$Z \to \mu^+\mu^-$ and $W \to \mu\nu$ counting in CMS

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Outline

- $Z \rightarrow \mu\mu$ selection in CMS
- PDF and QCD uncertainty studies
- $W \rightarrow \mu\nu$ selection in CMS
- Comments, questions

Selection criteria

- ✔ **Main aim: keep it simple in order to control systematics**
- ✔ Definition of 'hard' muon or track:
  - P_t > 20-25 GeV (triggers: dimuon > 7 GeV, single > 19 GeV)
  - $|\eta| < 2.0$ (trigger redundant and highly efficient in this range)
- ✔ Calorimeter isolation criteria for muon or tracks:
  - Already implemented at the HLT level

Selection criteria for Z->μμ

- ✔ EITHER 2 'hard isolated' GLOBAL muons

  OR

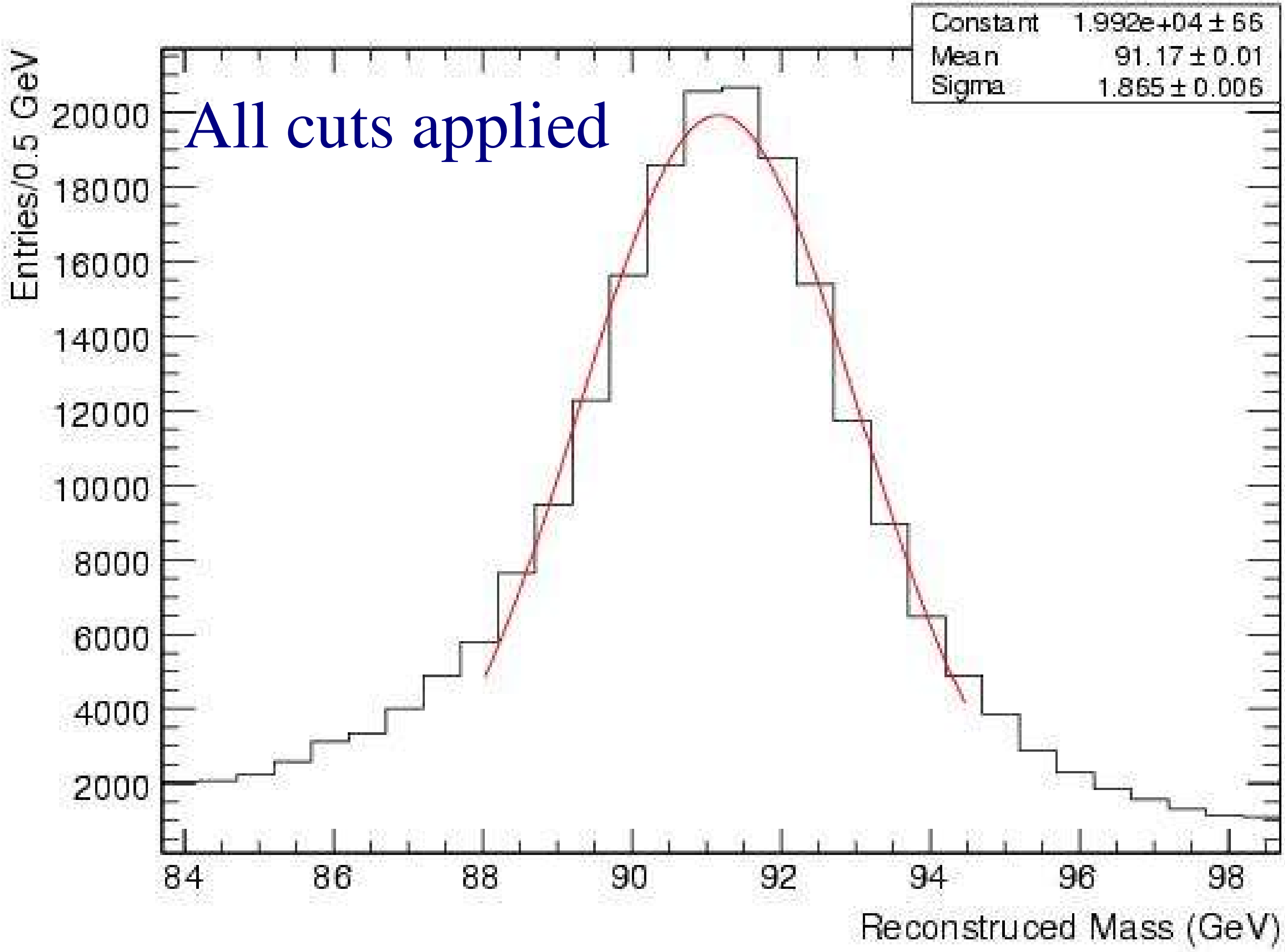
  1 'hard isolated' GLOBAL muon + 1 'hard isolated' track

- ✔ With invariant mass in the range

  $83.7\ \mathrm{GeV} < M_{\mu\mu} < 98.7\ \mathrm{GeV}$ (i.e. $\pm 3\Gamma_Z$)

- ✔ And Passing HLT trigger criteria

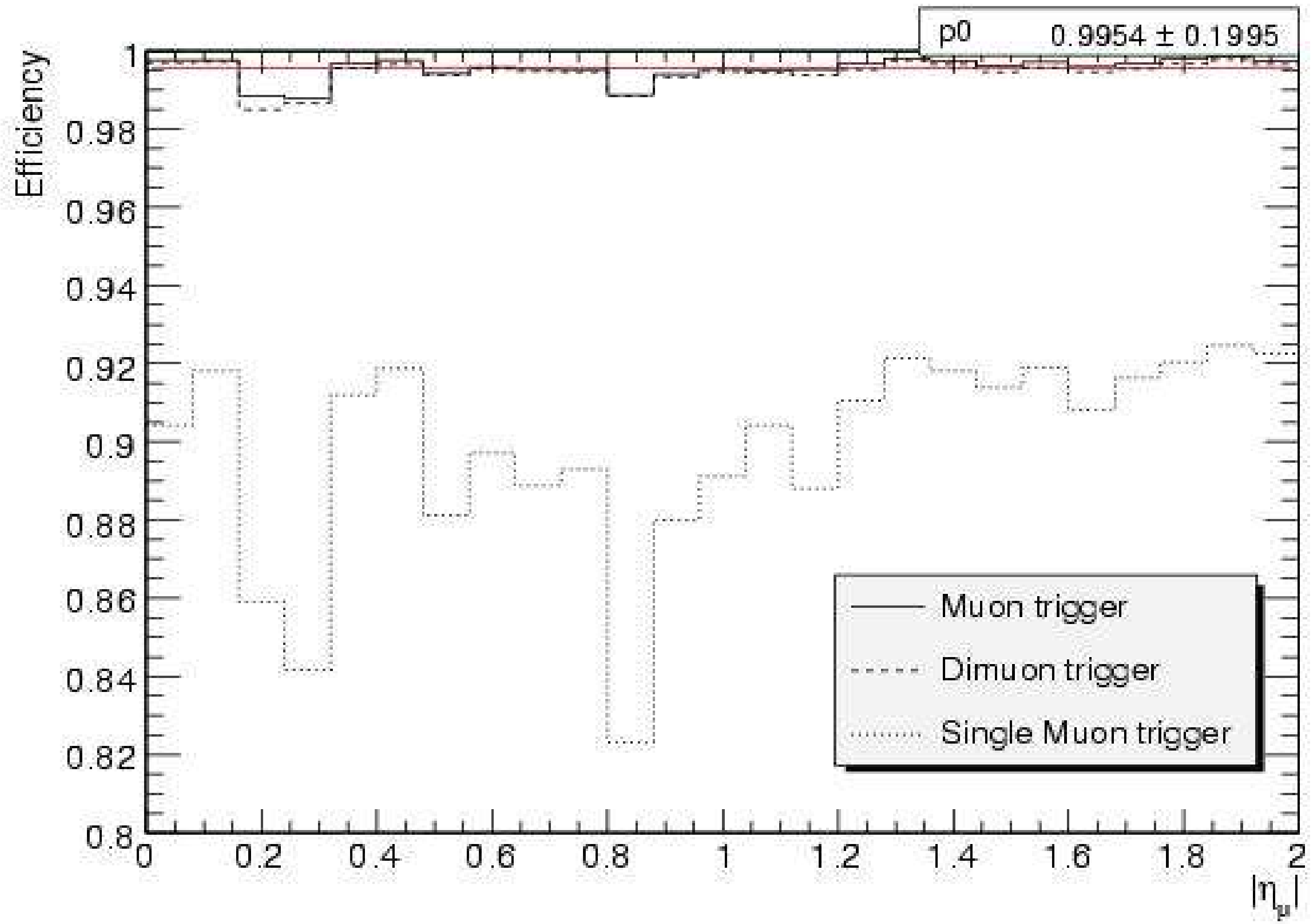
Selection criteria



Resolution ~ 1.9%

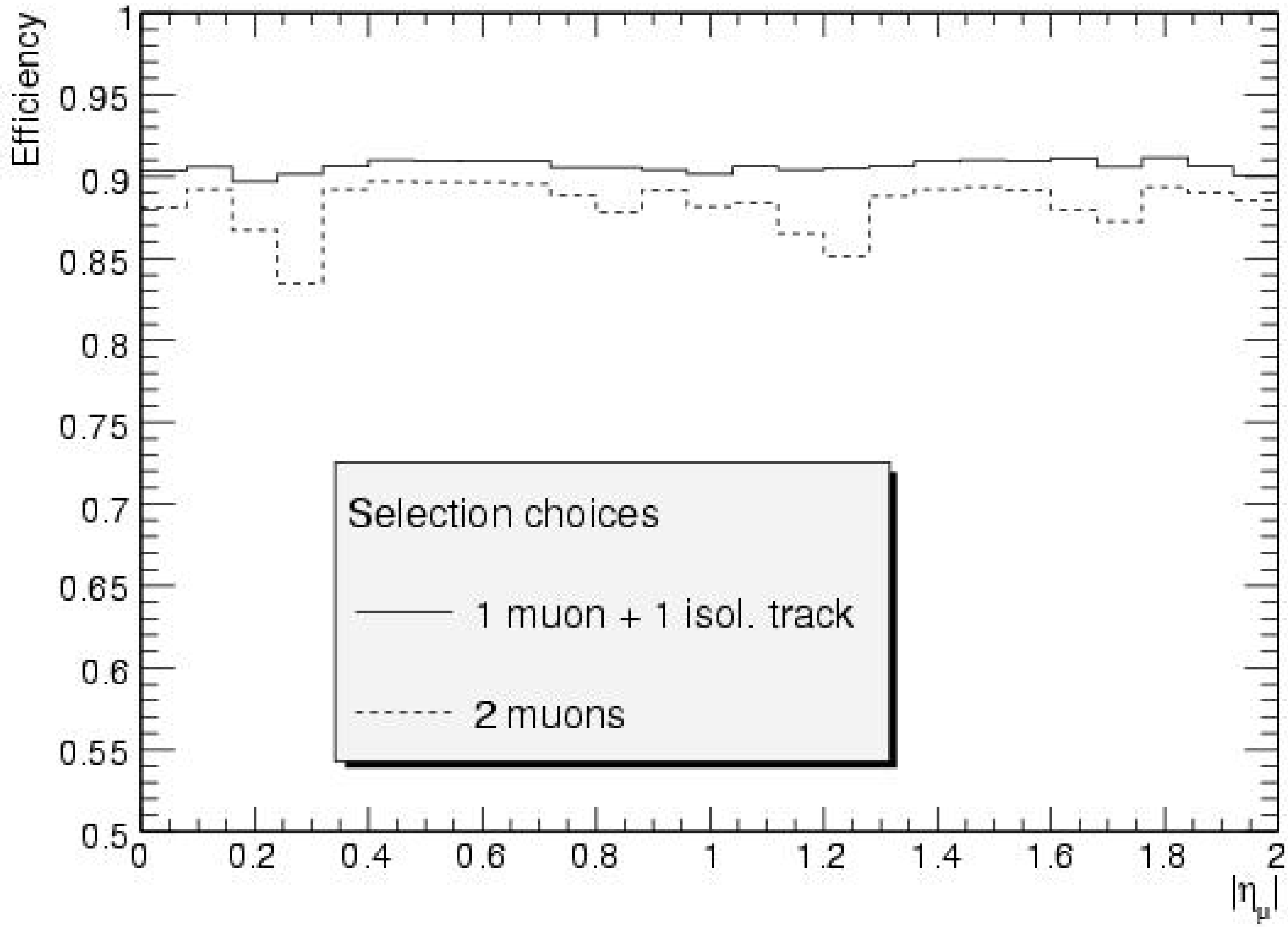
Note: tougher cut implies larger systematics at the first stages of the LHC

HLT efficiency



Systematics easy to control below the 0.1-0.2%

Muon acceptance



Messages: Uniform acceptance!
Even useful to 'measure' inefficiencies!

Experimental systematics in $Z \to \mu\mu$

Source	Uncertainty (%)
Tracker efficiency	1
Muon efficiency	-
Magnetic field knowledge	0.03
Tracker alignment	0.14
Trigger efficiency	0.2
Jet energy scale uncertainties	0.35
Transverse missing energy	-
Pile-up effects	0.30
Underlying event	0.21
Total exp.	1.1

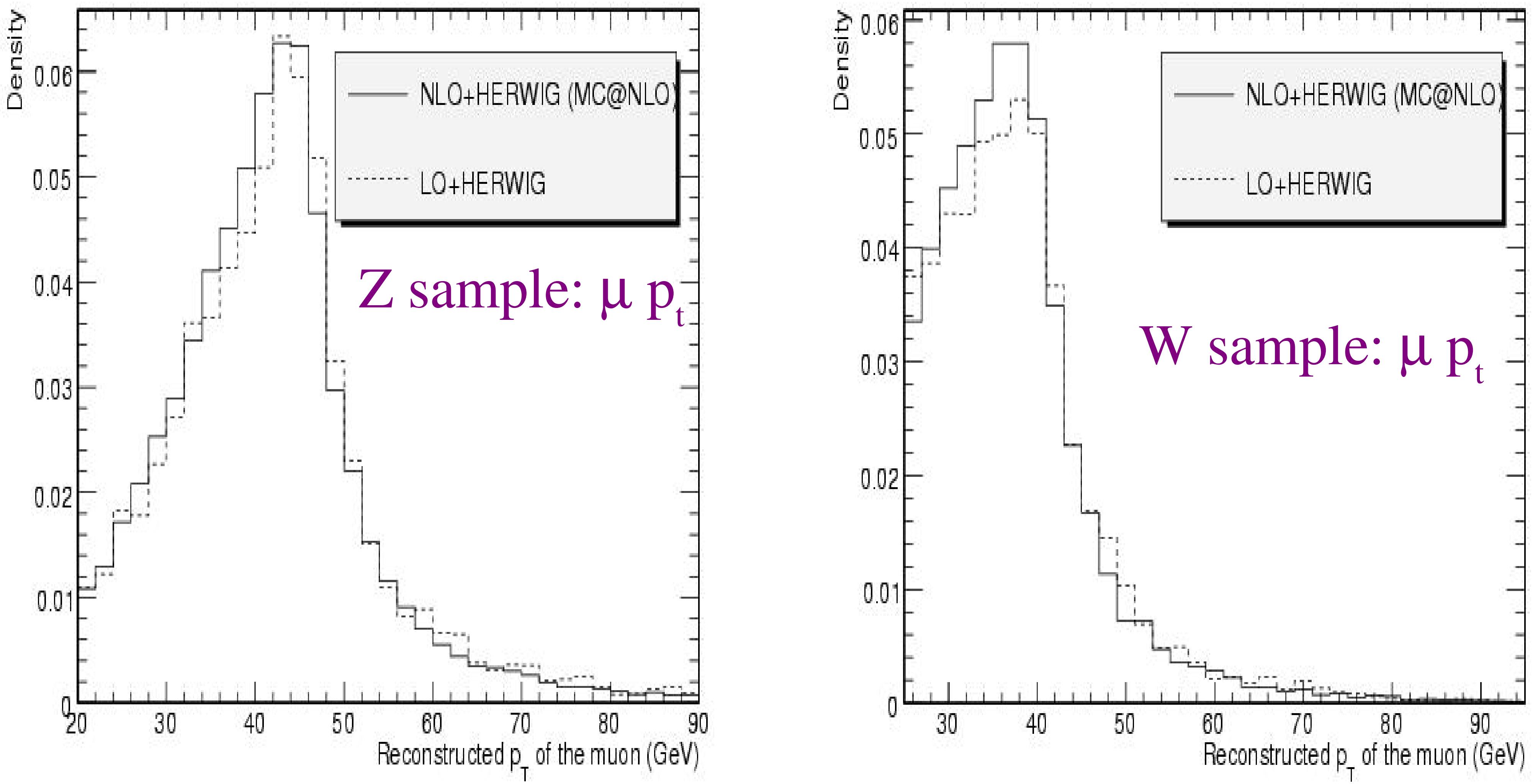
Dominated by tracker efficiency
for isolated tracks (estimated to be 0.5%)

Theoretical systematics in $Z \rightarrow \mu\mu$

Source	Uncertainty (%)
PDF choice (CTEQ61 sets)	0.7
ISR treatment	0.18
p_T effects (LO to NLO)	1.83
Total PDF/ISR/NLO	2.0

LO-NLO systematics

- LO -> NLO studies with MC@NLO are preliminary. Used to determine systematic uncertainties and k-factors.



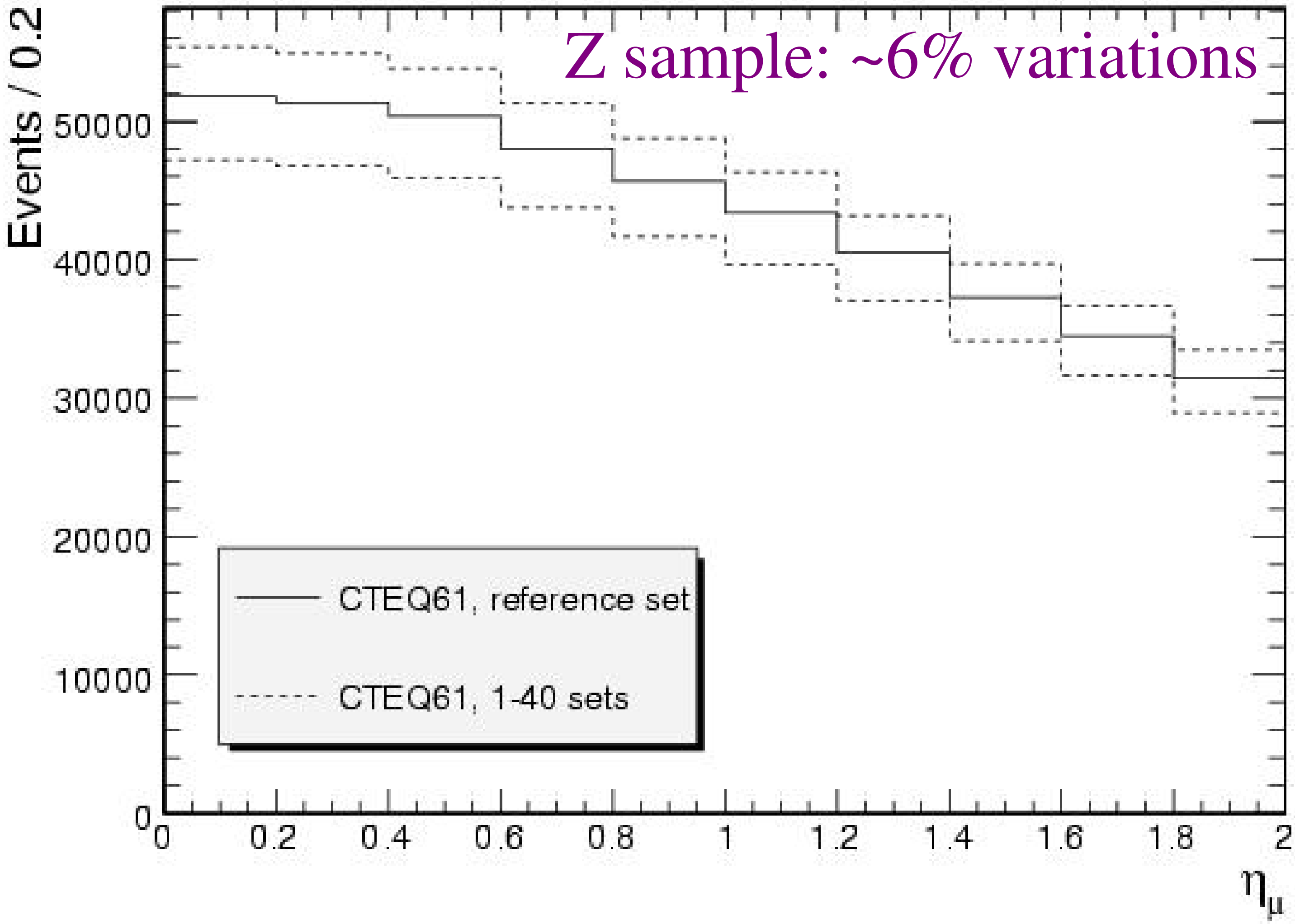
Theoretical systematics in $Z \to \mu\mu$

Source	Uncertainty (%)
PDF choice (CTEQ61 sets)	0.7
ISR treatment	0.18
p_T effects (LO to NLO)	1.83
Total PDF/ISR/NLO	2.0

In the future:

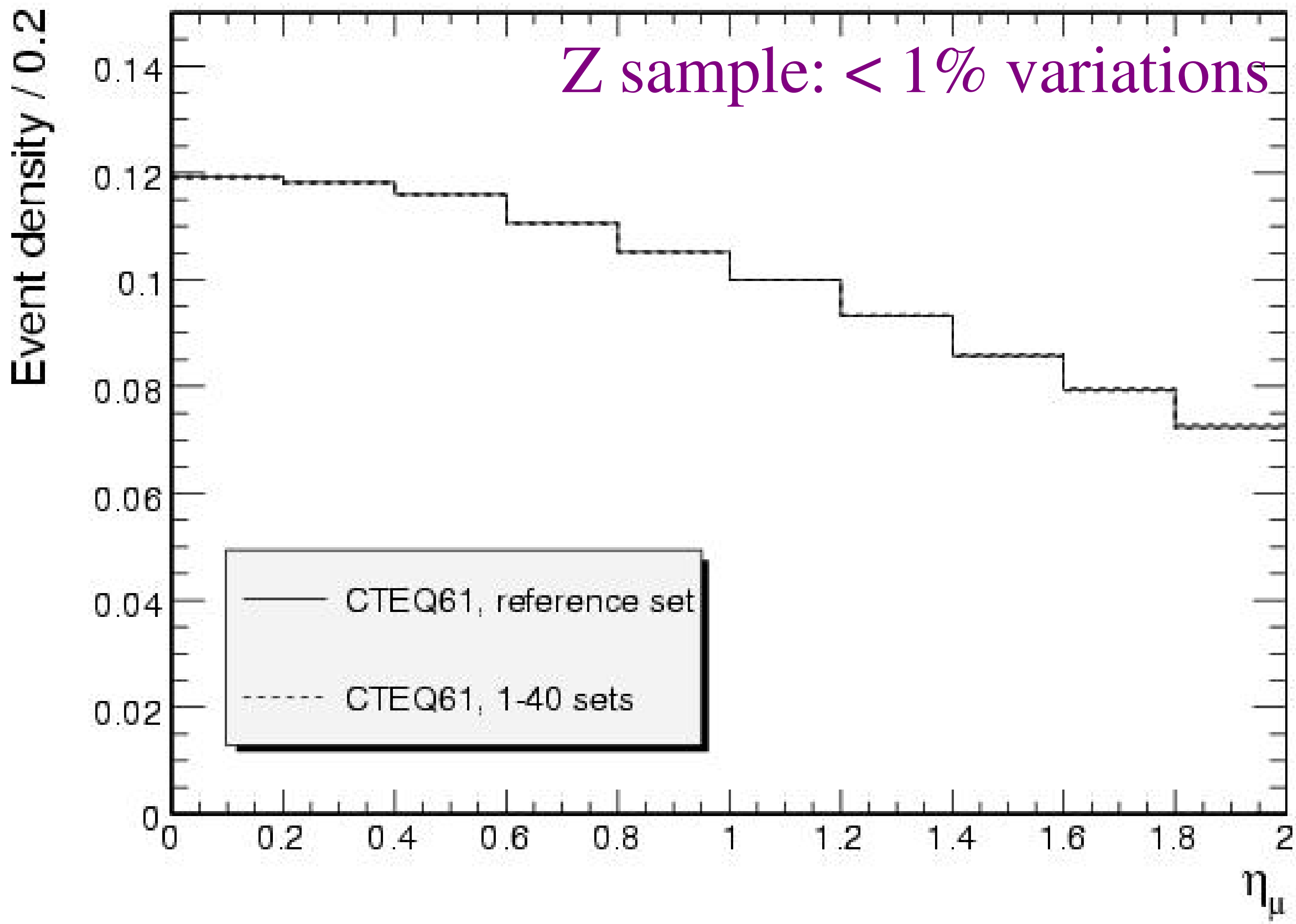
- p_T uncertainty should be smaller (NLO->NNLO)

PDF uncertainties if we want to determine luminosities from this



i.e. if we want to compare rates with theory expectations

PDF uncertainties if we want to determine just rates from this



i.e. if only theory uncertainties on the acceptance count

PDF uncertainties

Z sample

Test	Rate uncert. (%)	Acceptance uncert. (%)
CTEQ61(0)→CTEQ61(1:40)	$^{+5.8}_{-7.9}$	$^{+0.4}_{-0.7}$
MRST2001E(0)→MRST2001E(1:30)	$^{+2.0}_{-2.6}$	$^{+0.2}_{-0.3}$
CTEQ61→MRST2001E	1.5	0.1
ZEUS2005(0)→ZEUS2005(1:22)	$^{+4.9}_{-3.4}$	$^{+0.3}_{-0.3}$

W sample

Test	Rate uncert. (%)	Acceptance uncert. (%)
CTEQ61(0)→CTEQ61(1:40)	$^{+5.6}_{-7.4}$	$^{+0.6}_{-0.9}$
MRST2001E(0)→MRST2001E(1:30)	$^{+1.9}_{-2.3}$	$^{+0.4}_{-0.5}$
CTEQ61→MRST2001E	0.4	0.1
ZEUS2005(0)→ZEUS2005(1:22)	$^{+5.1}_{-3.4}$	$^{+0.3}_{-0.3}$

Theoretical systematics in Z→μμ

Source	Uncertainty (%)
PDF choice (CTEQ61 sets)	0.7
ISR treatment	0.18
p_T effects (LO to NLO)	1.83
Total PDF/ISR/NLO	2.0

In the future:

- PDF uncertainty further reduced?

Total systematics in Z→μμ

Source	Uncertainty (%)
Tracker efficiency	1
Muon efficiency	-
Magnetic field knowledge	0.03
Tracker alignment	0.14
Trigger efficiency	0.2
Jet energy scale uncertainties	0.35
Transverse missing energy	-
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

$W \rightarrow \mu\nu$ selection criteria

- ✔ 1 'hard isolated' GLOBAL muon with PT>25 GeV
- ✔ Events with two high-energy muons are rejected
- ✔ The system composed by the muon and the MET must have a TRANSVERSE INVARIANT MASS ($M^T_{\mu\nu}$) in the range:

$$40 \text{ GeV} < M^T_{\mu\nu} < 200 \text{ GeV}$$

- ✔ Specific cuts for ttbar
- ✔ The event must pass HLT trigger criteria

Total systematics in W→μν

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

Expected results for 1 fb^{-1}

$$\frac{\Delta\sigma}{\sigma}(pp \to Z + X \to \mu^{+}\mu^{-} + X) = \mathbf{0.13\,\% \pm 2.3\,\% \pm lumi\ uncert.}$$

$$\frac{\Delta\sigma}{\sigma}(pp \to W + X \to \mu\nu + X) = \mathbf{0.04\,\% \pm 3.3\,\% \pm lumi\ uncert.}$$

(cross sections in fiducial volume, LO->NLO k-factors applied)

Conversely, a comparison with the theoretical expectations can give a luminosity measurement with a 6-7% systematic uncertainty, even with today's knowledge

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

Some conclusions

- Z->μμ and W->μν decay rates should measurable at the LHC with 2-3% uncertainties, taking into account present experimental + theoretical knowledge. Z->μμ is much simpler than W->μν, even if the rate is 10 times smaller.

- As (more or less) expected, the theoretical uncertainties on the estimated acceptance for these processes are small. This is extremely useful for normalization purposes: σ(W)/σ(Z), σ(ZZ)/σ(Z), σ(H->ZZ->4mu)/σ(Z), ...

- Rapidity shape uncertainties: even if their effect on the global systematics is small, rapidity shapes will be the first thing to look at!

- Cross sections comparison with theory can be done at the 6-7% level precision. PDF uncertainties manifest as a global normalization factor, which can not be disentangled from a pure luminosity uncertainty. If these PDF uncertainties are reduced by a factor of 2 or so at HERA => luminosity measurement with a ~3% uncertainty.

Some questions

- PDF uncertainties with CTEQ are twice those obtained with MRST. But we expect just a sqrt(100/49)~1.4 factor from the different chi2 recipes used. Where is the rest coming from?

- Should we use HERA PDFs from now on?

- Once NLO Monte Carlos are in place, can we simply say that the theoretical uncertainty on the description of Pt spectra will be given by NLO-NNLO comparisons? Or is there anything else (re-summations,...) ?

- Most PDF uncertainties manifest as a global normalization factor, which can not be disentangled from a pure luminosity uncertainty:
  - Is this totally true, or is this factor absorbing some uncertainties in the description of the shapes? This would affect the acceptance, so it is not just a formal problem...
  - How much are HERA measurements going to help? To be followed.