ATLAS geometrical acceptance for
$W/Z \rightarrow \mu\nu/\mu^+\mu^-$
and its systematic uncertainty
at $\sqrt{s}$ = 14 TeV

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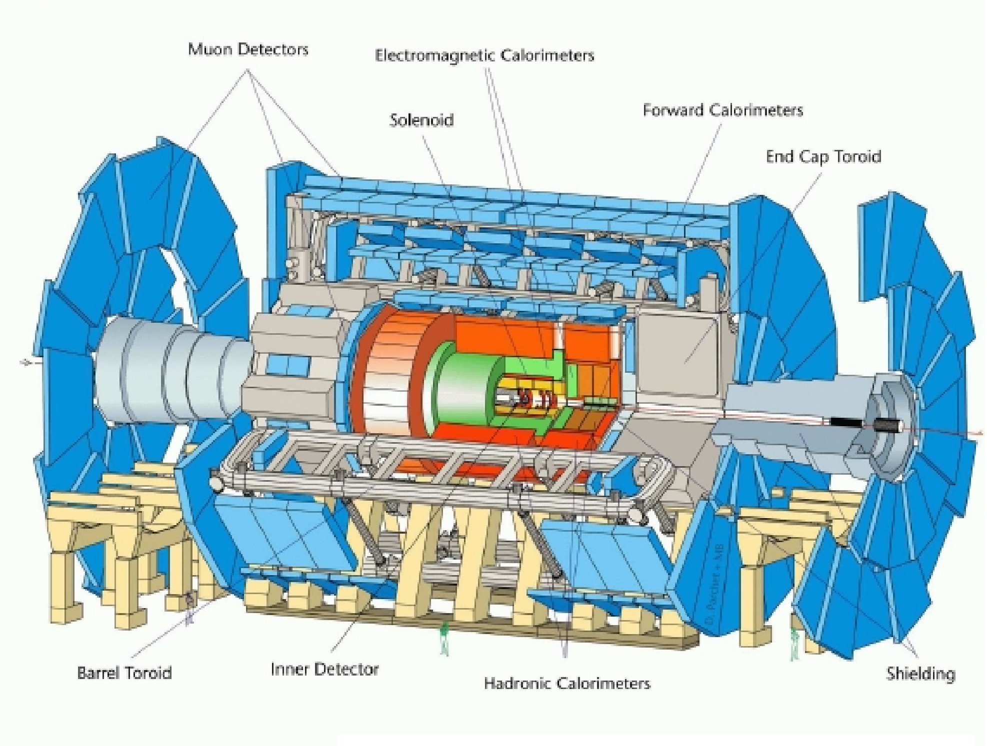
Outline

- Muon physics with the ATLAS detector
- The role of geometrical acceptance for

  $\sigma_{pp \to W/Z+X \to \mu\nu/\mu^+\mu^- + X}$ measurement at the LHC
- Monte Carlo simulations at Next to Leading Order
- Estimation of systematical error with
  - **CTEQ PDFs**
  - **Neural Network PDFs**
  - **Intrinsic k_T of partons**
- Conclusions

The ATLAS experiment

The ATLAS detector has been designed to provide clean and efficient muon identification, and precise momentum measurement over a wide range of energies and solid angles.

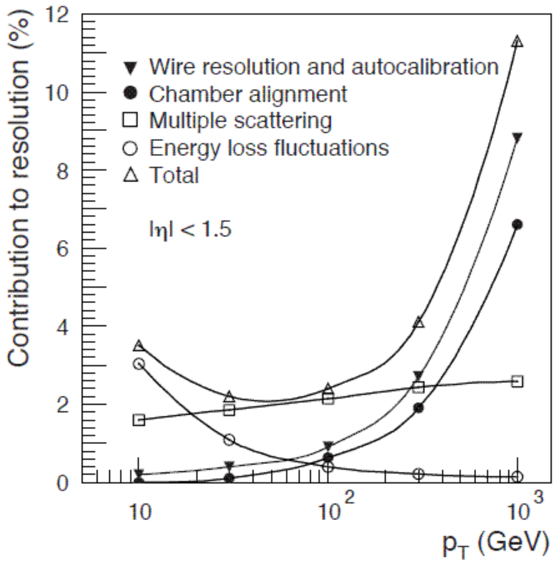


The muon system is based on the magnetic deflection of muon tracks in the superconducting toroid magnets.

The trigger system covers the range $|\eta|<2.5$. RPCs are used in the barrel and TGCs in the end-cap regions.

The muon spectrometer is the outermost ATLAS subdetector: befor reaching it, muons have to cover ~ 100 radiation lenghts:

muon momentum resolution dominates the efficiency uncertainty: it shifts from 12% for 0.1 fb^{-1} to 1% for 10 fb^{-1} .



Cross section measurement and its uncertainties

$$\sigma \equiv \sigma_{pp\to W/Z}\cdot \mathrm{Br}_{W/Z\to \ell\nu/\ell\ell} = \frac{N-B}{A\cdot\varepsilon\cdot\mathcal{L}}$$

geometrical acceptance

$$\frac{\text{Events inside kinematical cuts}}{\text{Total events}}$$

Cross section uncertainty:

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

statistical: $\frac{\delta N}{N}\sim\frac{1}{\sqrt{\mathcal{L}}}$

THEORETICAL

decrease with detector understanding

Estimated uncertainty sources:

After the first fb^{-1}, $\delta\sigma$ will be dominated by acceptance uncertainty

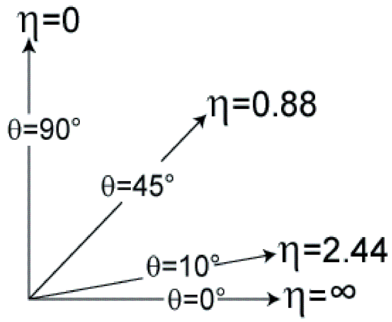
Process	$\delta\sigma/\sigma$ (stat)	$\delta\sigma/\sigma$ (sys)	$\delta\sigma/\sigma$ (lum)	
$W\to e\nu$	0.2 %	5.2 %	10 %	$50\,\mathrm{pb}^{-1}$
$Z\to e^+e^-$	0.8 %	4.1 %	10 %	
$W\to e\nu$	0.04 %	2.5 %	-	$1\,\mathrm{fb}^{-1}$
$Z\to e^+e^-$	0.2 %	2.4 %	-	

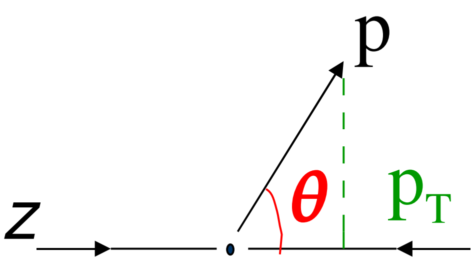
Geometrical acceptance definition

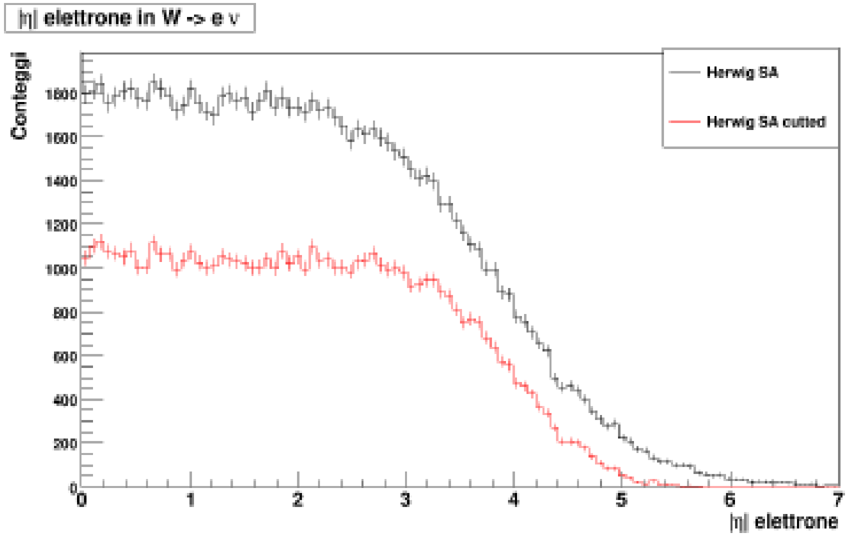
Geometrical acceptance = $\dfrac{\text{Events inside kinematical cuts}}{\text{Total events}}$

We impose kinematical and angular cuts on:

- **transverse momentum** $p_T = \sqrt{p_x^2 + p_y^2}$
- **pseudorapidity:** $\eta = -\ln\tan\left(\frac{\theta}{2}\right)$







electron pseudorapidity before (**black**) and after (**red**) p_T cuts

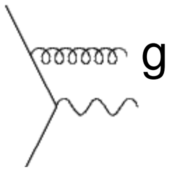
- p_T > 20 GeV for *e*, μ, ν to be separable from the background
  - this threshold will be optimized as a function of √s and luminosity
- $|\eta| < 2.5$ only for charged leptons: in order to make them triggerable

Monte Carlo simulations for acceptance calculations

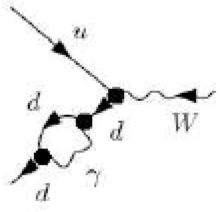
I studied the **Drell-Yan** production and decays of **W$^{\pm}$** and **Z** in **electrons** and **muons** with the following Monte Carlo generators:

- At Leading Order : **Herwig** and **Pythia**
- At Next to Leading Order : **Mc@Nlo** and **Horace**

NLO in α_s



NLO in α_{EW}



in the official ATLAS framework (Athena) and in stand-alone mode.

Systematic error is estimated with Mc@Nlo for the muon channel.

Starting from *default configuration*, I change one by one all the relevant parameters:

- **PDF**:
  - **CTEQ** error sets,
  - **Neural Network** PDFs,
- **intrinsic transverse momentum of partons ≠ 0**
- **initial state radiation**
- **electromagnetic and electroweak corrections**

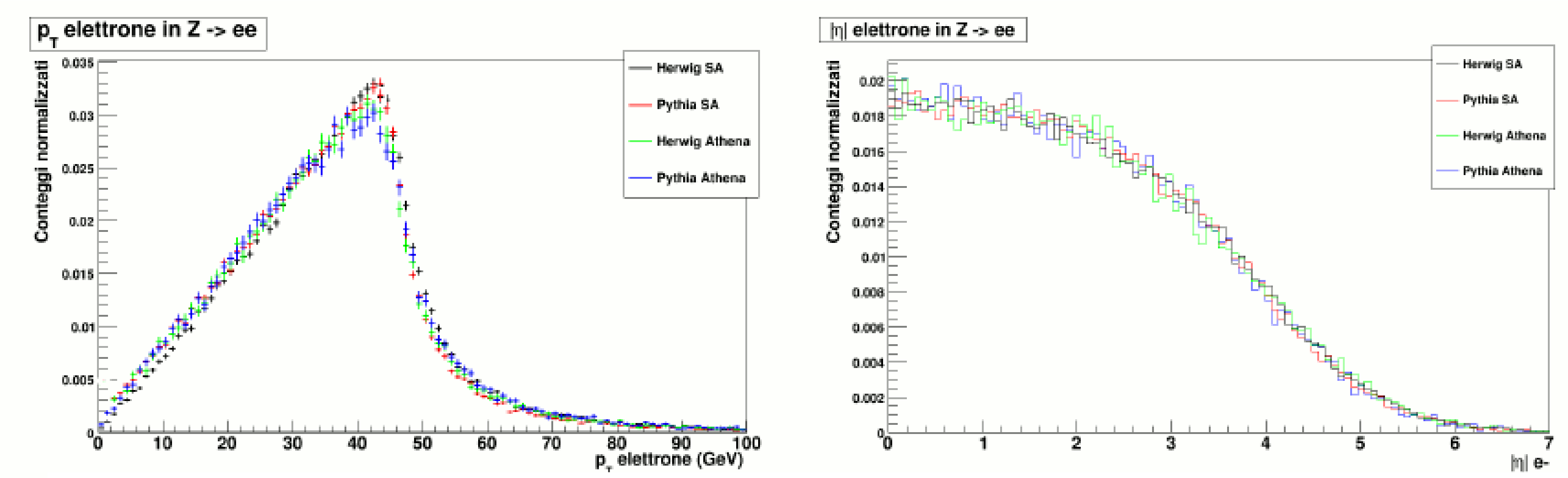
Geometrical acceptance: **results**

Work in progress

	$W^+ \rightarrow \mu^+\nu_\mu$	$W^- \rightarrow \mu^-\overline{\nu}_\mu$	$Z \rightarrow \mu^+\mu^-$
`Herwig`	45.45 ± 0.30		39.98 ± 0.26
`Pythia`	45.99 ± 0.31		39.75 ± 0.26
`Horace` Born	45.82 ± 0.30	46.01 ± 0.31	38.93 ± 0.25
`Horace` NLO	47.87 ± 0.32	47.61 ± 0.32	42.01 ± 0.28
`Mc@Nlo`	48.31 ± 0.34	48.28 ± 0.34	42.62 ± 0.29

Leading Order

Next to Leading Order



Transverse momentum and pseudorapidty distributions for e^- from Z -> e^+e^-

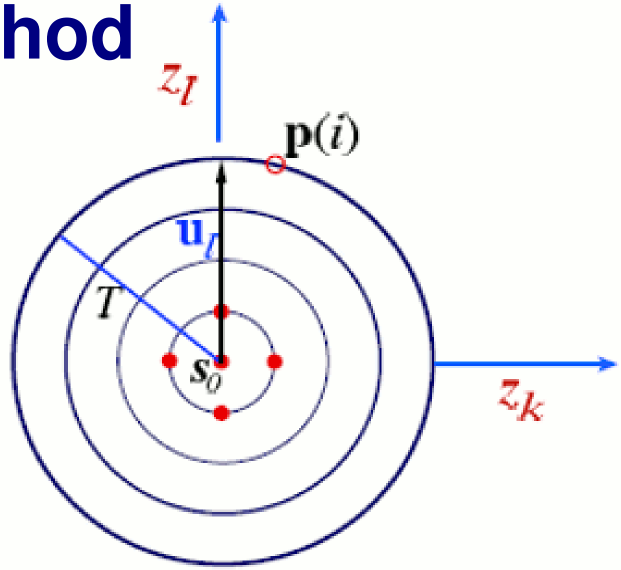
CTEQ PDFs

There are formidable difficulties when standard statistical methods are applied to global QCD analysis:

- Large body of data from many different experiments to fit, even mutually incompatible (~ 1800 data points from 15 experiments for CTEQ)
- Theoretical model has its own uncertainties

Solution: the Hessian method

The 20x20 Hessian matrix is iteratively diagonalized, resulting in 20 eigenvalues and 20 eigenvectors (20 is the number of free parameters chosen by CTEQ to parametrize PDFs).



Pumplin et al., arXiv:hep-ph/0101032

Master equation to calculate uncertainties on derived quantities:

$$\Delta X^{+}_{max} = \sqrt{\sum_{i=1}^{N} [max(X_i^{+} - X_0, X_i^{-} - X_0, 0)]^2}$$

$$\Delta X^{-}_{max} = \sqrt{\sum_{i=1}^{N} [max(X_0 - X_i^{+}, X_0 - X_i^{-}, 0)]^2}$$

Problem: tolerance criterion, *T*, is arbitrarily chosen!

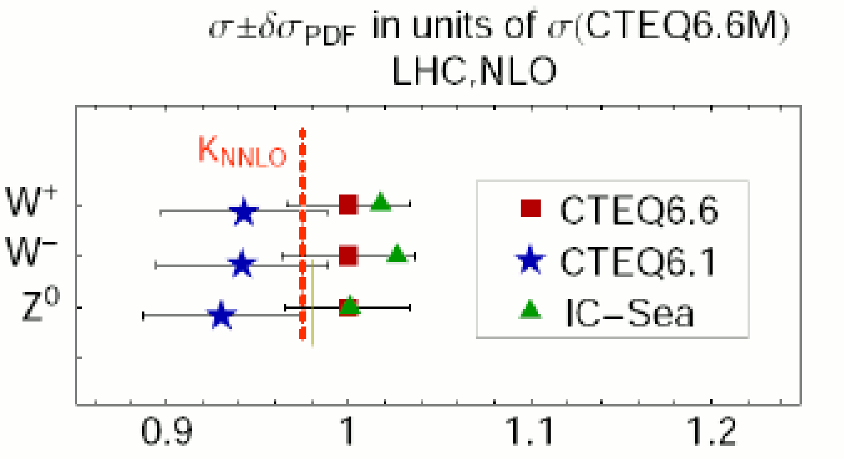
$$\chi^2_{\mathrm{global}} \leq T^2 = 100$$

CTEQ6.6: inclusion of mass effects

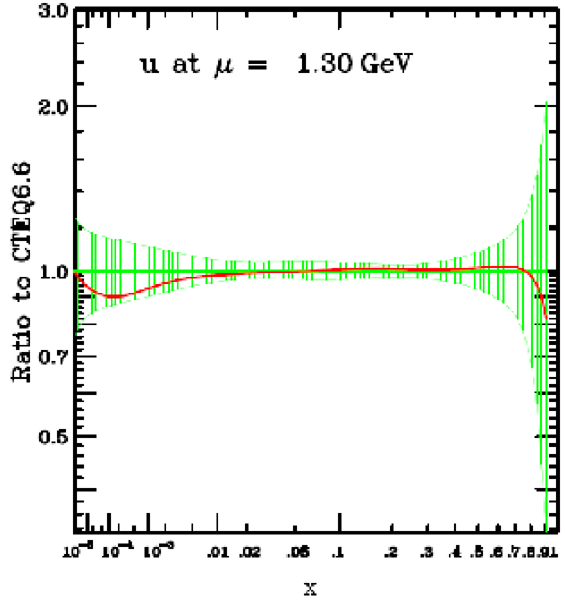
- CTEQ 6.6 analysis includes <u>mass effects</u> for heavy quarks (in the **General-Mass VFN** scheme).

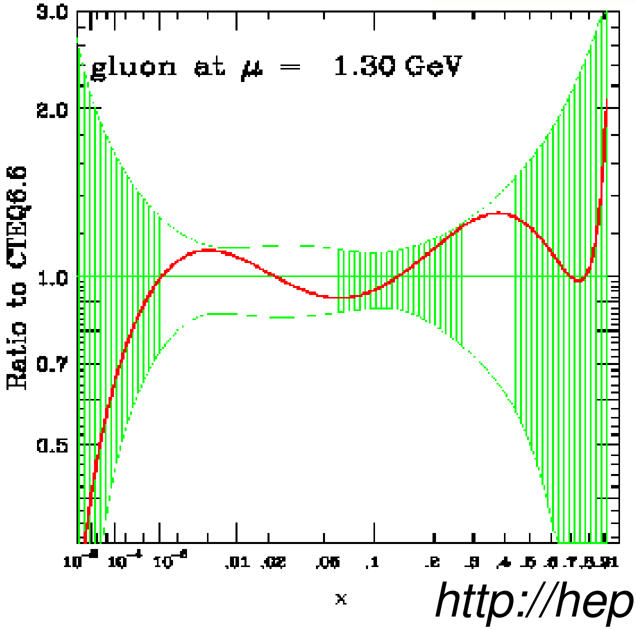
  This causes the reduction of *c*, *b* e *g* contributions at **small and medium values of *x***, and a corresponding increase in *u* and *d* distributions:

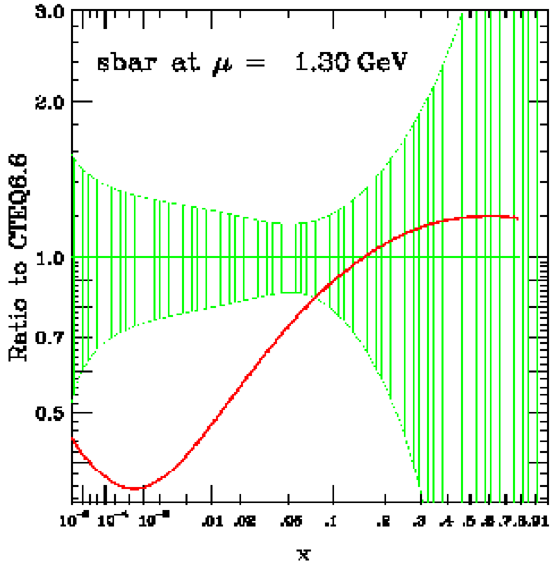
  <u>Big impact on W and Z production at the LHC: cross sections increase up to 6%.</u>



- **Strange** quark has 2 new degrees of freedom.



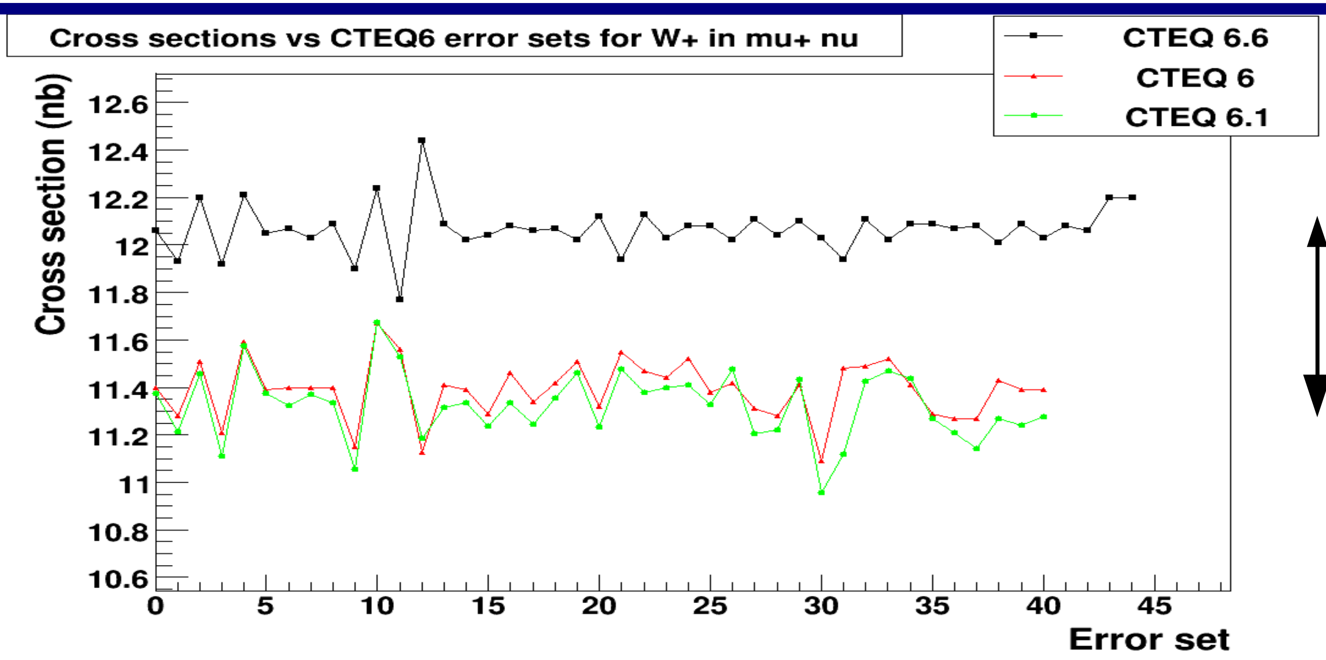




http://hep.pa.msu.edu/cteq/public/6.6/pdfs/

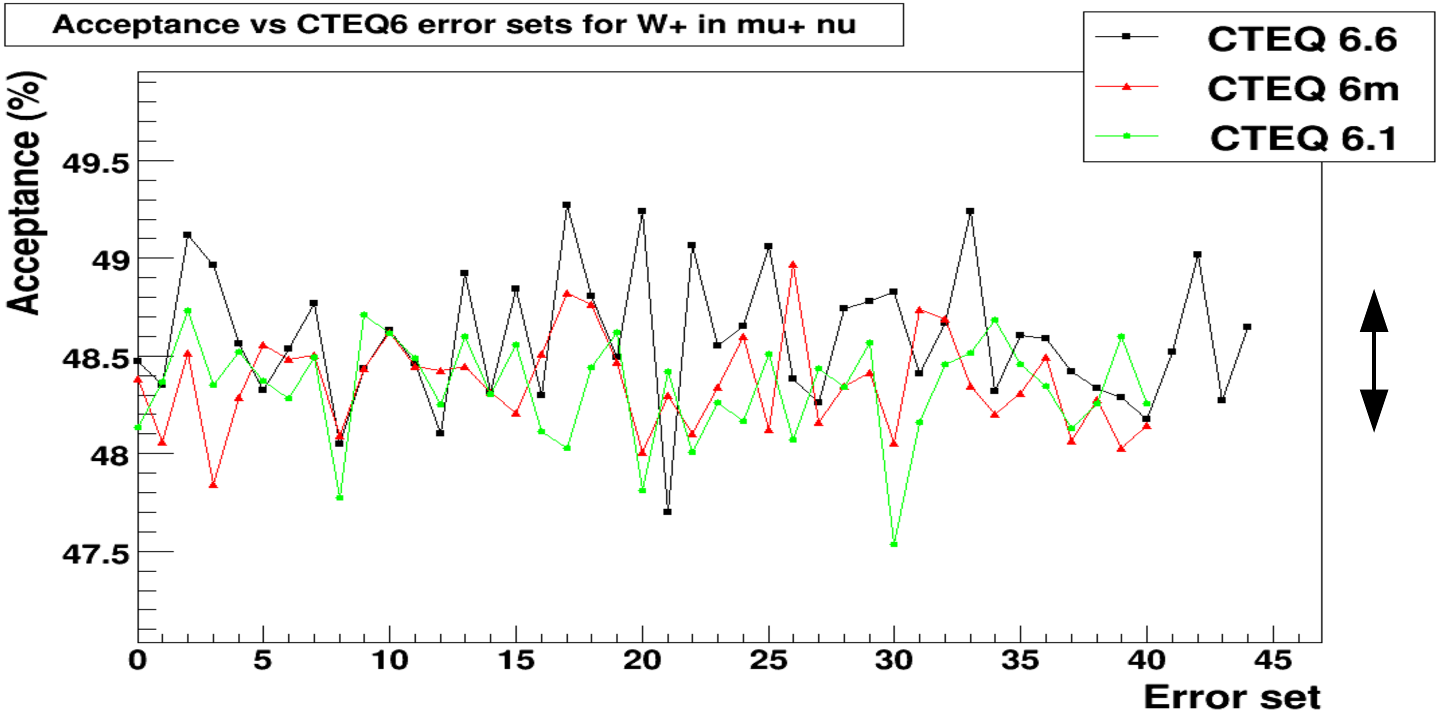
$W^+ \to \mu^+\nu_\mu$ Cross section and acceptance

Work in progress



difference ~ 5.5 %

as expected at the LHC



difference ~ 0.7 %

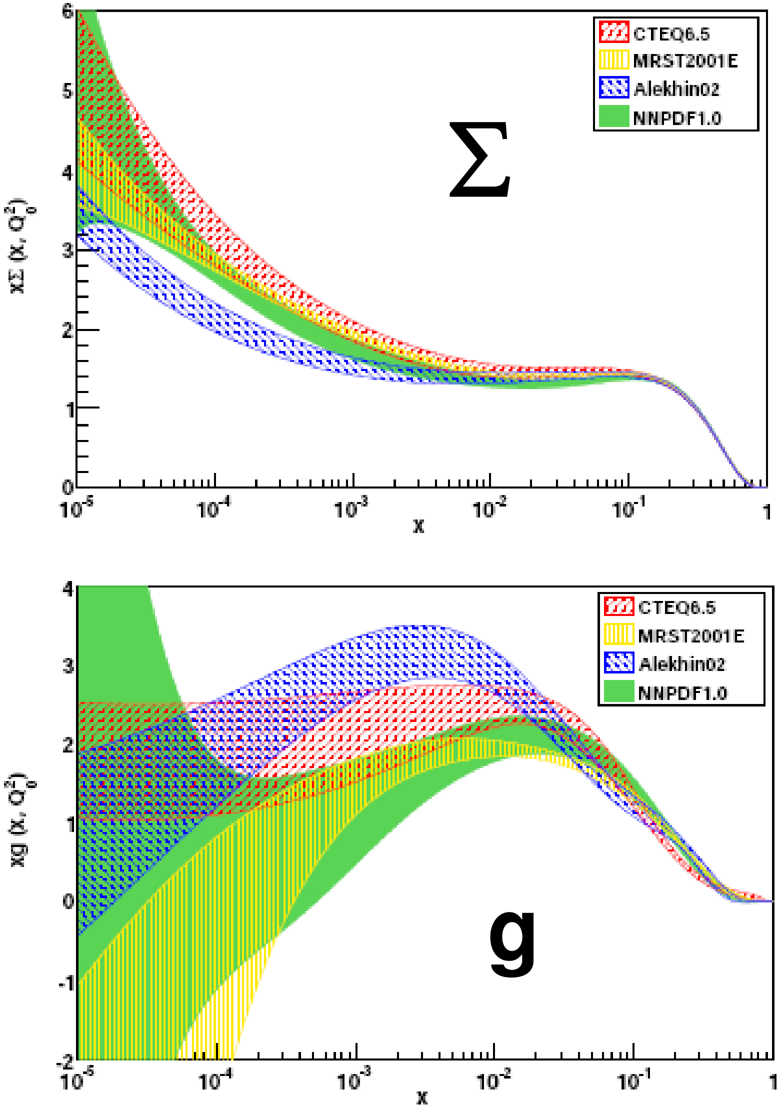
A different approach: Neural Network PDFs

Advantages

- No biassing *a priori* parametrization
- Resulting PDF sets follow a Gaussian distribution, and so can be easily interpreted in a statistical way, needing no ad hoc tolerance criterion

Present limitations

- NNPDFs are in the **Zero-Mass** scheme, at NLO
- **Strange** distribution proportional to light sea (disfavoured by recent data)
- Only a **restricted sample** of data is used



Ball et al., arXiv:hep-ph/0808.1231

Results

- **1000 replicas**, no best fit set
- The central values of all PDFs are **in agreement** with those from other parton sets, especially in the region where data are available
- **Uncertainties are difficult to compare**

Results for Z -> $\mu\mu$

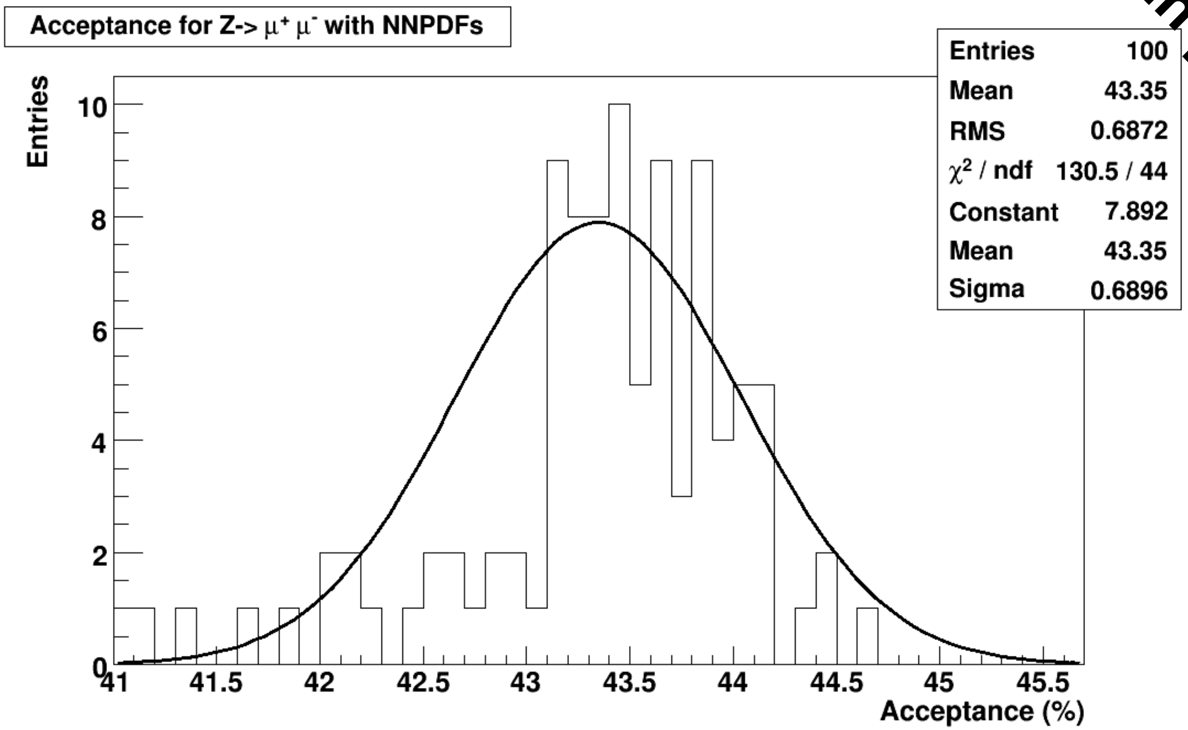
Work in progress

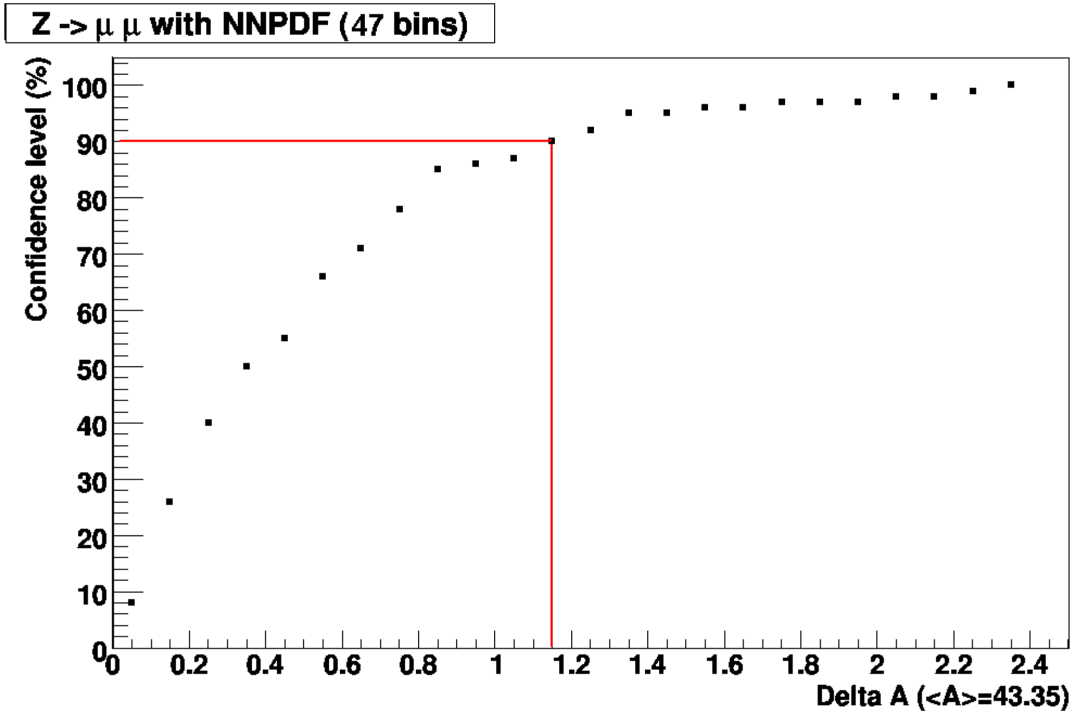
Gaussian fit:

χ^2 /ndf ≈ 3

A ± σ(A) =

43.35 ± 0.687





In this way we can compare

NN error

with the 90% confidence level

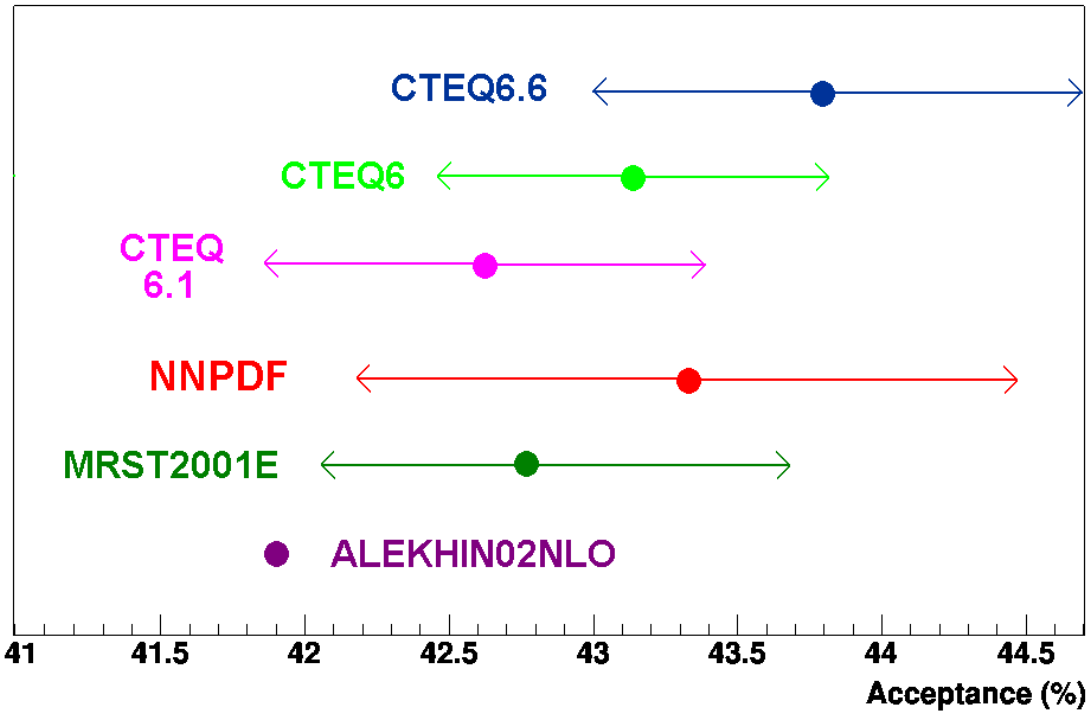
resulting (approximatively)

from CTEQ

tolerance criterion T = 10

NNPDFs vs standard PDF sets

Work in progress



Hessian master formula

$$\Delta A^{+} = \sqrt{\sum_{k=1}^{20} \left[\max\left(A_k^{+} - A_0, A_k^{-} - A_0, 0\right)\right]^2}$$

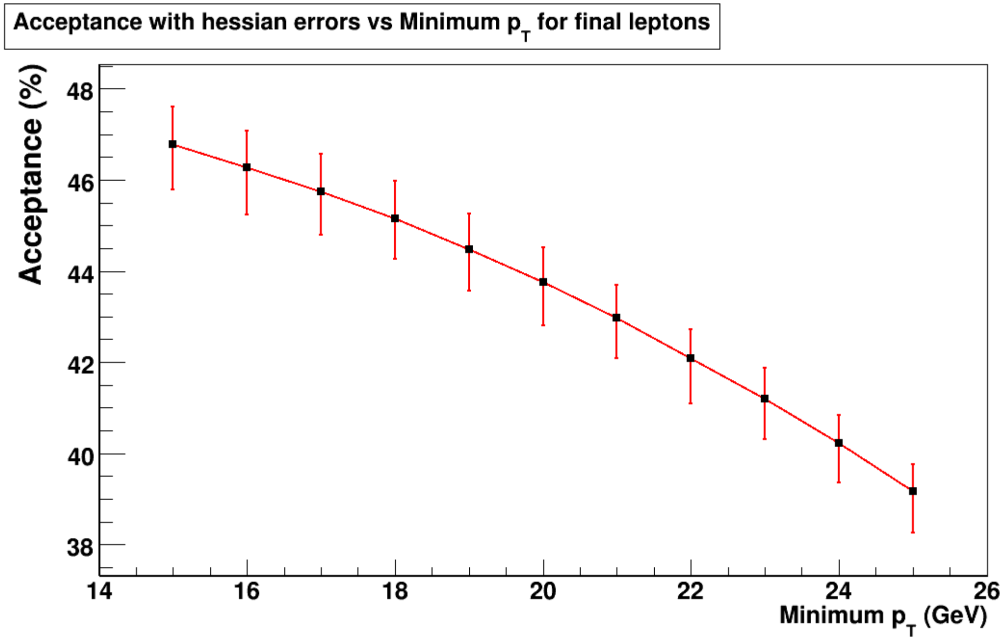
$$\Delta A^{-} = \sqrt{\sum_{k=1}^{20} \left[\max\left(A_0 - A_k^{+}, A_0 - A_k^{-}, 0\right)\right]^2}$$

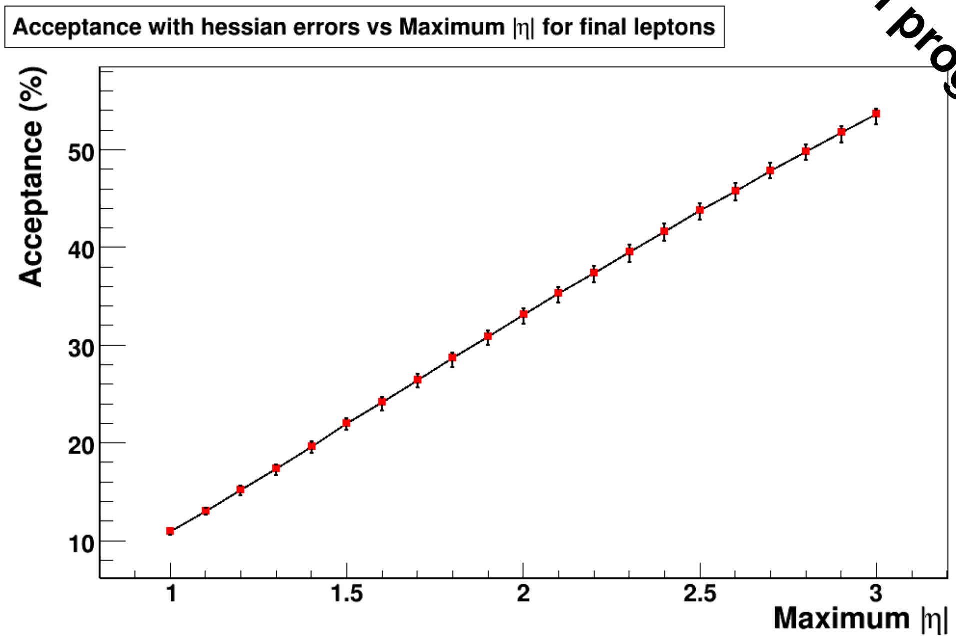
	A best fit (%)	$\Delta A^{+}/A_{bf}$ (%)	$\Delta A^{-}/A_{bf}$ (%)
CTEQ 6.6	43.75	2.14	1.75

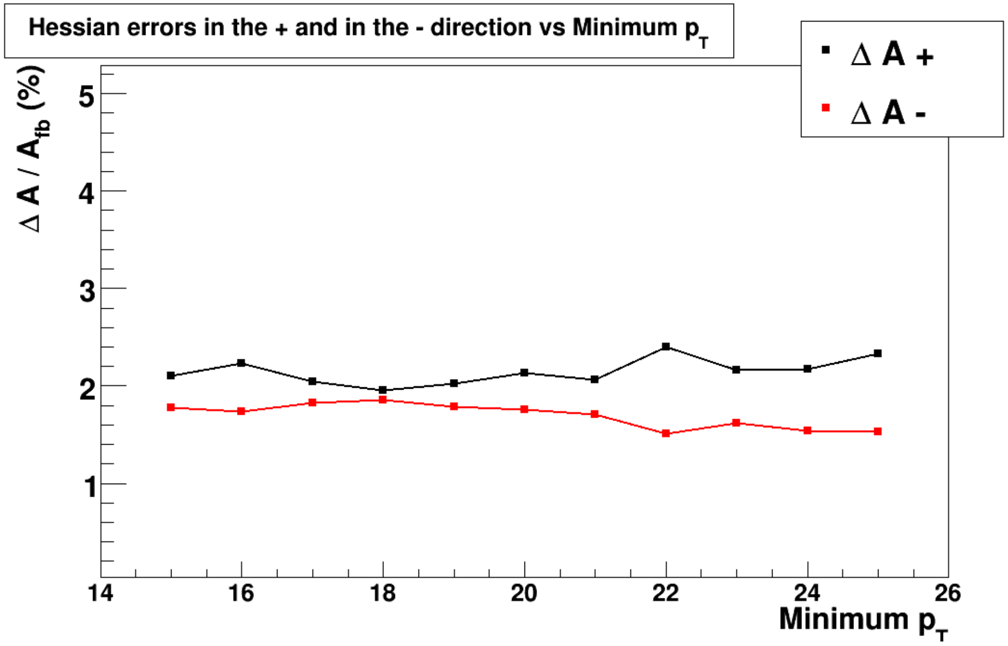
- All the sets used are at NLO
  - Alekhin and CTEQ 6.6 are the only including mass effects
- Central values of standard PDF sets are **inside the NN allowed range** (90% CL)
- **Uncertainties appear to be a little bigger for NN**

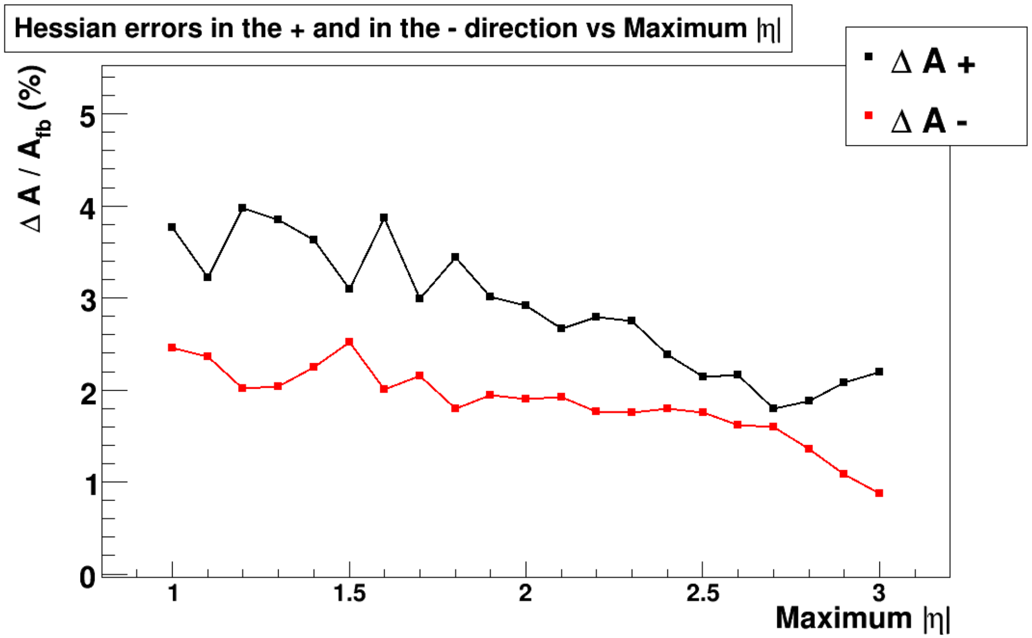
Preliminary results for Z -> $\mu\mu$

Work in progress


Acceptance with hessian errors vs Minimum p_T for final leptons


Acceptance with hessian errors vs Maximum |η| for final leptons


Hessian errors in the + and in the - direction vs Minimum p_T


Hessian errors in the + and in the - direction vs Maximum |η|

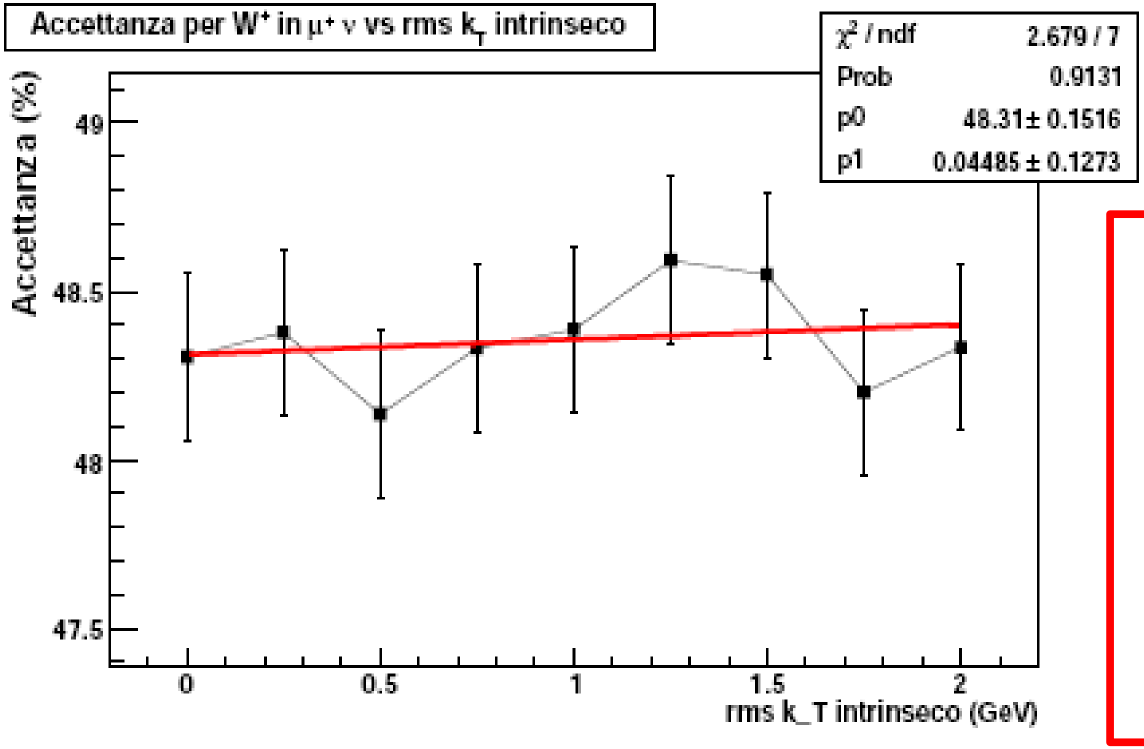
The goal is to end up with **look-up tables** to supply users with acceptances based on any possible cut

Partonic intrinsic k_T

Work in progress

Gaussian distribution, centered in $k_T = 0$, with a root mean square up to 2 GeV (in steps of 250 MeV)

$$\frac{1}{\sigma}\frac{\mathrm{d}^2\sigma}{\mathrm{d}^2 p_T} = \frac{b}{2\pi}\exp(-b p_T^2/2)$$



	W^+	W^-	Z
Default acceptance (%)	48.31	48.28	42.62
$\pm\,\delta A\,\%$ (fit)	0.08	0.15	0.14
$\pm\,\delta A\,\%$ $(A_{\mathrm{def}} - A_{1\,\mathrm{GeV}})$	0.08	0.13	0.15

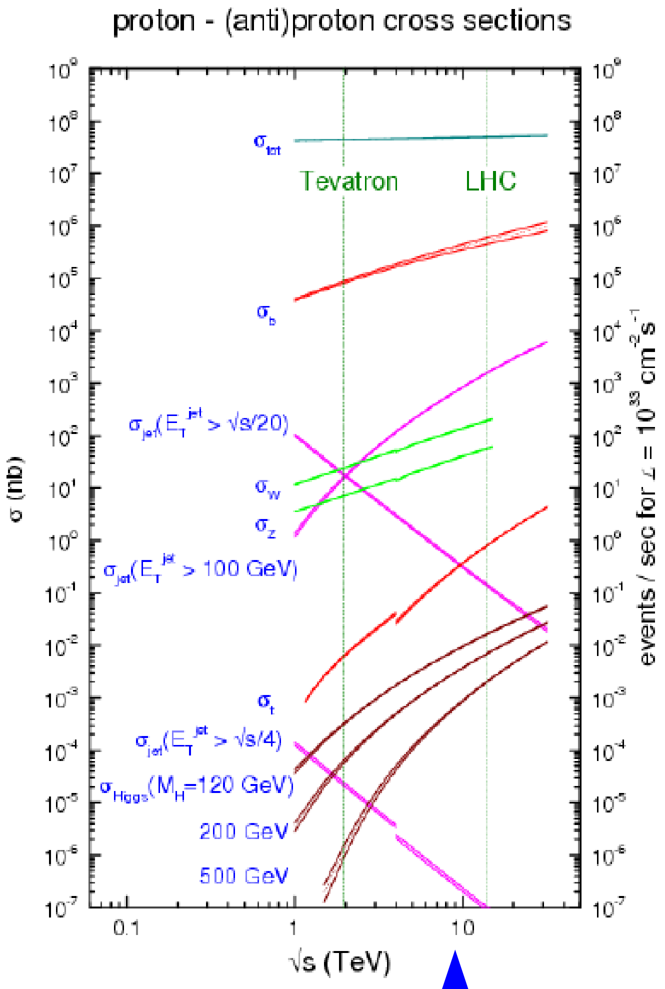
⇒ **Uncertainty is negligible wrt PDF one**

Conclusions

- Data taking will start in late 2009 at $\sqrt{s}$ = 10 TeV
- The goal is to collect an integrated luminosity up to 300 pb^{-1}, running without the winter shutdown
- Such a luminosity will be enough to re-discover Standard Model Physics, and it will allow a deeper detector knowledge

⟹ **LHC will be a W- and Z- factory**

	$\sqrt{s}$ [TeV]	$\sigma \cdot$BR
$Z \to \mu\mu$	14	2.02 nb
	10	1.35 nb



↑ **2009**

- **The measurement of W/Z cross sections will be soon dominated by systematics**: the study showed here confirms that the main source of this systematics will be due to **geometrical acceptance**, and in particular to **PDF** uncertainties