

“Vision From the Top”

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University of Wisconsin



At the “Top – 2010 Workshop”
June 4, 2010



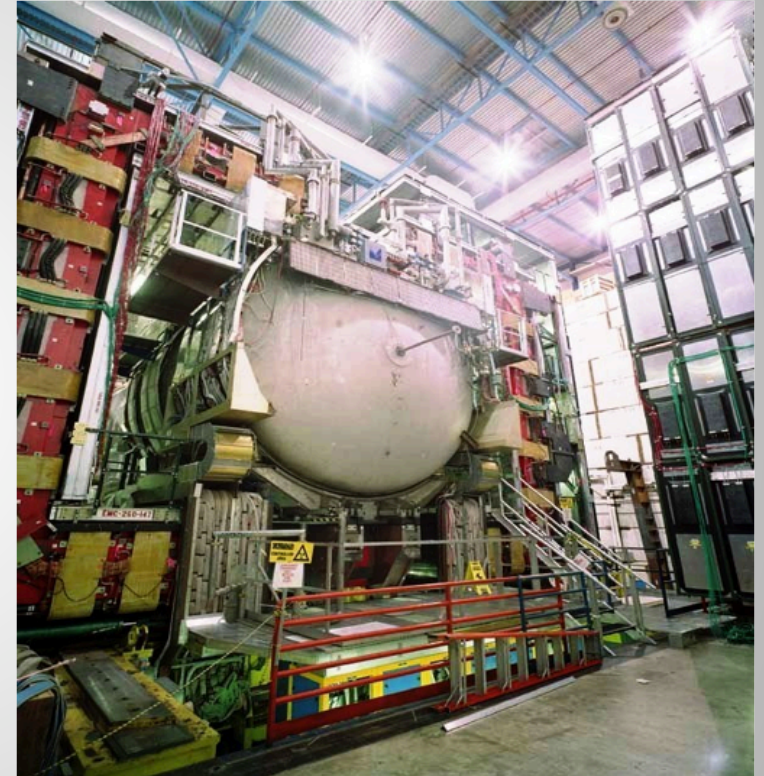
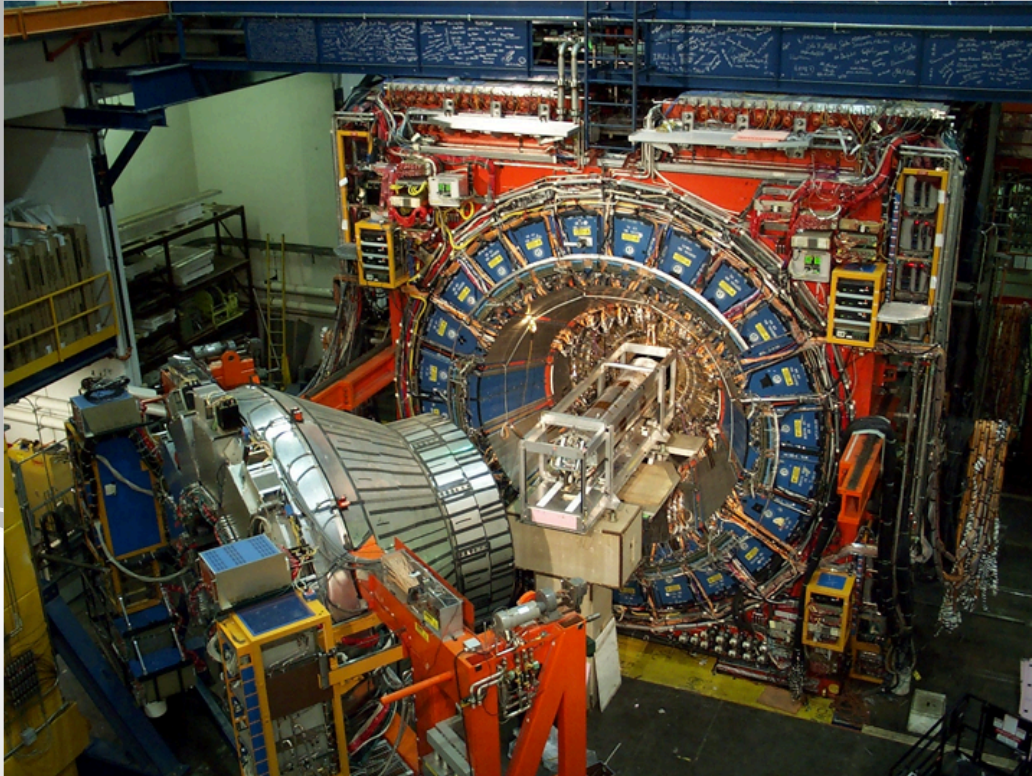
Tevatron is running at peak performance!



The LHC era has just begun!

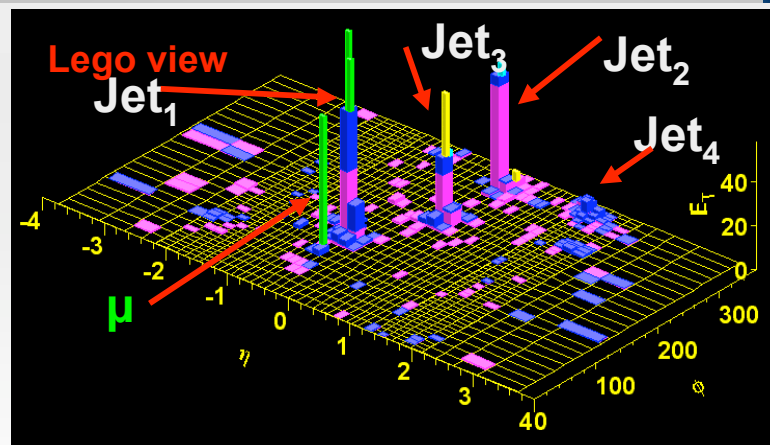
It is the most exciting time in HEP!

(1) On top, where we stand
Congrats and thanks to CDF/D0:



“Everything we know about the top ...”
--- Robin Erbacher

A spectacular
“top” view :



$$m_t = 173.1 \pm 0.6 \pm 1.1 \text{ GeV} \quad (\text{O. Brandt})$$

Best measured quark mass!

$$\sigma(tt)^{\text{CDF}} = 7.5 \pm 0.31 \pm 0.34 \text{ pb} \quad (\text{F. Deliot})$$

$$\sigma(tt)^{\text{QCD}} = 6.93 \pm 0.32 \pm 0.14 \text{ pb} \quad (\text{Moch, Uwer et al.})$$

• CDF: (J. Lueck)

$$\sigma(t) = 2.3 \pm 0.6 \text{ pb}$$

D0: (A. Heinson)

$$3.84 \pm 0.88 \text{ pb}$$

Heroic efforts: 5σ sensitivity!

$$|V_{tb}| > 0.71$$

$$> 0.78 \text{ @ } 95\% \text{ CL}$$

$$\Gamma_t^{\text{D0}} \approx 2.05 \pm 0.56 \text{ GeV}$$

T. Han (A. Heinson)

Plus much more ...
(Sorin, Datta, Harel)

On top: Search for new physics at Tevatron: (P. Sinervo)

■ Top provides unique access to new physics

- Extensive searches for H+
- Now setting limits on BR ~ 0.1 for Higgs masses 100-150 GeV/c²
- Moving to more sophisticated models

■ No evidence for high mass objects coupling to top

- Limits on t-tbar final state
 - > $M_X > 820 \text{ GeV}/c^2$ at 95% CL
- Limits on t-bbar final state
 - > $M_{W'} > 731 \text{ GeV}/c^2$ at 95% CL

■ Searches for 4th generation

- Limited by backgrounds
 - > $M_{\chi'} > 335 \text{ GeV}/c^2$ at 95% CL

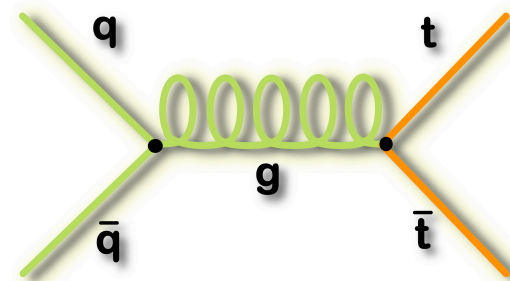
■ Stop search

■ Most of these analyses are based on 2-3 fb⁻¹

- Analyses are starting to appear with 4-5 fb⁻¹
- And have > 7 fb⁻¹ on “tape”

■ Most of these are background-limited by top production and/or SM processes

- Working to develop “next generation” studies



Tremendous efforts by theorists:

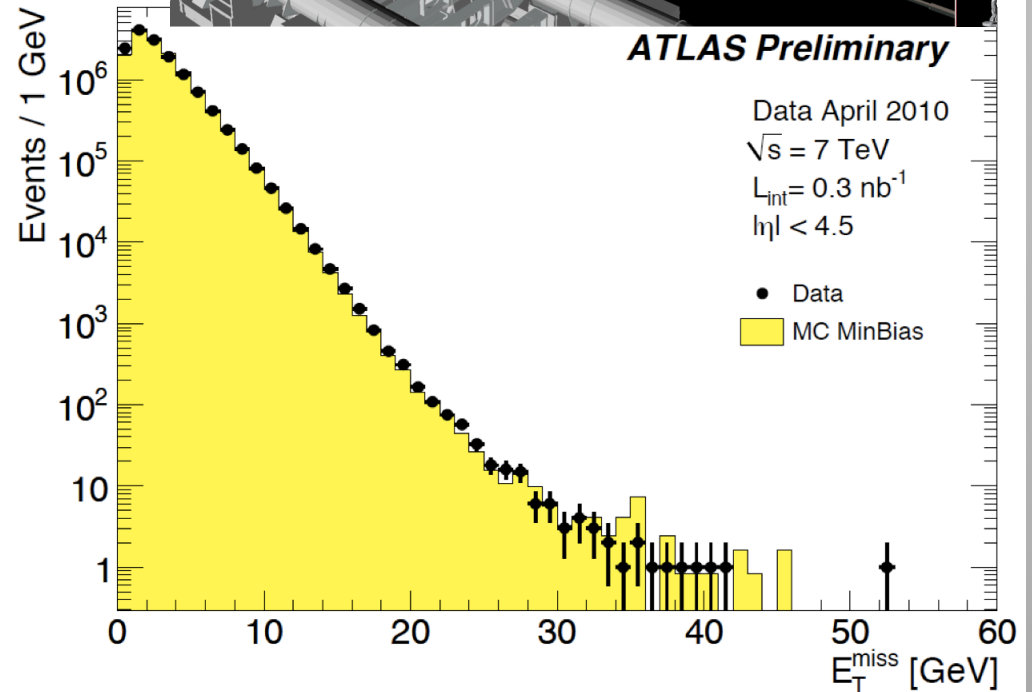
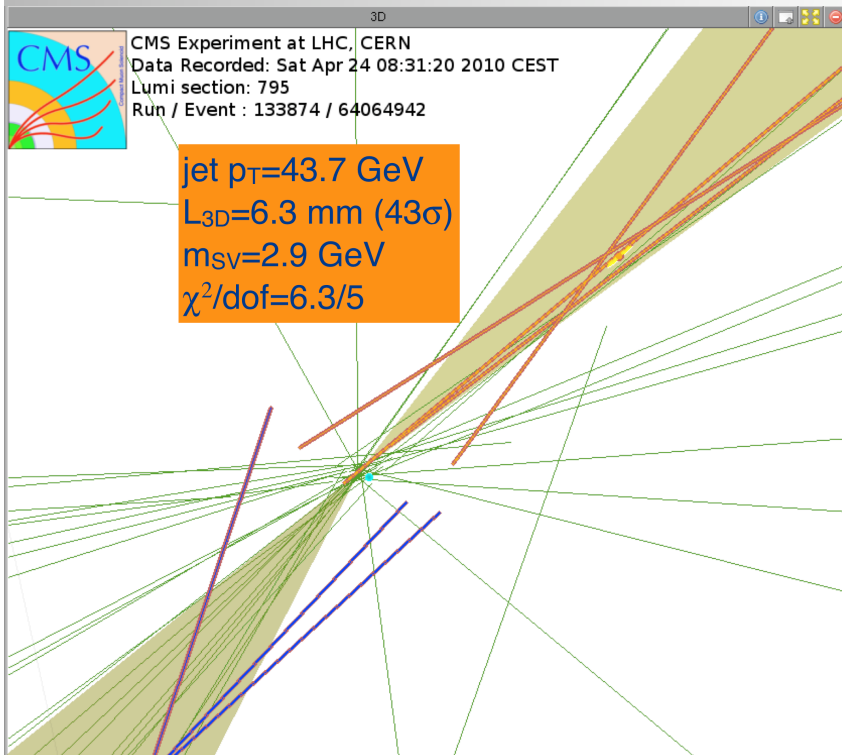
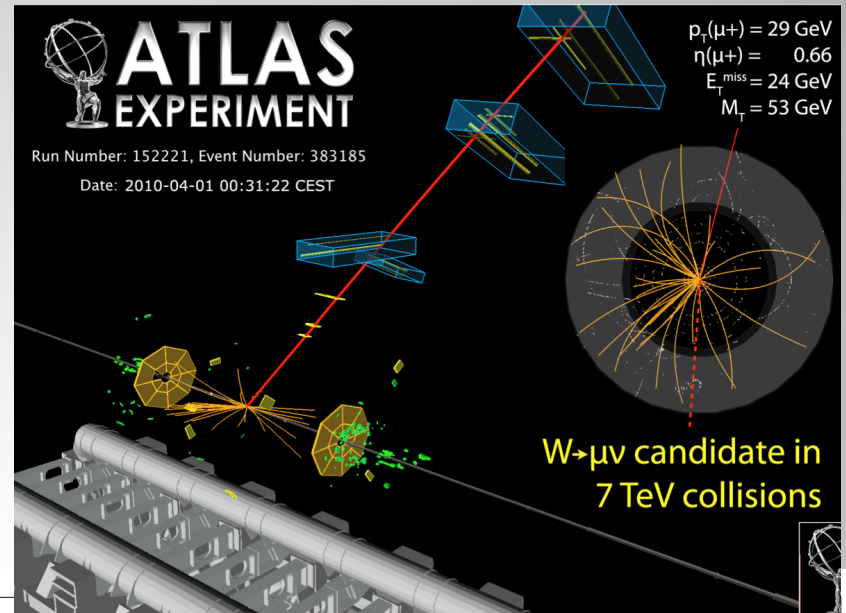
- ◆ Higher order radiative corrections to top production; showering, merging ...
(Cacciari et al., Moch, Uwer et al.; Nason; Worek; Kidonakis ...)
- ◆ b-flavor treatment for t-channel single top production
(Campbell, Maltoni et al.; Cacciari et al., Moch, Uwer et al.; White, ...)
- ◆ Improved PDF's: NNPDF (Guffanti et al.)
- ◆ top-mass definition and extraction (Corcella et al.)
- ◆ Background processes are better understood
(Schumann, Cerrito)

Progress is continuously being made both in theory and in experiments.

(2). March into the LHC era

W and Z events observed!
(Ecklund; Maettig)

B-tagging, E_Tmiss impressive!
(Maes, Van Vulpen)



The top quark is yet to be re-discovered,
even in a bird-eye view:

$\approx 30 \text{ events} / 10 \text{ pb}^{-1}$.

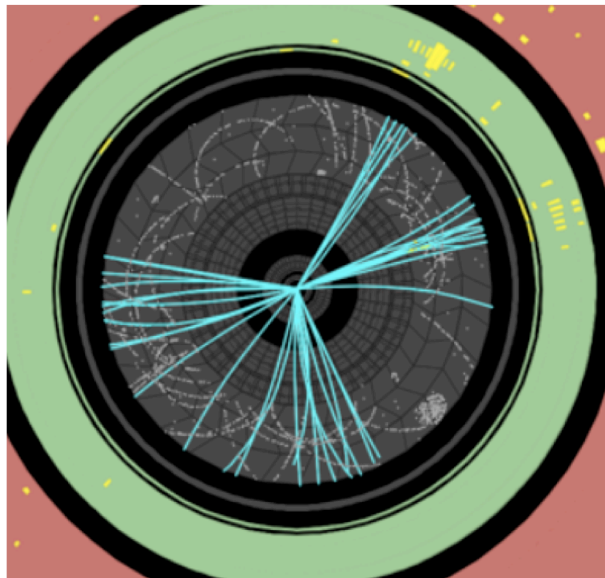
(Hwidong Yoo)



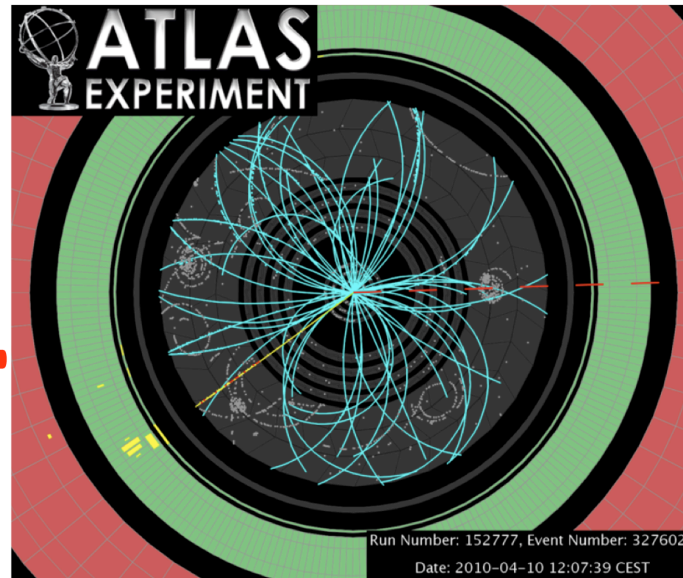
Every ingredient for finding top quarks at hand

Top =

4 jet



W



(Maettig)

The “top” view will be great!



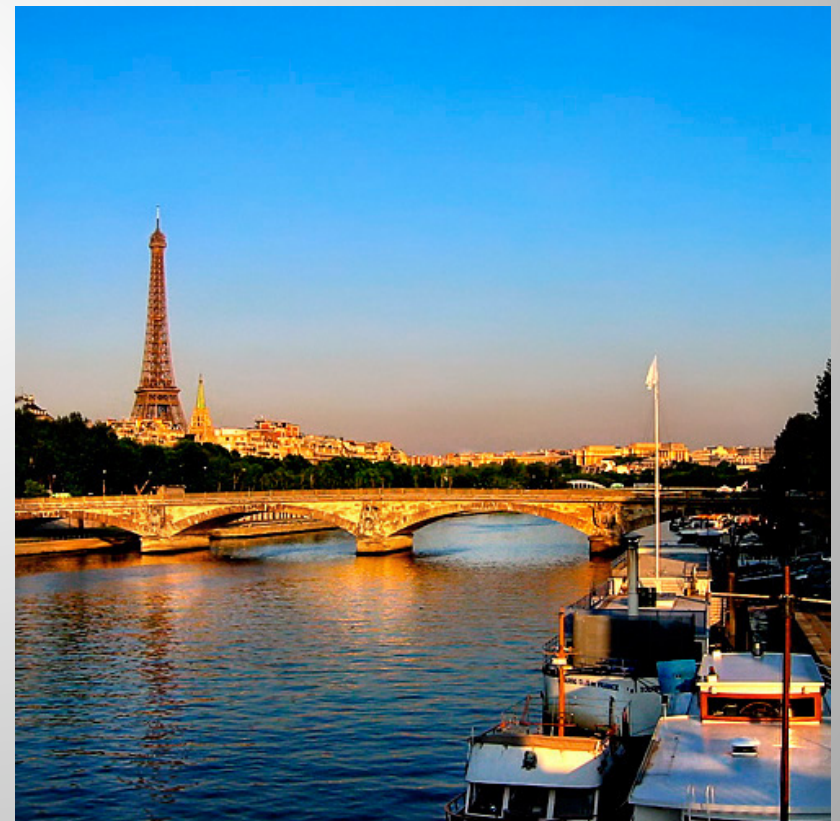
LHC as a top factory:
Mass, width, interactions,
new channels ...

Theoretical descriptions ...

(Hirschbuel; Barrett; Loginov;
Ghodbane; Wolf ...
Nason; Moch; Worek ...)

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T. Han



(3) Vision from the Top on new physics at LHC



new beauty



and unknowns

new territory





“View from the top”

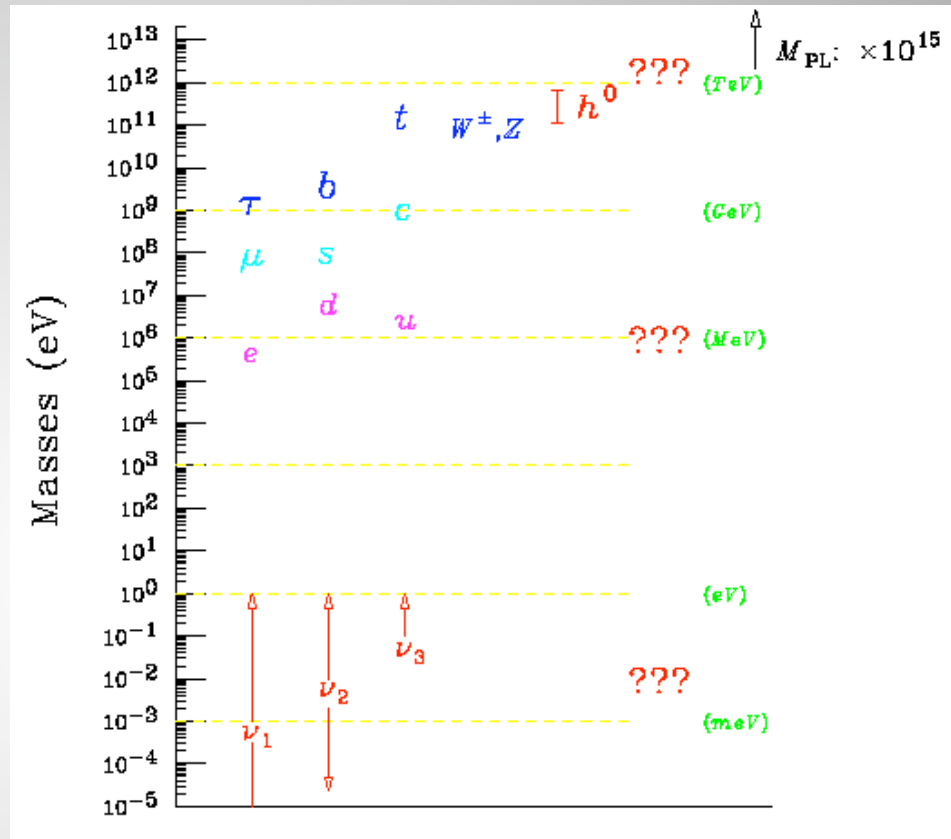
With persistence and hard work, Donna (Gwyneth Paltrow) realized her dream, to become a first-class flight attendant, and then discovered her true passion ...

The pursuit of top-quark physics at the LHC may be of similar spirits.

Top is unique!

The large mass right at the EW scale:

$m_t \approx v/\sqrt{2} \approx 174 \text{ GeV}$
(as heavy as a gold atom)



Pretty much in any new physics scenarios related to the EWSB, top quark will play a significant role.

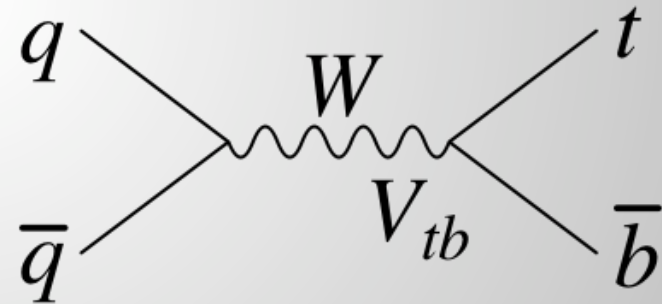
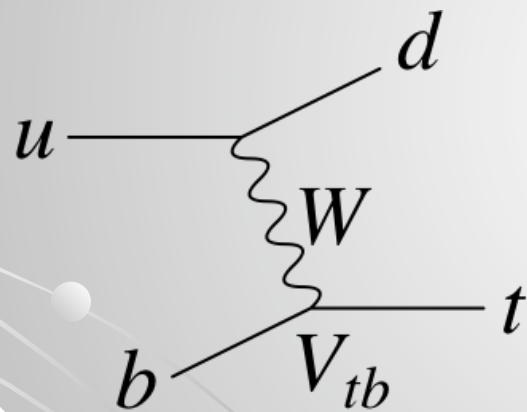
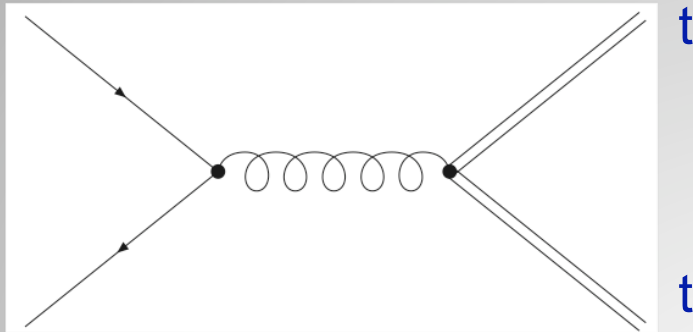
Top is unique!

Theory	Top role	Top imprints
EWSB	$t\bar{t}H$	$gg \rightarrow H, t\bar{t}H; H \rightarrow t\bar{t}, \dots$
2HDM	$t\bar{t}A, t\bar{t}H^\pm$	$t \rightarrow bH^\pm; gg \rightarrow A, b\bar{b}H(A); gb \rightarrow tH^\pm, \dots$
SUSY	\tilde{t}_R light radiative EWSB	$t \rightarrow \tilde{t}\chi; \tilde{t} \rightarrow t\chi, \dots$ m_h light, $\tan\beta$ large
Strong dynamics/ Extra Dim	enhanced couplings $\rho_{TC}^{0,\pm}$ $G_{KK}, g_{KK}, Z', W'^\pm \dots$	$WW \rightarrow t\bar{t}, \dots$ $\rightarrow t\bar{t}, t\bar{b}$
4 th family/ Little Higgs	t', b' naturalness TtH	$t', b' \rightarrow tX^0, bX^\pm, cX$ $T \rightarrow tA^0$

And far reaching:

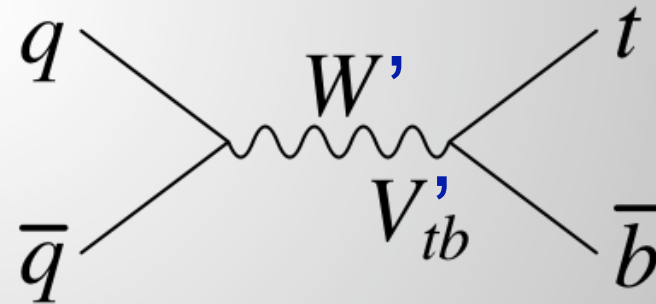
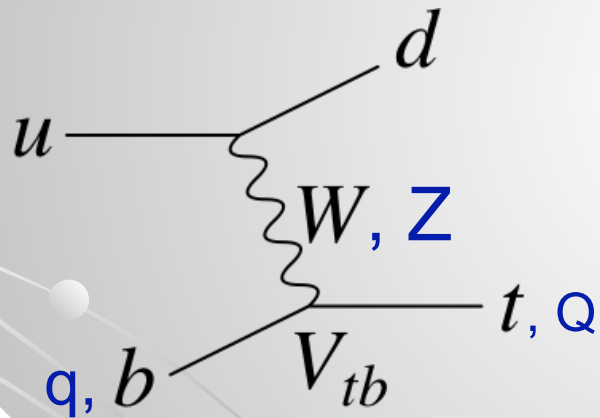
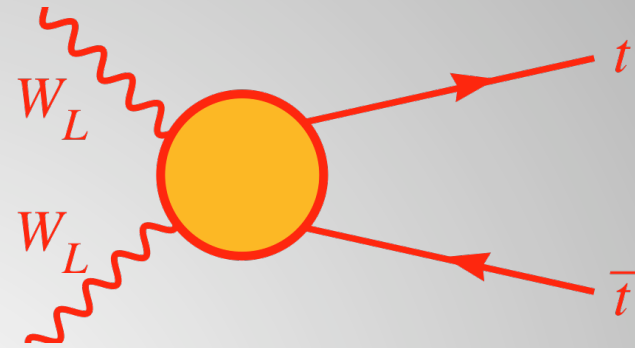
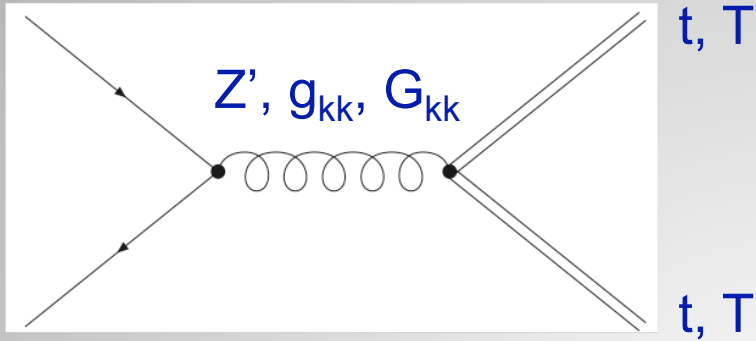
- top needs **partners** for naturalness in EWSB.
- light stop may help with EW **baryon genesis**.
- top + partner may reveal **dark matter** signal.

We have practiced the search:



Plus top rare decays

We have practiced the search:



(Hou; Lessard; Steggemann Ferrari)

Plus top rare decays

A few sample studies:

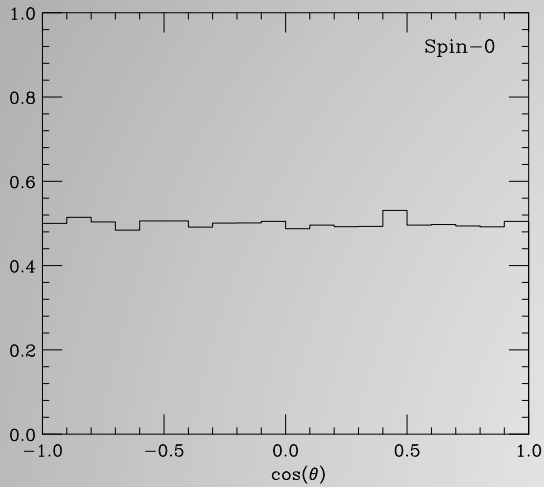
A. Resonance signal:

$$q\bar{q}, gg \rightarrow R^* \rightarrow t\bar{t}$$

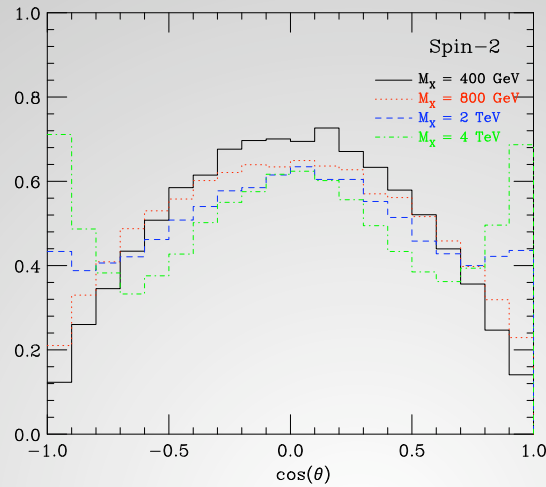
Spin	color	parity (1, γ_5)	some examples/Ref.
0	0	(1,0)	SM/MSSM/2HDM, Ref. [51, 52, 53]
0	0	(0,1)	MSSM/2HDM, Ref. [52, 53]
0	8	(1,0)	Ref. [54, 55]
0	8	(0,1)	Ref. [54, 55]
1	0	(SM,SM)	Z'
1	0	(1,0)	vector
1	0	(0,1)	axial vector
1	0	(1,1)	vector-left
1	0	(1,-1)	vector-right
1	8	(1,0)	coloron/KK gluon, Ref. [56, 57, 58]
1	8	(0,1)	axigluon, Ref. [57]
2	0	–	graviton “continuum”, Ref. [17]
2	0	–	graviton resonances, Ref. [18]

Table 1: The BSM particles included in the `topBSM` “model”.

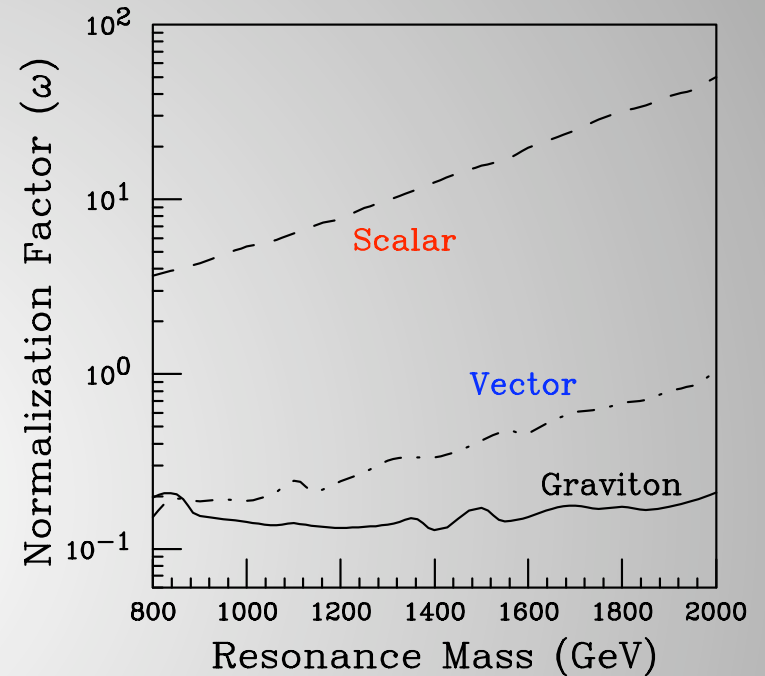
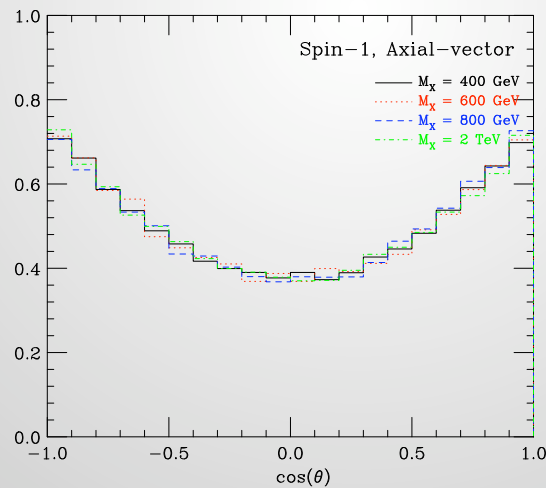
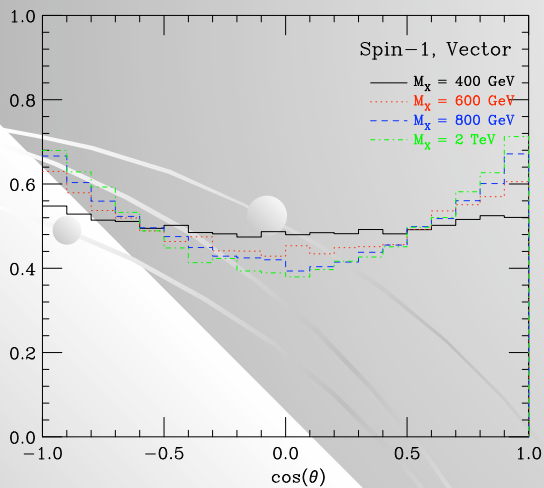
Resonance signal: (cont'd)



(a)



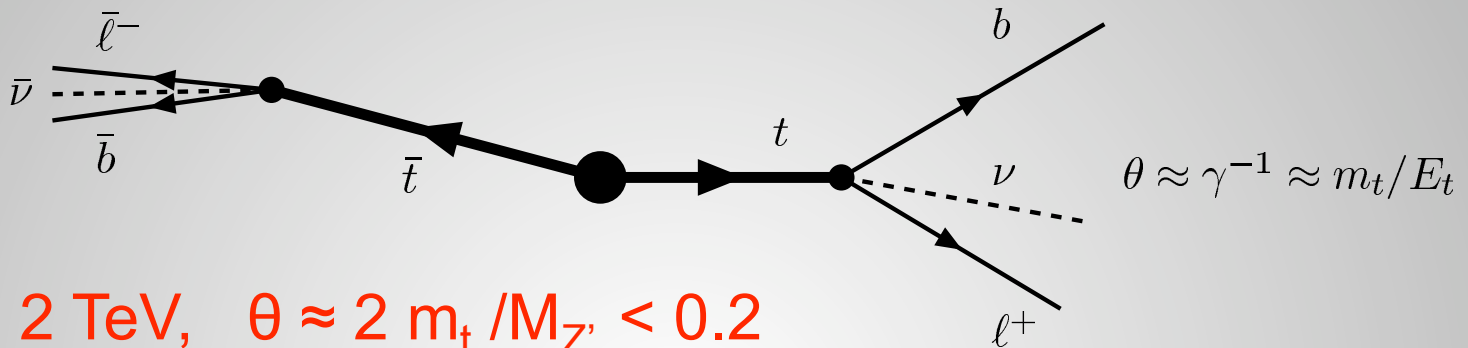
(b)



w.r.t. the SM couplings,
 5σ @ 10 fb^{-1}

Frederix and Maltoni, 0712.2355
Barger, Han, Walker, hep-ph/0612016

A new problem at higher energies: Boosted top / top jet!



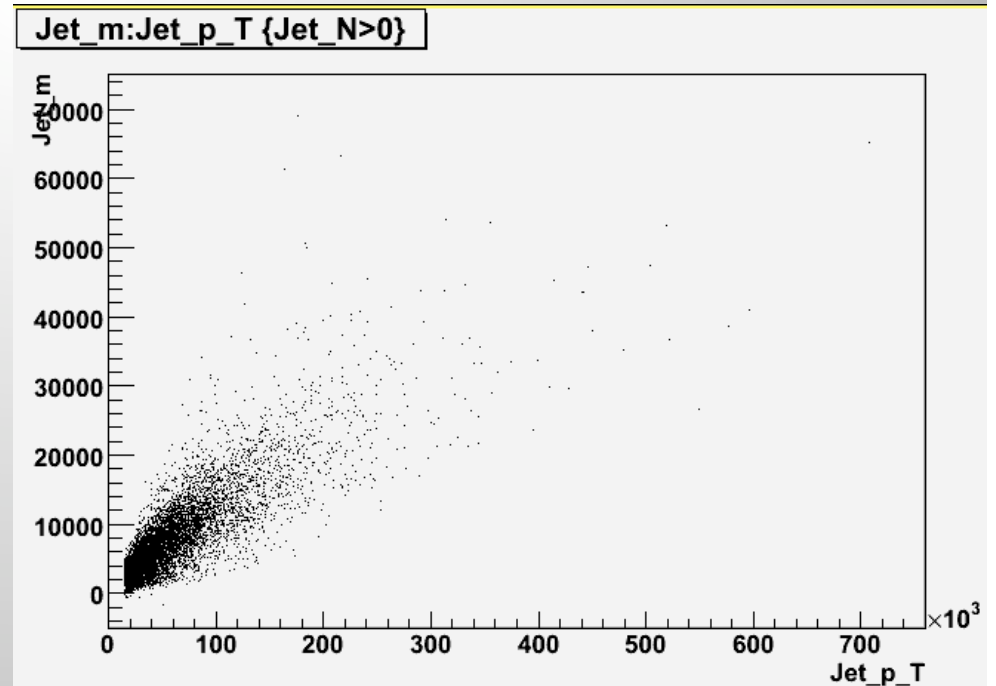
For $M_{Z'} = 2 \text{ TeV}$, $\theta \approx 2 m_t / M_{Z'} < 0.2$

→ lepton/b NOT isolated, inevitable !

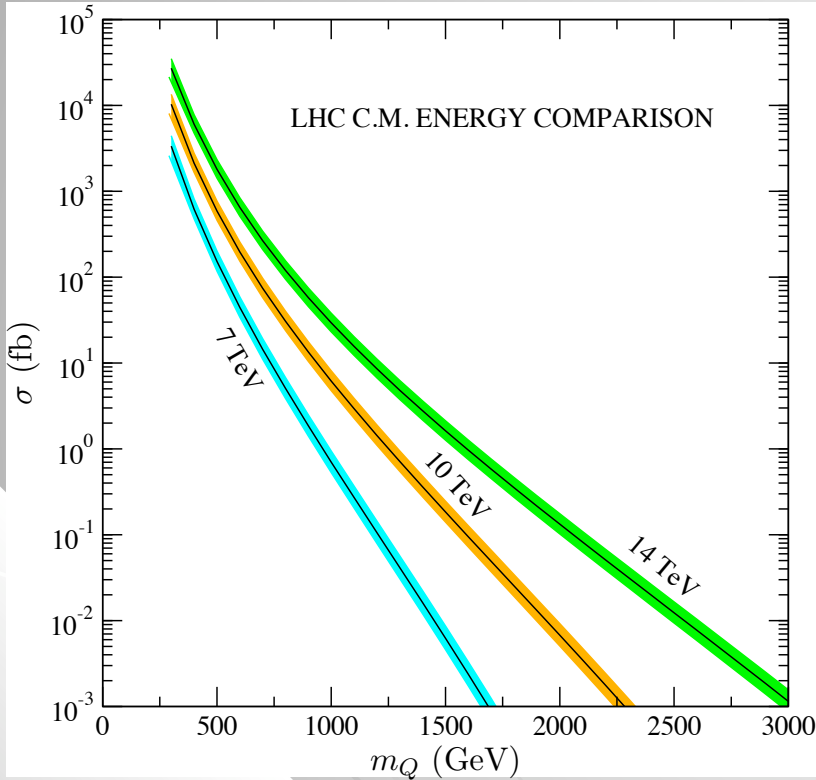
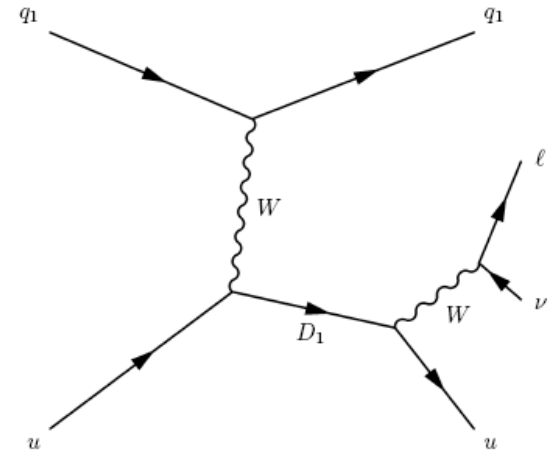
Much larger QCD backgrounds
(E. Chabert, J. Sjolin)

Jet mass?

Agashe et al. hep-ph/0612015;
Barger, Han, Walker, hep-ph/0612016;
Lillie, Randall, Wang: hep-ph/0701166.

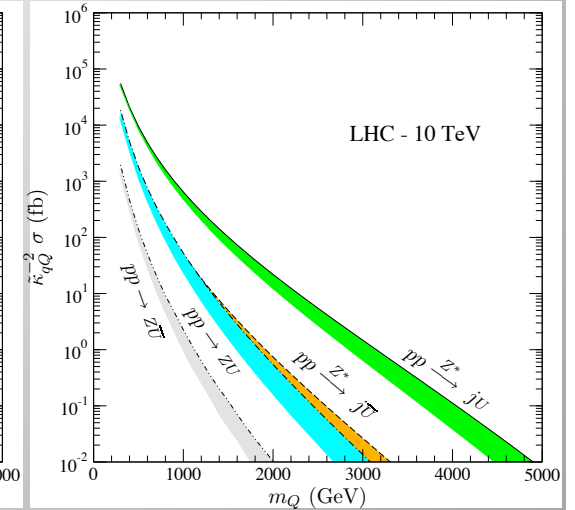
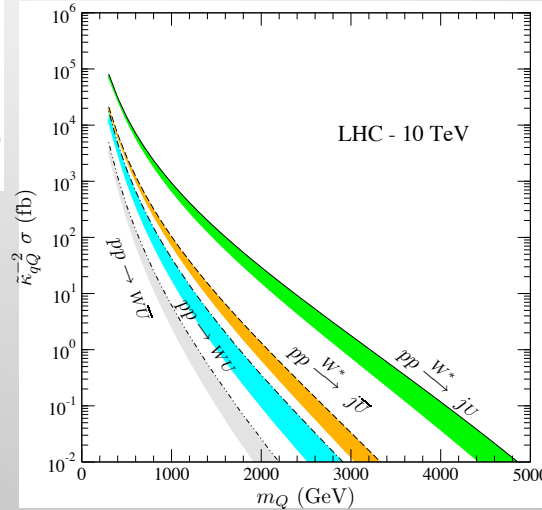
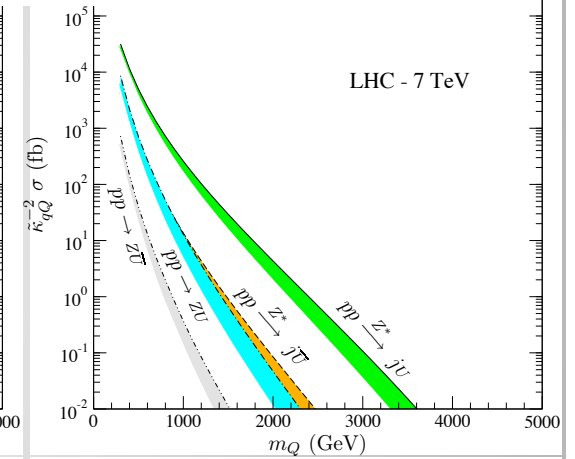
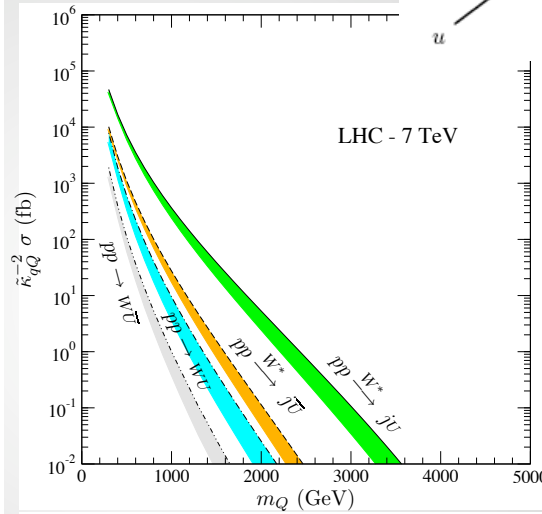


B. *t*-channel new physics: $q q' \rightarrow (V^*) \rightarrow q' Q$



QCD Pair production

(Atre, Carena, Han, Santiago)

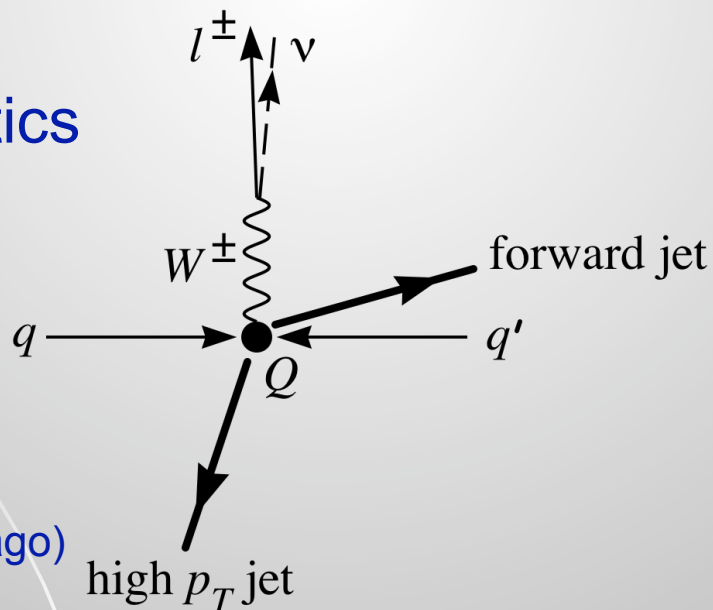


t-channel new physics: (cont'd)

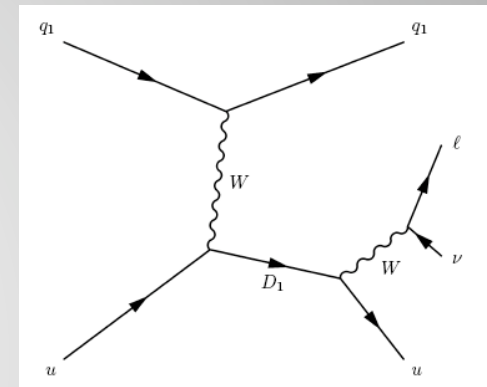
$$q q' \rightarrow (V^*) \rightarrow q' Q$$

- t-channel vector boson enhancement:
 $\ln(s/M_W^2)$
- longitudinal gauge boson enhancement:
 M_Q/M_W

* Unique kinematics



(Atre, Carena, Han, Santiago)



Tevatron reach:
 $600 \text{ GeV} / 8 \text{ fb}^{-1}$

LHC reach:
 $2 \text{ TeV} / 10 \text{ fb}^{-1}$

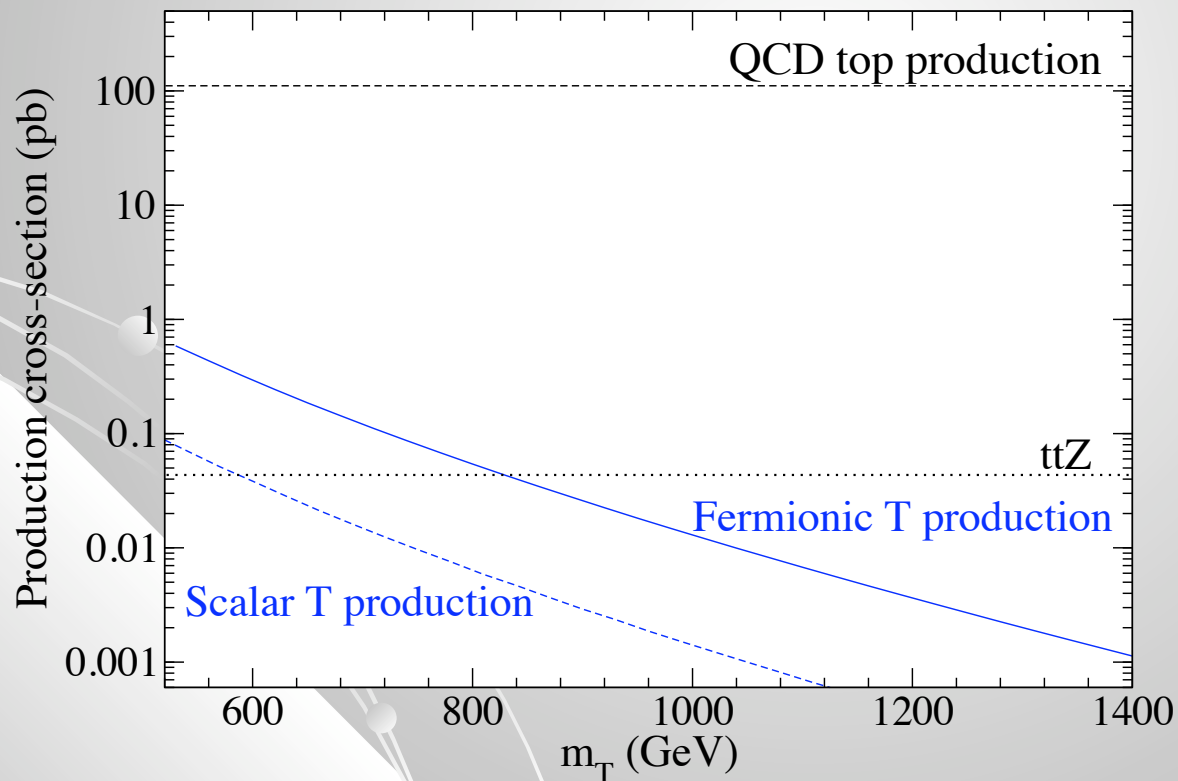
C. Top partners decay to tops

Quite general and well-motivated, there are top-partners:

In SUSY: \tilde{t} (scalar)

In Little Higgs: T (fermion)

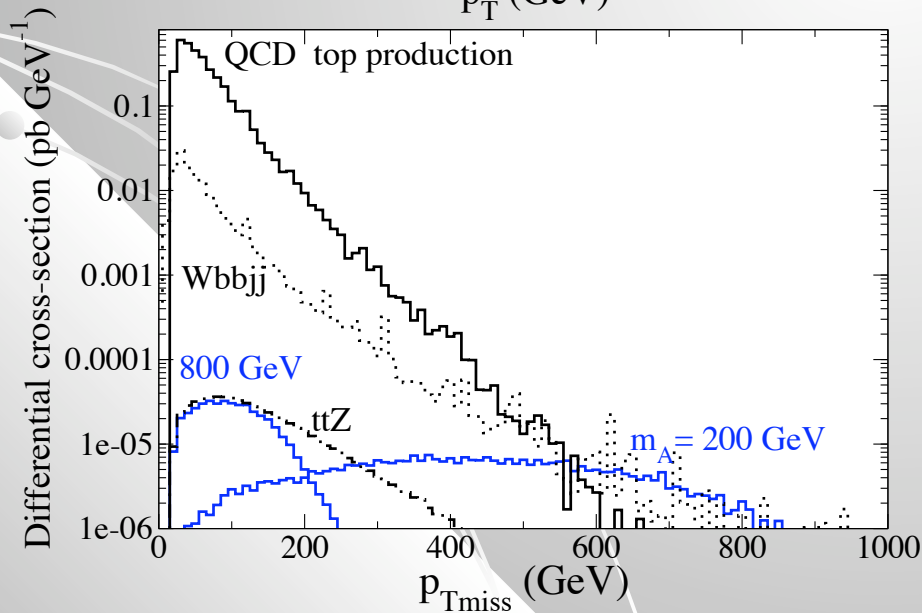
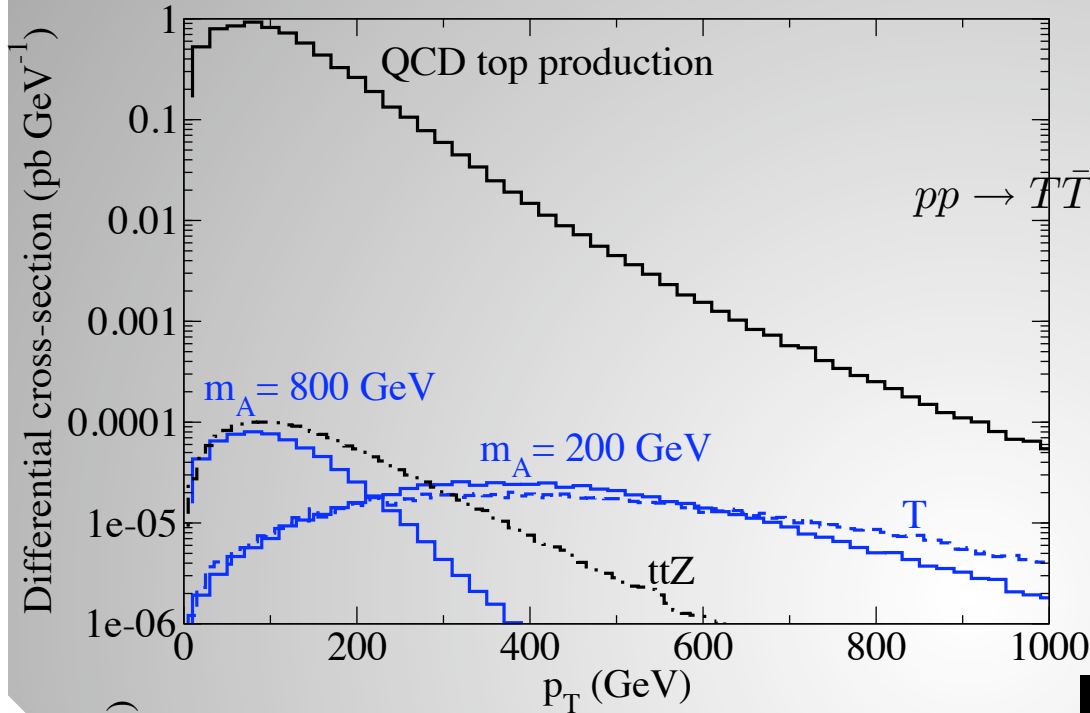
$$pp \rightarrow T\bar{T} \rightarrow tA^0 \bar{t}A^0 \rightarrow t\bar{t} + \cancel{E}_T + X,$$



$$* \sigma(TT) \approx 8 \sigma(\tilde{t}\tilde{t})$$

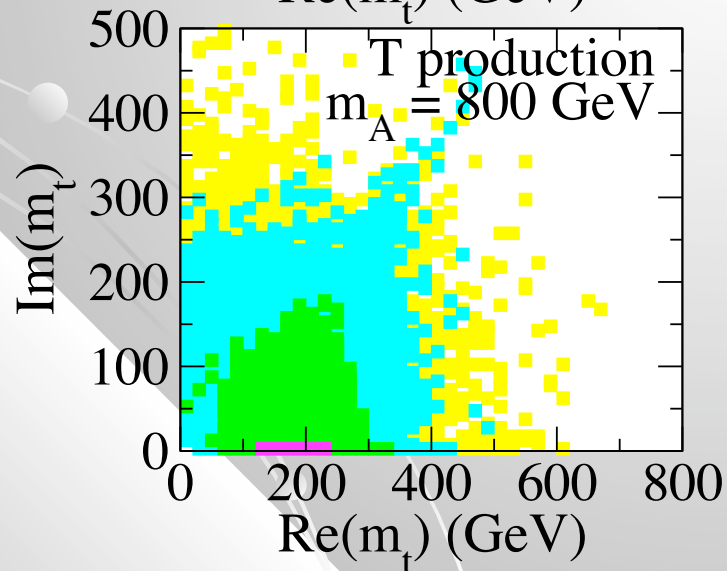
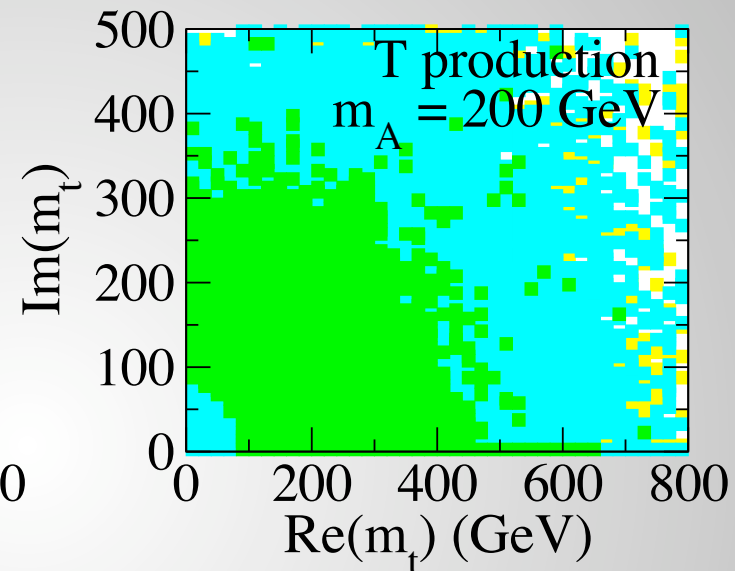
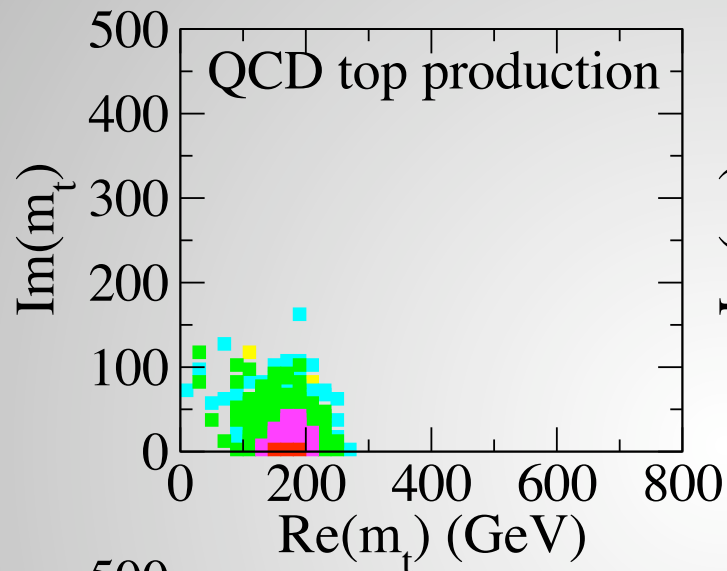
**Dark matter
connection**

How to dig the tops out?



Top mass reconstruction ?

$$(p_l + p_n)^2 = M_W^2, (p_l + p_n + p_b)^2 = m_t^2$$

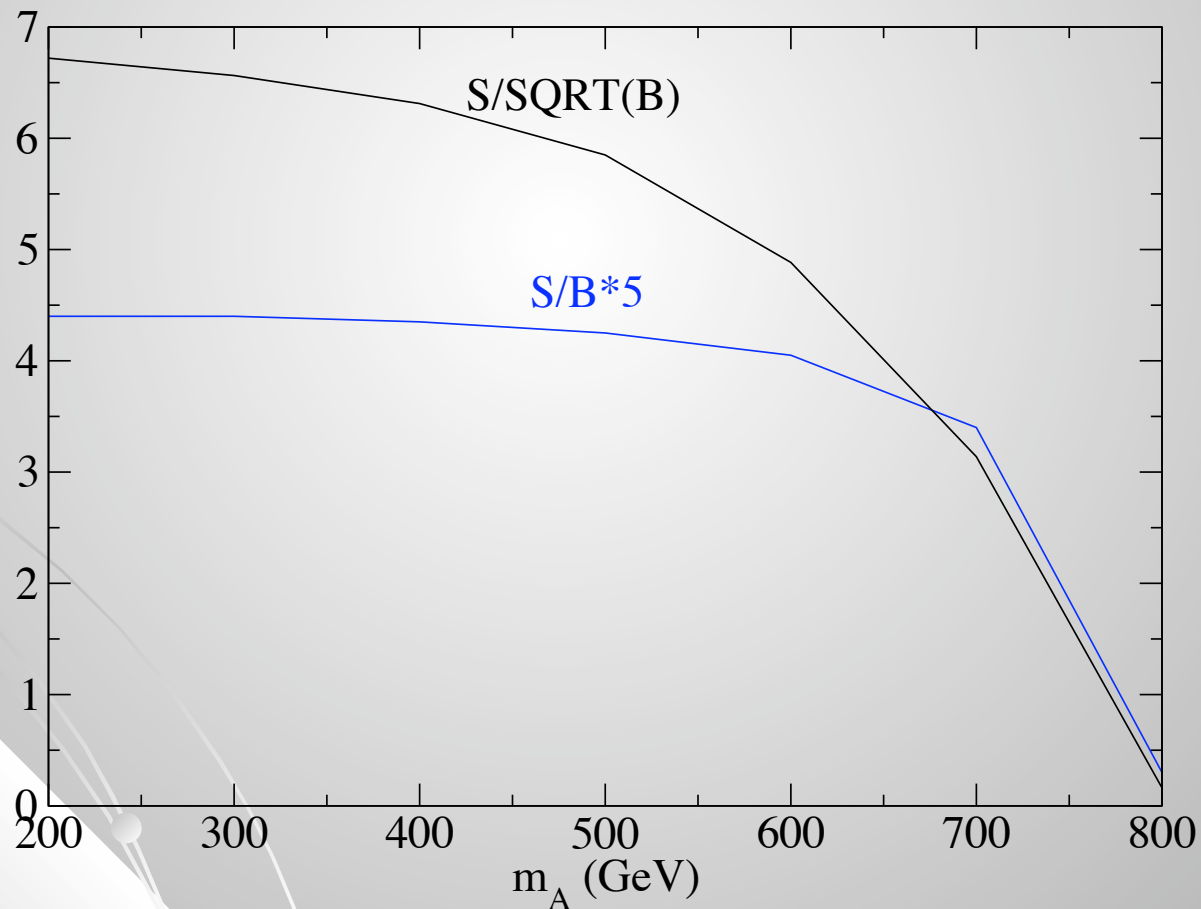


- σ (pb) < 10^{-10}
- $10^{-10} < \sigma$ (pb) < 10^{-8}
- $10^{-8} < \sigma$ (pb) < 10^{-6}
- $10^{-6} < \sigma$ (pb) < 10^{-4}
- $10^{-4} < \sigma$ (pb) < 10^{-2}

*For $m_T \gg m_t + m_A$,
Top pairs can be observed:*

$$70 \text{ GeV} < m_{jj} < 90 \text{ GeV},$$

$$120 \text{ GeV} < m_t^r|_{\text{had}} = m(b_1 jj) < 180 \text{ GeV}$$



*Top is unique:
Think it over again ...*

Practically, the prompt decay

$$\tau \approx 10^{-25} \text{ s} \ll 1/\Lambda_{\text{QCD}}$$

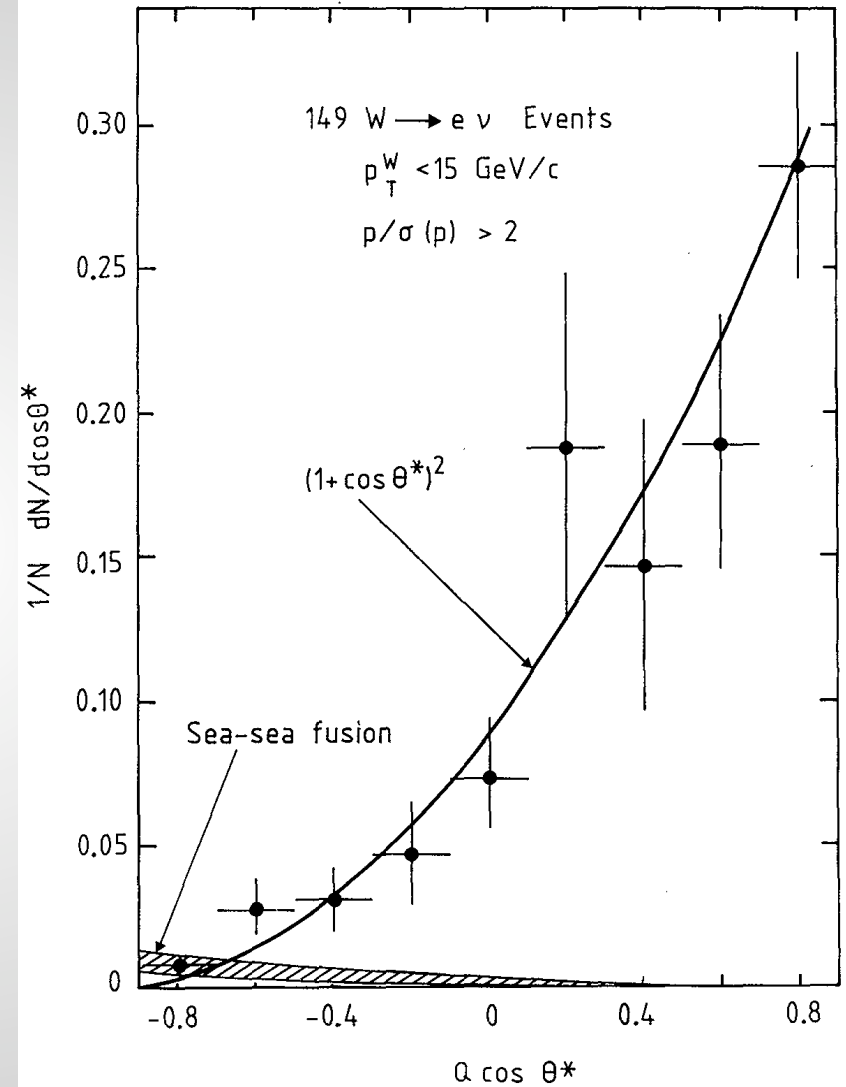
makes the top the only “bare quark” !

How does this help to uncover new physics ?

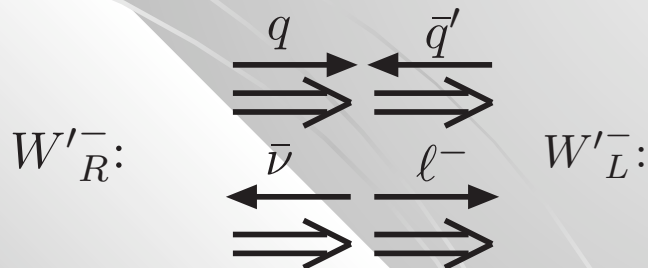
a. Spin, Helicity, Chirality

(Mahon,
Head)

History:
UA1
(1984)

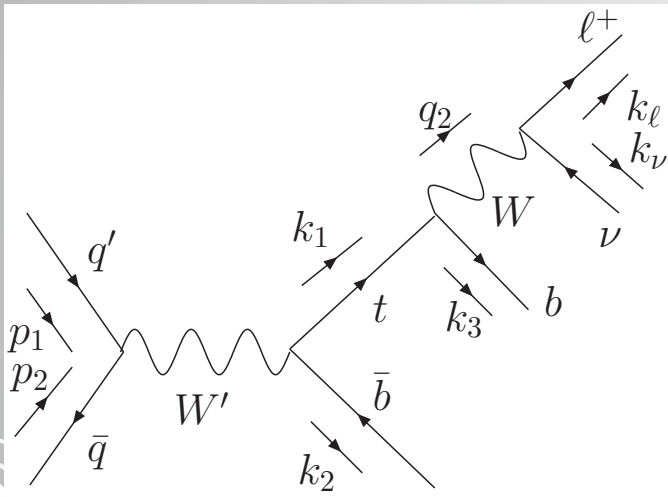


$d \bar{u} \rightarrow W^- \rightarrow e^- \nu$



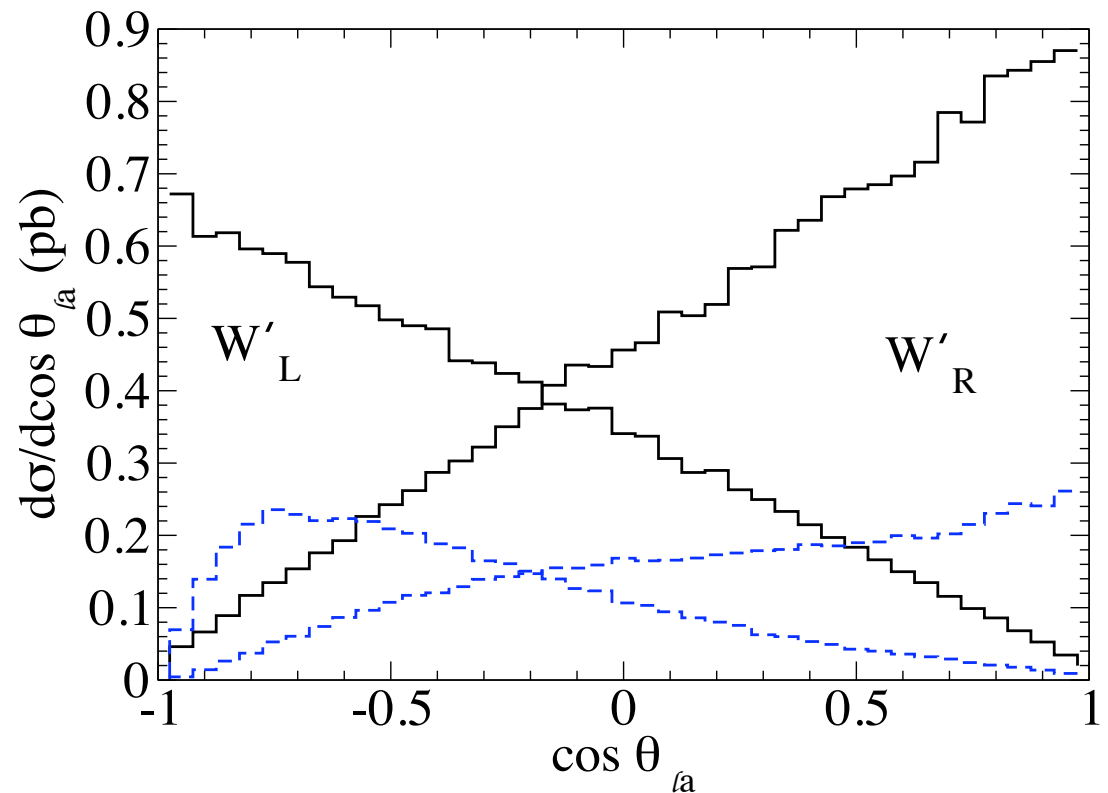
Only top quark can help!

Define a polar angle of a charge lepton
in the top-rest frame, w.r.t the top momentum direction:



$$\frac{d\hat{\sigma}}{d\cos\theta_\ell} \propto 1 + A \cos\theta_\ell,$$

$$A = \frac{g_R^{tb^2} - g_L^{tb^2}}{g_R^{tb^2} + g_L^{tb^2}}.$$



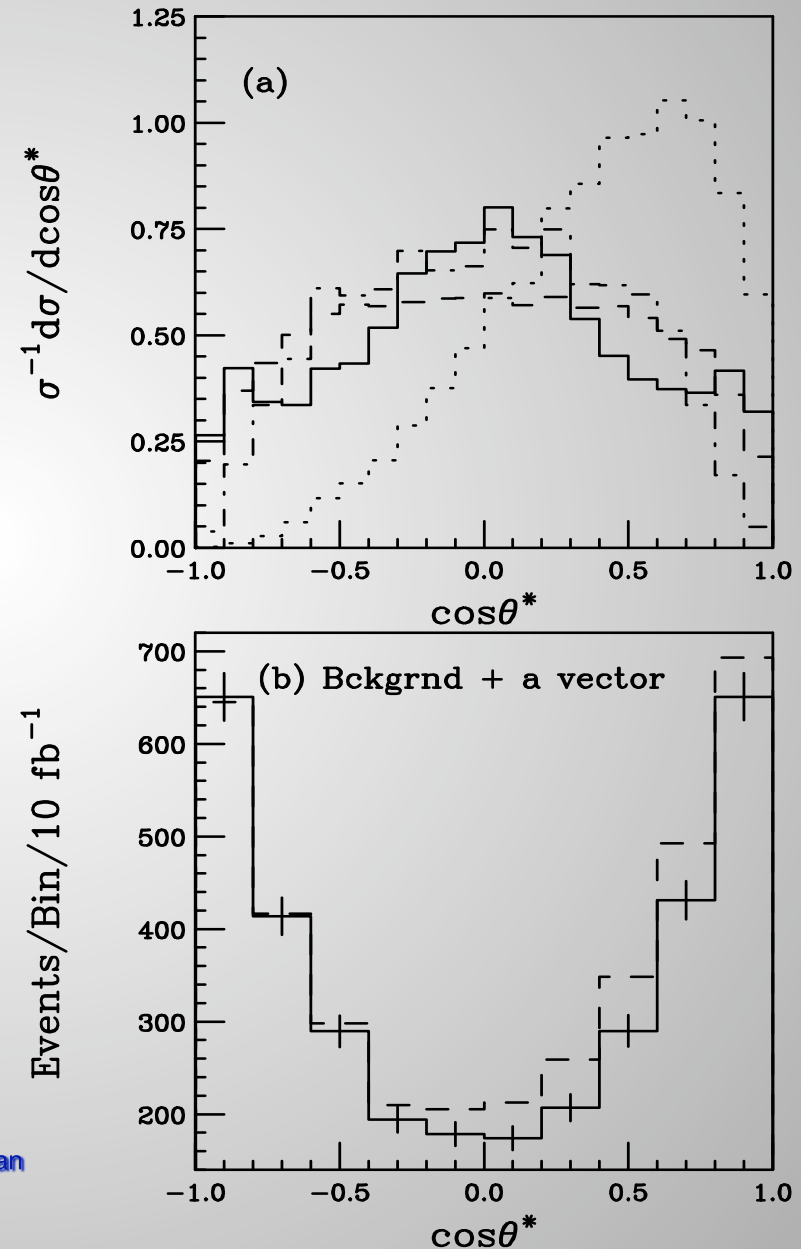
(Repko, Frere; Si et al.)

b. Charge, Parity, and CP

Top is the only quark that its **charge** can be kept track of via leptonic decay, and thus can test F-B symmetry (**parity**).
E.g.: a vector resonance:



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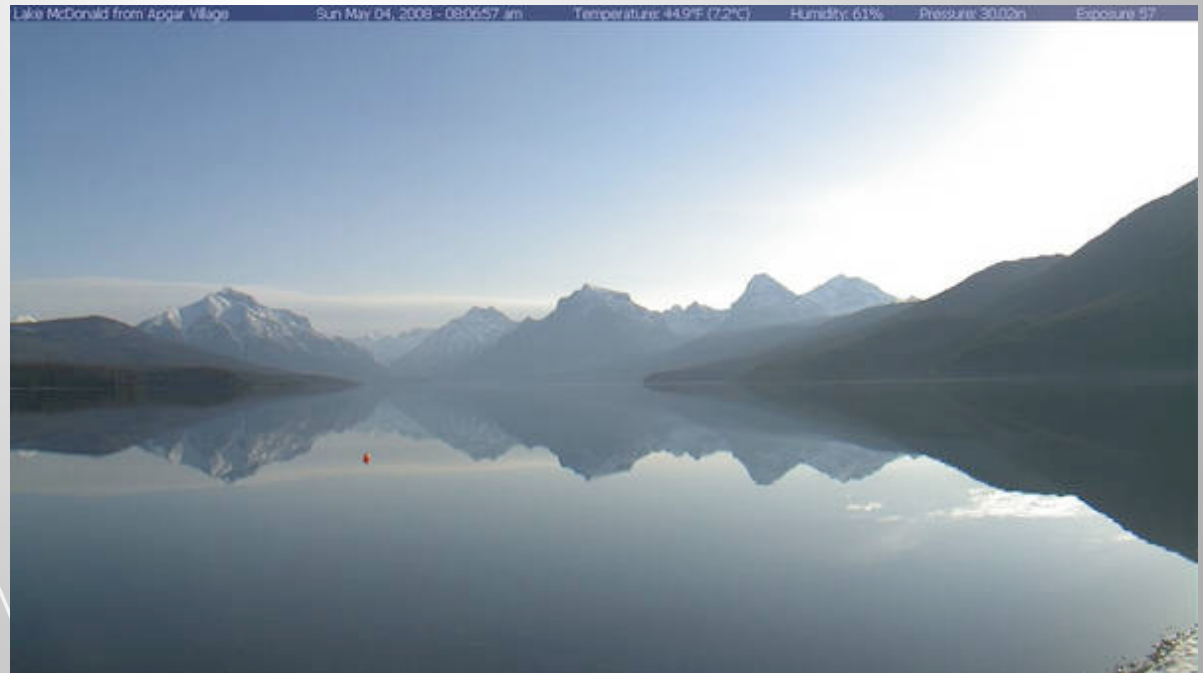
And possibly test **CP asymmetry** as well for tt-interactions:

$$p p \rightarrow t \bar{t} \rightarrow \mu^+ \mu^- \nu \bar{\nu} b \bar{b} X$$

3% asymmetry achievable. 5σ at 10 fb^{-1} .

- The time is ripe for experimental studies of CP violation in top physics: **any observation would signal new physics**. We urge the collaborations to carry them out.

(G. Valencia)



c. Top flavors

Non **tb** couplings of **top** are tiny in SM, and thus worth searching for.

Anomalous couplings may come from effects of heavier particles. (S. Willenbrock)



Some possible rare decays of the top quark into Standard Model particles, the Standard Model branching ratio predictions [67], existing experimental constraints, and prospects for experimental measurements at the LHC.

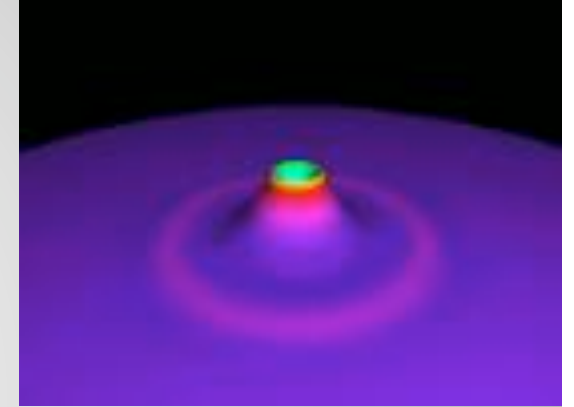
Decay Mode	SM BR	95% CL Tevatron	LHC Prospects 10 fb^{-1}
$t \rightarrow bW$	~ 1	> 0.79 [68]*	0.998 [69] ^{†*}
$t \rightarrow sW$	1.6×10^{-3}	(see above)	(see above)
$t \rightarrow dW$	10^{-4}	(see above)	(see above)
$t \rightarrow qZ$ ($q = u, c$)	1.3×10^{-13}	< 0.037 [70]	6.5×10^{-4} [71]
$t \rightarrow q\gamma$ ($q = u, c$)	5×10^{-13}	< 0.18 [72]	1.9×10^{-4} [71]
$t \rightarrow qg$ ($q = u, c$)	5×10^{-11}	< 0.12 [72]	10^{-2} (1 fb^{-1}) [9]
$t \rightarrow qh^0$ ($q = u, c$)	8×10^{-14}	–	1.4×10^{-4} [73]

d. Baryon Number?

The **baryon number** is necessarily broken, because:

Theory: **B, L** anomalous in SM;

Observation: **Matter-antimatter** asymmetry.



Can we test **B-violation at the LHC**, the energy frontier?

• beyond the only experiments **proton decay and $n-\bar{n}$ oscillation**

The top quark carries **$B=1/3$** ,
a possible chance to test B-violation.

No concrete proposals yet ...

(4) Final Remarks: “Top priority”

Top physics has entered a more exciting era!

- Hard to imagine that top won't lead the way for new physics discovery!
Should be the “Top priority”!
 - Efficient top event reconstruction
 - Boosted tops for heavy resonances:
jets, b-tagging at high p_T , isolation
 - Control systematics: ISR/FSR
(both expt. and theo.)
 - * Parton showering/merging, scale choice (theo.)
- Will keep us busy! Realize our dreams!



We all thank the organizers
for such an enjoyable workshop:

Jorgan D'Hondt
Andrea Giammanco
Fabio Maltoni
Catherine Vander Velde,
and Daisy Pirnay

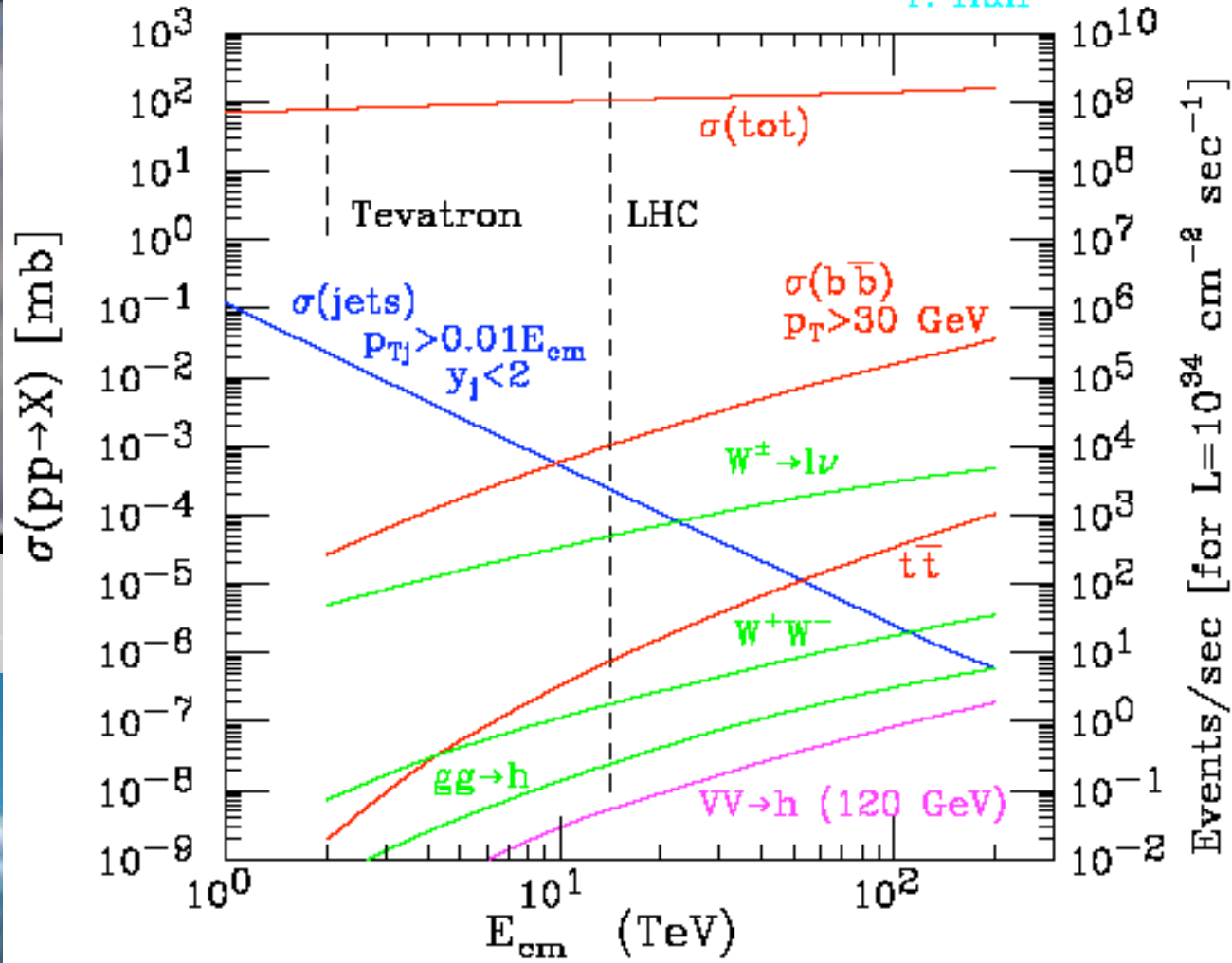
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New Symmetries:

T. Han



Great potential to open a new chapter of HEP !