Run II at the Tevatron

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Michigan State University / Fermilab

Outline

Status of Run II
- Accelerator
- CDF & DØ

Overview of Physics **

* Talk as an experimental physicist; these are **my** views, not necessarily the corporate views of CDF or DØ.

** experimental talk & view; since Run II has not started yet, NONE of the plots are shown are real, all are predictions (sometimes confusing lately.....)

A lot of work done in Run II workshops, which were held over the last two years.

New approach at FNAL; very different from Run I

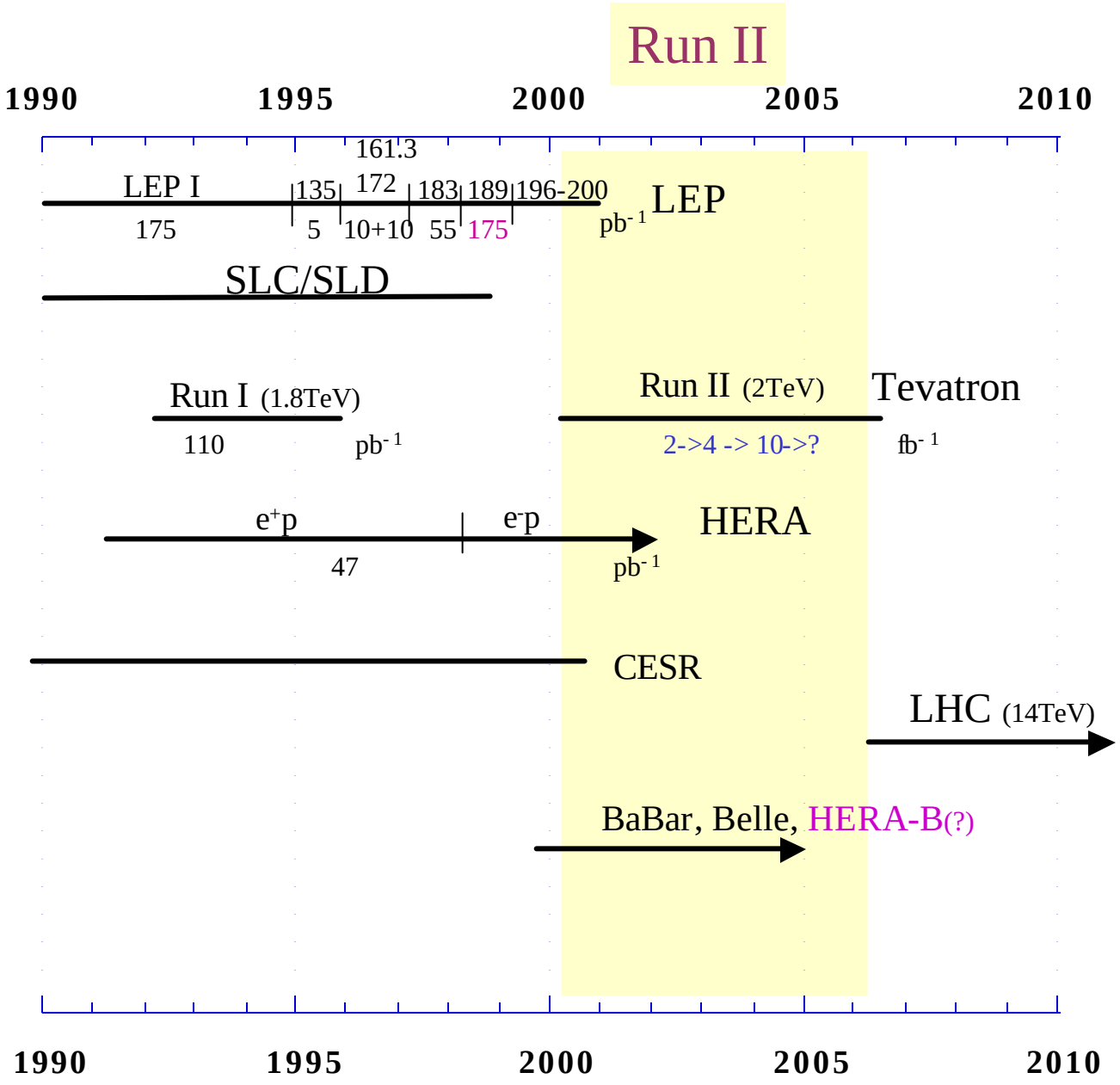
Supersymmetry/Higgs Workshop.
Thinkshop on Top-Quark Physics for Run II.
New strong dynamics.
QCD and Weak Boson Physics.
B Physics.

Identify physics potential of Run II

No way for me to do justice to all this work in this talk. My apologies before hand.

Especially since I have been doing (hardware &) administration for last year and have forgotten about physics….

Experimental program at accelerators



Not shown (bias ?):

- -neutrino beam lines
- -kaon beam lines

H.Weerts, January-2000

Worldwide HEP exp. program becoming thin.....

Run II status

Run II starting date is fixed !!

- Very serious & deliberate effort to stay on schedule
- All parties involved: Accelerator, CDF & DØ
- Fallback/descoping plans in place
- Guarantee start on Run II on March 1, 2001
- Different approach to schedule at Fermilab

schedule

CDF & DØ experiments

❖ Both upgraded and better detectors

- ➢ Decrease time between crossings (initially 396nsec ➔ 132 nsec)
- ➢ Higher instantaneous lum. , new tracking systems
- ➢ Improved physics capabilities

  - Better trackers (DØ solenoid)
  - Silicon detectors (b- tagging + triggering)
  - Better muon coverage
  - Improved missing E_t resolution (CDF forward calorimeters)

❖ Detectors "now" very similar; still different emphasis

- ✓ CDF: tracking emphasis
- ✓ DØ: calorimetry, muon ID

❖ Additional capabilities

- o CDF: time of flight, extra silicon layers
- o DØ: forward proton detector

❖ Radiation hardness

- ❁ No problem up to 2-4 fb^{-1} (Run IIA)
- ❁ Beyond that (Run IIB), need to replace parts of inner tracking systems; time scale being discussed

Lum. Projections for Run II

PHENO2000, Madison , WI
April 19, 2000; H.Weerts

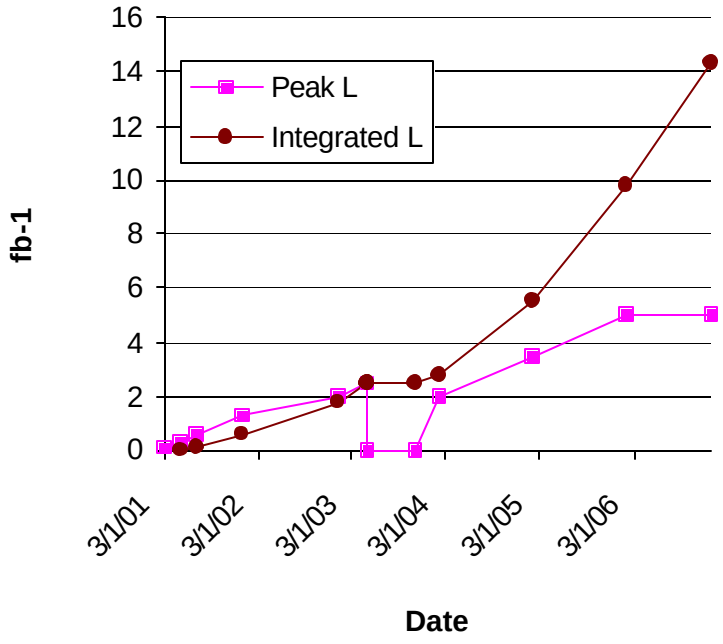
Possible Accumulation of Luminosity in the pre-LHC Era

(S.Holmes, ICFA '99

			Run
2001	Main Injector and Recycler	0.6 fb^{-1}	
2002	Initiate antiproton recycling	1.2 fb^{-1}	IIA
2003	6 month shutdown to install e-cool, 132 nsec, etc	0.8 fb^{-1}	
2004	Achieve $2x10^{32}$ $cm^{-2}sec^{-1}$	2.0 fb^{-1}	
2005	Achieve $3.5x10^{32}$ $cm^{-2}sec^{-1}$	3.5 fb^{-1}	IIB
2006	Achieve $5x10^{32}$ $cm^{-2}sec^{-1}$	2.3 fb^{-1}	
	6 month shutdown to install C-0.		
2007	Achieve $5x10^{32}$ $cm^{-2}sec^{-1}$	3.8 fb^{-1}	

TOTAL **~15 fb^{-1}**

per experiment



Peak Lum is in units of 10^{32}

Run II: my view of physics results

PHENO2000, Madison , WI
April 19, 2000; H.Weerts

Per experiment

Action	Int. Lum. (fb^{-1})	x Run I
Calibration & understand detector	< 0.1	< 1
(Some physics results)	0.2-0.3	2-3
New physics results for	0.5	5
Physics results up to	1.0	10
Physics results up to	2.0	20
Physics results up to	4.0	40
Break/upgrade		
Physics results up to	8.0	80
Physics results up to	15.0	100
	.....	

Crucial*

Run IIA

Run IIB

And always combine both experiments in working groups

Personal note:

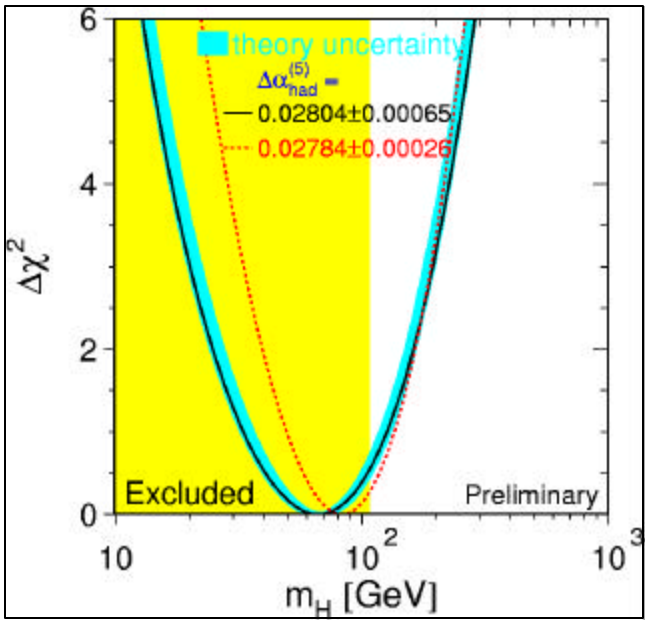
Most exiting possibilities in area of $\int L\,dt$ = 20-40 x Run I

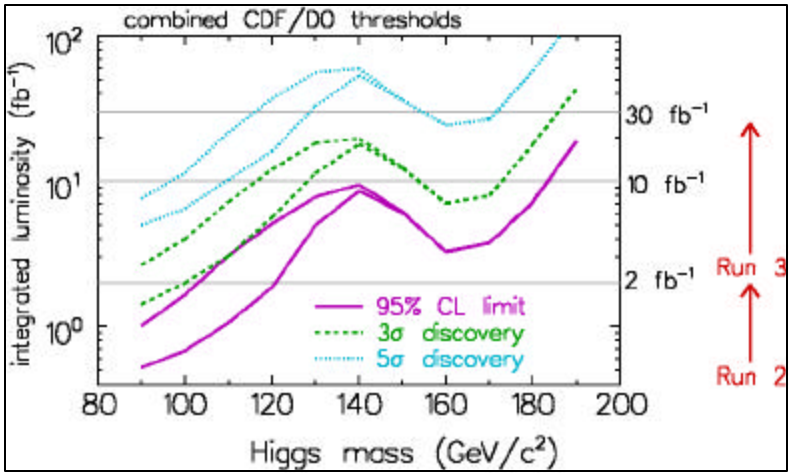
If hint of new physics ➔ continue
If no new physics: increase in lum by factors 2 to 3 not guaranteed worthwhile; wait for LHC ?

HEP is a world wide program and we have a plan.....

* New physics will not be obvious; precision measurements require calibration & understanding; not exploring totally new energy regime.

Higgs Hunting in Run 2b

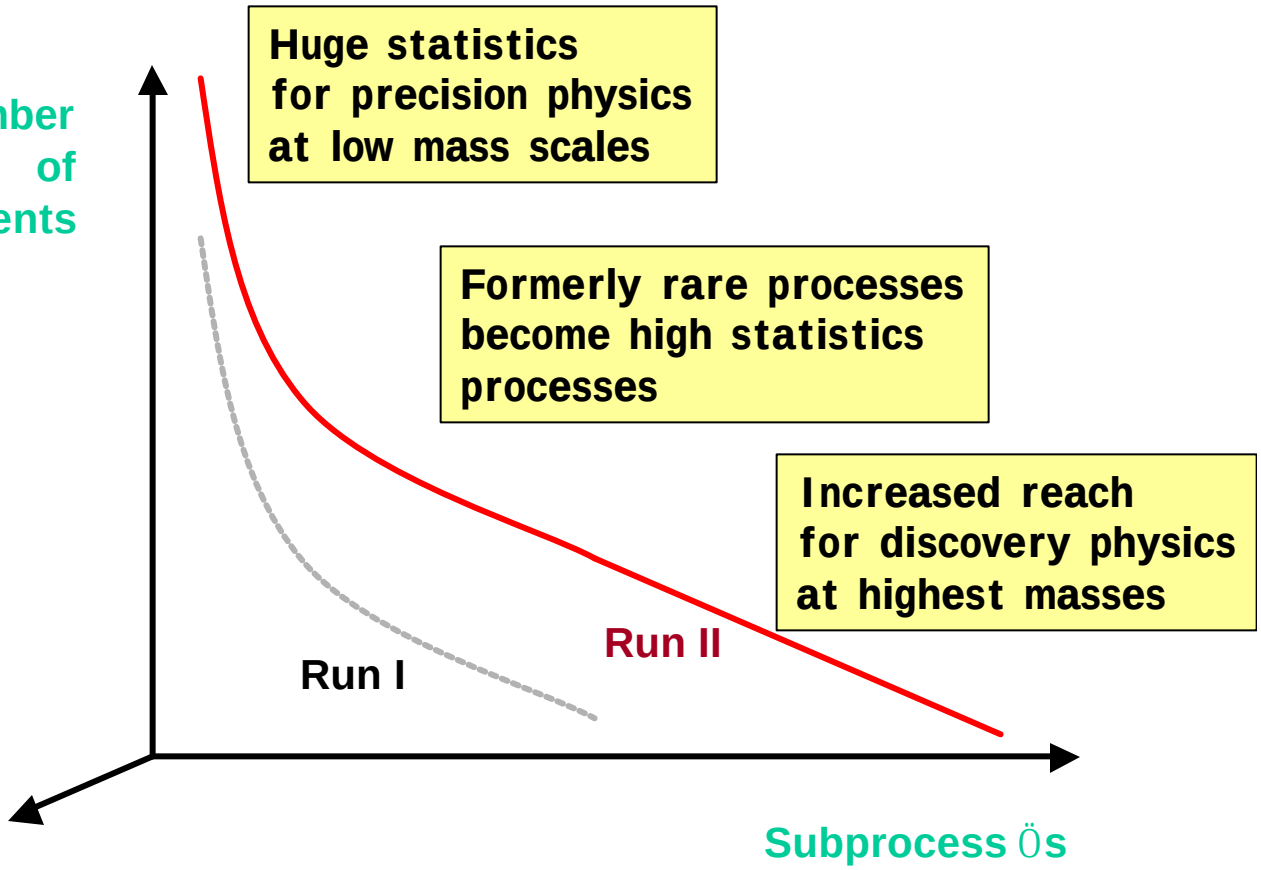




- Present SM Higgs Mass limits (95% CL):
  $M_H > 107.7$ GeV (direct)
  $M_H < 188$ GeV (indirect)
- With ~20 fb^{-1}, CDF+DØ have good sensitivity for SM Higgs:
  - 5+ s.d. discovery for m_H <125 GeV
  - 3+ s.d. discovery for $m_H < 180$ GeV
  - Exclude SM at 95% CL if there is no sign of the Higgs in Run 2b
- Higgs hunting is critically dependent on maximizing the integrated luminosity in Run 2b

Run I ® Run II

The Tevatron is a wide-band parton-parton collider



Extend the third orthogonal axis: the breadth of our capabilities

Three ways in which we gain I → II

- Statistics
  - Huge statistics at "low" mass scales
    - B-physics, QCD, W/Z-mass
  - Formerly rare processes enter the precision domain
    - QCD with vector bosons, thousands of top events
  - lay to rest some "undead" Run I anomalies ??
    - the high-E_T jet "excess", the CDF ee$\gamma\gamma$ event
    - only in one experiment (DØ had some W+jets)?

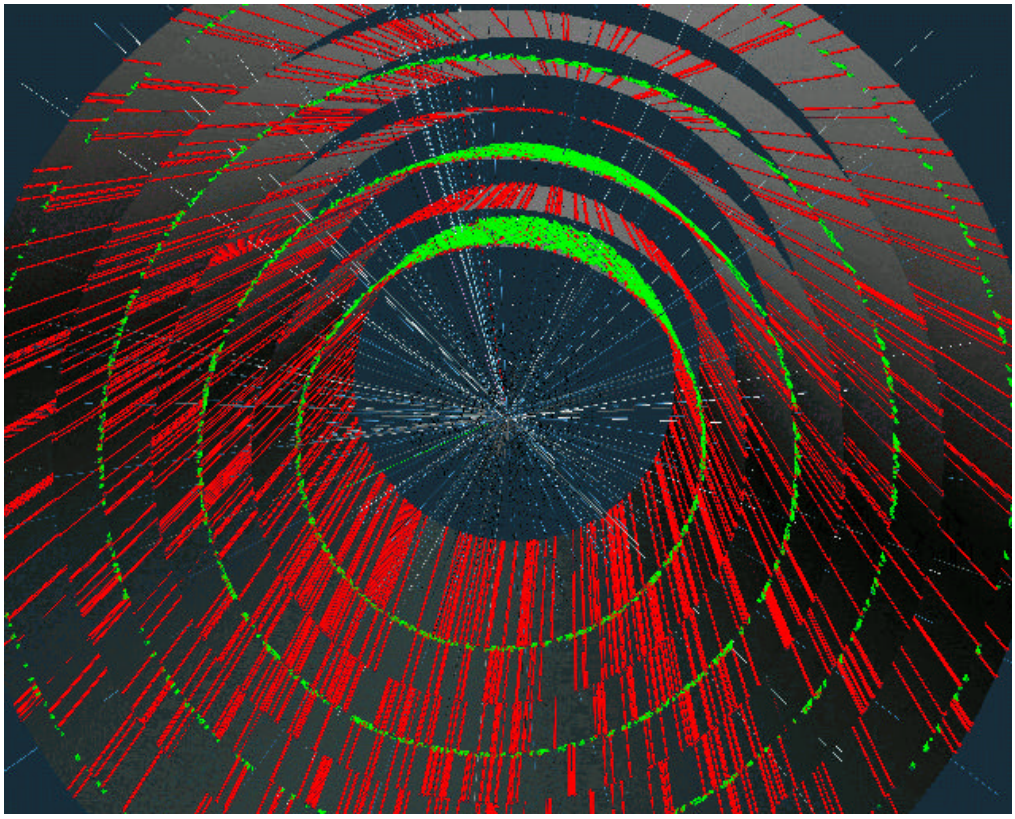
- Increased reach at the highest mass scales
  - electroweak symmetry breaking
    - SUSY, Higgs, etc.

- New detector capabilities

mentioned earlier

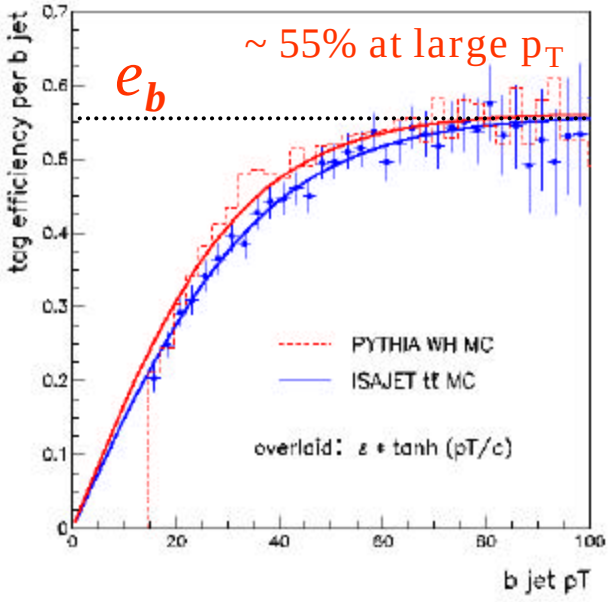
  - displaced vertex b-tagging
  - much improved muon momentum resolution
  - tracking triggers

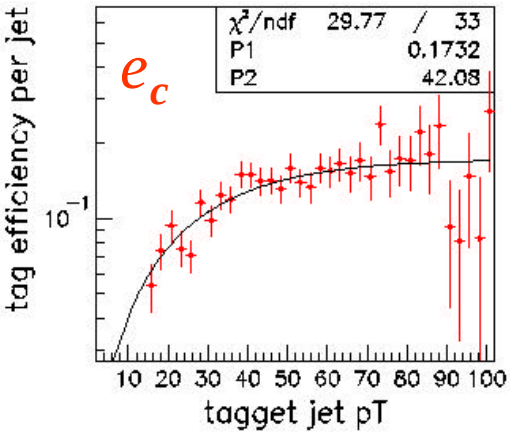
New Tools: charged particle tracking

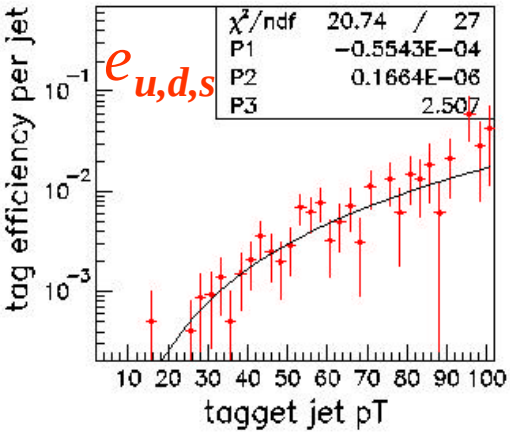


New tools: heavy flavor tagging; extensive silicon detectors

New for DØ
CDF old business, but better
Triggering on it new for both





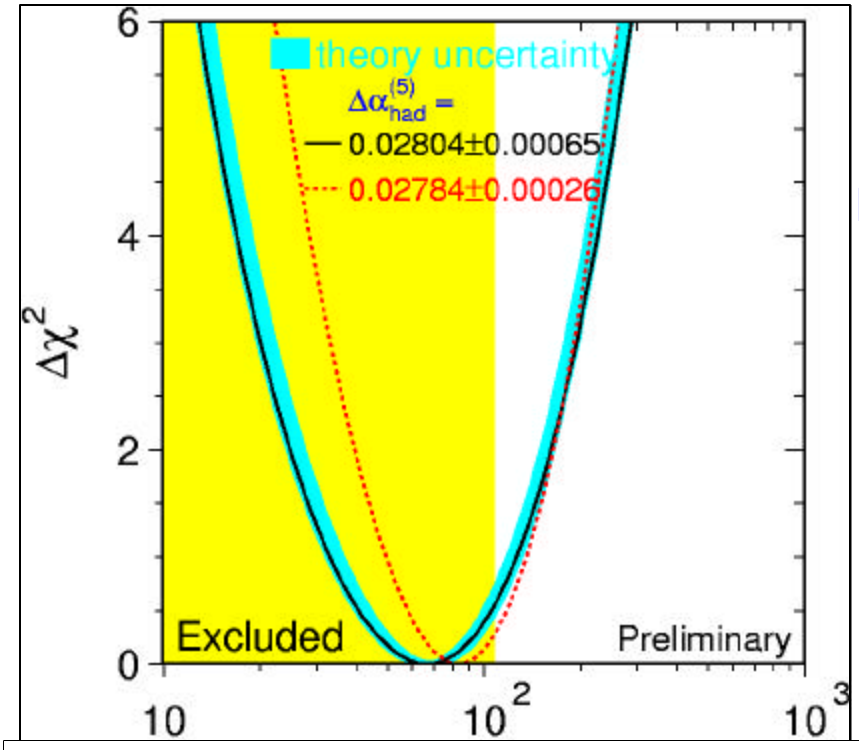


Physics Goals of Run II

- QCD
  - Nucleon structure (parton distributions, diffraction)
  - Jets, photons, Drell-Yan, vector bosons+jets, heavy flavour production
- Standard-Model Physics
  - → **High-statistics study of the top quark (mass, cross section, rare decays, single top production)**
  - Precision measurement of the W mass (< 50 MeV)
  - ➔ constrains the SM……
- b-physics
  - → **Targeted program including CP violation in B ® y K_S**
- Beyond the Standard Model
  - → **Supersymmetry**
  - → **Higgs searches**
  - → **Technicolor, compositeness, new vector bosons, etc.**

Take a closer look at the highlighted topics: low, medium and high mass scales

SM - EW precision



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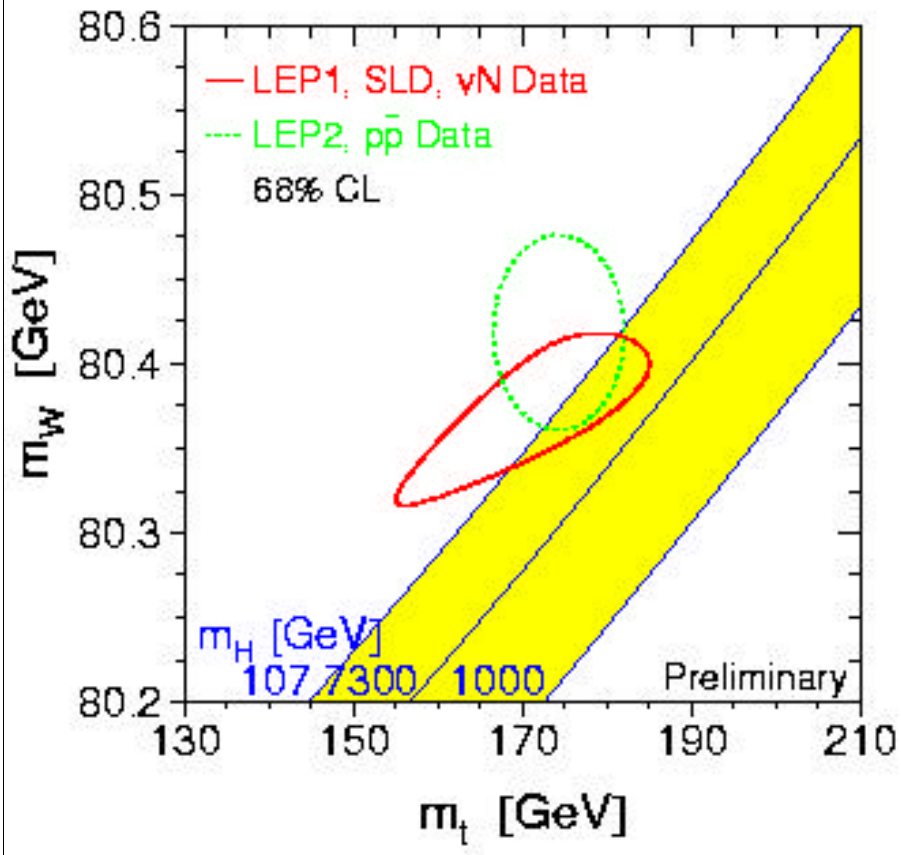
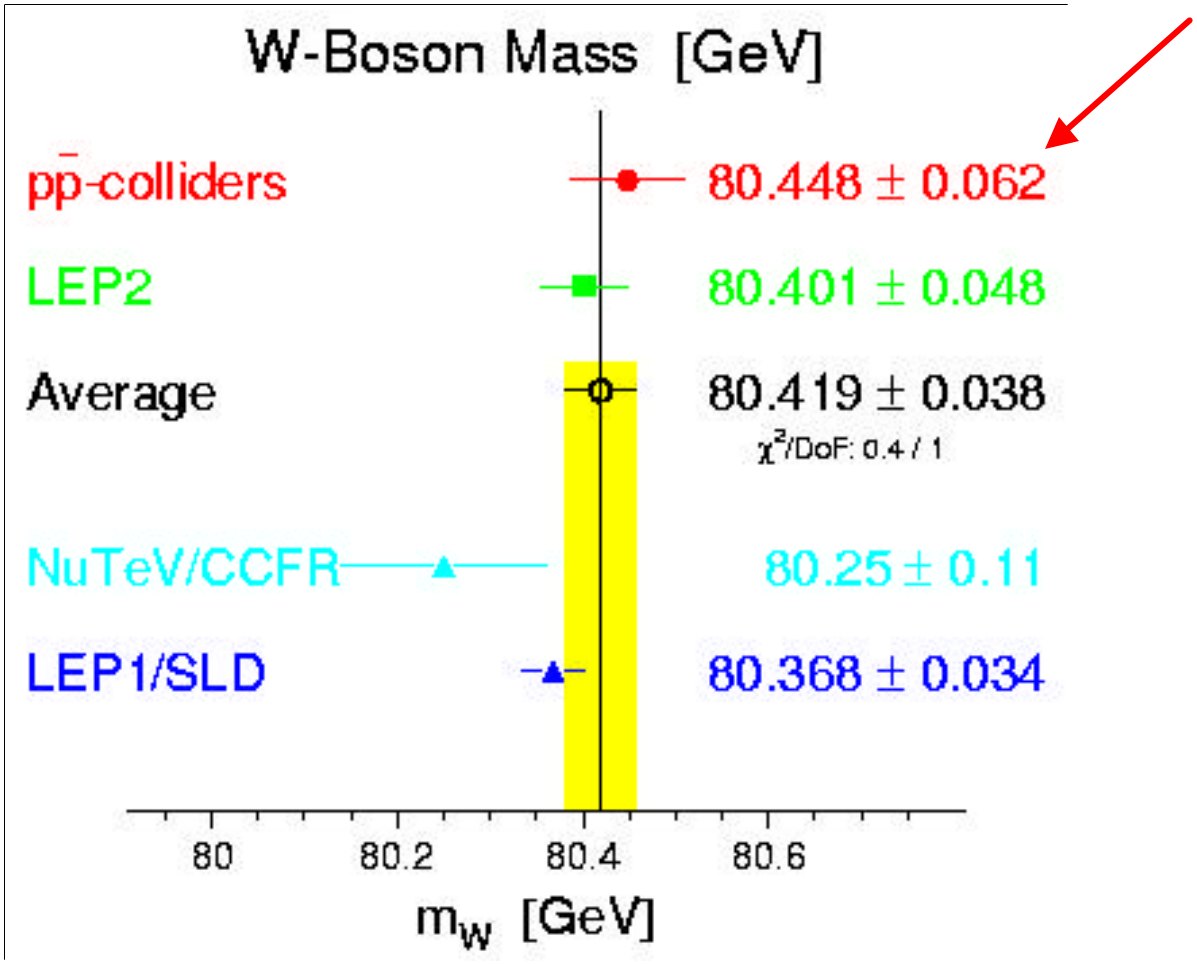


Plot emphasizes importance of top and W mass measurements.

"Bread & butter" physics of Run II

What is precision ?

W mass in Run II



Error is already incredibly small

Future:

Some more improvements from LEP II
Improvements at Tevatron for sure
However not easy, given the environment
(some indication already)

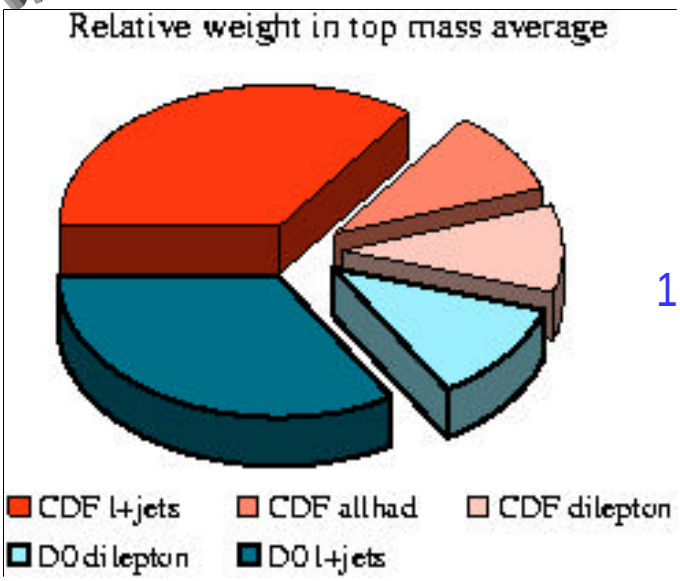
Scaling leads to error on order of:

15-20 MeV/c^2 per experiment in 2fb^{-1}

(with correlations)

Top mass future

(@1 TeV)



Run I result:

$174.3 \pm 3.2(stat) \pm 4.0(syst)$ GeV/c^2

174.3 ± 5.1 GeV/c^2

Run II
2 fb^{-1}

± 3 GeV/c^2

Event statistics
(pair prod.) in 2fb^{-1}

Channel	CDF	DØ
Dileptons (e,μ)	155	160
Dileptons (τ)	19	?
Lepton + >= 3 jets	1520	
Lepton + >= 4 jets		1200
Lept.+>=3 j + 1 btag	990	
Lept.+>=4 j + 1 btag		1000
Lept.+>=4 j + 2 btag	240	500

Key ingredient is jet energy scale calibration.

Top Physics Program

Production

- Top pair cross section
- o Single top cross sections
- ● Couplings: *gtt* *Wtb*
- o Spin correlations
- o $t\bar{t}$ invariant mass spectrum

Decay

- Mass m_{top} ←
- ● Width Γ_{top} ←
- ● CKM matrix element $|V_{tb}|$
- ● Gluon radiation
- ● *W* helicities
- ● Branching fractions
- ● p_T spectra
- ● Charge
- o Rare decays

● = new for Run II

o = very much improved for Run II

Run II Tevatron

We think we know about m_{top} and σ, but what about ...

... All the Other Measurements

Use the reconstructed $t\bar{t}$ and single top with $t \to Wb$ for:

From σ, m_{tt} set limits on	anomalous couplings *gtt, Wtb* $Z', V_8, \eta_T \to t\bar{t}$; $\tilde{g} \to t\tilde{t}$; $g \to \tilde{t}\bar{\tilde{t}}$
Like sign dileptons?	$\tilde{g} \to t\tilde{t}$
Tag rate suppressed?	$t \to Ws, Wd$ $\lvert V_{tb} \rvert$ etc.
Leptonic rate enhanced?	$\tilde{t} \to bl\tilde{\nu}$
Leptonic rate suppressed?	$t \to \tilde{t}\chi^0$, $\tilde{t} \to c\chi^0$
Kinematic distribs need m_{ν^*}	$t \to \tilde{t}\chi^0$, $\tilde{t} \to b\chi^+$; $\tilde{t} \to b\chi^+$ $t \to \tilde{b}\chi^+$, $\tilde{b} \to b\chi^0$
Angular distributions	production and decay helicities

Extra particles in final state:

g, γ, b, l (one or more)	SM radiative decays, plus others

Reconstruct $t\bar{t}$ in different decay modes:

Tau rate enhanced?	$t \to H^+ b$, $H^+ \to \tau\nu$
	$t \to \tilde{t}\chi^0$, $\tilde{t} \to \tau X$ (high $\tan\beta$)
Odd stuff	$t \to \pi_T^+ b$; $t \to \tilde{t}\tilde{g}$; $t \to \tilde{t}\tilde{G}$
	$t \to \tilde{\tau}^+ b$, $\tilde{b}_\tau$ (R parity violating)
	$t \to gc, gu, \gamma c, \gamma u, Zc, Zu$ (FCNC)
	$t \to h^0 c, h^0 u, \pi_T^0 c, \pi_T^0 u$ (FCNC)

Different modes of single top production:

More odd stuff	$g, Z, \gamma \to tc, tu$; $q \to Zt, \gamma t$

Requires CAREFUL COORDINATION between Top Group and New Phenomena Group so as not to get missed.

Info from Tao Han and Regina Demina

Changes from Run I – Effect on Top

Detector Improvements

Electrons	measure p_T
	fewer fakes
	use for b tagging
Muons	better p_T
	lower minimum p_T for tags
	better η coverage
	better triggers
Jets	charge for jet ID
	b tagging with secondary vertices
	b trigger with STT

Accelerator Improvements

11% higher energy

40% increase in $t\bar{t}$ and single top cross sections

5x higher integrated luminosity

Analysis Improvements

~25x higher statistics
better MC models
better parton distribution function sets
better analysis tools
more ways to control systematic errors
more experience

Data Sets

1. **e or μ + ≥ 1 central jet**
   - + $\not\!\!E_T$ for *l +jets/notag* background ($t\bar{t}$ and single top)
   - + $\not\!\!E_T$ + ≥ 2 jets for single top
   - + 'e' or 'μ' + ≥ 2 jets for lepton ID prob (single top)
   - + 'e' or 'μ' + ≥ 3 jets for lepton ID prob ($t\bar{t}$)
   - + e or μ + $\not\!\!E_T$ + ≥ 2 jets for $t\bar{t} \rightarrow$ *dileptons*, m_{top}
   - (μ) + low $\not\!\!E_T$ + ≥ 2 jets for fake μ backgd ($t\bar{t}$ and single top)
   - + $\not\!\!E_T$ + ≥ 3 jets for $t\bar{t} \rightarrow$ *lepton + jets / tag*
   - + $\not\!\!E_T$ + ≥ 4 jets for $t\bar{t} \rightarrow$ *lepton + jets / notag*, m_{top}

2. **≥ 6 jets (STT or prescaled?)**
   - for $t\bar{t} \rightarrow$ *alljets* Xsec and m_{top}

3. ***b*-tag + ≥ 2 jets (STT)**
   - $Z \rightarrow b\bar{b}$ for jet energy scale calibration
   - + ≥ 3 jets to measure secondary vertex tag prob, fake prob (if *b*-tag is in trigger)
   - + ≥ 4 jets for *single top* → *alljets*

4. **≥ 2 jets (≥ 1 central jet; prescaled)**
   - for $b\bar{b}$ continuum subtraction in energy scale calibration
   - + ≥ 3 jets fake electron background in $t\bar{t}$ and single top
   - and measure lepton tag rate functions
   - and measure secondary vertex tag prob, fake prob (if *b*-tag not in trigger)

5. **Various special sets for rare decay searches**

Signal Yields in 500 pb^{-1}

Reconstructed Top Events			
Exclusive Yields (m_{top} = 175 GeV)	Run I 10% tag	Run IIa 500 pb^{-1} 45% tag	65% tag
$t\bar{t} \to ll + \geq 2\,jets$	5	39	39
$t\bar{t} \to l + = 3\,jets/ = 1\,tag$		17	16
$t\bar{t} \to l + = 3\,jets/ = 2\,tags$		9	19
$t\bar{t} \to l + \geq 4\,jets\,/\,notags$	10	178	71
$t\bar{t} \to l + \geq 4\,jets/ = 1\,tag$	9	145	133
$t\bar{t} \to l + \geq 4\,jets/ = 2\,tags$		70	148
$t\bar{t} \to \geq 6\,jets/ = 1\,tag$	14	252	232
$t\bar{t} \to \geq 6\,jets/ = 2\,tags$	2	124	260
Total $t\bar{t}$ Events	**40**	**834**	**918**
$t\bar{b} + \bar{t}b \to l + \geq 2\,jets\,/\,notags$	~0.8	7	3
$t\bar{b} + \bar{t}b \to l + \geq 2\,jets/ = 1\,tag$	~0.2	11	10
$t\bar{b} + \bar{t}b \to l + \geq 2\,jets/ = 2\,tags$		5	10
$t\bar{b} + \bar{t}b \to \geq 4\,jets/ = 1\,tag$		29	27
$t\bar{b} + \bar{t}b \to \geq 4\,jets/ = 2\,tags$		12	25
Total s-channel single top	**~1**	**64**	**75**
$tq\bar{b} + \bar{t}\bar{q}b \to l + \geq 2\,jets\,/\,notags$	~2.0	17	7
$tq\bar{b} + \bar{t}\bar{q}b \to l + \geq 2\,jets/ = 1\,tag$	~0.3	28	26
$tq\bar{b} + \bar{t}\bar{q}b \to l + \geq 2\,jets/ = 2\,tags$		11	23
$tq\bar{b} + \bar{t}\bar{q}b \to \geq 4\,jets/ = 1\,tag$		72	66
$tq\bar{b} + \bar{t}\bar{q}b \to \geq 4\,jets/ = 2\,tags$		29	61
Total t-channel single top	**~2.3**	**157**	**183**

How to Improve the Analyses

Reduce the Errors

More statistics ... the following errors will go down by $1/\sqrt{N}$:

Electron ID efficiency	5 % (CC), 7 % (EC)
Fake electron probability	10 % (CC), 8 % (EC)
Muon ID efficiency	10 % (CF), 3 % (EF)
Fake muon probability	5 % (CF), 30 % (EF)
Tag muon ID efficiency	5 % (CF), 3 % (EF)

The following errors need more work to make them go down :

Integrated luminosity	5 %
Tag rate functions	8 %
Modeling tagging muons	10 %
PDF model of proton	1 – 10 %
Jet energy scale	1 – 10 %
Multiple interactions	3 – 10 %
Modeling jets	5 – 14 %

Increase the Efficiencies / Reduce the Fake Rates

Electron ID	strongly dependent on jet multiplicity 61 % (CC), 54 % (EC), for ≥2 jet events
Fake e probability	0.01 % (CC), 0.05 % (EC)
Muon ID	~ 45 %
Fake μ probability	7 – 16 % (CF), 45 – 63 % (EF)
Jet ID	kT jets for high efficiency at low E_T ?
b-tag efficiency	10 % / jet —> 40 % – 70 % / jet ?
Fake tag prob	~ 0.4 % / jet

Improve the MC Models

Jet Modeling

$t\bar{t}$ Signal

HERWIG 5.7 and 5.9 used in Run I

Version 5.9 had a bug in the *b* parton showering
—> Too much gluon radiation at large angles. Fixed in 6.0

Version 6.1 replaces the parton showering algorithms in top decay (FSR) with NLO matrix element calculations
—> Energy radiated ~same, angular distribution different

NLO matrix elements will be in top production (ISR) soon

Single Top Signal

Get NLO generator from Laenen (extension of DYTAG)

W+Jets Background

CompHEP could replace VECBOS
—> Quark masses are included (changes pT for *b* jets)

b-Decay Modeling

Get the latest CLEO model of *b* and *c* decays for HERWIG

PDFs

Update from CTEQ3M to CTEQ6M and/or MRS98

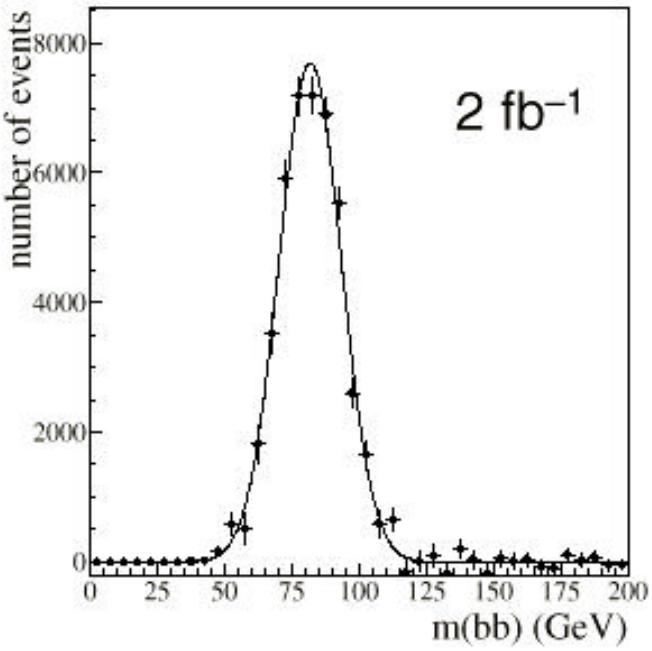
Improve the Jet Energy Scale Calibration

Narain and Heintz DØ Note 3604

Use STT with >= 2 jet events, at 20% efficiency
Able to reconstruct $Z \to b\bar{b}$ peak above 2 jet continuum

p_T balancing with dijet and $\gamma + jet$ events limited to ~1.5%
$Z \to b\bar{b}$ will reduce this to ~0.3% (Full Run II)

In 500 pb^{-1}, reconstruct ~10,000 $Z \to b\bar{b}$ on a ~140,000 $g \to b\bar{b}$ continuum



Try to do this with lepton-tagged jets too ?
Might need to if no STT. Calibrate lepton-correction to jet

Improve *b*-Tagging of Jets

Bookkeeping Problem

Run I Separate analyses for untagged and tagged events in cross section measurement
Separate treatment for untagged, single-tagged, and double-tagged events in mass measurement

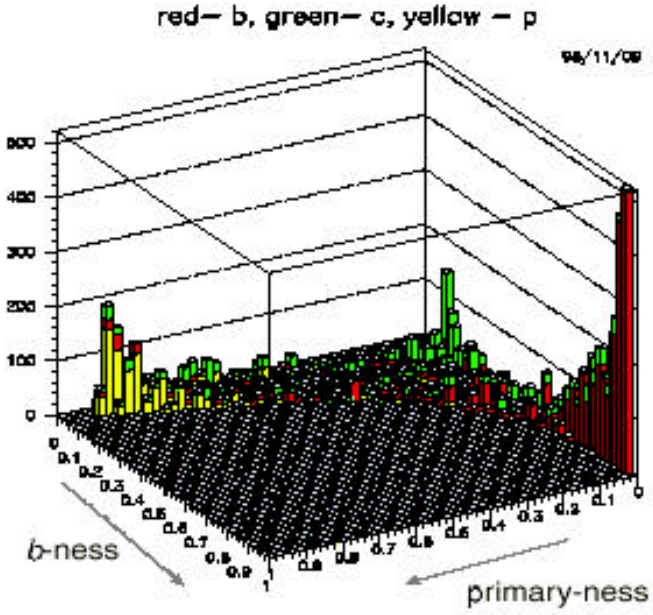
Run II Each jet can have:

(SMT) (e) (μ)
(SMT+e) (SMT+μ) (e+μ) (e+e?) (μ+μ)
(SMT+e+μ) (SMT+e+e?) (SMT+μ+μ)

Up to two combs / event — how many analyses?

Losing Information

If the SMT, e and μ tags are just yes/no information, then much is lost – must combine all available information in NN
CDF have developed a NN with 8 inputs and 3 outputs (b, c, p)



(D. Amidei, R. Demina
D. Wolinski)

We must do this too!
Optimized for DØ, better!

Summary of Key Issues

~ 900 $t\bar{t}$ pair events	S:B	5:1 (*ll*)	3:1 (*l+jets*) ?
~ 240 single top events	S:B	1:4 ?	

Yields are critically dependent on:

- keeping trigger efficiencies at Run I levels
- improving *e* ID efficiency in high occupancy environment
- improving μ ID efficiency
- using the STT for single top –> alljets

Signal:Background will be determined by:

- lowering fake rates for *e*, μ, *b*-tag
- getting high *b*-tagging efficiency

Highest quality measurements depend on:

- improving the jet energy scale calibration
- using better MC tools for modeling
- using neural networks wherever possible

Run II Tevatron

Summary of Top Physics with 500 pb^{-1}

We should publish papers (PRL and/or PRD) of the following measurements:

Major:

1. top quark mass
2. $t\bar{t}$ pair production cross section
3. s-channel and t-channel single top cross sections

Production:

4. anomalous coupling limits (from cross sections)
5. gluon radiation studies
6. high mass resonance search in m_{tt}
7. spin correlations

Decay:

8. W helicities
9. branching fractions
10. p_T spectra (perhaps with 5.)

11.–15. rare searches (several)

Combined:

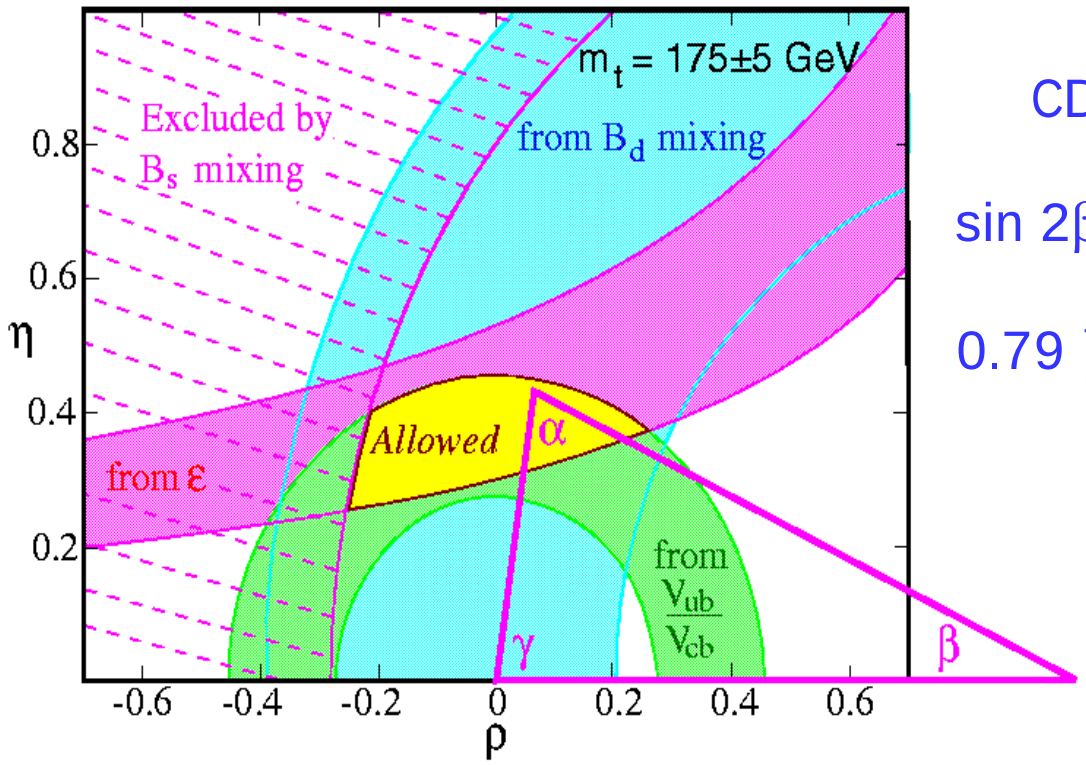
16. $|V_{tb}|$ and top width from single top cross section and $t\bar{t}$ decay branching fractions

B Physics in the 21st Century

Experiments will confront the Standard Model interpretation of CP violation

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

- A and λ have been measured to a few percent
- unitarity condition: $V_{tb}^* V_{td} + V_{cb}^* V_{cd} + V_{ub}^* V_{ud} = 0$



CDF:

$\sin 2\beta =$

$0.79\ ^{+0.41}_{-0.44}$

Sin2β Expectations for 2fb^{-1}

For a time independent analysis:

$$s(\sin 2b) \approx e^{x_d^2 \Gamma^2 s_t^2} \sqrt{\frac{1+4x_d^2}{2x_d}} \frac{1}{\sqrt{NeD^2}} \sqrt{1+\frac{B}{S}}$$

- (S/B ~ 0.75)
- e D^2 ~ 9.8 %
- σ_t ~ 128 fs

mode	$J/y \to m^+m^-$	$J/y \to e^+e^-$
trigger eff. (%)	**27**	**20**
reco'd events	**40,000**	**30,000**
$s(\sin 2b)$	**0.04**	**0.05**
	0.03	

And this is just in the first two years - 2 fb^{-1}. We won't stop there……

Summary/Conclusions

Run II at Tevatron: great and unique opportunity for experimental physics from 2001-2007.

Run II is a combination of:

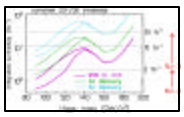
- Precision measurements (masses, B physics, QCD)
- Searches for new exp. signatures

requires

- Understanding of production processes (QCD)
- Close interaction with theory (phenomenology, not string)
- Accurate parton distributions (XMRS, CTEQ9, "GKK")
- HERA data as input (high x- searches)
- Continue cooperation CDF-DØ-Theory (a la Run II wrkshps)

Will not show the Higgs plot again

Be careful in using this to define Run IIb



Can not wait until first Run II collisions, but it will be painful until then.