



# LHC Phenomenology with MadGraph

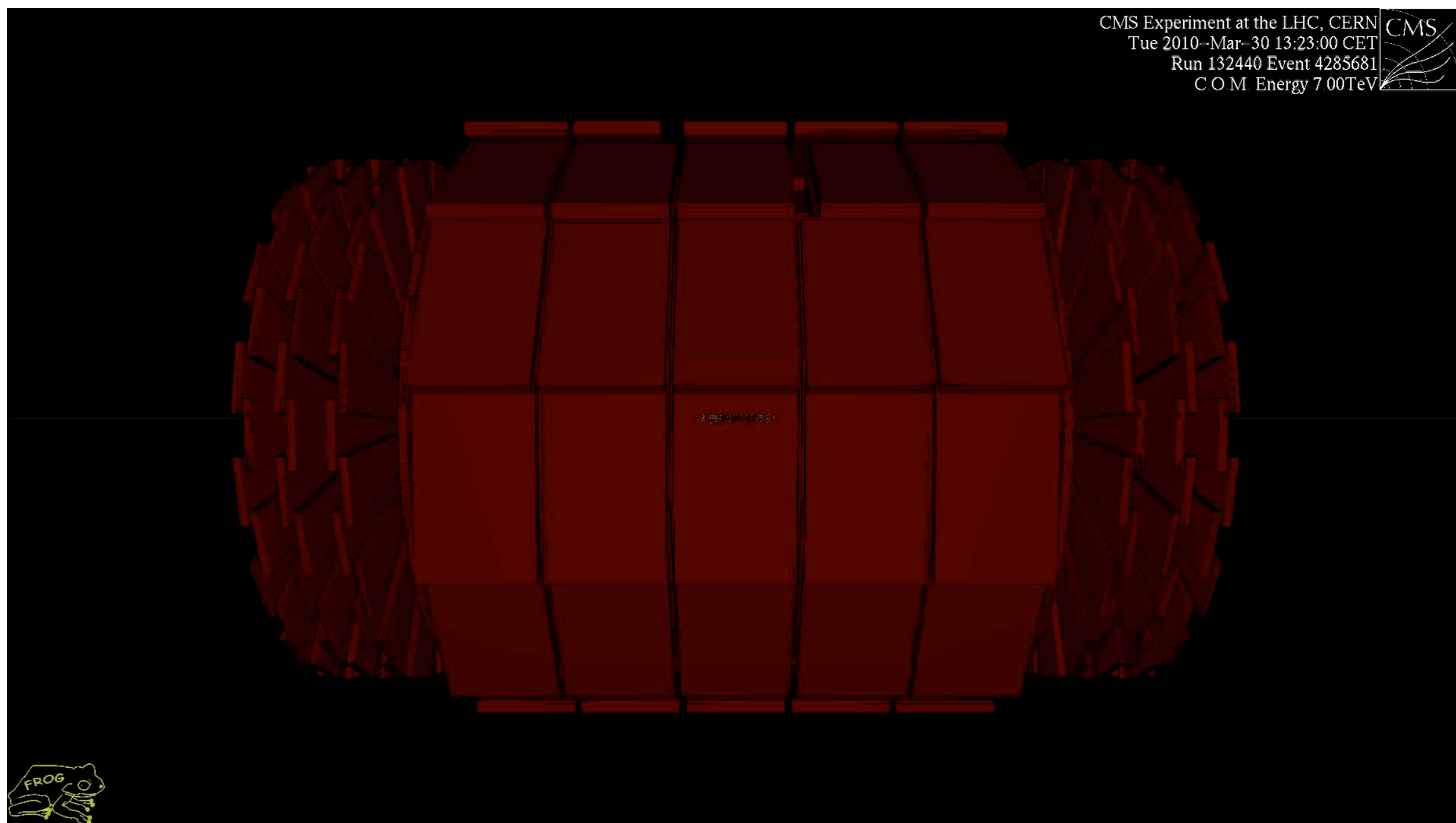
Three introductory lectures

Fabio Maltoni

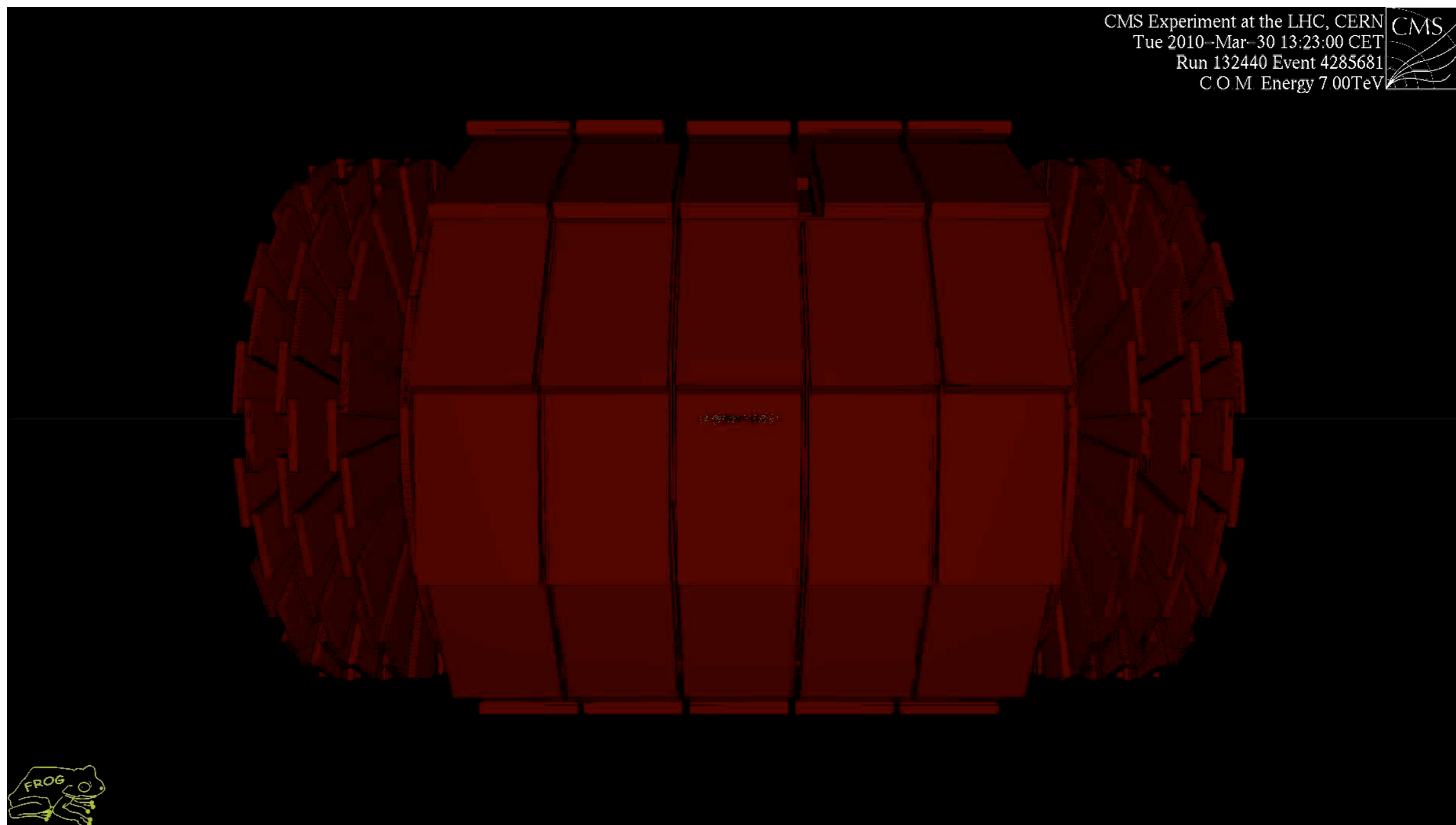
Centre for particle physics and Phenomenology  
Université de Louvain



CMS Experiment at the LHC, CERN  
Tue 2010-Mar-30 13:23:00 CET  
Run 132440 Event 4285681  
C O M Energy 7.00TeV



# LHC data is there!!!!





# Claims and Aims

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In fact, **new dimensions** have been added to  
Theory  $\Leftrightarrow$  Experiment interactions



# Claims and Aims



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**T. Edison :** Genius is 1% inspiration and 99% perspiration.

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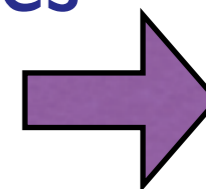
- **Perspective:** the big picture
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**T. Edison :** Genius is 1% inspiration and 99% perspiration.

**MadGraph:** ok, guys, let's improve on the 99% now...

# Claims and (your) Aims

More information and many more pheno exercises  
available on the MadGraph Wiki

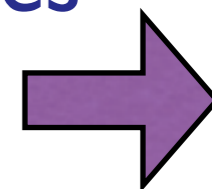


# Claims and (your) Aims



Think

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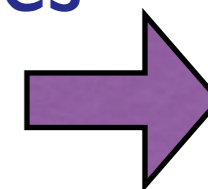


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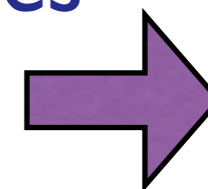


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# A simple plan

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- Intro: the LHC challenge

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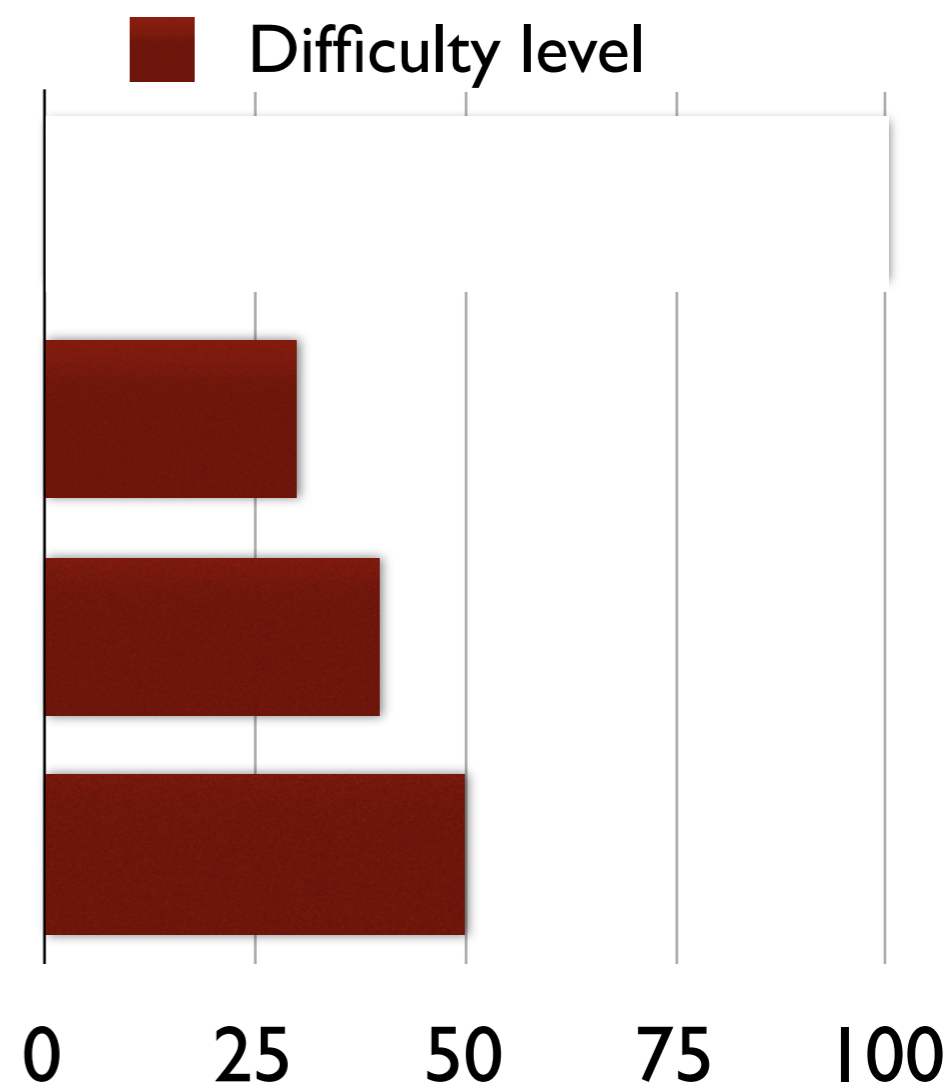
# A simple plan

■ Difficulty level

- Intro: the LHC challenge
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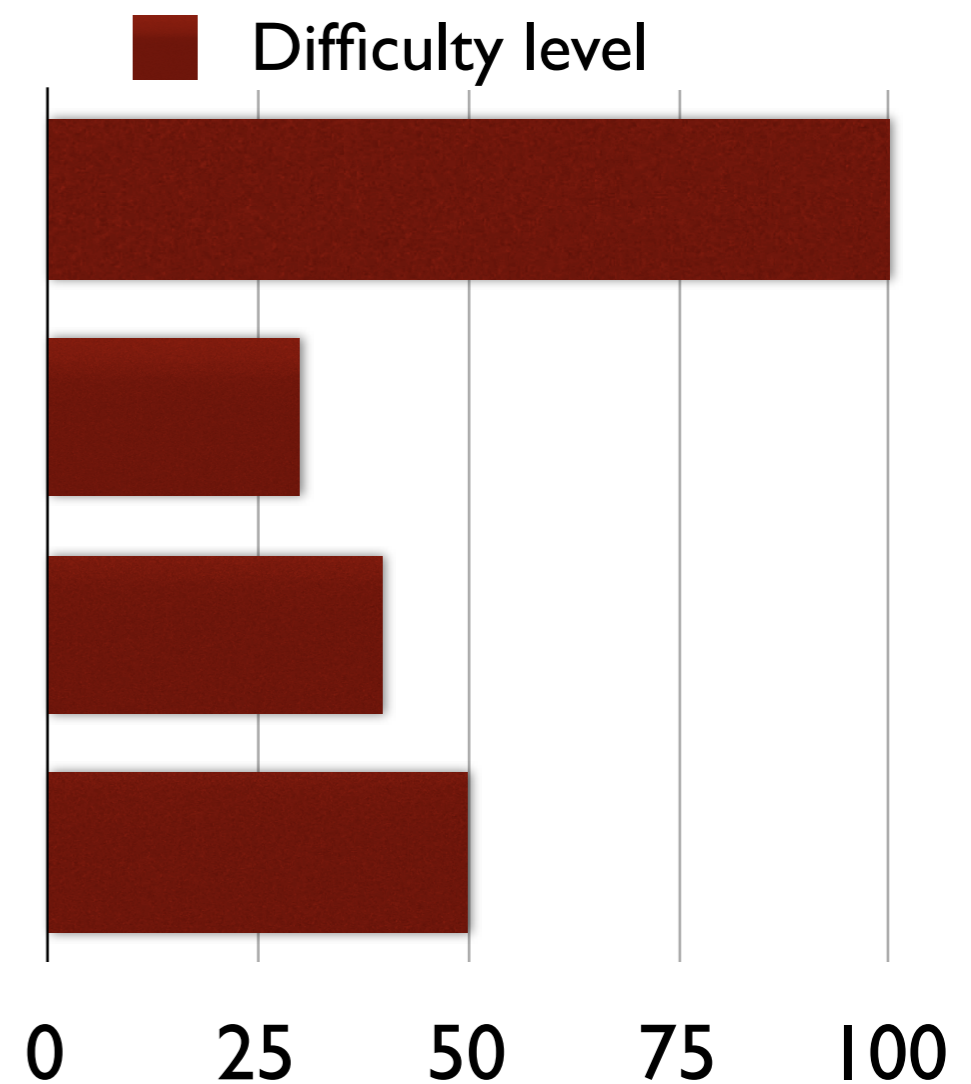
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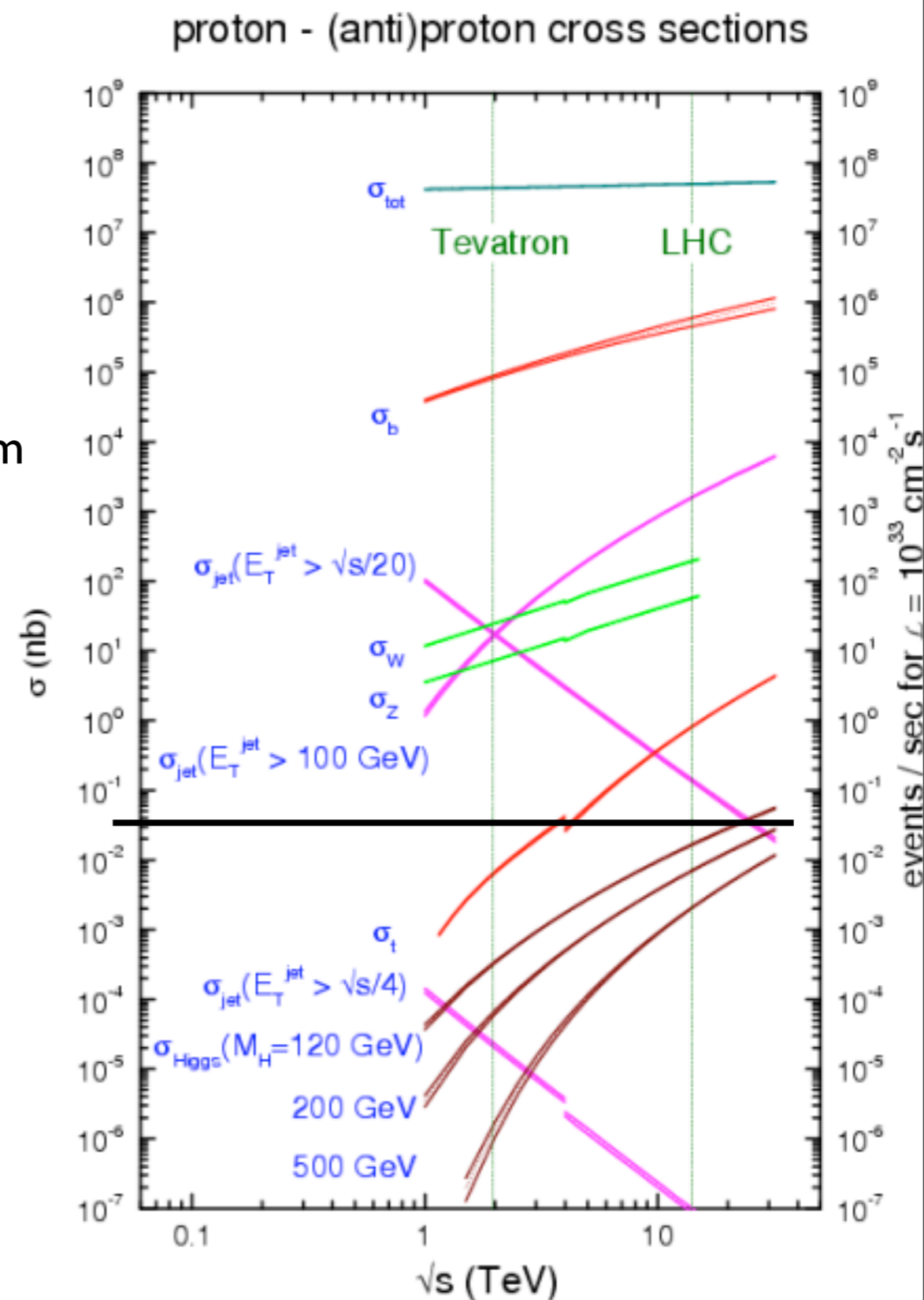


# The big picture

Let's look at the cross section for producing bottom quarks/W,Z,jets,top, and Higgs.

LHC physics = QCD +  $\epsilon$

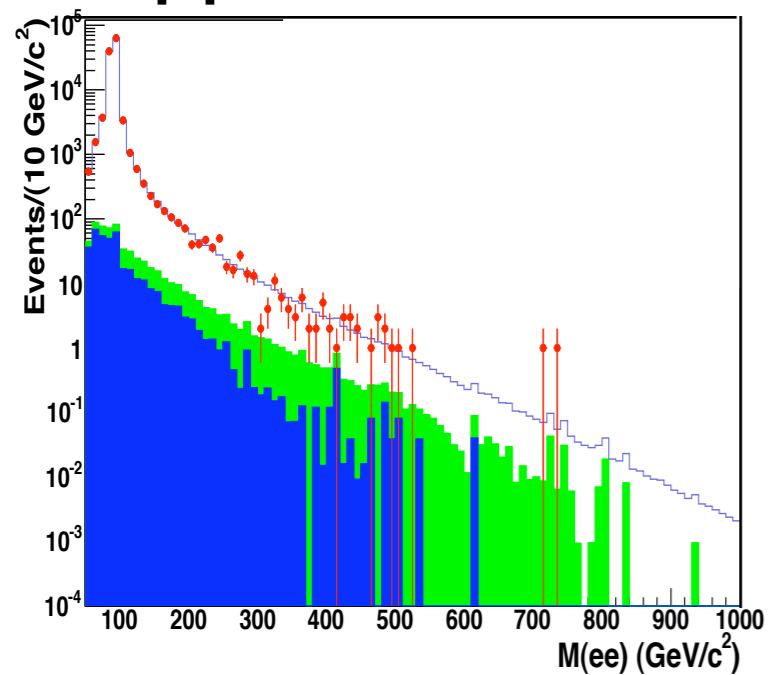
Need to understand QCD backgrounds well!



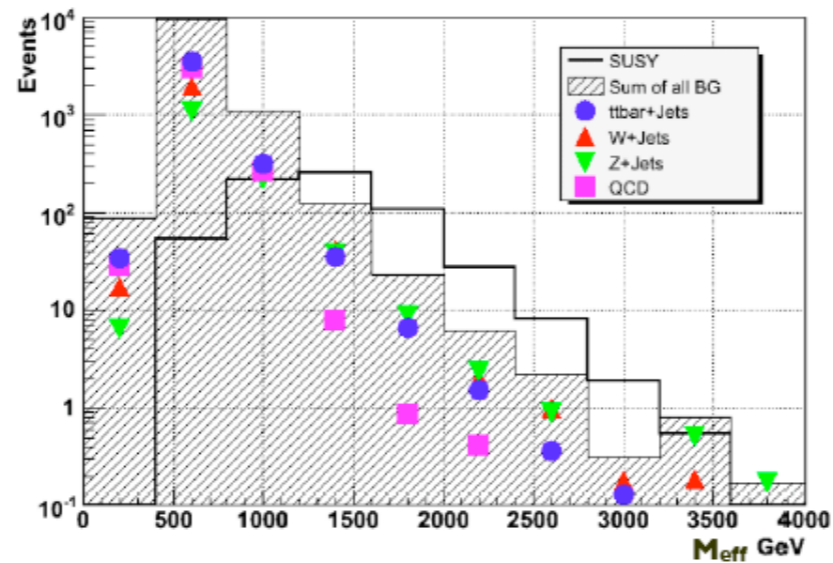
# Discoveries at hadron colliders

[from M.L. Mangano, 2008]

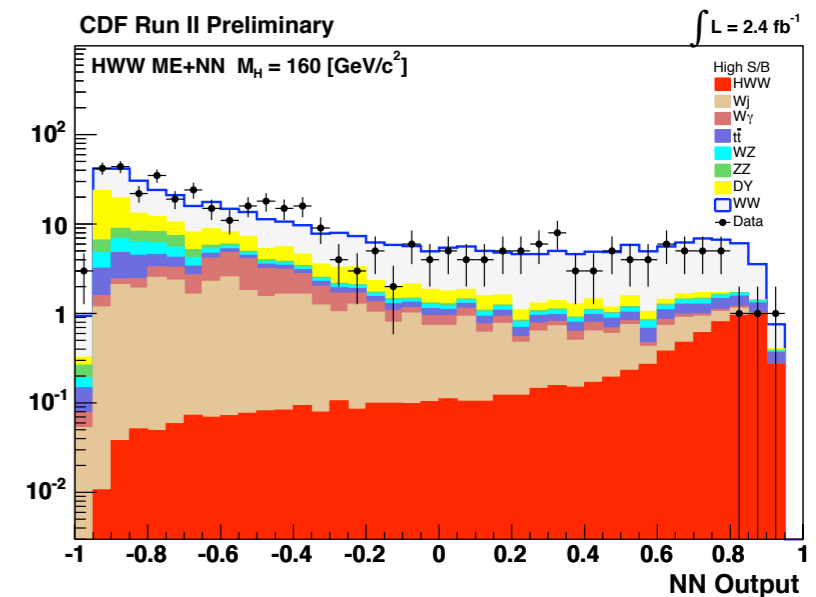
$$pp \rightarrow Z' \rightarrow e^+e^-$$



$$pp \rightarrow \tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q} \rightarrow \text{jets} + \cancel{E}_T$$



$$pp \rightarrow H \rightarrow W^+W^-$$

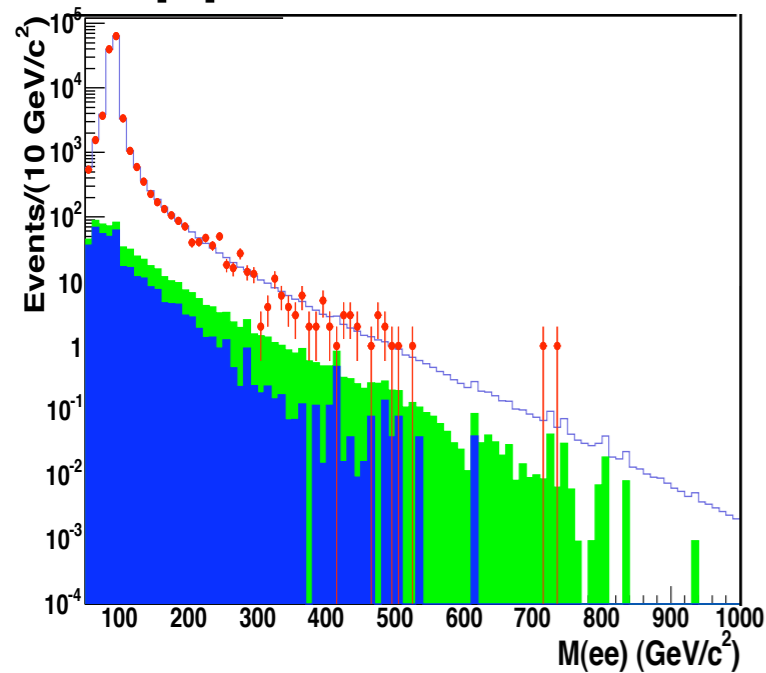


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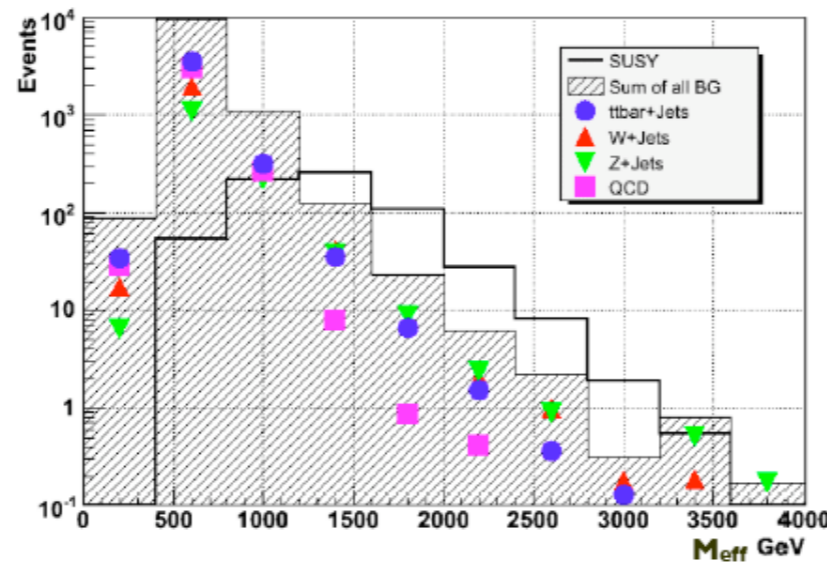
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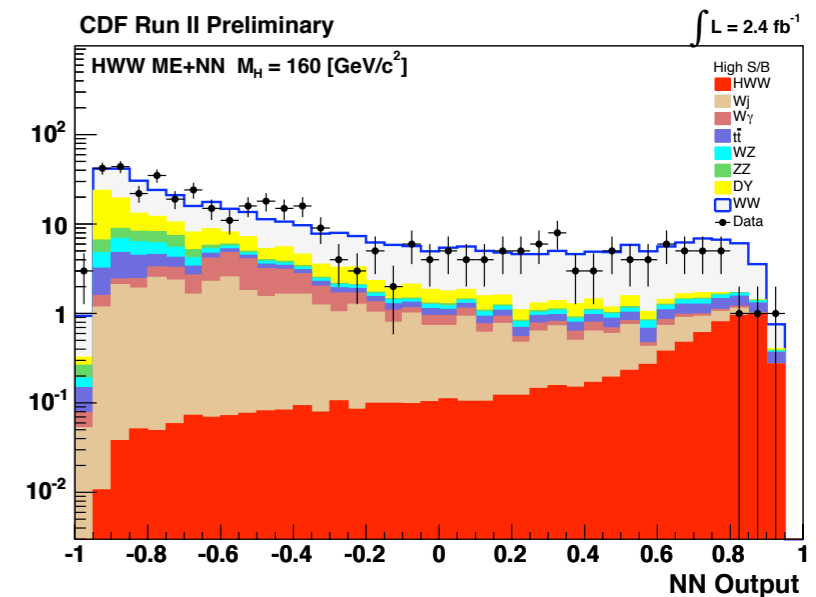
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Background directly measured from data. TH needed only for parameter extraction (Normalization, acceptance,...)

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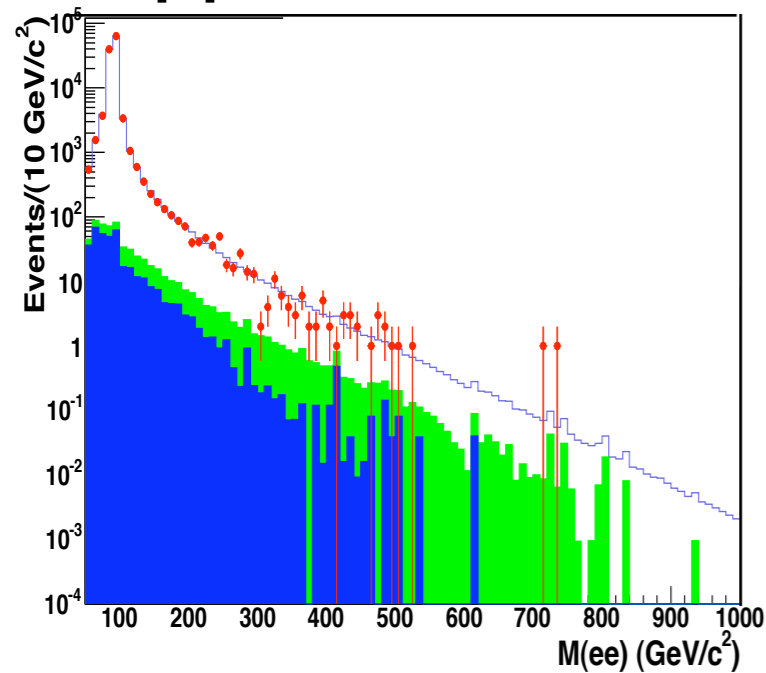


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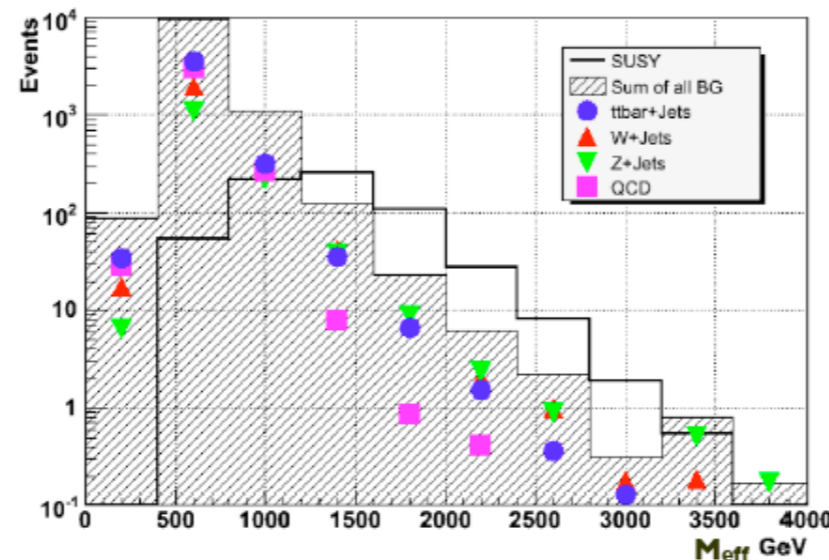


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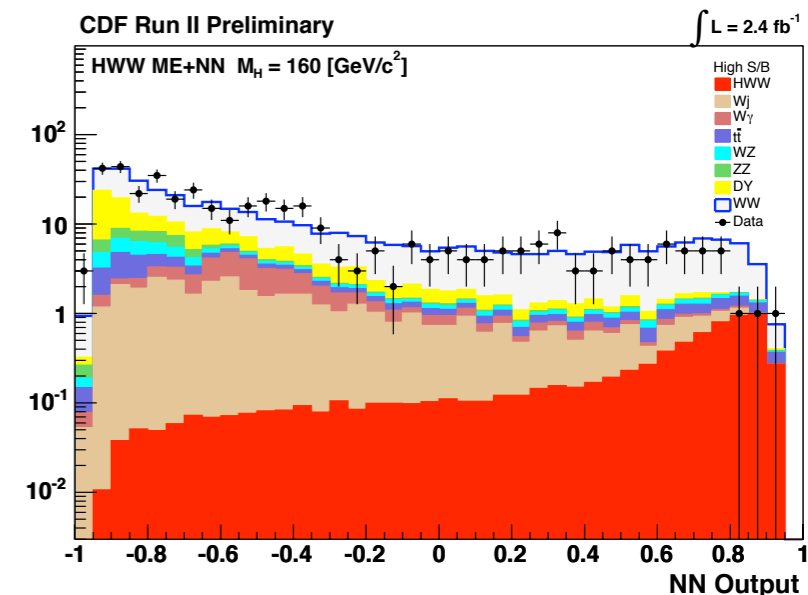
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Background shapes needed. Flexible MC for both signal and background tuned and validated with data.

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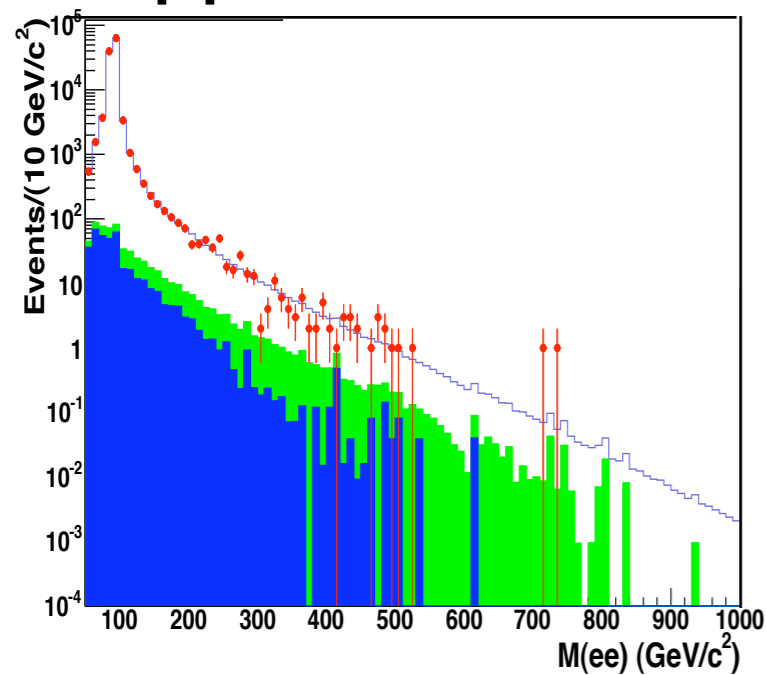


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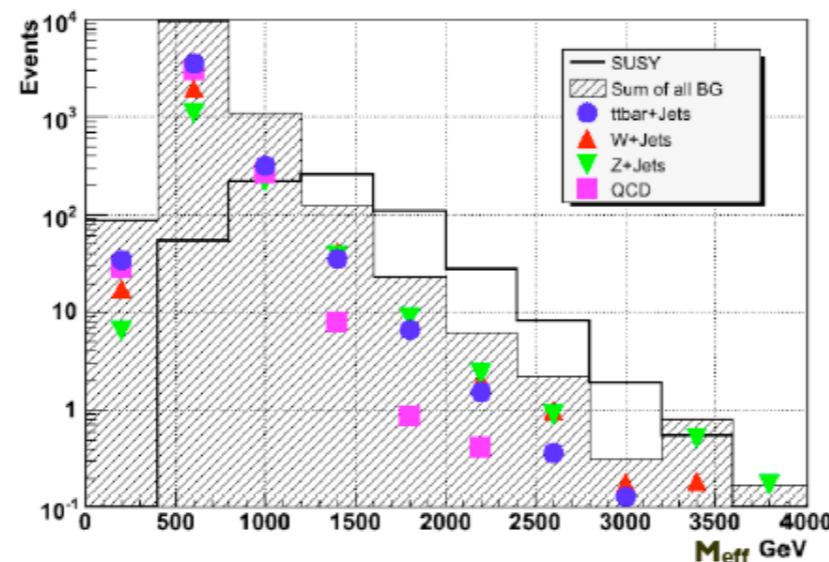


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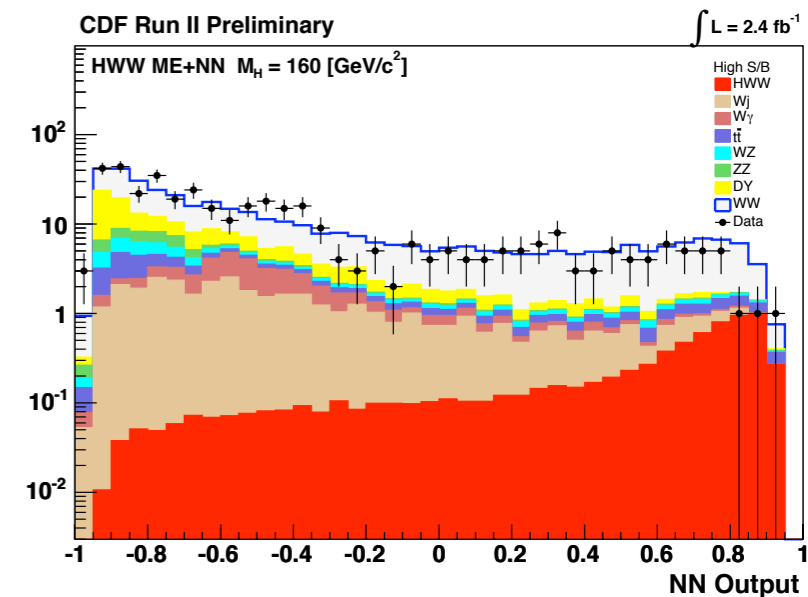


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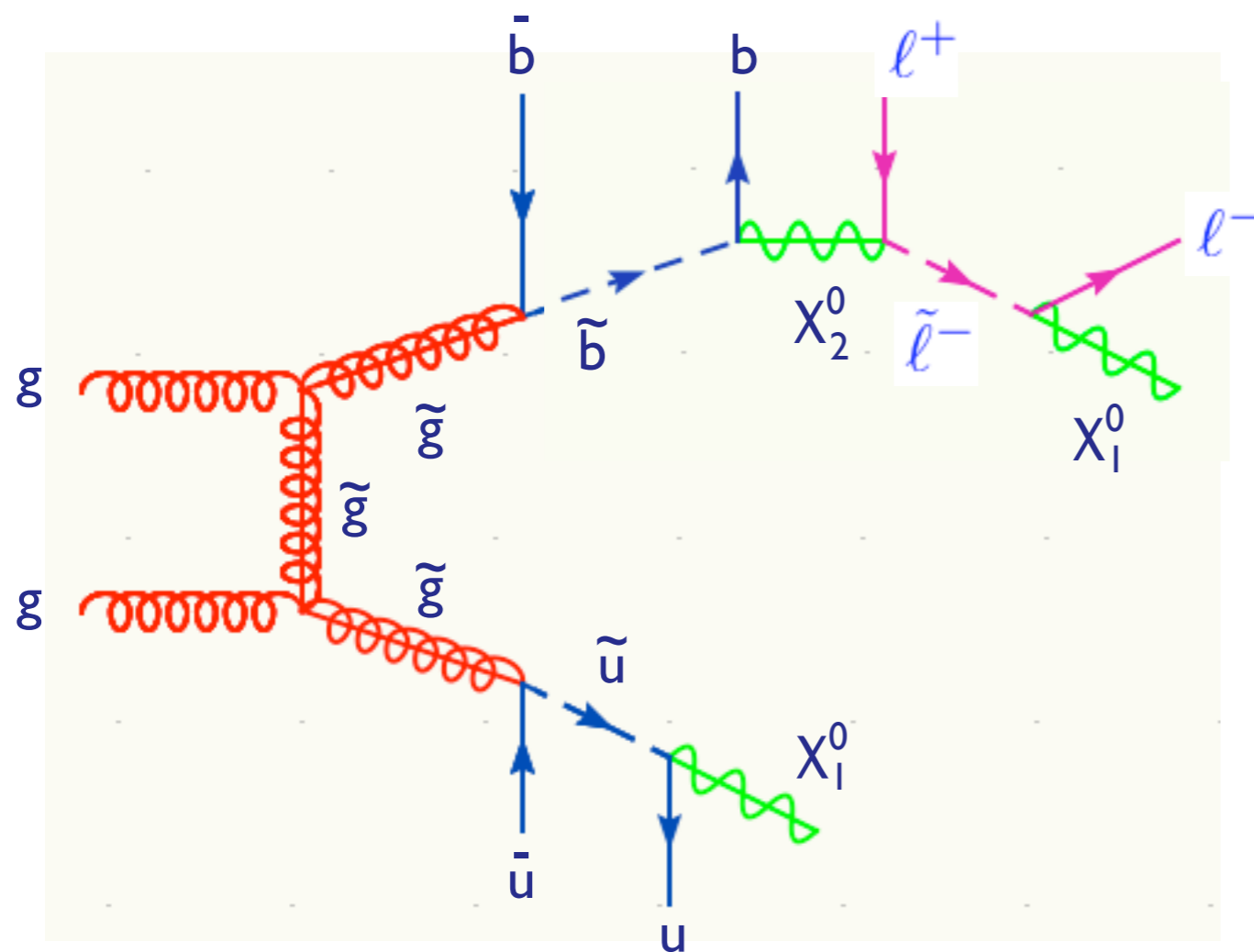
very hard

Background normalization and shapes known very well. Interplay with the best theoretical predictions (via MC) and data.

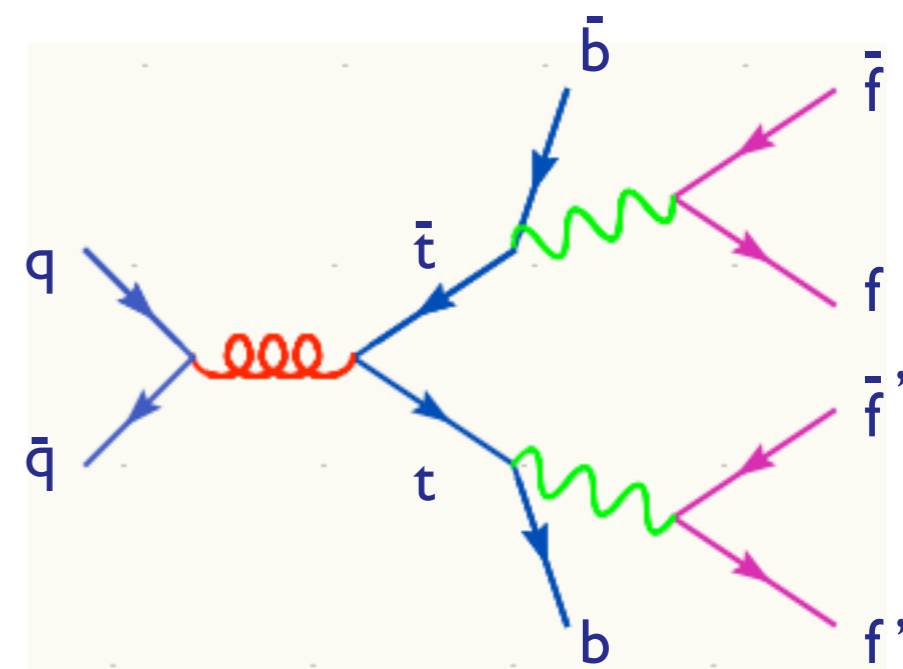


# A new challenge

Consider SUSY-like inclusive searches: heavy colored states decaying through a chain into jets, leptons and missing  $E_T$ ... We have already a very good example of a similar discovery!



VS

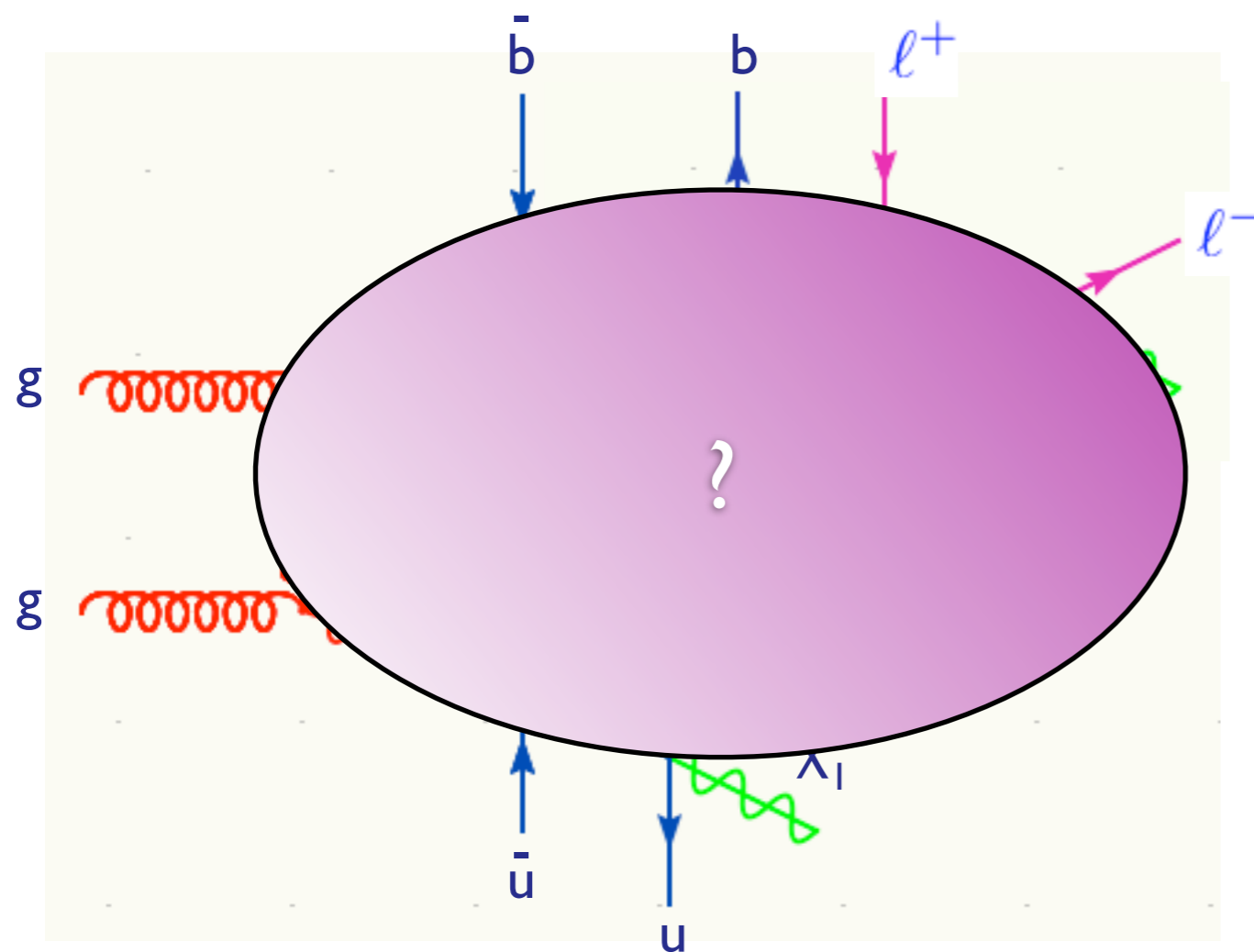


Follow the same approach of CDF in 1995 to establish first evidence of an excess wrt to SM-top and then consistency with SM top production [ $mt=174$ ,  $t \rightarrow b\bar{\nu}$ ,  $\sigma(tt)$ ], works for the SM Higgs, but in general beware that...

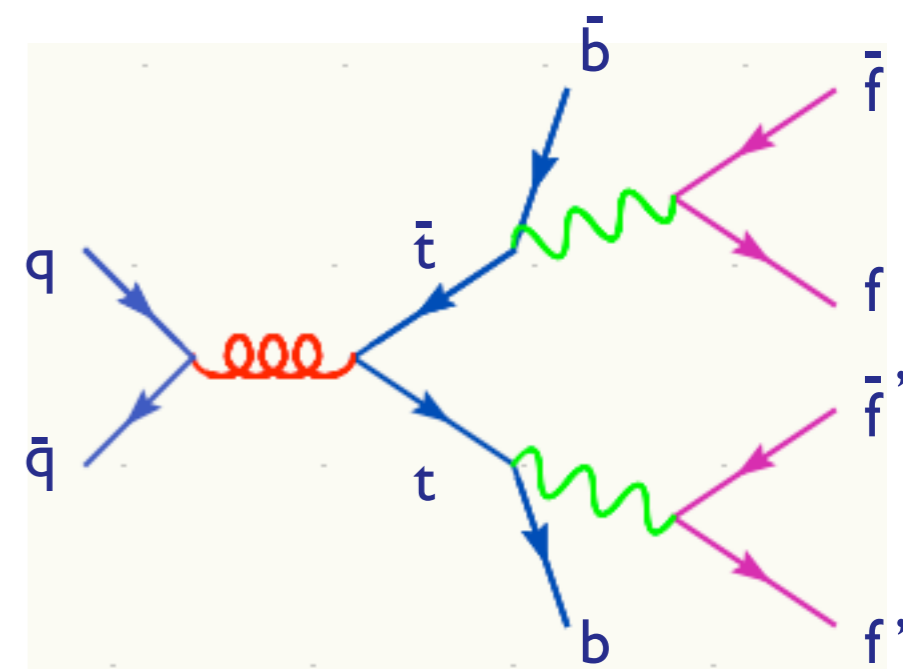


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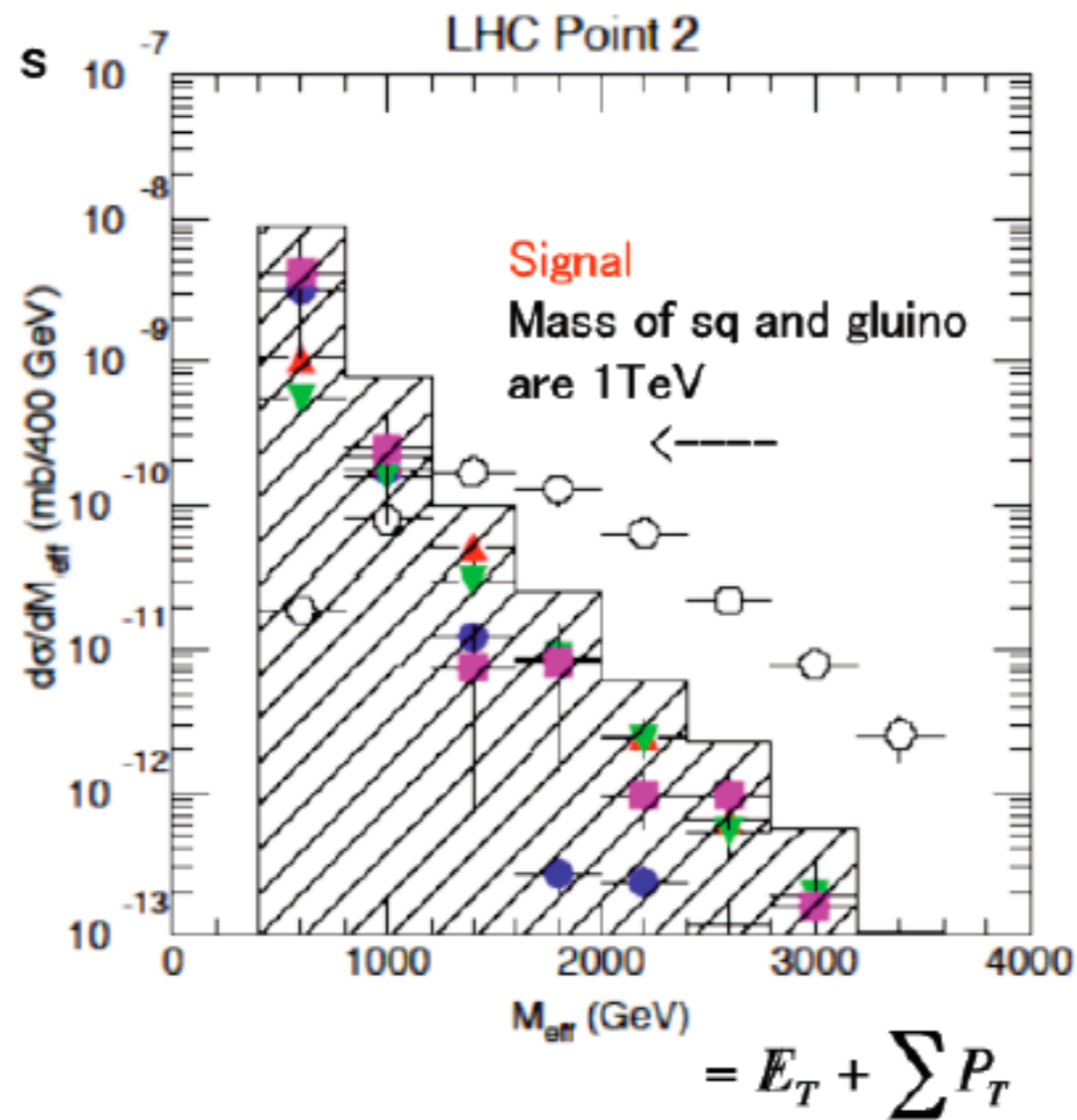


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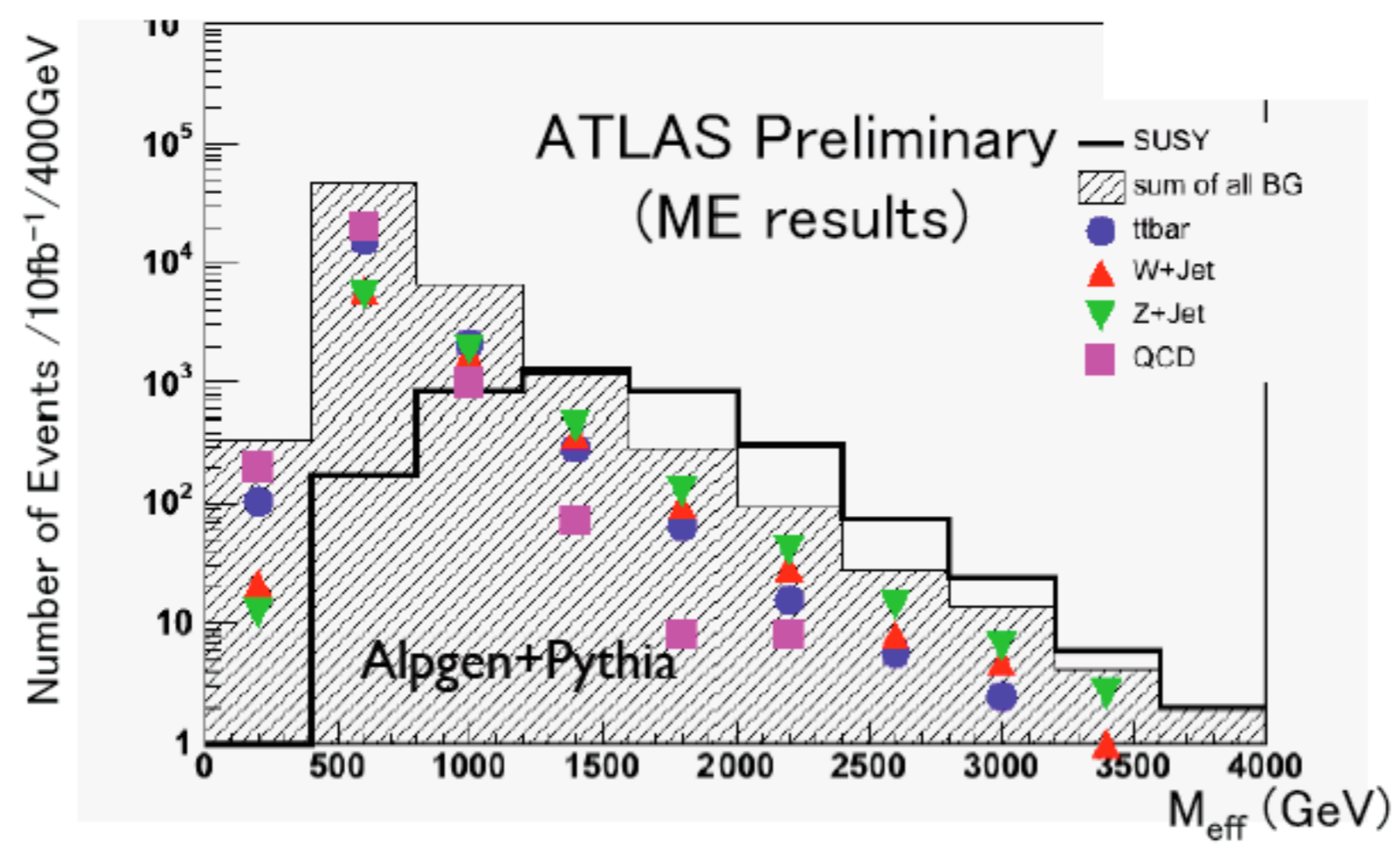
# Example: early discovery SuperSymmetry at the LHC



“Old MC”

**Background:**  $t \bar{t} + \text{jets}, (Z, W) + \text{jets}, \text{jets}$ . Very difficult to estimate theoretically: many parton calculation ( $2 \rightarrow 8$  gluons = 10 millions Feynman diagrams diagrams!!). Now MC's for this are available...

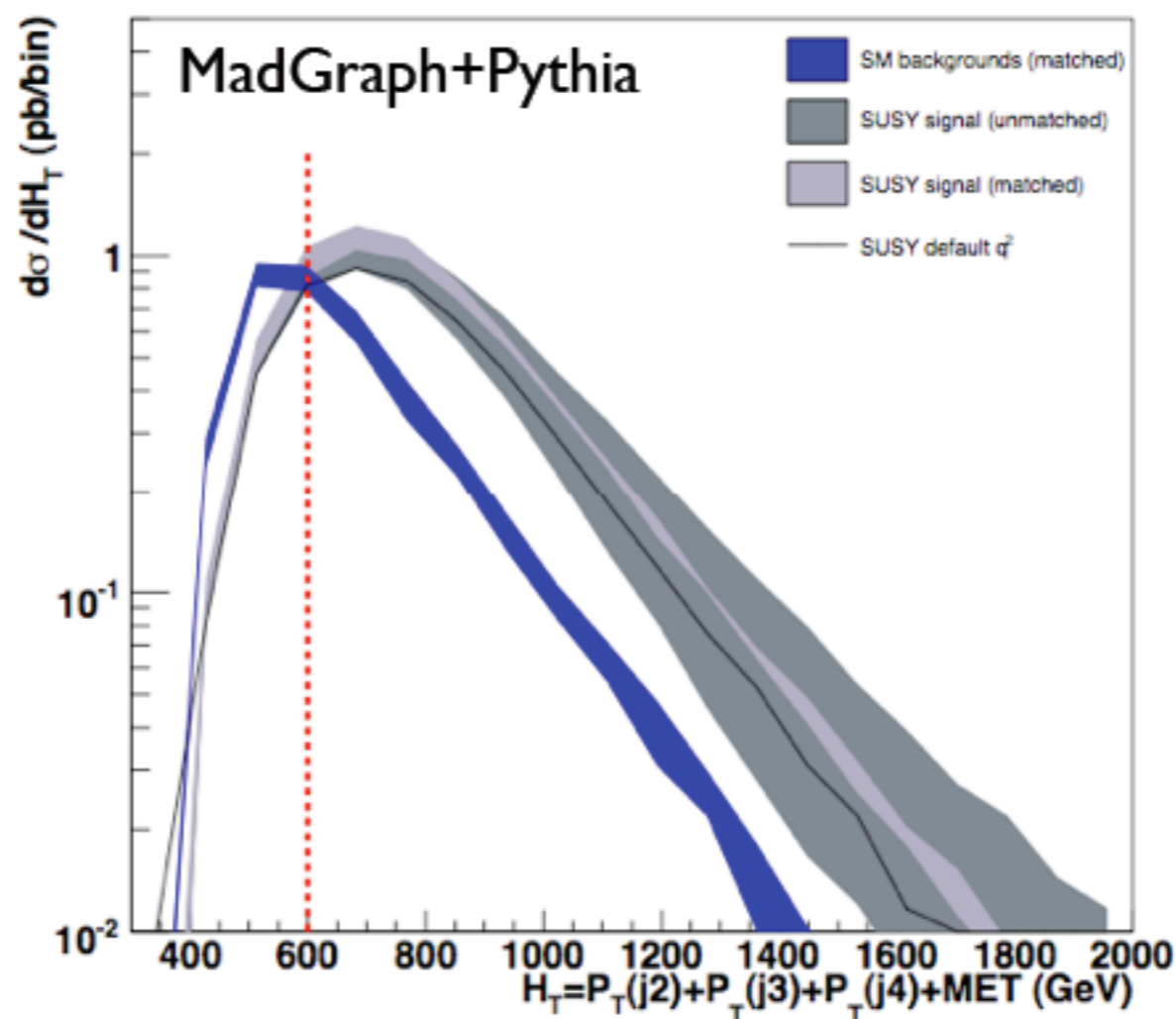
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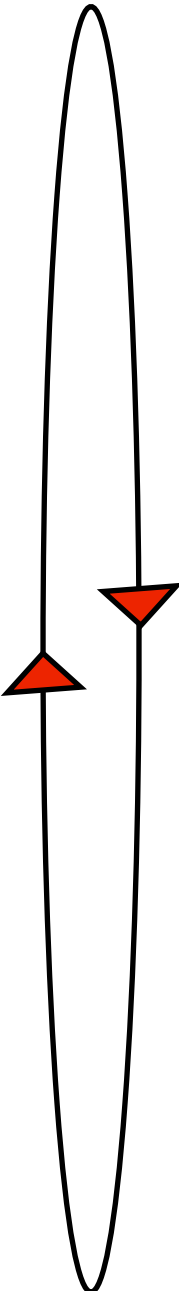
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**Texte:** signal matched ME+PS. Predictability improved. Same theoretical status as the background.

# The path towards discoveries

$$\text{LHC physics} = \text{QCD} + \epsilon$$



1. Rediscover the known SM at the LHC (top's, W's, Z's) + jets.

New regime for QCD. Exclusive **description** for rich and energetic final states with flexible MC to be validated and tuned to control samples. Shapes for multi-jet final states and normalization for key process important. Accurate **predictions** (NLO, NNLO) needed only for standard candle cross sections.

2. Identify excess(es) over SM

Importance of a good theoretical description depends on the nature of the physics discovered: from none (resonances) to fundamental (inclusive SUSY).

3. Identify the nature of BSM:  
from coarse information to  
measurements of mass spectrum,  
quantum numbers, couplings.

Not fully worked out strategy: **ROOM FOR IMPROVEMENT!** Only in the final phase accurate QCD predictions and MC tools for SM as well as for the BSM signals will be needed.

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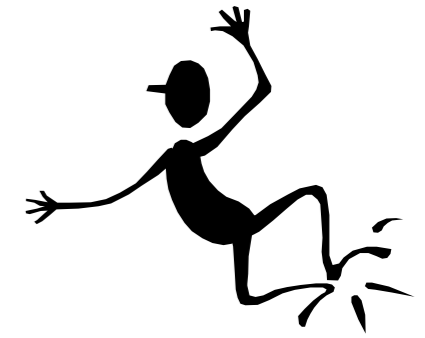
# Standard Model



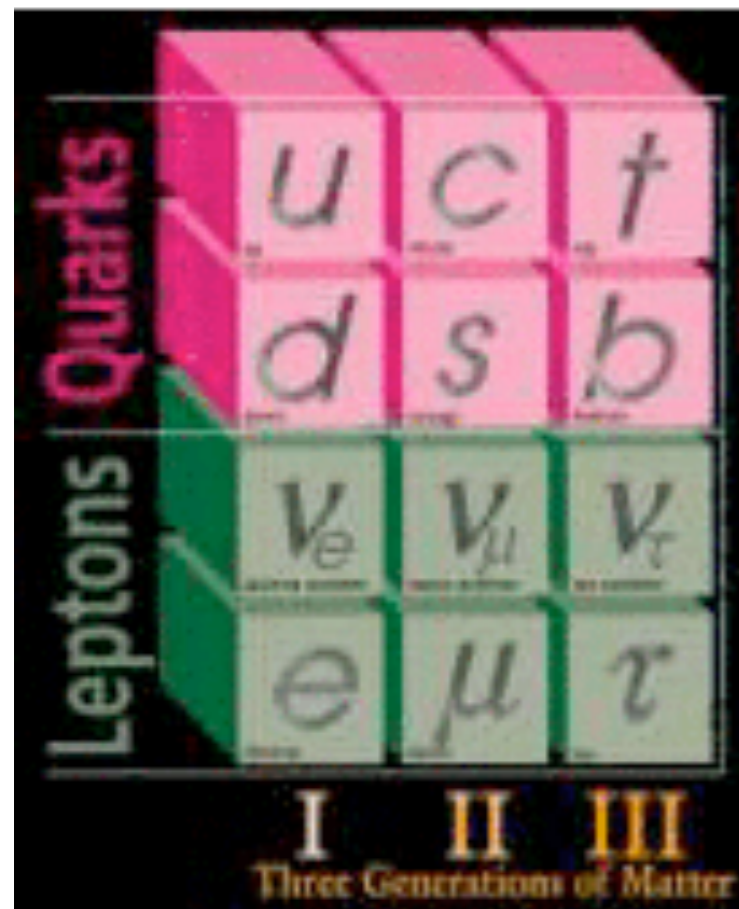
- **Good News!  $SU(3) \times SU_L(2) \times U(1)$** 
  - Most successful theory in physics!
  - Tested over 30 orders of magnitude!
    - (photon mass  $< 10^{-18}$  eV , Tevatron  $> 10^{12}$  eV)



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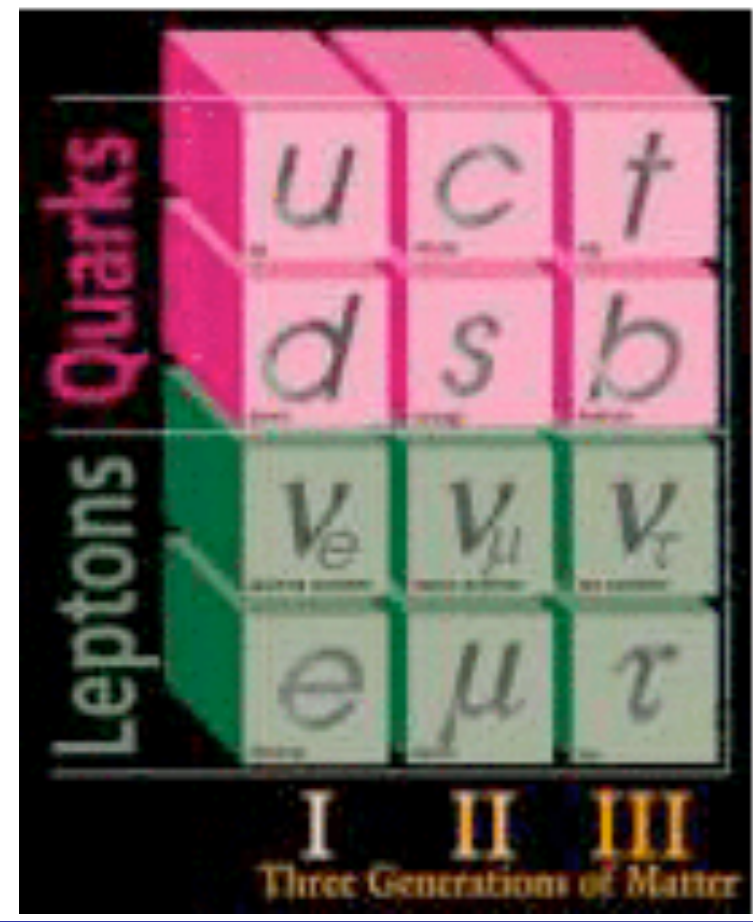


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Quarks		Leptons		Bosons
up	down	electron	neutrino e	photon
charm	strange	muon	neutrino μ	gluon
top	beauty	tau	neutrino τ	Z <sup>0</sup> W <sup>±</sup>
				Higgs

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$$\mathbf{W}_{\mu\nu} \equiv \frac{i}{g} [\mathbf{D}_\mu, \mathbf{D}_\nu] \equiv \frac{\vec{\sigma}}{2} \cdot \vec{W}_{\mu\nu} \rightarrow \mathbf{U}_L \mathbf{W}_{\mu\nu} \mathbf{U}_L^\dagger \quad ; \quad B_{\mu\nu} \equiv \partial_\mu B_\nu - \partial_\nu B_\mu \rightarrow B_{\mu\nu}$$

$$W_{\mu\nu}^i = \partial_\mu W_\nu^i - \partial_\nu W_\mu^i + g \varepsilon^{ijk} W_\mu^j W_\nu^k$$

$$\mathcal{L}_K = -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{2} \text{Tr}(\mathbf{W}_{\mu\nu} \mathbf{W}^{\mu\nu}) = -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} \vec{W}_{\mu\nu} \vec{W}^{\mu\nu} = \mathcal{L}_{\text{kin}} + \mathcal{L}_3 + \mathcal{L}_4$$

$$\begin{aligned} \mathcal{L}_3 &= -ie \cot \theta_w \left\{ (\partial^\mu W^\nu - \partial^\nu W^\mu) W_\mu^\dagger Z_\nu - (\partial^\mu W^{\nu\dagger} - \partial^\nu W^{\mu\dagger}) W_\mu Z_\nu + W_\mu W_\nu^\dagger (\partial^\mu Z^\nu - \partial^\nu Z^\mu) \right\} \\ &- ie \left\{ (\partial^\mu W^\nu - \partial^\nu W^\mu) W_\mu^\dagger A_\nu - (\partial^\mu W^{\nu\dagger} - \partial^\nu W^{\mu\dagger}) W_\mu A_\nu + W_\mu W_\nu^\dagger (\partial^\mu A^\nu - \partial^\nu A^\mu) \right\} \end{aligned}$$

$$\begin{aligned} \mathcal{L}_4 &= -\frac{e^2}{2 \sin^2 \theta_w} \left\{ (W_\mu^\dagger W^\mu)^2 - W_\mu^\dagger W^{\mu\dagger} W_\nu W^\nu \right\} - e^2 \cot^2 \theta_w \left\{ W_\mu^\dagger W^\mu Z_\nu Z^\nu - W_\mu^\dagger Z^\mu W_\nu Z^\nu \right\} \\ &- e^2 \cot \theta_w \left\{ 2 W_\mu^\dagger W^\mu Z_\nu A^\nu - W_\mu^\dagger Z^\mu W_\nu A^\nu - W_\mu^\dagger A^\mu W_\nu Z^\nu \right\} - e^2 \left\{ W_\mu^\dagger W^\mu A_\nu A^\nu - W_\mu^\dagger A^\mu W_\nu A^\nu \right\} \end{aligned}$$

# Predictions from SM



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- Cross Section:

$$\sigma = \frac{1}{2s} \int |M|^2 d\Phi$$

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$$M \approx \left\langle \mu^+ \mu^- \left| H_{\text{int}} \right| e^+ e^- \right\rangle + \frac{1}{2} \left\langle \mu^+ \mu^- \left| H_{\text{int}}^2 \right| e^+ e^- \right\rangle + \dots$$



## Example: $e^+e^- \rightarrow \mu^+\mu^-$

- Scattering cross section

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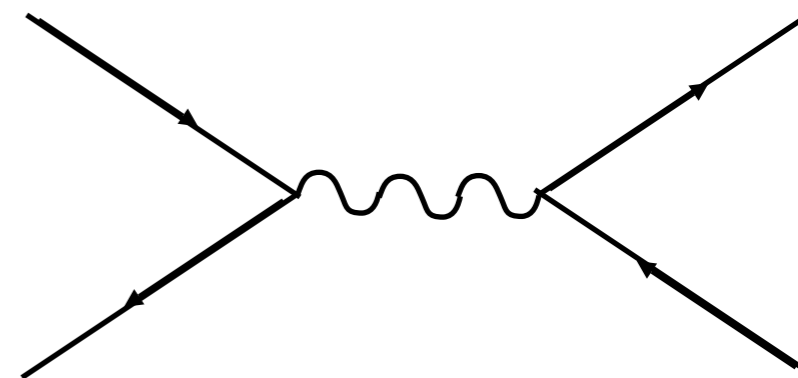
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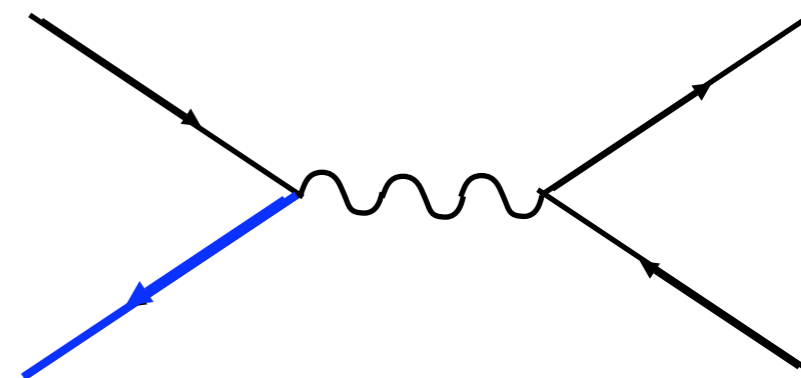
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$$M \approx \bar{v}(e^+)$$

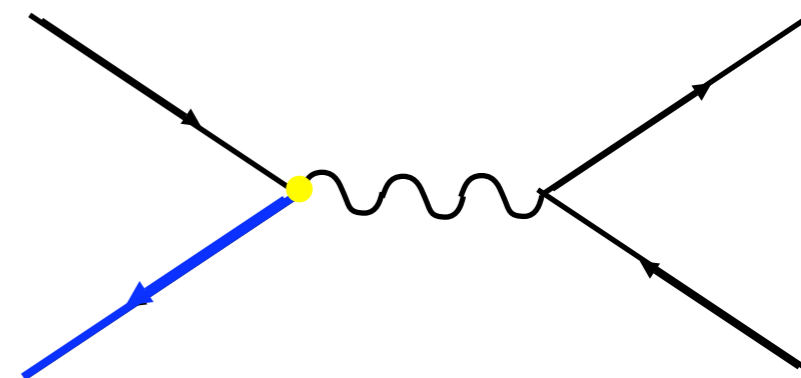
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$$M \approx \bar{v}(e^+) (-iq\gamma^\mu)$$

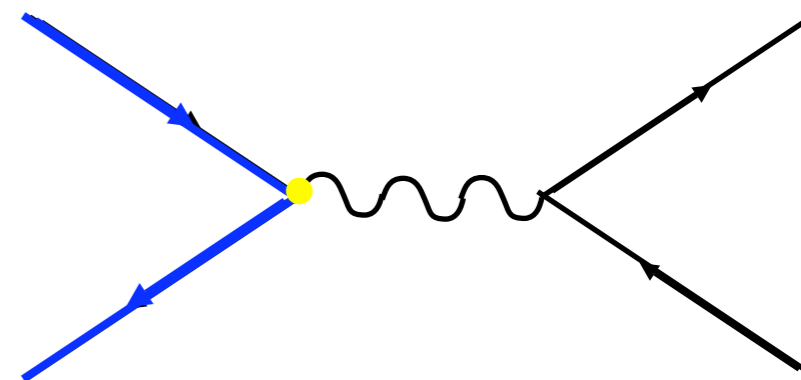
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$$M \approx \bar{v}(e^+) (-iq\gamma^\mu) v(e^-)$$

## Example: $e^+e^- \rightarrow \mu^+\mu^-$

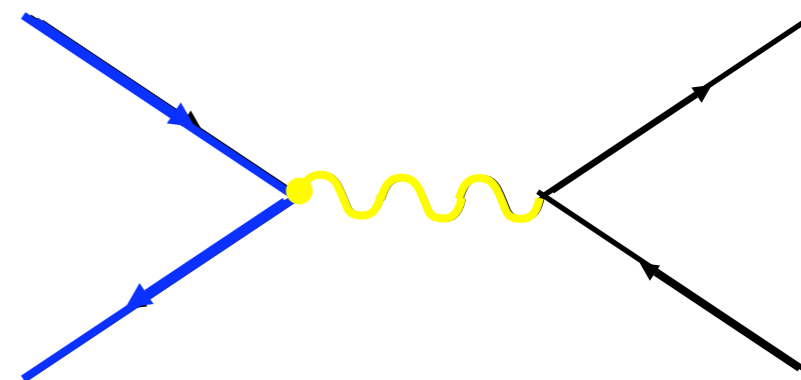
- Scattering cross section

$$\sigma = \frac{1}{2s} \int |M|^2 d\Phi$$

$$M \approx \langle \mu^+ \mu^- | H_{\text{int}} | e^+ e^- \rangle + \dots$$

- Feynman Diagrams

$$M \approx \bar{v}(e^+) (-iq\gamma^\mu) v(e^-) \frac{-ig_{\mu\nu}}{p^2}$$





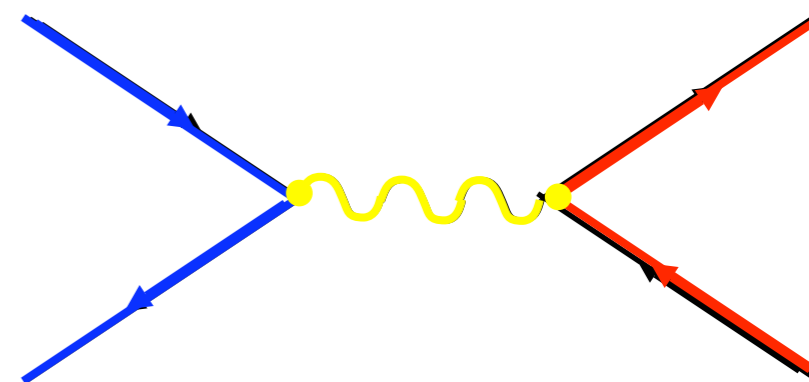
## Example: $e^+e^- \rightarrow \mu^+\mu^-$

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- Feynman Diagrams



$$M \approx \bar{v}(e^+) (-iq\gamma^\mu) v(e^-) \frac{-ig_{\mu\nu}}{p^2} \bar{u}(\mu^+) (-iq\gamma^\nu) u(\mu^-)$$

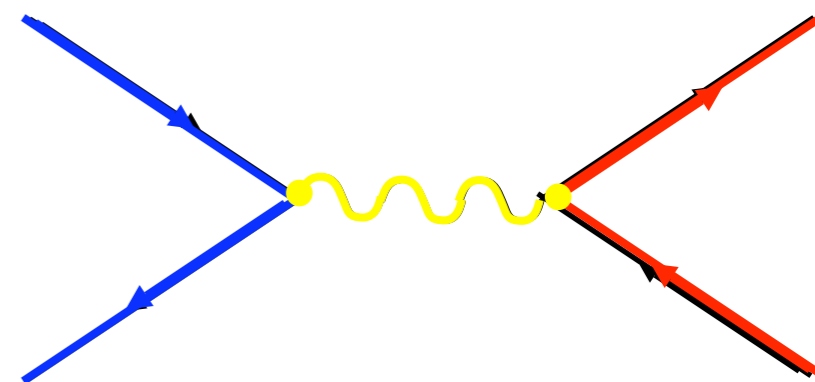
## Example: $e^+e^- \rightarrow \mu^+\mu^-$

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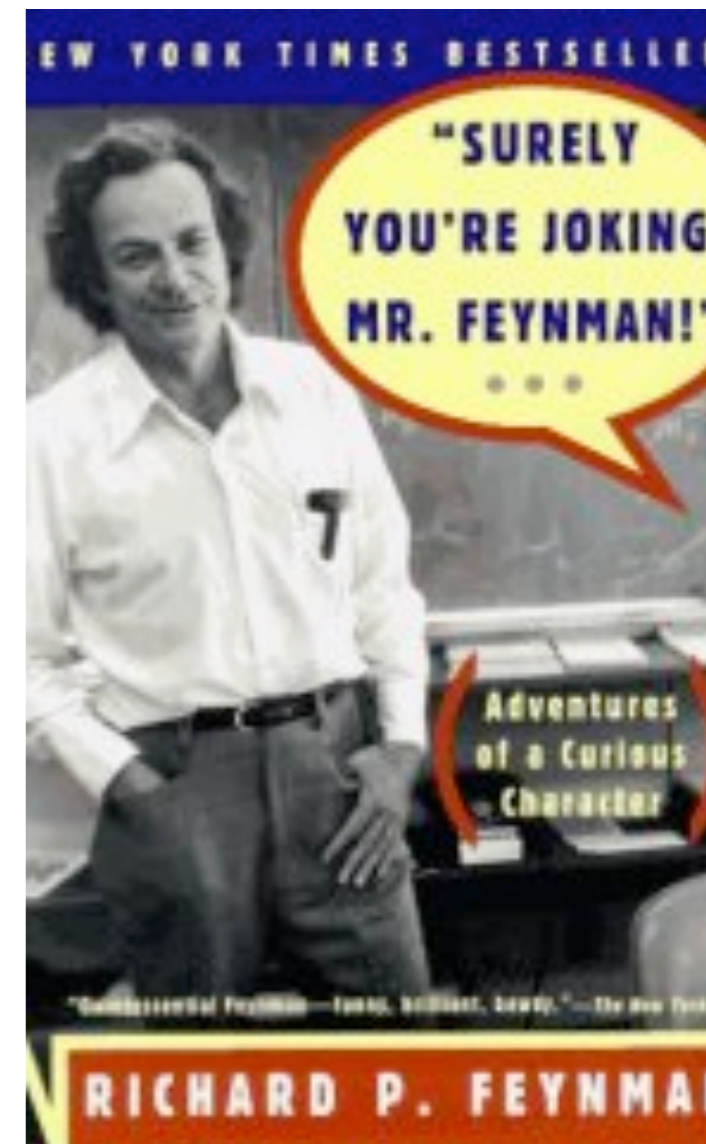
- Feynman Diagrams



$$M \approx \bar{v}(e^+) (-iq\gamma^\mu) v(e^-) \frac{-ig_{\mu\nu}}{p^2} \bar{u}(\mu^+) (-iq\gamma^\nu) u(\mu^-)$$

# Feynman Rules!

$\gamma$ 	<b>QED</b>	 $q\bar{q}\gamma \quad l^-l^+\gamma$	 $W^+W^-\gamma$	
$Z$ 	<b>QED</b>	 $q\bar{q}Z \quad l\bar{l}Z$	 $W^+W^-Z$	
$W^{+-}$ 	<b>QED</b>	 $q\bar{q}'W \quad l\nu W$		 $WWWW$
$g$ 	<b>QCD</b>	 $q\bar{q}g$	 $ggg$	 $gggg$
$h$ 	<b>QED</b> <b>(m)</b>	 $q\bar{q}h \quad l\bar{l}h$	 $W^+W^-h$	 $ZZh$



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# Feynman Rules!

- These are basic building blocks, combine to form “allowed” diagrams

– e.g.  $u u \sim \rightarrow t t \sim$

$\gamma$	<b>QED</b>	 $q\bar{q}\gamma$ $l^-l^+\gamma$	 $W^+W^-\gamma$	
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$Z$	<b>QED</b>	 $q\bar{q}Z$ $l^-l^+Z$	 $W^+W^-Z$	
$W$	<b>QED</b>	 $q\bar{q}'W$ $l\nu W$		 $WWWW$
$g$	<b>QCD</b>	 $q\bar{q}g$	 $ggg$	 $gggg$
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$g$	<b>QCD</b>	 $q\bar{q}g$	 $ggg$	 $gggg$
$h$	<b>QED</b> <b>(m)</b>	 $q\bar{q}h$ $l\bar{l}h$	 $W^+W^-h$	 $ZZh$



# Feynman Rules!

- These are basic building blocks, combine to form “allowed” diagrams

– e.g.  $u u \sim \rightarrow t t \sim$

- Draw Feynman diagrams:

–  $gg \rightarrow tt$

–  $gg \rightarrow tth$

$\gamma \sim$	<b>QED</b>	 $q\bar{q}\gamma \quad l\bar{l}\gamma$	 $W^+W^-\gamma$	
$Z \sim$	<b>QED</b>	 $q\bar{q}Z \quad l\bar{l}Z$	 $W^+W^-Z$	
$W \sim$	<b>QED</b>	 $q\bar{q}'W \quad l\nu W$		 $WWWW$
$g \sim$	<b>QCD</b>	 $q\bar{q}g$	 $ggg$	 $gggg$
$h \dots$	<b>QED (m)</b>	 $q\bar{q}h \quad l\bar{l}h$	 $W^+W^-h$	 $ZZh$

# Feynman Rules!

- These are basic building blocks, combine to form “allowed” diagrams










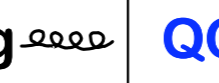
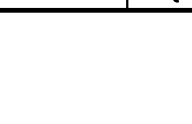


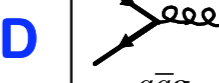
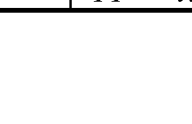


– e.g.  $u u \sim \rightarrow t t \sim$

- Draw Feynman diagrams:

–  $gg \rightarrow tt$

–  $gg \rightarrow tth$

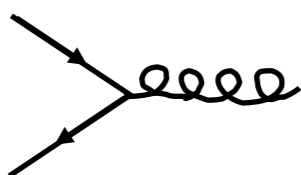
- Determine “order” for each diagram

$\gamma$ 	<b>QED</b>	 $q\bar{q}\gamma$ $l^-l^+\gamma$	 $W^+W^-\gamma$	
$Z$ 	<b>QED</b>	 $q\bar{q}Z$ $l^-l^+Z$	 $W^+W^-Z$	
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# Feynman Rules!

- These are basic building blocks, combine to form “allowed” diagrams

– e.g.  $u u \sim \rightarrow t t \sim$



- Draw Feynman diagrams:

–  $gg \rightarrow tt$

–  $gg \rightarrow tth$

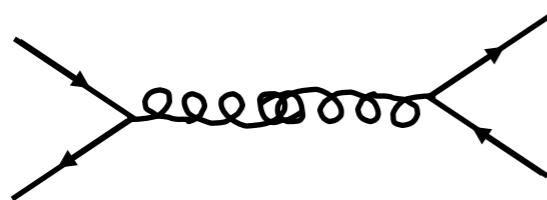
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$g$	<b>QCD</b>	$q\bar{q}g$	$ggg$	$gggg$
$h$	<b>QED</b> <b>(m)</b>	$q\bar{q}h$ $l^+l^-h$	$W^+W^-h$	$ZZh$

# Feynman Rules!

- These are basic building blocks, combine to form “allowed” diagrams

– e.g.  $u u \sim \rightarrow t t \sim$



- Draw Feynman diagrams:

–  $gg \rightarrow tt$

–  $gg \rightarrow tth$

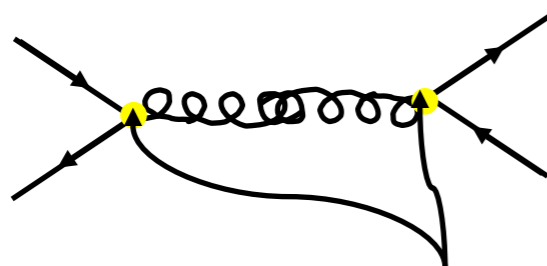
- Determine “order” for each diagram

$\gamma \sim$	QED			
$Z \sim$	QED			
$W \sim$	QED			
$g \sim$	QCD			
$h \dots$	QED (m)			

# Feynman Rules!

- These are basic building blocks, combine to form “allowed” diagrams

– e.g.  $u u \sim \rightarrow t t \sim$



Order is  $\text{QCD}^2$

- Draw Feynman diagrams:

–  $gg \rightarrow tt$

–  $gg \rightarrow tth$

- Determine “order” for each diagram

$\gamma \sim$	QED			
$Z \sim$	QED			
$W \sim$	QED			
$g \sim$	QCD			
$h \dots$	QED (m)			

# MadGraph on the Web



This material is based upon work supported by the National Science Foundation under Grant No. 0426272.  
Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation

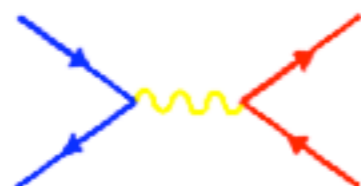
<http://madgraph.hep.uiuc.edu/>



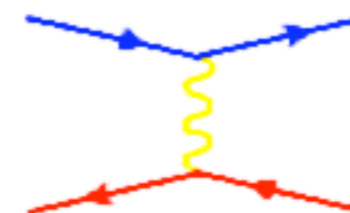
<http://madgraph.phys.ucl.ac.be/>



<http://madgraph.roma2.infn.it/>



[MadGraph](#) Version 4  
UCL UIUC Fermi  
by the [MG/ME Development team](#)



[Generate Process](#)

[Register](#)

[Tools](#)

[My Database](#)

[Cluster Status](#)

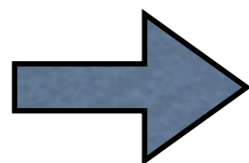
[Downloads](#)  
(needs [registration](#))

[Wiki/Docs](#)

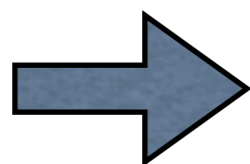
[Admin](#)

Three medium size clusters public access (+private clusters). ~1500 registered users.

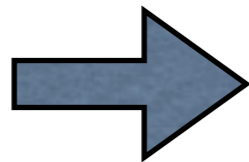
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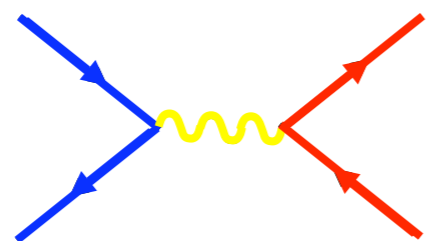
Movie 1



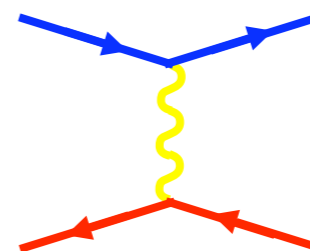
Movie 2



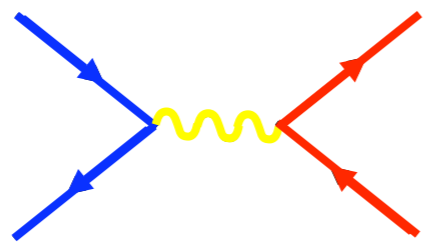
<http://madgraph.uiuc.edu>



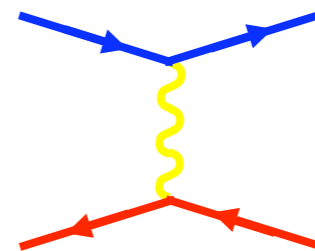
# MadGraph





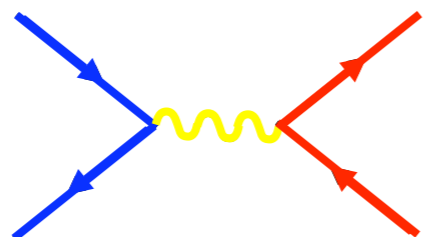


# MadGraph

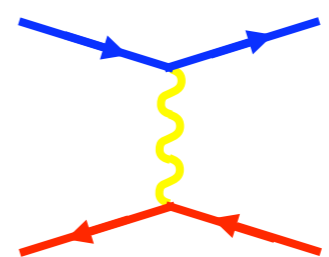


- User Requests:



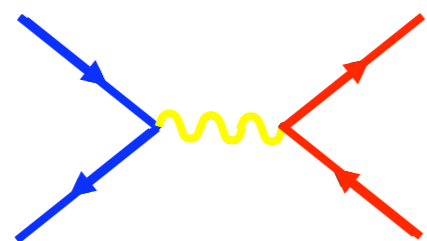


MadGraph

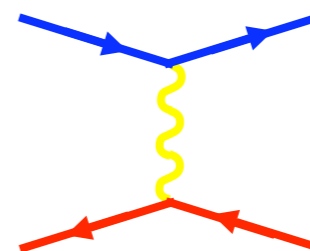


- User Requests:
  - $gg \rightarrow tt\sim bb\sim$



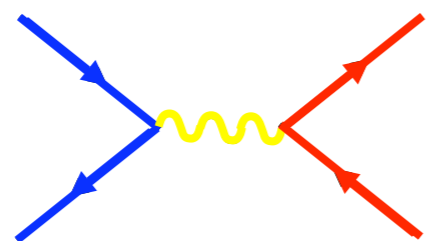


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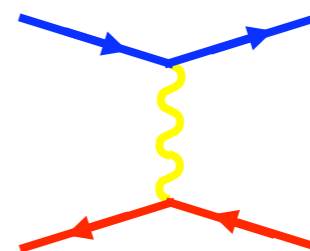


- User Requests:
  - $gg > tt\bar{b}b\bar{b}$
  - QCD Order = 4





# MadGraph



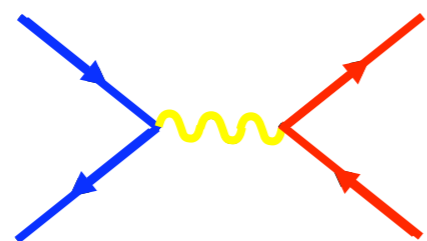
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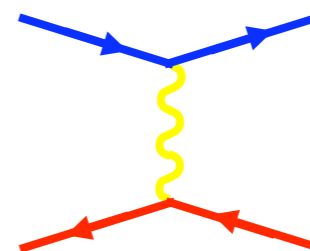
- QCD Order = 4

- QED Order = 0





# MadGraph



- User Requests:

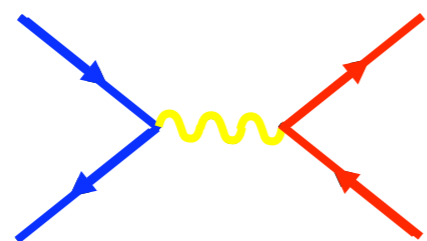
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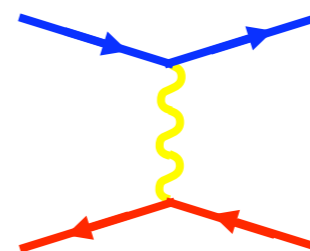
- QED Order = 0

- MadGraph Returns:



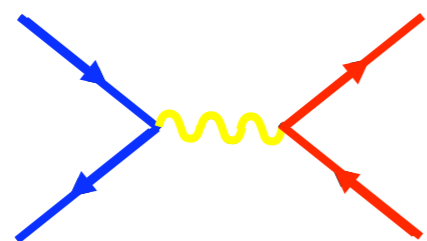


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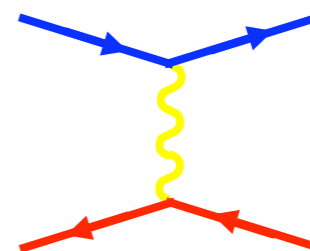


- User Requests:
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  - QCD Order = 4
  - QED Order = 0
- MadGraph Returns:
  - Feynman diagrams





# MadGraph



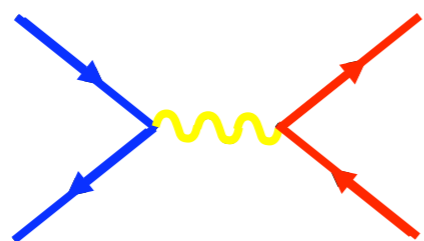
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- QCD Order = 4
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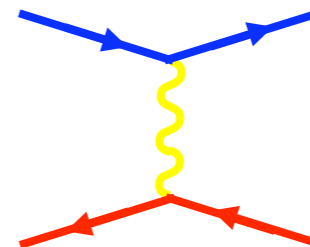


- MadGraph Returns:

- Feynman diagrams
- Self-Contained Fortran Code for  $|M|^2$



# MadGraph



- User Requests:

- $gg \rightarrow tt\bar{b}b\bar{b}$

- QCD Order = 4

- QED Order = 0

- MadGraph Returns:

- Feynman diagrams

- Self-Contained Fortran Code for  $|M|^2$

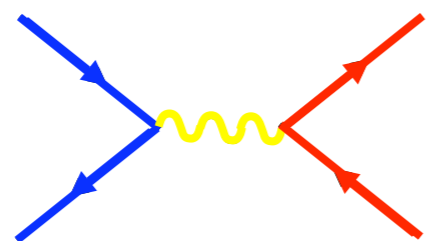
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SUBROUTINE SMATRIX(PI,ANS)
C
C Generated by MadGraph II Version 3.83. Updated 06/13/05
C RETURNS AMPLITUDE SQUARED SUMMED/AVG OVER COLORS
C AND HELICITIES
C FOR THE POINT IN PHASE SPACE P(0:3,NEXTERNAL)
C
C FOR PROCESS : g g -> t t~ b b~
C
C Crossing 1 is g g -> t t~ b b~
C      IMPLICIT NONE
C
C CONSTANTS
C
C   Include "genps.inc"
C   INTEGER          NCOMB,  NCROSS
C   PARAMETER (      NCOMB= 64, NCROSS= 1)
C   INTEGER  THEL
C   PARAMETER (THEL=NCOMB*NCROSS)
C
C ARGUMENTS
C
C   REAL*8 PI(0:3,NEXTERNAL),ANS(NCROSS)
C
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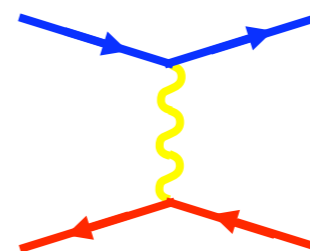
# Exercises

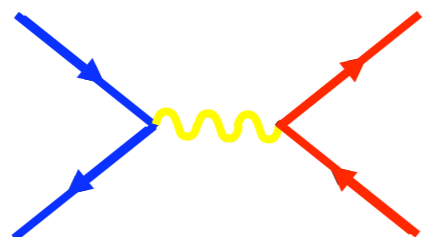


- List processes for signal  $pp \rightarrow h \rightarrow tt\sim bb\sim$ 
  - e.g.  $uu\sim \rightarrow h \rightarrow tt\sim bb\sim$
- List process for background  $pp \rightarrow ttbb$ 
  - e.g.  $uu\sim \rightarrow tt\sim bb\sim$
- List process for reducible background  $pp \rightarrow ttjj$ 
  - e.g.  $uu\sim \rightarrow tt\sim gg$

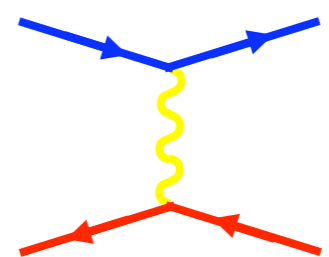


# MadGraph



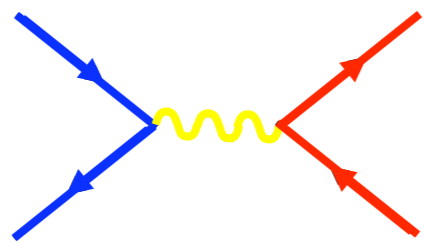


# MadGraph

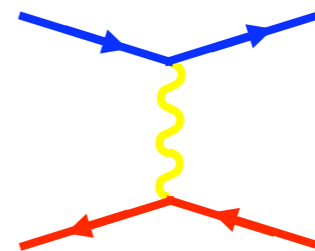


- User Requests:



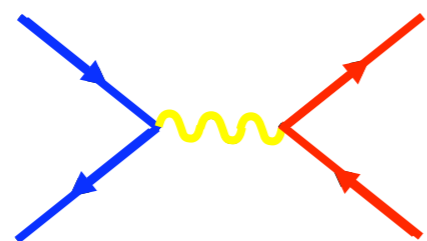


# MadGraph

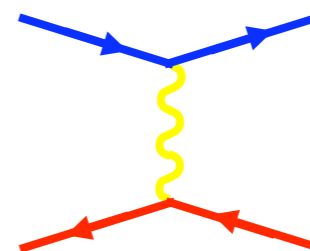


- User Requests:  
-pp -> bb~tt~



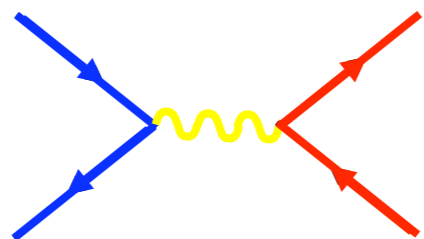


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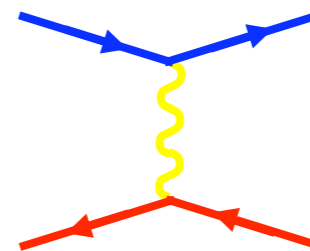


- User Requests:
  - pp -> bb~tt~
  - QCD Order = 4





# MadGraph



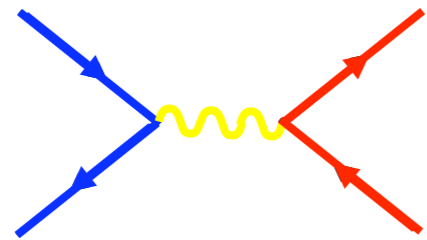
- User Requests:

- pp -> bb~tt~

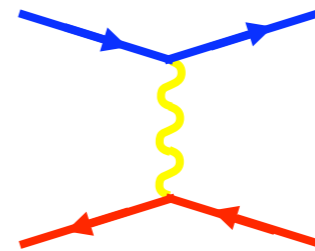
- QCD Order = 4

- QED Order = 0





# MadGraph



- User Requests:

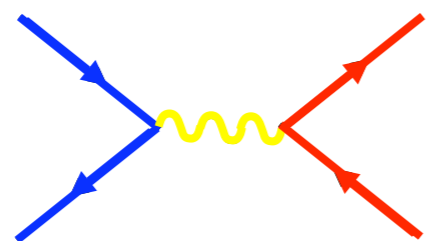
- pp -> bb~tt~

- QCD Order = 4

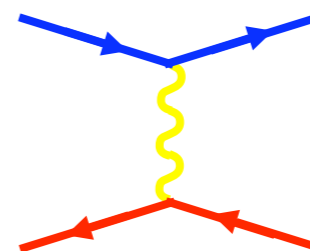
- QED Order = 0

- MadGraph Returns:





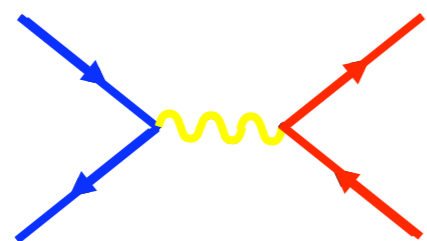
# MadGraph



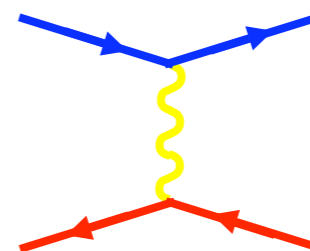
- User Requests:
  - $pp \rightarrow b\bar{b}t\bar{t}$
  - QCD Order = 4
  - QED Order = 0
- MadGraph Returns:
  - Feynman diagrams





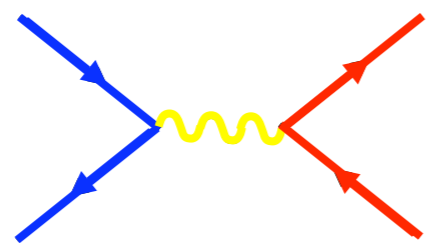


# MadGraph

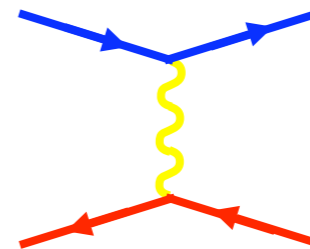


- User Requests:
  - $pp \rightarrow b\bar{b}t\bar{t}$
  - QCD Order = 4
  - QED Order = 0
- MadGraph Returns:
  - Feynman diagrams
  - Fortran Code for  $|M|^2$





# MadGraph



- User Requests:

- $pp \rightarrow b\bar{b}t\bar{t}$

- QCD Order = 4

- QED Order = 0

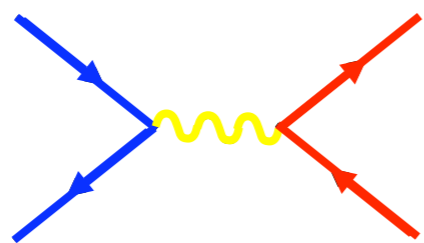
- MadGraph Returns:

- Feynman diagrams

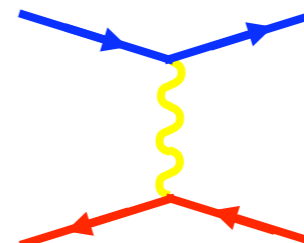
- Fortran Code for  $|M|^2$

- Summed over all sub processes w/ pdf





# MadGraph



- User Requests:

- pp -> bb~tt~
- QCD Order = 4
- QED Order = 0

- MadGraph Returns:

- Feynman diagrams
- Fortran Code for  $|M|^2$
- Summed over all sub processes w/ pdf

```

DOUBLE PRECISION FUNCTION DSIG(PP,WGT)
C *****
C Generated by MadGraph II Version 3.83. Updated 06/13/05
C RETURNS DIFFERENTIAL CROSS SECTION
C Input:
C pp 4 momentum of external particles
C wgt weight from Monte Carlo
C Output:
C Amplitude squared and summed
C *****

```

```

-----
IPROC=IPROC+1 ! u u~ -> t t~ b b~
PD(IPROC)=PD(IPROC-1) + u1 * ub2
IPROC=IPROC+1 ! d d~ -> t t~ b b~
PD(IPROC)=PD(IPROC-1) + d1 * db2
IPROC=IPROC+1 ! s s~ -> t t~ b b~
PD(IPROC)=PD(IPROC-1) + s1 * sb2
IPROC=IPROC+1 ! c c~ -> t t~ b b~
PD(IPROC)=PD(IPROC-1) + c1 * cb2
CALL SMATRIX(PP,DSIGUU)

```

```

dsig = pd(iproc)*conv*dsiguu

```



# How do I generate the diagrams?

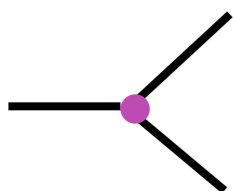


# How do I generate the diagrams?

## I. Generate the topologies

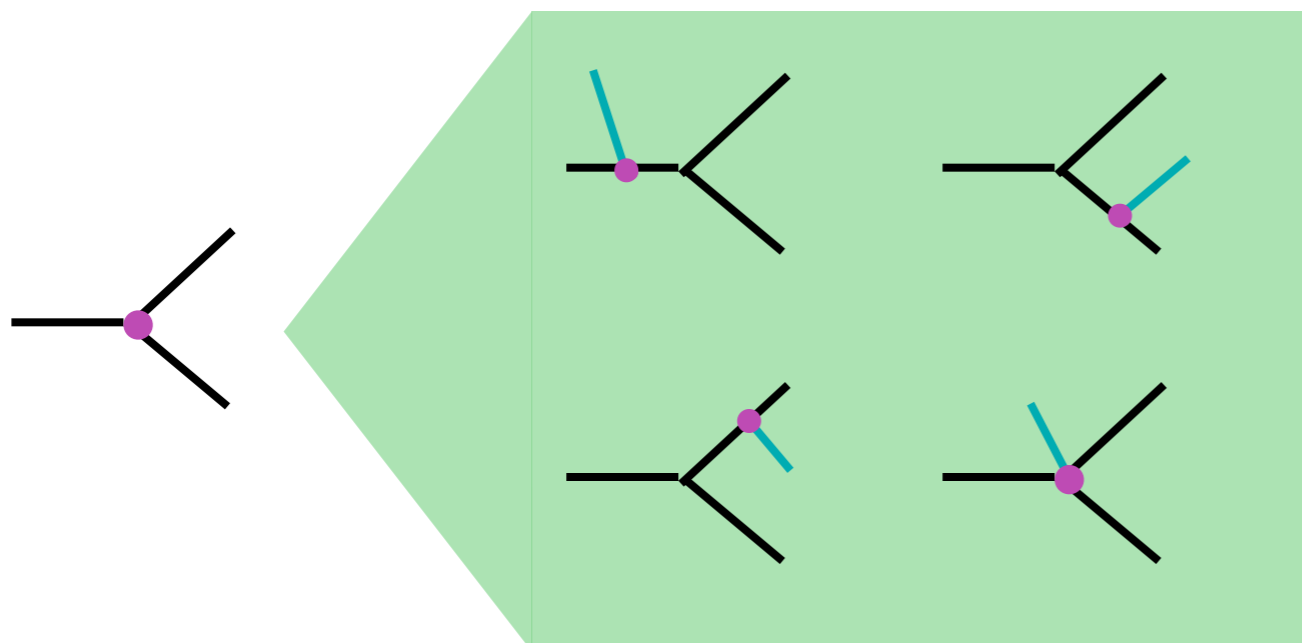
# How do I generate the diagrams?

## I. Generate the topologies



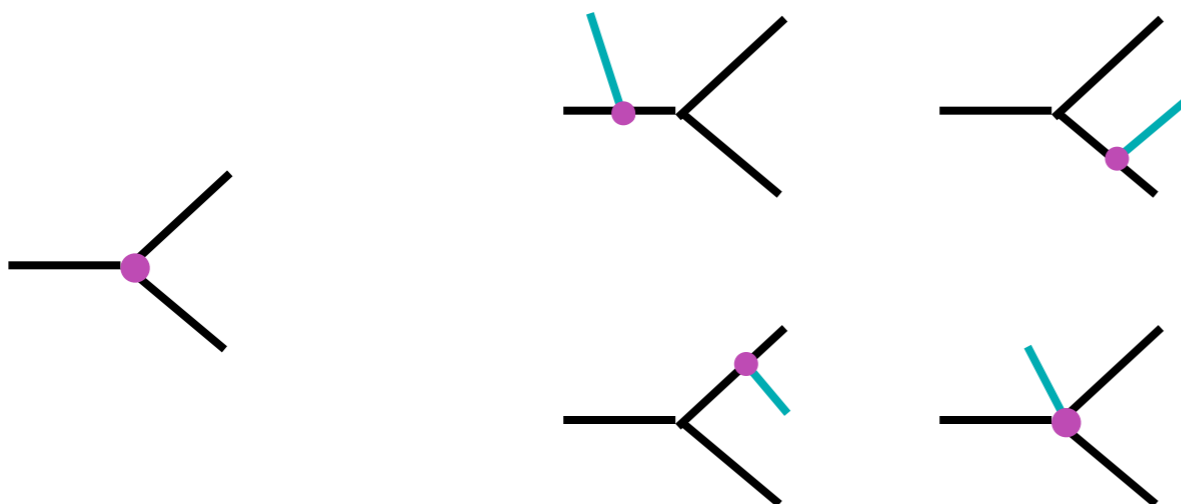
# How do I generate the diagrams?

## I. Generate the topologies



# How do I generate the diagrams?

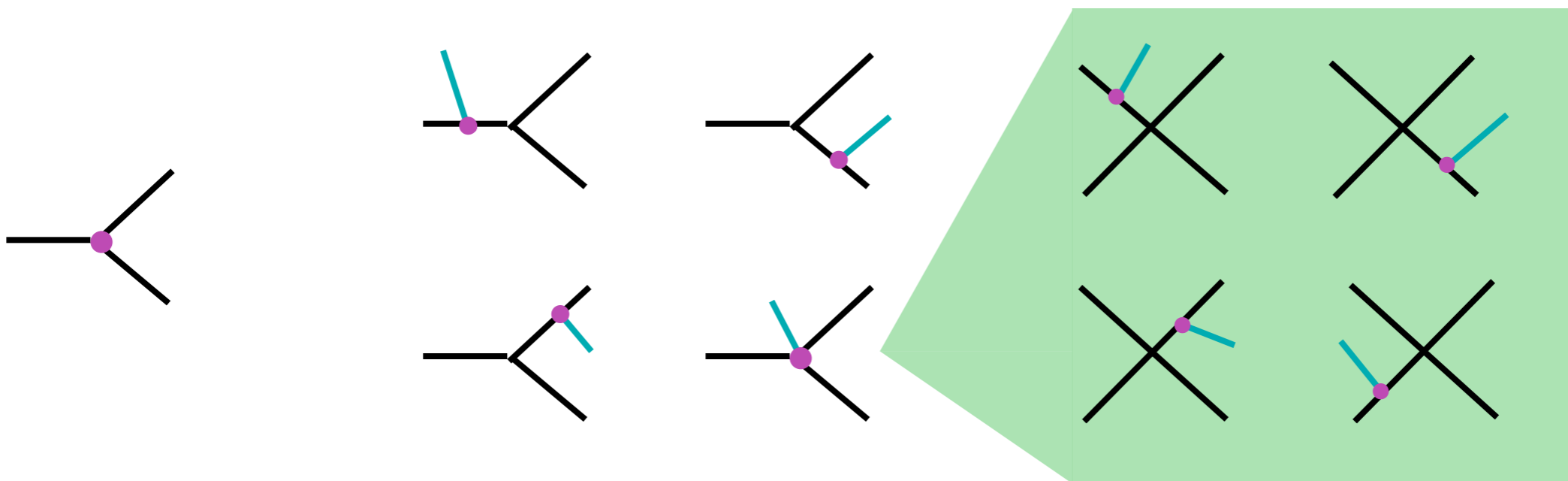
## I. Generate the topologies





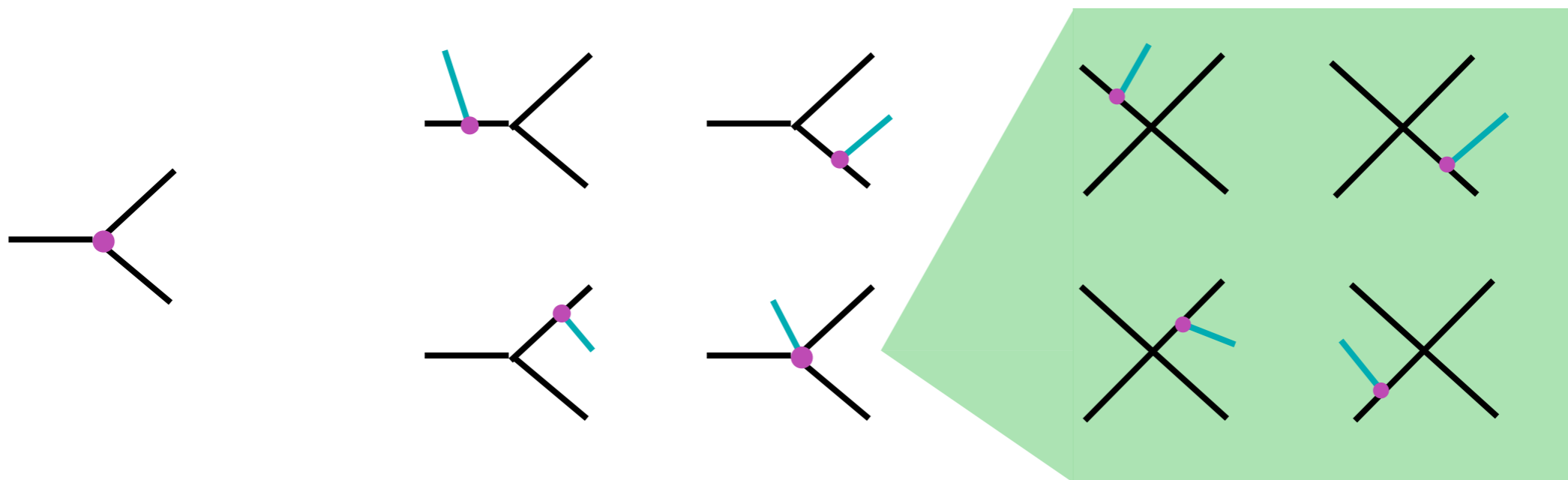
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## I. Generate the topologies



## How do I generate the diagrams?

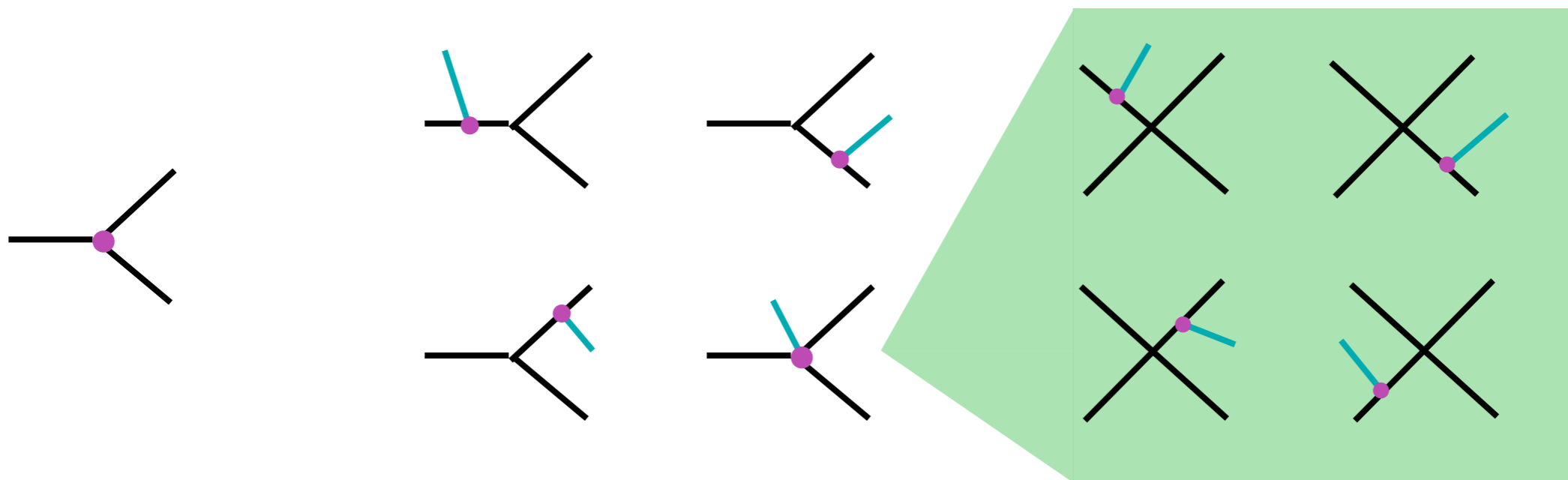
### 1. Generate the topologies



2. Dress the topologies with particles starting from the external particles and checking the existence of the corresponding vertices.

## How do I generate the diagrams?

### 1. Generate the topologies

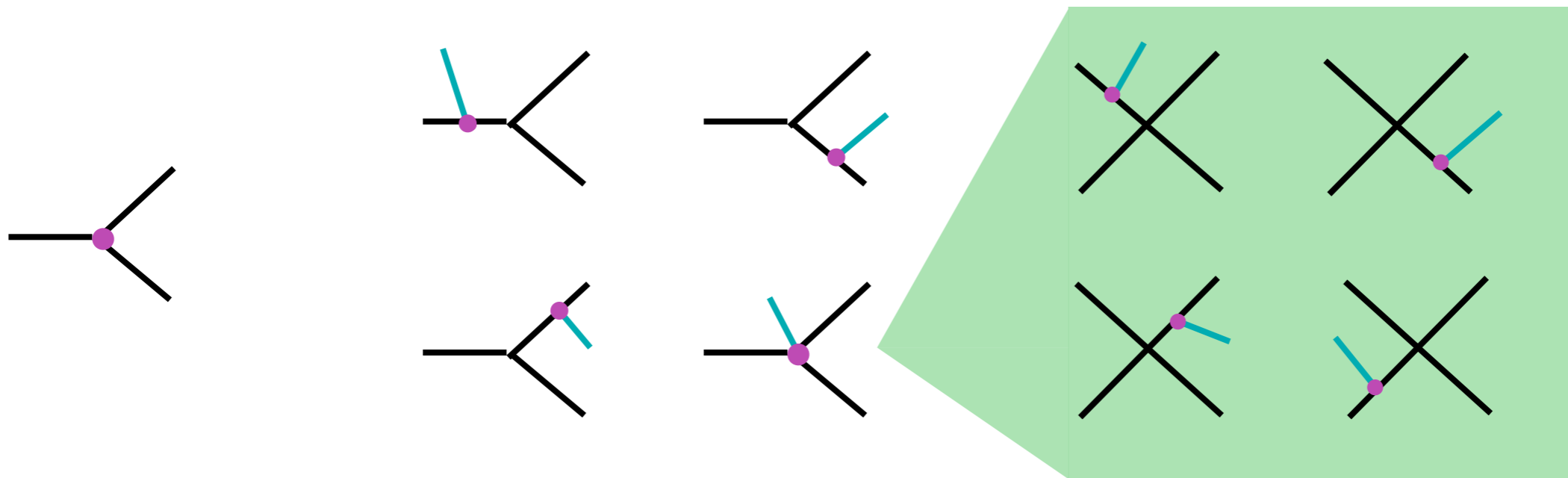


2. Dress the topologies with particles starting from the external particles and checking the existence of the corresponding vertices.

3. Write out a code based on the HELAS library.

# How do I generate the diagrams?

## 1. Generate the topologies



2. Dress the topologies with particles starting from the external particles and checking the existence of the corresponding vertices.

3. Write out a code based on the HELAS library.

“Only” a book-keeping problem!

# Beware of the factorial growth

n	full Amp	partial Amp	BG
4	4	3	3
5	25	10	10
6	220	36	35
7	2485	133	70
8	34300	501	126
9	559405	1991	210
10	10525900	7335	330
11	224449225	28199	495
12	5348843500	108280	715

$$(2n)!$$

$$3.8^n$$

$$n^4$$

- Complexity of plain vanilla Feynman calculations grows factorially
- “Old techniques” based on calculating simpler gauge invariant objects by a recursive techniques are much more powerful.
- In any case the calculation through partial amplitudes is not as efficient as the direct calculation of the full amplitude at fixed color through numerical recursive relations [ALPGEN, Moretti, Caravaglios, Mangano, Pittau, 1998; HELAC, Draggiotis, Kleiss, Papadopoulos, 1998], which has only an exponential growth.
- New twistor tree-level BCF or CSW, without or with color, relations don't improve on the “old” Berends-Giele recursive relations. [Dinsdale, Wernick, Weinzierl, 2006; Duhr, Hoeche, FM, 2006].



# Models in MadGraph

# Models in MadGraph

Previously:

- Standard Model  
(Higgs & backgrounds)

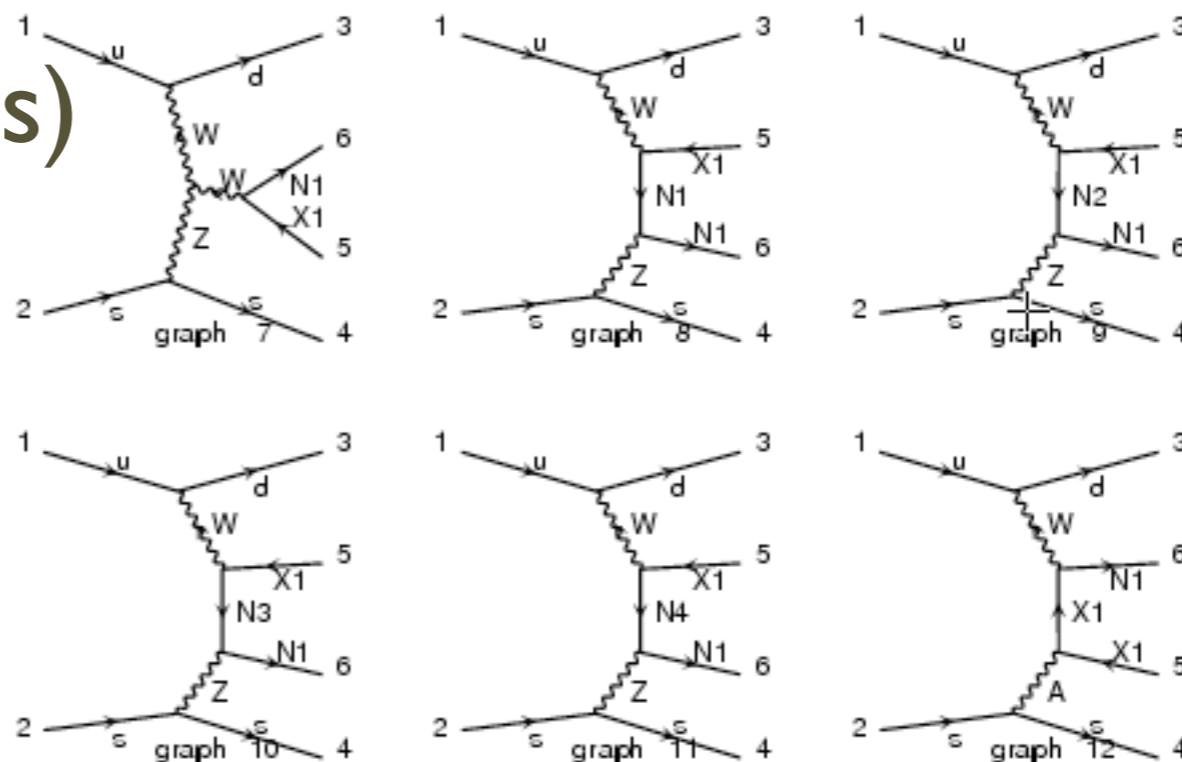
# Models in MadGraph

Previously:

- Standard Model  
(Higgs & backgrounds)

New models:

- MSSM





# Models in MadGraph

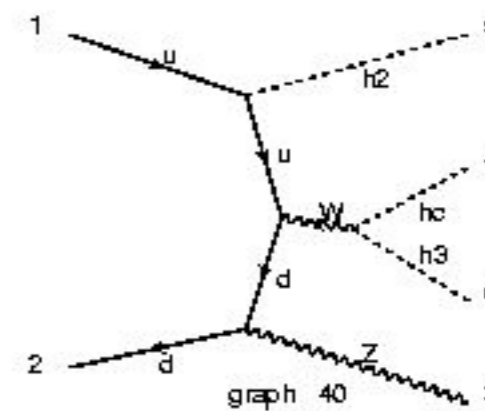
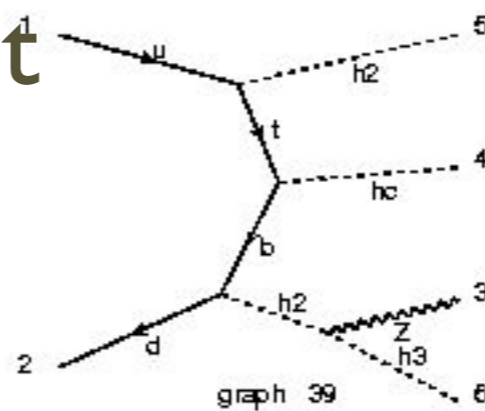
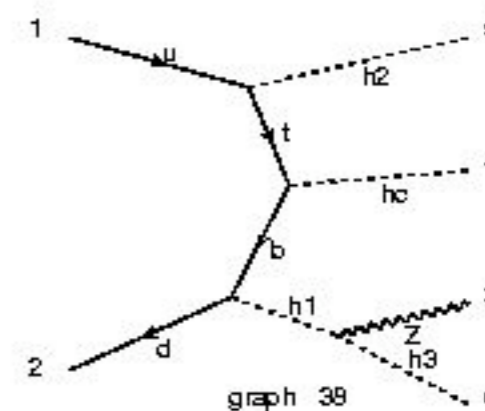
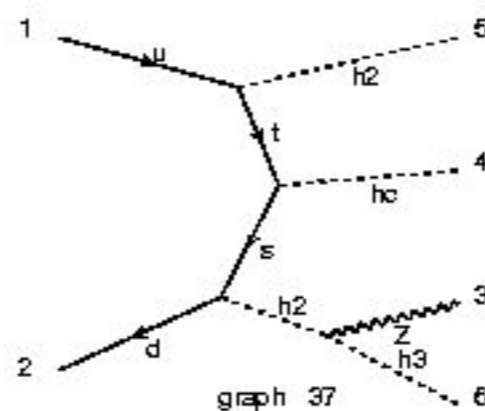
Previously:

- Standard Model  
(Higgs & backgrounds)

New models:

- MSSM

- General 2 Higgs Doublet  
Model (including CPV)



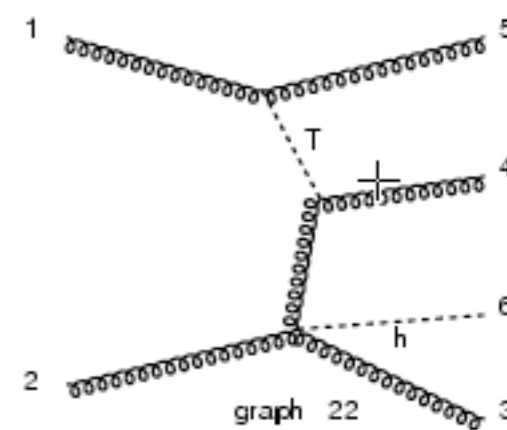
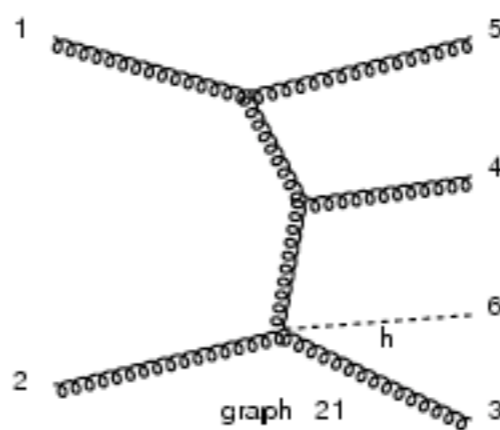
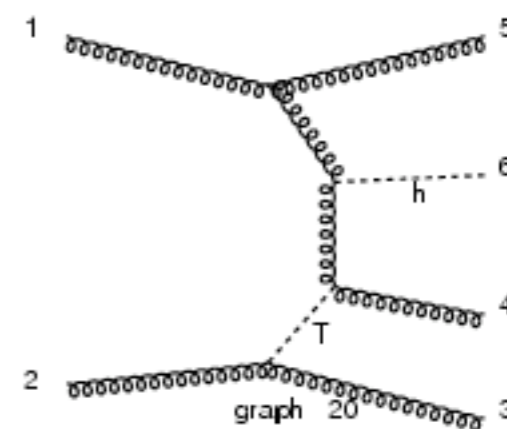
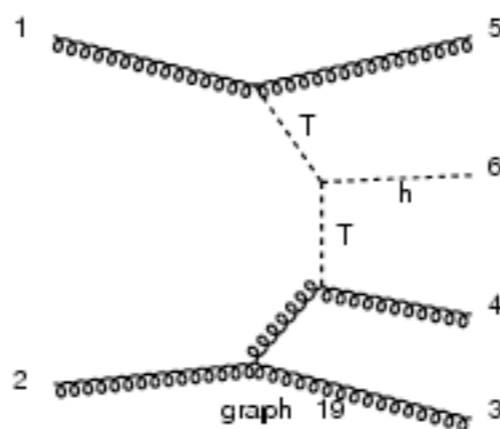
# Models in MadGraph

Previously:

- Standard Model  
(Higgs & backgrounds)

New models:

- MSSM
- General 2 Higgs Doublet Model (including CPV)
- Higgs EFT



# Models in MadGraph

## Previously:

- Standard Model  
(Higgs & backgrounds)

## New models:

- MSSM
- General 2 Higgs Doublet Model (including CPV)
- Higgs EFT
- **General framework for user-defined models**

# Models in MadGraph

Previously:

- Standard Model  
(Higgs & background)

New models:

- MSSM

- General 2 Higgs Doublet Model (including CPV)

- Higgs EFT

- General framework for user-defined models

#Name #xxx	anti_Name xxxx	Spin SFV	Linetype WSDC	Mass str	Width str	Color STO	Label str	Mod PDG
#								
#	Quarks							
#								
d	d~	F	S	ZERO	ZERO	T	d	1
u	u~	F	S	ZERO	ZERO	T	u	2
s	s~	F	S	ZERO	ZERO	T	s	3
c	c~	F	S	ZERO	ZERO	T	c	4
b	b~	F	S	BMASS	ZERO	T	b	5
t	t~	F	S	TMASS	TWIDTH	T	t	6

particles.dat

# Models in MadGraph

Previously:

- Standard Model  
(Higgs & background)

New models:

- MSSM

- General 2 Higgs Dc  
Model (including Cl)

- Higgs EFT

- General framework for user-defined models

```

#Name anti_Name Spin Linetype Mass Width Color Label Mod
#xxx xxxx SFV WSDC str str STO str PDC

#
# Quarks
#
d d~ F S ZERO ZERO T d 1
u u~ F S ZERO ZERO T u 2
s s~ F S ZERO ZERO T s 3
c c~ F S ZERO ZERO T c 4
b b~ F S BMASS ZERO T b 5
t t~ F S TMASS TWIDTH T t 6
  
```

particles.dat

```

#
# QCD interactions
#
d d g GG QCD
u u g GG QCD
s s g GG QCD
c c g GG QCD
b b g GG QCD
t t g GG QCD

g g g G QCD
  
```

interactions.dat