Topics in top quark physics

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DPF meeting'

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Outline

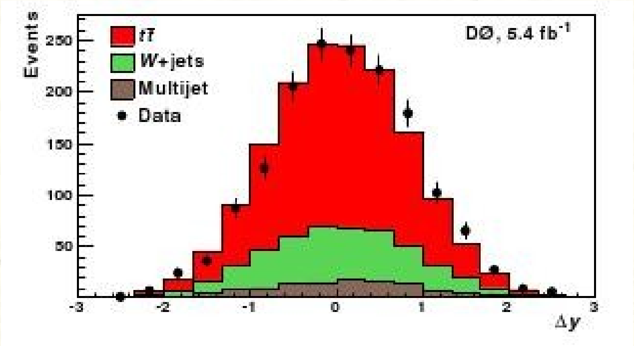
- Why top quarks
- Theoretical aspects
- Cross-sections
- Mass measurements
- Spin correlations
- Asymmetries
- Conclusions

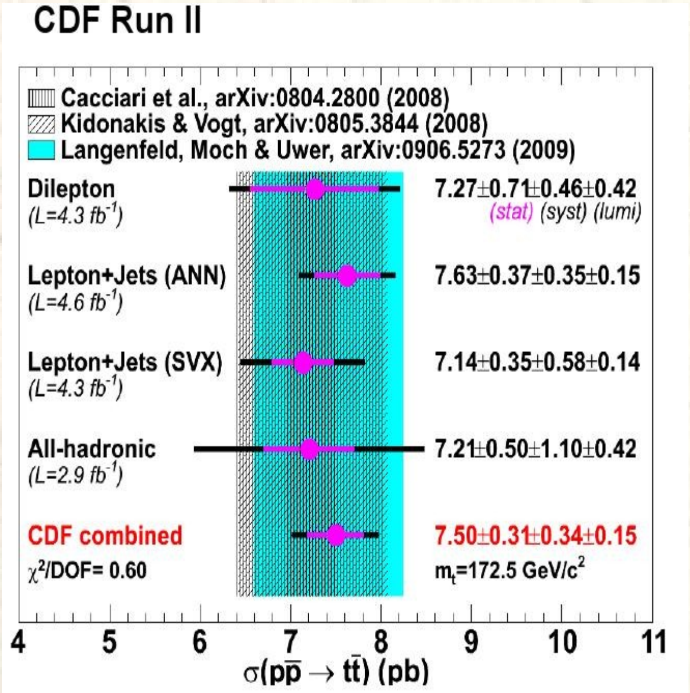
Why top quarks are interesting ?

- Top quark sector is the least studied sector of the Standard Model
- Certain top quantum numbers (electric charge), it couplings to electroweak gauge bosons (W,Z,gamma) are poorly known
- Top quarks are heavy, they may couple to New Physics stronger than other quarks and play special role in electroweak symmetry breaking
- Top quarks decay fast – paradoxically, this gives us an opportunity to look at a free, not-confined quark
- Top quark production may also be significant background to other BSM searches – need to be understood well. Seems to be possible since large top quark mass makes theoretical predictions reliable

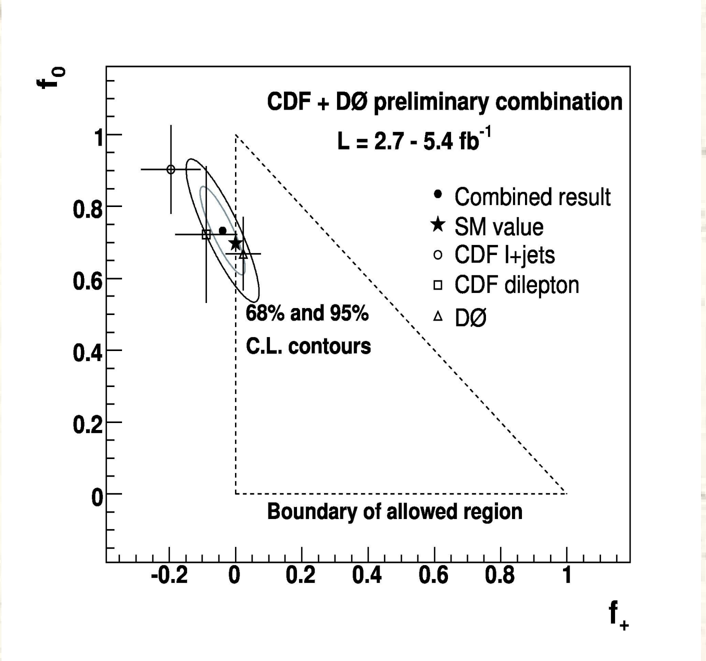
Tevatron top quark legacy

- Tevatron:
  - discovered the top quark
  - studied the top quark production cross-section (qq → tt, single top), its mass, main kinematic distributions
  - spin correlations and features of top quark decays (width, helicity fractions)
  - asymmetries

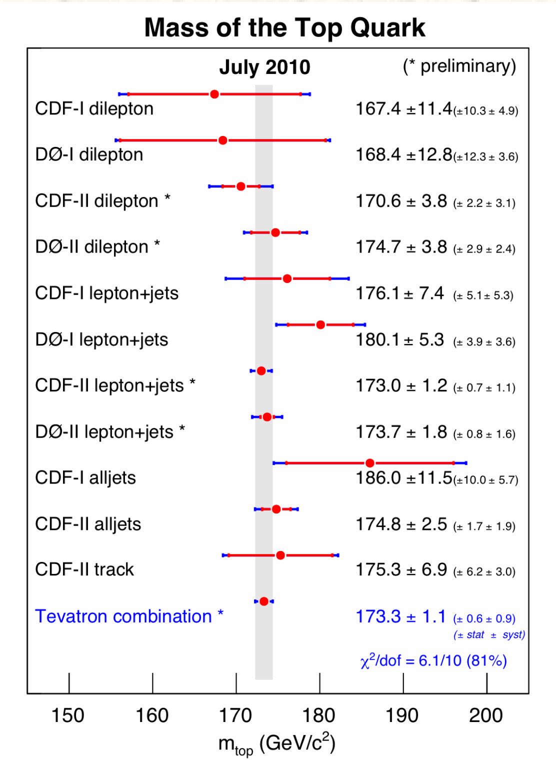




Top cross sections



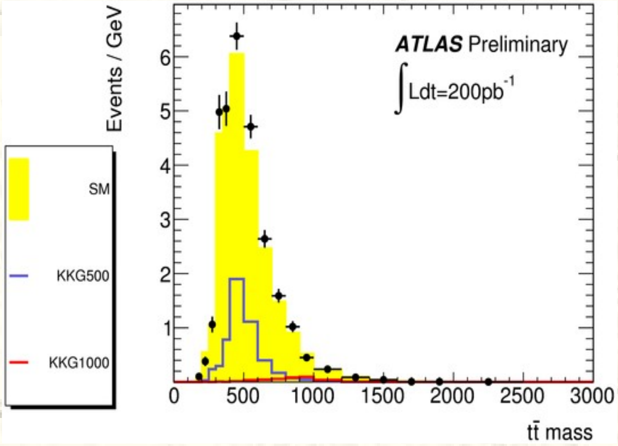
Helicity fractions



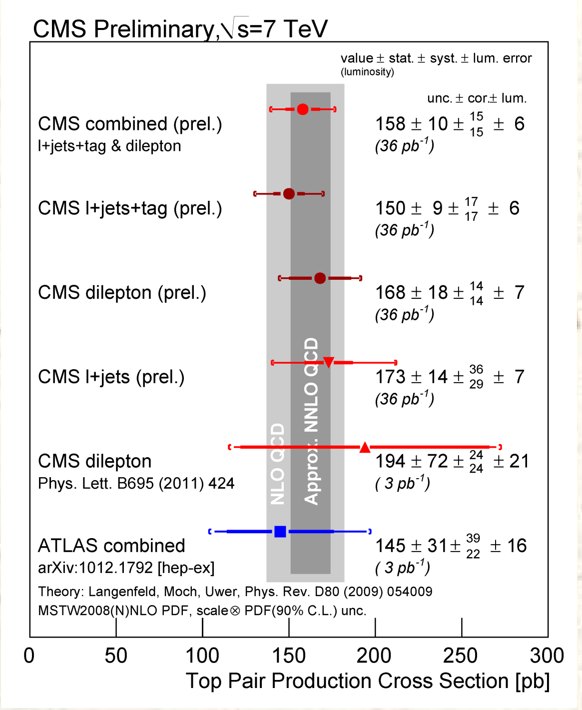
Top mass

LHC is off to a great start

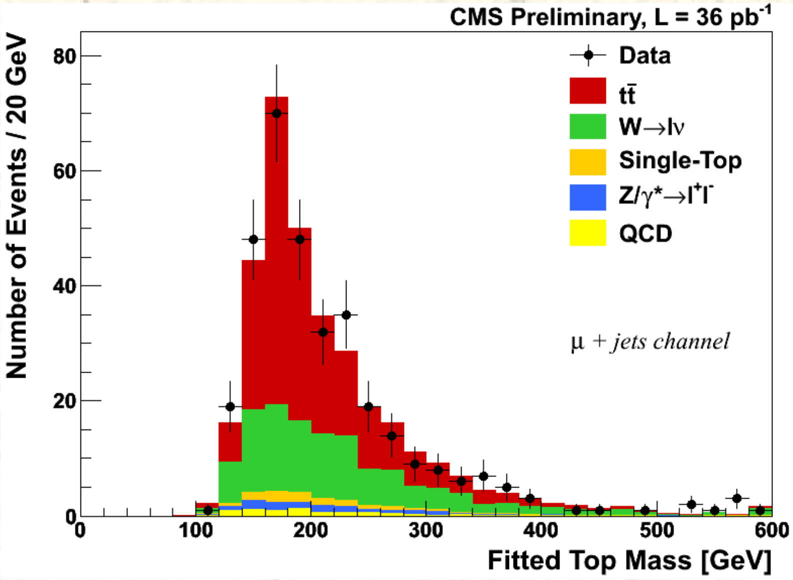
- LHC:
  - the top factory
  - precision measurements, production cross-section (gg → tt, single top), many kinematic distributions
  - associated production (tW, ttZ, ttgamma)
  - focus on physics beyond the Standard Model



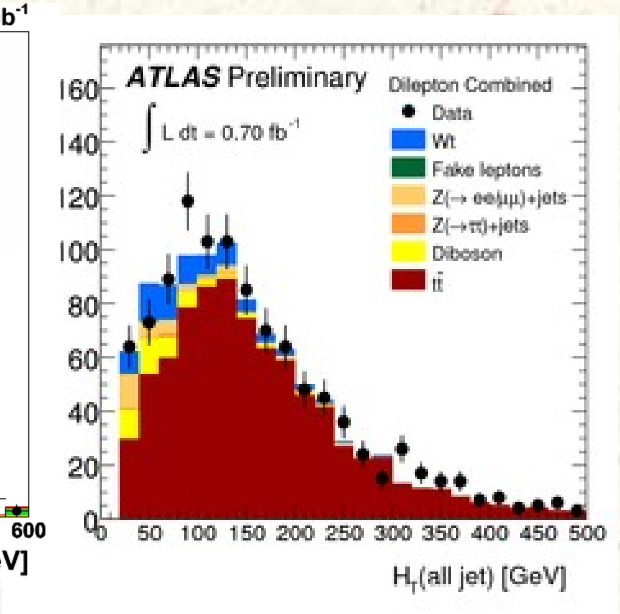
ttbar invariant mass



Top cross sections



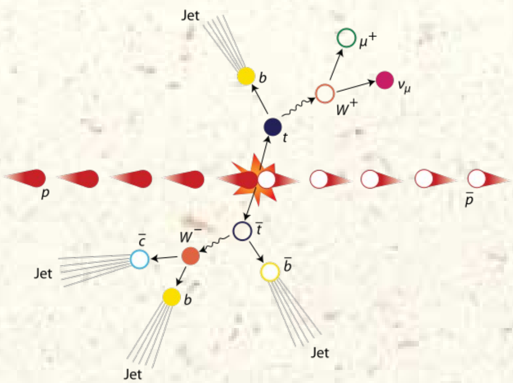
Top mass measurement



Wt production

Some theoretical issues that may become important

- A few points to keep in mind:
  - since top quarks decay; theory and experiment should communicate at the level of top decay products, not at the level of reconstructed tops
  - especially important if precision is a target since acceptances are subject to higher-order corrections
  - NLO and NNLO calculations for stable top quarks have nothing to say about effect of radiative corrections on the acceptances
  - MC@NLO includes radiative corrections to the production but decays are treated using parton shower. It is a non-parameteric approximation for not-fully-inclusive observables MCFM contains spin-correlations at NLO, but decays of top quarks are treated at leading order



The framework

- At leading order, there is no issue with including top quark decays and off-resonance contributions, but this approach becomes not feasible for NLO and NNLO QCD computations for sophisticated processes
- Realistic, accurate and feasible framework for top quark physics should be built around double-resonance approximation
  - top quarks are produced on the mass shell but then decay
  - all spin correlations are accounted for
  - description of the production process through N(N)LO QCD
  - description of the decay process through N(N)LO QCD
  - access to kinematics of final state particle

There has been some motion towards this framework in the theoretical work but we commonly used programs (MC@NLO, POWHEG, MCFM) omit various items from this list

Theory of top quark pair production

- Twenty five years ago – classic computations of NLO QCD corrections to stable top quarks

  Dawson, Ellis, Nason, Beenaker, Mertig, van Neerven,, Schuler, Smith, Mangano, Ridolfi

- Ten years ago NLO QCD/EW corrections to spin correlations in top quark pair production defined in a particular way

  Bernreuther, Brandenburg, Si, Uwer

- Two years ago -- top quark pair production through NLO QCD with spin correlations, corrections to the decays and arbitrary selection cuts on the final states

  Schulze, K.M., Bernreuther, Si, Ellis, Campbell

- Half a year ago – NLO QCD corrections to top quark pair production including all off-shell and non-factorizable effects

  Bevilacqua, Czakon, von Hameren, Papadopoulos, Worek

  Denner, Dittmaier, Kawlert, Pozzorini

- Many associated production processes – ttj, ttjj, ttbb, ttH, ttZ – are still only known in the approximation of stable top quarks

  Dawson, Reina, Wackeroth, Jackson, Dittmaier, Kramer, Petriello, Lazopoulis, McElmurry,Pozzorini, Czakon, Worek, Papadopoulos, Denner, Kawlert. Uwer, Weinzierl

- The two exceptions

  - results for ttbar + H and ttbar + jet with NLO accuracy in the production and parton shower accuracy in the decay

    Trocsanyi, Kardos, Garzelli,+ Papadopoulos

  - results for ttbar + photon with top decays (including radiative ones) and NLO QCD effects in the production and decay

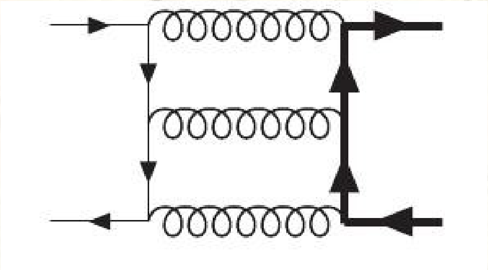
    Schulze, Scharf, K.M.

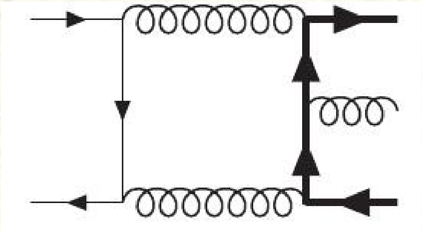
Towards top quark pair production at NNLO

- In addition to progress with NLO computations, there is a serious effort to compute top quark pair production through NNLO QCD. Currently, the most important motivation for this is the forward-backward asymmetry; beyond that – gluon PDFs

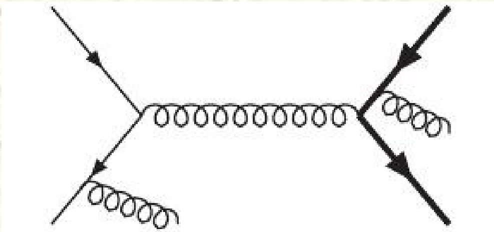
Czakon, Gehrmann, Ferroglia, Bonciani

- Complimentary approach – resummation of enhanced perturbative effects (soft, threshold, etc.)





Kidonakis, Langenfeld, Moch, Uwer
Beneke, Czakon, Mitov, Sterman
Ahrens, Ferroglia, Neubert, Pecjak, Yang



Remarkable progress occurred with understanding these contributions recently;

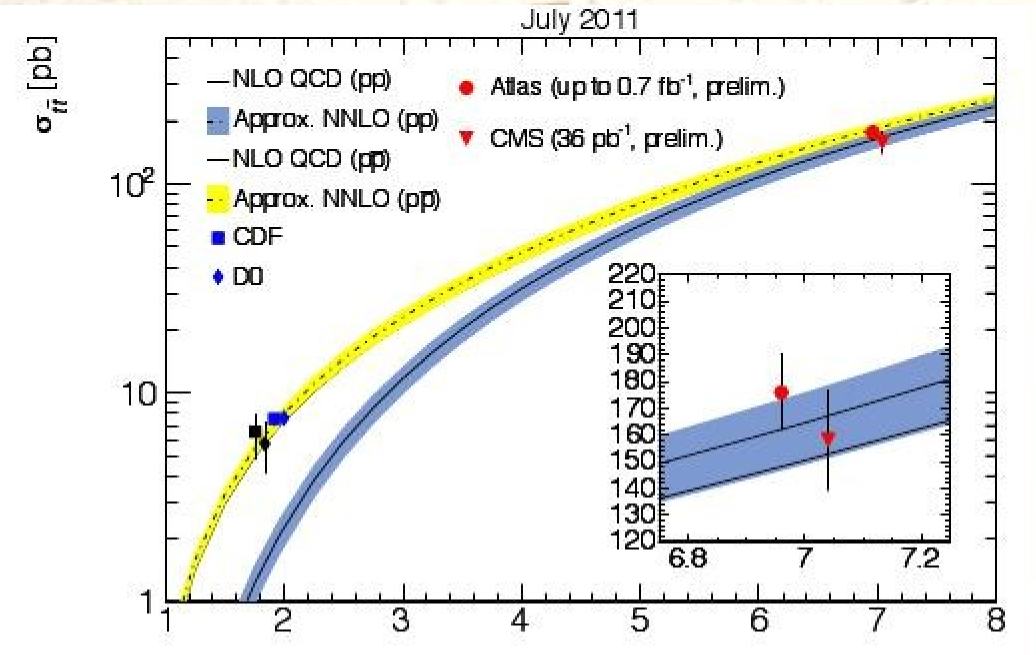
Currently, all the process-independent ingredients for evaluating top quark pair production at NNLO are known and there is an understanding of how to put things together

NNLO QCD prediction for top quark pair production is within reach

Czakon

Czakon and Mitov

Top quark pair production



F. Deliot, EPS 2011

We understand how top quarks are produced in hadron collisions quite well

Cross-section measurement constrains exotic contributions to top production

	σ (pb)	δσ (pb)	comment
ABKM09	139.55	7.96	combined PDF and α_s
CTEQ6.6	156.2	8.06	combined PDF and α_s *
GJR08	169	6	PDF only
HERAPDF1.0	147.31	+5.18 -13.76	combined PDF and α_s **
MSTW08	168.1	+7.2-6.0	combined PDF and α_s ***
NNPDF2.0	169	7	combined PDF and α_s ****

J. Stirling, January 2011

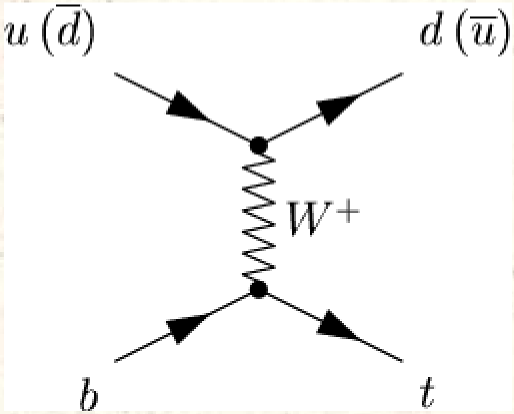
Why rush to present experimental results with (approximate!) NNLO cross-sections if, currently, we do this imperfectly EVEN at NLO ?

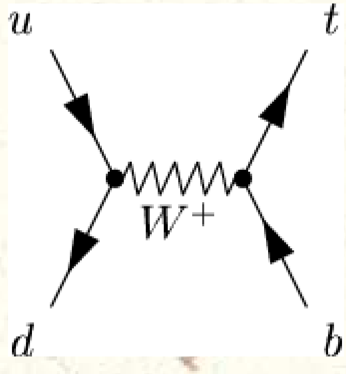
decay channel combined for $m_t = 172.5$ GeV:

CDF (up to 4.6 fb^{-1})	$\sigma(p\bar{p} \to t\bar{t}) =$	$7.5 \pm 0.31(\text{stat}) \pm 0.34(\text{syst}) \pm 0.15(\text{theory})$ pb
D0 (5.6 fb^{-1}, arXiv:1105.5384)	$\sigma(p\bar{p} \to t\bar{t}) =$	$7.56^{+0.63}_{-0.56}$ (stat + syst + lumi) pb
Atlas (up to 0.7 fb^{-1})	$\sigma(pp \to t\bar{t}) =$	$176 \pm 5(\text{stat})^{+13}_{-10}(\text{syst}) \pm 7(\text{lumi})$ pb
CMS (36 pb^{-1})	$\sigma(pp \to t\bar{t}) =$	$158 \pm 10(\text{uncor.}) \pm 15(\text{cor.}) \pm 6(\text{lumi})$ pb

Published LHC results still can be described by nearly all available PDF sets, although DIS-based sets (ABKM, HERAPDF) start looking somewhat less likely

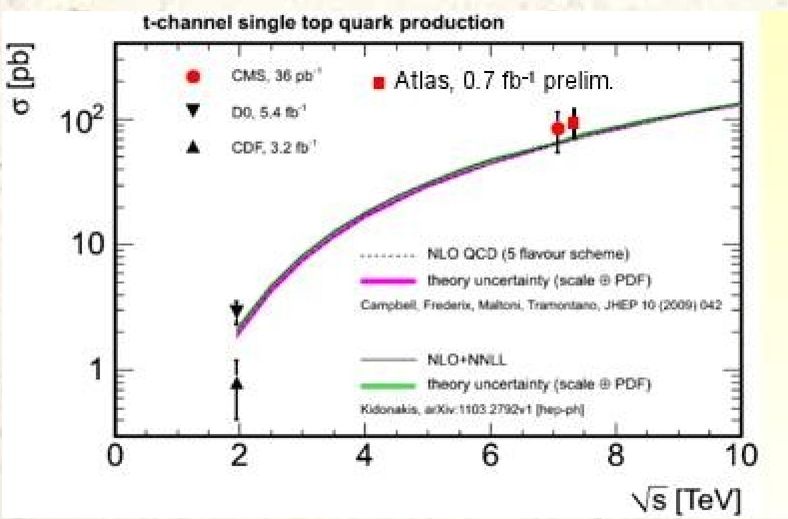
Electroweak top quark production

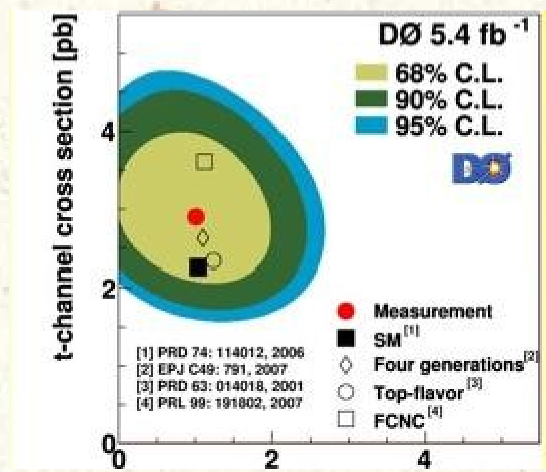




Tevatron established the existence of electroweak production mechanism of single top quarks

ATLAS and CMS see strong evidence of EW top production at the LHC



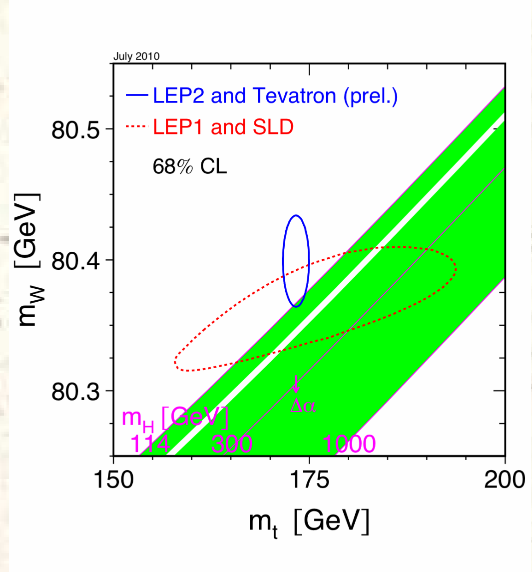


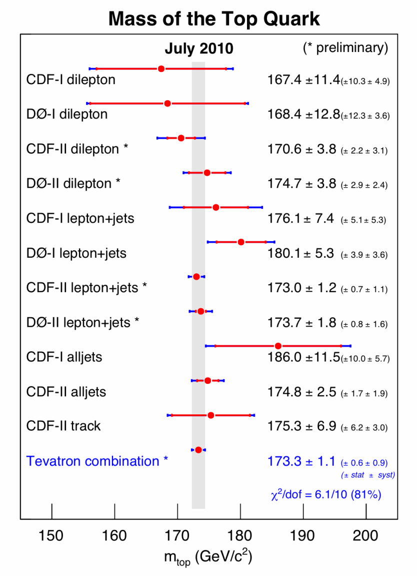
σ_{tqb} (pb) for $m_t = 172.5$ GeV:	
CDF (3.2 fb^{-1})	0.8 ± 0.4
D0 (5.4 fb^{-1}, arXiv:1105.2788)	2.90 ± 0.59
CMS (36 pb^{-1}, arXiv:1106.3052)	$83.6 \pm 29.8(\text{stat} + \text{syst}) \pm 3.3(\text{lumi})$
Atlas (0.7 fb^{-1})	90^{+32}_{-22}

F. Deliot, EPS 2011

The top quark mass

- Quarks can not be isolated from QCD fields → mass can not be assigned to them → in QCD, quark masses are renormalization -dependent parameters of the Lagrangian, similar to various couplings
- Issues of this nature – and their solutions – have been addressed in the context of B-physics
- The top quark mass is important for constraining the Higgs boson mass
- It is very precisely measured by the CDF and D0 (and soon CMS/Atlas) collaborations and used as the ``pole mass'' in electroweak fits but .. what exactly is it?
- The difference between the pole mass and the MS mass is large, O(10 GeV)



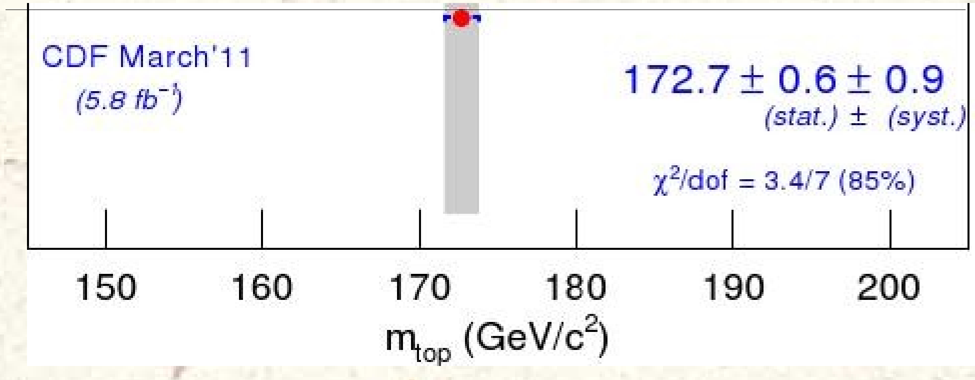


$$m_t = 173.2 \pm 0.9 \text{ GeV}$$

$$m_t^{\text{pole}} = \bar{m}_t(\bar{m}_t)\left(1 + \frac{4\alpha_s}{3\pi} + ..\right) \approx (170 + 7 + ..) \text{ GeV}$$

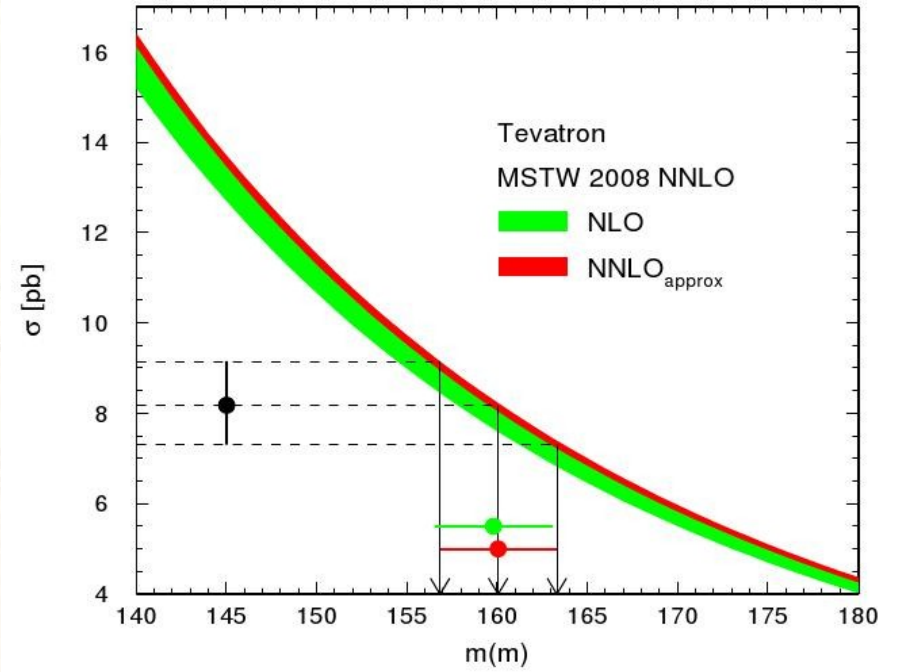
The top quark mass

- The philosophy adopted by the Tevatron collaborations is that any feature of the top production process should be used to beat down the error on top quark mass
- Possible, as any philosophy, but it ignores the following issues
  - not each observable is short-distance (i.e. can be described by perturbative QCD)
  - parton shower technology is not an exact science to handle non-perturbative physics
- It is important to have extraction of top quark masses from quantities that can be described by perturbative QCD (short-distance) because in this case we can switch between different renormalization schemes for the top quark mass
- Note that it is not clear how to combine the most popular and precise methods for the top mass extraction – the ``matrix element method'' and its various cousins – with perturbative QCD computations
- For this reason I would not discuss the result for the top quark mass shown but rather focus on two theoretically clean measurements in what follows



Top quark mass measurements

- The simplest observable for the top quark mass determination is the total cross-section
- Traditionally used to extract the pole mass of the top quark but extraction of the MS-mass appears to give very stable results



Langenfeld, Moch, Uwer

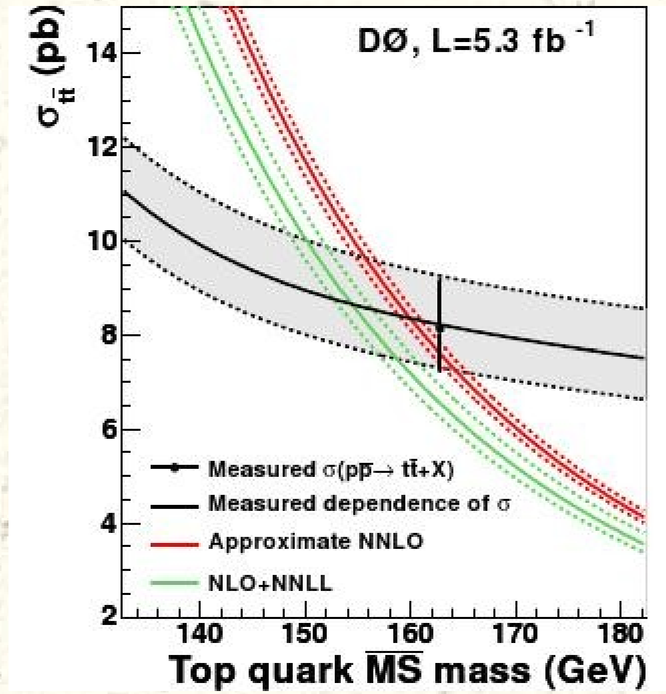
	$m(m)$ [GeV/c^2]	m_t [GeV/c^2]
LO	$159.2^{+3.5}_{-3.4}$	$159.2^{+3.5}_{-3.4}$
NLO	$159.8^{+3.3}_{-3.3}$	$165.8^{+3.5}_{-3.5}$
NNLO	$160.0^{+3.3}_{-3.2}$	$168.2^{+3.6}_{-3.5}$

The MS-mass from precision electroweak fit is 161.3 GeV – rather consistent with the direct determination results

No obvious consistency between theoretically clean and ``all possible" measurements $m_t = 173.3 \pm 1.1$ GeV

Top quark mass measurements

- D0 collaboration extracts the top quark mass from the total cross-section



Theoretical prediction	$m_t^{\overline{\rm MS}}$ (GeV)	$\Delta m_t^{\overline{\rm MS}}$ (GeV)
MC mass assumption	$m_t^{\rm MC} = m_t^{\rm pole}$	$m_t^{\rm MC} = m_t^{\overline{\rm MS}}$
NLO+NNLL [14]	$154.5^{+5.0}_{-4.3}$	-2.9
Approximate NNLO [15]	$160.0^{+4.8}_{-4.3}$	-2.6

Note differences in resulting top mass under different approximate estimates of higher-order terms !

Note changes in the top quark under different assumptions about the mass in the MC

	$m(m)$ [GeV$/c^2$]	m_t [GeV$/c^2$]
LO	$159.2^{+3.5}_{-3.4}$	$159.2^{+3.5}_{-3.4}$
NLO	$159.8^{+3.3}_{-3.3}$	$165.8^{+3.5}_{-3.5}$
NNLO	$160.0^{+3.3}_{-3.2}$	$168.2^{+3.6}_{-3.5}$

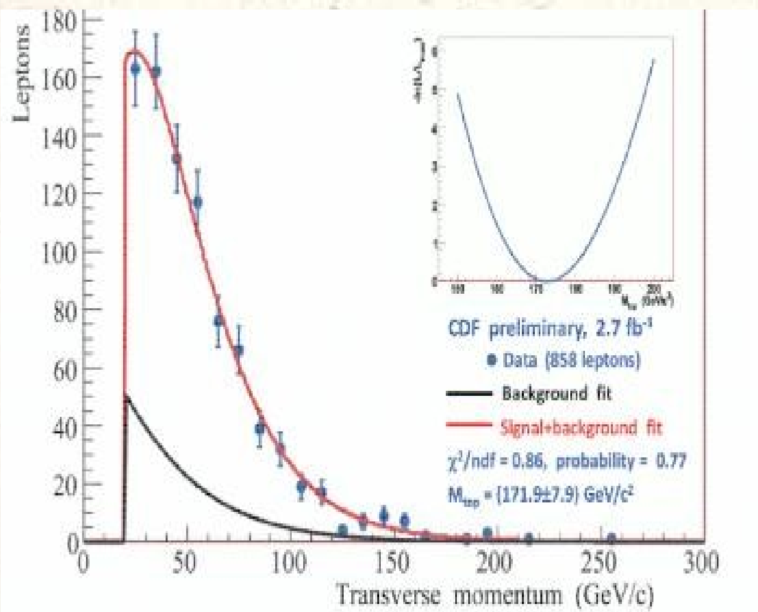
The MS-mass from precision electroweak fit is 161.3 GeV

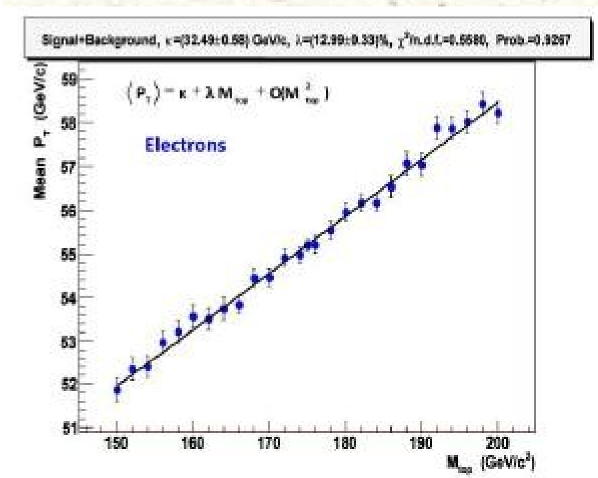
It will be instructive to see the D0 result for the MS mass as a function of order in PT

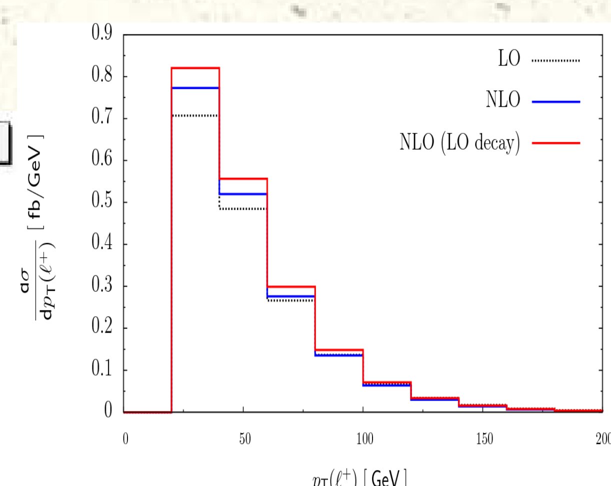
Mass entering MC is definitely not the MS mass. More likely – one of the so-called short-distance low scale masses

Top quark mass measurements

- CDF collaboration extracts the top quark mass from the average value of the lepton transverse momentum distribution. Measurement is dominated by statistical uncertainties but it is very attractive because the systematics is low and it is very clean theoretically
- Theoretical prediction for lepton transverse momentum require accurate description of radiation in the decay – which is not properly included in the experimental analysis







$$\langle p_\perp \rangle = 0.13 m_{\rm top} + 32.49 \text{ GeV}$$

$$p_\perp^{\rm LO} = 54.4 \text{ GeV}$$

$$p_\perp^{\rm NLO} = 52.6 \text{ GeV}$$

$$p_\perp^{\rm NLO}(\text{LO dec}) = 53.1 \text{ GeV}$$

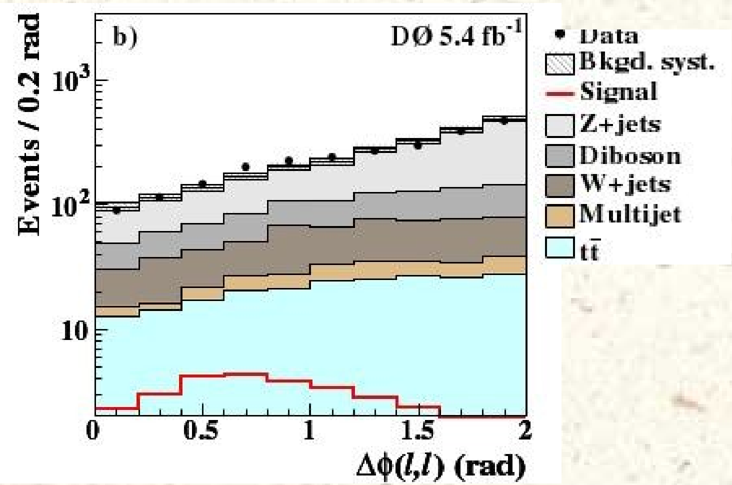
$$m_{\rm top} = 176.9 \pm 8.0_{\rm syst} \pm 2.7 \text{ GeV}$$

Spin correlations

- Top quarks interact with QCD vacuum fields that are too weak to change top and anti-top polarizations

$$\frac{|\Delta\vec{S}|}{|\vec{S}|} \sim \frac{\Lambda_{\rm QCD}}{m_t} \quad \frac{\Lambda_{\rm QCD}}{\Gamma_t}$$

- Kinematics of top quark decay products depends on the top quark polarization; spin correlations, etc.
- To describe spin correlations, we must consider production and decay at the same time, including radiative corrections. Stable top quarks are definitely not enough.



We care about spin correlations because they may affect lepton distributions, e.g. the relative opening angle.

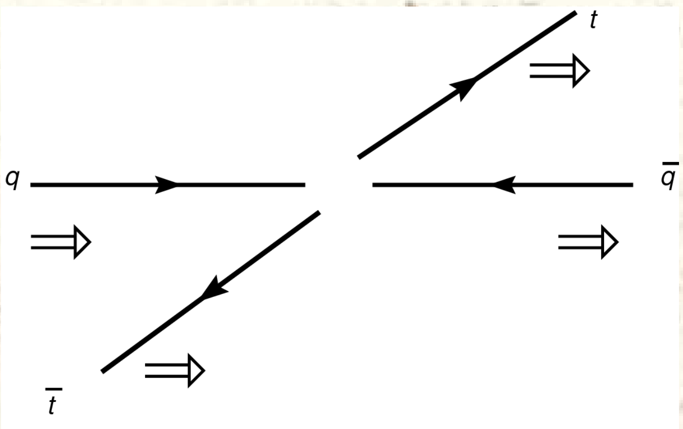
Such distributions are used to discriminate between signal and backgrounds (e.g. the Higgs boson).

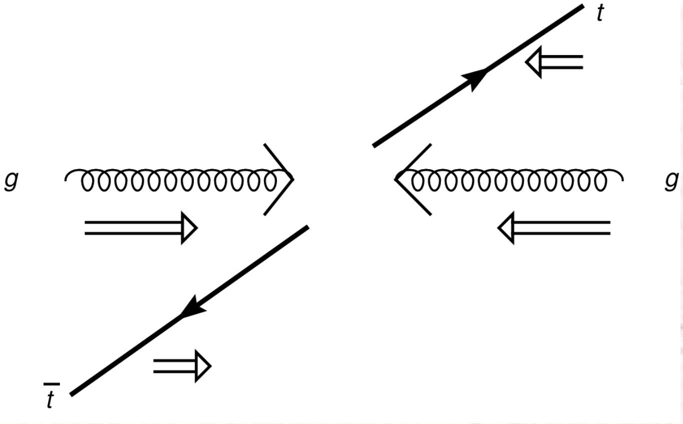
Spin correlations may also change IF couplings of top quarks to gauge EW bosons are different compared to SM expectations

Di-lepton opening angle; heavy Higgs search at the Tevatron

Spin correlations

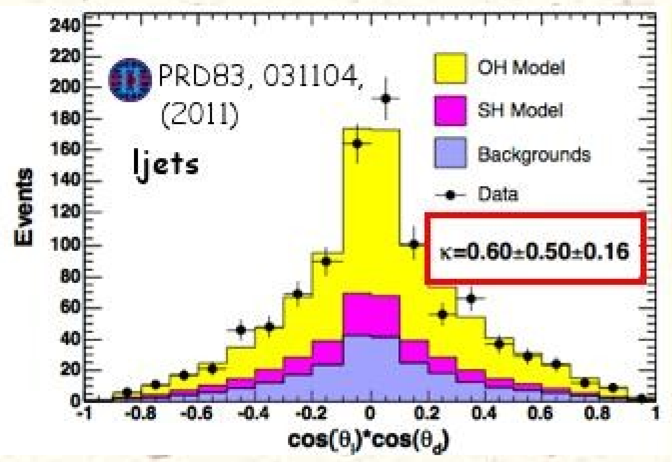
- If top quarks are produced in a polarized state, they decay in a correlated fashion
- Polarization of top quarks at the Tevatron and the LHC differ, because of different production mechanisms
  - Tevatron: qq → g → tt, J=1, S=1, L=0 (spins parallel)
  - LHC : gg → tt, J=0, L=0,S=0 (spins antiparallel)
- Since positron likes to follow the spin direction of the top quark and electron prefers to go into the direction opposite to that of the anti-top spin, leptons like to have parallel (anti-parallel) momenta at the LHC/Tevatron





Spin correlations

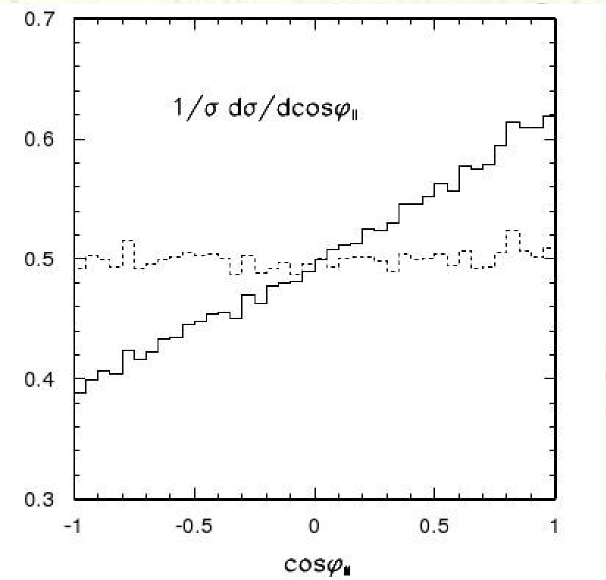
- Traditionally, top quark spin correlations are discussed in the context of lepton angular correlations in special reference frames
- The effect of spin correlations on these distributions is pronounced but it is hard to reconstruct those frames; as the result no conclusive proof of the existence of spin correlations existed until recently



$$\frac{\mathrm{d}^2\sigma}{\sigma \mathrm{d}\cos\theta_+ \mathrm{d}\cos\theta_-} = \frac{1-\kappa\cos\theta_+\cos\theta_-}{4}$$

$$\kappa = 0.60 \pm 0.50(\mathrm{stat}) + 0.16(\mathrm{syst})$$

CDF measurement, 2010

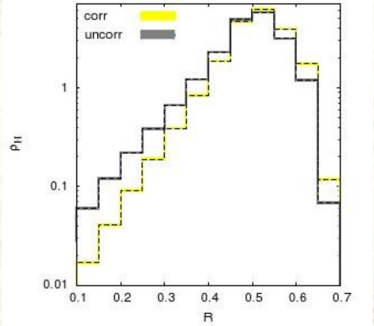


$$\frac{\mathrm{d}\sigma}{\sigma \mathrm{d}\cos\varphi} = \frac{1}{2} - \frac{D}{2}\cos\varphi$$

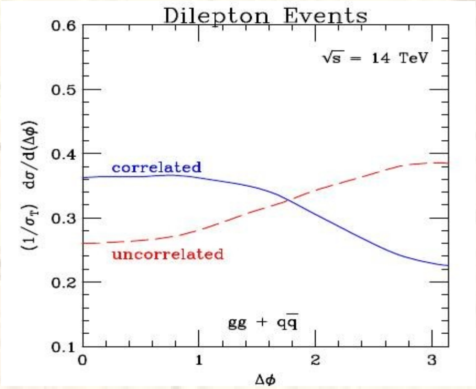
Bernreuther, Si

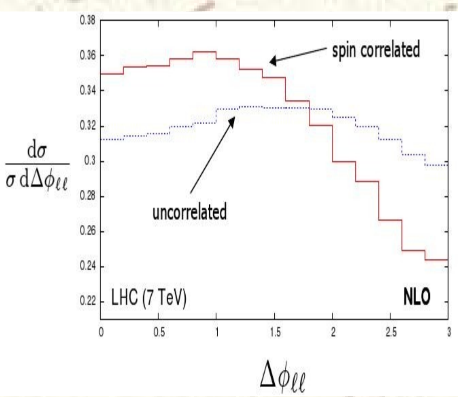
Spin correlations

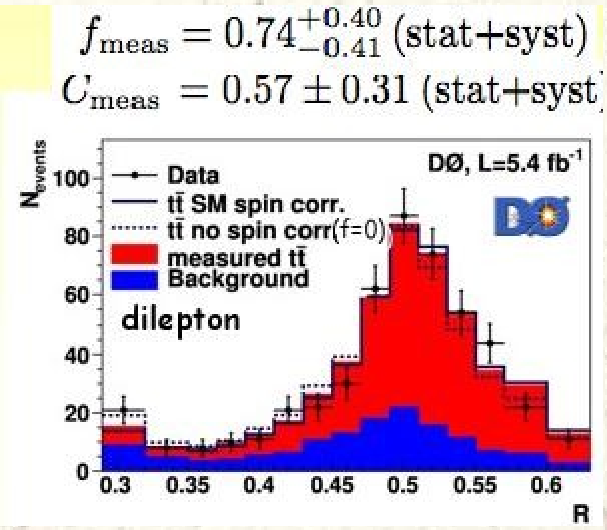
- Early in 2010 S. Parke and G. Mahlon suggested to look for alternative observables to study spin correlations. They pointed out that at the LHC the opening angle of the two leptons in the lab frame is sensitive to spin correlations. They also emphasized that a question if spin correlations exist – rather than what is the value of the correlation parameter – should be asked and answered
- A useful observable $$\mathcal{R}(\{x\}) = \frac{|M|^2_{\rm corr}(\{x\})}{|M^2|_{\rm uncorr}(\{x\}) + |M|^2_{\rm corr}(\{x\})}$$
- In reality – more complicated, since momentum of neutrinos can not be measured; integration can be done explicitly



Schulze, K.M.







D0 excludes the no-correlation hypothesis at about the 2 sigma level. The LHC experiments should already be able to do better, given larger production rates

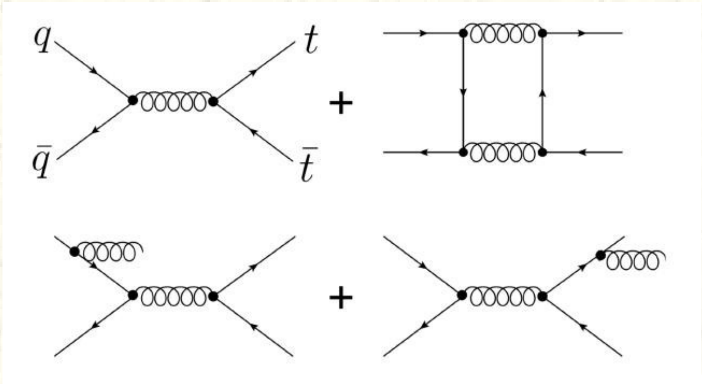
Forward-backward asymmetry

- In proton anti-proton collisions, top quarks are produced with forward-backward asymmetry

$$A_{\mathrm{lab}}(t\bar{t}) = \frac{N_t(y>0) - N_t(y<0)}{N(y_t>0) + N_(y_t<0)} \qquad A_{\mathrm{rest}}(t\bar{t}) = \frac{N_t(\Delta y>0) - N_t(\Delta y<0)}{N(\Delta y>0) + N_(\Delta<0)}$$

- The asymmetry only appears at one-loop in QCD

Kuhn, Rodrigo



$$A_{\mathrm{rest}}^{\mathrm{theory}} = 0.05 \pm 0.006$$

$$A_{\mathrm{rest}} = 0.15 \pm 0.05 \quad \mathrm{CDF}$$

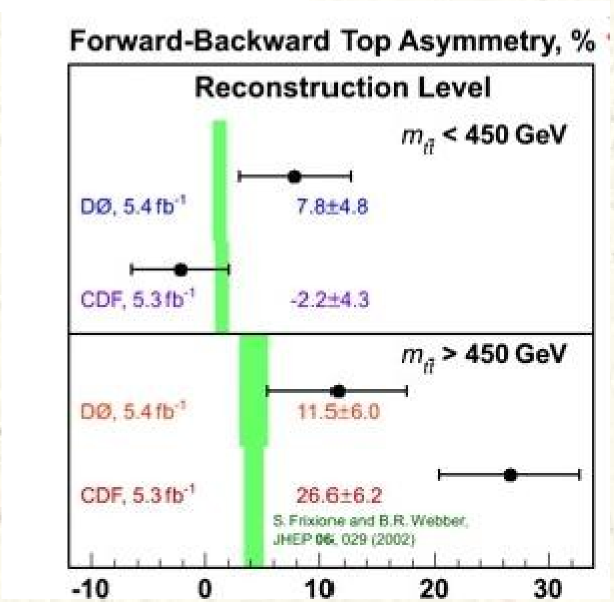
$$A_{\mathrm{rest}} = 0.196 \pm 0.065, \quad \mathrm{D0}$$

The discrepancy with the SM prediction is about two standard deviations.

CDF finds larger asymmetries/discrepancy at large invariant masses and large rapidities

D0 does not confirm that finding

Many BSM interpretations of this result, some already ruled out by the LHC



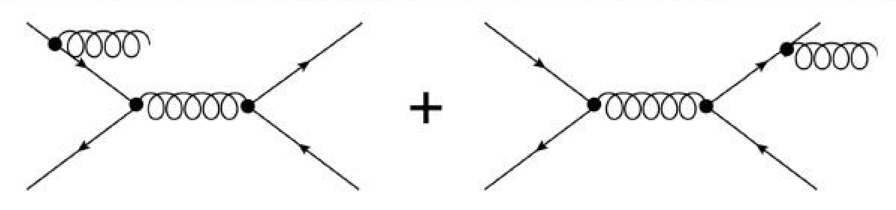
QCD predictions are robust

- How robust are predictions for the asymmetry? We should remember that NLO QCD corrections to top quark pair production gives rise to ``leading order '' asymmetry, so clearly out knowledge is very limited. In higher orders, one can imagine two types of effects – ``higher order effects'' for stable tops and ``acceptance effects'' for top quark decay products
- A standard tool for CDF/D0 uses MC@NLO which includes HERWIG parton shower matched to top quark pair production at next-to-leading order in QCD. This is a fine tool to use but there are limitation (e.g. MC@NLO does not include QCD effects in the decays and does not include spin correlations at next-to-leading order)
- Theoretical predictions for the asymmetries were found to be stable against
  - inclusion of (approximate) higher order corrections to top quark pair production
    Almeida, Sterman, Vogelsang
    Ahrens, Ferroglia, Neubert, Pecjak, Yang
  - allowing top quarks to decay and calculating asymmetries for realistic acceptances
    K.M., Schulze, Bernreuther, Si, Bevilacqua, Czakon, van Hammeren, Papadopoulos, Worek
  - off-shell effects, non-factorizable corrections and the interference with non-resonance backgrounds
    Bevilacqua, Czakon, van Hammeren, Papadopoulos, Worek
  - mixed QCD/QED effects
    Kuhn, Rodrigo
    Bernreuther, Si
    Hollik, Pagani

Forward-backward asymmetry and additional jet

- Asymmetry in $p\bar{p} \to t\bar{t} + j$ is often quoted as a example of large radiative corrections
- In contrast to $p\bar{p} \to t\bar{t}$ the asymmetry in $p\bar{p} \to t\bar{t} + j$ appears already at leading order ; so NLO QCD calculation for $p\bar{p} \to t\bar{t} + j$ will also give first-order correction to the asymmetry
- The result is peculiar: there is large positive correction to the asymmetry

$$A_{\rm lab}(t\bar{t}+j)^{\rm LO} \approx -8\ \% \ \ \Rightarrow A_{\rm lab}(t\bar{t}+j)^{\rm NLO} \approx -2.3\ \%.$$



Dittmaier, Uwer, Weinzierl
K.M., Schulze

Should we take this result as an indication that large POSITIVE corrections are to be expected in $p\bar{p} \to t\bar{t}$ asymmetries?

Forward-backward asymmetry and additional jet

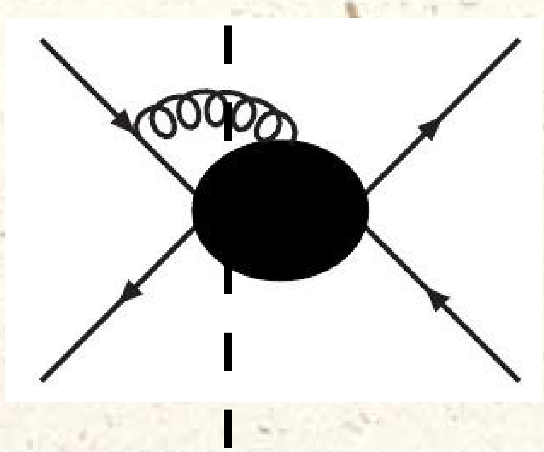
- At leading order the asymmetry in tt + jet is generated by soft, non-collinear exchange between initial and final state ; hence ``jet" is used to generate the asymmetry

$$\sigma_{t\bar{t}j} \sim \frac{2C_F\alpha_s}{\pi} \ln^2 \frac{m_t}{p_{\perp,j}} \sigma_{t\bar{t}}. \qquad \sigma(y_t > 0) - \sigma(y_t < 0) \sim \frac{C_F\alpha_s}{\pi} \ln \frac{m_t}{p_{\perp,j}} \sigma_{t\bar{t}}$$

$$A_{\rm FB} = \frac{\sigma(y_t > 0) - \sigma(y_t < 0)}{\sigma_{t\bar{t}j}} \sim \left[\ln \frac{m_t}{p_{\perp,j}}\right]^{-1}$$

- At NLO, we can generate asymmetry by hard exchanges and use soft initial-initial interference to provide regular double logarithmic enhancement of the cross-section. This mechanism is unique for ttj@NLO

K.M., Schulze



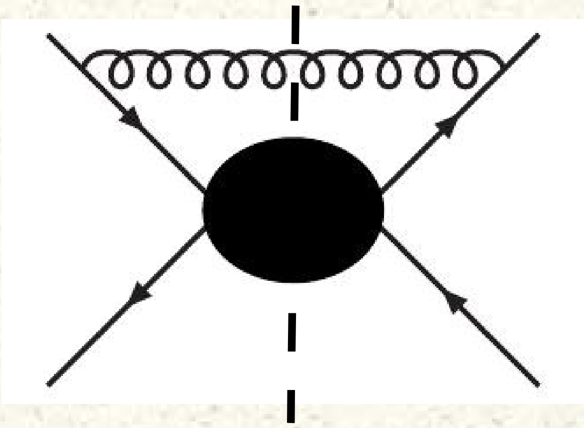


Diagram that shifts the ttj asymmetry by +5 % at NLO

Interesting results from D0

- In a recent paper, D0 collaboration presented a number of interesting results

hep-ex/1107.4995

- Asymmetry in inclusive pp → tt is a problem but asymmetry in pp → tt + jet is small and consistent with pQCD predictions. In the latter case, the NLO prediction for the asymmetry is -2%.

	$l+\geq 4$ jets	$e+\geq 4$ jets	$\mu+\geq 4$ jets	$l+4$ jets	$l+\geq 5$ jets
Raw N_F	849	455	394	717	132
Raw N_B	732	397	335	597	135
$N_{t\bar{t}}$	1126 ± 39	622 ± 28	502 ± 28	902 ± 36	218 ± 16
$N_{W+\text{jets}}$	376 ± 39	173 ± 28	219 ± 27	346 ± 36	35 ± 16
N_{MJ}	79 ± 5	56 ± 3	8 ± 2	66 ± 4	13 ± 2
A_{FB}(%)	9.2 ± 3.7	8.9 ± 5.0	9.1 ± 5.8	12.2 ± 4.3	-3.0 ± 7.9
MC@NLO A_{FB} (%)	2.4 ± 0.7	2.4 ± 0.7	2.5 ± 0.9	3.9 ± 0.8	-2.9 ± 1.1

- There is large asymmetry in the lepton rapidity distribution – an observable that is very clean theoretically and experimentally. Lepton asymmetries show disagreement between theory and experiment that seems to be very significant

TABLE VI. Lepton-based asymmetries.

	A^l_{FB} (%) Reconstruction level	A^l_{FB} (%) Production level
Data	14.2 ± 3.8	15.2 ± 4.0
MC@NLO	0.8 ± 0.6	2.1 ± 0.1

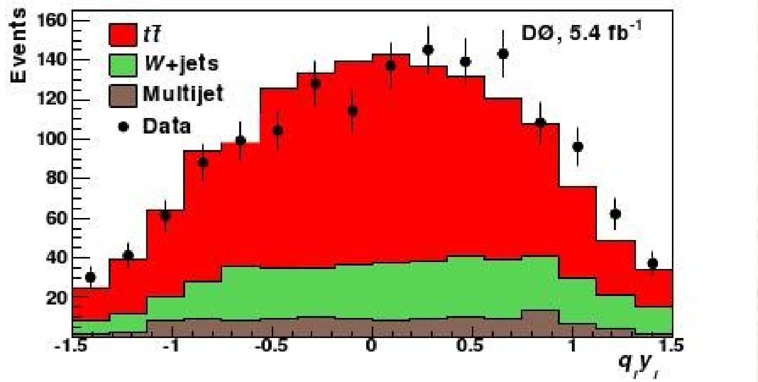
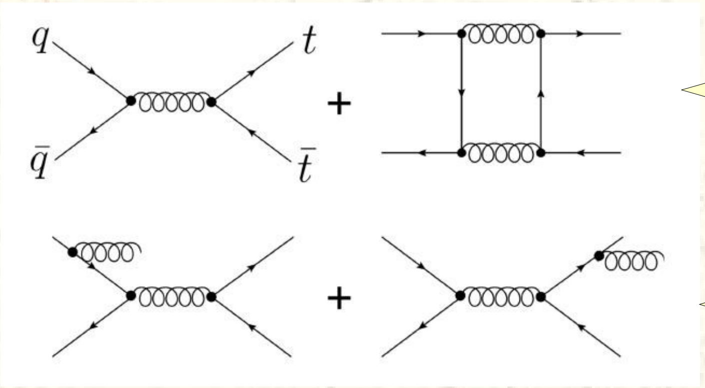


FIG. 4. The reconstructed charge-signed lepton rapidity.

Asymmetries and additional QCD radiation

- The dependence of the asymmetry on additional QCD radiation is strong: QCD prediction for the asymmetry is positive – for the inclusive tt and negative – for the tt+jet.



Positive asymmetry

Negative asymmetry

But, in reality both are infinite and can not be treated independently from each other

- Although it does not make sense to talk about the two contributions separately, the asymmetry may change significantly, if stringent cuts on additional radiation are imposed. A known story (jet veto, etc.) but perhaps in a new setting

- The importance of soft radiation in an inclusive asymmetry is marginal, as follows from results on gluon resummation

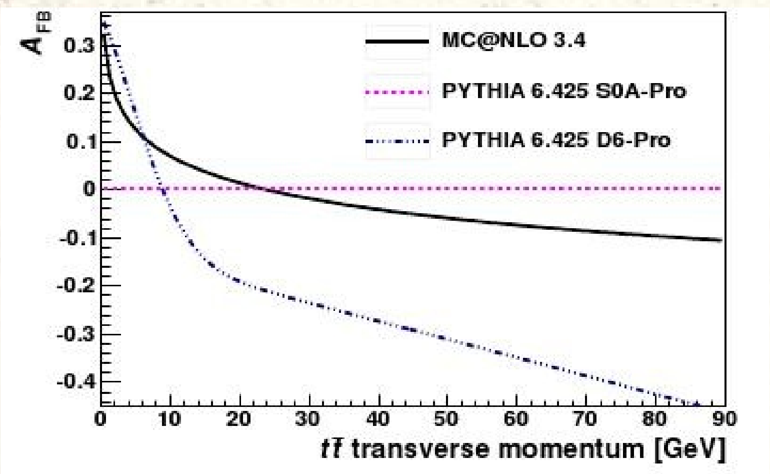
Almeida, Sterman, Vogelsang
Ahrens, Ferroglia, Neubert, Pecjak, Yang

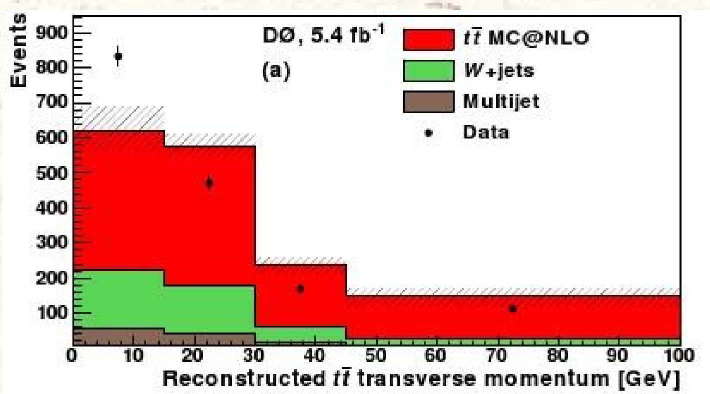
Asymmetries and additional QCD radiation

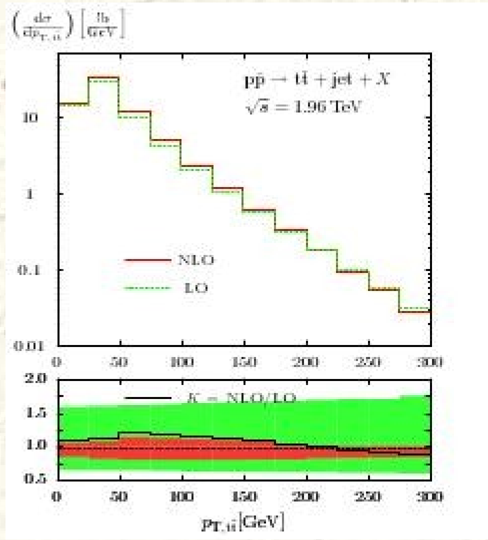
- D0 shows that the transverse momentum of the ttbar pair is not correctly described by MC@NLO
- This may be problem since asymmetry is a strong function of the transverse momentum of the ttbar system
- The pt-spectrum of the ttbar pair is known at NLO QCD; effects are moderate, no drastic re-shaping (but interesting bins are not shown)

Dittmaier, Uwer, Weinzierl

- Note that forcing color coherence in PYTHIA introduces large negative asymmetries at high ptt. Herwig (MC@NLO base) is angular-ordered, so similar effect should be expected. Can it be trusted?
- Recall that asymmetry is a large-angle emission effect – color coherence is supposed to improve treating large angle emissions correctly in parton showers







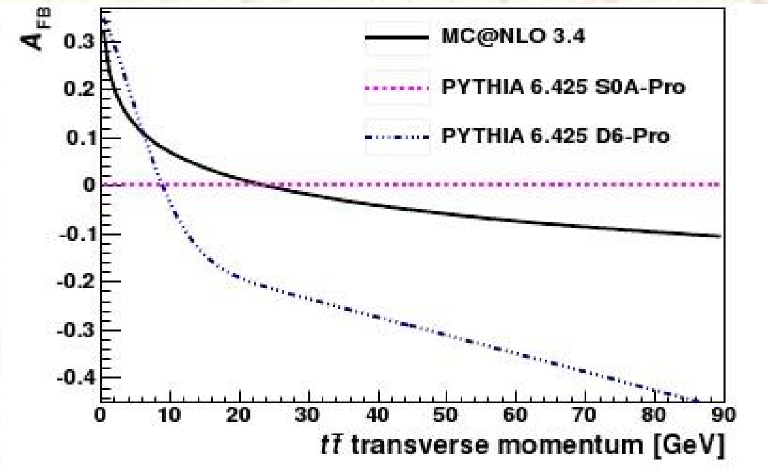
Asymmetries: do we have a problem?

- MC@NLO predictions for the asymmetry seems to be low when compared to DATA
- However, they also seem somewhat low when compared to OTHER pQCD computations

$$A_{\rm rest}^{\rm MC@NLO} = 0.05 \pm 0.006$$

$$A_{\rm rest}^{\rm NLO\ \ QCD} = 0.07 \pm 0.01$$

$$A_{\rm rest}^{\rm QCD+EW} = 0.09 \pm 0.01$$



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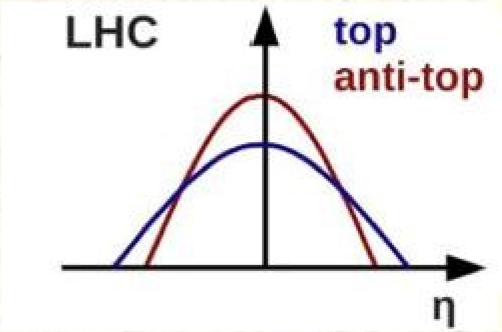
Asymmetry is an inclusive, short-distance quantity. It should not be affected by the parton shower.

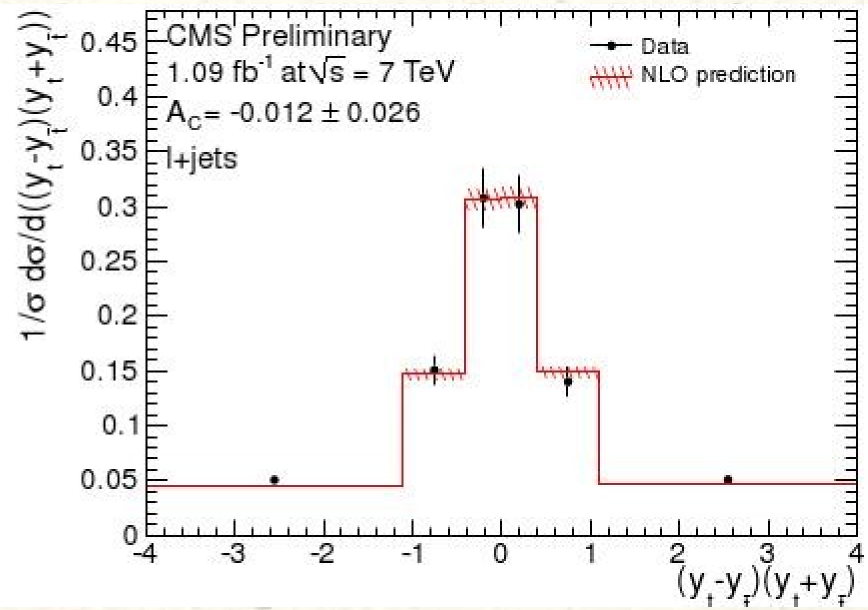
Estimates of errors, of course, should be taken with the grain of salt. It is quite plausible that NNLO corrections to the asymmetry change it by 20 – 30 %, typical for NLO QCD corrections. The discrepancy can become less than 1 sigma, if a couple of things move in the right direction

$$A_{\rm rest} = 0.15 \pm 0.05 \quad {\rm CDF} \qquad\qquad A_{\rm rest} = 0.196 \pm 0.065, \quad {\rm D0}$$

Asymmetries: the LHC weights in

- LHC is a symmetric machine so studying asymmetries is difficult
- Expect rapidity distributions of top quarks to be broader than distribution of anti-tops.
- Measurements by CMC and ATLAS, using 1/fb of data. No evidence for an asymmetry. However, uncertainties are quite large
-





	unfolded data	SM prediction
Altas: A_C^y (0.7 fb^{-1})	-0.024 ± 0.016 (stat) ± 0.023 (syst)	0.006 (MC@NLO)
CMS: A_C^η (1.1 fb^{-1})	-0.016 ± 0.030 (stat)$^{+0.010}_{-0.019}$ (syst)	0.0130

Conclusion

- Current state of the top quark physics is very interesting
  - On one hand – extraordinary results from the Tevatron
    - precision
    - tiny cross-sections measured
    - unexpected results
  - LHC is producing results at an extraordinary pace
  - Theory has almost caught up with these exciting developments
- The LHC will have much to say about ALL aspects of top physics since many measurements will not be statistics limited
- A true addition to the Tevatron physics results will be studies of associated production (tt + jet, tt + gamma, tW) and, perhaps, even ttH
- A very special year in the top quark physics – strong continuous program bound to make absolutely fundamental contributions to particle physics