

The Run II Physics Program

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Representing the CDF and DØ collaborations



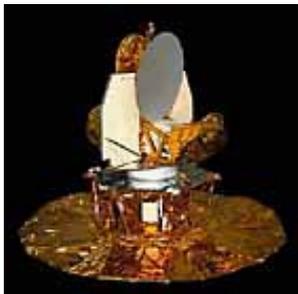
The Run II physics program

- A broad physics program which evolves as a function of luminosity
 - There is interesting physics at all luminosities, starting now with 50-100 pb⁻¹ and continuing through 0.3, 1, 2, 5, 8 ... fb⁻¹
- This physics program has begun
- The goal of the collaborations is to
 - Maximize this physics program
 - Exploit the full potential of the world's highest energy collider and the large investments we have made in the accelerator and detectors
 - Lay a firm foundation for the LHC and for future initiatives at the TeV scale
 - Attract and train the best students in the field
 - Clarify physics requirements
 - An international program in the US - groundwork for the future

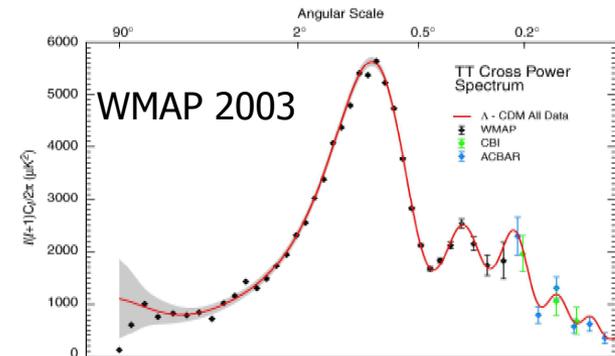
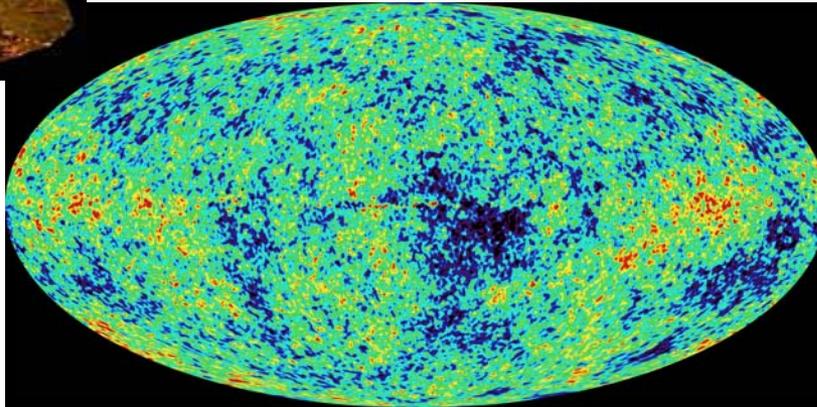


Big Questions at the Electroweak Scale

- The Tevatron is the only accelerator in operation that can help to answer
 - What is the structure and what are the symmetries of space-time?
 - Why is the weak force weak?
 - What is cosmic dark matter made of?



About six to seven times more mass in the universe ($27 \pm 4\%$) than there is baryonic matter ($4.4 \pm 0.4\%$)



What is this stuff? How can we get a firmer understanding of it?

Accelerators

- Run II is the only opportunity to make such a major discovery at an accelerator in the United States



The program

- **The Run II Physics program**
 - **Confront the standard model through precise measurements**
 - **The strong interaction, the quark mixing matrix, the electroweak force and the top quark**
 - **Directly search for particles and forces not yet known**
 - **Both those predicted (Higgs, supersymmetry, dark matter, extra dimensions) and those that would come as a surprise**
- **The program was developed in a series of workshops between 1998 and 2000**
 - <http://fnth37.fnal.gov/run2.html>
- **The program stretches from the GeV scale to the TeV scale**
- **Here I can attempt only a superficial survey and will concentrate on the physics that gains most from luminosity**
 - **Illustration of the breadth of the program:
110 talks from CDF and DØ at APS/DPF meeting in April**



Two Worldwide Collaborations

More than 50% non-US: a central part of the world HEP program



12 countries, 59 institutions

~~767~~ 706 physicists

John Womersley, slide 5



18 countries, 78 institutions

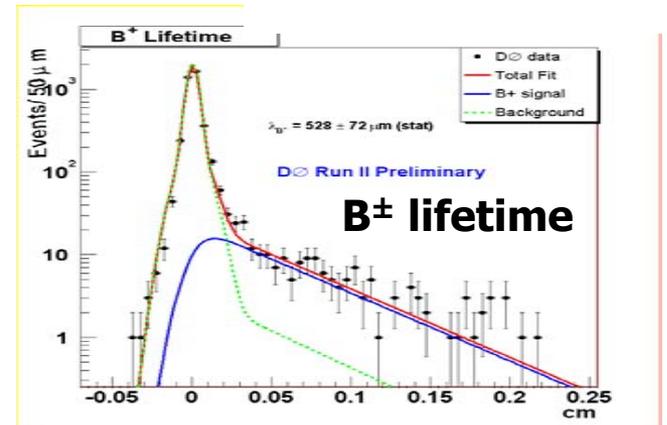
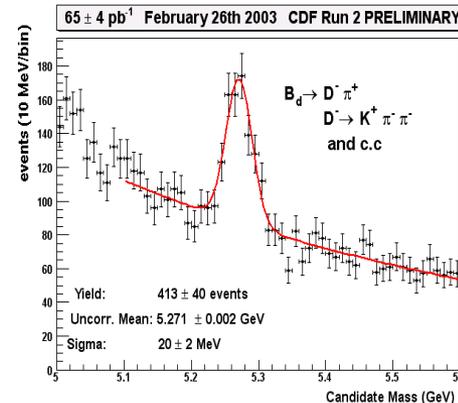
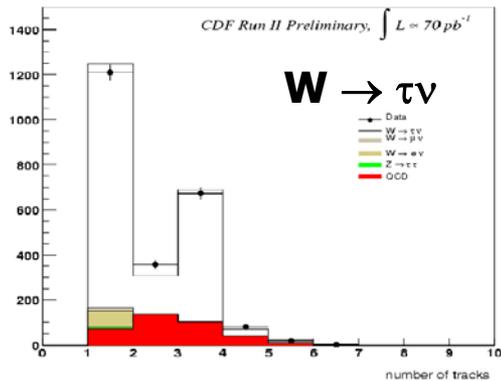
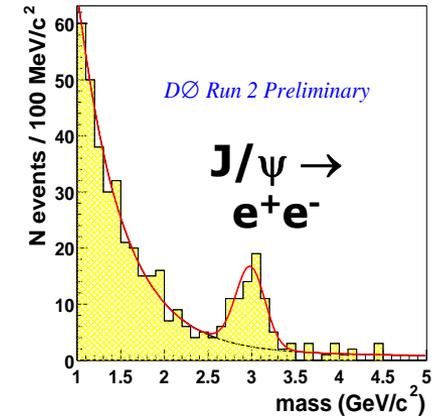
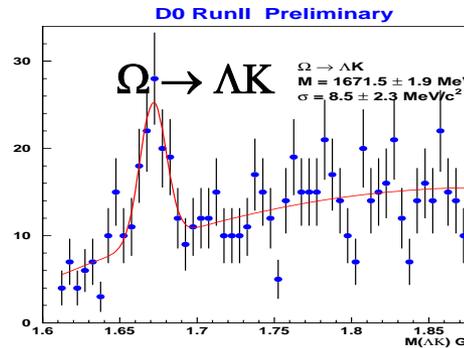
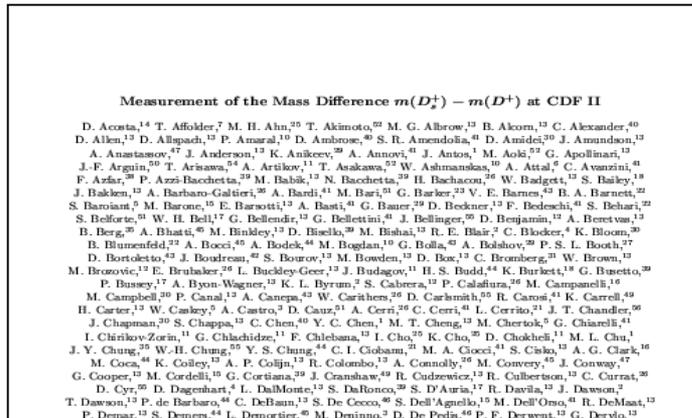
~~80~~ 664 physicists

670



Analysis

First Run II Paper

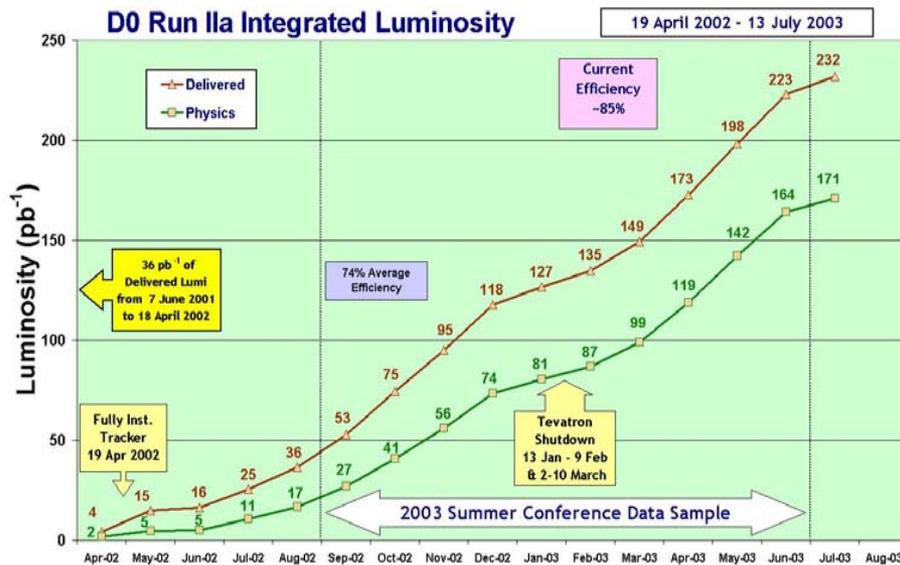


SVT triggered B-sample

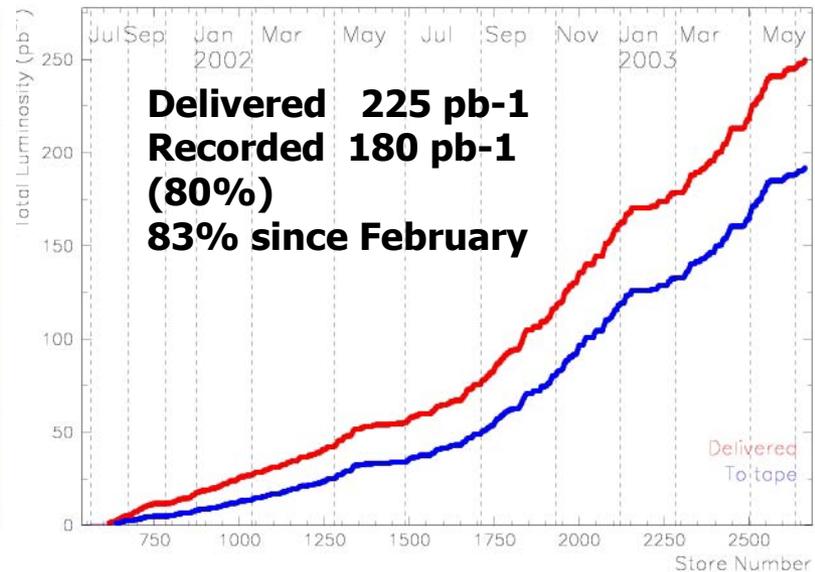


Operations Status

- Both experiments are operating well and recording physics quality data with high (85-90%) efficiency
- Data are being reconstructed within a few days
- 100-140 pb⁻¹ with all detectors integrated is being used for physics analysis for summer 2003



DØ



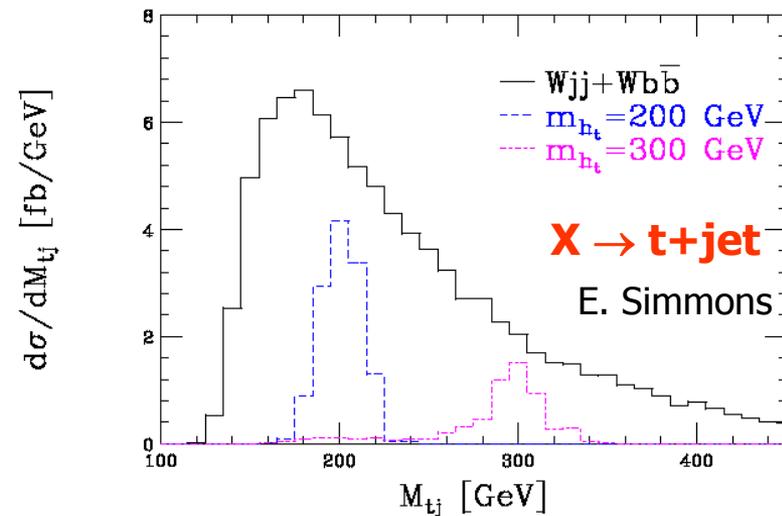
CDF

Since Feb 10 2003, silicon in 94% of time



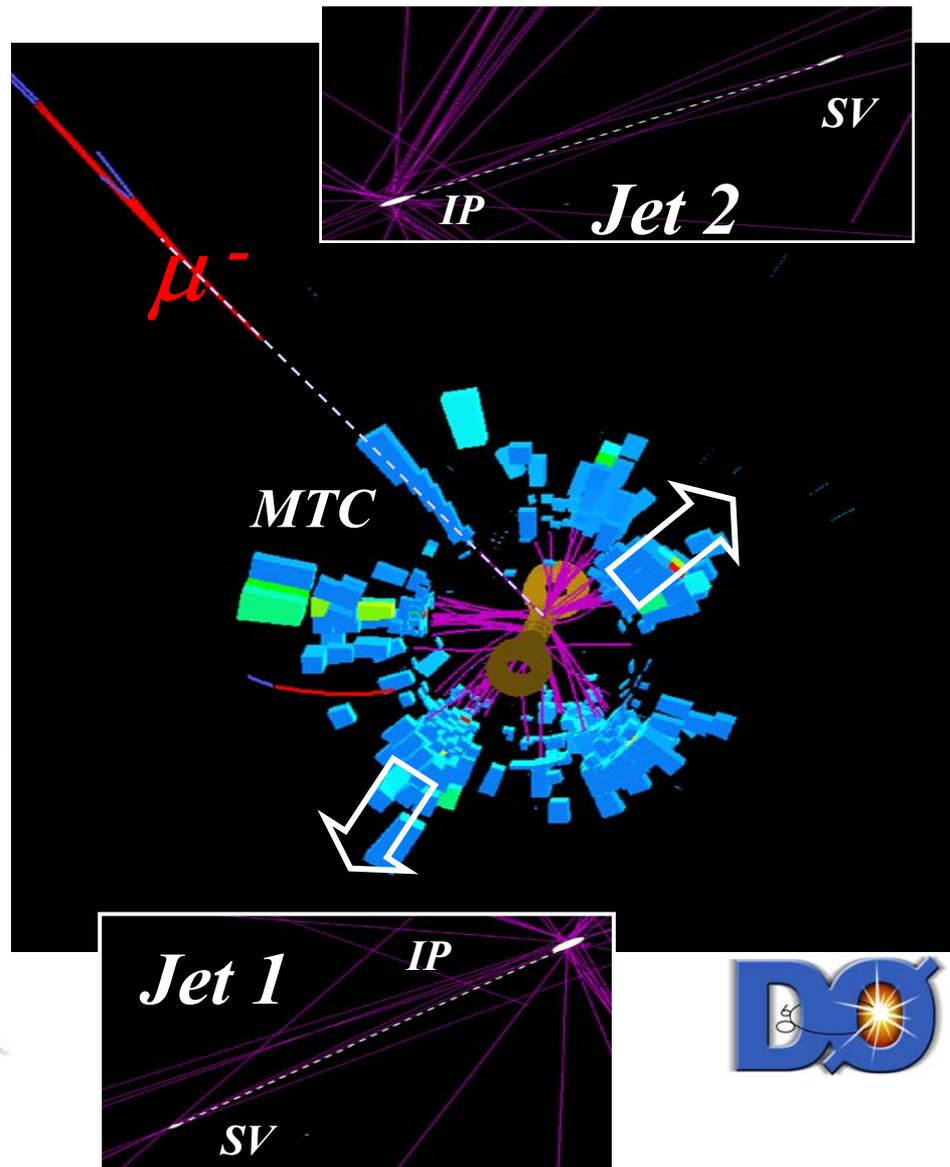
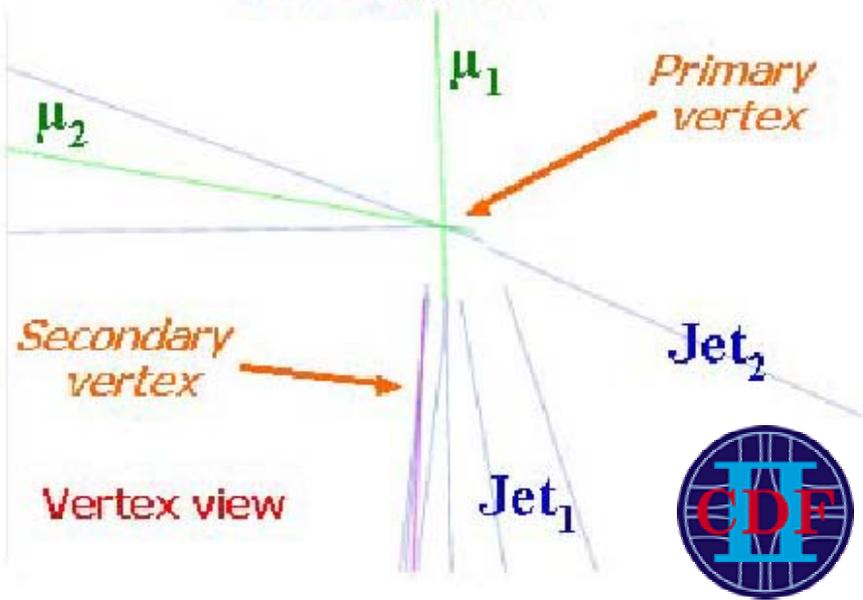
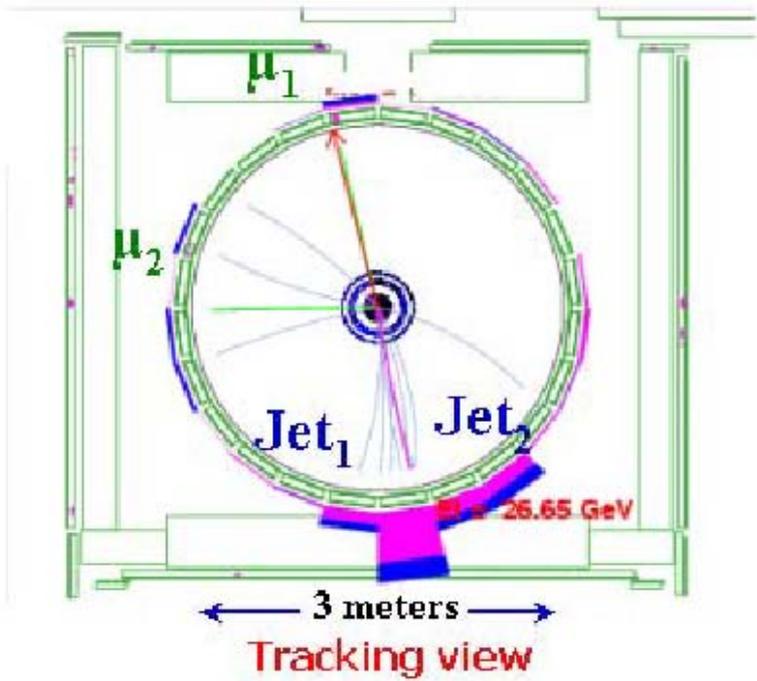
The Top Quark

- Why, alone among the elementary fermions, does the top quark couple strongly to the Higgs field?
 - Is nature giving us a hint here?
 - Is the mechanism of fermion mass generation indeed the same as that of EW symmetry breaking?
 - The top is a window to the origin of fermion masses
- The Tevatron Collider is the world's only source of top quarks
- We are measuring its
 - Mass
 - Production cross section
 - Spin
 - Through top-antitop spin correlations
 - Electroweak properties
 - Through single top production
- Any surprises, anomalies?



The Run II Top Physics Program has begun

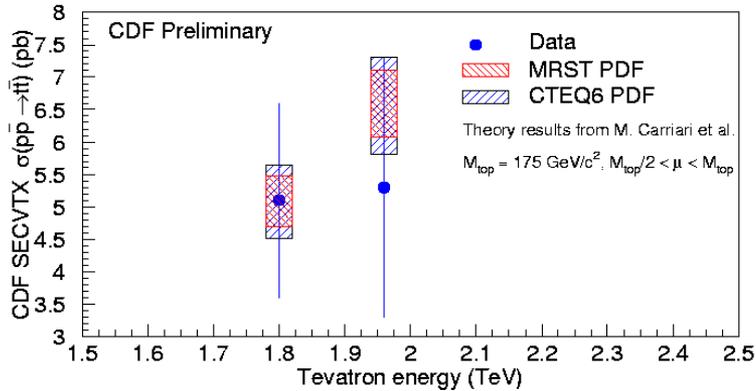




The top quark rediscovered, 2003

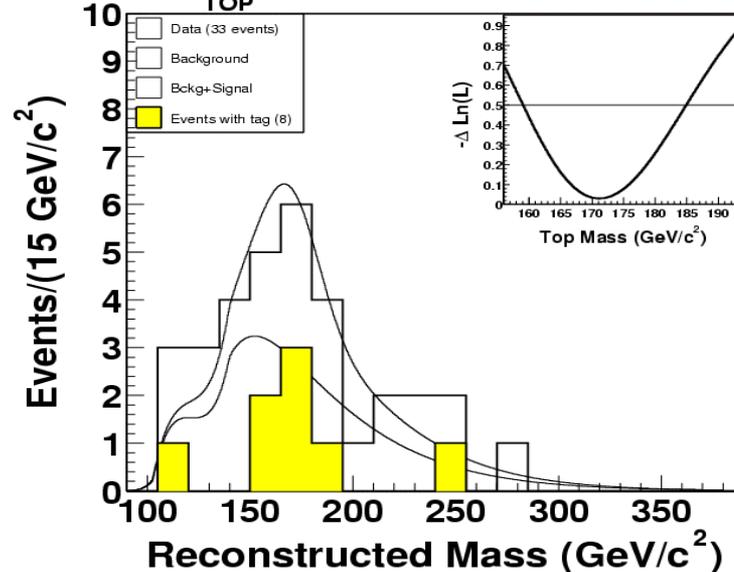
Cross section

CDF dileptons $\sigma = 13.2 \pm 5.9_{stat} \pm 1.5_{sys} pb$
CDF $l + jets$ $\sigma = 5.3 \pm 1.9_{stat} \pm 0.8_{sys} \pm 0.8_{lum} pb$
DØ (comb.) $\sigma = 8.5^{+4.5}_{-3.6} (stat)^{+6.3}_{-3.5} (sys) \pm 0.8(lum) pb$



CDF II Preliminary (72 pb⁻¹)

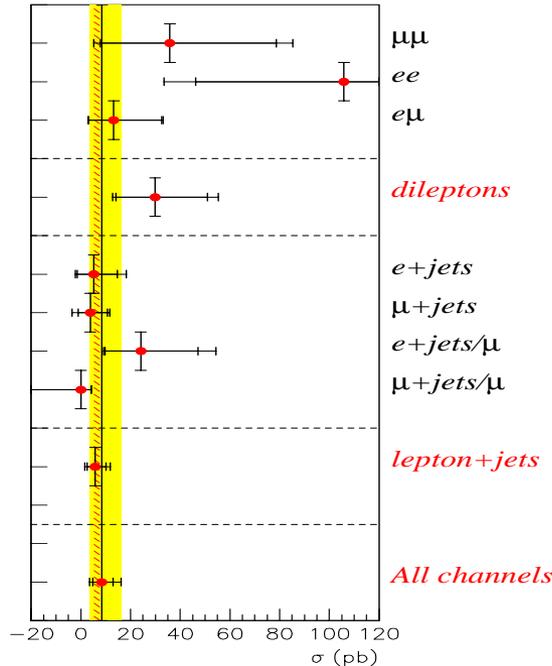
$$M_{TOP} = 171.2 \pm 13.4 \pm 9.9 \text{ GeV}/c^2$$



CDF mass

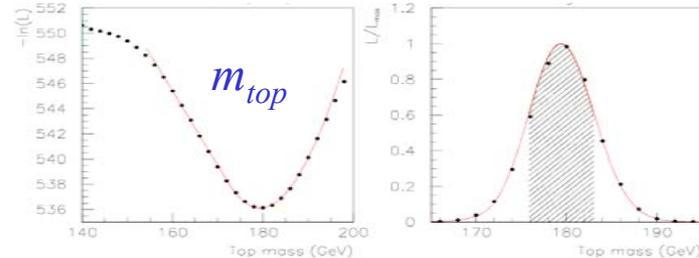
$$M_{top} = 171.2^{+14.4}_{-12.5} \text{ stat} \pm 9.9_{sys} \text{ GeV}/c^2$$

DØ Run II Preliminary



Top mass

- We can look forward to improved precision on m_t in the near future
 - More data (few hundred pb^{-1})
 - Expect ~ 500 b-tagged lepton+jets events per experiment per fb^{-1}
 - cf. World total at end of Run I ~ 50
- Improved techniques
 - e.g. new DØ Run I mass measurement is equivalent to a factor 2.4 increase in statistics:



$$m_{top} = 179.9 \pm 3.6 \quad (stat) \text{ GeV}/c^2 \quad (5.6 \text{ GeV from PRD 58 052001, 1998})$$

Improved top mass measurements help to constrain the Higgs mass

Δm_t	$l + \text{jets}$	dilepton
2 fb^{-1}	$\pm 2.7 \text{ GeV}$	$\pm 2.8 \text{ GeV}$
5 fb^{-1}	$\pm 2.2 \text{ GeV}$	$\pm 2.2 \text{ GeV}$

per experiment, using the "classic" technique

[from M. Grunewald et al., hep-ph/0111217 (2001)]

$$\Delta m_H / \Delta m_t \sim 50 \text{ GeV} / 4 \text{ GeV}$$



Top physics program

- Precise knowledge of m_t (~ 1 GeV) will be very useful even after a light Higgs is discovered

- Is it H_{SM} or SUSY h ?
- Constrain the stop sector:
[M. Beneke et al., hep-ph/0003033]

- Single top production

- The way to measure top width
- So far unobserved
- With $\sim 1 \text{ fb}^{-1}$ should be able to see signals for both s and t -channel production (have different sensitivity to new physics)

	$\Delta\sigma$ (s)	$\Delta V_{tb} $ (s)	$\Delta\sigma$ (t)	$\Delta V_{tb} $ (t)
2 fb⁻¹	21%	12%	12%	10%
5 fb⁻¹	13%	8%	8%	9%

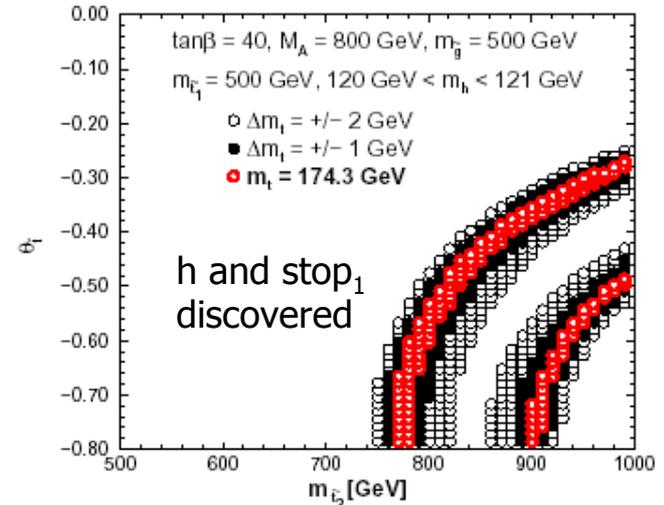
[scaled from T. Stelzer, Z. Sullivan and S. Willenbrock, Phys. Rev. **D58**, 094021 (1998)]

- Top-antitop spin correlations

- With 5fb^{-1} , distinguish spin-1/2 from spin-0 at the 3σ level

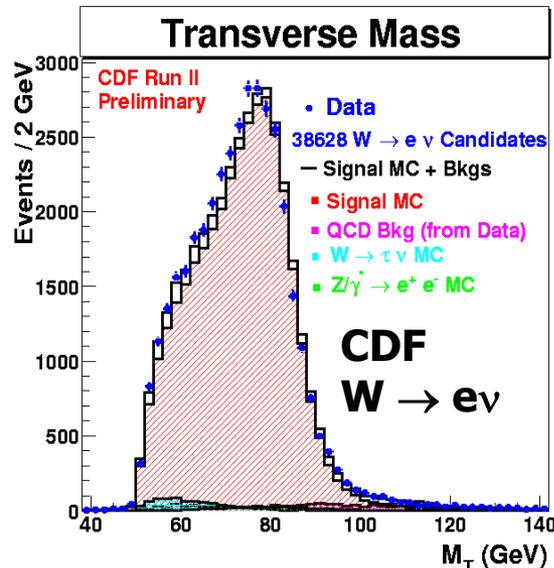
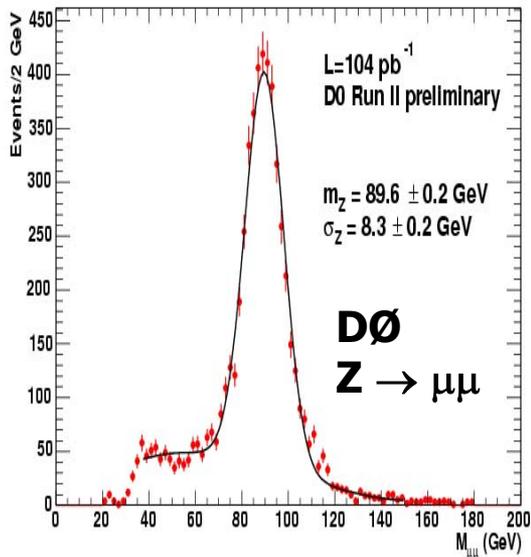
- New physics

- $t\bar{t}$ mass, top p_T , rare decays and nonstandard decays, anomalous single top ...

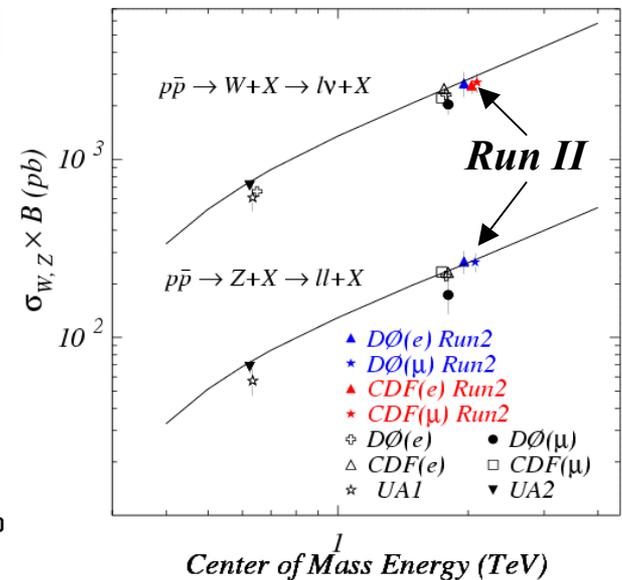


Electroweak Physics

- In Run II we will complement direct searches for new phenomena with indirect probes
 - New particles and forces can be seen indirectly through their effects on electroweak observables.
 - Tightest constraints come from improved determination of the masses of the W and the top quark.
- Both experiments have preliminary results from Run II samples of W and Z candidates:



DØ and CDF Run2 Preliminary



Prospects for W mass

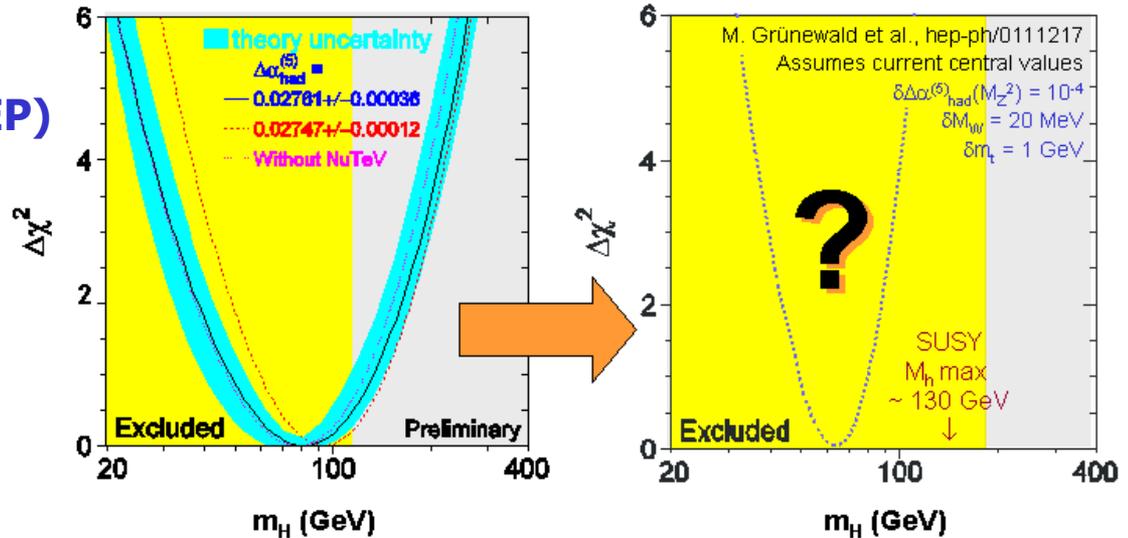
Current knowledge of m_W

- **hadron colliders:**
 - **80 454 ± 59 MeV**
- **World (dominated by LEP)**
 - **80 451 ± 33 MeV**

Run II prospects

(per experiment)

	Δm_W
2 fb⁻¹	±27 MeV
5 fb⁻¹	±22 MeV



[from M. Grunewald et al., hep-ph/0111217 (2001)]

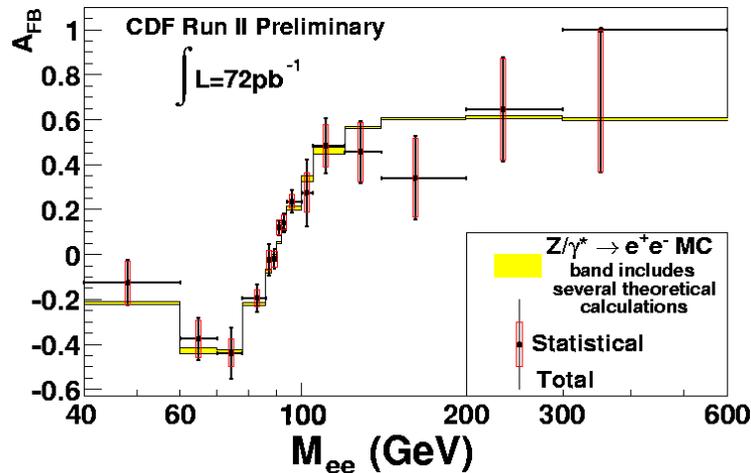
We have shown we can measure the W mass precisely at the Tevatron, but to improve on LEP will require $\sim \text{fb}^{-1}$ datasets - not a short term goal

$$\boxed{dm_H/dm_W \sim 50 \text{ GeV}/25 \text{ MeV}}$$

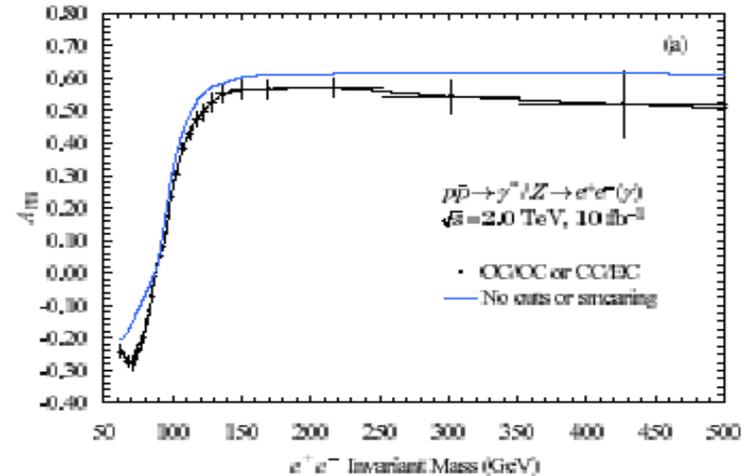


Other electroweak measurements

- Forward-backward asymmetry A_{FB} in $Z \rightarrow ee$



CDF – Paper in preparation



Projection for 10 fb^{-1}

- measure effective $\sin^2\theta_W$ to 0.0004 (5 fb^{-1}) and test γ^*/Z interference at \sqrt{s} much greater than LEP
- Other electroweak measurements
 - Multiboson production (test gauge couplings)
 - Boson plus jets
 - ...



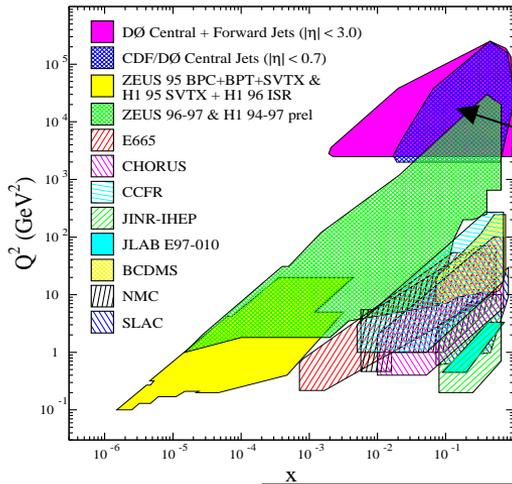
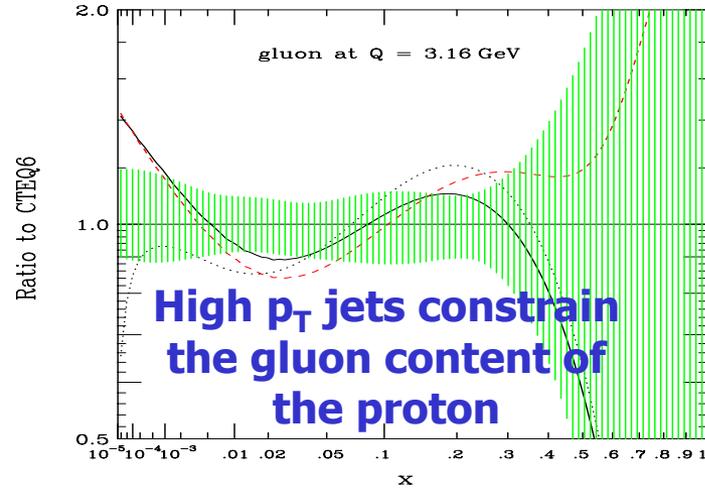
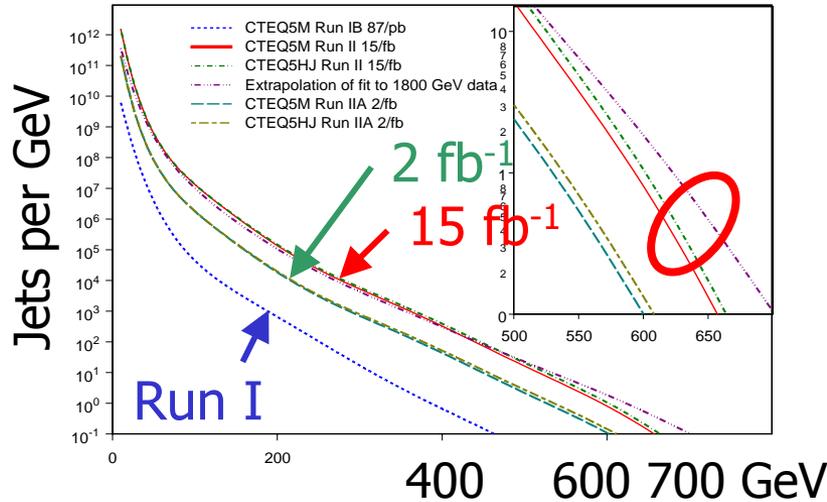
QCD

- **No one doubts that QCD describes the strong interaction between quarks and gluons**
 - **Its effects are all around us:**
 - **masses of hadrons (stars and planets)**
 - **But it is not an easy theory to work with**
- **Use the Tevatron to**
 - **Test QCD itself**
 - **Understand some outstanding puzzles from Run I**
 - **Develop the expertise to calculate, and confidence in, the backgrounds to new physics**
 - **Excellent interaction between the experimental and phenomenology communities**



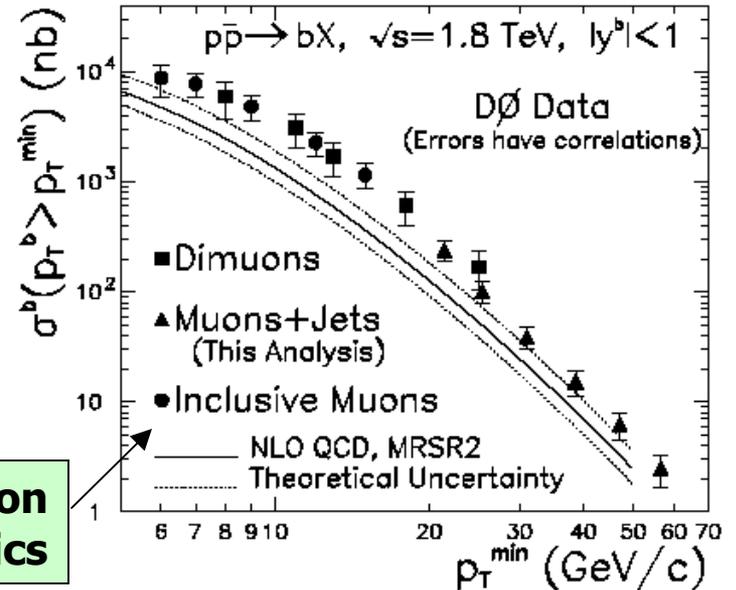
Some QCD Physics goals for Run II

Jet Yields Bin 1 - $0.1 < |y| < 0.7$

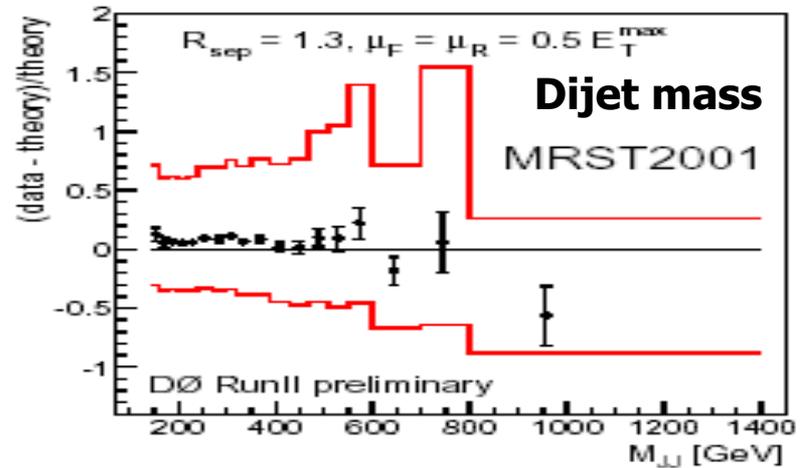
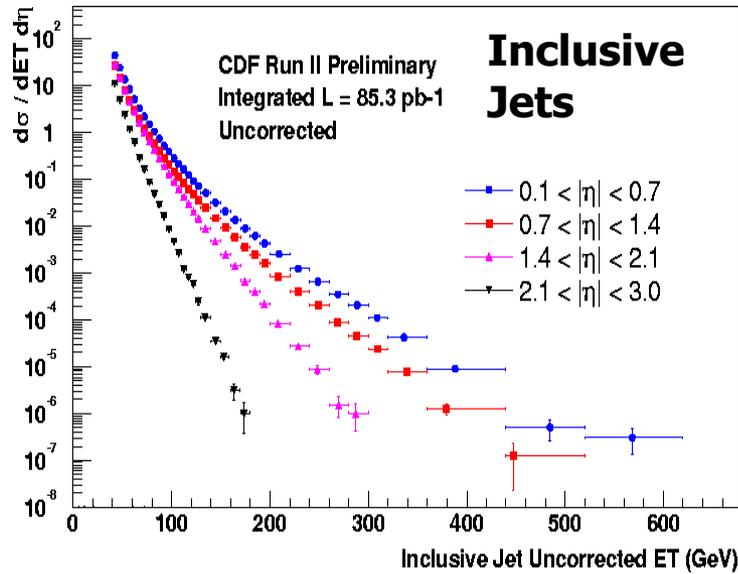


Run I jet data already used in CTEQ6 and MRST2001 parton distribution fits; complements HERA's kinematic range

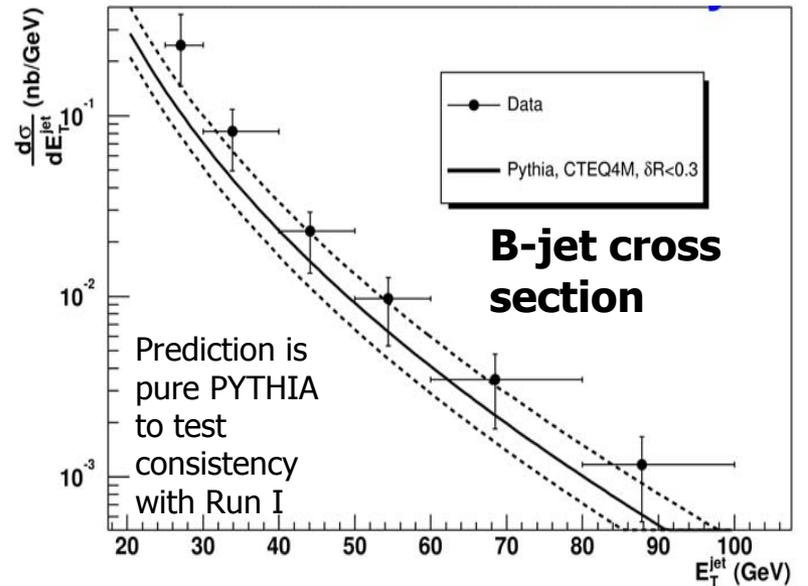
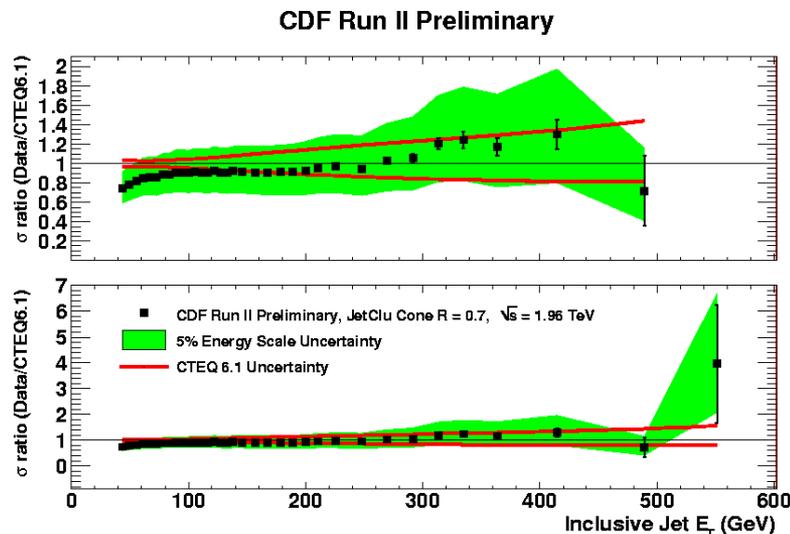
b-jet cross section Important background to new physics



Jets in Run II



DØ Run II Preliminary



Searches for New Physics

- The Tevatron, as the world's highest energy collider, is the most likely place to directly discover a new particle or force
- We know the SM is incomplete
 - Most popular extension: supersymmetry
- Predicts multiple Higgs bosons, strongly interacting squarks and gluinos, and electroweakly interacting sleptons, charginos and neutralinos
 - masses depend on unknown parameters, expected to be 100 GeV - 1 TeV

**Lightest neutralino is a good candidate for cosmic dark matter
Potentially discoverable at the Tevatron**



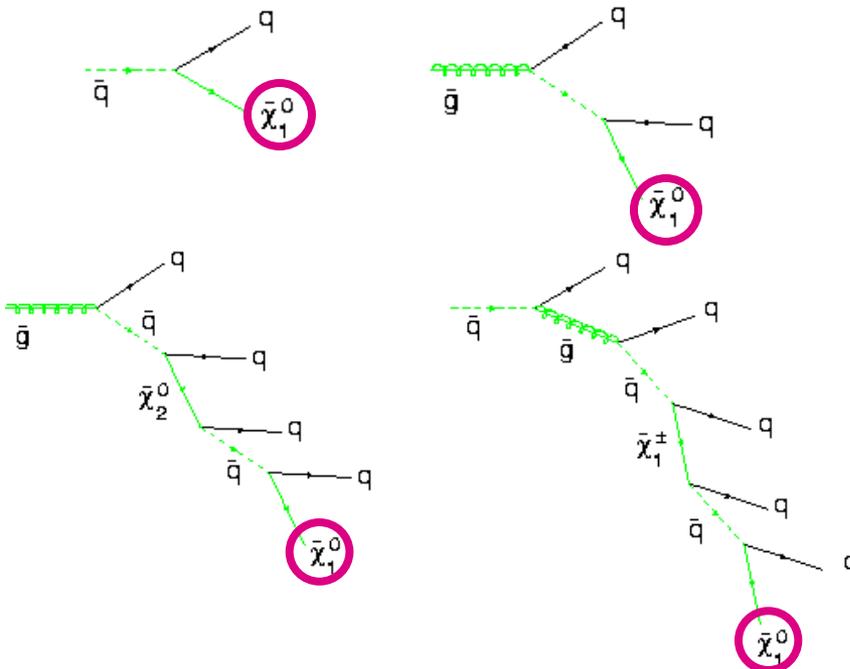
Supersymmetry signatures

- Squarks and gluinos are the most copiously produced SUSY particles
- As long as R-parity is conserved, cannot decay to normal particles
 - Jets plus missing transverse energy signatures

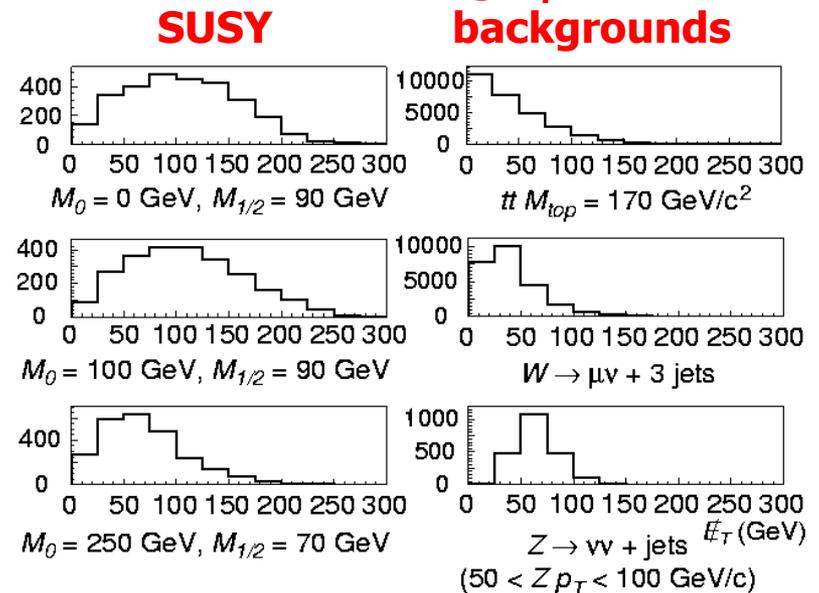
Make dark matter at the Tevatron!

Detect its escape from the detector

Possible decay chains always end in the LSP



Missing E_T backgrounds



Search region typically $> 75 \text{ GeV}$



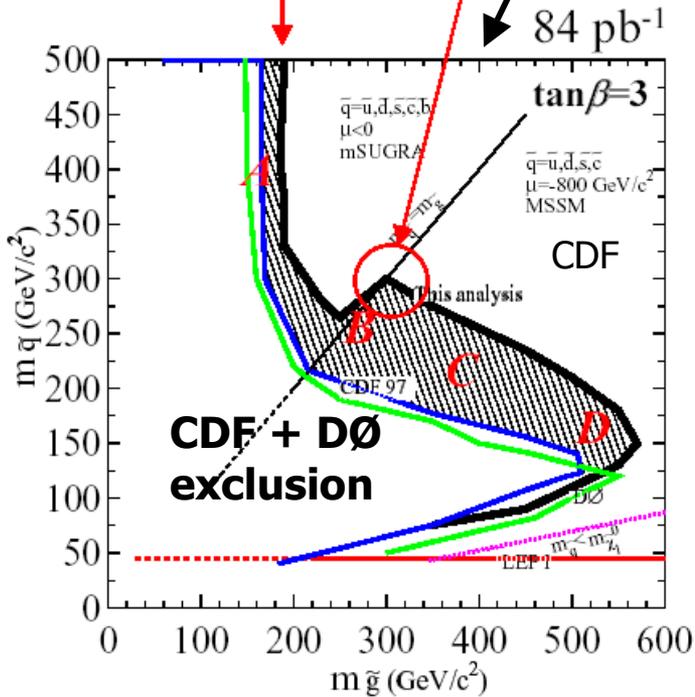
Searching for squarks and gluinos

Run I

$$M_{\tilde{g}} > 300 \text{ GeV}/c^2 \quad M_{\tilde{q}} \approx M_{\tilde{g}}$$

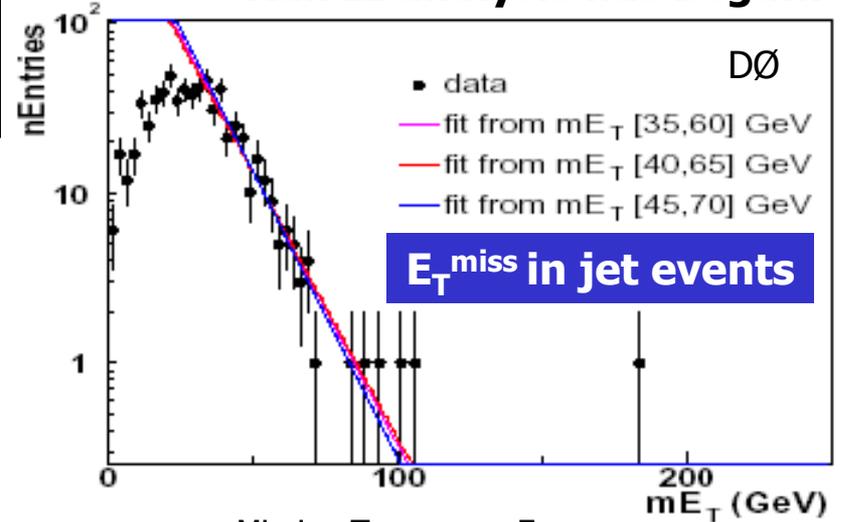
$$M_{\tilde{g}} > 195 \text{ GeV}/c^2$$

**With 2 fb⁻¹:
Reach in gluino
mass ~ 400 GeV**



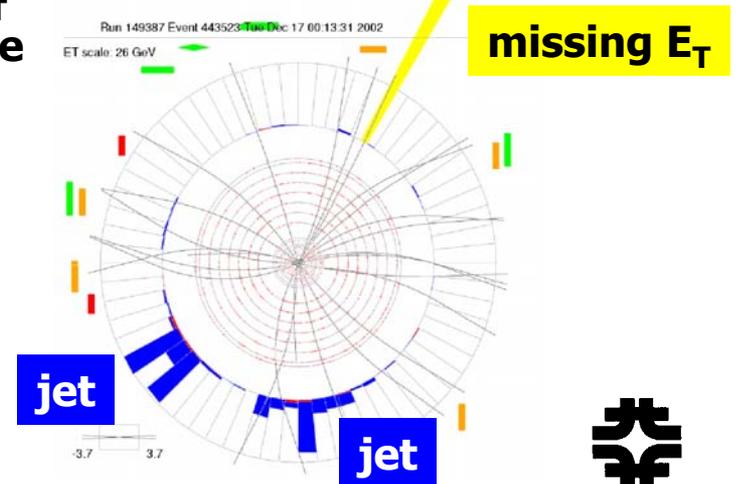
84 pb⁻¹

Run II analysis has begun:



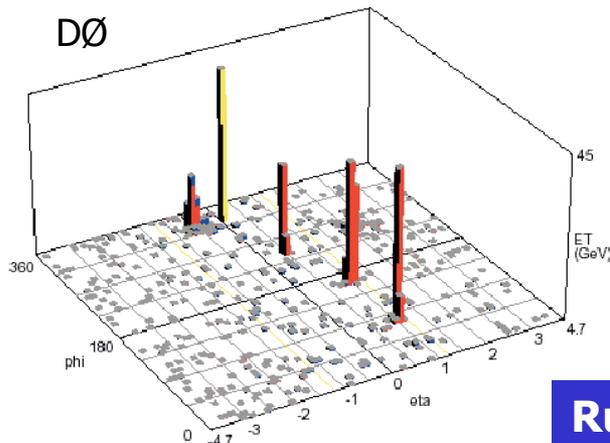
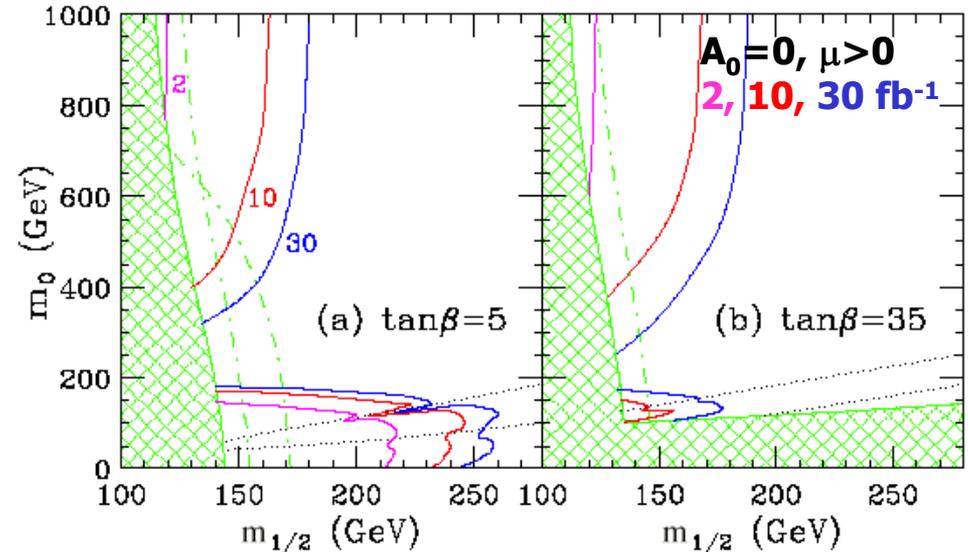
**High ME_T
candidate
event**

DØ



Chargino/neutralino production

- “Golden” signature
 - Three leptons
 - very low standard model backgrounds
- This channel becomes increasingly important as squark/gluino production reaches its kinematic limits (masses ~ 500 GeV)
- Reach on χ^\pm mass, $2\text{fb}^{-1} \sim 180$ GeV ($\tan \beta = 2, \mu < 0$)
 ~ 150 GeV (large $\tan \beta$)



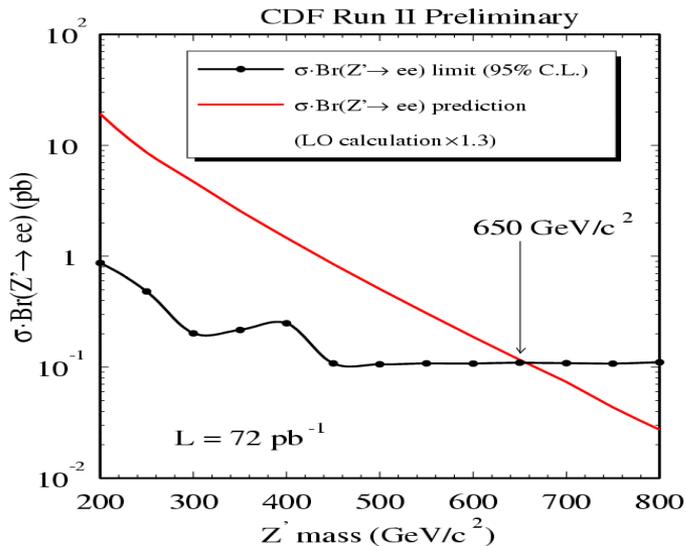
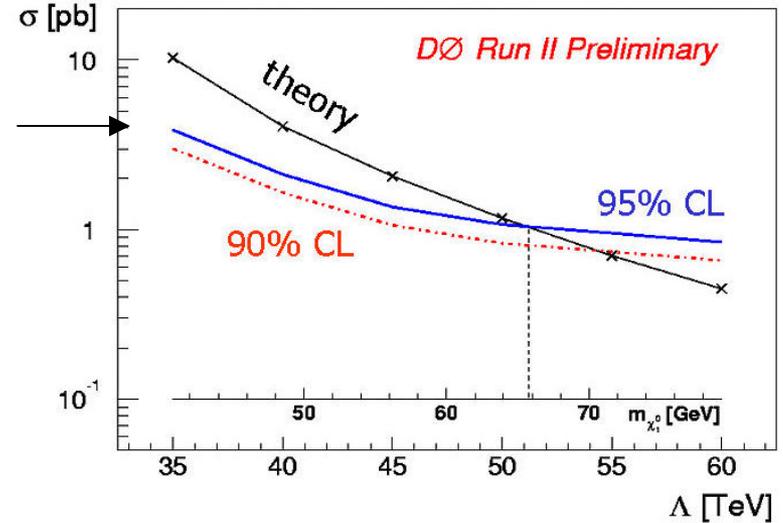
**Searches have begun.
 So far number of events is consistent with expectations — we need a lot more data, but the tools are in place**

Run II Trilepton candidate



Other Searches at the Tevatron

- Other Tevatron search channels for SUSY
 - GMSB \rightarrow Missing E_T + photon(s)
 - Stop, sbottom
 - RPV signatures
- Searches for other new phenomena
 - leptoquarks, dijet resonances, W', Z' , massive stable particles, doubly charged particles...



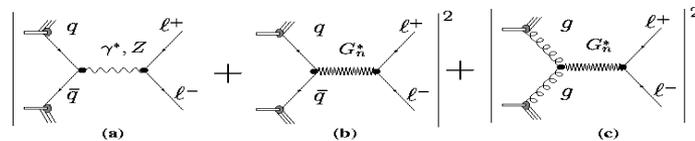
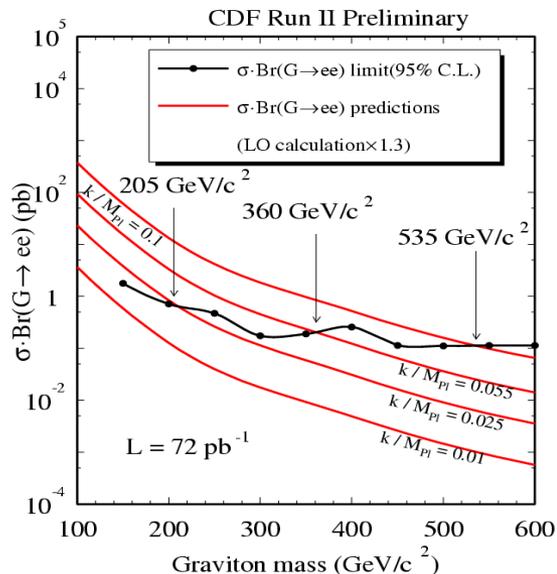
Many search results now comparable or better than Run I

CDF Run II $Z' > 650 \text{ GeV}/c^2$



Extra Dimensions

- Run II is also testing the new and exciting idea of extra dimensions
 - Can gravity propagate in more than four dimensions of space-time?
 - If these dimensions are not open to the other SM particles and forces, we would not perceive them
 - Particle physics experiments at the TeV scale could see effects (direct and indirect)
 - Measure the structure of space-time!

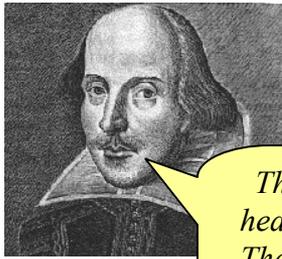


	GRW	HLZ for n:		Hewett
		2	7	$\lambda = +1$
diEM	1.12	1.16	0.89	1.00
diMU	0.79	0.68	0.63	0.71

DØ
Run II
Preliminary

With 2 fb^{-1} , we probe up to 2 TeV

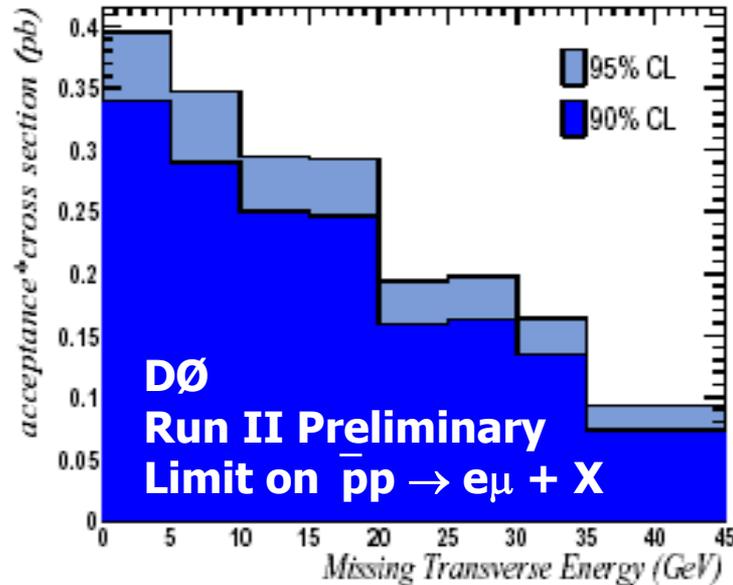




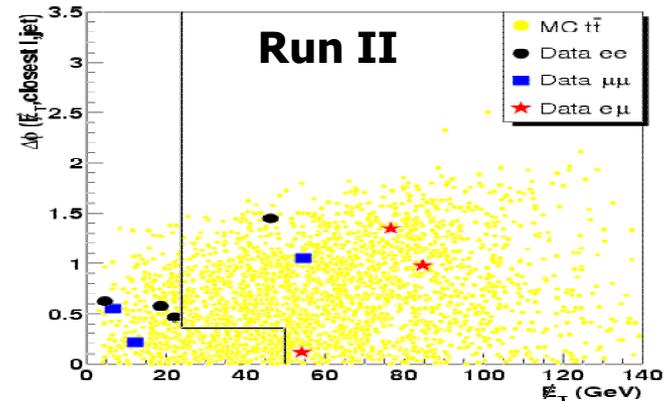
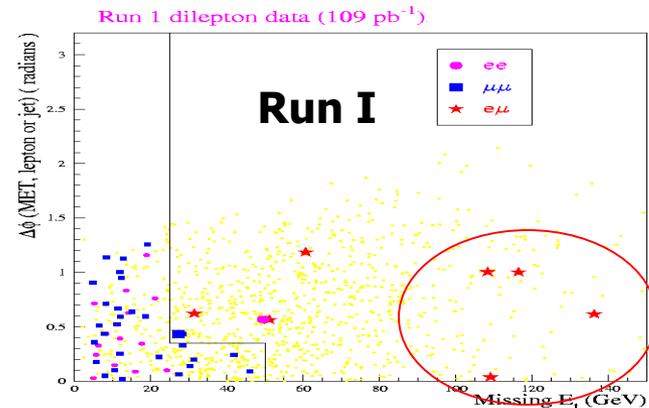
There are more things in heaven and earth, Horatio, Than are dreamt of in your philosophy.

Signature-based searches

We need to ensure that our searches are not constrained by our preconceptions of what might be "out there."



CDF dilepton top events



Follow up anomalies in Run I data, and set model-independent limits

"Sleuth" framework used very successfully by DØ

Phys. Rev. D {62} 92004 (2000)

John Womersley, slide 25



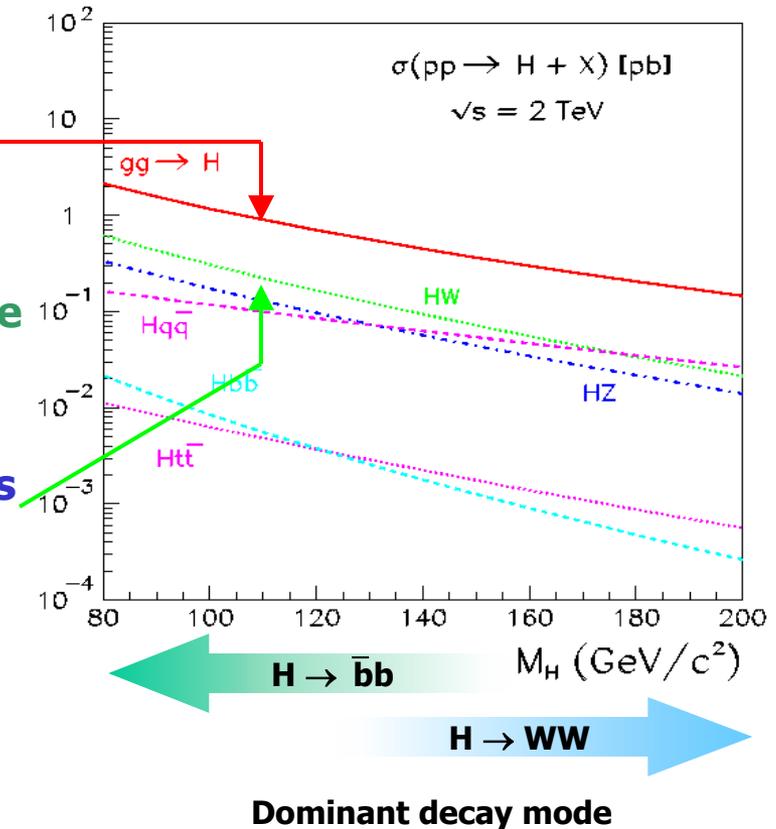
The Higgs Boson

- In the Standard model, the weak force is weak because the W and Z gain mass from a scalar field that fills the universe
- The same field is responsible for the mass of the fundamental fermions
- If it exists, we can excite the field and observe its quanta in the lab
 - **The Higgs boson**
 - Last piece of the SM
 - Key to understanding beyond-the-SM physics like supersymmetry: a light Higgs is a basic prediction of SUSY
- All the properties of the Higgs are fixed in the SM with the exception of its own mass: simulations have no free parameters



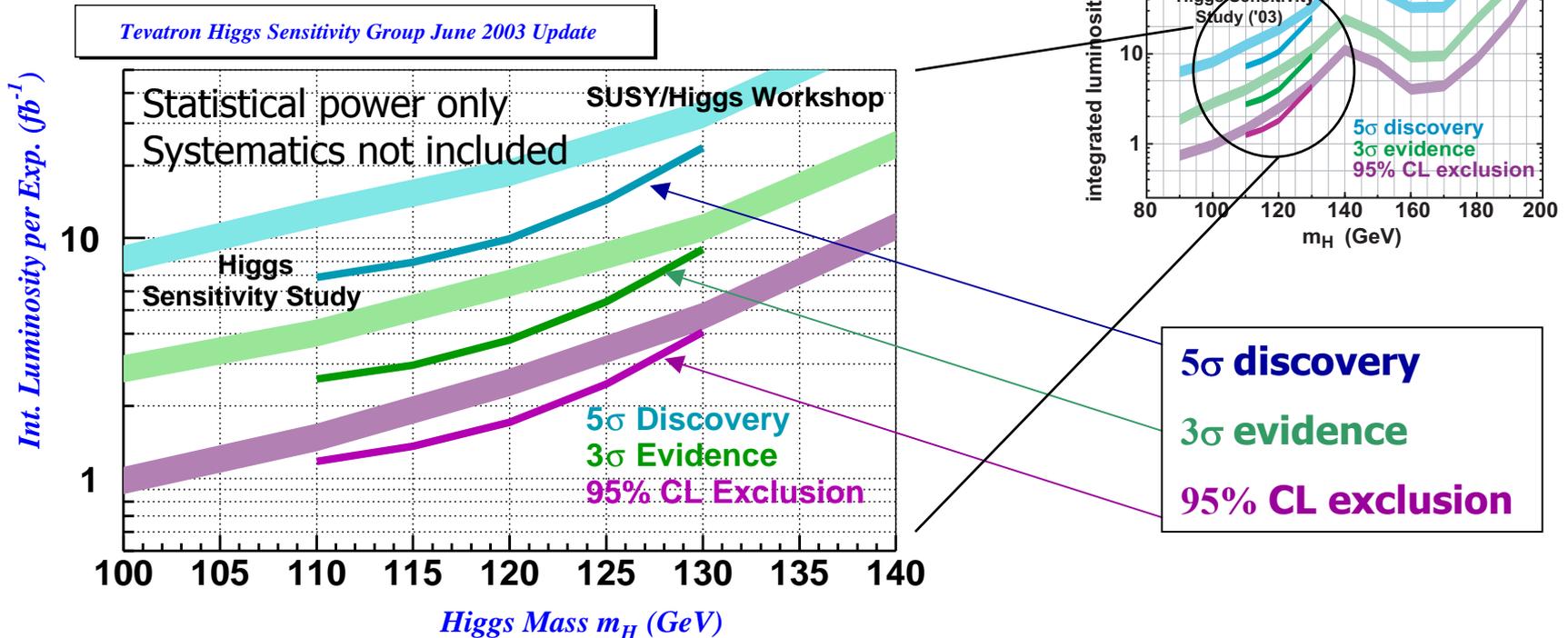
Higgs Hunting at the Tevatron

- For any given Higgs mass, the production cross section and decays are all calculable within the Standard Model
- Inclusive Higgs cross section is quite high: $\sim 1\text{pb}$
 - for masses below $\sim 140\text{ GeV}$, the dominant decay is $H \rightarrow b\bar{b}$ which is swamped by background
 - at higher masses, can use inclusive production plus WW decays
- The best bet below $\sim 140\text{ GeV}$ appears to be associated production of H plus a W or Z
 - leptonic decays of W/Z help give the needed background rejection
 - cross section $\sim 0.2\text{ pb}$



Update on Higgs sensitivity

- A CDF + DØ joint study has now updated the “famous” Higgs reach plot:

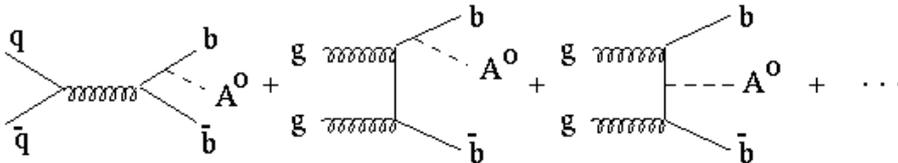


- Concentrated on low mass region (favored both in SM and SUSY)
- The Higgs reach at the Tevatron appears to be at least as good as was projected four years ago
- Our understanding will continue to improve



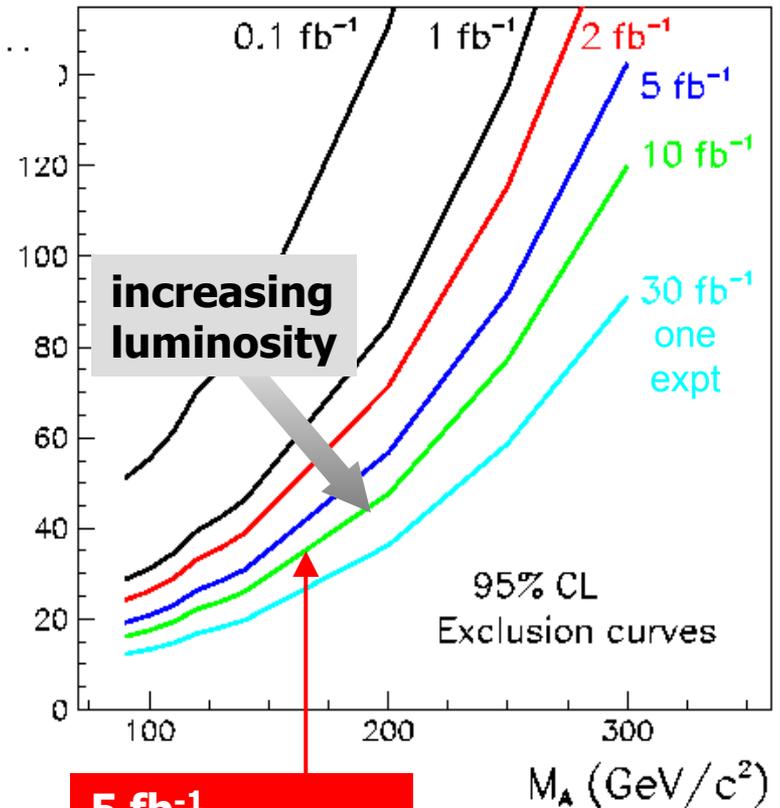
SUSY Higgs Production at the Tevatron

- $bb(h/H/A)$ enhanced at large $\tan \beta$:

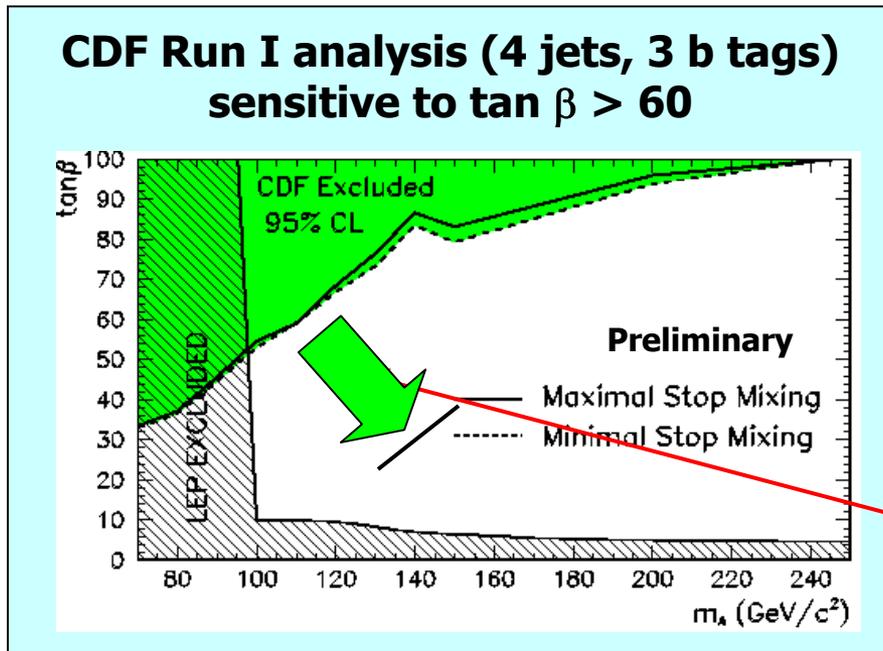


- $\sigma \sim 1 \text{ pb}$ for $\tan \beta = 30$ and $m_h = 130 \text{ GeV}$

$bb(h/A) \rightarrow 4b$



**5 fb⁻¹
m_A = 140 GeV,
tan β = 30**



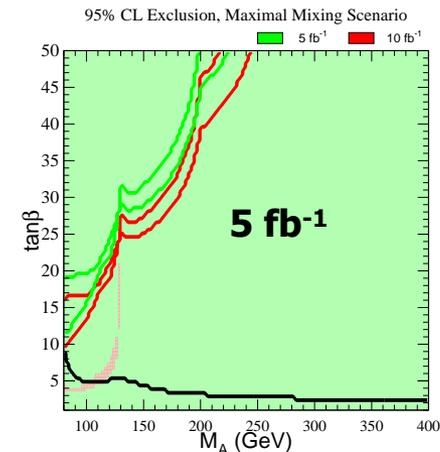
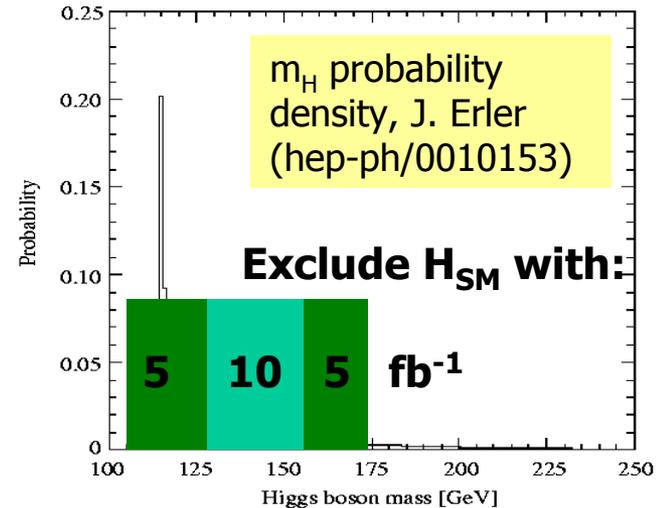
What if we see nothing?

Exclusion of a Higgs would itself be a very important result for the Tevatron

- In the SM, can exclude the LEP "hint" (115 GeV) with $\sim 2 \text{ fb}^{-1}$
- The most interesting mass range with $\sim 5 \text{ fb}^{-1}$
- Almost all the allowed mass range with $\sim 10 \text{ fb}^{-1}$

- In minimal SUSY, can potentially exclude all the remaining parameter space with 5 - 10 fb^{-1}
- Would certainly make life "interesting" for SUSY at the TeV scale

Note: the plots on this page do not yet take account of the Higgs reach update



Exclusion for SUSY Higgs sector
maximal stop mixing, sparticle masses = 1 TeV

Conclusions

- **The Run II physics program has begun**
 - **We now have more data than Run I, taken at a higher CM energy with better detectors**
- **The combination of highest accelerator energy, excellent detectors, enthusiastic collaborations, and data samples that double every year guarantees interesting and important new physics results at every step.**
- **Each step answers important questions, and each step leads on to the next.**
- **The physics program gains from luminosity. It is worthwhile to push the luminosity as far as we can go. But the program will be a success whatever level we reach.**

