Two lectures on top quark physics

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Contents:

Lecture 1:

- ✓ The basics
- ✓ Top and EW theory; precision fits
- ✓ Top pair production at hadron colliders [FO, threshold resummation]

Lecture 2:

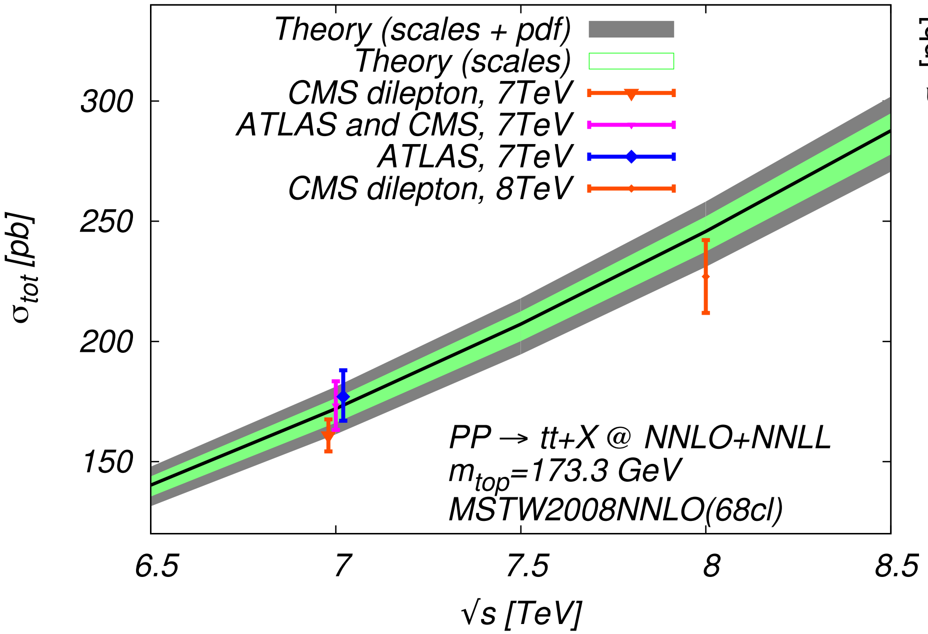
- ✓ (cont.) Top pair production at hadron colliders: cool applications
- ✓ Top decay
- ✓ Factorizable and non-factorizable corrections in top production and decay.
- ✓ Does it make sense to even speak of tops?
- ✓ Top Forward-Backward Asymmetry
- ✓ Single top production
- ✓ Top quark mass
- ✓ Top at e^+e^- colliders

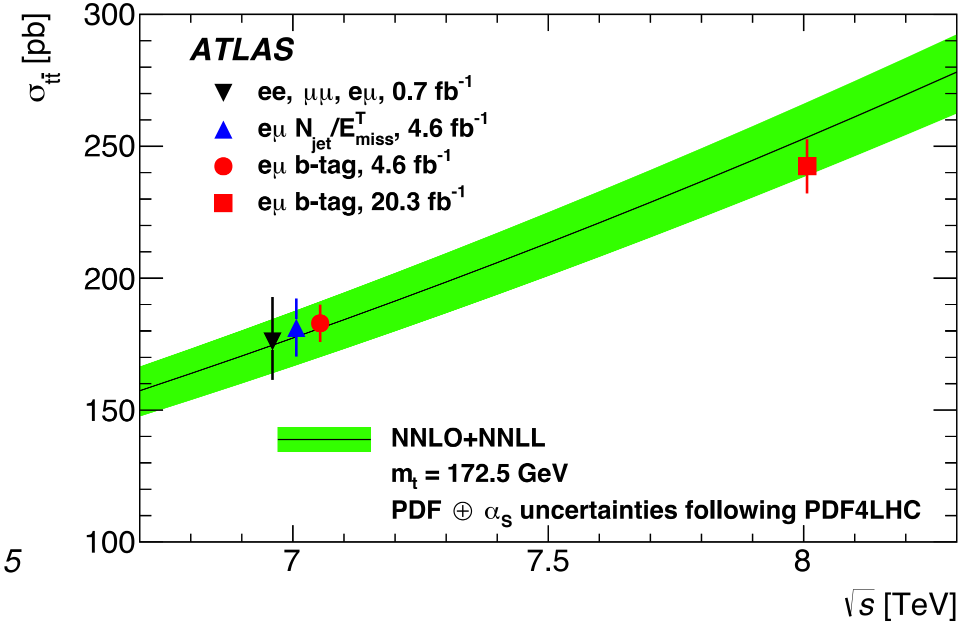
Additional readings:

- Werner Bernreuther [arXiv:0805.1333]

Top quark production (cont.)

NNLO+NNLL theory versus LHC measurements: excellent agreement.





✓ We have reached a point of saturation: uncertainties due to

- ✓ scales (i.e. missing yet-higher order corrections) ~ 3%
- ✓ pdf (at 68%cl) ~ 2-3%
- ✓ alpha$_S$ (parametric) ~ 1.5%
- ✓ m$_{top}$ (parametric) ~ 3%

→ All are of similar size!

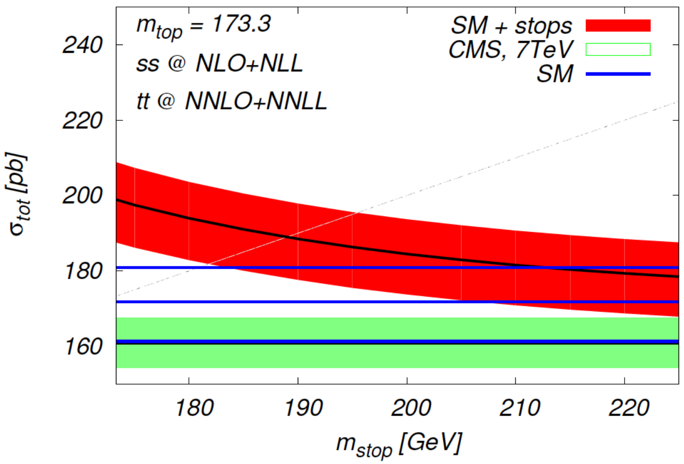
✓ Soft gluon resummation makes a difference: scale uncertainty 5% → 3%

How can a high-precision result be useful?
(i.e. what can be done with it, that could not be achieved with other commonly available tools)

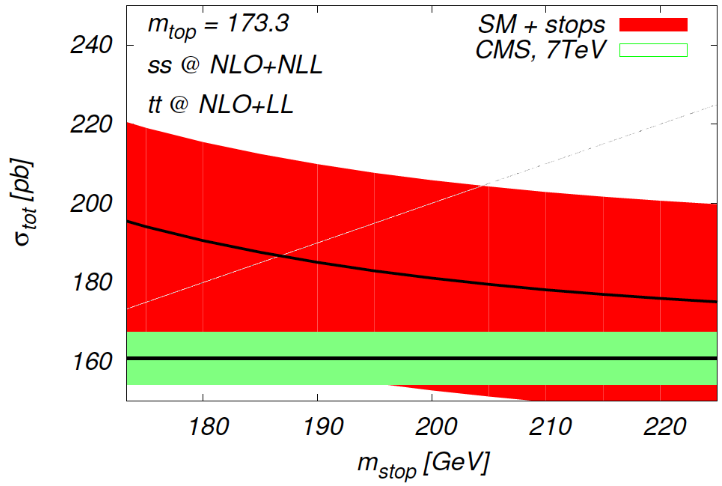
Closing the stop gap (i.e. excluding light "stealthy" top squarks)

See arXiv:1407.1043 for more

SM @ NNLO+NNLL does it…



… SM @ NLO+LL doesn't do it.



Light stop can be excluded based on rates:

- 5% uncertainty
- For $M_{stop} \sim M_{top}$ we have: $\sigma_{stop} \approx 0.15\, \sigma_{top}$
- Thus 3σ exclusion can be expected.

High-precision opens new horizons!
Think about how to explore it…

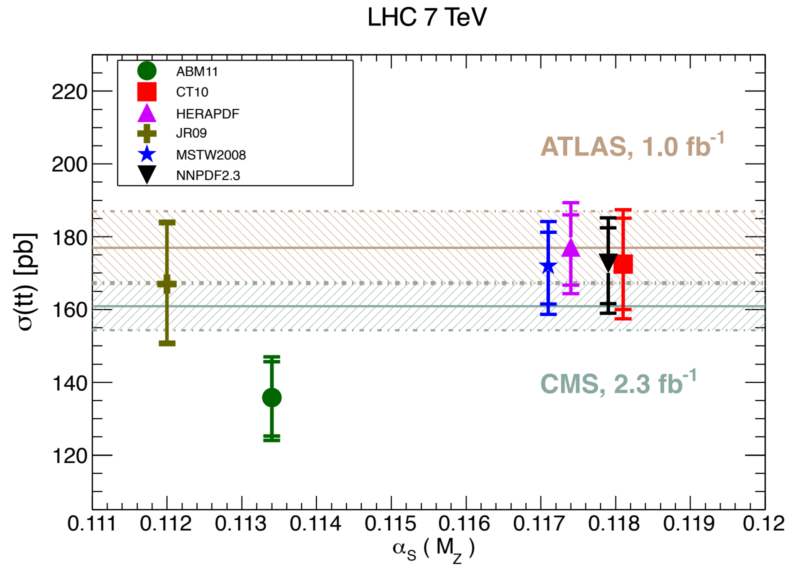
Top measurements and pdf's

- Precision top allows to discriminate among NNLO pdf sets:

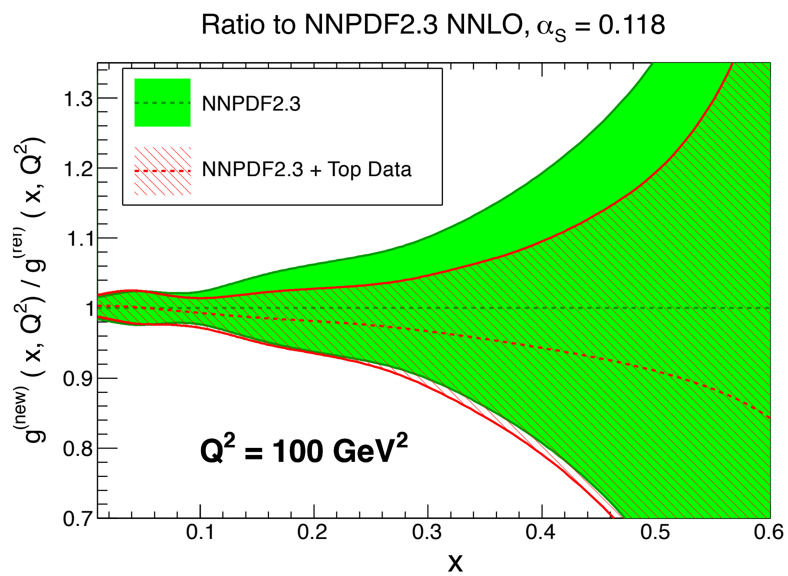
Question: Is it possible the difference be due to bSM physics??

Answer: NO; one can show the differences are purely from (understood) QCD effects.

See NNPDF collaboration '12

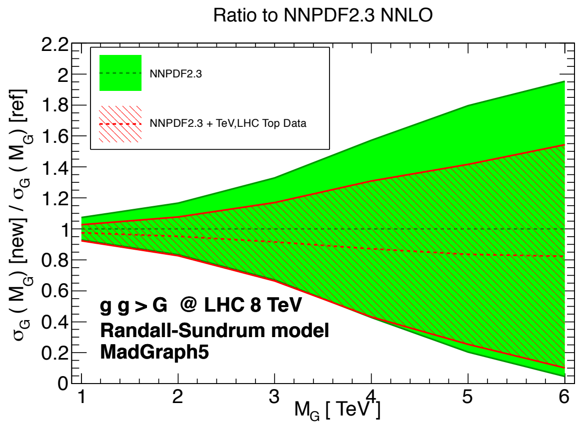


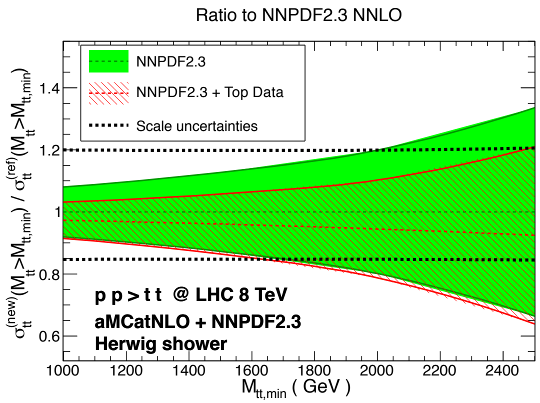
- Precision top allows to improve NNLO pdf sets:



Top measurements and pdf's

- Improved pdf fits then allow improved predictions for high-mass processes:

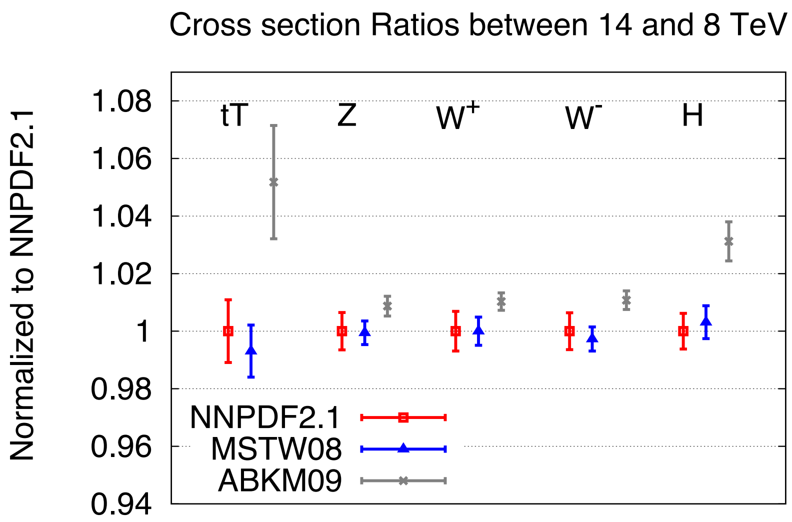




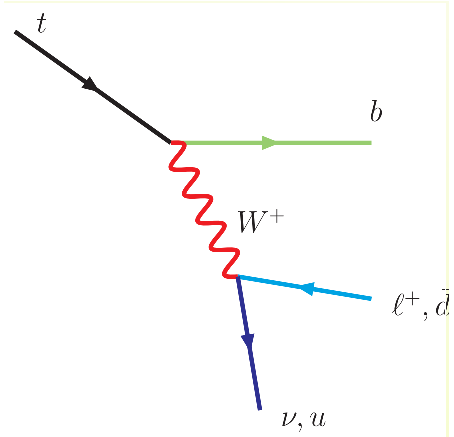
- The power of cross-section ratios:

See Mangano, Rojo '12 for details

- Many uncertainties cancel in ratios!

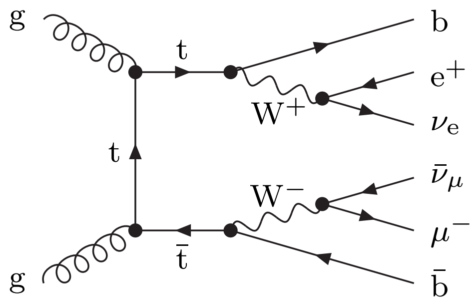


Top quark decay



$$t \longrightarrow W^+ + b$$
$$\quad \hookrightarrow l^+ + \nu$$

$$t \longrightarrow W^+ + b$$
$$\quad \hookrightarrow q + \bar{q}$$



- The top decays very fast, so it is unrealistic to treat it as a stable particle.
- But how to include the top decay?

- Use narrow width approximation

$$\lim_{\Gamma_t \to 0} \frac{1}{(p_t^2 - m_t^2)^2 + m_t^2 \Gamma_t^2} = \frac{\pi}{m_t \Gamma_t} \delta(p_t^2 - m_t^2)$$

$$\int d\sigma_{\mathrm{NtWA}} = \sigma_{t\bar{t}} \, \mathrm{BR}_{t \to i} \, \mathrm{BR}_{\bar{t} \to j},$$

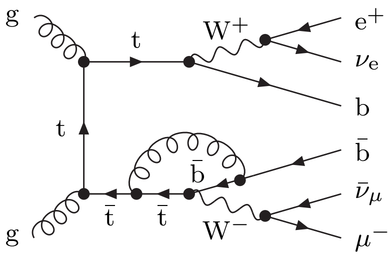
- Treat the top as a resonance with a complex mass

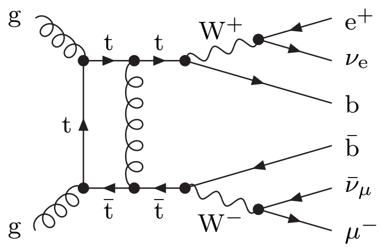
$$m_t^2 - i m_t \Gamma_t$$

- This way we completely separate top production from top decay; a tremendous simplification!

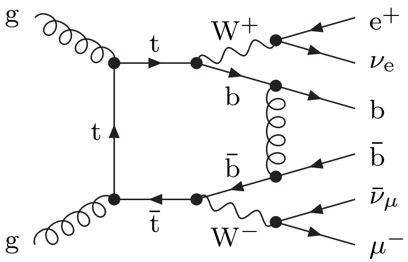
- Some factorizable corrections

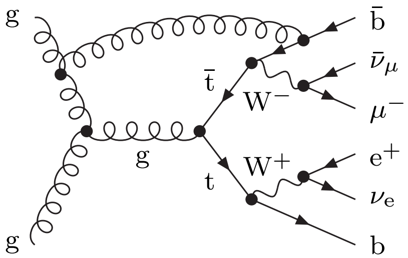
Plots from 1207.5018

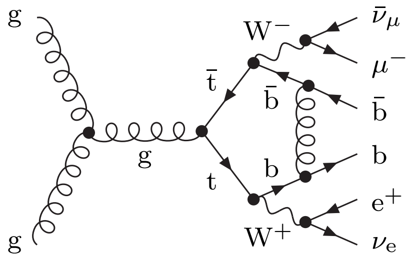




- … and some non-factorizable ones







Computing the full non-factorizable contributions is at the edge of current capabilities
The real question is if they matter?

- The Narrow Width approximation is correct up to correction of $\sim \Gamma_{top}/M_{top} \approx 1\%$.
- When is this the case?

- In general, we expect that inclusive observables are not very sensitive to NWA breaking effects
- Until few years ago no complete calculation existed and thus we didn't know for sure.
- Complete NLO calculations of tt production showed that indeed, this is the case
- In addition, large corrections are found in certain kinematic regions.

Bevilacqua, Czakon, van Hameren, Papadopoulos, Worek '10
Denner, Dittmaier, Kallweit, Pozzorini '11

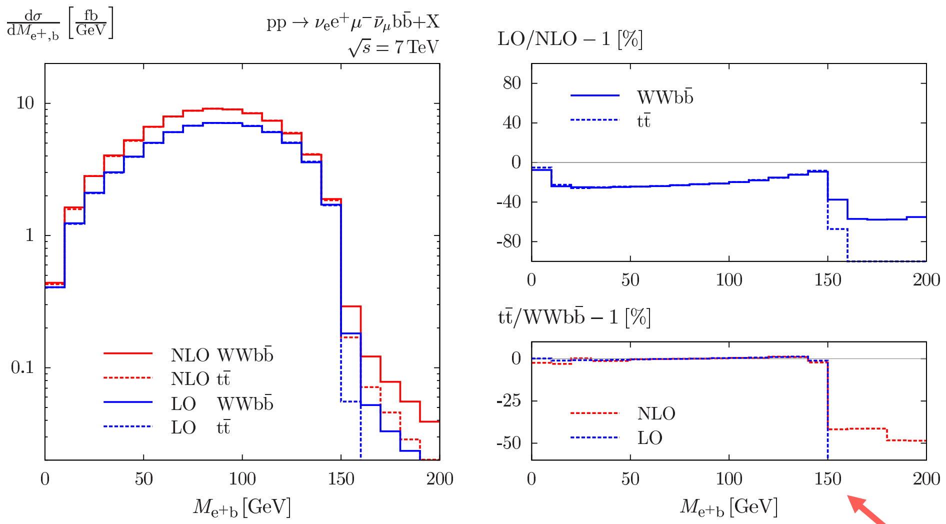


Fig. 27: Distribution in the invariant mass of the positron–b-jet system (as defined in the text) at the 7 TeV LHC: LO (blue) and NLO (red) predictions in narrow-width approximation ($t\bar{t}$, dashed) and including finite-top-width effects ($WWb\bar{b}$, solid). Plotted are absolute predictions (left) and relative deviations of LO (upper-right) and narrow-width (lower-right) approximations w.r.t. NLO and $WWb\bar{b}$ predictions, respectively.

From 1203.6803, page 62

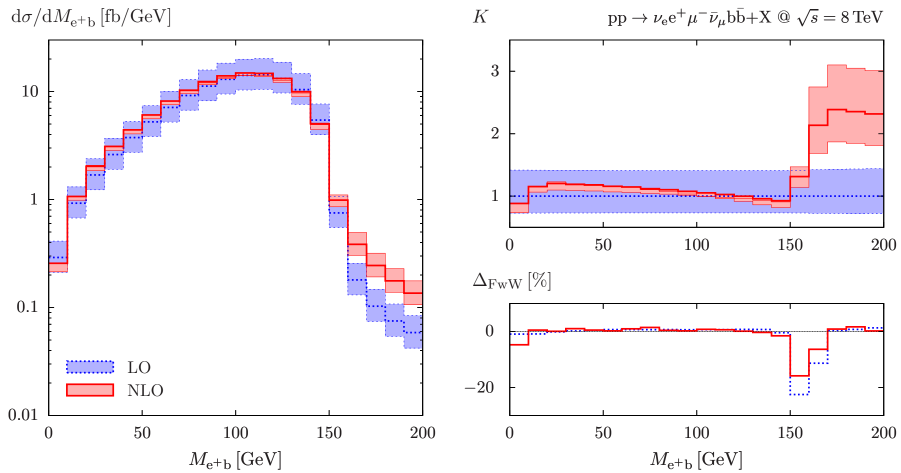


Figure 17: Invariant-mass distribution of positron–b-jet system with standard cuts for the LHC at $\sqrt{s} = 8\,TeV$ for dynamical scale $\mu_0 = E_T/2$.

Dramatic off-shell effects

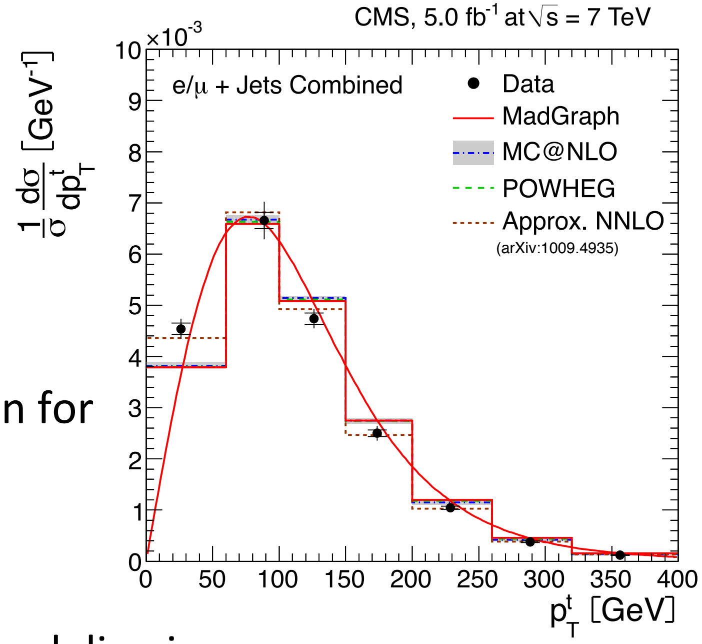
- This tail corrections might be relevant, for example, in top mass measurements (more later)

Does it make sense to even speak of tops?

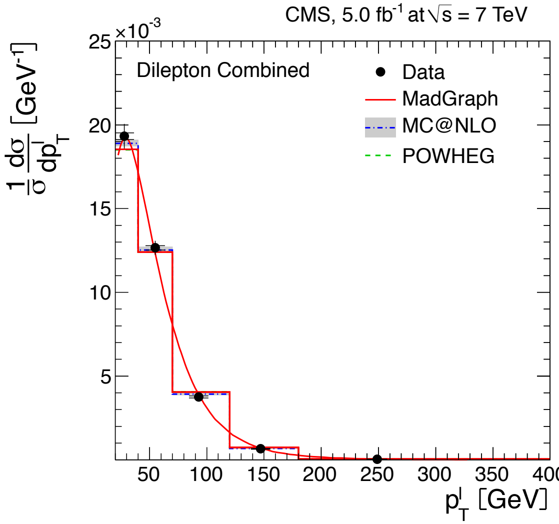
- Tops are never seen directly - just like many other particles (H, W, …).
- Unlike the above, the top-pair final state is very complex, typically associated by additional hard QCD radiation.
- Therefore, starting from certain precision level, it is very hard to try to define the tops.
- The real question is: do we *need* to speak of tops? Ideally theorists can do calculations directly at the level of final states (i.e. decayed tops) and compare this to measurements.
- While this may not be the case yet, this should certainly be the approach in the future.
- Let's look at one example…

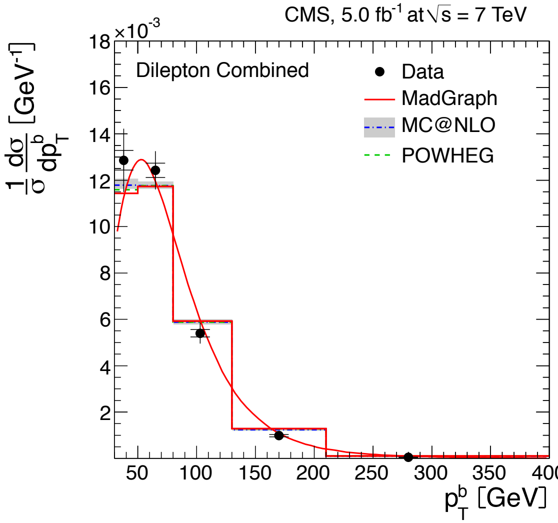
Does it make sense to even speak of tops?

- Same plot we saw at Lecture 1:
- Notable discrepancy between Exp and NLO SM
- The better agreement at NNLOapprox is questionable:
  - Beyond NLO corrections are not expected to modify shapes much, especially in the peak region,
  - After all, what is presented as a top is not measured, but is the result of modeling. Could this be the reason for the discrepancy?



- Indeed, lepton spectra are described well by NLO QCD
- b-jets are not described as well, but this could well be a modeling issue.



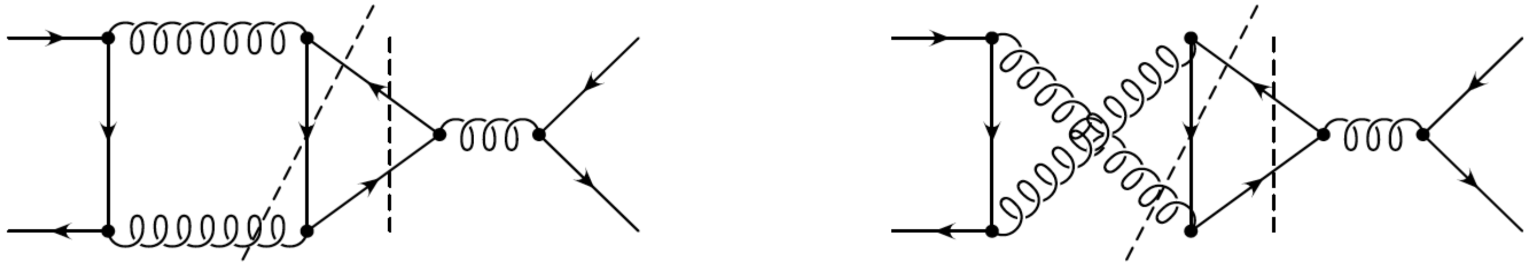


Nice problem for future research!

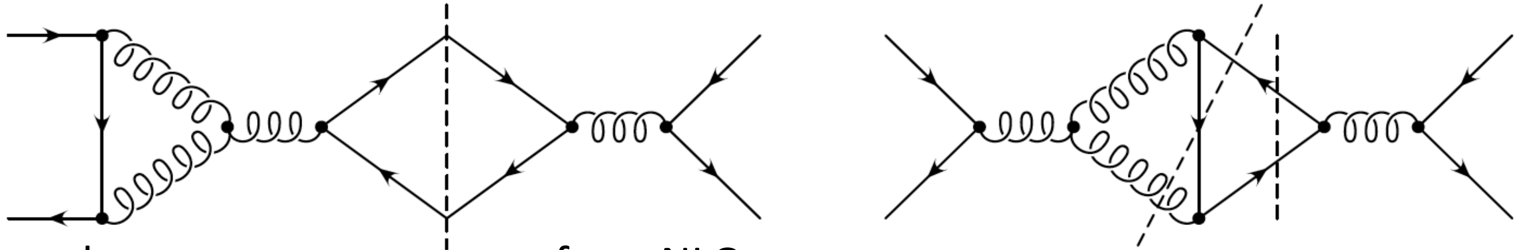
Tevatron Forward-Backward asymmetry

QCD diagrams that generate asymmetry:

Kuhn, Rodrigo '98



… and some QCD diagrams that do not:



✓ For ttbar: charge asymmetry starts from NLO

✓ For ttbar + jet: starts already from LO

✓ Asymmetry appears when sufficiently large number of fermions (real or virtual) are present.

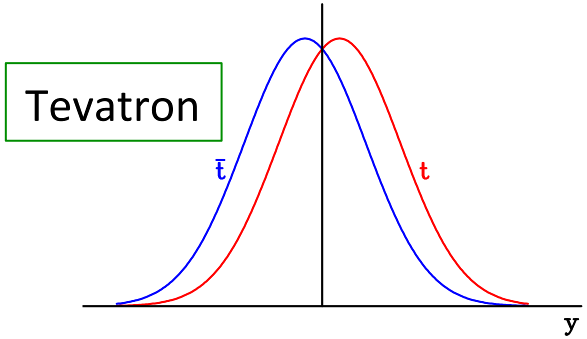
✓ The asymmetry is QED like.

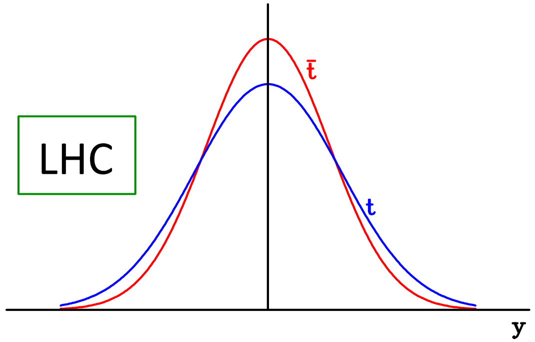
✓ It does not need massive fermions.

✓ It is the twin effect of the perturbative strange (or c- or b-) asymmetry in the proton!

Definition of the asymmetry:

$$A_{\rm FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$



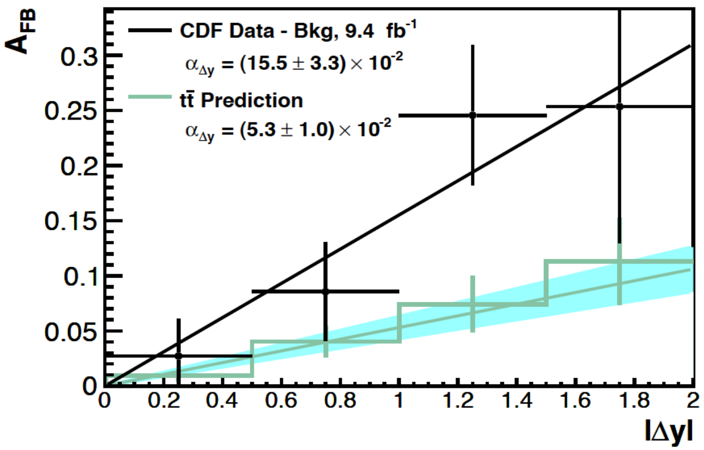


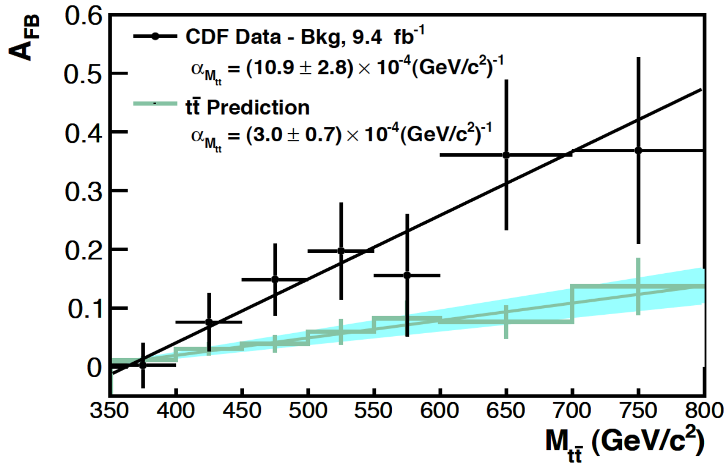
- Expect net asymmetry at the Tevatron, but not LHC
- At the LHC one has to look for the difference in the rapidity shapes

New (2014): D0 finds near agreement with SM…

The CDF measurement versus (known) SM:

Discrepancy w/r to SM ≤ 3σ





What is known about A_{FB} ?

- ✓ The largest known contribution to A_{FB} is due to NLO QCD, i.e. $\sim(\alpha_S)^3$.

  Kuhn, Rodrigo '98

- ✓ Higher order soft effects probed. No new effects appear (beyond Kuhn & Rodrigo).

  Almeida, Sterman, Wogelsang '08
  Ahrens, Ferroglia, Neubert, Pecjak, Yang `11
  Manohar, Trott '12
  Skands, Webber, Winter '12

- ✓ F.O. EW effects checked. Not as small as one might naively expect. Can't explain it.

  Hollik, Pagani '11

- ✓ BLM/PMC scales setting does the job? Claimed near agreement with the measurements.

  Brodsky, Wu '12

- ✓ Higher order hard QCD corrections? Not yet known. Expect very soon.

- ✓ Final state non-factorizable interactions? Unlikely.

  Mitov, Sterman '12
  Rosner '12

- ✓ Revisited matching of tt and ttj samples: improves data-SM agreement

  Hoche, Huang, Luisoni, Schonherr, Winter `13

Single top production

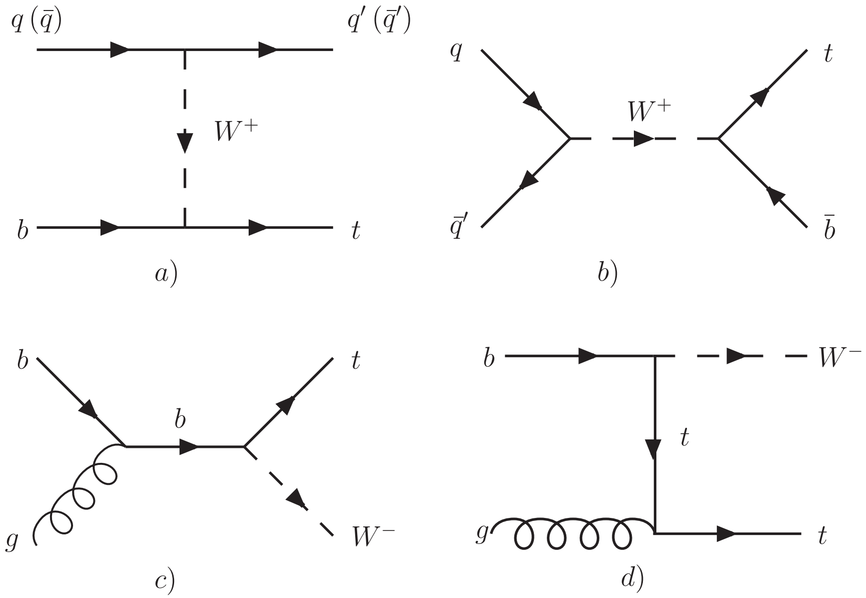
- The three channels for single top production:

t-channel

s-channel

Wt - production

Wt - production



- Typical cross-section values

cross section	t channel	s channel	tW mode
$\sigma^t_{\mathrm{Tevatron}}$	1.15 ± 0.07 pb	0.54 ± 0.04 pb	0.14 ± 0.03 pb
σ^t_{LHC}	150 ± 6 pb	7.8 ± 0.7 pb	44 ± 5 pb
$\sigma^{\bar{t}}_{\mathrm{LHC}}$	92 ± 4 pb	4.3 ± 0.3 pb	44 ± 5 pb

Note that top and anti-top s/t-channel x-sections are different at the LHC (due to pdf's)

- Good agreement between SM theory and measurements

From PDG 2013

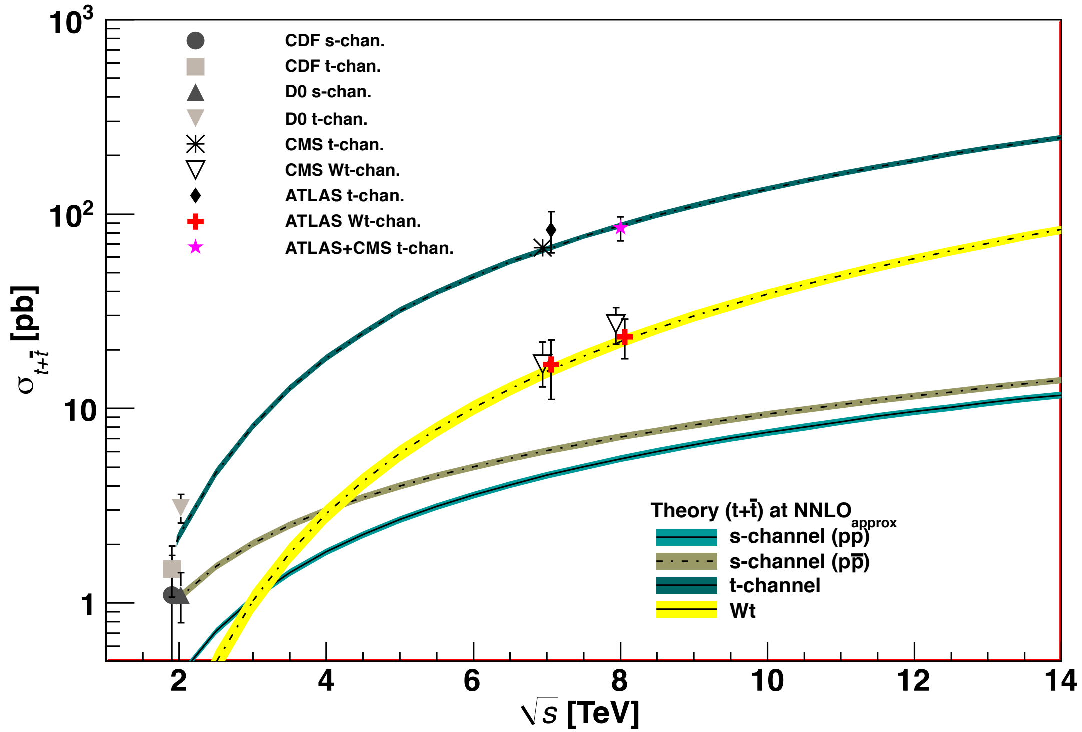


Figure 2: Measured and predicted single top production cross sections from Tevatron energies in $p\overline{p}$ collisions to LHC energies in pp collisions. Tevatron data points at $\sqrt{s} = 1.96$ TeV are from Refs. [57,60] and [62]. The ATLAS and CMS data points at $\sqrt{s} = 7$ TeV are from Refs. [64,66,74,78] and [79,65,75], respectively. The ones at $\sqrt{s} = 8$ TeV are from Refs. [67,69,76] and [68,69,77]. Theory curves are generated using [6,7,8].

- Single top t-channel production is now know through NNLO.
- Theory uncertainties are now tiny: 1% or less
- The production rate for single top at the LHC is large and comparable to top-pair
- It is much harder to measure single top due to not-so-distinct final state
- Single top could be used to measure directly top quark properties, especially Vtb
- Good playground for testing 4- versus 5-flavor number schemes
- Search for FCNC in top production
- Charged light Higgs boson

Top quark mass

Why do we care about the top quark mass?

- ✓ Precision EW tests: the place in collider physics that is most sensitive to m_{top} .
  With the discovery of the (presumably SM) Higgs boson the SM is complete and the tests are over-determined. Everything looks good. The "bottleneck" is the uncertainty on the W mass. Top mass will be competitive once the ultimate W mass precision (at LHC) is achieved.

- ✓ All other places in collider physics are even less sensitive to m_{top} .

- ✓ However: there is very strong dependence on m_{top} in models that rely on bottom-up approache
  These take some data at EW scale (measured) and then predict (through RG running) how the model looks at much larger scales, say $O(M_{Plank})$.

- ✓ Two types of uncertainties appear:

  - ✓ Due to running itself

    Chetyrkin, Zoller '12-13
    Bednyakov, Pikelner, Velizhanin `13

  - ✓ Due to boundary condition at EW. It is here m_{top} is crucial.

- ✓ Examples:

  Bezrukov, Shaposhnikov '07-'08
  De Simone, Hertzbergy, Wilczek '08
  Degrassi, Di Vita, Elias-Miro, Espinosa, Giudice, Isidori, Strumia '12

- ○ Higgs inflation. Model very predictive; relates SM and Λ_{CDM} parameters. Agrees with Planck data
- ○ Vacuum stability in SM. Change of 1 GeV in m_{top} shifts the stability bound for SM from 10^{11} to the Plank scale.

This is the place where high precision in m_{top} is needed most.

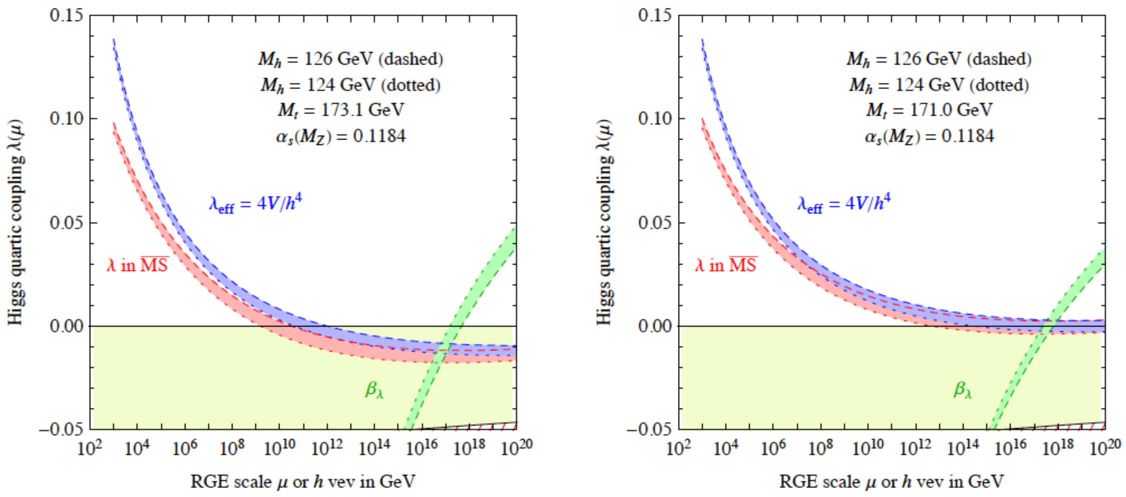
The fate of the Universe might depend on 1 GeV in M_{top}!

Higgs mass and vacuum stability in the Standard Model at NNLO.

Degrassi, Di Vita, Elias-Miro, Espinosa, Giudice, Isidori, Strumia ‘12

Vacuum stability condition: $V_{\rm eff} = -\frac{m^2}{2}h^2 + \frac{\lambda}{4}h^4 + \Delta V$

Quantum corrections (included)



Possible implication:

For the right values of the SM parameters (and we are right there) SM might survive the Desert.

✓ Currently a big push for better understanding of the top mass. Precision is crucial here…

Goals regarding top mass determination at hadron colliders

- ✓ The apparent sensitivity to m_{top} requires convincing m_{top} determination
- ✓ What do I mean by convincing?
  - ✓ m_{top} is not an observable; cannot be measured directly.
  - ✓ It is extracted indirectly, through the sensitivity of observables to m_{top}

$$\sigma^{\rm exp}(\{Q\}) = \sigma^{\rm th}(m_t, \{Q\})$$

  - ✓ The implication: the “determined” value of m_{top} is as sensitive to theoretical modeling as it is to the measurement itself

- ✓ The measured mass is close to the pole mass (top decays …)
- ✓ One needs to go beyond the usual MC’s to achieve theoretical control
- ✓ Lots of activity (past and ongoing). An up-to-date review:

Juste, Mantry, Mitov, Penin, Skands, Varnes, Vos, Wimpenny ‘13

Goals regarding top mass determination at hadron colliders

- A worry: can there be an additional systematic O(1 GeV) shift in m_{top} ?
  - Two types of possible hidden errors (***biases***):

✓ QCD related. As follows from the equation: $$\sigma^{\rm exp}(\{Q\}) = \sigma^{\rm th}(m_{\rm top}, \{Q\})$$

the precision in m_{top} determination reflects both the experimental uncertainty, and the error on the theory input. Therefore, unaccounted theory errors do matter!

Typical situation: using a MC to construct a likelihood and find the likeliest value of m_{top}. Combine with other methods/measurements to improve errors, etc. etc.
At each step the error seemingly decreases. But this may be an illusion if irreducible hidden errors exist. They lead to biases in the extracted mass.

This is not just an abstract possibility. Here are three most recent top mass measurements.
They are compatible with each other at 2σ…

$$m_t = 173.34 \pm 0.76\,{\rm GeV} \quad [\text{World Average}]$$
$$m_t = 172.04 \pm 0.77\,{\rm GeV} \quad [\text{CMS Collaboration}]\,,$$
$$m_t = 174.98 \pm 0.76\,{\rm GeV} \quad [\text{D0 Collaboration}]\,.$$

Such differences are possible in the context of this discussion: different theory systematics.

✓ bSM related. Unexplored territory. Conceptually the same as above, but the the role of higher order terms is now played by bSM physics: it contributes to the measurement but is not accounted for on the theory side. Basically, a kind of bias again.

Issues in top mass determination

Introduction: issues in top mass determination

✓ MC modeling.

Most methods for extraction of m_{top} rely on modeling the measured final state with typically LO+LL MC generators. The extracted mass then reflects the mass parameter in the corresponding MC generator. Identifying the nature of this mass parameter and relating it to common mass schemes, like the pole mass, is a non-trivial and open problem.
It may be associated with ambiguities of order 1 GeV.

Buckley, Butterworth, Gieseke et al Phys. Rep. '11

The effect of the top and bottom masses on parton-shower radiation patterns is generally included already in the LO+LL MC's and they screen collinear singularities.

✓ Non-perturbative corrections:

Mostly affect the MC modeling of the final state. Includes hadronization, color reconnection, Underlying Event, final state interactions (especially with jet vetoes).

Many such systematics are accounted for through the JES.
Color reconnection small at e+e- but O(500 MeV) at hadron colliders.

Recommendation: try methods with alternative systematics (unrelated to MC).

Introduction: issues in top mass determination

✓ Reconstruction of the top pair.

Often, the existing methods for extraction of the top quark mass implicitly or explicitly rely on the reconstruction of the top pair from final state leptons and jets.

This introduces uncertainties of both perturbative origin (through higher-order corrections) and non-perturbative origin (related to showering and non-factorizable corrections).

Methods that do not rely on such reconstruction are therefore complementary and highly desirable; two examples are the J/Ψ method and dilepton distributions.

✓ This is correlated with the attempt to define a pseudo top. How needed/useful is that? (recall our earlier discussion)

Introduction: issues in top mass determination

✓ Alternative top mass definitions.

Alternative mass definitions that reflect the physics are beneficial (known from e+e-).
Less clear at hadron colliders.

✓ Renormalon ambiguity in top mass definition.

Pole mass of the top quark suffers from the so-called renormalon ambiguity. This implies an additional irreducible uncertainty of several hundred MeV's on the top pole mass.
Not an issue for short distance masses. Currently, at hadron colliders, this is a subdominant uncertainty.

✓ Higher-order corrections.

Important source of uncertainty. State of the art NLO QCD; not always included.

Introduction: issues in top mass determination

✓ Unstable top and finite top width effects.

Understood for e+e-.

Computed at NLO for hadron colliders. Could affect certain distributions.

G. Bevilacqua, M. Czakon, A. van Hameren, C. G. Papadopoulos and M. Worek, JHEP **1102**, 083 (2011) [arXiv:1012.4230

A. Denner, S. Dittmaier, S. Kallweit and S. Pozzorini, JHEP **1210**, 110 (2012) [arXiv:1207.5018

Melnikov, Schulze

Not really used so far in top mass studies.

✓ Bound-state effects in top pair production at hadron colliders.

When the ttbar pair is produced with small relative velocity (i.e. close to threshold) bound-state formation begins. These effects can affect the shape of differential distributions within few GeV away from the threshold. Special care must be taken if a measurement is sensitive to such effects.

In usual "inclusive" observables (like total x-section) this effect is diluted

Methods for m_{top} determination

Methods for m_{top} determination: Matrix Element Methods

- ✓ The backbone of the Tevatron studies as well as the most precise LHC ones. Performed in all final states.

- ✓ Measured objects are compared with expectations from the LO tt production and decay diagrams convoluted with the detector response.

- ✓ Method's power comes from the fact that the likelihood for each event to be consistent with both tt and background production is calculated; greater weight is assigned to events that are more likely to be from tt when measuring m_{top}.

- ✓ Issue: incorrect modeling due to missing theory corrections.

Methods for m_{top} determination: Matrix Element Methods

Projections based on CMS lepton-plus-jet analysis:

S. Chatrchyan *et al.* [CMS Collaboration], JHEP **1212**, 105 (2012) [arXiv:1209.2319

	Ref.[2]	Projections				
CM Energy	7 TeV	14 TeV				
Cross Section	167 pb	951 pb				
Luminosity	$5 fb^{-1}$	$100 fb^{-1}$		$300 fb^{-1}$		$3000 fb^{-1}$
Pileup	9.3	19	30	19	30	95
Syst. (GeV)	0.95	0.7	0.7	0.6	0.6	0.6
Stat. (GeV)	0.43	0.04	0.04	0.03	0.03	0.01
Total	**1.04**	**0.7**	**0.7**	**0.6**	**0.6**	**0.6**
Total (%)	0.6	0.4	0.4	0.3	0.3	0.3

Scenario	Dominant Uncertainties
Ref.[2]	Jet Energy Scale, Hadronization, Soft QCD, ISR/FSR
100 fb^{-1}/19 PU	Jet Energy Scale, Hadronization, Soft QCD, ISR/FSR
100 fb^{-1}/30 PU	Jet Energy Scale, Hadronization, Soft QCD, ISR/FSR, Pileup
300 fb^{-1}/19 PU	Jet Energy Scale, Hadronization, Soft QCD, ISR/FSR
300 fb^{-1}/30 PU	Jet Energy Scale, Hadronization, Soft QCD, ISR/FSR, PIleup
3000 fb^{-1}/95 PU	Jet Energy Scale, Hadronization, Soft QCD, ISR/FSR, PIleup

TABLE II: Dominant systemic uncertainties for each scenario

- ✓ Projections beyond 14 TeV require full detector simulation. Not done here.
- ✓ Pileup and UE become more important at higher energy/pileup.
- ✓ ISR/FSR become dominant uncertainties at high luminosity (unlike current measurements)
- ✓ Extra 300MeV uncertainty added by hand.

Methods for m_{top} determination: CMS endpoint method

S. Chatrchyan *et al.* [CMS Collaboration], arXiv:1304.5783

A kinematical method: utilizes the strong correlation between the maximum of the M_{bl} distribution and m_{top}.

	Ref.[8]	Projections		
CM Energy	7 TeV	14 TeV		
Cross Section	167 pb	951 pb		
Luminosity	$5 fb^{-1}$	$100 fb^{-1}$	$300 fb^{-1}$	$3000 fb^{-1}$
Syst. (GeV)	1.8	1.0	0.7	0.5
Stat. (GeV)	0.90	0.10	0.05	0.02
Total	**2.0**	**1.0**	**0.7**	**0.5**
Total (%)	1.2	0.6	0.4	0.3

Scenario	Dominant Uncertainties
Ref.[8]	Jet Energy Scale, Hadronization, Soft QCD
$100\ fb^{-1}$	Jet Energy Scale, Hadronization, Soft QCD
$300\ fb^{-1}$	Jet Energy Scale, Hadronization, Soft QCD
$3000\ fb^{-1}$	Jet Energy Scale, Hadronization

TABLE IV: Dominant systemic uncertainties for each scenario

✓ ISR/FSR and pileup do not play a role at high luminosity. (unlike conventional methods)

✓ Does not rely on MC for internal calibration (analytical with data-driven backgrounds).

✓ Less likely to be affected by bSM corrections.

✓ Nonetheless, higher order effects do affect the endpoint position (particularly top widths) NLO calculations do exist – not utilized.

G. Bevilacqua, M. Czakon, A. van Hameren, C. G. Papadopoulos and M. Worek, JHEP **1102**, 083 (2011) [arXiv:1012.4230

A. Denner, S. Dittmaier, S. Kallweit and S. Pozzorini, JHEP **1210**, 110 (2012) [arXiv:1207.5018

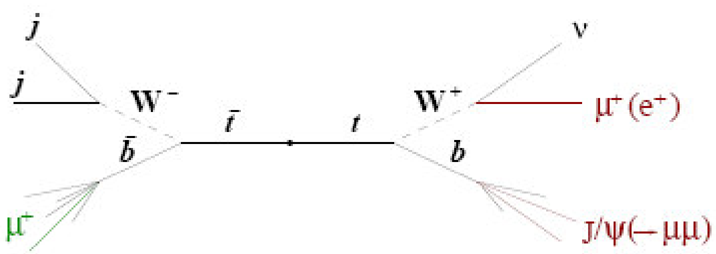
Methods for m_{top} determination: J/Ψ method

A. Kharchilava, Phys. Lett. B **476**, 73 (2000) [hep-ph/9912320]

A different method: no reconstruction is involved. Predict the M_{top} dependence of the peak of the invariant mass of the three leptons.
Note the very strong suppression due to B-> J/PSi

	Ref. analysis	Projections				
CM Energy	8 TeV	14 TeV			33 TeV	100 TeV
Cross Section	240 pb	951 pb			5522 pb	25562 pb
Luminosity	$20 fb^{-1}$	$100 fb^{-1}$	$300 fb^{-1}$	$3000 fb^{-1}$	$3000 fb^{-1}$	$3000 fb^{-1}$
Theory (GeV)	-	1.5	1.5	1.0	1.0	0.6
Stat. (GeV)	7.00	1.8	1.0	0.3	0.1	0.1
Total	-	**2.3**	**1.8**	**1.1**	**1.0**	**0.6**
Total (%)	-	**1.3**	**1.0**	**0.6**	**0.6**	**0.4**

TABLE VI: Extrapolations based on the J/Ψ method.



Estimates from NLO QCD.

(see also) S. Biswas, K. Melnikov and M. Schulze, JHEP **1008**, 048 (2010) [arXiv:1006.0910

A. Denner, S. Dittmaier, S. Kallweit and S. Pozzorini, JHEP **1210**, 110 (2012) [arXiv:1207.5018

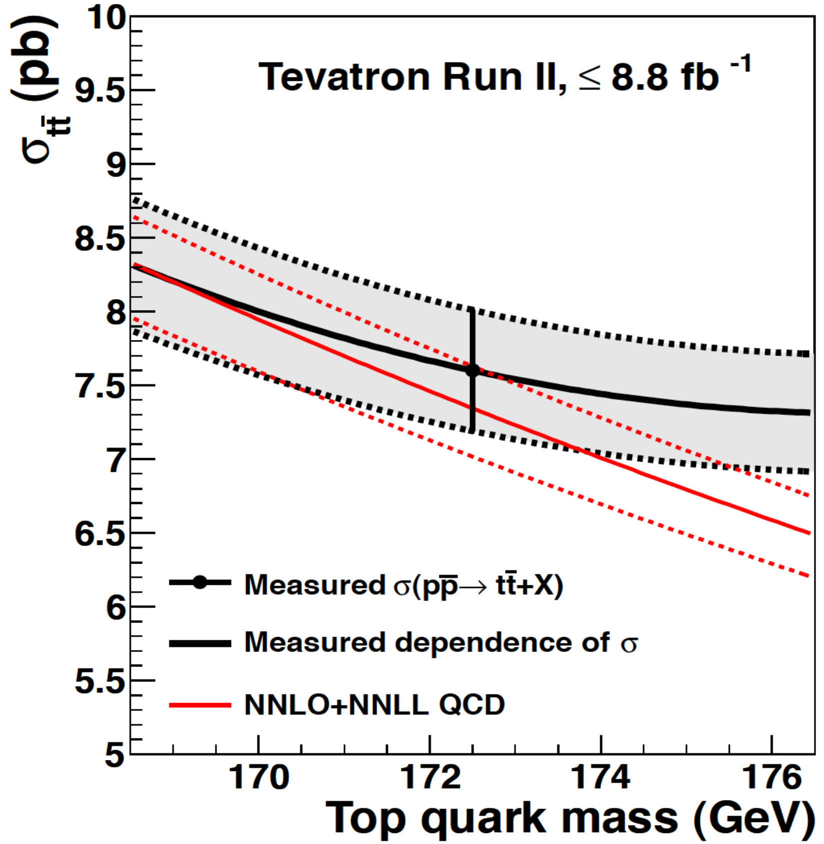
NNLO accuracy assumed in some extrapolations.

Main source: B-fragmentation. Likely will be irreducible unless new e+e- data.

Methods for m_{top} determination: m_{top} from kinematic distributions

✓ Total cross-section:

Allows extraction with about 3% uncertainty due to limited sensitivity to m_{top} .



Latest Tevatron Combination: 1309.7570

➢ Positive features:

Good theory control (NNLO)
Small non-perturbative and width effects

➢ Negatives:

Small sensitivity (unlikely to improve)

✓ At present there are inconsistently applied acceptance corrections (i.e. LO or NLO not NNLO). Still, likely a small effect.

- Recent extraction from ATLAS (note how far apart they are)

$$m_t^{\text{pole}} = 171.4 \pm 2.6 \ \text{GeV} \ (\sqrt{s} = 7\,\text{TeV})$$
$$m_t^{\text{pole}} = 174.1 \pm 2.6 \ \text{GeV} \ (\sqrt{s} = 8\,\text{TeV})$$

Methods for m_{top} determination: m_{top} from kinematic distributions

✓ Extraction suggested from tt+jet.

S. Alioli, P. Fernandez, J. Fuster, A. Irles, S. -O. Moch, P. Uwer and M. Vos, arXiv:1303.6415

Estimates for contributions from unknown corrections – below 1 GeV.

Method is MC dependent and involves t (tbar) reconstruction

✓ Dilepton distributions

- No reconstruction
- Minimal shower and NP sensitivity. Reliably computable at fixed order.
- Theory error estimate of 0.8 GeV
- Strong emphasis on combating theory biases!

Frixione, Mitov '14

New Physics contributions to m_{top}

- ✓ One hardly mentioned problem!

- ✓ There is the possibility that undetected corrections to top production might shift the top mass measurements (measure top+bSM but theory assumes pure SM).

  Example: stop -> top+X we discussed earlier

  If the stop is light, the event looks top-like!

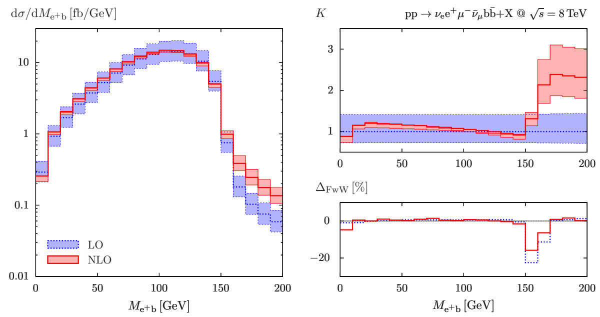


Figure 17: Invariant-mass distribution of positron–b-jet system with standard cuts for the LHC at $\sqrt{s} = 8\,\mathrm{TeV}$ for dynamical scale $\mu_0 = E_T/2$.

- ✓ The strongest constraint on bSM contributions to m_{top} comes from the CMS end-point method

  S. Chatrchyan *et al.* [CMS Collaboration], arXiv:1304.5783

- ✓ The method is kinematic: it measures the position of the end-point of the spectrum of top decay products. This is independent of the top production mechanism.

- ✓ The total error from the measurement is just above 2.0 GeV and agrees with the world average

- ✓ From here we can conclude that bSM contributions to M_{top} are not larger than ~2GeV.

- ✓ Dedicated studies are welcome. Likely they will be model dependent; any model-independent arguments would be very valuable.

Top quarks at a future e^+e^- collider

✓ The machine where the ultimate precision of 100MeV or less can be achieved.

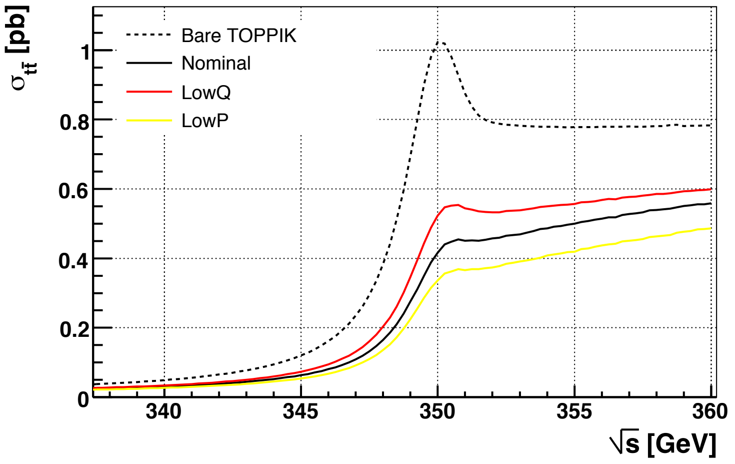
✓ Best approach is threshold scan.

✓ Continuum production also possible.

✓ Similar at ILC and CLIC.

✓ Interesting question: is it possible to measure m_{top} at c.m. energy of, say, 250GeV, i.e. below the threshold?

✓ Given the presumed ILC schedule this might imply few more years of waiting …



From 1310.0799

Figure 3. Top quark pair production cross-section in e^+e^- scattering near the $t\bar{t}$ threshold. The NNLO prediction based on the TOPPIK program [8], not including beam effects, is shown as the dashed line. Also shown are the predicted cross sections after convolution of the beam effects (beam energy spread, bremsstrahlung and beamstrahlung) corresponding to three different sets of ILC accelerator parameters (see text for details).