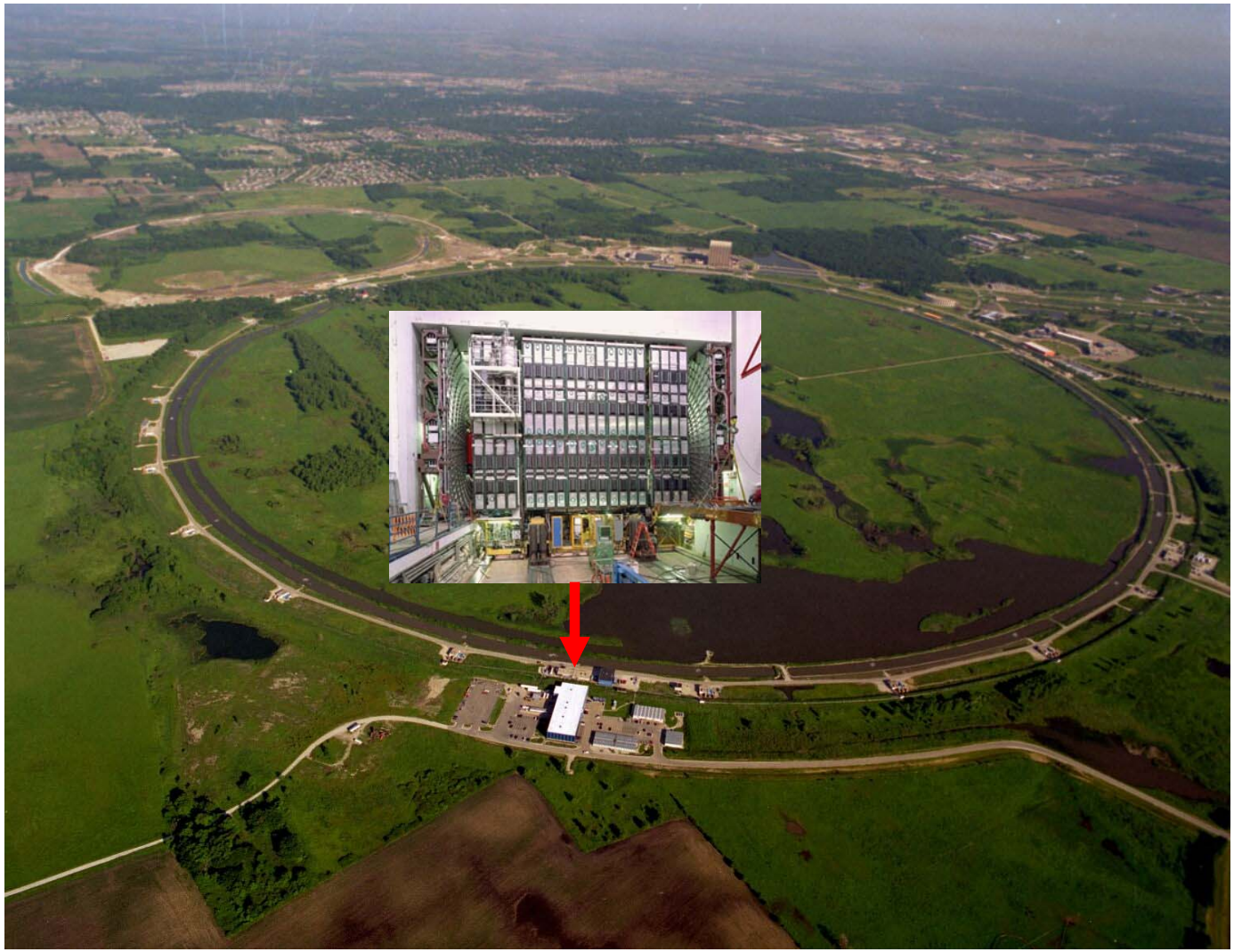
# The DØ Research Program



**Dmitri Denisov, Fermilab**

**April 22 2005, URA Review**

# The DØ Collaboration

**DØ is an international collaboration of ~ 670 physicists from 19 nations who have designed, built and operate a collider detector at the Tevatron**

**Institutions: 84 total, 35 US, 49 non-US**

**Collaborators:**
**~ 50% from non-US institutions**
**(note strong European involvement)**
**~ 100 postdocs, 140 graduate students**

# Physics Goals

**Precision tests of the Standard Model**

- **Weak bosons, top quark, QCD, B-physics**

**Search for particles and forces beyond those known**

- **Higgs, supersymmetry, extra dimensions….**

**Fundamental questions**

**Quarks sub-structure?**

**What is cosmic dark matter? SUSY?**

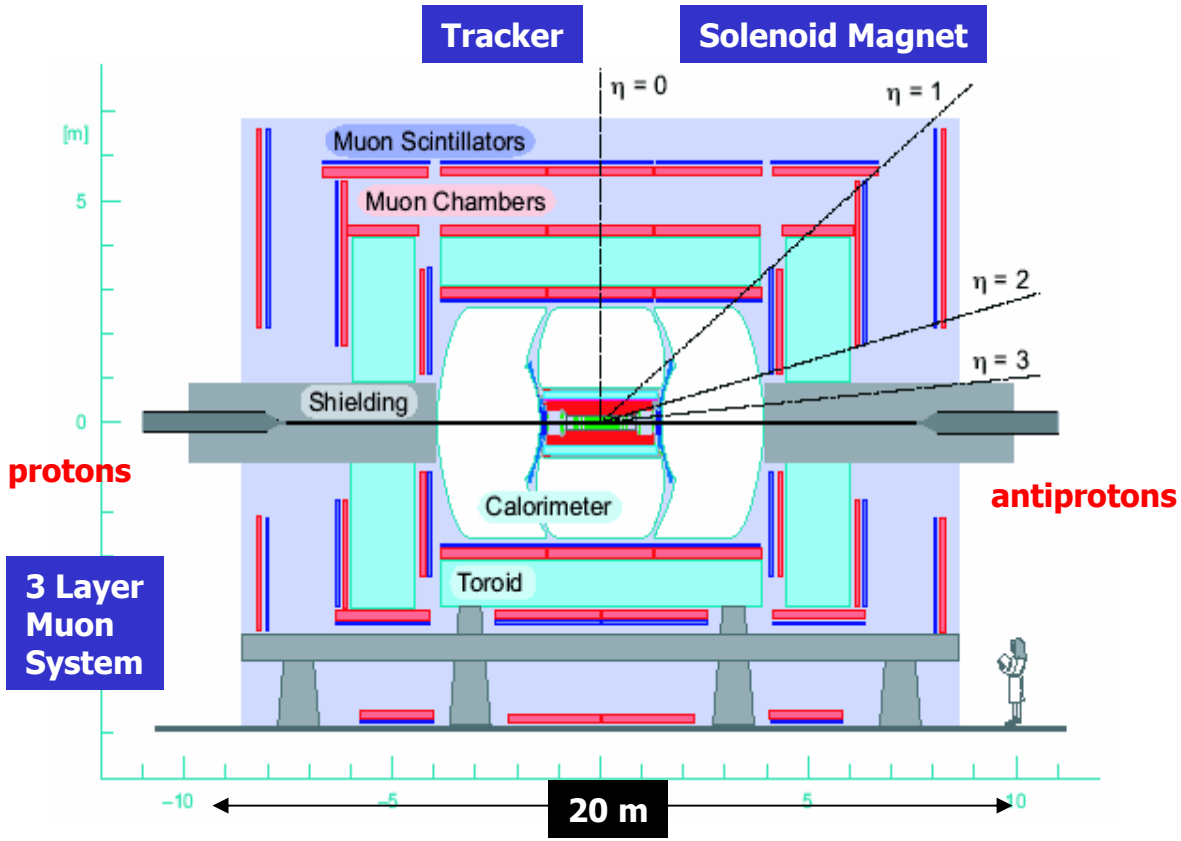
**What is spacetime structure? Extra dimensions?…**

**Driven by these goals, the detector emphasizes**

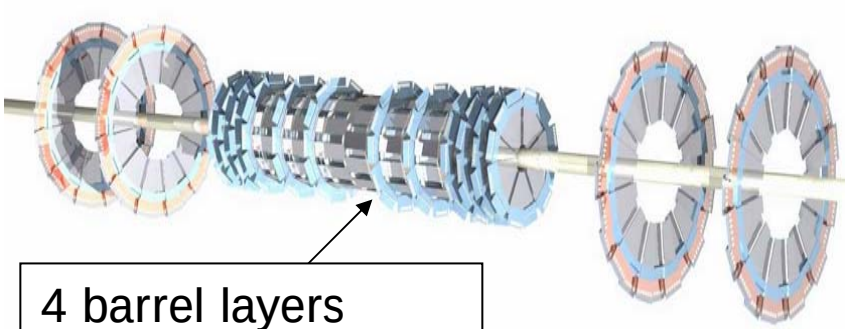
**Electron, muon** and **tau** identification

**Jets** and **missing transverse energy**

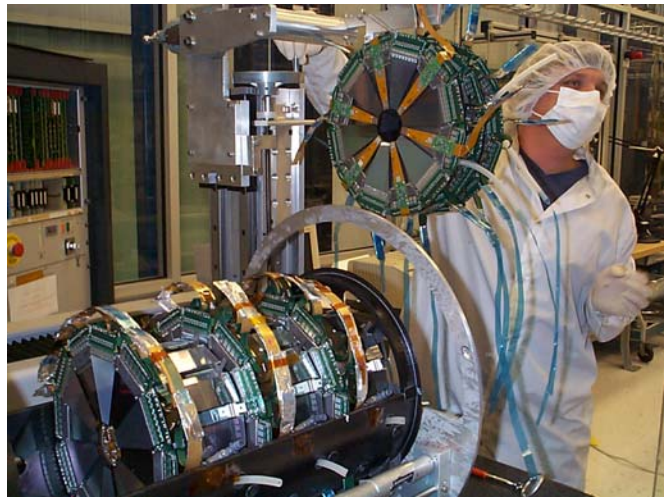
**Flavor tagging** through **displaced vertices** and **leptons**

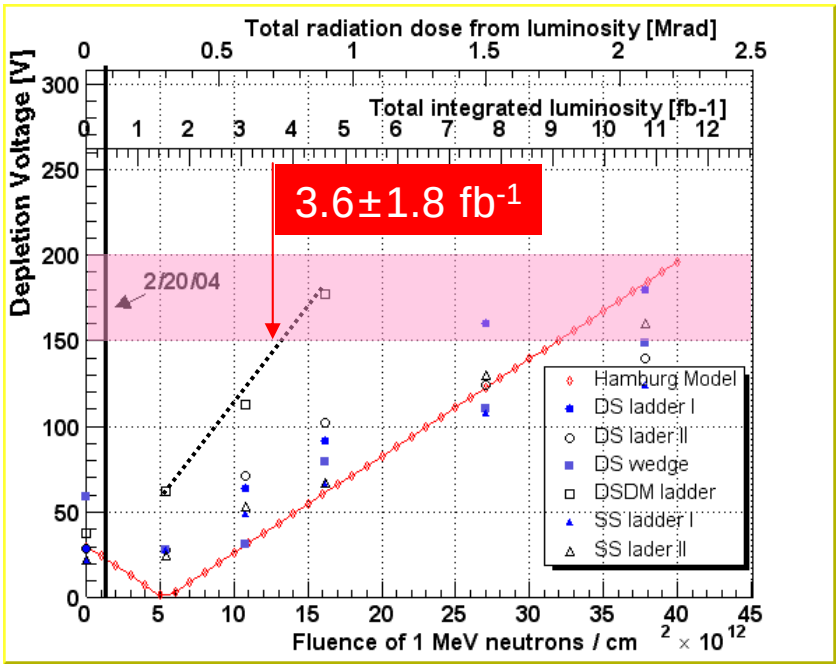


# Silicon Microstrip Tracker

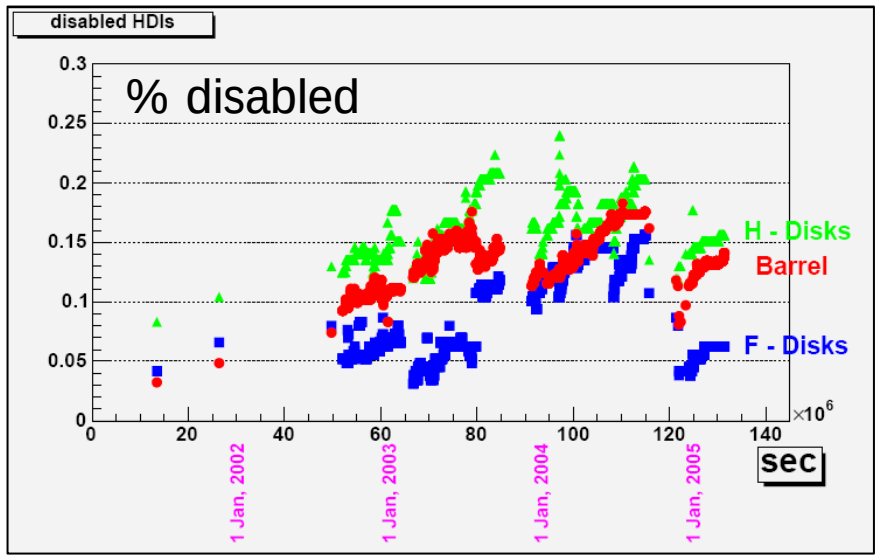


4 barrel layers
axial + stereo strips





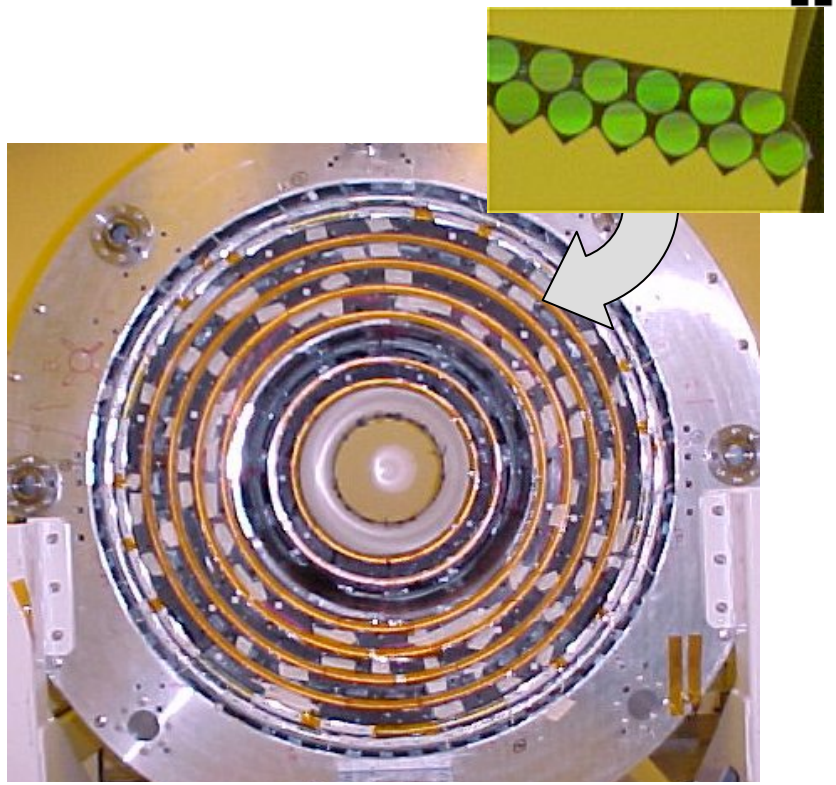

**Detector working very well**
There is some concern over mortality

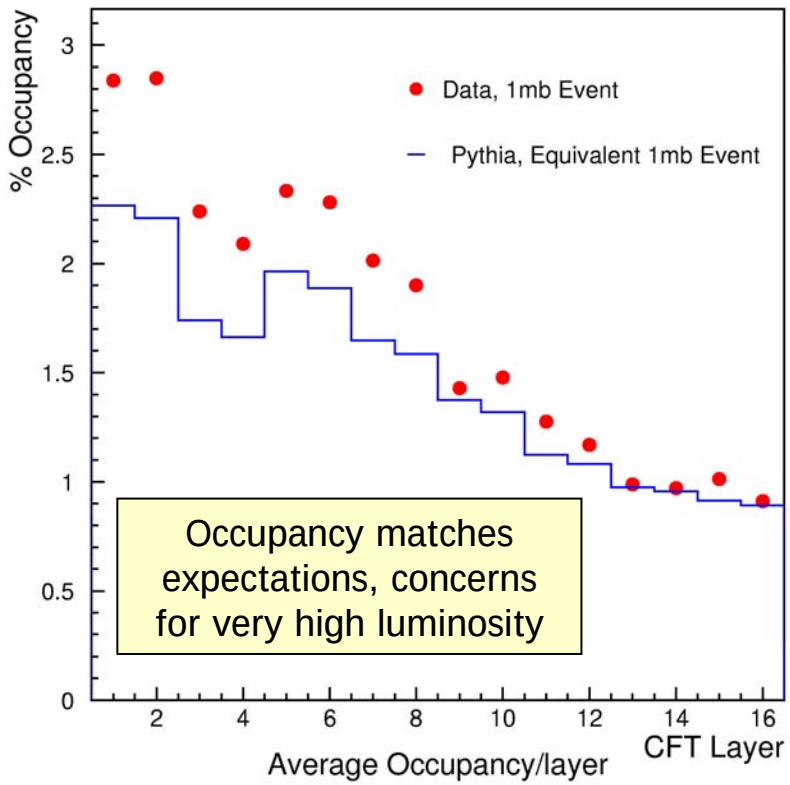



Radiation dose → no substantial changes in depletion voltage up to now

# Scintillating Fiber Tracker

- 8 axial, 8 stereo fibers double layers
- VLPC readout
- Performing well
  - good light yield of ~7 phe/mip
  - per layer $\varepsilon$ > 98%






Occupancy matches expectations, concerns for very high luminosity

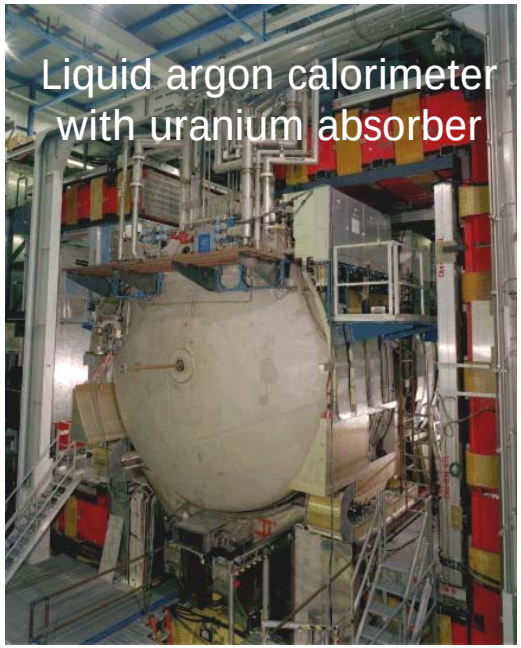
**~2% of VLPC channels not functional since November '03 shutdown**

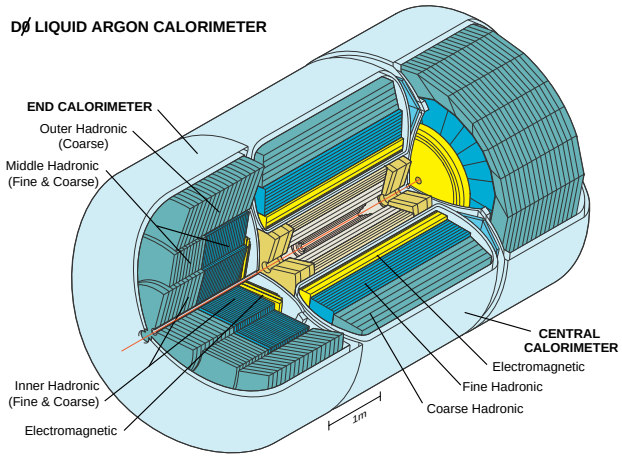
- Was 0.1% before
- Attributed to cryostat warm up/contamination

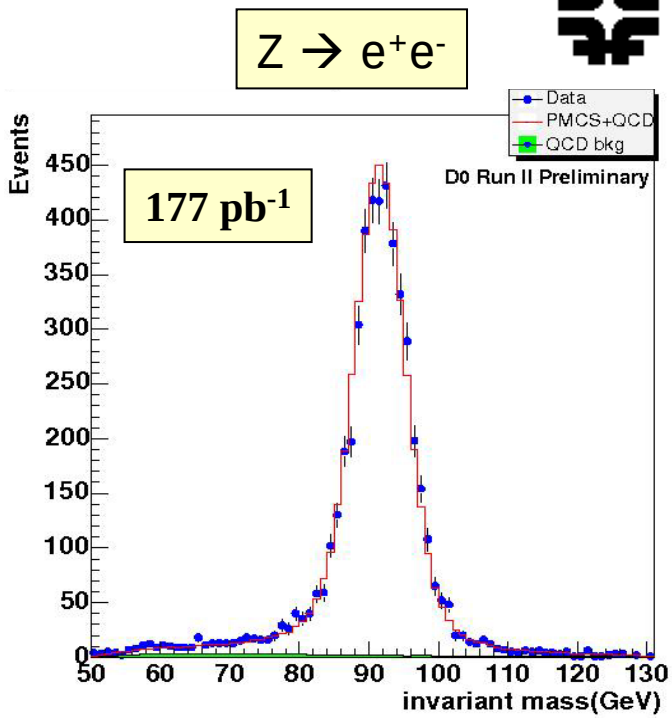
**Attempted to fix problem in November '04**

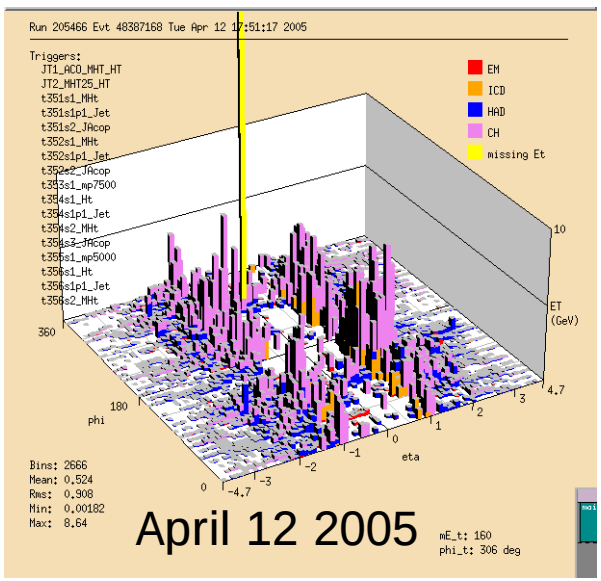
- Again ~2% not functional VLPCs?
- But different set of channels… watching closely

# Calorimeter




Stable and reliable operation

- less then 0.1% of non-working channels

**Periodic problems with noise (~1% of data affected)**

- **pickup from crane/welding**
- **muon toroids**
- **unknown**

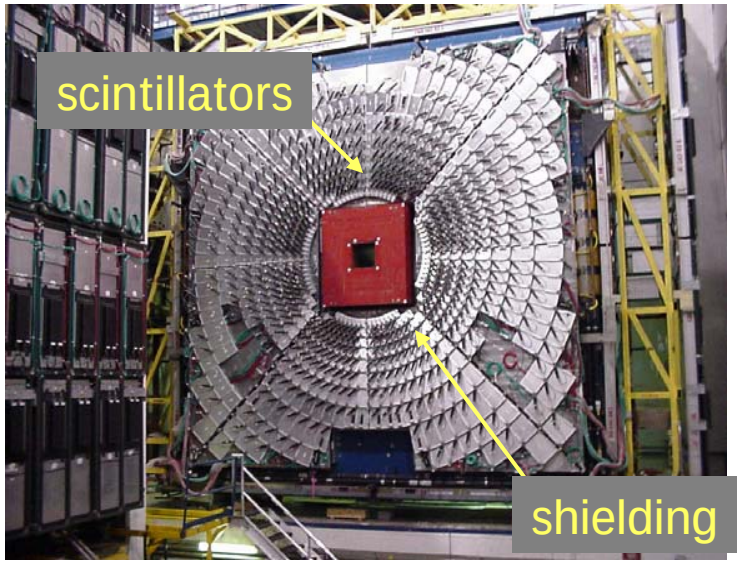
**Better detector grounding during '04 shutdown**

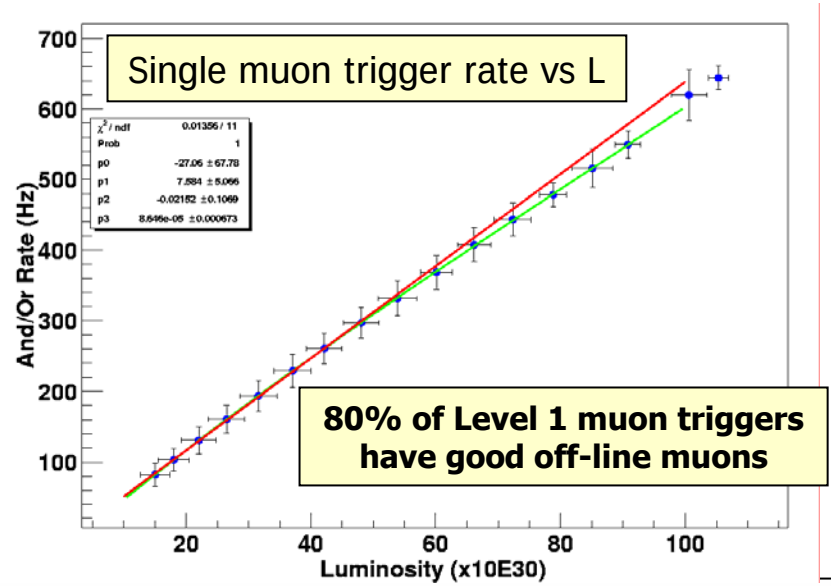
- **some sources of noise reduced**

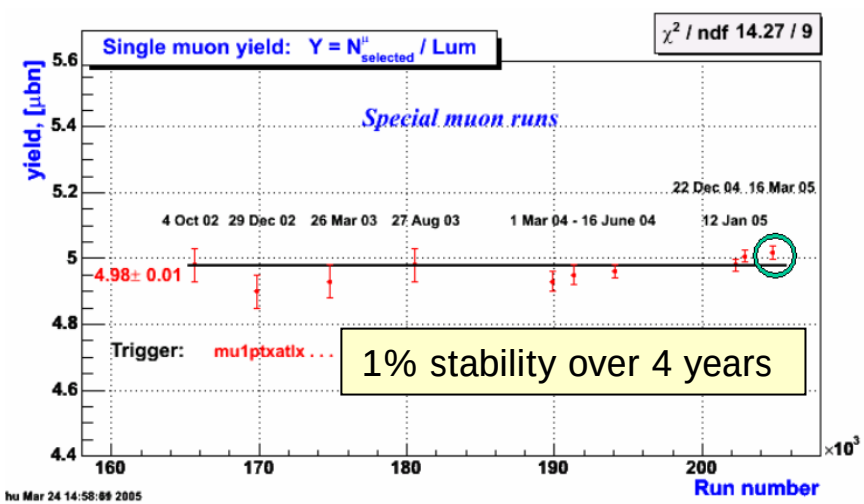
**Calibration of detector with electron drift time above bunch spacing is a challenging task**
**Collected large data set for calibration**

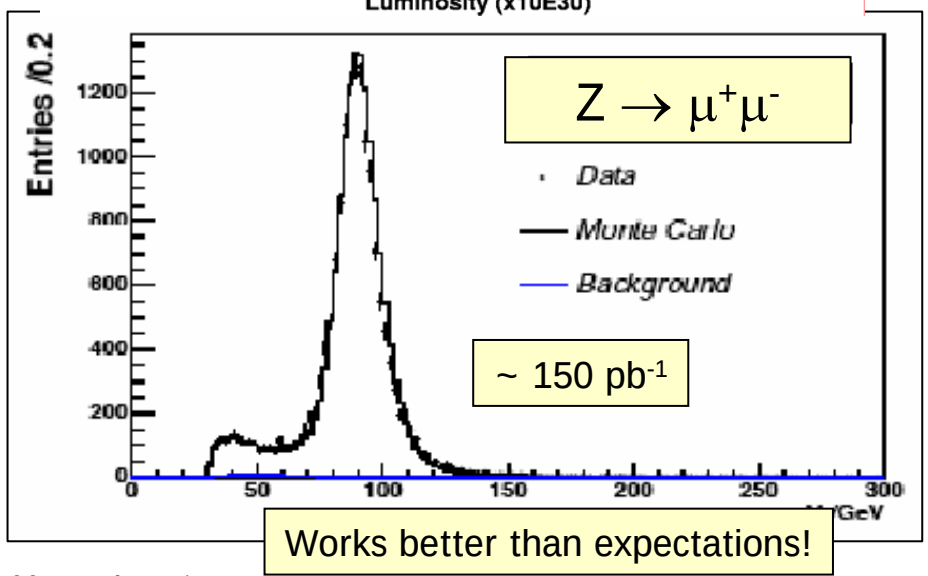
# Muon System

Three layers of scintillator planes for triggering
Three layers of drift tubes for muon track reconstruction



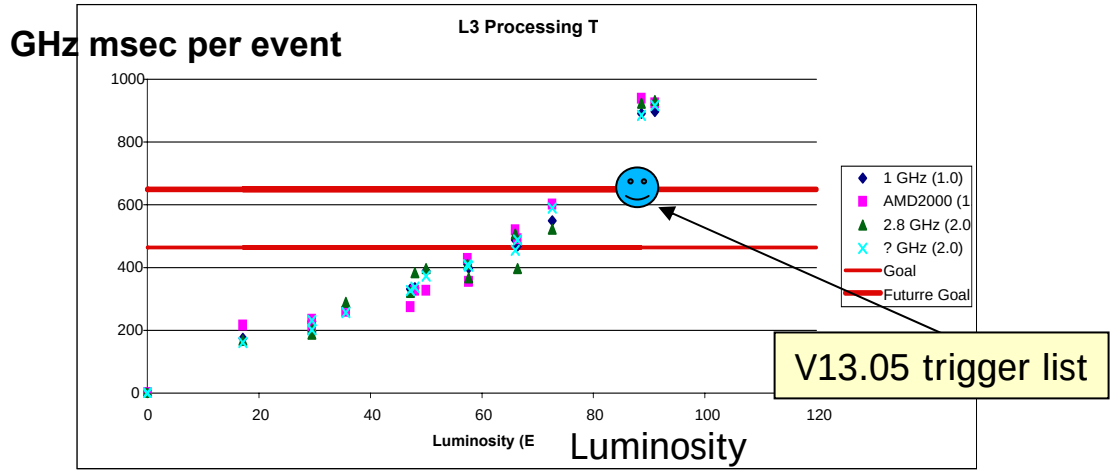



# Trigger System

**Trigger system has to select 50Hz of events to write to tape out of 1.7MHz interactions rate:**

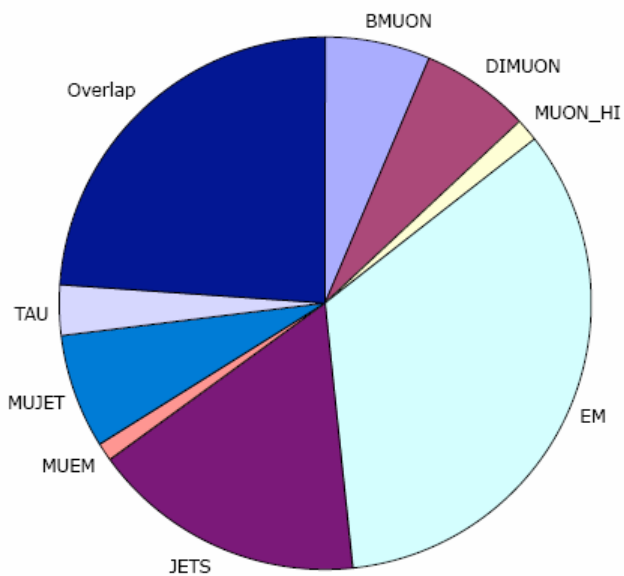
**~ $10^5$ rejection!**

Rate=Lxσ → have to cut harder at high L

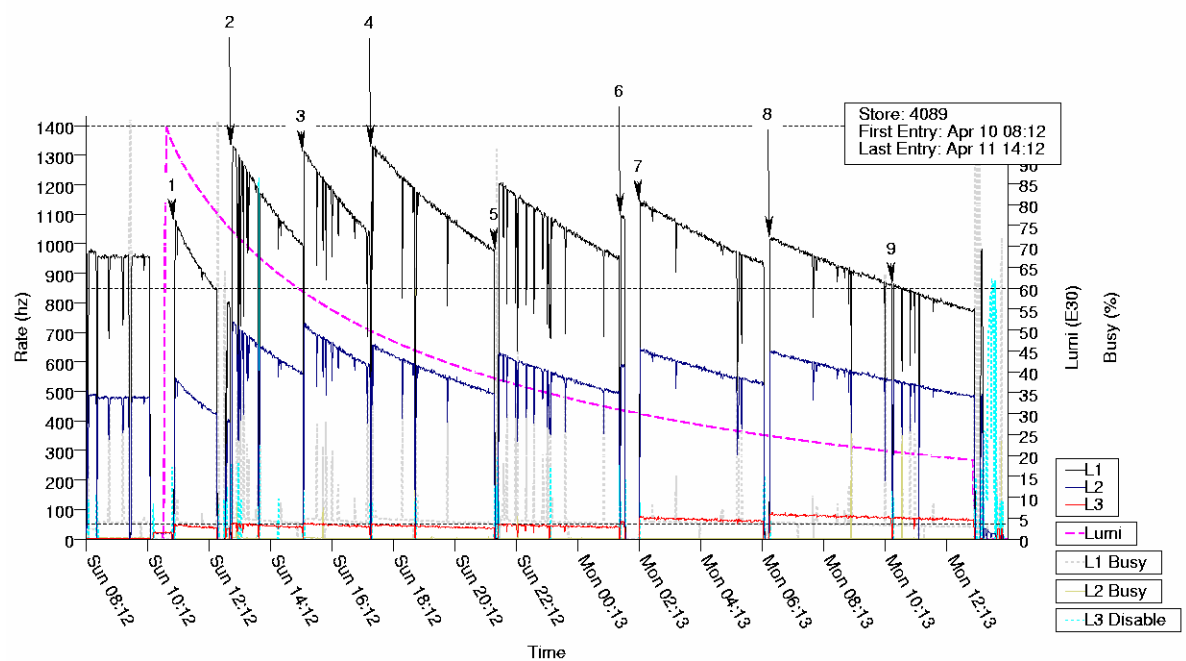



**Current DØ capabilities:**

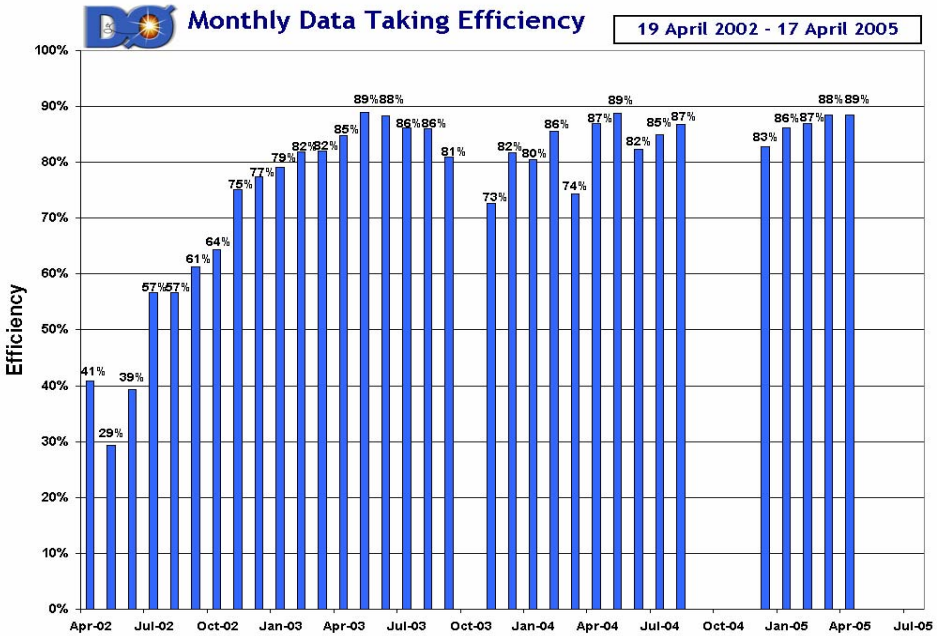
**Level 1 trigger ~2kHz**
**Level 2 trigger ~1kHz**
**Level 3 trigger ~50Hz**

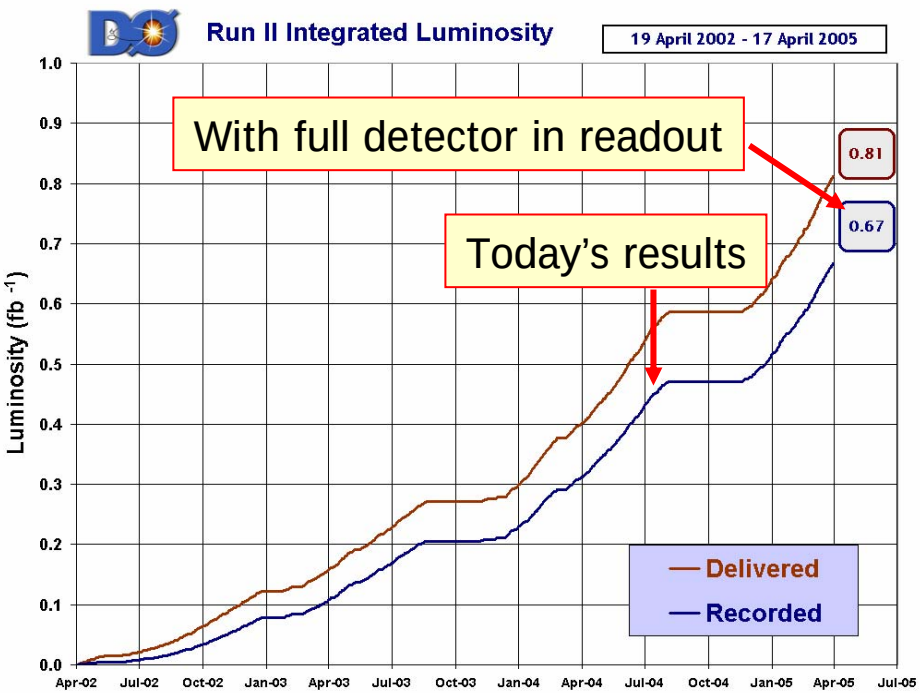



**Level 1 triggers, %**



# Operations




- The experiment is operating well and recording physics quality data with ~90% efficiency
  - Typical "good" day 2 $pb^{-1}$
  - Typical "good" week 14 $pb^{-1}$
    - Run I top quark discovery in 3-4 weeks!
- 90% data taking efficiency
  - 5% are trigger system disables
  - 5% are begin/end stores, failures
- As of today DØ has ~0.7 $fb^{-1}$ on tapes
  - All detectors functioning well
  - Most physics results are from data collected before end of 2004 shutdown

On-line data quality monitoring

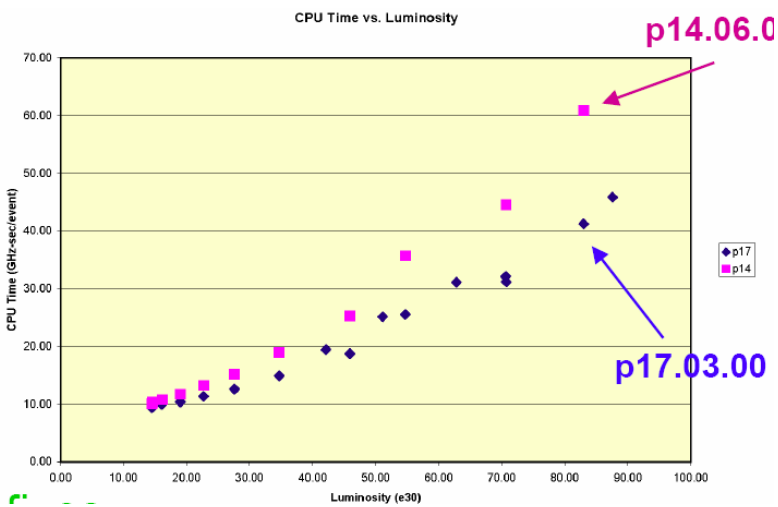
"remote" shifters from all over the World: Europe, Brazil, India, China...

Thanks to Accelerator Division for luminosity!

# Events Reconstruction

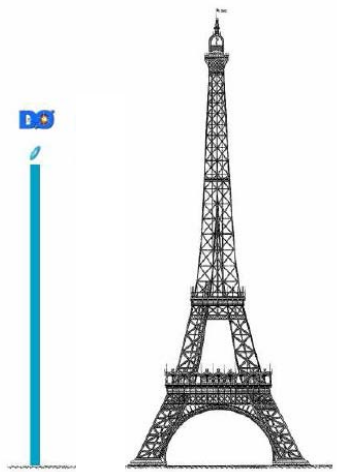
- **DØ collected over $10^9$ events!**
  - **Recently developed new reco program (Version p17)**
    - **Faster**
    - **Better performance**

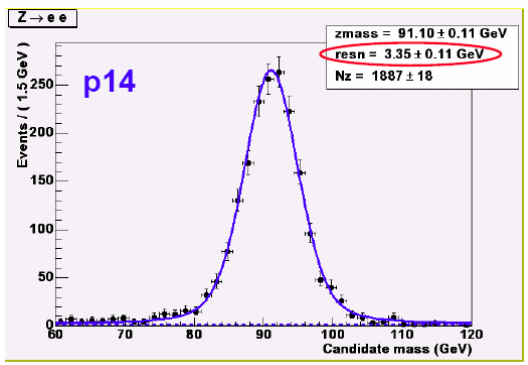
**For uniform and better quality data set have to reprocess all data collected before Autumn 2004 shutdown**

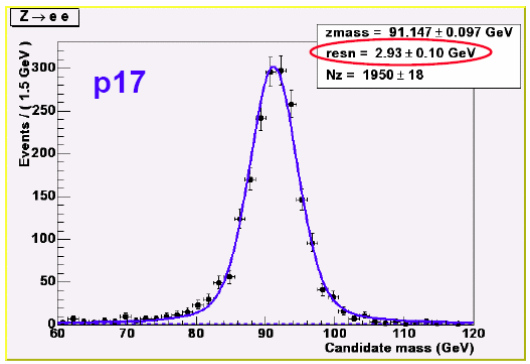



| | p17 reprocessing |
|---|---|
| Luminosity | $470\,\mathrm{pb}^{-1}$ |
| Events | 1G |
| Rawdata 250kB/Event | 250TB |
| DSTs 150kB/Event | 150TB |
| TMBs 20kB/Event | 20TB |
| Time $50s$/Event | $20,000$months |
| (on 1GHz Pentium III) | 3400CPUs for 6mths |
| Remote processing | 100% |

*A stack of CDs as high as the Eiffeltower*

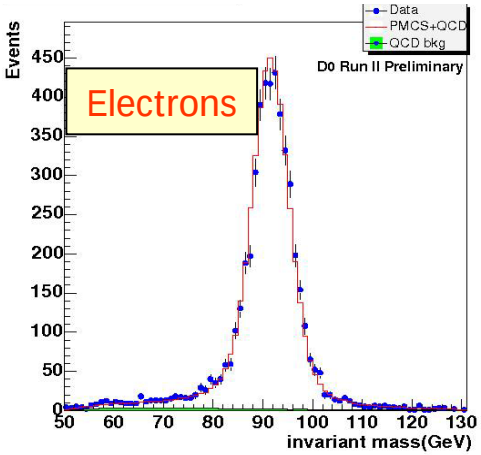


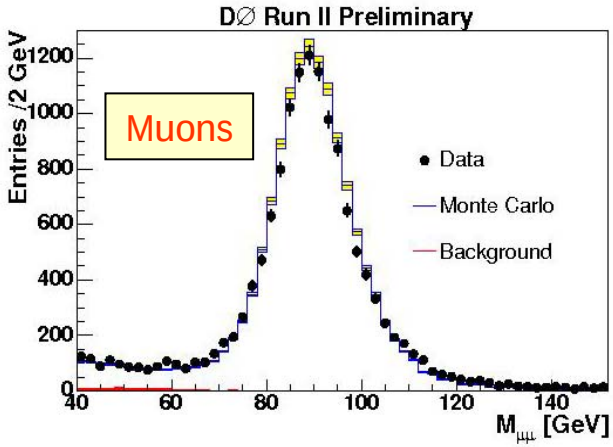


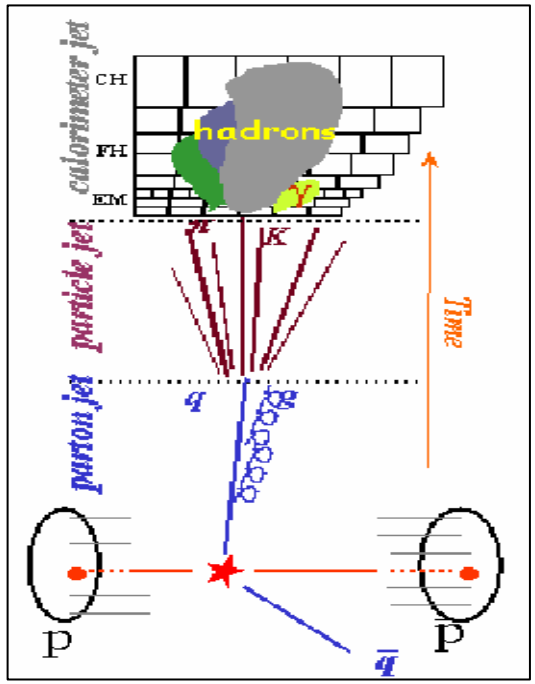



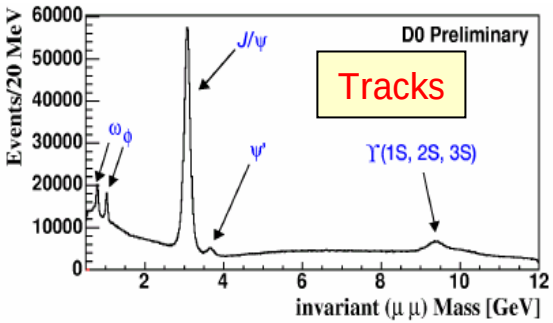

DØ has robust data-handling system (SAM)
which is fully integrated with GRID tools (SAMGRID/JIM)
All reprocessing will be done on remote farms worldwide and
expected to be finished in 6 months

# Objects Identification



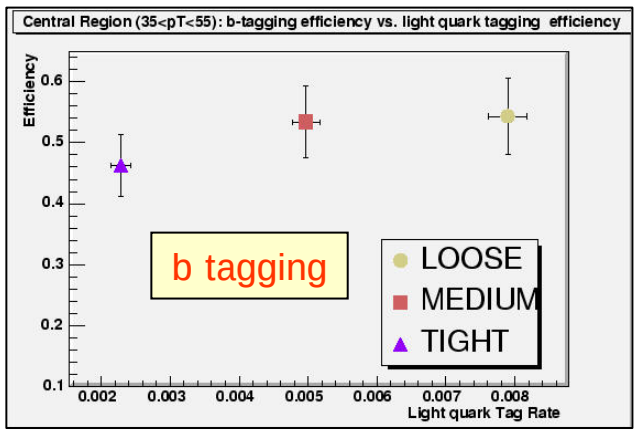



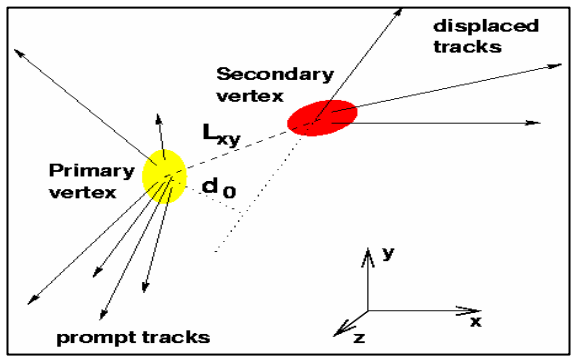



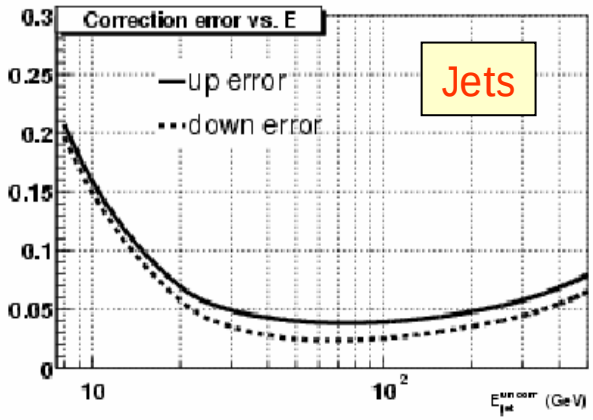




**Final decay products are**
- → electrons, photons
- → muons
- → jets (b)
- → missing $E_t$ (ν)
- → charged tracks

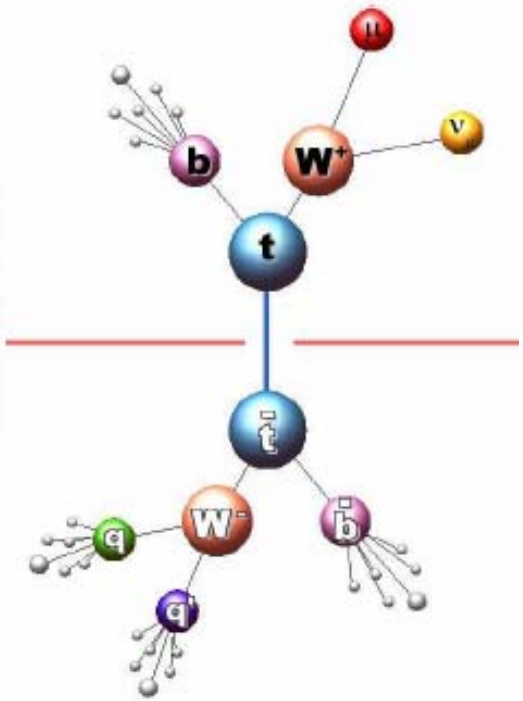
**Detection and MC optimization using known objects: Z/W, J/ψ, etc.**



# Top Quark Production Cross Section



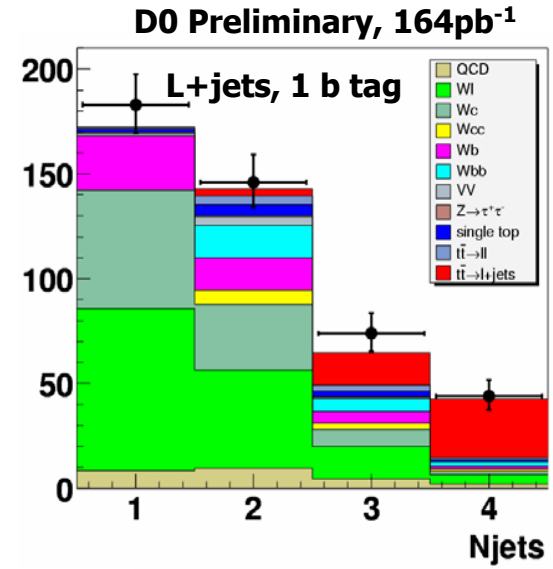

In triggering and analysis select events with

→ high $P_t$ leptons

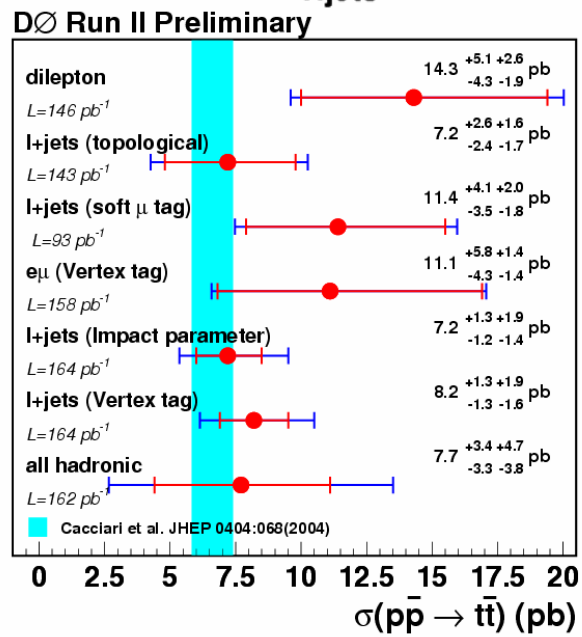
→ high $E_t$ multiple jets

→ large missing $E_t$ ($\nu$)

→ displaced vertex for b jets




$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{Bkg}}{\epsilon \int Ldt}$$




"Di-lepton" mode has

→ low backgrounds: di-bosons, Drell-Yan, ...

→ but low statistics: ~5% for e, μ decays

"Lepton+jets" very productive mode

→ 6 times more decays then di-lepton mode

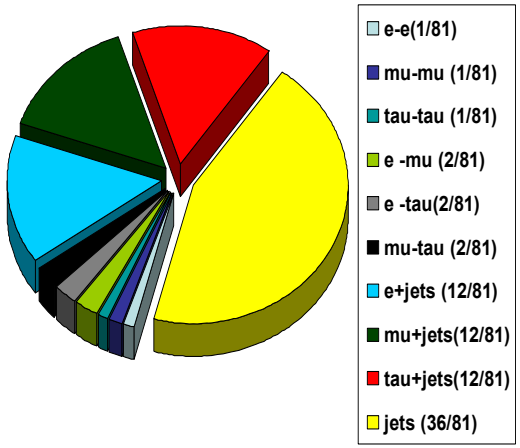
→ main background W+jets

→ good purity after b tagging

"All jets" mode

→ 44% branching

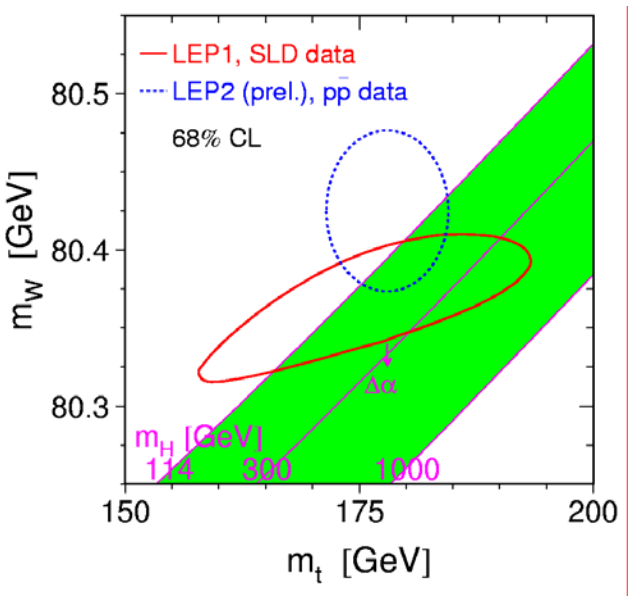
→ high QCD backgrounds, jets combinatoric

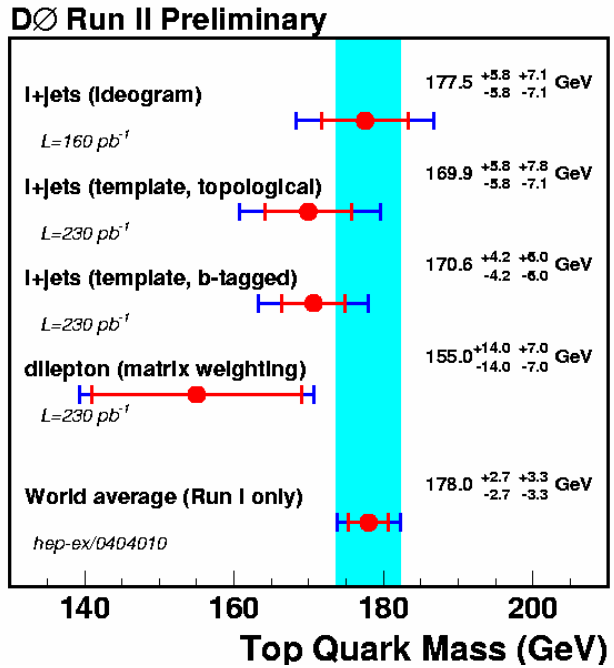



**Results demonstrate success of multiple top quark detection techniques**

# Top Quark Mass

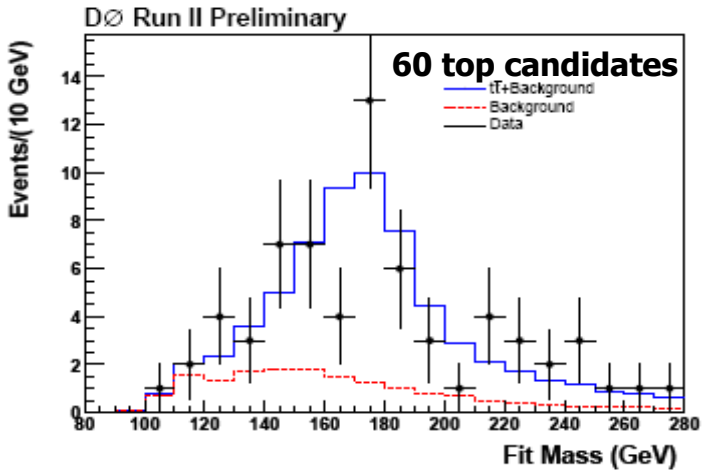
Top quark mass is a fundamental SM parameter
Provides constrain on Higgs mass




Different methods used
- "template"
- matrix element

All results are consistent with Run I World average
- jet energy scale is the dominant systematic error



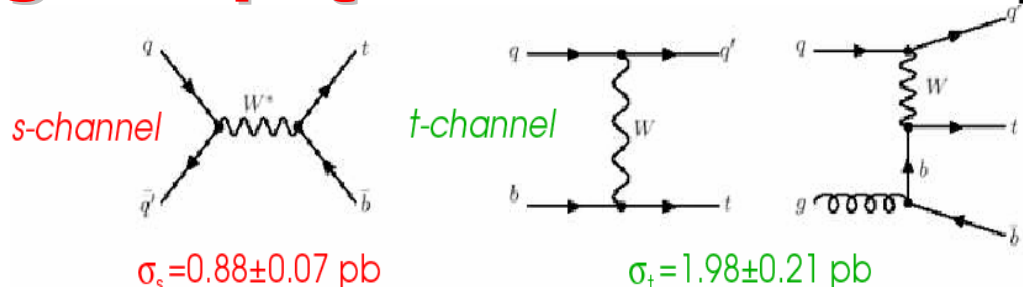

l+jets b-tagged template method, 230pb$^{-1}$

# Search for Single Top Quark Production

EW production of top quark

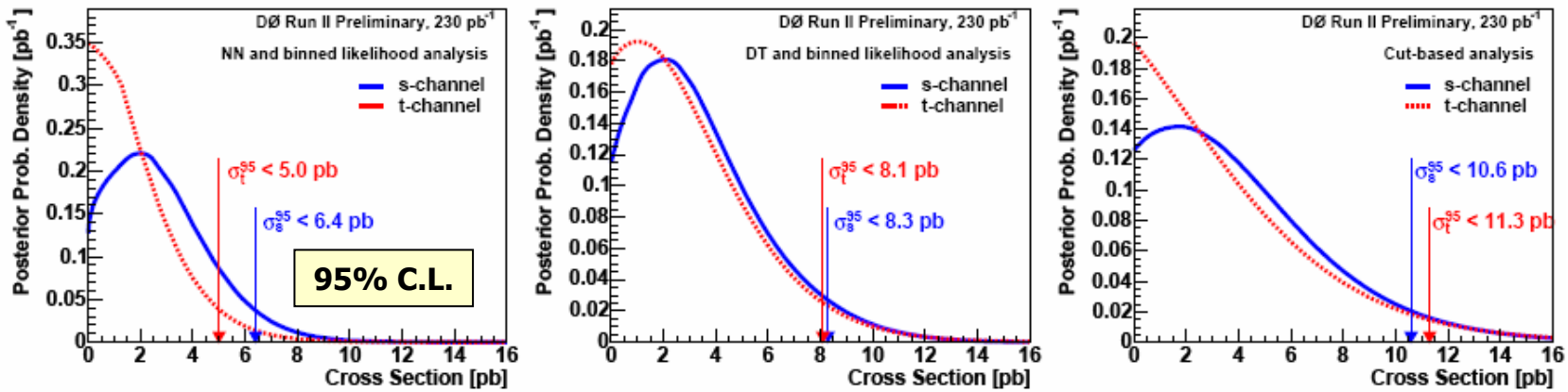
→ direct probe of $|V_{tb}|$

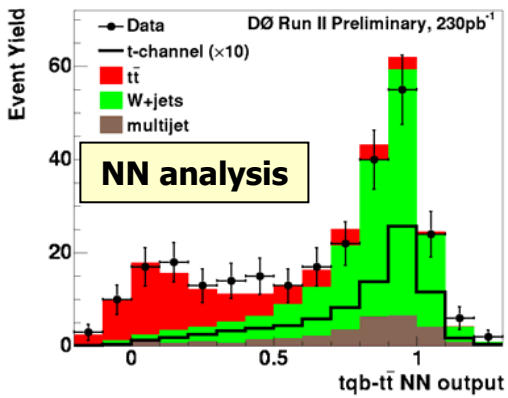
→ search for new physics




Events selection: similar to top pairs in l+jets mode, but with lower jets multiplicity

→ backgrounds (W+jets, tt, di-bosons) are substantial




World best limits on single top quark production

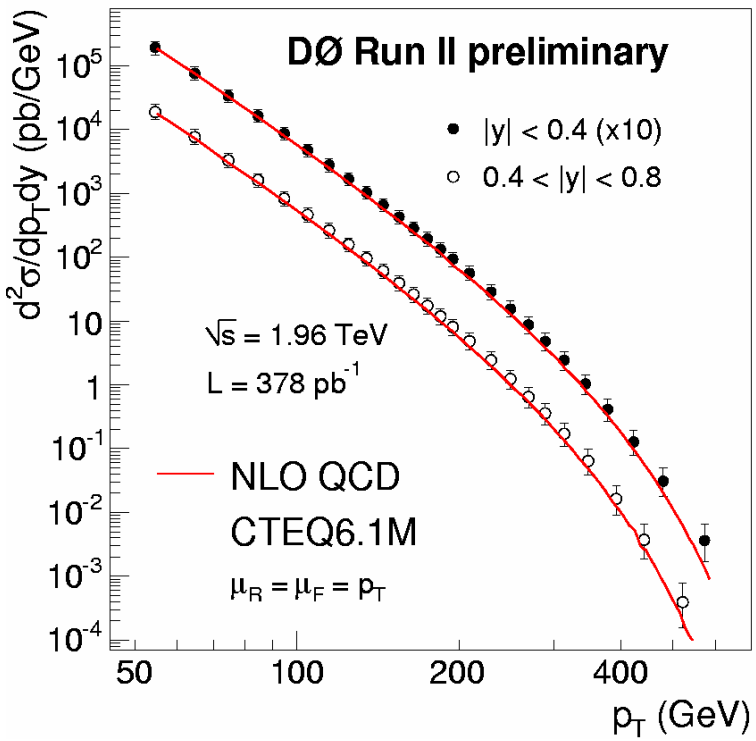
Expect:

→ x3 data set analyzed by the end of the year

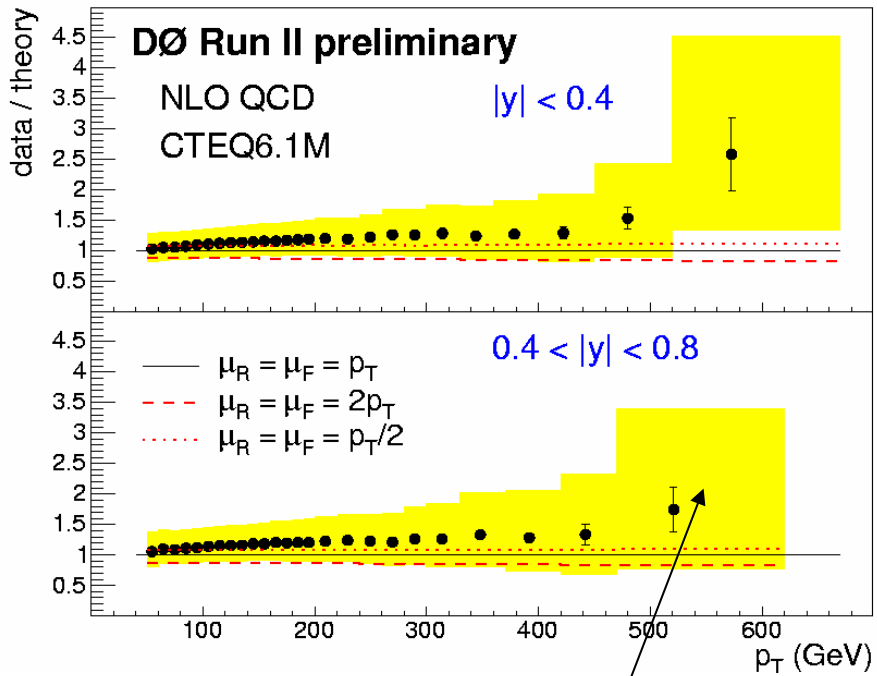
→ improvements in analysis

# QCD Studies

**Use well-understood processes to measure proton structure**
**→ quarks sub-structure?**
**Resolve some outstanding puzzles**
**→ e.g. heavy flavor production**
**Understand the backgrounds to physics beyond SM**
**Study diffractive production, new objects like X(3872)**




**8+ orders of magnitude σ changes**

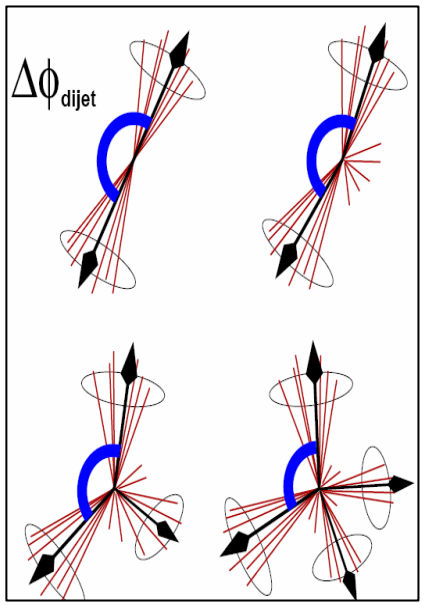


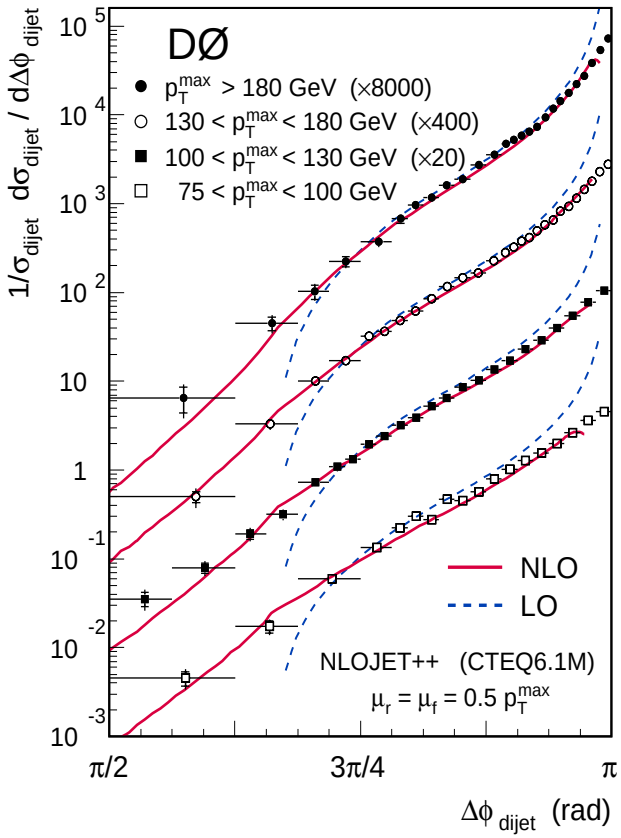

**Dominant systematic uncertainty is currently jet energy scale**

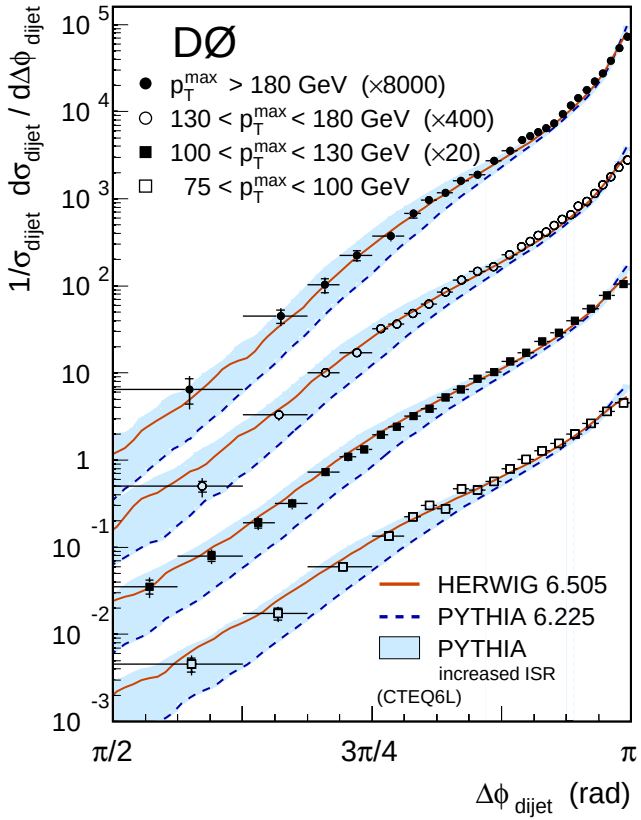
**→ derived from $p_T$ balance in photon + jet events**

# Dijet Angular Distributions

**Clean and simple way to study QCD radiative processes**
**Reduced sensitivity to jet energy scale**



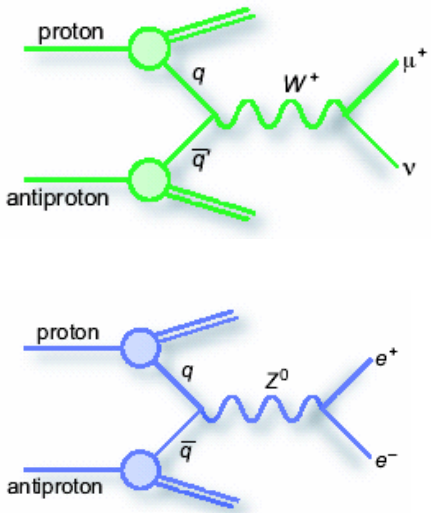

**LO is not describing distributions**
**Agreement with NLO predictions**

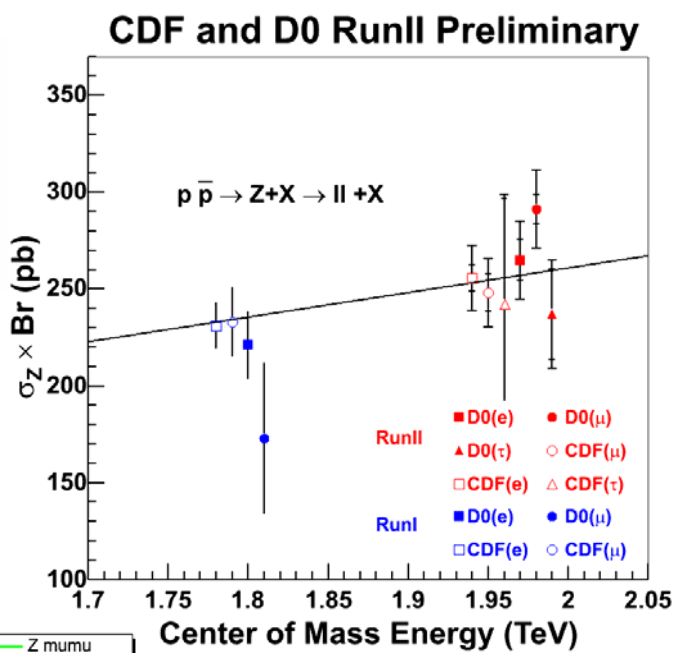
**HERWIG describes data well**

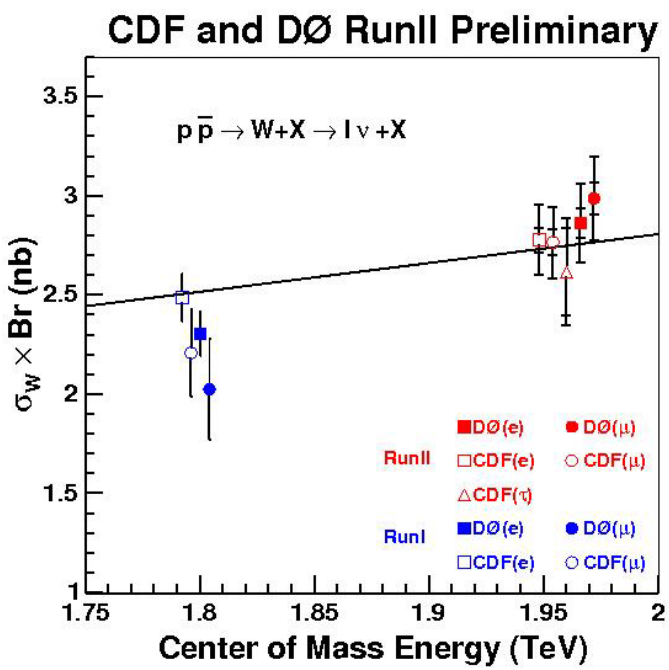
**PYTHIA needs adjustments to its default parameters**

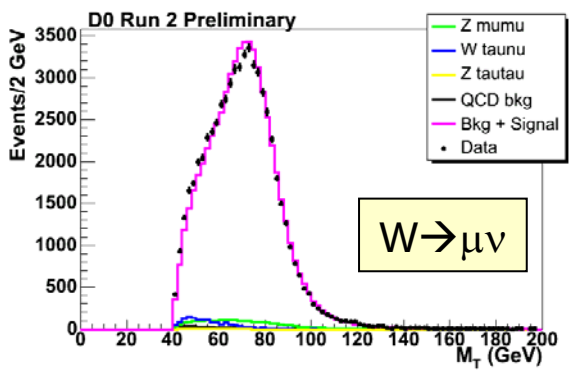
# Electroweak Physics

**Indirectly constrain new physics through precision measurements of electroweak parameters**
**Measure single and multiboson production, W production asymmetry, forward-backward asymmetry in Z production, …**



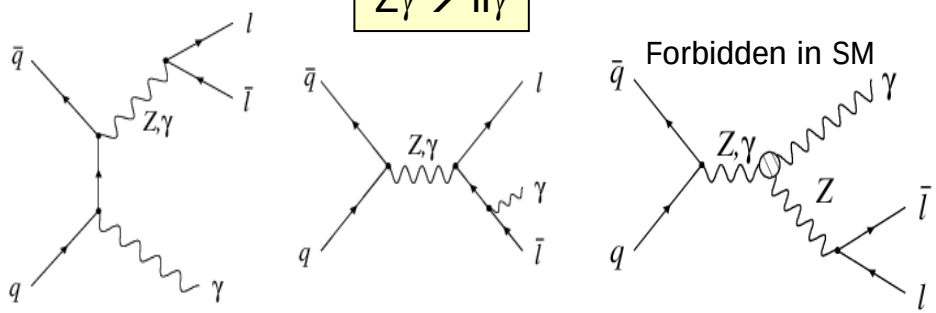



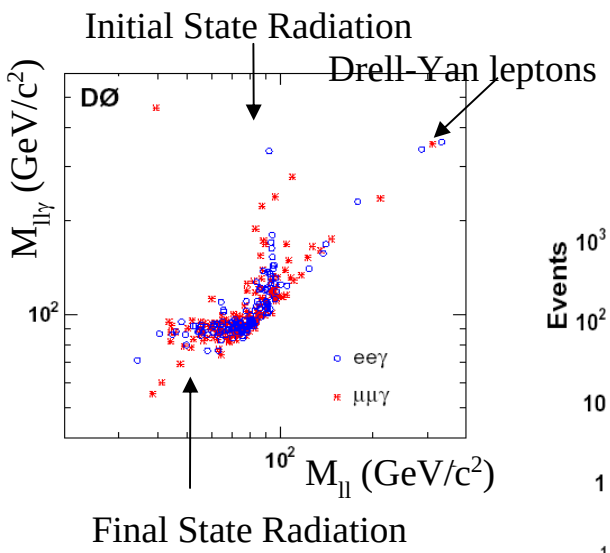

**Clean, relatively high cross section and well known signals**
**Test of the Standard Model**
**Require a high level of understanding of the detectors**
**→ e, μ, τ and missing $E_t$**
**Can be used to cross check luminosity measurement**

# Diboson Production

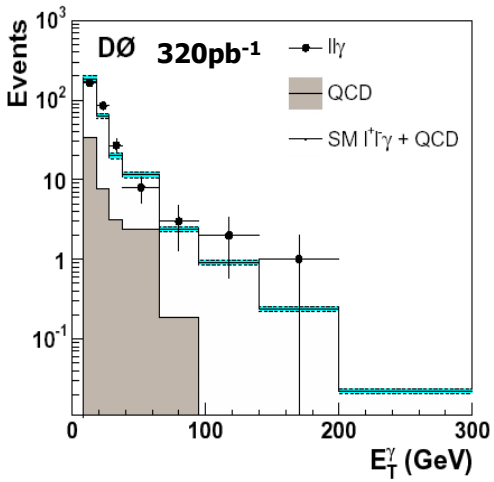
**WW, WZ, ZZ, Wγ, Zγ production test SM and tell us about boson self-coupling**
**Background to many interesting searches, like H→WW**

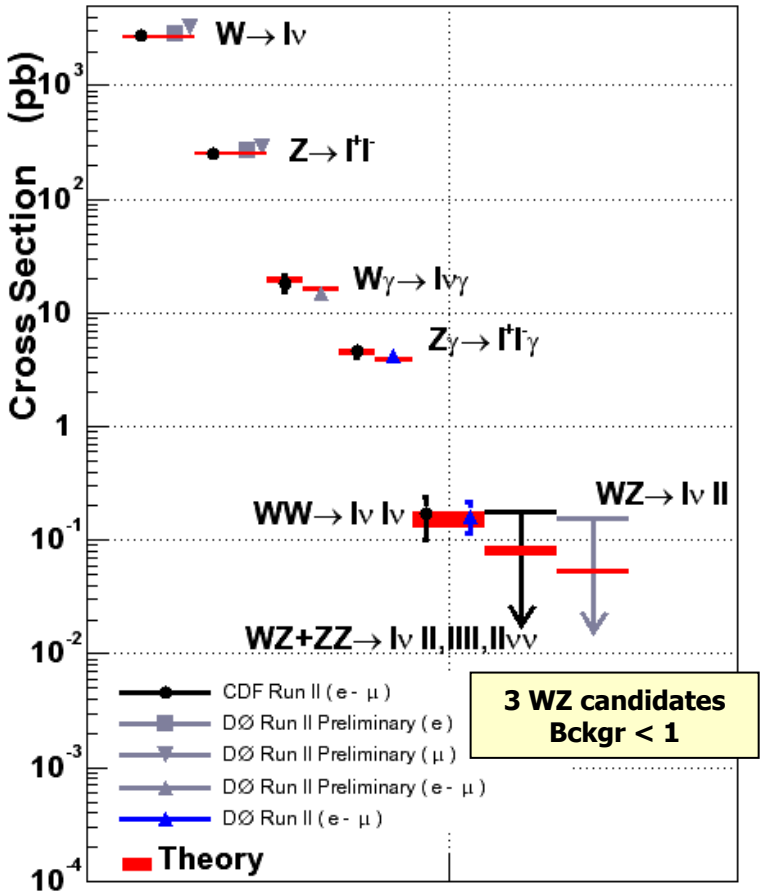
Zγ→ llγ




Limits on Anomalous Couplings set: world most stringent for WZ



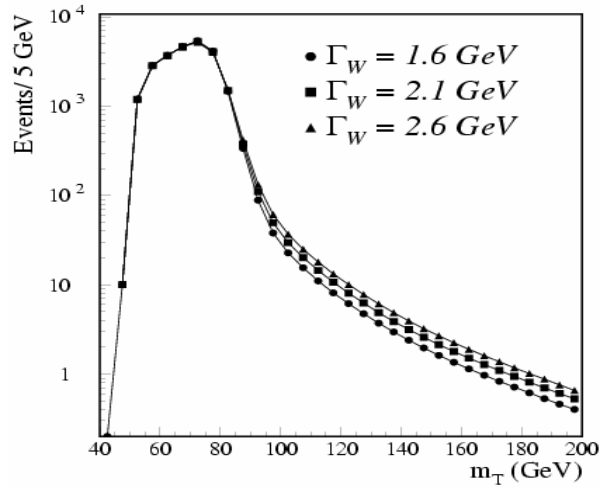




**3 WZ candidates**
**Bckgr < 1**

Cross sections are in good agreement with SM

# Direct Measurement of W Width

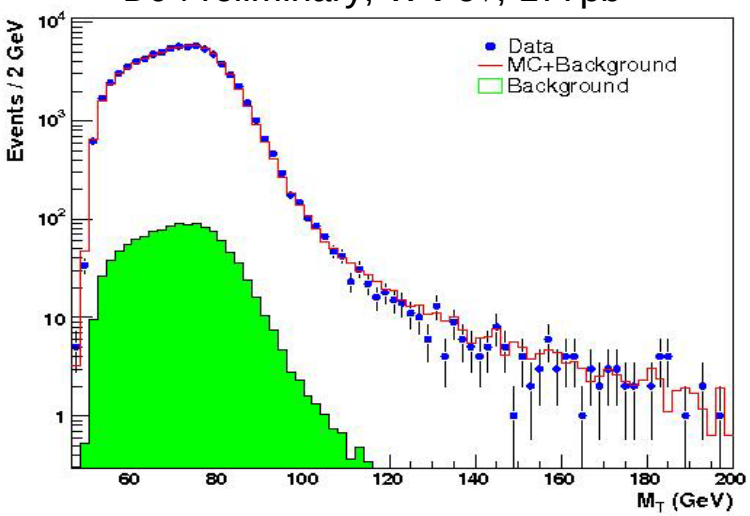
**On the road to W mass measurement: ~40MeV, better then $10^{-3}$ accuracy required**
**Method: fit the transverse mass distribution in the region $100 < M_T(W) < 200$ GeV**

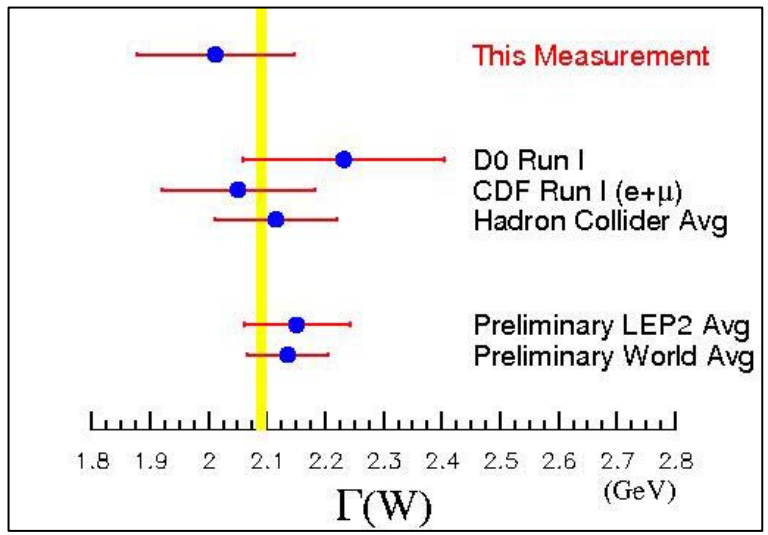



**Selection: $W \rightarrow e\nu$, 177 $pb^{-1}$**
**75910 candidates with $50 < M_T(W) < 200$ GeV**
**625 candidates with $100 < M_T(W) < 200$ GeV**

**Main systematic uncertainties:**
**Hadronic response and resolution ~ 64 MeV**
**Underlying event ~ 47 MeV**
**EM resolution ~ 30 MeV**

D0 Preliminary, W→eν, 177$pb^{-1}$



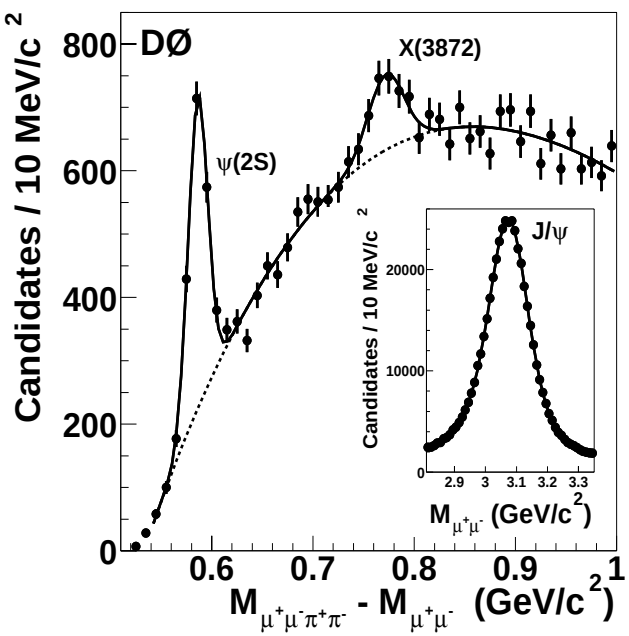

$\Gamma_W = 2.011 \pm 0.093$ (stat) $\pm 0.099$ (sys)

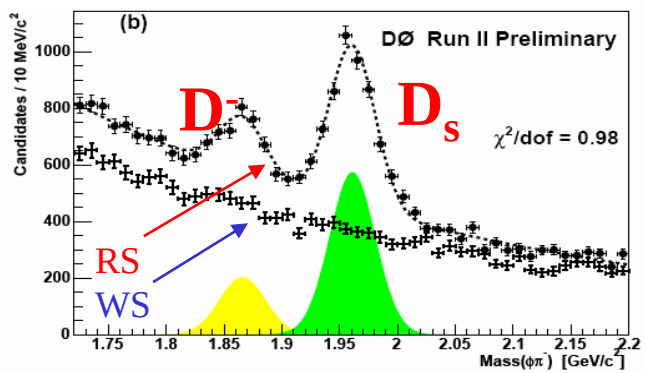
# Heavy Flavors Masses and Lifetimes

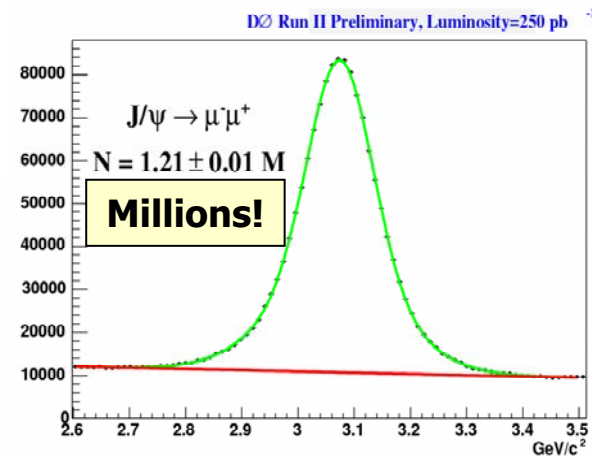
**Measure particles production and decays properties**
**Confront the unitarity triangle in ways that complement measurements at the $e^+e^-$ B-factories e.g. through the $B^0_s$ system**

**DØ benefits greatly from large muon acceptance and forward tracking coverage**

**$X(3872) \rightarrow J/\psi\ \pi^+\pi^-$**



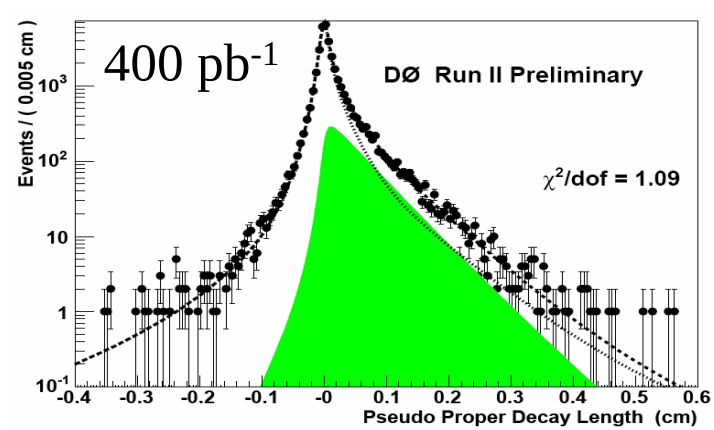

M(φπ)

**$B^0_s$ lifetime with $B_s \rightarrow l\nu D_s X$**

**Use $D_s \rightarrow \phi\pi$ decay**

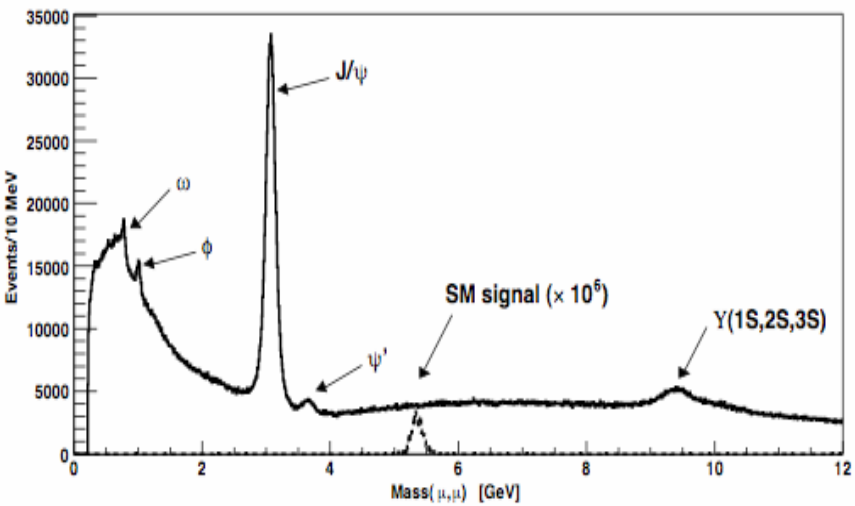
**Currently World's best:**

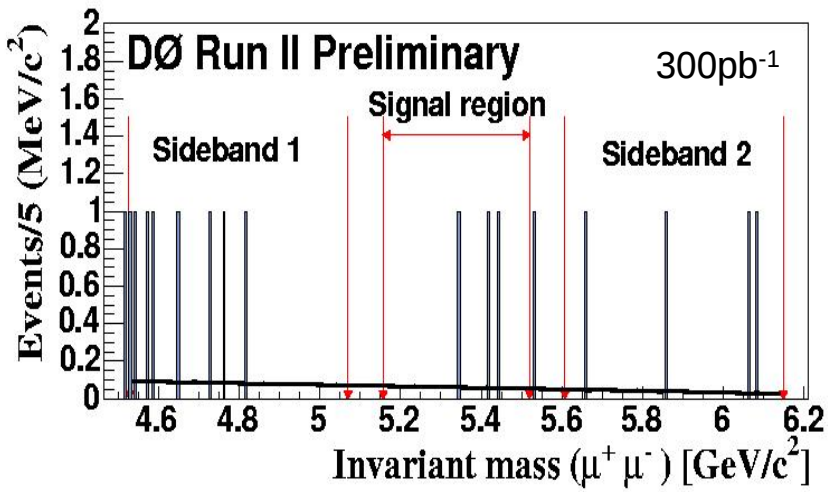
**$\tau(B_s)$=1.420±0.043±0.057 ps**



# Search for $B_s \rightarrow \mu\mu$ Decay

**Measure the rate of the rare decay $B_s \rightarrow \mu^+\mu^-$**
**In the Standard Model, cancellations lead to a very small branching ratio**
**→ SM BR= $3.7 \times 10^{-9}$**
**New particles (e.g. SUSY) contribute additional Feynman diagrams, increase BR**
**→ up to $10^{-6}$**



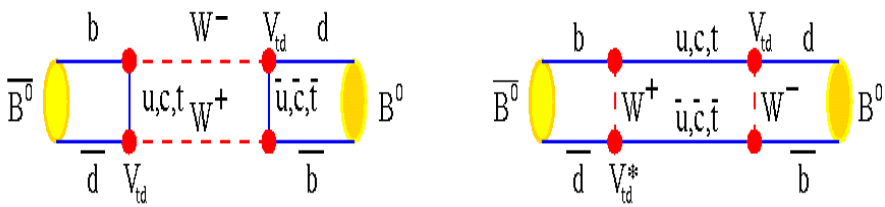




**World best limit from DØ**

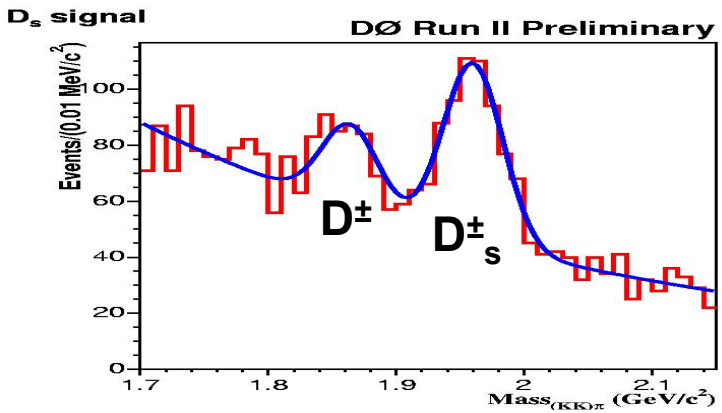
**BR($B_s \rightarrow \mu\mu$)<$3.7 \times 10^{-7}$ (95%CL)** ***(300pb$^{-1}$)***

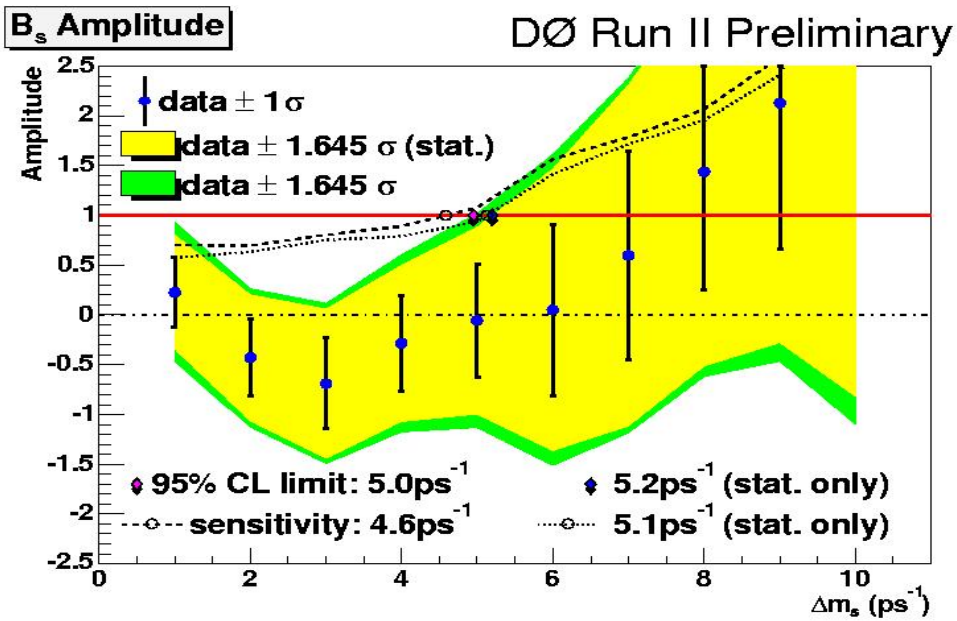
# $B_s$ Mixing

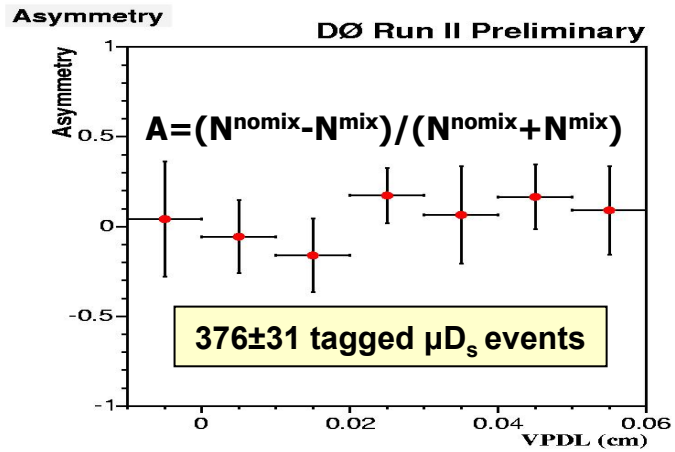
In SM B-mixing is explained by box diagrams
→ Constrains $V_{td}$ and $V_{ts}$ elements of CKM matrix
→ New physics → new particles in the box
→ $\Delta m_s/\Delta m_d$ is free from many theoretical uncertainties




Use semileptonic data sample $\mu D_s$ (muon triggering helps)
Decay mode $D_s \to \Phi\pi$, $\Phi \to K^+K^-$
13,300 candidates in 460 $pb^{-1}$
Charge of the muon provides Final State Tag



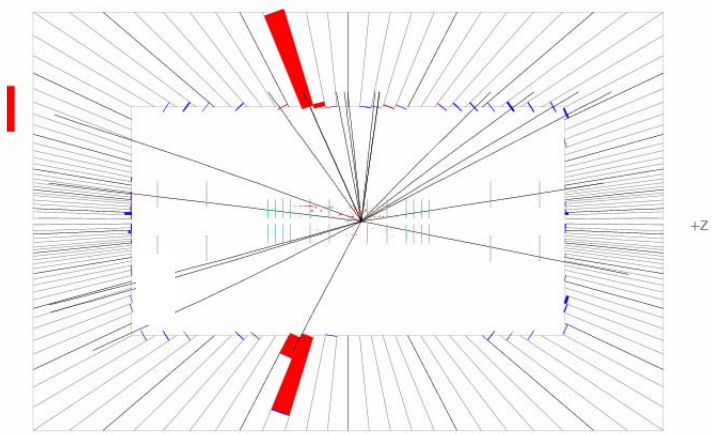

95% CL limit: $\Delta m_s$>5.0 $ps^{-1}$, statistically limited

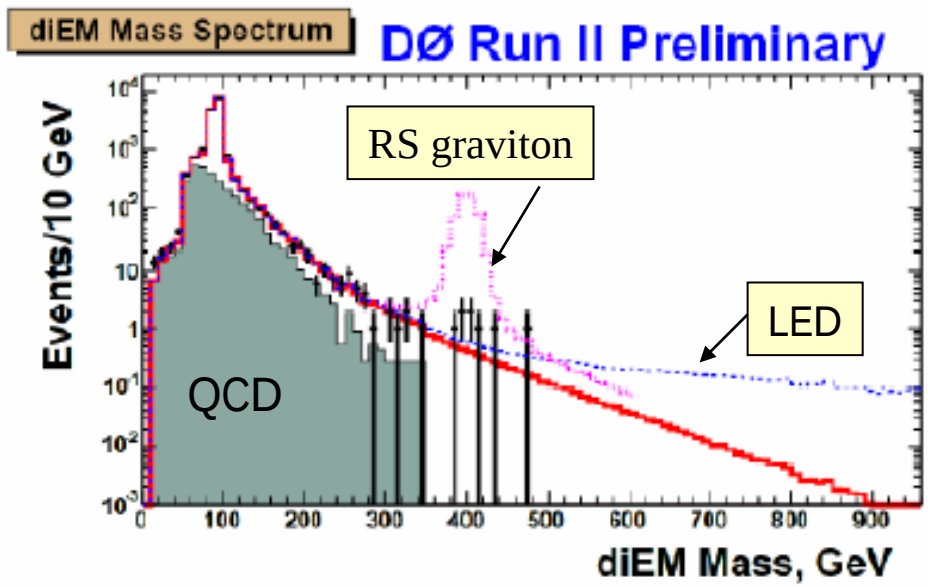
With anticipated DØ upgrades: $\Delta m_s$>20 $ps^{-1}$ with ~1 $fb^{-1}$

# Searching for Extra Dimensions

**Signal would be an excess of ee, μμ, γγ events at large mass due to virtual graviton exchange**

**High-mass electron pair event**
**Mass=475 GeV**






**Latest DØ limit from $\bar{p}p \rightarrow$ ee, μμ, γγ events**

**$M_S$(GRW) > 1.43 TeV** (200 $pb^{-1}$, 95% CL)

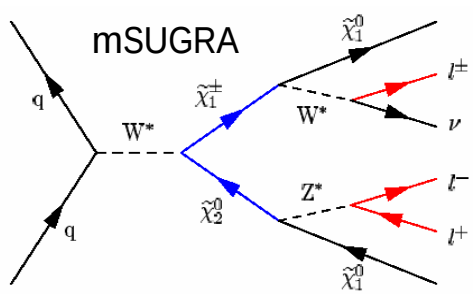
**most stringent limit to date on Large Extra Dimensions**

**Same dataset places limits on TeV-scale extra dimensions, Z' …**

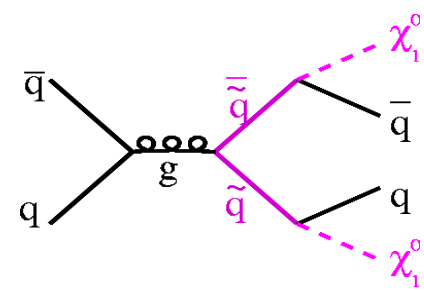
# Search for SUSY

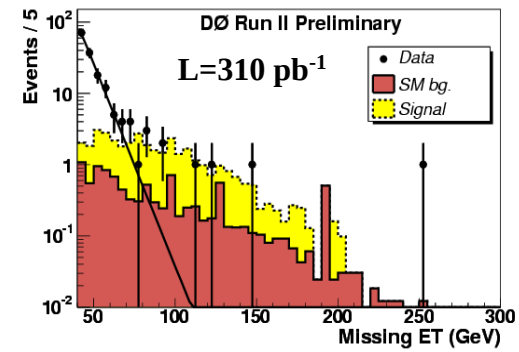
**SUSY solves "Hierarchy Problem", provides Grand Unification at the $10^{16}$ GeV scale, and is a good Dark Matter Candidate (LSP)…**

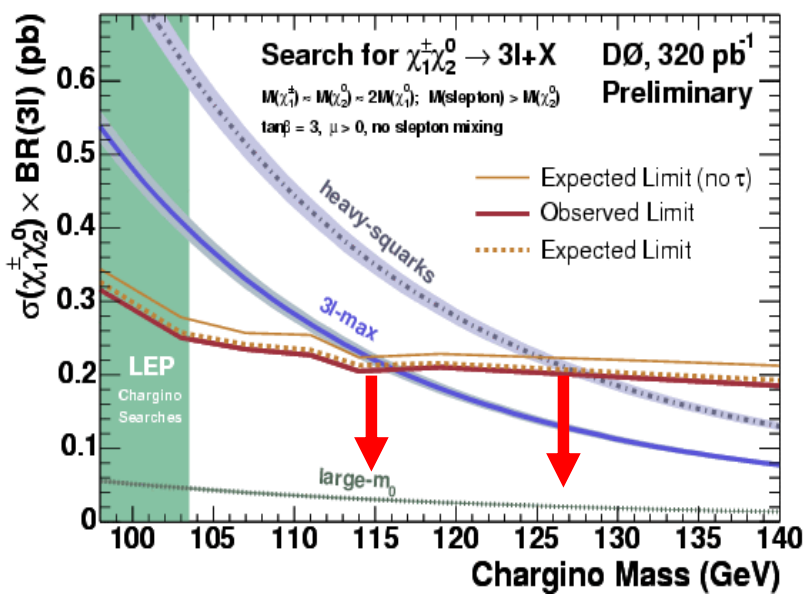
**Chargino/Neutralino production in 3l+$\not{E}_T$**

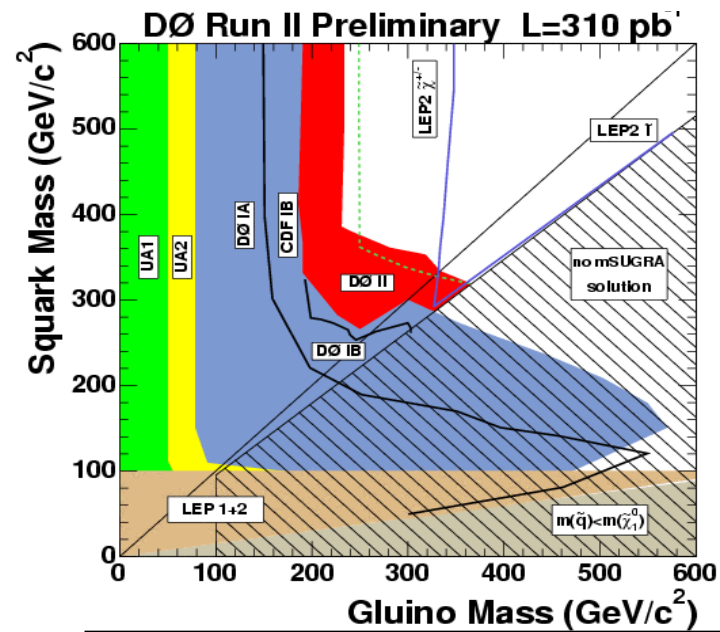



**Squarks and Gluinos in jets+$\not{E}_T$**



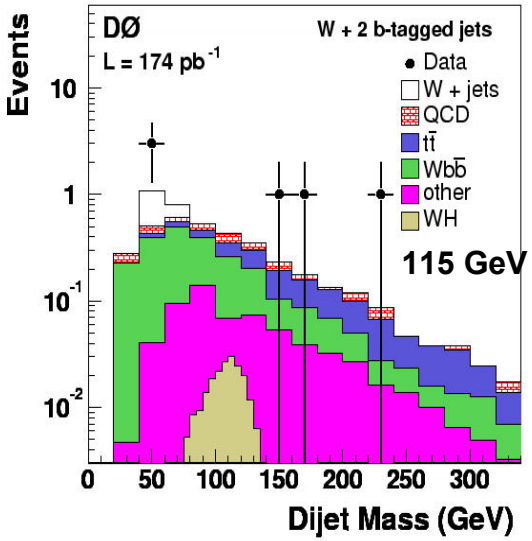




**Much better then Run I limits of 1.6 pb**

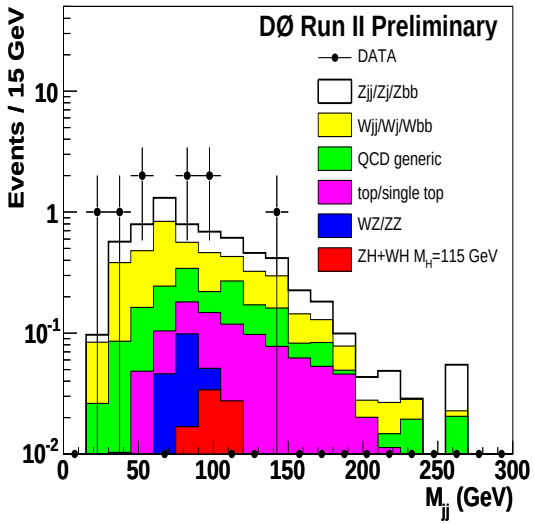
**DØ extends LEP mSUGRA reach!**

# Standard Model Higgs Search

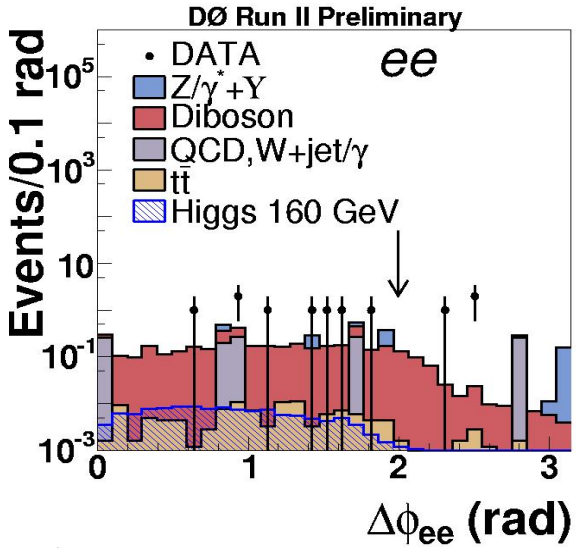
**WH→eνbb**

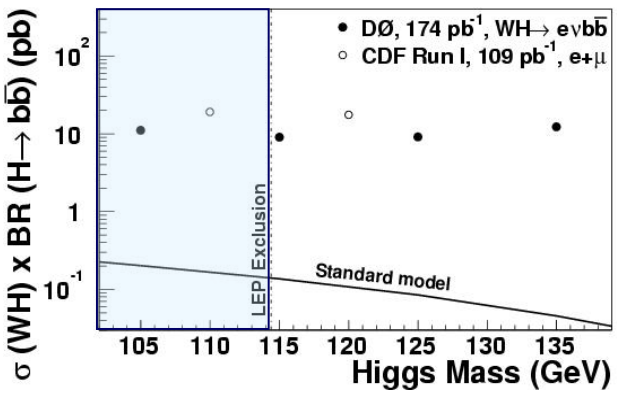


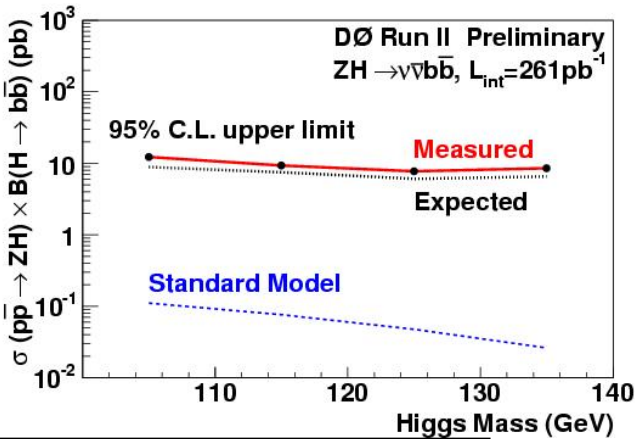

**ZH → ννbb**

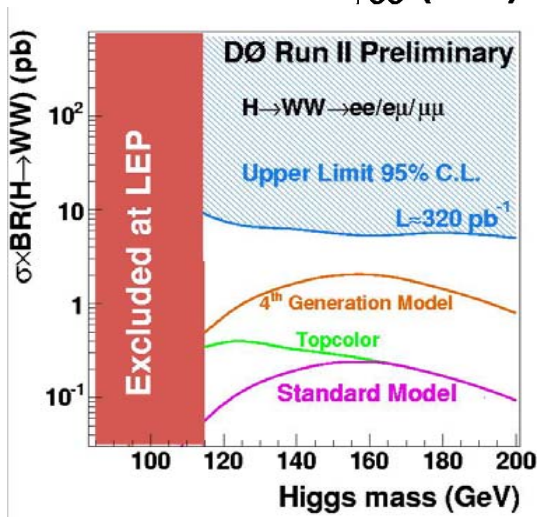



**H → W⁺W⁻ → ℓ⁺ℓ⁻νν**




**Light Higgs observed sensitivity is close to expected**

# MSSM Higgs Search

**MSSM predicts larger Higgs cross sections for some values of parameter space then SM**

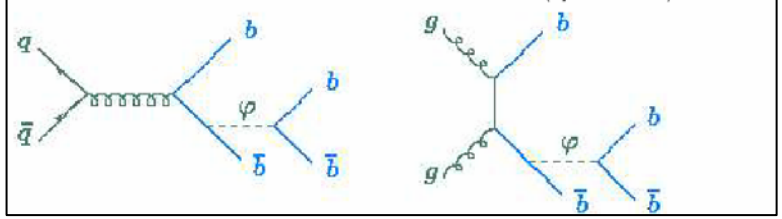
**Using NLO cross section calculations and assuming no difference between A and h/H DØ performs search for MSSM Higgs**

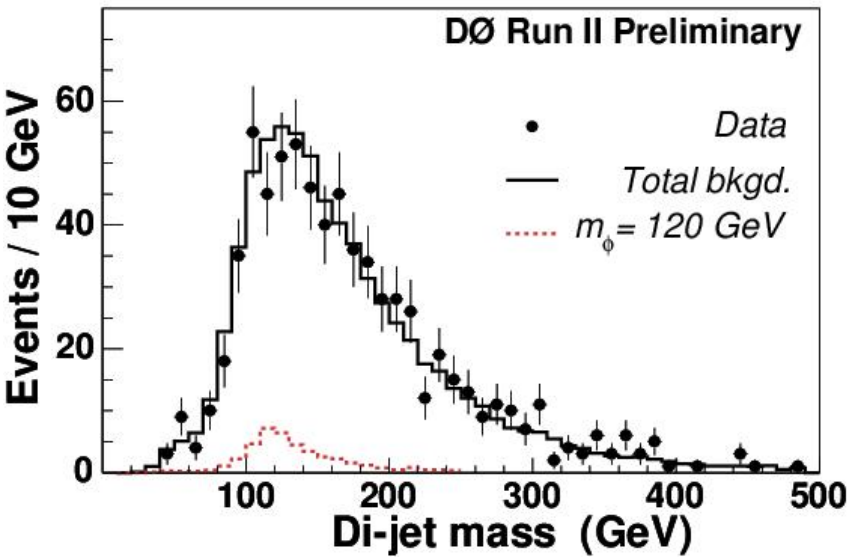
**→ multi-jet high $E_t$ sample**

**→3 or more jets b tagged**

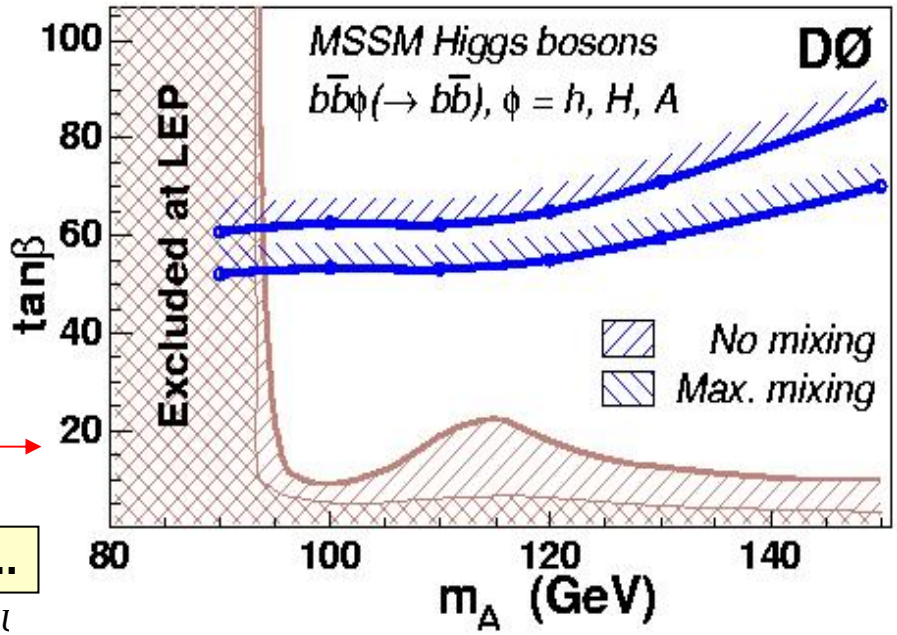
**Two Higgs Doublets $\mathcal{H}_1$, $\mathcal{H}_2$ and 5 physical states**

| | | |
|---|---|---|
| 2 CP-even neutral Higgses | $h^0, H^0$ | $m_h < m_H$ |
| 1 CP-odd neutral Higgs | $A^0$ | |
| 2 charged Higgses | $H^\pm$ | |
| Free parameters: | $\tan\beta = v_2/v_1$ | (VEV ratio) |
| | $\alpha$ | (mixing angle of h, H) |
| | $\mu$ | Higgs mass parameter |
| | $A_0$ | common trilinear Higgs-sfermion coupling |
| tree level: | $m_h < m_Z < m_H$ | |
| rad.corrected: | $m_h < 130$ GeV | $Br(\phi \to b\bar{b}) \sim 90\,\%$ |




**World's most stringent limit**

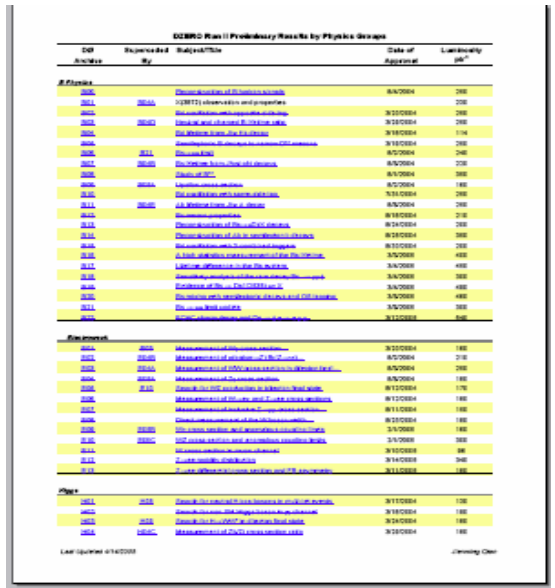


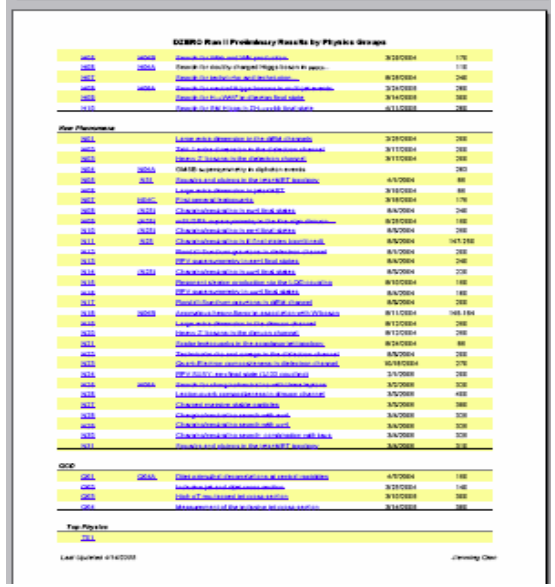

**Also fermiophobic Higgs, doubly charged Higgs …**

# Summary of Results, Talks, Publications

Too many to fit on 3 pages...

- **20 publications over last year**
  - **Quantum leap from 2 by April 2004**
- **74 new results approved for Conferences**
  - **Most will be published**
- **>250 invitations to Conferences per year**
  - **Invited talks at major Conferences**





**For full list of DØ approved results and publications visit**

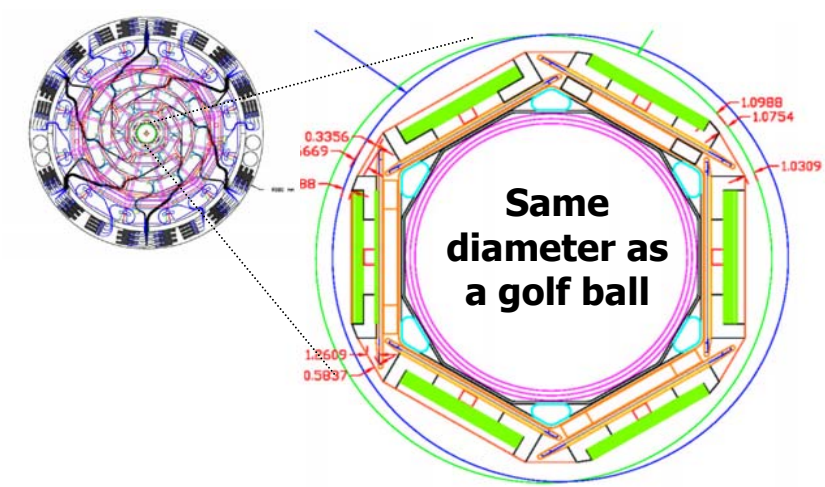
**http://www-d0.fnal.gov/Run2Physics/WWW/results.htm**

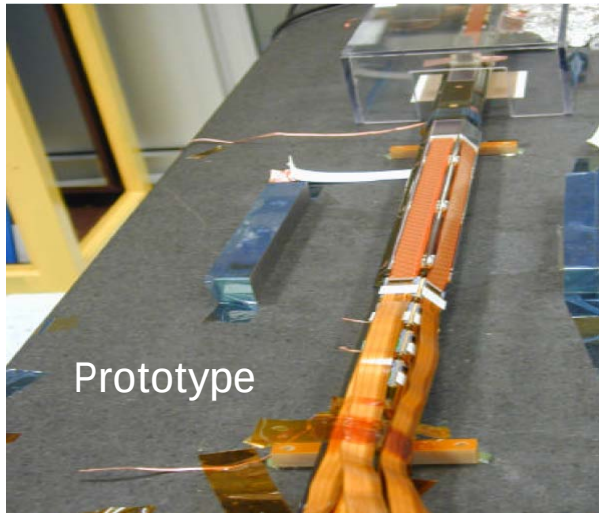
**including plain-English summaries**

**Celebrating World Year of Physics!**

# Detector Upgrades

In order to mitigate concerns over silicon detector radiation damage and pattern recognition in DØ, we are constructing a new Silicon Layer Ø




Calorimeter trigger upgrade is needed for managing trigger rates at high luminosity – in construction/commissioning stage

AFE II – new front-end electronics for fiber tracker
→ mitigate amplitude saturation at high counting rates
→ provide longitudinal coordinate measurement

Plan to install Layer Ø and calorimeter trigger upgrades in Autumn 2005

# Fermilab's DØ Group

- All of the above would not be possible without hard work of 100's of DØ Collaborators and Fermilab's/DØ group
- Fermilab's/DØ group currently consists of 61 members
  - Includes visiting scientists
  - ~10% of the Collaboration – largest DØ group
- As host Laboratory Fermilab's group provides strong contribution to the experiment
  - Operations – 10 of 25 group leaders (40%)
  - Software/algorithms – 2 of 13 group leaders (15%)
  - Computing – 7 of 14 group leaders (50%)
  - Physics analysis – 3 out of 12 conveners (25%)
  - Upgrade – 18 of 33 group leaders (55%)

**Fermilab/DØ group major responsibilities**

Responsible for major detector parts
Electrical and mechanical support of the experiment
Infrastructure support (buildings, computing,…)
Funding for the experiment operations
Software and Fermilab's reconstruction farms
Safety of the personnel and equipment
Active participation in physics analysis

Strong Fermilab/DØ group is critical for the success of DØ operations and data analysis

# Conclusions

- The DØ detector is working well with high data taking efficiency
  - Currently 0.7fb$^{-1}$ on tapes with full detector in readout
- Data processing is keeping pace

**Physics program is flourishing**

Top Quark

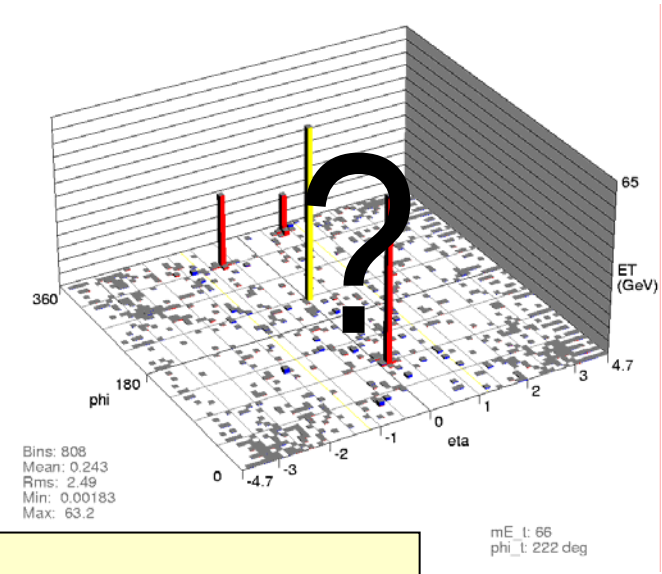
QCD

Electroweak

Heavy Flavor

Beyond SM searches

Higgs hunting




- Almost 100 approved physics analyses!
- Publishing with healthy rate
- The Collaboration is enthusiastic → 1 fb$^{-1}$ of data in 2005
- There are challenges → technical, manpower
- Preparing for the future

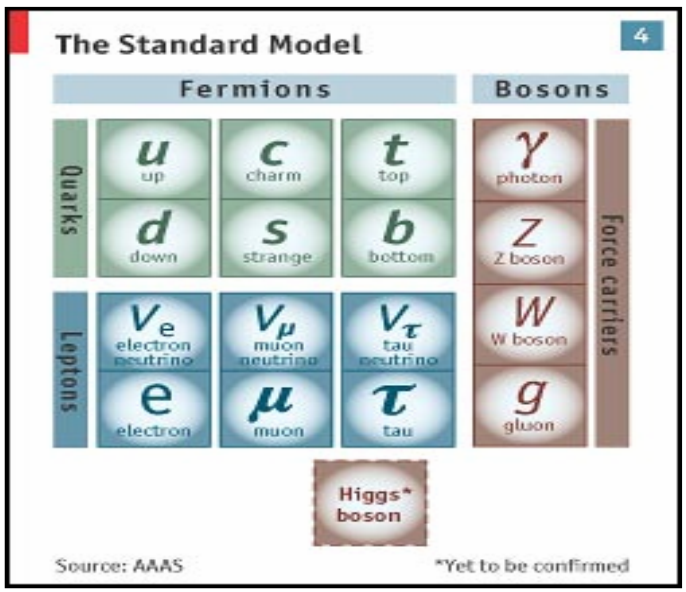
**We entered unexplored energy frontier territory – stay tuned!**

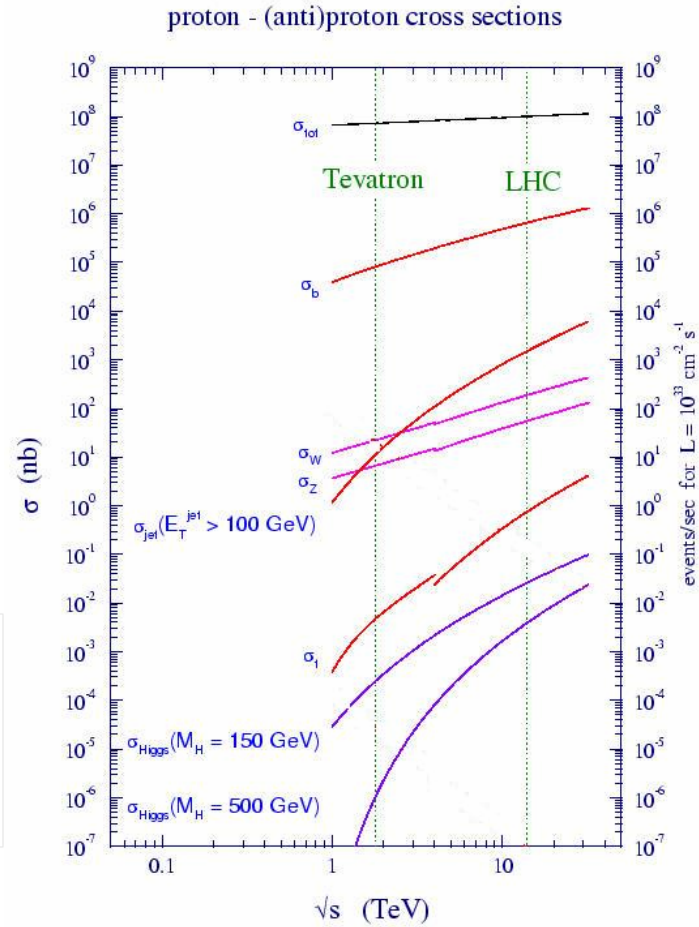
# Back-up Slide(s)

# Physics Goals

- **Study the Standard Model through**
  - **The top quark**
  - **The strong interaction**
  - **Precision electroweak measurements**
  - **The CKM matrix**
  - **The Higgs boson**

- **And directly search for new phenomena beyond the SM**




- "Quantum leap" in Run II publications over last 12 months
  - 2 by April 2004
  - 20 by April 2005
- In addition 74 new results were approved for Conferences
  - Most will be published in the near future

Celebrating World Year of Physics!

# The Top Quark

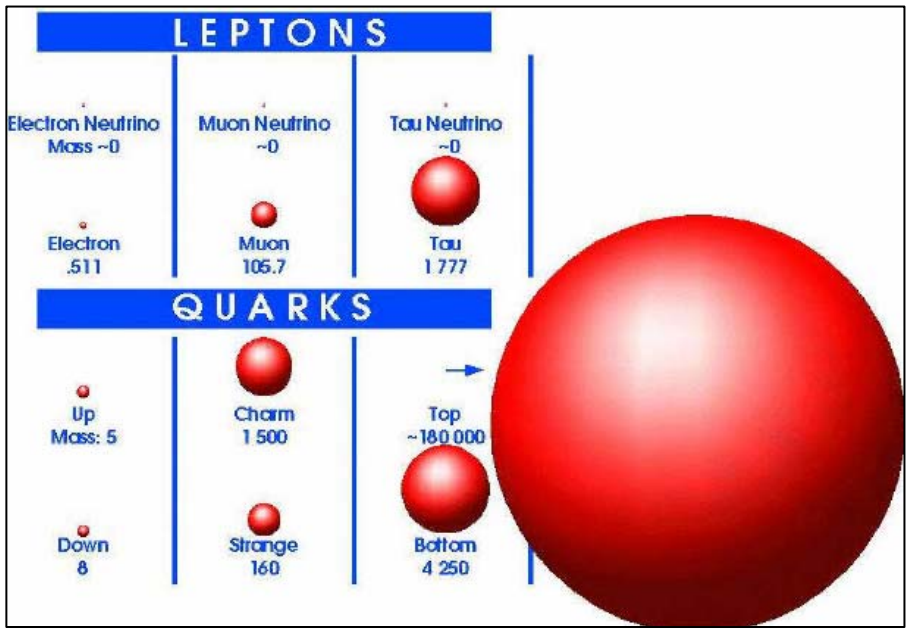
Heaviest known elementary particle: ~180GeV

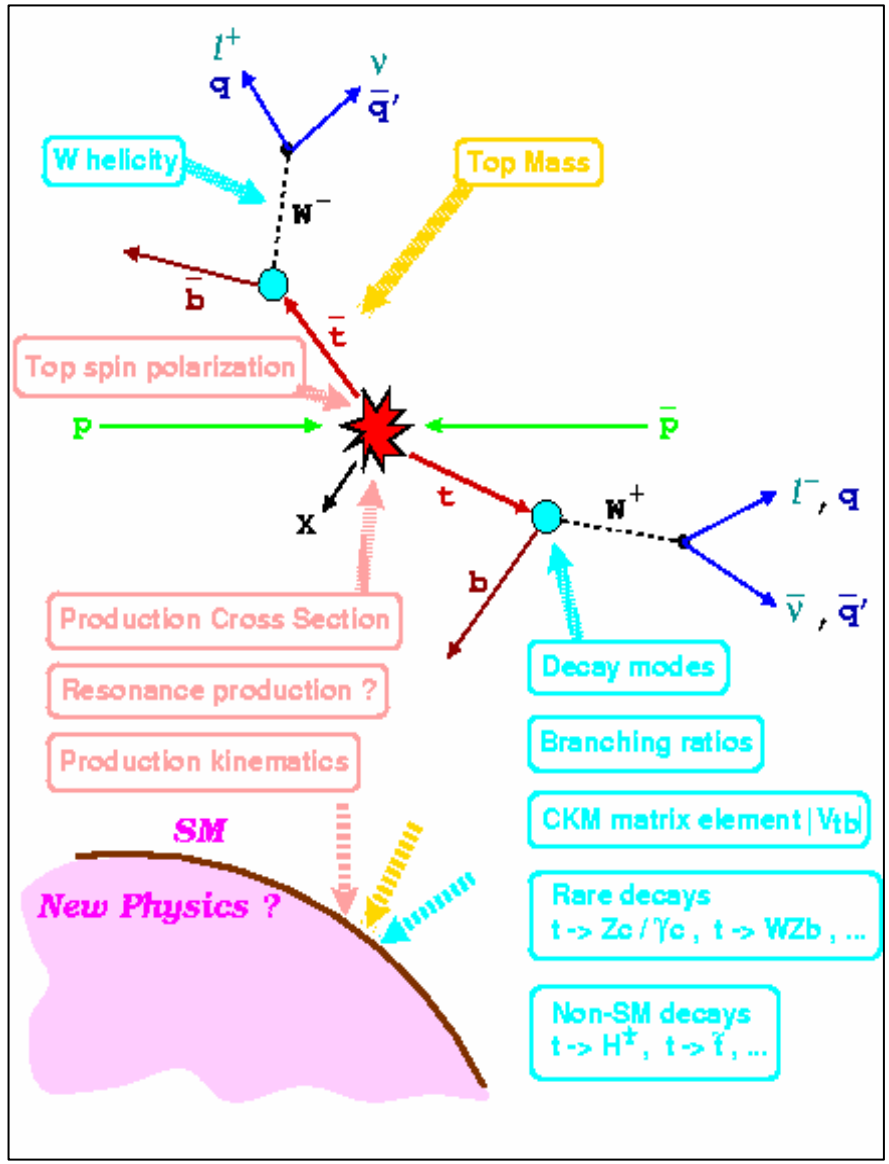
→ measure properties of least known quark

→ top quark mass constrains Higgs mass

→ sensitive to new physics

→ short life time: probe bare quark



# The Higgs Sector

**Discover (or exclude) scalar particles related to EWSB**
**Constrain their properties**

**Available experimental limits**

→ **direct searches at LEP**

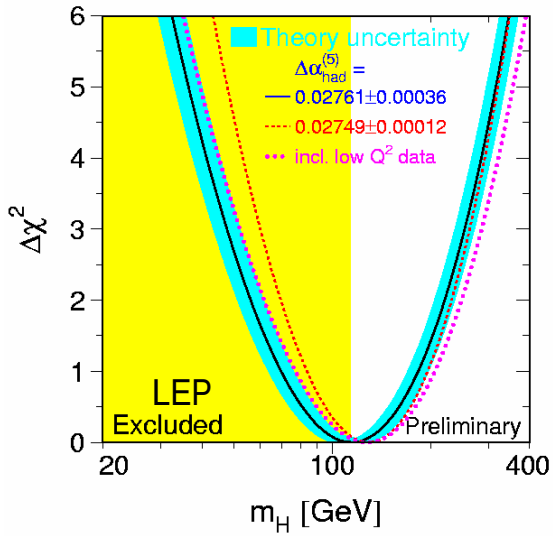
**$M_H$ >114 GeV at 95% C.L.**

→ **precision electroweak fits**

$$m_H = 126^{+73}_{-48} GeV$$

$$m_H \leq 280 GeV \quad \text{at 95\% C.L.}$$

**Light Higgs favored**



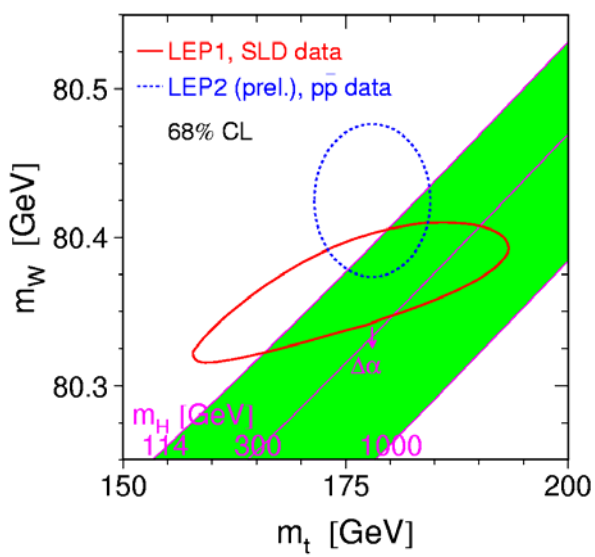

**DØ experiment**

**Precision $m_t$ and $m_w$ measurements**

**Direct searches:**

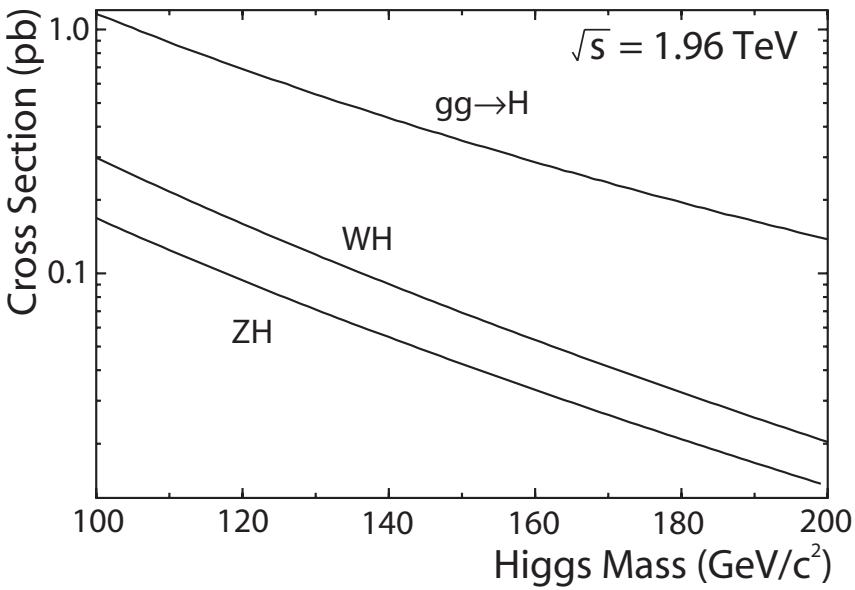
→ **SM Higgs**

→ **non-SM Higgs**

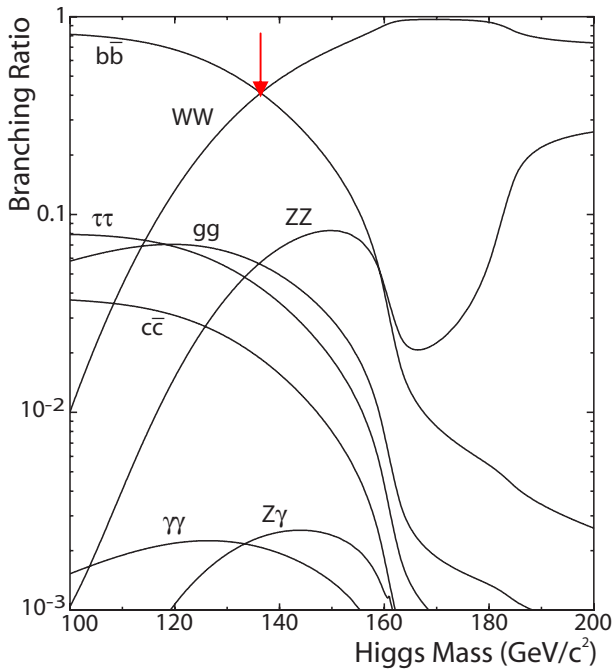


# Higgs Hunting

Production




Decays




**Search strategy:**

**$M_H$ <130 GeV associated production and bb decay W(Z)H → lν(l) bb**

**Backgrounds: top, Wbb, Zbb…**

**$M_H$ >130 GeV gg →H production with decay to WW**

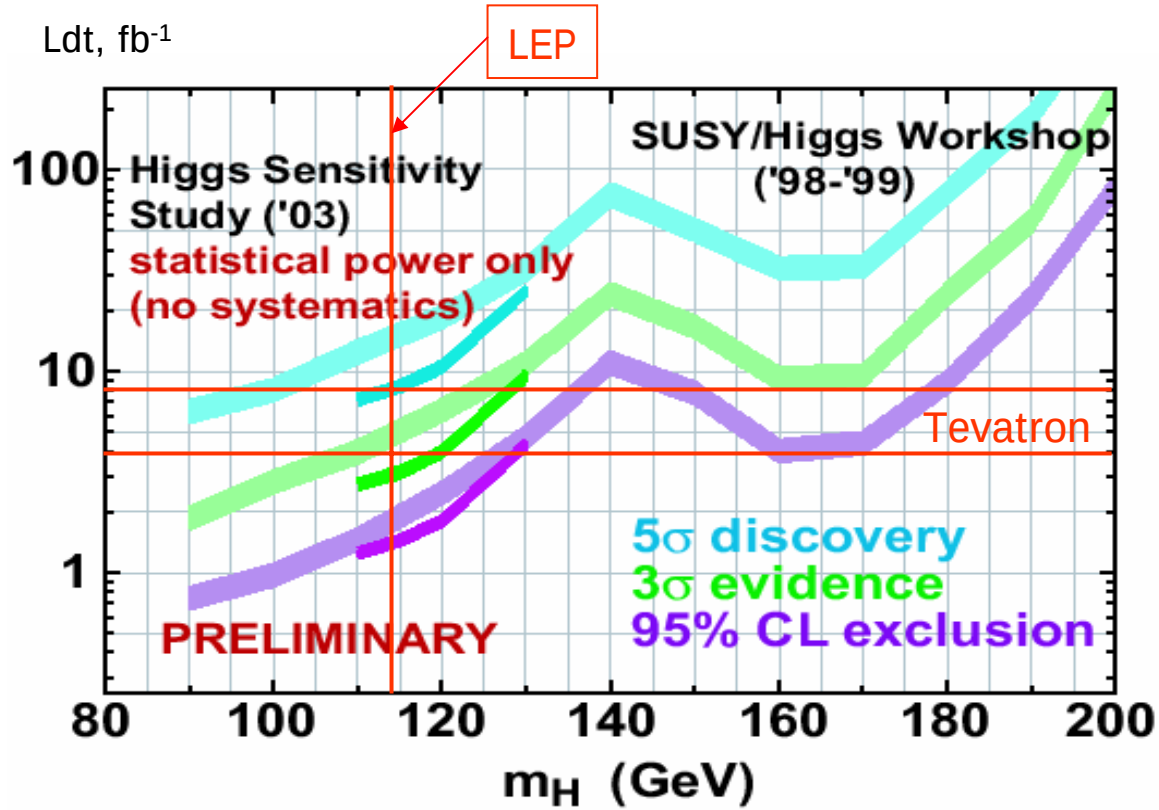
**Backgrounds: electroweak WW production…**

# Standard Model Higgs Search

Updated in 2003 in the low Higgs mass region W(Z)H→lν(νν,ll)bb to include

→using Run II data and full detector simulation

→ optimization of analysis

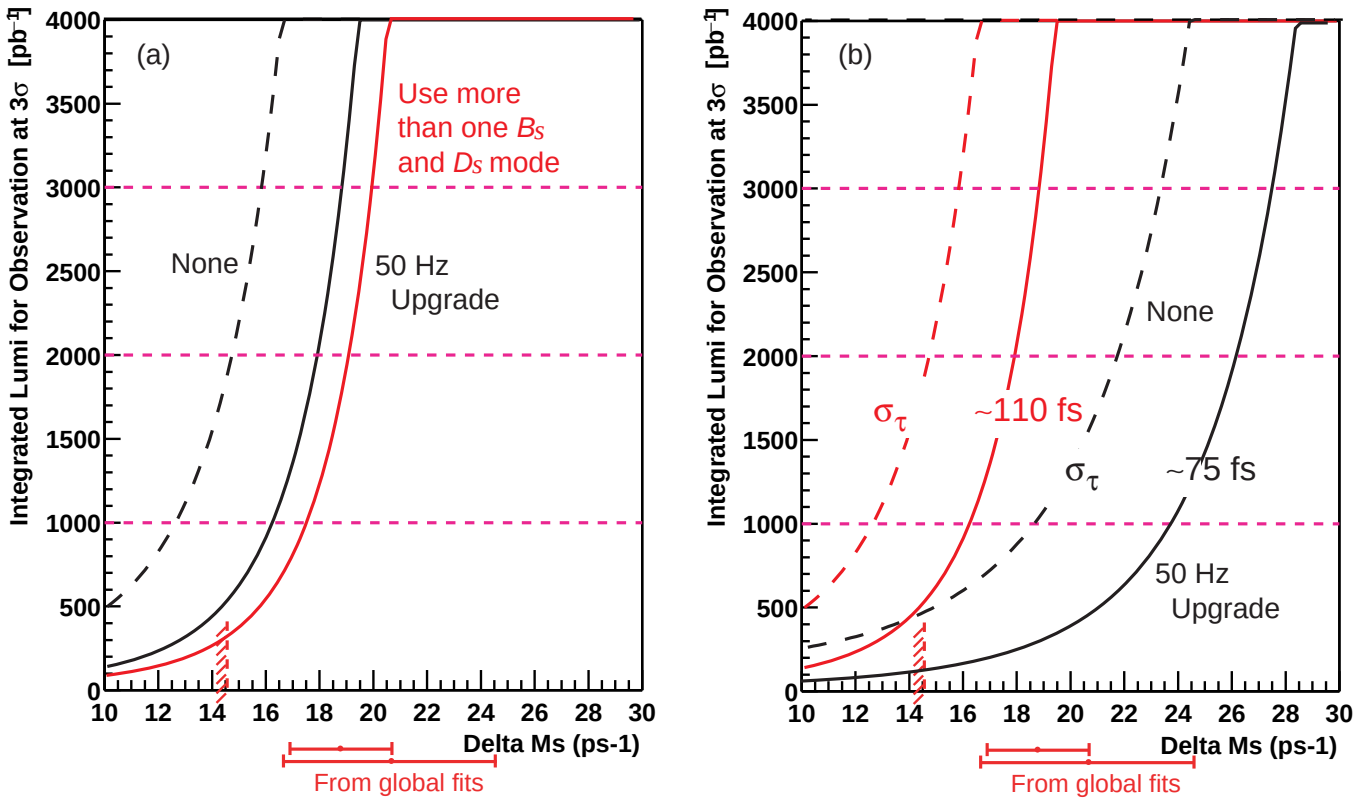



**Sensitivity in the mass region above LEP limit starts at ~2 fb$^{-1}$**

**Meanwhile**

**→ optimizing analysis techniques**

**→ understanding detectors better**

**→ searching for non-SM Higgs with higher production cross sections or enhanced branching into modes with lower backgrounds**

# D0 Run II $B_s$ Mixing Reach