>
<td>28</td>
<td>&lt; 28</td>
<td>28</td>
<td>&lt; 28</td>
</tr>
<tr>
<td>$\delta m_W$ ($\epsilon$)</td>
<td>14</td>
<td>–</td>
<td>14</td>
<td>–</td>
</tr>
<tr>
<td>$\delta m_W$ (recoil)</td>
<td>–</td>
<td>–</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>$\delta m_W$ (bkg)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>$\delta m_W$ (exp)</td>
<td>114</td>
<td>114</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>$\delta m_W$ (PDF)</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>167</td>
<td>158</td>
<td>239</td>
<td>238</td>
</tr>
</tbody>
</table>

Current uncertainties on $M_W$: LEP combined: 30 MeV
Tevatron combined: 40 MeV $\rightarrow$ 31 MeV
World: 25 MeV $\rightarrow$ 23 MeV

Long term: 14 TeV, 10/fb: $\Delta M_W = O(<10$ MeV) per channel & exp.
Assumes i.a. radiative corrections to be under control.

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Start-up scenario!

Summer 2009, see R. Wallny yesterday
See also A. Vicini yesterday

PDG Review 2009
SN-ATLAS-2008-070
W/Z plus Jets

Uncertainties for $Z \rightarrow ee$+jets, JES dominant

$W \rightarrow \mu v$ + Njets distribution, 14 TeV

Reduced uncertainties N jets/ (N+1) jets ratios

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ATLAS public results page

CMS PAS EWK-08-006

ATLAS Preliminary
$Z(\rightarrow \mu\mu)$+n calo-jets
$\sqrt{s}=10$ TeV, $L=100$ pb$^{-1}$
Establish SM diboson signals with significance > 5σ:

- **WW, WZ, Wγ & Zγ**: 100/pb
- **ZZ**: 1/fb
Correction to yesterday :-)

Rainer

KR

Google
Outlook

- At the LHC we will go beyond Tevatron limits to explore unknown territory in the Standard Model and hopefully find some new physics
- LHC is a superb laboratory to investigate weak boson and jet production
- Some tough experimental systematics to deal with (JES, Luminosity)
  - First LHC data will enable us to write the detector user manuals
  - Together with YOU we will get better tuned MC generators & better PDFs
  - More data not only reduces statistical uncertainties but also allows to:
    - improve the understanding of the detectors (efficiencies, …) and LHC (lumi)
    - combine different detector parts to beat down on systematics
- Of course we always hope for new theory tools and more precise calculations
- New measurements are just ahead!

Thanks to the organizers for inviting me to this workshop in Ascona as one experimentalist of the week.
Backups
Both experiments try for start-up:
- to avoid b-tagging and missing $E_T$ selections
- use data driven methods for background estimation wherever possible ($W+\text{jets} \ldots$)
- uncertainty estimates on $t\bar{t}$ cross section of $O(20\%)$ syst., dom. by JES
Further Top Reading

From ATLAS Report:
See also: ATLAS public results page

- Top Quark Physics at ATLAS (introduction)
- Triggering top quark events in ATLAS
- Jets from light quarks in ttbar events (including jet caloribration)
- Determination of the top quark pair production cross-section
- Prospects for single top quark cross-section measurements
- Top quark mass measurements
- Top quark properties (top charge, spin, polarisation, rare decays and reconstruction of ttbar resonances)

Recent ATLAS Notes:
- Prospects for measuring top pair production in the dilepton channel with early ATLAS data at sqrt(s)=10 TeV (ATL-PHYS-PUB-2009-086).
- Prospects for the top pair pair production cross-section at sqrt(s)=10 TeV in the single lepton channel in ATLAS (ATL-PHYS-PUB-2009-087).
- Prospects for associated single top quark production cross-section measurements in the dilepton decay mode with ATLAS (ATL-PHYS-PUB-2009-001).

From CMS Physics Analysis Summaries:
See: CMS public results page

- TOP-09-009: Study of the top-pair invariant mass distribution in the semileptonic muon channel at 10 TeV (July 2009)
- TOP-09-001: Probing the heavy flavor content of the t-tbar dilepton channel at 10 TeV (July 2009)
- TOP-09-010: Expectation for a measurement of the t-tbar production cross section in the muon+jets final state using a multivariate technique (July 2009)
- TOP-09-002: Expectations for observation of top quark pair production in the dilepton final state with early data at 10 TeV (Jun 2009) This analysis supersedes the following two older results:
  - TOP-08-001: Di-lepton ttbar cross section with 10 pb^-1
  - TOP-08-002: Di-lepton ttbar cross section with 100 pb^-1
- TOP-09-003: Plans for an early measurement of the t-tbar cross section in the muon+jets channel at 10 TeV (Jul 2009) This analysis supersedes the following older result:
  - TOP-08-005: Semi-leptonic (muon) ttbar cross section with 10 pb^-1
- TOP-09-004: Plans for an early measurement of the t-tbar cross section in the electron+jets channel at 10 TeV (Jul 2009)
- TOP-09-005: Prospects for the measurement of the single-top t-channel cross section in the muon channel with 200 pb^-1 at 10 TeV (Jul 2009)
- TOP-09-007: Plan for a B(t->Wb)/B(t->Wq) measurement in ttbar semi-leptonic decays at 10 TeV (Jul 2009)
- TOP-08-004: Di-lepton ttbar tau channels (en route to)
- TOP-07-004: Jet Energy Scale from top events

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Recent Higgses

See also: ATLAS public results page

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<td>Prospects for the Discovery of the SM Higgs Boson using the $H \rightarrow \gamma \gamma$ decay</td>
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<td>Searches for the Standardmodel $H \rightarrow ZZ^* \rightarrow 4\ell$</td>
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<td>Searches for the SM Higgs Boson via VBF production processes in the di-$\ell$ channel</td>
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<td>Study of signal and background conditions in $t\bar{t}H$, $H \rightarrow WW^<em>$ and WH, $H \rightarrow WW^</em>$</td>
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<td>Discovery potential of $h/H/\chi_0 \rightarrow t\bar{t}l\bar{l}$</td>
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<td>Charged Higgs boson searches</td>
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<td>Statistical combination of several important Standard Model Higgs boson searches</td>
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From CMS Physics Analysis Summaries:
See: CMS public results page

- HIG-08-003: Search for Higgs to $ZZ^*$ **NEW** (January 2009).
- HIG-08-006: Search for Higgs to $WW^*$ **NEW** (January 2009).
- HIG-08-008: Higgs to tau-tau **NEW** (October 2008).
- HIG-08-001: $q\bar{q}H$ production, with $H \rightarrow$ tau-tau
Add some Flavour

See also: ATLAS public results page

Introduction to B-Physics
Performance Study of the Level-1 Di-Muon Trigger
Triggering on Low-$p_T$ Muons and Di-Muons for B-Physics
Heavy Quarkonium Physics with Early Data
Production Cross-Section Measurements and Study of the Properties of the Exclusive $B^+ \rightarrow J/\psi K^+$ Channel
Physics and Detector Performance Measurements for $B^0_d \rightarrow J/\psi K^{0*}$ and $B^0_s \rightarrow J/\psi \phi$ with Early Data
Plans for the Study of the Spin Properties of the $\Lambda_b$ Baryon Using the Decay Channel $\Lambda_b \rightarrow J/\psi (\mu^+\mu^-)\Lambda(p\pi^-)$
Study of the Rare Decay $B^0_s \rightarrow \mu^+\mu^-$
Trigger and Analysis Strategies for $B^0$ Oscillation Measurements in Hadronic Decay Channels

From CMS Physics Analysis Summaries:
See: CMS public results page

- BPH-07-001: Study of $B_s \rightarrow \mu^+\mu^-$ NEW (Jul 2009)
- BPH-09-001: Measurement of Differential Production Cross Sections and Lifetime Ratio for Exclusive Decays of $B^+$ and $B^0$ Mesons in pp Collisions at 10 TeV NEW (Jun 2009)
- BPH-08-004: Study of $b\bar{b}$ correlations using $J/\psi$ + muon events NEW (Mar 2009)
- BPH-07-002: Feasibility study of a $J/\psi$ cross section measurement with early CMS data (July 2008)
Cross Section Ratios

Cross section ratios in 6 bins in rapidity $y$

**SISCone 0.7 / $k_T$ 0.6 @ 10 TeV**

- FastNLO/NLOJet++ NLO (CTEQ65)
- SISCone, $R=0.7$ / incl. $k_T$, $D=0.6$

About 14 – 8% higher cross section than $k_T$

**$k_T$ 0.6 10 TeV / 14 TeV**

- FastNLO NLO (CTEQ65)
- Incl. $k_T$, $D=0.6$

<table>
<thead>
<tr>
<th>$p_T$ range</th>
<th>Change pre-scales</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 ≤ $</td>
<td>y</td>
</tr>
<tr>
<td>0.55 ≤ $</td>
<td>y</td>
</tr>
<tr>
<td>1.10 ≤ $</td>
<td>y</td>
</tr>
<tr>
<td>1.70 ≤ $</td>
<td>y</td>
</tr>
<tr>
<td>2.50 ≤ $</td>
<td>y</td>
</tr>
<tr>
<td>3.20 ≤ $</td>
<td>y</td>
</tr>
</tbody>
</table>

Loss in $p_T$ reach
Jet Energy Calibration

- **Offset**: Correct for detector noise and pile-up (use random triggers = zero bias, special read-out for noise)
- **Relative (\(\eta\))**: Equalize jet response in \(\eta\) w.r.t. control region (barrel) (dijet balancing; or MC)
- **Absolute (\(p_T\))**: Correct measured jet \(p_T\) to particle jet \(p_T\) (photon + 1jet, Z + 1jet events)

Optional analysis dependent corrections: Electromagnetic fraction, flavour, … will not discuss here

Initial assumption on JEC uncertainty: 10%

CMS PAS JME-07-002

Klaus Rabbertz  
Ascona, Switzerland, 27.10.2009  
RADCOR 2009
Absolute Correction

CMS detector simulation, calorimeter towers, $E_{\text{CMS}} = 10$ TeV

Comparison of jet responses

Derived correction at the example of $Z(\rightarrow \mu\mu) + 1\text{jet}$

CMS Preliminary

$\int L dt = 100$ pb$^{-1}$

$Z(\rightarrow \mu\mu)$ jet $p_t$ correction for SISCones 0.5

Statistical uncertainty for $\int L = 1$ fb$^{-1}$

Klaus Rabbertz
Ascona, Switzerland, 27.10.2009
RADCOR 2009
Jet energy resolution (JER):

- Can be measured from data using the Asymmetry Method used:
  
  For dijet events:
  
  \[ A = \frac{(p_{T1}^{\text{jet}} - p_{T2}^{\text{jet}})}{(p_{T1}^{\text{jet}} + p_{T2}^{\text{jet}})} \Rightarrow \left( \frac{\sigma_{p_T}}{p_T} \right) = \sqrt{2} \sigma_A \]

  Used at Tevatron.

- Comparison using MC information (matched jets) gives consistent results

Jet reconstruction efficiency:

- From tag-and-probe with Z+1jet events, > 95% for \( p_{T_Z} \approx 25 \text{ GeV} \)
  
  \( \approx 100\% \) for \( p_T > 30 \text{ GeV} \)

Initial assumption on JER uncertainty: 10% rel.
Jet Angular Resolutions

CMS detector simulation, calorimeter towers, $E_{CMS} = 14$ TeV

Resolution in jet rapidity

Resolution in jet azimuth

CMS Preliminary

0.0 < $|\eta_{GEN}| < 1.4$

- $ICone \ R=0.5$
- $MConR \ R=0.5$
- $SISConR \ R=0.5$
- $k_T \ D=0.4$

Assumes vertex at (0,0,0), can be corrected with tracks

Can be improved somewhat for $p_T < 200$ GeV with tracks

Also did not yet fully exploit finer granularity of ECAL

CMS PAS JME-07-003

Klaus Rabbertz

Ascona, Switzerland, 27.10.2009

RADCOR 2009
### Signal & Backgrounds W/Z

#### Elektron channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>$\sigma (\times B_r)$</th>
<th>$\epsilon_{\text{filter}}$</th>
<th>$N_{\text{evt}} (\times 10^3)$</th>
<th>$\mathcal{L}$ (pb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W \rightarrow e\nu$</td>
<td>20510 pb</td>
<td>0.63</td>
<td>140</td>
<td>11</td>
</tr>
<tr>
<td>$\gamma/Z \rightarrow ee, \sqrt{s} &gt; 60$ GeV</td>
<td>2015 pb</td>
<td>0.86</td>
<td>399</td>
<td>230</td>
</tr>
<tr>
<td>$\gamma/Z \rightarrow ee, \sqrt{s} &lt; 60$ GeV</td>
<td>9220 pb</td>
<td>0.022</td>
<td>197</td>
<td>969</td>
</tr>
<tr>
<td>$W \rightarrow \tau\nu\tau$</td>
<td>20510 pb</td>
<td>0.20</td>
<td>32</td>
<td>8</td>
</tr>
<tr>
<td>$Z \rightarrow \tau\tau$</td>
<td>2015 pb</td>
<td>0.05</td>
<td>13</td>
<td>129</td>
</tr>
<tr>
<td>$\tau\tau$</td>
<td>833 pb</td>
<td>0.54</td>
<td>382</td>
<td>850</td>
</tr>
<tr>
<td>Inclusive jets ($p_T &gt; 6$ GeV)</td>
<td>70 mb</td>
<td>0.058</td>
<td>2480</td>
<td>0.0006</td>
</tr>
<tr>
<td>Inclusive jets ($p_T &gt; 17$ GeV)</td>
<td>2333 $\mu$b</td>
<td>0.09</td>
<td>3725</td>
<td>0.02</td>
</tr>
<tr>
<td>$WW \rightarrow (e\nu)(e\nu)$</td>
<td>1.275 pb</td>
<td>1.00</td>
<td>20</td>
<td>15608</td>
</tr>
<tr>
<td>$ZZ$</td>
<td>14.8 pb</td>
<td>1.00</td>
<td>43</td>
<td>2922</td>
</tr>
<tr>
<td>$WZ$</td>
<td>29.4 pb</td>
<td>1.00</td>
<td>50</td>
<td>1699</td>
</tr>
</tbody>
</table>

#### Muon channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>$\sigma (\times B_r)$</th>
<th>$\epsilon_{\text{filter}}$</th>
<th>$N_{\text{evt}} (\times 10^3)$</th>
<th>$\mathcal{L}$ (pb$^{-1}$)</th>
</tr>
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<tbody>
<tr>
<td>$W \rightarrow \mu\nu$</td>
<td>20510 pb</td>
<td>0.69</td>
<td>190</td>
<td>13</td>
</tr>
<tr>
<td>$\gamma/Z \rightarrow \mu\mu, \sqrt{s} &gt; 60$ GeV</td>
<td>2015 pb</td>
<td>0.89</td>
<td>446</td>
<td>249</td>
</tr>
<tr>
<td>$W \rightarrow \tau\nu\tau$</td>
<td>20510 pb</td>
<td>0.20</td>
<td>32</td>
<td>8</td>
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<tr>
<td>$Z \rightarrow \tau\tau$</td>
<td>2015 pb</td>
<td>0.05</td>
<td>13</td>
<td>129</td>
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<tr>
<td>$\tau\tau$</td>
<td>833 pb</td>
<td>0.54</td>
<td>382</td>
<td>850</td>
</tr>
<tr>
<td>$b\bar{b} \rightarrow \mu + X$</td>
<td>766 $\mu$b</td>
<td>$2.1 \times 10^{-4}$</td>
<td>110</td>
<td>0.67</td>
</tr>
<tr>
<td>$b\bar{b} \rightarrow \mu\mu + X$</td>
<td>25 $\mu$b</td>
<td>$1.6 \times 10^{-4}$</td>
<td>140</td>
<td>35</td>
</tr>
</tbody>
</table>
Silicon Tracker

**Pixel:**
1 m² area
66 M pixels

**Strips:**
200 m² area
10 M strips

**Momentum resolution (μ, 100 GeV):**
1 – 2% (up to |η| ≈ 1.6)

**Reconstruction efficiency:**
μ: ≈99%, π: ≈90% (up to |η| ≈ 1.6)
Barrel (EB):
- $\eta$ segments: 2x85
- $\phi$ segments: 360
$\rightarrow$ 61200 crystals (PbWO$_4$, 26 $X_0$)
$\rightarrow$ $\Delta \eta \times \Delta \phi \approx 0.0174 \times 0.0174$

Endcaps (EE):
- (x,y) grid on two halves
- Front face 28 x 28 mm$^2$
$\rightarrow$ 2 x 2 x 3662 crystals = 14648 (PbWO$_4$, 25 $X_0$)

Energy resolution from test beam:
$S = 2.8\%$, $N = 120$ MeV, $C = 0.30\%$

$$\left( \frac{\sigma}{E} \right)^2 = \left( \frac{S}{\sqrt{E}} \right)^2 + \left( \frac{N}{E} \right)^2 + C^2$$
Hadronic Calorimeter

HCAL (tower structure):
- Barrel (HB): |\eta| < 1.4, 2592 towers
- Endcaps (HE): 1.3 < |\eta| < 3.0, 2592 "
- Outside coil (HO): |\eta| < 1.26, 2160 "
→ Depth (Brass abs. & plast. scint., ≈ 6 - 10 \lambda_{N})
→ \Delta \eta \times \Delta \phi \approx 0.087 \times 0.087 \rightarrow 0.350 \times 0.175

- Forward (HF): 2.9 < |\eta| < 5.0 (not shown)
→ 2 x 864 towers (Brass,quartz fibers, ≈ 10 \lambda_{N})
→ \Delta \eta \times \Delta \phi \approx 0.111 \times 0.175 \rightarrow 0.302 \times 0.350

CASTOR calorimeter (not shown):
- 5.1 < |\eta| < 6.5, ≈ 22 X_{0}, ≈ 10 \lambda_{N}

Design energy resolution:
~ (100/\sqrt{E} + 5.0) %