LHC Phenomenology

A Bard's-Eye View

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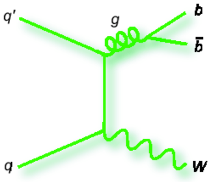
Computing Division
Fermilab

Aspen Winter Workshop 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!!!

Warm-Up

How much does the $t\bar{t}$ cross section change from TeV to LHC?

- $10\times$
- $100\times$
- $500\times$

[Kidonakis]

Warm-Up

How much does the $t\bar{t}$ cross section change from TeV to LHC?

- 10×
- 100×
- 500×

[Kidonakis]

Warm-Up

How much does the $\widetilde{\chi}^+\widetilde{\chi}^-(m_\chi = 200 \text{ GeV})$ cross section change from TeV to LHC?

- $10\times$
- $100\times$
- $500\times$

[Pythia]

Warm-Up

How much does the $\widetilde{\chi}^{+}\widetilde{\chi}^{-}(m_{\chi} = 200\ \mathrm{GeV})$ cross section change from TeV to LHC?

- $10\times$
- $100\times$
- $500\times$

[Pythia]

Warm-Up

How much does the $W4j$ cross section change from TeV to LHC?

- $10\times$
- $100\times$
- $500\times$

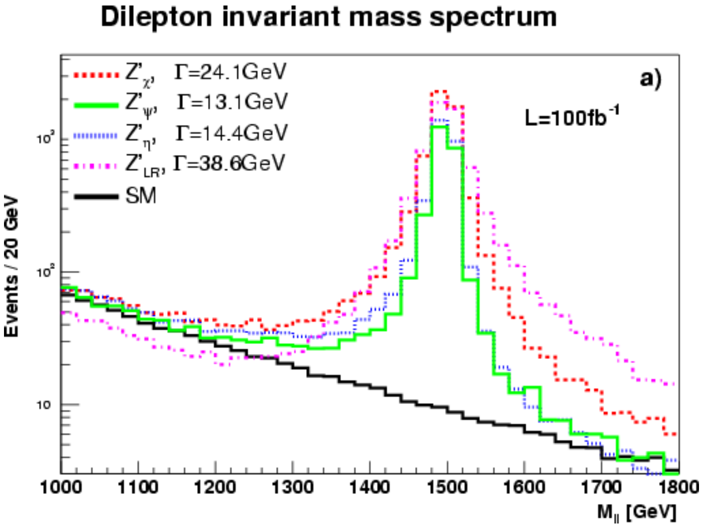
[MadEvent, $k_T > 20$ GeV]

How much does the $W4j$ cross section change from TeV to LHC?

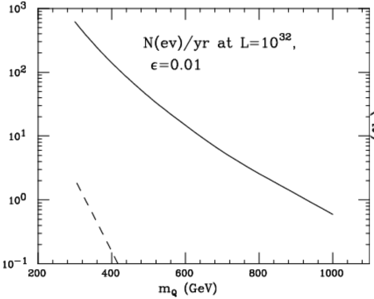
- $10\times$
- $100\times$
- $500\times$

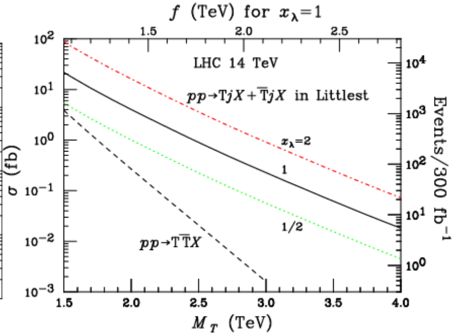
[MadEvent, $k_T > 20$ GeV]

$Z' \to \ell\ell$



DITTMAR,NICOLLERAT,DJOUADI 03 See also, Carena *et al.* for model-lines



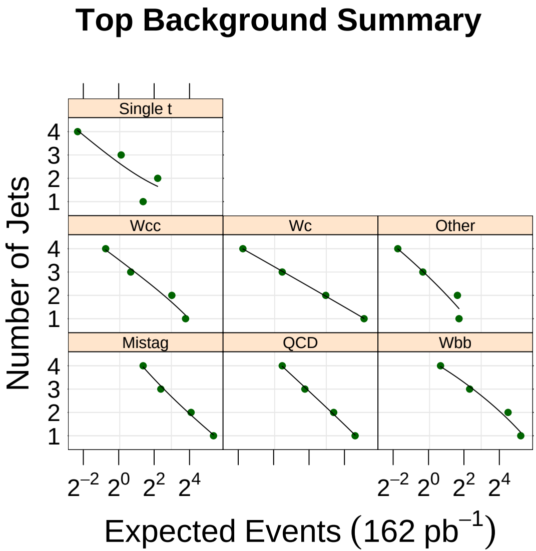


MLM

HAN,LOGAN,WANG

First Steps

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



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

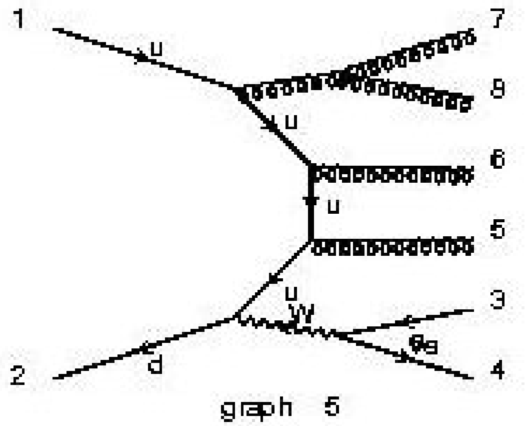
Measure $W + jets$ (no b-tag)

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

Wcj/Wbb from Monte Carlo

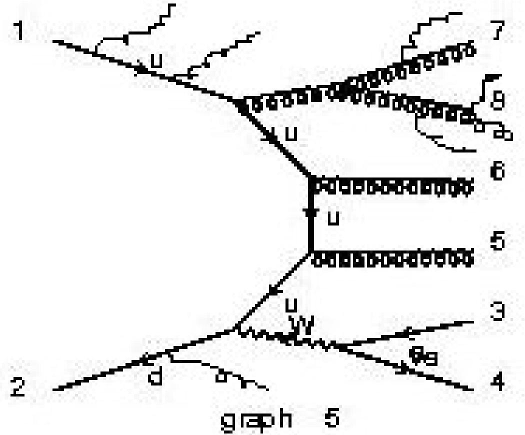
- Several R's

High Multiplicity Tree Graph

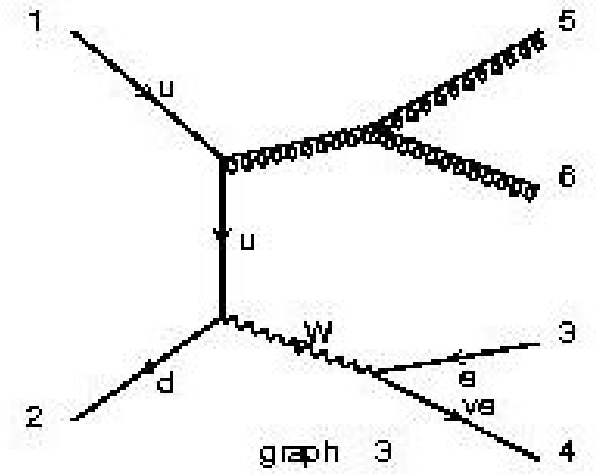


Toolkit

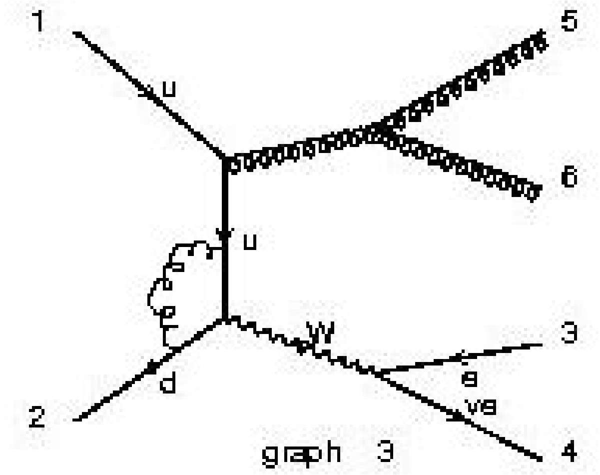
Tree Graph + Parton Shower



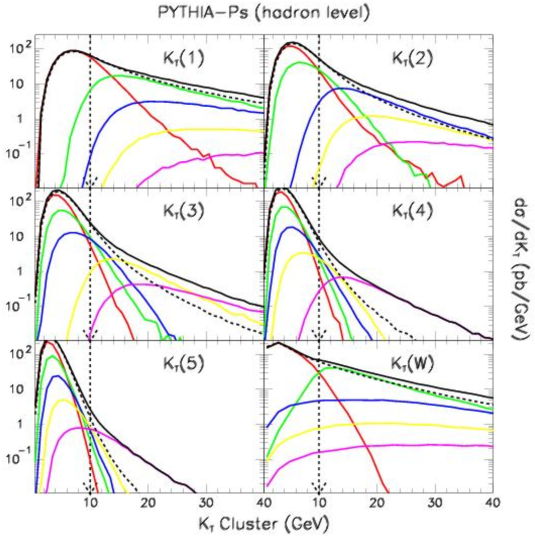
Lower Multiplicity Tree Graph



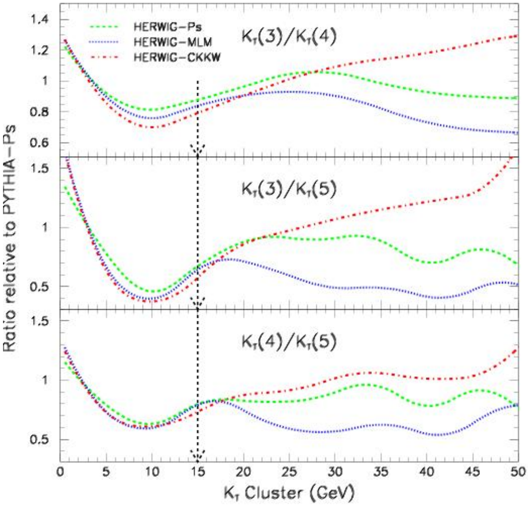
Lower Multiplicity NLO Graph



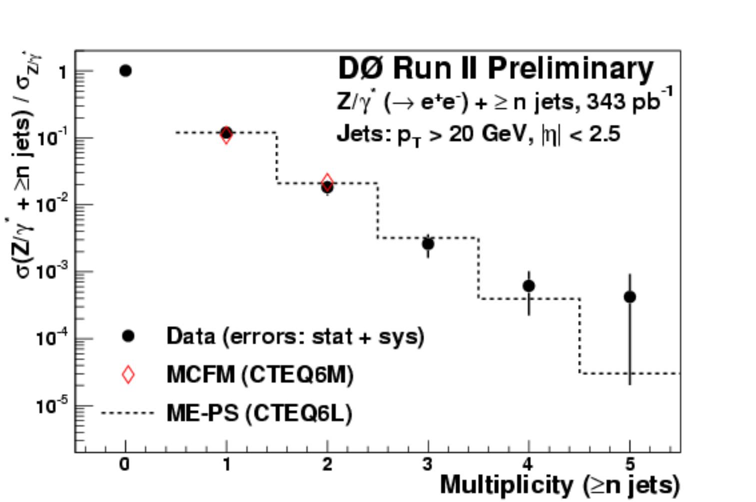
Make Better Predictions



Address Uncertainty



Cross check on Run2 data



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

Single Top

New Physics Warm-Up

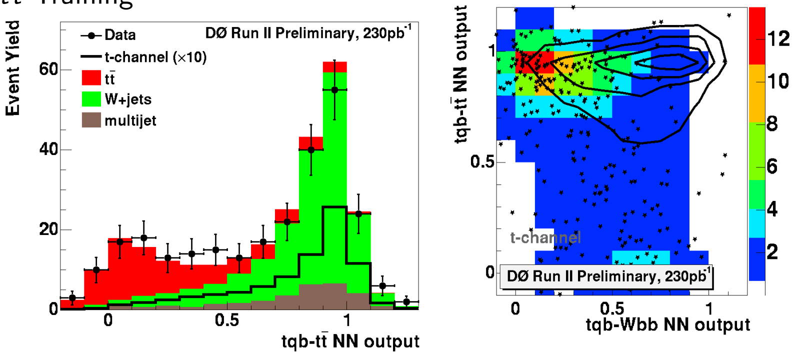
- current state of single-Top is where we will be at the LHC with a few quality fb^{-1}
- the size of other NP signals
- it is a playground for new analysis techniques
- it challenges our tools

  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				
$\Delta R(\text{jet1},\text{jet2})$	$\surd$	—	$\surd$	—
$Q(\text{lepton}) \times \eta(\text{jet1}_{\text{untagged}})$	—	—	$\surd$	$\surd$
$\cos(\text{lepton}, Q(\text{lepton})\times z)_{\text{top}_{\text{best}}}$	$\surd$	—	—	—
$\cos(\text{lepton}, \text{jet1}_{\text{untagged}})_{\text{top}_{\text{tagged}}}$	—	—	$\surd$	—
$\cos(\text{alljets}, \text{jet1}_{\text{tagged}})_{\text{alljets}}$	—	—	$\surd$	$\surd$
$\cos(\text{alljets}, \text{jet}_{\text{nonbest}})_{\text{all jets}}$	—	$\surd$	—	—

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

$t\bar{t}$ Training

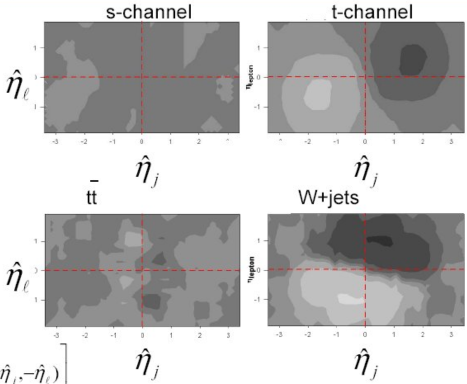


- How do we convince ourselves of a signal?
- How can we improve upon the search?

F_ For All Channels

Bowen et al

- At LO, tt removed
- t-channel and W+jets are comparable in size
- Caveat: NLO tt correction from Kuhn and Rodrigo, '98
- Expect QCD contribution to be small



pseudo-rapidity weighted by lepton charge

$$F_- = \frac{1}{2}\left[\frac{d^2\sigma}{d\hat{\eta}_j d\hat{\eta}_\ell}(\hat{\eta}_j,\hat{\eta}_\ell) - \frac{d^2\sigma}{d\hat{\eta}_j d\hat{\eta}_\ell}(-\hat{\eta}_j,-\hat{\eta}_\ell)\right]$$

4/29/2004 CERN TeV4LHC Meeting

Tevatron hard. Exploit charge asymmetry at LHC.

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

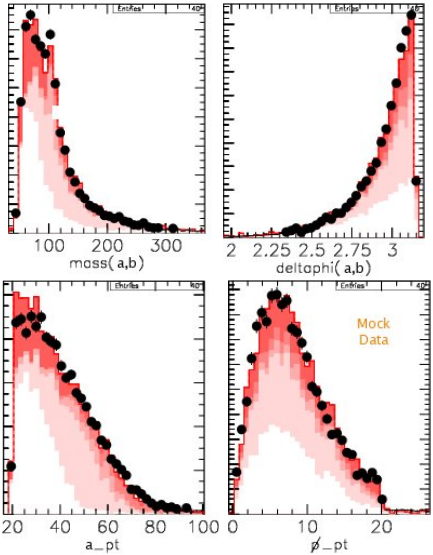
Final State	Chi2	data	bkg			
1b3j1pmiss_sumPt400+ [73]	9.0	451	374.5	+-	18	(pyth
2b1e+2j [-]	8.0	15	6.5	+-	1.9	(ttop
2j_sumPt0-400 [161]	6.0	69704	67013.6	+-	1171.2	(pyth
7b7j1ph1pmiss [-]	6.0	7	7.1	+-	1.6	(pyth
2j2mu+1pmiss [-]	-5.0	2	12.2	+-	3	(mad_
1b2e+2j [-]	5.0	9	3.9	+-	1.5	(mren
1j1ph1pmiss [5]	4.0	2591	2470.1	+-	37.7	(pyth
2j1mu+1ph [-]	4.0	11	11.2	+-	2.2	(mren
1e+1j1mu+ [-]	4.0	13	6.6	+-	2.1	(ztop
1e+2j1ph [-]	4.0	31	20.9	+-	2.7	(mad_
3j2mu+ [-]	4.0	34	23.2	+-	2.7	(mren
2b2j1pmiss_sumPt400+ [-]	-3.0	17	30.4	+-	4.2	(pyth
1b2j_sumPt400+ [229]	3.0	4669	4518.6	+-	72.7	(pyth
4j_sumPt0-400 [253]	-3.0	2611	2736.9	+-	42.3	(pyth
2b1j1ph1pmiss [-]	3.0	6	2.7	+-	1.5	(pyth
1b1j1mu+ [-]	3.0	67	53.8	+-	4.3	(pyth
1j1ph [277]	3.0	31738	31149.8	+-	352.1	(pyth
1e+1mu+ [-]	3.0	66	53.5	+-	3.2	(ztop
4j1mu+ [-]	3.0	73	61.3	+-	2.6	(pyth
5j [269]	3.0	448	406	+-	14.5	(pyth
1b5j [-]	3.0	8	8.9	+-	1.7	(pyth
1b1j1pmiss_sumPt0-400 [-]	2.0	120	104	+-	7.2	(pyth
2j1pmiss_sumPt0-400 [37]	2.0	2381	2281.2	+-	73.9	(pyth

...

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

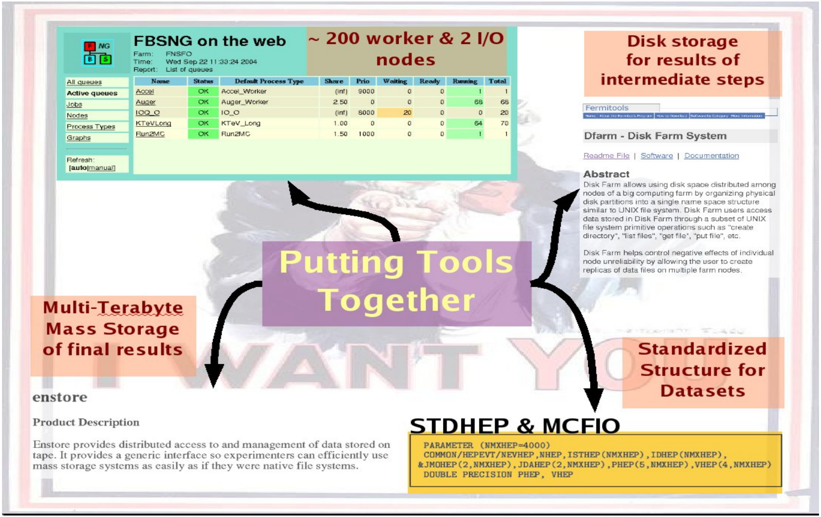
```
( mrenna_e+e-jjj = 1.9 , mad_e+e-jj = 0.5 , mrenna_e+e-jj = 0.4 , mad_e+e-b-b = 0.4 ,
        ztopcz = 0.3 , pyth_jj_040 = 0.2 , mad_aajj = 0.1 , mrenna_e+vejjjj = 0.1 ,
        hewk03 = 0.1 , wtop1z = 0.1 )
```

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
I WANT YOU
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

Georgios Choudalakis,* Khaldoun Makhoul,† Markus Klute,‡ Conor Henderson,§ and Bruce Knuteson¶
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 ≈ 600 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV reveals no indication of physics beyond the Standard Model.

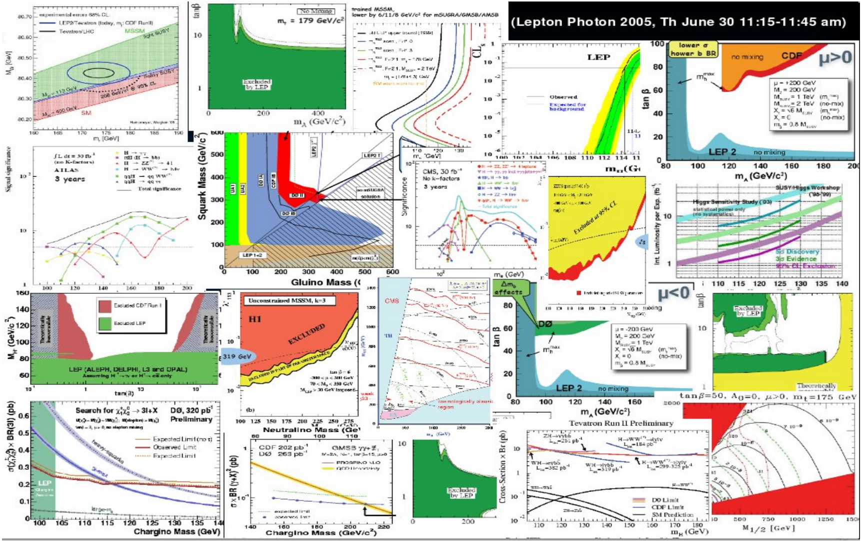
Contents

I. MOTIVATION

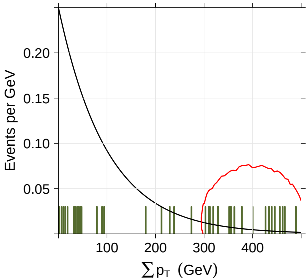
- Use the data to test our modelling of fakes

Midterm Summary

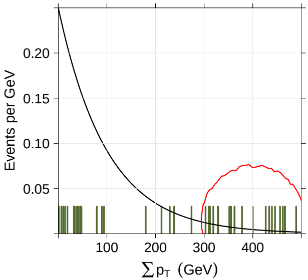
- The first New Physics to find is the Standard Model
- Need complete description of most important processes
- Understanding comes from looking at consistency of full dataset
- Then, how do we find New Physics?

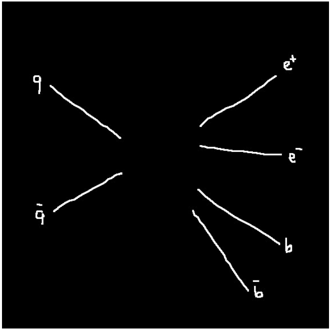

(Lepton Photon 2005, Th June 30 11:15-11:45 am)
No Mixing
Excluded by LEP
MSSM
SM
Squark Mass (GeV/c²)
Gluino Mass
LEP
Observed
Expected for background
CDF
μ>0
no mixing
LEP 2
tan β
ATLAS
3 years
Total significance
CMS, 30 fb⁻¹
No k-factors
3 years
SUSY/Higgs Workshop
Higgs Sensitivity Study ('03)
5σ Discovery
3σ Evidence
95% CL Exclusion
μ<0
Excluded CDF Run I
Excluded LEP
LEP (ALEPH, DELPHI, L3 and OPAL)
Unconstrained MSSM, k=3
H1
EXCLUDED
319 GeV
Neutralino Mass
CMS
DØ
LEP 2
Search for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3l+X$
DØ, 320 pb⁻¹
Preliminary
Expected Limit
Observed Limit
Chargino Mass (GeV)
CDF 202 pb⁻¹
DØ 263 pb⁻¹
GMSB γγ+$\not{E}_T$
Chargino Mass (GeV/c²)
Tevatron Run II Preliminary
Cross-Section × Br (pb)
DØ Limit
CDF Limit
SM Prediction
m_H (GeV)
tanβ=50, A₀=0, μ>0, mₜ=175 GeV
$M_{1/2}$ [GeV]

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

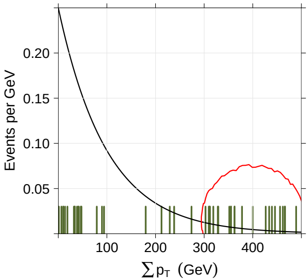


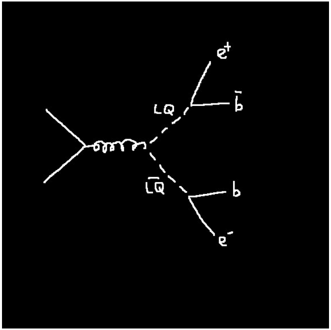
$e^+e^- b\bar{b}$ Final State



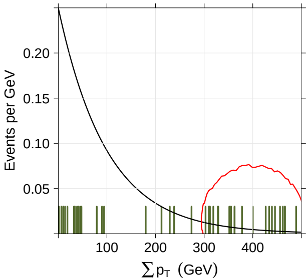


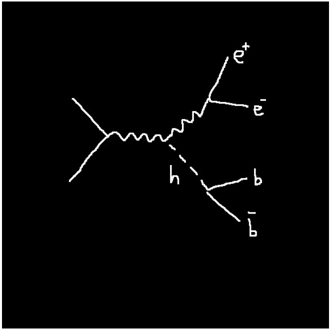
$e^+e^-b\bar{b}$ Final State



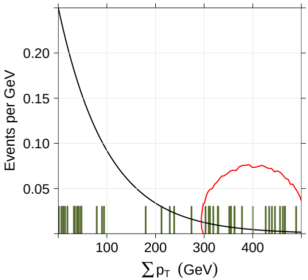


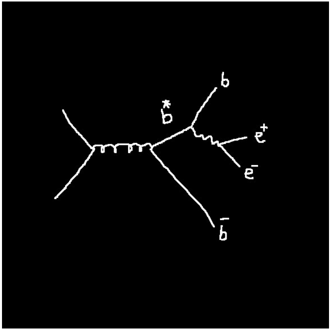
$e^+e^-b\bar{b}$ Final State

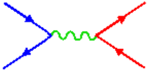




$e^+e^-b\bar{b}$ Final State

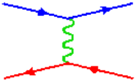






MadGraph HomePage

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 jjjj 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

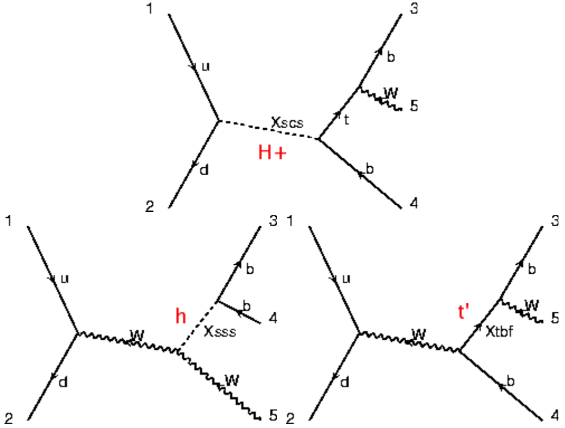
$$\mathcal{L}_{\tt FFV} = \bar{f}'\gamma^{\mu}\left({\tt G}(1)\frac{1-\gamma_5}{2} + {\tt G}(2)\frac{1+\gamma_5}{2}\right) f V_{\mu}^{*}$$

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

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

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

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


1
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W
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1
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W
h
Xsss
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W
5
1
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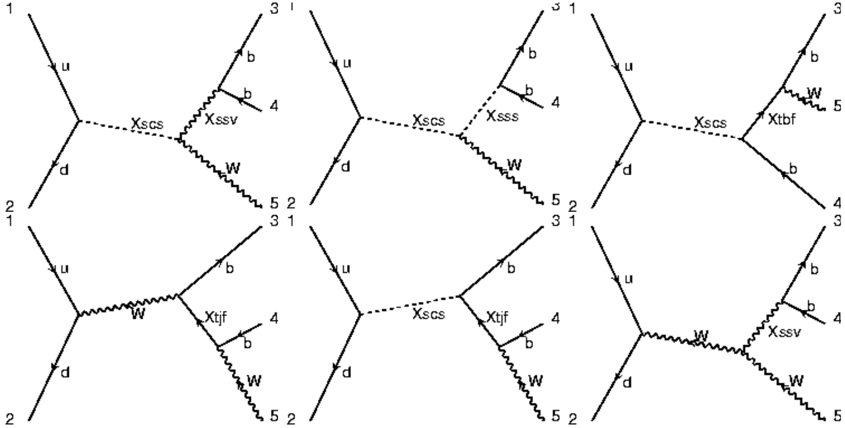
d
2
W
t'
Xtbf
3
b
W
5
b
4


1
u
d
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Xscs
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4
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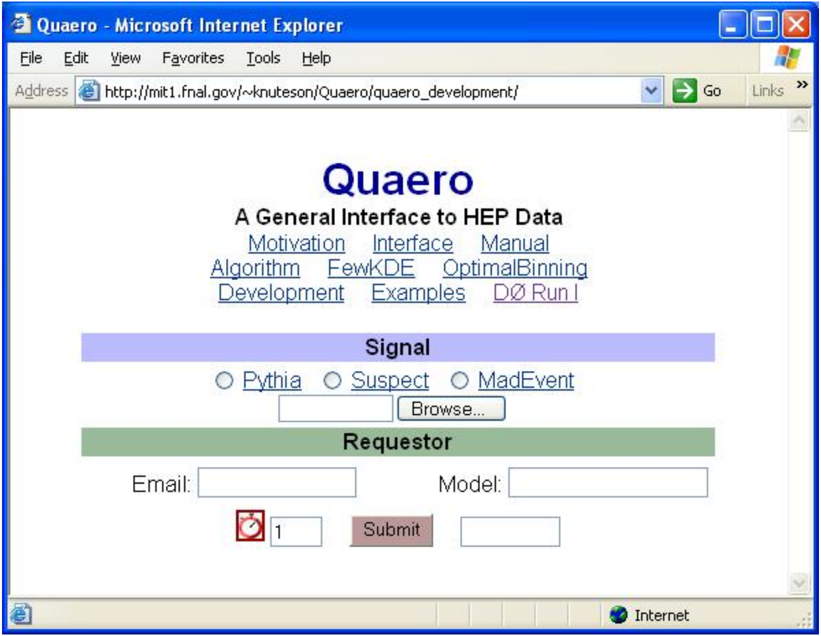
Xsss
Xtbf
W
b
Xtjf


Quaero - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Address http://mit1.fnal.gov/~knuteson/Quaero/quaero_development/
Go Links
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

Examples #11

Leptoquarks $\rightarrow$ ee 2j

Variables

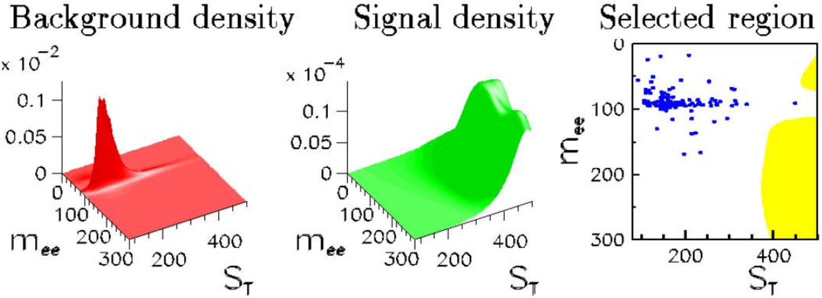
Constraints:

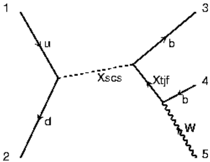
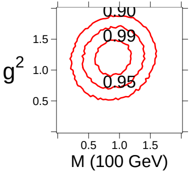
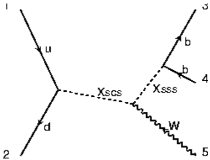
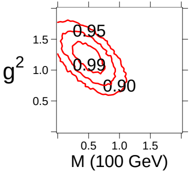
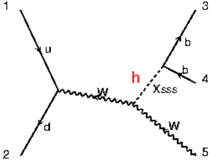
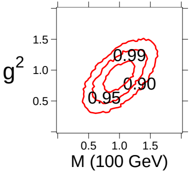
Variables:

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

v2 mass(e1,e2)

ε_{sig}	33%
$\hat{b}$	0.3 ± 0.1
N_{obs}	0
$\sigma^{95\%} \times \mathcal{B}$	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

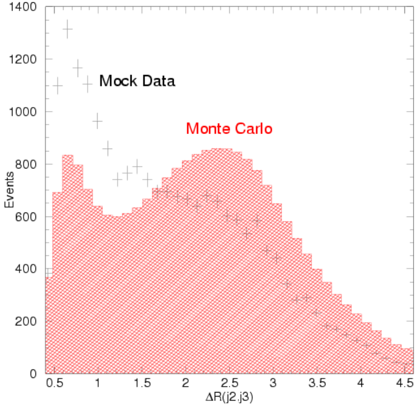
Subject: New Physics

```
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: Interpreting New Frontier Energy Collider Physics

Bruce Knuteson[*]
MIT

Stephen Mrenna[†]
FNAL



Mock Data
Monte Carlo
Events
ΔR(j2,j3)
1400
1200
1000
800
600
400
200
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

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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- LHC phenomenology begins with understanding the Standard Model
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- 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

Extra Slides

MLM Method

Parton shower and hadronization are essential for studying b-jets

- Parton shower W+Npartons but reject emissions that are too hard (i.e. each post-shower jet should have a pre-shower parton associated with it)
- Build up *inclusive* or *exclusive* samples (i.e. allow or disallow pure PS jets)
- $\delta R/R \sim 25-30\%$

Why it works

- For each N, PS does not add any jet harder than $p^2_{T\,cut}$
- Can safely add different N samples with no double-counting
  - Apply looser rejection on highest N
- Pseudo-showers assure correct PS limit, while retaining hard emissions
  - Interpolates between limits

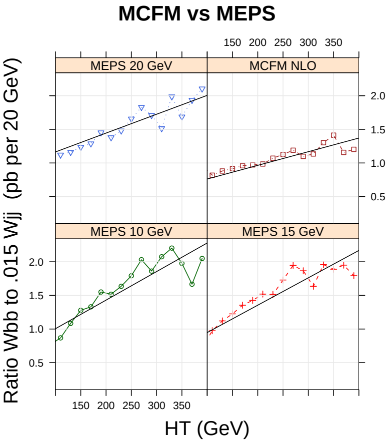
Understanding W+Jets is Critically Important

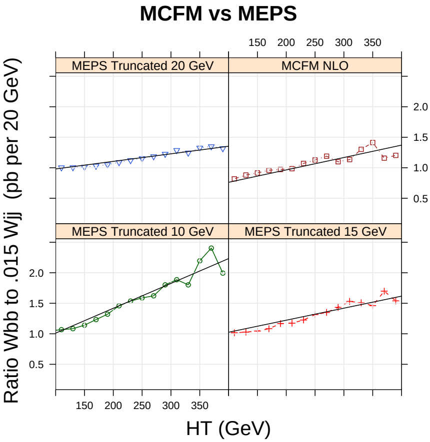
- Signature $Wb\bar{b} + X$ is common to unconfirmed Standard Model processes and many new physics processes
- we "know" that Standard Model top is there

$$\text{Top} \equiv \text{Data} - \text{Not-Top}$$

- As JES uncertainty is reduced (CDF m_t), understanding of Not-Top sets/limits understanding of Top
- Advanced (i.e. NN, DT) search techniques for single t exploit differences in many (11) kinematic variables
- Not-Top challenges our tools

Better tools $\Rightarrow$ more challenging questions



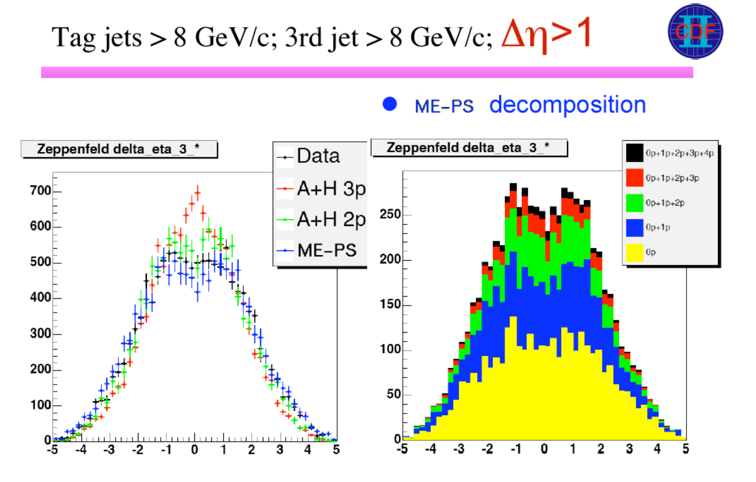


Matched Datasets have consistently steeper slopes (note: MCFM steeper than LO)

Truncated Datasets contain only $Wb\bar{b} + Wb\bar{b}j$

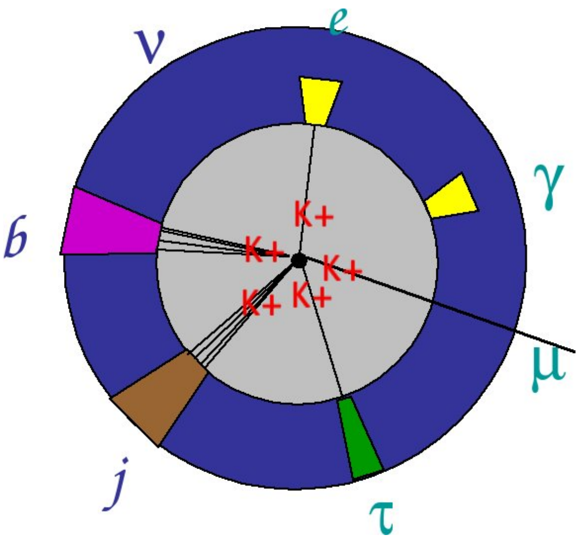
Slopes more consistent with MCFM

Kinematic comparisons with Run2 data



$$\eta_3^* = \eta_3 - \frac{\eta_1 + \eta_2}{2}, \text{ A+H} \equiv \text{Alpgen+Herwig}$$

Understanding Fakes



Understanding Fakes (cont)

Knuteson, Culbertson, *et al.*

	e^+	e^-	μ^+	μ^-	τ^+	τ^-	γ	j
e^+	62154	33	0	0	1161	1	3749	25913
e^-	24	62300	0	0	0	1156	3730	25817
μ^+	0	0	50330	0	15	0	0	596
μ^-	0	1	0	50294	0	11	0	573
γ	1381	1326	0	0	8	14	67732	21372
π^0	1196	1208	0	0	25	34	59727	31651
π^+	266	0	115	0	72113	42	117	23908
π^-	1	352	0	88	80	71491	169	24499
K^+	150	1	272	1	73333	36	49	21670
K^-	1	249	0	163	112	71701	151	23654

TABLE XIV: Central single particle misidentification matrix. Using a single particle gun, 10^5 particles of each type shown at the left of the table were shot with $p_T = 25$ GeV into the central CDF detector, uniformly distributed in θ and in ϕ.