$t\bar{t}\rightarrow 2l$ and single top with CMS

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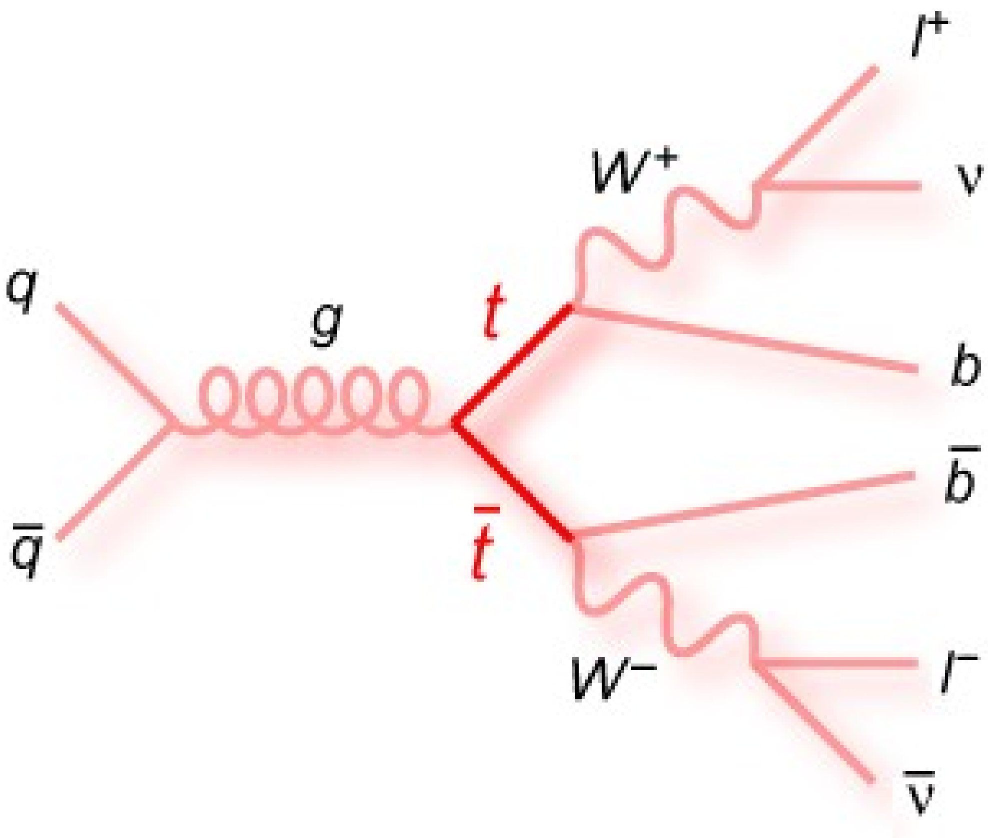
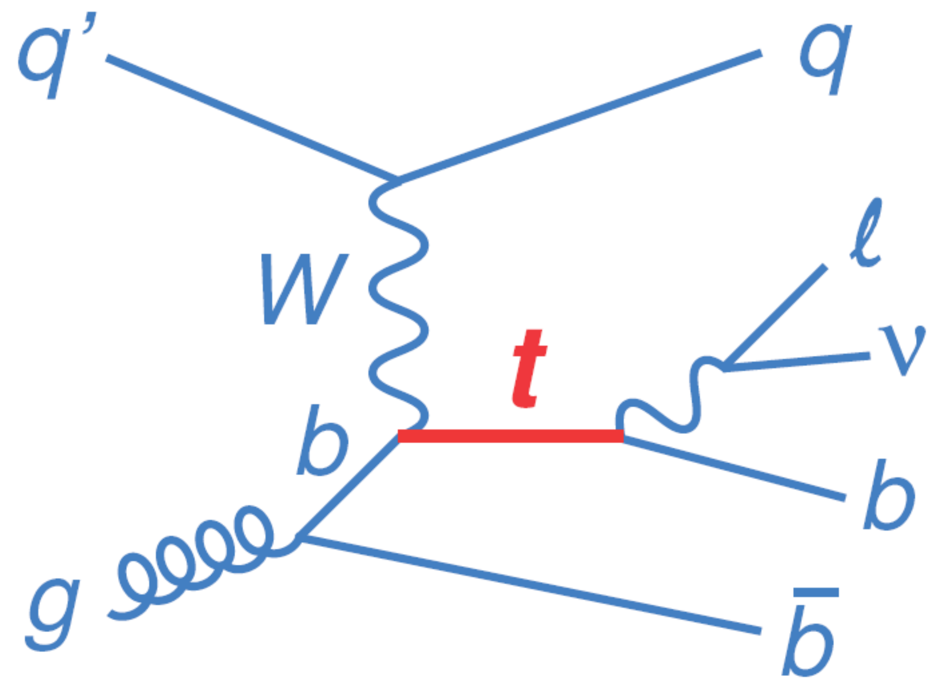
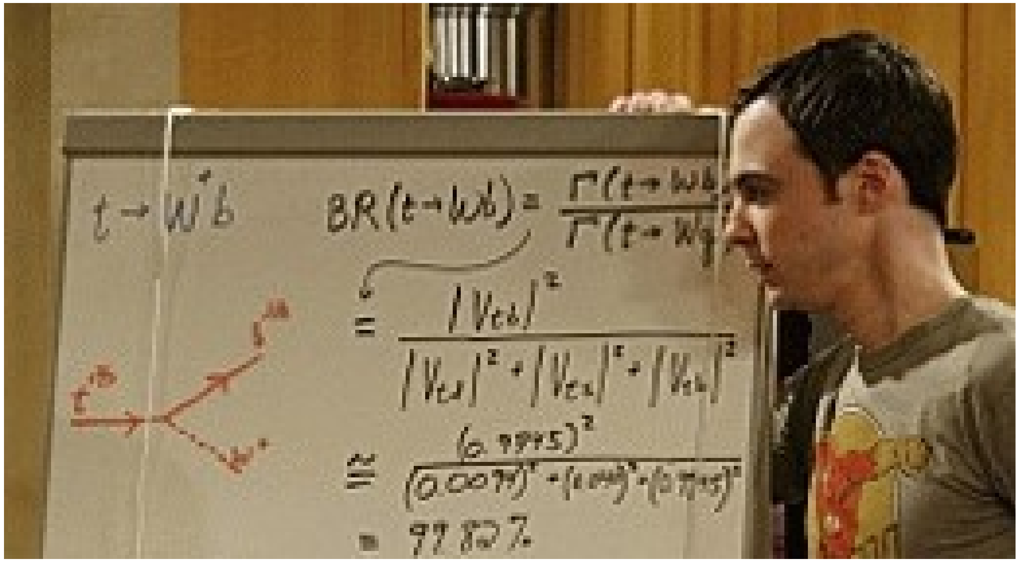




Lisbon, 13 March 2009

Outline

- **Introduction**
- **A motivation in common**
- **$t\bar{t}\rightarrow 2l$**
- **$tW\rightarrow 2l$, $1l$**
- **$tbj\rightarrow 1l$**



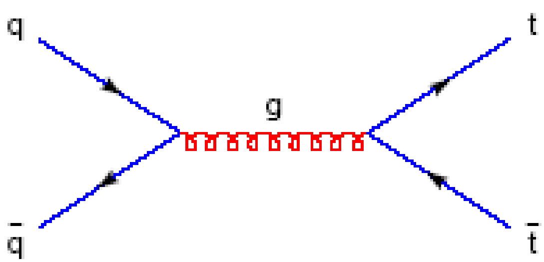
I will mostly base my talk on officially approved CMS results, showing a couple of “work in progress” plots/tables when really needed to make a point.

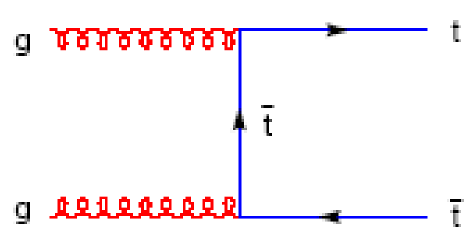
For **$t\bar{t}\rightarrow 2l$**, the most recent public results are at 14 TeV, from **TOP2008**; analysis at 10 TeV is ongoing, with a more complete background list (relevant for this discussion!).

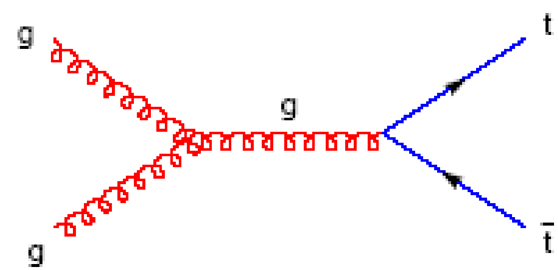
For **single top**, the most recent public results are from the **TDR (2006)**, assuming 14 TeV, 10 fb^{-1} on tape, ideal detector. An analysis at 14 TeV with early-data assumptions is now available as internal document, and the same analysis at 10 TeV is ongoing and will try to become public soon.

LHC is a top-quark factory
(with several production lines)

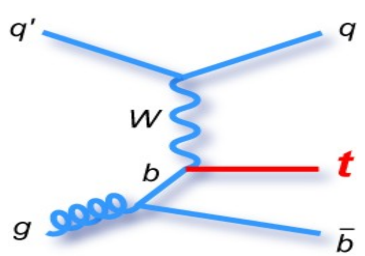
- $t\bar{t}$: gluon fusion (~90%) or $q\bar{q}$ annihilation (~10%)
  $\sigma_{NLL} = 833^{+52}_{-39}$ pb



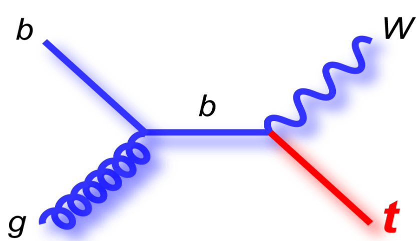




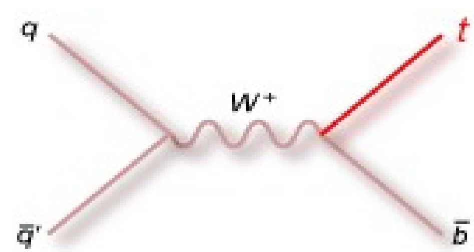
- Electroweak production (“single top”) is not negligible:



t-channel (tbj)
(σ_{SM} ~ 240pb)

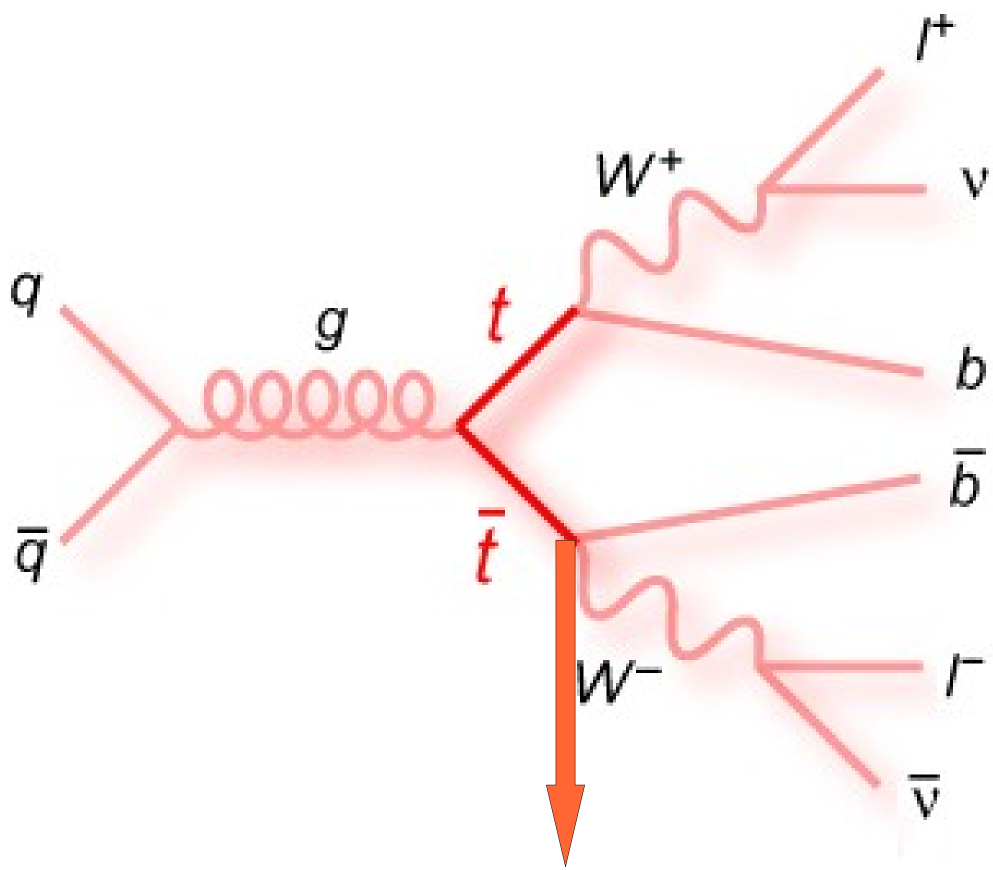


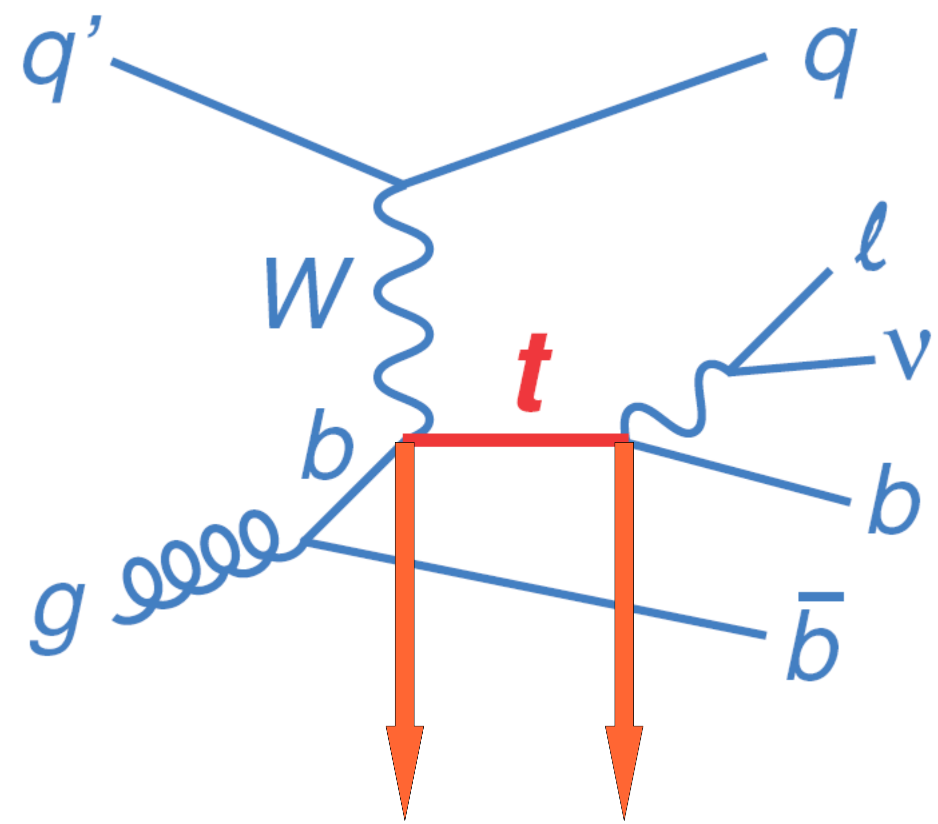
tW production
(σ_{SM} ~ 60pb)



s-channel
(σ_{SM} ~ 10pb)

Probing the *Wtb* coupling





R = BR(t→Wb) / BR(t→Wq), q: any

see talk by Pedro Silva

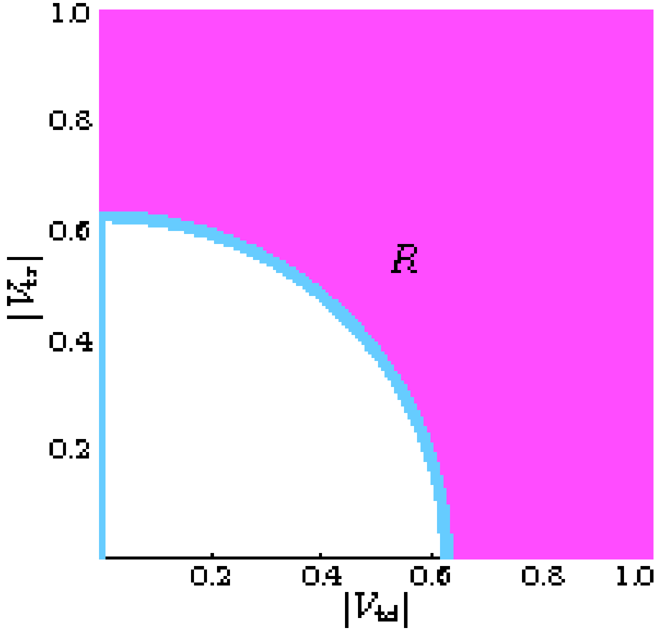
$\sigma(|V_{tb}|^2)\cdot R$

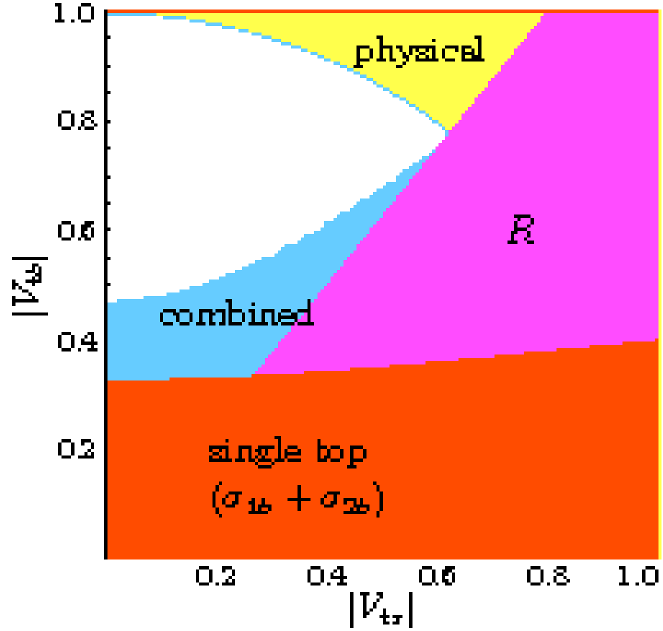
$$R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{td}|^2 + |V_{ts}|^2}$$

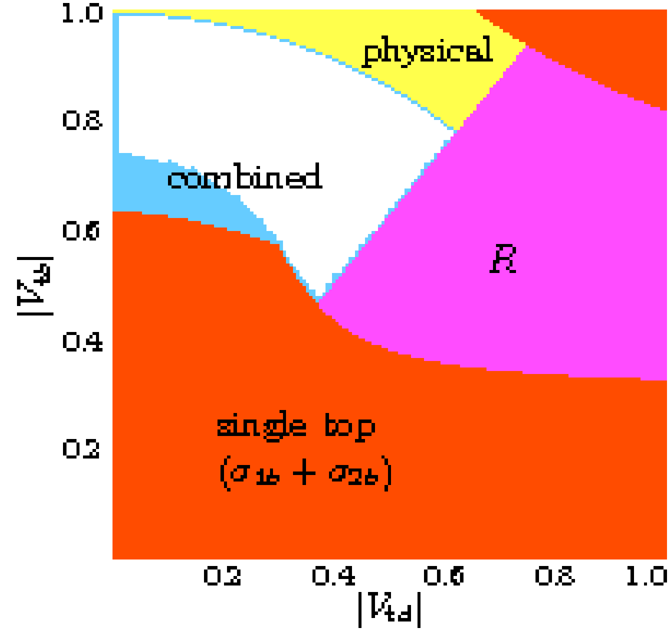
σ(obs)/σ(SM) ≠ $|V_{tb}|^2$, unless you assume **R~1** independently of V_{tb}

- *d,s→t* play a role for R<1: *d(x),s(x)>>b(x)*
- MVAs at CDF/D0 trained for SM kinematics

V_{ti} from R and single top



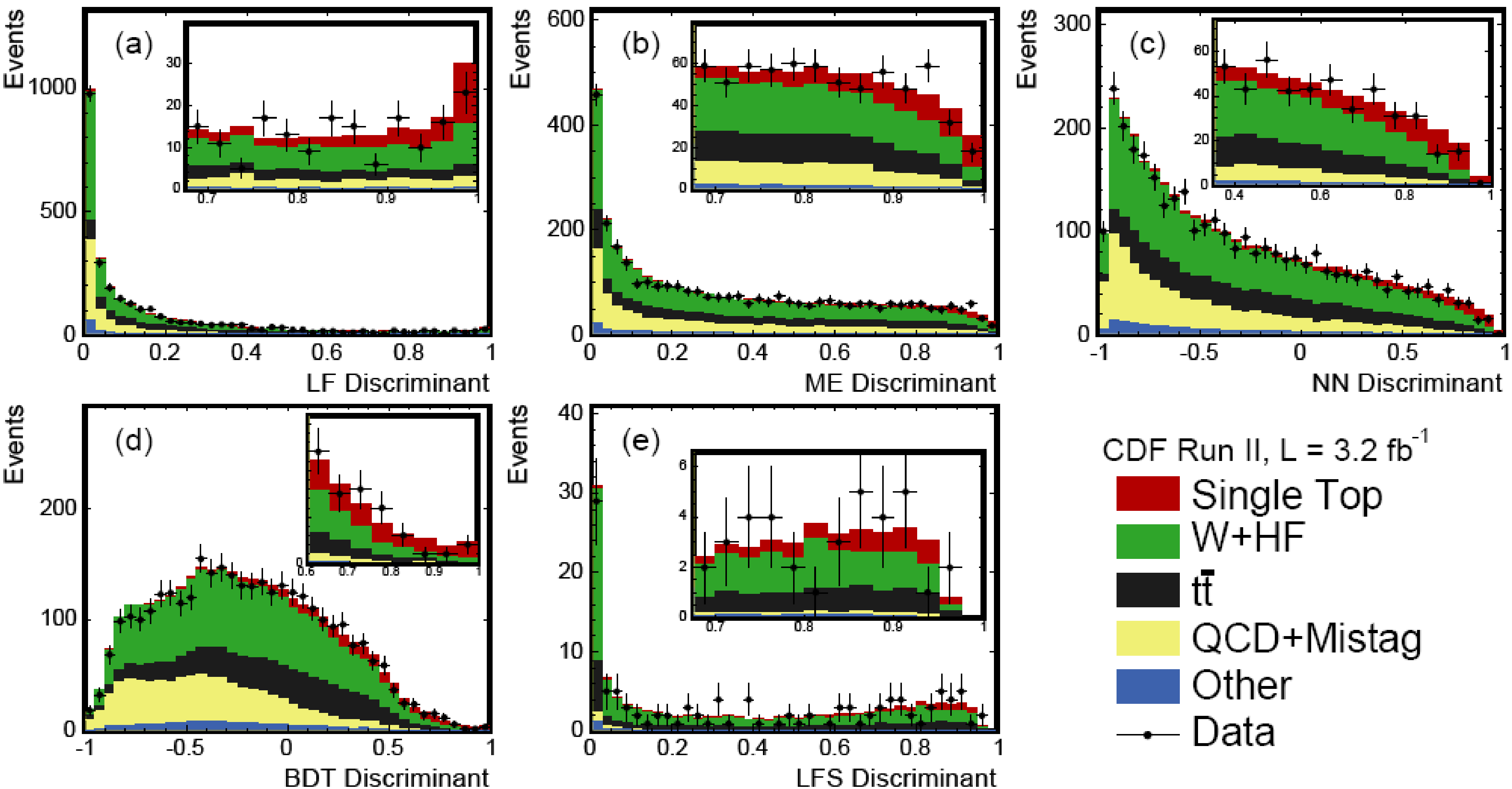




from hep-ph/0607115 (EPJ C 2007), using 2006 data on single top and R (updated in arXiv:0801.1800 [hep-ph]), and **no unitarity constraint**

...but as soon as you specify a possible extension to SM, EW-/B-physics tightly constrains the effective CKM elements!
Nevertheless, in **SM+t'** and in **SM+4th family**, **V_{tb}~0.9** is allowed.

Single top: hot news from Tevatron



5σ evidence from both CDF (3.2/fb) and D0 (2.3/fb) for signal defined as the sum of *t* and *s* channels (tW negligible)

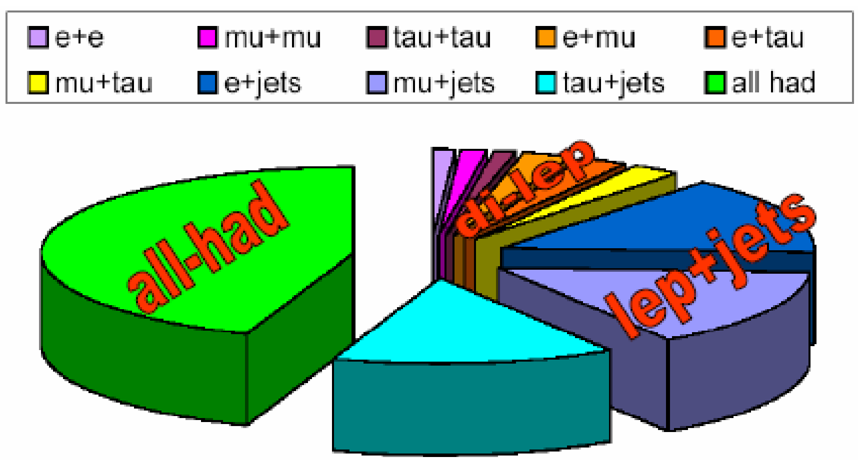
From Tevatron to LHC

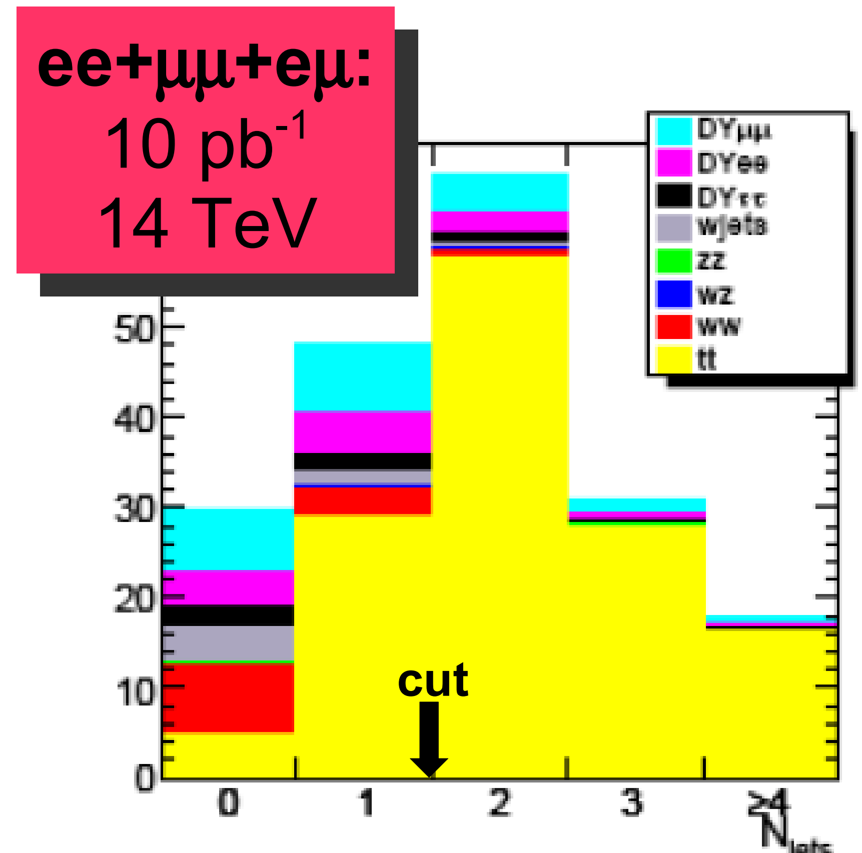
	1.96 TeV	14 TeV	
ttbar pairs	6.7±0.7 pb	833^{+52}_{-39} pb	(x120)
Single top (s-channel)	0.88±0.06 pb	10.7±0.7 pb	(x10)
Single top (t-channel)	1.98±0.14 pb	247±10 pb	(x120)
Single top (tW channel)	0.15±0.04 pb hopeless	66±2 pb "announced discovery"	(x400)
Wjj (*)	~1200 pb	~7500 pb	(x6)
bb+other jets (*)	$\sim 2.4 \times 10^5$ pb	$\sim 5 \times 10^5$ pb	(x2)

(*) with kinematic cuts in order to better mimic single top
Belyaev, Boos, and Dudko [hep-ph/9806332]

Early LHC data: how to discover the first european top quarks

- Despite the small BR, the 2l final states are the golden channel for the early reobservation of the top quark
- 1l suffers from W+jets and QCD bkg's





CMS AN 2008/015: In start-up analyses, we don't rely on b-tagging (very sensitive to misalignment), and minimally on MET (only ee/μμ). MC includes different misalignment/miscalibration scenarios.

CMS AN 2008/017: As above, but no Calorimetric info at all: only tracks are used to build jets and some topological variables.

Single top contamination to $t\bar{t} \rightarrow 2l$

- Unfortunately single top samples were not available at the time of TOP2008
  - Common wisdom was that single-top contamination would have been negligible
- It turned out that it is the dominant background!
  - Even after requiring 2 b-tags
    - Culprit: $tW \rightarrow 2l$; all other single top contributions are small
  - Luckily the signal purity is still very high
    - $\sigma(tW)/\sigma(tt) \sim 1/12$ before any selection
  - But this contamination has to be handled with care in precision measurements (e.g., R...)

At 10 TeV (work in progress)

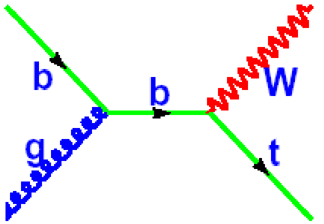
sample	nJet = 0	nJet = 1	nJet >= 2
TT->emu	1.7 +/- 0.1	11.7 +/- 0.2	35.6 +/- 0.4
tt->NonDil	0.0 +/- 0.0	0.0 +/- 0.0	0.5 +/- 0.0
WW	4.1 +/- 0.1	1.3 +/- 0.1	0.5 +/- 0.0
WZ	0.3 +/- 0.0	0.4 +/- 0.0	0.2 +/- 0.0
ZZ	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0
W+Jets	2.5 +/- 0.4	0.9 +/- 0.2	0.3 +/- 0.1
DYtautau	1.4 +/- 0.2	1.8 +/- 0.3	0.7 +/- 0.2
DYee	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0
DYmm	0.3 +/- 0.1	0.2 +/- 0.1	0.1 +/- 0.1
ppMuX	0.1 +/- 0.1	0.3 +/- 0.2	0.1 +/- 0.1
EM	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0
tW	0.5 +/- 0.0	2.0 +/- 0.1	1.4 +/- 0.1
VQQ	0.1 +/- 0.0	0.2 +/- 0.0	0.0 +/- 0.0

Handle: lepton quality cuts

ee+μμ+eμ:
10 pb^{-1}
10 TeV

CMS NOTE 2006/086

Single top: tW extraction



($\sigma_{SM} \sim$ 60pb)

Selection (2l):

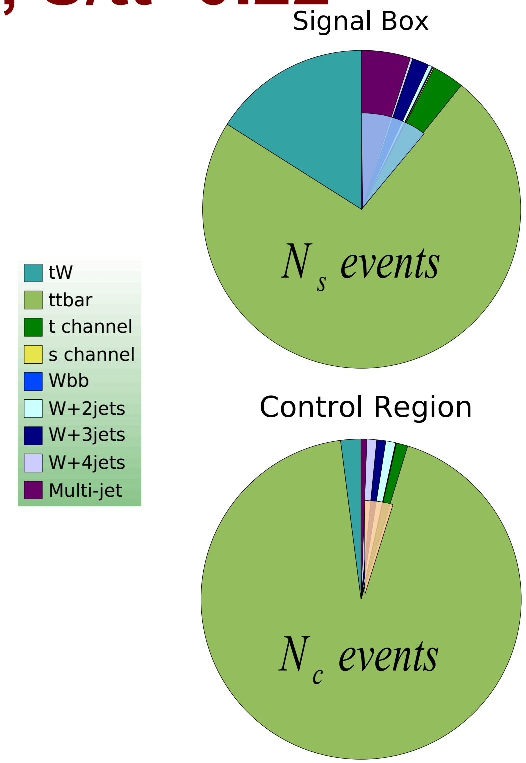
- $1e+1\mu$ (isolated), MET
- 1 jet, b-tagged
- **S/B=0.35, S/tt=0.39**

In both cases, almost all the surviving background is ttbar; normalization over data (control samples with one more jet, in both channels) cancels out most, but not all, of the systematics.

Selection (1l):

- $1 e/\mu$ (isolated), MET
- 3 jets, 1 b-tagged
- Cuts on M_T^W, M(jj), M_{top} and other topological variables
- **S/B=0.18, S/tt=0.22**

10 fb^{-1}
14 Tev

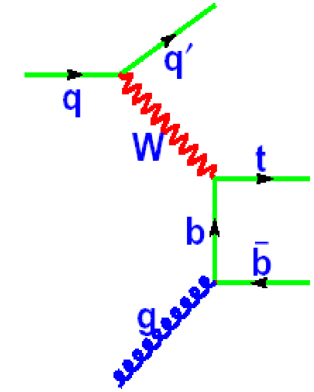


$\Delta\sigma/\sigma$ (2l)=8.8%(stat)+23.9%(syst)+5%(lumi)

$\Delta\sigma/\sigma$ (1l)=7.5%(stat)+16.8%(syst)+5%(lumi)

CMS NOTE 2006/084

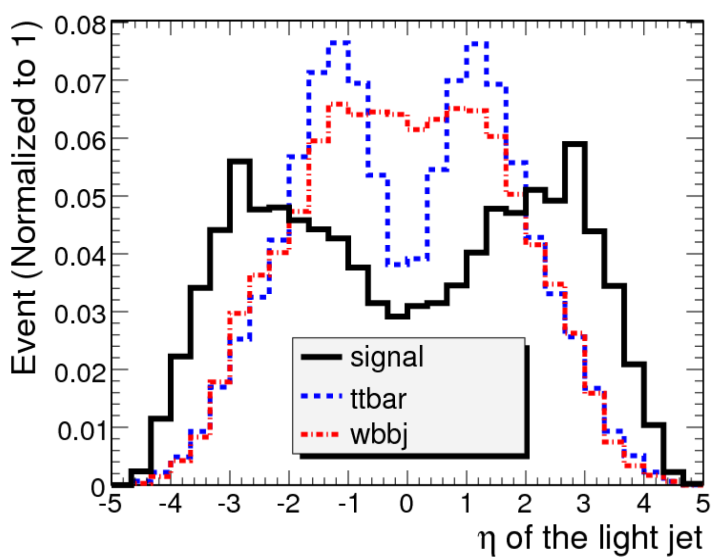
Single top: t channel (tbj)



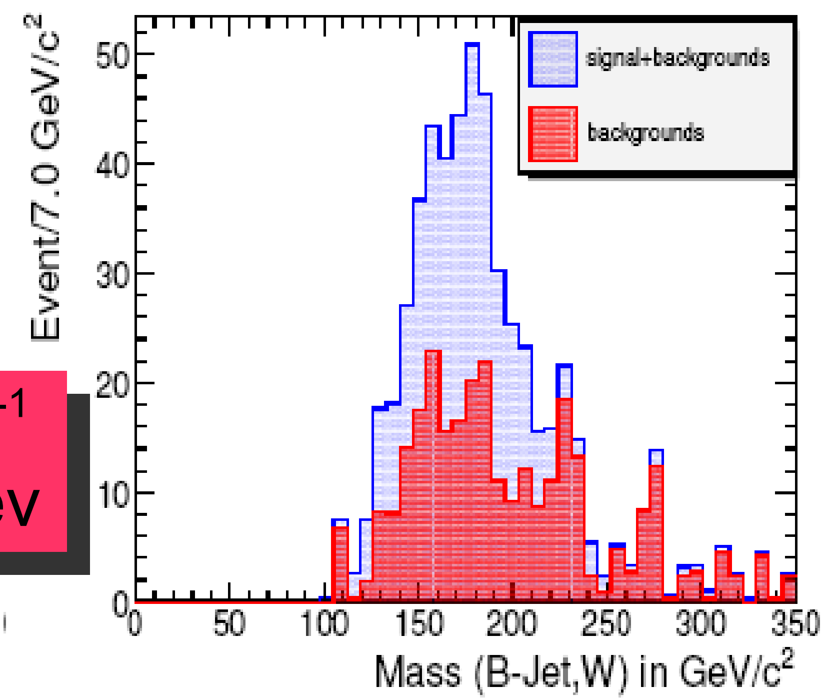
(σ_{SM} ~ 240pb)

Selection:

- 1 muon (isolated), MET (corrected), 2 jets
- 1 jet b-tagged and central, 1 jet forward
- Cuts on M_T^W and M(lνb)
- **S/B=1.3, S/tt=2.0**



10 fb^{-1}
14 Tev

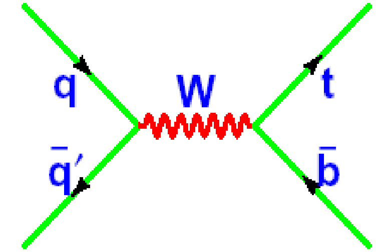


$\Delta\sigma/\sigma$ = 3% (stat) + 8% (syst) + 5% (lumi) = 10% @10fb^{-1}

→ $\Delta V_{tb}/V_{tb}$ ~ 5%; sufficient to constrain minimal SM extensions

CMS NOTE 2006/084

Single top: s channel (tb)



($\sigma_{SM} \sim$ 10pb)

10 fb^{-1}
14 Tev

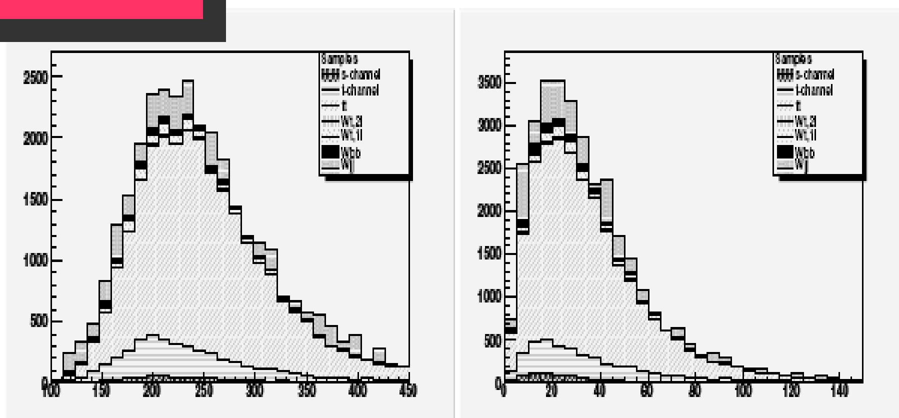


Figure 13: Distribution of the scalar (left) and of the vectorial (right) sum in the transverse plane of the momenta of the lepton, of the $\not{E}_T$ and of the two b-jets.

Selection:

- 1 e/μ (isolated), MET)
- 2 jets, both b-tagged
- Cuts on Σ_T, M_T^W, M_{top} and other topological variables
- **S/B=0.13, S/tt=0.22**

A normalization over data is crucial (two control samples: one for $t\bar{t}$->1l, one for $t\bar{t}$->2l) in order to keep under control the tt background and cancel most of the systematics. What remains is mostly due to the JES systematic alone.

$\Delta\sigma/\sigma$ = 18% (stat) + 31% (syst) + 5% (lumi) = 36% @10fb^{-1}

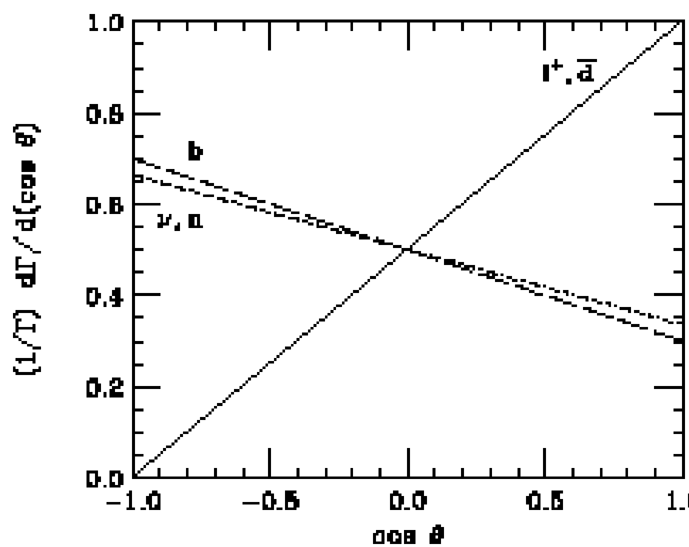
Backgrounds to single top

- The current single top selection (not public yet, sorry) is an analysis aiming at the rediscovery in the most favourable channel: tbj
- Before b tagging, W+jets and QCD are a trouble; applying a tight threshold, these can be greatly reduced, and $t\bar{t}$ remains as main bkg
- This is true for all 3 single-top modes, but in particular for tW
- A crucial analysis element for all 3 processes is the control of this background: $t\bar{t}$-enriched orthogonal control samples

Strategies for tt/tbj separation

- Charge asymmetry:
  - tbj,tb: initial state has more often a u than a d
  - => $N_t > N_{\bar{t}}$
  - => Excess of l^+ over l^-
  - QCD, $t\bar{t}$, tW are symmetric
  - W+jets is asymmetric, but its σ and asymmetry will be quickly extracted from data
  - Measured W asym. → PDF constraint → infer tbj asym. → σ(tbj) from N_{l+}-N_{l-}

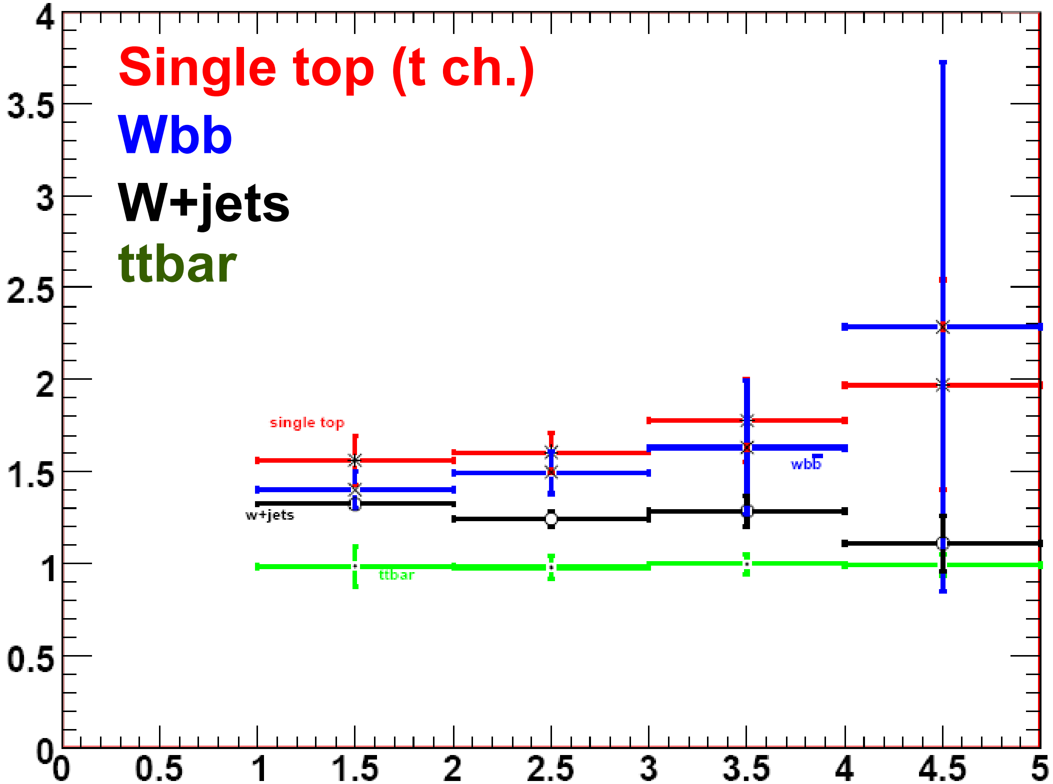
- Top polarization:
  - tbj,tb: 100% polarization
  - 100% inherited by lepton
  - Angle btw lepton and recoil jet in the top rest frame:



  - $t\bar{t}$ is flat

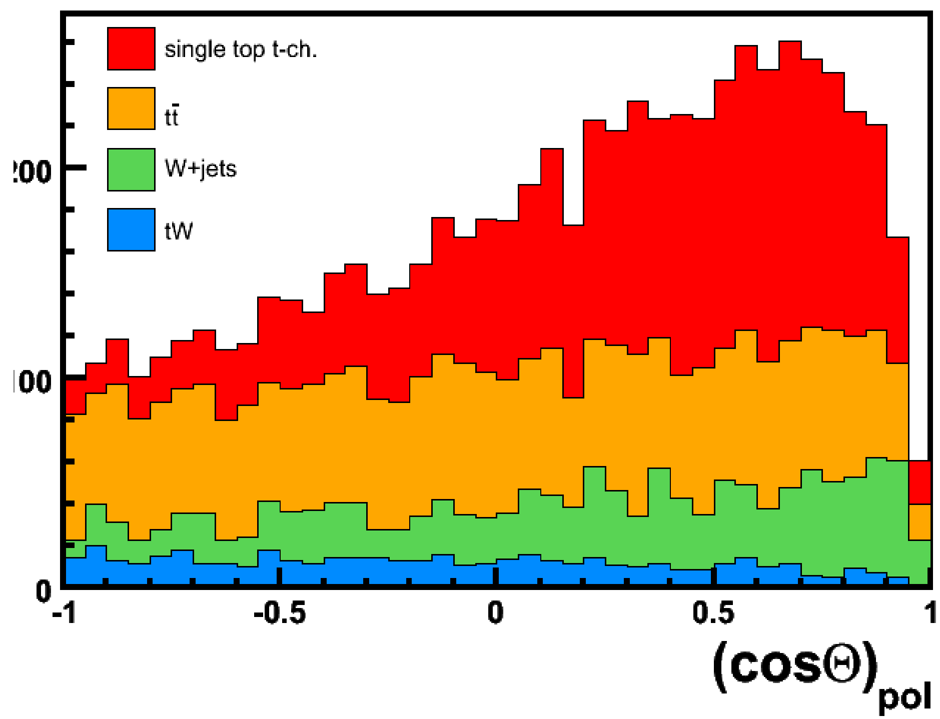
Some work in progress:

- Charge ratio:



  - ~3σ w/ 1fb^{-1}, @14 & 10 TeV
  - W constrained from the 1j bin

- Top polarization:

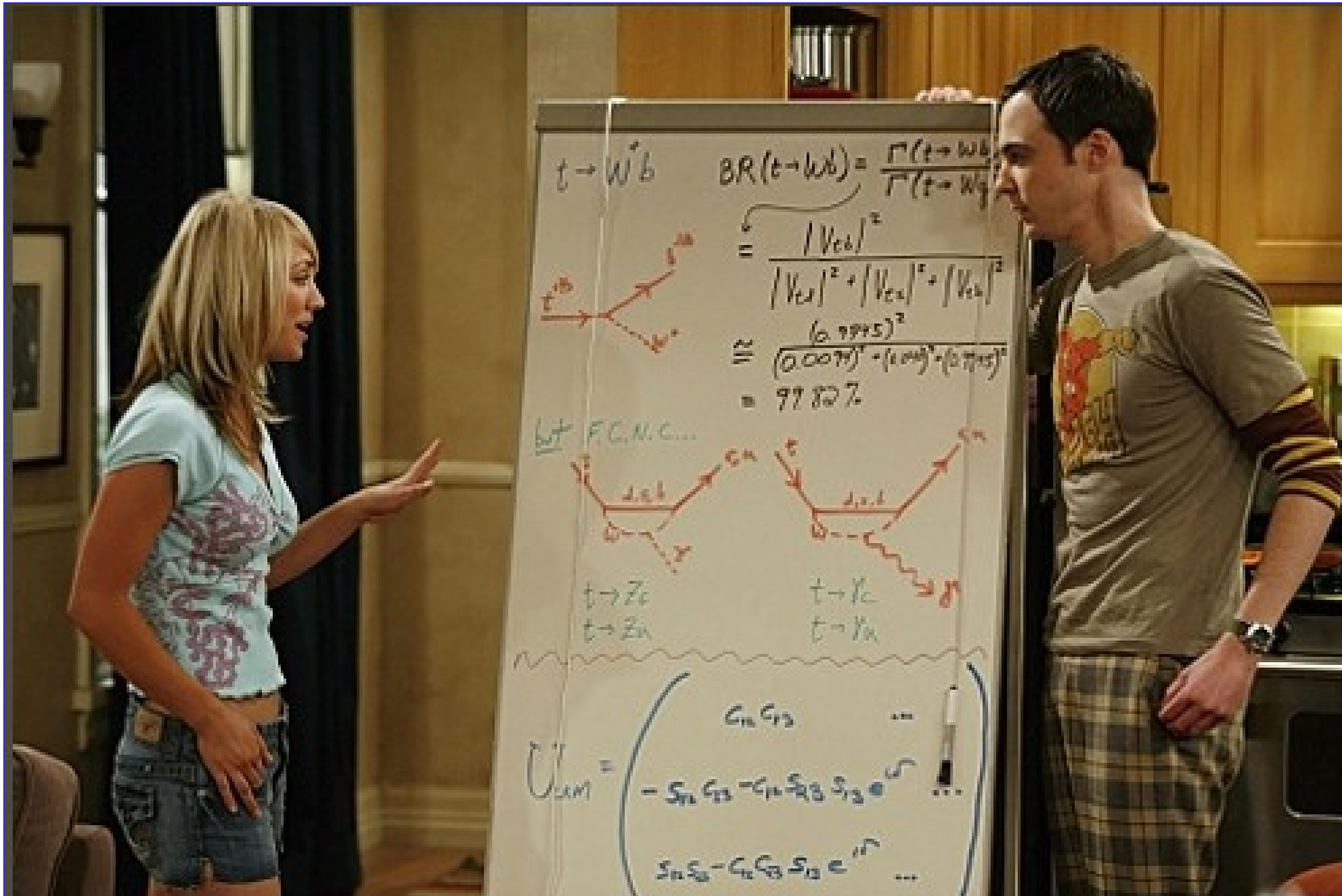


  - Note: once you constrain the bkg's independently, the offset measures new physics contributions!

Conclusions

- Precise measurements of single-top events are a powerful probe for physics beyond the SM
  - Recent 5σ evidence from Tevatron
  - LHC analyses will be quite different
  - Goals: separation of the 3 channels, precise $\sigma \bullet R$ measurement, less reliance on SM assumptions
- For the purpose of $|V_{tb}|$ extraction, single-top cross-section(s) and R must be both measured
- Single top and $t\bar{t}$ will mutually contaminate each other, especially in the 2l final states
  - Simultaneous extraction?

BACKUP



V_{tb} in a 4x4 or 4x3 matrix

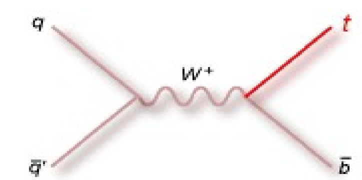
- SM, 3x3: $0.9990<|V_{tb}|<0.9992$ @90%CL
- Alwall et al., hep-ph/0607115 (EPJ C 2007) reexamined the direct and indirect experimental constraints when CKM is minimally extended to a 4^{th} family, or to a single b'/t'
- $V_{tb} \sim V_{tb}^{CKM}\cos\theta$; θ: t-t' mixing angle (u-t' and c-t' mixings are very tightly constrained); limits depend on $M_{t'}$ (Tevatron: $M_{t'}/M_t>1.5$)
- With 4^{th} family: $V_{tb}>0.93$
- With pseudo-vector t': $V_{tb}>0.91$

This sets a clear goal for the precision that we want to achieve on Vtb

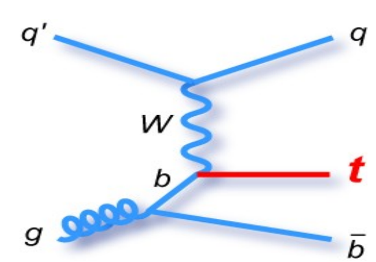
- Nota bene: here is assumed that no other particles exist; a more rich zoology at low energy can further relax the limits

Single Top and new physics

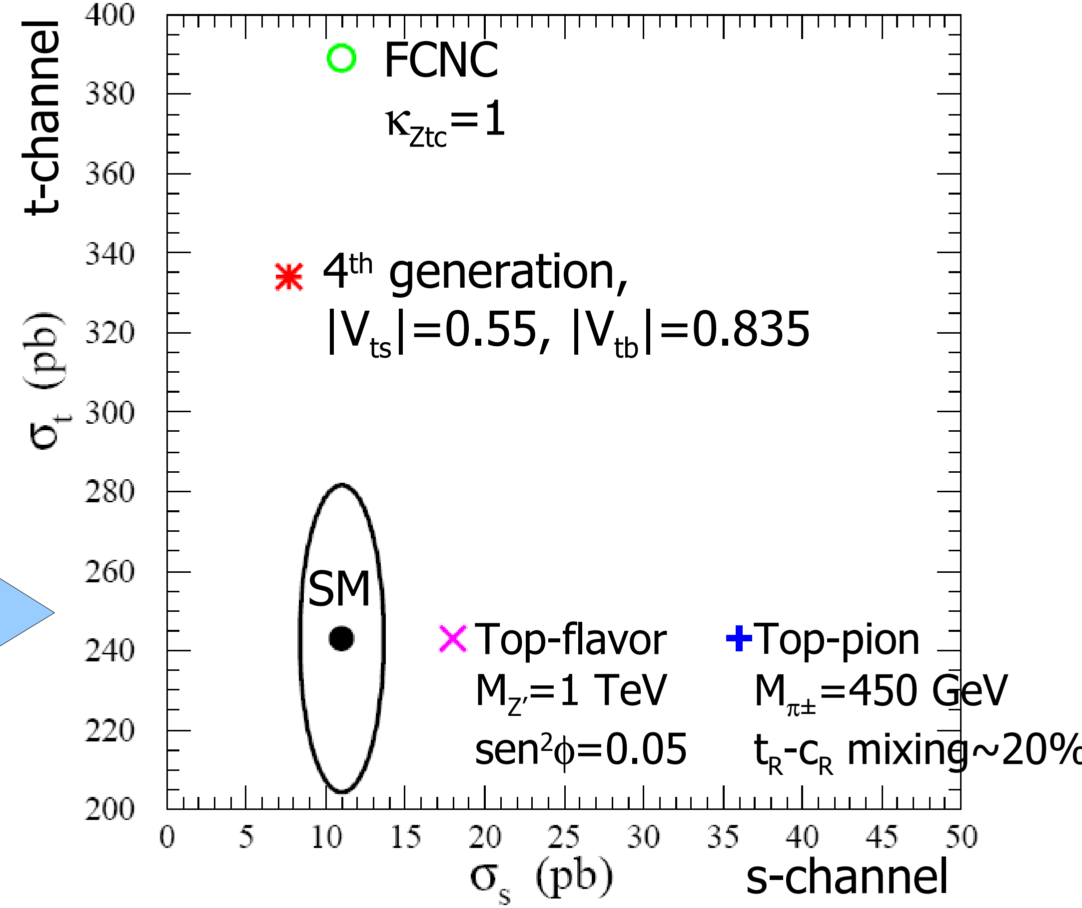
- t': if $M_{b'}>M_{t'}$, main decay is Wb
  - And for $M_{t'}>270$ GeV, the t'q production mode is favored over t't': enhancement of t-channel at high m(lνb) / high H_T
- W' (including W*, W_{KK}, ...) enhances the s-channel



  - If coupling is SM (e.g. W_{KK}), observation in leptonic decays much earlier than in single top...
  - ... but BR's are model dependent; in some models the coupling to lν is suppressed (W_R) / tb enhanced (W*)
- Any model with FCNC (e.g. SUSY) enhances t-channel: while SM needs a **b** in the initial state, FCNCs can have a **u** (and *u(x)>>b(x)* for our *x*'s)



Top measurements sensitive to New Physics

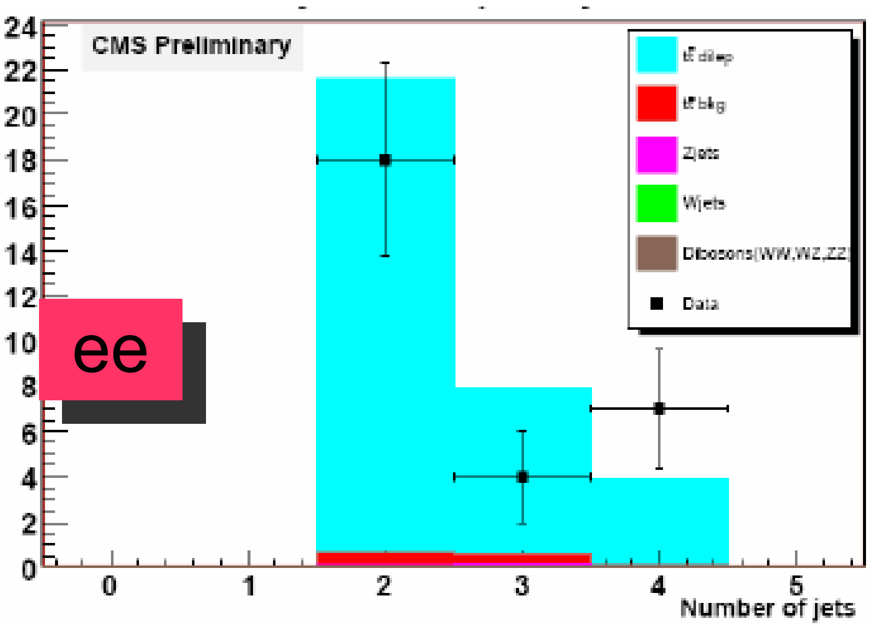


T.Tait, C.-P.Yuan, Phys.Rev. D63 (2001) 0140018

- Single top
- Rare decays
- “Impossible” topologies

Tt2l analysis in a 100 pb^{-1} scenario

- Misalignment now doesn't affect too much b-tagging performance
  - In particular the Track Counting algorithm: at least N tracks with IP/σ_{IP} > threshold
  - Here N=2 and threshold=2.3
  - Despite this being considered a loose cut, the effect on backgrounds is dramatic



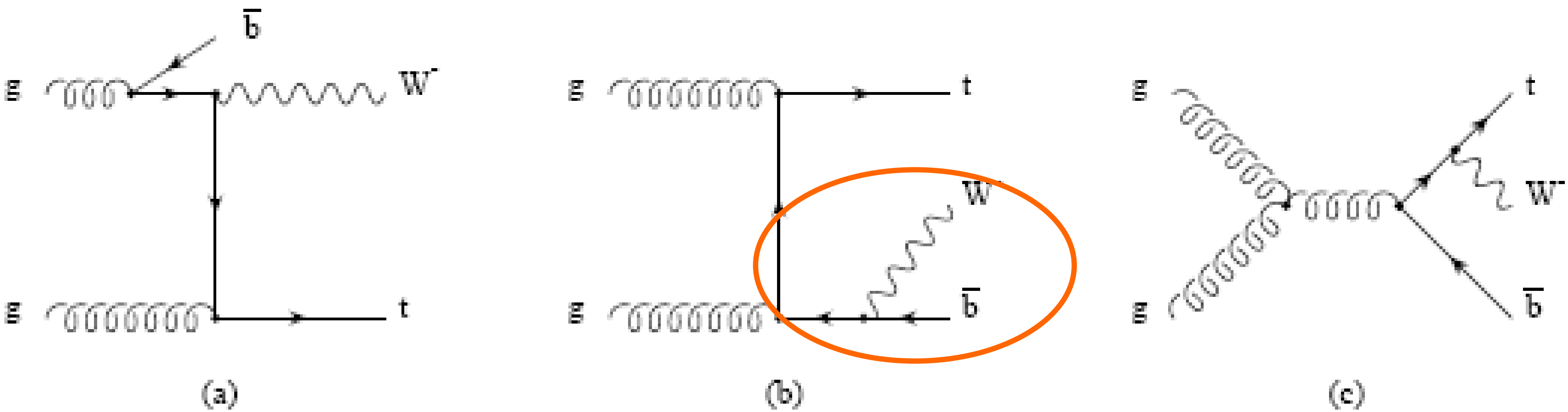
- MET is also used (>50 GeV)
- $\Delta\sigma/\sigma$(stat): 15% ee, 18% eμ, 11% $\mu\mu$

Maximize redundancy: alternative dileptonic analyses

- Standard top analyses rely to some extent on hadronic calorimetry; we explored two alternative approaches:
  - Method A (inclusive leptonic): very tight $e\mu$ selection, with very high pT thresholds; very few events survive, and ttbar is the dominant component (bkg: WW, DY$\rightarrow\tau\tau$)
  - Method B (track-based): like a standard selection, but with TrackJets instead of CaloJets, Σp_T(tk) instead of H_T, etc...
- The rationale is robustness against anything like "one noisy cell giving randomly a large fake signal"
  - This would affect many global variables: Njets, H_T, MET
  - (Symmetric goal, i.e. robustness against Tracker faults, is naturally achieved by any standard analysis w/out b-tag)

Wt/tt interference

Problem: At NLO, Wt mixes with tt.
A MC-friendly definition of tW is needed in order to avoid double counting.
Solution (Les Houches 2005): The full set of gg→btW diagrams is left out and Wt is DEFINED by a b-jet veto.
Already implemented in MCFM.



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Tait, Phys.Rev. D61 (2000) 034001

Boos and Belayev, Phys.Rev. D63 (2001) 034012

Campbell and Tramontano, Nucl.Phys. B726 (2005) 109-130