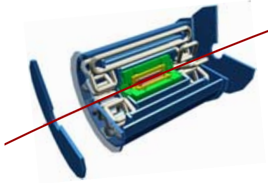
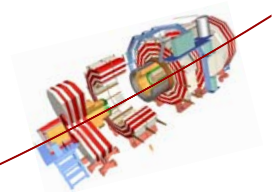
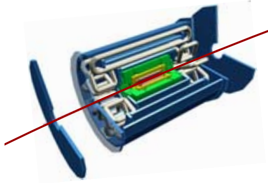


LHC POTENTIAL FOR STANDARD MODEL MEASUREMENTS

Maarten Boonekamp, CEA-Saclay
Physics at LHC, July 2006

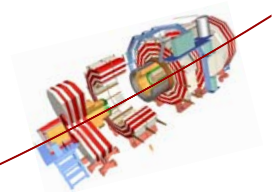
Standard processes as a background
and as a signal. Refining discoveries
and their interpretation

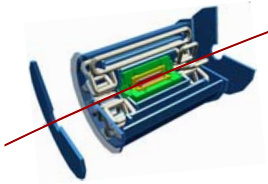




Acknowledgements

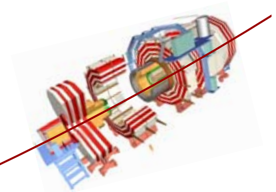
- Thanks to all CMS and ATLAS contributors for providing many new results (I'll reference notes when they exist, and names if they are only foreseen…)
- Apologies for the uncovered parts : I try to discuss what is not on the menu this afternoon, and link to the talks when relevant





Outline

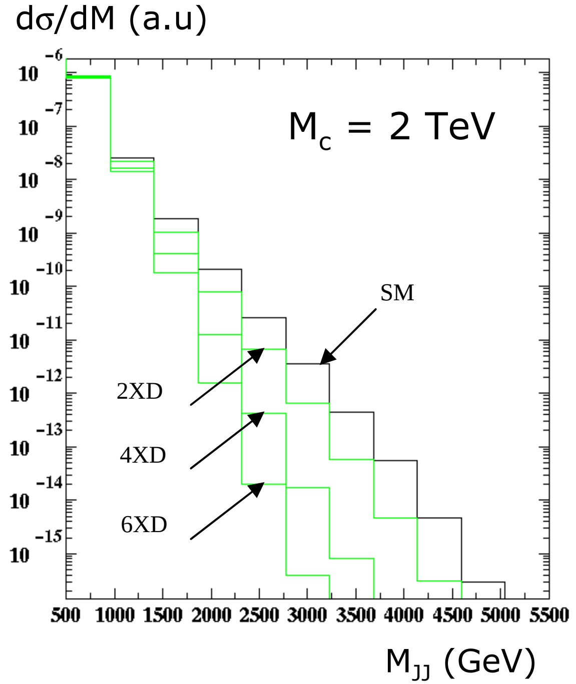
- Needs and prospects for standard processes measurements. A few examples:
  - Main argument : dijets and dileptons
  - Also : multijets, multilepton signals
- Precision measurements
  - Main argument : M_W
  - Consequences : M_t
- Conclusions

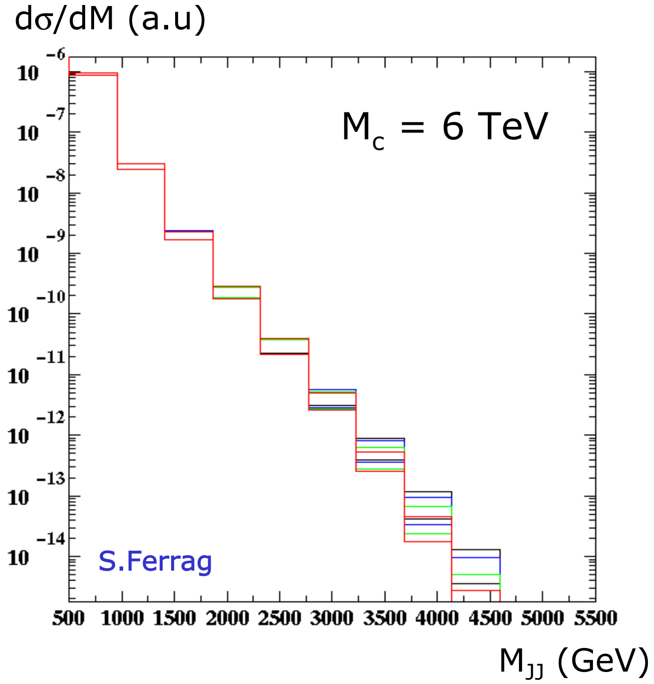


Measurements of Standard Processes
(a few examples)

Dijets and dileptons (1)

- Non-resonant extra-dimension signals predict deviations in dilepton or dijet spectra:

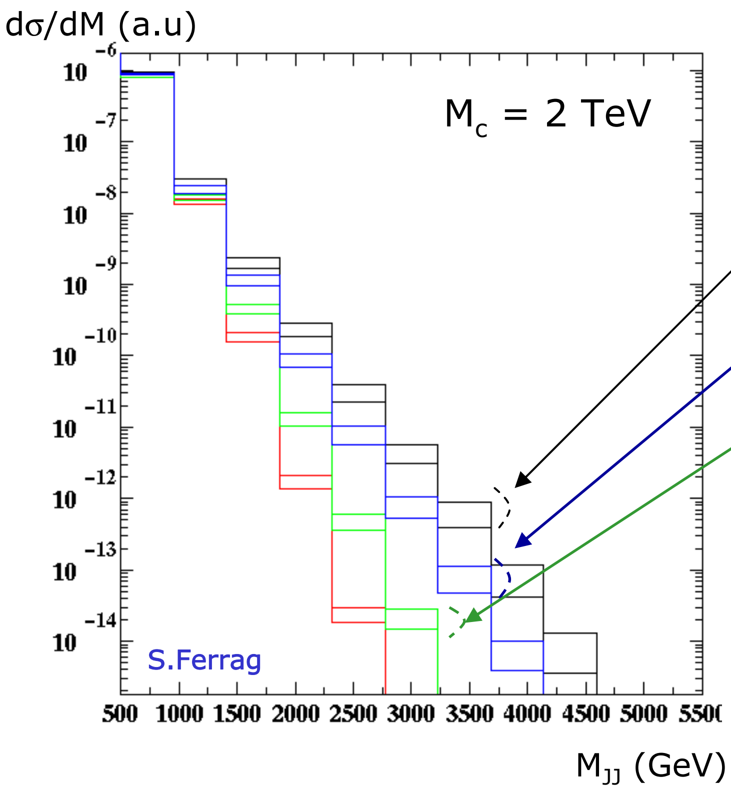




- Cf. talk by N.Brett, poster by M.Kazana

Dijets and dileptons (2)

- What is the uncertainty on the dijet cross-section?



Up to ~50% at high mass :

SM + structure function uncertainty band

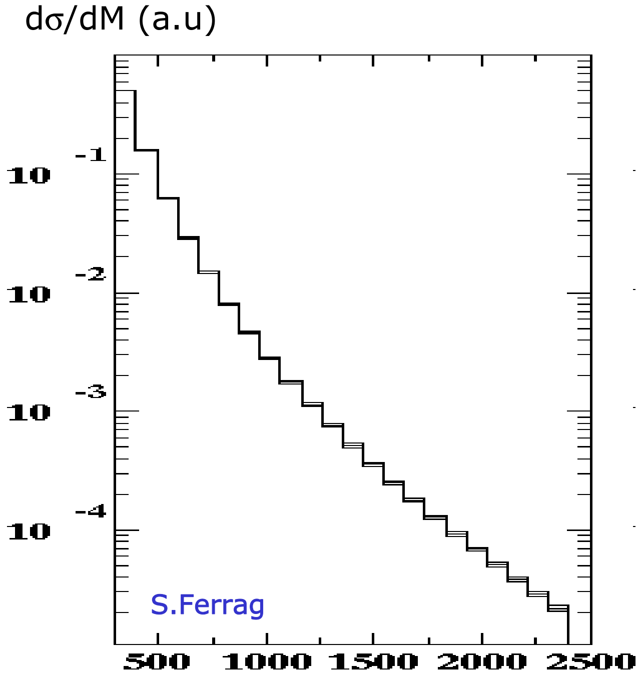
2XD + structure function uncertainty band

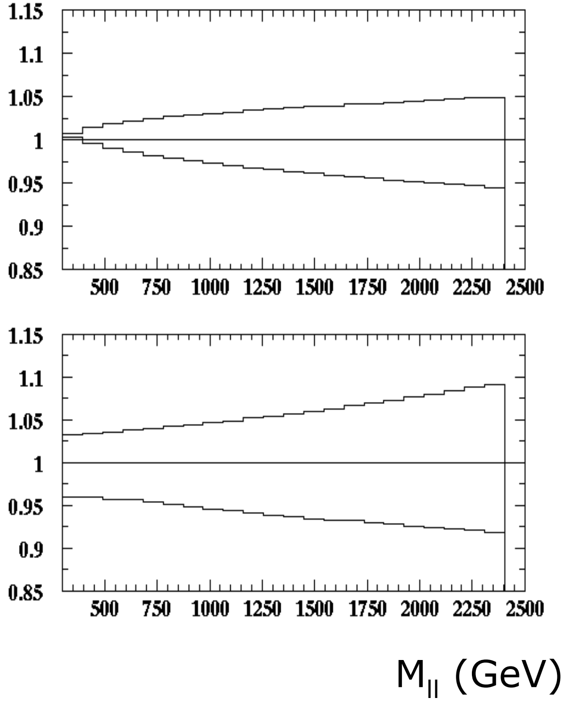
4XD + structure function uncertainty band

→Enough to lose sensitivity to higher compactification scales

Dijets and dileptons (3)

- Similarly, for dileptons :





Scale uncertainty (factor 10 variation) : ~ 5% at high mass

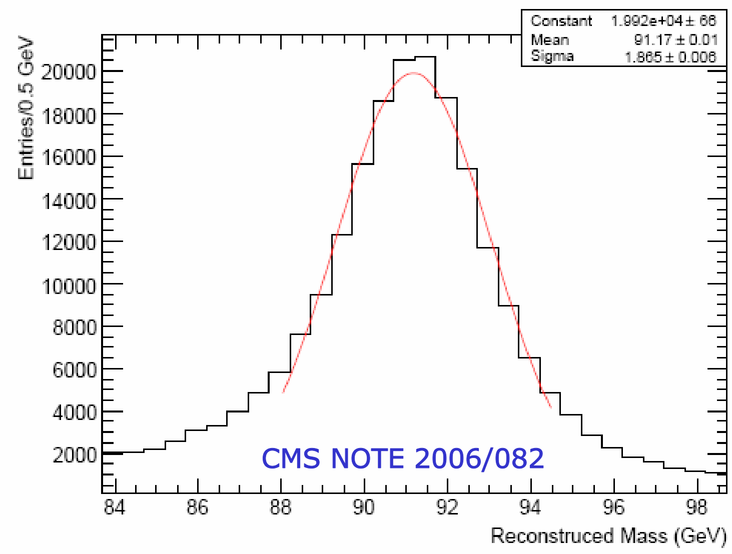
Structure function uncertainty : ~ 5-10%

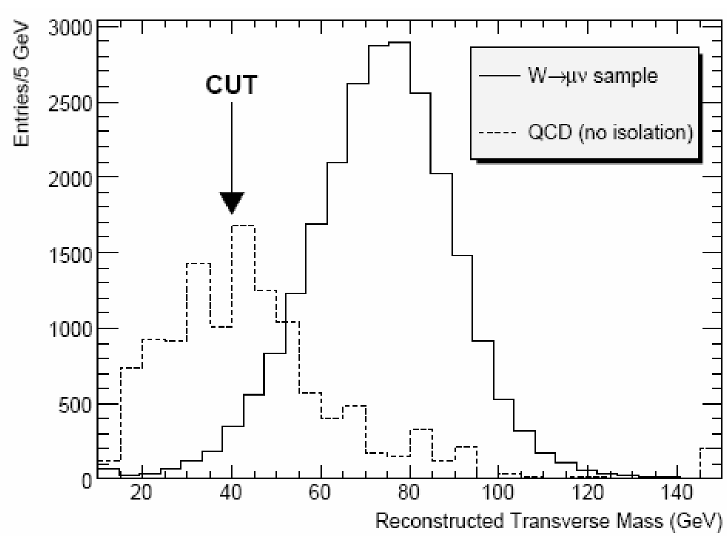
- How to improve without absorbing the effect of possible new physics?

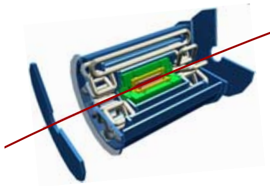
Dijets and dileptons (4)

- Measure standard cross-sections sensitive to the same sources of uncertainty, efficiently triggered, and unlikely to hide new physics : W,Z

- Recent analysis (CMS)
  - Z : 2 isolated muons with p_T>20 GeV, |η|<2, 84<$M_{\mu\mu}$<99 GeV, no jet nearby, …
  - W : 1 isolated muon with p_T>25 GeV, |η|<2, 40<$M_T(\mu,E_T Miss)$ <200 GeV, …







Dijets and dileptons (5)

- Results, for 1 fb^{-1} (or ~600k $Z \rightarrow \mu\mu$, ~6M $W \rightarrow \mu\nu$ events):
  - Cross-sections :
    - $\sigma(Z \rightarrow \mu\mu + X)$ = 1160 ± 1.5 (stat) ± 27 (syst) pb
    - $\sigma(W \rightarrow \mu\nu + X)$ = 14700 ± 6 (stat) ± 485 (syst) pb

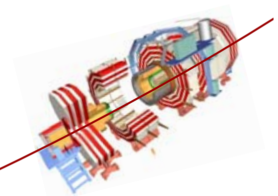
    Already dominated by systematics.

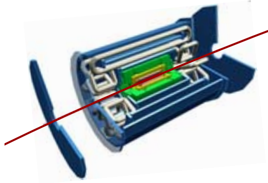
  - Systematics breakdown: theory dominated (acceptance).

CMS NOTE 2006/082

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

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





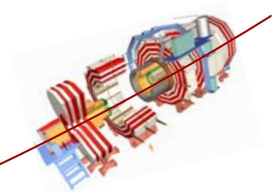
Dijets and dileptons (6)

- So this is a first step : total cross-sections don't teach us much about how to constrain the theory; the effects that hinder our high-mass predictions are also playing here.

- Specifically, the acceptance uncertainties (not knowing how many events are outside the y, M, $p_T(l)$ windows we select) should be improved.

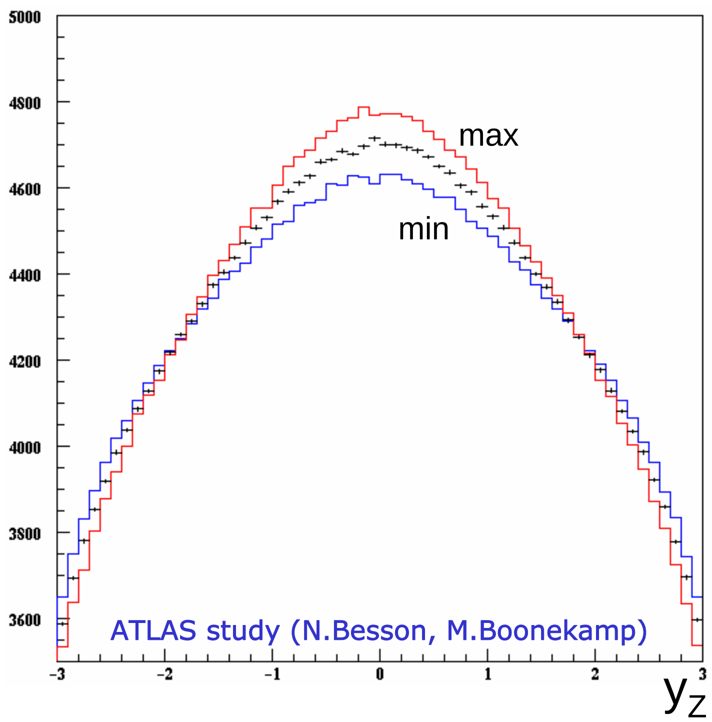
- It is thus important to analyse the shapes : $d\sigma/dy$, $d\sigma/dp_T$, $d\sigma/dM$. Z events are better than W in this respect (fully measured). Since the Z decay is well known, the acceptance uncertainty on differential cross-sections is very small.

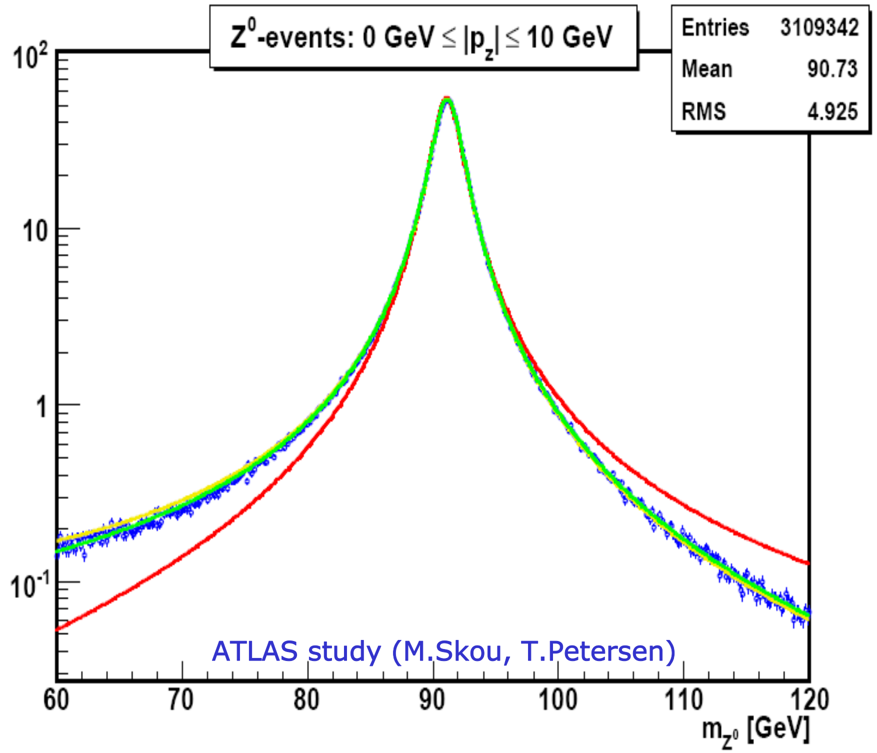
- Improvement on the theoretical description then comes from:
  - Confronting data and theory within the analysed (y,p_T,M) domain
  - Better extrapolation outside the analysed domain



Dijets and dileptons (7)

- Two examples on structure functions :





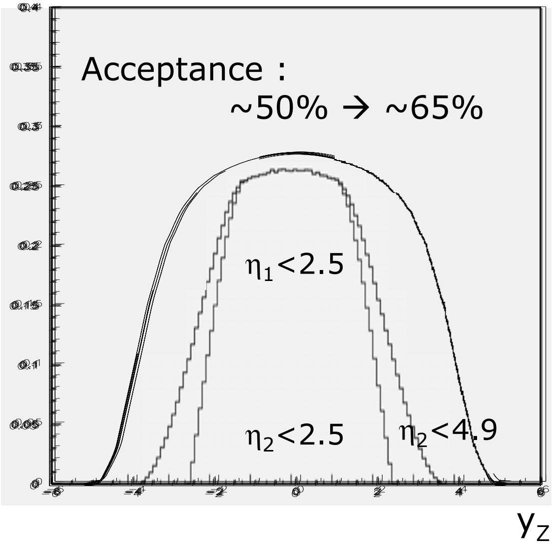
$\delta(d\sigma_Z/dy) \sim 4\%$

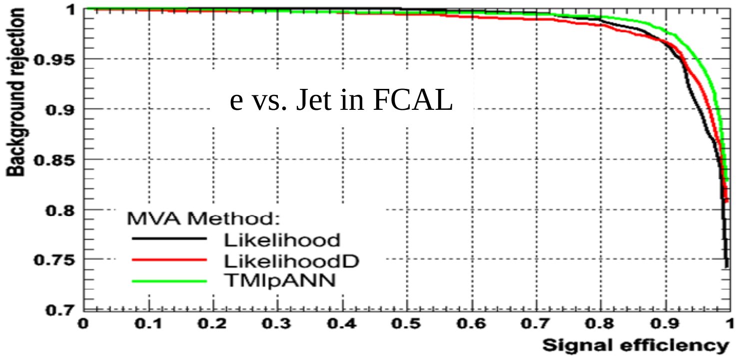
→ ~ 0.2% with ~10 fb^{-1}

A 1σ pdf variation (today) becomes a 5σ effect with ~10 fb^{-1}

Dijets and dileptons (8)

- It is important to extend the y_Z acceptance if possible, reducing the extrapolation uncertainty. Consider the Z → ee channel:

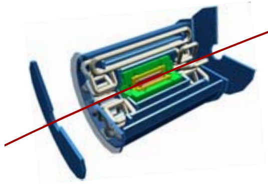




Eff(%)	Rej: 100	Rej: 10
likelihood	77	95
ANN	81	98
likelihoodD	66	97

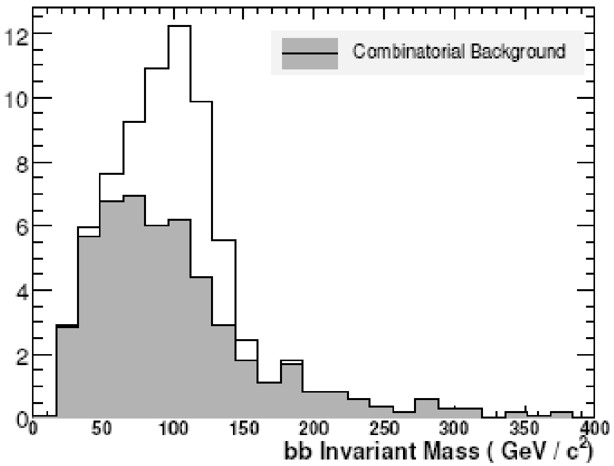
ATLAS studies (M.Aharrouche)
in progress

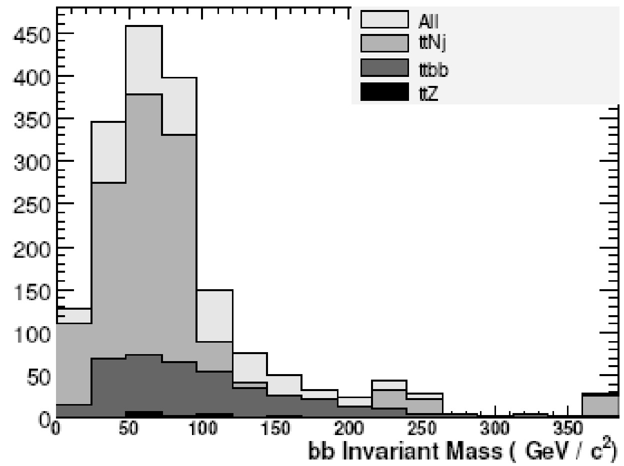
- Link with high mass dileptons :
  - central heavy object (~2.5-3 TeV) has $x \sim M/\sqrt{s} \sim 0.2$
  - Can be controlled by Z events if forward enough : $x_{1,Z} \sim 0.2$ if $y_Z \sim 3.5$
  - Expect ~800k events in $2.5<y_Z<4$ for 10 fb^{-1}



Multijets (1)

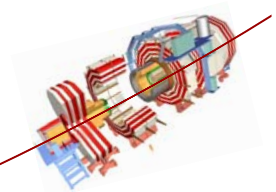
- Higgs search – the ttH → eνqqbbbb (!) channel :





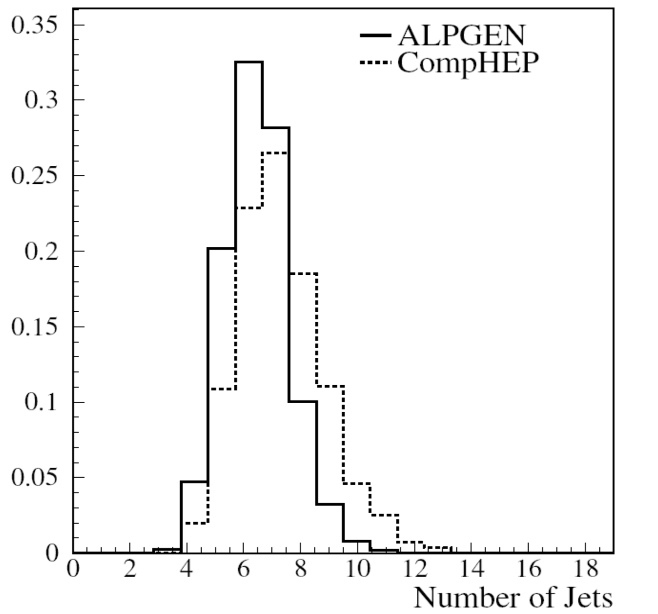
CMS NOTE 2006/119

- Challenges :
  - tt properties (talk by Ivo van Vulpen)
  - Precise jet distributions (talk by Maria Jose Costa)
  - Experimental performance control

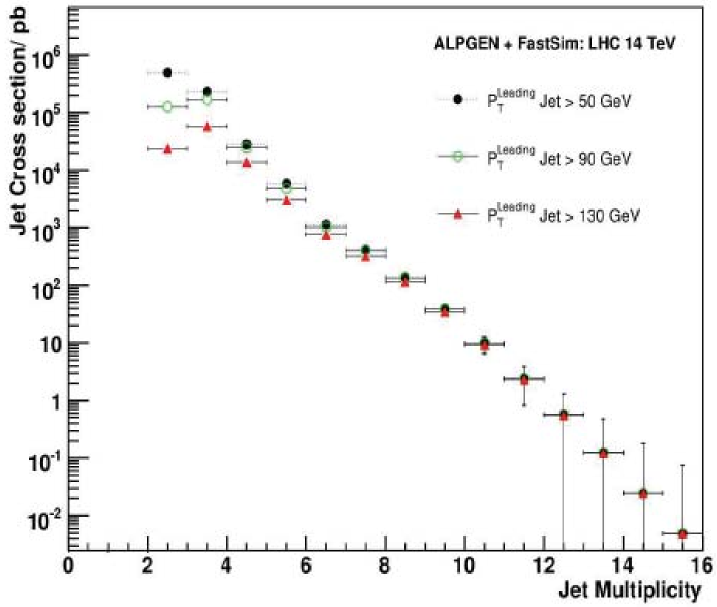


Multijets (2)

- Jet multiplicity predictions :

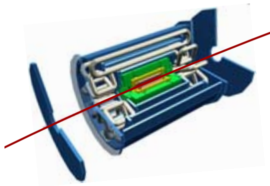


CMS NOTE 2006/119 (with $E_T > 20$ GeV)



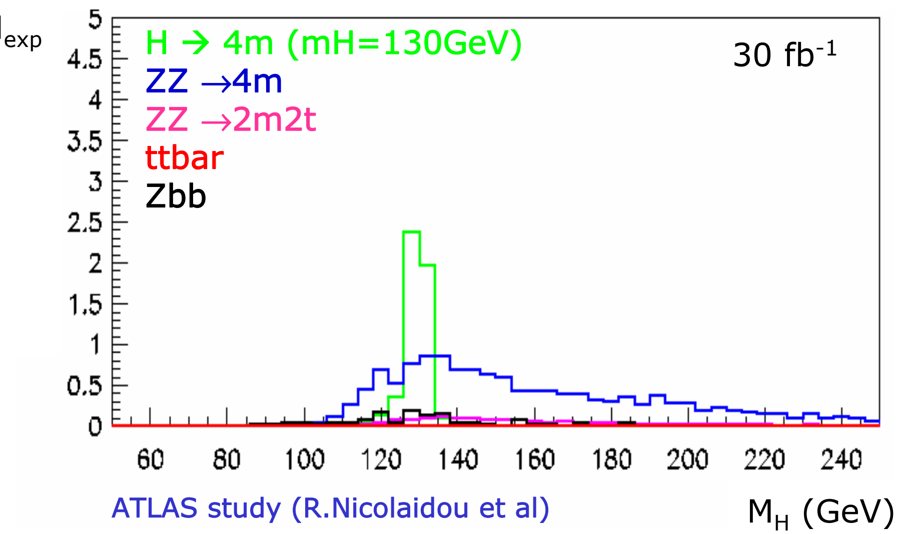
ATLAS study (S.Padhi) (with $E_T > 50$ GeV, $|\eta|<5$)

- Large uncertainty. However, data will tell to 1%, even for $N_{jet}\sim10$

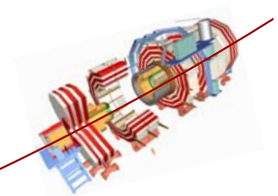


Four-lepton processes

- The main background to the H → 4l and 2l2ν channels



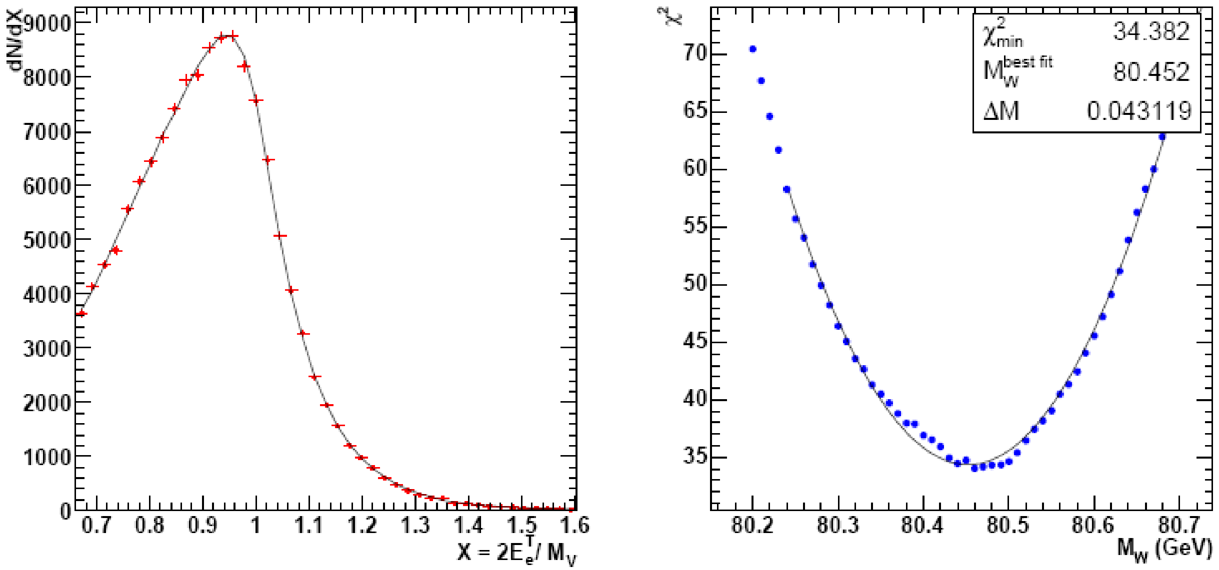
- Measurement prospects : talk by V.Briglievic, poster by N.Vranjes
  - WW production most copious; will normalize ZZ production
  - Cross-section measurements and anomalous couplings



Precision Measurements

Precision measurements : M_W

- Simple and powerful in principle: consider e.g the $p_T(l)$ spectrum



Example fit from CMS NOTE 2006/061

- Statistical sensitivity : ~2 MeV (1 channel/experiment, 10 fb^{-1})
- But need to predict the spectrum precisely!

Precision measurements : M_W

- Ingredients
  - Lepton energy scale and resolution. Linearity. Reconstruction efficiency
  - W dynamics : rapidity, transverse momentum, polarization, final state radiation

- Current consensus (hep-ph/0003275…)
  - Lepton energy scale: 15 MeV (limitation : Z → W extrapolation. Linearity)
  - PDF's : 10 MeV (from comparison of existing sets)
  - QED FSR : 10 MeV (calculation up to $O(\alpha^2)$)
  - Lepton resolution : 5 MeV
  - QCD corrections : 5 MeV (limitation : Z → W extrapolation)

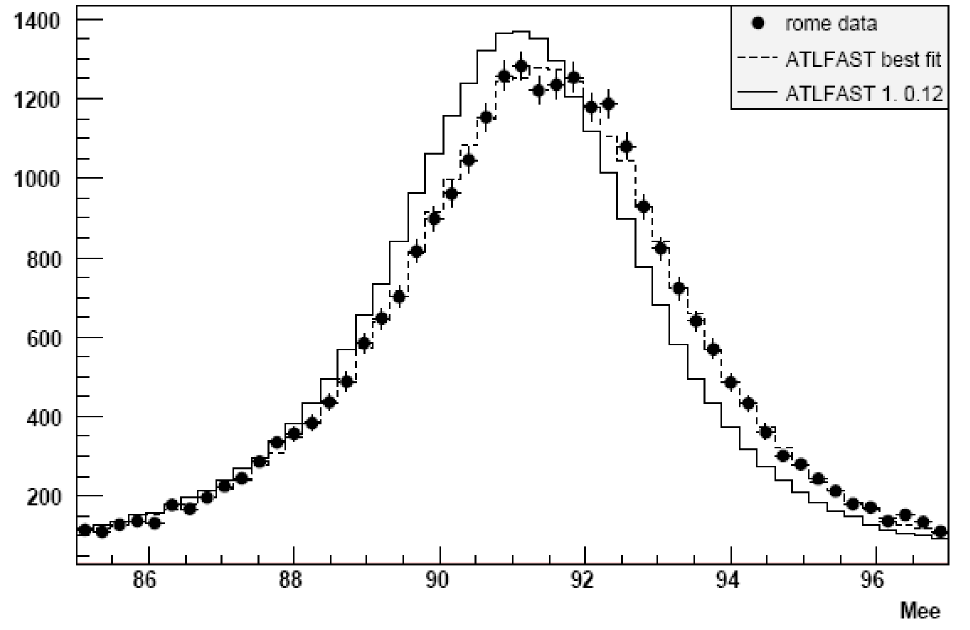
- → The Z calibration sample revisited
  - Improvements on the above. Expected performance

- Recent studies by CMS (note 2006/061) and ATLAS (t.b.p)

M_W : energy scale and resolution (1)

- The mass scale (β) and mass resolution (σ) from the Z peak :
  - $M_{data} \equiv (1+\beta)\, M_{MC}$; $\sigma_{data} \equiv \sigma_{MC}$

ATLAS-PHYS-PUB-2006-07



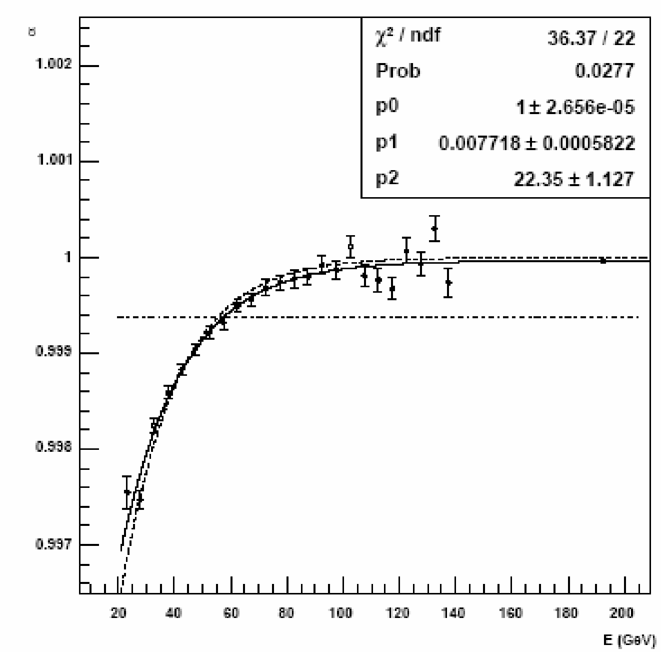
  - Achievable precision : $\delta\beta \sim 10^{-5}$, $\delta\sigma \sim 10^{-4}$

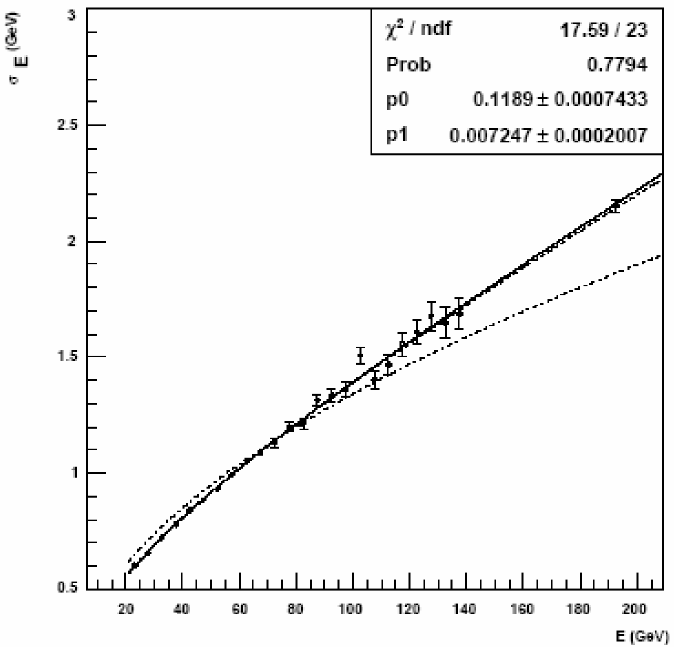
- But indeed, how does this translate to a W-mass measurement?

M_W : energy scale and resolution (2)

- Now differentiate in energy (i.e consider lepton energy bins i, j). Repeat previous fit for every pair configuration (i,j):
  - $M_{ij}^2 = E_iE_j(1\text{-}\cos\theta)$; $(1+\beta_{ij})^2\, M_{ij}^2 = (1+\alpha_i)E_i(1+\alpha_j)E_j(1\text{-}\cos\theta)$
  - $\Rightarrow \beta_{ij} \sim (\alpha_i+\alpha_j)/2$; $\sigma_{ij}^2/M^2 = \sigma_i^2/E_i^2 + \sigma_j^2/E_j^2$; write this for all (i,j)
  - and solve the linear system (least squares) to get the α_i and σ_i^2

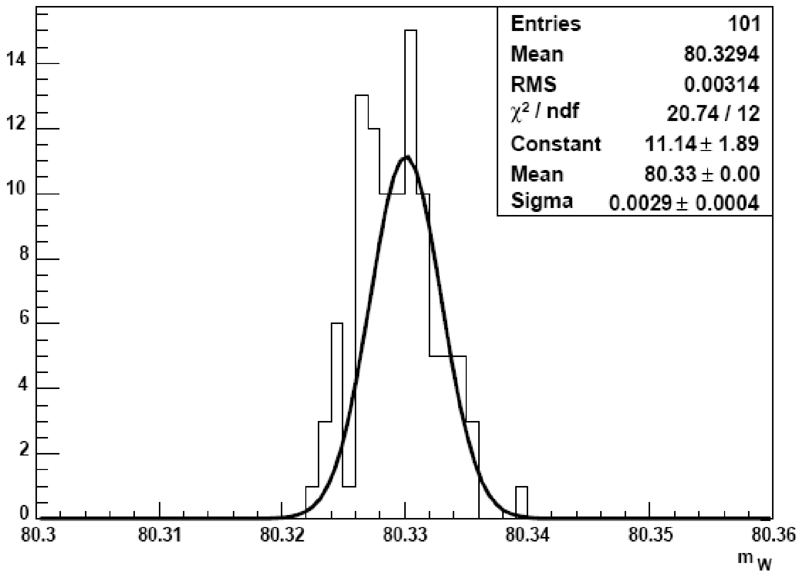
ATLAS-PHYS-PUB-2006-07





M_W : energy scale and resolution (3)

- Propagation to M_W : vary the linearity and resolution functions within their uncertainties (at random), distribute M_W(fit) :



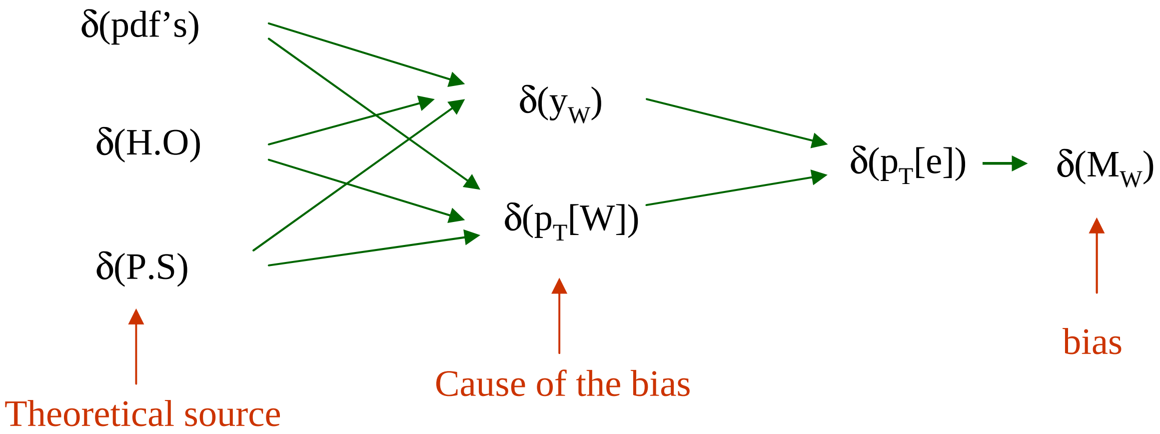
- → δM_W(scale) = 3 MeV (one channel/experiment, 10 fb^{-1})

- After combinations, get ~1 MeV → strong correlation with δM_Z!

M_W : W dynamics

- The observed lepton distributions result from
  - W → l angular distribution
  - W distributions (cut by detector acceptance): the difficult part!

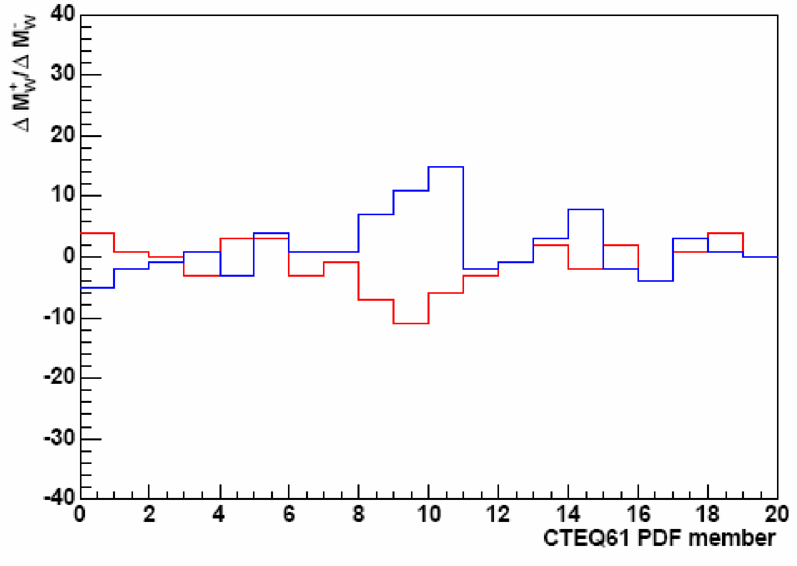
- What happens:



- What can we say here?

M_W : structure functions (1)

- Directly affect y_W (…and indirectly p_{TW})
- Using CTEQ6 pdf "uncertainty sets", one can evaluate the current uncertainty :

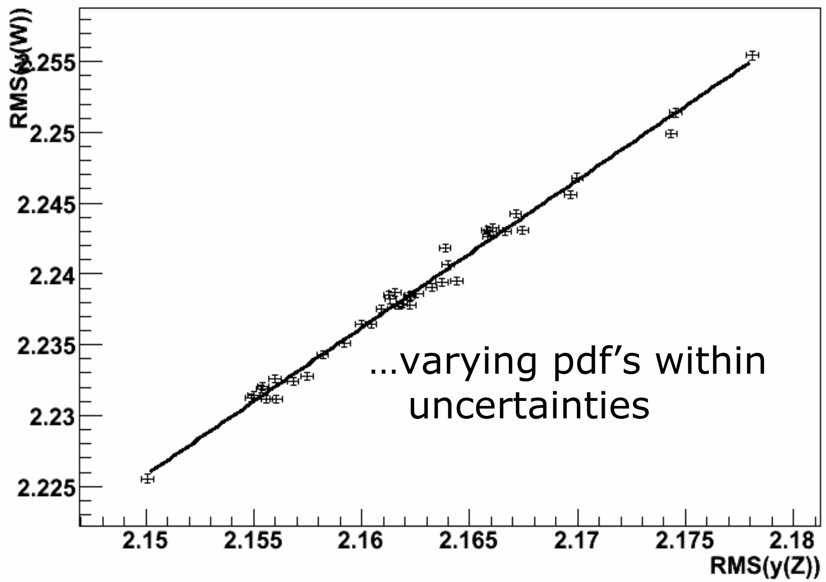


- $\delta M_W \sim 20$ MeV : worse than expected!

M_W : structure functions (2)

- But how do W and Z production relate?

W rapidity shape



Z rapidity shape

- The Z rapidity uncertainty will be divided by ~20 (10 fb^{-1})
  - (see also earlier comments on $d\sigma_Z/dy$)

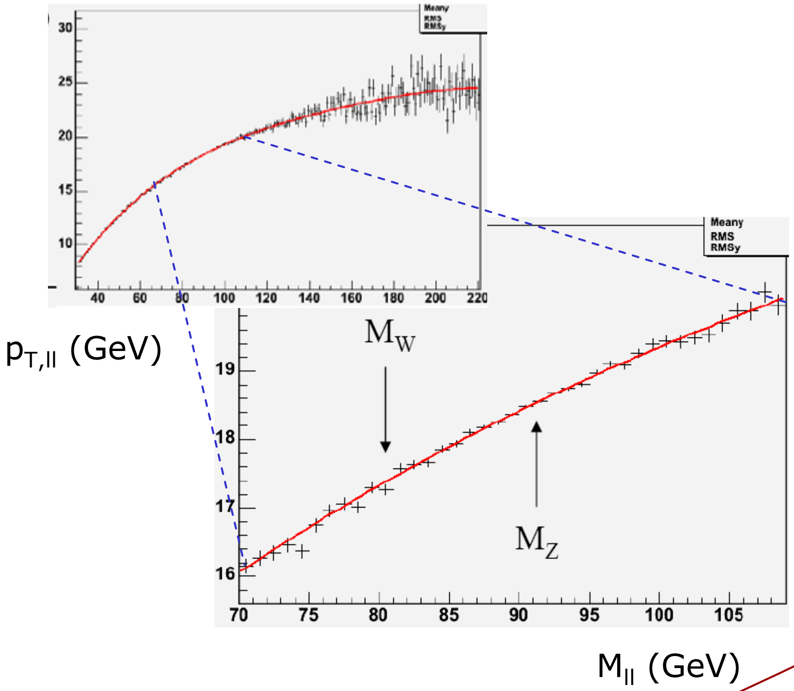
- And so will the W rapidity uncertainty : as a result, dM_W(pdf's)~1 MeV

M_W : p_T spectrum (1)

- W,Z p_T predictions is currently a busy subject. Large uncertainties remain

- However, QCD tells that the mechanisms at work in W and Z production are identical. Differences come from phase space ($M_W \neq M_Z$) and different couplings of W and Z to the partons in the proton.

- Consider $p_{T,ll}$ as a function of M_{ll} :



Thanks to high precision at the peak and the large lever arm provided by the continuum:

- $\delta p_T(M_{ll}=M_Z) \sim 5$ MeV
- $\delta p_T(M_{ll}=M_W) \sim 7$ MeV

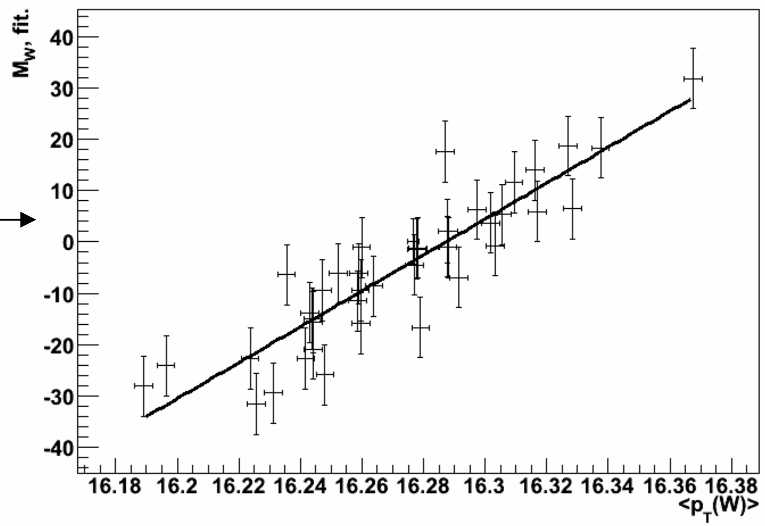
M_W : p_T spectrum (2)

- Not to say that $p_{T,W}=p_{T,ll}(M_{ll}=M_W)$! Non-universalities (EW) need to subtracted.
  Can be precisely computed (need precision MC!)
  Measuring the off-peak $p_{T,ll}$ allows to get rid of the phase space difference and control the non-perturbative effects.

- This improves over the “ratio method”, where all W distributions are defined from Z distributions rescaled by M_W/M_Z – this is an approximation probably not well suited to LHC statistics.

- To finish : $\delta M_W = 0.3\ \delta p_T$ →

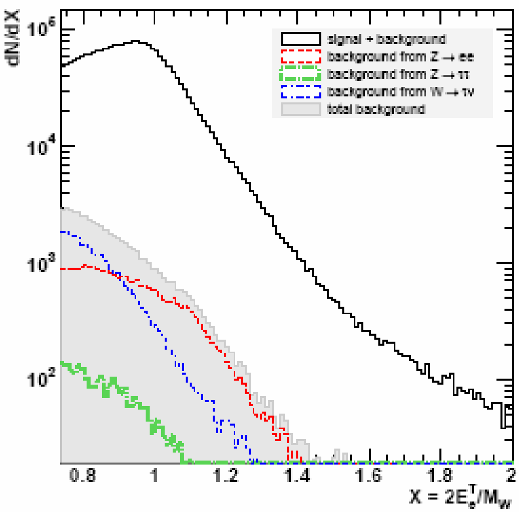
  So $\delta p_T(M_{ll}=M_W)$~7 MeV
  gives δM_W~2 MeV

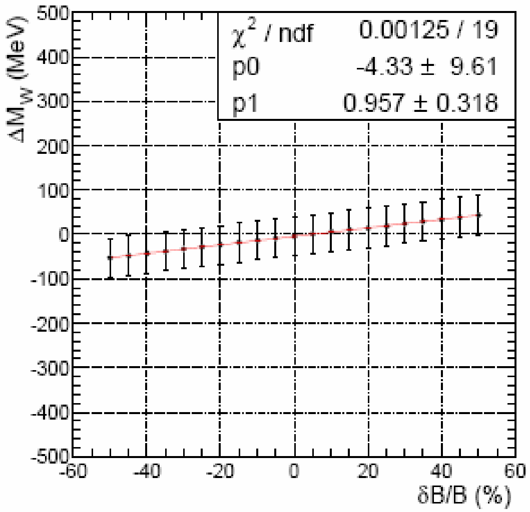


M_W : backgrounds

- Backgrounds distort the $p_T(l)$ spectrum
  - Main expected sources : Z → ll (1-2%), W → τν (1-2%), Z → ττ (0.2%)
  - QCD expected small (0.1%) after tight lepton selections

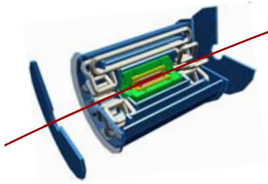
- CMS studied the impact of imperfectly known background rates:





CMS NOTE 2006/061

concluding δM_W (MeV)= δB/B (%) ; δB/B = 5% giving δM_W=5 MeV.



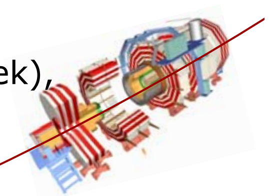
M_W : summary

- So far, per channel/experiment for 10 fb^{-1}:

(source)	(old est.)	(updated estimate)	(tool)
Energy scale, linearity:	15 MeV	~3 MeV	Z lepton spectra
Lepton resolution :	5 MeV	<1 MeV	"
PDF's :	10 MeV	~1 MeV	$d\sigma_Z/dy$, $d\sigma_Z/dM$
QCD corrections :	5 MeV	~2 MeV	$d\sigma_Z/dp_T$
Backgrounds :	5 MeV	~5 MeV	known to ~5% (conservative)

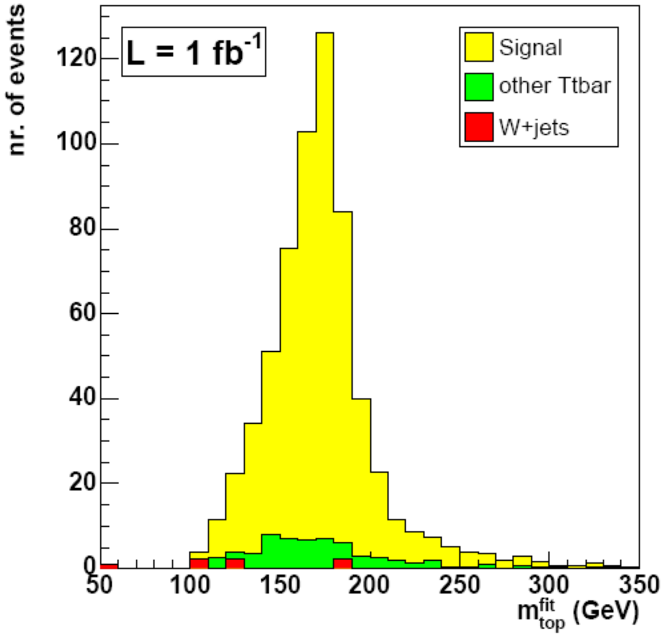
- $\delta M_W \leq 5$ MeV looks achievable when combining, or with higher luminosity

- No results yet, but encouraging situation :
  - QED FSR : recently much improved PHOTOS program (Golonka, Was), now includes radiation up to $O(\alpha^4)$ and exponentiation.
  - W polarisation : purely W_T at p_T~0, a W_L component develops when p_T>0. This affects the lepton distributions and can be studied using WINHAC (Jadach, Placzek), in development



Precision measurements : M_t

- Similar situation!
  - Best channel : tt → (lνb)(jjb)
  - Exploit the (j,j,b) invariant mass; profit from $M_{jj} \sim M_W$
  - δM_t(stat) ~ 0.2 GeV ; δM_t(syst) ~ 2 GeV (10 fb^{-1})

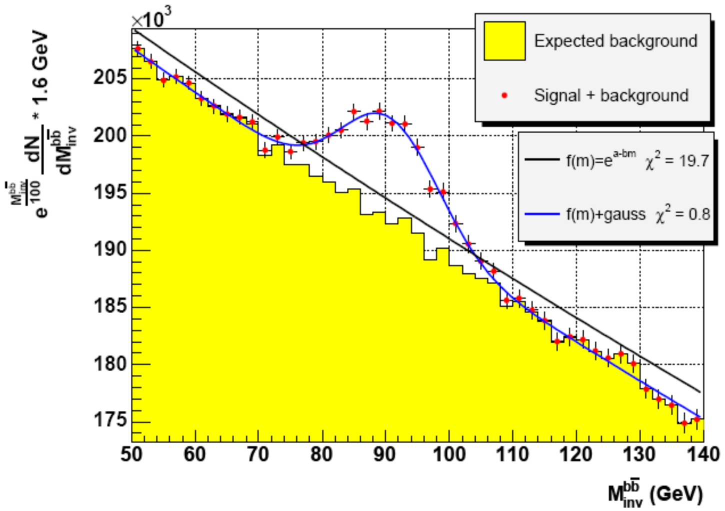


CMS NOTE 2006/066	Full Scan Ideogram Δm_t (GeV/c^2)
Pile-Up	1.2
Underlying Event	0.5
Jet Energy Scale (light)	0.1
Jet Energy Scale (heavy)	1.2
Radiation (pQCD)	0.2
Fragmentation	0.3
b-tagging	0.3
Background (*)	0.4
Parton Density Functions	0.1
Total Systematical uncertainty	1.9
Statistical Uncertainty (10fb^{-1})	0.21
Total Uncertainty	1.9

- Talk by M. Duda

M_t measurement : a few aspects

- B-jet scale :
  - visibility of the Z resonance in three-jet events (p_{T1} > 190 GeV [trigger], $p_{T2,3}$ > 40 GeV, b-tagging, plot M_{23}):



δ(peak position) ~ 0.9 GeV with 30 fb^{-1}

→ b-jet scale within 1%

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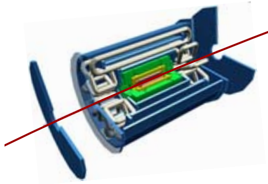
  - Additionally : "close the system" by comparing light jets to b-jets in dijet events

- MinB, U.E : currently large uncertainty, but will improve significantly with data (talk by M.J.Costa, poster by L.Fano)



Summary

- Firmly establishing discoveries needs well controlled standard processes.

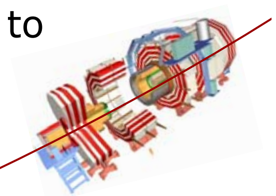
  It is crucial to go beyond "background control" and measure cross-sections (in full differential glory), because this is what will constrain the theory.

- An improved study of the M_W potential tells us that we should aim at $\delta M_W \leq 5$ MeV. This is reasonably close to the absolute lower bound given by δM_Z, and follows from the exploitation of all distributions of the Z and its decay particles.

- Given $\delta M_W \sim 5$ MeV, the (reasonable) M_t goal is $\delta M_t \sim 500$ MeV. This requires precise measurements of the soft QCD environment, and exploits the possibility to over-constrain the b-jet scale.

- Certainly not easy, but worth the effort!

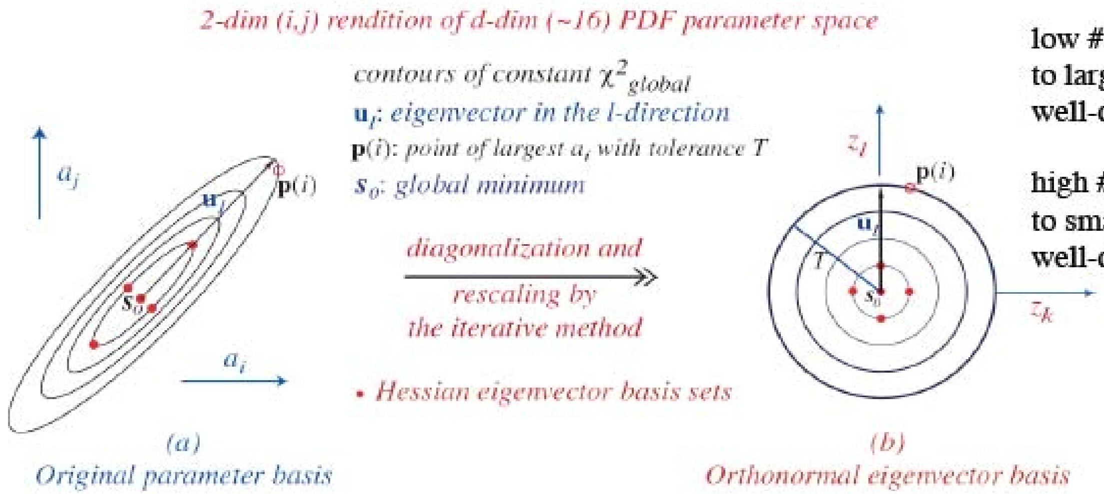
- As a reward, the LHC will have an EW output that will allow the experiments to constrain the underlying theory well beyond earlier prospects.



Extras

CTEQ6.1 error pdf's

- There are 20 free pdf parameters in the CTEQ6.1 global pdf fit
  - for u,d,g, d-bar/u-bar,d-bar+u-bar
- With Hessian method, a 20X20 matrix is diagonalized resulting in 20 eigenvalues and 20 orthonormal eigenvectors



low # eigenvectors correspond to large eigenvalues, well-determined directions

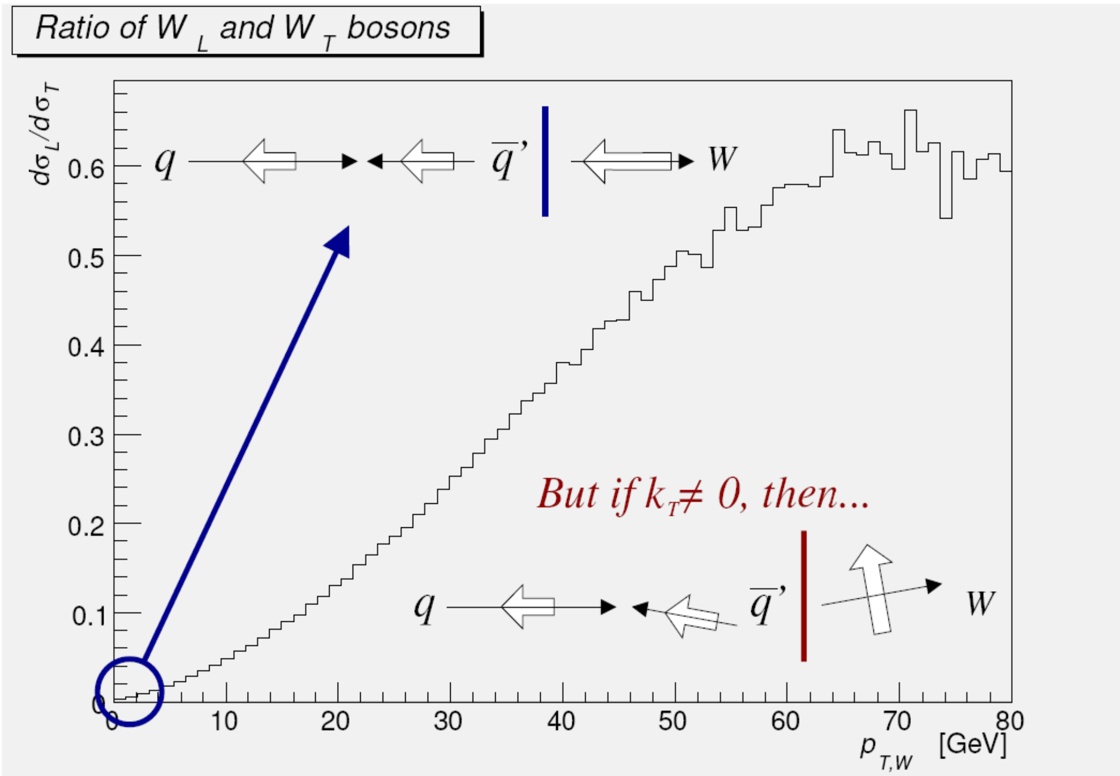
high # eigenvectors correspond to small eigenvalues, less well-determined directions

8

WINHAC (Jadach, Placzek et al)

WINHAC (8/14)
└ 2. The MC event generator WINHAC
  └ 2.2 Program test

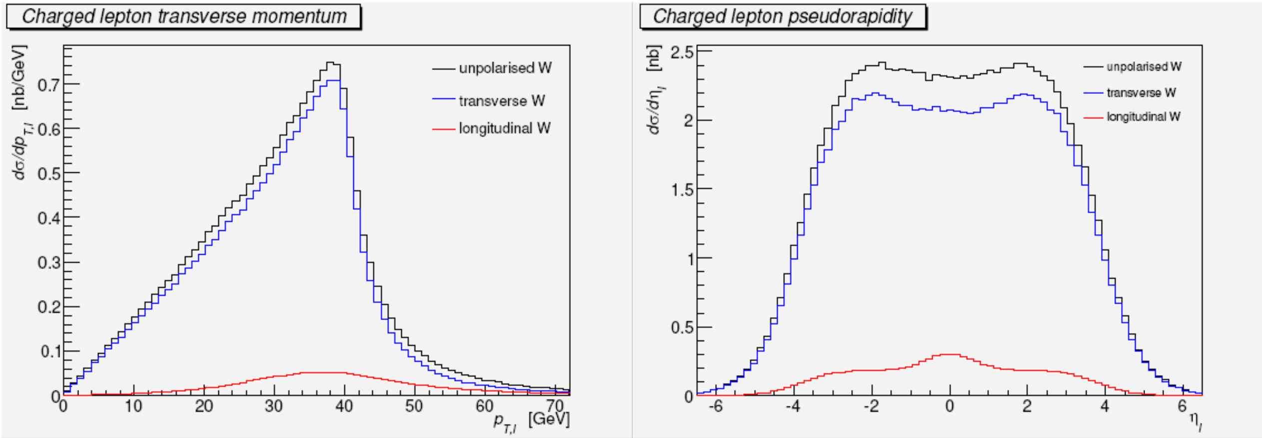
Polarised W bosons 1/3



WINHAC (Jadach, Placzek et al)

Polarised W bosons 2/3

- Example of two important plots : $p_{T,l} \rightarrow M_W$ & $\eta_l \rightarrow PDF$

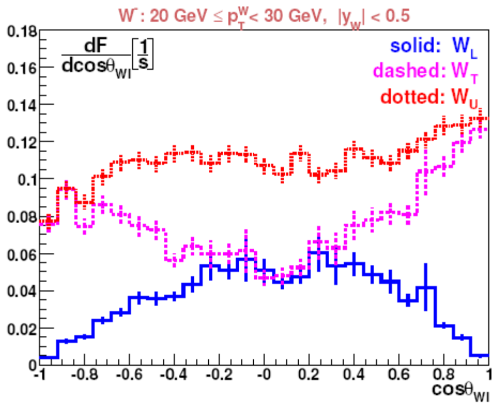


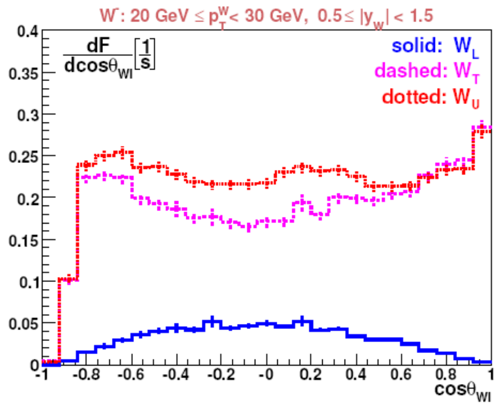
- We are interested by the consequences of W_L/W_T contribution on the measurements
- But, what if we misjudge the proportion of W_L/W_T...

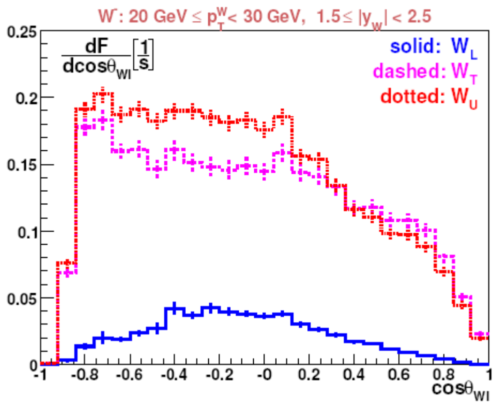
WINHAC (Jadach, Placzek et al)

Polarised W bosons 3/3

Distribution in $\cos\theta_{W,l}$ in the CMS with $p_{T,l} > 20\,\mathrm{GeV}$ & $\eta_l < 2.5$







- . . . then we can ajdust experimentally the proportion of W_T/W_L