# Preparing for Discovery

*A Bard's-Eye View*

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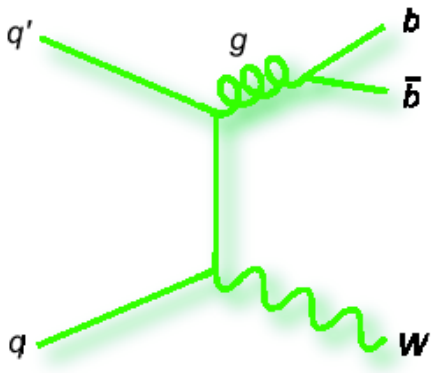
Computing Division
Fermilab

MC4BSM 2006



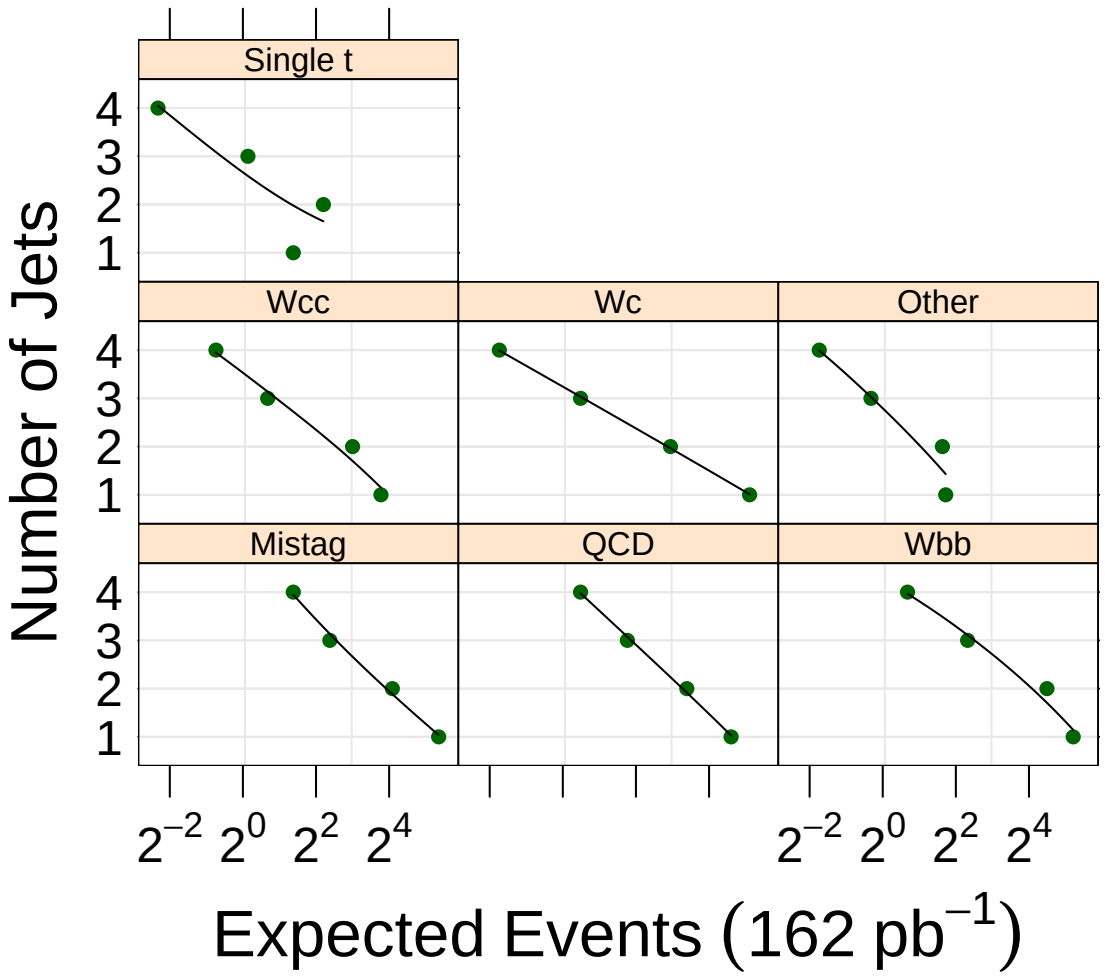
# Shakespeare's Writing Method

- Develop a large vocabulary
- Play with words
- Invent new words and phrases
- Develop the common touch
- Read great literature
- Study the great orators, actors and the popular
- Live with passion
- Write, write, write!!!

# First Steps

- LHC phenomenology begins with rediscovering the Standard Model
- The path starts at the Tevatron

## Top Background Summary




**Complicated**

$t\bar{t}$ contamination in Njets=3,4 (1.0,1,3)

work on Mistags,Wbb,QCD

QCD,Mistags reducible

# Mixing the Cocktail

## Method 2

Monte Carlo ratio
$R = (W + b - jets)/(W + jets)$

- Common factors cancel

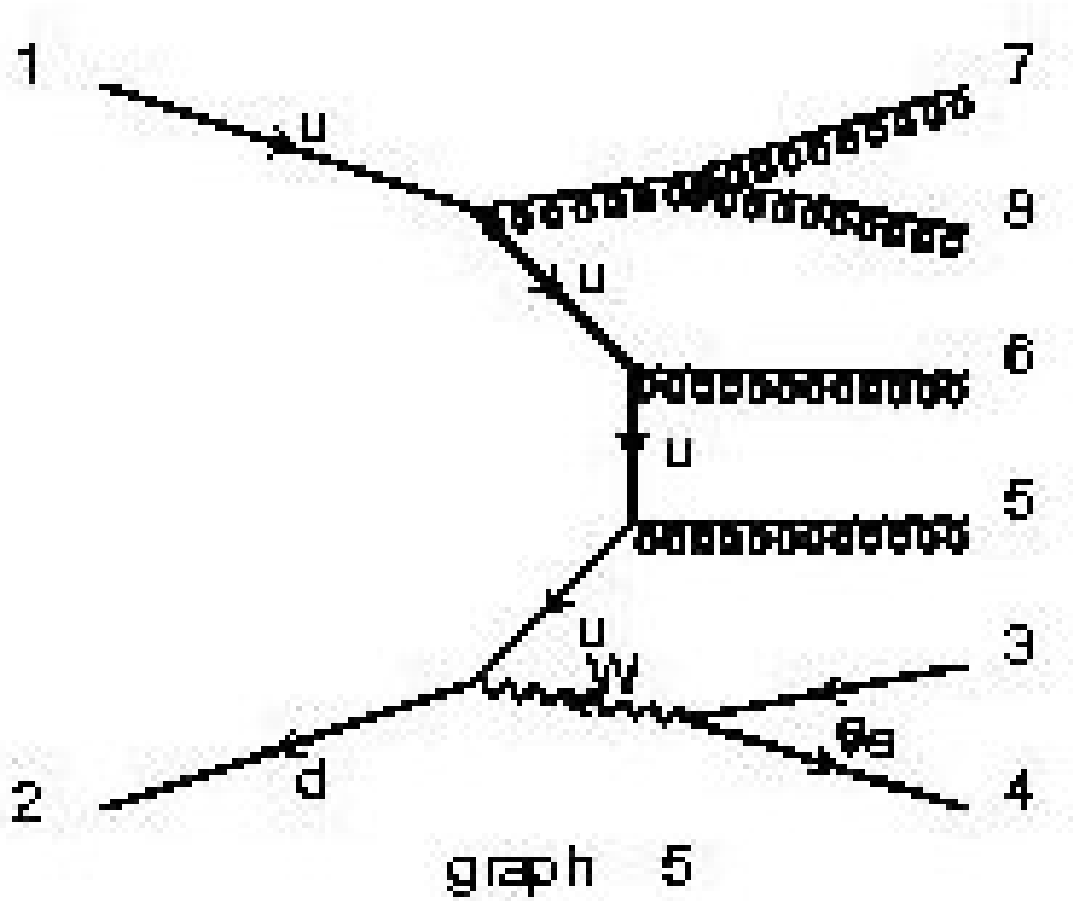
Measure $W + jets$ (no b-tag)

$\text{data}(W + b - jets) = R \times \text{data}(W + jets)$

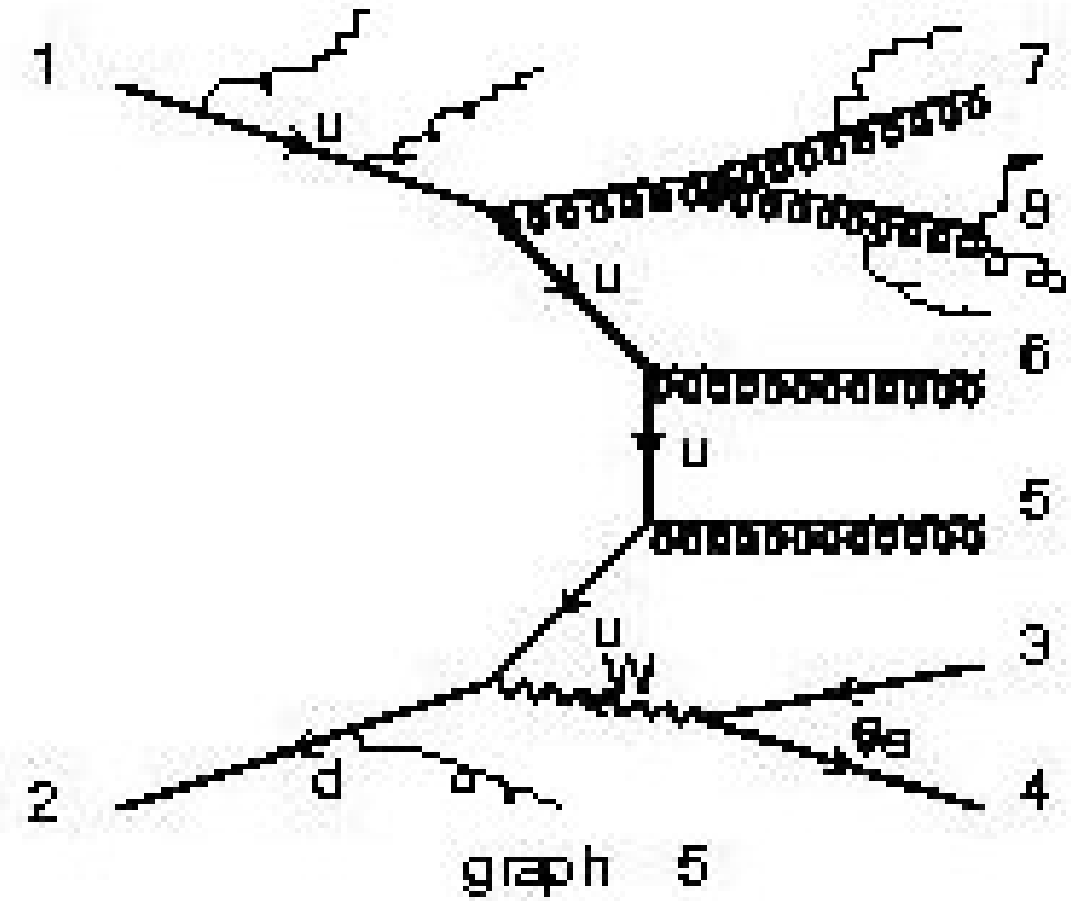
$Wcj/Wbb$ from Monte Carlo

- Several R's

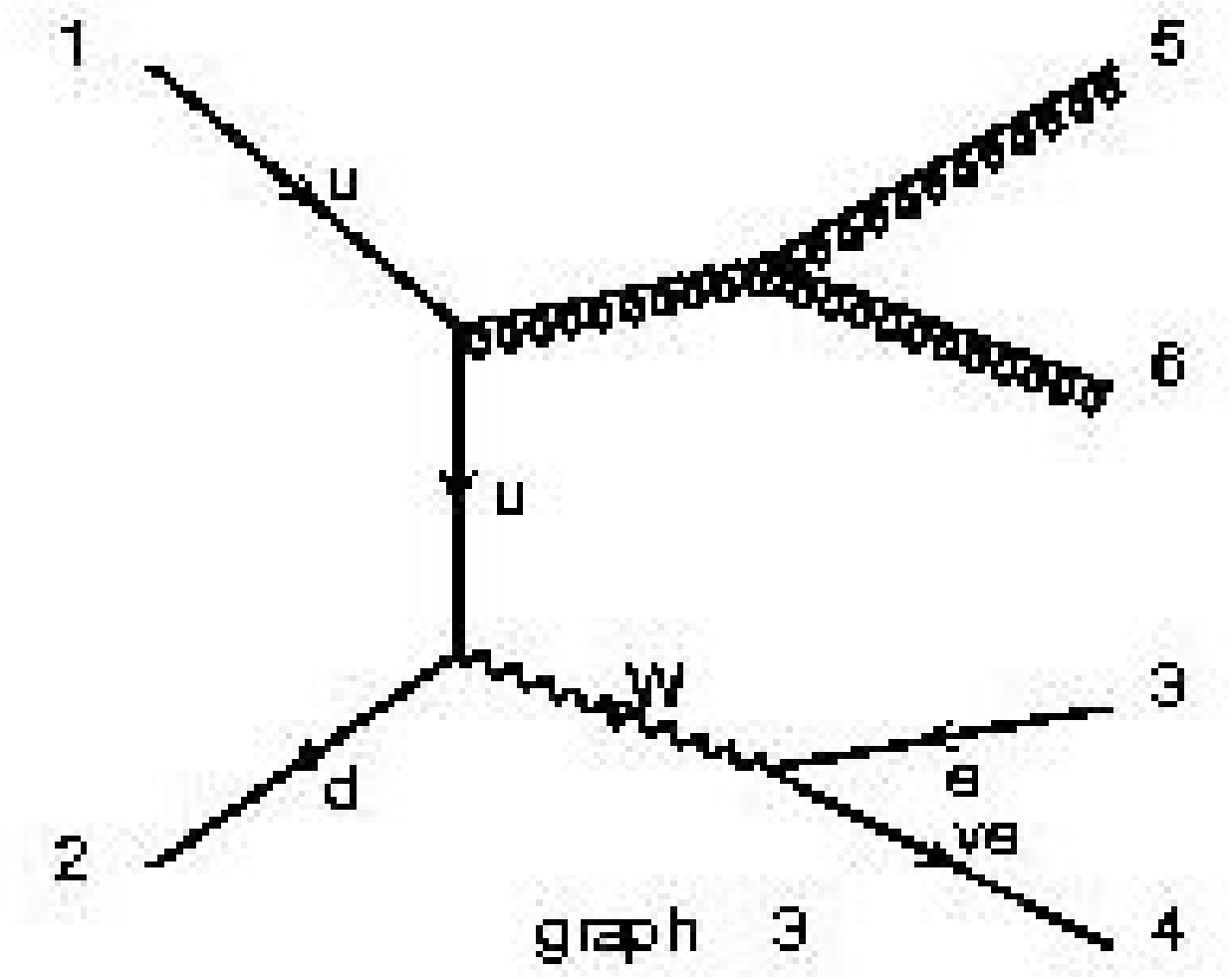
## High Multiplicity Tree Graph



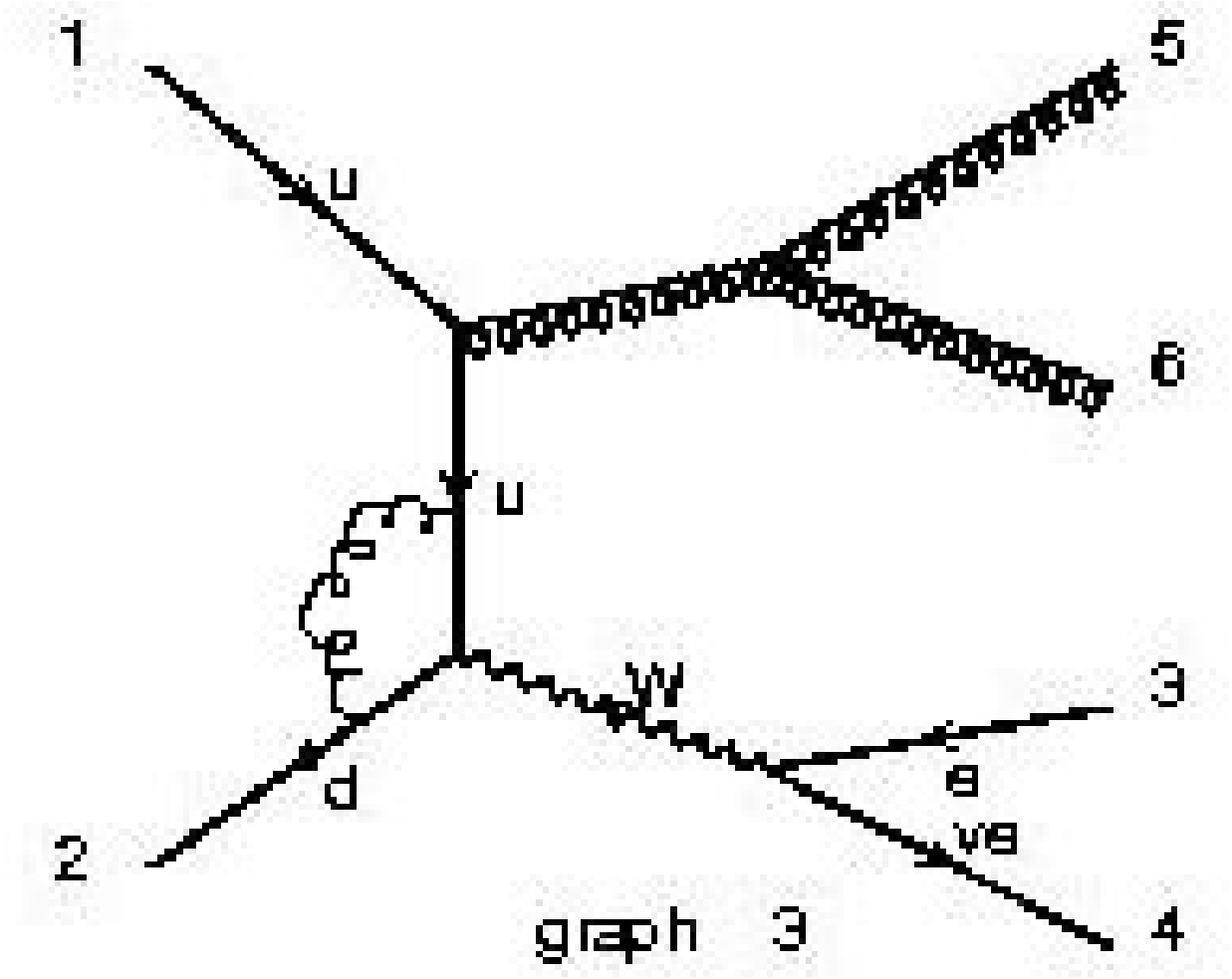
## Tree Graph + Parton Shower



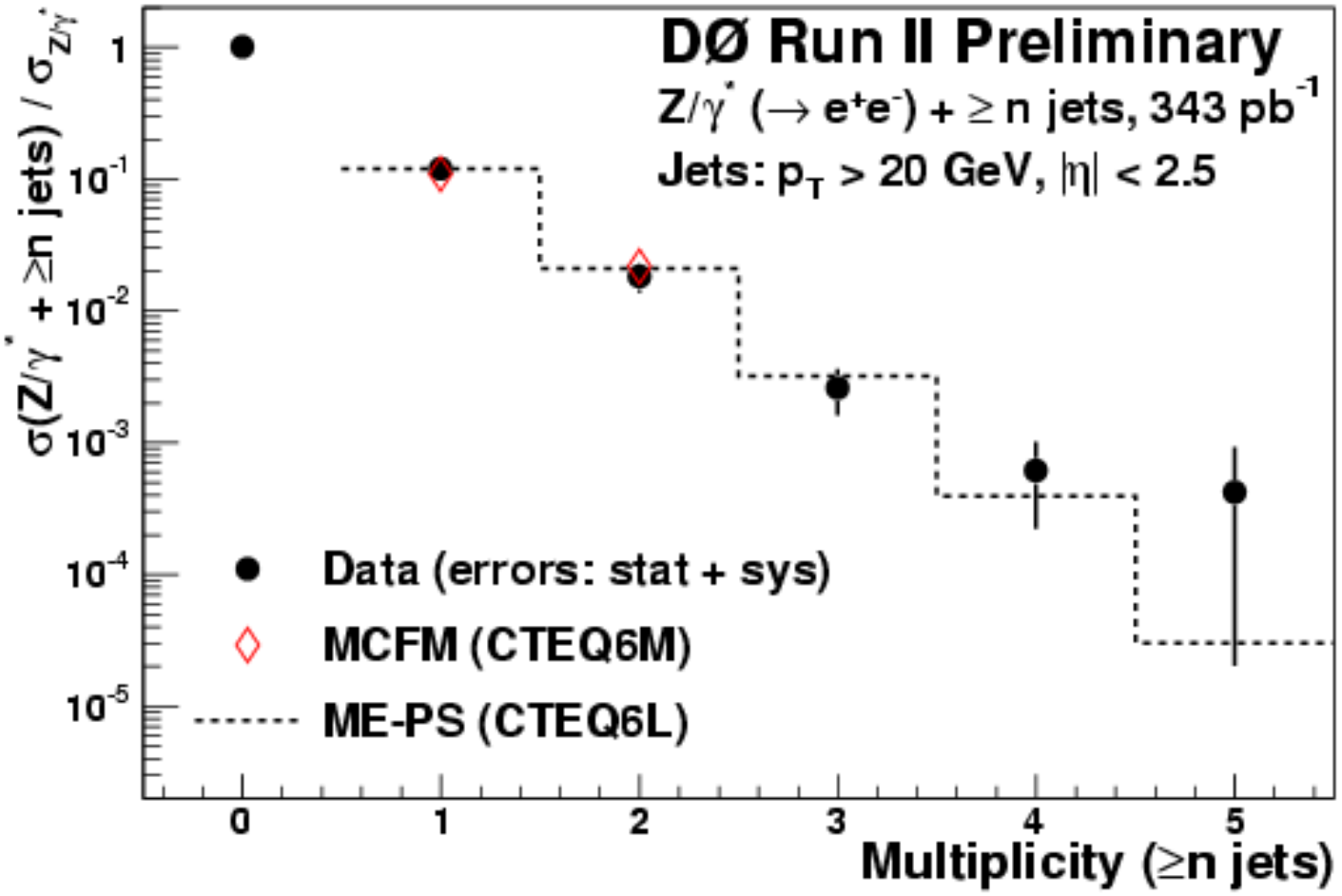
## Lower Multiplicity Tree Graph



## Lower Multiplicity NLO Graph



## Cross check on Run2 data




Includes up to $Zjjj$, $j = q, g$

# Single Top

## New Physics Warm-Up

- current state of single-Top is where we will be at the LHC with a few quality fb$^{-1}$
- the size of other NP signals
- it is a playground for new analysis techniques
- it challenges our tools

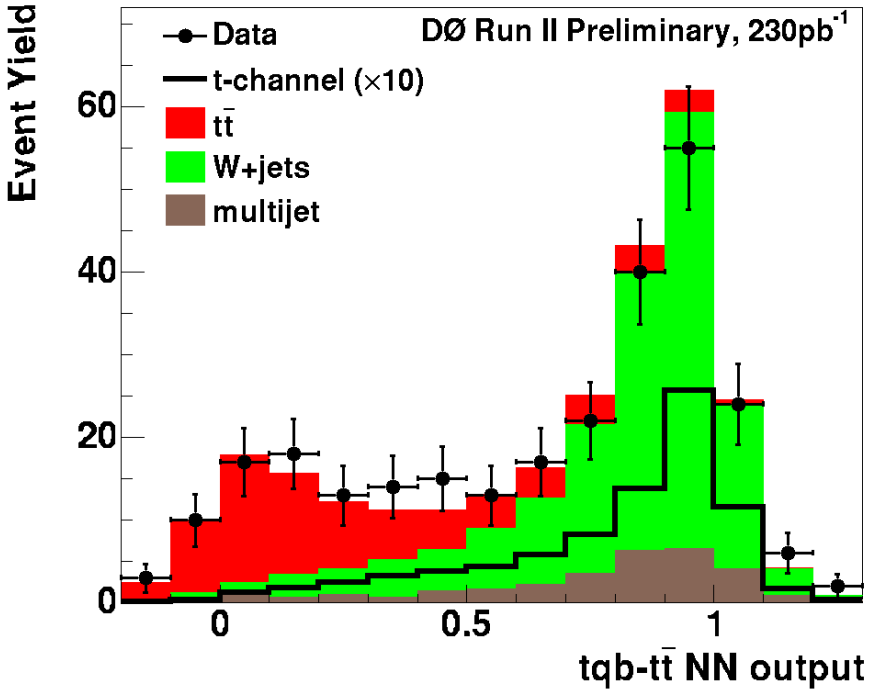
  Not specific to NN analyses: may be more sensitive
  *Many (11) Kinematic Variables*

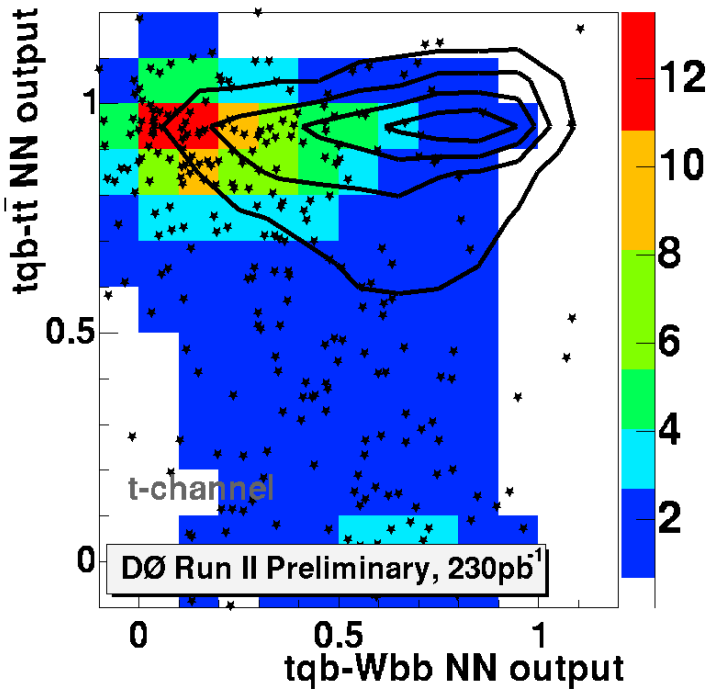
| | Signal-Background Pairs | | | |
|---|---|---|---|---|
| | $tb$ | | $tqb$ | |
| | $Wbb$ | $t\bar{t}$ | $Wbb$ | $t\bar{t}$ |
| **Individual object kinematics** | | | | |
| $p_T(\text{jet1}_{\text{tagged}})$ | $\surd$ | $\surd$ | $\surd$ | — |
| $p_T(\text{jet1}_{\text{untagged}})$ | — | — | $\surd$ | $\surd$ |
| $p_T(\text{jet2}_{\text{untagged}})$ | — | — | — | $\surd$ |
| $p_T(\text{jet1}_{\text{nonbest}})$ | $\surd$ | $\surd$ | — | — |
| $p_T(\text{jet2}_{\text{nonbest}})$ | $\surd$ | $\surd$ | — | — |
| **Global event kinematics** | | | | |
| $M_T(\text{jet1},\text{jet2})$ | $\surd$ | — | — | — |
| $p_T(\text{jet1},\text{jet2})$ | $\surd$ | — | $\surd$ | — |
| $M(\text{alljets})$ | $\surd$ | $\surd$ | $\surd$ | $\surd$ |
| $H_T(\text{alljets})$ | — | — | $\surd$ | — |
| $M(\text{alljets}-\text{jet1}_{\text{tagged}})$ | — | — | — | $\surd$ |
| $H(\text{alljets}-\text{jet1}_{\text{tagged}})$ | — | $\surd$ | — | $\surd$ |
| $H_T(\text{alljets}-\text{jet1}_{\text{tagged}})$ | — | — | — | $\surd$ |
| $p_T(\text{alljets}-\text{jet1}_{\text{tagged}})$ | — | $\surd$ | — | $\surd$ |
| $M(\text{alljets}-\text{jet}_{\text{best}})$ | — | $\surd$ | — | — |
| $H(\text{alljets}-\text{jet}_{\text{best}})$ | — | $\surd$ | — | — |
| $H_T(\text{alljets}-\text{jet}_{\text{best}})$ | — | $\surd$ | — | — |
| $M(\text{top}_{\text{tagged}}) = M(W,\text{jet1}_{\text{tagged}})$ | $\surd$ | $\surd$ | $\surd$ | $\surd$ |
| $M(\text{top}_{\text{best}}) = M(W,\text{jet}_{\text{best}})$ | $\surd$ | — | — | — |
| $\sqrt{\hat{s}}$ | $\surd$ | — | $\surd$ | $\surd$ |
| **Angular variables** | | | | |
| $\Delta R(\text{jet1},\text{jet2})$ | $\surd$ | — | $\surd$ | — |
| $Q(\text{lepton}) \times \eta(\text{jet1}_{\text{untagged}})$ | — | — | $\surd$ | $\surd$ |
| $\cos(\text{lepton}, Q(\text{lepton}) \times z)_{\text{top}_{\text{best}}}$ | $\surd$ | — | — | — |
| $\cos(\text{lepton},\text{jet1}_{\text{untagged}})_{\text{top}_{\text{tagged}}}$ | — | — | $\surd$ | — |
| $\cos(\text{alljets},\text{jet1}_{\text{tagged}})_{\text{alljets}}$ | — | — | $\surd$ | $\surd$ |
| $\cos(\text{alljets},\text{jet}_{\text{nonbest}})_{\text{all jets}}$ | — | $\surd$ | — | — |

# Network Outputs

http://www-d0.fnal.gov/Run2Physics/top/public/winter05/singletop/

## $t\bar{t}$ Training




- How do we convince ourselves of a signal?
- How can we improve upon the search?

- To understand the data, look at the Vista of final states

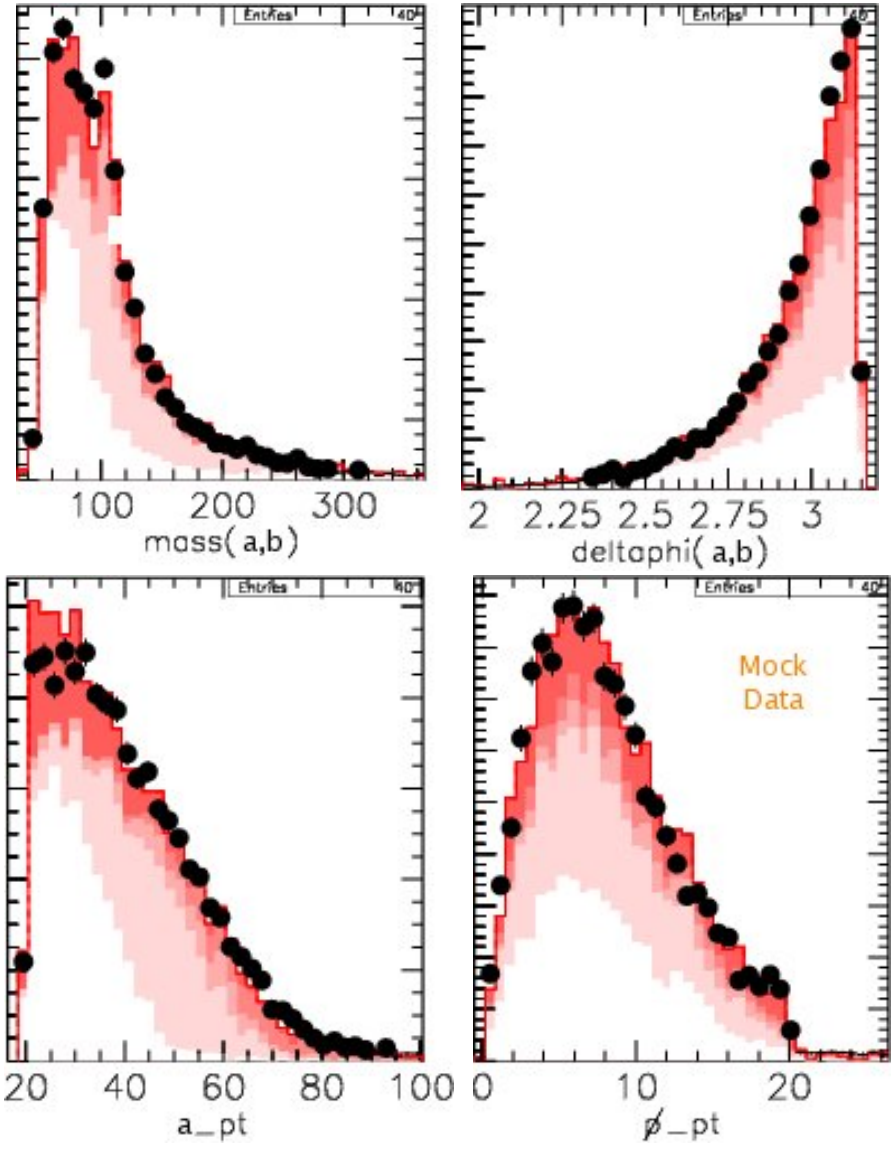
| Final State | Chi2 | data | bkg | |
|---|---|---|---|---|
| 1b3j1pmiss_sumPt400+ [73] | 9.0 | 451 | 374.5 +- 18 | ( pyth_jj_200 = 166.8 , pyth_jj_150 |
| 2b1e+2j [-] | 8.0 | 15 | 6.5 +- 1.9 | ( ttop0z = 2.3 , pyth_jj_040 = 1.9 |
| 2j_sumPt0-400 [161] | 6.0 | 69704 | 67013.6 +- 1171.2 | ( pyth_jj_018 = 33563 , pyth_jj_040 |
| 2j2mu+1pmiss [-] | -5.0 | 2 | 12.2 +- 3 | ( mad_mu+mu-jj = 4.1 , mrenna_mu+mu |
| 1b2e+2j [-] | 5.0 | 9 | 3.9 +- 1.5 | ( mrenna_e+e-jjj = 1.9 , mad_e+e-jj |
| 1j1ph1pmiss [5] | 4.0 | 2591 | 2470.1 +- 37.7 | ( pyth_pj_045 = 702.7 , pyth_jj_060 |
| 2j1mu+1ph [-] | 4.0 | 11 | 11.2 +- 2.2 | ( mrenna_mu+mu-jj = 1.3 , mrenna_mu |
| 1e+1j1mu+ [-] | 4.0 | 13 | 6.6 +- 2.1 | ( ztop5i = 3.4 , wtop1w = 1.3 , hew |
| 1e+2j1ph [-] | 4.0 | 31 | 20.9 +- 2.7 | ( mad_aajj = 6.3 , hewk03 = 3.7 , m |
| 3j2mu+ [-] | 4.0 | 34 | 23.2 +- 2.7 | ( mrenna_mu+mu-jjj = 13.2 , mrenna_ |
| 2b2j1pmiss_sumPt400+ [-] | -3.0 | 17 | 30.4 +- 4.2 | ( pyth_jj_200 = 10.6 , pyth_jj_150 = |
| 1b2j_sumPt400+ [229] | 3.0 | 4669 | 4518.6 +- 72.7 | ( pyth_jj_200 = 2164.7 , pyth_jj_15 |
| 4j_sumPt0-400 [253] | -3.0 | 2611 | 2736.9 +- 42.3 | ( pyth_jj_040 = 1074.3 , pyth_jj_01 |
| 2b1j1ph1pmiss [-] | 3.0 | 6 | 2.7 +- 1.5 | ( pyth_jj_200 = 0.8 , pyth_pj_080 = |
| 1b1j1mu+ [-] | 3.0 | 67 | 53.8 +- 4.3 | ( pyth_jj_018 = 13.5 , pyth_jj_040 = |
| 1j1ph [277] | 3.0 | 31738 | 31149.8 +- 352.1 | ( pyth_pj_045 = 14520.4 , pyth_jj_0 |
| 1e+1mu+ [-] | 3.0 | 66 | 53.5 +- 3.2 | ( ztop5i = 38.8 , tewk1m = 5.8 , he |
| 4j1mu+ [-] | 3.0 | 73 | 61.3 +- 2.6 | ( pyth_jj_040 = 11 , pyth_jj_060 = |
| 5j [269] | 3.0 | 448 | 406 +- 14.5 | ( pyth_jj_040 = 155.1 , pyth_jj_060 |
| 1b5j [-] | 3.0 | 8 | 8.9 +- 1.7 | ( pyth_jj_060 = 1.6 , pyth_jj_040 = |
| 1b1j1pmiss_sumPt0-400 [-] | 2.0 | 120 | 104 +- 7.2 | ( pyth_jj_040 = 36.5 , pyth_jj_018 = |
| 2j1pmiss_sumPt0-400 [37] | 2.0 | 2381 | 2281.2 +- 73.9 | ( pyth_jj_018 = 1026.3 , pyth_jj_04 |

...

| Final State | Chi2 | data | bkg |
|---|---|---|---|
| 1b2e+2j [-] | 5.0 | 9 | 3.9 +- 1.5 |

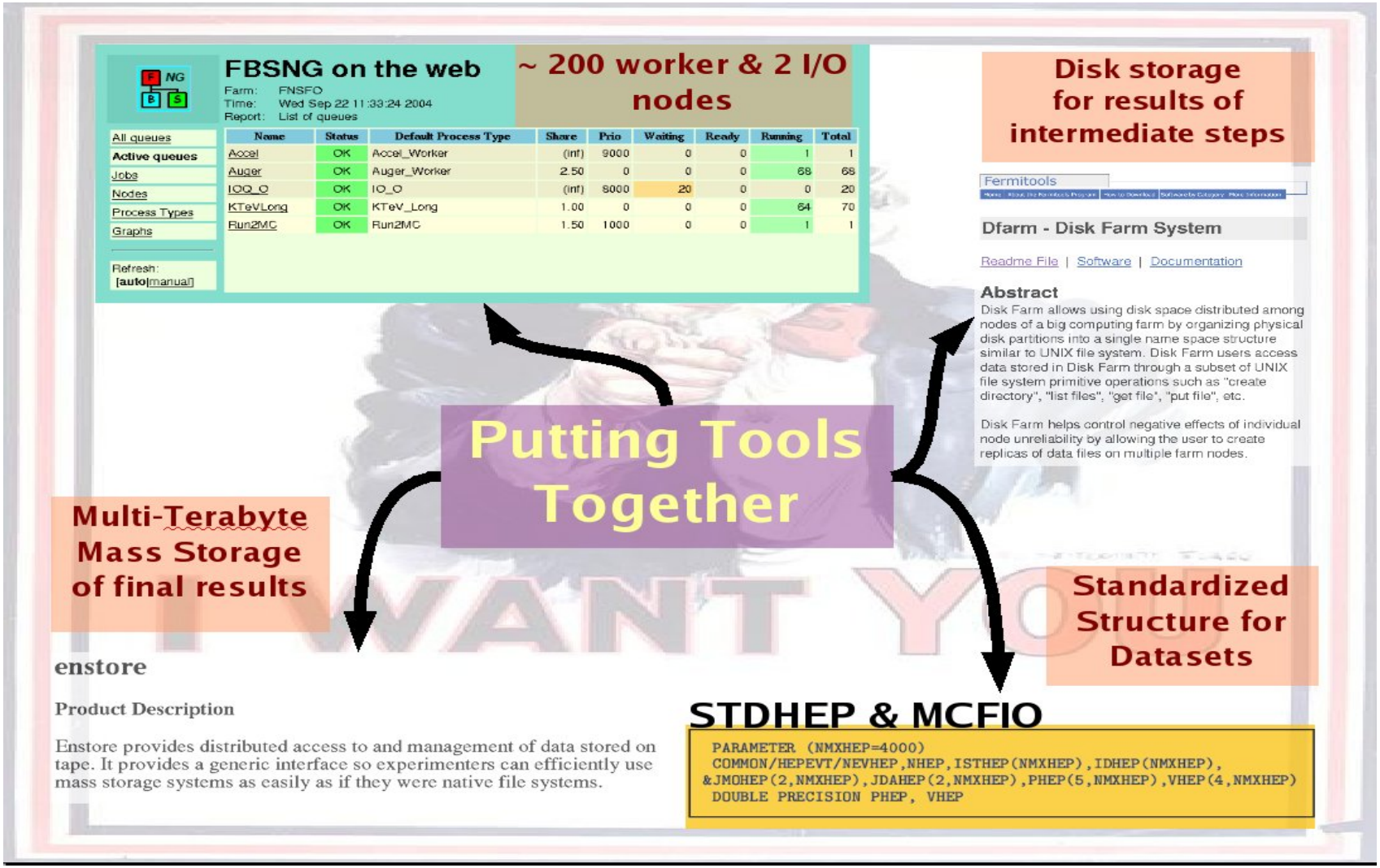
```
( mrenna_e+e-jjj = 1.9 , mad_e+e-jj = 0.5 , mrenna_e+e-jj = 0.4 , mad_e+e-b-b = 0.4 ,
          ztopcz = 0.3 , pyth_jj_040 = 0.2 , mad_aajj = 0.1 , mrenna_e+vejjjj = 0.1 ,
          hewk03 = 0.1 , wtop1z = 0.1 )
```

# Distributions



- Give a complete description of the Standard Model with the best tools

# Patriot


FBSNG on the web
Farm: FNSFO
Time: Wed Sep 22 11:33:24 2004
Report: List of queues
~ 200 worker & 2 I/O nodes
All queues
Active queues
Jobs
Nodes
Process Types
Graphs
Refresh: [auto|manual]
Name | Status | Default Process Type | Share | Prio | Waiting | Ready | Running | Total
Accel | OK | Accel_Worker | (inf) | 9000 | 0 | 0 | 1 | 1
Auger | OK | Auger_Worker | 2.50 | 0 | 0 | 0 | 68 | 68
IOQ_O | OK | IO_O | (inf) | 8000 | 20 | 0 | 0 | 20
KTeVLong | OK | KTeV_Long | 1.00 | 0 | 0 | 0 | 64 | 70
Run2MC | OK | Run2MC | 1.50 | 1000 | 0 | 0 | 1 | 1
Disk storage for results of intermediate steps
Fermitools
Dfarm - Disk Farm System
Readme File | Software | Documentation
Abstract
Disk Farm allows using disk space distributed among nodes of a big computing farm by organizing physical disk partitions into a single name space structure similar to UNIX file system. Disk Farm users access data stored in Disk Farm through a subset of UNIX file system primitive operations such as "create directory", "list files", "get file", "put file", etc.
Disk Farm helps control negative effects of individual node unreliability by allowing the user to create replicas of data files on multiple farm nodes.
Putting Tools Together
Multi-Terabyte Mass Storage of final results
Standardized Structure for Datasets
enstore
Product Description
Enstore provides distributed access to and management of data stored on tape. It provides a generic interface so experimenters can efficiently use mass storage systems as easily as if they were native file systems.
STDHEP & MCFIO
PARAMETER (NMXHEP=4000)
COMMON/HEPEVT/NEVHEP,NHEP,ISTHEP(NMXHEP),IDHEP(NMXHEP),
&JMOHEP(2,NMXHEP),JDAHEP(2,NMXHEP),PHEP(5,NMXHEP),VHEP(4,NMXHEP)
DOUBLE PRECISION PHEP, VHEP

# Model-Independent and Quasi-Model-Independent Search for New Physics at CDF

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*MIT*

Ray Culbertson**
*FNAL*

CDF Collaboration††
(Dated: February 1, 2006)

Data collected in Run II of the Fermilab Tevatron are searched for indications of new electroweak scale physics. Rather than focusing on particular new physics scenarios, CDF data are analyzed for discrepancies with the Standard Model prediction. A model-independent approach considers the gross features of the data, and is sensitive to new large cross section physics. A quasi-model-independent approach emphasizes the high-$p_T$ tails, and is particularly sensitive to new electroweak scale physics. This global search for new physics in $\approx 600$ pb$^{-1}$ of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV reveals no indication of physics beyond the Standard Model.

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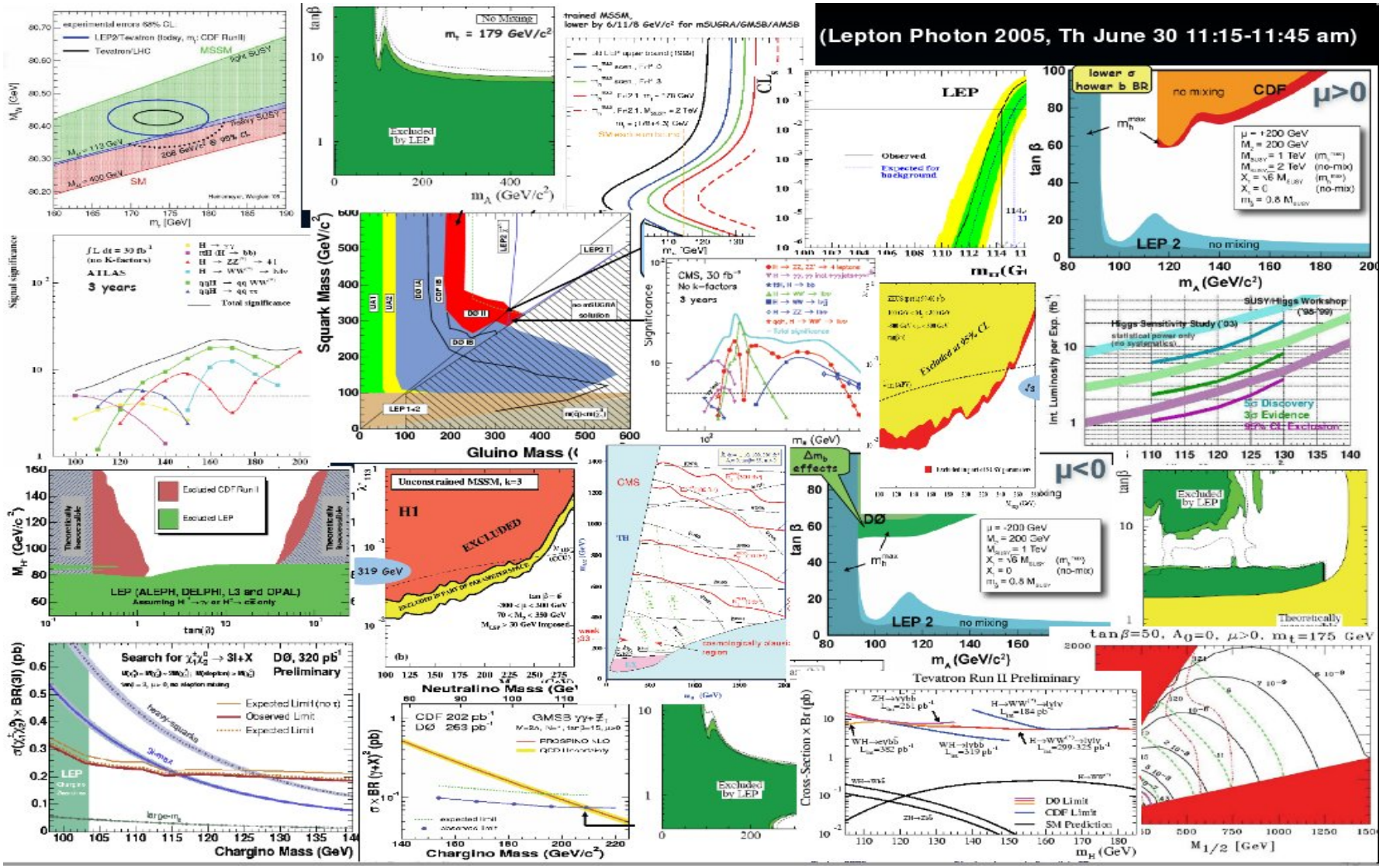
## I. MOTIVATION

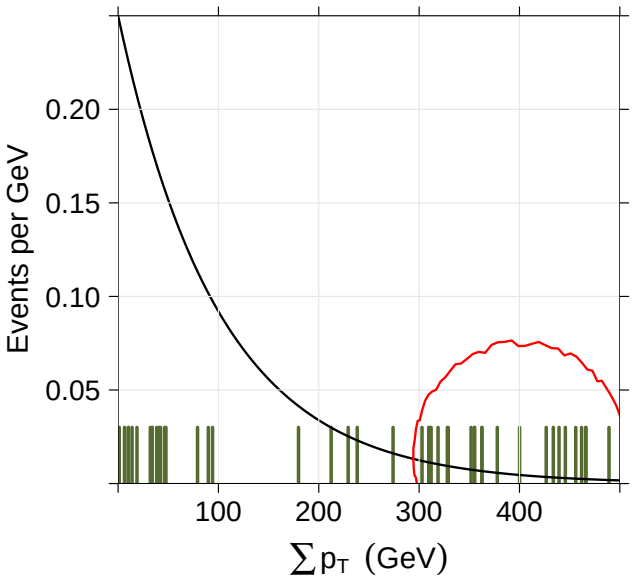
- Use the data to test our modelling of fakes

# Midterm Summary

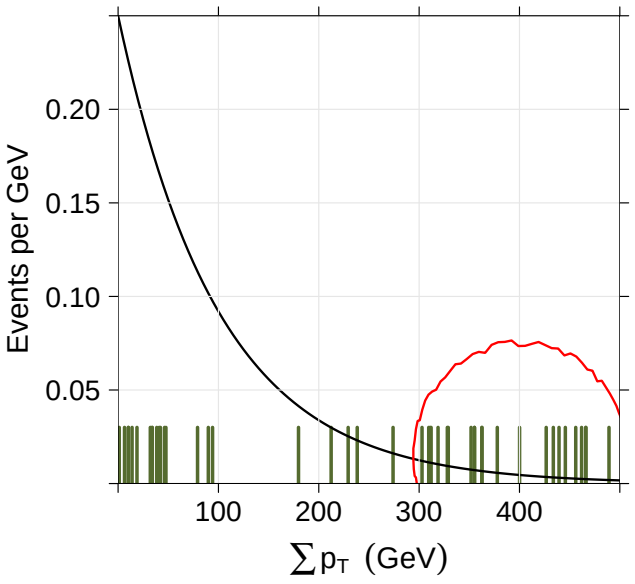
- The first New Physics to find is the Standard Model
- Need complete description of most important processes
- Understanding comes from looking at consistency of full dataset
- Then, how do we find New Physics?

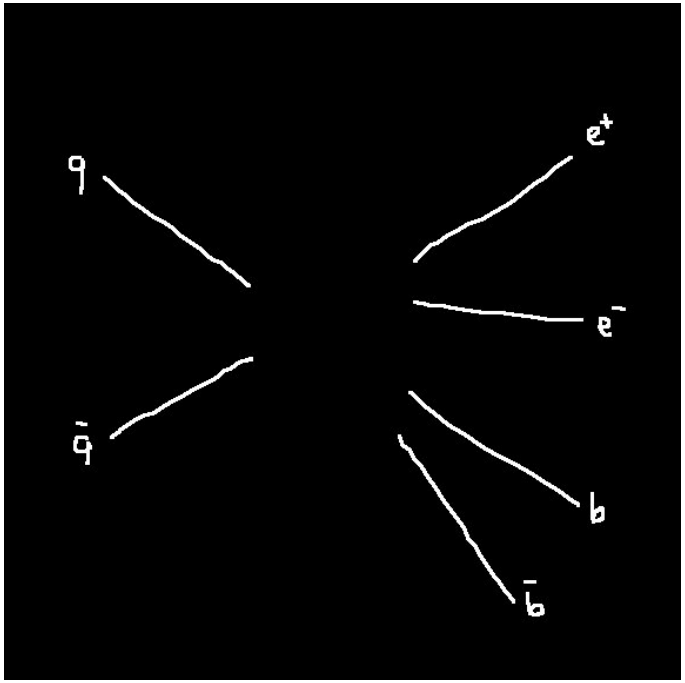

(Lepton Photon 2005, Th June 30 11:15-11:45 am)
No Mixing
$m_t$ = 179 GeV/c²
excluded by LEP
$m_A$ (GeV/c²)
tan β
LEP
Observed
Expected for background
lower σ
lower b BR
no mixing
CDF
μ>0
LEP 2
no mixing
$m_h^{max}$
$m_A$ (GeV/c²)
ATLAS
3 years
Total significance
Squark Mass (GeV/c²)
Gluino Mass
LEP 1+2
no mSUGRA solution
CMS, 30 fb⁻¹
No k-factors
3 years
Significance
Excluded at 95% CL
SUSY/Higgs Workshop
Higgs Sensitivity Study ('03)
statistical power only
(no systematics)
5σ Discovery
3σ Evidence
95% CL Exclusion
Int. Luminosity per Exp. (fb⁻¹)
Excluded CDF Run I
Excluded LEP
Theoretically Inaccessible
LEP (ALEPH, DELPHI, L3 and OPAL)
Assuming H⁺→τν or H⁺→ cs̄ only
tan(β)
Unconstrained MSSM, k=3
H1
EXCLUDED
319 GeV
Neutralino Mass (GeV)
CMS
TH
Δm_b effects
DØ
μ<0
LEP 2
no mixing
$m_A$ (GeV/c²)
Excluded by LEP
Theoretically
tanβ=50, A₀=0, μ>0, m_t=175 GeV
Search for $\chi_1^+\chi_2^0 \to 3l+X$
DØ, 320 pb⁻¹
Preliminary
Expected Limit (no τ)
Observed Limit
Expected Limit
heavy squarks
3l-max
large-m₀
Chargino Mass (GeV)
CDF 202 pb⁻¹
DØ 263 pb⁻¹
GMSB γγ+E̸_T
Chargino Mass (GeV/c²)
Excluded by LEP
Tevatron Run II Preliminary
Cross-Section × Br (pb)
DØ Limit
CDF Limit
SM Prediction
$m_H$ (GeV)
$M_{1/2}$ [GeV]

## $e^+ e^- b\bar{b}$ Final State

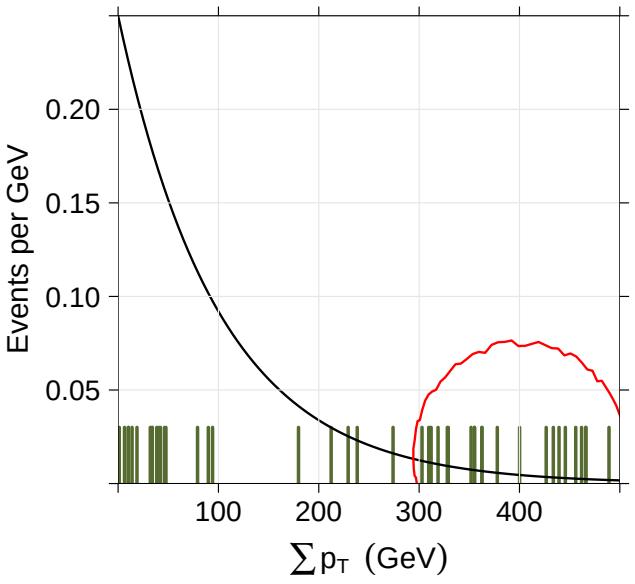


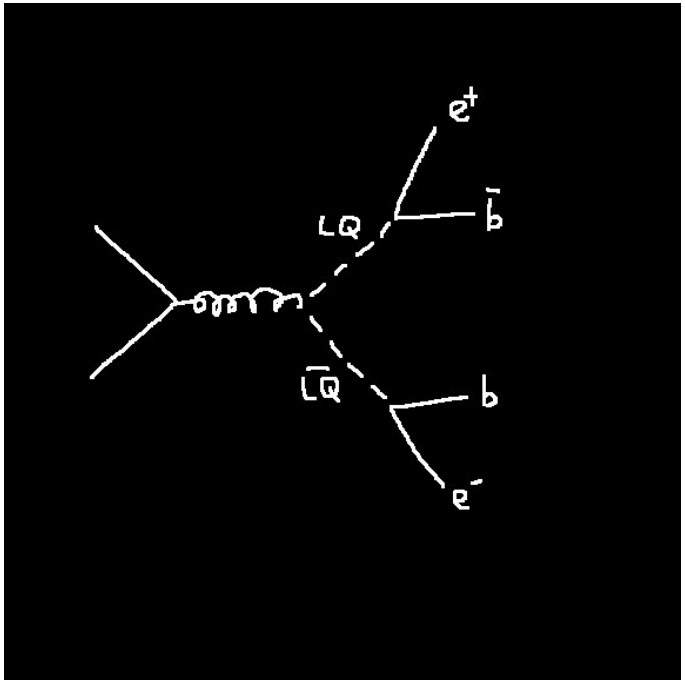
## $e^+ e^- b\bar{b}$ Final State



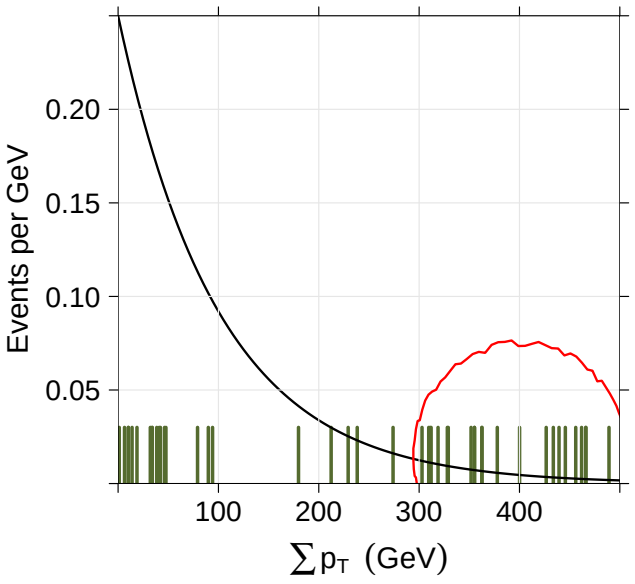



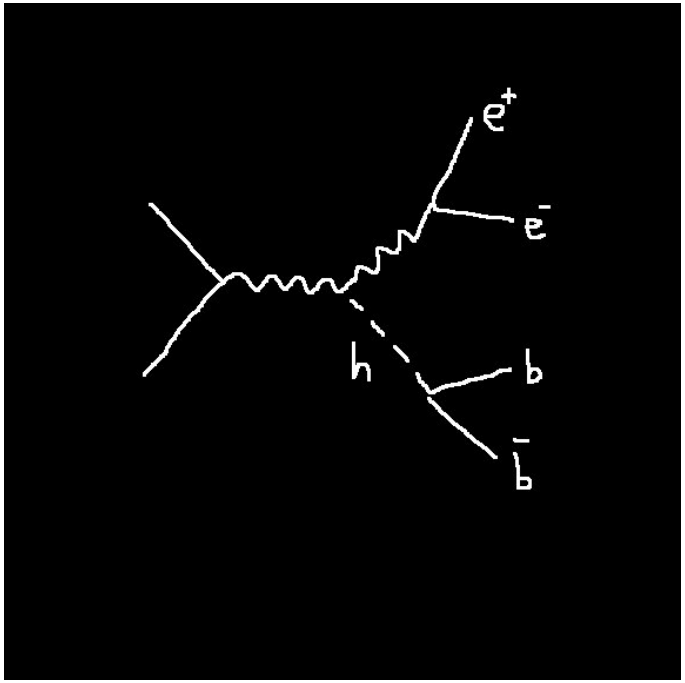
## $e^+ e^- b\bar{b}$ Final State



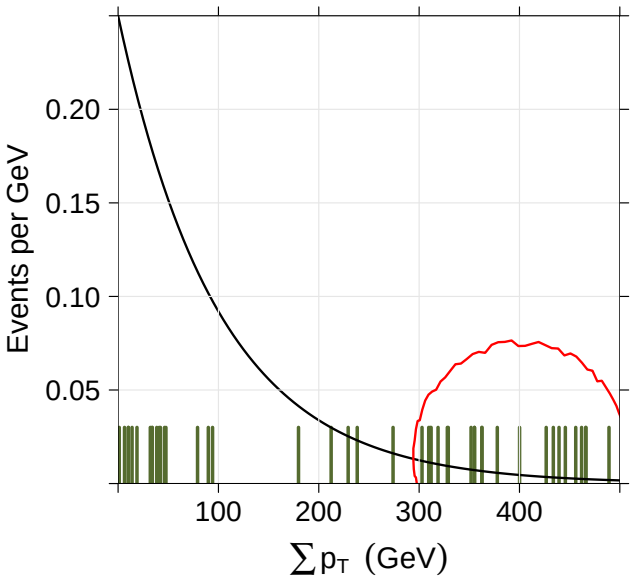



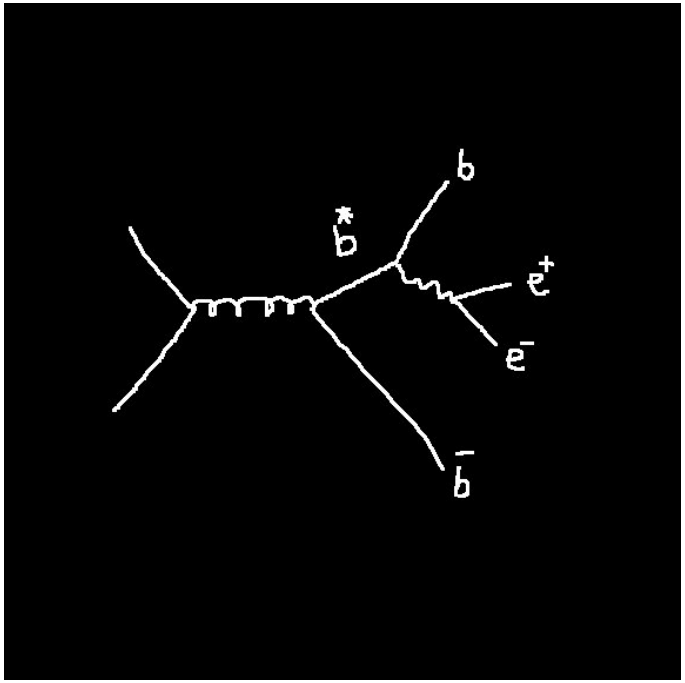
## $e^+ e^- b\bar{b}$ Final State



## $e^+ e^- b\bar{b}$ Final State

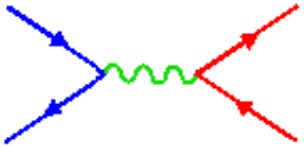


File Edit View Go Bookmarks Tools Window Help

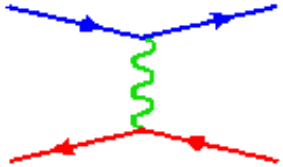
http://madgraph.hep.uiuc.edu/ Search

Home Bookmarks



# MadGraph HomePage

by Fabio Maltoni and Tim Stelzer



Generate Process | Calculated Cross Sections | Source Codes | FAQ Developments | Other approaches | Citations

## Generate Process Code On-Line

Quarks: d u s c b t d~ u~ s~ c~ b~ t~

Leptons: e- mu- ta- ve vm vt e+ mu+ ta+ ve~ vm~ vt~

Bosons: A Z W+ W- h g

Special: P j (sums over d u s c d~ u~ s~ c~ g)

Process: PP > W+ > e+ ve jjj Submit EXAMPLES

Max QCD Order: 4

Max QED Order: 2

To improve our web services we now request that you register. Registration is quick and free. You may register for a password by clicking here

## Generic Particles and Vertices

$$\mathcal{L}_{\mathtt{FFV}} = \bar{f}'\gamma^\mu \left( \mathtt{G}(1)\frac{1-\gamma_5}{2} + \mathtt{G}(2)\frac{1+\gamma_5}{2} \right) f V_\mu^*$$

$$\mathcal{L}_{\mathtt{FFS}} = \bar{f}' \left( \mathtt{GC}(1)\frac{1-\gamma_5}{2} + \mathtt{GC}(2)\frac{1+\gamma_5}{2} \right) f S^*$$

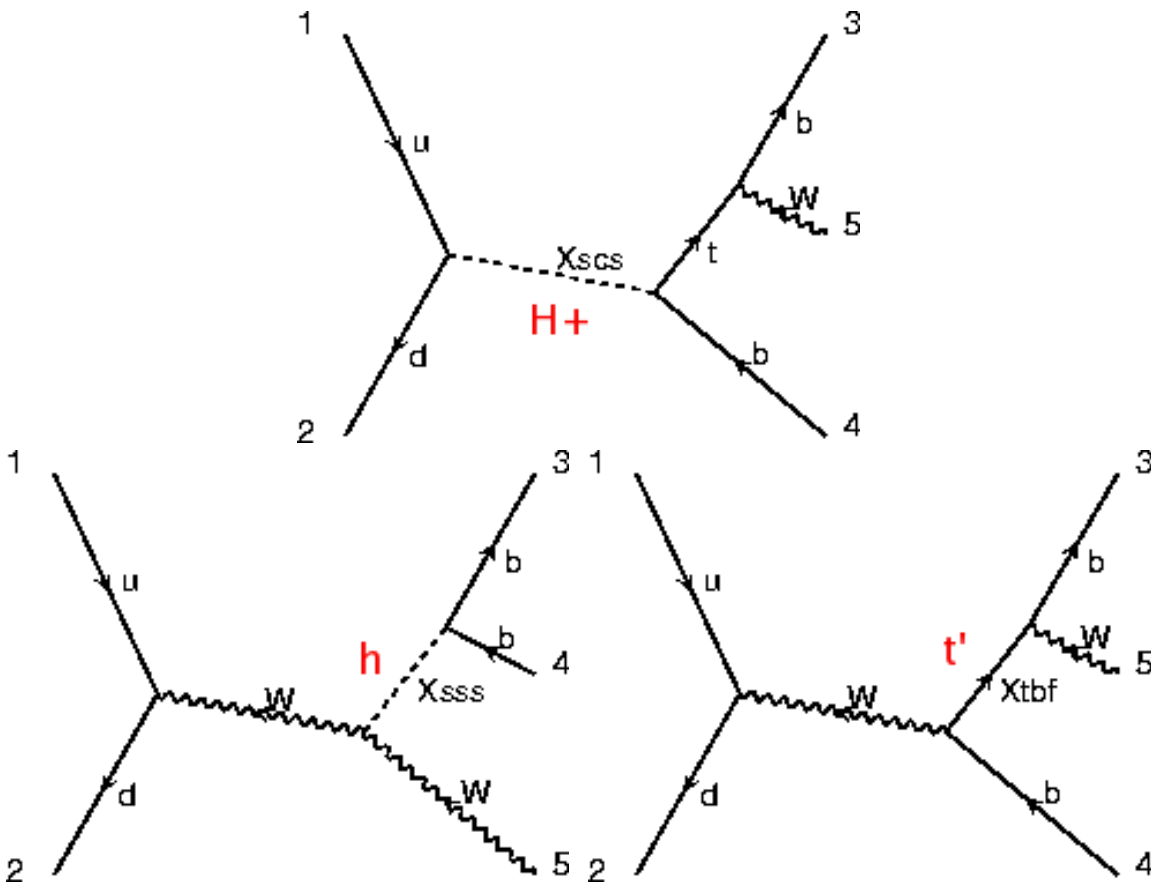
$$\begin{aligned} \mathcal{L}_{\mathtt{VVV}} \;=\; -i\mathtt{G} \;\; \{ & (\partial_\mu V_{1\nu}^*)(V_2^{\mu*}V_3^{\nu*} - V_2^{\nu*}V_3^{\mu*}) \\ & +(\partial_\mu V_{2\nu}^*)(V_3^{\mu*}V_1^{\nu*} - V_3^{\nu*}V_1^{\mu*}) \\ & +(\partial_\mu V_{3\nu}^*)(V_1^{\mu*}V_2^{\nu*} - V_1^{\nu*}V_2^{\mu*})\} \end{aligned}$$

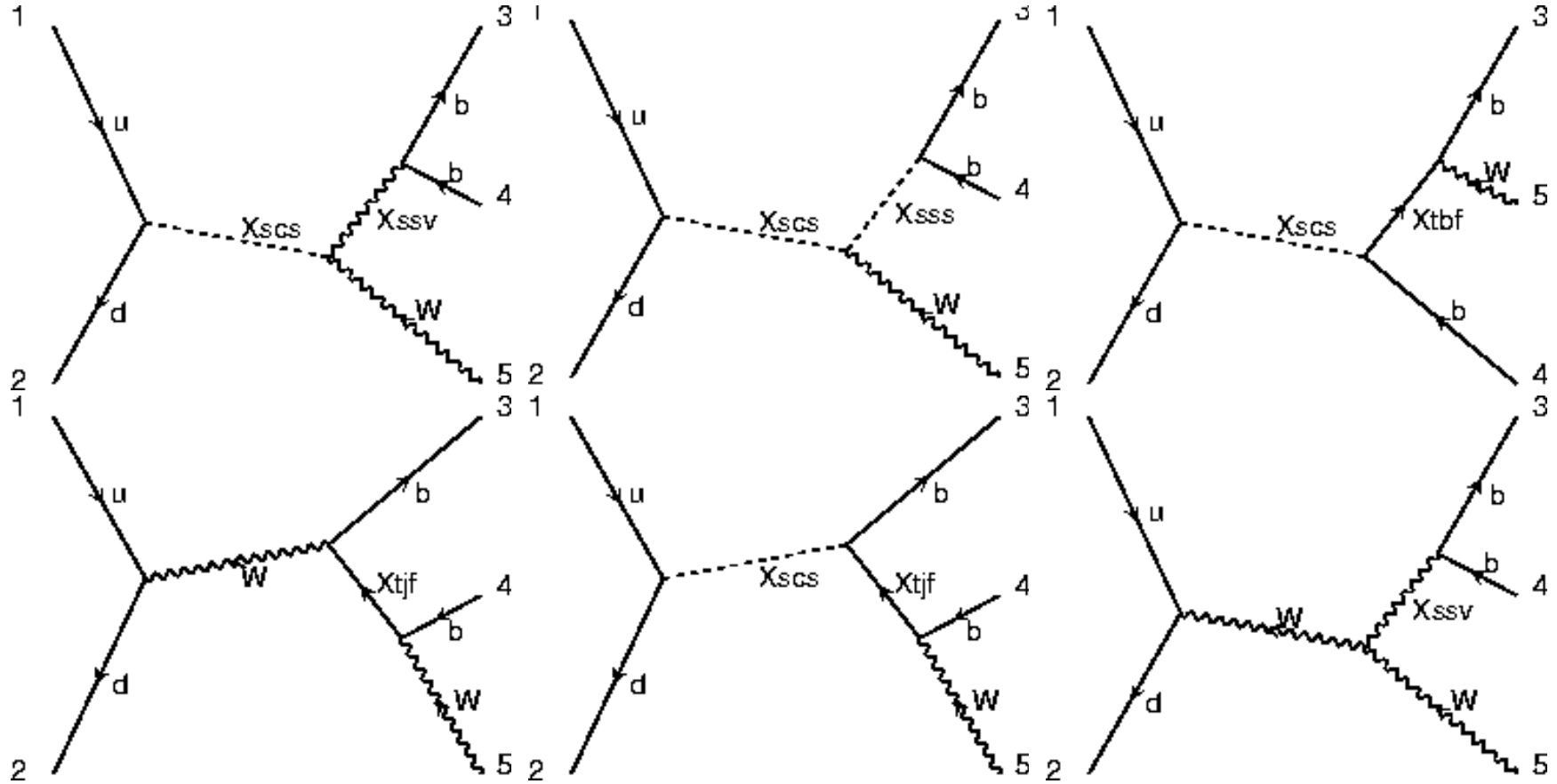
$$\mathcal{L}_{\mathtt{VVS}} = \mathtt{G} V_1^{\mu*} V_{2\mu}^* S^*$$

$$\mathcal{L}_{\mathtt{SSS}} = \mathtt{G}\, S_1^* S_2^* S_3^* \qquad\qquad \mathcal{L}_{\mathtt{VSS}} = i\mathtt{G} V_\mu^* S_2^* \overleftrightarrow{\partial}^\mu S_1^*$$

# Simpler Problem

## $Wb\bar{b}$ Anomaly

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W
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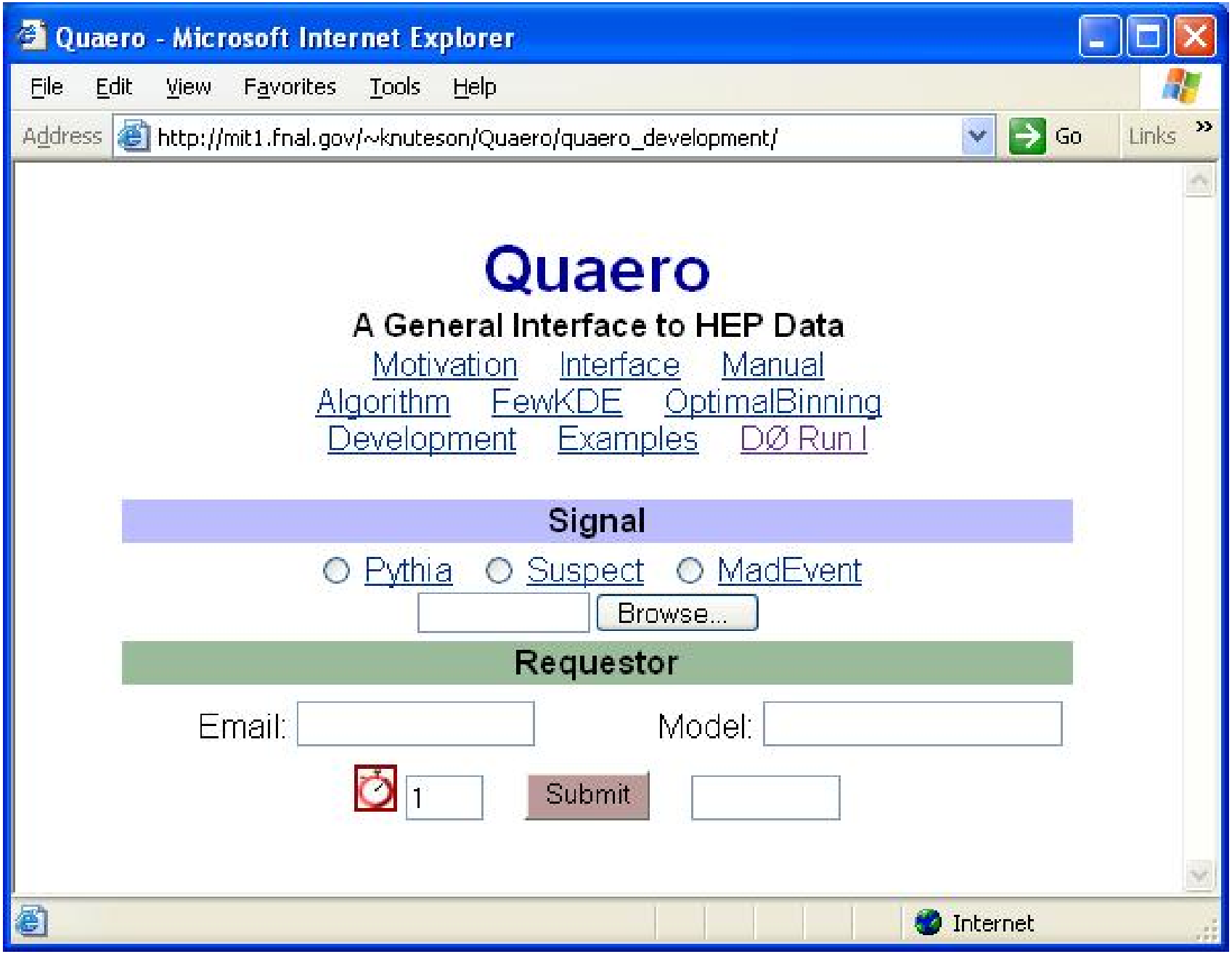
Xtbf
Xtjf
W


Quaero - Microsoft Internet Explorer
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Quaero
A General Interface to HEP Data
Motivation Interface Manual
Algorithm FewKDE OptimalBinning
Development Examples DØ Run I
Signal
Pythia Suspect MadEvent
Browse...
Requestor
Email:
Model:
1
Submit
Internet

## Leptoquarks → ee 2j

**Variables**

Constraints:

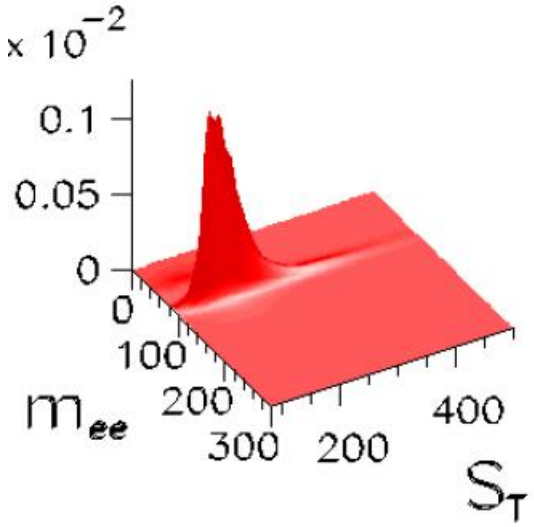
Variables:

v1 e1_pt + e2_pt + j1_pt + j2_pt + j3_pt + j4_pt

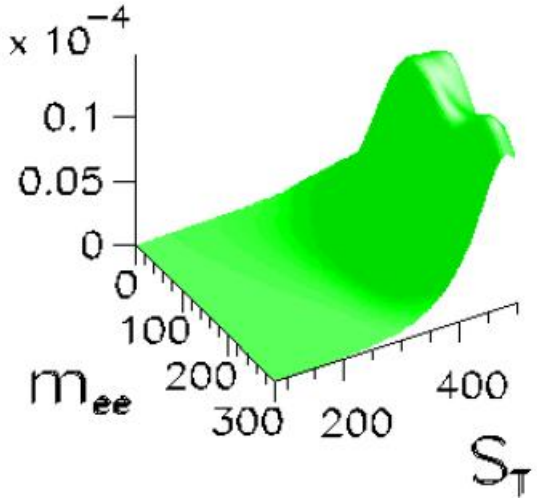
v2 mass(e1,e2)

| | |
|---|---|
| $\varepsilon_{sig}$ | 33% |
| $\hat{b}$ | $0.3 \pm 0.1$ |
| $N_{obs}$ | 0 |
| $\sigma^{95\%} \times \mathcal{B}$ | 0.07 pb |

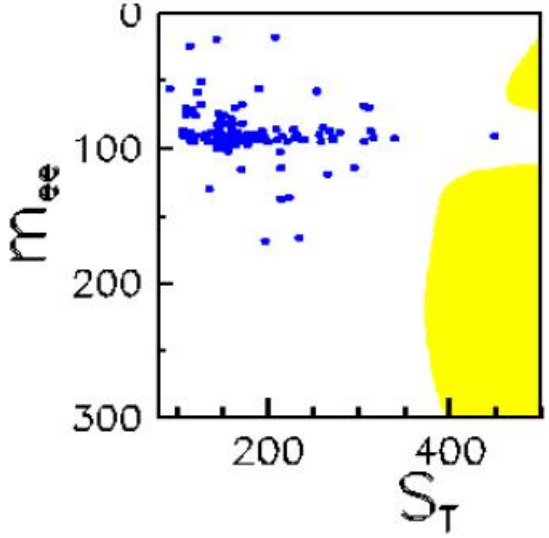
Background density




Signal density




Selected region



DESY 04–140 ISSN 0918–9833

arXiv:hep-ex/0408044 v1 12 Aug 2004

# A general search for new phenomena in $ep$ scattering at HERA

H1 Collaboration

**Abstract**

A model-independent search for deviations from the Standard Model prediction is performed in $e^+p$ and $e^-p$ collisions at HERA using H1 data corresponding to an integrated luminosity of 117 pb$^{-1}$. For the first time all event topologies involving isolated electrons, photons, muons, neutrinos and jets with high transverse momenta are investigated in a single analysis. Events are assigned to exclusive classes according to their final state. A statistical algorithm is developed to search for deviations from the Standard Model in the distributions of the scalar sum of transverse momenta or invariant mass of final state particles and to quantify their significance. A good agreement with the Standard Model prediction is observed in most of the event classes. The most significant deviation is found for a topology containing an isolated muon, missing transverse momentum and a jet, consistent with a previously reported observation.

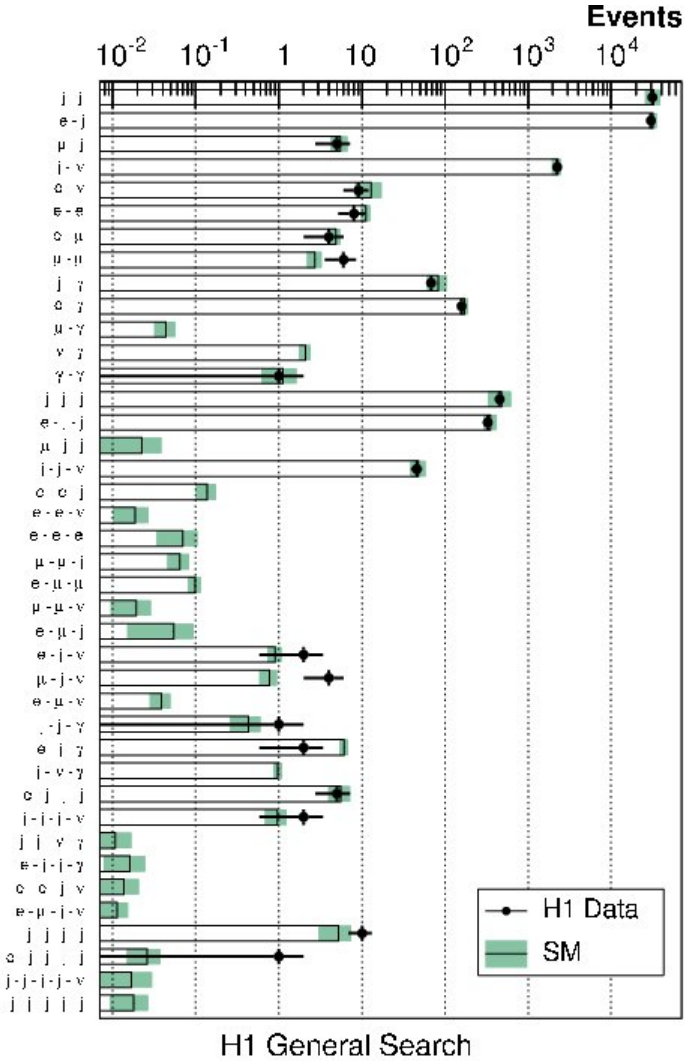
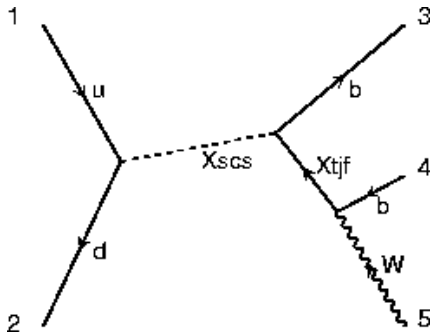
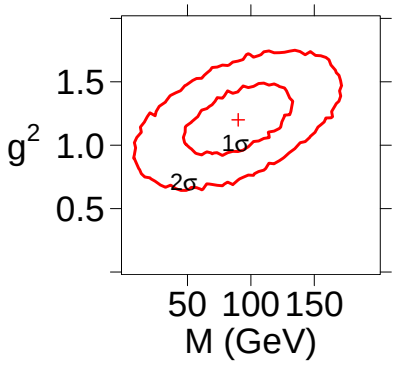
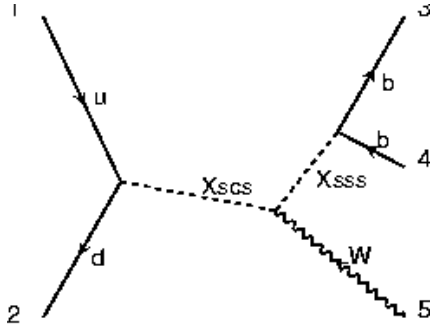
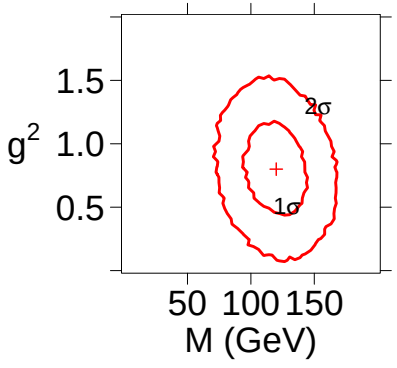
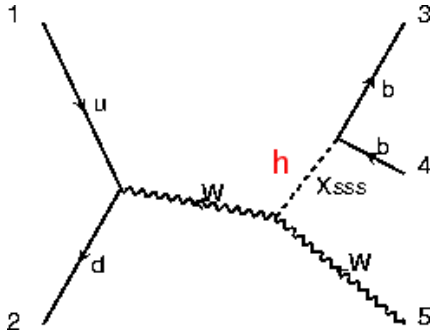
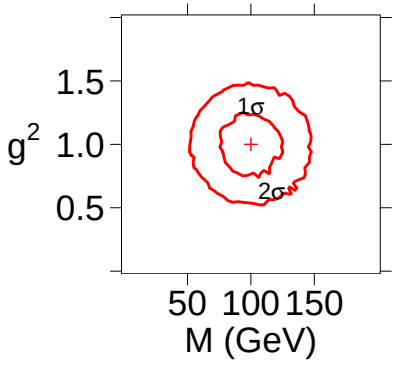



Figure 1: The data and the SM expectation for all event classes with a SM expectation greater than 0.01 events. The analysed data sample corresponds to an integrated luminosity of 117 $pb^{-1}$. The error bands on the predictions include model uncertainties and experimental systematic errors added in quadrature.

- ALEPH and L3 analyses underway

# Quaero: DØ, hep-ex/0106039

| Process | $\epsilon_{\rm sig}$ | $\hat{b}$ | $N_{\rm data}$ | $\sigma^{95\%} \times \mathcal{B}$ |
|---|---|---|---|---|
| $WW \to e\mu \not{E}_T$ | 0.14 | $19.0 \pm 4.0$ | 23 | 1.1 pb |
| $ZZ \to ee\, 2j$ | 0.12 | $19.7 \pm 4.1$ | 19 | 0.8 pb |
| $t\bar{t} \to e \not{E}_T\, 4j$ | 0.13 | $3.1 \pm 0.9$ | 8 | 0.8 pb |
| $t\bar{t} \to e\mu \not{E}_T\, 2j$ | 0.14 | $0.6 \pm 0.2$ | 2 | 0.4 pb |
| $h_{175} \to WW \to e \not{E}_T\, 2j$ | 0.02 | $29.6 \pm 6.5$ | 32 | 11.0 pb |
| $h_{200} \to WW \to e \not{E}_T\, 2j$ | 0.07 | $66.0 \pm 13.8$ | 69 | 4.4 pb |
| $h_{225} \to WW \to e \not{E}_T\, 2j$ | 0.06 | $43.1 \pm 9.2$ | 44 | 3.6 pb |
| $h_{200} \to ZZ \to ee\, 2j$ | 0.15 | $17.9 \pm 3.7$ | 15 | 0.6 pb |
| $h_{225} \to ZZ \to ee\, 2j$ | 0.15 | $18.8 \pm 3.8$ | 12 | 0.4 pb |
| $h_{250} \to ZZ \to ee\, 2j$ | 0.17 | $18.1 \pm 3.7$ | 18 | 0.6 pb |
| $W'_{200} \to WZ \to e \not{E}_T\, 2j$ | 0.05 | $27.7 \pm 6.3$ | 29 | 3.4 pb |
| $W'_{350} \to WZ \to e \not{E}_T\, 2j$ | 0.23 | $22.7 \pm 5.2$ | 27 | 0.7 pb |
| $W'_{500} \to WZ \to e \not{E}_T\, 2j$ | 0.26 | $2.1 \pm 0.8$ | 2 | 0.2 pb |
| $Z'_{350} \to t\bar{t} \to e \not{E}_T\, 4j$ | 0.11 | $18.7 \pm 4.0$ | 20 | 1.1 pb |
| $Z'_{450} \to t\bar{t} \to e \not{E}_T\, 4j$ | 0.14 | $18.7 \pm 4.0$ | 20 | 0.9 pb |
| $Z'_{550} \to t\bar{t} \to e \not{E}_T\, 4j$ | 0.14 | $3.8 \pm 1.0$ | 2 | 0.3 pb |
| $Wh_{115} \to e \not{E}_T\, 2j$ | 0.08 | $37.3 \pm 8.2$ | 32 | 2.0 pb |
| $Zh_{115} \to ee\, 2j$ | 0.20 | $19.5 \pm 4.1$ | 25 | 0.8 pb |
| $LQ_{225}\overline{LQ}_{225} \to ee\, 2j$ | 0.33 | $0.3 \pm 0.1$ | 0 | 0.07 pb |

| Story | Fit | $\log_{10} \frac{p(s+b)}{p(b)}$ |
|---|---|---|
|   |   | 7 |
|   |   | 5 |
|   |   | 3 |

Compose: New Physics <2>

File Edit View Options Tools Window Help

Send Address Attach Spell Security Save

From: Bard <bard@fnal.gov>

To: witten@ias.princeton.edu

Subject: New Physics

```
Dear Prof Witten,

    I have analyzed the excesses observed in the data,
and have determined the following stories, ranked in descending
log likelihood:

Story 1
Particles (SU(3),Q,type)
          sss            osv            t4/3f

Mass (GeV)
          251+/-12       1043+/-102     341+/-73

Interactions
          sss b b        sss w+ w-      sss t4/3f t4/3f~ ....

Coupling
          .1+/-.03       .3+/-.1        1.0+/-0.3  ....

Story 2
...
...


Could you please tell us the correct string vacuum?


Sincerely,
the Bard
```

# Bard

HEP-PH 0602101

**BARD: Interpreting New Frontier Energy Collider Physics**

Bruce Knuteson*
*MIT*

Stephen Mrenna†
*FNAL*

# New Particles

```
sss     sss     s   d   npm(1)   npW   s   Xsss   31
ssf     ssf~    f   s   npm(2)   npW   s   Xssf   32
szs     szs     s   d   npm(3)   npW   s   Xszs   33
szf     szf~    f   s   npm(4)   npW   s   Xszf   34
sas     sas~    s   d   npm(5)   npW   s   Xsas   35
saf     saf~    f   s   npm(6)   npW   s   Xsaf   36
sbs     sbs~    s   d   npm(7)   npW   s   Xsbs   37
sbf     sbf~    f   s   npm(8)   npW   s   Xsbf   38
scs     scs~    s   d   npm(9)   npW   s   Xscs   39
scf     scf~    f   s   npm(10)  npW   s   Xscf   40
...
oss     oss     s   d   npm(51)  npW   o   Xoss   81
osf     osf~    f   s   npm(52)  npW   o   Xosf   82
ozs     ozs     s   d   npm(53)  npW   o   Xozs   83
ozf     ozf~    f   s   npm(54)  npW   o   Xozf   84
ssv     ssv     v   w   npm(55)  npW   s   Xssv   85
osv     osv     v   w   npm(56)  npW   s   Xosv   86
scv     scv~    v   w   npm(57)  npW   s   Xscv   87
...
```

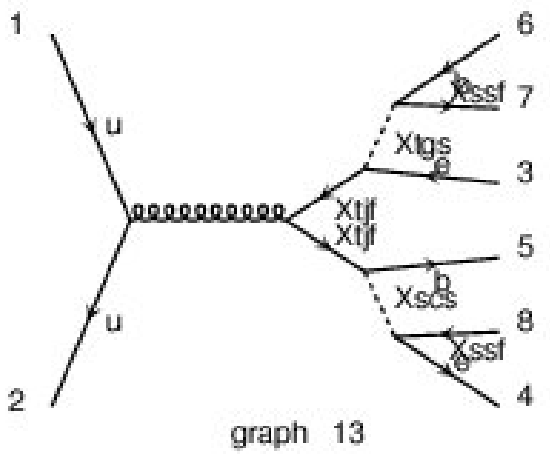
# New Interactions

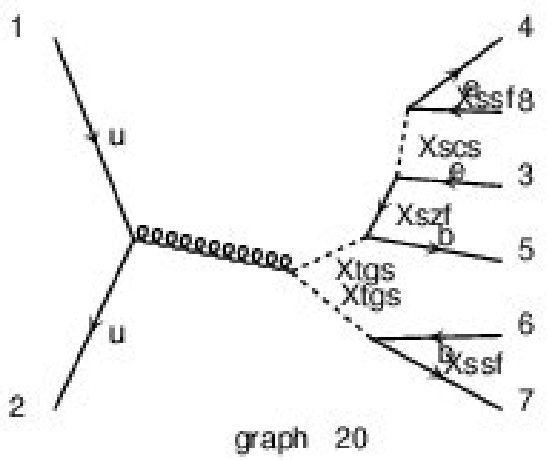
```
a      sas    sas~     np_coupl_c(453)   QNP
a      sbs    sbs~     np_coupl_c(455)   QNP
a      scs    scs~     np_coupl_c(457)   QNP
...
b      u      scs~     np_coupl_cLR(261)   QNP
b      u      scv~     np_coupl_rLR(41)   QNP
d      b      oss      np_coupl_cLR(408)   QNP
d      b      osv      np_coupl_rLR(27)   QNP
d      b      ozs      np_coupl_cLR(418)   QNP
d      b      sss      np_coupl_cLR(183)   QNP
...
z      tss    tzs~     np_coupl_c(466)   QNP
z      tzs    tzs~     np_coupl_c(474)   QNP
z      w+     scs~     np_coupl_c(438)   QNP
...
```

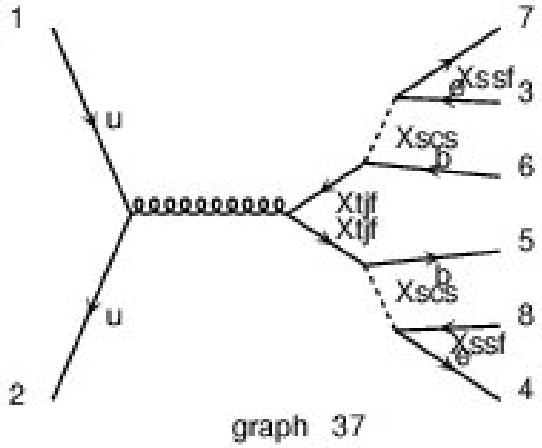
# Pruning Rules

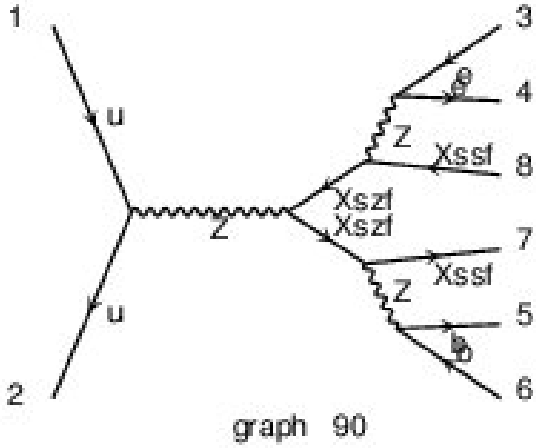
1. NP must couple to the initial state or an annihilation particle
2. SM particles must couple to either the initial or final state
3. No more than $n$ NP particles can appear in a given diagram
4. NP particles can appear twice only in separate chains
5. $\cdots$

# Pmiss Final States

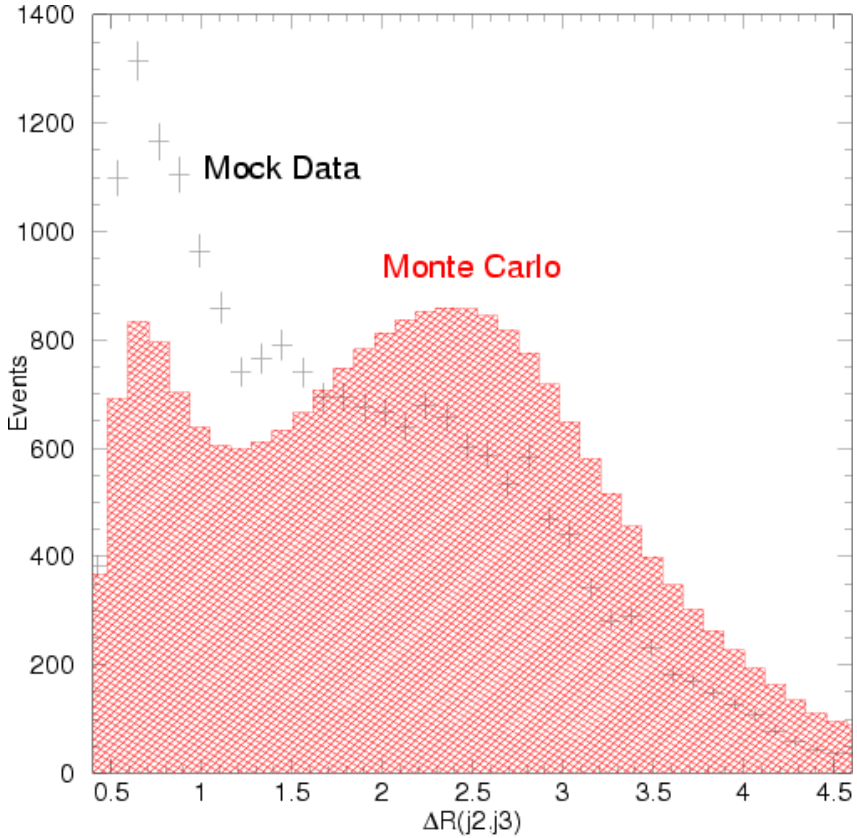


# *Debunking* Anomalies
## Unexpected Consequences



# The Bard at the LHC

- LHC phenomenology begins with understanding the Standard Model
- A look at the full Vista of final states at once is necessary to disentangle the components
- Discrepancies can and will arise in specific final states
- Bard can write a series of ranked stories to describe each
  - bottom-up
- Can test this on Run2 data

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- It works

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- Discrepancies can and will arise in specific final states
- Bard can write a series of ranked stories to describe each
  - bottom-up
- Can test this on Run2 data
- It works
- No, we haven't found anything $\cdots$ yet

## Algorithm — Signal events

1) The signal Monte Carlo is processed

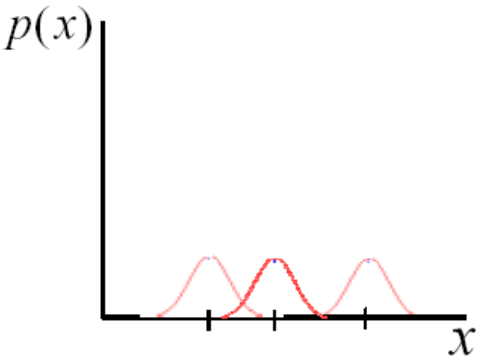
- (events are generated using Pythia, if requested)
- events are smeared with a fast detector simulation
- selection criteria are applied for desired final state
- particle identification efficiencies are considered

This gives

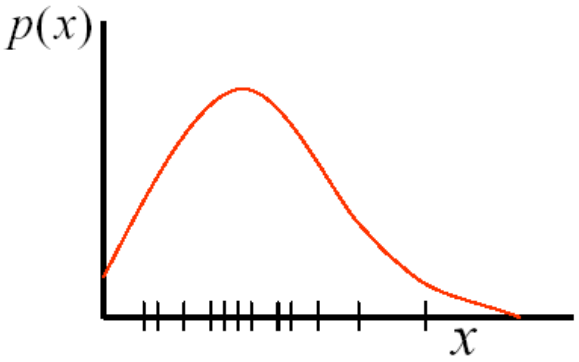
- total number of expected signal events in final state
- Monte Carlo signal events as they would look in the detector

2) An optimal region is chosen in the variables provided

a) Estimate signal and background densities using kernels




1) place "bumps of probability" around each Monte Carlo point




2) sum these bumps into a continuous distribution

$$p(x) = \sum_{i=1}^{N} \mathrm{gauss}(x - x_i)$$

The multivariate generalization is immediate

b) Define a *discriminant*

$$D(x) = \frac{p(x \mid s)}{p(x \mid s) + p(x \mid b)}$$

and choose a cut on D(x) that minimizes

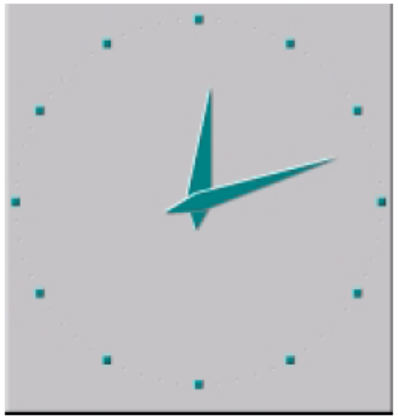
*the 95% CL cross section limit you would expect to set assuming the data contains no signal.*

We call 1/this quantity the "sensitivity"

Note that so far we have made no use of the data

3) Comparing number of observed events in the data to expected bkg, set 95% CL cross section limit on signal

4) Result is returned by email



Total elapsed time ≈ 1 hour

**From:** quaero@fnal.gov
**Subject:** Quaero Request #29

$W_R \to t\bar{b} \to e\not{E}_T\, 2j$

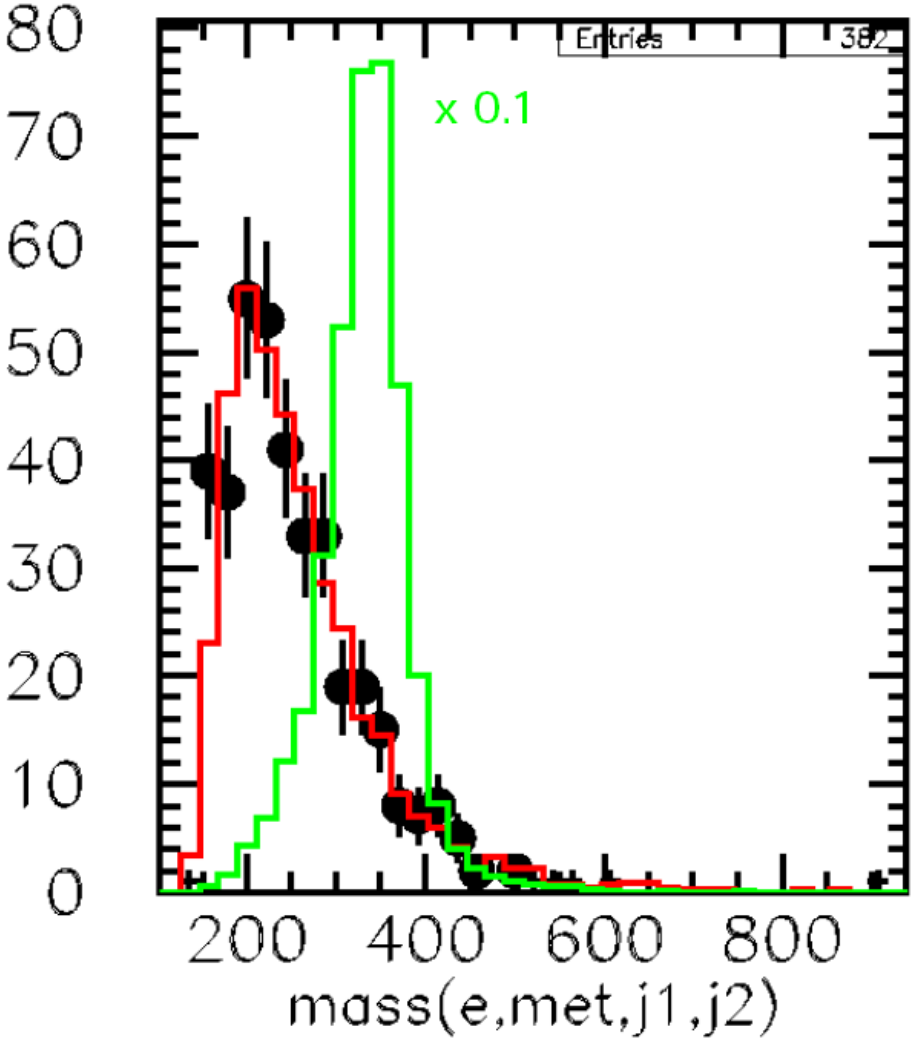
## Result

Pythia cross section x branching ratio = 1.68 pb.

Upper limits on the cross section to this process at confidence levels of 50%, 90%, and 95% are found to be 0.8 pb, 1.8 pb, and 2.1 pb, respectively. Maximal sensitivity (0.73 $pb^{-1}$) is achieved in a region of variable space with 17.6 signal events expected, 32.7 +- 7.1 background events expected, and 36 events observed in the data.

## Plots

Plots of the variables that you used are available for viewing at http://quaero.fnal.gov/quaero/requests/plots/29.ps. The red curve is the expected background; the green curve is your signal multiplied by a factor of 10; the black dots are D0 data.


80
70
60
50
40
30
20
10
0
Entries
382
x 0.1
200
400
600
800
mass(e,met,j1,j2)

## Leptoquarks → ee 2j

**Variables**

Constraints:

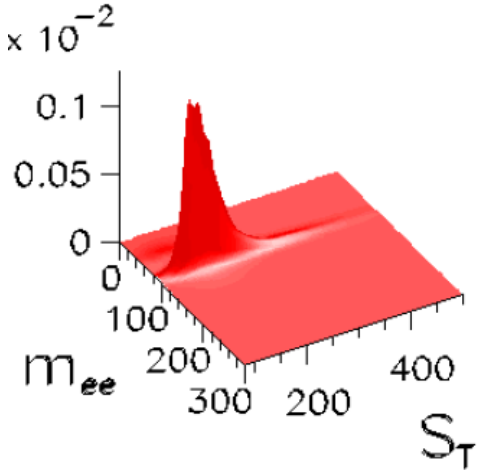
Variables:

v1 e1_pt + e2_pt + j1_pt + j2_pt + j3_pt + j4_pt

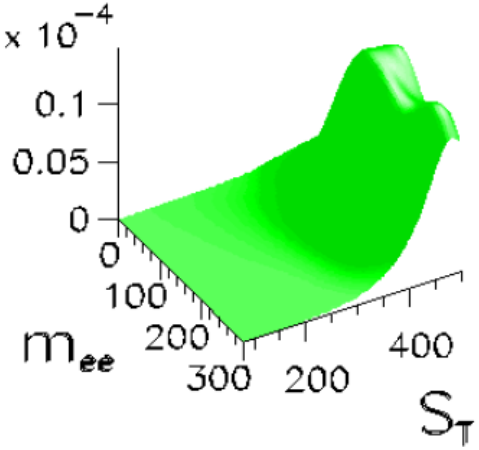
v2 mass(e1,e2)

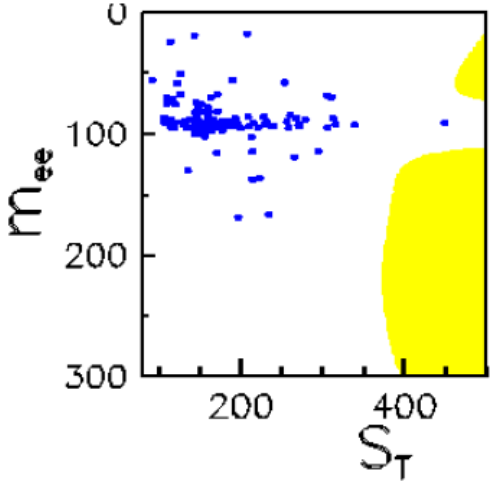
| | |
|---|---|
| $\varepsilon_{sig}$ | 33% |
| $\hat{b}$ | $0.3 \pm 0.1$ |
| $N_{obs}$ | 0 |
| $\sigma^{95\%} \times \mathcal{B}$ | 0.07 pb |

Background density




Signal density




Selected region