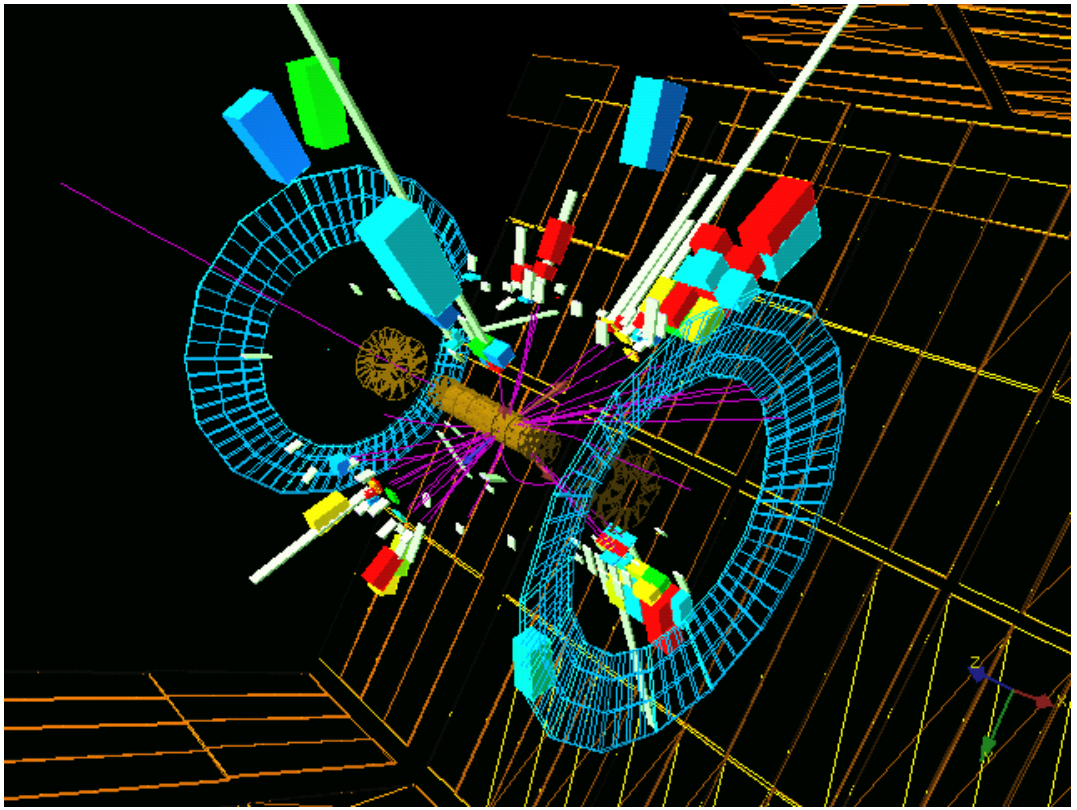
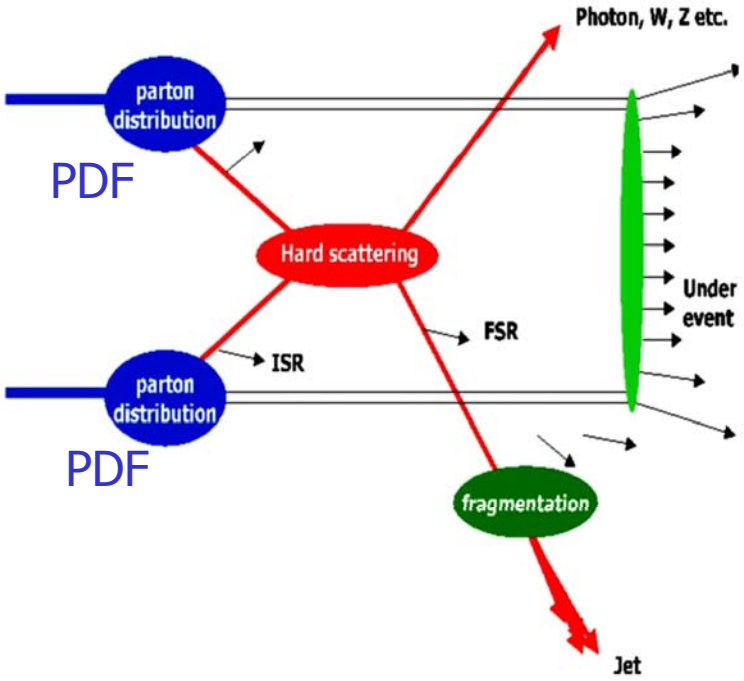
Latest Physics Results from DØ



Daniel BLOCH
IReS
Strasbourg

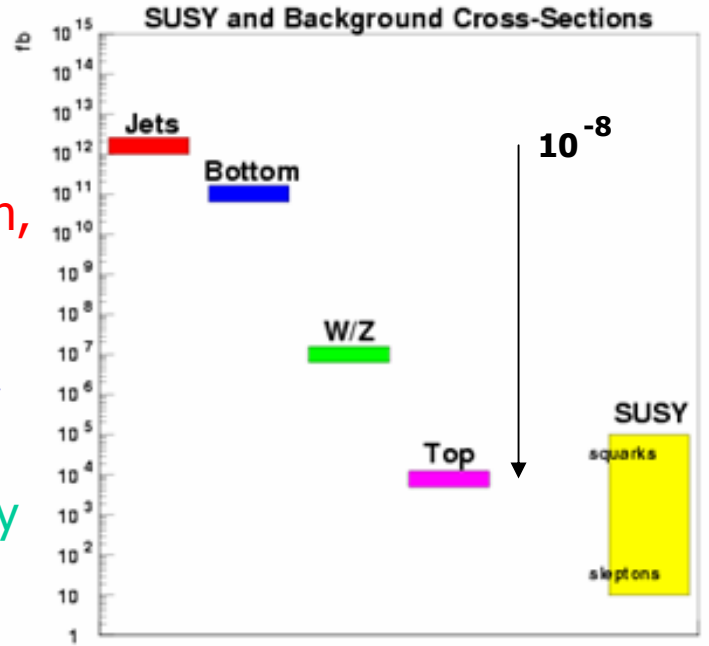
- QCD
- Electroweak
- Top
- Higgs search
- New Phenomena
- B physics

TEV4LHC
Workshop, CERN
April 28, 2005



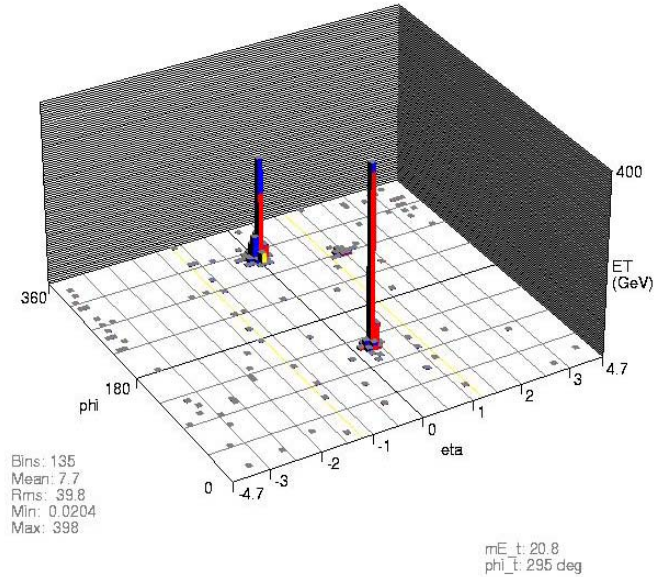
QCD

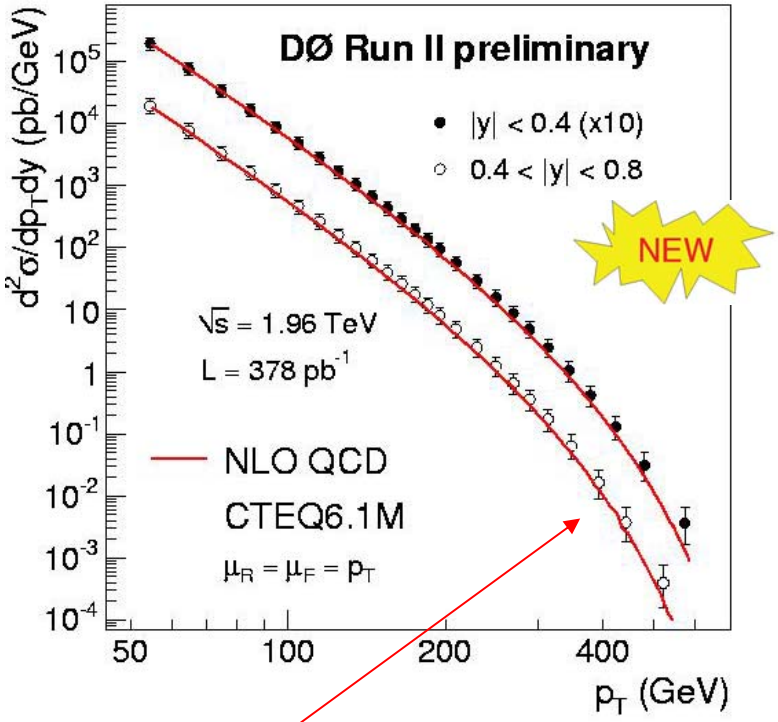
QCD jets are the main background
for many SM measurements
and new physics searches

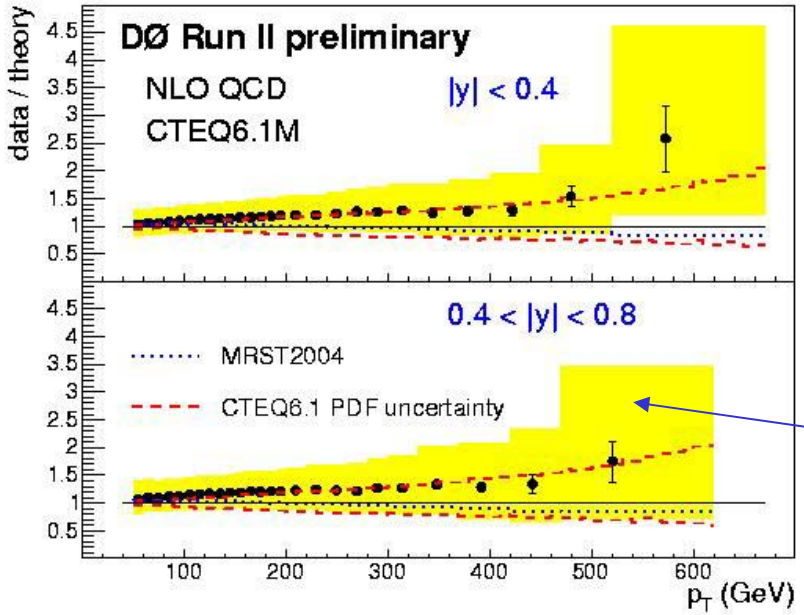


- **Understand** perturbative and non-perturbative QCD (PDF, gluon/quarks radiation, fragmentation, underlying event, …)
- **Benefits from higher beam energy and higher luminosity at Tevatron RunII :** study high p_T dijets (or high dijet mass, prelim.2004), theoretical uncertainty at high p_T is dominated by gluon density function at large x
- **Search for new physics :** compositeness, excited quarks, Z', …

QCD: central jet inclusive cross section

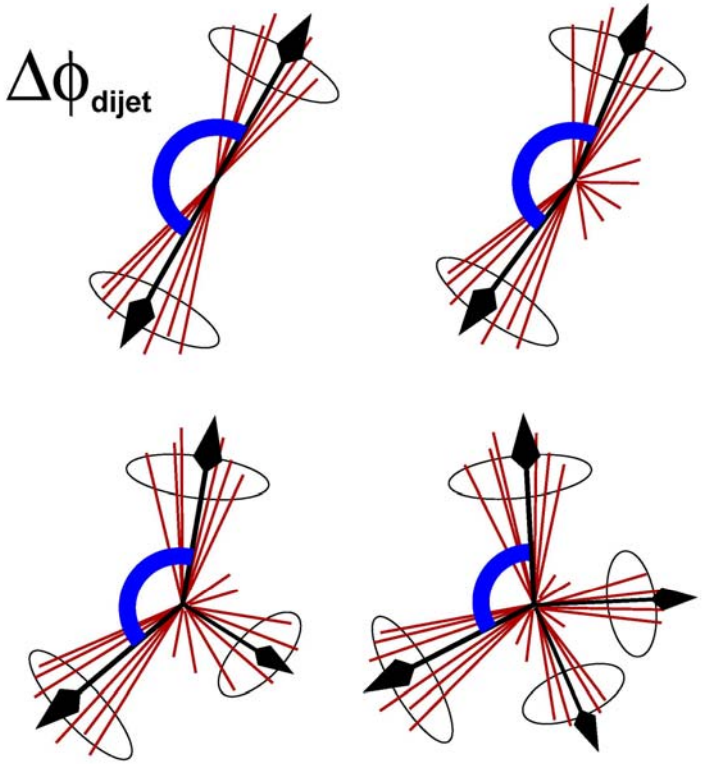




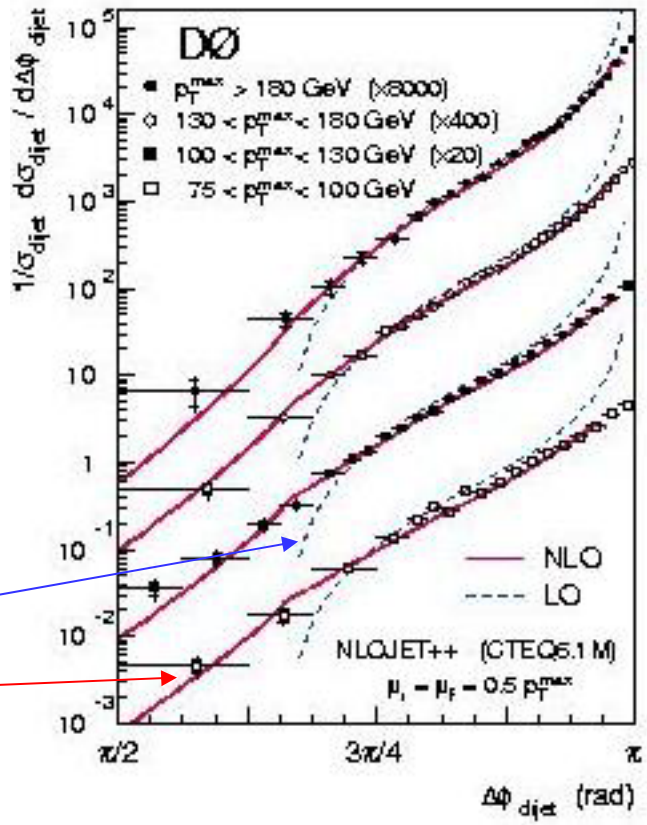


- good agreement with NLO QCD over 8 orders of magnitude
- exp. systematics dominated by jet energy calibration

QCD: dijet azimuthal correlations

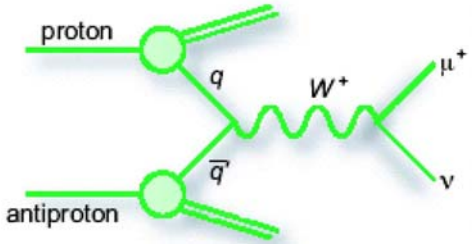


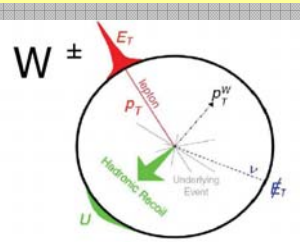
- different regions in $\Delta\Phi_{dijet}$ are sensitive to different jet production and QCD radiative processes
- almost not sensitive to jet energy calib. (hep-ex/0409040, submitted to PRL)



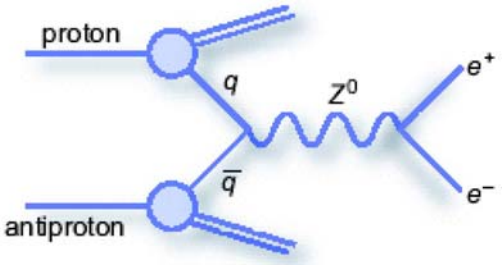
at LO:
nothing expected with $\Delta\Phi_{dijet} < 2\pi/3$
at NLO: good agreement observed

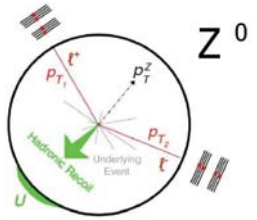
Electroweak physics





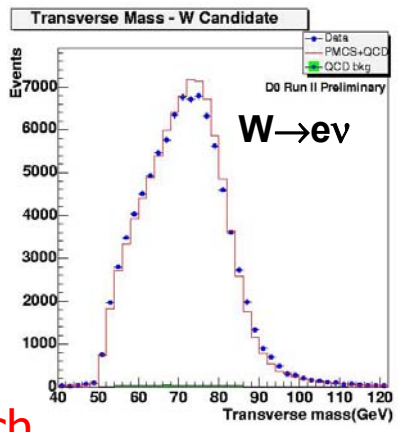
- energetic lepton
- missing E_T ("$\not\!\!E_T$")

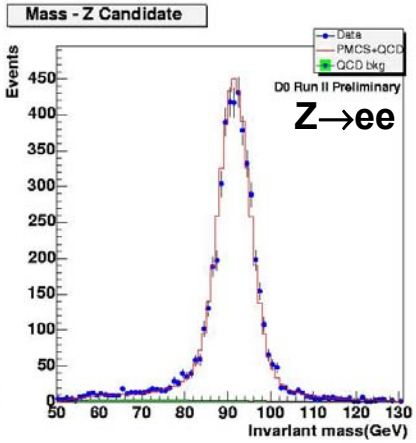


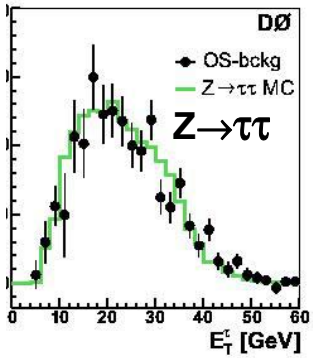


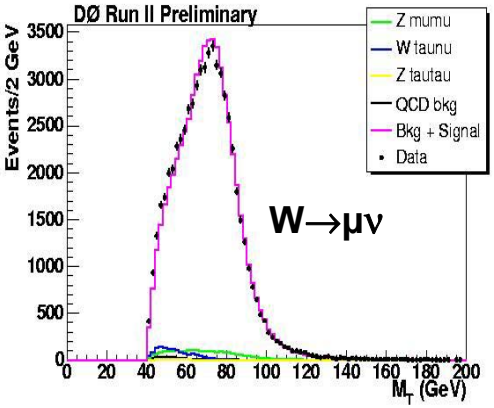
- 2 energetic leptons
- (leptons w/ opposite sign

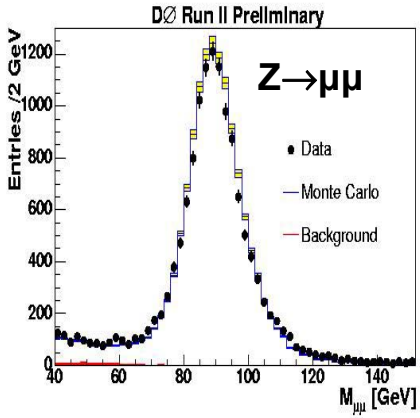
- standard candles:
  Z and W cross-sections
  (e, μ and τ channels only)
- precision measurements:
  W mass and width, Afb(Z)
- di-boson production:
  small SM cross-sections
  but bkg for SM Higgs search
  limit on anomalous couplings
- W+jets and Z+jets: test of QCD
  also a bkgd for top physics, Higgs
  and new phenomena searches









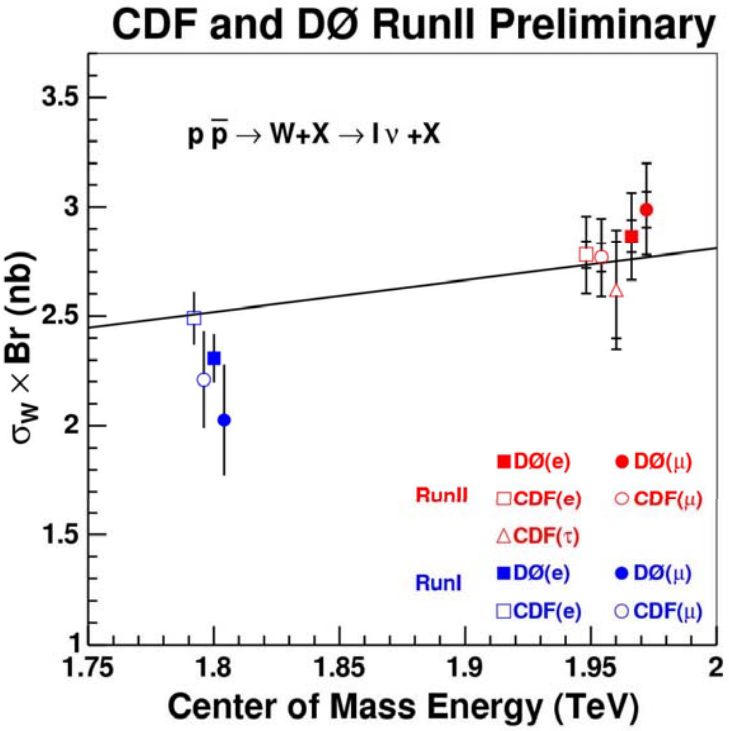


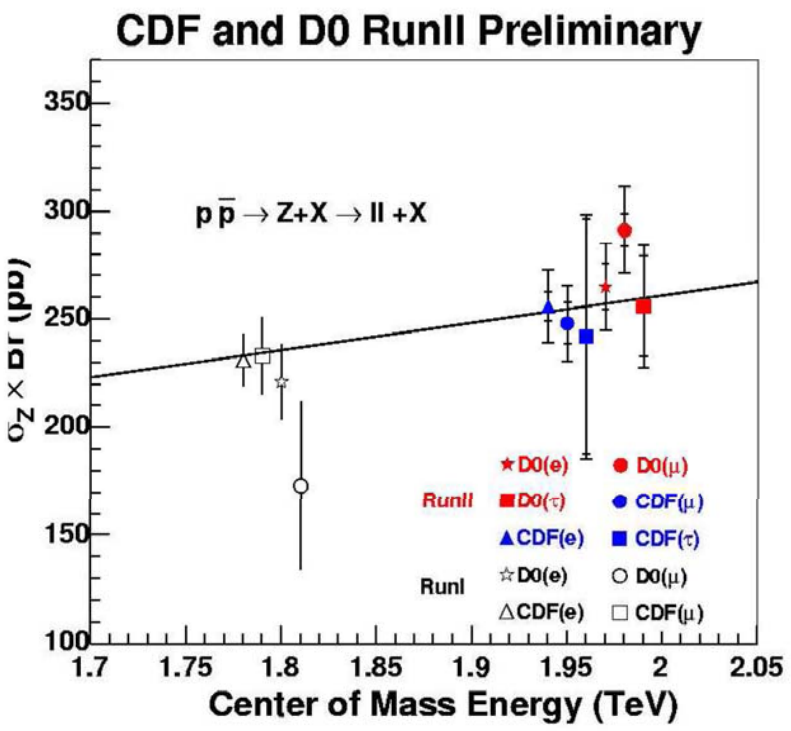
W and Z cross-sections

W→eν (prelim.2004), μν (NEW prelim.2005),
Z→ee, μμ (prelim.2004), ττ (PRD 71, 072004 (2005))

good agreement with SM (Hamberg et al., Nucl.Phys. B359, 343 (1991))

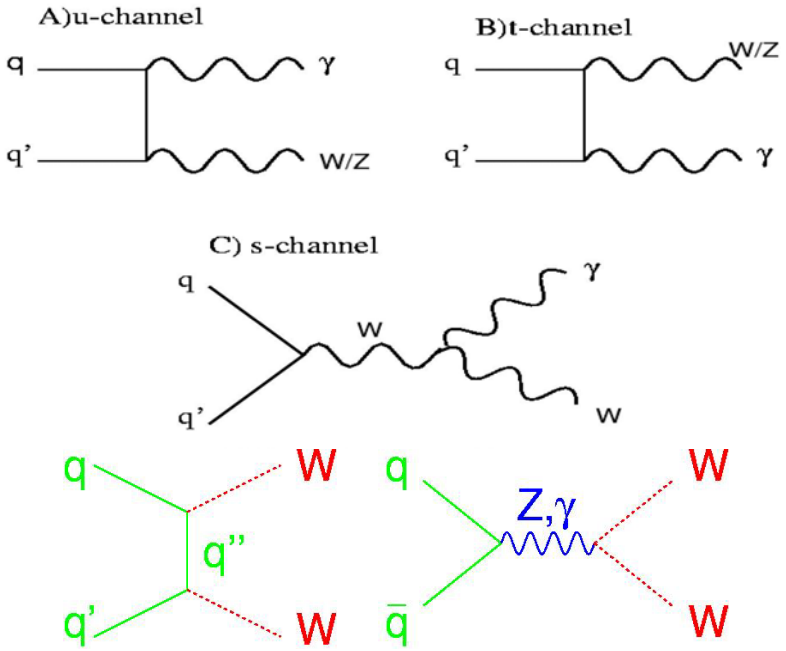
limitations: luminosity (6.5%), PDF (1.5%), Z statistics (here use 100-200 pb^{-1})
allows to validate lepton id !



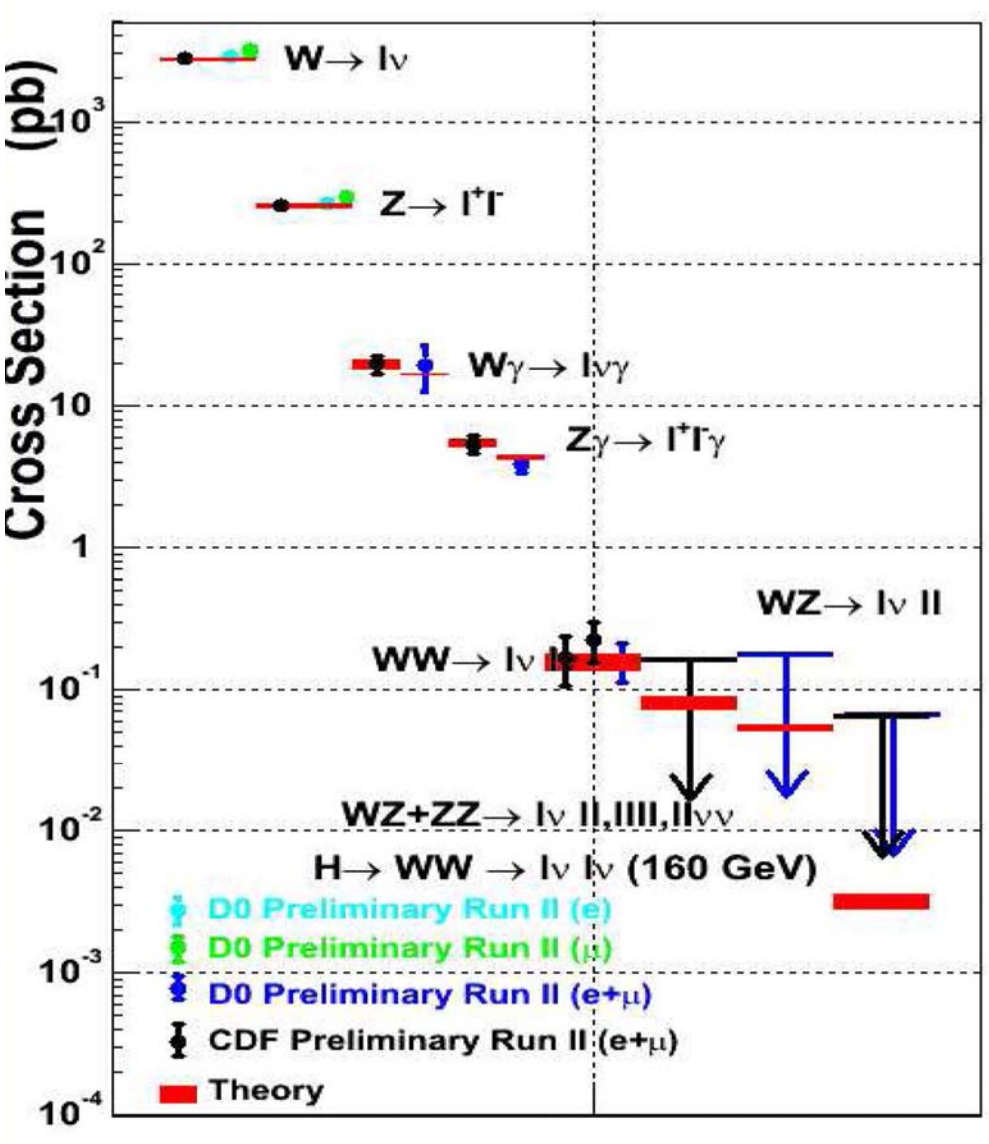


di-boson final states

small cross sections
(10^{-2} to 10^{-4} of single boson)
analyses limited by statistics

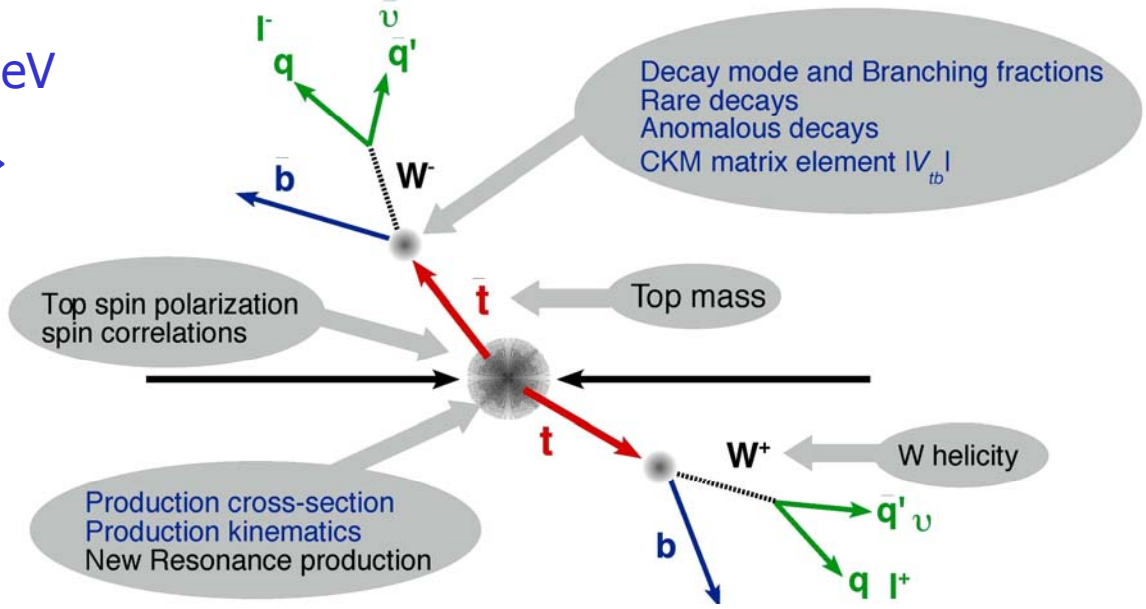


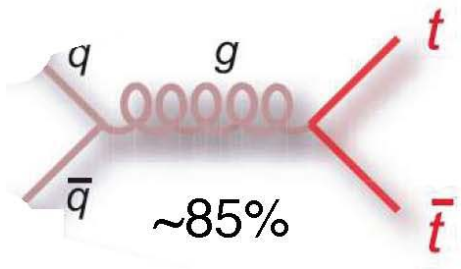
Results provided (with 200-300 pb^{-1}):
Wγ (hep-ex/0503048, PRD),
Z γ, ZZγ, Zγγ (hep-ex/0502036, PRL),
WW (PRL 94, 151801 (2005)) and
WZ (hep-ex/0504019, PRL)
⇒ agreement with SM
and limits on anomalous couplings

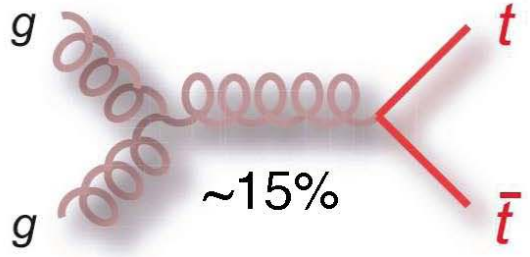


Top physics

- heaviest quark : m_t =178±4 GeV
- decays before hadronization ⇒ direct probe of weak interaction
- strongest coupling to Higgs (Htt Yukawa coupling ~1) precision measurement → sign of new physics ?
- many studies at Tevatron







pair production at Tevatron:
30% increase of cross-section between 1.8 and 1.96 TeV

Br(t→Wb)~100%
⇒ 2 b quark-jets in each event

type of events:
5% in ee, eμ, μμ + 2 jets
30% in e/μ + 4 jets
44% all hadronic, 21% τ

top pair cross section

various methods: rely on ~150 pb^{-1}

di-leptons: cleanest but few events,

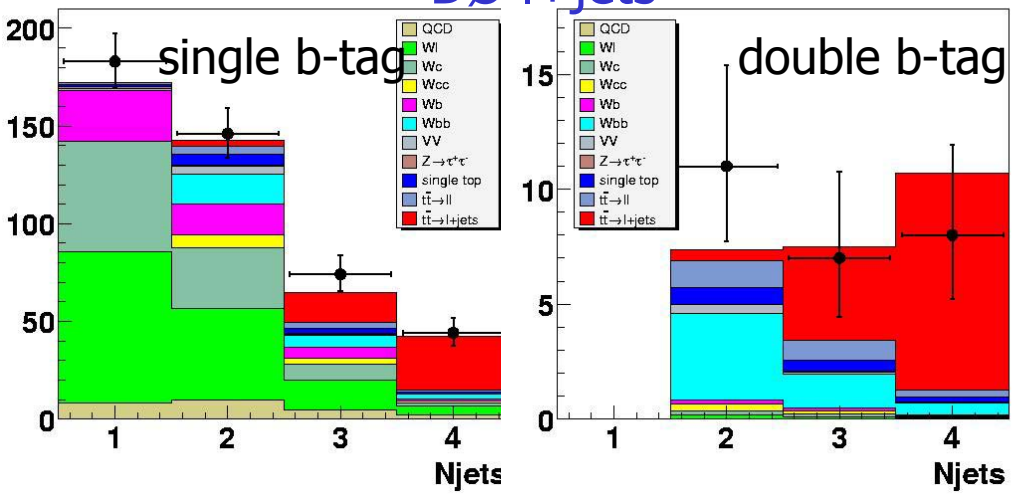
lepton+jets: topological or b-tagging

(both sent to PRL this week)

hadronic: with NN and b-tag

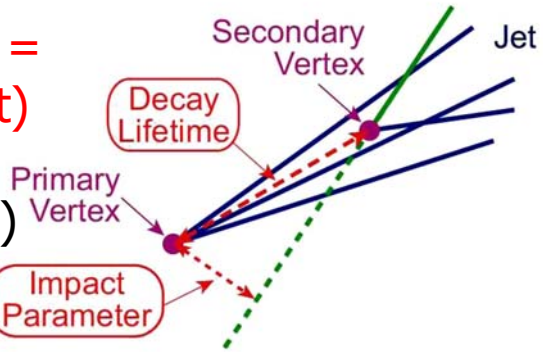
NEW

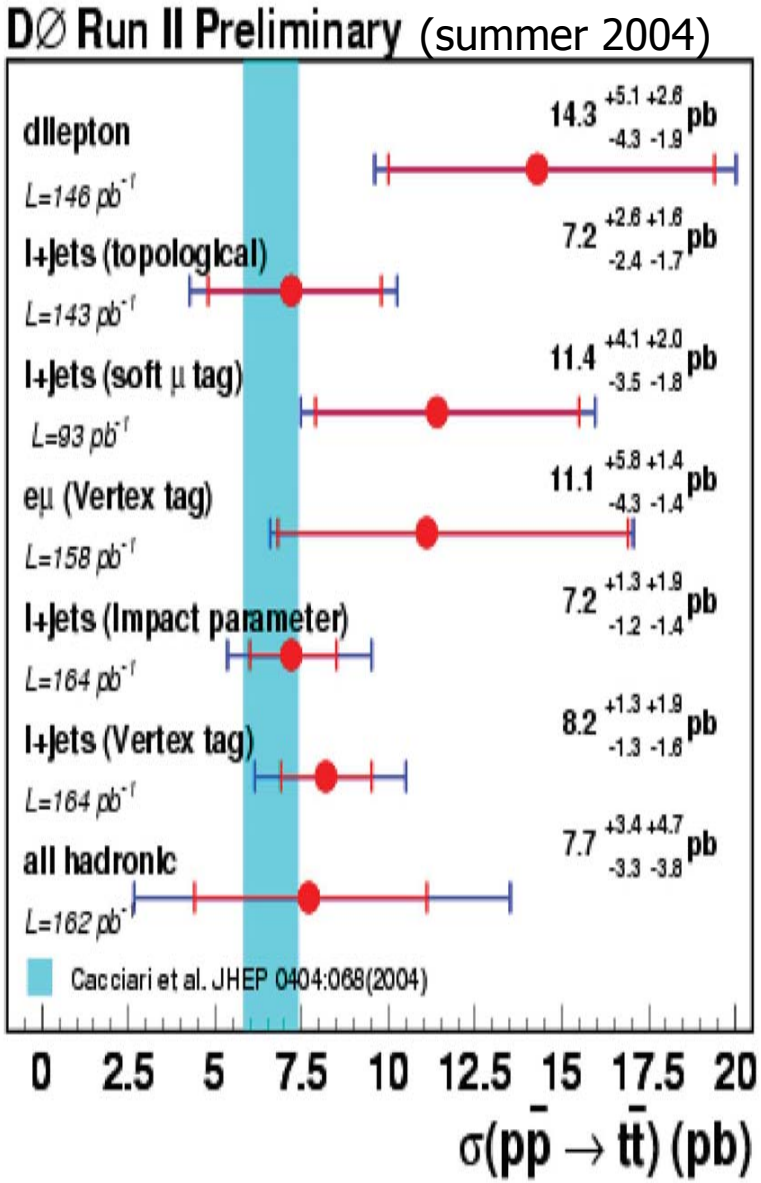
DØ l+jets



⇒ Br(t→Wb)/ Br(t→Wq) = 0.70±0.26(stat)±0.11(syst)

(compatible with 1; from summer 2004 l+jets b-tag)



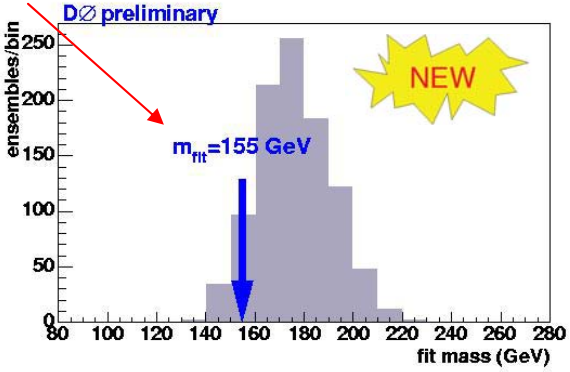


top mass measurement

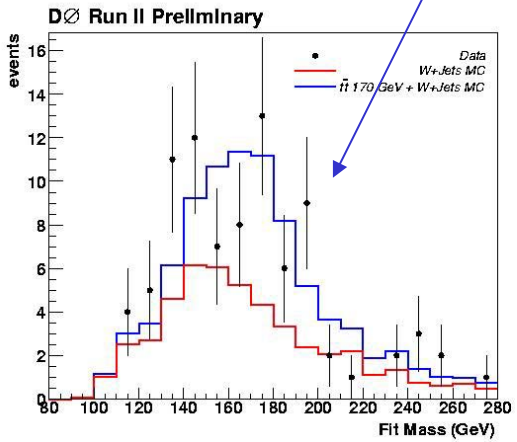
Run I (DØ update 2004+CDF): m_t=178.0±4.3 GeV ⇒ **Run II objective: ±2 GeV**

at present: only preliminary results (160-230 pb^{-1})
main systematic is jet energy scale

di-leptons (NEW): 13 evts, expect 3 bkg
weight each event vs mass hypothesis
likelihood fit: 155±14±7 GeV

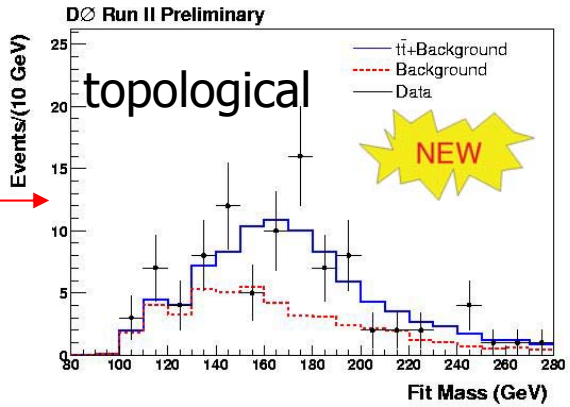


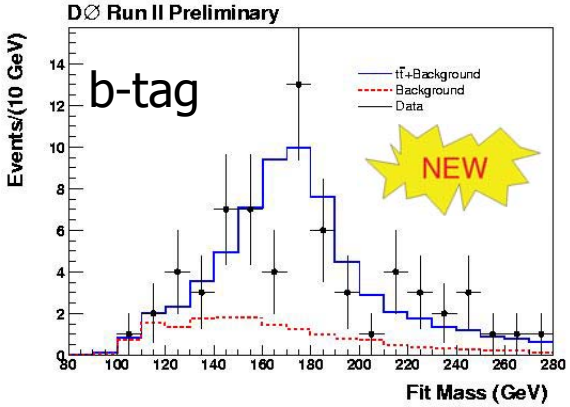
l+jets ideogram (prelim.2004):
use all jet permutations
likelihood discriminant for s/b
fit: 170±7±8 GeV



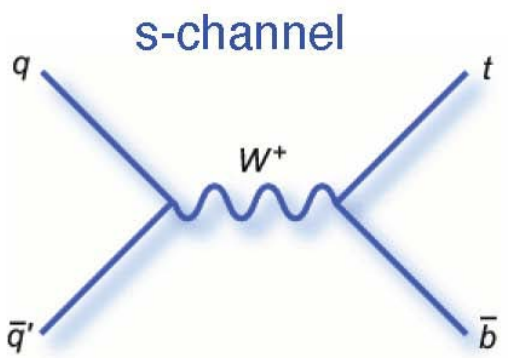
- already close to Run I
- will still improve soon

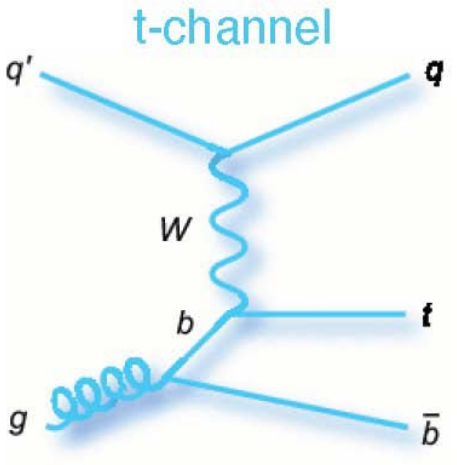
l+jets templates (NEW):
topological and b-tag analyses
kinematic fit: keep
permutation with best χ^2
mass templates for s/b
fit: 170±6±7 GeV (topo)
. 171±4±6 GeV (b-tag)





single top search





0.88$\pm$0.11pb

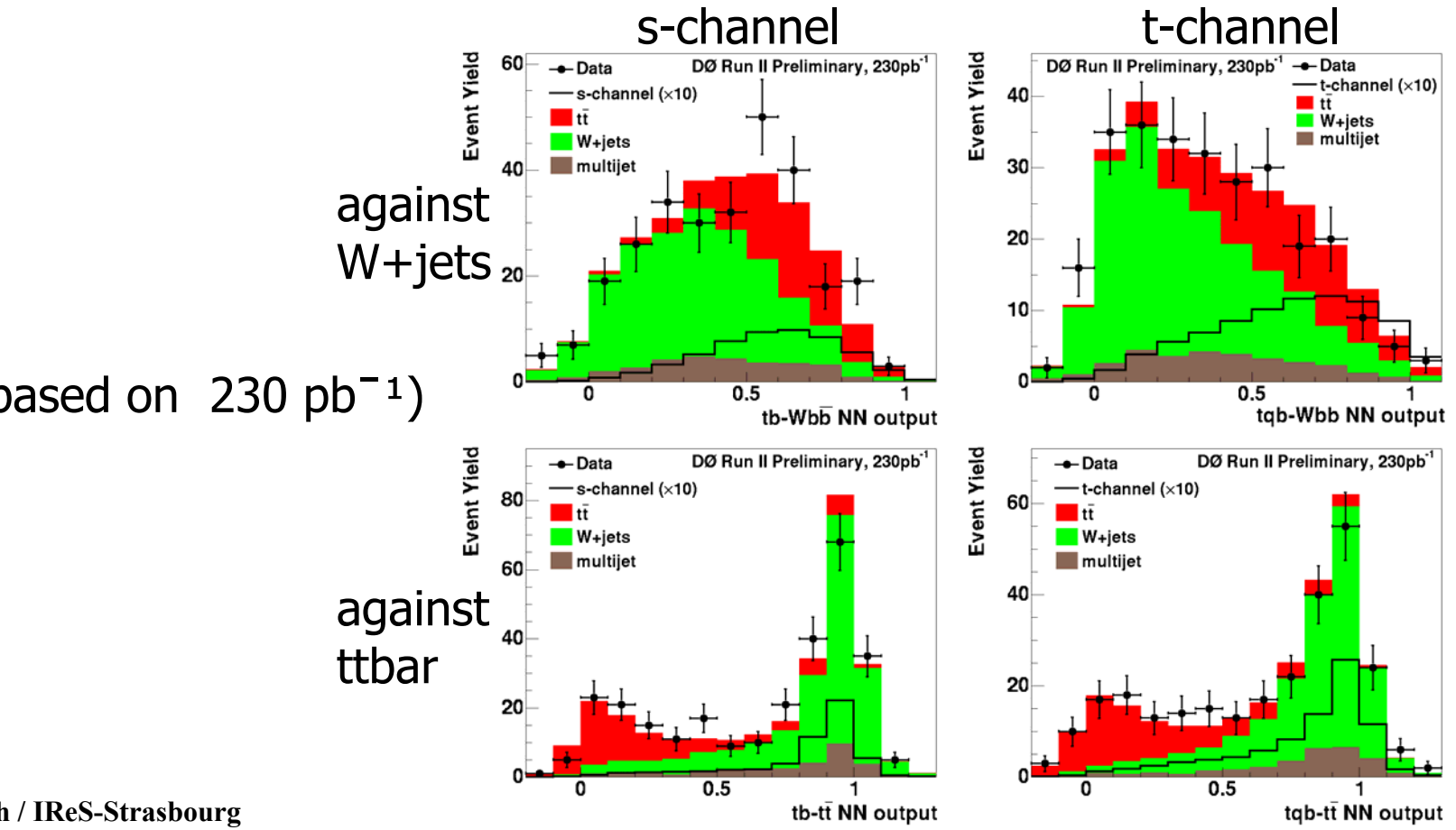
1.98$\pm$0.25pb

- electroweak production of top quark $\rightarrow$ direct meas. of $|V_{tb}|$
- not observed yet
- single top cross section (2.9 pb) close to ttbar (6.7 pb), but much larger backgrounds (mostly W+jets and ttbar) because there are fewer jets
- 2 b-quark jets in each event $\rightarrow$ b-tagging

single top analysis

- Use 11 topological variables (energy or angular/spin related, top mass)
- distinguish e or μ+jets, single or double b-tag, s or t channels
- 3 independent analyses: **sequential cuts**, **decision tree** and **Neural Network** (with 2 NN's: one against W+jets and one against ttbar)

(based on 230 pb^{-1})



single top results

NEW

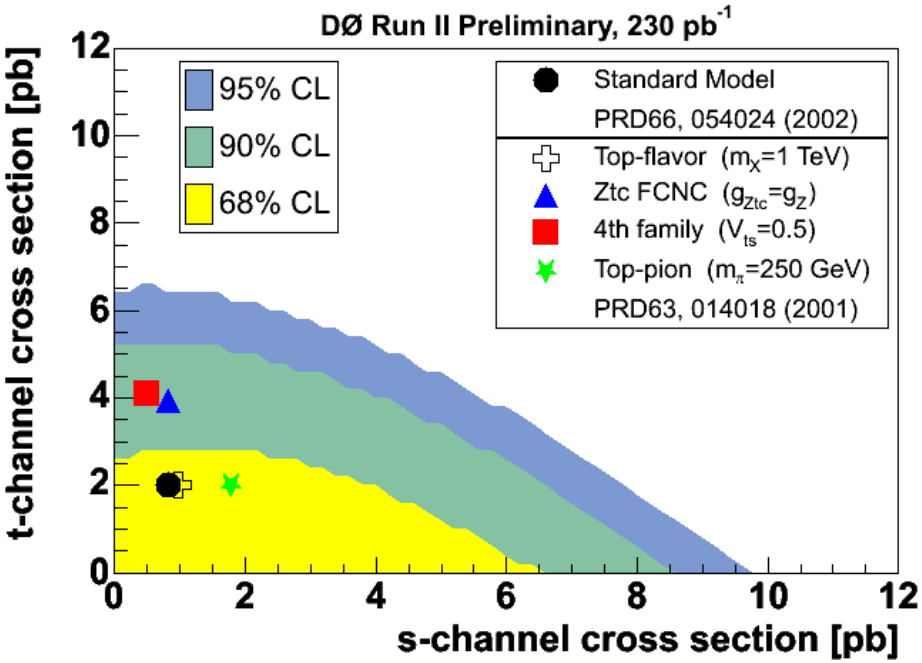
	Upper limits on production cross-section (pb) at 95% CL	
	s-channel	t-channel
Cut-based	**10.6** (9.8)	**11.3** (12.4)
Decision Tree	**8.3** (4.5)	**8.1** (6.4)
Neural Network	**6.4** (4.5)	**5.0** (5.8)

measured limit
(expected sensitivity)

(being to be published)

world best limit so far

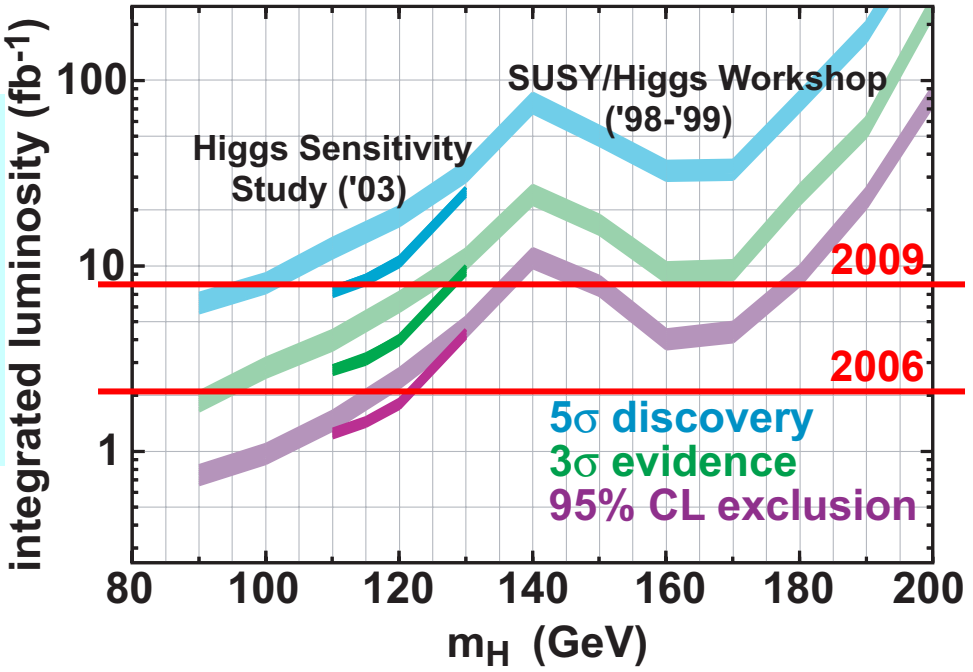
but observation would need ~10 times more data, if no further improvement done



Higgs search

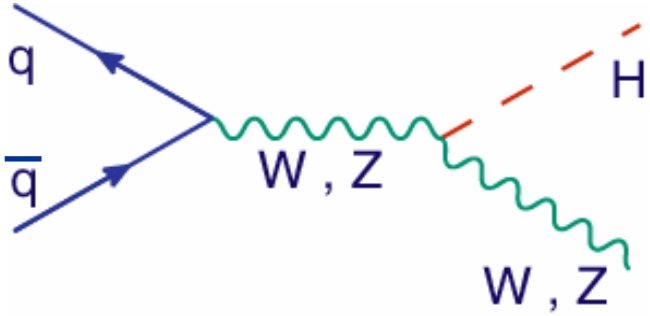
The last unknown brick in Standard Model
but also a link to new physics

difficult quest at Tevatron:
various channels (and experiments) to be combined, very sensitive to detector resolution and performance, large backgrounds to be understood and rejected, need high luminosity



present limits:
m_H > 114.4 GeV (95% C.L.) from LEP
m_H < 280 GeV (95% C.L.) and
$m_H = 126\ ^{+73}_{-48}$ GeV from EW+mt fit ⇒ **favors a relatively light Higgs**

SM Higgs production at Tevatron:
- gg fusion has highest cross section
- association with W, Z (higgsstrahlung) is 5 times smaller (few 10^{-2} to 10^{-1} pb) but one can trigger on high-p_T leptons

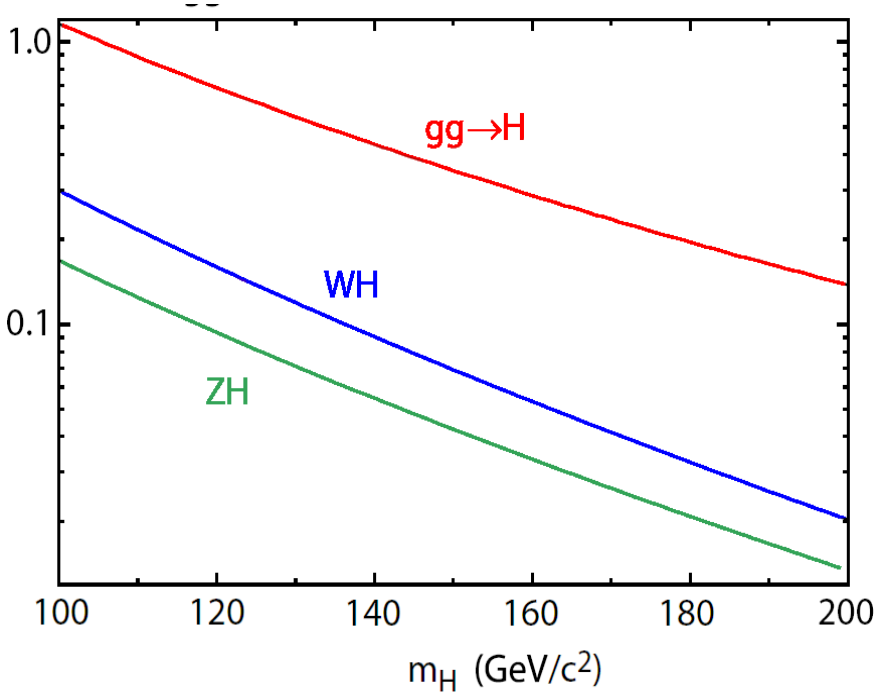


SM Higgs search strategy

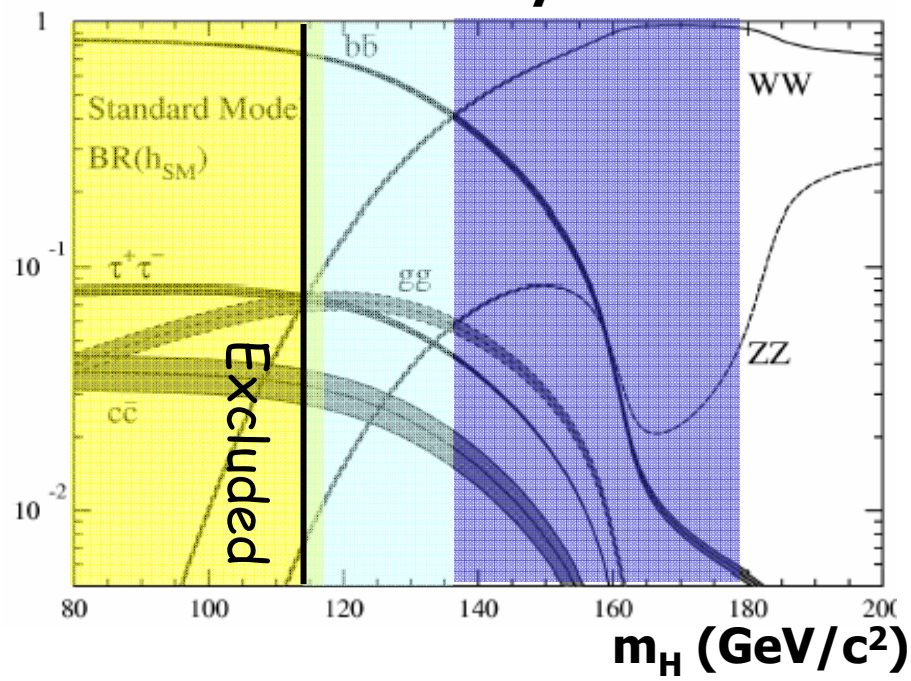
- **mH < 135 GeV: (W/Z)H prod with H→bb**
  - qq′→W*→WH→**lνbb**: bkgd Wbb, WZ, tt, t(q)b
  - qq →Z* →ZH → **llbb**: bkgd Zbb, ZZ, tt
  - or **ννbb**: bkgd QCD, Zbb, ZZ, tt
- **mH > 135 GeV: gg→H→W+W-→lνlν**
  - with bkgd Drell-Yan ll, WW, ZZ, tt, ττ

require to identify leptons (e,μ), missing E_T from ν, tag b-jets, good bb mass resolution, angular correlations for WW

production



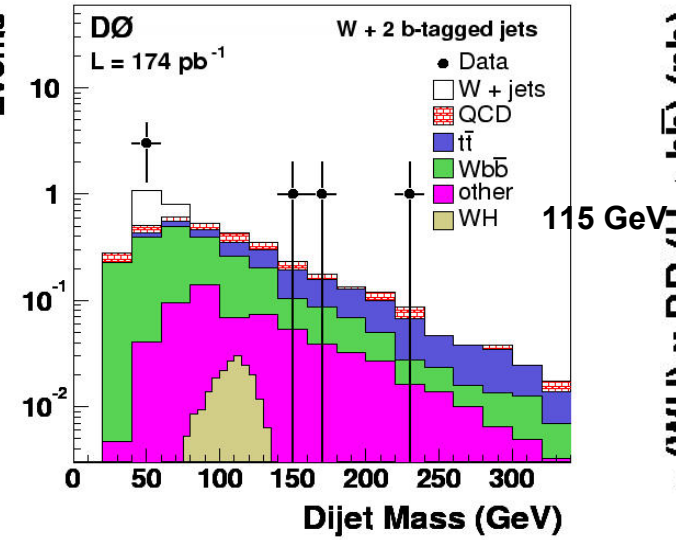
decay



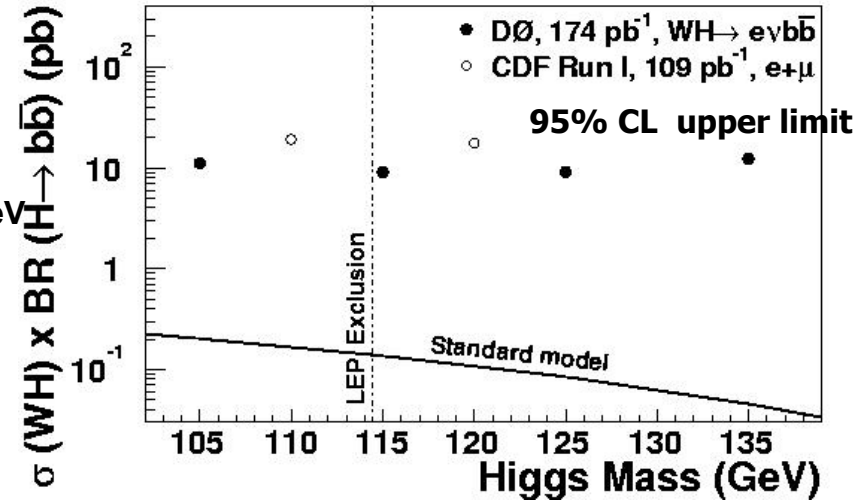
low mass SM Higgs search

PRL 94, 091802 (2005)

W(→eν)+bb
if 2 b-tag jets:
6 candidates
bkgd 4.4±1.2

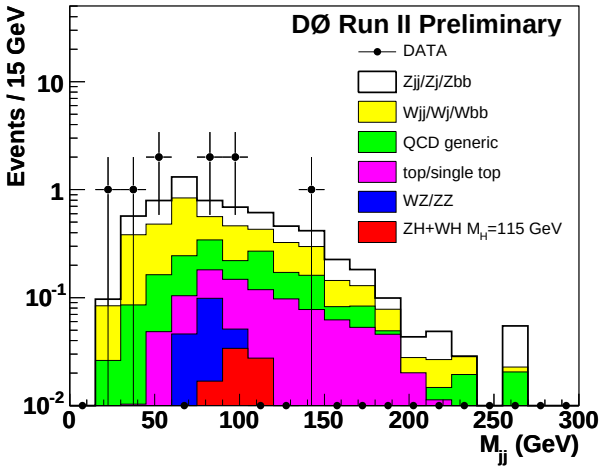


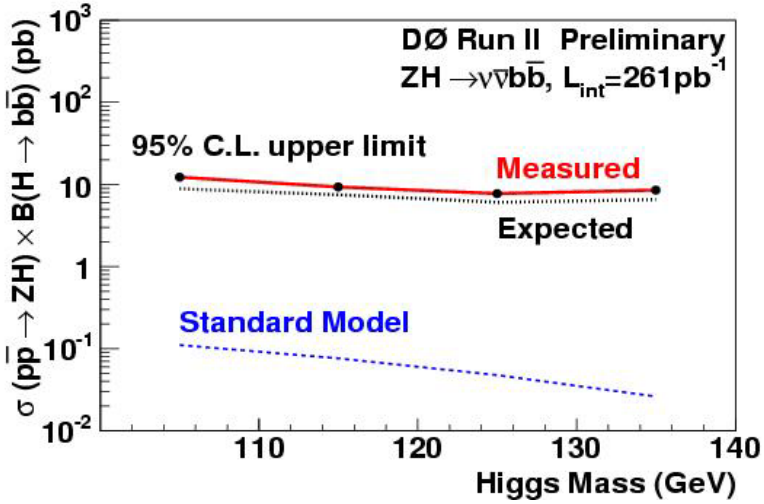
115 GeV



NEW

Z(→νν)+bb
if 2 b-tag jets:
9 candidates
bkgd 6.4±2.1

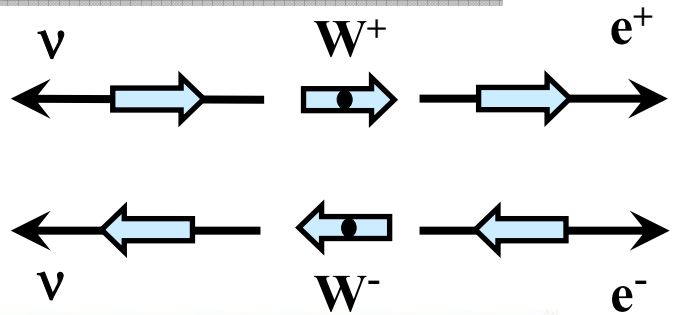


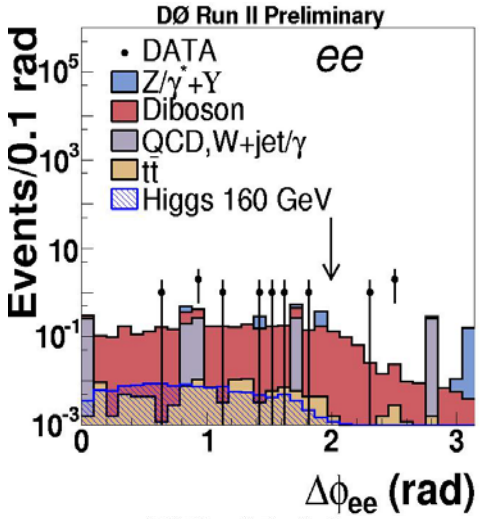


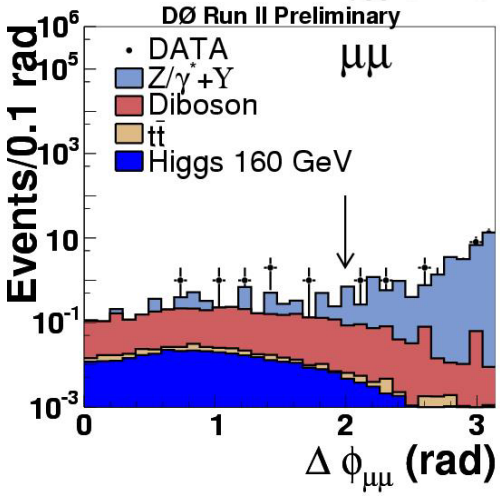
NEW

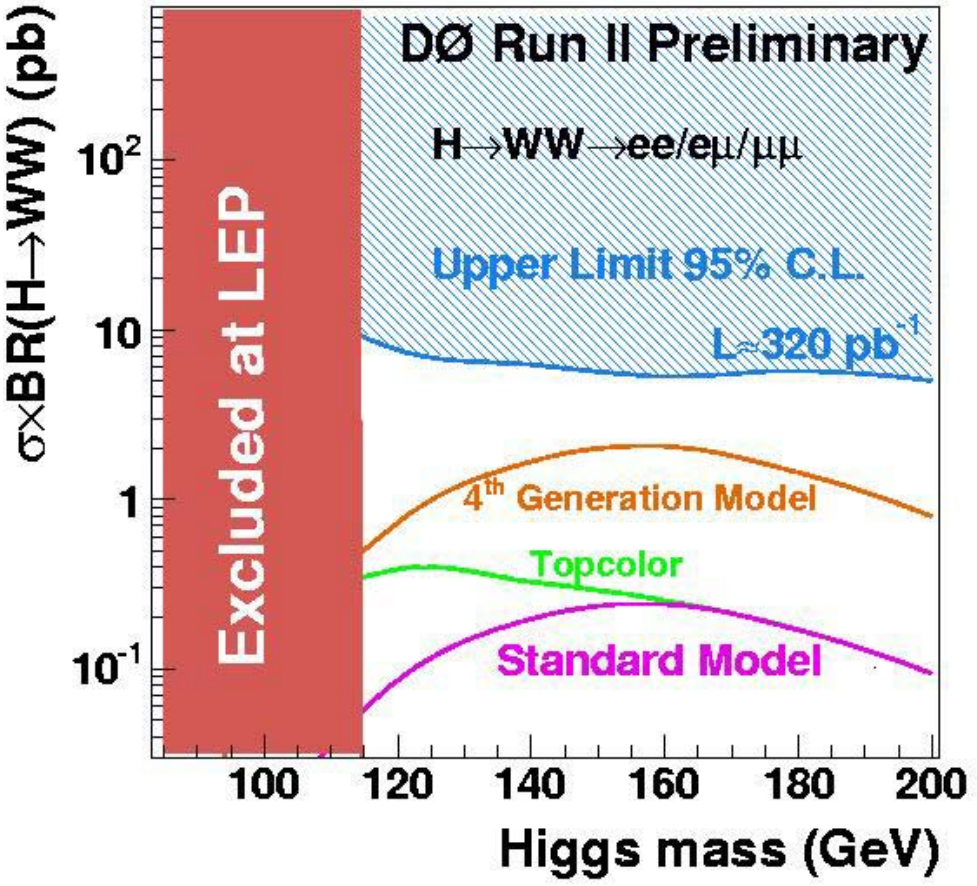
H → W^+W^- → $\ell^+\ell^-\nu\nu$ search ($\ell\ell$=ee, eμ, $\mu\mu$)

selection based on lepton pt, missing E_T, di-lepton mass and lepton production angles (WW spin correlation)



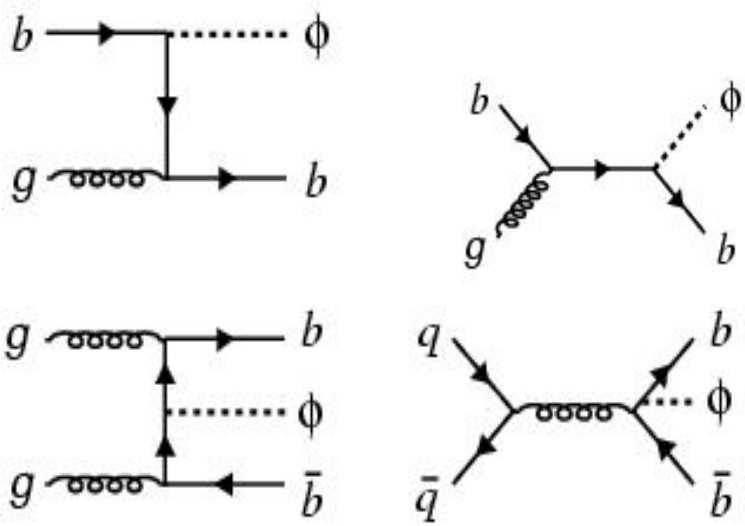






search for SUSY Higgs bosons

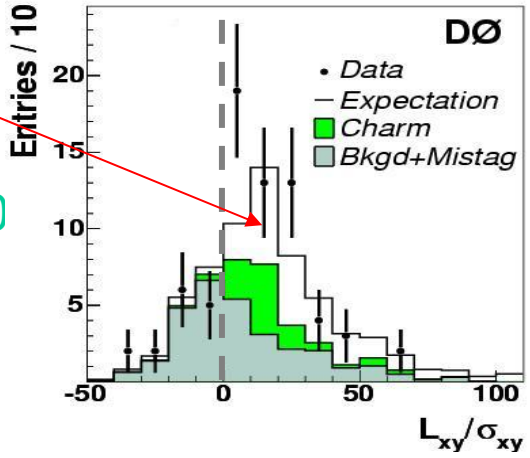
- two Higgs doublet fields in MSSM
  - H_u (H_d) couple to up- (down-) type fermions
  - the ratio of their VEV's $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$
  - 5 Higgs particles after EWSB: h, H, A, H^+, H^-
  - h is 'guaranteed' to be light: $m_h <\sim 130\text{-}140$ GeV
- at large tanβ, coupling to bb is enhanced wrt SM and at tree level production cross section rise as $(\tan\beta)^2$
- CP conservation is assumed in the analysis



but first check SM background
Zb production with Z→ee, μμ
(hep-ex/0410078, PRL)

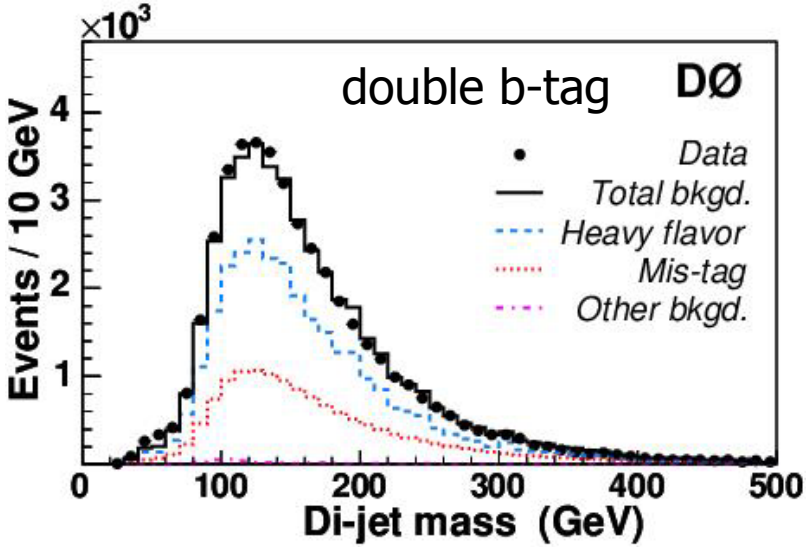
$\sigma(Z+b)/\sigma(Z+jet) =$
$0.023 \pm 0.004 \pm 0.003$

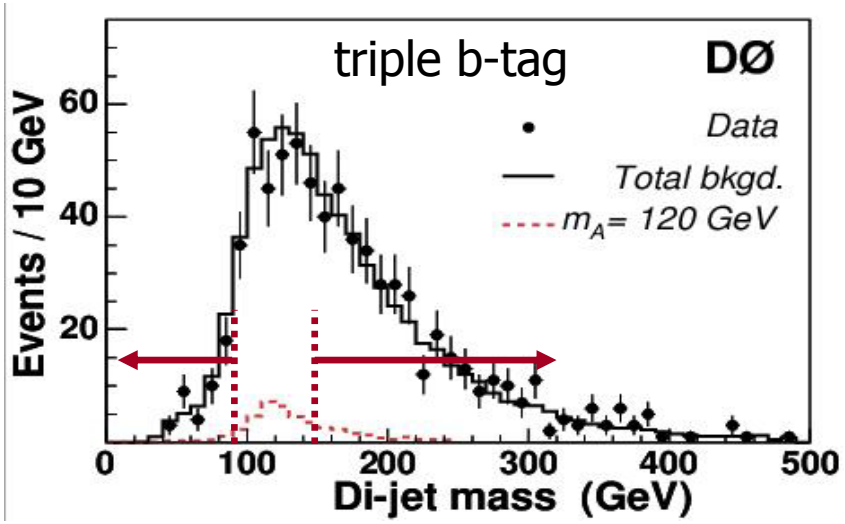
NLO QCD = 0.018±0.00
(Campbell et al.,
PRD69 (2004) 074021)



SUSY Higgs boson search (cont)

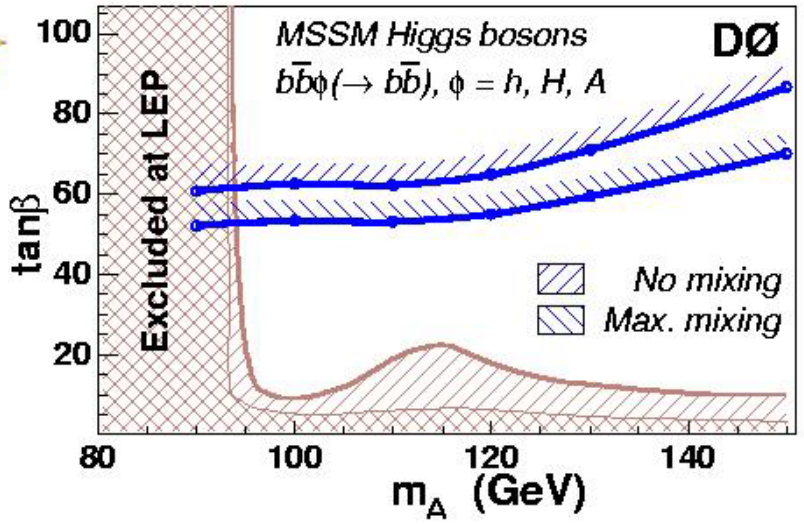
use dijet double b-tag events to infer QCD bckd on 3 jets tripple b-tag events:
no excess observed ⇒ infer limit on SUSY Higgs production (hep-ex/0504018, PRL)





(260 pb^{-1}) NEW

95% C.L. upper limit on tanβ as
a function of mA and
for two scenarios of MSSM



News in New phenomena searches

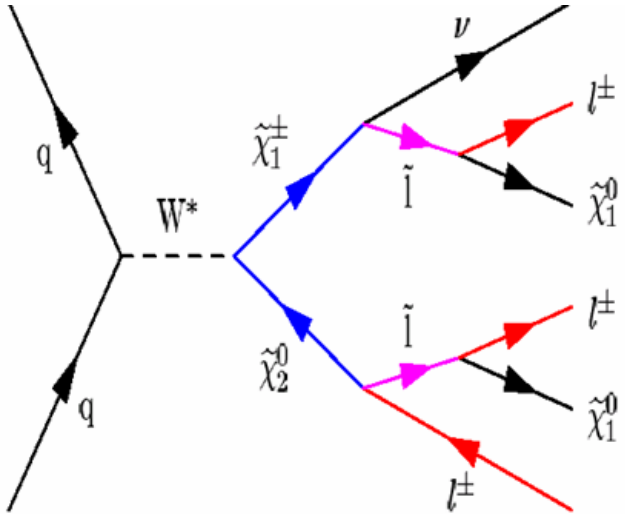
- **R parity Conserving SUSY**: mSUGRA, GMSB (NEW <= presented here)
- **R parity Violating SUSY**: tri-leptons (prelim.2004)
- **Extra Dimensions**: Large ED, Randall-Sundgrum graviton (prelim.2004)
- **Exotics**:
  - Z' (prelim.2004),
  - technicolor (prelim.2004),
  - compositeness in ee (prelim.2004) and μμ (NEW)
  - 1rst generation leptoquarks (hep-ex/0412029,PRL),
  - superjets (hep-ex/0411084, PRL)

mSUGRA trileptons searches

mSUGRA is the simplest SUSY model,
it requires only 5 parameters:
m_0, $m_{1/2}$, tanβ, sign(μ), A_0

trileptons final state:

- a clean SUSY signature for chargino-neutralino production, decaying into WZ or sleptons + 2 LSP
- low SM background, but also small signal cross section (σ BR < 0.5 pb)
- strategy: using ~320 pb-1
  combine eel, μμl, eμl, $\mu^{+-}\mu^{+-}$(l), eτl, μτl
- selection:
  2 well identified leptons (pt>~10GeV)
  3rd lepton = isolated track (pt>~5GeV)
  missing E_T >~20 GeV

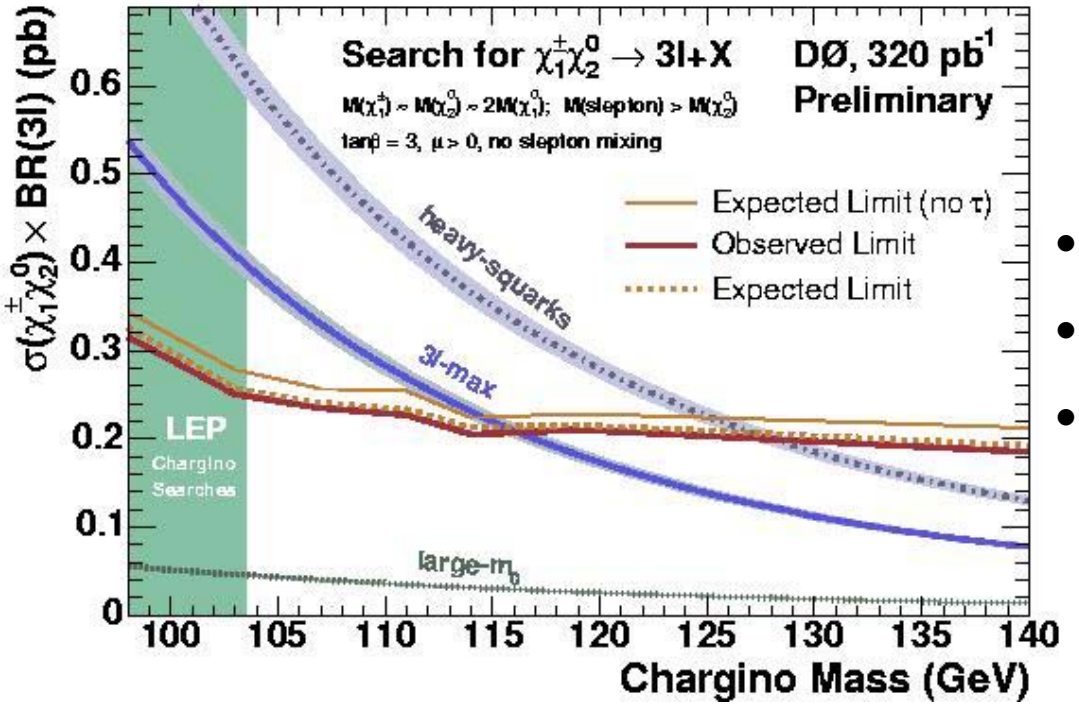


mSUGRA trileptons combined result

(hep-ex/0504032, to PRL)

	data	bkg
eel	0	0.21 ± 0.11 ± 0.05
eμl	0	0.31 ± 0.13 ± 0.03
μμl	2	1.75 ± 0.37 ± 0.44
$\mu^{\pm}\mu^{\pm}$l	1	0.64 ± 0.36 ± 0.13
eτl	0	0.58 ± 0.11 ± 0.09
μτl	1	0.36 ± 0.12 ± 0.06
total	4	3.85 ± 0.57 ± 0.49

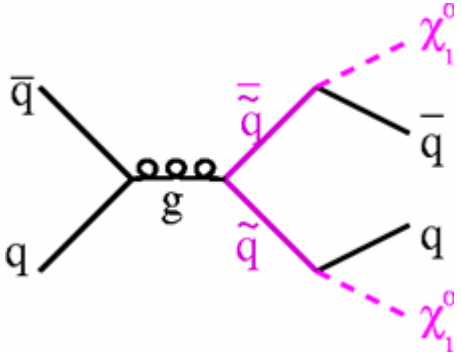
NEW



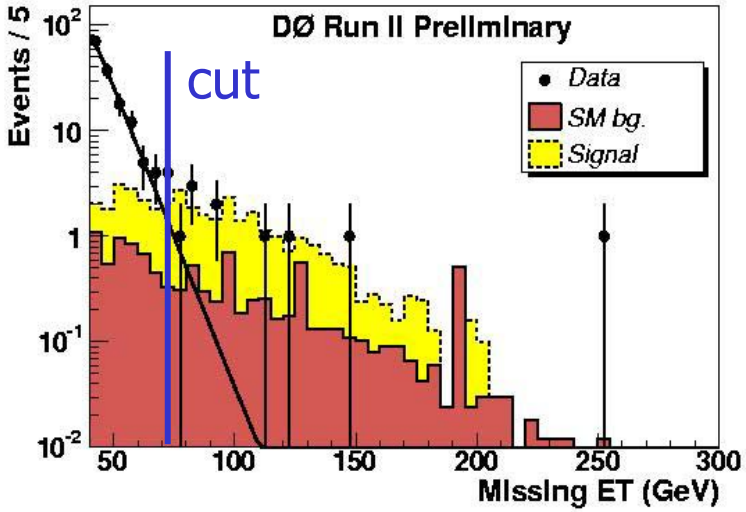
- limits provided within
  tanβ=3, μ>0, no slepton mixing
- and compared to 3 scenarios (Beenakker et al., PRL 83 (1999) 3780)
  - heavy squarks and light sleptons without negative interference at production)
  - 3lmax: light slepton mass > m(χ^0_2)
  - large m0: jaugino decay to virtual W*/Z* only
- adding taus help, even at low tanβ
- better than at Run I (limit ~1.5 pb)
- will still improve with higher luminosity

mSUGRA squark/gluino search

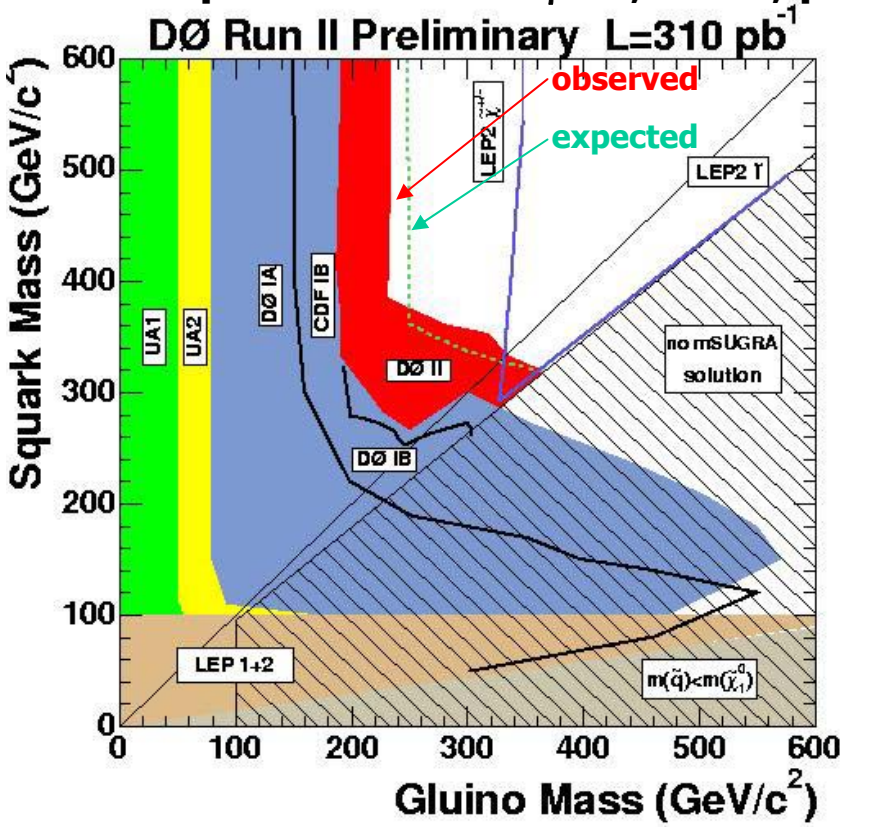
- 4 production processes: $\tilde{q}\bar{\tilde{q}}, \tilde{q}\tilde{q}, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$
- the dominant Br are into **jets + missing E_T**
- 3 mass figures considered:
  1) $m(\tilde{g})>m(\tilde{q})$: accoplanar dijets
     expected 12.8±5.4, observed 12
  2) $m(\tilde{q})>m(\tilde{g})$: multi (>=4) jets
     expected 7.1±0.9, observed 10
  3) $m(\tilde{q})\sim m(\tilde{g})$: 3 jets
     expected 6.1±3.1, observed 5



example of >= 4jets

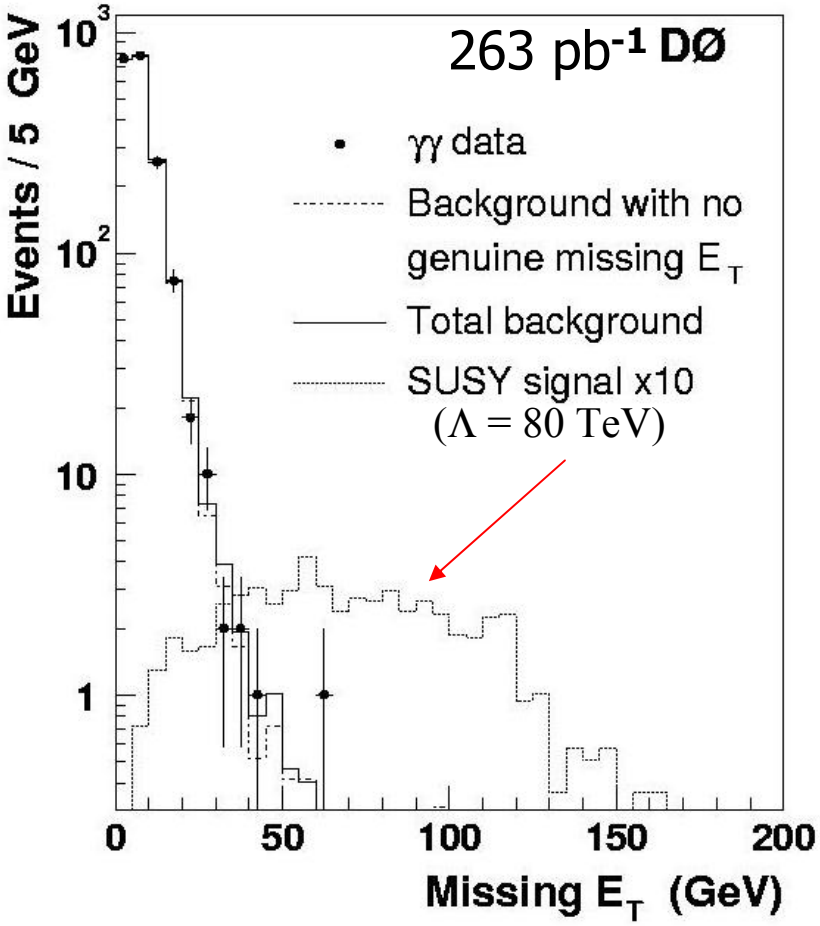


limits provided for tanβ=3, A0=0, μ<0



GMSB analyses

if $\tilde{\chi}_1^0$ is the NLSP, than it decays into $\tilde{G}\,\gamma$ and as it is produced in pair, one can detect 2 energetic photons + missing E_T: apply E_T (γ) >20 GeV, $\not{E}_T$ > 40 GeV



2 observed candidates, 3.7±0.6 expected:
$m(\tilde{\chi}_1^0) > 108$ GeV (95% CL)
$m(\tilde{\chi}^\pm) > 195$ GeV (95%CL)
most precise to date (PRL 94 (2005) 041801)

if stau NLSP and gravitino/goldstino LSP:
possibility to have a long stau lifetime
⇒ would look like muons, but with non-consistent invariant mass and speed
rely on the timing of μ+μ- pair candidates measured in muon sub-detector NEW

Can be extrapolated to stable charginos and allow to infer 95% CL limits:
Gaugino-like chargino mass > 174 GeV
Higgsino-like chargino mass > 140 GeV
(using 390 pb^{-1})
best limits to date for stable charginos

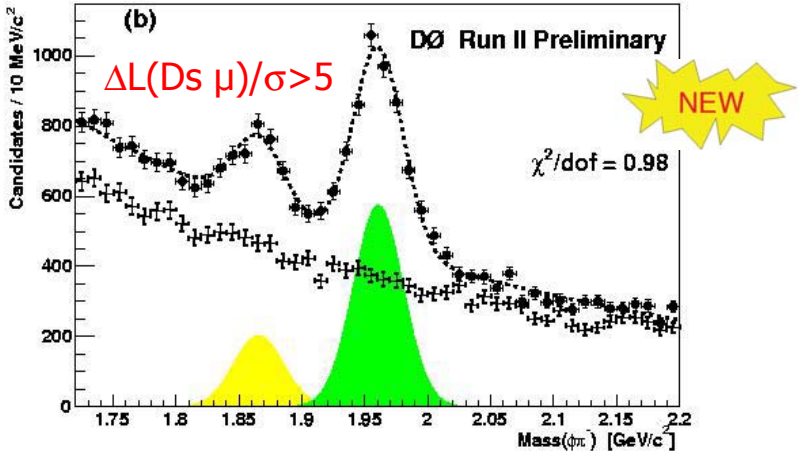
B physics

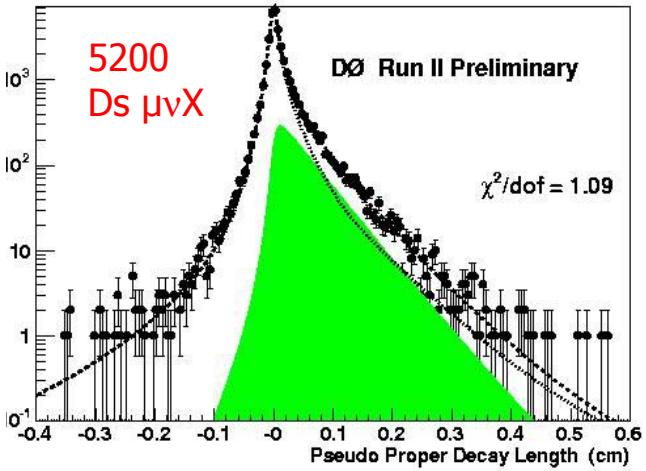
- B-hadron lifetimes
- Rare B and D decays
- Bs mixing
- Bs lifetime difference

b-hadron lifetimes

(*) Gabbiani et al., PRD 70, 094031 (2004)

			PDG 2004	theory (*)
B^0 (J/Ψ)	220pb^{-1} PRL 94, 042001 (2005)	1.473±0.051±0.023 ps	1.536±0.014 ps	
B^-/B^0 (s.l)	440pb^{-1} hep-ex/0410052 (PRL)	1.080±0.016±0.014	1.086±0.017	1.06±0.02
Bs (s.l)	400pb^{-1} prelim.2005	1.420±0.043±0.057 ps	1.461±0.057 ps	
(J/Ψ)	220pb^{-1} PRL 94, 042001 (2005)	1.444±0.094±0.020 ps		
Bs/B^0 (J/Ψ)	" "	0.980±0.074±0.003	0.951±0.038	1.00±0.01
Λb (J/Ψ)	250pb^{-1} hep-ex/0410054 (PRL)	1.22±0.20±0.04 ps	1.229±0.080 ps	
Λb/B^0 (J/Ψ)	" "	0.97±0.16±0.03	0.800±0.053	0.86±0.05
Bc (s.l)	210pb^{-1} prelim.2004	0.45±0.11±0.12 ps	0.46±0.17 ps (CDF Run I)	





most precise to date

rare decays

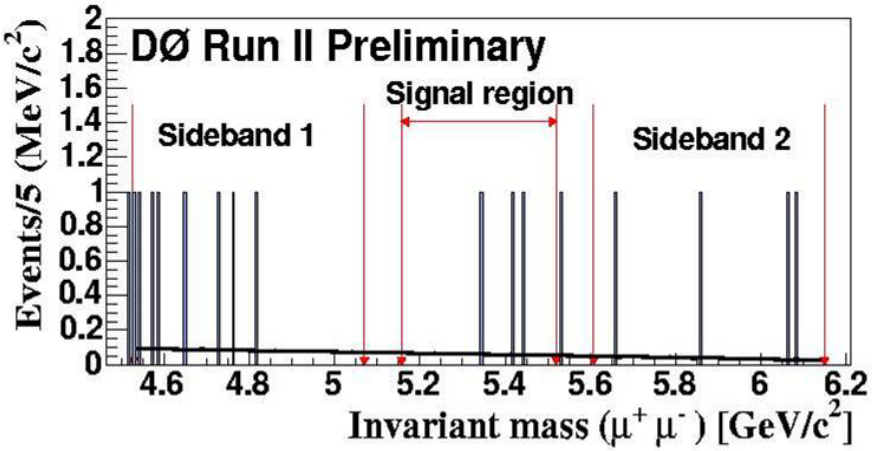
FCNC searches :

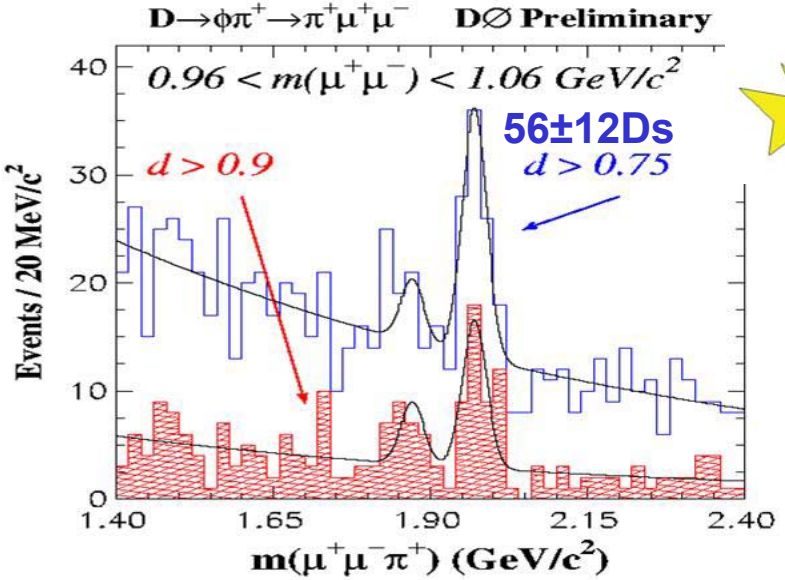
Bs→μ+μ-

2004 analysis (PRL 94 (2005) 071802) with 240 pb^{-1}: Br<5.0 10-7 (95%CL)

2005 update with 300 pb^{-1}:

. Br<3.7 10-7 (95%CL)





NEW

56±12 $D_s^- \to \Phi\pi^- \to \mu^+\mu^-\pi^-$ observed

upper limit on $D^- \to \Phi\pi^- \to \mu^+\mu^-\pi^-$

with 508 pb^{-1}: Br < 3.1 10-6 (90% CL)

Bs / $\bar{B}$s mixing

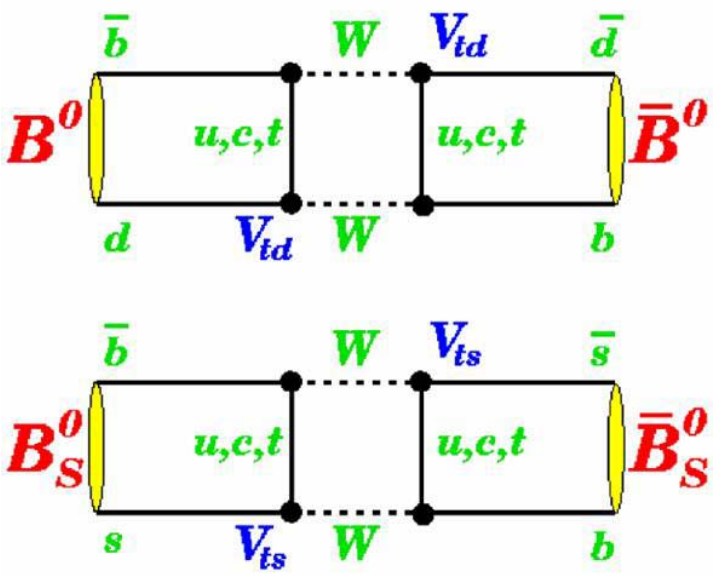
B/$\bar{B}$ mixing: 2 physical states, Heavy and Light

$$i\frac{d}{dt}\begin{pmatrix}|B_s(t)\rangle\\|\bar{B}_s(t)\rangle\end{pmatrix}=\left(M-i\frac{\Gamma}{2}\right)\begin{pmatrix}|B_s(t)\rangle\\|\bar{B}_s(t)\rangle\end{pmatrix}$$

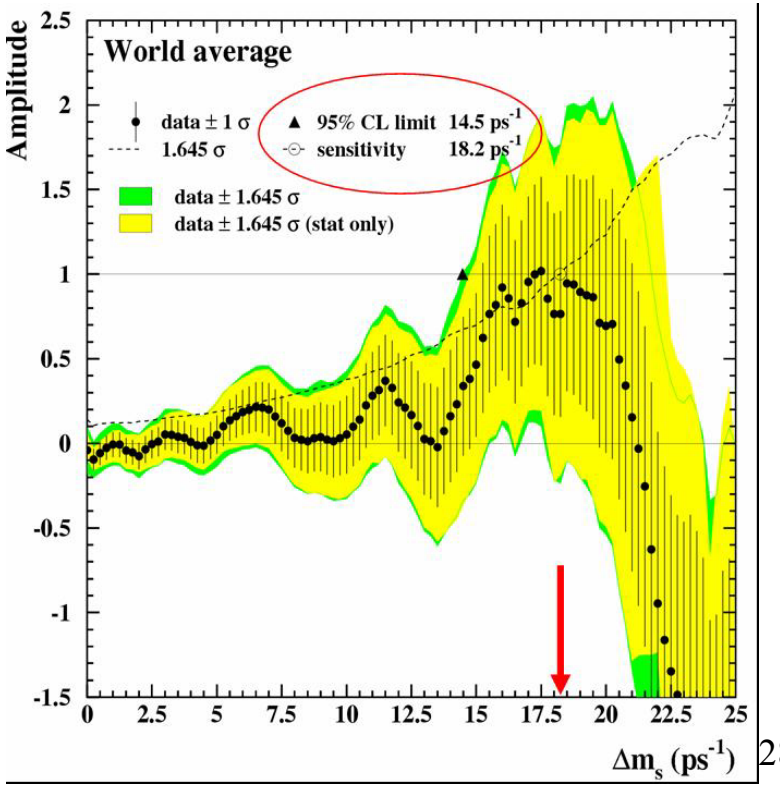
$$\Delta m = M_H - M_L \approx 2|M_{12}|$$

$$\Delta\Gamma = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos\phi$$

CP violating phase $\phi = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$



- In SM: constrains Vtd and Vts elements of CKM matrix
- new physics ($\delta\Phi$) → new particles in the box
- mixing frequency **Δmd** measured with high precision at B factories : **0.510 ± 0.005 ps^{-1}**, HFAG 2005
  (0.456 ± 0.034 ± 0.025 ps^{-1}, D0 prelim.2004)

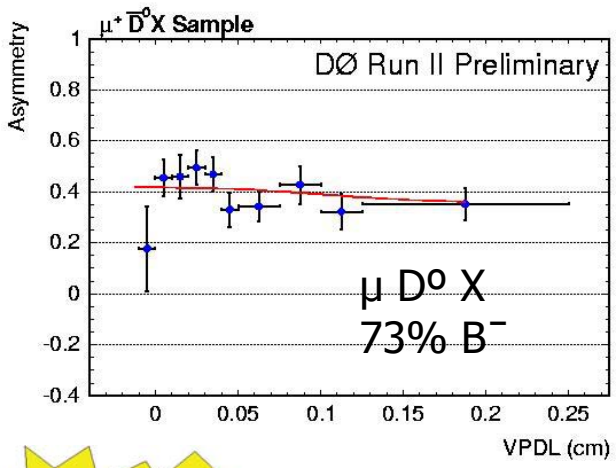


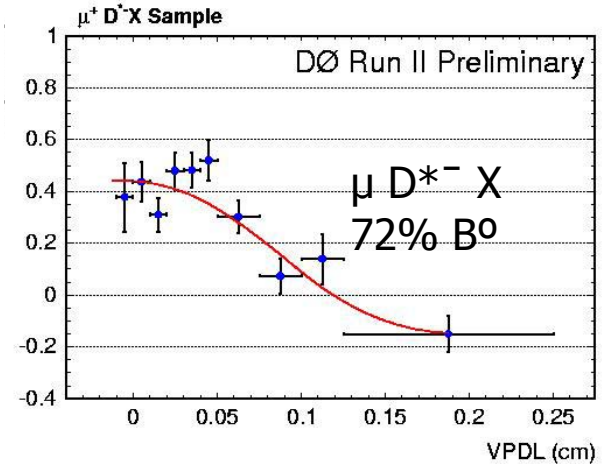
- $\Delta m_s/\Delta m_d$ is free from many theoretical uncertainties
- fit data to P = ½ Γ exp(-Γt) [1 ± **A** cos(Δms t)]
- but oscillation in Bs system hasn't been observed yet:
  only limit so far : Δms < 14.5 ps^{-1} (95% CL)
  SM fit : Δms = 20.6 ± 3.5 ps^{-1}

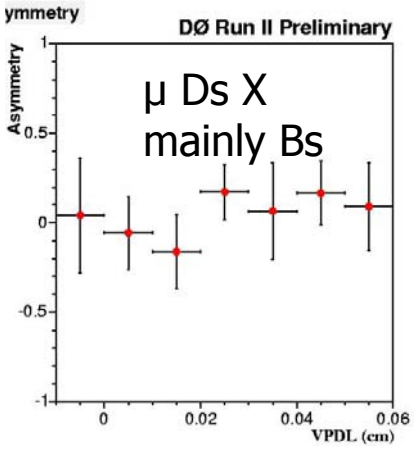
Bs mixing analysis

- with 450 pb^{-1}:
use 680 Bs→Ds μ X (Ds→Φπ, Φ→KK)
with ΔL<0.06cm (best σ(t) resolution)

- opposite side tag with μ+sec.vertex
- check method on D^0μX and D^{*-}μX (Δm_d)

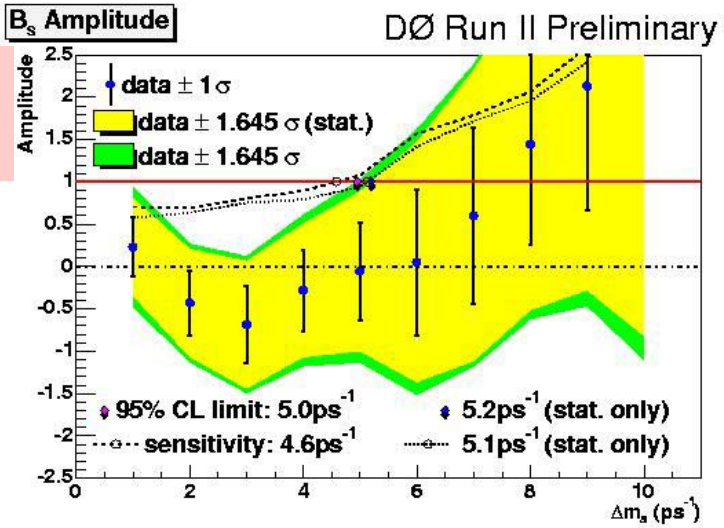






NEW

No oscillation observed in Ds μ X sample: **$\Delta m_s > 5.0\ ps^{-1}$ (95% CL)**



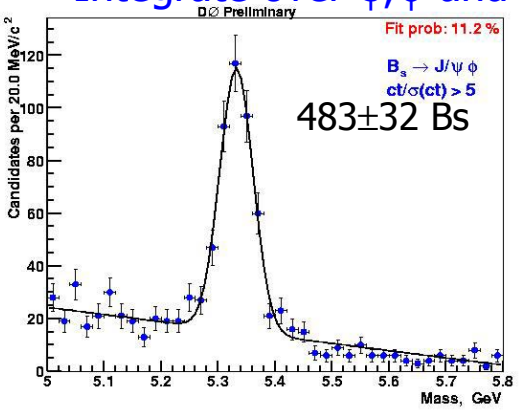
improvements foreseen:
- more Bs decay channels (K*K, KºK, 3π), improve σ(t) resolution, flavor tag (e), Bs purity
- then SMT layer 0 (2006) + proposal for dedicated 50Hz data taking rate)

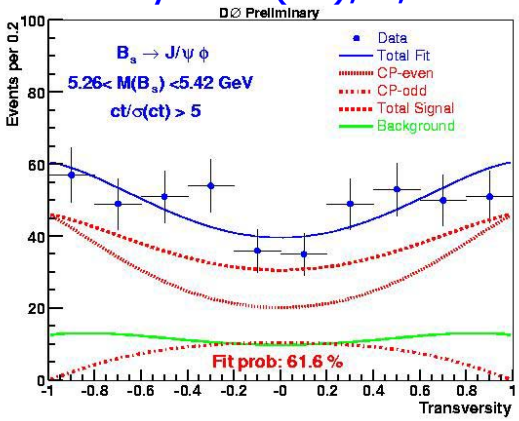
$\Delta\Gamma_s/\Gamma_s$ angular analysis

- **$B_s \to J/\psi\,\Phi$** is a mixture of CP =+1 and CP = -1 states
- three-angle distribution for B_s decay (θ,φ,ψ are muon and K angles in J/ψ and Φ rest frames)

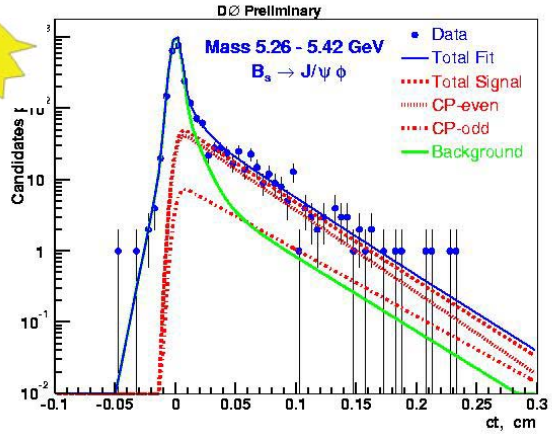
$$\Gamma[B_s(t) \to J/\psi(\to l^+l^-)\phi(\to K^+K^-)] \Big/ d\cos\theta\, d\varphi\, d\cos\psi = \Gamma(\theta,\varphi,\psi,t)$$

- Integrate over φ,ψ and simultaneously fit m(Bs), θ, and ΔL(Bs)





NEW



- **preliminary results:** (with 450 pb-1)

  measure: $\Delta\Gamma/\Gamma = 0.21^{+0.27}_{-0.40}$, $\tau(Bs) = 1.39 \pm 0.14$ps

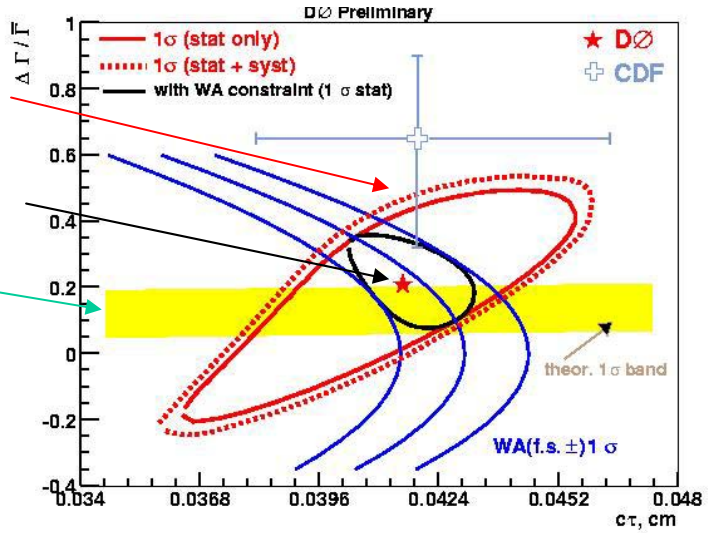
  if fix $\tau(B_s \to D_s l\nu X) = 1.42 \pm 0.07$ps:

  . $\Delta\Gamma/\Gamma = 0.23 \pm 0.17$, $\tau(Bs) = 1.39 \pm 0.05$ps

  if fix $(\Delta\Gamma/\Gamma)_{SM} = 0.12 \pm 0.05$ and $\Phi_{SM} = -0.03$

  CP violating angle $\cos(\delta\Phi) = 1.46 \pm 0.71$

  (compatible with $\delta\Phi = 0$)



Conclusion

- Most analyses are already more precise than at Run I,
  B physics is new for DØ and is performing quite well,
  one explores SUSY mass limits higher than at LEP

- All analyses will benefit from increased statistics: at present
  200-500 pb^{-1} have been studied, 680 pb^{-1} are already on tapes,
  expect ~ 2 fb^{-1} in 2006, ~ 4 fb^{-1} in 2007, ~ 8 fb^{-1} in 2009

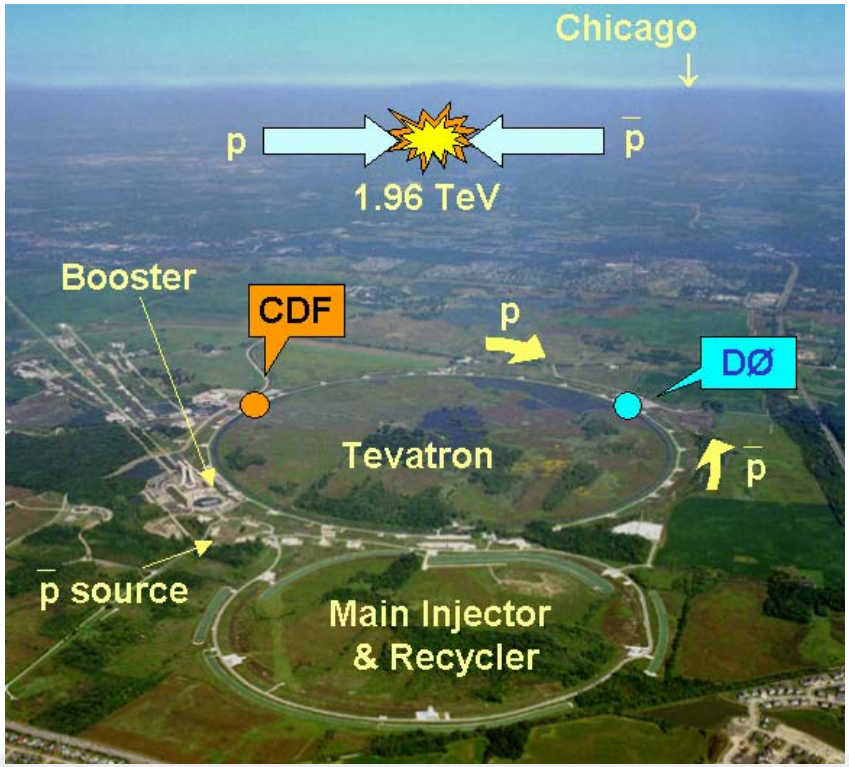
- But for many topics, the systematics have already to be reduced:
  jet energy calibration (affects almost everything), but
  higher statistics will help as systematics rely also on real data

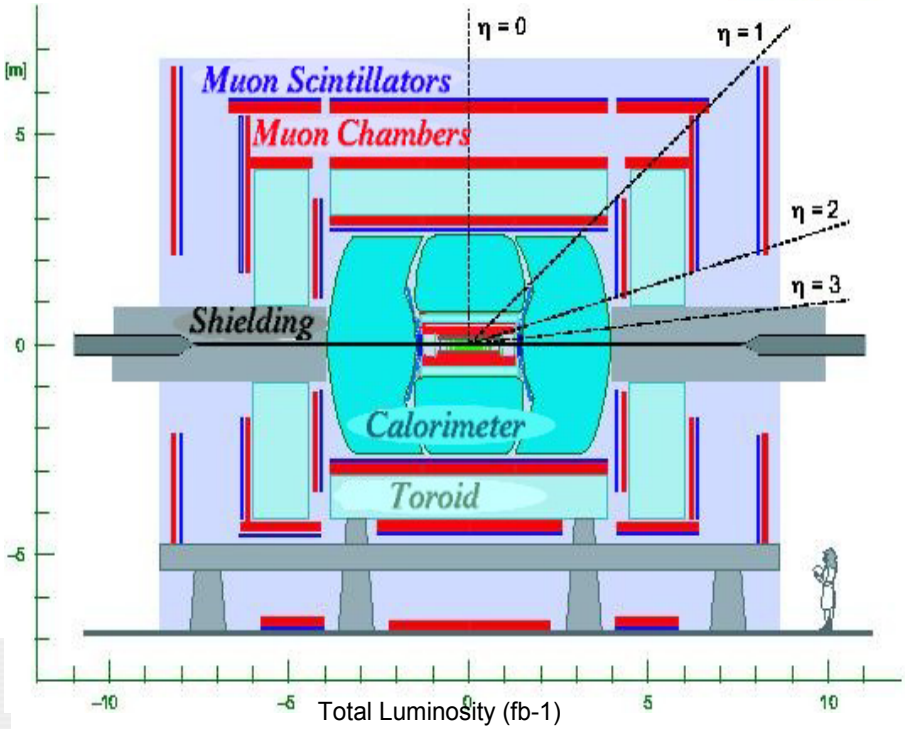
- Identification efficiencies can still improve (lepton-id, b-tagging)

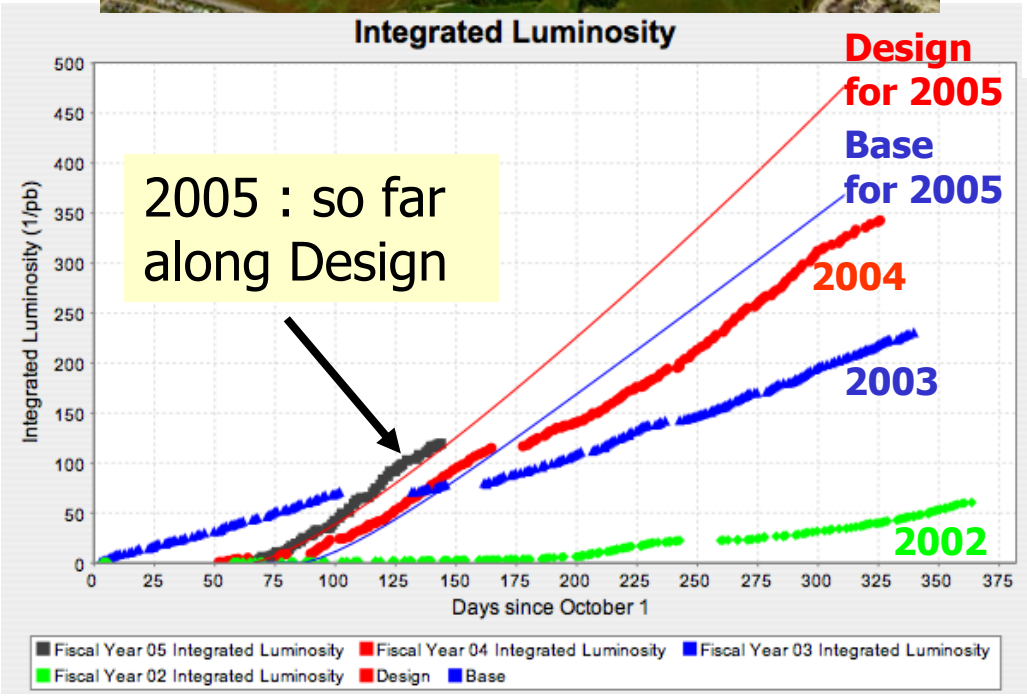
- 2006 upgrade:
  - new silicon tracker layer 0 : further improvement in b-tagging
  - proposal for dedicated 50Hz data taking rate for B physics

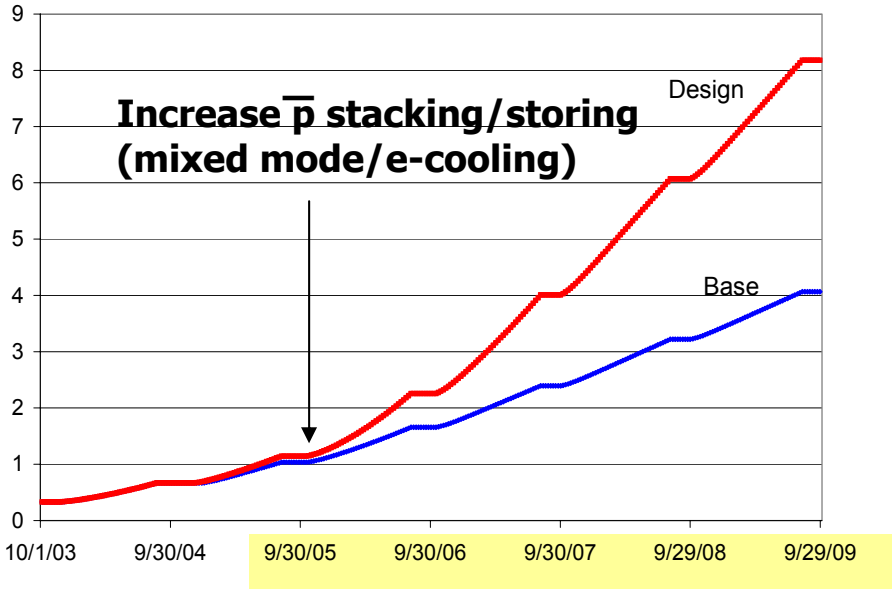
a very rich physics program expected in the coming years !

BACKUP


Chicago
p
p̄
1.96 TeV
Booster
CDF
p
DØ
Tevatron
p̄
p̄ source
Main Injector
& Recycler


η = 0
η = 1
η = 2
η = 3
[m]
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid
Total Luminosity (fb-1)


Integrated Luminosity
Design
for 2005
Base
for 2005
2004
2003
2002
2005 : so far
along Design
Integrated Luminosity (1/pb)
Days since October 1
Fiscal Year 05 Integrated Luminosity
Fiscal Year 04 Integrated Luminosity
Fiscal Year 03 Integrated Luminosity
Fiscal Year 02 Integrated Luminosity
Design
Base


Increase p̄ stacking/storing
(mixed mode/e-cooling)
Design
Base
10/1/03
9/30/04
9/30/05
9/30/06
9/30/07
9/29/08
9/29/09