Tevatron Run 2b: Physics and Detectors

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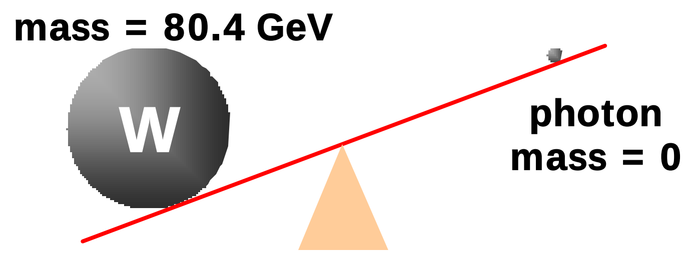
The Higgs Mechanism



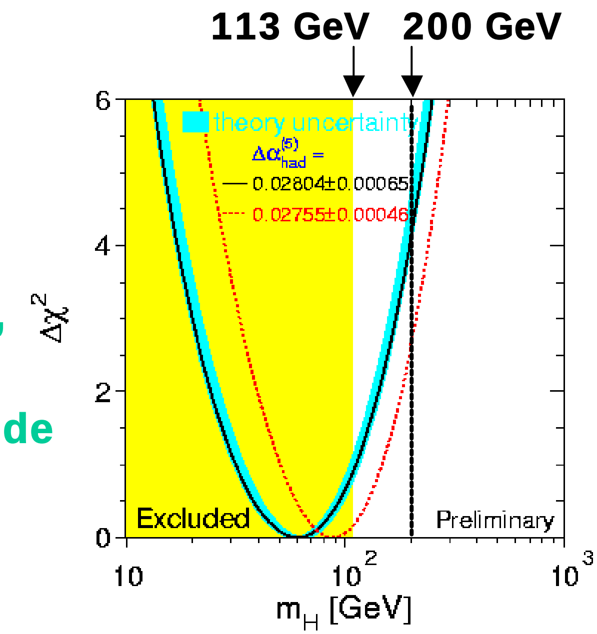
- **In the Standard Model**
  - Electroweak symmetry breaking occurs through introduction of a scalar field ϕ $\rightarrow$ masses of W and Z
  - Higgs field permeates space with a finite vacuum expectation value = 246 GeV
  - If ϕ also couples to fermions $\rightarrow$ generates fermion masses

- **An appealing picture: is it correct?**
  - One clear and testable prediction: there exists a **neutral scalar particle** which is an excitation of the Higgs field
  - All its properties (production and decay rates, couplings) are fixed except its own mass

Highest priority of worldwide high energy physics program: find it!

Searching for the Higgs

- **Over the last decade, the focus has been on experiments at the LEP e^+e^- collider at CERN**
  - precision measurements of parameters of the W and Z bosons, combined with Fermilab's top quark mass measurements, set an upper limit of $m_H \sim 200$ GeV
  - direct searches for Higgs production exclude $m_H < 113$ GeV



- **Summer and Autumn 2000: Hints of a Higgs?**
  - the LEP data may be giving some indication of a Higgs with mass 115 GeV (right at the limit of sensitivity)
  - despite these hints, CERN management decided to shut off LEP operations in order to expedite construction of the LHC

- **All eyes on Fermilab:**
  - until about 2007, we have the playing field to ourselves

Higgs at the Tevatron

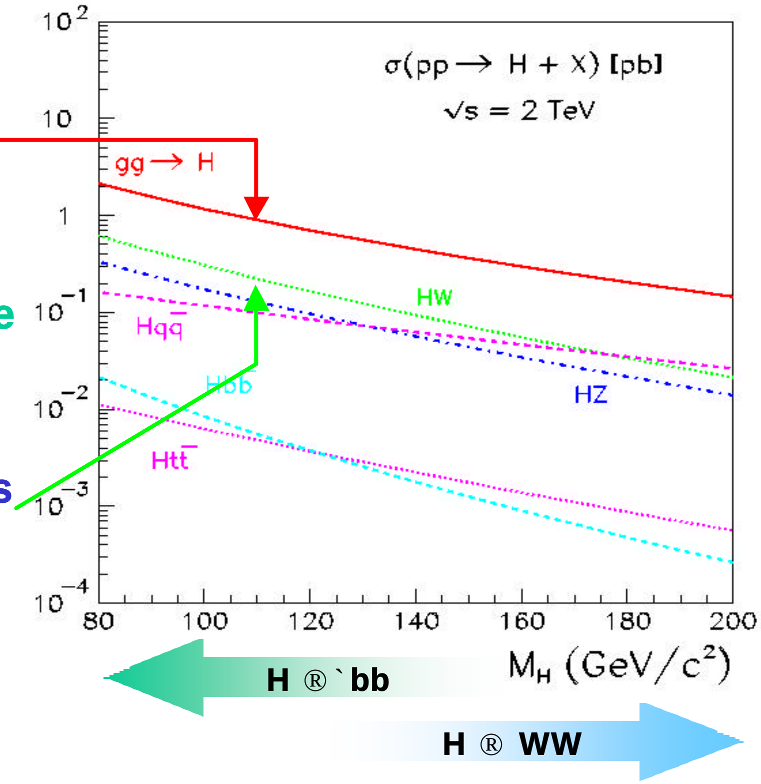
- **Search for mechanism of EWSB motivated the SSC (and LHC)**

- **Post-SSC, there was a resurgence of interest in what was possible at 2 TeV**
  - **Ideas from within accelerator community ("TeV33")**
  - **Stange, Marciano and Willenbrock paper 1994**
  - **TeV2000 Workshop November 1994**
  - **Snowmass 1996**
  - **TeV33 committee report to Fermilab director**
  - **Run II Higgs and Supersymmetry Workshop, November 1998**

- **Consensus resulting from a convergence of**
  - **technical ideas about possible accelerator improvements**
  - **clear physics motivation for integrated luminosities, before LHC turn-on, much larger than the (then) approved 2fb^{-1}**

Higgs Hunting at the Tevatron

- For any given Higgs mass, the production cross section and decays are all calculable within the Standard Model
- Inclusive Higgs cross section is quite high: ~ 1pb
  - for masses below ~ 140 GeV, the dominant decay is H ® bb which is swamped by background
  - at higher masses, can use inclusive production plus WW decays
- The best bet below ~ 140 GeV appears to be associated production of H plus a W or Z
  - leptonic decays of W/Z help give the needed background rejection
  - cross section ~ 0.2 pb

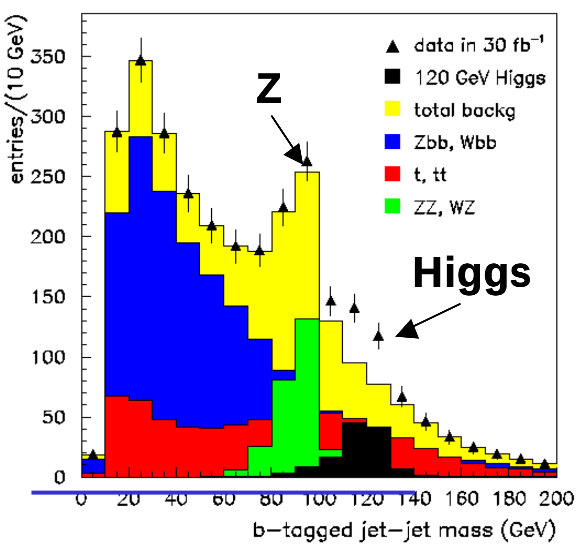


Dominant decay mode

$m_H \lesssim$ 140 GeV: H ® `bb

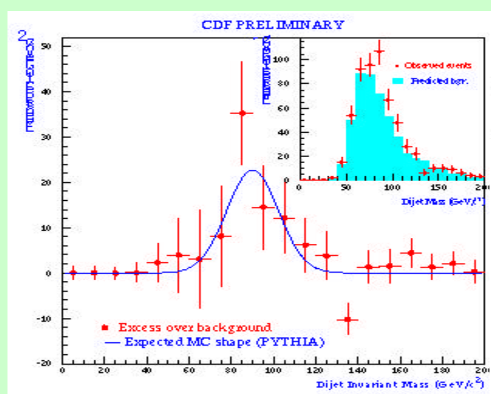
- **WH ® ` qq'`bb is the dominant decay mode but is overwhelmed by QCD background**
- **WH ® l±n` bb** — **backgrounds W`bb, WZ,`tt, single top**
- **ZH ® l+l-` bb** — **backgrounds Z`bb, ZZ,`tt**
- **ZH ® nn` bb** — **backgrounds QCD, Z`bb, ZZ,`tt**
  - **powerful but requires relatively soft missing E_T trigger (~ 35 GeV)**

m_H = 120 GeV

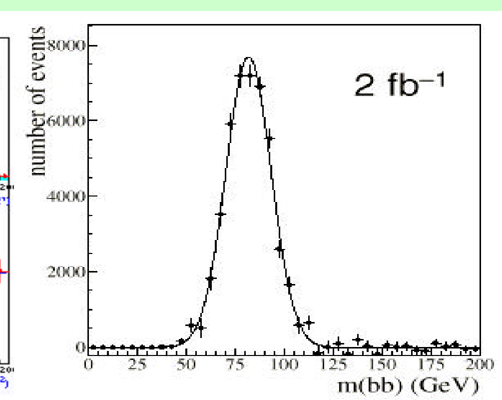


2 ´ 15fb-1 (2 experiments)

`bb mass resolution
Directly influences signal significance
Z ® `bb will be a calibration



CDF Z ® `bb in Run I



DØ simulation for 2fb-1

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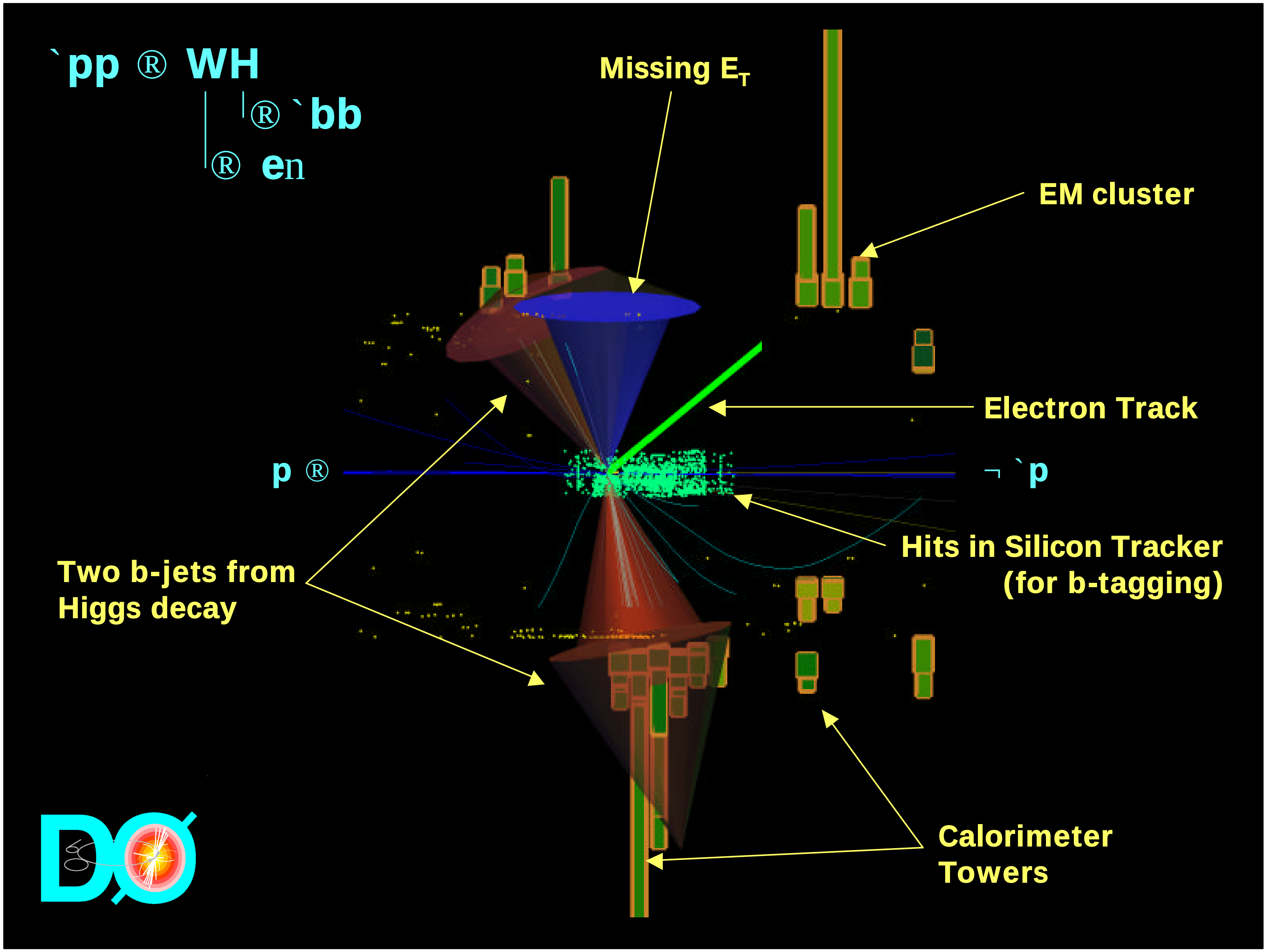

`pp ® WH
® `bb
® en
Missing E$_T$
EM cluster
Electron Track
p ®
¬ `p
Hits in Silicon Tracker
(for b-tagging)
Two b-jets from
Higgs decay
Calorimeter
Towers

Example: m_H = 115 GeV

- ~ 2 fb^{-1}/expt (2003): exclude at 95% CL
- ~ 5 fb^{-1}/expt (2004-5): evidence at 3σ level
- ~ 15 fb^{-1}/expt (2007): expect a 5σ signal

Every factor of two in luminosity yields a lot more physics

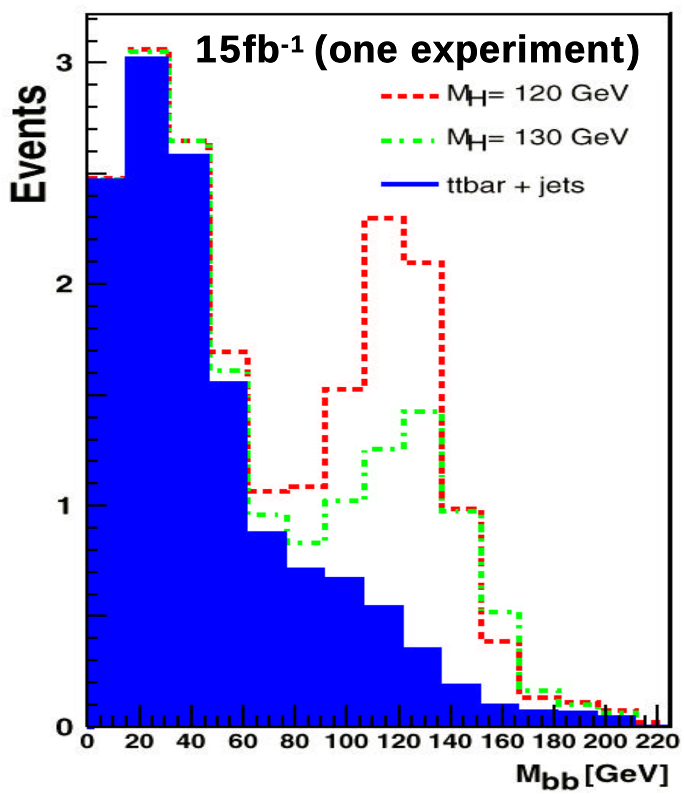
- Events in one experiment with 15 fb^{-1}:

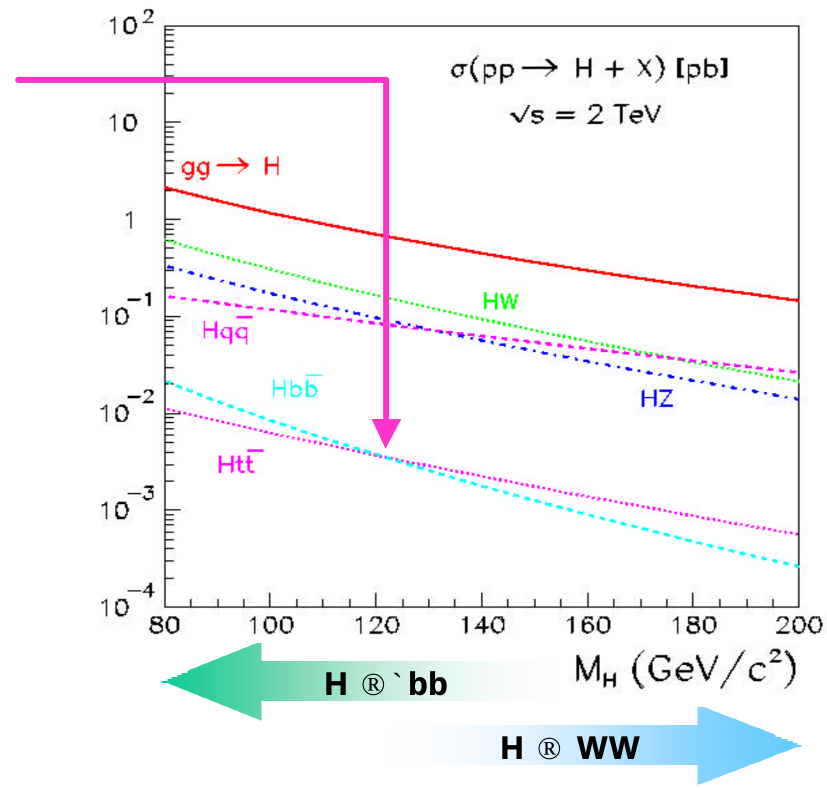
Mode	Signal	Background	$S/\sqrt{B}$
$\ell \nu bb$	92	450	4.3
$\nu\nu bb$	90	880	3.0
$\ell \ell bb$	10	44	1.5

- If we do see something, we will want to test whether it is really a Higgs by measuring:
  - mass
  - production cross section
  - Can we see $H \rightarrow WW$? (Branching Ratio ~ 9%)
  - Can we see $H \rightarrow \tau\tau$? (Branching Ratio ~ 8%)

Associated production `tt + Higgs

- Cross section very low (few fb) but signal:background good
- Major background is `tt + jets
- Signal at the few event level:





Tests top quark Yukawa coupling

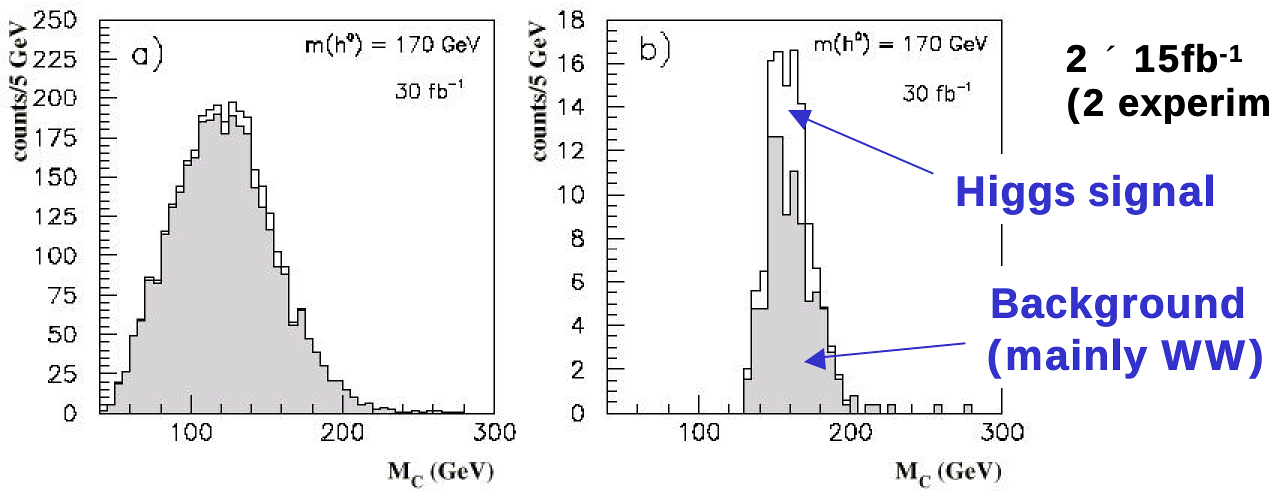
$m_H \gtrsim 140$ GeV : $H \rightarrow WW^{(*)}$

- $gg \rightarrow H \rightarrow WW^{(*)} \rightarrow l^+l^- \nu\nu$

  Backgrounds **Drell-Yan, WW, WZ, ZZ, tt, tW,** $t\bar{t}$

  Initial signal:background ratio ~ 10^{-2}

  – **Angular cuts to separate signal from "irreducible" WW background**



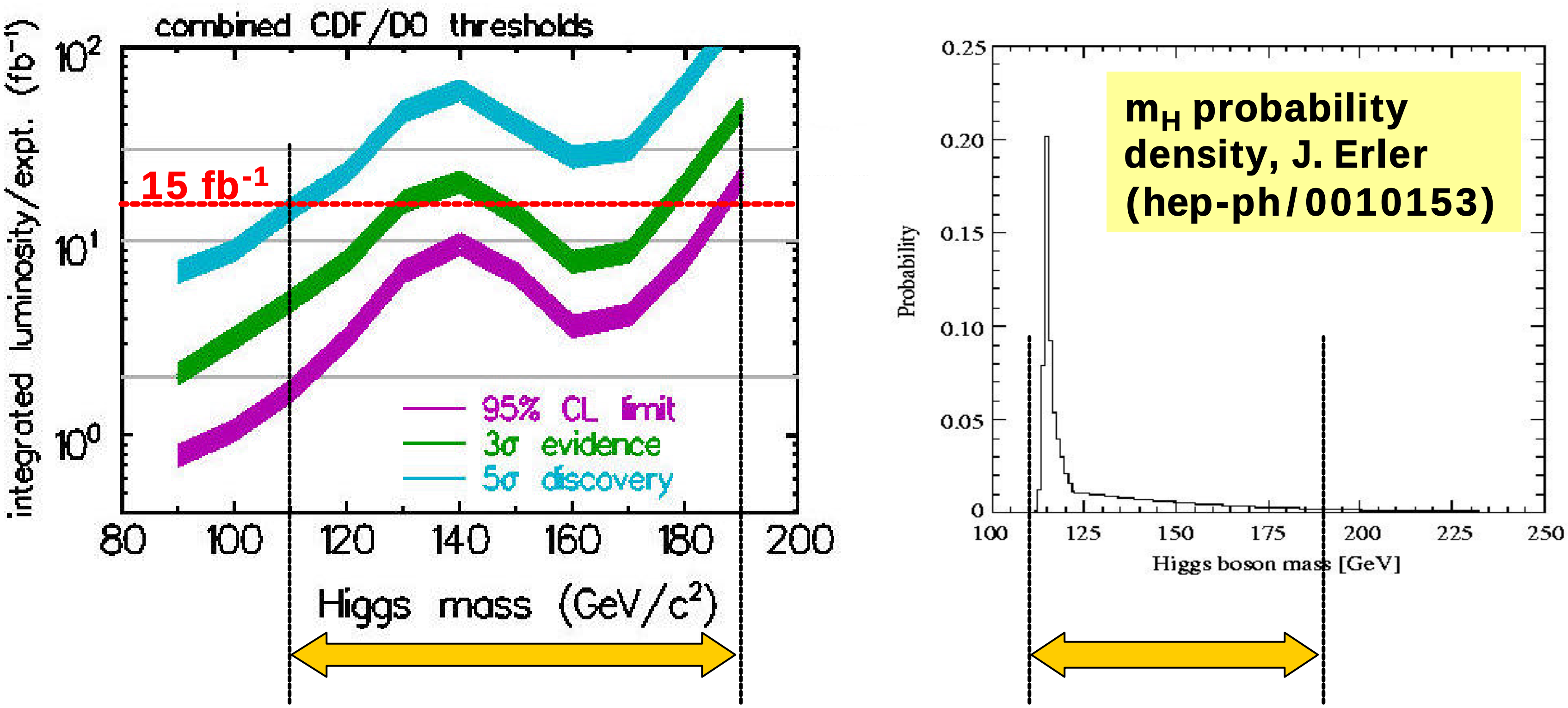
2 × 15fb^{-1}
(2 experiments)

Before tight cuts: verify WW modelling

After tight cuts

M_C = *cluster transverse mass* $= \sqrt{p_T^2(\ell\ell) + m^2(\ell\ell)} + \not{E}_T$

Combined Higgs mass reach

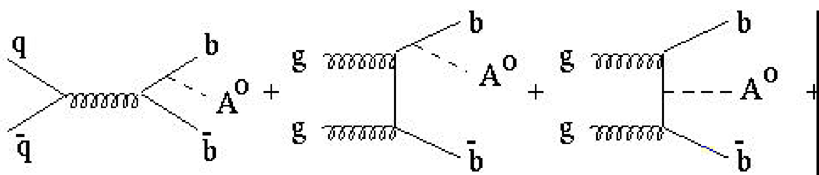


110-190 GeV

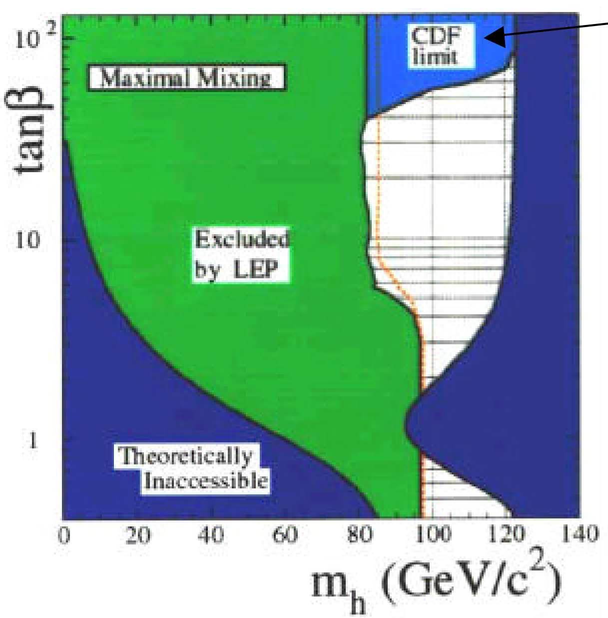
"that's where the money is"

Strong SUSY Higgs Production

- bb(h/H/A) enhanced at large tan b:

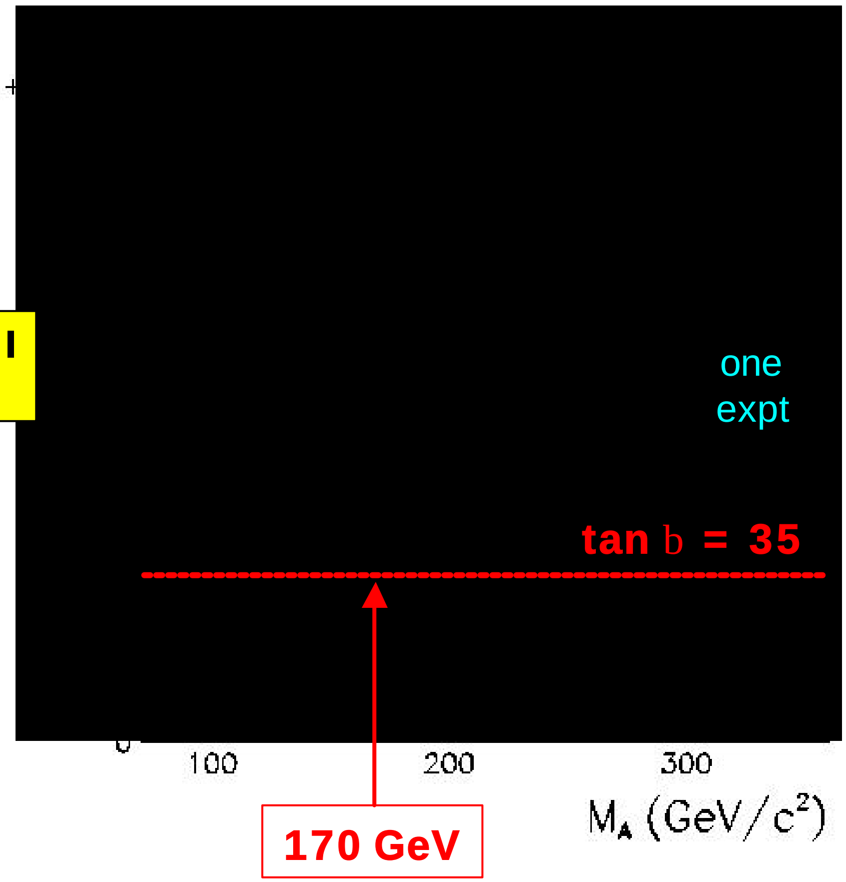


- s ~ 1 pb for tanb = 30
  and m_h = 130 GeV



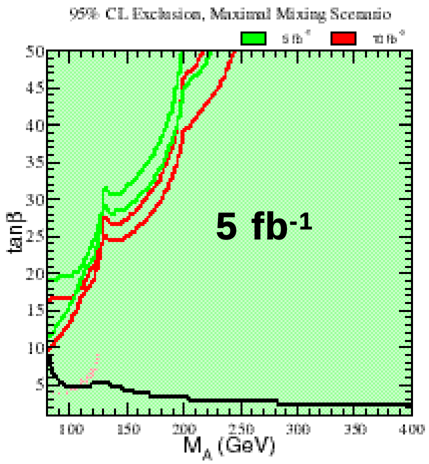
CDF Run I
3 b tags

bb(h/A) ® 4b

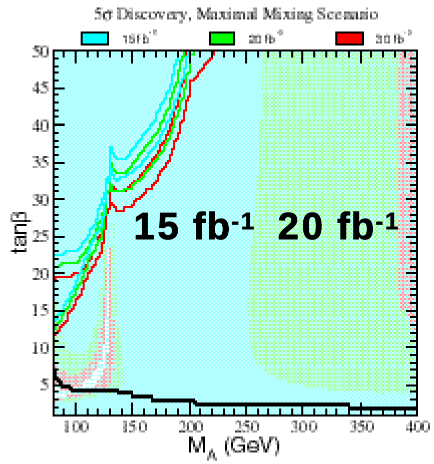


SUSY Higgs sector

95% exclusion

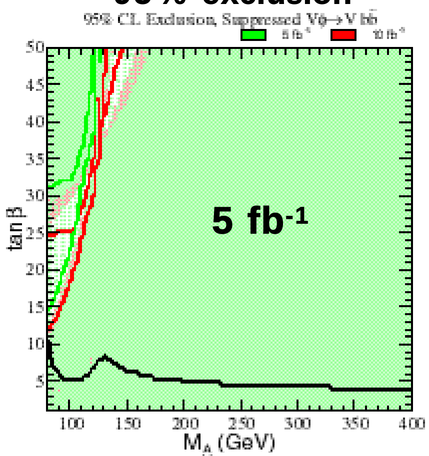


5σ discovery

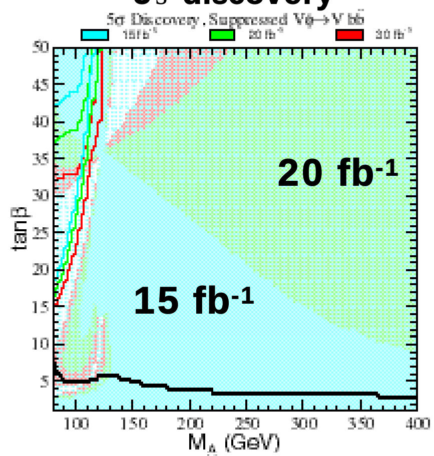


Exclusion and discovery for maximal stop mixing, sparticle masses = 1 TeV

95% exclusion



5σ discovery



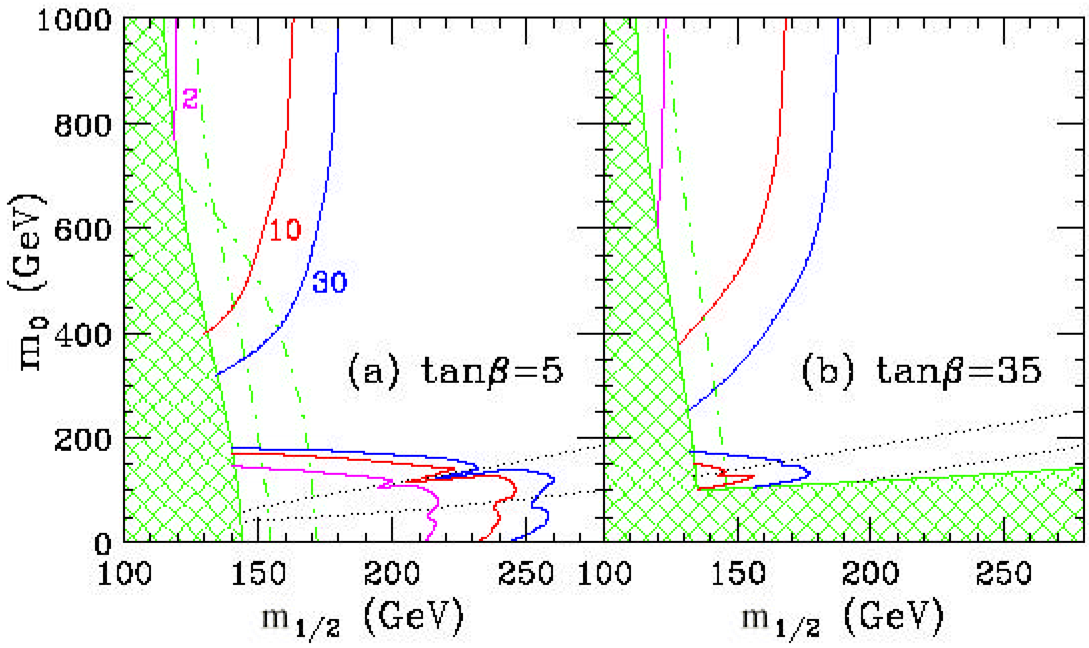
Most challenging scenario: suppressed couplings to bb

Enhances h → γγ ?

Luminosity per experiment, CDF + DØ combined

Run 2b significantly extends SUSY reach

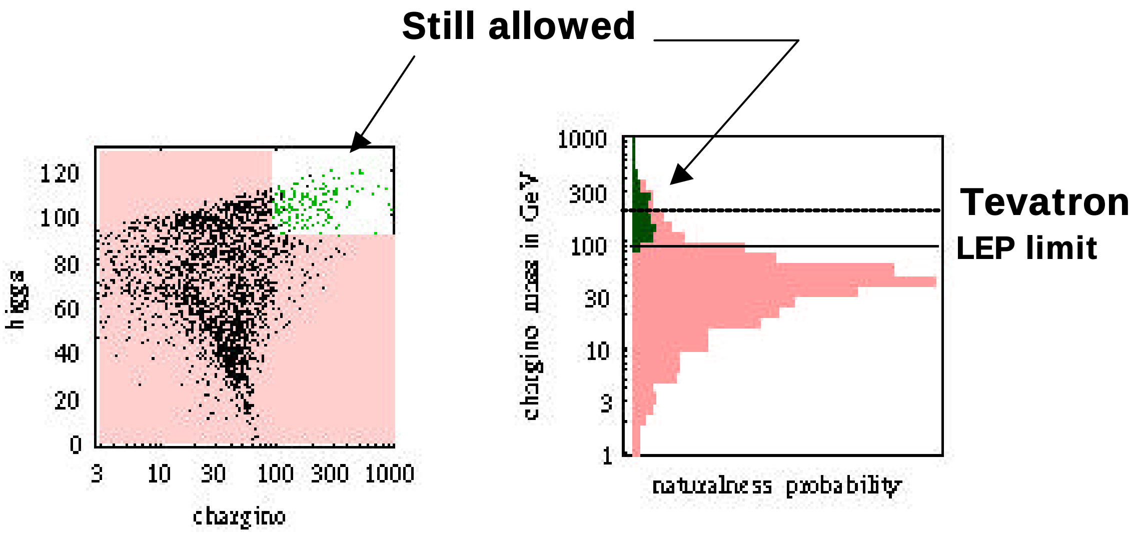
- Major gain comes from chargino / neutralino production in multilepton final states:



- Exclusion contours in MSUGRA ($A_0 = 0$, $m > 0$) using $3l^{\pm}$ final state for 2, 10, 30 fb^{-1}

Excluding SUSY

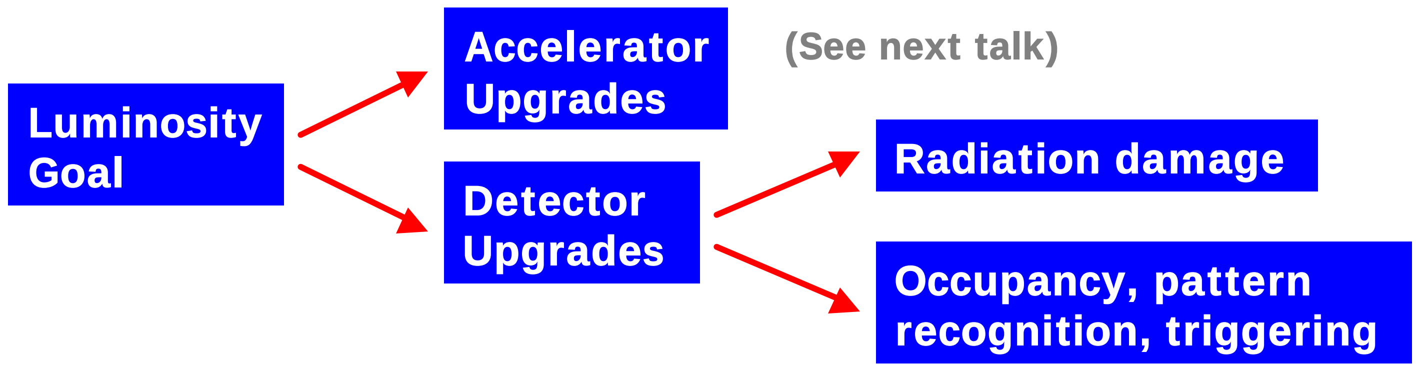
- It is amusing to note that typical minimal supergravity-inspired SUSY models are already excluded at the 95% level
  (e.g. Strumia, hep-ph/9904247)



- Run 2b has the capability of covering the rest of the plane, at least to first order in model “evasiveness”

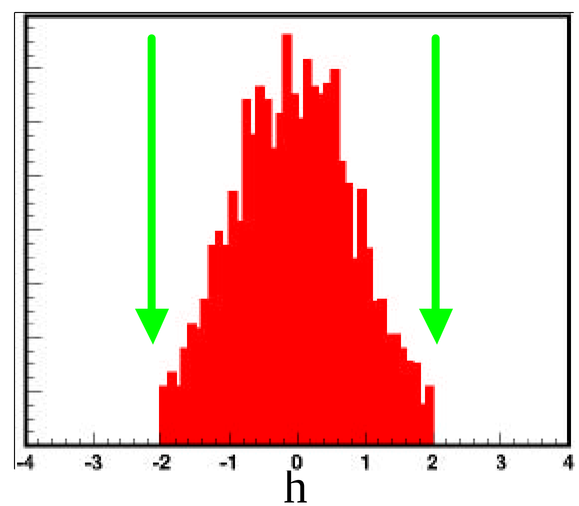
Detector upgrades

- The physics drives the luminosity needed
  - The Director has set 15 fb^{-1} as an achievable goal



- Run 2b physics goals require
  - jet energy and missing E_T measurements
  - isolated leptons
  - b-tagging
- Kinematic range for all objects is typically p_T > 15 GeV, |h| < 2

SUSY trileptons

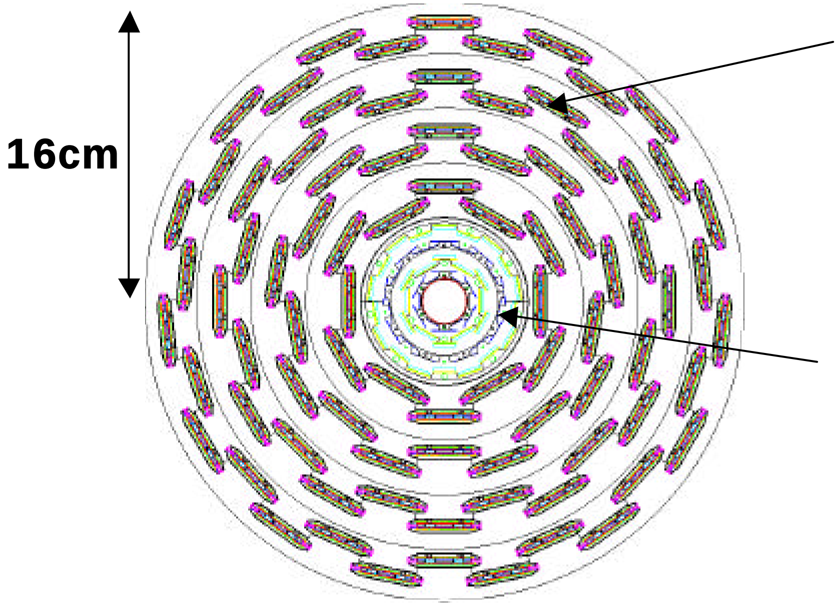


Silicon tracker upgrades

- **Longevity**
  - the present CDF and DØ trackers will not last more than ~ 4 fb^{-1}
- **Both collaborations have decided to build replacement trackers**
  - avoid long down-time and high risk associated with partial replacement
- **Primary goals**
  - retain current capabilities with a more robust and simple system
    - helps meet the tight schedule
  - use only single-sided silicon
  - minimize number of ladder types
  - benefit from experience building the present detectors
- **Secondary goals**
  - enhance performance where possible without significant additional cost or schedule risk

Layout

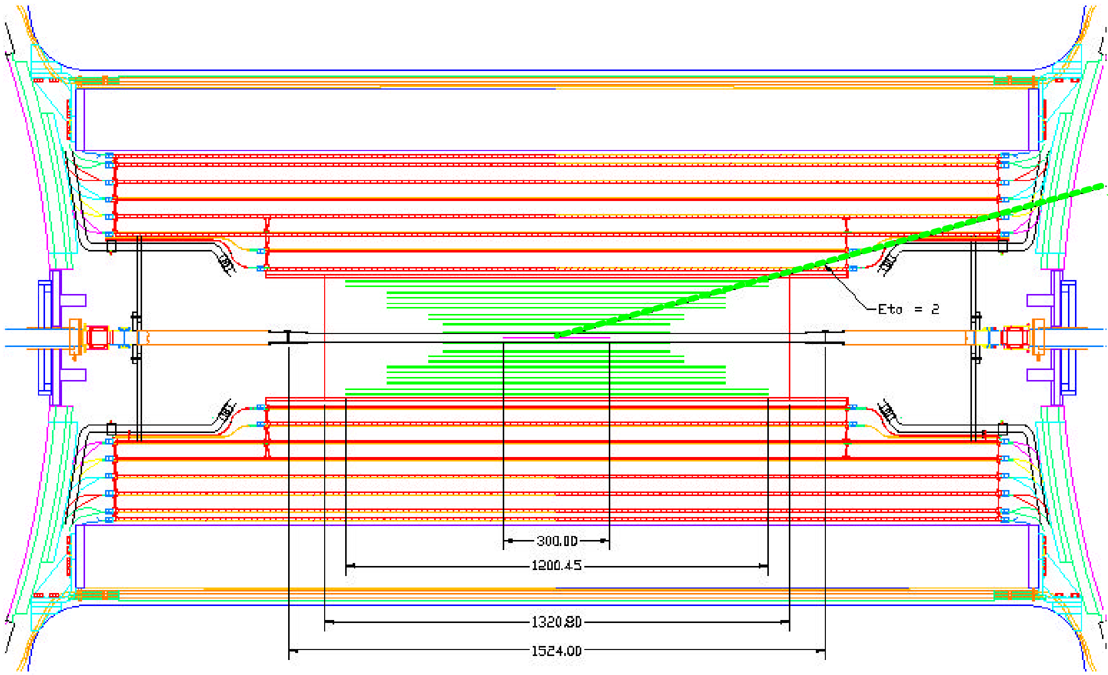
- Both collaborations propose six layer devices with two groups of silicon sensor layers
- DØ design for illustration:

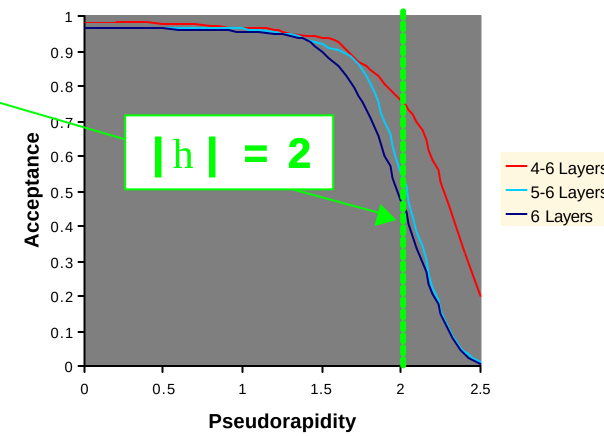


3 or 4 outer layers:
Tracking detectors
axial + small angle stereo
pattern recognition and sagitta

2 or 3 inner layers:
Vertexing detectors
axial (+ large angle stereo?)
impact parameter resolution
similar to present CDF L00

DØ Tracker Side View



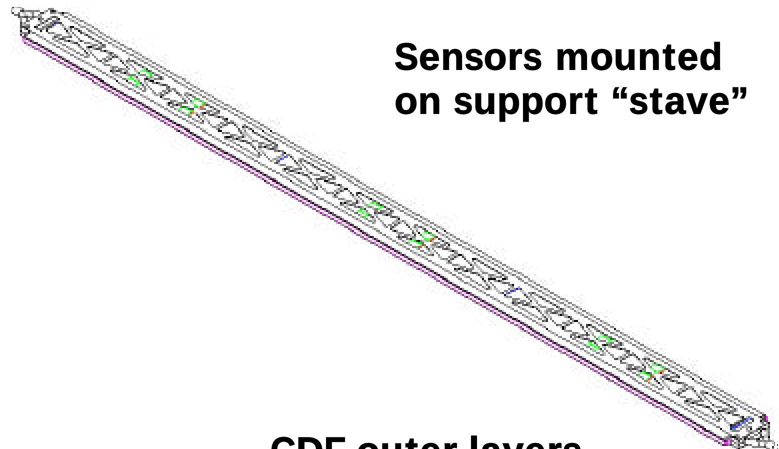


Silicon Acceptance
1.2m long outer barrel
vertex s_z = 15 cm

- **Outer radius constrained to fit inside existing fiber tracker**
- **Barrel length (1.2m) governed by desired acceptance**
  - **DØ can install a single unit up to 1.3m long without roll-out**
- **Inner layer sensors mounted on new 1” diameter beam pipe**
- **Channel count ~ 500-900k (depends on pitch in outer layers)**

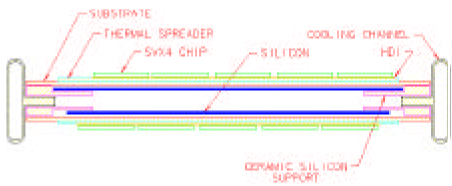
Mechanical engineering

- **Cooling and support approaches are being studied in both experiments**

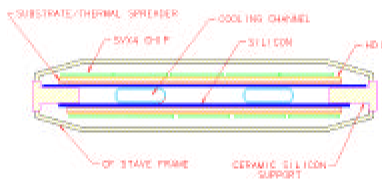


Sensors mounted on support "stave"

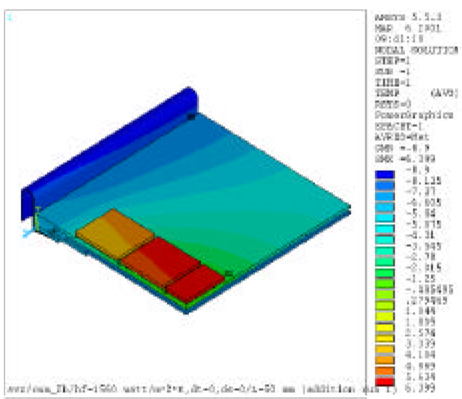
DØ outer layers: two cooling variants

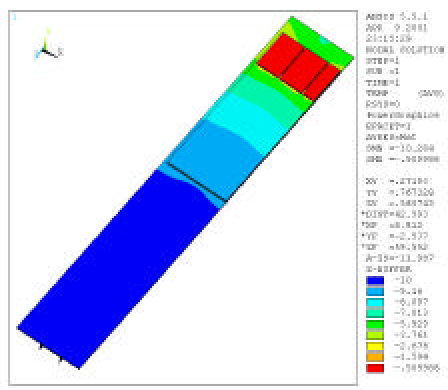


Edge cooling

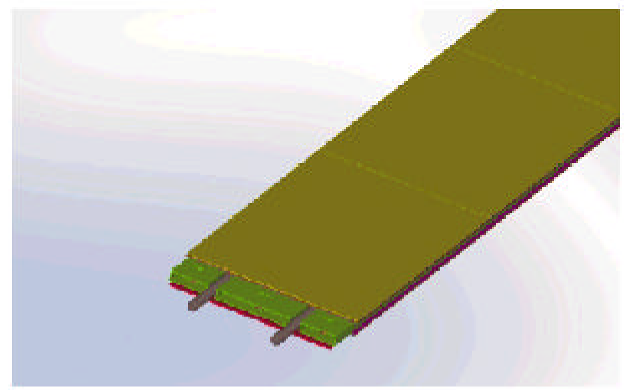


Interior cooling





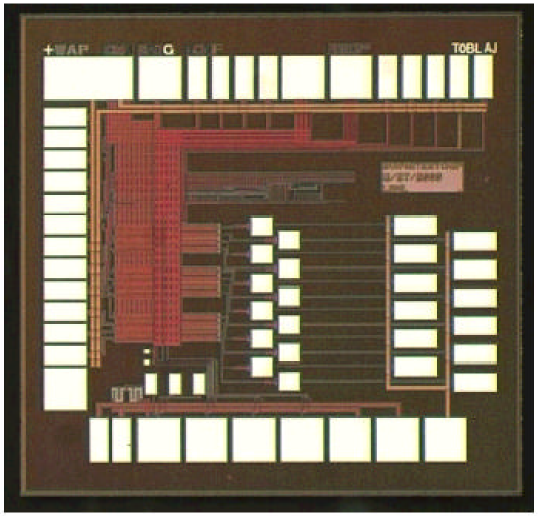
CDF outer layers



Readout

- Maintain existing downstream infrastructure as much as possible
- Both experiments will use the SVX4 chip
  - 0.25 μm CMOS technology
  - Radiation hard > 30 MRad
  - Replaces SVX2 (DØ) and SVX3 (CDF)
  - Joint project Fermilab-LBNL-Padova
- Specifications agreed
- SVX2 emulation tested with an SVX3 chip
- Schedule
  - Design review at LBNL in April
  - Engineering submission this summer
  - Production orders in 2002
  - Chips available spring 2003

Analog test chip

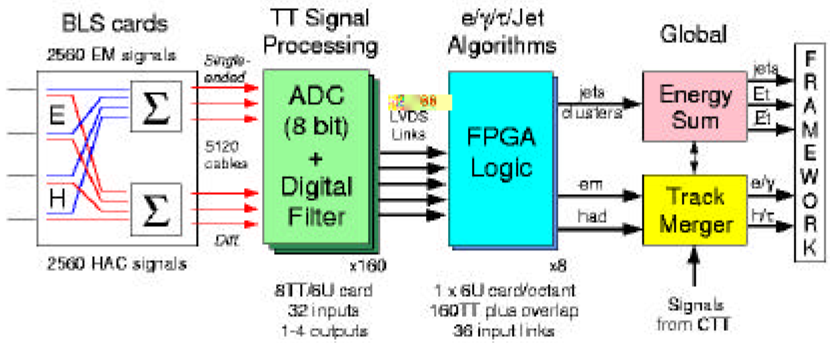


Organization

- Both collaborations are putting project management in place
- Laboratory has set up a Task Force to explore and promote commonalities between the designs
  - obviously good, but . . .
- First cost and manpower estimates presented at April PAC meeting, now being reviewed within the lab
  - cost will be of order $10M per detector
- Technical design reports: Autumn 2001
  - some R&D needed:
    - sensor evaluation, prototypes, radiation tests . . .
- Trackers installed and ready for collisions by end of 2004

DØ Trigger Upgrades

- At $5 \times 10^{32} cm^{-2} s^{-1}$, the Level 1 trigger rate will exceed the 5-10 kHz limit set by deadtime, and the Level 2 trigger rate will exceed the 1.8 kHz limit set by the calorimeter readout
- Trigger upgrades being simulated and evaluated:
  - Calorimeter Level 1 trigger
    - Digital signal processing
    - Improved energy resolution, jet clustering and EM isolation
    - Double granularity of trigger towers in ϕ ($0.2 \rightarrow 0.1$)
    - Match tracks and calorimeter objects at L1



  - Fiber tracker trigger upgrades (narrower roads, stereo fibers)
  - Additional muon trigger scintillator

Other CDF upgrades

Studies are underway concerning additional possible upgrades:

- **deadening of the inner superlayer COT sense wires for large |z|**
- **central preshower and crack chamber replacement**
- **EM calorimeter timing improvements**
- **Address CSX (muon scintillator) light loss issue**
- **Stereo segment finder in XFT (level 1 track finder)**
- **Upgrade event-builder and level 3 farm**
- **Online system upgrades**

Offline Computing

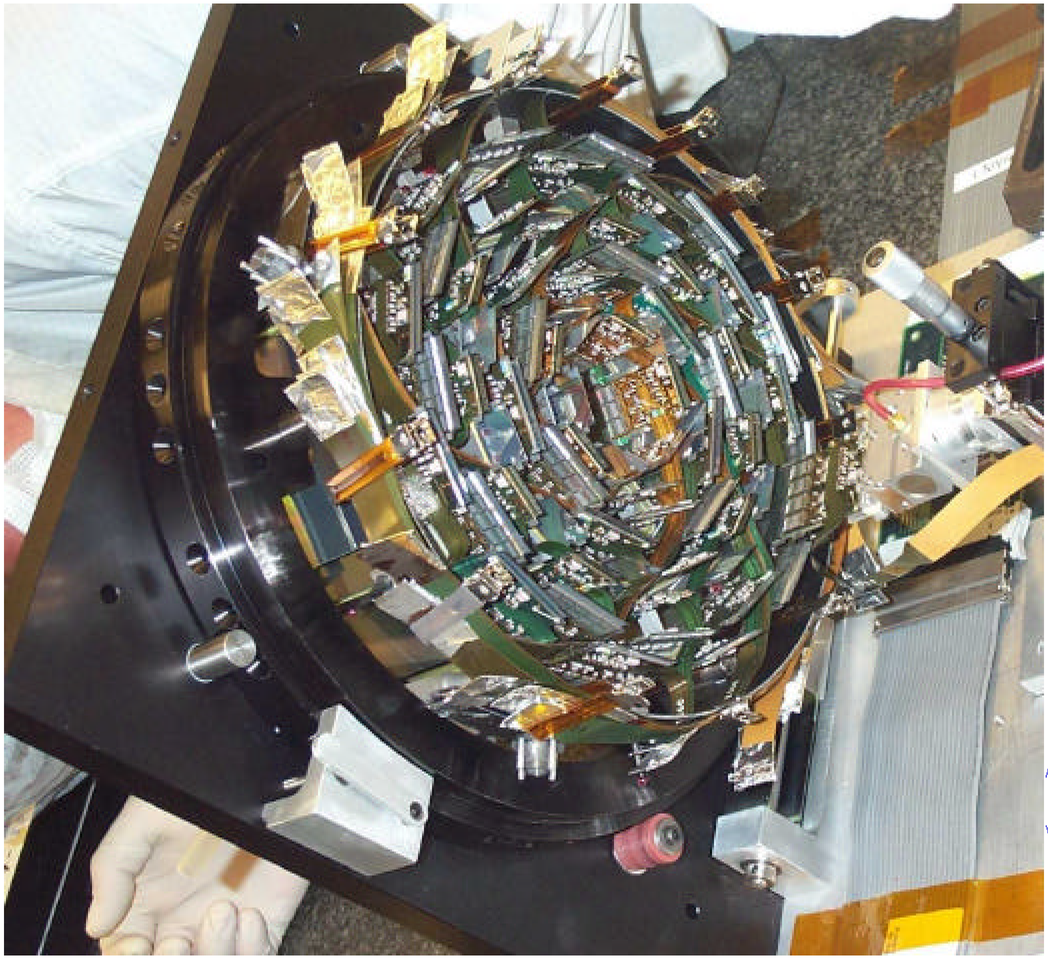
- Hardware cost mainly scales with data volume
  - run 2b data volume ~ 5 times greater than Run 2a
  - 5-8 petabytes per experiment
- Computing price/performance evolution:
  - a factor of two every 1.5 years
  - factor 8 improvement after 4.5 years
- Therefore costs will be similar to the systems acquired for Run 2
  - $9M per experiment in equipment costs
  - spending profile best spread over 3 years starting with 2003/4, so funds are needed after the bulk of the detector upgrade projects are finished
- Clearly this is an investment comparable to the detector upgrades, and while less “visible” it is just as important to the physics

Conclusions

- The Tevatron collider program in the next 5-7 years offers a real opportunity to significantly advance our understanding of the fundamental properties of space-time and matter
- It is an exciting, challenging program that goes straight to the highest priorities of high energy physics worldwide
- The physics case has never been more compelling, and it is of great importance politically as well as scientifically
- What worries me most is our ability to execute the program in the time available; while it is the highest priority of the laboratory and of the experiments, we'll need adequate resources to carry it out

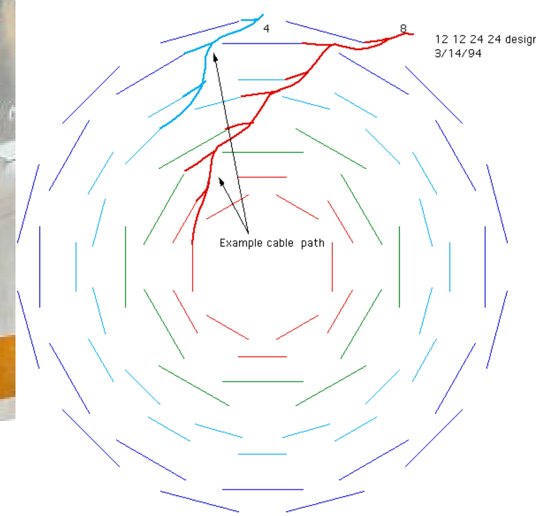
Backup slides

Why not rebuild the existing trackers?



A short shutdown is critical to our Physics Program

Reuse of any part of the existing silicon trackers would require an estimated 10-14 months shutdown



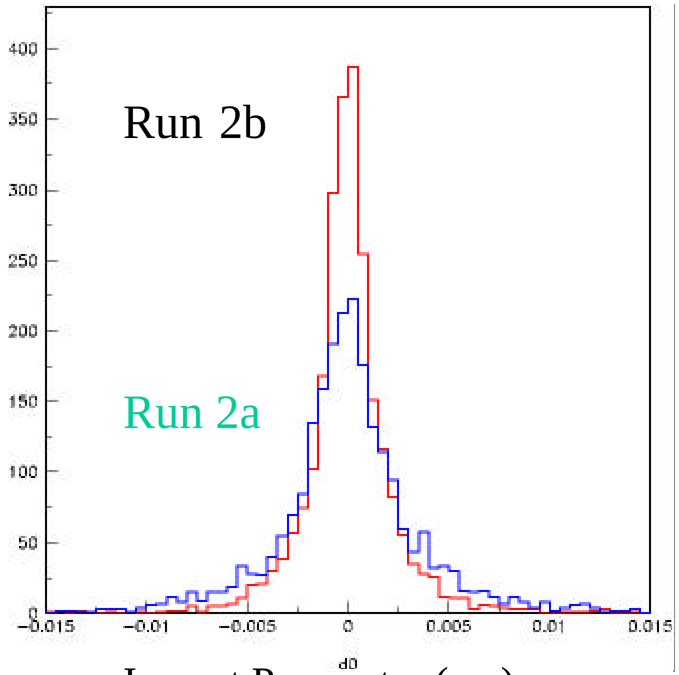
Complementarity with LHC

- **The Physics goals of the Tevatron upgrade and the LHC are not very different, but the discovery reach of the LHC is hugely greater**
  - **SM Higgs:**
    - **Tevatron < 180 GeV** **LHC < 1 TeV**
  - **SUSY (squark / gluino masses)**
    - **Tevatron < 400-500 GeV** **LHC < 2 TeV**

Despite its lesser reach, the Tevatron is interesting because both Higgs and SUSY “ought to be” light and within reach

- **For Standard Model physics, systematics may dominate:**
  - **Top mass precision**
    - **Tevatron ~ 2 GeV** **LHC ~ 1 GeV?**
  - **m_W precision**
    - **Tevatron ~ 20 MeV?** **LHC ~ 20 MeV?**

Tracker Performance



Impact Parameter (cm)

- L0, L5 added to Run 2a GEANT MC (not Run 2b geometry)
- Full tracking/pattern recognition
- Simple b-tagging algorithm
- L0 significantly enhances b-tagging efficiency at low luminosity
- L5 provides pattern recognition to recover efficiency in busy events

Option	$\sigma(d_0)$, μm	ε_b (%) $t\bar{t} + 0$ Minbias	ε_b (%) $t\bar{t} + 6$ Minbias
SMT	25	40	30
SMT+L0	15	47	35
SMT+L0+L5	15	48	40