Results from CDF and DØ (everything but the B)

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for the CDF and DØ Collaborations

Run II has started!

(we haven't found the Higgs)

YET

Big Questions

1. *Why is there Mass?* — **EW Symmetry Breaking**
   a. direct searches for Higgs / new particles
      * need highest possible energy (or lowest)
   b. precision measurements of EW param's
      * sensitivity to H.O. effects from Higgs/New Phys
   c. effects in rare processes
      * New Phys couples to mass $\Rightarrow$ t-, b-, τ-decays
2. *Where's the Antimatter?* — **Weak vs. Mass Eigenstates**
   a. Quarks $\Rightarrow$ Mixing, CP Violation,…
      * B^0, K^0 decays
   b. Leptons $\Rightarrow$ Neutrino Oscillations
      * neutrino mass, mixing & CP
3. *What about Matter?* — **Strong Interactions**
   a. Perturbative vs. Non-perturb.

The Tevatron is a good place to study all of these!

Physics Galore!

- **Run II Tevatron Working Groups**
  - http://www-theory.fnal.gov
  - Higgs hep-ph/0010338
  - SUGRA hep-ph/0003154
  - BTMSSM hep-ph/0006162
  - RPV hep-ph/9906224
  - GM SUSY hep-ph/0008070
  - EW Fermi-PUB-00/297
  - Top see web (above)
  - B hep-ph/0201071
- **Snowmass 2001**
  - http://snowmassserver.snowmass2001.org

- **CDF/DØ Results at ICHEP02**
  - http://www.ichep02.nl
  - http://www-d0.fnal.gov/Run2Physics/ichep2002.html
  - http://www-cdf.fnal.gov/ichepsum.html
  - CDF Overview F.Bedeschi
  - DØ Overview M.Narain
  - SUSY V.Zutshi
  - MSSM A.Connolly
  - Searches W.Orejudos
  - LED G.Bernardi
  - Top I.Iashvili
  - EW Prospects D.Glenzinski
  - W Mass & Width S.Eno
  - W Properties K.Bloom
  - Heavy Q Prod C.Pauss
  - Heavy Flavor Cerri
  - Photons/Jets J.Dittman
  - Photons/Jets M.Zielinski
  - kT Jets U.Bassler
  - Rapidity Gaps Hatakeyama
  - Detector Talks 5
  - **21 Talks !!!**

What You're In For

- **A Whirlwind Tour of all CDF/DØ Physics (!)**
  - **except for Heavy Flavors (see F.Wuerthwein's seminars)**

- **What I will emphasize**
  - **Common experimental themes in these topics**
  - **Differences from B-Physics**
  - **What to look for from the Tevatron in the coming years**
  - **A sampling of where we stand now**

- **What I will tragically ignore**
  - **Experimental status & detector performance**
  - **New Run I results**
  - **A lot of Run II work**
  - **Explanation of measurements**

- **Please do NOT be offended if I leave out your favorite result**
  - **take comfort in the fact that I would just gloss over it anyway**

Acknowledgements

Needless to say – I did not do all this work myself

Many Thanks to:

- **ICHEP Speakers**
  - **from whom I stole shamelessly**
- **Good Advice from:**
  - **B.Ashmanskas, G.Brooijmans, J.Dittmann, Y.Gershtein, A.Goshaw, J.Houston, J.Krane, G.Landsberg, N.Lockyer, M.Narain, G.Steinbrück, J.Womersley, S.Worm**
- **SLAC Summer Institute Organizers**
  - **for putting up with all my last minute requests**
- **Standard Disclaimer**
  - **all MISTAKES are MINE and should not be attributed to any of the above, their funding agencies, relatives, friends, pets, etc., etc…**

Life at the Tevatron

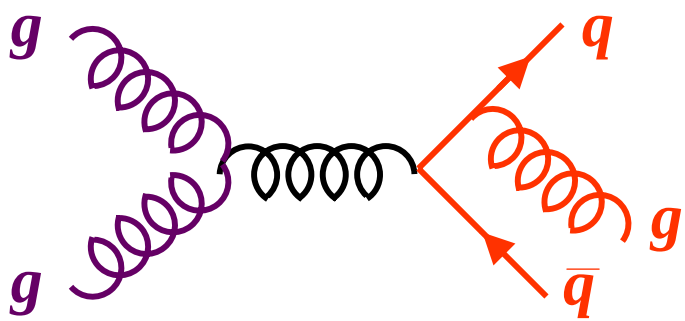
		Ib 92-96	IIa 01-04	IIb 05-08…
Tot. Anti-p	($x10^{12}$)	0.3	1.1	11
Bunches		6x6	36x36	140x103
Spacing	[ns]	3500	396	132
E-CM	[GeV]	1800	1960	1960
Typ. Lumi. ($x10^{32}$)	[$cm^{-2}s^{-1}$]	0.016	0.86	5.2
Lumi/week	pb^{-1}	3.2	17.3	105
Tot Lumi	fb^{-1}	0.125	2	15
Int's/X'ing		2.5	2.3	4.8

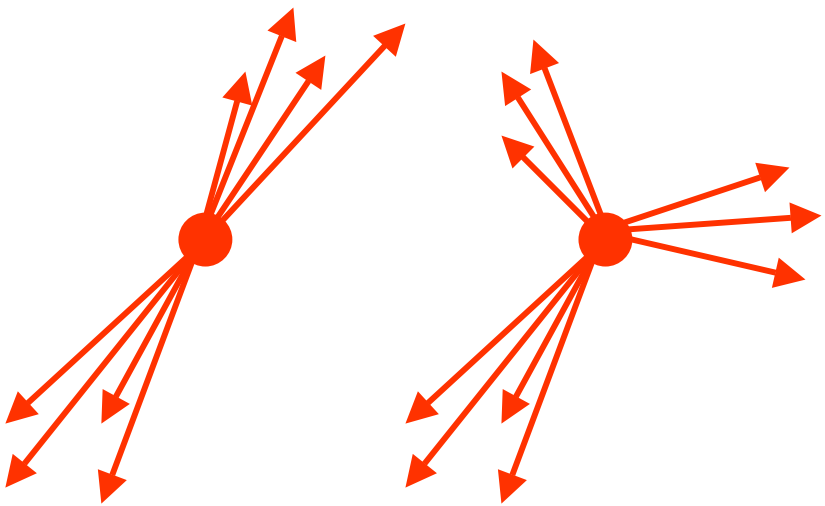
Two Ways to Win!

1. **Integrated Luminosity:** x20 (IIa) x150 (IIb)
2. **Cross-Sections:** increase when E_{CM}: 1800 → 1960 GeV
   - W/Z x1.1
   - Top x1.35
   - Jets @ P_t > 400 GeV x2

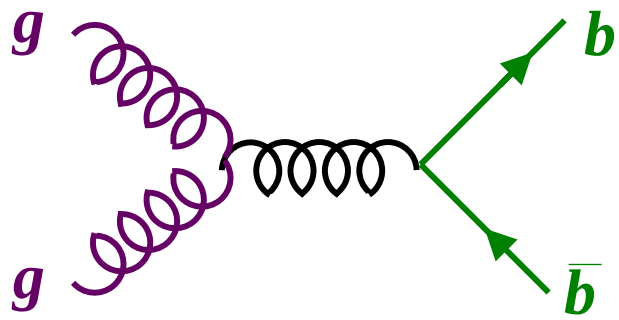
Soft Physics

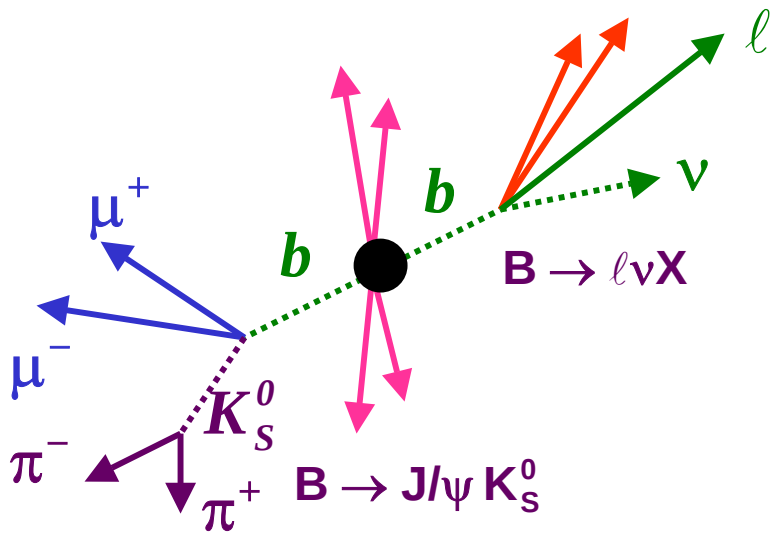
$p\bar{p} \rightarrow q\bar{q}g$





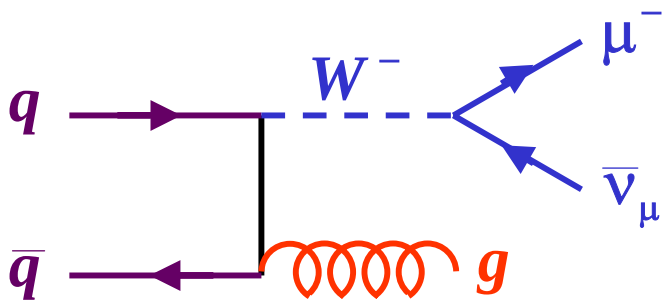
$p\bar{p} \rightarrow b\bar{b}X$



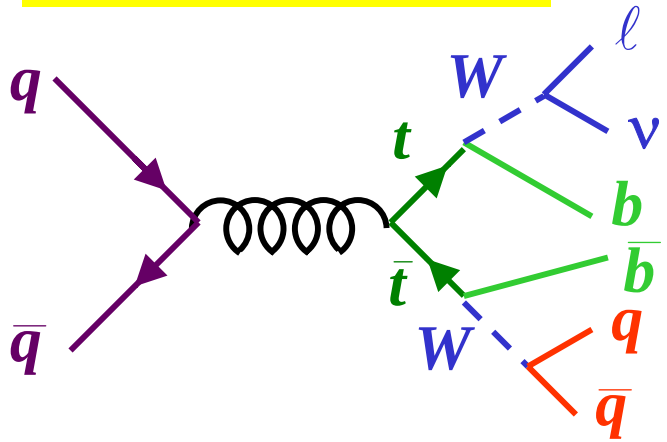


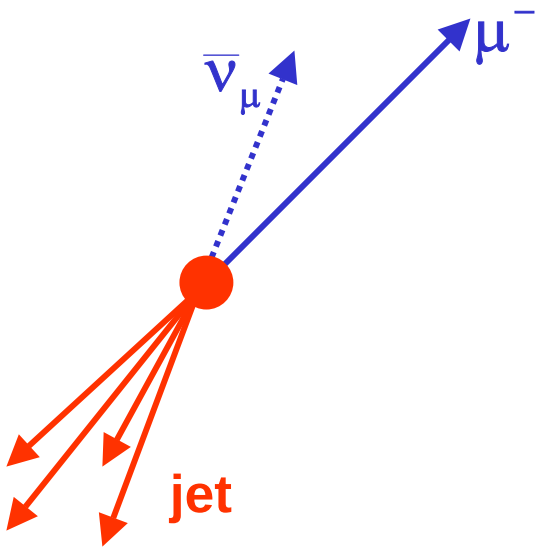
Vector Bosons & Top

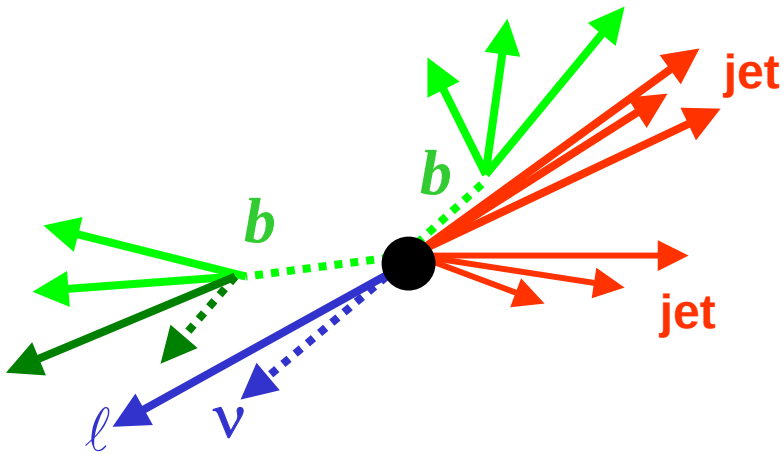
$p\bar{p} \rightarrow WX$



$p\bar{p} \rightarrow t\bar{t} \rightarrow \ell\nu b\bar{b}jj$

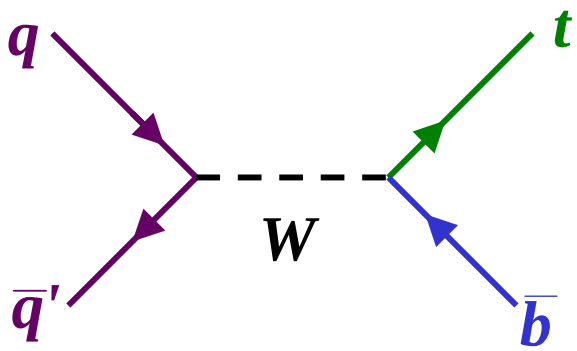




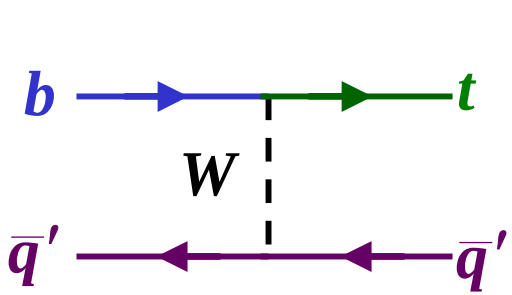


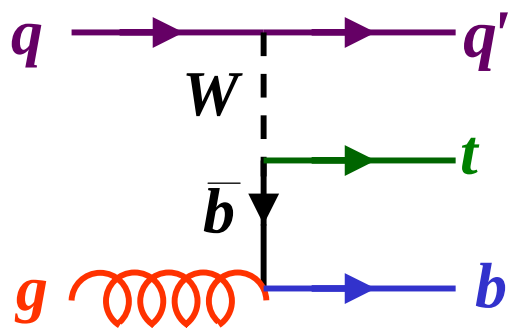
Single Top

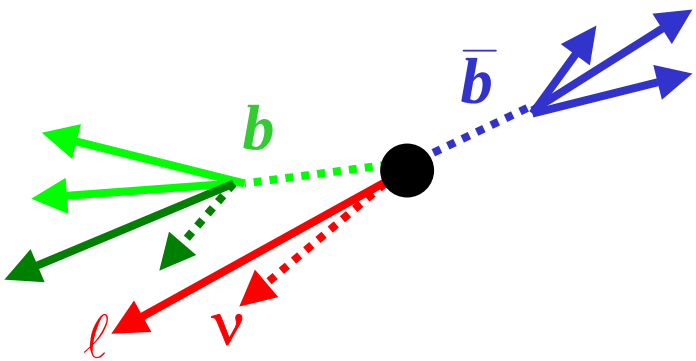
s-channel

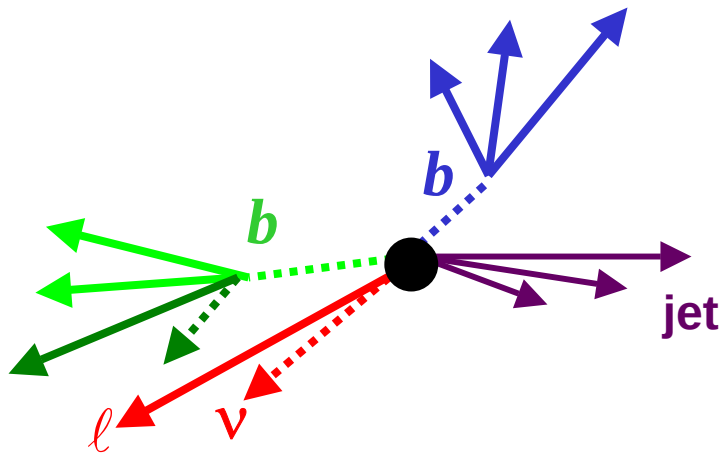


t-channel



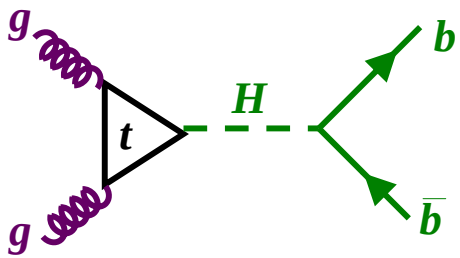


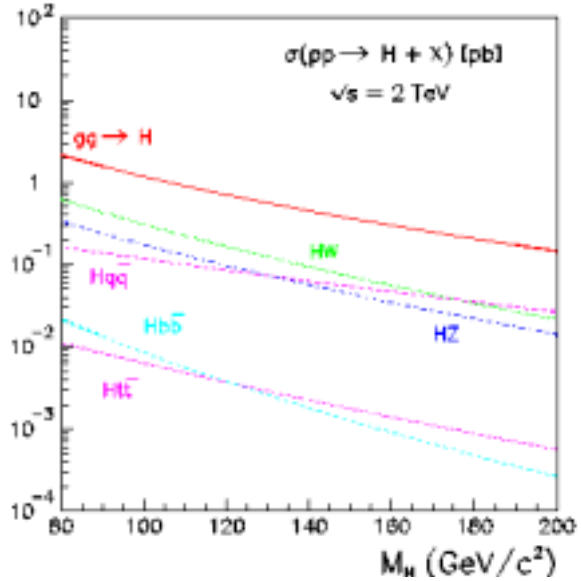




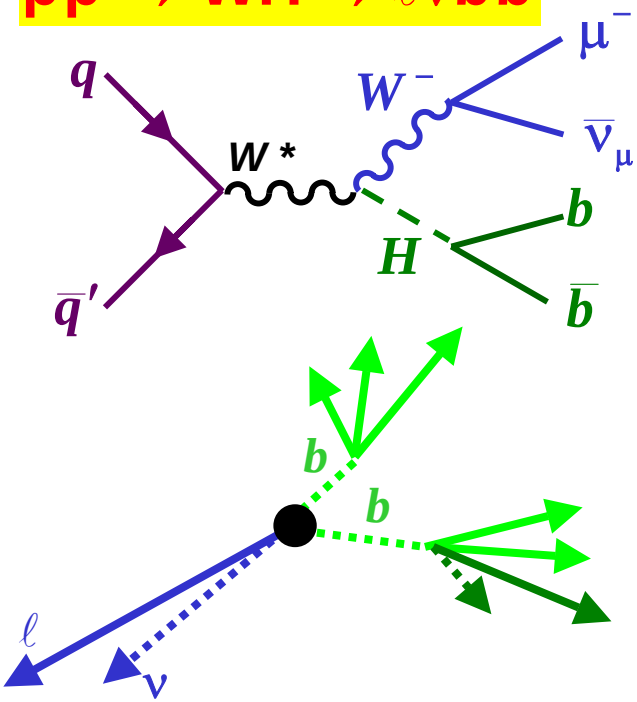
The Higgs

$p\bar{p} \to H \to b\bar{b}$

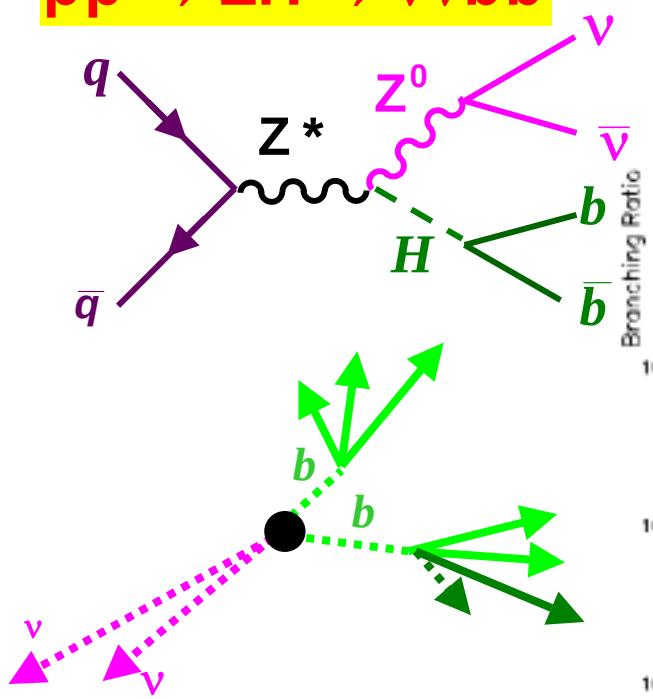


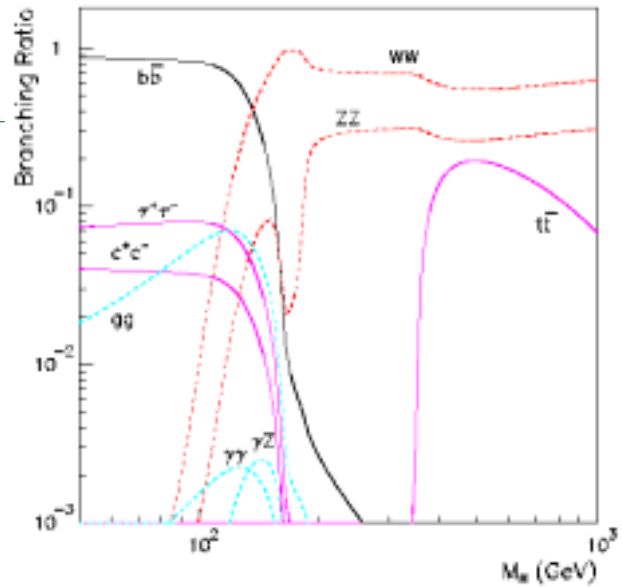


$p\bar{p} \to WH \to \ell\nu b\bar{b}$



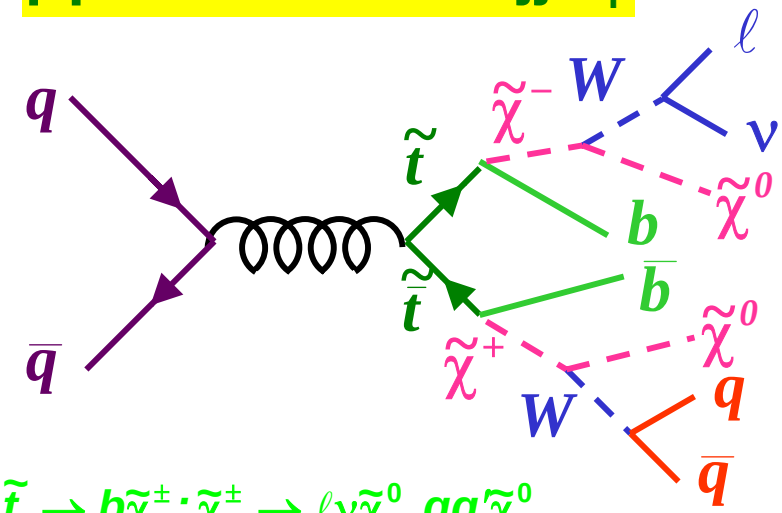
$p\bar{p} \to ZH \to \nu\bar{\nu}b\bar{b}$



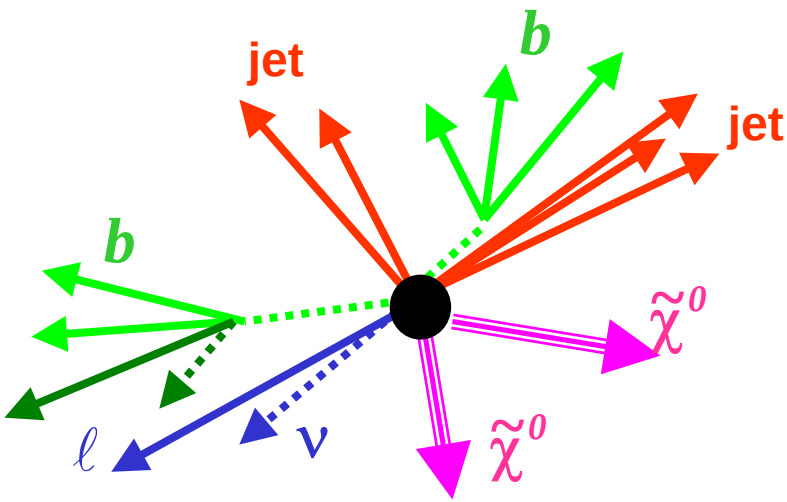


The Unexpected

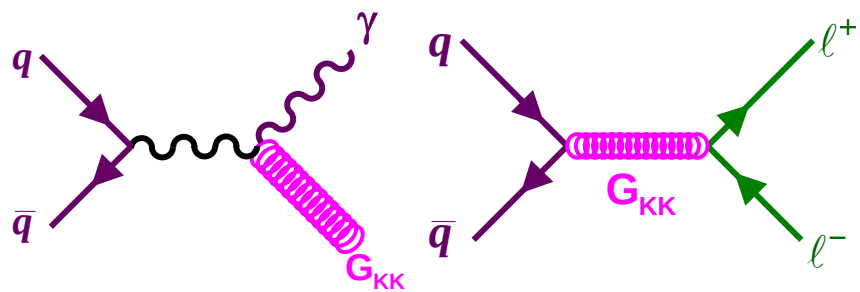
$p\bar{p} \to \tilde{t}\tilde{t}X \to bb\ell jj \not{E}_T$

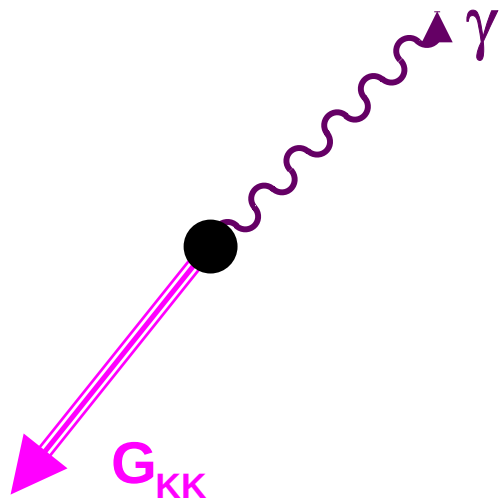


$\tilde{t} \to b\tilde{\chi}_1^{\pm}; \tilde{\chi}_1^{\pm} \to \ell\nu\tilde{\chi}_1^0, qq\tilde{\chi}_1^0$



LED: the Graviton





Wheat from Chaff

Mode	X-sect	$\langle E_t^{jet} \rangle$ [GeV]	$\langle E_t^{lept} \rangle$ [GeV]	$\langle ME_t \rangle$ [GeV]	Displ. Vert.	Bgrd's
Inelastic $p\bar{p}$	50 mb	low	none	~0	none	
$p\bar{p} \to b\bar{b}$ ($y < 1$)	50 μb	~6	~1	~0	few mm	• QCD
$p\bar{p} \to WX \to \ell\nu X$	4 nb		~45	~45	none	• QCD
$p\bar{p} \to ZX \to b\bar{b}X$	1 nb	~45	low	~0	~5 mm	• Instrument
$p\bar{p} \to t\bar{t} \to \ell$ + jets	2.5 pb	~50	~45	~50	~5 mm	• W/Z+jets,VV'
$p\bar{p} \to tX$ (s)	1 pb					• QCD + instr
$p\bar{p} \to tX$ (t)	2 pb					
$p\bar{p} \to W/Z\,H(*)$	425 fb					• W/Z+jets,VV'
$\ell\nu b\bar{b}$		~45	~45	~45	~5 mm	•Top
$\nu\nu b\bar{b}$		~45	none	~70	~5 mm	• QCD + instr
Beyond SM	lo-hi	high	high	high	large	• varies

Some Comparisons

		DØ – Run II	CDF – Run II	
Field	T	2.0	1.4	Tracking
η accept		<3.0(Si) ; <1.7 (CFT)	<2.0(Si) ; <1.0(COT)	
Radii	cm	2.8-10.0(Si) ; <52(CFT)	1.6-10.7(Si) ; <132(COT)	
$\delta P_T/P_T$	%	$2 \oplus 0.2 p_t$	$0.7 \oplus 0.1 p_t$	
Imp par	μm	$13 \oplus 50/p_t$	$6 \oplus 22/p_t$	
Prim Vtx	μm	15-30(rφ)	10-35(rφ)	
Sec Vtx	μm	40(rφ) ; 80(rz)	14(rφ) ; 50(rz)	
Mass res (J/$\rightarrow\mu\mu$)	MeV	27	15	
PID		PreShower	dE/dx,TOF	
η accept		<4.0	<3.6	Calo
$\Delta\eta\times\Delta\varphi$		0.1×0.1	0.1×0.26	
EM res	%	$14/\sqrt{E}$	$16/\sqrt{E}$	
Jet res	%	$80/\sqrt{E}$	$80/\sqrt{E}$	
Layers		3	1	Muon
η accept		<2.0	<1.5	
φ cover		>90%	80% (cen)	
Shield	λ_I	12-18	5.5-20	
standalone $\delta P/P$	%	$18 \oplus 0.3p$	—	

Triggers are the Key

Process	X-Sect or BR	Rate (L=2x10^{32})
Beam X'ing		7.5 MHz (132 ns)
Inelastic $p\bar{p}$	50 mb	10 MHz
$p\bar{p} \to b\bar{b}$ $(y<1)$	50 μb	10 kHz
$p\bar{p} \to WX$	22 nb	4.4 Hz
$p\bar{p} \to ZX \to b\bar{b}X$	1 nb	0.2 Hz
$p\bar{p} \to t\bar{t}$	7.2 pb	5 / hour
$\to W^+bW^-\bar{b}$	~100%	
$\to e/\mu$ + jets	35%	
$\to$only jets	44%	
$p\bar{p} \to W/Z\,H(*)$	425 fb	7 / day
$e/\mu + b\bar{b}$	22%	
$q\bar{q} + b\bar{b}$	56%	*m(H)=100 GeV

Conclusion: too much Physics!

	CDF (Hz)		DØ (Hz)	
Level	now	goal	now	goal
Input	7.6M		7.6M	
L1 hardware	6k	50k	200	5k
L2 custom computer	240	300	140	1k
L3 PC Farm	30	50	50	50

- Now Lumi 2.4x10^{31} cm^{-2}s^{-1}
- Goal Lumi 8.6x10^{31} cm^{-2}s^{-1}

QCD

Probing QCD

- tests of (N)NLO QCD
  - lepton angular distribution in W decays
- searches for new physics in QCD dominated distributions
  - bumps in dijet mass spectra
- direct photon production
- diffractive physics
  - properties of the pomeron

QCD: Everyone's Favorite Background $\Rightarrow$ Understand It

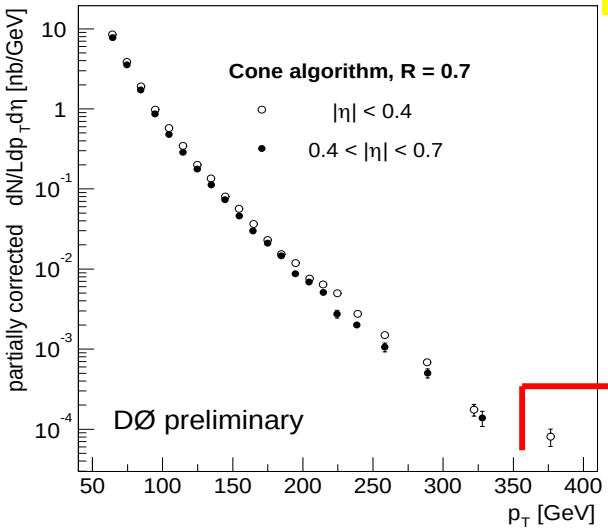
- tuning Monte Carlo
- measuring Parton Distribution Functions
  - W P_t distributions, lepton asymmetries
  - high E_t jet data $\Rightarrow$ better gluon PDFs
- develop/understand jet finding algorithms
  - differences in agreement with NLO QCD at high E_t for different algo's

Crucial Detector Elements

- jet Energy: resolution scale
- photons, (leptons)

Jets in Run II

Inclusive jet p_T spectrum

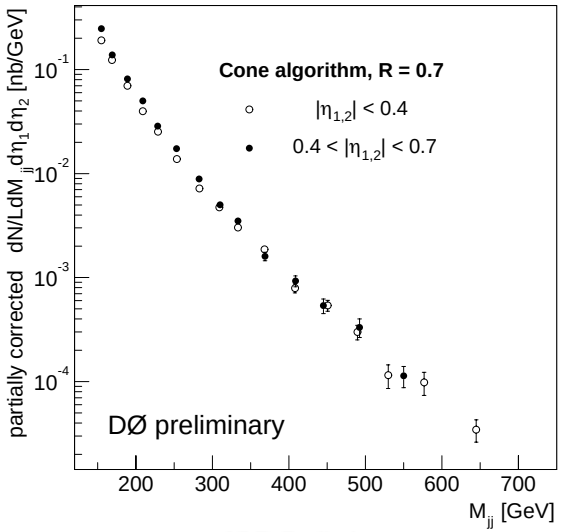


DØ Prelim Jet Spectra

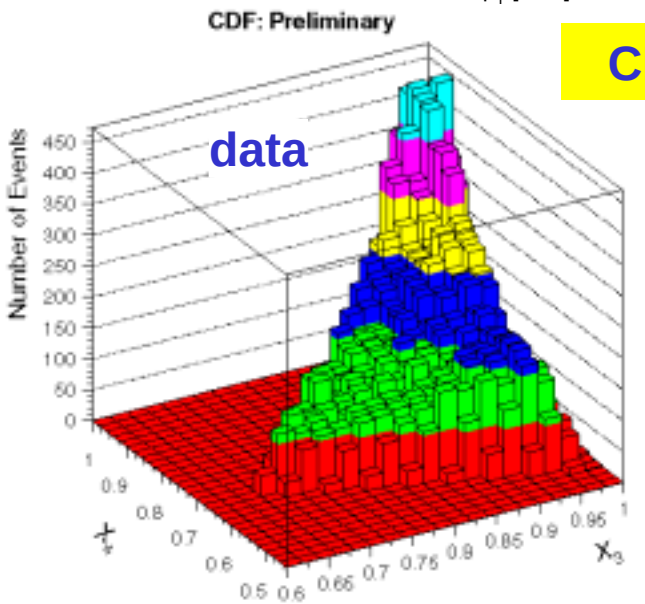
- stat errors only
- prelim jet E-scale
- not fully corrected (unsmearing, eff.)

things get interesting !

Dijet mass spectrum



CDF Prelim 3-Jet Cross-Section

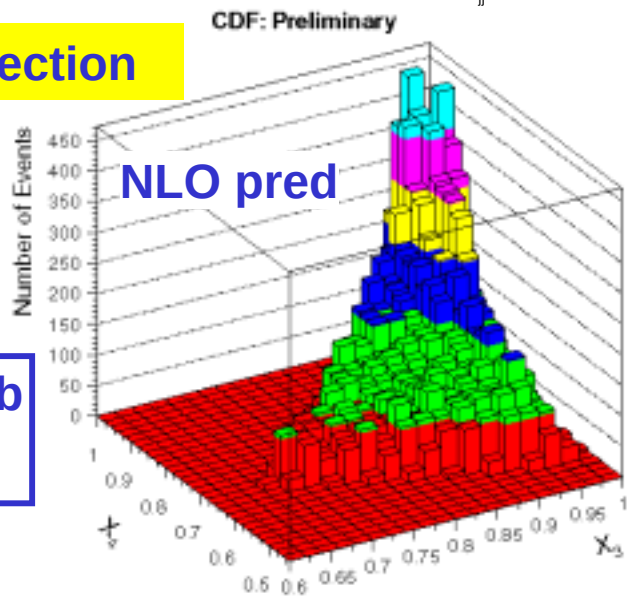


Dalitz Plots:

$X_i = 2E_i / m(3\text{-jet})$

$\sigma(\text{meas}) = 466 \pm 2\ ^{+206}_{-71}$ pb

(NLO QCD : 402 ± 3 pb)



Electroweak Physics

		Run II / exp.		
Meas	**Run I**	**2 fb^{-1}**	**15 fb^{-1}**	**LHC (LC)**
$W \to \ell\nu$	77k	2300k	17250k	huge
$Z \to \ell^+\ell^-$	10k	202k	1515k	huge
$t\bar{t}$ (mass)	~20	~800	~6000	8×10^6
tX	0	150	1200	3×10^6
Γ(W) [GeV]	2.158 ± 0.042	± 0.040		
$\delta\sin^2\theta_W$ (A_{FB})	± 5.1×10^{-4} LEP EW-WG		± 4×10^{-4}	± 1.4×10^{-4}
M_W [GeV]	80.451 ± 0.033	± 0.027	± 0.017	(± 0.01)
M_t [GeV]	174.3 ± 5.1	± 2.7	± 1.3	(0.1)
$\delta M_H / M_H$ ind	>50%	35%	25%	18%(14%)
$\sigma(p\bar{p} \to tX)$	<13.5	20%	8%	
$\lvert V_{tb}\rvert$		12%	5%	<5%
BR(t→W_ob)	0.91 ± 0.39	9%	4%	1.6%
V-A check				

More Electroweak

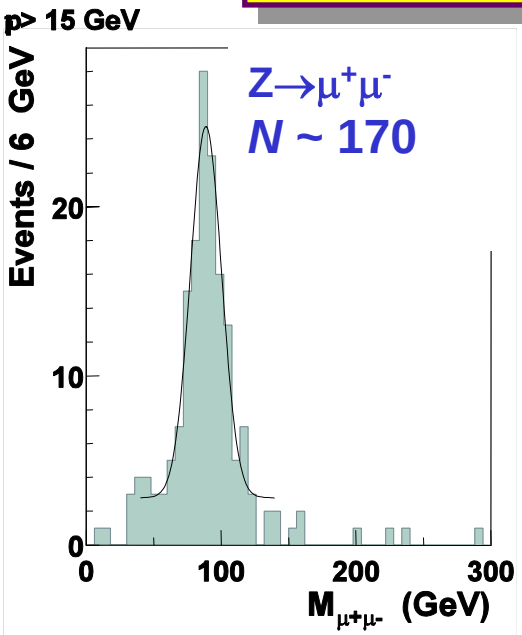
Also watch for

- WW, WZ, ZZ, WWγ, ZZγ, Z$\gamma\gamma$ production: trilinear gauge couplings
- Quartic couplings
- Lepton Forward-Backward Asymmetry
- Luminosity measurement using W cross-section
- top spin correlations
- top-antitop resonances
- rare top decays
- …

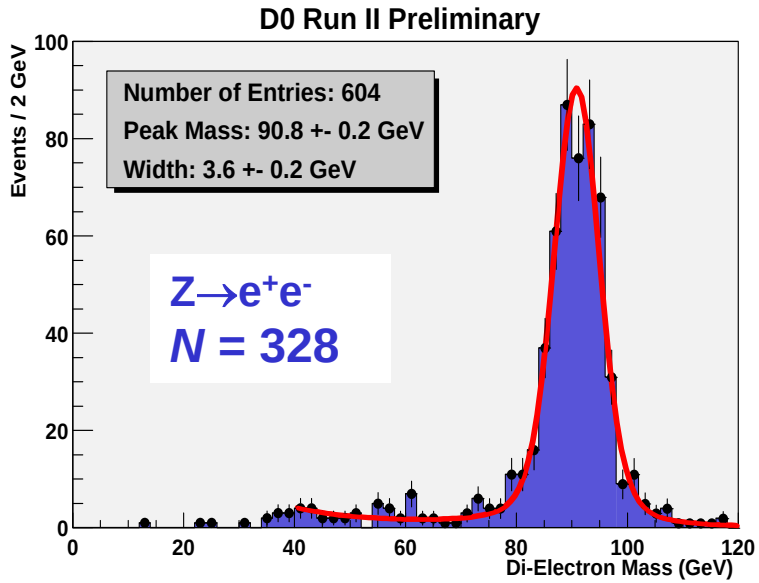
Critical Detector Elements

- Leptons
- b-ID
- missing E_t

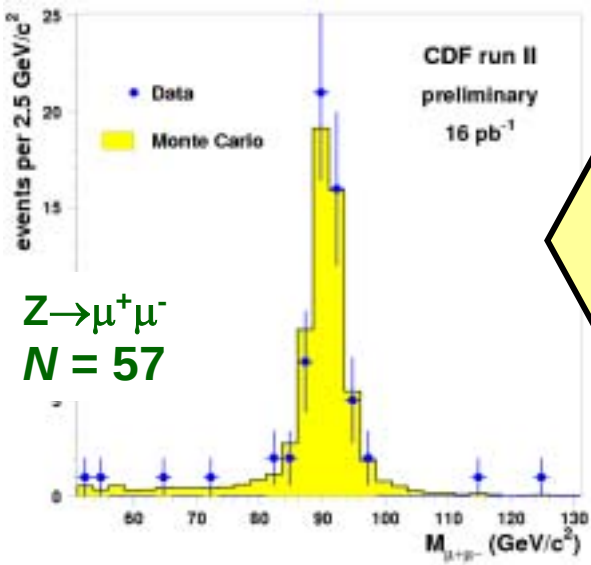
Z-Peaks

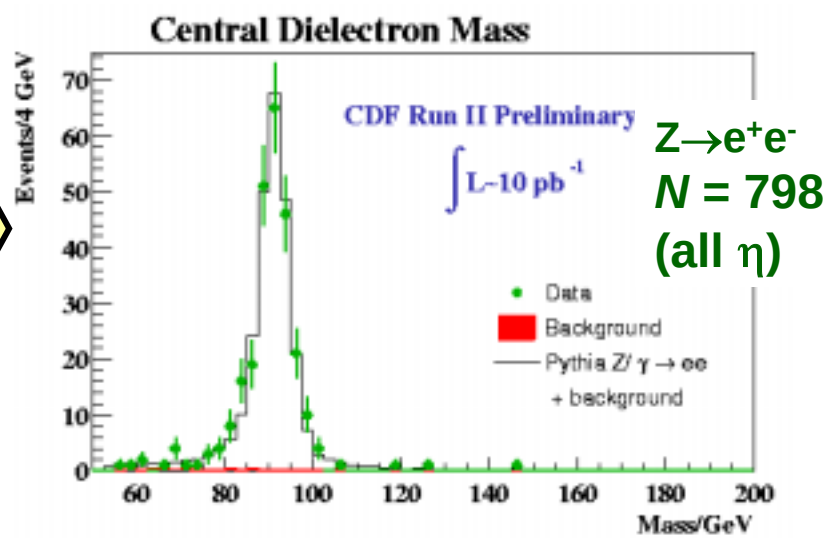


DØ Run II Prelim

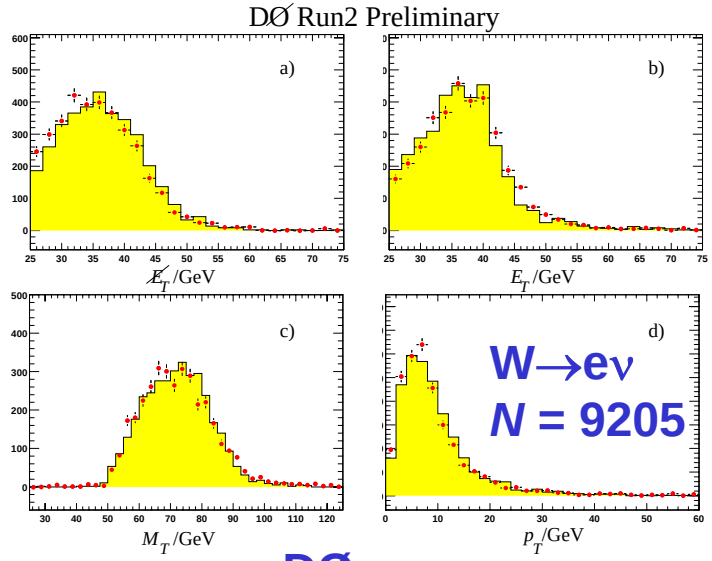


CDF Run II Prelim

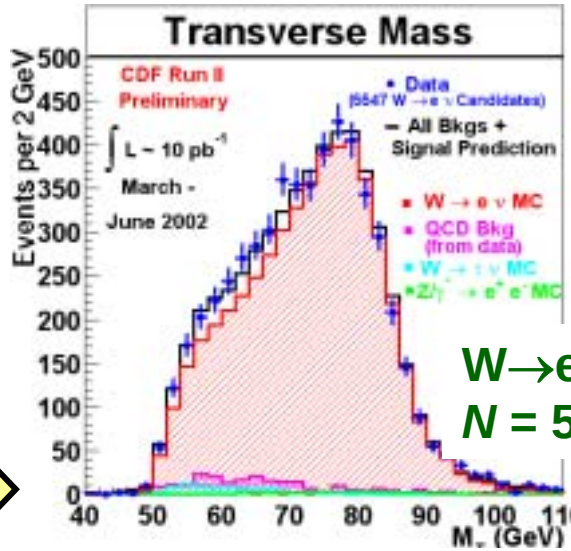




W Bosons

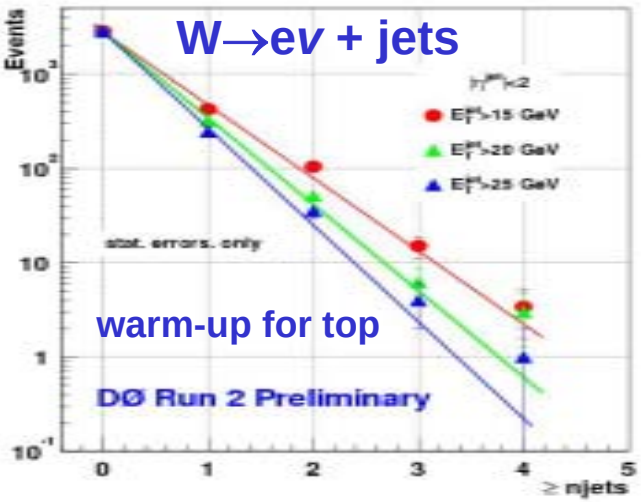


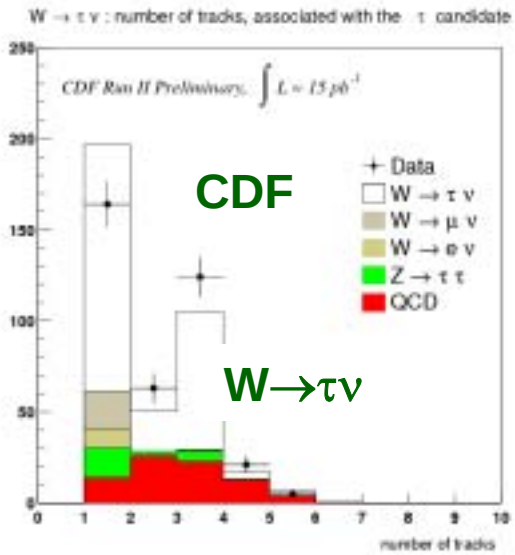
DØ Run II Prelim

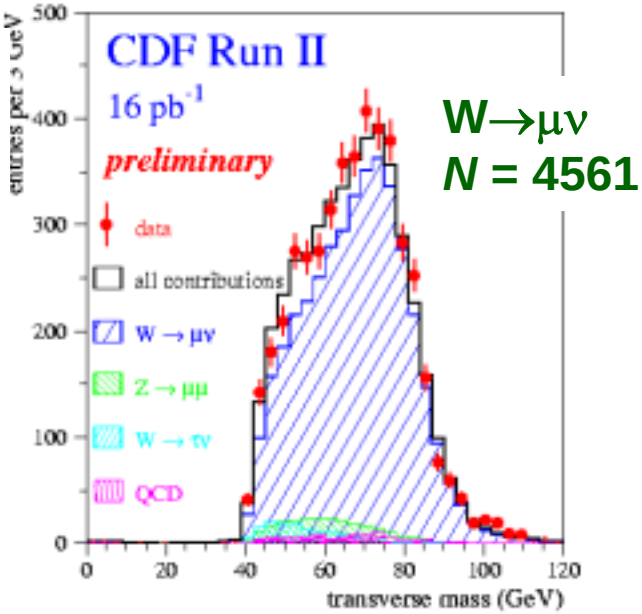


CDF Run II Prelim

DØ



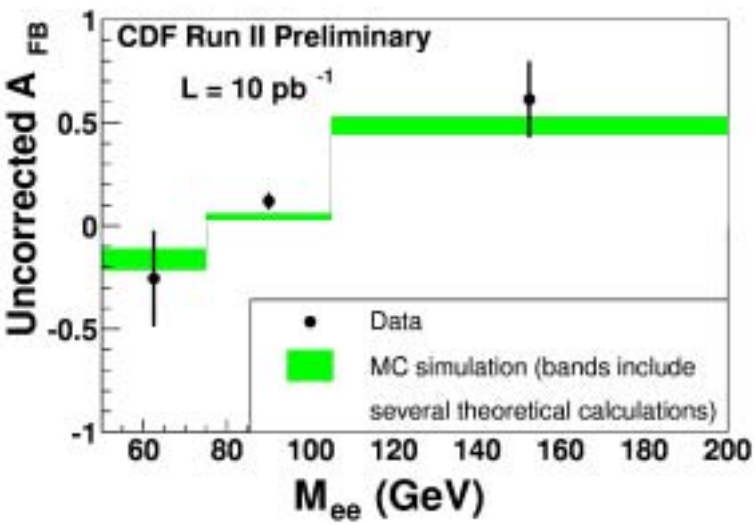


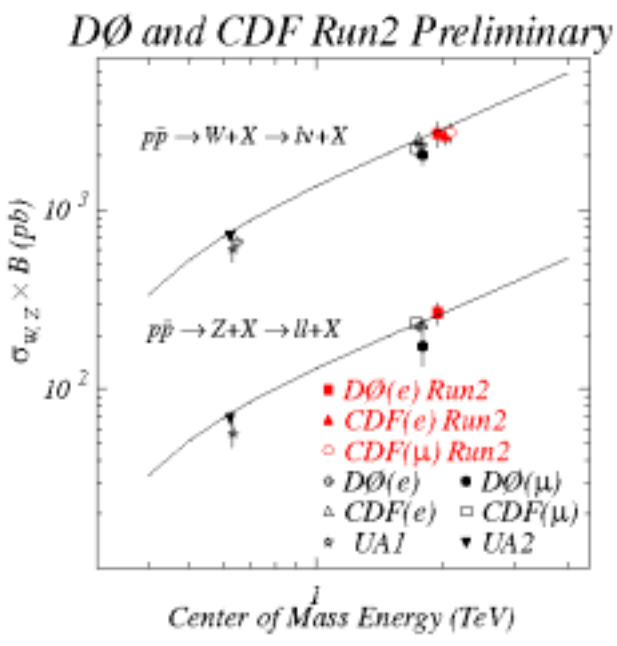


Cross Sections

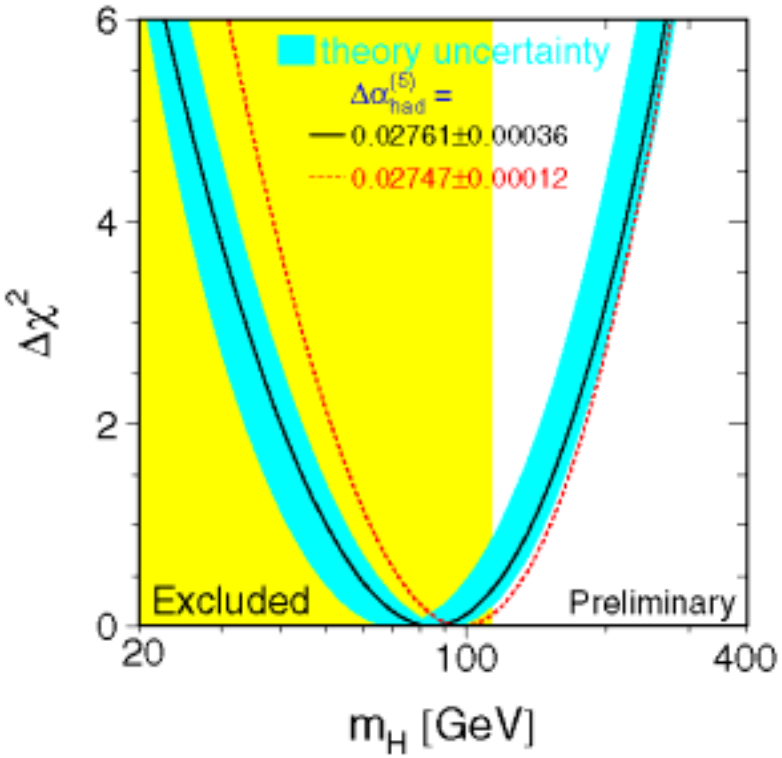
Meas	CDF	DØ
$\sigma_W B(W\to e\nu)$	$2.60\pm0.03_{stat}\pm0.13_{syst}\pm0.26_{lumi}$ nb	$2.67\pm0.06_{stat}\pm0.33_{syst}\pm0.27_{lumi}$ nb
$\sigma_Z B(Z\to ee)$	—	$266\pm20_{stat}\pm20_{syst}\pm27_{lumi}$ pb
$\sigma_W B(W\to \mu\nu)$	$2.70\pm0.04_{stat}\pm0.19_{syst}\pm0.27_{lumi}$ nb	—
$\sigma_Z B(Z\to \mu\mu)$	—	—
Γ_W (from W/Z)	$1.67\pm0.24_{stat}\pm0.14_{syst}$ GeV	$2.26\pm0.18_{stat}\pm0.29_{syst}\pm0.04_{th}$ GeV
World Ave	2.135 ± 0.069 GeV	

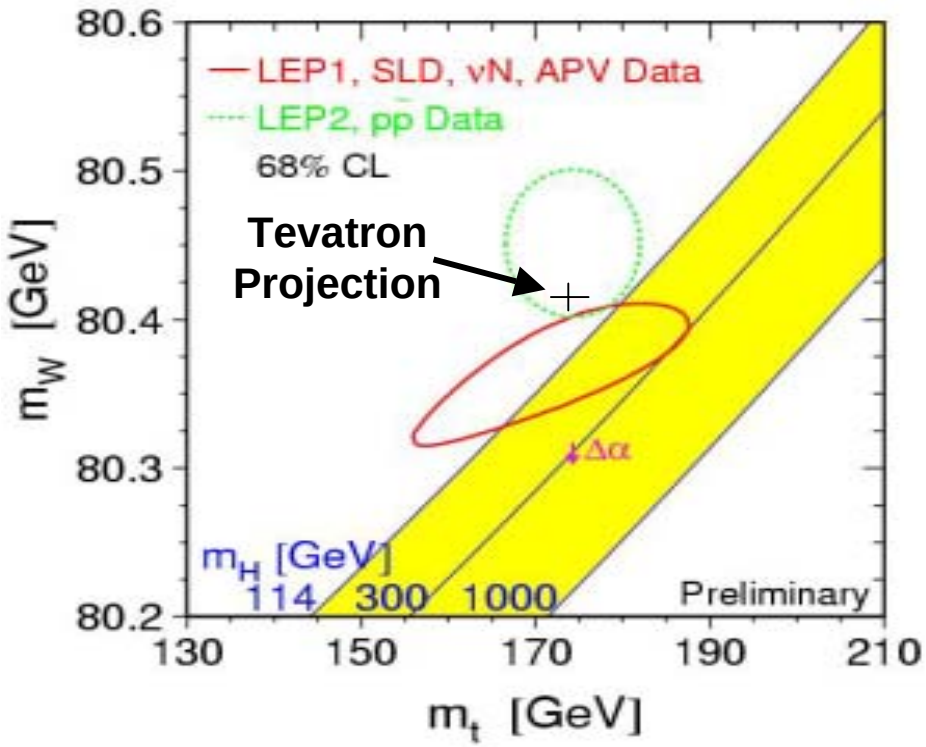
CDF Run II Prelim





To the Higgs (indirectly)

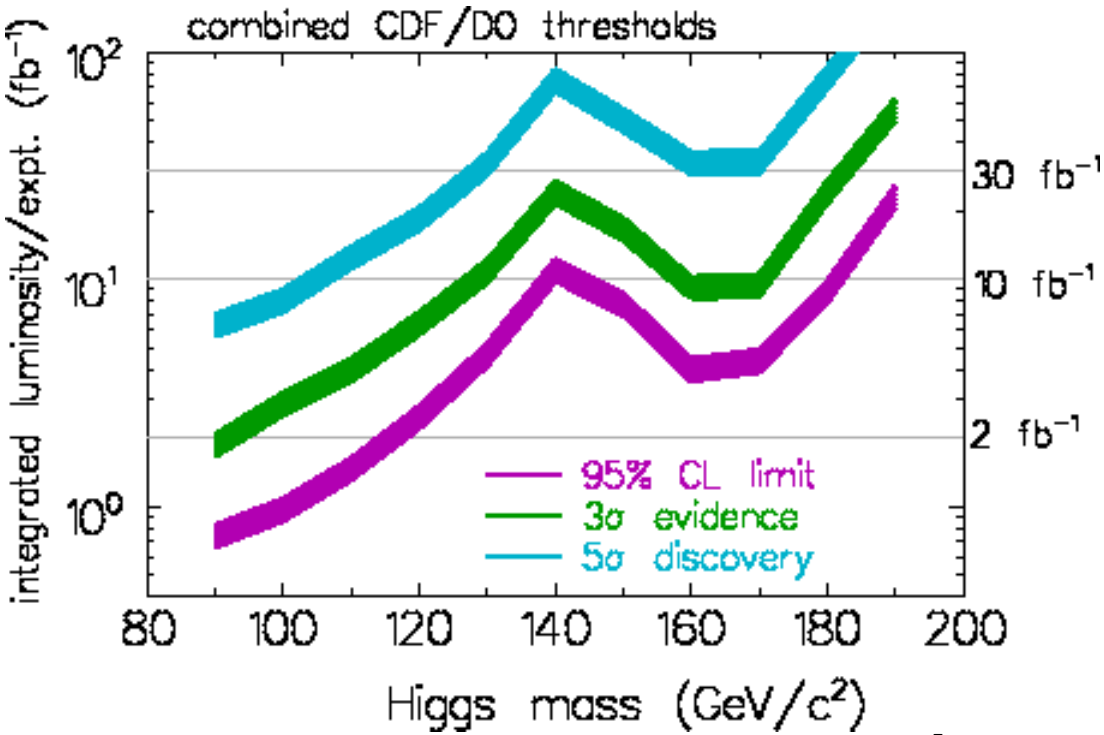


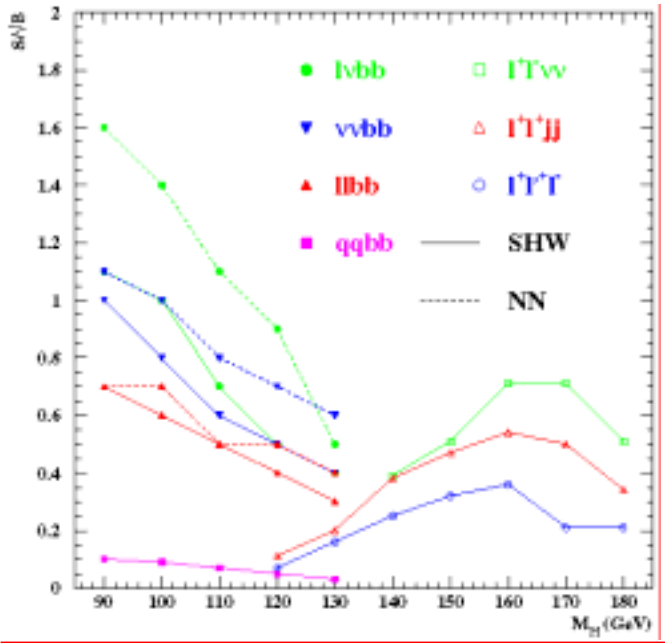


LEP EW WG Winter 2002 Fits:

- **$M_H = 81_{-33}^{+52}$ GeV <193 GeV (95%)**

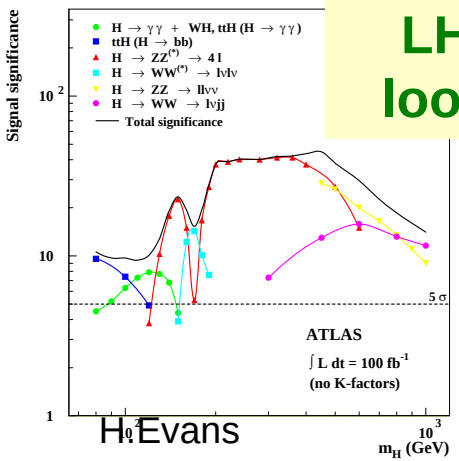
To the Higgs (directly)





All Channels Important

LHC is looming



5σ

Assumes

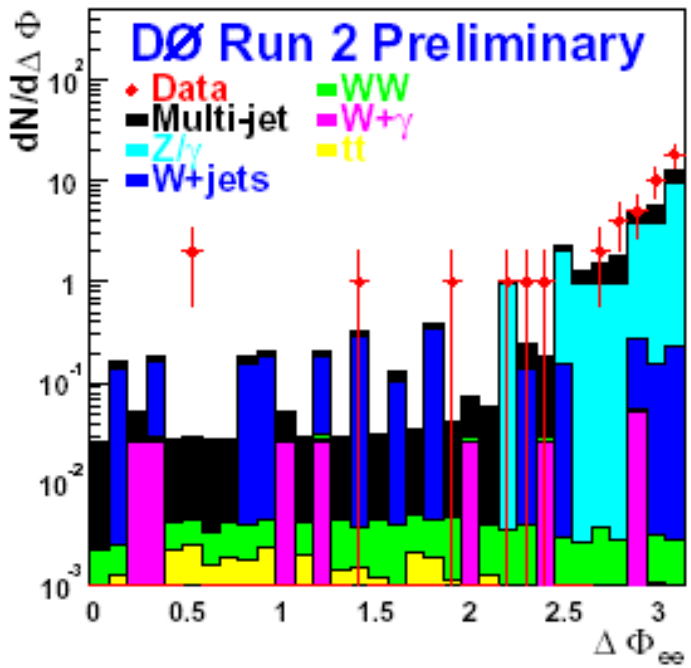
- **High Trigger eff's for signal:**
  - **~100% for P_T(lept)>20 GeV**
  - **~100% for jets + miss Et**
- **Good b-ID**
  - **b-tagging eff: 60-75%**
  - **bb mass resolution ~ 30%**

Warming Up for the Higgs

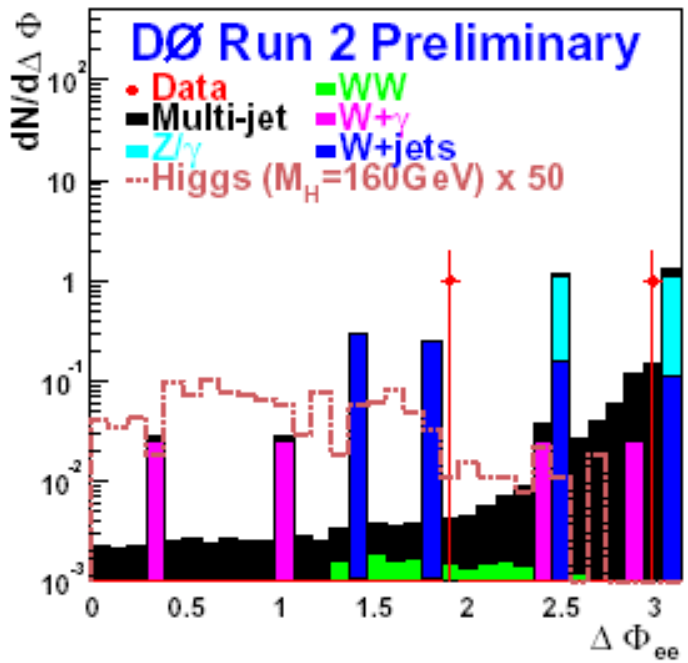
$H \rightarrow WW \rightarrow ee\nu\nu$ or Background ???

- **Fermiophobic Higgs $\Rightarrow$ $B(H \rightarrow WW) \sim 98\%$ for $M_H > 100$ GeV**
- **build confidence in background modeling for more data**

good e^+e^-



good e^+e^- + ME_t + no jets



Into the Beyond

Model	Observe	Current	DØ (20 fb^{-1})	LHC (100 fb^{-1})
SUSY	tanβ,M_A	excl tanβ: 0.9-7.7 / 0.5-2.3	almost all at 5σ	all
	$m_{1/2}$ [GeV]	> ~100 (LEP2)	180–280*	~all
rare top	t →q Z	<33%	2%	2 ×10^{-4}
	t →q γ	<3.2%	0.3%	1 ×10^{-4}
	t →b H^+	<45%	11%	3%
LED	M_S [TeV]	>1.0–1.4	2.1–3.5	6–8
new bosons	$M_{Z'}$ [GeV]	>500-600	900-1200	2000

Also look for (limited only by imagination)

- the SUSY particle zoo
- technicolor
- your favorite Beyond the SM idea

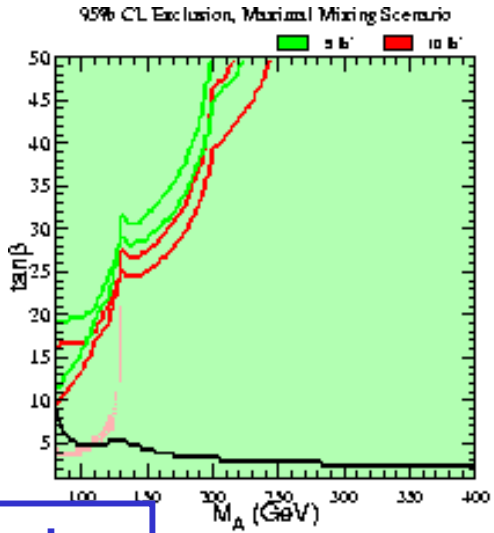
A Bewildering Array of Models ⇒ Everything is Important

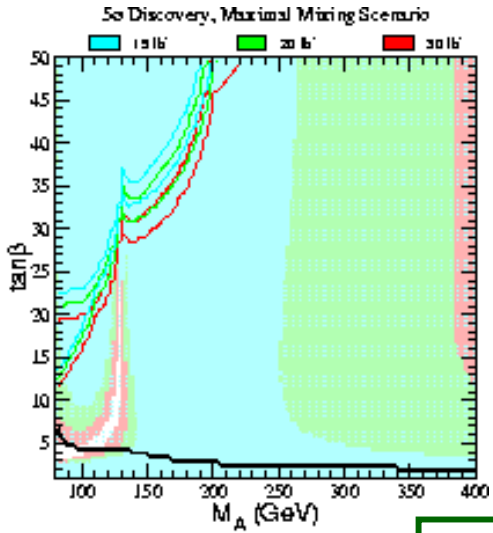
- **Universally Crucial: Leptons, Photons, Jets, Missing E_t, b-ID**

Closing Holes in SUSY

10 fb^{-1}

5 fb^{-1}





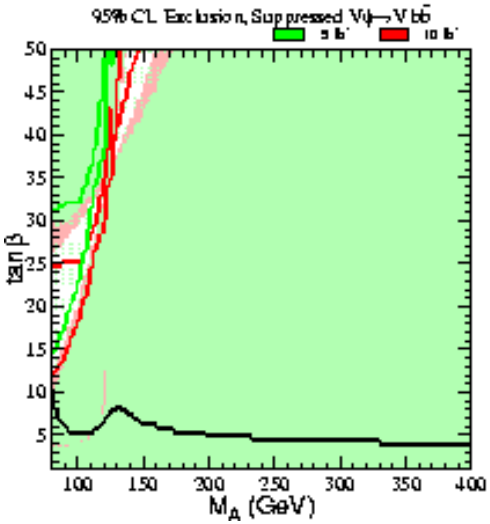
30 fb^{-1}

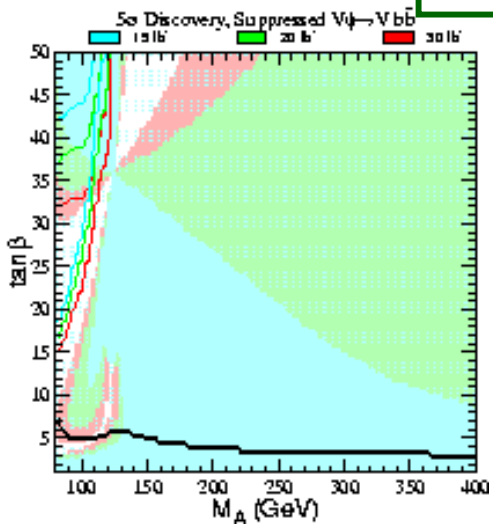
20 fb^{-1}

10 fb^{-1}

95% CL exclusion

5σ discovery





SUSY Searches at Run II

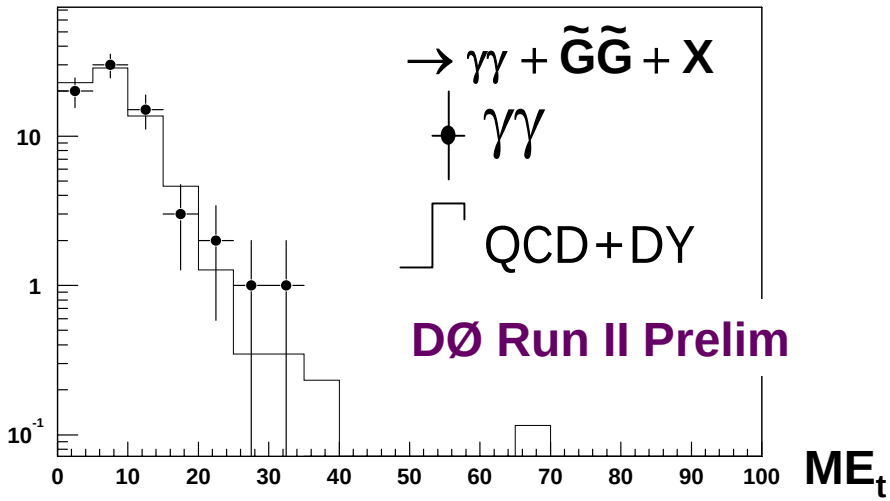
First Looks at Run II

GM SUSY

$p\bar{p} \rightarrow$ gauginos

$\rightarrow W/Z/\gamma + \chi_1^0\chi_1^0$

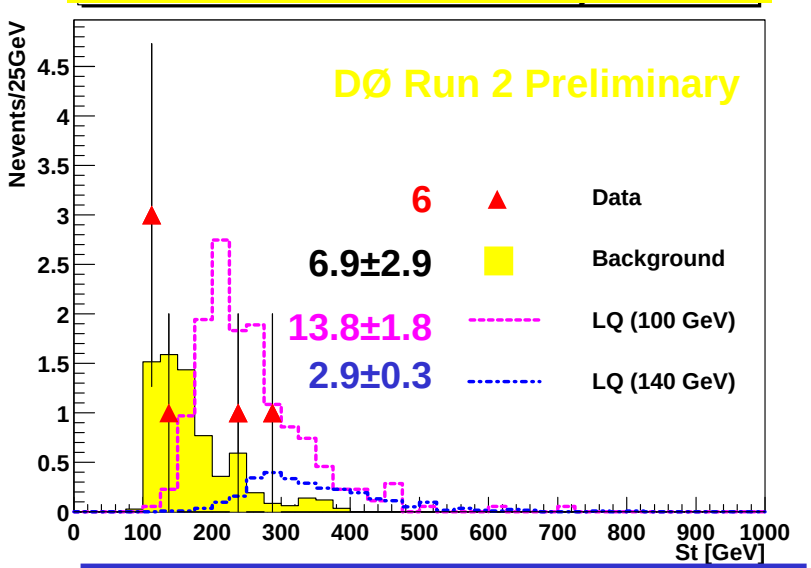
$\rightarrow \gamma\gamma + \tilde{G}\tilde{G} + X$



"Model Indep" Limit: σ < 0.9 pb

- **Phenomenology**
  - LSP = Gravitino
  - NLSP = neutralino, slepton
- **Sensitivity**
  - still too low to exclude any of SUSY parameter space

Leptoquarks: eejj

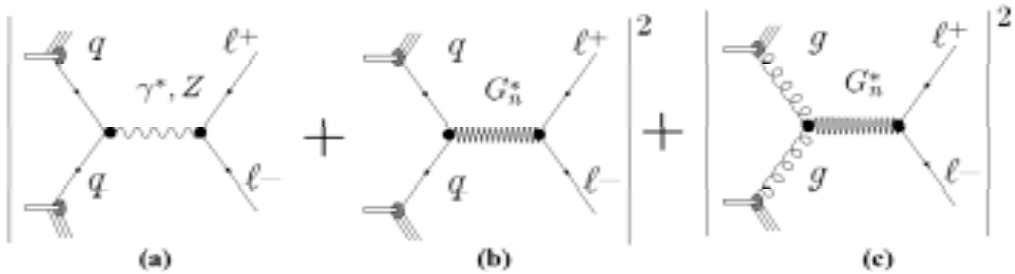


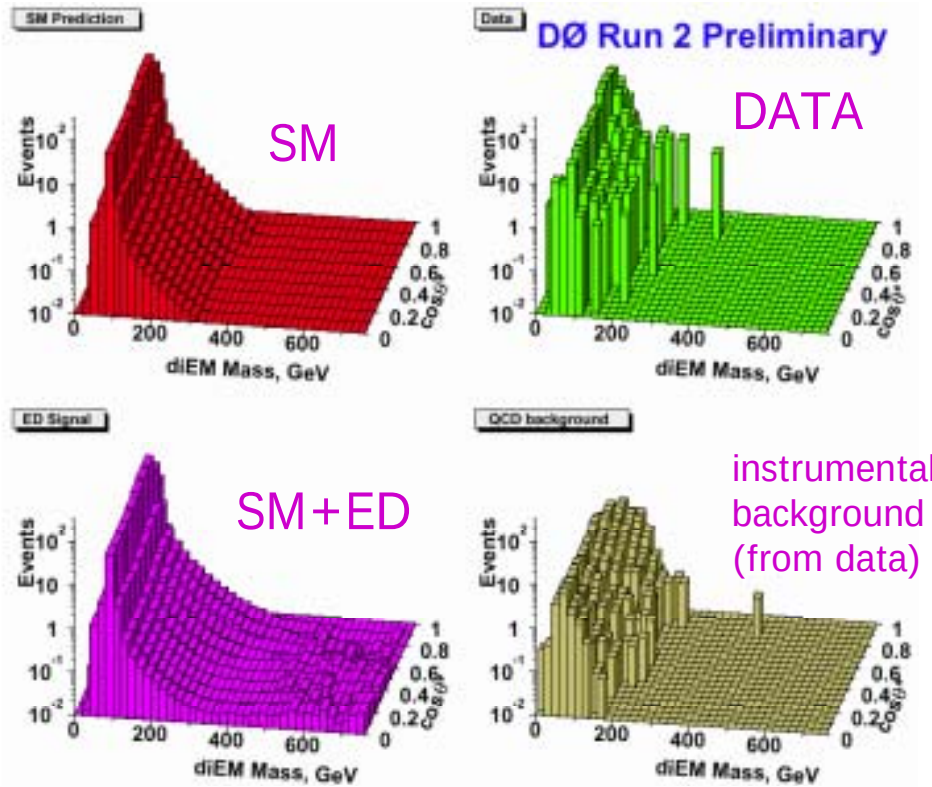
M_{LQ} > 113 GeV @95% (β=1)

- **Phenomenology**
  - particles w/ both quark & lepton number
  - restores q-*l* symmetry
- **Sensitivity**
  - consistent with Run I result

More Looks in More Dimensions

- **Search for LED via virtual Graviton effects**
  - **ee/γγ channel**
- **DØ Run II Prelim Limit**
  - **M_S(GRW) > 0.92 TeV**
- **DØ Run I Limit**
  - **M_S(GRW) > 1.2 TeV**





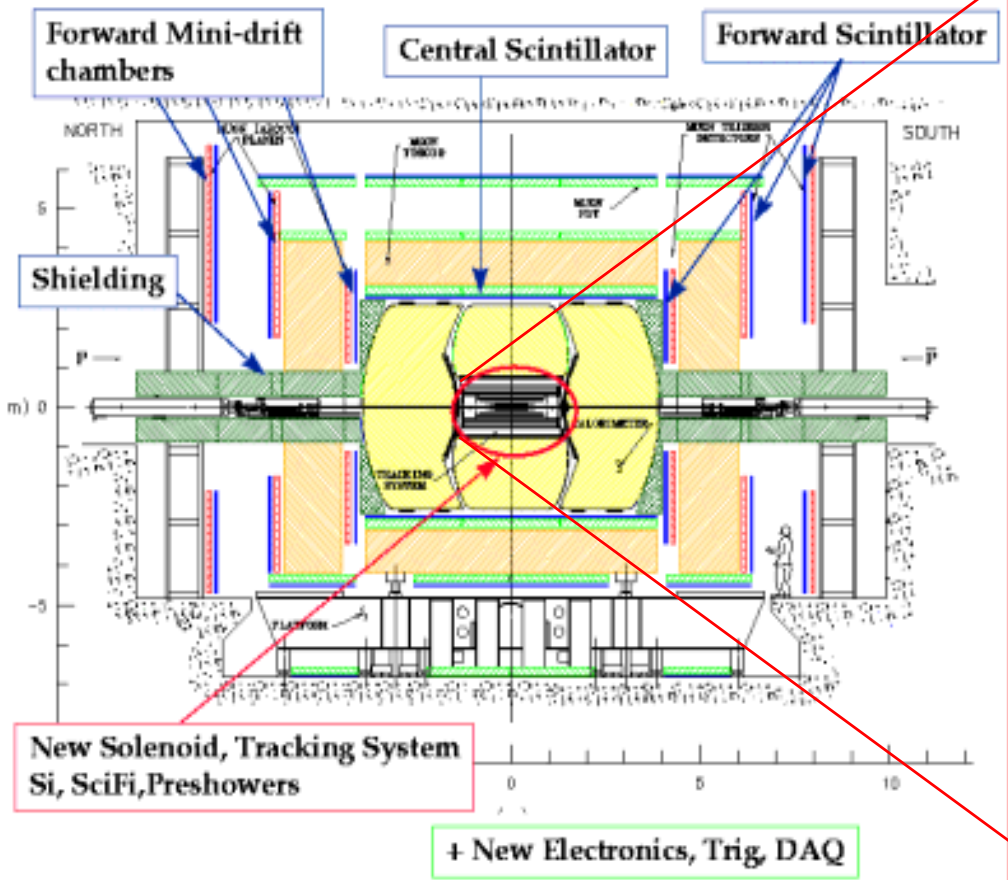
Conclusions

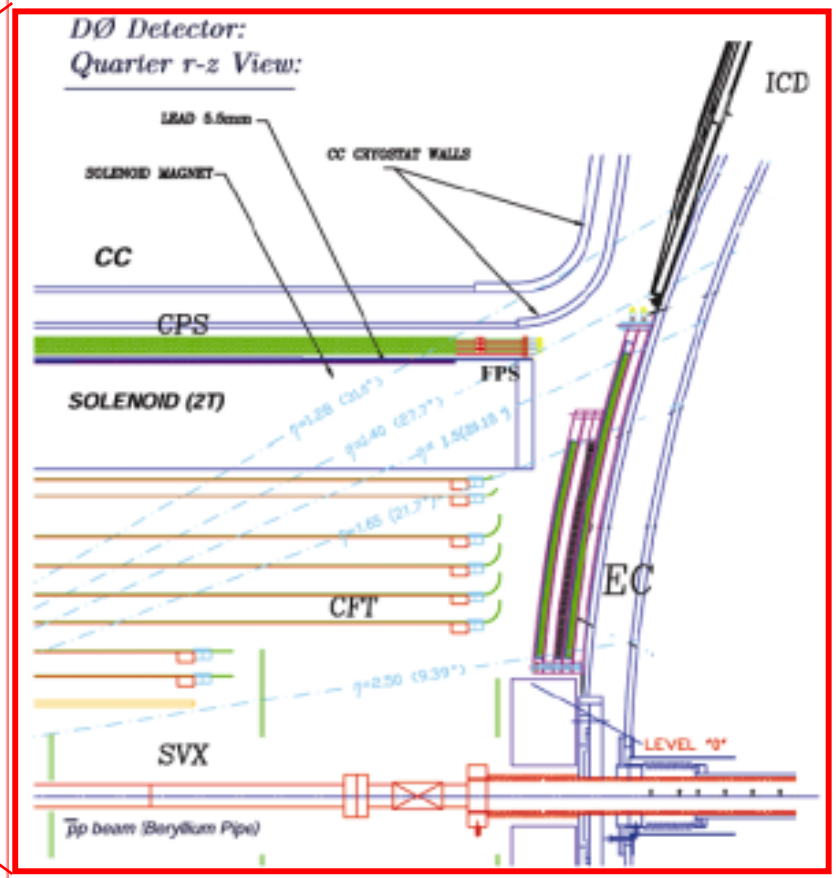
What can we conclude???

We've barely started!!!

Tevatron vs. The Standard Model Fightcard					
Precision (2 fb^{-1})		**Searches (20 fb^{-1})**		**Quark M vs Weak (2 fb^{-1})**	
M_W	30 MeV	H_{SM}	180	sin2β	0.03
M_t	2.7 GeV	tanβ,M_A	most 5σ	x_s	70
$\|V_{tb}\|$	12%	rare top	$\times$10–40	$K^*\mu^+\mu^-$	700 evts
		LED	2–3.5 TeV		
etc…		etc…		etc…	

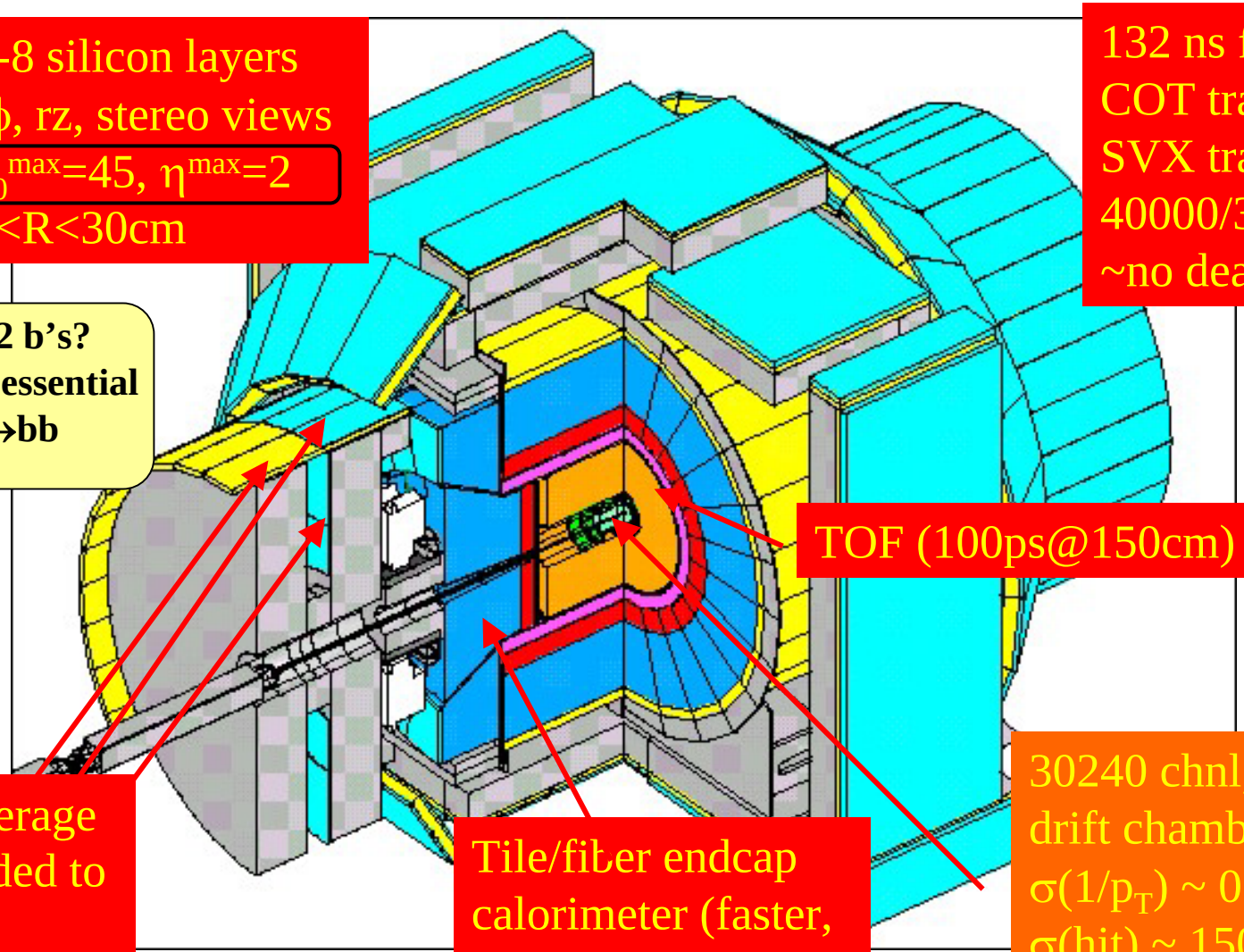
DØ Run II Upgrade





- **Old Strengths: Calorimeter, Central Muons**
- **New Features: Magnetic Tracking, Silicon, Forward Muon, 3-Level Trigger, DAQ, Electronics**

CDF Run II Upgrade



7-8 silicon layers
rϕ, rz, stereo views
z_0^{max}=45, η^{max}=2
2<R<30cm

132 ns front end
COT tracks @L1
SVX tracks @L2
40000/300/70 Hz
~no dead time

2 b's or not 2 b's?
Double tags essential for M_{top}, H→bb

TOF (100ps@150cm)

μ coverage extended to η=1.5

Tile/fiber endcap calorimeter (faster, larger F_{samp}, no gap)

30240 chnl, 96 layer drift chamber
$\sigma(1/p_T)$ ~ 0.1%/GeV
σ(hit) ~ 150μm