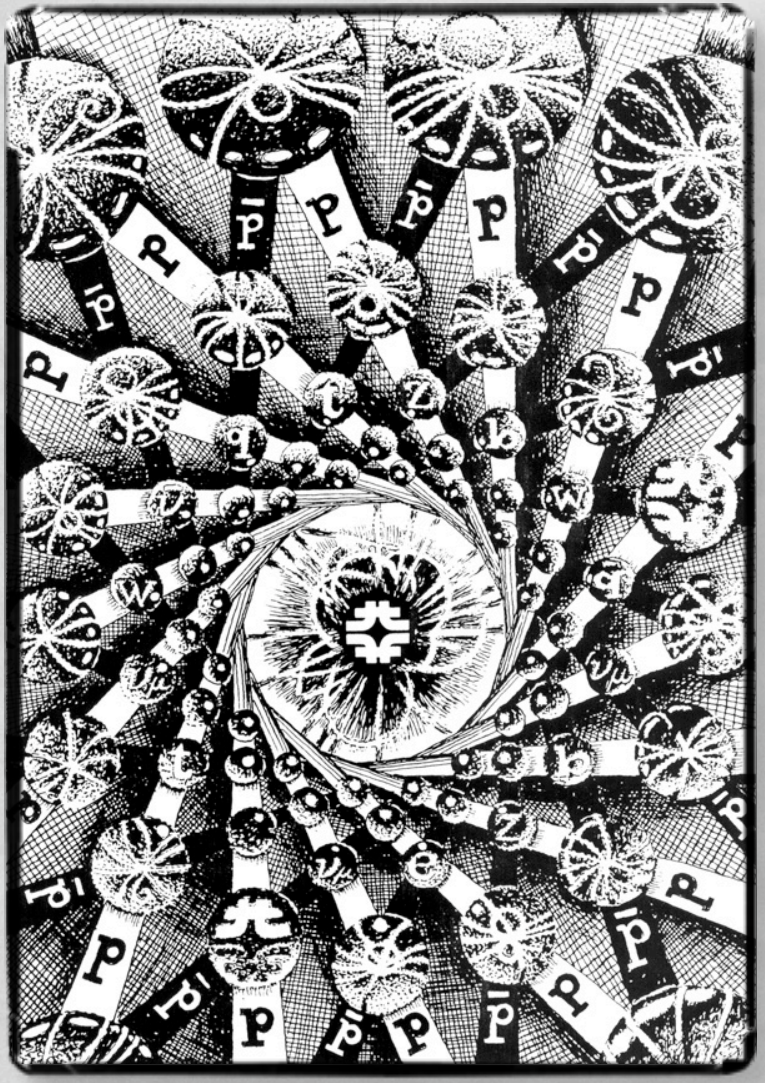
Outlook for the Tevatron

Jacobo Konigsberg, Univ. of Florida

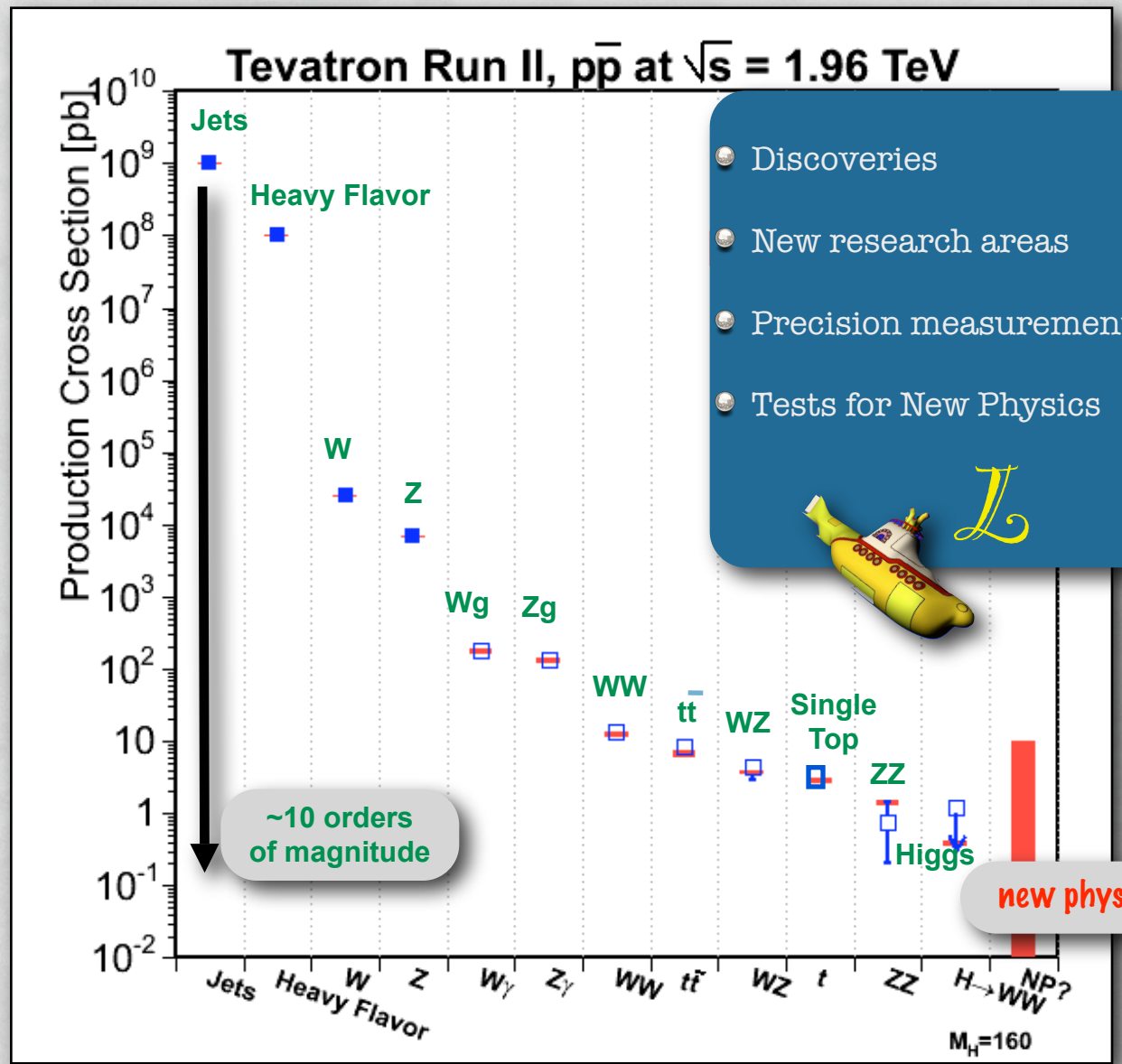
HCP, Evian, 20 Nov. 2009

Quite a story so far !



- Discoveries
  - New elementary particles
  - New composite particles
  - Rare SM processes
  - Subtle behavior
- New research areas
- Precision measurements
- Tests for New Physics

A Luminosity Story



- Discoveries
- New research areas
- Precision measurements
- Tests for New Physics

The Tevatron Physics Program

- Precision, new research, discoveries
  - Mixing, CKM Constraints, and CP-Violation
  - Heavy Flavor Spectroscopy
  - New Heavy Baryon states
  - Tests of QCD and HF production
  - Top-quark and W-boson Masses
  - Top quark properties
  - Di-Boson production and SM Gauge Couplings
  - New exclusive/diffractive processes
- Unique window into the unknown
  - Searches for Supersymmetry, Extra Dimensions, Exotica
  - Still at the Energy Frontier
    - Probing the Terascale as the luminosity increases
- The Standard Model Higgs is now within reach !

We're addressing questions of fundamental importance

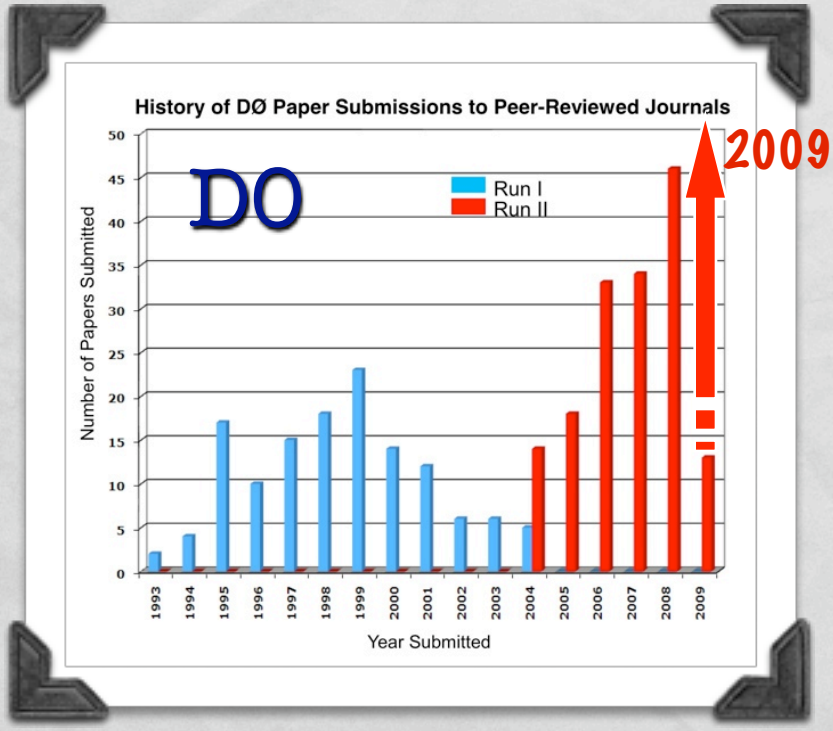
The Tevatron Physics Program

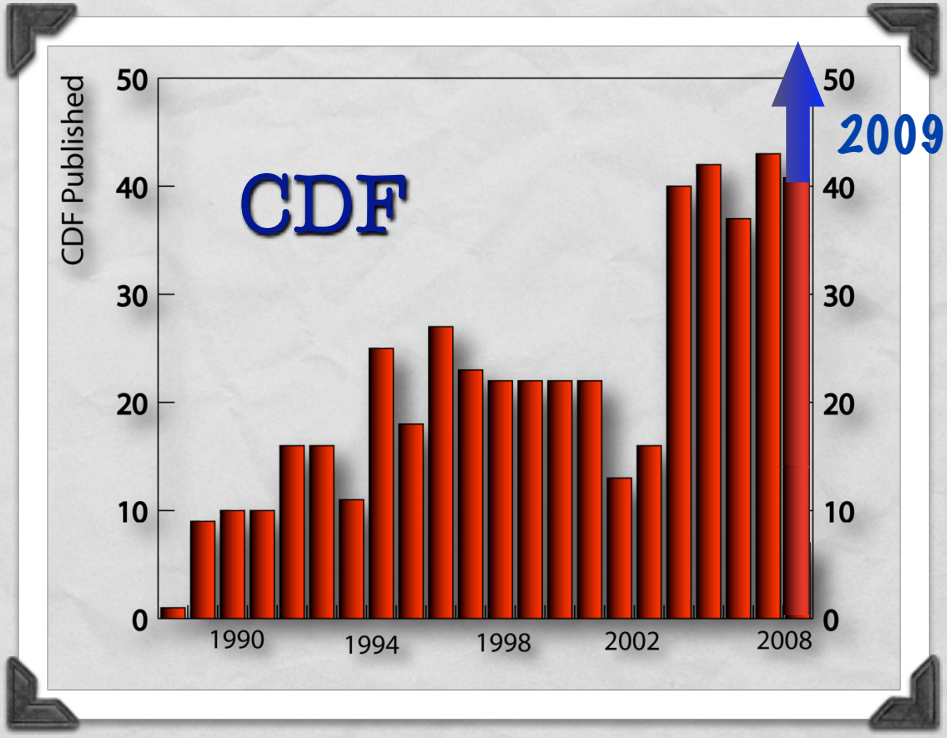
- Precision, new research, discoveries
  - Mixing, CKM Constraints, and CP-Violation
  - Heavy Flavor Spectroscopy
  - New Heavy Baryon states
  - Tests of QCD and HF production
  - Top-quark and W-boson Masses
  - Top quark properties
  - Di-Boson production and SM Gauge Couplings
  - New exclusive/diffractive processes
- Unique window into the unknown
  - Searches for Supersymmetry, Extra Dimensions, Exotica
  - Still at the Energy Frontier
    - Probing the Terascale as the luminosity increases
- The Standard Model Higgs is now within reach !

See the excellent presentations given at this workshop

Tevatron Physics Output

- Stable tools and well understood detectors and data

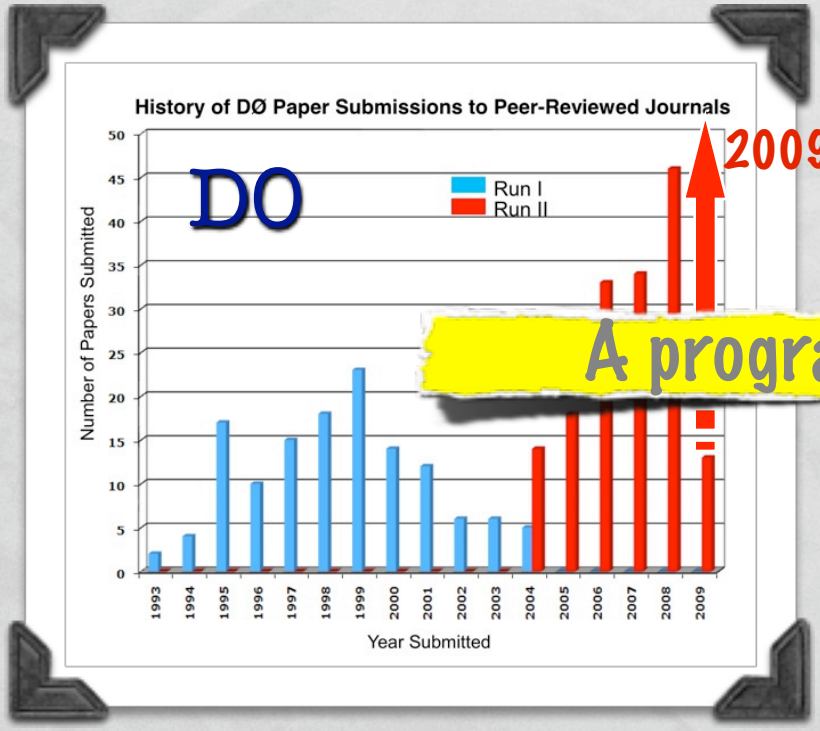


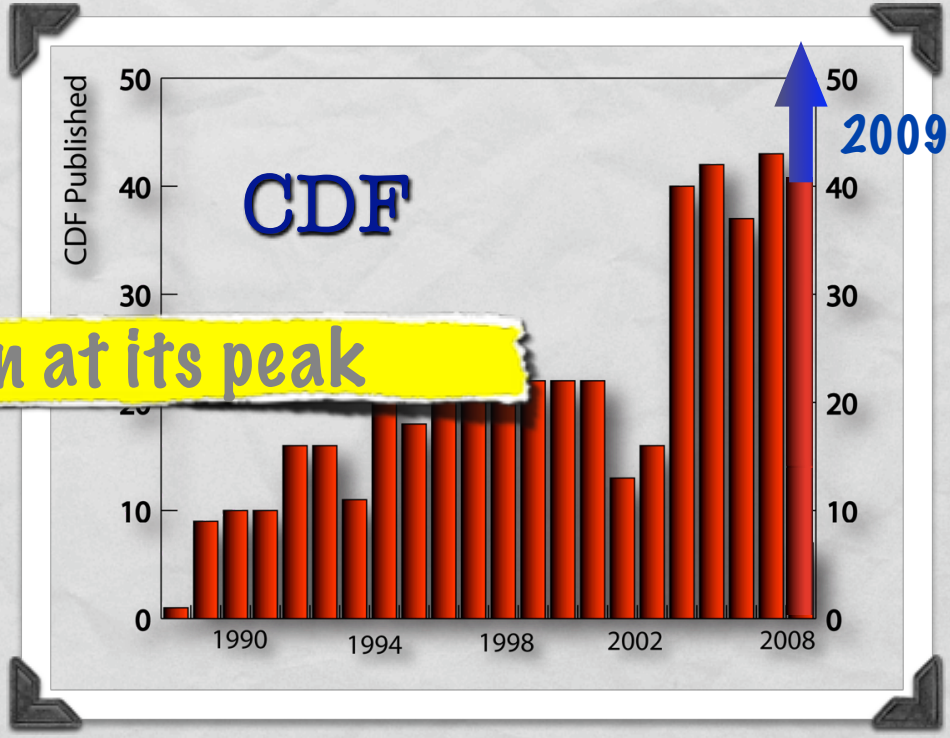


- Reached about 50 journal publications/experiment/yr
- About 60 Ph.D.'s / year over the last few years
- 80 new results Winter'09 => Summer'09
- And many new ones already for HCP

Tevatron Physics Output

- Stable tools and well understood detectors and data



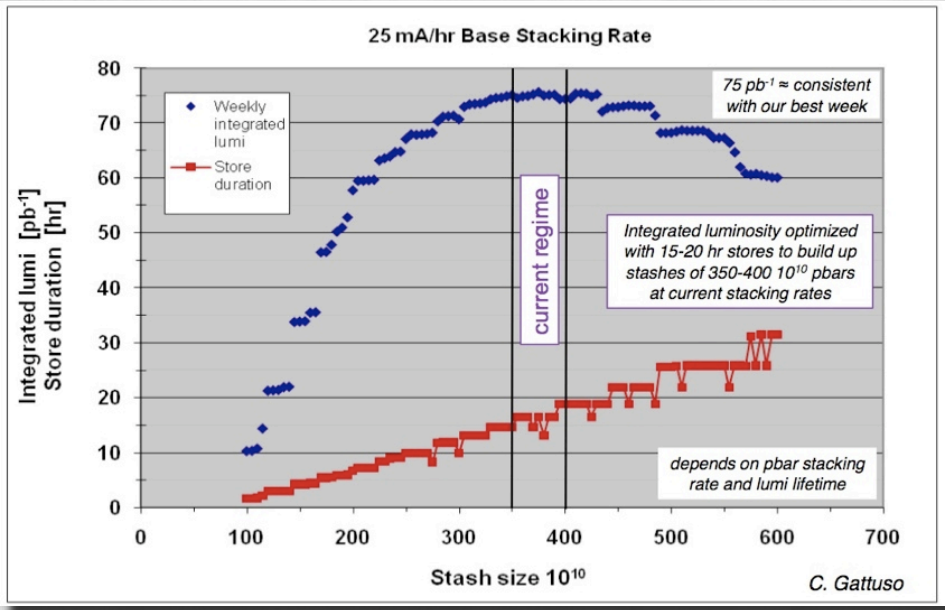


A program at its peak

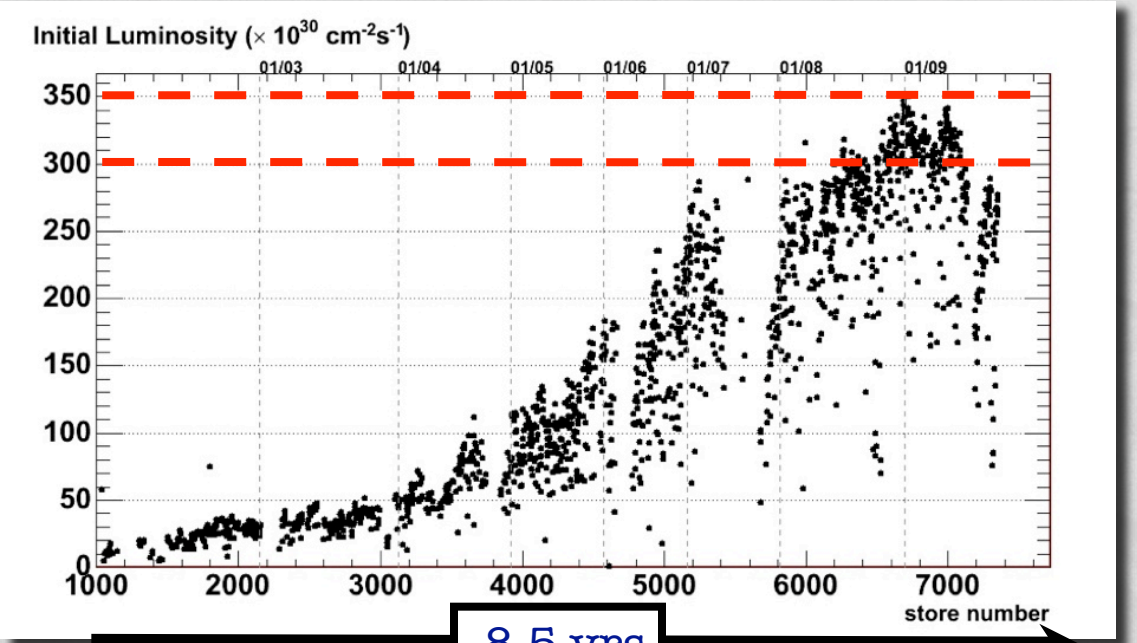
- Reached about 50 journal publications/experiment/yr
- About 60 Ph.D.'s / year over the last few years
- 80 new results Winter'09 => Summer'09
- And many new ones already for HCP

The road ahead

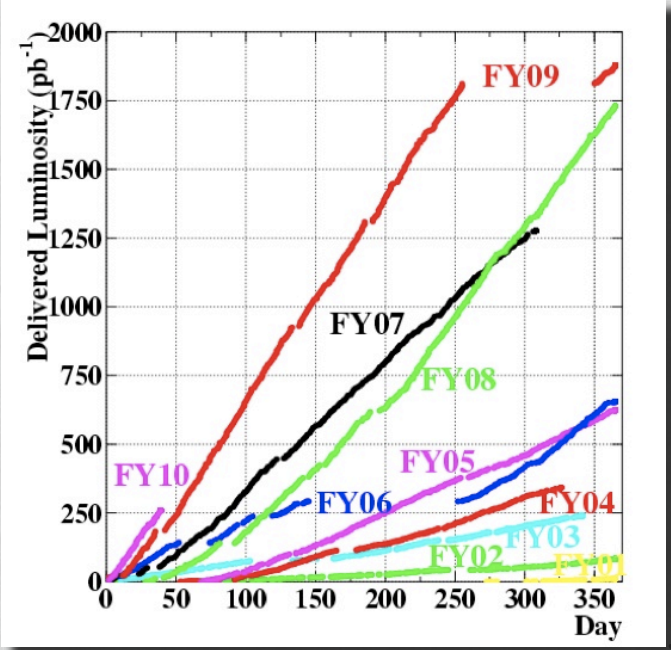
The Tevatron



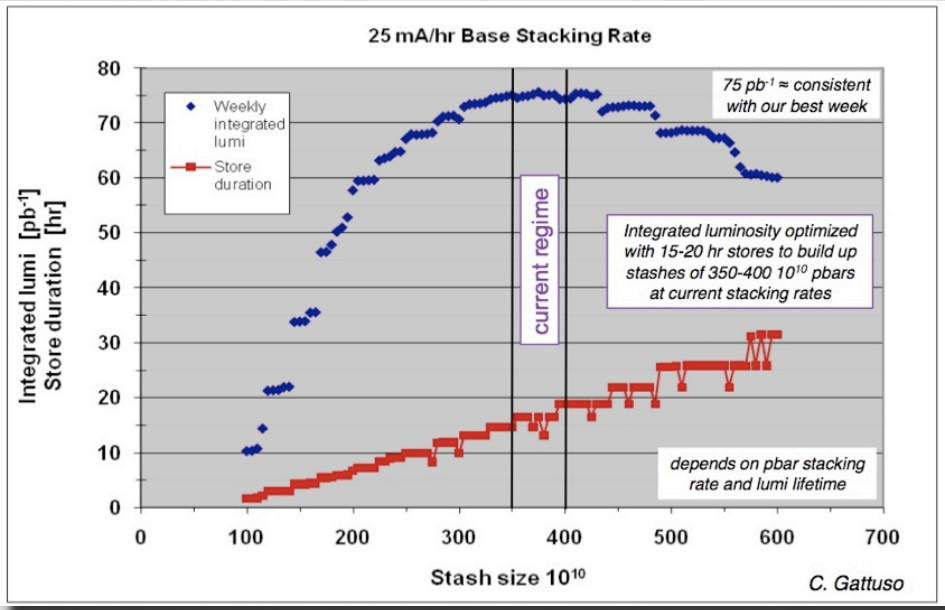
Tevatron's luminosity is optimized



8.5 yrs

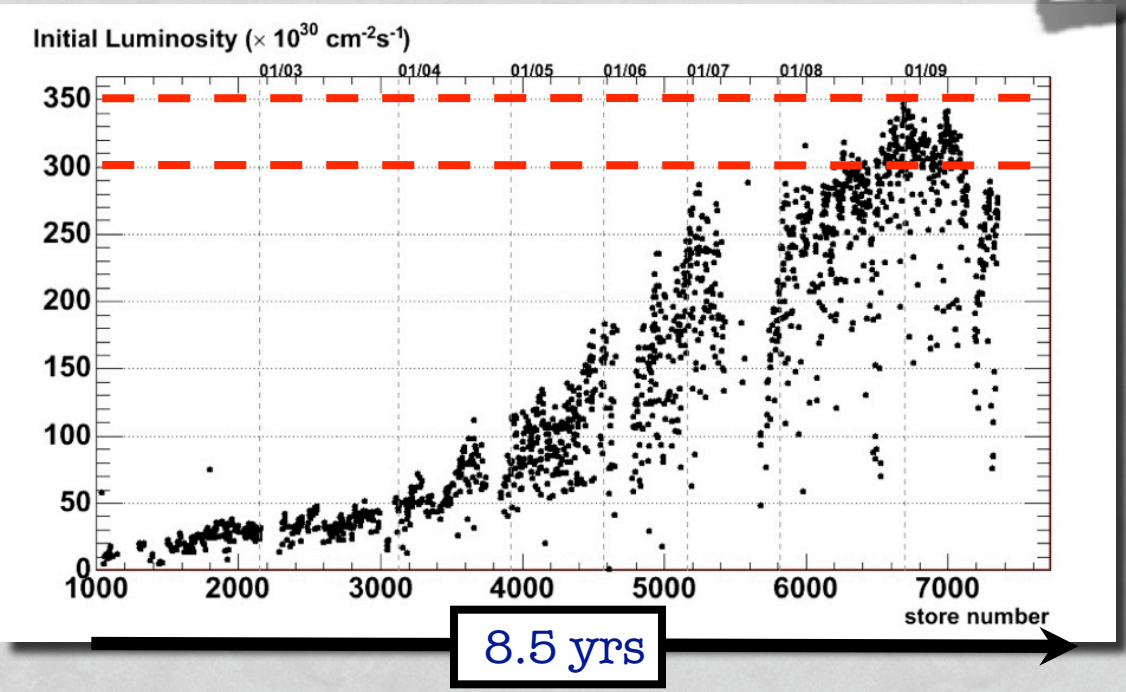


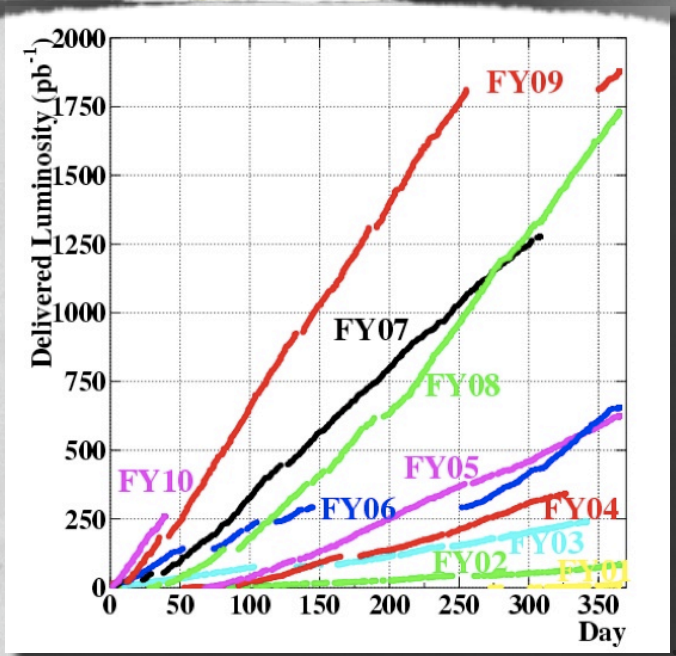
The Tevatron



Tevatron's luminosity is optimized

Can deliver ~2.5 fb^{-1}/year

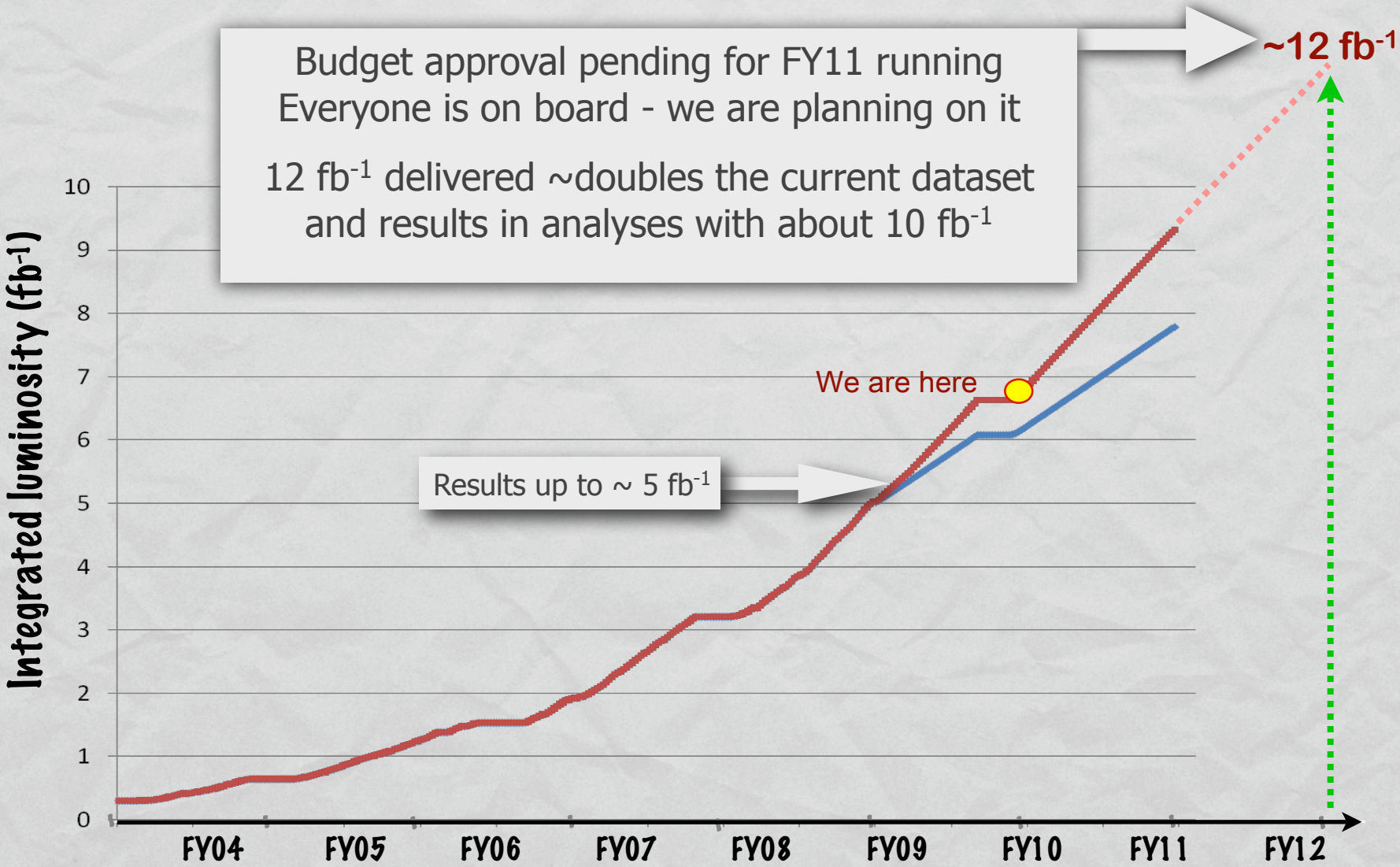




Luminosity Outlook

Budget approval pending for FY11 running
Everyone is on board - we are planning on it

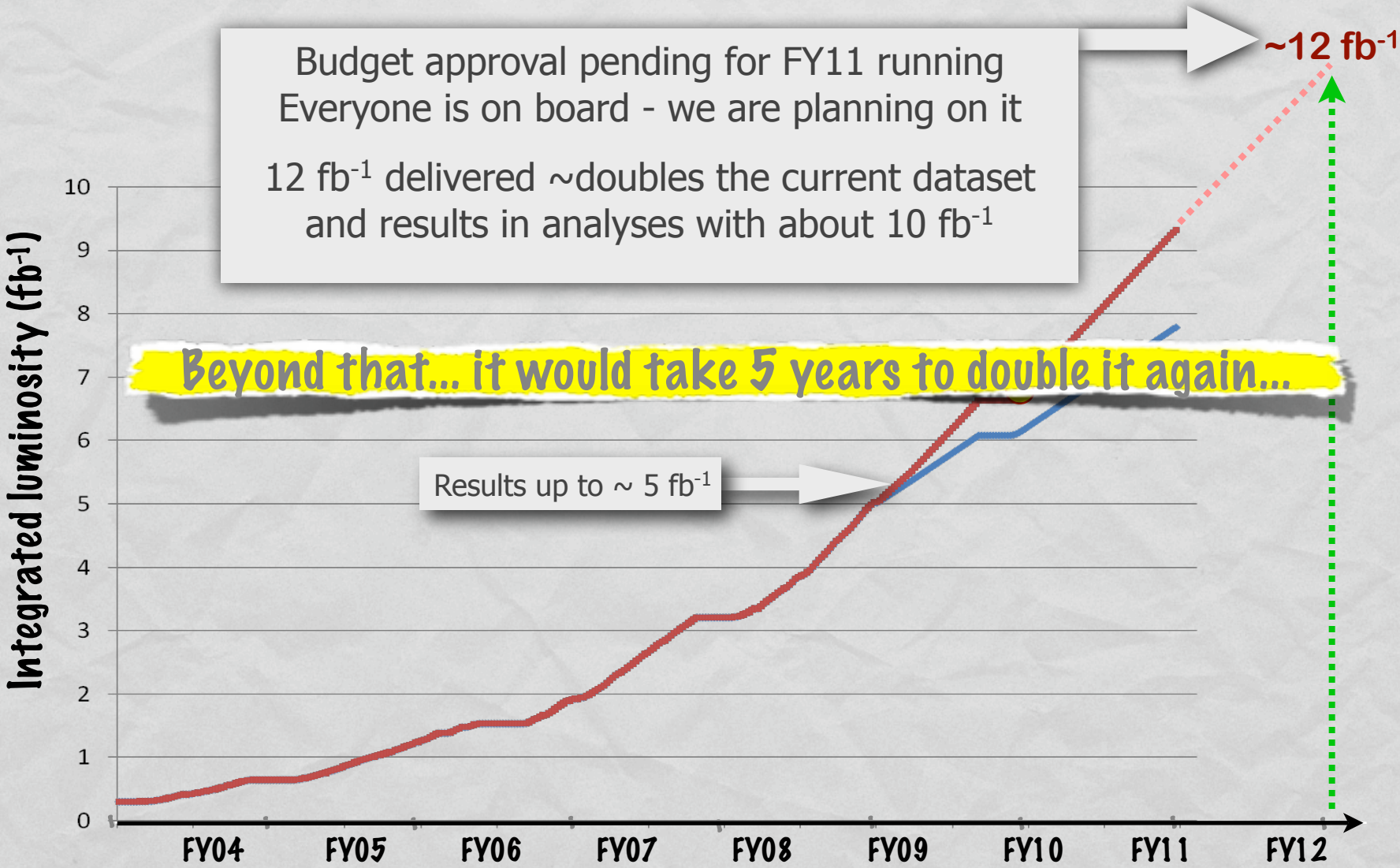
12 fb^{-1} delivered ~doubles the current dataset and results in analyses with about 10 fb^{-1}



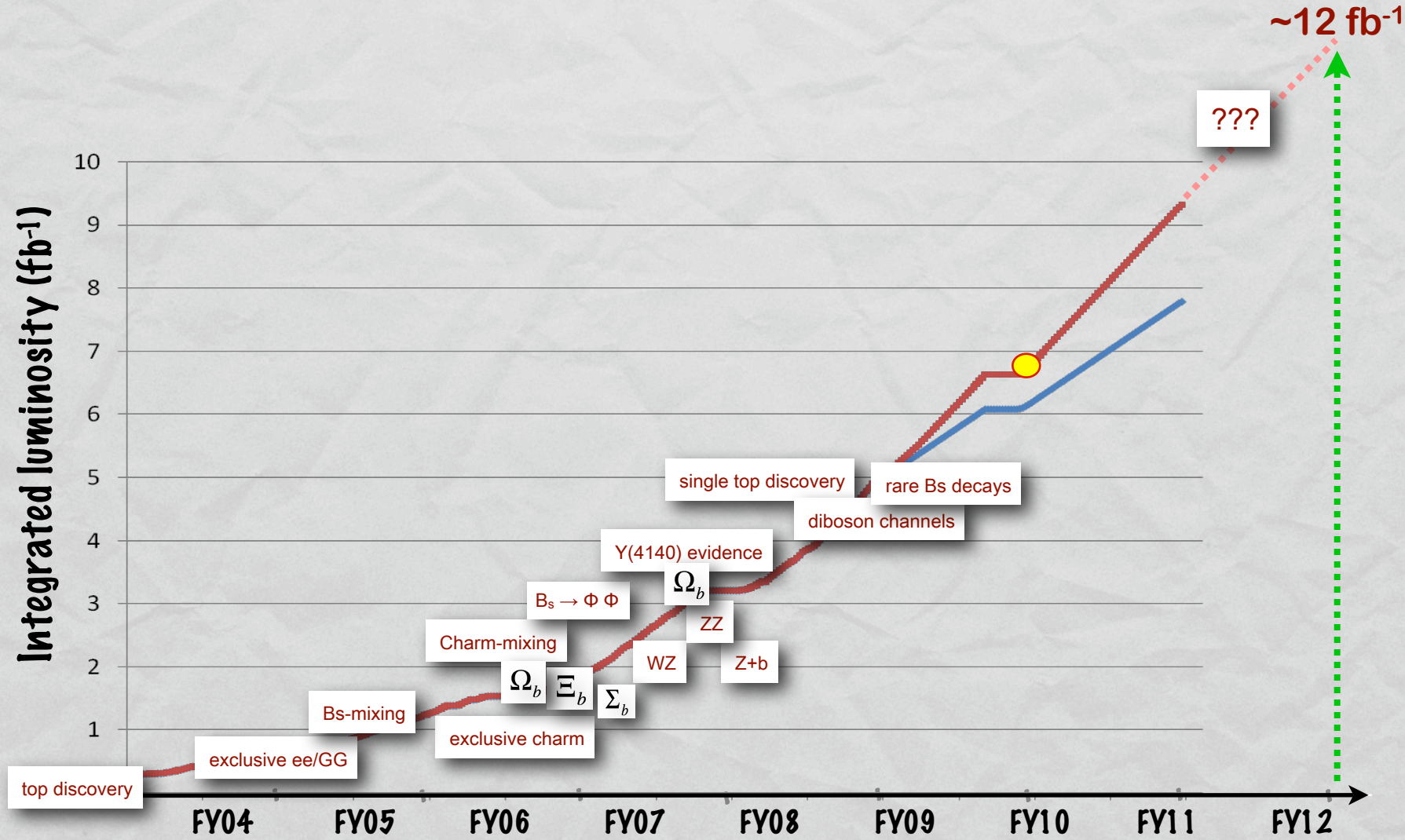
Luminosity Outlook

Budget approval pending for FY11 running
Everyone is on board - we are planning on it

12 fb^{-1} delivered ~doubles the current dataset and results in analyses with about 10 fb^{-1}



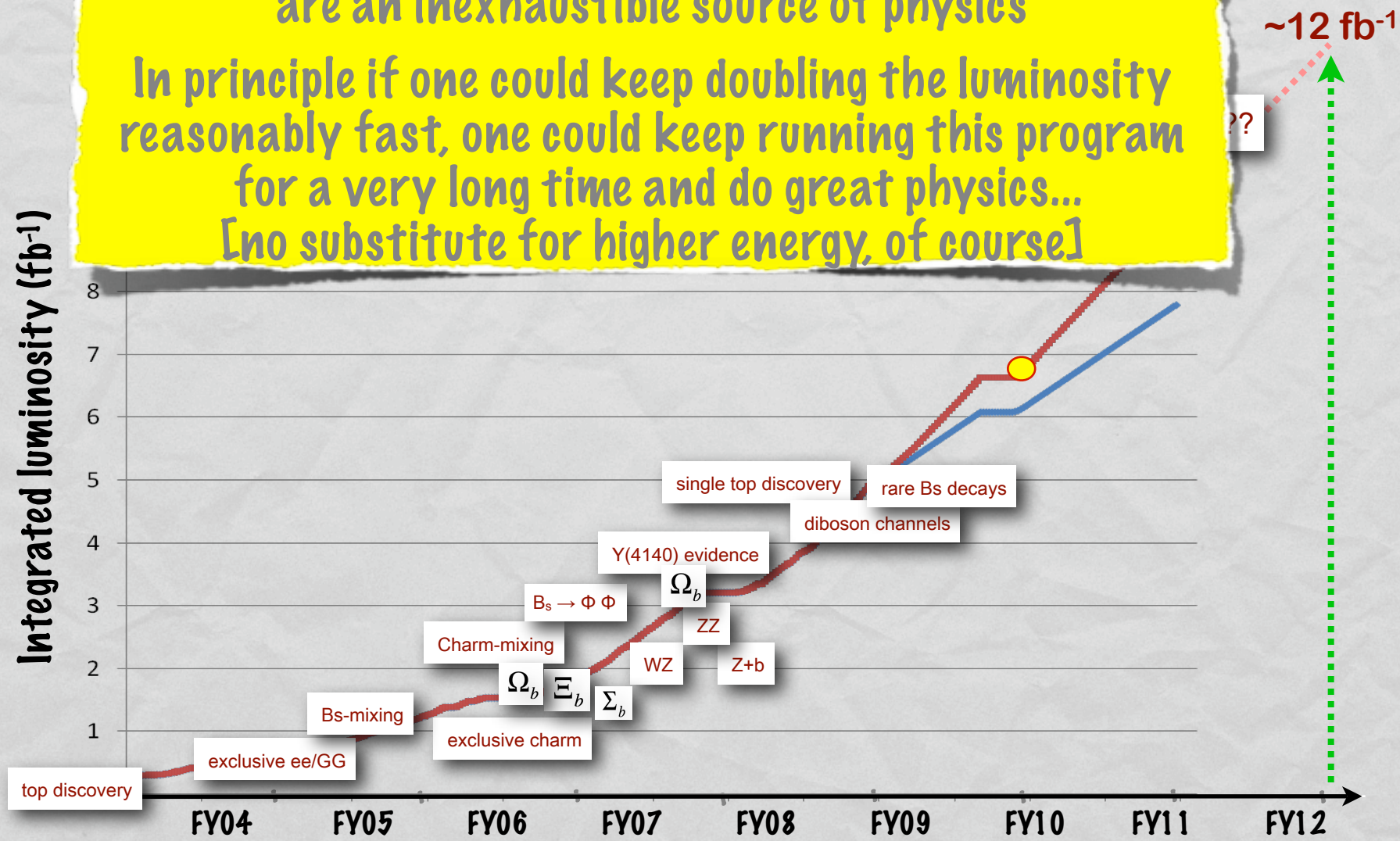
Still, physics shows up throughout...



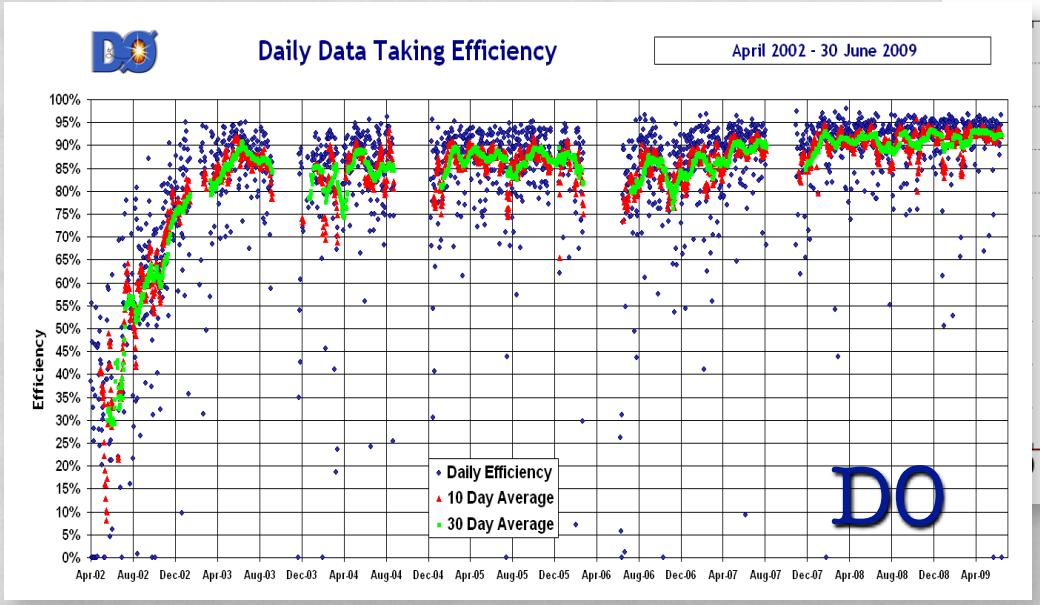
Still, physics shows up throughout...

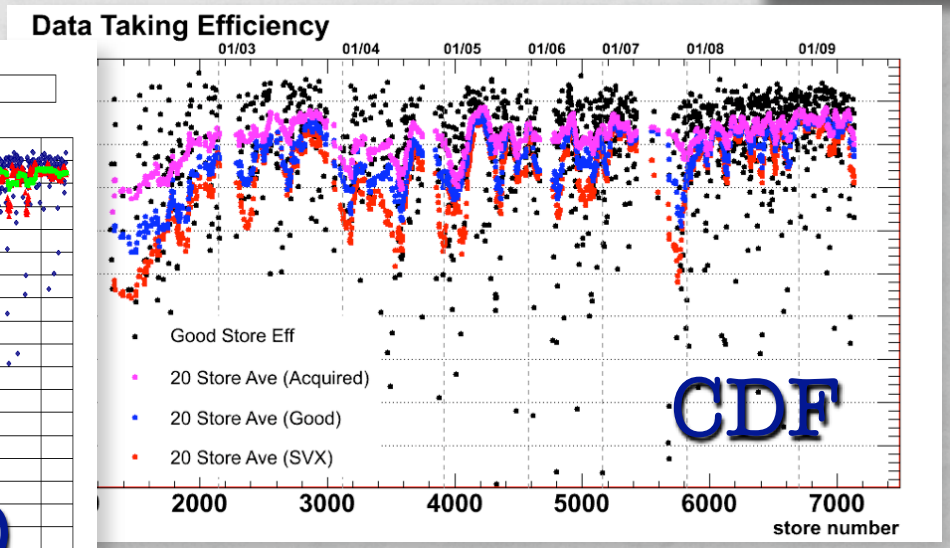
In many ways - even at fixed E - hadron colliders are an inexhaustible source of physics

In principle if one could keep doubling the luminosity reasonably fast, one could keep running this program for a very long time and do great physics...
[no substitute for higher energy, of course]



The Detectors Outlook





We record: 85-90 % of delivered luminosity

In analyses: 75-90 % of delivered luminosity

Expected to remain stable & operate well for another 2 yrs

Significant challenges

- Some anticipated, some not - all conquered so far -
- Present along the whole way
- Ex: CDF
  - Beam losses: detector trips, power supplies
  - COT degradation, Silicon cooling
  - Gain drops in calorimeter, TOF, Lum monitor
  - Quad rotations, beam pipe kink
  - High Luminosity: triggers, physics algorithms
  - Computing: large datasets, fast turnaround, the ever "evolving" Grid

Significant challenges

- Some anticipated, some not - all conquered so far -
- Present along the whole way
- Ex: CDF
  - Beam losses: detector trips, power supplies
  - COT degradation, Silicon cooling
  - Gain drops in calorimeter, TOF, Lum monitor
  - Quad rotations, beam pipe kink
  - High Luminosity: triggers, physics algorithms
  - Computing: large datasets, fast turnaround, the ever "evolving" Grid

People migration [mainly to LHC experiments]

The Collaborations Outlook

- Migration started a long time ago => collaborations shrinking
- We've taken many measures to mitigate the impact on the experiments
  - Streamlined and automated many tasks in operations and in physics analysis
- Other important factors that have slowed down the migration:
  - Steady luminosity increase
  - The experiment are running very well
  - Very rich and exciting physics program
  - LHC delays
  - Many opportunities for people to make a mark - both in physics and leadership
  - People are still joining the experiments - students, postdocs
  - People are welcome to join - lot's of flexibility, talk to us

The Collaborations Outlook

- Migration started a long time ago => collaborations shrinking
- We've taken many measures to mitigate the impact on the experiments
  - Streamlined and automated many tasks in operations and in physics analysis
- **Enough people to operate the detectors and do the analyses - not all of them -**
  - The experiment are running very well
  - Very rich and exciting physics program
  - LHC delays
  - Many opportunities for people to make a mark - both in physics and leadership
  - People are still joining the experiments - students, postdocs
  - People are welcome to join - lot's of flexibility, talk to us

Physics with more data

- A lot happens with more data - beyond statistics -
  - Problems are revealed: systematic limitations, work theorists still need to do, Monte Carlo shortcomings etc.
  - Tools and techniques improve and evolve: JES, b-tagging, triggering, multivariate analyses etc.
  - Better handles on backgrounds, cross checks across channels
- More physics reach
  - Precision, study of differential distributions and properties
  - New channels open up ==> new research areas
  - Sample higher sqrt(s) collisions ==> tails, push sensitivity reach in E, mass.
  - Fluctuations settle, or not...
  - <u>A note about CDF & Dzero</u>
    - Competition, cross-pollination, combinations, statistical tools
    - Great value in having two experiments

Physics with more data

- A lot happens with more data - beyond statistics -
  - Problems are revealed: systematic limitations, work theorists still need to do, Monte Carlo shortcomings etc.
  - Tools and techniques improve and evolve: JES, b-tagging, triggering, multivariate analyses etc.
  -

"Sqrt(L) progress at hadron colliders is a myth
- except at the very very end, when there is nothing left to do but to surrender " (JK)

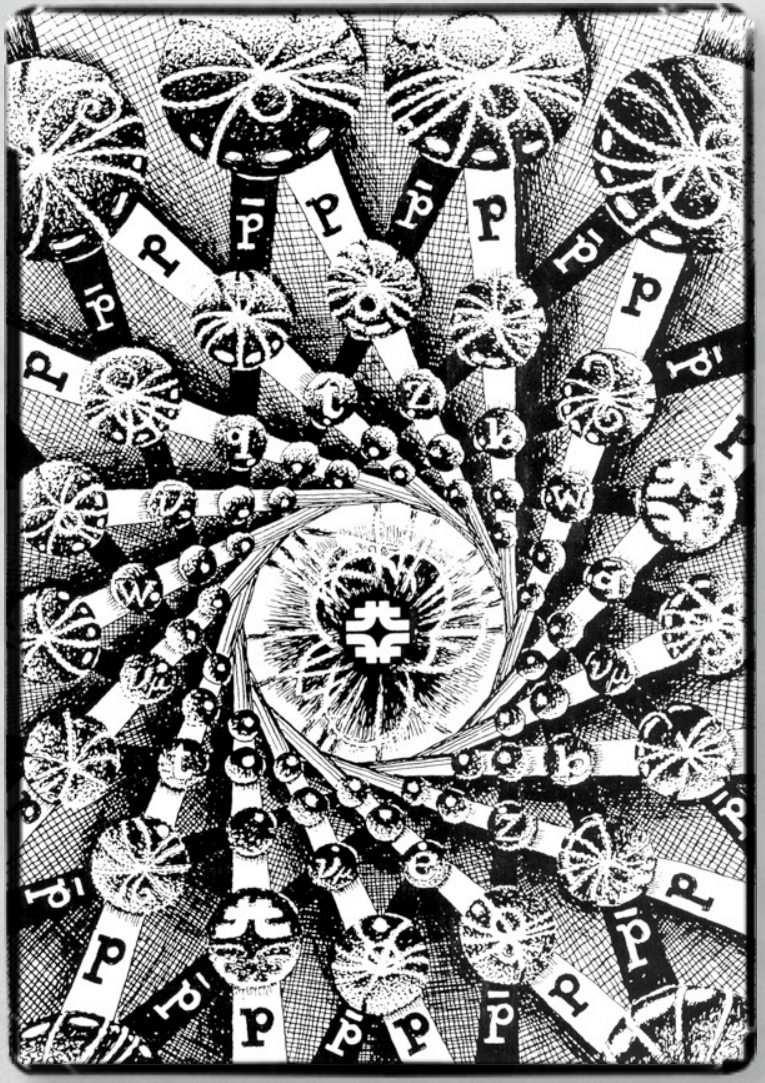
- M
  - Precision, study of differential distributions and properties
  - New channels open up ==> new research areas
  - Sample higher sqrt(s) collisions ==> tails, push sensitivity reach in E, mass.
  - Fluctuations settle, or not...
- A note about CDF & Dzero
  - Competition, cross-pollination, combinations, statistical tools
  - Great value in having two experiments

Program Goals

- Operational
  - For 2009: analyze up to 5 fb^{-1} ==> done
  - Run through FY11
  - Analyze ~2 fb^{-1} more each year for key results
  - Maintain easy access to analysis tools
  - Need to keep people engaged & teams in place for key analysis

- Physics
  - Revisit what should go on with increasing lum & what should wrap up
  - Extract as much juice from the data as possible
    - New processes & measurements, precision, New Physics, Higgs
    - Persist on puzzles, 2-sigma effects & try to leave no stone unturned
    - Find new ways of looking at the data

Some of the chapters ahead

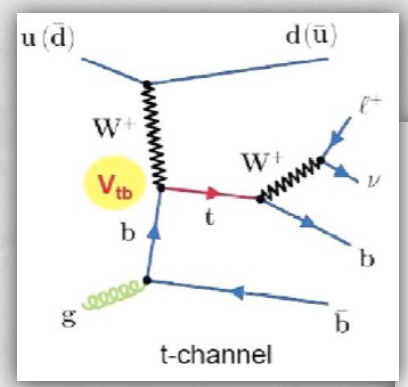


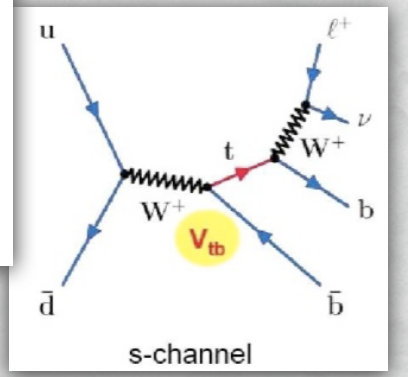
- New research areas
- More precision
- More reach
- Hints to pursue
- Puzzles
- Tests for New Physics

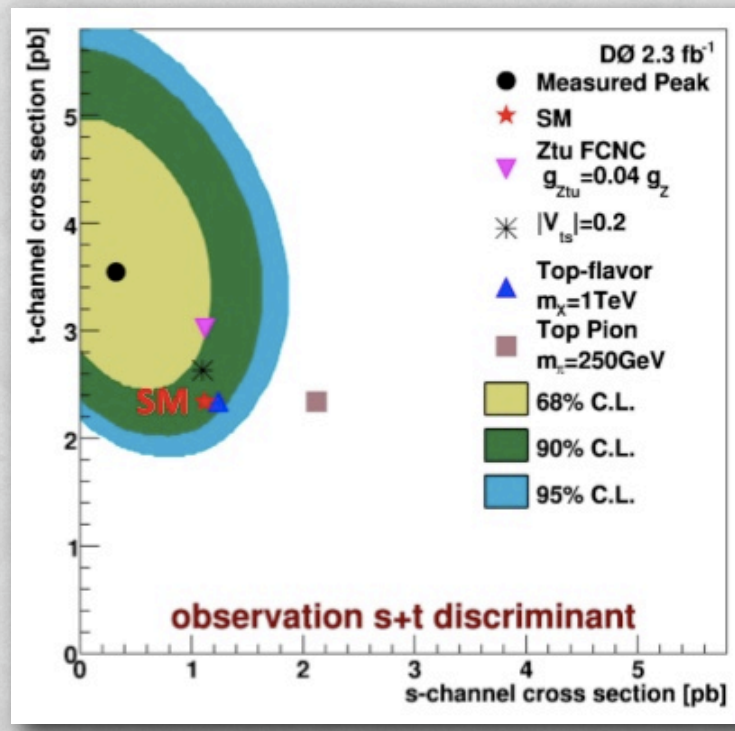
New research: single top

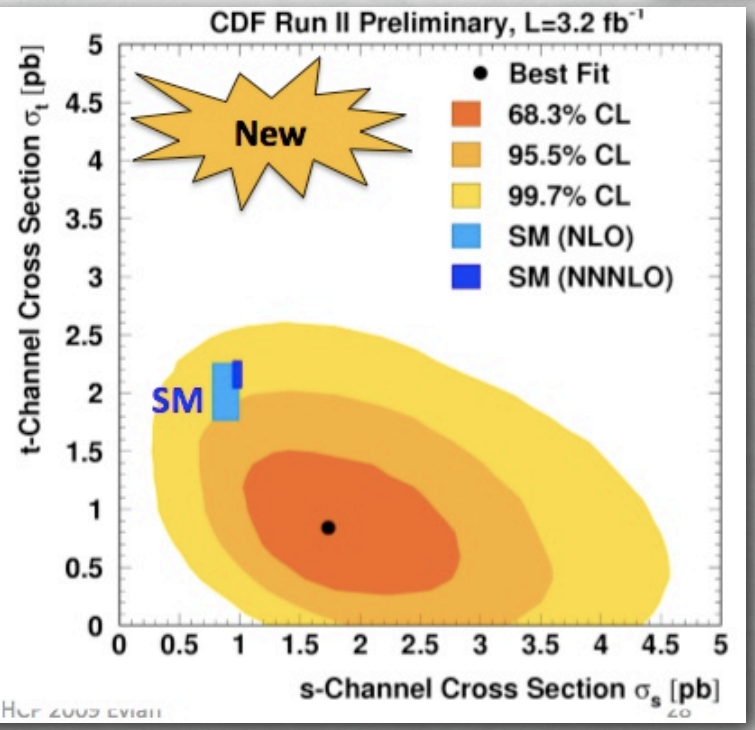
Note: multivariate techniques for discovery!

- Test S vs T channels
- Measure Vtb with more precision





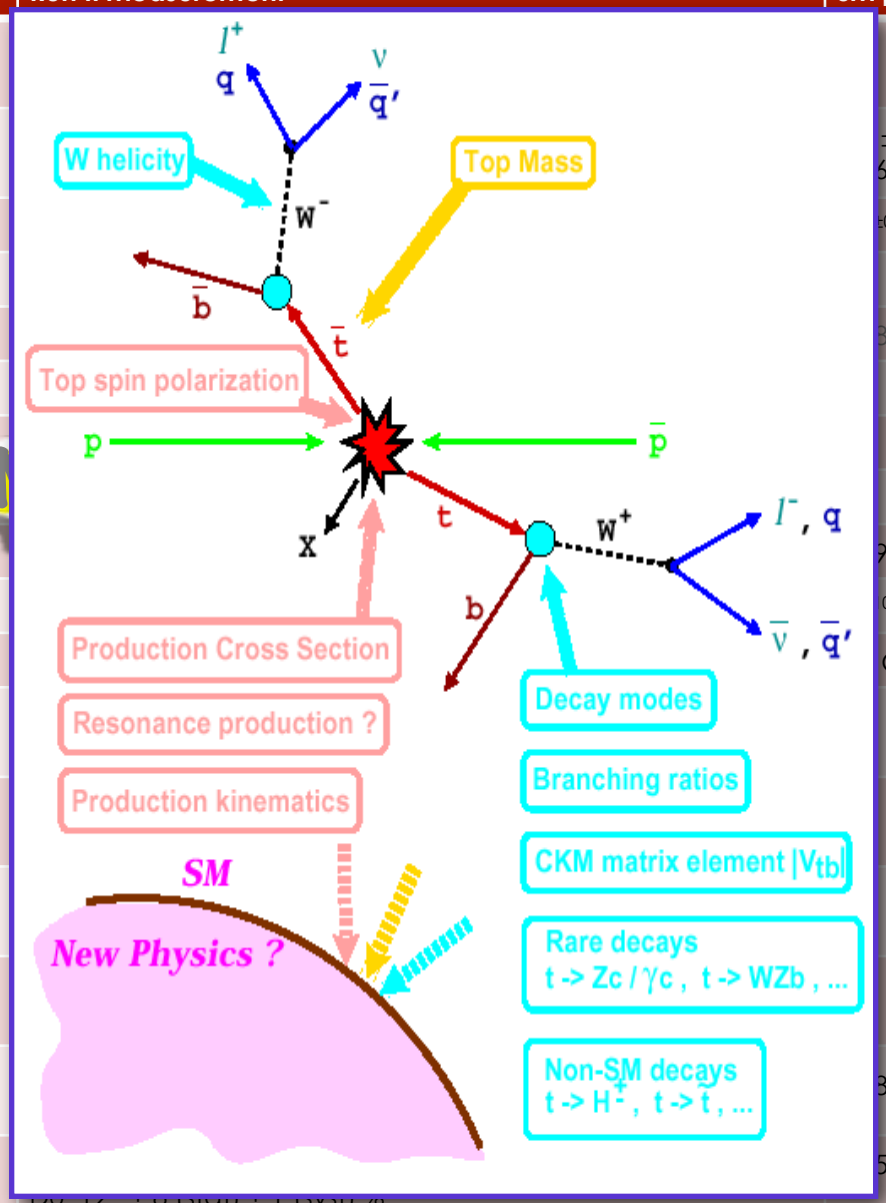




measure it with max. luminosity

Top: a very broad research program

Property	Run II Measurement	SM prediction	Luminosity (fb^{-1})
m_t			4.3 3.6
σ_{ttbar} (@m_t=172.5 GeV) σ_{ttbar} (@m_t=170 GeV)		± 0.6 pb 6 +0.6 pb	4.5 1
$\sigma_{singletop}$ (@m_t=170 GeV)		±0.8 pb	3.2-2.3
$\|V_{tb}\|$			3.2-2.3
σ(gg->ttbar)/σ(qq->ttbar)		3	1
m_t - m_{tbar}			1
σ(tt∴ ll)/σ(tt∴ l+jets)			1
σ(tt∴ τl)/σ(tt∴ ll + l+jets)			1
$\sigma_{ttbar+jets}$ (@m_t=172.5 GeV)		9+0.16 -0.31 pb	4.1
CTtop		0 μm	0.3
Ttop		GeV	1
BR(t->Wb)/BR(t->Wq)			0.2 0.9
F_0			2 2.7
F_+			2 2.7
Charge			1.5 0.37
Spin correlations		3 -0.022 +0.027	2.8 4.2
Charge asymmetry		5 +- 0.015	3.2 0.9

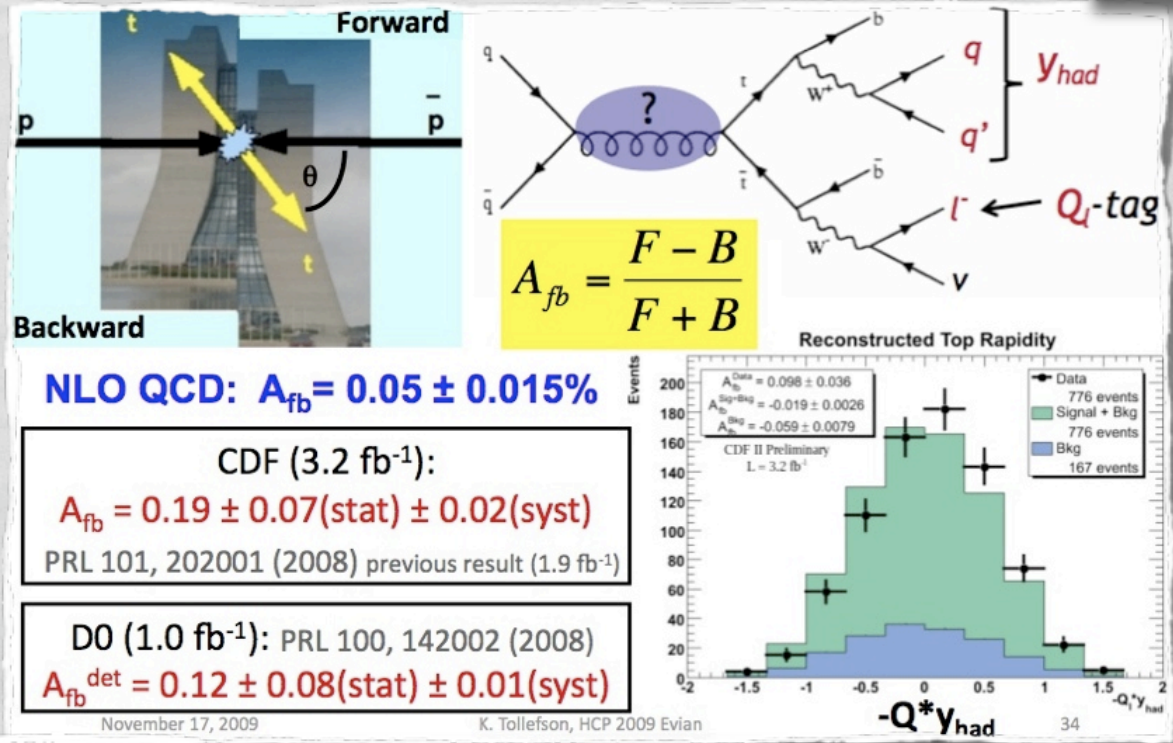


Top: a very broad research program

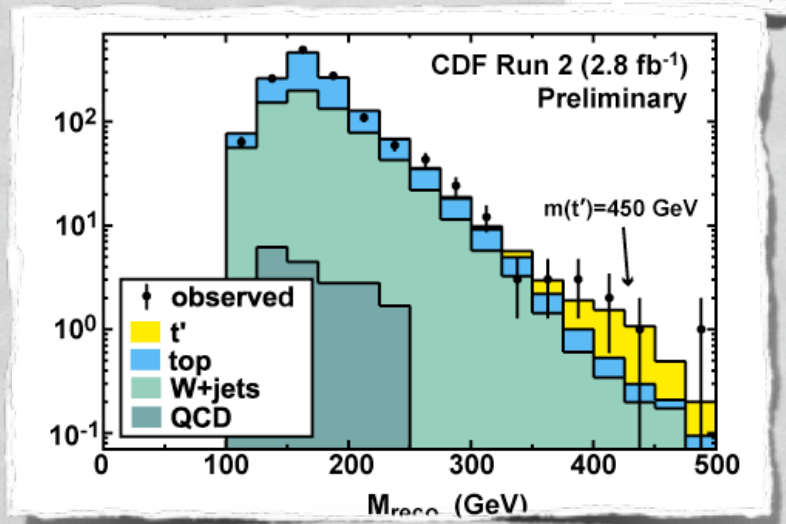
Property	Run II Measurement	SM prediction	Luminosity (fb^{-1})
m_t	CDF: 172.6 ± 0.9(stat) ± 1.2(syst) GeV D0: 174.2 ± 0.9(stat) ± 1.5(syst) GeV		4.3 3.6
σ_{ttbar} (@m_t=172.5 GeV) σ_{ttbar} (@m_t=170 GeV)	CDF: 7.50 ± 0.31 (stat) ± 0.34 (syst) ± 0.15 (lumi) pb D0: 7.84 $^{+0.46}_{-0.45}$ (stat)$^{+0.66}$-$_{0.54}$ (syst) $^{+0.54}_{-0.46}$ (lumi) pb	7.4 ± 0.6 pb 8.06 +0.6 pb	4.5 1
$\sigma_{singletop}$ (@m_t=170 GeV)	Tevatron: 2.76 $^{+0.58}_{-0.47}$ (stat+syst)	2.86±0.8 pb	3.2-2.3
$\|V_{tb}\|$	Tevatron: 0.91 ± 0.08 (stat+syst)	1	3.2-2.3
σ(gg->ttbar)/σ(qq->ttbar)	D0: 0.07+0.15-0.07(stat+sys)	0.18	1
m_t - m_{tbar}	D0: 3.8 ± 3.7 GeV	0	1
σ(tt∴ ll)/σ(tt∴ l+jets)	D0: [illegible] $^{+0.19}$ [illegible] (stat+syst)	1	1
σ(tt∴ τl)/σ(tt∴ ll + l+jets)			1
$\sigma_{ttbar+jets}$ (@m_t=172.5 GeV)	CDF: 1.6 ± 0.2 (stat) ± 0.5 (syst)	1.79+0.16 -0.31 pb	4.1
cτtop	CDF: 52.5μm @ 95%C.L.	10^{-10} μm	0.3
Ttop	CDF: <13.1 GeV @ 95%C.L.	1.5 GeV	1
BR(t->Wb)/BR(t->Wq)	CDF: >0.61 @ 95% C.L. D0: 0.97 $^{+0.09}_{-0.08}$ (stat+syst)	1	0.2 0.9
F_0	CDF: 0.62 ± 0.11 D0: 0.490 ±0.106 (stat) ±0.085 (syst)	0.7	2 2.7
F_+	CDF: -0.04 ± 0.05 D0: 0.110 ±0.059 (stat) ±0.052 (syst)	0.0	2 2.7
Charge	CDF: - 4/3 excluded with 87% C.L. D0: 4e/3 excluded at 92% C.L.	2/3	1.5 0.37
Spin correlations	CDF: ϰ = 0.32 + 0.55 - 0.78, -0.46 < K < 0.87 @ 68%C.L. D0: ϰ = –0.17 $^{+0.65}_{-0.53}$ (stat + syst)	0.78 $^{+0.027}_{-0.022}$	2.8 4.2
Charge asymmetry	CDF: 0.19 ± 0.07(stat) ± 0.02(syst) % D0: 12 ± 8 (stat) ± 1 (syst) %	0.05 +- 0.015	3.2 0.9

Much is statistically limited

tt samples - keep an eye on:

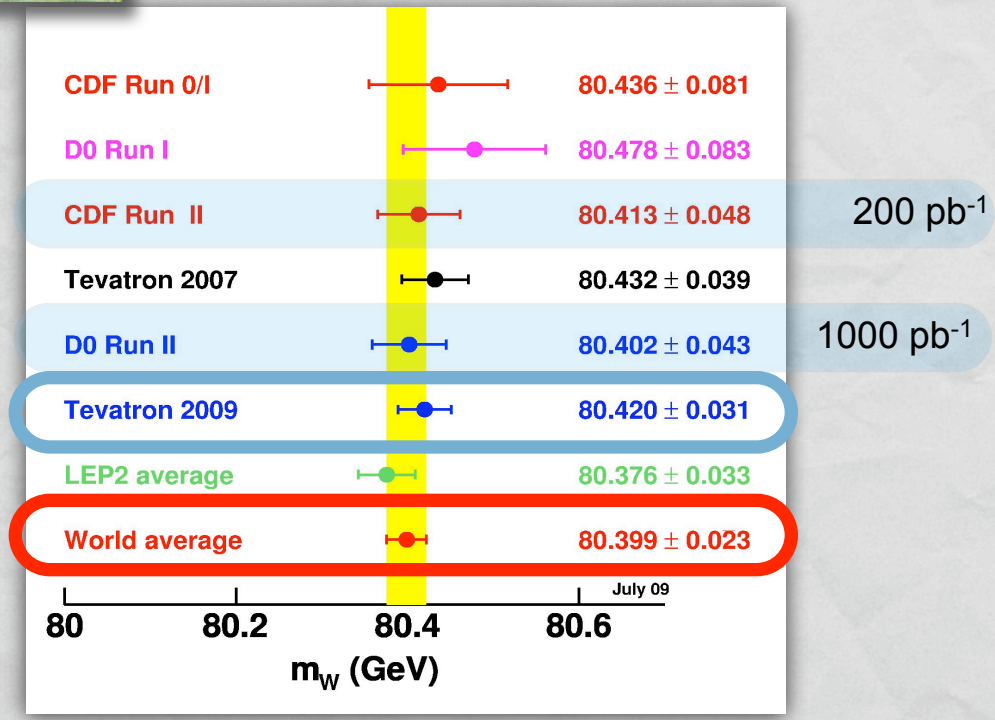


t-prime search

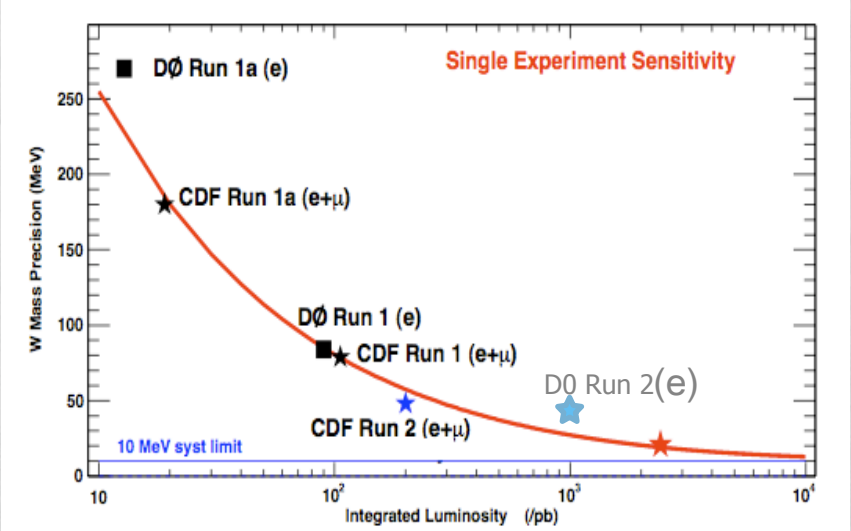


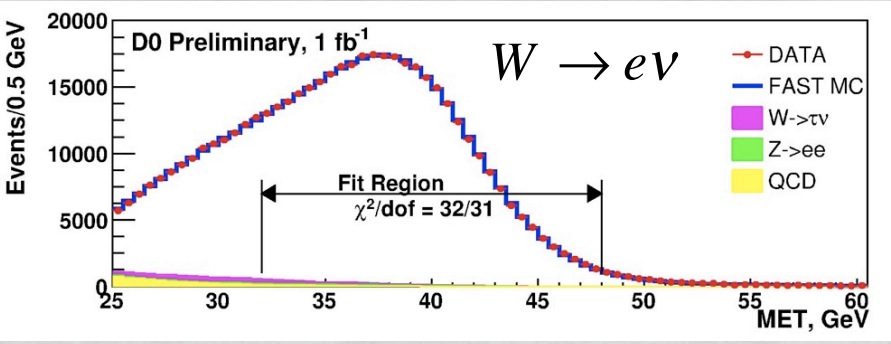
forward-backward asymmetry

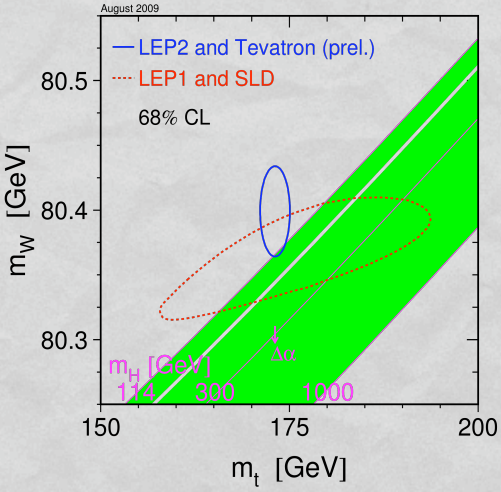
Precision Mw measurement - Outlook



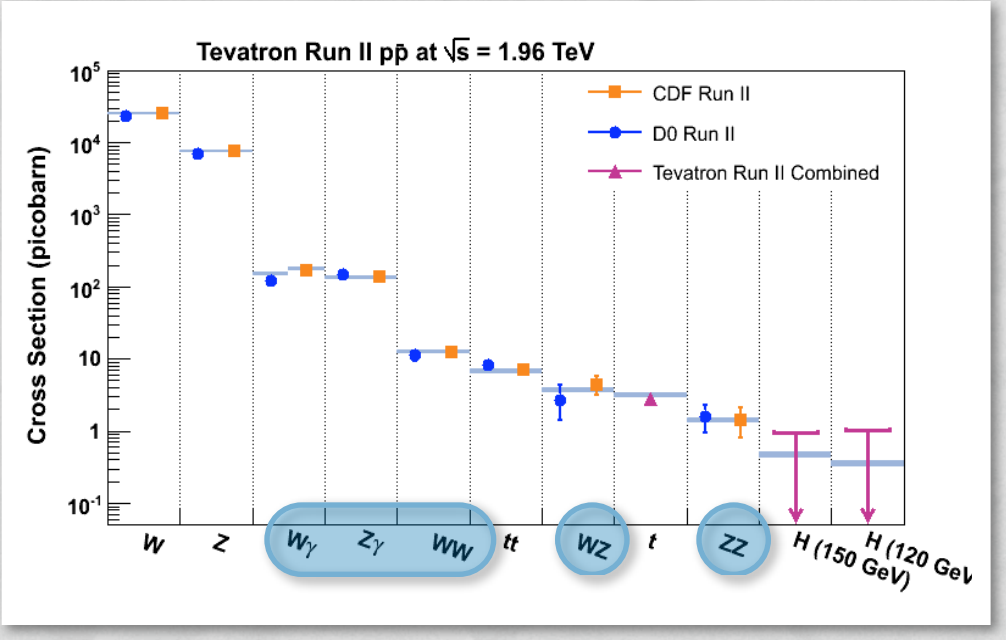
Next rounds:
aim for ~20 MeV uncertainty per experiment







Dibosons galore



Until recently the cleaner/easiest channels were observed: smaller background, doable with lower statistics

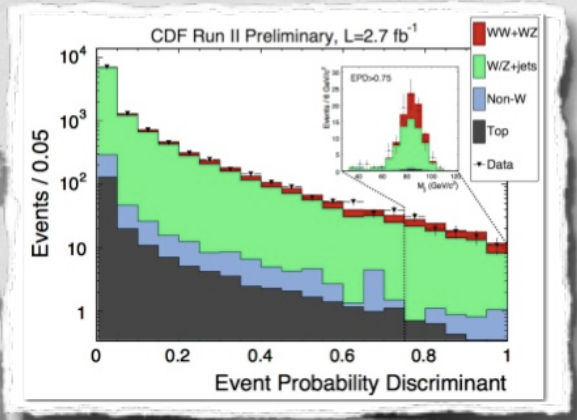
$W\gamma \rightarrow l\nu\gamma$ $Z\gamma \rightarrow ll\,\gamma$ $WW \rightarrow l\nu l\nu$ $WZ \rightarrow l\nu ll$ $ZZ \rightarrow llll$

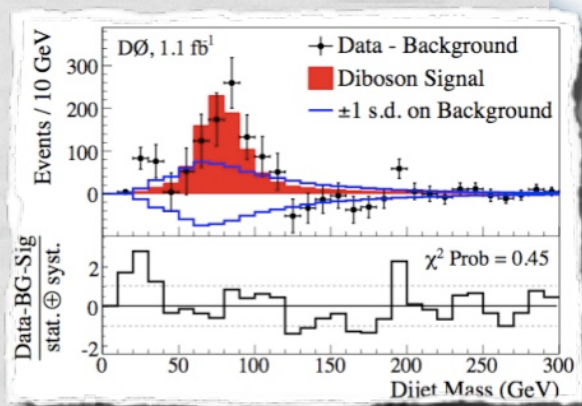
New: more data/experience enables the more difficult channels: large backgrounds, no simple kinematical handles

$Z\gamma \rightarrow \nu\nu\gamma$ $WW \rightarrow l\nu jj$ $WZ \rightarrow l\nu jj$ $ZZ \rightarrow \nu\nu jj$ Single top $\rightarrow l\nu jj$

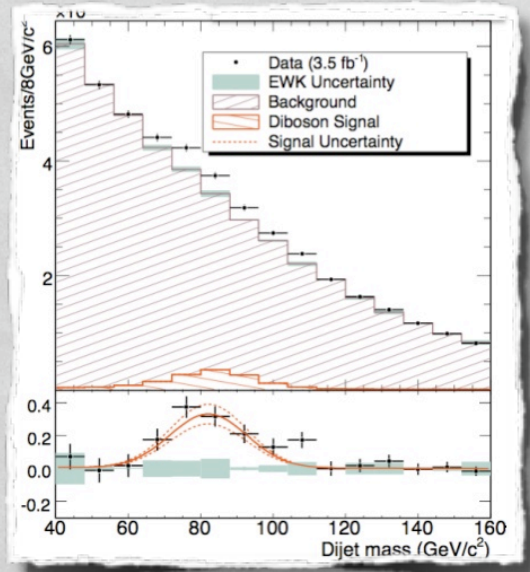
“Dibosons pave the road to the Higgs”

WW/WZ=>l,nu,jj

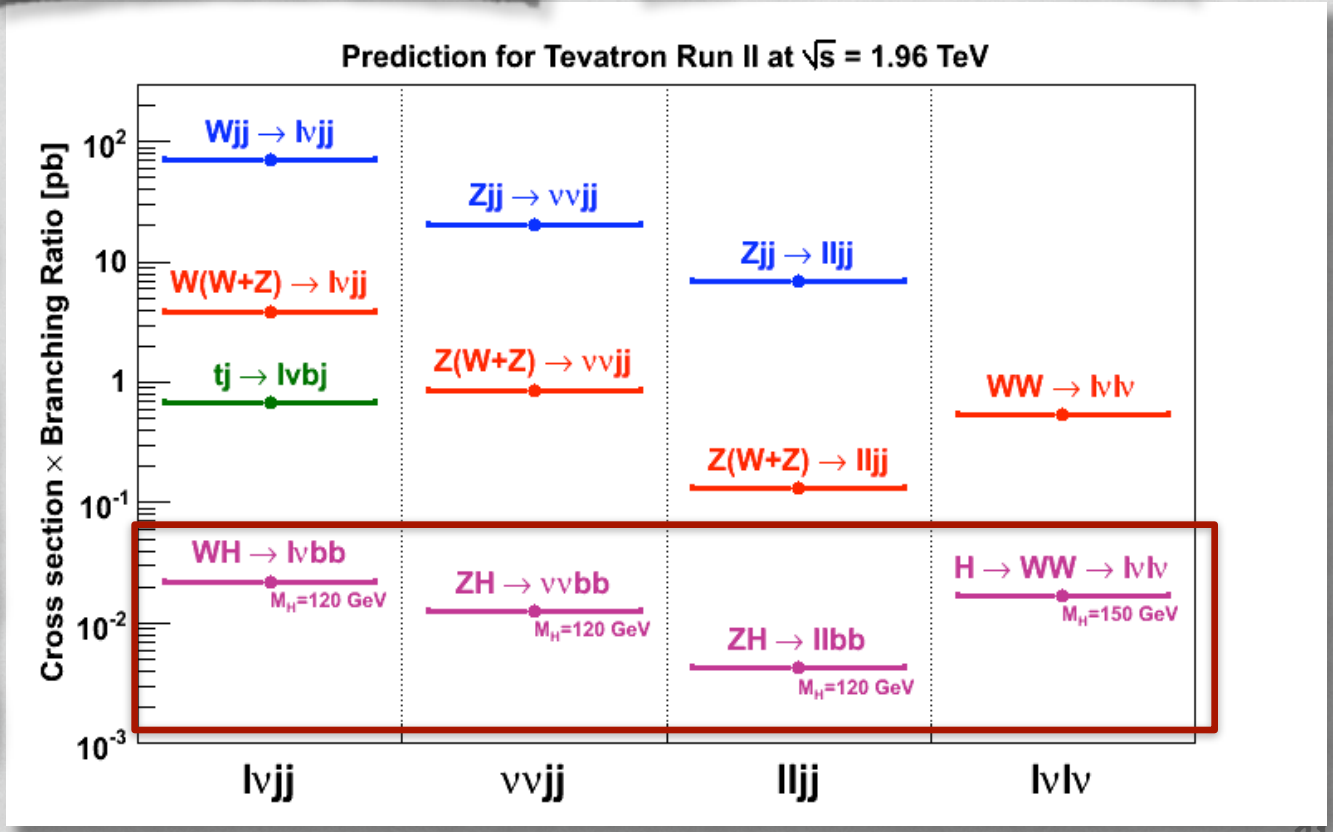




- The more difficult signatures are also backgrounds in the Higgs searches

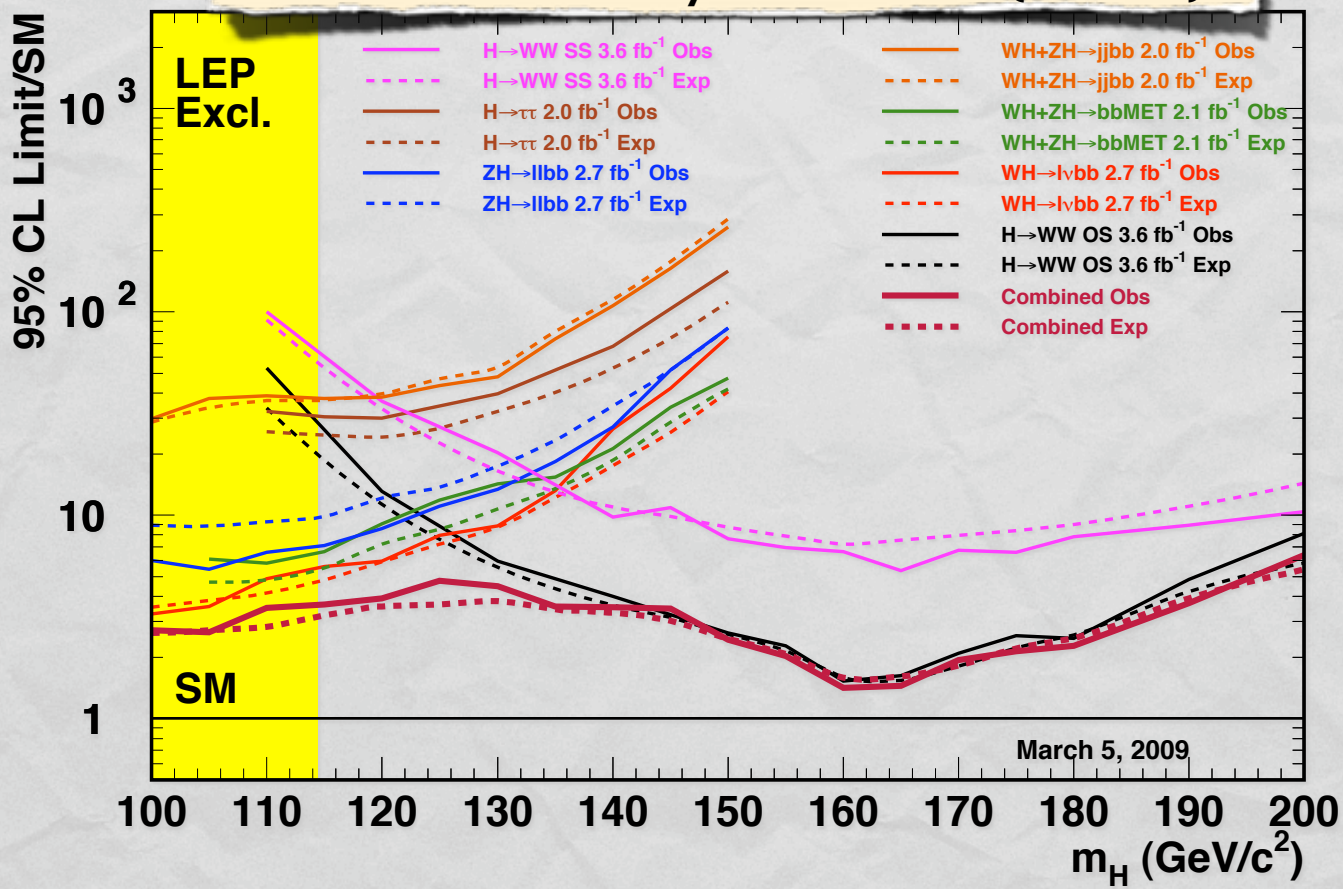


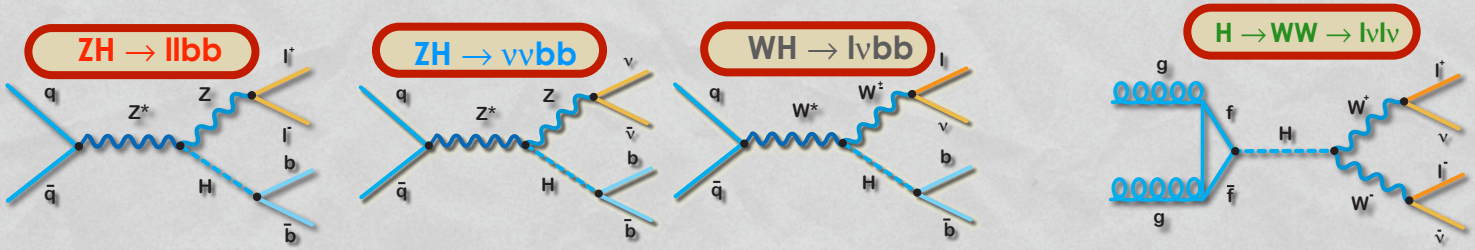
WW/WZ=>met+jj



The Higgs search: a monumental effort

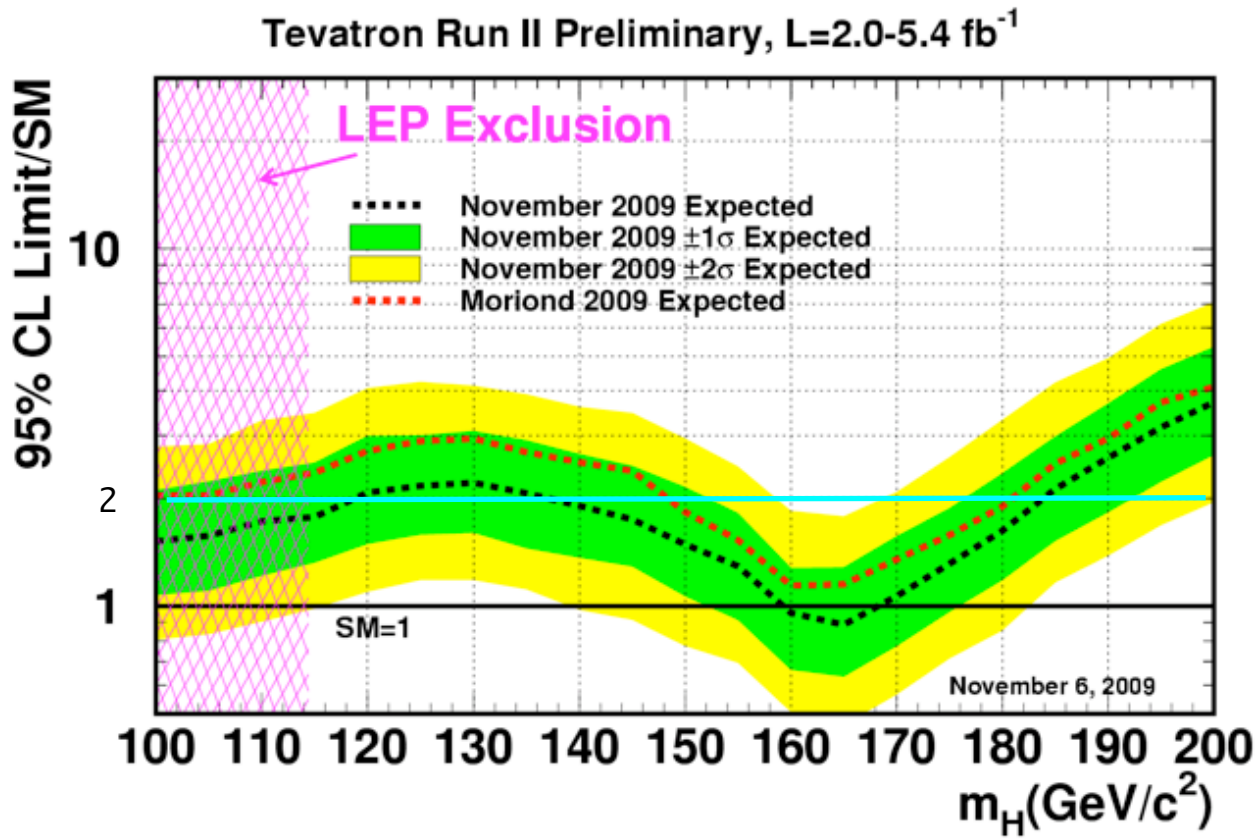
>100 distinct analysis channels (cdf+d0)





Higgs Update: increased sensitivity

updated analyses and added luminosity

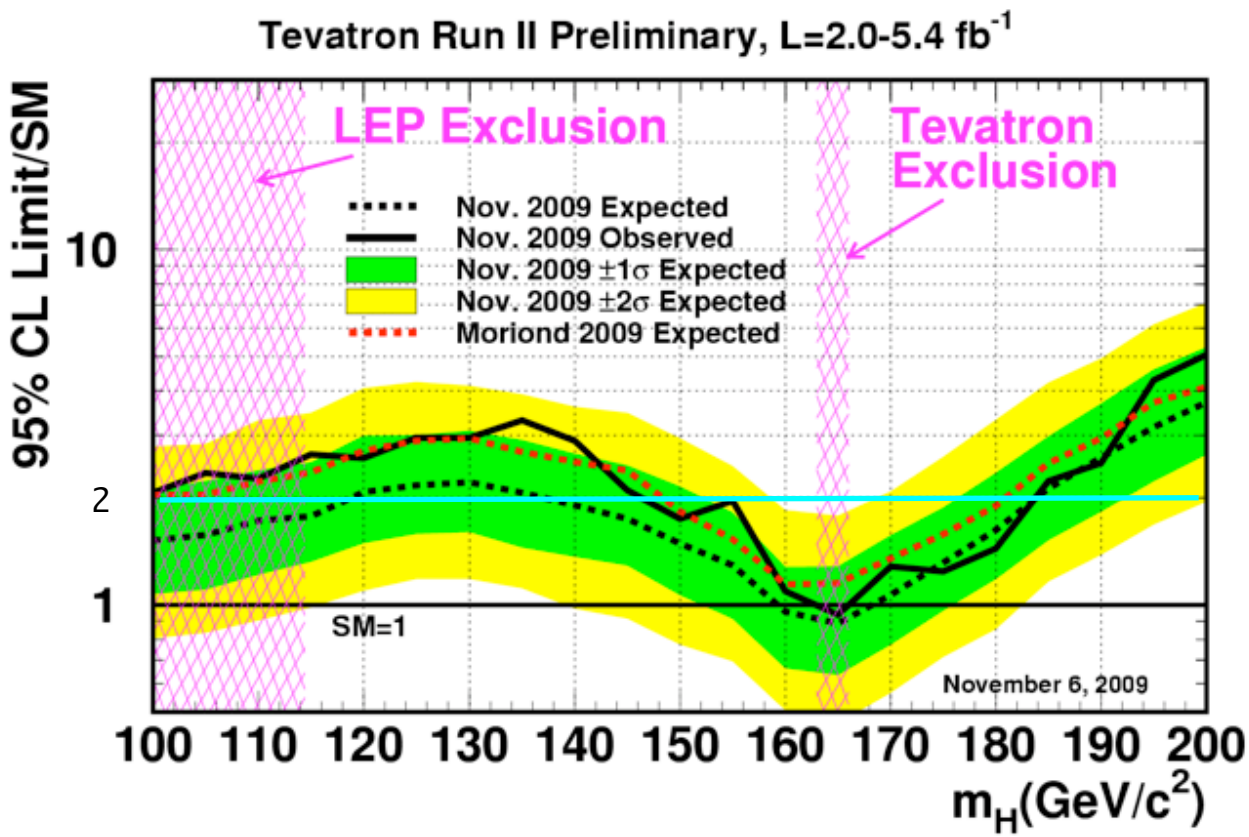


improved sensitivity across the whole mass range !

Larger 95% exclusion mass region expected now

Higgs Update: increased sensitivity

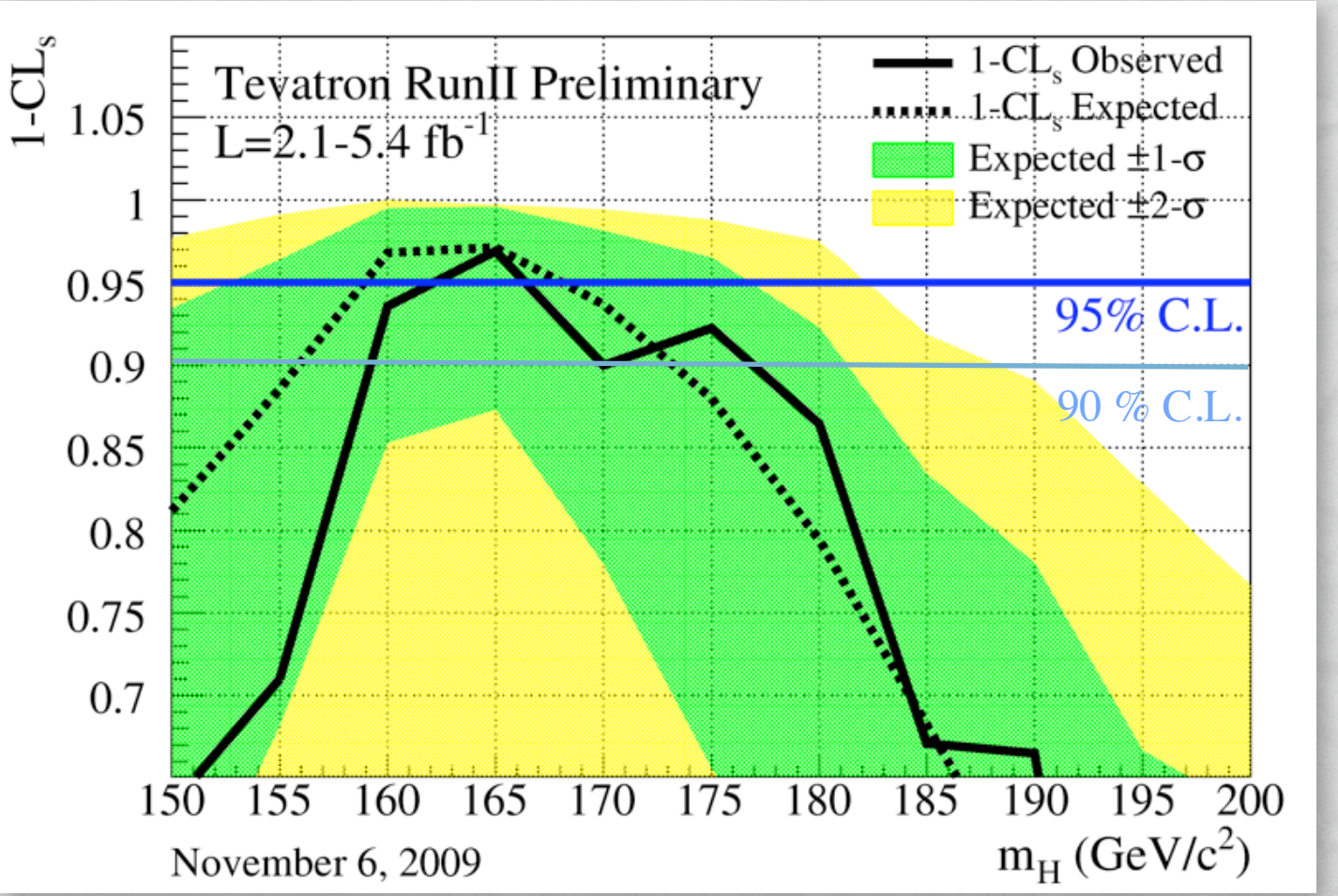
updated analyses and added luminosity



improved sensitivity across the whole mass range !

But the observed 95% exclusion is smaller...c'est la vie

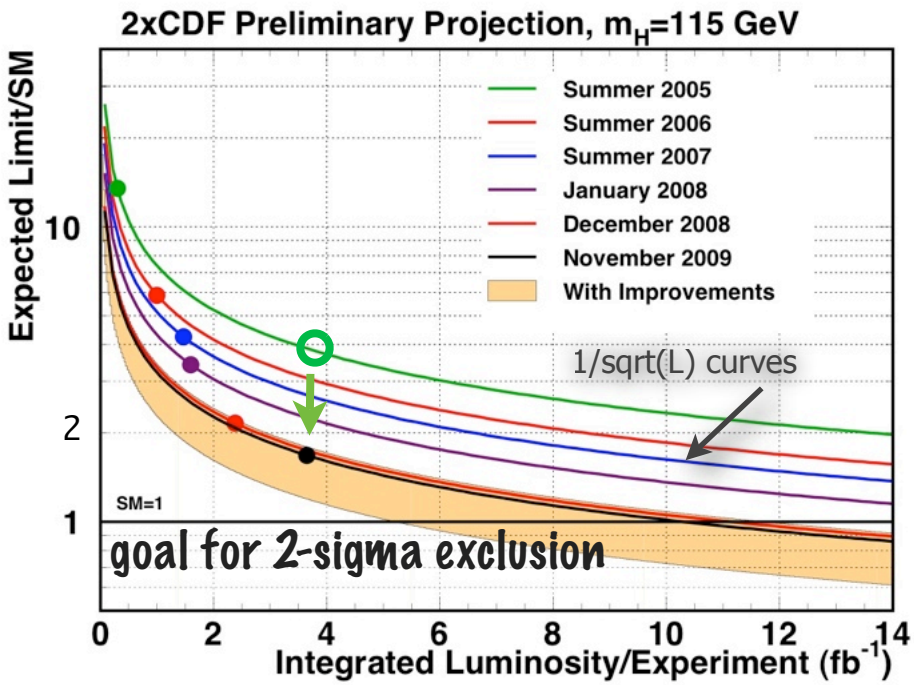
Higgs Update: exclusion probability vs mass

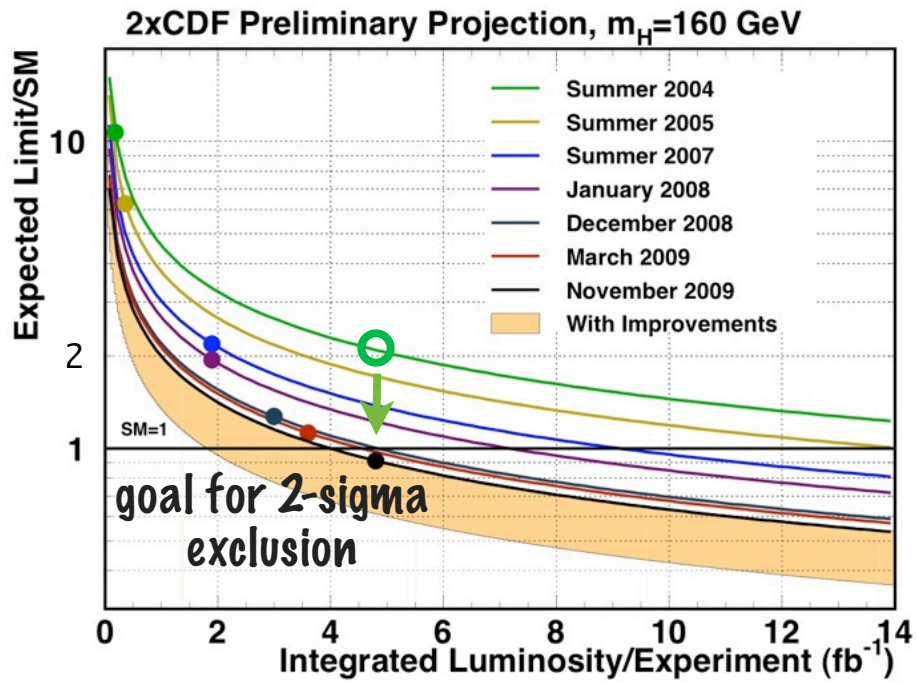


160-170 range still excluded at 90 to 97% CL

Higgs Search Progress

We are on track -through lum and improvements- long & exciting road

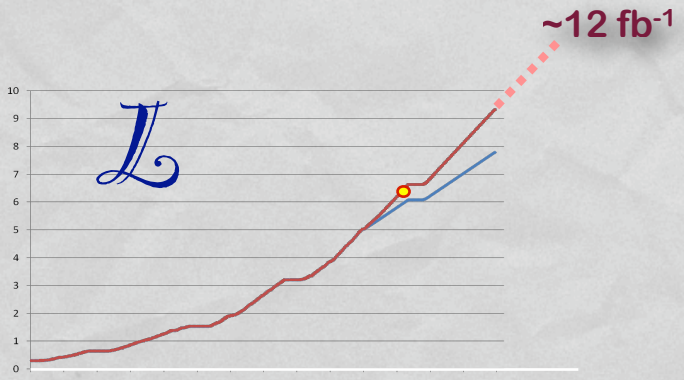




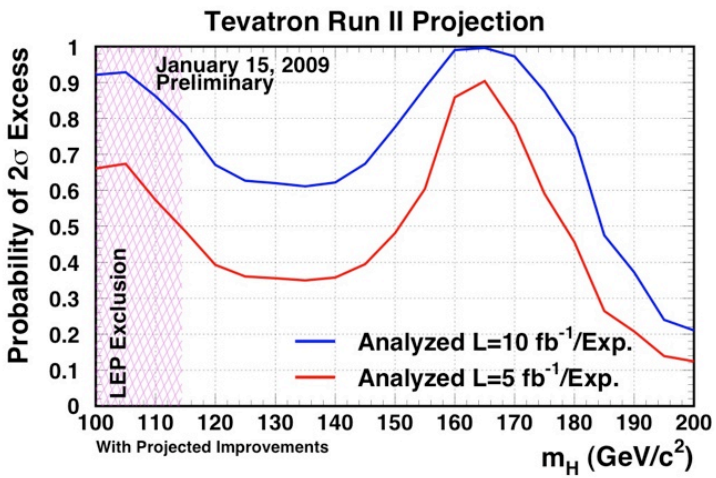
Orange band = expected improvement factors from 2007 analyses [x1.5 and x2.25]

Higgs Outlook

Higgs reach with FY11 running and continued analysis improvement [bottom orange band]

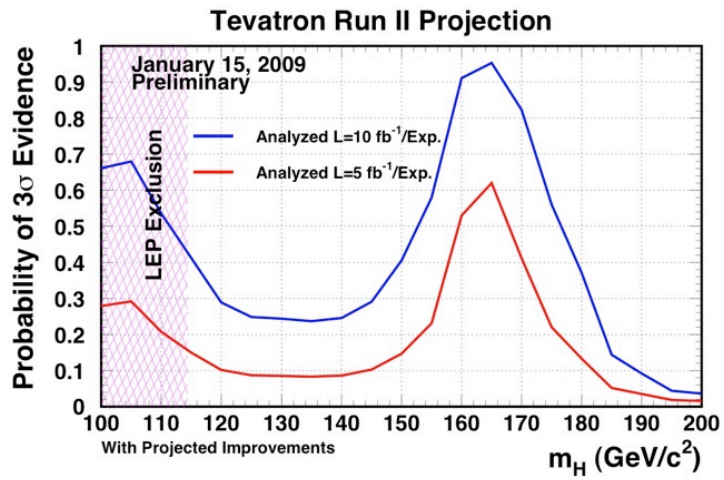


2-sigma



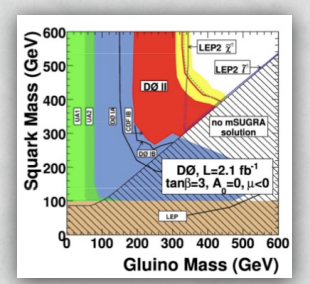
a-priori sensitivities

3-sigma



New Physics Tests - Status

- SUSY pushed up in energy
  - charginos/neutralinos > 160 GeV
  - squarks > 380 GeV (all gluino masses)
  - gluinos > 280 GeV (all squark masses)
  - stop > 200 GeV
  - sbottom > 250 GeV
  - limits on tan_beta & BSM higgs

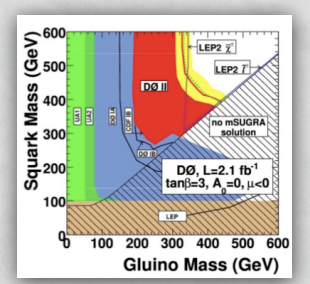


- Other models and new generation particles also up
  - b' and t' > 300+ GeV
  - W' and Z' >600-800 GeV

- Informative but disappointing
- We are not necessarily done
- Checked many final states and distributions - many not with full luminosity
- A few indications of excesses or inconsistencies
  - t-prime, A_{FB}(top), tt spin correlations, multimuons, Mww etc.
  - we've seen things come and go, maybe one will stay?
- **Need to keep studying the data - will we leave stones unturned?**

New Physics Tests - Status

- SUSY pushed up in energy
  - charginos/neutralinos > 160 GeV
  - squarks > 380 GeV (all gluino masses)
  - gluinos > 280 GeV (all squark masses)
  - stop > 200 GeV
  - sbottom > 250 GeV
  - limits on tan_beta & BSM higgs



- Other models and new generation particles also up
  - b' and t' > 300+ GeV
  - W' and Z' >600-800 GeV

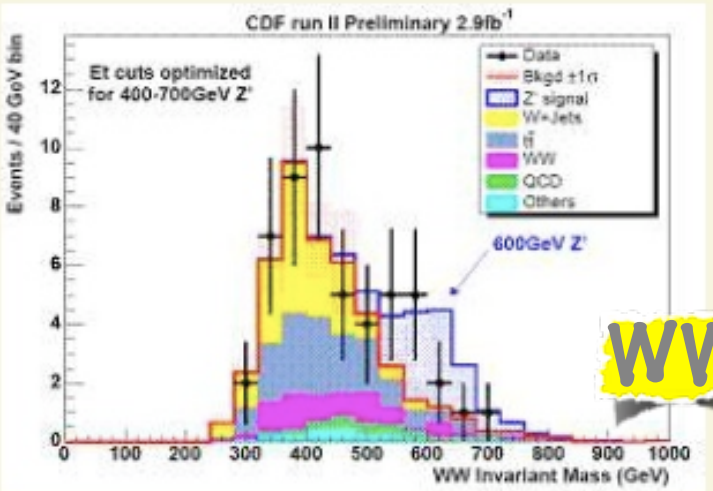
Reaching 1 TeV scale...

- Informative but disappointing
- We are not necessarily done
- Checked many final states and distributions - many not with full luminosity
- A few indications of excesses or inconsistencies
  - t-prime, A_{FB}(top), tt spin correlations, multimuons, Mww etc.
  - we've seen things come and go, maybe one will stay?
- **Need to keep studying the data - will we leave stones unturned?**

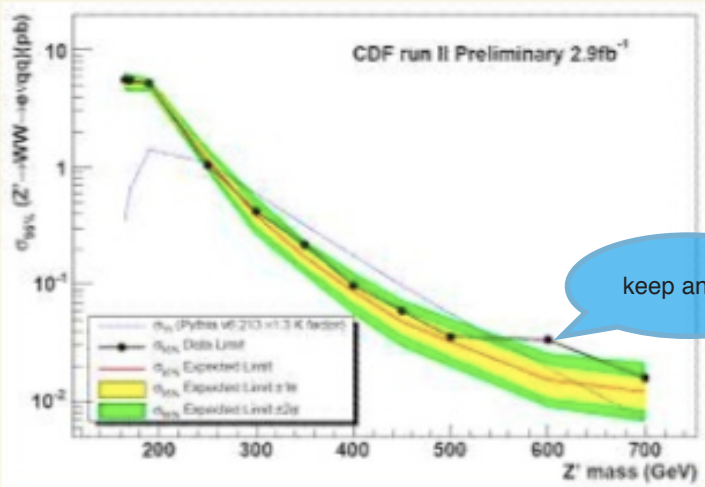
Example: high-E tails

A few have hints

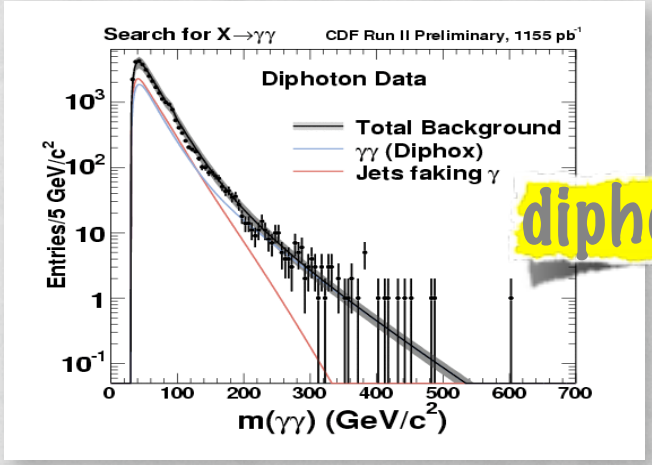
Many not [yet ?]



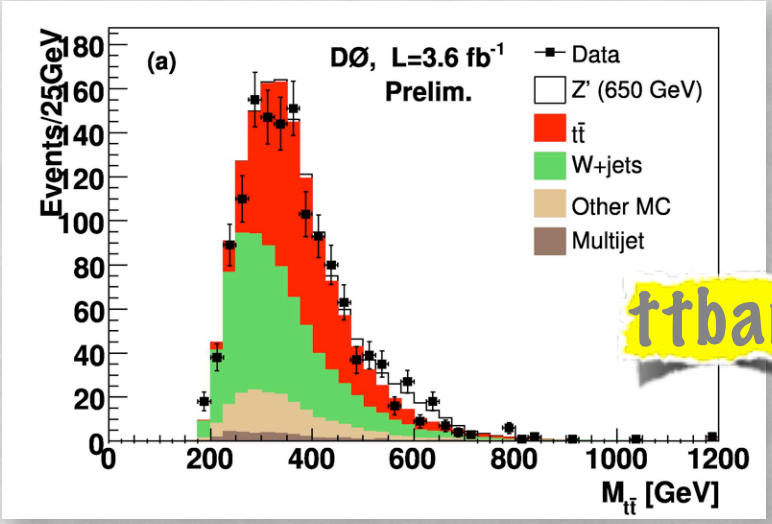
WW



keep an eye

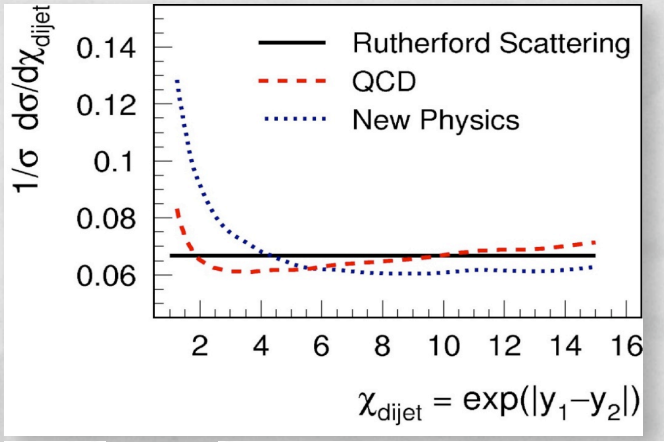


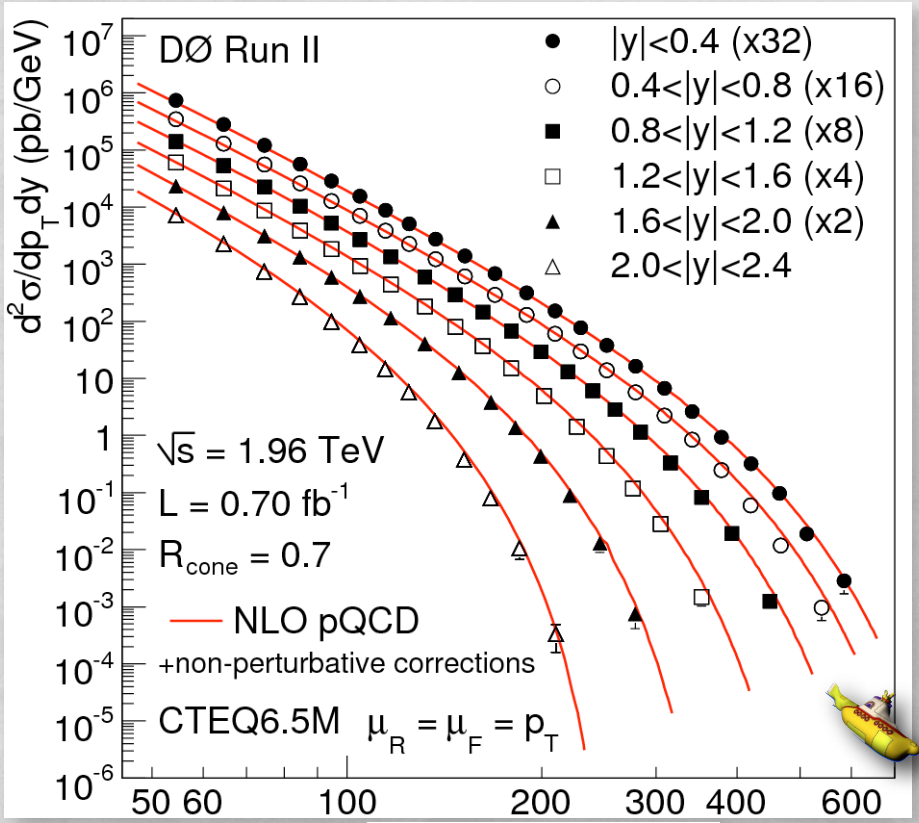
diphoton

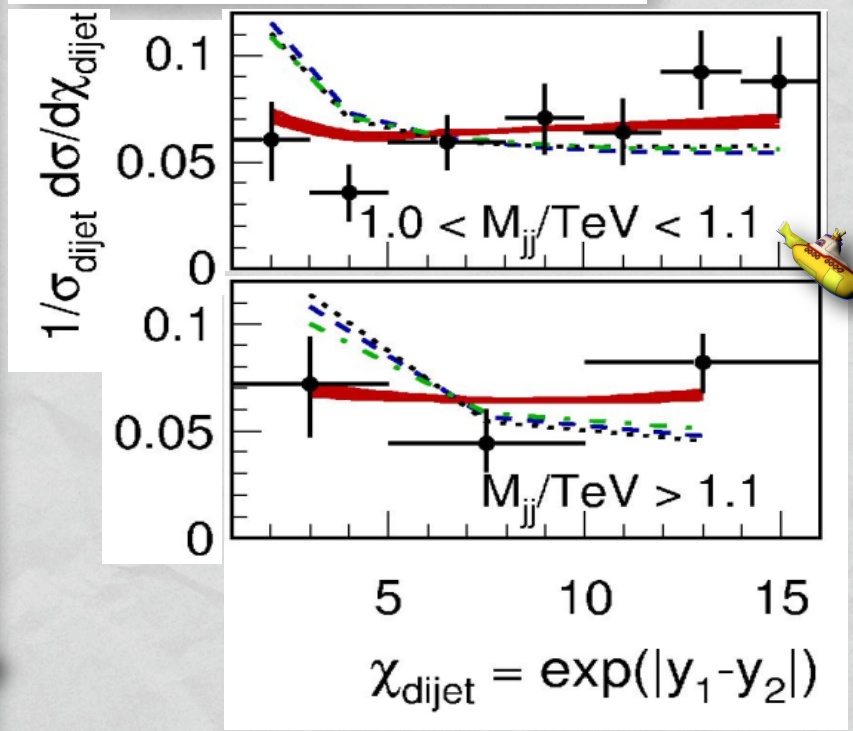


ttbar

Inclusive jets

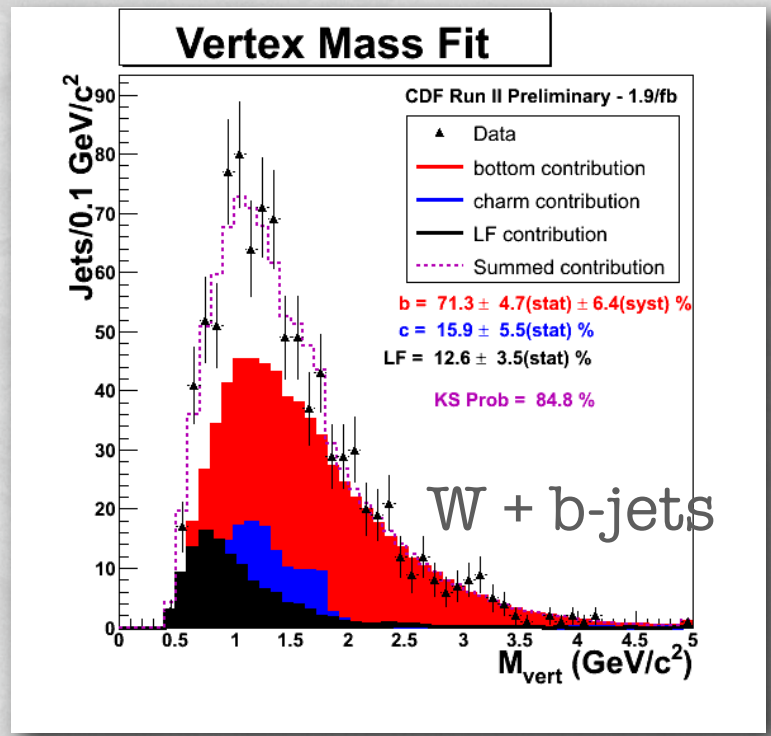


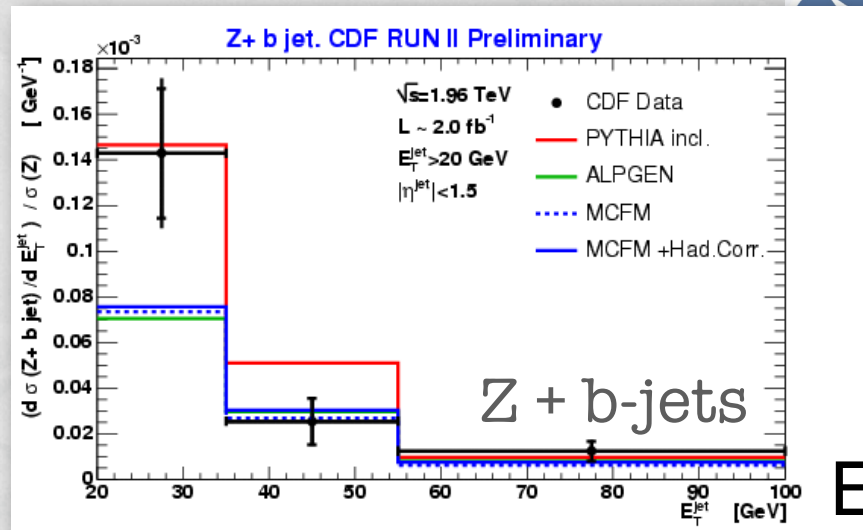




- Quark Compositeness Λ > 2.9TeV
- ADD LED (GRW) Ms > 1.6 TeV
- TeV-1 ED Mc > 1.6 TeV

W/Z + (b)-jets

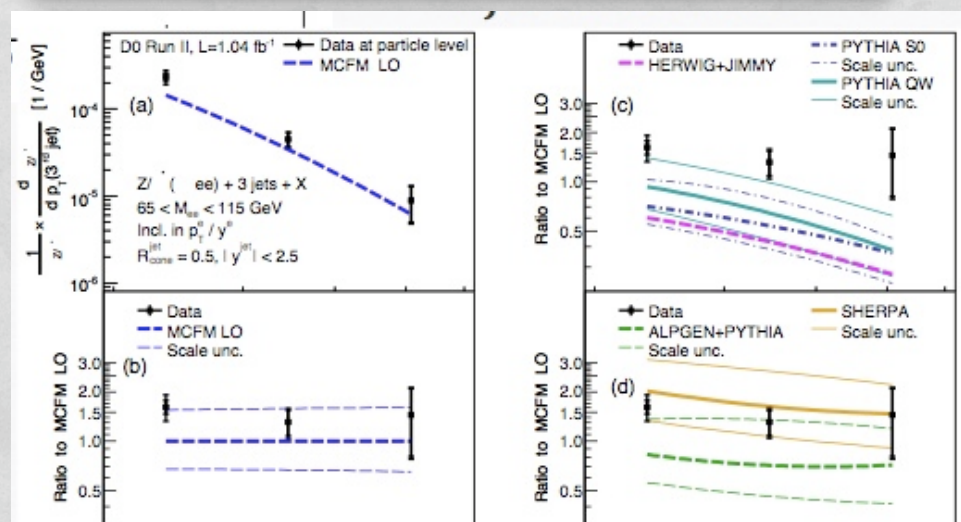




$E_T(j)$

σ b-jets (W+b-jets) · BR(W → l ν) =

2.74 ± 0.27 (stat) ± 0.42(syst) pb

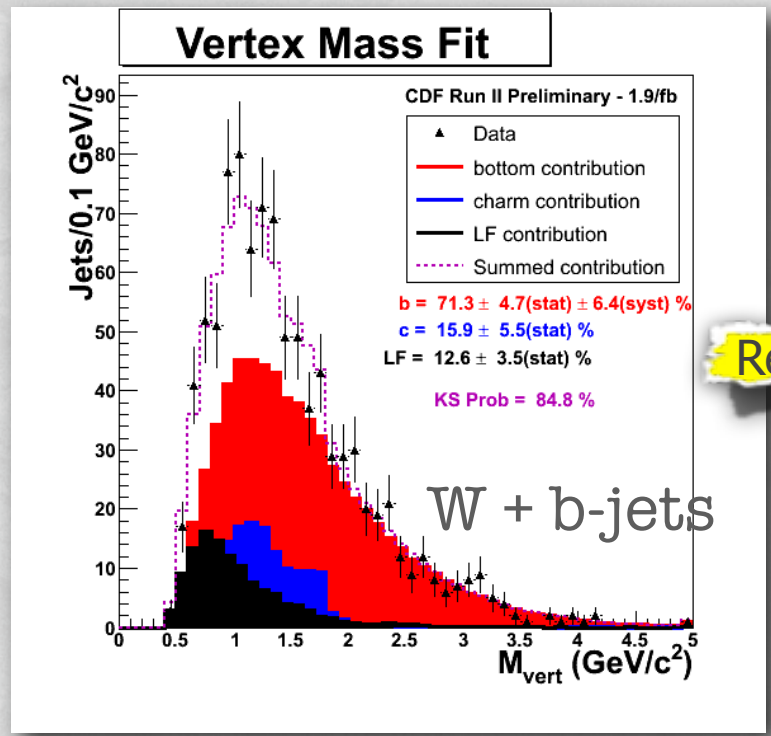


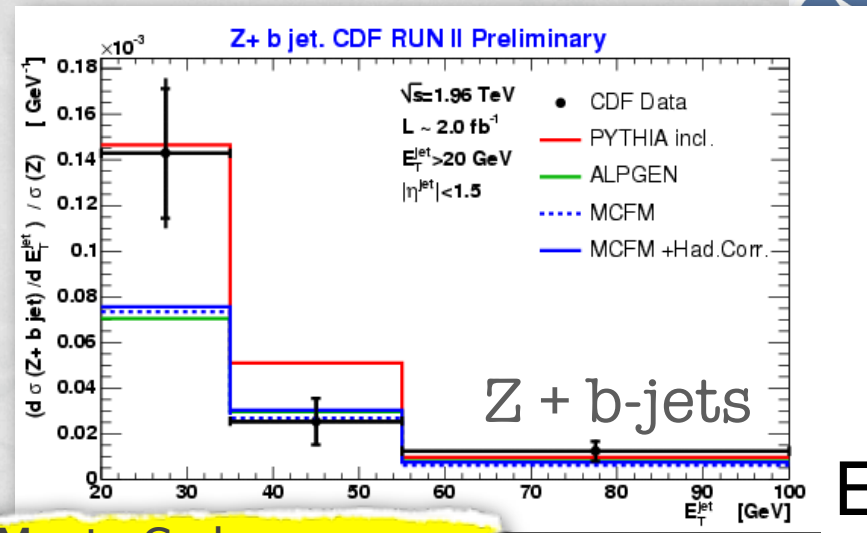
$p_T(j3)$

x2.5-3.5 larger than Pythia/Alpgen/NLO

Can improve significantly differential distributions with x5 more data

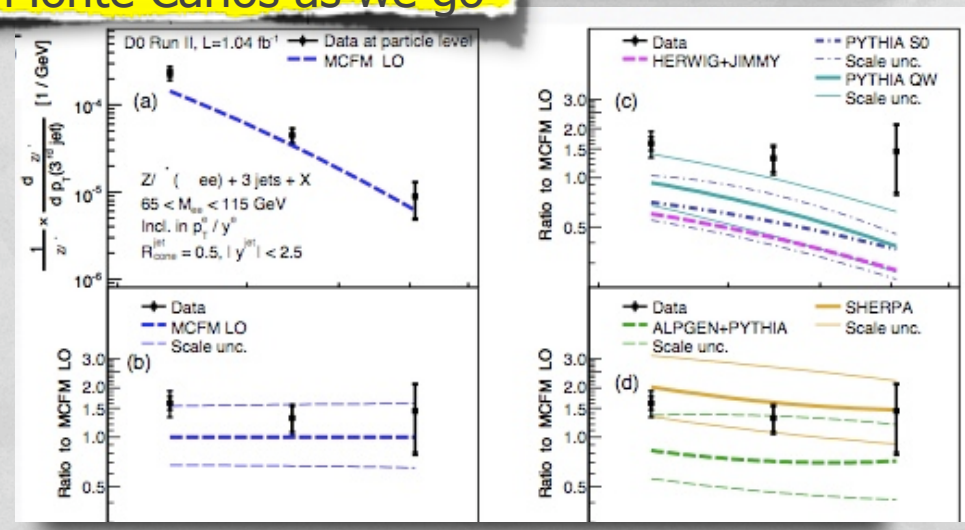
W/Z + (b)-jets





$E_T(j)$

Revisit Monte Carlos as we go



Z + jets

$p_T(j3)$

σ b-jets (W+b-jets) · BR(W → l ν) =

2.74 ± 0.27 (stat) ± 0.42(syst) pb

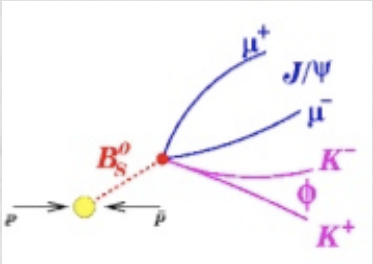
x2.5-3.5 larger than Pythia/Alpgen/NLO

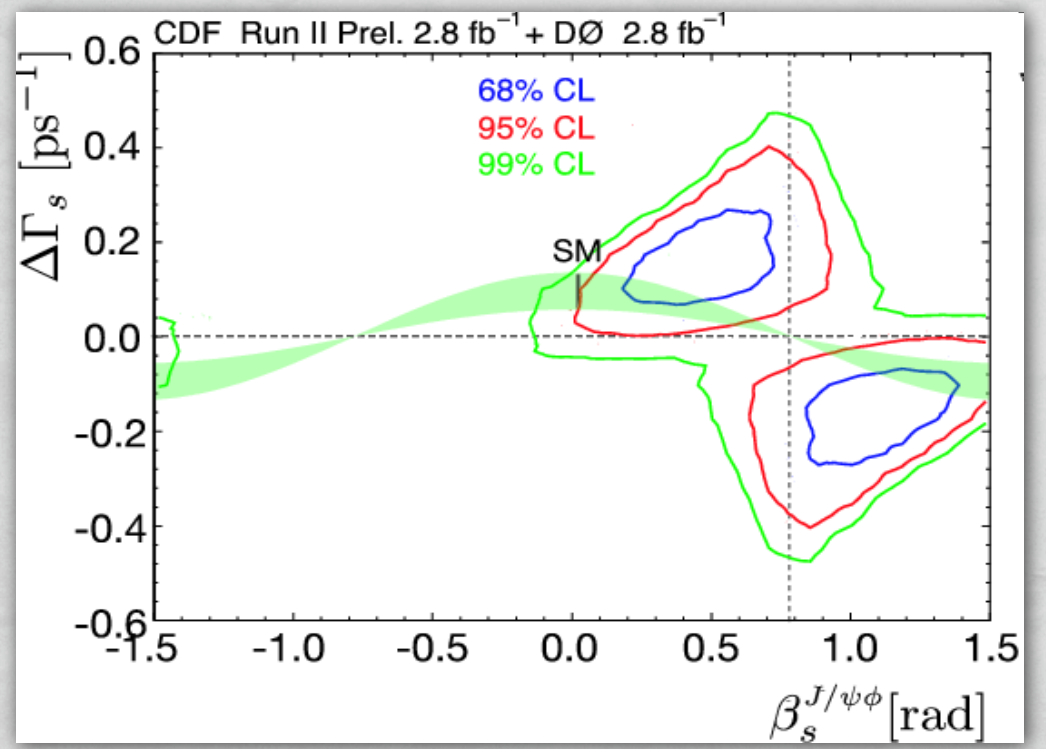
Can improve significantly differential distributions with x5 more data

Need to keep at it: CPV in B_s

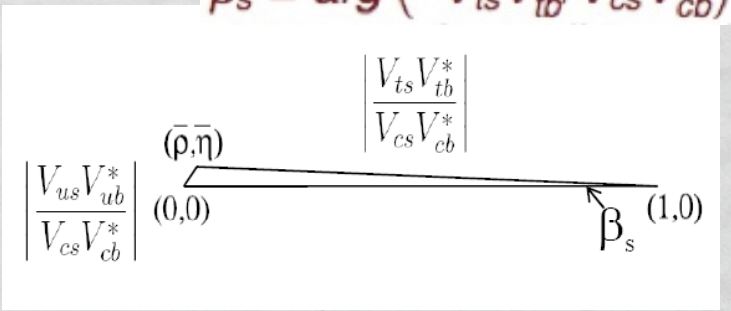
$$B_s \to J/\psi\,\varphi$$

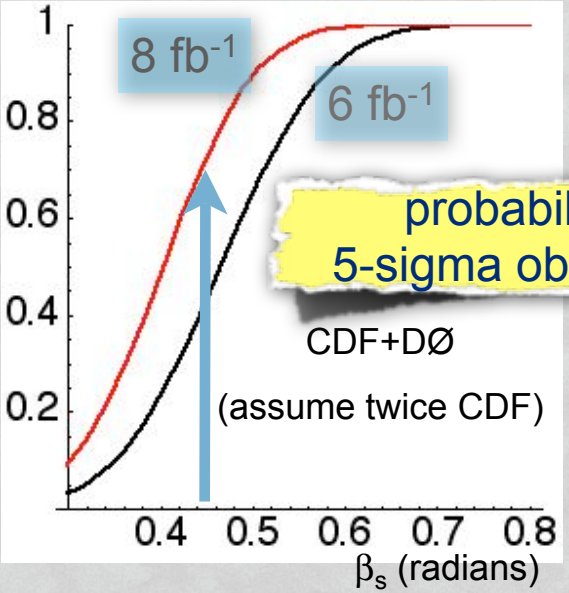
Both CDF and DØ measured CP violation parameter β_s in $B_s \to J/\Psi\Phi$ decays with 2.8 fb^{-1}





$$\beta_s \equiv \arg\left(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*\right)$$



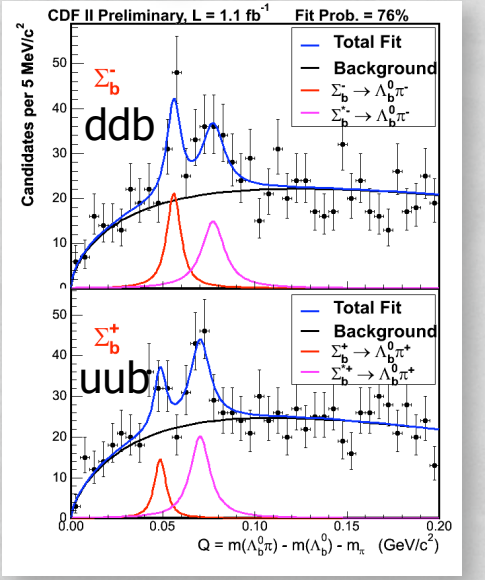


probability for 5-sigma observation

2.1 sigma from SM predictions

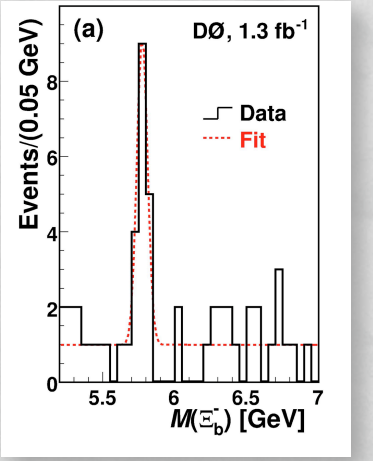
Observation of new heavy baryons

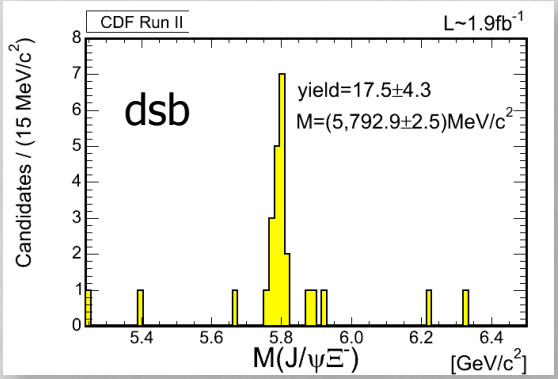
Σ_b



2006

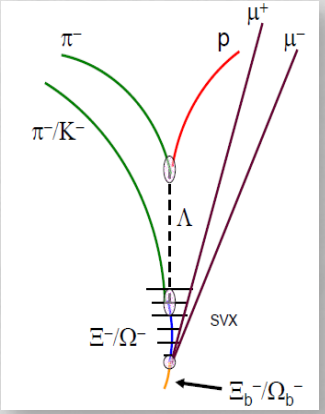
Ξ_b

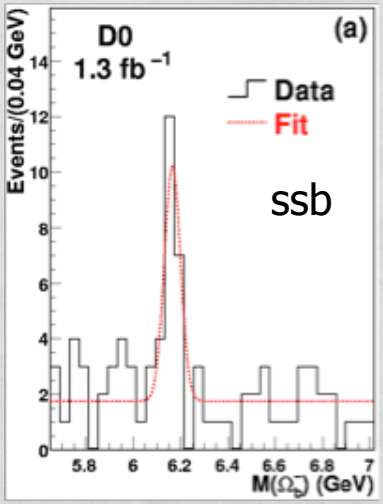


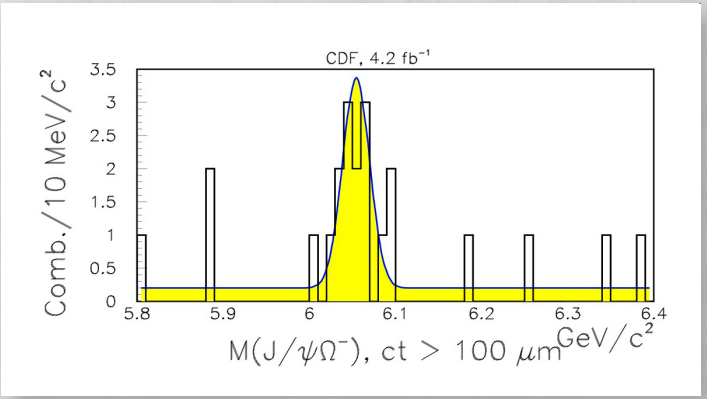


2007

Ω_b







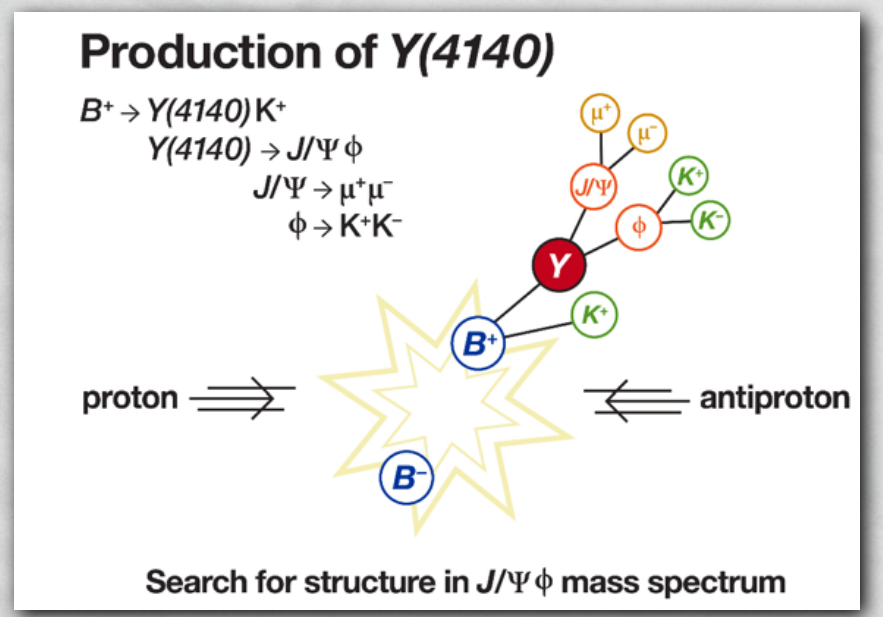
2008/2009

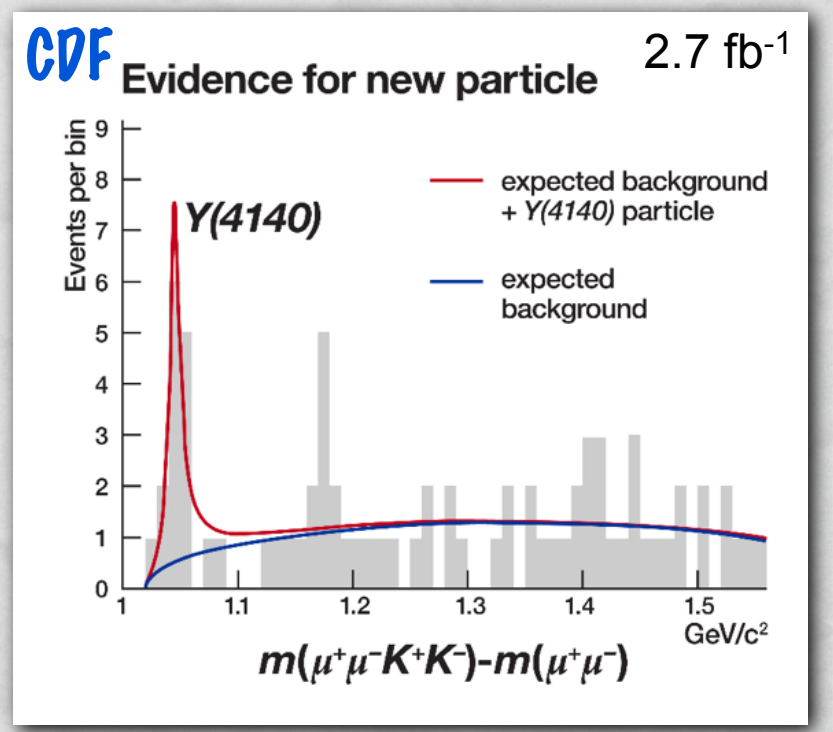
Ω_b puzzle: masses differ significantly

With more data : emergence of a new particle

Y(4140)

unknown composition





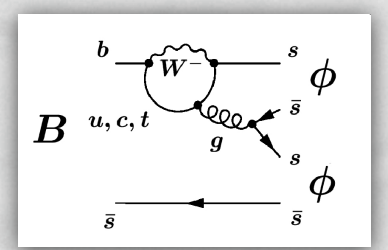
2009

All these new discoveries yield a few events/fb^{-1}
==> new areas of research @ 10 fb^{-1}

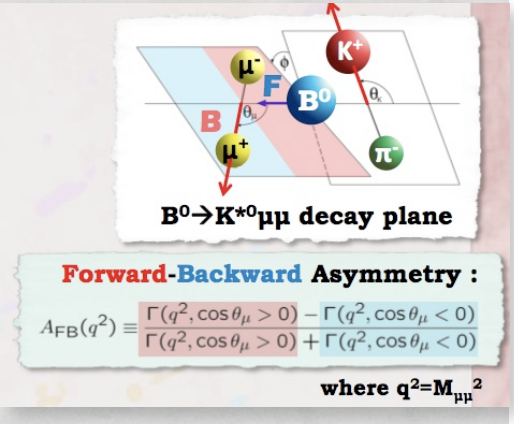
New processes

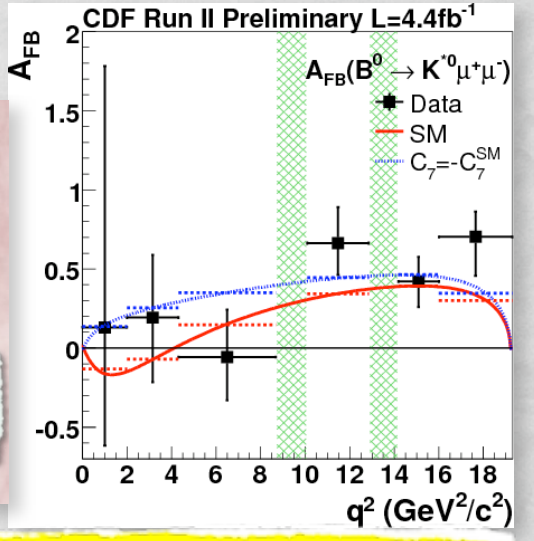
New for HCP!

CDF's displaced track trigger:
a unique window to flavor physics

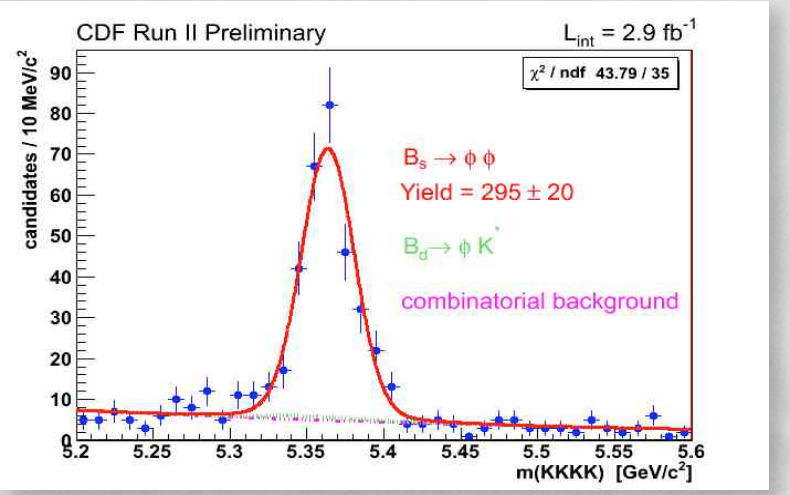


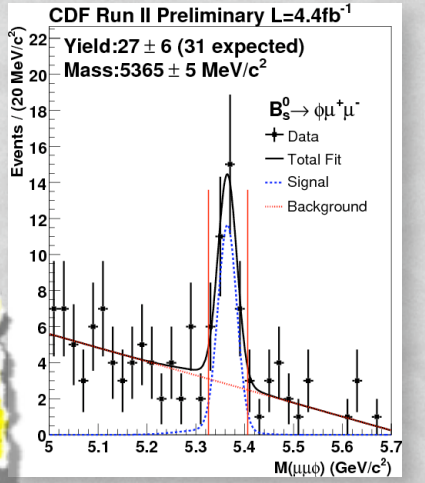
$B_s \to \phi\phi \to KKKK$ **gluonic penguin**





1st measurement of $B^0 \Rightarrow K^*\mu\mu$ F/B asymmetry in hadron collisions
-consistent w/ SM and BSM and Belle -





Bonus : first observation (6 σ) of B^0_s to $\varphi\,\mu\mu$
the rarest B^0_s decay so far: $(1.44 \pm 0.33 \pm 0.46)10^{-6}$
Brand new probe of new physicsC

Final comments

- The Tevatron program continues to be remarkably successful
  - A Legacy of discoveries and extraordinary results
  - The program remains very rich
    - lots of balloons left to pop !
- So far only 1 to 5 fb^{-1} of data analyzed
  - This could increase by factors of 2 to 10 with data from running through 2011
- Exciting potential for future discoveries
  - The Higgs search is in full gear

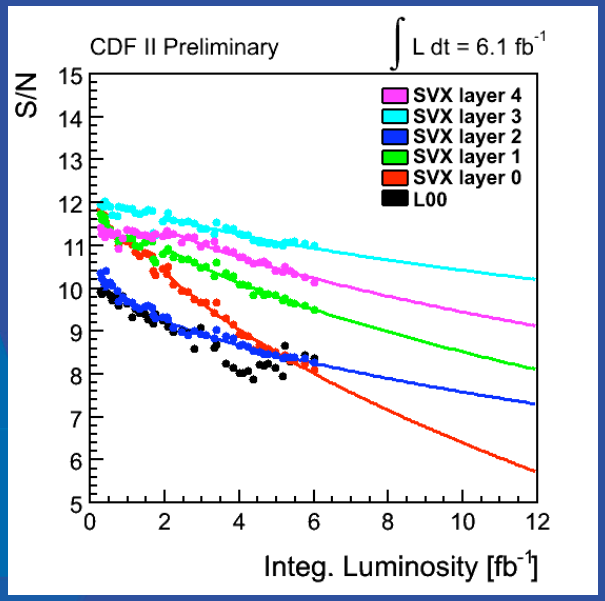
Final comments

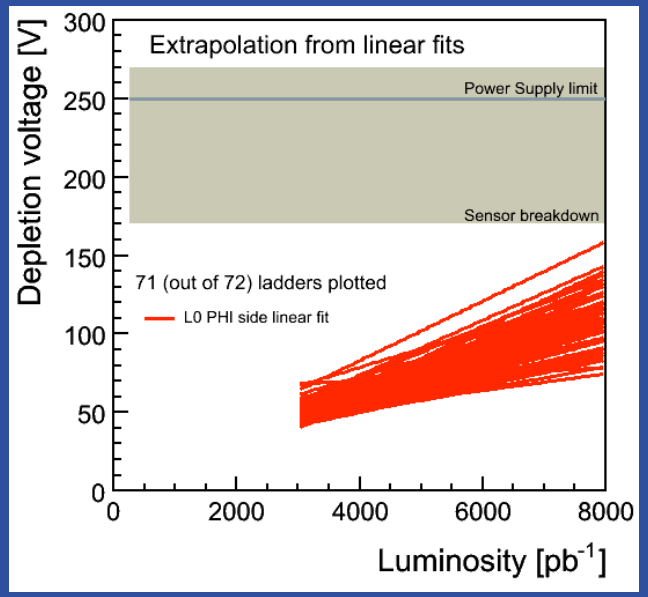
- The Tevatron program continues to be remarkably successful
  - A Legacy of discoveries and extraordinary results
  - The program remains very rich
    - lots of balloons left to pop !
- So far only 1 to 5 fb^{-1} of data analyzed
  - This could increase by factors of 2 to 10 with data from running through 2011
- **We all very much look forward to the LHC startup and first physics results - best of luck !**
  - The Higgs search is in full gear

BACKUP

CDF detector status (I)

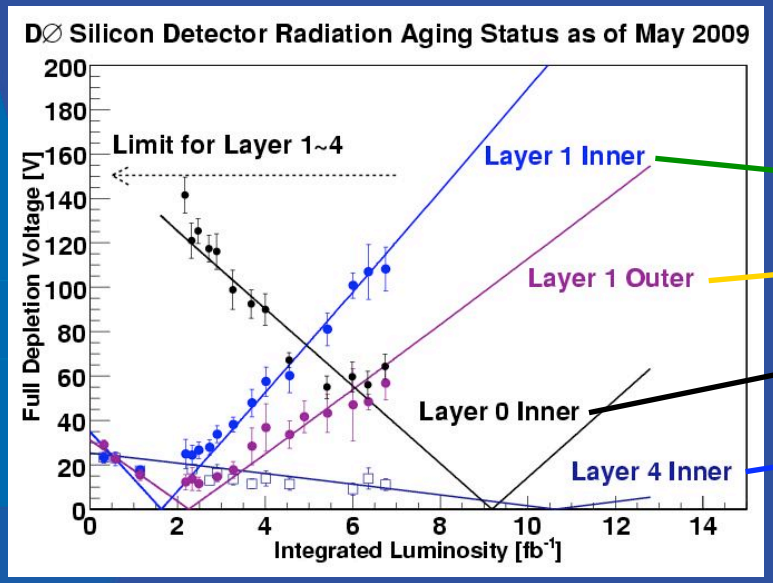
- Silicon detector:
  - ~90% of Si ladders are integrated in data taking (in 8 years 2-3% drop), ~80% return data with <1% error rate;
  - signal/noise projections: no tracking degradation expected;
  - cooling lines: check performed in October 2008 indicates that 2007 repairs are holding;
  - radiation aging: bulk of ladders will be fully depleted through 12 fb^{-1}.

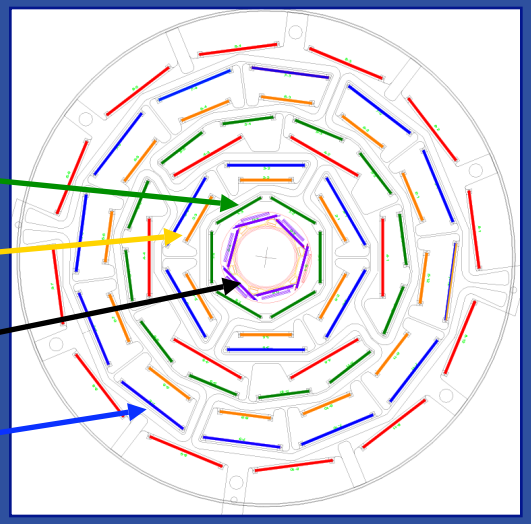




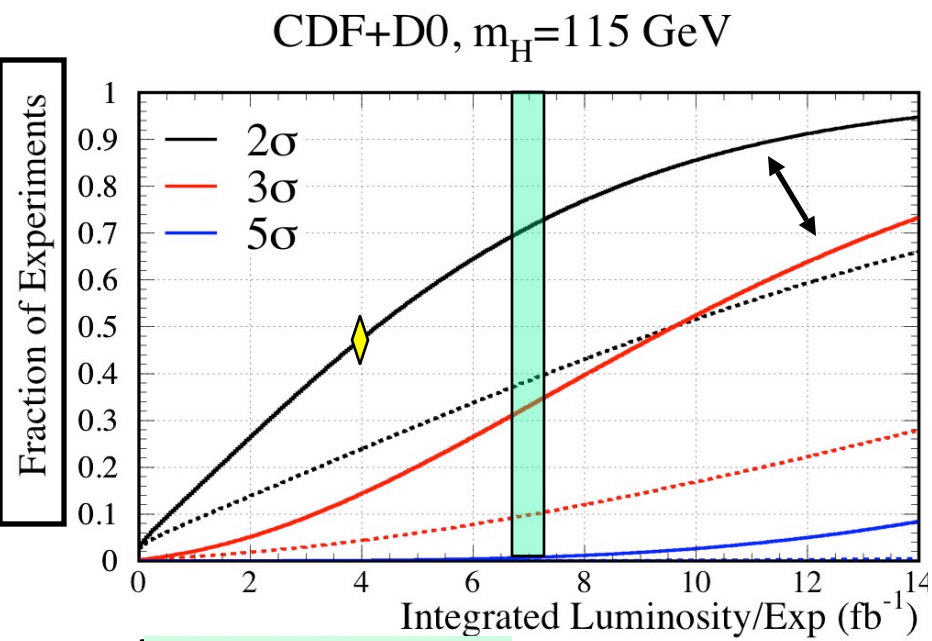
DØ detector status (I)

- Silicon detector:
  - used 2008 shutdown access time to recover ~5% channels which had been previously incapacitated;
  - optimized (and automated) high voltage ramping rate to minimize downtimes at begin and end of store;
  - optimizing operating bias voltages, pedestals and readout thresholds;
  - monitoring impact of radiation damage and adjusting bias voltages accordingly:
    - anticipate that the inner Layer 1 sensors may not be fully depleted beyond > 8 fb^{-1} delivered;
  - layer 0 was installed in 2006 to enhance impact parameter resolution and compensate for consequences of rad damage.

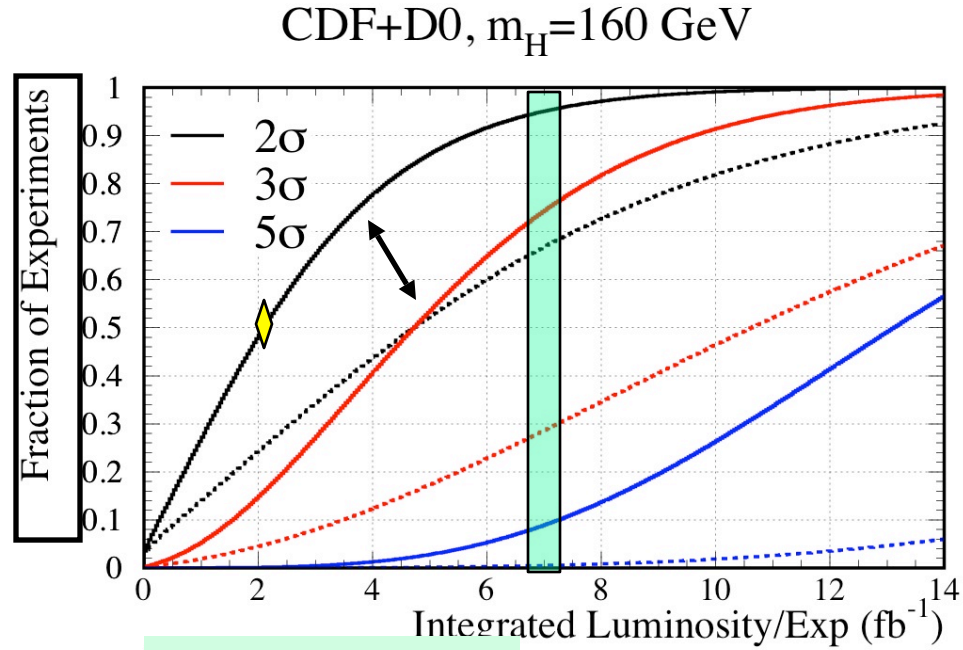




Higgs: On any given roll of the dice



Analyzed Lum.



Analyzed Lum.

Solid lines = x2.25 improvement from 2007
Dash lines = x1.50 improvement from 2007

x2.25 improvement @ 115 GeV

7 fb^{-1} => 70% experiments w/2σ
30% experiments w/3σ

x2.25 improvement @ 160 GeV

7 fb^{-1} => 95% experiments w/2σ
75% experiments w/ 3σ

Fermilab's new schedule

- Presented at last October's HEPAP meeting

Draft 2010-13 Fermilab Accelerator Experiments' Run Schedule

Typically Revised Annually - This Version from October, 2009

Calendar Year		2010	2011	2012	2013
Tevatron Collider		CDF & DZero	CDF & DZero	OPEN	OPEN
Neutrino Program	B	MiniBooNE	MiniBooNE		OPEN
		OPEN	OPEN		MicroBooNE
	MI	MINOS	MINOS		OPEN
		MINERvA	MINERvA		MINERvA
		ArgoNeuT			
				NOvA	NOvA
SY 120	MT	Test Beam	Test Beam		Test Beam
	MC	OPEN	OPEN		OPEN
	NM4	E-906/Drell-Yan	E-906/Drell-Yan		E-906/Drell-Yan

This draft schedule is meant to show the general outline of the Fermilab accelerator experiments schedule, including unscheduled periods.

Major components of the schedule include shutdowns:

In Calendar 2010, a 4-6 week shutdown for maintenance is shown.

In Calendar 2011, no shutdown for maintenance is shown.

A 2012-3 11-month shutdown is shown to upgrade the proton source and change the NuMI beam to the Medium Energy (ME) config.

RUN/DATA

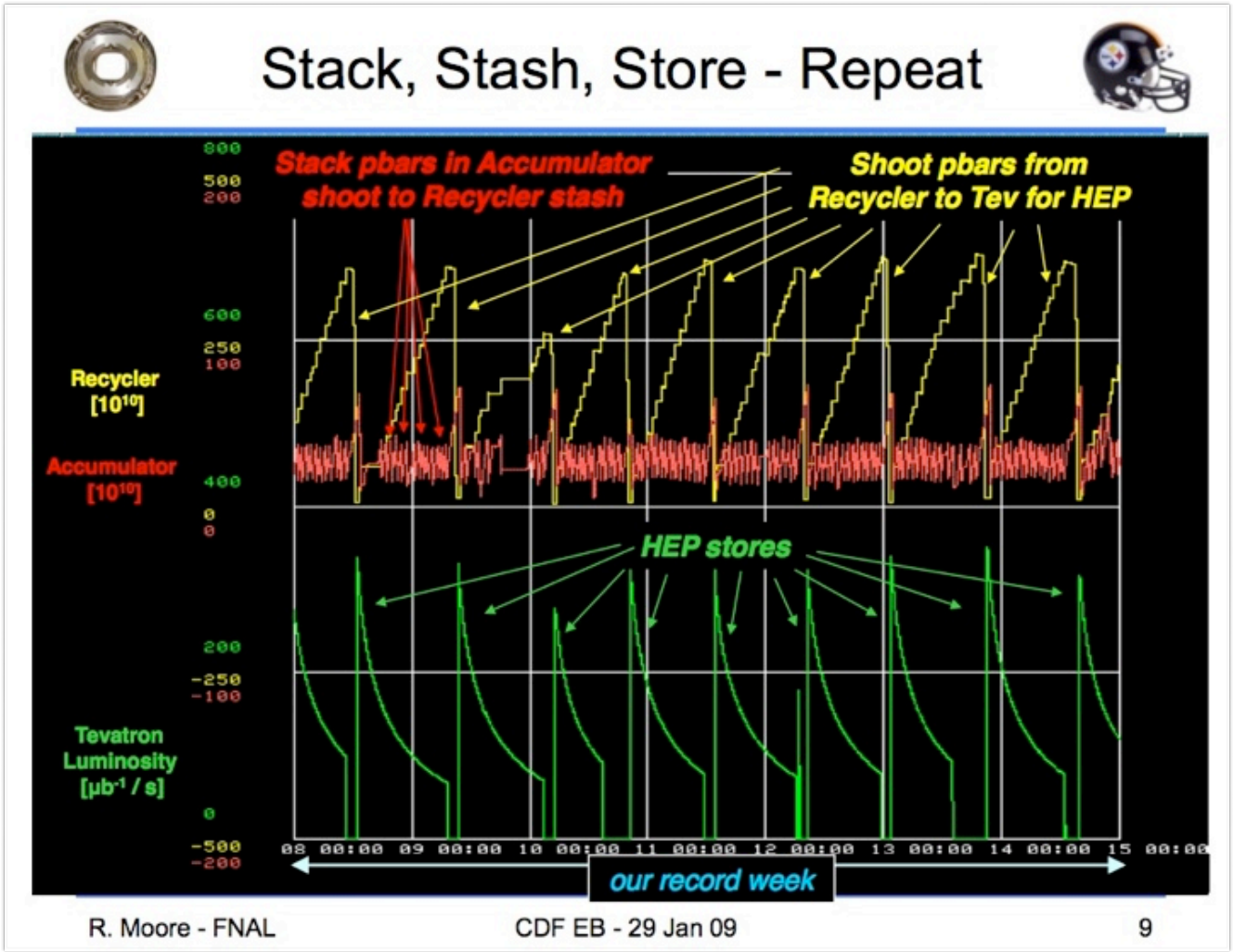
STARTUP/COMMISSIONING

INSTALLATION

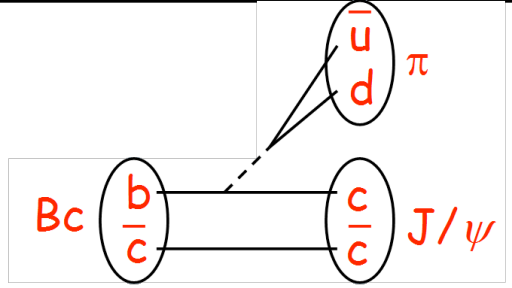
M&D (SHUTDOWN)

19-Oct-09

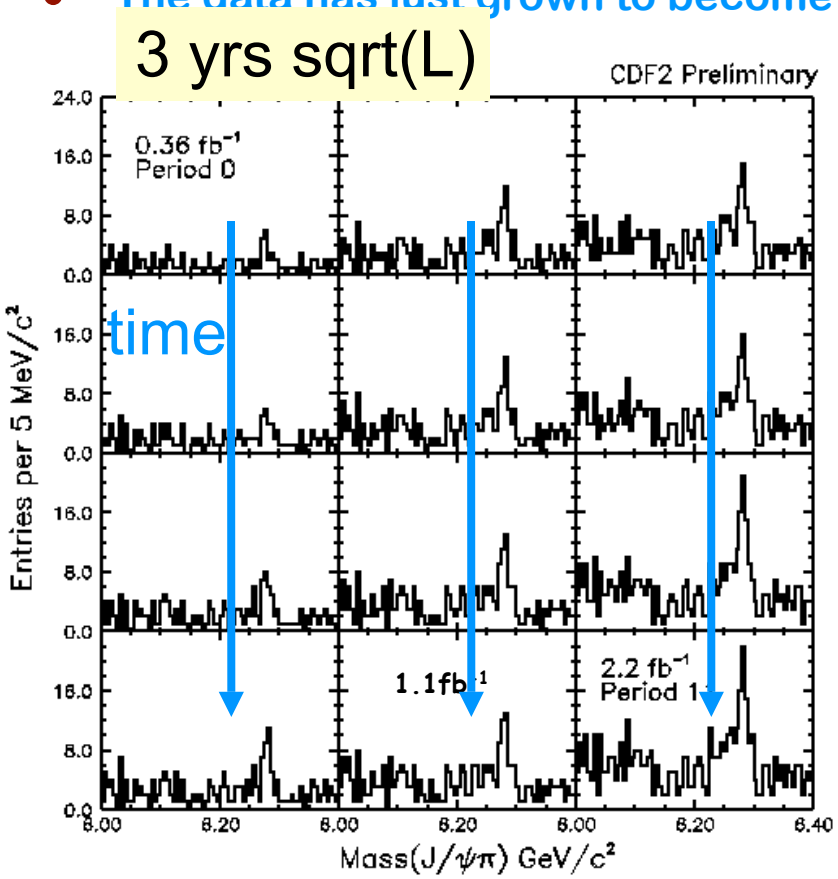
A perfect week at the Tevatron

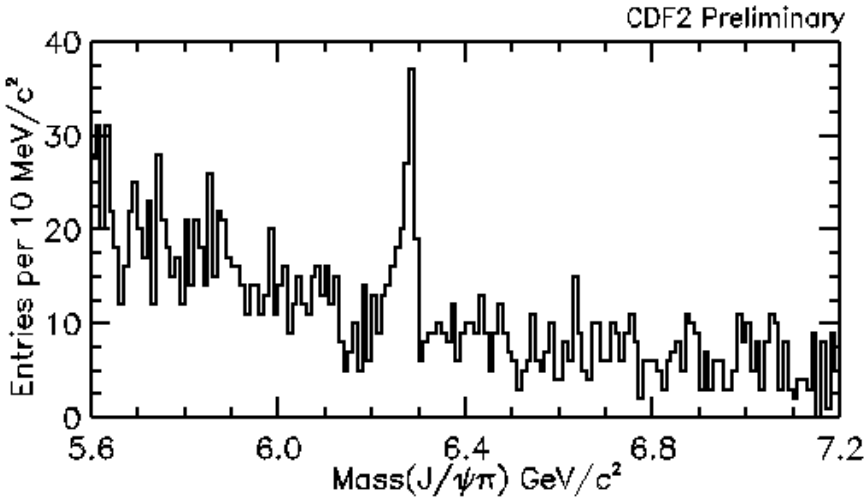


Bc => J/ψ π with 2.2 fb^{-1}



- Bc is a unique system of two distinct heavy quarks and is not produced at B factories. Full reconstruction allows for a mass measurement.
- The analysis was tuned on Bu==>J/ψK at 360pb^{-1} before "opening the box"
- The data has just grown to become <3σ, then 6σ, and now 8σ





$M(Bc)_{CDF}$ = 6274.1 +/- 3.2 +/- 2.6 MeV/c^2

$M(Bc)_{LATTICE}$ = 6304 $^{+18}_{-0}$ +/- 12

Δ~ 30 MeV/c^2