Top Conclusions (preliminary, selected, in-progress)

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Organization: 6 working groups

- Mass (contacts: A. Mitov, M. Vos. S. Wimpenny): Sun. 2 pm.
- Couplings (J. Adelman, M. Baumgart, A. Garcia-Bellido, A. Loginov): Sun. 4.30 pm.
- Kinematics (A. Jung, M. Schulze, J. Shelton): Tues. 10.15 am.
- Rare decays (N. Craig, M. Velasco): Sun. 4.30 pm.
- New particles decaying into top-like final state (T. Golling, A. Ivanov, J. Hubisz, M. Perelstein): Mon. 1.30 pm.
- Detection algorithms (S. Chekanov, J. Dolen, J. Pilot, R. Poeschl): Tues. 2 pm.

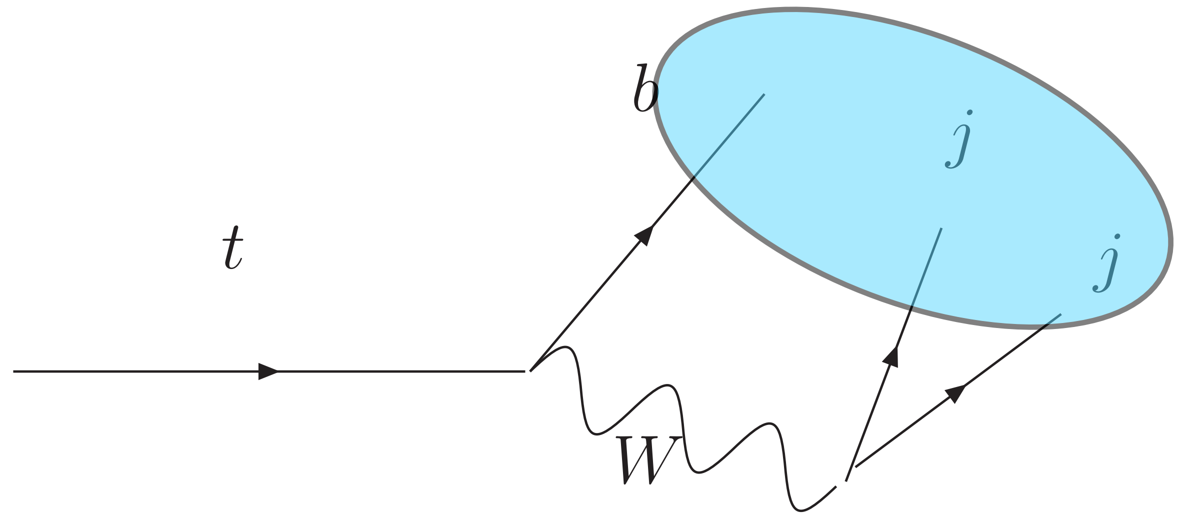
More details/references in top sessions: presentation by contacts + discussion

MASS

(Motivation: fundamental parameter of SM;enters calculation of other observables)

Conventional methods

- Basic idea: reconstruct (full) decay of top

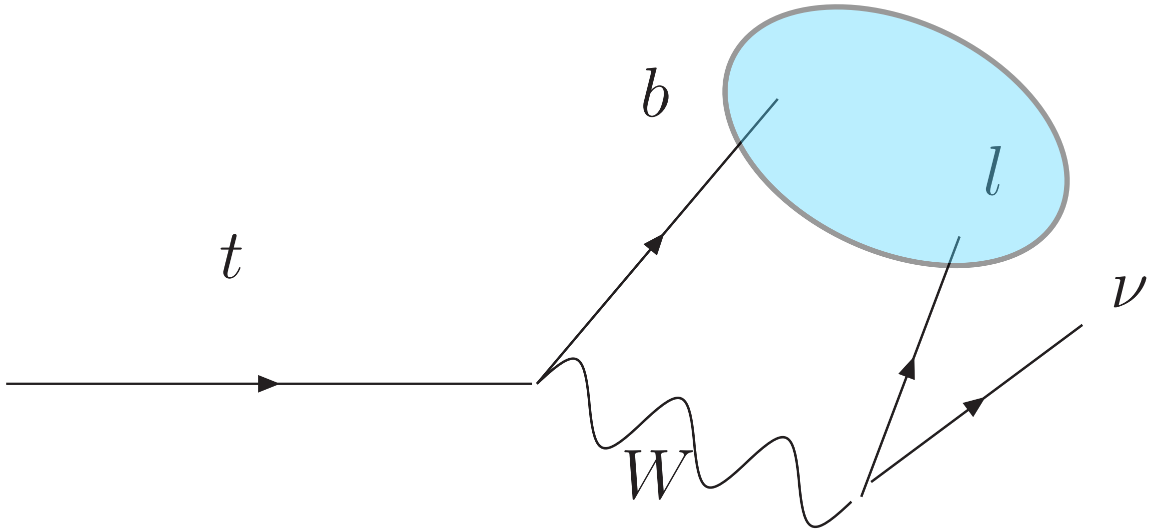


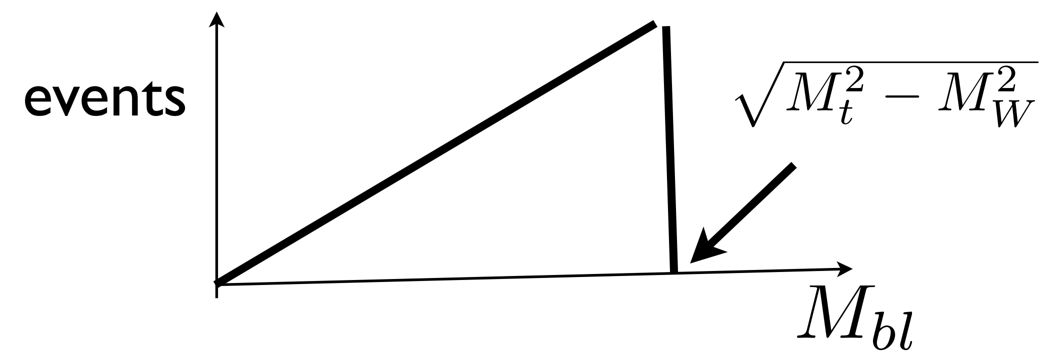
- can achieve O(0.6 GeV) uncertainty at LHC14, with 300/fb

- further gain may be possible with 3000/fb by using a more extended approach to constraining uncertainties using data

- Simulation (using SM matrix element in production) is used to handle combinatorics

Latest: endpoint of M_{bl}





- more cleanly interpreted as measurements of the pole quark mass

- combinatorics resolved with*out* assuming SM matrix element in production
  resulting top quark mass immune to possible contaminations from New Physics in production of top quarks

- can provide precision competitive with more conventional methods, especially using 3000/fb at LHC14

In development: J/ψ method

- "clean" like endpoint
- 100 TeV (*V*LHC) can give similar precision to previous methods
- LHC14, 3000/fb gives O(1.1) GeV error

ILC/CLIC + what to do with precision

- theoretically well defined way (either from threshold scan or by direct reconstruction of Breit-Wigner peak at a higher-energy): O(0.1 GeV) uncertainty at ILC/CLIC
- Muon colliders, with smaller beamstrahlung, can probably be used to measure top quark mass with even higher precision, but detailed studies are not available
- Physics case for measuring top quark mass with 0.1 GeV precision, compared to 0.6 GeV precision, is not very clear: e.g., for precision electroweak fits, full use of even 0.6 GeV error on top quark mass requires decreasing error on the W mass to 4 MeV (which might be possible with 3000/fb at LHC14).
- If no New Physics is seen up to very high scales, vacuum stability may be an issue, where exact value of the top quark mass is important: careful consideration of this scenario clearly goes beyond mandate of top quark group

COUPLINGS

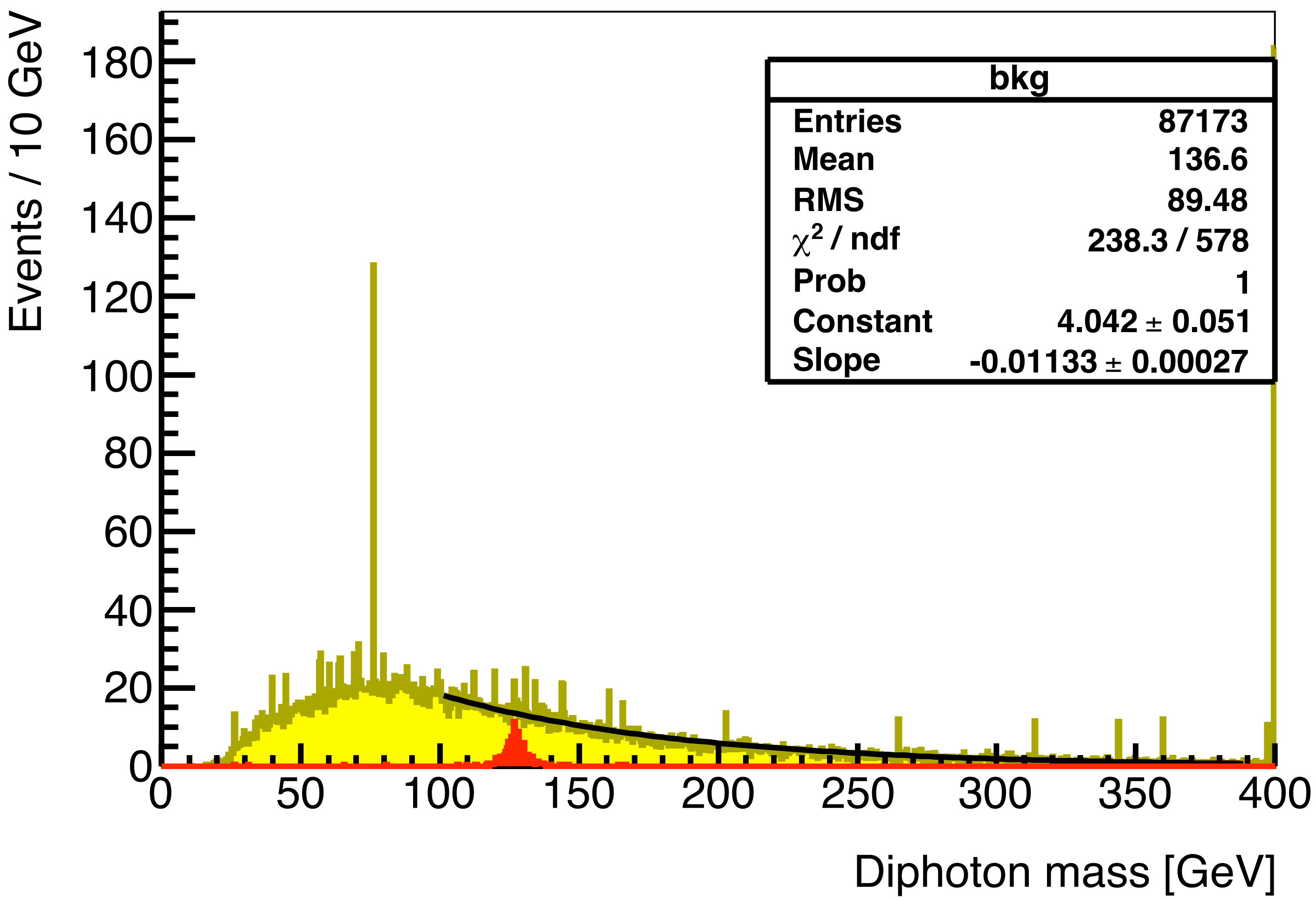
(Motivation: precision test of SM + new physics, especially related to hierarchy problem, likely to modify)

Theory + LHC

- Measurements of top quark couplings requires theory predictions for many associated production (and background) processes, through NLO QCD.
- Many are available (ttZ, ttγ, ttH) including decays of top quarks, radiation in decay and matched to parton showers
- More robust predictions (e.g. for ttA or arbitrary admixtures of left/right currents in ttZ, tWb) can be obtained using existing framework
- Other couplings being studied: ttZ (expected precision 20-50%); ttγ (~5%) at LHC14 with 300/fb (improves by ~2 for 3000/fb); tbW (at percent level expected via single top) and ttH

ttH at LHC

- Expected sensitivity to tth, with $h \to \gamma\gamma$ at 3000/fb LHC14 is ~6 σ (300/fb is inconclusive); tth, with $h \to \mu\mu$ underway



$\langle \mu \rangle = 140$

ILC/CLIC

- allows study of pure EW top production (no QCD background)
- Beam polarization is major asset: it allows disentangling of top coupling to photon and Z and collecting samples enriched in left/right-handed helicities
- As a result of above, electroweak couplings can be determined at a percent level, allowing probe of new physics as well
- ttH: 11 (4)% (with H→bb) at 500 (1000) GeV, with 1000/fb

Kinematics of top-like final states

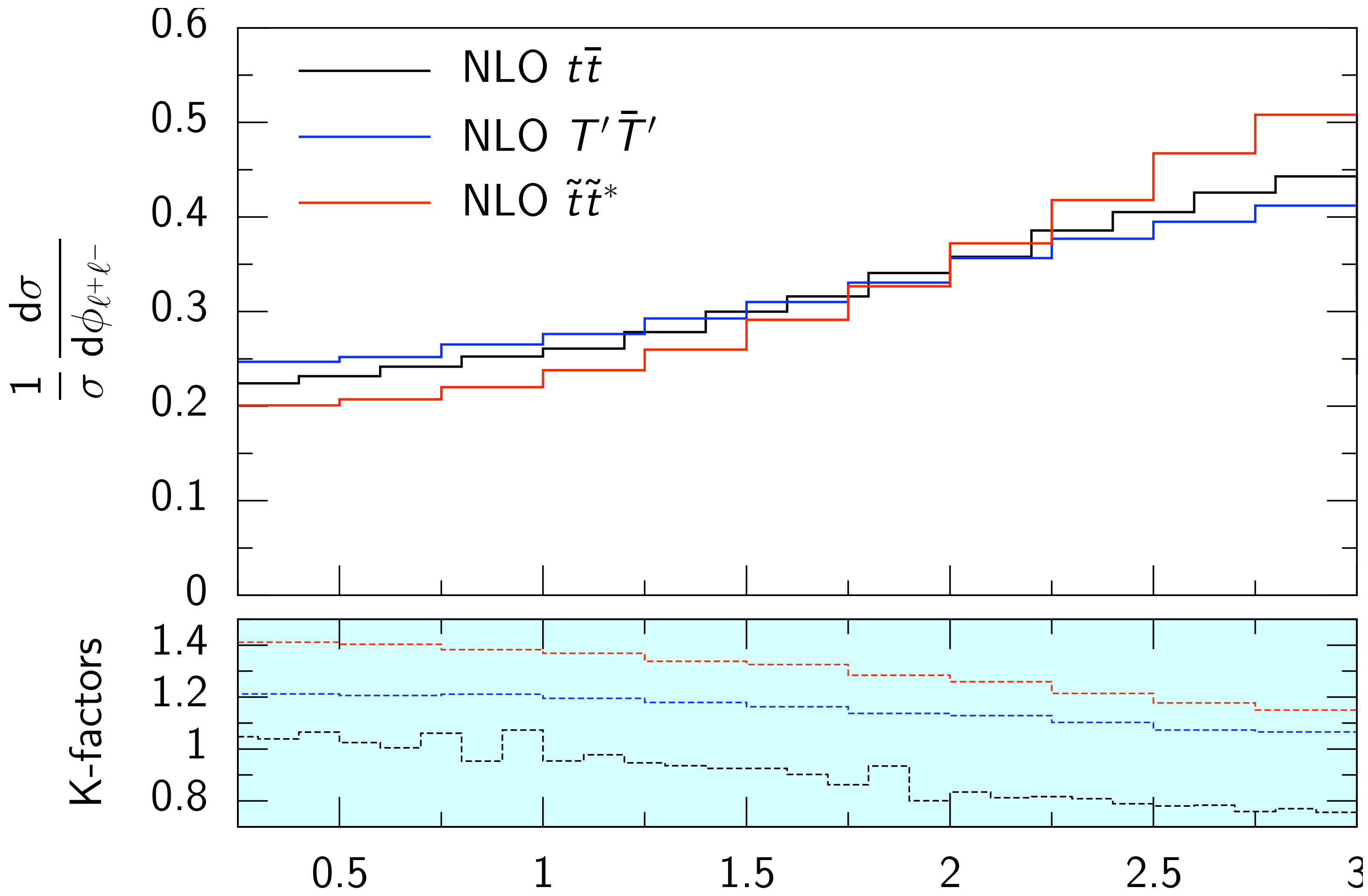
(Motivation: precision test of SM + new physics can modify kinematics)

Basic distributions

- Current theoretical understanding (NNLO) makes it possible to predict the total cross-section for top quark pair production to ~5% (scale + PDF)
- basic kinematic distributions to within 15-20 percent (NLO)
- Accuracy of kinematic distributions will be improved within a few years by extending existing theory for kinematic distributions also to NNLO and by better understanding of PDF's in relevant kinematic range.
- Precision (especially, uncertainty from PDF's) deteriorate if boosted regime is considered

Spin-correlations

- Normalized angular distributions, in particular ones that are sensitive to spin-correlations of top quarks, often appear to be less affected by theoretical uncertainties than other (energy-related) distributions.
- This suggests that use of angular kinematic distributions in searches for physics beyond the Standard Model may be quite powerful.



Forward-backward asymmetry

- It is important to understand if LHC experiments are able to clarify the issue of forward-backward asymmetry observed at the Tevatron.
- LHCb will provide their sensitivity soon
- estimates of ultimate reach of ATLAS/CMS for the asymmetry at LHC, including the high-luminosity option, will be provided by Minnesota

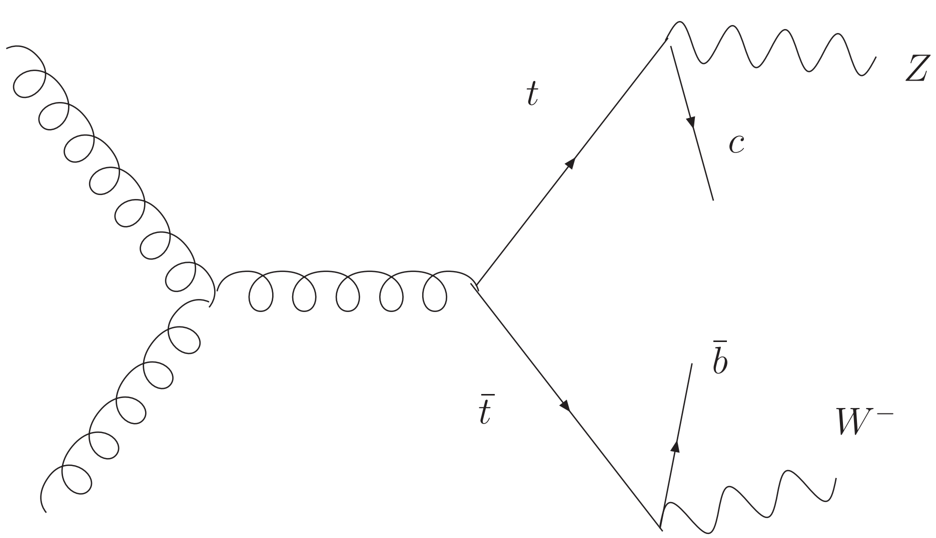
Rare Decays

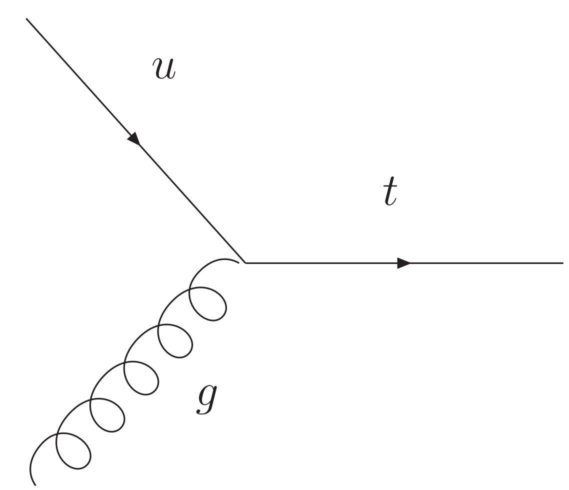
Model predictions + how to probe

Table 1: SM and NP predictions for branching ratios of top FCNC decays.

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

- observation is signal for new physics!
- Use flavor-changing coupling in decay (pair production of tops) or in single-top production





Current limits

Table 1: Current direct limits on top FCNC. (*) denotes unofficial limits obtained from public results. The q in the final state denotes sum over $q = u, c$.

Process	Br Limit	Search	Dataset
$t \to Zq$	7×10^{-4}	CMS $t\bar{t} \to Wb + Zq \to \ell\nu b + \ell\ell q$	19.5 fb^{-1}, 8 TeV
$t \to Zq$	7.3×10^{-3}	ATLAS $t\bar{t} \to Wb + Zq \to \ell\nu b + \ell\ell q$	2.1 fb^{-1}, 7 TeV
$t \to gu$	5.7×10^{-5}	ATLAS $qg \to t \to Wb$	2.05 fb^{-1}, 7 TeV
$t \to gc$	2.7×10^{-4}	ATLAS $qg \to t \to Wb$	2.05 fb^{-1}, 7 TeV
$t \to \gamma u$	6.4×10^{-3}	ZEUS $e^{\pm}p \to (t \text{ or } \bar{t}) + X$	474 pb^{-1}, 300 GeV
$t \to \gamma q$	3.2×10^{-2}	CDF $t\bar{t} \to Wb + \gamma q$	110 pb^{-1}, 1.8 TeV
$t \to hq$	2.7×10^{-2}	CMS* $t\bar{t} \to Wb + hq \to \ell\nu b + \ell\ell qX$	5 fb^{-1}, 7 TeV
$t \to$ invis.	9×10^{-2}	CDF $t\bar{t} \to Wb$	1.9 fb^{-1}, 1.96 TeV

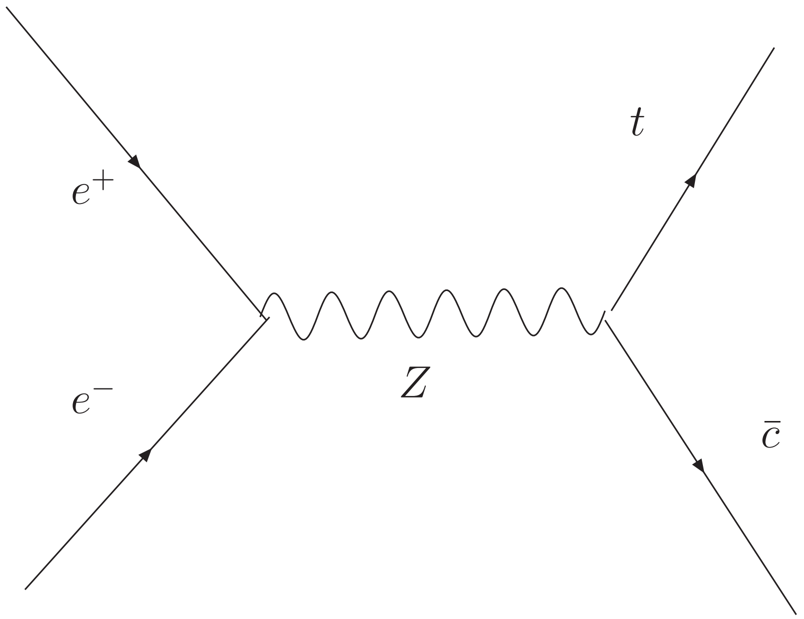
- don't quite probe most interesting parameter space

LHC14 projections

- Rare decays of top quarks can be measured at ~ 10^{-5} level
- high-luminosity option gives a factor of two gain in sensitivity to rare decays.

ILC/CLIC

- In general, LHC and the ILC /CLIC can reach similar sensitivities.
- LHC and ILC/CLIC are complementary: LHC can do more channels but is not so good for understanding the Lorentz structure of couplings, while ILC/CLIC can not study well flavor-changing couplings of tops to gluons
- At 250 GeV ILC (below threshold) limits can be set using single top production.



New particles decaying into top-like final states

General idea

- existing projections for LHC14 for stops; top-partners and $t\bar{t}$ resonances

- improve using new variables, techniques (so far applied only for 7-8 TeV in some cases)

Stops (motivation: below 1 TeV for naturally solving hierarchy problem)

Vanilla: $\tilde{t} \to t\tilde{\chi}^0$

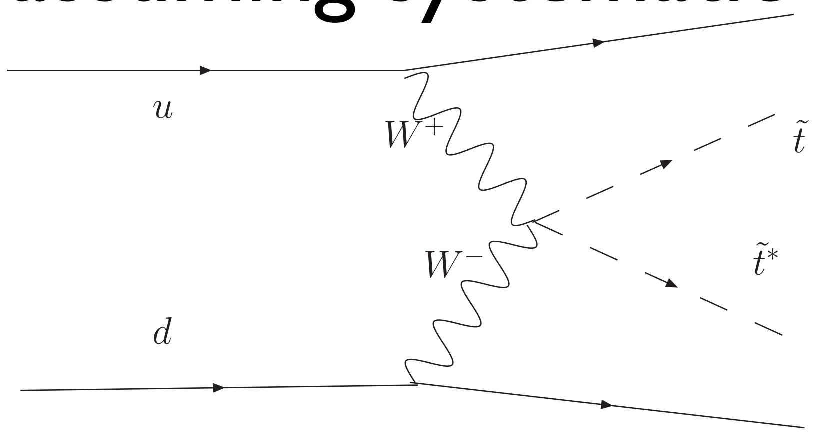
- 14 TeV LHC with 3000/fb can barely observe stops up to masses of 1TeV using existing methods (ATL-PHYS-PUB-2012-001)
- ongoing studies by ATLAS/CMS groups with better background estimates, boosted top, no leptons + phenomenological study with M_{T2} -type variables...will hopefully go beyond 1 TeV

Asymmetric: $\tilde{t}\tilde{t}^* \to (t\tilde{\chi}^0)\,(\bar{b}\tilde{\chi}^-)$

- use ``topness'': 2-3 σ for 1 TeV stop at LHC14, even with 30/fb (no detector effects...)

Stealthy stops: $m(\tilde{t}) \approx m_t \gg m(\tilde{\chi}^0)$, look like $t\bar{t}$

- At LHC14 with 100/fb, using spin correlations: more than 5σ -level sensitivity for mass 180-200 GeV, assuming systematic uncertainties are small enough

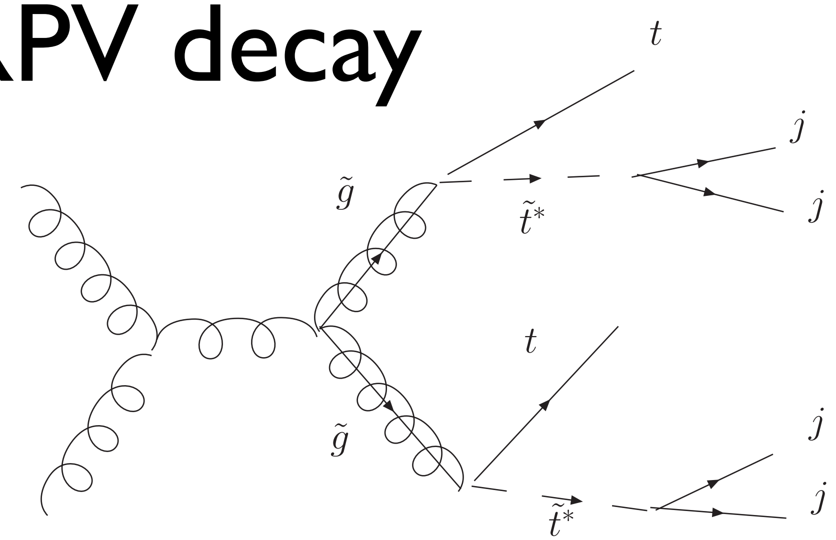


- Using VBF production for stops 5σ reach in stop mass of 200-250 GeV with 300/fb at LHC14 is possible: talk by K. Sinha (Mon. lunch)

- Further studies at ILC/CLIC through stop threshold scan can give definitive information and lead to precise measurements of stop mass, couplings etc.

Gluino-initiated, but RPV decay

- Extend LHC8 analysis to LHC14



Top-partners (motivation: alternative solution to hierarchy problem + below 1 TeV for naturalness)

- charge 2/3, -1/3 and 5/3
- charge 5/3 gives same-sign dileptons
- single and pair production
- pair production cross-section same for 0.8, 1.1 and 2 TeV mass at 8,14 and 33 TeV LHC

Rough reach is 1.1 and 2 TeV at LHC14 and 33, based on simple cross-section-only scaling from current bound of about 0.8 TeV from LHC8

(For more updates, see Mon. afternoon joint top/BSM and Tues. morning BSM)

$t\bar{t}$ resonances

(motivation: new physics solving hierarchy problem couples more strongly to top)

- Kaluza-Klein gluons with masses up to about 6 TeV with 3000/fb at 14 TeV LHC can be observed in lepton + jets channel (ATL-PHYS-PUB-2012-001)

- phenomenology study: apply template-overlap technique (less sensitive to pile-up effects) to improve reach for KK gluon (fully hadronic and leptonic)

- study by ATLAS group (add substructure techniques + all hadronic): statistics-only limits for 3 TeV Z' are 1.8 (0.5) x SM cross-section, with 300/fb (3000/fb) at LHC14

t (light quark) resonances

- study KK gluon $\rightarrow t\bar{c}$ (flavor-violating) and $W' \rightarrow t\bar{b}$

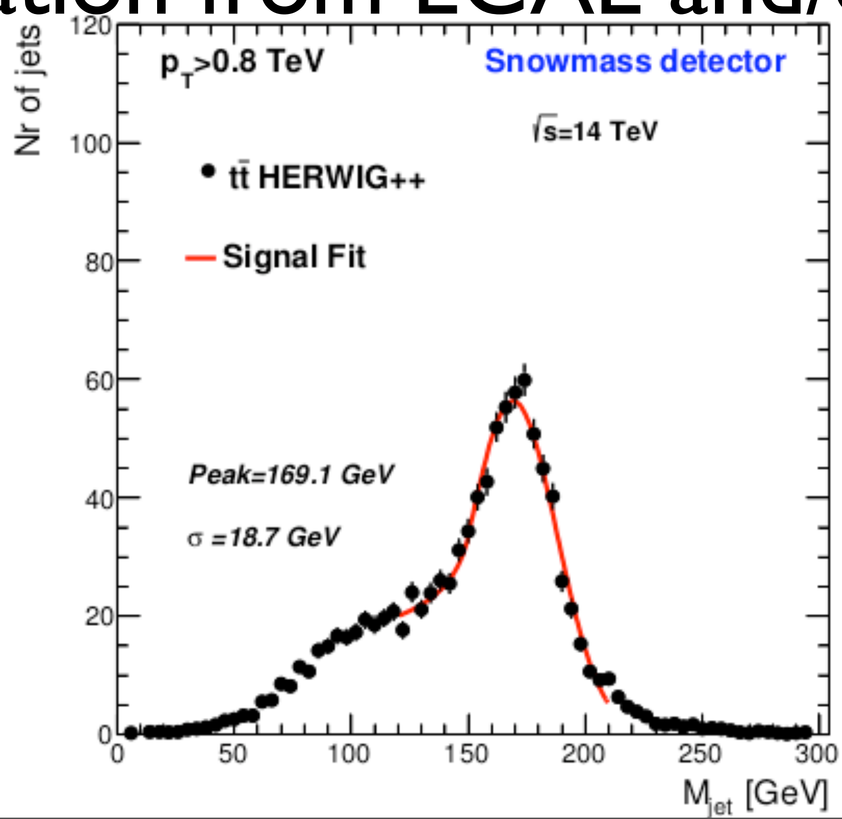
Detectors/Algorithms

LHC: low p_T

- Reach of precision measurements (whether in SM or searching for new physics), which are based on reconstruction of p_T < 100 GeV jets, is reduced at HL-LHC. This is due to pile-up corrections leading to large uncertainty in jet-energy (not intrinsic to detector, unlike at low luminosity)
- Due to above, it is unlikely that we can achieve a precision better than expected theory uncertainties for such precision measurements

LHC: high p_T

- truly boosted regime (p_T of jet > 0.8 TeV) at LHC14: decay products of top quark will be within cone of R = 0.5
- observe using top-jet mass distribution with R = 0.5
- Efficiency of jet mass/substructure algorithms degrades with increase of p_T above 1 TeV, caused by growing ISR/FSR contamination and (hadronic) calorimeter granularity
- Above effect could be mitigated by applying substructure-based grooming, using a jet cone size that decreases with p_T, and information from ECAL and/or tracker



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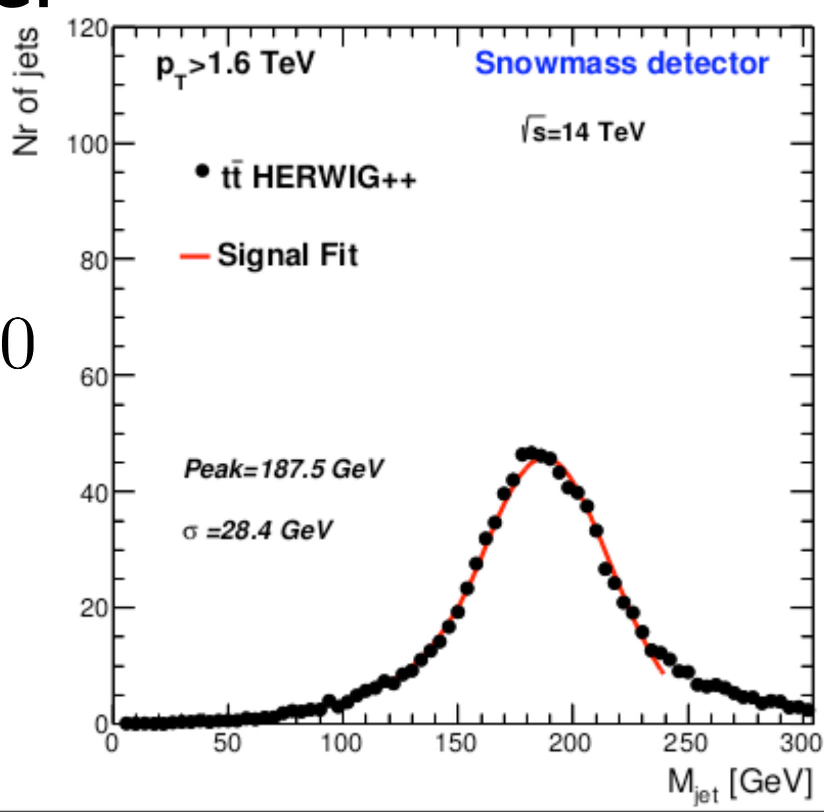

ILC/CLIC

- any residual pile-up (overlay events from photon collisions) are under control
- Charge of bottom quark can be measured at purity of 60% (useful for observables like top forward-backward asymmetry)
- To achieve goal of percent level precision in EW couplings, luminosity and beam polarizations have to be measured precisely: current estimates suggest that this can be done to better than 0.5%

EXTRAS

Top mass tables

	Ref.: 1209.2319	Projections				
CM Energy	7 TeV	14 TeV				
Cross Section	167 pb	951 pb				
Luminosity	$5fb^{-1}$	$100fb^{-1}$		$300fb^{-1}$		$3000fb^{-1}$
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

conservative

Table 1: Extrapolations based on the published CMS lepton-plus-jets analysis

	Ref. 1304.5783	Projections		
CM Energy	7 TeV	14 TeV		
Cross Section	167 pb	951 pb		
Luminosity	$5fb^{-1}$	$100fb^{-1}$	$300fb^{-1}$	$3000fb^{-1}$
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

Table 1: Extrapolations based on the published CMS Endpoint analysis

	Ref. analysis	Projections				
CM Energy	8 TeV	14 TeV			33 TeV	100 TeV
Cross Section	240 pb	951 pb			5522 pb	25562 pb
Luminosity	$20fb^{-1}$	$100fb^{-1}$	$300fb^{-1}$	$3000fb^{-1}$	$3000fb^{-1}$	$3000fb^{-1}$
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 1: Extrapolations based on the J/Ψ method.

Rare decay tables

Table 1: Projected limits on top FCNC at the 14 TeV LHC. "Extrap." denotes estimates based on extrapolation as described in the text.

Process	Br Limit	Search	Dataset	Reference
$t \to Zq$	2.2×10^{-4}	ATLAS $t\bar{t} \to Wb + Zq \to \ell\nu b + \ell\ell q$	300 fb^{-1}	ATL-PHYS-PUB-2012-001
$t \to Zq$	7×10^{-5}	ATLAS $t\bar{t} \to Wb + Zq \to \ell\nu b + \ell\ell q$	3000 fb^{-1}	ATL-PHYS-PUB-2012-001
$t \to \gamma q$	8×10^{-5}	ATLAS $t\bar{t} \to Wb + \gamma q$	300 fb^{-1}	ATL-PHYS-PUB-2012-001
$t \to \gamma q$	2.5×10^{-5}	ATLAS $t\bar{t} \to Wb + \gamma q$	3000 fb^{-1}	ATL-PHYS-PUB-2012-001
$t \to gu$	4×10^{-6}	ATLAS $qg \to t \to Wb$	300 fb^{-1}	Extrap.
$t \to gu$	1×10^{-6}	ATLAS $qg \to t \to Wb$	3000 fb^{-1}	Extrap.
$t \to gc$	1×10^{-5}	ATLAS $qg \to t \to Wb$	300 fb^{-1},	Extrap.
$t \to gc$	4×10^{-6}	ATLAS $qg \to t \to Wb$	3000 fb^{-1}	Extrap.
$t \to hq$	2×10^{-3}	LHC $t\bar{t} \to Wb + hq \to \ell\nu b + \ell\ell qX$	300 fb^{-1}	Extrap.
$t \to hq$	5×10^{-4}	LHC $t\bar{t} \to Wb + hq \to \ell\nu b + \ell\ell qX$	3000 fb^{-1}	Extrap.
$t \to hq$	5×10^{-4}	LHC $t\bar{t} \to Wb + hq \to \ell\nu b + \gamma\gamma q$	300 fb^{-1}	Extrap.
$t \to hq$	2×10^{-4}	LHC $t\bar{t} \to Wb + hq \to \ell\nu b + \gamma\gamma q$	3000 fb^{-1}	Extrap.

Table 1: Projected 95% CL limits on top FCNC at the ILC/CLIC.

Process	Br Limit	Search	Dataset	Reference
$t \to Zq$	$5\,(2) \times 10^{-4}$	ILC single top, γ_μ ($\sigma_{\mu\nu}$)	500 fb^{-1}, 250 GeV	Extrap.
$t \to Zq$	$1.5\,(1.1) \times 10^{-4\,(-5)}$	ILC/CLIC single top, γ_μ ($\sigma_{\mu\nu}$)	500 fb^{-1}, 500 GeV	hep- ph/0102197
$t \to Zq$	$1.6\,(1.7) \times 10^{-3}$	ILC/CLIC $t\bar{t}$, γ_μ ($\sigma_{\mu\nu}$)	500 fb^{-1}, 500 GeV	hep- ph/0102197
$t \to \gamma q$	6×10^{-5}	ILC single top	500 fb^{-1}, 250 GeV	Extrap.
$t \to \gamma q$	6.4×10^{-6}	ILC/CLIC single top	500 fb^{-1}, 500 GeV	hep- ph/0102197
$t \to \gamma q$	1.0×10^{-4}	ILC/CLIC $t\bar{t}$	500 fb^{-1}, 500 GeV	hep- ph/0102197