Tevatron Physics from Now till 2007

II Workshop Italiano sulla Fisica di ATLAS e CMS
October 13, 2004
Napoli, Italy

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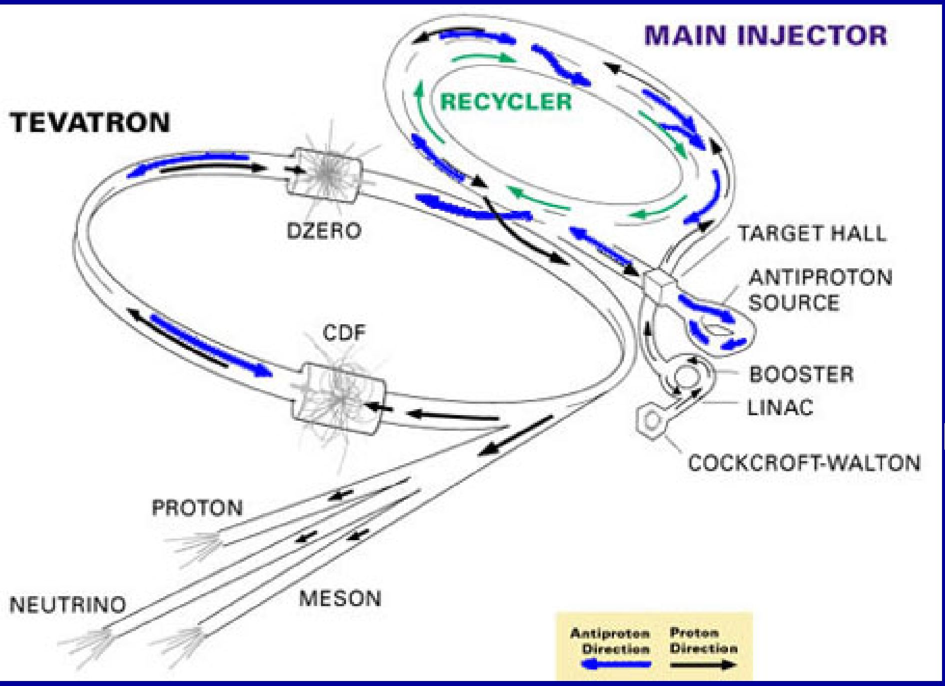
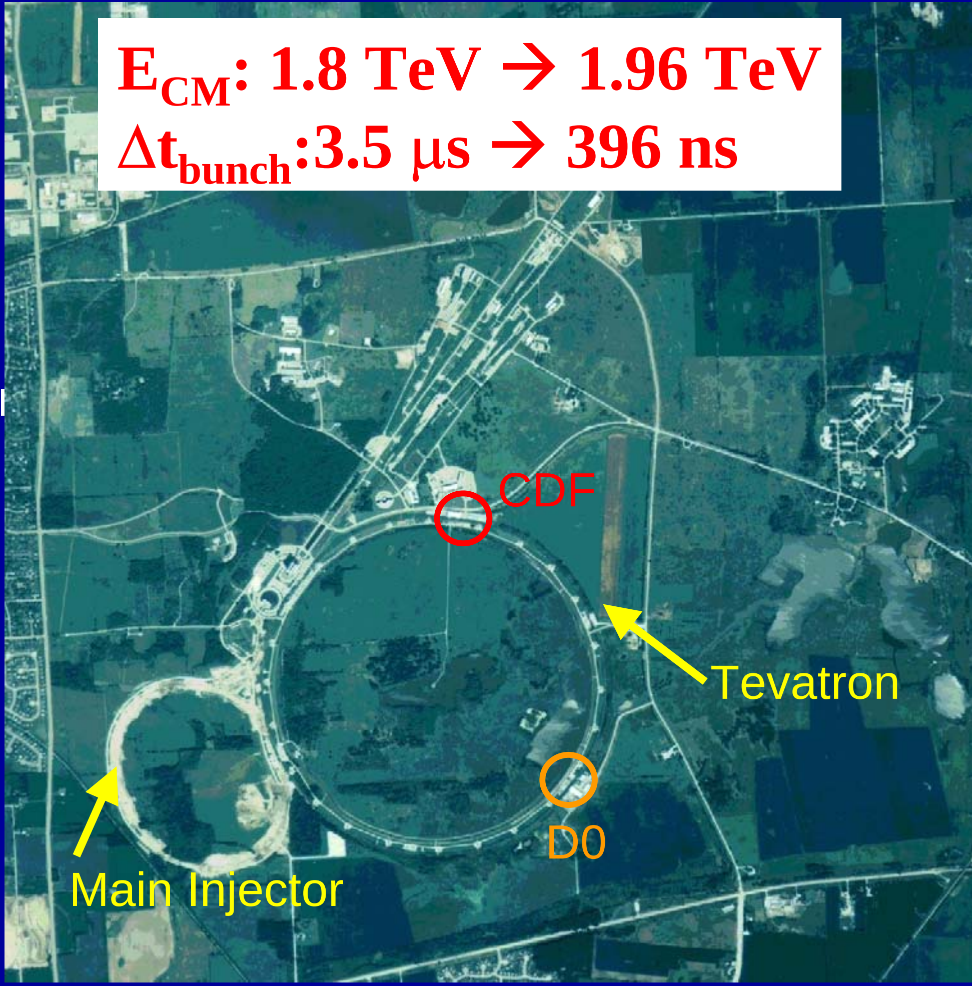
OUTLINE

- The Tevatron
- CDF and D0
- Current Run II results and expectations for 2007 … and beyond

Upgraded Tevatron: Run II

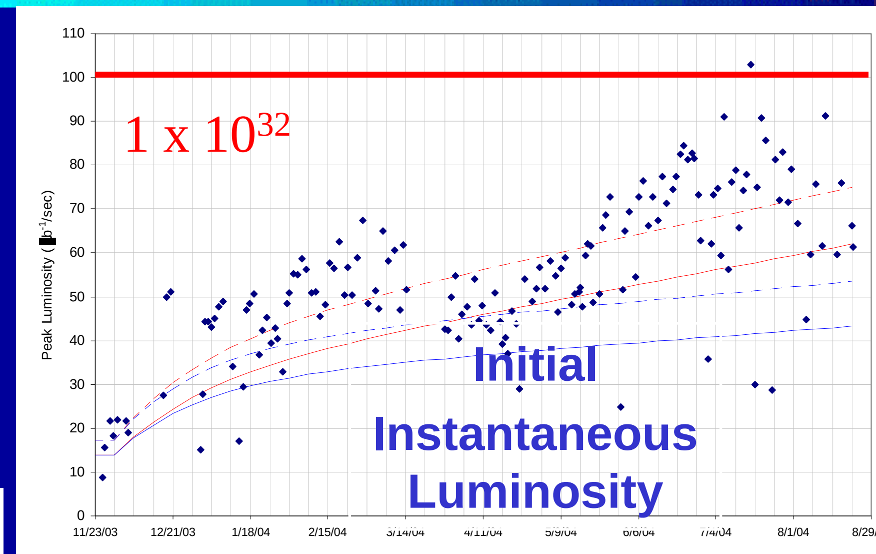


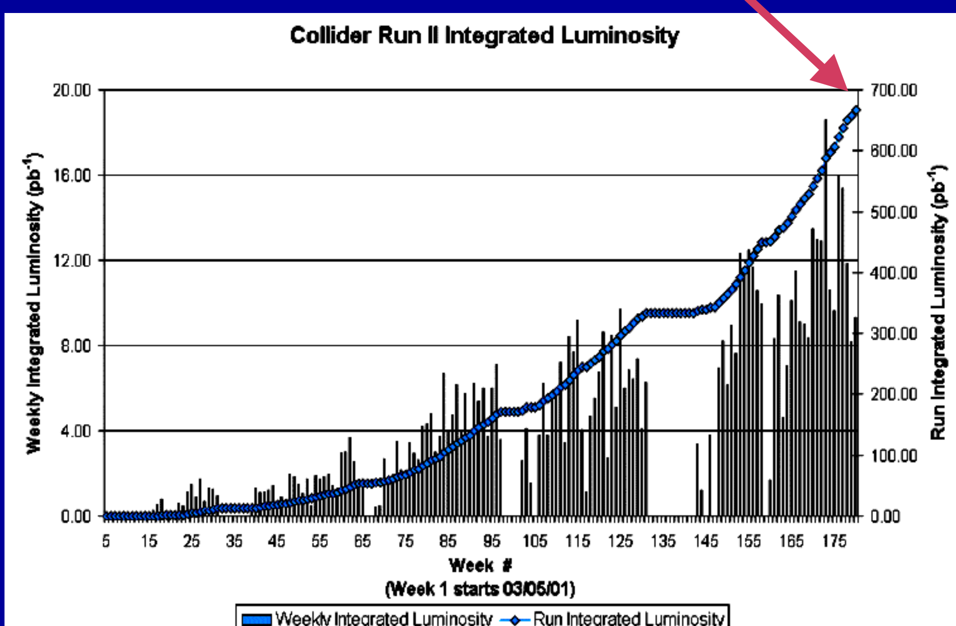


- New Main Injector:
  - Improve p-bar production
- Recycler ring:
  - Improve p-par accumulation

TeV Luminosity (current situation)

- Peak luminosity
  - Best > 1.0 x10^{32} !!!
- Delivered 680 pb^{-1}
  - 540 pb^{-1} on tape
- Next data set for analysis
  - ~ 350 – 450 pb^{-1} > 3-4 x Run 1





- Shutdown in progress
  - Install electron cooling
- FY 2005
  - Continue mixed mode
  - Proton slip stacking
  - +25% p-bar production acceptance
  - Commission e-cooling by end of FY05

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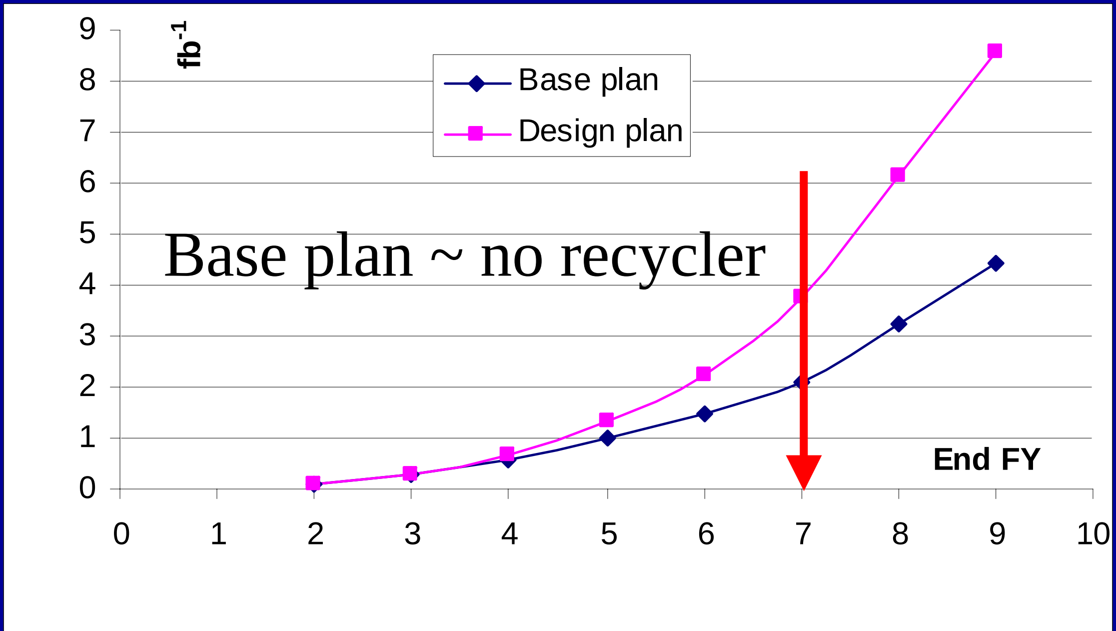
Extended Tev goals

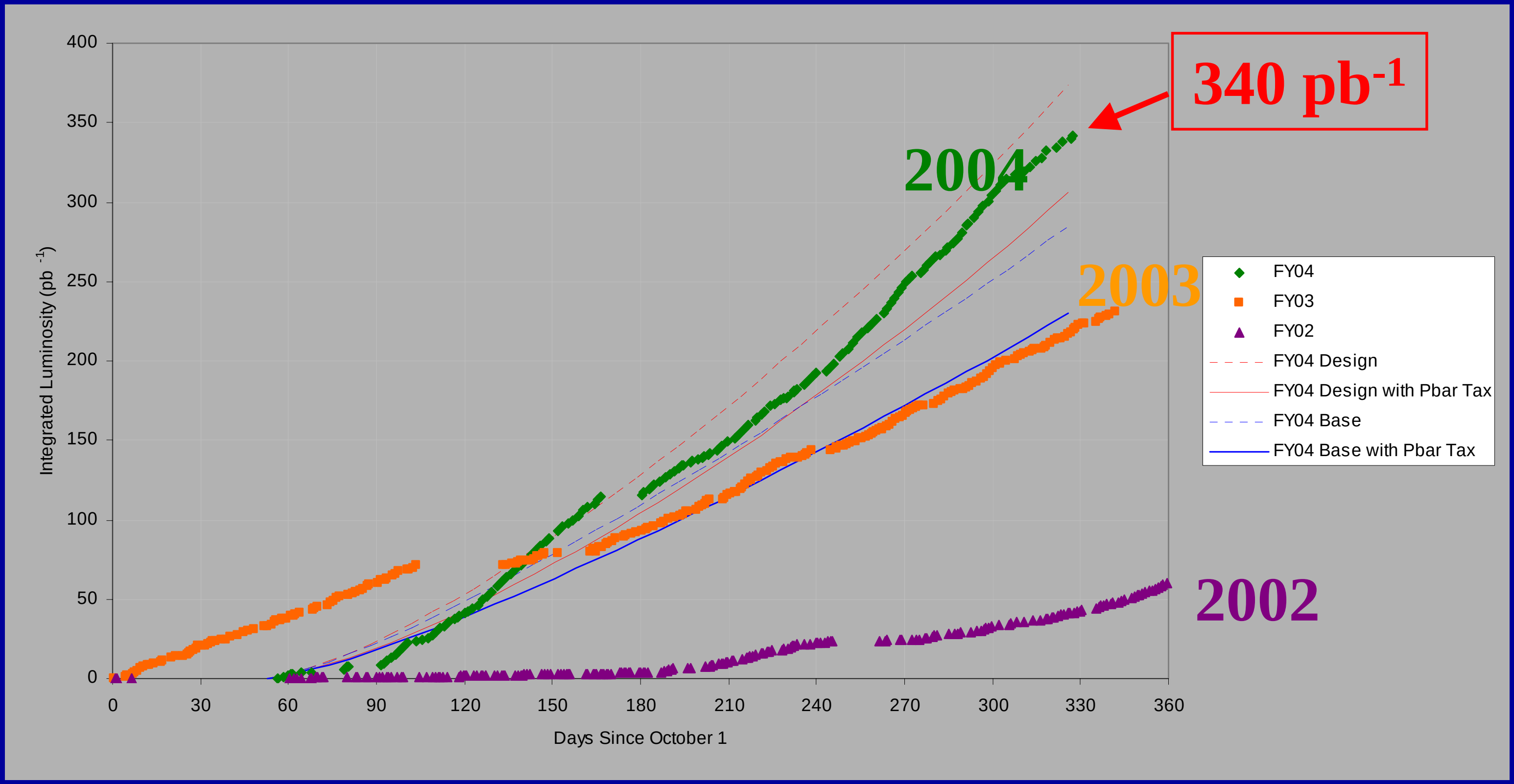
- Luminosity plan 2002
- Goals 2002 - 04 accomplished
- Goals 2004 ~ 310 - 380 pb^{-1}
  - Tevatron is performing very well
  - Key is good recycler performance

$\mathcal{L}_{max}$ = 2-3 x 10^{32}

Year	Base plan luminosity/yr (fb^{-1})	Design plan Luminosity/yr (fb^{-1})
FY02	0.08	0.08
FY03	0.20	0.22
FY04	0.31	0.38
FY05	0.39	0.67
FY06	0.50	0.89
FY07	0.63	1.53
FY08	1.14	2.37
FY09	1.16	2.42
Total	4.41	8.56



Integrated luminosity profile



Tevatron performance projections much more reliable now:

→ **2 – 4 fb^{-1} by end of FY07**

→ **5 – 10 fb^{-1} by end of Tevatron operation**

Extended FNAL plan

- Fermilab long range plan

(FNAL Official schedule: March 5, 2004)

	RUN or DATA
	STARTUP/COMMISSIONING
	INSTALLATION
	M&D (SHUTDOWN)

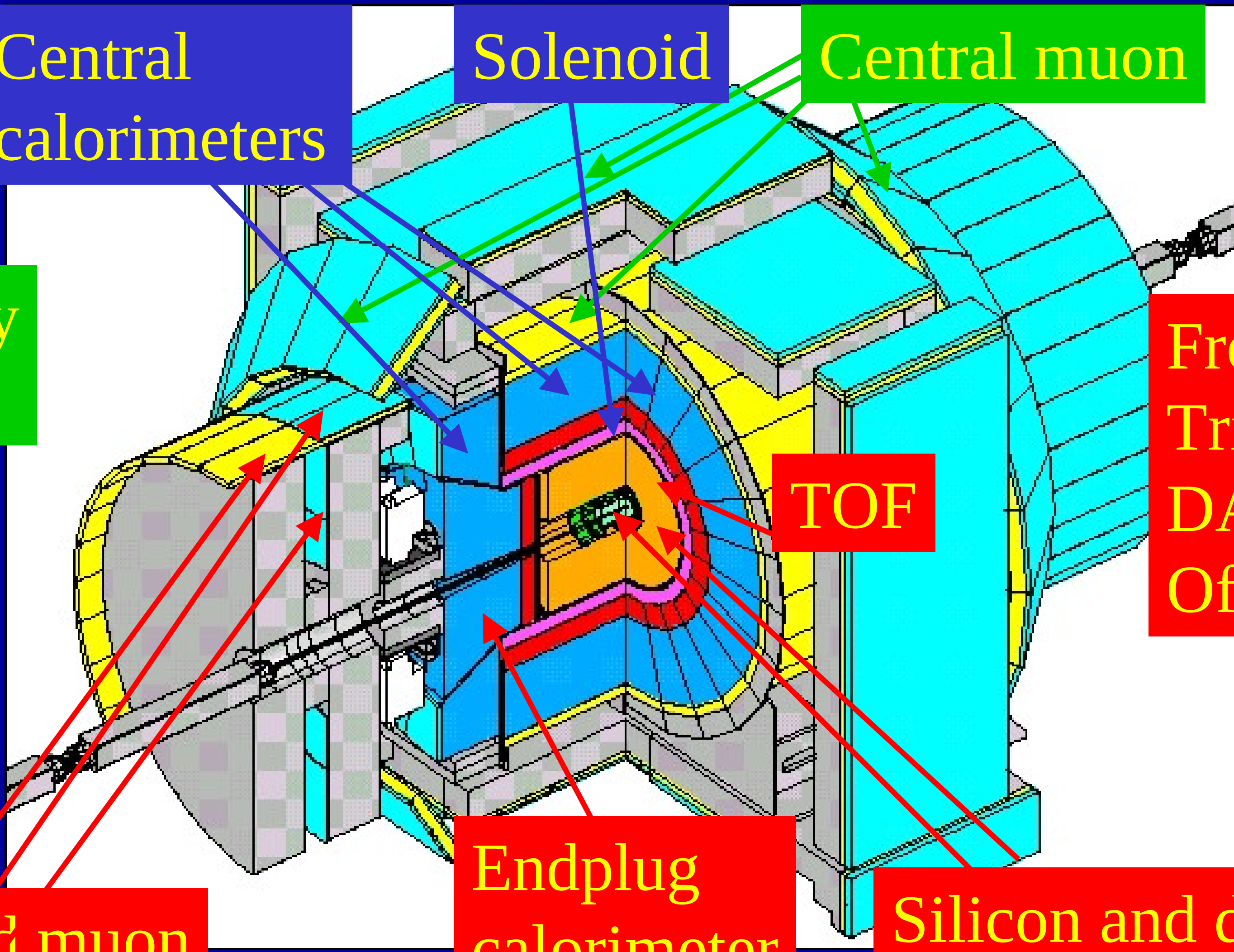
Calendar Year		2006	2007	2008	2009	
Tevatron Collider		BTeV	BTeV	BTeV	BTeV	BTeV
		CDF & D0	CDF & D0	CDF & D0	CDF & D0	Open
Neutrino Program	B	OPEN	OPEN	OPEN	OPEN	OPEN
	MI	MINOS	MINOS	MINOS	MINOS OPEN	OPEN
Meson 120	MT	TestBeam	TestBeam	TestBeam	TestBeam	TB
	MC	OPEN	OPEN	E906#	E906#	E906#
	ME	OPEN	OPEN	OPEN	E921*	E921*

The Upgraded CDF Detector

New

Old

Partially new

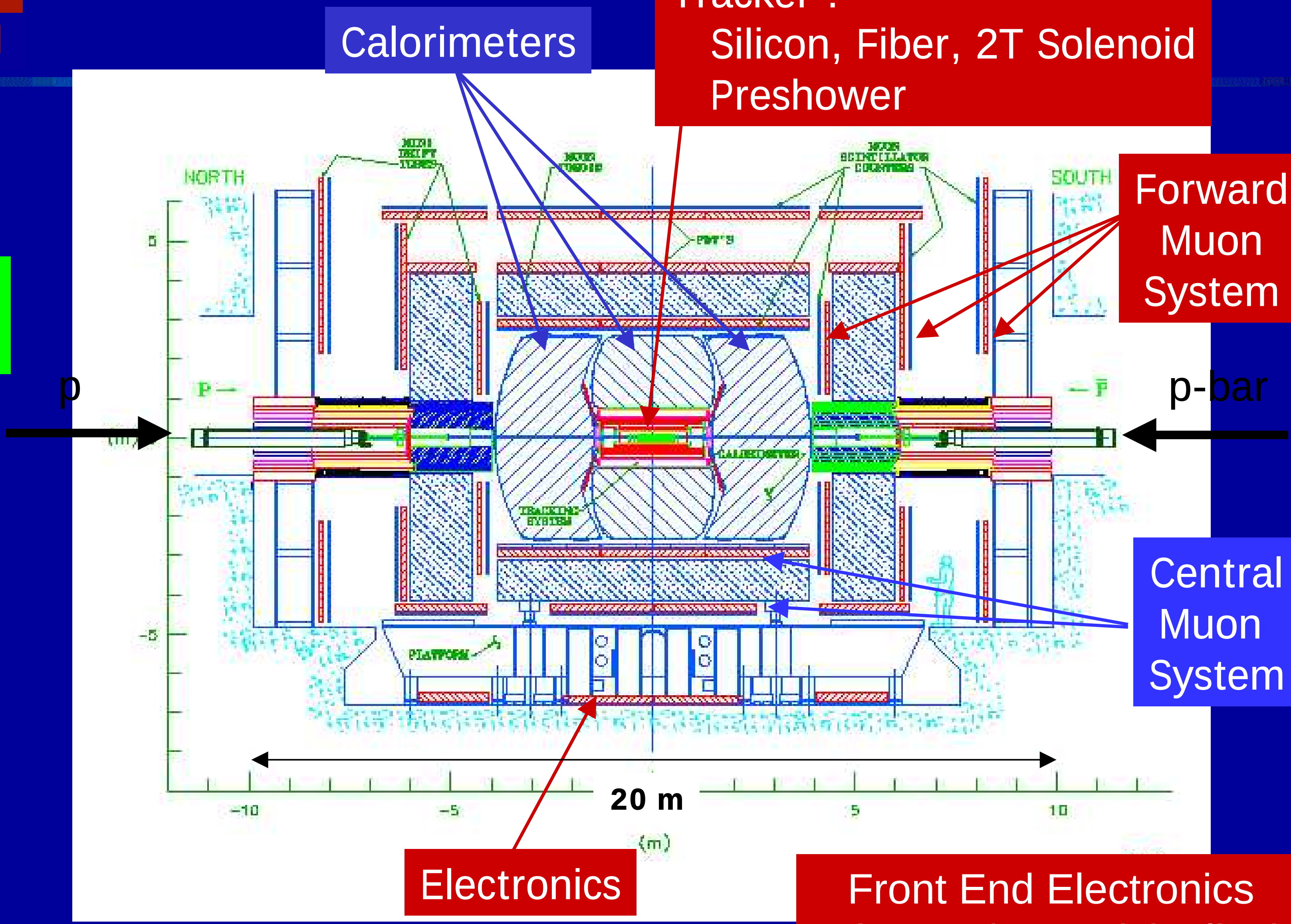


D0: side view

New

Old

Partially New



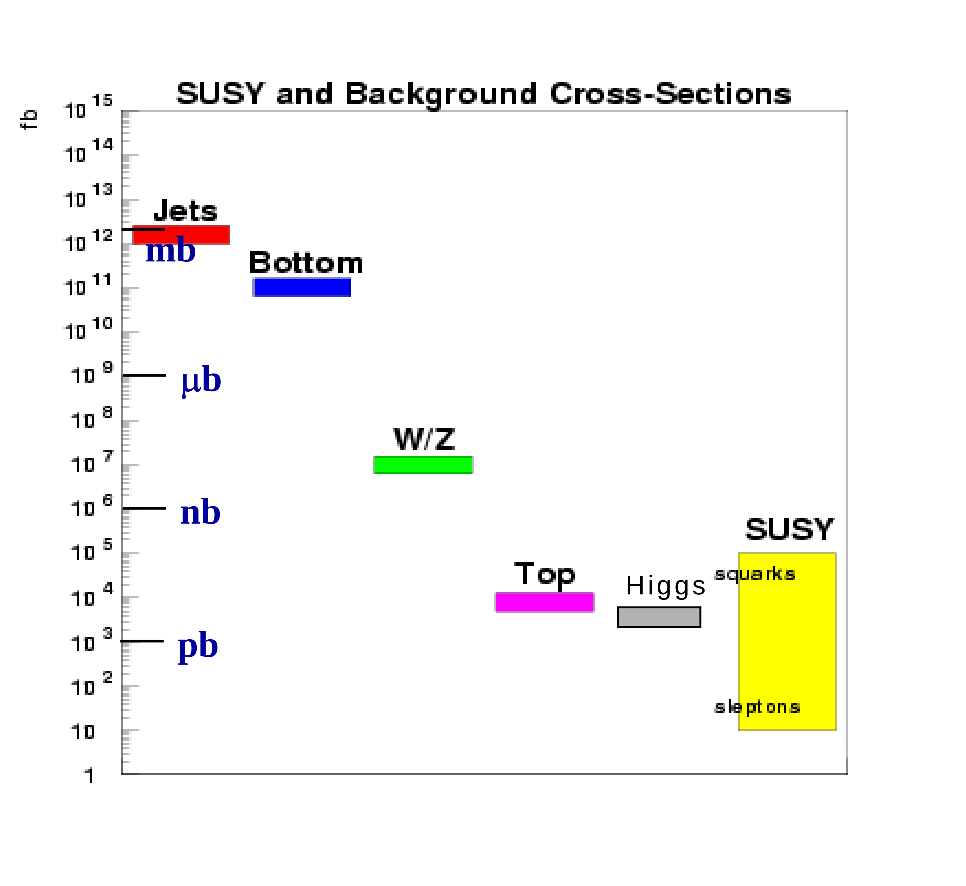
Front End Electronics
Triggers / DAQ (pipeline)
Online & Offline Software

Physics Highlights and Prospects

- Will be biased toward CDF results!
- Will cover only selection of results
  - Based on $200 \pm 50\ pb^{-1}$ data sample (until Feb. 13, 2004: start of CDF COT crisis)
- Whenever possible will try to show how far we can push the measurements

Tevatron Physics

- Access to all aspects of SM
  - Jets
  - charm/beauty/top
  - Vector bosons
- Sensitivity to new physics
  - Higgs
  - SUSY
  - Anything else ?
    - Large extra dimensions, Leptoquarks, Technicolor, etc.
  - NP covered by large backgrounds
    - Need very good understanding of more frequent phenomena

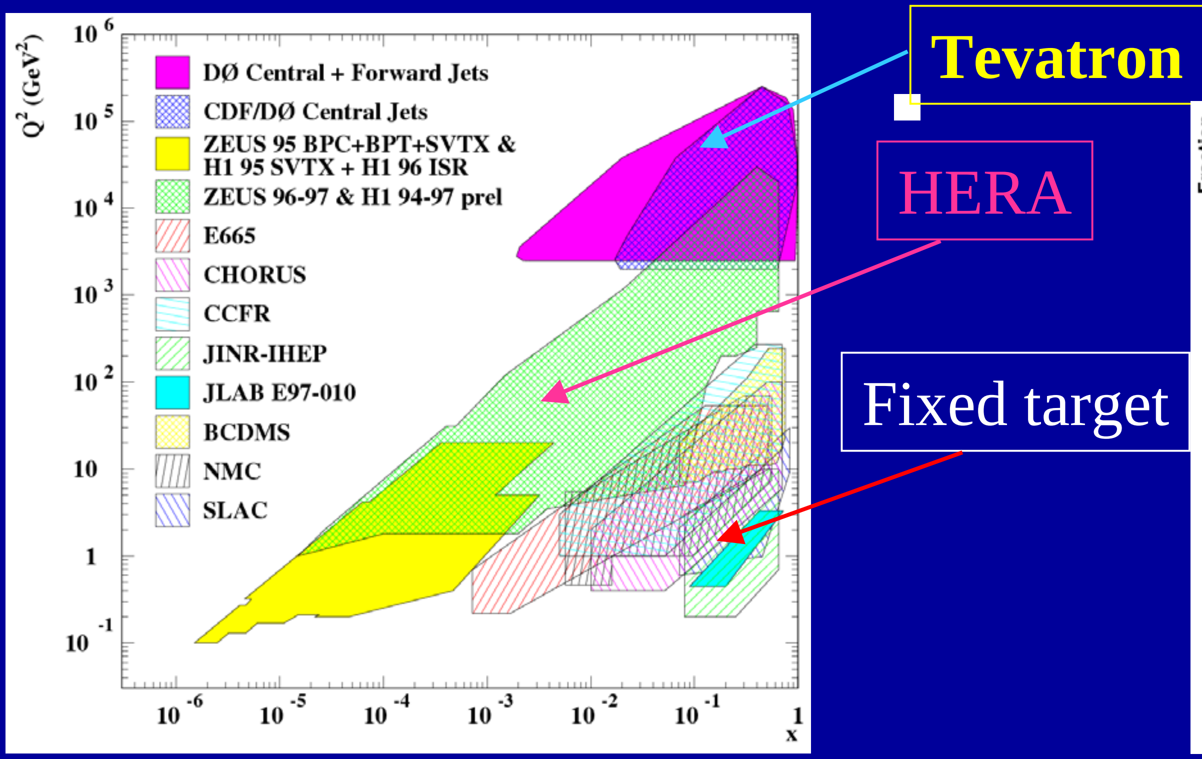


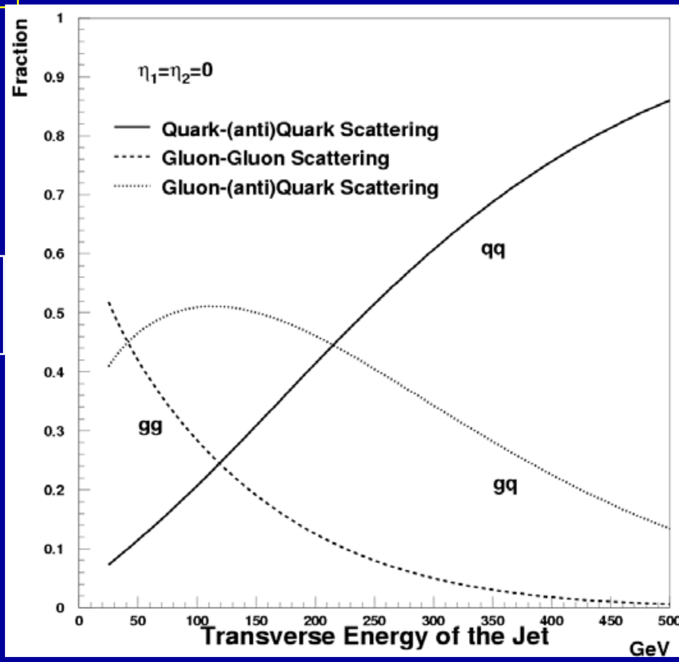
QCD

- The mother of all backgrounds!
  - Current description much improved over run 1
- New physics in highest energy jets
  - Quark compositeness changes Et distr.
  - Bumps in di-jet mass signal NP
  - More high Et jets due to Tev energy increase
- Study also photons and W/Z + jets

Jets and pdf's

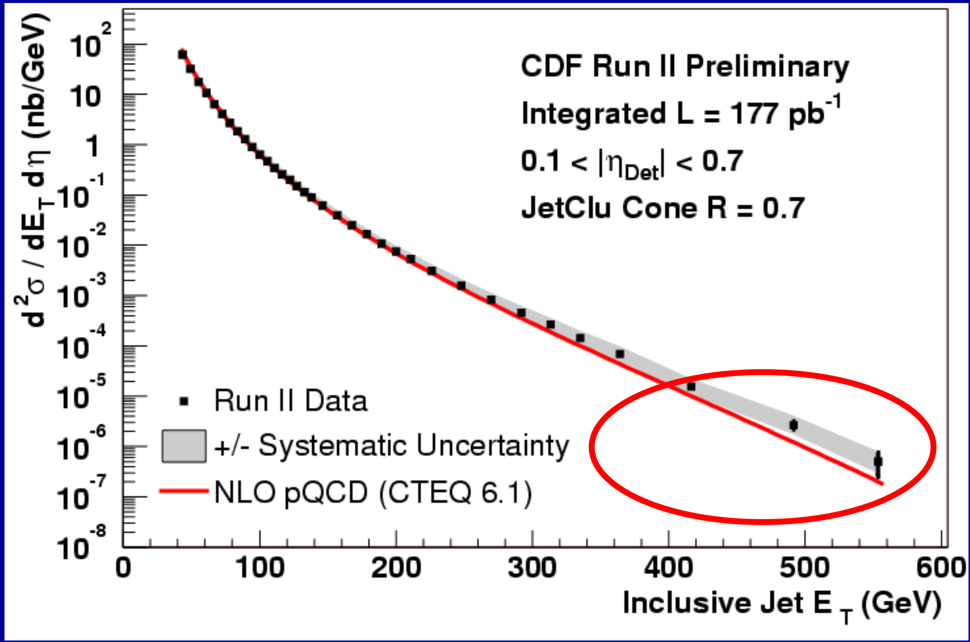
- Tevatron extends pdf coverage to high values of x, Q
- Direct sensitivity to gluon pdf
- New physics modifies Et or Mjj distributions

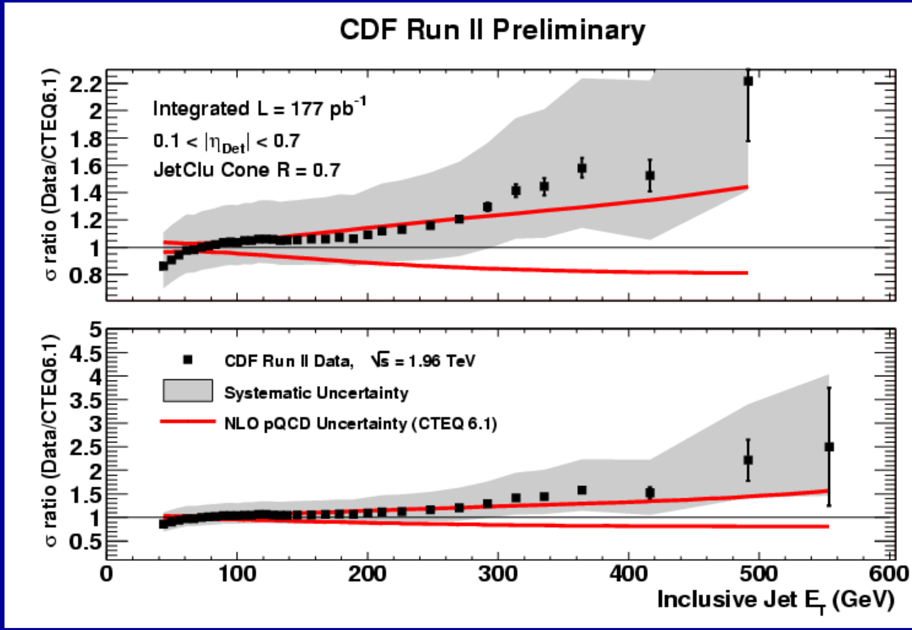




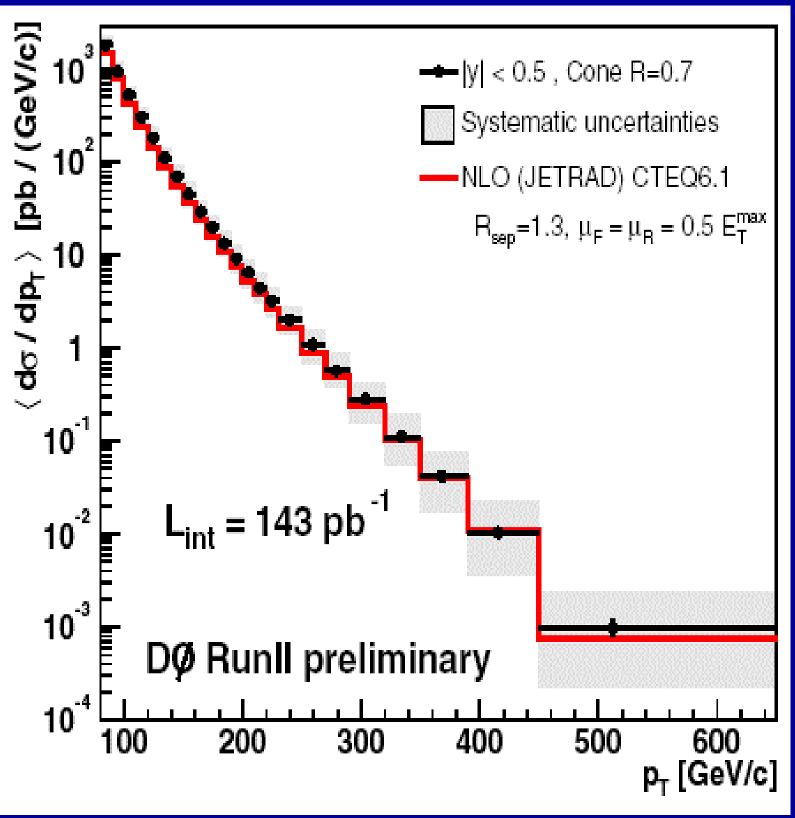
Inclusive Jet Et

- Updated results with 177 pb^{-1} of data
  - Consistent with NLO pQCD with CTEQ6.1
    - No obvious high Et excess
    - Energy scale uncertainty ~ 3% - Major systematics
  - Other similar results with Kt and mid-point clustering

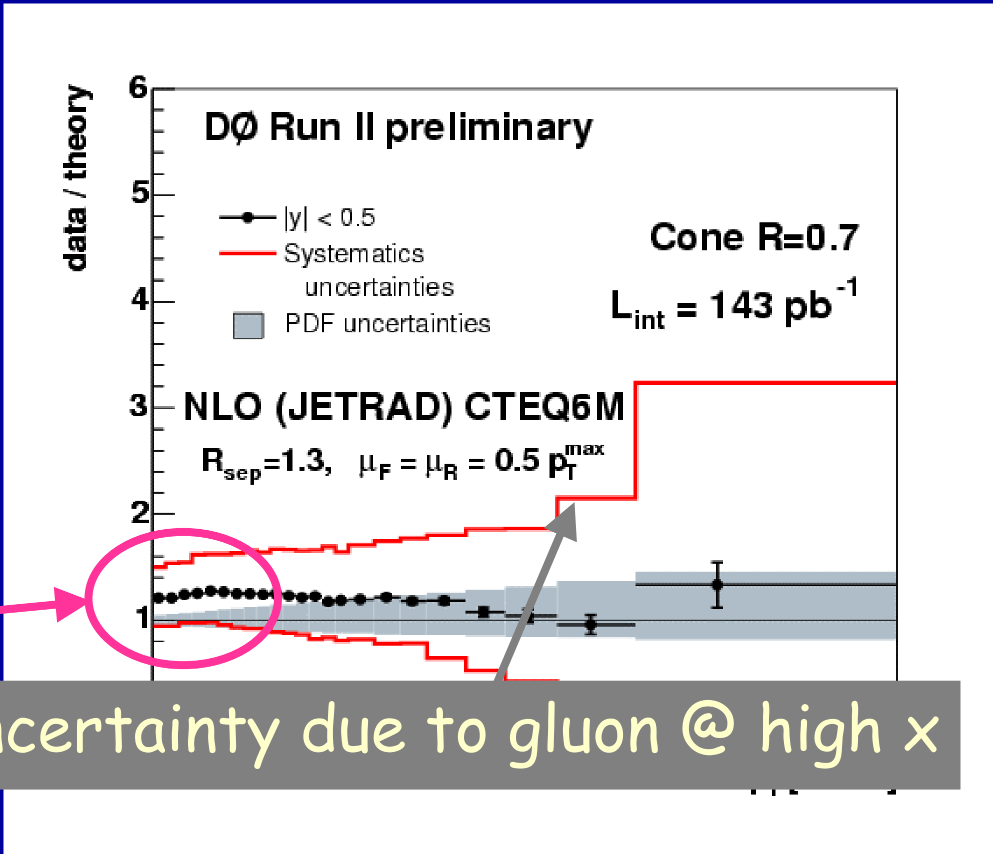




Di-jet mass



Agreement with theory within systematic uncertainties (dominated by jet-energy scale)

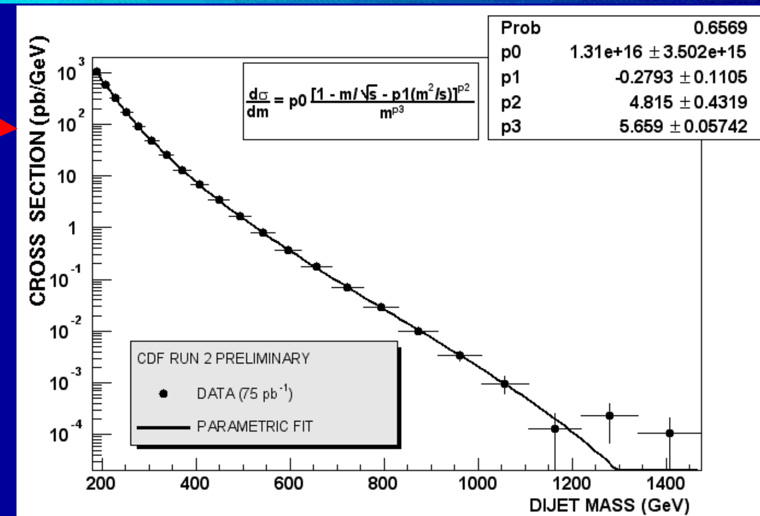


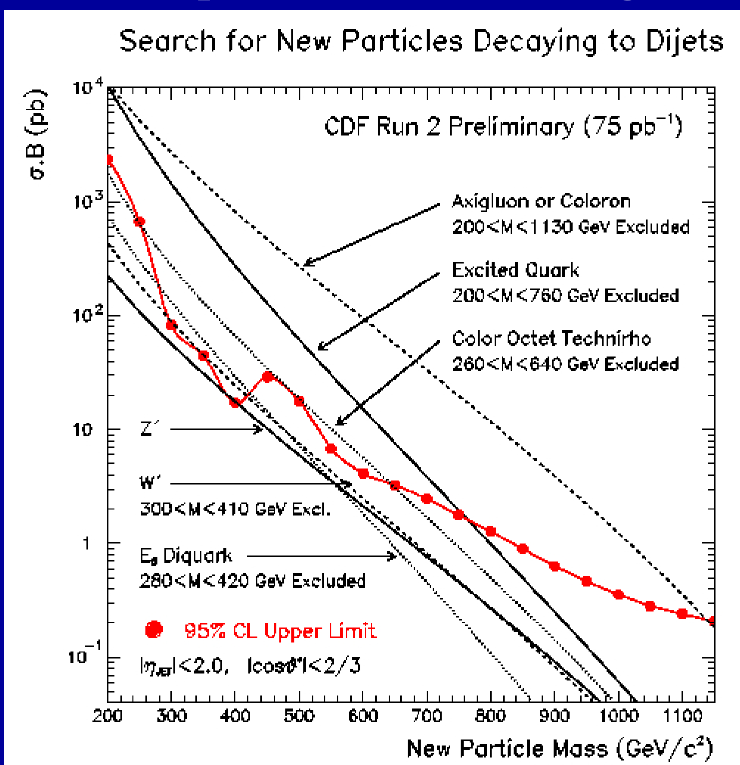
Hadronization correction needed?

NLO uncertainty due to gluon @ high x

Di-jet mass

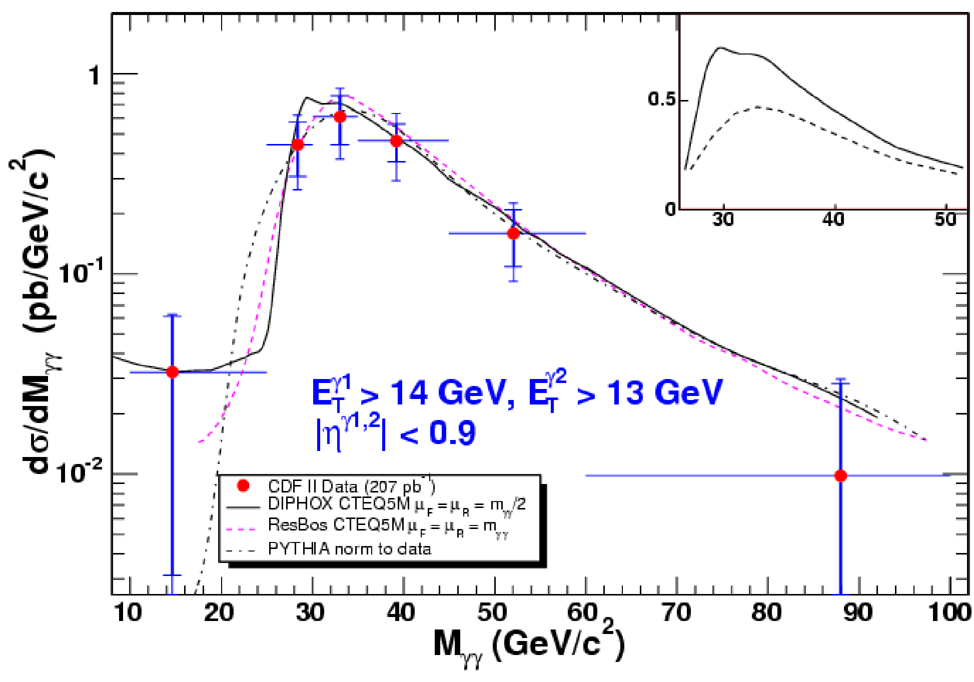
- Old '03 result (75 pb^{-1}) used to set limits on jet-jet resonances
  - Need work on jet corrections to improve limits with higher statistics





Exotic state	Run I exclusion range (GeV)	Run II exclusion range (GeV)
Axigluon	200 - 980	**200 - 1130**
Excited quarks	200 - 760	**200 - 760**
technirho	260 - 480	**260 - 640**
E6 di-quark	290 - 420	**280 - 420**
W'	300 - 420	**300 - 410**
Z'	-	**-**

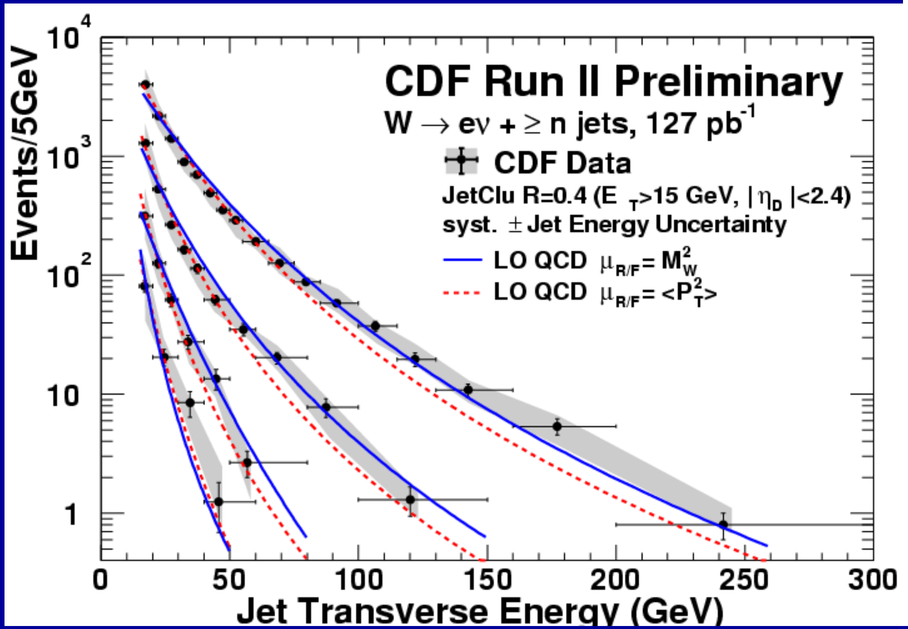
γγ production

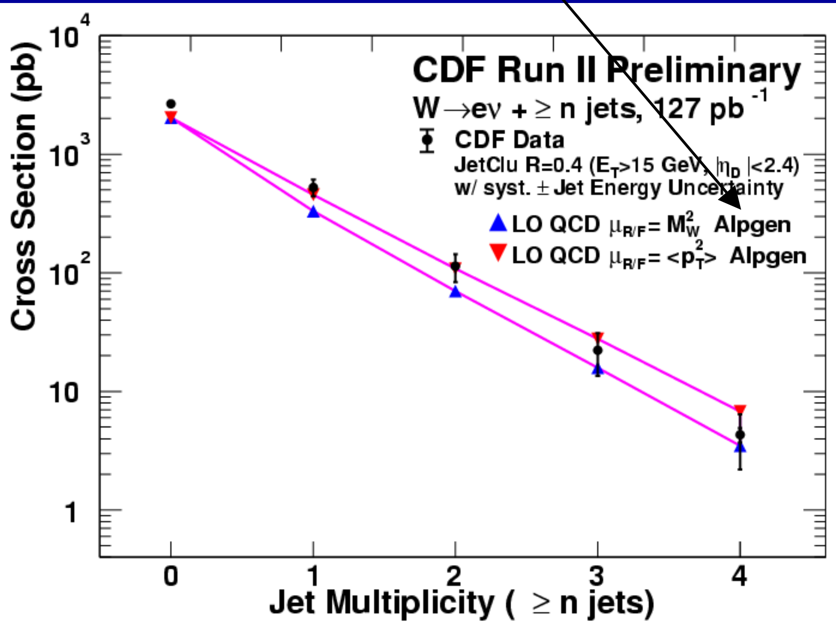


- New results (207 pb^{-1}) on γγ production
  - Data are not consistent with PYTHIA Tune A
    - Need to rescale normalization
  - Models with soft/collinear gluon resummation explain better data

W+Jets

- W + jets production is the background for many signals including top quarks and Higgs bosons
  - Significant improvement in agreement with MC



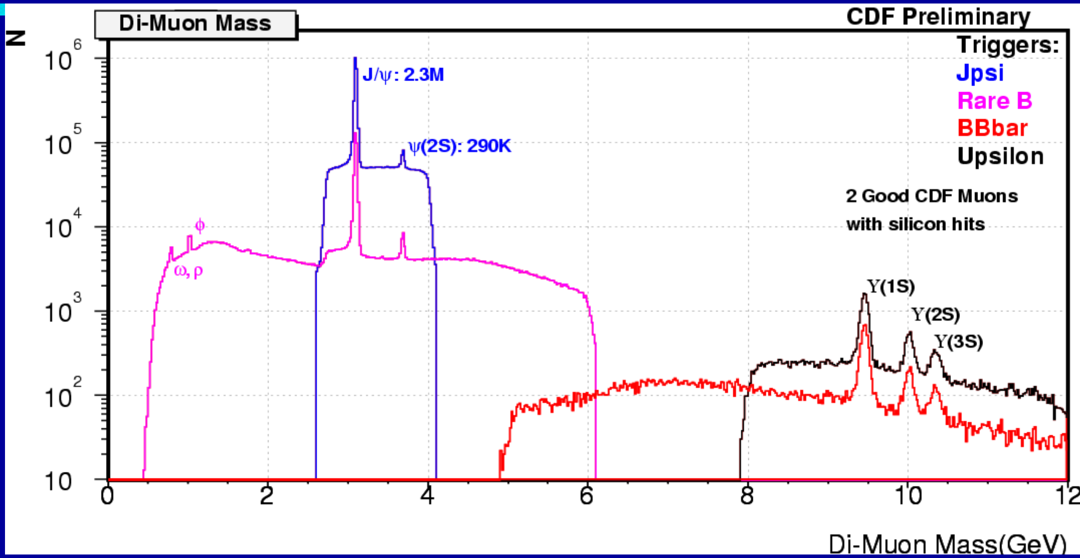


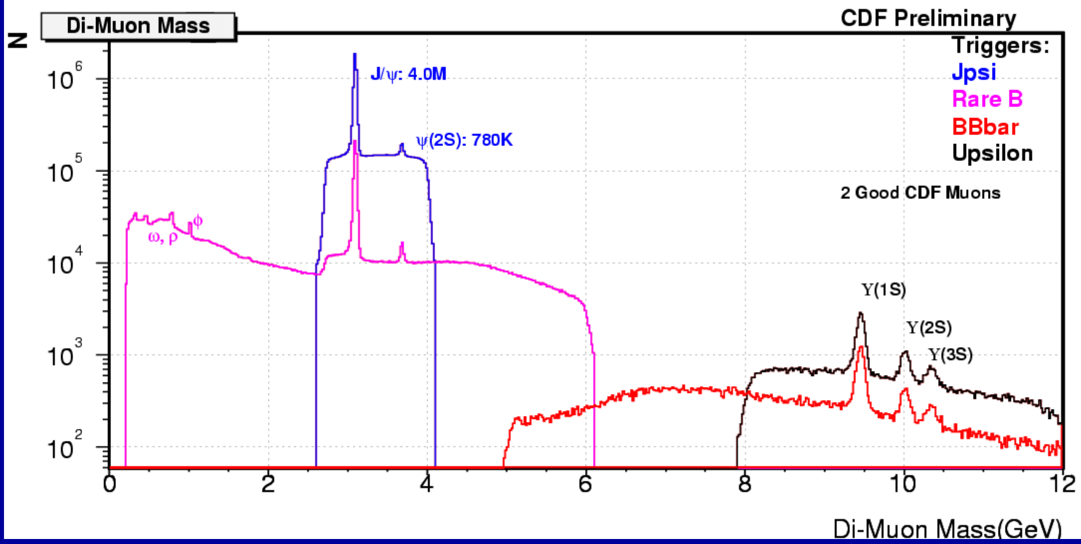
B physics

- Only selected topics:
  - Production x-section
  - Rare decays: B→μμ
  - Bs mixing (indirect/direct)
  - CP violation with 2 body B decays

Di-muons

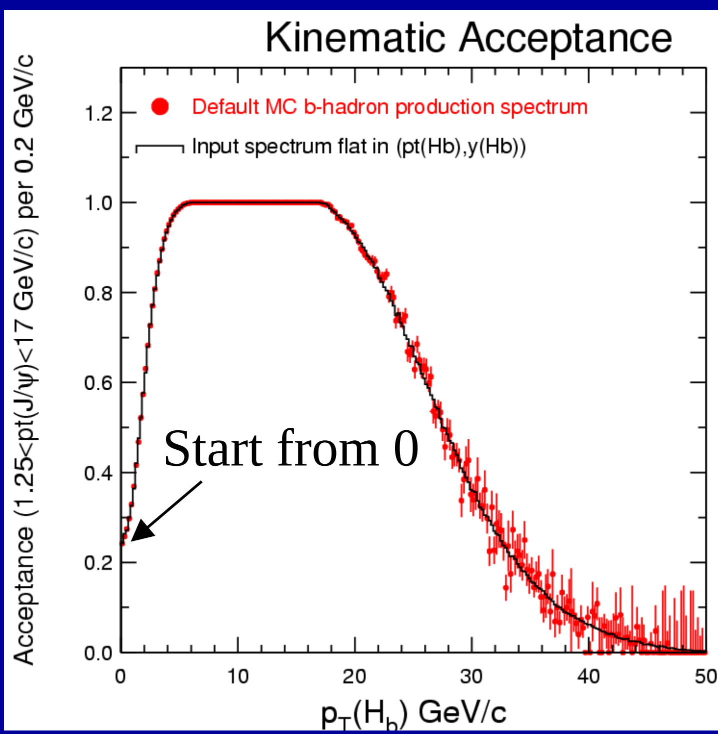
- Very efficient di-muon triggers span wide range of invariant mass
  - B physics with J/ψ
  - Rare B decays
  - Ψ, Υ are important calibration samples for momentum scale

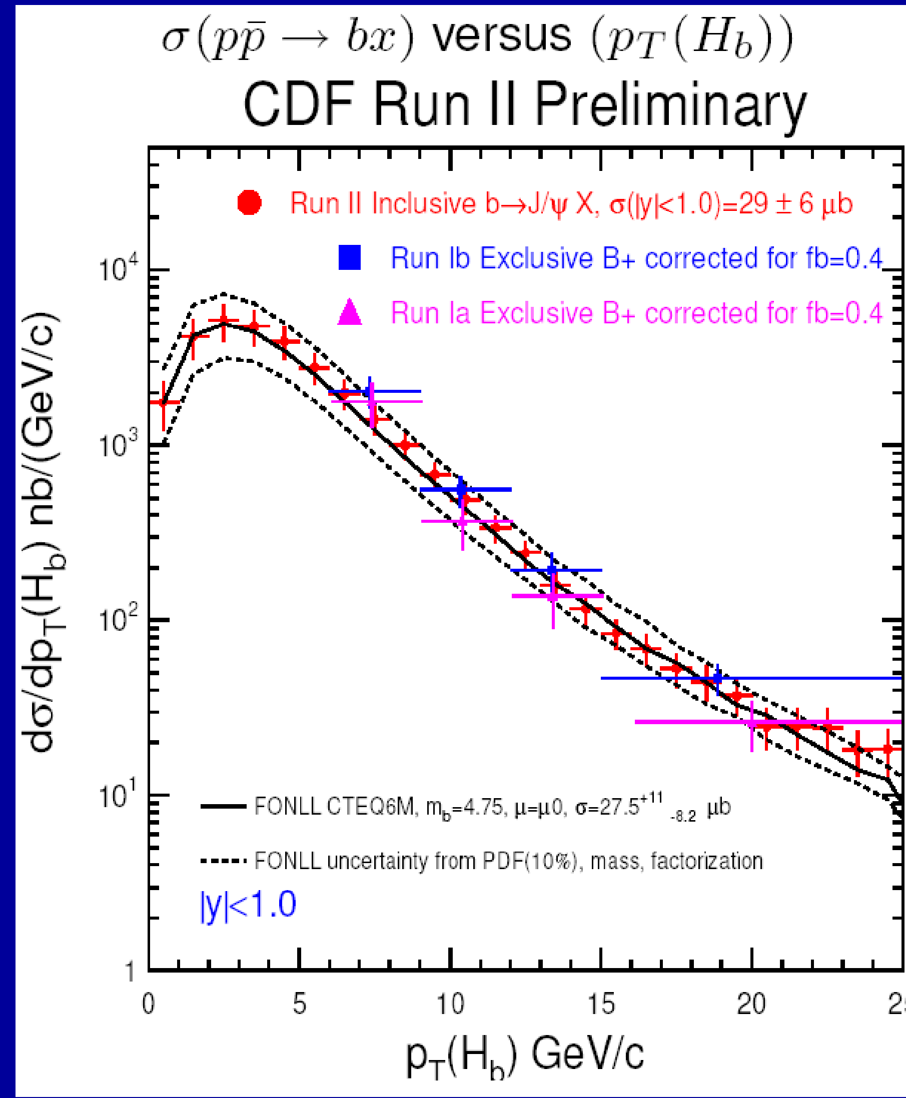




"b→J/ψ + X" x-section

- Consistent with Theory!
  - Data: σ = 29.6 μb,
  - FONLL: σ = 27.5 μb (CTEQ6M, m_b = 4:75, $\mu = \mu_0$)





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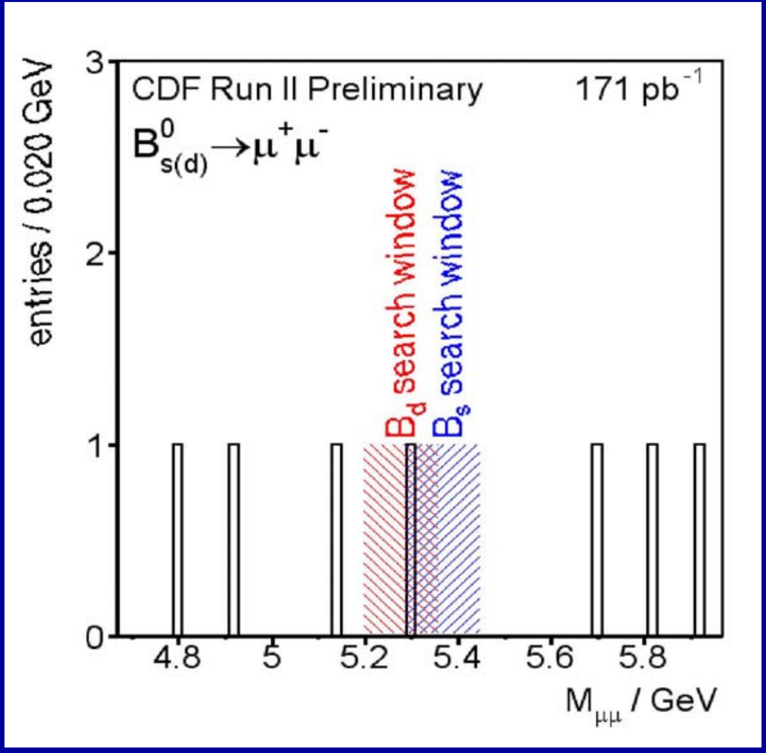
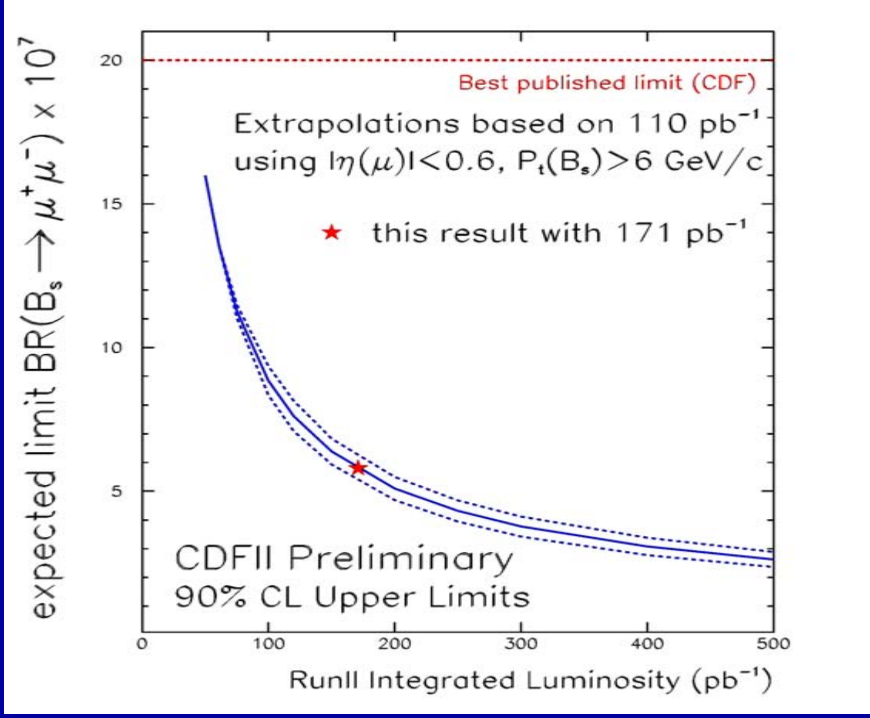
Rare decays

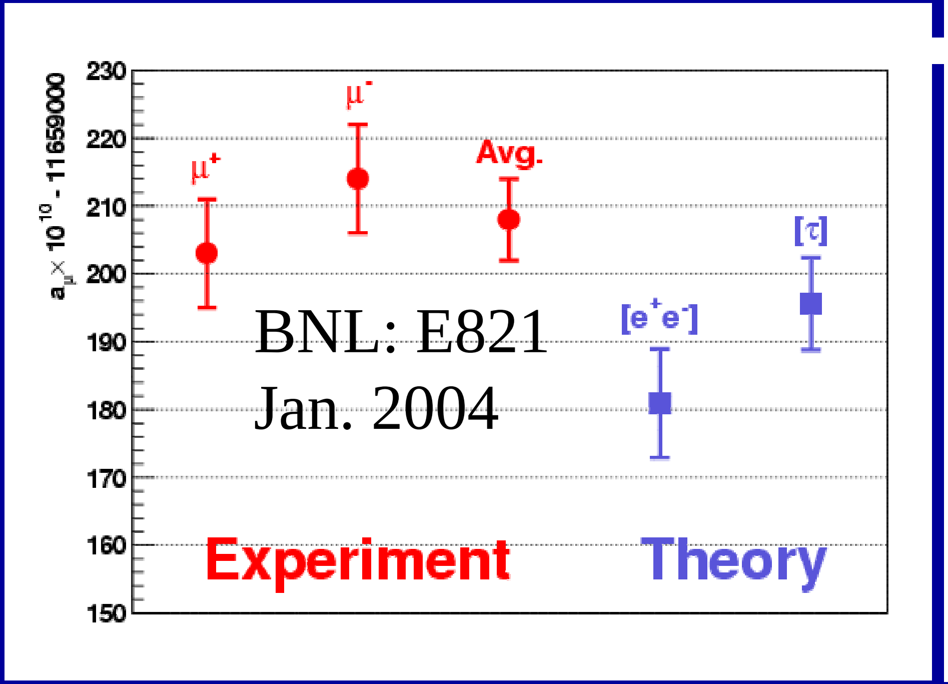
- B_s: 1 event seen/ 1. 05 ± 0.30 bck expected
  - **5.8E-7 @ 90% CL (7.5E-7 @ 95% CL) [CDF Run 1:** 2.6E-6 @ 95% CL]
- B_d: 1 event seen/ 1. 07 ± 0.31 bck expected
  - **1.5E-7 @ 90% CL (1.9E-7 @ 95% CL) [BaBar: 8.3E-8 @ 90% CL]**

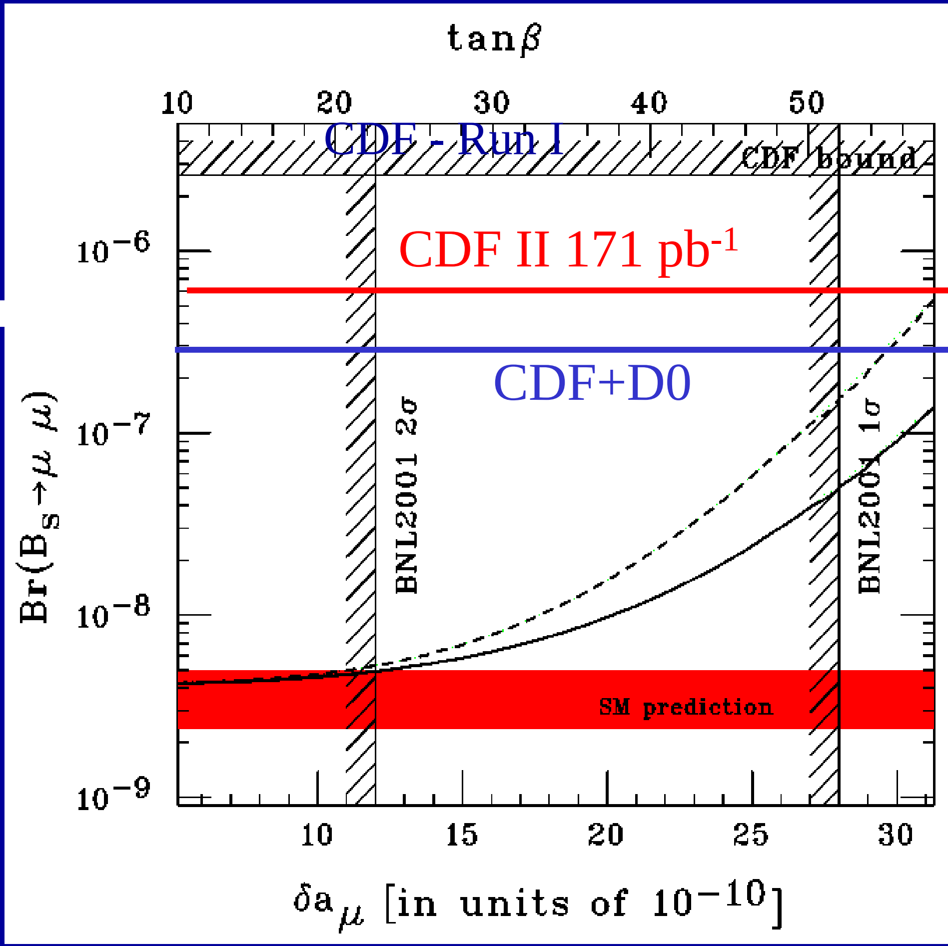




Rare Decays

- Sensitive to SUSY
  - Bs result combined with D0:
    - BR < 2.7 x 10^{-7} @ 90% CL
  - Better than 1 x 10^{-7} by 2007
    - Needs update of analysis selection



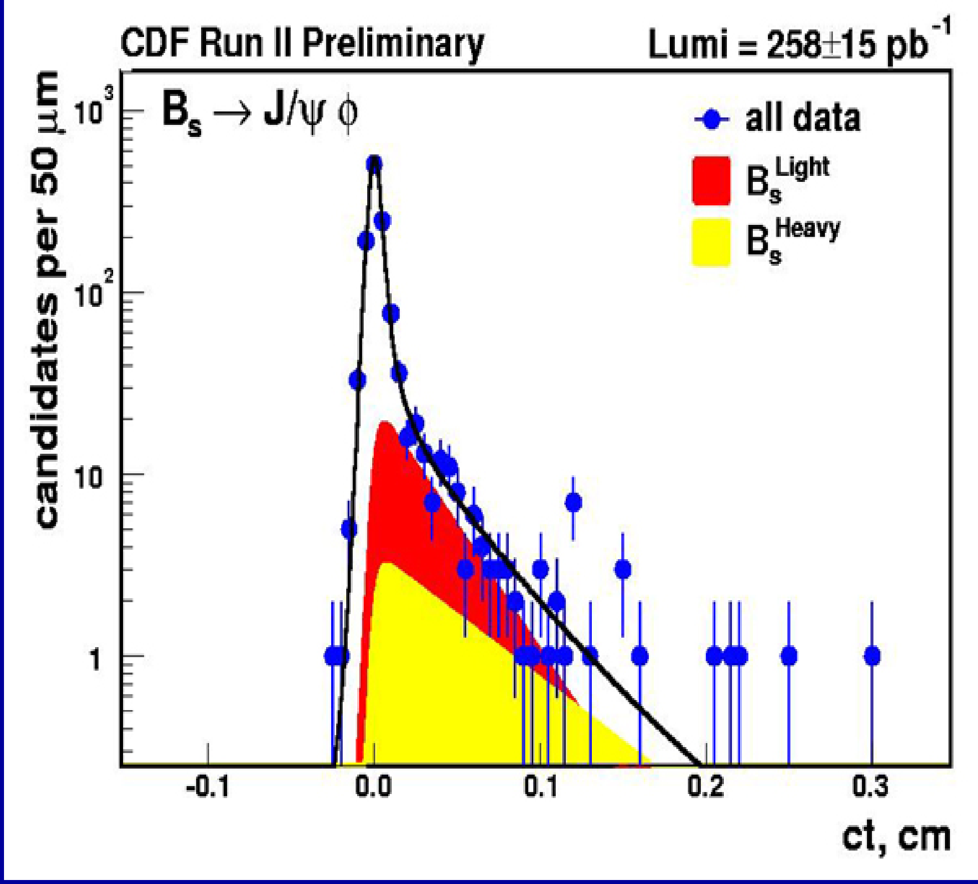


Bs Mixing

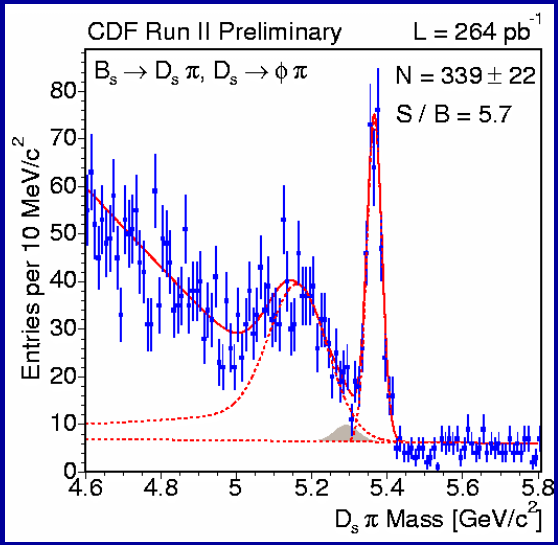
- Indirect measurement with $\Delta\Gamma/\Gamma$
  - First measurement out this summer
- Major progress this year on direct searches
  - Use more Bs final states
  - Semileptonic included
  - Opposite side taggers established
  - Finalizing same side taggers
  - 30% $c\tau$ resolution improvement
- Expect new relevant limits on Δm_s next winter
- Measurement hard but within reach by 2007 and hopefully much sooner!

Bs States: $\Delta\Gamma$ / Γ

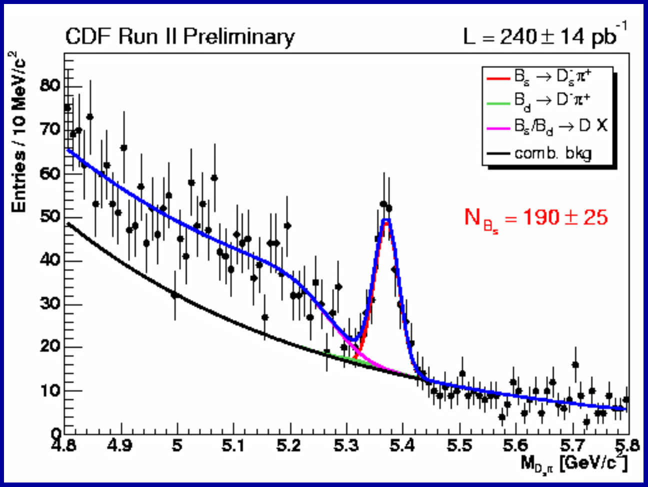
- $B_S \rightarrow J/\psi\ \phi \rightarrow \mu^+\mu^- K^+K^-$
- Heavy state and light state decay with distinct angular distributions and different lifetimes.
- Decay angular distributions
  - 1/4 heavy state
    3/4 light state
  - Lifetime - $\tau_{heavy} \sim 2 \times \tau_{light}$
  - $.\Delta\Gamma_S / \Gamma_S = 0.71\ ^{+0.24}_{-0.28} \pm 0.01$
- Lifetime difference measures "same" CKM element as Δm (oscillation frequency)
- Exciting!! Need more data
  - ~ 5 % sensitivity by 2007
  - $\Delta m_s = 10\ ps^{-1} \rightarrow \Delta\Gamma_S / \Gamma_S = 7\%$



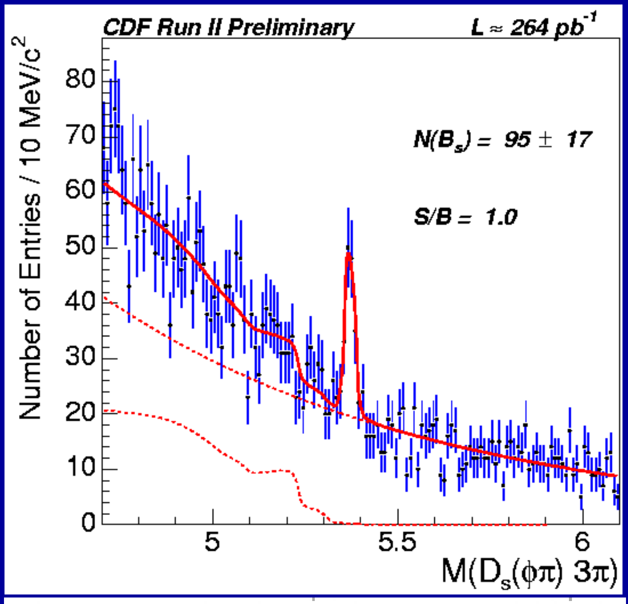
Bs hadronic signals



$B_s \to D_s\pi(D_s \to \phi\pi)$



$B_s \to D_s\pi(D_s \to K^*K)$

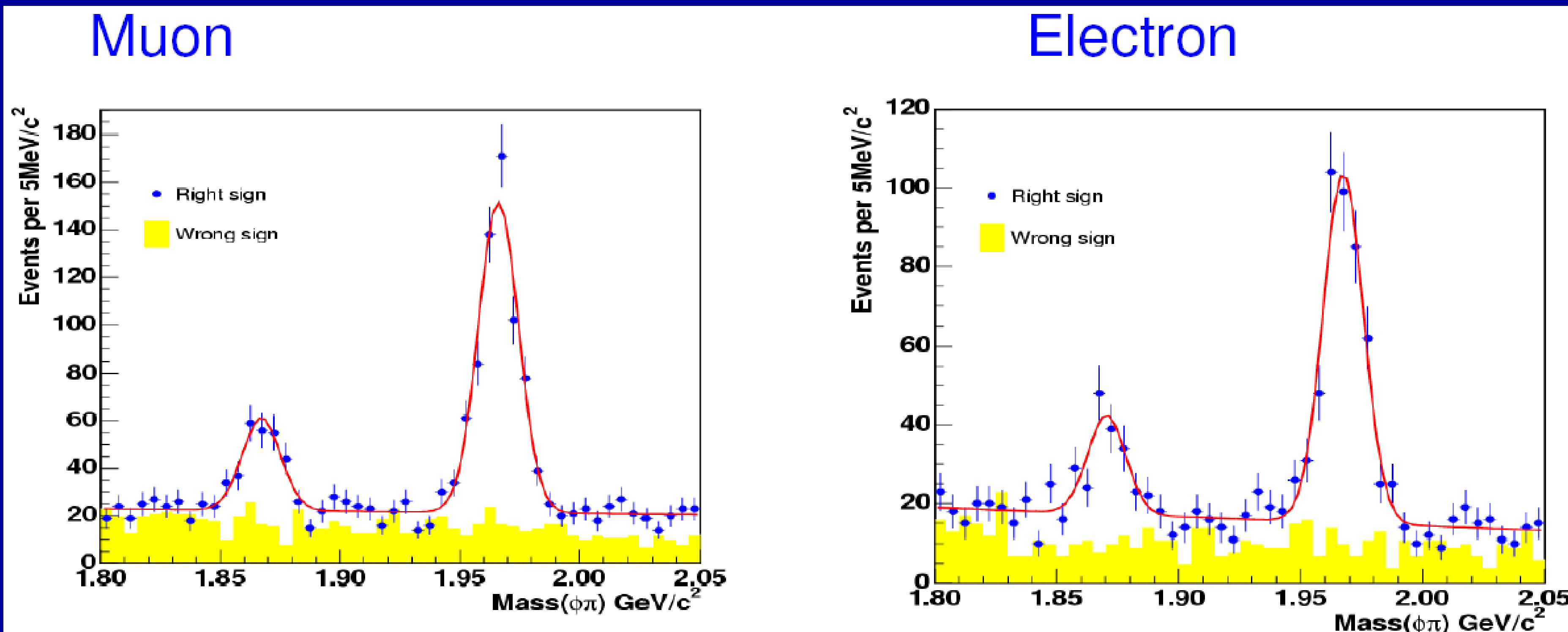


$B_s \to D_s 3\pi(D_s \to \phi\pi)$

Raw yield ~3 pb

Channel	Observed events	Luminosity (pb^{-1})	Yield per 250 pb^{-1}	S/B
$B_s \to D_s\pi(D_s \to \phi\pi)$	339 ± 22	264	320	5.7
$B_s \to D_s 3\pi(D_s \to \phi\pi)$	95 ± 17	264	90	1.0
$B_s \to D_s\pi(D_s \to K^*K)$	190 ± 25	240	200	1.3
$B_s \to D_s\pi(D_s \to 3\pi)$	57 ± 11	124	115	1.75

Bs semileptonic signals



Channel	Observed events	Luminosity (pb^{-1})	Yield per 250 pb^{-1}	S/B
$B_s \to \ell \nu D_s X (D_s \to \phi\pi)$	2342 ± 66	245	2400	3.5

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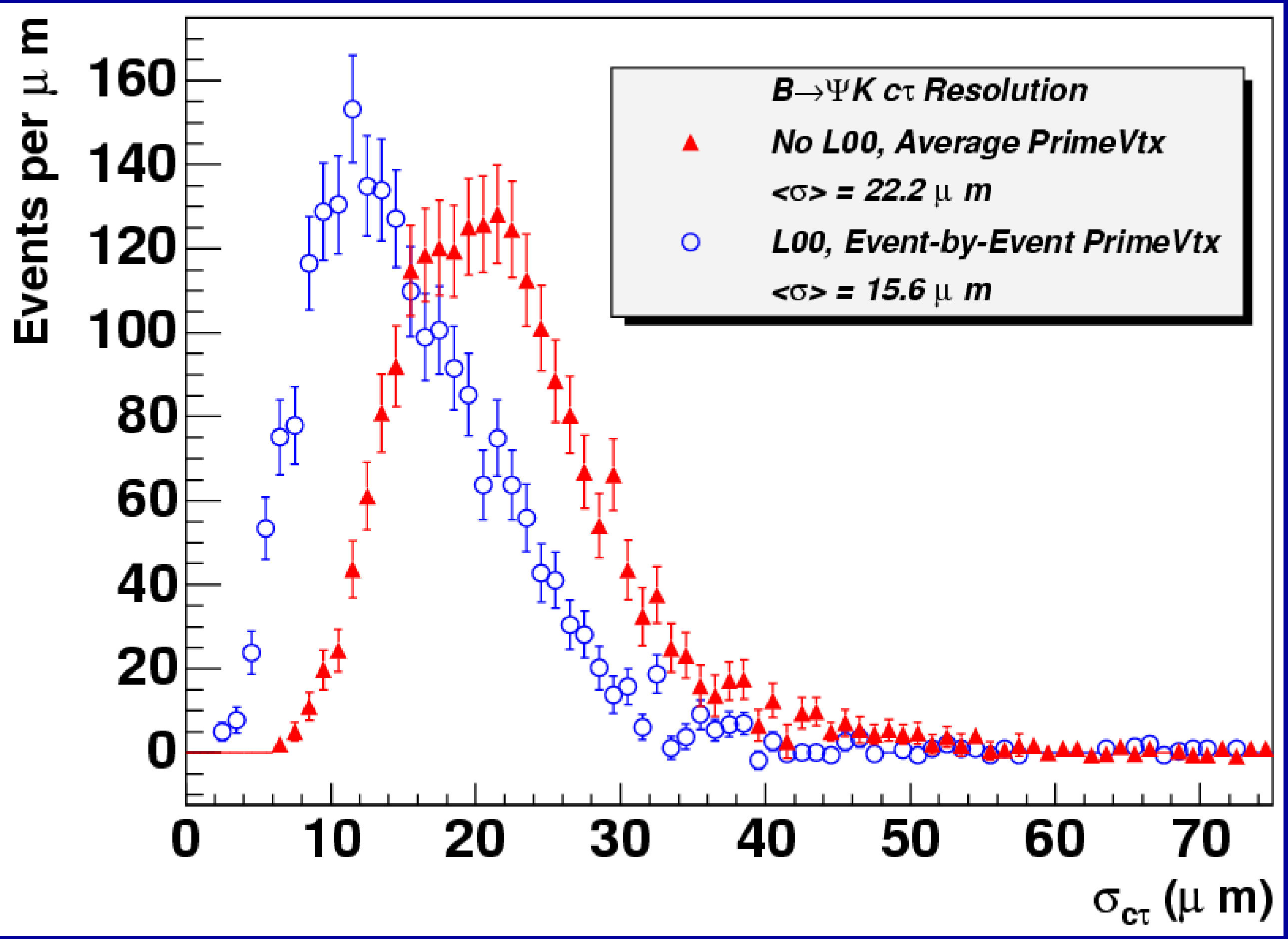
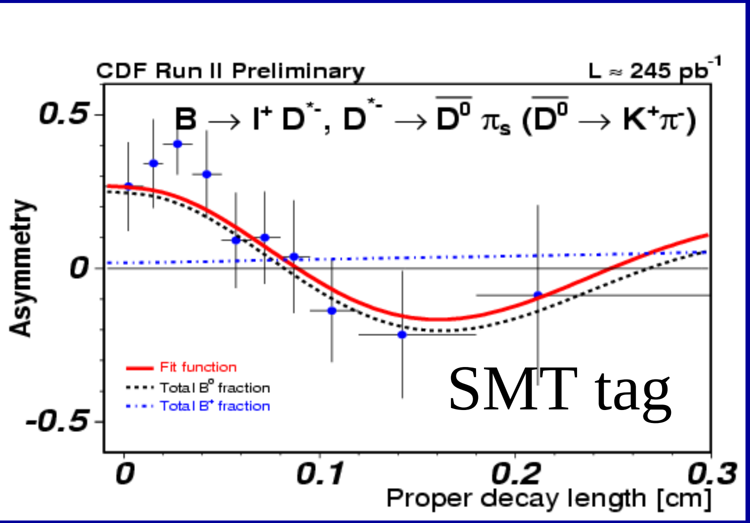
cτ resolution with L00

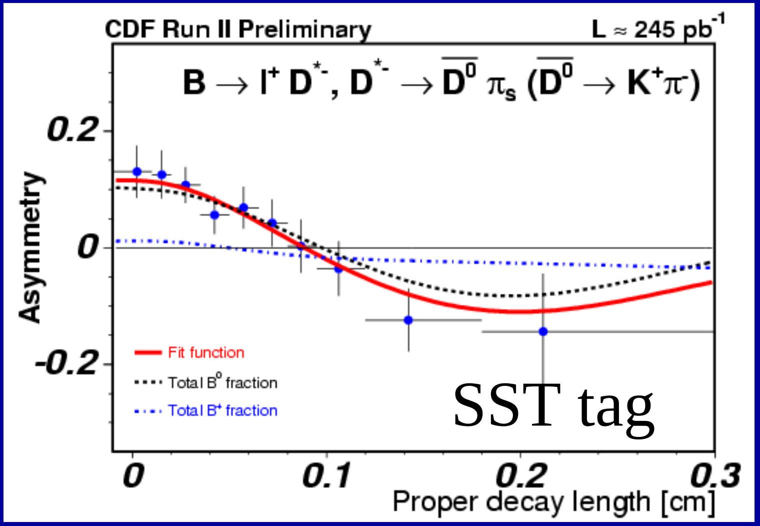
- No EbE/L00:
  - σ ~ 67 fs
- With EbE/L00:
  - σ ~ 47 fs
  - 30% improvement



Mixing and flavor tag

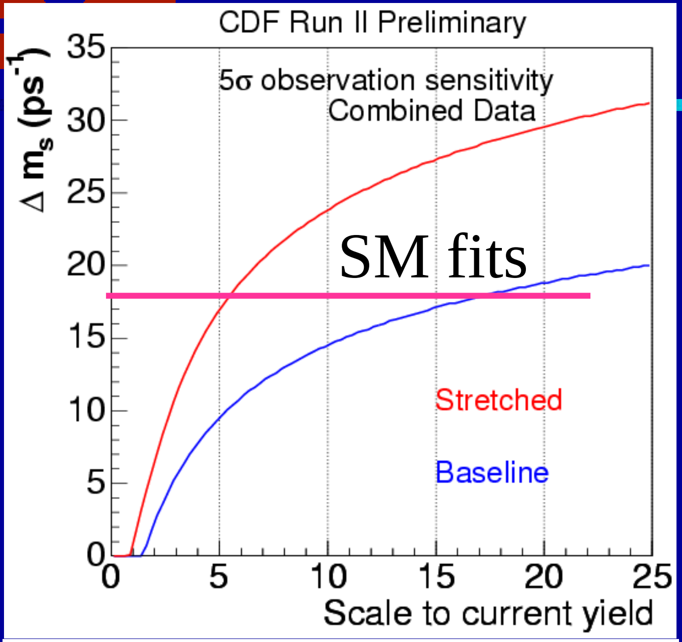
- Major progress on mixing:
  - Test whole machinery on B_d
    - Consistent Δm_d values
    - Taggers characterized
  - Combined OST $\varepsilon D^2 = 1.6\%$
    - Include correlations
  - Currently developing K tags both on same side and opposite side

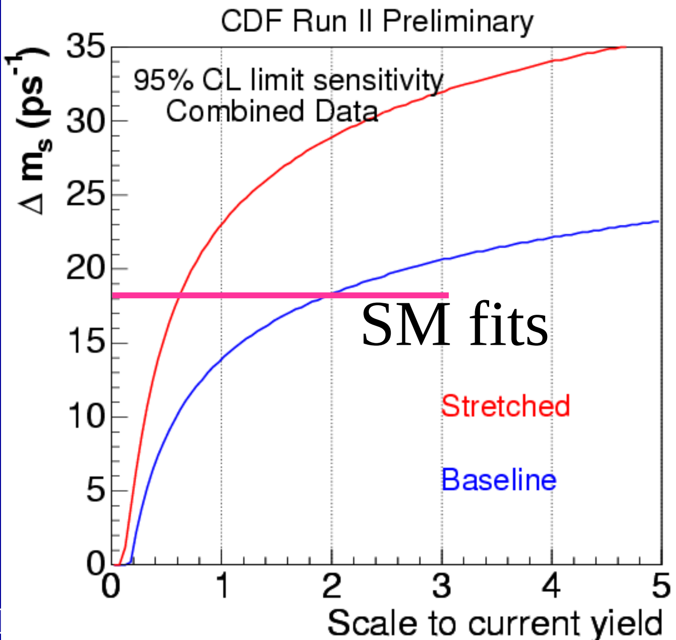


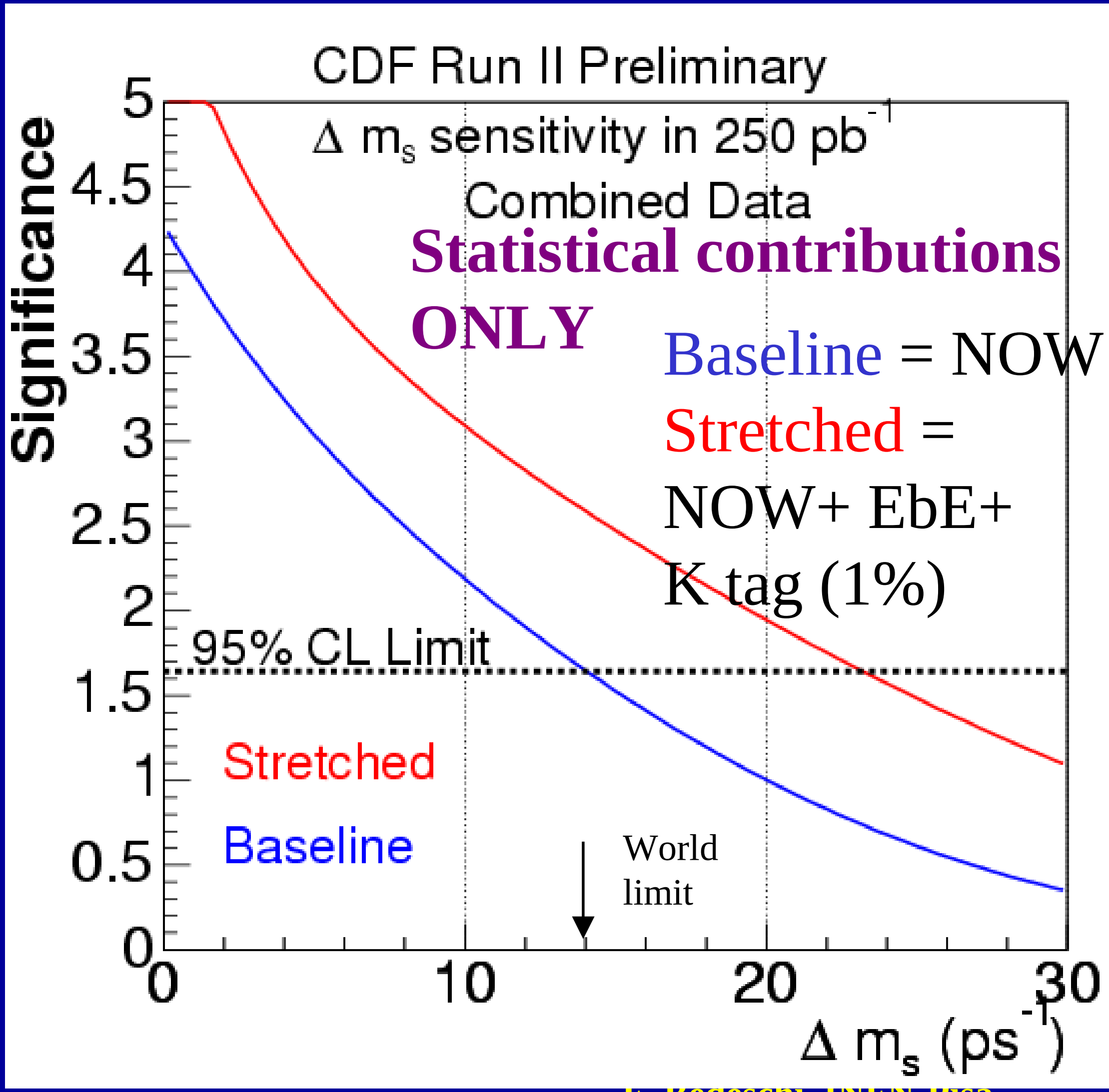


εD^2(%)	CDF	D0
SST	$1.04 \pm 0.35 \pm 0.06$	1.00 ± 0.36
Soft μ	$0.698 \pm 0.042 ^{+0.051}_{-0.027}$	1.00 ± 0.38
Soft e	0.35 ± 0.05(stat)	-
Jet-Q	0.715 ± 0.027	~1

Bs Mixing measured by 2007!

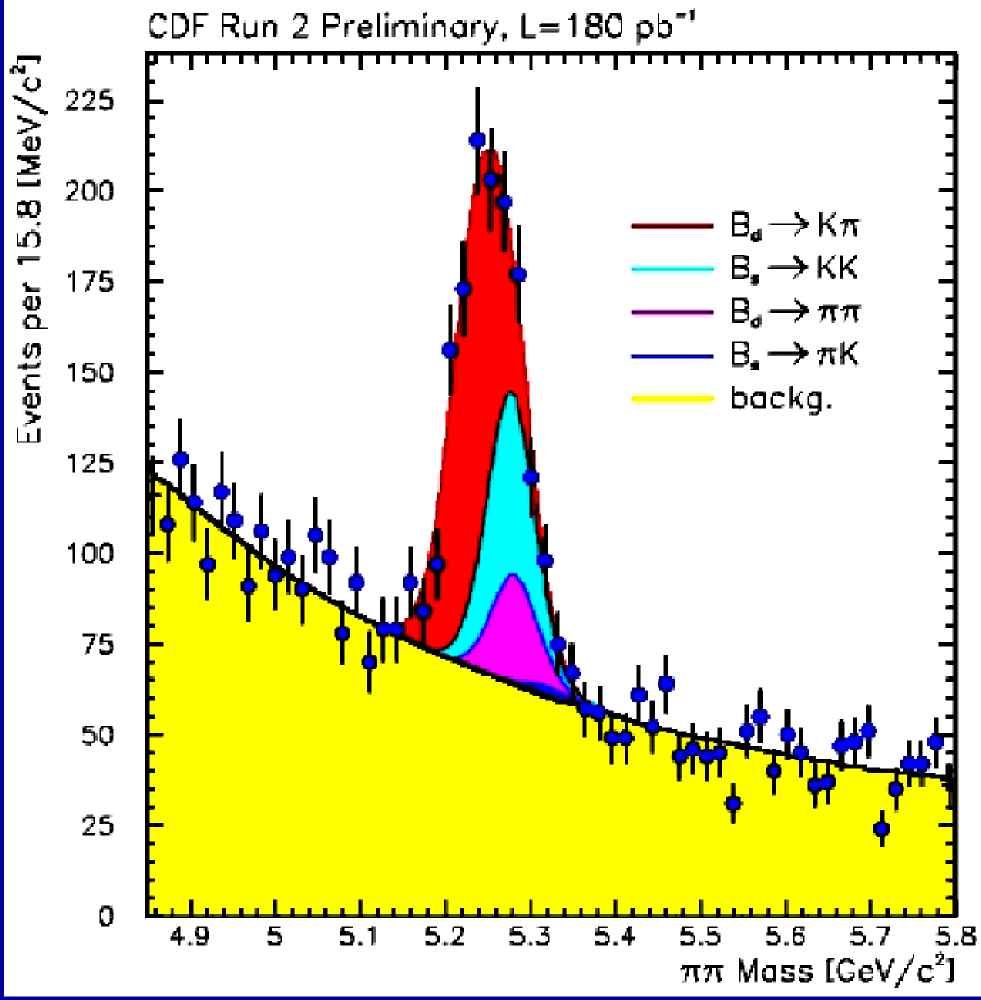






B→ hh

- Several new results based on this sample presented at ICHEP
  - Branching fractions
  - Integrated CP asymmetries
  - Time dependent CP asymmetries will be next
    - Potential to extract γ with accuracy ~ 10°
    - See next pages for expectations



$B \to hh$

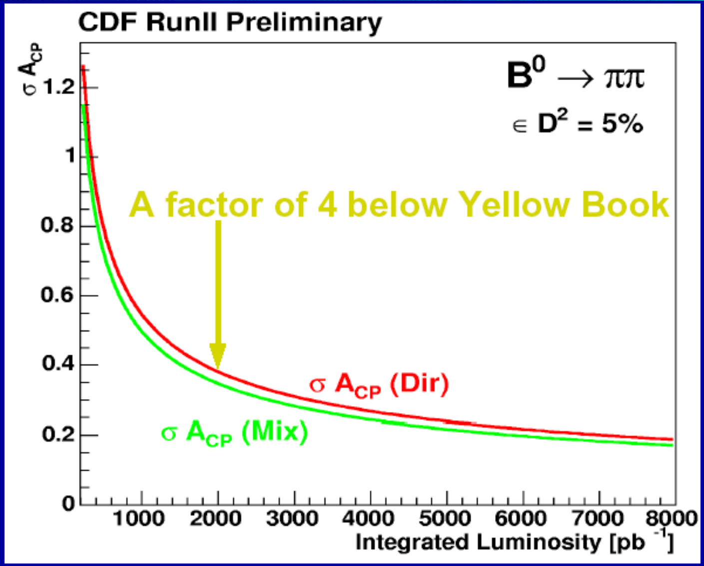
Branching ratios and CP asymmetry

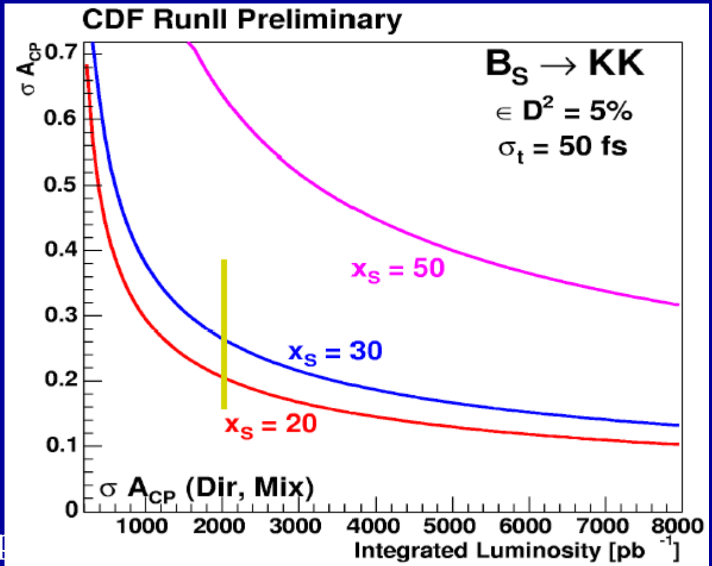
	CDF/180 pb^{-1}	Babar/200 fb^{-1}	Belle/140 fb^{-1}
$N(B_d \to K^+\pi^-)$	509	1600	1030
$\frac{BR(B_d \to \pi^+\pi^-)}{BR(B_d \to K^+\pi^-)}$	0.24±0.06±0.04	0.26±0.036±0.015*	0.24±0.035±0.018*
$A_{CP}(B_d \to K^+\pi^-)$	-0.04±0.08±0.01	-0.133±0.03±0.009	-0.088±0.03±0.013

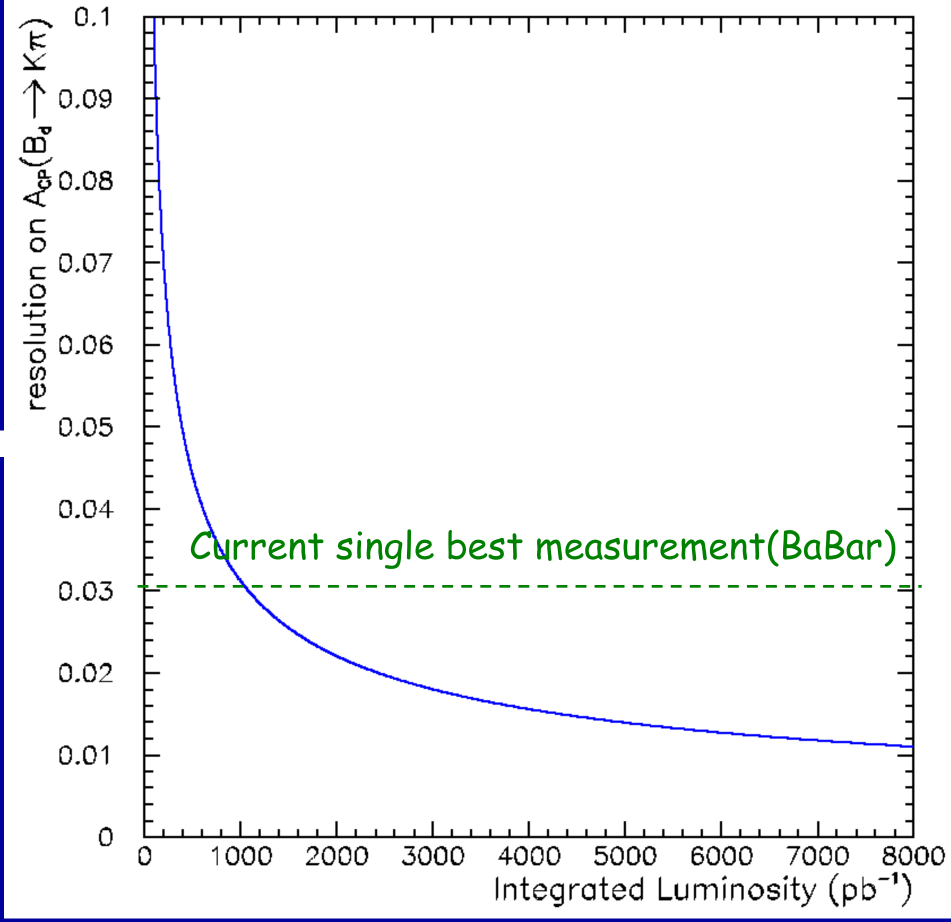
Rare two body decay modes

	CDF/180 pb^{-1}	PDG 2004	expectations
$BR(B_d \to K^+K^-)$	$< 0.17^* BR(B_d \to K^+\pi^-)$ ⇒ < 3.1*	< 0.6	[0.01 - 0.2] [Beneke&Neubert]
$BR(B_s \to \pi^+\pi^-)$	$< 0.10^* BR(B_s \to K^+K^-)^{**}$ ⇒ < 3.4*	< 1700	0.42 ± 0.06 [Li et al. hep-ph/0404028] [0.03 - 0.16] [Beneke&Neubert]

B→hh expectations







Scaling from current yields

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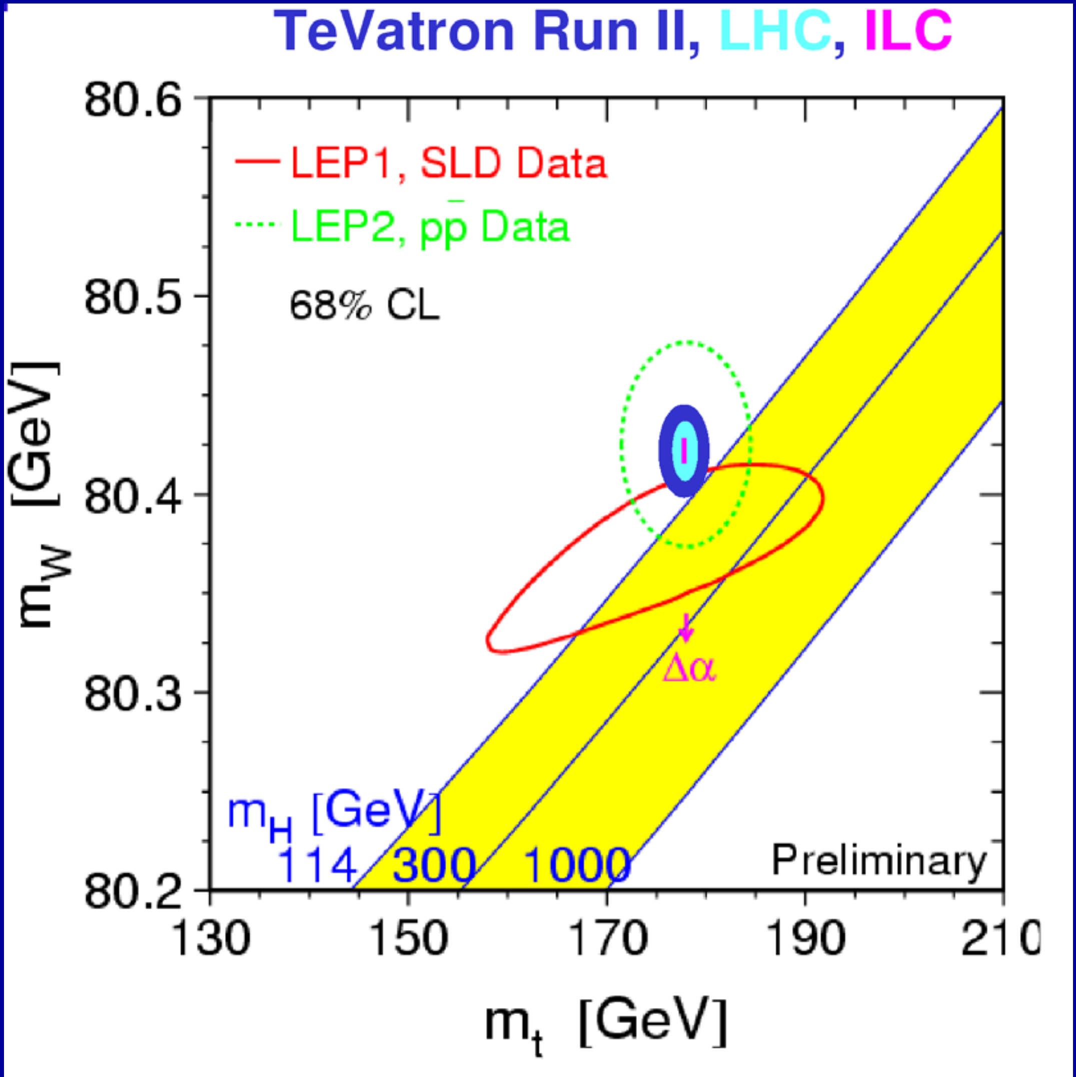
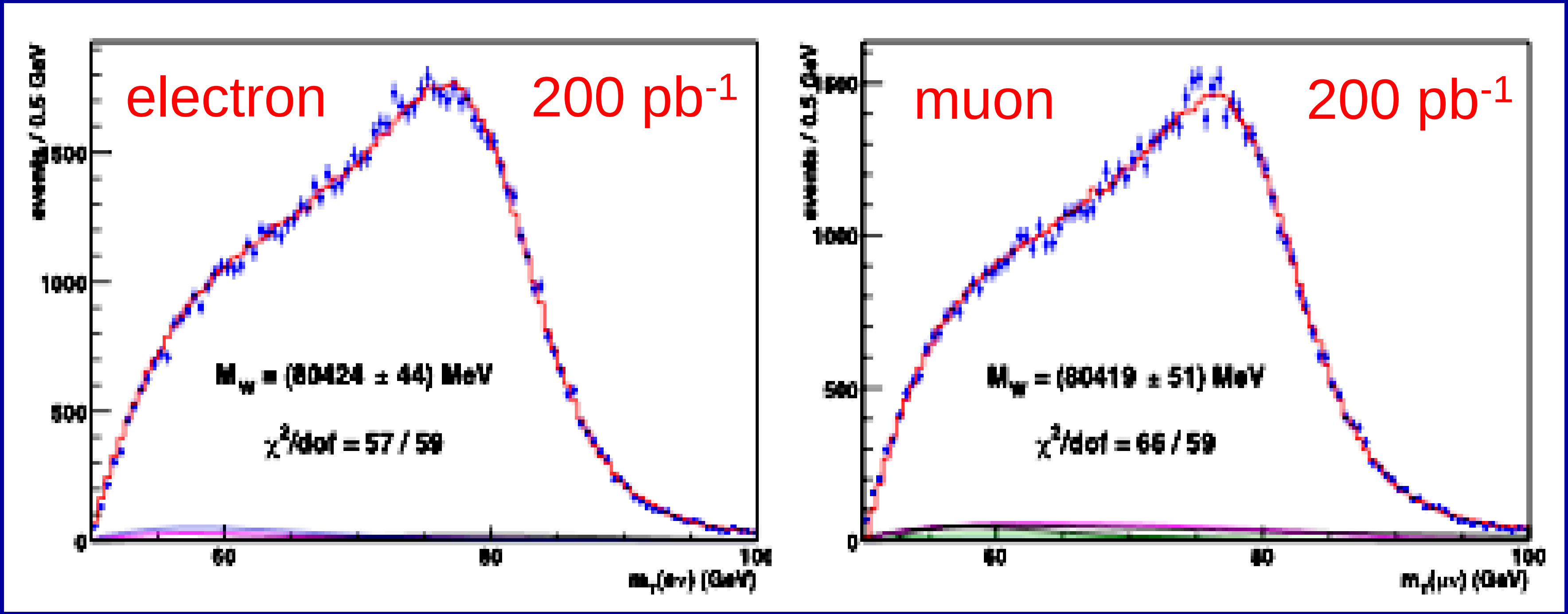
Electroweak results

- Run II:
  - Major expectations for M_{top} and M_W
  - Currently close or improving Run I results



W Mass



$M_W(e)$ = 80.424 ± 0.044 (stat.) ± 0.090 (syst.) GeV

$M_W(\mu)$ = 80.419 ± 0.051 (stat.) ± 0.069 (syst.) GeV

Run II: M_W = 80.421 ± 0.073 GeV (to be blessed)

Run I : M_W = 80.433 ± 0.079 GeV

W mass systematics

Systematic	Electrons (Run 1b)	Muons (Run 1b)
Lepton Energy Scale and Resolution	70 (80)	30 (87)
Recoil Scale and Resolution	50 (37)	50 (35)
Backgrounds	20 (5)	20 (25)
Statistics	45 (65)	50 (100)
Production and Decay Model	30 (30)	30 (30)
Total	105 (110)	85 (140)

CDF RUN II PRELIMINARY

- ✓Work in progress on recoil model
- ✓Work in progress on e-energy scale (passive material)
- ✓Now combined error is 76 MeV (stat+syst)
  - Expect 50 MeV combined (CDF only) by next year
- ❖Goal is ~ 20 - 30 MeV/experiment by end of run II

W mass

W mass

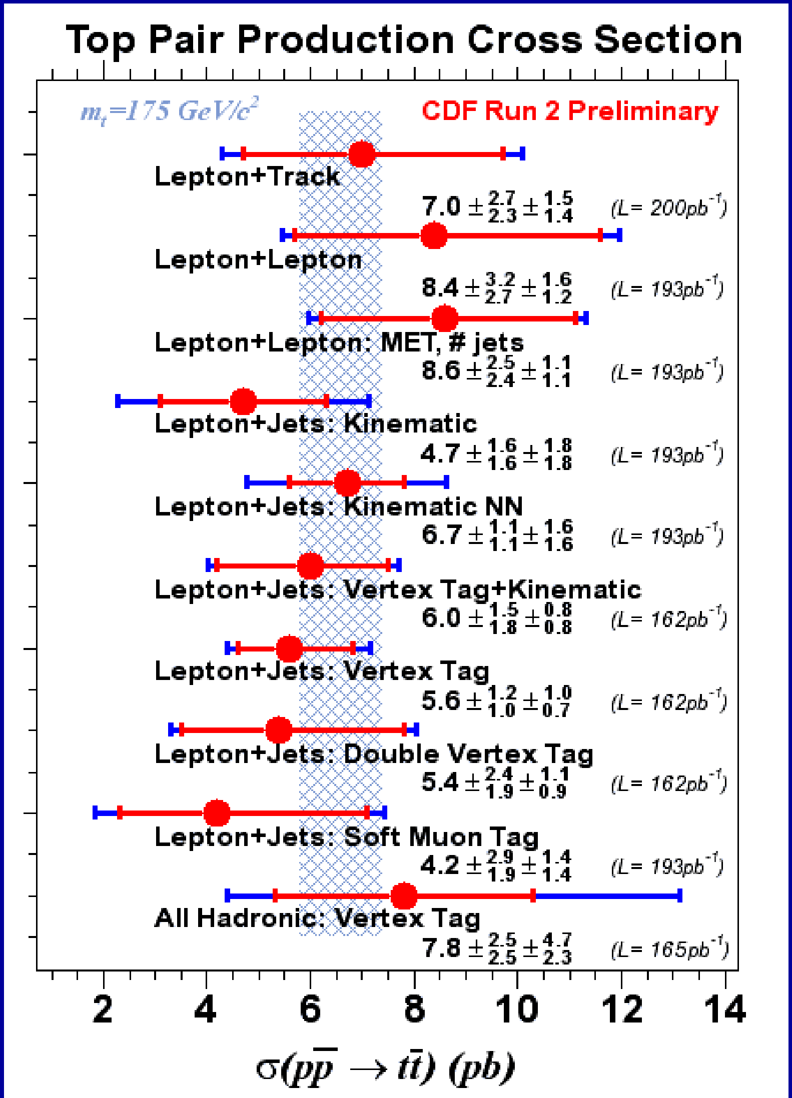
- Most systematics scale with luminosity
  - E.g. size of Z control sample
- $\sigma(M_W)$ ~20-30 MeV/c^2/experiment expected using all channels

Run II W mass expectations for the W →e ν channel

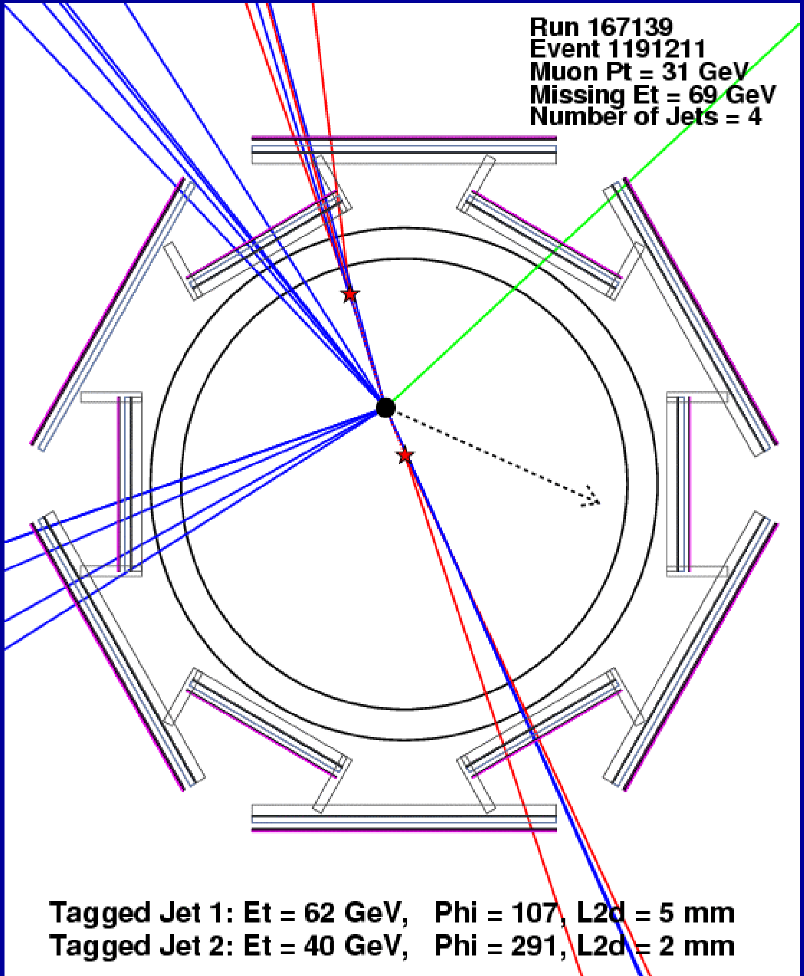
Integral Luminosity (fb^{-1})	Run I (0.1)	2	15
Number of W-> eν	50K	1M	8M
Statistical uncertainty	65	14	5
Systematic uncertainty	92	39	17
productio/decay model	47	32	13
backgrounds	5	5	5
Lepton resolution	25	8	4
Energy scale	75	20	10
Total uncertainty	113	41	17

$$dm_H/dm_W \sim 50\ GeV/25\ MeV$$

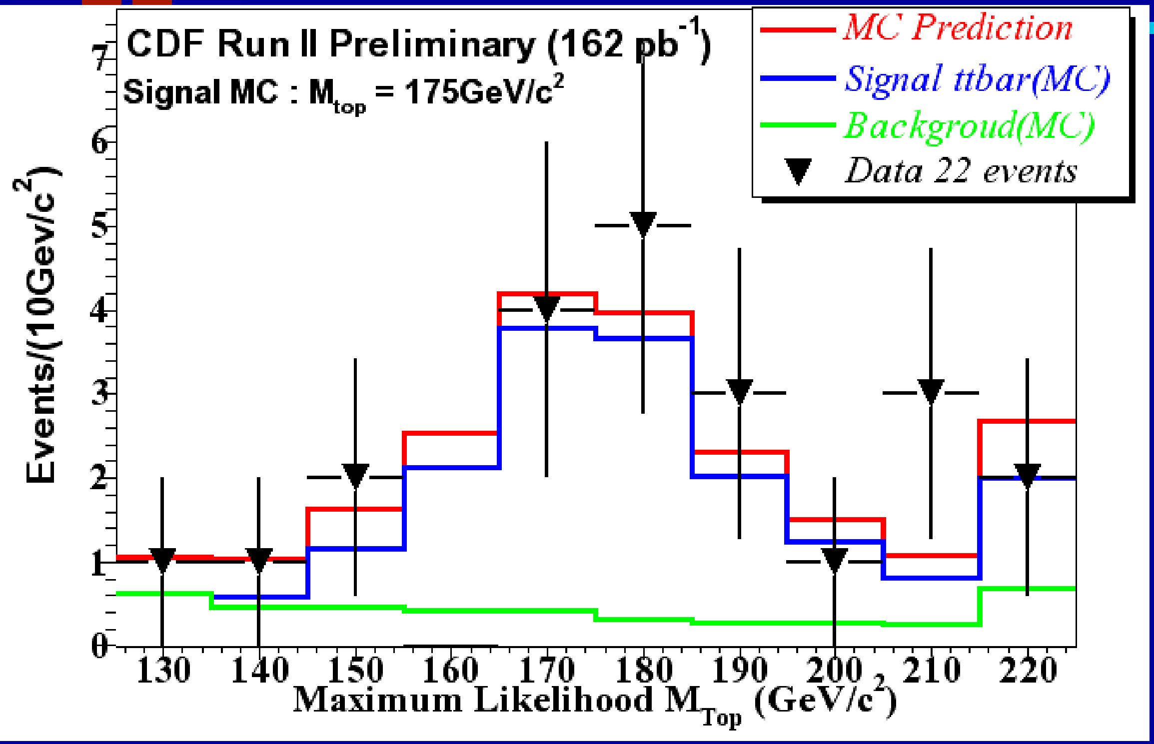
Top pair Cross sections



- Most x-sections updated with ~200 pb^{-1} in many different channels



Top Mass (l+jets)



Most likely top quark masses determined in each event by Dynamical Likelihood Method. (Same as D0 best run 1 result).

- Energy scale systematics is still the dominant issue

$M_{top}^{run\ II} = 177.8^{+4.5}_{-5.0}$(stat.)±6.2(syst.) = $177.8^{+7.7}_{-8.0}$GeV (DLM)

$M_{top}^{run\ I}$ = 176.1 ± 7.3 GeV/c^2 (template)

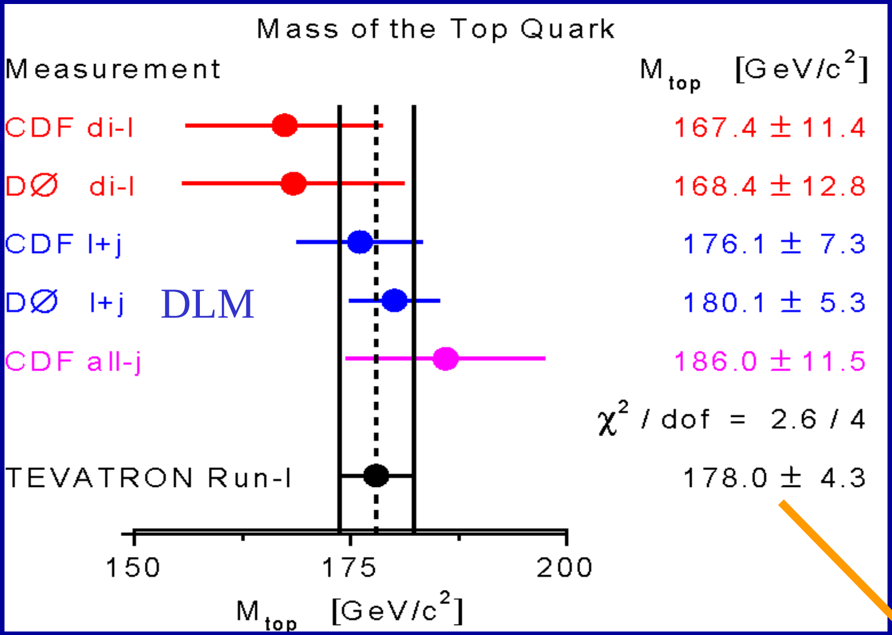
Run II checks:

M_{top} = 179.6 $^{+6.4}_{-6.3}$ (stat.) ± 6.8 (syst.) GeV/c^2 (multivariate template)

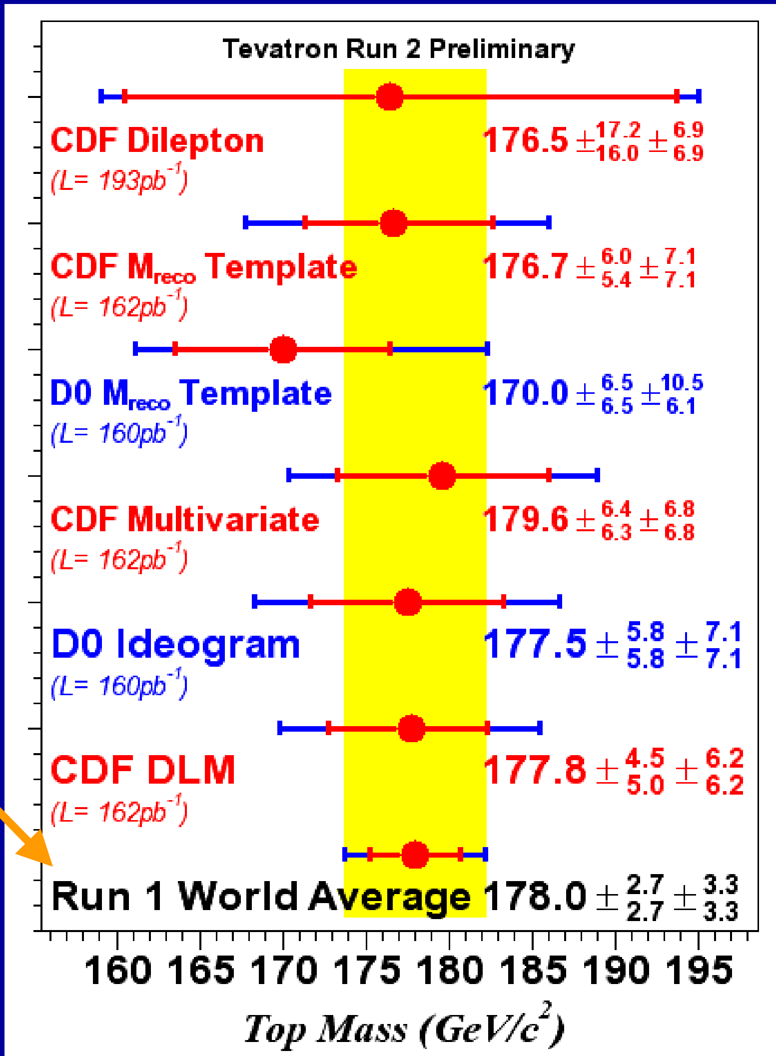
M_{top} = 174.9 $^{+7.1}_{-7.7}$ (stat.) ± 6.5 (syst.) GeV/c^2 (template)

Top mass and reach

Run 1



Run 2

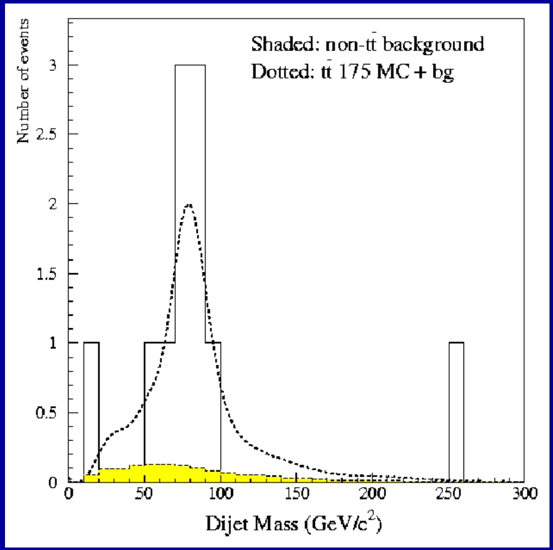


- Systematics still dominated by jet energy scale uncertainty
- Expect major reduction by next round of conferences
- Goal is 2 – 3 GeV/exp. by end of Run II

Top quark

- How much better can we do in Run II?

Invariant mass from untagged quarks calibrates light q energy scale and gluon radiation (FS)

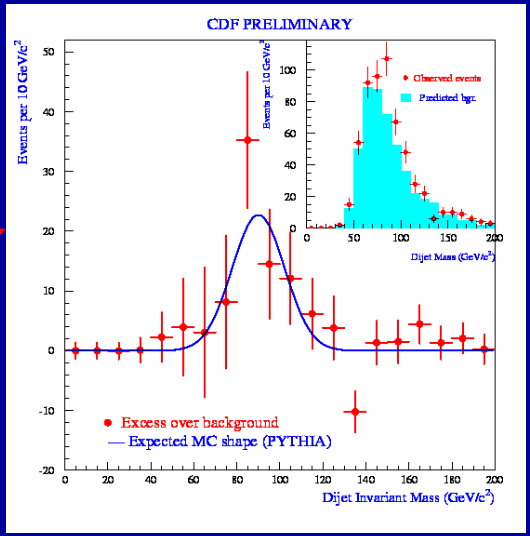


Integral Luminosity (fb^{-1})	Run I (0.1)	2	15
Double b-tag W + jet	5	240	1,800
Statistical uncertainty	4.8	1.7	0.63
Systematic uncertainty	5.3	2.1	1.2
jet scale (light quarks)	4.4	1.8	0.64
jet scale (beauty quarks)	-	0.5	0.19
background	1.3	-	-
gluon radiation	2.6	1.1	0.97
Total uncertainty	7.2	2.7	1.1

Per experiment

Similar for di-leptons

Use Z→bb to calibrate b-jet energy scale

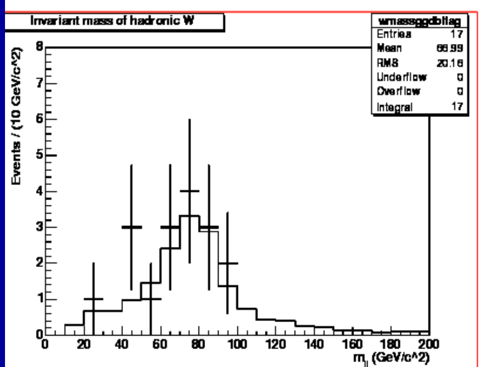


$dm_H/dm_t \sim 50$ GeV/4 GeV

Top mass (progress)

- Progress using double tags as in TDR

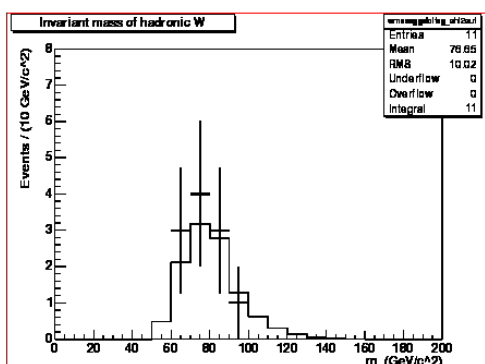
all 17 double tagged events



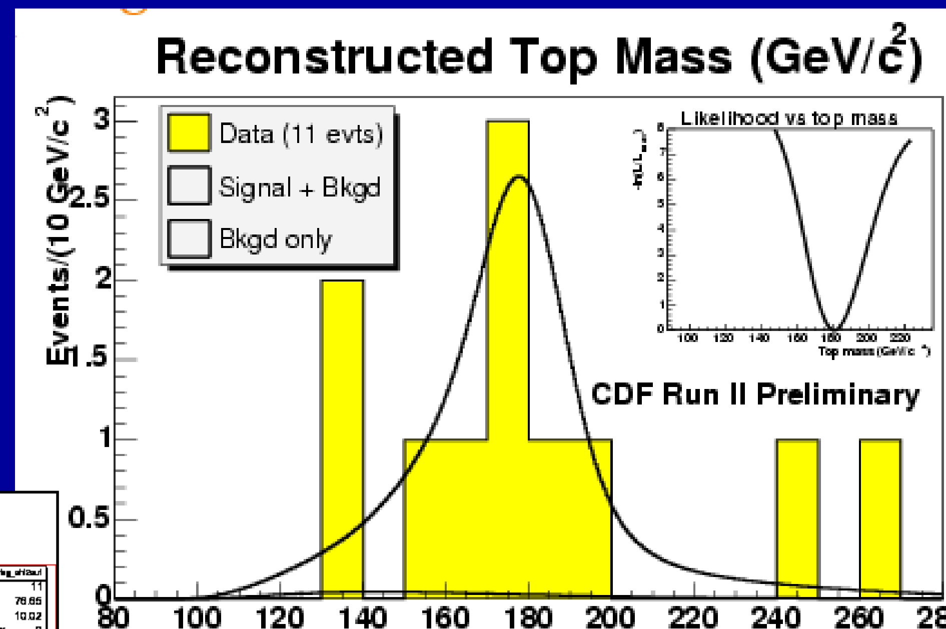
mean	67.0 GeV/c^2
rms	20.2 GeV/c^2
Nevt	17

Untagged di-jet mass (W)

11 events after χ^2 cut



mean	76.7 GeV/c^2
rms	10.0 GeV/c^2
Nevt	11



$M_{top} = 180.9^{+6.1}_{-5.8}$ (stat.) GeV/c^2

162 pb^{-1}

New Physics Searches

- Searches for new physics
  - Infinite spectrum of possibilities!
  - Example1: Squarks & gluinos
  - Example2: Chargino-neutralino searches
  - Example3: SM and BSM Higgs searches

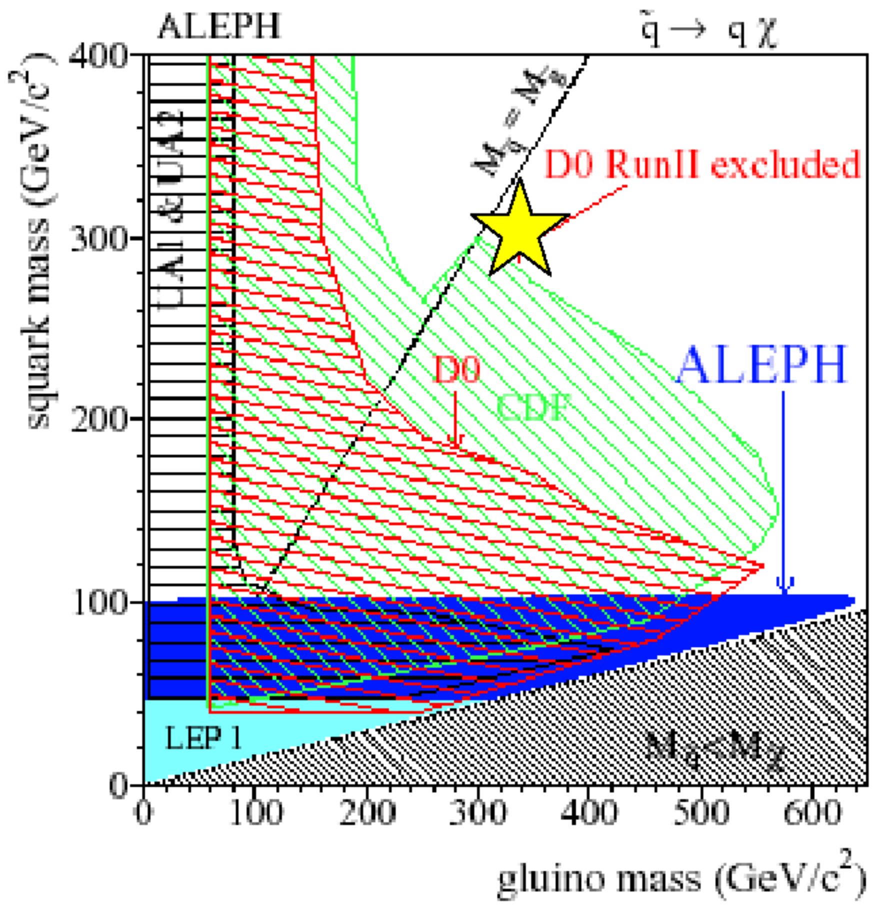
SUSY

❖ Squark & gluino searches

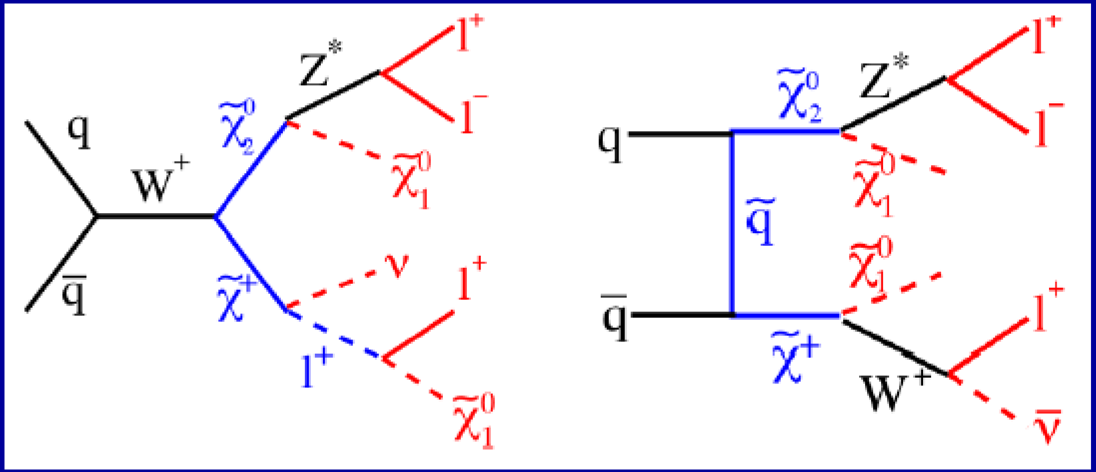
$$p\bar{p} \to \tilde{g}\tilde{g} \to (\bar{q}\tilde{q})(\bar{q}''\tilde{q}'') \to \bar{q}(q'\tilde{\chi}_1^{\pm})\bar{q}''(q'''\tilde{\chi}_1^{\pm})$$

χ_i^0 χ_i^0

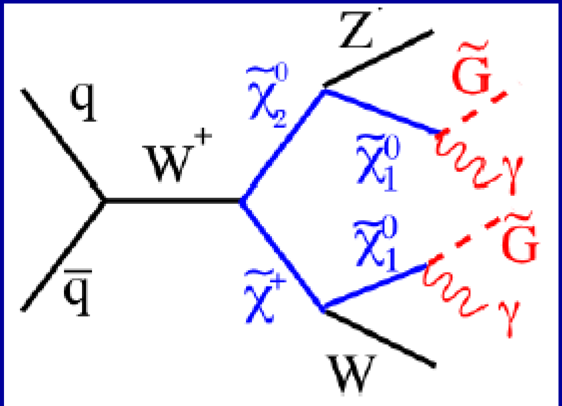
- Look for hadronic decays:
  - Charginos & heavier neutralinos eventually decay to quarks and neutral LPS
- Signature is jets +MET
- Requires accurate study of SM backgrounds
- Run 1 results
- Preliminary run II result from D0



Charginos & Neutralinos



- mSUGRA
  - Neutralino is LSP
- GMSB
  - Gravitino is LSP
  - Neutralino (NLSP) → gravitino γ
    - Look for γγ + MET + X



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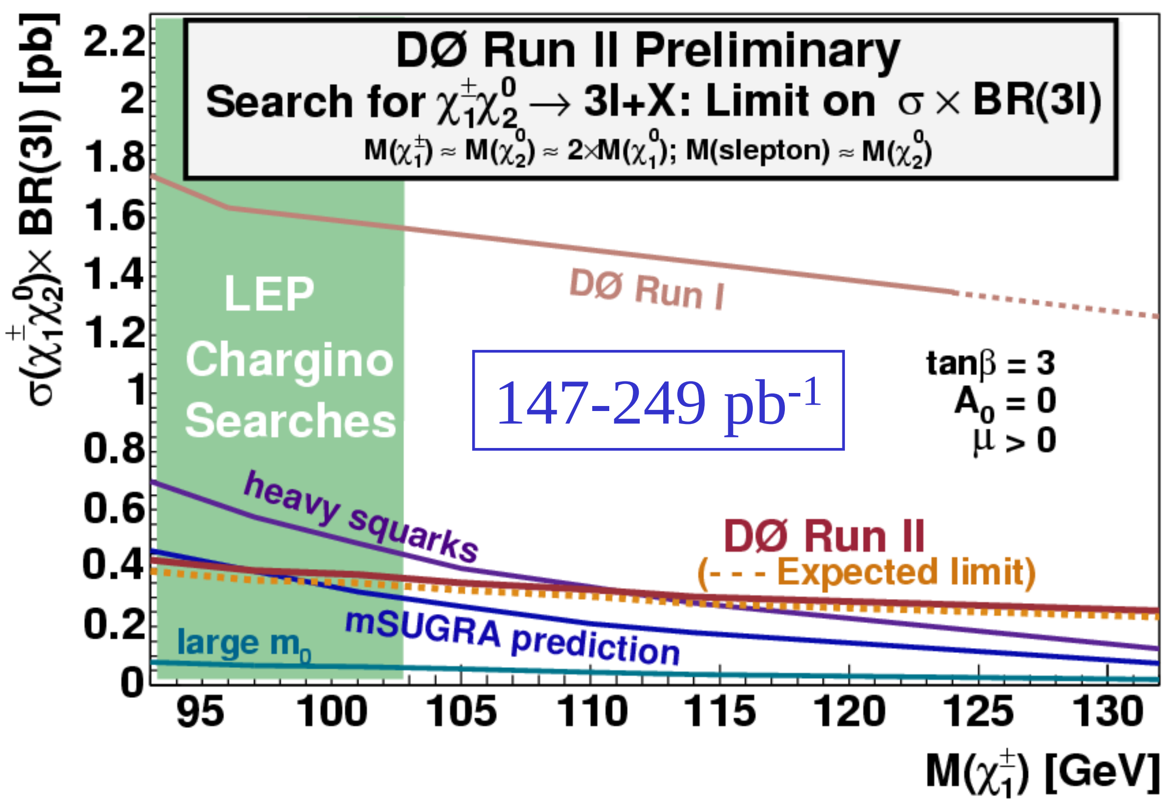
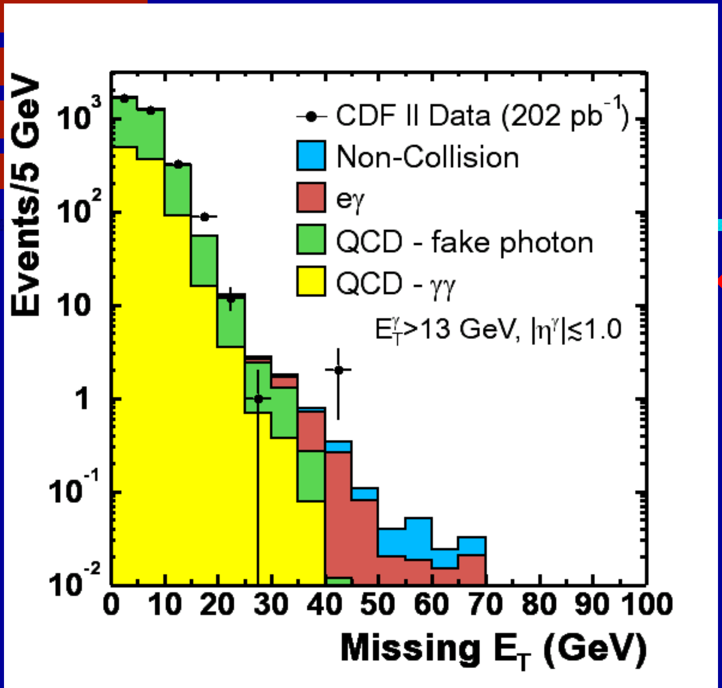
Tri-lepton search

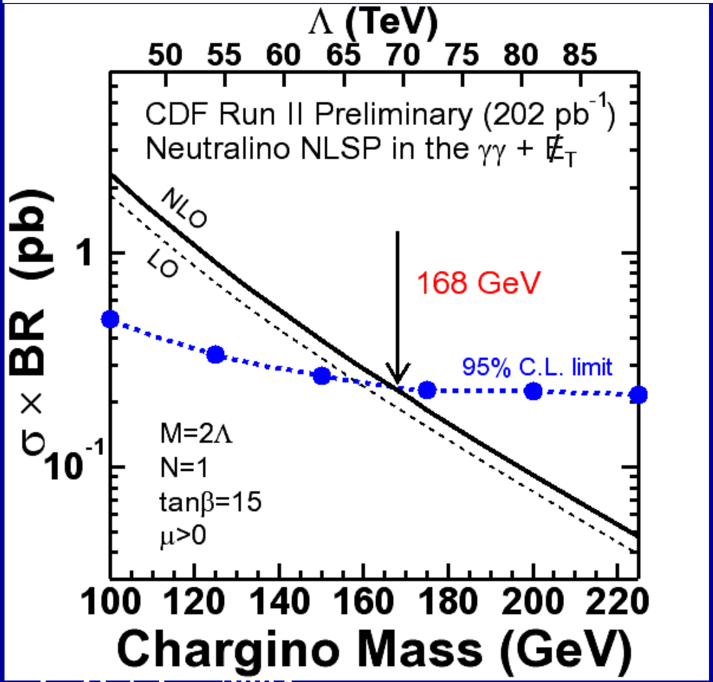
- D0 limit @95% CL:
  - $\chi^{\pm} < 97$ GeV
- CDF (run II) limit close to being complete
- Expect updates for 2005 to improve LEP result
- No competition before LHC results

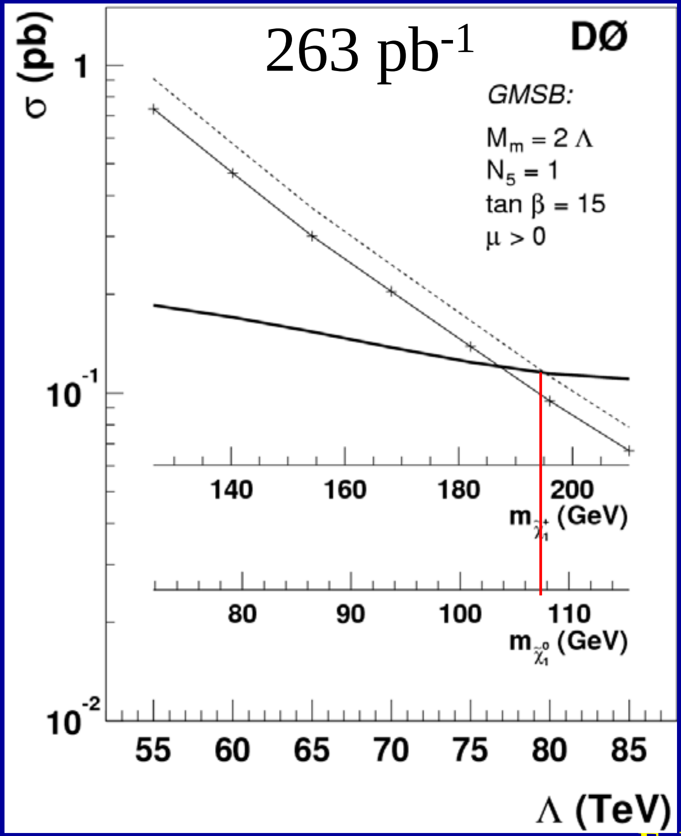


γγ + MET searches

- Sensitive to $\tilde{\chi}^0_1 \rightarrow \tilde{G}\gamma$
  - CDF limit: $\tilde{\chi}^\pm_1 > 168$ GeV@ 95% CL
  - D0 limit: 195





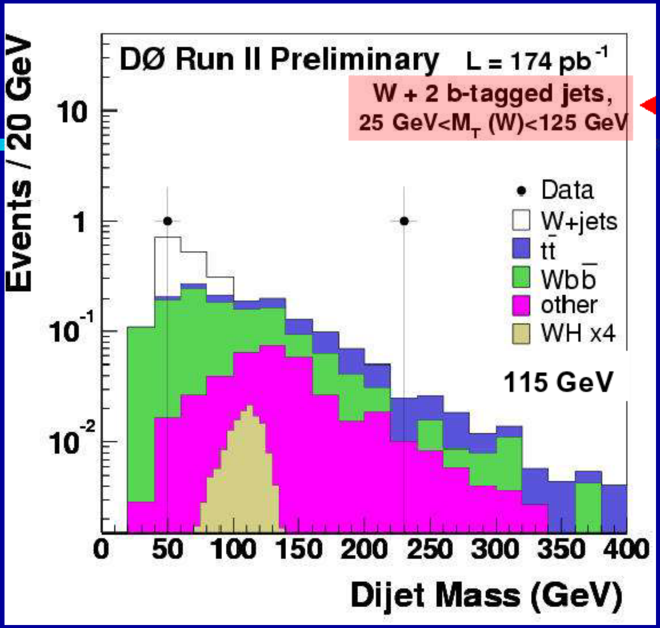


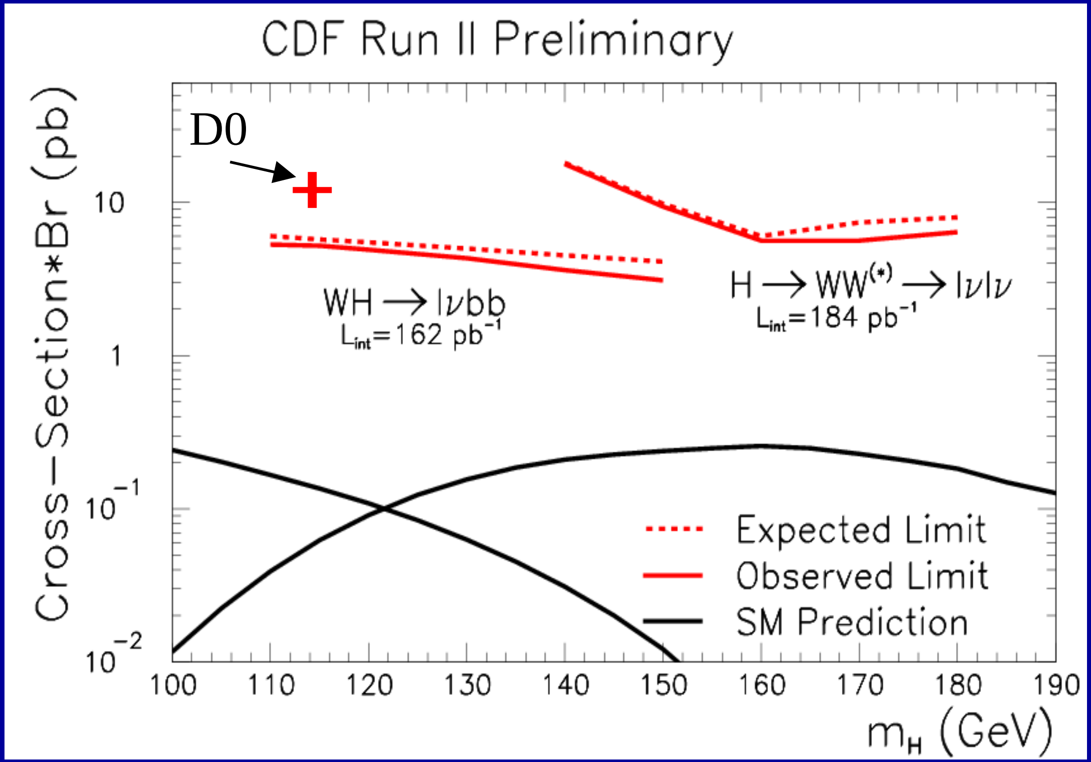
Run 1:
-120 GeV CDF
-150 GeV D0

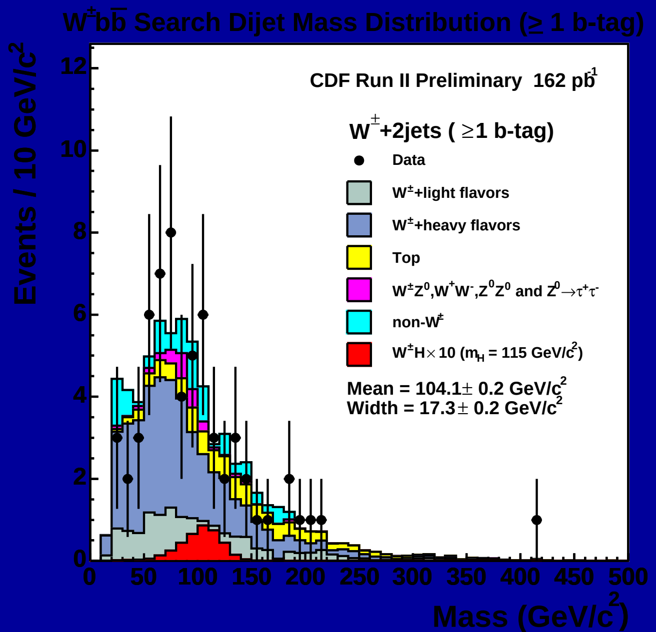
SM Higgs

95% CL limit (162 - 184 pb^{-1})

Need more channels/energy resolution improvement e.g. $\nu\nu bb$







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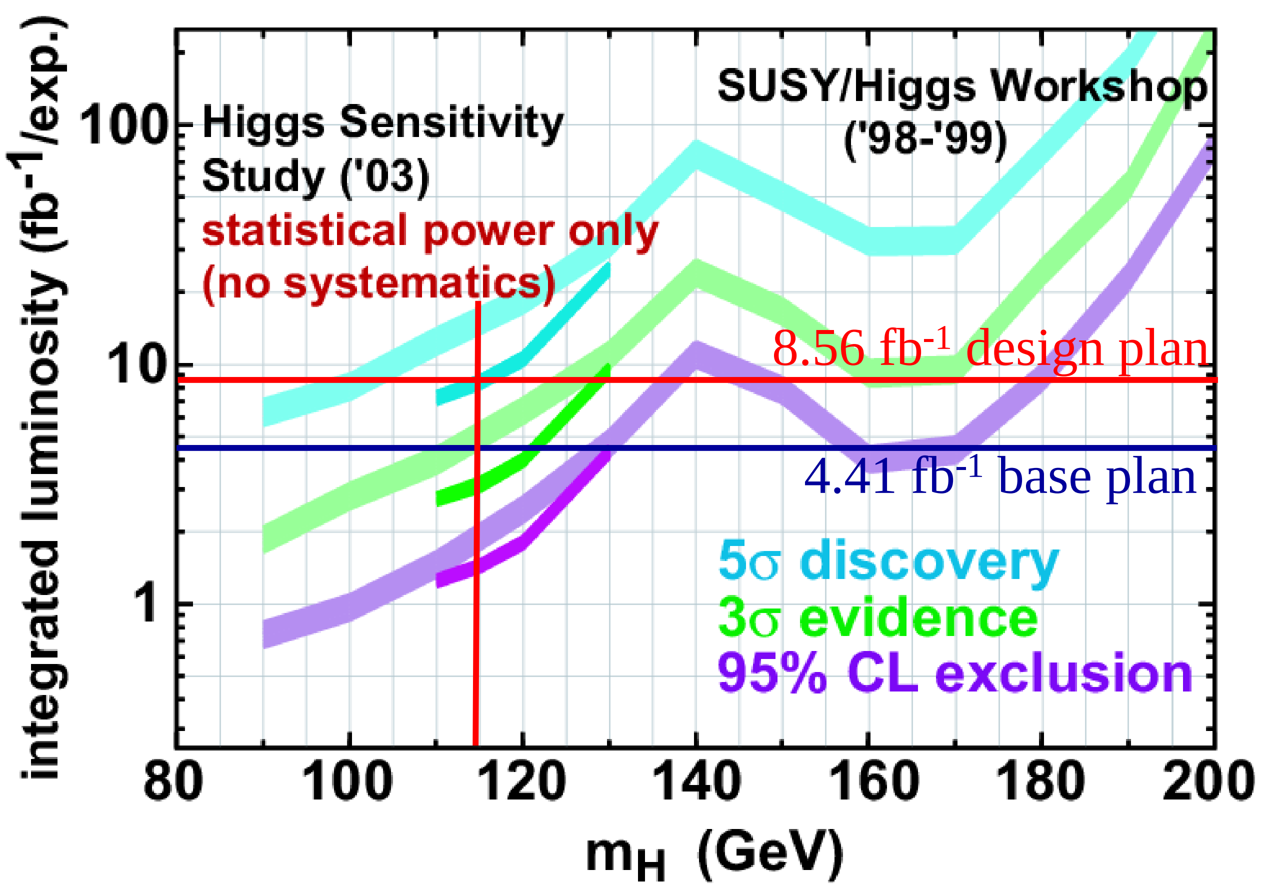
Higgs search

CAUTION!

- **Sensitivity re-evaluated in June 2003**



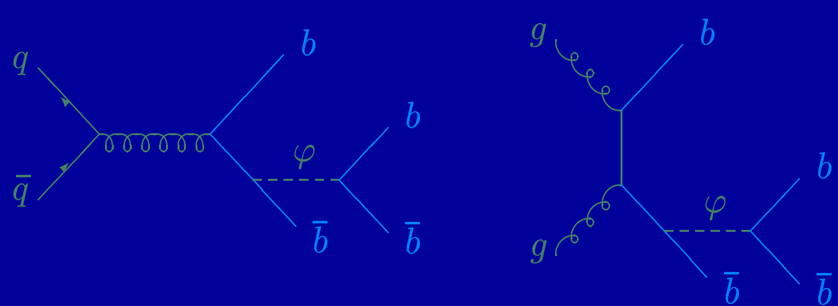
SUSY - Higgs

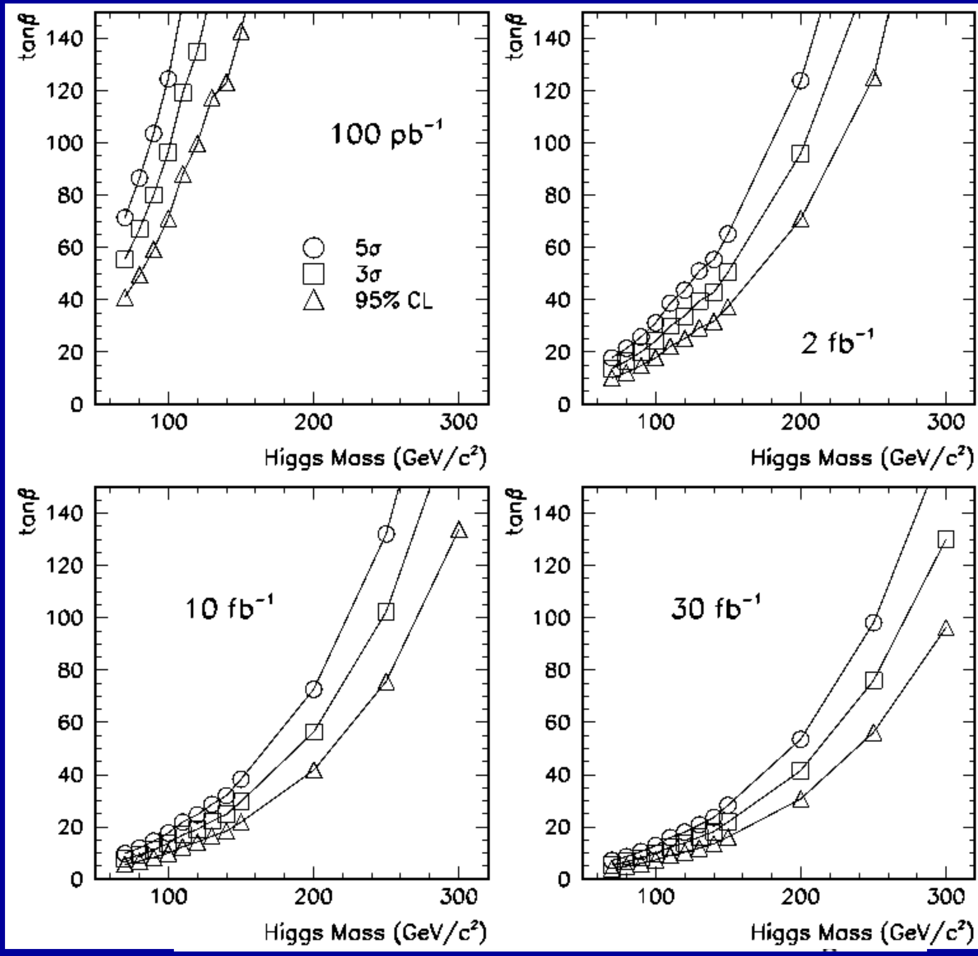
- Could be easier than SM:
  - 4 b final states are very strong signature
    - Do no need associated W/Z if tan β is large

$$\sigma(p\bar{p} \rightarrow b\bar{b}\varphi) = (g_b^{h,A,H})^2 \sigma(p\bar{p} \rightarrow b\bar{b}H_{SM})$$

$g^2 \sim 1/\cos^2(\beta) = 1 + tg^2\beta$

φ = h, A, H





Conclusions (1)

- Tevatron is (finally!) picking up
  - Could exceed even best luminosity expectations!
- CDF & D0 are working well and delivering a wide range of physics results
- ~ 400 pb^{-1} analyzed for winter ’05
  - Expect many interesting new results

Conclusion (2)

- By end of FY2007 will have 2 - 4 fb^{-1} delivered and possibly 1.5 - 3 analyzed:
  - Top mass resolution ~ 3 GeV/exp and improving
  - W mass resolution ~ 25 GeV/exp and improving
  - Rare decays in B sector
    - Limit on Bs→μμ in the 10^{-8} range
  - Bs mixing is measured
  - CP in B→hh: measured time evolution with 15 –20 % resolution on asymmetries and improving → sensitive to γ
  - New particle searches:
    - Tevatron leads until LHC turn on
    - Will keep improving limits on SM Higgs and other more exotic particles
    - With luck and a consistent Tevatron performance we may observe hints of the Higgs boson or new physics!

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Backup Slides

Expected Run II Top Quark Studies Accuracy

Measurement	Precision
Top Mass	2-3 GeV/c^2
$\delta\sigma$(ttbar)	9%
$\delta\sigma$(ll)/σ(l+j)	12%
$\delta B(t \rightarrow Wb)$	2.8%
$\delta B(W_{longitudinal})$	5.5%
δV_{tb}	13%
$B(t \rightarrow c\gamma)$	$<2.8 \times 10^{-3}$
$B(t \rightarrow Zc)$	$<1.3 \times 10^{-2}$

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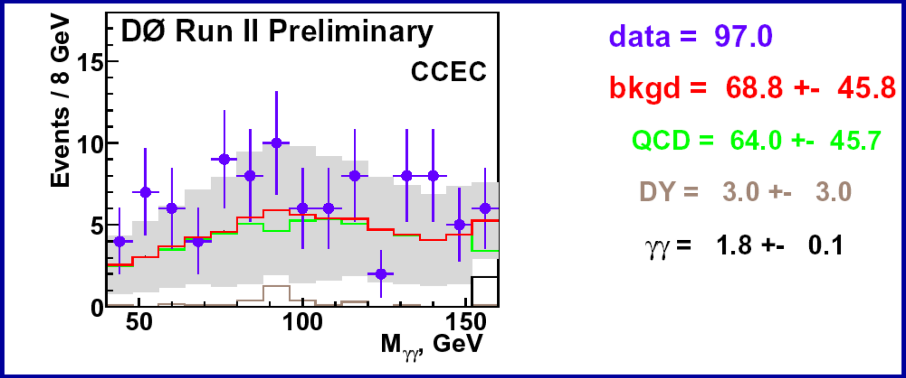
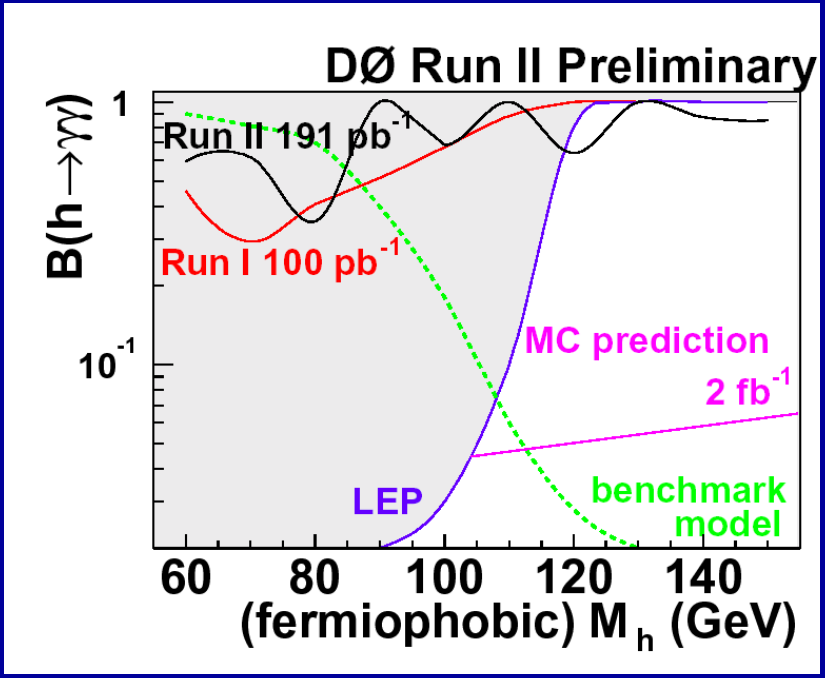
Search for H → γγ

In the SM Higgs → γγ has Br~10^{-3}
→ search for SM Higgs decaying to gamma pair is not practical at Tevatron

Many SM extensions allow enhanced gamma pair decay rate largely due to suppressed coupling to fermions
→ Fermiphobic Higgs
→ Topcolor Higgs

Search strategy:
Look for peaks in γγ mass spectrum for high P_t isolated γ's





SUSY search expectations

- Old Run II sensitivity estimates consistent with current results