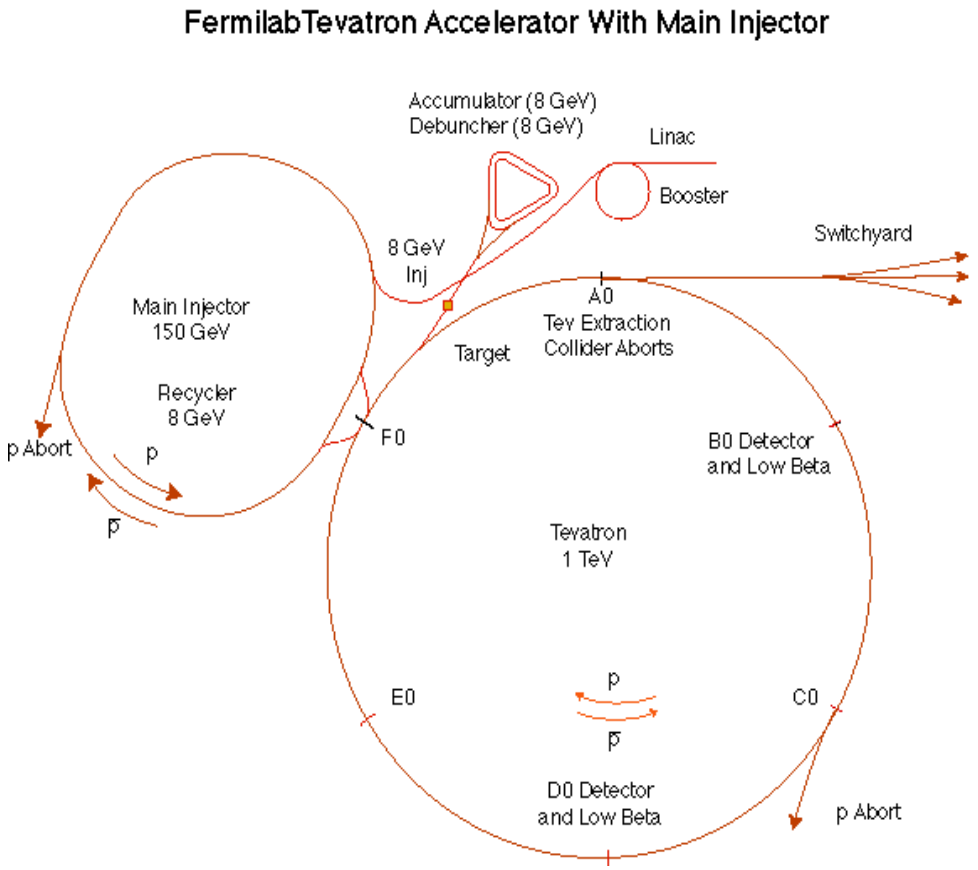
Higgs and SUSY at the TeVatron

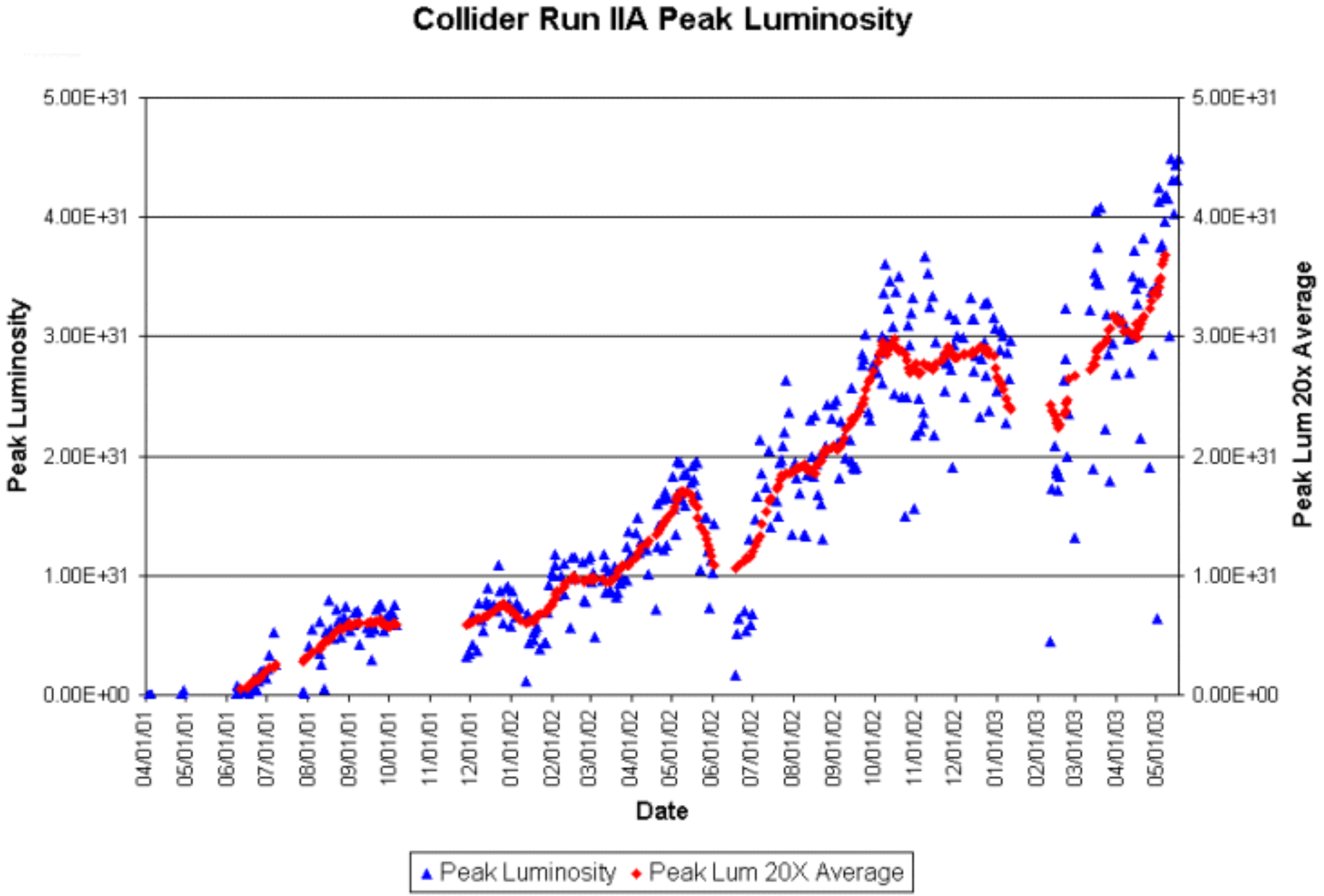
Laurent Duflot - LAL Orsay

- Status of the TeVatron and perspectives
- Status of the CDF and D0 experiments
- Higgs
  - predictions from the 1998 workshop
  - recents results
- SUSY
  - recent results
- All experimental results shown here are preliminary

New accelerator complex

- New Main Injector: 150 GeV, store protons, shoot to target for anti-proton production
- New Recycler: permanet magnet storage ring for anti-proton
  - anti-proton recycling abandonned
- Beam energy 980 GeV, was 900 GeV
- 36 bunches (396ns) instead of 6 (2.4 μs)
- Increased luminosity:
  - Run 1 maximum 2 x 10^{31} $cm^{-2}\,s^{-1}$
  - Run 2 goal 2-4 x 10^{32} $cm^{-2}\,s^{-1}$




Collider Run IIA Peak Luminosity
Peak Luminosity
Peak Lum 20x Average
5.00E+31
4.00E+31
3.00E+31
2.00E+31
1.00E+31
0.00E+00
04/01/01
05/01/01
06/01/01
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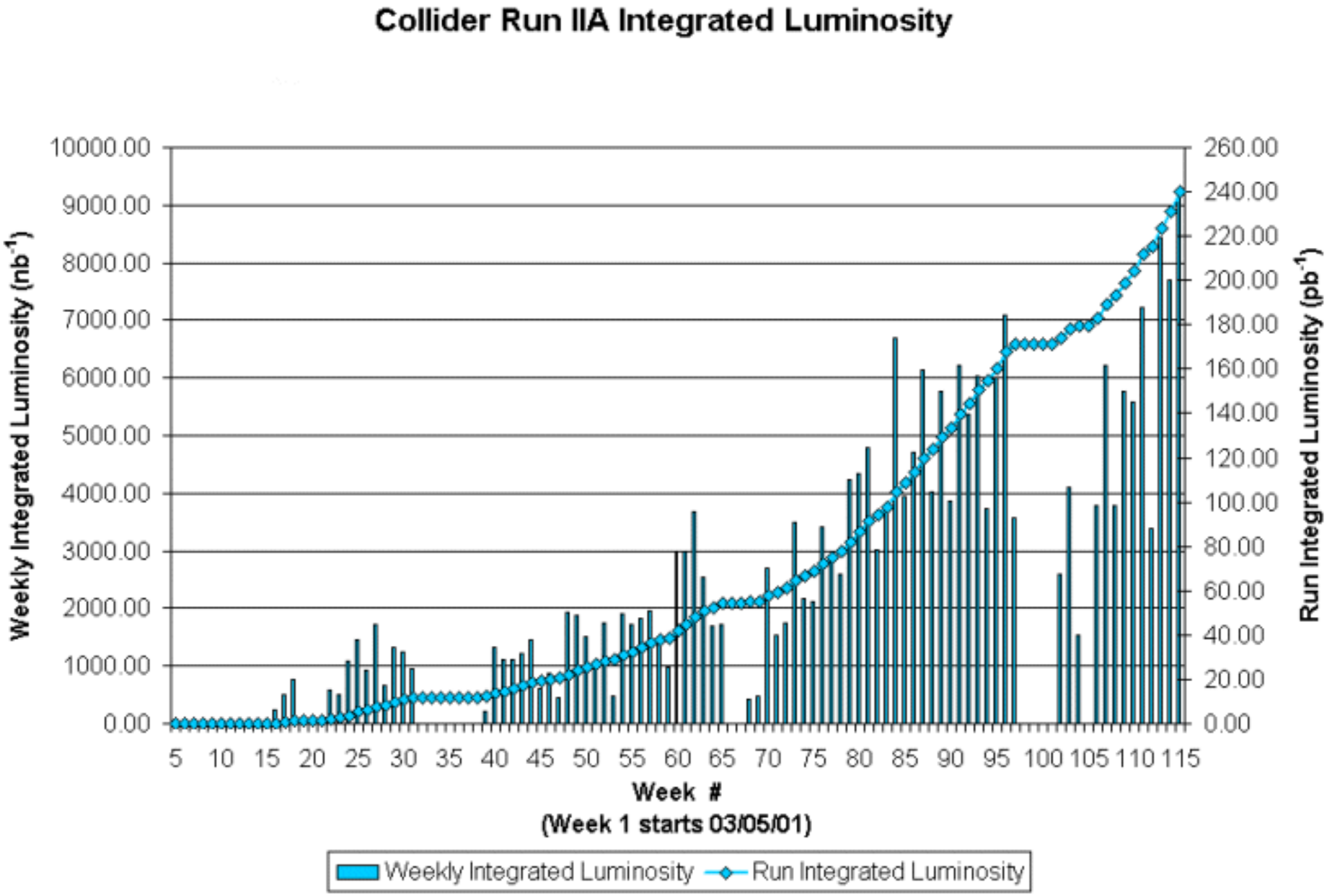
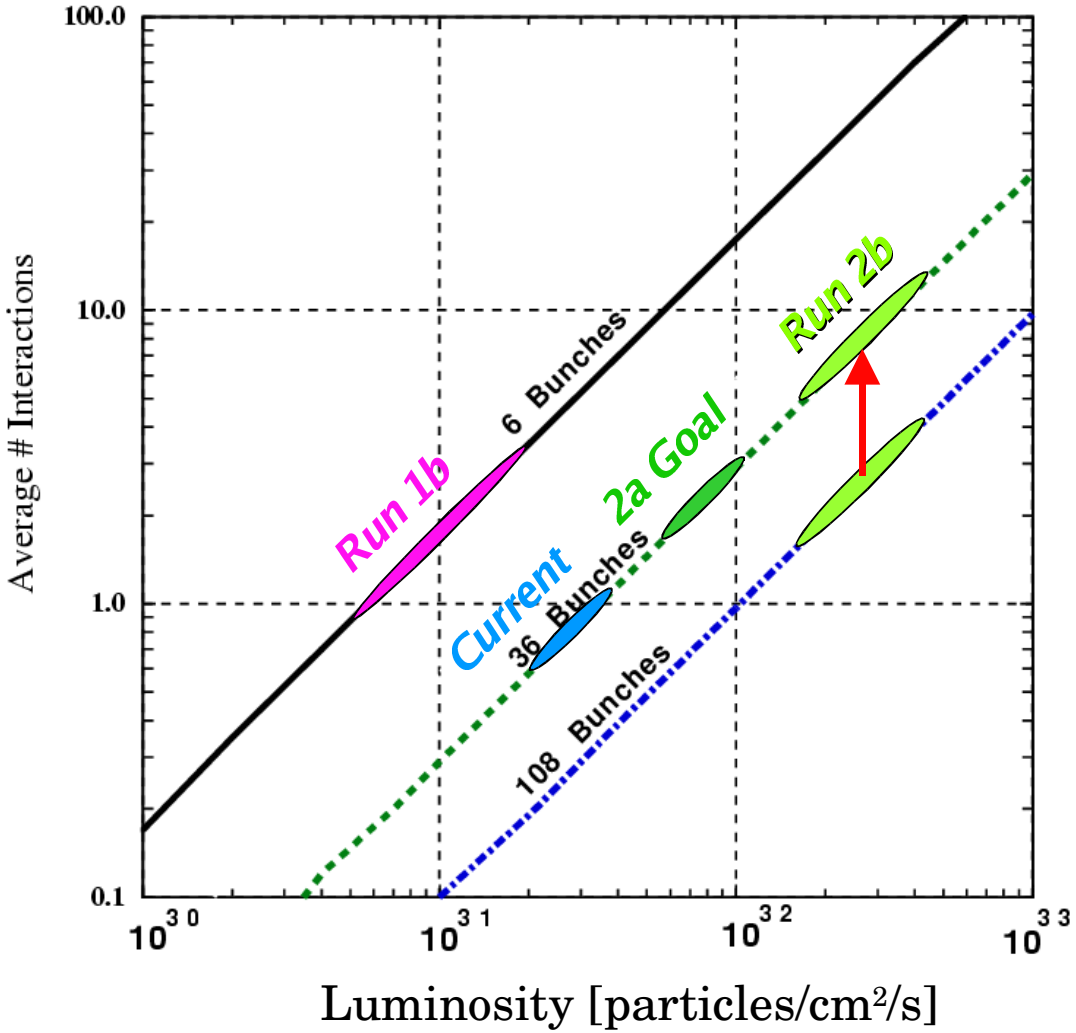
05/01/03
Date
Peak Luminosity
Peak Lum 20X Average

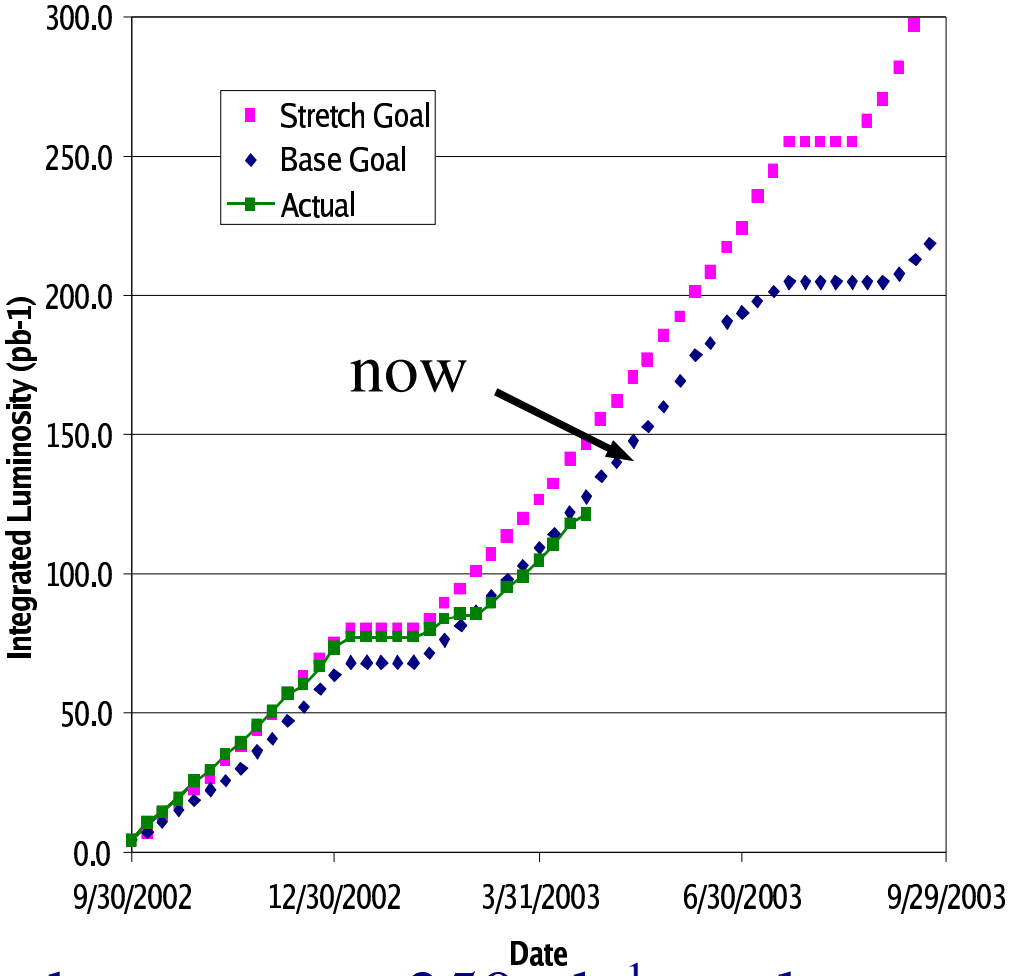

Collider Run IIA Integrated Luminosity
Weekly Integrated Luminosity (nb-1)
Run Integrated Luminosity (pb-1)
10000.00
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
260.00
240.00
220.00
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115
Week #
(Week 1 starts 03/05/01)
Weekly Integrated Luminosity
Run Integrated Luminosity

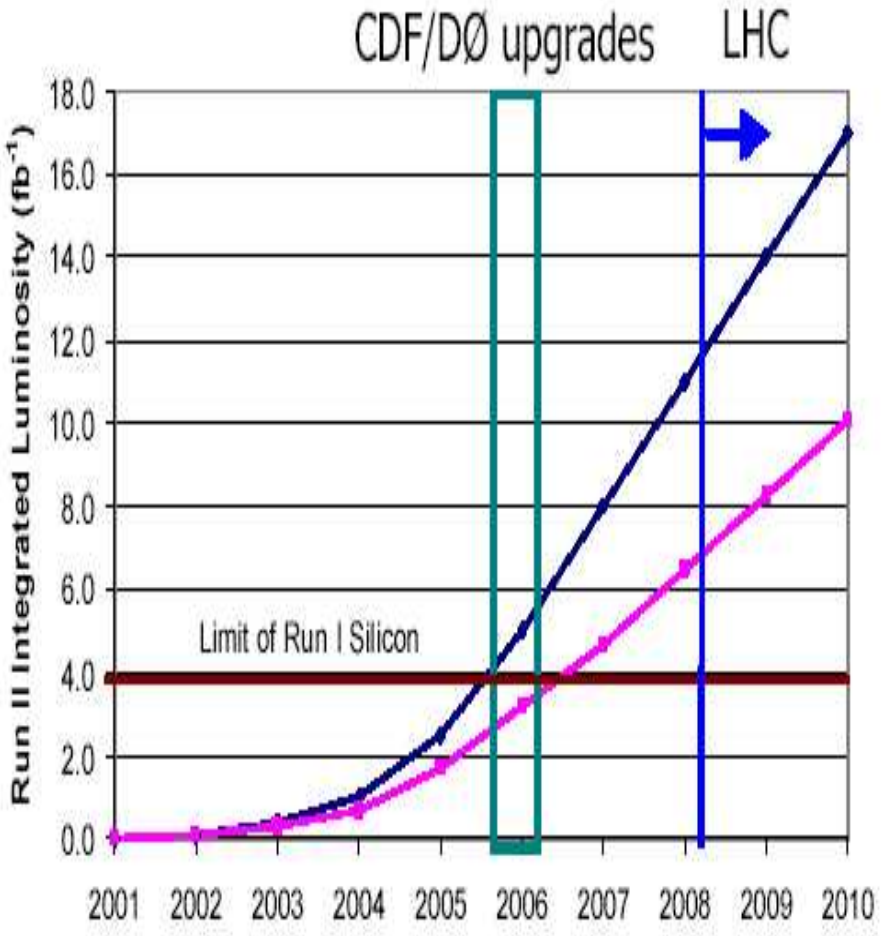
Revised goals



- Run IIa ≡ ~2-4 fb^{-1}
- Goal for Run IIa $\mathcal{L}$ ~9.10^{31}
  - now $\mathcal{L}_{max}$ ~4.10^{31}
- Run IIb: 132ns and crossing angle abandoned
- Goal for Run IIb $\mathcal{L}$~2.10^{32}

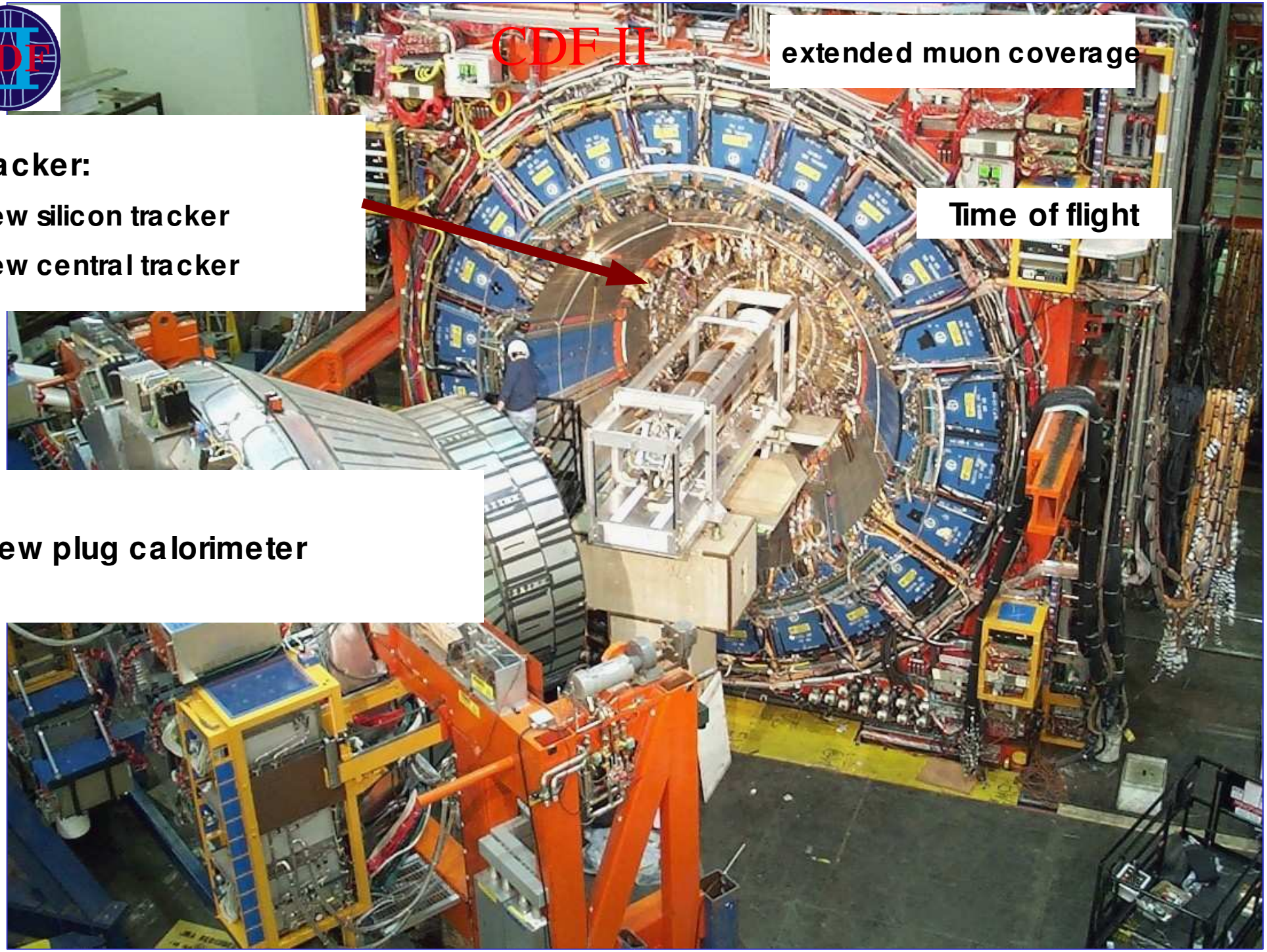
Luminosity goals





short term: ~350 pb^{-1} total delivered in 09/2003

long term: 5-9 fb^{-1} by 2009



Tracker:

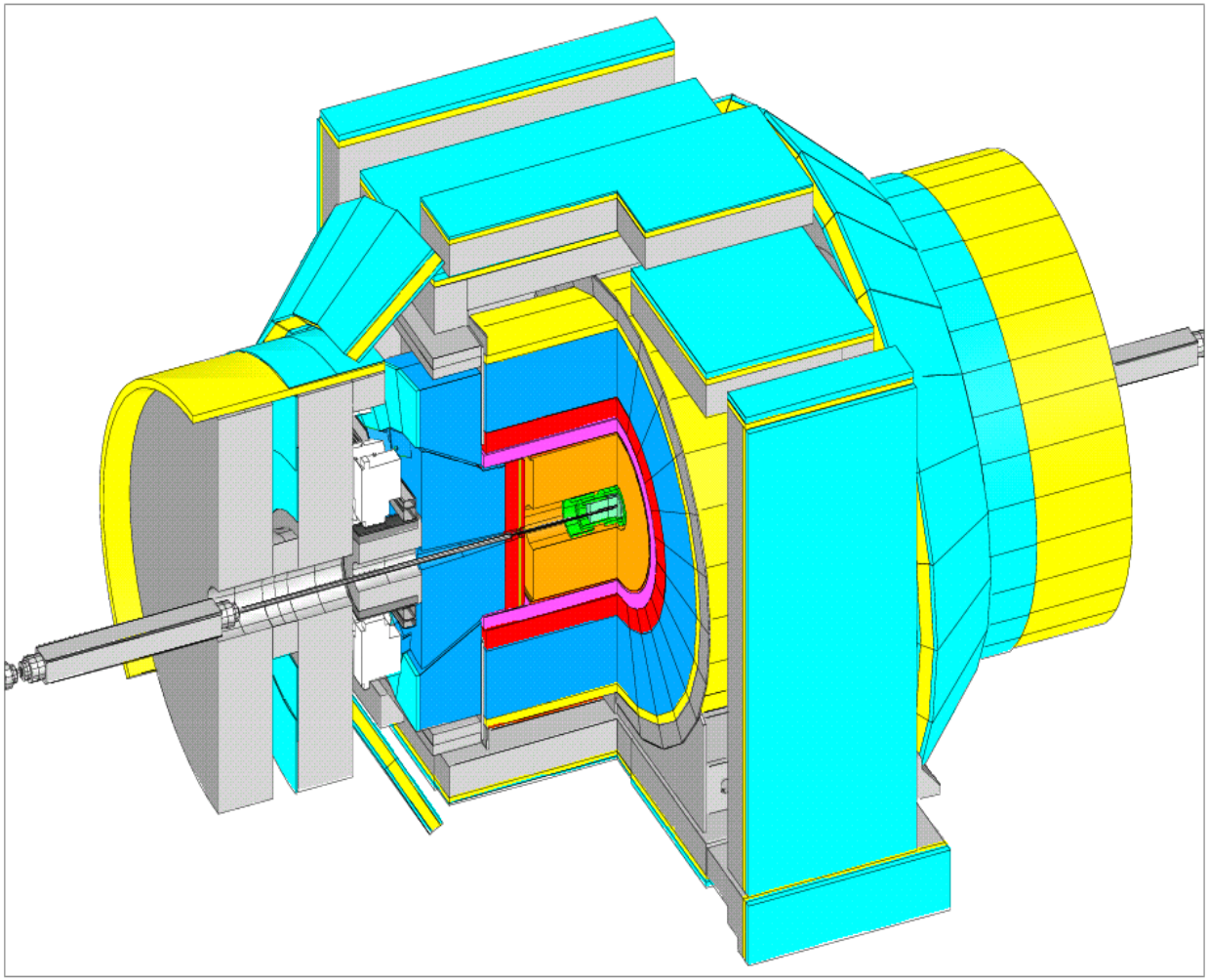
New silicon tracker

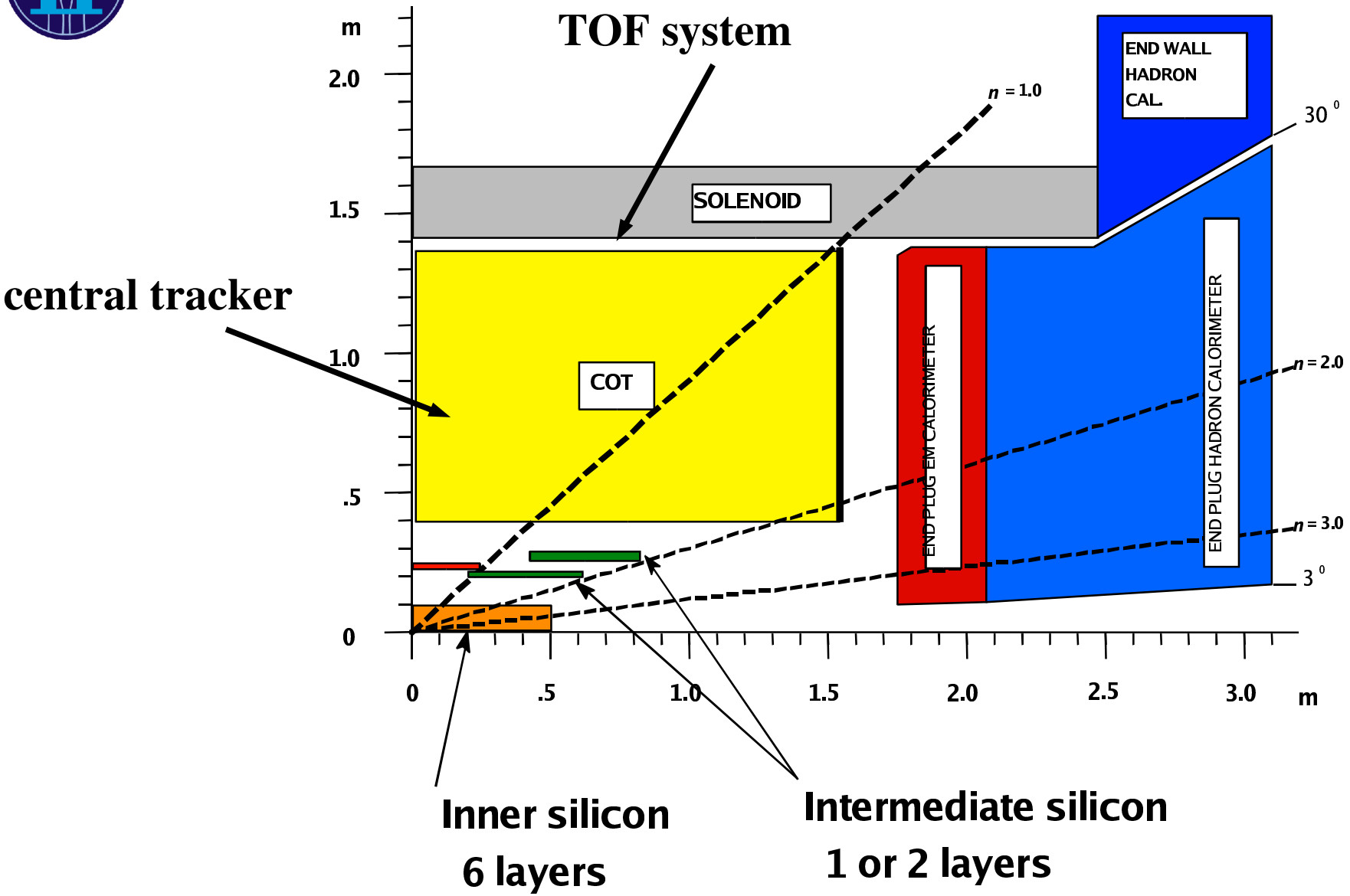
New central tracker

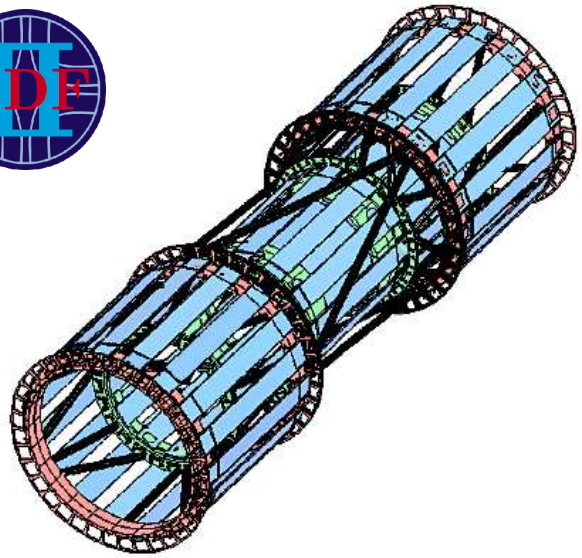
·New plug calorimeter

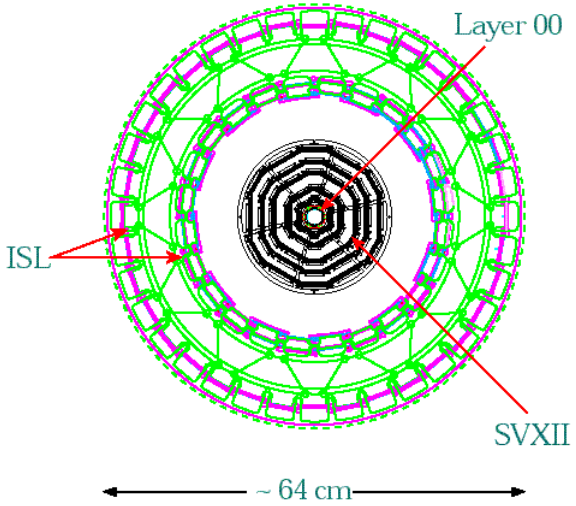
CDF upgrade overview

- Improved Si coverage
  - $|\eta| < 2$
  - 8 layers
- Central Drift Chamber
  - 96 layers
- Time of Flight
- Expanded μ coverage
- Forward Calorimeter
- Trigger
  - COT tracks at L1
  - Silicon tracks at L2

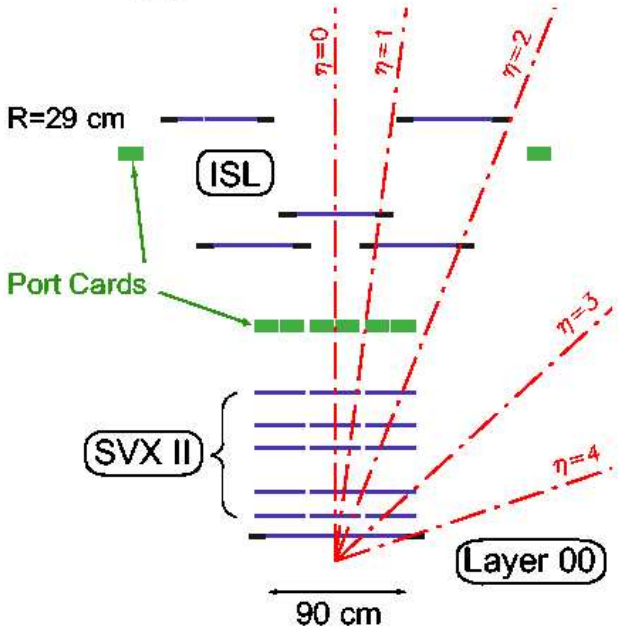


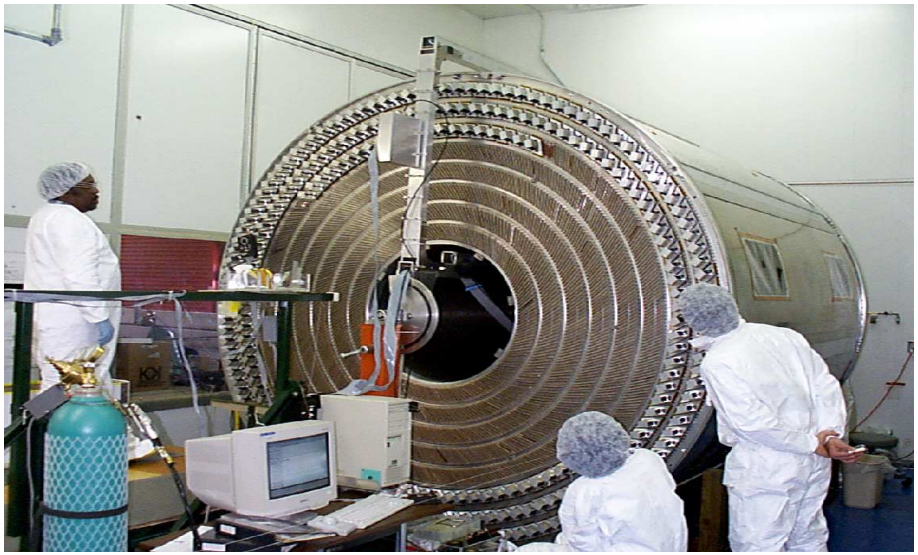

TOF system
central tracker
m
2.0
1.5
1.0
.5
0
SOLENOID
COT
END WALL
HADRON
CAL.
END PLUG EM CALORIMETER
END PLUG HADRON CALORIMETER
n = 1.0
n = 2.0
n = 3.0
30 0
3 0
0
.5
1.0
1.5
2.0
2.5
3.0
m
Inner silicon
6 layers
Intermediate silicon
1 or 2 layers





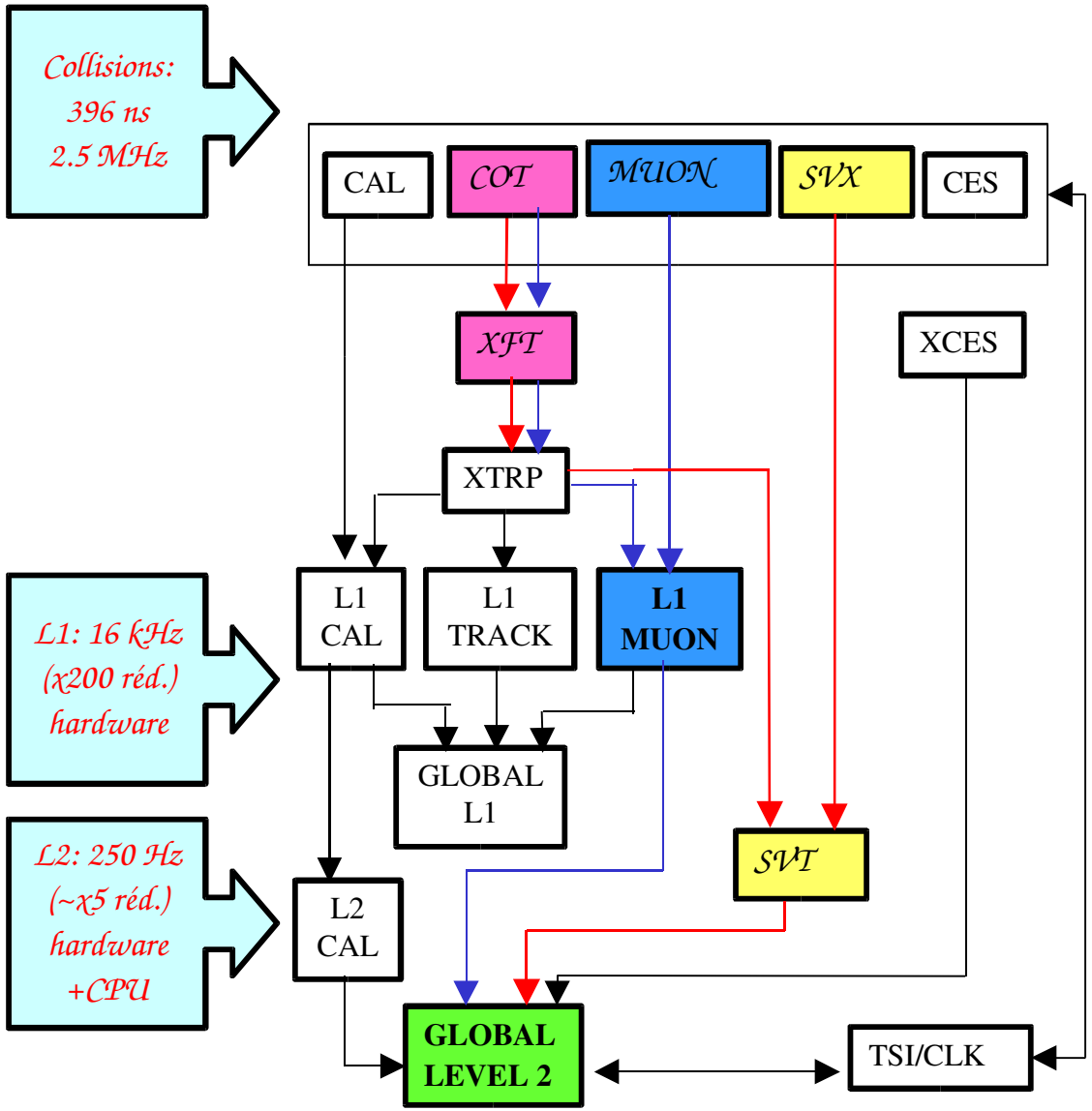
- L00: R ~1.5 cm
- SVX:
  - 5 layers
  - R = 2.5-10.6cm
- ISL: R = 20-28cm
- COT: R to 1.4m

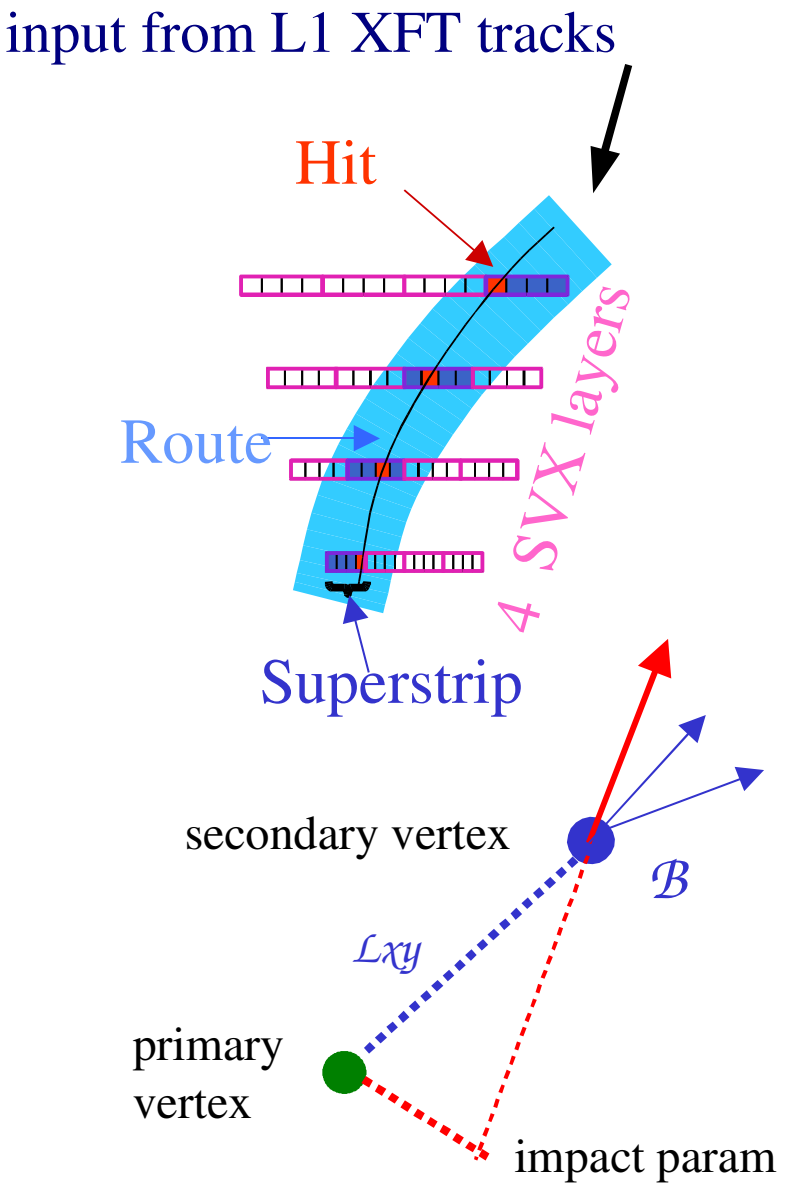


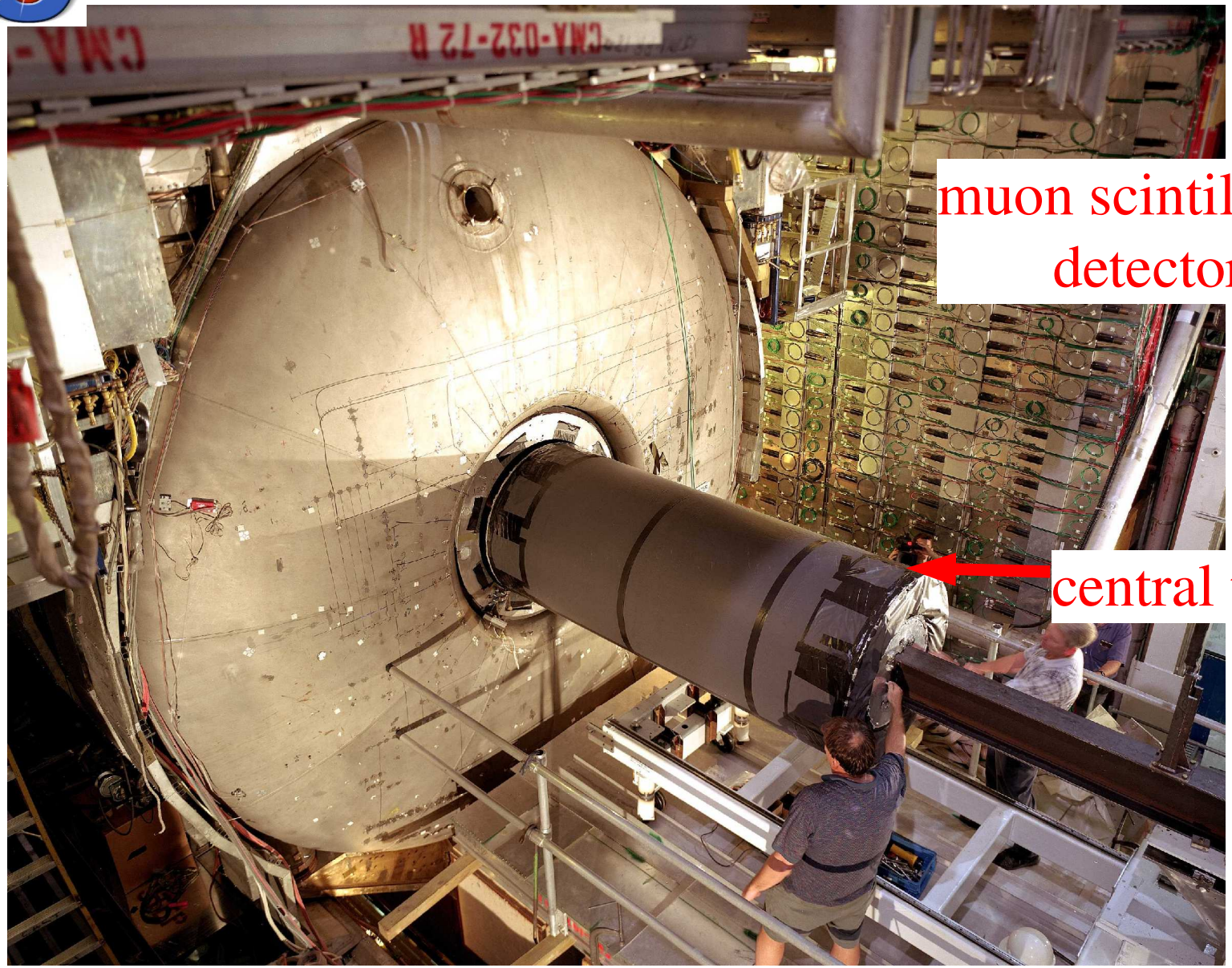


A sophisticated trigger system

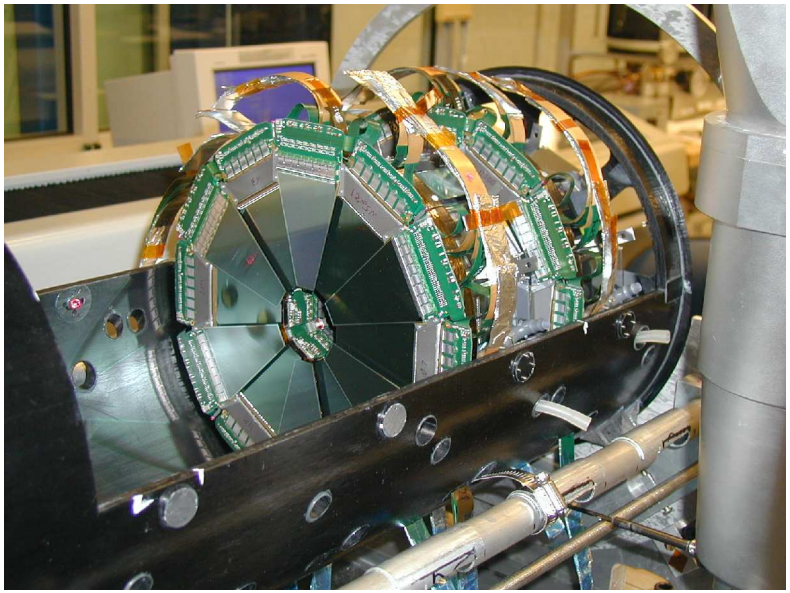
impact parameter track trigger

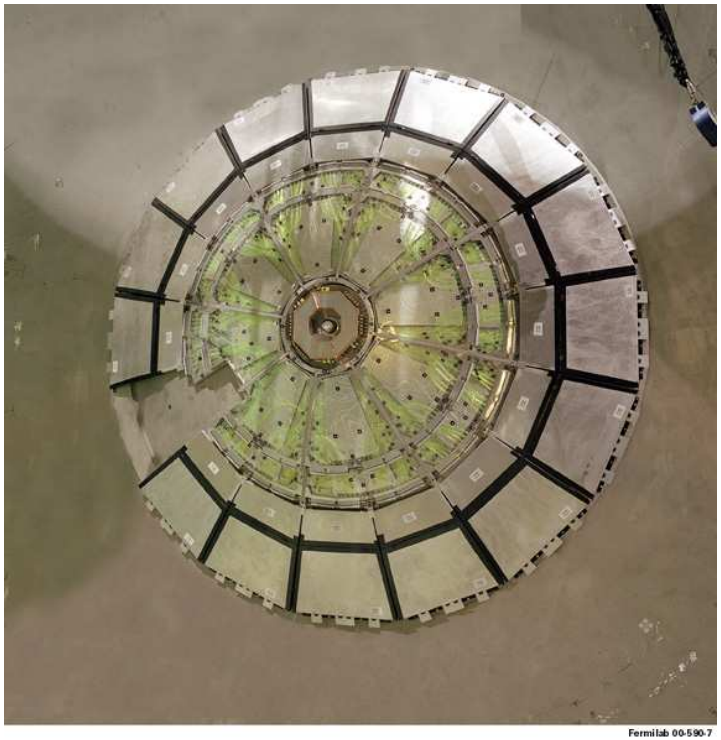





muon scintillator detector
central tracker

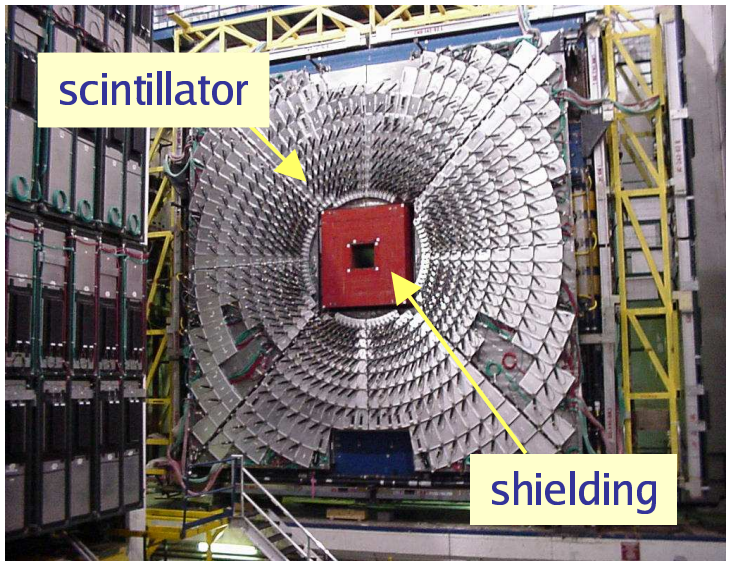
silicon tracker



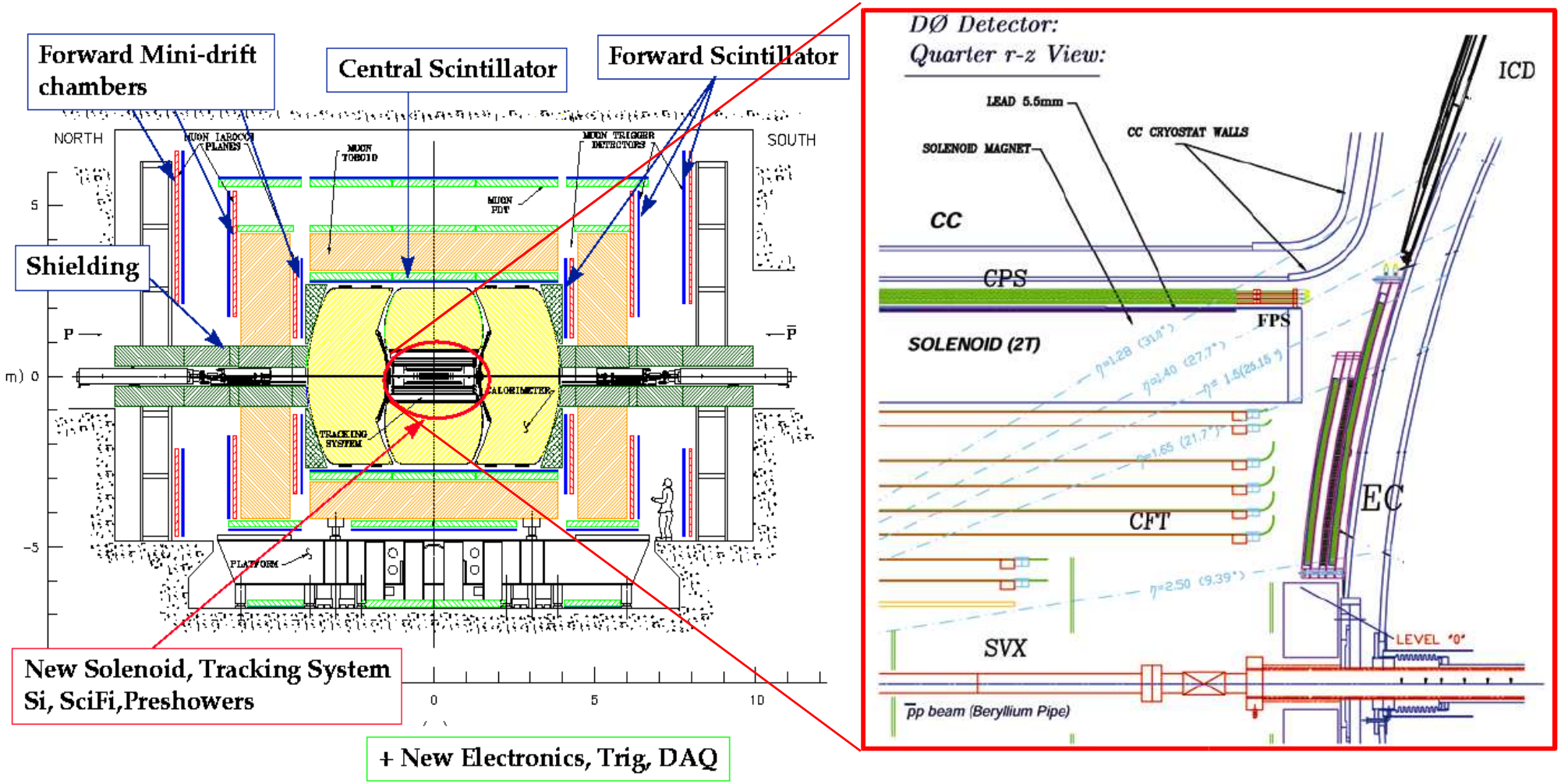


forward preshower

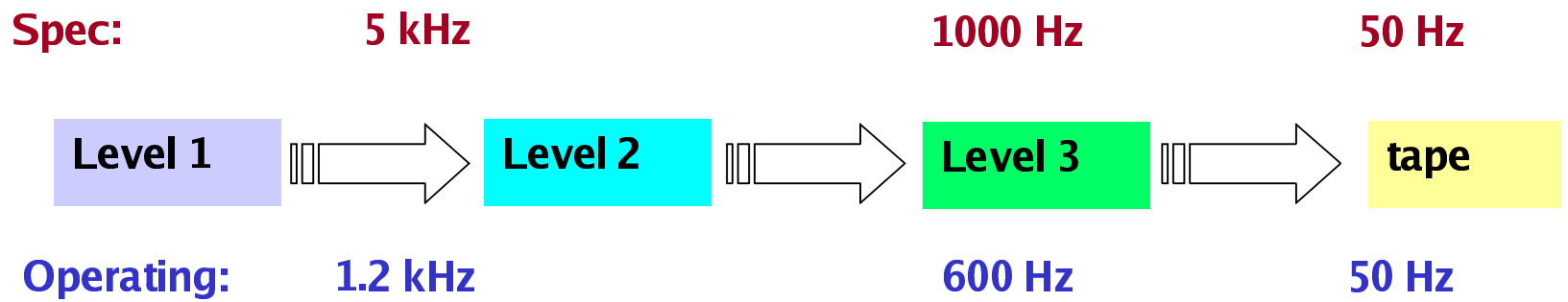
forward muon



DØ upgrade overview



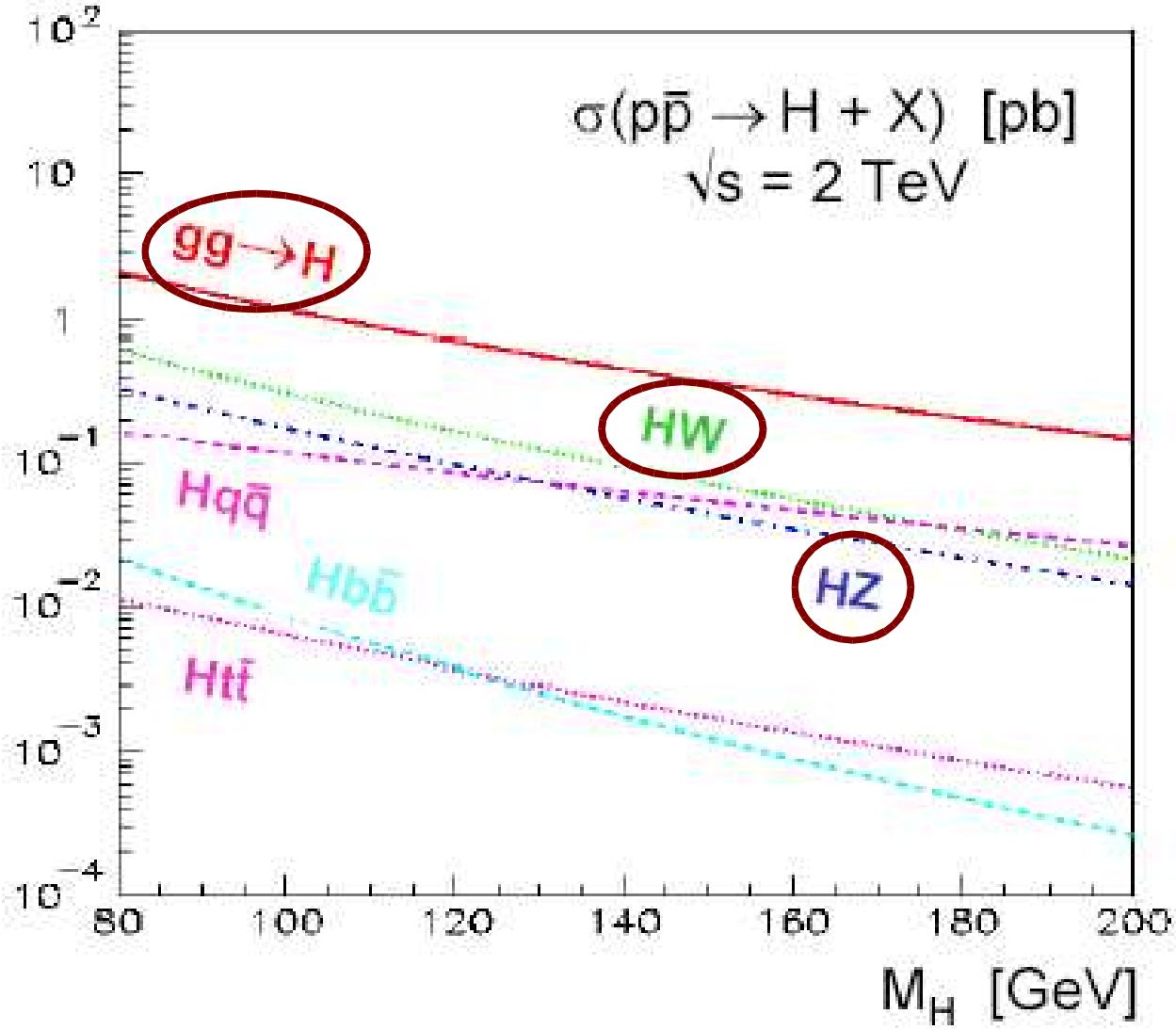
Trigger system



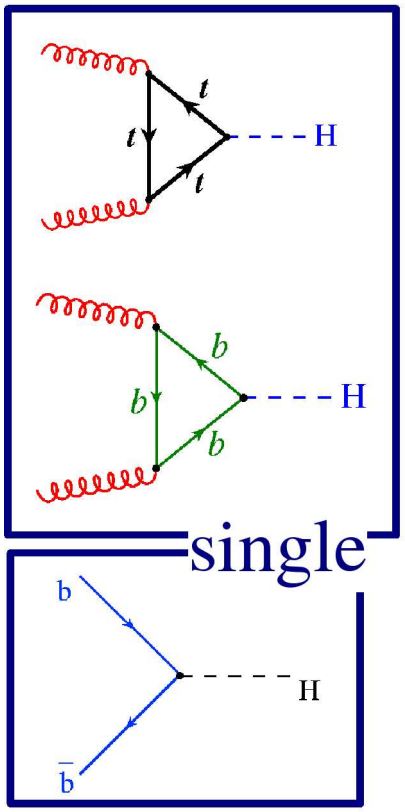
- L1 trigger with central tracker and preshowers being commisionned
  - better triggers for leptons
- L2 track trigger based on impact parameter coming online this summer
  - triggering on b jets

Higgs

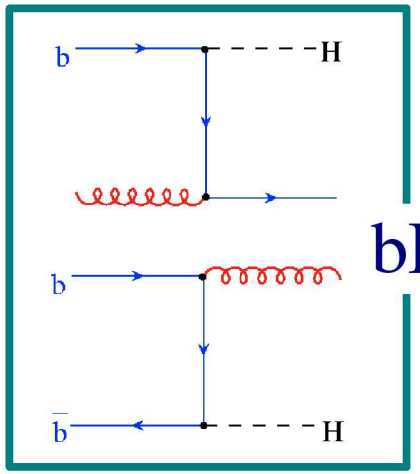
SM Higgs cross-section



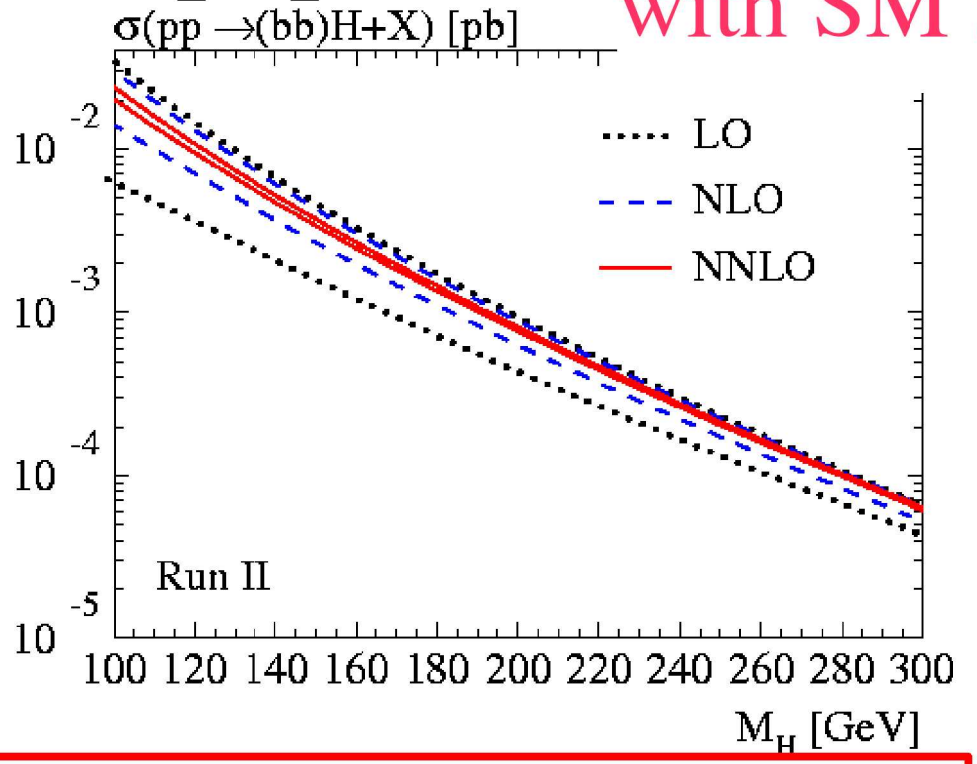
- New calculations of gg → H at NNLO
  - Harlander+Kilgore, Anastasiou+Melnikov, etc
  - ~30% increase in cross-section (NB: differential xsect)
- Other cross-sections relevant for LHC are ususally too small for the TeVatron
- Diffractive Higgs production : cross-section probably too small.
- SUSY:
  - bbϕ : sizeable cross section at large tanβ
  - (b)(b)ϕ (non detectable jet) at large tanβ Harlander + Kilgore....
    - with $\phi \rightarrow \tau\tau$?
  - associated production with SUSY particles: in general small cross-section, relevant for light SUSY partners, e.g. Higgs + stop pair
  - look for H^+ in top decays

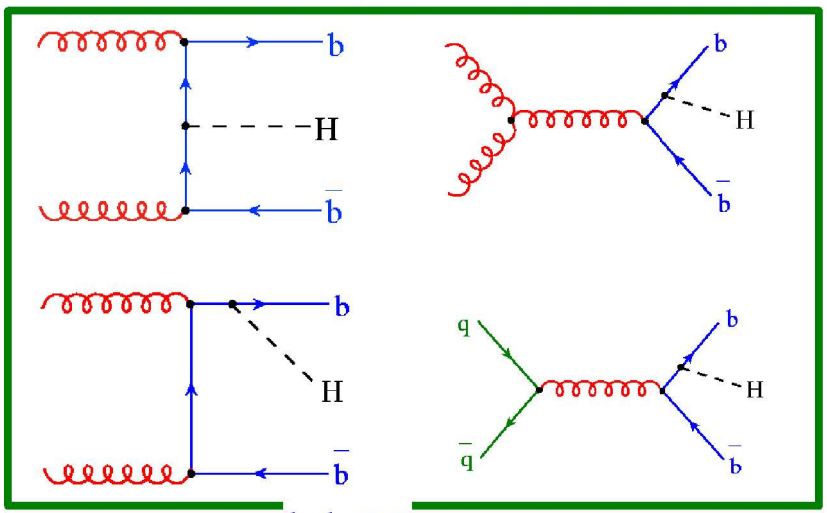


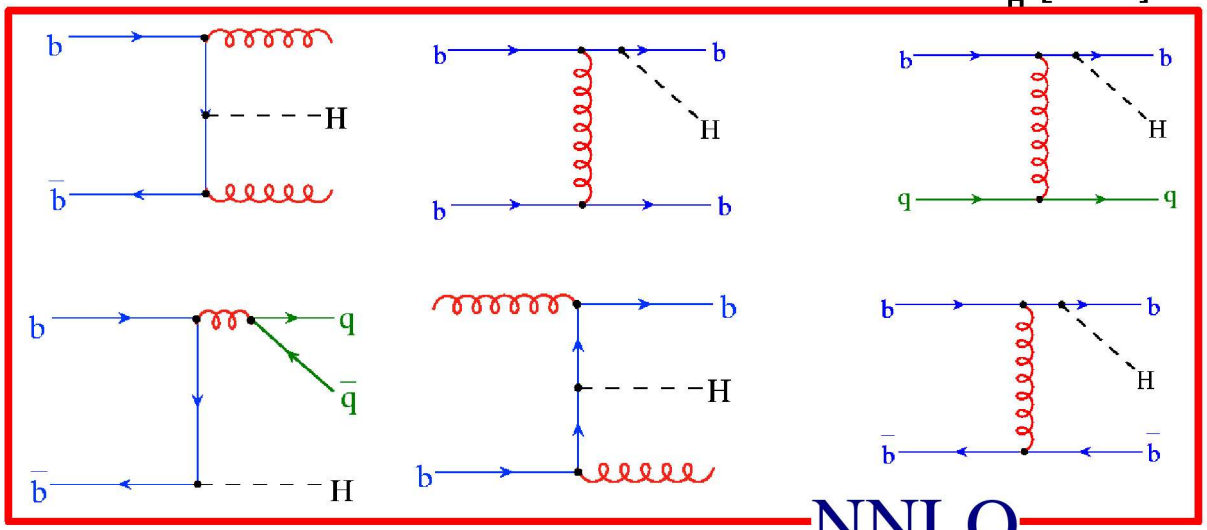
hep-ph 0304035
Harlander+Kilgore



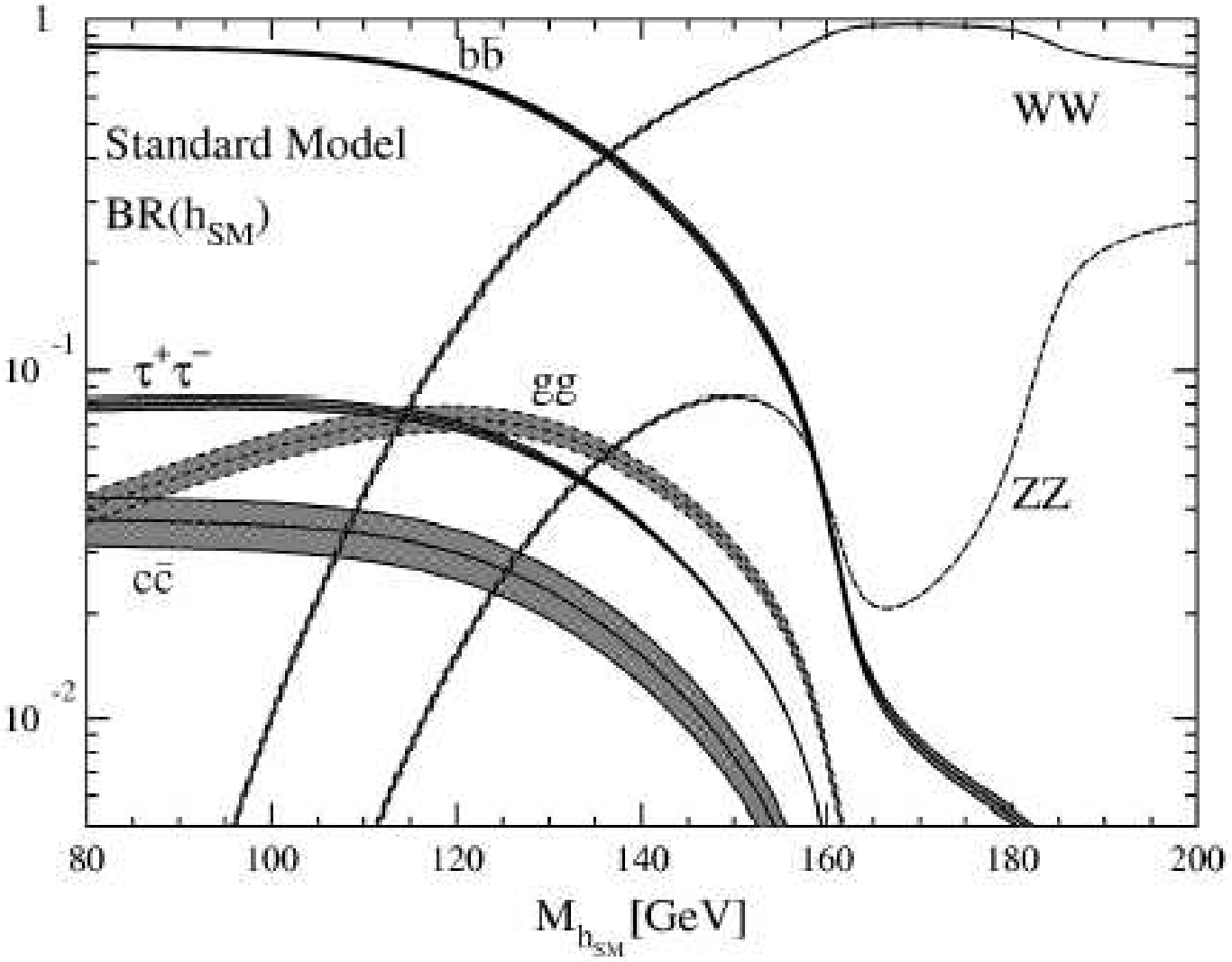
with SM λ_b







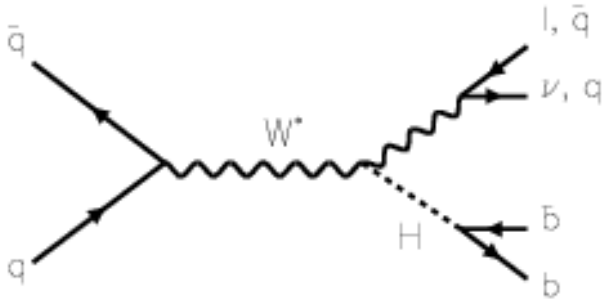
SM Higgs branching ratios

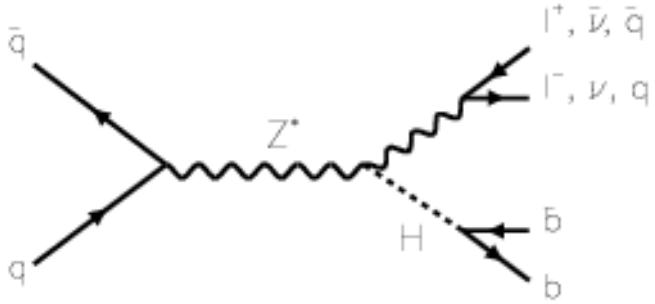


SUSY

- In SUSY, in general, the situation is much more complicated because a number of SUSY particles enter the loops and some may even be light enough to appear in the decays of the Higges.
- Because the reach in mass is limited, the phenomenology is a little simpler at the TeVatron, at least for models with nearly universal soft terms:
  - in the decoupling limit, the phenomenogy is similar to the SM
  - otherwise, we must plan to look for h, H, A and H^+ in the 90 to 200GeV mass region
- In non universal models, there could be decays of Higges to SUSY particles.

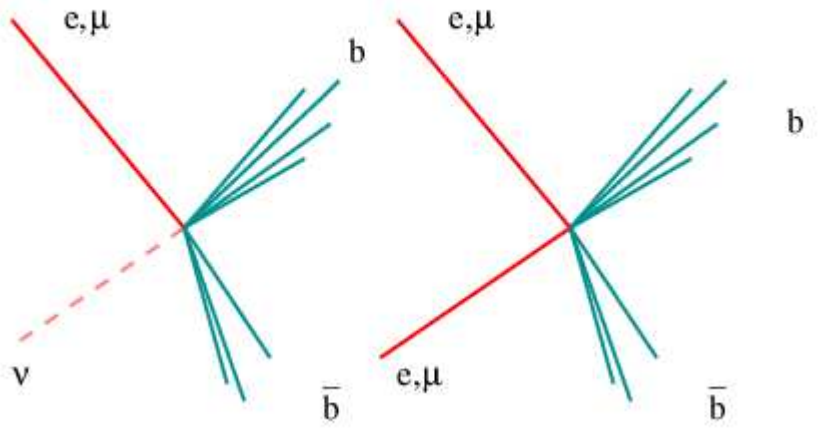
low mass Higgs: WH, ZH production





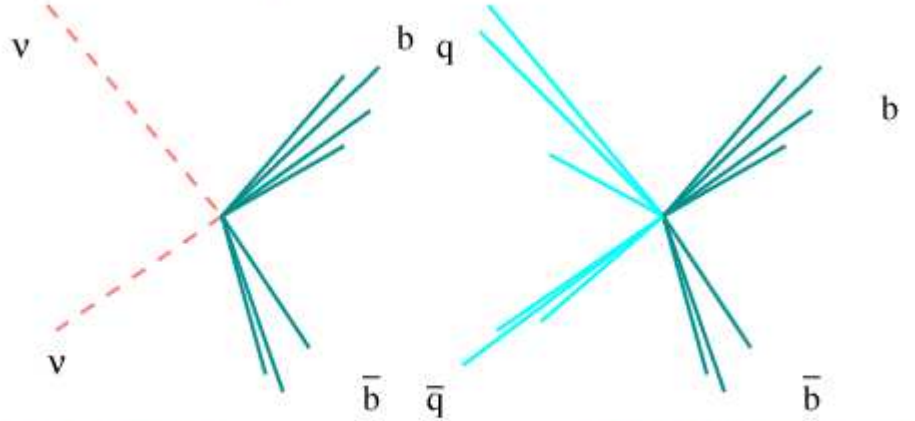
investigate gg → H(+jet) with
H → $\tau\tau$

Topologies:



BG: $Wb\bar{b}, t\bar{t}, WZ, t\bar{b}, tbq$

BG: $Zb\bar{b}, t\bar{t}, ZZ, t\bar{b}$

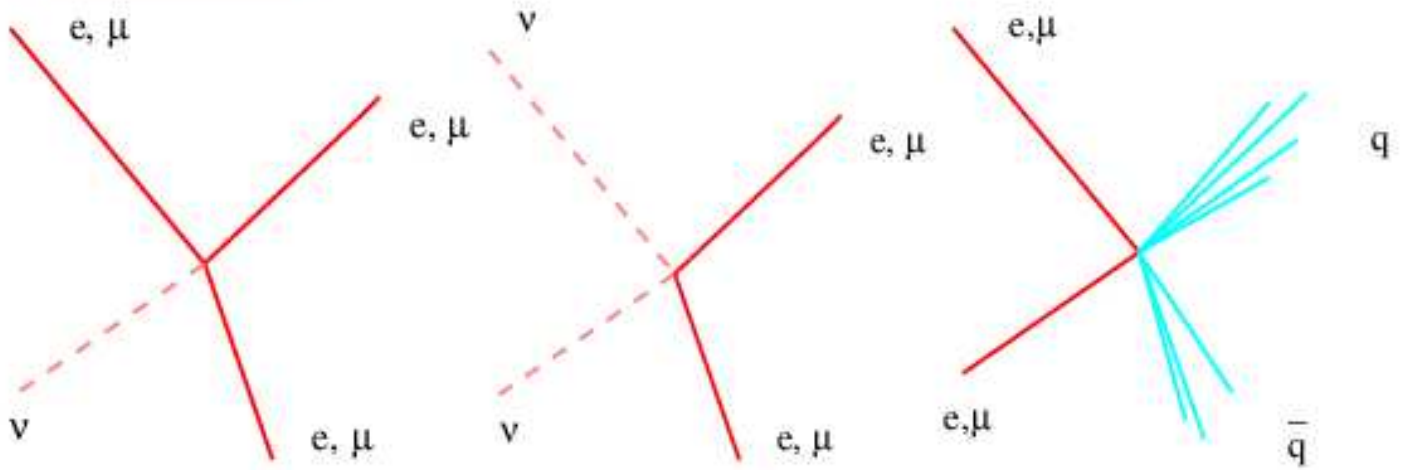


BG: $Zb\bar{b}, t\bar{t}, ZZ, t\bar{b}$

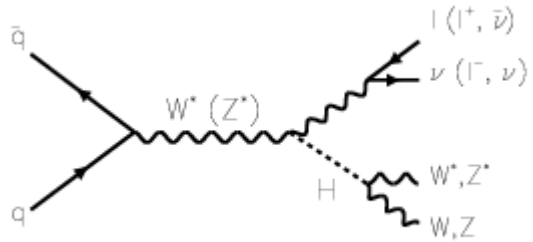
BG: QCD multijets

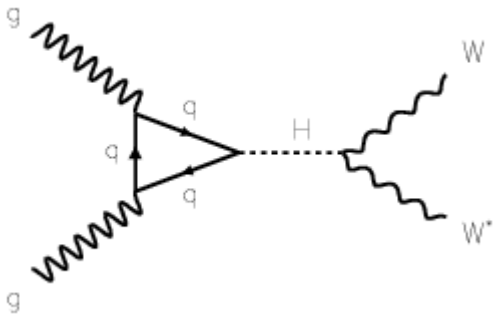
High mass Higgs

Topologies:

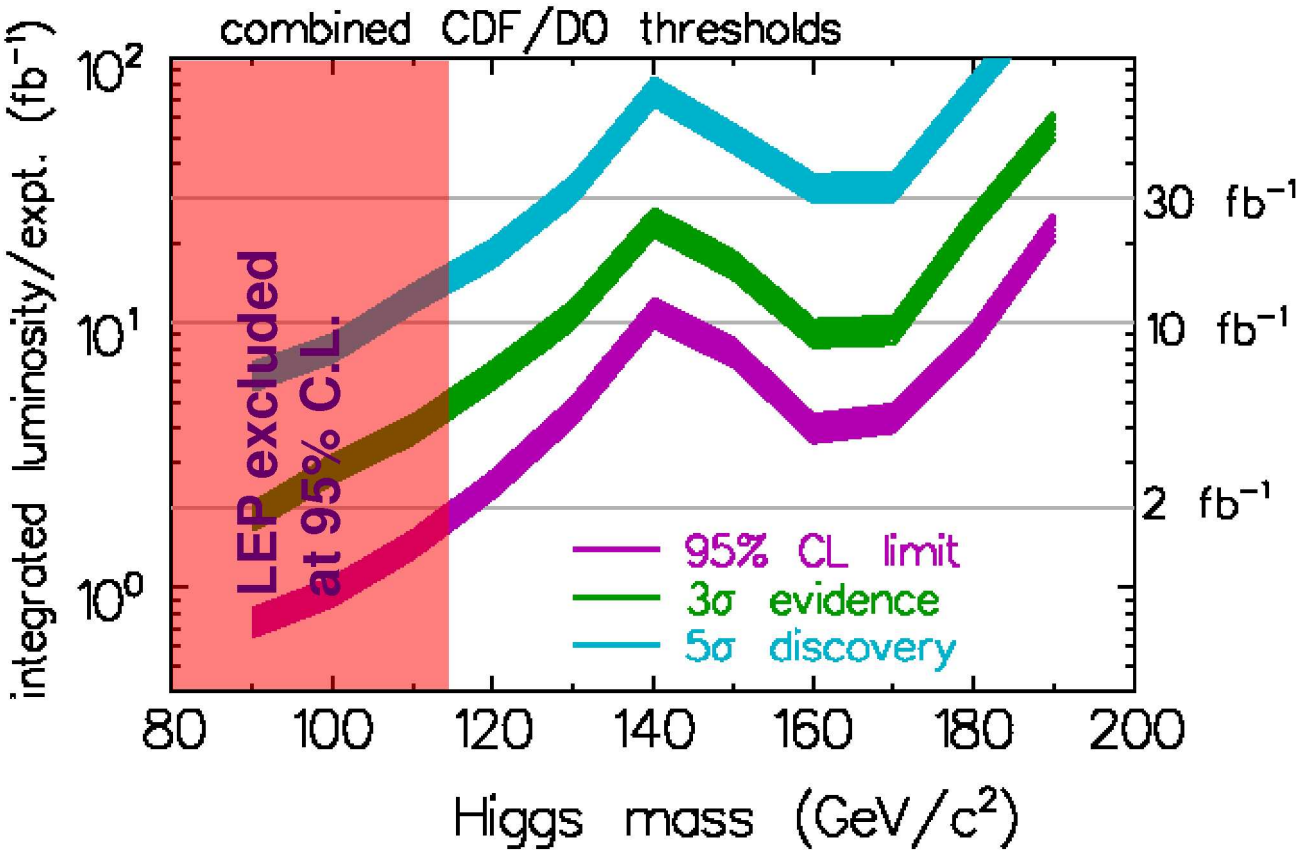


BG: WZ, WW, ZZ $WW, t\bar{t}, WZ, ZZ$ $WW, WZ, ZZ, t\bar{t}, W/Zjj$



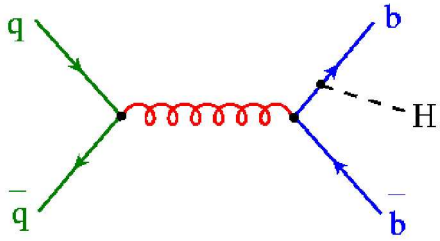


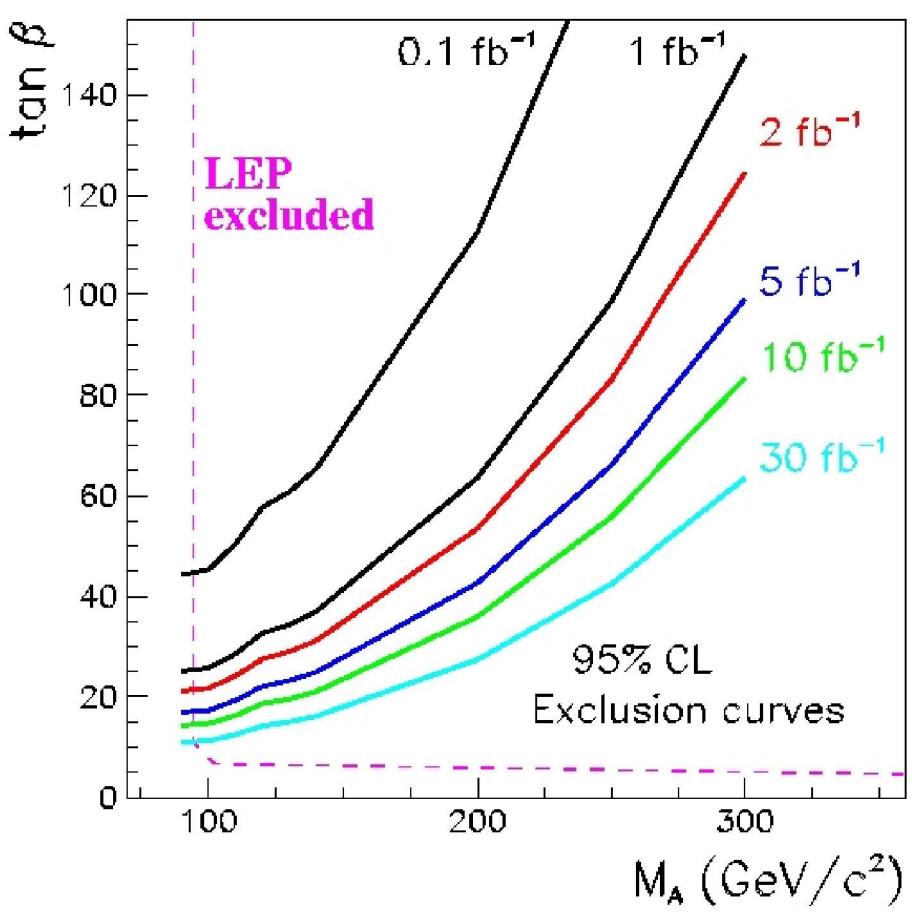
predictions from 1998

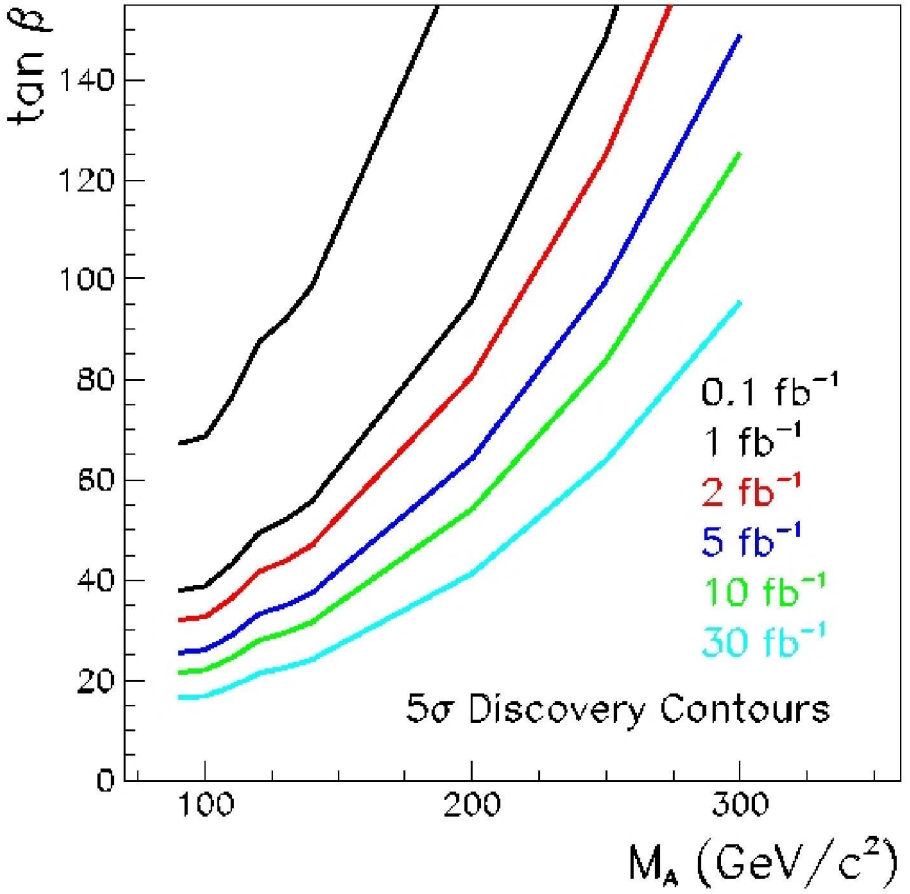


CDF and D0 are re-investigating the Higgs reach in some of the channels, with results expected in June

SUSY : bbA production



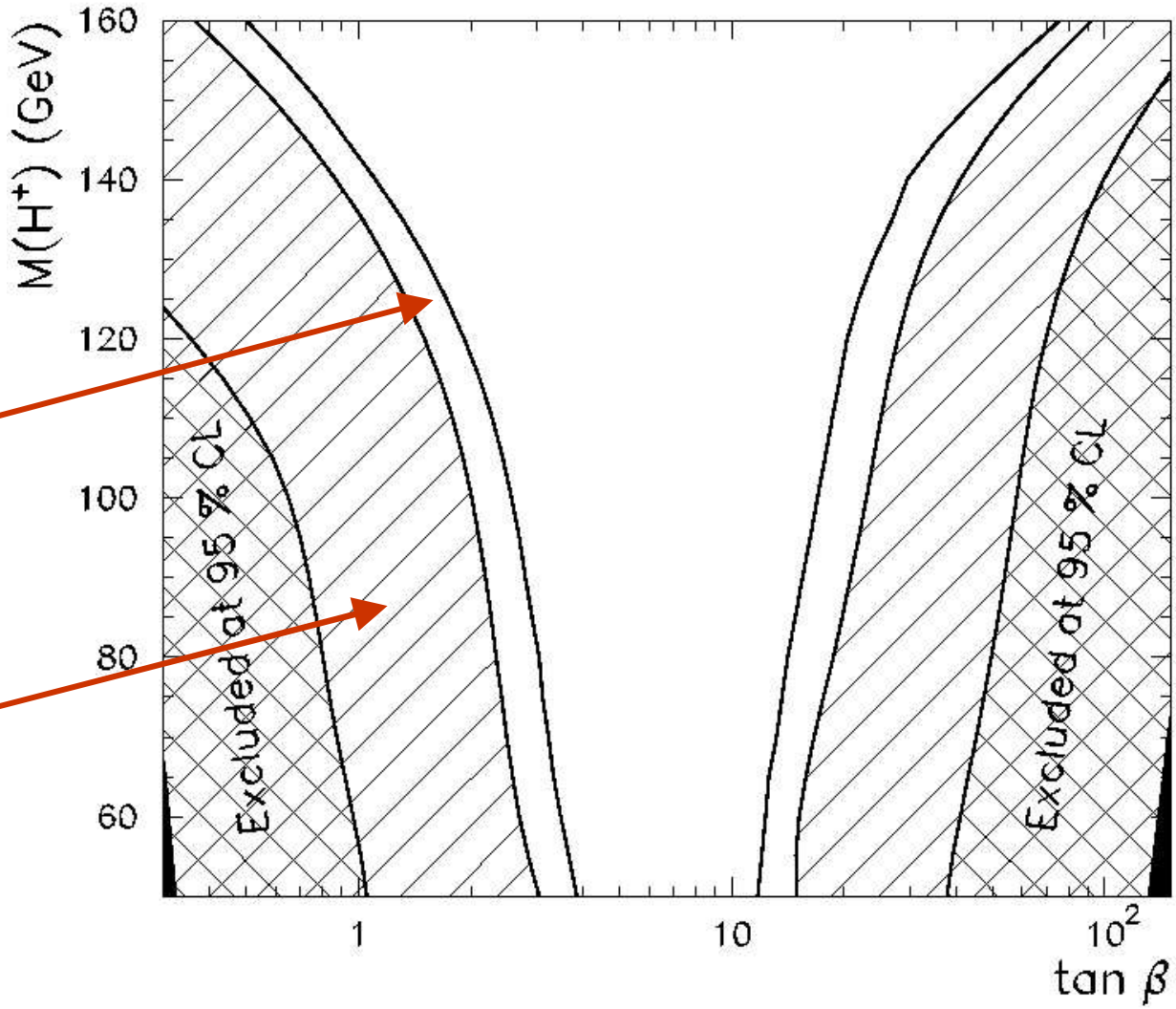




Charged Higgs in top decays

10 fb-1

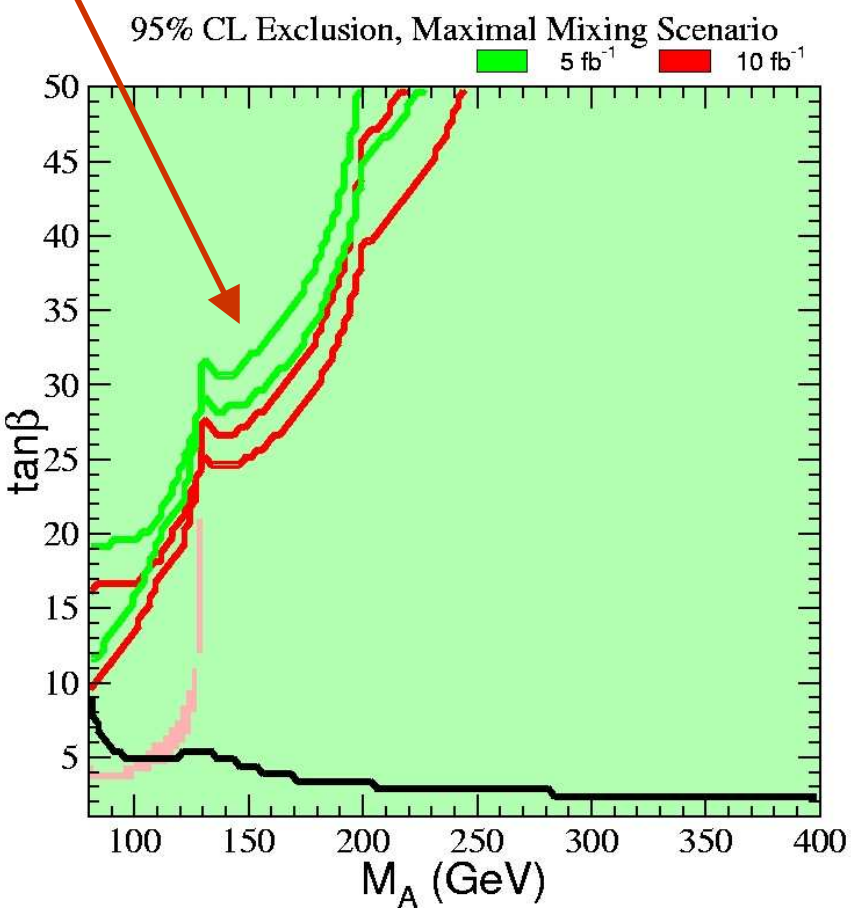
2 fb-1

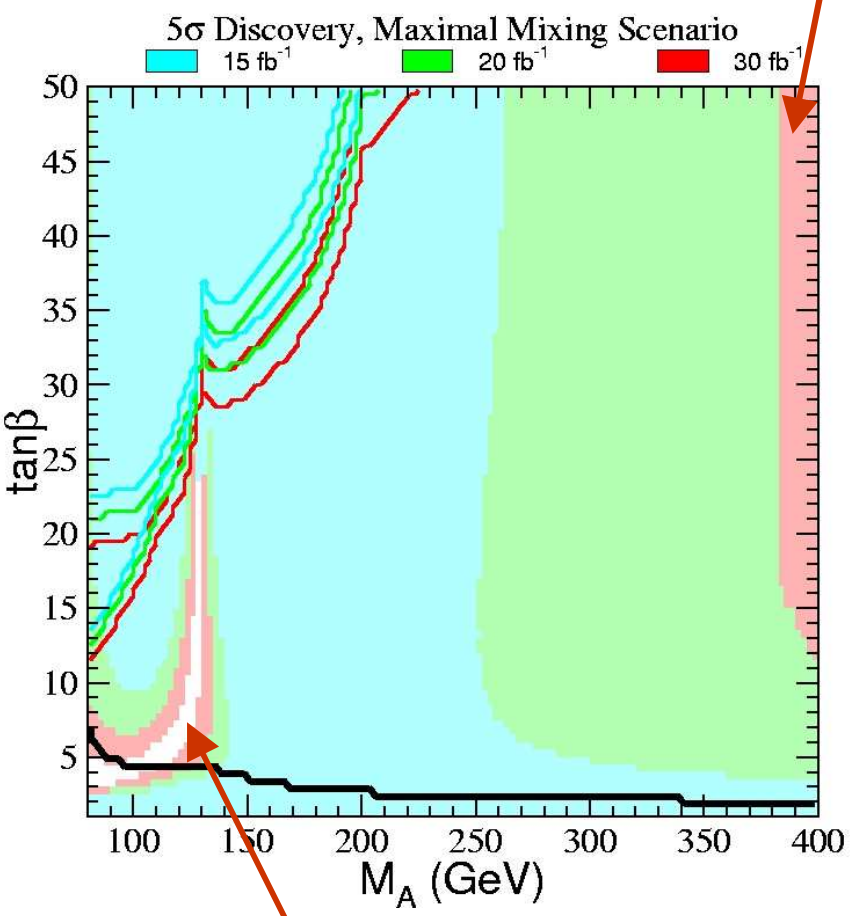


SUSY Higgs

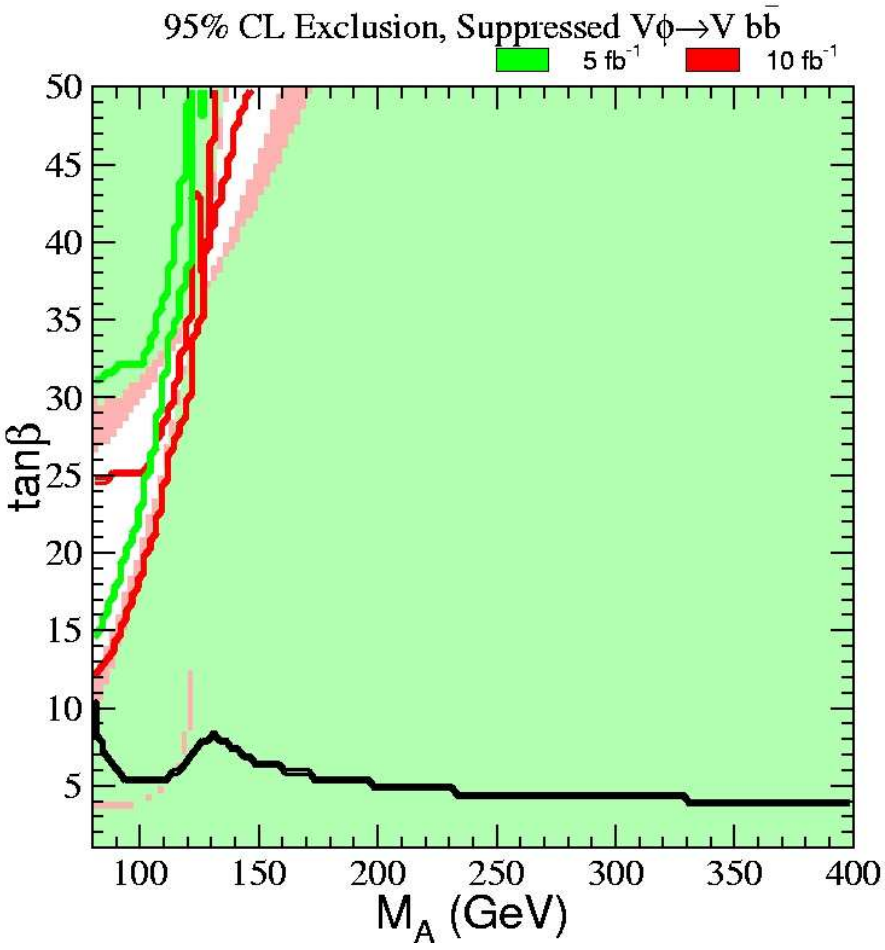
bbϕ production

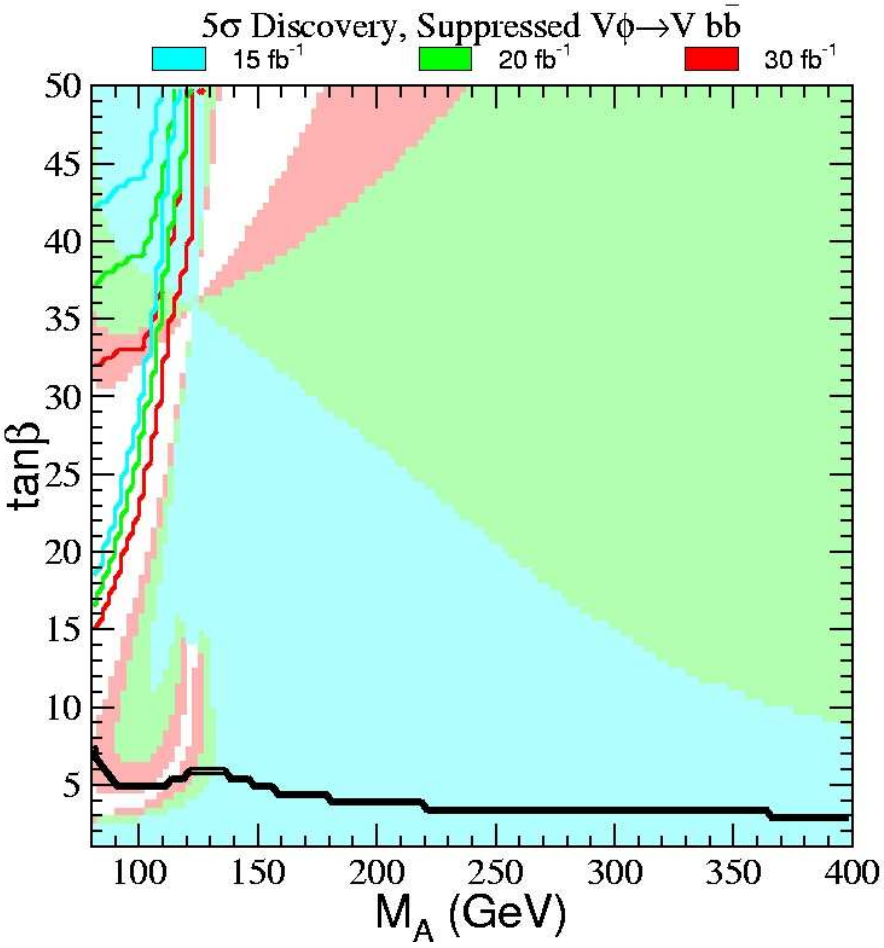
"heavy" SM-like h



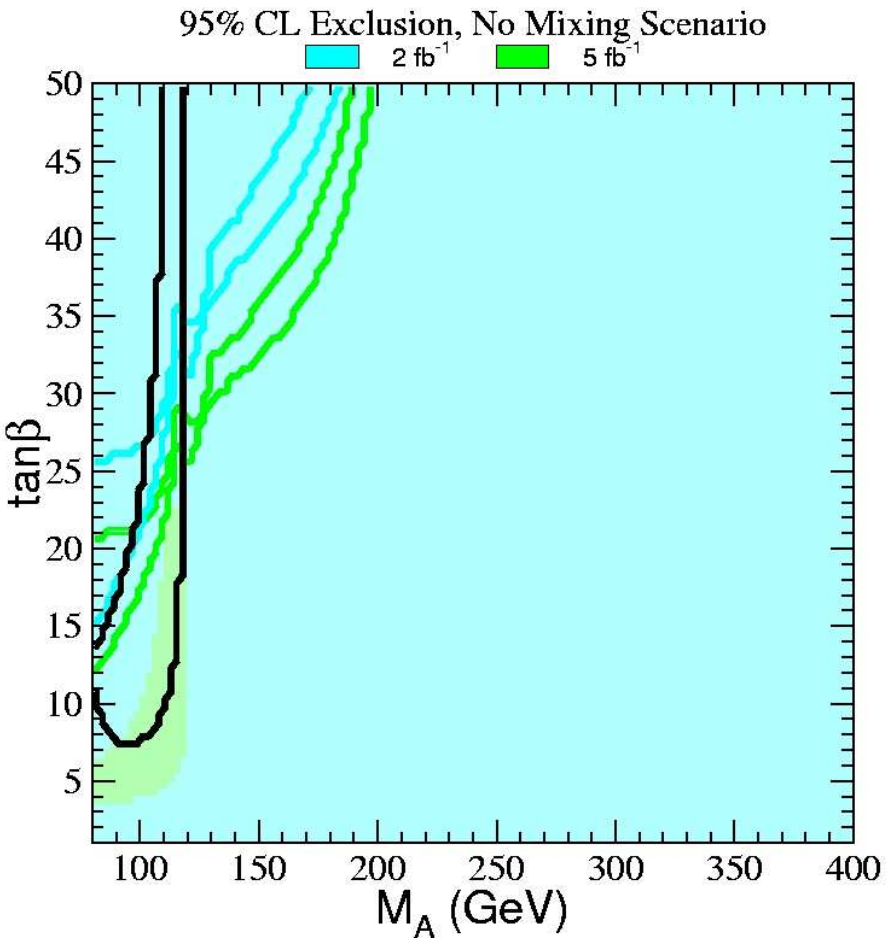


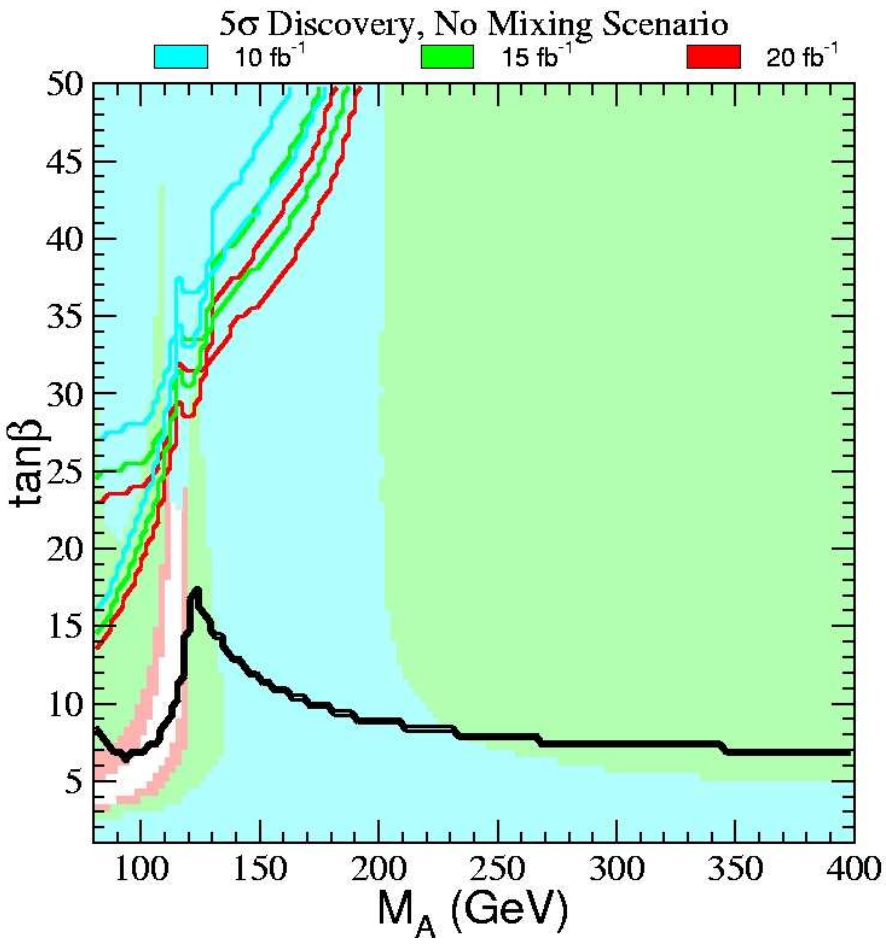
maximal mixing





suppressed bb coupling


95% CL Exclusion, No Mixing Scenario
2 fb-1
5 fb-1
tanβ
M_A (GeV)


5σ Discovery, No Mixing Scenario
10 fb-1
15 fb-1
20 fb-1
tanβ
M_A (GeV)

no mixing

What we need to get there...

low mass

- b tagging (performance, angular coverage)
- bb mass resolution
- analyze all channels....
  - some of them are very challenging
- and combine them and the two experiments in a clever way

high mass

- lepton identification
  - taus ?
- few handles to separate from background
  - optimized combination of variables
- no mass peak so.....

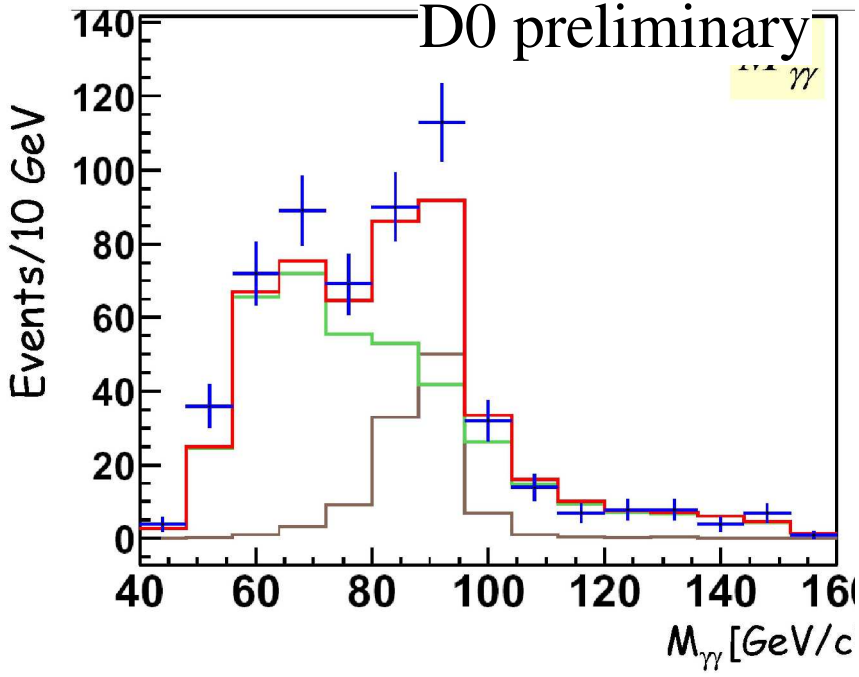
good control and understanding of the backgrounds

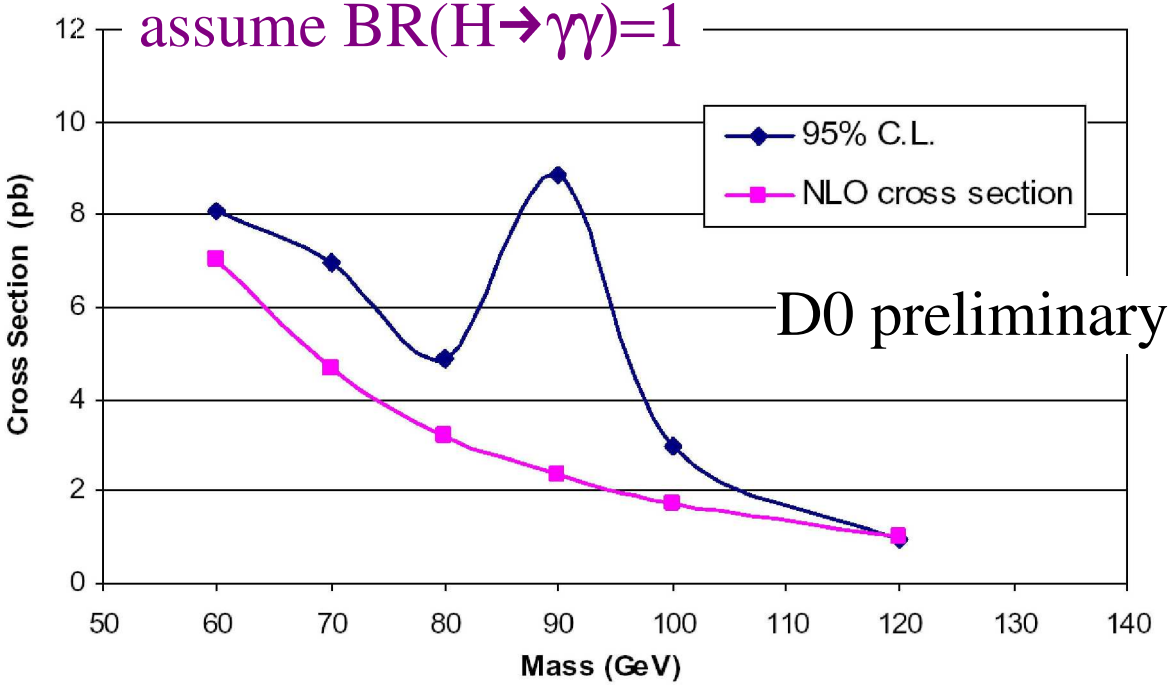
Where are we ?

- We have a limited statistics (less than Run I) but data is coming in quickly
- We need to develop the basic tools
  - efficient lepton ID, including taus
  - tracking and b tagging
  - understanding of jet measurement, energy resolution, mass resolution
- We need to measure the background and compare with prediction
  - a long process, we need to start now
  - in some sense we need to get the analyses on their way, even if the goal is to measure the background, not (yet) look for the Higgs

gg → H → γγ

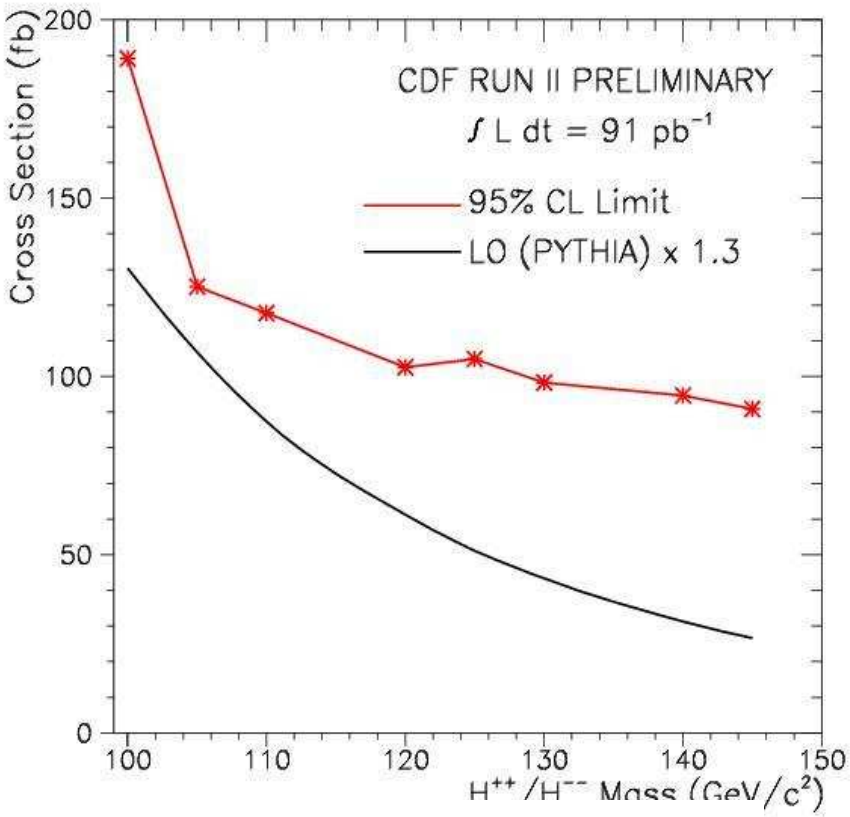
- integrated luminosity 51.8 pb^{-1}
- standard photon ID + mass window around Higgs mass
- background : Drell-Yann and QCD
- at TeVatron, meaningful for "exotic models", e.g. fermiophobic Higgs

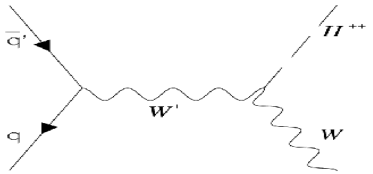


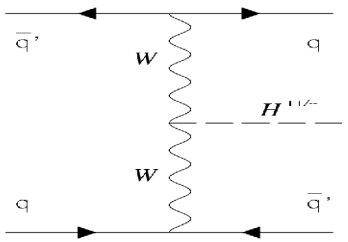


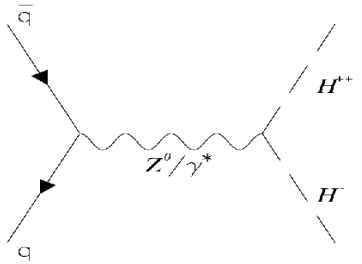
$H^{++} \rightarrow e^+ e^+$

- look for same sign di-electron events
  - define mass 10% mass window
  - signal region above Z mass :M>100
  - control region M<80
- very low background ~0.6 evt in 91pb^{-1}
  - W/Z + fake e
  - WZ
  - Drell-Yann + wrong sign







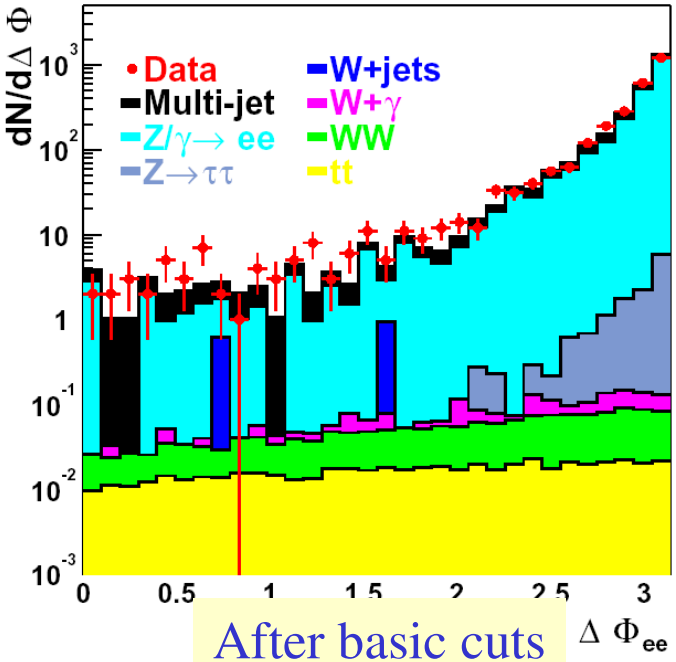


H→WW* →eeνν

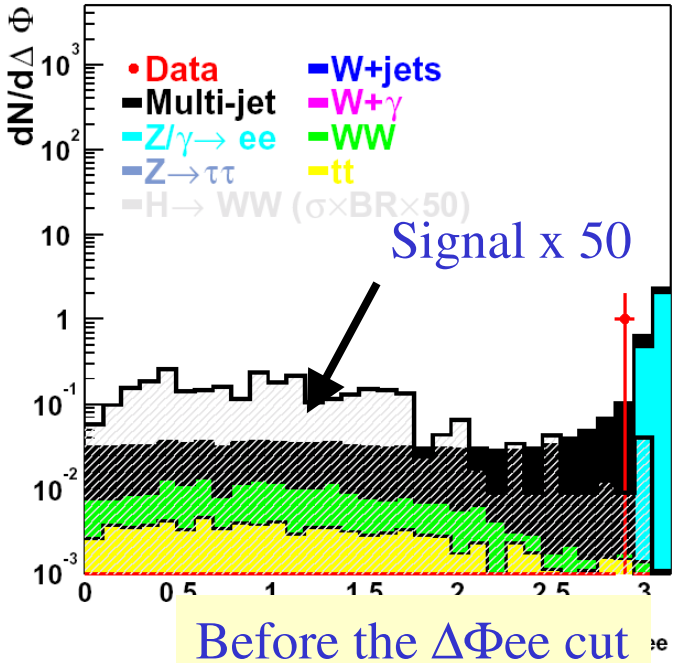
~44.5 pb^{-1}

Selection optimized for $m_H = 120$ GeV

Event selection	Expected background	DATA
Lepton ID, p_T>10, 20 GeV	2748 ± 42 ± 245	2753
$m_{ee} < m_H/2$	264 ± 18.6 ± 4.3	262
Missing E_T > 20 GeV	12.3 ± 2.5 ± 0.7	11
$m_T < m_H + 20$ GeV	3.6 ± 1.4 ± 0.2	1
Spin correlation → $\Delta\Phi_{ee} < 2.0$	0.7 ± 1.4 ± 0.1	0



After basic cuts



Before the ΔΦee cut

also in
$e\mu\nu\nu$
$\mu\mu\nu\nu$

still far from constraining models

W+dijet studies as bkg for (W→lν)(H →bb)

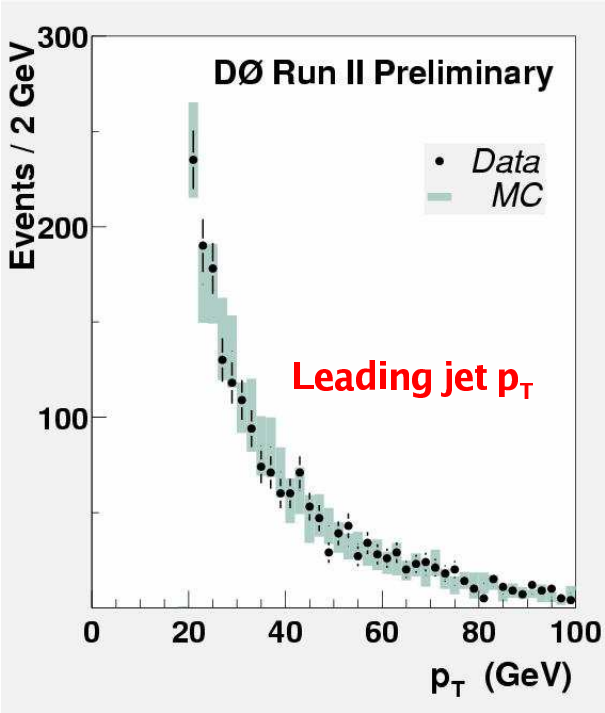
Select events with

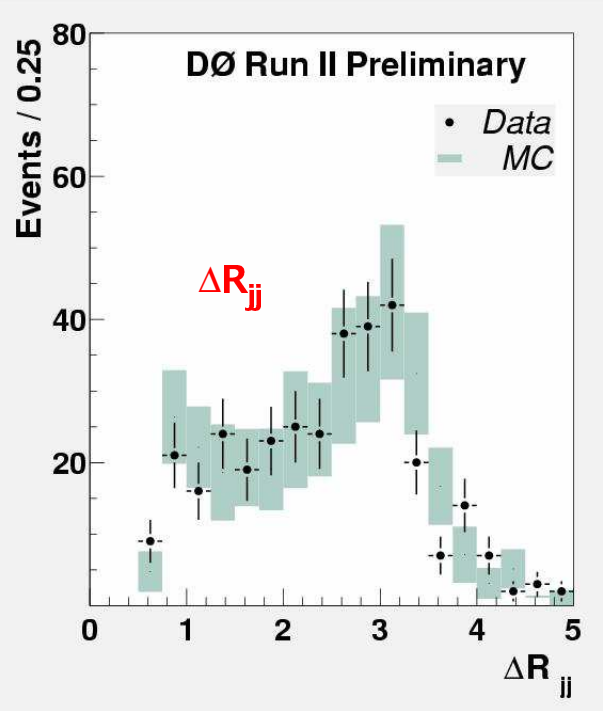
- an isolated high p_T lepton (e or μ)
- large missing E_T

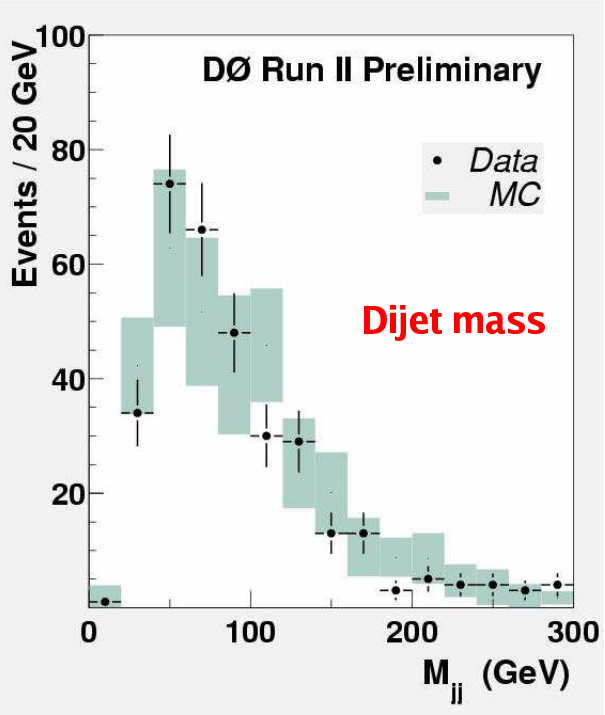
and investigate jet properties

similar studies in Z+dijet

MC : Pythia & Alpgen







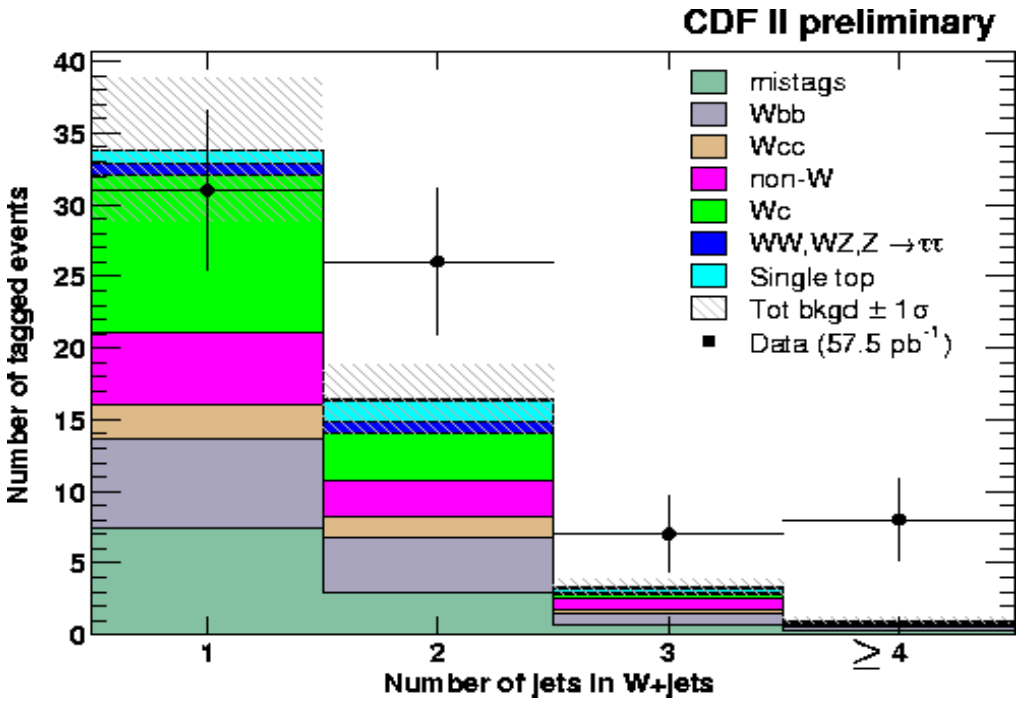
Errors include statistical and systematic error from Jet Energy Scale

b content in W+jets

Jet Multiplicity in b-tagged W+jets events

CDF Run II Preliminary

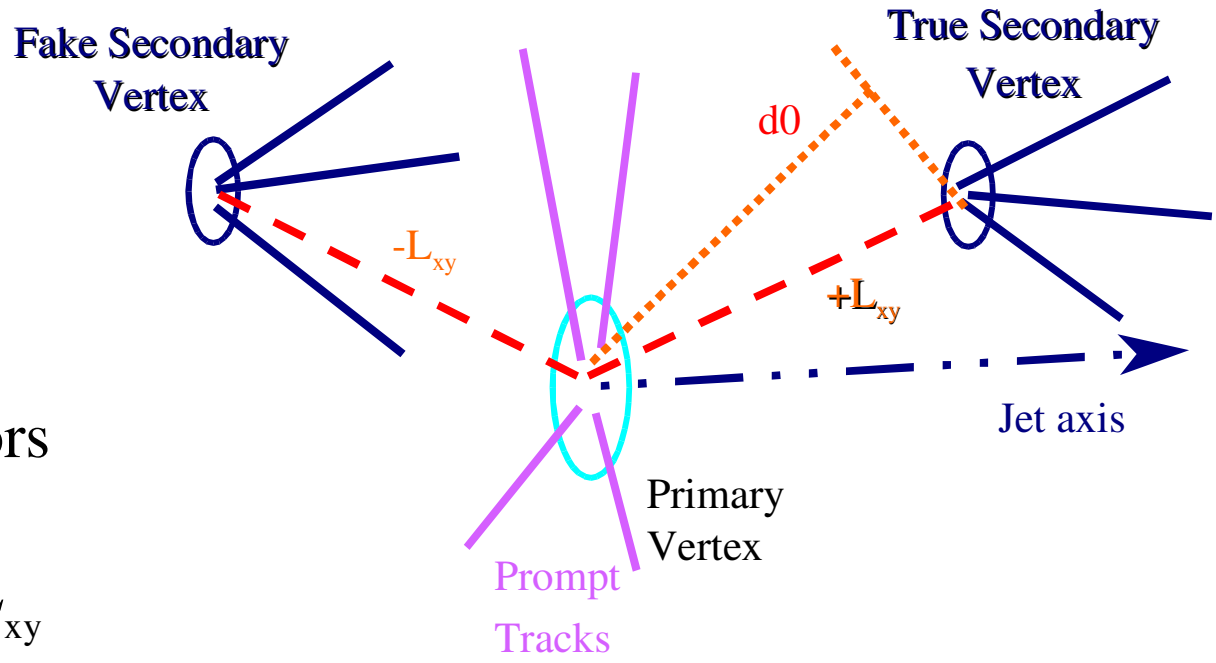
15 Candidates in ~ 57.5 pb^{-1}



Source	W+ 1jet	W+ 2jets	W+ 3jets	W+ ≥4jets
Background	33.8±5.0	16.4±2.4	2.9±0.5	0.9±0.2
SM Bkgnd + $t\bar{t}$	34.0±5.0	18.7±2.4	7.4±1.4	7.6±2.0
Events before tagging	4913	768	99	26
Events after tagging	31	26	7	8

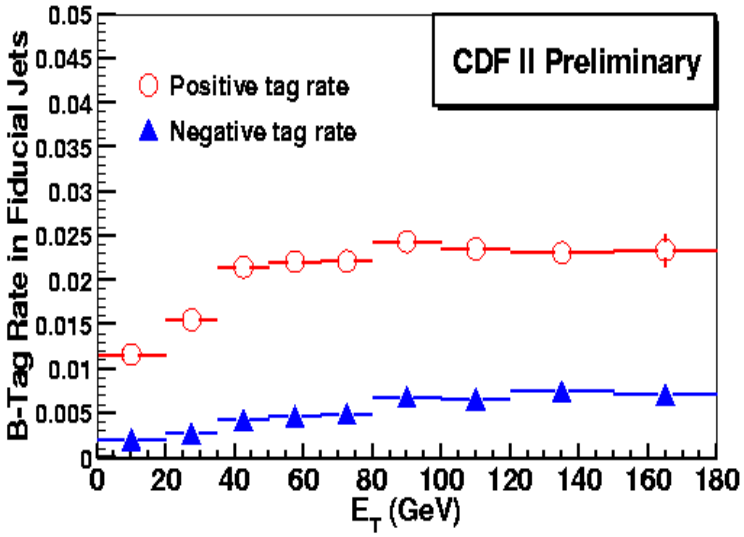
b tagging at CDF

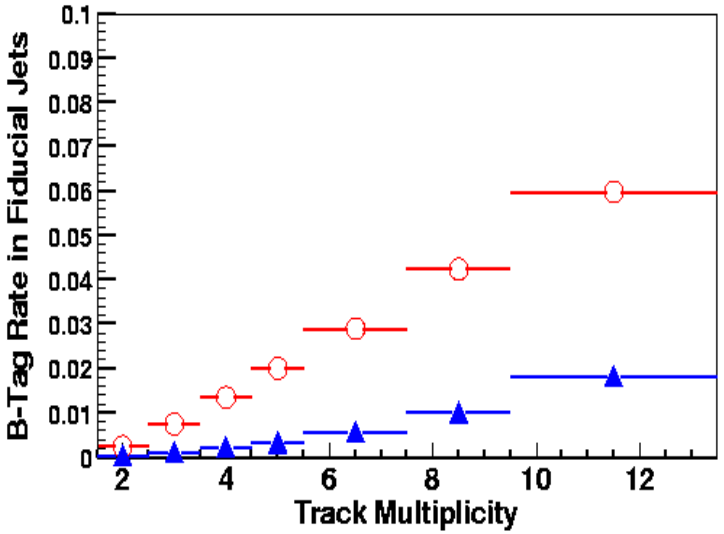
- B hadrons travel L_{xy} ~ 3 mm before decay: tag with displaced vertices
- algorithm:
  - look for vertices in 2 track combinations
  - jet is tagged if $L_{xy}/\sigma_{xy} > 3$ (typical σ_{xy} ~150μm)

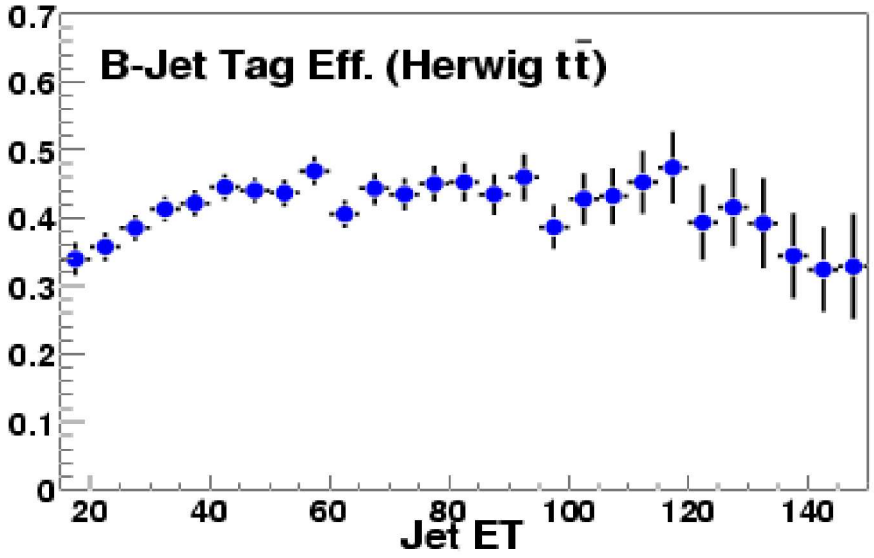


mistag from u/d/s
- resolutions
- pattern recognition errors
- etc

- measure using negative L_{xy}







- The performances are already at the level of those of the CDF Run I algorithm
- Many improvements on the way
  - using inner and outer Si layers
  - 3D algorithms
  - ....
- The performances are similar to those conjectured in the 1998 Higgs workshop

SUSY

Cross-sections at the TeVatron

Arrows correspond to:

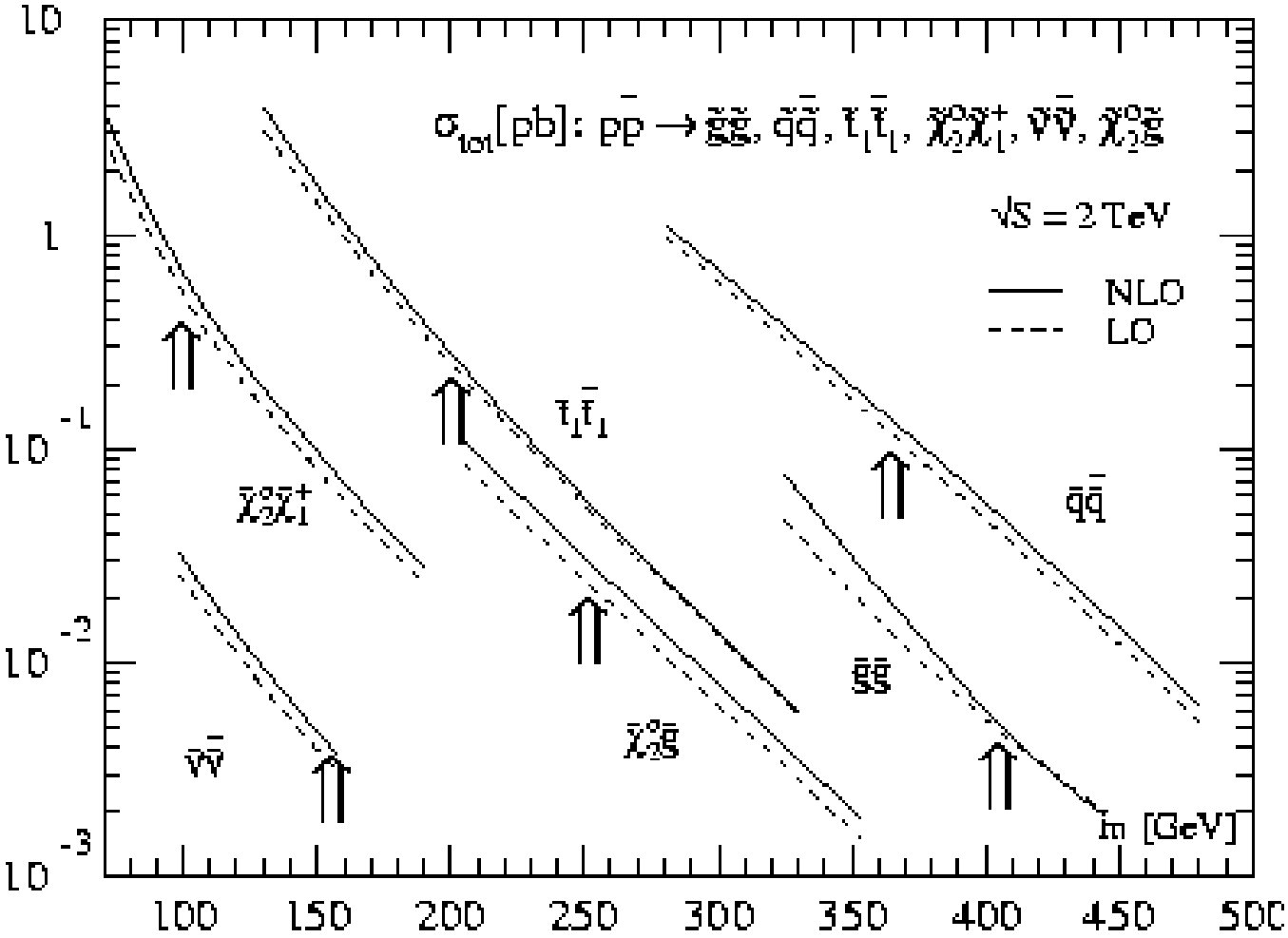
m_1/2 = 150 GeV

m_0 = 100 GeV

A_0 = 300 GeV

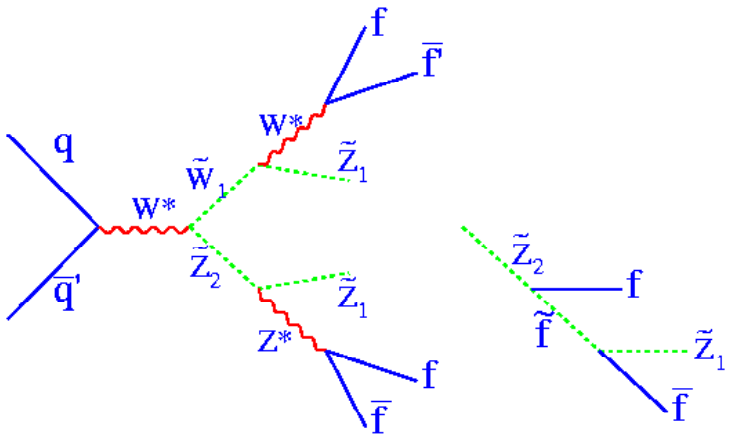
tanβ = 4

μ > 0



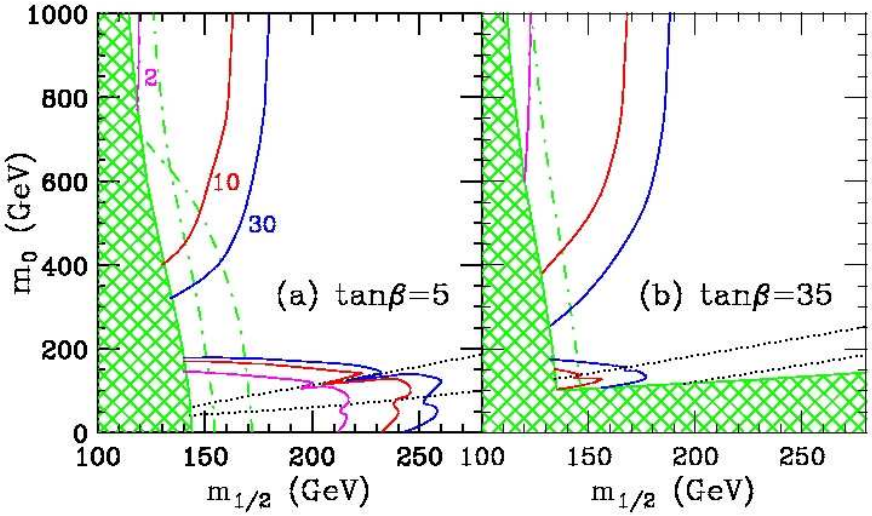
- There have been more recent work on calculating NLO corrections to cross-sections, not reviewed here
- The main channels for gravity mediated SB are
  - chargino neutralino production: trilepton, very clean but needs large luminosity
  - squarks and gluinos in general, stop and sbottom in particular
  - but keep on eye on other channels like gluino-gaugino production,
  - given the constraints from LEP, must look at non universal scenarios
- Other SUSY models considered: RPV, GMSB, etc
- I won't talk about Run I results, but there have been a number of recent results with significant improvements : it shows that optimizing the analyses is a long process and making predictions is difficult.

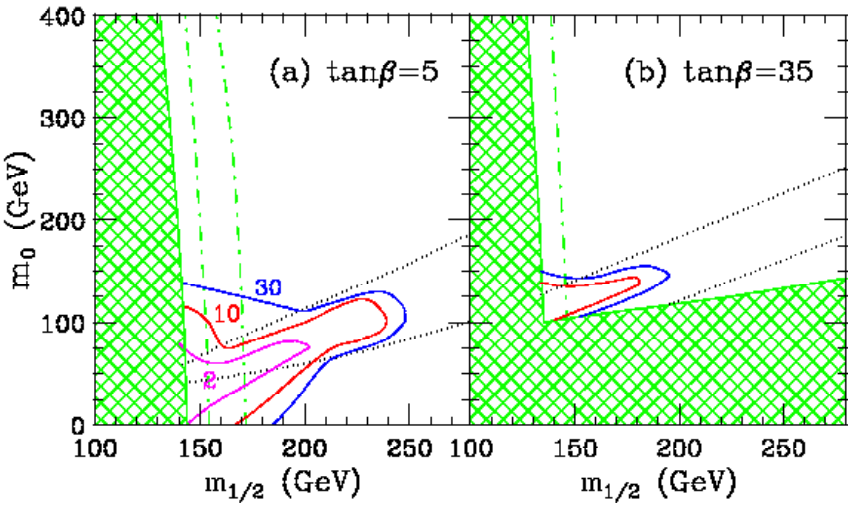
trileptons



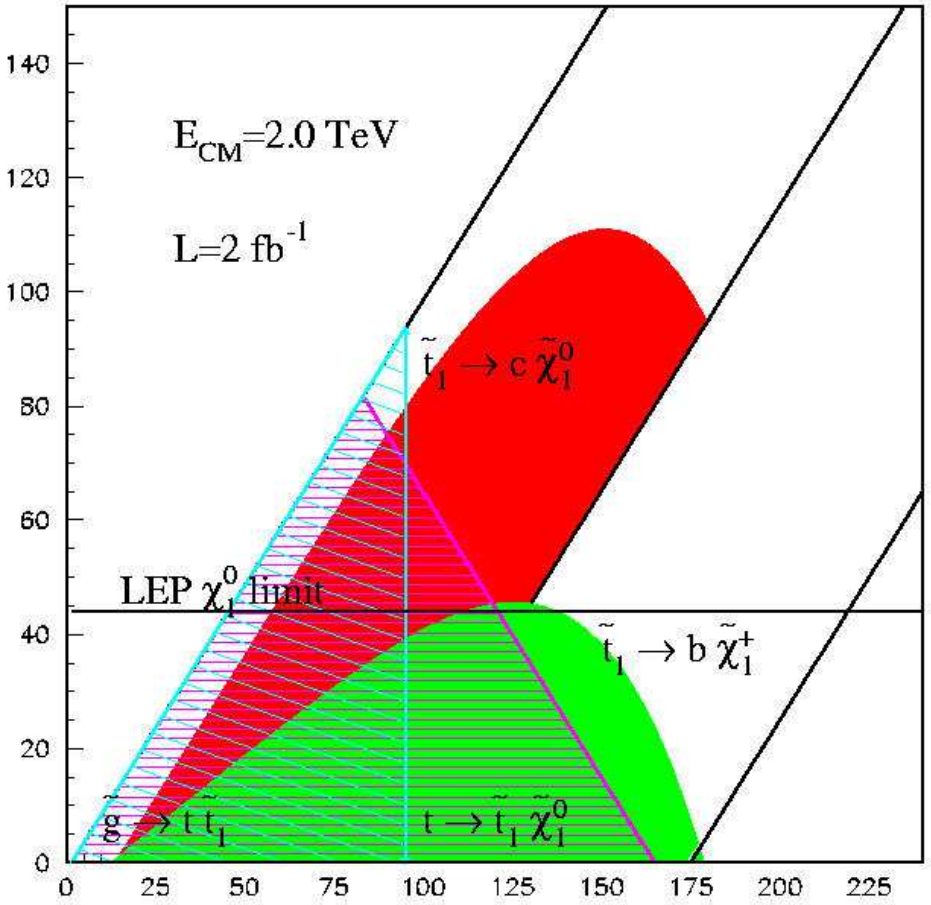
Wino–Zino production and decays in Tevatron

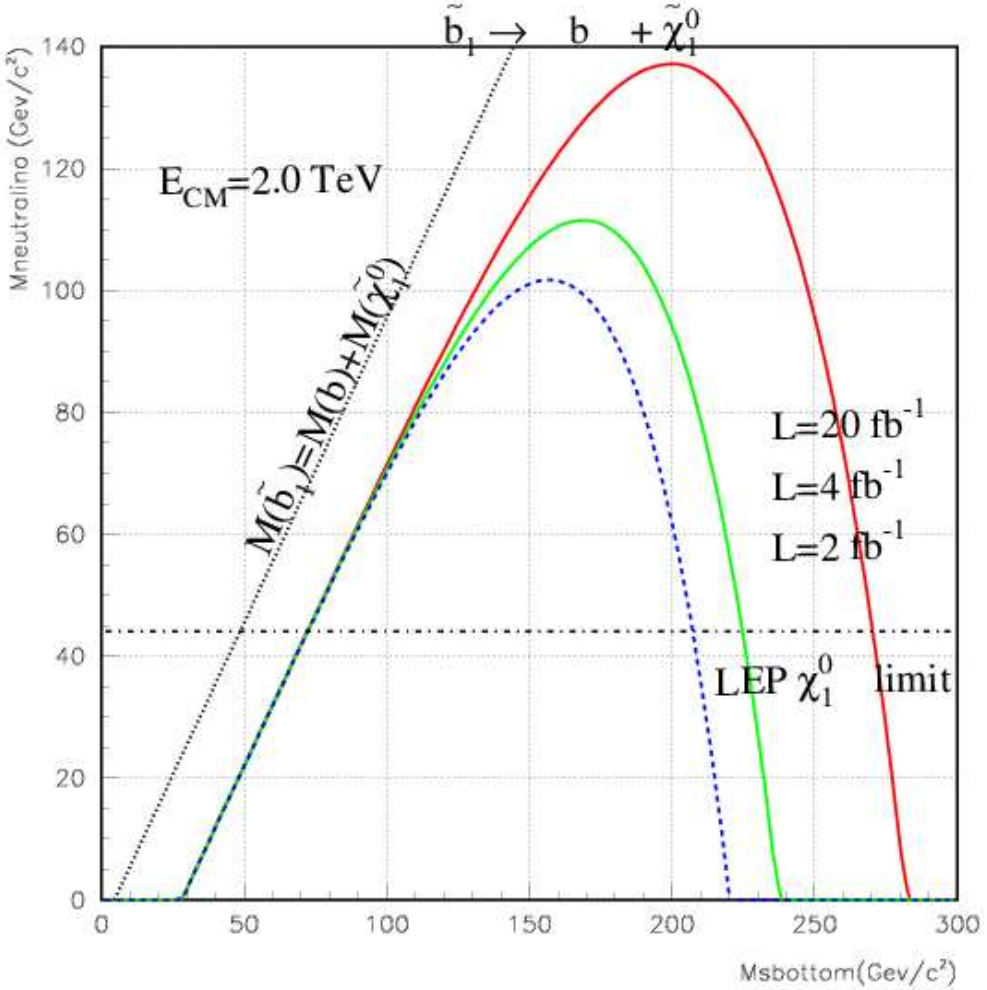
- l l l with l = e or μ
  - very small background ~0.5 fb
- l l τ
  - τ as narrow jet
  - B ~ 5 – 60 fb
- like-sign dileptons
  - have similar reach
  - complementary





stop and sbottom





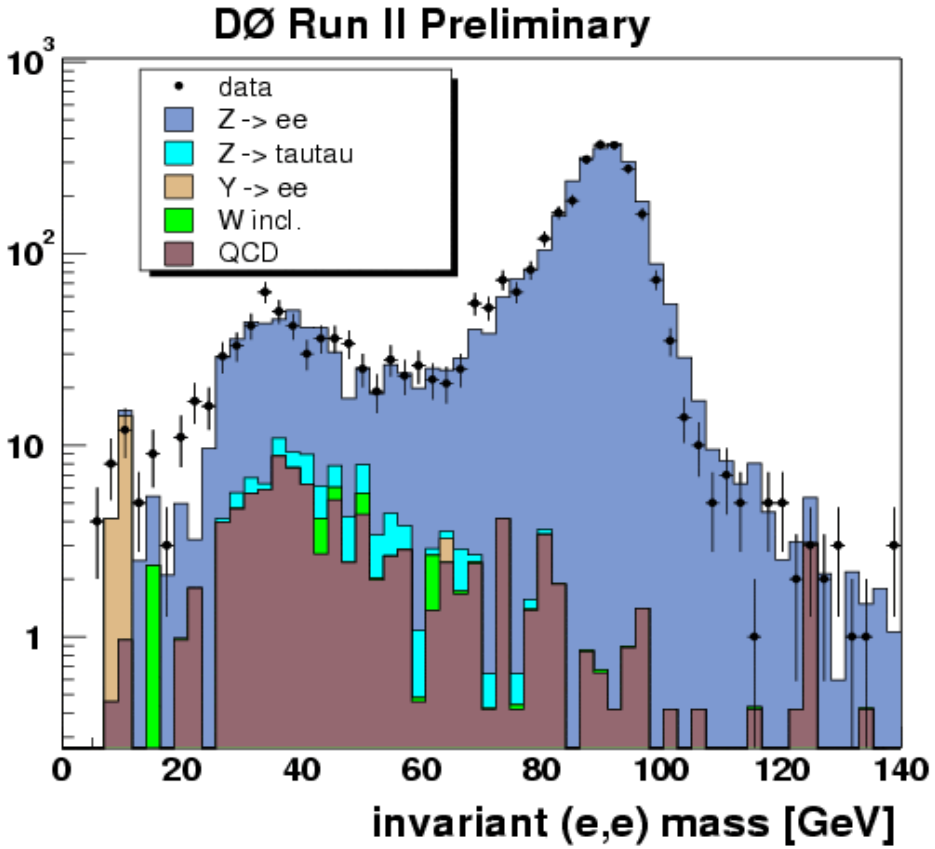
trileptons : eel channel

Similar analysis in the eμl channel

Start from dielectron sample (~40 pb^{-1})

	Backgrounds	Data
$p_T(e_1) > 15$ GeV, $p_T(e_2) > 10$ GeV	3216± 43.2	3132
10 GeV < M(ee) < 70 GeV	660.2± 19.1	721
$M_T > 15$ GeV	96.4± 8.1	123
→ Add. Isolated Track, $p_T > 5$ GeV	3.2 ± 2.3	3
Missing $E_T > 15$ GeV	0.0 ± 2.0	0

allows for τ→h



Typical mSUGRA selection efficiency:
3 to 4% at the edge of the excluded region

Sensitivity still about a factor 7 away from extending the excluded domain

GMSB at D0

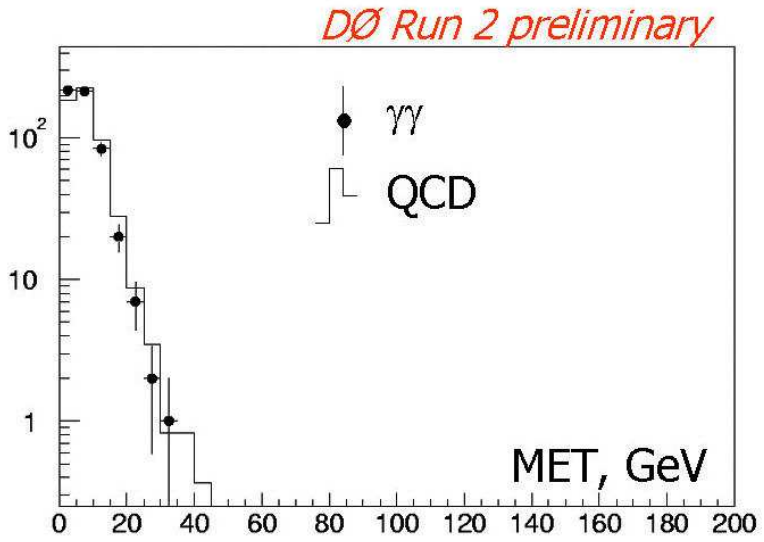
In GMSB, the LSP is a light gravitino
With a "bino" NLSP, the signature is therefore
two photons with missing E_T: $\chi^0_1 \rightarrow \gamma G$

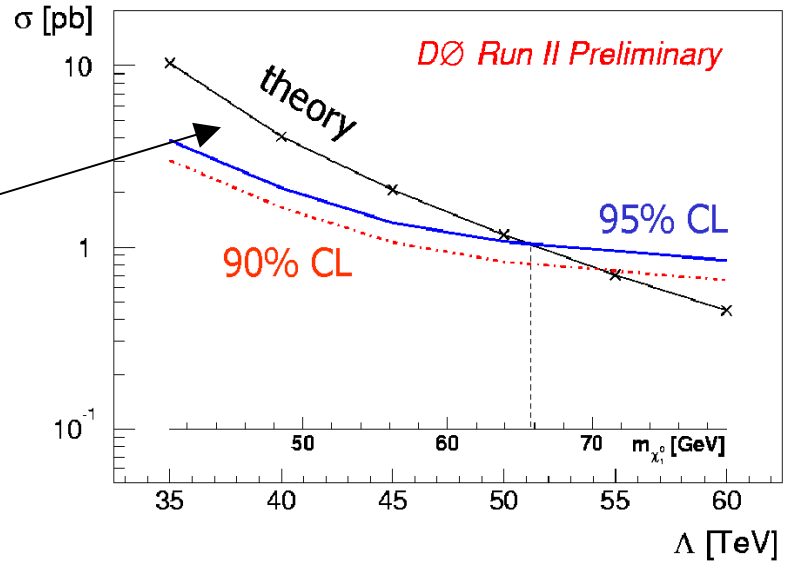
Require two isolated photons
with $p_T > 20$ GeV
Apply topological cuts

Determine the instrumental
QCD background from the data
(inversion of photon quality cuts)

Theory = "Snowmass" slope:
$M = 2\Lambda$, $N_5 = 1$, $\tan\beta = 15$, $\mu > 0$

With ~50 pb-1, the Run I limit is approached

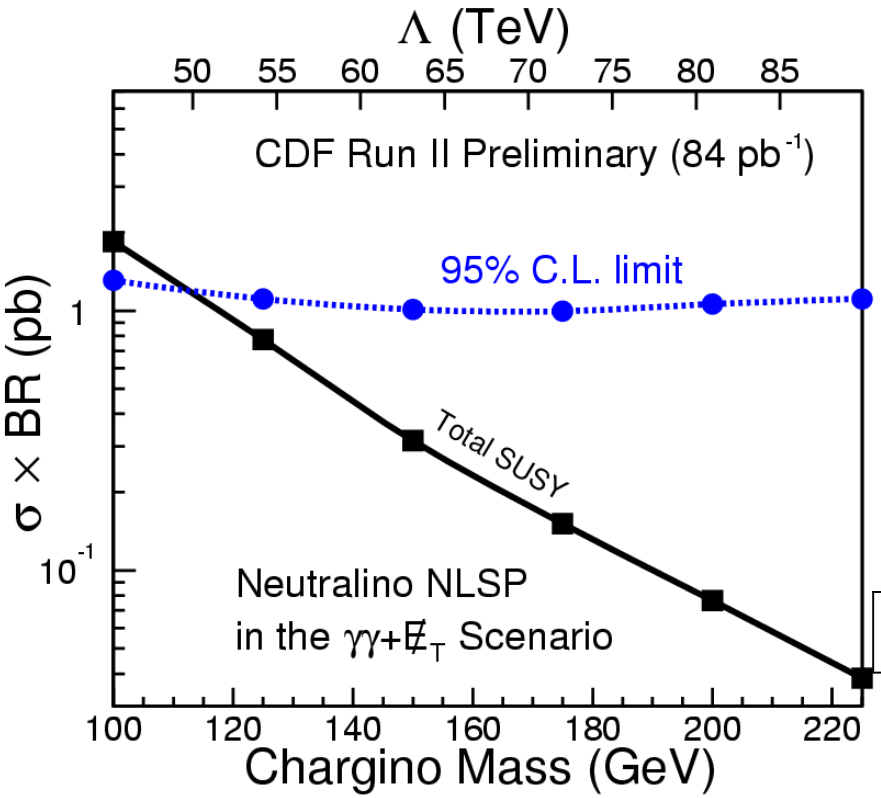


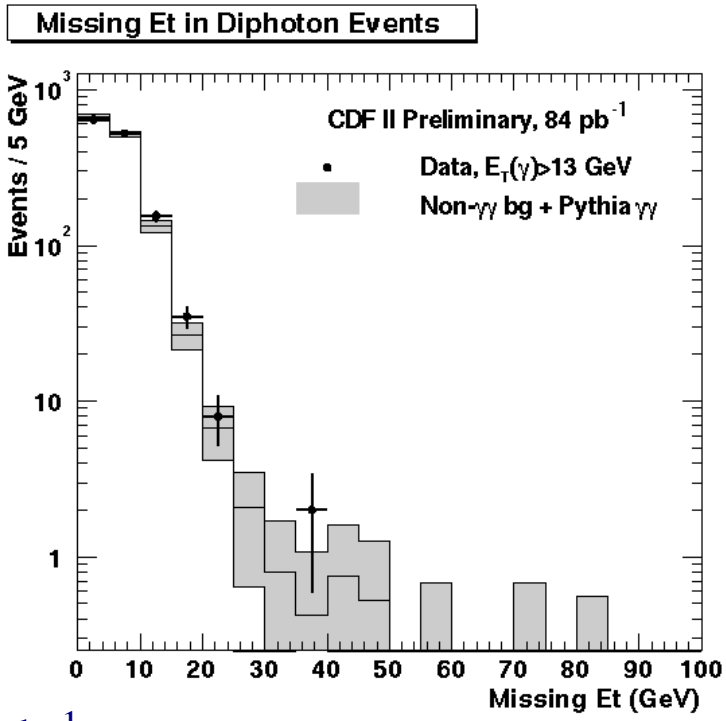


for long χ^o lifetimes, photon pointing will be used

GMSB at CDF

two central photons sample
reject cosmics
use missing ET





- in 84 pb^{-1}
  - expect 2±2 events from bkg
  - 2 events observed

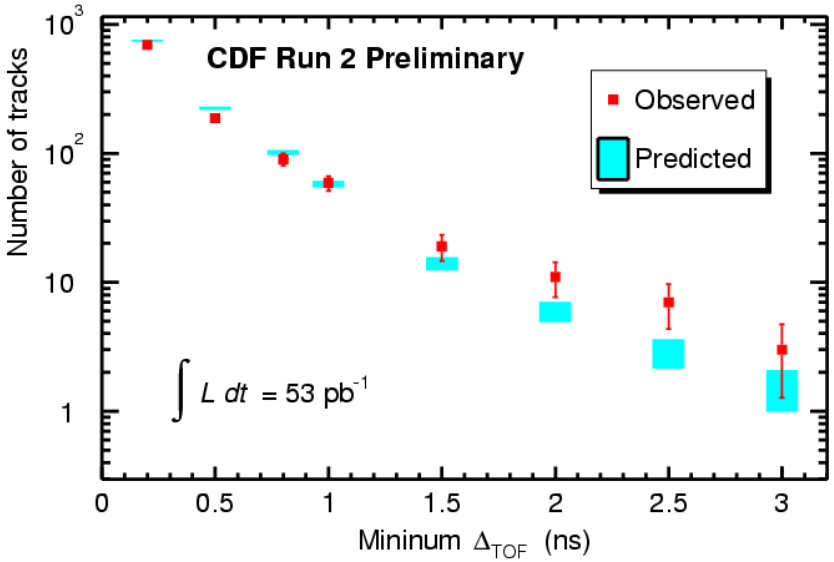
Theory : M = 2Λ, N_5 = 1, tan β= 15, μ> 0

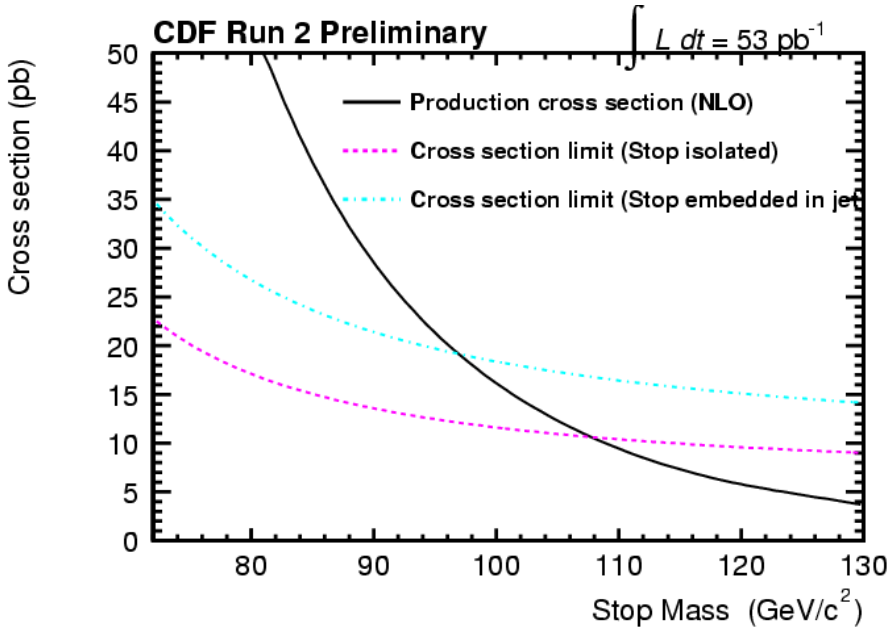
$M_{\chi+} > 113$ GeV /c^2 at 95% C.L.

Charged massive stable particles

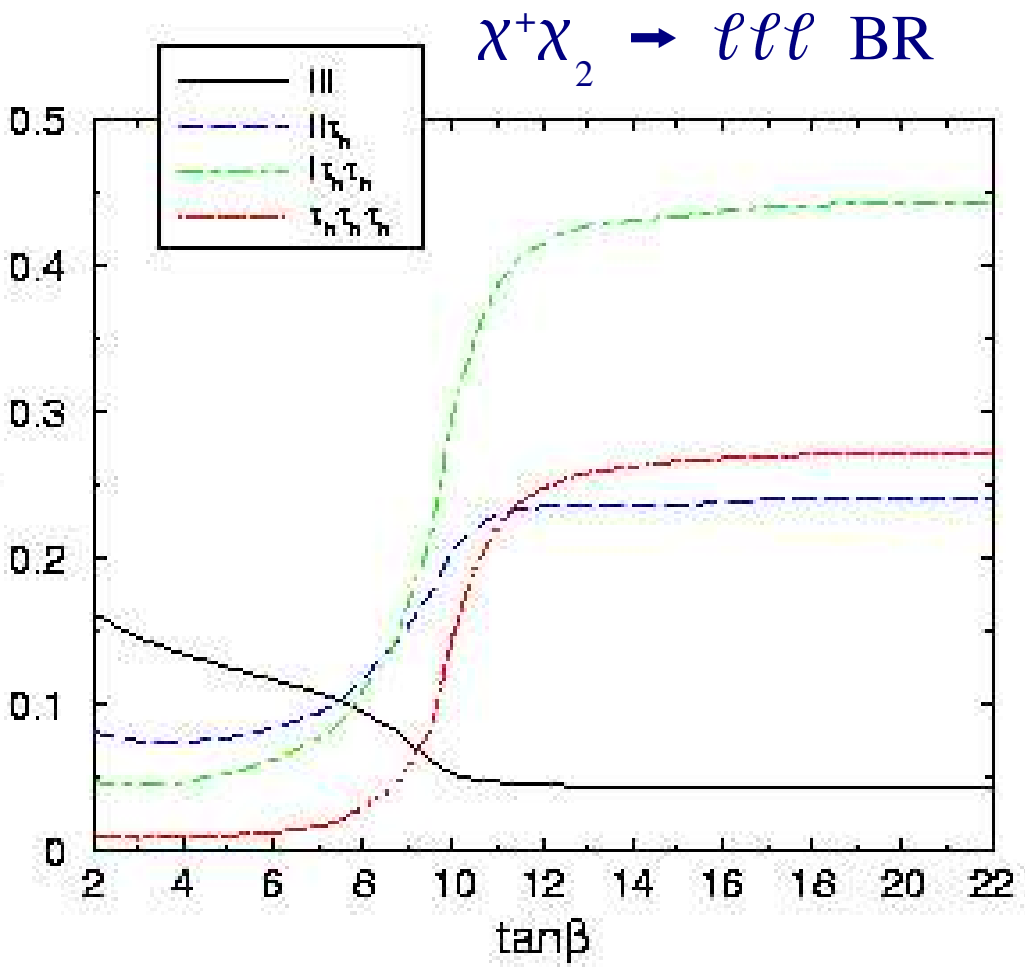
- long lived stable particles escaping the detector ("heavy muon")
- isolated, slow moving:
  - use the Time Of Flight detector

- 2.9±0.7±3.1 background evts expected in 53 pb^{-1}
- 7 evts observed
- stable stop scenario: M_{stop}>107 GeV @ 95%CL



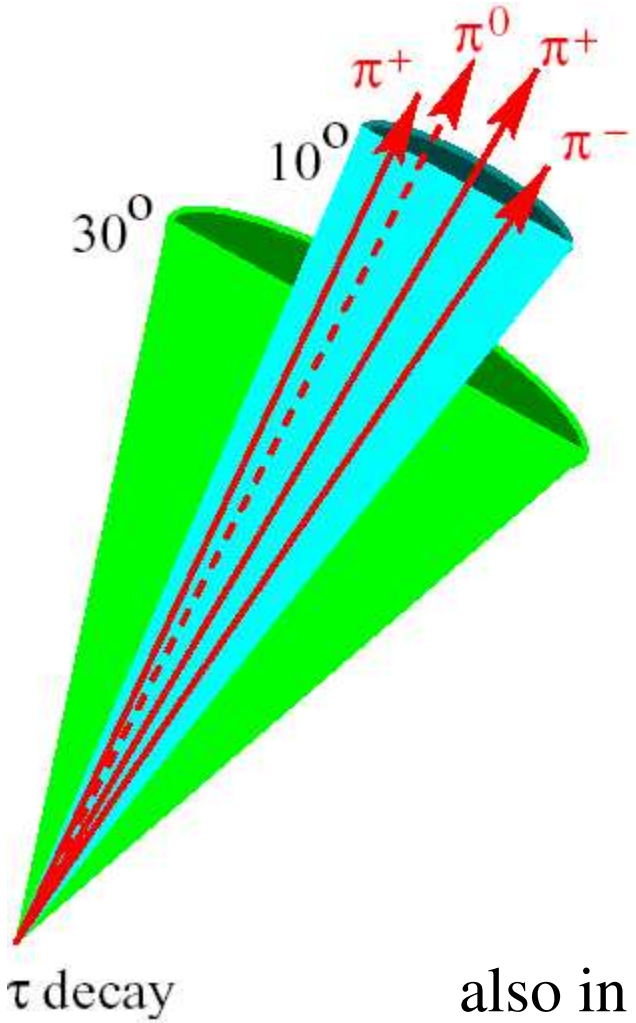


Of the importance of the tau lepton....

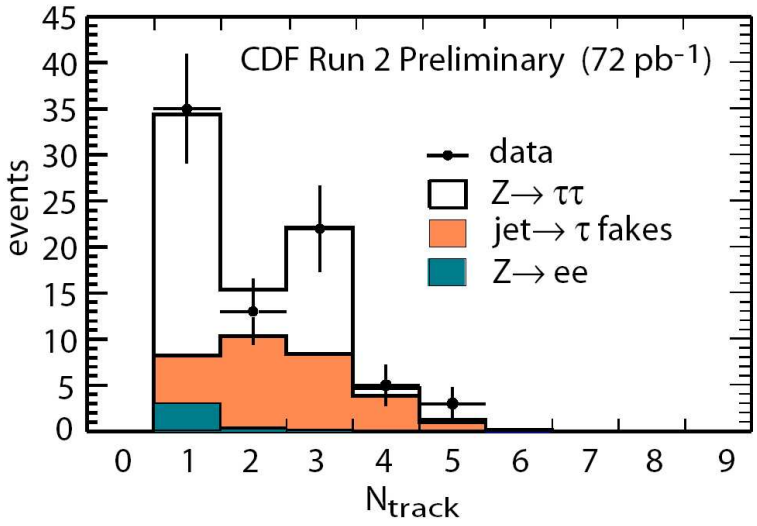


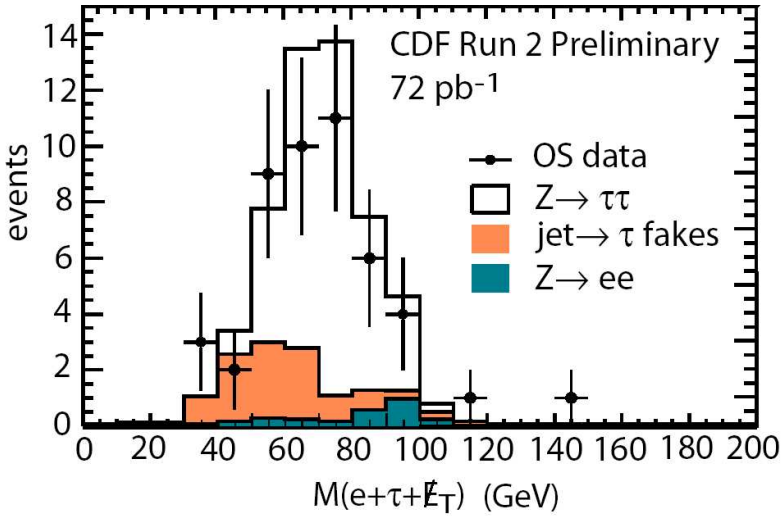
- Higgs
  - investigate tau channels to extend sensitivity
- SUSY
  - include tau's to increase sensitivity of leptonic channels
  - anyway, tau dominate at large tanβ

$Z \rightarrow \tau^+ \tau^- \rightarrow e\nu\nu \quad h\nu$



- cluster+track seed
- 10° signal cone
  - tracks
  - reconstruct π^os
  - mass < 1.8 GeV
- 30° track isolation cone
- compare E_{cal} and sum E tracks and π^os





also in $W \rightarrow \tau\nu$

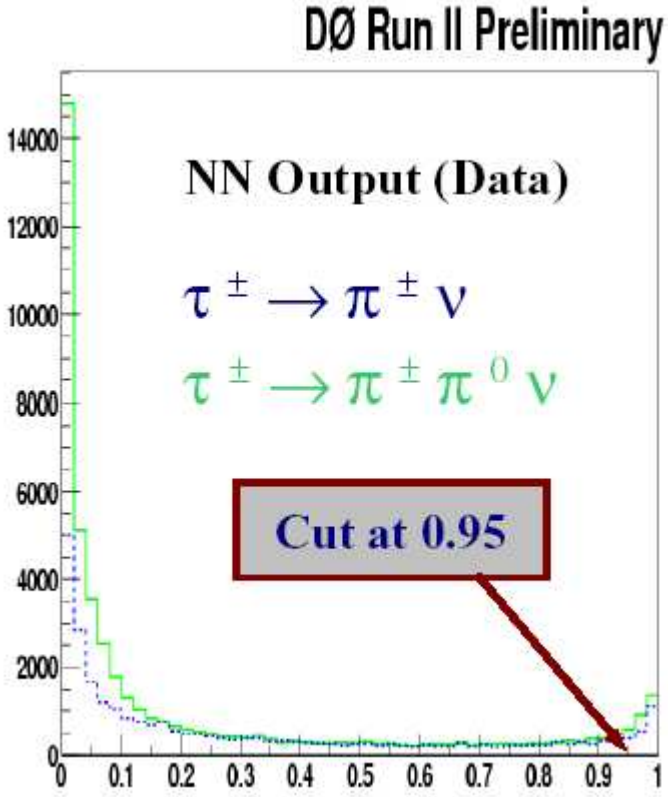
$Z \rightarrow \tau^+ \tau^- \rightarrow e\nu\nu \quad h\nu$

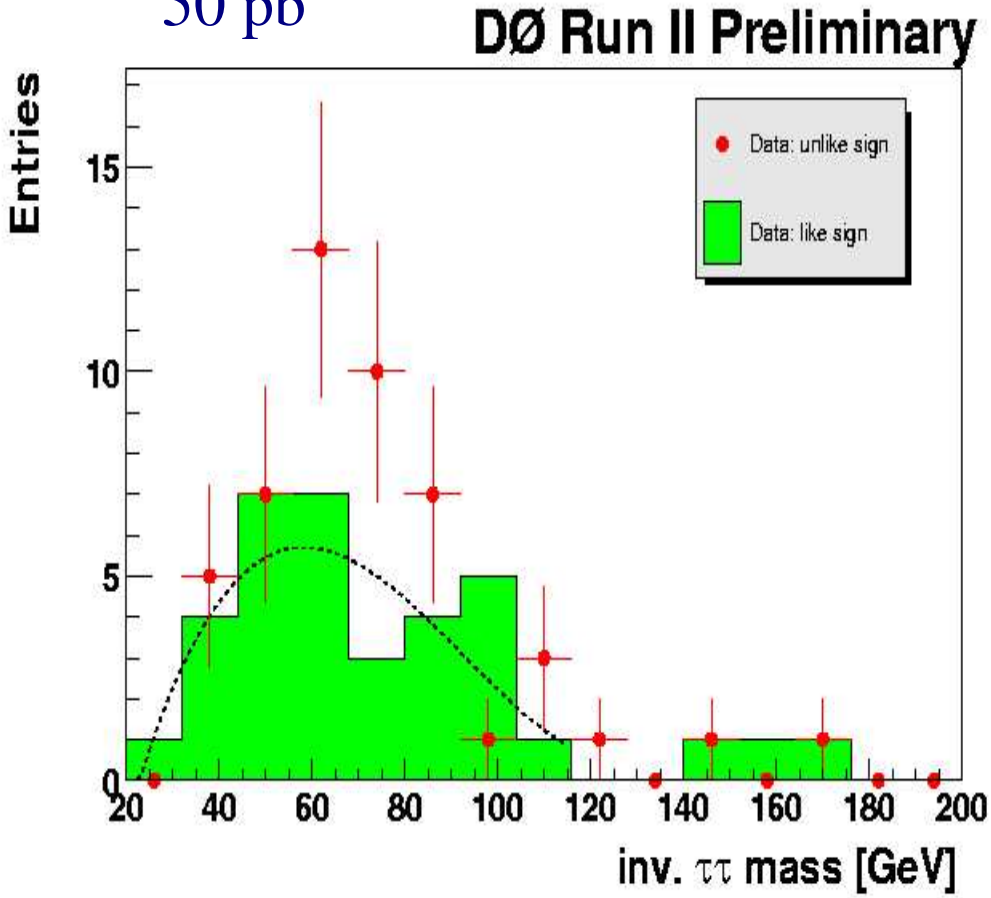
New at DØ

Isolated electron opposite to narrow, single track jet.
use NN for tau ID

(similar study in $Z \rightarrow \tau\tau \rightarrow \mu\tau_h$)

50 pb^{-1}





Conclusions

- The detectors are working and producing physics results
- The current luminosity is small compared to the final expected luminosity from Run II
  - working on the algorithms and techniques
  - working on understanding the backgrounds
  - sensitivity close to that of Run I in several channels
    - high energy, much better detectors
  - still, we'll have more than Run I by the summer, expect physics results in SUSY
- A lot of beautiful physics at the TeVatron: W and top mass, B physics, etc....