W- and Z-boson physics with early LHC data

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Physics at the LHC
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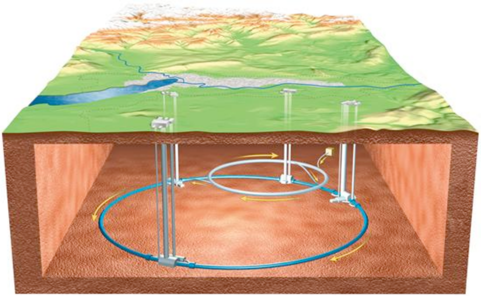
ATLAS EXPERIMENT
http://atlas.ch

Outline

1. Introduction: LHC, ATLAS and CMS
2. Standard Model measurements at LHC
3. Reconstruction efficiency calculation
4. W and Z signatures for cross-section measurements
5. Background estimation for $A \to \mu\mu$ Higgs searches
6. Summary

The Large Hadron Collider



The LHC in figures:

- pp collider with $\sqrt{s} = 14\,\text{TeV}$
- $27\,\text{km}$ circumference
- Magnetic field: $8.33\,\text{T}$
- Design luminosity $\mathcal{L} = 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$
- Integrated luminosity: $20 - 100 fb^{-1}$ per year
- First collisions: Winter 2010
- First year of operation: $\sim 200\,\text{pb}^{-1}$ @ $\sqrt{s} = 10\,\text{TeV}$

4 Experiments:

- **LHC-B** - b-Physics: CP-Violation, matter-antimatter-asymmetrie
- **ALICE** - Heavy ion physics: Quark-Gluon-Plasma
- **ATLAS & CMS** - multi purpose, search for new particles

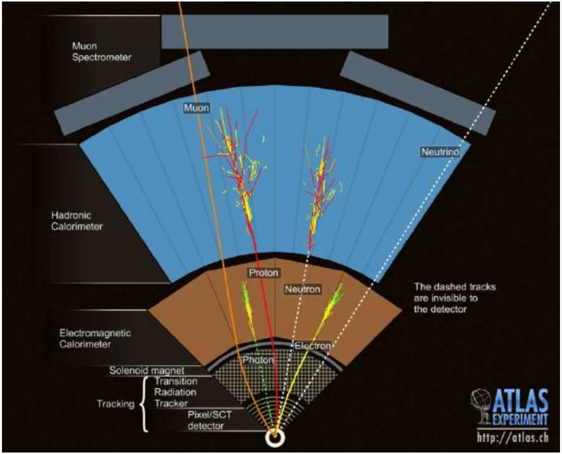
Particle identification

Stable particles in the final state:

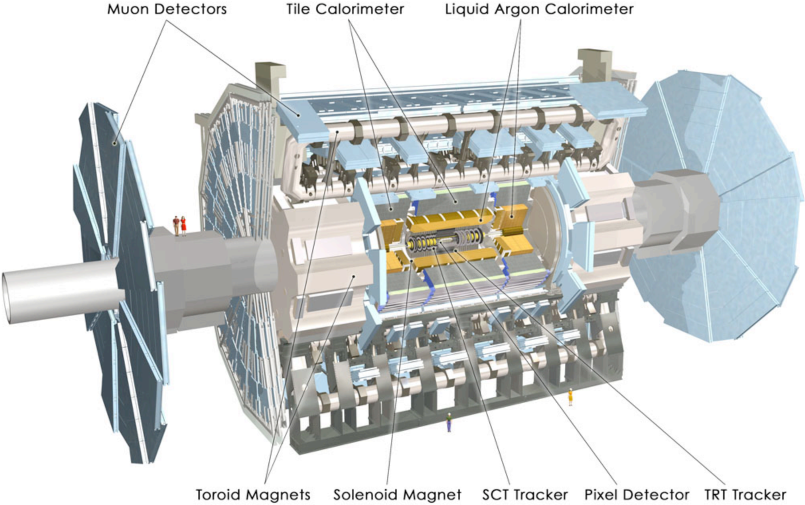
- Photons
- Electrons
- Neutrinos
- Muons
- Mesons, Baryons

Particles detectable via their decay:

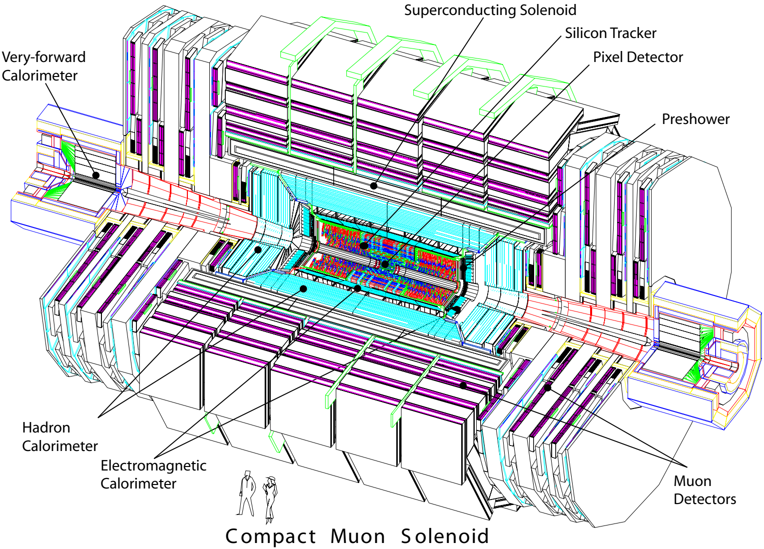
- b quarks $\rightarrow$ b-jet
- u, d, s, c quarks $\rightarrow$ light jets
- τ leptons $\rightarrow$ τ-jet
- t quarks $\rightarrow$ secondary vertex



The ATLAS detector



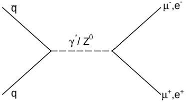
The CMS detector

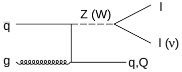


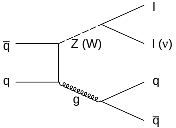
SM measurements with LHC data

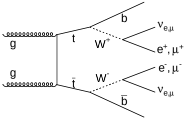
Why to measure Standard Model processes at the LHC?

- Performance tests
  - reconstruction efficiencies
  - jet reconstruction algorithms
  - MC generators
- Precision measurements
  - t-, b-quark physics
  - precision measurements of the m_W
  - cross-section measurements
- Background for new physics
  - high SM backgrounds for Higgs/SUSY searches
  - sensitive to systematic detector uncertainties









I - Efficiency calculation

$10\,\text{pb}^{-1}$ CMS data at $\sqrt{s} = 14\,\text{TeV}$

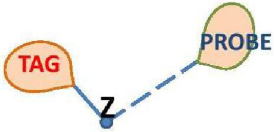
The tag-and-probe method

- Reconstruction, trigger and cut efficiencies important parameters for determination of detector performance
- calculation with MC data suffers from large uncertainties

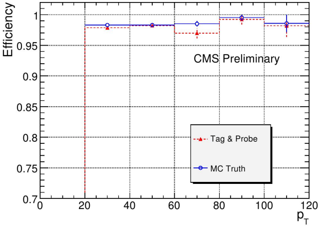
⇒ One can measure efficiencies directly from data using the tag-and-probe methods.

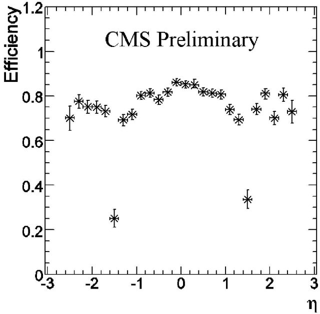
Tag-and-probe method

- Look for $Z \to \mu\mu$ events with high purity
- Tight cuts applied on one muon ⇒ "tag"-muon
- Second muon ("probe") has to pass only a subset of cuts
- $M^2 = (E_1 + E_2)^2 - \|\vec{p_1} + \vec{p_2}\|^2 \approx M_Z^2$



Electron and Muon efficiencies





Muon reconstruction efficiency:

- Tag-muon: passed all event selection criteria
- Probe-muon: track in inner detector

$$\text{Efficiency} = \frac{\#\ \text{reconstructed probe muons}}{\#\ \text{tag muons}}$$

Electron trigger efficiency:

- Tag-electron: passed full event selection and single isolated electron High Level Trigger
- Probe-electron: passed full event selection

$$\text{Efficiency} = \frac{\#\ \text{probe muons passed trigger}}{\#\ \text{tag muons}}$$

II - W and Z signatures for cross-section measurements

$10\,\text{pb}^{-1}$ CMS data at $\sqrt{s} = 14\,\text{TeV}$

Z signatures with early CMS data I

- Inclusive $pp \rightarrow Z + X \rightarrow ll + X$ cross-section measurements
- with $10\,\text{pb}^{-1}$ CMS data @ $14\,\text{TeV}$
- could be achieved in ~ 1 day data taking

Cross section calculation

$$\sigma_Z \times BR(Z \rightarrow ll) = \frac{N_Z^{pass} - N_Z^{bkgd}}{A_Z \times \epsilon_Z \times \int \mathcal{L} dt}$$

- N_Z^{pass} Number of selected events
- N_Z^{bkgd} Number of background events
- A_Z acceptance due to geometric and kinematic constraints
- ϵ_Z selection efficiency
- $\int \mathcal{L} dt$ integrated luminosity

Z signatures with early CMS data II

Various other SM processes with $\mu\mu$ or ee final states provide a background for Z signal

$\Rightarrow$ good event selection criteria to minimise background!

$\mu\mu$ final state

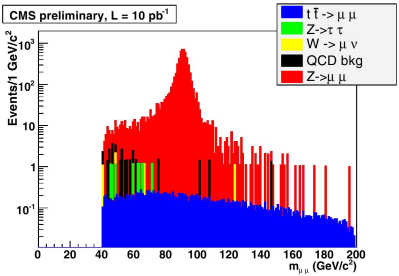
- 2 muons with transverse momentum $p_T > 20$ GeV
- $\sum_{tracks} p_T^{cone0.3} < 3$ GeV
- invariant mass cut: $M_{\mu\mu} > 40$ GeV

ee final state

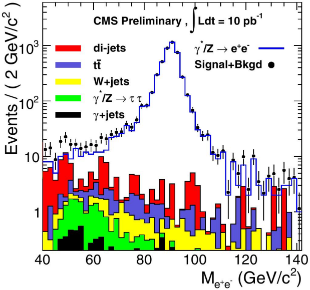
- 2 high-p_T electrons: high-p_T track & high-E_T supercluster with $E_T > 20$ GeV
- inside ECAL fiducial region $\eta < 2.5$
- $\sum_{tracks} \frac{p_T^{track}(0.02<\Delta R<0.6)}{p_T^{elec}} < 0.02$
- electron ID criterion satisfied

Z signatures with early CMS data III

$Z \rightarrow \mu\mu$



$Z \rightarrow ee$



$N_{selected} - N_{background}$	3914 ± 63
Tag-and-Probe ϵ_{total}	0.681 ± 0.006
Acceptance	0.3239 ± 0.0018
int. luminosity	$10pb^{-1}$
$\sigma_Z \times BR(Z \rightarrow ee)$	$1775 \pm 34pb$
Ref. cross section	$1787pb$

W signatures with early CMS data I

Event selection for inclusive $pp \to W + X \to l\nu + X$ searches

$\mu\nu$ final state

- transverse momentum $p_T > 25$ GeV
- $\sum_{tracks} p_T^{cone0.3}/p_T < 0.09$
- transverse mass $M_T > 50$ GeV

$e\nu$ final state

- high-p_T electron: high-p_T track & high-E_T supercluster $E_T > 30$ GeV
- inside ECAL fiducial region $\eta < 2.5$
- no track inside cone 0.6 around electron
- $\sum E_T^{cone0.3}$ in ECAL $< 3\%$, HCAL $< 10\%$ of E_T^{elec}
- tight electron ID cuts

W signatures with early CMS data II

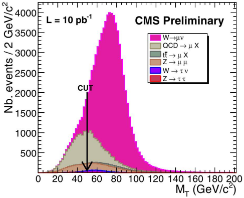
In $W \rightarrow l\nu$: neutrino escapes with a fraction of energy

$\Rightarrow$ Large missing energy in transverse plane

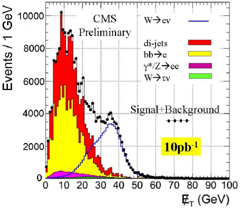
$\Rightarrow$ E_T^{miss} interpreted as E_T^{ν}

$\Rightarrow$ W-system built in transverse plane by combination of E_T^{lepton} & E_T^{miss}

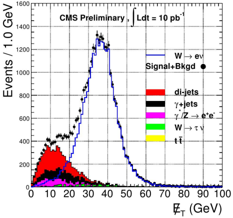
Transverse mass in $W \rightarrow \mu\nu$



Missing E_T in $W \rightarrow e\nu$ loose cuts



Missing E_T in $W \rightarrow e\nu$ tight cuts



For $W \rightarrow e\nu$ with loose cuts: $N_{sel} - N_{bkdg} = 67954 \pm 674$

$\Rightarrow \sigma \times BR = 19.97 \pm 0.25\,nb$ (Ref. cross-section $19.78\,nb$)

III - SM processes as a background for Higgs searches

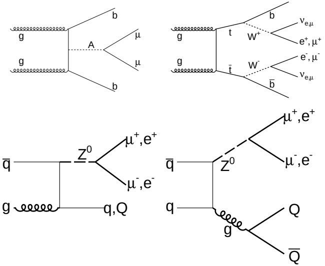
$1\,\text{fb}^{-1}$ ATLAS data at $\sqrt{s} = 10\,\text{TeV}$

Neutral MSSM-Higgs searches

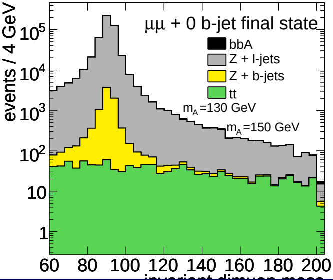
MSSM Higgs sector in a nutshell

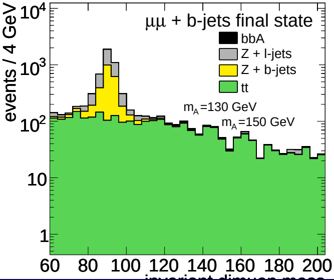
- MSSM requires <u>two</u> isospin doublets of complex scalar fields $\Rightarrow$ 8 DOF
- 3 DOF are absorbed in $W^{\pm}$, Z
- Remaining DOF correspond to 5 Higgs bosons: H, A, h, $H^{\pm}$
- At tree-level only two parameters are independent: m_A and $\tan\beta$

- Dominant production mode: bbA
- $A \rightarrow \mu\mu$: excellent mass resolution
- Various SM processes provide large background
- Most severe: $Z \rightarrow \mu\mu$



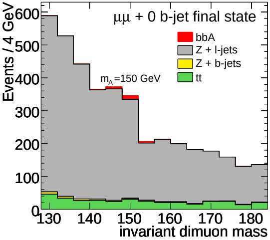
- Preselection cuts: 2 leptons with $p_T > 5$ GeV & $\eta < 2.5$
- Quality cuts on electrons and muons
- Isolation cuts: $\frac{E_T^{cone0.3}}{p_T} < 0.2$
- b-jet veto / b-jet requirement
- Opposite charge requirement
- Transverse momentum cut $p_T > 20$ GeV





$A \rightarrow \mu\mu$ cut evolution

- For $1fb^{-1}$: only 0 b-jet final state relevant



Cross-section $\times$ selection efficiency at $1fb^{-1}$

	bbA	Zbb	$Z+$ l-jets	$t\bar{t}$
no cut	62	$20 \cdot 10^3$	$610 \cdot 10^3$	$375 \cdot 10^3$
preselection	56	$14 \cdot 10^3$	$315 \cdot 10^3$	$44 \cdot 10^3$
quality cut	52	$13 \cdot 10^3$	$295 \cdot 10^3$	$40 \cdot 10^3$
isolation	49	$12 \cdot 10^3$	$275 \cdot 10^3$	$7.6 \cdot 10^3$
b-jet veto	42	$9.1 \cdot 10^3$	$270 \cdot 10^3$	$2.5 \cdot 10^3$
opp charge	42	$9.1 \cdot 10^3$	$270 \cdot 10^3$	$2.3 \cdot 10^3$
p_T cut	40	$7.3 \cdot 10^3$	$235 \cdot 10^3$	$1.5 \cdot 10^3$

- Even after various cuts: background several orders of magnitude higher than the signal
- Therefore a good background estimation needed!

$A \rightarrow \mu\mu$ background estimation I

Background estimation from data with signal-free final states:

- $BR(A \rightarrow ee) \simeq 0$
- $BR(Z \rightarrow ee) = BR(Z \rightarrow \mu\mu)$
- $BR(t\bar{t} \rightarrow e\mu) = BR(t\bar{t} \rightarrow ee) = BR(t\bar{t} \rightarrow \mu\mu)$
- A and Z cannot decay in $e\mu$ final state

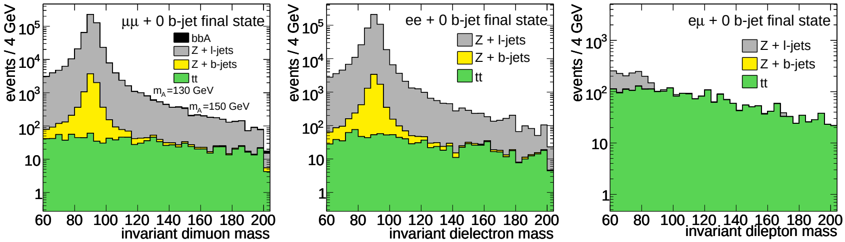
$\Rightarrow$ **Recipe for background estimation:**

1. Measure $t\bar{t}$ background with $e\mu$ final state
2. Subtract this from the measured ee and $\mu\mu$ final states
3. A pure $Z \rightarrow ee$ background and a $\mu\mu$ final state from A, Z remains
4. Subtract ee from $\mu\mu$ final states

$\Rightarrow A \rightarrow \mu\mu$ events survive

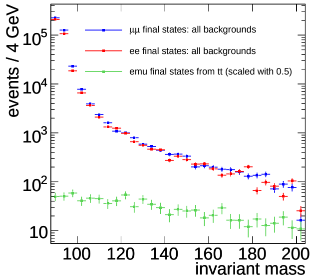
$A \to \mu\mu$ background estimation II

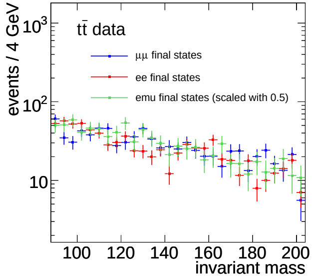
$\Rightarrow$ for this background estimation: search for 3 different final states



After a rough look on mass distributions...

- ee and $\mu\mu$ distributions are equal
- $e\mu$ distribution only from $t\bar{t}$ events

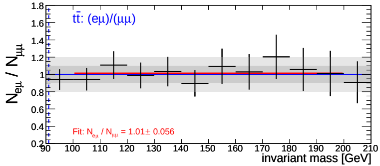


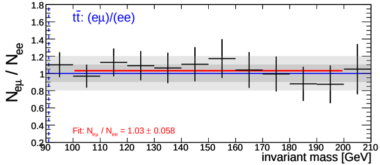


Step 1: The $e\mu$ final state...

...to estimate the $t\bar{t}$ background

$\Rightarrow$ With the measured $e\mu$ final states one can estimate the ee and $\mu\mu$ final states from $t\bar{t}$ perfectly!



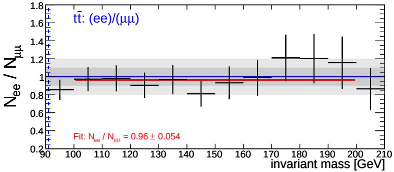


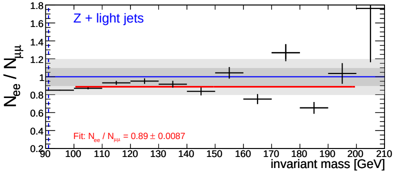
First results with $1\ fb^{-1}$ @ 10 TeV II

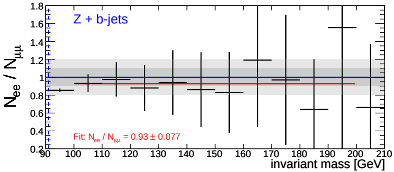
Step 2: The ee final state...

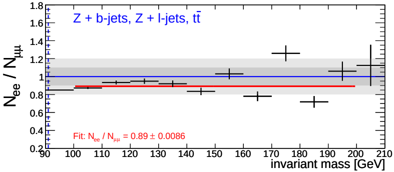
...to estimate the $\mu\mu$ background for $A \to \mu\mu$

$\Rightarrow$ The $\mu\mu$ final states from all background processes can be estimated with ee final states with an uncertainty of $\sim 10\%$









Summary

- Importance of SM measurements at LHC was shown on 3 different applications
- With very ealy data $(10pb^{-1})$:
  - $Z \to ll$ for detector performance
  - Cross-section measurements of SM processes
- For integrated luminosity $> 1fb^{-1}$:
  - SM processes for data-driven background estimation