Dzero Physics Results

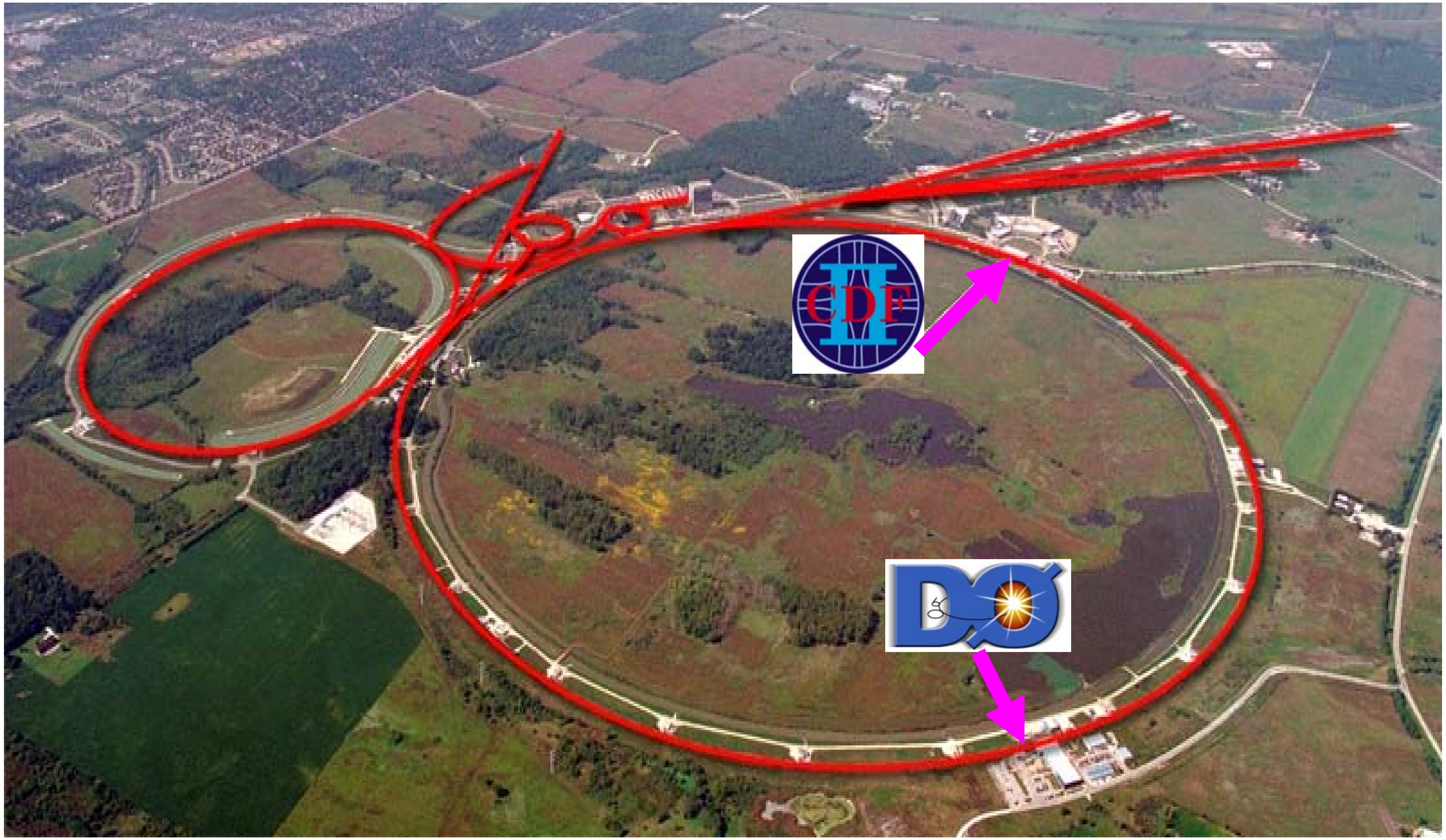
GGI seminar

Gregorio Bernardi, LPNHE Paris

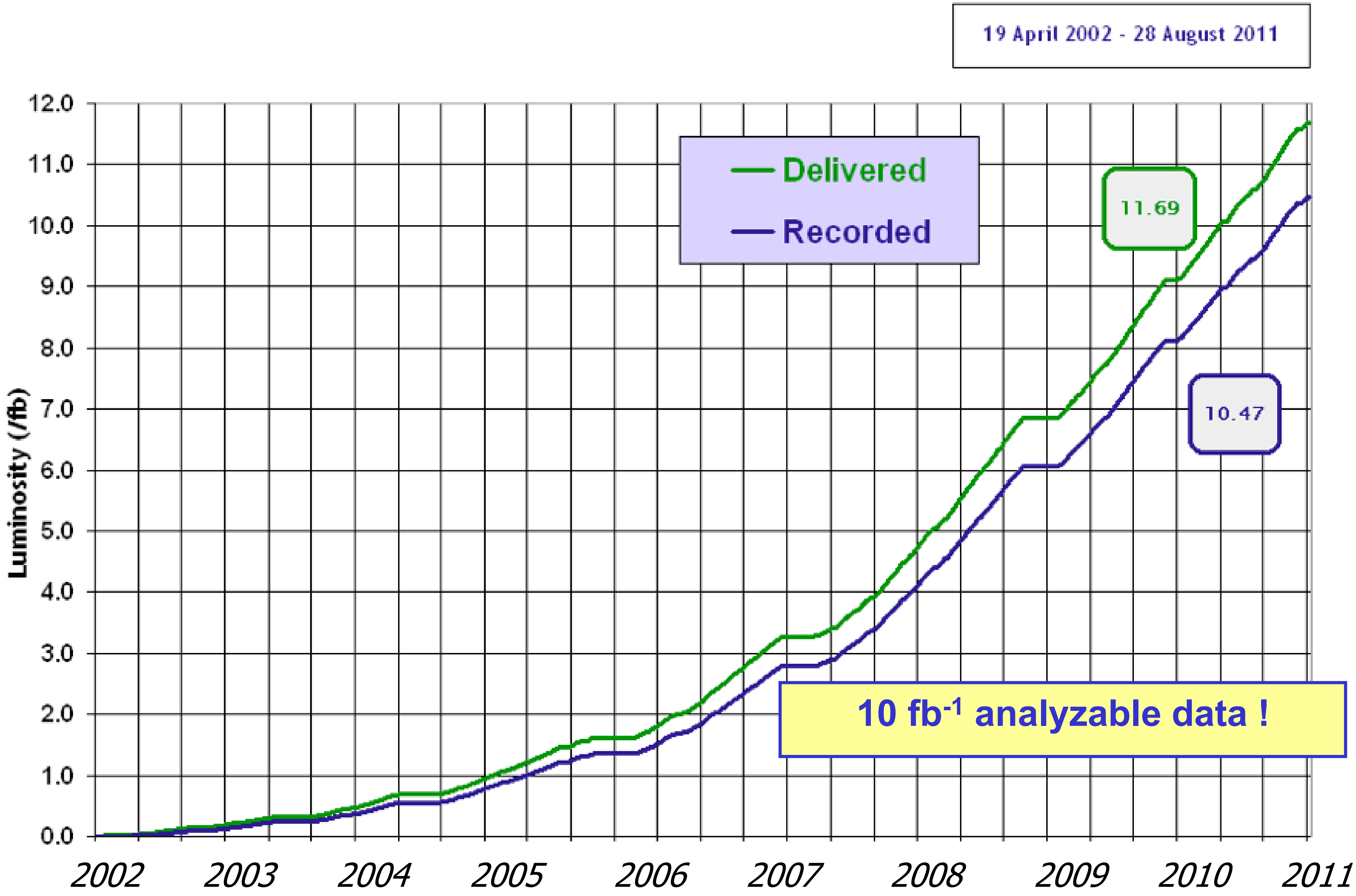
October 7th 2011

Thanks to all Tevatron colleagues, in particular

F.Deliot, S.Lammers, M. Williams



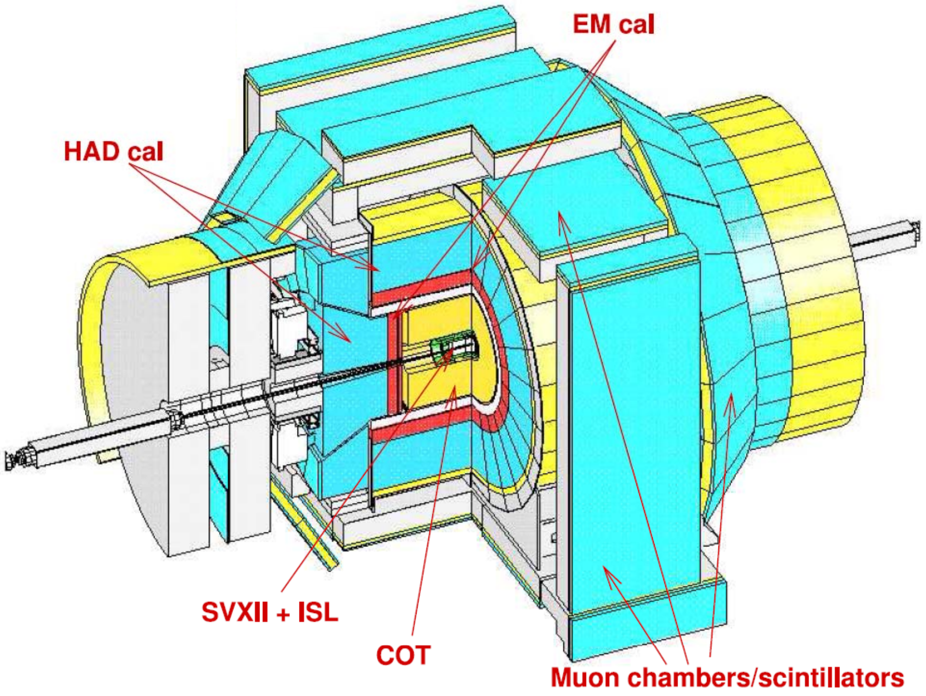
Tevatron Luminosity

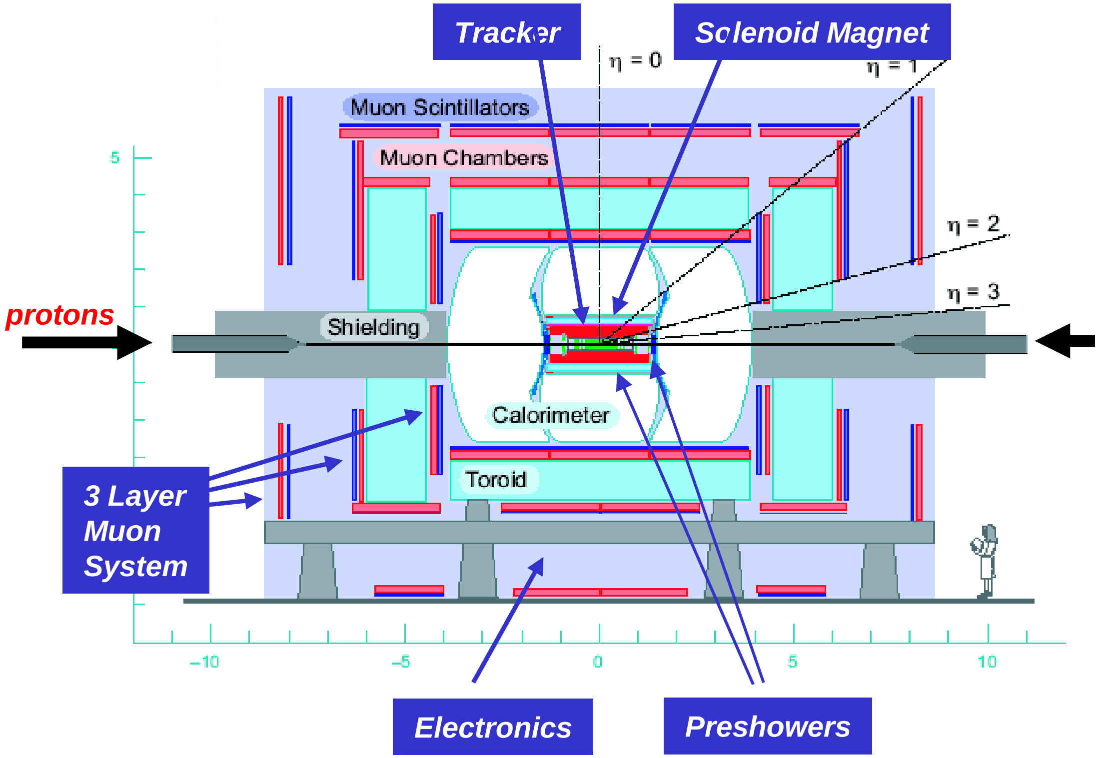


10 fb^{-1} analyzable data !

Thanks to the Tevatron Accelerator Group for such a performance!

CDF and DØ Detectors





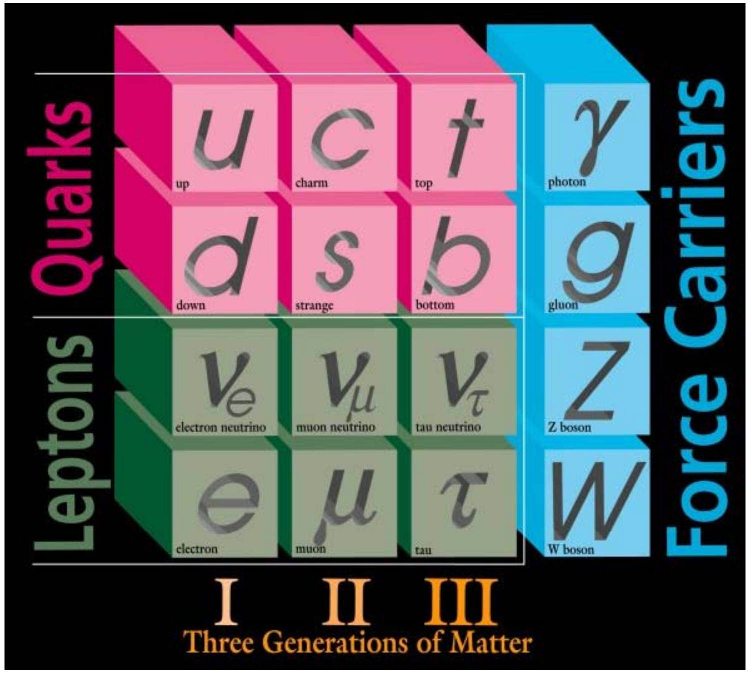
- General purpose detectors
- Good hermeticity
- Mature algorithms
- Well understood under all pile-up conditions

Rapidity coverage

	CDF	Dzero
Track	2.0	2.5
Calorimeter	3.6	4.2
Muon	1.0	2.0
B-field	1.4 T	2.0 T

Introduction

Standard Model very successful, predicts large range of phenomena;



However, many problems once you leave the low-energy regime:

- Hierarchy/naturalness problem;
- Dark matter;
- No unification of forces;
- Not enough CPV for baryogenesis;
- Why 3 generations?
- No Higgs boson observed yet
- …

We expect 'new physics' to appear somewhere, but where?!

Many extensions to SM, which make testable predictions, generally with new particle content.

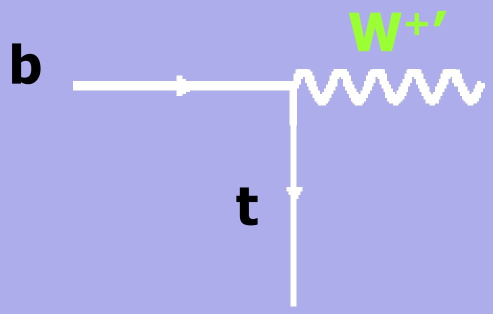
Outline

- NP
- B
- QCD
- Electroweak
- Top
- Higgs

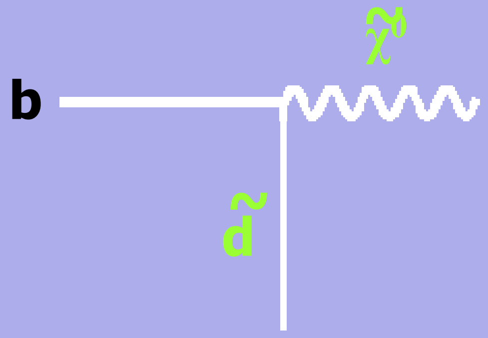
How to Find New Physics…

New Phenomena analyses: direct searches for signatures of new particles:

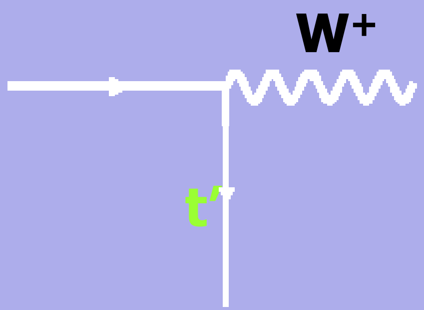
New Gauge Groups:

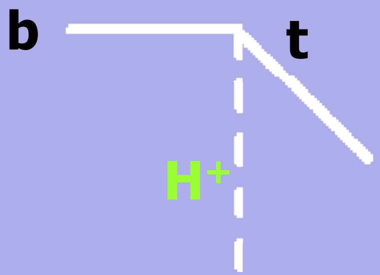


Supersymmetry:



New Quarks:



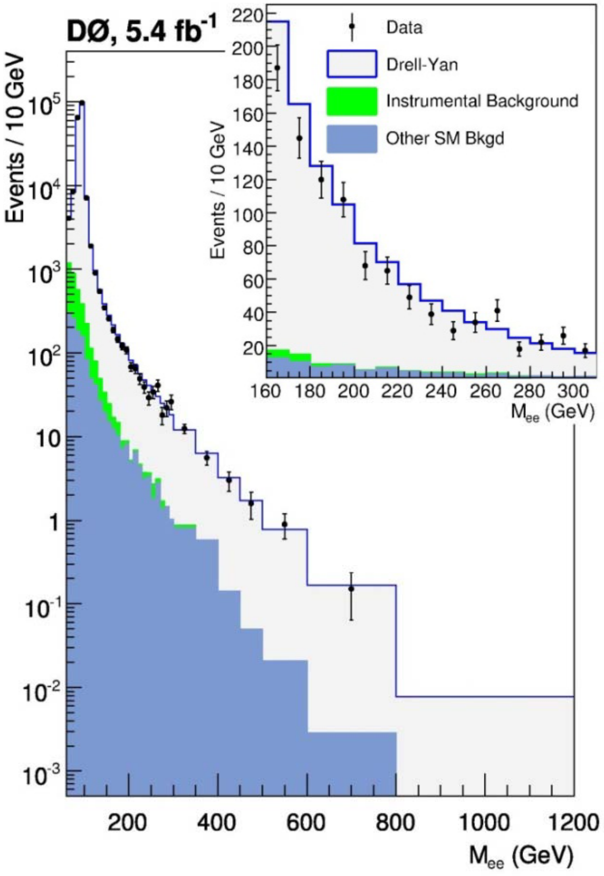


New particles on mass shell: limited by √s

Heavy Resonances

Experimental Signature

Narrow M(ee) resonance

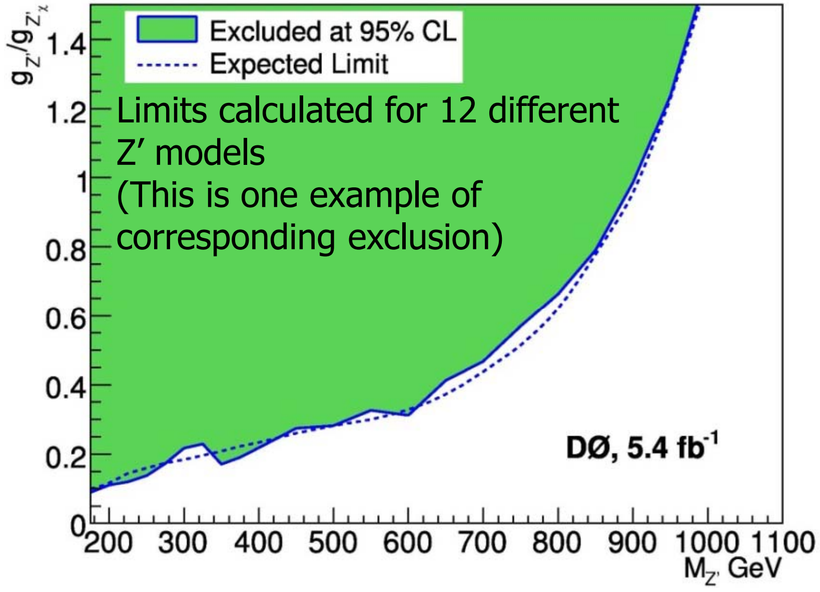


Theoretical Model

Extensions to SM with additional U(1) group, i.e. **Z′ boson**

Coupling strength $g_{Z'}$

Mass $M_{Z'}$

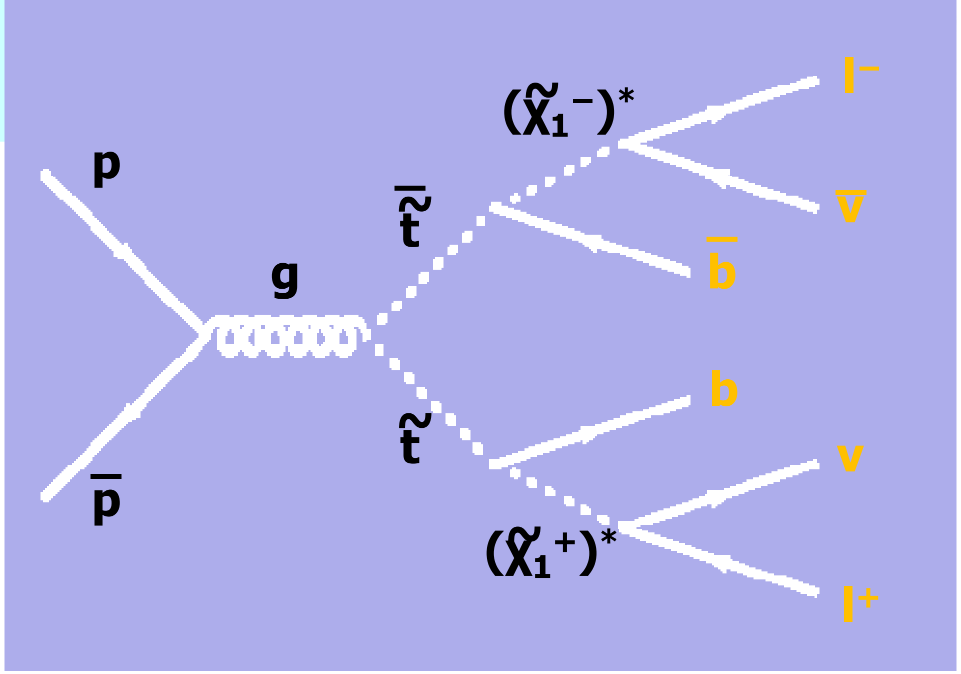


Limits calculated for 12 different Z′ models (This is one example of corresponding exclusion)

Phys. Lett. B 695, 88 (2011)

Also use M(ee), M(γγ) to place limits on KK graviton mass/coupling in Randall-Sundrum models. PRL 104, 241802 (2010)

Squark Production

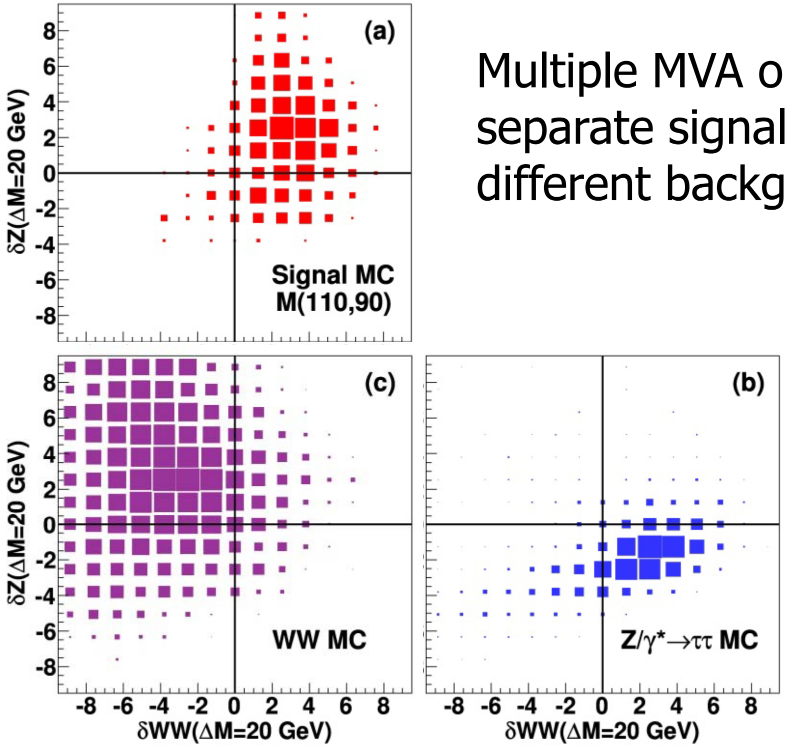


stop pair search

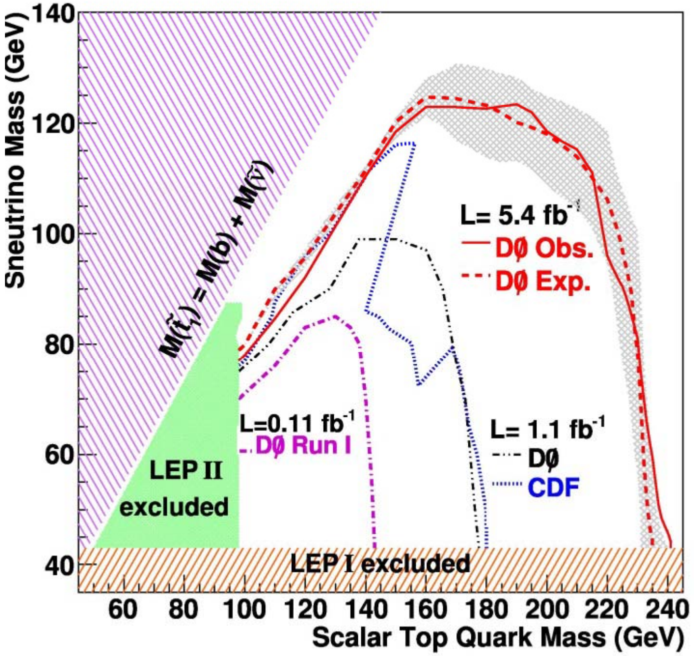
Signature: 2 b-jets, $e^{\pm}\mu^{\mp}$ + MET

Model: $\tilde{t}\tilde{t} \rightarrow bbe\mu\tilde{\nu}\tilde{\nu}$

Sneutrino $\tilde{\nu}$ is LSP, or decays invisibly

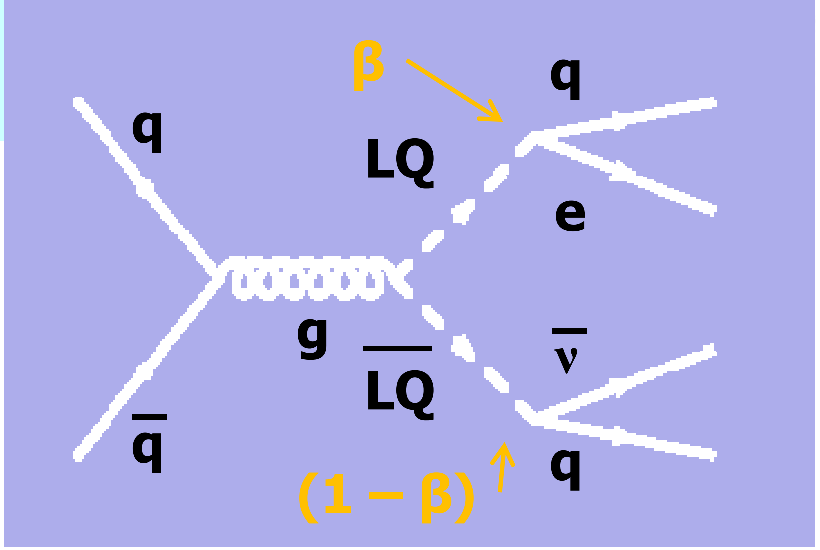


Multiple MVA outputs to separate signal from different backgrounds.



Phys. Lett. B 696, 321 (2011)

Leptoquarks

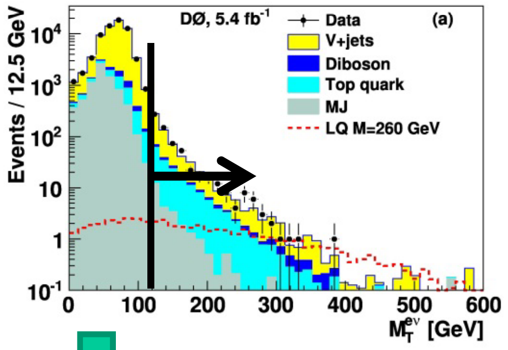


Many extensions of SM have **lepton↔quark symmetry**;

Mediating bosons, ‘leptoquarks’ (LQ) with both quark and lepton number.

Search for 1st generation scalar LQ pairs:

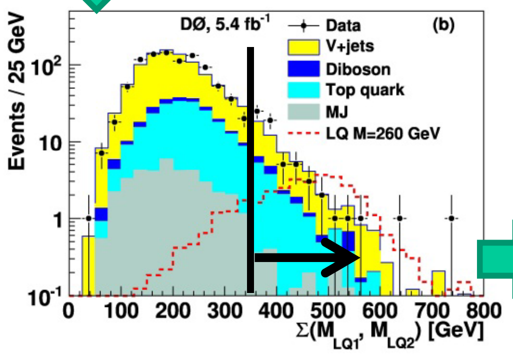
$(LQ)(\overline{LQ}) \rightarrow (e^{\pm}q)\ (\nu_e q`)$

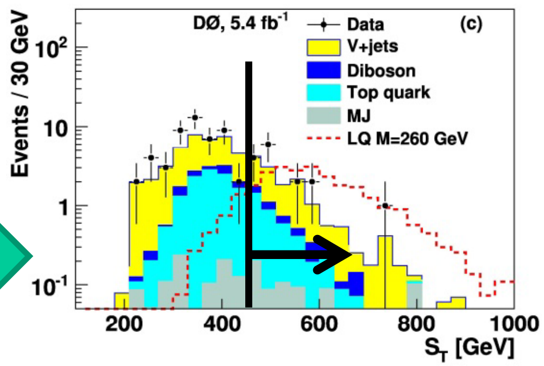


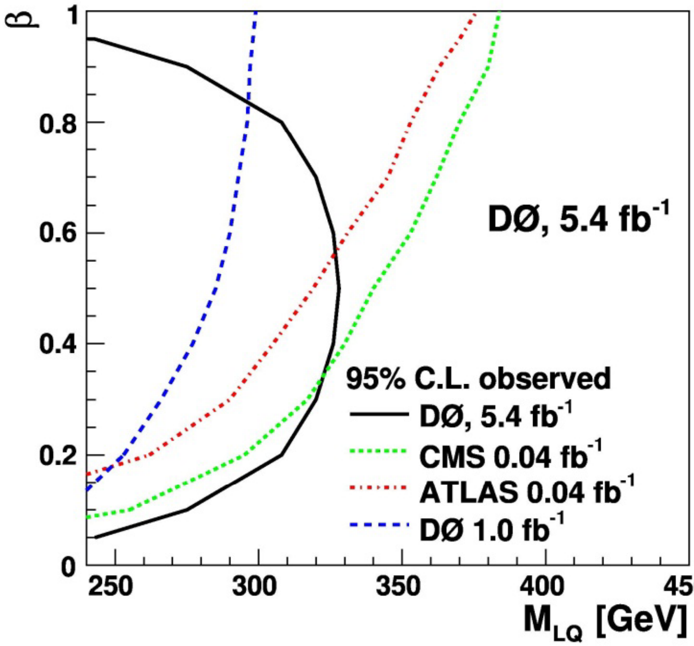
$M_T > 110$ GeV

$\Sigma M_{LQ} > 350$ GeV

$S_T > 450$ GeV







Better than published LHC results for $\beta < 0.3$

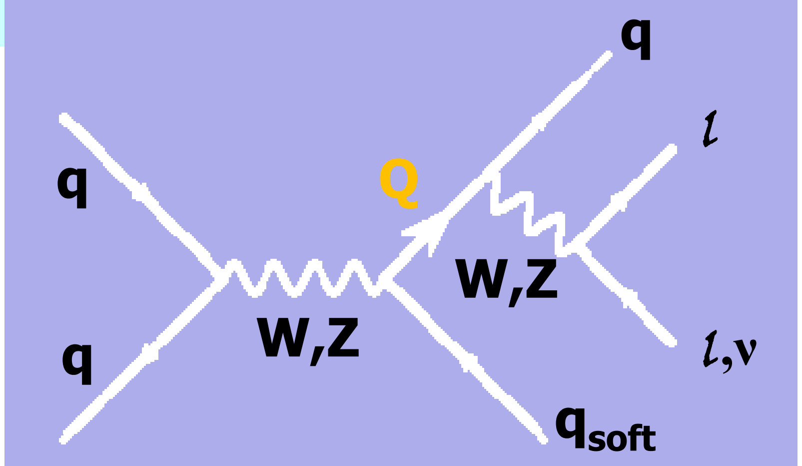
arXiv:1107.1849 [hep-ex]
Accepted by PRD-RC

Vector-like Quarks, Q

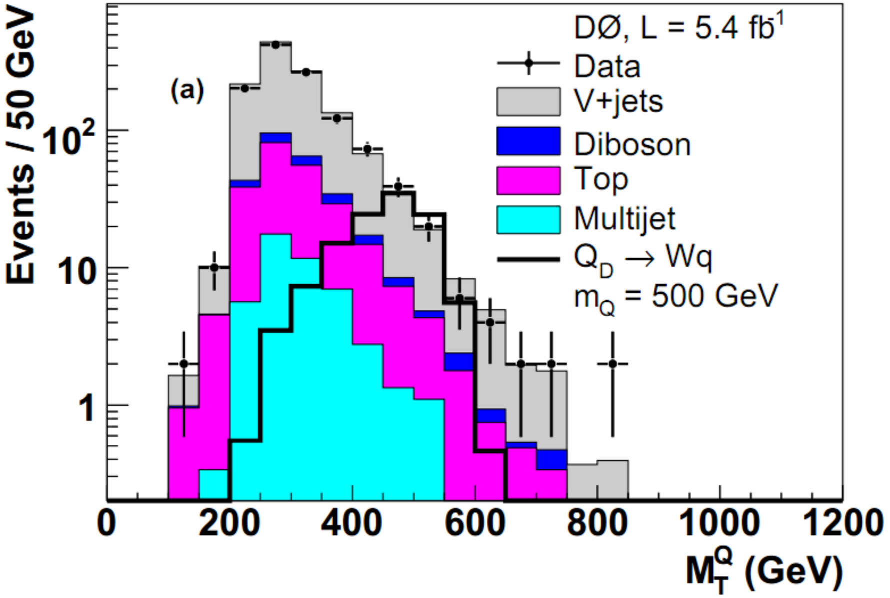
Predicted by certain little Higgs, UED, and warped ED models;

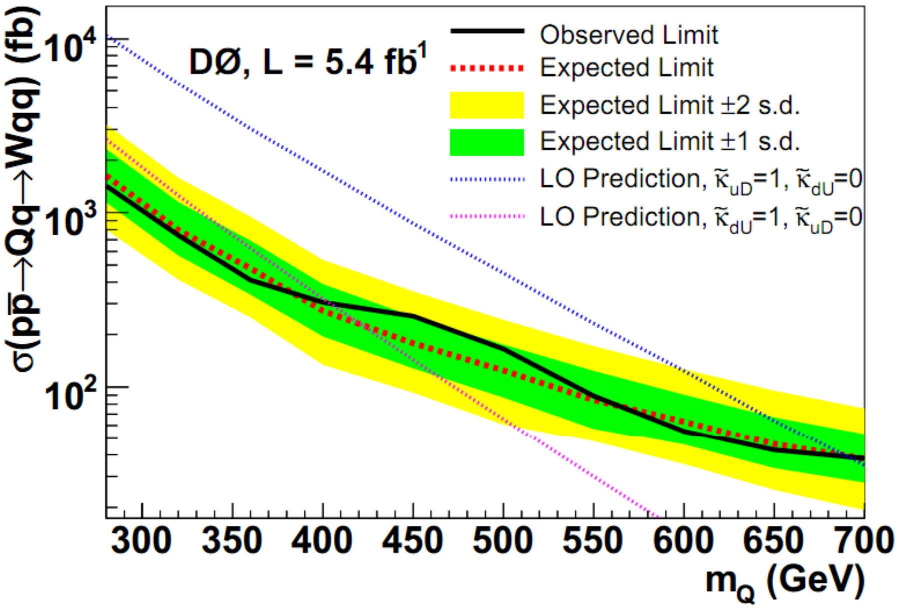
'Vector-like' = left- and right- handed components transform in same way in SU(3)×SU(2)×U(1);

Production:
- **Pair:** strong interaction, limited mass reach;
- **Single:** EW interaction, mixing with SM quarks;



Final state: $q_{soft} + \ell^+\ell^- q$
or: $q_{soft} + \ell^\pm \nu q$

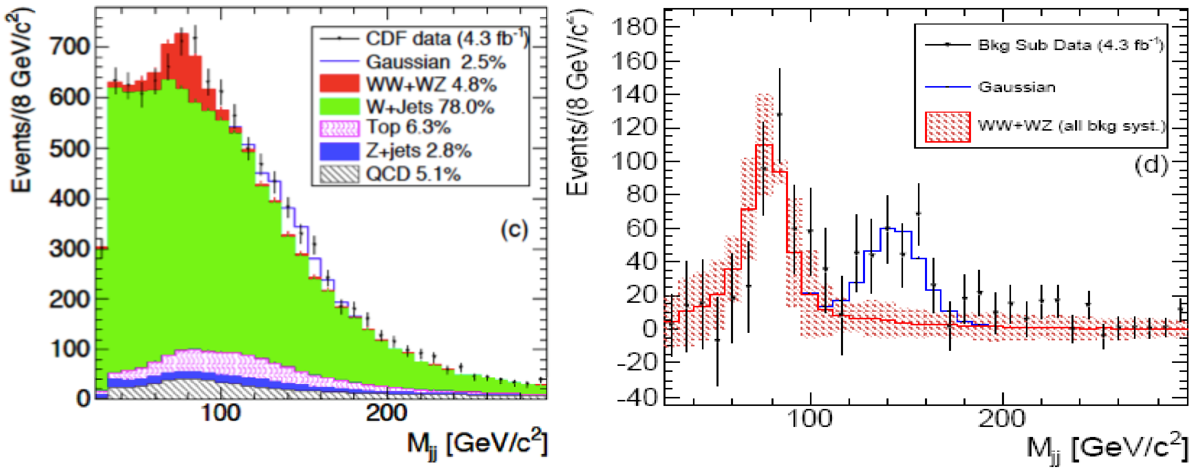


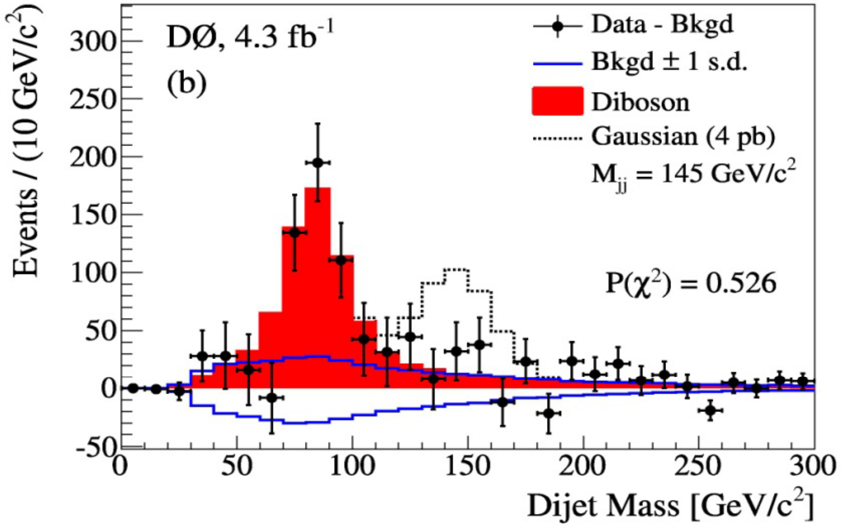


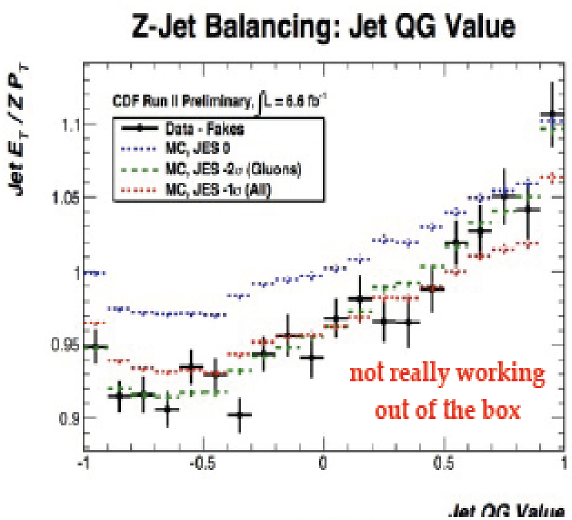
PRL 106, 081801 (2011)

$M(Q_d \to Wq) < 696$ GeV
$M(Q_u \to Zq) < 449$ GeV

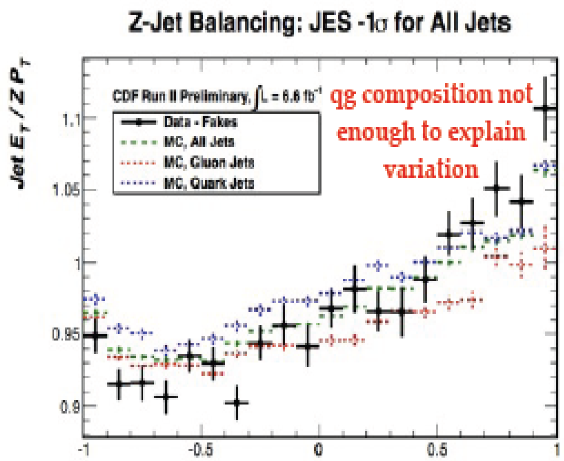
Wjj: CDF vs. DZero



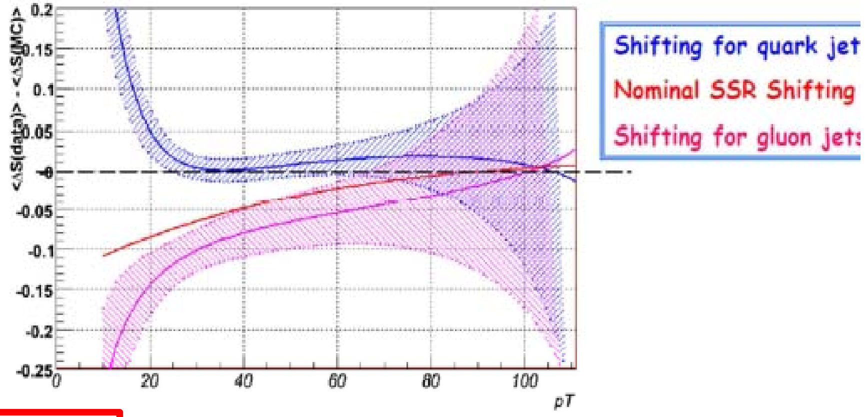




not really working out of the box



qg composition not enough to explain variation



- q/g energy scale differences.
- Cone size and out of cone corrections.
- Different treatment of systematic errors and fit to nuisance parameters.

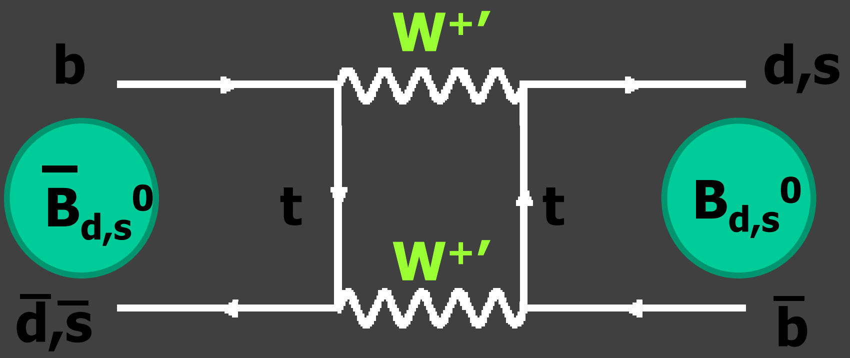
After updated value of CDF, discrepancy with Dzero is smaller (~2.5 sigmas)
- the task force has been disbanded. We wait for next CDF paper on the subject

How to Find New Physics with B's

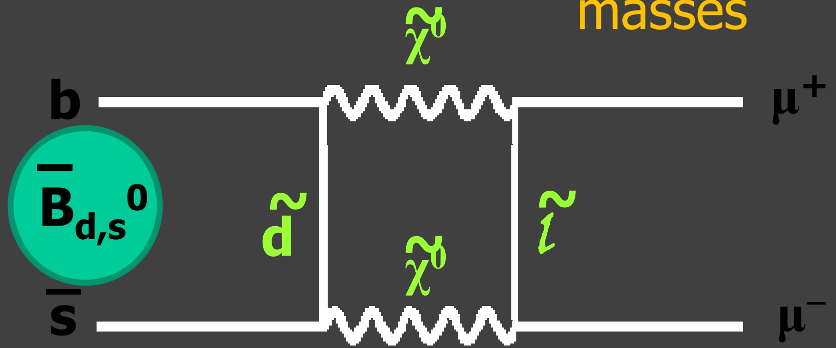
B Physics analyses: Measure parameters sensitive to indirect NP contributions:

New particles in loops: access to all masses

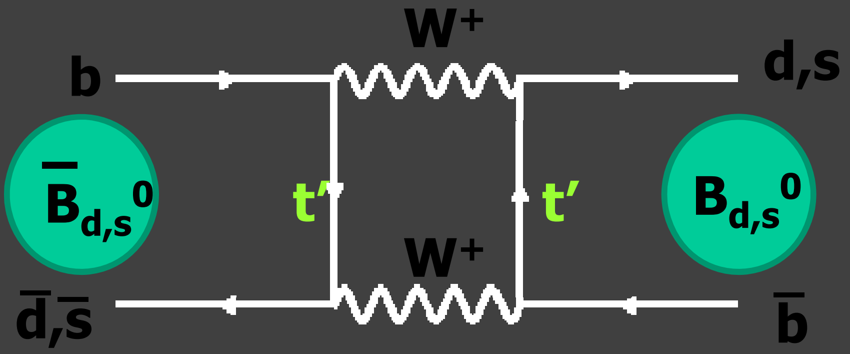
New Gauge Groups:

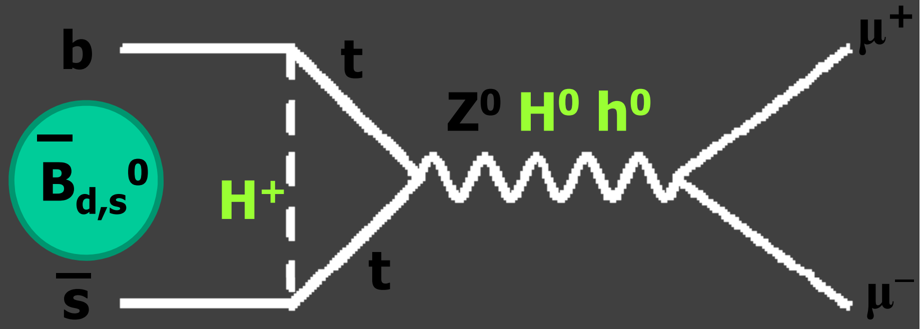


Supersymmetry:



New Quarks:



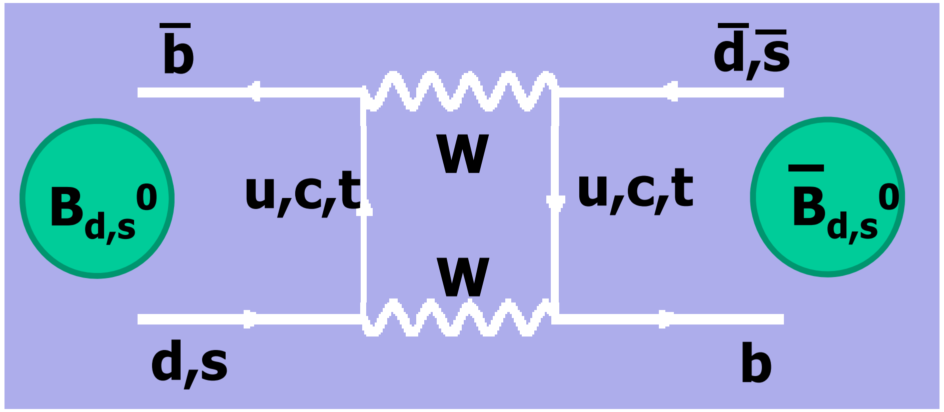


New physics in B meson mixing

B meson mixing, asymmetries and CP Violation

Neutral B mesons mix into their antiparticles;

Not CP symmetric: complex phases φ in CKM matrix, i.e. $\Gamma(\bar{B}^0 \rightarrow B^0) \neq \Gamma(B^0 \rightarrow \bar{B}^0)$



Define flavor-specific semileptonic asymmetry:

$$a^{s,d}_{sl} = \frac{\Gamma(\bar{B}^0 \rightarrow B^0 \rightarrow \mu^+ X) - \Gamma(B^0 \rightarrow \bar{B}^0 \rightarrow \mu^- X)}{\Gamma(\bar{B}^0 \rightarrow B^0 \rightarrow \mu^+ X) + \Gamma(B^0 \rightarrow \bar{B}^0 \rightarrow \mu^- X)} = \frac{\Delta\Gamma_{s,d}}{\Delta M_{s,d}} \tan\varphi_q$$

Physical parameters of $B_{s,d}^0$ system

SM prediction tiny for both B^0 and B_s^0 systems;

New particles in box diagrams can give large enhancements to asymmetry.

Loop integral: sensitive to new particles of **any mass**.

CP violation in neutral B meson semileptonic decays

Direct semileptonic decay

Neutral *B* meson oscillation and then semileptonic decay

Measure *CP* violation in mixing via

$$\boxed{A^b_{sl} = \frac{N_b(\mu^+\mu^+) - N_b(\mu^-\mu^-)}{N_b(\mu^+\mu^+) + N_b(\mu^-\mu^-)}}$$

- Dominant systematics controlled by:
  - reversing field directions
  - measuring difference in K± → μ± rates in data

Asymmetry is a linear combination semileptonic charge asymmetries of B^0_d and B^0_s

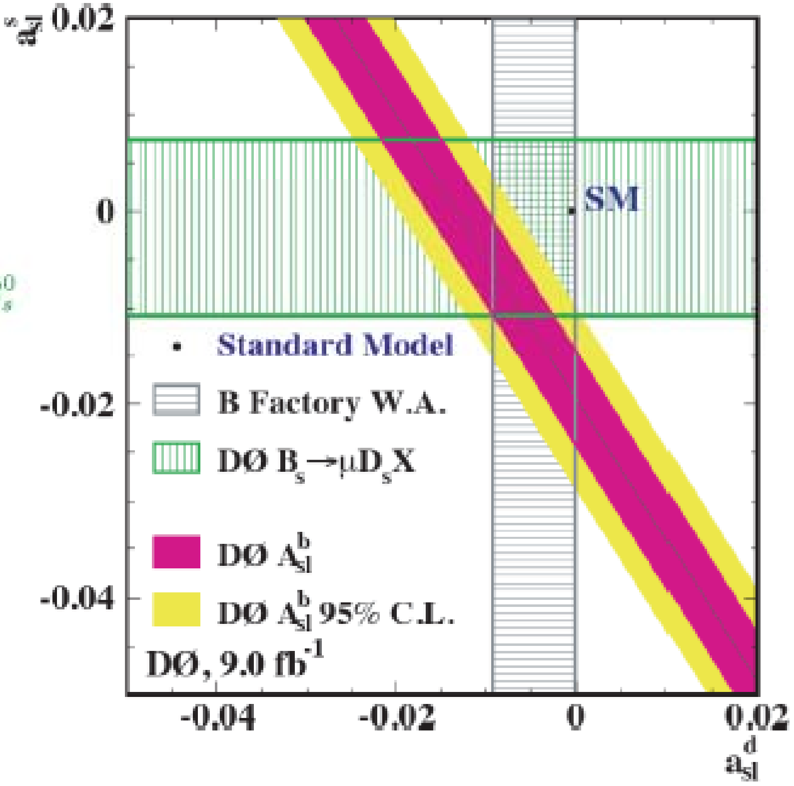
$$A^b_{sl} = C_d a^d_{sl} + C_s a^s_{sl} \;; \qquad a^b_{sl} = \frac{\Gamma(\overline{B} \to \mu^+ X) - \Gamma(B \to \mu^- X)}{\Gamma(\overline{B} \to \mu^+ X) + \Gamma(B \to \mu^- X)}$$

Coefficients depend on mean mixing probability and production fractions

DØ Update 9.0 fb^{-1}

$$\boxed{A^b_{sl} = (-0.787 \pm 0.172 \pm 0.093)\%}$$

Now a 3.9σ deviation from SM prediction



Anomalous Like-sign Dimuon Asymmetry

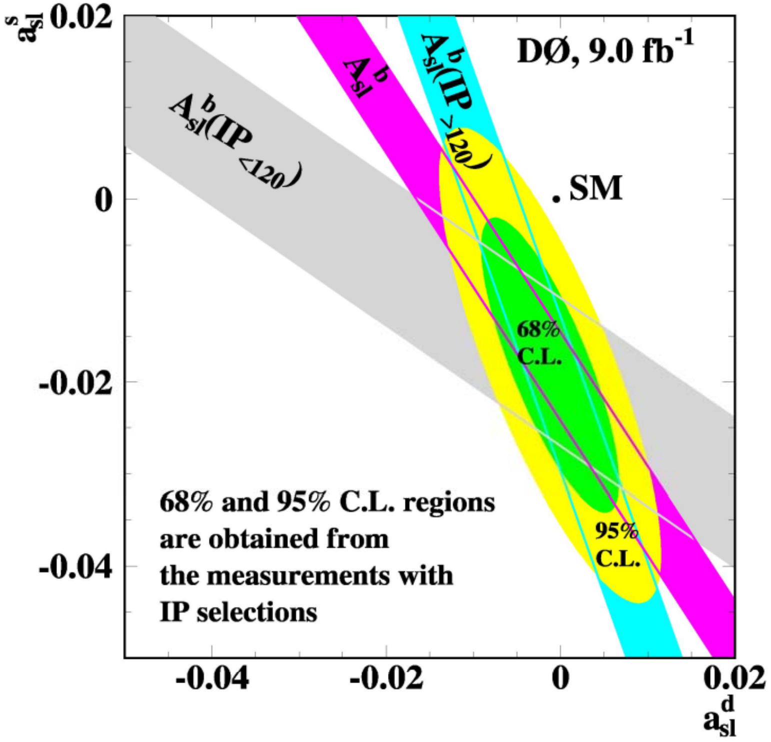
In same-sign dimuon sample, ~30% of muons come from decays of neutral B mesons after mixing.

‘Flavor blind’ – around 50% from B_s^0, 50% from B_d^0;

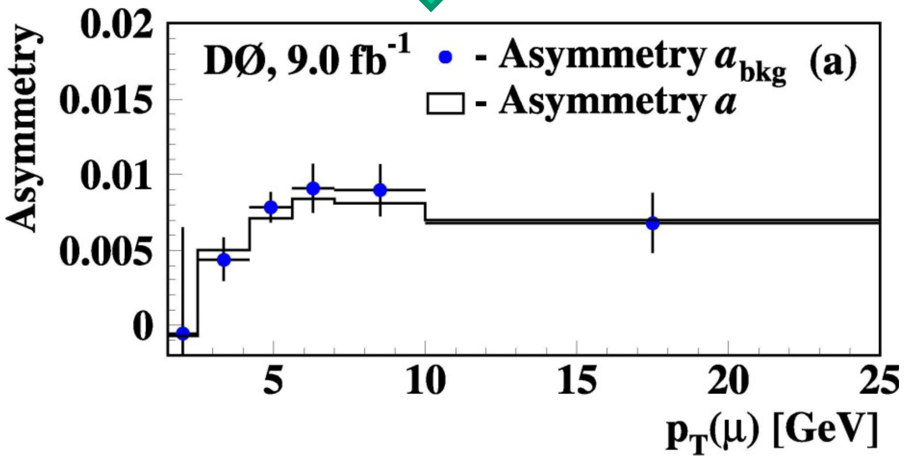
Count events; correct for background asymmetries; correct for dilution from symmetric processes;

Measurement repeated in different IP bins – gives sensitivity to a^d_{sl}, a^s_{sl} separately.

Use background-dominated single muon sample to constrain detector asymmetries and reduce systematic uncertainty.



Asymmetry 3.9σ from SM prediction



PRD 84, 052007 (2011)

Anomalous Like-sign Dimuon Asymmetry

Now working on final paper:

1) Use **full dataset**. Equalise N(μμ) per polarity sample;

2) Use **local muon system variables**; to constrain K/π→μ decay-in-flight fraction;

3) Extend use of **muon impact parameter**. Maximise sensitivity by separating signal and BG dominated regions;

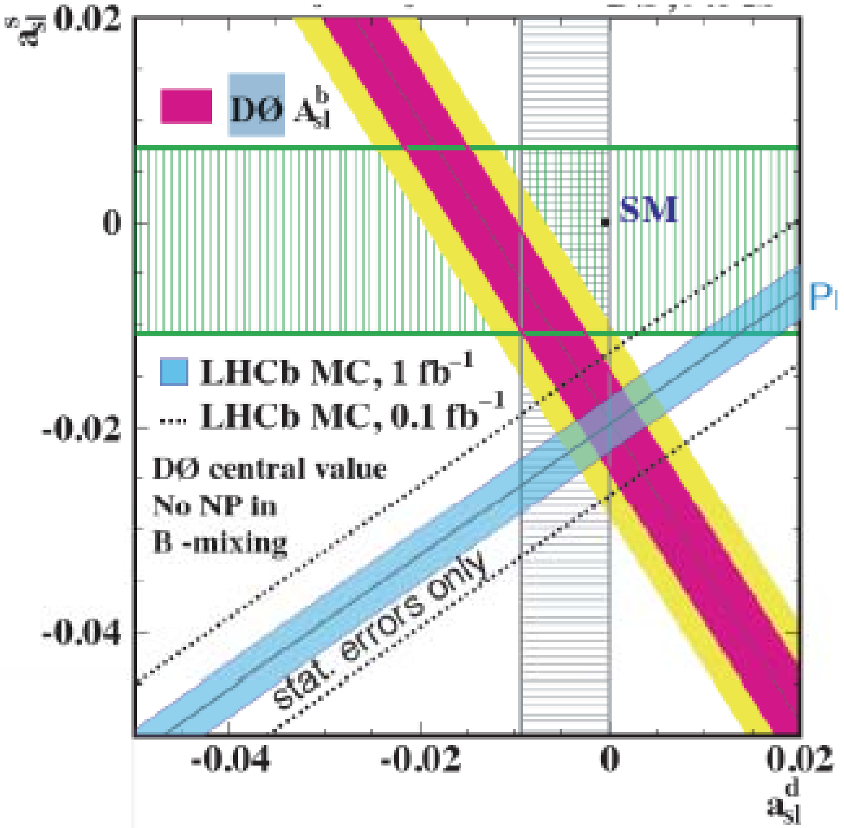
4) Measure **integrated mixing probability χ_0** (probability that a B meson has mixed prior to decay). Validation of many aspects of asymmetry measurement.

Asymmetry is a linear combination semileptonic charge asymmetries of B_d^0 and B_s^0

$$A^b_{sl} = C_d a^d_{sl} + C_s a^s_{sl} \; ; \qquad a^b_{sl} = \frac{\Gamma(\overline{B}\to\mu^+X)-\Gamma(B\to\mu^-X)}{\Gamma(\overline{B}\to\mu^+X)+\Gamma(B\to\mu^-X)}$$

Coefficients depend on mean mixing probability and production fractions

- LHCb starts with CP non-invariant initial state:
  - measure difference between Bd and Bs asymmetries
- LHCb MC sensitivity study with 1 fb^{-1}



Flavor-specific Asymmetries

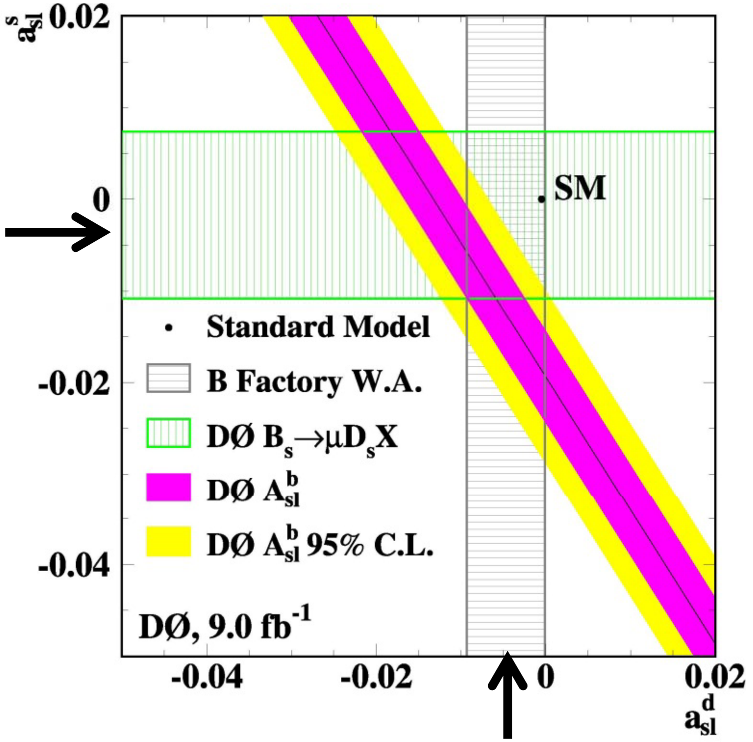
Coming soon…

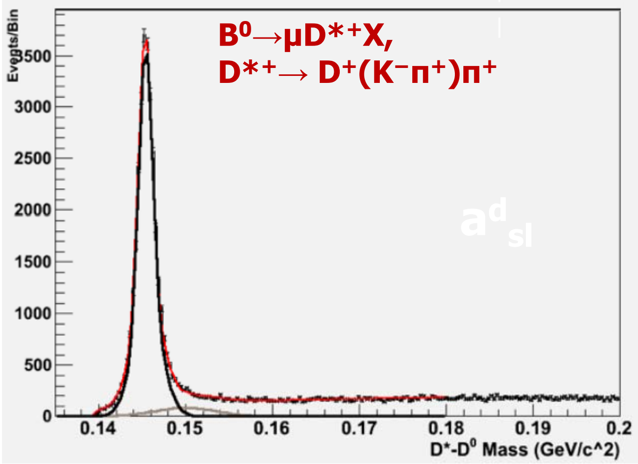
Semi-exclusive decay channels: direct extraction of raw signal asymmetry in B_d^0 and B^0_s decays;

Measure reconstruction asymmetries of final state particles (muons, kaons, pions) – use data driven methods.

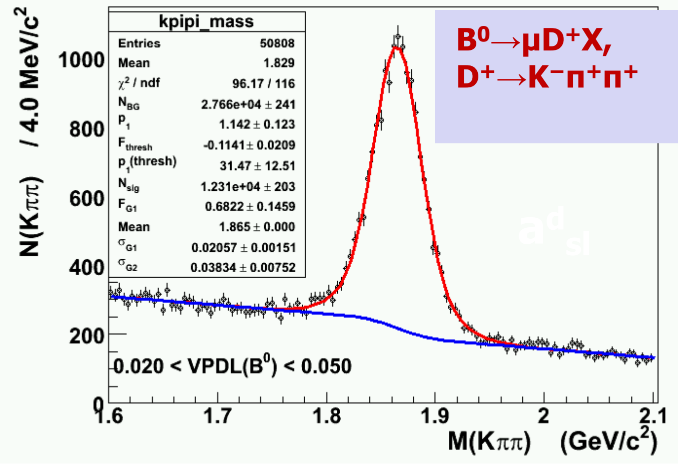
Measure fraction of oscillated mesons using simulation – i.e. account for dilution from charge symmetric processes.

Produce world's best measurements to narrow the constraints in the (a^d_{sl}, a^s_{sl}) plane.





$B^0 \to \mu D^{*+} X$,
$D^{*+} \to D^+(K^- \pi^+)\pi^+$



$B^0 \to \mu D^+ X$,
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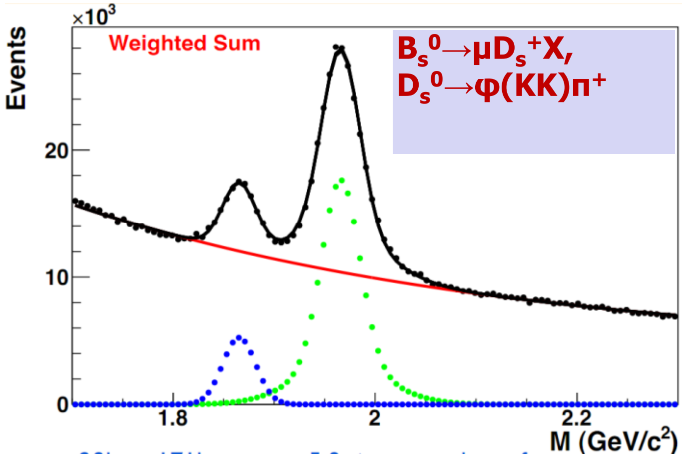
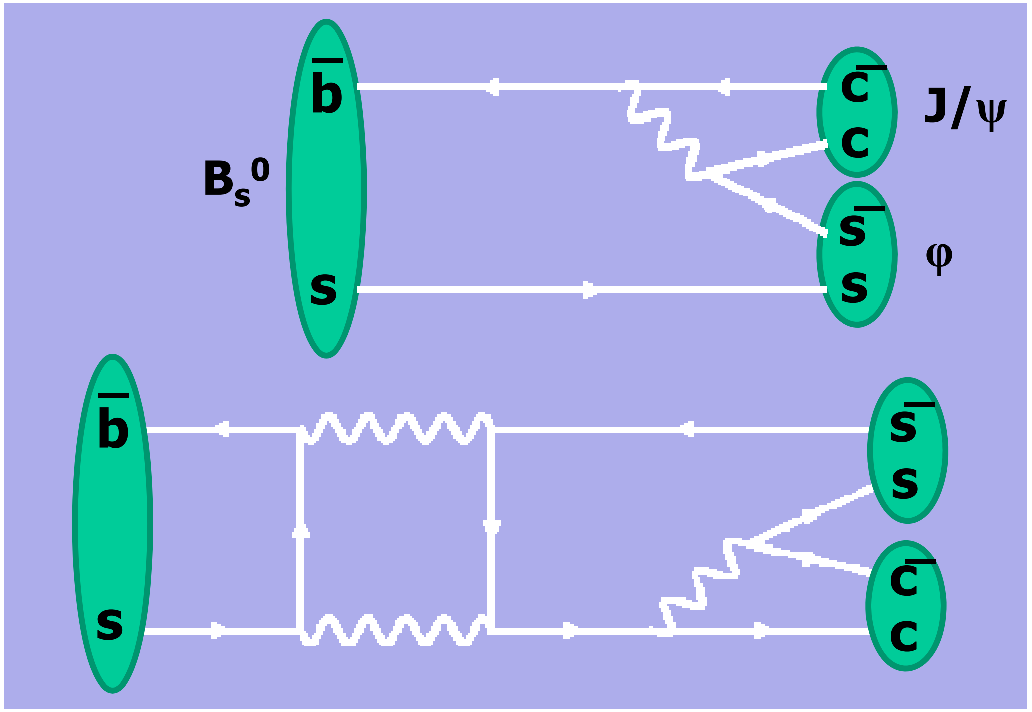


$B_s^0 \to \mu D_s^+ X$,
$D_s^0 \to \varphi(KK)\pi^+$

CP Violation in $B_s^0 \to J/\psi\varphi$

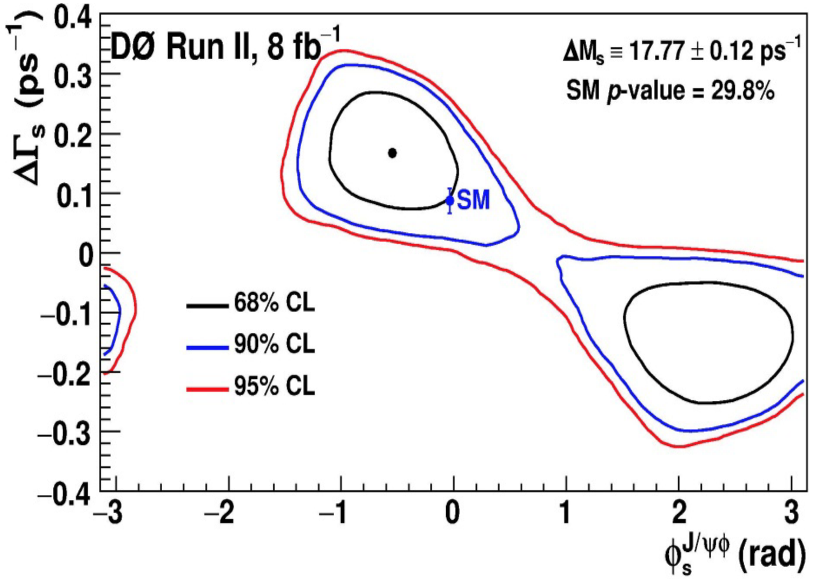


Same final states in ‘mixed’ and ‘direct’ decay ⇒ interference between diagrams;

CPV arises from overall complex phase $\varphi_s^{J/\psi\varphi}$

If NP enhancements present: $\varphi_s^{J/\psi\varphi} \approx \varphi_s$

Extract physical parameters including $\varphi_s^{J/\psi\varphi}$, **$\Delta\Gamma_s$, $\tau(B_s^0)$**, in lifetime-dependent angular fit, including flavor tagging.



arXiv:1109.3166 [hep-ex]
Submitted to Phys. Rev. D

Final iteration of this interesting analysis at D0.

Now working on combination paper with CDF.

CP Violation in $B_s^0 \rightarrow J/\psi\varphi$

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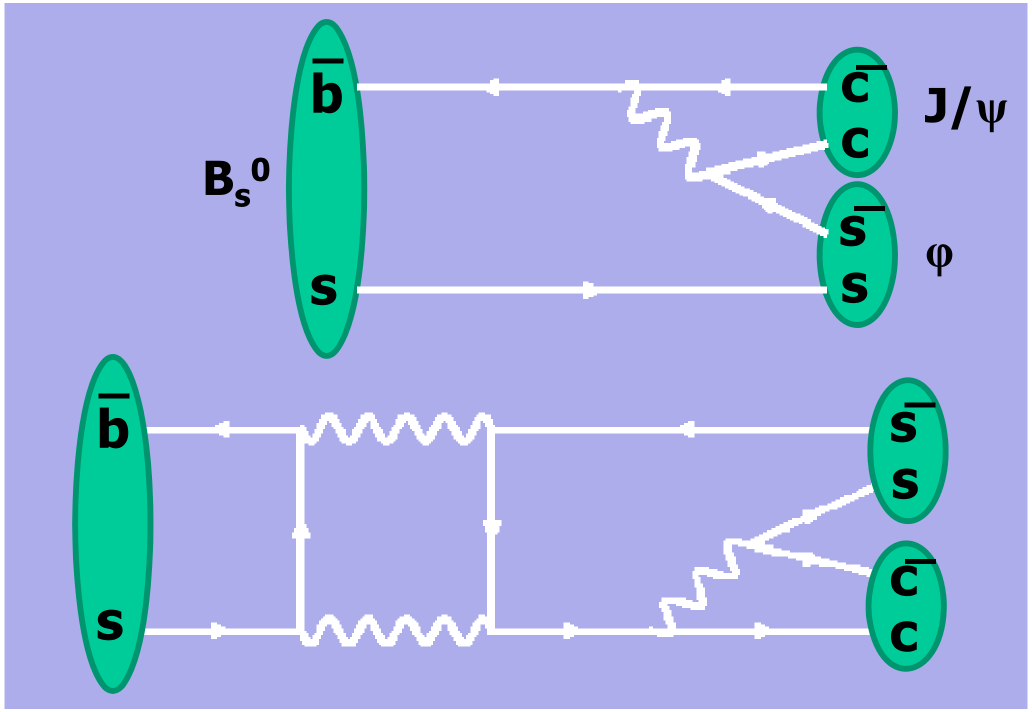

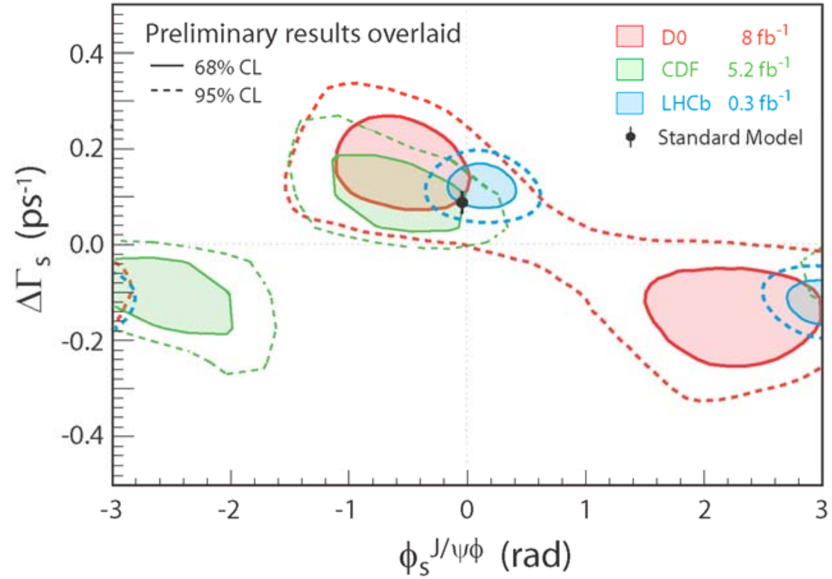

arXiv:1109.3166 [hep-ex]
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QCD & Electroweak

Three Main Motivations in SM measurements

Test best available theory predictions

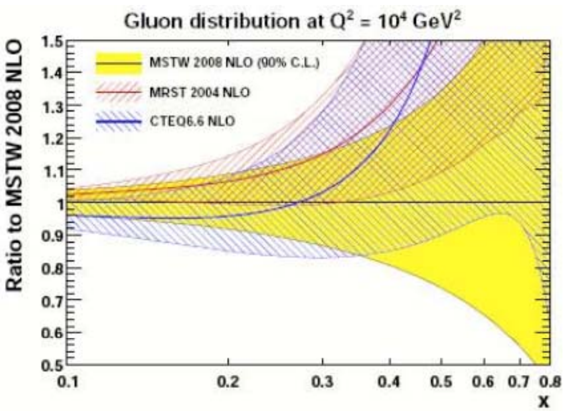
- Explore new kinematic regimes
- provide important inputs to PDFs

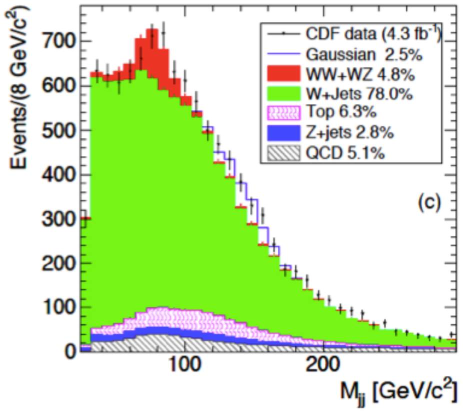
Search for New Physics

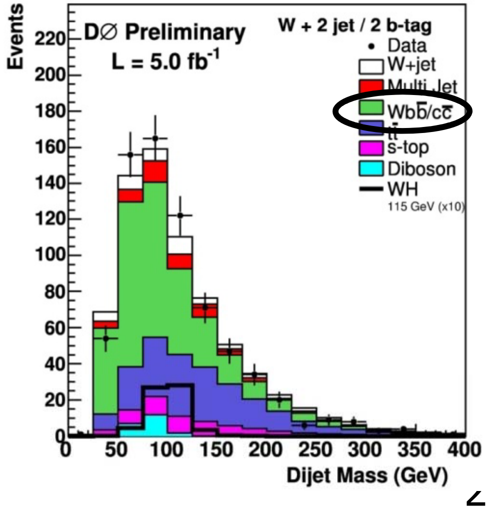
- anomalous cross sections
- resonances can show up in jets too!
- use SM as a guide

Measure important backgrounds to New Physics

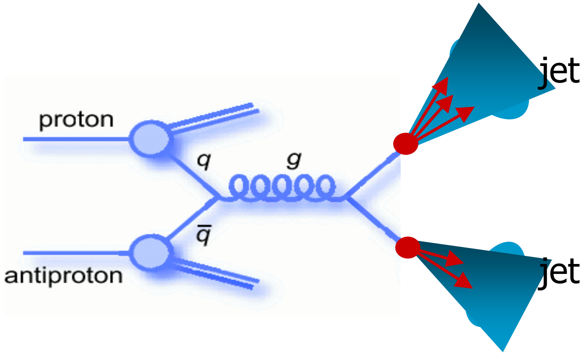
- N(N)LO predictions not available for many processes of interest, particularly those with large jet multiplicities and heavy flavor components => data measurements crucial
- New Physics share signatures with irreducible backgrounds that are currently being pinned down.
- Interplay between fragmentation models, tunes, PDFs and scale choices needs to be understood to model SM backgrounds



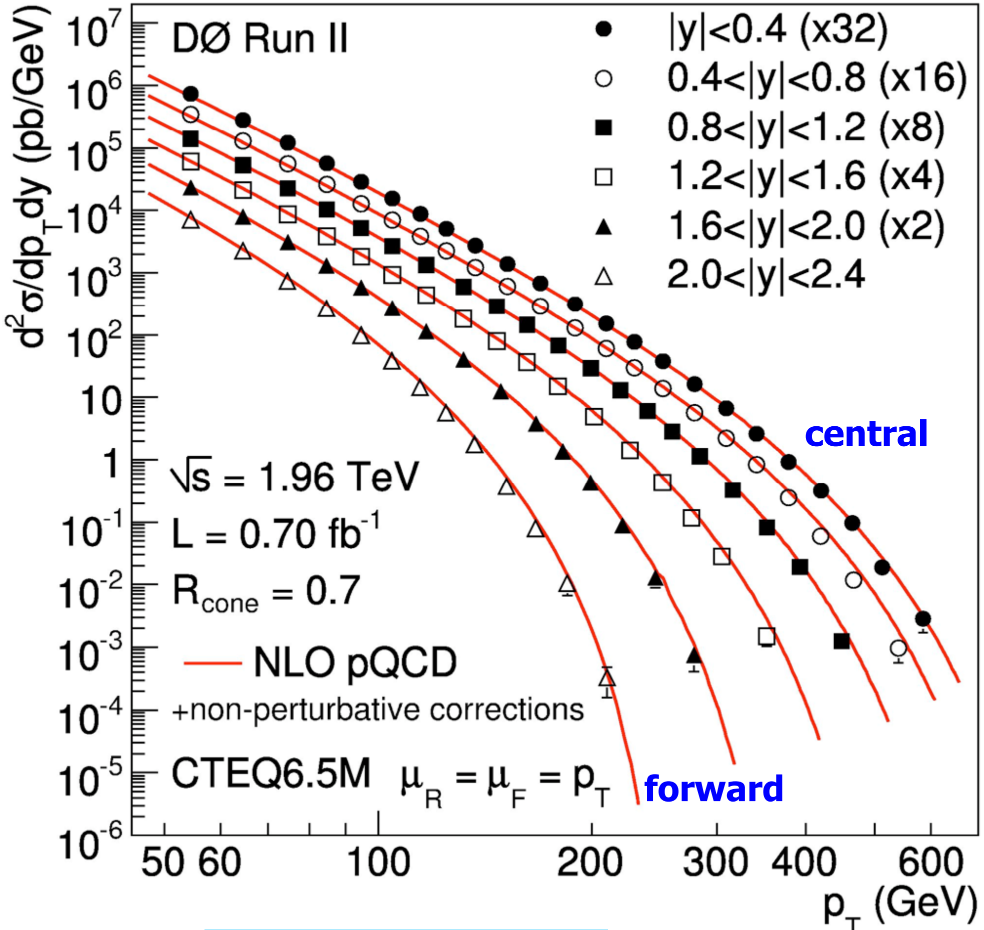




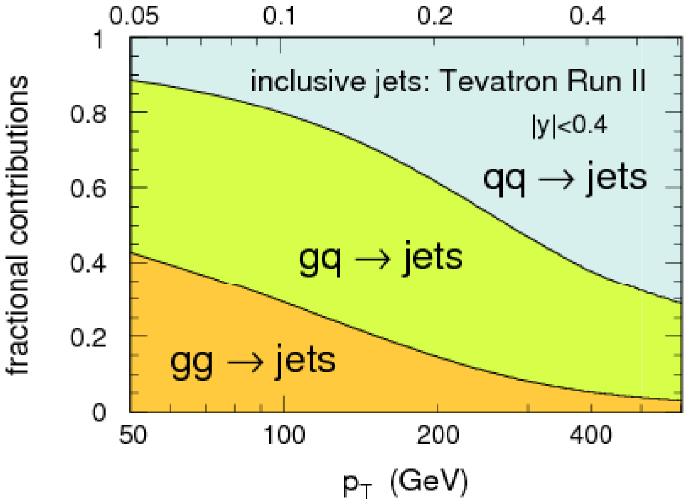
Inclusive Jets



Sensitive to gluon content of the proton



PRL 101, 062001 (2008)



NLO theory is accurate to ~10%
(in the absence of new physics)

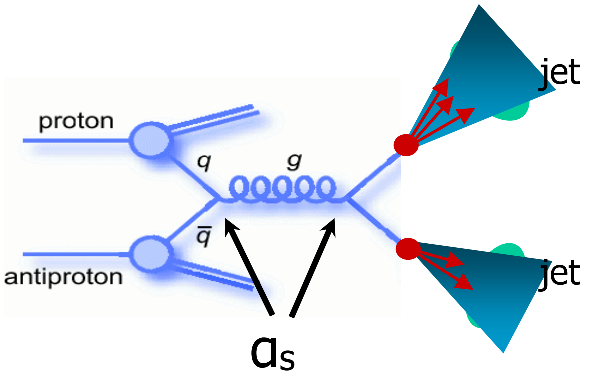
steeply falling p_T spectrum:

- 1% error in jet energy calibration
- 5-10% (10-25%) error in central (forward) x-section

benefit from:

- high luminosity in Run II
- increased Run II cm energy → high p_T
- hard work on jet energy calibration

α_s extraction

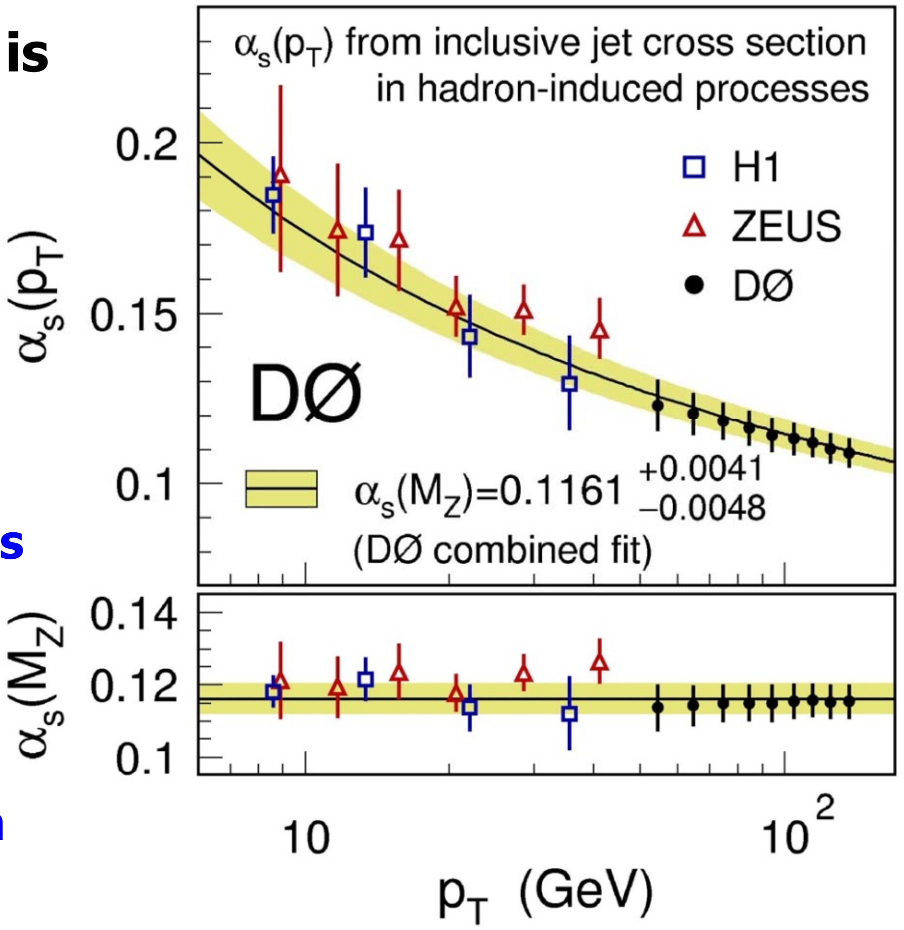


Inclusive Jet Cross Section is sensitive to α_s

$$\sigma_{\text{pert}}(\alpha_s) = \left(\sum_n \alpha_s^n c_n\right) \otimes f_1(\alpha_s) \otimes f_2(\alpha_s)$$

The coupling strength, α_s, is scale dependent: $\alpha_s(\mu_R)$ Renormalization Group Equation predicts μ_R-dependence

Extract α_s from 22 (out of 110) inclusive jet cross section data points at $50<p_T<145$ GeV
→ Exclude data points with large influence on PDF set



- **NLO + 2-loop threshold corrections**
- **MSTW2008NNLO PDFs**
- **Extends results from HERA to high p_T**

precise α_s measurement:

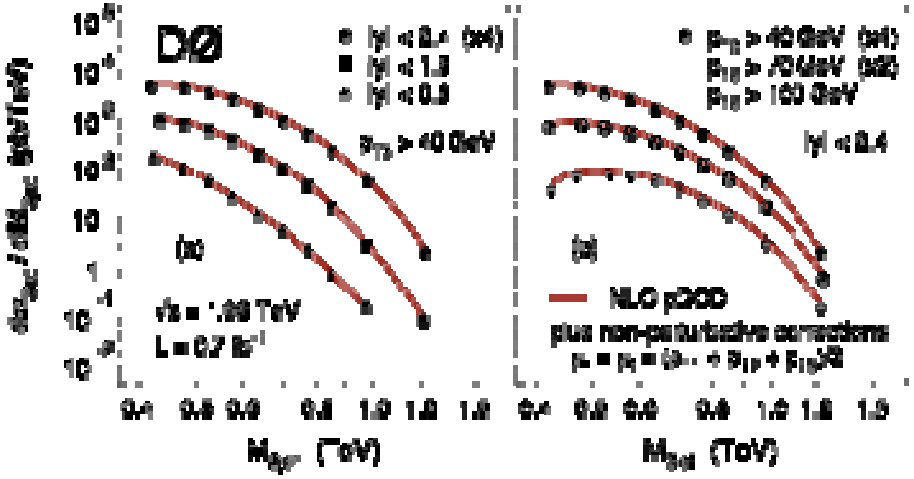
$$\alpha_s(M_Z) = 0.1161^{+0.0041}_{-0.0048}$$

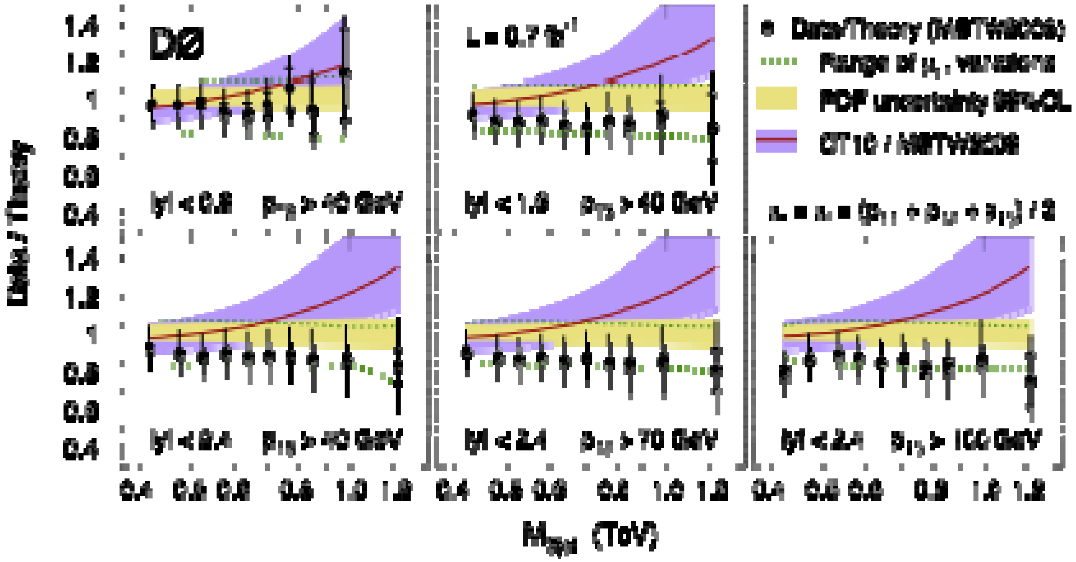
Trijets and R3/2

- Tests of pQCD at high jet multiplicity
- Additional opportunities to extract αs (future)

σ(3jet)/σ(2jet)

3-jet mass





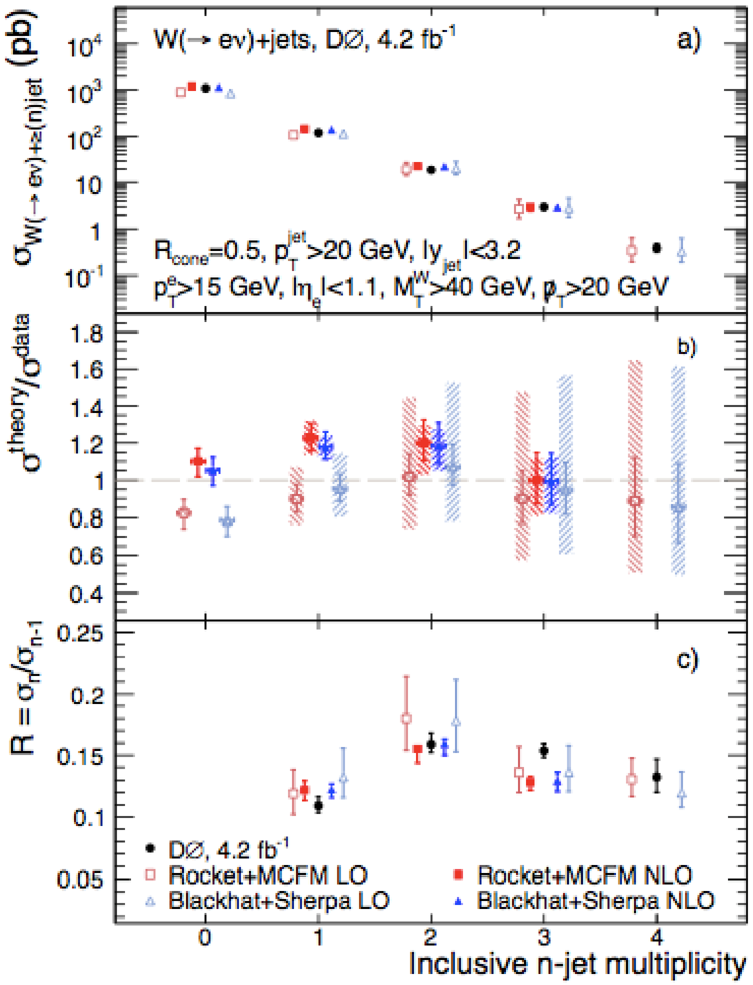
Differential cross sections measurements:

- data are corrected to particle level
- particle level measurements are compared to NLO theory
- NLO theory is corrected to particle level using parton shower MC

W→ eν+jets

Precise measurements of W+(n)jet (n=1,2,3,4) inclusive cross sections and differentially as function of n^{th} jet p_T

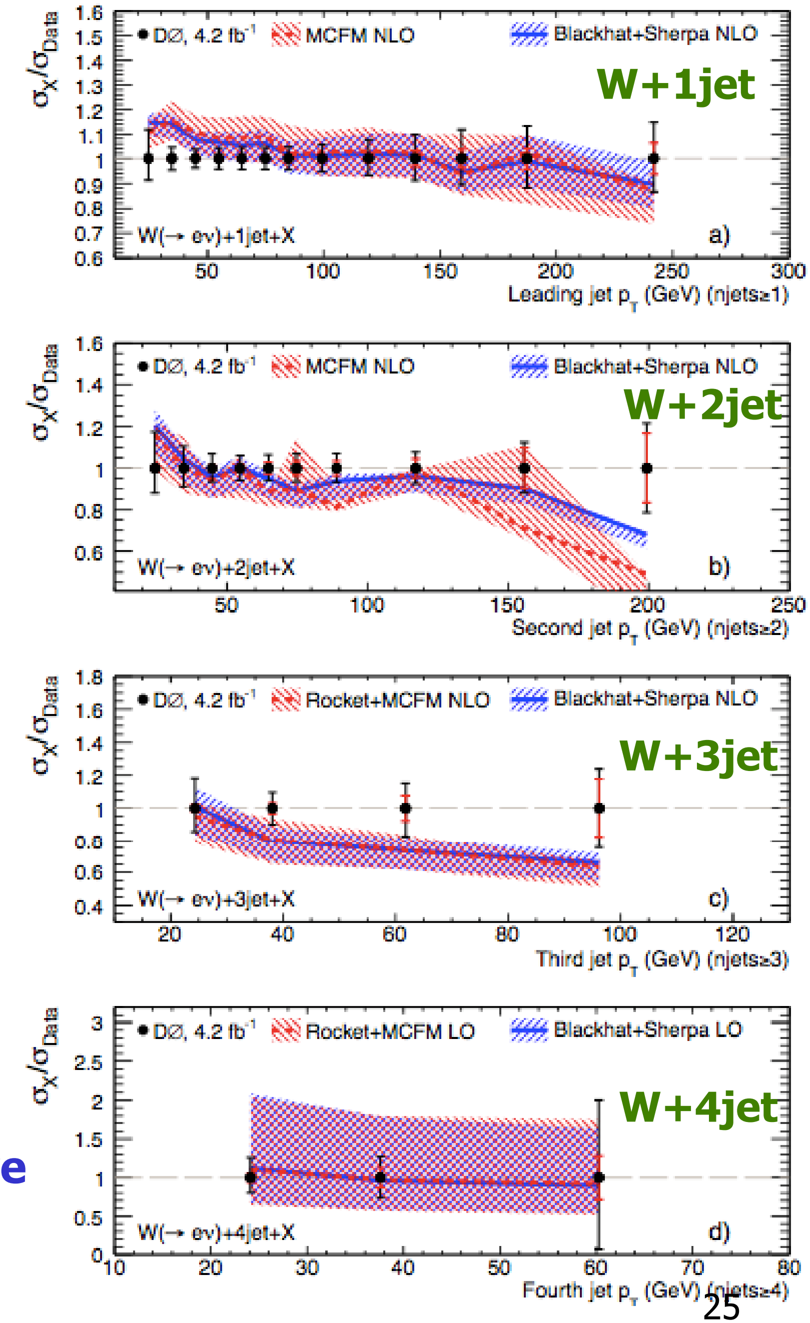
Small data uncertainties allow detailed study of NLO theory



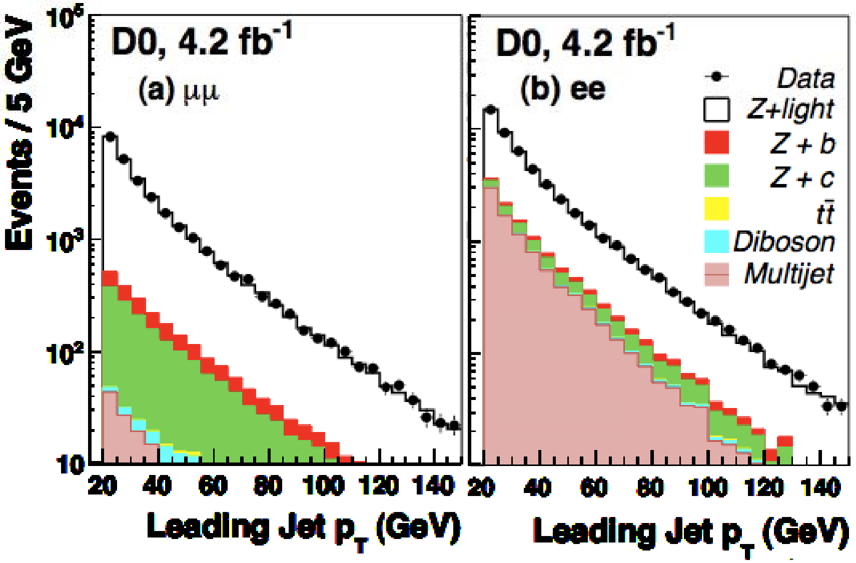
Data compared to two indep. NLO implementations
- led to bug fixes in MCFM

Differences in NLO theory attributed to choice of scale

PRD in preparation with comprehensive set of observables



Z+b jets



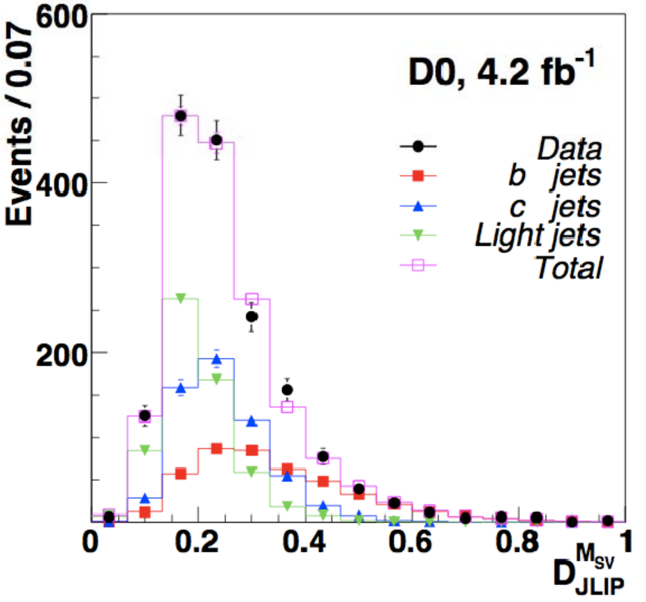
Interesting test of pQCD predictions and b-quark fragmentation.

Important background to the SM Higgs search in the ZH(→bb) channel.

Probe of b-quark parton distribution function

σ(Z+b) / σ(Z+j) benefits from cancellations of many systematic uncertainties
⇒ precise comparison with theory

Z+b/Z+jet = .0193 ± .0022(stat) ± .0015 (syst)
-- in agreement with NLO pQCD
(which has 20-25% scale uncertainty)



γ+b differential cross section vs p_T also in agreement with NLO

new W+b and updated W+c, Z+b, γ+b, γ+c measurements in preparation

Inclusive W and Z

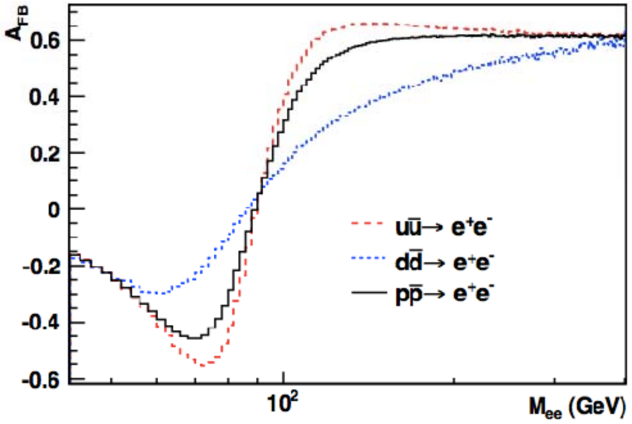
Z/γ* Forward-Backward Asymmetry

$A_{FB} = (\sigma_F - \sigma_B)/(\sigma_F + \sigma_B)$ where σ_F (σ_B) is $\theta>0$ ($\theta<0$)

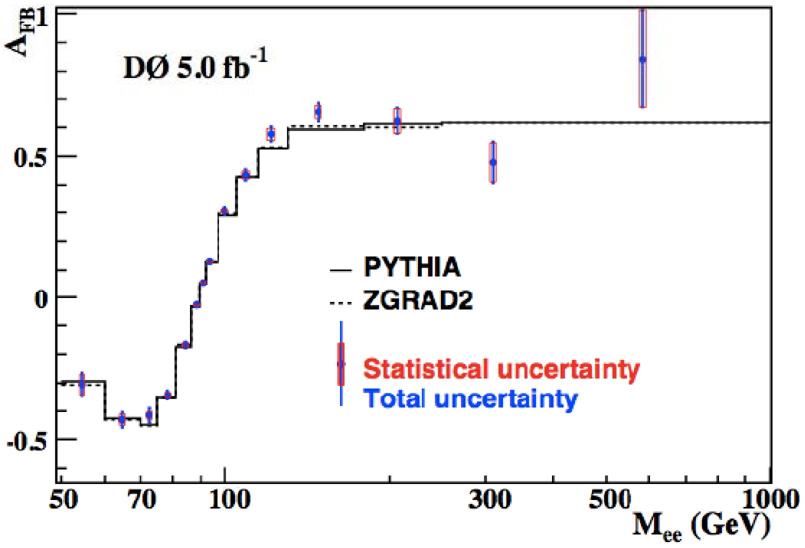
Interference between Z and γ* diagrams leads to an enhanced symmetry away from Z pole

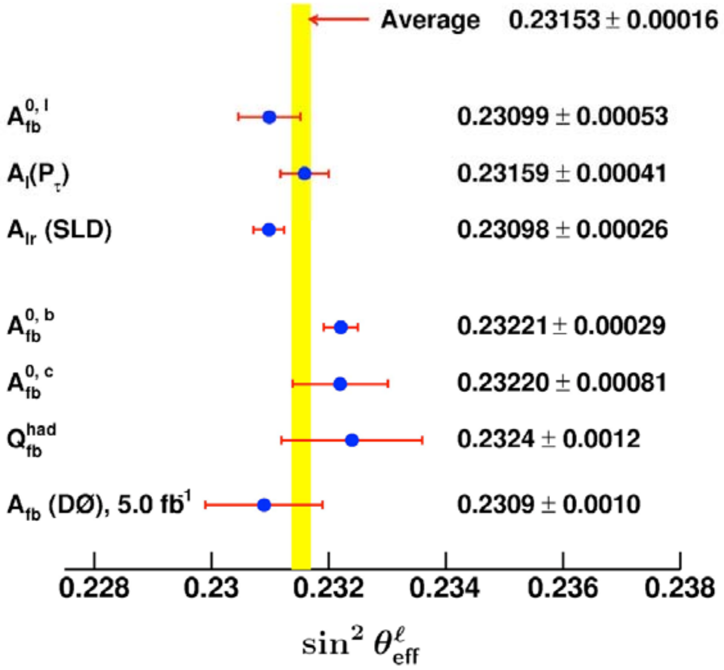
-- high mass dominated by Z - γ* interference

-- near the Z pole, sensitive to **$\sin^2\theta_{eff}$**



Extraction of effective weak mixing angle:
$\sin^2\theta_{eff}$ = .2309 ± .0008 (stat) + .0006 (syst)
- agrees well with world average





Z/γ* Forward-Backward Asymmetry

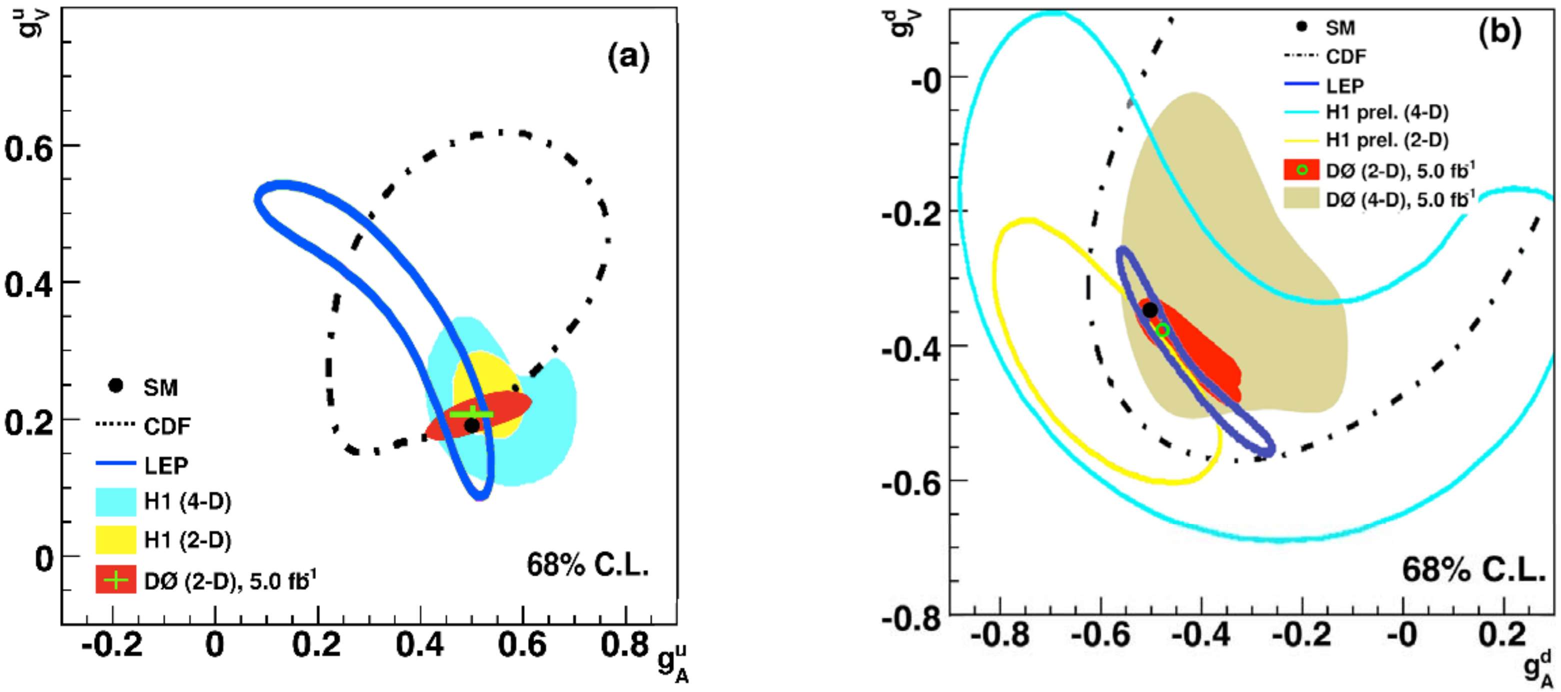
$A_{FB} = (\sigma_F - \sigma_B)/(\sigma_F + \sigma_B)$ where σ_F (σ_B) is $\theta>0$ ($\theta<0$)

A_{FB} sensitive to couplings of the light quarks to the Z

most precise measurements of these light quark couplings to the Z to date!

2-D and 4-D fits are made to u, d vector and axial vector couplings to Z

68% confidence level contours of g_V^u, g_A^u and g_V^d , g_A^d compared to other experiments

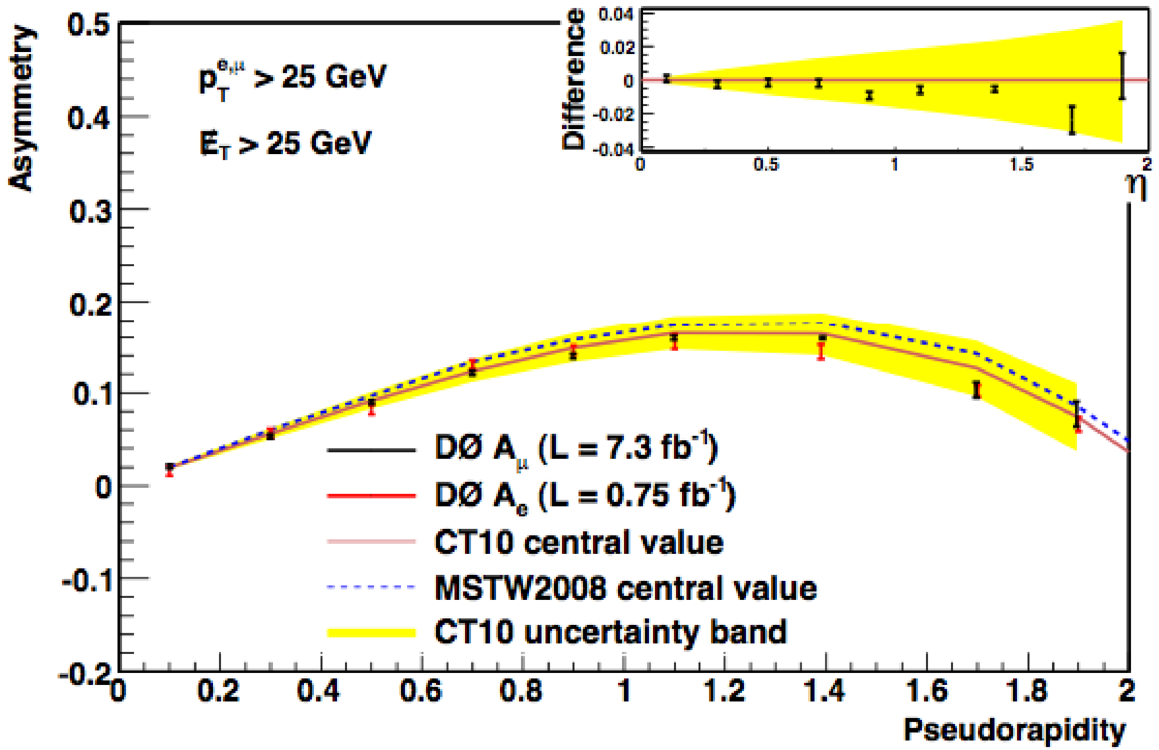


Lepton Charge Asymmetry in W→lν

$$A(\eta) = \frac{d\sigma(\mu^+)/d\eta - d\sigma(\mu^-)/d\eta}{d\sigma(\mu^+)/d\eta + d\sigma(\mu^-)/d\eta}$$

Lepton asymmetry is convolution of W boson asymmetry and asymmetry from (V-A) nature of W boson decay

Precise measurement provides important PDF inputs



Data precision better than PDFs

Excellent agreement between electron and muon channels

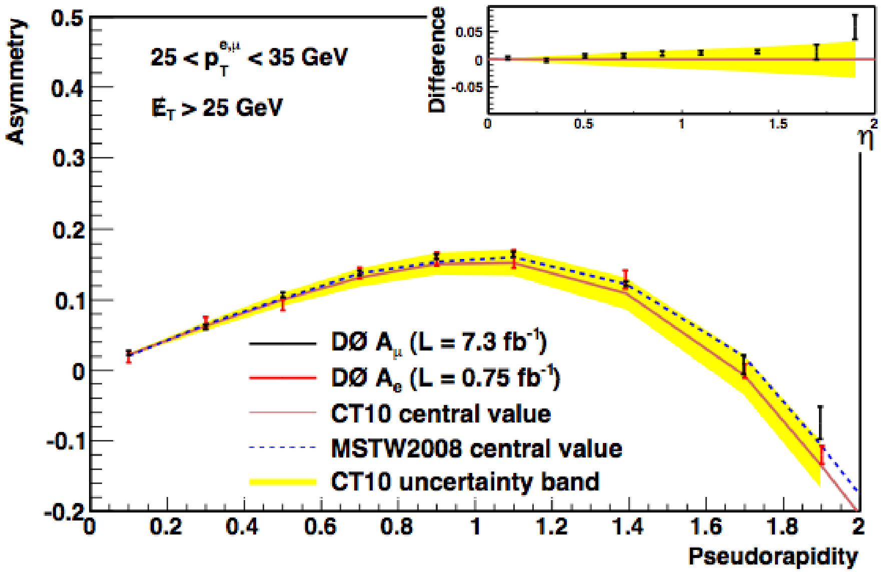
Lepton Charge Asymmetry in W→lν

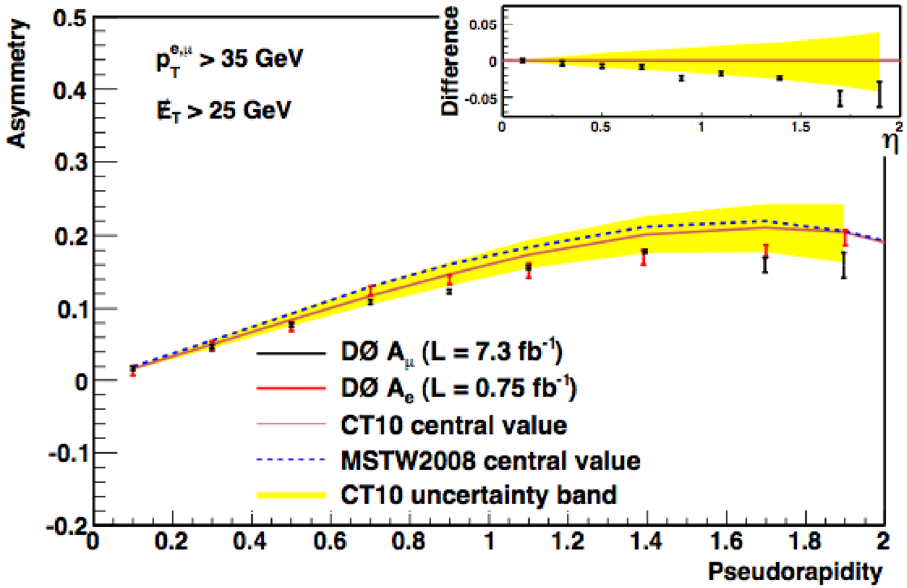
$$A(\eta) = \frac{d\sigma(\mu^+)/d\eta - d\sigma(\mu^-)/d\eta}{d\sigma(\mu^+)/d\eta + d\sigma(\mu^-)/d\eta}$$

Lepton asymmetry is convolution of W boson asymmetry and asymmetry from (V-A) nature of W boson decay

Precise measurement provides important PDF inputs

Two bins of lepton E_T probe different regions of W rapidity → finer probe of x-dependence

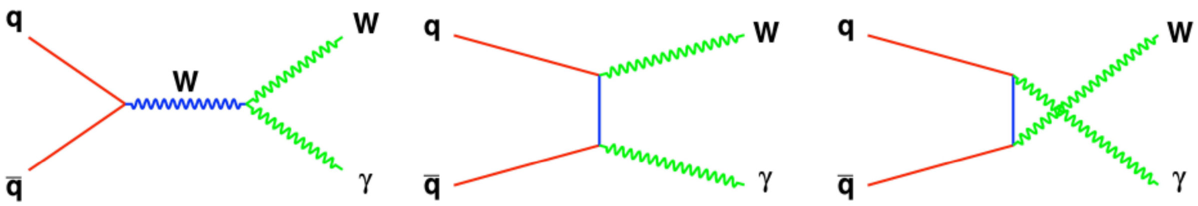




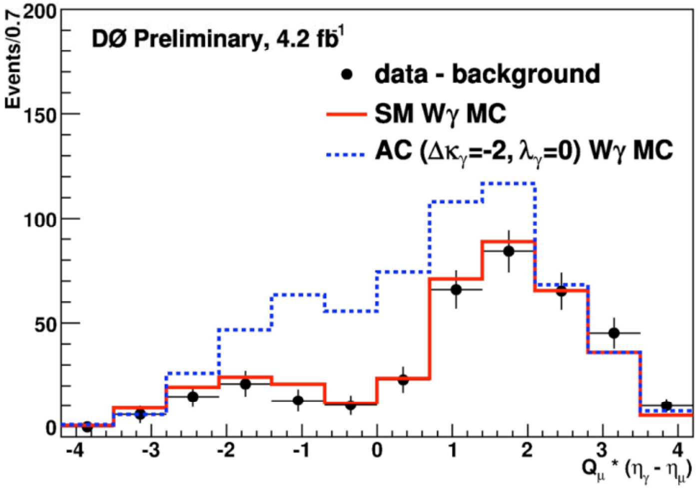
Dibosons

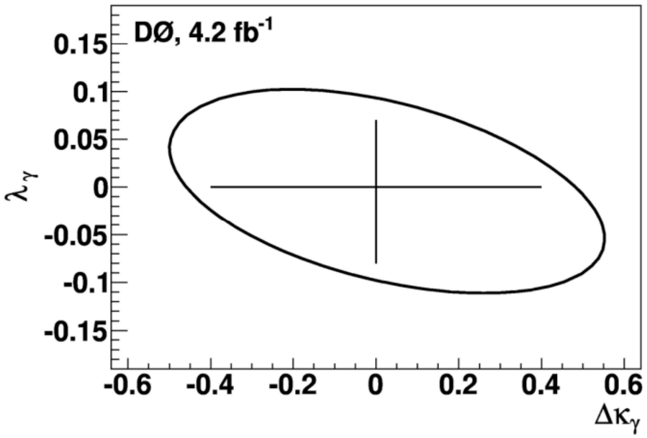
Dibosons - Wγ

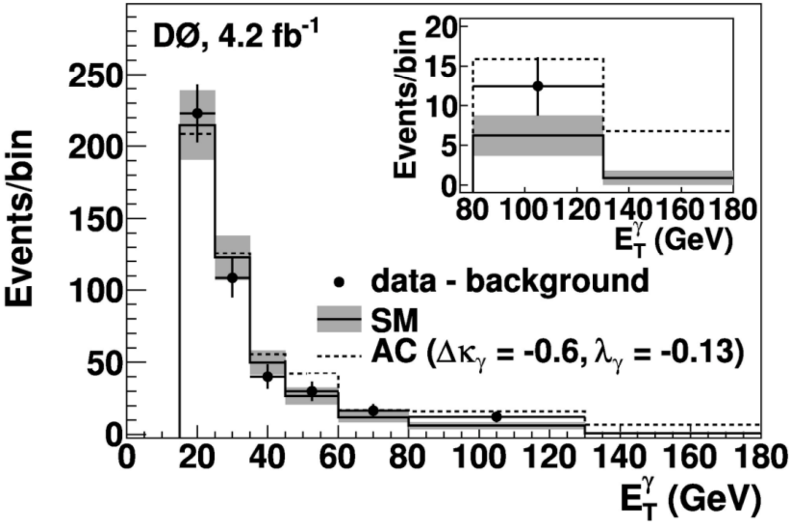
Wγ



- search for radiation amplitude zero (RAZ)
- seen as a dip in signed γ-l rapidity difference
- look for anomalous couplings







Results are in agreement with SM prediction, and we produce some of the best AC limits at hadron collider to date!

Submitted to PRL arXiv:1109.4432

Dibosons - WW, WZ, ZZ

Large dataset allows us to measure processes with σ as low as~ 1pb

- **100 leptonic WW events in 1.1 fb-1**

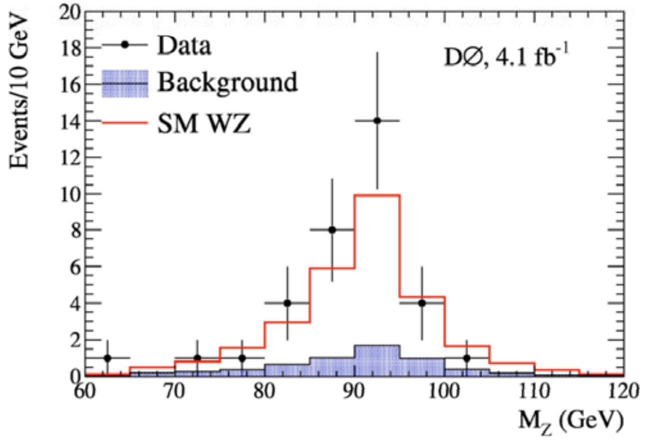
$$\sigma(p\bar{p} \to WW) = 11.5 \pm 2.1(syst + stat) \pm 0.7(lumi)$$

- **34 leptonic WZ events in 4.1 fb-1**

$$\sigma(p\bar{p} \to WZ) = 3.9^{+1.06}_{-0.9}\ pb$$

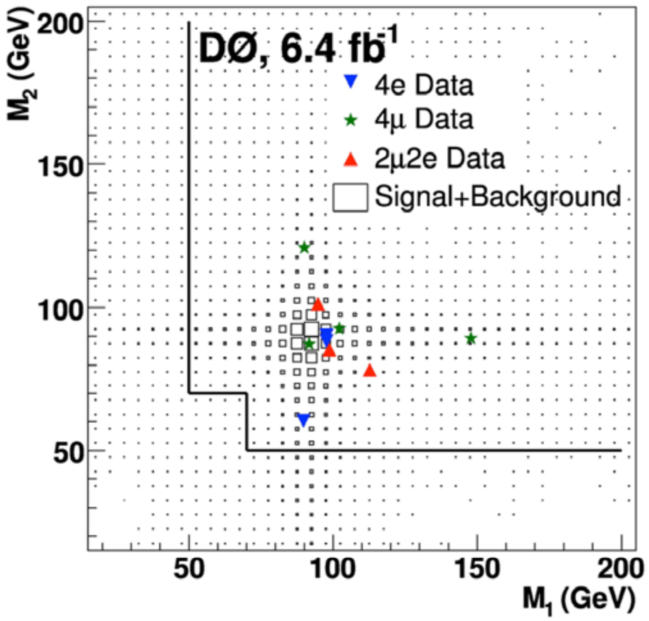
- **10 leptonic ZZ events in 6.4 fb-1**

$$\sigma(p\bar{p} \to ZZ) = 1.45^{+0.53}_{-0.43}\ pb$$



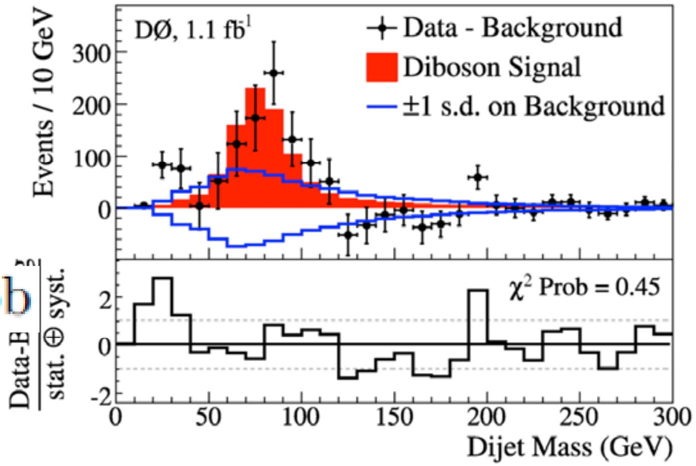
All in agreement with SM, stringent AC limits set

Coupling relation	95% C.L. Limit
$\Delta g_1^Z = \Delta\kappa_Z = 0$	$-0.075 < \lambda_Z < 0.093$
$\lambda_Z = \Delta\kappa_Z = 0$	$-0.053 < \Delta g_1^Z < 0.156$
$\lambda_Z = \Delta g_1^Z = 0$	$-0.376 < \Delta\kappa_Z < 0.686$
$\Delta\kappa_Z = 0$ (HISZ)	$-0.075 < \lambda_Z < 0.093$
$\lambda_Z = 0$ (HISZ)	$-0.027 < \Delta\kappa_Z < 0.080$



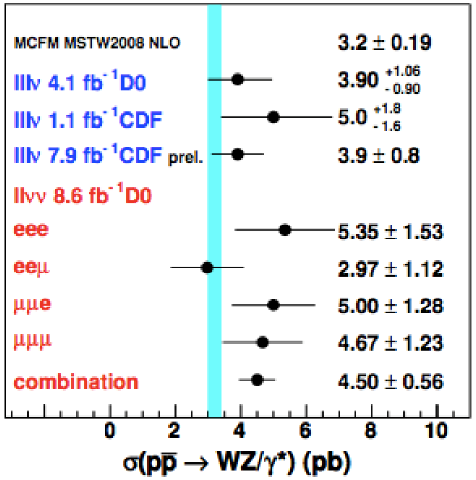
First evidence (4.2σ) for WV→lνjj at the Tevatron

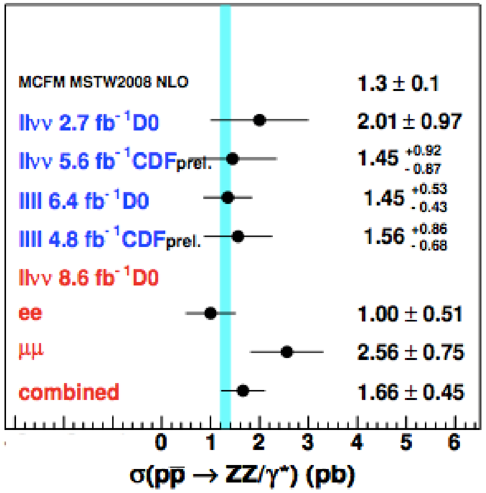
$$\sigma(WV) = 20.2 \pm 4.5\ \text{pb}$$



Dibosons - WZ, ZZ

Fully leptonic final state





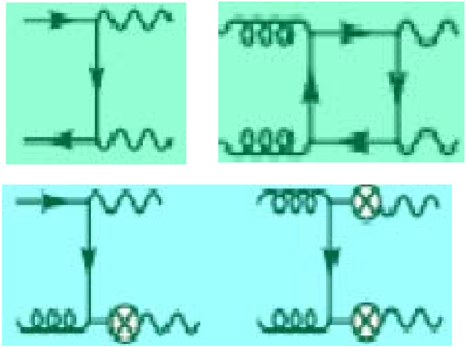
Updated measurement uses 8.6 fb^{-1}

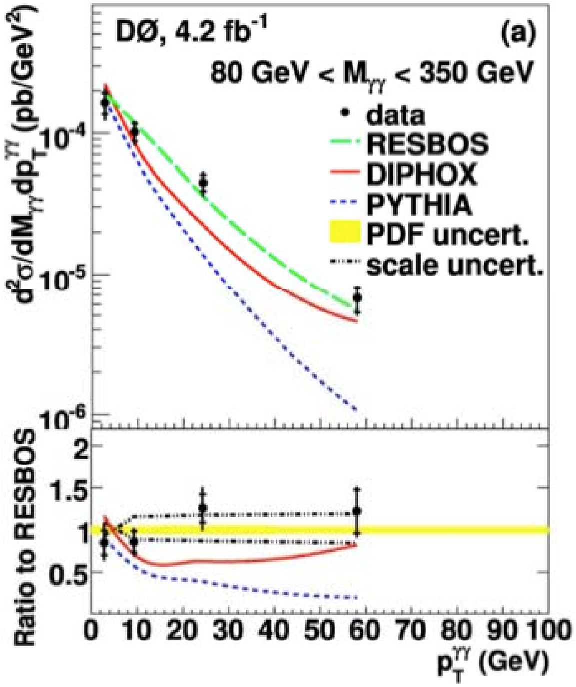
Lepton + jets final state

work in progress!

Prompt Diphoton Production

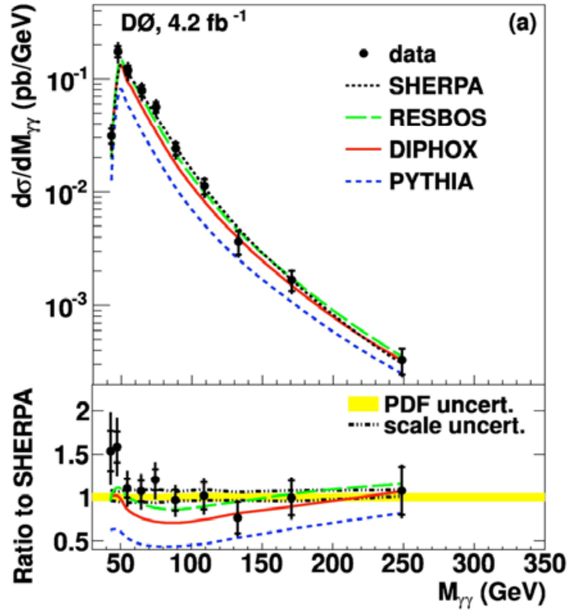
- Prompt diphotons are produced directly in hard scattering or through quark fragmentation
- sensitive to energy scale, ISR, fragmentation, PDFs





H->γγ currently main channel for SM Higgs discovery at low mass at LHC

Theory predictions:
PYTHIA: Parton Shower
DIPHOX: fixed order NLO calculation
RESBOS: Resummed calculation (to NNLL)



In region where SM Higgs and New Physics is of most interest, RESBOS gives excellent data description

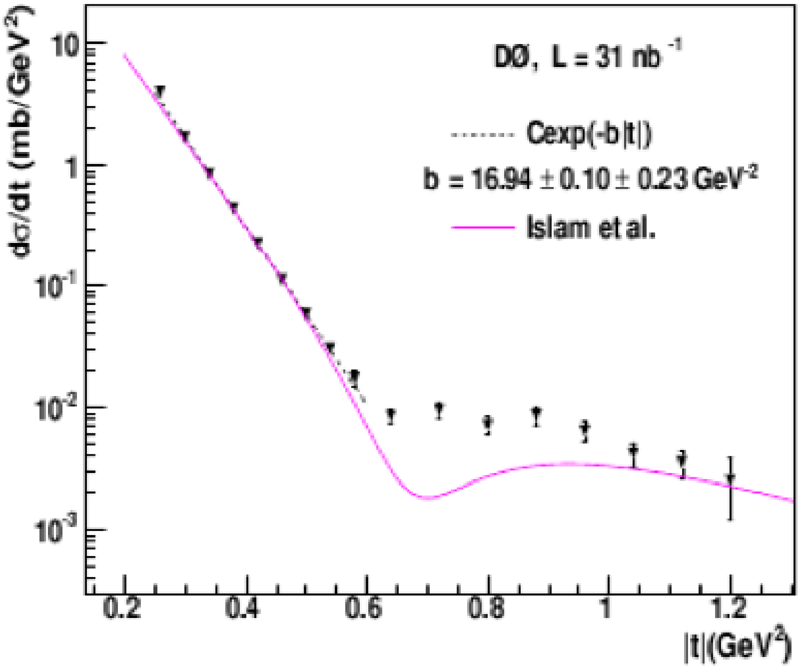
Data is not described at lowest diphoton masses

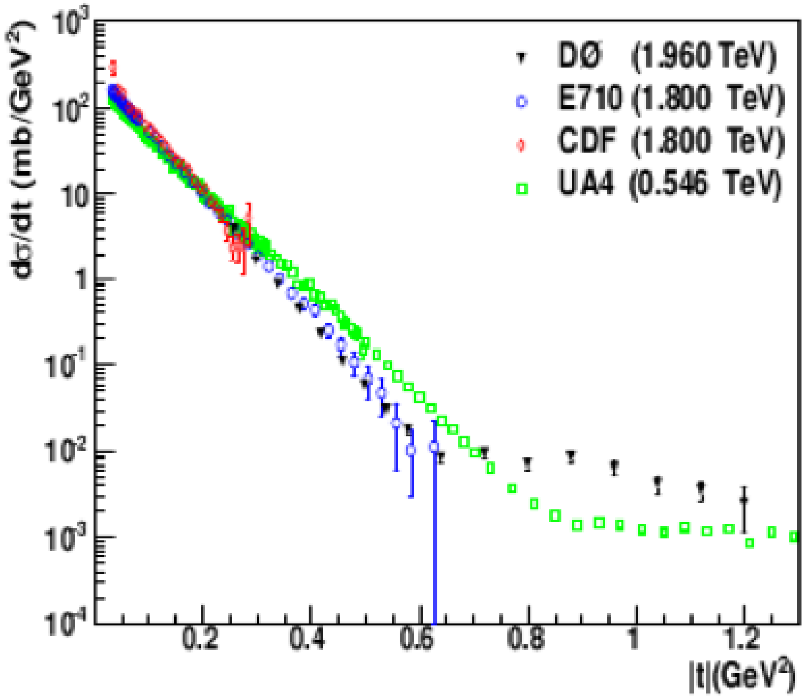
Phys. Lett. B **690**, 108 (2010), arXiv.org:1002.4917

Diffraction and Elastic Scattering

Total Elastic Cross Section

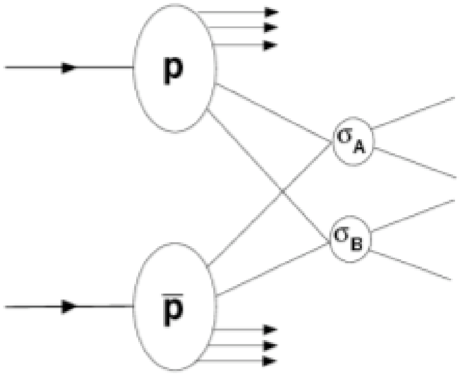
- Fundamental measurement of dσ/dt   t = 4-momentum transfer
- Gives information on nucleon structure, non-perturbative effects
- First measurement using FPD, data taken in special runs
- Compare to phenomenological models, other experiments





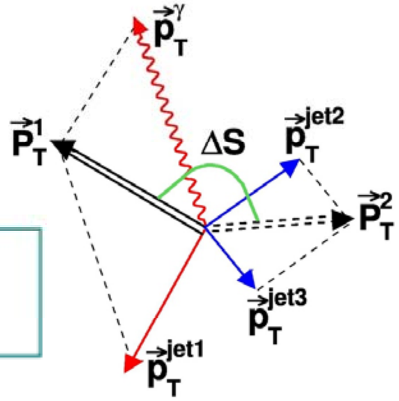
Double Parton Interactions

Look for two hard scatters
in same p-pbar interaction



✦ **Provides complementary information on proton structure**
✦ **May be important background for high-p_T searches**

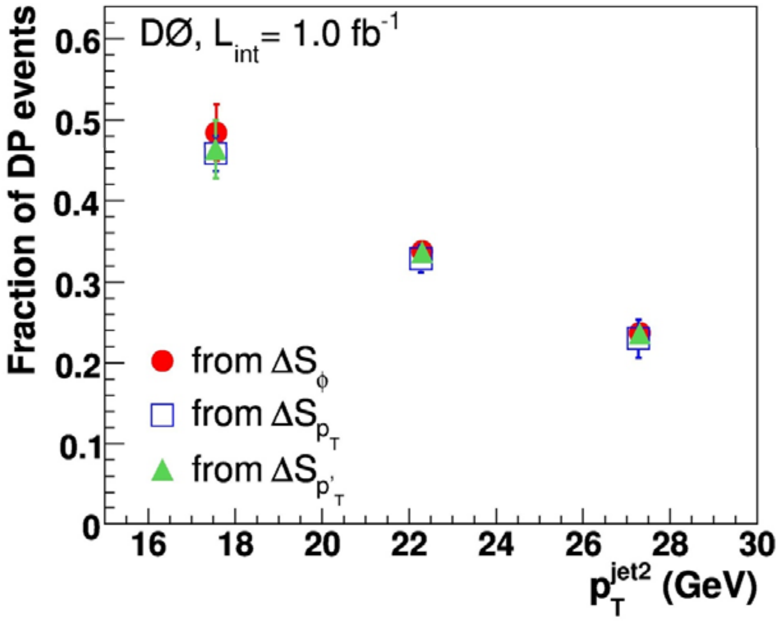
Uses γ + 3 jet topology



Discriminant:

$$\Delta S = \Delta\phi\left(\vec{p}_T^{\,\gamma,jet_i},\ \vec{p}_T^{\,jet_j,jet_k}\right)$$

Δφ - an azimuthal angle between
two best pT-balanced pairs.



DP Updates in the works:
- unfolding distributions
- triple parton interactions
- γ + b + 2 jets topology
- parton x correlations

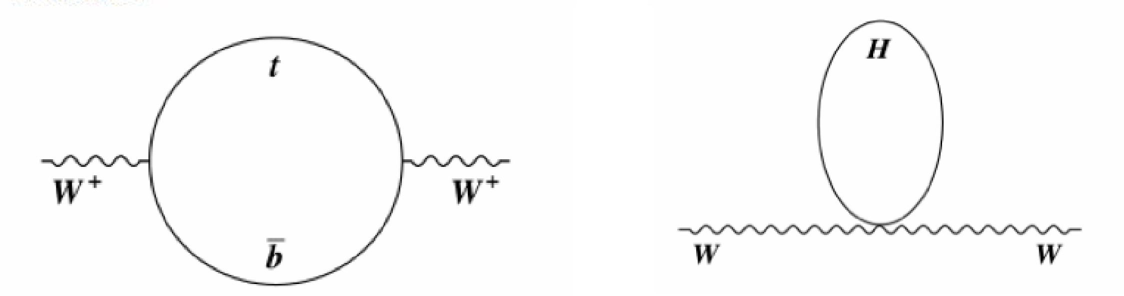
➡ provides information for building optimal MPI model

W mass

W mass is a key parameter in the Standard Model. This model does not predict the value of the W mass, but it predicts this relation between the W mass and other experimental observables:

$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}}\frac{1}{\sin\theta_W\sqrt{1-\Delta r}}$$

Radiative corrections (Δ r) depend on M_t as $\sim M_t^2$ and on M_H as $\sim\log M_H$. They include diagrams like these:

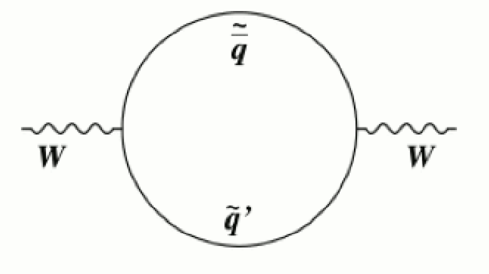


Precise measurements of M_W and M_t constrain SM Higgs mass.

For equal contribution to the Higgs mass uncertainty need:
$\Delta M_W \approx 0.006\ \Delta M_t$.

The limiting factor here will be ΔM_W, not ΔM_t !

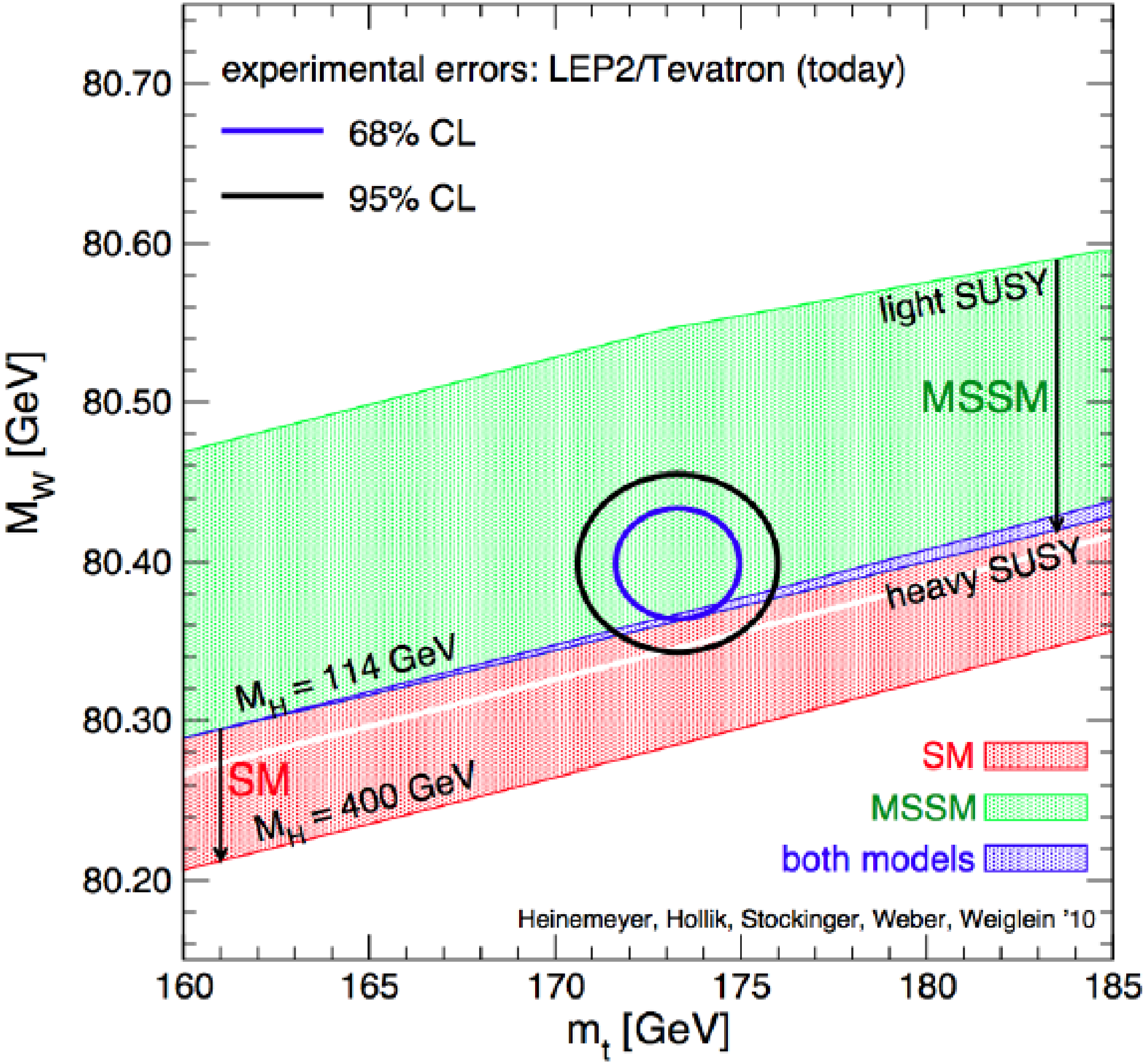
Additional contributions to Δr arise in various extensions to the Standard Model, *e.g.* in SUSY:



W mass

$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}}\,\frac{1}{\sin\theta_W\sqrt{1-\Delta r}}$$

(Δ r) depend on M_t as ~M_t^2 and on M_H as ~log M_H



Heinemeyer, Hollik, Stockinger, Weber, Weiglein '10

For equal contribution to the Higgs mass uncertainty need:

$\Delta M_W \approx 0.006\ \Delta M_t$.

Current Tevatron average:

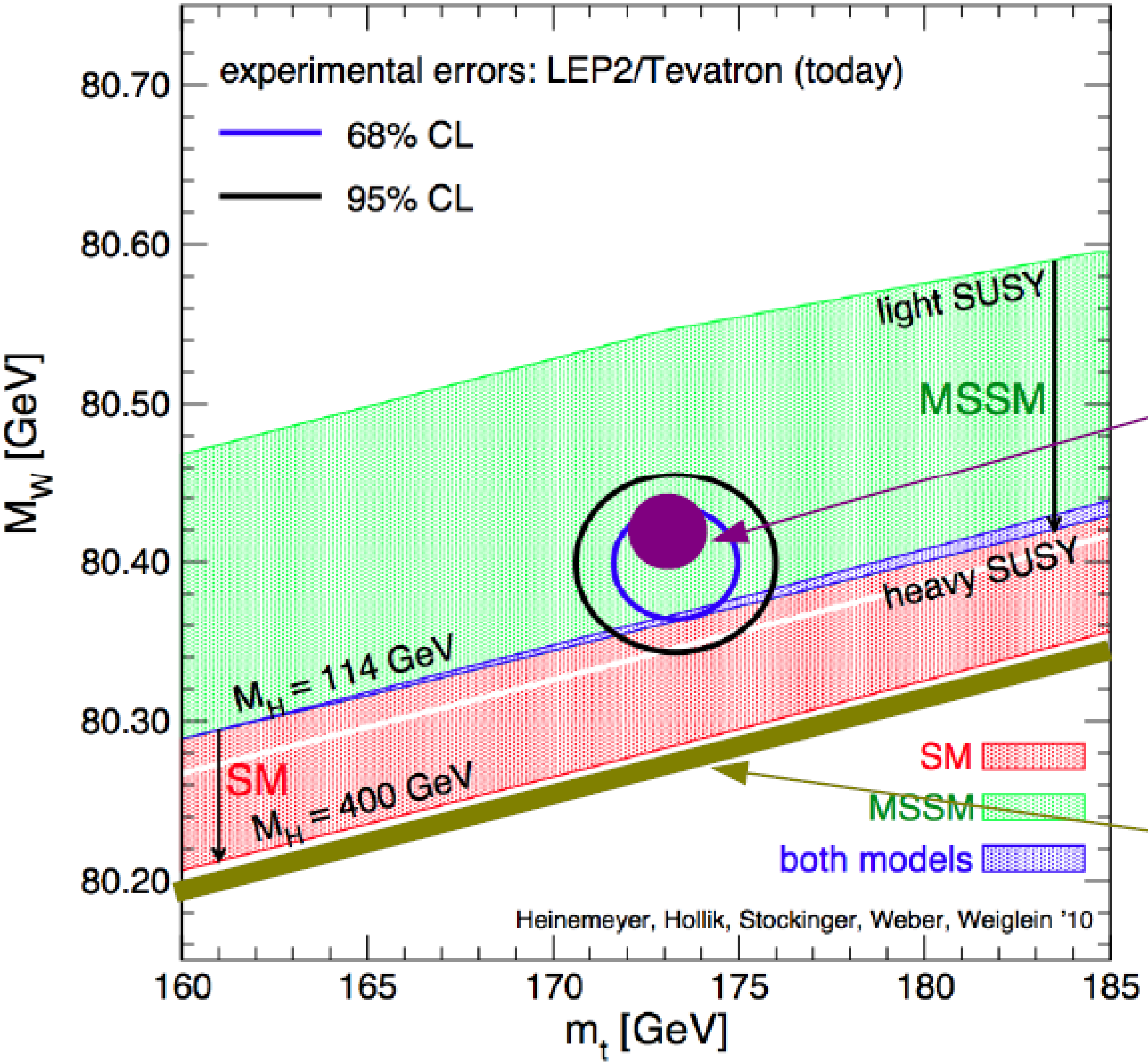
$\Delta M_t = 0.9$ GeV

$\Rightarrow$ would need: ΔM_W = 5 MeV

Currently have: ΔM_W = 23 MeV

At this point, *i.e.* after all the precise top mass measurements from the Tevatron, the limiting factor here is ΔM_W, not ΔM_t .

Impact of W mass

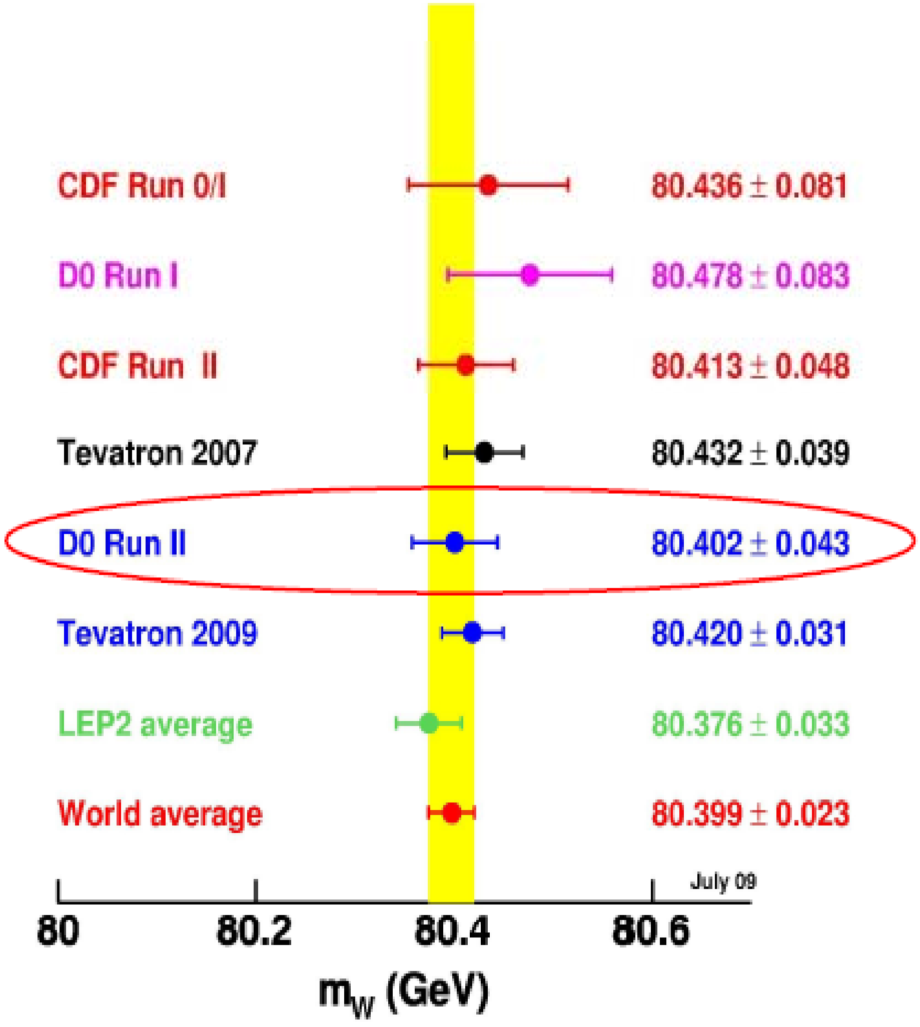


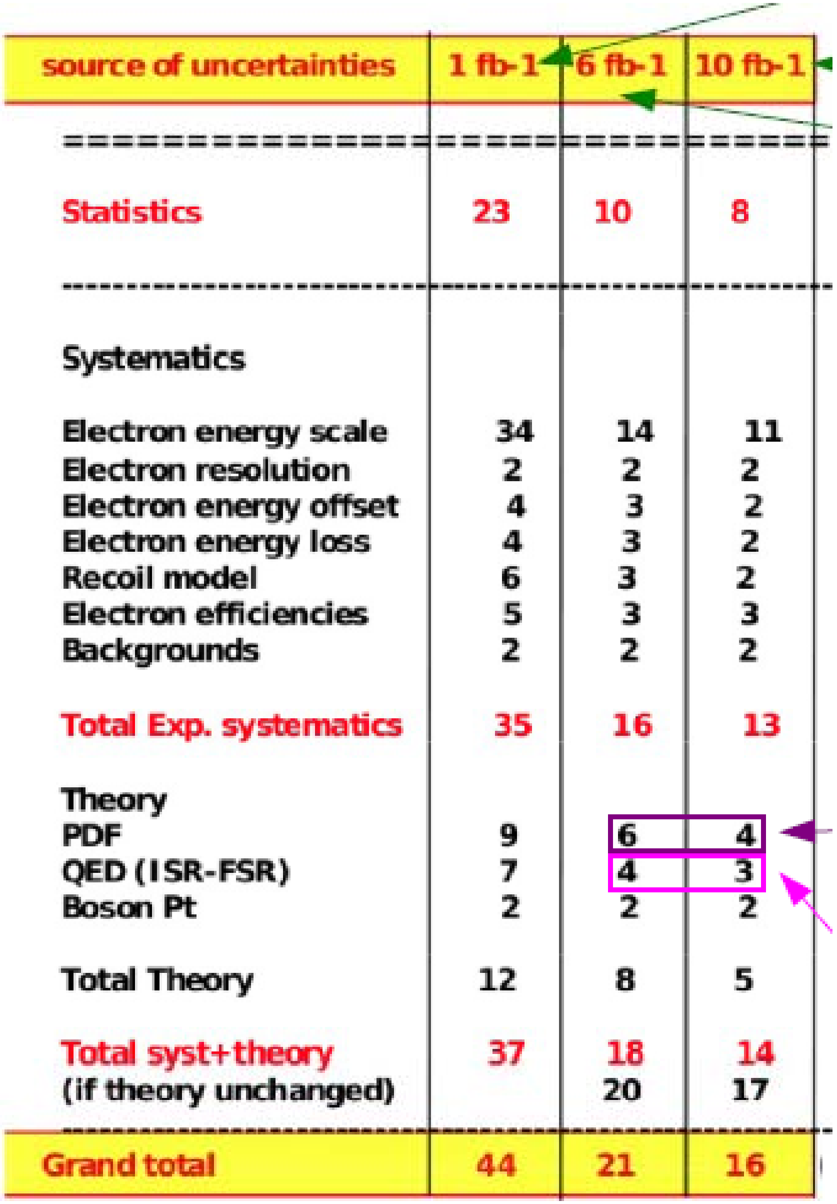
$\Delta M_t = 0.7$ GeV

$\Delta M_W = 15$ MeV

Higgs discovery at a large mass

W mass, now and soon





source of uncertainties	1 fb-1	6 fb-1	10 fb-1
Statistics	23	10	8
Systematics			
Electron energy scale	34	14	11
Electron resolution	2	2	2
Electron energy offset	4	3	2
Electron energy loss	4	3	2
Recoil model	6	3	2
Electron efficiencies	5	3	3
Backgrounds	2	2	2
Total Exp. systematics	35	16	13
Theory			
PDF	9	6	4
QED (ISR-FSR)	7	4	3
Boson Pt	2	2	2
Total Theory	12	8	5
Total syst+theory	37	18	14
(if theory unchanged)		20	17
Grand total	44	21	16

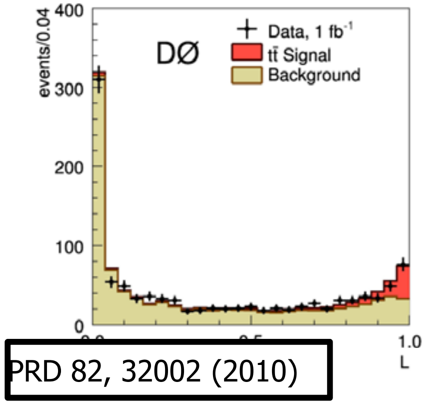
Summary for QCD and Electroweak

- QCD and EW legacy measurements
  - unprecedented precision
  - extract fundamental constants like α_s and $\sin^2\theta_W$ from measurements
  - we will learn more by looking at the full dataset
- Precision physics => this has taken us years to achieve, techniques have been ported to the LHC experiments
- Our inputs to PDF fits have large impact
- W/Z/γ + jets, diboson measurements crucial for understanding backgrounds to New Physics and SM Higgs searches
- Anomalous coupling limits are some of the world's best
- Expect to see several new results using the full 10 fb^{-1} in 2012

Top

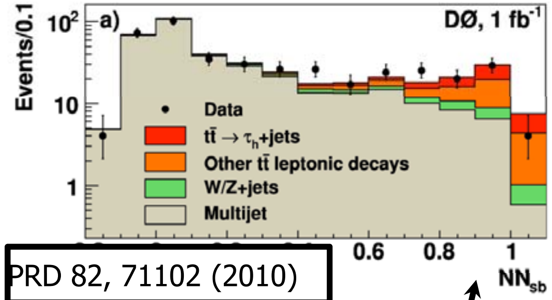
Top Pair Measurements in All Possible Channels

alljets:
large rate, large background

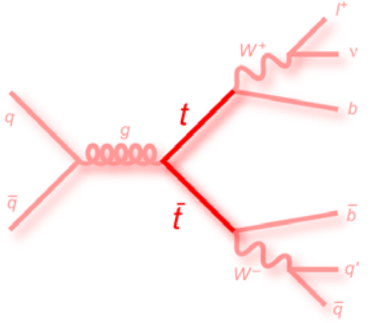


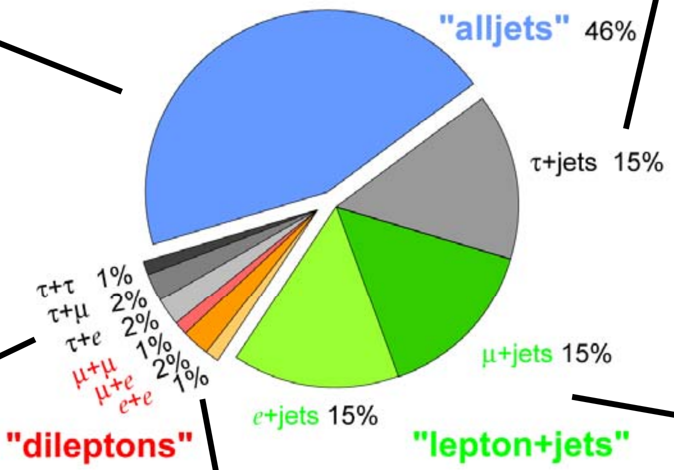
PRD 82, 32002 (2010)

τ+jets: small rate, large background

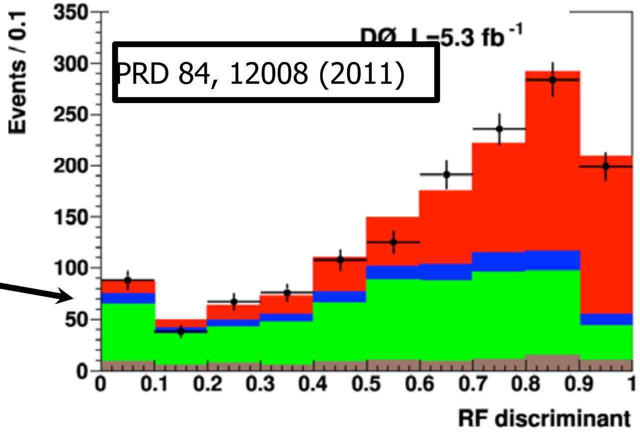


PRD 82, 71102 (2010)



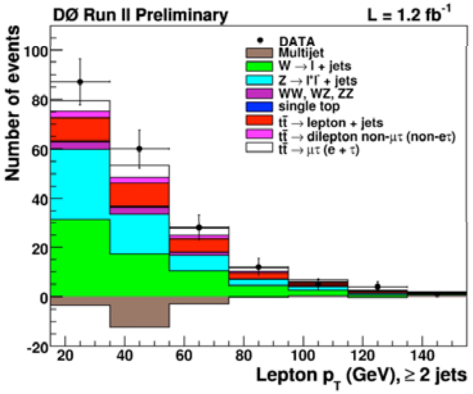


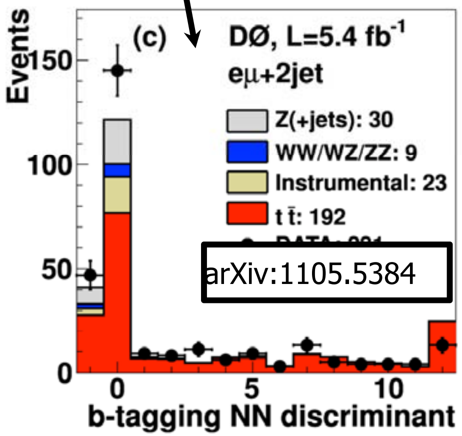
l+jets: good rate,
reasonable background



PRD 84, 12008 (2011)

lepton+τ+jets: small rate,
large background

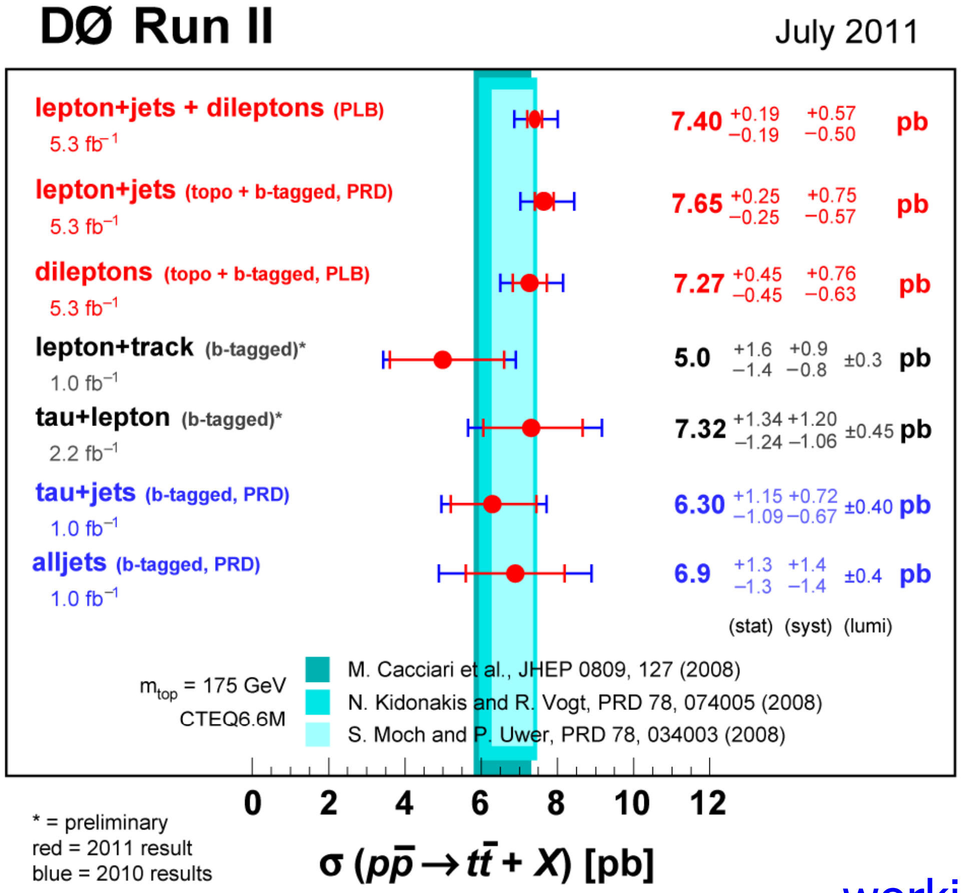


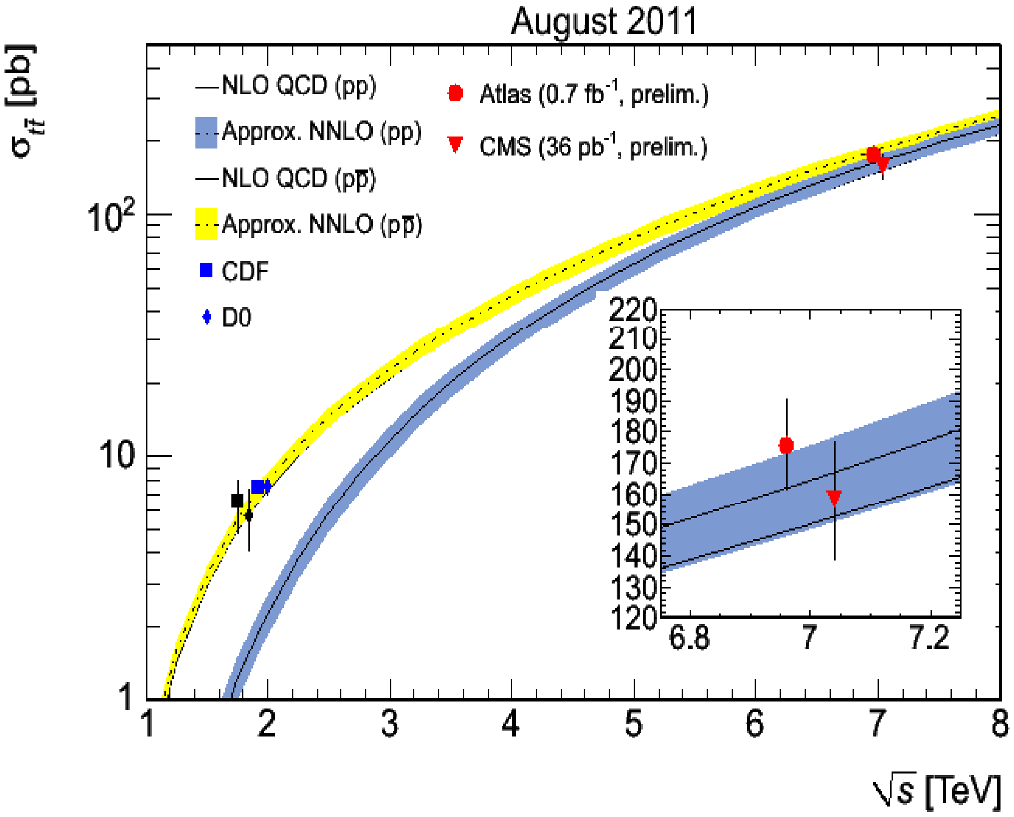


arXiv:1105.5384

dilepton: small rate,
small background

Top Pair Cross Sections at 1.96 TeV





working on the CDF-D0 combination

- in addition to the cross section

- cross section ratios (limit on t->H⁺b)
- fit the cross section together with R to extract V$_{tb}$:

$$R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

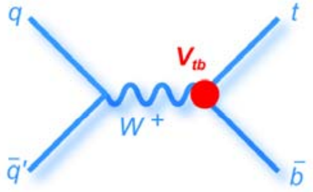
$|V_{tb}| = 0.95 \pm 0.02$ assuming CKM unitarity

arXiv:1106.5436

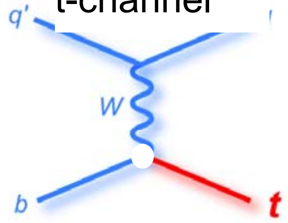
Future measurements will focus on differential cross sections
Only Tevatron can measure them at 1.96 TeV ;)

Electroweak Top Production at Hadron Colliders

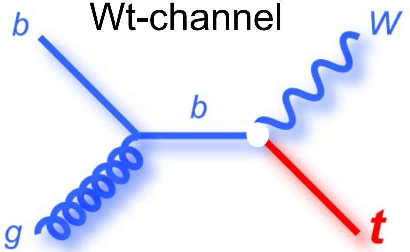
s-channel



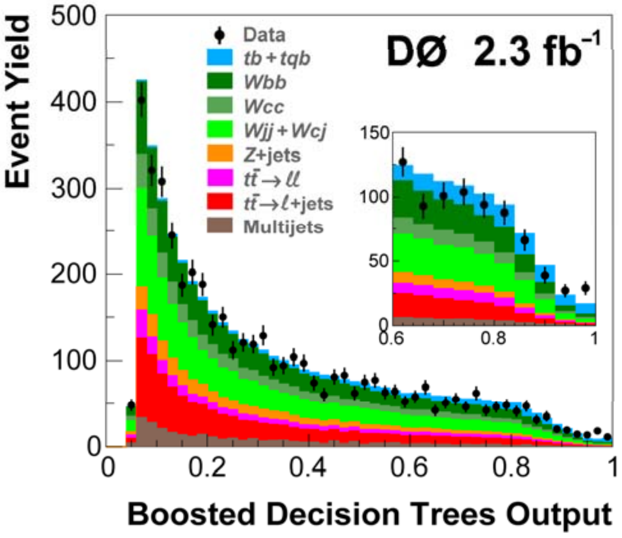
t-channel

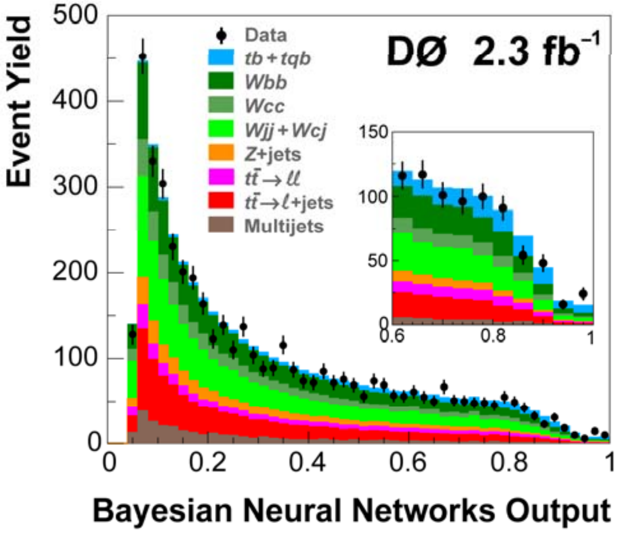


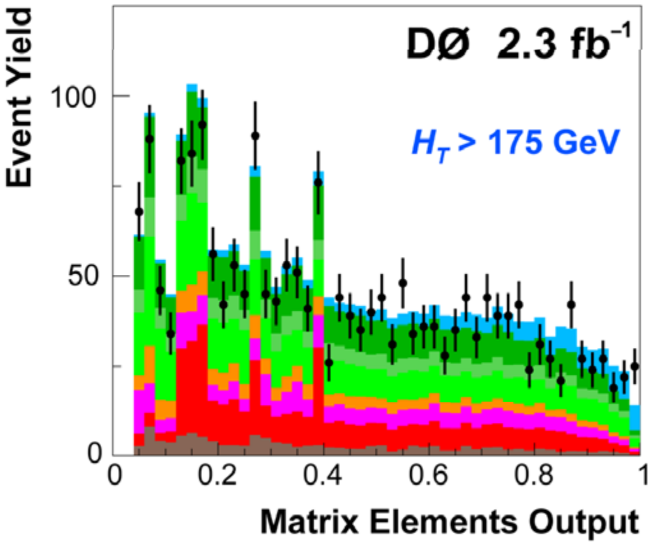
Wt-channel



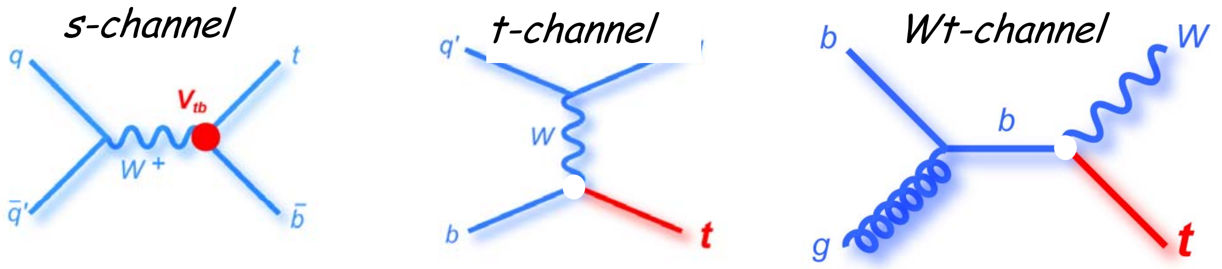
- **predicted since the 80s**
- **allows to directly measure V_{tb}**
- **challenging to measure**
- **- small cross section and background similar signature than signal**
- **- not possible with counting only (bkg uncertainty larger than the signal):**
- **multivariate techniques**





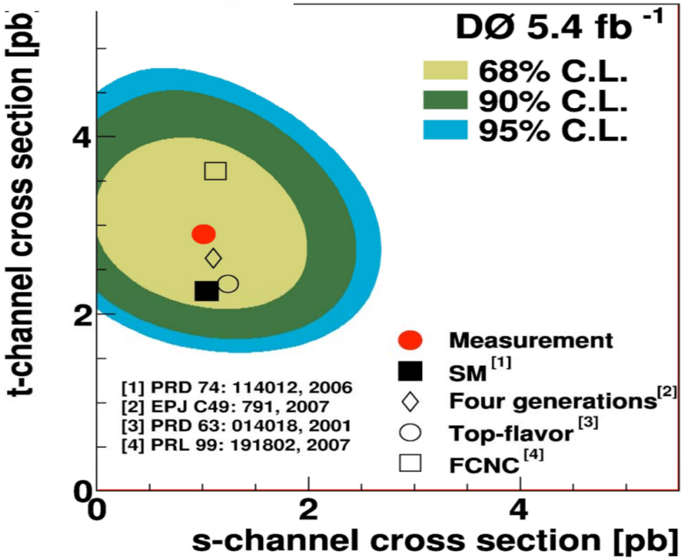


Single Top Cross Section



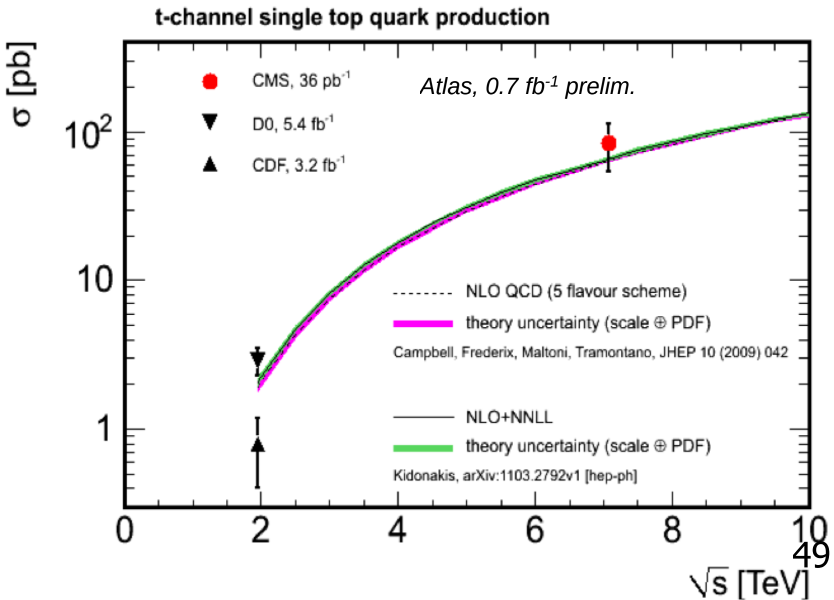
➔ discriminate between the single top channels:

- new physics can affect the single top channels differently
- signal: t-channel, background (other single top, W+jets, tt):
  - Tevatron: multivariate (Neural Networks, Boosted Decision Trees, ...)
  - LHC: cut-based or multivariate



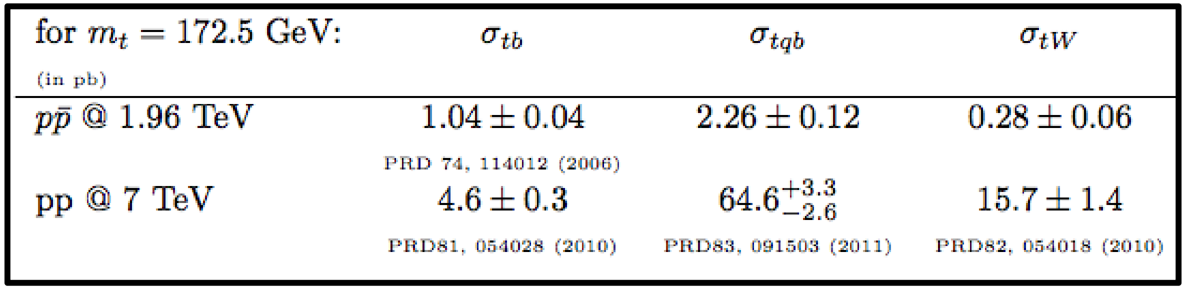
σ_{tqb} (pb) for $m_t = 172.5$ GeV:

CDF (3.2 fb^{-1})	0.8 ± 0.4	
D0 (5.4 fb^{-1}, arXiv:1105.2788)	2.90 ± 0.59	5.5σ
CMS (36 pb^{-1}, arXiv:1106.3052)	$83.6 \pm 29.8(\text{stat}+\text{syst}) \pm 3.3(\text{lumi})$	3.7σ
Atlas (0.7 fb^{-1})	90^{+32}_{-22}	7.6σ



Observation of t-channel single top in 2011

Single Top Perspectives at the Tevatron

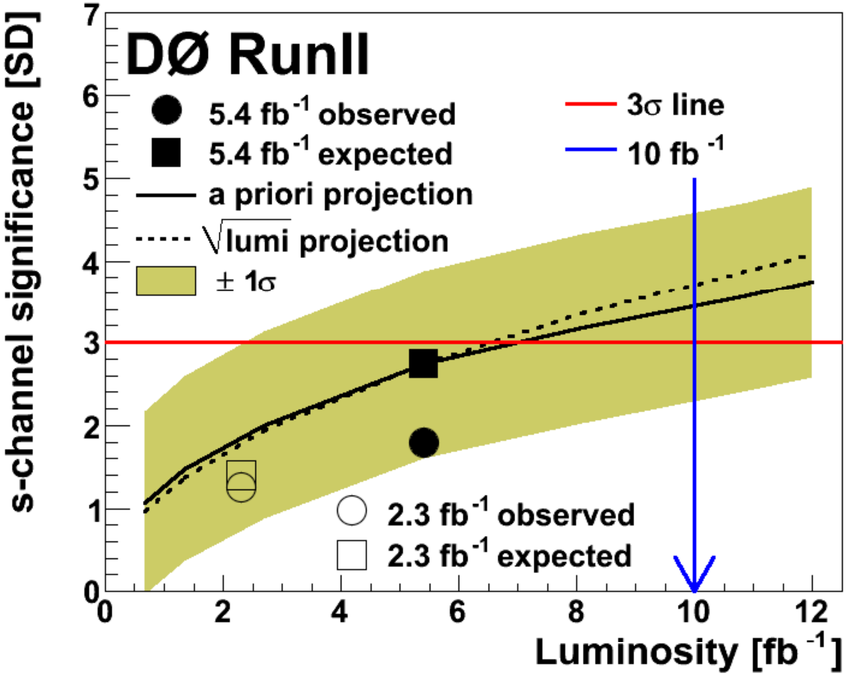


for $m_t = 172.5$ GeV: (in pb)	σ_{tb}	σ_{tqb}	σ_{tW}
$p\bar{p}$ @ 1.96 TeV	1.04 ± 0.04	2.26 ± 0.12	0.28 ± 0.06
	PRD 74, 114012 (2006)		
pp @ 7 TeV	4.6 ± 0.3	$64.6^{+3.3}_{-2.6}$	15.7 ± 1.4
	PRD81, 054028 (2010)	PRD83, 091503 (2011)	PRD82, 054018 (2010)

- **s-channel**

- challenging at LHC
- legacy measurement of the Tevatron

latest D0 measurement
(5.4 fb-1, arXiv:1105.2788):
expected sensitivity close to 3σ



with 10 fb^{-1}, should get evidence
maybe observation when combination with CDF ?

Top Quark Mass

- the top quark is the only “natural” quark:

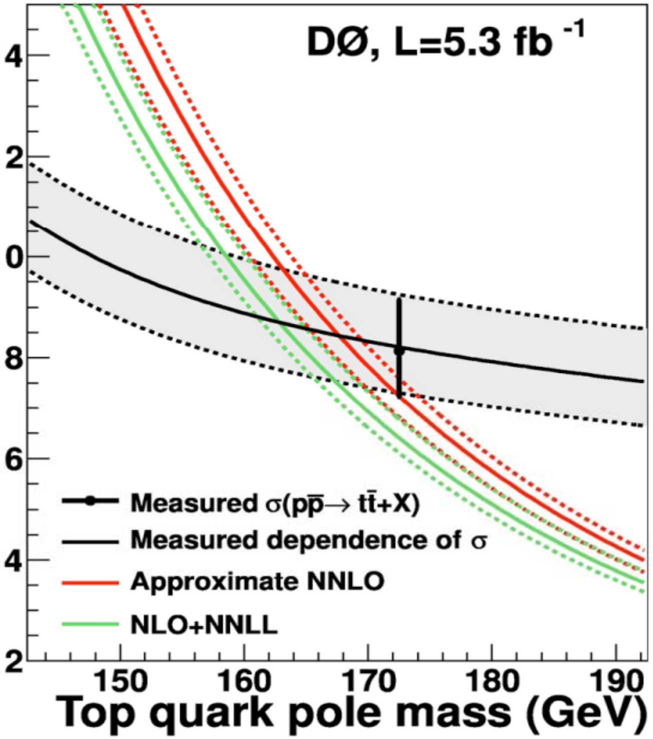
- coupling to the Higgs boson close to 1: special role in the electroweak symmetry breaking ?

$$\boxed{\mathcal{L}_{\text{Yukawa}} = -\lambda_t \overline{\psi_{Lt}} \Phi \psi_{Rt}}$$

- together with M_W, predict the Higgs boson mass

$\lambda_t \approx 1$!!
$m_t >> m_b$

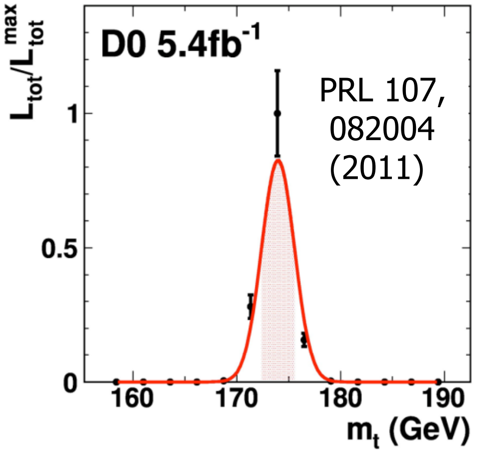
- how to measure the top mass ?
  - <u>template method</u>:
  * compare an observable in data with MC generated with different masses
  - <u>ideogram method</u>:
  * event likelihood computed as a convolution of a Gaussian resolution function with a Breit-Wigner (signal)
  - <u>matrix element method</u>:
  * build an event probability based on the LO tt matrix element using the full kinematics of the event



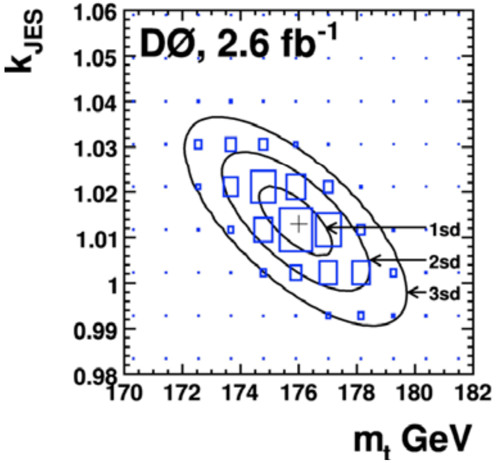
- mass extraction from the tt cross section
  - using the experimental and theoretical cross sections vs. mass (well defined renormalization scheme): method first used at D0 to extract both the pole mass and the MS mass
  (PLB 703, 422 (2011))

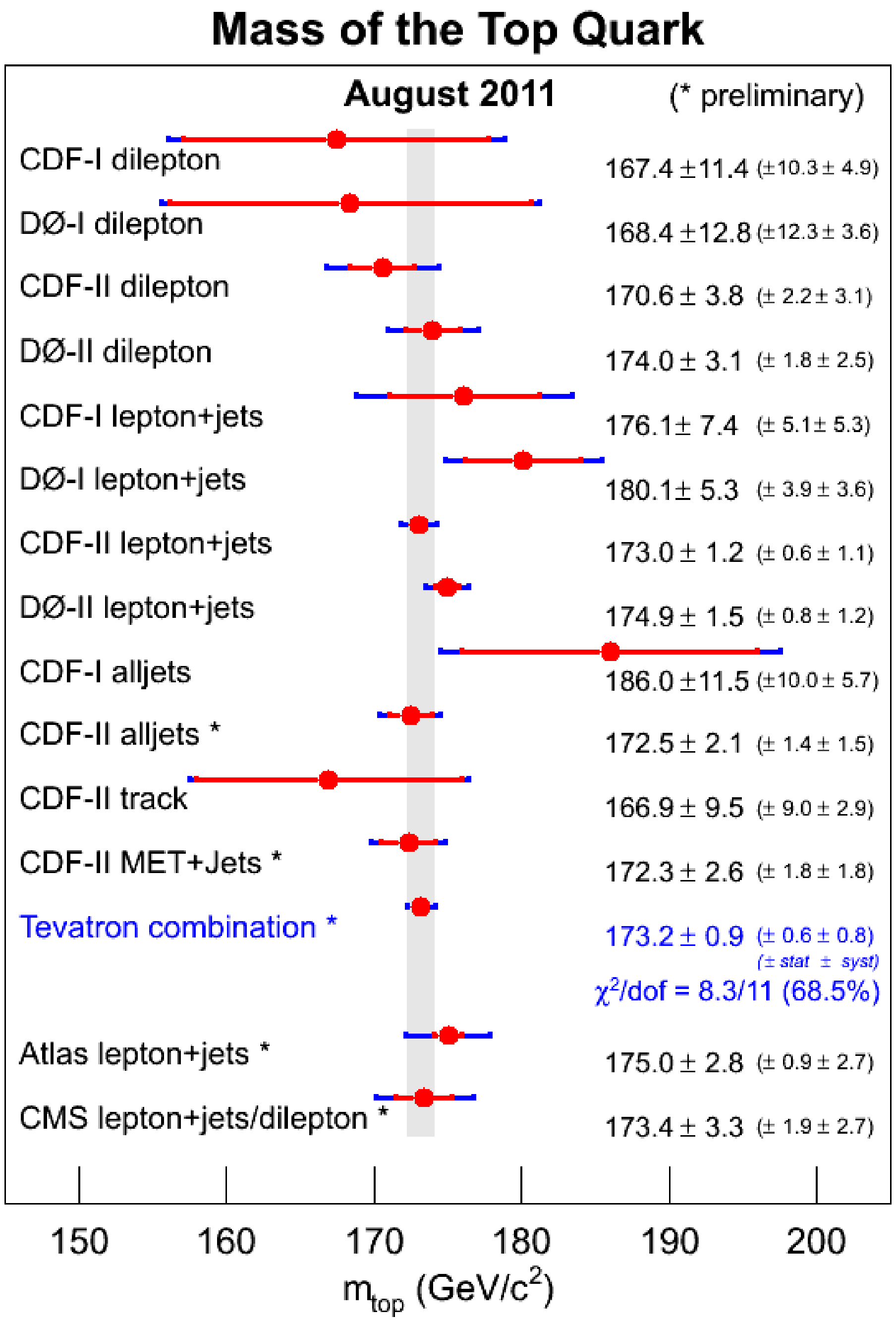
Top Quark Mass Measurements

- discovery:
  - lepton+jets: ±30 GeV (50 pb^{-1})
- first D0 Run II measurement:
  - lepton+jets: ±4.5 GeV (0.37 fb^{-1})
- latest D0 measurements:
  - lepton+jets (3.6 fb^{-1}):
    mt = 174.94 ± 1.49 GeV
  - dilepton (5.4 fb^{-1}):
    mt = 174.0 ± 3.1 GeV



PRD 84, 032004 (2011)





- new Tevatron combination (arXiv:1107.5255):

- uncertainty below 1 GeV

- all channels give consistent results

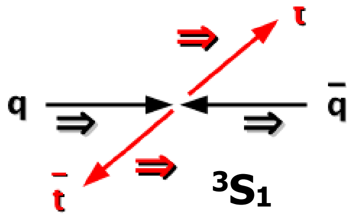
- still working on decreasing the systematic uncertainties

Top Pair Spin Correlations

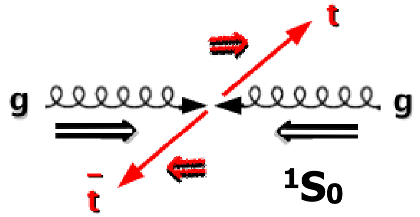
- **in the SM, the spin of the top and of the antitop are produced correlated**

- correlation preserved in the decay products

- very sensitive observable to search for new physics



	$q\bar{q}$	gg
$p\bar{p}$ @ 1.96 TeV	85 %	15 %
pp @ 7 TeV	15 %	85 %



- **measurement method:**

- latest measurements use a new method based on matrix element: measure f, fraction of events with spin correlation using a template fit of R

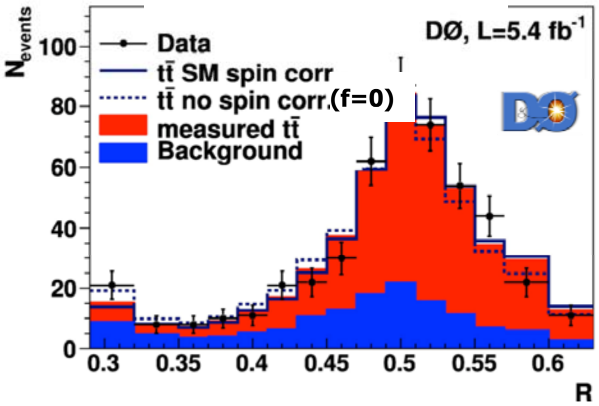
$$R = \frac{P_{\text{sgn}}(H=c)}{P_{\text{sgn}}(H=u) + P_{\text{sgn}}(H=c)}$$

dilepton channel

using ME without spin corr.

$$f_{\text{meas}} = 0.74^{+0.40}_{-0.41}\ (\text{stat+syst})$$

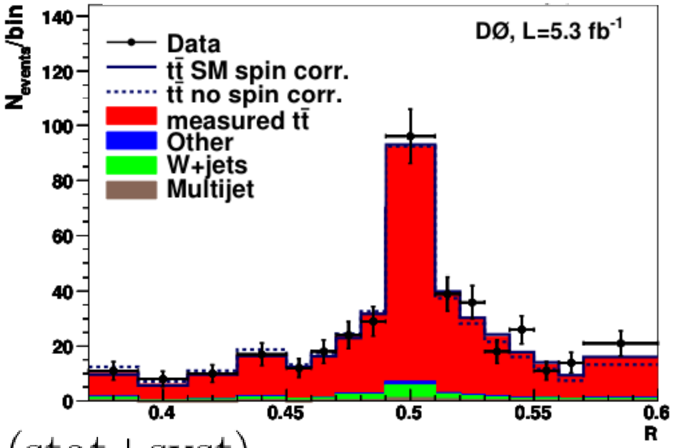
PRL 107, 032001 (2011)



using ME with spin corr.

ljets channel:

$$_{\text{eas}} = 1.15^{+0.42}_{-0.43}(\text{stat} + \text{syst})$$

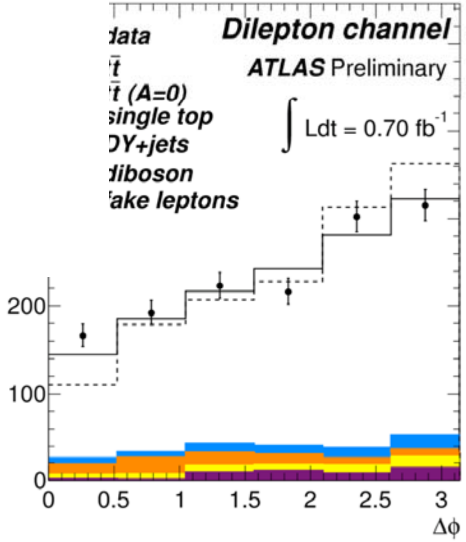


$$C_{\text{meas}} = 0.66 \pm 0.23\ (\text{stat+syst})$$

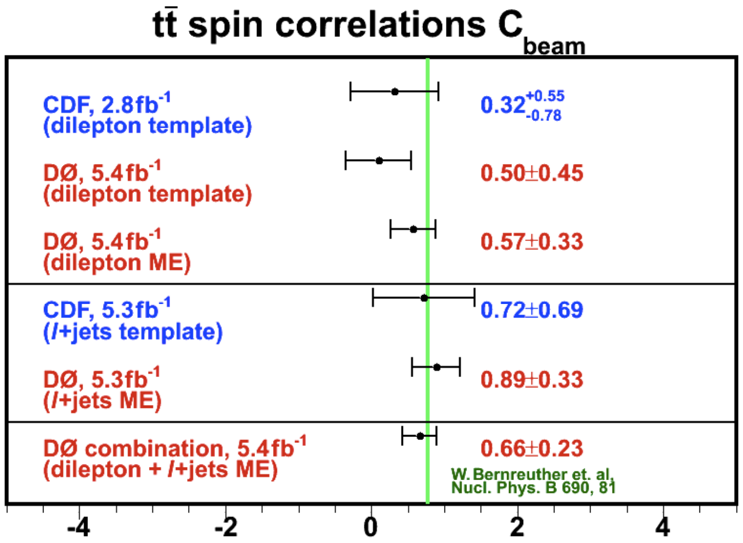
Perspectives for Spin Correlation Measurements

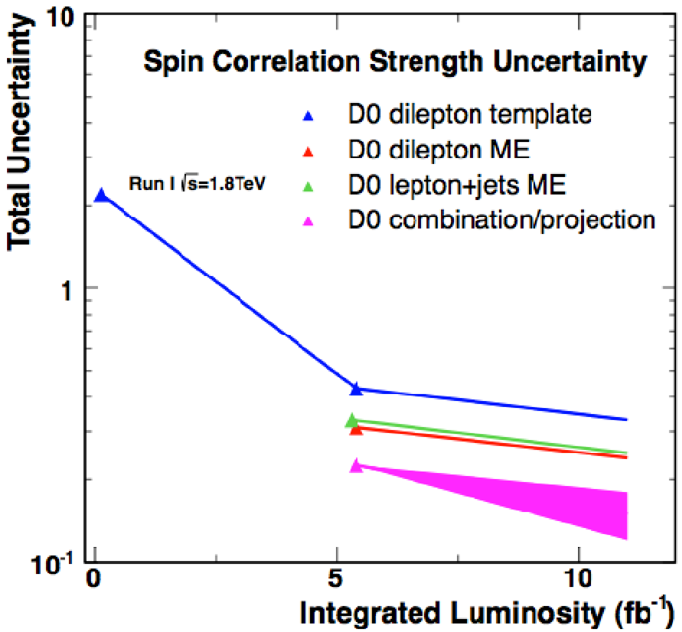
- **complementary measurement at the LHC**
  - **mainly gg-> tt**
  - **ATLAS dilepton: $A=0.34^{+0.15}_{-0.11}$ (helicity basis, $A_{SM}=0.32$)**
  - **also ~ 3σsensitivity**

$\Delta\Phi = |\Phi_{l+}-\Phi_{l-}|$
(in the lab frame)



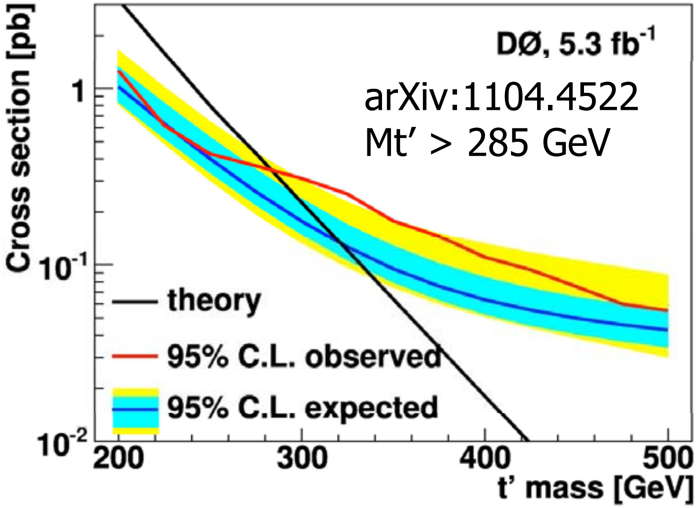
- **at the Tevatron, still statistically limited**
  - **using the full dataset should at least improve the error by √2**
  - **possible analysis improvement (c-tagging in the lepton+jets channel)**
  - **combination with CDF**



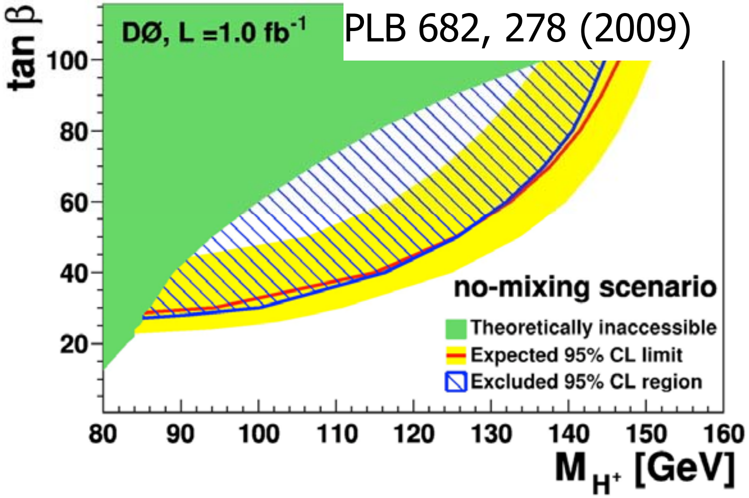


Searches in the Top Sector

- only a few examples

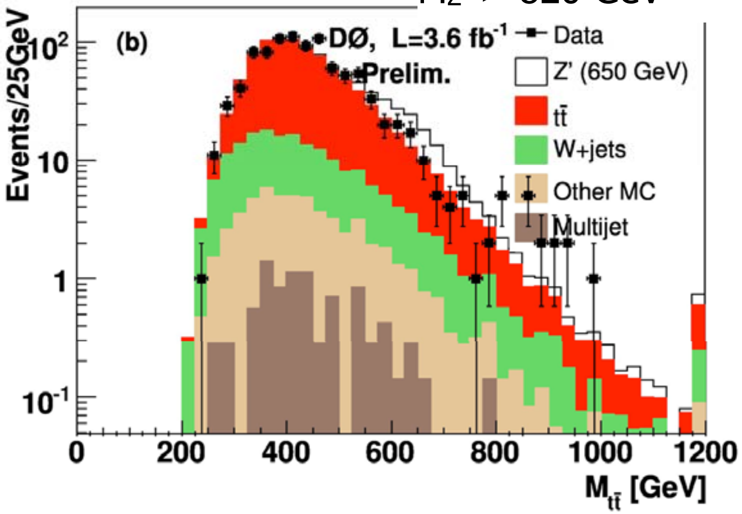


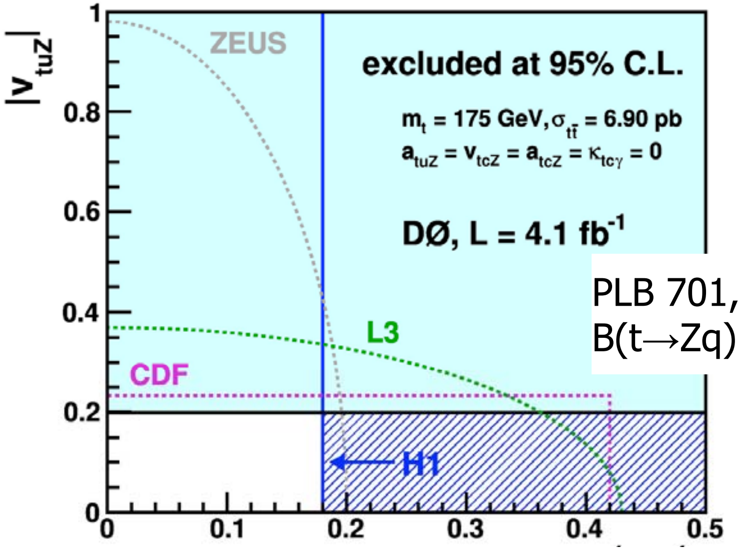
arXiv:1104.4522
Mt' > 285 GeV



PLB 682, 278 (2009)

$M_{Z'}$ > 820 GeV





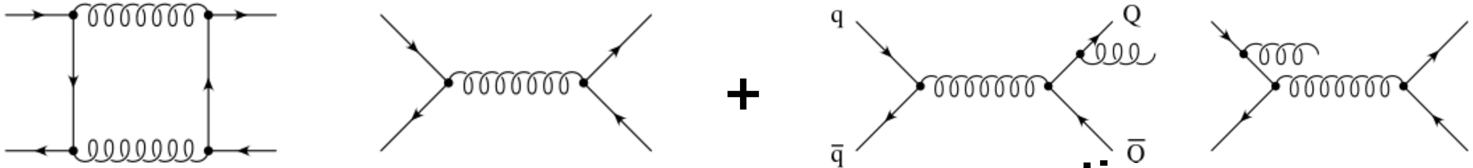
PLB 701, 313 (2011)
B(t→Zq) < 3.2%

No sign of new physics so far, but….

Top-Antitop Charge Asymmetry

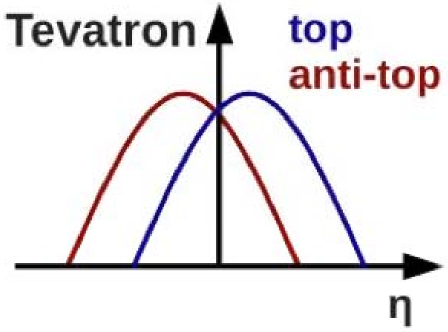
At NLO, QCD predicts an asymmetry for tt produced via qq initial state - the top quark is predicted to be emitted preferably in the direction of the incoming quark

- the exchange of new particles like Z’ or axigluon could modify it

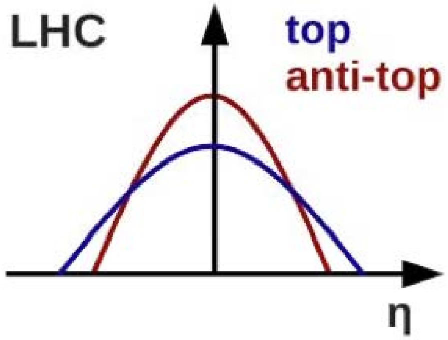


positive asymmetry

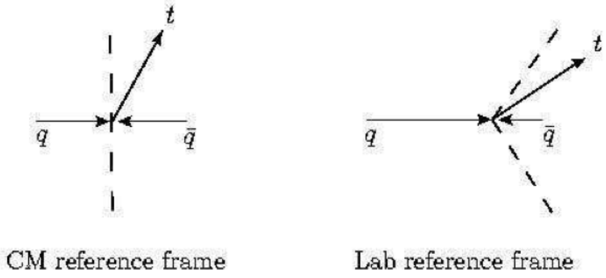
negative asymmetry



forward-backward asymmetry



central-forward asymmetry



$$A^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$$\Delta y = y_t - y_{\bar{t}}$$

$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

$$\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$$

smaller at LHC since low qq fraction

Tevatron Top Charge Asymmetry Results

- **CDF measurements**

ljets, PRD83, 112003 (2011)

$A_{t\bar{t}}$	ljets	ljets ($M_{t\bar{t}} \geq 450$ GeV)	dilepton
unfolded data	0.158 ± 0.074		0.42 ± 0.16
SM prediction (MCFM)	0.058 ± 0.009		0.06 ± 0.01

3.4 σ difference

- **D0 ljets measurement**
  - unfold the reconstructed distribution to correct for acceptance and detector effects

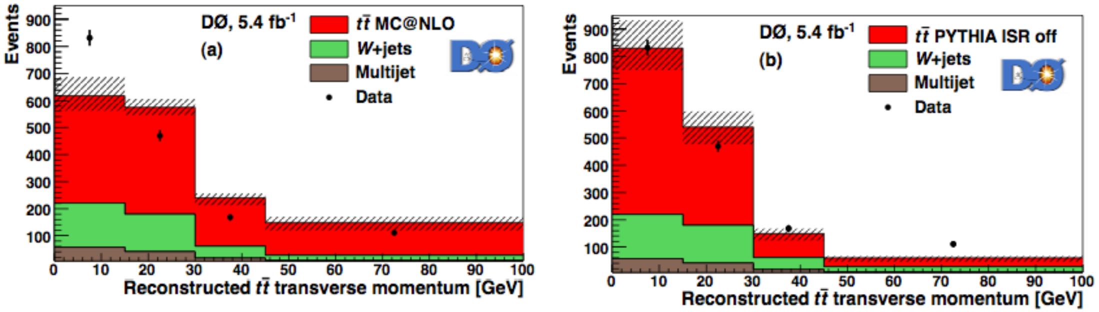
	A_{FB} (%) Reconstruction level	A_{FB} (%) Production level
Data	9.2 ± 3.7	19.6 ± 6.5
MC@NLO	2.4 ± 0.7	5.0 ± 0.1

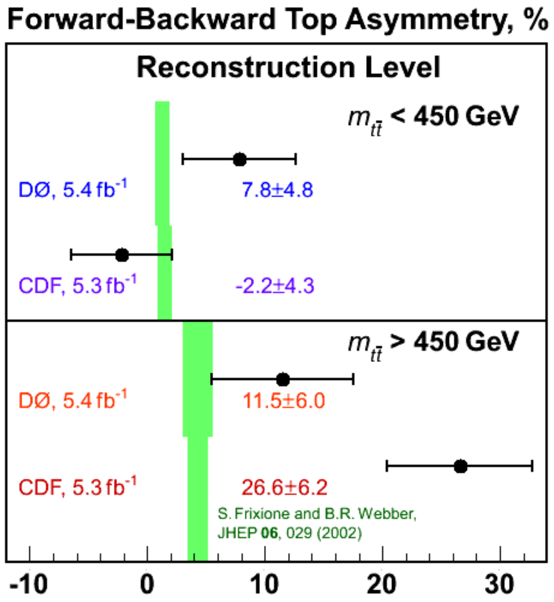
~ 2.4 σ

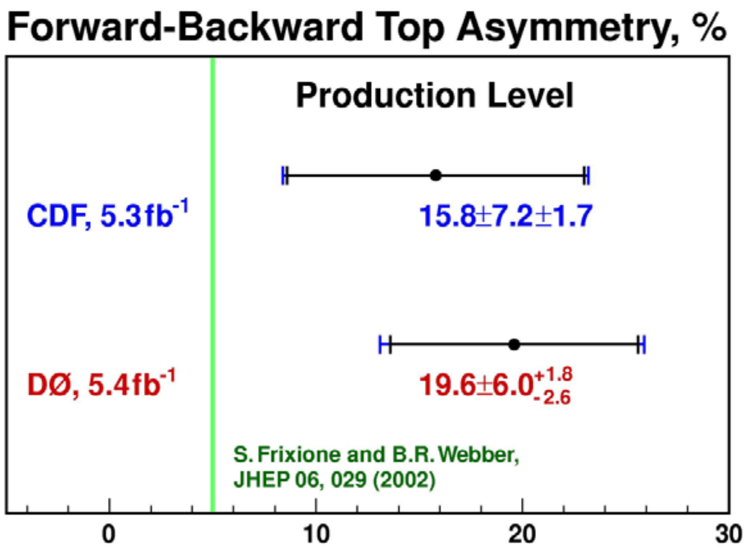
$$A^{l}_{FB} = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

	A^{l}_{FB} (%) Reconstruction level	A^{l}_{FB} (%) Production level
Data	14.2 ± 3.8	15.2 ± 4.0
MC@NLO	0.8 ± 0.6	2.1 ± 0.1

> 3 σ







Statistically limited measurements, need better understanding of the predictions

Top Charge Asymmetry Prospect

- **LHC results**

- different observables

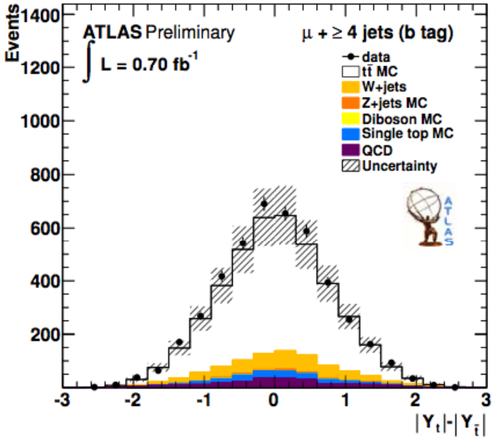
- not yet sensitive to a potentiel Tevatron excess

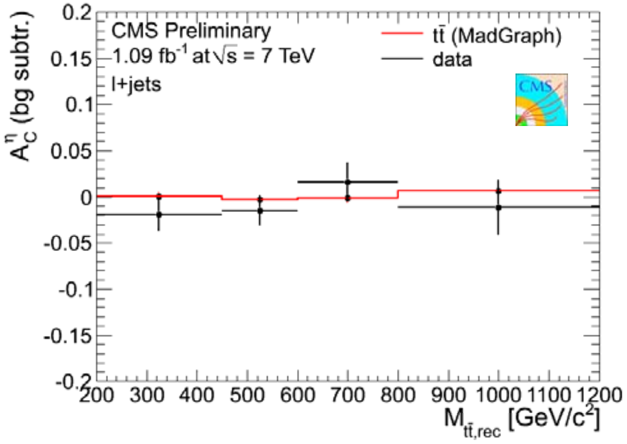
$$\frac{- N(\Delta < 0)}{+ N(\Delta < 0)}$$

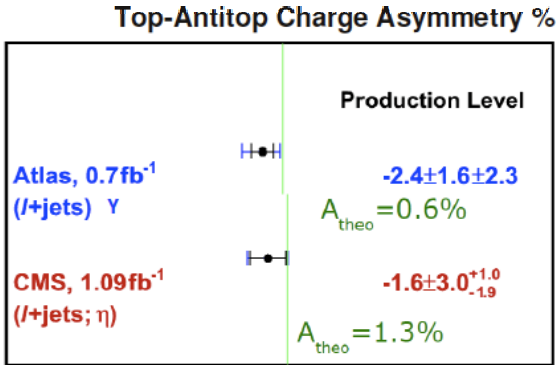
- Atlas: $\Delta^{y} = |y_t| - |y_{\bar{t}}|$

- CMS: $\Delta^{\eta} = |\eta_t| - |\eta_{\bar{t}}|$

$$\Delta^{y^2} = (y_t - y_{\bar{t}})(y_t + y_{\bar{t}})$$







Currently no deviation from the predictions

- **Tevatron perspectives**

- D0 dilepton result with 5.4 fb^{-1} soon in review :
√2 improvement

- combination with CDF: another √2

- we have to conclude on the effect with the full dataset:
is it really new physics ?

Searching for the Higgs Boson

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

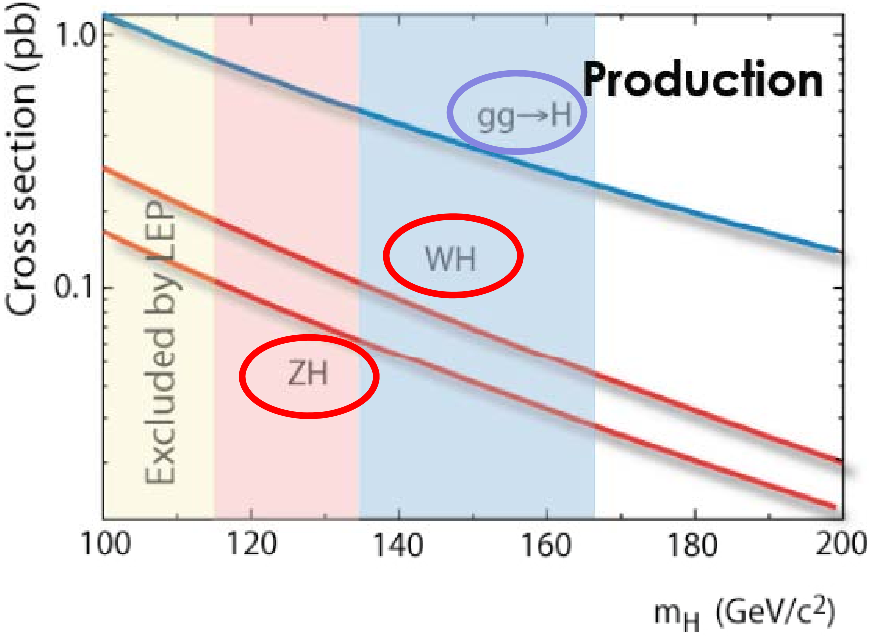
- ***Direct limits***:

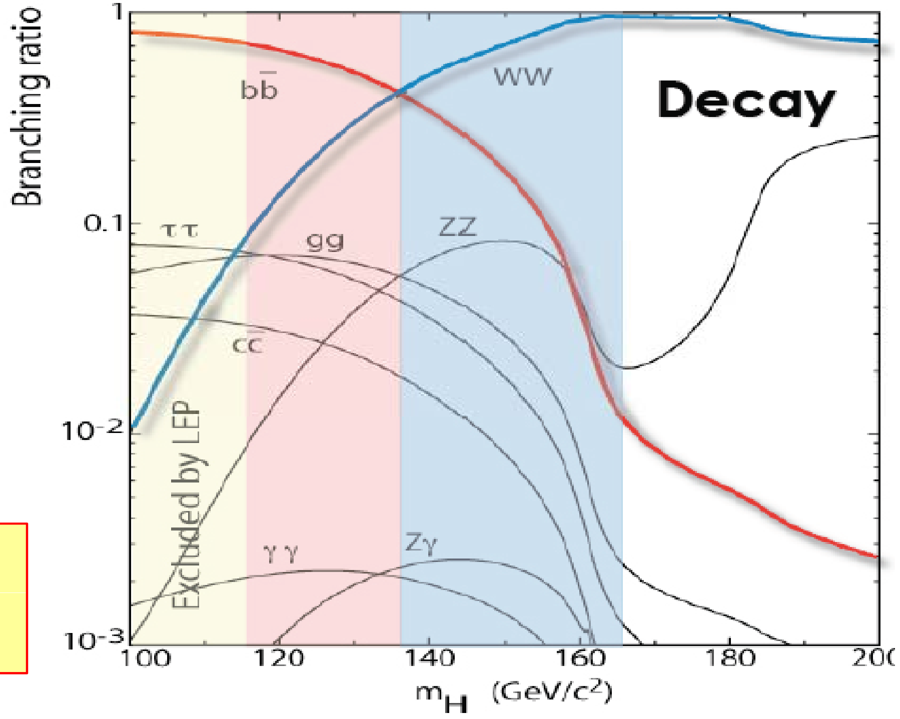
LEP: $m_{Higgs} > 114$ GeV @ 95% CL
TEV: $m_{Higgs} \neq [158;173]$ GeV @ 95% CL   (3/2011

- **Combining Direct and Indirect Limits (2010)**

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

Data from LHC start to confirm that if there is a SM Higgs, it has a rather low mass (<~ 145 GeV)





What did we learn so far on SM Higgs?

Tevatron has already shown that the “high mass” part of the electroweak-favored range is excluded ➔ SM Higgs is between ~115 and ~150 GeV.

This summer, LHC has confirmed and extended these limits: it is also starting to confirm directly that higher masses (> 180 GeV) are not possible for SM Higgs (work to be completed with more LHC luminosity).

➔ Higgs has a low mass and is in a region where its Branching Ratios vary rapidly as a function of its mass

Challenge: we need to combine all decay modes to find it, but we also need individual measurements to identify it as the SM Higgs boson!

➔ Remind Tevatron strategy, starting from the high mass channels, then moving to the H→bb search, where Tevatron has unique capabilities

Higgs Search Strategy @ Tevatron

Optimize all channels individually, based on production and decay properties.

Select inclusive candidate samples maximizing acceptance to potential Higgs signals (different masses probed)

Separate further these channels into multiple analysis sub-channels of different S/B, to improve the sensitivity.

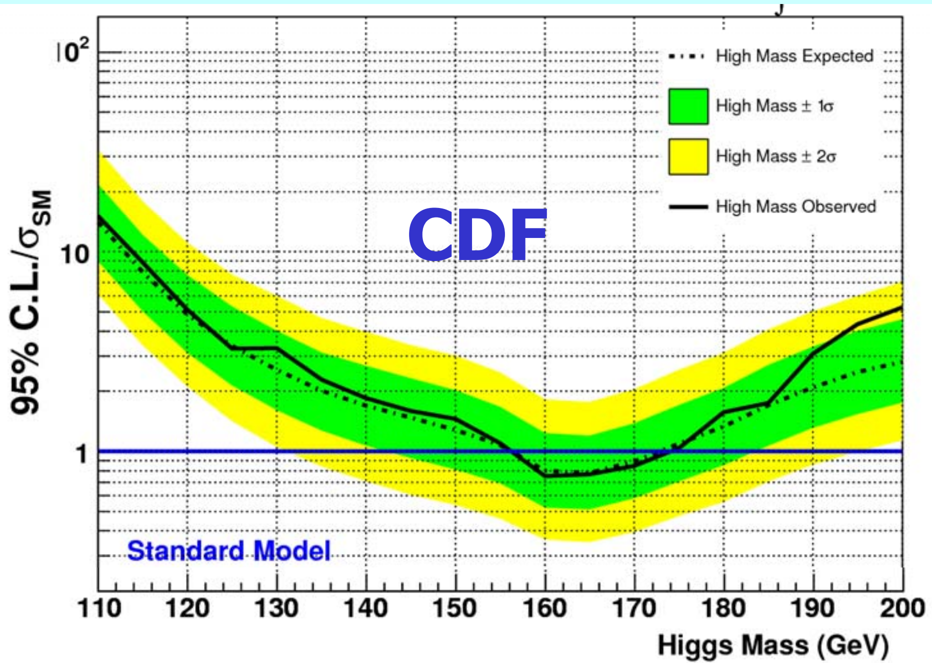
Model all backgrounds using simulation and data, with detailed verifications on independent control regions in data

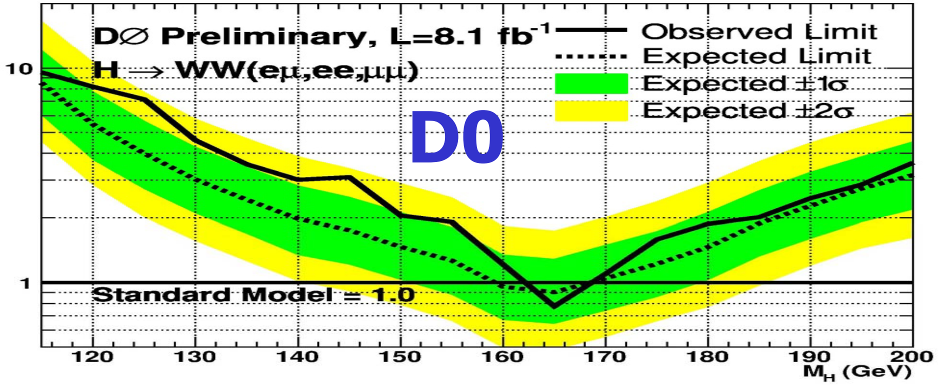
Use advanced multivariate analysis tools to separate signal from background based on the full event kinematics

Derive systematic uncertainties from independent measurements, both in normalization and on the shape of their distributions.

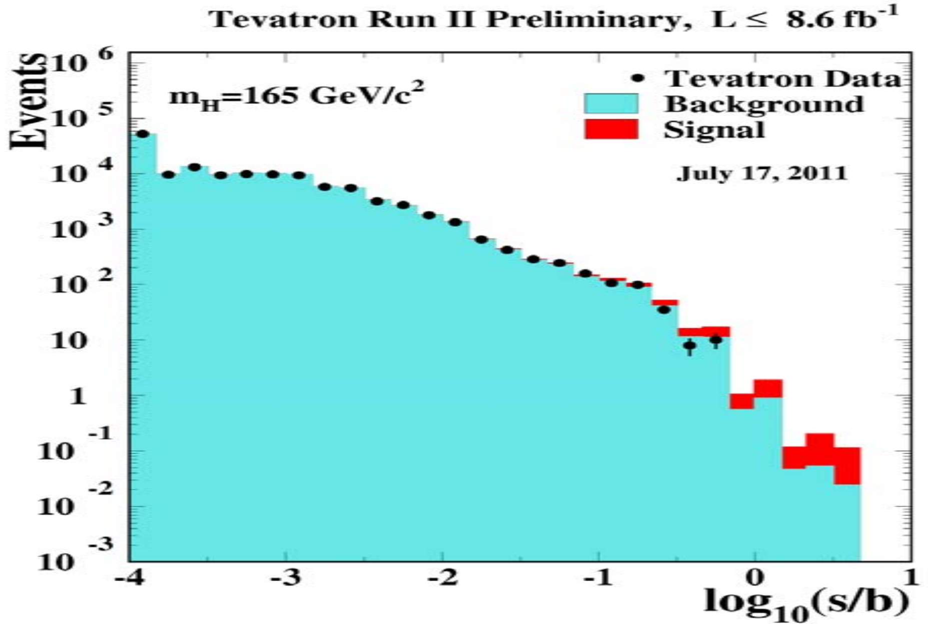
Use standard statistical approaches and constrain the systematic uncertainties to the data, to obtain the best search results.

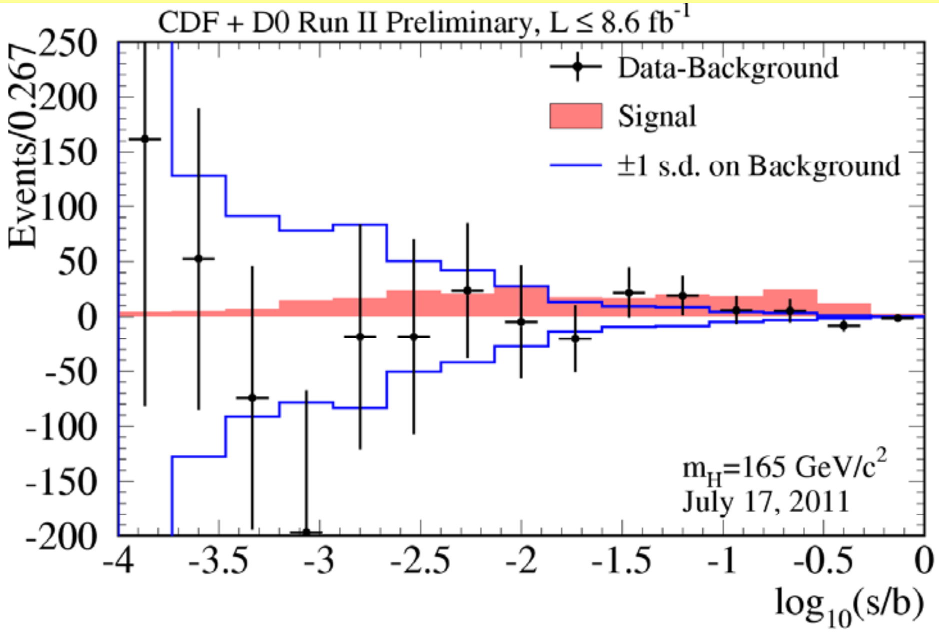
CDF/D0 H→WW→lνlν Limits





Both experiments exclude SM Higgs boson around 165 GeV ➔ combined yield:





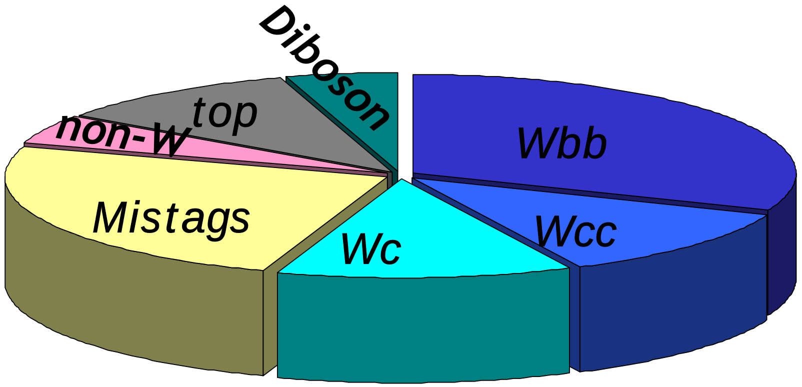
No sign of Higgs here, let's move to low mass!

Low Mass Higgs Searches

Increase lepton reconstruction and selection efficiencies

Understand background

$WH \to l\nu bb$

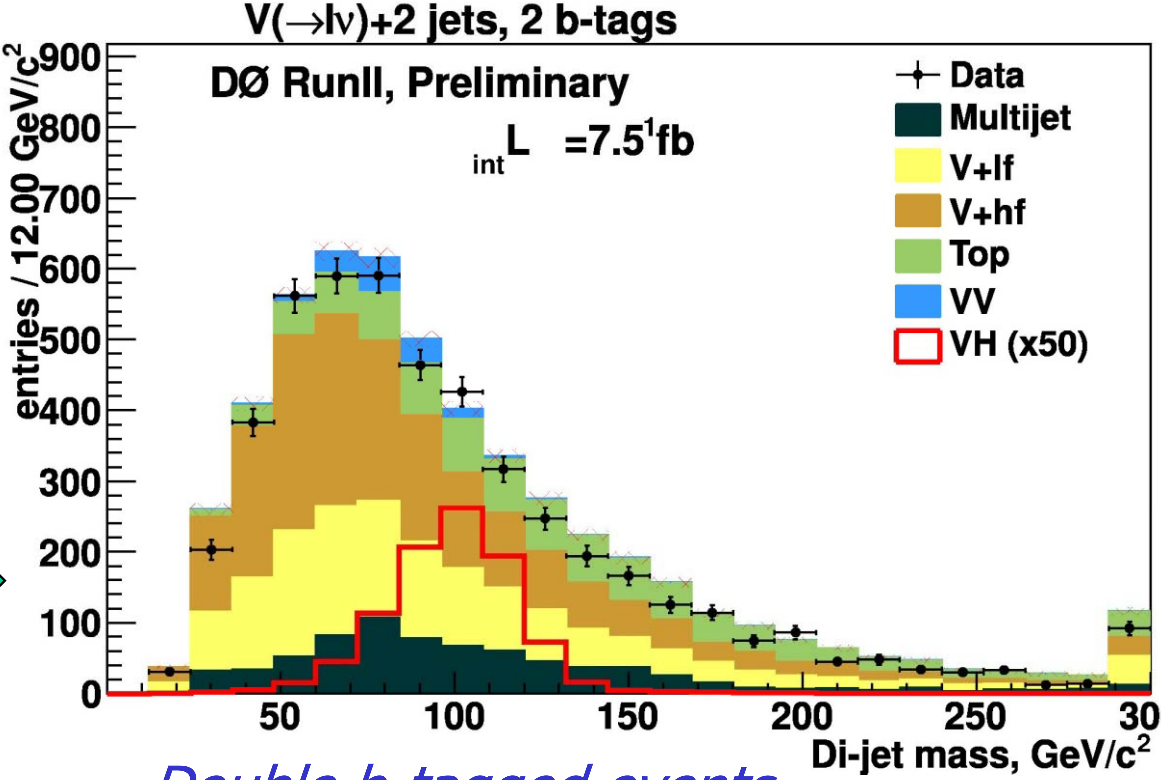


Specific to low mass analyses:

Optimize dijet mass resolution
➔ needs precise calibration and resolution for gluon and quark jets separately
➔ new techniques explored (NN, tracks + calorimeter cells) we are not done yet!

- **Improve the efficiency for tagging b-quark jets**

- separate b,c,light.



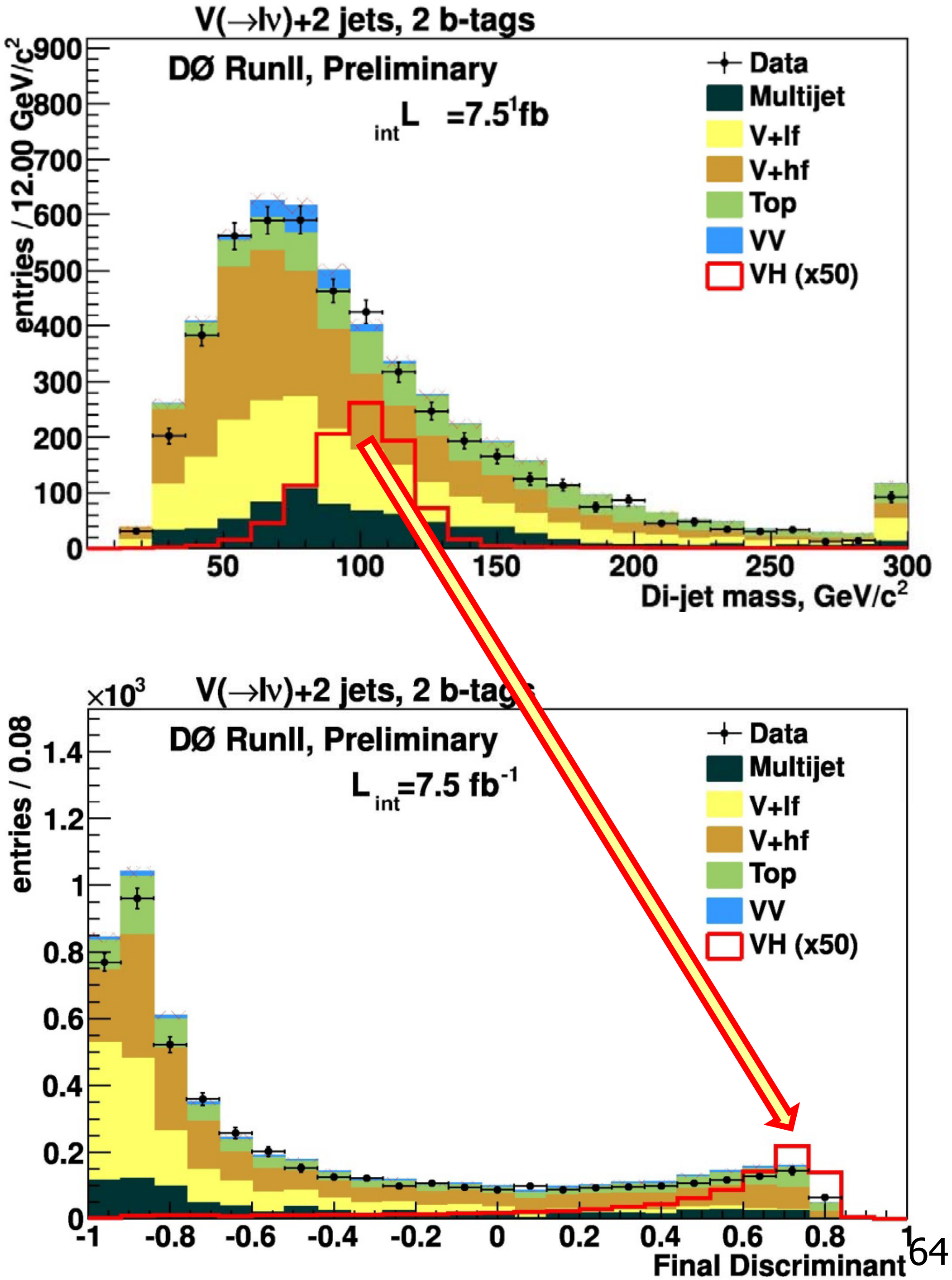
Double b-tagged events

From Dijet mass to Multi Variate Analysis

- To improve S/B ➔ utilize full kinematic event information

- Multi Variate Analyses are used to maximize search sensitivities
  - Neural Networks
  - Boosted Decision Trees
  - Matrix Element Calculations

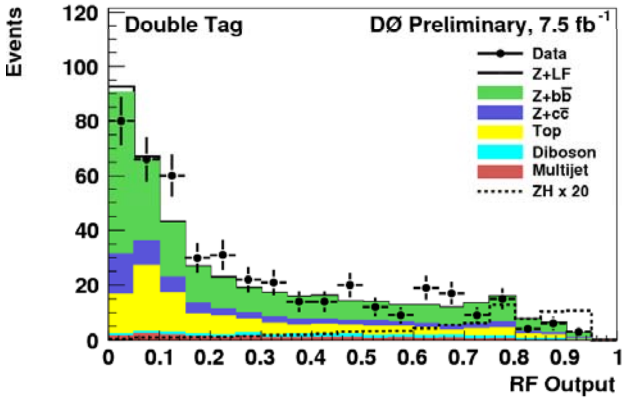
- Visible gain obtained (~20% in sensitivity)

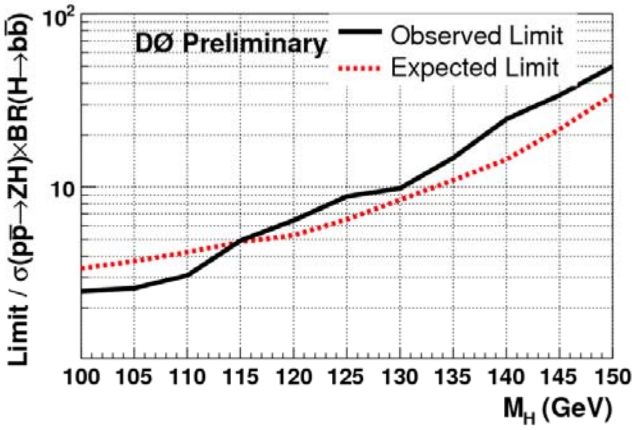


Results from DØ

ZH→llb$\bar{b}$

∫Ldt=**8.6** fb^{-1}

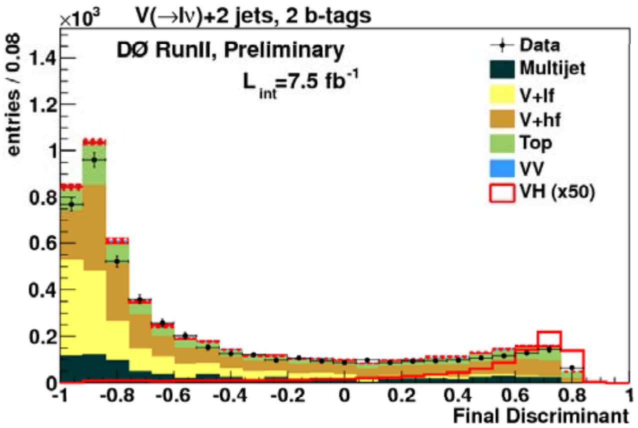


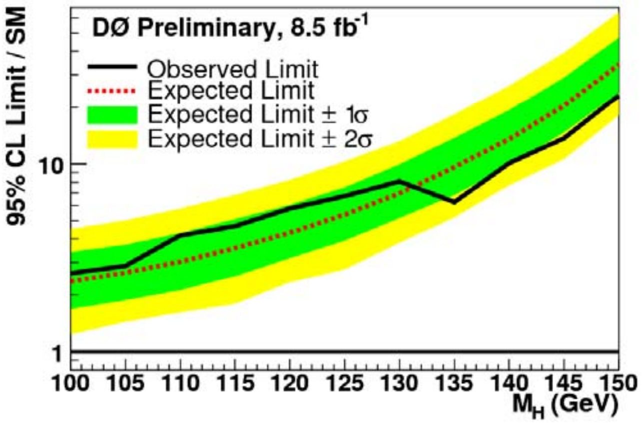


95% CL Exp (obs)
Limit **4.8** (**4.9**) x SM
@ MH=115 GeV

WH→lνb$\bar{b}$

∫Ldt=**8.5** fb^{-1}

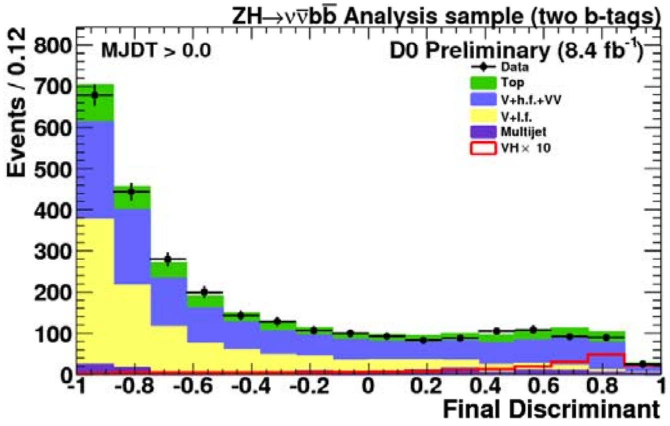


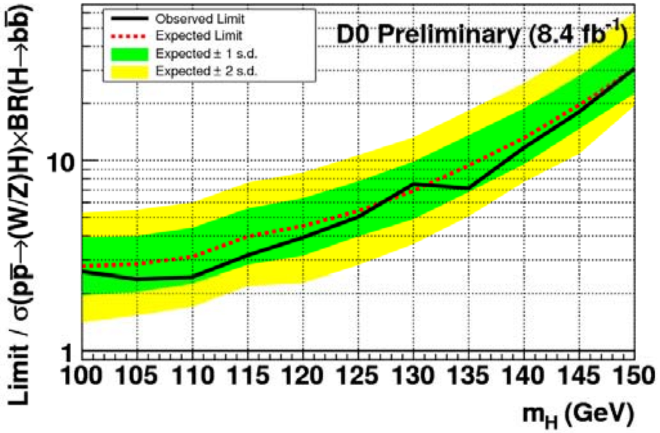


95% CL Exp (obs)
Limit **3.5** (**4.6**) x SM
@ MH=115 GeV

ZH→ννb$\bar{b}$

∫Ldt=**8.4** fb^{-1}





95% CL Exp (obs)
Limit **4.0** (**3.2**) x SM
@ MH=115 GeV

~10% gain on sensitivity
(i.e. on top of gain due to luminosity)

Dibosons with Heavy Flavor Jets

Benchmark of H→bb searches with real data.

VZ→leptons + heavy flavor jets

For m_H=115 GeV

WH→lνbb: σ = 26 fb
ZH→ ννbb:σ = 15 fb
ZH→ llbb: σ = 5 fb

Total VH: σ = 46 fb

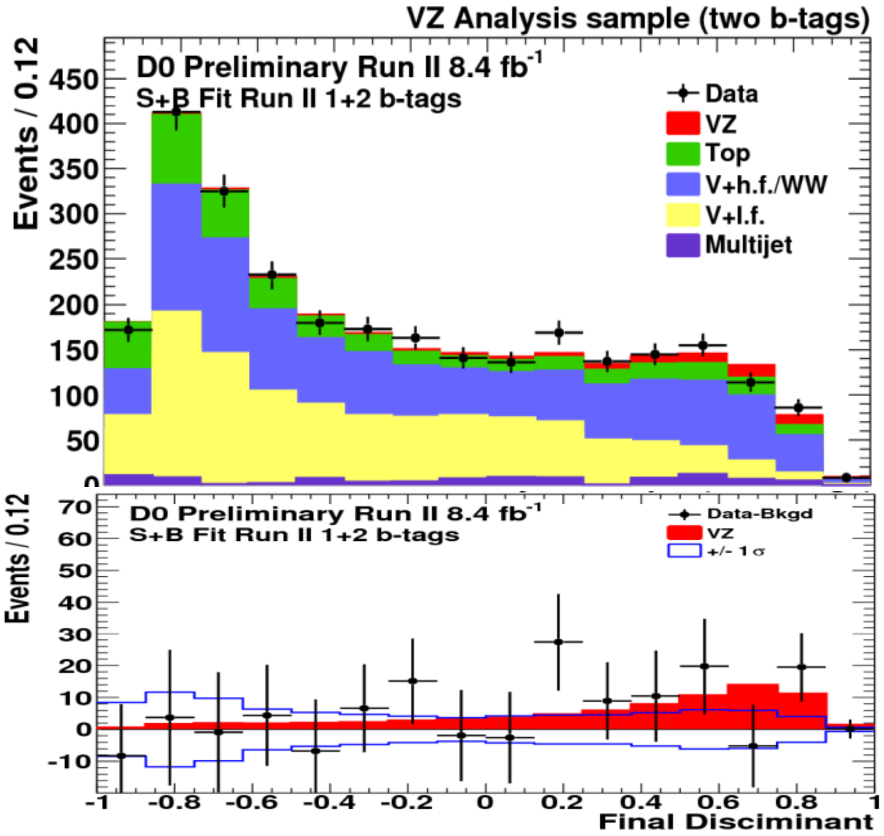
Replace H with Z

WZ→lνbb: σ = 105 fb
ZZ →ννbb: σ = 81 fb
ZZ → llbb: σ = 27 fb

Total VZ: σ = 213 fb

Z→bb yields is 5 times larger, but more W+jets, and also background from WW.

_MET + HF jets

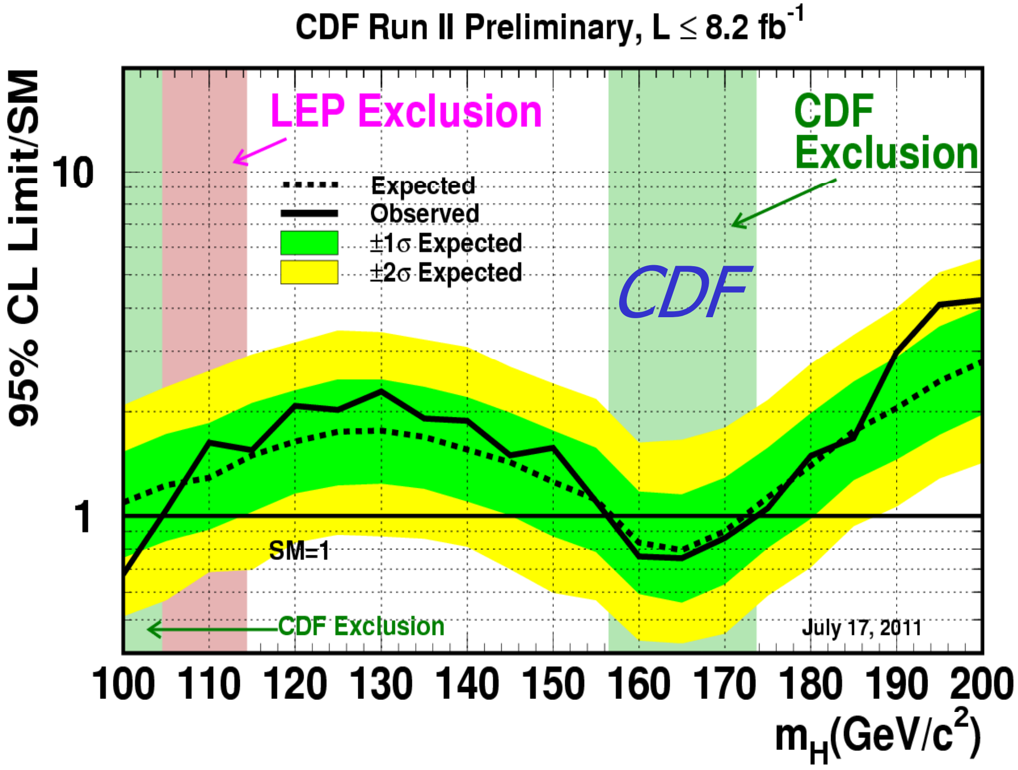


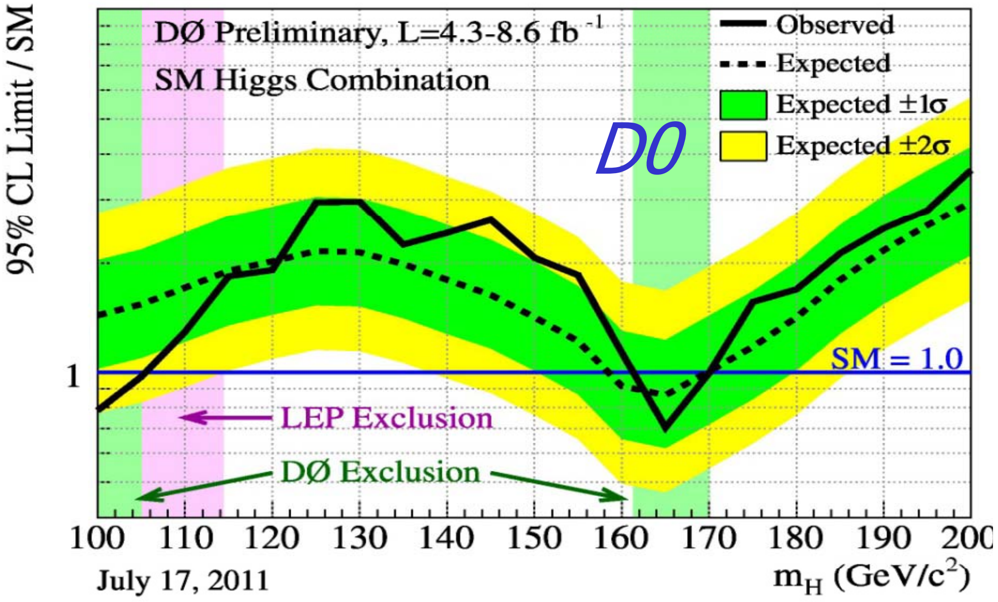
Apply similar analysis as low mass H→bb analysis, and check sensitivity.

Cross-section measurement:
$\sigma(WZ+ZZ)_{mes} / \sigma_{SM}$= **1.5 ± 0.5**

2.8 s.d. from BG-only hypothesis

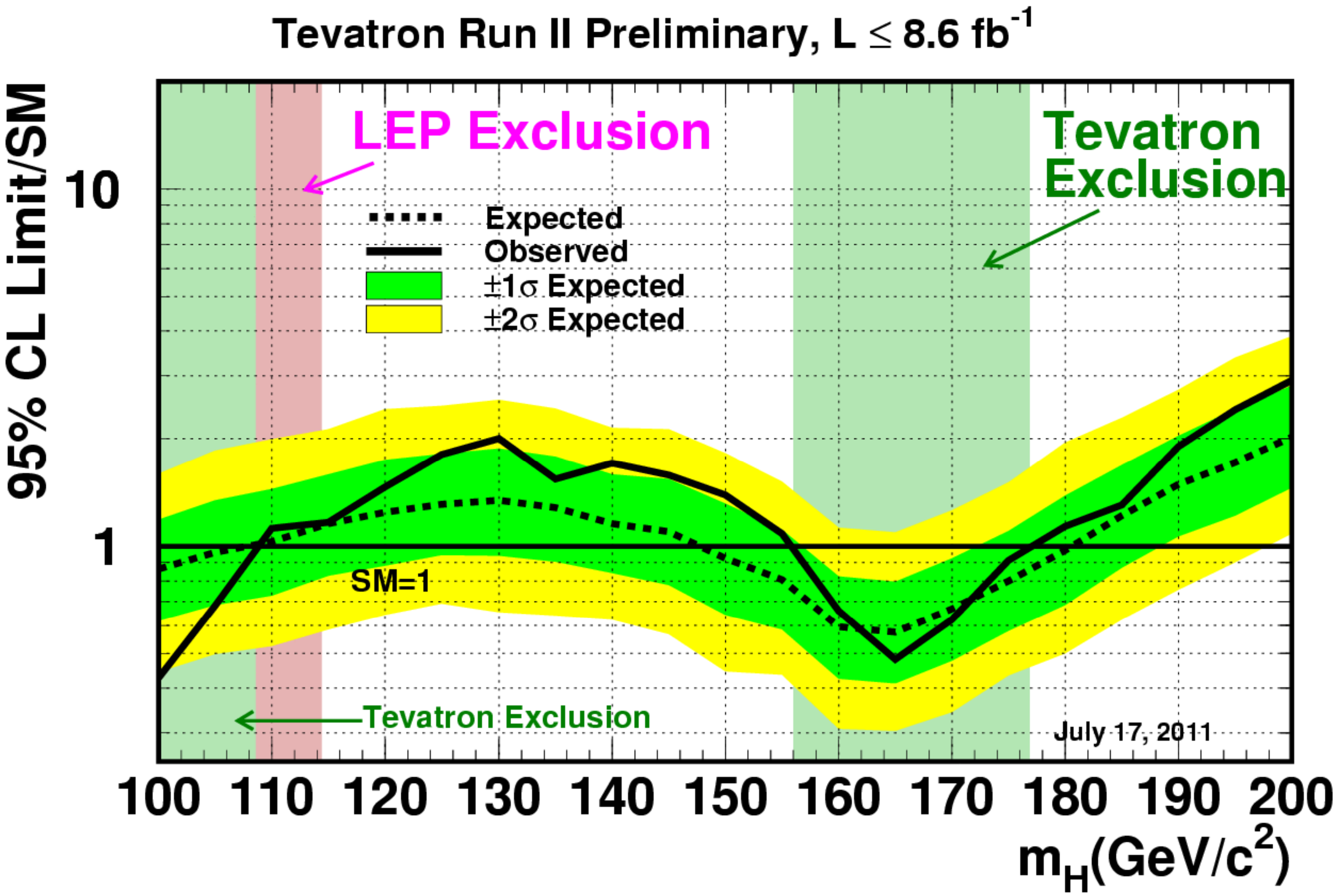
CDF/D0 Limits





Similar shapes: small deficit below 115 GeV,
small but broad excess around 130 GeV,
exclusion around 160 GeV

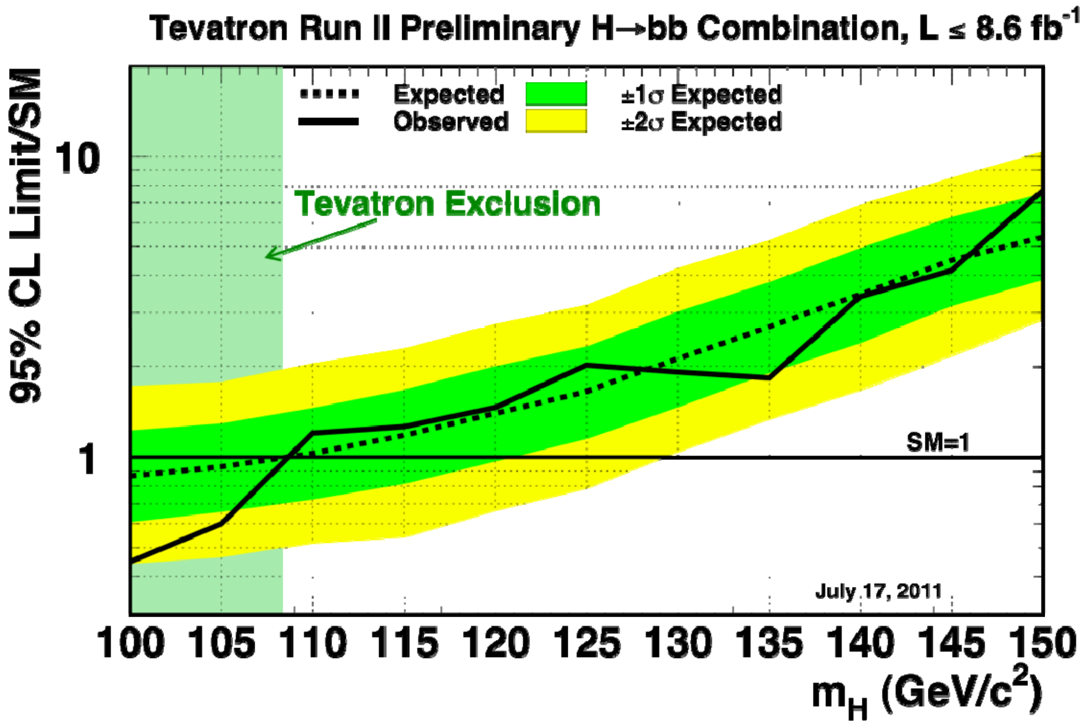
New Tevatron Combination



Observed Exclusion : 100-109 and 156-177 GeV

Expected Exclusion : 100-108 and 148-181 GeV

H→bb



H→bb channel provides best sensitivity in the mass region just above the LEP bounds

Evidence/observation of this decay mode is important for establishing that a Higgs-like signal found in other channels is in fact the SM Higgs. It will be best done at the Tevatron in the foreseeable future.

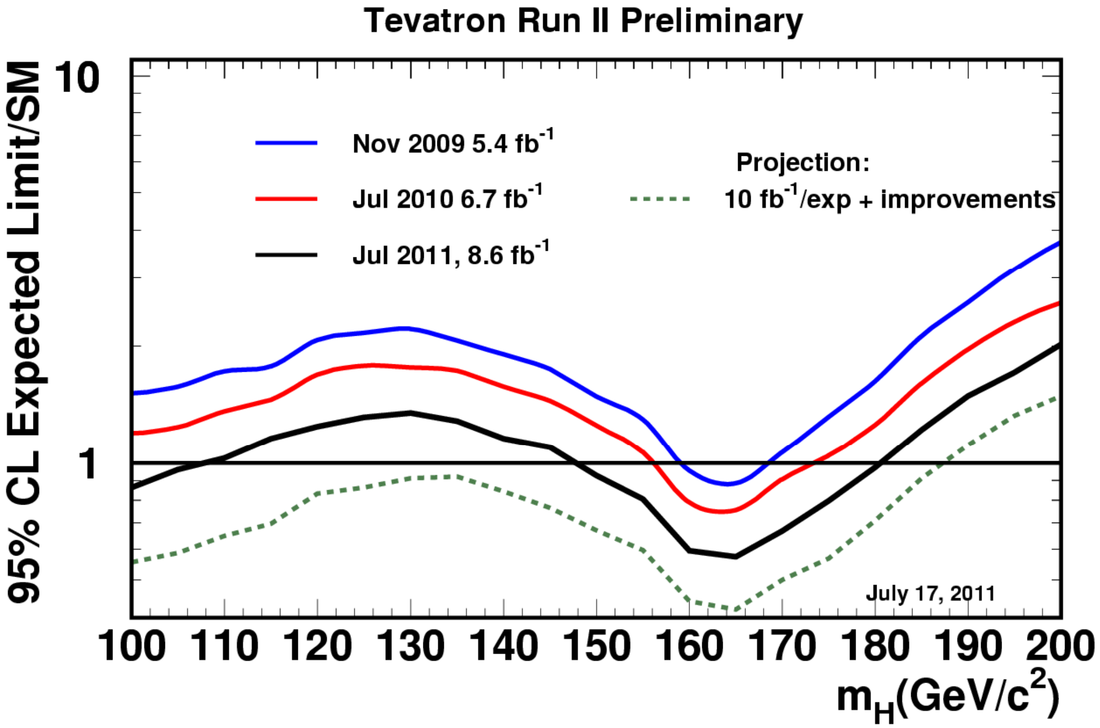
Conclusions and Outlook on Higgs

Tevatron exclusion has been extended at high mass

Tevatron is reaching exclusion sensitivity at lowest mass (~115 GeV)

On track to reach 95% CL exclusion sensitivity over expected m_H range, i.e. from 100 to 185 GeV

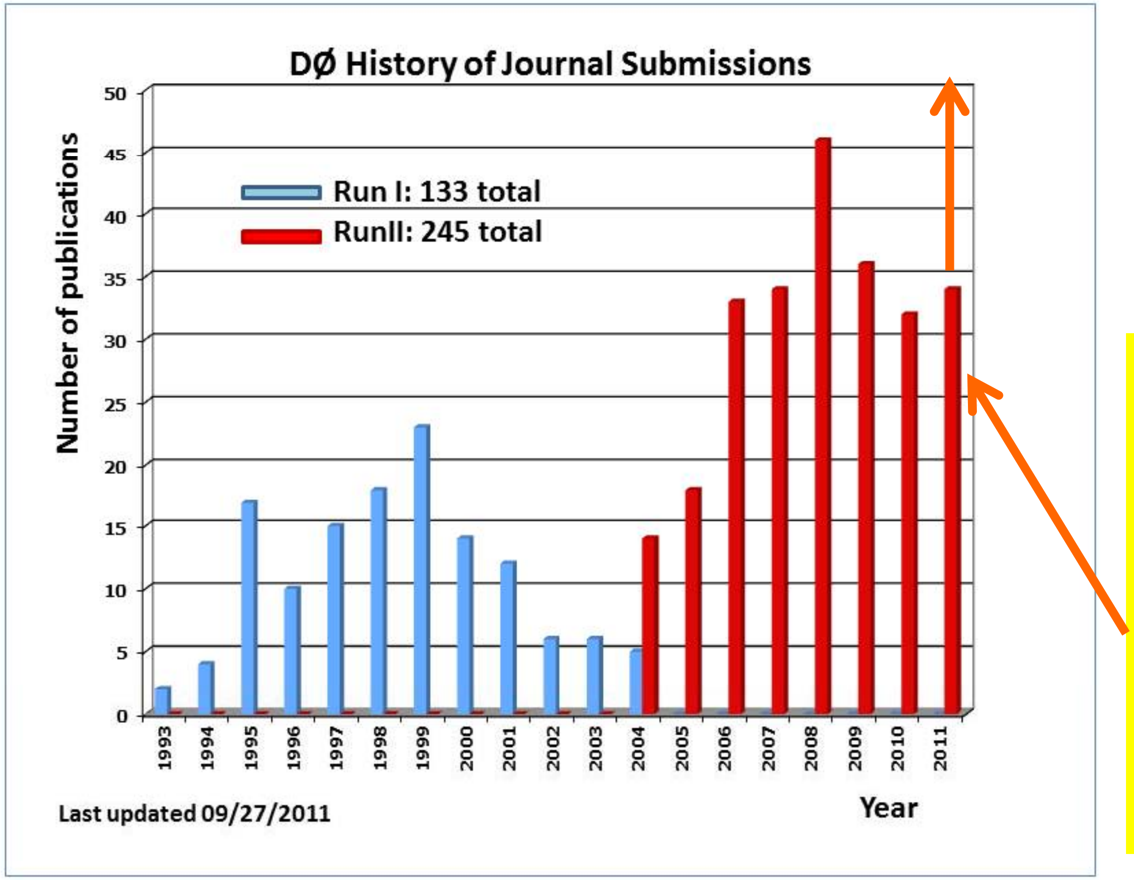
Best sensitivity to H→bb ,
→Tevatron will remain complementary to LHC at least until 14 TeV Run



Publications

32 publications in 2010
Very good first part of 2011, already 34 publications,
Aiming at breaking the year record of 46!

247 total



26 papers in the first six months of 2011, Best ever # of papers/6 months.

Future is in front of us !! ;)

$\Lambda_b \to J/\psi\Lambda$ Branching Fraction

Particle properties (masses, decay BRs, lifetimes etc) sensitive to different models of non-perturbative QCD.

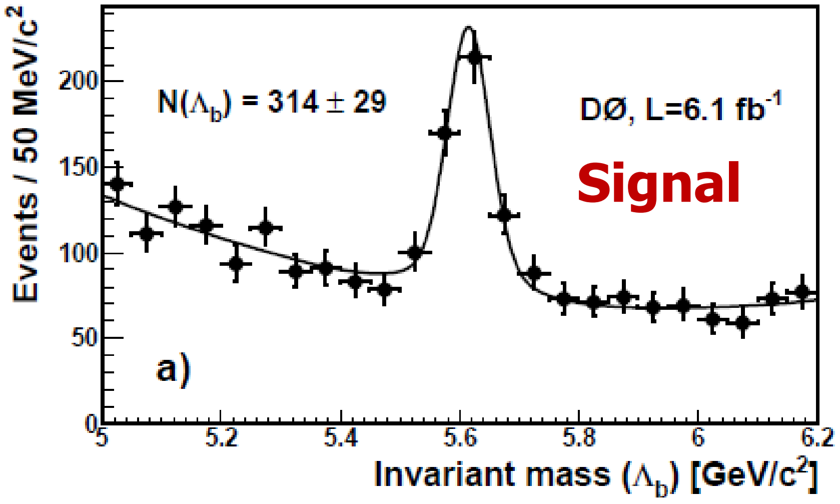
Measure BR relative to topologically similar, well-measured reference channel $B^0 \to J/\psi K_S^0$:

$$\sigma_R \equiv \frac{f(b\to\Lambda_b)\cdot ß(\Lambda_b\to J/\psi\Lambda^0)}{f(b\to B^0)\cdot ß(B^0\to J/\psi K_S^0)} =$$

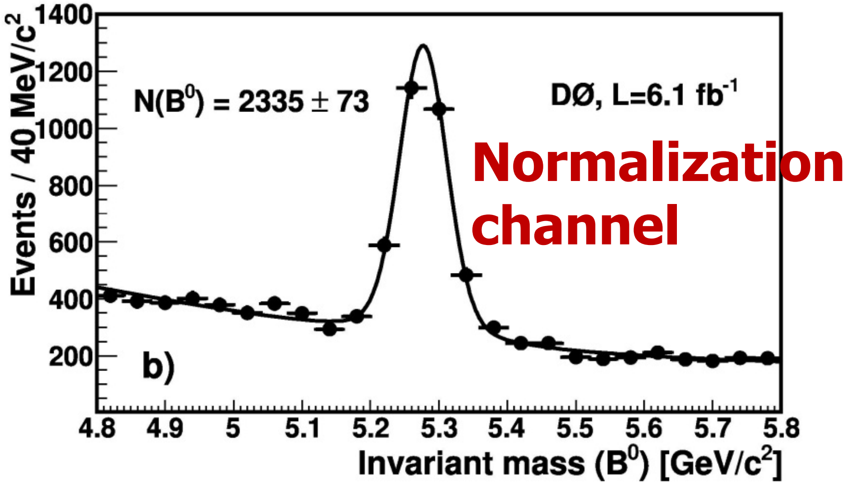
0.345 ± 0.034 (stat.) ± 0.033 (syst.) ± 0.003 (PDG)

(existing WA: 0.270 ± 0.130)

Factor 3 improvement on previous W.A. precision.



Signal

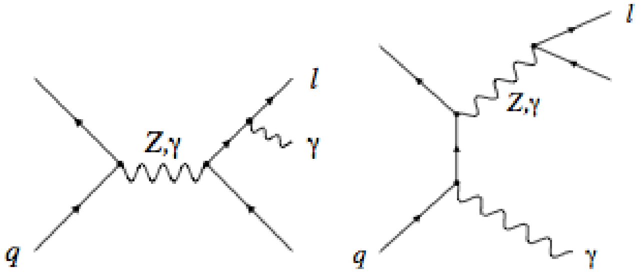


Normalization channel

PRD-RC 84, 031102 (2011)

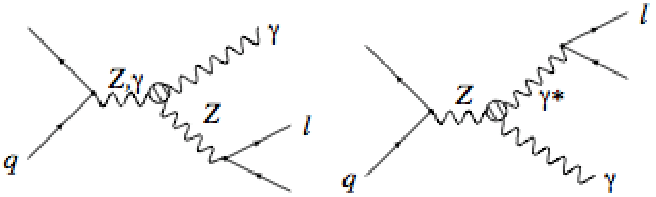
Dibosons - Zγ

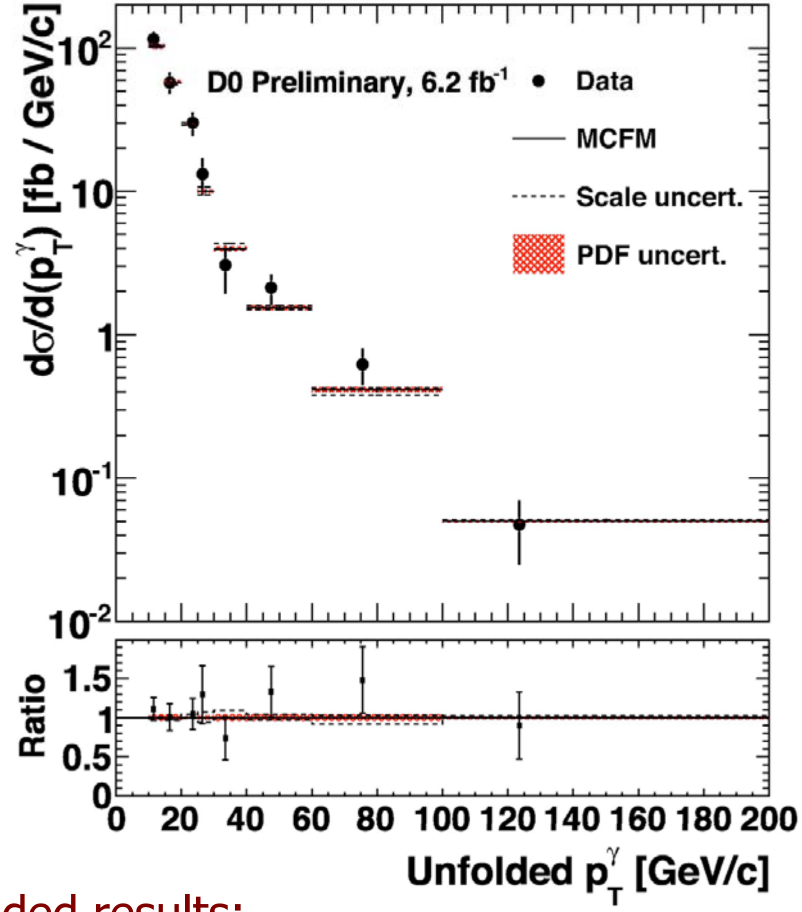
Zγ

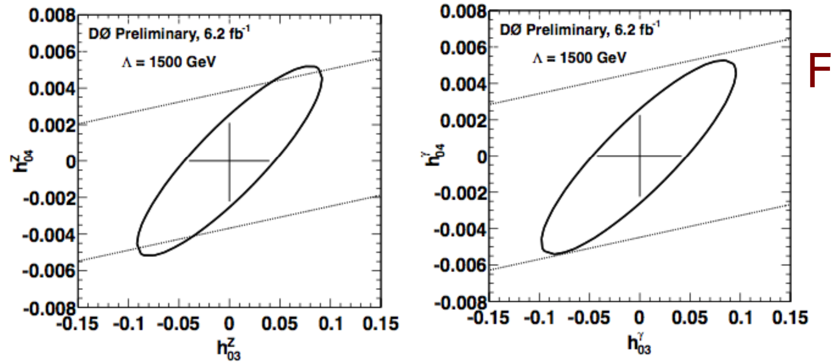


- Zγ couplings not allowed in SM
- search for anomalous ZZγ couplings

:







Fully unfolded results:

	$\sigma \times \mathcal{B}$ [pb]
$ee\gamma$ Data	1.03 ± 0.06 (stat.) ± 0.06 (syst.)
$\mu\mu\gamma$ Data	1.16 ± 0.06 (stat.) ± 0.07 (syst.)
$ll\gamma$ Combined Data	1.09 ± 0.04 (stat.) ± 0.07 (syst.)
NLO MCFM	1.10 ± 0.03

Z/γ* transverse momentum

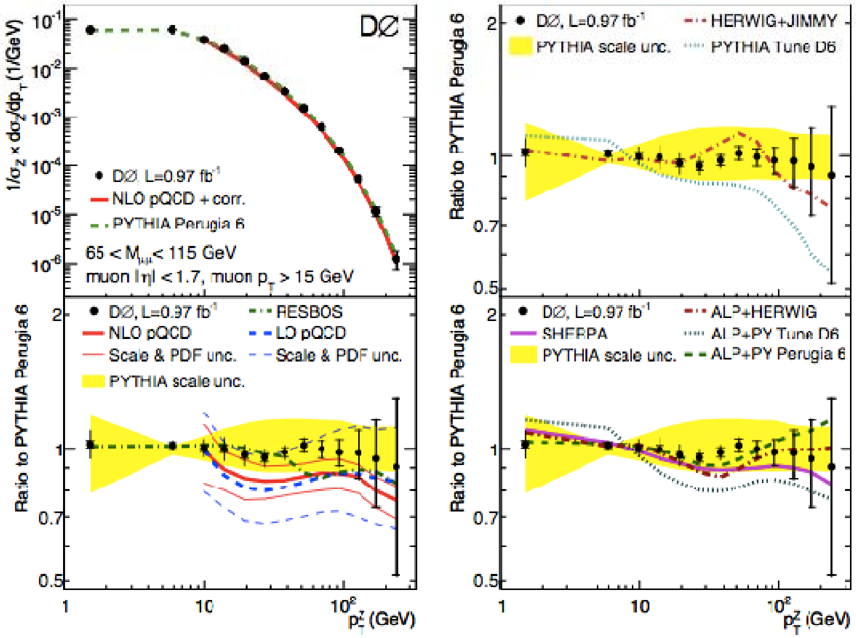
- **Z/γ* kinematics provides colorless probe of underlying collision process**
- **Z /γ* p_T is excellent probe of ISR**
- **results are presented at particle level**
- **Pythia Perugia6 gives best description of data over entire kinematic range**
- **p_T distribution uncertainty dominated by detector resolution and efficiencies**
- **alternate approach:**

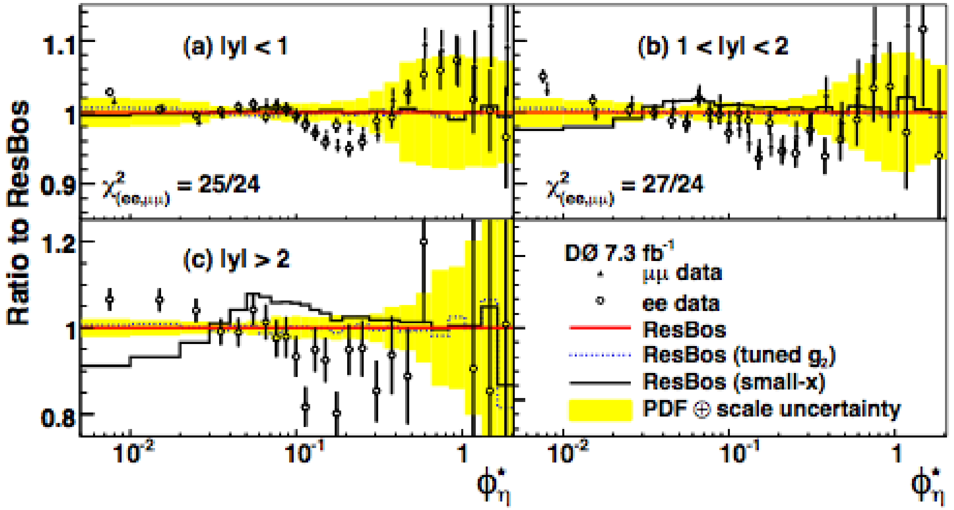
$$\phi^*_\eta = \tan([(\pi - \Delta\phi)/2]\sin\theta^*$$

where

$$\cos\theta^* = \tanh[(\eta^{(-)} - \eta^{(+)})/2]$$

- **sensitive to same physics, but much reduced detector uncertainties**



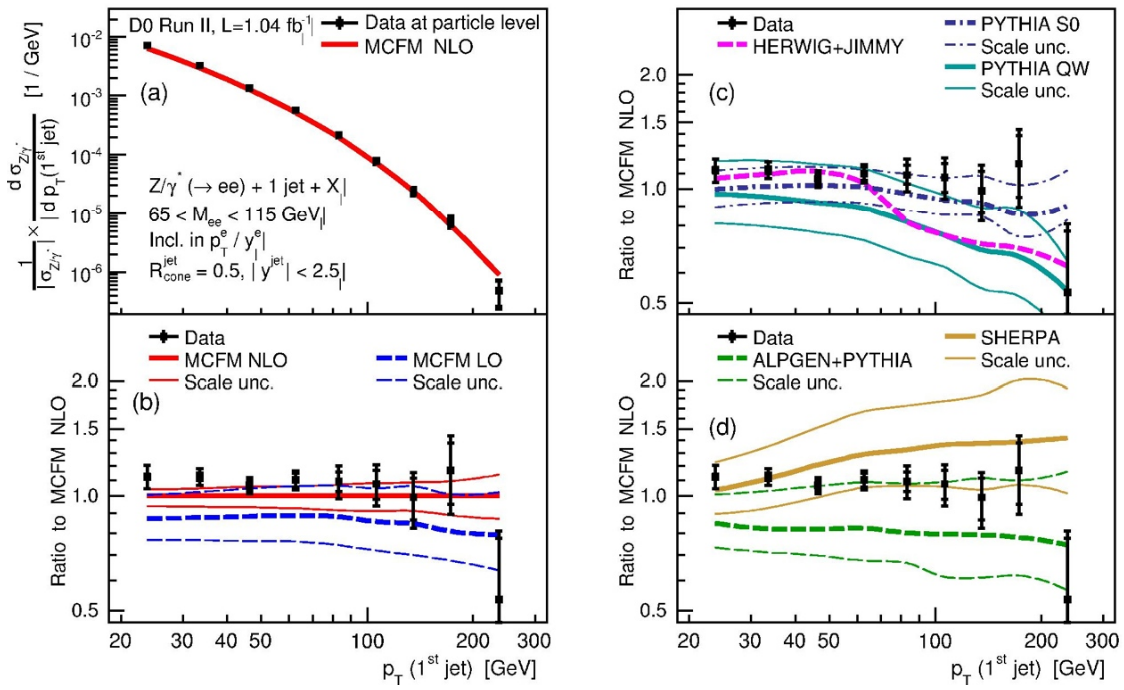


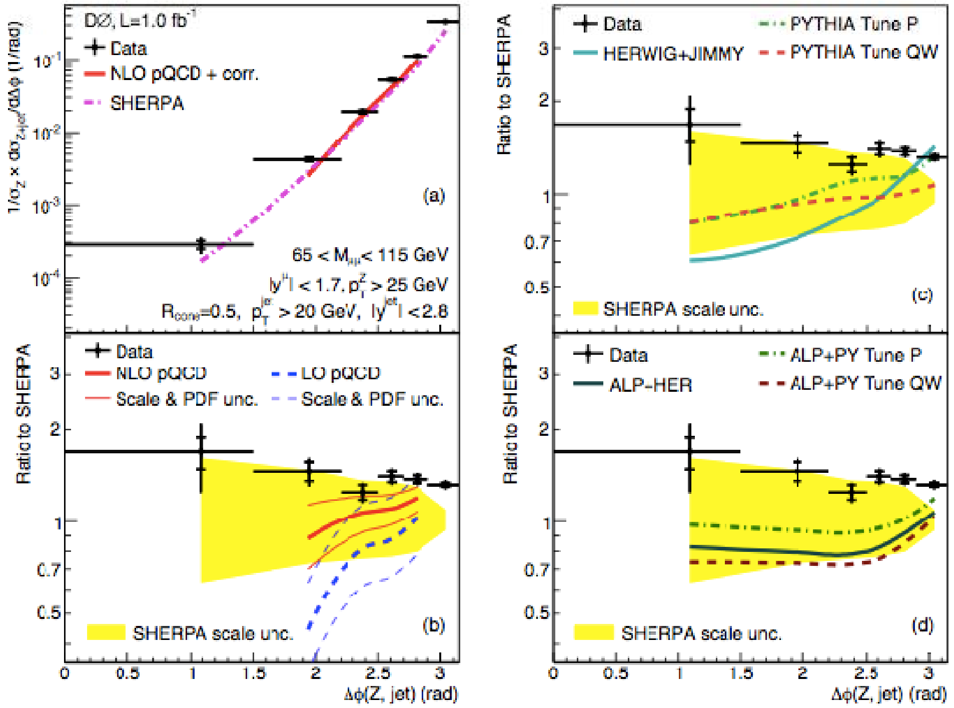
Data are compared with resummed calculation: small uncertainties allow for detailed comparison

ResBos cannot reproduce data everywhere

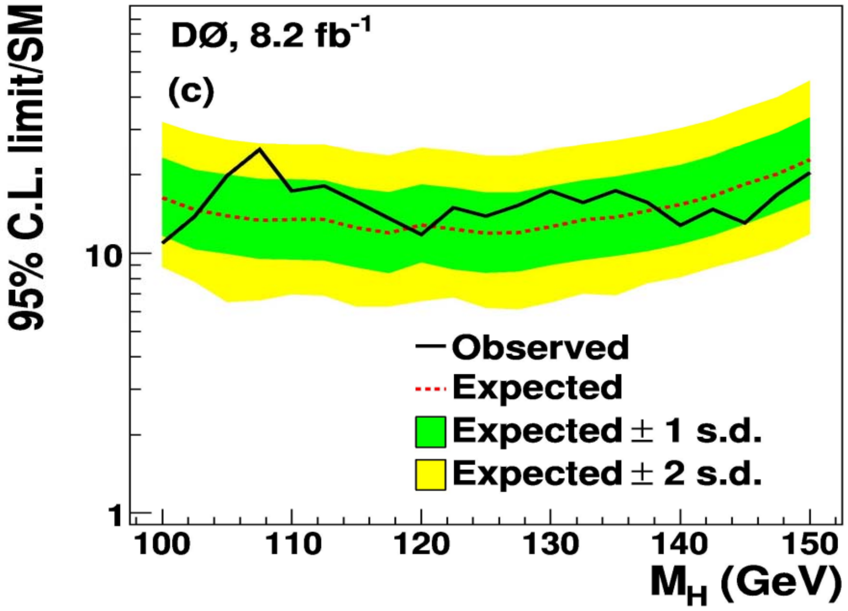
Z/γ* → ll + jets

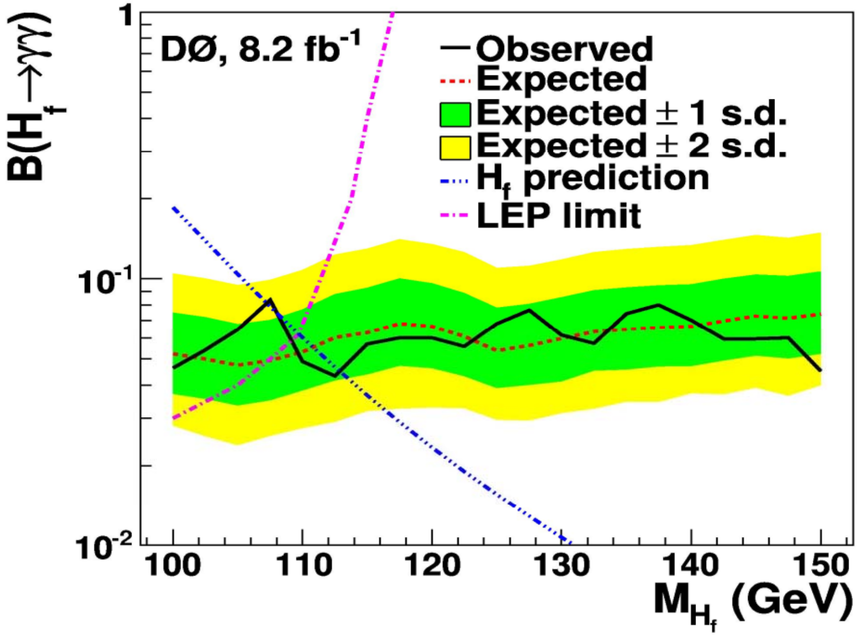
- Z provides colorless probe of collision and hard scale → study kinematics of hadronic recoil
- Extensive set of measurements carried out in electron and muon decay channels which examined jet p_T (1,2,3 jets), Z p_T, angular correlations
- Novel techniques employed for unfolding, thorough study of systematics
- Careful studies of different theoretical effects: NLO corrections, PDFs, MC tunes
- Techniques have been carried forward to other V+jets measurements





SM and Fermiophobic Higgs in γγ final state





CDF-D0 combinations: Best fermiophobic Higgs limits: mH > 119 GeV