New Approaches in Determining the Top-Quark Mass

Alternative Techniques and Differential Measurements

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DESY

for the CMS Collaboration

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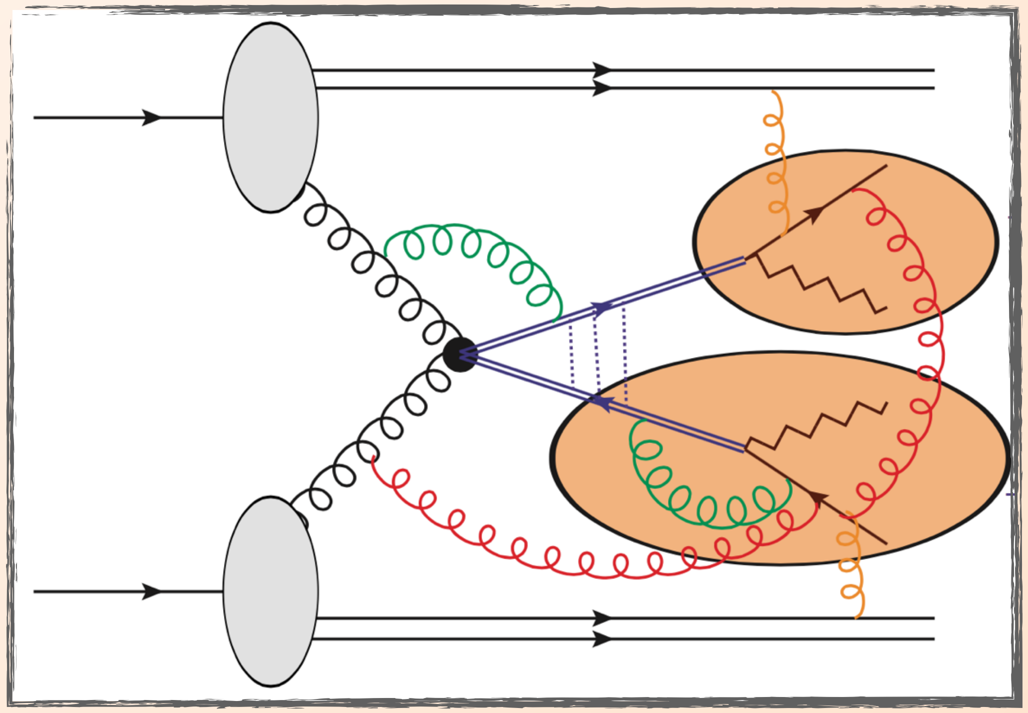
- Extraordinary precision in ‘direct’ top-quark mass measurements
  - Reconstruct event kinematics
  - Calibrate to mass employed in MC (incl. PS)
  - Measure “MC mass” m_t

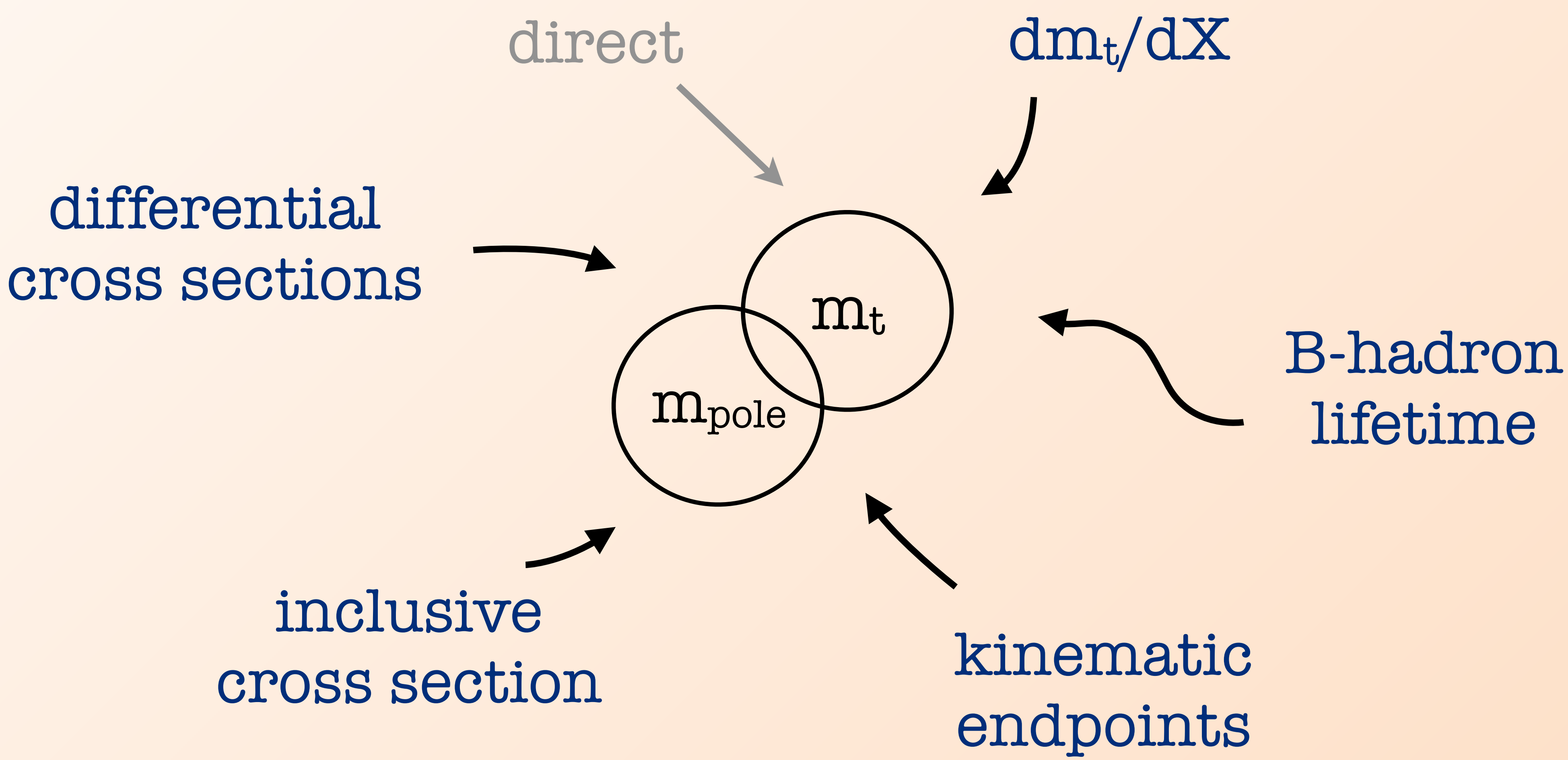


- What is the top-quark mass?
  - Parameter in the Lagrangian m_0
  - Beyond LO: Renormalization
  - m_t becomes scheme dependent
    - Pole mass: absorb full self-energy in mass
      → ambiguity Λ_{QCD}
    - Short-distance ‘running masses’
      e.g. MSbar: absorbs UV div, only, scale dependent → not discussed here

- Studies suggest: difference between MC mass and pole mass O(1 GeV) arXiv:1405.4781, arXiv:0808.0222

Alternative Measurements: Outline

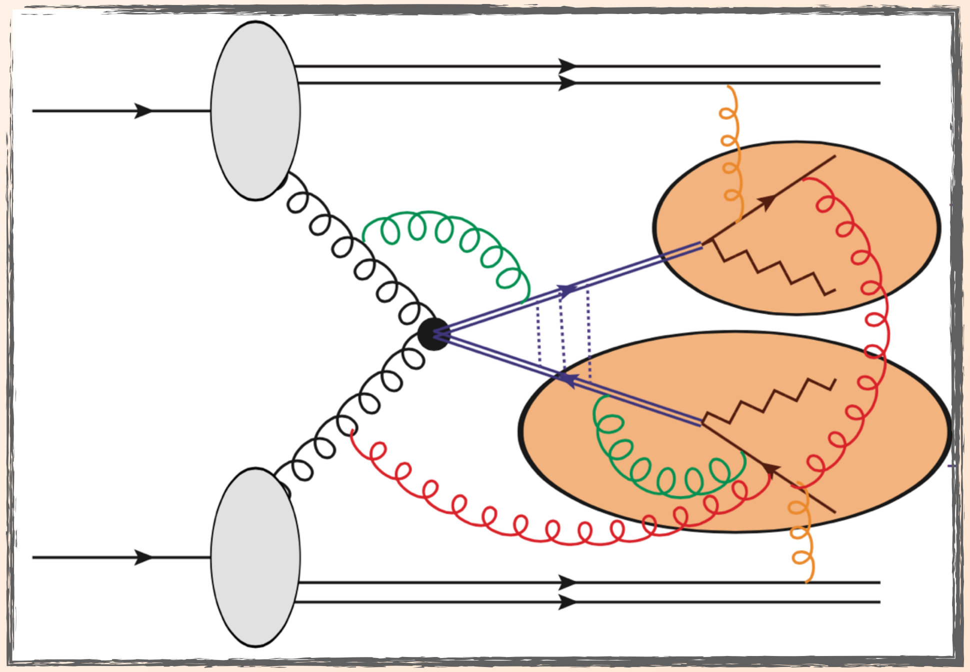
- Study properties of top-quark mass in detail and from many perspectives
  - kinematic dependence of m_t
  - Use extraction methods complementary to standard measurements
  - Minimize dependence on simulation
  - Extract mass in well defined scheme by confronting measured and predicted observables



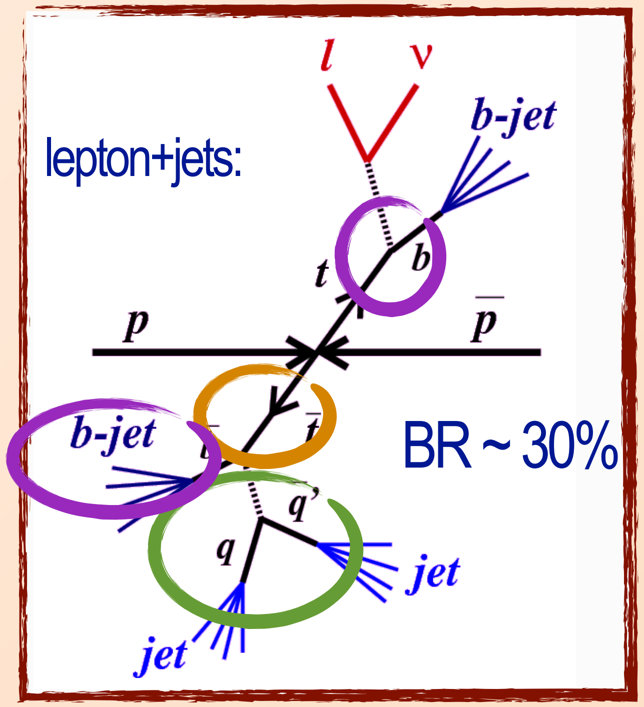
Dependence on Event Kinematics

PAS TOP-12-029, TOP-14-001

- 8 (7) TeV, l+jets channel, 19 (5) fb^{-1}
- 'Direct' measurements calibrate using MC mass
- MC mass depends on event kinematics?
- Is expected dependence described by MC?



- Measure difference between average m_t and m_t for a part of the phase-space
  - Employ 2D ideogram method to derive global JSF, $\langle m_t \rangle$
  - Calibrate globally to MC m_t
  - Apply same procedure to subset of events according to event observable (keeping global calibration fixed)
    - light-quark jets, b-jets, hadronic top, H_T



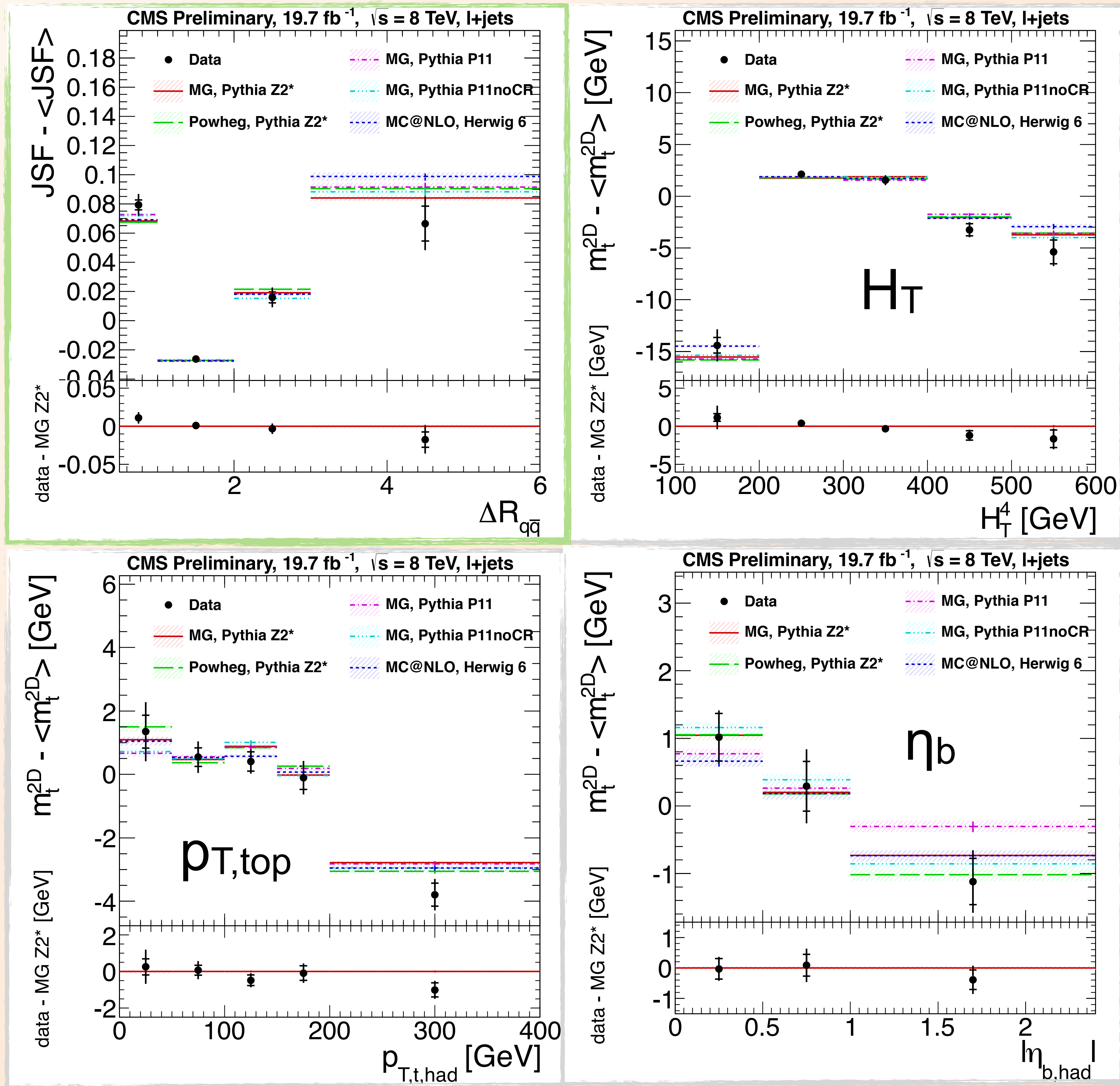
Selected Distributions

PAS TOP-12-029, TOP-14-001

- JES calibration factor well described, even for jets close in ΔR
- Significant turn on wrt H_T, but well described by all predictions
- Low dependence observed wrt top-quark p_T or b-jet rapidity.

➡ All distributions well described → m_t calibration procedure validated

➡ Data not (yet) able to clearly discriminate between predictions



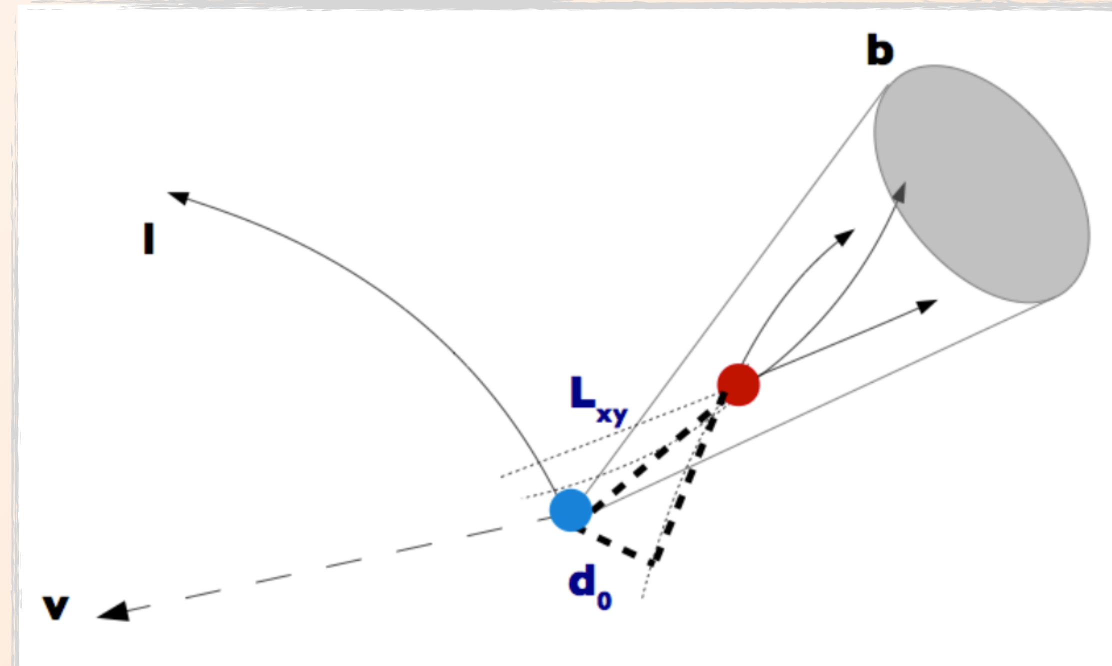
Top-quark Mass from B-Hadron Lifetime

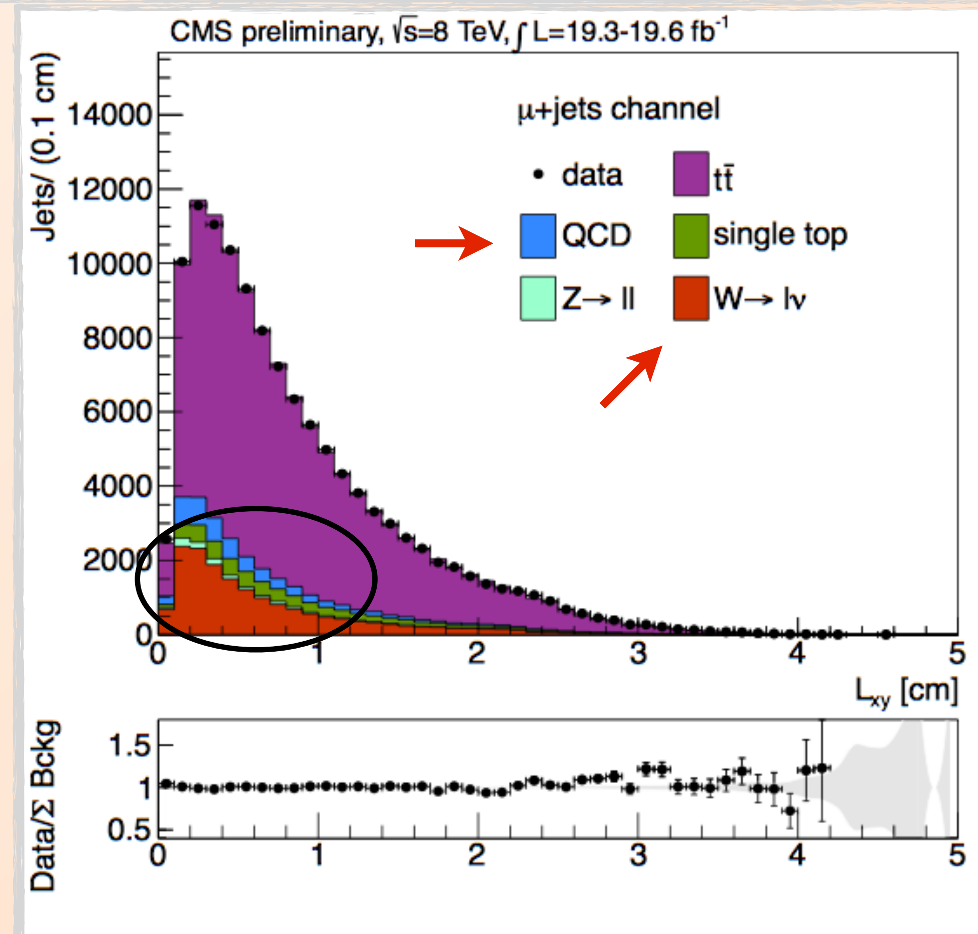
PAS TOP-12-030

- 8 TeV, l+jets, eμ dilepton, 19 fb^{-1}
  - eμ: at least two opposite charged isolated leptons
  - jet with max L_{xy}: central rapidity
- Extract top-quark mass from L_{xy}

$$L_{xy} \approx 0.4 \frac{m_t}{m_B} \beta_B \tau_B,\ \mathcal{O}(7\,\mathrm{mm})$$

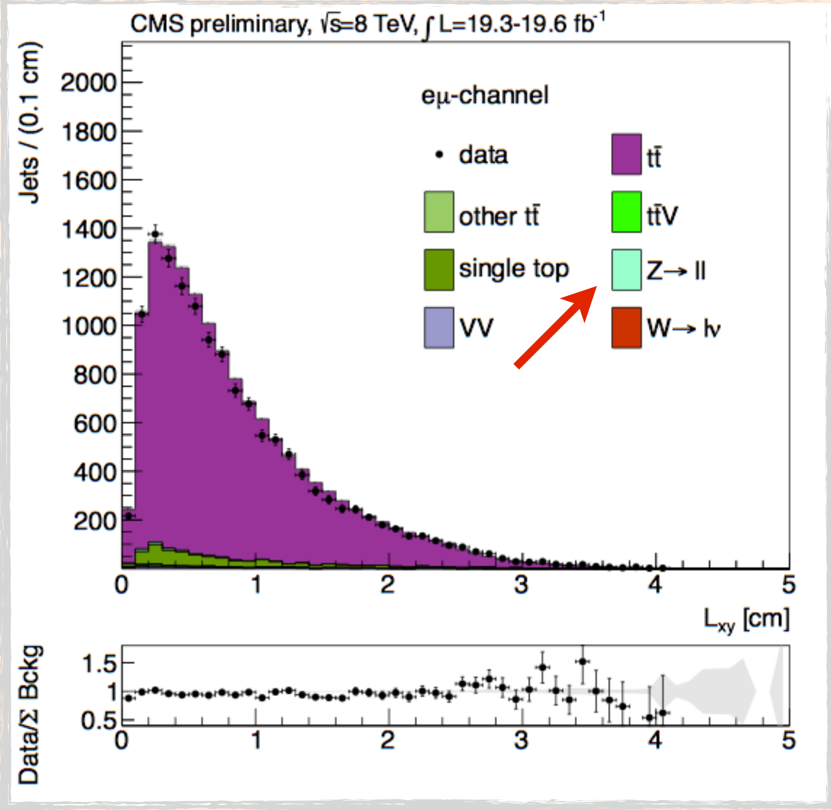
- Consider secondary vertex with max L_{xy}, at least 3σ significance wrt primary vertex
- Complementary approach to 'direct' measurements:
  - reduced sensitivity to jet-energy modelling
  - more dependence on modelling of production process
- Crucial: description of background shapes and rates



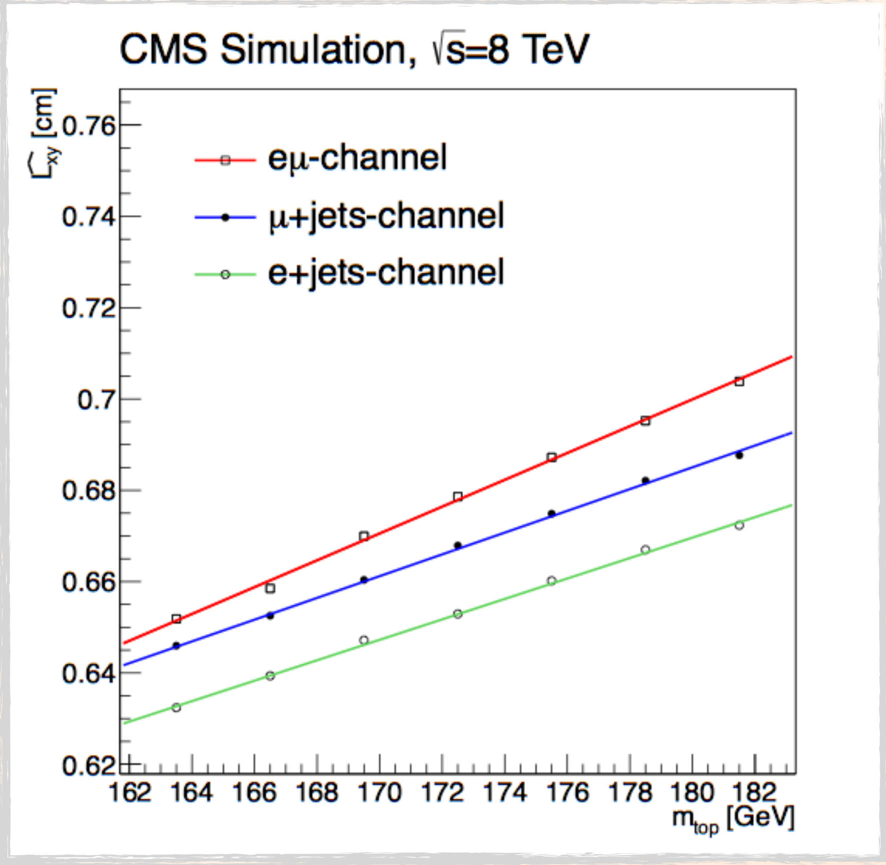


Top-quark Mass from B-Hadron Lifetime (2)

PAS TOP-12-030



- Backgrounds from data (l+jets)
  - $W \rightarrow l\nu$
  - QCD
- Backgrounds from data (eμ)
  - $Z \rightarrow ll$



- Cross check of L_{xy} calibration using p_T balanced dijet events
- Combine channels (using BLUE)
- Dominant uncertainties
  - Background determination
  - Top-quark p_T modeling

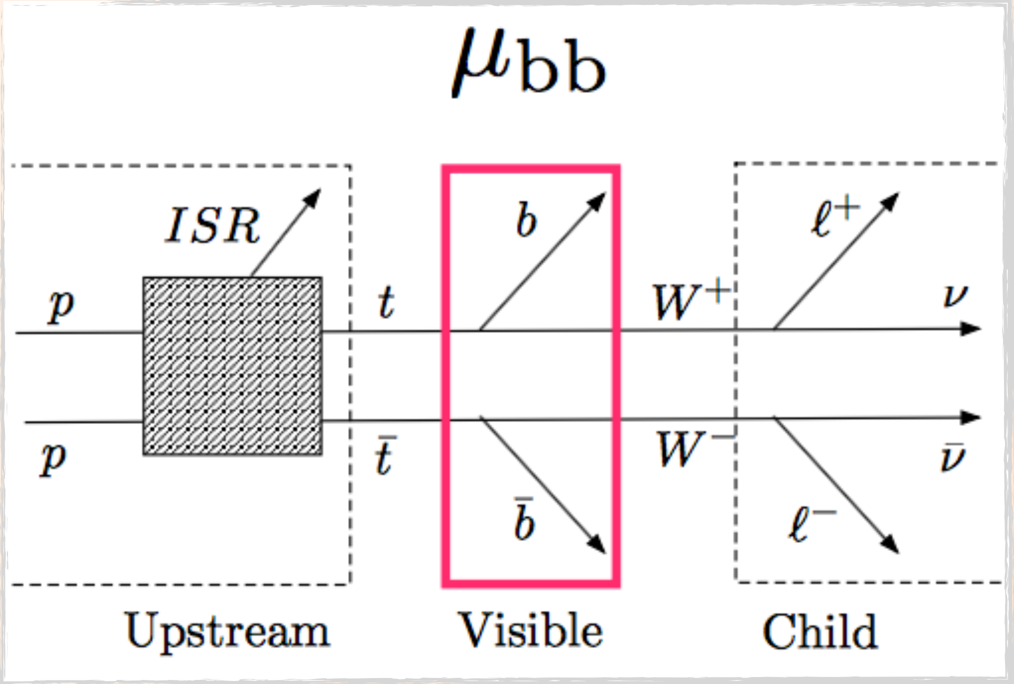
see talk by Ulrich Husemann (differential cross sections)

m_t=173.5 ±1.5(stat) ±1.3(syst) ±2.6(top p_T) GeV

Extraction from Endpoints

Eur. Phys. J. C 73 (2013) 2494

- 7 TeV, dilepton, 5 fb^{-1}
  - 2 isolated, opposite charged leptons (e/μ), for ee,μμ veto 76 < m_{ll} < 115 GeV
  - 2 b-tagged high p_T jets, high missing transverse energy
- Perform mass measurement with minimal input from simulation

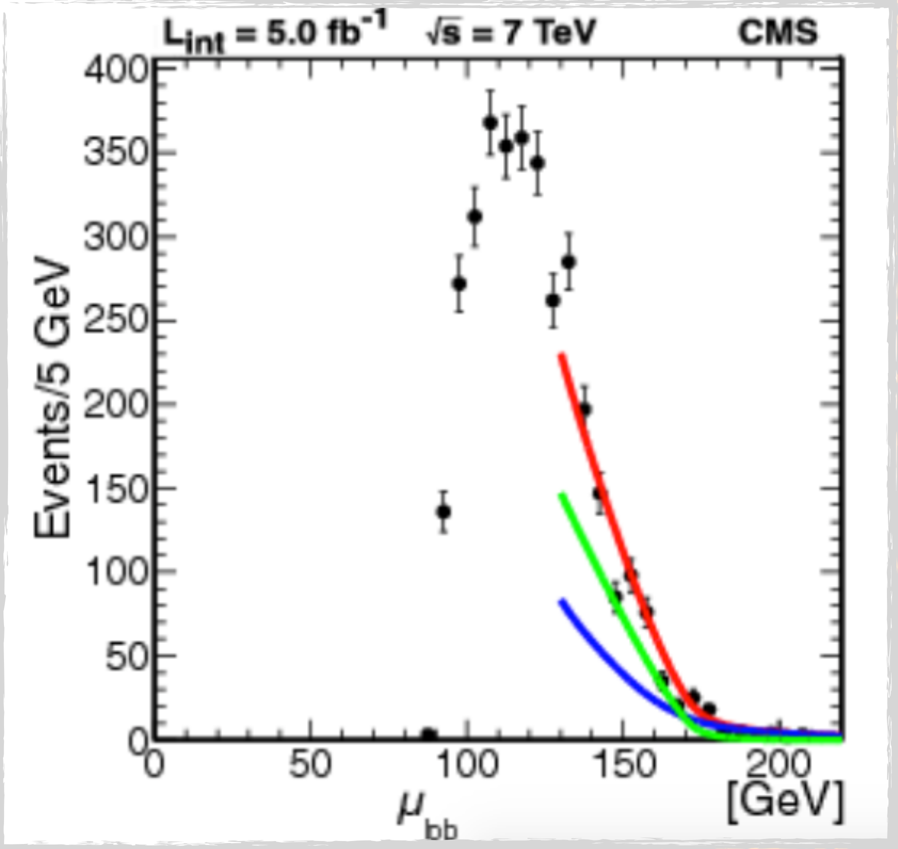


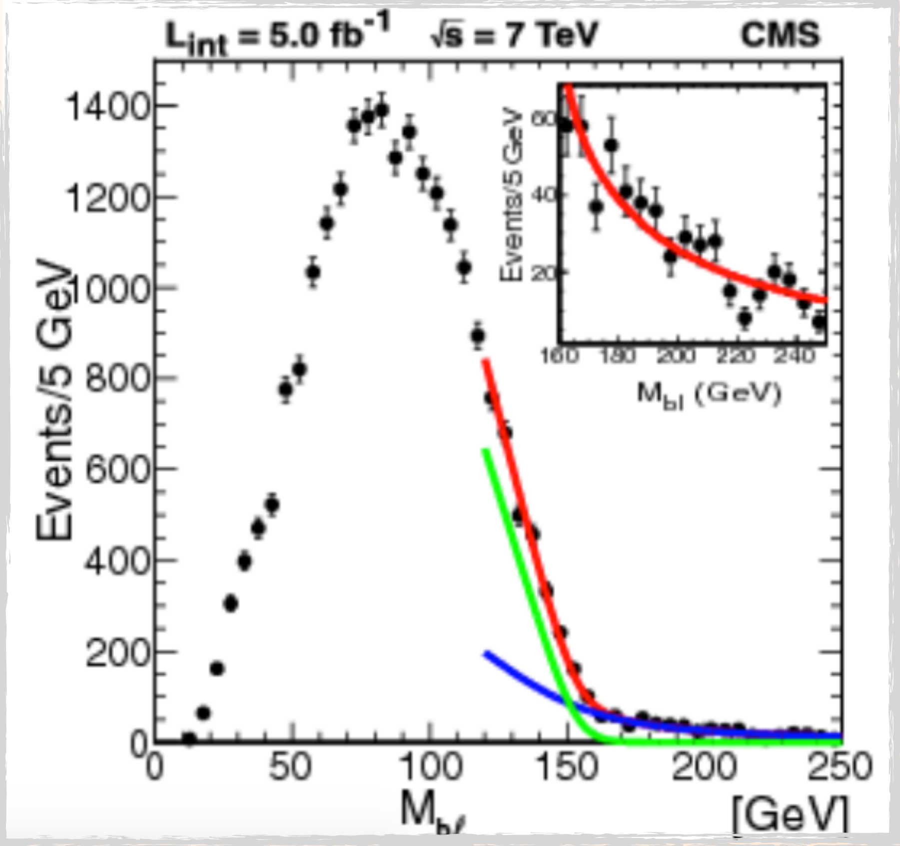
- Construct kinematic observable with endpoint that relates to m_t
  - transverse mass of ttbar pair $M_{T2} = \min_{p_T^{\nu_a} + p_T^{\nu_b} = p_T^{miss}} \left[\max(m_T^a, m_T^b)\right]$
  - reduce sensitivity to ttbar p_T/ISR $M_{T2} \to M_{T2\perp} = \mu_{bb}$
  - Endpoint $\mu_{bb}^{max} = m_t$
- Similar to μ_{bb}: μ_{ll}
- Invariant mass of b-jet and lepton M_{bl}

Extraction from Endpoints (2)

Eur. Phys. J. C 73 (2013) 2494

- Perform event-by-event combined unbinned likelihood for all observables
- For each observable analytic function for
  - background
  - resolution
  - endpoint





- Estimate all uncertainties in data
- Dominant uncertainty: jet energy scale

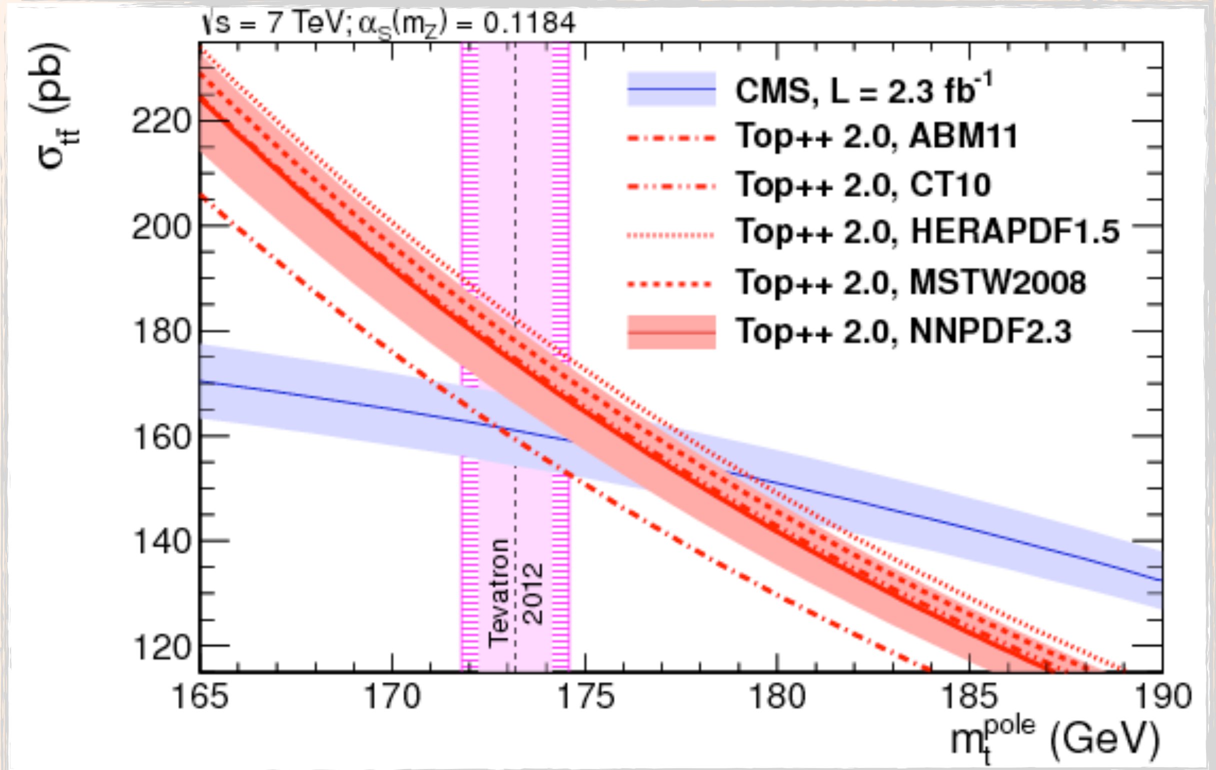
m_t = 173.9 ±0.9 (stat) +1.7 -2.1 (syst) GeV

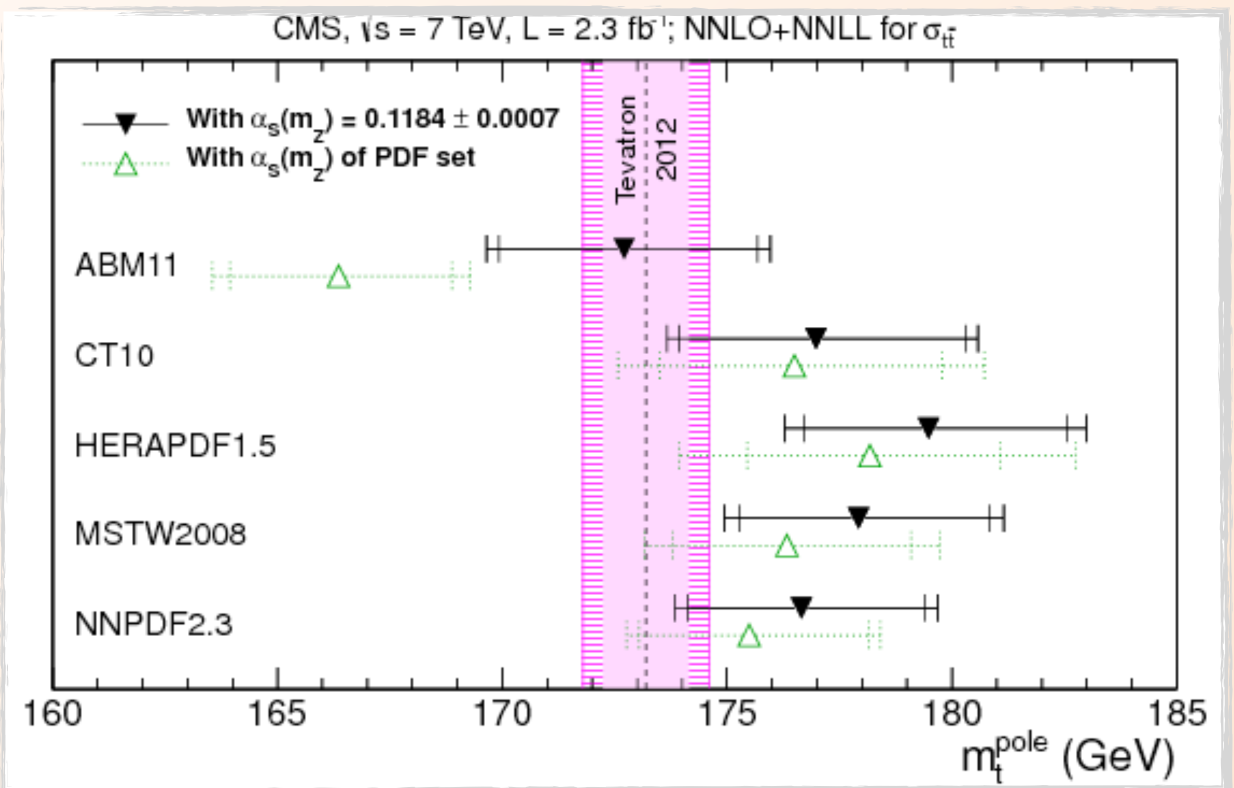
- In principle also applicable to BSM searches with undetected particles

Extraction from Inclusive Cross Section

Phys. Lett. B 738 (2014) 526-528

- 7 TeV, dilepton, 2.3 fb^{-1}
  - based on measurement JHEP 11 (2012) 067
- Predicted cross section shows steeper slope than measurement
- Prediction employs well defined top-quark mass in pole scheme





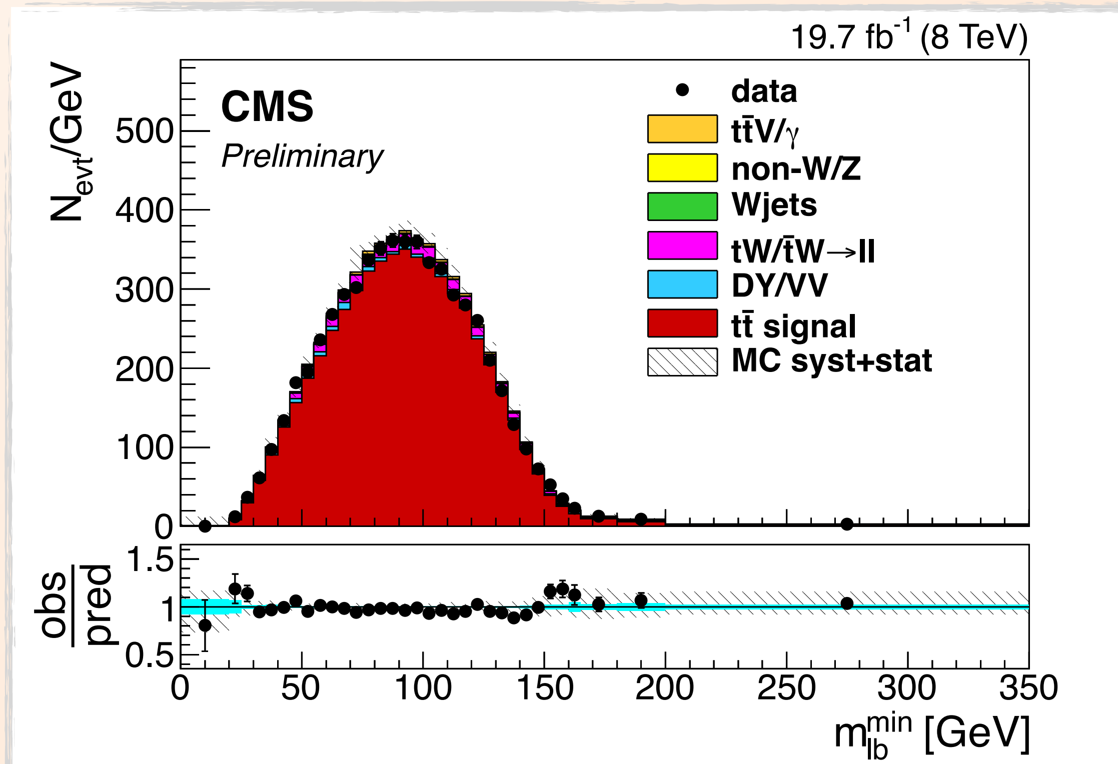
- Measured dependence expressed in terms of MC mass
  - Consider additional uncertainty by varying measured curve by ±1 GeV
- Dominant uncertainties
  - Measured cross section
  - PDF

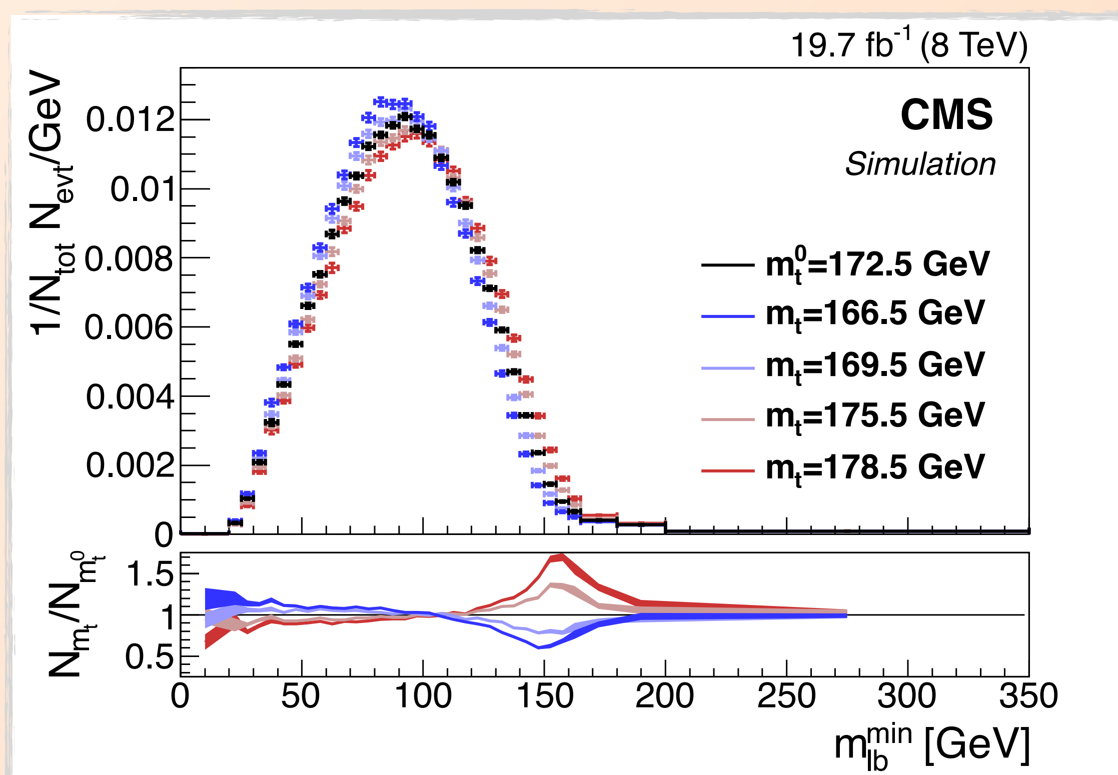
$m_{t,pole}$=176.7 +3.0 -2.8 GeV (NNPDF 2.3)

TOP-14-014

- 8 TeV, eμ dilepton, 19 fb^{-1}
  - ≧2 opposite charged isolated leptons
  - ≧2 high p_T jets, ≧1 b-tagged

- Extract m_t from differential cross-section (m_{lb}) arXiv:1006.0910
- Define m_{lb}: choose permutation with minimum m_{lb}
  - On detector level
    - leading b-jet + opposite charged leptons
  - On prediction level
    - leading b quark + leptons
    - visible phase space
- Precise knowledge of lepton kinematics, leading b-jet: less JES uncertainties





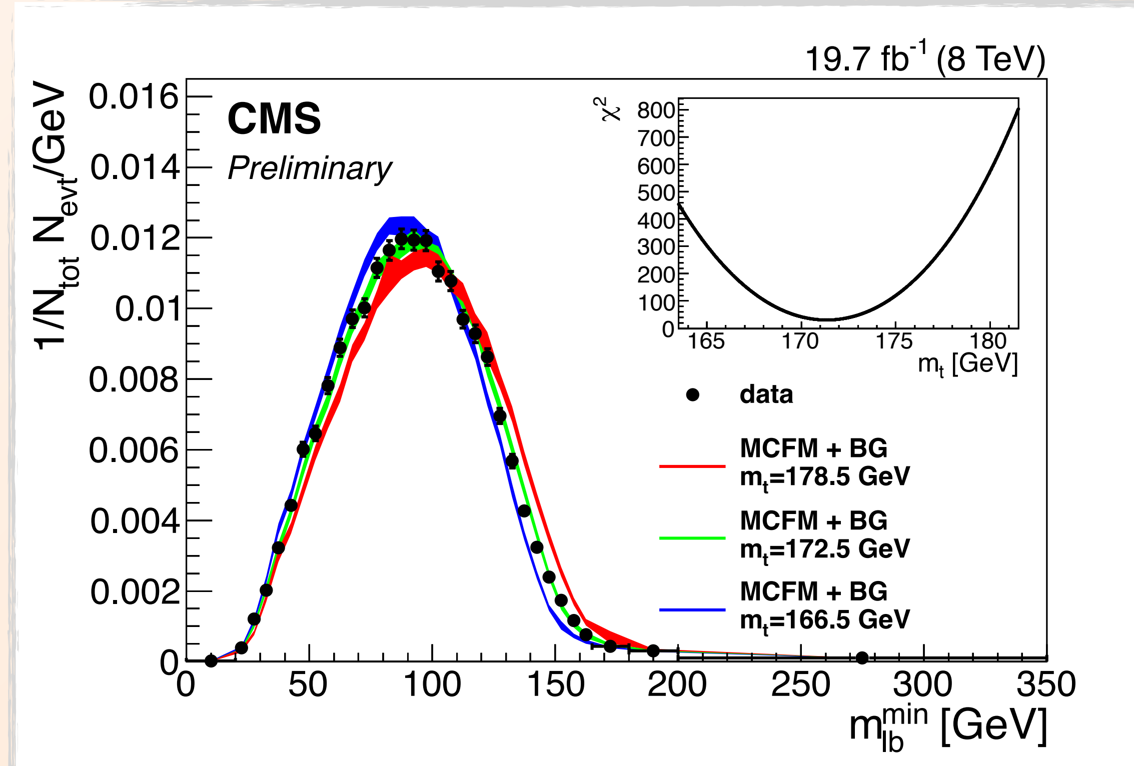
Extraction from Differential $d\sigma/dm_{lb}$ (2)

TOP-14-014

- Use MCFM to generate m_{lb} (LO decay)
- Use response matrix to fold to detector level (matrices will be published)

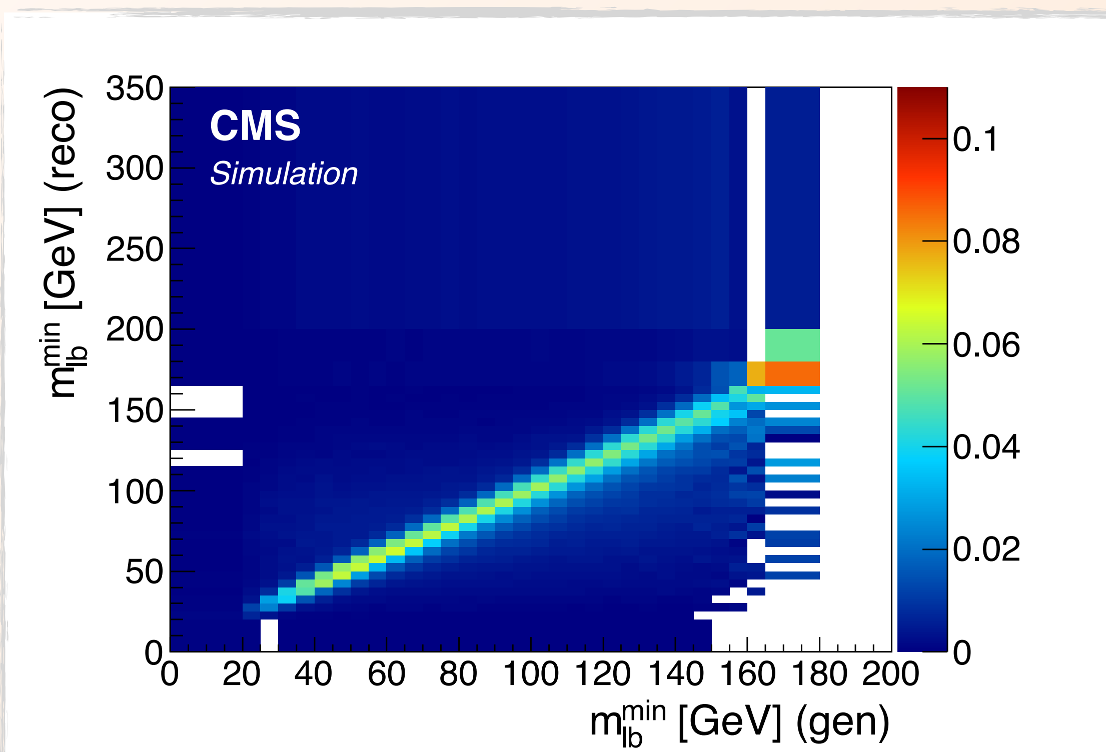
$$\vec{x}_{reco} = \mathcal{L} \cdot M^{resp} \quad \vec{x}_{pred}$$

- Extract m_t by product of bin-wise likelihoods
  - similar to extraction from incl. σ_{tt}



Prediction	Fit method	Fitted m_t [GeV] from m_{lb}^{min}
MCFM (LO)	shape	$171.5\ ^{+1.1}_{-1.1}$
MCFM (NLO)	shape	$171.4\ ^{+1.0}_{-1.1}$

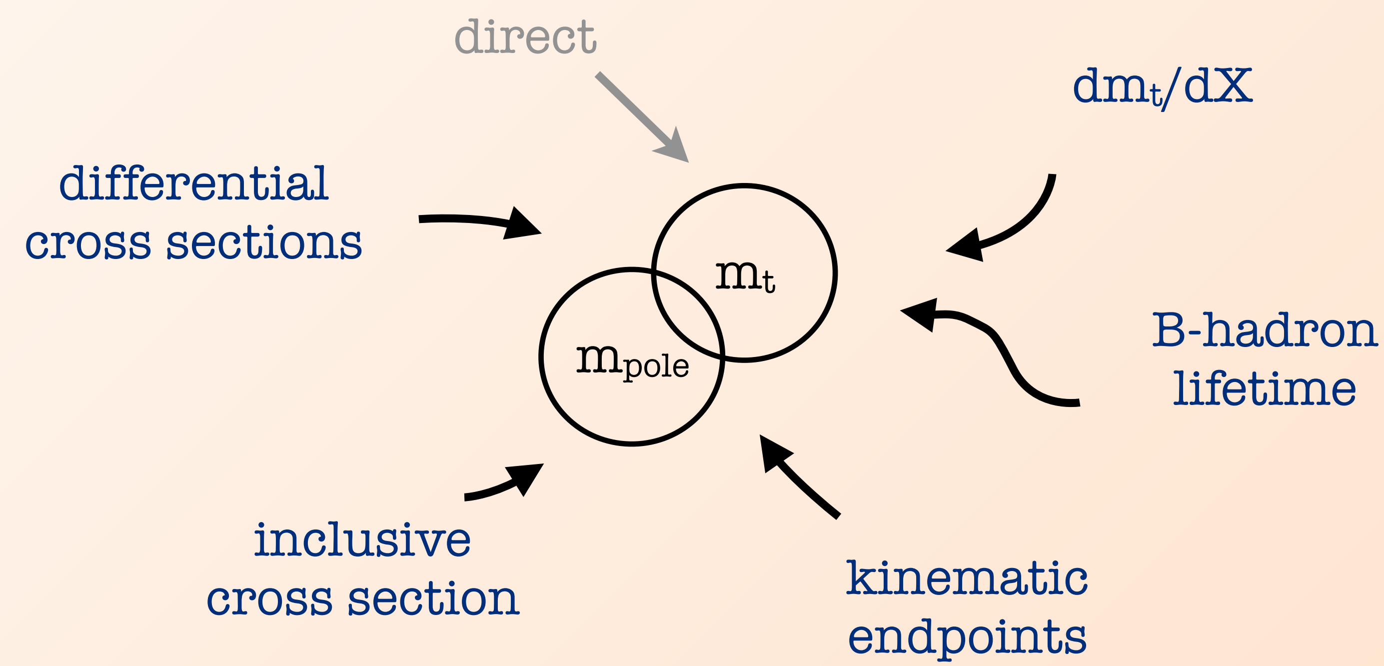
production



- Dominant: JES, Q^2 scale
- No sensitivity to production mechanism
- Method for precise $m_{t,pole}$ determination

Summary

- Large variety of alternative m_t measurements



- dm_t/dX well described by MC
  - gained trust in MC calibration procedure
- Consistent and complementary results from direct, B-hadron lifetime methods
- Simulation-independent measurement from kinematic endpoints
  - In principle extendable to BSM searches
- Well-defined pole-mass extraction from inclusive cross section
- Robust procedure to extend to differential cross sections → higher precision

- Plan to extend variety:
  - Possibly study $d\sigma/dm_{lb}$ defined based on generated b-jets instead of partons → independence of pQCD accuracy
  - Exploit larger statistics at 13 TeV: m_t from J/Psi decays and further refined studies