# Precision Measurements, Small Cross-sections, and Non-Standard Signatures: The Learning Curve at a Hadron Collider

Henry Frisch
University of Chicago

**Theme: What Wu-Ki knows and has been telling us- careful and thoughtful understanding of the parton/hadron (and hadron/parton) relationship is essential at the Tevatron and LHC. Most folks haven't yet caught on-but they will!**

# This is The Wisdom about working at the Tevatron or LHC

## Global QCD Analysis and Hadron Collider Physics*

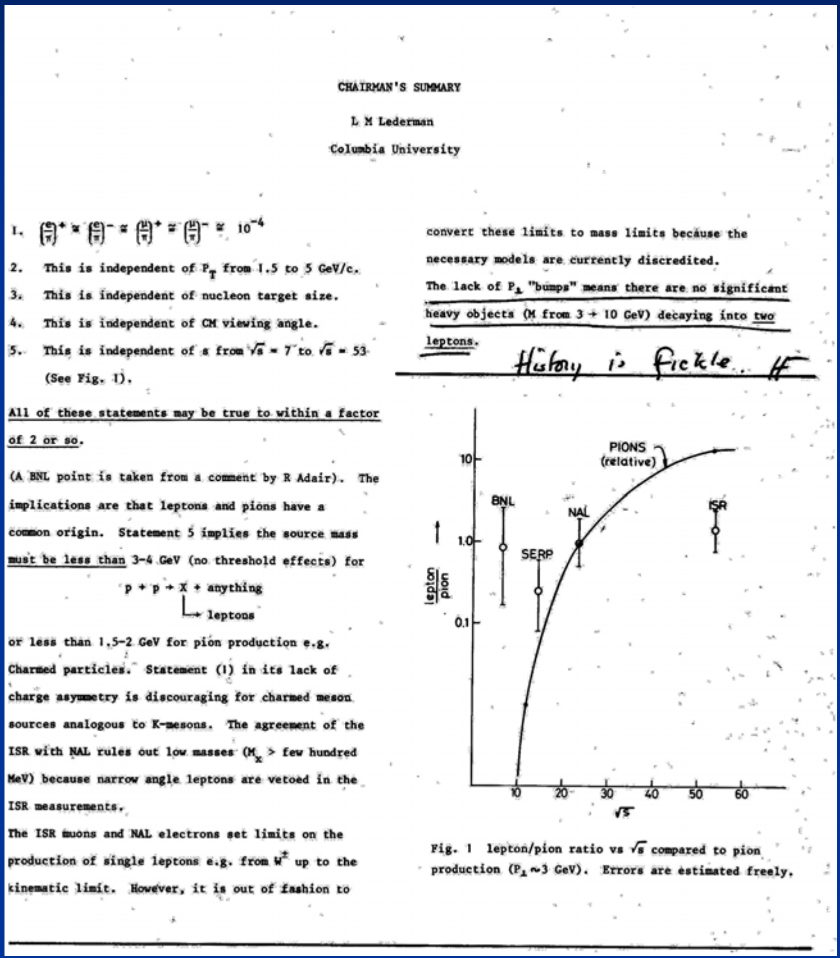
Wu-Ki Tung†
Michigan State University, E. Lansing, MI, USA

0139v1 10 Oct 2004

**Abstract**

The role of global QCD analysis of parton distribution functions (PDFs) in collider physics at the Tevatron and LHC is surveyed. Current status of PDF analyses are reviewed, emphasizing the uncertainties and the open issues. The stability of NLO QCD global analysis and its prediction on "standard candle" W/Z cross sections at hadron colliders are investigated. The importance of the precise measurement of various W/Z cross sections at the Tevatron in advancing our knowledge of PDFs, hence in enhancing the capabilities of making significant progress in W mass and top quark parameter measurements, as well as the discovery potentials of Higgs and New Physics at the Tevatron and LHC, is emphasized.

# Two cases of non-understanding of ‘What’s Beneath’



CHAIRMAN'S SUMMARY

L M Lederman

Columbia University

1. $\left(\frac{e}{\pi}\right)^+ \approx \left(\frac{e}{\pi}\right)^- \approx \left(\frac{\mu}{\pi}\right)^+ \approx \left(\frac{\mu}{\pi}\right)^- \approx 10^{-4}$
2. This is independent of $P_T$ from 1.5 to 5 GeV/c.
3. This is independent of nucleon target size.
4. This is independent of CM viewing angle.
5. This is independent of s from $\sqrt{s} = 7$ to $\sqrt{s} = 53$ (See Fig. 1).

All of these statements may be true to within a factor of 2 or so.

(A BNL point is taken from a comment by R Adair). The implications are that leptons and pions have a common origin. Statement 5 implies the source mass must be less than 3-4 GeV (no threshold effects) for

$$p + p \to X + \text{anything}, \quad X \to \text{leptons}$$

or less than 1.5-2 GeV for pion production e.g. Charmed particles. Statement (1) in its lack of charge asymmetry is discouraging for charmed meson sources analogous to K-mesons. The agreement of the ISR with NAL rules out low masses ($M_X$ > few hundred MeV) because narrow angle leptons are vetoed in the ISR measurements.

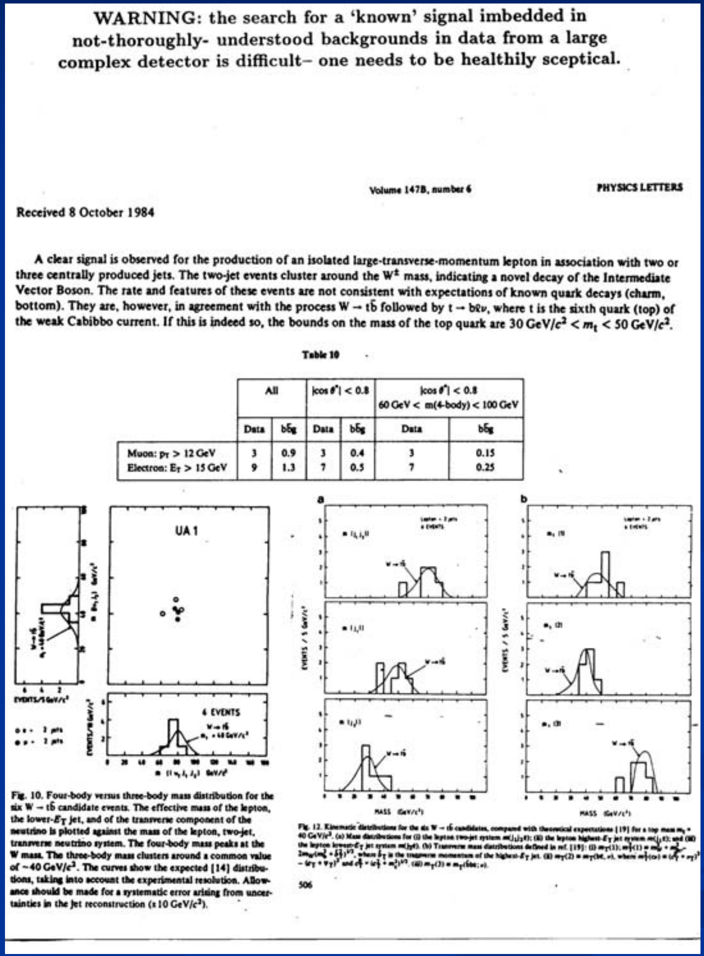
The ISR muons and NAL electrons set limits on the production of single leptons e.g. from $W^{\pm}$ up to the kinematic limit. However, it is out of fashion to convert these limits to mass limits because the necessary models are currently discredited.

The lack of $P_\perp$ "bumps" means there are no significant heavy objects (M from 3 → 10 GeV) decaying into two leptons.

History is fickle... H



Fig. 1 lepton/pion ratio vs $\sqrt{s}$ compared to pion production ($P_\perp \sim 3$ GeV). Errors are estimated freely.



WARNING: the search for a ‘known’ signal imbedded in not-thoroughly- understood backgrounds in data from a large complex detector is difficult– one needs to be healthily sceptical.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A clear signal is observed for the production of an isolated large-transverse-momentum lepton in association with two or three centrally produced jets. The two-jet events cluster around the $W^{\pm}$ mass, indicating a novel decay of the Intermediate Vector Boson. The rate and features of these events are not consistent with expectations of known quark decays (charm, bottom). They are, however, in agreement with the process $W \to t\bar{b}$ followed by $t \to b\ell\nu$, where t is the sixth quark (top) of the weak Cabibbo current. If this is indeed so, the bounds on the mass of the top quark are $30\ \mathrm{GeV}/c^2 < m_t < 50\ \mathrm{GeV}/c^2$.


Table 10

| | All | | $\lvert\cos\theta^*\rvert < 0.8$ | | $\lvert\cos\theta^*\rvert < 0.8$, 60 GeV < m(4-body) < 100 GeV | |
|---|---|---|---|---|---|---|
| | Data | $b\bar{b}g$ | Data | $b\bar{b}g$ | Data | $b\bar{b}g$ |
| Muon: $p_T$ > 12 GeV | 3 | 0.9 | 3 | 0.4 | 3 | 0.15 |
| Electron: $E_T$ > 15 GeV | 9 | 1.3 | 7 | 0.5 | 7 | 0.25 |



Fig. 10. Four-body versus three-body mass distribution for the six $W \to t\bar{b}$ candidate events. The effective mass of the lepton, the lower-$E_T$ jet, and of the transverse component of the neutrino is plotted against the mass of the lepton, two-jet, transverse neutrino system. The four-body mass peaks at the W mass. The three-body mass clusters around a common value of ~40 GeV/$c^2$. The curves show the expected [14] distributions, taking into account the experimental resolution. Allowance should be made for a systematic error arising from uncertainties in the jet reconstruction (±10 GeV/$c^2$).

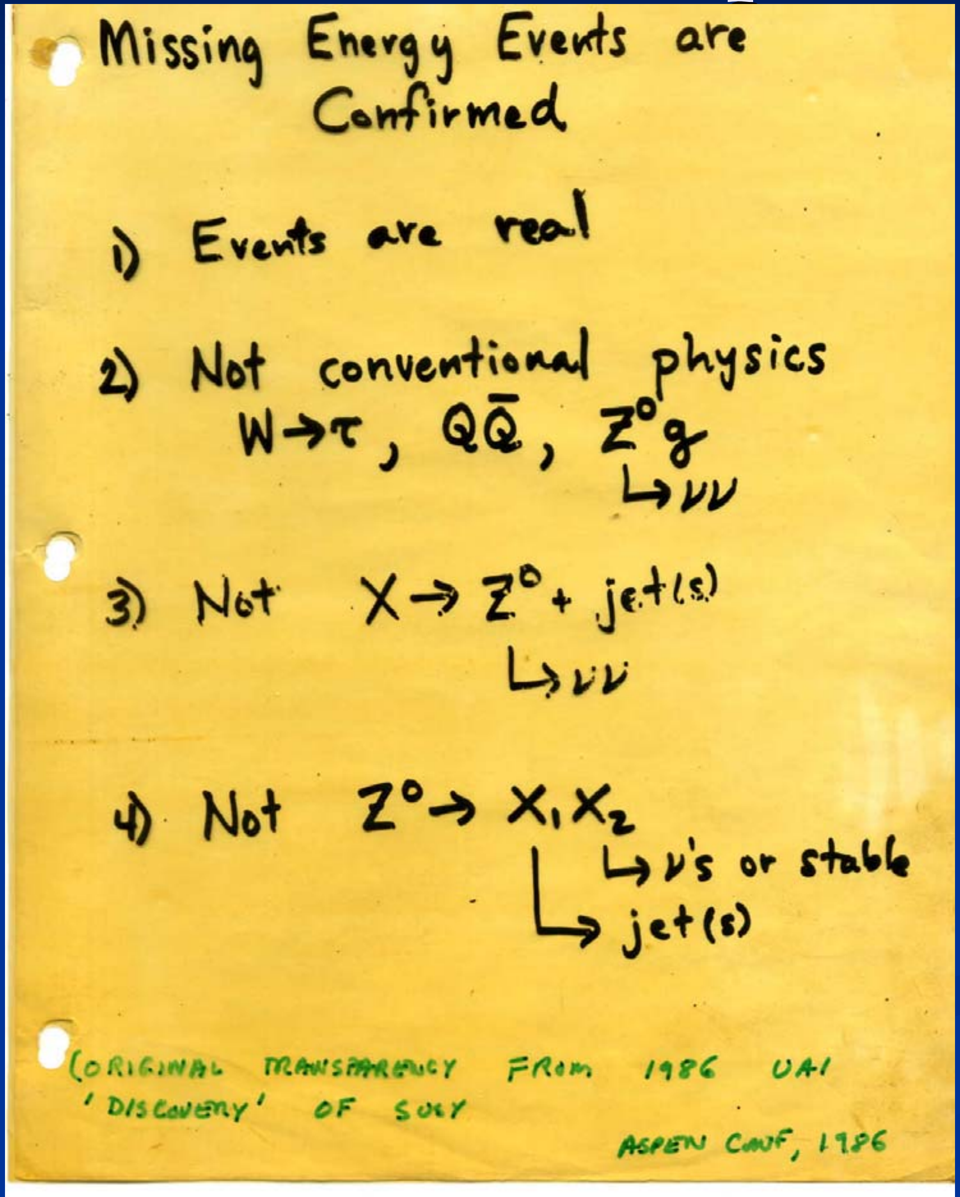
Fig. 12. Kinematic distributions for the six $W \to t\bar{b}$ candidates, compared with theoretical expectations [19] for a top mass $m_t$ = 40 GeV/$c^2$. [illegible]



Leon Lederman and 1971 J/Psi Non-discovery

Carlo and the 1984 Top ‘Discovery’

# Classic example of the importance of thorough SM predictions of what you expect



Missing Energy Events are Confirmed

1) Events are real

2) Not conventional physics
$W \to \tau$, $Q\bar{Q}$, $Z^0 g$
↳ $\nu\nu$

3) Not $X \to Z^0 + \text{jet(s)}$
↳ $\nu\nu$

4) Not $Z^0 \to X_1 X_2$
↳ $\nu$'s or stable
↳ jet(s)

(ORIGINAL TRANSPARENCY FROM 1986 UA1 'DISCOVERY' OF SUSY

ASPEN CONF, 1986

**1986 UA1 SUSY 'Discovery'! (ask Steve Ellis for details!)**

# Some topics woven in the talk: (part of the hadron collider culture)

1. 'Objects' and their limitations (e.g. em clusters)
2. Fake rates and efficiencies (z=1 limit and I-spin)
3. The rationale for signature-based searches
4. The problem of communicating experimental results in a model-independent way
5. The problem of Njets
6. Systematics-limiting variables
7. The doubling time: luminosity vs learning

# Acknowledgements

- Thanks to many CDF and D0 colleagues whose work I'll show… Also SM MC generator folks!
- Opinions are my own-

# 'Understanding Objects' and their limitations

## Example- electro-magnetic (em) cluster

Identify an em cluster as one of 3 objects: (CDF)

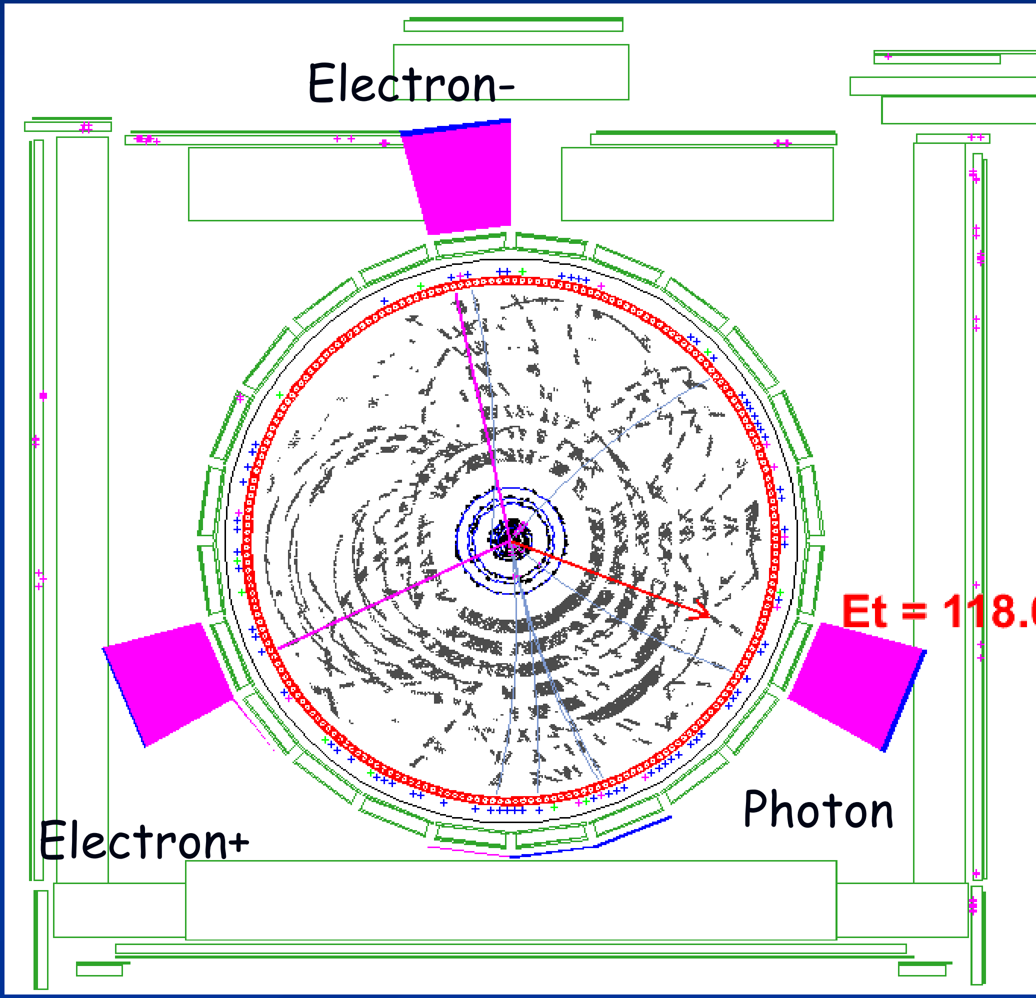
E/p < 2: Electron

E/p> 2: Jet

P <1: Photon

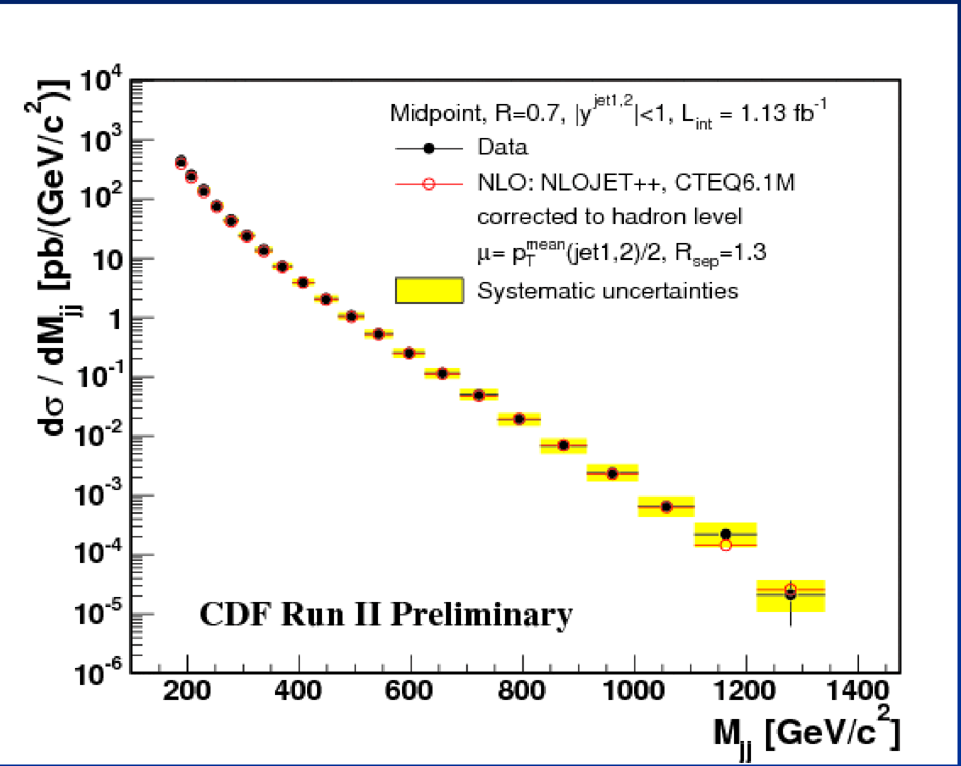
**Where p is from track, E is from cal**

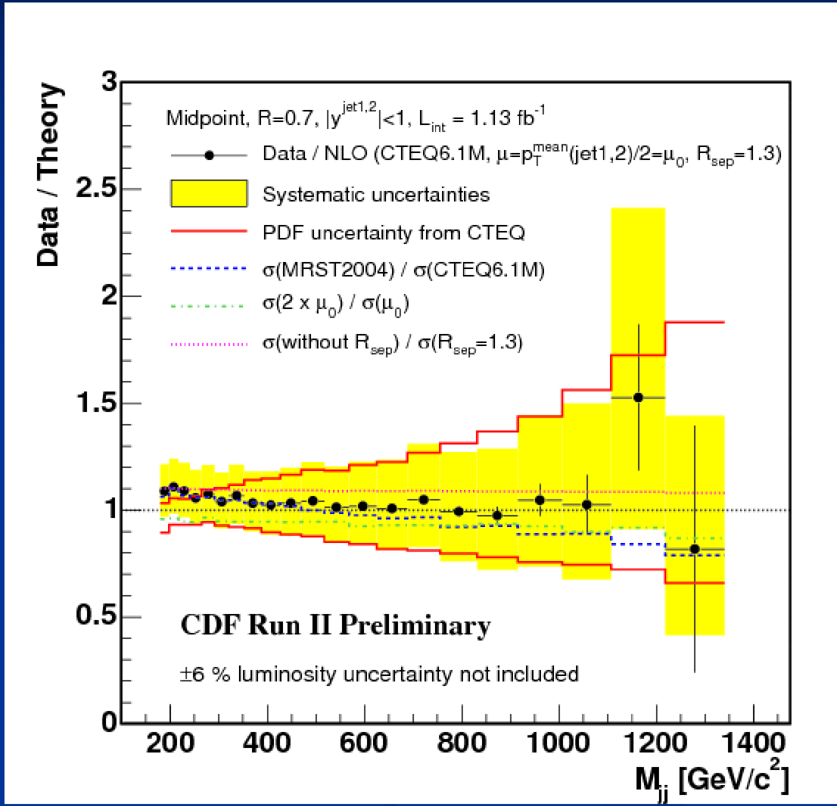
**E/p measures bremstrahlung fraction**




**Recent 'typical' zoo event (only an example)**

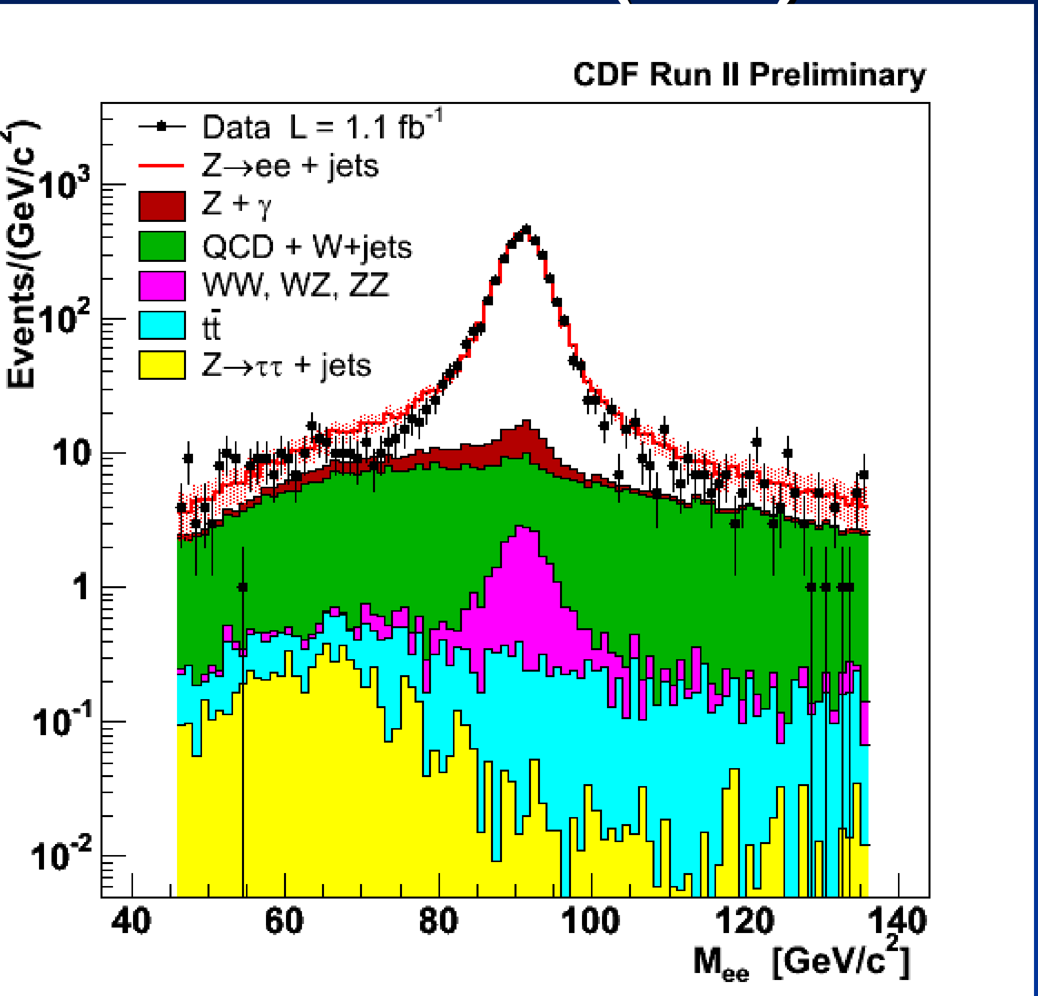
# High PT Jet Production and PDF's

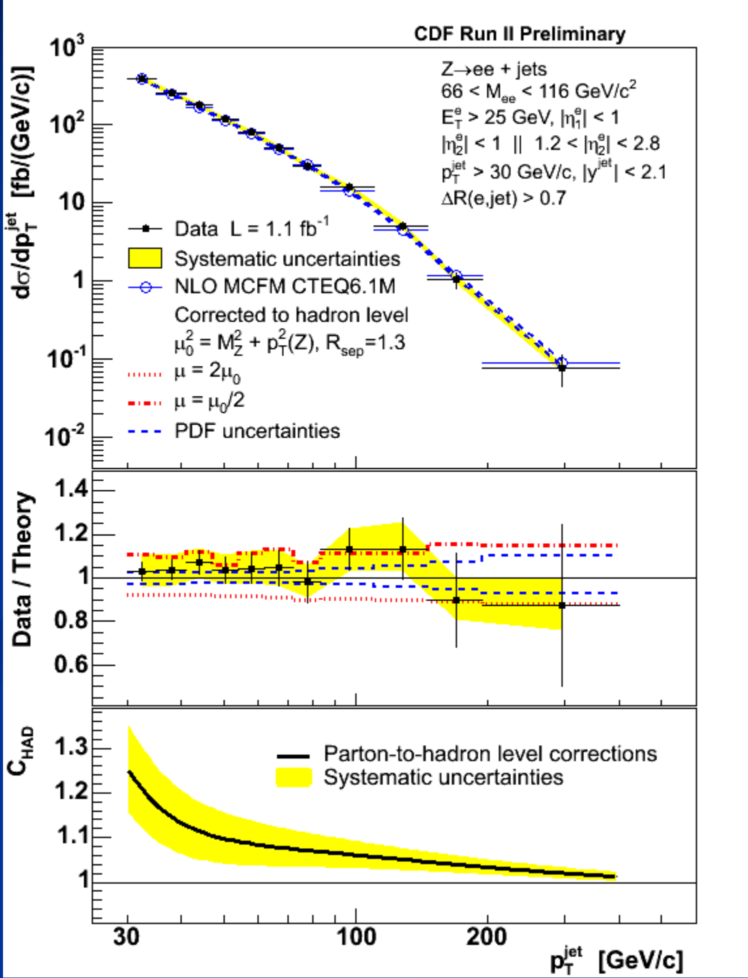



Really remarkable agreement with CTEQ PDF's in Mass (JJ)- note # of decades, systematic uncertainty bands

# Z+jet Production- THE Standard Candle (SC) and PDF's

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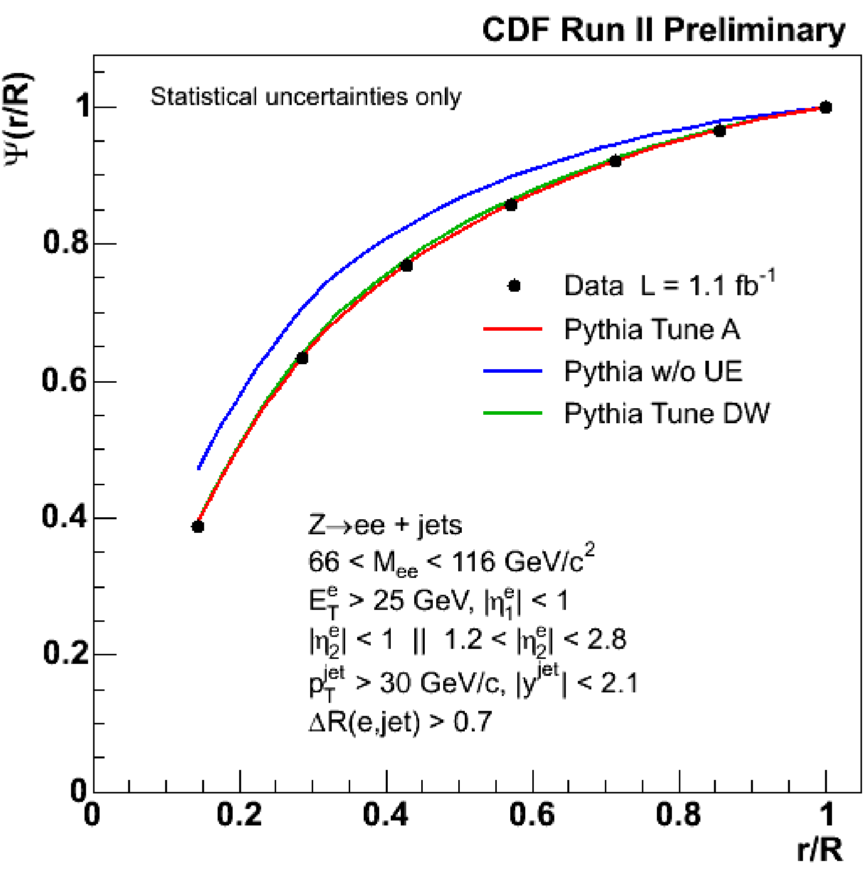
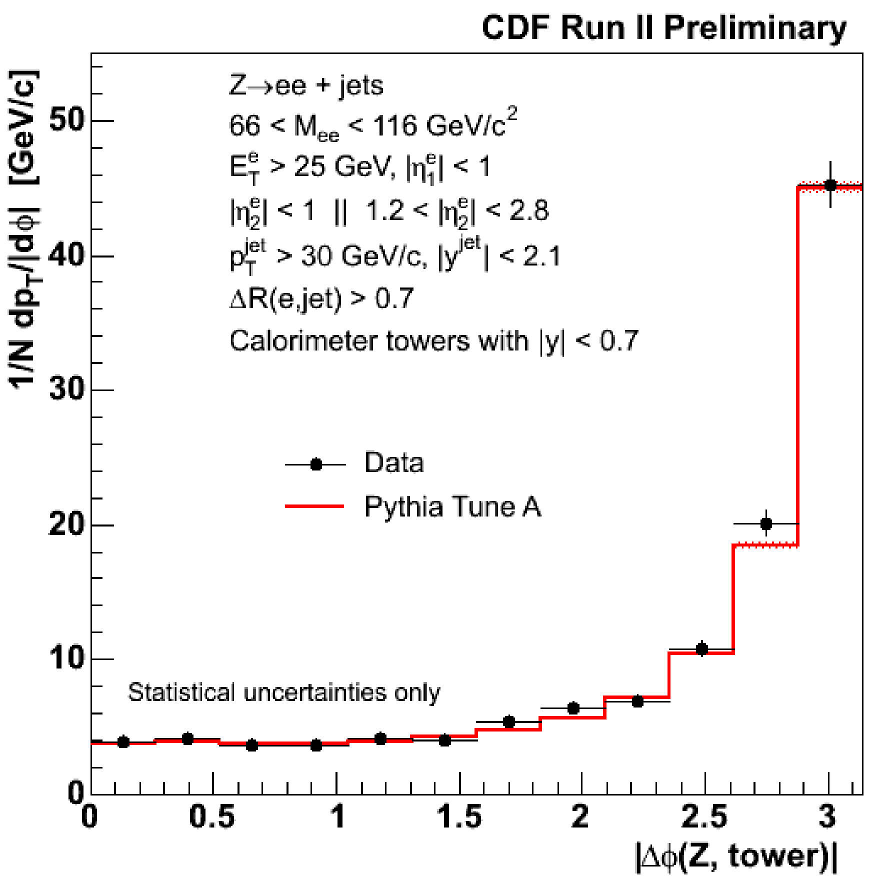


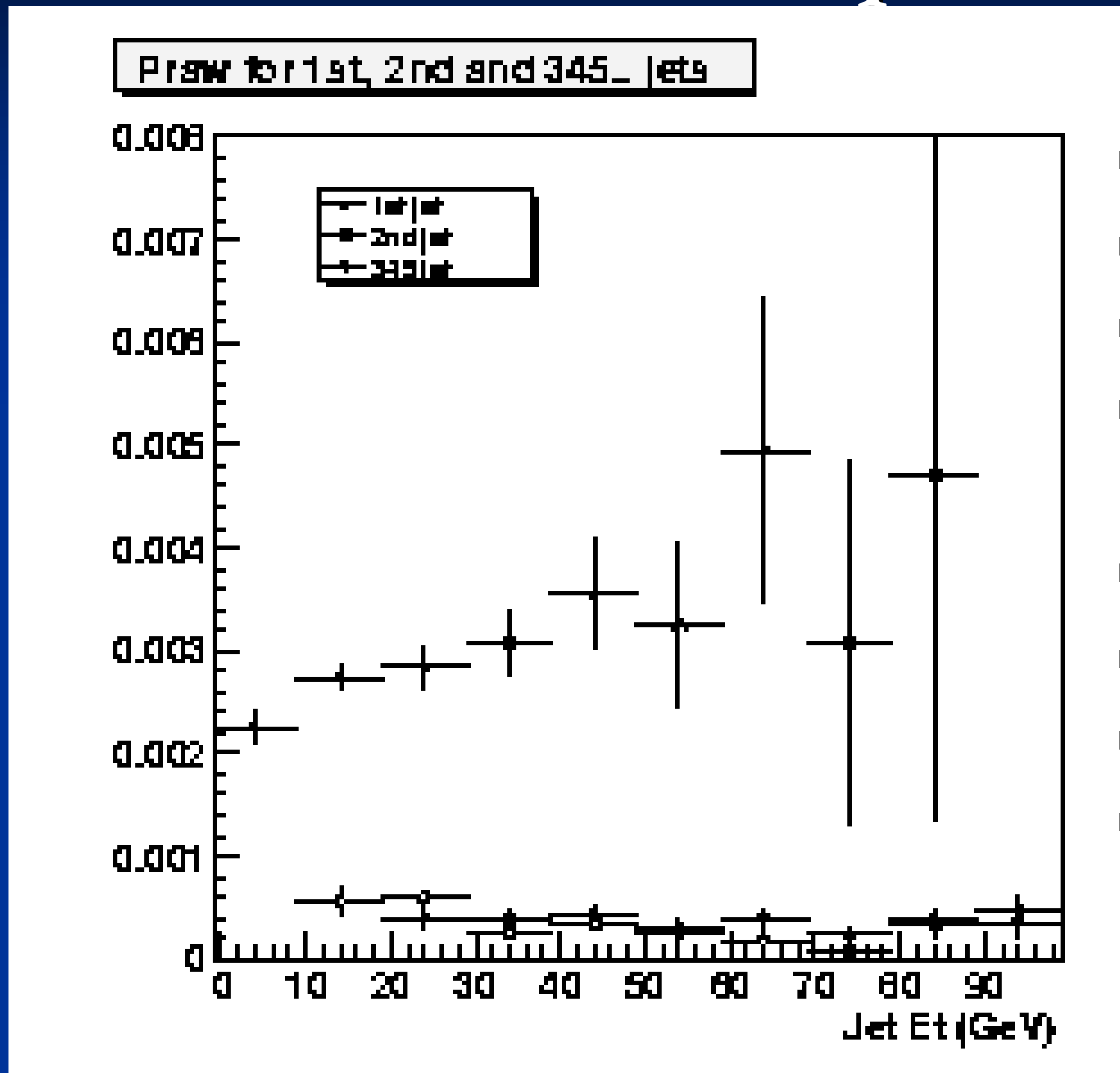

Jet Shape in eta-phi space (R)

Energy flow in |Delta-y|=0.7

**Really remarkable agreement with CTEQ PDF's - note # of decades, systematic uncertainty bands**

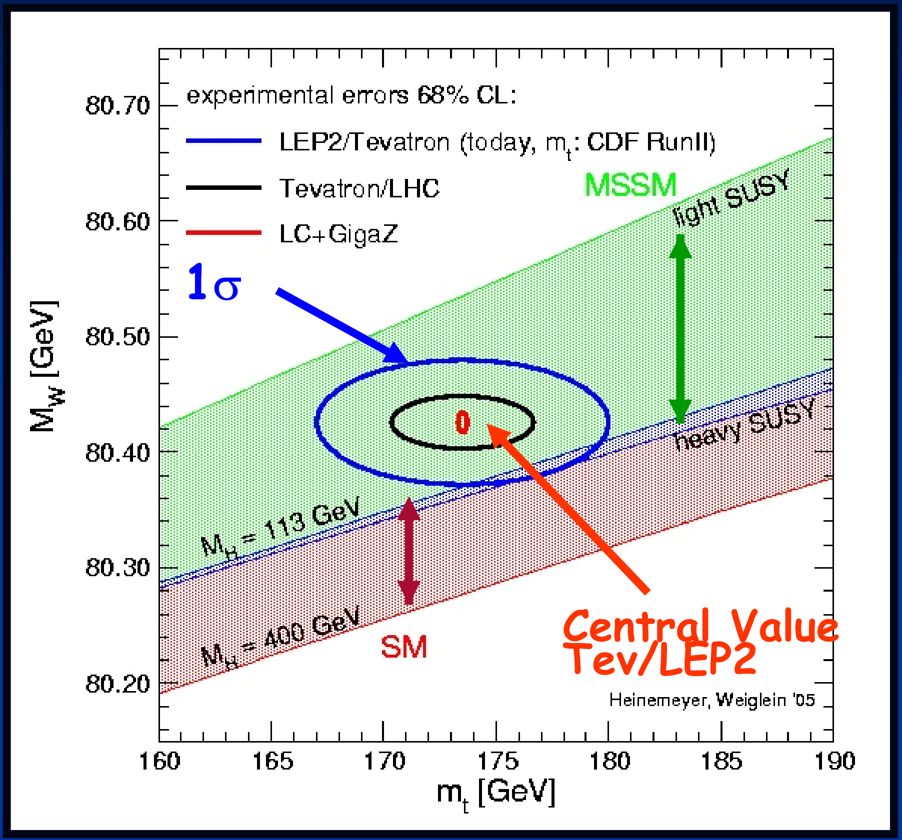
# It's not just partons inside hadrons- we need hardrons inside partons!

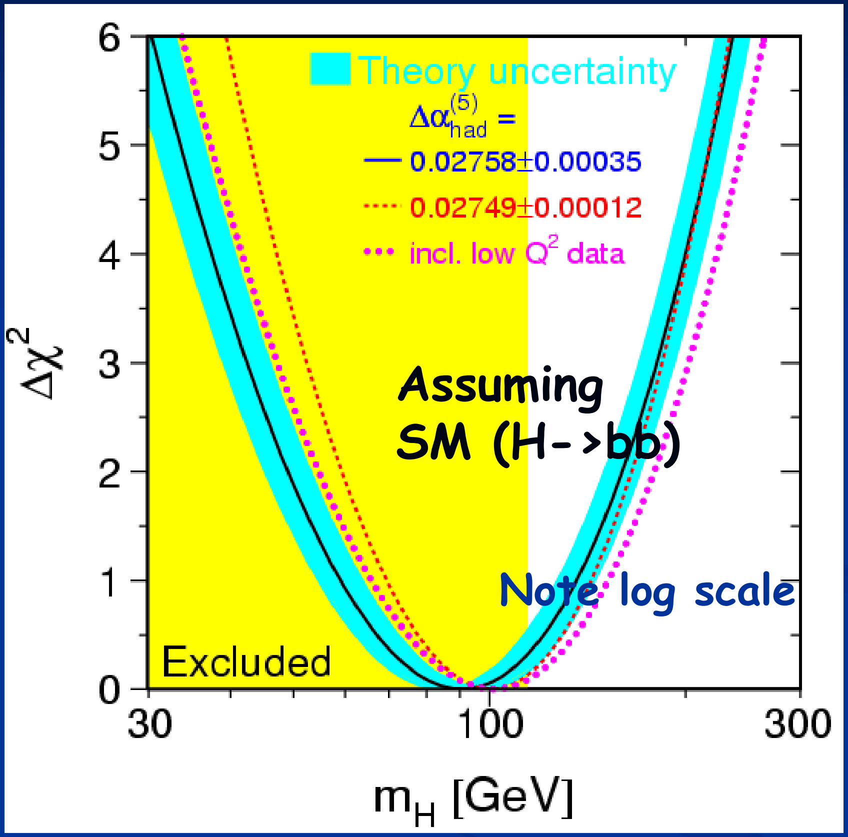
'Raw Fake' rate for a jet faking a photon- jets are ordered in Et




**Z=1 limit of jet fragmentation determines fake rates for isolated photons- really different for q,g,b,c,…!**

# Where is the Higgs? $M_{top}$ vs $M_W$




$M_{top}$ vs $M_W$ Status as of Summer 2006 (update below)

Central value prefers a light (too light) Higgs

**Puts a High Premium on Measuring Mtop and MW precisely, no matter what happens at the LHC (really diff. systematics at Tevatron.)**

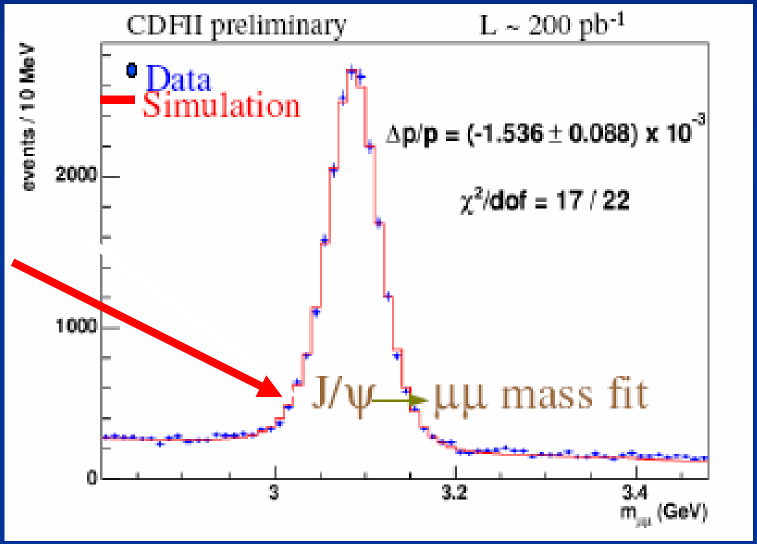
# New (Jan. 5, 07) CDF W Mass

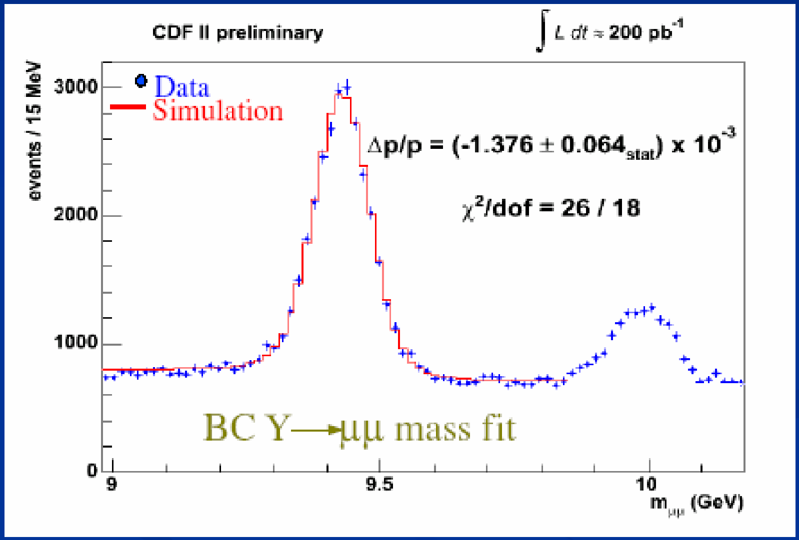
Data from Feb. 02-Sept 03

218 $pb^{-1}$ for e; 191 $pb^{-1}$ for $\mu$

A Systematics Intensive Measurement..
This is a precision spectrometer!

N.B.

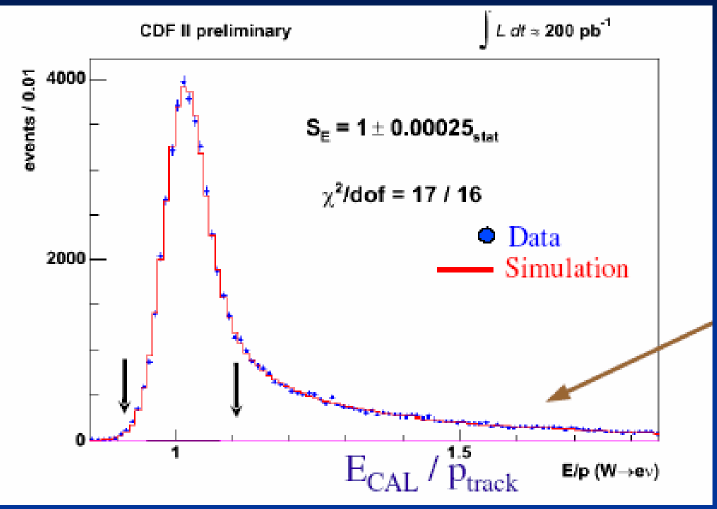


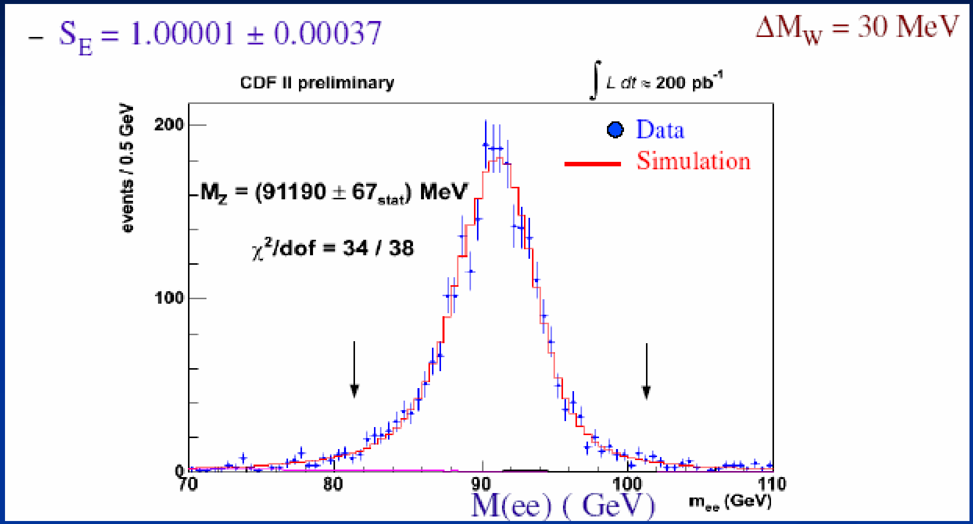




First, Calibrate the spectrometer momentum scale on the J/Psi and Upsilon- material traversed by muons really matters in electron Wmass measurement.

Note: This is a small fraction of data taken to date- this is to establish the calibrations and techniques (so far) for Run II.

# New (Jan. 5, 07) CDF W Mass




**Run Ib Problem Now Solved: 2 Calibrations of EM calorimeter: Zmass ≠ E(cal)/p(track)**

**Electron and Muon Transverse Mass Fits**

1. Electrons radiate in material near beam-pipe, but cal (E) gets both e and g; spectrometer sees only the momentum (not the g):
2. Use peak of E(cal)/p(spectrometer) to set EM calorimeter scale
3. Use tail of E/p to calibrate the amount of material
4. Check with mass of the Z. Run I didn't work well (Ia, Ib). Now understood (these were 2 of the dragons).

# New (Jan. 5, 07) CDF W Mass

See William Trischuk's talk for details, explanations

Transverse Mass Fit Uncertainties (MeV)

| | *electrons* | *muons* | *common* |
|---|---|---|---|
| W statistics | 48 | 54 | 0 |
| Lepton energy scale | 30 | 17 | 17 |
| Lepton resolution | 9 | 3 | -3 |
| Recoil energy scale | 9 | 9 | 9 |
| Recoil energy resolution | 7 | 7 | 7 |
| Selection bias | 3 | 1 | 0 |
| Lepton removal | 8 | 5 | 5 |
| Backgrounds | 8 | 9 | 0 |
| pT(W) model (g2,g3) | 3 | 3 | 3 |
| Parton dist. Functions | 11 | 11 | 11 |
| QED rad. Corrections | 11 | 12 | 11 |
| Total systematic | 39 | 27 | 26 |
| Total | 62 | 60 | |

Systematic uncertainties shown in green: statistics-limited by control data samples

| | *W mass* (MeV) |
|---|---|
| DELPHI | 80336 ± 67 |
| L3 | 80270 ± 55 |
| OPAL | 80416 ± 53 |
| ALEPH | 80440 ± 51 |
| CDF-I | 80433 ± 79 |
| D0-I | 80483 ± 84 |
| LEP Average | 80376 ± 33 |
| Tevatron-I Average | 80454 ± 59 |
| Previous World Average | 80392 ± 29 |
| CDF-II (preliminary) | 80413 ± 48 |
| New Tevatron Average | 80429 ± 39 |
| New World Average | 80398 ± 25 |

**Note: This is with only 0.2 $fb^{-1}$ and 1 experiment: have ~2 $fb^{-1}$...**

N.B. 48 Mev/80 GeV

CDF Wmass group believes each systematic in green scales like a statistical uncertainty =>

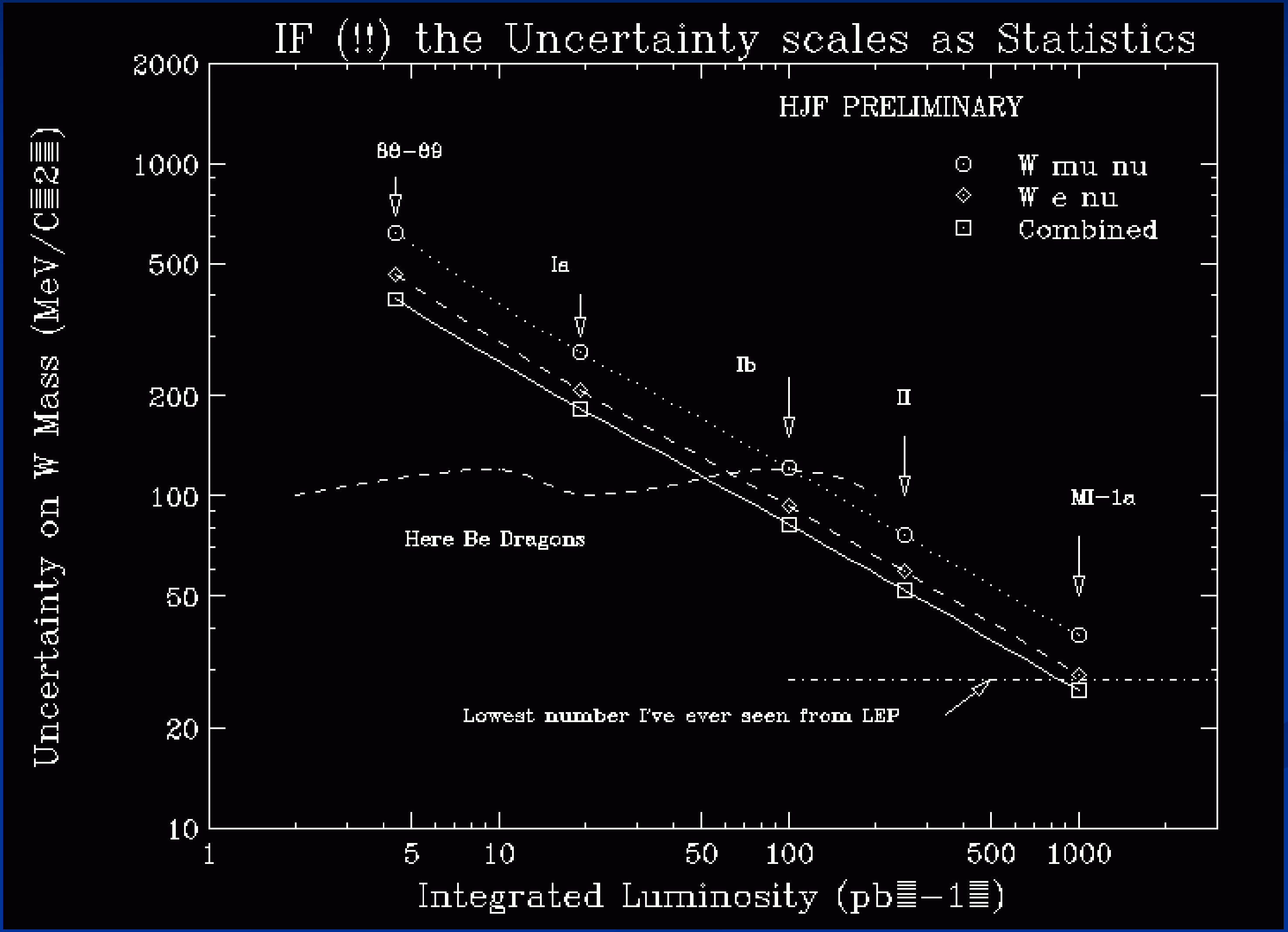
We will enter another round of learning at 600-1000 pb (typically a 3 year cycle or so)

# The Learning Curve at a Hadron Collider ($\tau_L$)

Take a systematics-dominated measurement: e.g. the W mass.

Dec 1994 (12 yrs ago)-

`Here Be Dragons' Slide: remarkable how precise one can do at the Tevatron (MW,Mtop, Bs mixing, …)- but has taken a long time- like any other precision measurements requires a learning process of techniques, details, detector upgrades….




Theorists too(SM)

# Tevatron experience indicates:

It will not be luminosity-doubling time but systematics-halving time that determines when one will know that one no longer needs the Tevatron. We should NOT shut off the Tevatron until we have relatively mature physics results from the LHC (i.e. it's clear that we won't need the different systematics.)

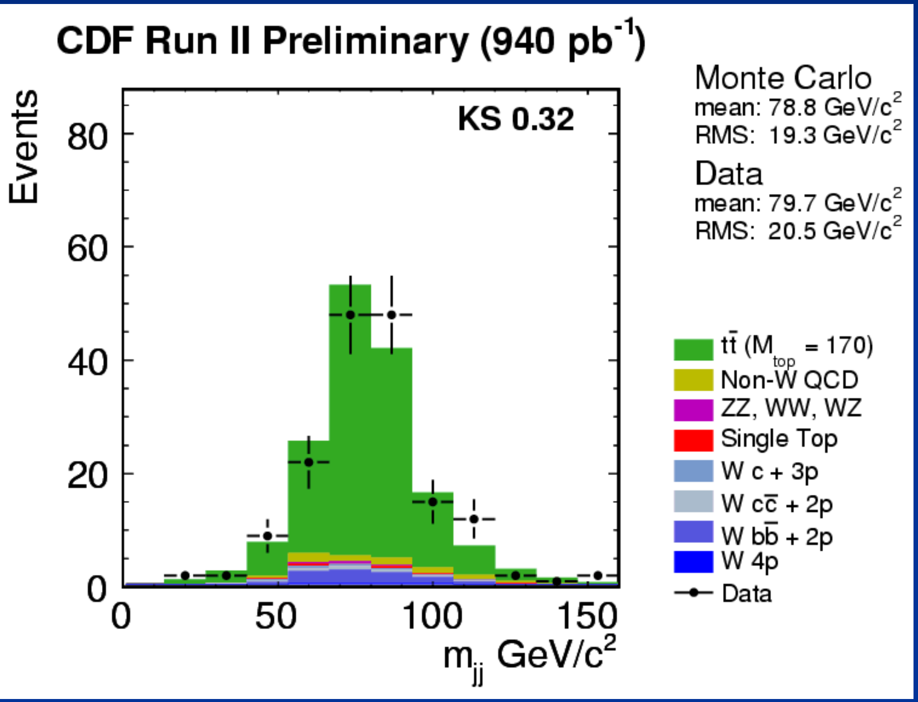
Have lots of hadron-collider experience now-

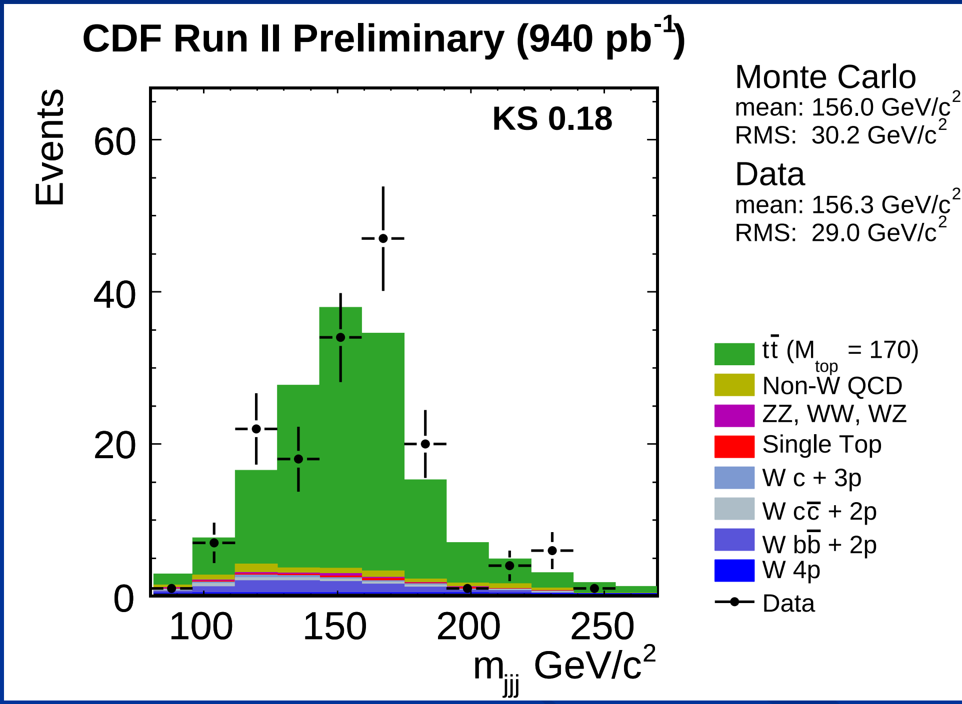
1. remarkable precision in energy scales possible (e.g. MW to better than part per mil)

2. remarkable precision in real-time reconstruction and triggering (e.g. SVT triggering on B's at CDF);

3. remarkably long and hard development of tools (e.g. jet resolution, fake rates, tau id, charm, strange id).

# Precision Measuremnt of the Top Mass




M(2-jets)- should be $M_W$

M(3-jets)- should be $M_{top}$

**CDF e/μ-Met+4 Jets (1b) - 0.94 $fb^{-1}$, ~170 ttbar events**

# A real CDF Top Quark Event

## T-Tbar -> $W^+bW^-$bbar

Measure transit time here (stop)

W->charm sbar

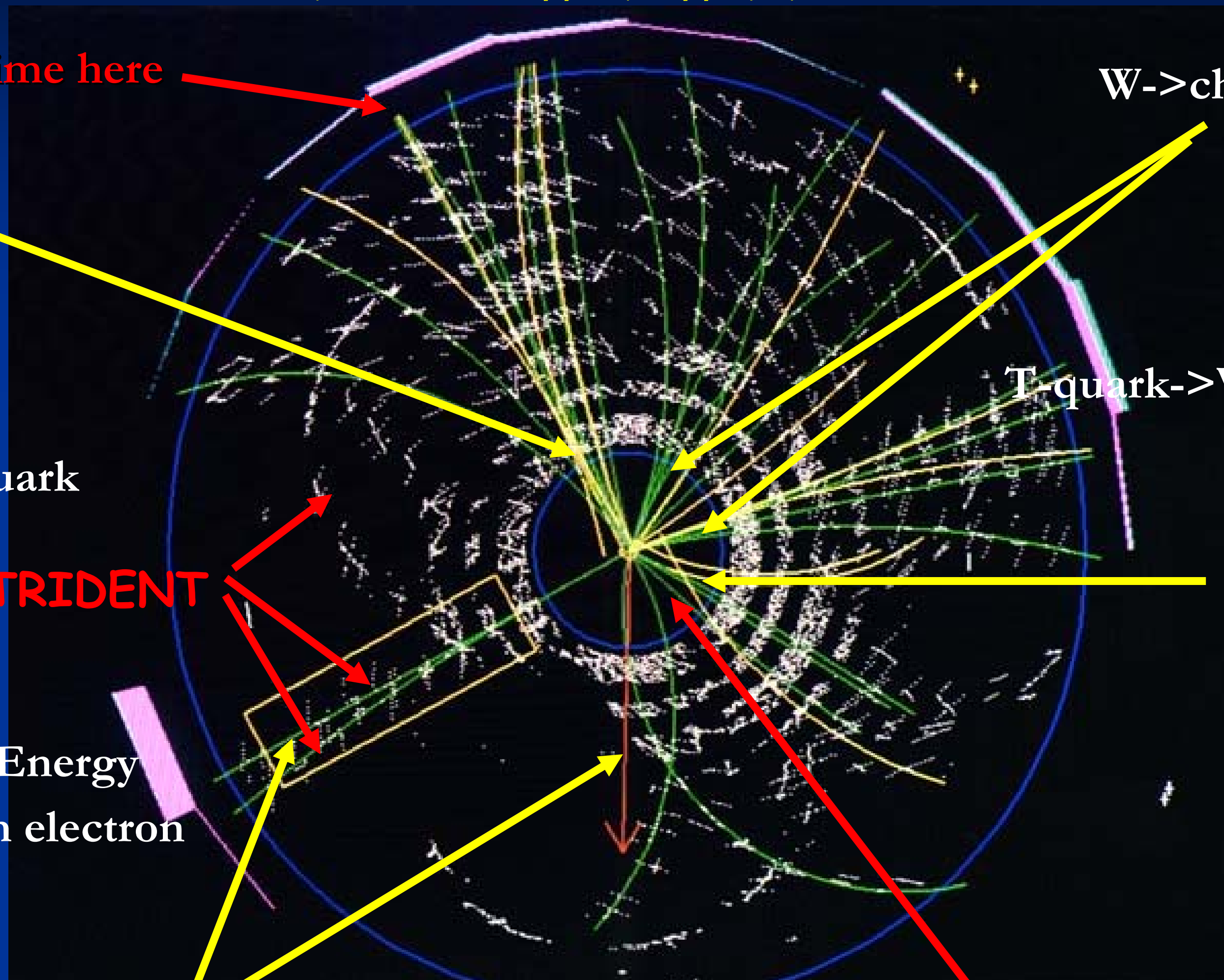
B-quark

T-quark->W+bquark

T-quark->W+bquark

TRIDENT

B-quark



Cal. Energy From electron

W->electron+neutrino

Fit $t_0$ (start) from all tracks

**Can we follow the color flow through kaons, charm, bottom? TOF!**

# Precision Msremnt* of the Top Mass

*like Mrenna

**CDF Lepton+4jets:**

**Systematics:**

Jet Energy Scale (JES)

Now set by MW (jj)

| Systematic uncertainties ($GeV/c^2$) | | |
|---|---|---|
| JES residual | 0.42 | 4 |
| Initial state radiation | 0.72 | 2 |
| Final state radiation | 0.76 | 1 |
| Generator | 0.19 | |
| Background composition and modeling | 0.21 | |
| Parton distribution functions | 0.12 | |
| b-JES | 0.60 | 3 |
| b-tagging | 0.31 | |
| Monte Carlo statistics | 0.04 | |
| Lepton $p_T$ | 0.22 | |
| Multiple Interactions | 0.05 | |
| Total | 1.36 | |

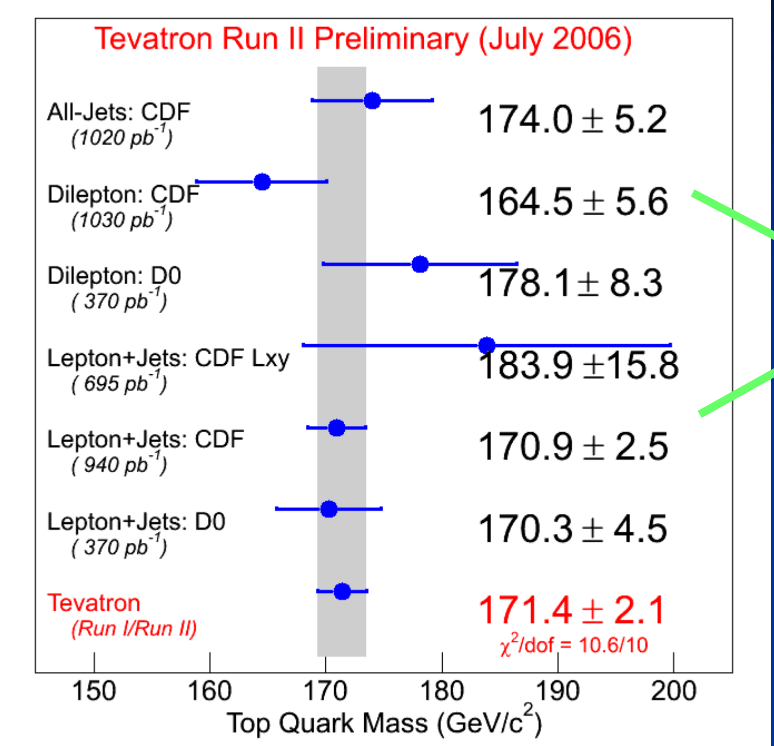
Note FSR, ISR, JES, and b/j JES dominate- all measurable with more data, at some level…

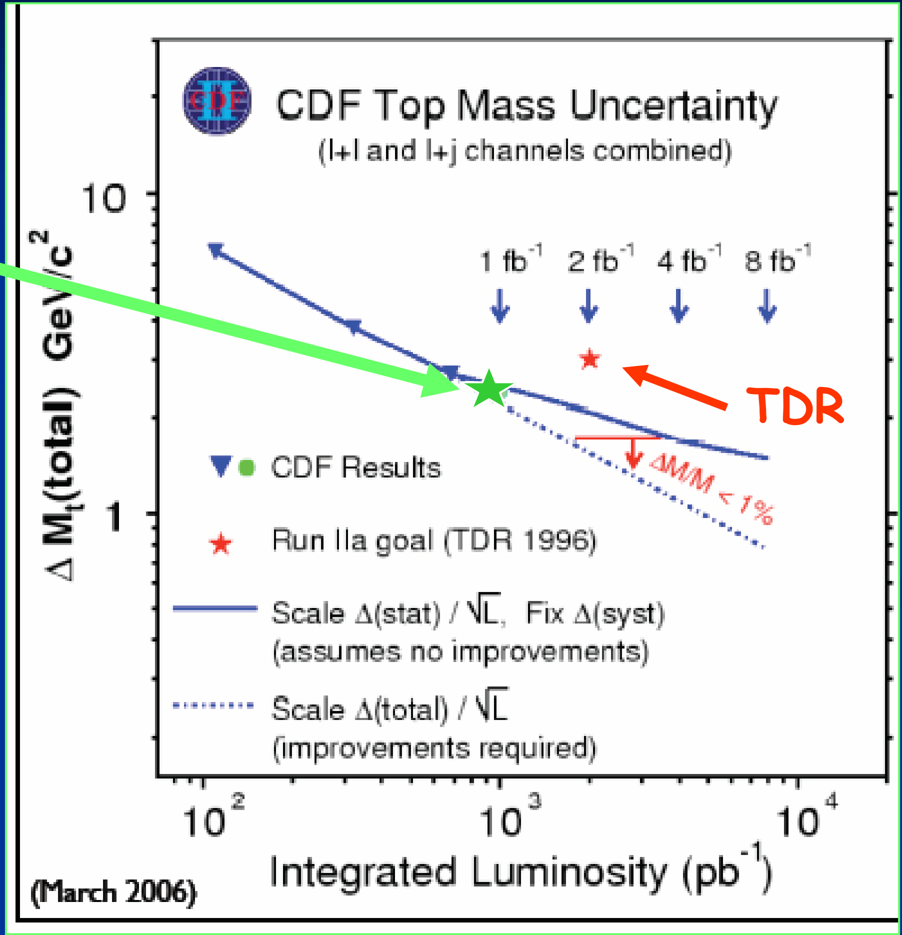
Again- systematics go down with statistics- no `wall' (yet)

# The Importance of the $M_W$ - $M_{Top}$-$M_{Higgs}$ Triangle

- Much as the case for Babar was made on the closing of the CKM matrix, one can make the case that closing the $M_W$ - $M_{Top}$-$M_{Higgs}$ triangle is an essential test of the SM.
- All 3 should be measured at the LHC- suppose the current central values hold up, and the triangle doesn't close (or no H found!). Most likely explanation is that precision $M_W$ or $M_{Top}$ is wrong. Or, H -> 4tau or worse, or, …? (low Et, met sigs)
- The systematics at the Tevatron are completely different from those at the LHC- much less material, known detectors, qbarq instead of gg, # of interactions, quieter events (for $M_W$).
- =>Prudent thing to do is don't shut off until we see $M_W$ - $M_{Top}$-$M_{Higgs}$ works.

# Precision Measurement of the Top Mass




**Aspen Conference Annual Values**
**(Doug Glenzinski Summary Talk)**

Jan-05: ΔMt = +/- 4.3 GeV
Jan-06: ΔMt = +/- 2.9 GeV
Jan-07: ΔMt = +/- 2.1 GeV

Note we are doing almost 1/root-L even now

Setting JES with MW puts us significantly ahead of the projection based on Run I in the Technical Design Report (TDR). Systematics are measurable with more data (at some level- but W and Z are bright standard candles.)

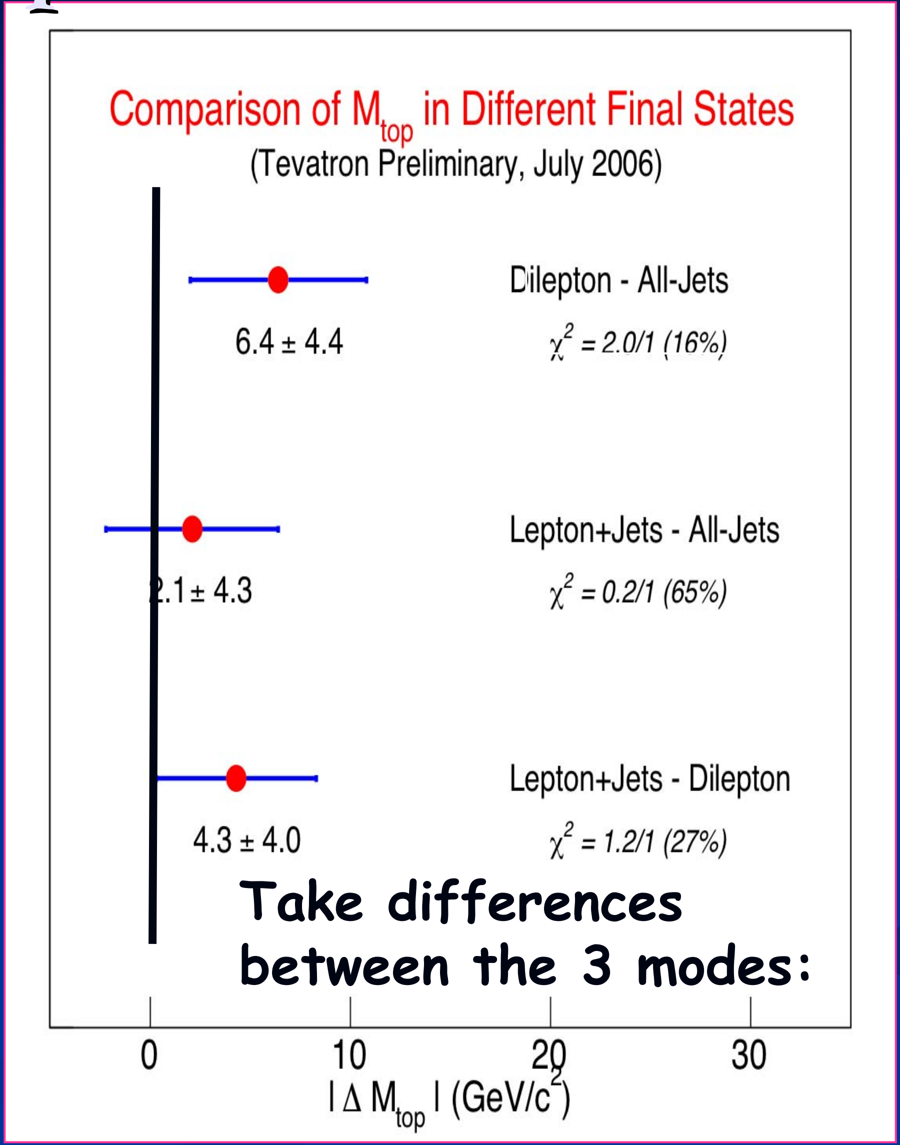
# Aside- One old feature may be going away-top mass in dileptons was too low…

$M_{top}$(All Jets) = 173.4 ± 4.3 GeV/$c^2$

$M_{top}$(Dilepton) = 167.0 ± 4.3 GeV/$c^2$

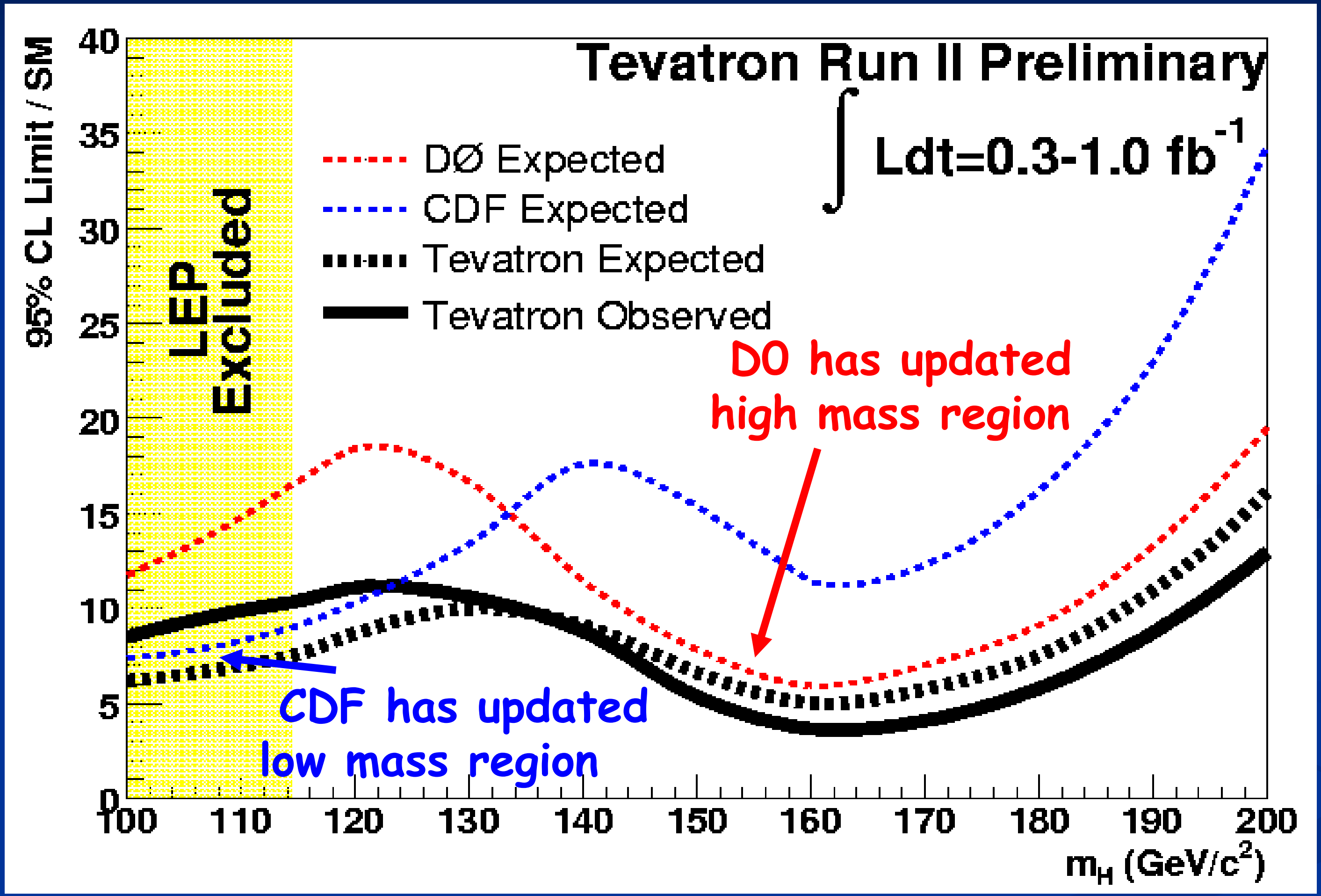
$M_{top}$(Lepton+Jets) = 171.3 ± 2.2 GeV/$c^2$

( Rainer Wallny, Aspen 07)



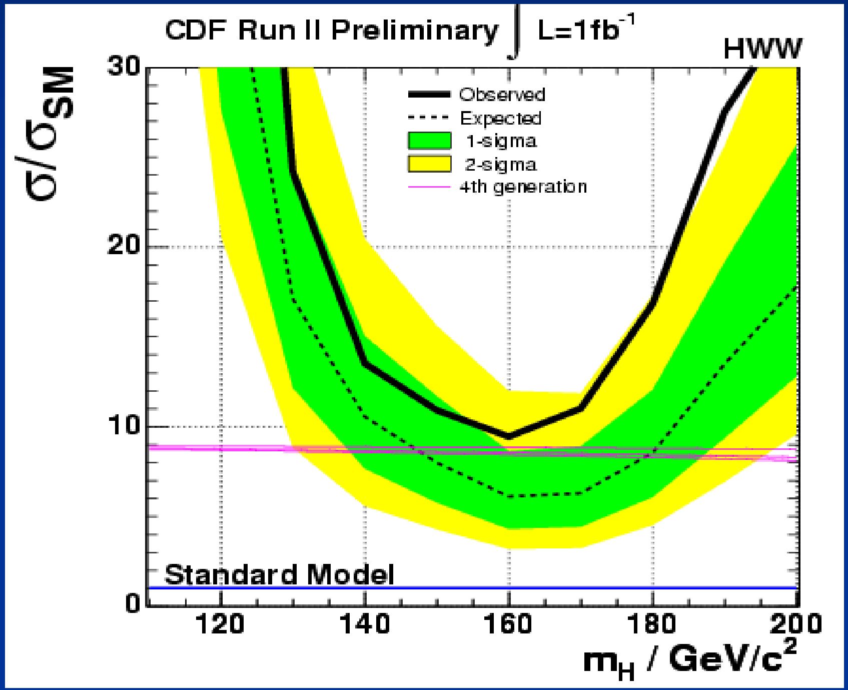

Dilepton a little low, but statistically not significant- also DO number not low now…

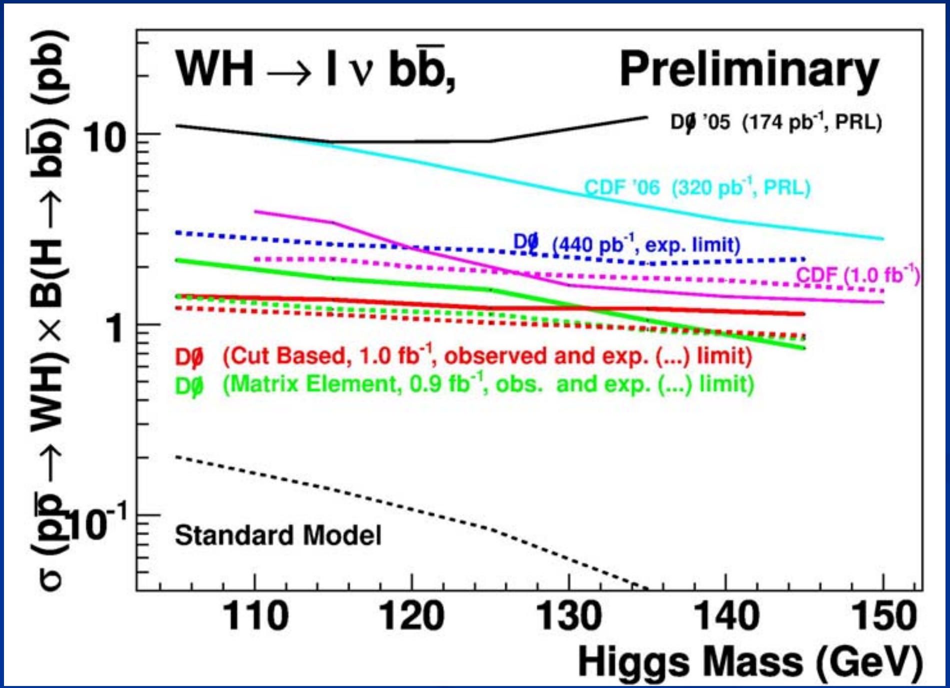
# Direct Limits on SM Higgs




This is the factor one needs to get the 95% CL downto the SM Higgs Xscn

# Direct Limits on SM Higgs-cont.



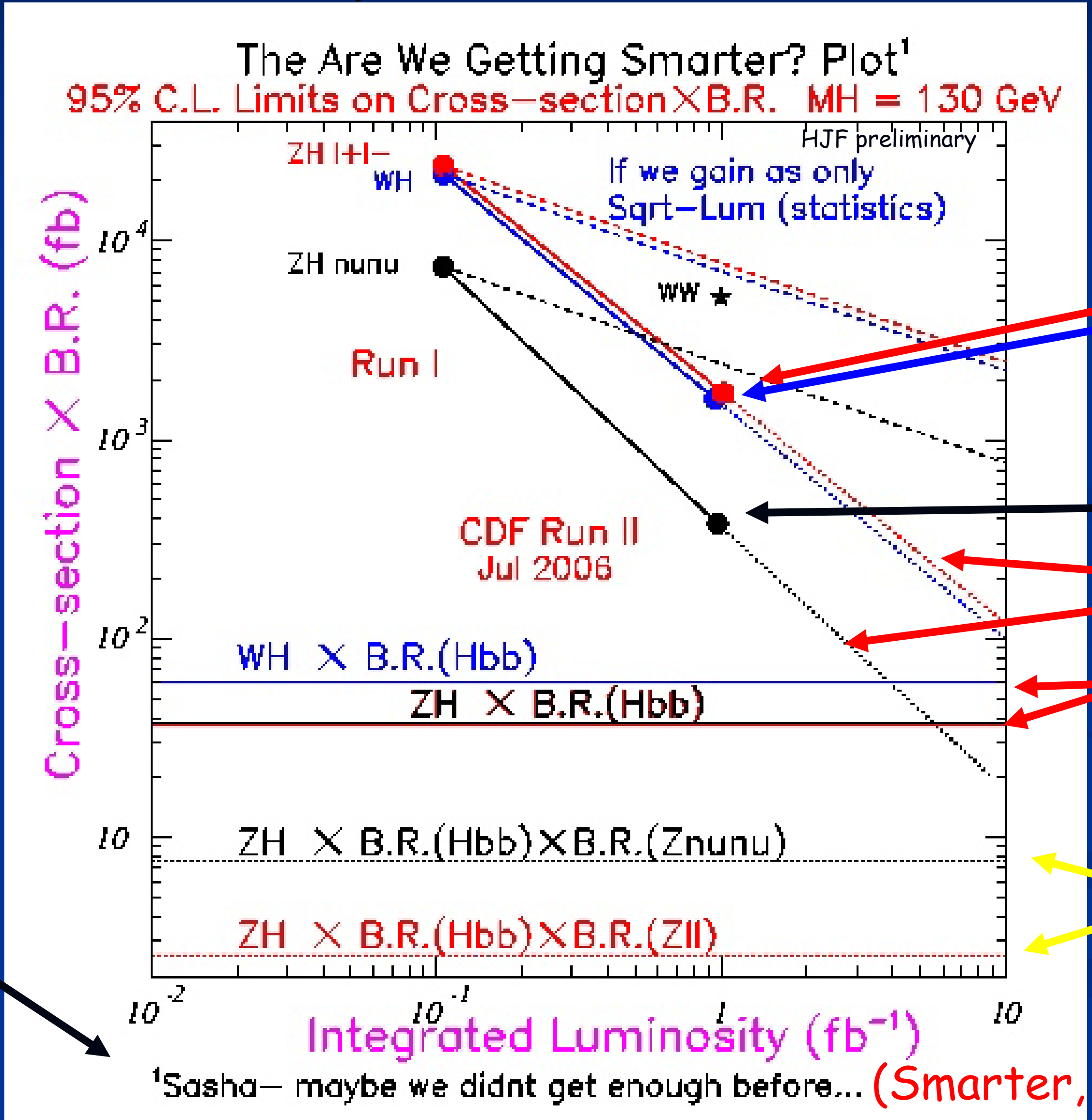




CDF has recently (1/31/07) updated high mass region

D0 has recently (3/12/07) updated low mass region

I'm not willing to prognosticate (other than to bet $ we don't see the SM Higgs)- would rather postnosticate. However, lots of tools not yet used- we're learning many techniques, channels,…

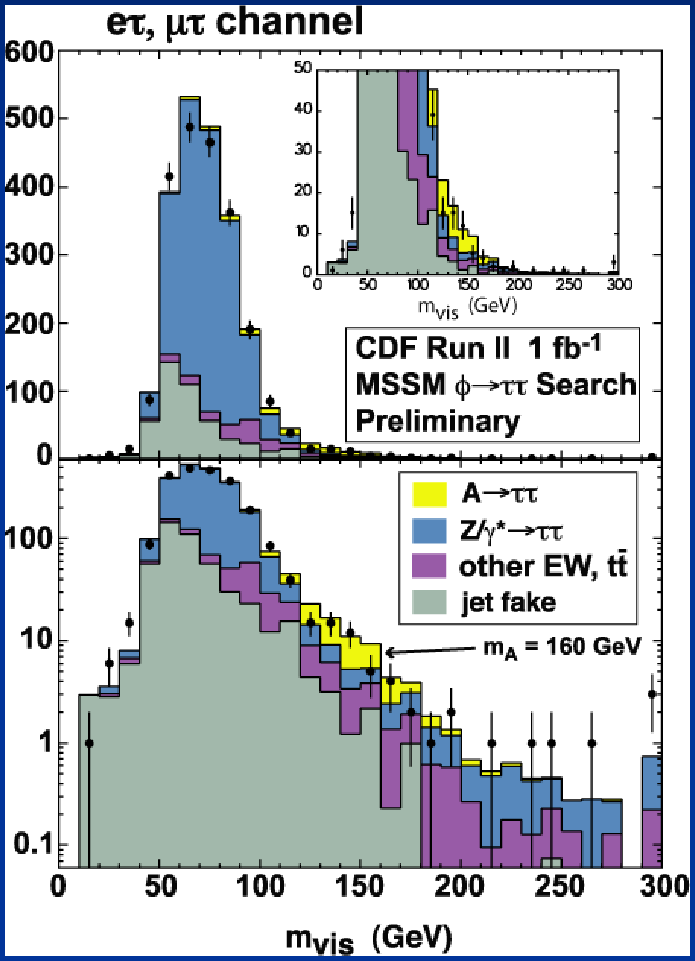
# Higgs Limits have gone faster than 1/root-L; faster than 1/L,even

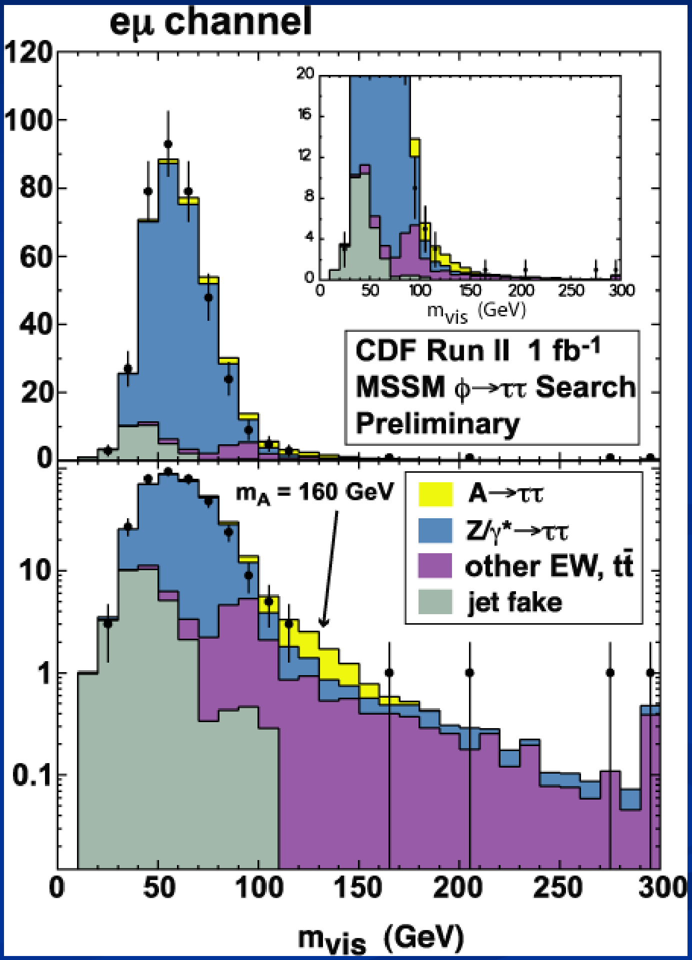



Comment from already smart Russian grad student on seeing plot

(Smarter, that is)

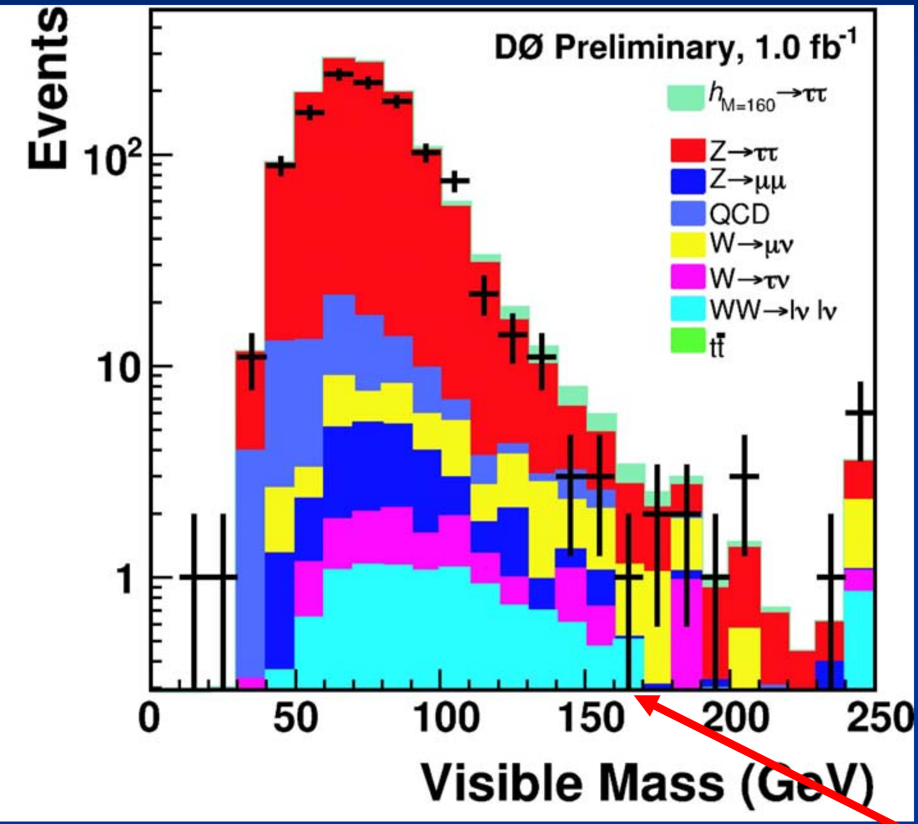
# Recent Measurement in τ–τ Channel- CDF

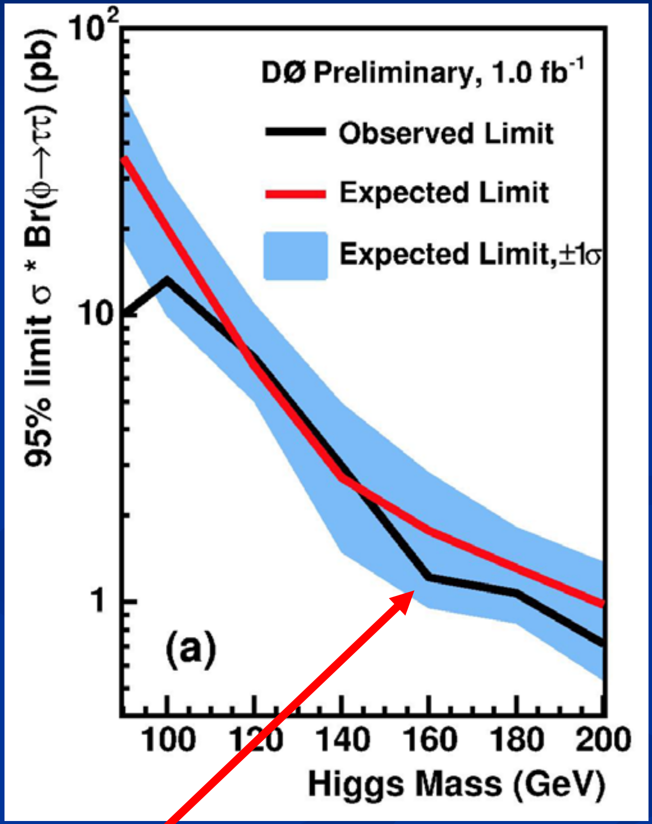



"The Excess is not Statistically Signficant- We need more data…before we draw any conclusions"- CDF

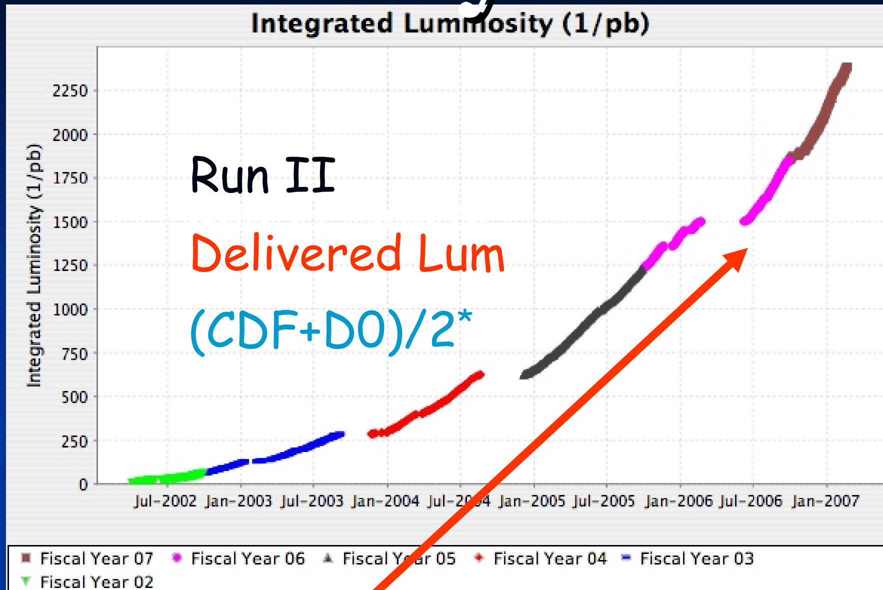
# Recent Measurement in τ–τ Channel- D0

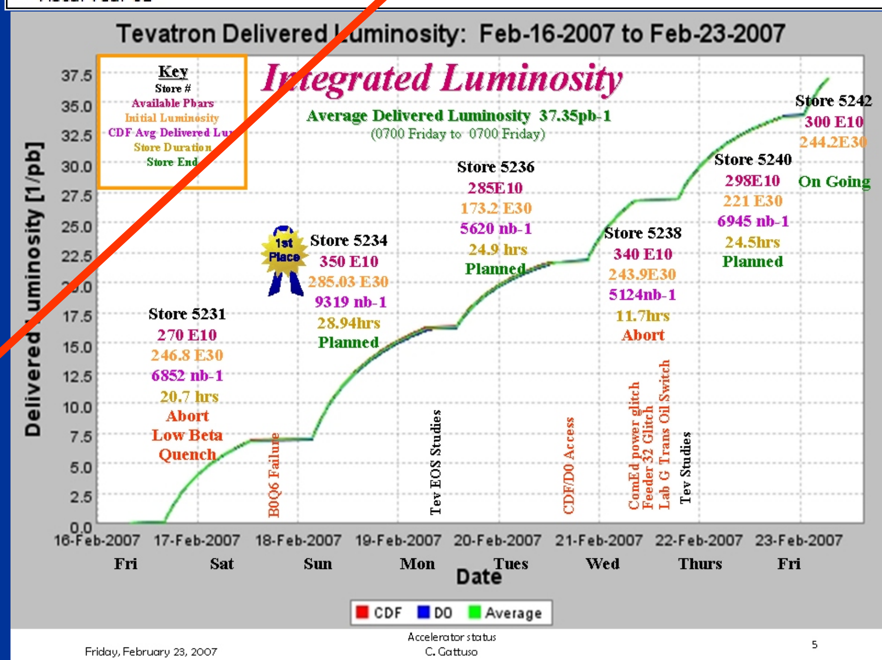



D0 has a dip at 160 in the same channel. (It pays to be patient and hang in there on the Higgs- a learning process…)

# Luminosity vs Time



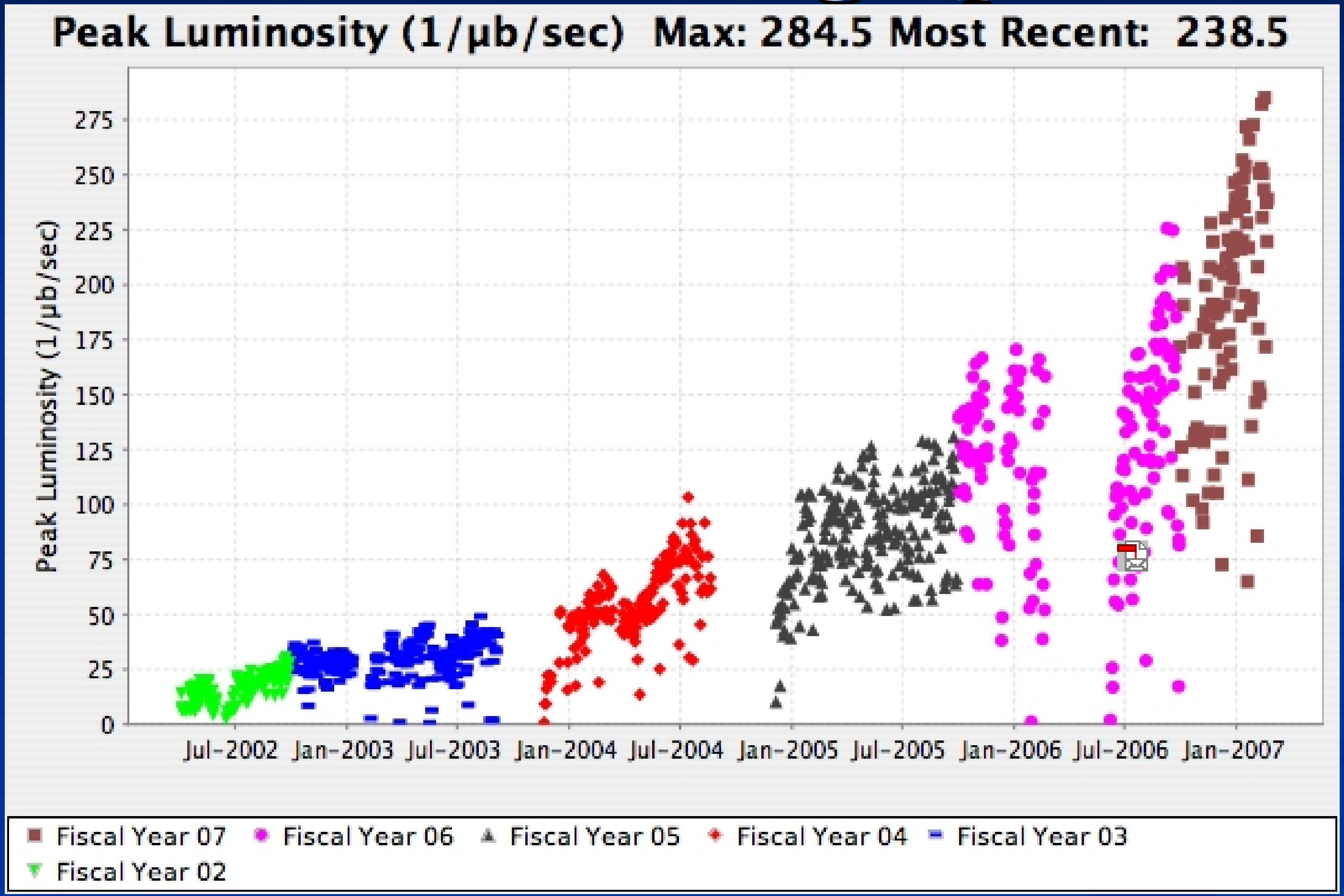
Note pattern- integral grows when you don't stop, with increasing slope

*(Protons are smaller on this side (joke))

> 40 pb-1/wk/expt (x 40 wks/yr, e.g.)

WuKFest 4/12/07

# Peak Lum coming up on 3E32




40-50 pb-1/wk times 40 weeks/yr = 2 fb-1/year delivered per expt-

There are more pbars even now. Peak lum problem =>Luminosity leveling?

BUT: don't focus on big improvements- steady improving X running=>smarts

# Low-mass/low met SM, ..e.g. eeggmet Event Followup (lg+X,gg+X)

RunI eegammagamma+met event;

also,in g-l+X found a 2.7s excess over SM. From PRL:

CDF Run I PRL: .."an interesting result, but … not a compelling observation of new physics. We look forward to more data…"

# eeggmet Event Followup

Andrei Loginov repeated the lgmet analysis- same cuts (no optimization- kept it truly a priori. Good example of SM needs…

**Run II: 929 pb-1 at 1.96 TeV vs Run I: 86 pb-1 at 1.8 TeV**

| CDF Run II Preliminary, $929pb^{-1}$ | | | |
|---|---|---|---|
| Lepton+ Gamma + $\not{E}_T$ Events | | | |
| Standard Model Source | $e\gamma \not{E}_T$ | $\mu\gamma \not{E}_T$ | $(e+\mu)\gamma \not{E}_T$ |
| $W^{\pm}\gamma$ | $41.65 \pm 4.84$ | $29.85 \pm 5.62$ | $71.50 \pm 10.01$ |
| $Z^0/\gamma + \gamma$ | $3.65 \pm 1.31$ | $14.10 \pm 2.36$ | $17.75 \pm 3.65$ |
| $W^{\pm}\gamma\gamma$ | $0.32 \pm 0.042$ | $0.18 \pm 0.025$ | $0.50 \pm 0.064$ |
| $Z^0/\gamma + \gamma\gamma$ | $0.087 \pm 0.012$ | $0.38 \pm 0.048$ | $0.47 \pm 0.058$ |
| $t\bar{t}\gamma$ | $0.22 \pm 0.029$ | $0.13 \pm 0.019$ | $0.35 \pm 0.045$ |
| $Z^0 \rightarrow e^+e^-, e \rightarrow \gamma$ | $9.59 \pm 0.76$ | – | $9.59 \pm 0.76$ |
| Jet faking $\gamma$ | $21.5 \pm 4.80$ | $6.2 \pm 3.60$ | $27.7 \pm 6.00$ |
| $\tau\gamma$ contribution | $2.15 \pm 0.56$ | $0.76 \pm 0.24$ | $2.91 \pm 0.65$ |
| QCD(Jets faking $\ell$ and $\not{E}_T$) | $15.0 \pm 4.12$ | $0.0 \pm 0.100$ | $15.0 \pm 4.12$ |
| DIF (Decays-In-Flight) | – | $2.3 \pm 0.72$ | $2.3 \pm 0.72$ |
| Total | $94.17 \pm 4.71(stat) \pm 6.64(sys)$ | $53.90 \pm 1.94(stat) \pm 6.84(sys)$ | $148.07 \pm 5.10(stat) \pm 11.93(sys)$ |
| | $94.17 \pm 8.14(tot)$ | $53.90 \pm 7.11(tot)$ | $148.07 \pm 12.97(tot)$ |
| Observed in Data | 96 | 67 | 163 |

**Conclude that eeggmet event, l+g+met `excess', Run II Wgg event all were Nature playing with us- a posteriori searches show nothing with more data…**

# Signature-Based High Pt Z+X Searches

**Look at a central Z +X, for Pt > 0, 60, 120 GeV, and at distributions…**

**Need SM predictions even for something as `simple' as this… (not easy-ask Rick**

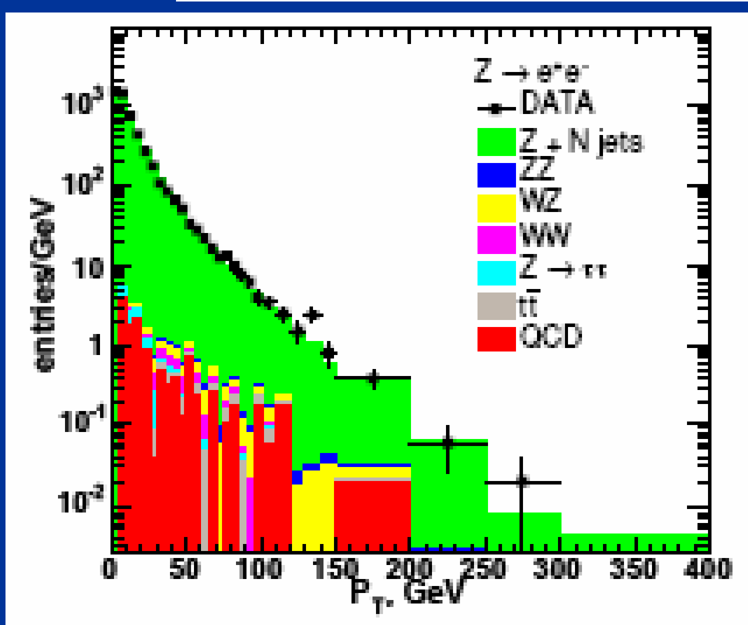
## 5 Observed and Expected events in each $P_T$-category

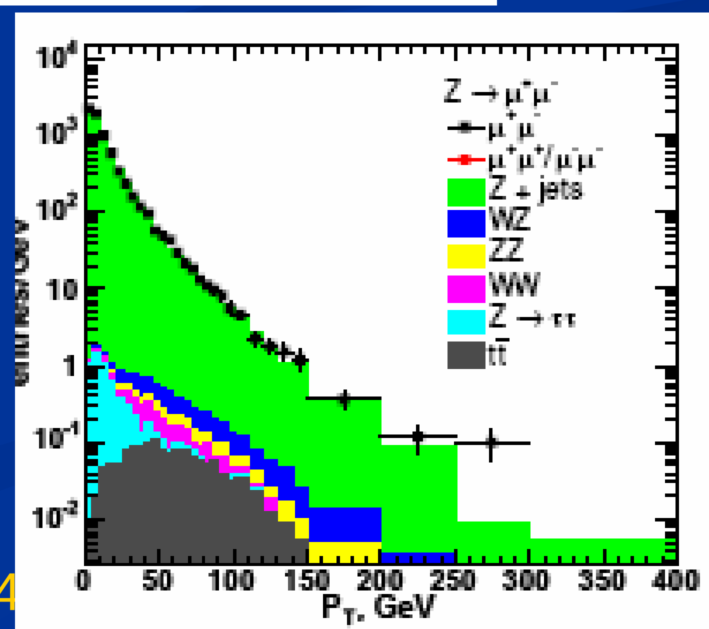
| Z + X | Inclusive | $P_T(Z) > 60$ GeV | $P_T(Z) > 120$ GeV |
|---|---|---|---|
| $Z \to e^+e^-$ | 25079 | 587 | 70 |
| $Z \to \mu^+\mu^-$ | 34222 | 721 | 74 |

Table 1: Number of Z + X events observed in each category.

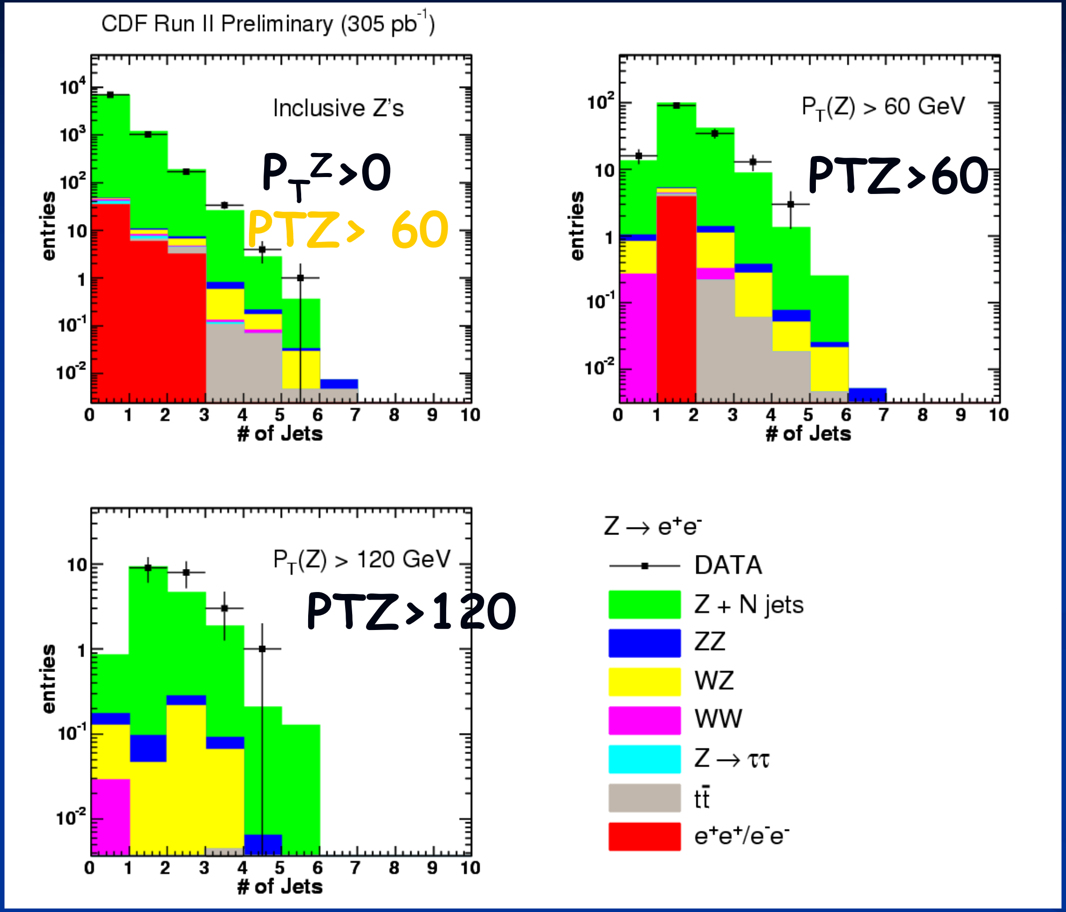
| Z + X | Inclusive | $P_T(Z) > 60$ GeV | $P_T(Z) > 120$ GeV |
|---|---|---|---|
| $Z \to e^+e^-$ | 25079 | 500 | 53.7 |
| $Z \to \mu^+\mu^-$ | 34222 | 650 | 61.8 |

Table 2: Number of Z + X events expected in each category.



# Signature-Based High Pt Z+X Searches




$N_{jets}$ for $P_T^Z$>0, $P_T^Z$> 60, and $P_T^Z$>120 GeV Z's vs Pythia (Tune AW)- this channel is the control for Met+Jets at the LHC (excise leptons - replace with neutrinos).

# Signature-Based High Pt Z+X+Y

**Simple Counting Expt- ask for a Z + one object, or Z+ 2objects**

**One Object**

| X | Observed | Expected |
|---|---|---|
| Lepton | 3 | 1.6 |
| Photon | 14 | 12.4 |
| Missing Energy | 97 | 85.4 |
| Ht | 45 | 36 |

**Z+X+anything**

**Two Objects**

| X+Y | Observed | Expected |
|---|---|---|
| Lepton+Photon | 0 | 0.001 |
| Lepton+Missing Energy | 0 | 0.8 |
| Lepton+Ht | 0 | 0.14 |
| Photon+Missing Energy | 0 | 0.19 |
| Photon+Ht | 0 | 0.28 |
| Missing Energy+Ht | 6 | 3.5 |

**Z+X+Y+anything**

# Communicating results of searches to Theorists

**Proposal** (R. Culbertson et al, Searches for new physics in events with a photon and b-quark jet at CDF. Phys.Rev.D65:052006,2002. hep-ex/0106012)- Appendix A:

3 Ways:

A. Object Efficiencies (give cuts and effic. for e, mu, jets,b's. met,....

B. Standard Model Calibration Processes (quote W$\gamma$, Z$\gamma$, W$\gamma\gamma$ in l$\gamma$met,e.g..)

C. Public Monte Carlos (e.g. John Conway's PGS)

True Acceptnce | Ratios to True (ABC)

Comparison of full MC with the 3 methods:

Conclusion- good enough for most applications, e.g. limits...

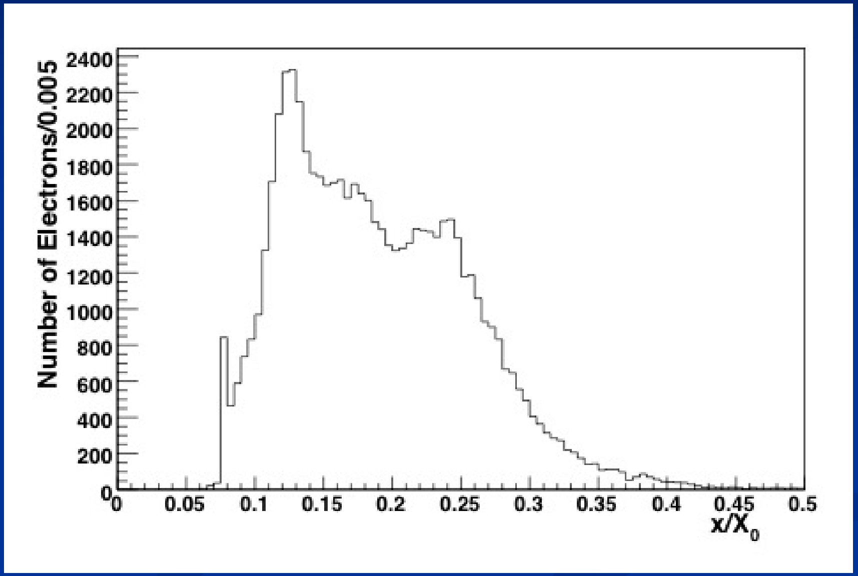
| Model | $M_s$ | BR(%) | $A$ | $A \cdot \epsilon$ | $R_{obj}$ | $R_{WW}$ | $R_{SHW}$ |
|---|---|---|---|---|---|---|---|
| GMSB $M_s = M_{\tilde{\chi}_1^\pm}$ | 130 | 3 | 65.0 | 27.50 | 2.79 | 3.03 | 1.07 |
| | 147 | 20 | 49.8 | 7.45 | 0.91 | 1.00 | 0.70 |
| | 170 | 23 | 51.7 | 8.35 | 0.97 | 1.00 | 0.87 |
| | 186 | 18 | 54.7 | 11.44 | 1.26 | 1.22 | 1.11 |
| $\tilde{\chi}_2^0 \to \gamma\tilde{\chi}_1^0$ $\tilde{q}, \tilde{g}$ production $M_s = M_{\tilde{g}}$ | 185 | 30 | 17.0 | 1.97 | 0.91 | 0.68 | 0.48 |
| | 210 | 30 | 22.0 | 2.98 | 1.04 | 0.73 | 0.90 |
| | 235 | 30 | 24.0 | 3.23 | 1.01 | 0.68 | 0.90 |
| | 260 | 30 | 24.5 | 2.69 | 0.82 | 0.52 | 0.75 |
| | 285 | 30 | 19.7 | 2.16 | 0.84 | 0.48 | 0.72 |
| $\tilde{\chi}_2^0 \to \gamma\tilde{\chi}_1^0$ $\tilde{q}, \tilde{g}$ production $M_s = M_{\tilde{\chi}_1^\pm}$ | 110 | 100 | 13.5 | 0.93 | 0.54 | 0.54 | 0.59 |
| | 130 | 100 | 12.6 | 1.41 | 0.88 | 0.80 | 0.87 |
| | 140 | 100 | 14.8 | 1.29 | 0.68 | 0.60 | 0.66 |
| | 150 | 100 | 13.7 | 1.34 | 0.77 | 0.65 | 0.78 |
| | 170 | 100 | 11.5 | 1.27 | 0.85 | 0.68 | 0.65 |

TABLE XIX. The results of comparing the methods of calculating $A\epsilon$ using the model-independent methods and the rigorously-derived $A\epsilon$. Each row is a variation of a model of supersymmetry as indicated by the label in the first column and the mass of a supersymmetric particle listed in column two (GeV). The column labeled $A$ is the acceptance of the model in % and the next column is the rigorously-derived $A\epsilon$. The columns labeled with $R$ are the ratios of the rigorously-derived $A\epsilon$ to $A\epsilon$ found using the model-independent method indicated.

Case for gamma+b-quark+met+x (good technisig)

# Tevatron aspects complementary to LHC strengths to compare capabilities

- Obvious ones (pbar-p,..)
- Electron, photon, tau ID has much less material- ultimate $M_W$, H->taus,?
- Tau-ID; photon/pizero separation (shower max)
- Triggering at met~20GeV
- Triggering on b, c quarks (SVT)- also (?) hyperons,…

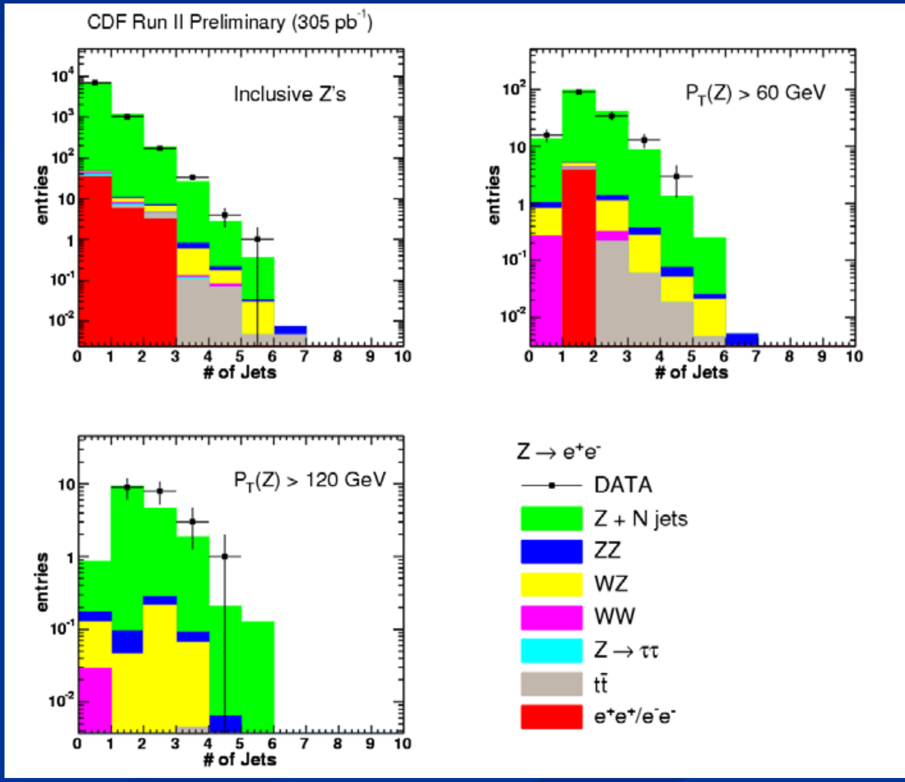



Fraction of a radiation length traversed by leptons from W decay (CDF Wmass analysis)- << 1 $X_0$

# Tools needed at the Tevatron (20 yrs later)

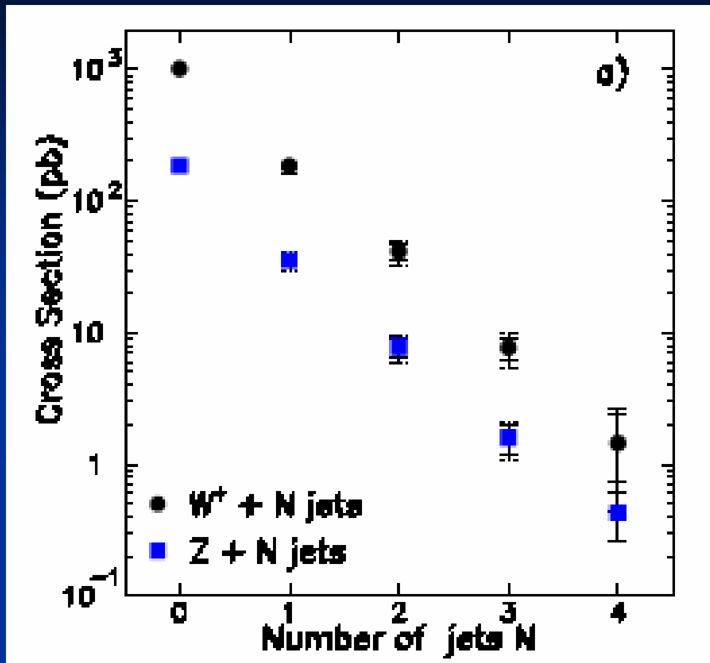
Some topical typical examples:

- **Jet fragmentation in the Z=1 limit for photon, tau fake rates (see a difference in u,d,c,b, gluon jets)**
- **Njets >2,3,4,… for $\gamma$,W,Z**
- **W,Z, $\gamma$ + Heavy Flavor (e.g. Zb,Zbj,Zbbar ,Zbbbarj,….-normalized event samples)**
- **Better, orthogonal, object ID**
- **Optimized jet resolution algorithms**
- **etc….** (tools get made when it becomes essential- `mother of invention…')

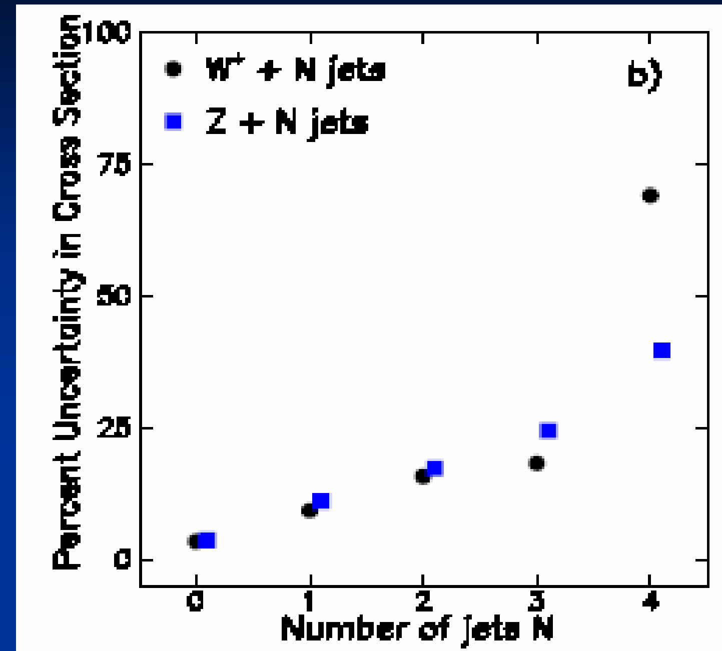



HT for $P_T^Z$>0, $P_T^Z$> 60, and $P_T^Z$>120 GeV Z's: ee (Left) and $\mu\mu$ (right)

# Problem of Njets (W+Nj,Z+Nj)




Crossection vs number of jets in W and Z events




% uncertainty vs number of jets in W and Z events

| Event and W Properties | | W/Z Ratio Method Reach | |
|---|---|---|---|
| N(Jets) | $\sigma_W$ | $\sigma_{new}$ 2 $fb^{-1}$ | $\sigma_{new}$ 15 $fb^{-1}$ |
| 0 | 1896 pb | 20 pb (1.0%) | 20 pb (1.0%) |
| 1 | 370 pb | 4.4 pb (1.2%) | 3.7 pb (1.0%) |
| 2 | 83 pb | 1.5 pb (1.8%) | 0.9 pb (1.1%) |
| 3 | 15 pb | 0.5 pb (3.5%) | 240 fb (1.6%) |
| 4 | 3.1 pb | 230 fb (7.5%) | 95 fb (2.9%) |
| 5 | 650 fb | 100 fb (16%) | 40 fb (6%) |
| 6 | 140 fb | 50 fb (36%) | 18 fb (13%) |
| 7 | 28 fb | 20 fb (78%) | 8 fb (29%) |
| 8 | 6 fb | —— | 4 fb (63%) |

So, switch to a measurable that is more robust: look for new physics by precise measurements of (W+Njets)/(Z+Njets)

Systematics at few % level (PRD68,033014;hep-ph/030388

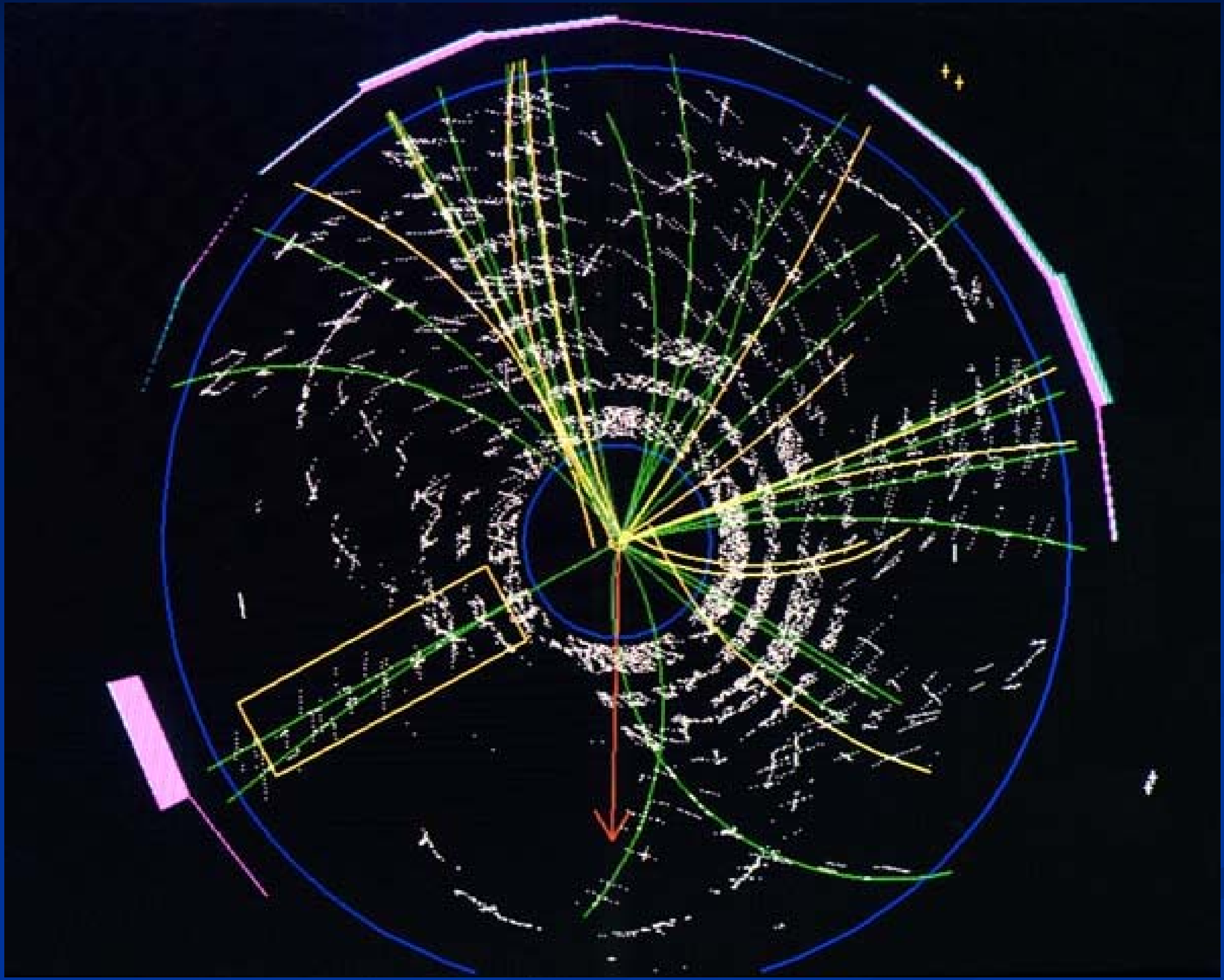
# Summary of Tevatron Now

1. Tevatron running well – expect >= 1.5-2 fb-1/yr/expt of all goes well (could even be somewhat better- there are more pbars).
2. Experiments running pretty well and producing lots of hands-on and minds-on opportunities (lots of room for new ideas, analyses, and hardware upgrades (great for students!)
3. Doubling time for precision measurements isn't set by Lum- set by learning. Typical time constant ~ one grad student/postdoc.
4. Precision measurements- MW, Mtop, Bs Mixing, B states- MW and Mtop systematics statisics-limited
5. Can make a strong argument that pbar-p at 2 TeV is the best place to look for light SUSY, light Higgs,…; as met at EWK scale, (MW/2, Mtop/4) doesn't scale with mass, root-s, and tau's (maybe b's) are better due to lower mass in detector, and SVT and L1 tracking triggers,
6. All of which implies keep the Tevatron running until we know that we don't need it (and keep Fermilab strong for the ILC bid too!)

# And Thanks to Wu-Ki

1. The CTEQ PDF work is critical to all we do at the Tevatron- it's on of the strongest components of our foundation- we owe an enormous debt to Wu-Ki and collaborators..
2. Wu-Ki set the tone and standards for teaching and responsibility when I showed up at UC- had an enormous impact on me
3. I still regularly refer to Wu-Ki's book on Group Theory
4. And Wu-Ki's and Beatrice's recipe for cooking pike is still a standard in our household!

# THE END



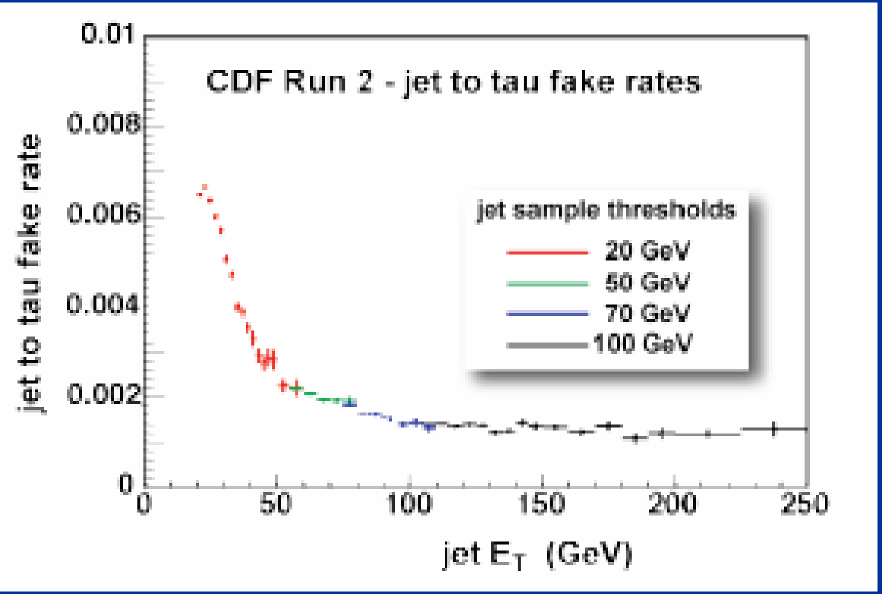
"You could be up to your belly-buttons in (SUSY) and not know it.."- C. Prescott

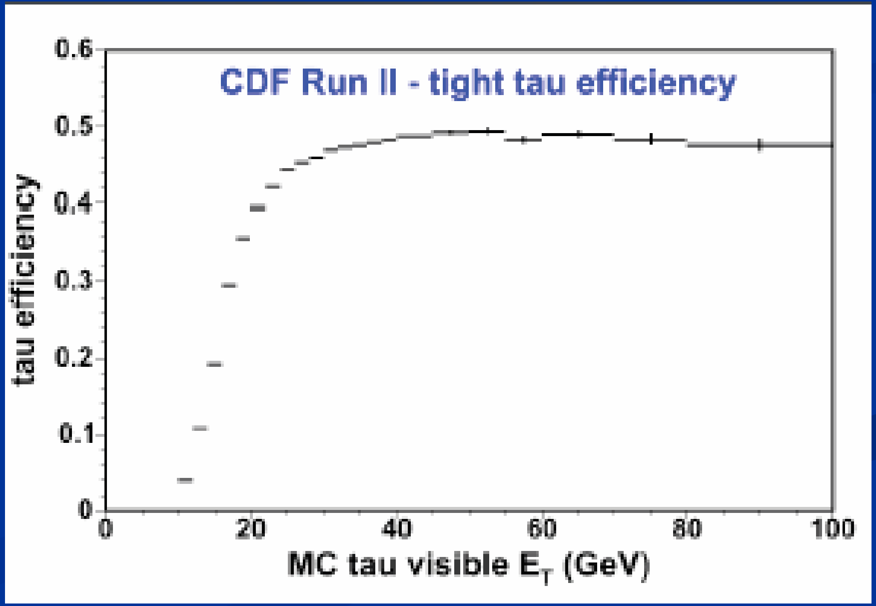
# BACKUP SLIDES

# New CDF Higgs to taus result:

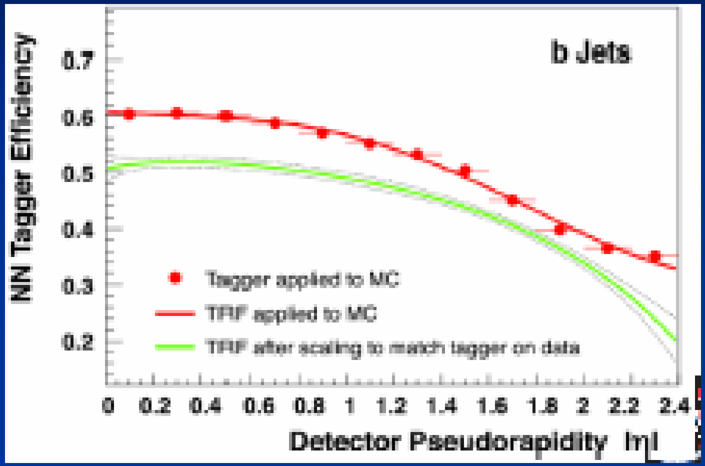
Tau ID depends on good tracking,  photon ID- clean environment (all good at the Tevatron). Key numbers are efficiency and jet rejection:

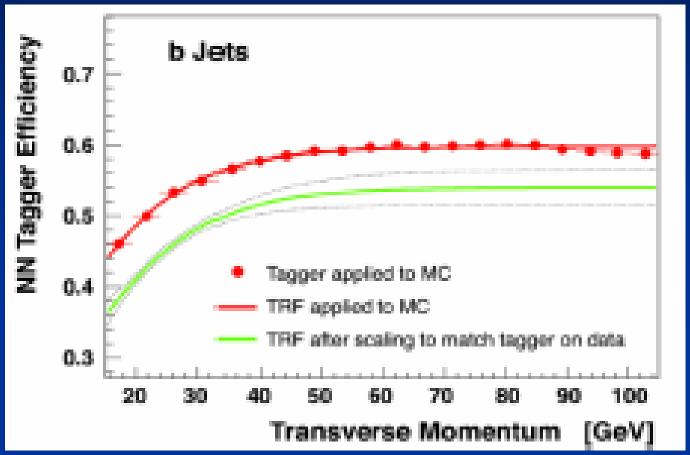
This may be an area in which the Tevatron is better.



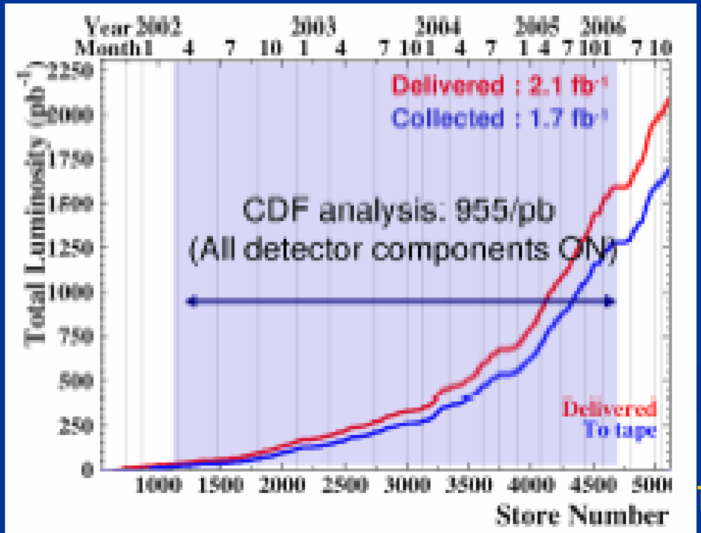



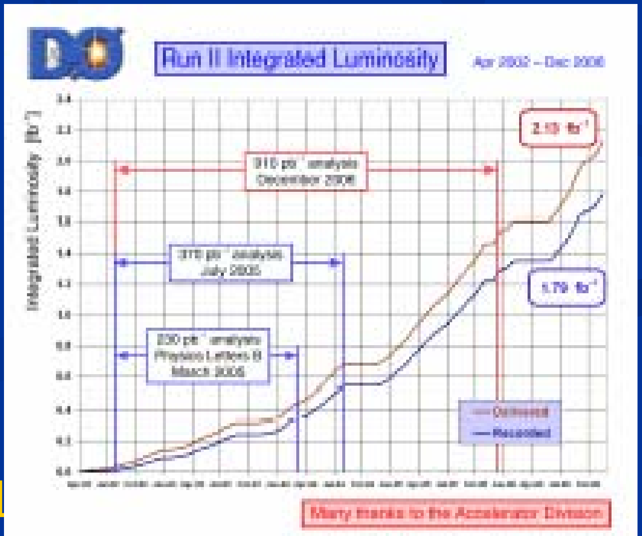
# Backup- D0 btagging



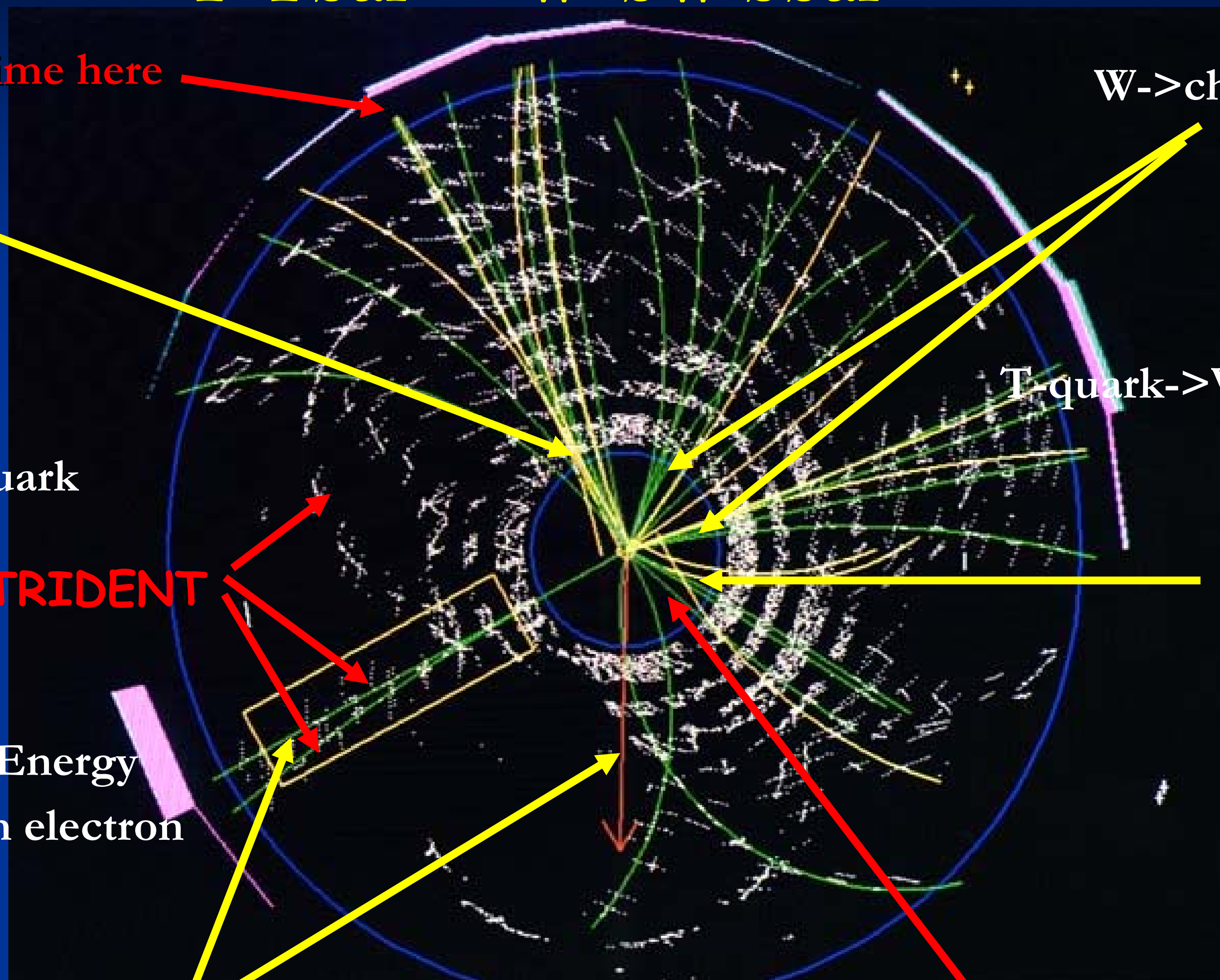

# Backup- lum on tape



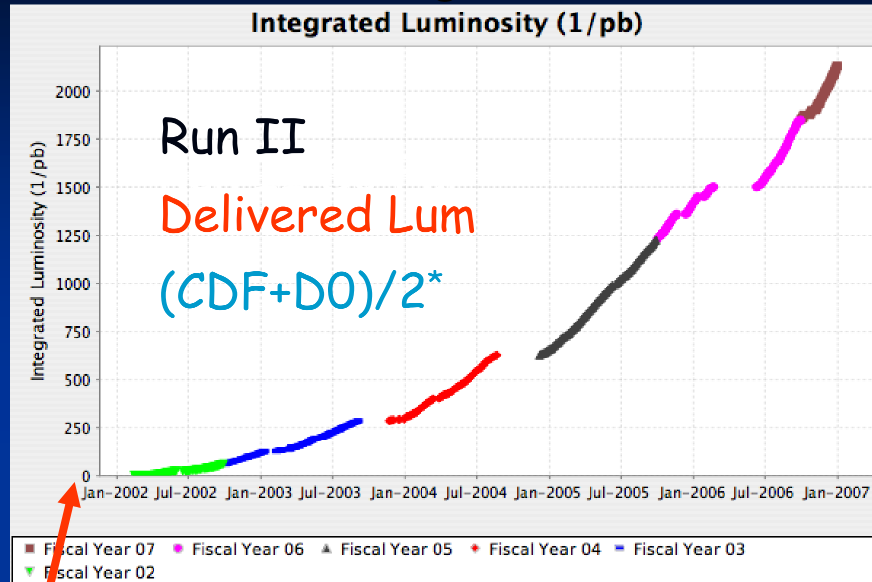
# A real CDF Top Quark Event

## T-Tbar -> $W^+bW^-$bbar

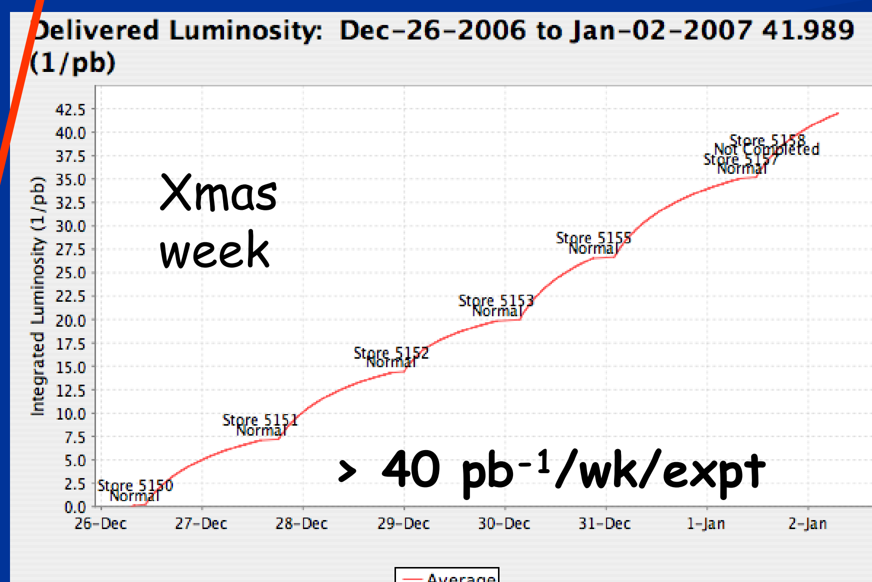



**Follow the color flow!**

# Luminosity vs Time






Note pattern- integral grows when you don't stop, with increasing slope

*(Protons are smaller on this side (joke))