Standard Model Physics with ATLAS and CMS

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On behalf of the ATLAS *and* CMS *Collaborations*

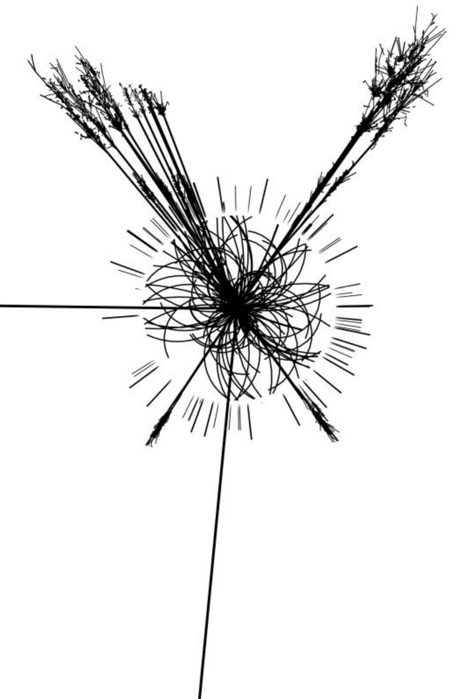
Outline

LHC was built as a discovery machine

- Target: find the Higgs and any new physics beyond the Standard Model (SM);

- Key issues to be addressed before any discovery is possible:
  - Understanding of the detectors;
  - SM processes W,Z,t (benchmark processes)

1. Introduction
2. Inclusive Z and W cross sections measurements
3. W mass measurements
4. Top quark mass measurements
5. Summary



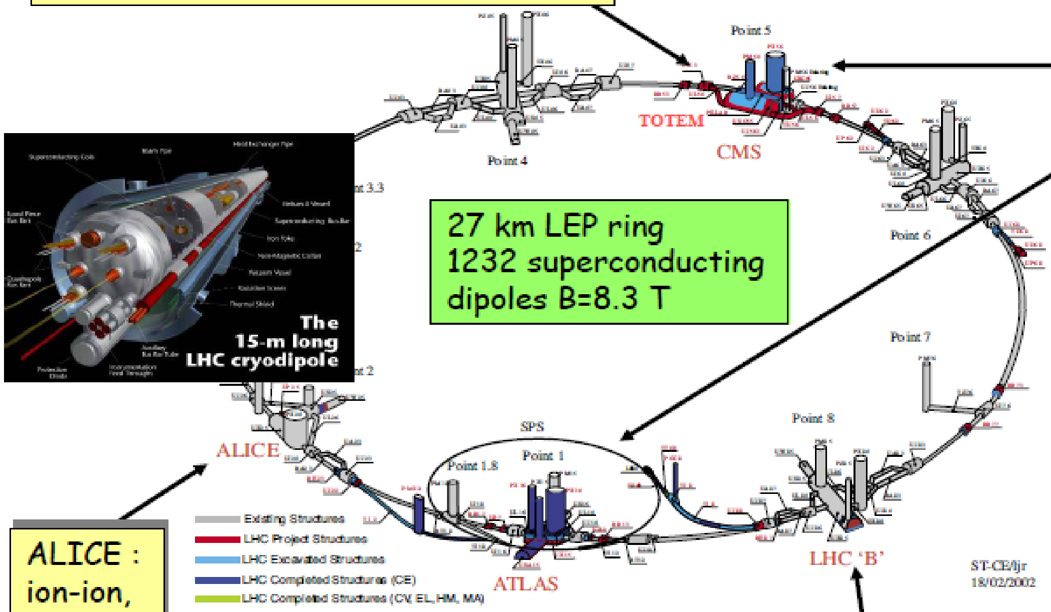
LHC

TOTEM (integrated with CMS):
pp, cross-section, diffractive physics

ATLAS and CMS :
general purpose

27 km LEP ring
1232 superconducting
dipoles B=8.3 T

Here:
ATLAS and CMS



ALICE :
ion-ion,
p-ion

LHCb :
pp, B-physics, CP-violation

LHC design parameters:
pp collisions at $\sqrt{s}$=14TeV
L=10^{34} $cm^{-2}s^{-1}$

Startup scenario:

- Machine cold by September-> first collisions late in October
- Beam physics running during winter 2009- autumn 2010
- start with 450 GeV up to 5 TeV per beam;
- goal: integrate ~200 pb^{-1}

ROMA TRE

Introduction

Standard Model physics - motivations:

- EW parameters: m_{top}, m_W, Γ_W, $\sin^2\theta_W$ and couplings -> SM precision test and consistency
- Direct sensitivity to new physics (e.g. rare top decays ..)
- High precision cross sections to test QCD predictions
- Constraints on Parton density functions
- Measure background to many physics channels

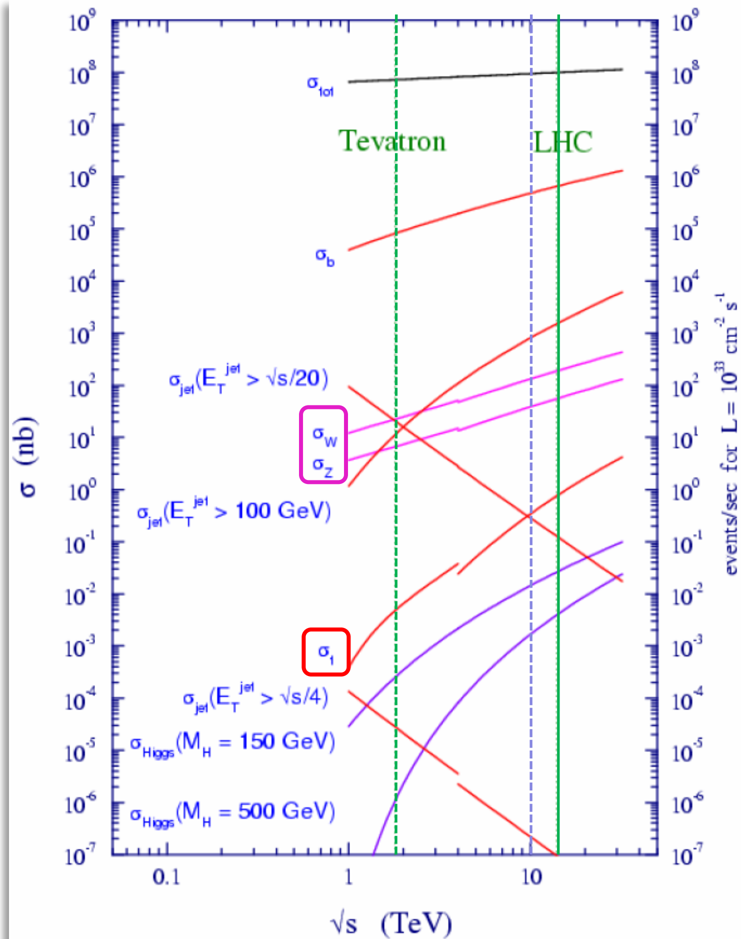
All these measurements foreseen at the LHC.

W/Z and top production sections,
W mass , Top mass

In this talk

	$\sqrt{s}$ [TeV]	Cross section
W-> lν	14	20.5 nb
	10	14.3 nb
Z-> ll	14	2.02 nb
	10	1.35 nb
ttbar	14	833 pb
	10	396 pb

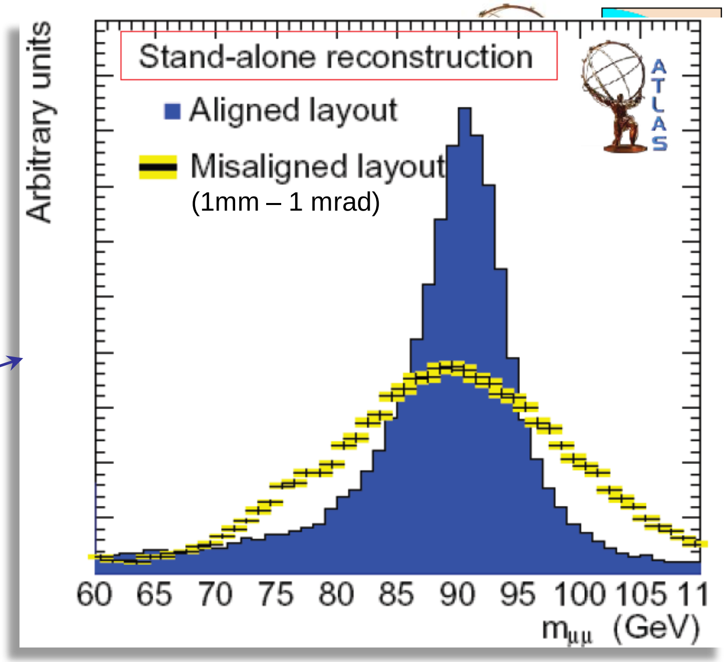
- Z,W ~6 times larger than at Tevatron
- ttbar ~100 times than Tevatron

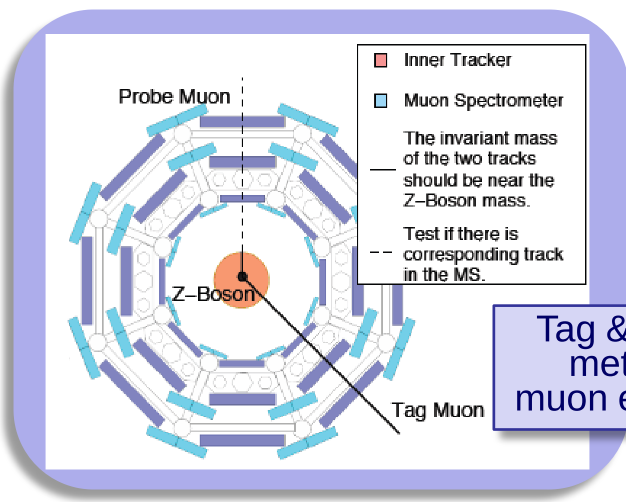


Introduction

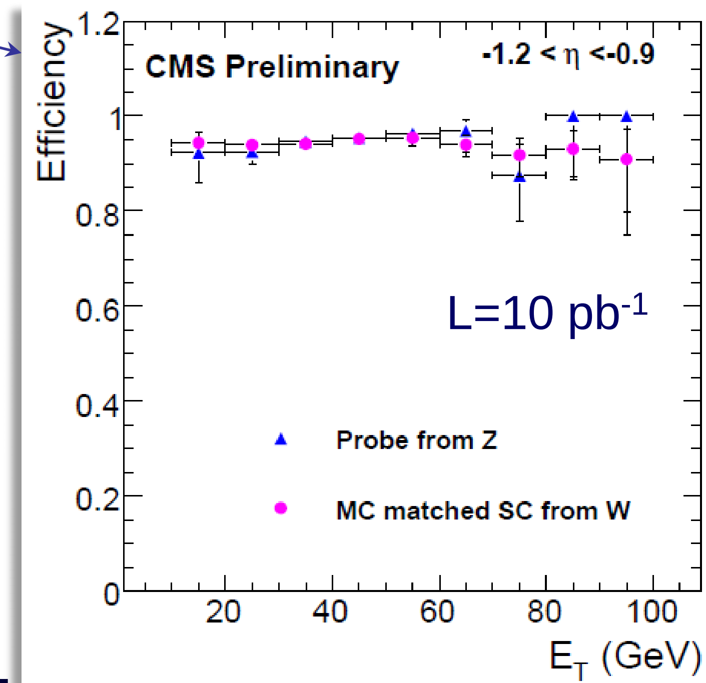
Motivation (II):
Clean processes with large and well predicted cross-sections-> “standard candles” for:

- MC tuning;
- calibration and alignments;
- Electron/Muon/Jets/Missing E_T energy scales and resolutions;
- Lepton identification/triggering efficiencies;





Tag & probe method: muon example

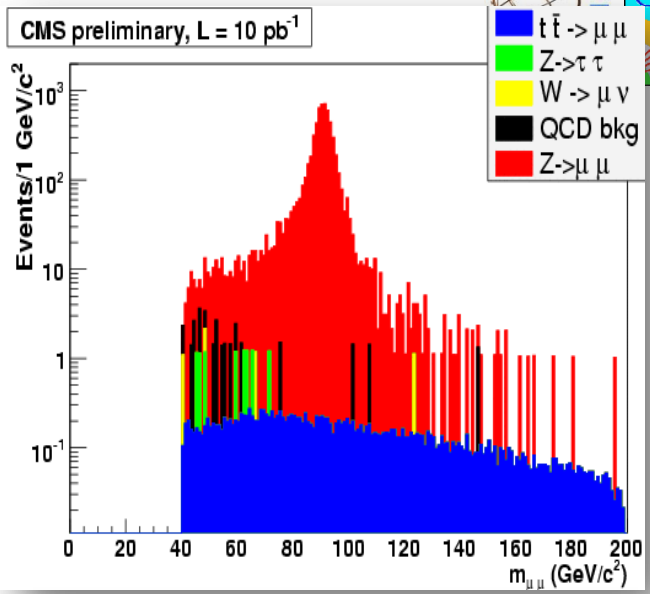


Z and W inclusive cross-sections

Z->ee,μμ events selections

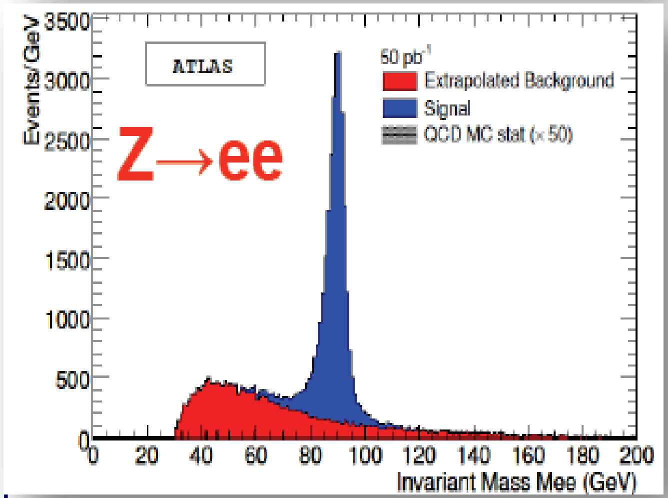
Z->μμ

- trigger: single muon HLT
- Hits from Tracker + Muon Chambers
- 2 high p_T muons (p_T>20.0 GeV, |η|<2.0)
- Opposite charge sign
- Track Isolation (Σp_T<3 GeV, ΔR<0.3)
- $M_{\mu,\mu}$ > 40 GeV



Z->ee

- trigger: One electron, p_T>10 GeV
- 2 EM clusters (E_T>15 GeV, |η|<2.4)
- Loose electron identification criteria
- isolation ($\Sigma E_T/E_T^e$ < 0.2, ΔR<0.45)

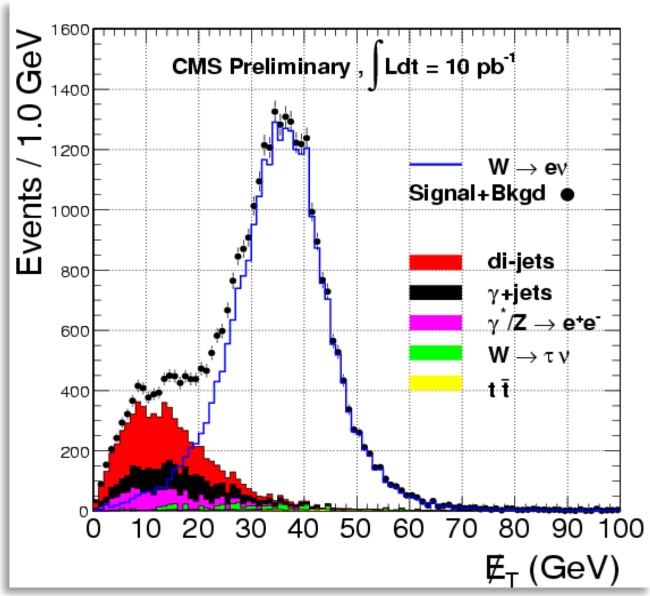


- Use only robust cuts:
  common vertex and impact parameter not included.
- Background estimation from sidebands and/or simultaneous fit to signal & background. A low background sample, in particular in the muon case.

W events selections

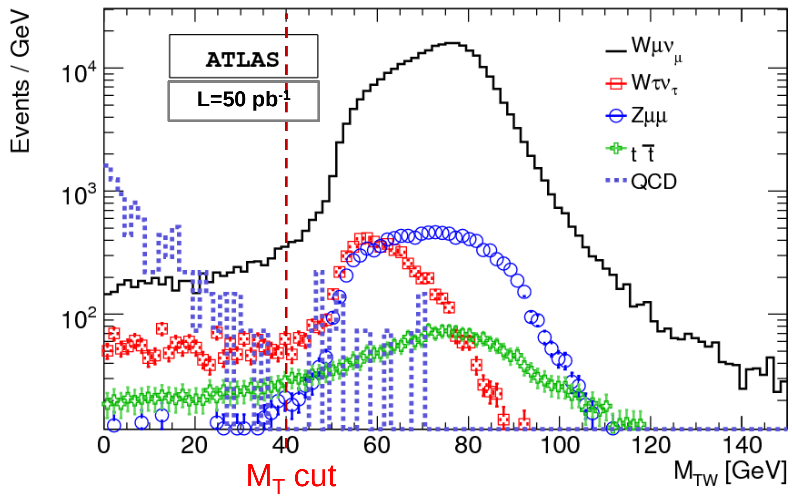
W->eν

- Trigger: Single Isolated electron HLT
- A high E_T electron (E_T>30.0 GeV, |η|<2.5)
- Track Isolation (no tracks p_T>1.5 GeV in ΔR<0.6)
- ECAL isolation ($\Sigma E_T/E_T^e < 0.02$; ΔR<0.3)
- HCAL isolation ($\Sigma E_T/E_T^e < 0.10$; 0.15<ΔR<0.3)
- tight electron Identification;
- Reject events with 2nd electron having E_T>20.0 GeV.



W->μν

- trigger: One muon, p_T>20 GeV
- A high p_T muon (p_T>25.0 GeV, |η|<2.5)
- isolation (ΣE < 5 GeV, ΔR<0.4)
- ETMiss > 25 GeV
- M_T > 40 GeV



Electron final state:

major bck are jet final state events;

CMS: obtained from a data sample passing electron selection with isolation criteria inverted

ATLAS: bkg shape obtained from a “γ+jets” sample (same selection but no ID track).

Muon final state: Z->μμ, W->τν major bkg. Estimated from MC (well understood).

Z and W cross-sections

Event selections
Background estimation
from data (if possible)

$$\sigma_{W(Z)} \times BR(W(Z) \rightarrow leptons) = \frac{N^{obs}_{W(Z)} - B_{W(Z)}}{\varepsilon_{W(Z)} \cdot A_{W(Z)} \int \mathcal{L} dt}$$

Acceptance studies from MC simulations using most up to date QCD and EW predictions

Trigger and reconstrucion efficiencies from data (Tag&Probe)

$$\frac{\delta\sigma}{\sigma} = \frac{\delta N \oplus \delta B}{N - B} \oplus \frac{\delta\varepsilon}{\varepsilon} \oplus \frac{\delta A}{A} \oplus \frac{\delta \mathcal{L}}{\mathcal{L}}$$

Luminosity:Large uncertainty in earliest data (up to 10%, down to 2-3% in later years)

CMS expectation for 10 pb^{-1}

$\Delta\sigma/\sigma$(pp-> Z+X -> ee+X) = 1.9 (stat) ± 2.3 (syst) %
$\Delta\sigma/\sigma$(pp->W+X -> e+X) = 1.2 (stat) ± ~5 (syst) %

- Identification/reconstruction efficiency: ~1% from data
- Backgrounds: 5% (e)
- Theory (including acceptance) ~2% (PDFs, ISR)

ATLAS expectation for 50 pb^{-1}

$\Delta\sigma/\sigma$(pp-> Z+X -> μμ+X) = 0.8 (stat) ± 3.8 (syst) %
$\Delta\sigma/\sigma$(pp->W+X -> μ+X) = 0.2 (stat) ± 3.1 (syst) %

- Identification/reconstruction efficiency : 2-3%
- Backgrounds: <1% (muons)
- Theory (including acceptance) ~2% (PDFs, ISR)

On a longer timescale:

CMS expectation for 1 fb^{-1}

$\Delta\sigma/\sigma$(pp-> Z+X -> μμ+X) = 0.13 (stat) ± 2.3 (syst) %
$\Delta\sigma/\sigma$(pp->W+X -> μ+X) = 0.04 (stat) ± 3.3 (syst) %

ATLAS expectation for 1 fb^{-1}

$\Delta\sigma/\sigma$(pp-> Z+X -> ee+X)= 0.20 (stat) ± 2.4 (syst) %
$\Delta\sigma/\sigma$(pp->W+X -> e+X) = 0.04 (stat) ± 2.5 (syst) %

- Eff unc. <1% with data-driven methods
- Background reduced with selections

W MASS

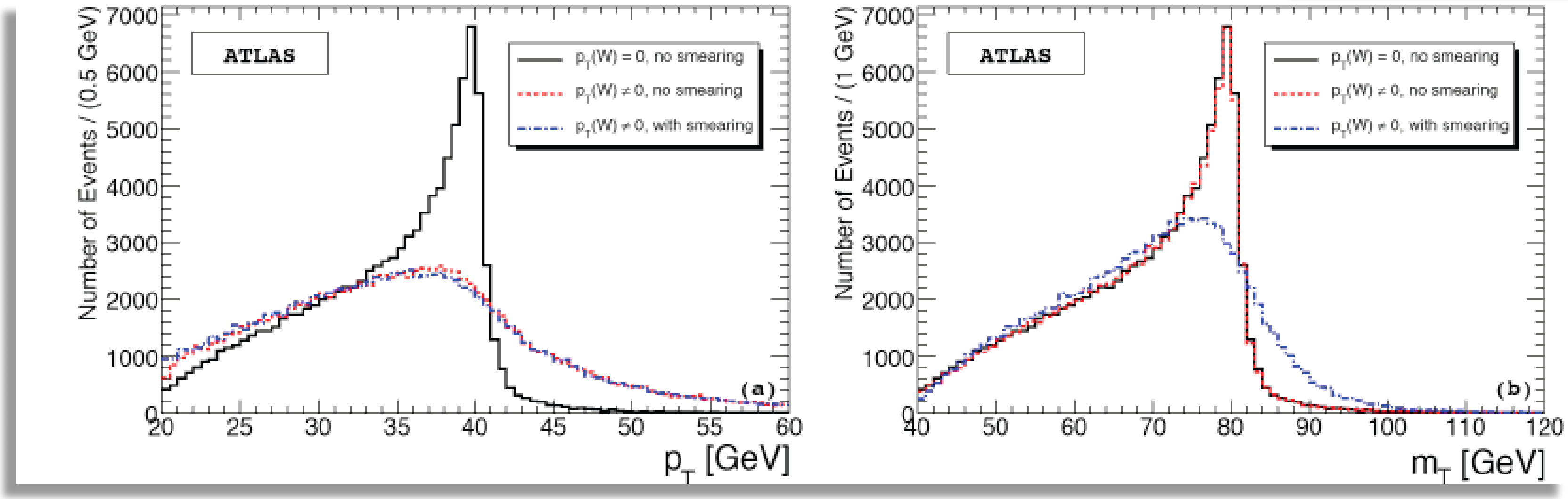
W mass measurements

m_W: fundamental parameter of the theory linked to m_{top} and M_H.

- m_W and m_{top} need to be measured with highest precision
- LHC can improve current world average (m_W= 80399±25 MeV)

1. Select W candidate events (as in previous analysis).
2. Use the two best observables that are sensitive to the W mass:

$$m_T^W = \sqrt{2 p_T^l p_T^\nu (1-\cos\Delta\phi)}$$



3. Build templates distributions $p_t(m_W)$ and $M_T(m_W)$;
4. Fit the templates to data -> find m_W .

Z events are crucial:

1) Building the templates;
2) lepton energy scale, energy resolution; differential reconstruction efficiency

W mass measurements

Uncertainties on m_W [MeV] for 15 pb^{-1} (ATLAS).				
	$p_T(e)$	$p_T(\mu)$	$M_T(e)$	$M_T(\mu)$
Statistical	120	106	61	57
Experimental	114	114	230	230
Theo (PDF)	25	25	25	25
TOTAL	167	158	239	238

Not competitive with current experiments.

The analysis performed with 15pb^{-1} is intended as a study to set the method and to understand what can be done with very early data.

Build templates:

ATLAS:

- Generate the p_T and M_T distributions
- Get energy and momentum scales, resolutions and MET response from Z events

CMS:

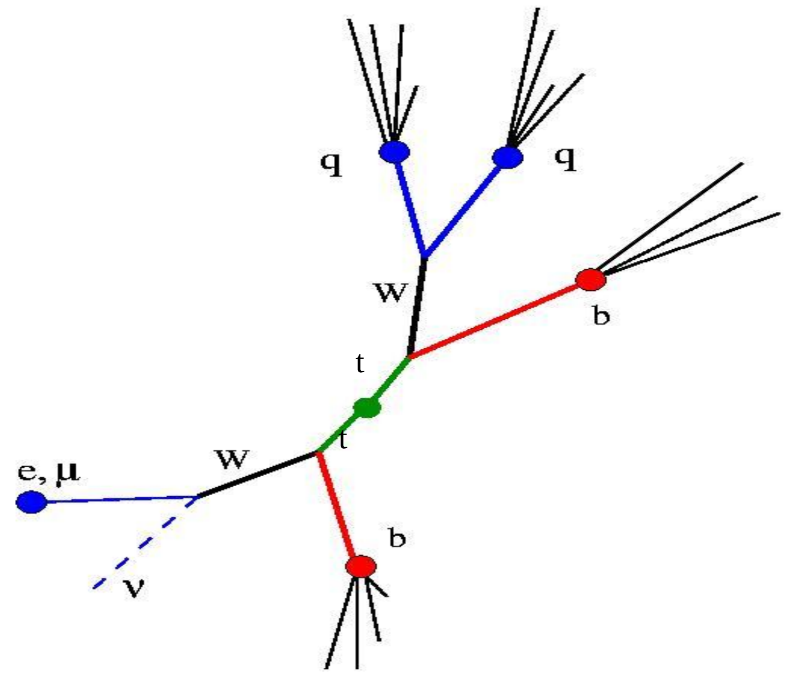
Transformation event by event

(Kinematic transformation):

1) Rescale lepton momentum in Z rest-frame by m_W/m_Z;
2) remove one lepton (simulate neutrino);
3) boost back to detector frame.

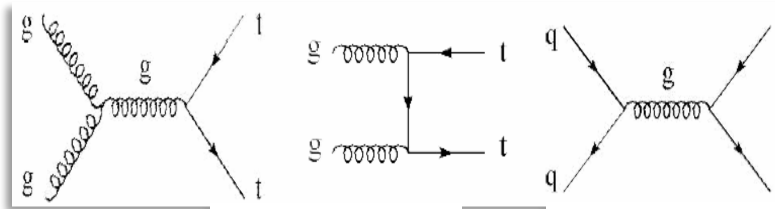
Uncertainties on m_W [MeV] for the scaled $M_T(\mu)$ method (CMS)		
	1 fb^{-1}	10 fb^{-1}
Statistical	40	15
Experimental	64	<30
Theo (PDF)	~20	~10

TOP QUARK



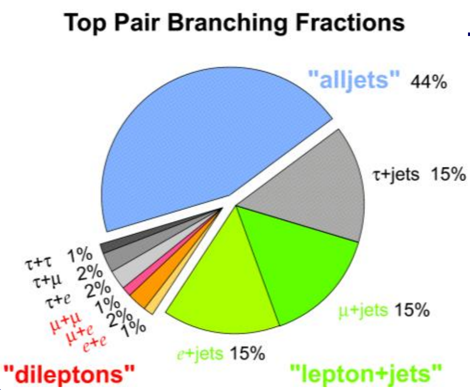
Top Quark physics

- Top quark events Contain all relevant signatures:
  (e,mu, jet, Etmiss, b-jet) -> a milestone in physics commissioning
- LHC will be a "top factory"
  σ_{tt}~830pb (~x100 TeVatron)



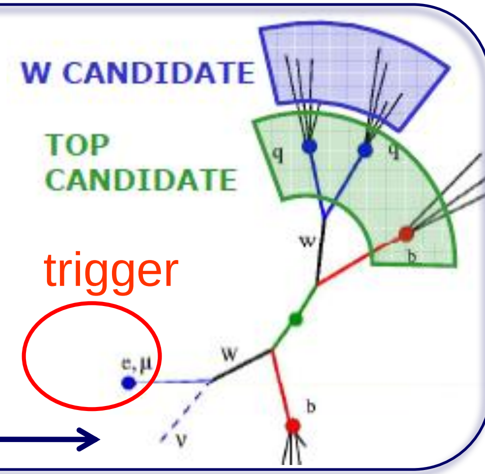
gg->ttbar~90%

qq->ttbar~90%



Decay: BR(t->Wb) ~100%

- "all jets":
  - High BR
  - Full event reconstruction
  - High BKG and combinatorics
- "dilepton":
  - Low BR
  - Final state difficult to reconstruct
  - Lower bkg and combinatorics
- "lepton+jets": golden channel



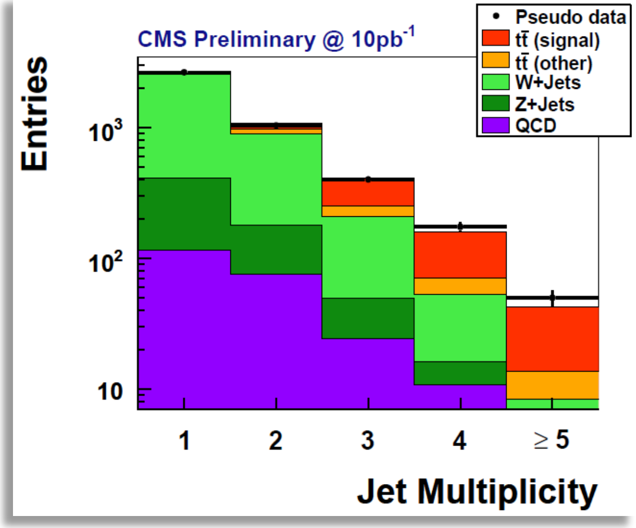
Backgrounds:

- W+jets (dominant)
- Z+jets (Z->ll)
- ttbar in other channels
- single top events
- QCD Multijet -> fake leptons and MET
  Very large cross section + tiny efficiency -> Very difficult to simulate (data driven methods needed!) Smaller than W+jet estimate.

Top Quark pair production (10pb^{-1})

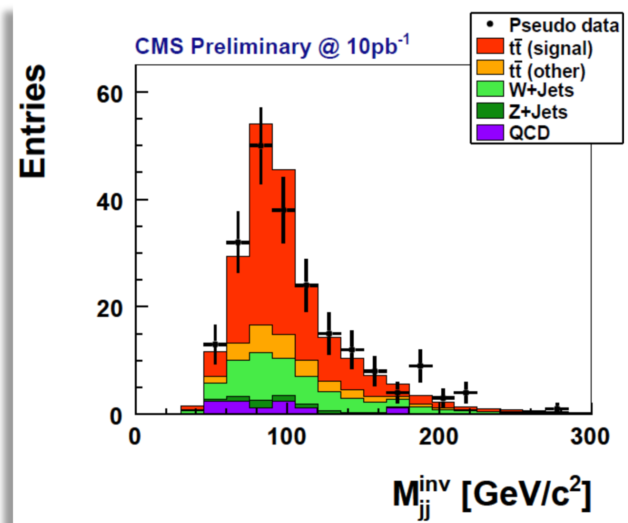
CMS muon channel selection cuts :

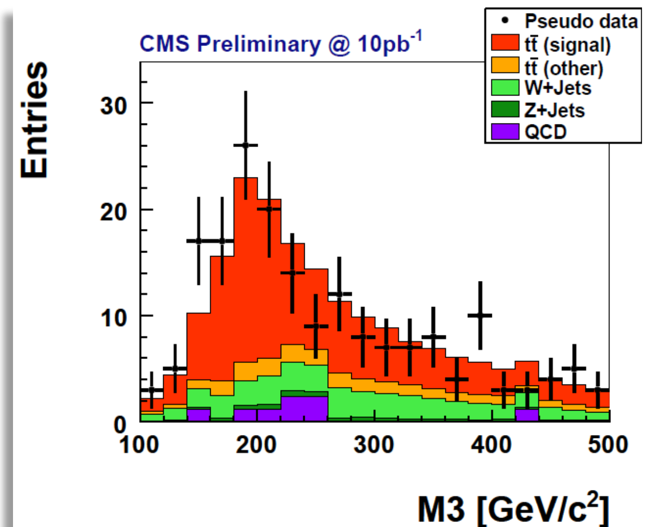
- One muon p_T>30 GeV, $|\eta|$<2.1 (loose)
- Isolation: E_{calo}^{iso} < 1 GeV and $dR_{\mu\text{-jet}}$ > 0.3
- at least 4 jets; |eta|<2.4, E_T>65,40,40,40 GeV
- no b-tagging



- For 10 pb^{-1}: 128/90 signal/background
- Overall selection efficiency (including acceptance): 10.3%.
- Shapes of the W/Z+jets bck from simulation

  (Normalizations by comparison with a control sample at low jet multiplicities.)



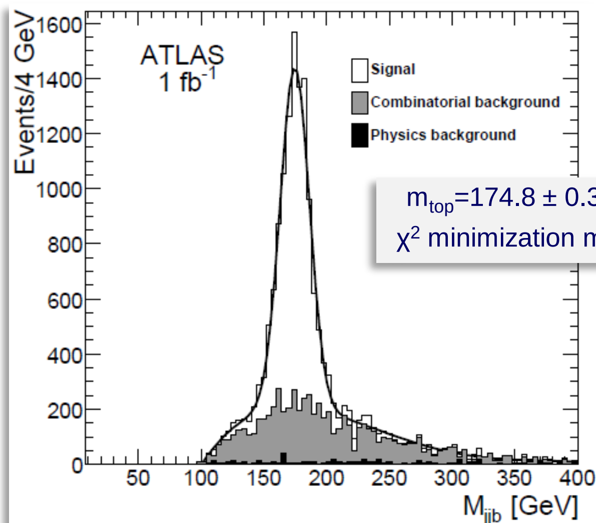


mis-alignments and mis-calibrations as expected for early data are considered.

Top quark mass measurement

Standard cuts |η|<2.5 :

- 1 isolated lepton p_T>20(25) GeV for μ (e)
- Missing E_T>20 GeV (reduces QCD bkg)
- at least 4 jets p_T>40 GeV
- two b-tagged jets



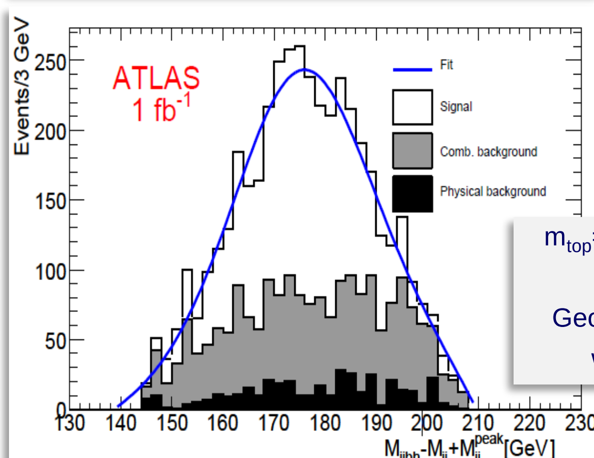
m_{top}=174.8 ± 0.3 GeV
χ^2 minimization method

Systematic uncertainty	χ^2 minimization method
Light jet energy scale	0.2 GeV/%
b jet energy scale	0.7 GeV/%
ISR/FSR	$\simeq$ 0.3 GeV
b quark fragmentation	$\leq$ 0.1 GeV
Background	negligible
Method	0.1 to 0.2 GeV

- Jet Energy Scale main source of systematic uncertainties (reduced with rescaling)
- b-jets JES initially modelled from light JES, complemented with Z+(b-jet) data

With JES=1% and using b-tagging

Δm_{top}=0.3 GeV (stat.) ±1 GeV (syst.)



m_{top}=175.2 ± 0.5 GeV
No b-tagging
Geometrical method
with rescaling

Systematic uncertainty	1 *b*-tagged jet	No *b*-tagging
Light jet energy scale	0.3 GeV/%	0.4 GeV/%
b jet energy scale	0.7 GeV/%	0.7 GeV/%
ISR/FSR	$\simeq$ 0.4 GeV	$\simeq$ 0.4 GeV
b quark fragmentation	$\leq$ 0.1 GeV	$\leq$ 0.1 GeV
Background	< 1 GeV	1 GeV

Summary

- The LHC will start providing collisions late October this year;
- First steps: understand detector response and establish SM signatures;
- A strategy for the measurement of W/Z cross sections has been developed also for early data;
  - Simple & Robust selections for electrons & muons to cope with the imperfections in calibration and alignment of the detectors;
- W mass and top mass require a detailed detector understanding and will come at a later stage;
- Tag & Probe (applied on Z events) will provide the selection, reconstruction & trigger efficiencies from data;
- Some methods to estimate QCD background from data were also developed.

I covered only few aspects. For more details:

- CMS "Physics Analysis Summaries“ (https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults)
- ATLAS “Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics” (http://arxiv.org/abs/0901.0512)

Many thanks to the collegues of the ATLAS and CMS collaborators
(in particular the SM and Top WG Conveeners)
and to the conference organizers

BACKUP SLIDES

Cross sections

ENERGY	Tevatron	CSC	10 TeV	14 TeV
PROCESS	Xsec(nb)			
Z	7.153		40.065	57.881
Z->ll (BR=3.36%)	0.240	2.020	1.346	1.945
W	25.032		132.671	188.919
W->lν (BR=10.8%)	2.574	20.500	14.328	20.402
W^+	11.920		77.524	108.859
W^+->lν (BR=10.8%)	1.287		8.372	11.756
W^-	11.920		55.147	80.060
W^-->lν (BR=10.8%)	1.287		5.956	8.646
tt	7.112 pb	0.833	0.396	0.876
$t^+W^- + t^-W^+$	0.138 pb	0.066	0.028	0.061
$t^+q + t^-q$ (t channel)	2.050 pb	0.246	0.134	0.250
$t^+b + t^-b$ (s channel)	0.942 pb	0.011	0.071	0.011

Notes:

Cross sections at NNLO

CSC: value used for ATLAS CSC notes, Z: m_{ll}>60GeV

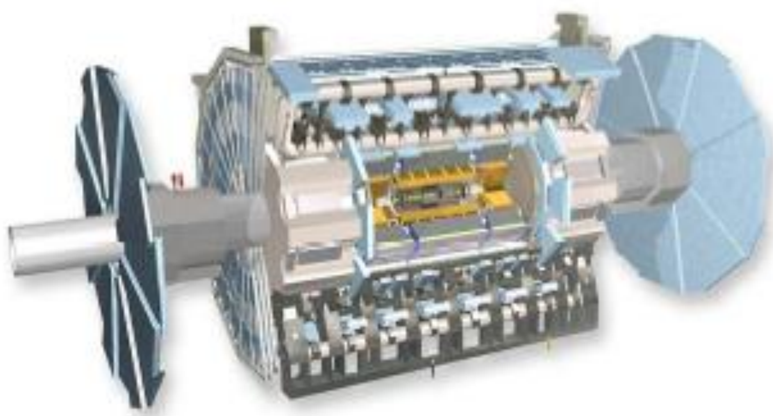
L=50 pb^{-1}

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

L=1 fb^{-1}

Process	$N(\times 10^5)$	$B(\times 10^5)$	$A \times \varepsilon$	$\delta A/A$	$\delta\varepsilon/\varepsilon$	σ (pb)
$W \to e\nu$	45.34 ± 0.02	1.22 ± 0.41	0.215	0.023	0.004	$20520 \pm 9 \pm 516$
$W \to \mu\nu$	60.08 ± 0.02	4.02 ± 0.05	0.273	0.023	0.004	$20535 \pm 7 \pm 480$
$Z \to ee$	5.42 ± 0.01	0.46 ± 0.02	0.246	0.023	0.007	$2016 \pm 4 \pm 49$
$Z \to \mu\mu$	5.14 ± 0.01	0.02 ± 0.001	0.254	0.023	0.007	$2016 \pm 4 \pm 49$

- ATLAS Detector
- CMS Detector



	ATLAS	CMS
Tracker	$\|\eta\|<2.5$ *coverage* $\sigma / p_T \approx 5 \cdot 10^{-5} p_T \oplus 0.01$ [GeV]	$\|\eta\|<2.6$ *coverage* $\sigma / p_T \approx 1.5 \cdot 10^{-5} p_T \oplus 0.005$
EM Calorimeter	$\|\eta\|<4.9$ *coverage* $\sigma / E \approx 10\% / \sqrt{E}$ [GeV]	$\|\eta\|<4.9$ *coverage* $\sigma / E \approx 2-5\% / \sqrt{E}$
HAD Calorimeter	$\|\eta\|<4.9$ *coverage* $\sigma / E \approx 50\% / \sqrt{E} \oplus 0.03$ [GeV]	$\|\eta\|<4.9$ *coverage* $\sigma / E \approx 100\% / \sqrt{E} \oplus 0.05$
Muon Spectrometer	$\|\eta\|<2.7$ *coverage, 1TeV muons:* $\sigma / p_T \approx 0.07$ *(standalone)*	$\|\eta\|<2.6$ *coverage, 1TeV muon:* $\sigma / p_T \approx 0.10$ *(standalone)*

SYSTEM	ATLAS	CMS
INNER TRACKER	Silicon pixels + strips TRT → particle ID (e/π) B=2T $\sigma/p_T \sim 4\times10^{-4}\, p_T \oplus 0.01$	Silicon pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\times10^{-4}\, p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ Uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2.5\%\sqrt{E}$ no longitudinal segmentation
HAD CALO	Fe-scint. + Cu-liquid argon $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Cu-scint. (> 5.8 l +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON SYSTEM	Air-core toroids $\sigma/pT \sim 10\%$ at 1 TeV standalone	Fe ⇒ $\sigma/p_T \sim 5\%$ at 1 TeV combining with tracker
MAGNETS	Inner tracker in solenoid (2T) Calorimeters in field-free region Muon system in air-core toroids	Solenoid 4T Calorimeters inside the field

Examples of additional cuts in top selection

- Cut **C2**: the invariant mass of the hadronic W boson and the b-jet associated to the leptonic W boson must be greater than 200 GeV.
- Cut **C3**: the invariant mass of the lepton and the b-jet associated to the leptonic W boson must be lower than 160 GeV.