CDF through 2010

Jacobo Konigsberg & Robert Roser
CDF spokespeople
Doug Glenzinski - Phys. Coord.

The Luminosity Story…

- Run II is not about energy – its about integrated luminosity
- When science historians write about Run II, they will tell the story of…
  - How the amount of delivered luminosity impacted the ultimate success of the physics program
  - The total luminosity will set the scale for the legacy of the Tevatron

- Q: What should the integrated luminosity be to define success?

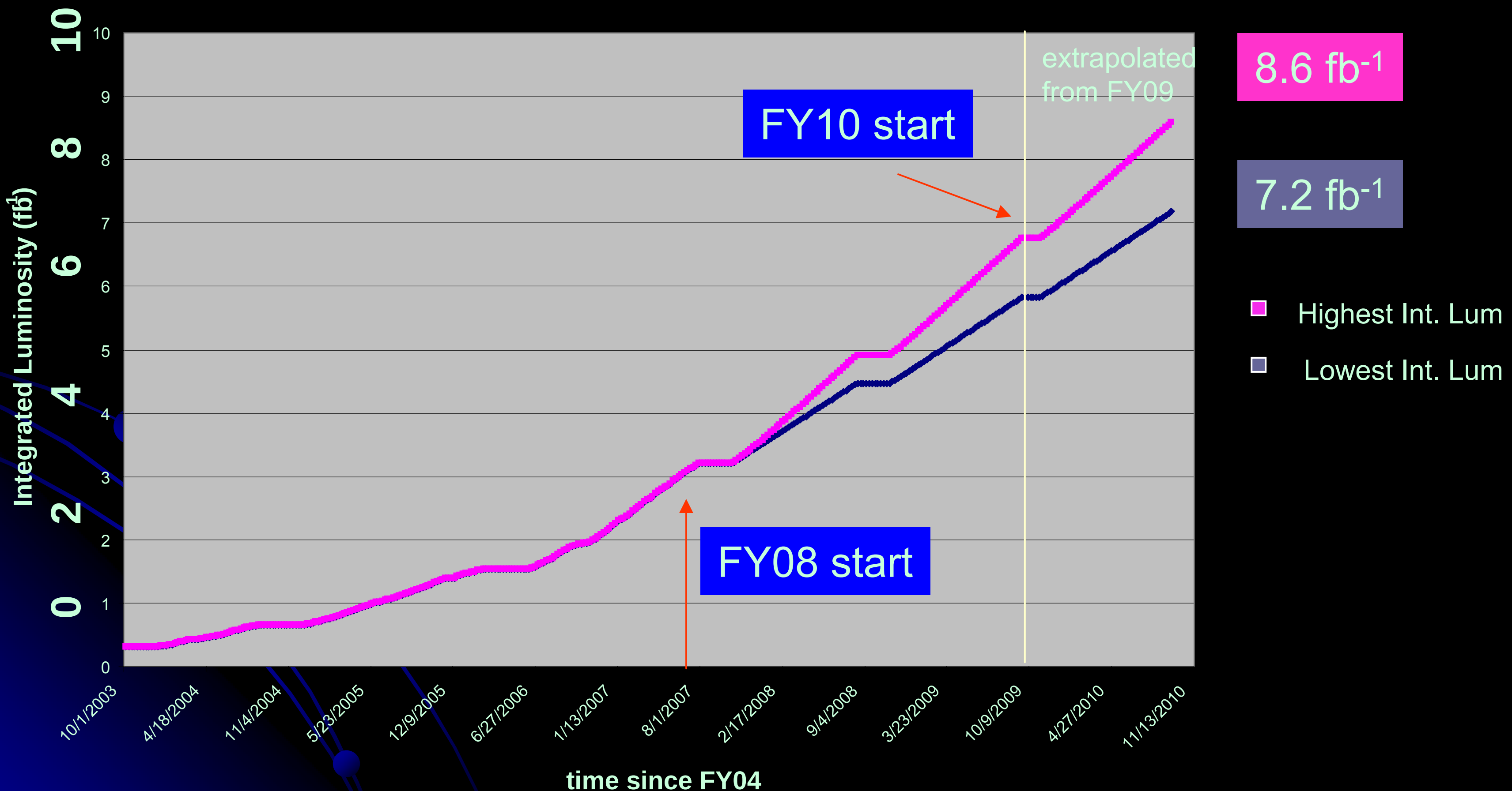
The Answers…

- More detailed explorations on new areas we've opened
  - Single top, di-bosons, CP in B-physics are all examples
  - Each benefits from having the largest statistical sample available
- Test maximum E_{cm}
  - What is in the tails…..
- Investigating today's possibilities
  - We already see a number of 2-sigma and 3-sigma results in our data based on 2 fb^{-1} analyzed
  - Want x3 - 4 our current dataset to find out whether any of these discrepancies arise from new physics
- Higgs potential
  - SM exclusion should be the benchmark
  - With 7-8 fb-1 of data, we can exclude at the 95% C.L. the entire interesting mass range

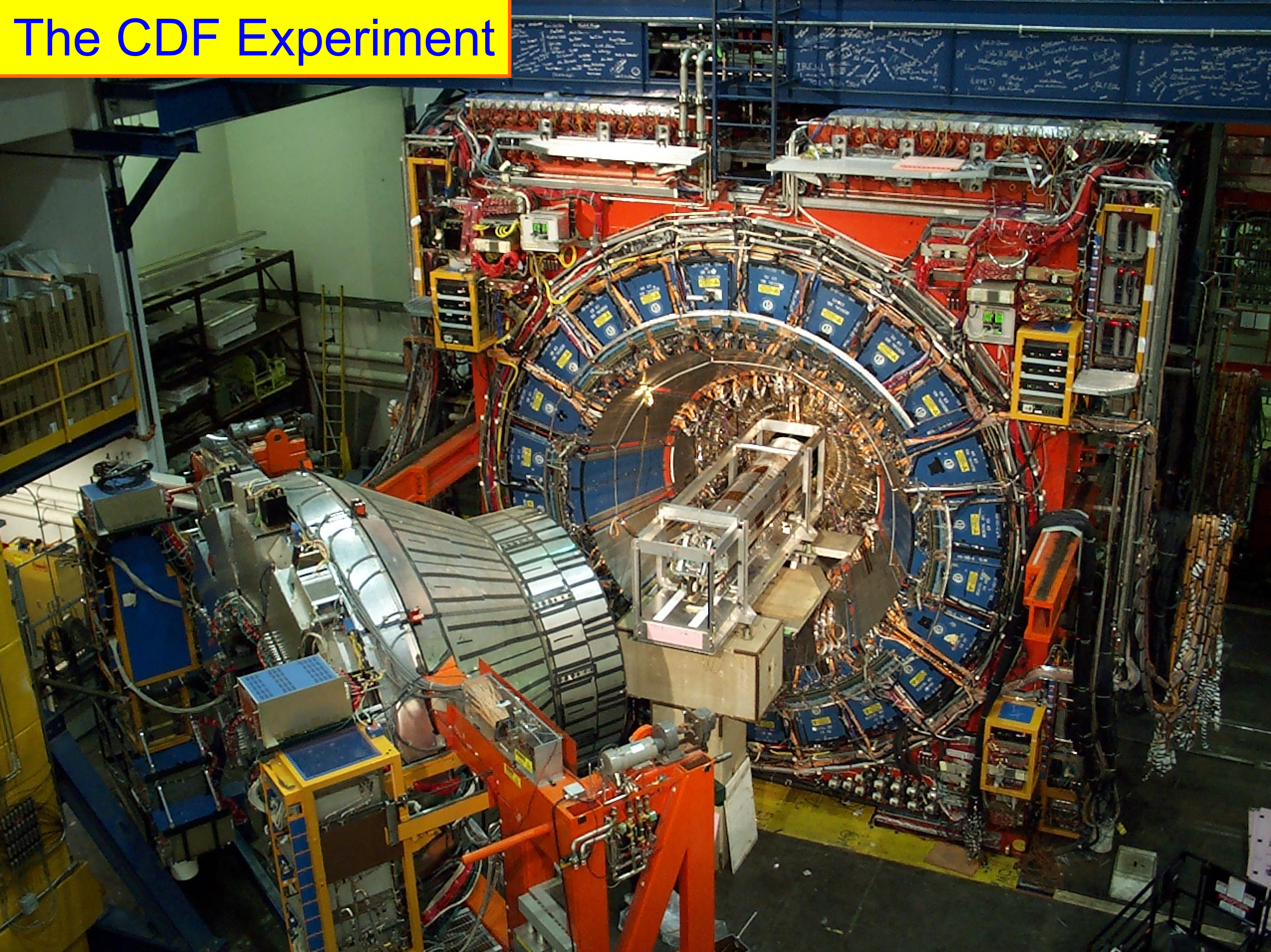
⇒ 8 fb-1 is a worthy target to accomplish all this

Luminosity projection curves for 2008-2010

Running through FY10 will provide such datasets !



The CDF Experiment

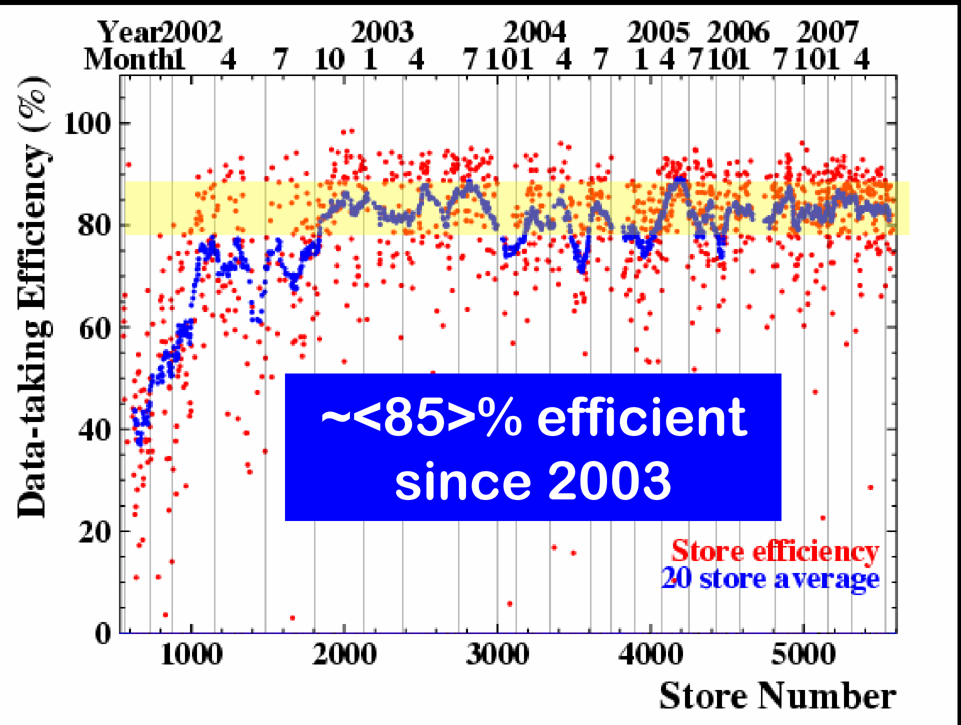


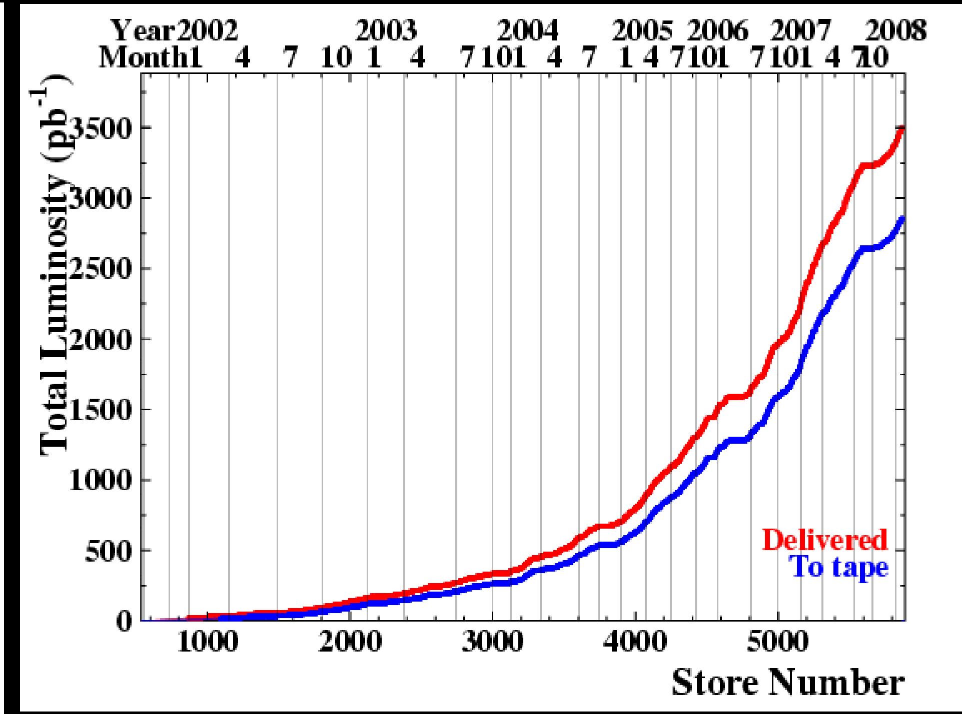
Detector Status - Summary

- Stable data collection
  - ~85% recorded and ~80% of delivered used in analysis
- Tracking chamber (COT)
  - Aging not a problem, will be ok through 2010
- Silicon longevity
  - Expect silicon detector to last beyond 2010
    - Radiation not expected to be a problem
- All other systems are operating well
- High Luminosity Running
  - Inst. Lum expectations are now clear < 300-350 e^{30}
    - Trigger & DAQ
      - Recently completed upgrade on tracking and calorimeter
      - We are collecting high-Pt data with high efficiency up to $3e^{32}$
    - Physics
      - No significant effect up to $3e^{32}$

Expected to be in good shape through FY10

Taking data happily…





- Sources of inefficiency include:
  - Trigger dead time and readout ~ 5%
    - Intentional - to maximize physics to tape
  - Start and end of stores ~5%
  - Problems (detector, DAQ) ~5%

About 80% of Delivered Luminosity is available for physics analysis

The CDF Collaboration

Current Collaboration

- 621 Authors
  - 150 Graduate Students
  - 105 Post Doc's
- # of Ph.D.'s completed
  - 27 in 2006
  - 40 in 2007
- Post Doc's
  - ~25 new post doc's hired this past year

People

- People are migrating to the LHC [and other experiments]
  - This is not new, started a long time ago
- We've taken many measures to mitigate the impact on CDF
  - We have stabilized, streamlined and automated many tasks in operations and in physics analysis
  - We spend considerable effort retaining, recruiting and planning ahead
- But very importantly:
  - Luminosity increase has made a tremendous difference
  - The experiment is running very well
  - Very rich and exciting physics program
  - LHC delays have also made a difference
  - Many opportunities for people to make a mark here: physics and leadership
  - The collaboration age profile is young, yet excellent
  - Try to keep senior people engaged at all levels
  - We have focused our physics program through Higgs search
- Collaborators have not left as quickly as the HEPAP (brock) survey of 2004 indicated

Resources Available

Table represents responses from all CDF institutions (Feb 2007)

Numbers in Units of FTE

	CY 2007	2008	2009
Total US + Non US	392	297	236
Post Doc's	101	73	53
Students	147	102	77

2010 numbers will be similar to 2009 IF groups are given sufficient time to secure the needed funding

Resources Needed

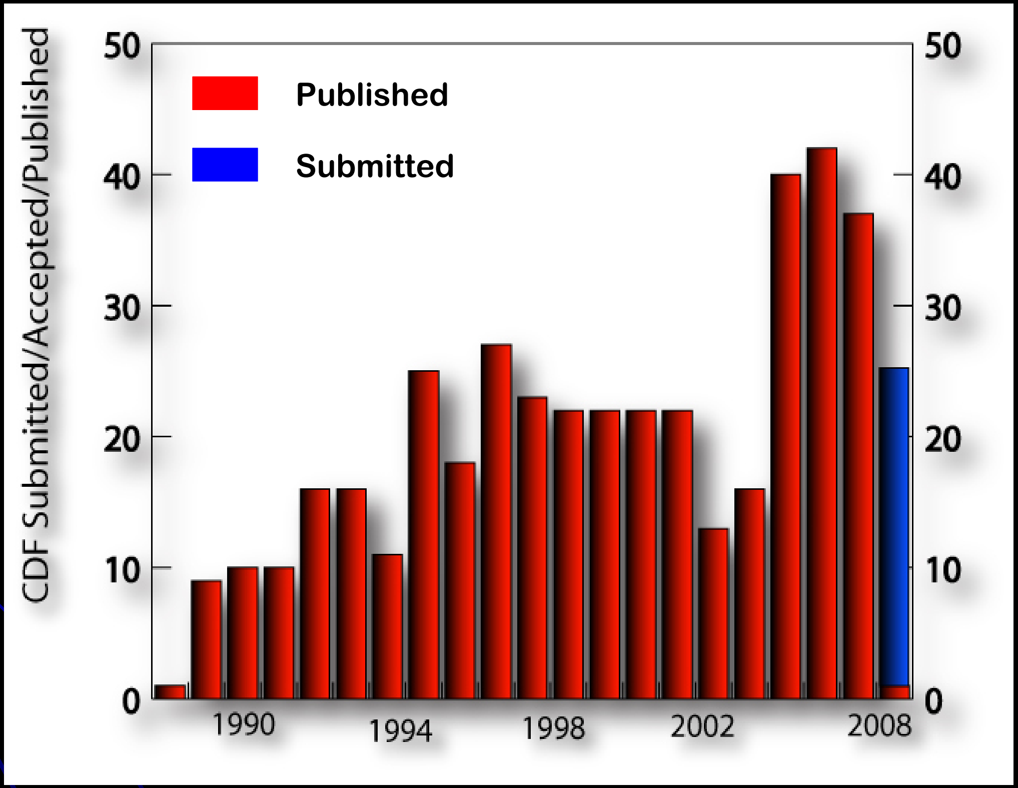
Based on 2007 Needs (bottoms up)

	CY 07	CY 09
Detector Ops	50	45
Offline	26	20
Algorithms	32	21
Management	10	10
Total	118	96
Resources Available	392	236
FTE for Physics	392 – 118 = 284	140

Numbers in Units of FTE

CDF Publication History

- 415 total
- ~145 Run 2 publications so far !
- 26 submitted papers
- >50 additional papers under internal review !



We are publishing our results as we go

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Number 850, December 13 , 2007 by Phil Schewe and Jason S. Bardi

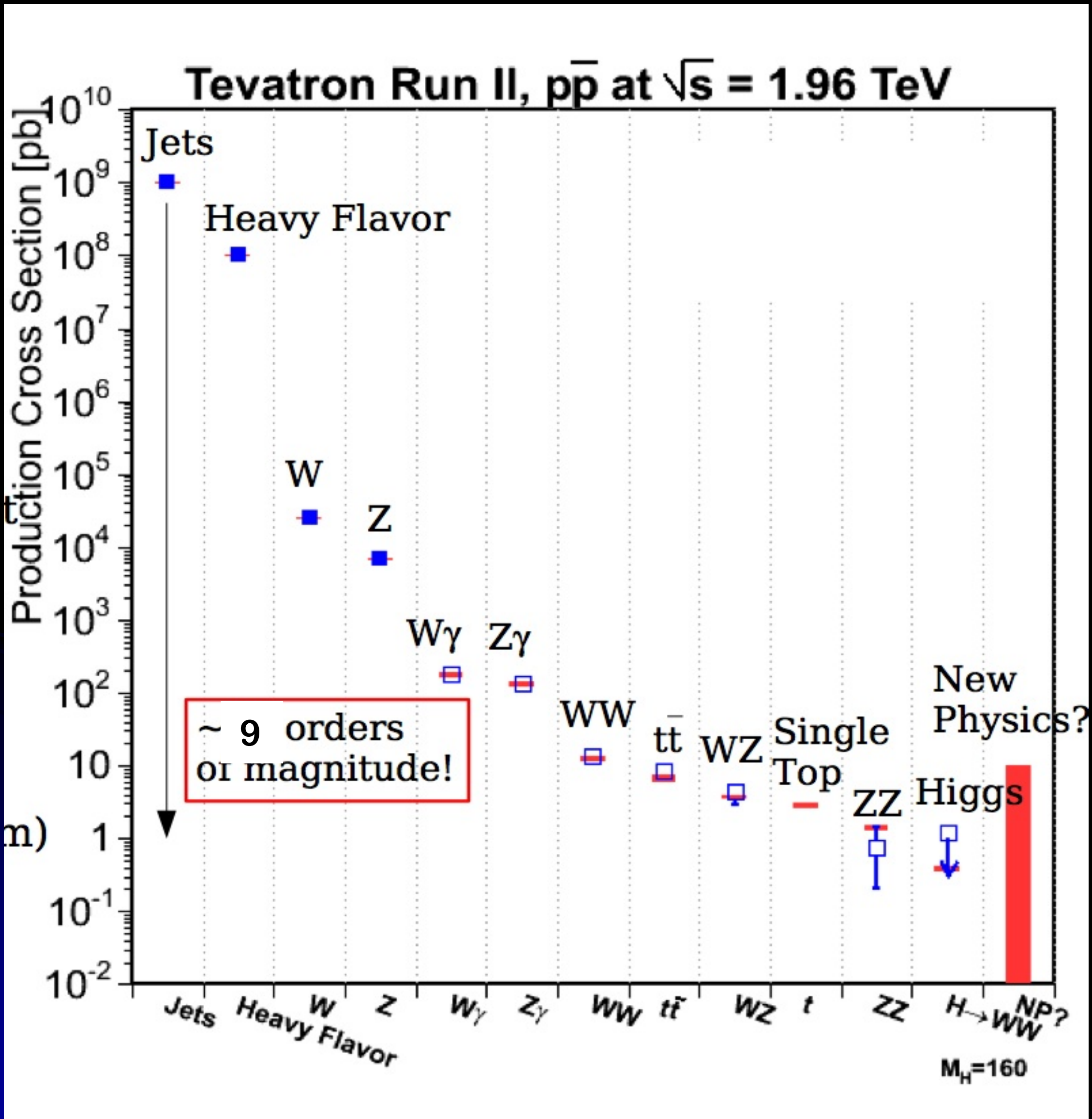
Ten Top Physics Stories for 2007

In chronological order during the year: light, slowed in one Bose Einstein condensate (BEC), is passed on to another BEC (http://www.aip.org/pnu/2007/split/812-1.html); electron tunneling in real time can be observed with the use of attosecond pulses (http://www.aip.org/pnu/2007/split/818-2.html); laser cooling of coin-sized object, at least in one dimension (http://www.aip.org/pnu/2007/split/818-1.html); the best test ever of Newton's second law, using a tabletop torsion pendulum (http://www.aip.org/pnu/2007/split/819-1.html); first Gravity Probe B first results, the measurement of the geodetic effect---the warping of spacetime in the vicinity of and caused by Earth-to a precision of 1%, with better precision yet to come (http://www.aip.org/pnu/2007/split/820-2.html).

The MiniBooNE experiment at Fermilab solves a neutrino mystery, apparently dismissing the possibility of a fourth species of neutrino (http://www.aip.org/pnu/2007/split/820-1.html); the Tevatron, in its quest to observe the Higgs boson, updated the top quark mass and observed several new types of collision events, such as those in which only a single top quark is made, and those in which a W and Z boson or two Z bosons are made simultaneously (http://www.aip.org/pnu/2007/split/821-1.html).

The shortest light pulse, a 130-attosecond burst of extreme ultraviolet light (http://www.aip.org/pnu/2007/split/823-1.html); based on data recorded at the Auger Observatory, astronomers conclude that the highest energy cosmic rays come from active galactic nuclei (http://www.aip.org/pnu/2007/split/846-1.html); and the observation of Cooper pairs in insulators (http://www.aip.org/pnu/2007/split/849-1.html).

Doing Physics at 2 TeV



With more luminosity

- Observe new SM processes
- Compelling precision measurements
- First explorations of the Tera-scale
- Open up new areas of research
- Test for New Physics
  - Direct searches
  - Indirectly via rare processes
- Reach the Higgs horizon

Physics Highlights from 1-2 fb^{-1}

Observation of Bs-mixing

Δm_s = 17.77 +- 0.10 (stat) +- 0.07(sys)

Observation of new baryon states

Σ_b and Ξ_b

WZ discovery (6-sigma)

Measured cross section 5.0 (1.7) pb

ZZ observation

4.4-sigma

Single top evidence (3-sigma) with 1.5 fb^{-1}

cross section = 2.9 pb

$|V_{tb}|$= 1.02 ± 0.18 (exp.) ± 0.07 (th.)

Measurement of Sin(2β_s)

Most are world's best results

Precision W mass measurement

Mw_cdf = 80.413 GeV (48 MeV)

Precision Top mass measurement

Mtop_cdf = 172.7 (2.1) GeV

W-width measurement

2.032 (.071) GeV

Observation of new charmless B==>hh states

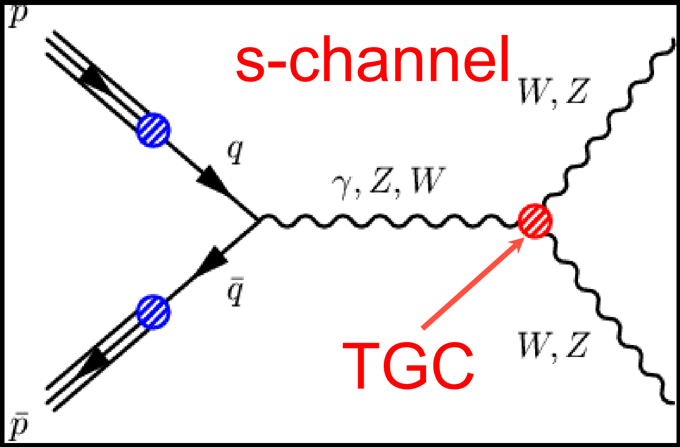
Observation of D^o-D^obar mixing

Constant improvement in Higgs Sensitivity

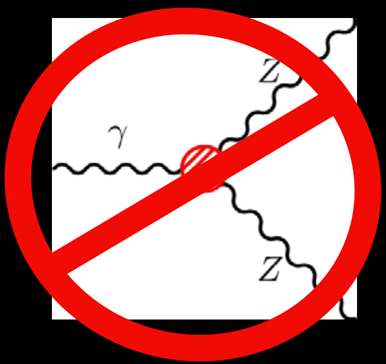
Wine & Cheese seminars on all these topics and more

New Window – Di-Bosons

- Tests gauge structure $SU(2)_L \otimes U(1)_Y$ of electroweak sector of the SM
- Test new physics (anomalous couplings, compositeness, extended gauge, SUSY, extra dimensions
- Heavy dibosons are discovery channels for Higgs ($H \rightarrow WW^{(*)}$, $ZZ^{(*)}$)



- Neutral TGC absent in the SM



ZZ Production

Brand new Hep-ex:0801.4806

3 //// events observed and a background of 0.1 events

$\sigma(zz) = 1.4\ ^{+0.7}_{-0.6}$ (stat + sys) pb

(NLO XS = 1.4 ± 0.15 pb)

WZ Production

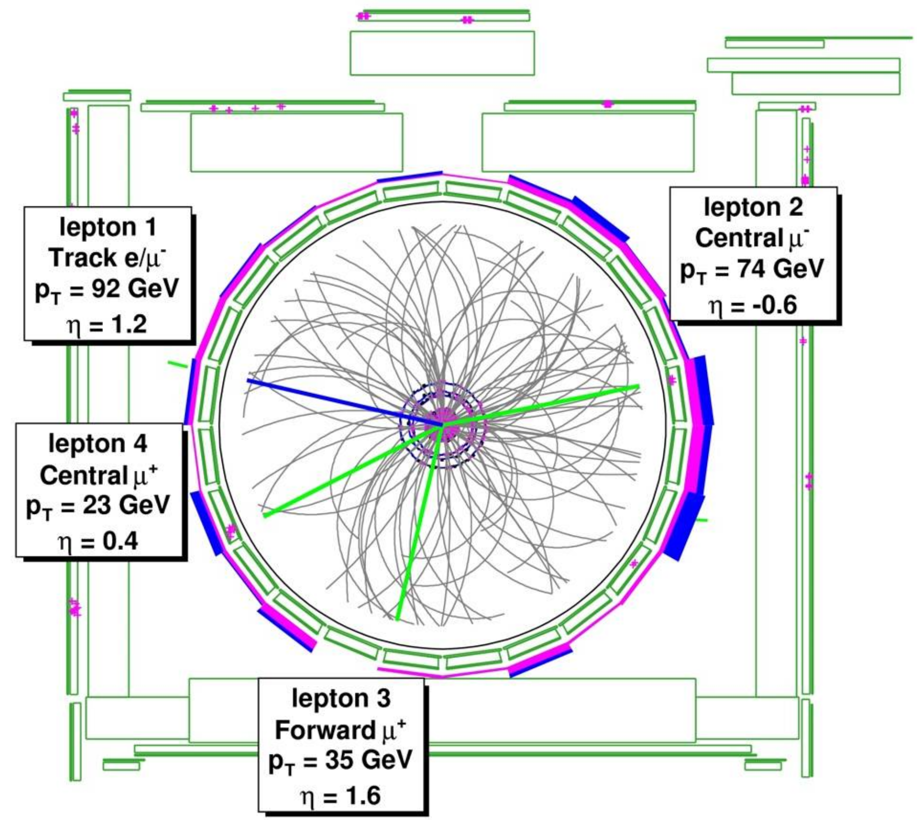
25 observed with an bckg of 5.2 events

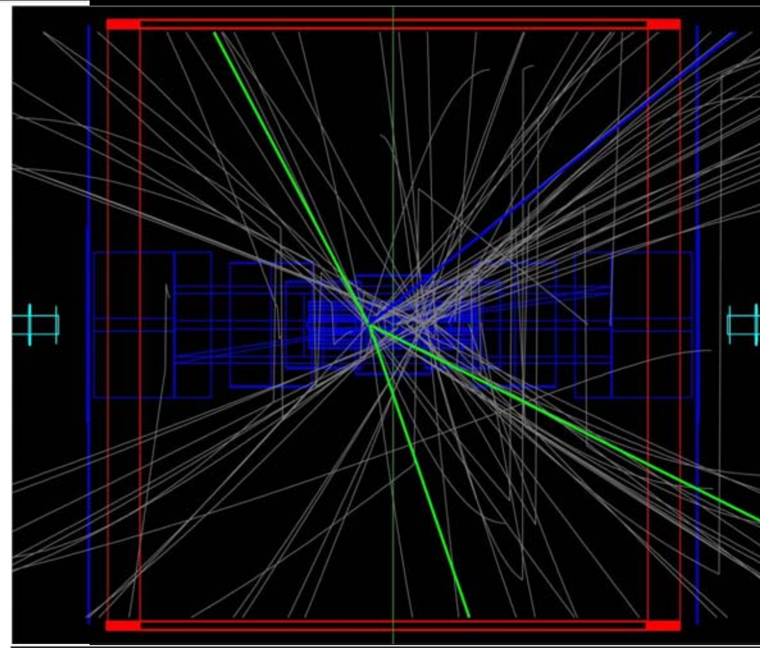
$$\sigma(WZ) = 4.3^{+1.3}_{-1.0}(\mathrm{stat}) \pm 0.2(\mathrm{syst}) \pm 0.3(\mathrm{lumi})\ \ \mathrm{pb}$$

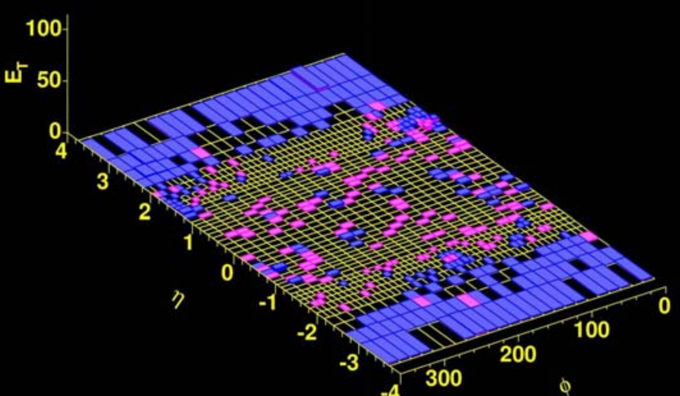
(NLO XS = 3.7 ± 0.3 pb)

Both CDF first observations !

ZZ→$\mu\mu\mu\mu$ Candidate







m_{ll1}=90.92 GeV

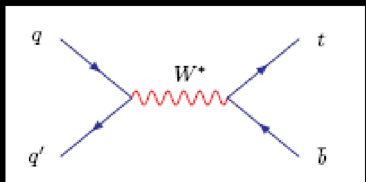
m_{ll2}=83.03 GeV

M_{llll}=312.4 GeV/c^2

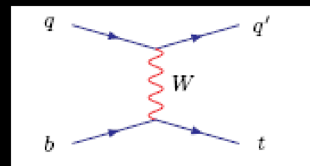
$|\not{E}_T|$=8.7 GeV

N_{jets} = 0

New Window: Single Top

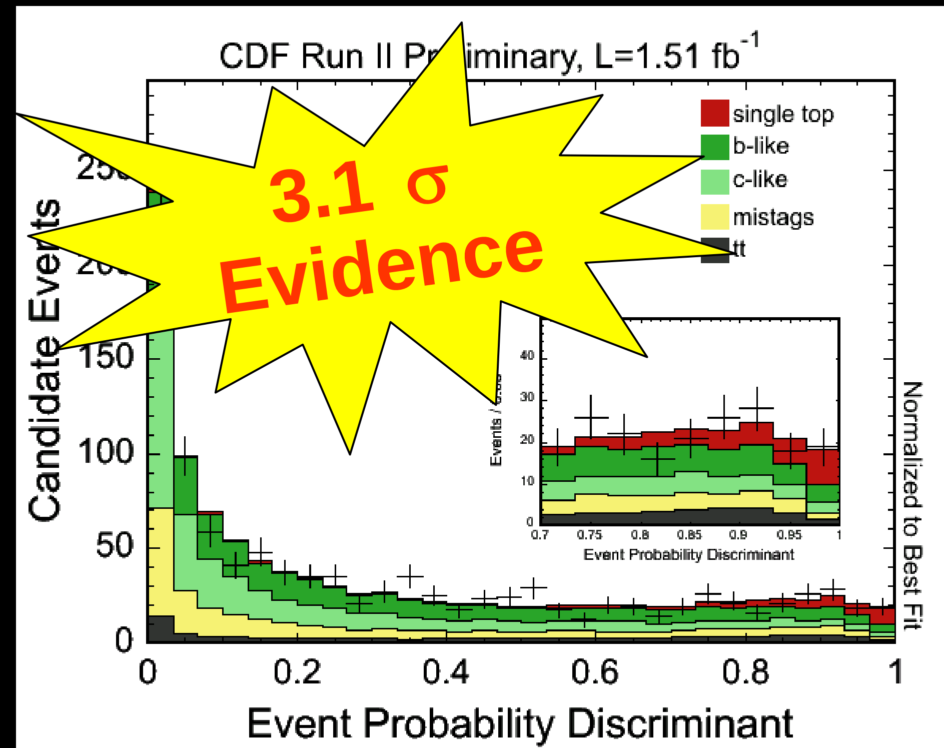


S channel



t channel

- Probes the *W−t−b* vertex
- Provides a direct determination of the CKM M.E. |*Vtb*|
- Offers a source of almost 100% polarized top quarks
- Probes exotic models beyond the Standard Model, like flavor-changing neutral currents or heavy *W'* bosons

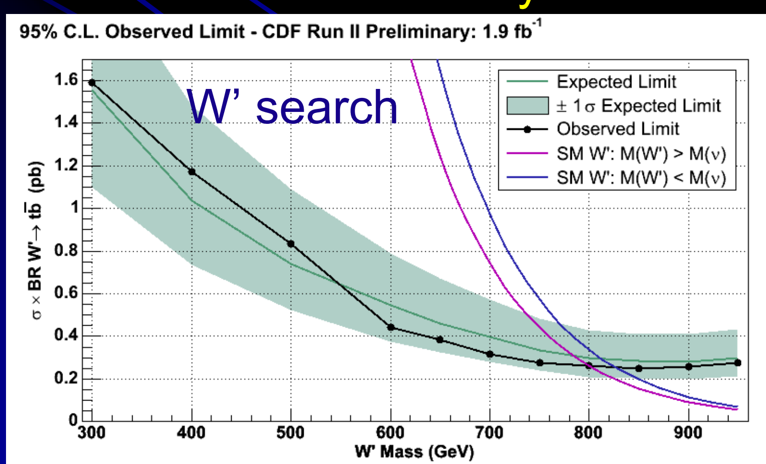


~60 Candidate Events

σ_{s+t}= 3.0 ± 1.2 pb

σ_s= 1.1, σ_t =1.9 pb

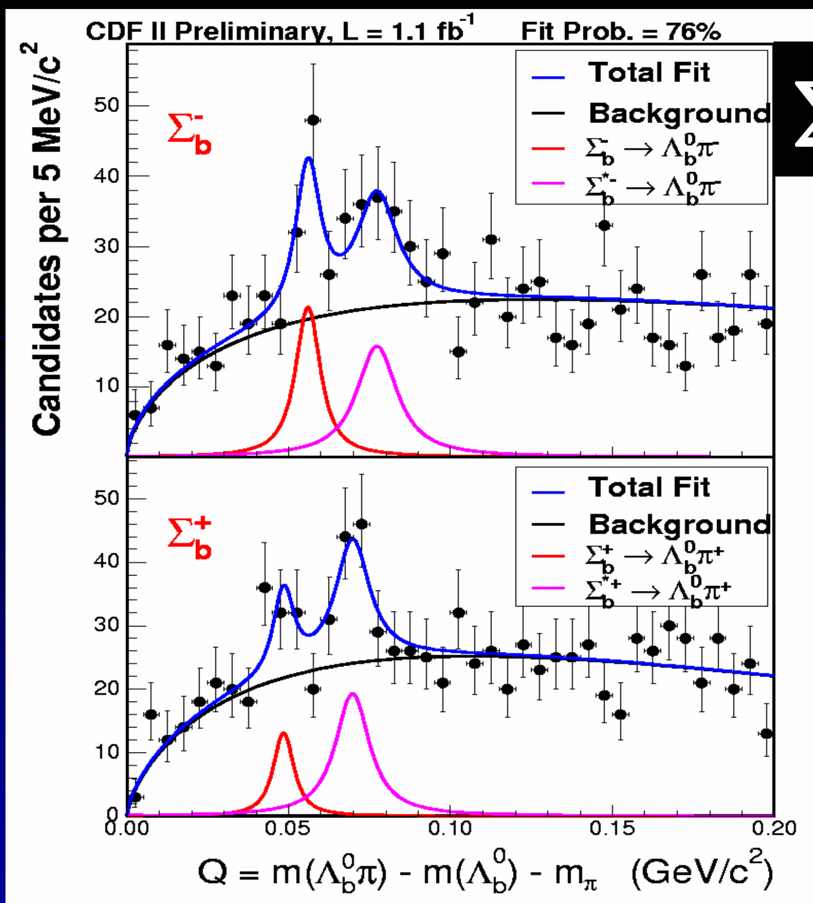
$|V_{tb}|$= 1.02 ± 0.18 (expt) ± 0.07 (theory)



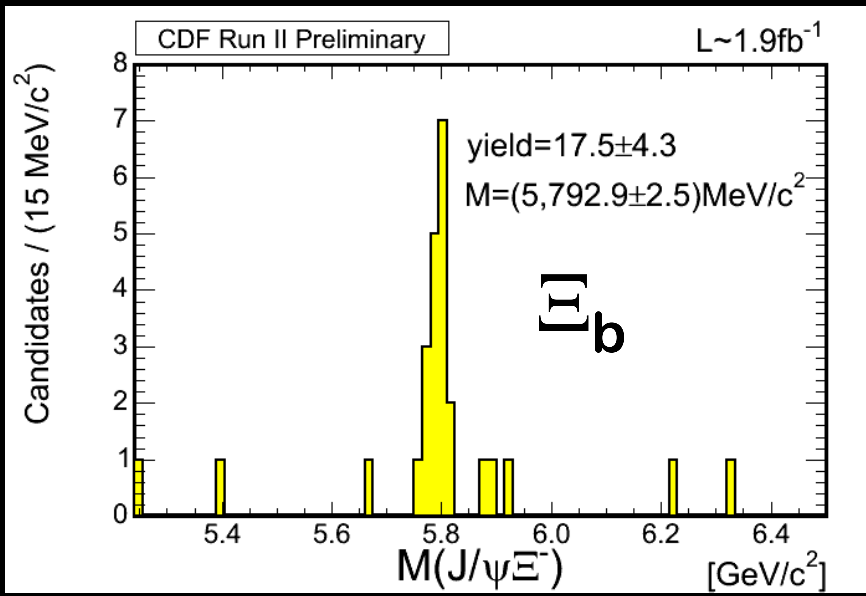
New Window: First Look at Rare HF Particles

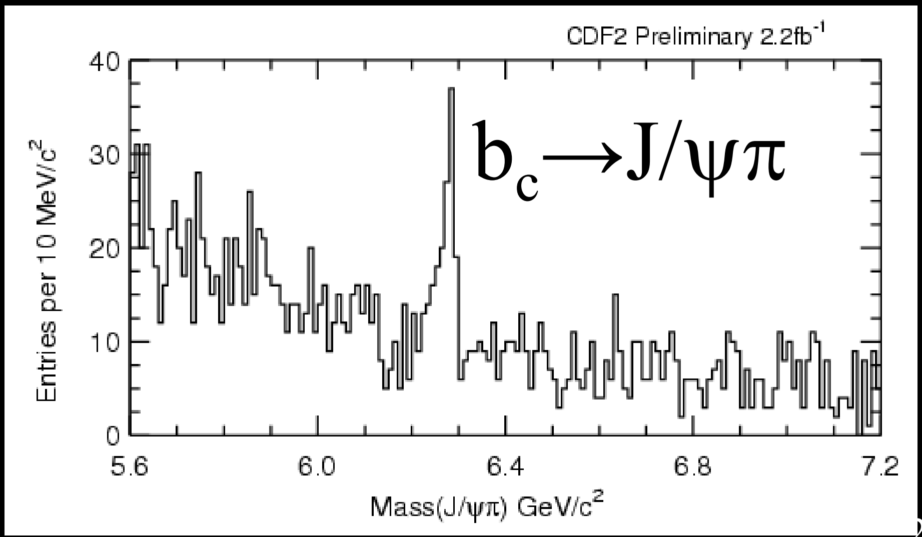
[with much lum] The Tevatron is excellent at producing rare species of particles containing b,c quarks

(B_u, B_d, B_s, B_c, Σ_b, Ξ_b,Λ_b)



Σ_b

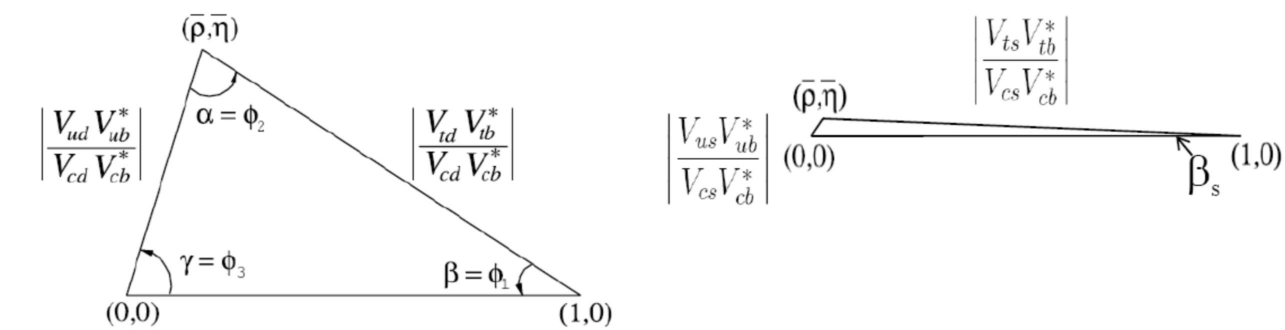




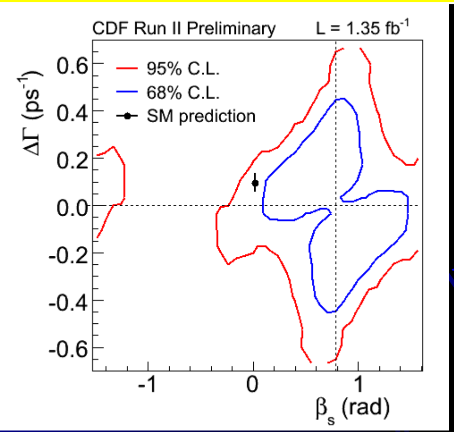
New Window: B_s CP-violation

- B_s are produced in numbers at the Tevatron
- SM predicts very small CP violation in $B_s \rightarrow J/\psi\phi$ channel ($\beta_s \sim 0.02$)
- Good place to probe New Physics

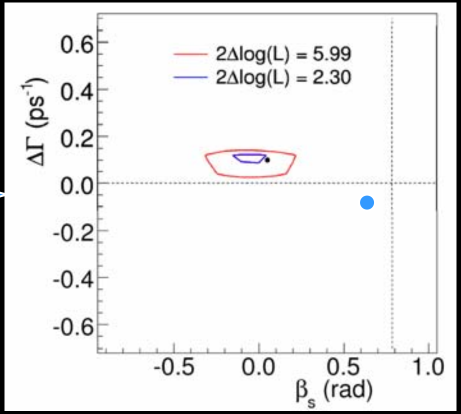
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \qquad V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

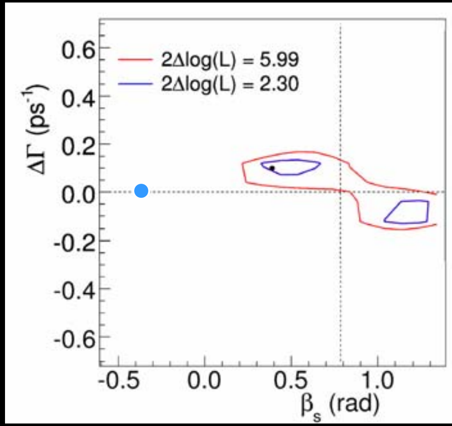


Brand new hep-ex:0712.2397/8



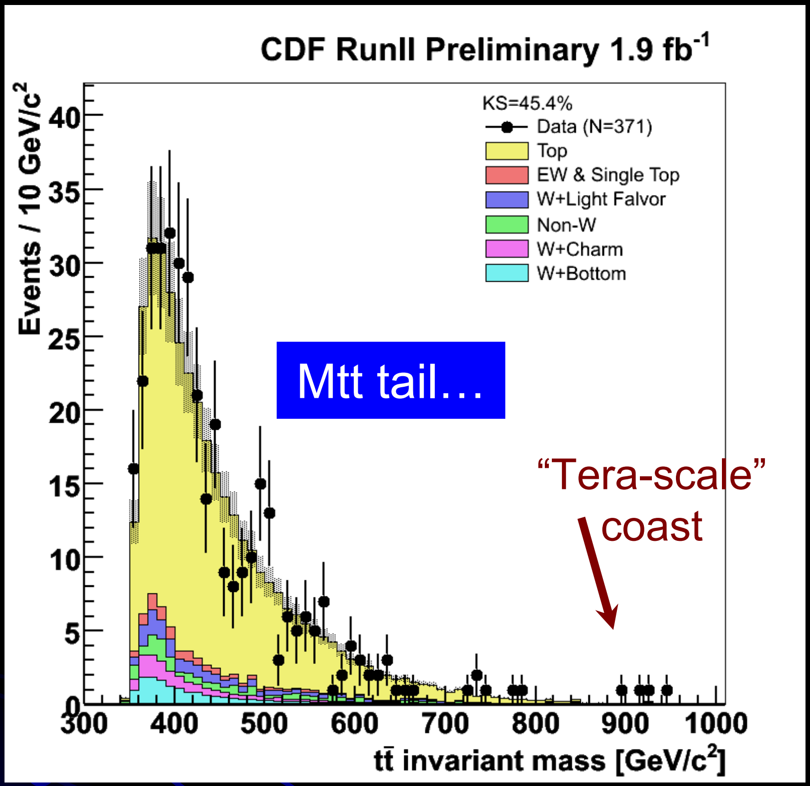
~8 fb^{-1}

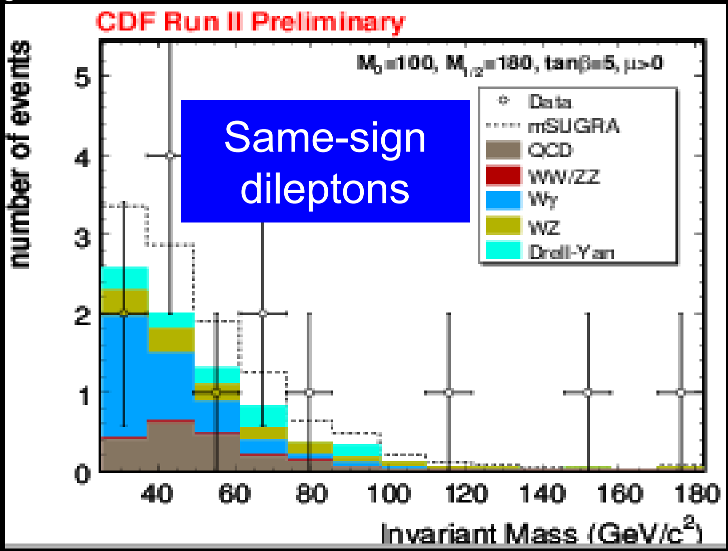


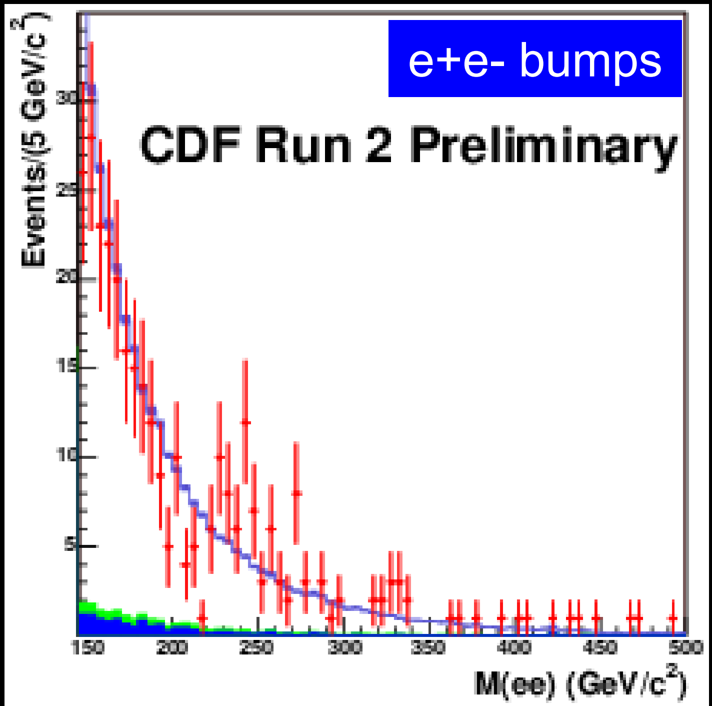


Today 1.4 fb^{-1} Exclude NP or find NP

Open discovery possibilities







A factor of 4 more data could turn these [and other excesses we have] into a discovery !

How we make progress in our program

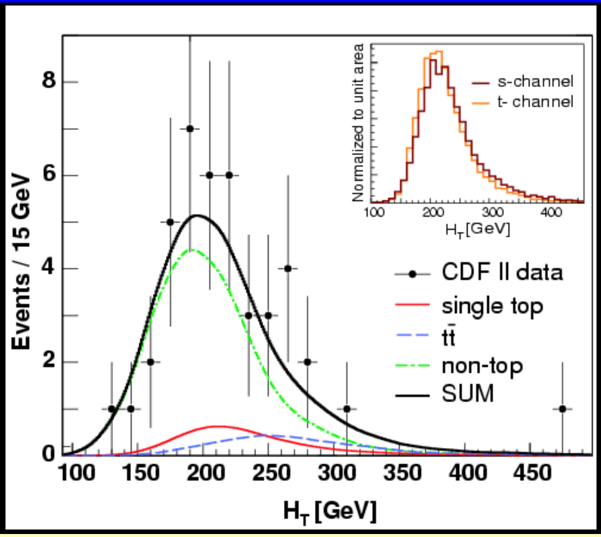
- Program driven by intellectual curiosity and the thrill of possibility
- People tend to go after the physics that are accessible to them
  - Pragmatic and sociological reasons
- Then they push and innovate, especially when they see the possibilities
  - Things start to come together
- It is engrained in us to want to make progress
- We get creative, adaptive and adoptive and, most importantly: we learn from the data all the time
- One cannot fully lay out a roadmap and know where every measurement or search will end up, given time and more data
- $\sqrt{(L)}$ is a myth in hadron collider physics, except at the very very end, when there is nothing left to do but to surrender

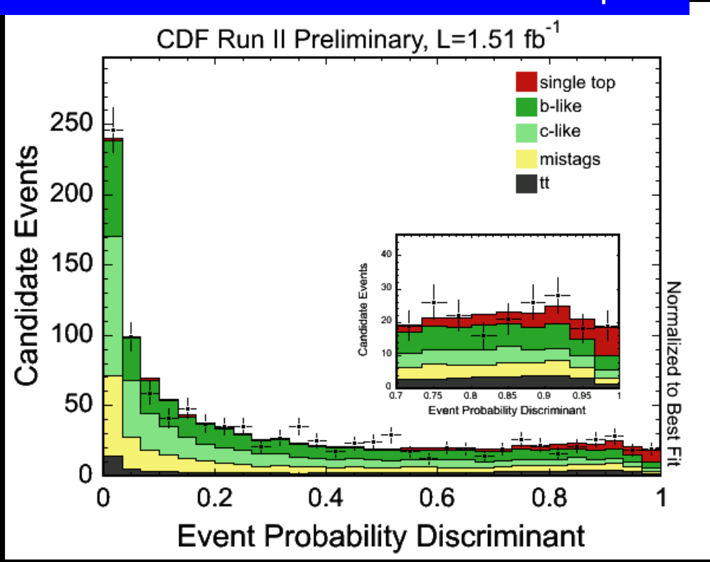
Single Top Story

2004: Simple analysis while refining Monte Carlo samples and analysis tools

2 years

2006: Established sophisticated analyses
Check robustness in data control samples

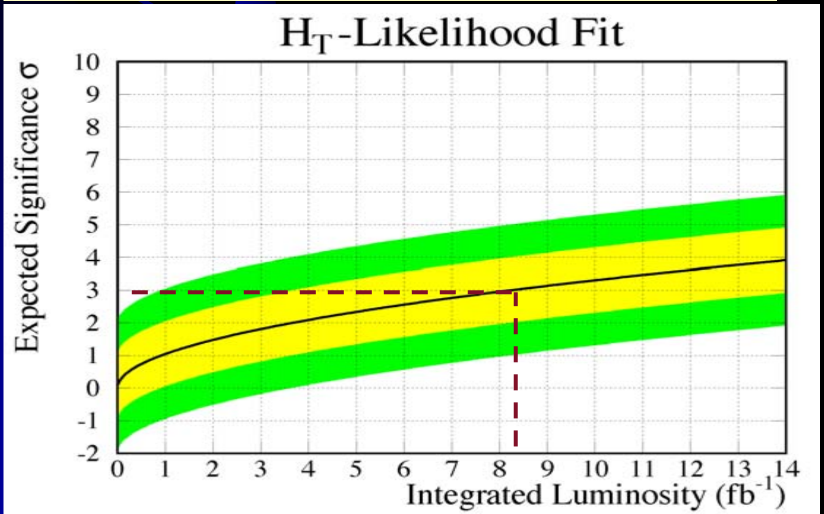


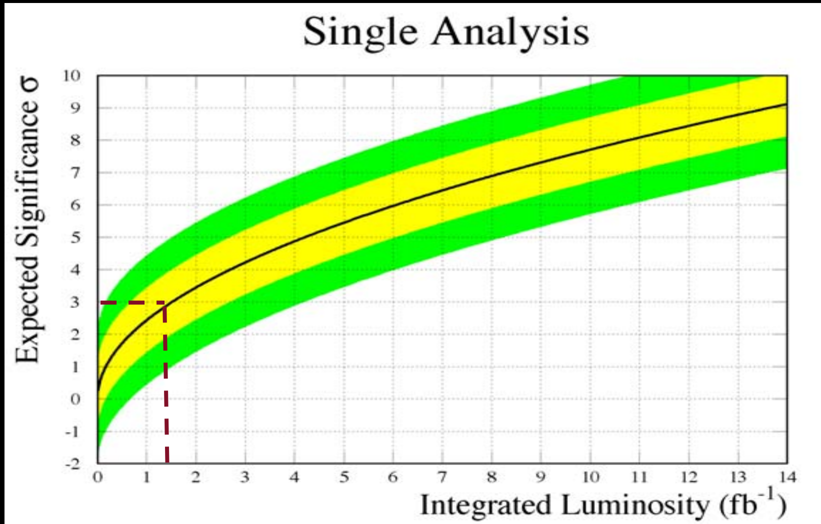


- *New analysis techniques (Matrix Element, NN, Likelihoods)*
- *More triggers*
- *More acceptance*
- *More data*

First Tevatron Run II result using 162 pb^{-1}
$\sigma_{single\ top}$ < 17.5 pb at 95 % C.L.

2007: 3-σ evidence for single top quark production using 1.5 fb^{-1}





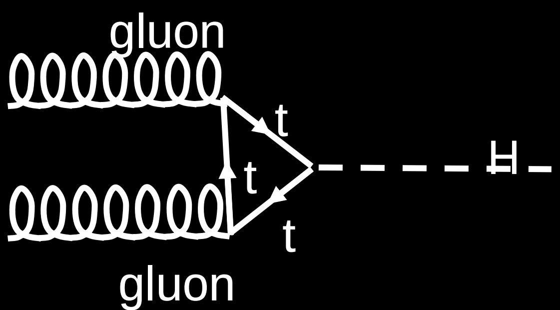
Reaching for the Higgs Horizon

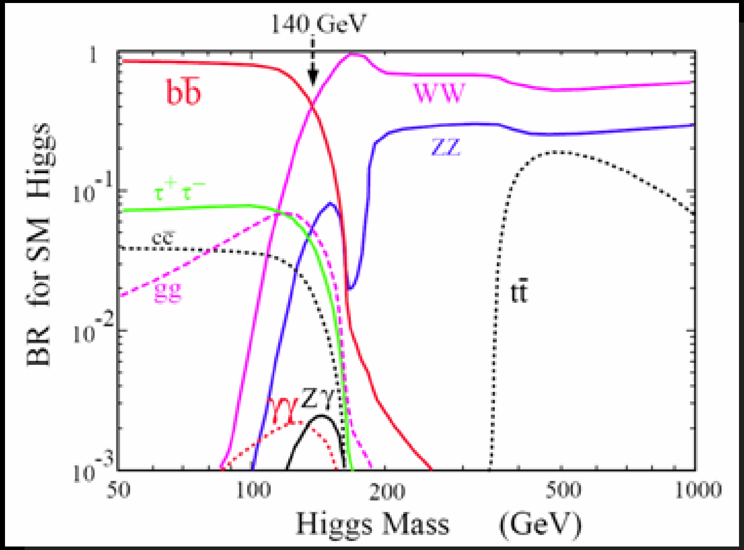
Towards the Higgs

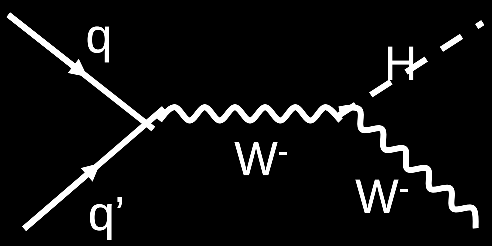
Higgs is very challenging - smaller production cross section than anything we have talked about thus far

Small signal on top of a very large background

Need sophisticated analysis techniques, a suite of triggers, and lots of data







Gluon Fusion

- Dominates in hadron machines
- Low mass: H==>bb backgrounds too large
- High mass: H ==> WW very doable with leptons in final state

Associated Production

- Produced much less frequently
- Easier to search for in final states w/ high pt leptons and MET

CDF Higgs Effort

- Since Fall 2006, the Higgs effort at CDF intensified
  - It became clearer that the Tevatron can deliver enough lum.
  - Established the Higgs Discovery Physics Analysis Group
  - Established a Higgs Trigger Task Force to revisit the entire trigger table to maximize our Higgs acceptance
  - Launched a L2 Calorimeter trigger upgrade to significantly improve acceptance to Higgs in missing energy channels
  - Established several working groups to develop algorithmic improvements to further increase our sensitivity
    - jet-E resolution, b-tagging, lepton acceptance, tools
  - Techniques from other measurements now being incorporated
- Over the last year there's been a dramatic infusion of people, effort and ideas, aimed at finding the Higgs
  - Added well over a dozen new people to analysis since last P5 in September

Example: CDF Higgs Trigger Task Force

To open the trigger maximally for Higgs

Report of the Higgs Trigger Task Force

S. Amerio, A. Anastassov, A. Annovi, A. Apresyan, V. Boisvert, A. Buzatu,
S. Camarda, F. Canelli, A. Canepa, E. Cartman, B. Casal, M. Casarsa, G. Chiarelli,
G. Cortiana, G. De Lorenzo, J. Donini, S. Donati, R. Erbacher, C. Ferrazza,
G. Flanagan, R. Forrest, I. Furic, J. Garcia, O. Gonzalez, C. Group, A. Heijboer,
B. Heinemann, M. Herndon, A. Ivanov, E. James, T. Junk, B. Kilminster,
N. Krumnack, M. Kruse, K. Lannon, S. Leone, J. Lewis, A. Lister, T. Liu, R.-S. Lu,
D. Lucchesi, T. Maruyama, A. Mitra, O. Norniella, C. Neu, E. Nurse, S. Pagan Griso,
E. Pianori, K. Pitts, L. Ristori, V. Rusu, R. St. Denis, L. Sartori, F. Sforza, A. Sidoti,
A. Soha, A. Taffard, S. Torre, P. Totaro, V. Veszpremi, S.-M. Wang, A. Warburton,
D. Waters, R. Wilson, T. Wright, A.M. Zanetti, X. Zhang

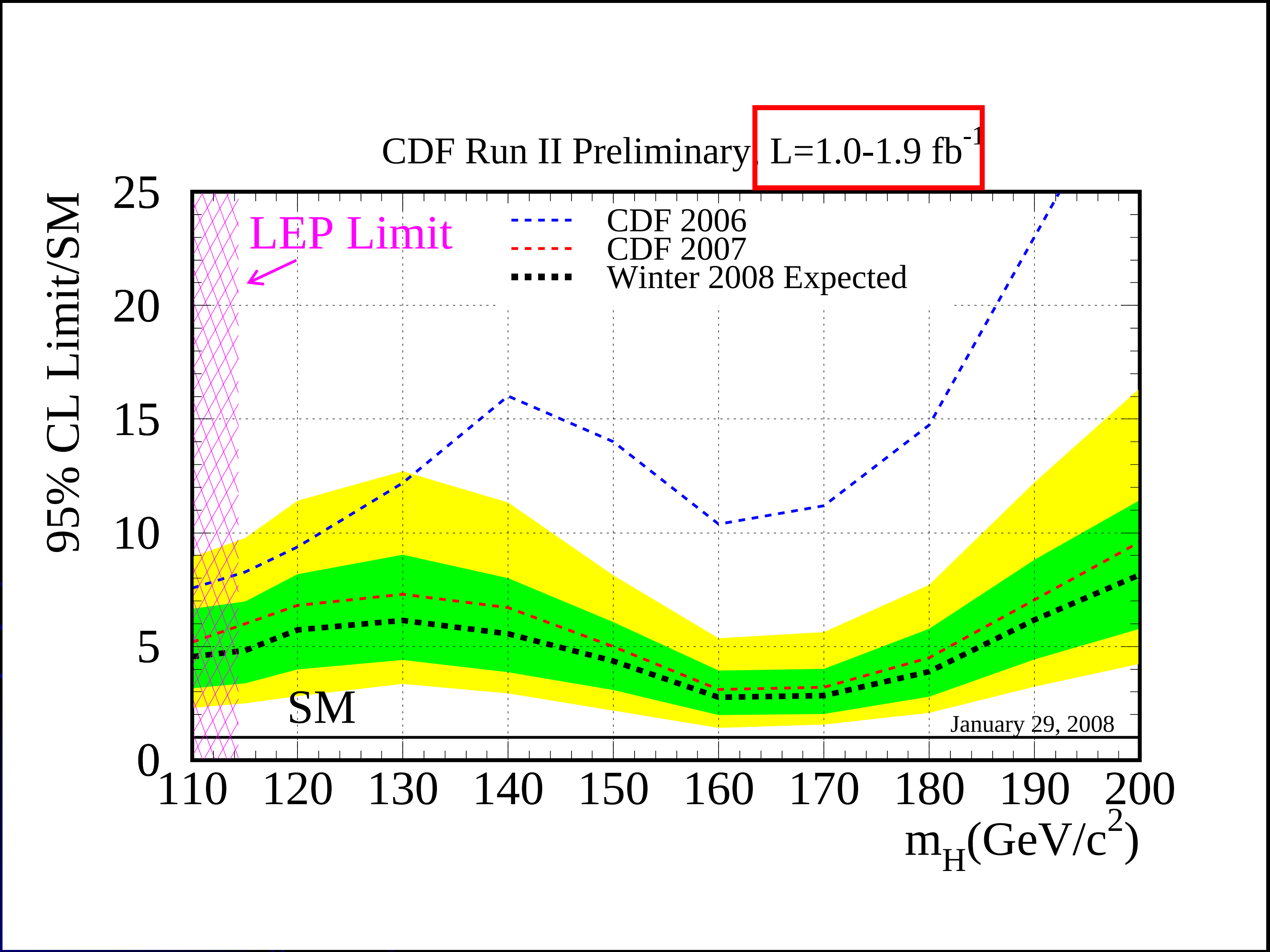
From existing triggers and new ones: expected increase in Higgs events ~ 2X

Abstract

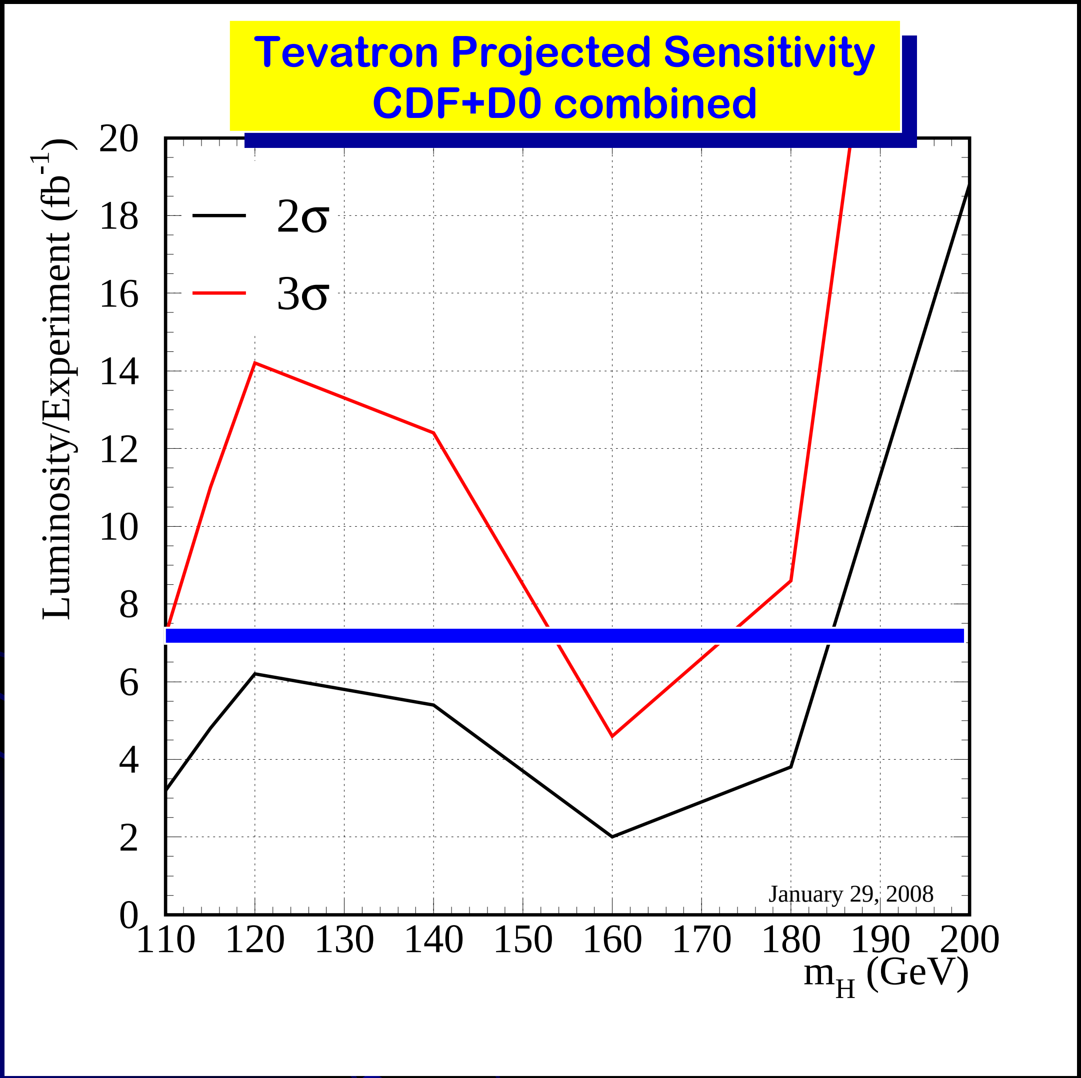
This report outlines a strategy on how to trigger on the Higgs boson in the most optimal way for the remainder of CDF Run II. Taking advantage of the CDF Run 2b trigger and data acquisition upgrades, we find that we can improve the purity of our triggers and significantly improve our acceptance for the Higgs.

CDF's Progress

Factor away in sensitivity from SM



Tevatron Higgs reach with FY10 run



With 7 fb^{-1} analyzed

- exclude all masses !!! [except real mass]
- 3-sigma sensitivity 155:170 LHC's sweet spot

We find this very compelling

SM Higgs Projections

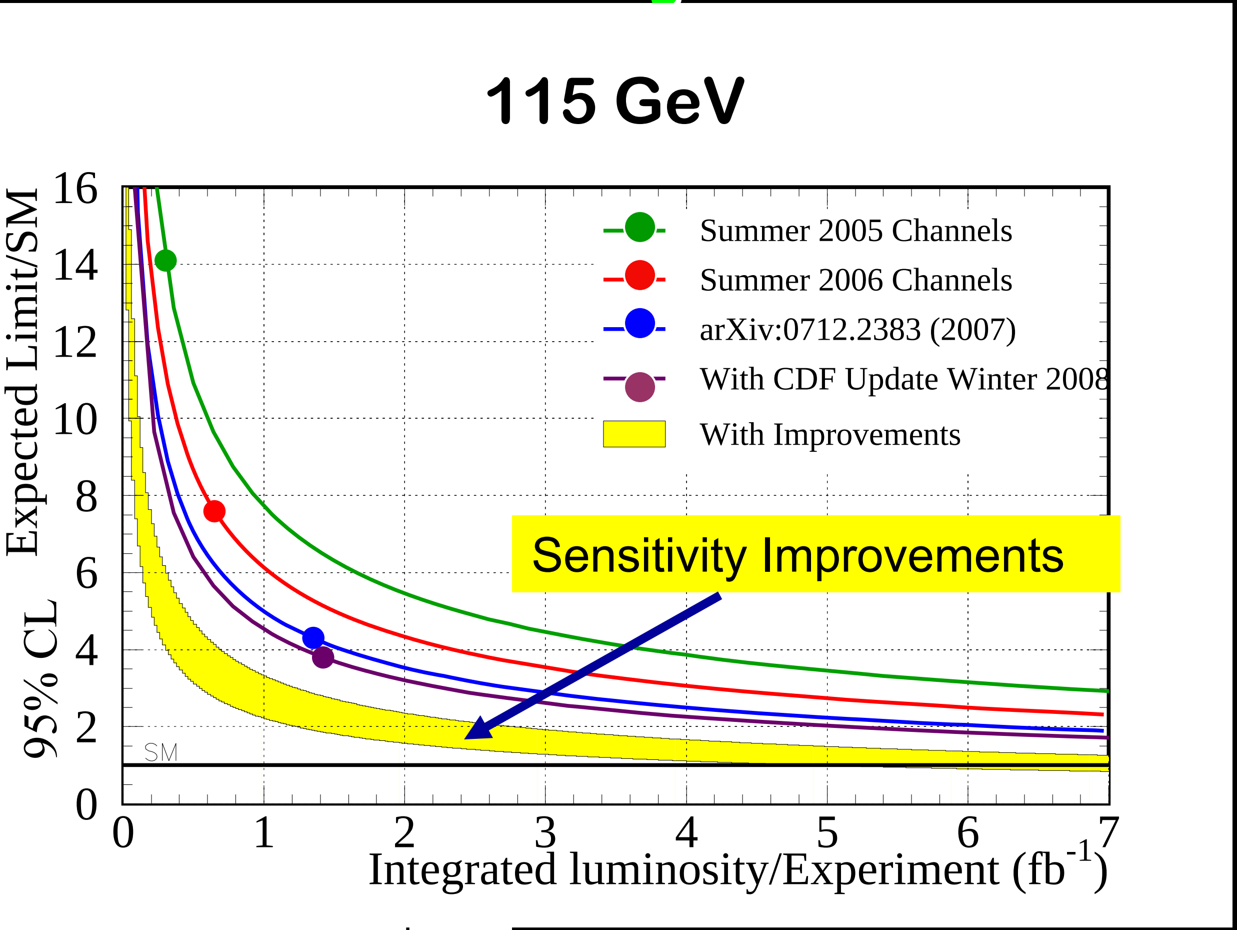
- Revisited and presented to P5 in Sept.
- Only with improvements benchmarked in data
- Two sets of projections
  - “Minimum achievable”
    - Improvements that have been incorporated in one channel and need to be propagated to all channels
  - “Further achievable”
    - Advanced stage but not yet on any analyses

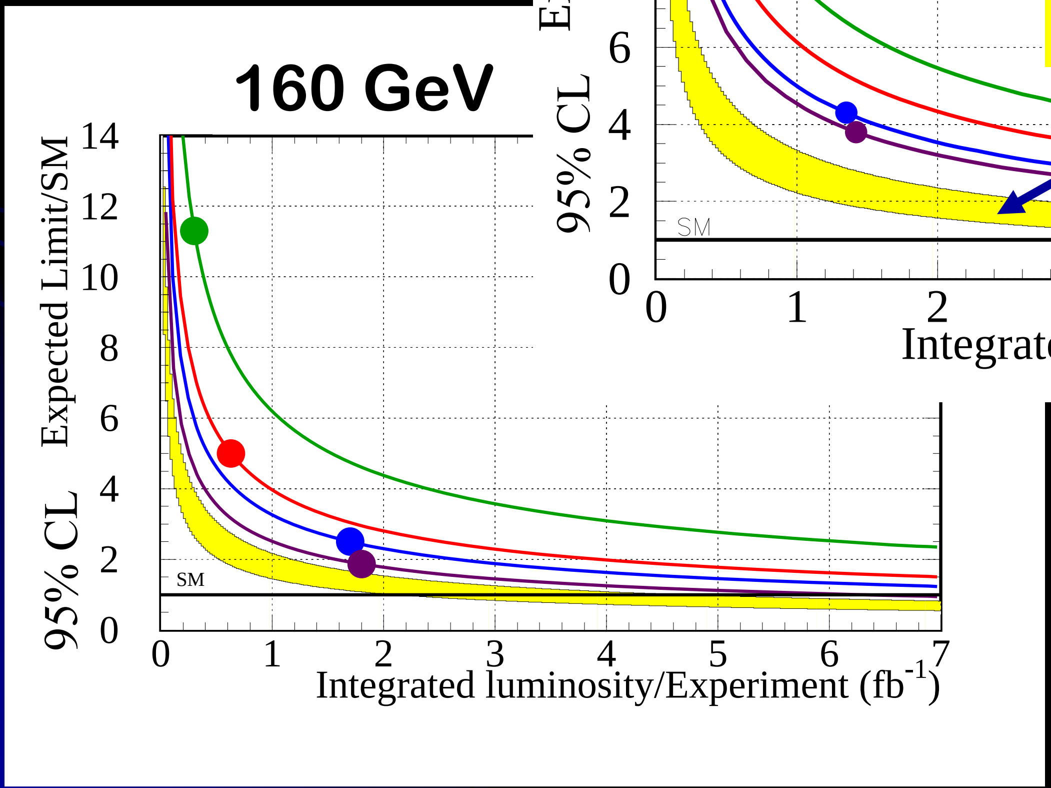
For each “projection category” we estimated x1.5 improvement in sensitivity for all masses

Higgs Status and Projections

CDF+D0 Combined

We continue to make significant progress

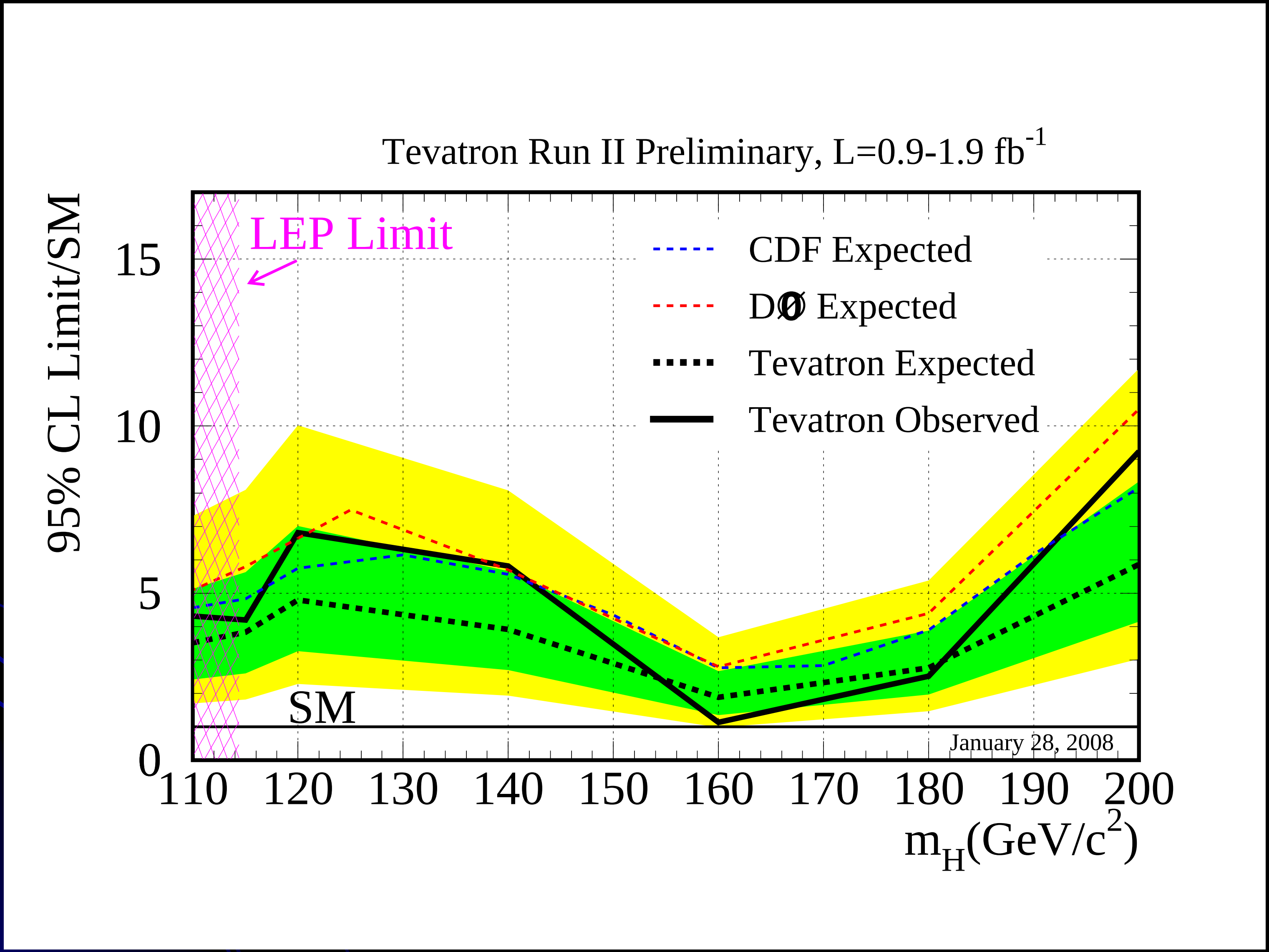




Analyzed Lum

Combined status plot

Factor away in sensitivity from SM



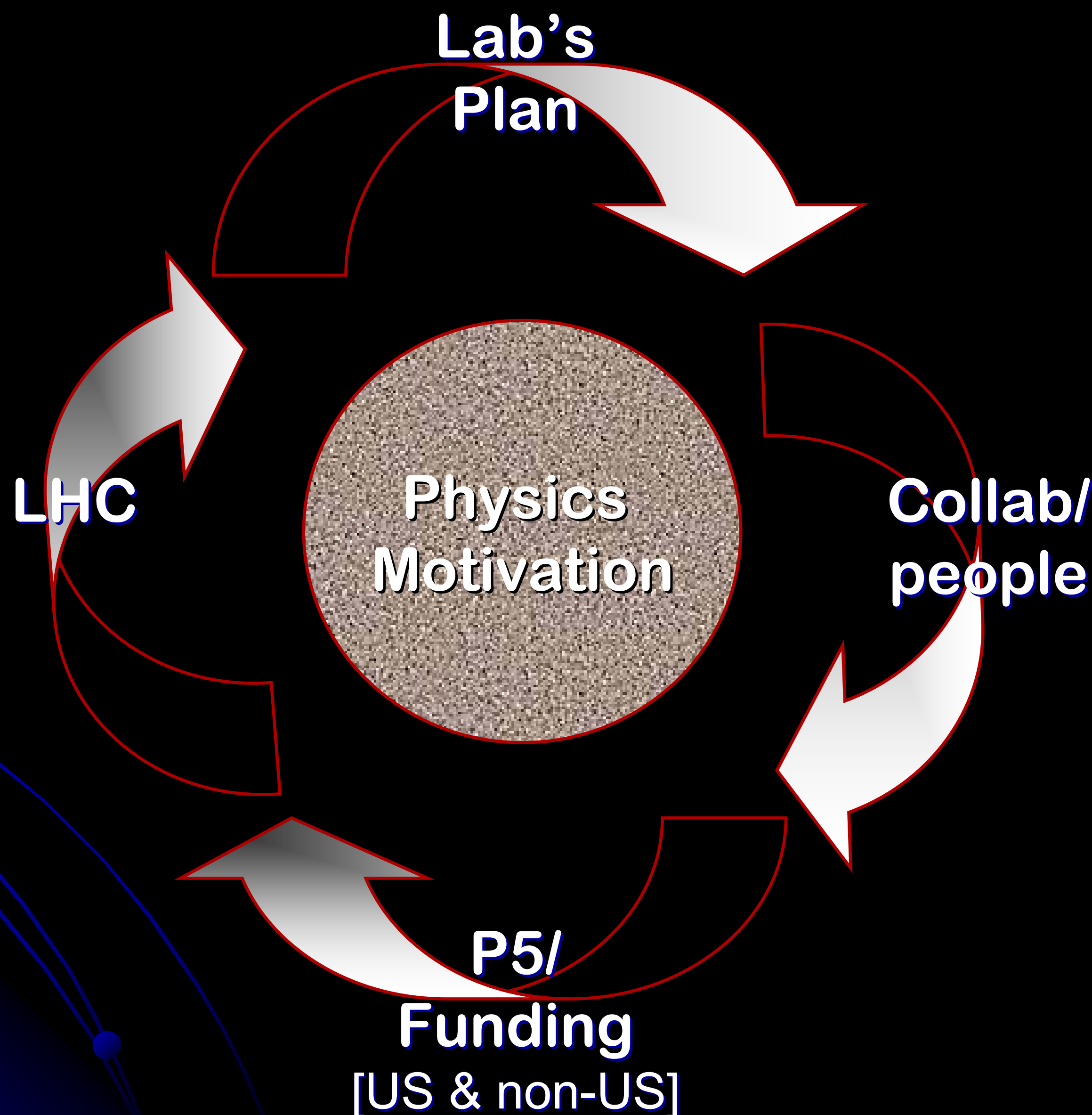
CDF's Private Combination, not endorsed by TEVNPHWG

Aside: notes on possibility

- We already have “fluctuations” in the data
- Which one is from a real new physics source?
- The top discovery experience at CDF:
  - 19 pb-1 ~3-sigma EVIDENCE with 13 l+j evts, 2 dileptons
  - 19-40 ~ pretty barren
  - 40-67 a lot more… DISCOVERY
    - Which third are we in today?
- Some existing new physics sources might not yet have revealed themselves - but we could still gather sufficient #’s of events for a discovery before the end of Run 2
- Some may already be there
- Who knows for sure today?

→ let’s keep the door open

Running in 2010



Conclusions

- The CDF detector will operate well through FY10
- Collaboration committed through FY09 and beyond if given sufficient time to plan
- We have a very rich and exciting and physics program
  - Windows of research continue to open up with these large datasets
  - Higgs search needs data + a large effort
    - The effort is under our control and is well matched, the size of the data set is up to all of us to decide.
  - There is discovery potential -in general- as we gather more data
  - Improvements are continuously coming into the game
- An 8 fb-1 program is well motivated, compelling, and achievable

Backup

Low Mass Higgs (115 GeV)

Minimum Achievable Improvements

- 25% b tagging (improved usage of existing taggers)
  - Into ZH=>llbb and VH=>MET+bb [~1.1]
    - Implemented in WH=>lnubb Summer'07
      - + 1.1 in sensitivity from single-tag category [x1.1]
- 25% trigger acceptance (pre-existing triggers)
  - Into ZH/WH => llbb, lnubb (with forward-e [x1.1], muons not yet)
    - Completed S vs B studies
- 20% from advanced analysis techniques studies & better usage of MET
  - Into MET+bb and lnubb [x1.1]
    - Implemented in ZH=>llbb Summer'07

%'s are in sensitivity

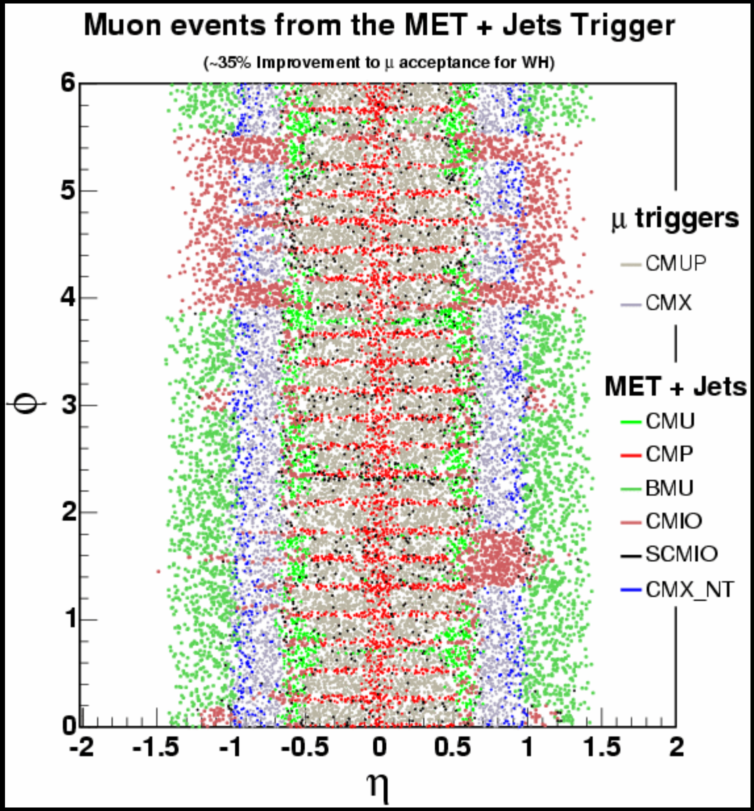
Achieved 1.5X in Sensitivity √

Low Mass Higgs (115 GeV)

%'s are in sensitivity

Further Achievable Improvements

- 25% b tagging (NN-based)
  - All channels
    - Tagger in advanced stage
    - Efficiency studied
- 25% trigger acceptance
  - More pre-existing triggers [1.25]
    - Based on HTTF studies
- 10% Tau channels (hadronic)
  - Solidified studies further [1.1]



Good progress on additional x1.5 sensitivity

Status:
- Btagging still work in progress
- Trigger and Tau progressed and promoted to "Minimally Achievable"

High Mass Higgs (160 GeV)

Range of achievable improvement

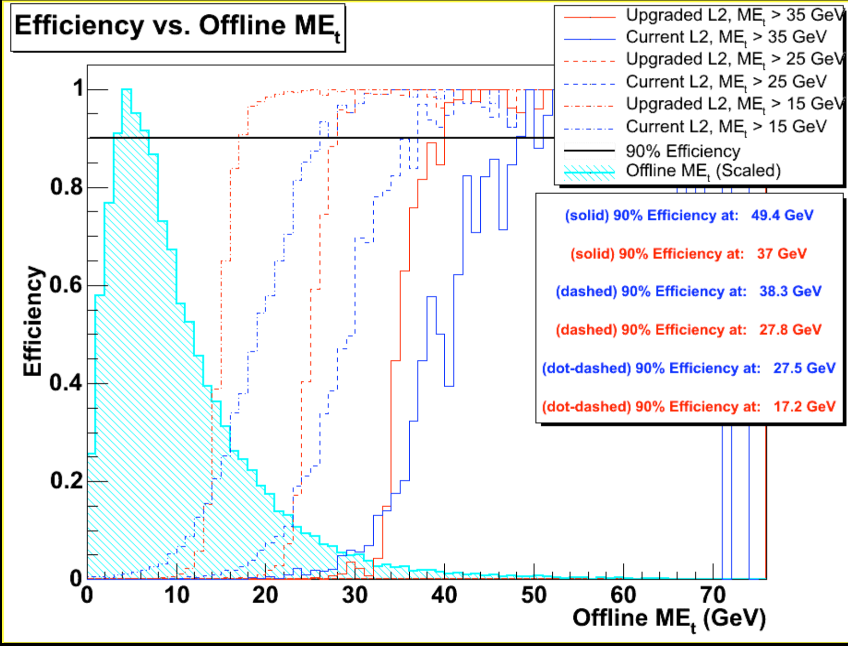
%'s are in sensitivity

- 10-20% (from ME+NN)
  - Done
- 25-40% VH=>VWW and VBF (jj in final state)
  - Expect good S/B
  - 20% by Winter Conferences
- 10-20% from hadronic taus in W decay (including+better id)
  - Ongoing studies
- 10-15% more triggers (existing triggers)+ more leptons

Expect to achieve 1.5X in Sensitivity by Winter Conf.

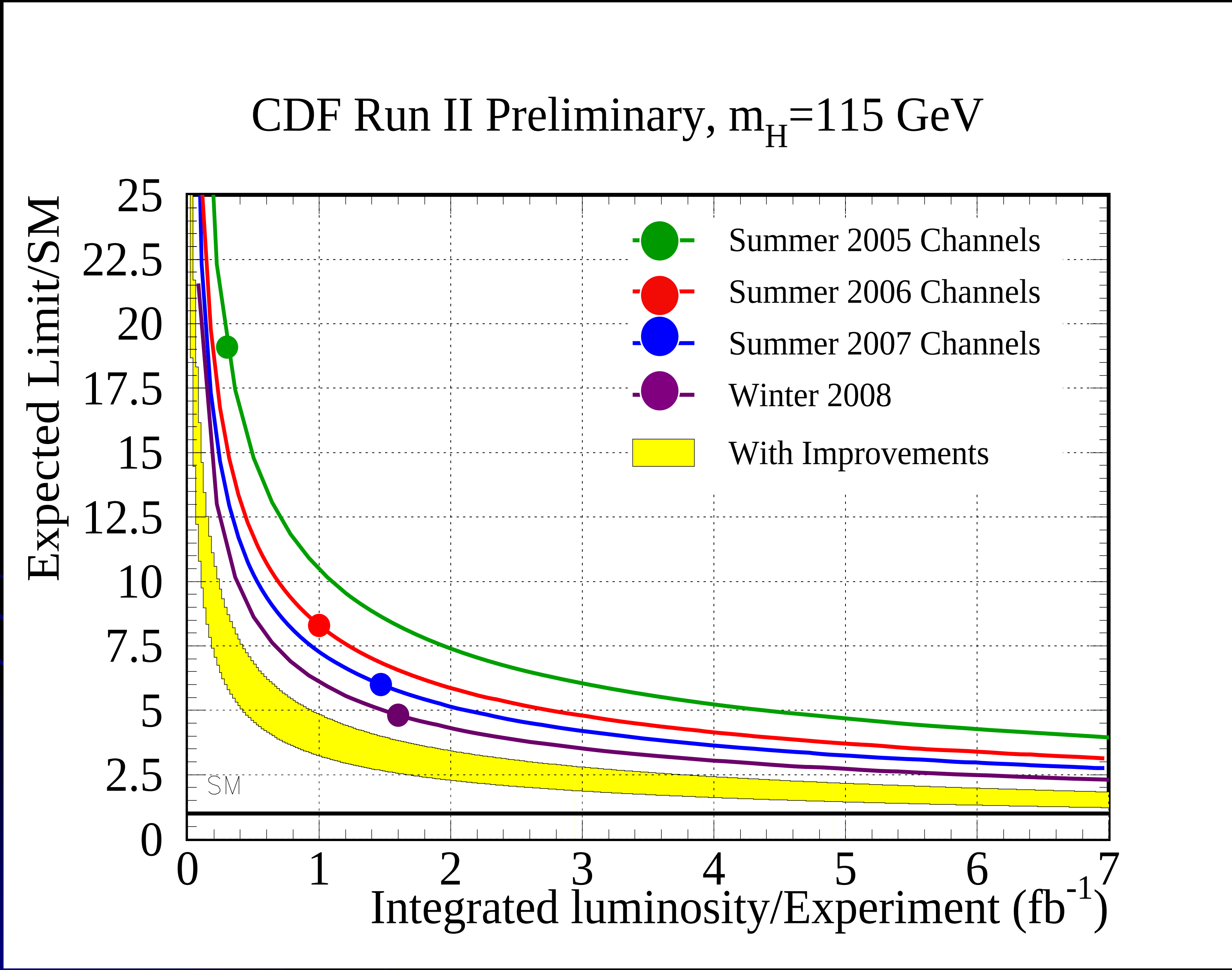
Other work in progress

- New triggers from L2 Cal upgrades and new paths from HTTF
  - In the works: sharp MET efficiency turn-on
- Forward tracking and forward b-tagging
  - Tracking is advanced, b-tagging is not yet
- High-pt b-tagging triggers
  - A team working on it
- Improve bb mass resolution
  - Task force with HDG
- WZ/WH channels with W,Z=> jets
  - Advancing
- Other ideas we have
- Other ideas that we'll have

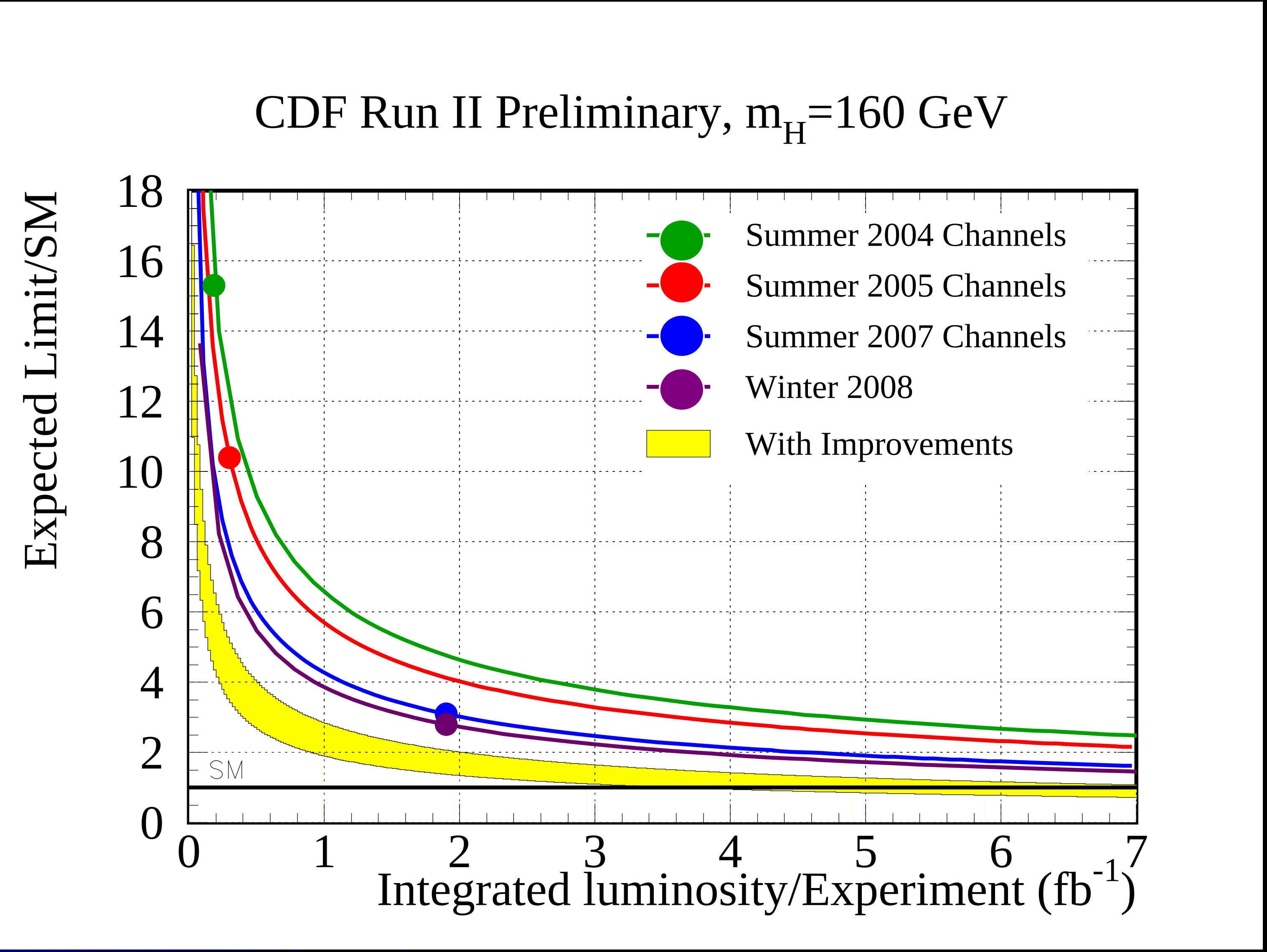


None of this is included [yet] in the "minimum" or "further" achievable improvement factors

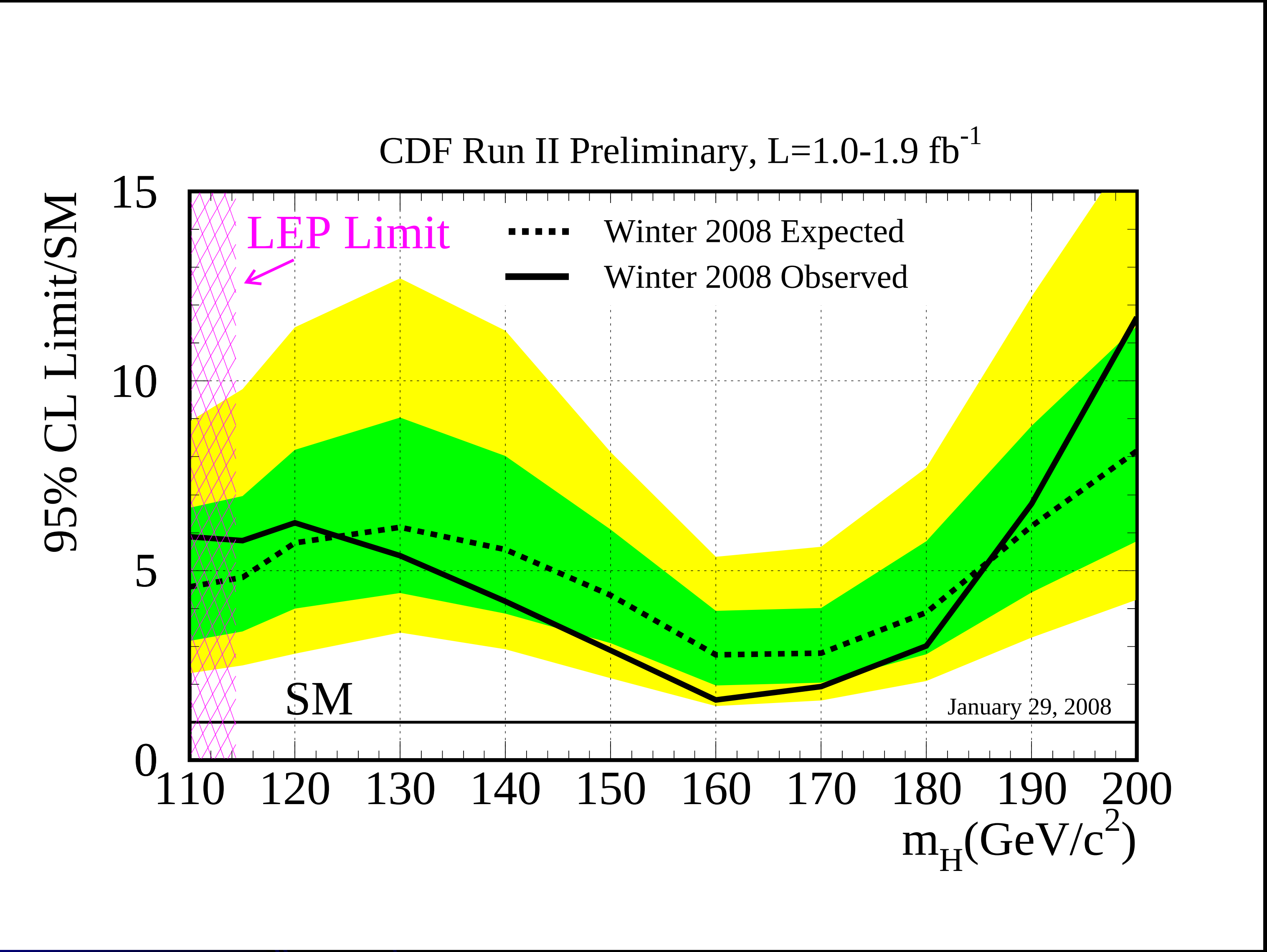
Need both the improvements and the luminosity



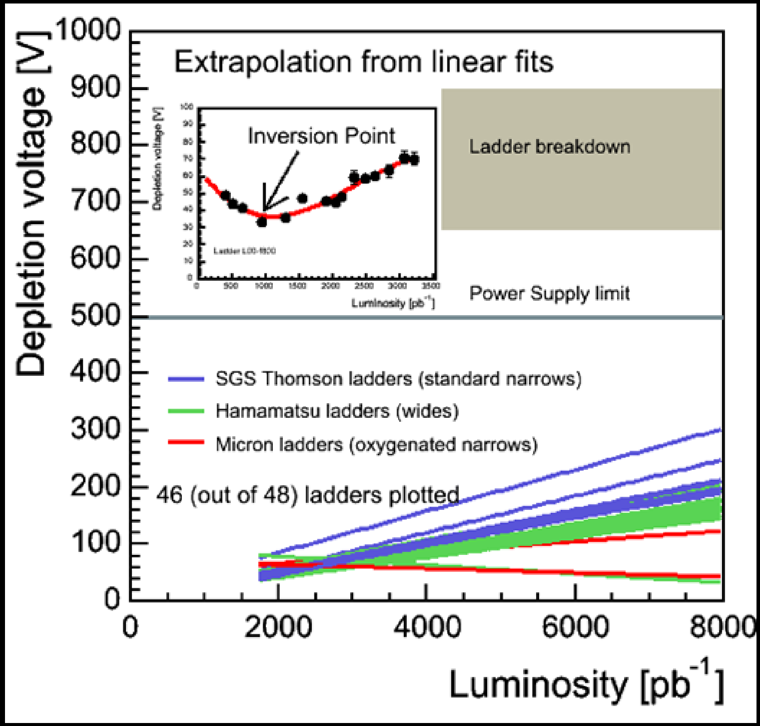
Need the improvements and the luminosity



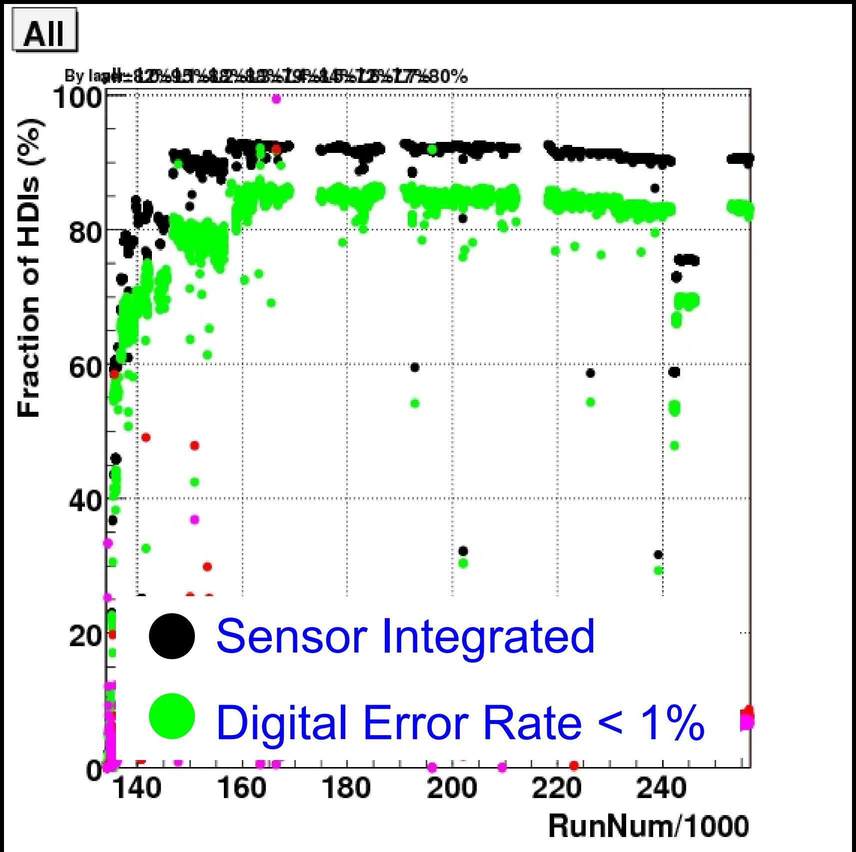
CDFs Current Status



Silicon status & lifetime



- Sensors used for physics lies in between green and black



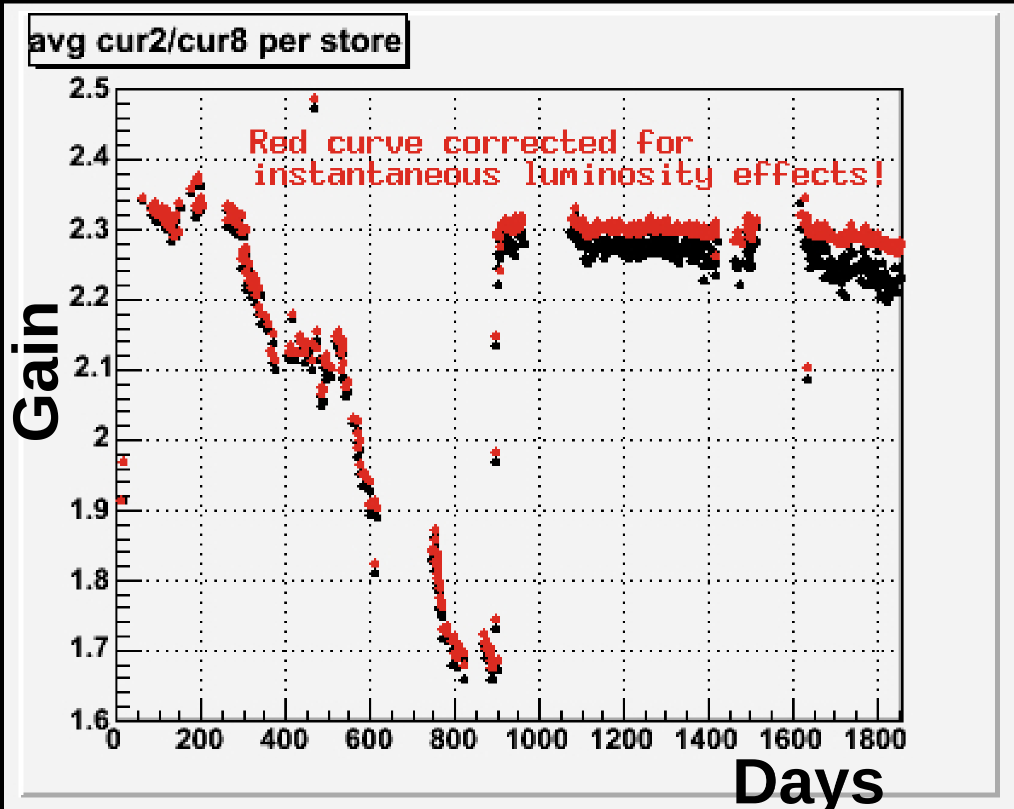
- Layer 00 of SVX II inverted at about 1 fb-1
- Data from signal scans indicate that it will function well past 8 fb-1

Silicon should operate well for the duration of Run 2

Central Outer Tracker

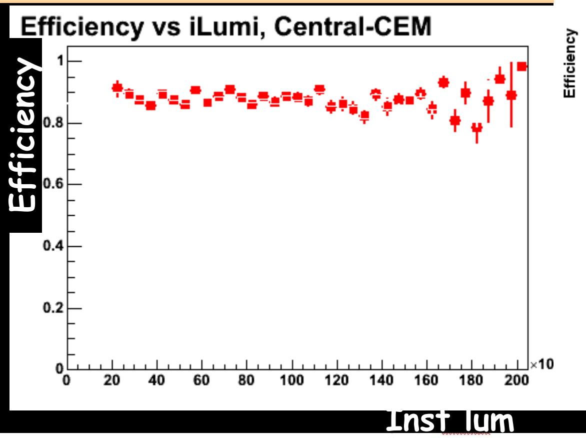
Central Outer Tracker aging problem was successfully addressed in 2004

- Hydrocarbon growth on wires affected gain
- Addition of O_2 to gas in June 2004 to correct problem
- Further Precautions
  - Gas purification system to cleans re-circulated gas
  - Boosted O_2 from 70 to 100ppm

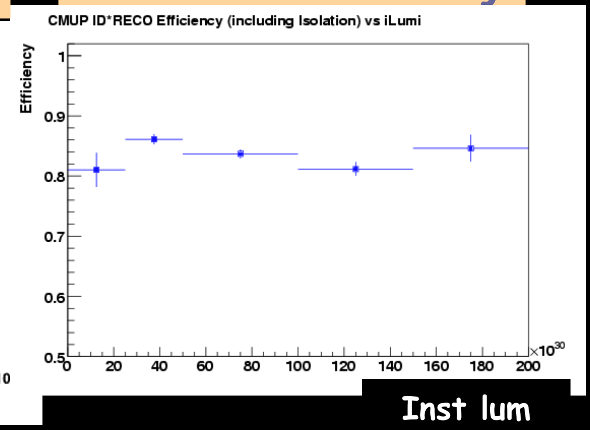


Physics at High Luminosity

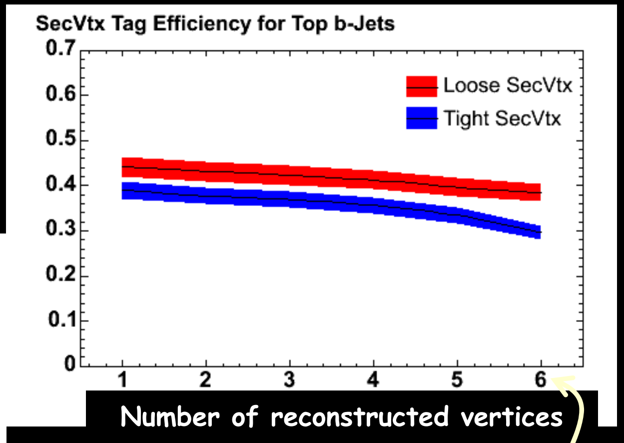
Electron ID efficiency



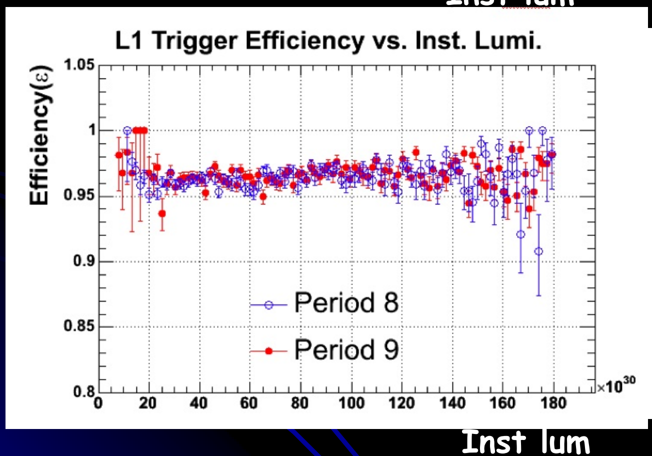
Muon ID efficiency

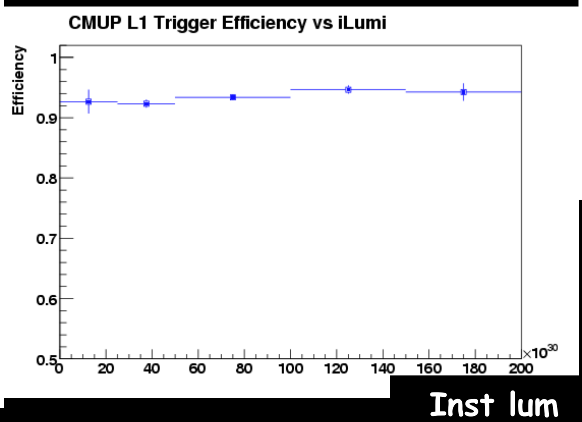


b-tagging efficiency



~3e32



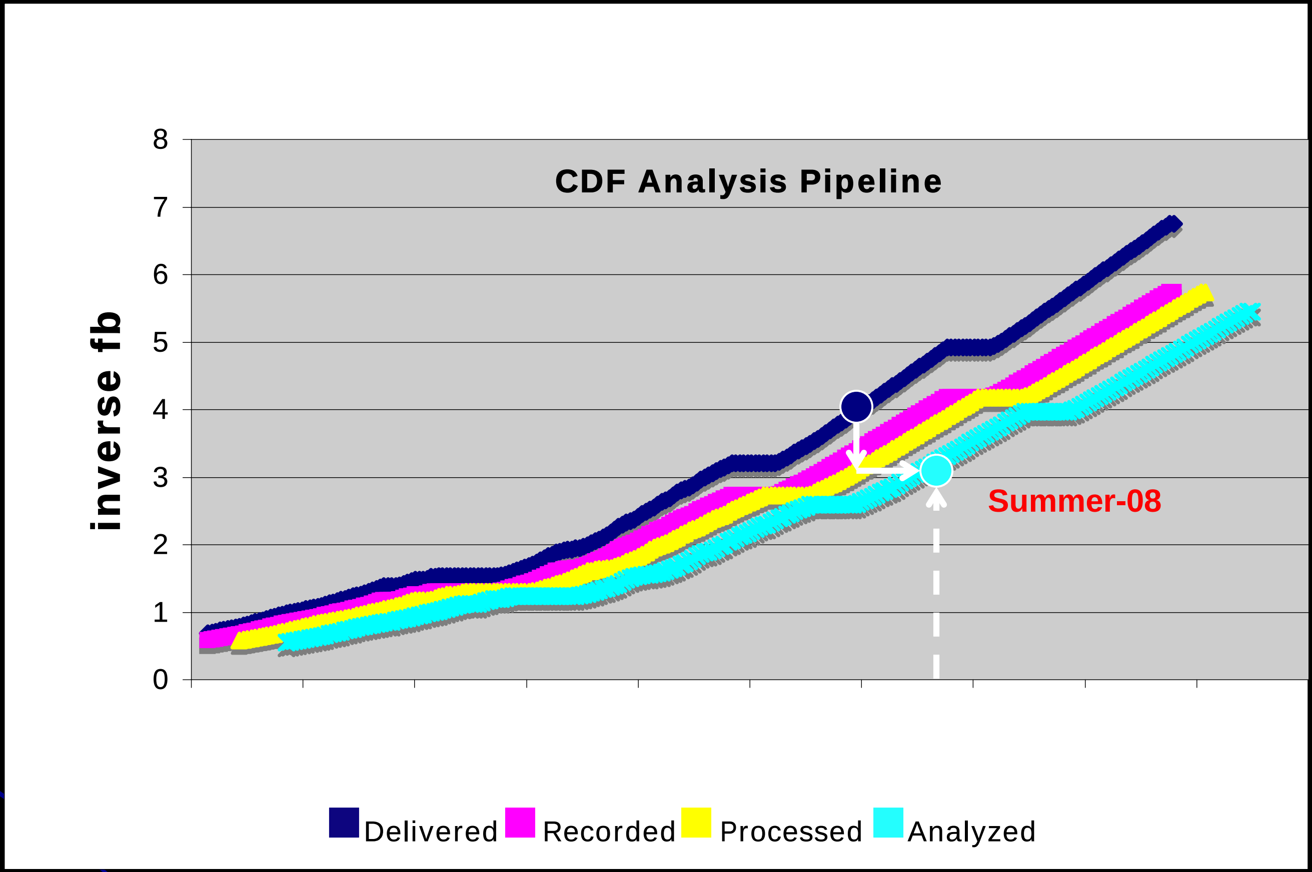


Electron L1 trigger eff.

Muon L1 trigger eff.

Physics at high luminosity is under control

From data taking to public results



Expect 3 fb^{-1} results for Summer 08

The Need for Expediency

- <u>Example:</u> The CDF International Finance Committee met last Tuesday, October 30th
  - Includes representatives from the funding agencies from all non-U.S. countries that participate in CDF

- Statements from committee on running in FY10
  - Impressed with the program
  - Impressed with the health of the collaboration and the experiment
  - <u>Will support running in FY10 if their groups want to do this</u>

  - But funding for 2010 not requested yet. Need to know Fermilab's plan to be able to make requests in the next funding cycle
    - For many, this is spring 2008

- Question to the community: how soon can we make this plan firm?

History of CDF Path to First Physics

- First Collisions March 2001
- Detector declared ready for physics Feb 2002
- In that 1 year
  - Detector conditions changing rapidly
  - Calibrations, energy scale and alignment with beam all had to be done
  - Learning how to operate detectors with beam
  - Solving hardware, trigger & DAQ problems that only showed up with radiation and random event lengths
- Then integrated physics quality data with stable detector, performed analysis and published
  - First physics results ICHEP'02
  - First ~10 papers were all lepton based
    - 6 pb^{-1} published in July'03
      - Peak lum ~ 30E30
    - 200 pb^{-1} published Apr'04
      - Peak lum ~ 55E30