HEP Theory and Phenomenology For The Early LHC Run

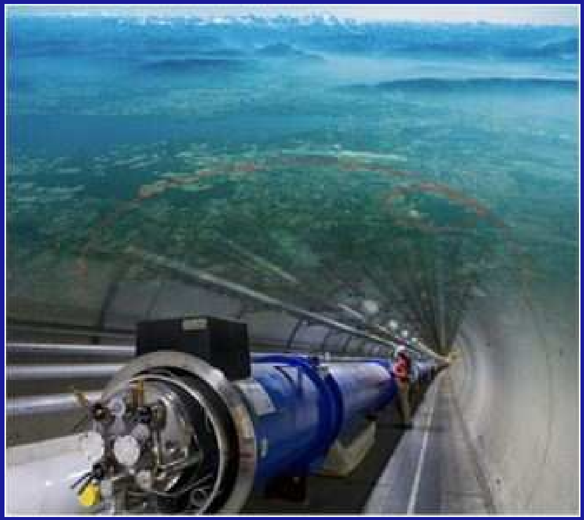
Tao Han

University of Wisconsin

LHC Symposium

PSROC Annual Meeting

(Jan. 26, 2011)



Outline:

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⇒ Examples for BSM and Beyond Tevatron

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$\Longrightarrow$ Examples for BSM and Beyond Tevatron

- Summary

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The collider and detectors all perform superbly!

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Experiments reached the crucial step:

The Standard Model has been re-discovered,

marching to the discovery!

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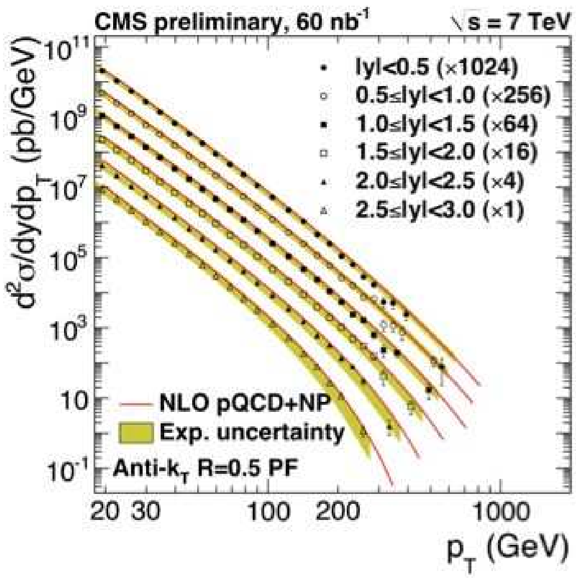
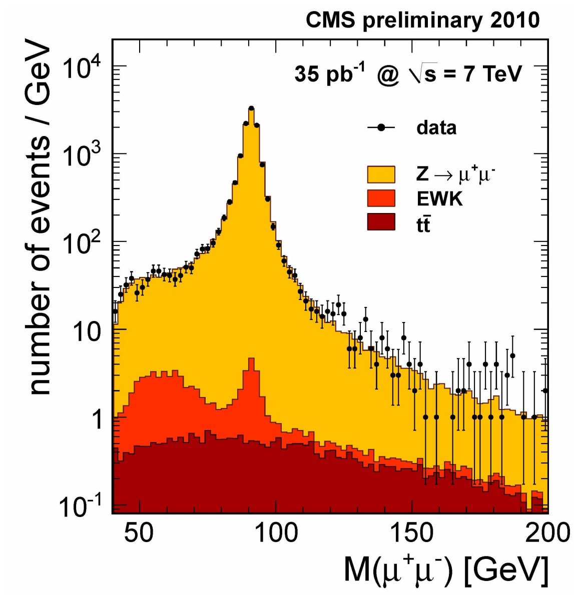
Congratulations to the LHC accelerator physicists!

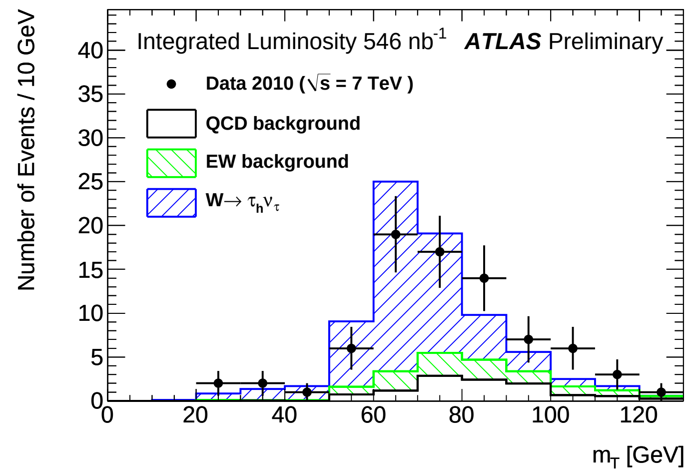
Congratulations to the detector designers/makers!

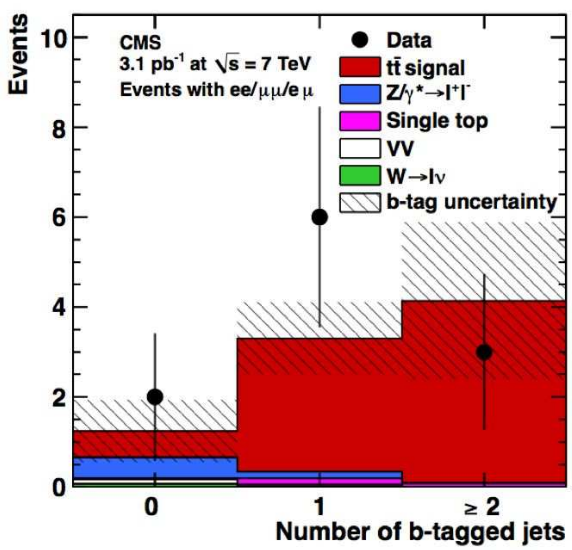
Congratulations to the HEP community!

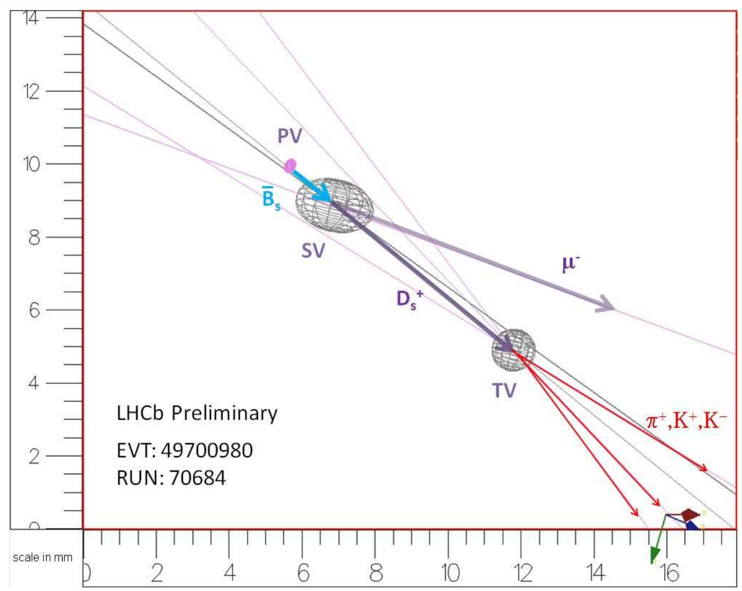
The SM re-discovery:



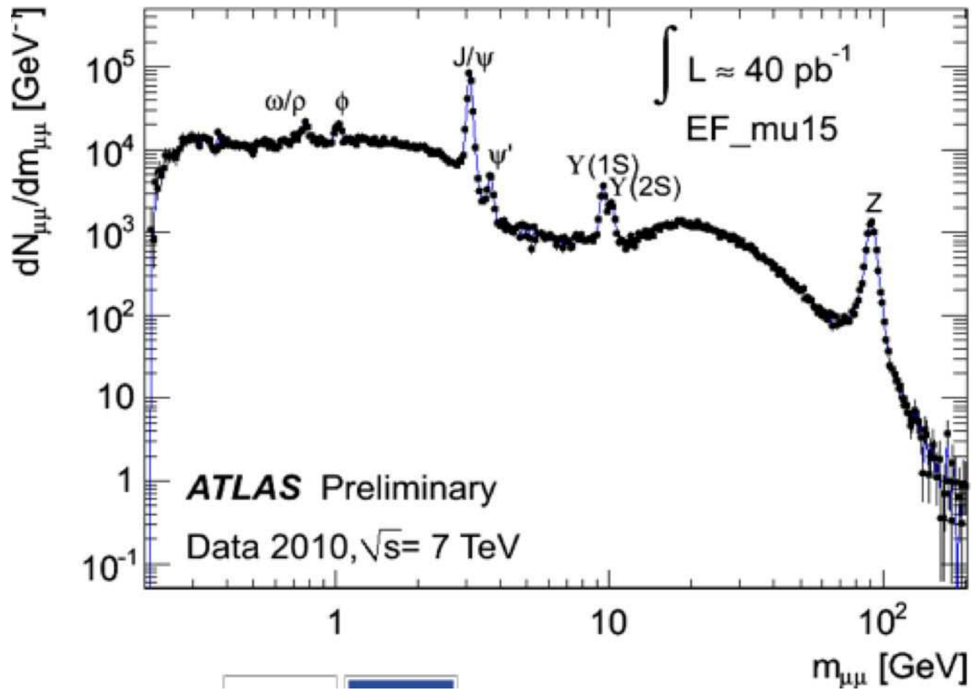








One of my favorite plots: $\mu^+\mu^-$ spectrum



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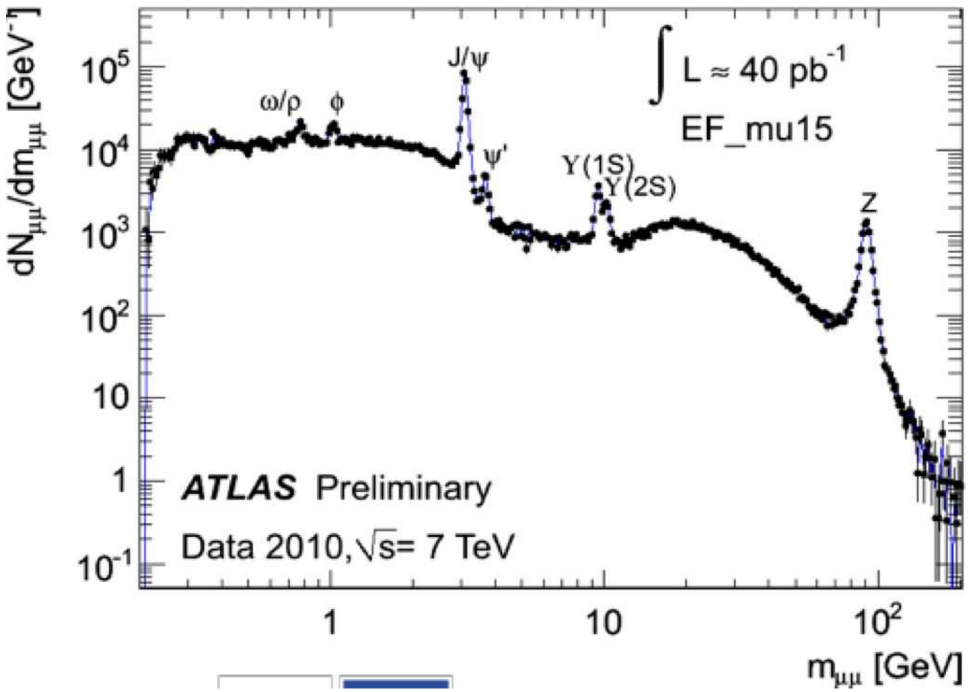

Hadronic production cross section:

$$\sigma(S) = \sum_{ij} \int d\tau \, \frac{dL_{ij}}{d\tau} \, \sigma_{ij}(s), \quad \tau = s/S = (p_i + p_j)^2/S, \quad s > (1 \text{ GeV})^2,$$

$$\frac{dL_{ij}}{d\tau} \equiv \int_\tau^1 dx_1 \int_{\tau/x_1}^1 dx_2 \; f_i(x_1) f_j(x_2) \; \delta(x_1 x_2 - \tau) = \int_\tau^1 \frac{dx_1}{x_1} f_i(x_1, Q^2) \; f_j(\frac{\tau}{x_1}, Q^2).$$

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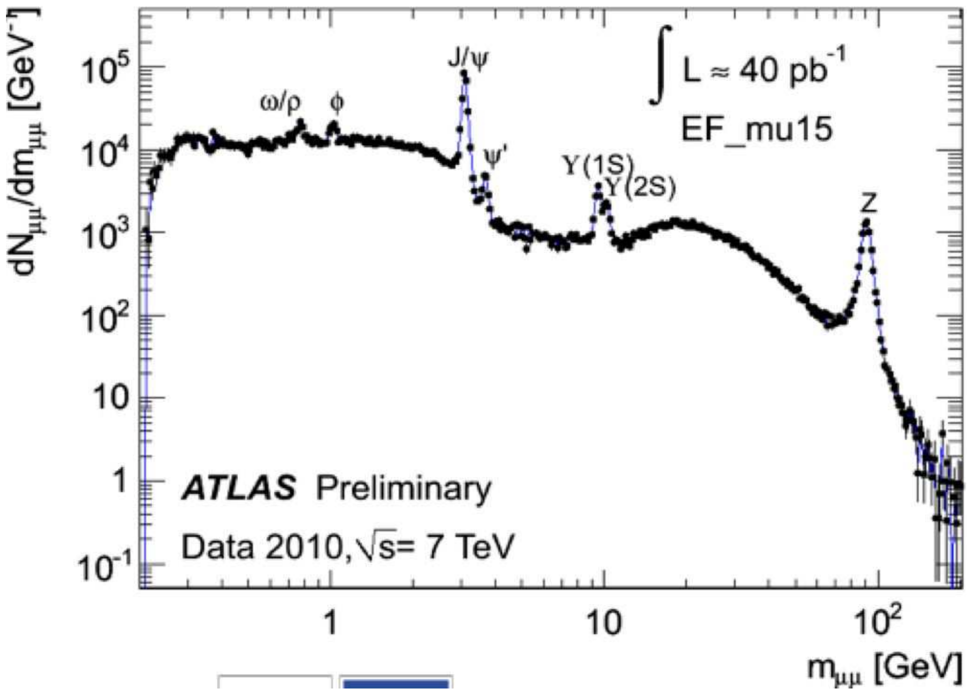

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- Beautiful confirmation of the discovery history;
  - Powerful experiments for future discovery.

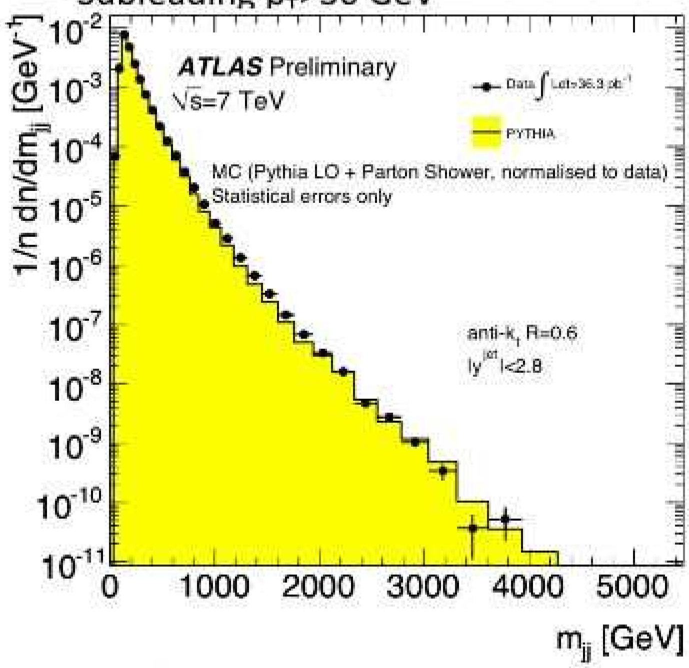
Some results have gone BEYOND the Tevatron !

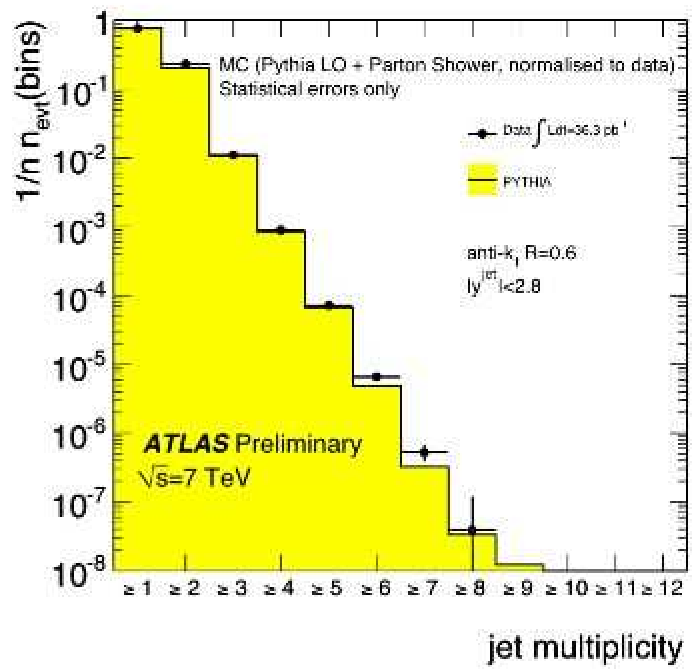
ATLAS jet distributions: $m^2(jj) = (p_{j_1} + p_{j2})^2$.

Dijets and multi jets

- Count jets with p_T>60 GeV
- One event with 8 jets

- Leading jet p_T>60 GeV,
- Subleading p_T>30 GeV





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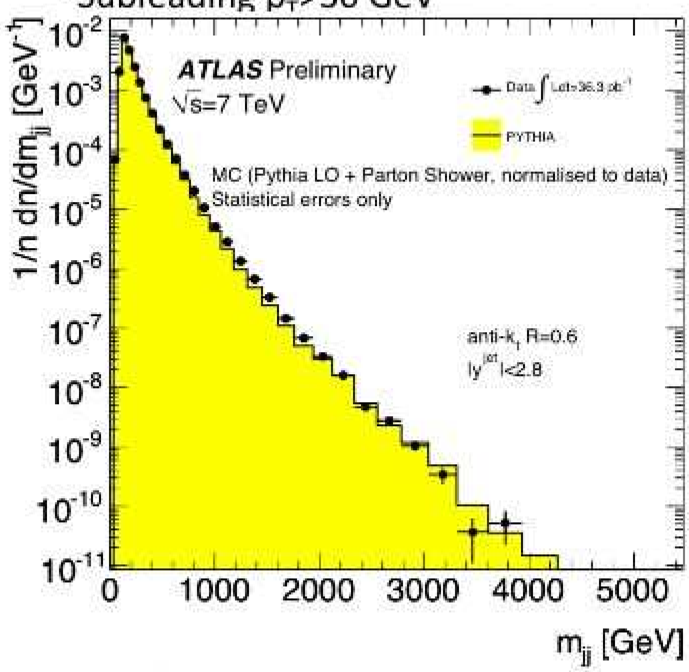

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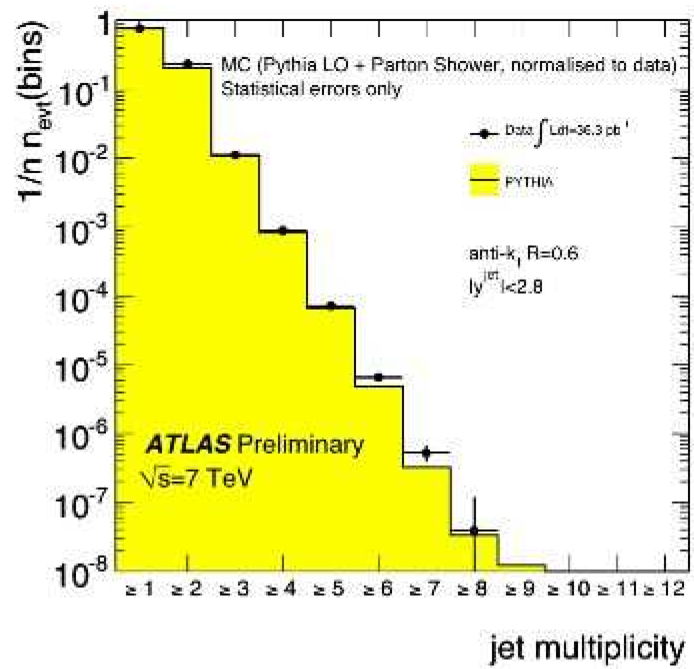

Pippa Wells, ATLAS 17 Nov 2010 31

We are in the stage of discovery at the Tera-scale!

Theoretical Expectations

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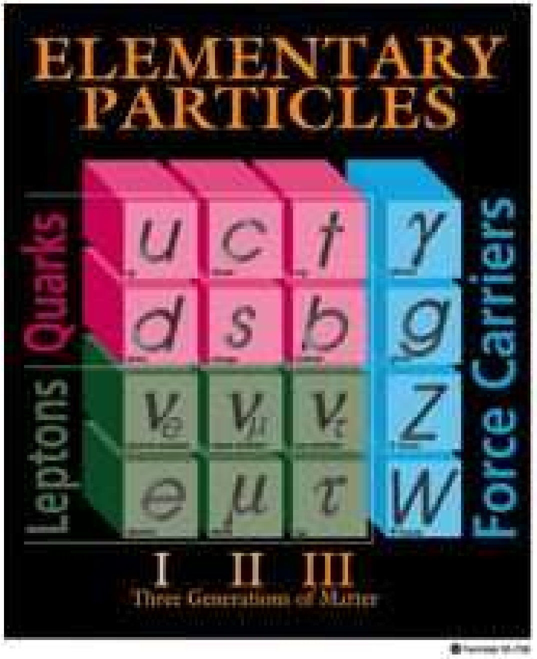
Despite the tremendous success of SM, there are more questions than answers.



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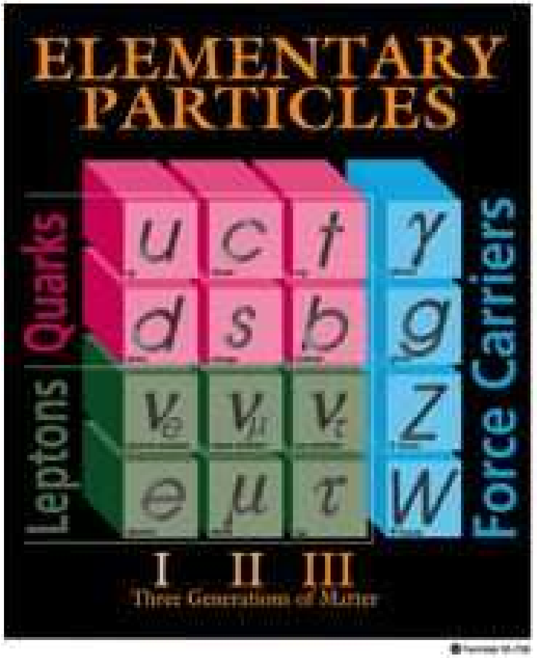

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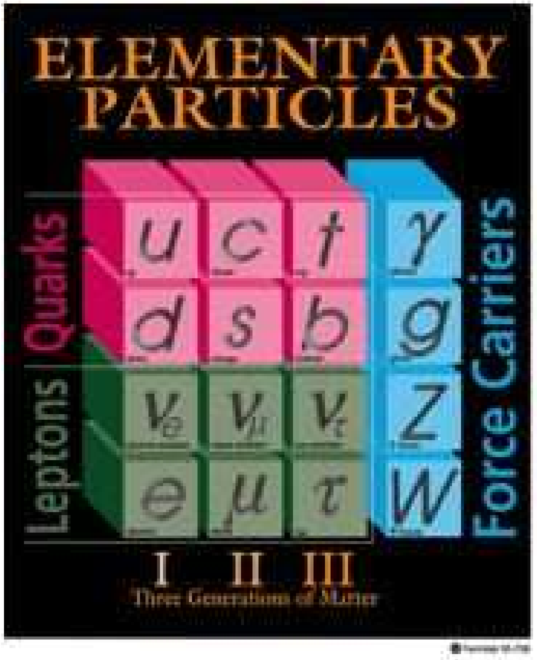

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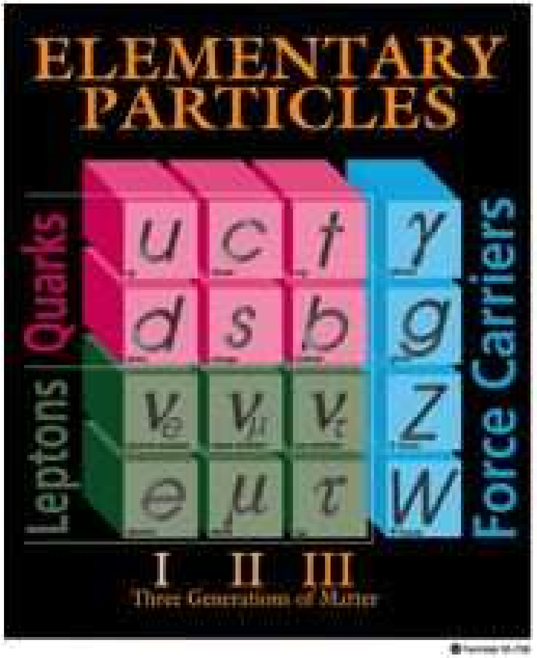

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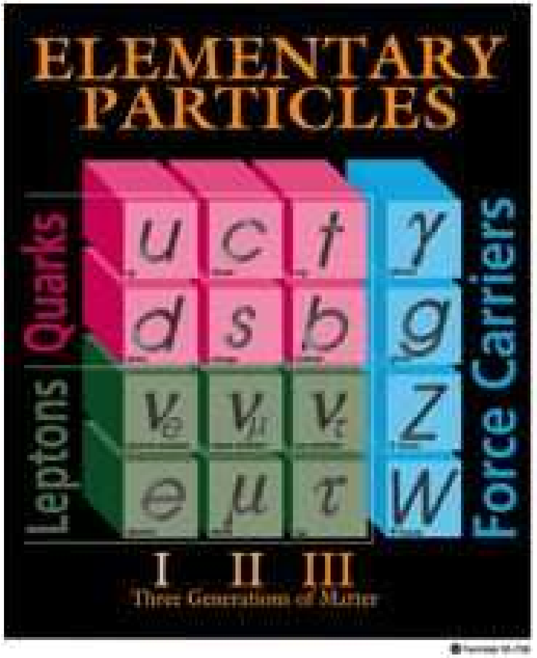

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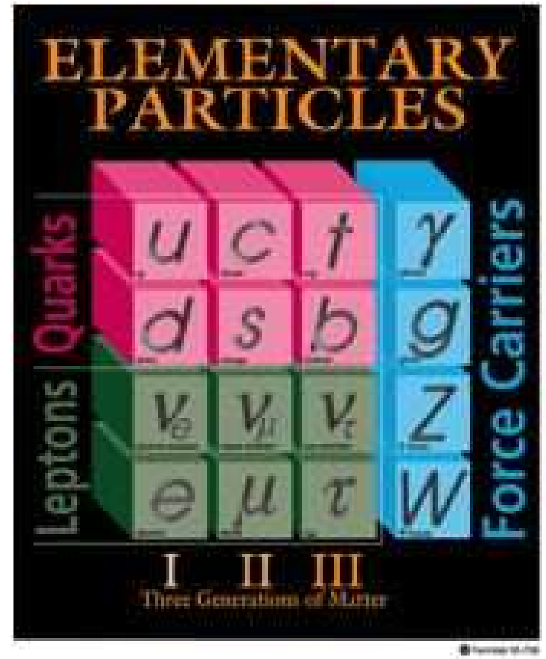

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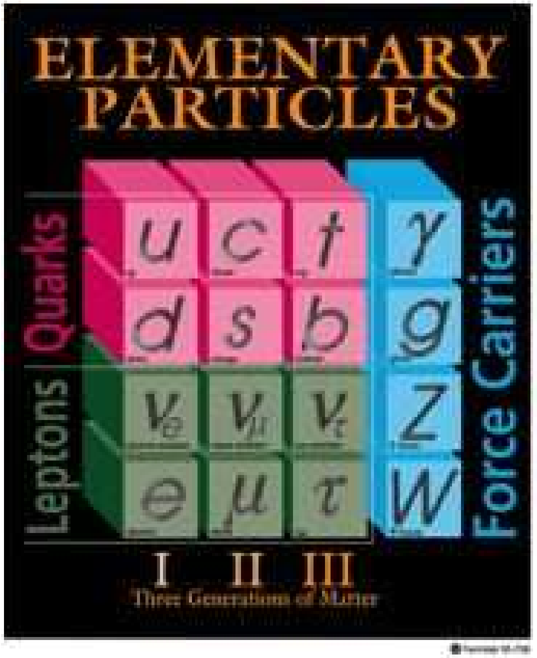

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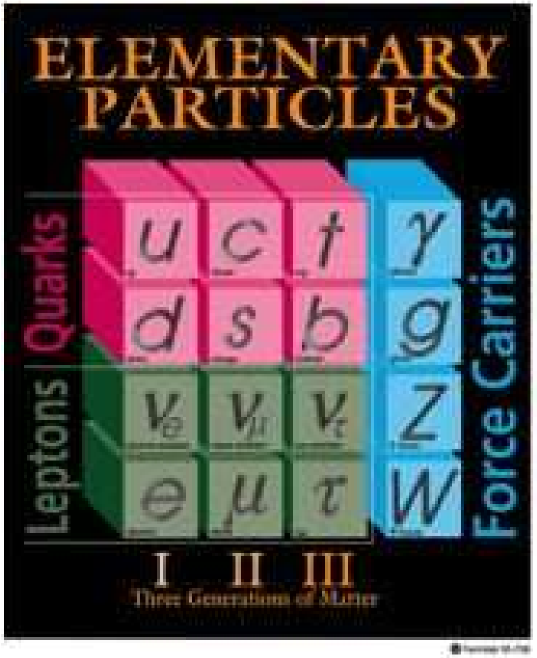

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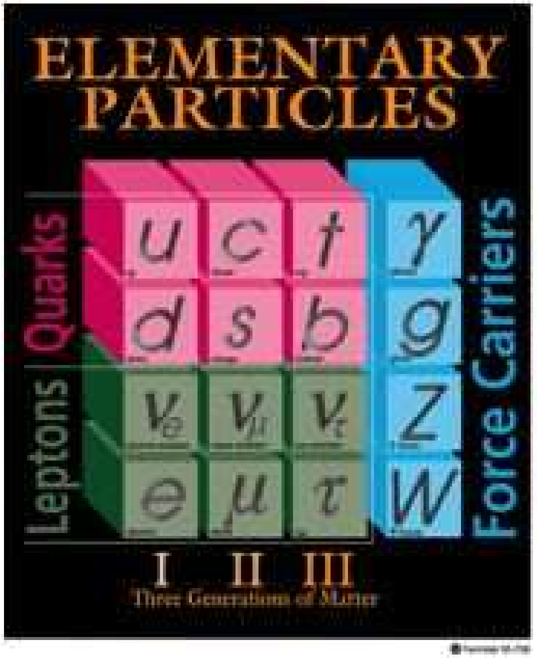

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But theorists are not short of ideas (imagination)!

Outline of BSM Physics Possibilities – From H. Murayama

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#1 : "Most-wanted" New Physics:

- Electroweak Symmetry Breaking and Mass Generation

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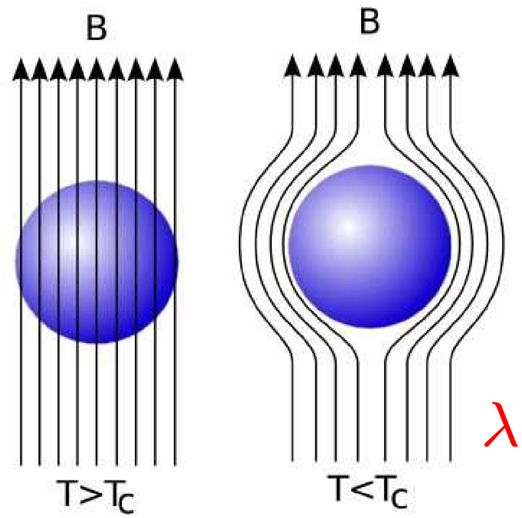
Long-range force



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$E^2 = p^2c^2 + m^2c^4$

gap leads to $\sim exp(-r/\lambda)$

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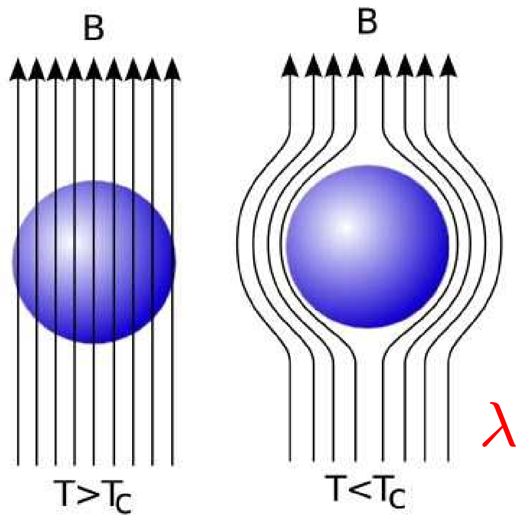

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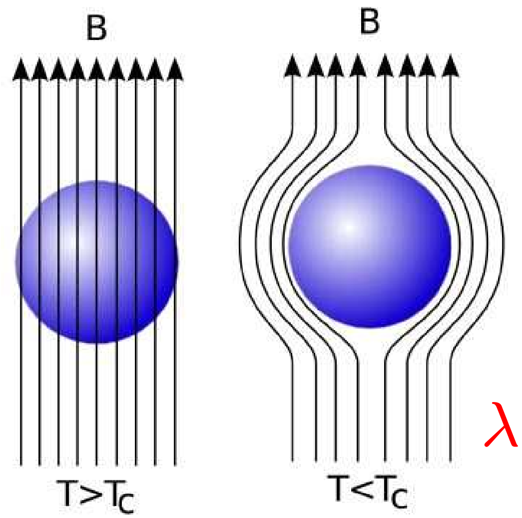

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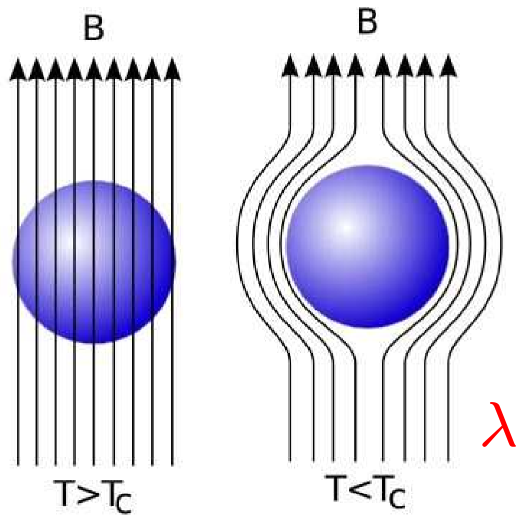

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- A “No-Lose Theorem”

Recollection: In Fermi’s weak interaction theory

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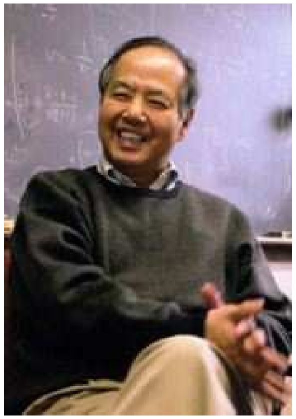
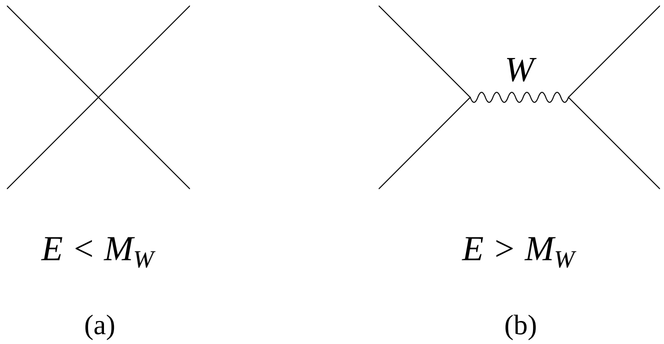


Due to Lee and Yang (1960):

Partial-wave unitarity (probability conservation) demands

New Physics to enter for rescue, before $E_\nu < 300$ GeV.



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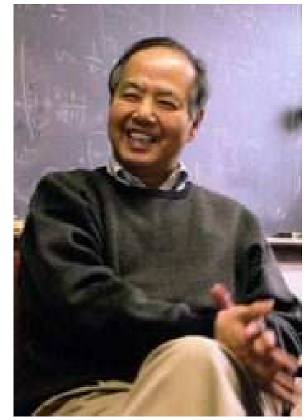

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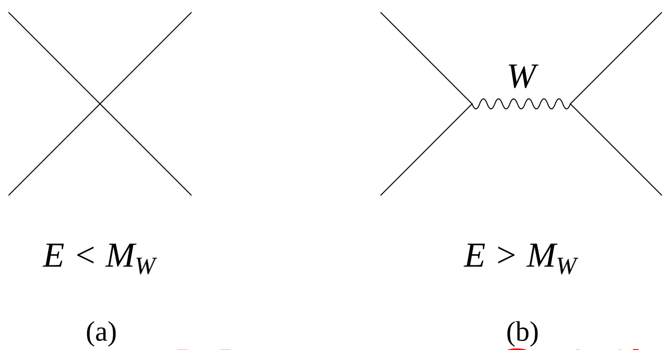
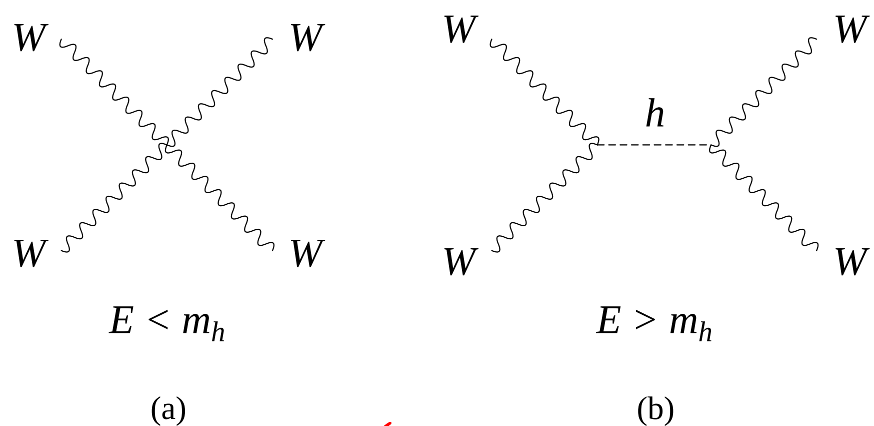


$\Rightarrow \quad M_W \approx 80$ GeV!

$W^\pm/Z^0$ discovery (1983)!

Consider the massive gauge boson scattering:



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Partial-wave unitarity demands

$$a_0 = \frac{1}{16\pi} \frac{m_h^2 \ or\ E_{cm}^2}{v^2} \lesssim 1$$
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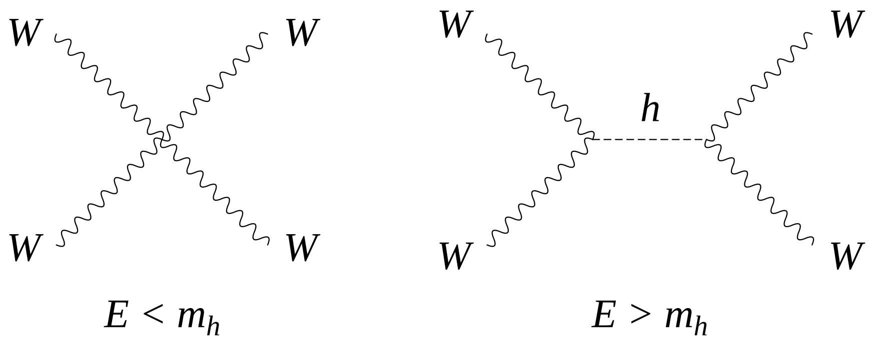

(a) (b)

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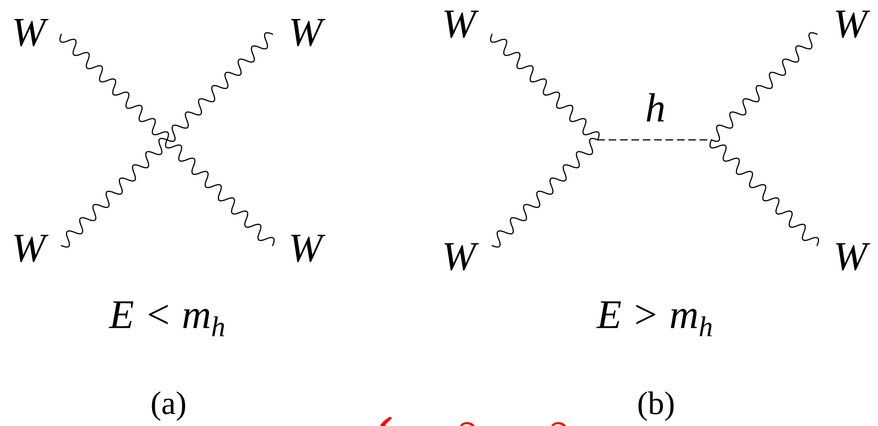

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Higgs or alike: $h^0, \ H^0, A^0, \ H^\pm ...$

Or related new dynamics: $\pi_{TC}, \ \rho_{TC}, \ V_{KK}, \ ...$

to show up below $\mathcal{O}(1 \text{ TeV})$!

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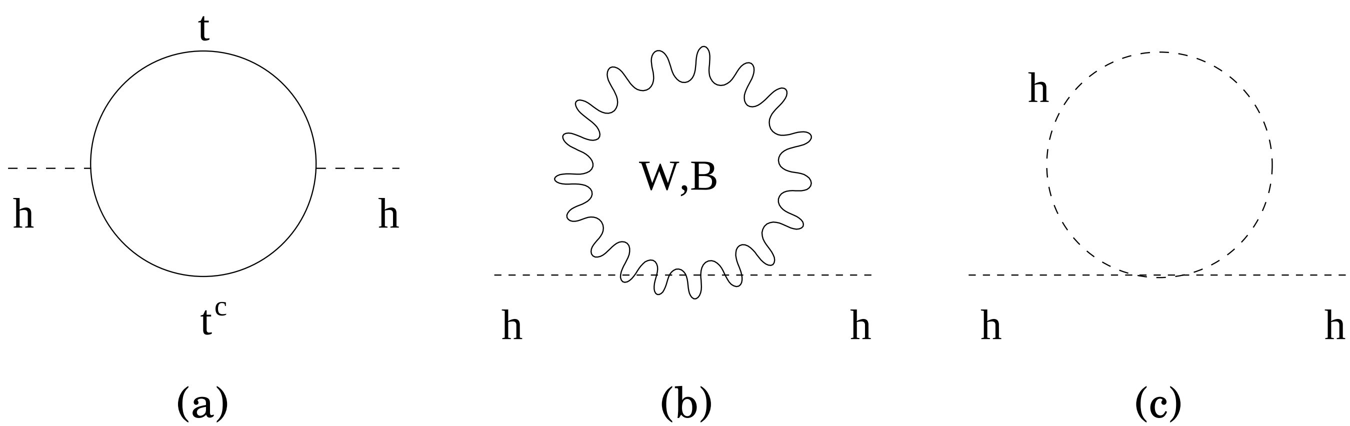

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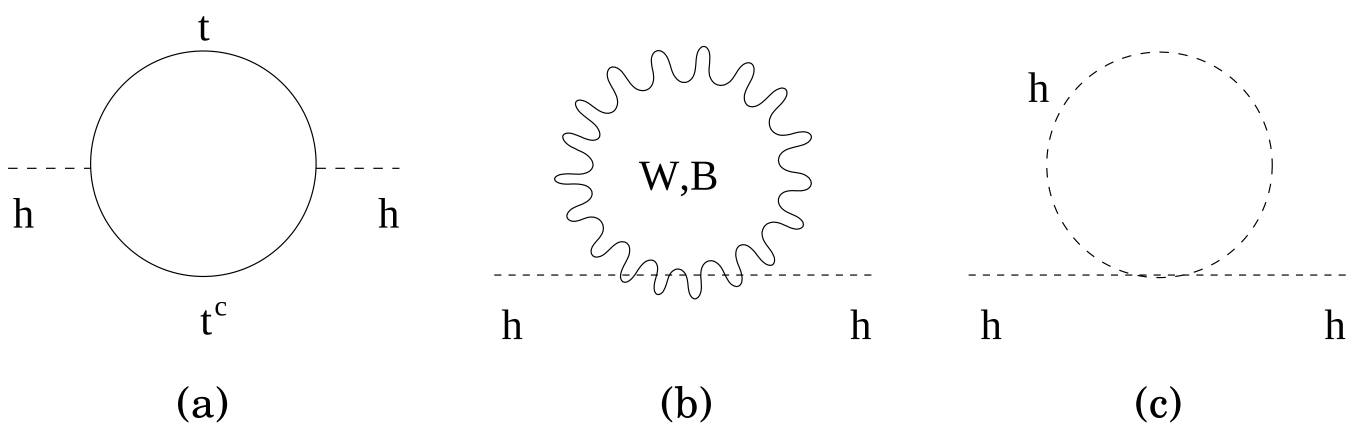

$$m_H^2 = m_{H0}^2 \quad - \frac{3}{8\pi^2} y_t^2 \Lambda^2 \quad + \frac{1}{16\pi^2} g^2 \Lambda^2 \quad + \frac{1}{16\pi^2} \lambda^2 \Lambda^2$$

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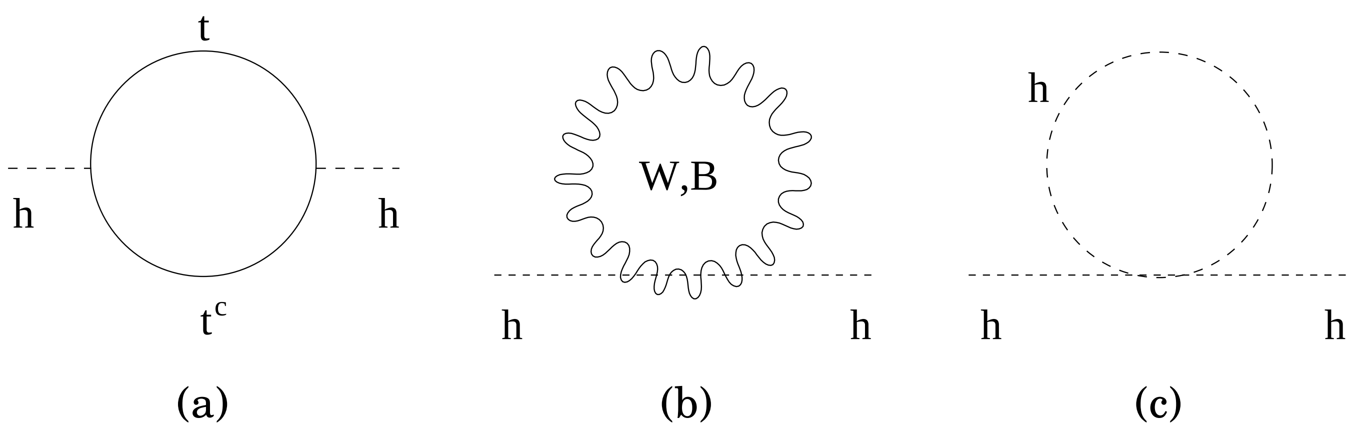

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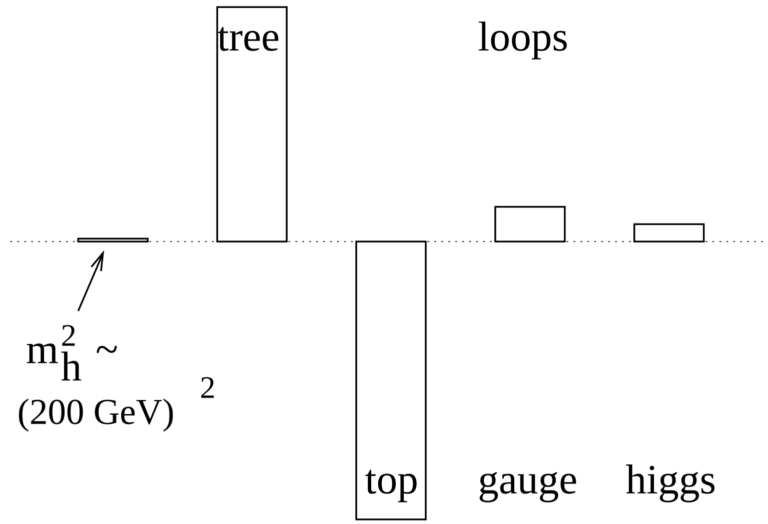
If $\Lambda^2 \gg m_H^2$, then unnaturally large cancellations must occur.

Put the "fine tune" in perspective:



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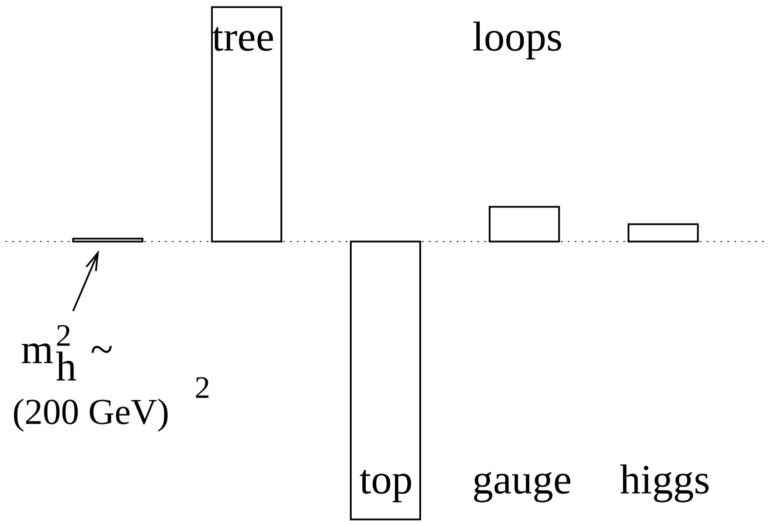

$$(200\ \text{GeV})^2 = m_{H0}^2 + \left[-(2\ \text{TeV})^2 + (700\ \text{GeV})^2 + (500\ \text{GeV})^2\right]\left(\frac{\Lambda_{t,W,H}}{10\ \text{TeV}}\right)^2$$

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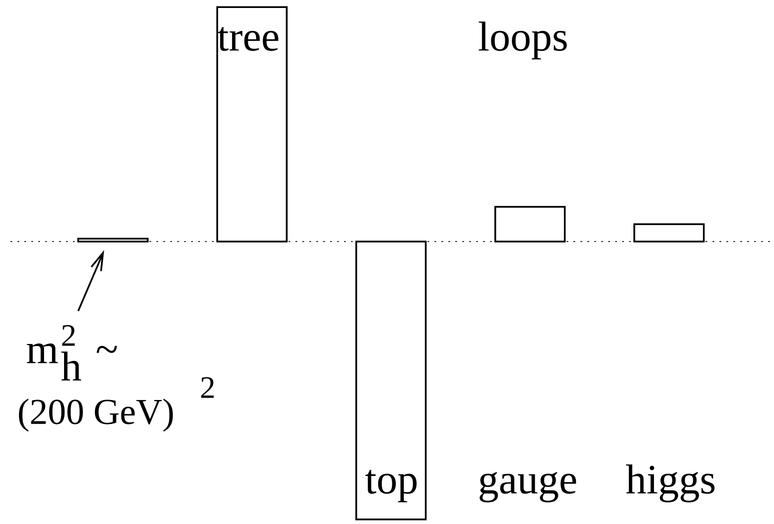

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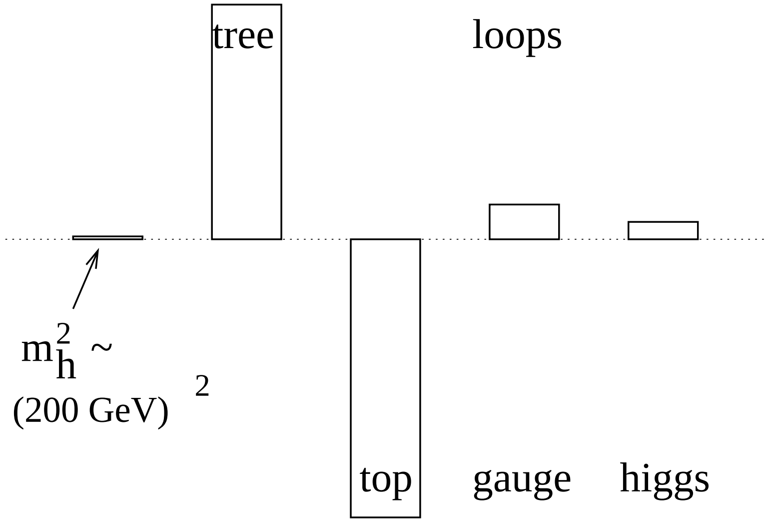

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"Naturalness requirement": less than 90% cancellation on m_H^2

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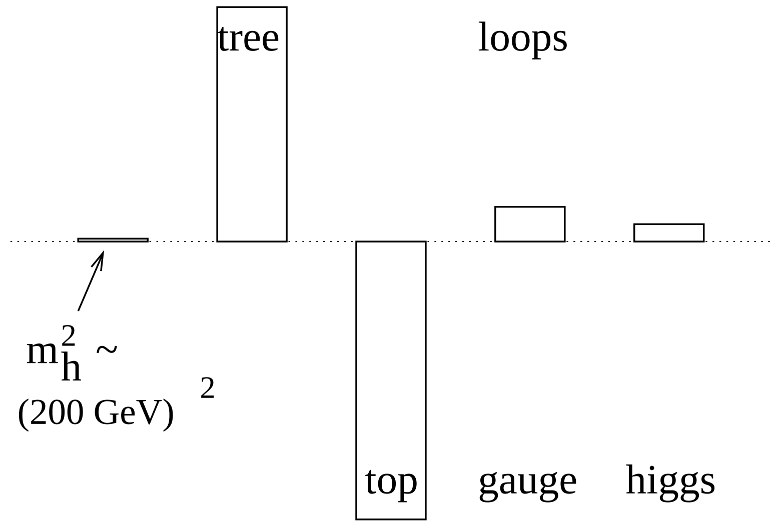

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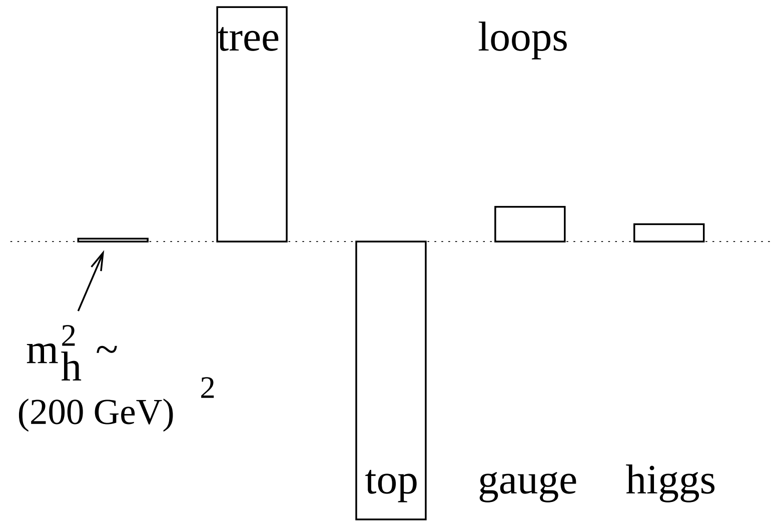

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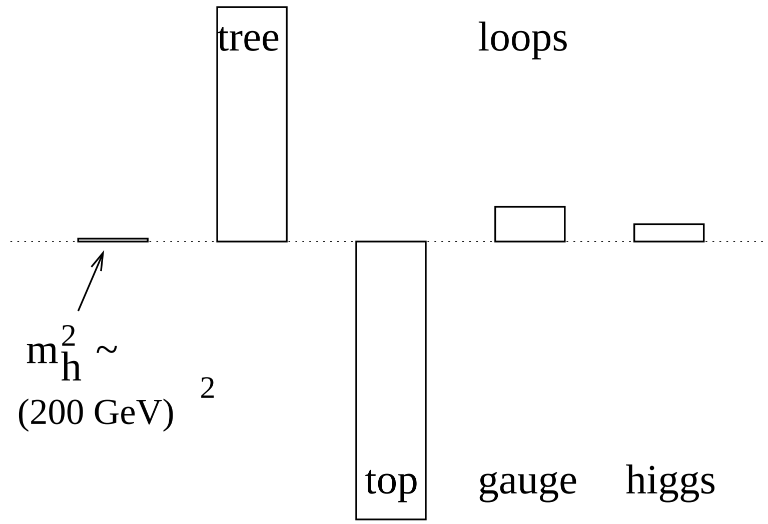

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Theorists have a first thought.
Experimenters have the last words.

Phenomenology

in The Discovery Era

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Traditional phenomenological approach:

For a favorite theoretical model (of yours):

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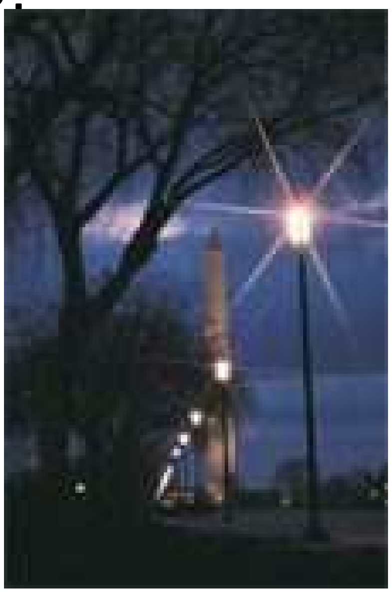
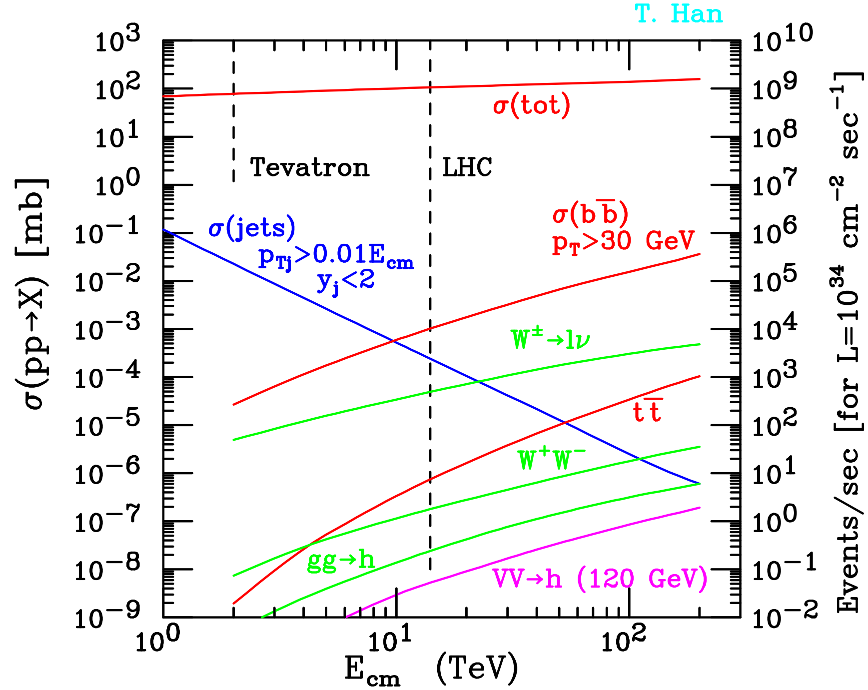


"Lamp-post approach."

Event rates dictate the search:



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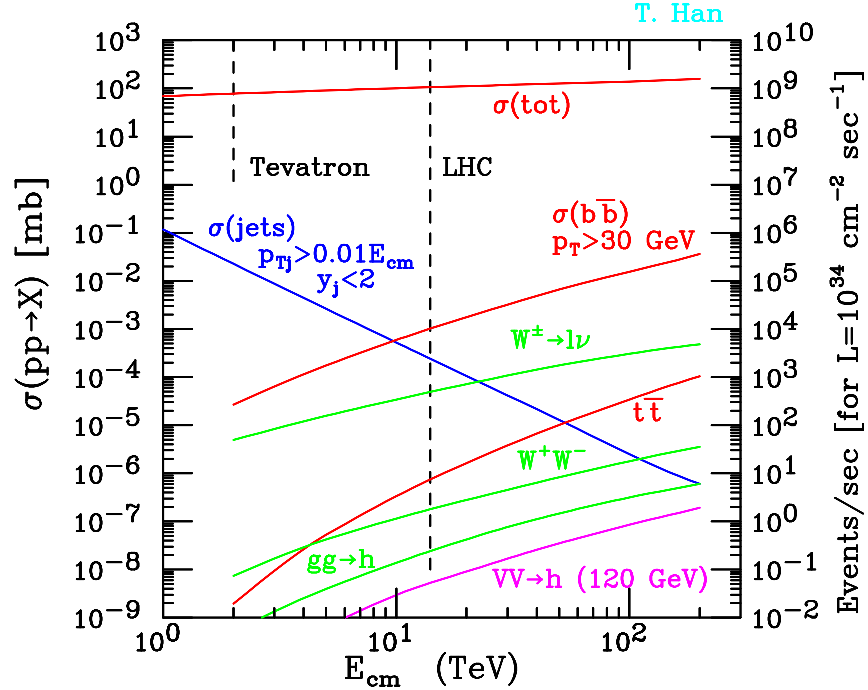

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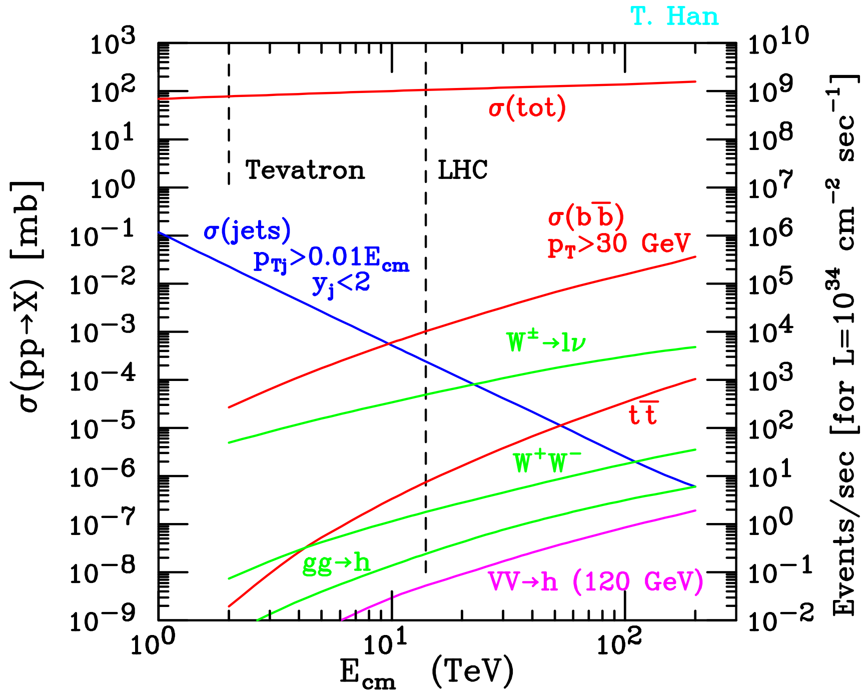

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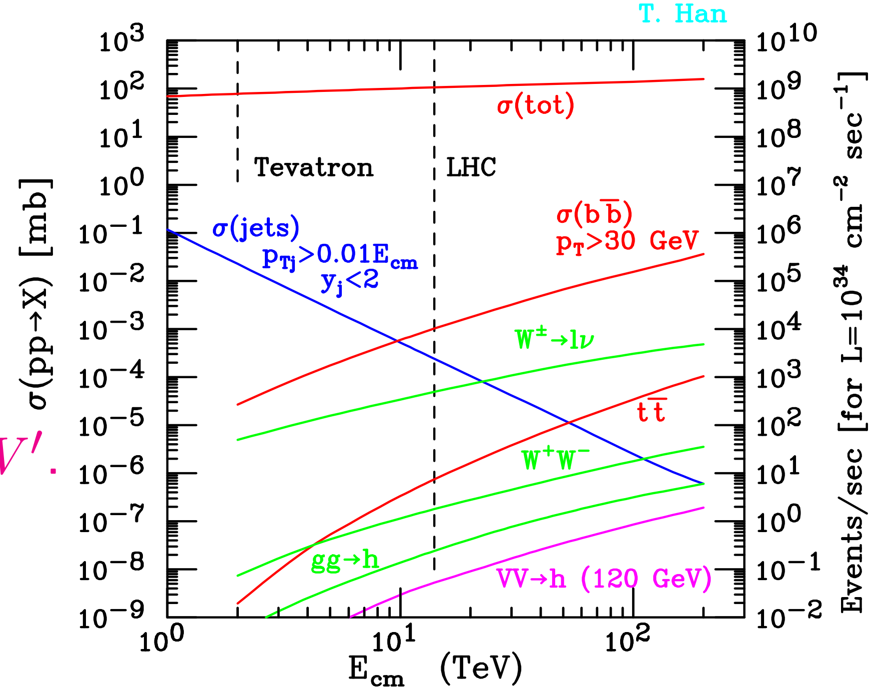

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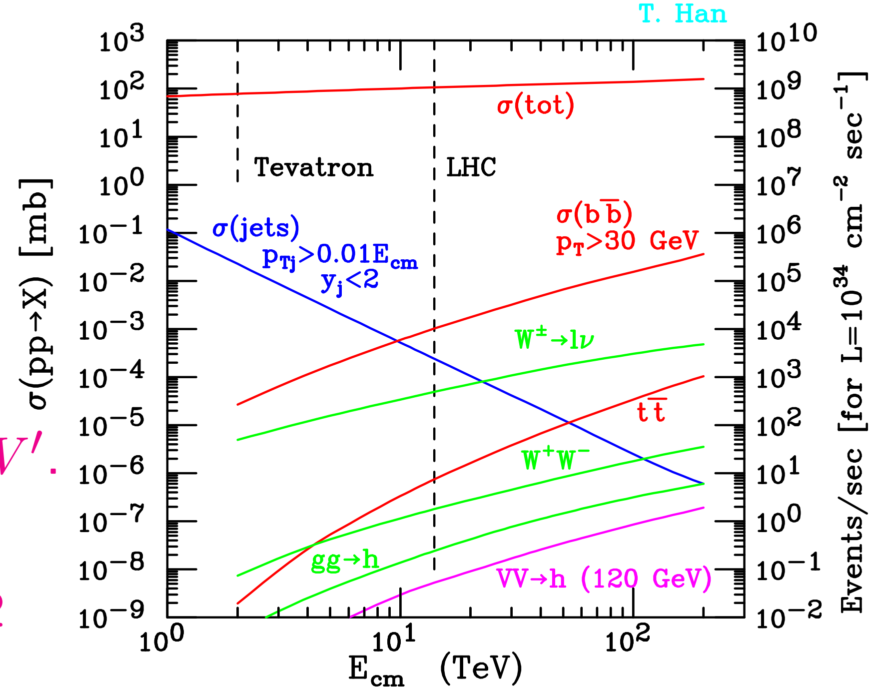

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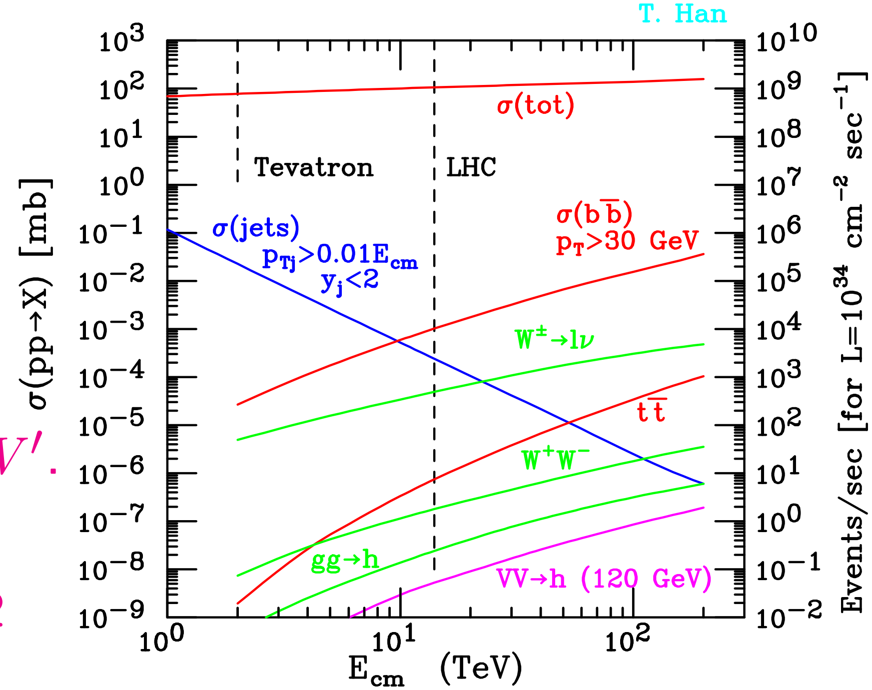

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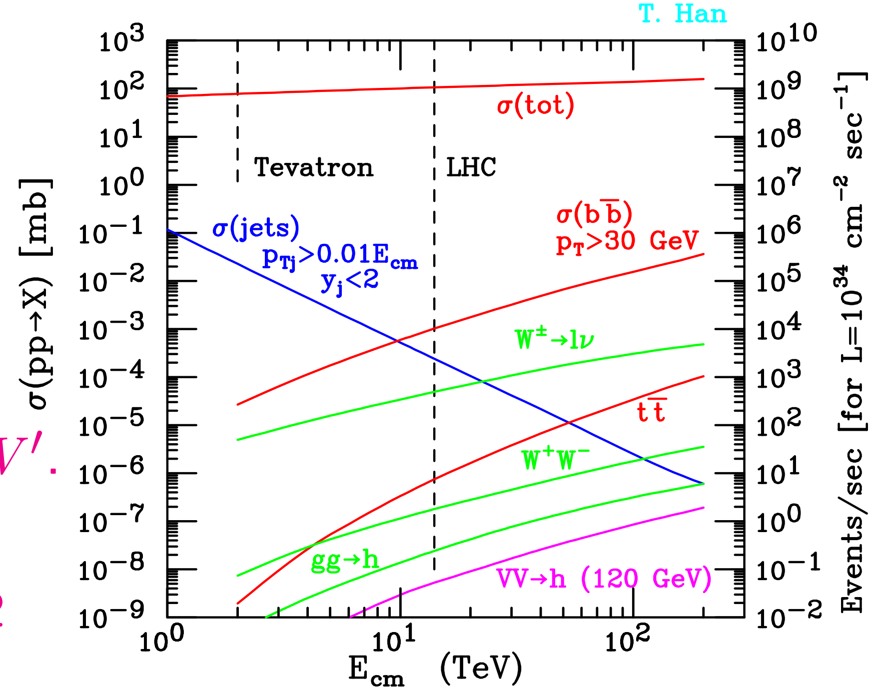

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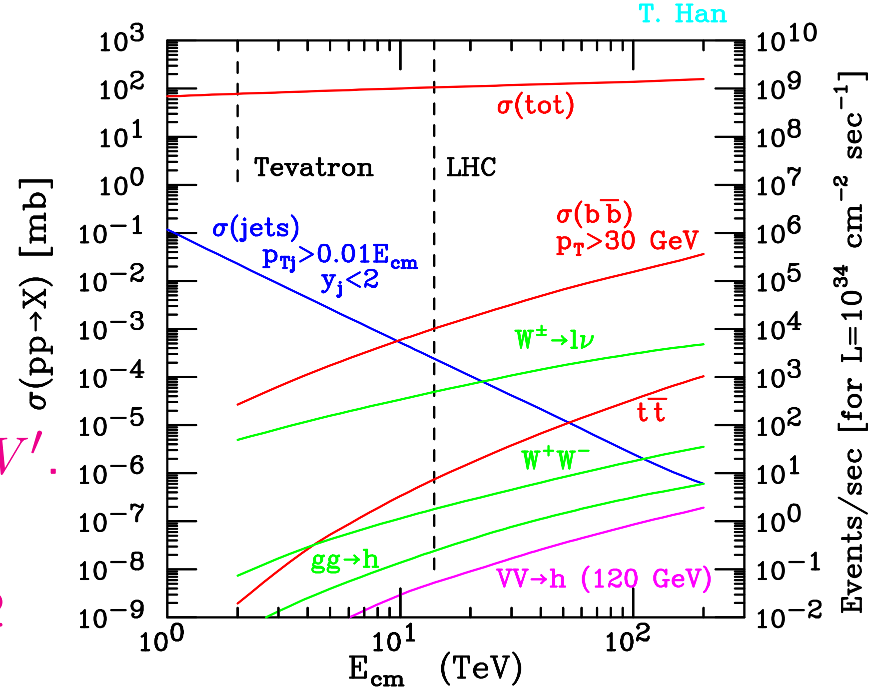

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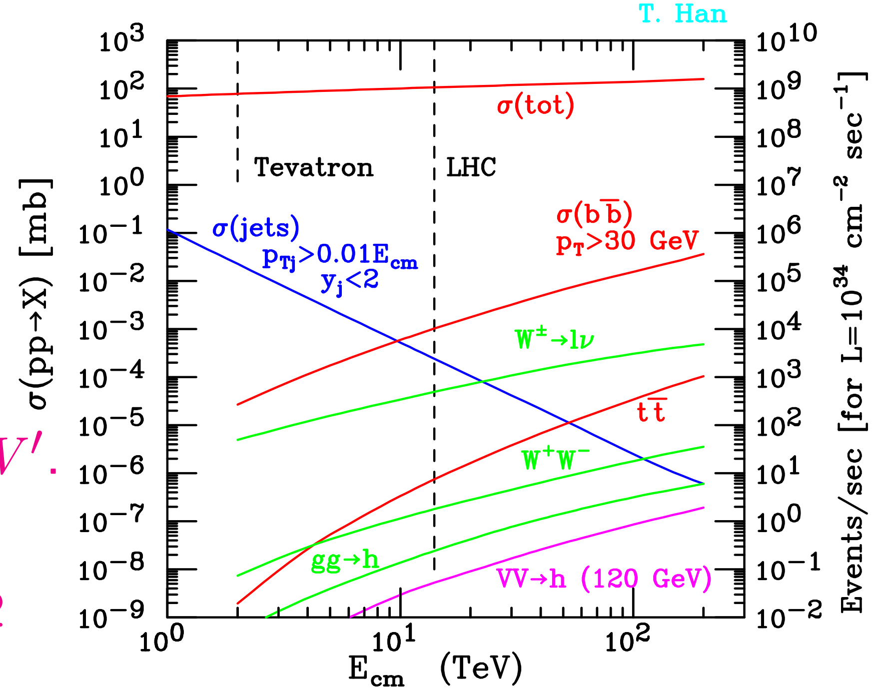

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This is likely the order of experimental (and thus theory) publications.

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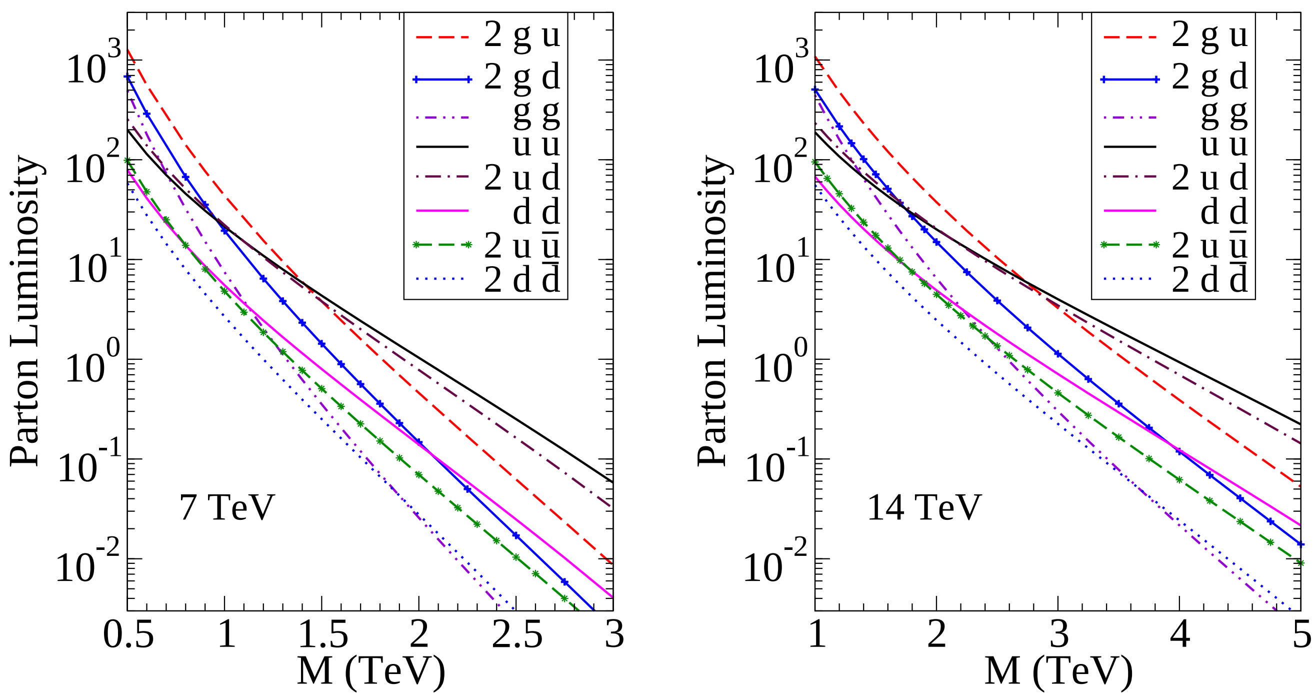

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Plenty of Examples (in well-motivated theories).

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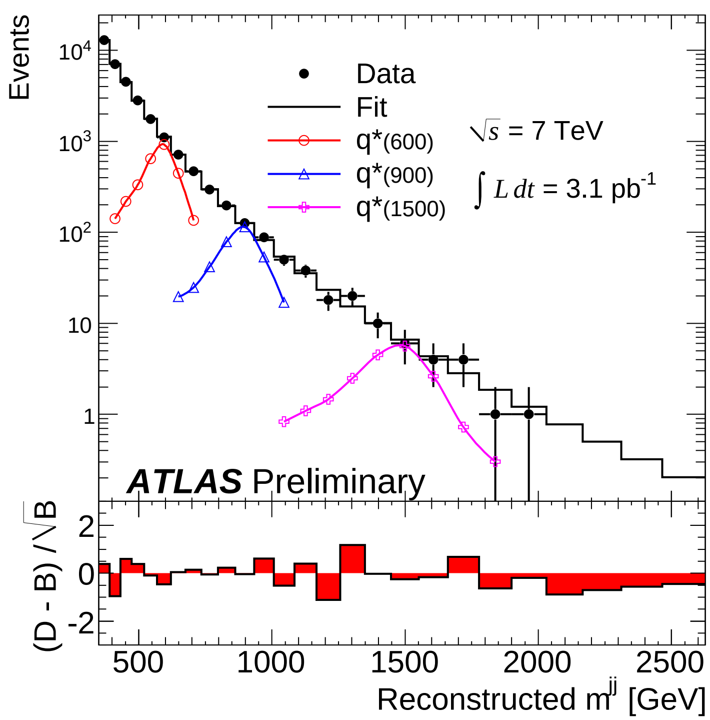

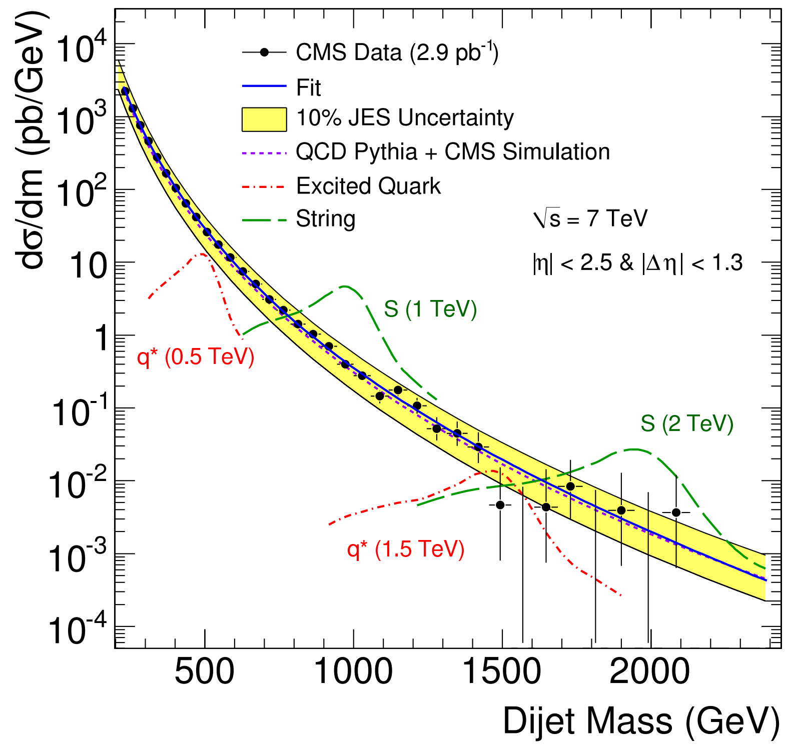

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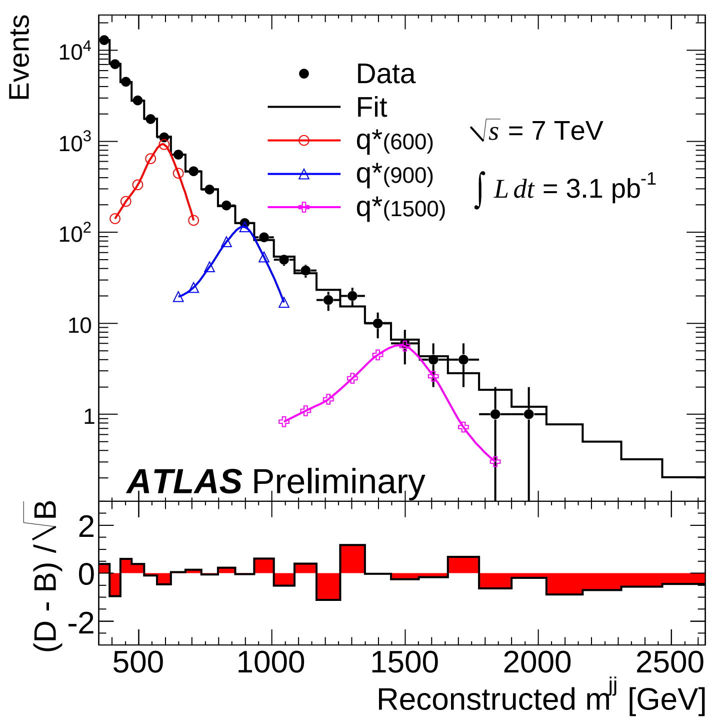

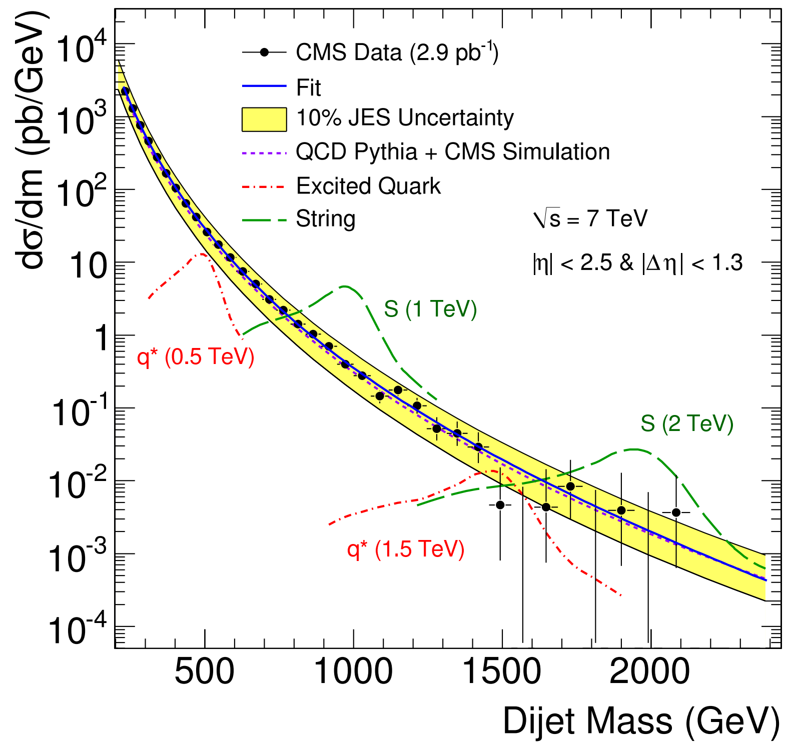

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First BSM physics search beyond the Tevatron reach!

Colored resonances: Theoretical extension*

Particle Names (leading coupling)	J	$SU_C(3)$	$\|Q_e\|$	B	Related models
$E^{\mu}_{3,6}$ (uu)	0, 1	$\mathbf{3}$, $\overline{\mathbf{6}}$	$\frac{4}{3}$	$-\frac{2}{3}$	scalar/vector diquarks
$D^{\mu}_{3,6}$ (ud)	0, 1	$\mathbf{3}$, $\overline{\mathbf{6}}$	$\frac{1}{3}$	$-\frac{2}{3}$	scalar/vector diquarks; $\tilde{d}$
$U^{\mu}_{3,6}$ (dd)	0, 1	$\mathbf{3}$, $\overline{\mathbf{6}}$	$\frac{2}{3}$	$-\frac{2}{3}$	scalar/vector diquarks; $\tilde{u}$
$u^{*}_{3,6}$ (ug)	$\frac{1}{2}$, $\frac{3}{2}$	$\mathbf{3}$, $\overline{\mathbf{6}}$	$\frac{2}{3}$	$\frac{1}{3}$	excited u; quixes; stringy
$d^{*}_{3,6}$ (dg)	$\frac{1}{2}$, $\frac{3}{2}$	$\mathbf{3}$, $\overline{\mathbf{6}}$	$\frac{1}{3}$	$\frac{1}{3}$	excited d; quixes; stringy
S_8 (gg)	0	$\mathbf{8}_S$	0	0	π_{TC}, η_{TC}
T_8 (gg)	2	$\mathbf{8}_S$	0	0	stringy
V^0_8 $(u\bar{u},\ d\bar{d})$	1	$\mathbf{8}$	0	0	axigluon; g_{KK}, ρ_{TC}; coloron
$V^{\pm}_8$ $(u\bar{d})$	1	$\mathbf{8}$	1	0	$\rho^{\pm}_{TC}$

*TH, Ian Lewis, Zhen Liu, arXiv:1010.4309 [hep-ph].

Mass bounds (coupling constant and BR of unity):

E_6^μ	2.5 TeV (CMS)	E_6	2.1 TeV
D_6^μ	2.3 TeV (CMS)	D_6	1.9 TeV
U_6^μ	$0.8, 0.9 - 1.1, 1.4 - 1.6$ TeV (CMS)	U_6	0.5 TeV
D_3^μ	1.9 TeV (CMS)	D_3	$0.8, 0.9 - 1.2, 1.3 - 1.7$ TeV
u_6^*	1.7 TeV (CMS), 1.6 TeV (ATLAS)	d_6^*	1.1 TeV, 1.2 TeV
$V_8^\pm$	1.7 TeV (CMS)	V_8^0	1.6 TeV
S_8	0.8 TeV (CMS)	T_8	0.7 TeV ,

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D_3^μ	1.9 TeV (CMS)	D_3	$0.8, 0.9 - 1.2, 1.3 - 1.7$ TeV
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This is NOT our goal. This is for preparation.

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D_6^μ	2.3 TeV (CMS)	D_6	1.9 TeV
U_6^μ	$0.8, 0.9-1.1, 1.4-1.6$ TeV (CMS)	U_6	0.5 TeV
D_3^μ	1.9 TeV (CMS)	D_3	$0.8, 0.9-1.2, 1.3-1.7$ TeV
u_6^*	1.7 TeV (CMS), 1.6 TeV (ATLAS)	d_6^*	1.1 TeV, 1.2 TeV
$V_8^\pm$	1.7 TeV (CMS)	V_8^0	1.6 TeV
S_8	0.8 TeV (CMS)	T_8	0.7 TeV ,

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Hopefully, this preparation will be paid off for discovery!

Example II: W' Search: $\ell^{\pm} + \not{E}_T$ channel

W': Hint for Extra Dimensions

Search for W'→eν

Very <u>massive W' Bosons</u> would indicate the existence of <u>extra dimensions</u>

95% CL mass limit <u>$m_{W'}$<1.3 TeV</u> for W' Bosons with standard model-like couplings and branching fractions

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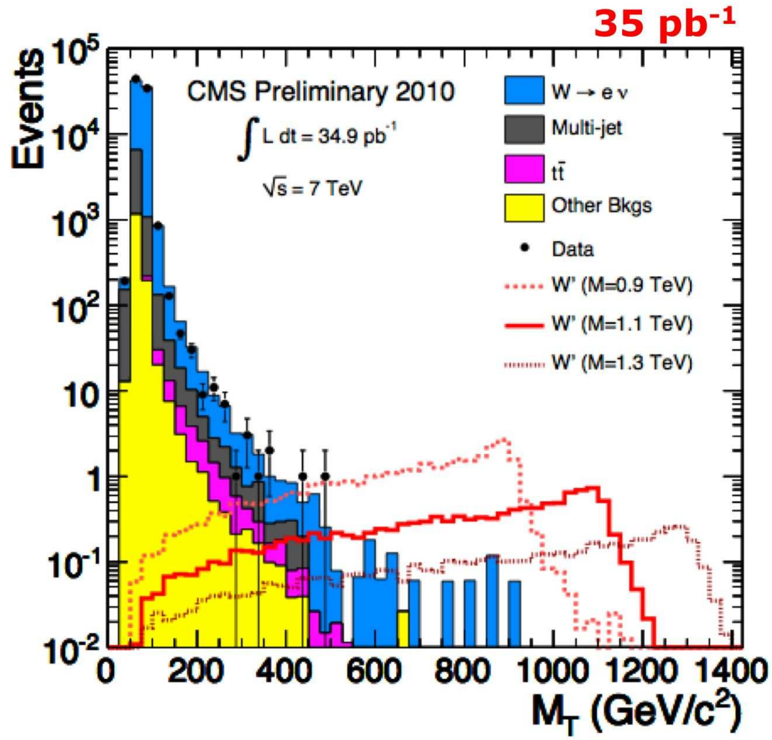

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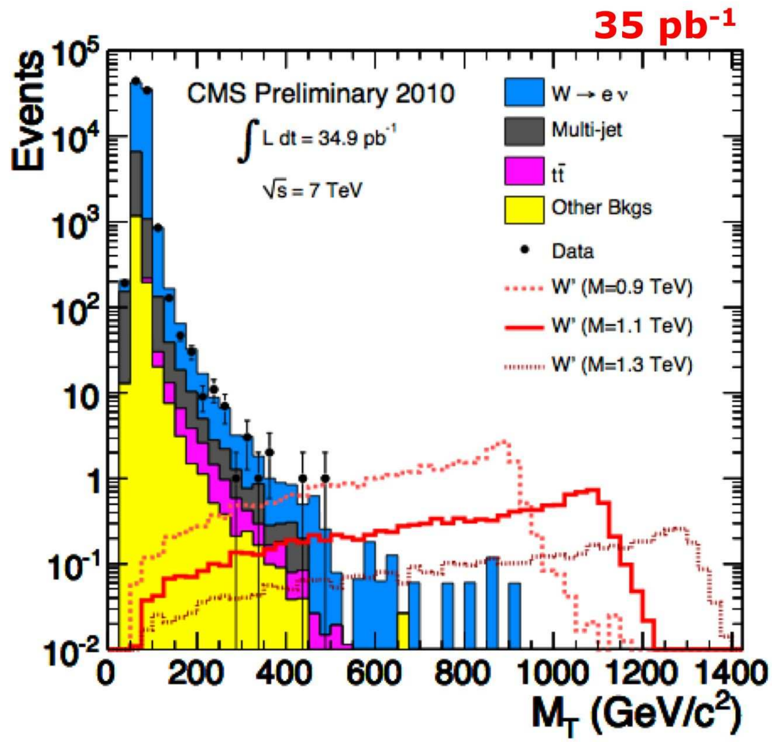


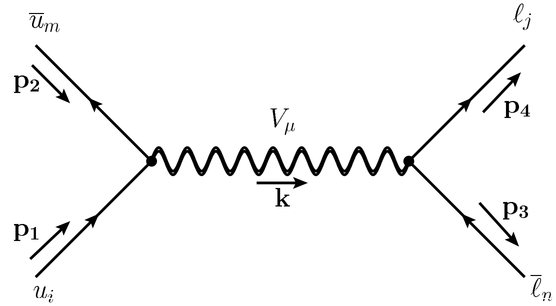
Already way beyond the Tevatron bound ($\sim$ 900 GeV)!

The Z' bound is slightly weaker.

Theoretical extension*

Name	$SU(3)_c$	$\lvert Q_e\rvert$	J	Partonic processes
V	$\mathbf{1}$	0	$0,1,2$	$u\overline{u} \to \overline{\ell}\ell$, $d\overline{d} \to \overline{\ell}\ell$, $gg \to \overline{\ell}\ell$
V'	$\mathbf{1}$	1	$0,1,2$	$u\overline{d} \to \overline{\ell}\nu, d\overline{u} \to \ell\overline{\nu}$

TABLE I: Summary of the s-channel resonance particles: their color representations, electric charges, spin quantum numbers, and the processes they contribute to.



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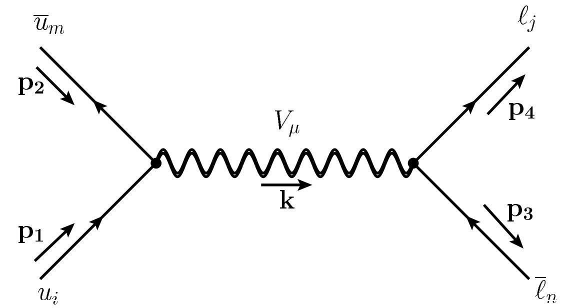

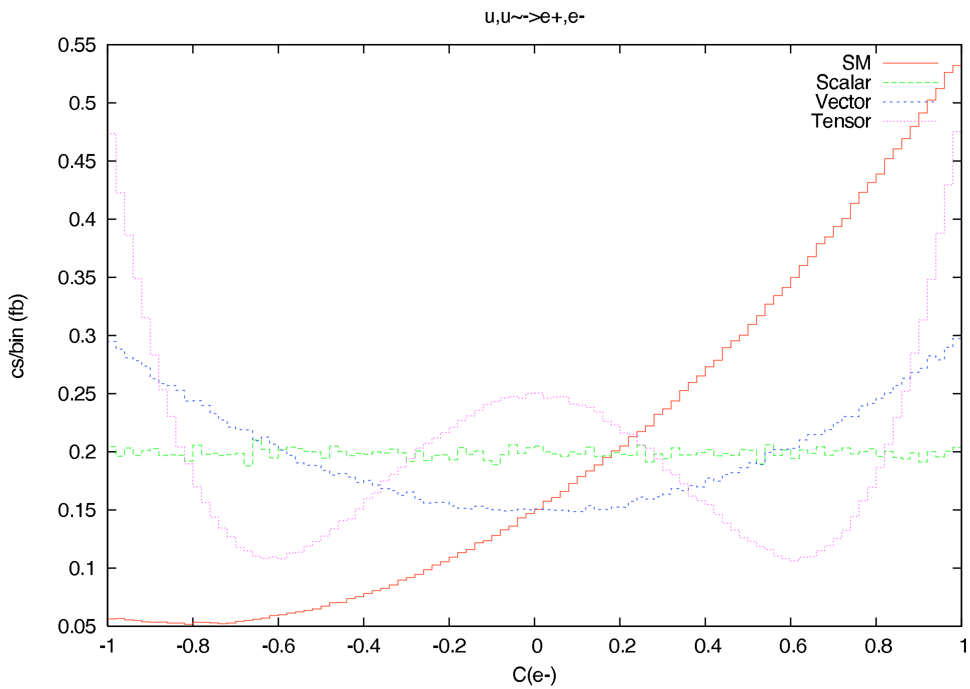

Once observed, we will need the details studies.

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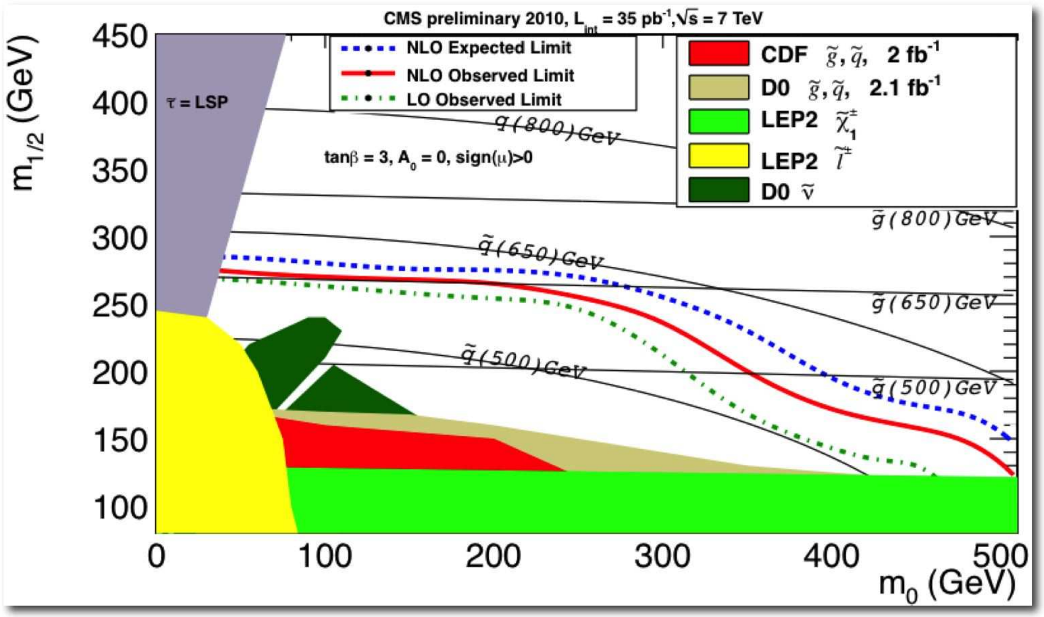
Example III: MSUGRA exclusion in $\not{E}_T$+jets channel:

First SUSY Result at the LHC!

Search for high mass <u>squark & gluino</u> production in events with large missing transverse energy and two or more jets



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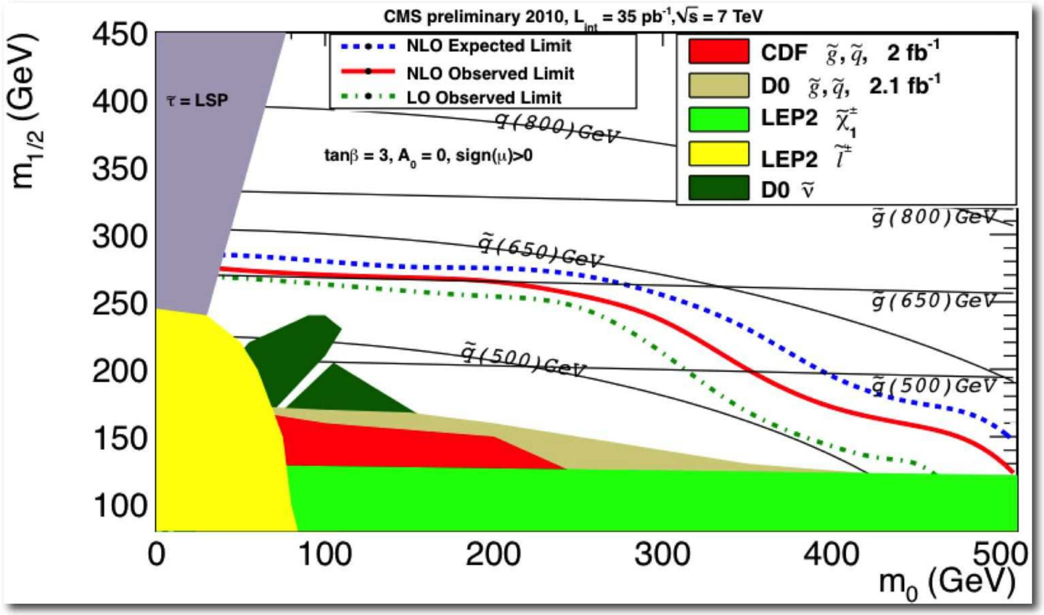

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More results will come in the near future.

We are marching toward discoveries!

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Real excitement for discovery and thereafter
yet to come !