# Tevatron and LHC:

## Similarities and Complementarities


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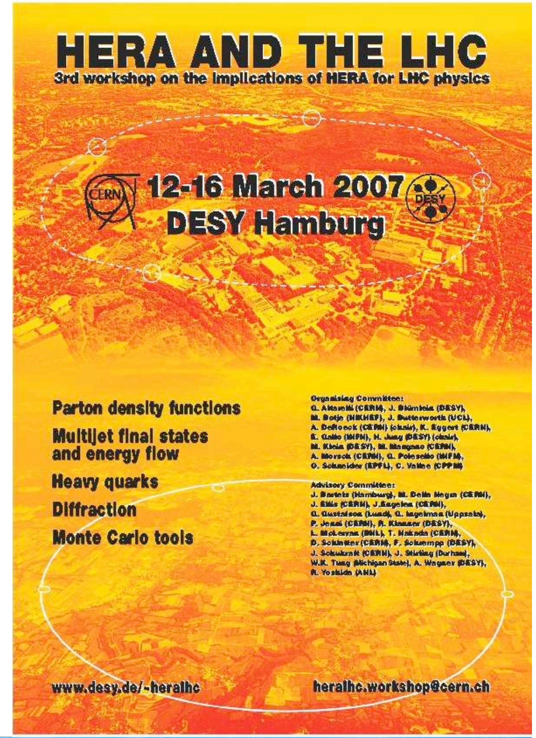
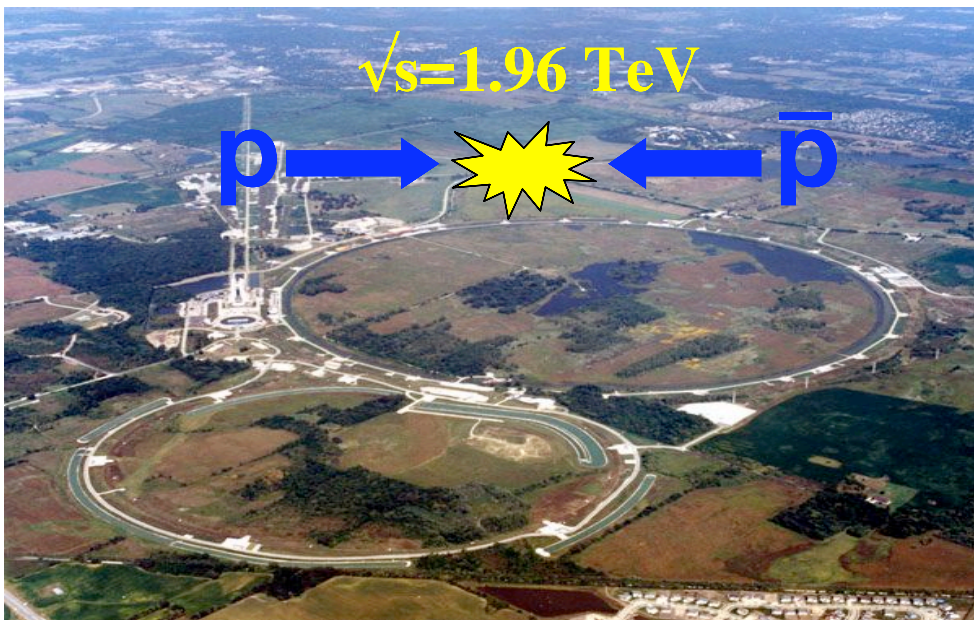
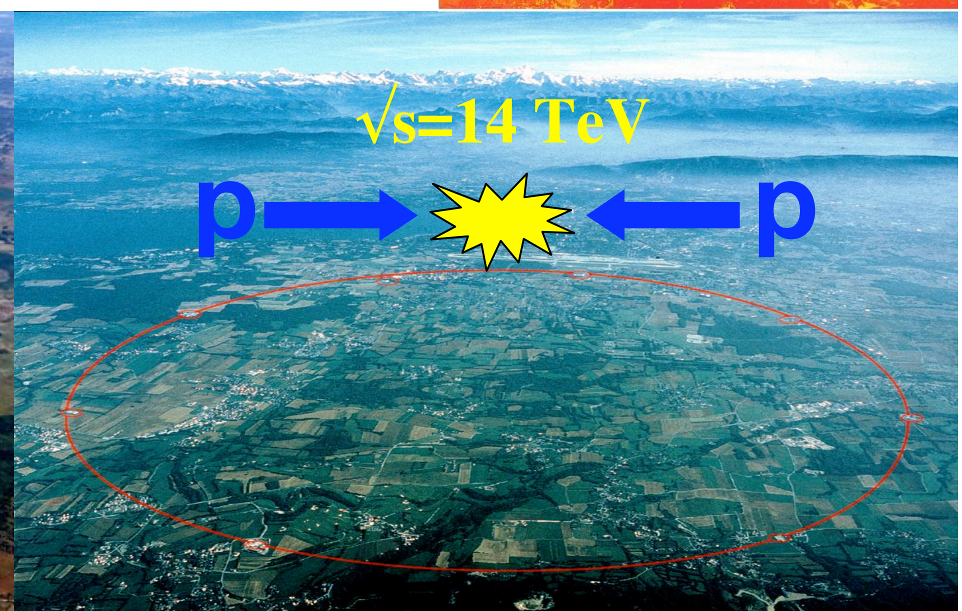



HERA and the LHC workshop, DESY, March 2007

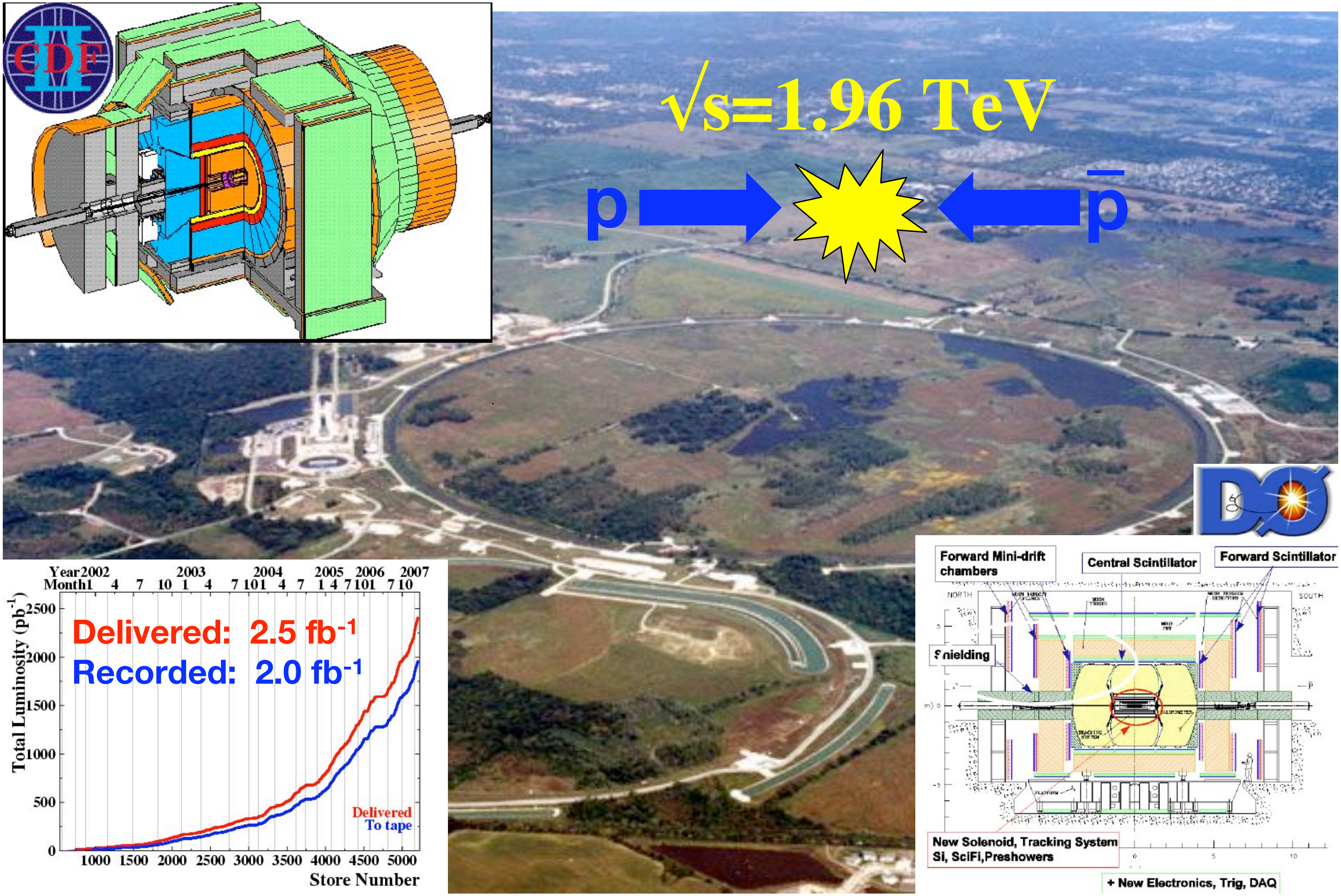
# Tevatron vs LHC

- Physics goals are similar:
  - Finding the Higgs boson
    - Stronger focus at LHC
  - Finding new physics, e.g. SUSY, Z′ etc.
    - Better opportunity at LHC due to its higher energy
  - Precision masurements of $m_W$, $m_{top}$
    - Takes time to understand detector well enough
  - B-physics
    - Stronger focus at Tevatron than at ATLAS and CMS
      - focus of LHCb
- Large multi-purpose detectors
  - For electrons, muons, tau's, jets, missing $E_T$, b-tagging
  - LHC detectors more modern and larger
    - CDF is 22 years old!

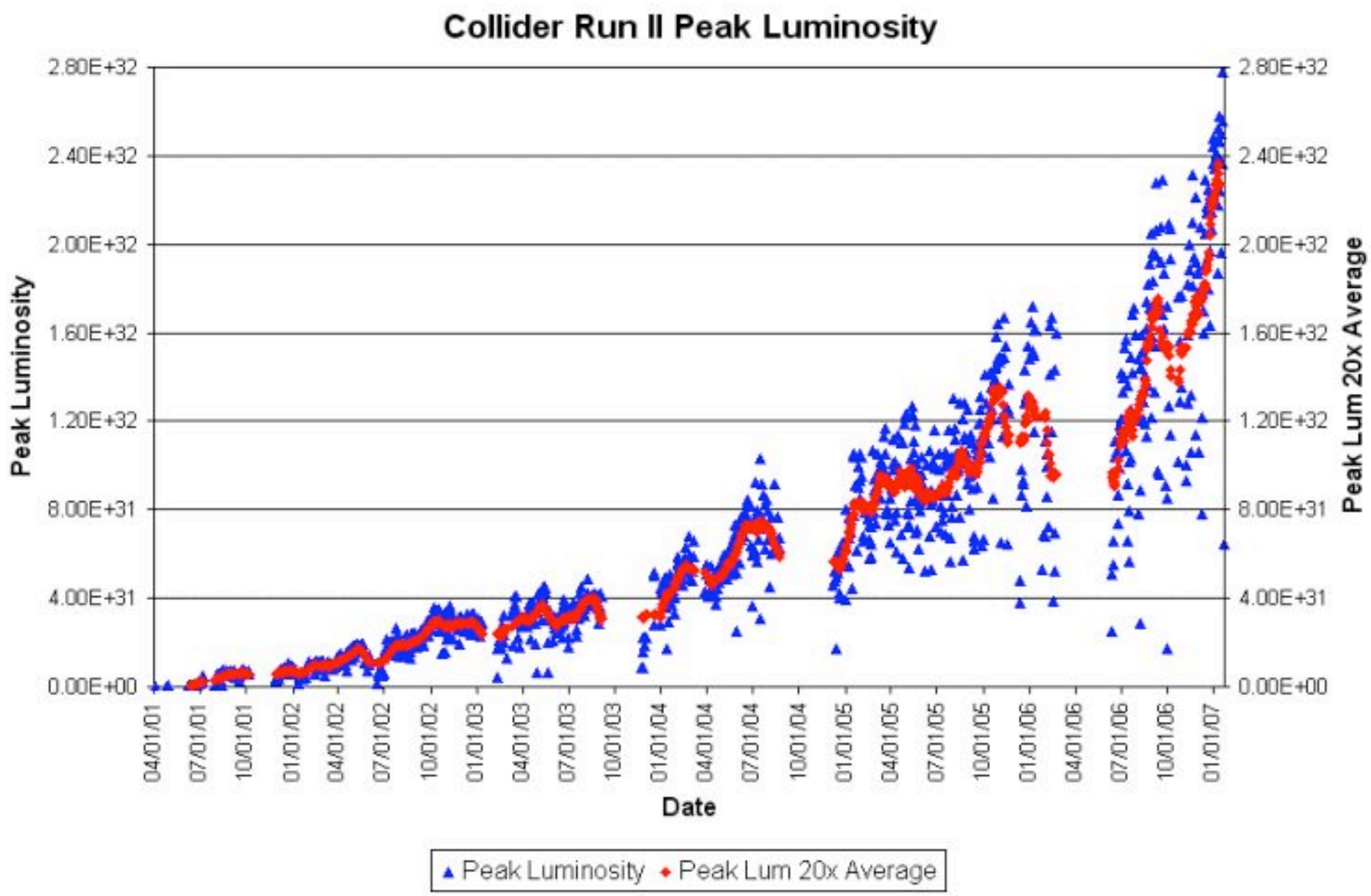
# TeV4LHC Workshop

- Workshop:
  - http://conferences.fnal.gov/tev4lhc
- 4 meetings:
  - Fermilab, September 16-18 2004
  - Brookhaven, February 3-5 2005
  - CERN, April 28-30 2005
  - Fermilab, October 20-22 2005
- 3 reports (100 pp each):
  - Higgs: hep/ph-0612173
  - QCD: hep/ph-0610012
  - Discoveries: hep-ph/0608322
- Focus:
  - Detector and machine commissioning
  - computing
  - Physics

# Tevatron Run II

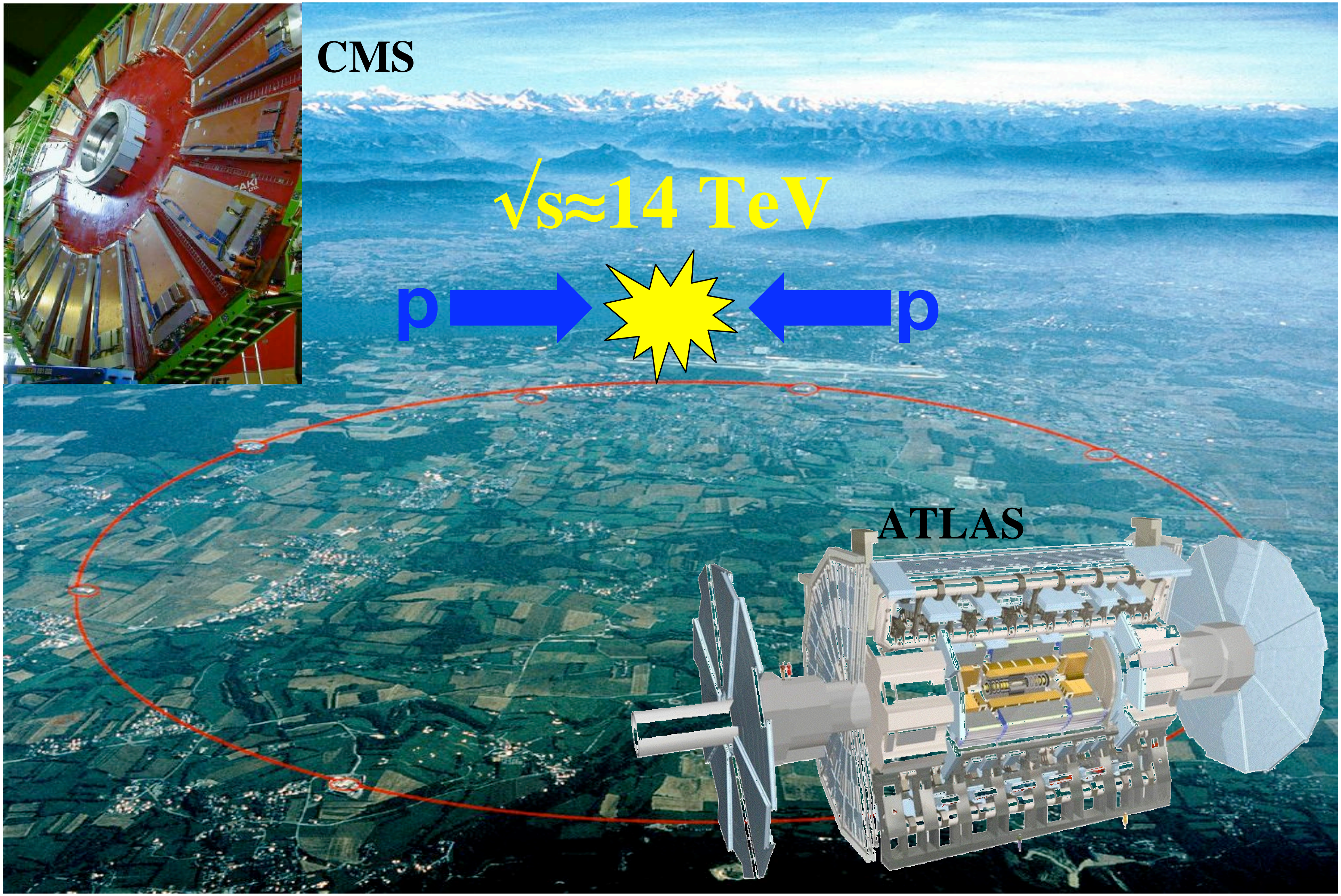


# Instantaneous Luminosity



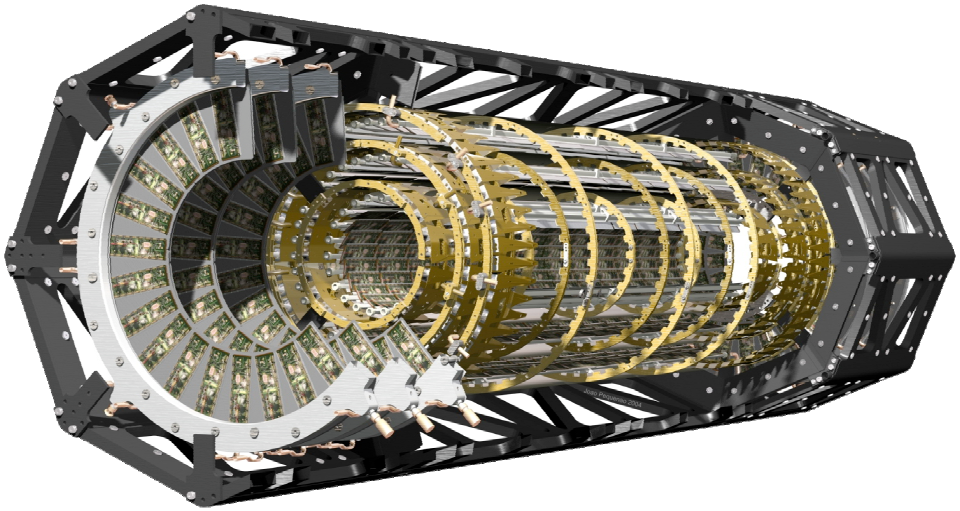

- Tevatron achieved design: $3 \times 10^{32}$ cm$^{-2}$ s$^{-1}$

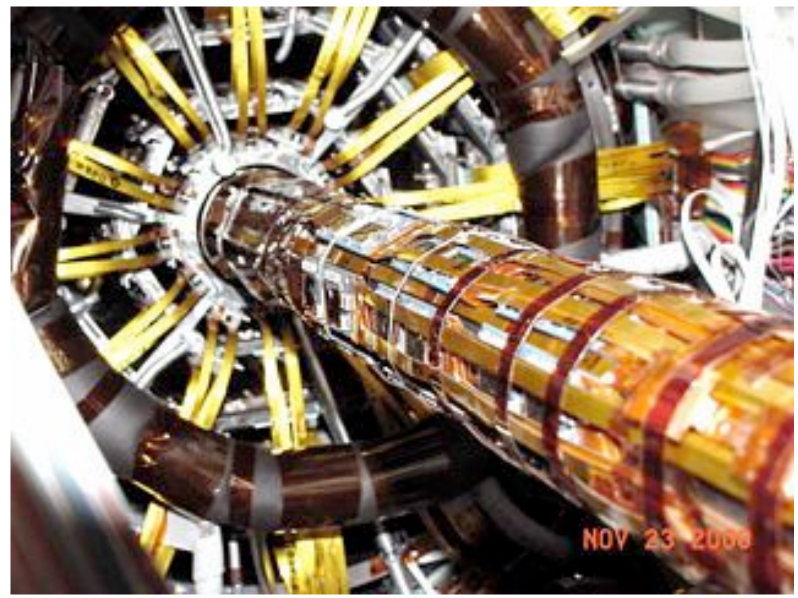
# The Large Hadron Collider (LHC)

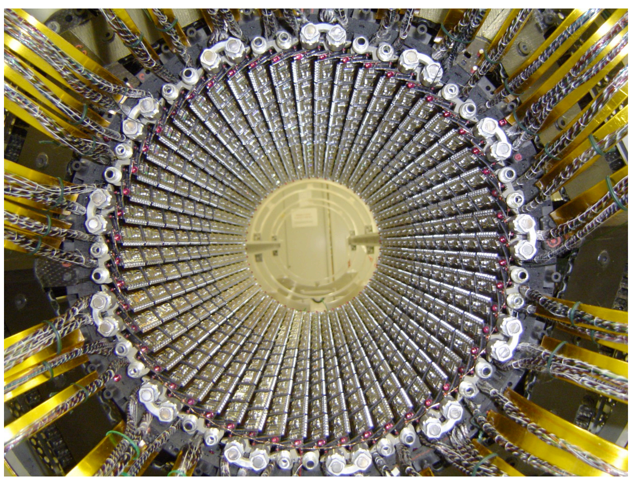


# Detectors, Calibration and Triggers

# Silicon Detectors





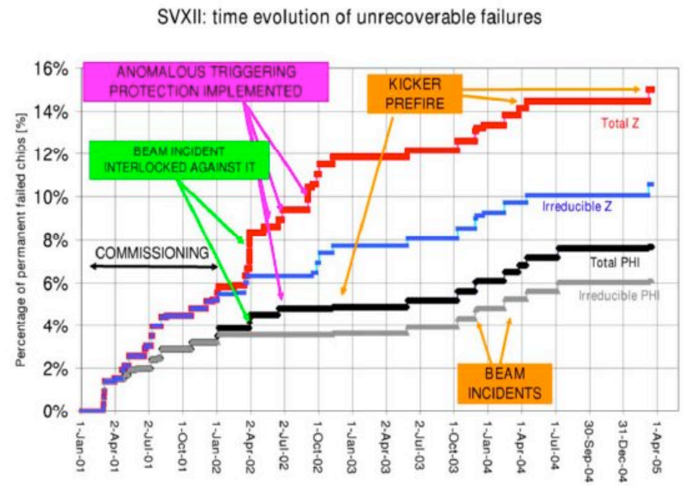
**ATLAS pixels:**
**80M readout channels**

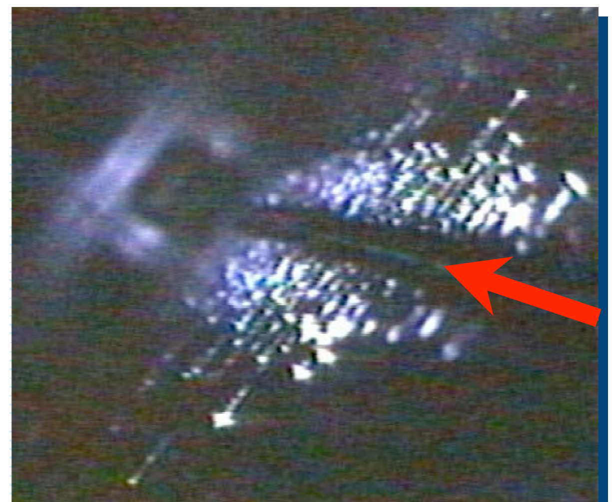
**CDF strip detectors:**
**720,000 readout channels**

# Beam Incidents

- **Tevatron:**
  - 1 MJ/beam = kinetic energy equivalent to a race car at 200 km/h
- **Beam incidents:**
  - Major concern for longevity of silicon detectors (other than continuous radiation damage)
  - CDF lost 2.5% silicon channels in 1 year due to beam incidents
- **LHC**
  - 350 MJ/beam = "80 kg of TNT or 70 kg of Swiss Chocolate" *(S.Peggs)*

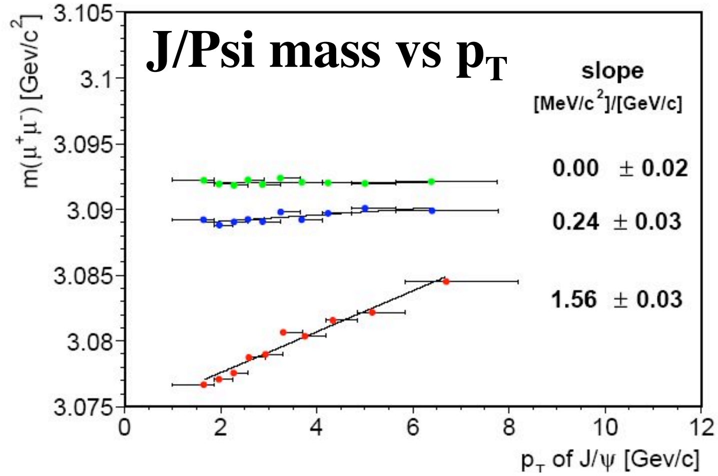
=> Beam condition monitoring and fast beam abort system essential to protect sensitive detectors.



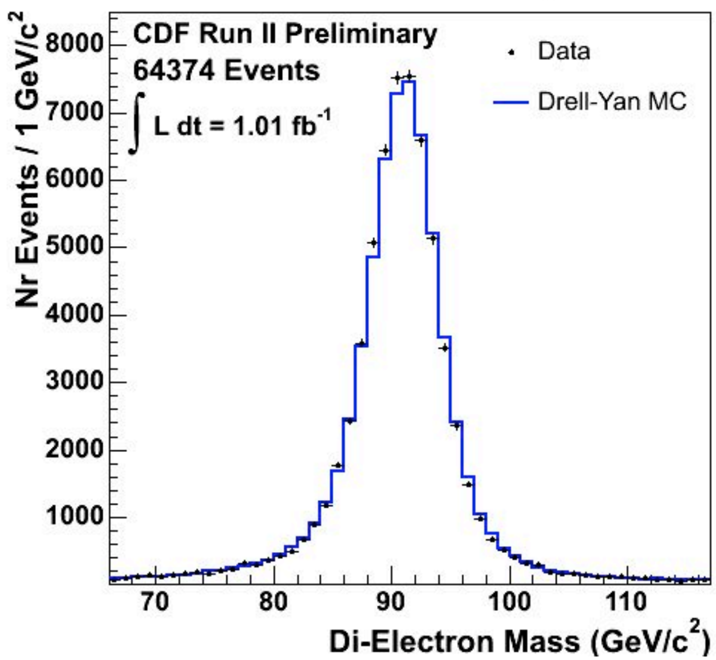


Tevatron collimator damaged in beam incident

# Alignment and Calibration

- Using in situ data for calibrations very similar for both colliders:
  - Track momentum scale:
    - J/Psi, $W \rightarrow \mu\nu$, $Z \rightarrow \mu\mu$, E/p
    - Photon conversions (material)
  - Electron energy scale:
    - E/p, $W \rightarrow e\nu$, $Z \rightarrow ee$
    - LHC requires better calibration for $H \rightarrow \gamma\gamma$
  - Jet energy scale:
    - single tracks, prompt photon, top
  - Lepton efficiency measurements:
    - Z sample
  - Photon efficiency
    - $Z+\gamma$ sample
  - B-tagging efficiency
    - Top sample more powerful at LHC due to higher statistics



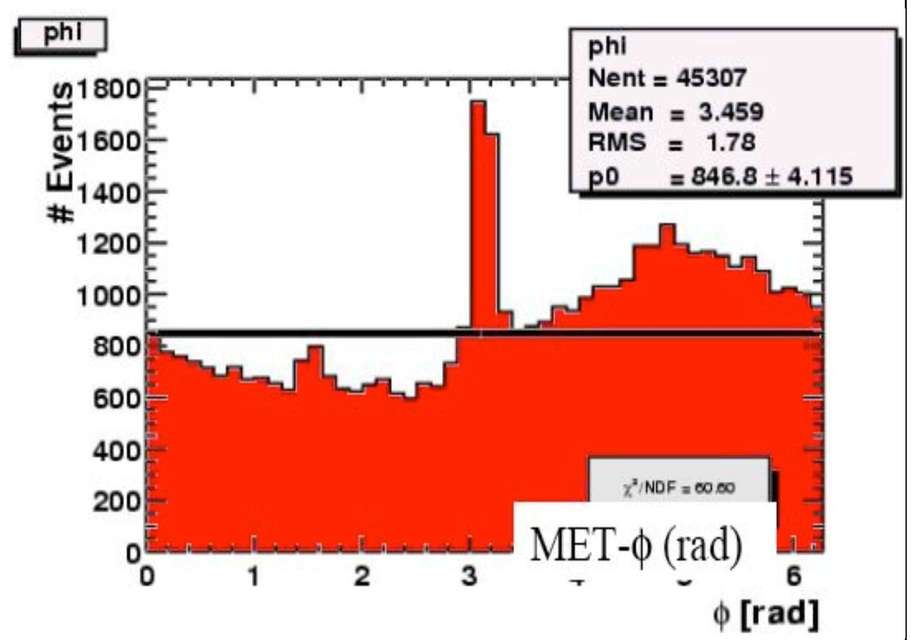

Di-Electron Invariant Mass Spectrum



# Missing $E_T$ and Beam Backgrounds

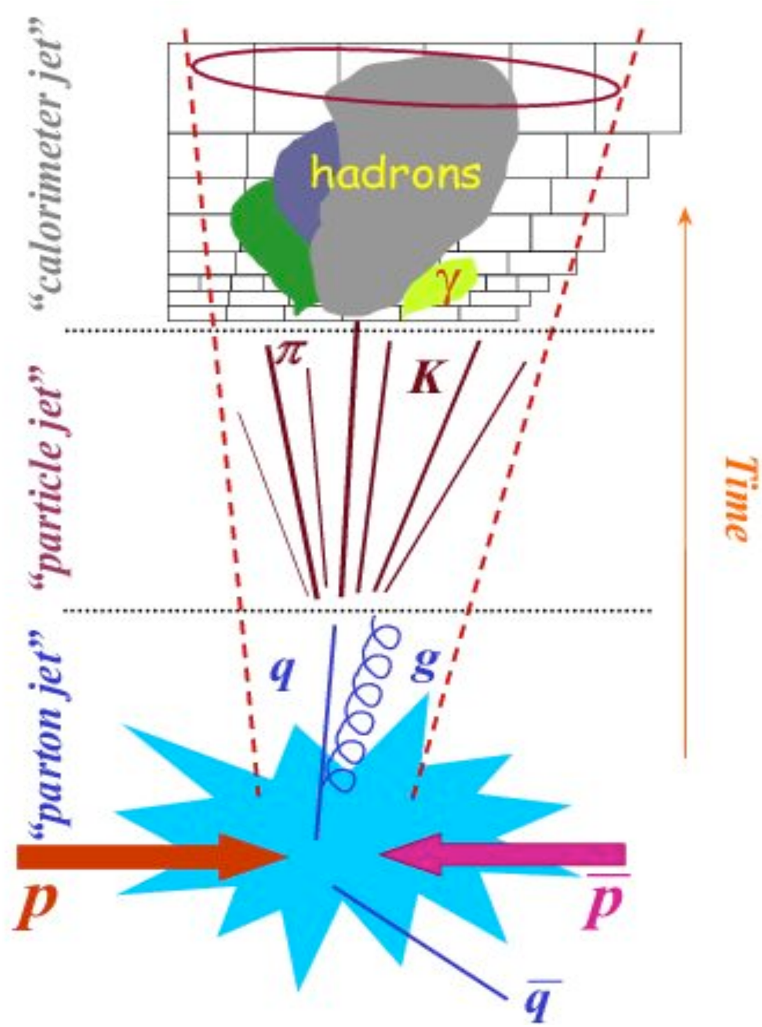
- Beam halo can produce spurious $E_T^{MISS}$ in detector
  - Disappeared in CDF after interactions between machine and experiments
  - Important to watch at the beginning
- Important to develop cuts against beam-halo and cosmics
  - As e.g. also in HERA charged current analyses

CDF online plot of phi of $E_T^{MISS}$

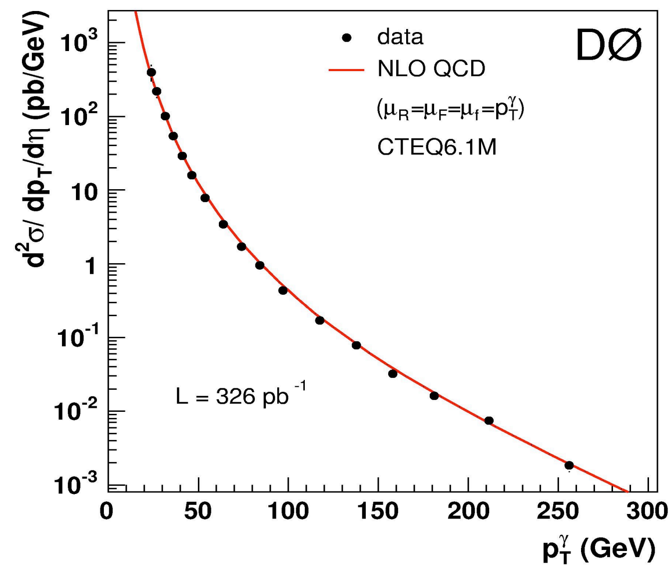


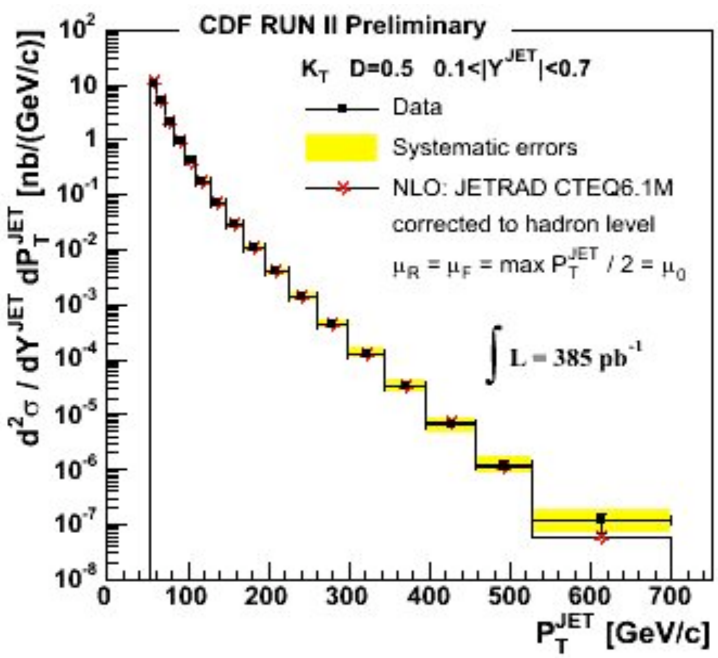
# Jet Energy Scale

- Jet energy scale
  - Determine the energy of the partons produced in the hard scattering process
  - Instrumental effects:
    - Non-linearity of calorimeter
    - Response to hadrons
    - Poorly instrumented regions
  - Physics effects:
    - Initial and final state radiation
    - Underlying event
    - Hadronization
    - Flavor of parton
- Problems:
  - No perfect calibration process up to high energies
    - Unlike neutral current process in DIS
  - Calibration sensitive to physics effects



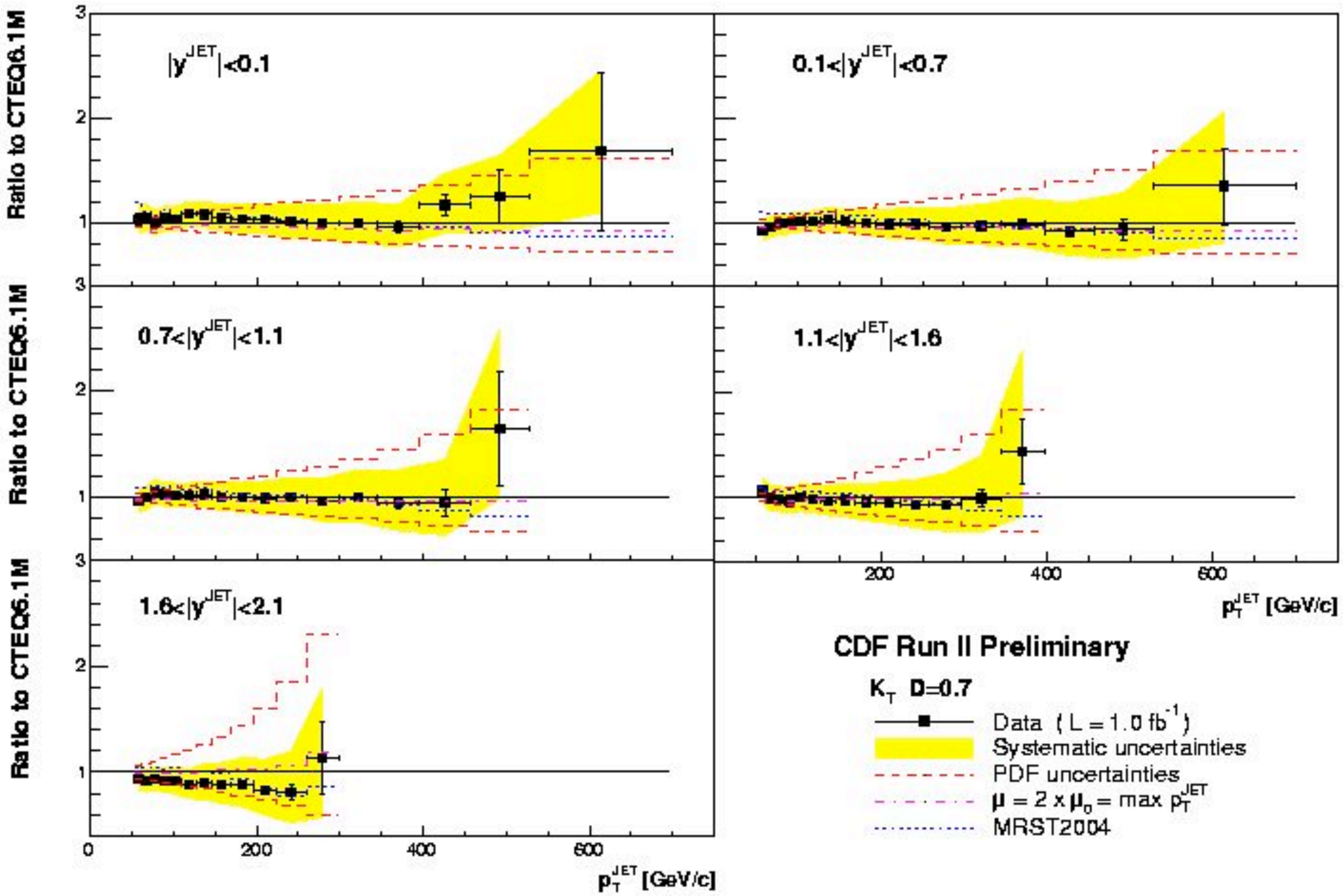
# Prompt Photon vs Jet Cross Section



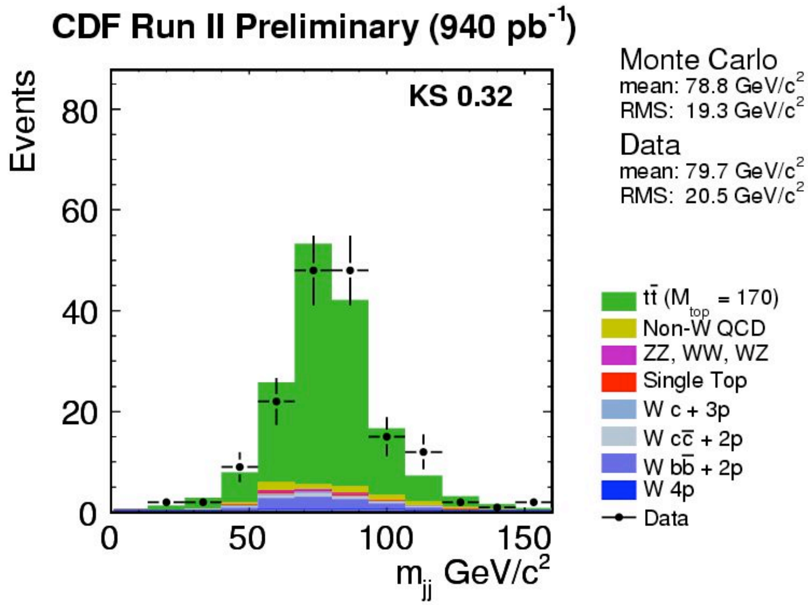



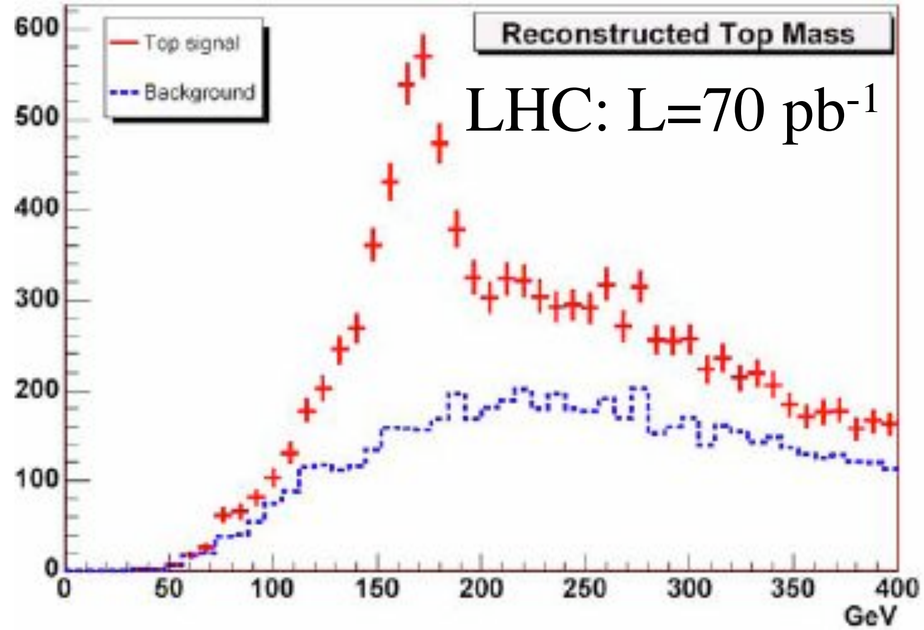

- Jet cross section factor >1000 larger than prompt photon cross section
  - No high statistics calibration signal to access highest energies
  - Need for extrapolation to high $E_T$>200 GeV
    - CDF tunes single particle response in simulation (GFLASH)
    - DØ exploits their homogeneous calorimeter extrapolating from forward to central region

# Jet Cross Section



# Using Top for Calibration

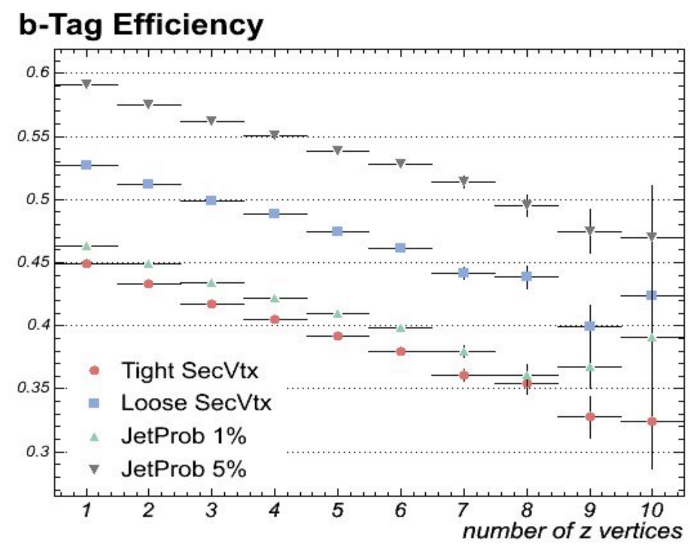



- top pair production cross section:
  - At LHC100 times larger than at Tevatron: "top factory"
- W→jj very good calibration signal
  - Already being used for Tevatron top mass measurements:
    - CDF: Data/MC=0.99±0.02(stat.) with 166 events
  - LHC can also use top mass value for calibration as long as top mass measurement is not attempted in early data

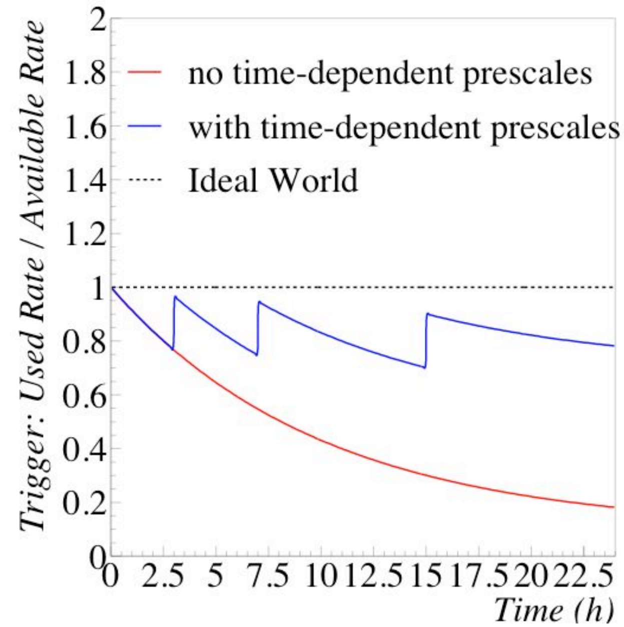
# Reconstruction Software

- More than 1 interaction per bunch crossing:
  - Tevatron: $L \leq 3 \times 10^{32}\ cm^{-2}s^{-1}$: <N>=6
  - LHC: $L \leq 1 \times 10^{34}\ cm^{-2}s^{-1}$: <N>=20
  - Particularly challenging for tracking and tagging b-jets in high occupancy events
    - Requires measuring efficiencies and mis-identification versus # of interactions
- At LHC # of vertices reconstruction more difficult as luminous region smaller:
  - Tevatron: $\sigma_z \approx 30$ cm
  - LHC: $\sigma_z \approx 7$ cm
    - But high precision pixel detector can resolved it



# Trigger and Computing

- Large event rates written to tape:
  - Tevatron: 100 Hz, LHC: 200 Hz
- Large event sizes:
  - Tevatron: 200 kB, LHC: 1 MB
    - LHC: 100 kB for compressed format
- Large data sets:
  - Tevatron: 0.5 PByte per year
    - Streamed depending on trigger decision to make data more accessible
  - LHC: 5-10 PByte per year
    - Datasets also organized in streams defined by triggers
- Dynamic trigger prescales used to optimally use bandwidth:
  - LHC trigger more selective:
    - 25ns vs 396 ns bunch crossing rate
    - No track triggers at L1 at LHC



# Physics

## Similarities

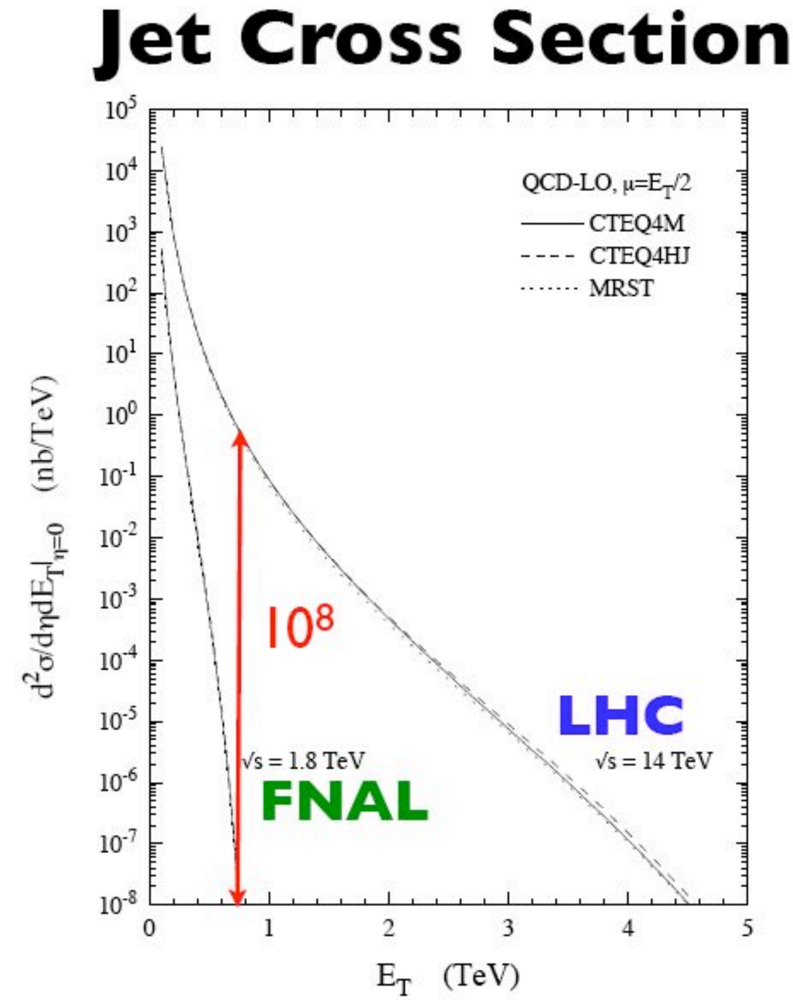
- Unknown which partons interacted with each other
  - Known on average from parton density functions
- Huge cross section of jet production
  - total cross section >> available trigger bandwidth
  - Difficult background to many physics processes
- Physics program:
  - Precision measurements
  - Searches for new physics

## Complementarities

- LHC energy nearly 10 times higher than Tevatron
  - LHC probes lower Bjorken-x with same process
- Process mixture different:
  - Different signals and backgrounds are important
- LHC operates at 10 times larger energy than any collier before
  - More room for early surprises/discoveries than at Tevatron

# Cross Sections: Tevatron vs LHC

| Cross Sections of Physics Processes (pb) | | | |
|---|---|---|---|
| | Tevatron | LHC | Ratio |
| $W^{\pm} \rightarrow e\nu$ (80 GeV) | 2600 | 20000 | 10 |
| $t\bar{t}$ (2x172 GeV) | 7 | 800 | 100 |
| gg->H (120 GeV) | 1 | 40 | 40 |
| $\tilde{\chi}^{+}_{1}\tilde{\chi}^{2}_{0}$ (2x150 GeV) | 0.1 | 1 | 10 |
| $\tilde{q}\tilde{q}$ (2x400 GeV) | 0.05 | 60 | 1000 |
| $\tilde{g}\tilde{g}$ (2x400 GeV) | 0.005 | 100 | 20000 |
| Z′ (1 TeV) | 0.1 | 30 | 300 |

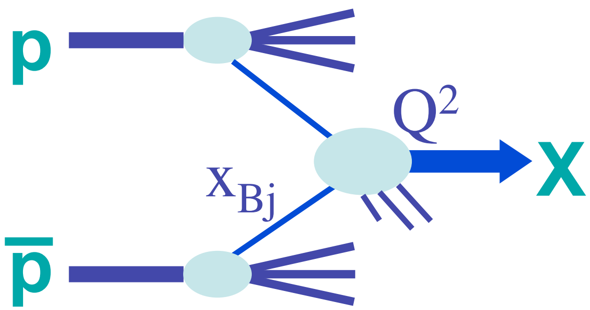


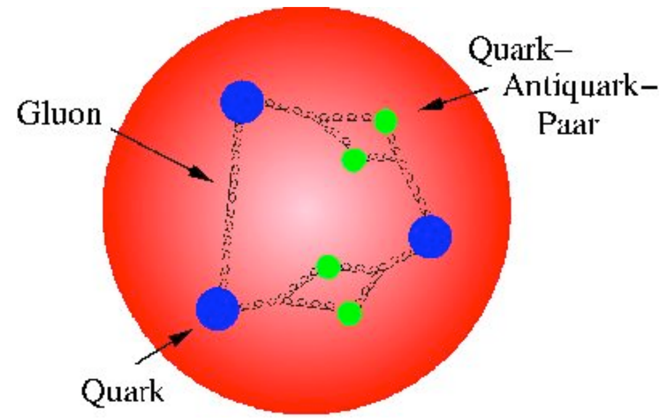

- Amazing increase for strongly interacting heavy particles
  - Opportunity!

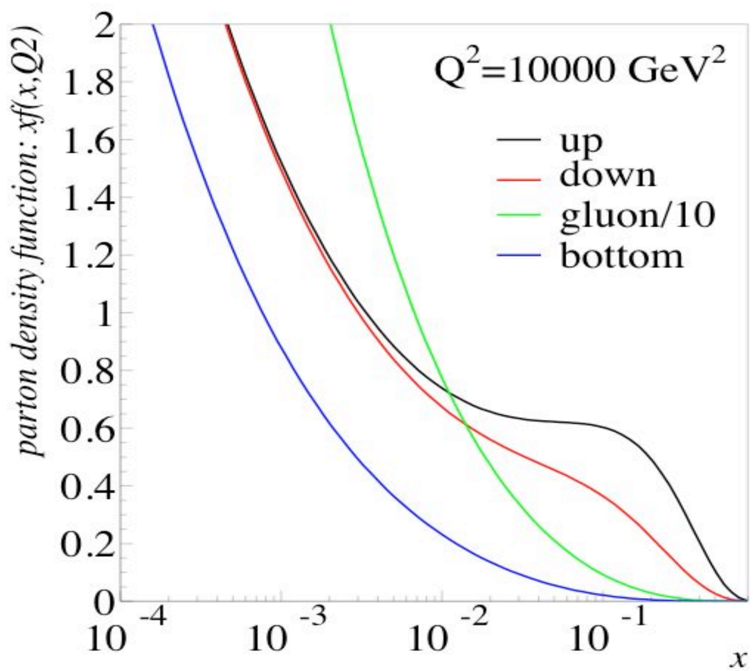
# The Proton

- It's complicated:
  - Valence quarks
  - Gluons
  - Sea quarks
- Exact mixture depends on:
  - $Q^2$: ~$(M^2+p_T^2)$
  - $x_{Bj}$: fractional momentum carried by parton
- Hard scatter process:

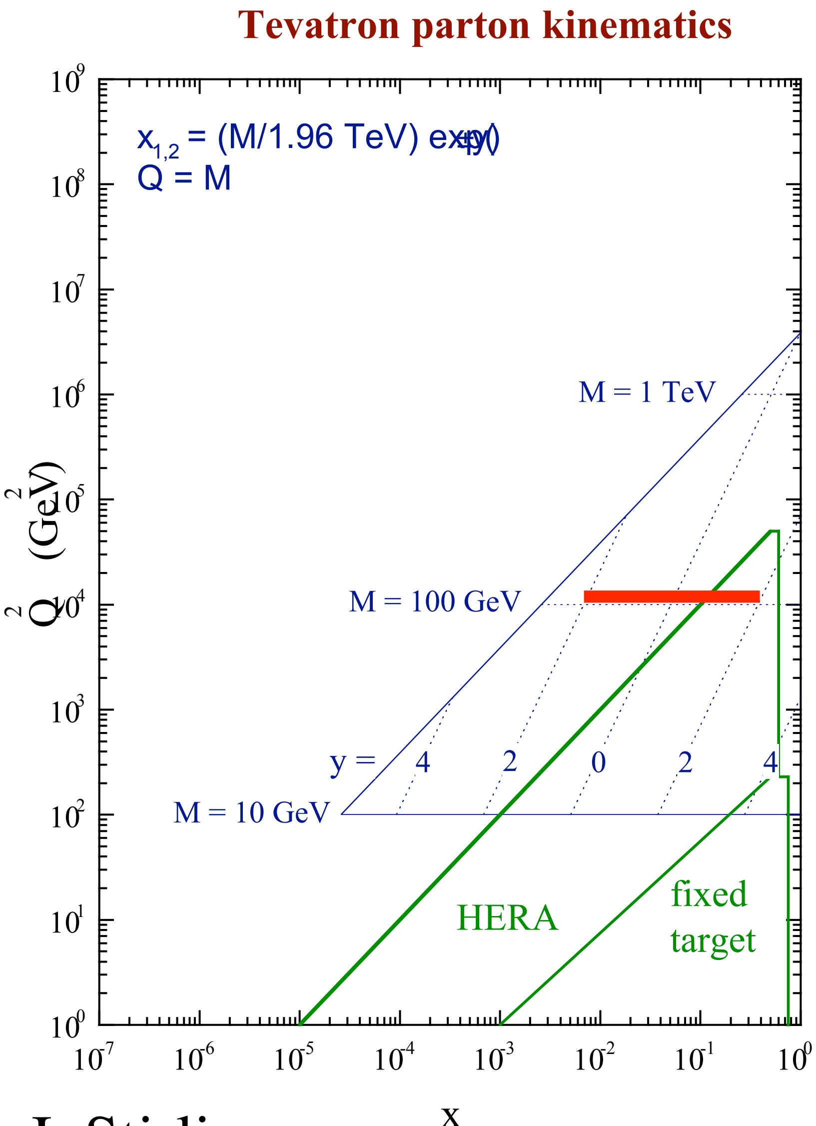
$$\hat{s} = x_p \cdot x_{\bar{p}} \cdot s$$

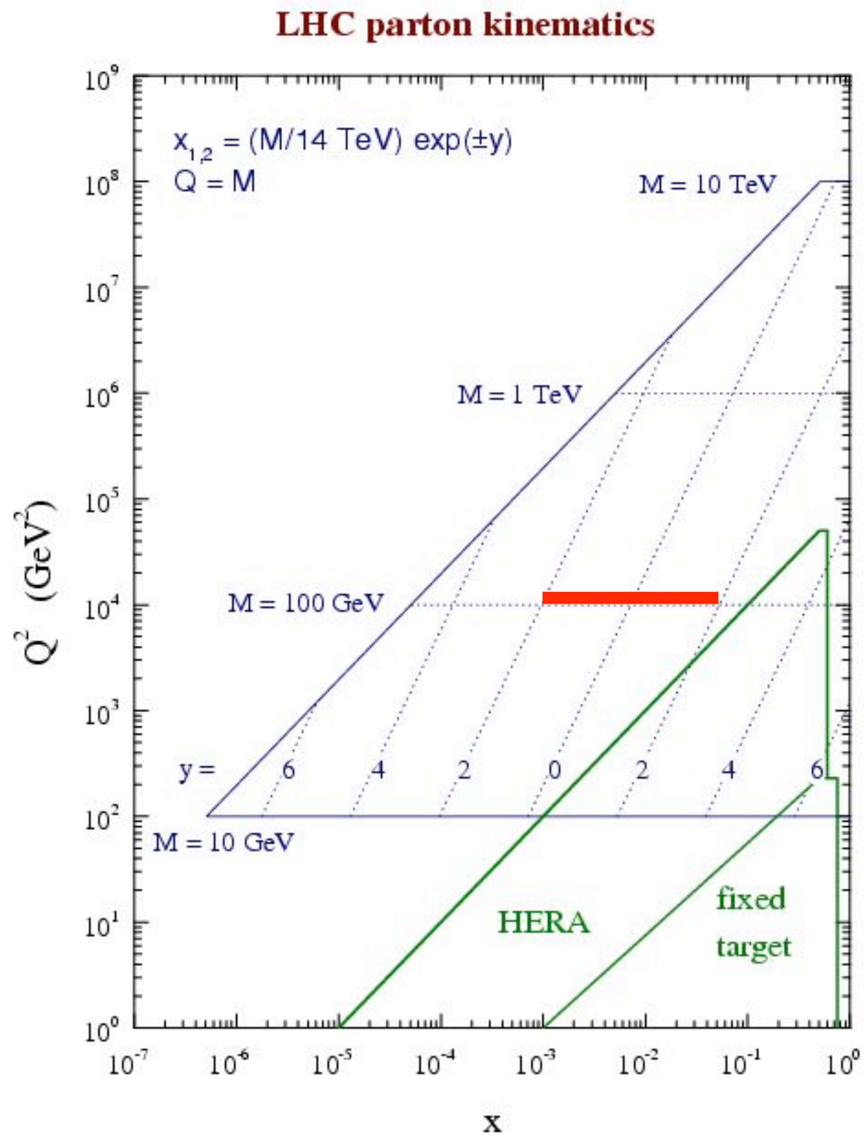


# Parton Kinematics

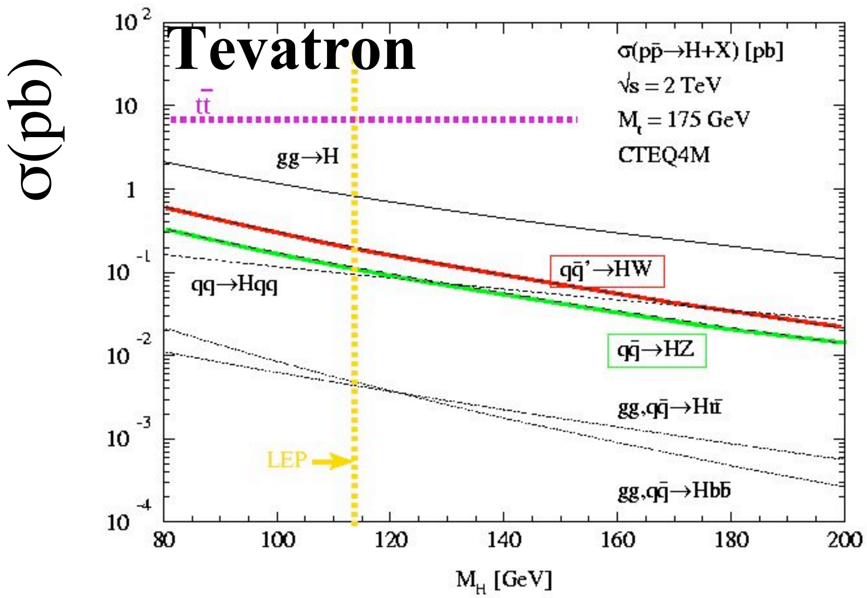


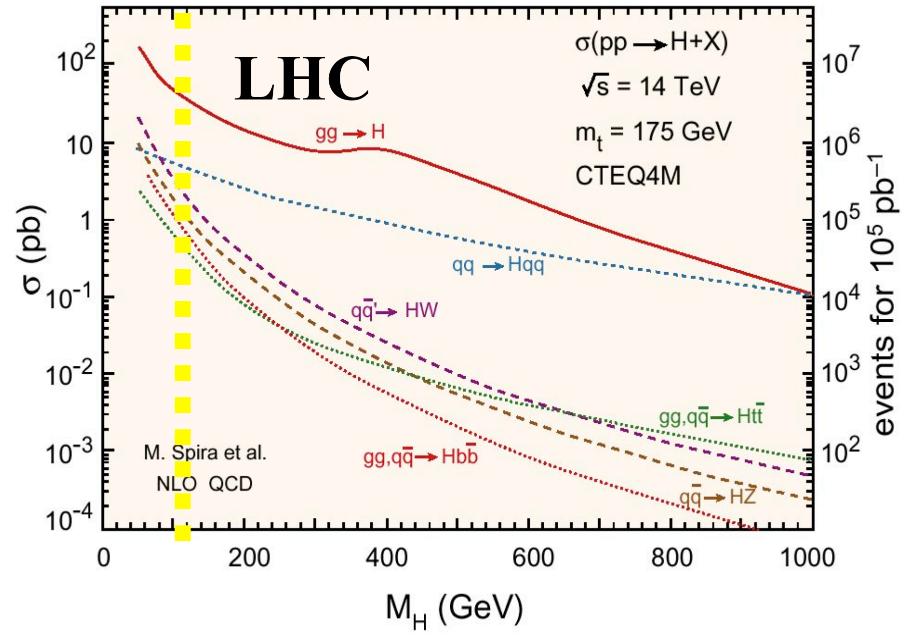



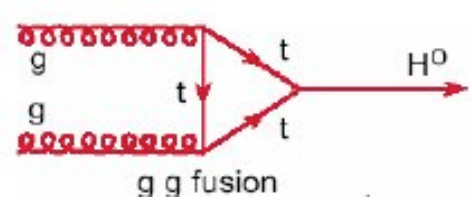

J. Stirling

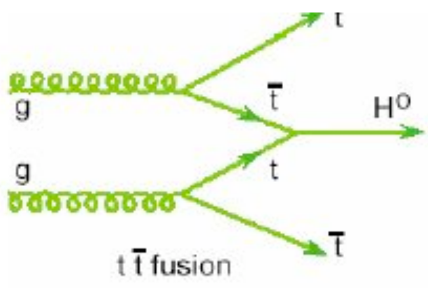
For fixed Mass: probe 3 times higher Borken x at Tevatron than LHC

# Higgs Production: Tevatron and LHC

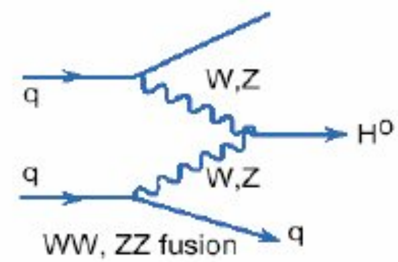


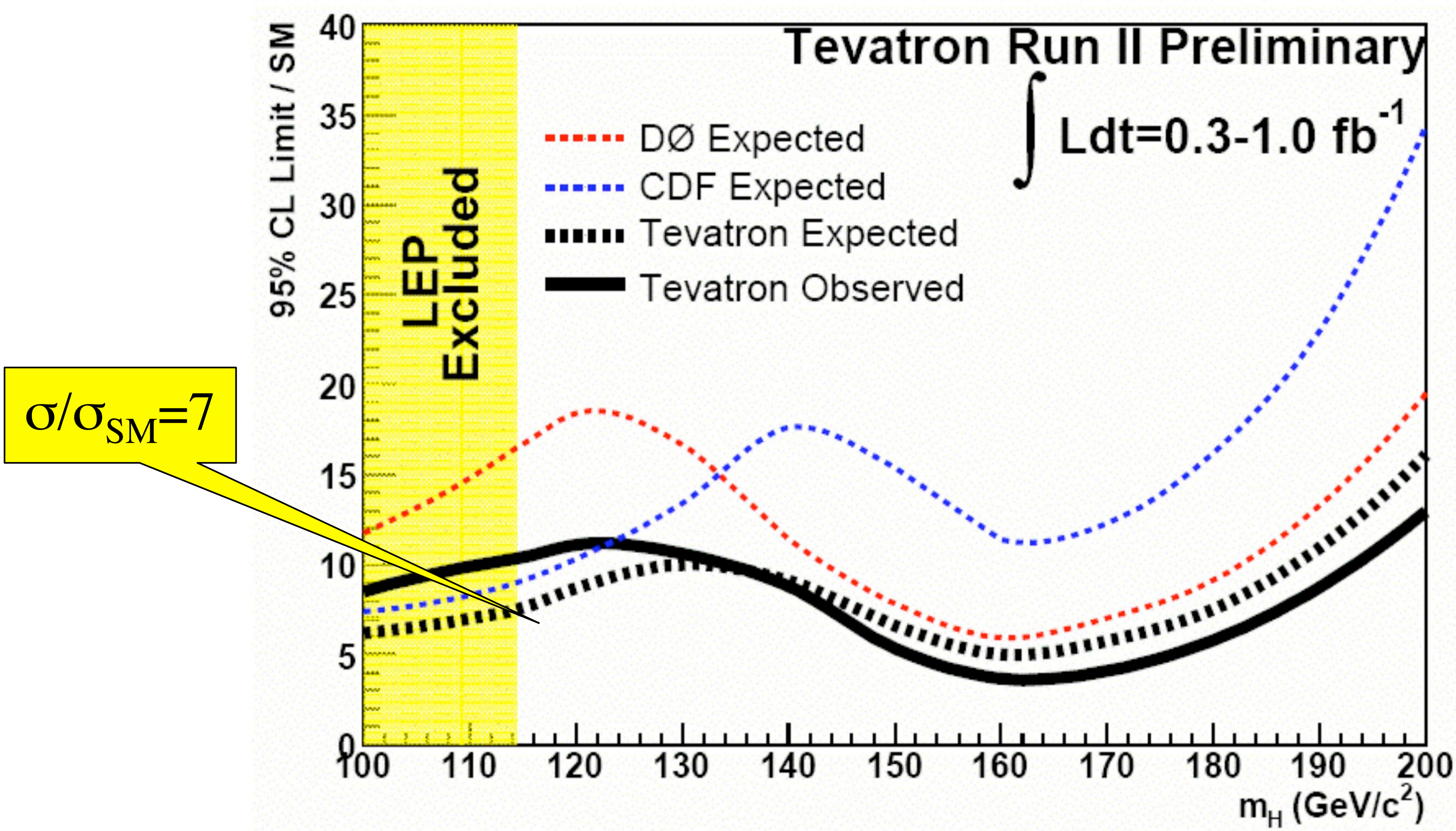





dominant: gg→ H

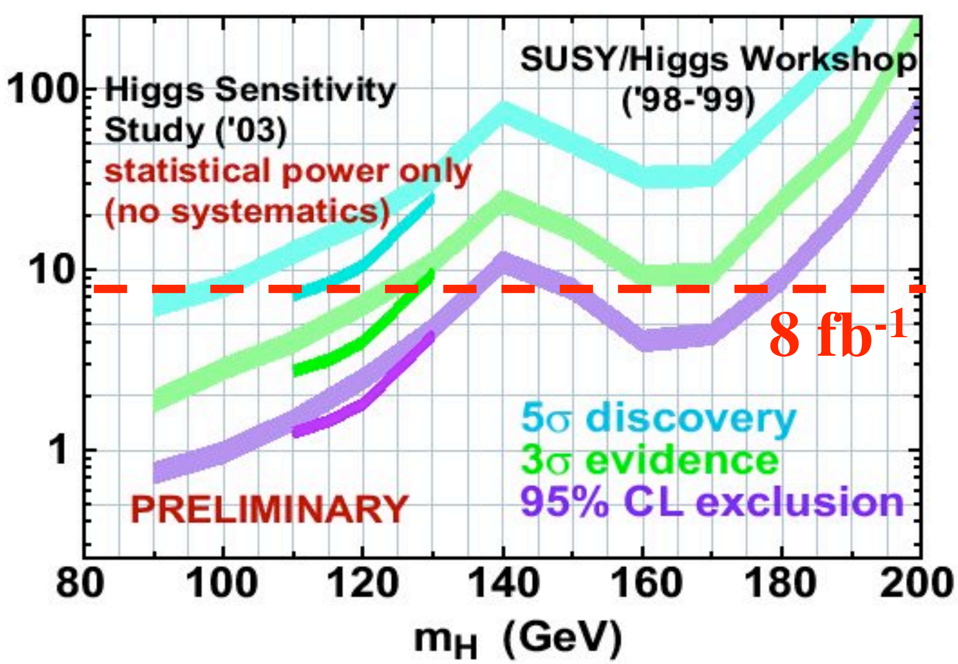
subdominant: HW, HZ (Tevatron), Hqq (LHC)

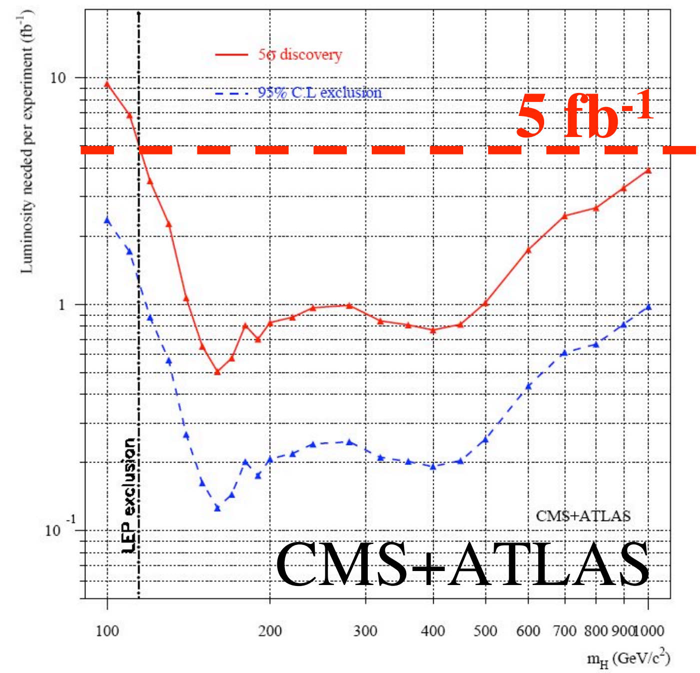
# Higgs Searches Status




- Equivalent to 0.65 $fb^{-1}$ per experiment
- Tevatron is closing in on the Higgs boson
  - still quite a long way to go but many analysis improvements are ongoing

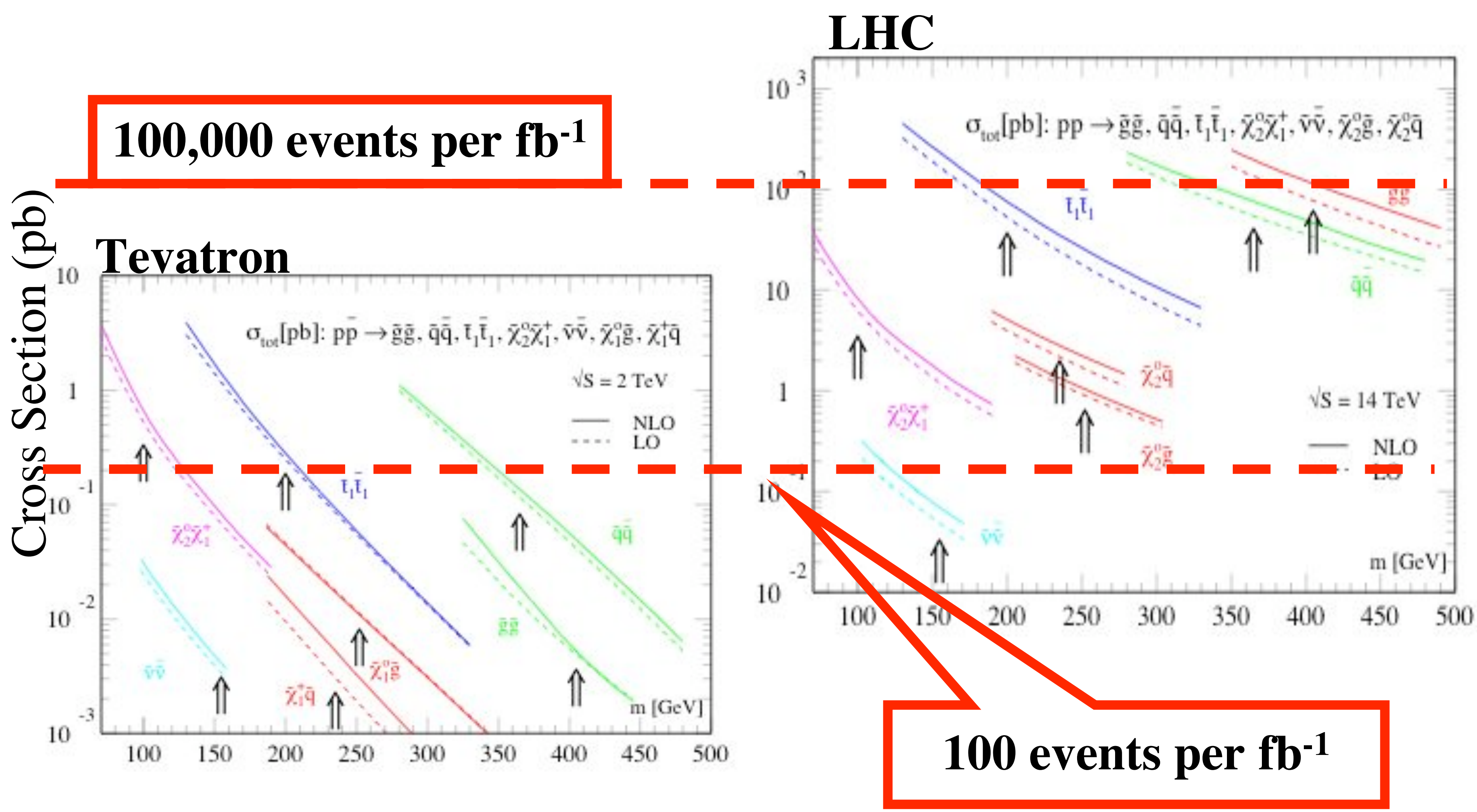
# Higgs Boson Discovery Prospects




- Tevatron:
  - might see a 3σ evidence with full luminosity (2009/2010?)
- LHC:
  - cover full mass range with 5σ significance with 5 $fb^{-1}$ (2009/2010?)
    - Could be earlier if $m_H \geq 2 * m_W$
  - At low mass sensitive to three production and decay modes:
    - $gg \to H \to \gamma\gamma$, $WW \to H \to \tau\tau$, $ttH \to ttbb$

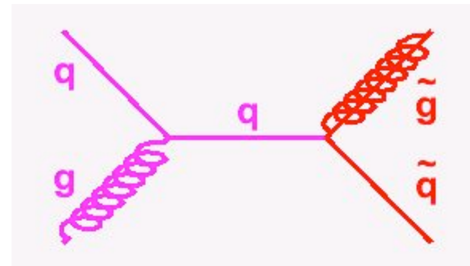
# Sparticle Cross Sections

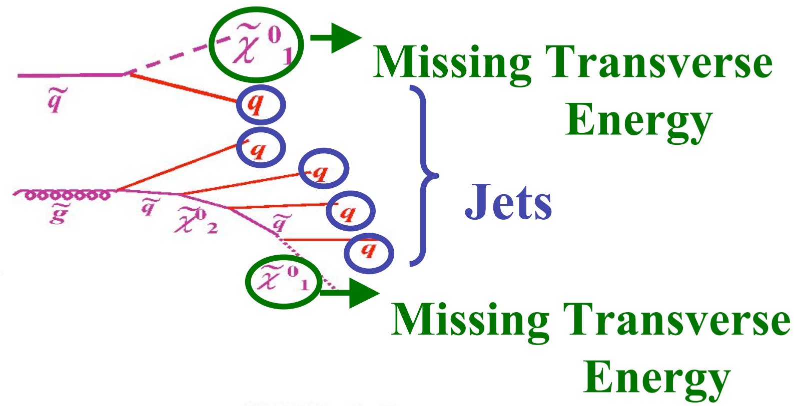


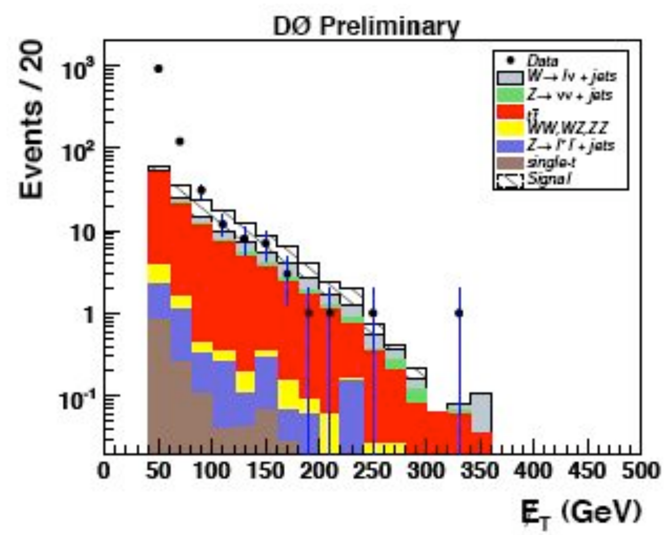

T. Plehn, PROSPINO

# Generic Squarks and Gluinos

- Squark and Gluino production:
  - Signature: jets and $\not{E}_T$
  - Lepton veto applied at Tevatron
    - Long cascade decays at LHC may result in lepton decays
- Strong interaction => large production cross section
  - for M(g) ≈ 500 GeV/c²:
    - Tevatron: x=0.7
    - LHC: x=0.26
  - Due to steep x-dependence of pdf's
    - Much larger cross section at LHC
- Background control is essential
  - Top
  - W/Z+jets
  - QCD multijet
    - Different treatment by CDF and DØ

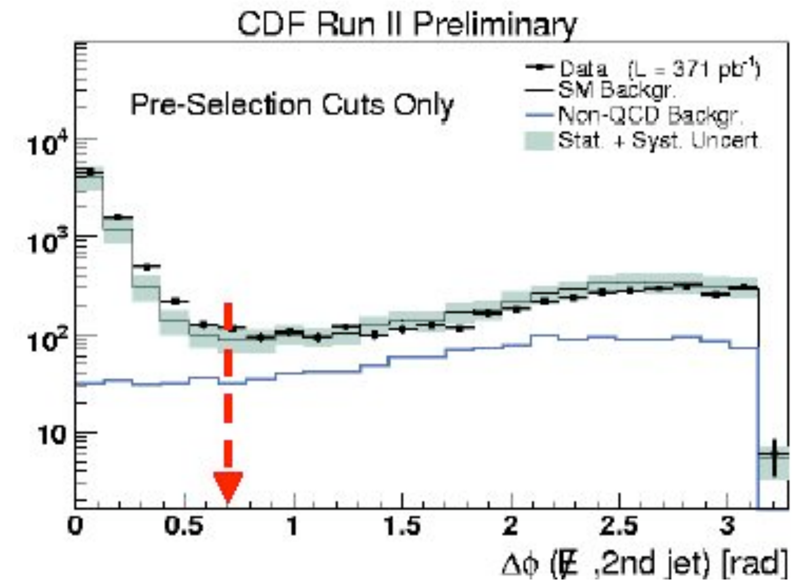


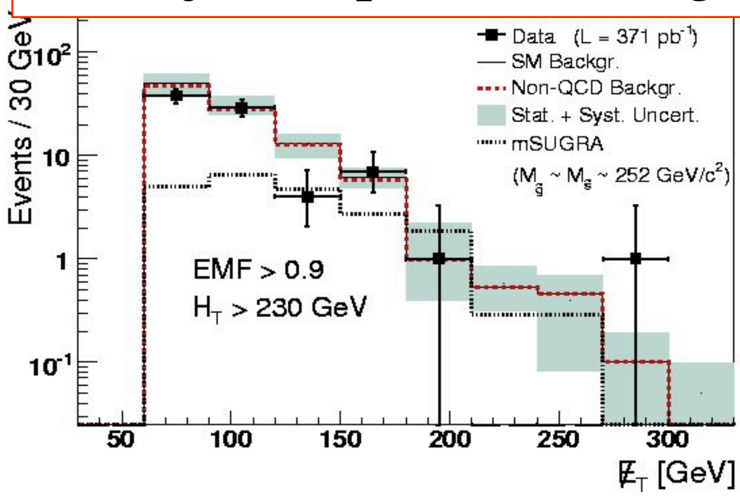



# Backgrounds and Control Regions

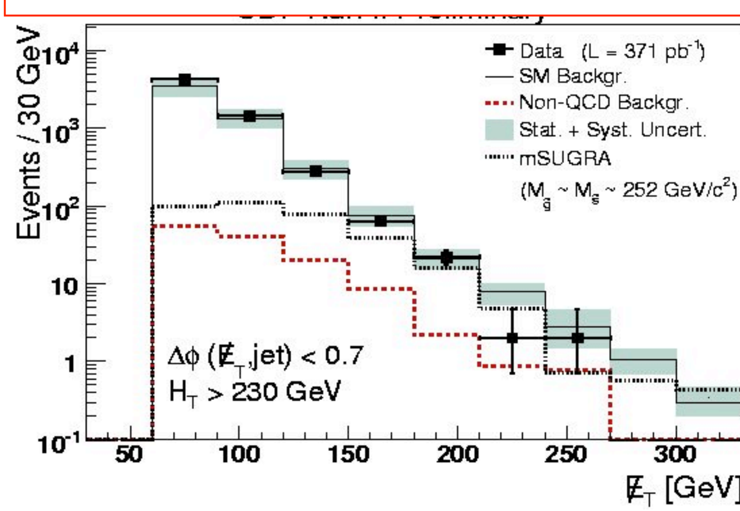
- Background sources:
  - QCD multijet:
    - Make all selection cuts but invert deltaphi cut
    - CDF simulates jet background
      - Very CPU intensive
    - DØ demonstrate it is negligible
  - W/Z+jets, top
    - Make all selection cuts but invert lepton veto
    - May not work at LHC as simply due to cascade decays to leptons




W/Z+jets, top Control Region

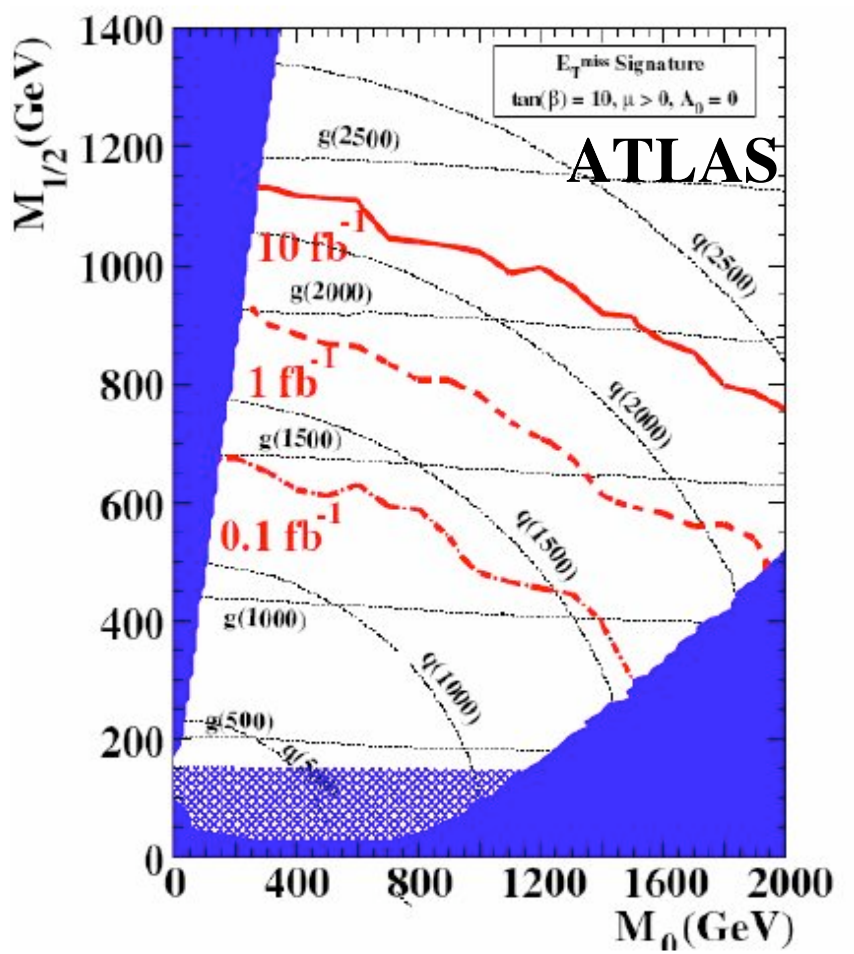


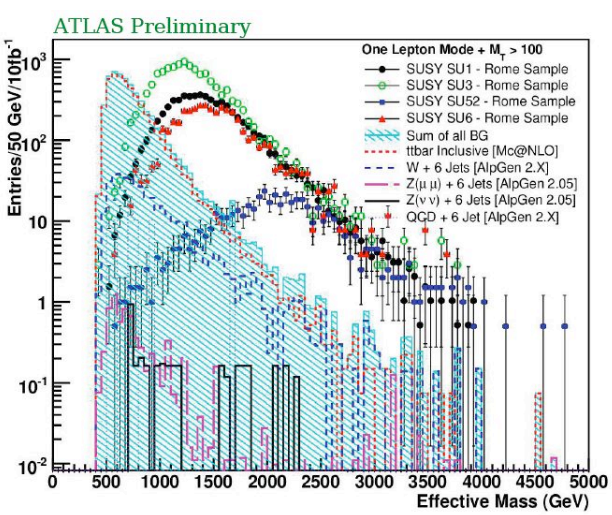

QCD Multijet Control Region



# SUSY Discovery at the LHC

- May be found relatively quickly!
- Jets+missing $E_T$ analysis most promising:
  - Will improve upon Tevatron sensitivity with <100 $pb^{-1}$ of data!
- Signal could be large compared to SM background
  - Control region strategy of Tevatron could be less powerful in presence of big signal




Due to possibly large signal at LHC Tevatron techniques must be evaluated carefully and possibly modified

# Similarities and Complementarities

- Detector operation
  - Very large complex detectors in harsh beam environment
    - Although much larger scale and harsher at LHC
  - Commissioning at Tevatron Run 2 could build a lot on Run 1
- Calibration
  - Very similar processes and techniques can be employed
    - although e.g. top can be used more strongly at LHC
- Trigger
  - Much more selective at LHC
    - Triggering well is key and one of the biggest challenging in my view
- Physics
  - Similar goals at Tevatron and LHC
    - Many analysis techniques from Tevatron can be applied at LHC
    - The Higgs subject could be very interesting in 2010
  - At LHC New physics signal could be very large
    - Implication on strategy in terms of background control

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