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

Patricia Fernández
Instituto de Física Corpuscular
IFIC-UV, Valencia

based on arXiv:1303.6415
Eur. Phys. J. C (2013) 73:2438 (on May 2013)

S. Alioli, PF, J. Fuster, A. Irles, S. Moch, P. Uwer, M. Vos

Taller de Altas Energías 2013 Benasque, 15-28th September

Outline

- Top-quark physics
- A new method: Top-quark mass from jet rates
  - Definition of the observable
  - Top-quark mass dependence
  - Theoretical uncertainties
  - Experimental viability
- Conclusions

based on arXiv:1303.6415

S. Alioli, PF, J. Fuster, A. Irles, S. Moch, P. Uwer, M. Vos

Eur. Phys. J. C (2013) 73:2438 (on May 2013)

Top-quark physics

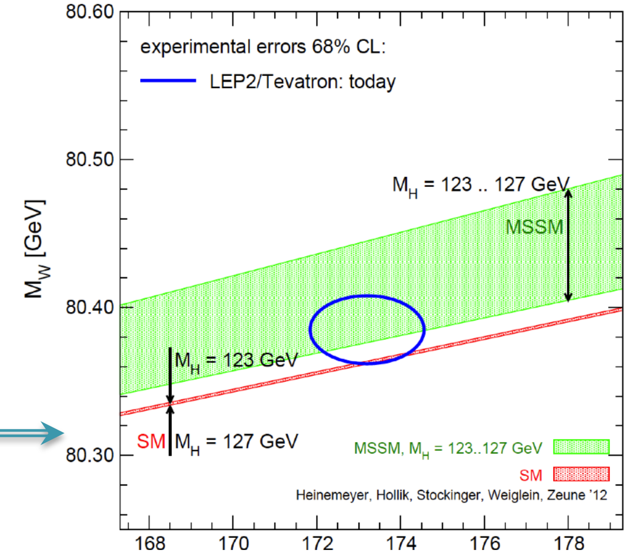
❑ Motivation

$M_{top} \approx M_{AU} >> M_b$

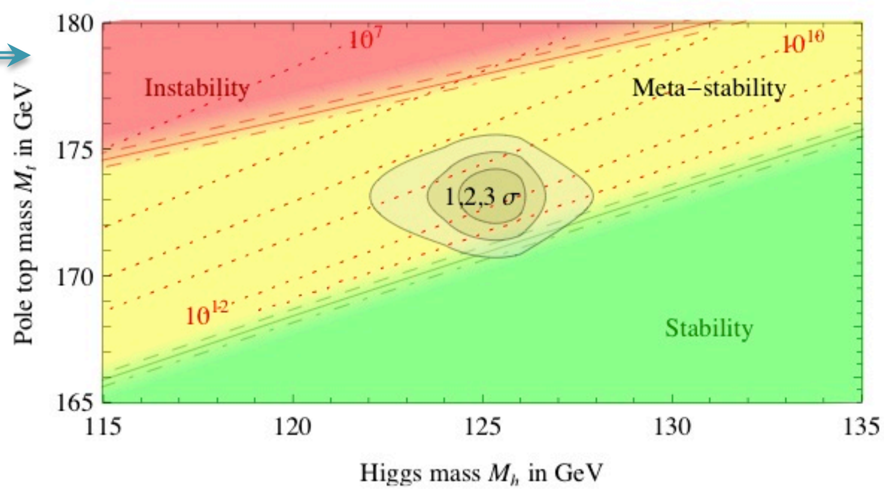
- Heaviest particle in Standard Model (SM)
- Decays before hadronization ~ quasi-free quark
- Strong coupling to Higgs boson
- M_{top} correlated to M_H and M_W
- BSM theories, new physics searches
- Implications on EW vacuum

EWSB mechanism

Heinemeyer, Holik, Stockinger, Weiglen, Zeune '12



SM consistency



Vacuum stability

Alekhin, Djouadi, Moch '12
Degrassi, Di Vita, Elias-Miro, Spinosa, Giudici '12

High accuracy on top-quark properties is needed for precision tests on SM and new physics

Top-quark physics

❑ Top-quark mass

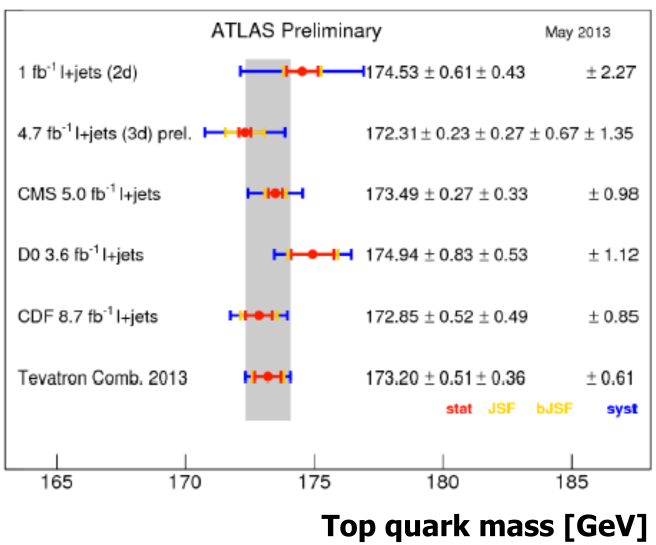
- Quarks don't exist free due to confinement → mass is not an observable

⇒ Top-quark mass is a parameter of the SM Lagrangian → renormalization scheme is needed

⇒ At least a NLO calculation is required to fix renormalization scheme

- Usual mass definitions (related through QCD)
  - → pole mass, m_t^{pole} (ambiguous beyond Perturbation Theory ~ Δ_{QCD})
  - → running mass, $m_t(\mu)$

Current top-quark mass measurements

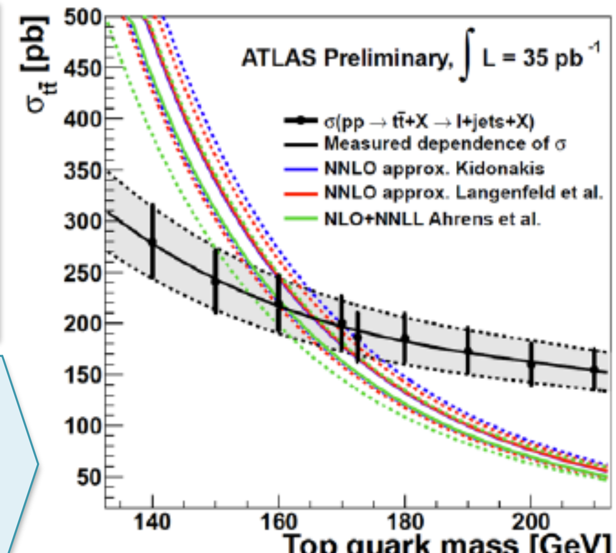


Kinematical reconstruction: Template method → M_t^{pole}

- ✓ Highest precision
- ✗ No renorm. scheme fixed
- ✗ Color reconnection effects
  $m_{MC} = m_{pole}(1 + \Delta)$
  $\Delta \sim 500$ MeV
- ✗ M_t^{pole} ambiguity ~ Δ_{QCD}

Extraction from observable: Cross section measurement

- ✓ Well-defined renorm. scheme
- ✗ Low sensitivity to top mass
- ✗ High experimental errors



A new method

❑ Definition of the observable

- New proposal: Use tt+1-jet events
  Jet requirement → P_T > 50 GeV (IR-safe observable)
  - → Large event rates at the LHC (~ 30%)
  - → NLO and NLO+shower corrections available
  - → Gluon emission depends on quark mass

The observable

$$\mathcal{R}(m_t^{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s}(m_t^{\text{pole}}, \rho_s);$$

where $\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}j}}}$ and m_0 = 170 GeV

⇒ Normalized 3-jet differential cross section as a function of the inverse of the system invariant mass

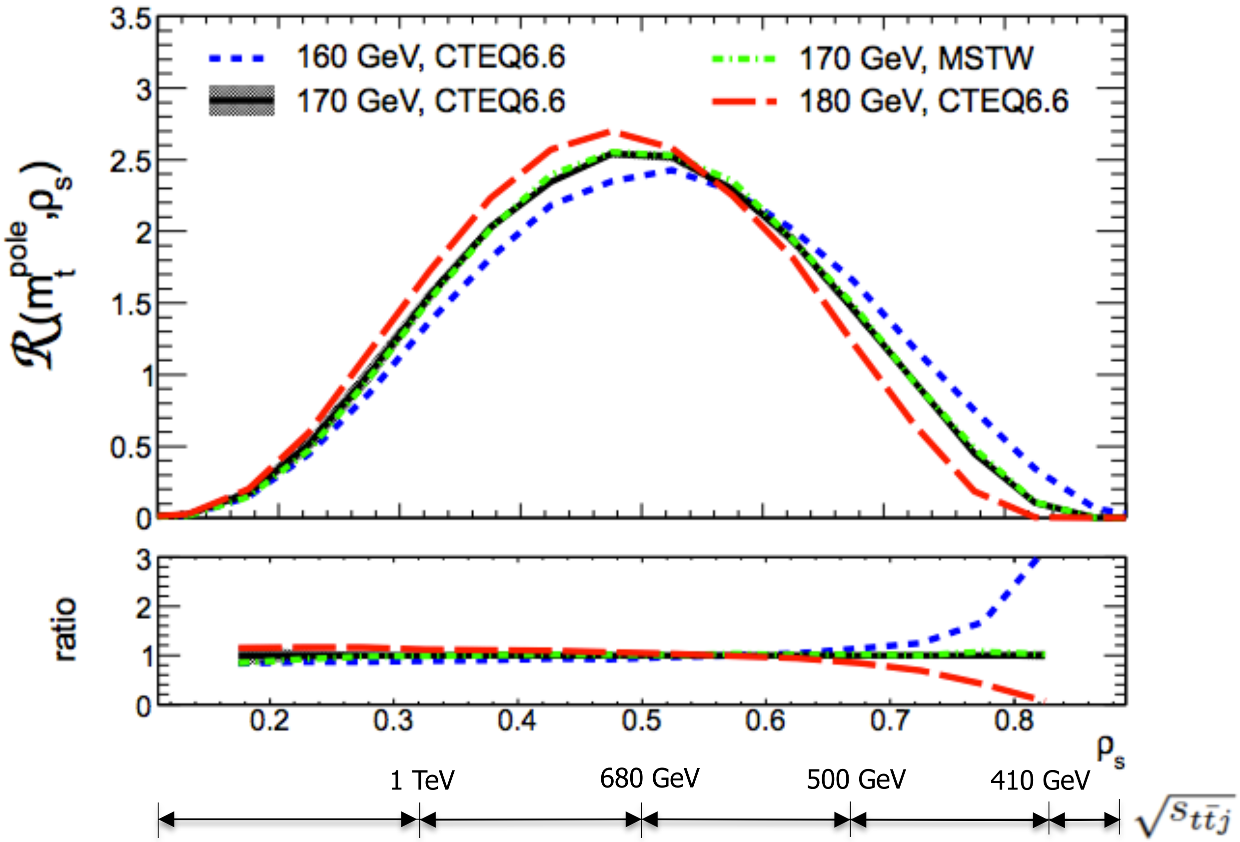
- Renormalization scheme is fixed through NLO calculation → m_t^{pole} defined here
- Differential distribution enhance the top-quark mass sensitivity
- Theoretical and experimental uncertainties are minimized through normalization

Theoretical calculations including radiative corrections at NLO
[S. Dittmaier, P. Uwer, Weinzierl Eur. Phys. J. C. (2009) 59: 625-646]

A new method

- **Definition of the observable**

$$\mathcal{R}(m_t^{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s}(m_t^{\text{pole}}, \rho_s)$$

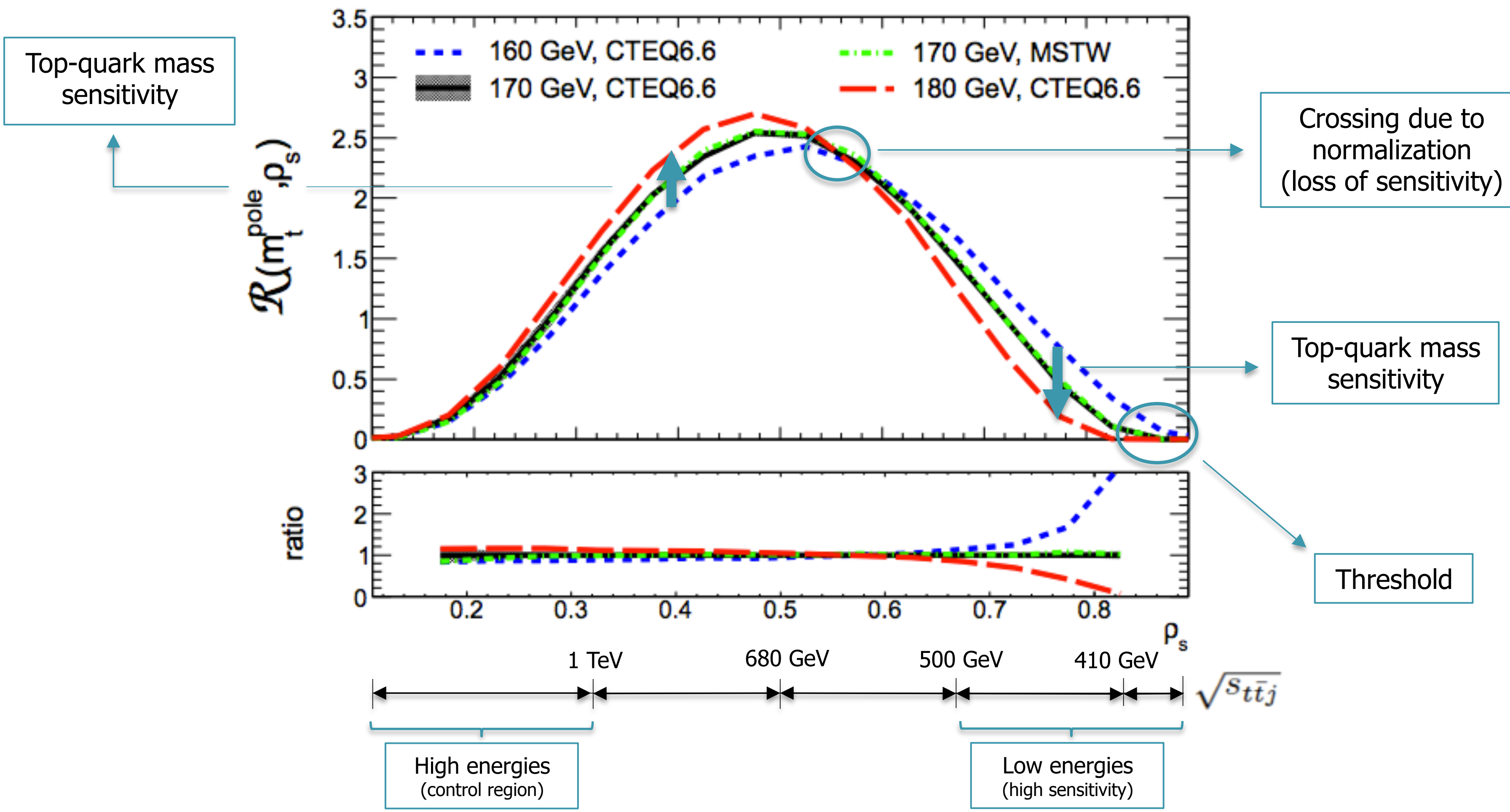


The observable is calculated perturbatively at NLO

A new method

- **Definition of the observable**

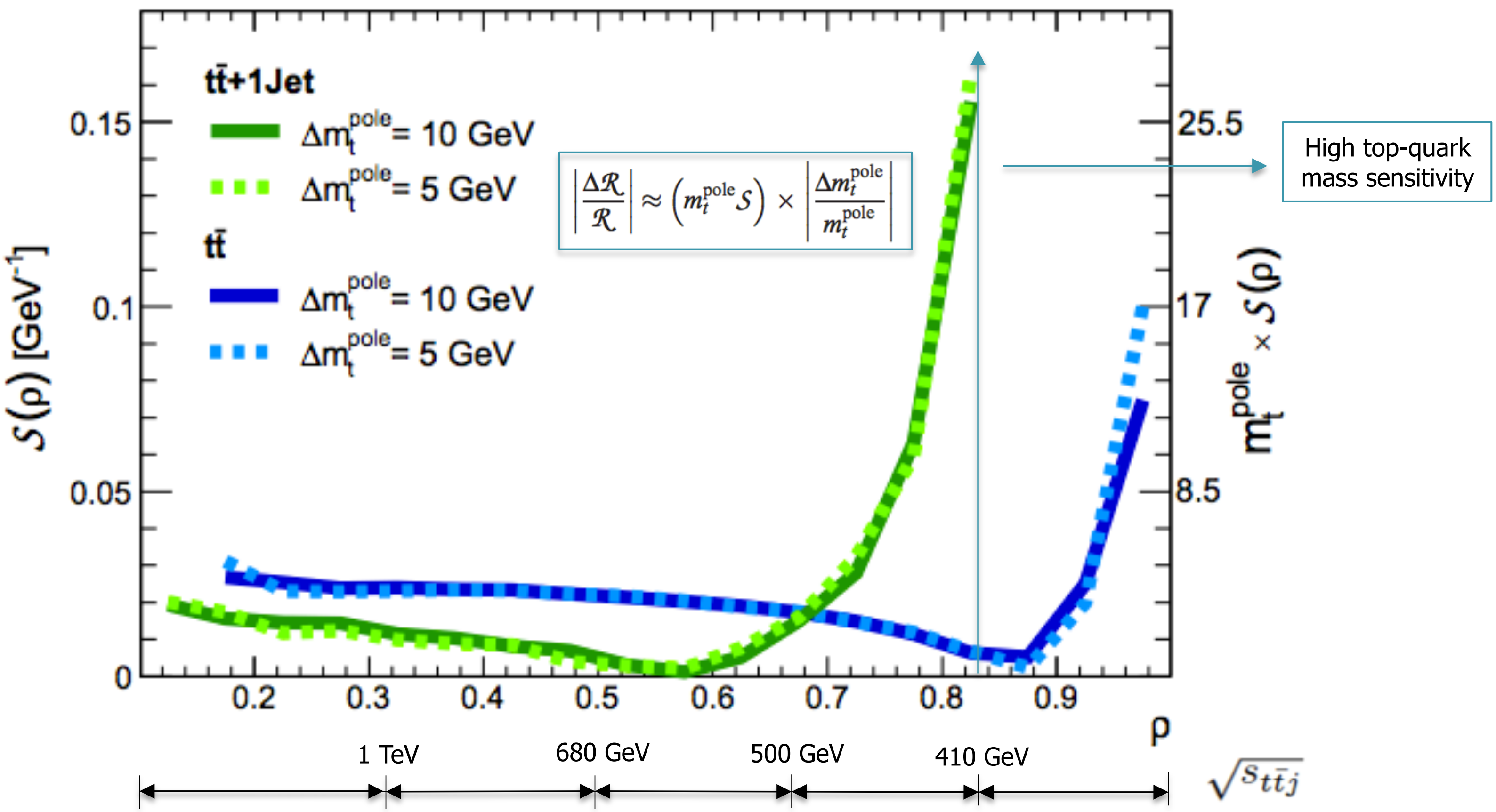
$$\mathcal{R}(m_t^{\text{pole}}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s}(m_t^{\text{pole}}, \rho_s)$$



A new method

❑ Top-quark mass dependence

- Linear approximation: $\mathcal{S}(\rho_s) = \sum_{\eta=\pm1} \frac{|\mathcal{R}(m_t^{\text{pole}}, \rho_s) - \mathcal{R}(m_t^{\text{pole}} + \eta\Delta m_t^{\text{pole}}, \rho_s)|}{2|\Delta|\mathcal{R}(m_t^{\text{pole}}, \rho_s)}$



A new method

❑ Theoretical uncertainties

$\Longrightarrow$ Defined perturbatively at NLO

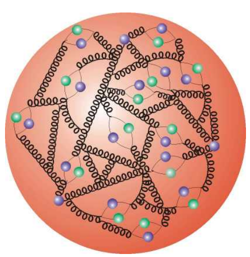
Scale and PDF uncertainties $\Longrightarrow$ $\frac{\Delta\mathcal{R}_{\mu}/\mathcal{R}(m_t^{\text{pole}},\rho_s)}{\mathcal{S}(\rho_s)}$ and $\frac{\Delta\mathcal{R}_{\text{PDF}}/\mathcal{R}(m_t^{\text{pole}},\rho_s)}{\mathcal{S}(\rho_s)}$

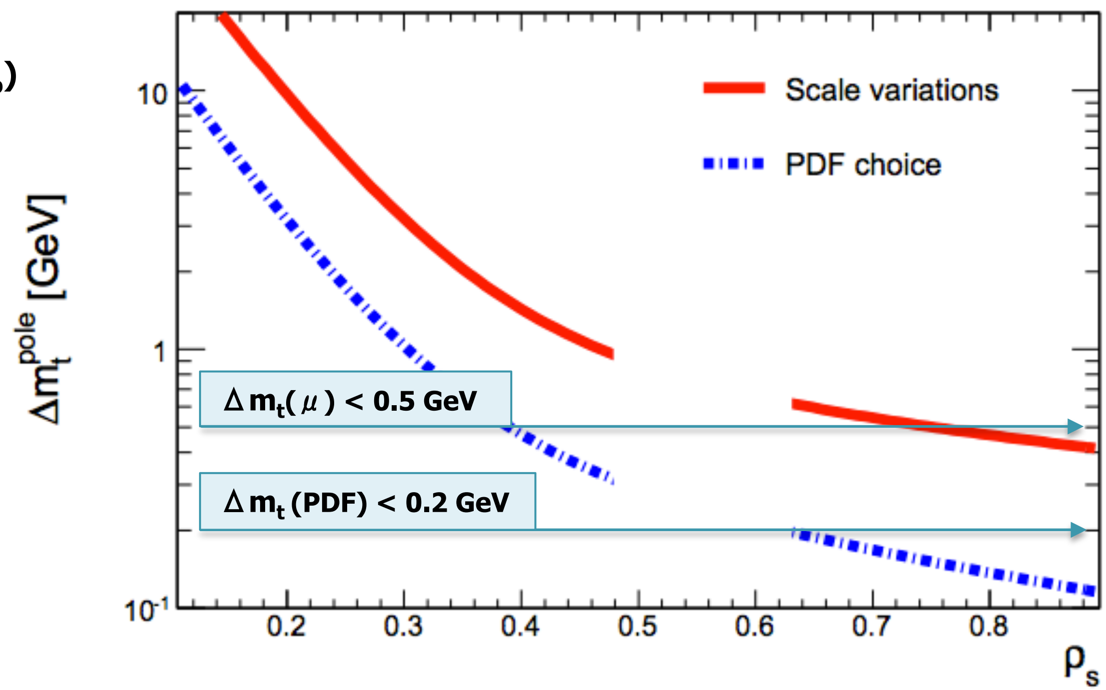
- PDF sets comparison: CTEQ6.6 vs. MSTW2008nlo90cl
- Scale variations in range: $0.5 \cdot m_t < \mu < 2 \cdot m_t$

$$\sigma_{tt} = \sigma_{tt}\,(f_1(x_1, \mu_F), f_2(x_2, \mu_F), \mu_F, \mu_R, s, m_{top})$$

PDF
Parton Distribution Function

SCALES
Renormalization scale, μ_R
Factorisation scale, μ_F
$\mu_R = \mu_F = \mu$



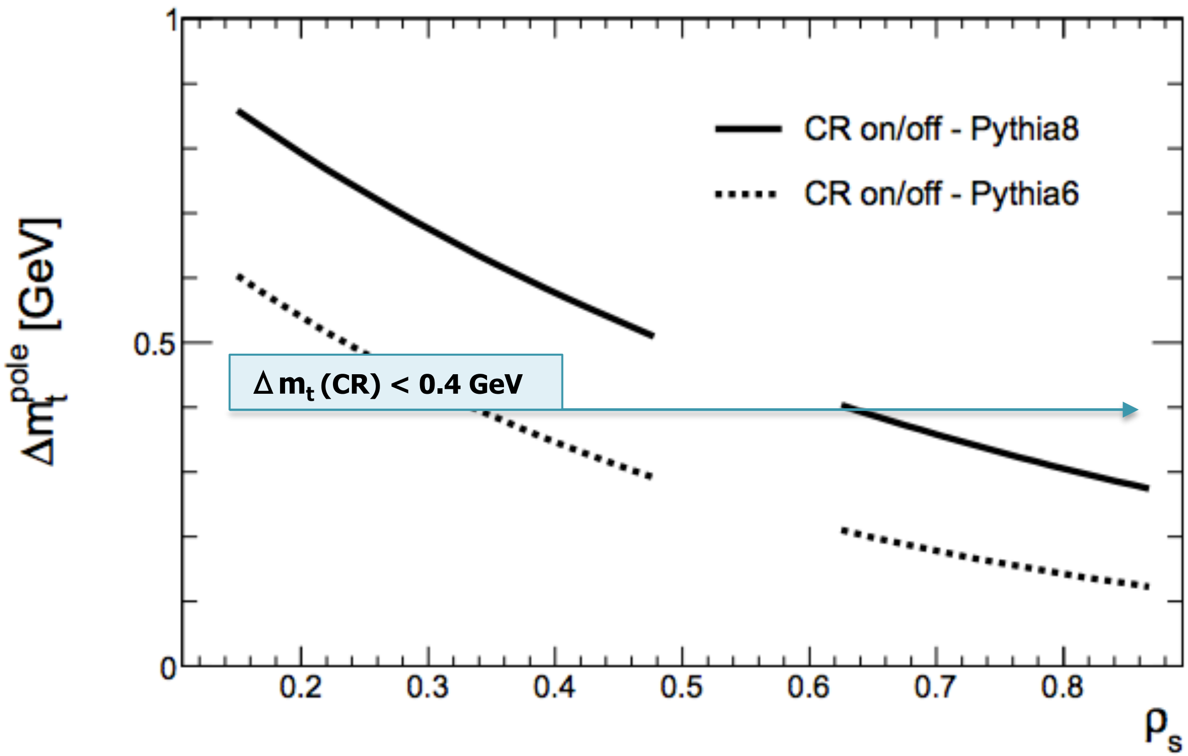


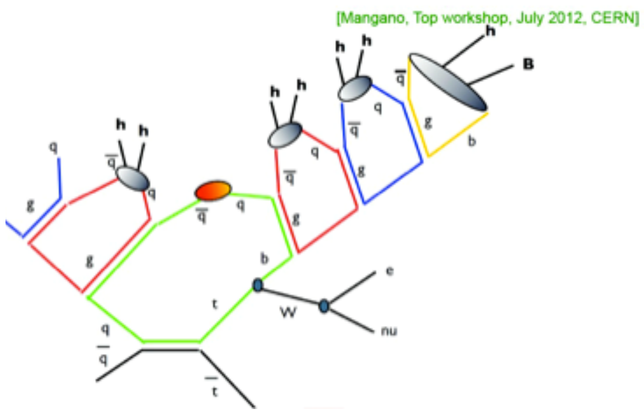
A new method

Color reconnection

⟹ Comparison between different CR models

⟹ At particle level (stable particles) with **Pythia6** vs. **Pythia8**





⟹ Switching on/off CR:
very conservative estimation

A new method

- **Experimental viability** $\Longrightarrow$ Using Powheg tt + Pythia8 at Particle level (stable particles)
  - Preliminary study with no detector-specific tools
  - Event selection: lepton + jets

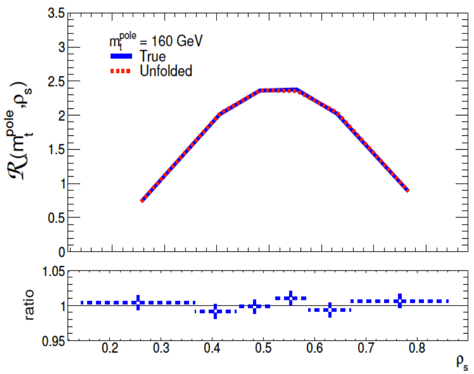
    $\Longrightarrow$ Specific selection criteria on leptons and jets $\rightarrow$ See reference in arXiv:1303.6415

Qualitative study of experimental error sources

Statistical errors
5fb^{-1} luminosity, 1% efficiency
$\Delta m_t \approx$ 1.5 GeV

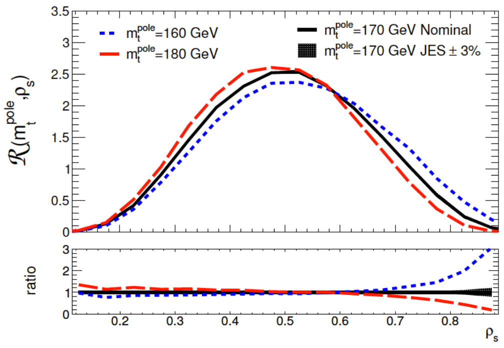
Backgrounds estimation
QCD, W+jets, single top
~ 5-10 %

Monte Carlo generators
Powheg vs. Mc@Nlo
$\Delta m_t \approx$ 0.2 ± 0.2 GeV



Unfolding procedure
top-mass independent
$\Delta m_t \approx$ 0.3 GeV

Jet Energy Scale (JES)
Shift of +/- 3%
$\Delta m_t \approx$ 1 GeV



A total syst. error $\lesssim$ 1 GeV is achievable

$\rightarrow$ **A detailed analysis is detector specific**

- Backgrounds are low, well under-control
- Real challenge: maximization of reconstruction purity

Conclusions

- Importance of a very precise top-quark mass measurement
- A new method to measure the top-quark mass has been presented
- The observable, $\mathcal{R}$, has been calculated perturbatively at NLO
- This observable shows high sensitivity to the top-quark mass
- Theoretical uncertainties are well-defined below ~ 0.5 GeV
- A generic study of its experimental viability has been done:
  - ⇒ Experimental uncertainties well under-control
  - ⇒ Detector specific analysis could achieve $\lesssim$ 1 GeV

The renormalization scheme is fixed and the top-quark mass is uniquely defined through NLO calculations

This method is proposed as an alternative, complementary to existing approaches

Future work: Detailed analysis with detector specific tools → IN ATLAS