top FCNC after the LHC

Rui Santos

(U. Southampton)

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In collaboration with R. Guedes and M. Won

Outline

1. Why top FCNC?
2. A framework for top FCNC physics – the effective operator approach
3. The story so far I – LEP, Hera and the Tevatron
4. The story so far II – limits from B physics
5. The future (at the LHC)
6. Is there top FCNC left to explore?
7. Conclusion

1.Why top FCNC

Process	SM	QS	2HDM	MSSM	$\not{R}$ SUSY	TC2
$t \to uZ$	$\mathcal{O}(10^{-17})$	$\mathcal{O}(10^{-4})$	–	$\mathcal{O}(10^{-6})$	$\mathcal{O}(10^{-5})$	$\mathcal{O}(10^{-5})$
$t \to u\gamma$	$\mathcal{O}(10^{-16})$	$\mathcal{O}(10^{-9})$	–	$\mathcal{O}(10^{-6})$	$\mathcal{O}(10^{-6})$	$\mathcal{O}(10^{-5})$
$t \to ug$	$\mathcal{O}(10^{-14})$	$\mathcal{O}(10^{-7})$	–	$\mathcal{O}(10^{-5})$	$\mathcal{O}(10^{-4})$	$\mathcal{O}(10^{-5})$
$t \to cZ$	$\mathcal{O}(10^{-14})$	$\mathcal{O}(10^{-4})$	$\mathcal{O}(10^{-7})$	$\mathcal{O}(10^{-6})$	$\mathcal{O}(10^{-5})$	$\mathcal{O}(10^{-5})$
$t \to c\gamma$	$\mathcal{O}(10^{-14})$	$\mathcal{O}(10^{-9})$	$\mathcal{O}(10^{-6})$	$\mathcal{O}(10^{-6})$	$\mathcal{O}(10^{-6})$	$\mathcal{O}(10^{-5})$
$t \to cg$	$\mathcal{O}(10^{-11})$	$\mathcal{O}(10^{-7})$	$\mathcal{O}(10^{-4})$	$\mathcal{O}(10^{-5})$	$\mathcal{O}(10^{-4})$	$\mathcal{O}(10^{-5})$

Any hint of FCNC related to the top is a signal for new physics

2. DIY
- a minimal set of effective operators for top physics

1. Write all possible dimension 6 operators that have at least one top quark

Complete list of dimension 6 effective operators:
Buchmüller e Wyler, *Nucl. Phys.* B268 (1986) 621.

2. Use equations of motion to further reduce the number of operators

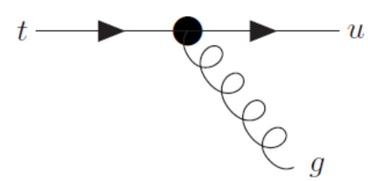
$$\mathcal{O}^L_{itG} = i\frac{\alpha^{S,L}_{it}}{\Lambda^2}\,\bar{q}^i_L\;\lambda^a\gamma_\mu D_\nu q^3_L\,G^{a\mu\nu}$$

$$\mathcal{O}^R_{itG} = i\frac{\alpha^{S,R}_{it}}{\Lambda^2}\,\bar{u}^i_R\;\lambda^a\gamma_\mu D_\nu t_R\,G^{a\mu\nu}$$

$$\mathcal{O}_{itG\phi} = \frac{\beta^S_{it}}{\Lambda^2}\;(\bar{q}^i_L\;\lambda^a\,\sigma^{\mu\nu}\,t_R)\;\tilde{\phi}\,G^a_{\mu\nu}$$

$$\mathcal{O}^L_{itG} = F^L\,(\mathcal{O}_{itG\phi},\,(\mathcal{O}_{itG\phi})^\dagger,\,\mathcal{O}_{NC},\,\mathcal{O}_{4F})$$

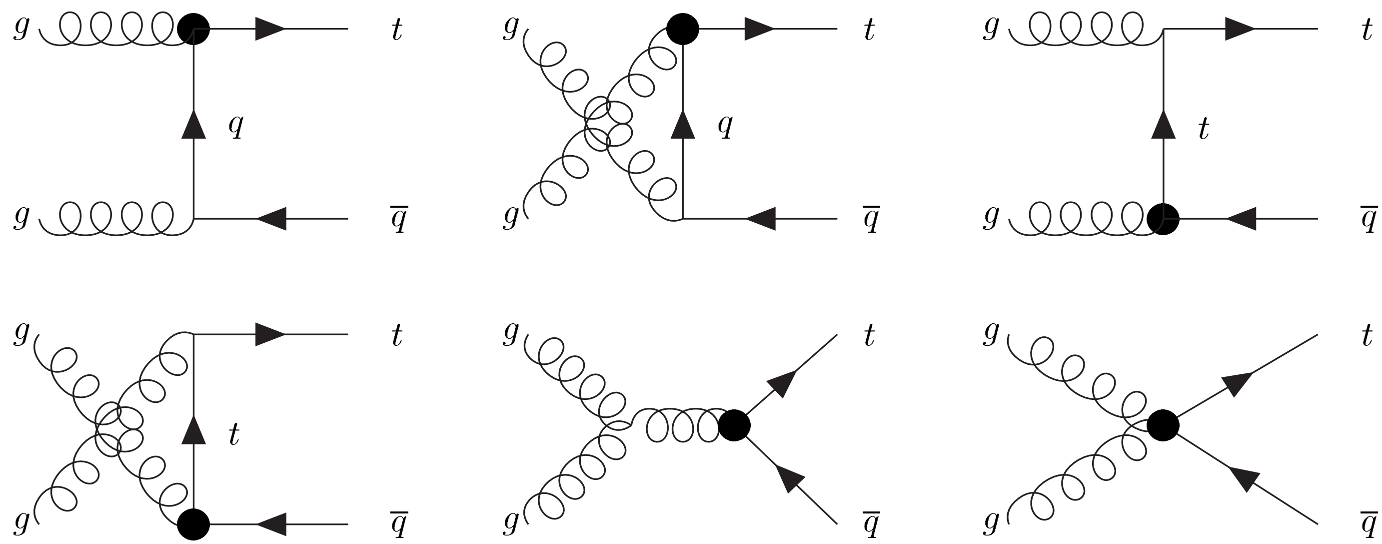
$$\mathcal{O}^R_{itG} = F^R\,(\mathcal{O}_{itG\phi},\,(\mathcal{O}_{itG\phi})^\dagger,\,\mathcal{O}'_{4F})$$



If there are no 4-fermion operators involved in the physical process we can keep one type of operator only!

Now let us see this happening!

3a. without 4F operators (contribution to pp → tj)

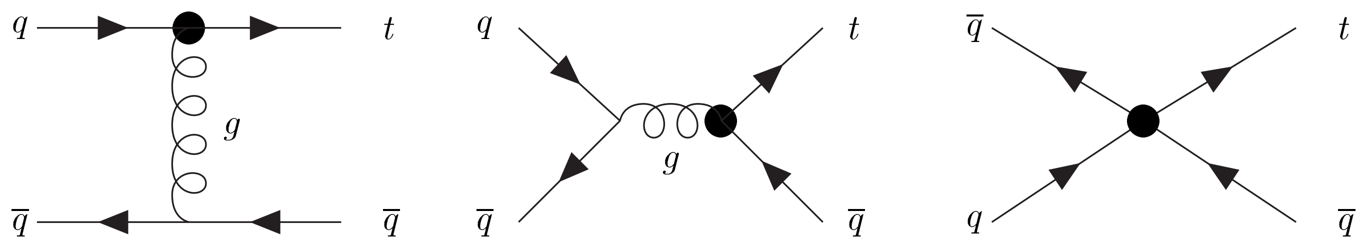


$$\frac{d\sigma(g\,g \to t\,\bar{u})}{dt} = -\frac{g_s^2}{4\,m_t^3}\,\frac{F_{gg}}{u\,t\,s^3\,(s+t)^2\,(s+u)^2}\,\Gamma(t \to u\,g)$$

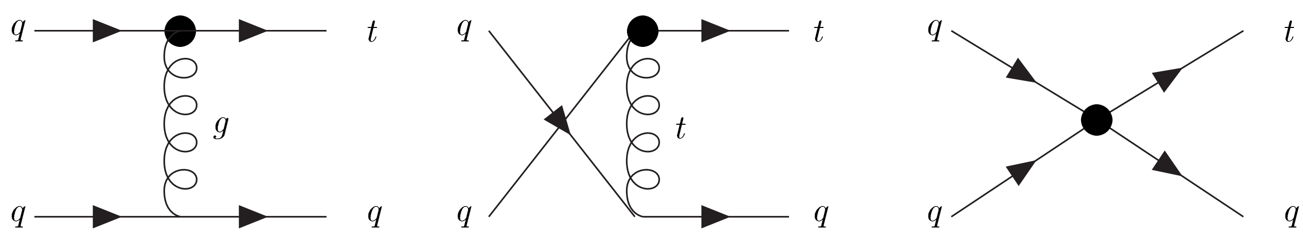
$$\begin{aligned} F_{gg} = {} & 4\,s^2\,t\,(s+t)^3\,(s^2+2\,s\,t+2\,t^2) + s\,(s+t)^2\,(4\,s^4+11\,s^3\,t+48\,s^2\,t^2+52\,s\,t^3+18\,t^4)\,u \\ & + 2\,(s+t)\,(10\,s^5+27\,s^4\,t+69\,s^3\,t^2+90\,s^2\,t^3+45\,s\,t^4+9\,t^5)\,u^2 \\ & + (s+t)\,(44\,s^4+115\,s^3\,t+203\,s^2\,t^2+162\,s\,t^3+36\,t^4)\,u^3 \\ & + 2\,(26\,s^4+85\,s^3\,t+135\,s^2\,t^2+99\,s\,t^3+27\,t^4)\,u^4 + 4\,(2\,s+t)\,(4\,s^2+9\,s\,t+9\,t^2)\,u^5 \\ & + 2\,(4\,s^2+9\,s\,t+9\,t^2)\,u^6 \end{aligned}$$

3b. with 4F operators (contribution to pp → tj)

$q\,\bar{q} \to t\,\bar{q}$



$q\,q \to t\,q$



$$\sigma^{(u)}_{4F} = [32|\alpha_{ut}|^2 + 32|\alpha_{tu}|^2 - 19\,\mathrm{Re}(\alpha_{ut}\alpha_{tu}) + 90\,\mathrm{Im}(\alpha_{ut}\beta_{tu}) - 90\,\mathrm{Im}(\alpha_{tu}\beta^*_{tu}) + 178(|\beta_{tu}|^2 + |\beta_{ut}|^2)$$
$$- 21\,\mathrm{Re}(\alpha_{ut}\gamma_{u_1}) + 21\,\mathrm{Re}(\alpha_{tu}\gamma^*_{u_1}) + \mathrm{Im}(\beta_{tu}\gamma^*_{u_1}) + 3\,\mathrm{Re}(\alpha_{ut}\gamma_{u_2}) - 1\,\mathrm{Re}(\alpha_{tu}\gamma^*_{u_2}) - \mathrm{Im}(\beta_{tu}\gamma^*_{u_2})$$
$$+ 56|\gamma_{u_1}|^2 + 26|\gamma_{u_2}|^2 + 35|\gamma_{u_3}|^2]\frac{1}{\Lambda^4}\ \mathrm{pb}$$

4-fermion operators spoil the beautiful proportionality to the BR

$$\mathcal{O}_{u_1} = \frac{g_s\,\gamma_{u_1}}{\Lambda^2}\,(\bar{t}\,\lambda^a\,\gamma^\mu\,\gamma_R\,u)\,(\bar{q}\,\lambda^a\,\gamma_\mu\,\gamma_R\,q) + \mathrm{h.c.}$$

$$\mathcal{O}_{u_2} = \frac{g_s\,\gamma_{u_2}}{\Lambda^2}\,[(\bar{t}\,\lambda^a\,\gamma_L\,u')\,(\bar{u}''\,\lambda^a\,\gamma_R\,u) + (\bar{t}\,\lambda^a\,\gamma_L\,d')\,(\bar{d}'\,\lambda^a\,\gamma_R\,u)] + \mathrm{h.c.}$$

$$\mathcal{O}_{u_3} = \frac{g_s\,\gamma^*_{u_3}}{\Lambda^2}\,[(\bar{t}\,\lambda^a\,\gamma_L\,u)\,(\bar{d}'\,\lambda^a\,\gamma_L\,d'') - (\bar{t}\,\lambda^a\,\gamma_L\,d)\,(\bar{d}'\,\lambda^a\,\gamma_L\,u'')] + \mathrm{h.c.}$$

4a. Total non-4F operators from electroweak sector

The equations of motion relate these operators with <u>4F ones</u> (in $\gamma\gamma$ world they do not have a say!)

$$\mathcal{O}_{tB} = i\frac{\alpha_{it}^{B,R}}{\Lambda^2}\,\bar{u}_R^i\;\gamma_\mu D_\nu t_R\,B^{\mu\nu}$$

$$\mathcal{O}_{qB} = i\frac{\alpha_{it}^{B,L}}{\Lambda^2}\,\bar{q}_L^i\;\gamma_\mu D_\nu q_L^3\;B^{\mu\nu}\quad,\qquad \mathcal{O}_{qW} = i\frac{\alpha_{it}^{W,L}}{\Lambda^2}\;(\bar{q}_L^i\;\tau_I\gamma_\mu D_\nu q_L^3)\;W_{\mu\nu}^I$$

$$\mathcal{O}_{tB\phi}^{RL} = \frac{\beta_{it}^B}{\Lambda^2}\;(\bar{q}_L^i\;\sigma^{\mu\nu}\;t_R)\;\tilde{\phi}\,B_{\mu\nu}\quad,\qquad \mathcal{O}_{tW\phi}^{RL} = \frac{\beta_{it}^W}{\Lambda^2}\;(\bar{q}_L^i\;\tau_I\;\sigma^{\mu\nu}\;t_R)\;\tilde{\phi}\,W_{\mu\nu}^I$$

$$\mathcal{O}_{tB\phi}^{LR} = \frac{\beta_{ti}^B}{\Lambda^2}\;(\bar{q}_L^3\,\sigma^{\mu\nu}\;u_R^i)\;\tilde{\phi}\,B_{\mu\nu}\quad,\qquad \mathcal{O}_{tW\phi}^{LR} = \frac{\beta_{ti}^W}{\Lambda^2}\;(\bar{q}_L^3\;\tau_I\;\sigma^{\mu\nu}\;u_R^i)\;\tilde{\phi}\,W_{\mu\nu}^I$$

2 + 2 constants

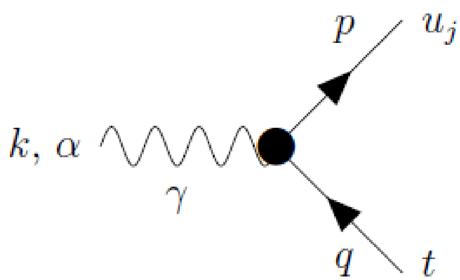
$$\mathcal{O}_{D_t} = \frac{\eta_{it}}{\Lambda^2}\;(\bar{q}_L^i\;D^\mu\,t_R)\;D_\mu\tilde{\phi}\quad,\quad \mathcal{O}_{\bar{D}_t} = \frac{\bar{\eta}_{it}}{\Lambda^2}\;(D^\mu\bar{q}_L^i\;t_R)\;D_\mu\tilde{\phi}$$

$$\mathcal{O}_{\phi_t}^R \;= i\,\theta_{it}^R\,(\phi^\dagger D_\mu\phi)\,(\bar{u_R^i}\gamma^\mu t_R)$$

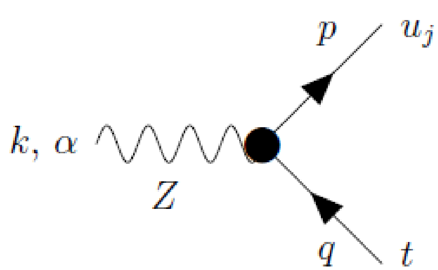
$$\mathcal{O}_{\phi(1)}^L \;= i\,\theta_{it(1)}^L\,(\phi^\dagger D_\mu\phi)\,(\bar{q_L^i}\gamma^\mu q_L^3)\quad,\quad \mathcal{O}_{\phi(3)}^L \;= i\,\theta_{it(3)}^L\,(\phi^\dagger D_\mu\tau_I\phi)\,(\bar{q_L^i}\gamma^\mu\tau_I q_L^3)$$

$3 \rightarrow 2$ constants

4b. Therefore for photon colliders the FCNC top interactions can safely be reduced to the following form



$$\frac{v}{\Lambda^2}\,\sigma_{\mu\nu}\,(\beta^{\gamma}_{jt}\gamma_R + \beta^{\gamma^*}_{tj}\,\gamma_L)(k^\mu\, g^{\nu\alpha} - k^\nu\, g^{\mu\alpha})$$



$$\frac{v}{\Lambda^2}\Big[i\,v\gamma_\alpha(\theta^R\,\gamma_R + \theta^L\,\gamma_L) + \sigma_{\mu\nu}\,(\beta^{Z}_{jt}\gamma_R + \beta^{Z^*}_{tj}\,\gamma_L)(k^\mu\, g^{\nu\alpha} - k^\nu\, g^{\mu\alpha})\Big]$$

5. … while for lepton colliders we add the 4F operators

$$\mathcal{M}_{4F} = \frac{1}{\Lambda^2}\sum_{i,j=L,R} V_{ij}(\bar{e}\gamma_\mu P_i e)(\bar{t}\gamma^\mu P_j c) + S_{ij}(\bar{e}P_i e)(\bar{t}P_j c) + T_{ij}(\bar{e}\sigma_{\mu\nu}P_i e)(\bar{t}\sigma^{\mu\nu}P_j c)$$

$$S_{LL} = S_{LR} = S_{RL} = T_{LL} = T_{LR} = T_{RL} = 0$$

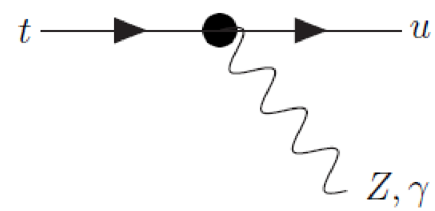
Bar-Shalom and Wudka, PRD60, 1999.

Operators and redundancy

$$O_1 + O_2 + O_{4F} = 0$$

$$O_{4F} = \bar{u}\gamma_\mu t\ (\bar{u}\gamma^\mu u + \bar{e}\gamma^\mu e)$$

If processes do not include 4F operators,



$$O_1 + O_2 = 0$$

Otherwise we can use

$$O_2 \quad \text{and} \quad O_{4F}$$

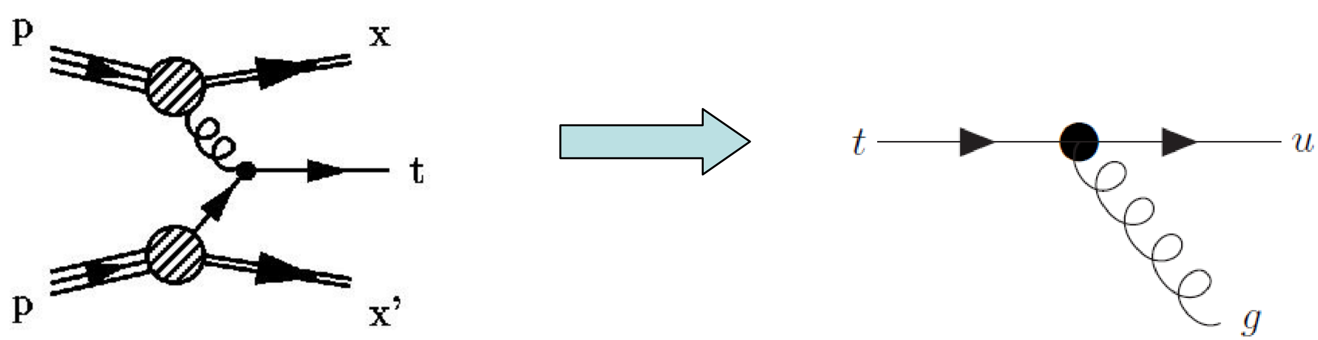
Aguilar-Saavedra, *Nucl. Phys.* B812, 2008.

3.The story so far I – LEP, Hera and the Tevatron

	LEP	HERA	Tevatron
$Br(t \to q\,Z)$	$< 7.8\%$	$< 49\%$	$< 3.7\%^{d}$
$Br(t \to q\,\gamma)$	$< 2.4\%$	$< 0.64\%(u)$	$< 3.2\%^{d}$
$Br(t \to q\,g)$	$< 17\%$	$< 13\%$	$< 0.045\%$

- Indirect limits – cross sections converted to branching ratios
- Direct limits – from top decays (Tevatron only)

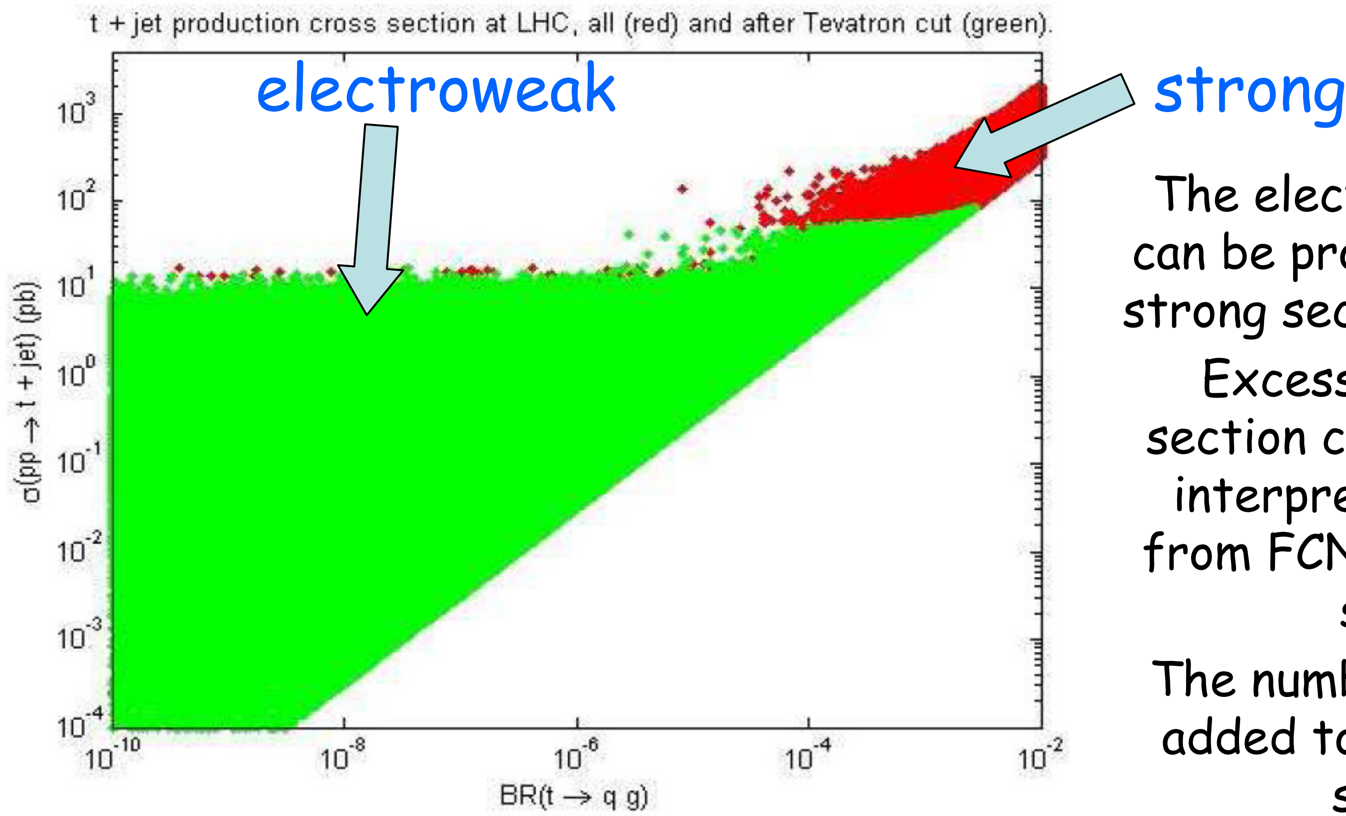
Do indirect limits have any meaning?



In the case of direct top production we can consider only one operator.

Indirect limits

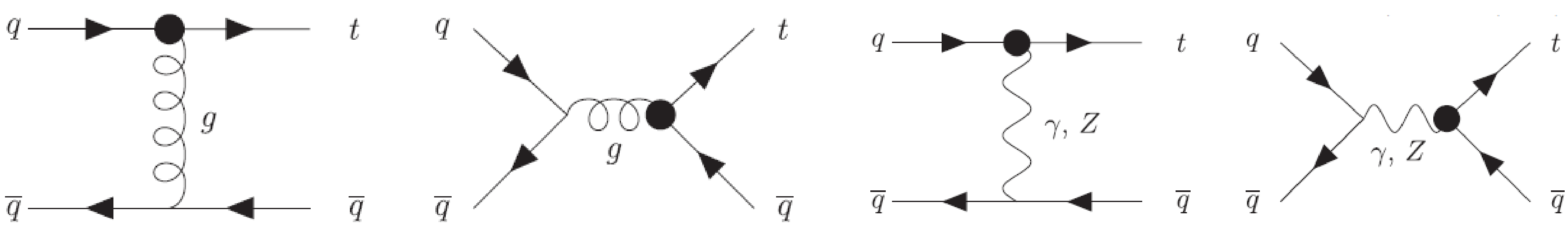
It can be strong or electroweak



The electroweak sector can be probed even if the strong sector is negligible.

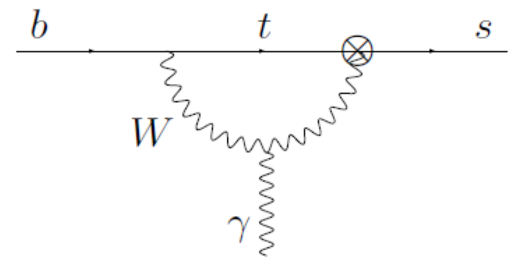
Excess in the cross section could be wrongly interpreted as coming from FCNC in the strong sector.

The numbers have to be added to the SM cross section.



4.The story so far II - limits from B physics

B physics constraints from
Fox et al, PRD78 054008, 2008.

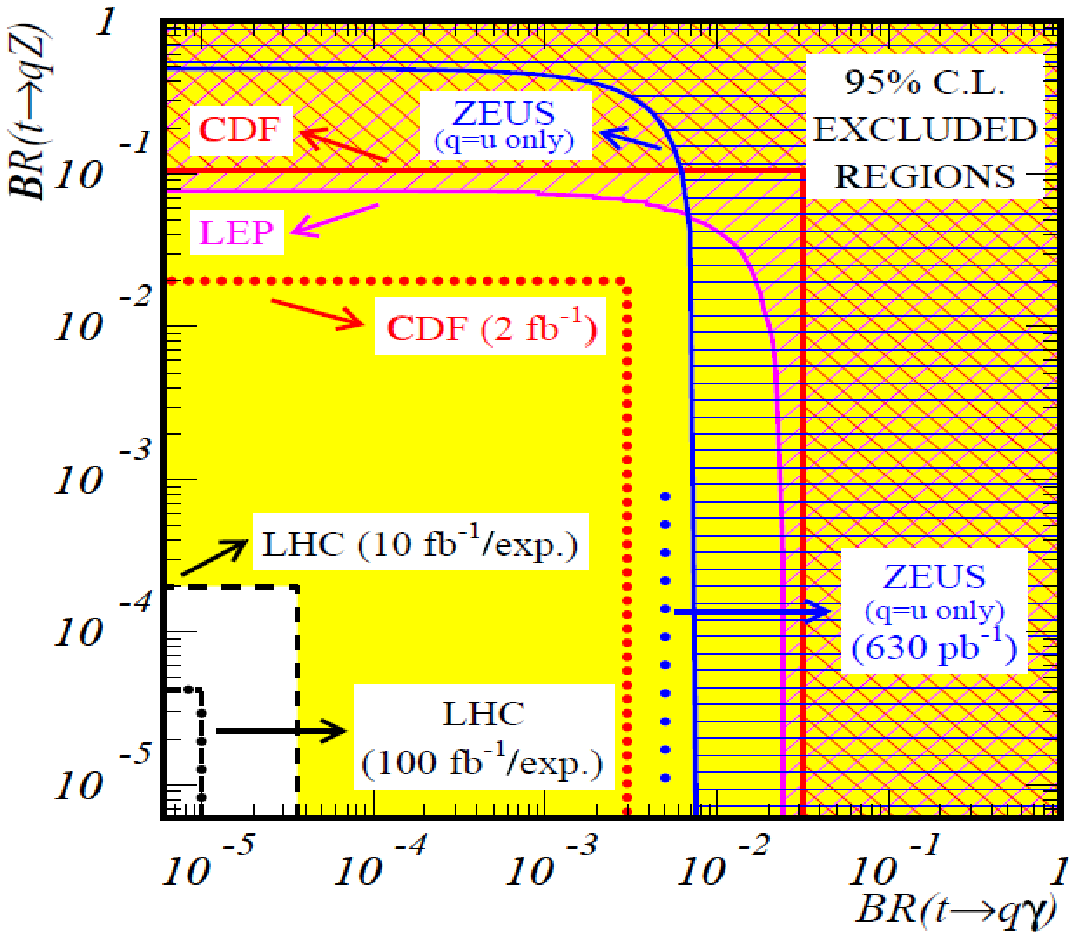


	$\mathcal{O}_{\phi}^{L}$	$\mathcal{O}_{tW\phi}^{RL}$	$\mathcal{O}_{tB\phi}^{RL}$	$\mathcal{O}_{tW\phi}^{LR}$	$\mathcal{O}_{tB\phi}^{LR}$	$\mathcal{O}_{\phi t}^{R}$
$Br(t \to c\,Z)$	$\mathcal{O}(10^{-6})$	3.4×10^{-5}	8.4×10^{-6}	4.5×10^{-3}	d	d
$Br(t \to c\,\gamma)$	–	1.8×10^{-5}	4.8×10^{-5}	2.3×10^{-3}	d	d
$Br(t \to u\,Z)$	$\mathcal{O}(10^{-5})$	4.1×10^{-5}	1.2×10^{-4}	3.2×10^{-3}	d	d
$Br(t \to u\,\gamma)$	–	2.1×10^{-5}	6.7×10^{-4}	1.6×10^{-3}	d	d

Limits can only improve but each bound in the table just takes one operator at a time - all remaining couplings vanish.

5. The future (at the LHC)

	ATLAS & CMS (10 fb^{-1})	ATLAS & CMS (100 fb^{-1})
$Br(t \to qZ)$	2.0×10^{-4}	4.2×10^{-5}
$Br(t \to q\gamma)$	3.6×10^{-5}	1.0×10^{-5}
$Br(t \to qg)$ (ATLAS)	1.3×10^{-3}	4.2×10^{-4}



LHC: the (100 fb^{-1}) future

Report of Working Group 1 of the CERN Workshop Flavor in the Era of the LHC.
EPJC57 (183) 2008.

$$BR^{10\,fb^{-1}}(t \to qg) < 9 \times 10^{-5}$$

Cheng and Teixeira-Dias, ATL-PHYS-PUB-2006-029.

100 fb^{-1} used as benchmark for the "future"!

6.Is there life for anomalous top FCNC after the LHC?

- $e^+e^- \to t\bar{q} + q\bar{t}$
- $e^+e^- \to t\bar{q}g + q\bar{t}g$
- $\gamma\gamma \to t\bar{q} + q\bar{t}$

Our approach is to use physical observables whenever possible - starting with cross sections involving the top and top branching ratios. Other observables will be considered in the future.

A generator based on CalcHEP to use in FCNC top physics is being tested.

Direct limits on the anomalous FCNC top BR

$$e^+e^- \to t\bar{t} \to bW\,\bar{q}X$$

Aguilar-Saavedra and Riemann, hep-ph/0102197

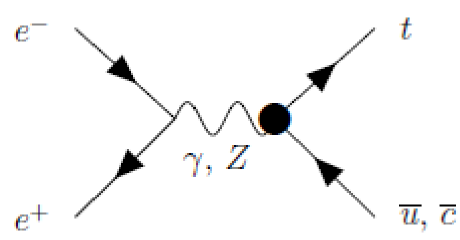
Aguilar-Saavedra, PLB502, 2001.

	$\sqrt{s} = 500$ GeV $(300 fb^{-1})$
$Br(t \to q\,Z)$	$\mathcal{O}(10^{-3})$
$Br(t \to q\gamma)$	$\mathcal{O}(10^{-4})$

Limits do not improve with energy. The scenario for the direct bounds does not look very promising.

It seems the LHC can do better.

Single FCNC top production

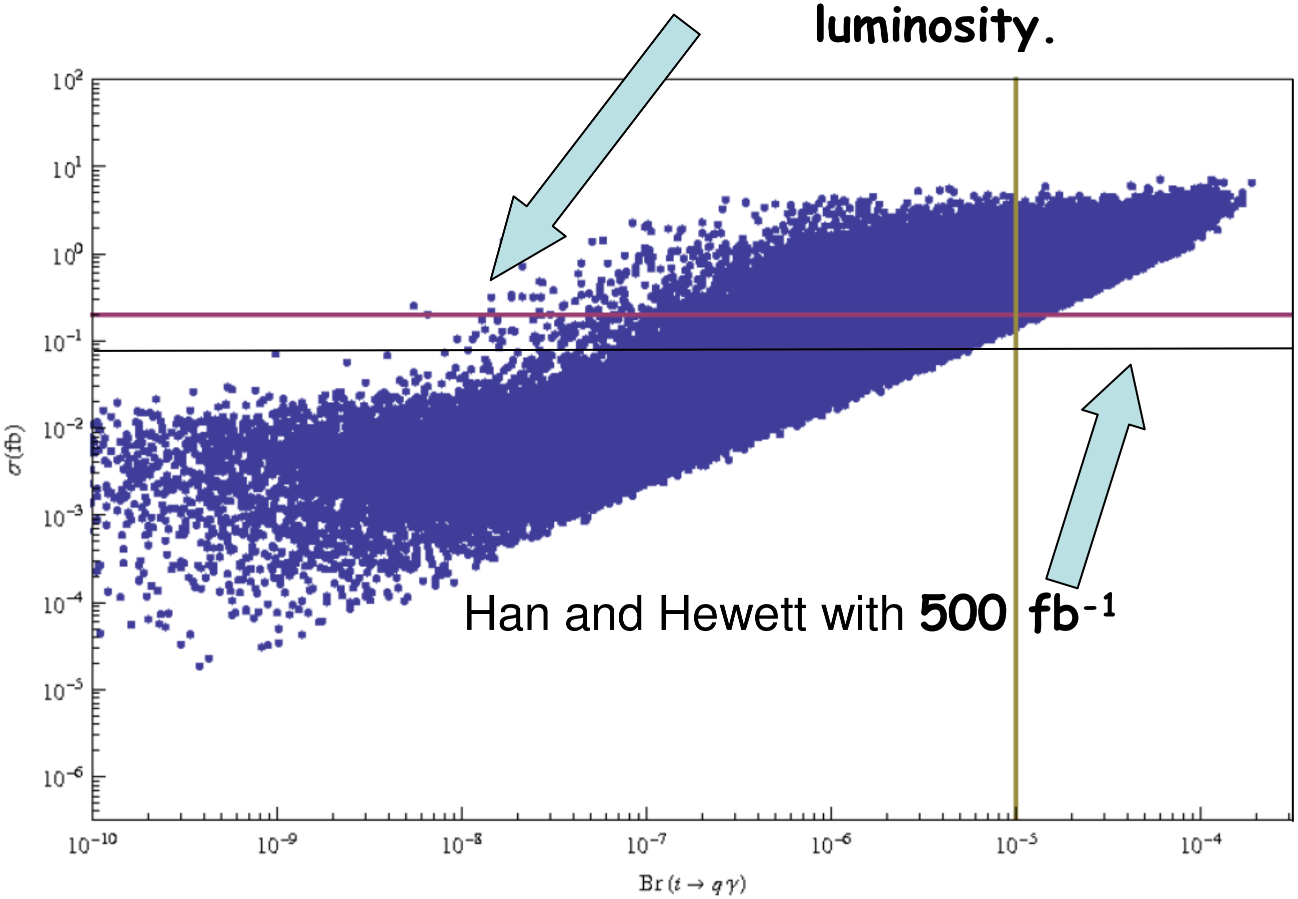


Han and Hewett, PRD60, 1999.

Aguilar-Saavedra and Riemann, hep-ph/0102197

Aguilar-Saavedra, PLB502, 2001.

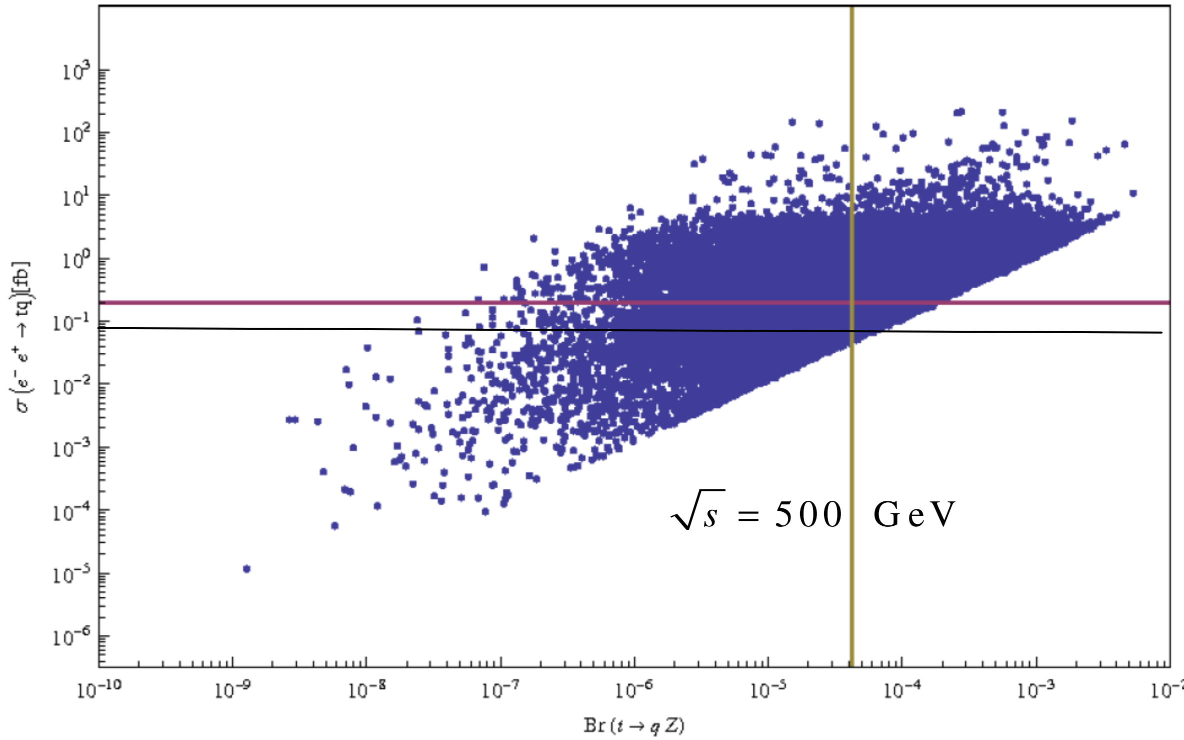
All analysis reach similar conclusions – a cross section of roughly 0.2 fb can be probed with 300 fb^{-1} of integrated luminosity.

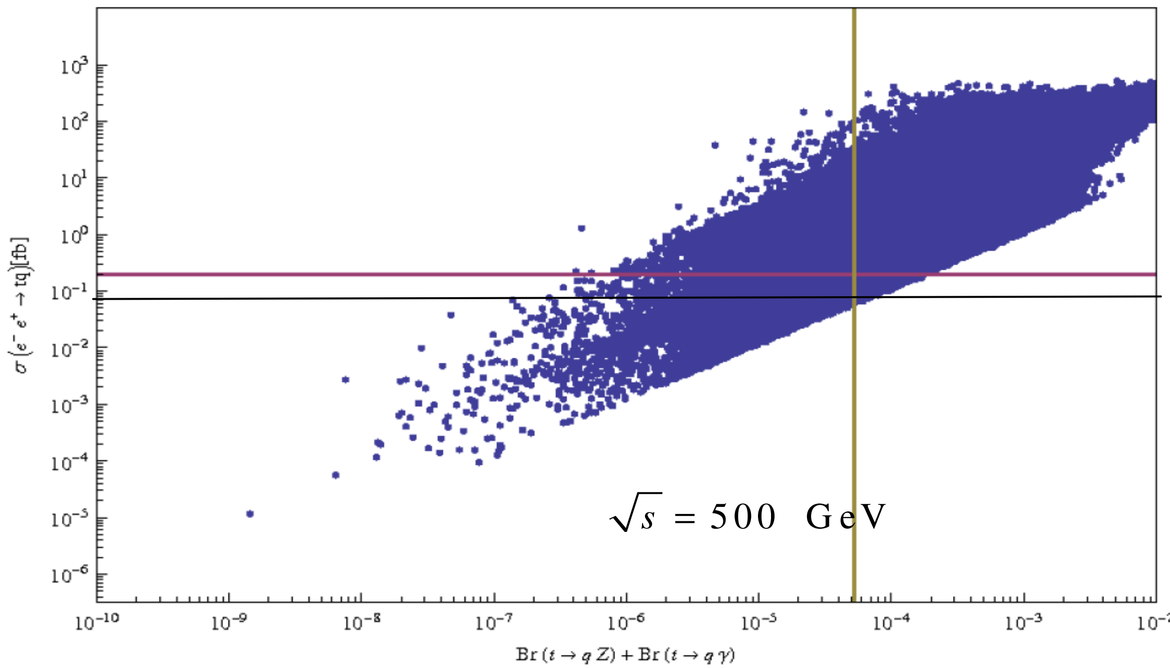


Anomalous coupling constants are generated randomly and cross section and BR are calculated (500000 points generated).

All predicted bounds for the LHC 100 fb^{-1} are used.

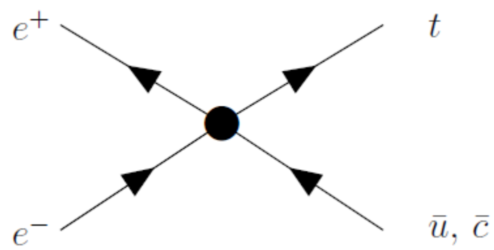
Same as before but now plotted against BR(t-> qZ).





And for the sum of BR's.

The 4F contribution



$$\Gamma_{4F}^{t\to qe^+e^-} = \frac{m_t^5}{2048\pi^3\Lambda^4}\left(S_{RR}^2 + 48T_{RR}^2 + 4V^2\right)$$

$$\sigma_{4F}^{e^+e^-\to qt} = \frac{(m_t^2 - s)^2}{32\,\pi\, s^2\Lambda^4}\left(2\,m_t{}^2\,\left(16\,T_{RR}^2 + V^2\right) + s\,\left(3\,S_{RR}^2 + 4\,\left(4\,T_{RR}^2 + V^2\right)\right)\right)$$

$\sqrt{s}$	L	$V_{ij}=1$	$S_{RR}=1$	$T_{RR}=1$
200 GeV	2.5 fb^{-1}	1.5 TeV	1.3 TeV	2.5 TeV
500 GeV	50 fb^{-1}	9.3 TeV	8.5 TeV	13.6 TeV
1000 GeV	200 fb^{-1}	19.3 TeV	17.9 TeV	27.5 TeV

Bar-Shalom and Wudka
PRD60, 1999.

TRR=1 (560 pb^{-1}) → Λ=1.2 TeV

Andringa et al
DELPHI 2006-003 CONF749 2006.

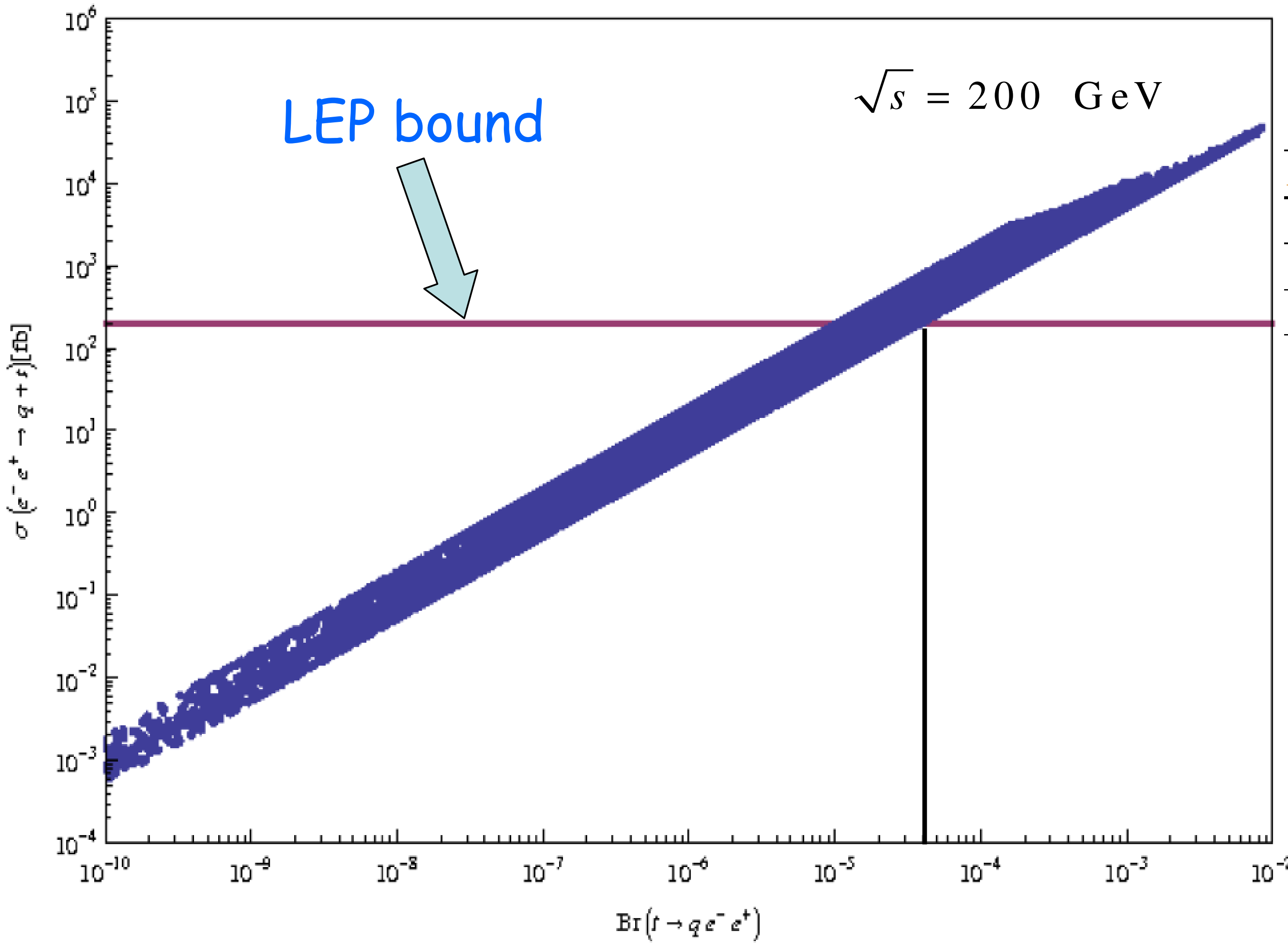
L3 Coll. PLB549, 2002.

Last DELPHI paper on FCNC limits to appear soon.

Using LEP data - bound for the FCNC BR of the three body decay of the top

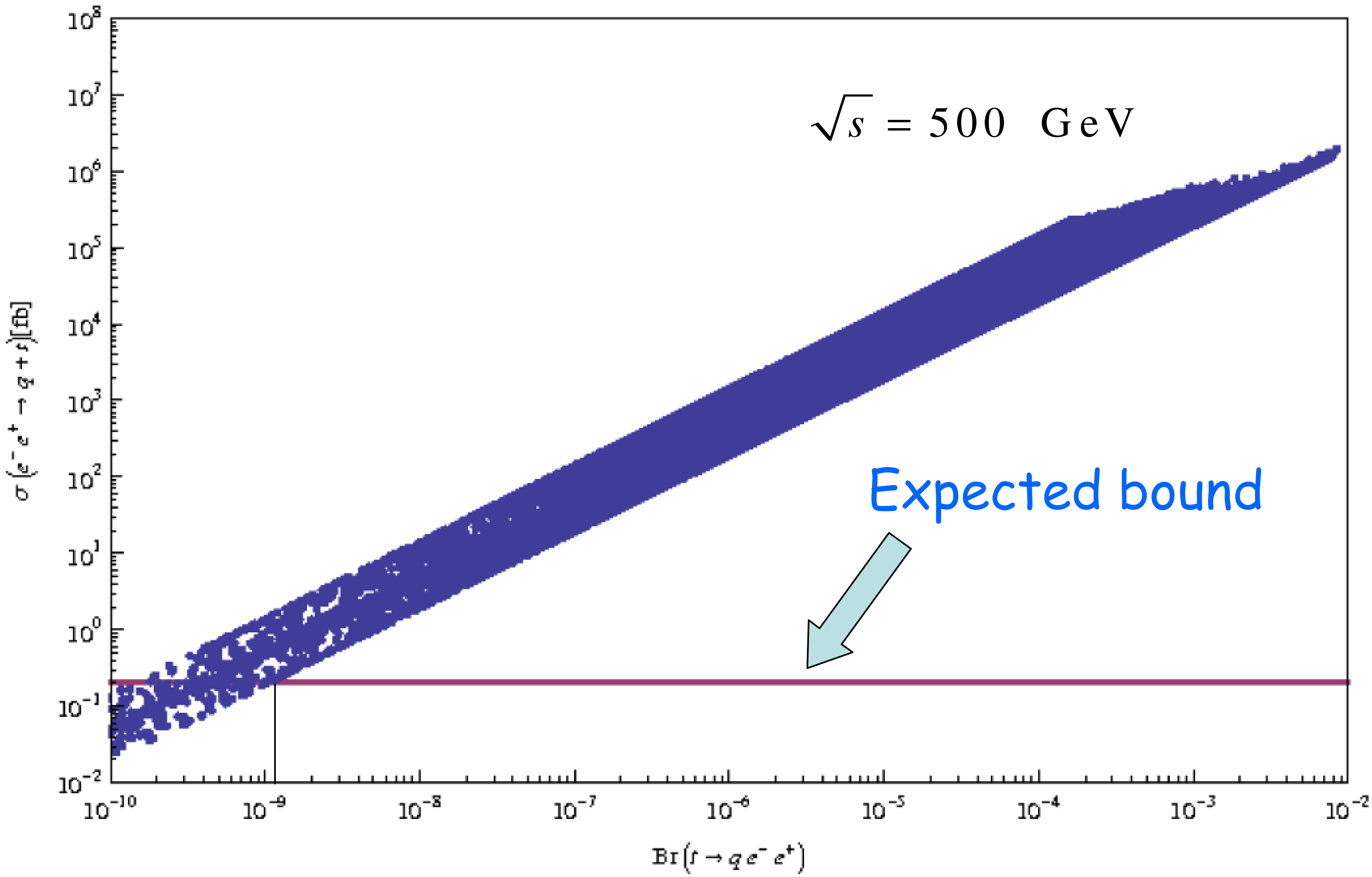
$$t \rightarrow q e^+ e^-$$

There is still no prediction available for the LHC.

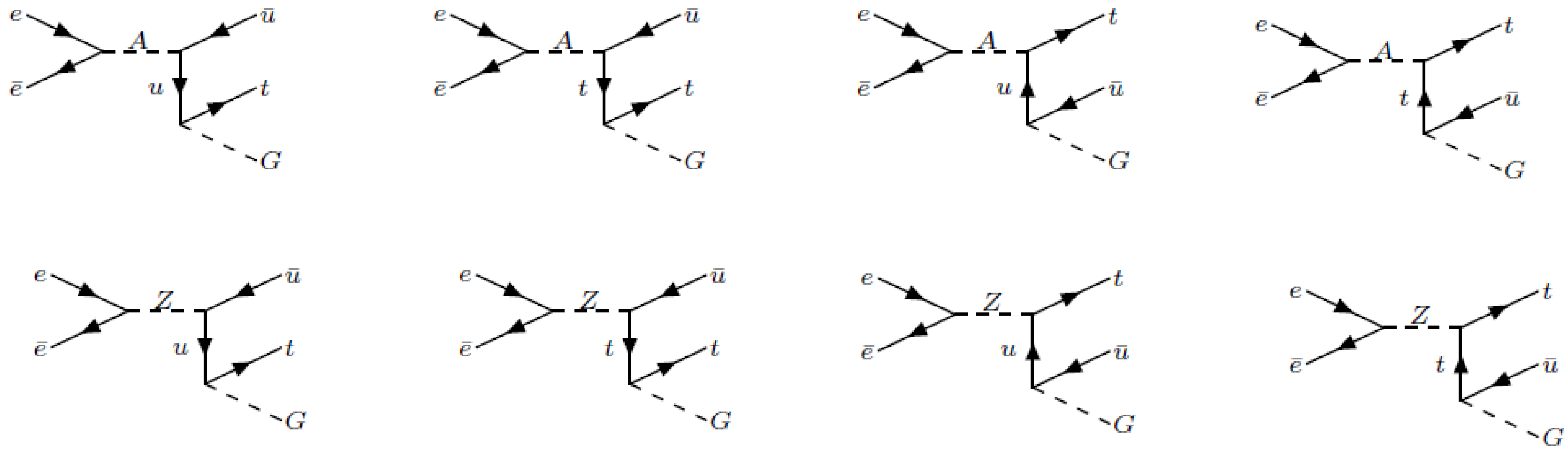


ATLAS & CMS ($100 fb^{-1}$)
4.2×10^{-5}
1.0×10^{-5}
4.2×10^{-4}

For a 500 GeV collider we again use 0.2 fb (Han and Hewett; Aguilar-Saavedra and Riemann) **as the cross that can be probed with 300 fb^{-1} of integrated luminosity. This is slightly more pessimistic than the cross section value predicted in** Bar-Shalom and Wudka.



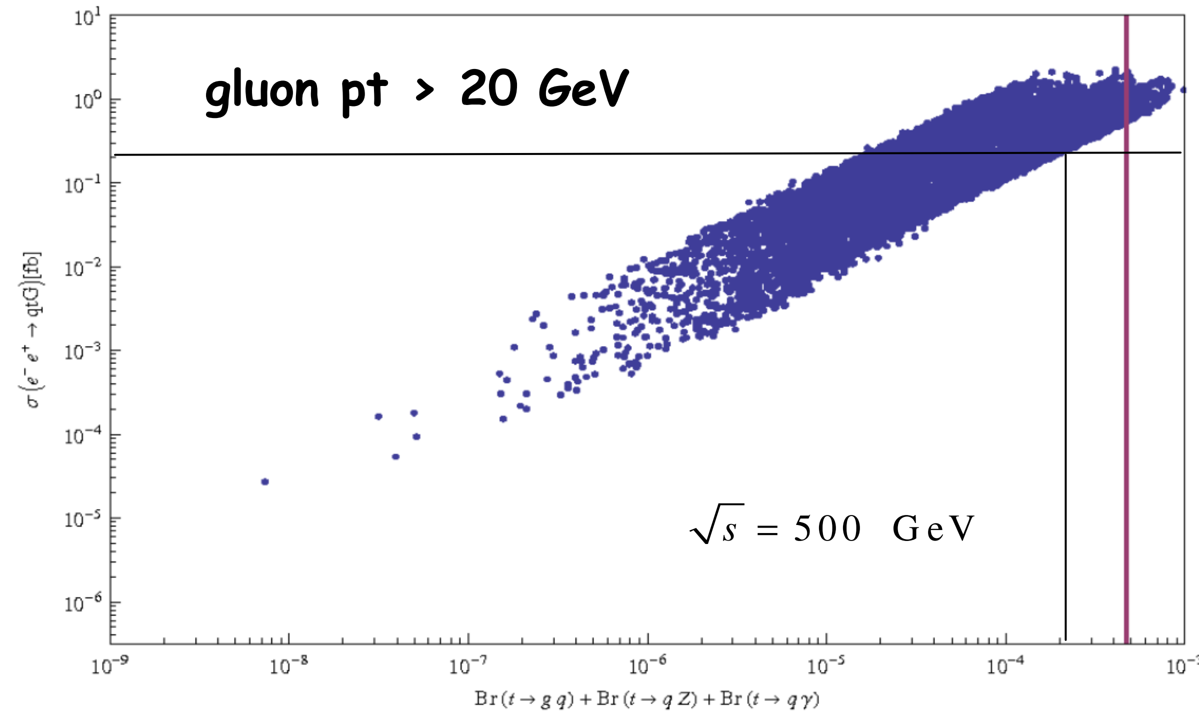
Single FCNC top+jet production

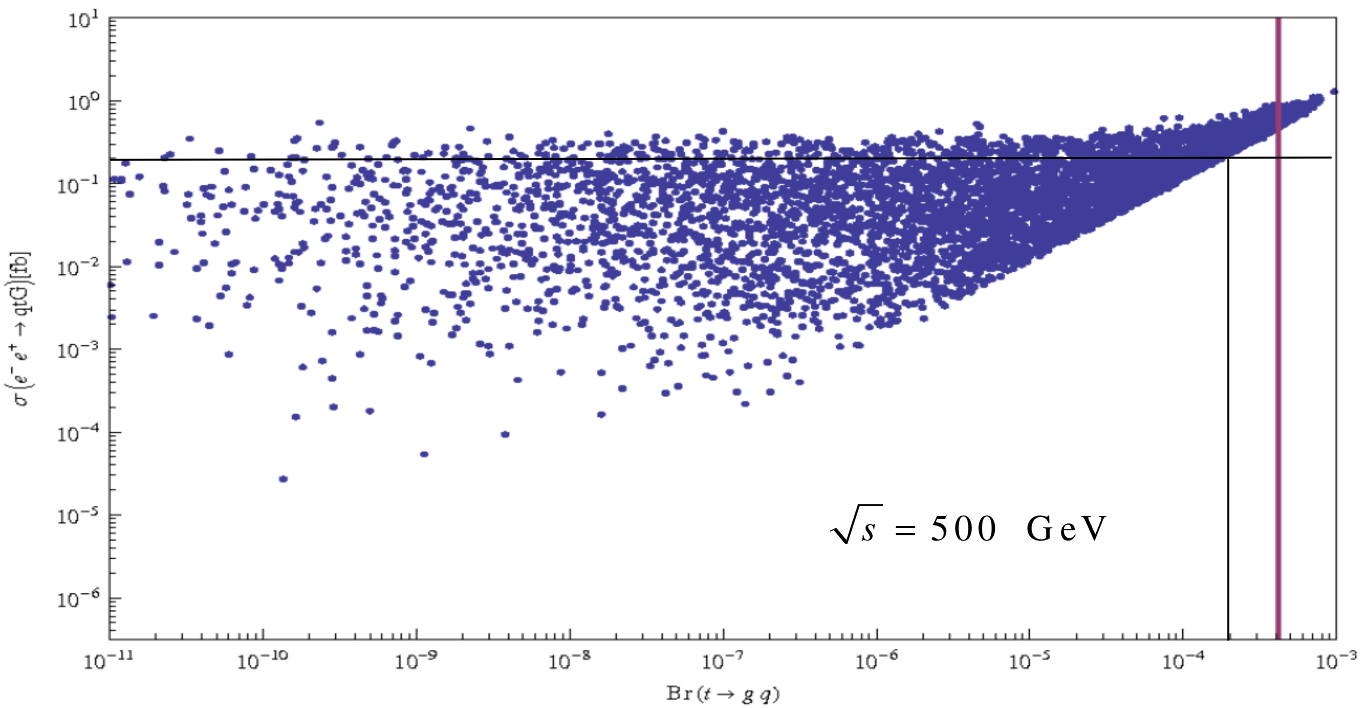


This is one of the simplest way to test anomalous strong FCNC top couplings. So far, no analysis was performed for this final state. The top decays to bW and therefore we will be looking for a final state blνjj. The gluon has pt > 20 GeV.

Anomalous coupling constants are generated randomly and cross section and BR are calculated (10000 points generated).

All predicted bounds for the LHC 100 fb^{-1} are used.

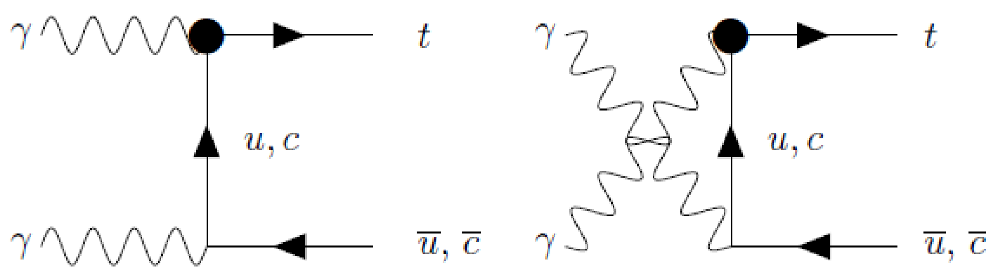




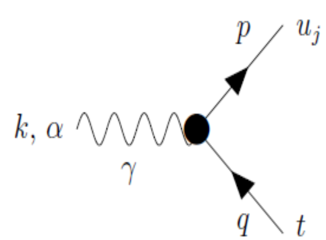
No improvement in the Z and photon BR.

At a $\gamma\gamma$ collider

Very clean process where a measurement of the cross section is truly equivalent to a measurement of the branching ratio

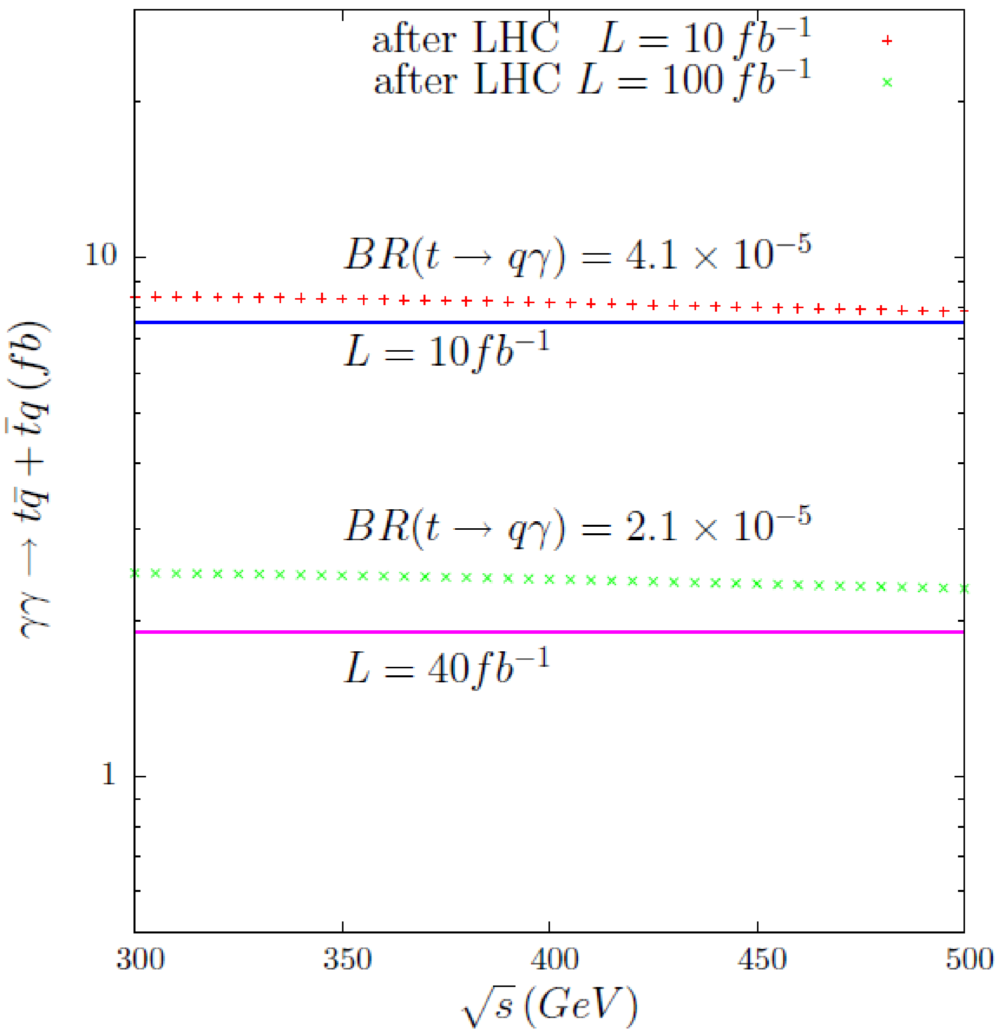


The vertex has the simple form



$$\frac{v}{\Lambda^2}\sigma_{\mu\nu}\left(\beta^{\gamma}_{jt}\gamma_R + \beta^{\gamma^*}_{tj}\gamma_L\right)(k^\mu g^{\nu\alpha} - k^\nu g^{\mu\alpha})$$

At a $\gamma\gamma$ collider



Detailed study for 400 and 500 GeV c.o.m. energy:

Abraham, Whisnant, Young, *PLB* 419 (1998) 381.

$$BR\,(t \to q\gamma) \approx 10^{-6}$$

QCD corrections

QCD corrections based on our chosen set of operators show little difference in the BR's to Z and photon but a significant difference in the decay to gluon. QCD corrections for tq and tqg production in an electro-positron collider are not available.

Zhang et al, PRL102, 2009.

BR [in unit of $(\frac{\kappa_{tq}^{V}}{\Lambda}\mathrm{TeV})^2$]	LO	NLO	NLO/LO
$t \to q + g$	1.0010	1.1964	1.195
$t \to q + \gamma$	0.0544	0.0542	0.996
$t \to q + Z$	0.0448	0.0458	1.022

Both corrections have to be taken into account in future analysis.

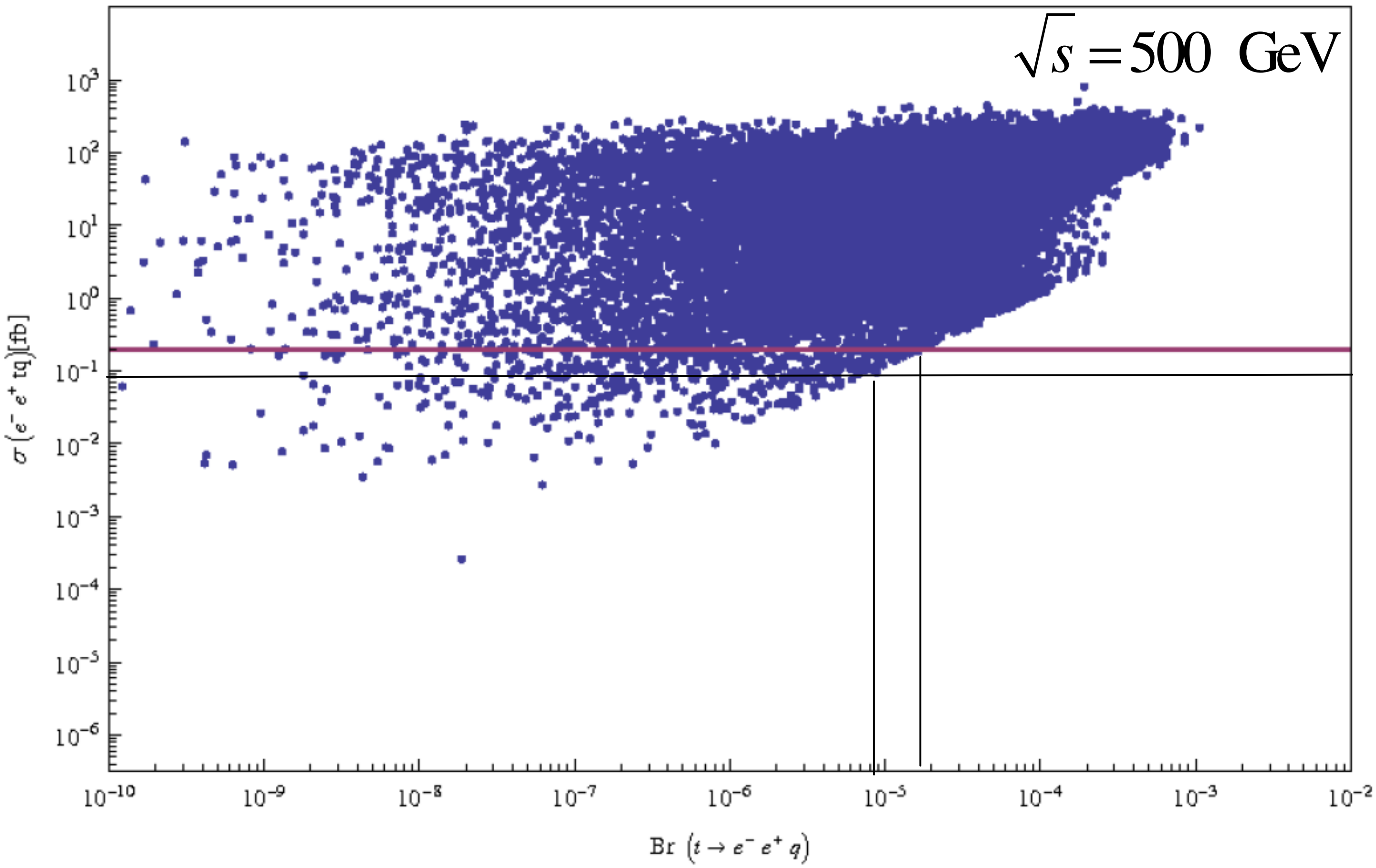
Conclusions

- We have considered a minimal set of operators for top anomalous FCNC production at a future linear collider.
- The future was set to LHC's 100 fb^{-1}.
- In this scenario, improving the LHC bounds depend on the energy and especially on the luminosity of the future collider. If new physics is founds, particular operators can be probed with definite observables.
- Better sensitivity to the FCNC BR($t \rightarrow qee$).
- "The" photon-photon collider will most certainly improve the bound on the top to photon FCNC branching ratio.
- Generator will "soon" be available.

The end

Extra slides

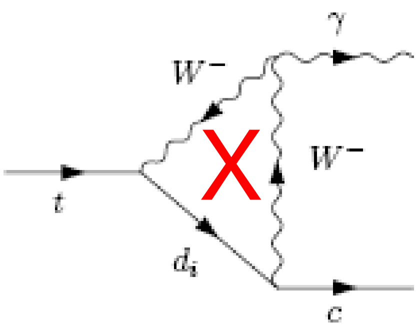
Contribution from the non 4F operators – cross section is smaller – bound is not as good as for the 4F operators.



A framework for top FCNC physics – the effective operator approach

$$L = L_{SM} + \frac{1}{\Lambda} L^{(5)} + \frac{1}{\Lambda^2} L^{(6)} + O\left(\frac{1}{\Lambda^3}\right)$$

Λ is the scale of new physics.



X is from a new untested model (the same SM particles in the external lines). It can have the same or a different Lorentz structure.

$\overline{t}c\gamma$

electroweak

strong

$$\mathcal{O}_{tW\phi} = \frac{\beta^W_{it}}{\Lambda^2} \left(\bar{q}^i_L \, \tau_I \, \sigma^{\mu\nu} \, t_R\right) \phi \, W^I_{\mu\nu}$$

$$\mathcal{O}_{tB\phi} = \frac{\beta^B_{it}}{\Lambda^2} \left(\bar{q}^i_L \, \sigma^{\mu\nu} \, t_R\right) \phi \, B_{\mu\nu}$$

$$\mathcal{O}_{tG\phi} = \frac{\beta^S_{it}}{\Lambda^2} \left(\bar{q}^i_L \, \lambda^a \, \sigma^{\mu\nu} \, t_R\right) \phi \, G^{a\mu\nu}$$

All terms are invariant under the SM gauge group.

Operators and observables

In a simple world, in the top FCNC case suppose we had only three observables and three operators! However…

$$\mathcal{O}_{tW\phi} = \frac{\beta^W_{it}}{\Lambda^2}\,(\bar{q}^i_L\,\tau_I\,\sigma^{\mu\nu}\,t_R)\,\phi\,W^I_{\mu\nu}$$

$$\mathcal{O}_{tB\phi} = \frac{\beta^B_{it}}{\Lambda^2}\,(\bar{q}^i_L\,\sigma^{\mu\nu}\,t_R)\,\phi\,B_{\mu\nu}$$

$$\mathcal{O}_{tG\phi} = \frac{\beta^S_{it}}{\Lambda^2}\,(\bar{q}^i_L\,\lambda^a\,\sigma^{\mu\nu}\,t_R)\,\phi\,G^{a\mu\nu}$$

$$\rightleftarrows$$

$$\sigma_{pp \to tj}$$

$$\sigma_{pp \to t\bar{t}}$$

$$A_{FB}$$

…this is not the case. Therefore we have to find as many physical observables as possible. The number of operators we already know is huge.

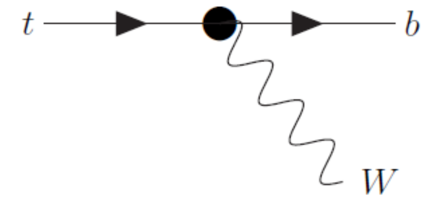
Even in this simple case we need

- Great precision from the theoretical side
- Great precision from the experimental side

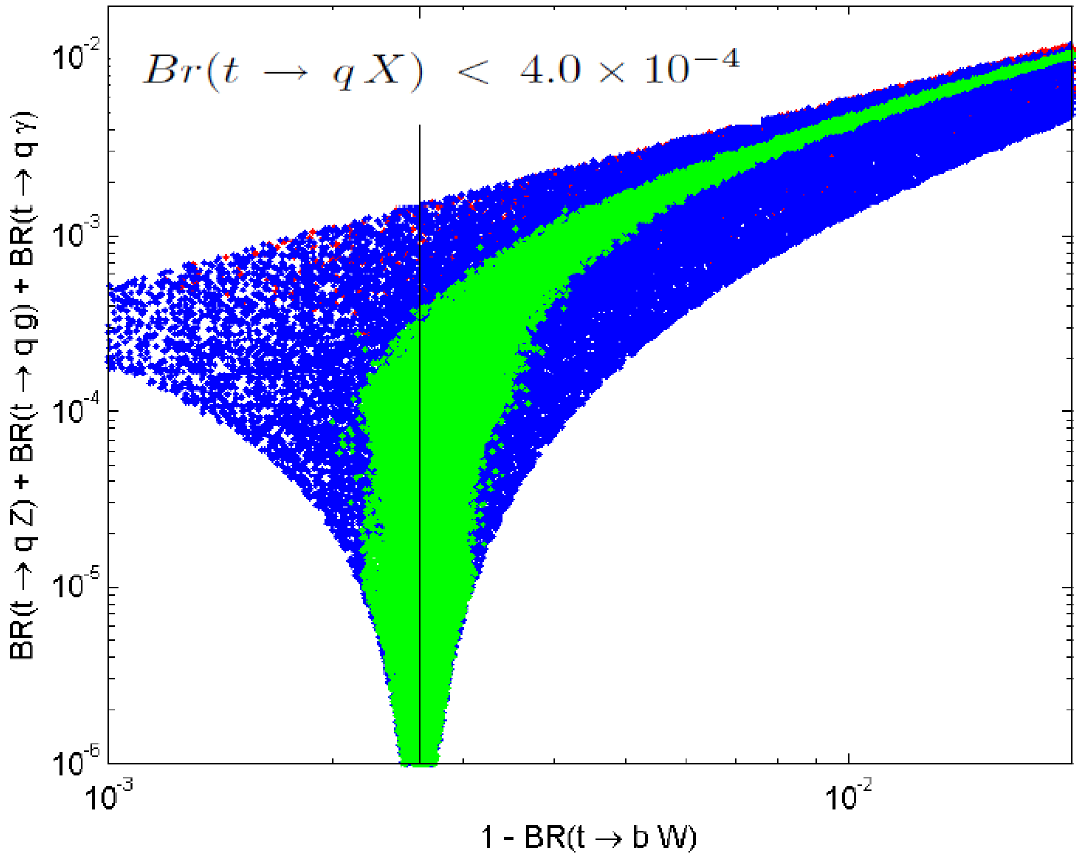
to look for the small deviations from the SM.

Relating observables

$$\Gamma(t \to dW) = 1.42\,|V_{td}|^2 - \frac{3\,g}{8\,\pi\,\Lambda^2}\,\frac{m_t^4 - m_W^4}{m_t^2}\,v\,\mathrm{Re}\left(V_{td}\,\beta_{ut}^W\right)$$



$$BR(t \to bW) = \frac{\Gamma(t \to bW)}{\sum_{q=u,c}\left[\Gamma(t \to qg) + \Gamma(t \to q\gamma) + \Gamma(t \to qZ)\right] + \sum_{q=d,s,b}\Gamma(t \to qW)}$$



1. Use the Tevatron results for single top production.

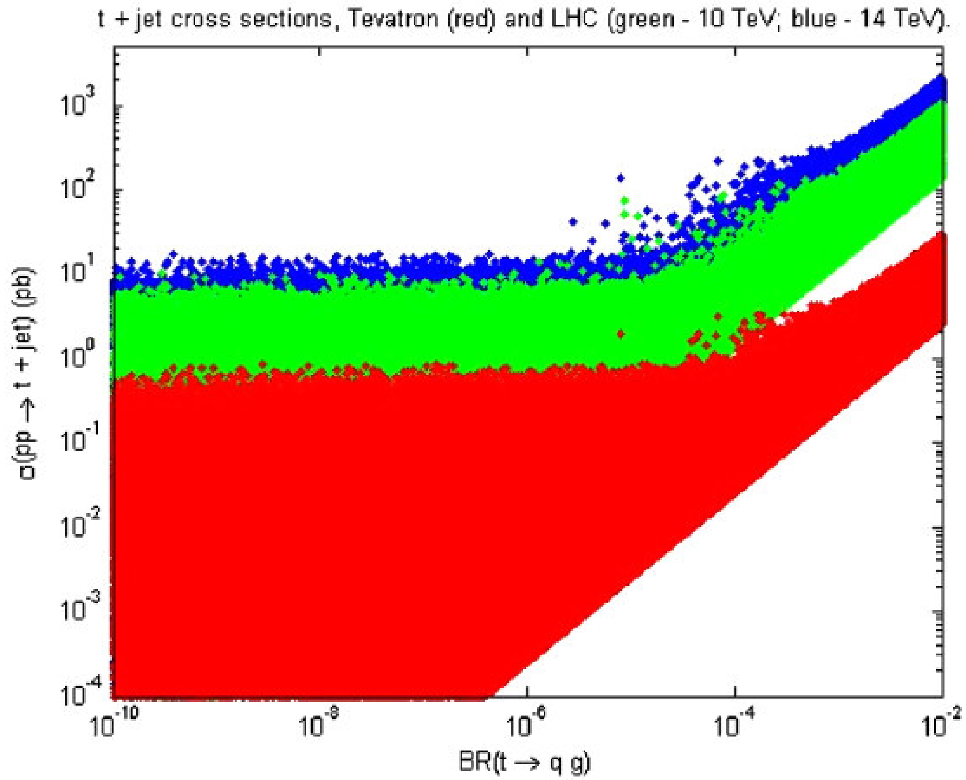
2. B physics constraints from Fox et al, PRD78 054008, 2008.

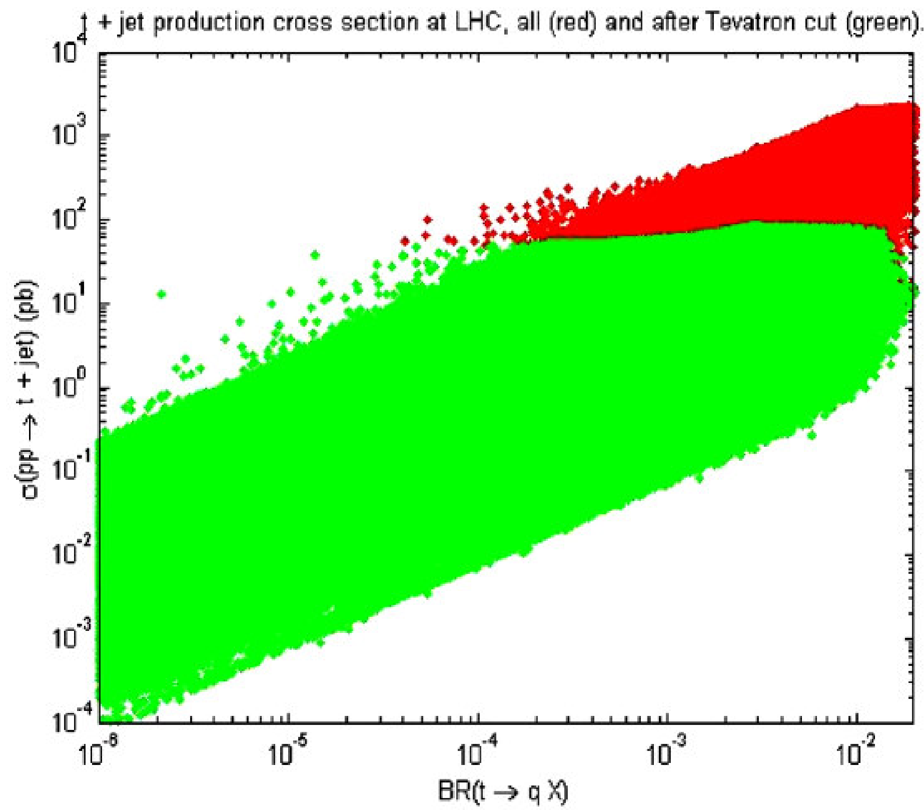
Tevatron bound

1.0×10^{-3}

Results

3a. Tevatron LHC10 and LHC14





When we increase the energy from 500 GeV to 1 TeV the cross section increases by a factor 4.

Depending on the luminosity extremely small values of the 4F BR could be reached.