Title: Physics at the Tevatron

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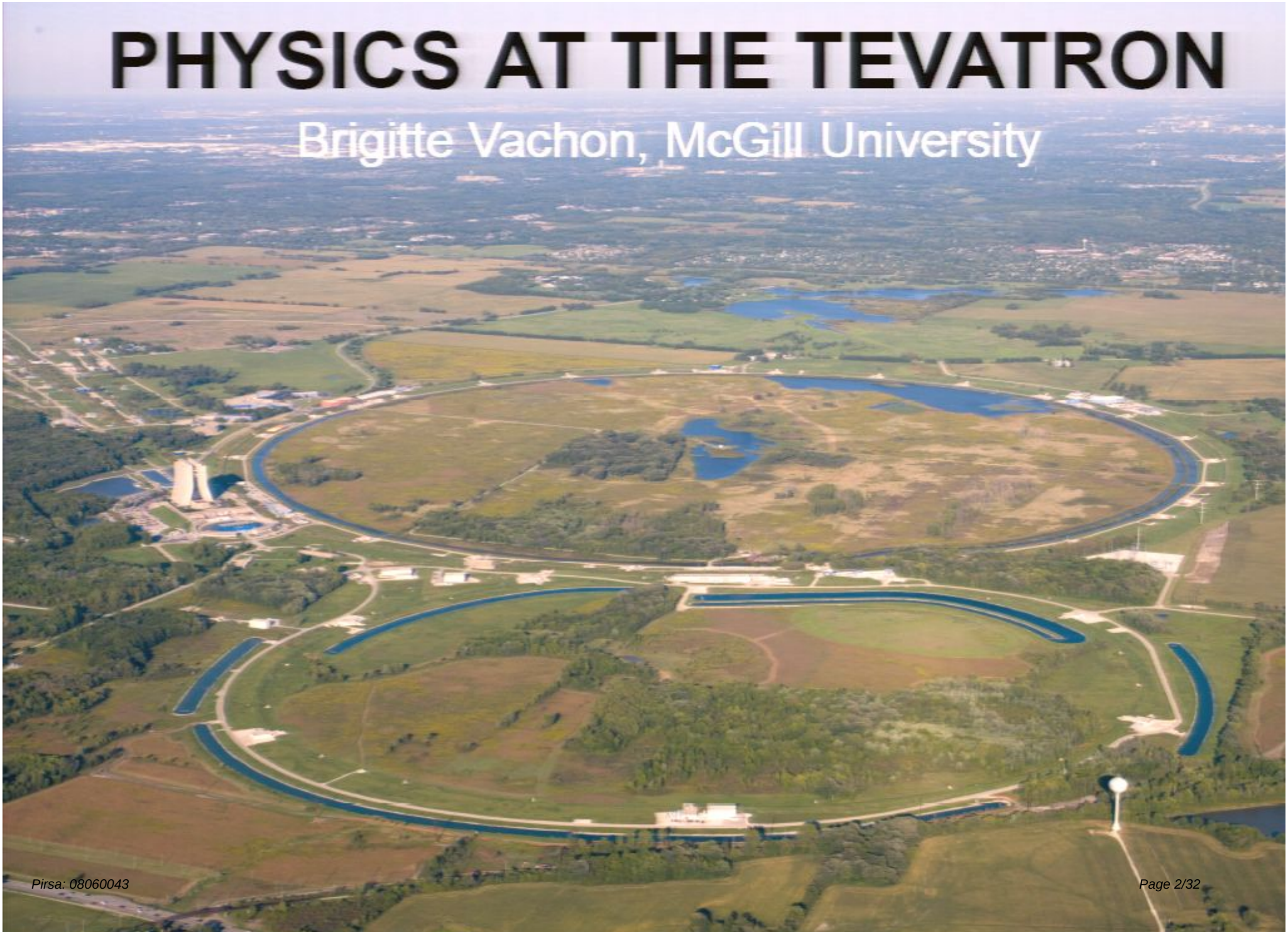
Abstract: The Fermilab Tevatron is currently the highest energy particle collider in the world and is host of the CDF and DZero experiments. Measurements performed by these two international collaborations have significantly improved our knowledge of subatomic physics and helped further constrain different scenarios of physics beyond the Standard Model. A summary of some of the latest results and future experimental goals of the Tevatron\'s experiments will be presented.

PHYSICS AT THE TEVATRON

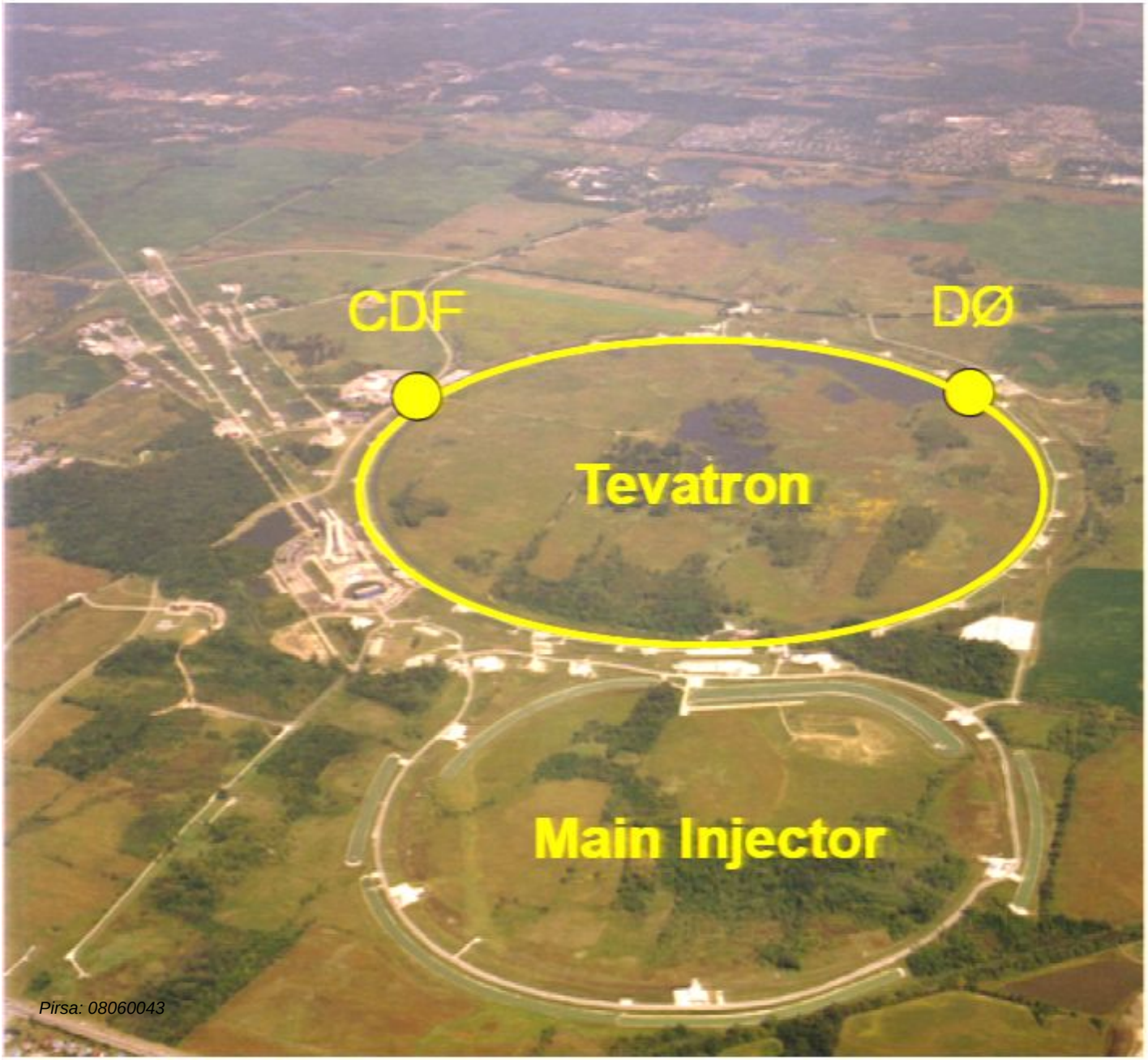
Brigitte Vachon, McGill University



Outline

- Introduction
- Status of collider
- Status of experiments
- Physics results
- Summary

The Fermilab Tevatron



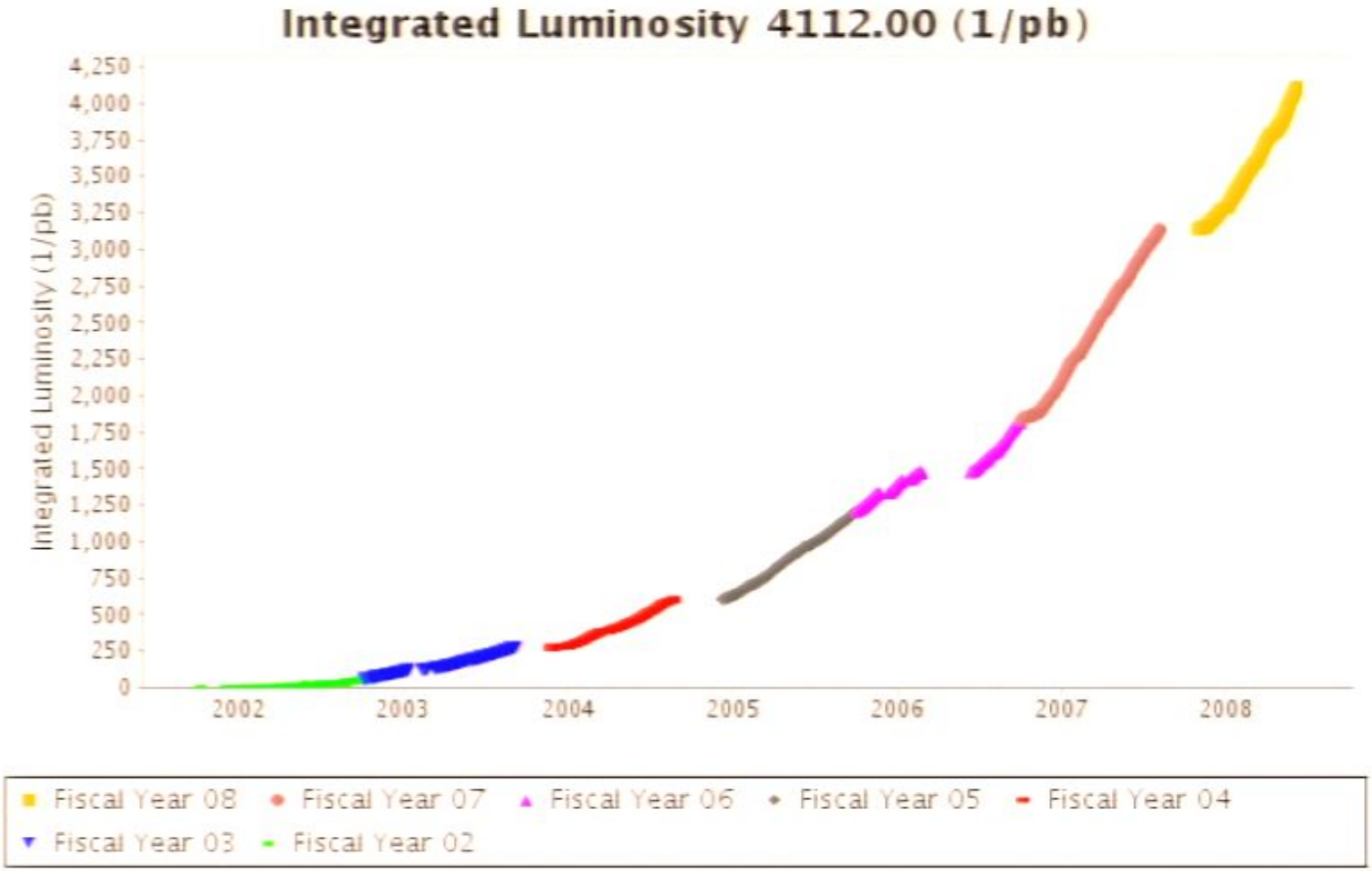
- $p\bar{p}$ collisions at world's highest energy:

  $\sqrt{s}$ = 2 TeV

- Run-I
  - 1990-1995
  - 110 pb^{-1} / expt

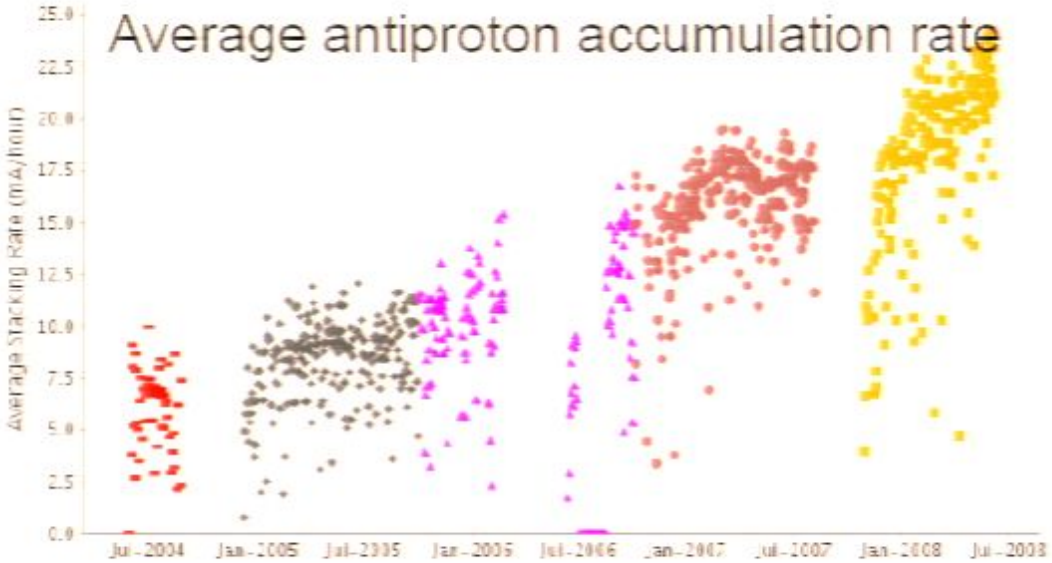
- Run-II
  - 2001-2009
  - ~ 6-7 fb^{-1} /expt (expected)

Tevatron Performance

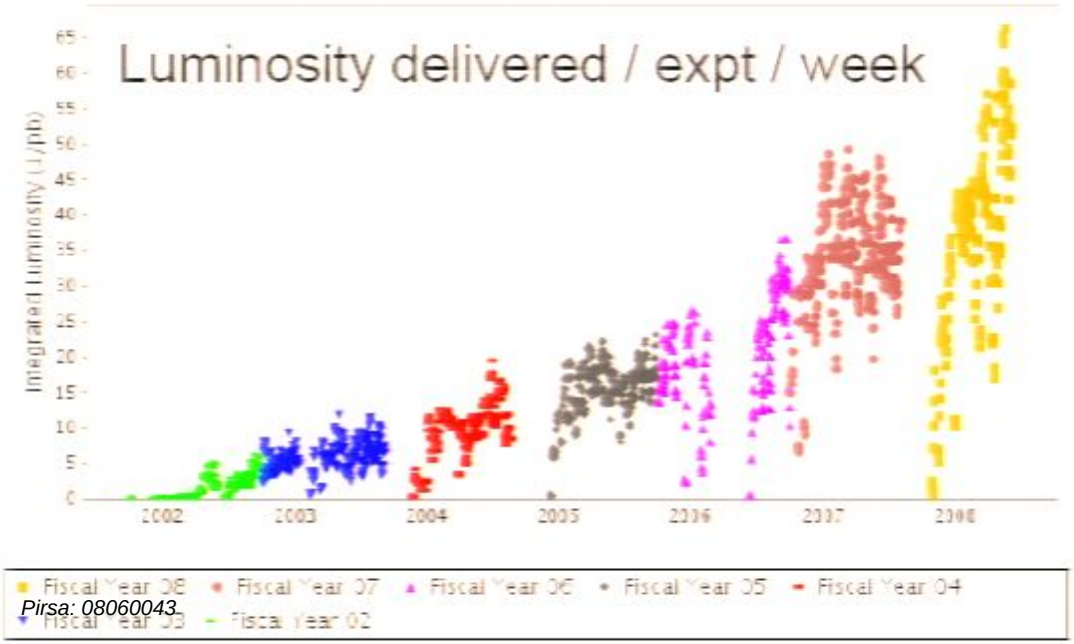


- Doubled dataset each year for four years
- Expect 1.5-2.0 fb^{-1} per year ≥ 2007

Tevatron Performance



- Anti-protons
  - Doubled accumulation rate over last two years
  - No longer limiting factor

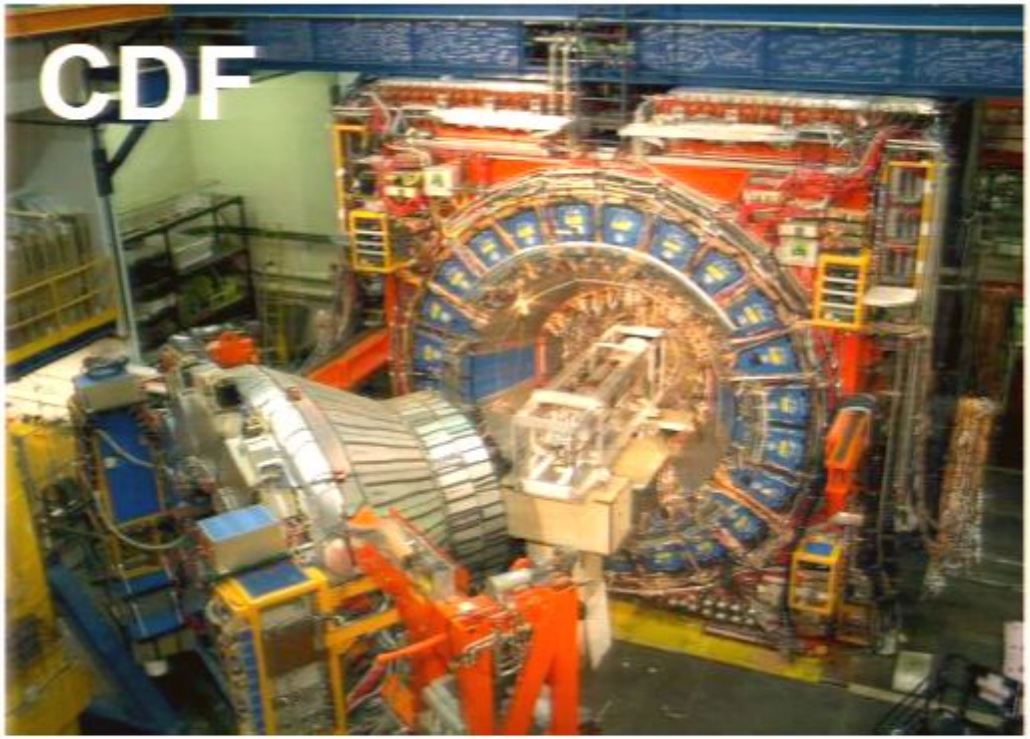


- Accelerator complex up time
  - 20 years old
  - Exceeding original design specs by x300
  - Require constant vigilance

Tevatron luminosity projection

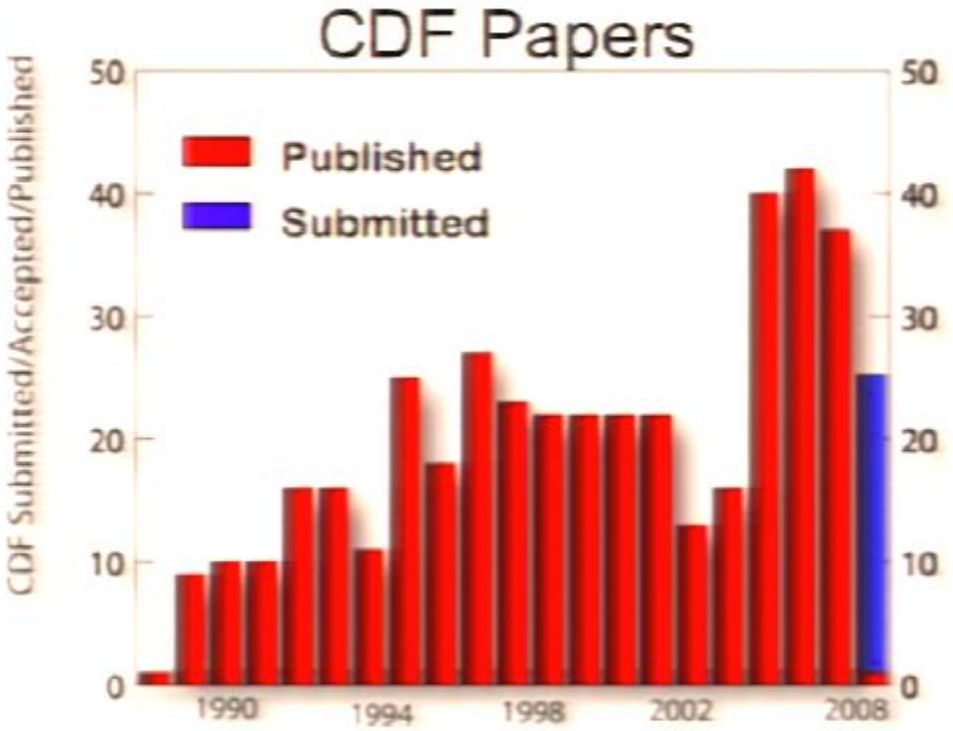
- Expect ~ 6.5 fb^{-1}/experiment by end of 2009
- Could reach ~ 8 fb^{-1}/experiment with 2010 run

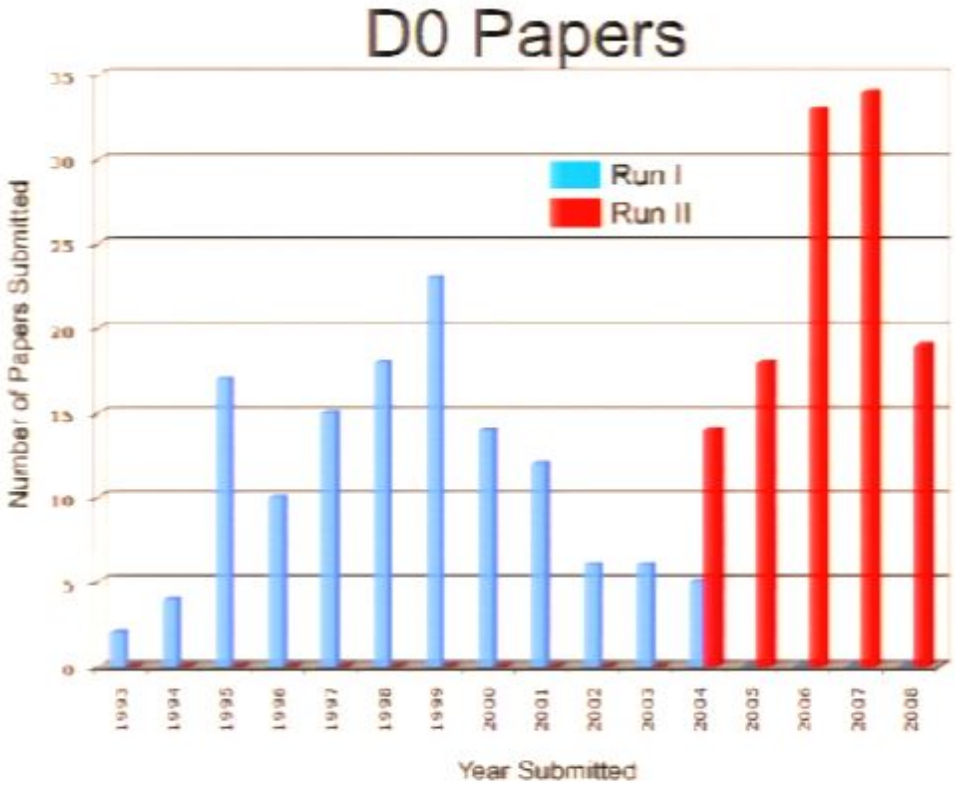
Tevatron experiments



- Two multipurpose detectors with different strengths
- International collaborations of ~ 600 members

Physics productivity

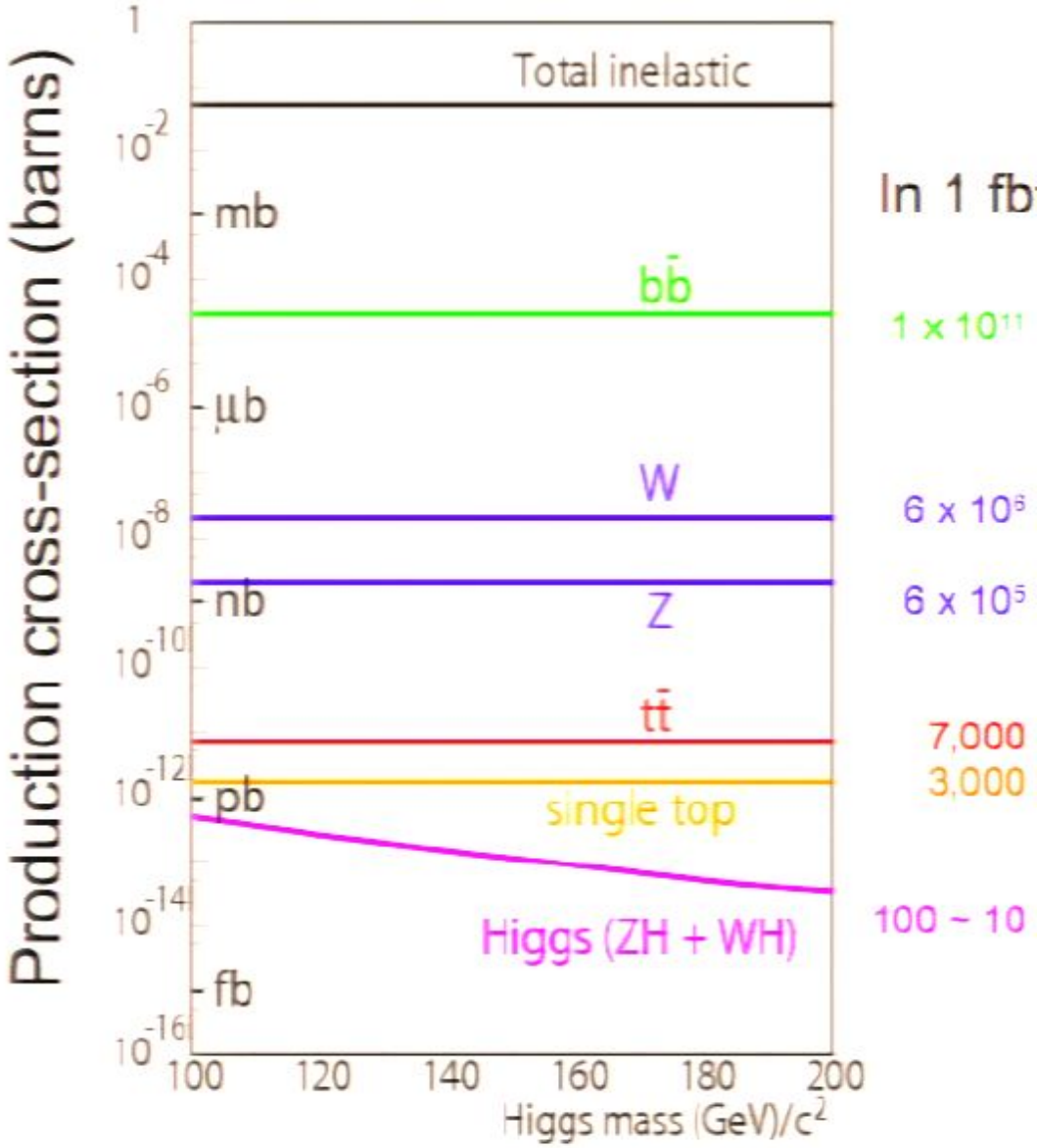




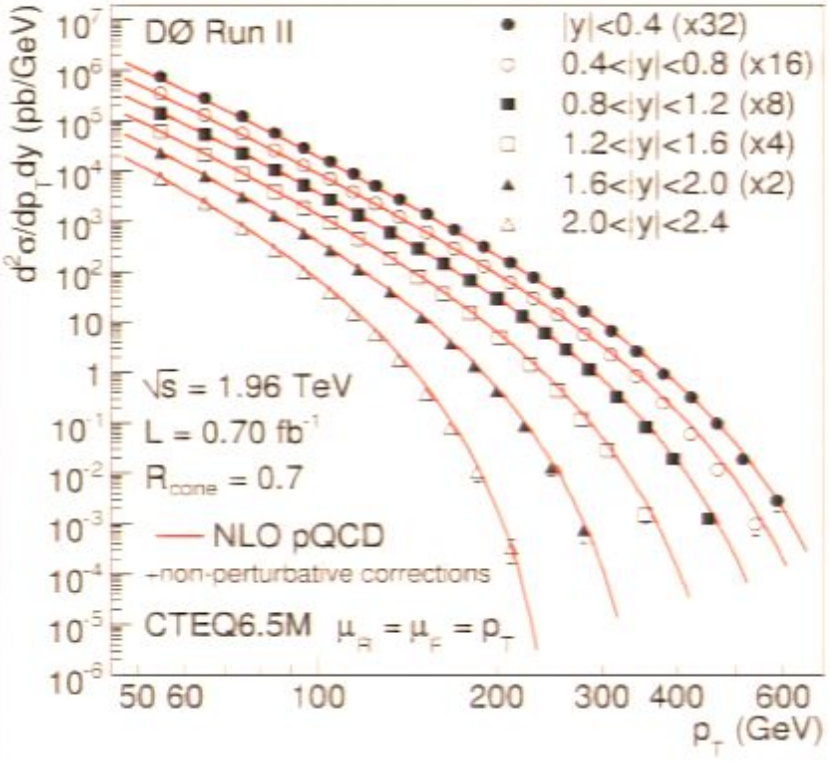
- CDF and D0 each publishing ~ 30-35 papers/year

Physics environment

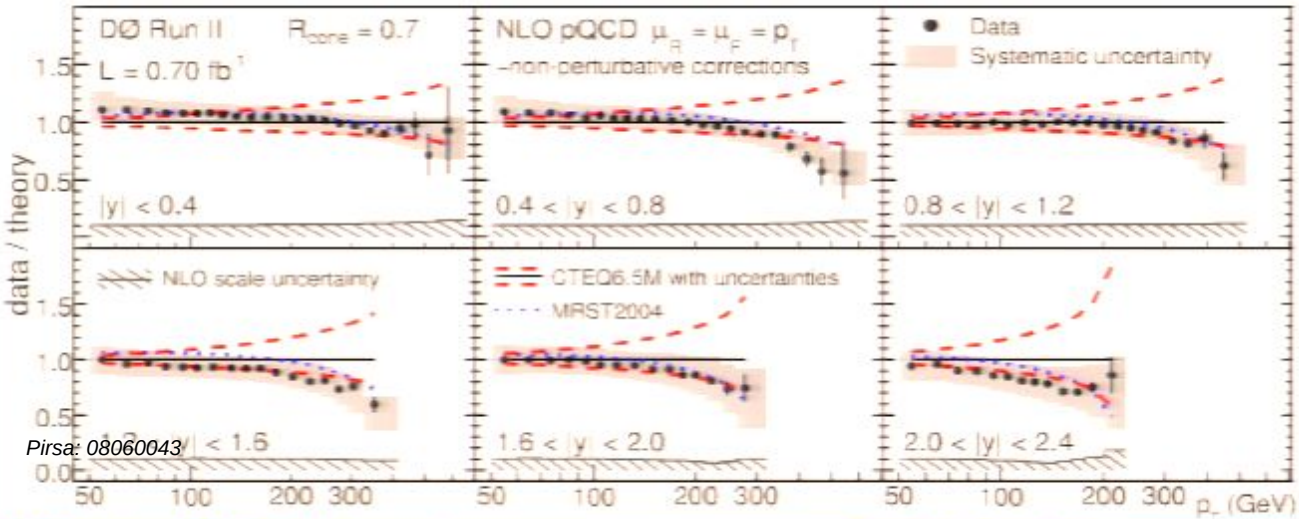
- QCD
- Heavy flavour
- Electroweak
- Top quark
- New Phenomena



Inclusive jet cross-section

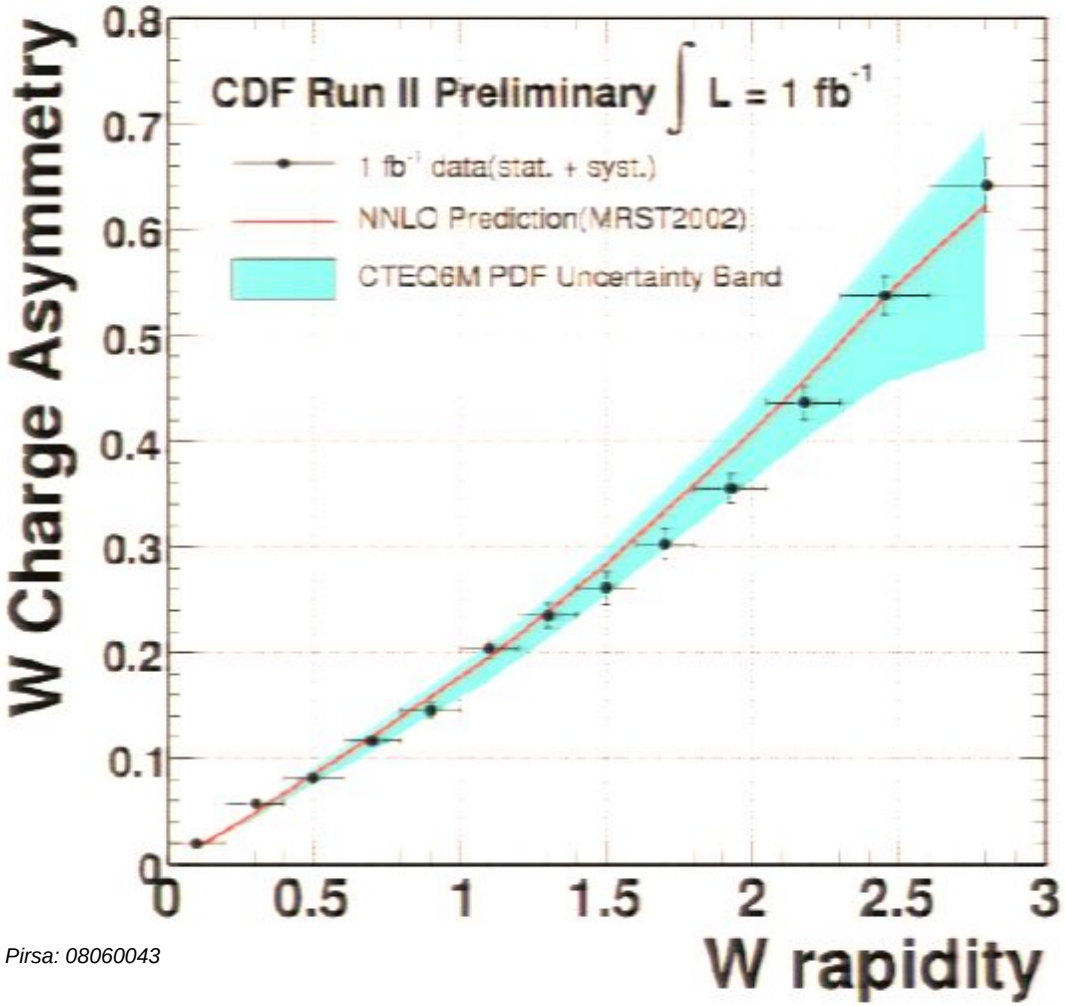


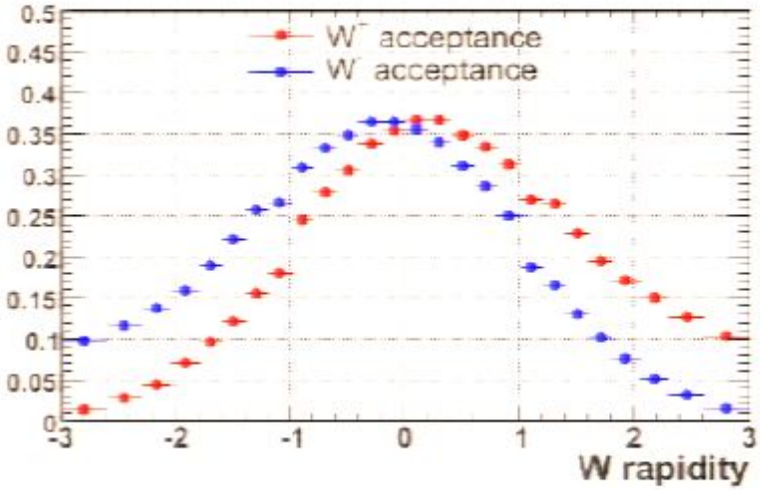
- Test of pQCD
  - Agreement with QCD over 8 order of magnitudes
- Determination of (anti)proton PDFs
  - Powerful constraints of gluon PDF from cross-section at high y
- Sensitivity to new physics at highest energy (at low y)
- Understanding bkg for other analyses (top, Higgs, W/Z,...)



W charge asymmetry

- u quarks carry more momentum than d quarks

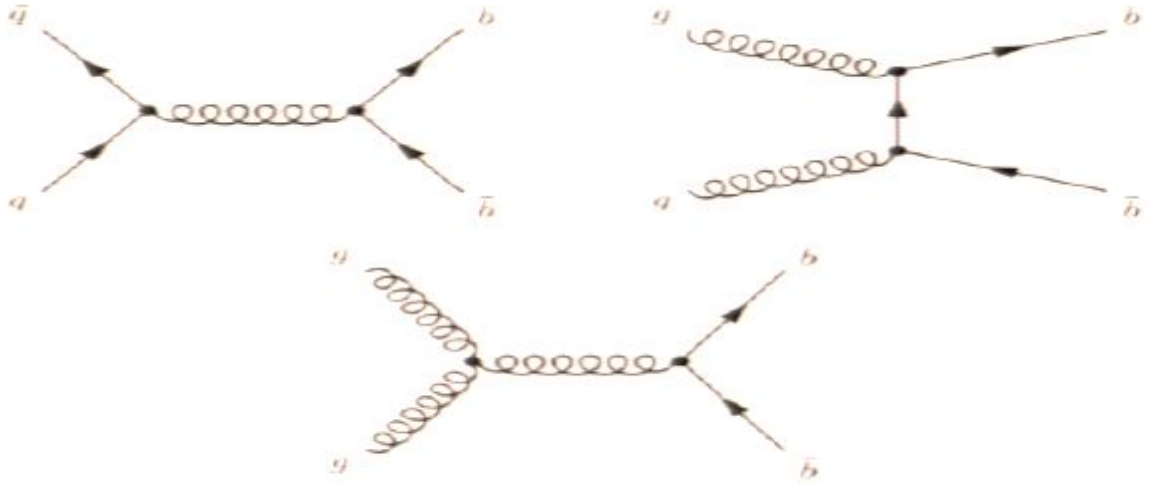




- Constrain $u(x)$ and $d(x)$ PDFs in important region for LHC

Heavy flavour physics

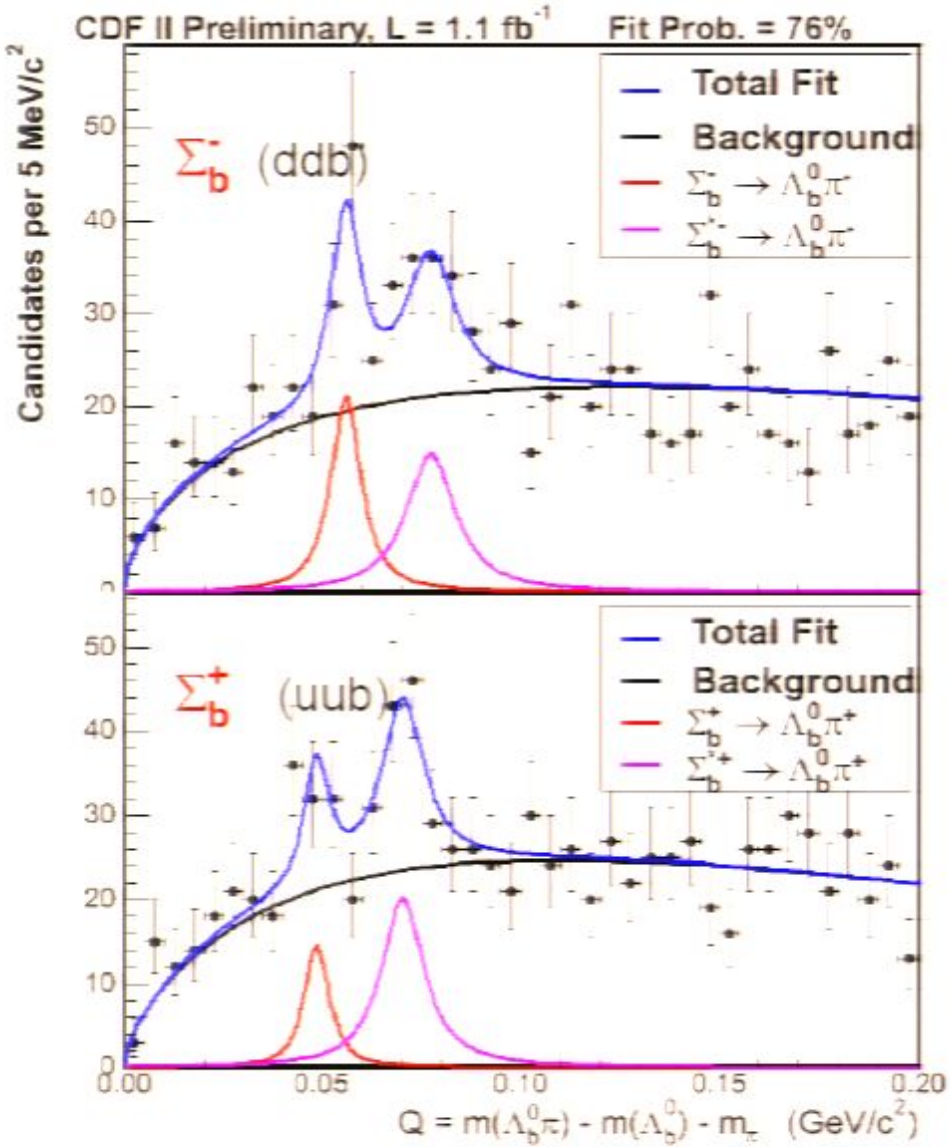
- Large $b\bar{b}$ cross-section $O(10\ \mu b)$

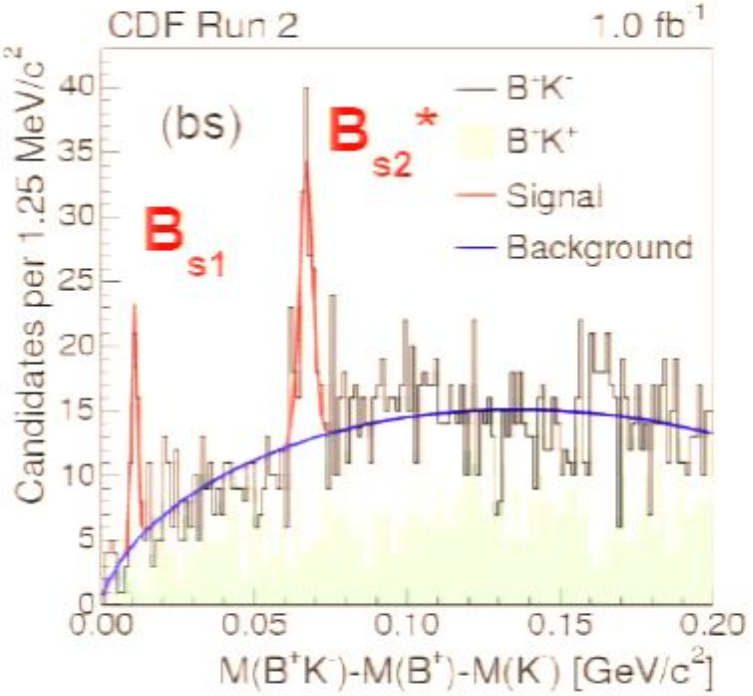


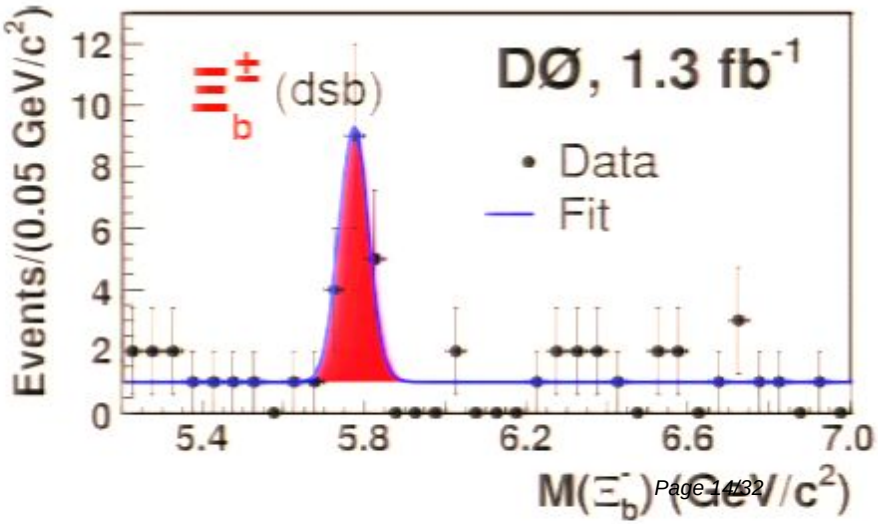
- Many hadrons only directly produced at Tevatron: B_s ,B_c , Λ_b , Σ_b , Ξ_b..

- Heavy flavour physics probes:
  - CKM matrix
  - QCD parameters
  - BSM processes
  - Effective field theories (HQET, NRQCD, lattice QCD...)

Spectroscopy

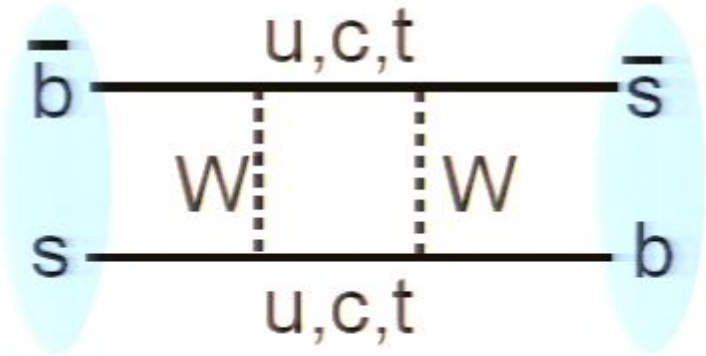


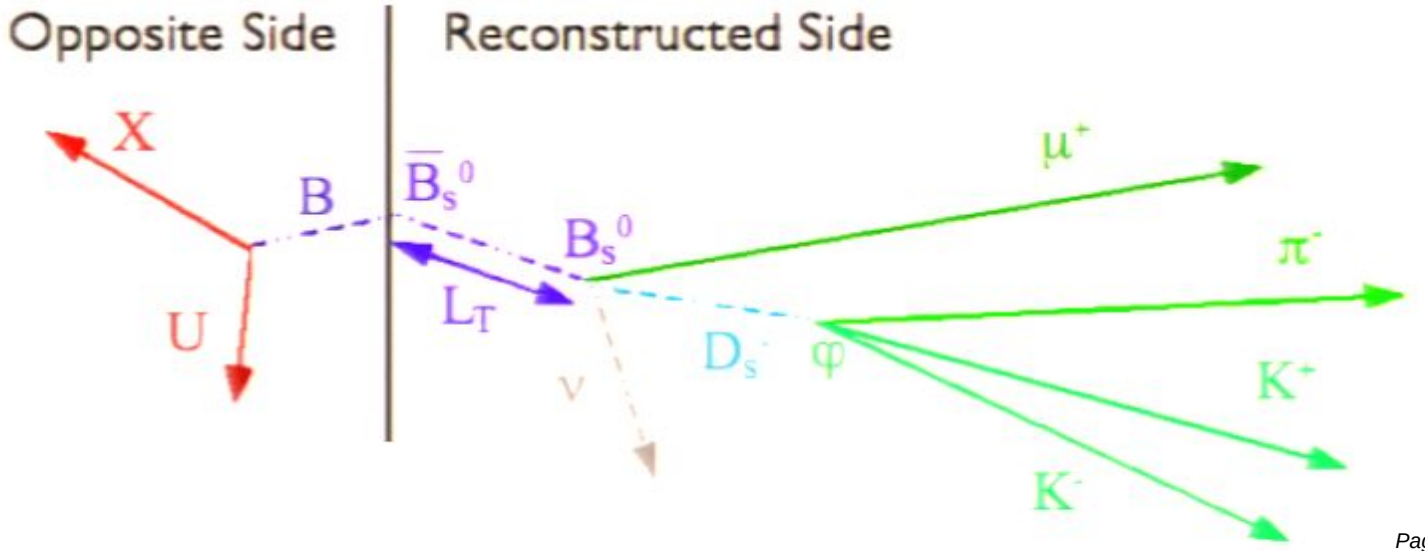




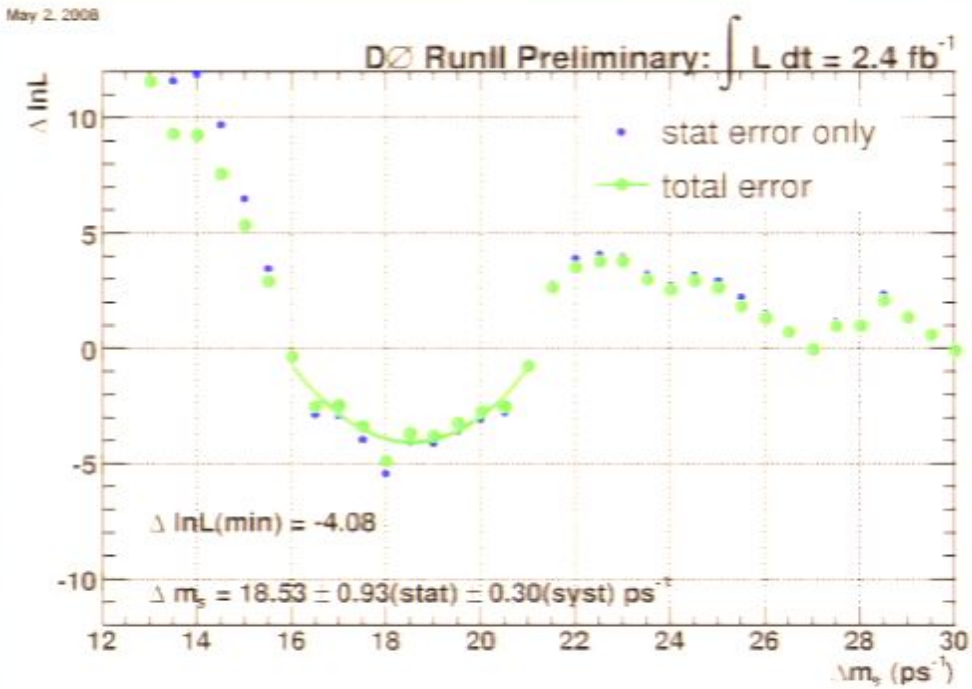
B_s oscillation

- mass eigenstates ≠ weak eigenstates
- Process (dominantly) mediated by box diagrams
- Sensitive to new heavy particles in loops

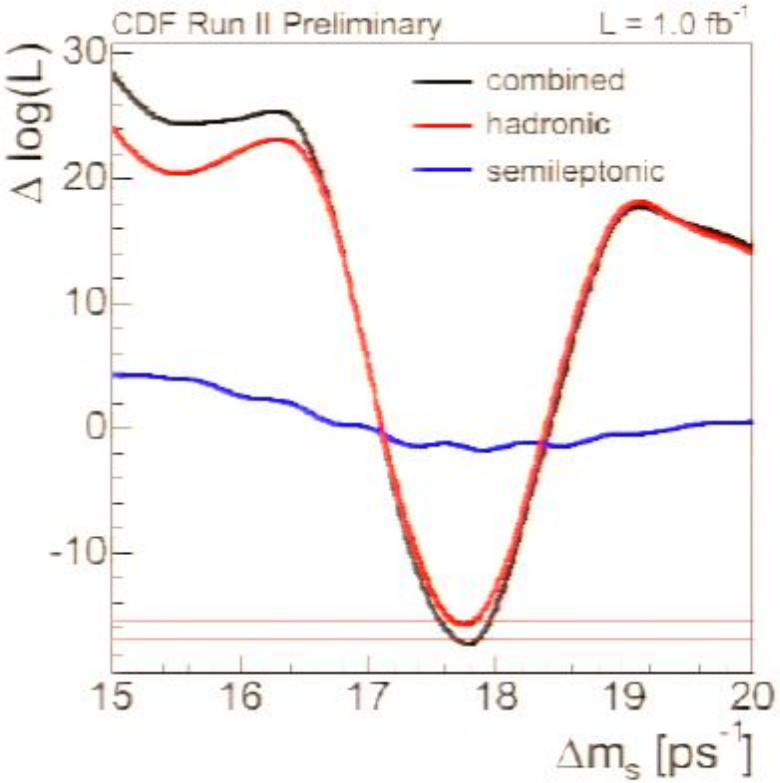




B_s oscillation



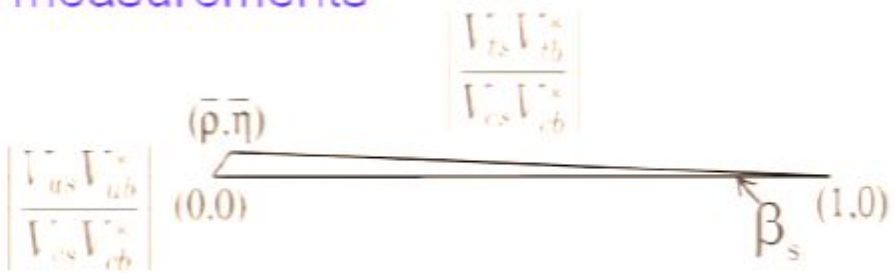
$\Delta m_s = 18.53 \pm 0.93(\text{stat}) \pm 0.30(\text{syst})\ \text{ps}^{-1}$



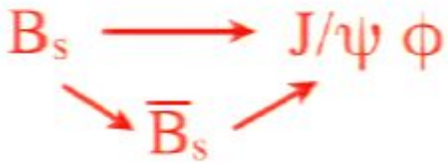
$\Delta m_s = 17.77 \pm 0.10(\text{stat}) \pm 0.07(\text{syst})\ \text{ps}^{-1}$

CP violation in B_s

- CP violation in B_s unconstrained by B_d measurements



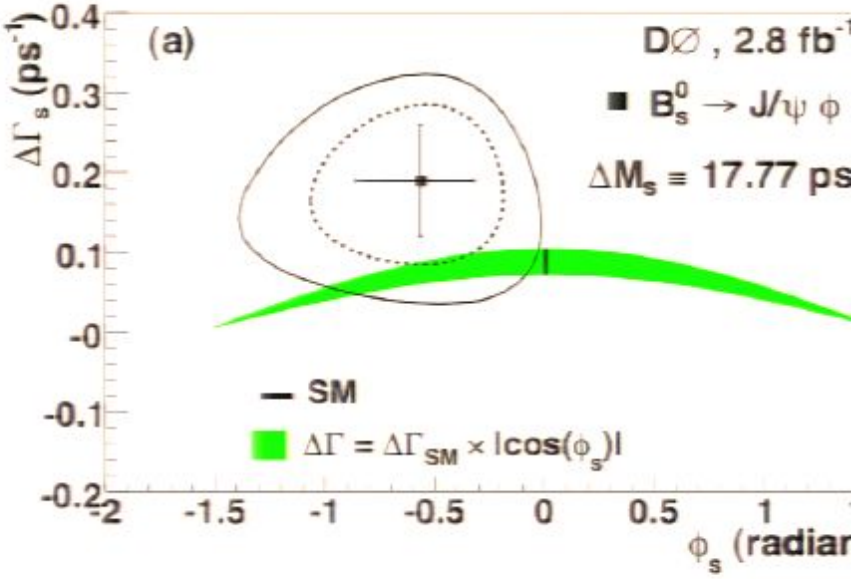
- Arises from interference between B_s mixing and decay

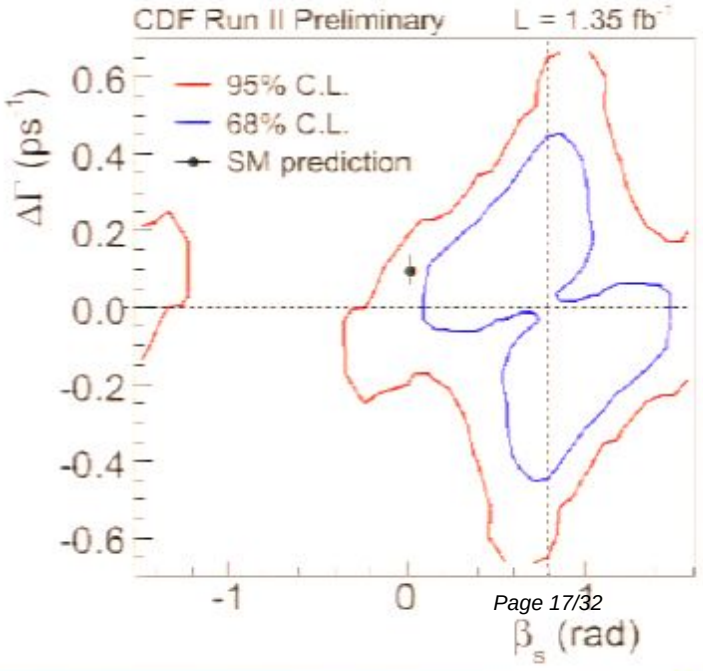


- Small effect in SM: $\phi_s = -2\beta_s \sim -0.04$

  [JHEP 0706 (2007) 072]

  - New physics can have a large impact





- Use B-mixing techniques (ex. flavour tagging)

First hint of new physics?

- Combinations of B_s mixing measurements performed by the **UT***fit* collaboration
  - Phase of the B_s mixing amplitude deviates more than 3σ from SM
- All fit inputs include Tevatron results $(\Delta m_s, A_{SL}^s, A_{SL}^{\mu\mu}, \tau_{B_s}^{FS}, \phi_s, \Delta\Gamma_s, \tau_{B_s})$
- Uncertainties in unfolding of strong phases from DØ results
  - Different combination procedures all lead to ≥ 3σ deviation from SM
- Fit input measurements currently statistically limited
  - Precision will still improve
- Could be first hint of CP violation outside CKM mechanism

arXiv:0803.065

FIRST EVIDENCE OF NEW PHYSICS IN b ↔ s TRANSITIONS

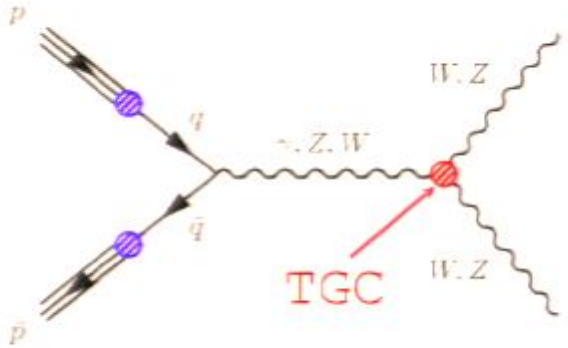
(**UT***fit* Collaboration)

M. Bona,[1] M. Ciuchini,[2] E. Franco,[3] V. Lubicz,[2,4] G. Martinelli,[3,5] F. Parodi,[6] M. Pierini,[1] P. Roudeau,[7] C. Schiavi,[6] L. Silvestrini,[3] V. Sordini,[7] A. Stocchi,[7] and V. Vagnoni[8]

[1] *CERN, CH-1211 Geneva 23, Switzerland*

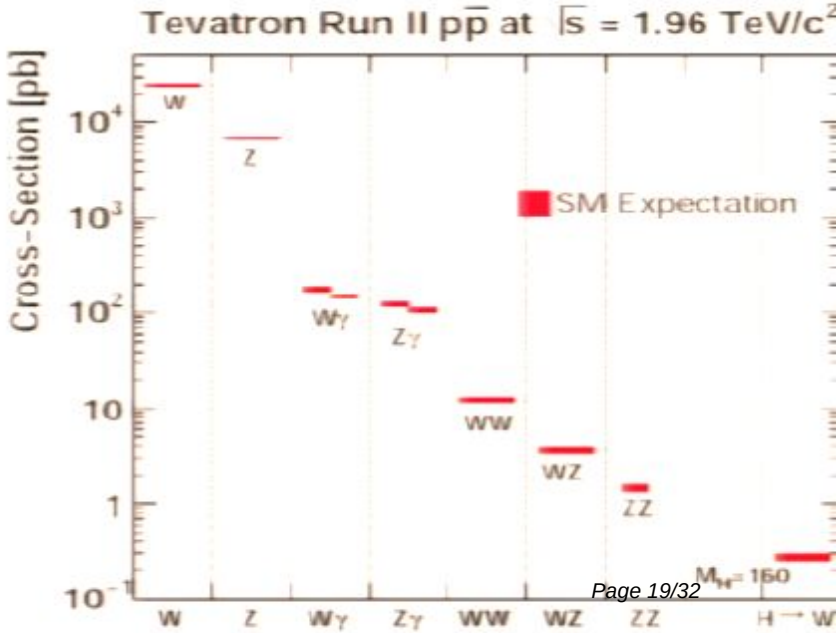
Dibosons and TGCs

- Test gauge structure of SM with WW, WZ, ZZ, Wγ and Zγ samples
  - Neutral couplings: ZZZ, ZZγ, Z$\gamma\gamma$ (better sensitivity than LEP2)
  - Charged couplings: WWZ, WWγ (complementary to LEP2)
- Sensitive to new physics
- Important processes for Higgs and SUSY searches

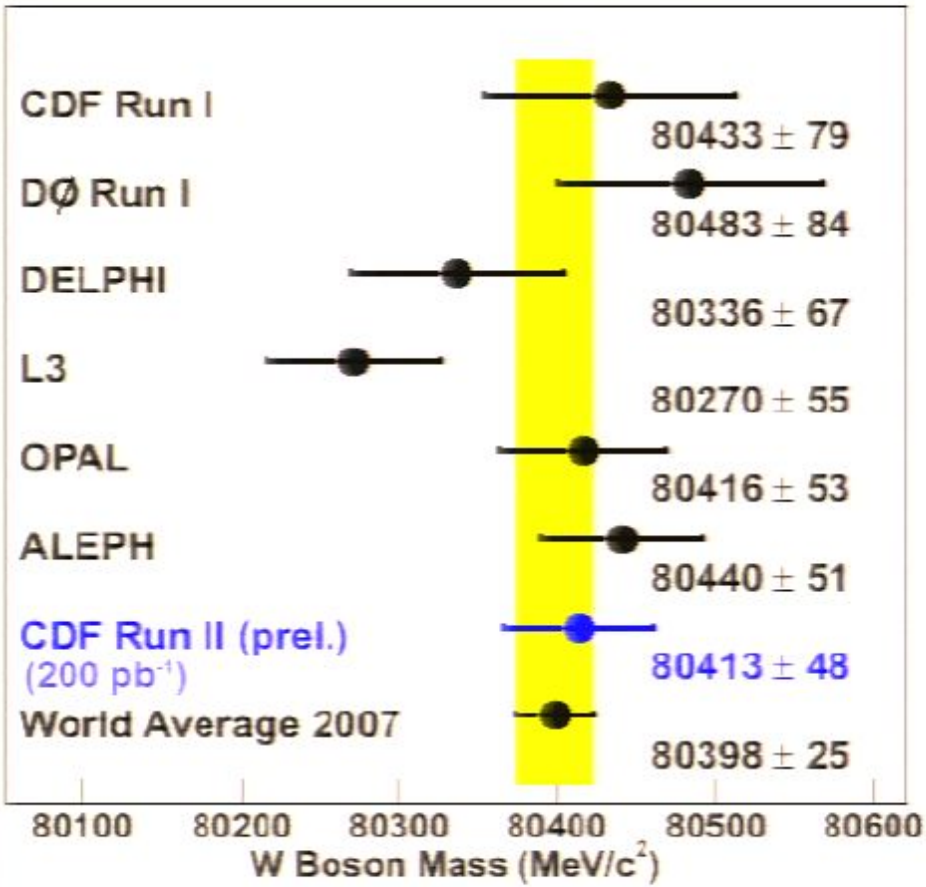


DØ, 1 fb^{-1} (Λ=1.2 TeV)

$q\bar{q} \to Z/\gamma \to ZZ$	$-0.26 < f_{40}^{\gamma} < 0.26$
	$-0.28 < f_{40}^{Z} < 0.28$
	$-0.30 < f_{50}^{\gamma} < 0.28$
	$-0.31 < f_{50}^{Z} < 0.29$
$q\bar{q} \to Z/\gamma(*) \to Z\gamma$	$-0.085 < h_{30}^{\gamma} < 0.084$
	$-0.083 < h_{30}^{Z} < 0.082$
	$-0.0053 < h_{40}^{\gamma} < 0.0054$
	$-0.0053 < h_{40}^{Z} < 0.0054$

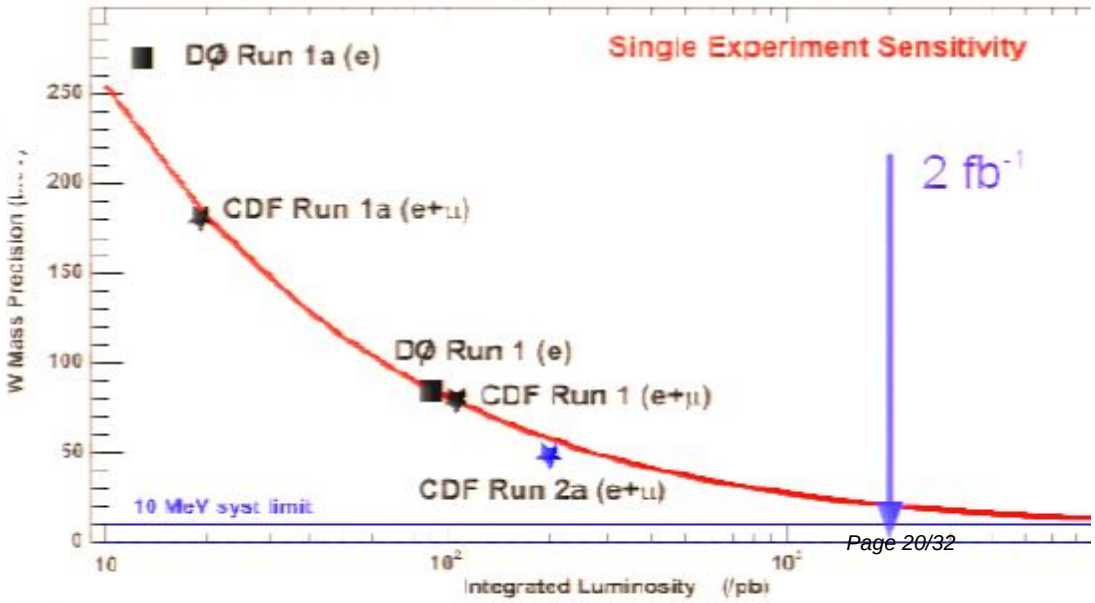


W mass



- Both experiments aim for new results at ICHEP:

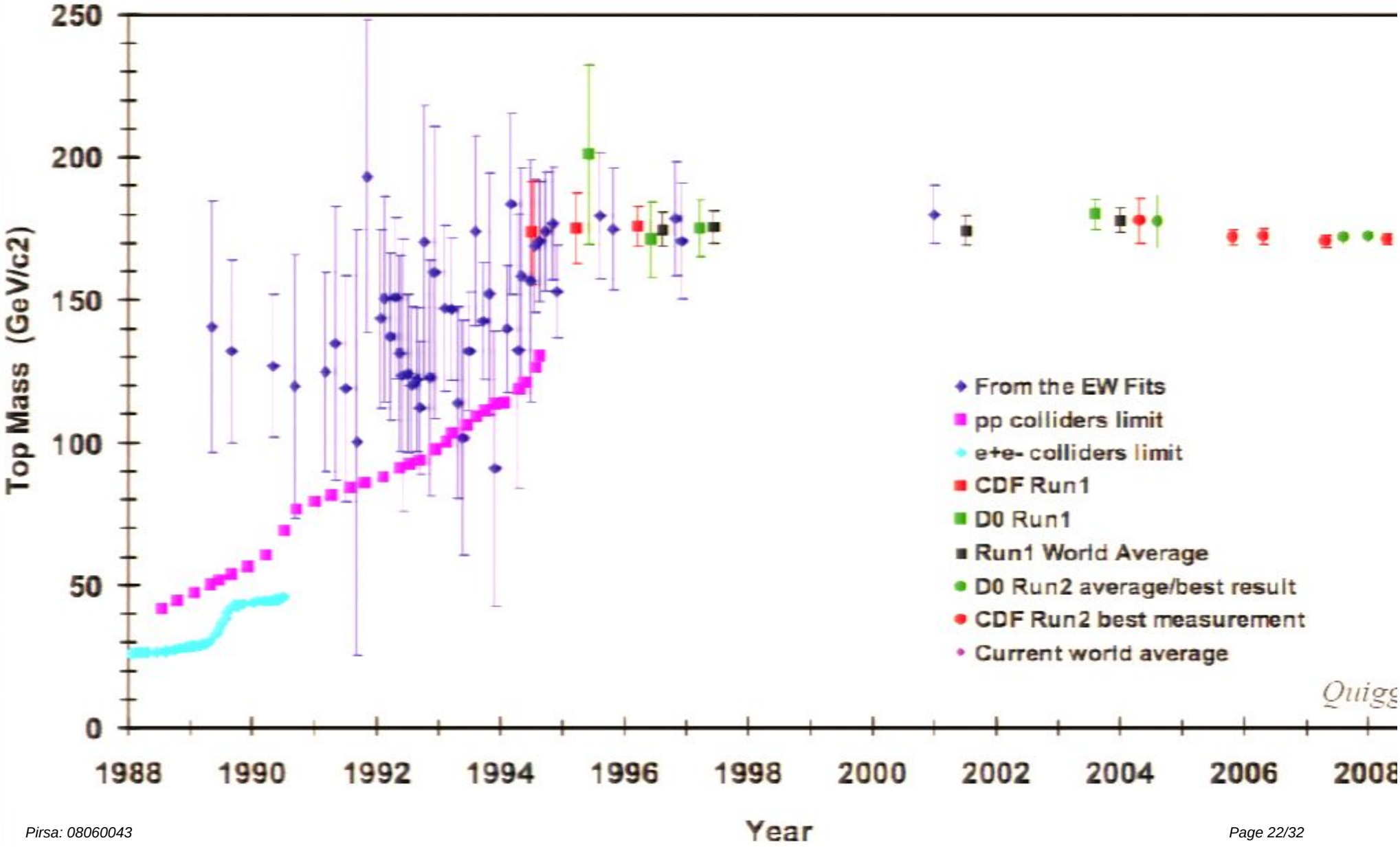
  With ~ 2 fb^{-1}, CDF extrapolates to $\Delta M_W \sim 25$ MeV/c^2 (comparable with current world average)



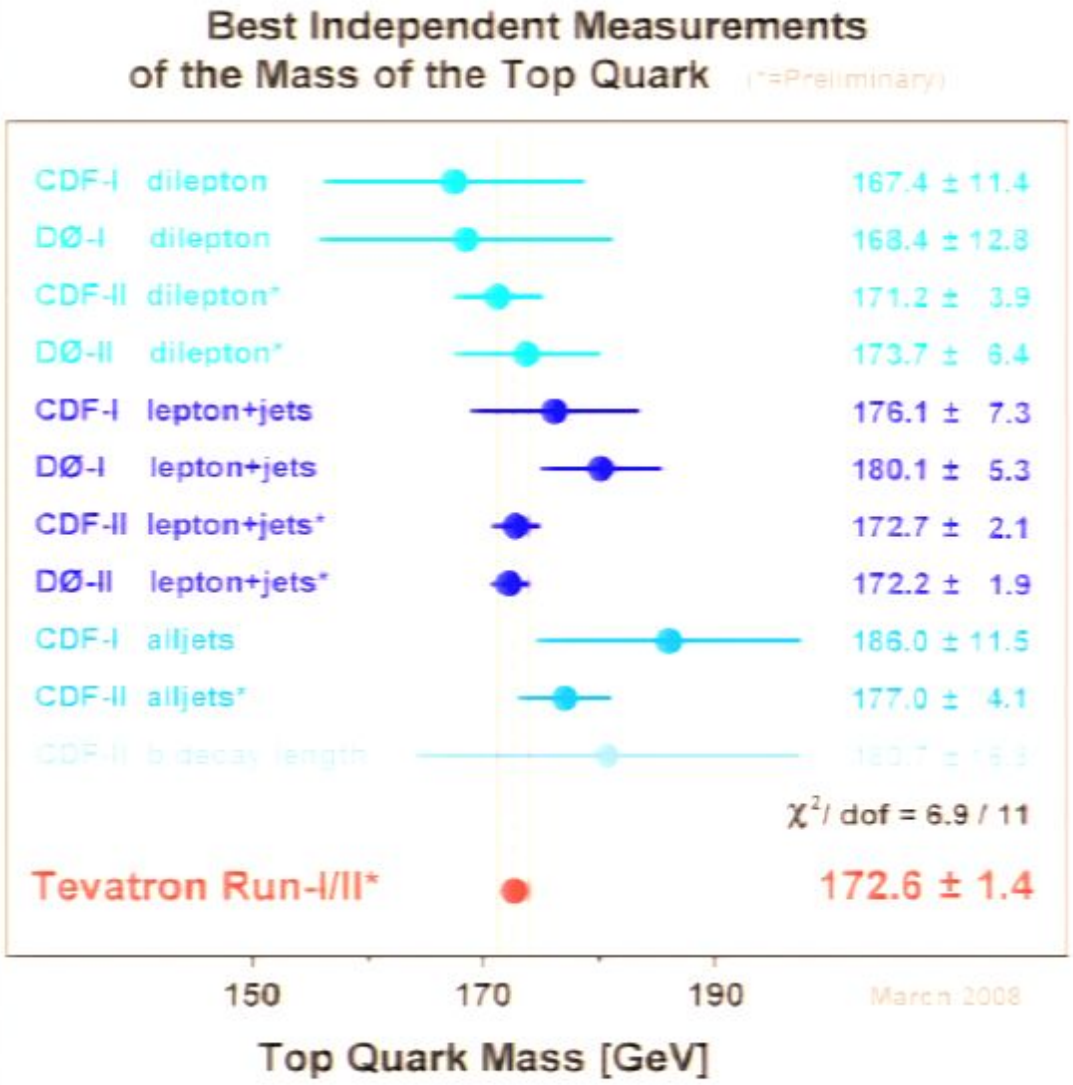
Top quark properties

- **Charge**: Exclude 4/3e hypothesis @ 92% CL [D0, 370 pb^{-1}]
- **Width**: $\Gamma_t < 12.7\,\mathrm{GeV}$ @ 95% CL [CDF, 1 fb^{-1}]
- **Production**:
  - production cross-section: $\sigma(p\bar{p}\to t\bar{t}) = 6.2^{+0.9}_{-0.9}(\mathrm{stat})\ ^{+0.8}_{-0.7}(\mathrm{syst}) \pm 0.4(\mathrm{lumi})\,\mathrm{pb}$ [D0, 1 fb^{-1}]
  - production mechanism: $\frac{\sigma(gg\to t\bar{t})}{\sigma(p\bar{p}\to t\bar{t})} = 0.07 \pm 0.14(\mathrm{stat}) \pm 0.07(\mathrm{syst})$ [CDF, 1 fb^{-1}]
  - top charge asymmetry: $A_{FB} = 0.17 \pm 0.07(\mathrm{stat}) \pm 0.04(\mathrm{syst})$ [CDF, 1.9 fb^{-1}]
  - single top production: $\sigma(p\bar{p}\to tb) = 4.7^{+1.3}_{-1.3}\,\mathrm{pb}$ (3.6σ) [D0, 0.9 fb^{-1}]
- **Decay**:
  - $R = \frac{B(t\to Wb)}{B(t\to Wq)} = 0.97^{+0.09}_{-0.08}$ [D0, 0.9 fb^{-1}]
  - W helicity: $F_0 = 0.65 \pm 0.19(\mathrm{stat}) \pm 0.03(\mathrm{syst})$
    $F_+ = -0.03 \pm 0.07(\mathrm{stat}) \pm 0.03(\mathrm{syst})$ [CDF, 1 fb^{-1}]

Top Mass

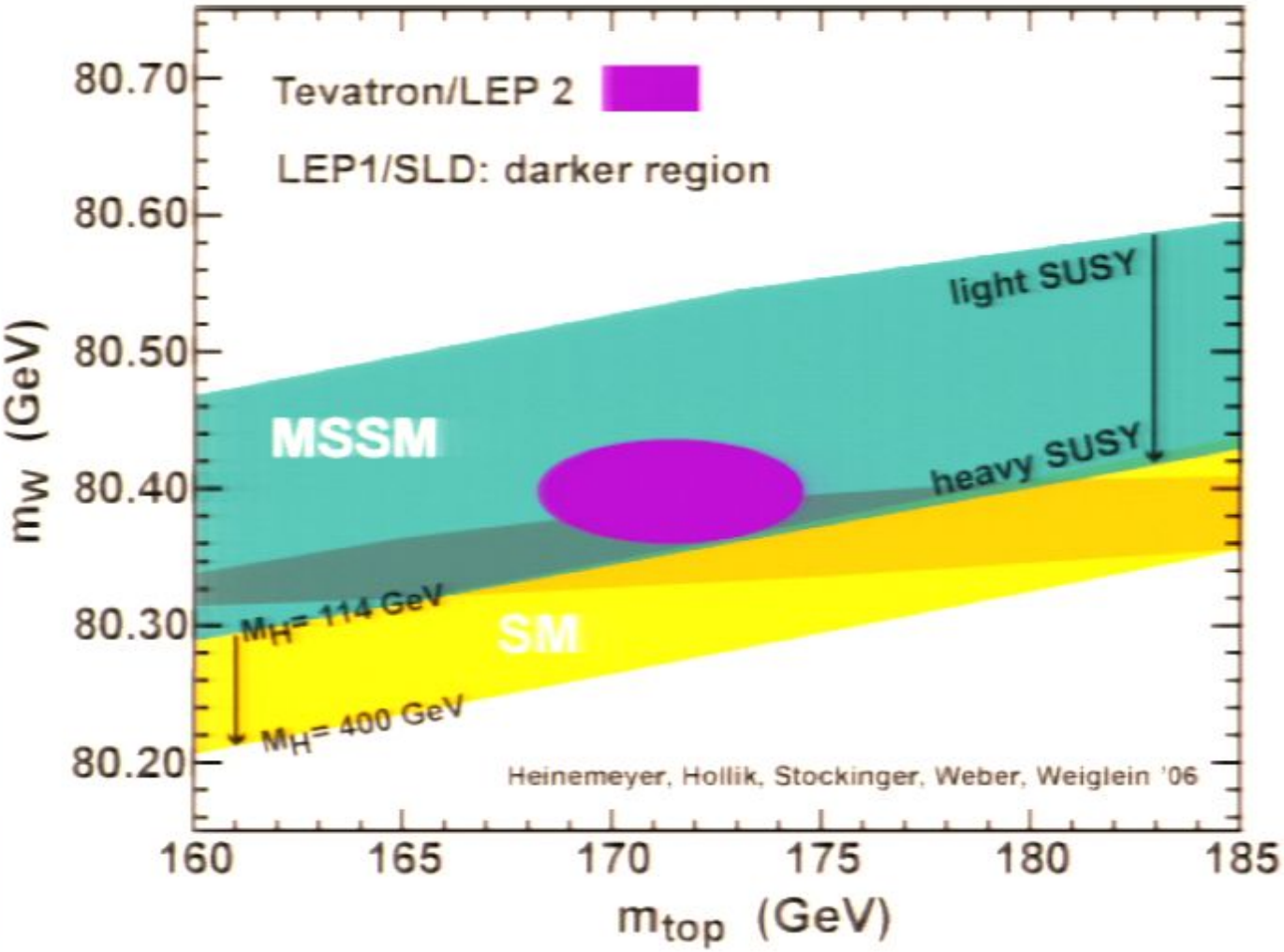

Top Mass (GeV/c2)
250
200
150
100
50
0
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Year
From the EW Fits
pp colliders limit
e+e- colliders limit
CDF Run1
D0 Run1
Run1 World Average
D0 Run2 average/best result
CDF Run2 best measurement
Current world average
Quigg

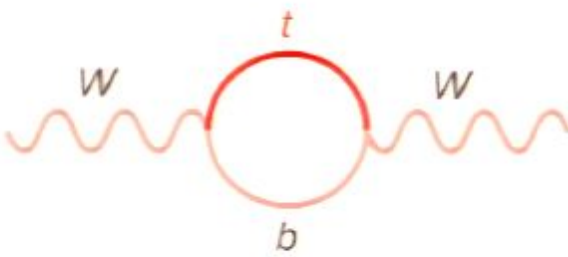
Top Mass



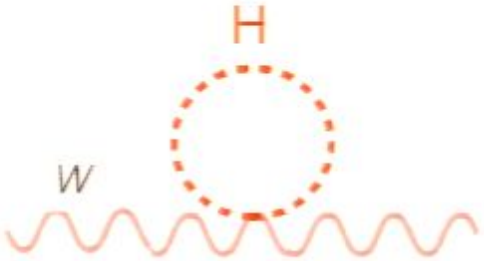
- New results in all three decay channels
- ΔM_t = 1.4 GeV/c^2 (0.8 %)
- Exceeded Run II goals by x2
- Measurements systematics limited
- Ongoing work to reduce dominant systematic uncertainties
  - Jet Energy Scale
  - ISR/FSR
  - Background modelling
- Could reach ΔM_t = 1.0 GeV/c^2

M_t vs M_W vs M_H





$$\delta m_W \propto m_t^2$$

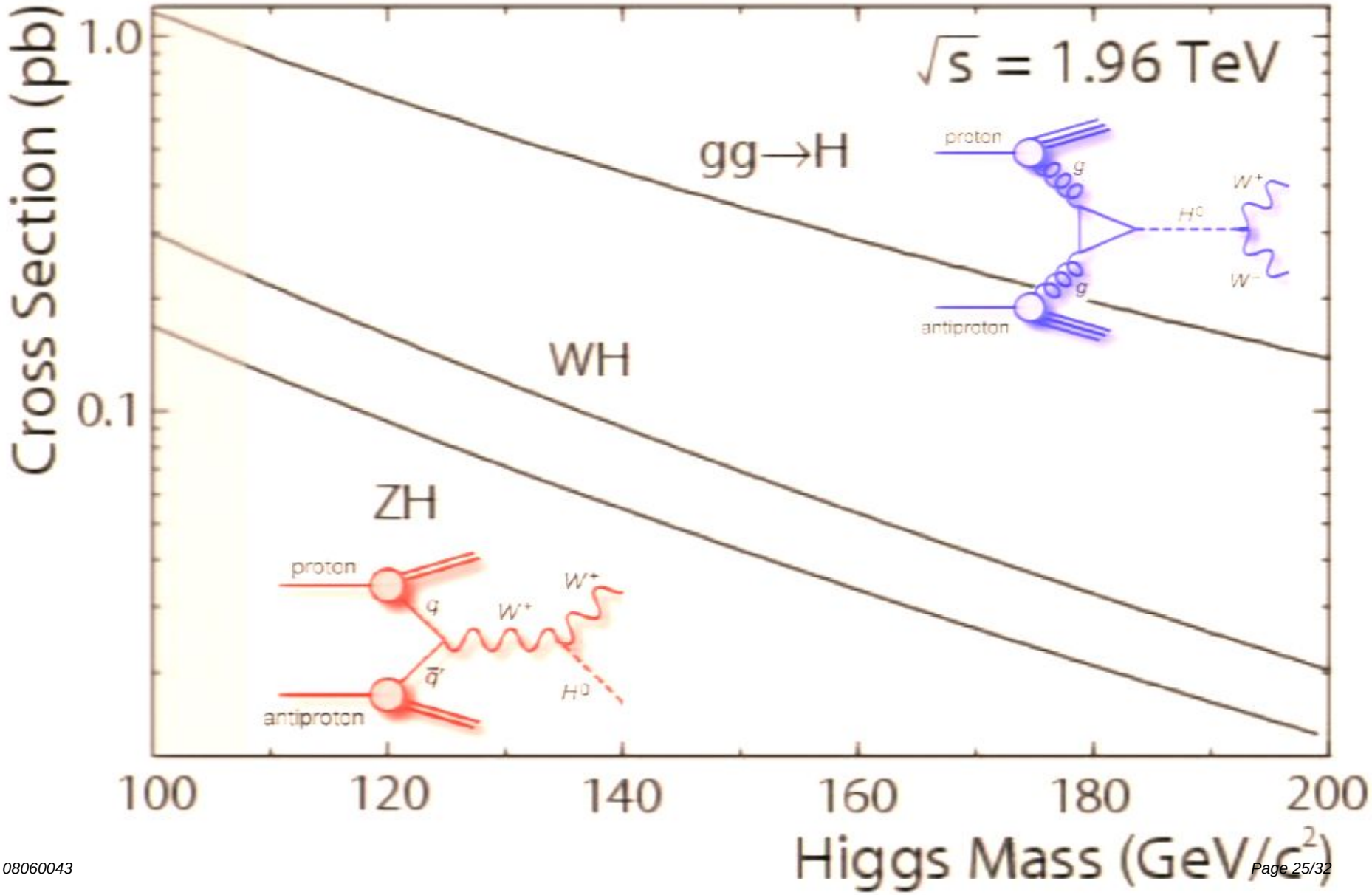


$$\delta m_W \propto \ln m_H$$

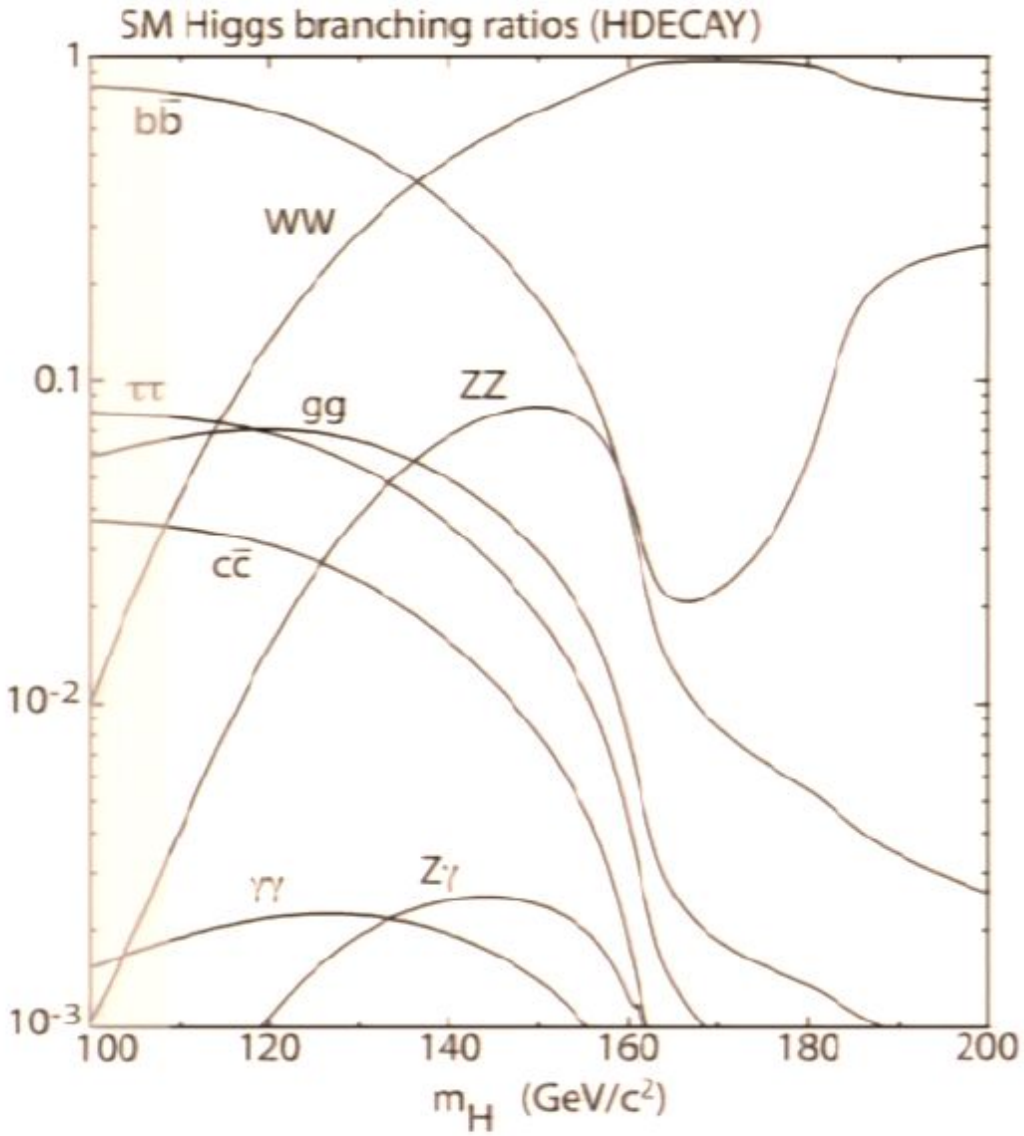
$$M_H^{Best\ fit} = 87^{+36}_{-27}\ \mathrm{GeV/c^2}$$

$$114\ \mathrm{GeV/c^2} < M_H < 190\ \mathrm{GeV/c^2}\ @\ 95\%\ \mathrm{CL}$$

SM Higgs production



SM Higgs decay



Most important decays:

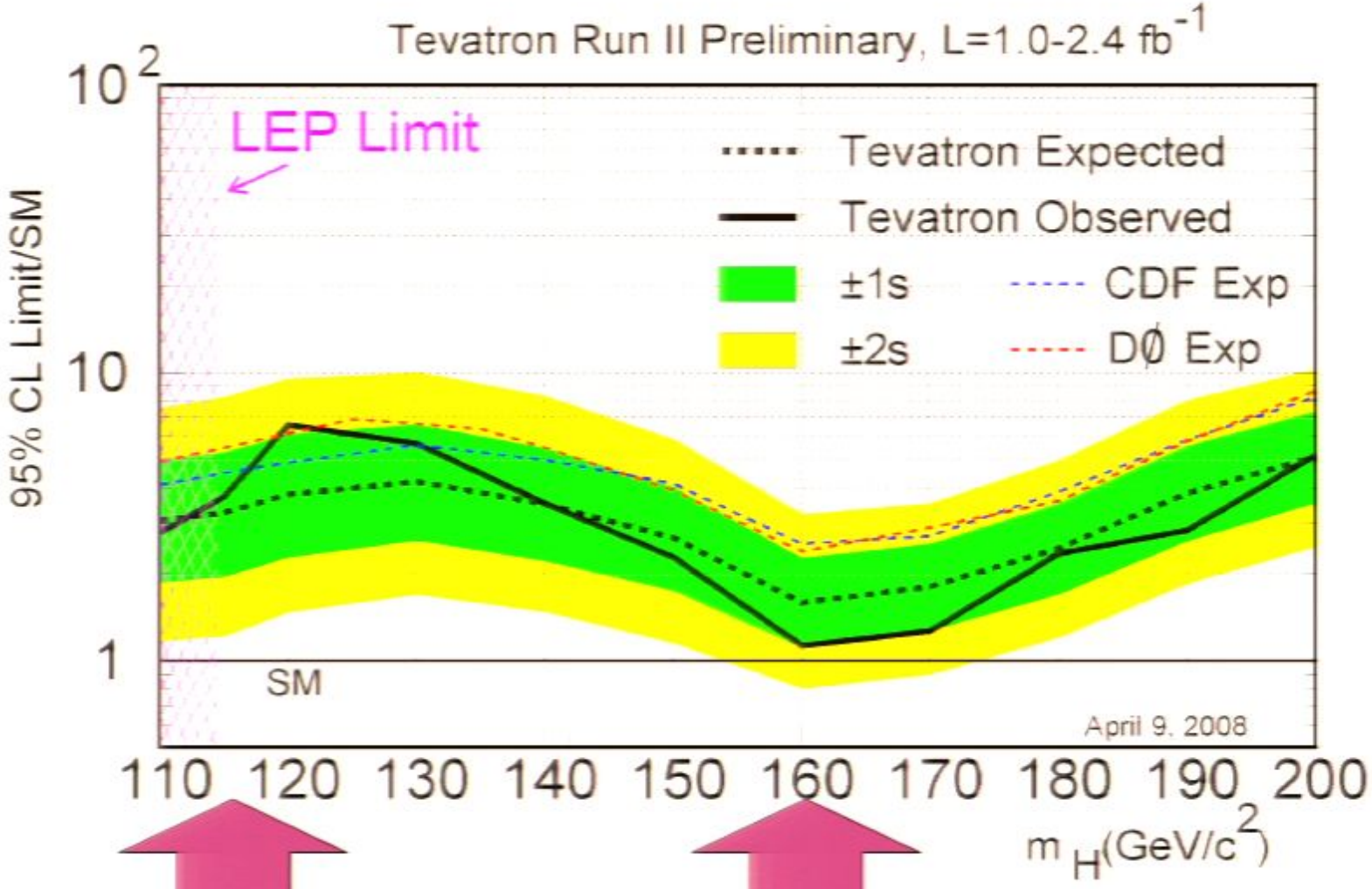
- Low mass

$$H^0 \to b\bar{b}, W^+W^-, \tau^+\tau^-$$

- High mass

$$H^0 \to W^+W^-$$

Tevatron combined Higgs limit

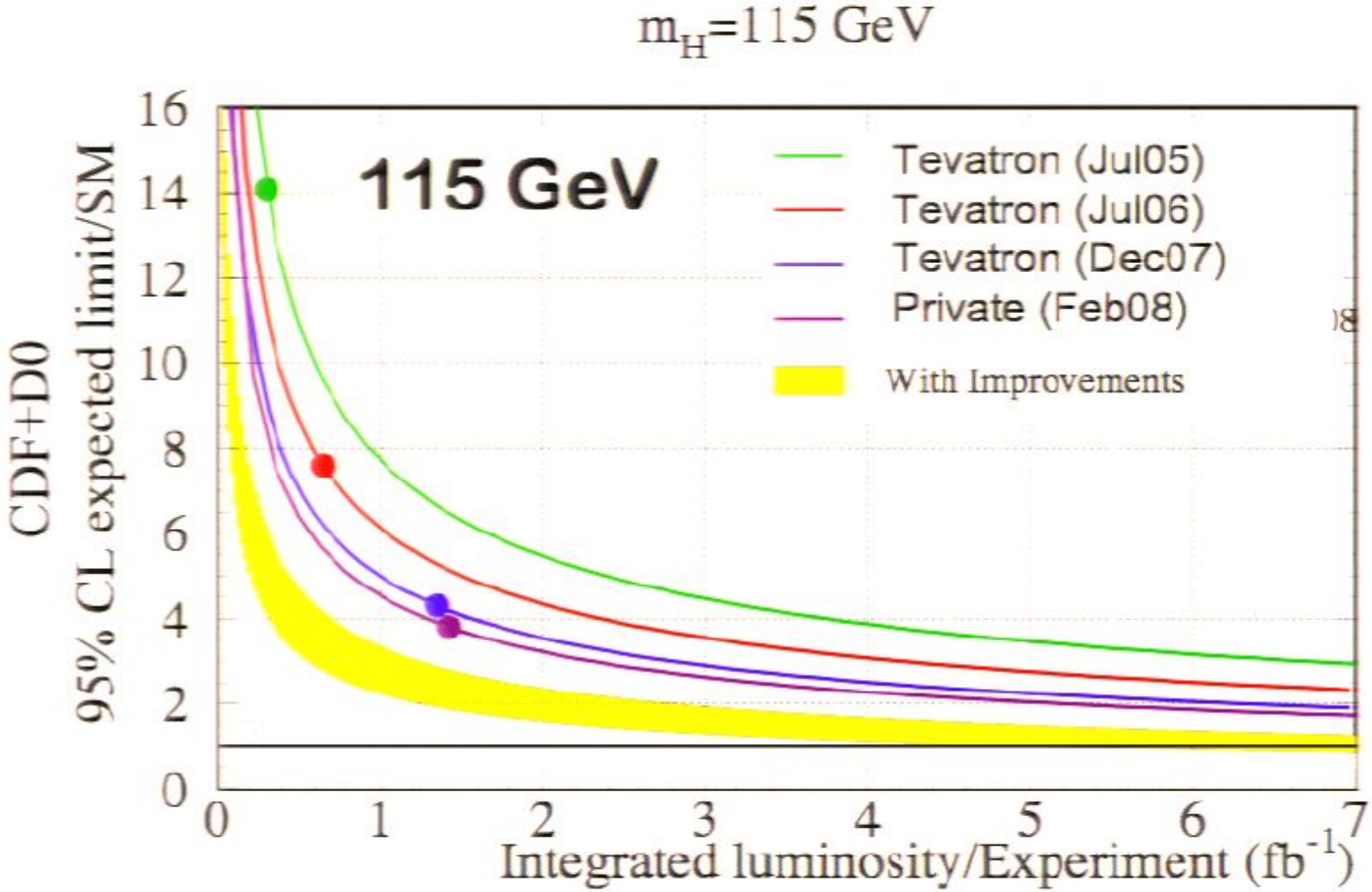


M_H=115 GeV/c^2
Expected: 3.3
Observed: 3.7

M_H=160 GeV/c^2
Expected: 1.6
Observed: 1.1

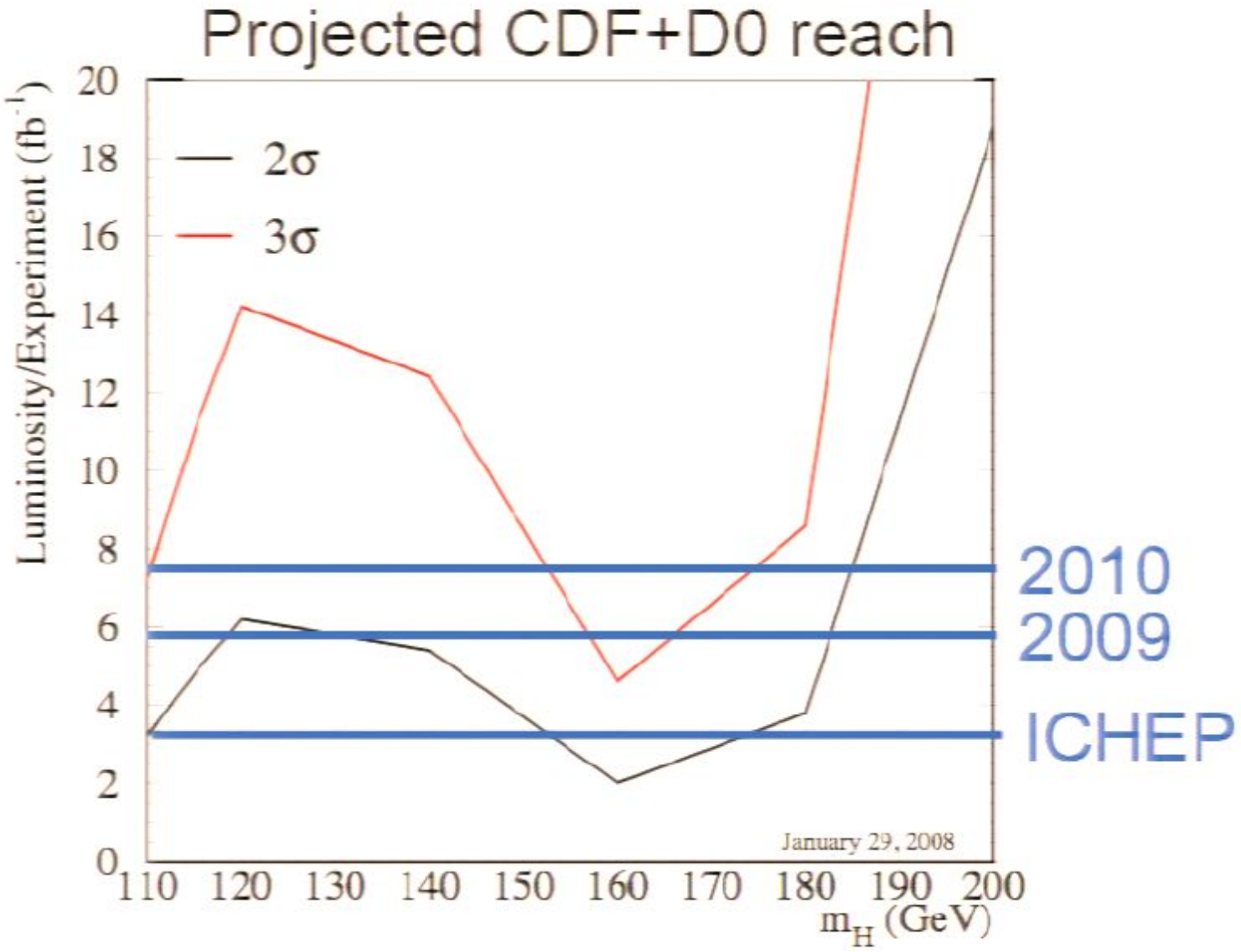
arXiv:/0804.3423 [hep-e

Tevatron Higgs sensitivity



Higgs sensitivity improving faster than $1/\sqrt{\mathcal{L}}$

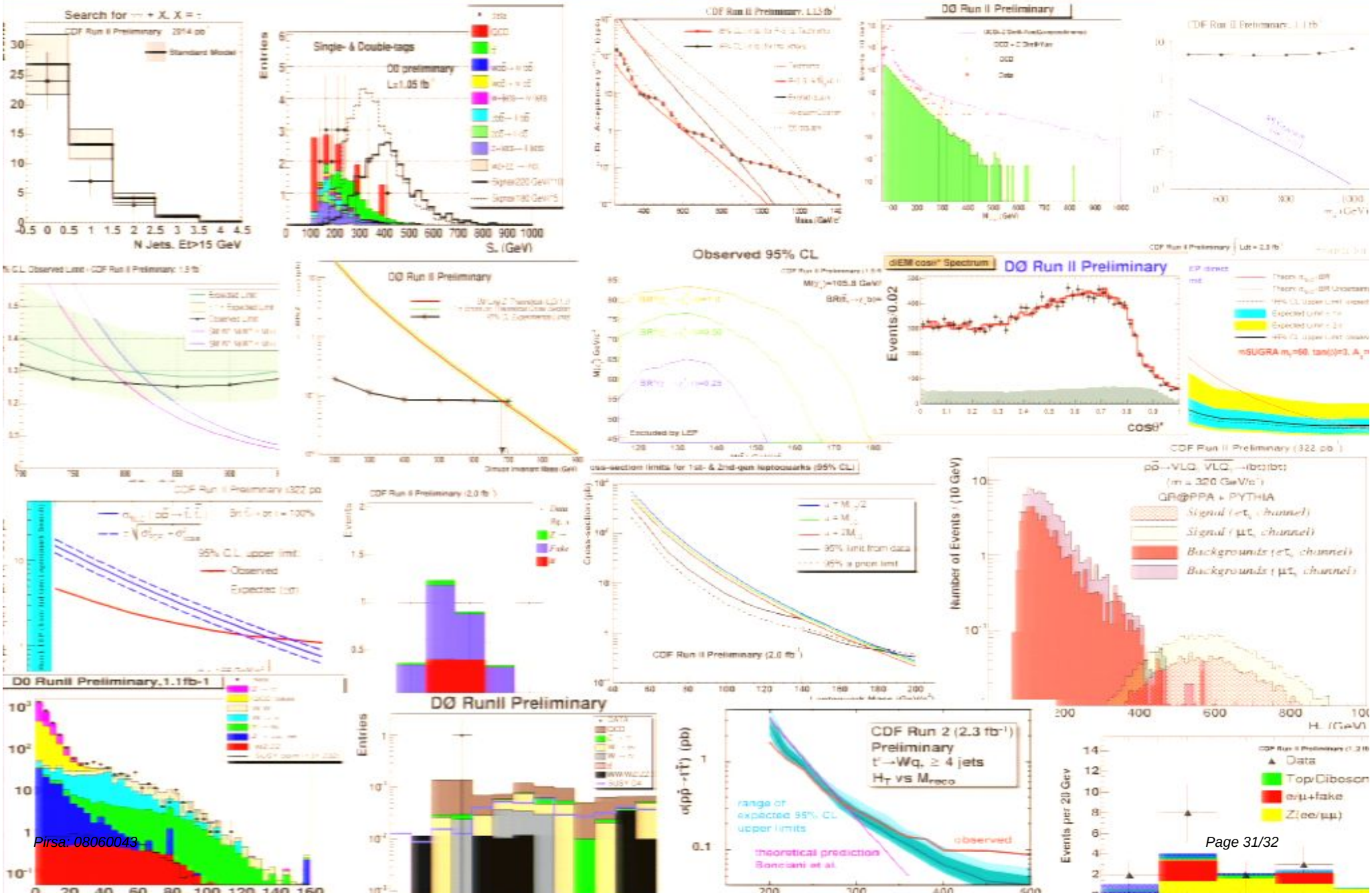
Tevatron Higgs projection



Search for new phenomena

Physics at the energy frontier implies that Tevatron experiments have the world's best sensitivity to many different New Physics signatures.

Search for new phenomena



Summary

- Tevatron collider and experiments performing well
  - 4 fb^{-1} / experiment recorded
  - Expect 6-8 fb-1 / experiment by the end of Run-II
- CDF and D0 are carrying out an extensive physics program
  - Ready to take advantage of new data
- Physics legacy
  - Precise determination of Δm_s and constraints on CP phase β_{Bs}
  - Precision measurements of M_t (δM_t = 1.0-1.5 GeV/c^2) and M_W (δM_W = 15-25 MeV/c^2).
  - A more restrict parameter space of New Physics
  - ... a Higgs mass