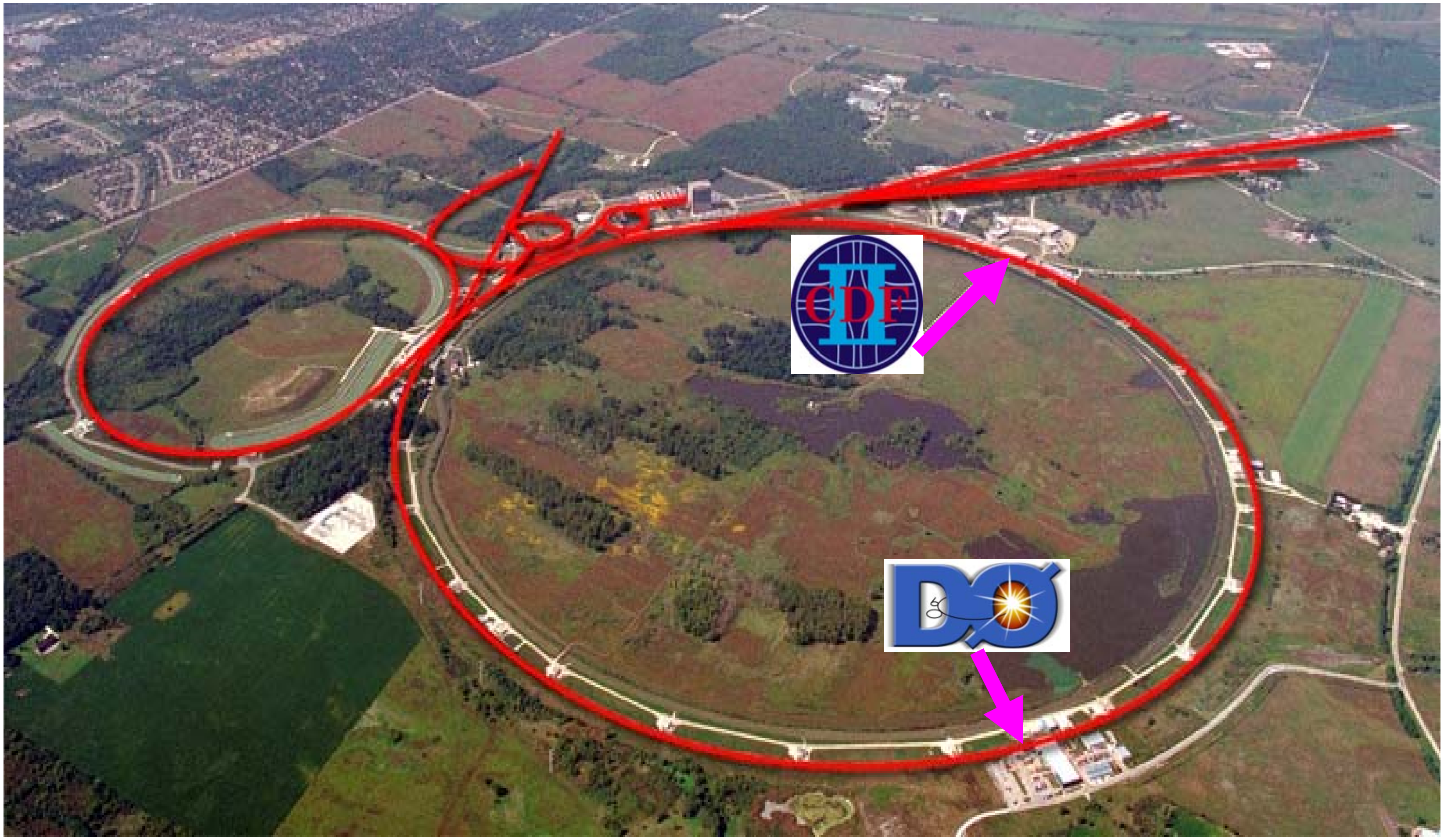
Recent Results from the Tevatron

Gregorio Bernardi,
LPNHE Paris

On behalf of CDF and DØ

September16th 2010

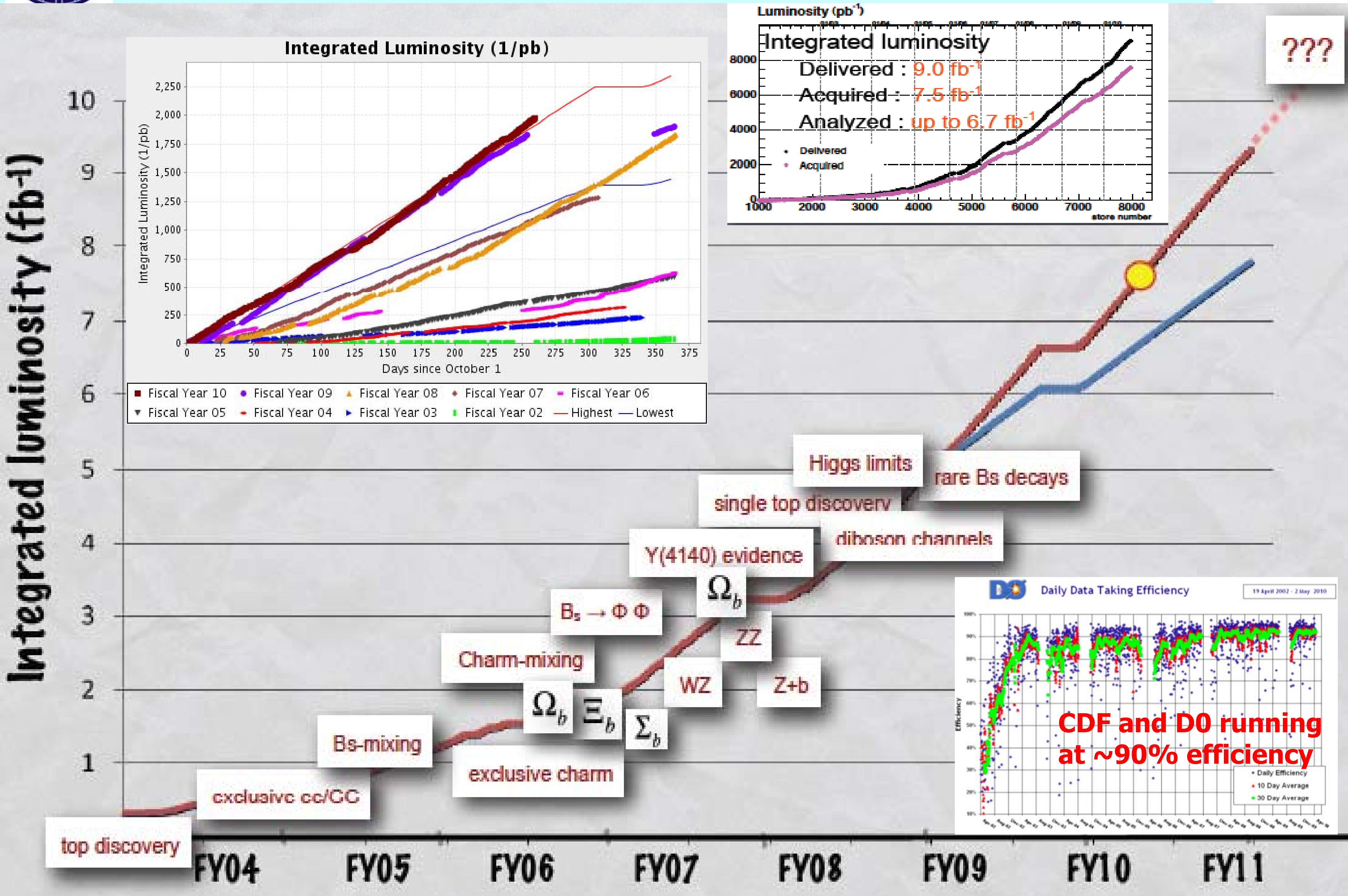
Thanks to all cdf & d0 colleagues



Outline

- **The Tevatron**
  - Status and performance vs LHC
- **Standard Model precision measurements**
  - From QCD physics to the electroweak precision measurements
- **Searches for BSM Physics**
  - In electroweak physics
  - Signature-based searches
  - Evidence for anomalous like-sign dimuon charge asymmetry
- **Higgs boson search**
  - Current exclusion limits and the physics case for running beyond 2011

The Fermilab Tevatron



Tevatron vs LHC / Physics Results

LHC in 2010-2011:

- 3.5 times more energy than TeV, but pp collisions

< 10 times less integrated luminosity

Currently < 10000 less integrated luminosity

➔ Tevatron results have dominated HEP part of ICHEP 2010,

But LHC has also shown an impressive capability to exploit its data rapidly, starting to rediscover the SM. Tevatron now has serious competition

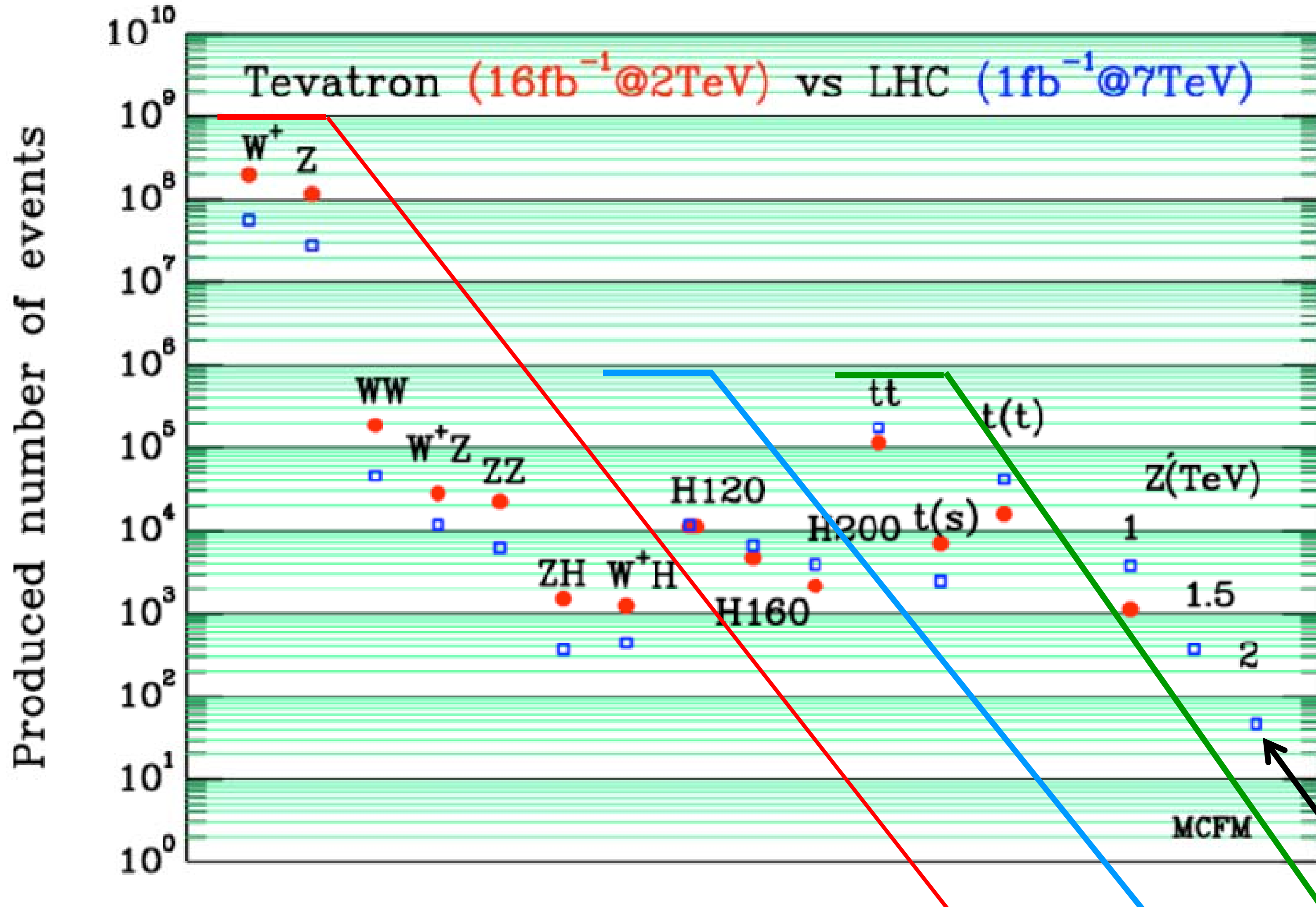
LHC from (mid?) 2013

- 7 times more energy

- 5-10 fb^{-1} (or more) of integrated luminosity per year

➔ going to be very tough for the Tevatron, but we'll be in 2014 or 2015….maybe the Higgs will be already found..

16 fb^{-1} @ Tevatron vs 1 fb^{-1} @ LHC



Larger electroweak W, Z, diboson samples

Comparable direct Higgs production

Comparable ttbar, single top is singular,

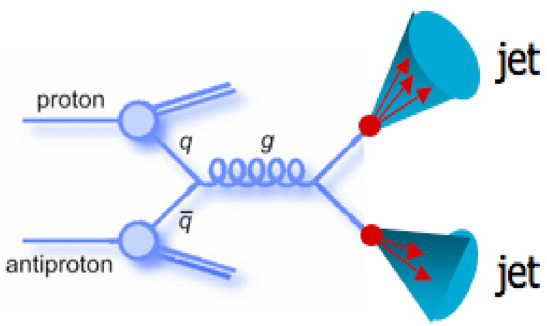
Z', let's talk about something else

Precision Measurements

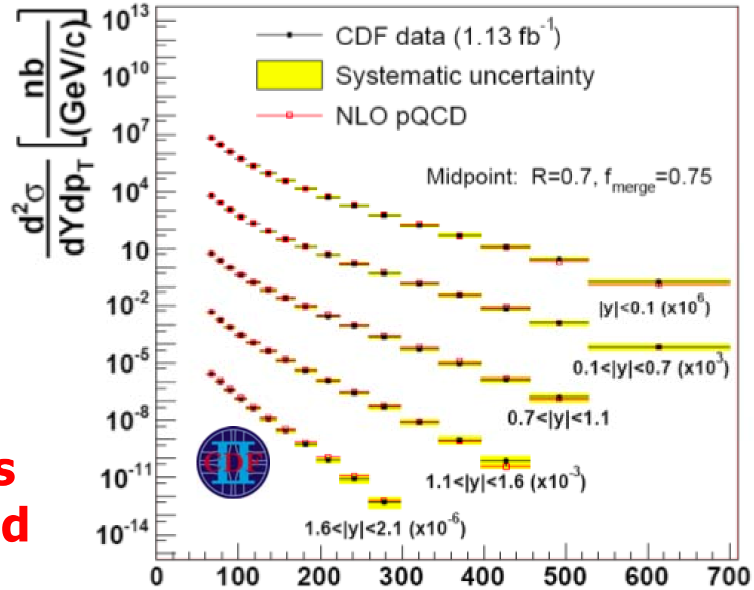
- **Tests of QCD**
  - Inclusive Jets production
  - Diphotons
  - High mass exclusive Dijet production

- **Electroweak Physics**
  - Top, W, Higgs Mass
  - Diboson production

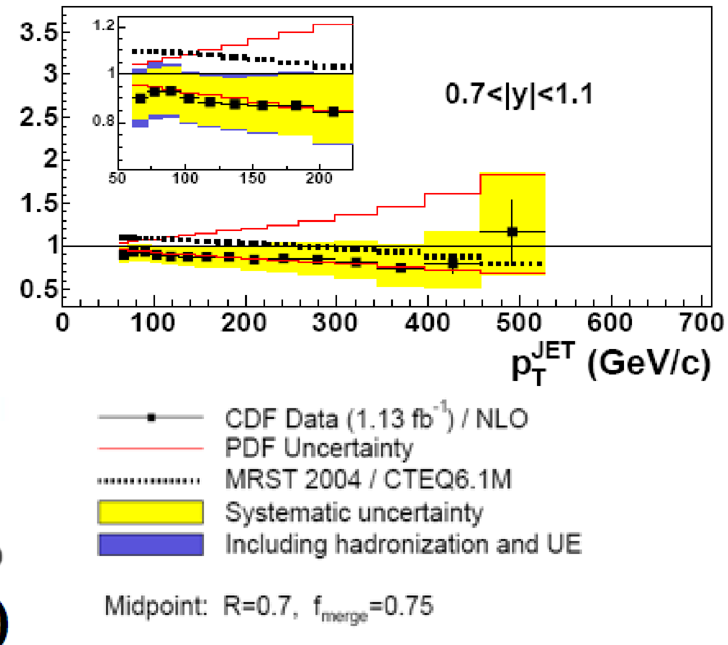
Inclusive Jet Production



Collimated jet of particles originating from quark and gluon fragmentation



Phys. Rev. D 78, 052006 (2008)



Sensitive to:

Hard partonic scattering

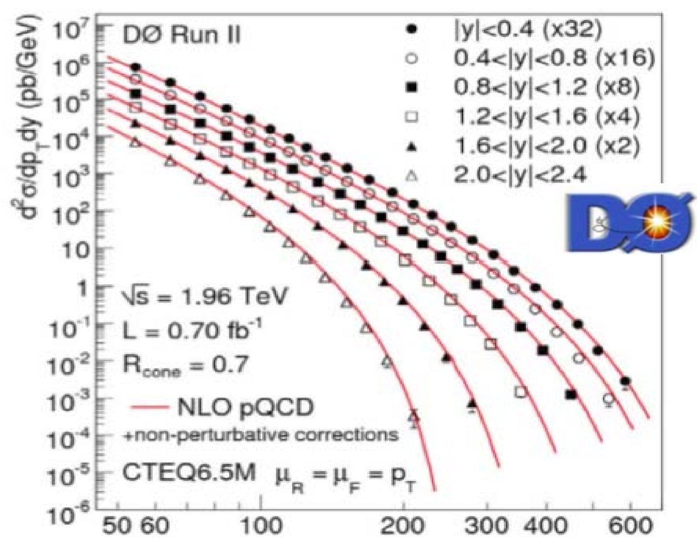
strong coupling constant

proton's parton content

→ unique sensitivity to high-x gluon dynamics of interaction

- validity of approximations (NLO, LLA, …)

- QCD vs. BSM



Phys. Rev. Lett. 101, 062001 (2008) p_T (GeV/c)

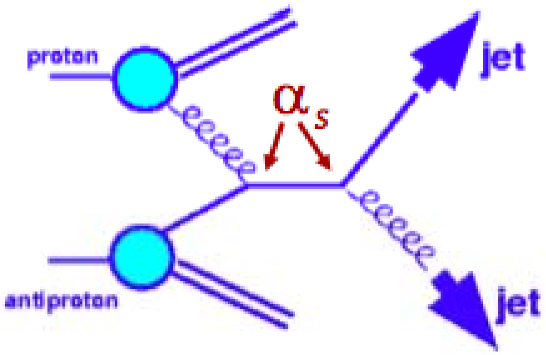
Experimental precision now exceeds the PDF theoretical uncertainty

data are used in PDF fits:

• included in MSTW2008 PDFs

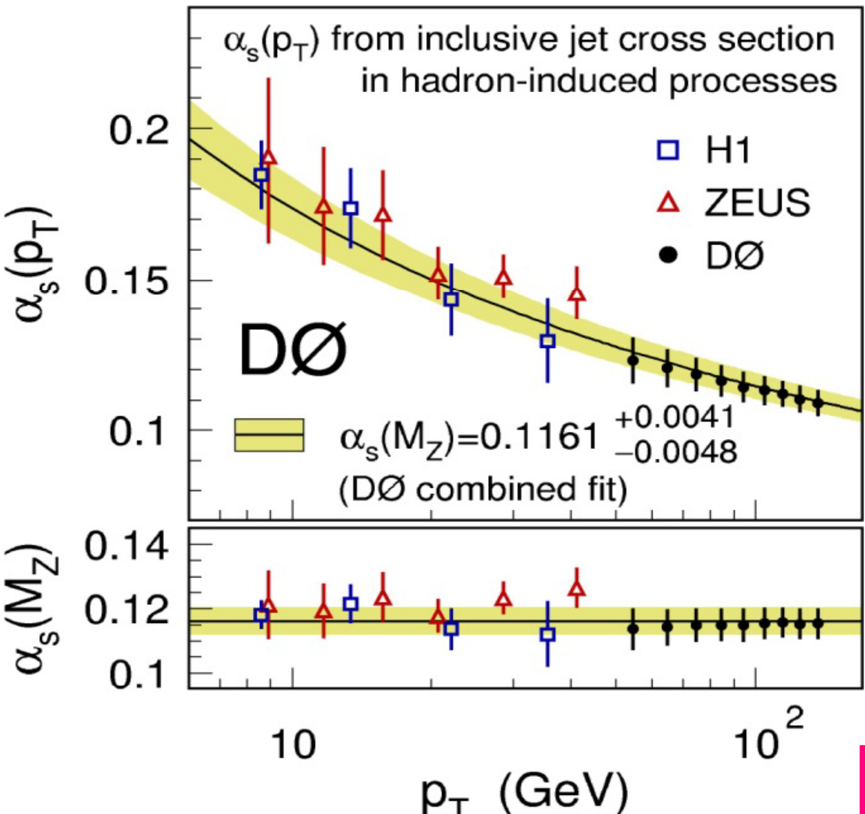
→forthcoming CTEQ PDFs

Strong Coupling Constant



Measurement uses the P_T dependence of the jet x-section
-χ^2 minimization of data/theory points
- **-22/110 points in the inclusive jet cross section used**
  - **-50 < P_T < 145 GeV/c,**
  - **- high points excluded to minimize PDF uncertainty correlations**

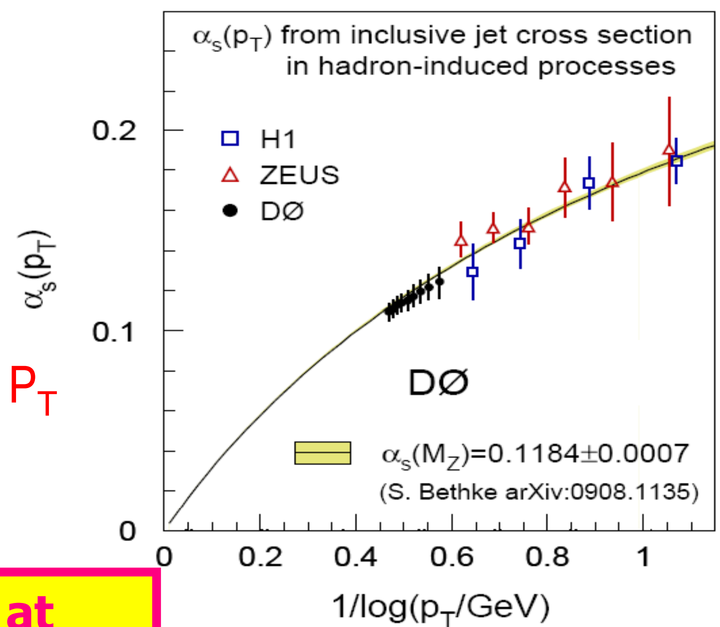
- NLO+2 loop thresholds corrections
- MSTW2008NNLO PDF's



$$\alpha_s(M_Z) = 0.1161^{+0.0041}_{-0.0048}$$

Phys. Rev. D 80, 111107 (2009)

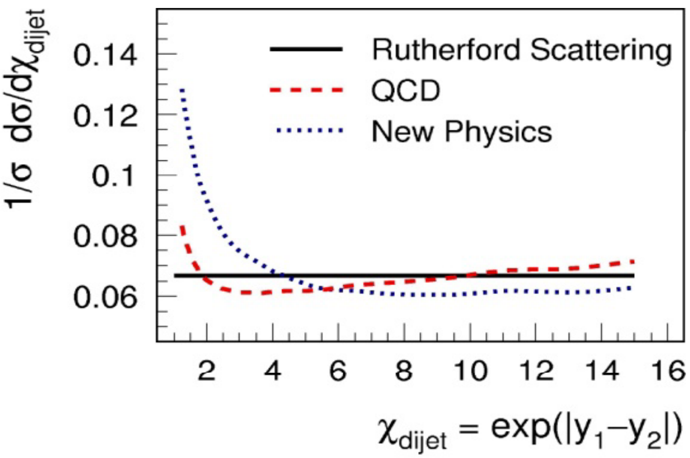
HERA results extended to high P_T



Most precise result at hadron-hadron collider !

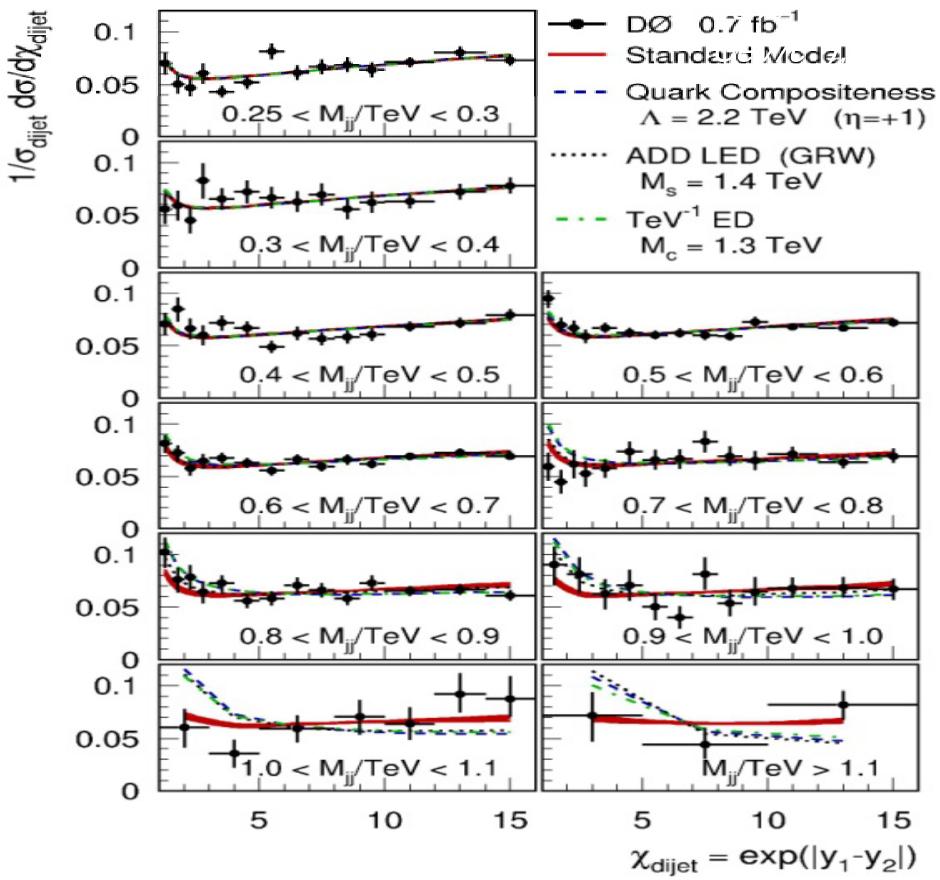
Dijet angular and mass distributions

Dijet angular distribution (in dijet mass bins)

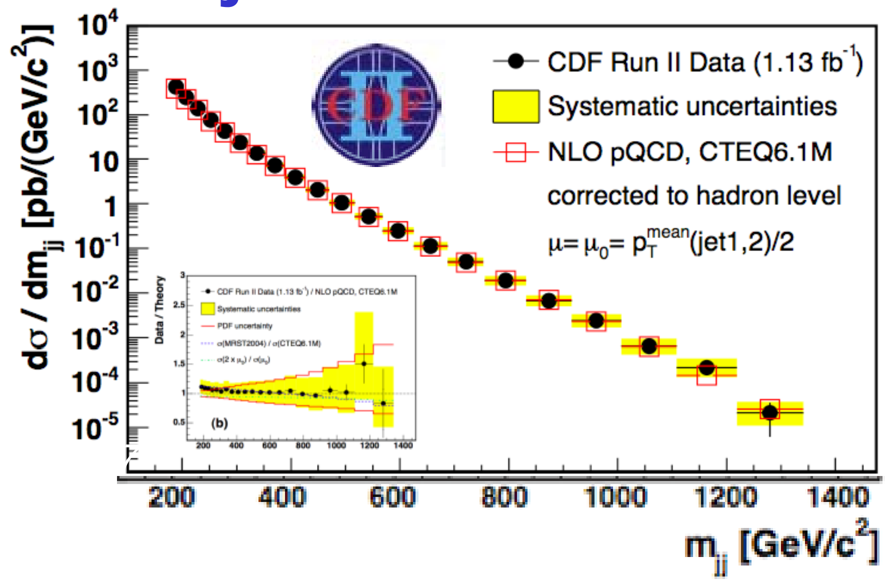


Limits on Compositeness & LED

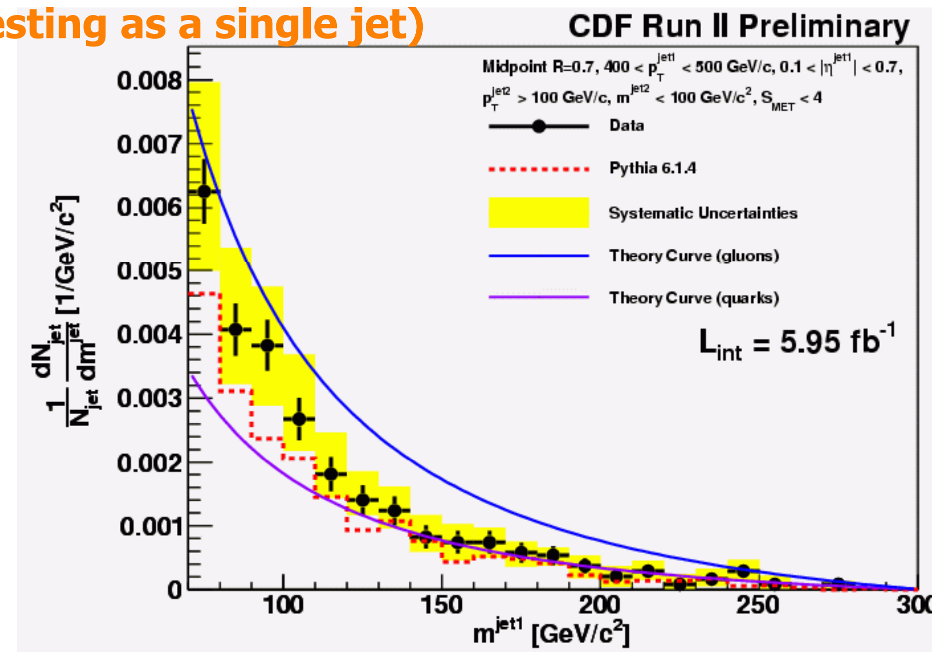
- Quark Compositeness Λ > 2.9TeV
- ADD LED (GRW) Ms > 1.6 TeV
- TeV-1 ED Mc > 1.6 TeV



Dijet mass distribution

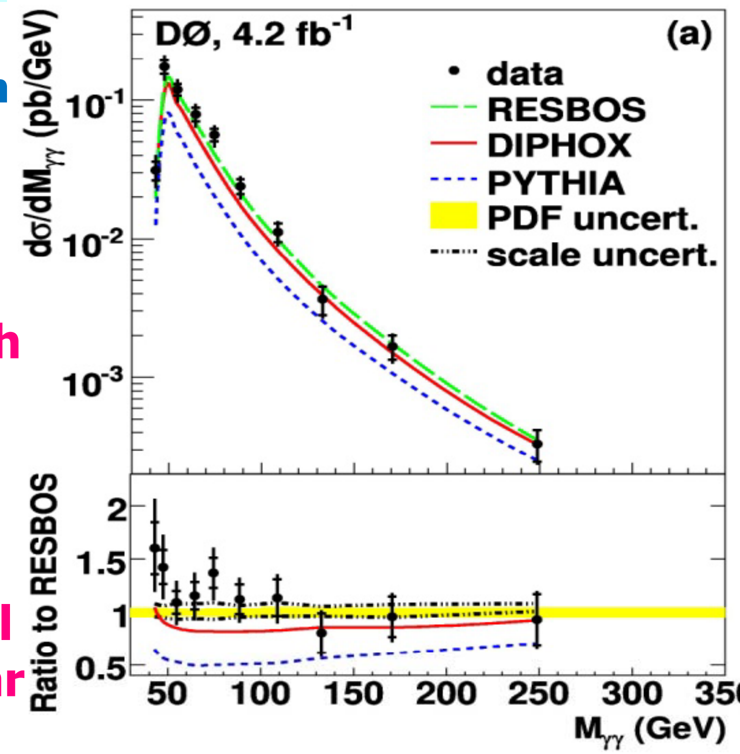


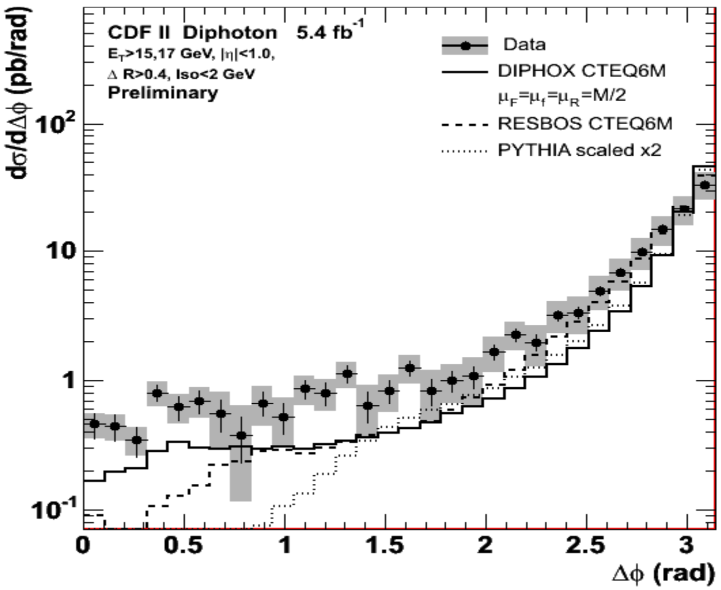
The substructure of very high PT jets : studied via the energy flow and jet mass (boosted particles manifesting as a single jet)



Diphotons in QCD and beyond

- Signature for very interesting physics processes
- Invariant mass distribution can be measured with good precision
-The direct measurement of the transverse momentum of the $\gamma\gamma$ system (q_T) is sensitive to initial state soft gluon radiation

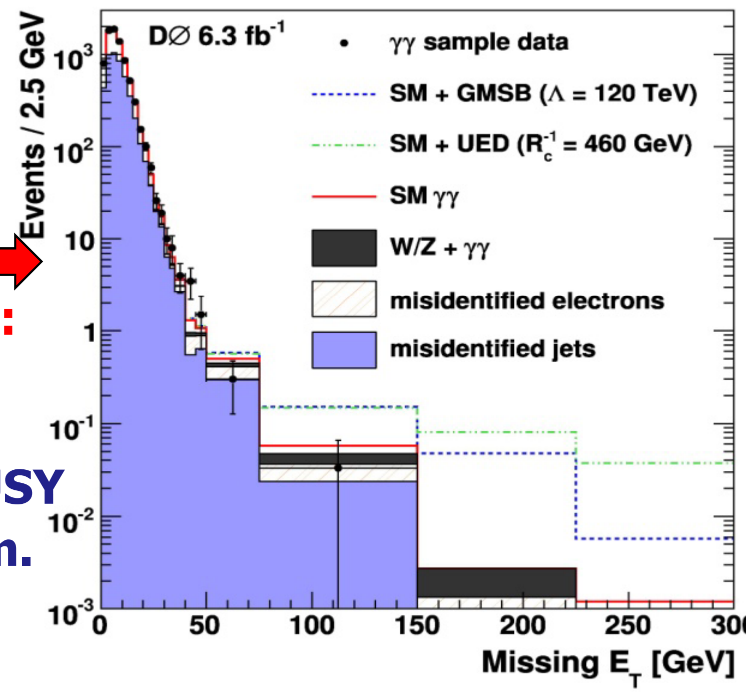




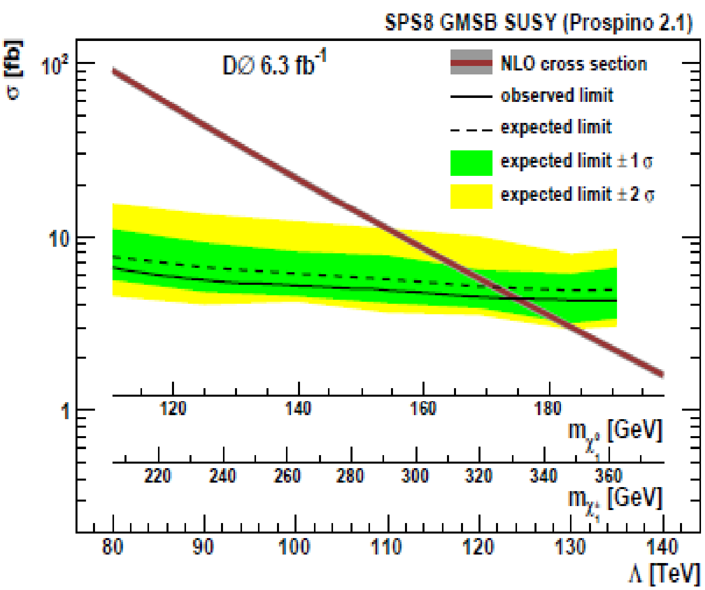
Results are compared with a variety of theoretical predictions

Higher order corrections (beyond NLO) needed as well as resummation to all orders of soft and collinear initial state gluons

Diphoton + X as an example of model independent searches:

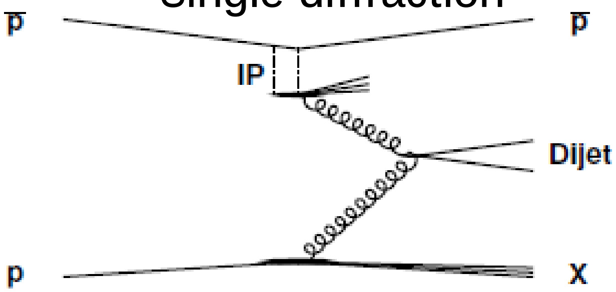


Also interpreted as a
- Search for GMSB SUSY
- Search for extra-dim.

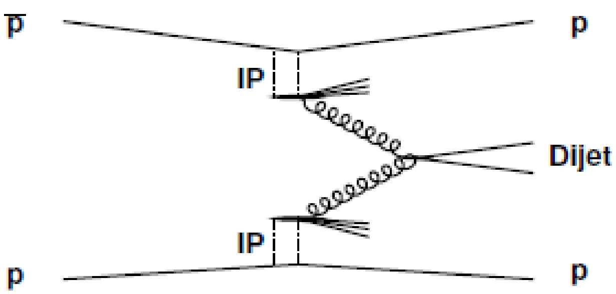


High mass exclusive dijet production

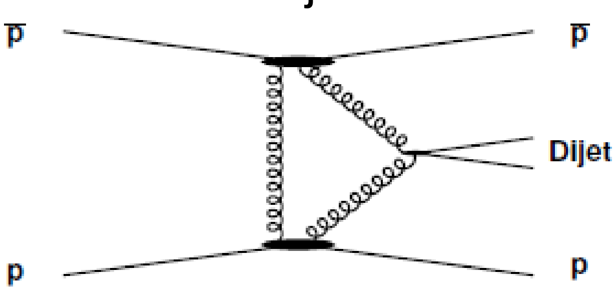
Single diffraction

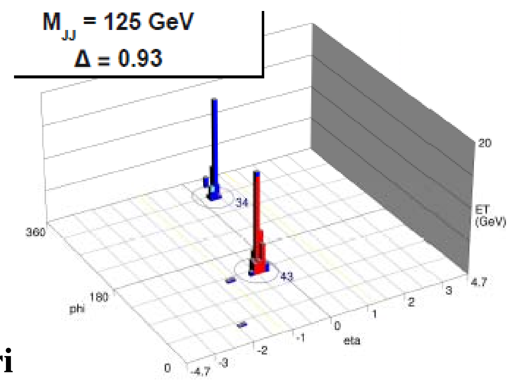


Inclusive Double Pomeron



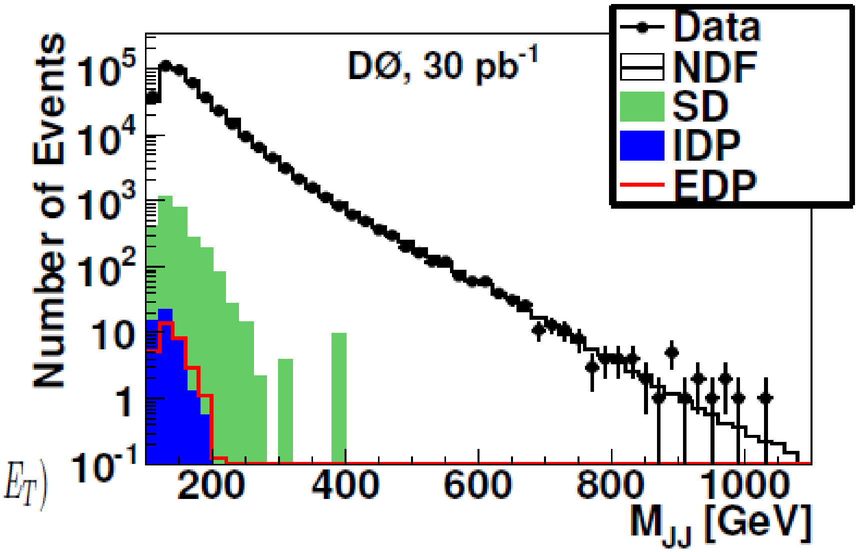
Exclusive Dijet Production

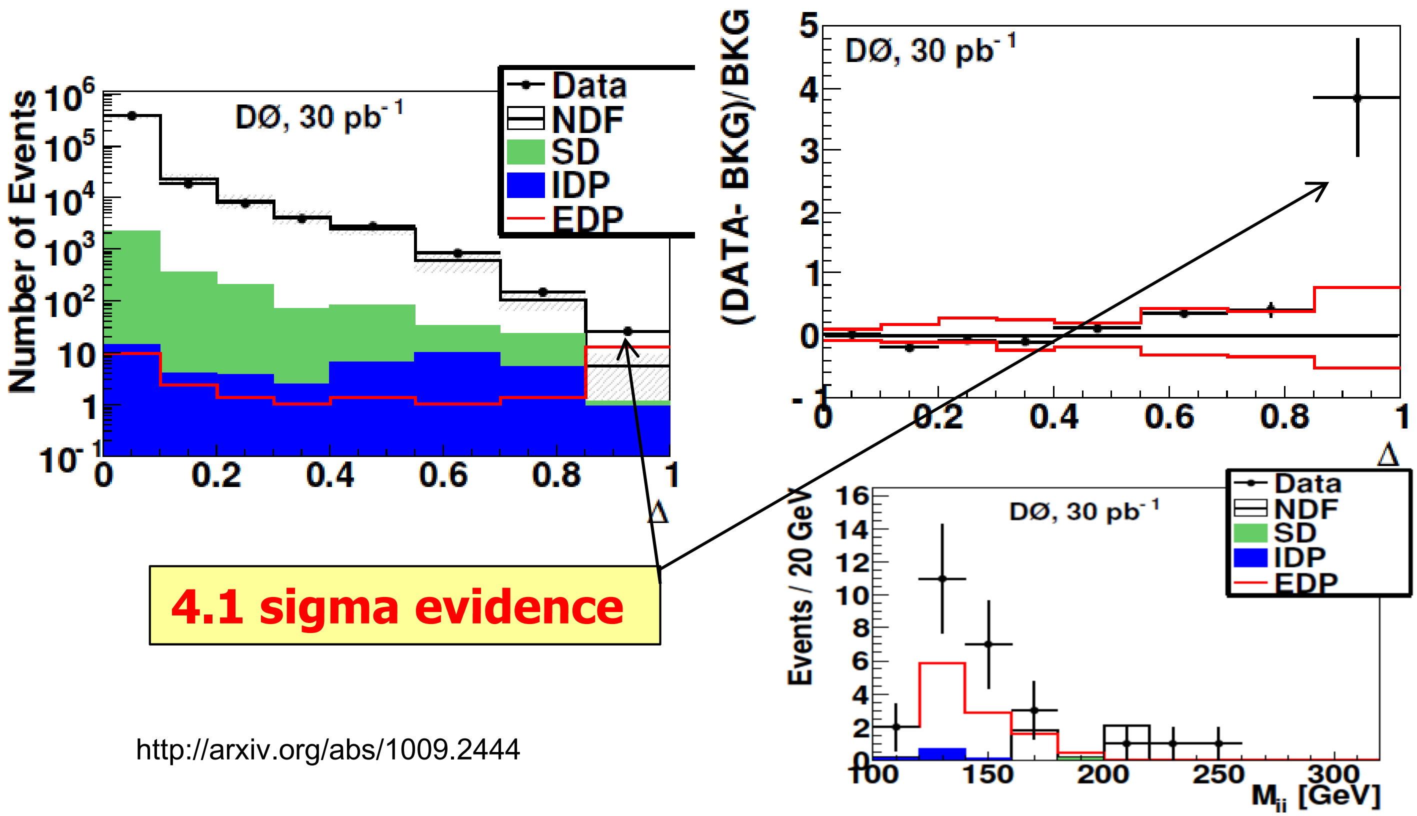




Select dijet events with small forward activity, using forward and very forward energies in the calorimeter with new Δ variable:

$$\Delta = \frac{1}{2}\exp\left(-\sum_{2<|\eta|<3} E_T\right) + \frac{1}{2}\exp\left(-\sum_{3<|\eta|<4.2} E_T\right)$$





4.1 sigma evidence

http://arxiv.org/abs/1009.2444

Gregori

Top Quark Physics

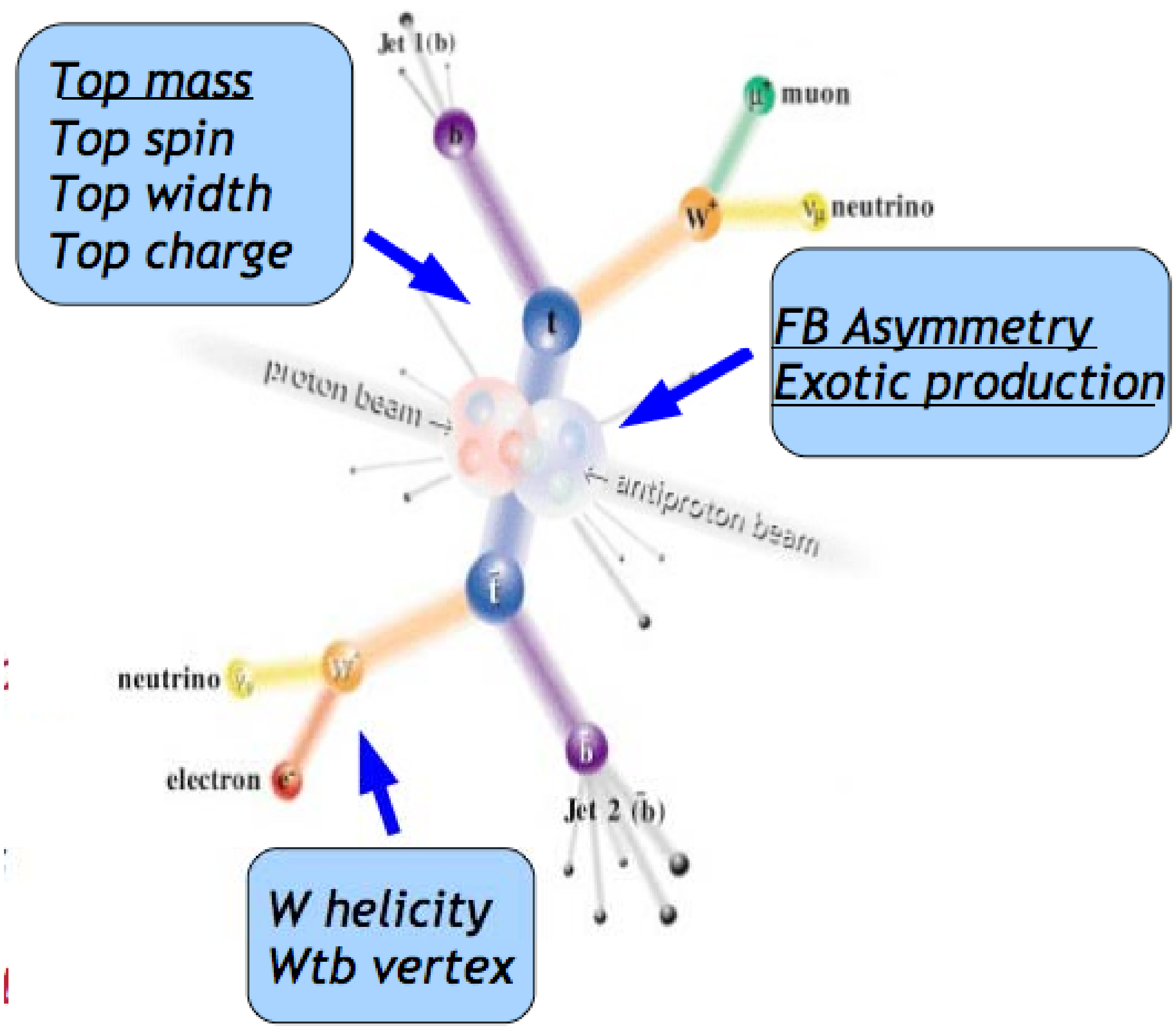
The Tevatron program explores all top properties as well as sources of new physics

top quark ***production***
- *top pair production*
- *Single top production*

top quark ***properties***
- *Mass, spin, width, charge*

top quark ***decay***
- *W boson helicity in top decays*
- *Probe the W-t-b vertex*

Exotic sources *of top quarks*
- *Non SM top*
- *Forward-backward asymmetries*

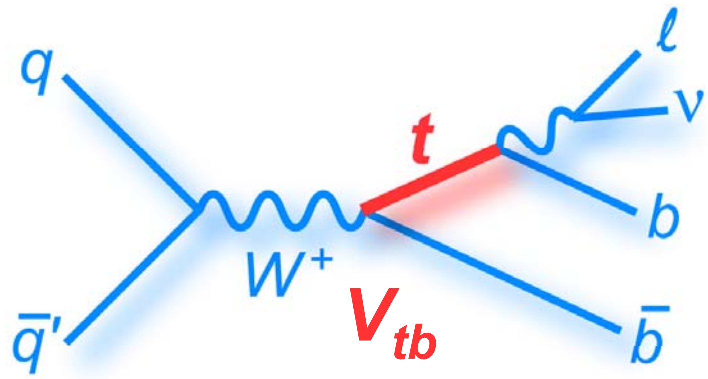


Single Top Quark Production

direct measurement of $|V_{tb}|$

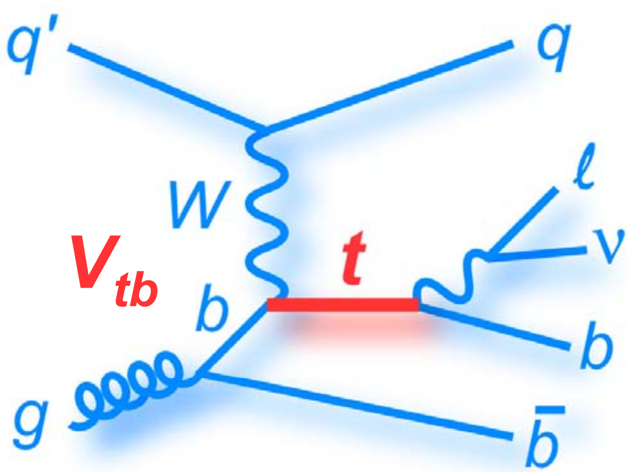
PRD 74, 114012 (2006)

s-channel: σ_{tb} = 1.04 ± 0.04 pb
NNNLO$_{approx}$, m_{top} = 172.5 GeV

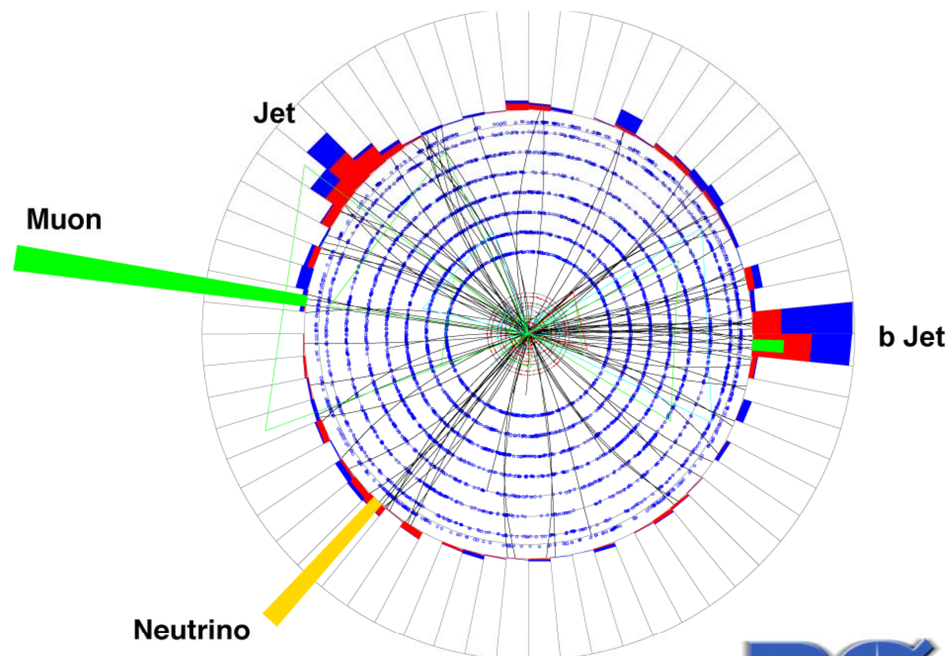


$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

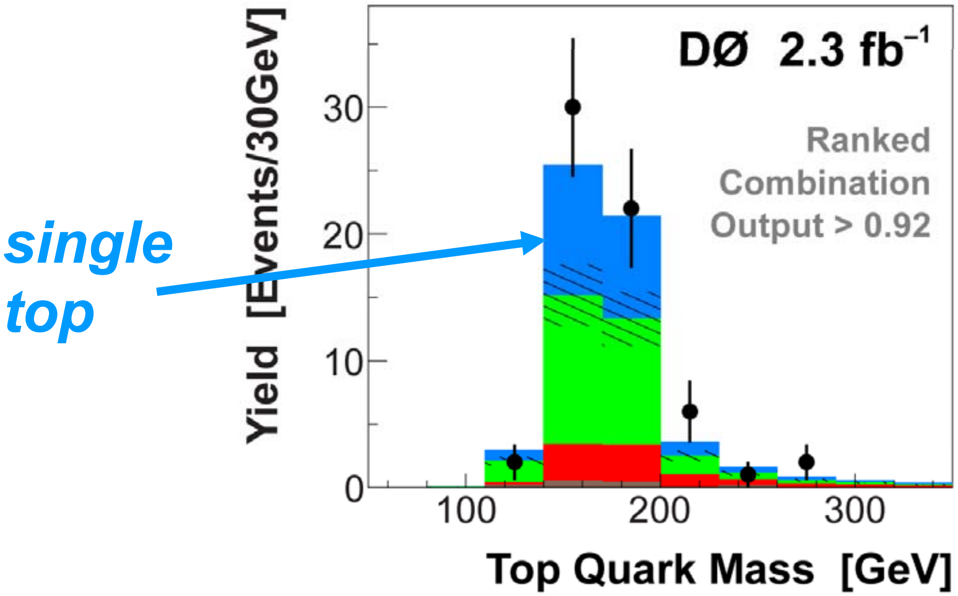
t-channel: σ_{tb} = 2.26 ± 0.12 pb
NNNLO$_{approx}$, m_{top} = 172.5 GeV



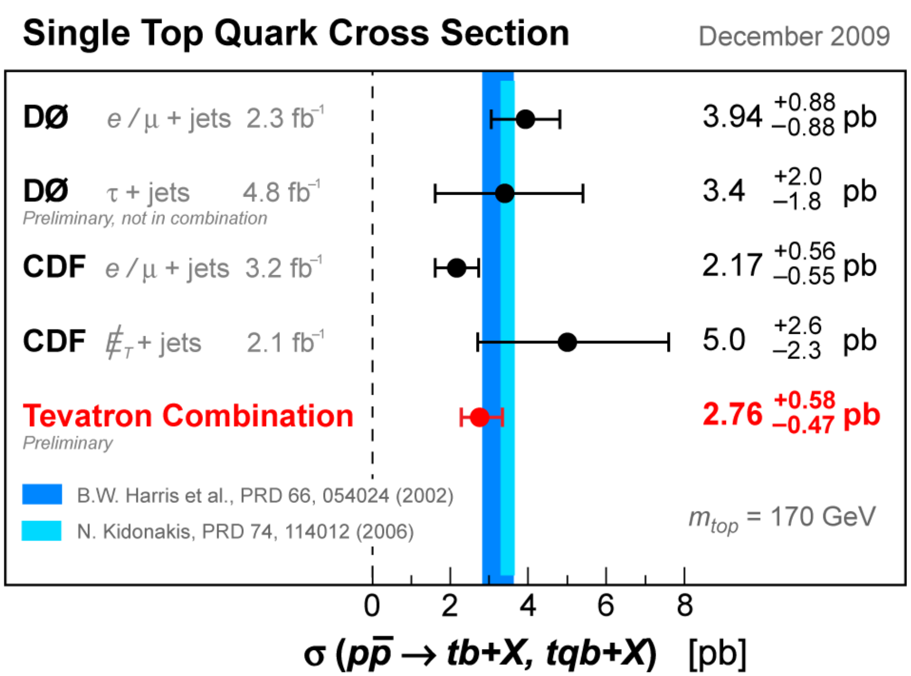
- jets
- lepton
- missing E_T
- b-jets

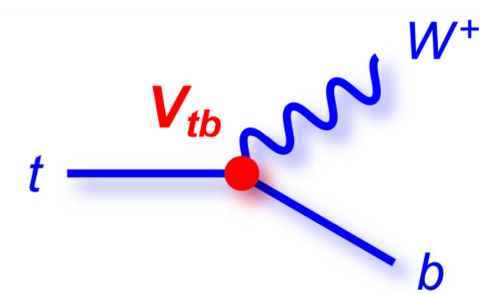


Single Top Observation



Single Top Cross Section	Signal Significance: Expected	Signal Significance: Observed
DØ 2.3 fb^{-1} arXiv:0903.0850 m_{top} = 170 GeV		
3.94 ± 0.88 pb	4.5 σ	5.0 σ
CDF 3.2 fb^{-1} arXiv:0903.0885 m_{top} = 175 GeV		
2.3 $^{+0.6}_{-0.5}$ pb	>5.9 σ	5.0 σ





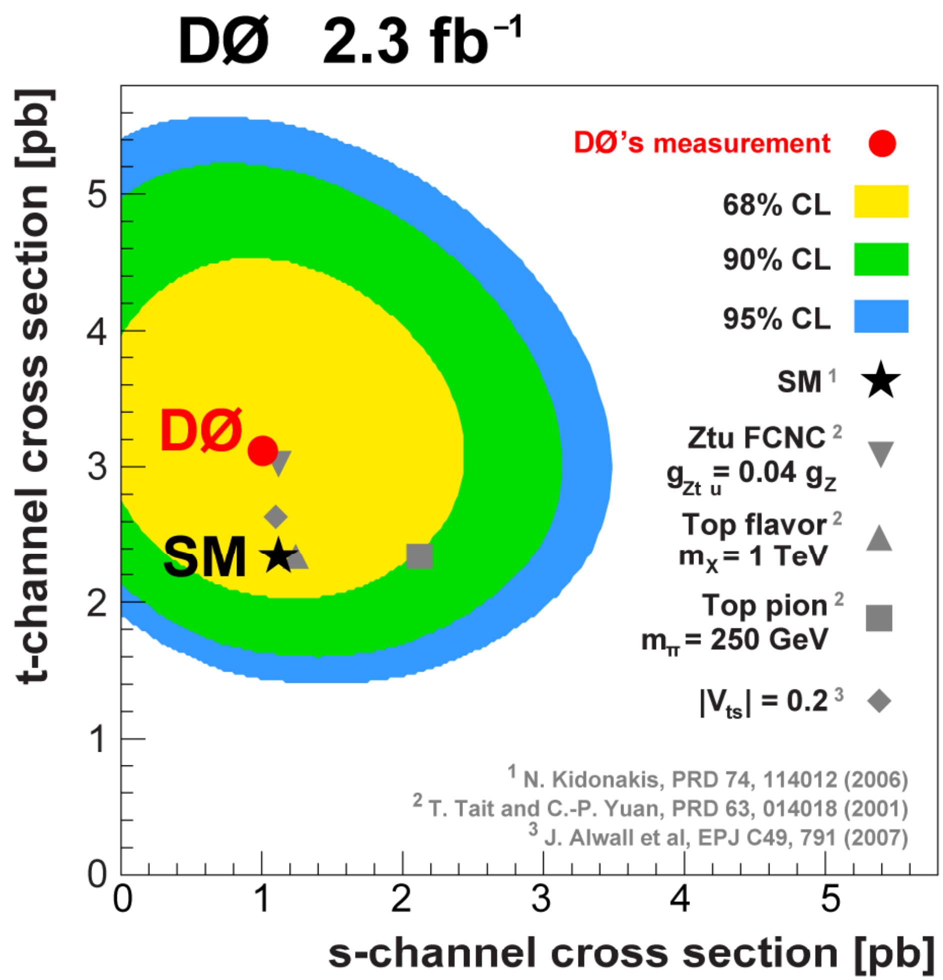
DØ: $|V_{tb}| = 1.07 \pm 0.12$

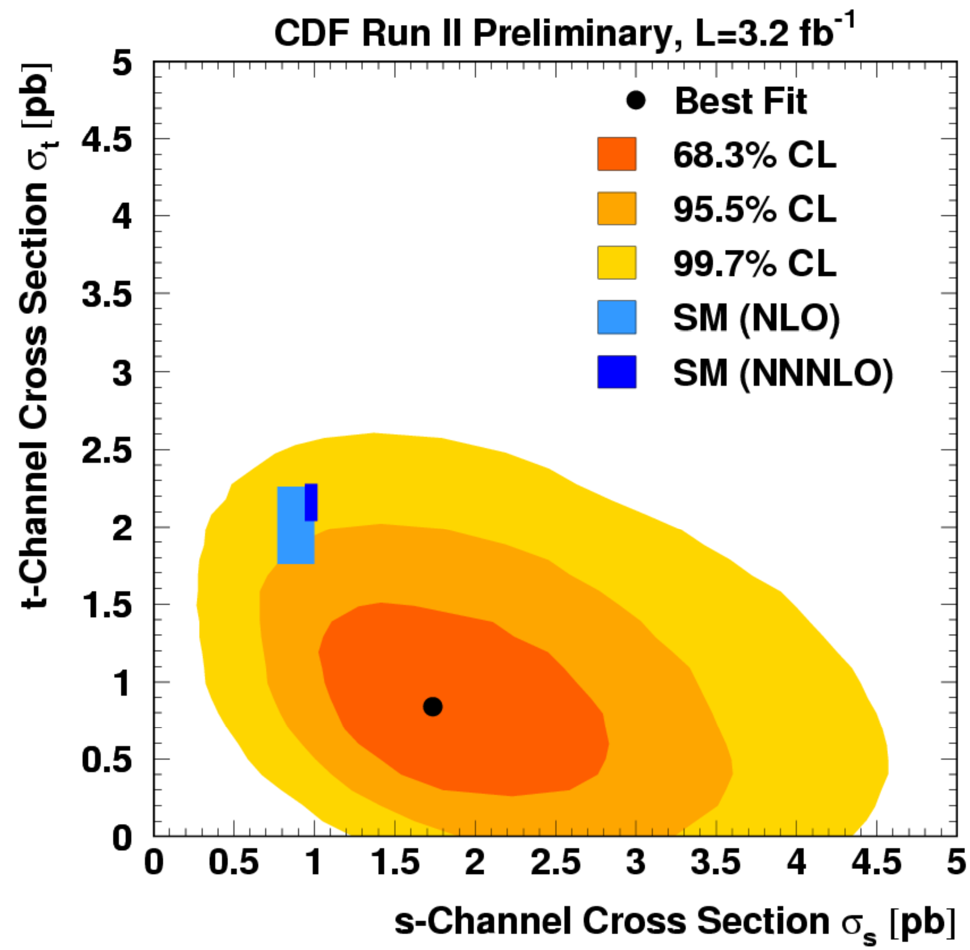
CDF: $|V_{tb}| = 0.91 \pm 0.13$

t-channel vs. s-channel

$$\sigma(\text{t-channel}) = 3.14^{+0.94}_{-0.81}\ \text{pb}$$

evidence with 4.8σ



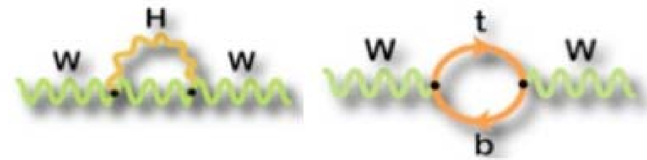


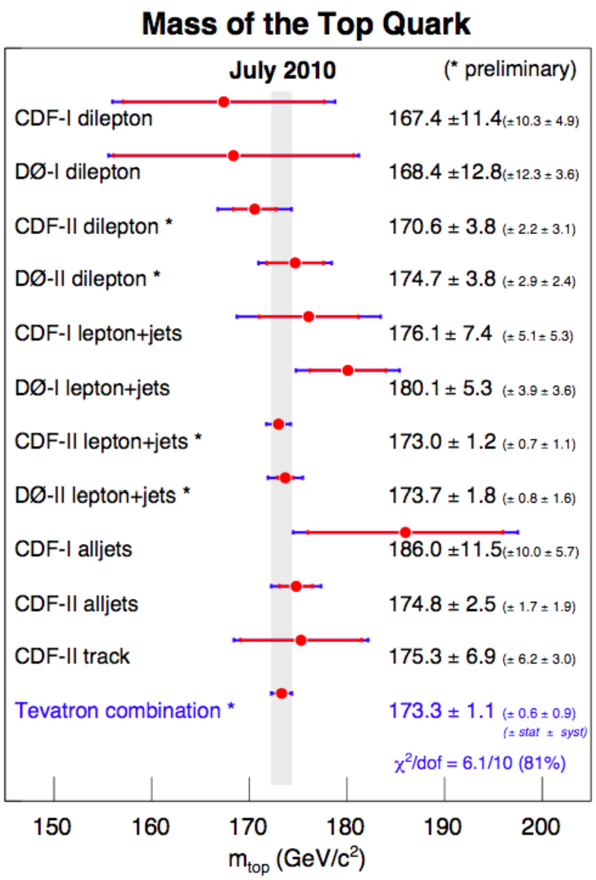
Check with more statistics agreement with SM prediction

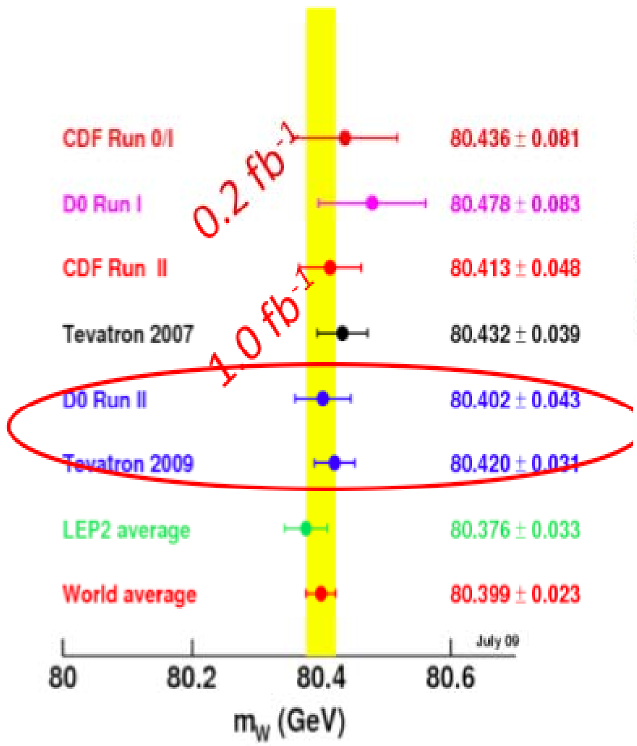
Top Quark, W Mass, Higgs Mass

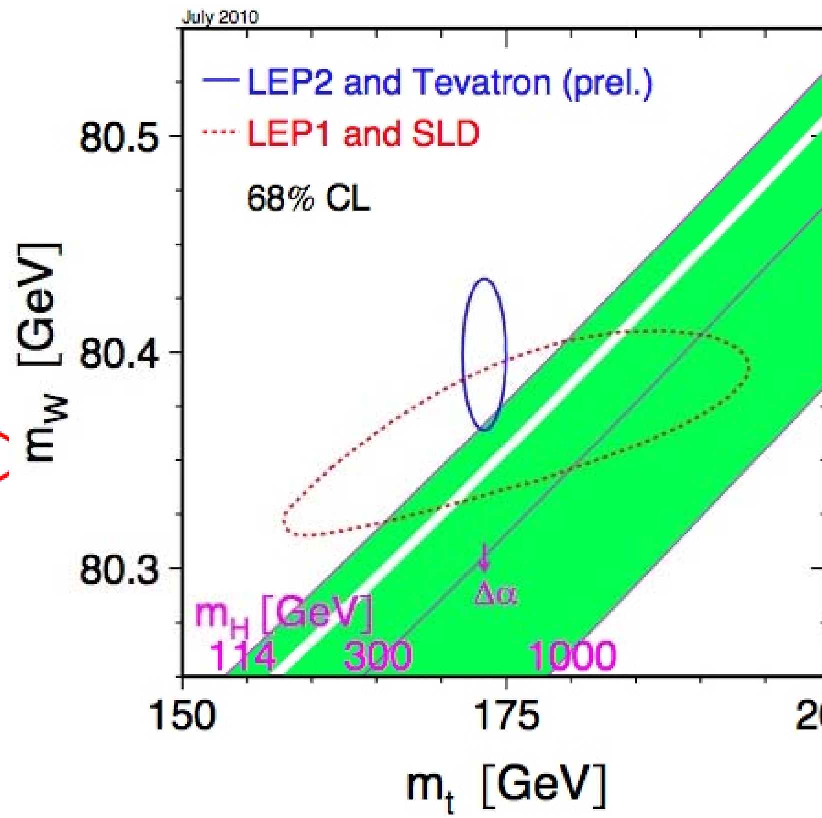
Top Mass is a fundamental parameter of the Standard Model

Due to the large M(top), quantum loops involving top quarks are important when calculating the theoretical value of precision observables .









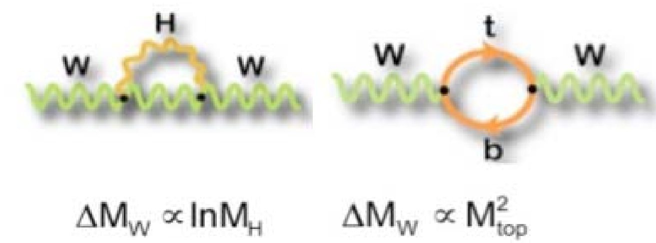
Precision on top mass is now limited mainly by systematic uncertainty - joint effort on improving its understanding

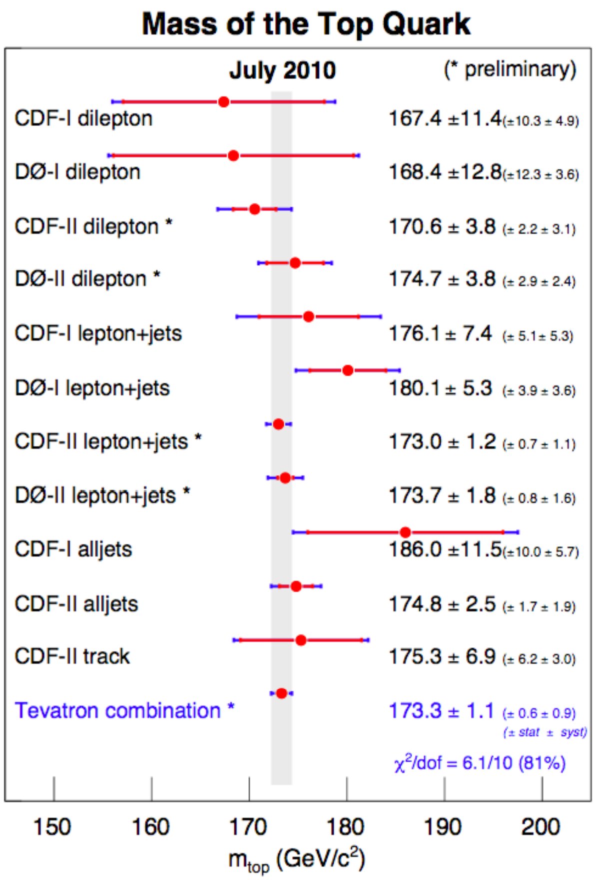
Precision on W mass has still statistical limitations (systematics driven by Z statistics)

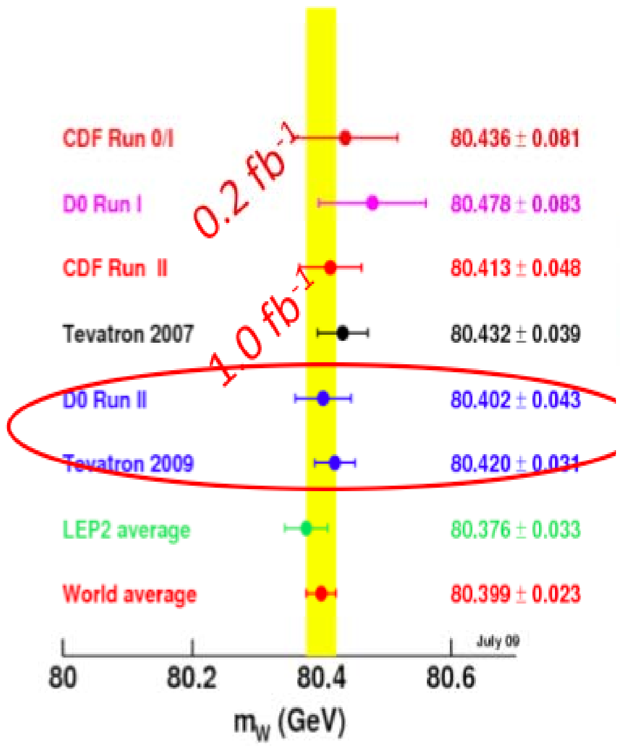
Top Quark, W Mass, Higgs Mass

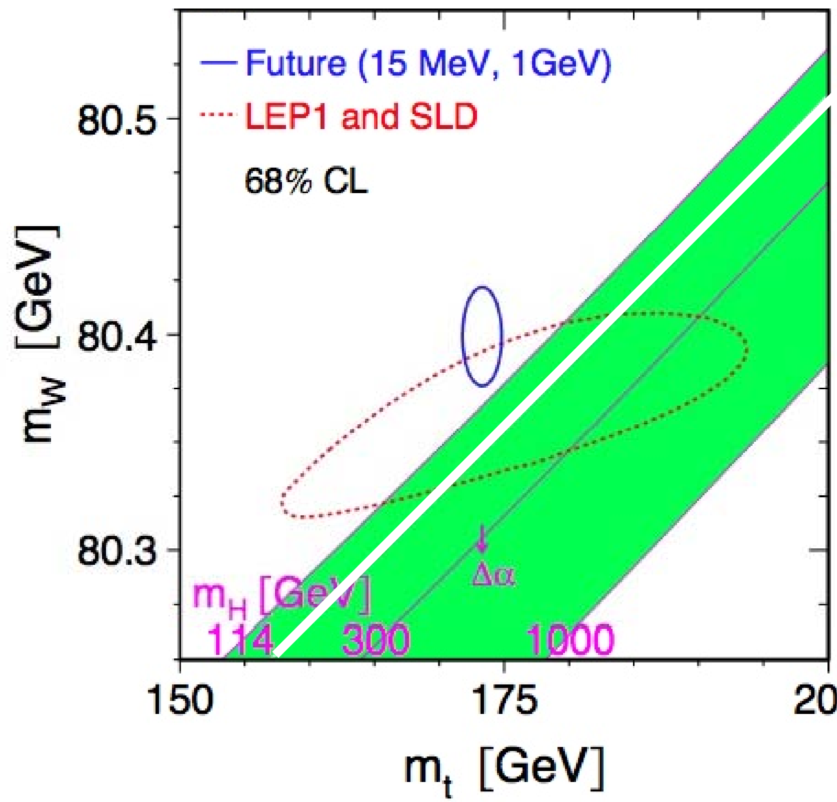
Top Mass is a fundamental parameter of the Standard Model

Due to the large M(top), quantum loops involving top quarks are important when calculating the theoretical value of precision observables .









Precision on top mass is now limited mainly by systematic uncertainty - joint effort on improving its understanding

Precision on W mass has still statistical limitations (systematics driven by Z statistics)

Diboson Production

•Diboson production is one of the least tested areas of the SM

•The triple gauge vertices are sensitive to physics beyond the SM

•SM diboson production share many characteristics and represent background to Higgs and SUSY searches

WW+WZ (With one W or Z decaying hadronically)

D0: σ (WW+WZ) = 20.2 4.5 pb evidence at 4.4σ

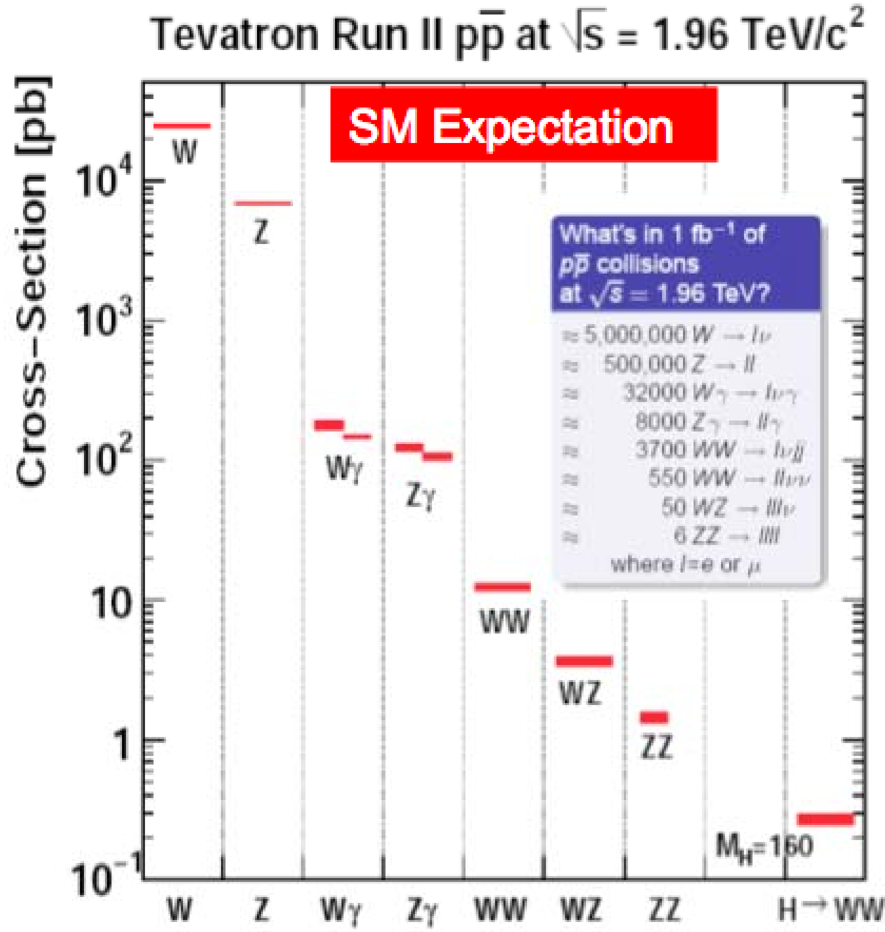
CDF: σ (WW+WZ) = $16.5^{+3.3}_{-3.0}$ observation at 5.4σ

WW+WZ+ZZ

CDF: σ (WW + WZ+ ZZ) = 18.± 2.8(stat) ±2.4(sys) ±1.1(lum)pb

SM prediction = 16.8 ± 0.5 pb (MCFM+CTEQ6M)

observation at 5.3σ significance



note: this is σ, not $\sigma \times$ BR

Search for New Physics

Searches in electroweak physics

- Top
- Dibosons

Signature-based searches

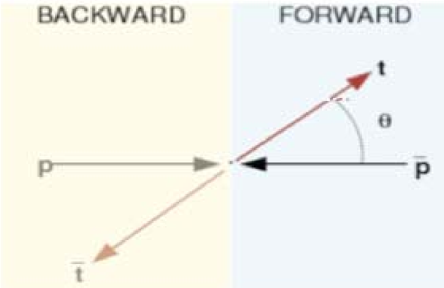
- Dilepton
- Diphotons
- Complex final states (MET, jets, heavy flavor)
  - Leptoquarks
  - SUSY

BSM in Flavor Physics

- Anomalous like-sign dimuon asymmetry

Anomalies in ttbar Events

Forward-backward asymmetry

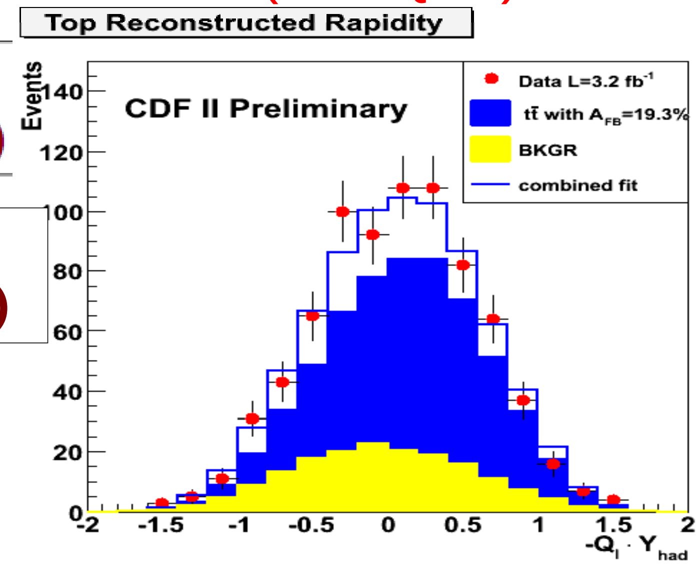


$$A_{fb} = \frac{F - B}{F + B}$$

New physics could give rise to asymmetry (Z', axigluons etc)
Standard Model predicts: A_{FB} = 0.005±0.0015 (NLO QCD)

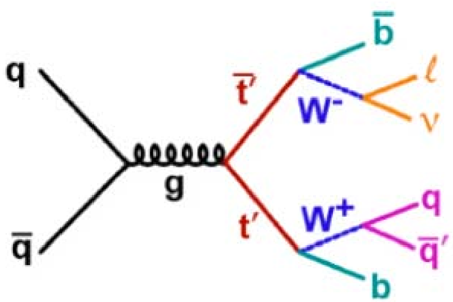
CDF (3.2 fb^{-1}):
Afb = 0.19 ± 0.07 (stat) ± 0.02 (syst)

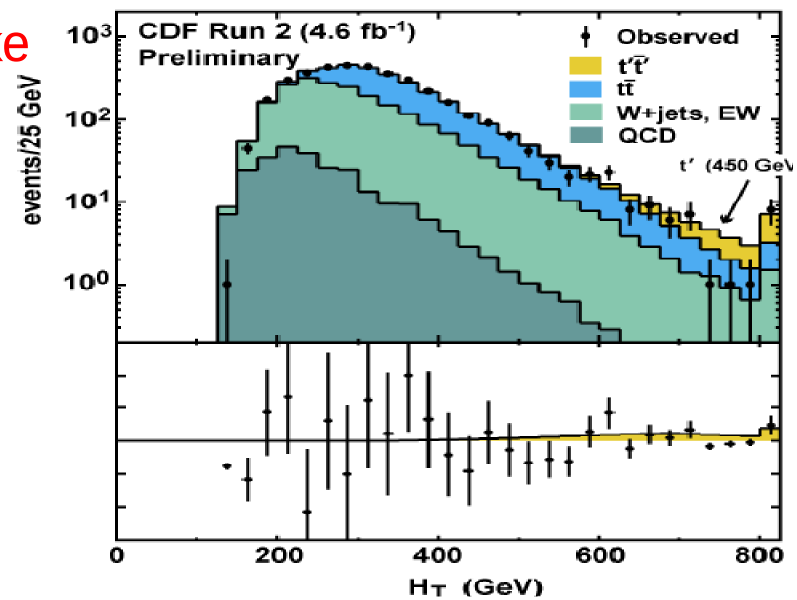
D0 (4.3fb^{-1}):
Afb^{unc} = 0.08 ±0.04(stat)±0.01(sys)

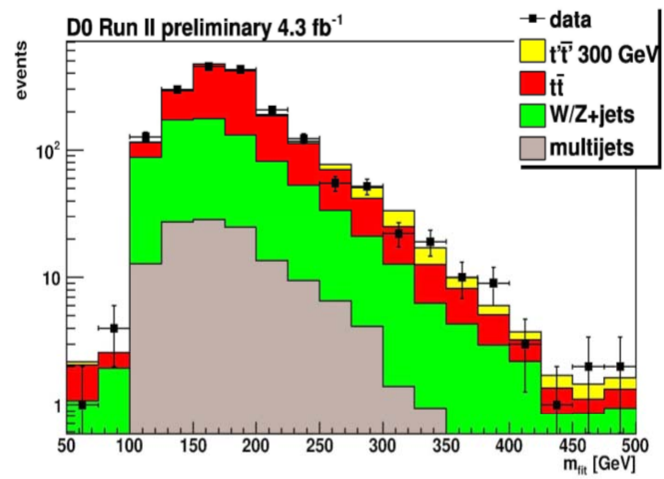


4th generation top'

Search for a heavy top-like quark, decaying to Wb in the same way as top

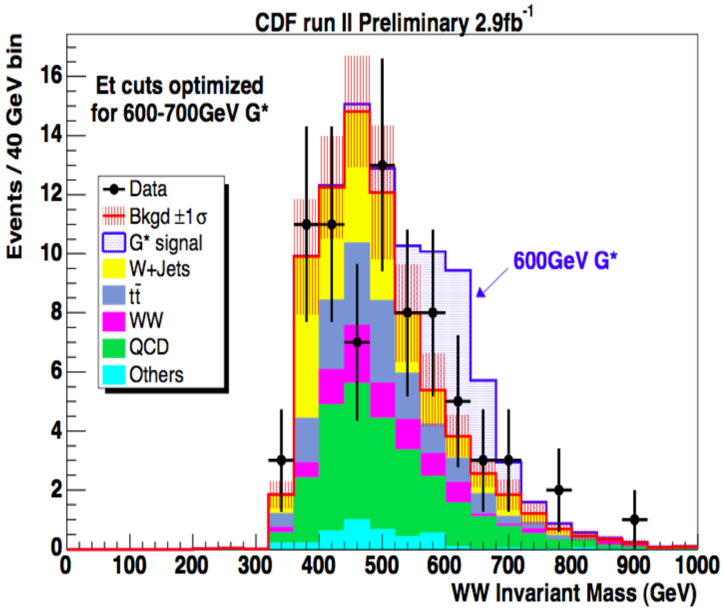


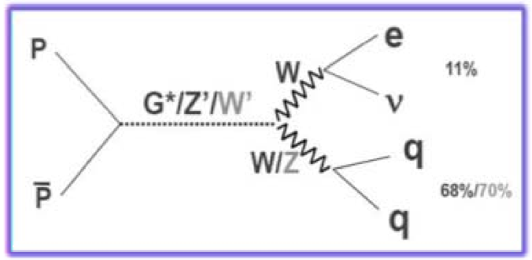


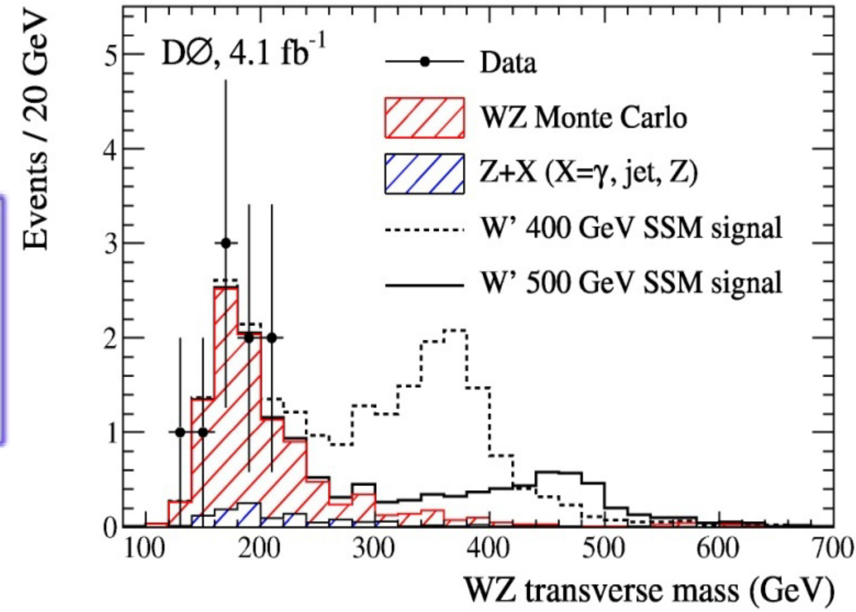


~2σ significance
from H_T =sum of all objects E_T

Search for BSM Physics in Dibosons



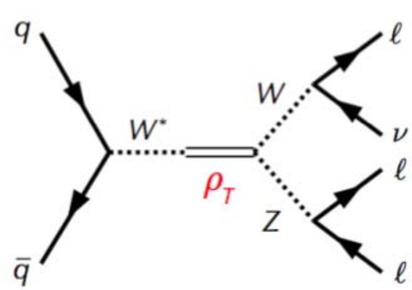


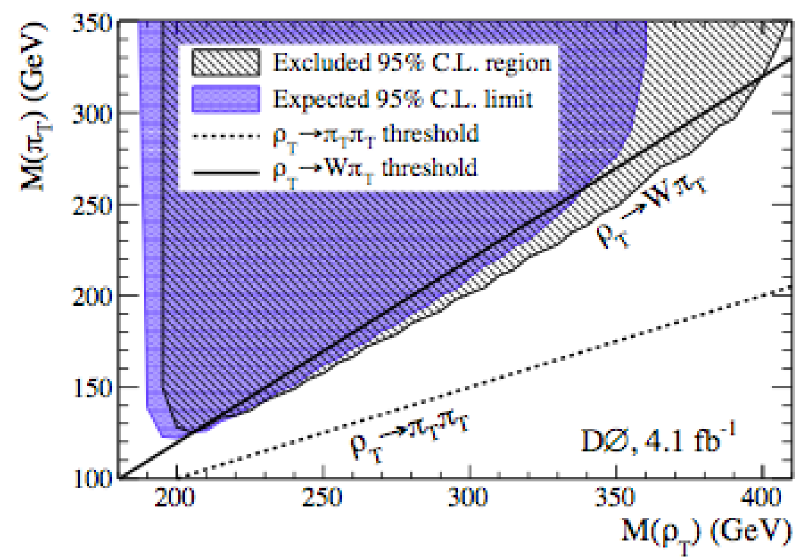


$M_G > 607$ GeV ($k/M_p = 0.1$) $M_{Z'} \notin (247,545)$ GeV $M_{W'} \notin (284,515)$ GeV

Technicolor scenario with $m(\rho_T) < m(\pi_T) + M(W)$

Excluded mass 208-408 GeV @ 95% CL





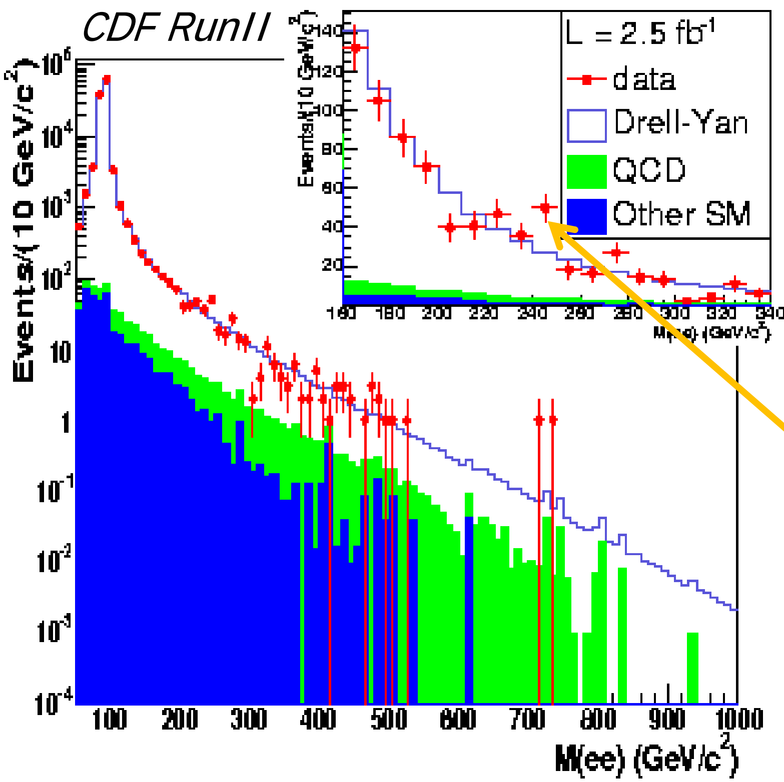
Dilepton final states

Searching for mass resonances

-Z production and decay into ee/$\mu\mu$ precisely measured
-Lepton ID/Reco and Trigger efficiencies high and very well understood
-Background low and easily determined (QCD fakes)

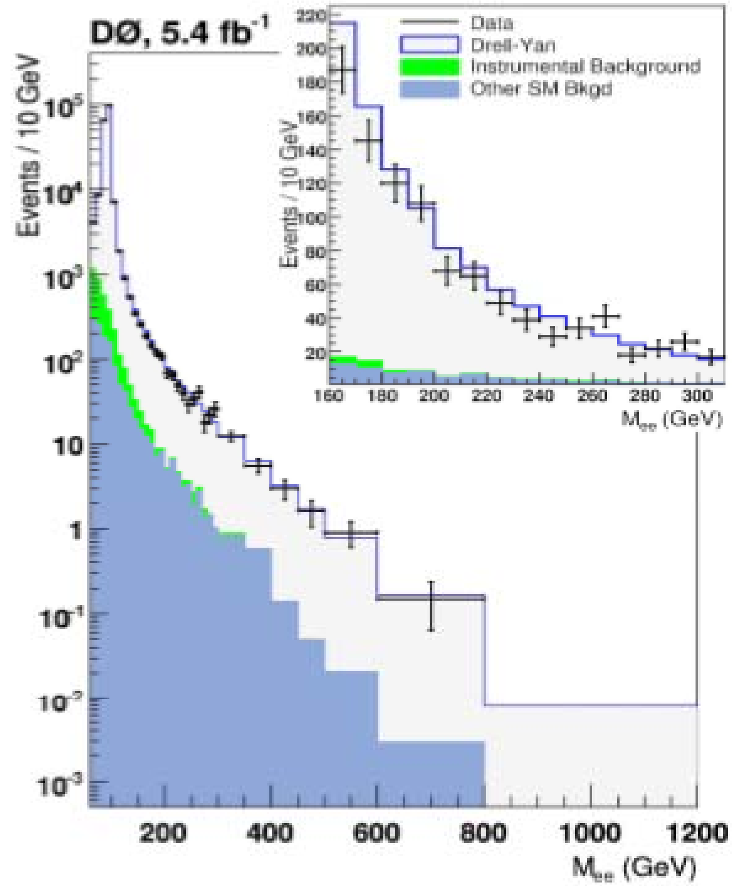
CDF: 2.5 fb^{-1}
D0: 5.4 fb^{-1}

PRL 102, 031801 (2009)



The most significant region of excess for an e^+e^- invariant mass window of 240 GeV (CDF) 2.5 stand. deviations above the SM prediction

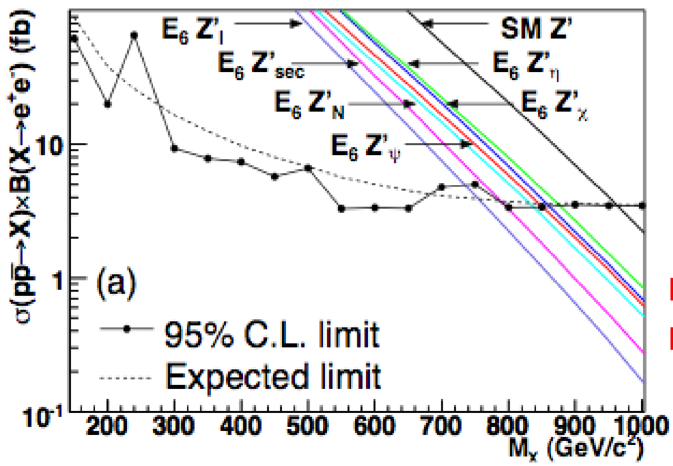
D0 does not see any deviation from SM in ee channel



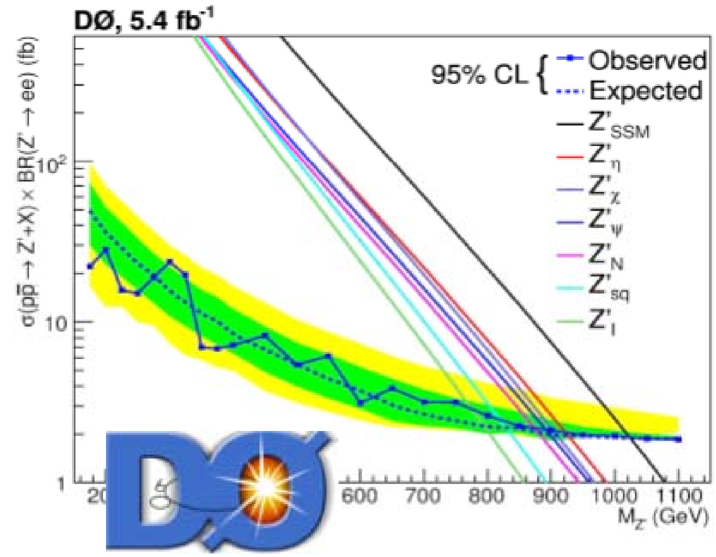
Searching Z', Randall-Sundrum Gravitons

Once the data spectrum is well understood in terms of SM background, the acceptances for resonant states for different spin particles are derived from MC (Z', RS Graviton) and the expected number of BSM events is calculated.

If no excess in data ➔ 95% CL limits on production x-sections and mass of new particles

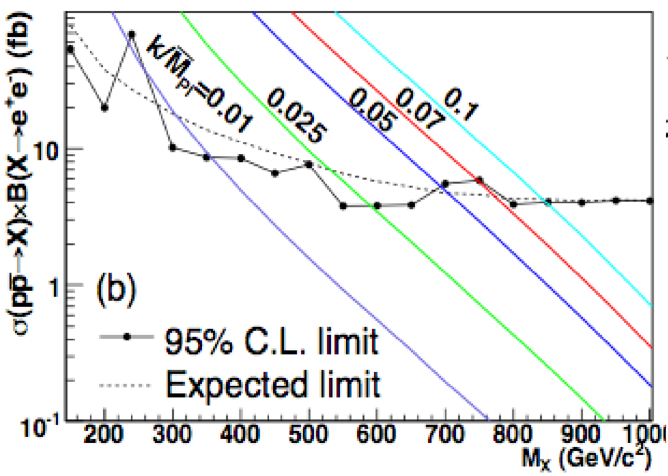


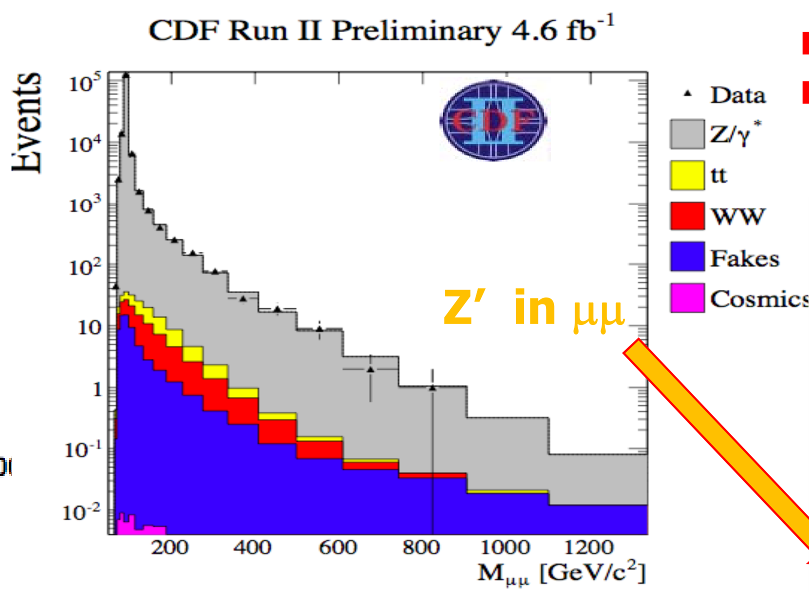
$m_{Z'}$ > 966 GeV (SM couplings)
m_{RSG} > 850 GeV (k/M_{Pl} = 0.1)



$m_{Z'}$ > 1023 GeV (SM couplings)
m_{RSG} > 1040 GeV (k/M_{Pl} = 0.1)

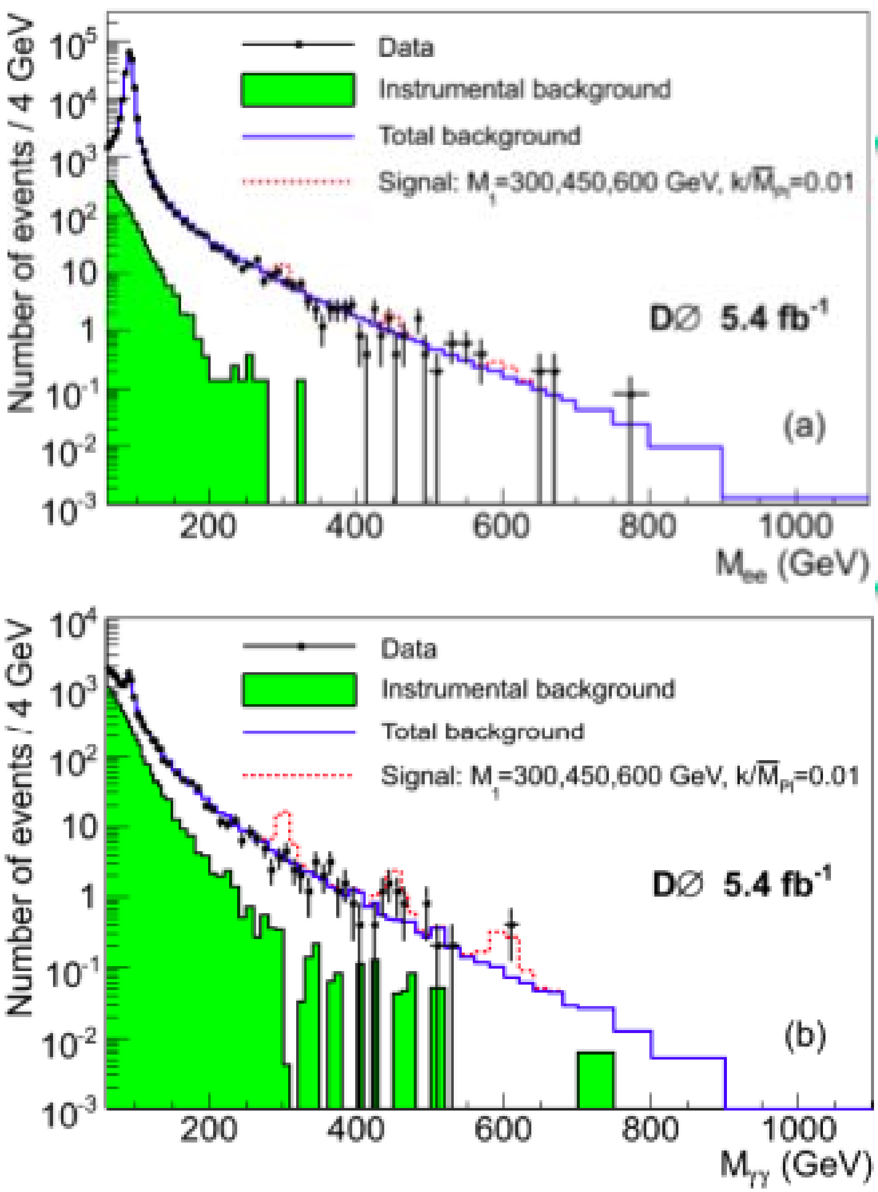
CDF 2.5fb^{-1}





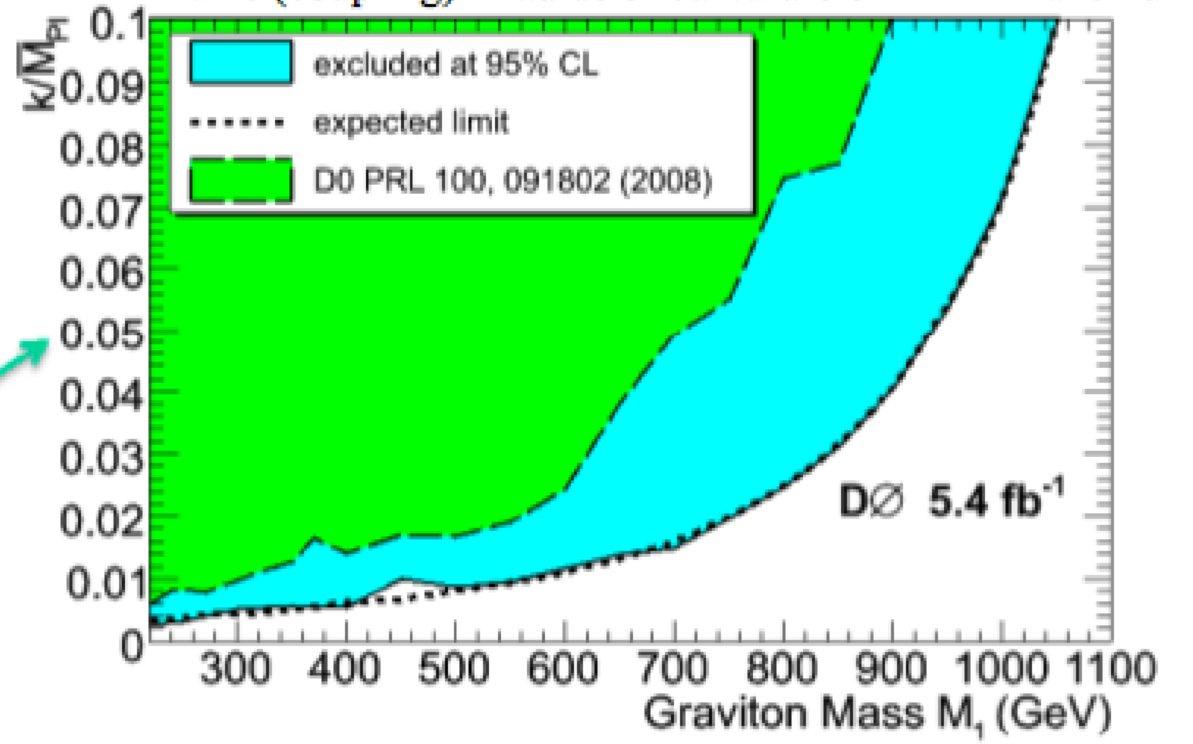
Model	Mass Limit (GeV/c^2)
Z'_I	817
Z'_{sec}	858
Z'_N	900
Z'_ψ	917
Z'_χ	930
Z'_η	938
Z'_{SM}	1071

Dielectron and Diphotons final states @ D0



Graviton KK excitation mass limits:
560 - 1040 GeV for $0.01 \leq k/MPl \leq 0.1$

Y axis (coupling) – radius of curvature of ED in Planck u

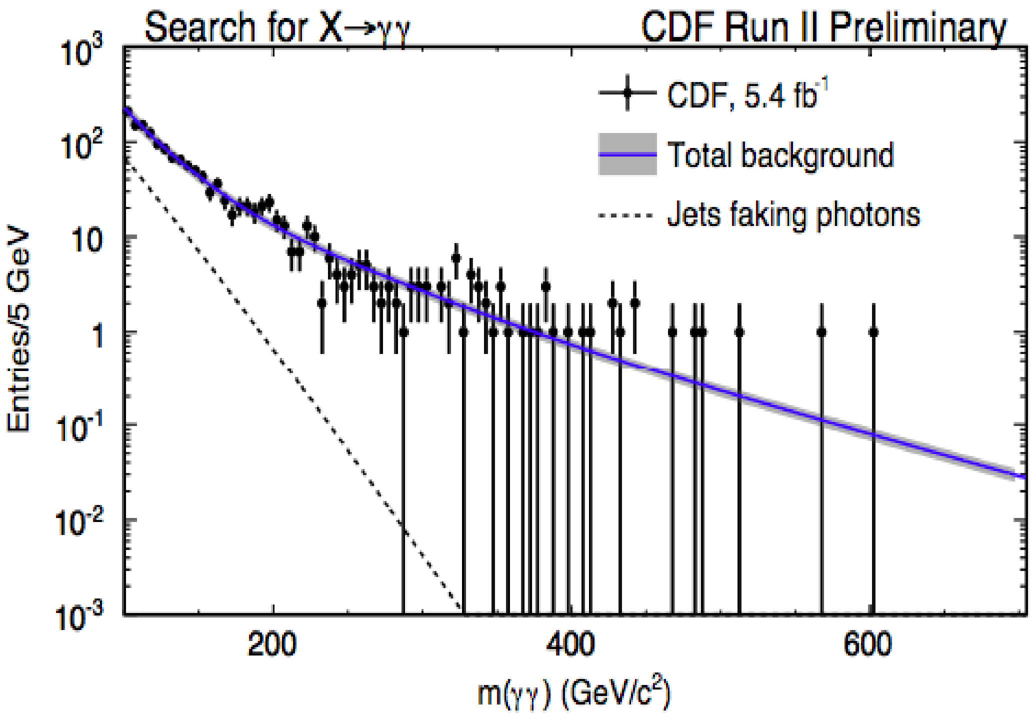


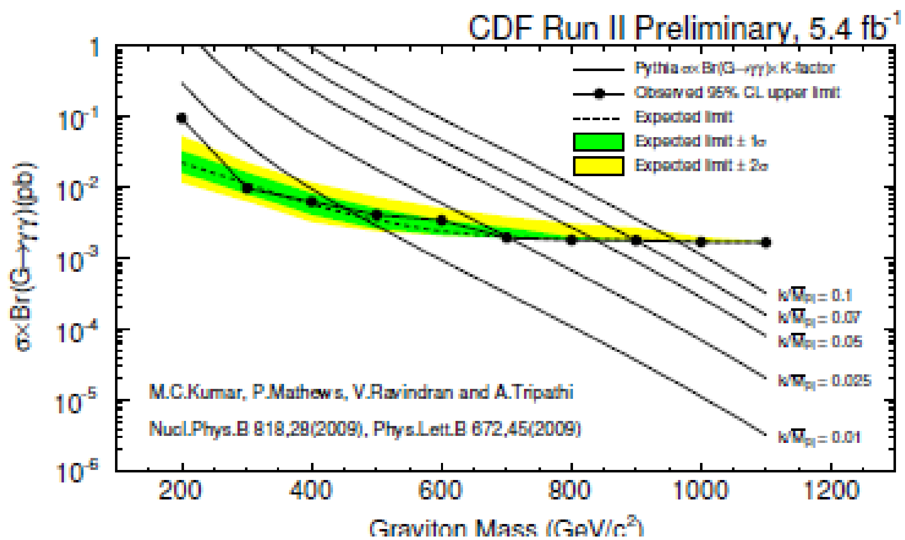
Small excess at 450 GeV (diphoton)
2.3σ significance - CDF does not see it

arXiv.org:1004.1826

Diphotons @ CDF

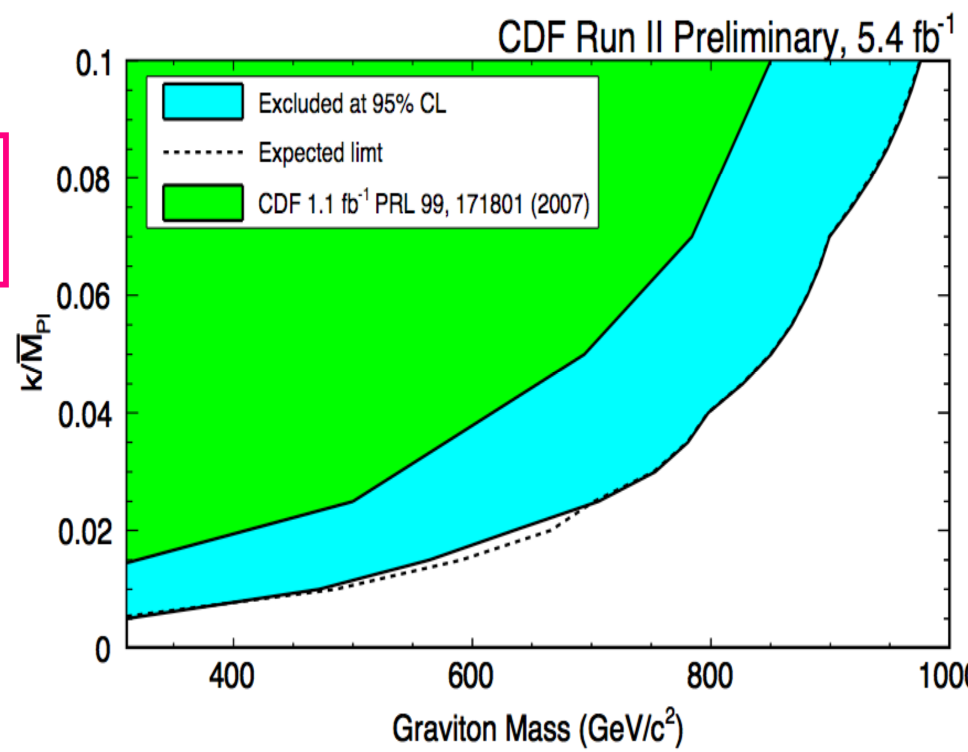
CDF:5.4fb^{-1}



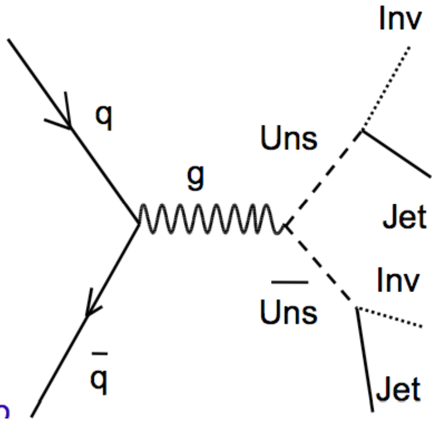


Largest excess at 200 GeV
< 2σ significance - D0 does not see it..

$k/\overline{M}_{Pl}$	Lower Mass Limit (GeV
0.1	976
0.07	899
0.05	850
0.025	706
0.01	472

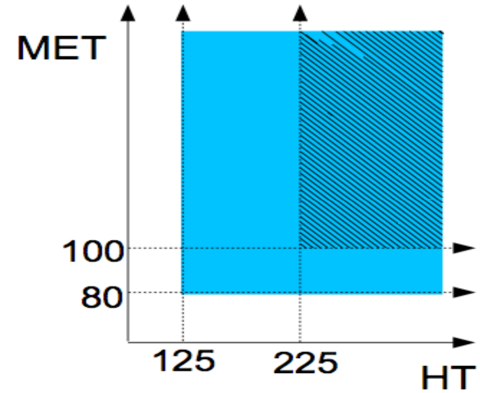


Jets+MET final state: Leptoquarks



The analysis is a counting experiment examining two different kinematic regions (each region being more sensitive to different models) defined by HT and MET cuts.

Cuts are not optimized for a specific model.

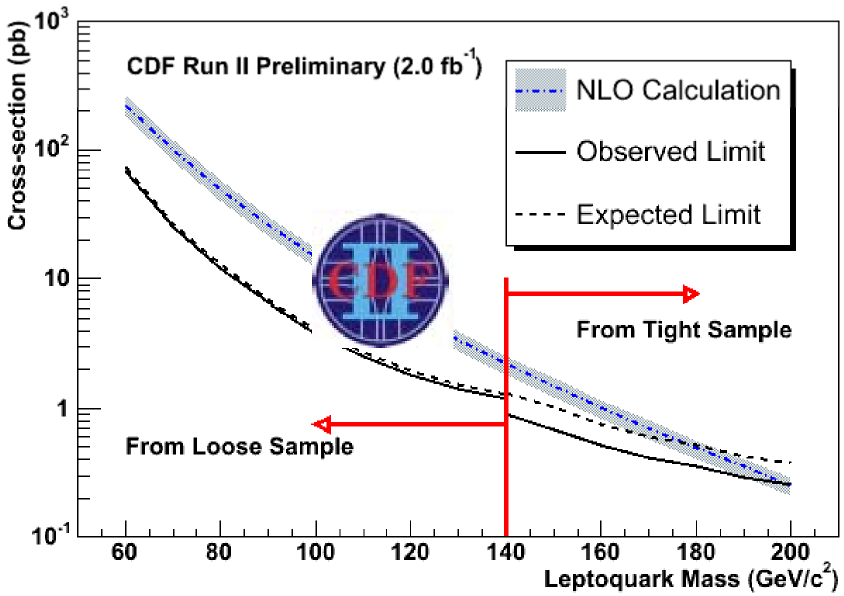


Main backgrounds:

- Z $\rightarrow \nu\nu$ + jets (irreducible background)
- W $\rightarrow l\nu$ + jets (with charged lepton lost)
- Residual QCD and non-collision backgrounds.

Data driven prediction

arXiv:0912.4691

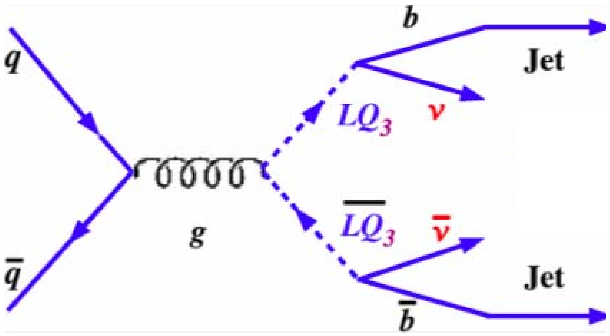


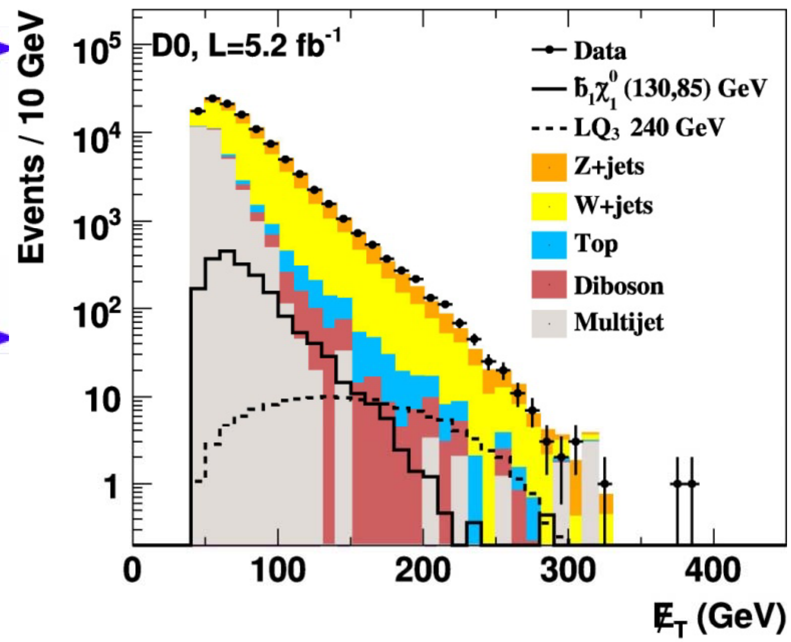
Background	Number of Events
Z -> ν ν	888 +/- 54
W -> τ ν	669 +/- 42
W -> μ ν	399 +/- 25
W -> e ν	256 +/- 16
Z -> l l	29 +/- 4
Top Production	74 +/- 9
Diboson Production	90 +/- 7
QCD	49 +/- 30
Gamma plus Jet	75 +/- 11
Non-Collision	4 +/- 4
Total Predicted	2533 +/- 151
Data Observed	2506

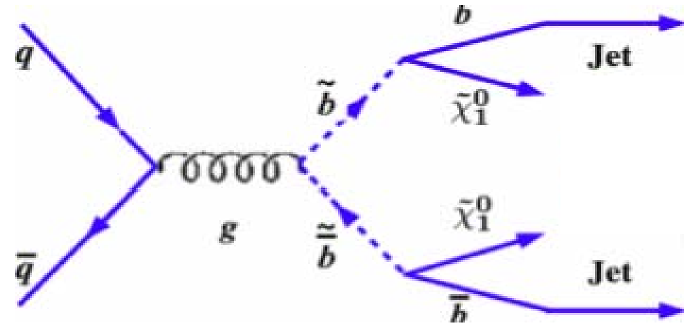
Background	Number of Events
Z -> ν ν	86.4 +/- 12.7
W -> τ ν	50.6 +/- 8.0
W -> μ ν	32.9 +/- 5.2
W -> e ν	14.0 +/- 2.2
Z -> l l	1.7 +/- 0.2
Top Production	10.8 +/- 1.7
Diboson Production	4.9 +/- 0.4
QCD	9.0 +/- 9.0
Gamma plus Jet	4.8 +/- 1.1
Non-Collision	1.0 +/- 1.0
Total Predicted	216.1 +/- 29.8
Data Observed	186

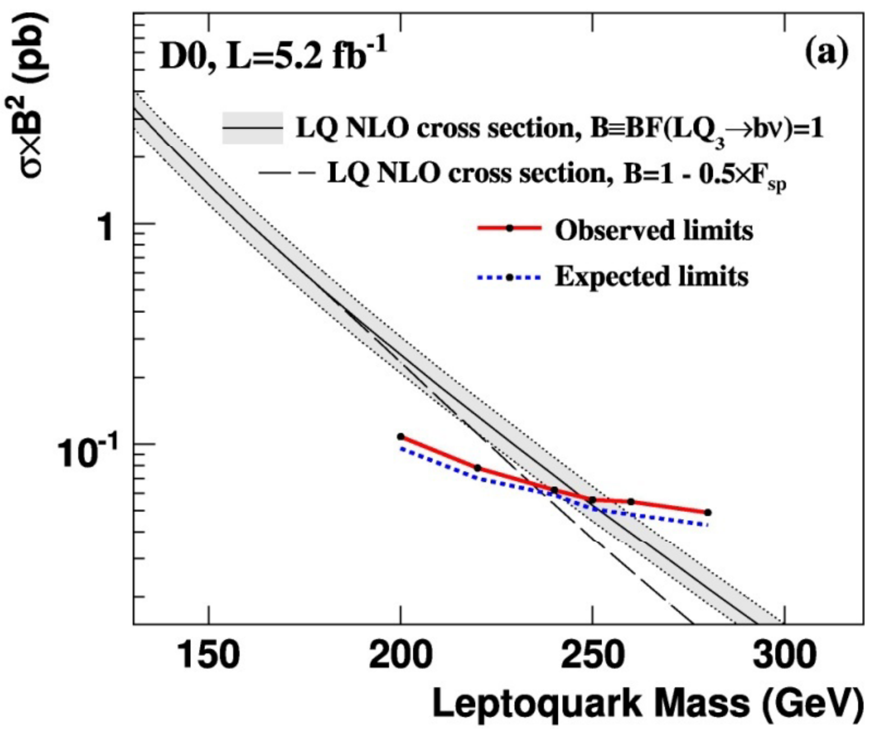
$M_{lq1,lq2}$ > 187 GeV

MET + b-jets: LQ_3 and SUSY

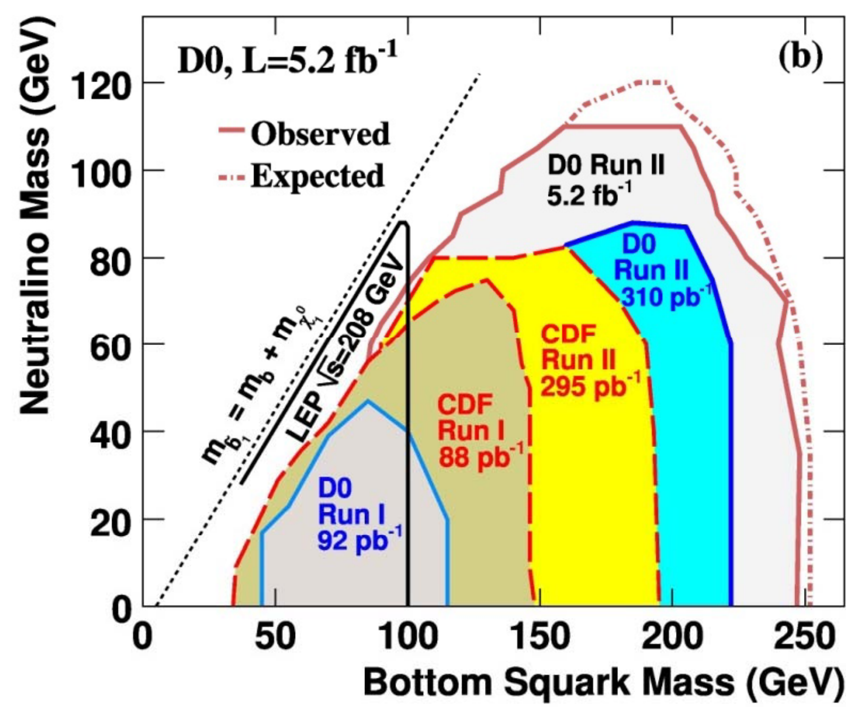








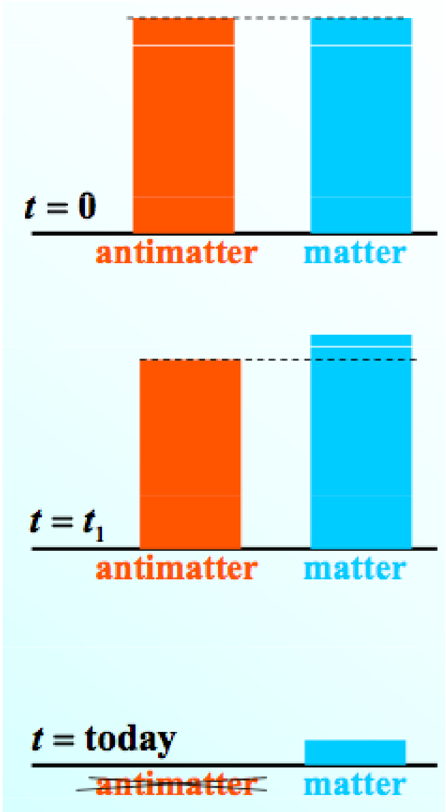
5.2fb^{-1}



Like-sign dimuon asymmetry

Today's Matter dominance in the Universe could be traced back to Matter-AntiMatter differences:

Even starting with a matter and anti-matter symmetry at the Big-Bang, we could be in the current situation with enough CP-violation



- **CP-violation is naturally included in the SM via the CKM matrix**
- **Many different measurements of CP-violation are in excellent agreement with the SM**

- **However the SM source of CP-violation is not enough to explain the imbalance between matter and antimatter**

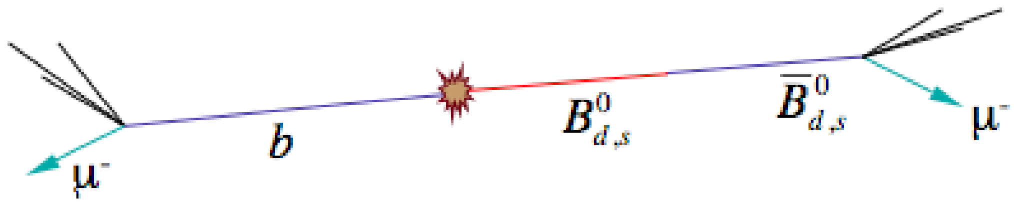
- **New sources of CP-violation are required to explain the matter dominance, often found in BSM models**

Like-sign dimuon asymmetry: Analysis

Goal : study CP violation in the mixing of the B_d and B_s systems
The magnitude of CP-violation predicted by the SM is negligible

$$A_{sl}^b = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$$

Contribution of new physics sources can significantly alter the SM prediction



dimuon charge asymmetry of semileptonic b-decays

$$A_{sl}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

inclusive muon charge asymmetry

$$a \equiv \frac{n^+ - n^-}{n^+ + n^-}$$

$$a = k\, A_{sl}^b + a_{bkg}$$
$$A = K\, A_{sl}^b + A_{bkg}$$

- N_b^{++}, N_b^{--} – number of events with two b hadrons decaying semileptonically and producing two muons of the same charge
- One muon comes from direct semileptonic decay $b \to \mu^- X$
- Second muon comes from direct semileptonic decay after neutral B meson mixing: $B^0 \to \overline{B}^0 \to \mu^- X$

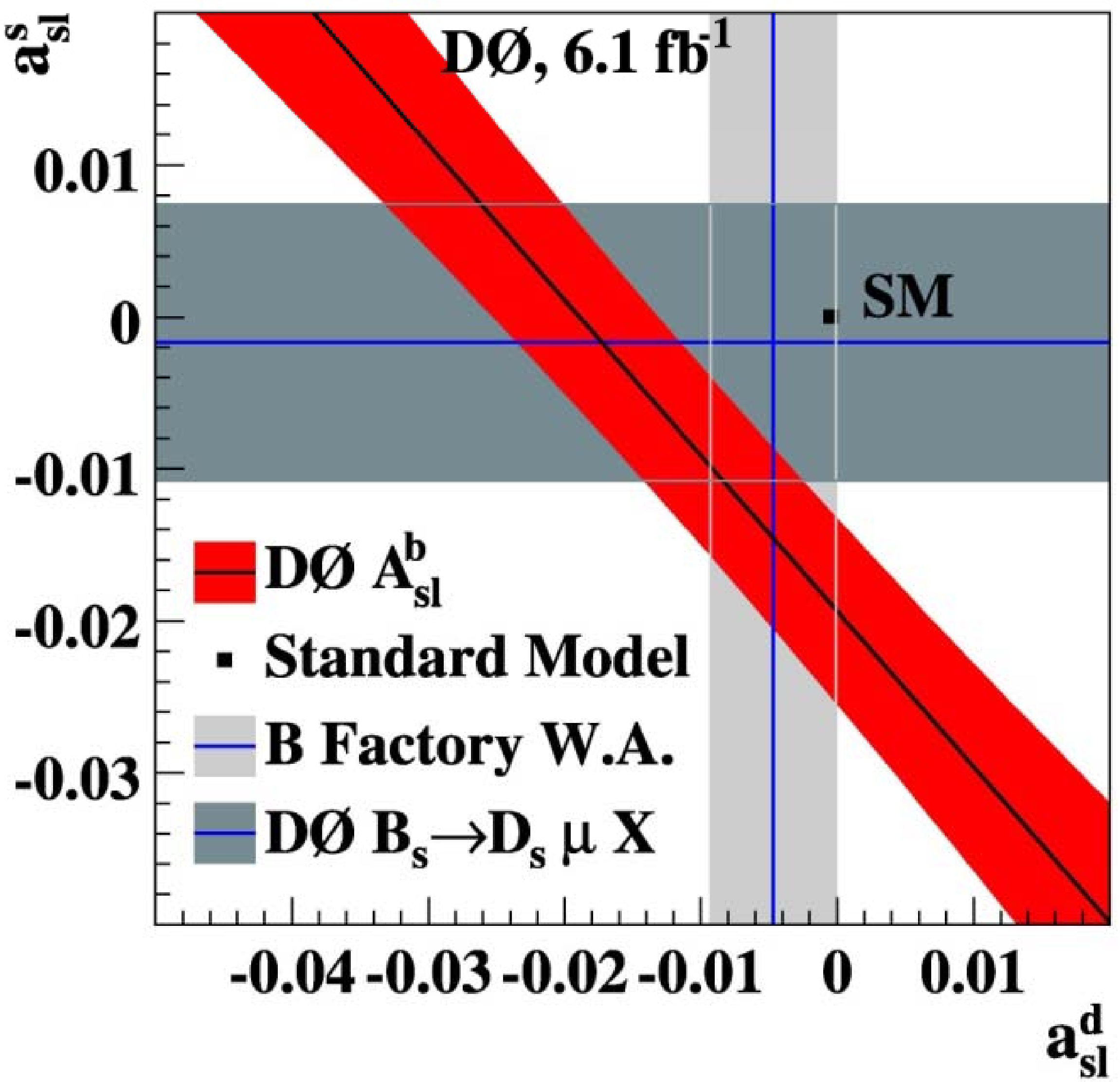
$$A' \equiv A - \alpha\, a$$

The coefficient α is chosen as to minimize the uncertainty of A_{sl}^b

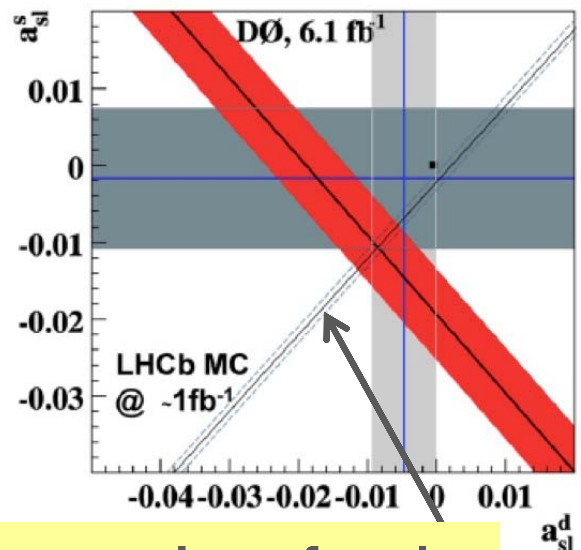
Like-sign dimuon asymmetry: Results

$$A^b_{sl} = (-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst}))\%$$

3.2σ (99.8% C.L.) disagreement with SM



$$A^b_{sl} = 0.506\, a^d_{sl} + 0.494\, a^s_{sl}$$



it cannot be refuted at LHCb / $B_{s,d} \rightarrow D\mu\nu$ in 2011, but j/psiPhi...

Can be tested at the 4-5 sigma level with 2011 Tevatron data

Can we Test the Hypothesis of Spontaneous EW Symmetry Breaking ?

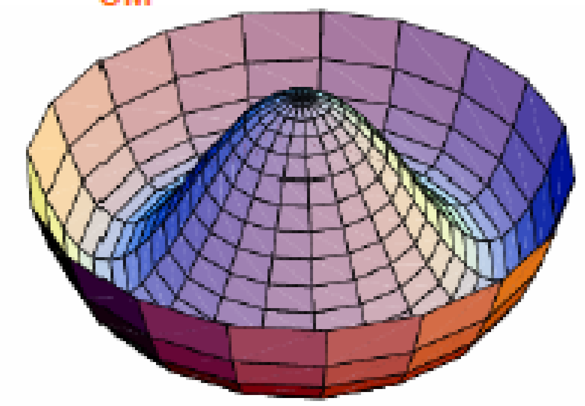
- $SU(2)_L \times U(1)_Y$ is very well tested in collider experiments

- But it is not a symmetry of our vacuum – otherwise quarks, leptons, and gauge bosons would all be massless

➔ $$L_{EM} = (\partial_\mu - ieA_\mu)\phi^*(\partial_\mu + ieA_\mu)\phi - [\mu^2\phi^*\phi - \lambda(\phi^*\phi)^2] - \frac{1}{4}F_{\mu\nu}F_{\mu\nu}$$

- Simplest model – one complex doublet of scalar fields in a ϕ^4 potential resulting in a non-zero "Vacuum Expectation Value"
  W^+, W^- and **Z** get three of the four ***d.o.f*** ➔ ***become massive,***
  one ***d.o.f*** left over → fundamental scalar particle H_{SM}

- Not the only possibility
  - Supersymmetric Higgs (d
  - General 2HDM
  - Higgs Triplets
  - Little Higgs
  - Technicolor



How to determine the Higgs Boson Mass?

The **Higgs mass is not known** from theory
But: We can set experimental constraints

- **Indirect limits**:

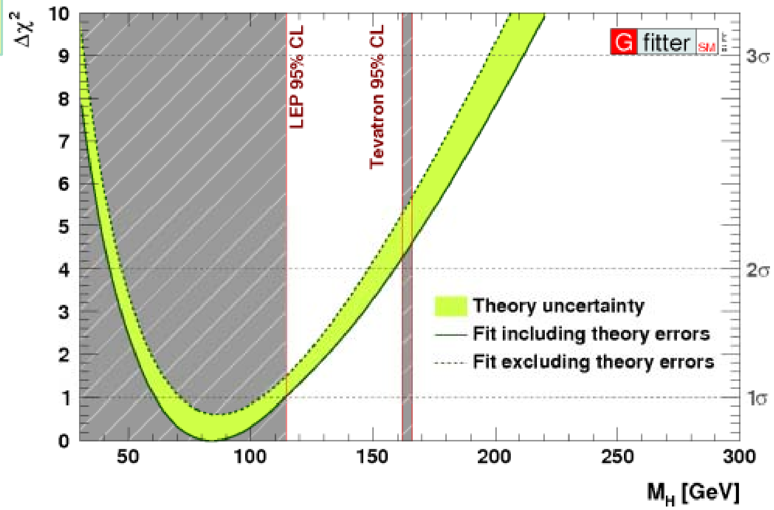
Electroweak precision measurements

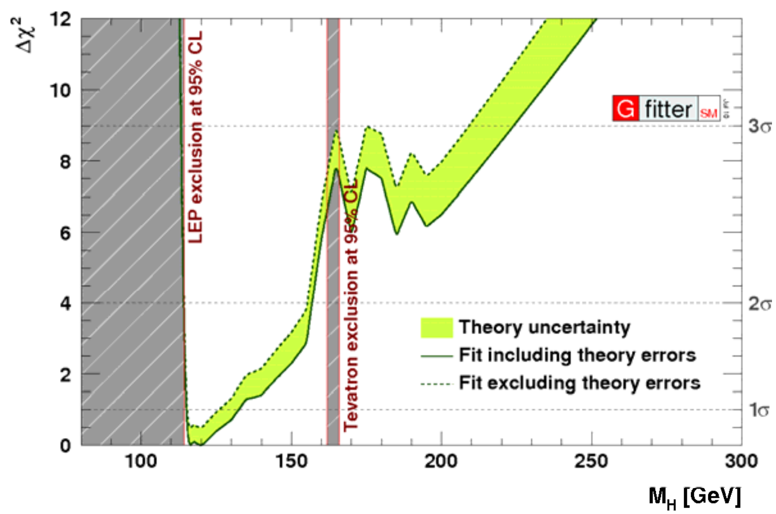
Constraints from top quark mass, W boson mass

Precision EW fit:
m_H = [47,159] GeV@95%CL

- **Direct limits**:

LEP: m_{Higgs} > 114 GeV @ 95% CL
TEV: m_{Higgs} ≠ [158;175] GeV @ 95% CL

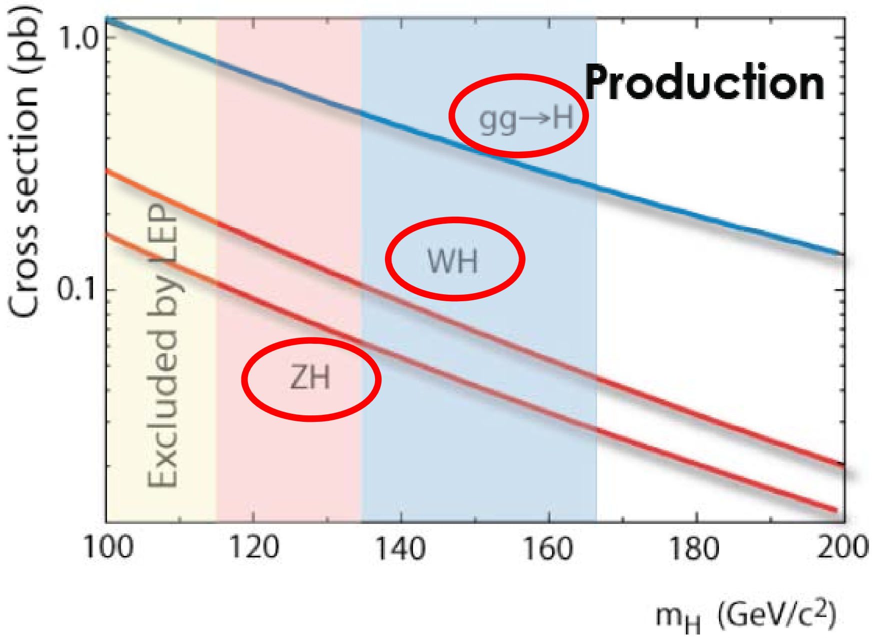


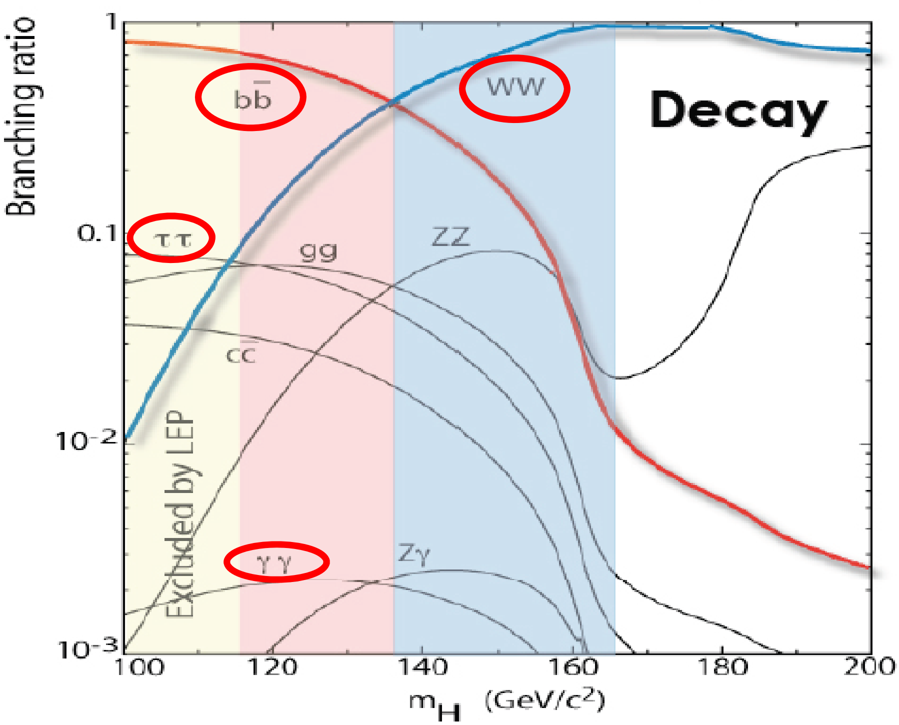


- **Combining Direct and Indirect Limits, GFITTER :**

m_{Higgs} = [114, 157] GeV @ 95 % CL

Higgs Production and Decay at the Tevatron

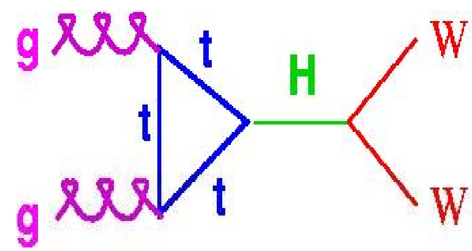




High mass (m_H > 135 GeV) dominant decay:

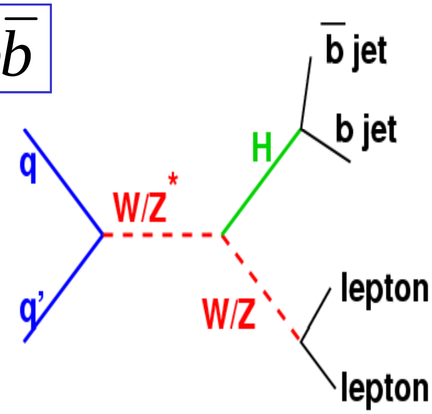
$$H \rightarrow WW^{(*)}$$

$$WW \rightarrow \ell\nu\ell'\nu'$$



Low mass (m_H < 135 GeV) dominant decay:

$$H \rightarrow b\bar{b}$$



$$WH \rightarrow \ell\nu b\bar{b}$$

$$ZH \rightarrow \ell^+\ell^- b\bar{b}$$

$$ZH \rightarrow \nu\bar{\nu} b\bar{b}$$

use associated production modes to get better S/B

These are the main search channels, but there is an extensive program of measurement in other channels to extend the SM and BSM sensitivities.

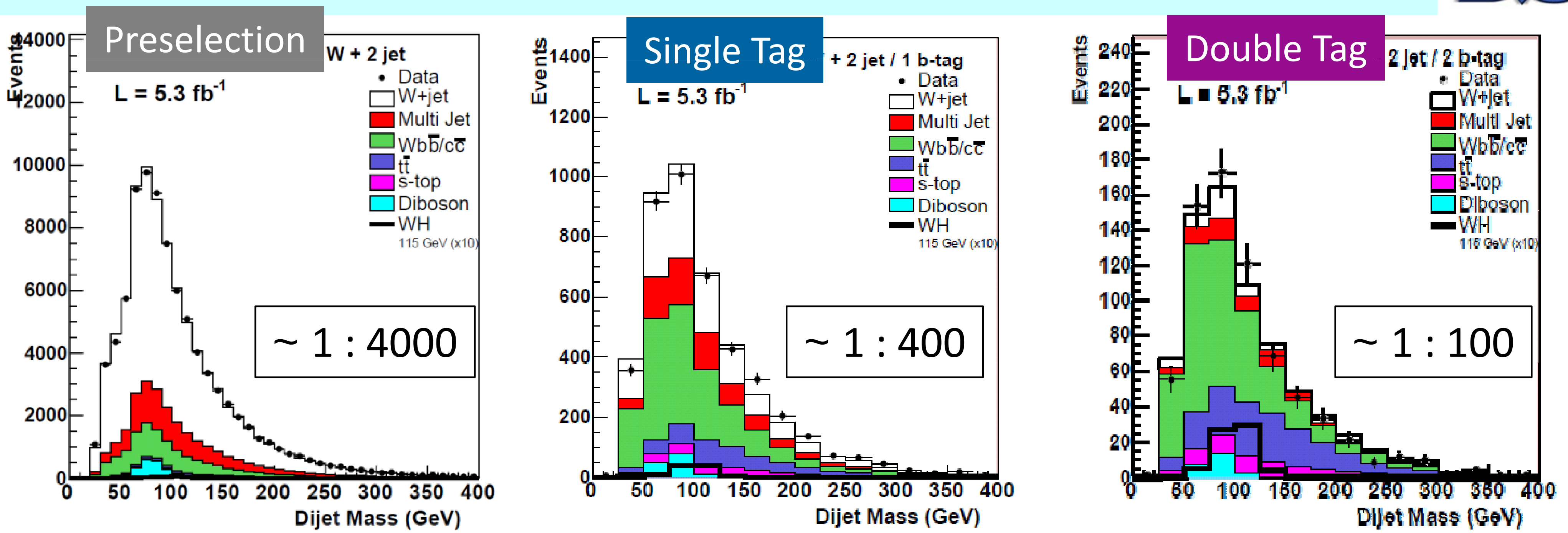
Summary of Higgs Results @ ICHEP

Channel	Expt	Dataset now	Increase since Nov. 2009 combination
$H \to WW$	D0	6.7	24%
$H \to WW$	CDF	5.9	23%
$WH \to l\nu bb$	CDF	5.7	30%
$WH \to l\nu bb$	D0	5.3	6%
$ZH/WH \to METbb$	CDF	5.7	60%
$ZH/WH \to METbb$	D0	6.4	23%
$ZH \to llbb$	CDF	5.7	40%
$ZH \to llbb$	D0	6.2	45%
$H \to \gamma\gamma$	CDF	5.4	New!
$H \to \gamma\gamma$	D0	4.2	0%
$H \to \tau\tau$	CDF	2.3	15%
$H \to \tau\tau$	D0	4.9	0%
$ZH/WH \to qqbb$	CDF	4	100%
ttH	D0	2.1	0%

Each channel represents several "sub-channels"

$H \to WW$ Sub-channels
opposite sign leptons + 0-jets
opposite sign leptons + 1-jets
opposite sign leptons + 2-jets
opposite sign leptons , low M_{ll}
same sign leptons
trileptons, no Z candidate
trileptons, Z candidate, 1-jet
trileptons, Z candidate, 2-jet
electron + hadronic tau
muon + hadronic tau
leptons + jets

Example of WH analysis



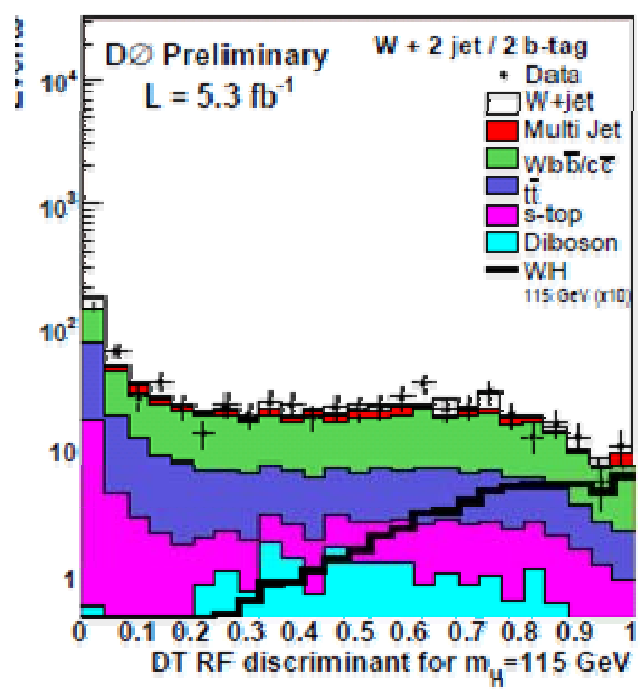
Event selection according to the desired topology

Verify/adjust the background description of the data

Dijet Mass (Higgs) Reconstruction / b jet tagging

Application of a multivariate technique to improve sensitivity

Limit calculation for σ (pp→WH) x **B** (H→bb)



W+jet	61070	1290	58
Wbb/cc	9316	1601	346
top	1517	620	235
Bckgrd Sum	**86483** (ntd)	**4326**	**718**
WH	**24**	**10**	**7**
Data	**86483**	**4316**	**709**

SM combined Higgs Limits, 9 months later

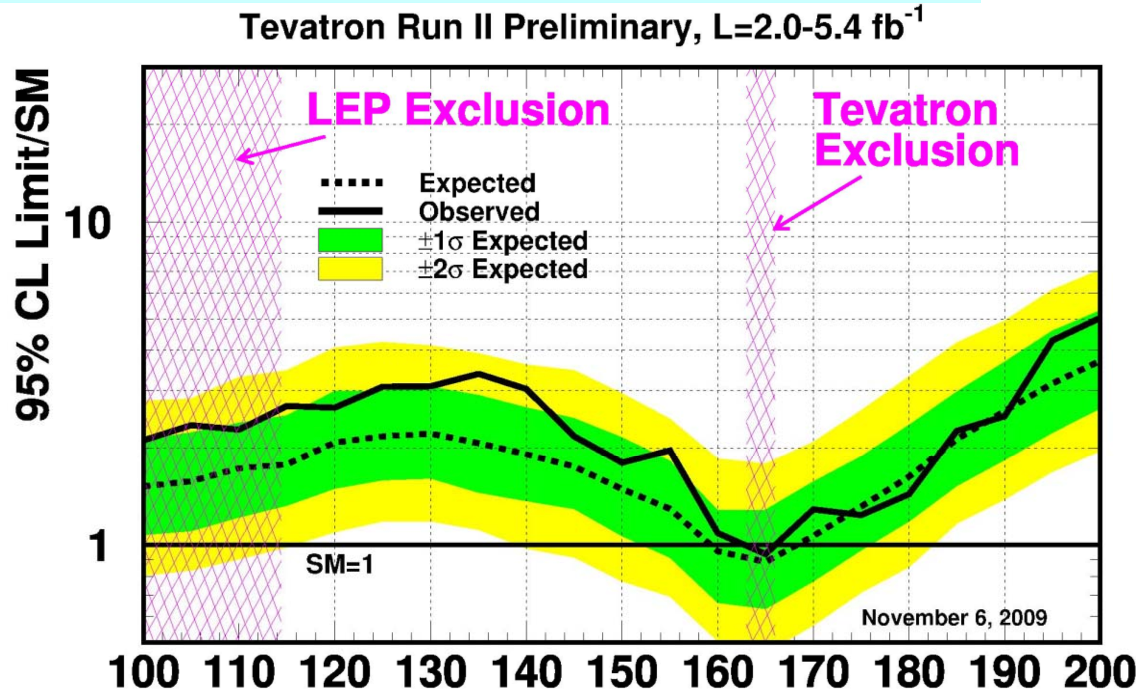
2009

Joint CDF/DØ publication on 1st Higgs exclusion above the limit set by LEP

First time also an expected exclusion range ➔ from **159 to 168 GeV**

Better than **2.2 x σ_{SM}** sensitivity for all mass points **below 185 GeV**

1.8 x σ_{SM} sensitivity @ **m_H = 115 GeV** (average lumi ~3.6/fb)



2010

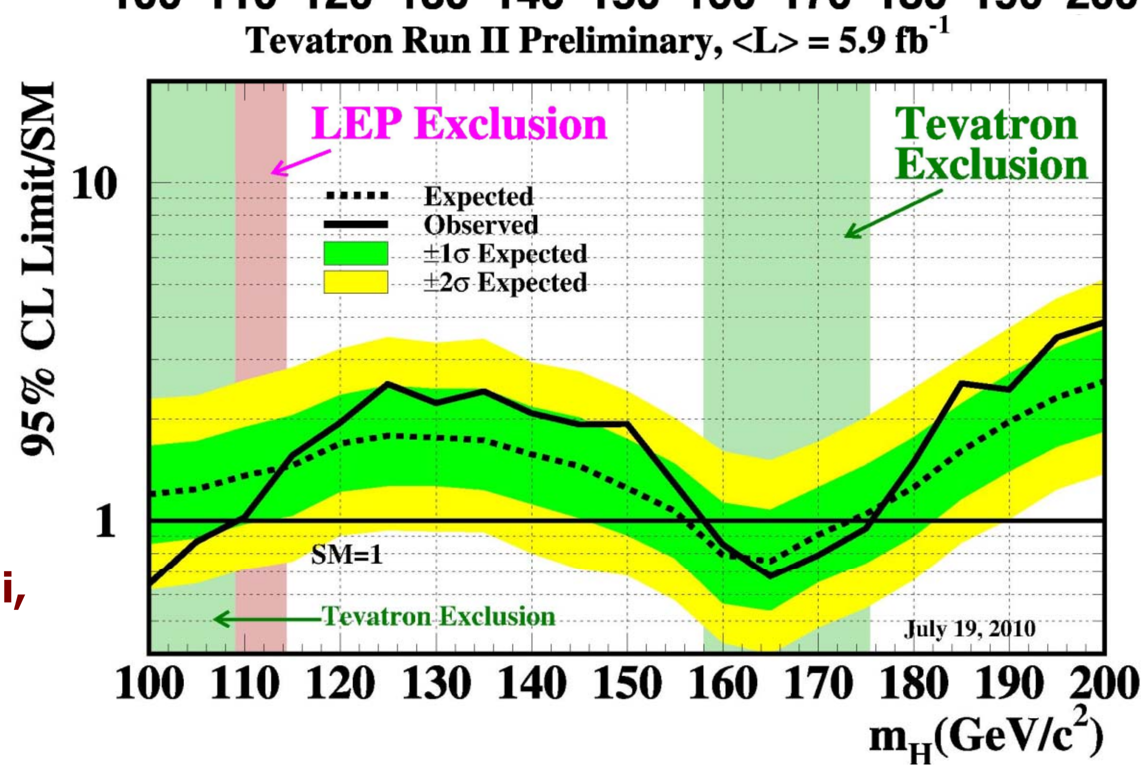
Lumi/improvements expected exclusion now ➔ from **156 to 173 GeV**

Better than **1.8 x σ_{SM}** sensitivity for all mass points **below 185 GeV**

1.45 x σ_{SM} sensitivity @ **m_H = 115 GeV** (average lumi ~5.8/fb)

New: exclusion at low mass <109 GeV

ALL 6 LOW mass channels have more lumi, sometimes significantly more



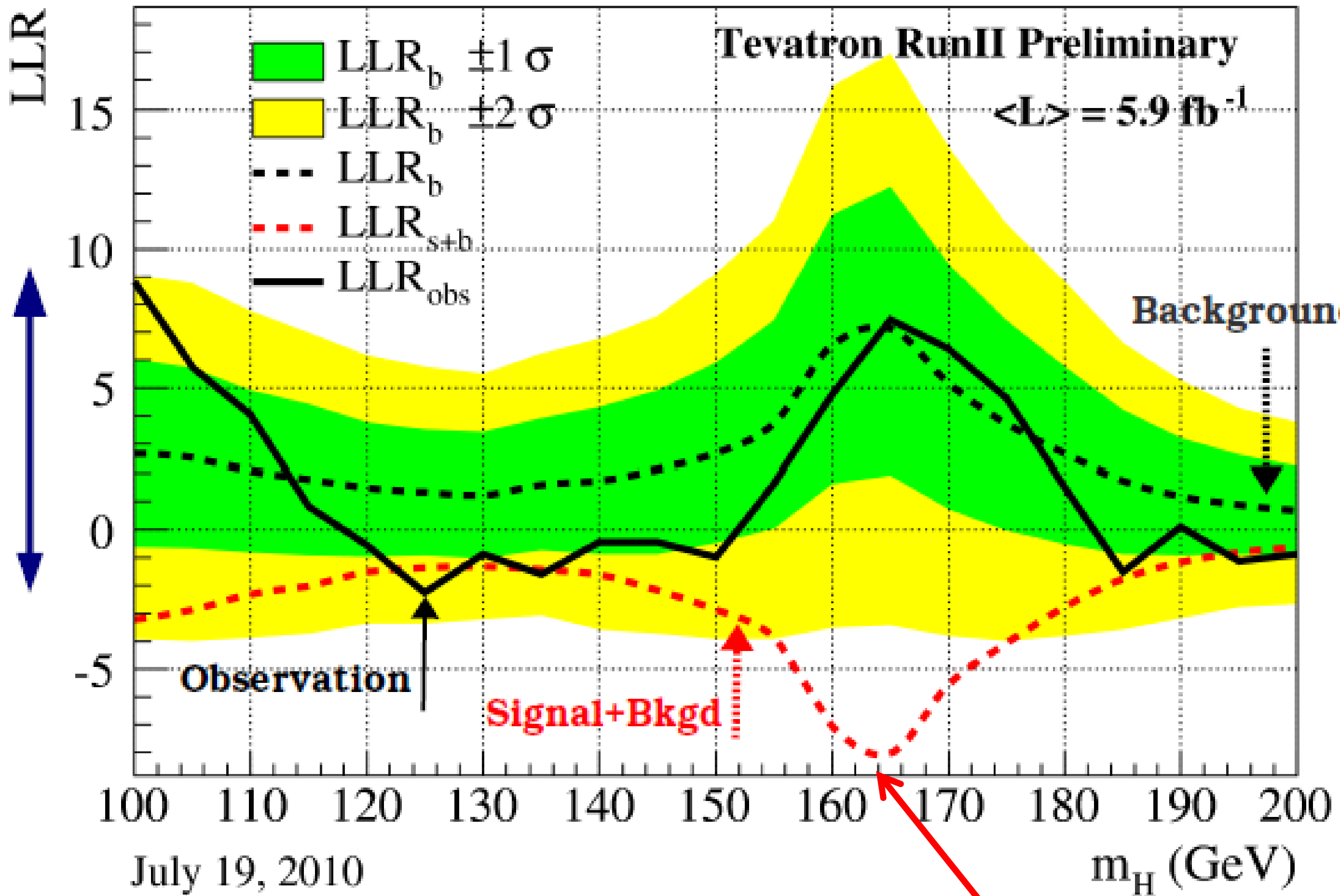
Current Sensitivity

The Log-Likelihood Ratio:

Basic test statistic of the Frequentist statistical method used here.

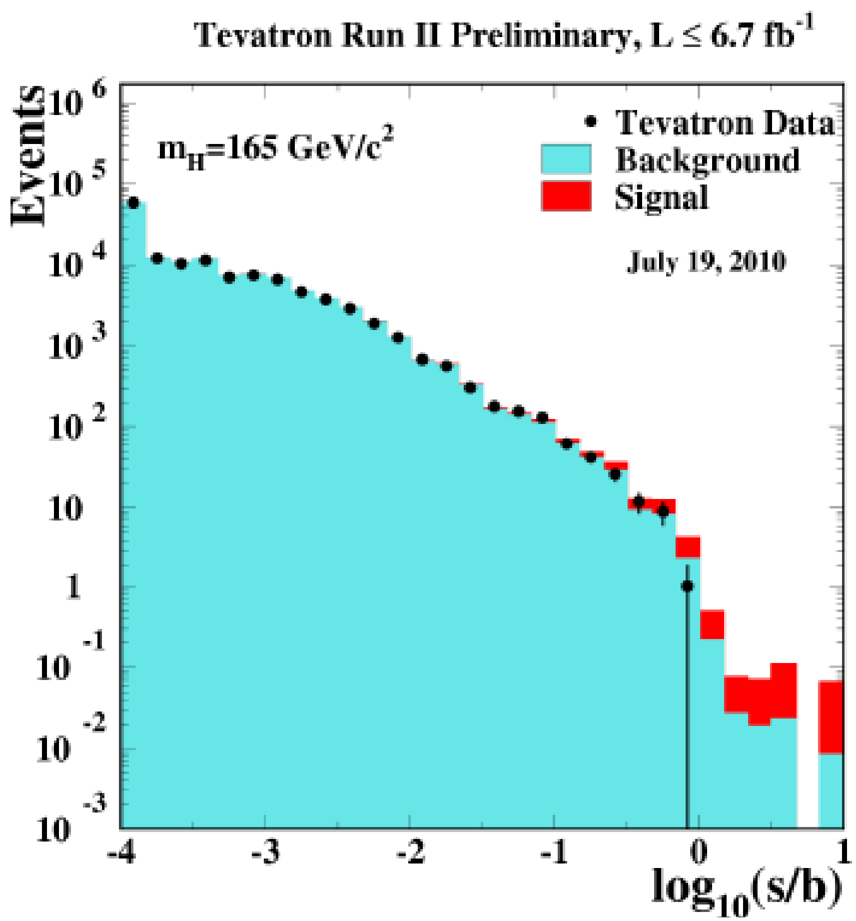
Arise from the ratio of Poisson likelihoods for TEST & NULL hypotheses.

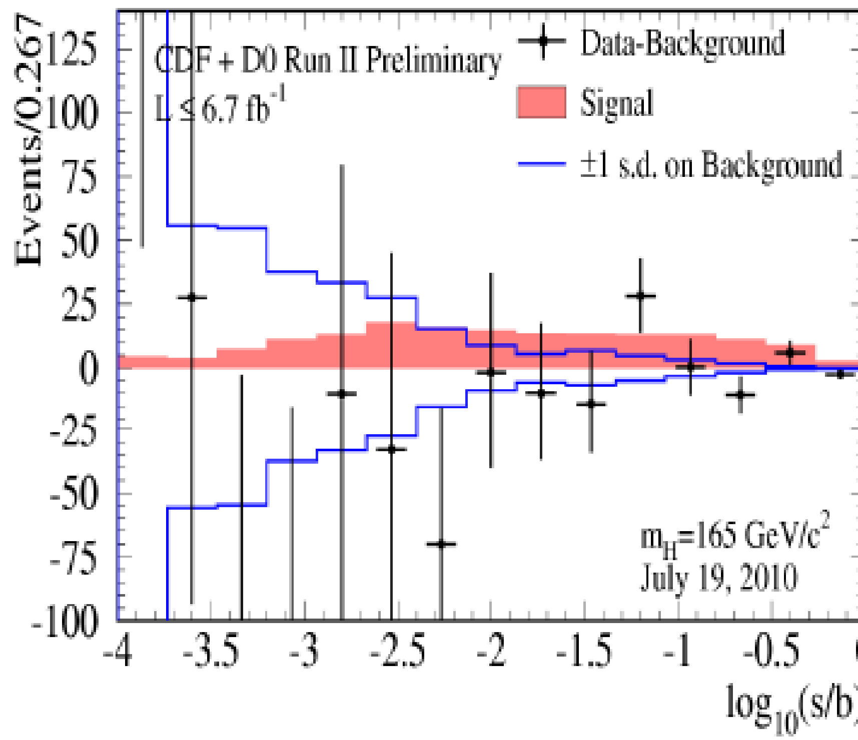
Distances between Points behave like model $\Delta\chi^2$s



If Higgs was at 165 GeV, we could be seeing a ~3 σ excess

S/B at high mass

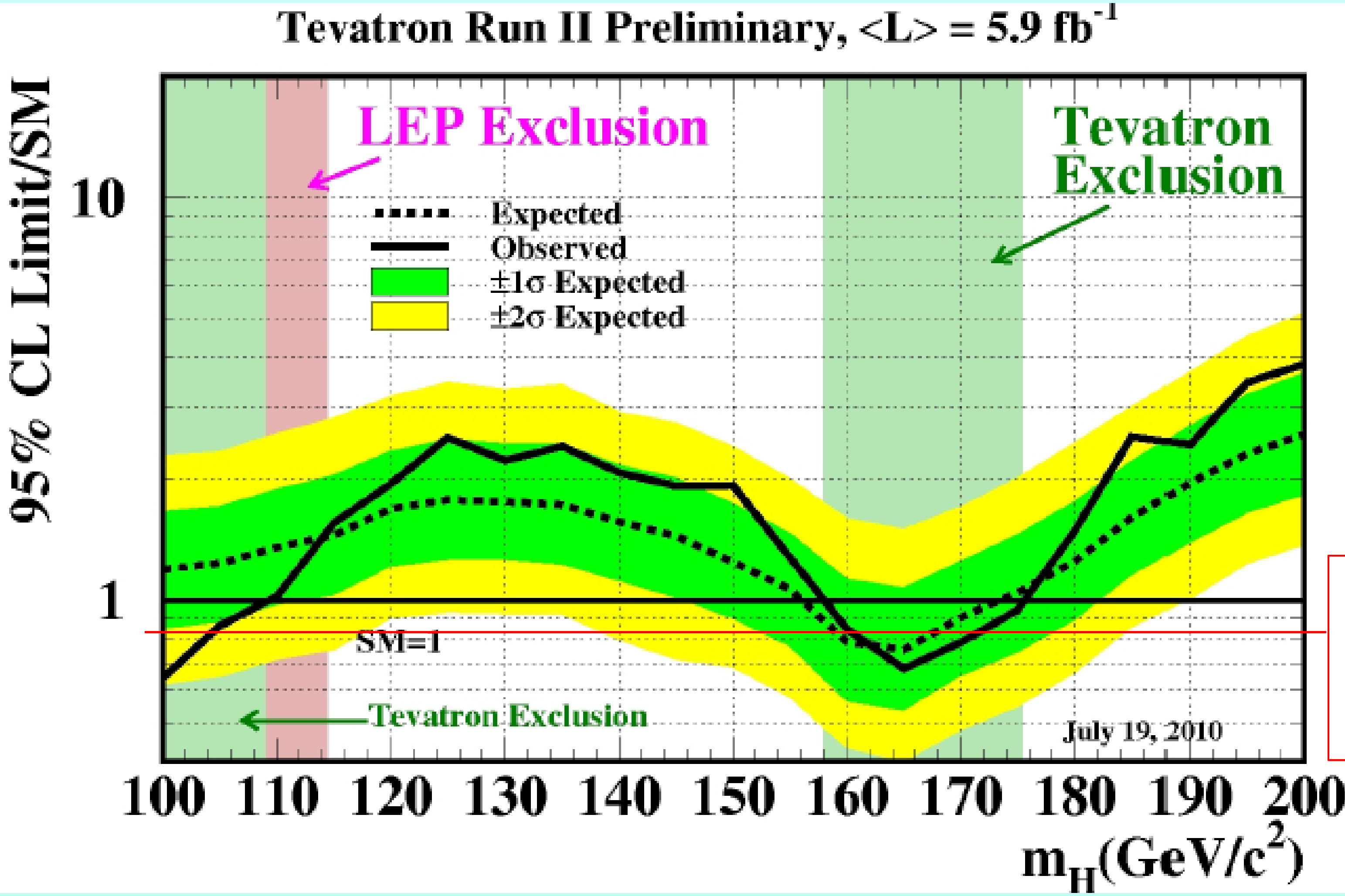




At High Mass, good agreement data/mc at all s/b,

if anything, a small "negative fluctuation" of data for high s/b

Higgs Limits/Exclusions @ ICHEP 2010



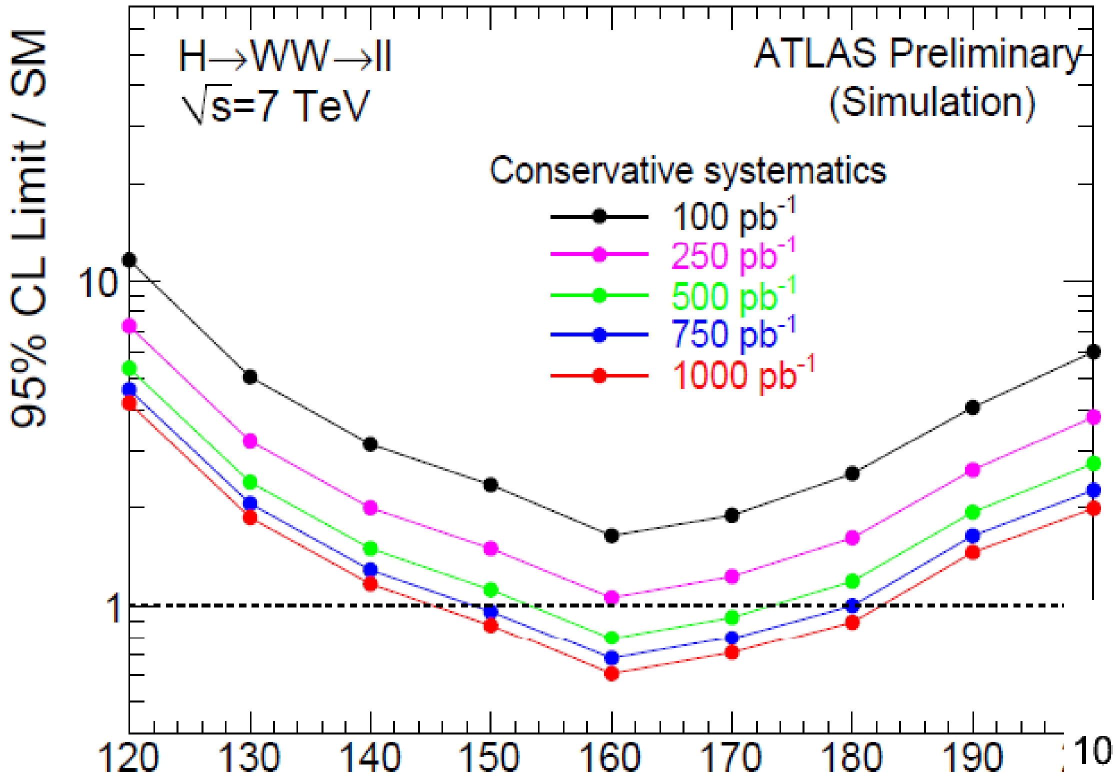
Assume (for a test) ~ -20% less on gg→H, don't forget W/ZH,VBF

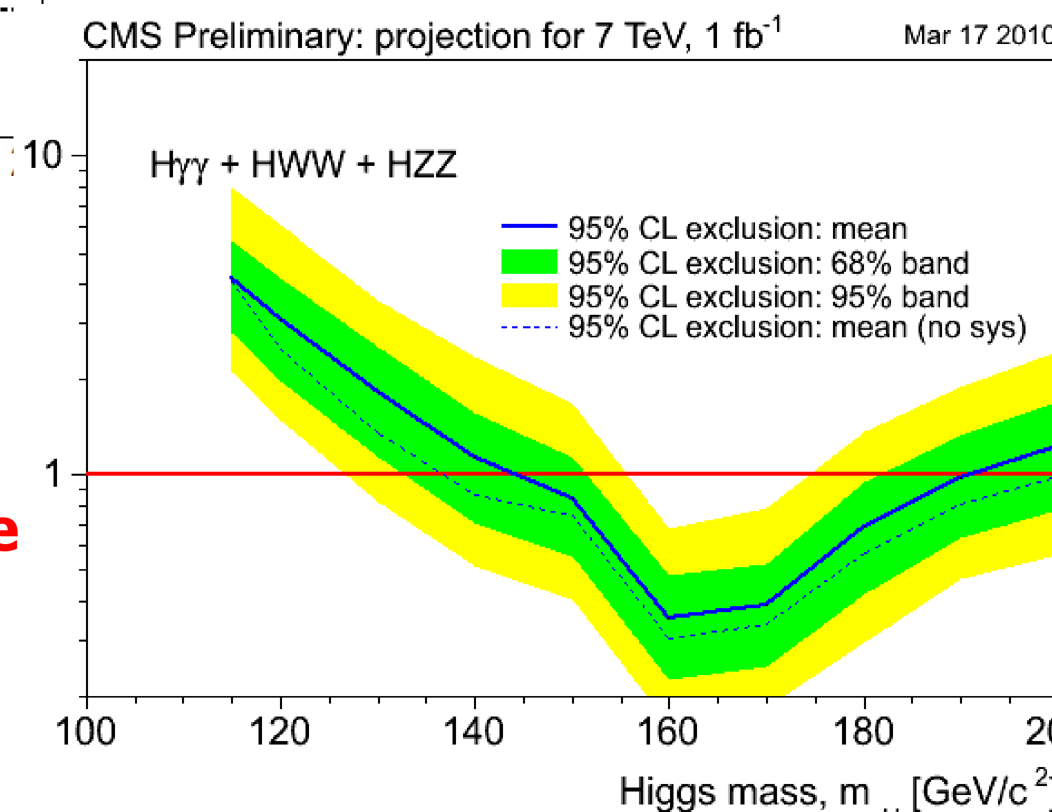
High mass exclusion between 158 and 175 GeV

The dependence on the theoretical x-section is weak: with 20% less on gg→H the exclusion would still be ~ 160-172 GeV, effect of large systematics even weaker.

In any case, no hint of a signal in the 155-175 GeV region where you would expect a > 2 sigma excess

LHC first projections shown at ICHEP





Both foresee an exclusion 145-185 GeV with 1 fb^{-1}

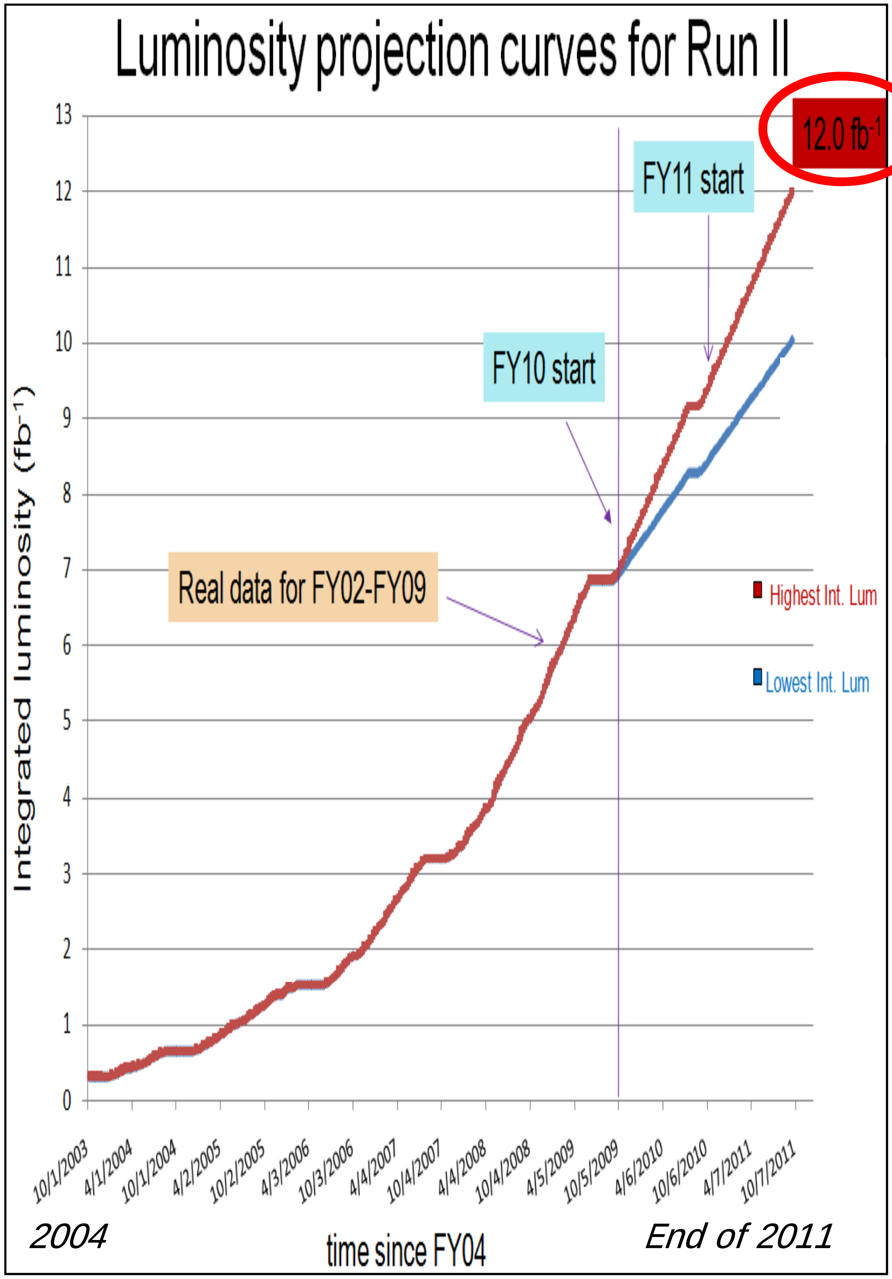
➔Need to improve and/or combine to be competitive with Tevatron.

From 2011 to 2014 @ Tevatron

- **Expect 2 fb-1 of recorded data for each year after 2011**

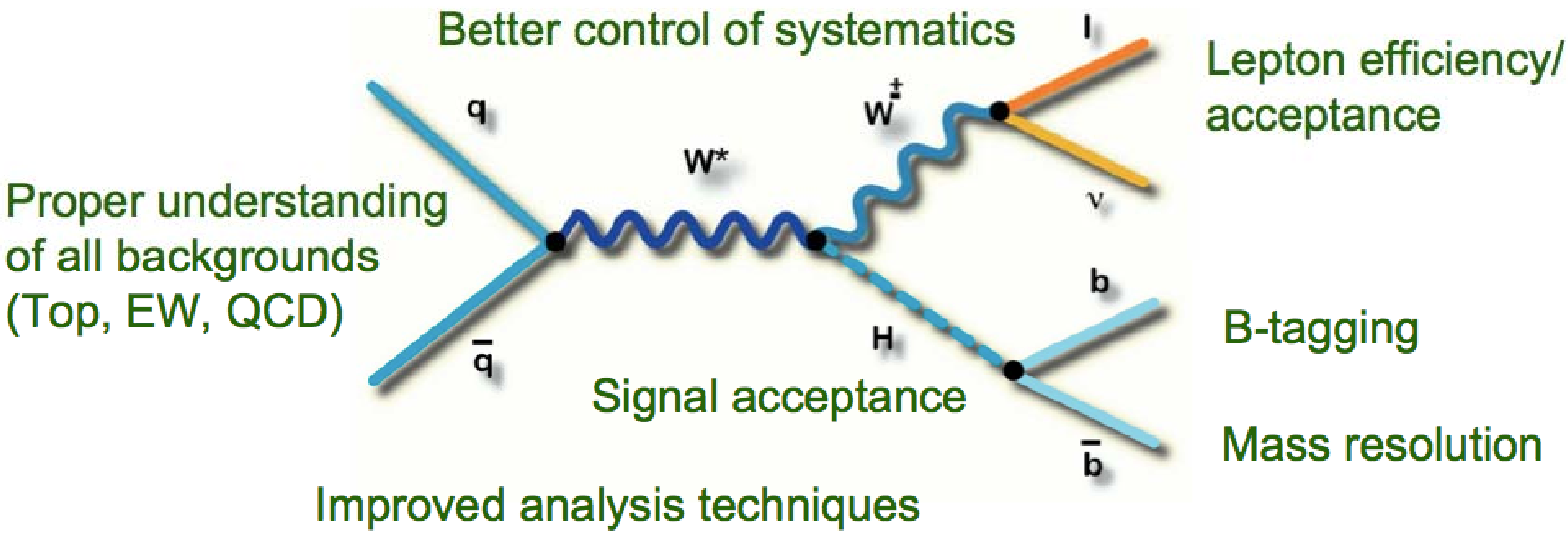
➔ **12 fb-1 analyzed end of 2012**

➔ **16 fb-1 analyzed end of 2014**



Improvement Perspectives

Continue to make improvements over a wide range of areas

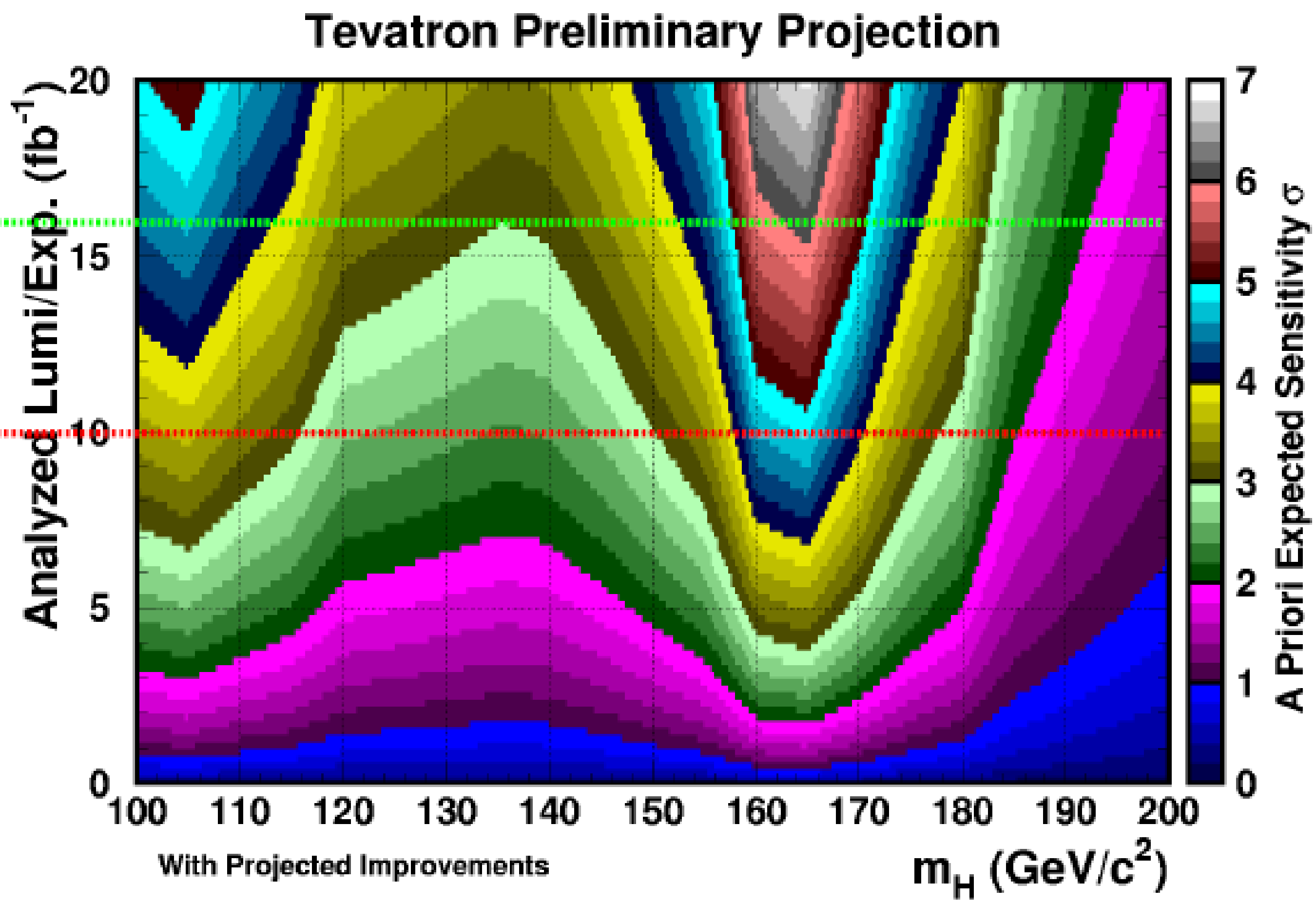


Sensitivity projections

16 fb^{-1}:
3σ expected from 100-180 GeV

~4σ at 115 GeV

End of 2011:
$>2.4\sigma$ expected over entire mass range



5 SM Scenarios (personal view)

- **Heavy SM Higgs (above 185 GeV)**

➔ good for LHC run II (>2013), Tevatron can try up to ~200 GeV
not likely scenario though given E-W fits.

- **145 GeV SM Higgs**

➔ ~ 50% probability to have 3 σ evidence @ Tevatron-2011
➔ similar at LHC with 1 fb^{-1} (combining or improving)

- **130 GeV SM Higgs**

➔ ~ 25% probability to have 3 σ evidence @ Tevatron-2011
➔ ~ 50% probability to have 3 σ evidence @ Tevatron-2014
➔ LHC needs > 2 fb^{-1} (even combining and barring significant improvements)

- **115 GeV SM Higgs**

➔ ~ 50 (80)% (probability to have 3 σ evidence @ Tevatron-2011 (2013),
good chances to reach 4 σ (if lucky and 2014, 5 σ observation!)
➔ LHC needs significant time in Run II

- **No SM Higgs**

➔ Tevatron exclude 115-185 GeV @ Tev-2011, LHC confirms down to 140 GeV

Conclusions - Higgs

- We're getting into the crucial moments for the SM Higgs if Tevatron continue running beyond end of 2011… else there is a serious danger to have to wait until >2014 to discover a light SM Higgs.
- We need to validate the b-bbar observation mode at the Tevatron, with WZ/ZZ CDF-D0 combined observation
- We need to keep searching for Susy Higgses to make sure we don't let them slip away (another talk ;))
- Tevatron could very well be the best place to measure HWW and HZZ couplings if Higgs is at low mass.

More Conclusions

- The Tevatron is a Discovery Machine.
  - Despite its age, it keeps performing very well and with increased luminosity records
- A wide range of physics processes are studied:
  - Precision measurements in QCD jet physics
    - most precise hadron colliders measurement of α_s
  - Precision measurement of the top quark and W masses
    - Known now at % experimental precision
    - Critical input to EW theory fit for Higgs boson mass
  - Searches for new physics
    - Small cross-section phenomena now accessible due to large luminosity
    - Evidence for new physics in B_s mixing
- CDF and D0 are working very hard to discover the Higgs

  Evidence for it in the mass range favored by current theoretical fits of EW data is within reach at the Tevatron especially if the machine will continue to run past 2011

Backup slides

Multivariate Techniques

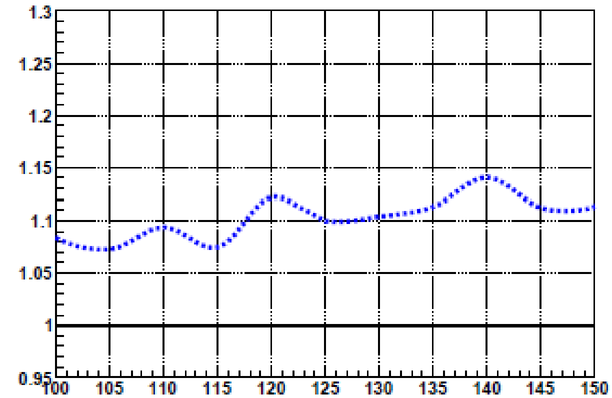
Why?

- Signal / Background ratio is << 1
- At low Higgs mass, the dijet Mass is a powerful variable by itself, but Combination of many variables can increase sensitivity

➔ **Multivariate techniques combine several variables in a single distribution**

Neural Network, Random Forest, Matrix Element, …

We find with the WH analysis the Random Forest to be the most discriminant Multivariate technique

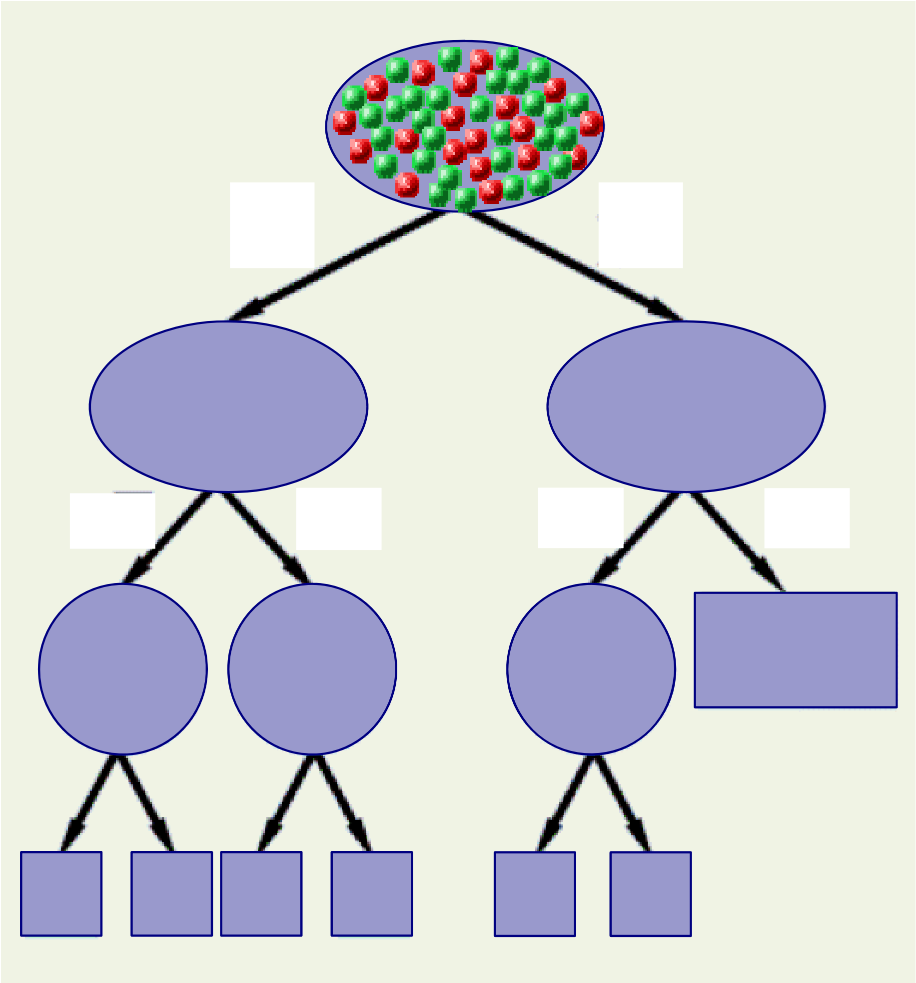


Ratio RF performance against NN performance

Random Forest = a "forest" of Decision Trees

Decision Trees

- Classify events into signal-like and background-like according to specific cuts on a number of variables



RFs

- Randomly choose a subset of events and variables for each tree

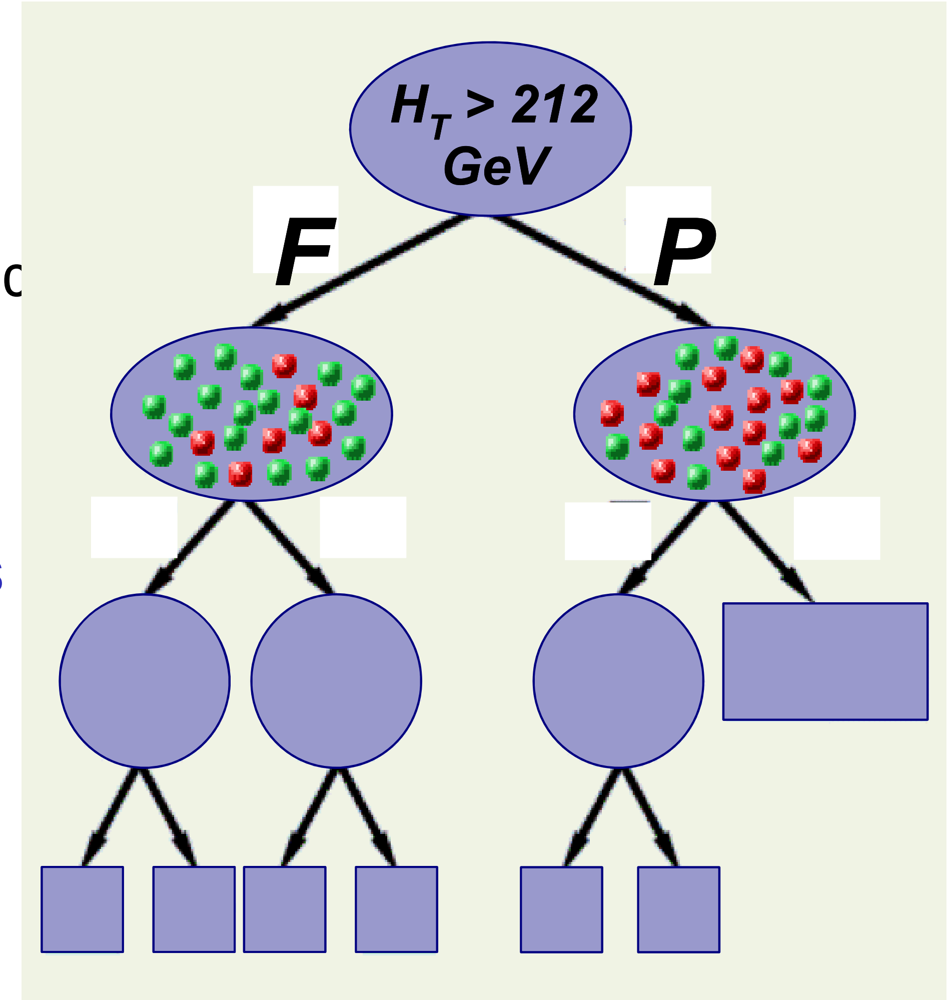
- Combine many trees to avoid training instabilities

Multivariate Analysis: Random Forest

Random Forest = a “forest“ of Decision Trees

Decision Trees

- Classify events into signal-like and background-like according to specific cuts on a number of variables



RFs

- Randomly choose a subset of events and variables for each tree
- Combine many trees to avoid training instabilities

Multivariate Analysis: Random Forest

Random Forest = a “forest“ of Decision Trees

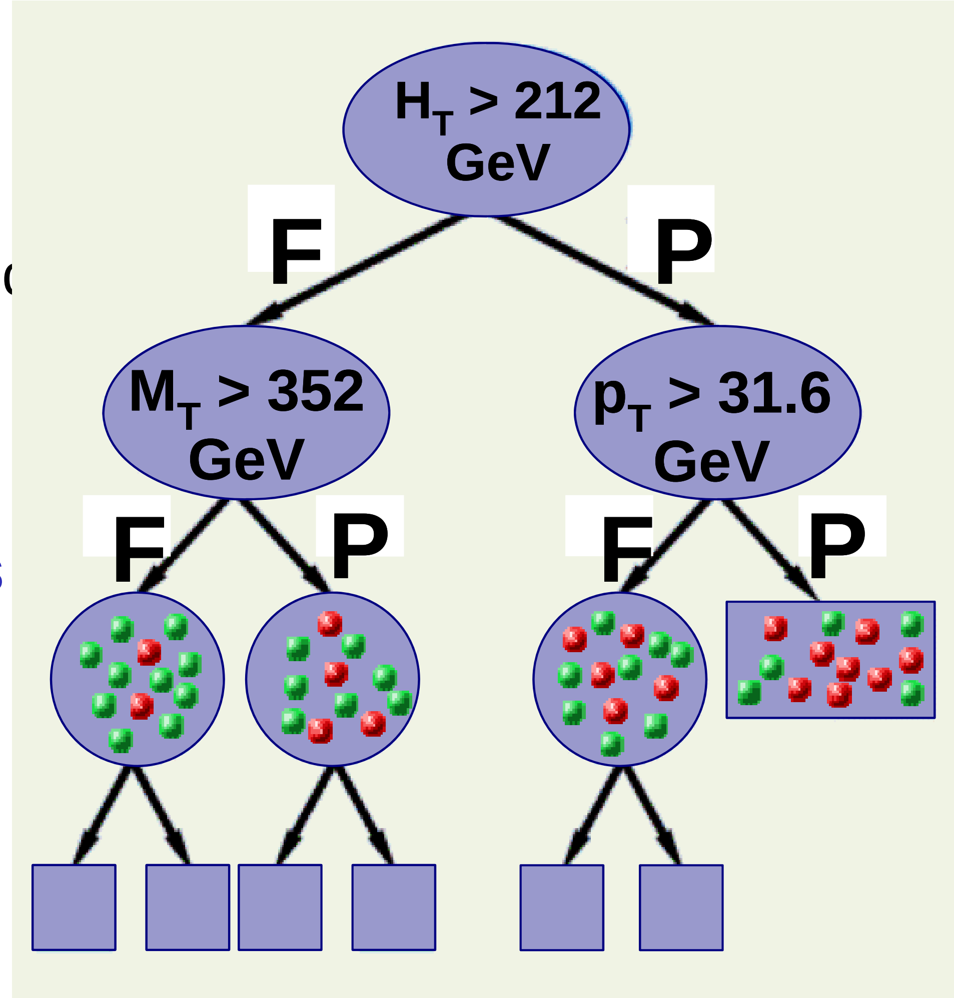
Decision Trees

- Classify events into signal-like and background-like according to specific cuts on a number of variables

RFs

- Randomly choose a subset of events and variables for each tree

- Combine many trees to avoid training instabilities



Multivariate Analysis: Random Forest

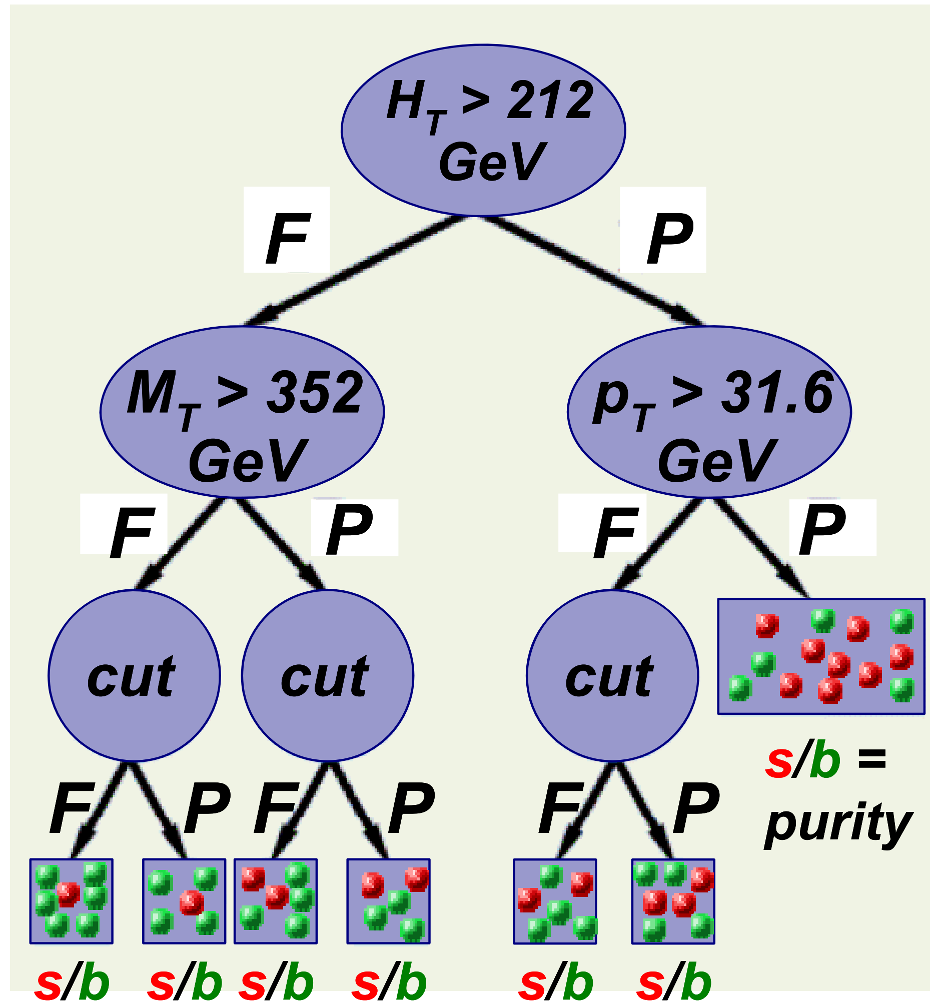
Random Forest = a "forest" of Decision Trees

Decision Trees

- Classify events into signal-like and background-like according to specific cuts on a number of variables

RFs

- Randomly choose a subset of events and variables for each tree
- Combine many trees to avoid training instabilities



...back to our Random Forest: Training

Input variables for the WH Random Forest

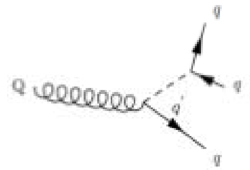
- p_T(leading jet), p_T(second leading jet)
- ΔR(jets), $\Delta\phi$(jets), p_T(dijet system), dijet invariant mass
- $p_T(\ell$-$\not\!\!E_T$ system)
- $\Delta\phi(\ell$, leading jet)
- $\not\!\!E_T$
- Aplanarity (total p_T-component transverse to the dijet-(ℓ-ν) plane),
- $\sqrt{s}$, invariant mass of the neutrino-lepton-dijet system
- ΔR(dijet system,ℓ-ν system)
- lepton-$\not\!\!E_T$ invariant mass
- H_T, H_Z,sum of the transverse and z-momenta of all jets in the event, respectively
- $\cos\theta*$, $\cos\chi$, spin correlation variables

A total of 20 variables is used to separate events

- **The RF is trained separately on the Single Tag and Double Tag Samples**
- **Training events are not used in the analysis**

Multijets resonances

Model independent search for pp→QQ→3j+3j=6jets



Start with 6 jets selection

- **separate three-jet combinations that are potentially correlated using diagonal cut**
- **Optimize for each mass point**

QCD background parameterized from 5-jet events

Set limit on RPV gluino scenario

Most significant excess (2σ) near top mass (~1 event expected from MC)