A new observable to measure the top quark mass at hadron colliders

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MC comparisons, systematic uncertainties, unfolding method etc

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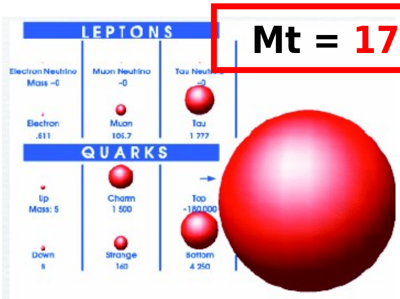
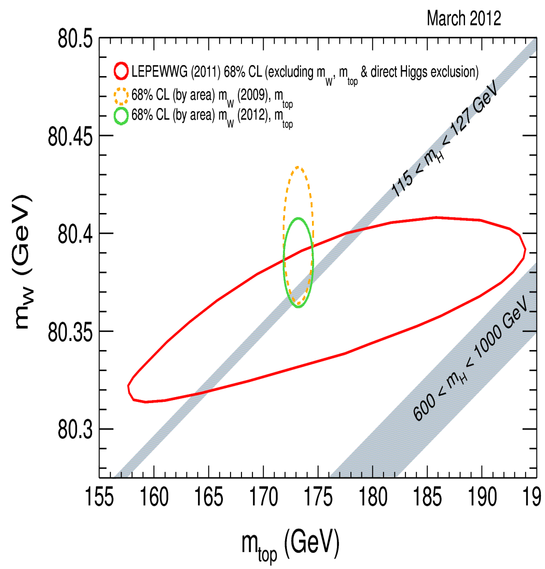
Top Quark Mass

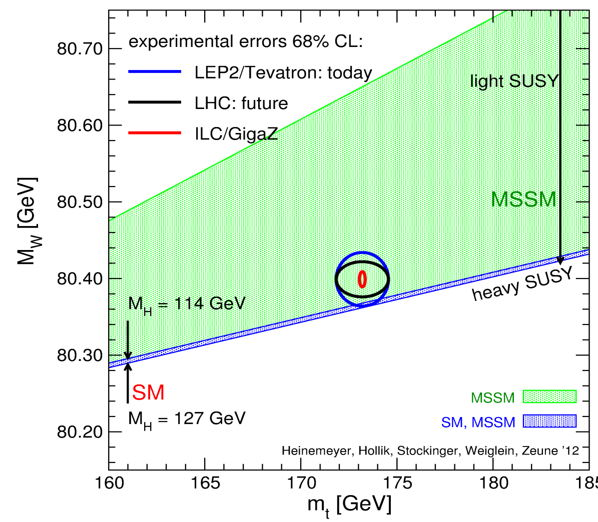
The top quark was discovered by CDF and D0 at Tevatron in 1995,
observing its decay channels (one b-jet and a reconstructed W)

Mt = 173.2±0.9 GeV

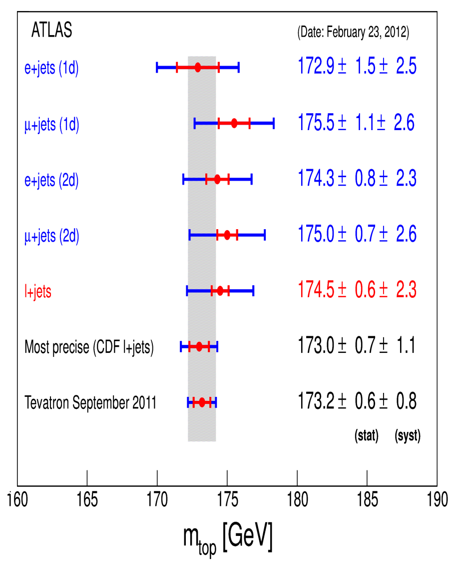


Special role in the electroweak sector in the Standard Model (SM) and in Beyond Standard Models (BSM) due to its large mass

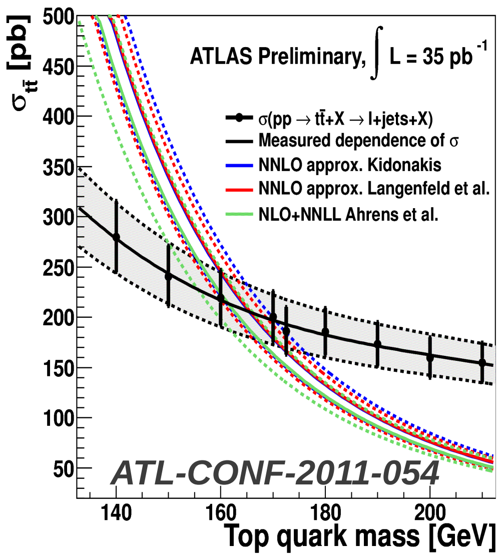




Kinematic measurements



Measurement from the cross section



TOP QUARK MASS MEASUREMENTS

ATLAS: from cross section

$$m^{pole}_{top} = 166.4^{+7.8}_{-7.3}\ \text{GeV}$$

ATLAS: kinematic measurement (comb.)

$$M_{top} = 174.5 \pm 0.6_{(stat)} \pm 2.3_{(syst)}\ \text{GeV}$$

Tevatron: kinematic measurement (comb.)

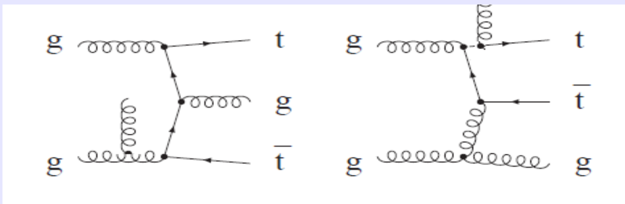
$$M_{top} = 172.3 \pm 0.6_{(stat)} \pm 0.8_{(syst)}\ \text{GeV}$$

A new observable to measure the top quark mass at hadron colliders.

The observable: $dn_3/d\rho_s$. **Theoretical calculations**

$t\bar{t}$+1Jet theoretical calculations at NLO

S. Dittmaier, P. Uwer, Weinzierl Eur. Phys. J. C. (2009) 59: 625-646



Definition of the Observable

New observable defined for ttbar+1Jet topologies.

$$\frac{dn_3}{d\rho_s}(m_{top}^{pole},\mu)=\frac{1}{\sigma_{t\bar{t}+1\mathrm{Jet}}}\frac{d\sigma_{t\bar{t}+1\mathrm{Jet}}}{d\rho_s}(m_{top}^{pole},\mu)$$

is based on the normalized differential cross section of ttbar+1Jet.

$$\rho_s=\frac{2m_0}{\sqrt{s_{t\bar{t}+1\mathrm{Jet}}}}$$

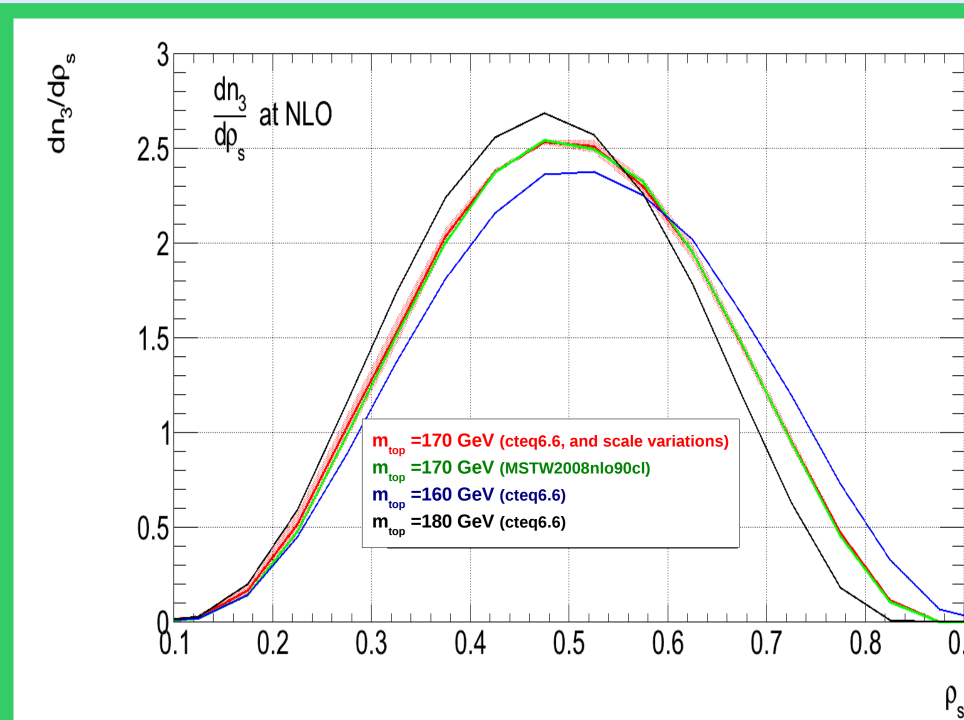
The **$dn_3/d\rho_s(m_{top},\mu)$** distribution at **NLO** for different top quark masses (160, 170 and 180 GeV)

The observable is defined :

- **At NLO**
- **In a defined mass scheme (pole mass)**

The observable is sensitive to the top quark mass.

Theoretical uncertainties (scale & PDF) are small.



A new observable to measure the top quark mass at hadron colliders.

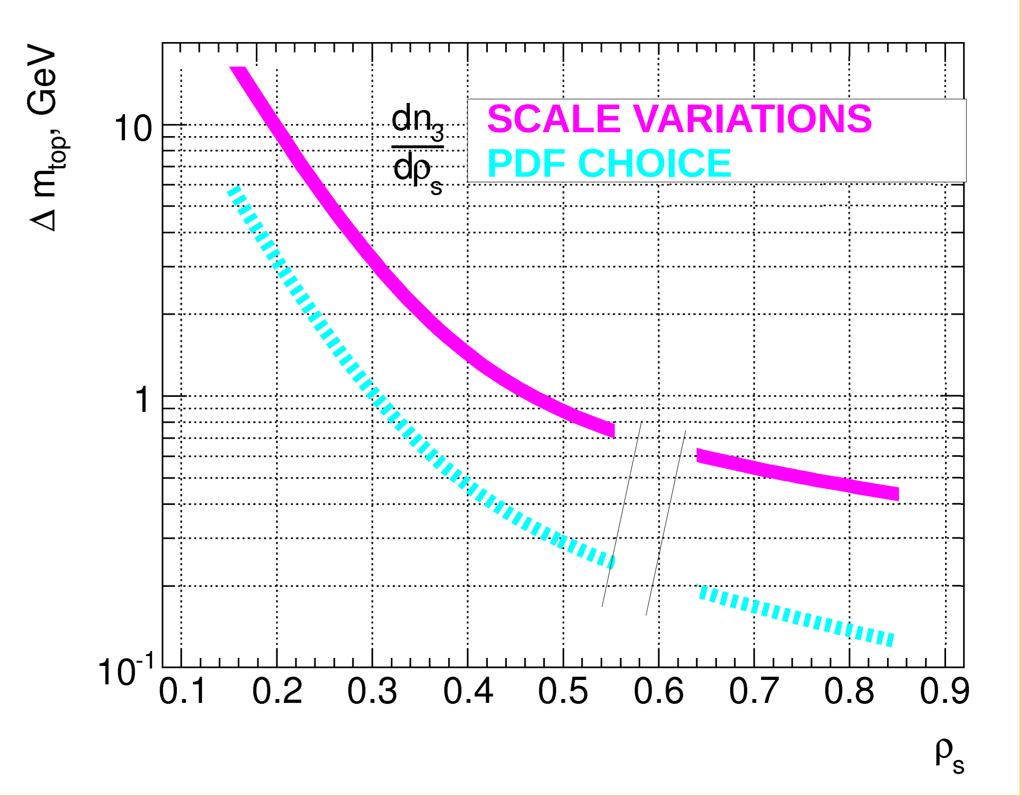
The observable: $dn_3/d\rho_s$. Theoretical behaviour

Perturbative predictions very stable:

- Small differences: LO vs NLO.
- Small scale uncertainties.
  ($0.5\, m_{top} < \mu < 2 m_{top}$)
- Small PDF uncertainties.
  (cteq6.6 vs MSTW2008mlo90cl)

Combining the mass sensitivity of the distribution and the scale and PDF uncertainties

Estimation of the impact on the scale and PDF uncertainties on the precision of the measurement



Impact to the top mass value (for m_{top}=170 GeV) of the **scale variations** and the **PDFs choice.**

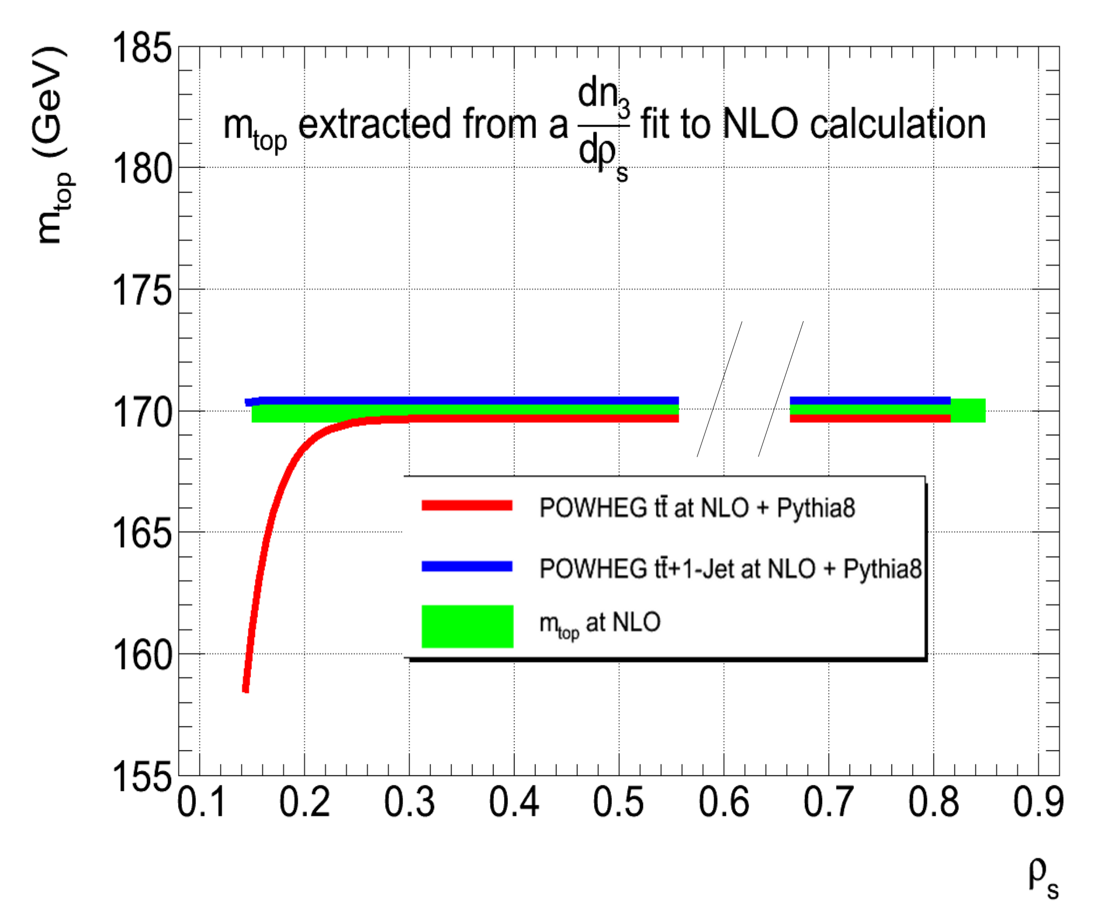
Theoretical uncertainties from the scale variations and the PDF choice are small ~0.5GeV

A new observable to measure the top quark mass at hadron colliders.

Generator and MC dependences

The $t\bar{t}$+1Jet NLO predictions of the $dn_3/d\rho_s$. observable has been compared with NLO calculations matched with parton shower algorithms using the POWHEG method

- POWHEG: **$t\bar{t}$ at NLO +** Pythia8
- POWHEG: **$t\bar{t}$+1Jet at NLO +** Pythia8



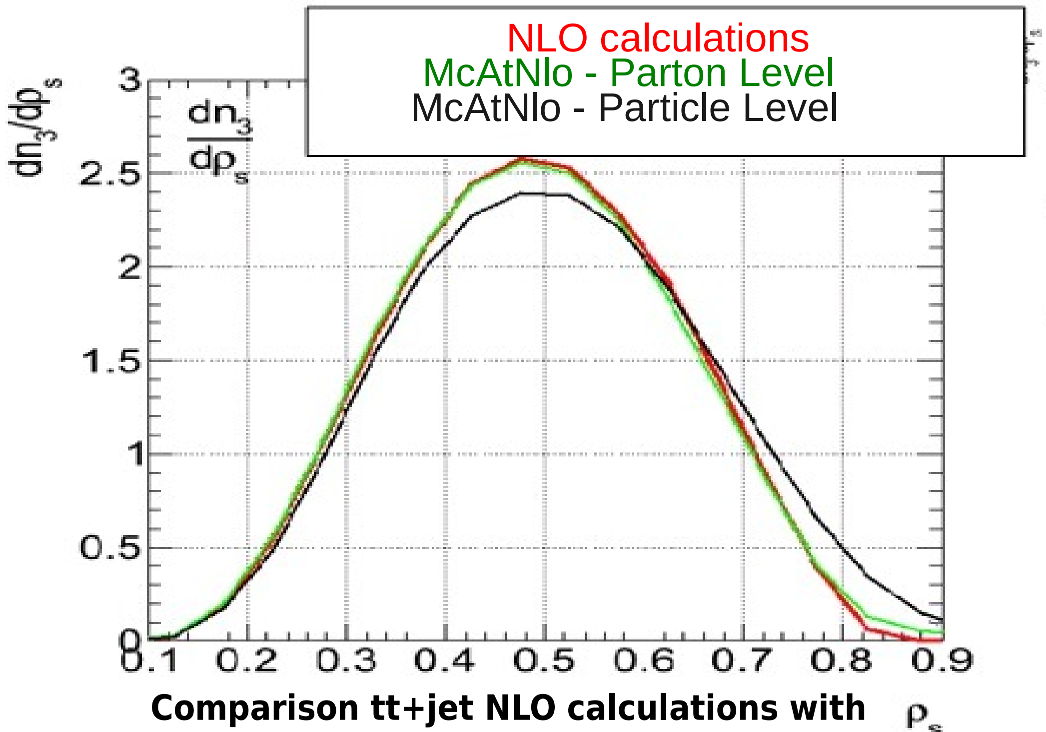
The NLO $dn_3/d\rho_s(m_{top},\mu)$ distribution is used as reference and the equivalent curves for for **POWHEG $t\bar{t}$ at NLO and $t\bar{t}$+1Jet at NLO** are computed to reproduce the same $dn_3/d\rho_s(m_{top},\mu)$ value.

Good agreement between the different calculations.

JHEP 0709 (2007) 126, arXiv:0707.3088
JHEP 1201 (2012) 137 arXiv:1110.5251 [hep-ph]

Experimental viability

Studies with complete MC samples (semileptonic -e, mu- top quark decay, parton showering and hadronization) are being studied.



Comparison tt+jet NLO calculations with McAtNlo+HERWIG

for m_{top}=172.5,

Good agreement among McAtNlo+HERWIG and POWHEG+Pythia tt at NLO samples.

Small sensitivity of the jet energy evaluation (Jet Energy Scale JES)

$\Delta m_{top} \approx 0.8$ GeV (ΔJES = 3%)

Mass independent unfolding procedure is being investigated.

$\Delta m_{top} \approx 1.2$ GeV for 5fb-1

(A conservative event efficiency selection of ~ 0.5% → 4000 events/5fb-1 is assumed)

These preliminary studies indicate that the extraction of the top quark mass using this method is achievable with good precision.

CONCLUSIONS & PROSPECTS

A new method to measure the top quark mass:

- **Pole mass defined through NLO calculations.**
- **Perturbative uncertainties are small and different MC approaches give consistent results.**
- **Theoretical uncertainties are estimated to be below 0.5 GeV.**
- **A generic study of the experimental viability is being performed.**

Summary of some of the systematic uncertainties studied.

	Source of uncertainty	Impact on the top quark mass
Theoretical uncertainties	μ variations	~ 0.4 GeV
	PDF choice	~ 0.2 GeV
Experimental uncertainties	MC comparison	~ 0.4 ± 0.3 GeV
	JES	~ 0.8 GeV
	Statistics (5 fb-1)	~ 1.2 GeV

$\Delta m_{top} \approx 1$ GeV can be achieved

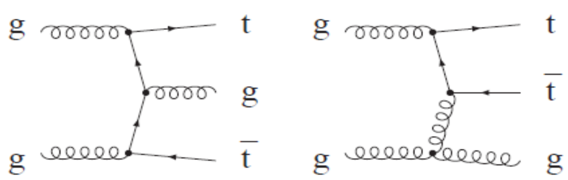
$\rho_s > 0.65$ (that corresponds to σ (NLO, m=170 GeV) ~ 3.5 pb)

A new observable to measure the top quark mass at hadron colliders: ttbar+jet calculations

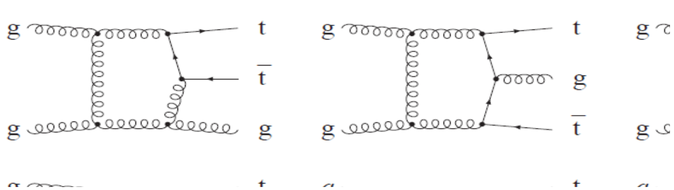
$t\bar{t}$+1Jet theoretical calculations at NLO

S. Dittmaier, P. Uwer, Weinzierl Eur. Phys. J. C. (2009) 59: 625-646

NLO corrections to the generic 0->ttggg and 0->ttqqg LO matrix elements have been studied to obtain integrated and differential cross sections.



Representative gg->ttg LO (BORN) diagrams.



Example of virtual correction (one-loop corrections to the LO reactions) diagrams.

Schematically NLO contributions:

$$\langle O \rangle^{NLO} = \int_{n+1} O_{n+1}\, d\sigma_R + \int_n O_n\, d\sigma_V + \int_n O_n\, d\sigma_C$$

$$n = 2\; initial\ partons + t\,\bar{t} + 1(2)\; final\ partons$$

- **$d\sigma_R$ denotes the real-emission contribution** (tt+2 partons in the final state)
- **$d\sigma_V$ is the virtual contribution** whose matrix elements are given by interference term of the 1-loop amplitudes (tt+1parton f.s) with the corresdpondig Born amplitude.
- **$d\sigma_C$** denotes a **collinear subtraction term** (from the factorization of the initial-states collinear singularities)
- **The function O_n** defined in the n-particle phase space is needed to defined an **IR-safe observable**

The IR-safe observable *has been obtained by defining a jet reconstructed from the final (non-top) partons with the* ***anti-Kt algorrithm (R=0.4)***

FastJet Package (Phys. Lett. B 641 (2006) 57) and the anti-Kt algorithm (JHEP 0804 (2008) 63).

Theoretical uncertainties

- **PDF selection:** for study the impact of the PDF selection, the results obtained using two different sets (CTEQ6.6 & MSTW2008nlo90cl) have been compared.
- **Scale variations:** The usual convention where $\mu_r = \mu_f = \mu$ and it is in the interval of 0.5 $m_{top} < \mu < 2\, m_{top}$ has been followed.

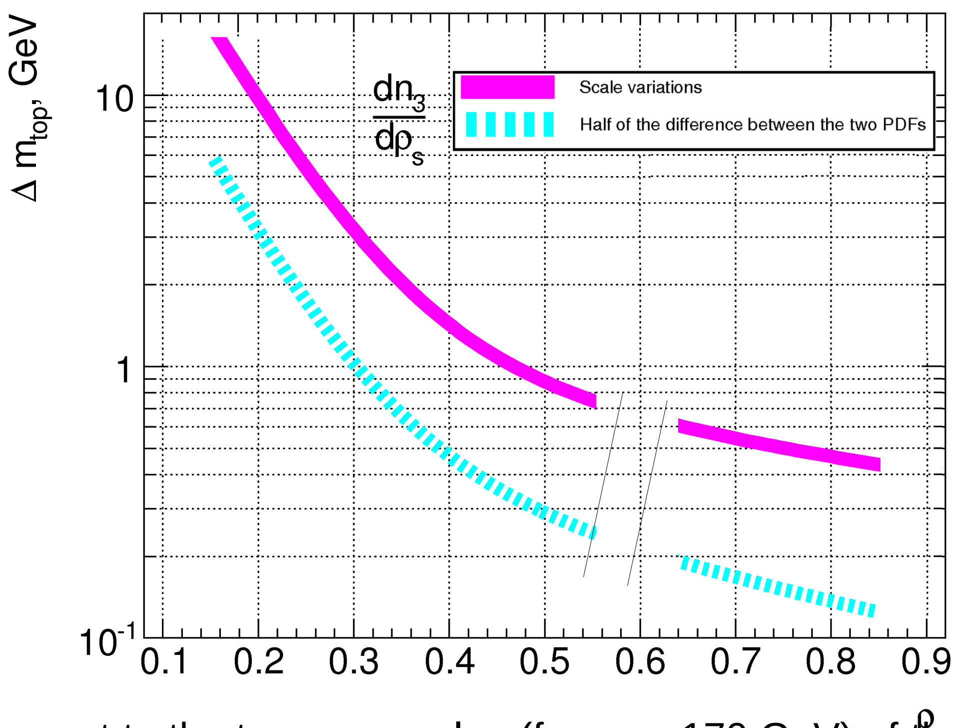
Theoretical uncertainties with the PDF election and the scale variations

Mass sensitivity **s(GeV^{-1})** is defined as:

$$s(\Delta m_t, m_t) = \frac{|n_3(m_t) - n_3(m_t + \Delta m_t)| + |n_3(m_t) - n_3(m_t - \Delta m_t)|}{2 \cdot n_3(m_t) \cdot \Delta m_t}$$

Scale and PDF sistematic dependences on the mass are evaluated as: $\frac{\Delta\mu \backslash \Delta PDF}{s(GeV^{-1})}$

where Δμ and ΔPDF are the scale and PDF sistematic dependences on the $dn_3/d\rho_s$

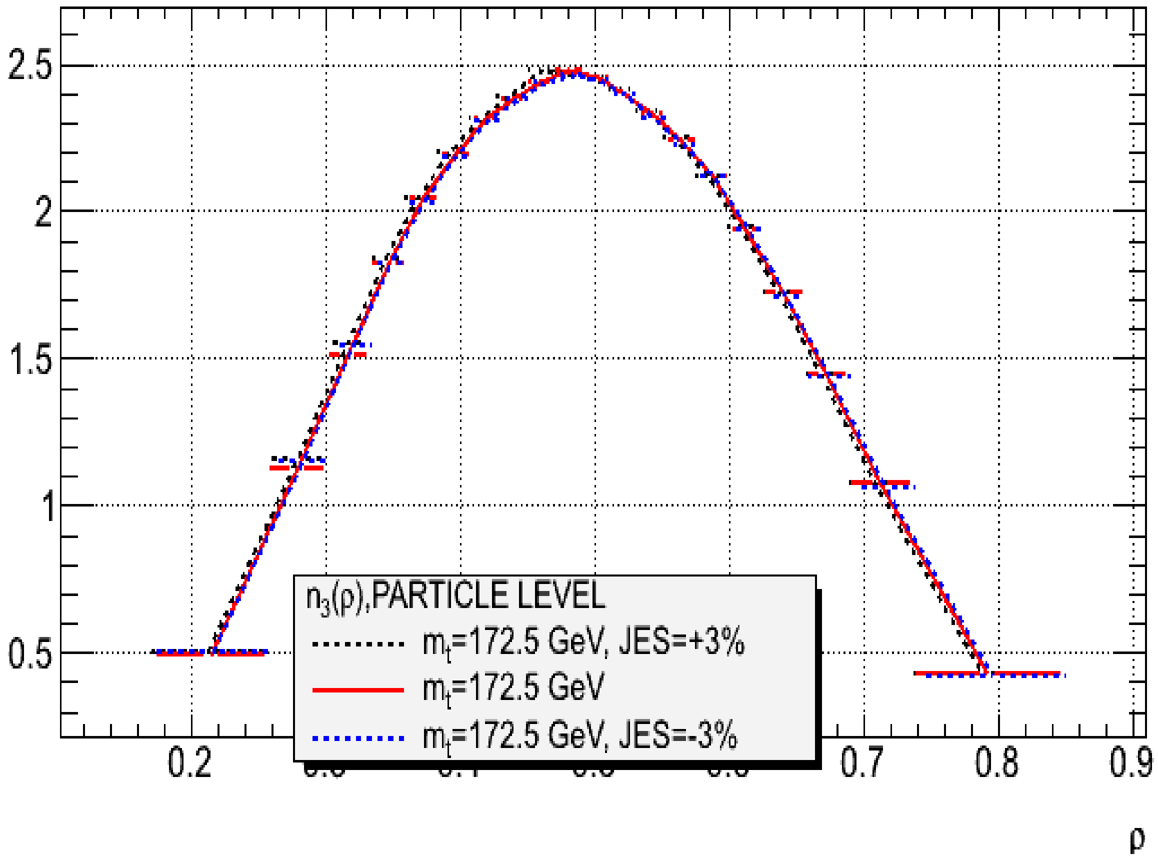


Impact to the top mass value (for m_{top}=170 GeV) of the **scale**. The equivalent impact of the difference between the two **PDFs** considered in this exercise is also shown.

Dependences lower than 1 GeV for the low invariant mass region

Estimation of JES (Jet Energy Scale) uncertainties

The uncertainty of the n3 distribution due to JES has been evaluated by variation of the JES by ±3% And after, applying the JES correctionts to all reconstructed jet, n3 distribution is reevaluated.

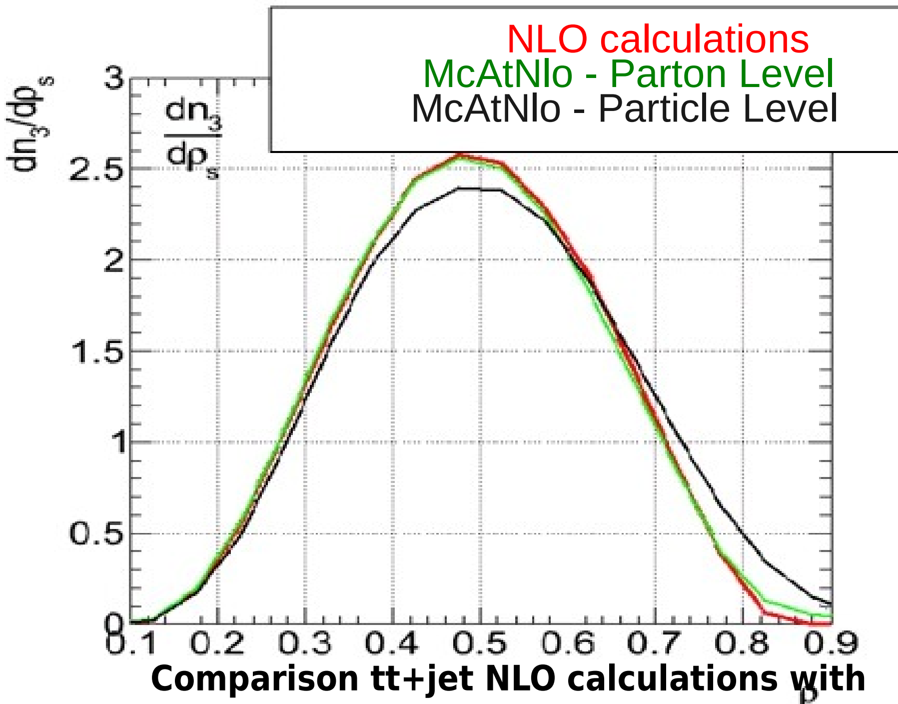


The impact on the top quark mass of the jet energy (JES) evaluation has been estimated → 700-900 MeV (ΔJES = 3%)

Comparison with other MC

Objects, at Particle Level:

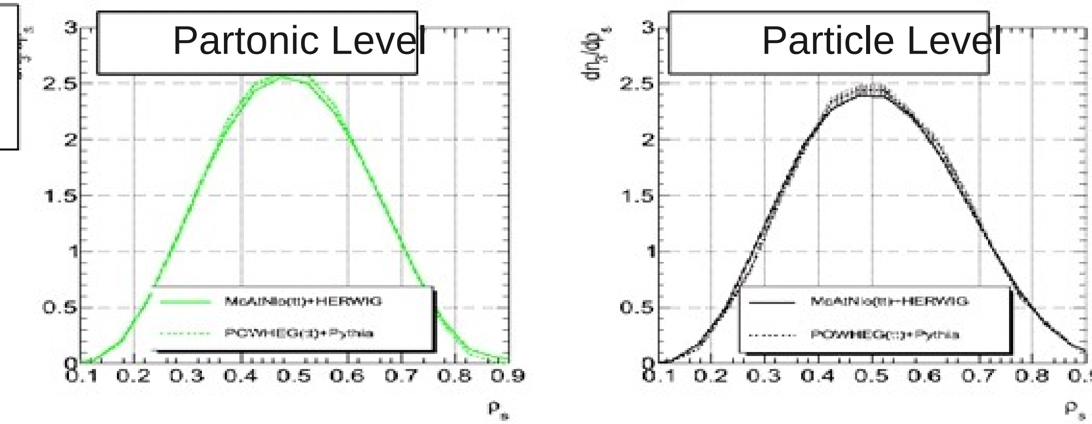
- **Good Electrons:** dressed electrons with pT>25 GeV, |η|<2.47
- **Good Muons:** pT>20 GeV, |η|<2.5
- **Neutrinos:** neutrinos coming from W boson. pT>20 GeV (muon channel), pT>35 GeV (electron channel)
- **Particle Jets:** AntiKtTruthJets with pT>25 GeV, |η|<2.5



Comparison tt+jet NLO calculations with McAtNlo+HERWIG

$dn_3/d\rho_s(m_{top},\mu)$ distribution at NLO for m_{top}=172.5, GeV obtained using:

- tt+Jet NLO calculations
- McAtNlo+HERWIG at Partonic Level
- McAtNlo+HERWIG at Particle Level. (TruthParticle objects)



Comparison : McAtNlo+HERWIG vs POWHEG+Pythia for the selection partonic level (left) and selection at particle level (right).

ATLAS MonteCarlo samples show good agreement with our calculations and are compatible between them.