Challenges in Searching For New Physics at Hadron Colliders

Tao Han
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TeV4LHC Workshop, Fermilab, Oct. 20, 2005

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The Fun in Searching For New Physics at Hadron Colliders

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Integrated luminosity over 1 fb^{-1};

Peak luminosity record high $\approx 1.3 \times 10^{32}\ cm^{-2}s^{-1}$;

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C.M. energy $> \times 7$; Integrated luminosity $> \times 100$.

New physics discovery fully anticipated.

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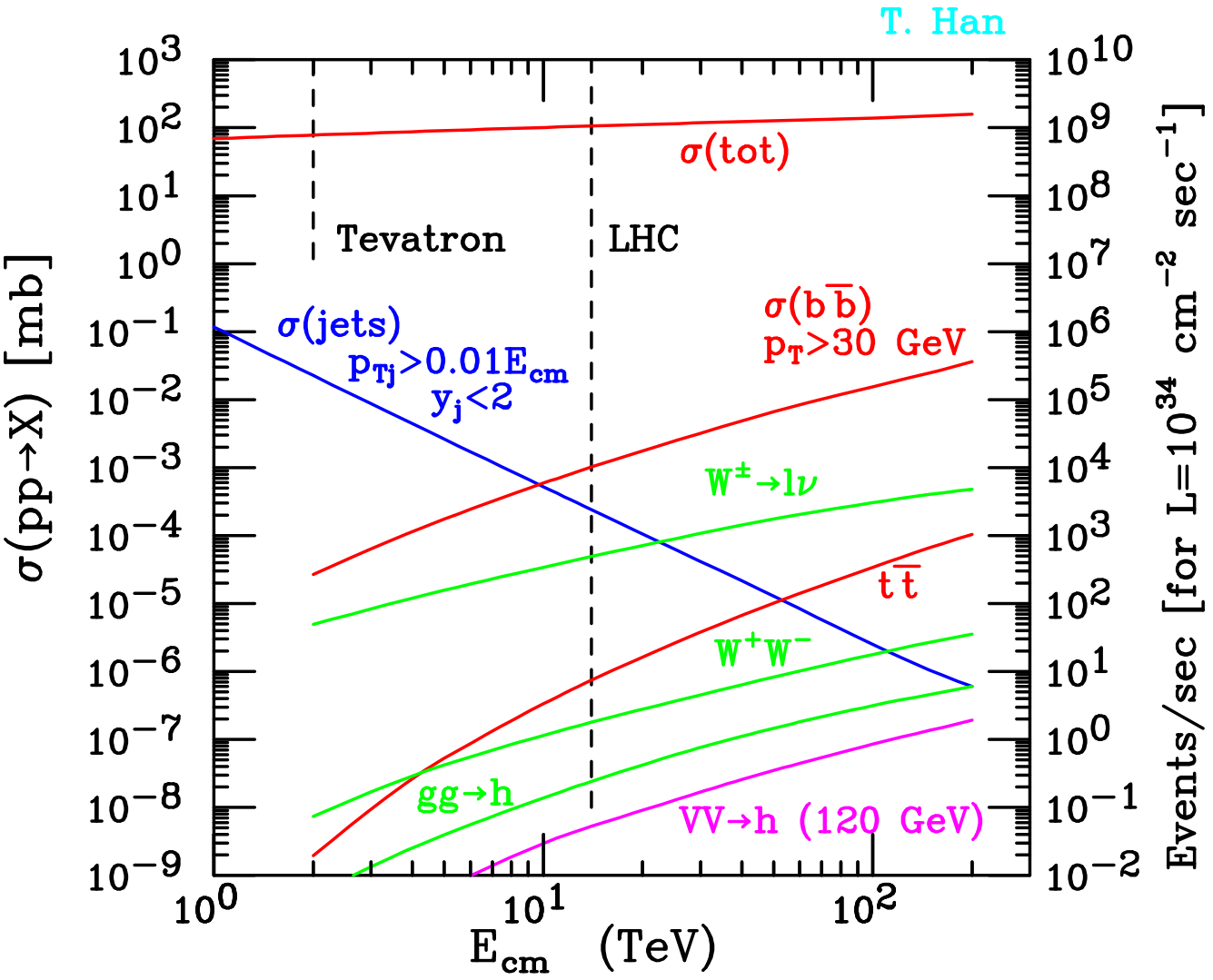
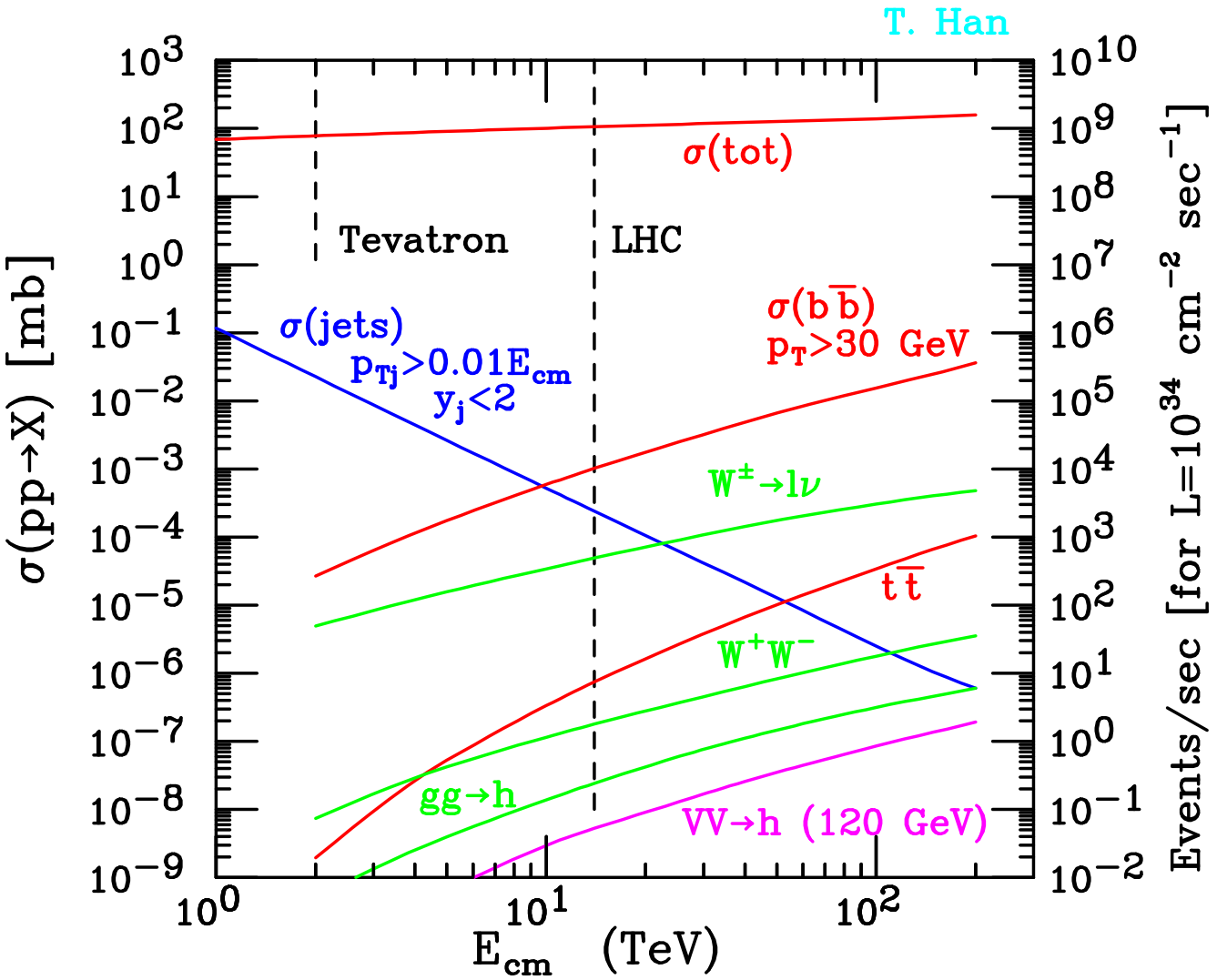
However, it will be challenging
to both theorists and to experimenters.

Re-discover the Standard Model



Re-discover the Standard Model



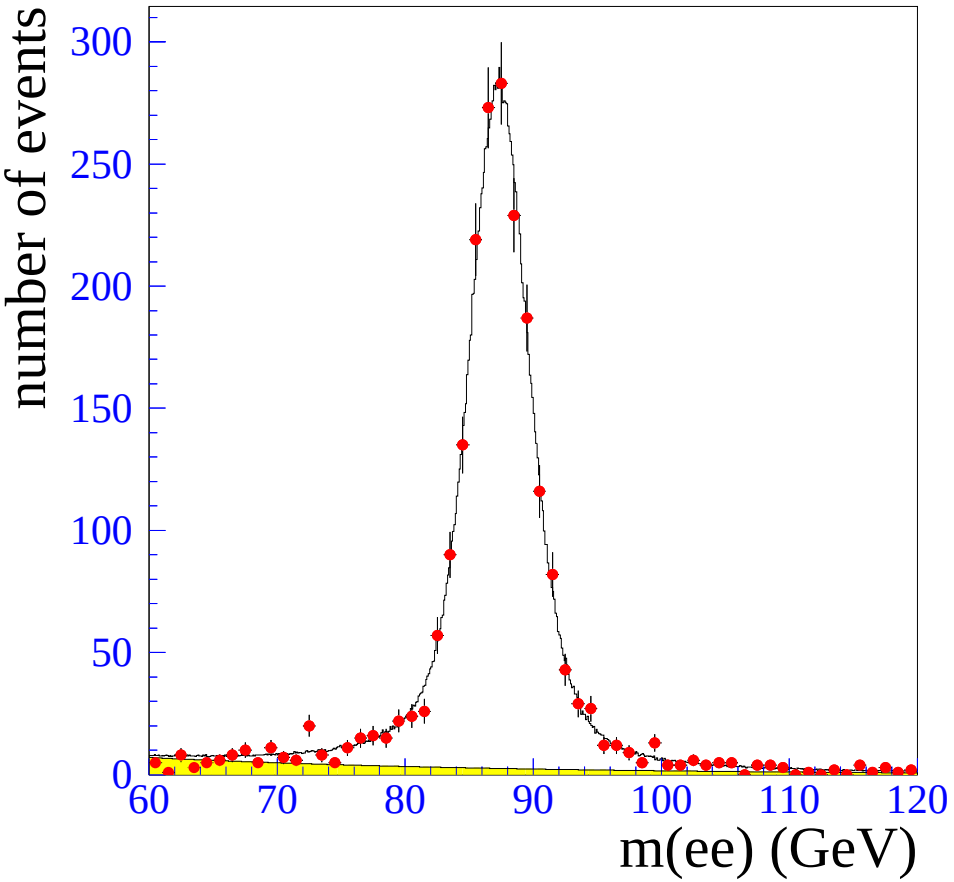
At the LHC, the large rate turns to a hostile environment:

$\approx$ 1 billion event/sec.

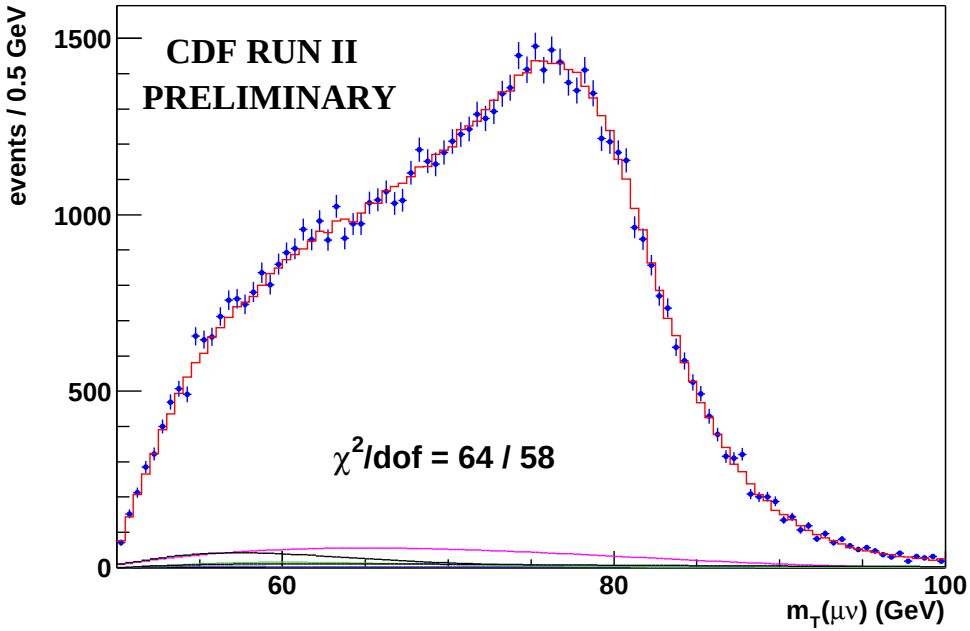
$\approx$ 25 overlapping events/bunch crossing.

Appreciate the beautiful results from the Tevatron:

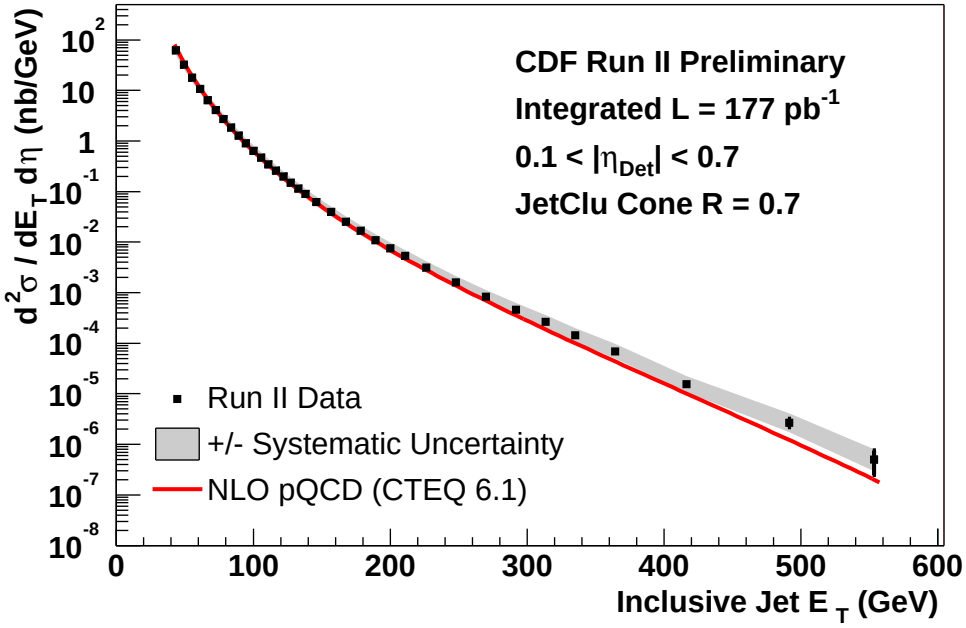
D0 $Z \to e^+e^-$



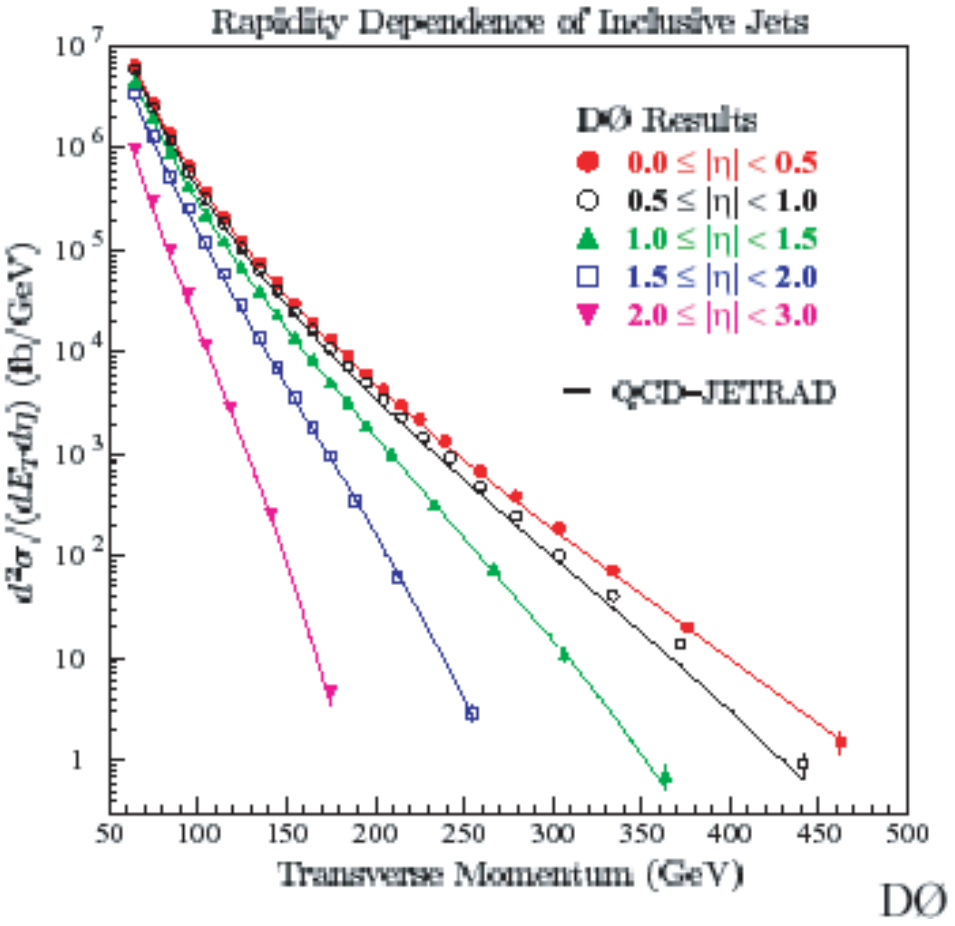
CDF $W \to \mu\nu$



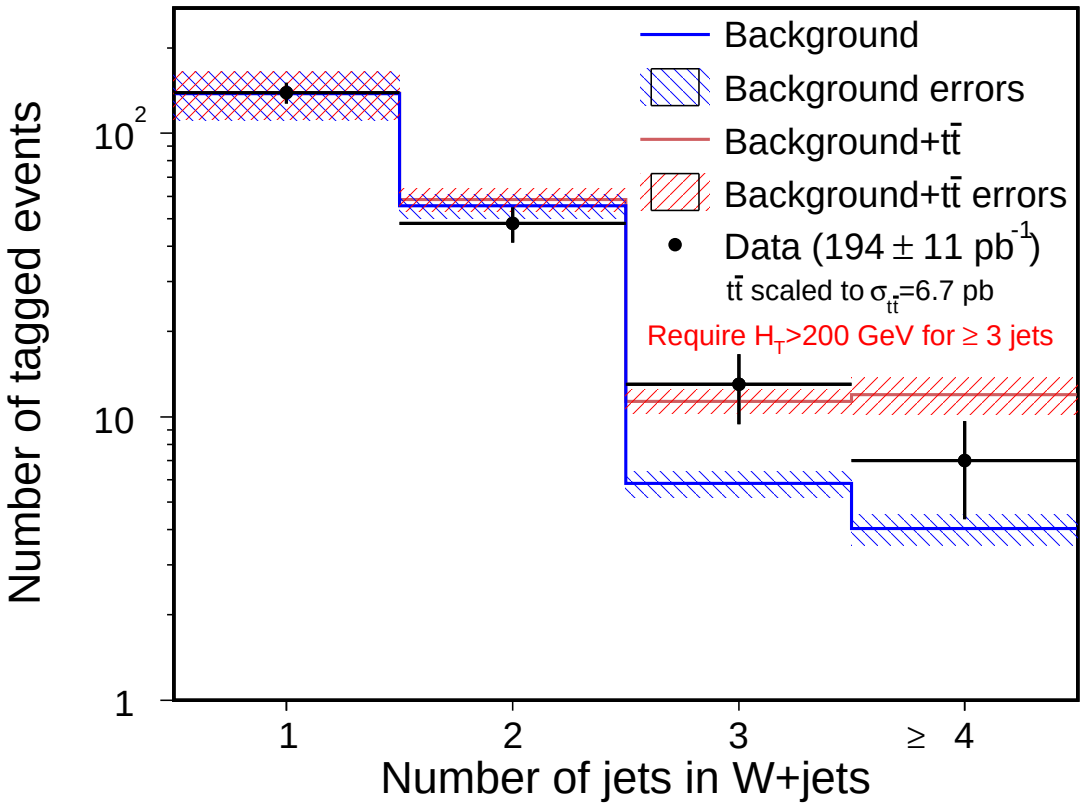
CDF 1-jet inclusive



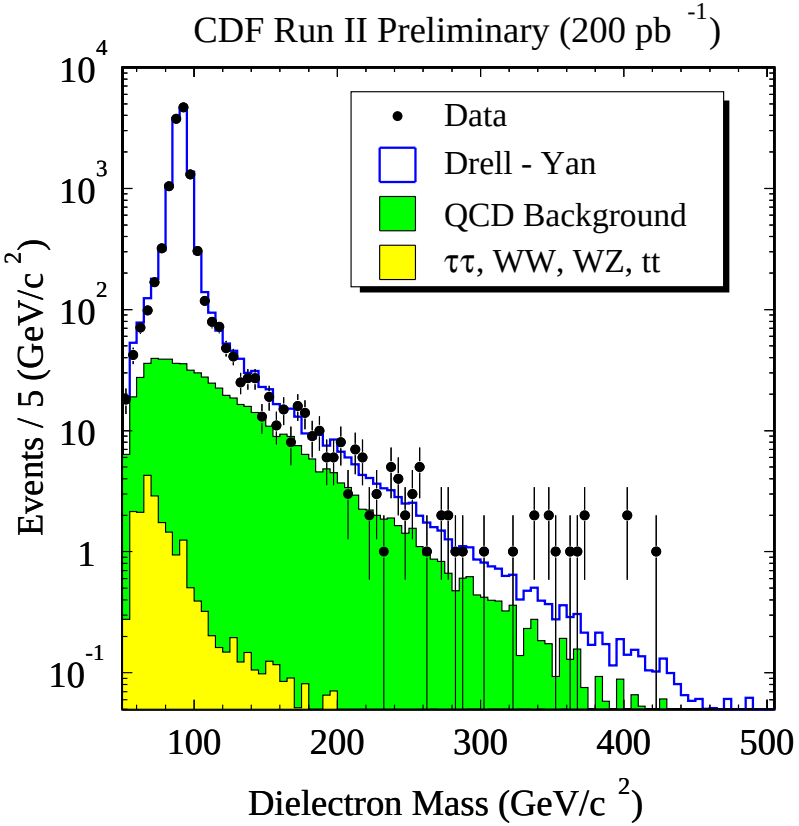
D0 1-jet in rapidity ranges

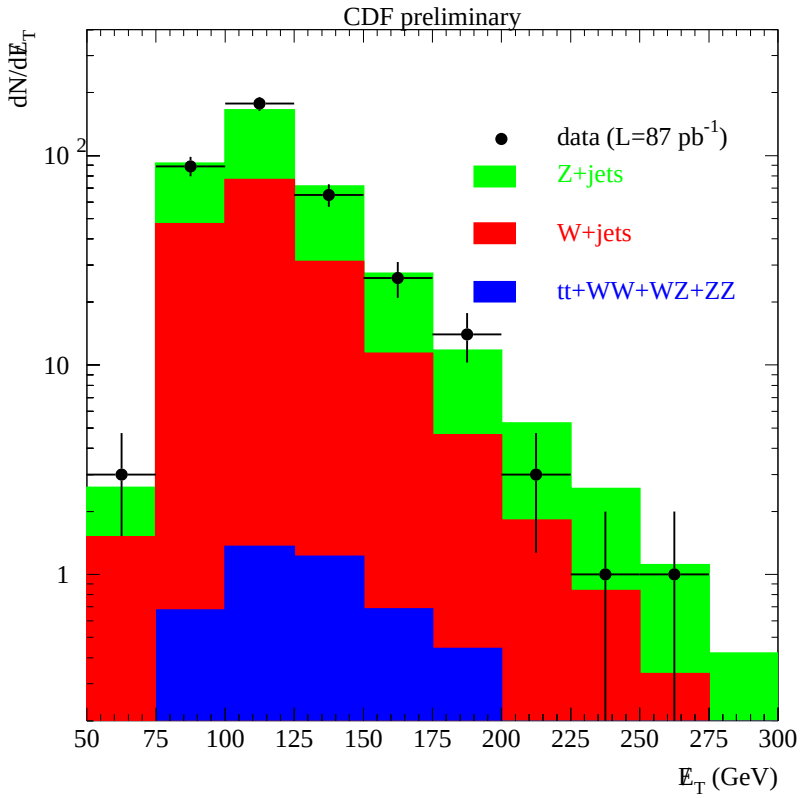


CDF W+jets sample and top-quark events



CDF M_{ee} and $\not\!\!E_T$





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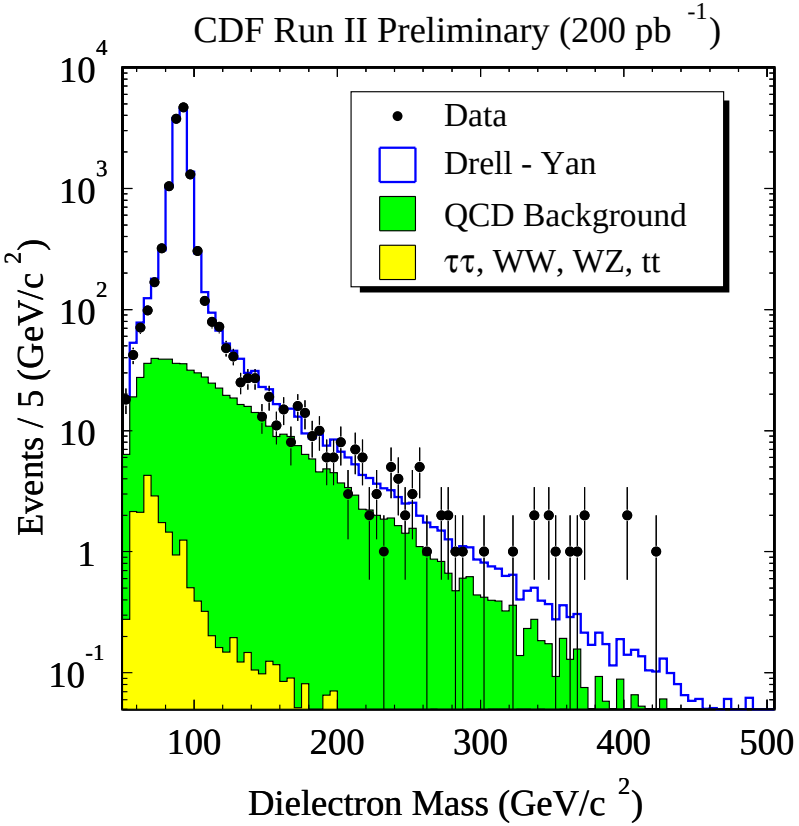

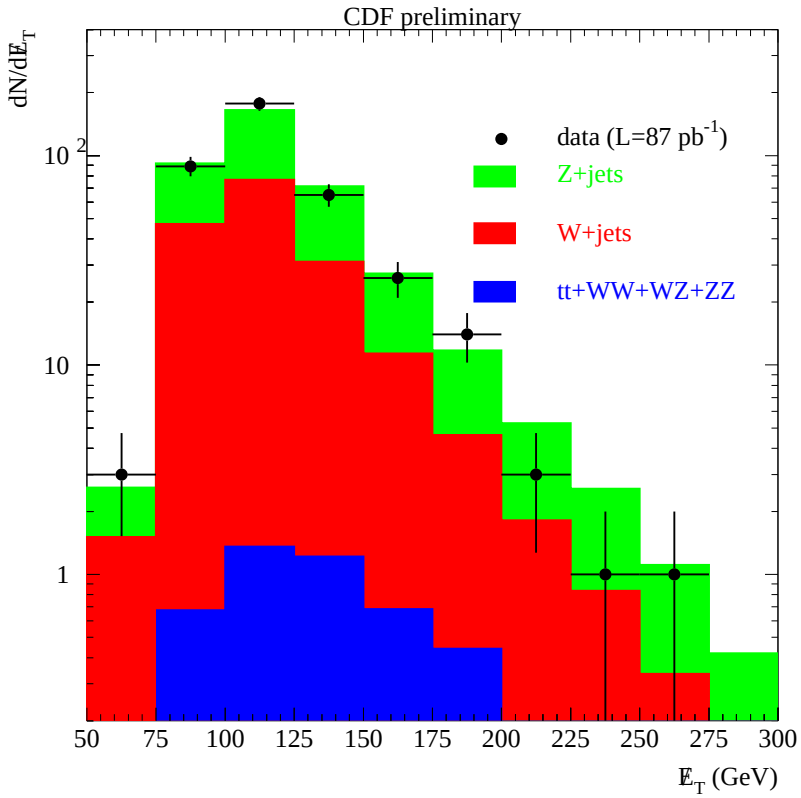

LHC: don't claim new physics till ...

- Z/γ^*, $W^\pm$ Drell-Yan rate and spectrum;
- jet inclusive to $p_T^j \sim 300 - 400$ GeV;
- near thresholds of WW, WZ, ZZ, $W\gamma$, γ+jets.

Discover New Vector Bosons

(A). "Electroweak" vector bosons: Z', W'

Bump search is our best! *

$\sigma(M_{Z'} = 2 \text{ TeV}) \approx 1 \text{ pb.} \Longrightarrow$ discovery in $M(\ell^+\ell^-)$ with 300 pb^{-1}.

*Michael Schmitt, next talk for real.

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This is applicable to searches:

- Z' in string-inspired models;
- Z_R, W_R in L-R symmtric models;
- Z_{KK}, W_{KK} in R-S bulk, Universal Xdim, Higgsless;
- Z_H, W_H in Little Higgs.

And even higher spin states:

- G^n_{KK} R-S gravitons;
- V_J string resonances.

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Challenge: What is it ?

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First note $\Gamma_V \approx (50\ \text{GeV}) \frac{M_V}{1\ \text{TeV}}\ \kappa^2$.

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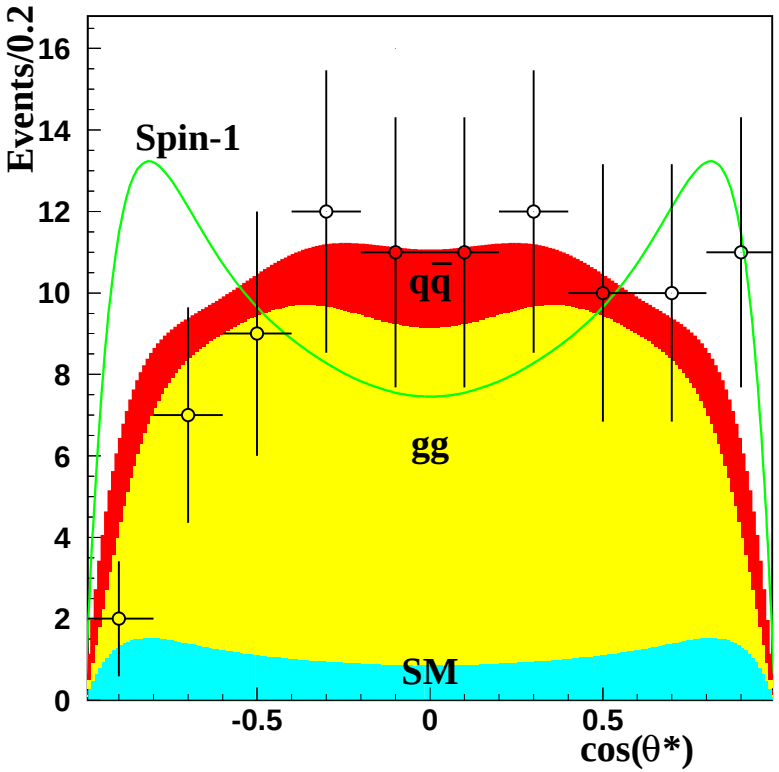
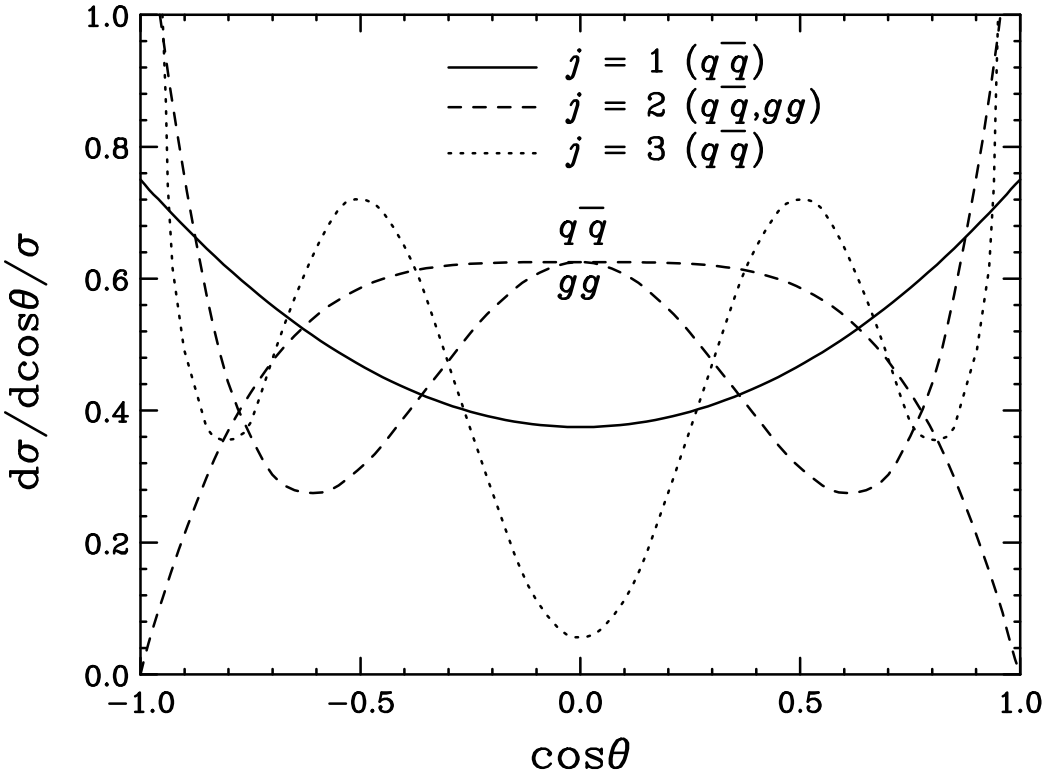
Polar angular distributions with different j: *



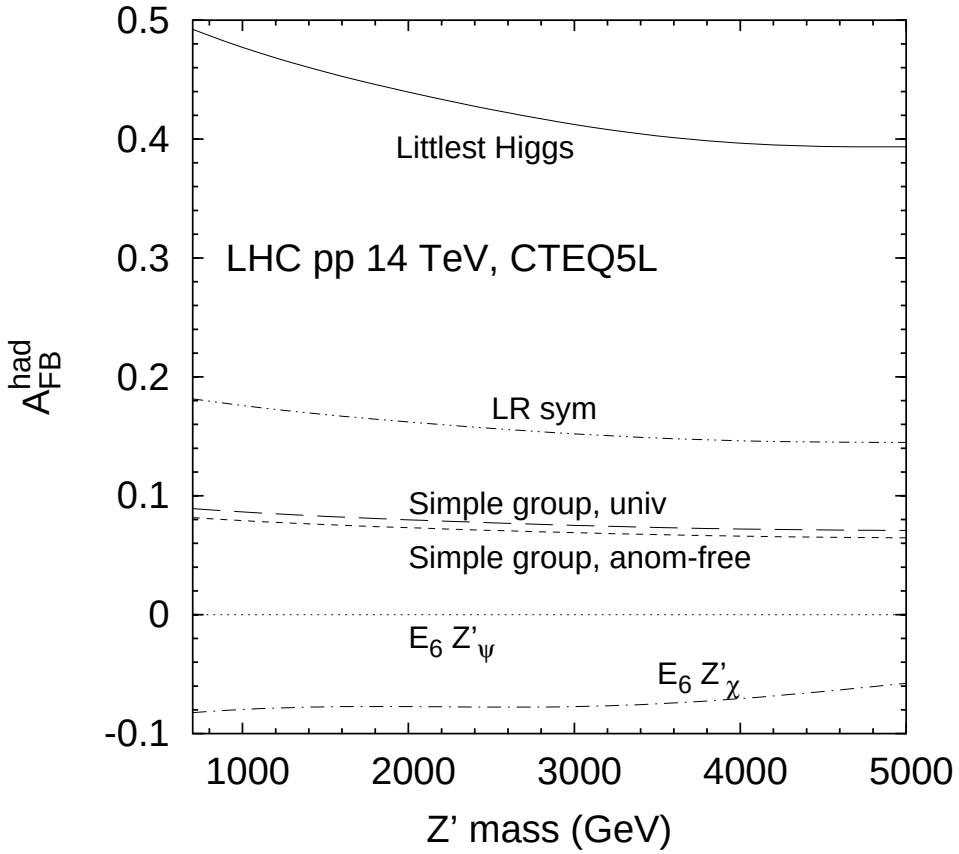


Straightforward angular measurements and fitting.

*Allanach et al., hep-ph/0006114; Burikham et al., hep-ph/0411094.

Forward-backward charge asymmetry:*

$$A_{FB}^{i,f} = \frac{3}{4} A_i A_f, \quad A_i = \frac{g_L^2 - g_R^2}{g_L^2 + g_R^2}.$$



*Langacker, Rosner, Robinett (1984); Carena, Daleo, Dobrescu, Tait, `hep-ph/0408098`; Hewett, Rizzo; Han, Logan, Wang, `hep-ph/0506313`.

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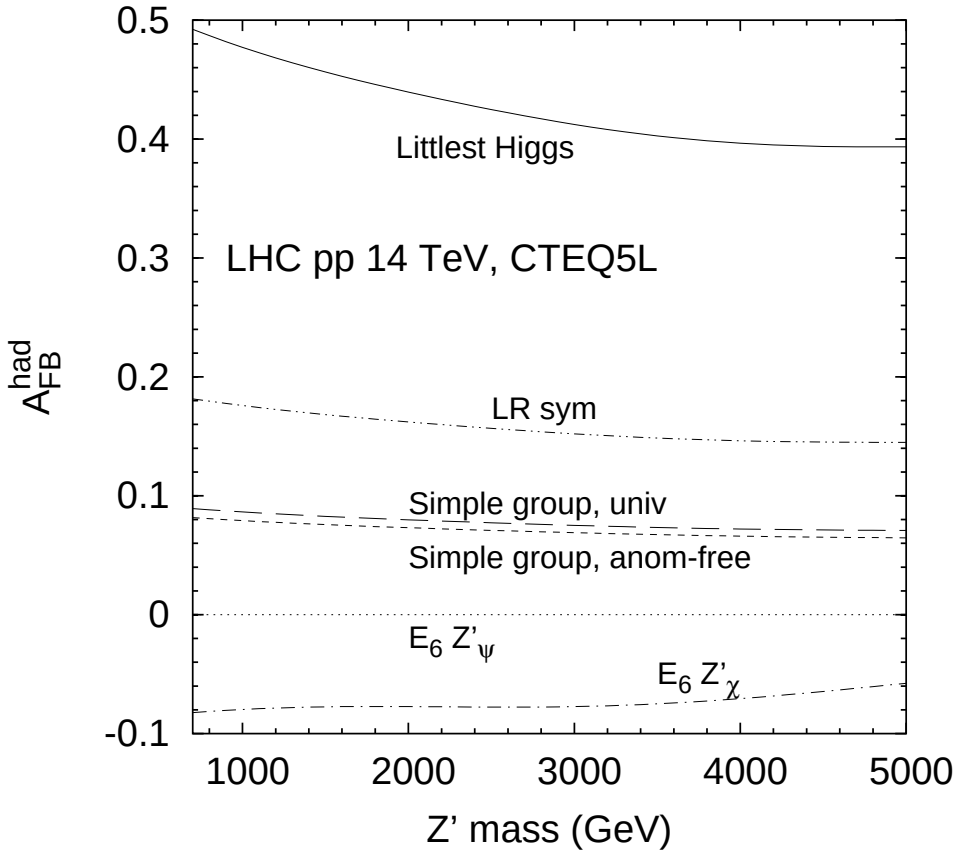

Challenge to experiments :

Lepton charge identification for $p_T^\ell > 1$ TeV:

ATLAS: $\frac{\Delta p_\mu}{p_\mu} \sim 10\% \; \frac{p_\mu}{1 \text{ TeV}}$.

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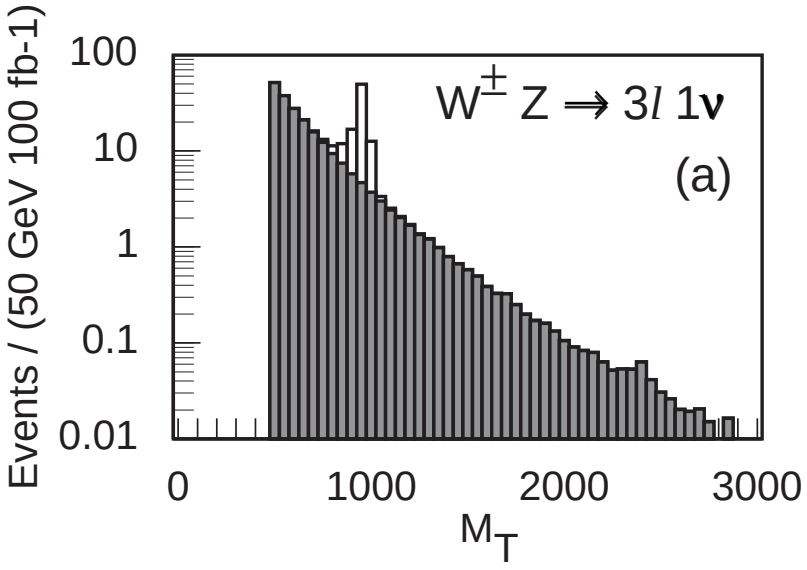
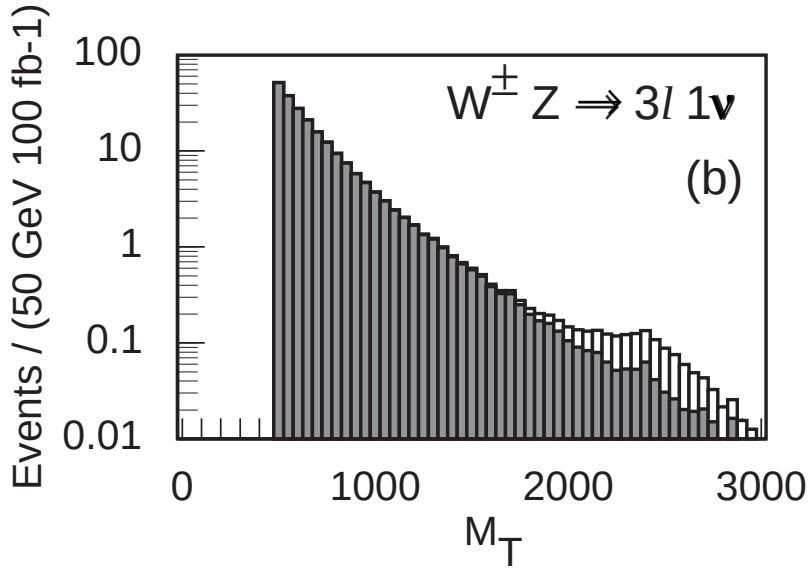
(B). Strongly-interacting "Electroweak" vector bosons: ρ_{TC}[†]

$$q\bar{q} \to \rho_{TC}^{\pm,0} \to W_L^{\pm} Z_L,\ W_L^{+} W_L^{-},\ t\bar{t},\ t\bar{b};$$
$$qq \to qq\ \rho_{TC}^{\pm,0} \to qq\ W_L^{\pm} Z_L,\ W_L^{+} W_L^{-},\ t\bar{t},\ t\bar{b}.$$





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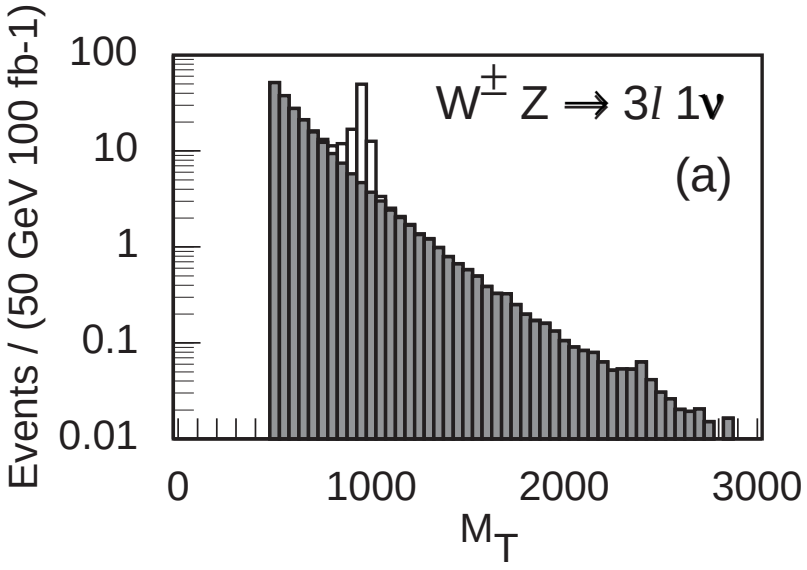

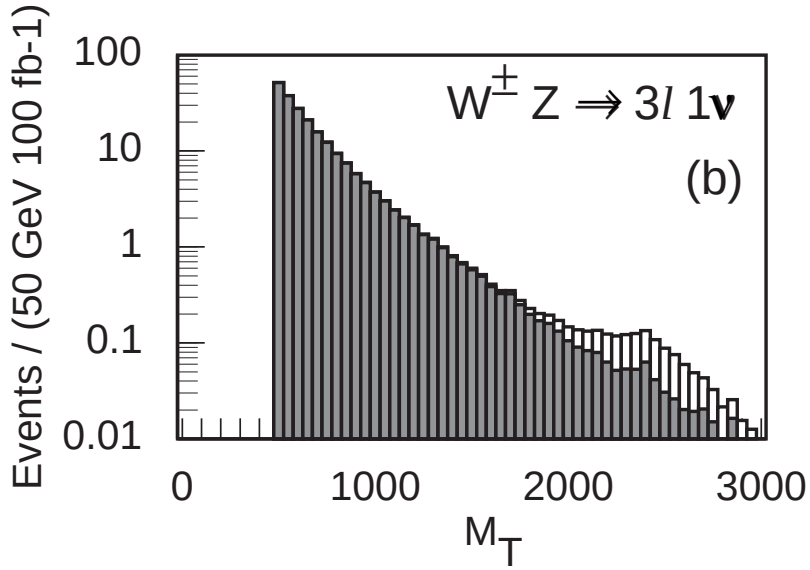

(C). Colored bosons: $\eta_8,\ \pi_8,\ \rho_8,\ Z_8 \to t\bar{t}$. [‡]

$$\Gamma \gtrsim 20\%\ M_V, \quad \sigma \sim \sigma_{QCD}(t\bar{t}).$$

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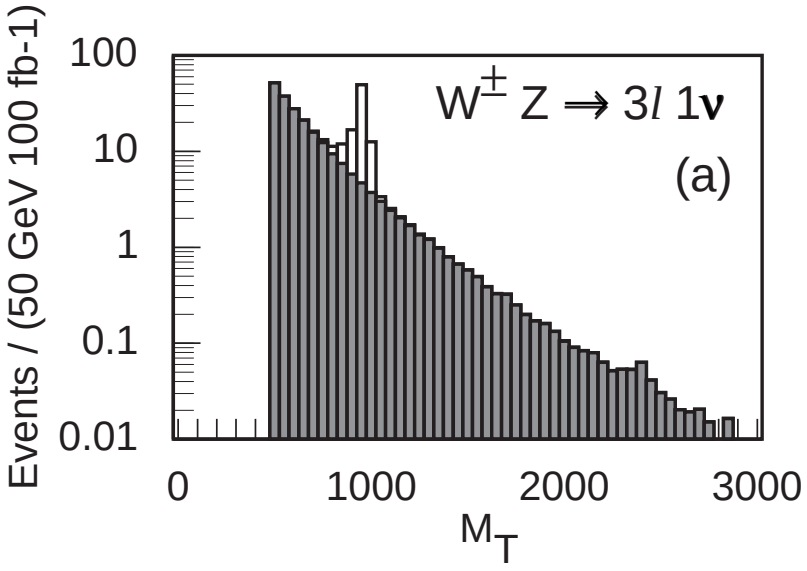

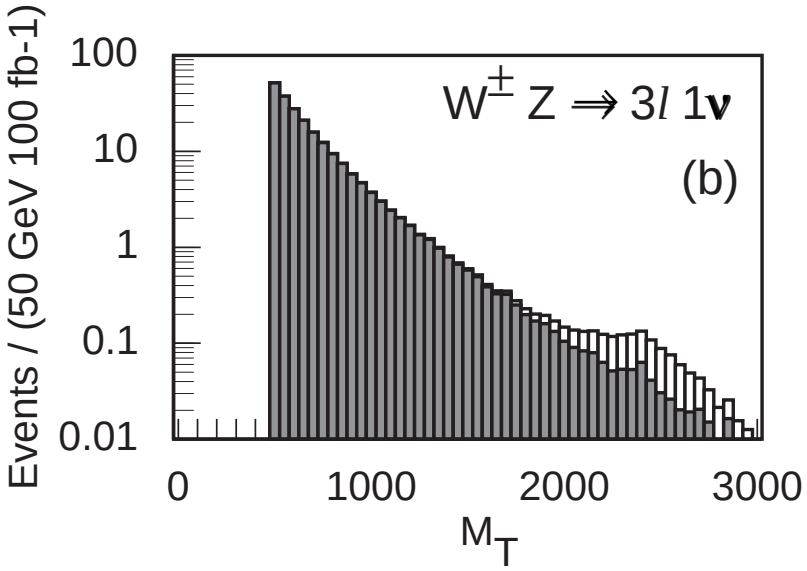

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Challenge : beat the SM backgrounds $WW,\ WZ,\ t\bar{t}$ etc.
Tevatron Input : How to reconstruct energetic tops ?

[†]Bagger et al., PRD (1995.)

[‡]Eichten, Lane; Hill, Parke (1993).

Discover New Heavy Quarks

- T in topcolor/top seasaw (Hill, Dobrescu, He, Tait);
- T, U, D in Little Higgs models

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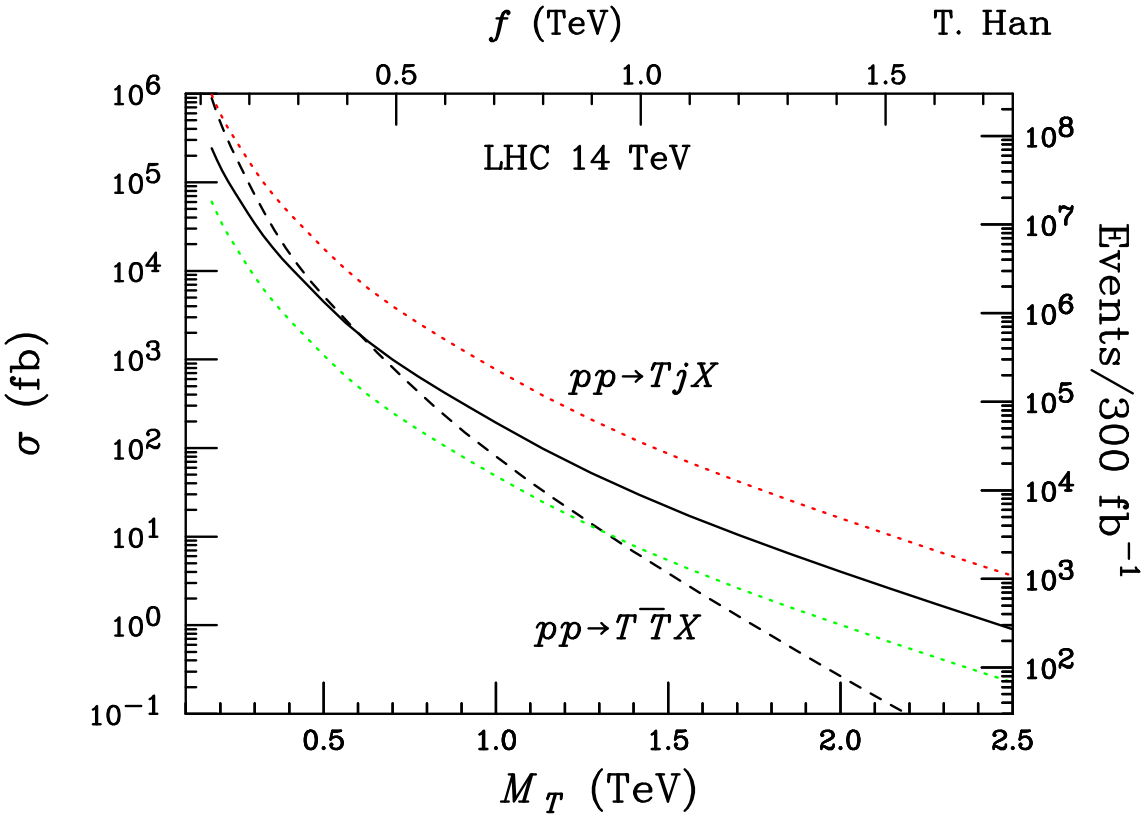

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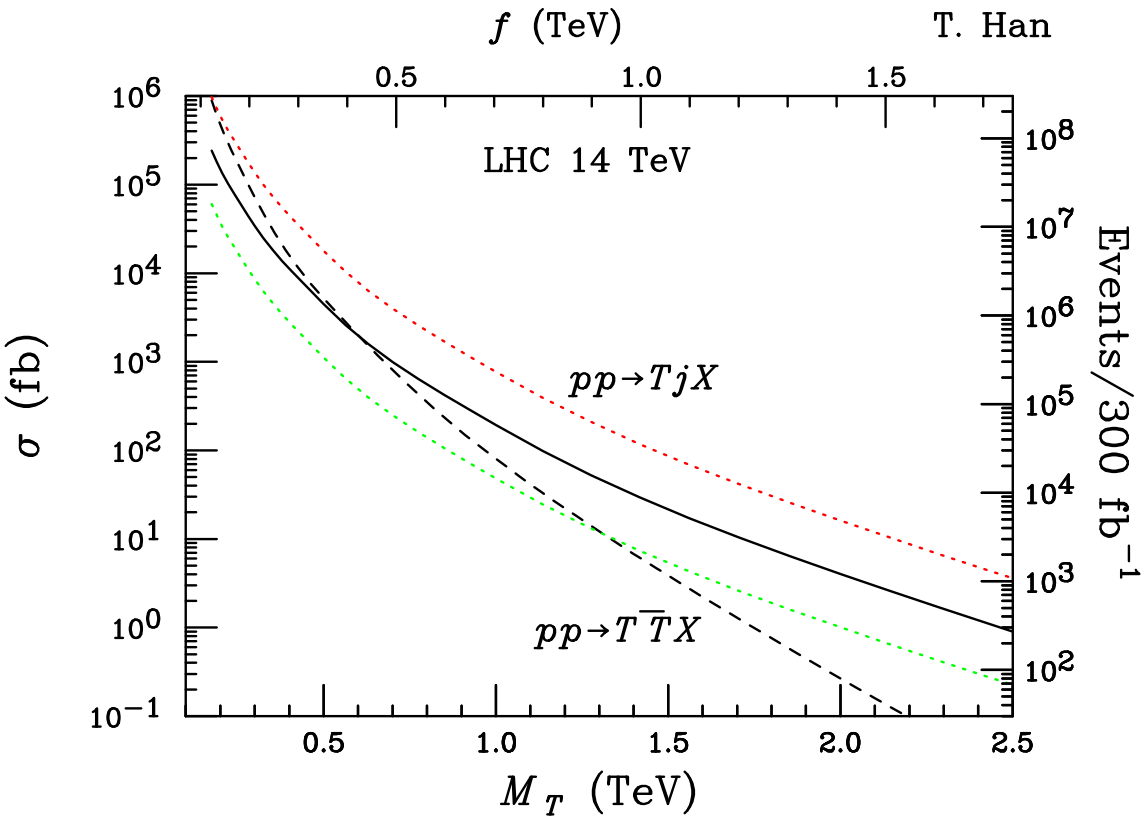


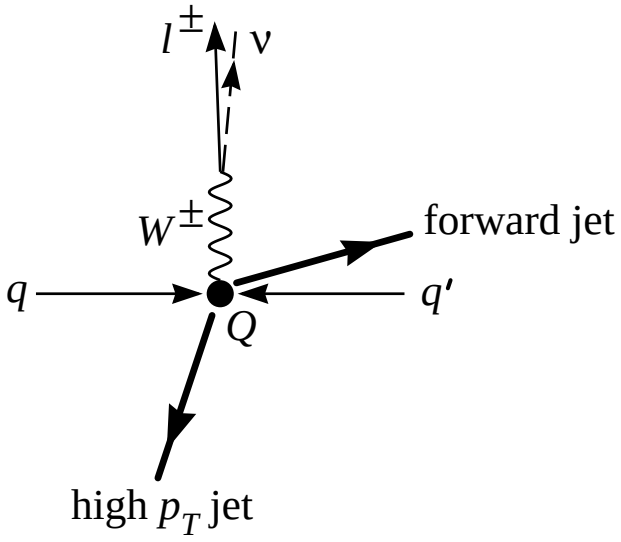
Important: EW (t-channel) $W_L b \to T$ dominates over QCD $q\bar{q},\ gg \to T\bar{T}$.*

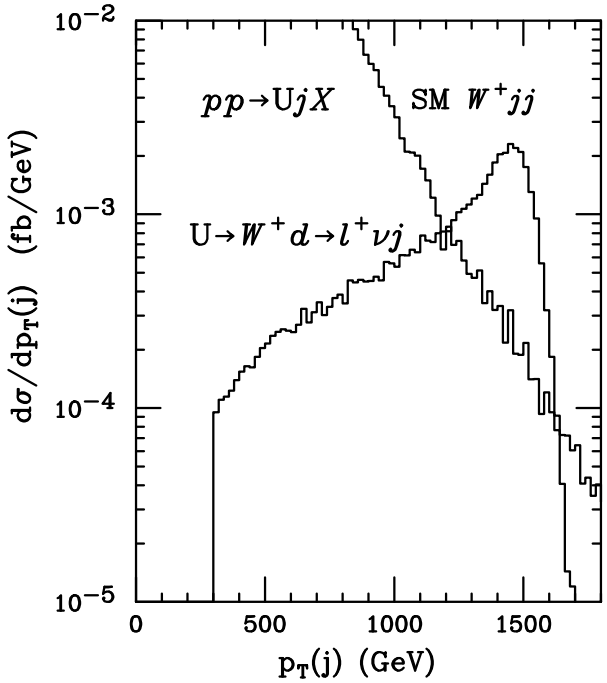
$\Longrightarrow$ Tevatron Input : Single top physics !§

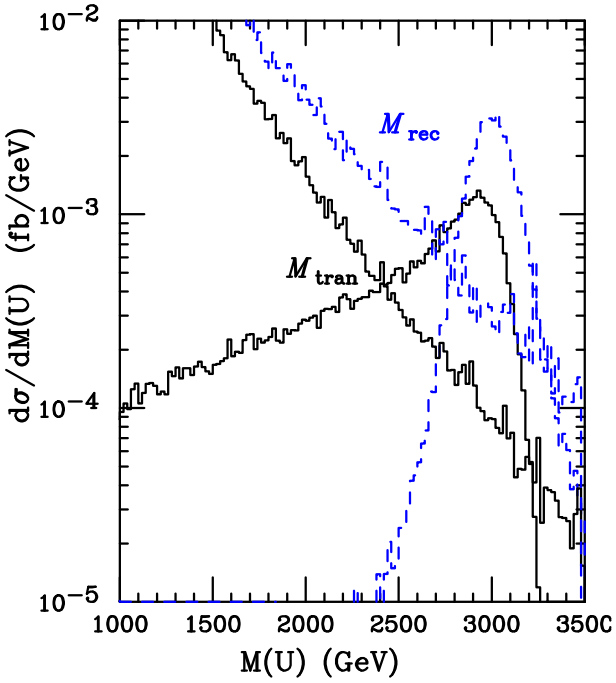
*Dicus, Willenbrock (1986).

§Sullivan, Willenbrock; Yuan, Cao, Tait; Bowen, Ellis, Strassler; Schwienhorst.

Unique kinematics: $qb \to q' W_L \; b \to q' \; T \to q' \; W^+ b$







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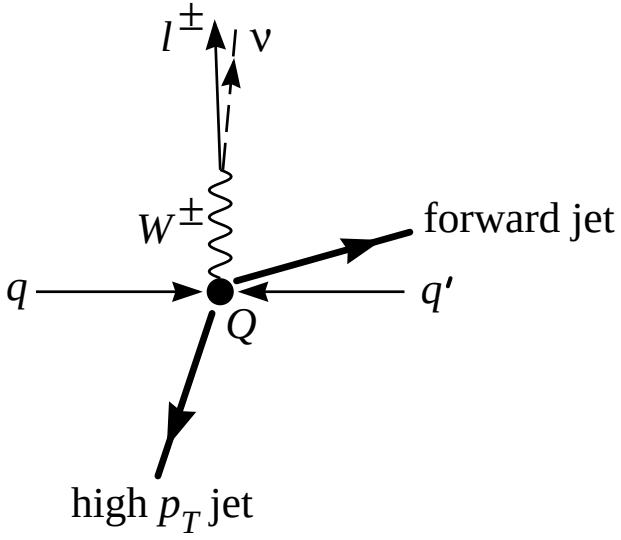
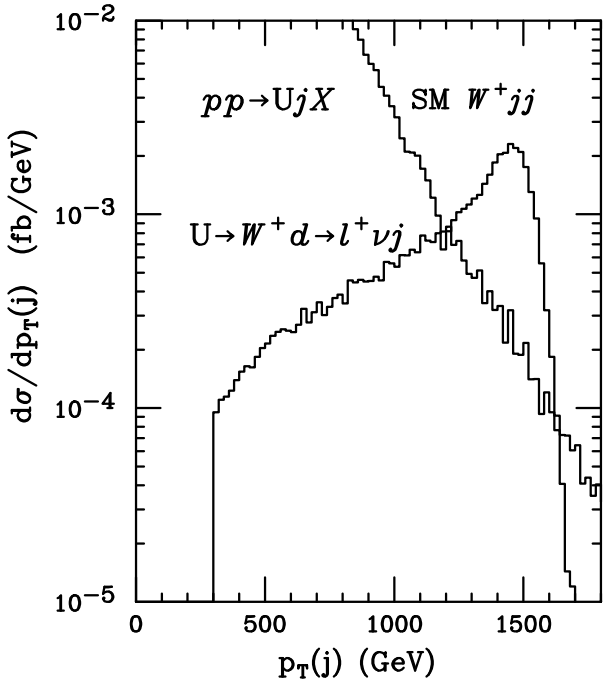
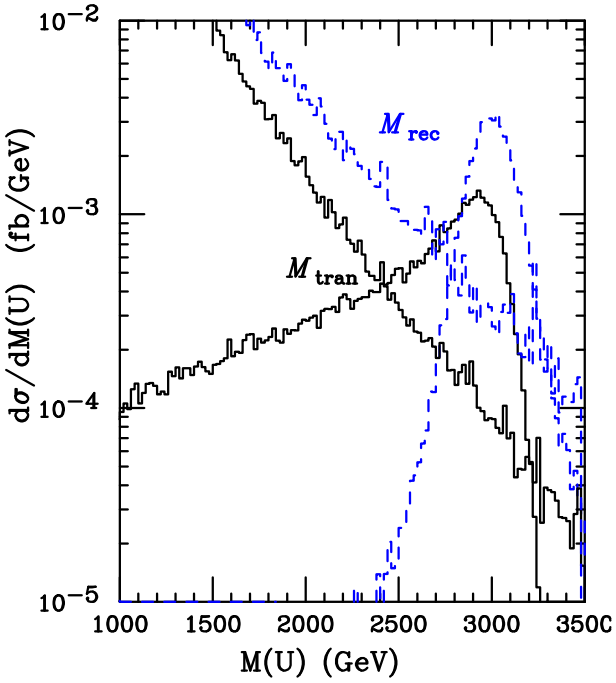






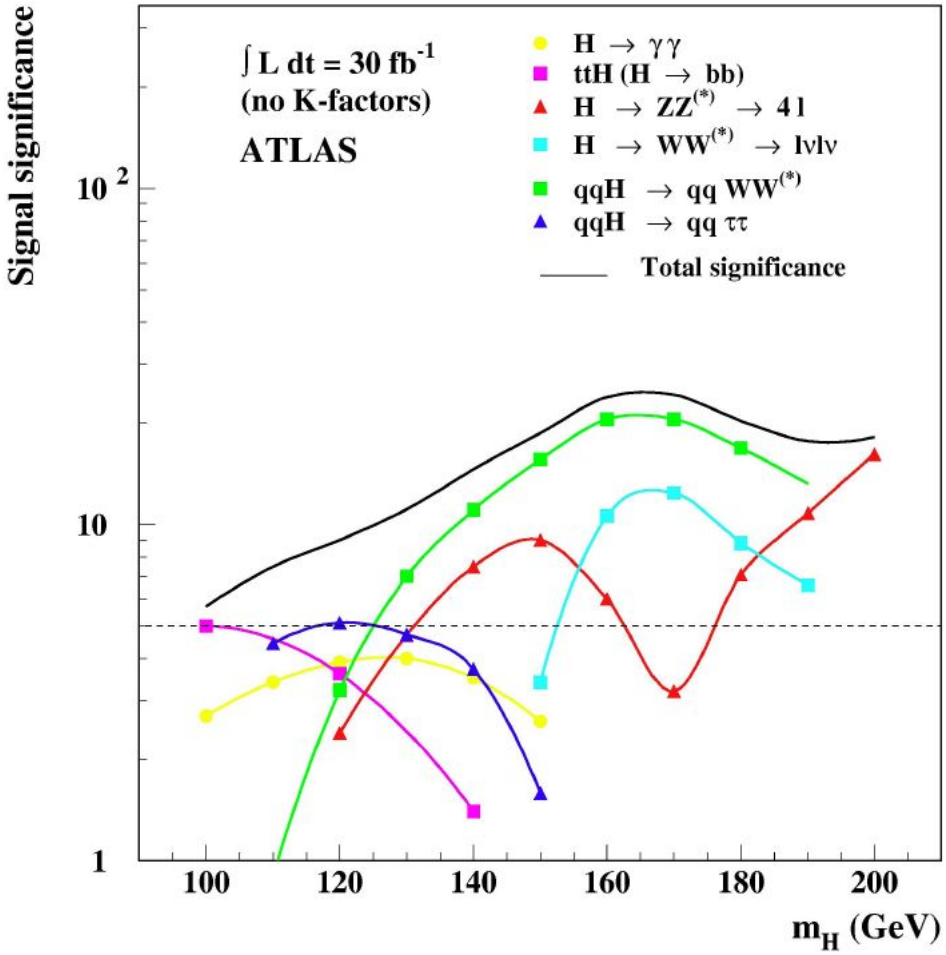
Challenge to experiments : Heavy mass reconstruction; collimated $W \to jj$.

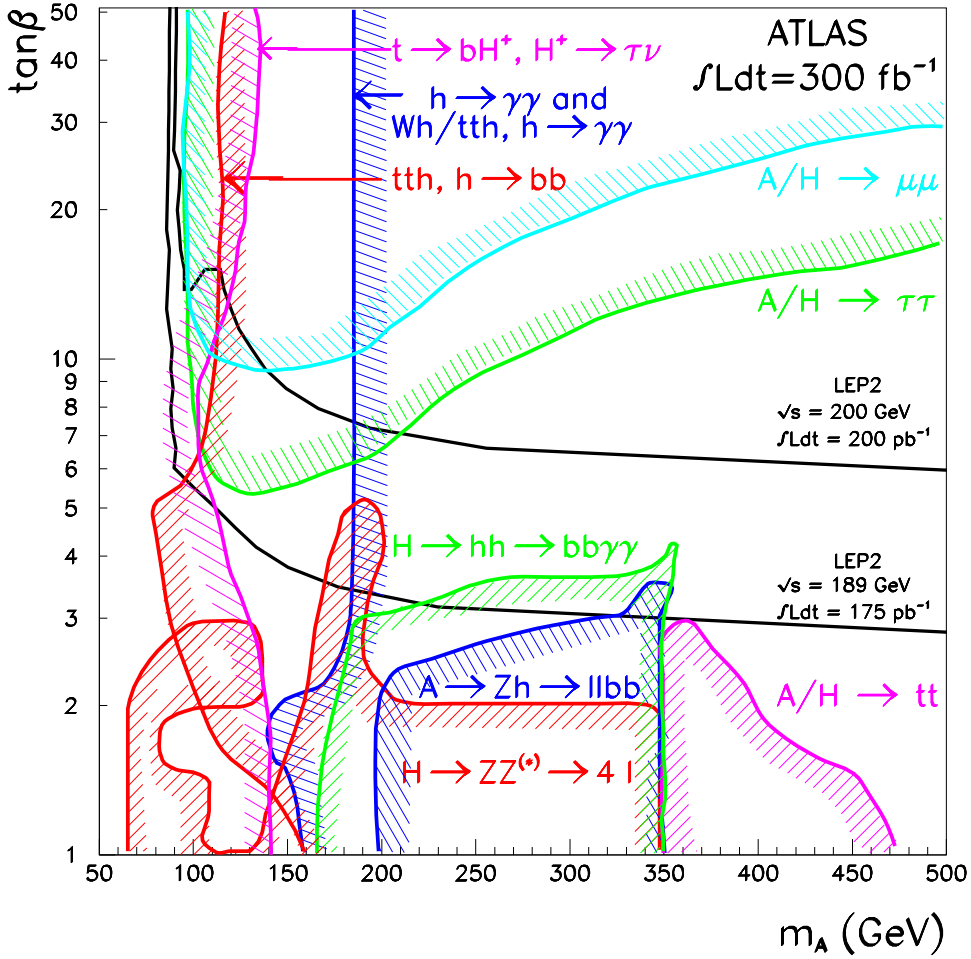
Tevatron Input : top quark reconstruction;

signal top kinematics: forward jet tagging ?

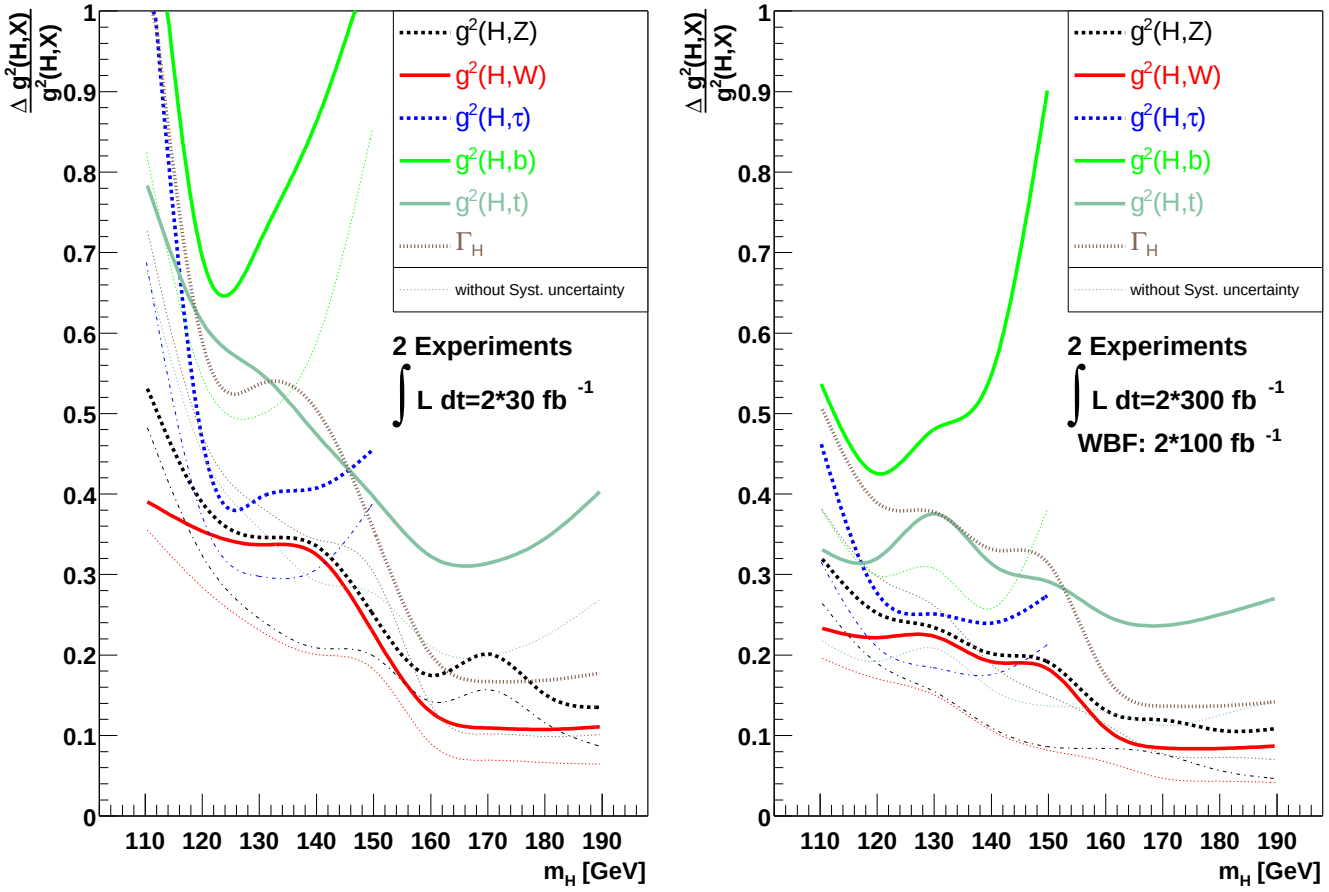
The Higgs and Cousins

"No-lose theorem" for the SM/MSSM Higgs at the LHC:





How Higgsy is it?[¶]



[¶]Duhrssen, Heinemeyer, Logan, Rainwater, Weiglein, Zeppenfeld, `hep-ph/0407190`.

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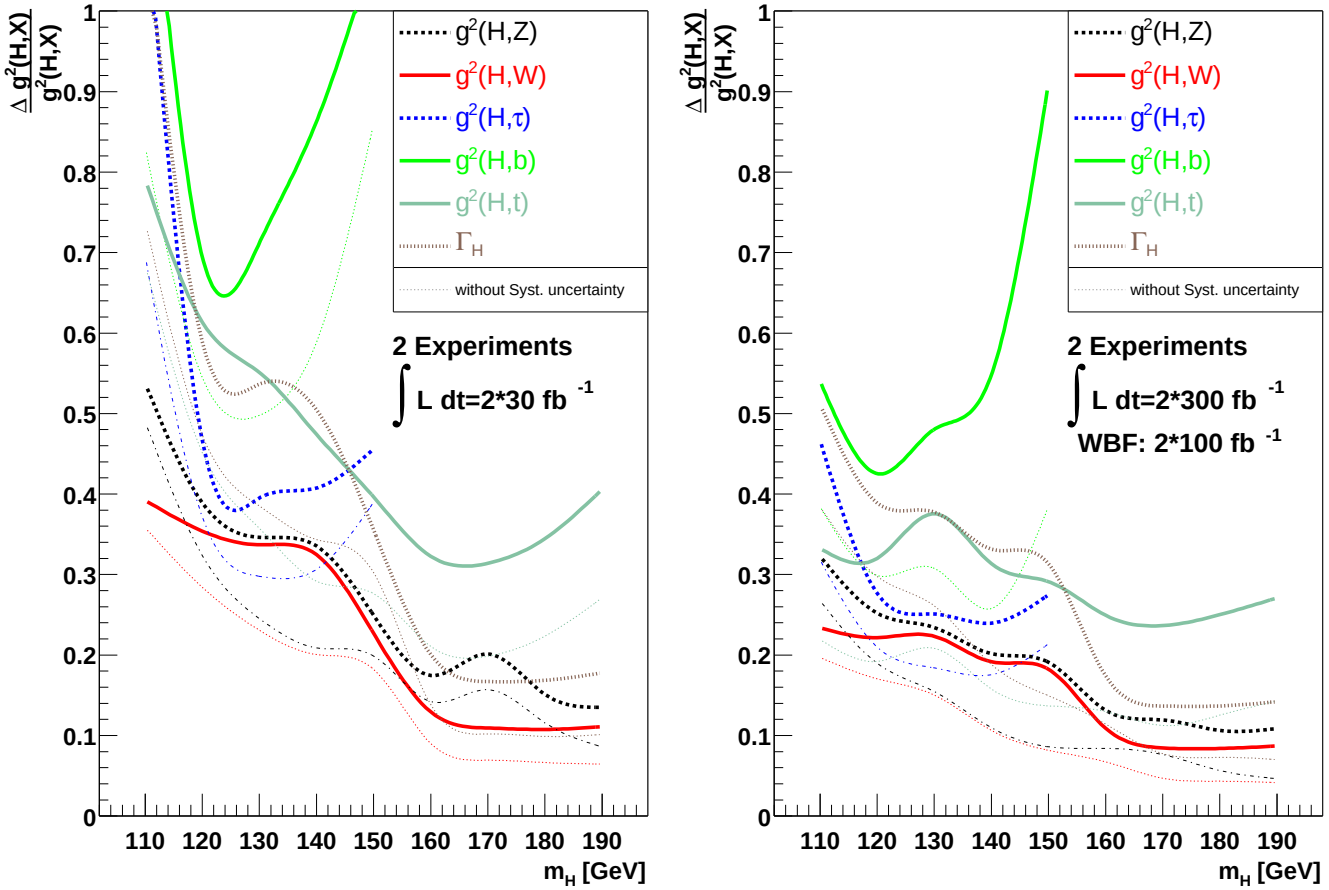

Challenge to theorists : Theoretical understanding of the S, B:
higher order corrections;‖ PDF uncertainties.**

¶Duhrssen, Heinemeyer, Logan, Rainwater, Weiglein, Zeppenfeld, `hep-ph/0407190`.

‖Harlander, Kilgore; Anastasiou, Melnikov, Petriello; Willenbrock, Maltoni; Berger, Qiu; Figy, Oleari, Zeppenfeld; Dawson, Orr, Reina, Wackeroth; Ellis, Campbell, Giele...

**Belyaev, Pumplin, Tung, Yuan, `hep-ph/0508222`.

Challenge to experiments : Background control: $M_{\gamma\gamma}$; b-tagging; τ-ID;
forward-jet tagging;* central mini-jet veto ...

*B. Mellado, parallel session.

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Beyond the SM/MSSM:

In (slightly) extended Higgs sector, N^{n}MSSM,††.
signals may become very challenging:
e.g.: $H \to a_i a_j \to 4b$; $bb, \tau\tau$; or $H \to$ invisible.

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††Gunion, Dermisek; Ellwagner, Gunion, Hugonie, `hep-ph/0503203, ...`;
Han, Langacker, McElrath, `hep-ph/0405244`

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Tevatron Input : The Tevatron might have a better chance due to lower QCD backgrounds.‡‡

*B. Mellado, parallel session.

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‡‡Carena, Han, Huang, Wagner, parallel session.

Inclusive Signatures

(A). SUSY: Is it easy ?

Ian Hinchliffe: "If SUSY is correct, it'll be found with in few weeks (of LHC running), with a debugged detector."

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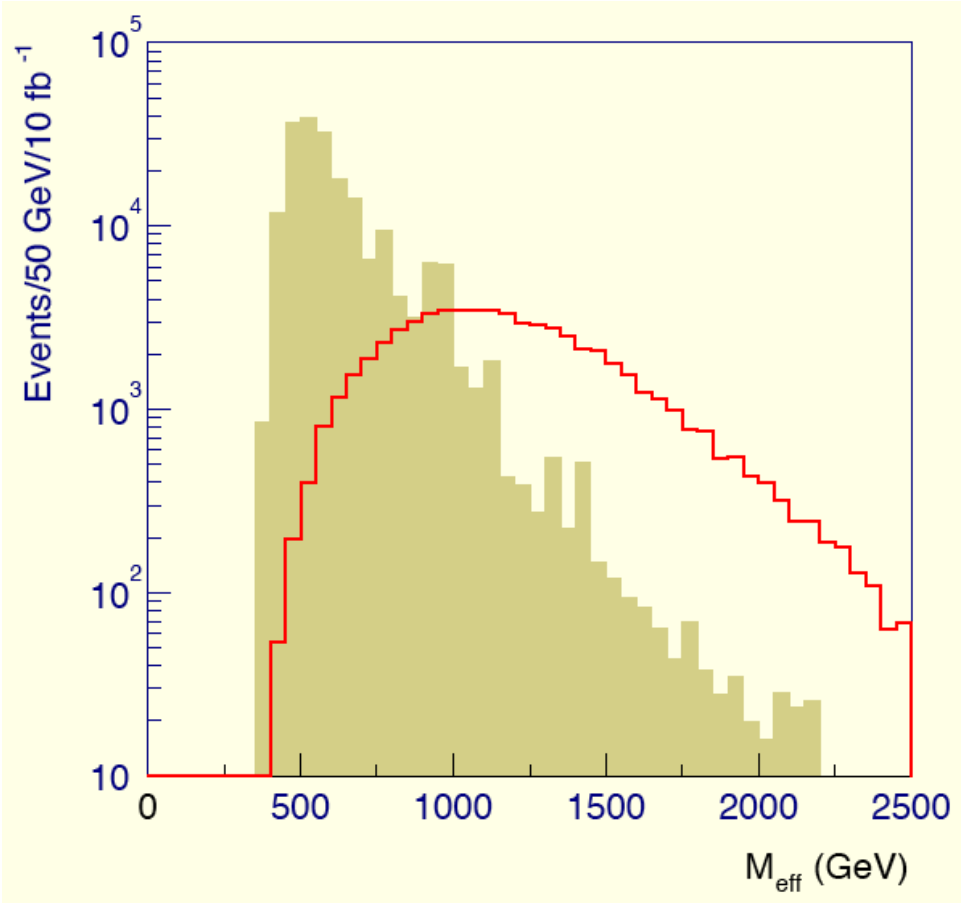

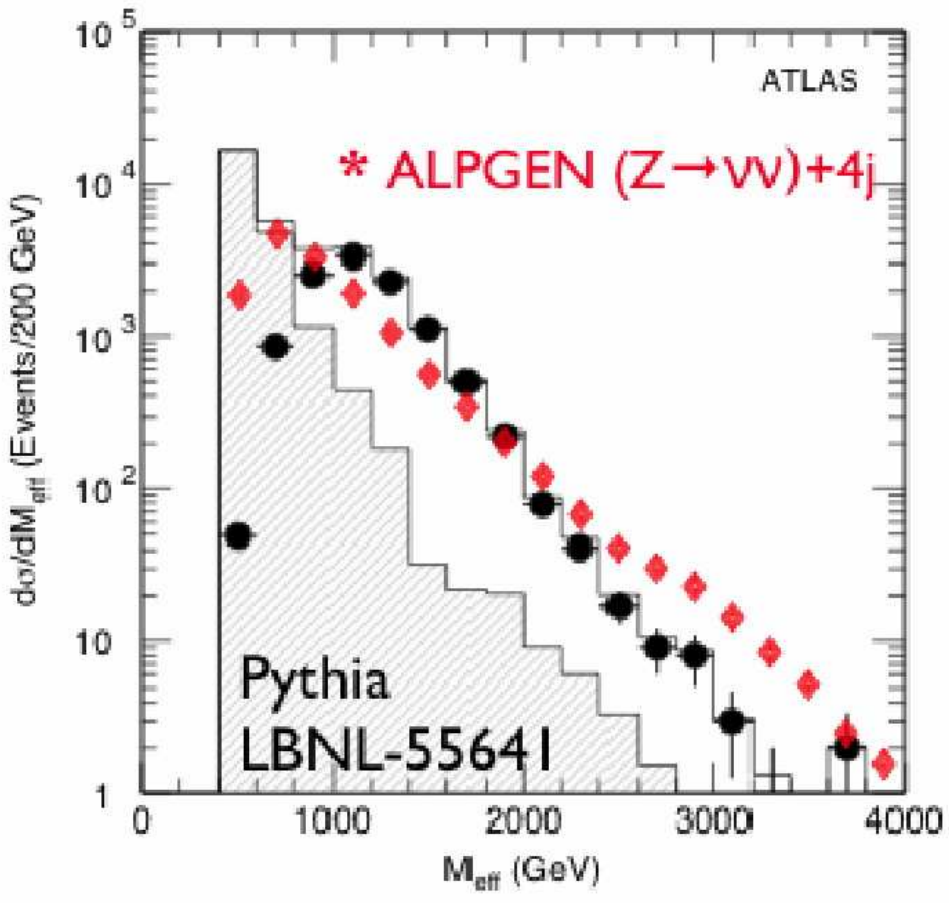

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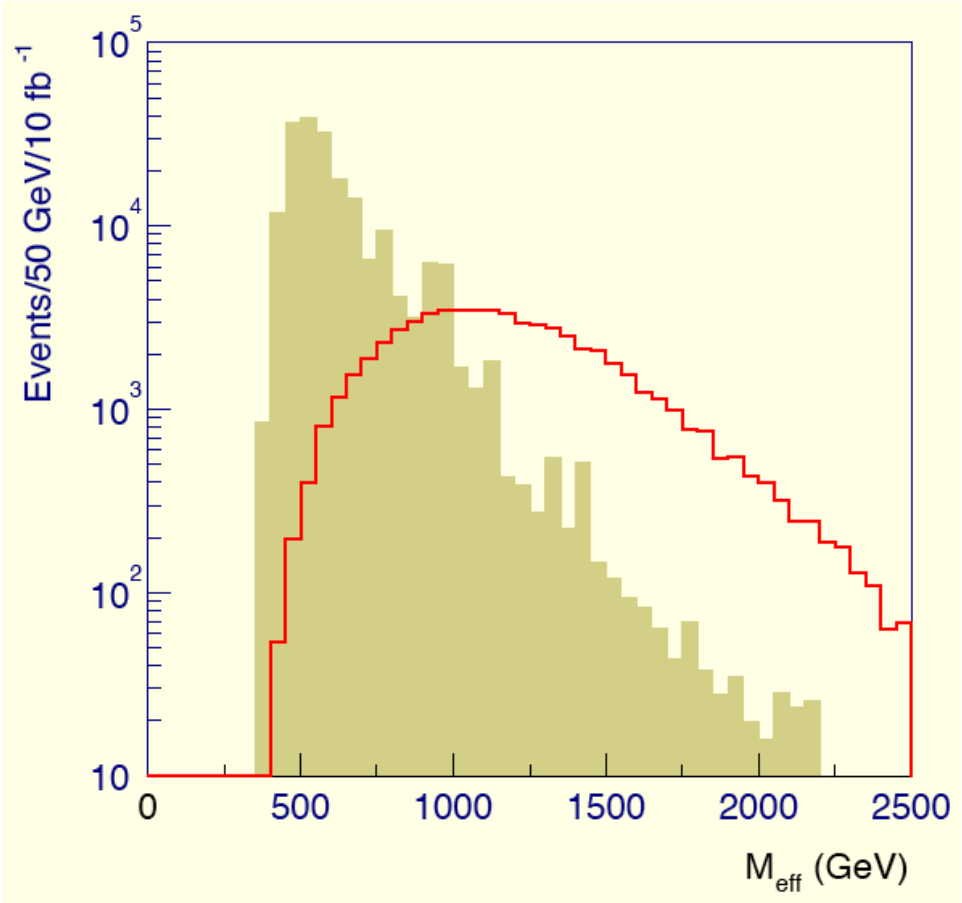

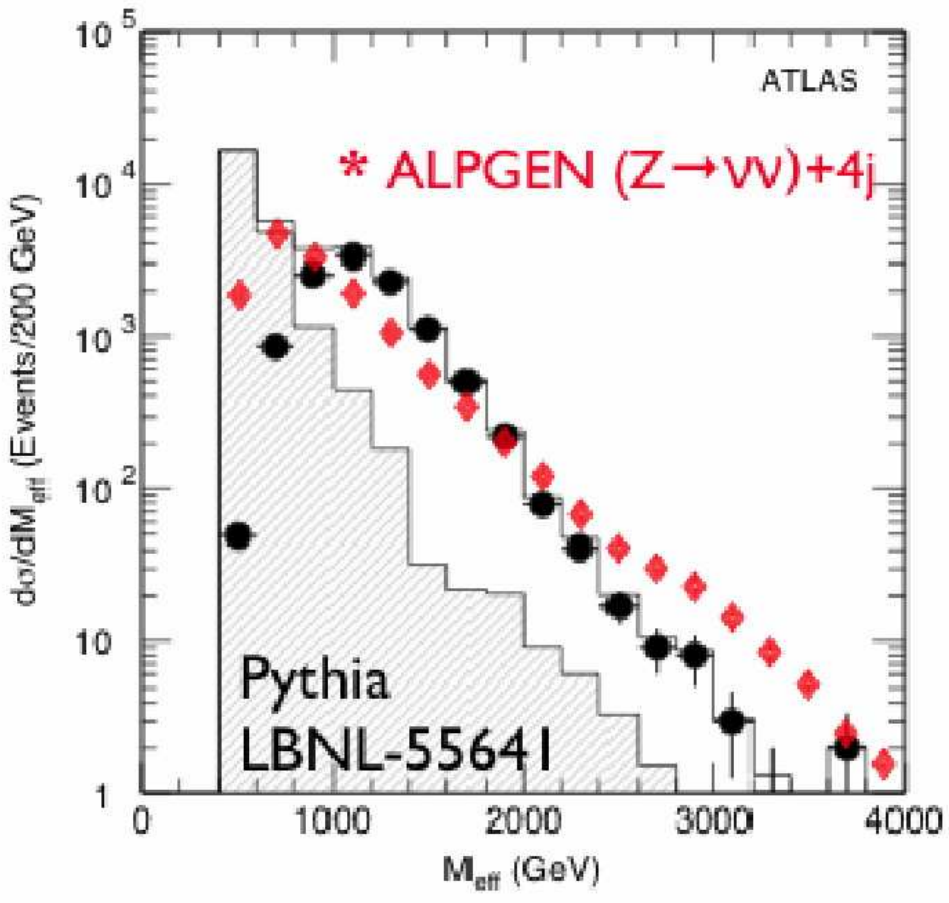

Challenge to theorists : Understand the SM backgrounds !

(B). What underlying theory at work ?

Observation of a signal beyond the SM is great,
correct interpretation is even more important:

Given a model $\Rightarrow$ signatures: EASIER;

($\not{E}_T + 1\ell$; 2ℓ; $SS - 2\ell$; $OS - 2\ell$; 3ℓ; $\#jets$; $\#b$ ...)

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(C). Confusion in inclusive signatures: e.g. $t\bar{t} + \not{E}_T$

$\tilde{t}\tilde{\bar{t}} \to t\chi^0\ \bar{t}\chi^0$ (SUSY)

$t_1\bar{t}_1 \to t\gamma_1\ \bar{t}\gamma_1$ (UED)

$T\bar{T} \to tA_H\ \bar{t}A_H$ (Little Higgs with T $-$ parity).

Challenge to theorists : sort out the underlying theory. †

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†Datta, Kong, Matchev, parallel session; Datta, Kane, Toharia, hep-ph/0510204.

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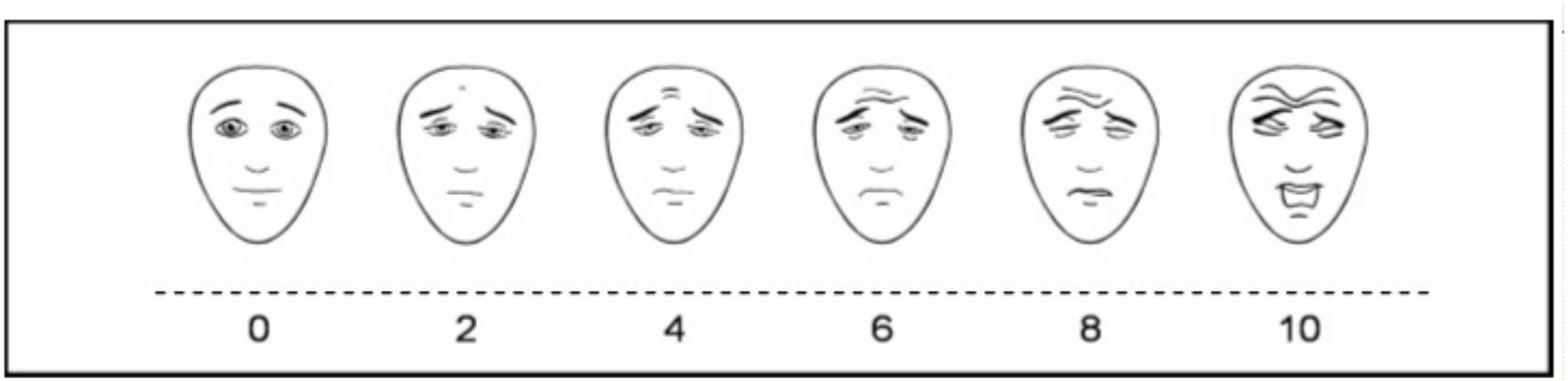
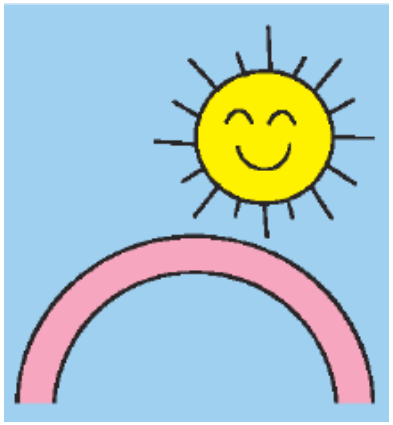


Randall's Clinic Pain Scale

Life may be more rewarding: Pleasant surprises



Black holes? String balls? Extra dimensions? Unexpected ...

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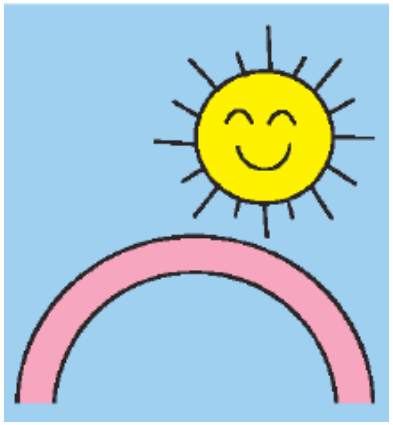

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Go for the energy frontier !