Early Electroweak Measurements in CMS and ATLAS

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XLII Rencontres de Moriond (EW), La Thuile

11 *March 2007*

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Outline

- Early electroweak measurements at startup: why and what for?
- W/Z into leptons
- W/Z + jets
- Diboson production
- Early top production
- Conclusions

What is discussed in this talk

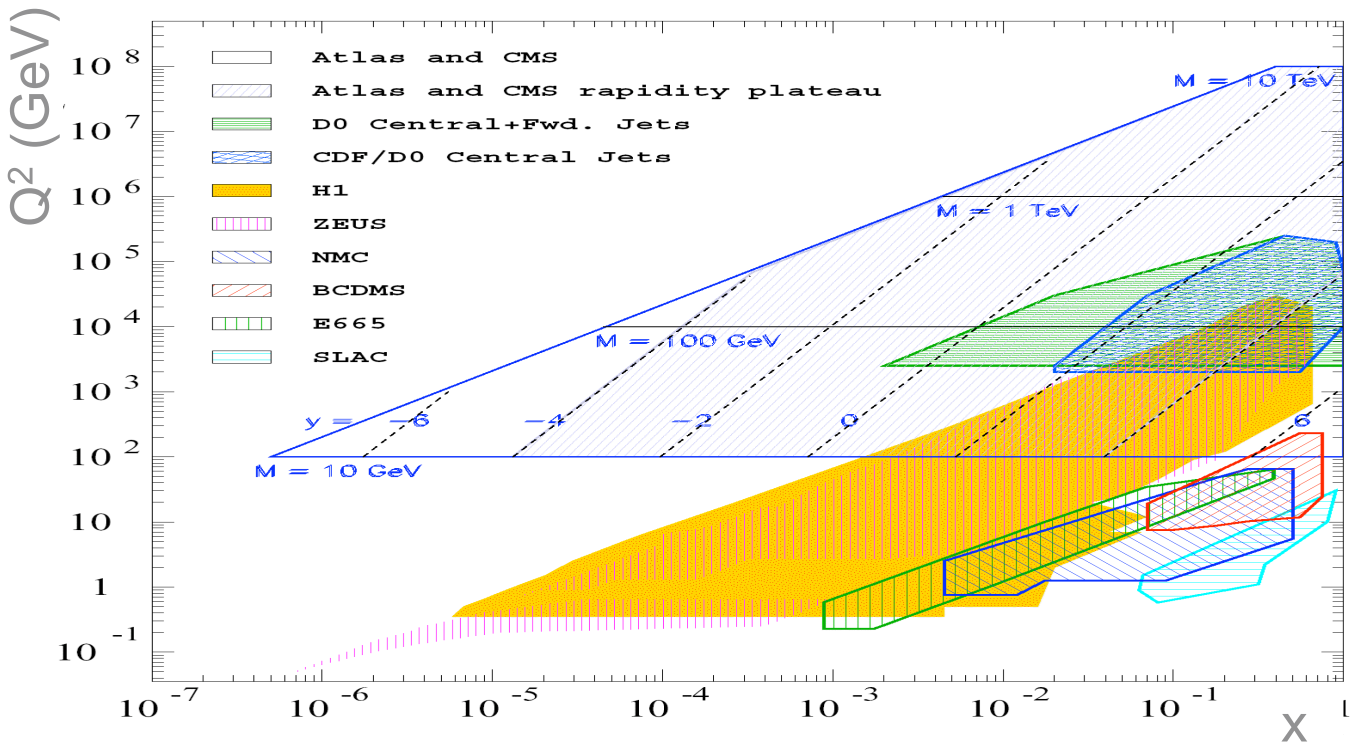
- NOT discussed: initial “engineering” LHC running at $\sqrt{s}$ = 900 GeV
- This talk deals with Electroweak Physics at $\sqrt{s}$ = 14 TeV for instantaneous luminosities of the order of 10^{33} cm^{-2} s^{-1} .
- ...and an integrated luminosity < 1 fb^{-1} (=> no m_w measurement, for instance, and no high statistics precision measurements in general).
- The idea is to discuss EARLY ELECTROWEAK MEASURENTS AT THE LHC.

Why are early EW measurements interesting?

- 1) Because they are related with ‘known’ physics...
  - EW properties precisely studied in previous colliders like LEP, HERA, Tevatron.
  - W/Z/γ*/top production well understood/studied in previous hadronic colliders (Tevatron)
- ... they become a unique tool to understand:
  - Calibrate our detectors and their response (muons, electrons/photons, jets)
  - Understand backgrounds for new physics signals
  - Understand detector details and develop sophisticated tools (b-tagging, b-jets, measurement of missing transverse energy).

Why are early EW measurements interesting?

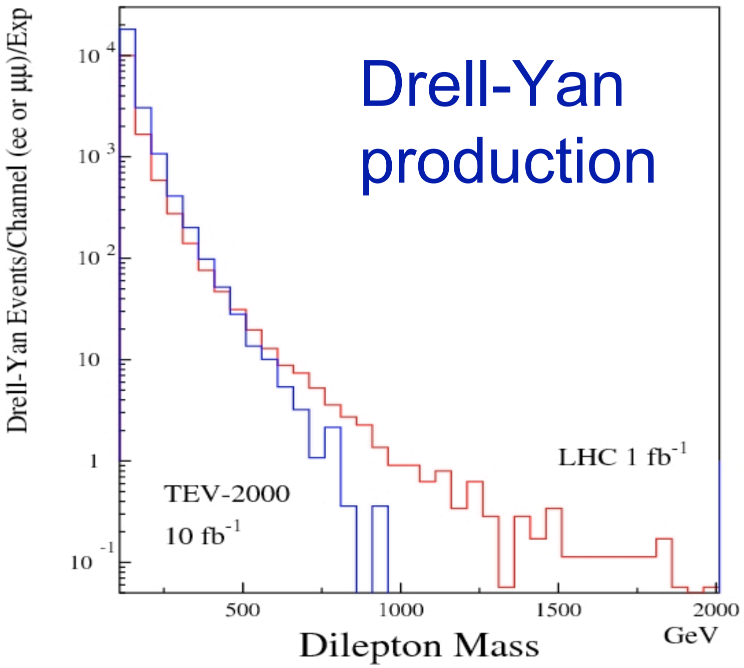
- 2) Because they are NOT so well 'known' processes at the LHC:
  - This is a new (x, Q^2) regime... Are parton density functions (PDF) as 'predicted'?
  - Gluons play a more dominant role at higher energies.
  - Top precision physics in a starting phase.

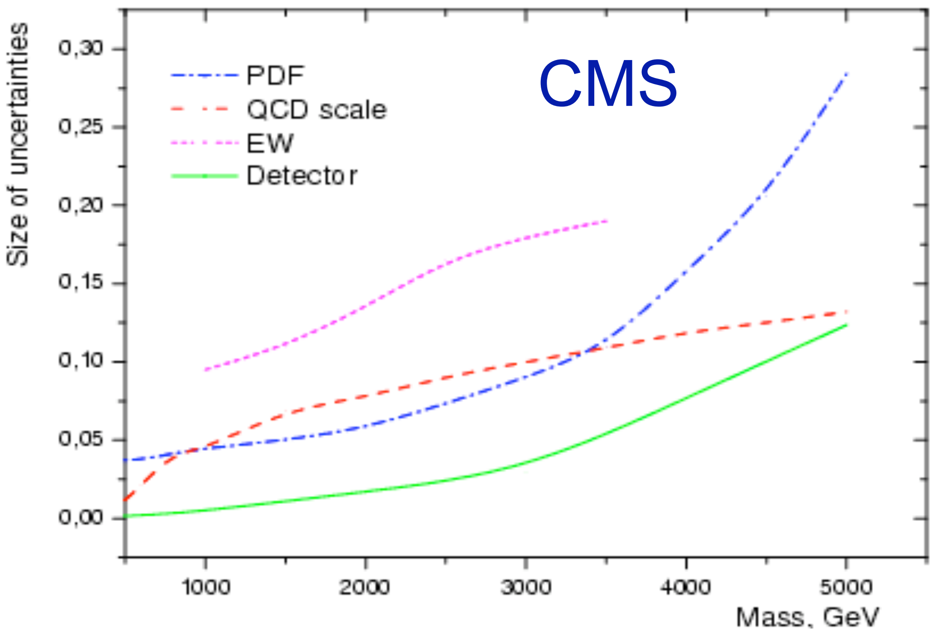


Why are early EW measurements interesting?

- 3) Because physics channels involving Z,W,γ^*,top production are easily distorted by almost any new physics sources at the new energy scales opened up by the LHC, even with low luminosity:

$$\sqrt{s}\,(\text{LHC}) \sim 7\text{-}10\ \sqrt{s}\,(\text{Tevatron, LEP})\ !!$$





Systematic error ~ 10%

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Inclusive W/Z production...

- **First 'electroweak' signals to be observed. Already at a luminosity of 1 pb^{-1}, thousands of W/Z leptonic decays will be at our disposal: σ(LHC) ~ several nb ~ 10 σ(Tevatron).**

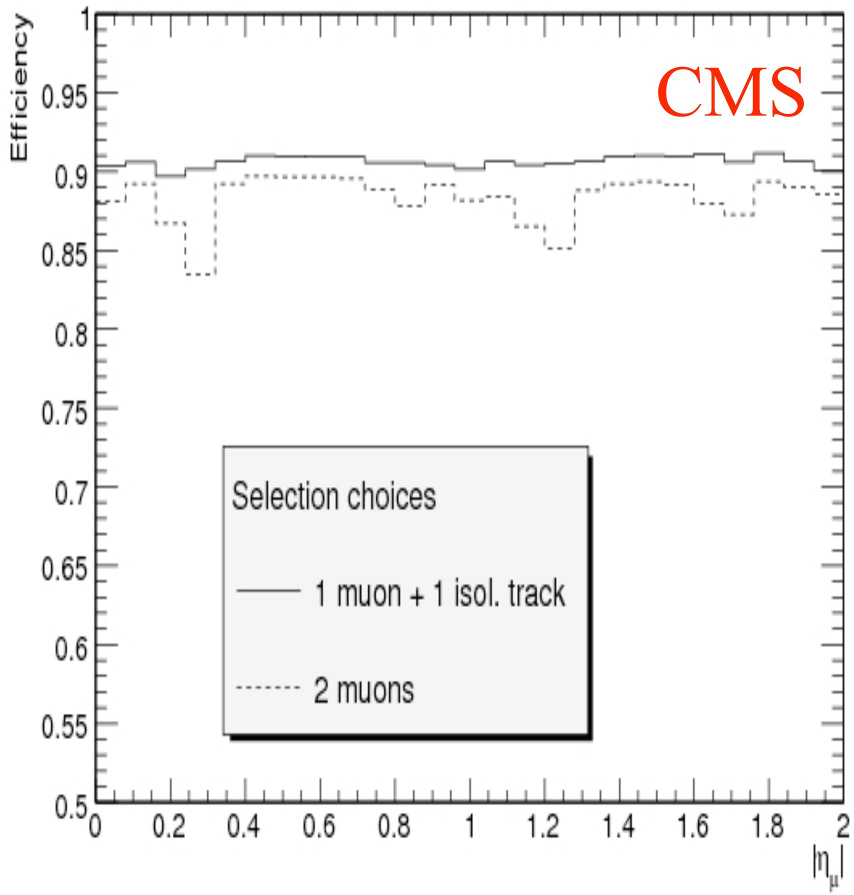
- **New studies from CMS TDR:**

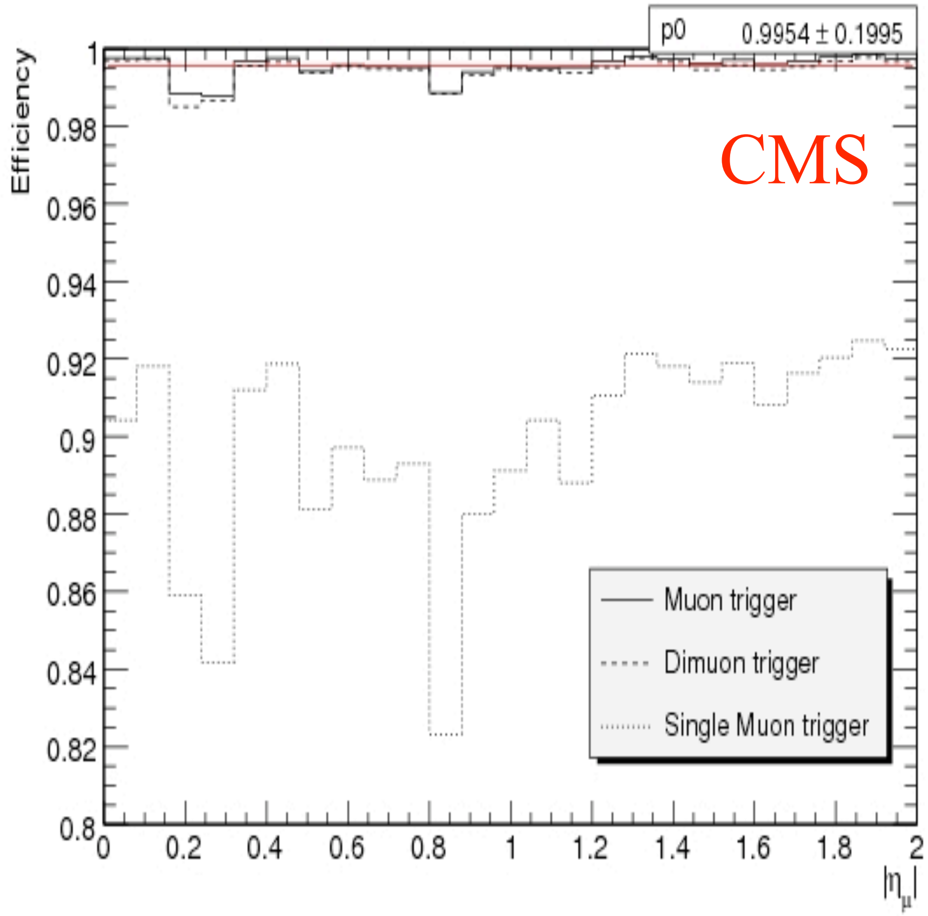
  - Selection W and Z samples with decays into leptons of high purity

  - Simple criteria

  - Minimally dependent on calibration uncertainties and limited knowledge of the detector response (i.e. startup oriented).

Minimizing uncertainties in Z→μμ





Enough level arm to control and understand systematics

Total systematics in Z→μμ

Source	Uncertainty (%)
Tracker efficiency	1
Magnetic field knowledge	0.03
Tracker alignment	0.14
Trigger efficiency	0.2
Jet energy scale uncertainties	0.35
Pile-up effects	0.30
Underlying event	0.21
Total exp.	1.1
PDF choice (CTEQ61 sets)	0.7
ISR treatment	0.18
p_T effects (LO to NLO)	1.83
Total PDF/ISR/NLO	2.0
Total	2.3

(CMS, for L ~ fb^{-1})

- 600 events recorded/pb: size of statistical uncertainties ~ systematic uncertainties at L ~ 3 pb^{-1}.

- Most of the sources assume a detector understood with L=1 fb^{-1} => systematics will be a bit larger at start-up, and decrease with time

- Theory uncertainties are an interesting field of study by themselves (see next slides).

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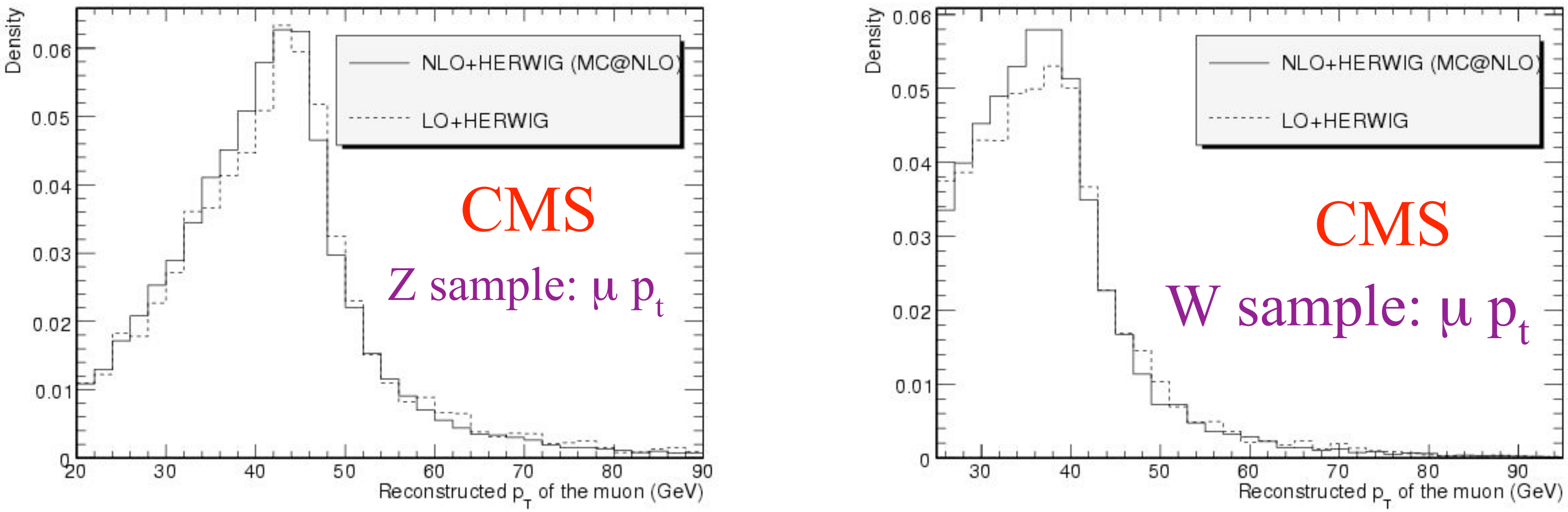
Studies with MC@NLO

- LO -> NLO studies with MC@NLO: used to determine systematic uncertainties on the acceptance (~ 2 %) and to calculate k-factors.



- In the long term, once NLO effects are understood, and low pt shapes well reproduced, systematics can be assigned according to NLO vs. NNLO comparisons.

PDF uncertainties (CMS)

Z sample

Test	Rate uncert. (%)	Acceptance uncert. (%)
CTEQ5L→CTEQ5M	18.2	1.1
CTEQ61(0)→CTEQ61(1:40)	$^{+5.8}_{-7.9}$	$^{+0.4}_{-0.7}$
CTEQ61→MRST2001E	1.5	0.1

W sample

Test	Rate uncert. (%)	Acceptance uncert. (%)
CTEQ5L→CTEQ5M	15.8	2.0
CTEQ61(0)→CTEQ61(1:40)	$^{+5.6}_{-7.4}$	$^{+0.6}_{-0.9}$
CTEQ61→MRST2001E	0.4	0.1

1. We are experimentalists: we will study the rapidity distributions in data, confront them to the existing PDF sets and improve these sets if possible.
2. To improve PDFs at the beginning we can study rapidity 'shapes', but we can not impose the normalization in any way (luminosity will be not very precise...). With a limited lepton rapidity coverage at start-up this is a very hard job.
3. What about theoretical uncertainties? Are the small differences between CTEQ and MRST approaches expected or really due to common theoretical assumptions?

pp->W/Z + jets

- Not so different from inclusive W/Z production. Jet must be identified and the QCD background must eliminated via very stringent lepton isolation cuts

New analysis from CMS (E_T(jet) > 50 GeV)

Number of W+jets events for L = 1 fb^{-1}

Channels	W+≥1jet	W+≥2jet	W+≥3jet	W+≥4jet
W+jets	260652 ± 828	56702 ± 390	10964 ± 178	2164 ± 81
Z+jets	9340 ± 96.6	3237 ± 56.9	972 ± 31.2	259 ± 16.1
$t\bar{t}$+jets	12897 ± 113.6	11842 ± 108.8	9052 ± 95.2	5420 ± 73.6
WW/WZ/ZZ+jets	1077 ± 32.8	714 ± 26.7	386 ± 19.6	151 ± 12.3
total	283966 ± 842	72495 ± 409	21374 ± 205	7994 ± 111

sizeable top background in W+jet channels

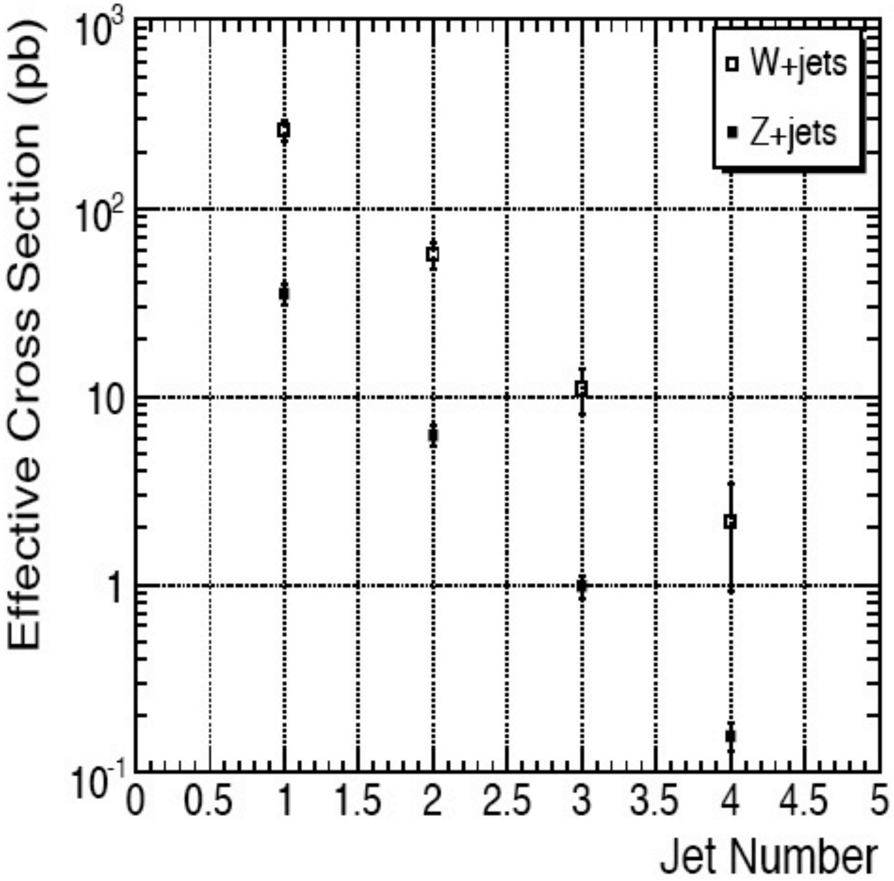
Number of Z+jets events for L = 1 fb^{-1}

Channels	Z+≥1jet	Z+≥2jet	Z+≥3jet	Z+4≥jet
Z+jets	35109 ± 187	6185 ± 78.6	977 ± 31.3	156 ± 12.5
$t\bar{t}$+jets	64 ± 8.0	58 ± 7.6	49 ± 7.0	32 ± 5.6
WW/WZ/ZZ+jets	33 ± 5.8	17 ± 4.2	5 ± 2.3	2 ± 1.4
total	35206 ± 188	6260 ± 79.1	1031 ± 32.2	190 ± 13.8

Z + 4 jets already observable with L ~ 100 pb^{-1}

pp->W/Z + jets

CMS: visible cross sections [pb]
(= #events seen / pb)



This channel is relevant for:

- Physics: QCD studies
- Reduce jet energy scale uncertainties (via Z + jet)
- It is an important background for many new particles searches (looking for leptons and jets)

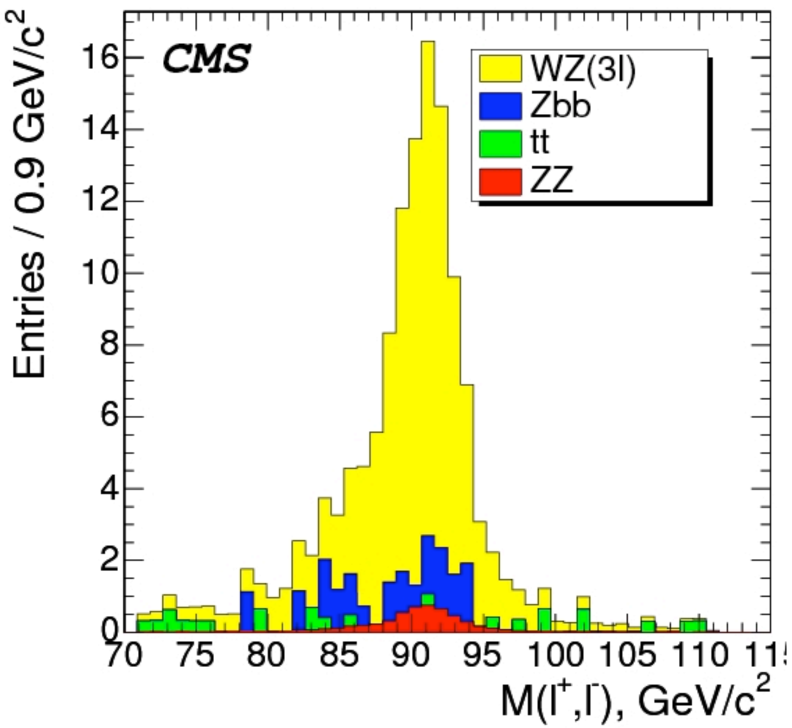
Diboson production (L=1 fb-1)

CMS	$e^\pm e^+ e^-$	$\mu^\pm e^+ e^-$	$e^\pm \mu^+ \mu^-$	$\mu^\pm \mu^+ \mu^-$	Total	Efficiency
$W^\pm Z^0 \to \ell^\pm \ell^+ \ell^-$	14.8	26.9	28.1	27.0	96.8	6.1%
$Z^0 Z^0$	0.63	1.54	1.50	1.51	5.18	4.7%
$t\bar{t}$	0.93	1.55	-	0.31	2.79	0.02%
$\mu^+\mu^- b\bar{b}$	-	-	6.54	4.9	11.4	0.005%
$e^+e^- b\bar{b}$	1.21	1.82	-	-	3.03	0.005%

ATLAS	N_{eee}	$N_{ee\mu}$	$N_{\mu\mu e}$	$N_{\mu\mu\mu}$	$N_{total}(1fb^{-1})$
N_{signal}	16.9	17.1	21.9	19.8	75.7
N_{bkg}	1.71	0.88	1.73	2.00	6.32
S/B	9.84	19.4	12.7	9.92	12.0
$S/\sqrt{B}$	12.9	18.2	16.7	14.0	30.1

Diboson production is important for:

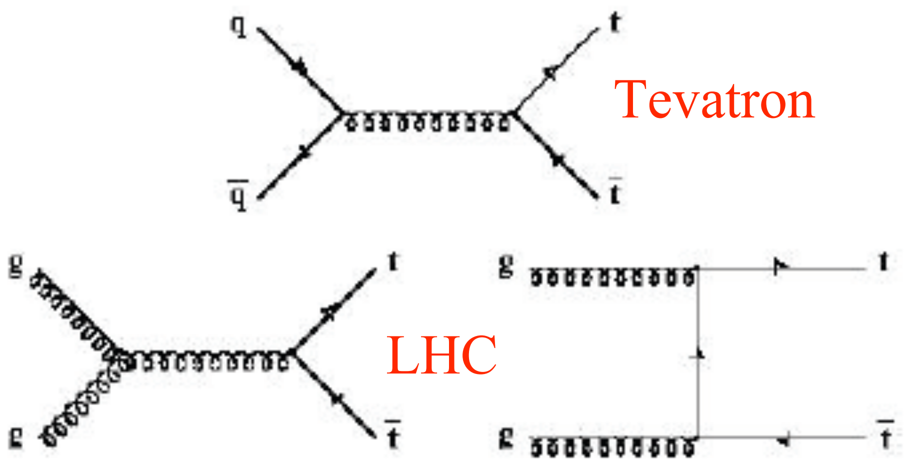
- TGC measurements (but not early)
- Understand background for new physics (H->WW, for instance)

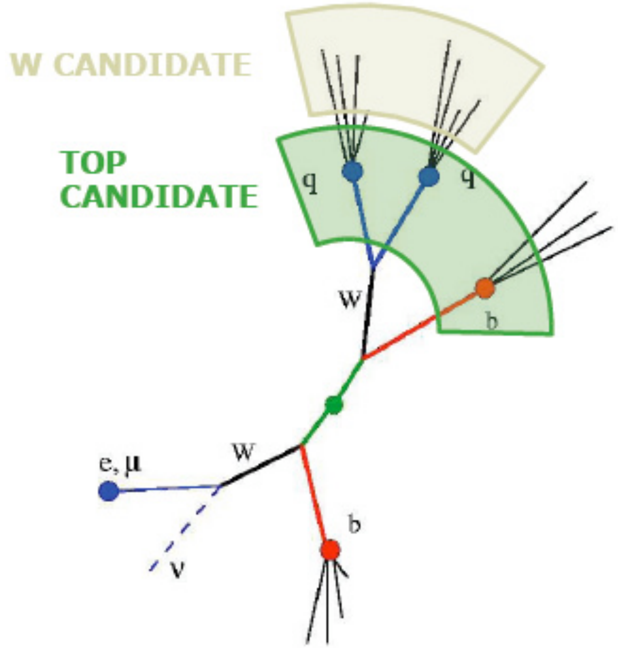


WZ production already observable in CMS (5σ) with L = 150 pb^{-1} !!

Top production

- ✓ Top production is huge at the LHC: σ ~ 800 pb, dominant process is gg->$t\bar{t}$, rate ~ 100 times Tevatron for the same luminosity.



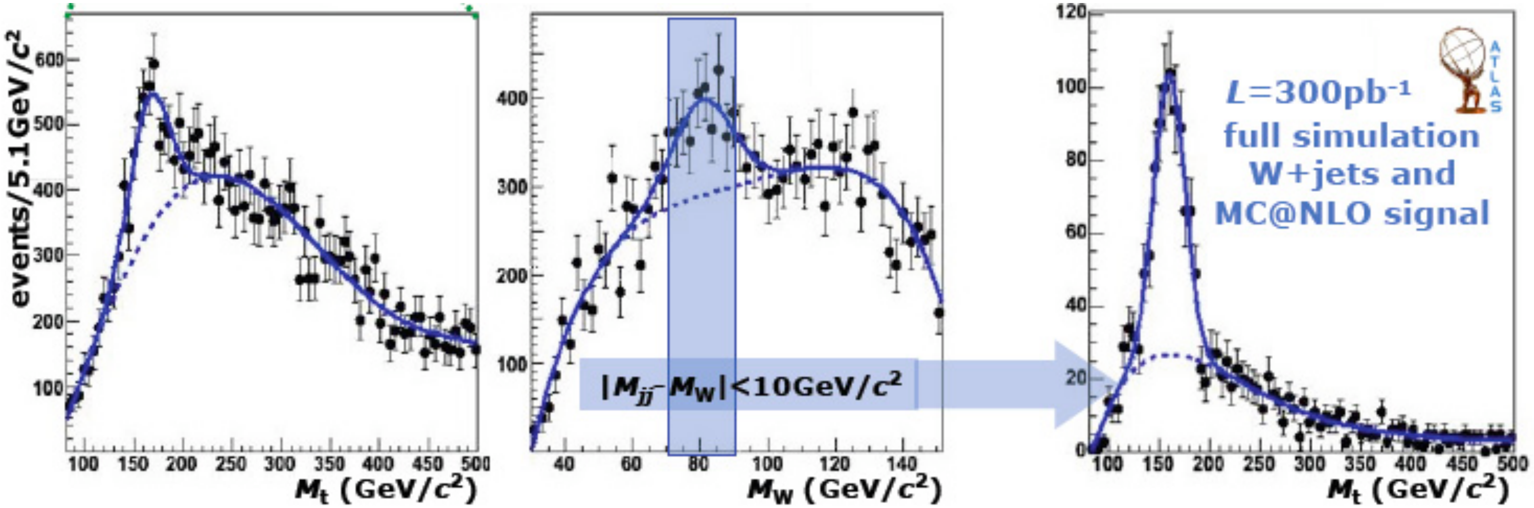


- ✓ Understanding top production => understanding the whole detector: lepton identification, resolutions, isolation, jets, missing energy, b-tagging, ... => spin-offs: jet scale calibration, b-tagging efficiencies,...

Top production

- ✓ Progressive scenarios are considered by both experiments (ATLAS, CMS):
  - ✓ L = 20-30 pb^{-1}: rediscover the top (leptonic W decays, semileptonic channels, measure cross sections for the first time)
  - ✓ L = 200-300 pb^{-1}: establish methods, precise measurement of cross sections, first measurements of the top mass, start to understand detector effects in more detail.
  - ✓ L = 1 fb^{-1}: detector 'almost' understood, exploit full physics potential.

ATLAS, 300 pb^{-1}, semileptonic analysis, no b-tagging, imperfect detector



Conclusions

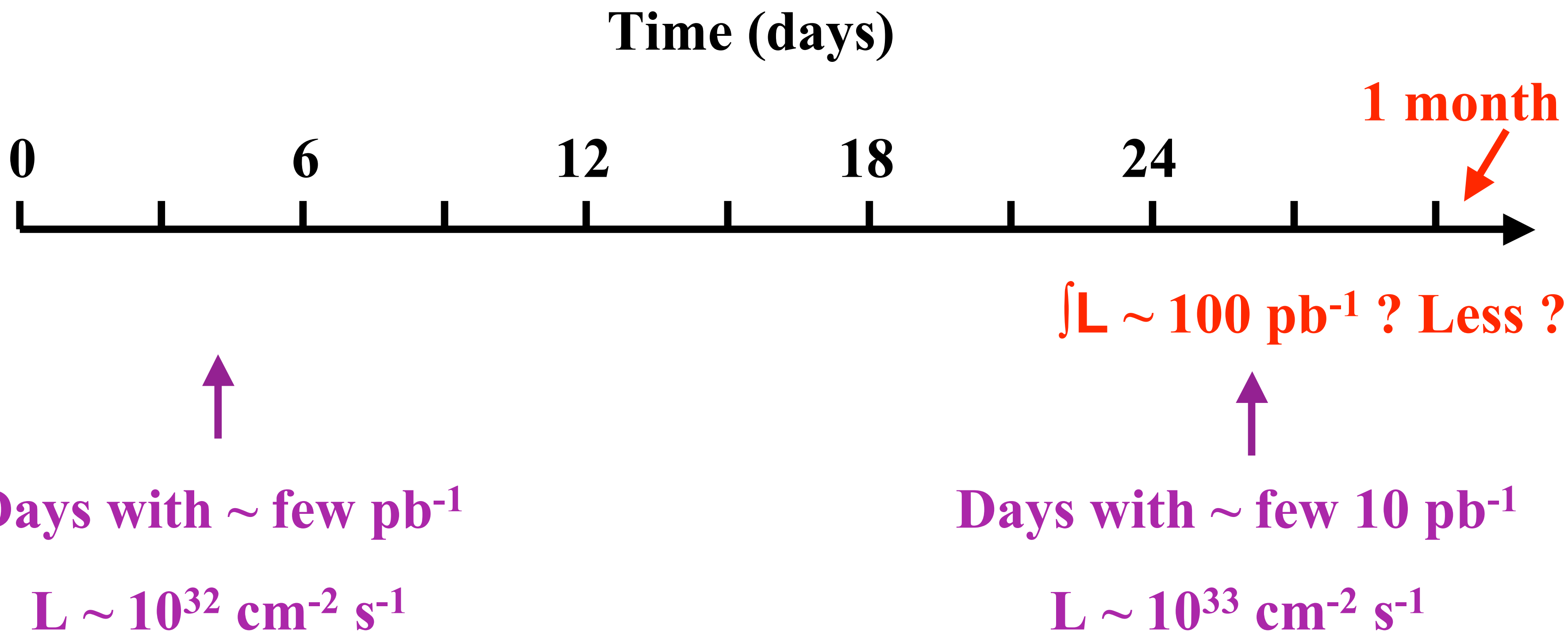
- EW processes at start-up are extremely important in the LHC programme:
  - They are unique tools to understand our detectors and algorithms
  - They are not so well known: PDF uncertainties in a new (x,Q^2) regime.
  - They are the main background for our searches and maybe the first ‘warning flag’ for early new physics.

- These processes will provide sizeable samples already at luminosities as low as few pb^{-1} (W/Z). New channels will start to be visible before reaching 1 fb^{-1}: top (~ 20 pb^{-1}), W/Z + 4 jets (~100 pb^{-1}) ,dibosons (WZ, ~150 pb^{-1}), ...

- LHC experiments are developing strategies and organizing efforts to understand and use these processes at startup. And the amount of work to do in such a short time interval is huge!

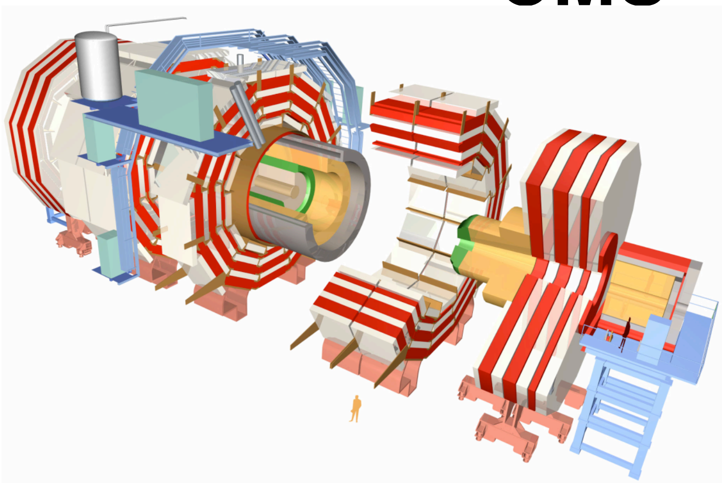
Backup slides

A hypothetical LHC startup month in 2008...

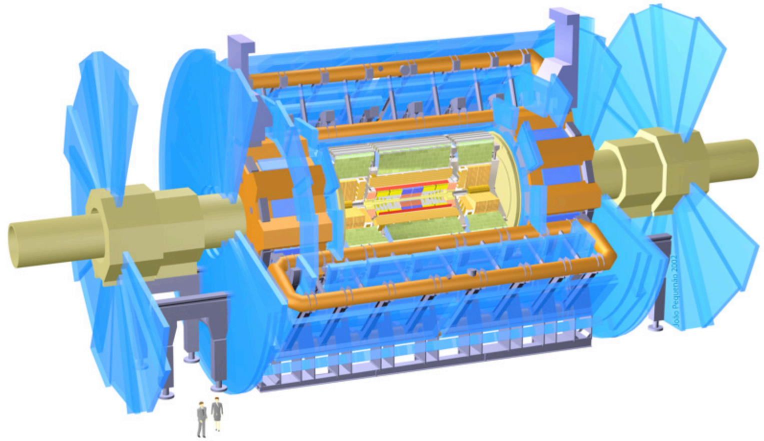


LHC detectors are similar but not equal...

CMS



ATLAS



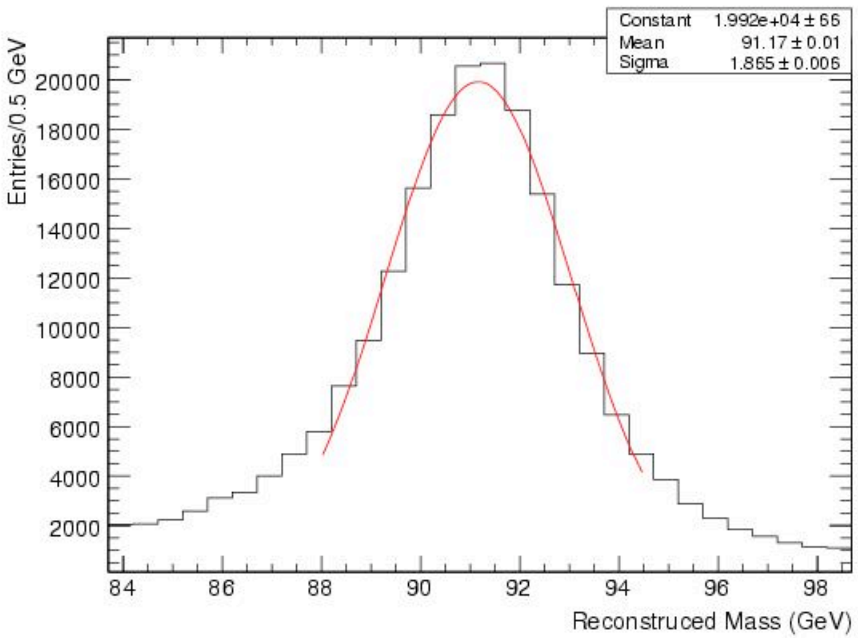
- Weight and size
- Magnetic field: (CMS: big solenoid 4 T; ATLAS: solenoid 2 T + air toroids).
- Inner tracking: (CMS: silicon, 15% at 1 TeV; ATLAS: silicon + transition radiation tracker. 50% at 1 TeV)
- Electromagnetic calorimeter: (CMS: $PbWO_4$ crystals, very good energy resolution, 5% at 1 GeV; ATLAS: liquid argon, 10% at 1 GeV, but very good granularity and uniformity).
- Muon spectrometer: (CMS: very redundant detection/trigger system; ATLAS: very good “stand-alone” momentum resolution, 7% at 1 TeV)

Example: Z/W->muons in CMS

- Safe definitions of 'hard' muon or track:
  - P_t > 20 GeV for Z, 25 GeV for W (well above trigger thresholds)
  - $|\eta|$ < 2.0 (trigger redundancy and efficiency)
  - Relaxed muon-tracker matching conditions for one of the muons in Z decays.
- No isolation criteria for muons:
  - Already applied in the High Level Trigger filtering step.
- Relaxed cuts in general: reconstructed masses, ...

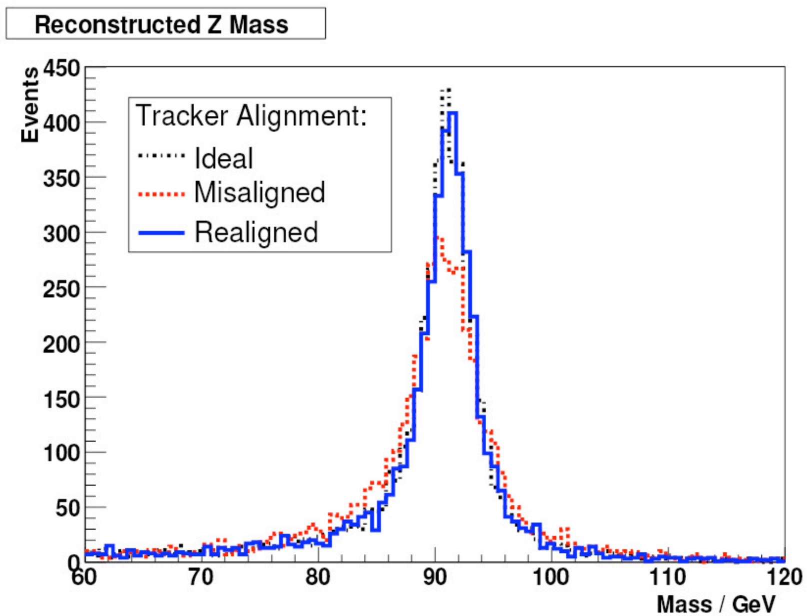
Z→μμ: invariant mass criteria

CMS, all cuts applied



$|m_{\mu\mu} - m_Z| < 3\ \Gamma_Z$

CMS, tracker alignment exercise



Initial tracker misalignment does not distort the shape dramatically =>
selection criteria OK to get initial samples for alignment and energy scale calibration

Total systematics in $W \to \mu\nu$

Source	Uncertainty (%)
Tracker efficiency	0.5
Muon efficiency	1
Magnetic field knowledge	0.05
Tracker alignment	0.84
Trigger efficiency	1.0
Transverse missing energy	1.33
Pile-up effects	0.32
Underlying event	0.24
Total exp.	2.2
PDF choice (CTEQ61 sets)	0.9
ISR treatment	0.24
p_T effects (LO to NLO)	2.29
Total PDF/ISR/NLO	2.5
Total	3.3

(CMS, for $L \sim 1\ fb^{-1}$)

- 6000 events recorded/pb : already dominated by systematic uncertainties at $L = 1\ pb^{-1}$.
- W production is a good place to understand the calorimetry response for (rather) low values of the missing transverse energy.
- Theory uncertainties are an interesting field of study by themselves (see next slides).

Cross sections (CMS, L=1 fb^{-1})

$$\sigma(pp \rightarrow Z+X \rightarrow \mu^{+}\mu^{-}+X) = 1160 \pm 2\,(stat.) \pm 28\,(syst.) \pm \text{lumi uncert.}\,[\text{pb}]$$

i.e.

$$\frac{\Delta\sigma}{\sigma} = 0.13\,\% \pm 2.4\,\% \pm \text{lumi uncert.} \qquad (\text{k-factor}=1.45)$$

$$\sigma(pp \rightarrow W+X \rightarrow \mu\nu+X) = 14700 \pm 6\,(stat.) \pm 540\,(syst.) \pm \text{lumi uncert.}\,[\text{pb}]$$

i.e.

$$\frac{\Delta\sigma}{\sigma} = 0.04\,\% \pm 3.8\,\% \pm \text{lumi uncert.} \qquad (\text{k-factor}=1.36)$$

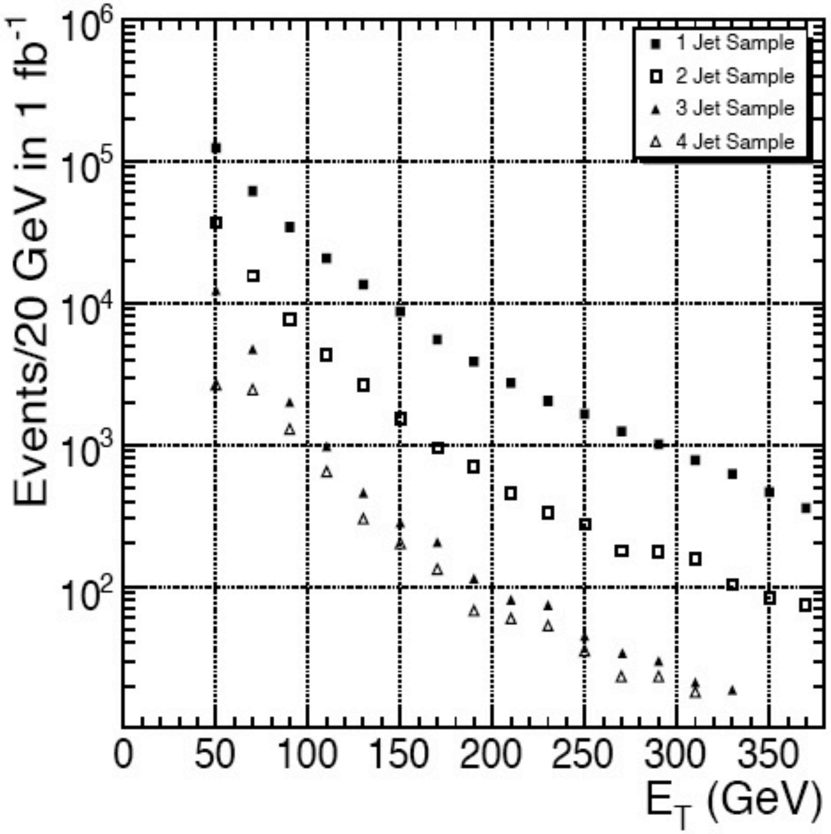
Conversely, a luminosity measurement with a 6-7% systematic uncertainty is possible, if today's estimates are proven to be correct (to be confronted to the first rapidity distributions obtained at the LHC).

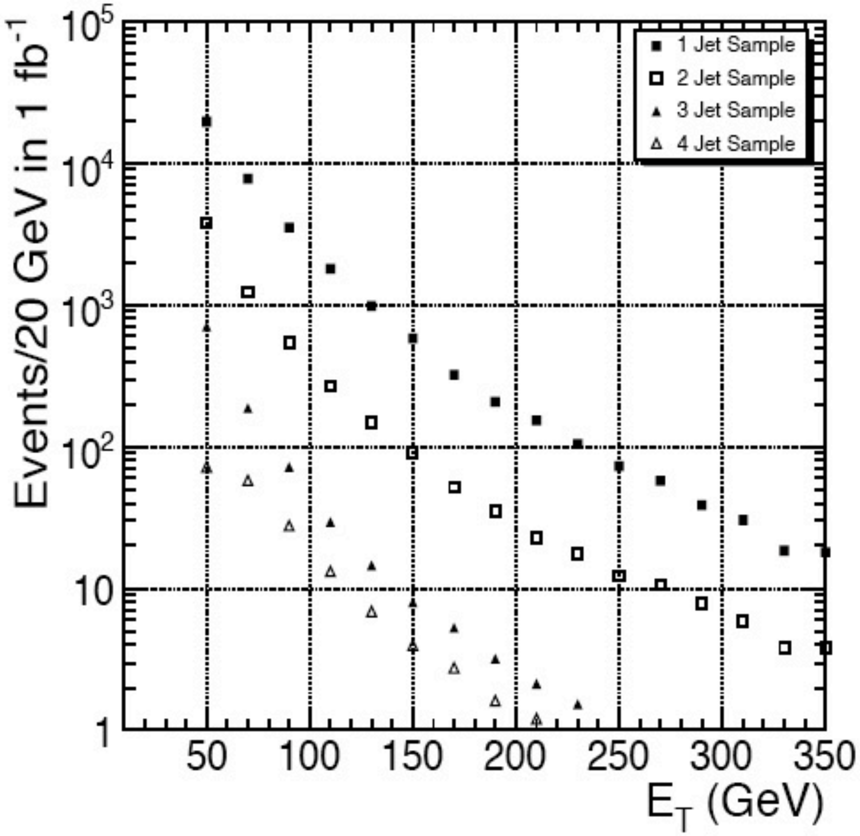
(PDF uncertainties in the theoretical expected rate ~ 6%)

pp->W/Z + jets

- Not so different from inclusive W/Z production. The key idea is to eliminate the dangerous QCD background => stringent cuts for lepton isolation

New analysis from CMS (E_T(jet) > 50 GeV):





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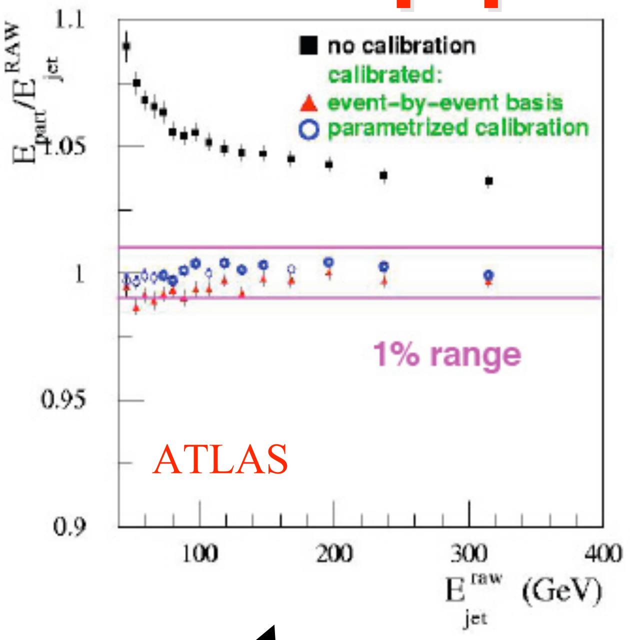
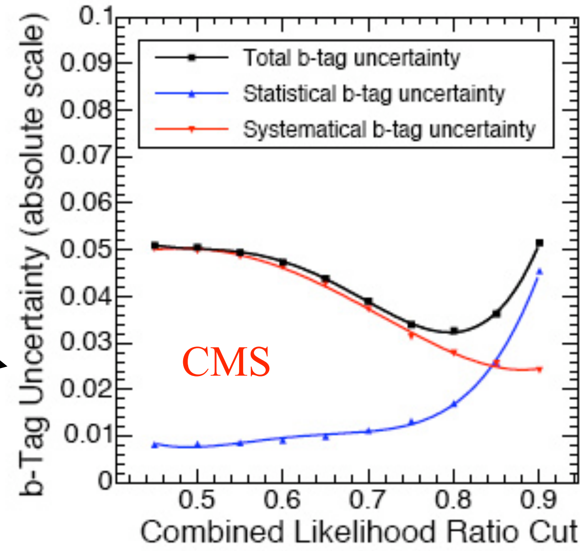
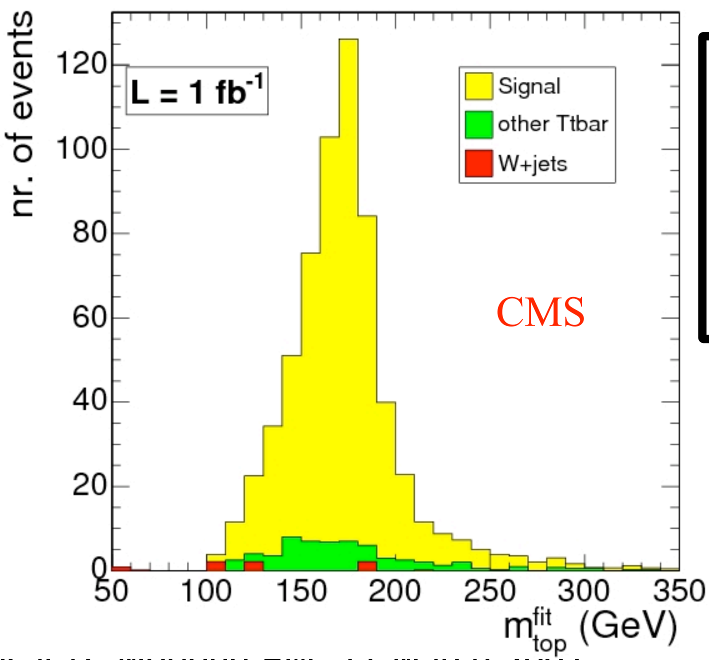
Top production, L ~ 1 fb^{-1}



b-tagging efficiency determination (in $t\bar{t}$ events)



Energy scale calibration (with W bosons in $t\bar{t}$ events)



+ many other inputs (alignment, calibrations, missing ET,...)

Final mass plot

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