Latest Results from the Tevatron

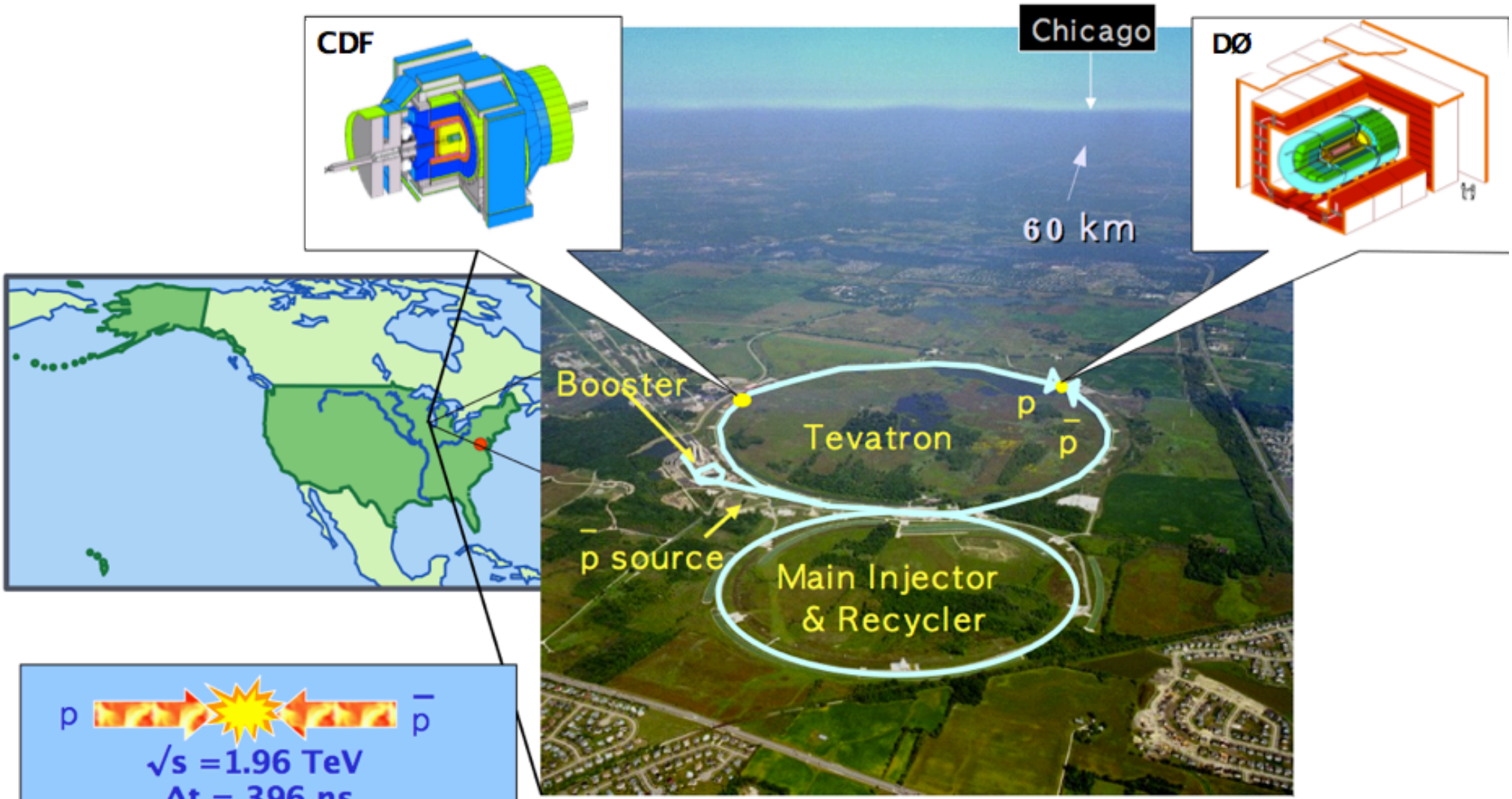
Christian Schwanenberger

University of Manchester

IoP Joint HEPP and APP Meeting

Queen Mary, 4 April, 2012

The Tevatron Collider at Fermilab



p $\bar{p}$

$\sqrt{s}$ =1.96 TeV

Δt = 396 ns

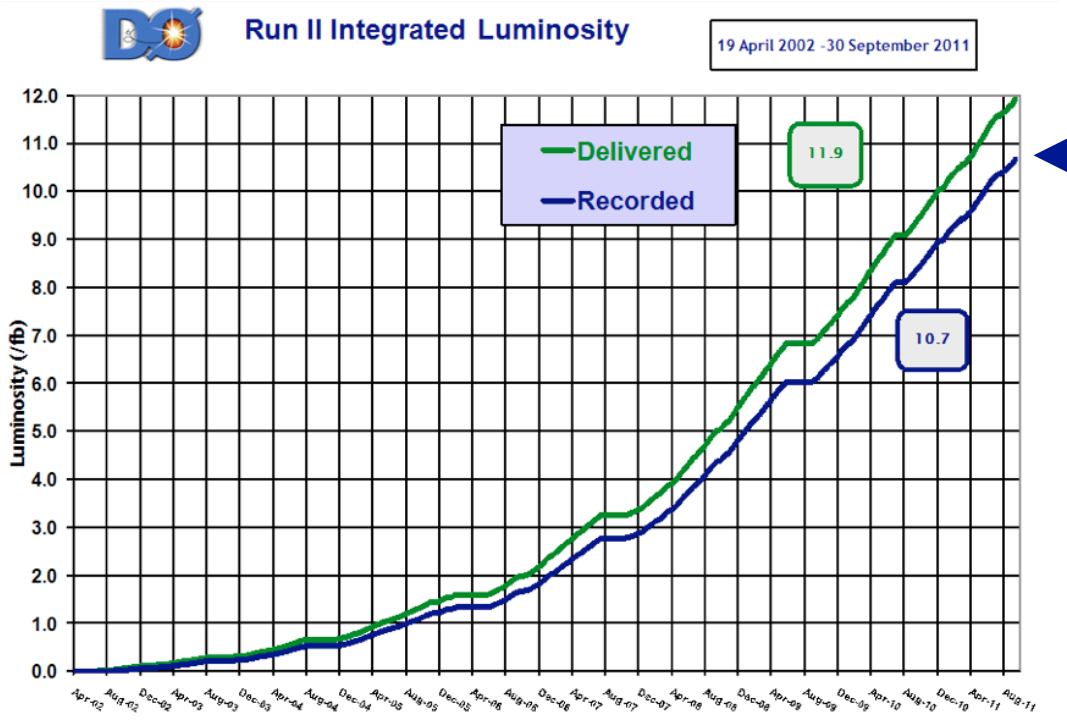
Run I 1987 (92)–95
Run II 2001–11: 100x larger dataset at increased energy

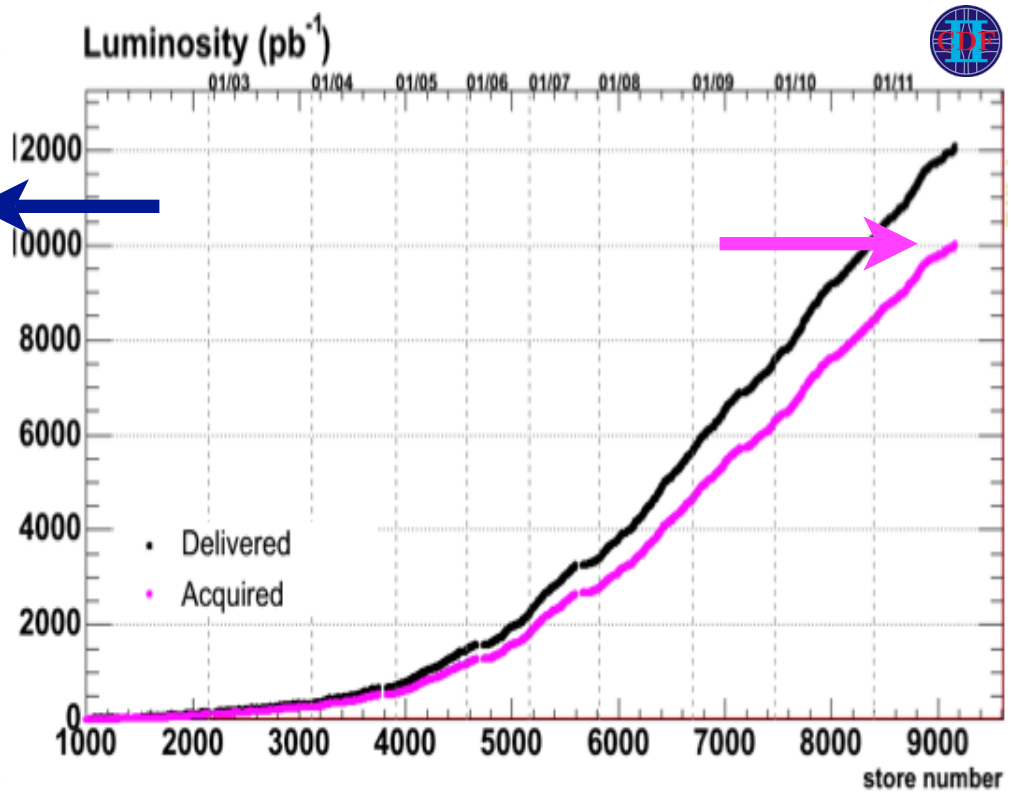
10^{-12}s after big bang!

30 September 2011

Tevatron complex shut down after 26 years of successful operation.

Many Thanks to Accelerator Division!





full data set analysed

New Results for Winter 2012

CDF

Exotic Physics

Analysis	Luminosity	More Information
Search for a new particle decaying to top+jet	8.7 fb^{-1}	WebPage
Search for dark matter in monotop events	7.7 fb^{-1}	WebPage
Search for dark matter in monojet events	6.7 fb^{-1}	WebPage
Search for new physics in same sign dilepton with ττ	6.0 fb^{-1}	WebPage
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Measurement of BR(t→Wb)	7.5 fb^{-1}	WebPage
Measurement of single top production cross section	7.5 fb^{-1}	WebPage
Measurement of the W boson polarization from top quark decays using dilepton events	5.1 fb^{-1}	WebPage
Measurement of ttbar spin correlation coefficient	5.1 fb^{-1}	WebPage
Tevatron combination of the W boson polarization from top quark decays	≤5.4 fb^{-1}	WebPage

Higgs Physics

Analysis	Luminosity	More Information
Tevatron Higgs combination	≤10 fb^{-1}	WebPage
CDF Higgs combination	≤10 fb^{-1}	WebPage
CDF fermiophobic Higgs combination: H→γγ	≤10 fb^{-1}	WebPage
Search for Higgs boson in WH→(e/mu/tau) γ bb	9.4 fb^{-1}	WebPage
Search for Higgs boson in WH/ZH→MET+bb	9.5 fb^{-1}	WebPage
Search for Higgs boson in ZH→llbb	9.5 fb^{-1}	WebPage
Search for Higgs boson in WH/ZH in the all-hadronic final state	9.5 fb^{-1}	WebPage
Search for H → WW	9.7 fb^{-1}	WebPage
Search for the Higgs boson in association with Top quarks	9.4 fb^{-1}	WebPage
Search for H→4 leptons	9.7 fb^{-1}	WebPage
Search for a SM Higgs with the diphoton final state	10 fb^{-1}	WebPage
Search for a SM Higgs boson in the τ τ+jets final state	8.3fb^{-1}	WebPage
Search for a fermiophobic Higgs with the diphoton final state	10 fb^{-1}	WebPage
Search for a fermiophobic Higgs in VH→VWW	7.6 fb^{-1}	WebPage

Electroweak Physics

Analysis	Luminosity	More Information
Measurement of the W boson mass	2.2 fb^{-1}	WebPage
Measurement of Z Pt spectrum	2.1 fb^{-1}	WebPage

Bottom Physics

Analysis	Luminosity	More Information
Search for $B_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$ Decays at CDF II	9.7 fb^{-1}	Webpage
Measurement of the B_s^0 mixing phase $\beta_s^{J/\psi\,\Phi}$ with the full CDF II data sample	9.6 fb^{-1}	Webpage
Delta ACP ($D^0 \to hh$) with full dataset	9.7 fb^{-1}	Webpage
Upsilon Decay Angular Distribution Analysis	6.7 fb^{-1}	Webpage
A Study of Quark Fragmentation using Kaons Produced in Association with Prompt D_s^{Φ}/D^{Φ} Mesons	0.4 fb^{-1}	Webpage
Search for CP Violation in $D^0 \to K_s\,\pi^+\,\pi^-$	6.0 fb^{-1}	Webpage
Measurement of $B_s \to D_s^{*+} + D_s^{*-}$ Branching Ratios	6.8 fb^{-1}	Webpage
Measurement of the B_s lifetime using $B_s \to J/\psi\,\pi$	6.7 fb^{-1}	Webpage

QCD Physics

Analysis	Luminosity	More Information
Measurement of the Z+b-jet cross section	7.9 fb^{-1}	WebPage
Measurement of the Z+jets cross section	8.2 fb^{-1}	WebPage
Measurement of the W+charm cross section	4.3 fb^{-1}	WebPage

http://www-cdf.fnal.gov/physics/W12CDFResults.html

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Bottom Physics

Analysis	Luminosity	More Information
Confirmation of a new narrow state decaying to Υ(1S)+gamma	1.0 fb^{-1}	Publication
Measurement of the relative branching ratio B0s→J/psi f0(980) to B0s→J/psi phi	8.0 fb^{-1}	Publication

Electroweak Physics

Analysis	Luminosity	More Information
Measurement of the W boson mass with the D0 detector	4.3+1.0 fb^{-1}	Publication
A measurement of the WZ and ZZ production cross sections using leptonic final states in 8.6 fb-1 of ppbar collisions	8.6 fb^{-1}	Publication
Measurements of WW and WZ production in W + jets final states in ppbar collisions	4.3 fb^{-1}	Publication
Zgamma production and limits on ZZgamma and Zgammagamma couplings in ppbar collisions at sqrt(s)=1.96 TeV	6.2 fb^{-1}	Publication
W+gamma production and limits on anomalous WWgamma couplings in ppbar collisions at sqrt(s)=1.96 TeV	4.2 fb^{-1}	Publication

New Phenomena

Analysis	Luminosity	More Information
Search for Z gamma events with large missing transverse energy in 6.2 fb-1 of ppbar collisions	6.2 fb^{-1}	Publication
A Search for pair production of the scalar top quark in muon+tau final states	7.3 fb^{-1}	Publication
Search for universal extra dimensions in ppbar collisions	7.3 fb^{-1}	Publication
A search for charged massive long-lived particles	5.2 fb^{-1}	Publication

Higgs Physics

Analysis	Luminosity	More Information
Combined CDF and D0 Search for Standard Model Higgs Boson Production with up to 10 fb-1 of Data	up to 10 fb^{-1}	Preliminary
Combined Search for the Standard Model Higgs Boson from the D0 experiment in up to 9.7 fb-1 of Data	up to 9.7 fb^{-1}	Preliminary
Combined CDF and D0 measurment of WZ and ZZ production in final states with b-tagged jets	9.7 fb^{-1}	Preliminary
Search for the standard model Higgs boson in tau lepton pair final states	9.7 fb^{-1}	Preliminary
Search for Associated Higgs Boson Production VH --> e+- nu_e mu+- nu_mu with Like Charged Electron Muon pairs using 9.7 fb-1 of ppbar Collisions at sqrt(s) = 1.96 TeV	9.7 fb^{-1}	Preliminary
Search for Higgs boson production in dilepton plus missing transverse energy final states with 8.6-9.7 fb-1 of ppbar collisions at sqrt(s)=1.96 TeV	9.7 fb^{-1}	Preliminary
Search for Higgs boson in final states with lepton, missing energy and at least two jets using b-jet identification in 9.7 fb-1 of Tevatron data	9.7 fb^{-1}	Preliminary
Search for ZH->llbb production in 9.7 fb-1 of ppbar collisions	9.7 fb^{-1}	Preliminary
Search for the standard model Higgs boson in the ZH->vvbb channel in Run II data	9.5 fb^{-1}	Preliminary
Search for standard model Higgs boson in the tau tau mu + X final state in 7.0 fb-1 of ppbar collisions at sqrt(s) = 1.96 TeV	7.0 fb^{-1}	Preliminary
Search for standard model Higgs boson with trileptons and missing transverse energy with 9.7 fb-1 of ppbar collisions at sqrt(s) = 1.96 TeV	9.7 fb^{-1}	Preliminary
Search for a Fermiophobic Higgs Boson in the di-photon final state using using 9.7 fb-1 of D0 data	9.7 fb^{-1}	Preliminary
Search for the Standard Model Higgs Boson in gammagamma + X final states at D0 using 9.7 fb-1 data	9.7 fb^{-1}	Preliminary
Evidence for WZ and ZZ production in final states with b-tagged jets	7.5-8.6 fb^{-1}	Preliminary
Search for WH associated production with 8.5 fb-1 of Tevatron data (including WZ+ZZ cross section)	8.5 fb^{-1}	Preliminary
Search for ZH-->llbb production in 8.6 fb-1 of ppbar collisions (including WZ+ZZ cross section)	8.6 fb^{-1}	Preliminary
Search for WH associated production in ppbar collisions at sqrt(s)=1.96 TeV	5.3 fb^{-1}	Publication
Search for Higgs bosons of the minimal supersymmetric standard model in ppbar collisions at sqrt(s)=1.96 TeV	5.2-7.3 fb^{-1}	Publication

QCD Results

Analysis	Luminosity	More Information
Measurement of the photon+b-jet production cross section in ppbar collisions at sqrt(s) = 1.96 TeV	8.7 fb^{-1}	Publication
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http://www-d0.fnal.gov/Run2Physics/D0Winter2012.html

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very strong contributions from the UK

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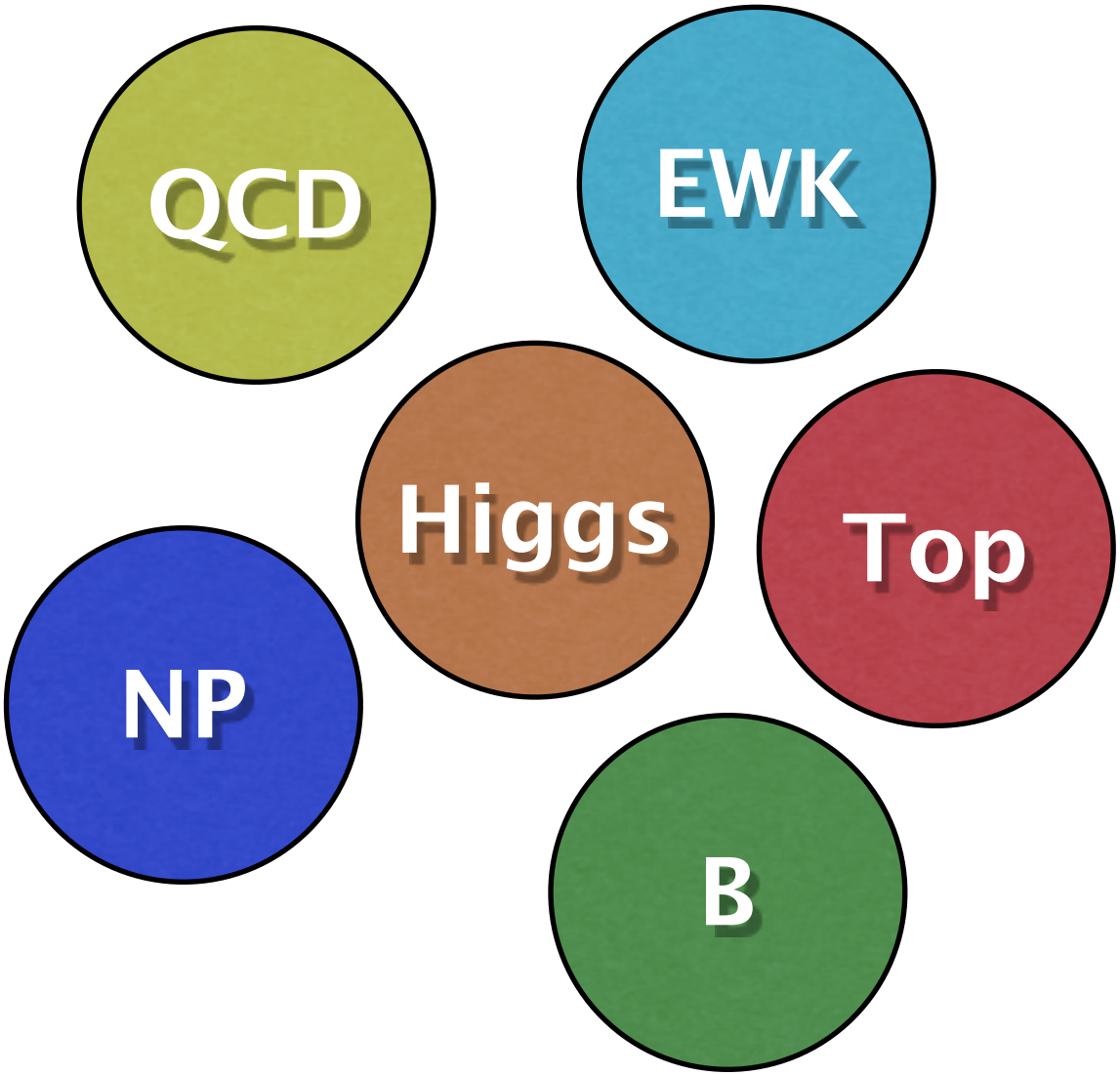
http://www-d0.fnal.gov/Run2Physics/D0Winter2012.html

Tevatron Results for Winter 2012



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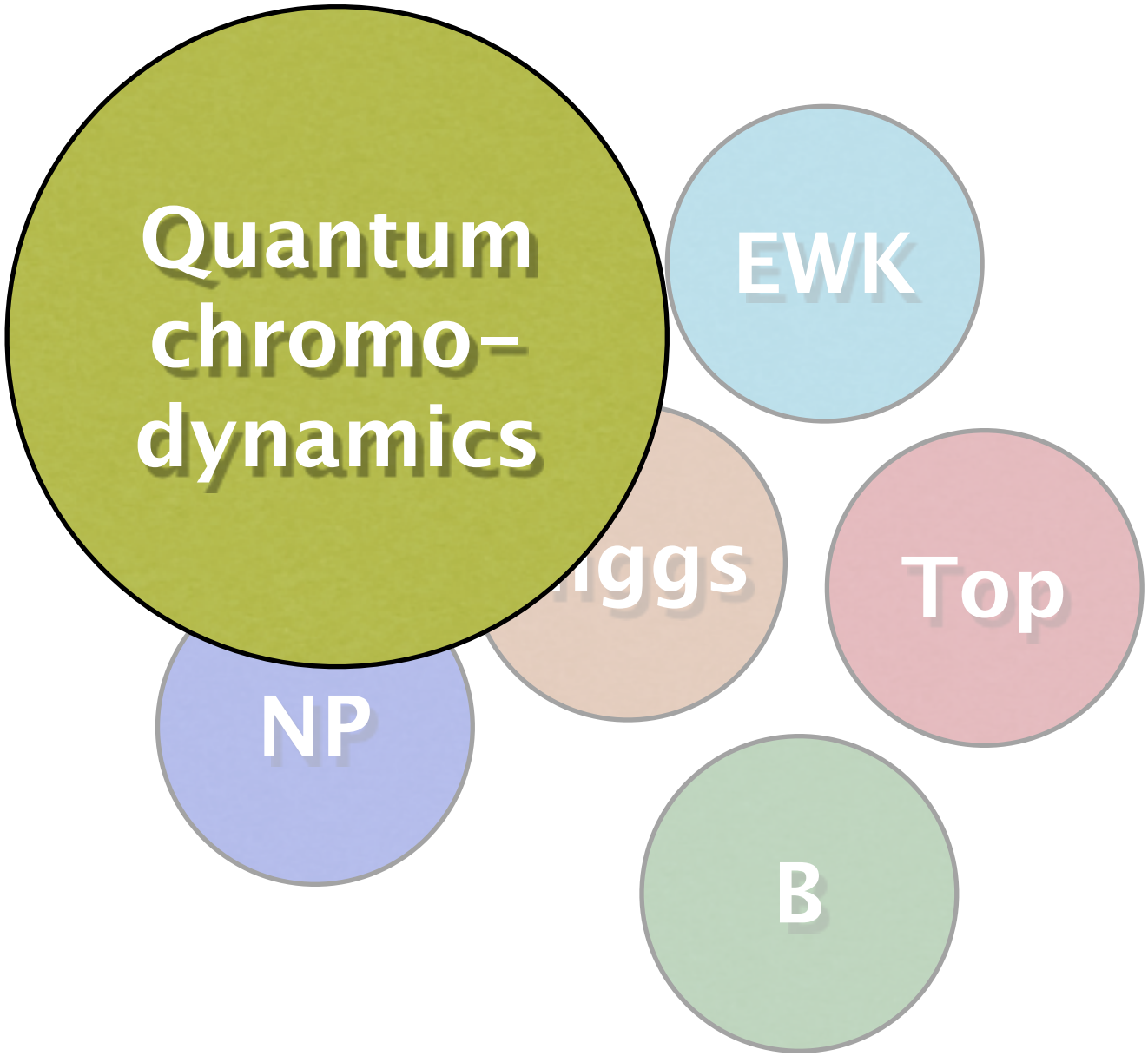
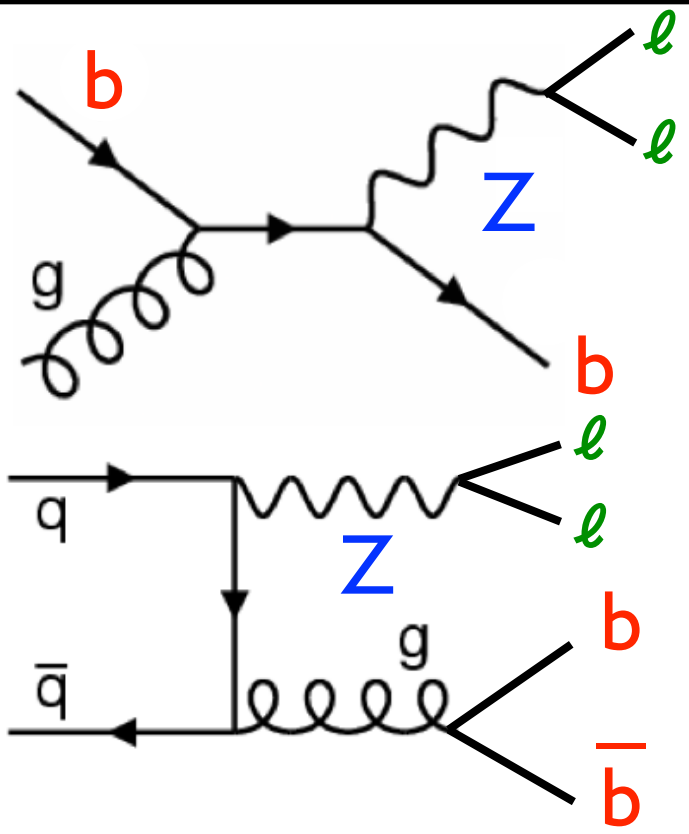
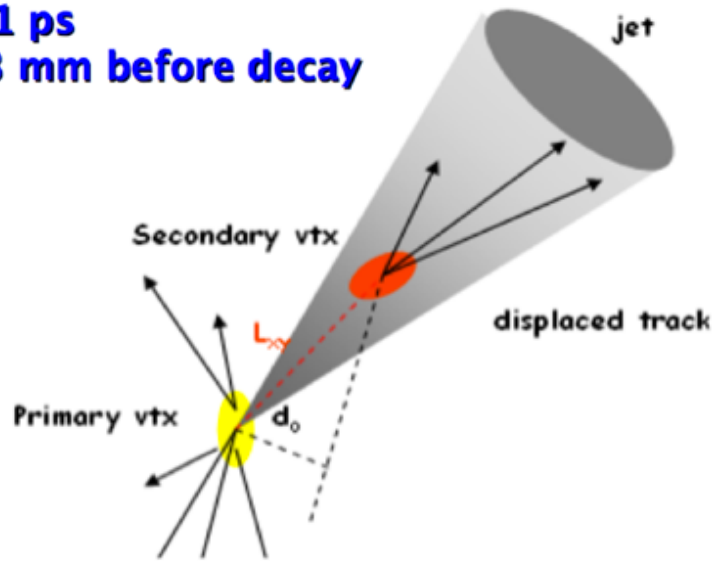


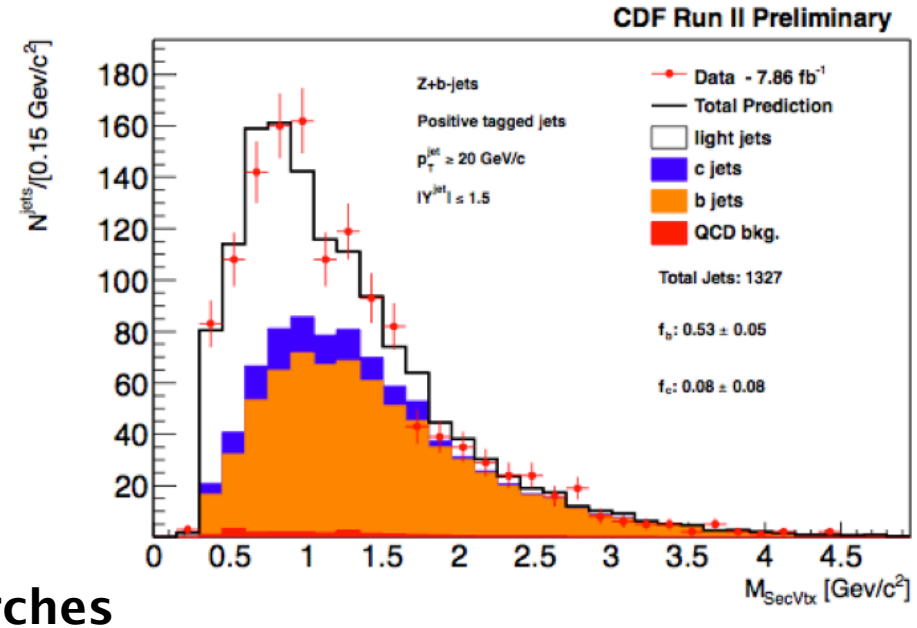
Z+b-jet Cross Section



- B hadron lifetime τ ~ 1 ps
- B hadron travel L_{xy} ~ 3 mm before decay

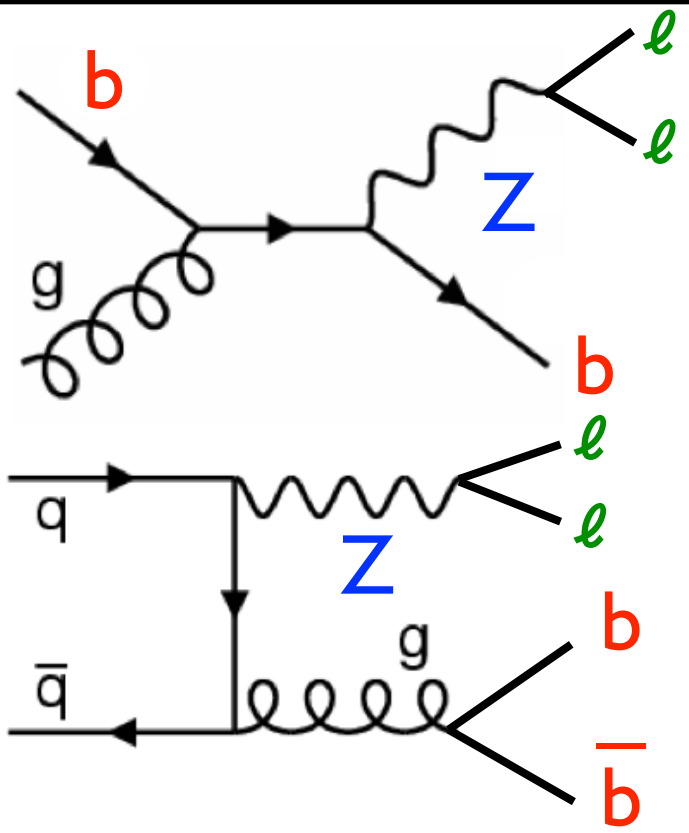


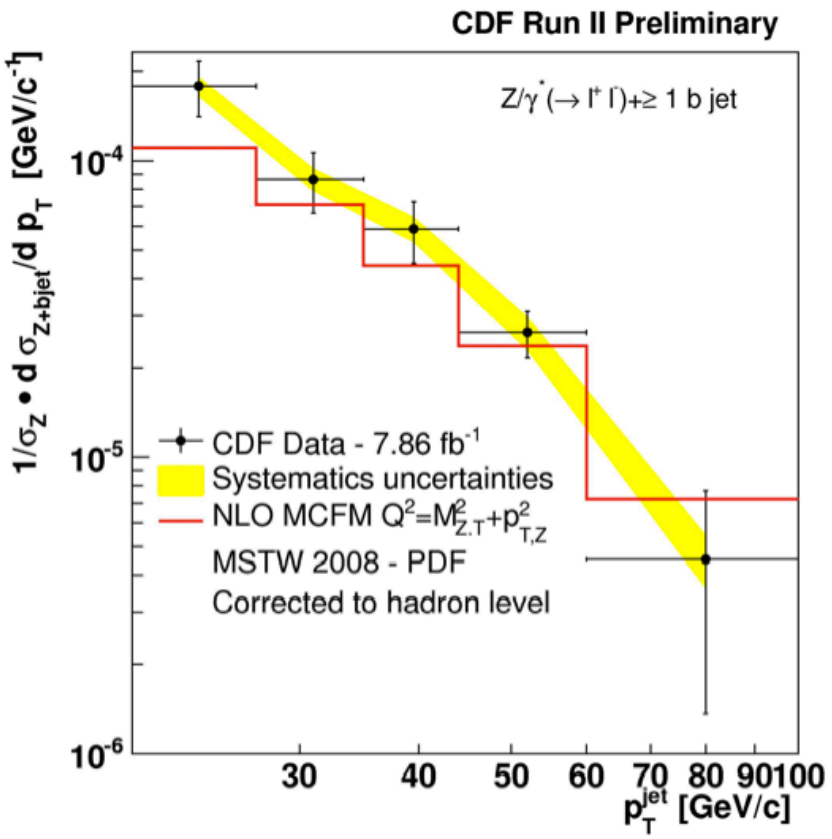
Liverpool



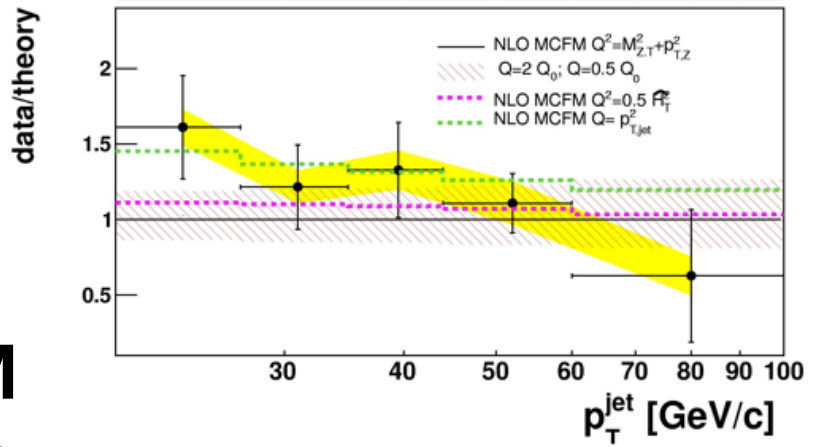
- Z bosons come unaltered from hard subprocess:
  → direct probe of hard scattering
- sensitive to b quark and gluon densities
- important background to NP and Higgs searches

Z+b-jet Cross Section





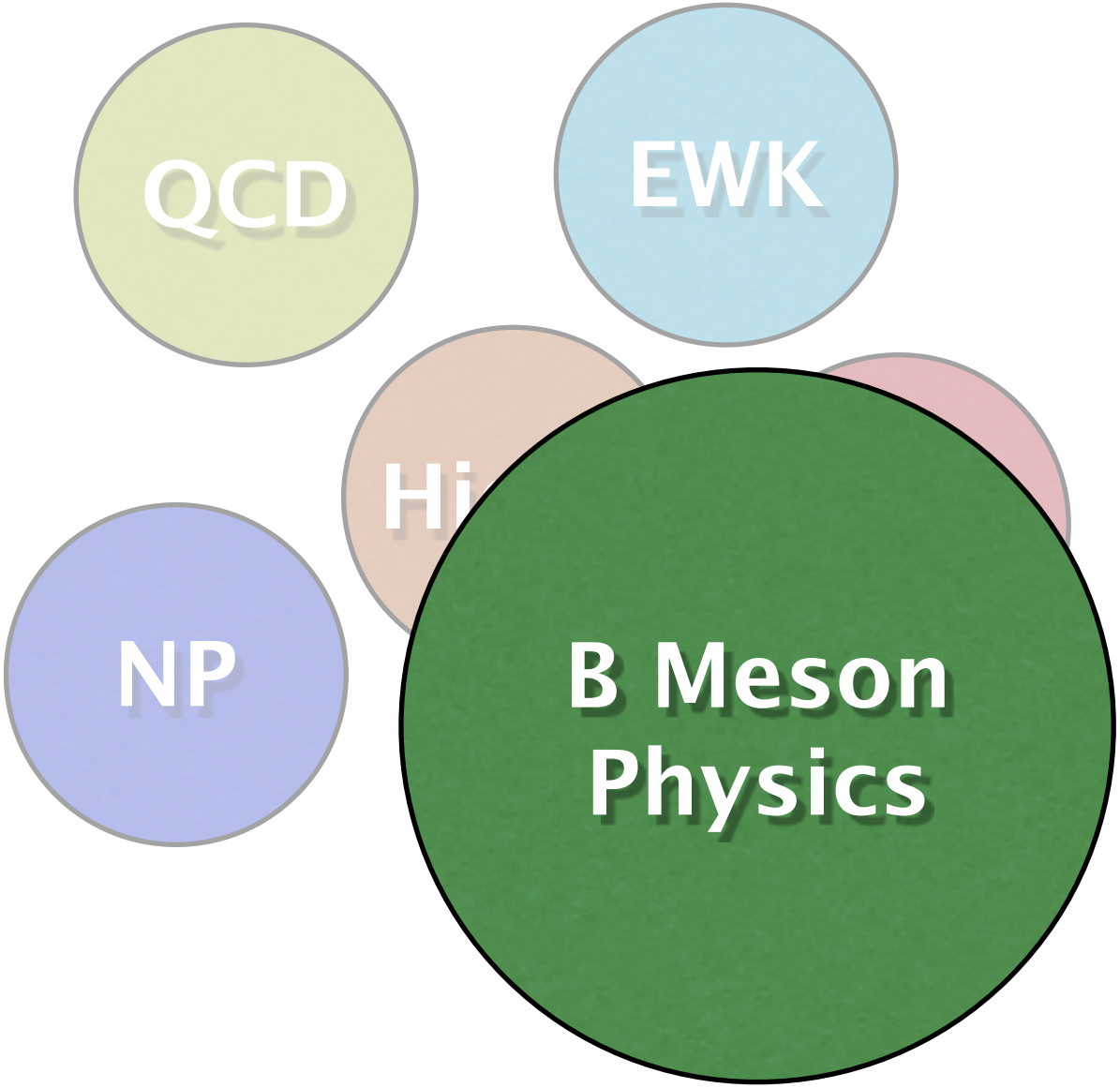
$$\frac{\sigma_{Z\_bjet}}{\sigma_Z} = 0.293 \pm 0.030^{stat} \pm 0.036^{syst}\,\%$$



MCFM NLO: 0.27%

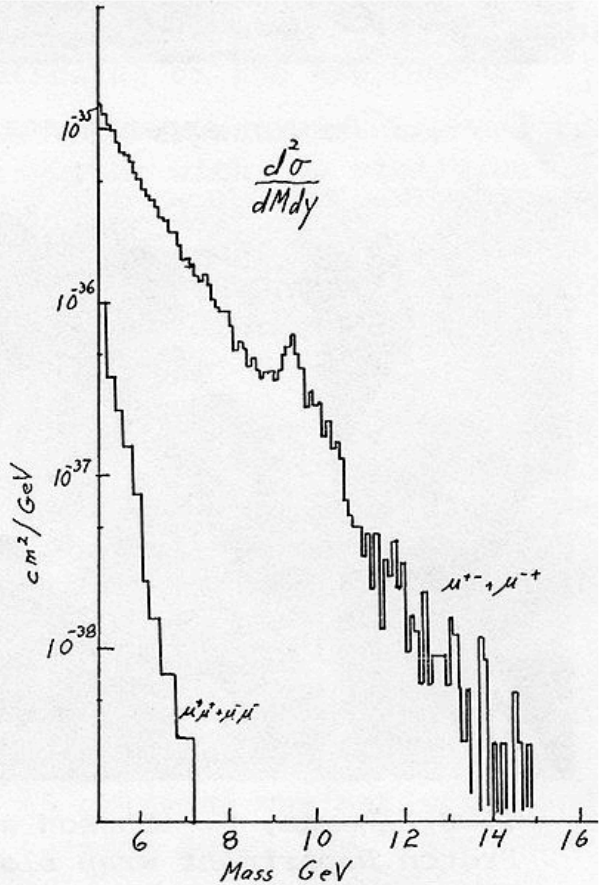
→ **good agreement with the SM**

DØ Physics Results for Winter 2012



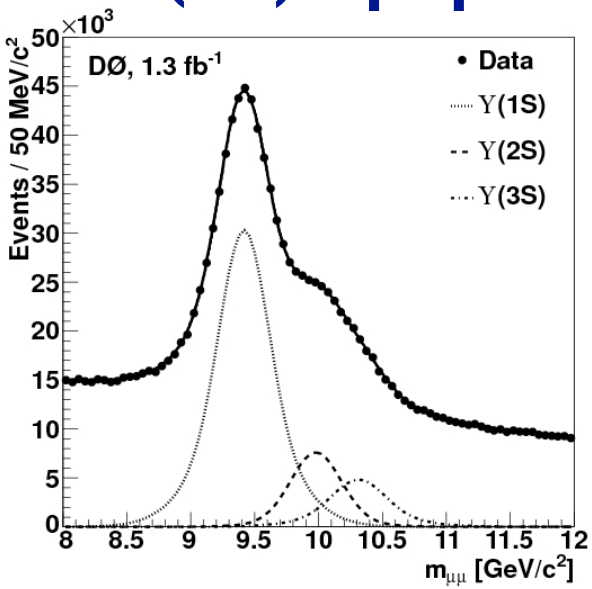
New Narrow Mass State Decaying into Υ(1S)+γ

Υ discovery:
E288 collaboration



New Narrow Mass State Decaying into Υ(1S)+γ

$\Upsilon(1S) \rightarrow \mu^+\mu^-$



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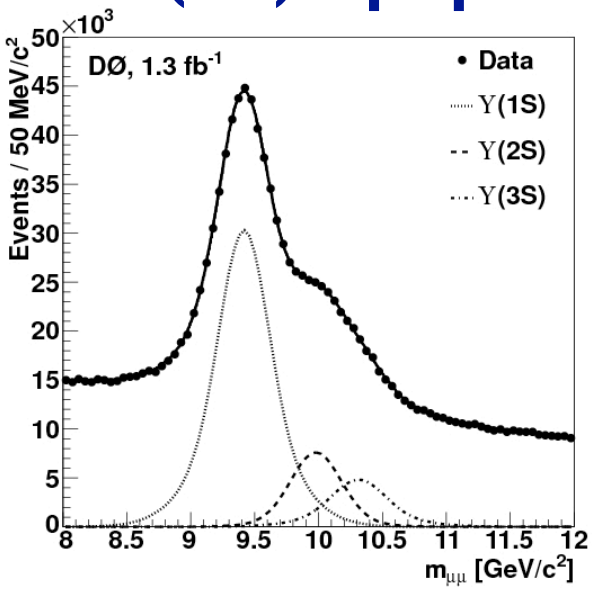
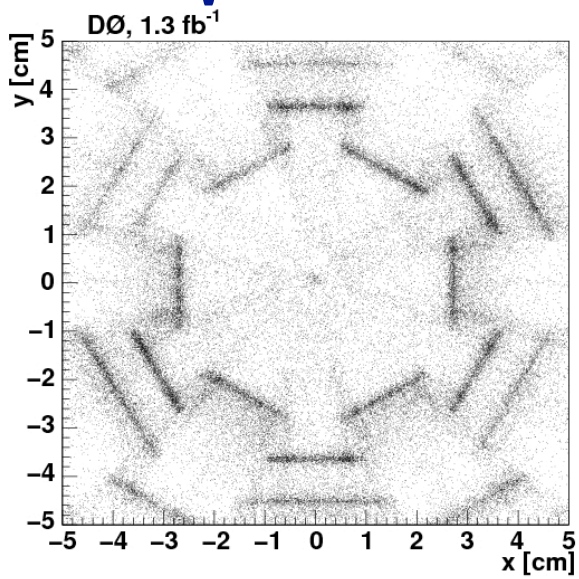


$\gamma \rightarrow e^+e^-$



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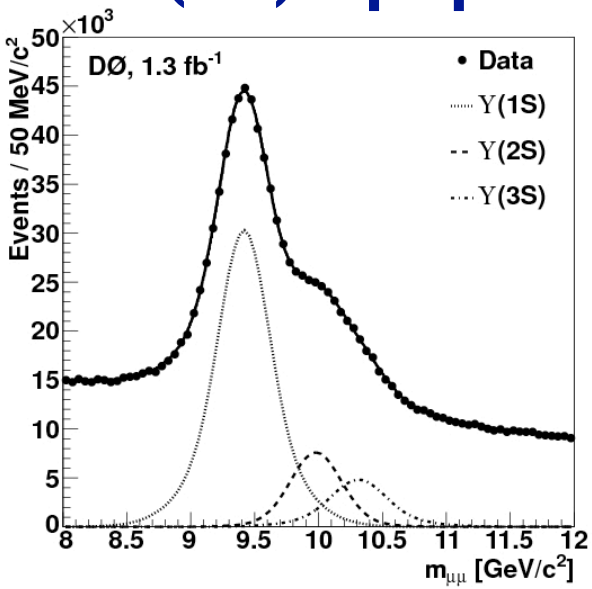

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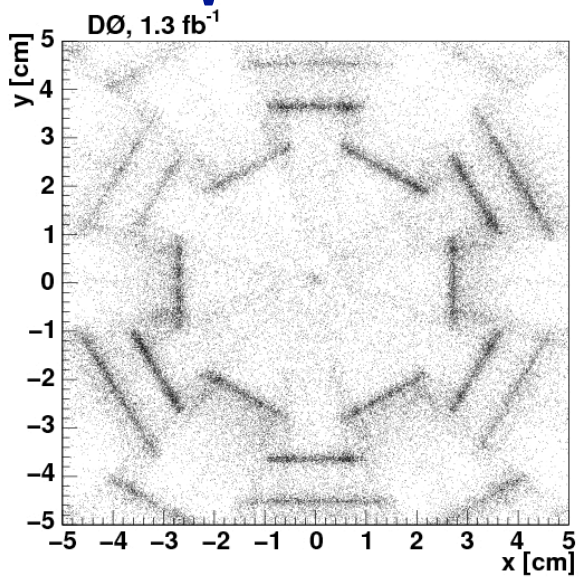

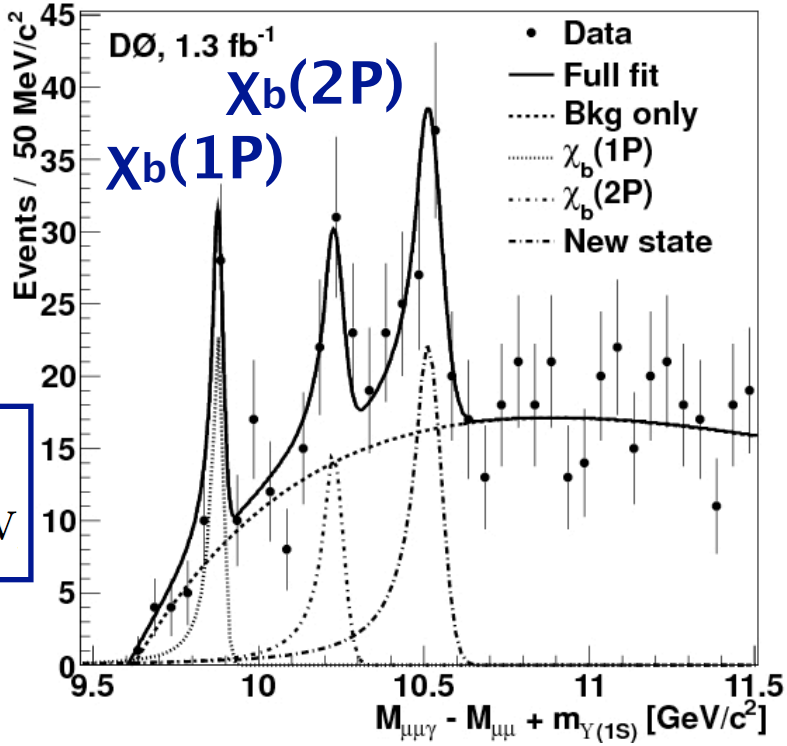

ATLAS:

$\chi_b(3P)$:

$10.530 \pm 0.005(\text{stat.}) \pm 0.009(\text{syst.})$ GeV

background model:

combine Υ(1S) with photons from different events

New Narrow Mass State Decaying into Υ(1S)+γ

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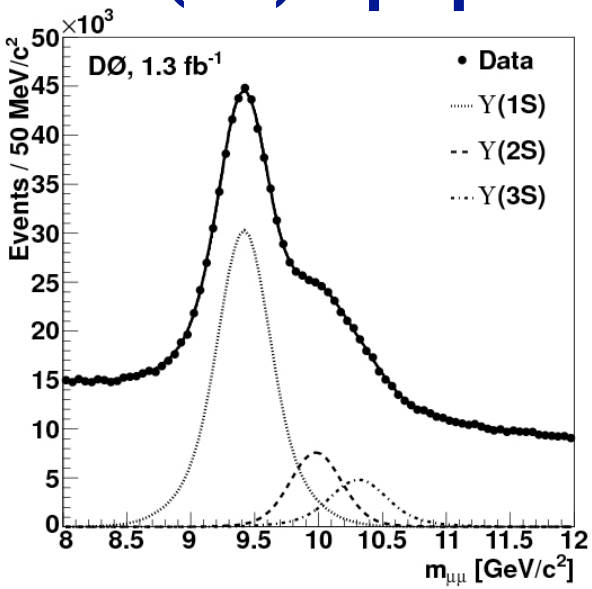
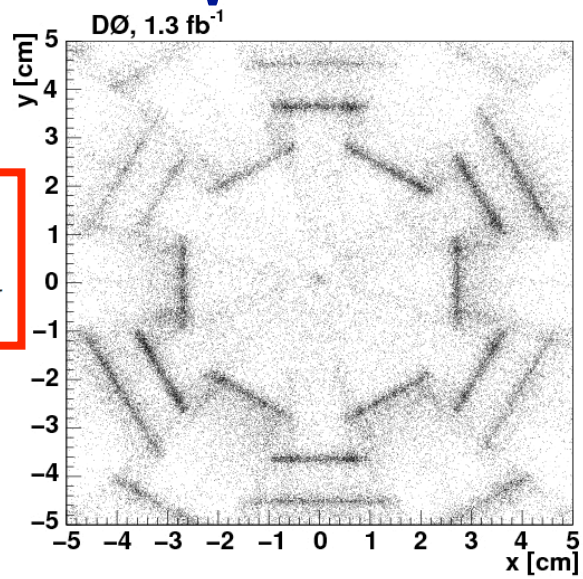


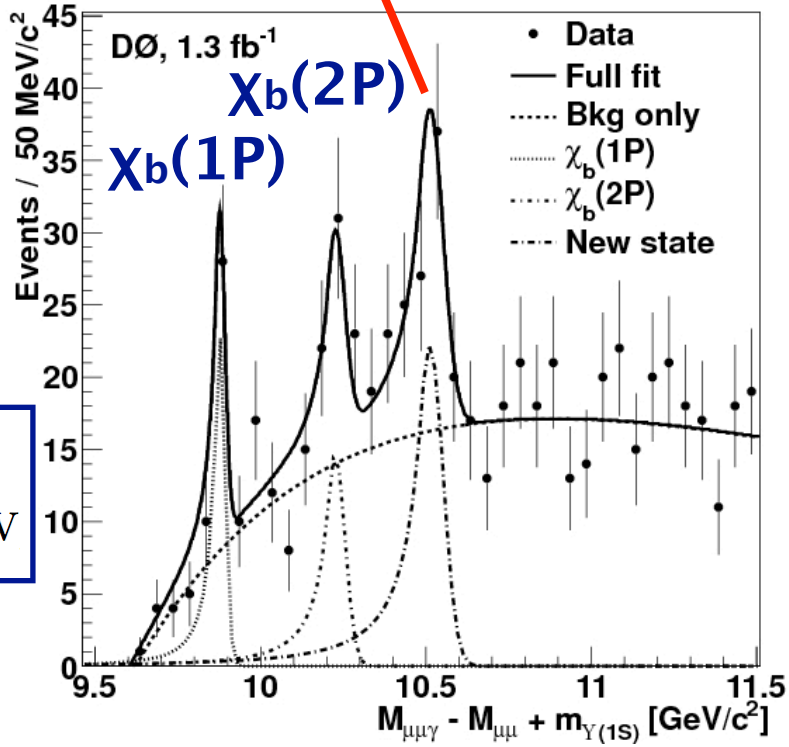
$\chi_b(3P) \rightarrow \Upsilon(1S)+\gamma$

$\chi_b(3P)$: (?)

$10.551 \pm 0.014(\text{stat.}) \pm 0.017(\text{syst.})$ GeV

$\gamma \rightarrow e^+e^-$





ATLAS:

$\chi_b(3P)$:

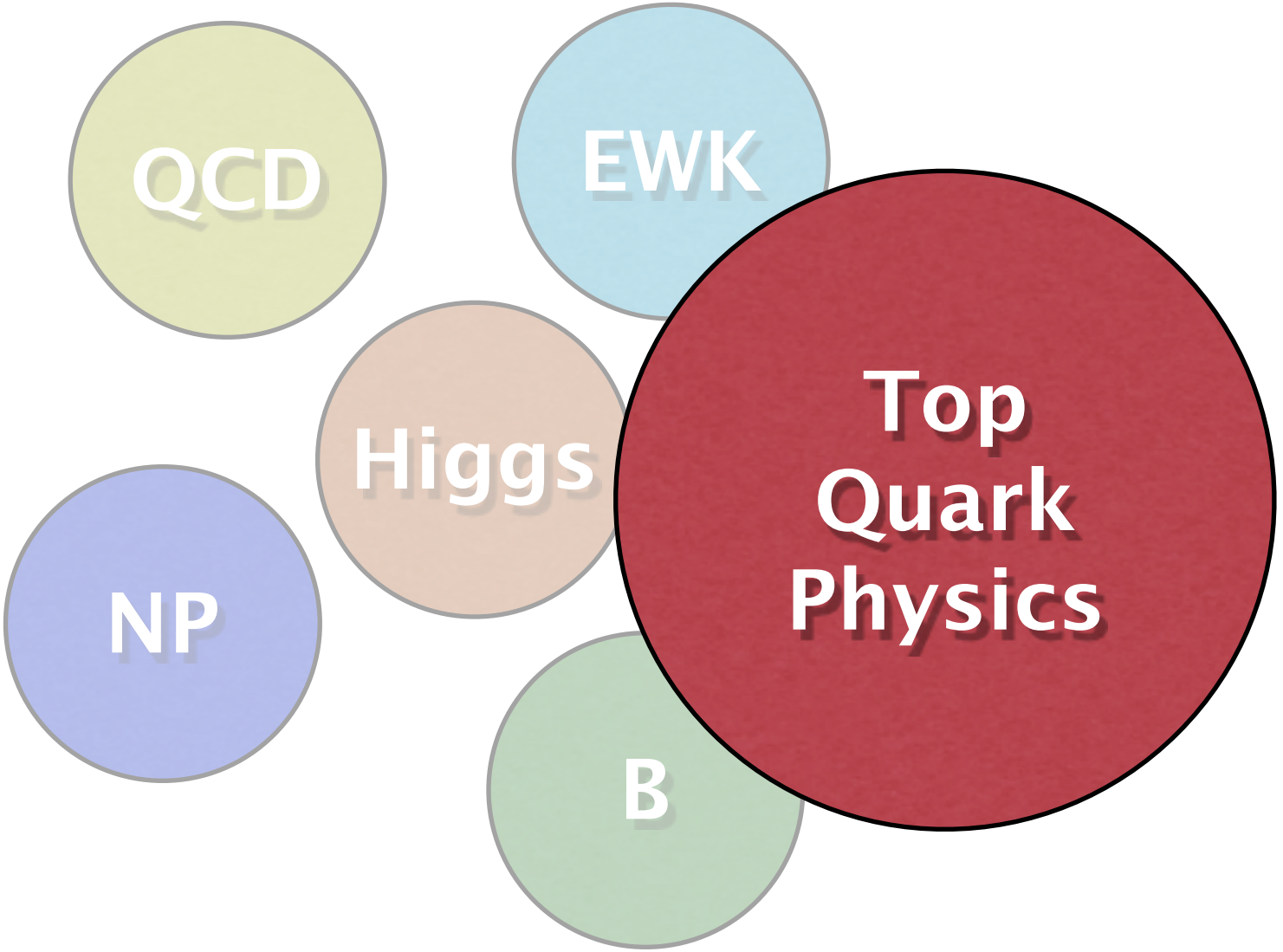
$10.530 \pm 0.005(\text{stat.}) \pm 0.009(\text{syst.})$ GeV

⇒ confirmation: 6σ

many more interesting measurements to do...

Lancaster

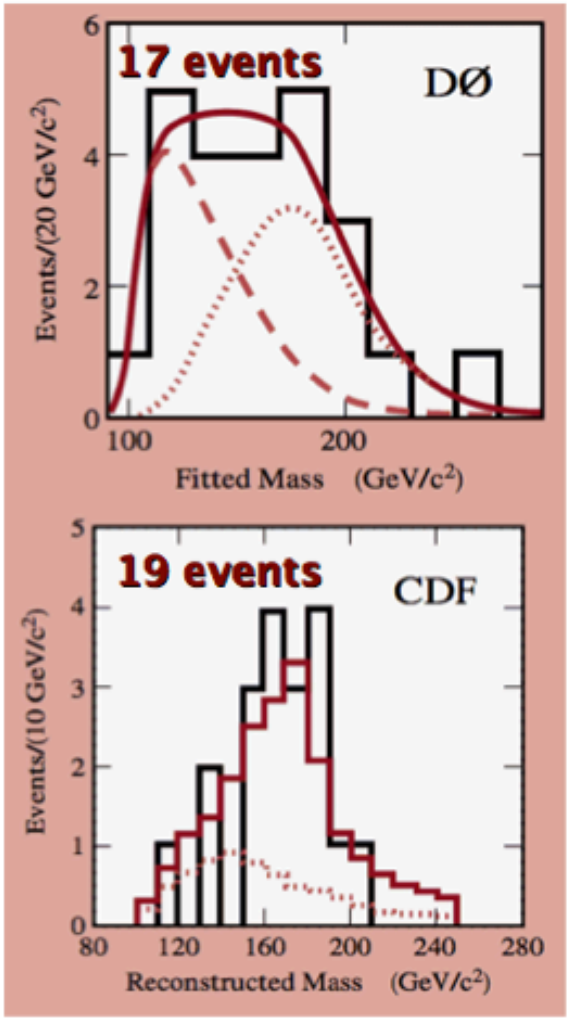
DØ Physics Results for Winter 2012



The TevatrOn Particle

discovery

PRL 74, 2632 (1995)
PRL 74, 2626 (1995)



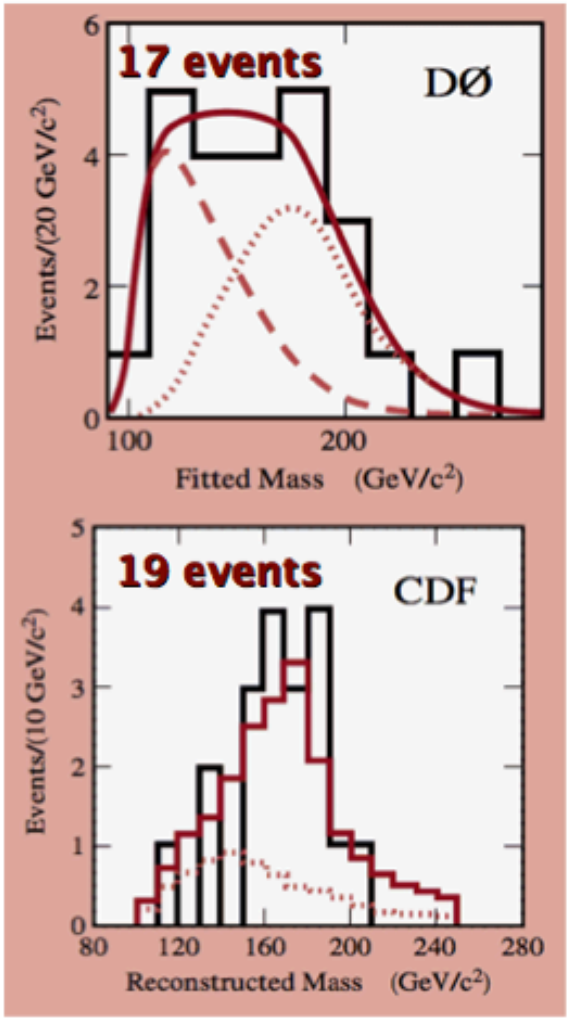
1995, CDF and DØ experiments, Fermilab

March 2nd, 1995:
First announcement of Top Discovery
in public seminar at Fermilab

The TevatrOn Particle

discovery

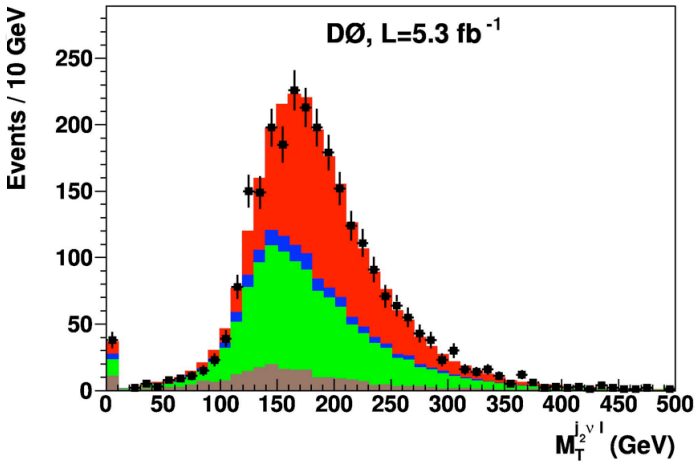
PRL 74, 2632 (1995)
PRL 74, 2626 (1995)



1995, CDF and DØ experiments, Fermilab

today

1000s of events



The TevatrOn Particle

discovery

PRL 74, 2632 (1995)
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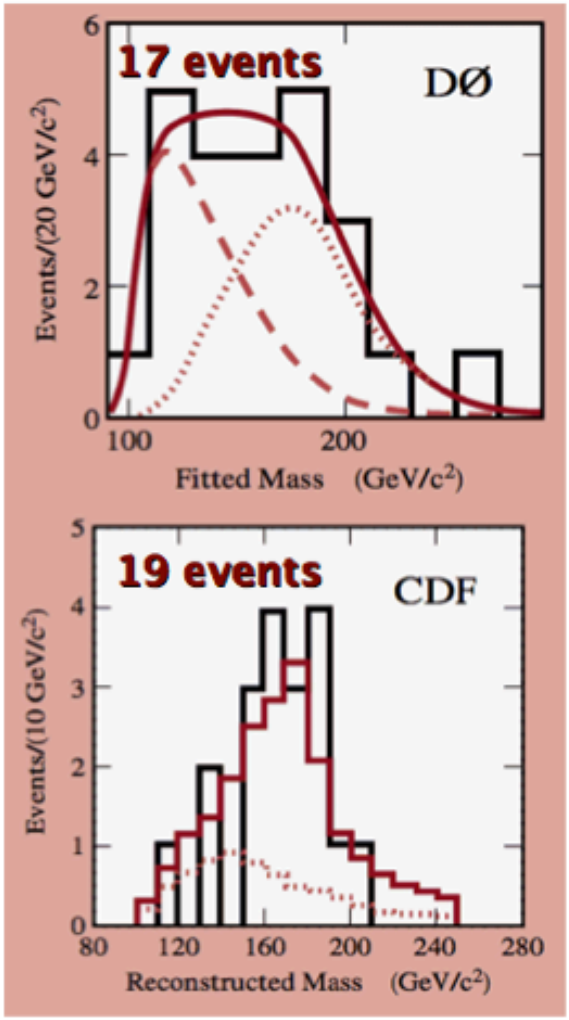
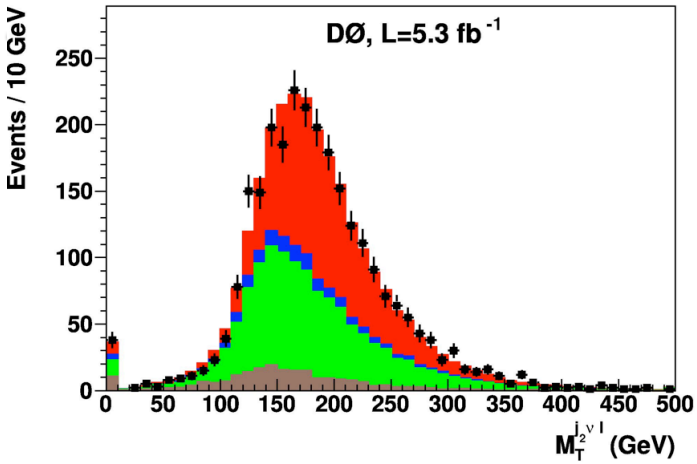


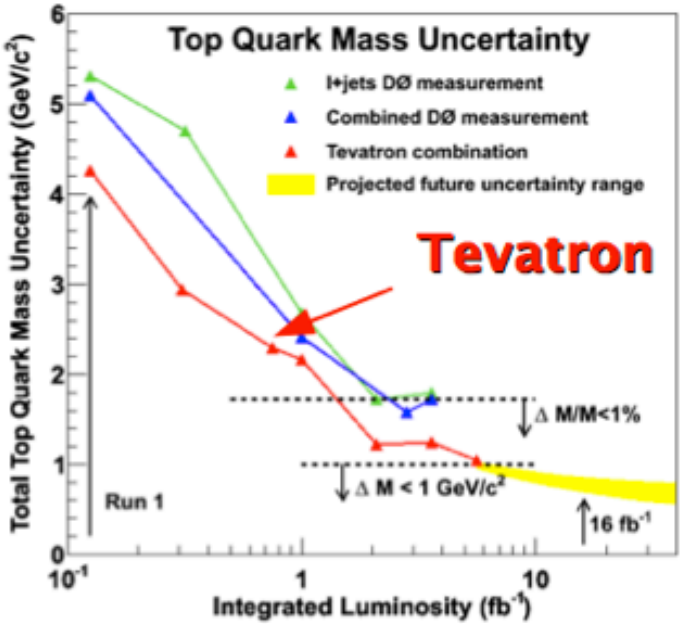
1995, CDF and DØ experiments, Fermilab

today

1000s of events



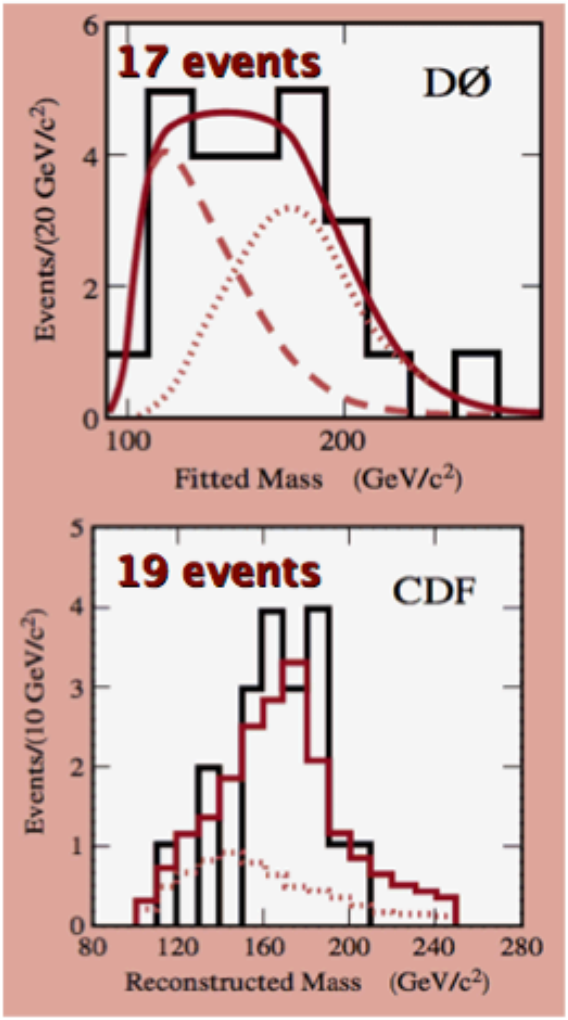
precision



The TevatrOn Particle

discovery

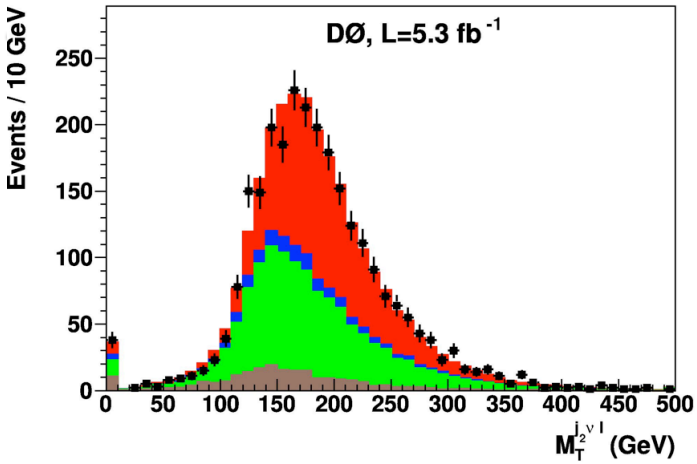
PRL 74, 2632 (1995)
PRL 74, 2626 (1995)



1995, CDF and DØ experiments, Fermilab

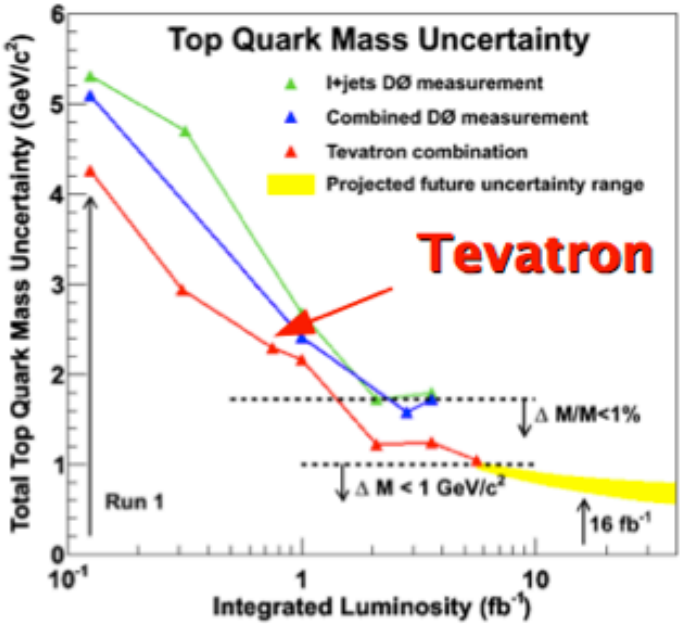
today

1000s of events



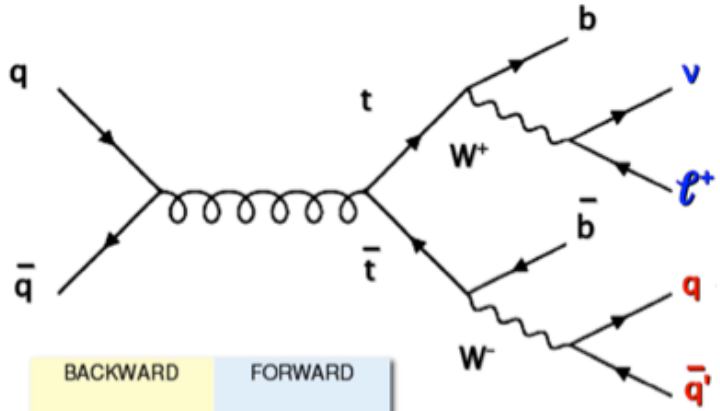
hints & excesses?

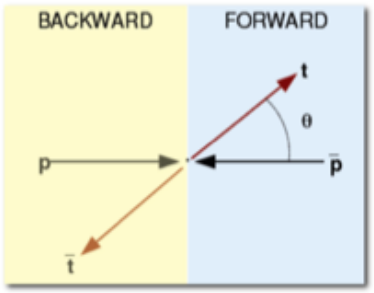
precision



searches

Forward Backward Asymmetry





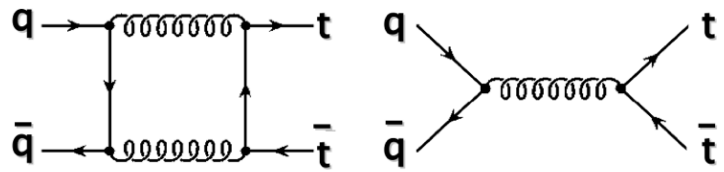
$$A_{fb} = \frac{F - B}{F + B}$$

- complementary to the LHC

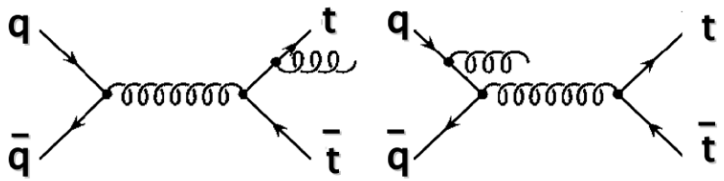
- asymmetry in $O(\alpha_s^3)$

NLO QCD

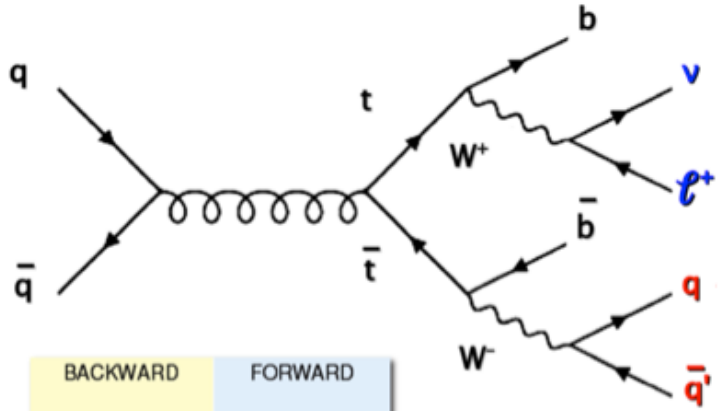
interference between:



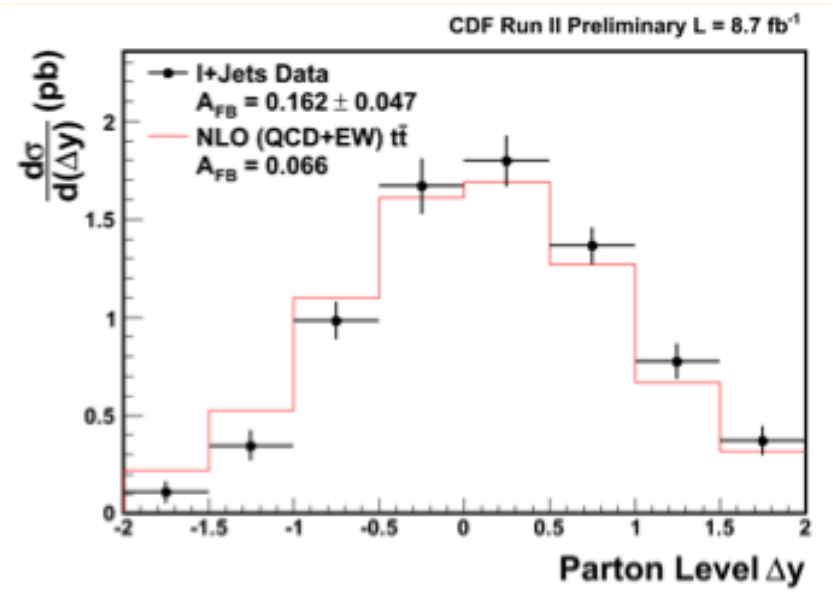
interference between:



Forward Backward Asymmetry

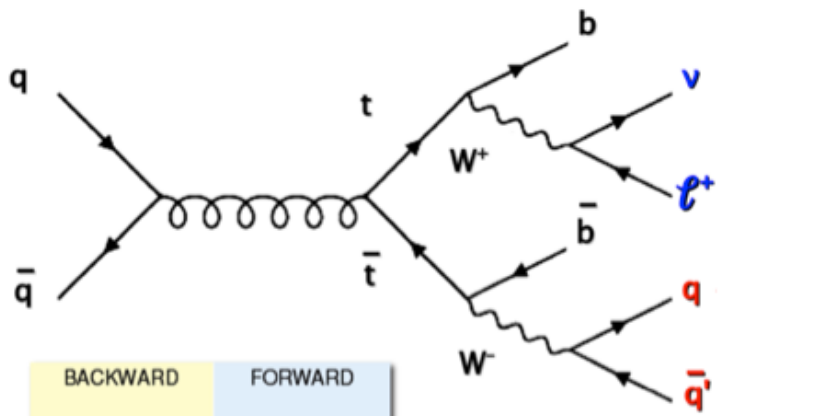


$$A_{fb} = \frac{F - B}{F + B}$$



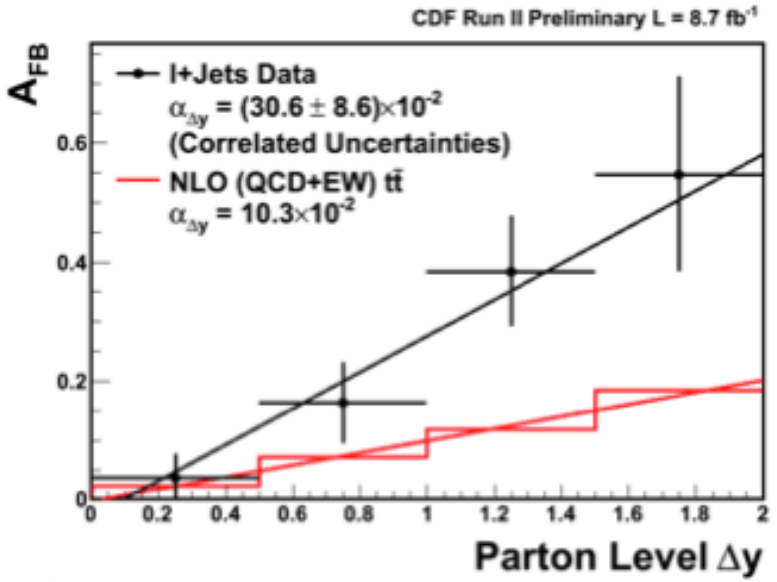
- complementary to the LHC

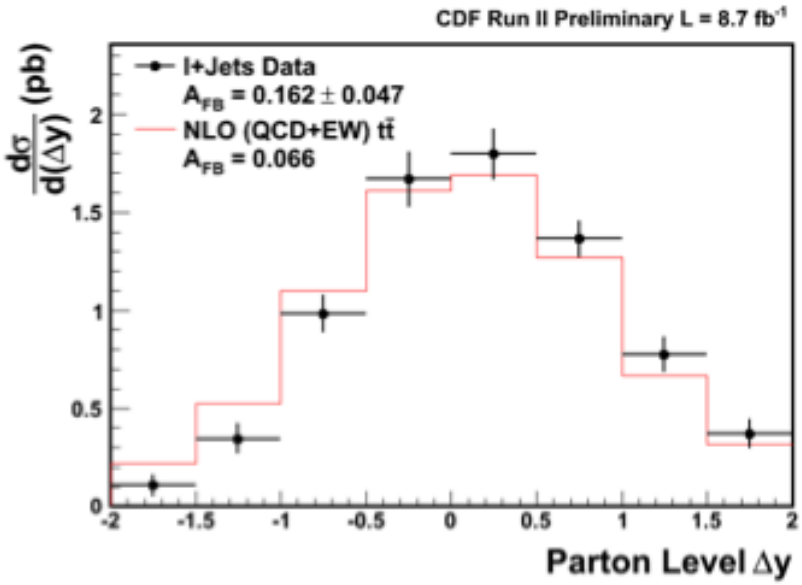
Forward Backward Asymmetry

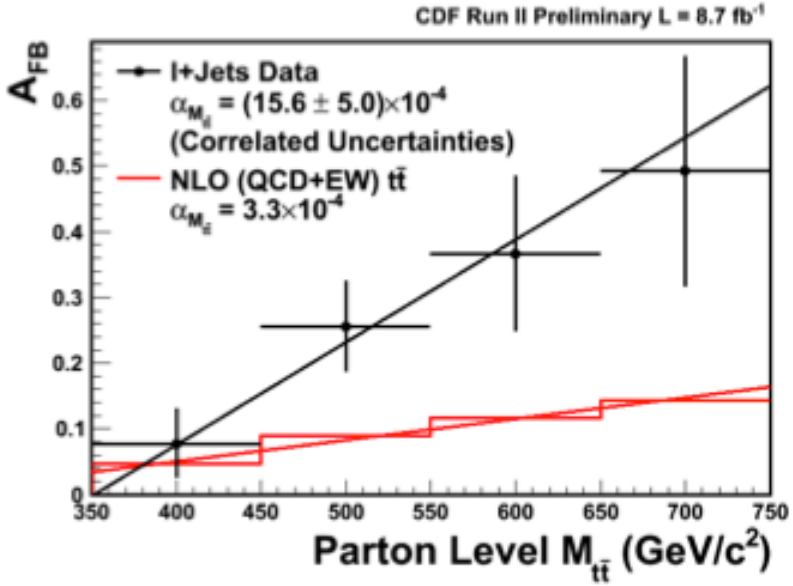


$$A_{fb} = \frac{F - B}{F + B}$$

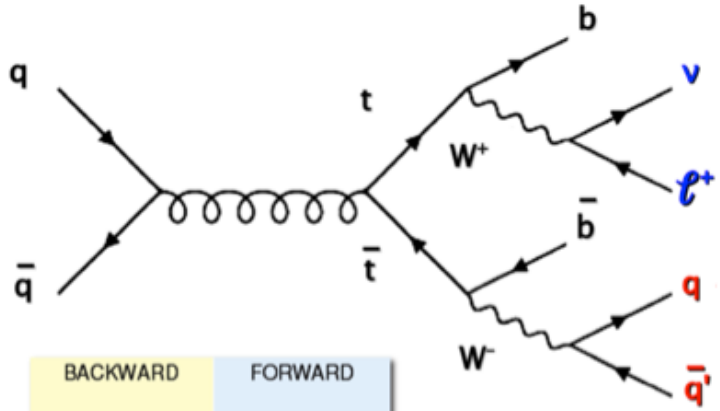
- complementary to the LHC

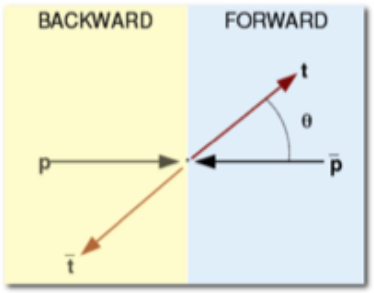






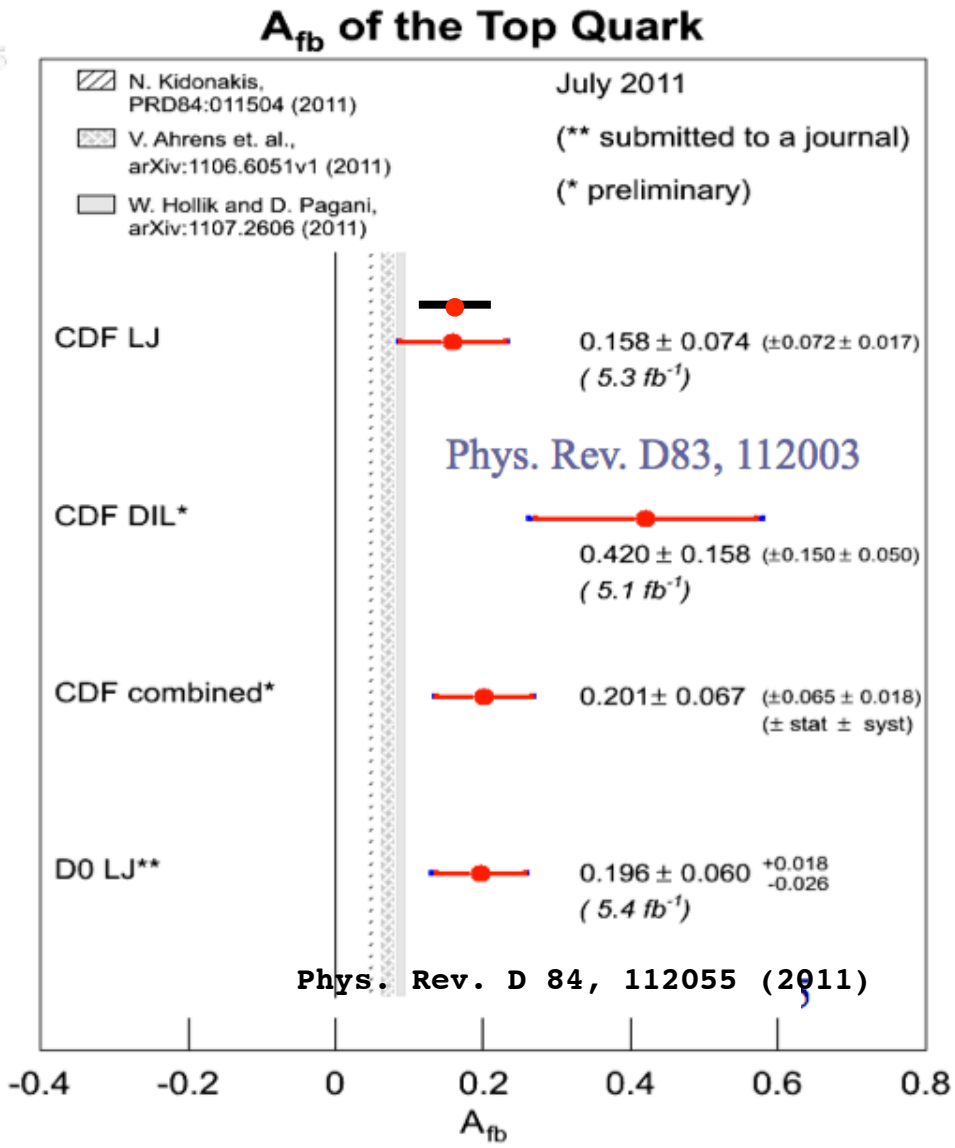
Forward Backward Asymmetry





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

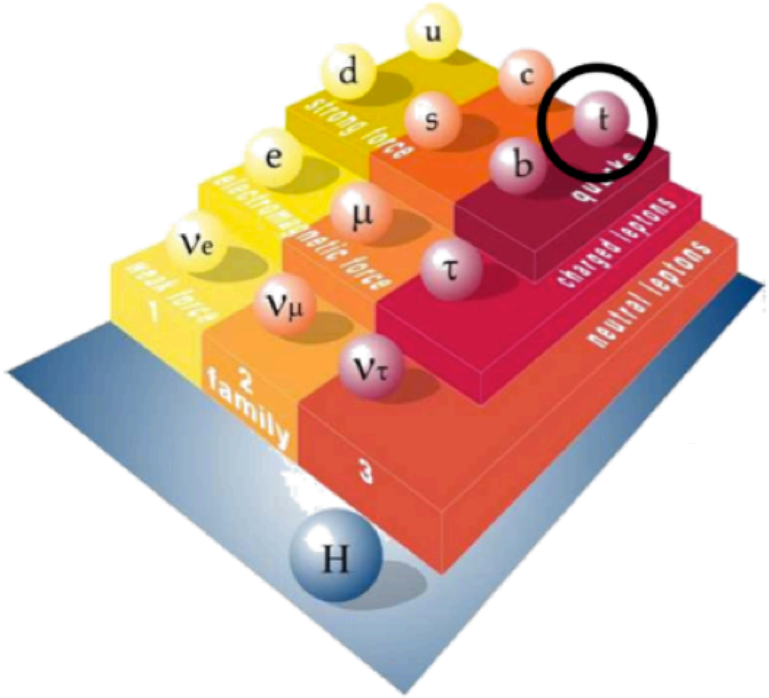
- complementary to the LHC



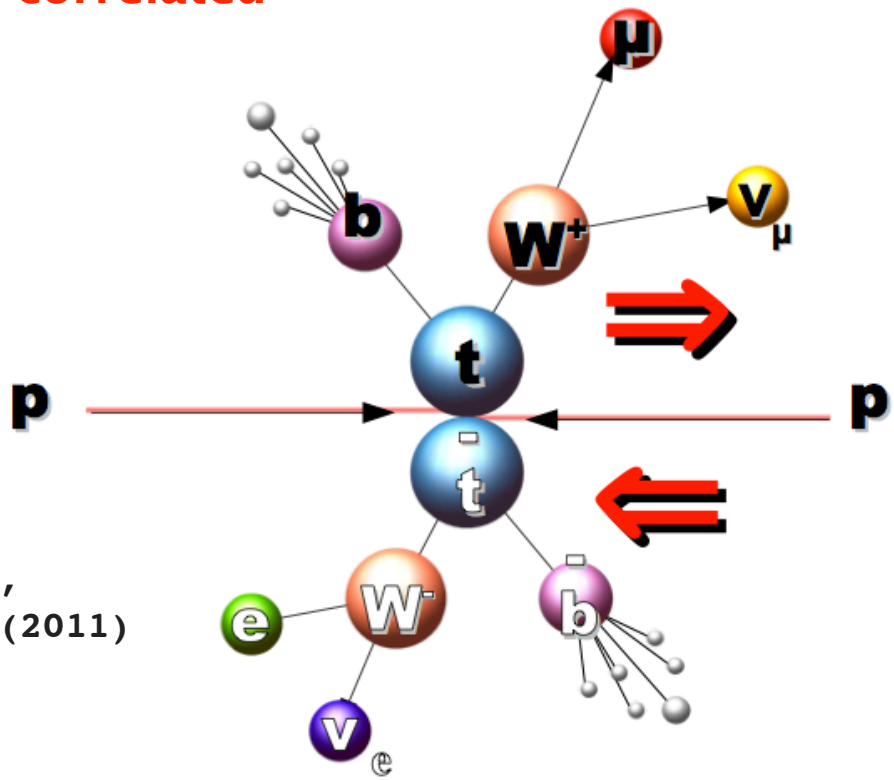
A_{fb} = 0.162 ± 0.047 (stat.+syst.)

Manchester: dilepton for DØ
(see talk by T. Head)

Top Pair Spin Correlation



- top quark: discovered in 1995 by CDF&DØ
- does the top quark have spin 1/2?
- top quark pair production: top quarks are not polarised, but spin of top and anti-top quarks are correlated



- top quarks have short lifetime:

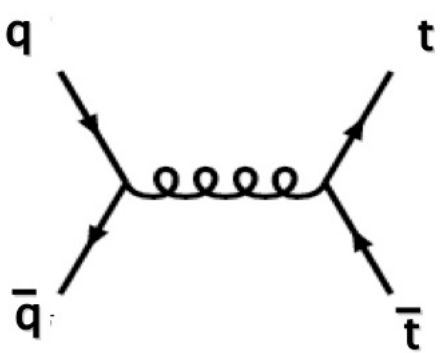
$$\tau_t = (3.3^{+1.3}_{-0.9}) \times 10^{-25}\ \mathrm{s}$$

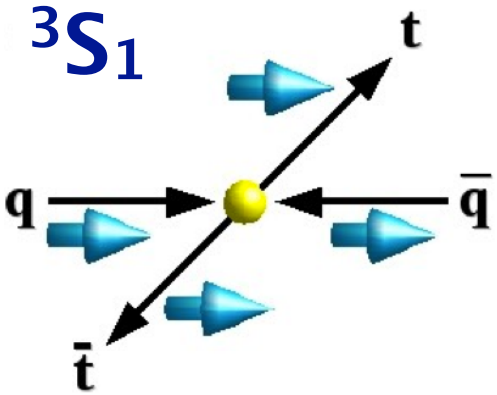
DØ Collaboration, PRL 106, 022001 (2011)

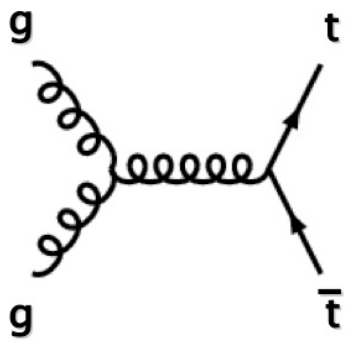
- decay before spins can flip
- spin information is contained in decay product
- measure $t\bar{t}$ spin correlation: consistent with SM prediction for a spin 1/2 particle?

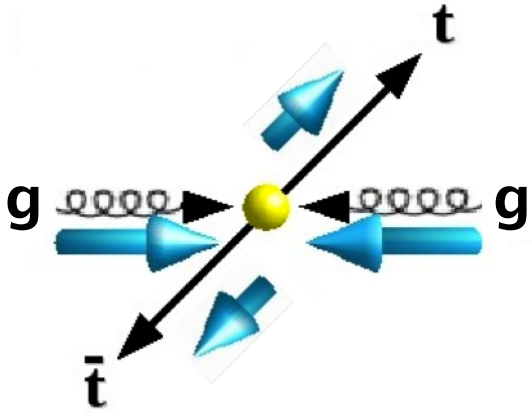
Spin correlation strength

$$C = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}}$$









Tevatron

- dominated by $q\bar{q}$ annihilation
- $t\bar{t}$ pairs close to the threshold
- beam axis as spin quantisation axis

NLO QCD: C = 0.78

Bernreuther, Brandenburg, Si, Uwer, Nucl. Phys. B690, 81 (2004)

- optimised "off-diagonal" basis

LHC

- dominated by gg fusion
- $t\bar{t}$ pairs far off the threshold
- helicity basis as spin quantisation axis

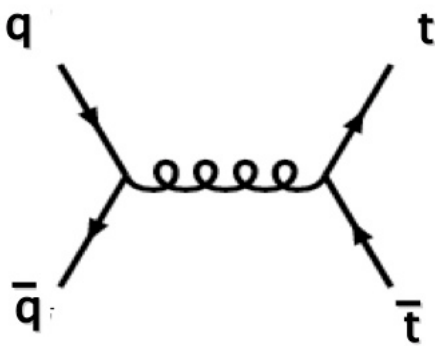
NLO QCD: C = 0.32

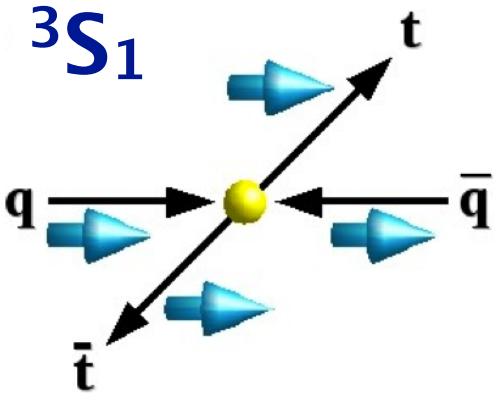
- maximal basis

complementary between Tevatron and LHC

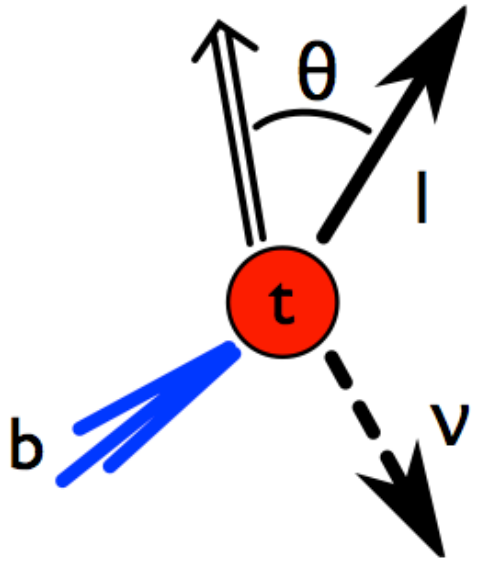
Spin correlation strength

$$C = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}}$$





Tevatron



- dominated by $q\bar{q}$ annihilation
- $t\bar{t}$ pairs close to the threshold
- beam axis as spin quantisation axis
  NLO QCD: C = 0.78

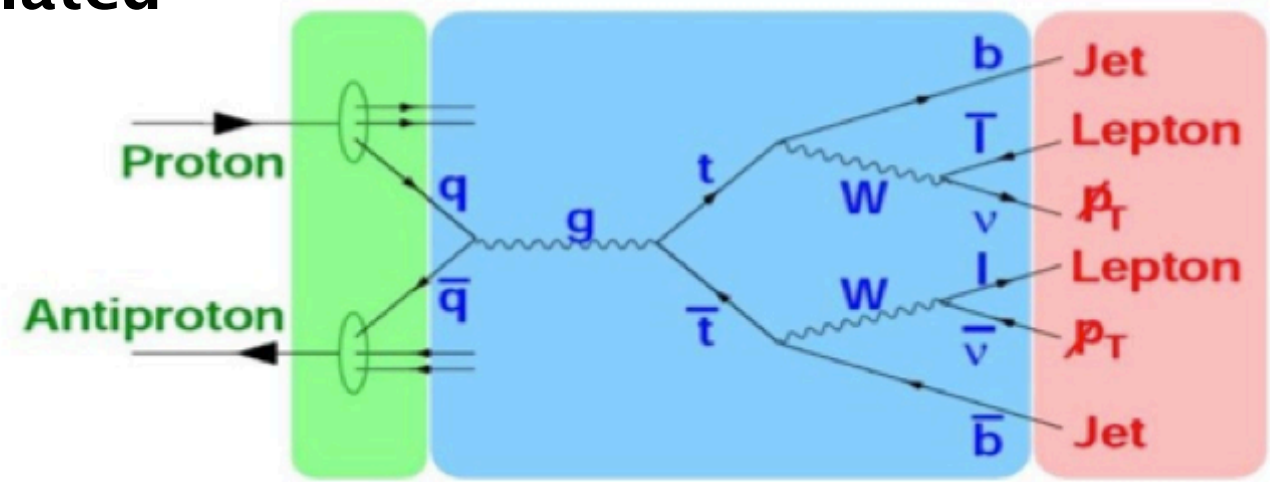
- optimised "off-diagonal" basis

complementary between Tevatron and LHC

Matrix Element Method

$$P_{\text{sgn}}(x; m_t, H) = \frac{1}{\sigma_{\text{obs}}(m_t)} \int f_{\text{PDF}}(\epsilon_1)\, f_{\text{PDF}}(\epsilon_2) \mathrm{d}\epsilon_1 \mathrm{d}\epsilon_2 \cdot \frac{(2\pi)^4 \left|\mathcal{M}(y, m_t, H)\right|^2}{\epsilon_1 \epsilon_2 s} W(x, y)\, \mathrm{d}\Phi_6$$

H=correlated
or
H=uncorrelated
spins



PDF's **LO-Matrix element**

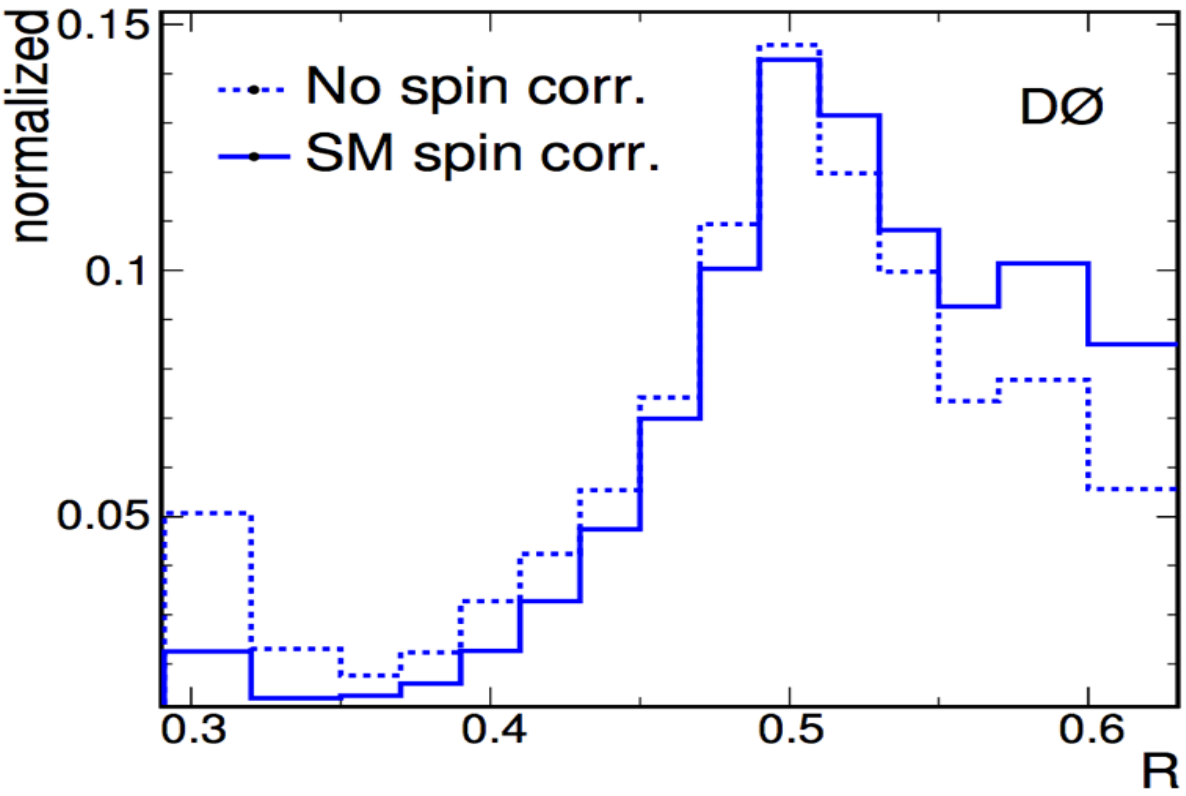
transfer functions (probability to measure x when y was produced)

Measurement of Spin Correlation

MEs: per event ↔ spin correlation: ensemble of events

discriminant

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



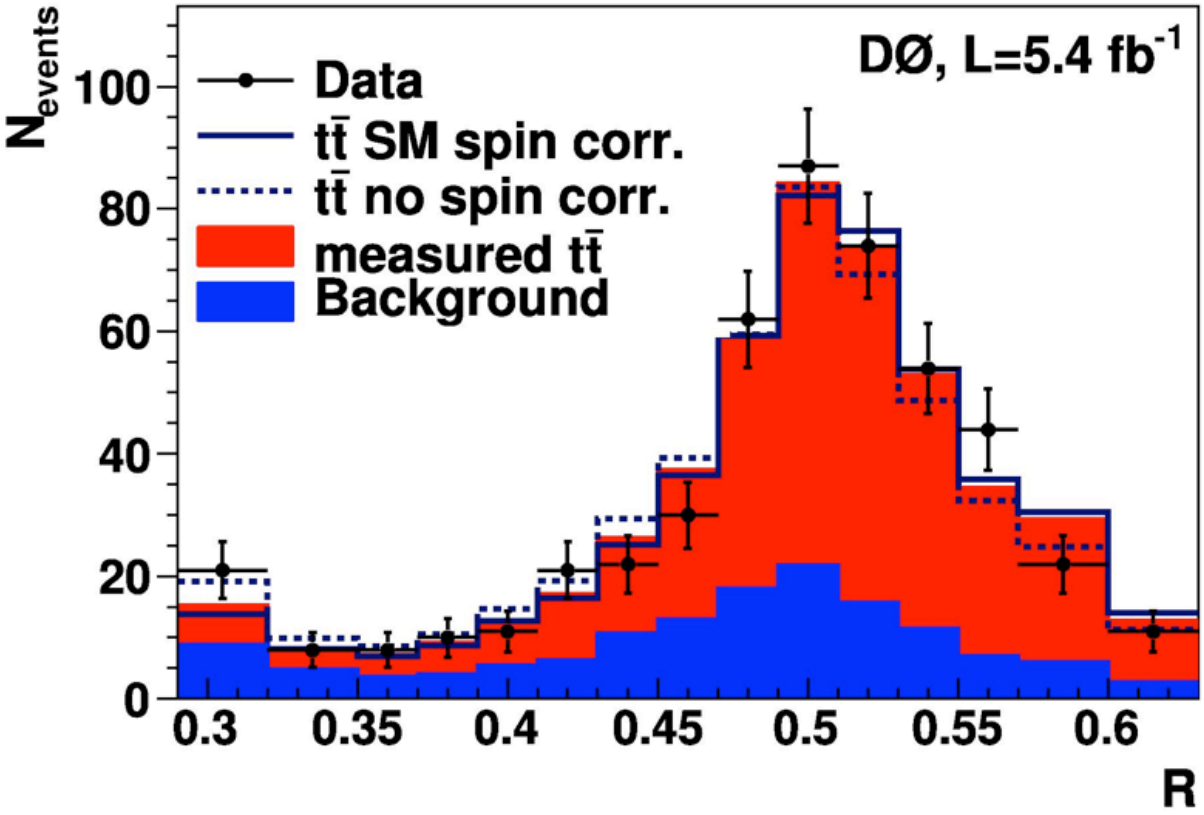
MC@NLO
on parton level

Measurement of Spin Correlation

MEs: per event ↔ spin correlation: ensemble of events

discriminant

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



dilepton

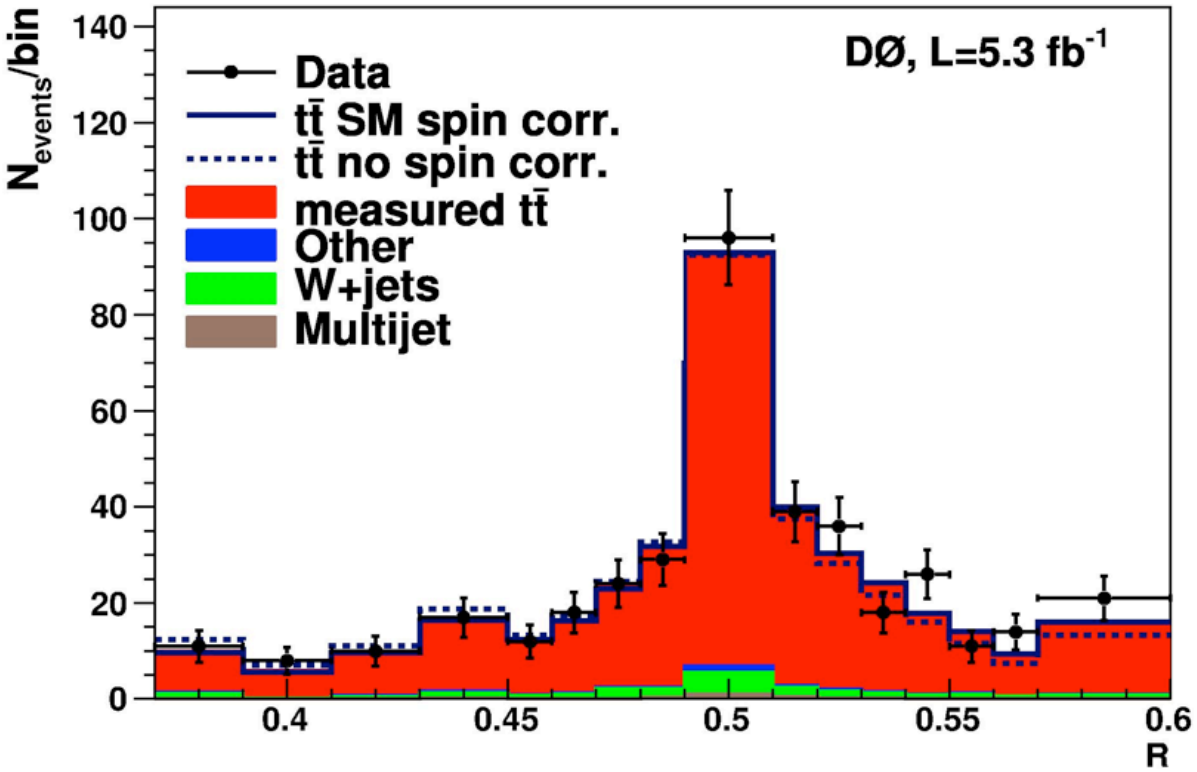
Phys. Rev. Lett. 107, 032001 (2011)

Measurement of Spin Correlation

MEs: per event ↔ spin correlation: ensemble of events

discriminant

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



l+jets

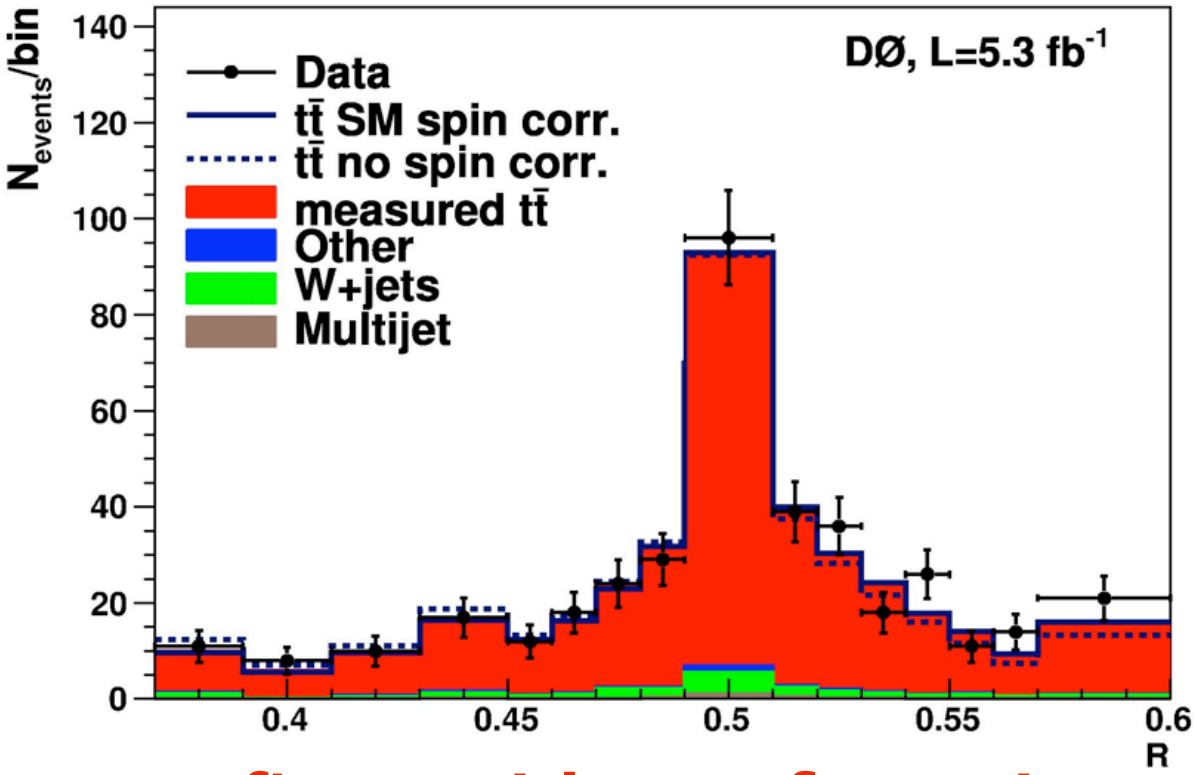
Phys. Rev. Lett. 108, 032004 (2012)

Measurement of Spin Correlation

MEs: per event ↔ spin correlation: ensemble of events

discriminant

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



combination: dilepton & l+jets

Phys. Rev. Lett. 107, 032001 (2011)

Phys. Rev. Lett. 108, 032004 (2012)

correlation strength:

$$C = 0.66 \pm 0.23\,(\mathrm{stat+syst})$$

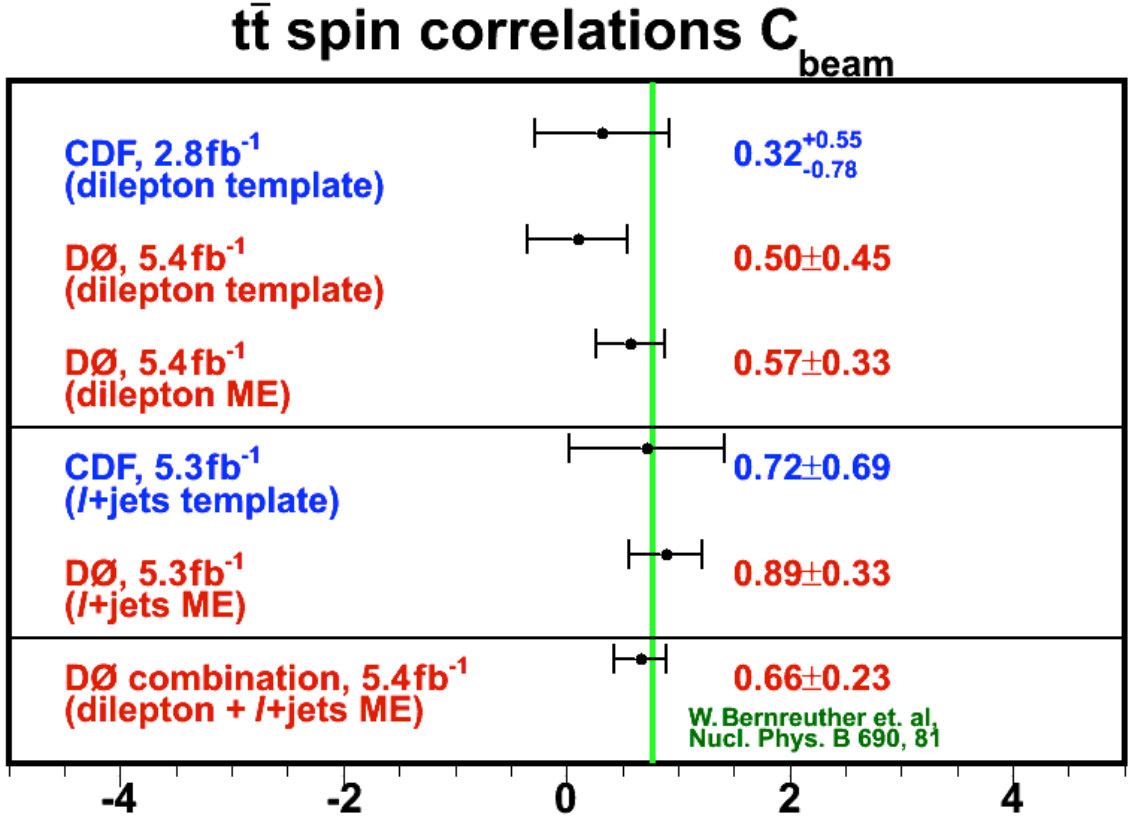
NLO QCD: $C = 0.777^{+0.027}_{-0.042}$

→ first evidence for spin correlation with 3.1σ

Tevatron Results

- template measurements at the Tevatron using $\cos(\theta)\cdot\cos(\theta)$ in dilepton and l+jets channels
- need matrix element technique to be sensitive enough to reject no correlation hypothesis
- first evidence for SM spin correlation
- still statistically limited: double data set
- at LHC so far only used $\Delta\Phi$ in dilepton channel

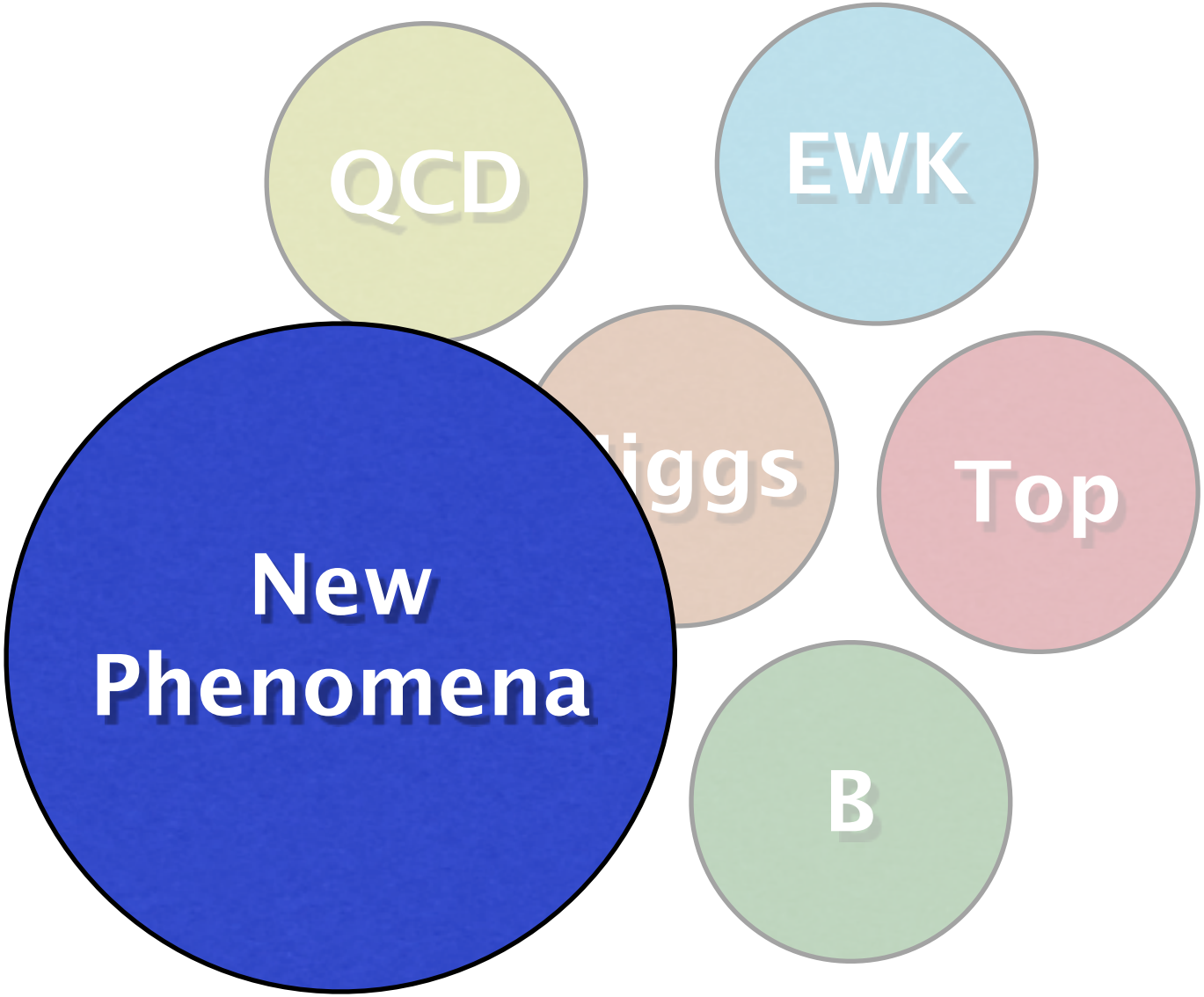
Manchester



⇒ first observation for SM spin correlation by ATLAS

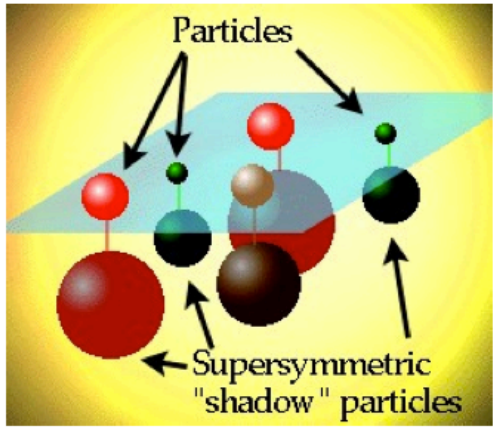
(see parallel session talks from J. Howarth, T. McLaughalan)

Tevatron Results for Winter 2012



Beyond the Standard Model

Supersymmetry

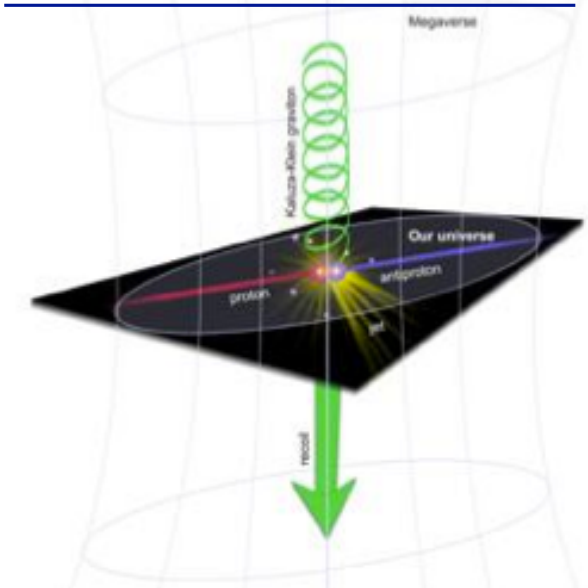


Name	Spin	Superpartner	Spin
Electron	1/2	Selectron	0
Muon	1/2	Smuon	0
Tau	1/2	Stau	0
Neutrino	1/2	Sneutrino	0
Quark	1/2	Squark	0

Name	Spin	Superpartner	Spin
Graviton	2	Gravitino	3/2
Photon	1	Photino	1/2
Gluon	1	Gluino	1/2
$W^{+,-}$	1	$Wino^{+,-}$	1/2
Z^0	1	Zino	1/2
Higgs	0	Higgsino	1/2

Many new models tested for the first time by Tevatron data.

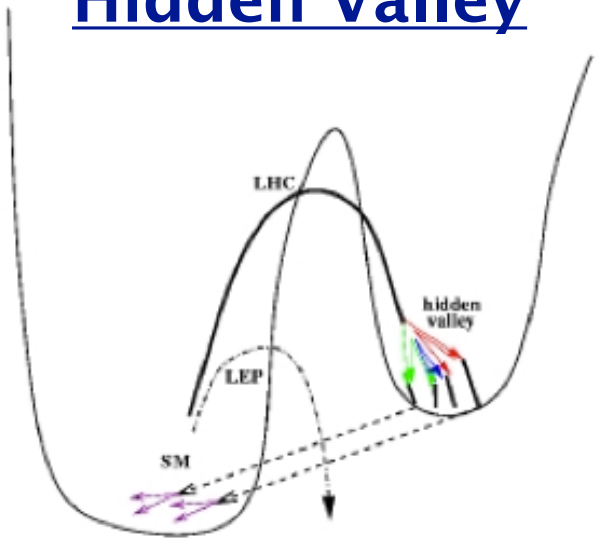
Extra dimensions



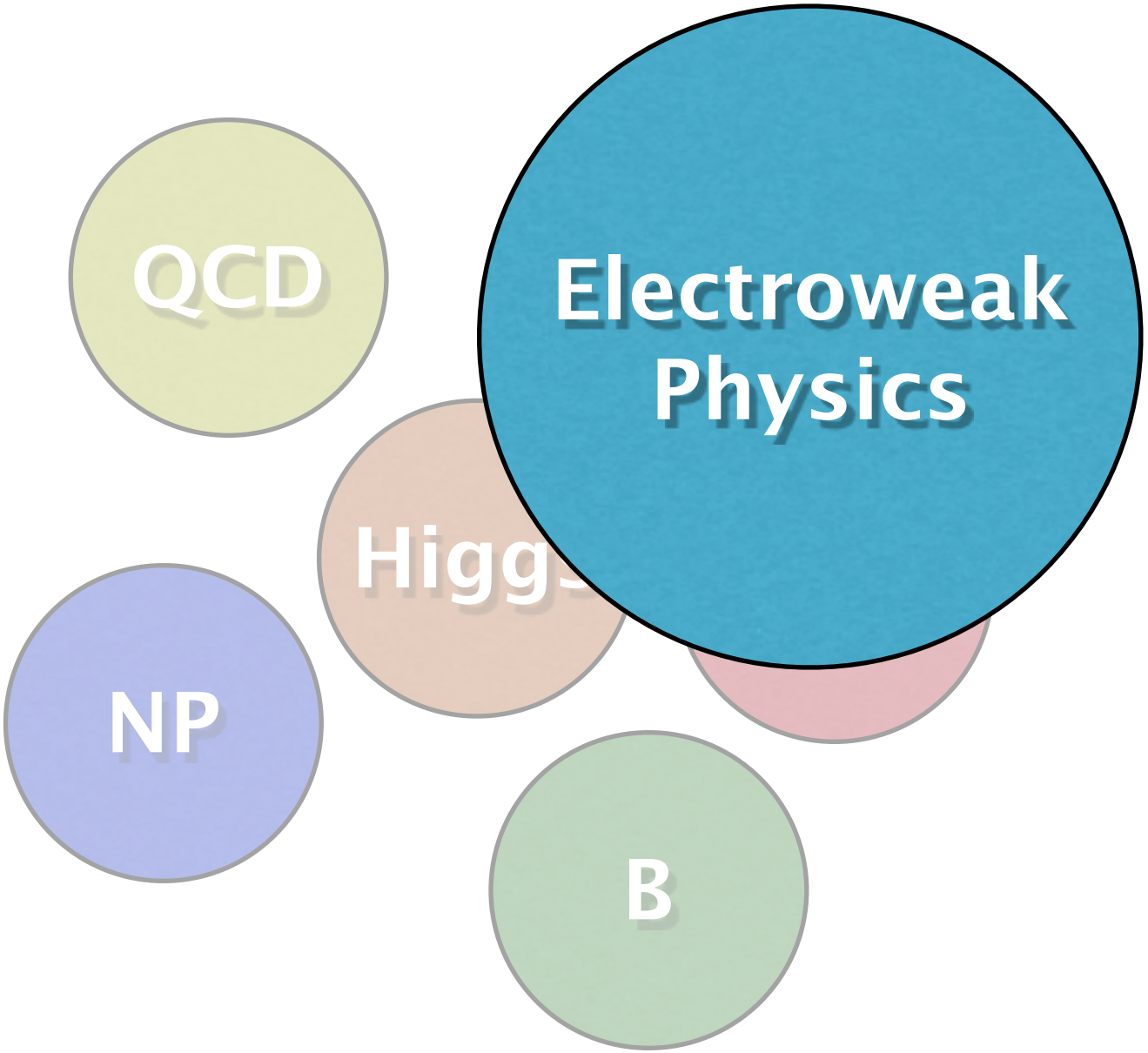
Wealth of results on

SUSY, leptoquarks, large extra dimensions, excited quarks, t', W', Z', quirks, hidden valleys, new heavy gauge bosons, compositeness, Randall-Sundrum gravitons, long-lived particles, FCNC and model-independent searches.

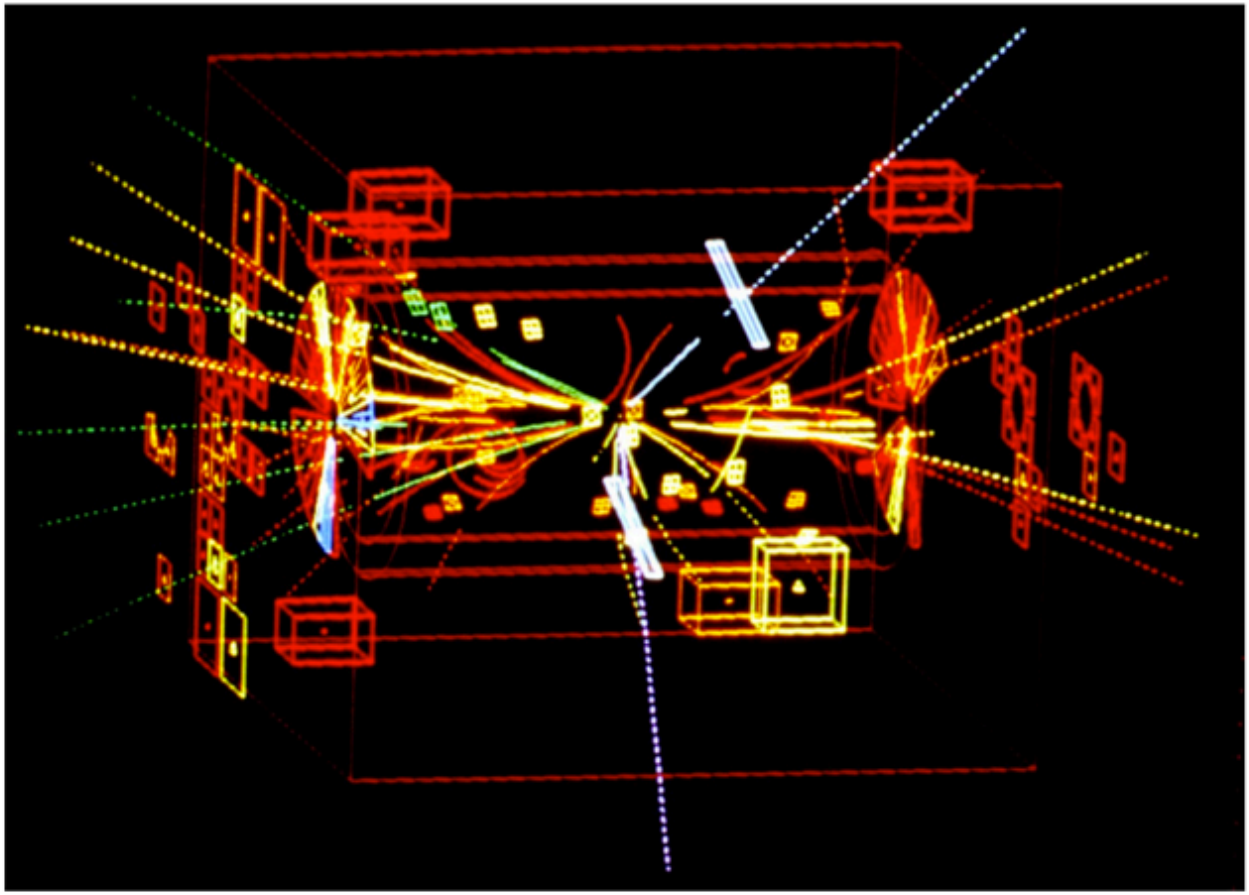
Hidden Valley



Tevatron Results for Winter 2012



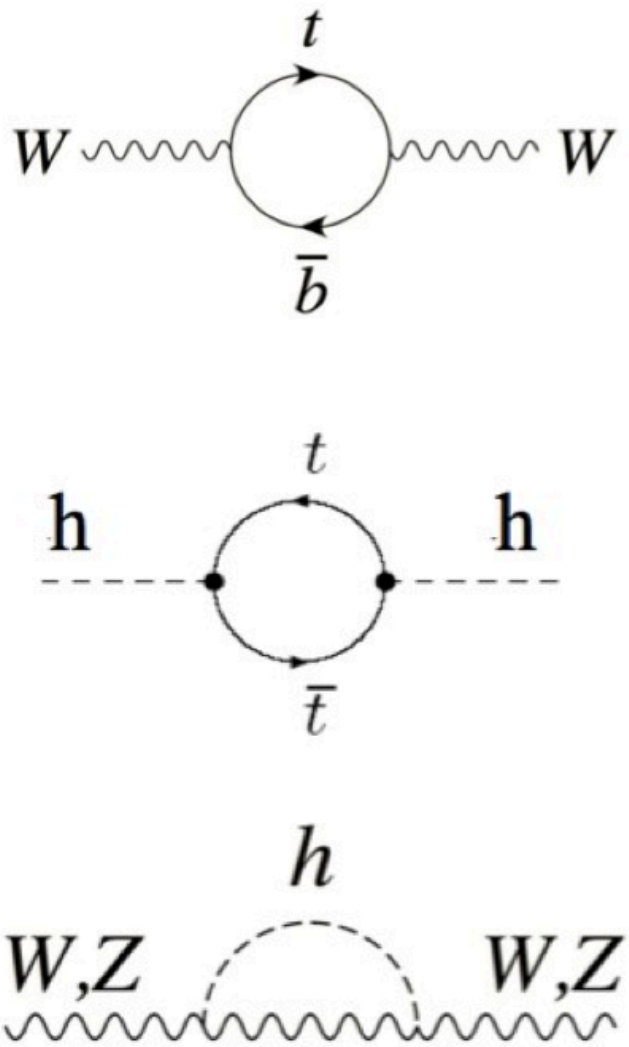
Electroweak Interaction

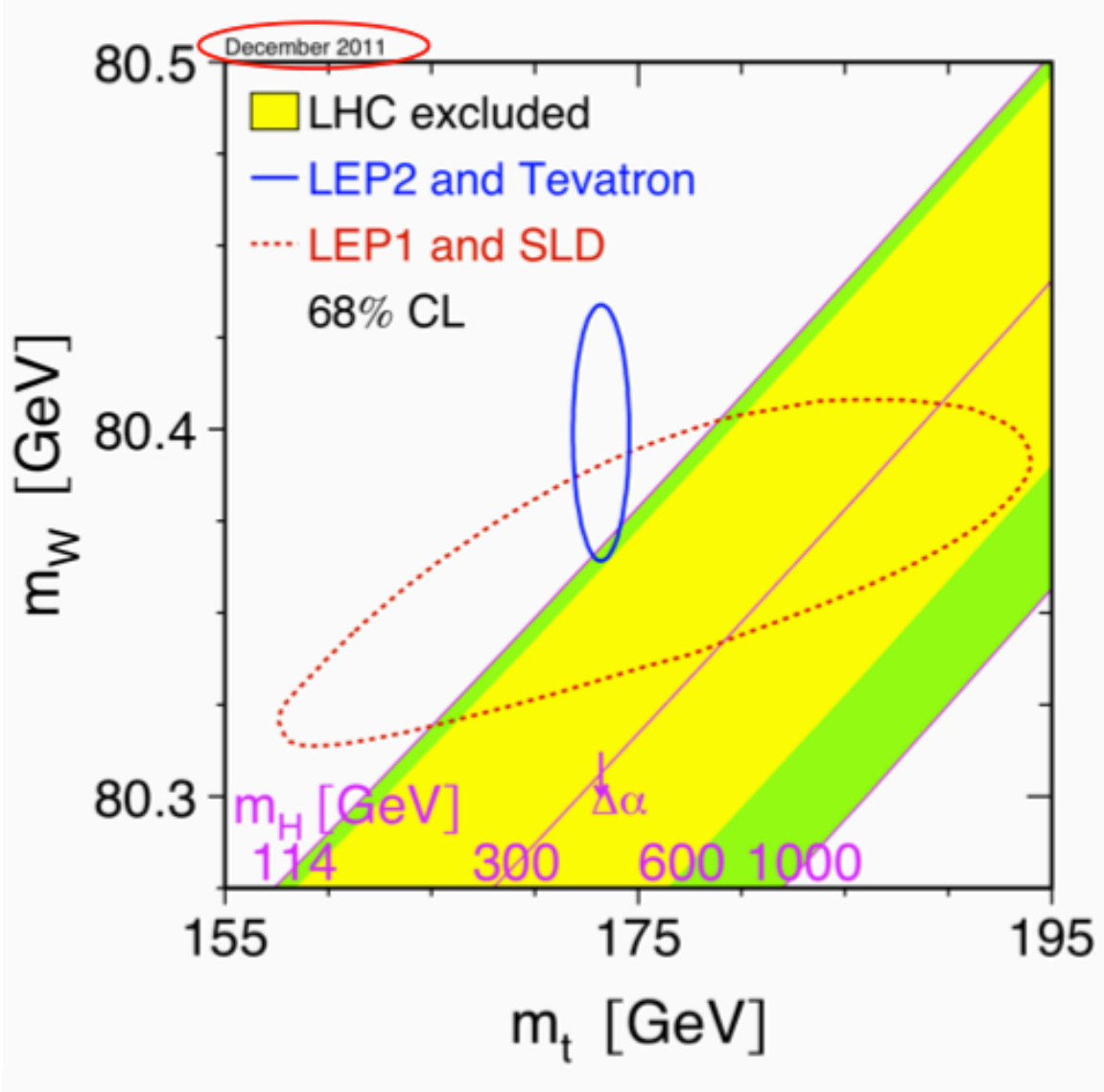


1983, UA1 experiment, $\sqrt{s}$=540 GeV

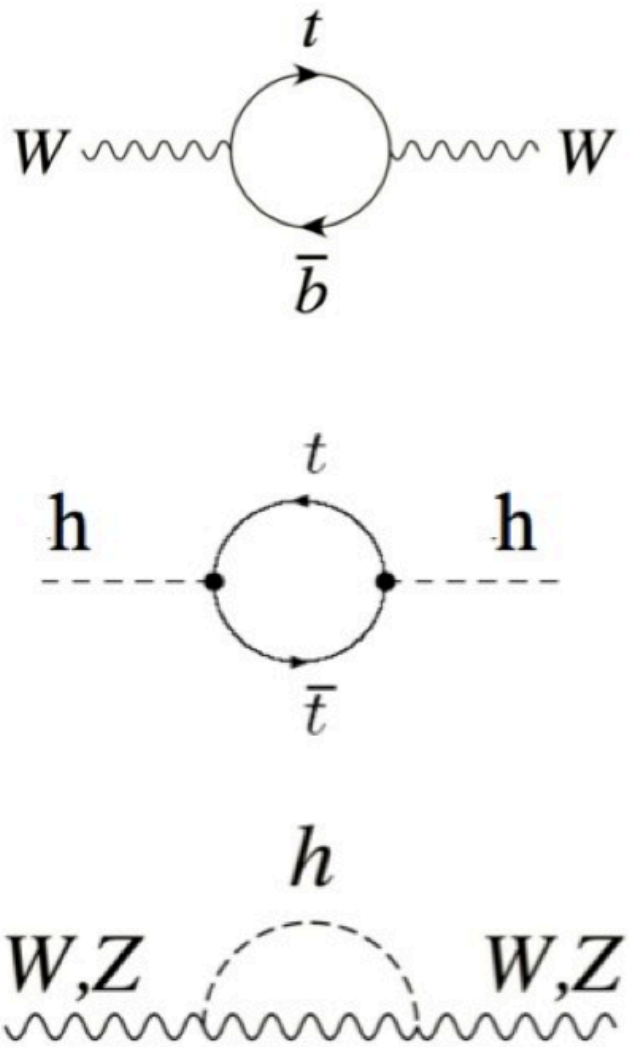
discovery of Z boson at $\bar{p}p$ accelerator SPS (CERN, Geneva)

W mass measurement

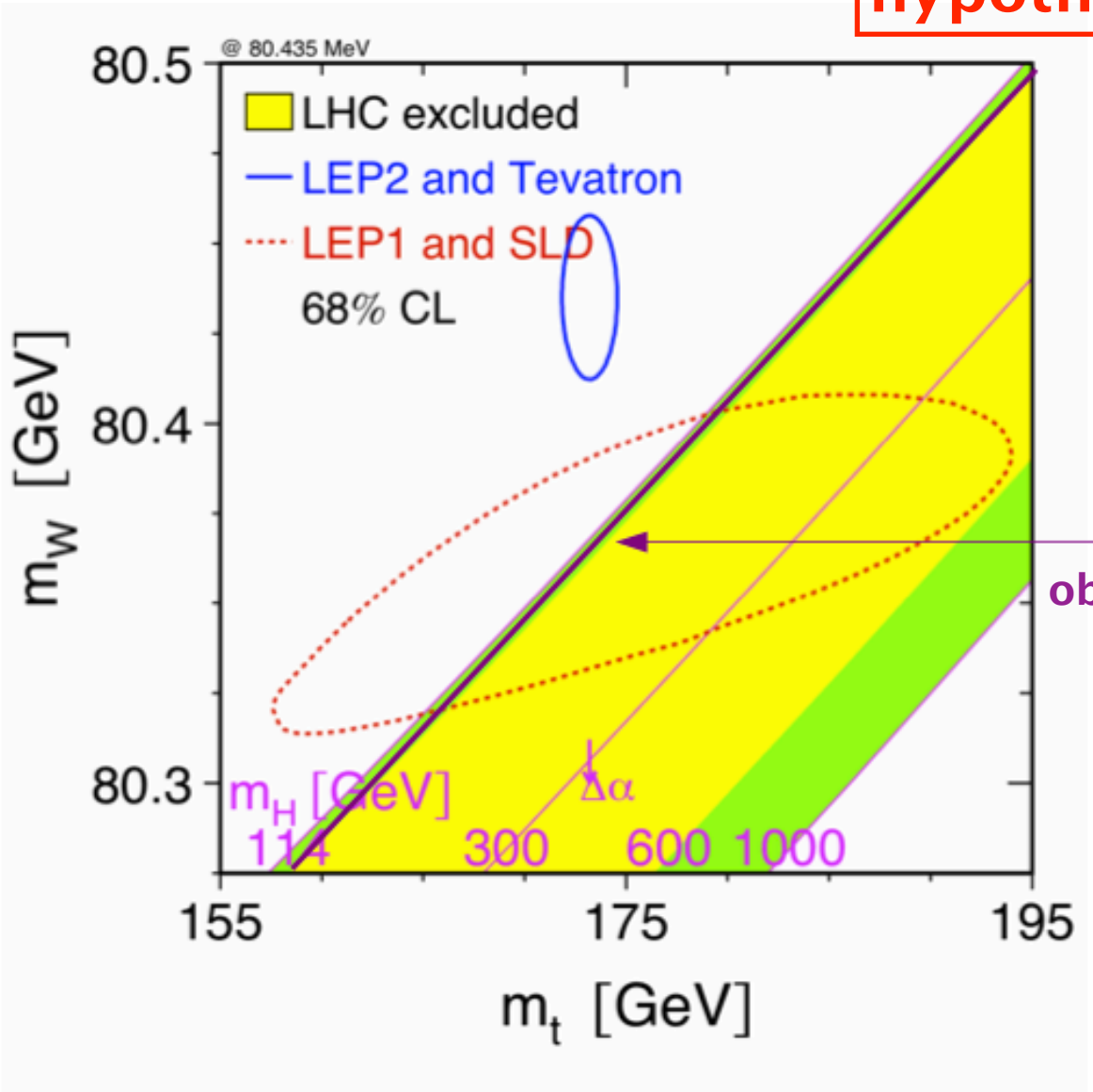




W mass measurement



hypothetical



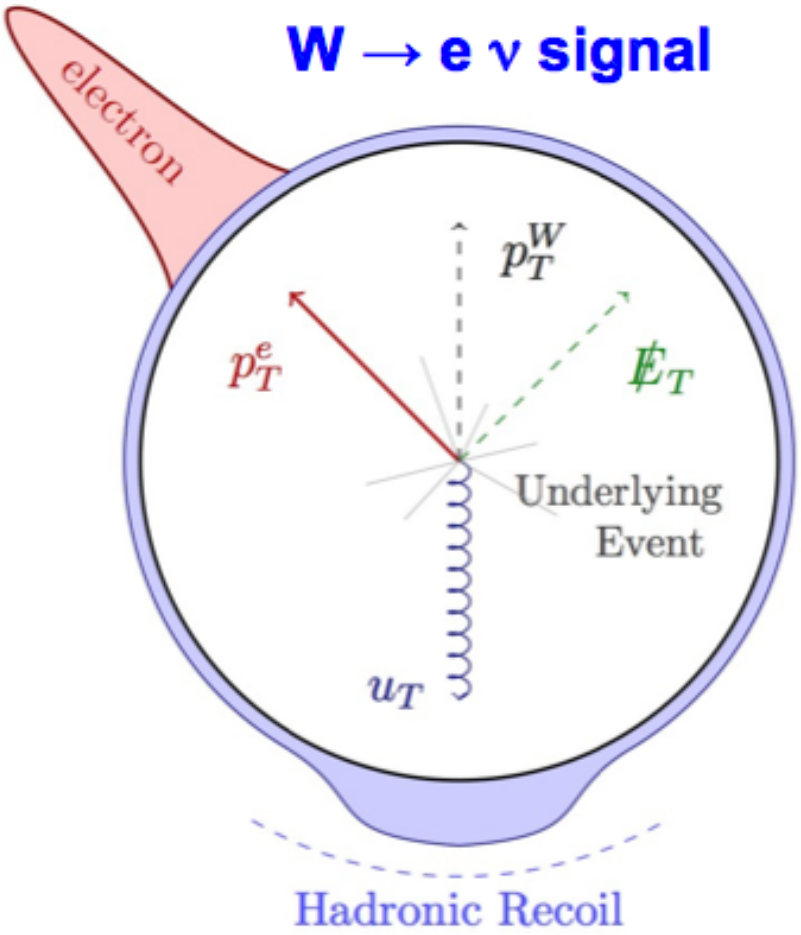
observation

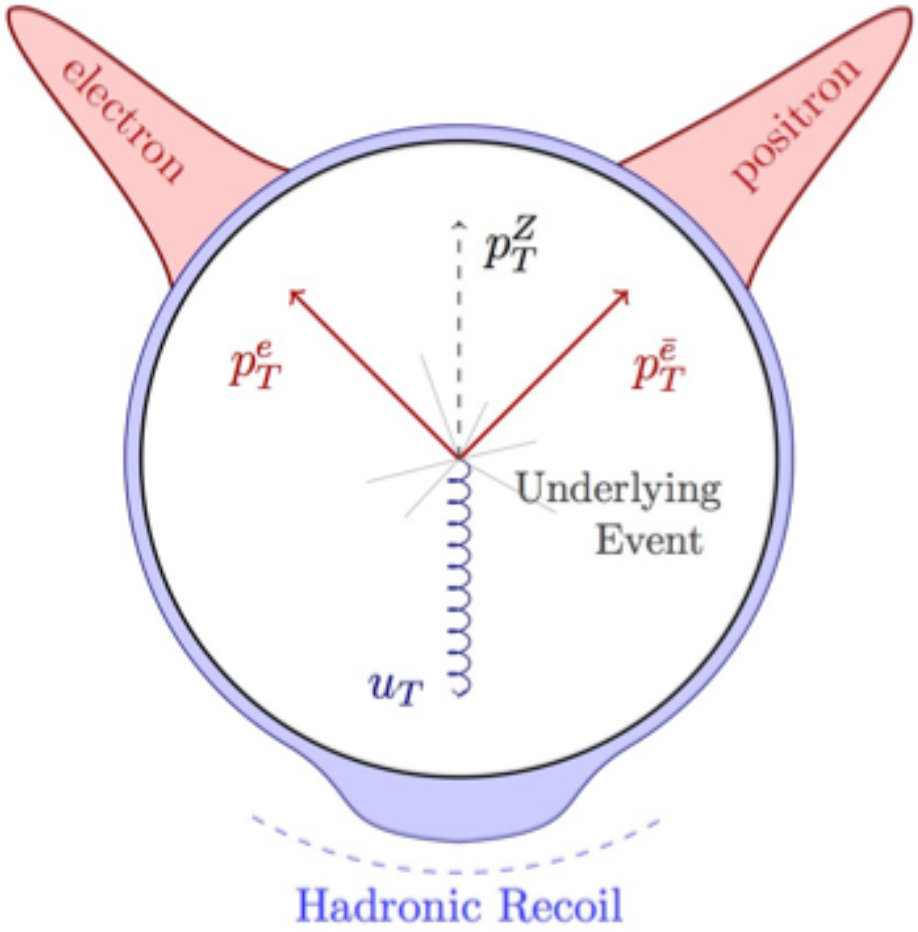
W mass measurement

need energy measurement with 0.1 per-mille precision (!)

Z → e e events provide critical control sample

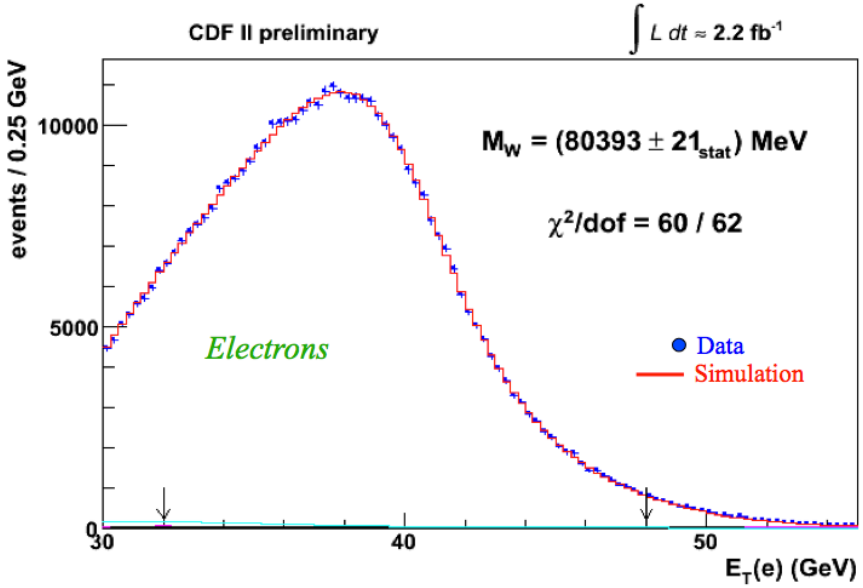
W → e ν signal

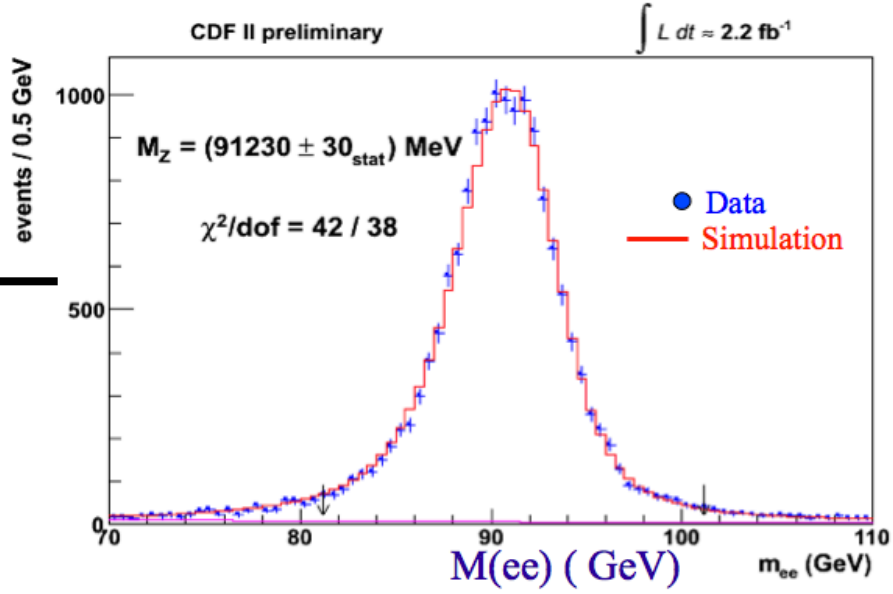


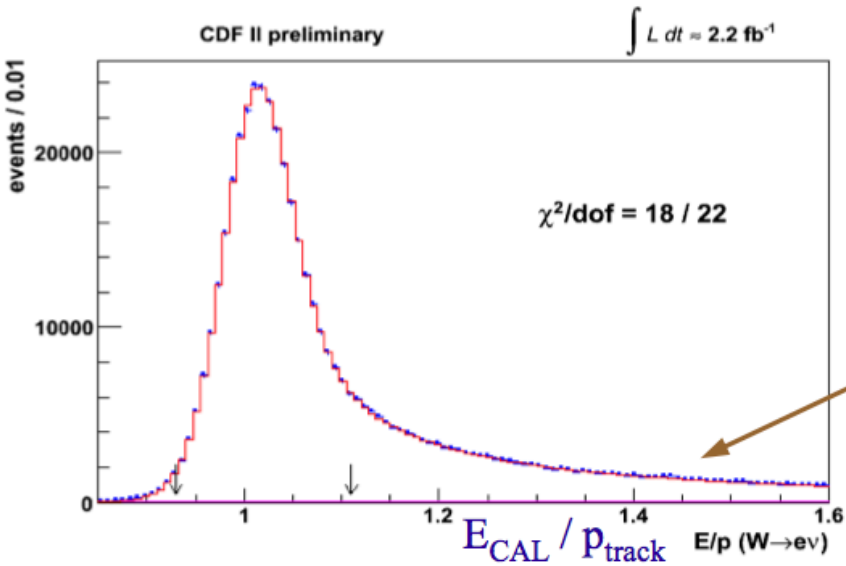


need ~1% precision

W mass measurement



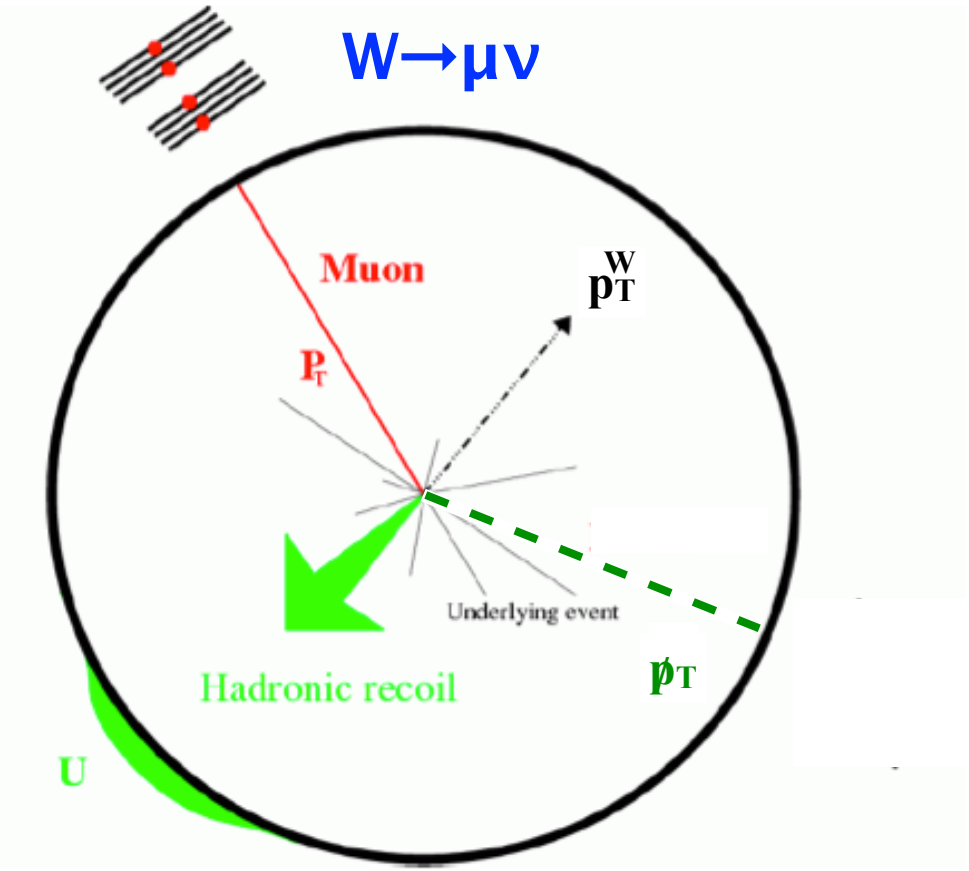


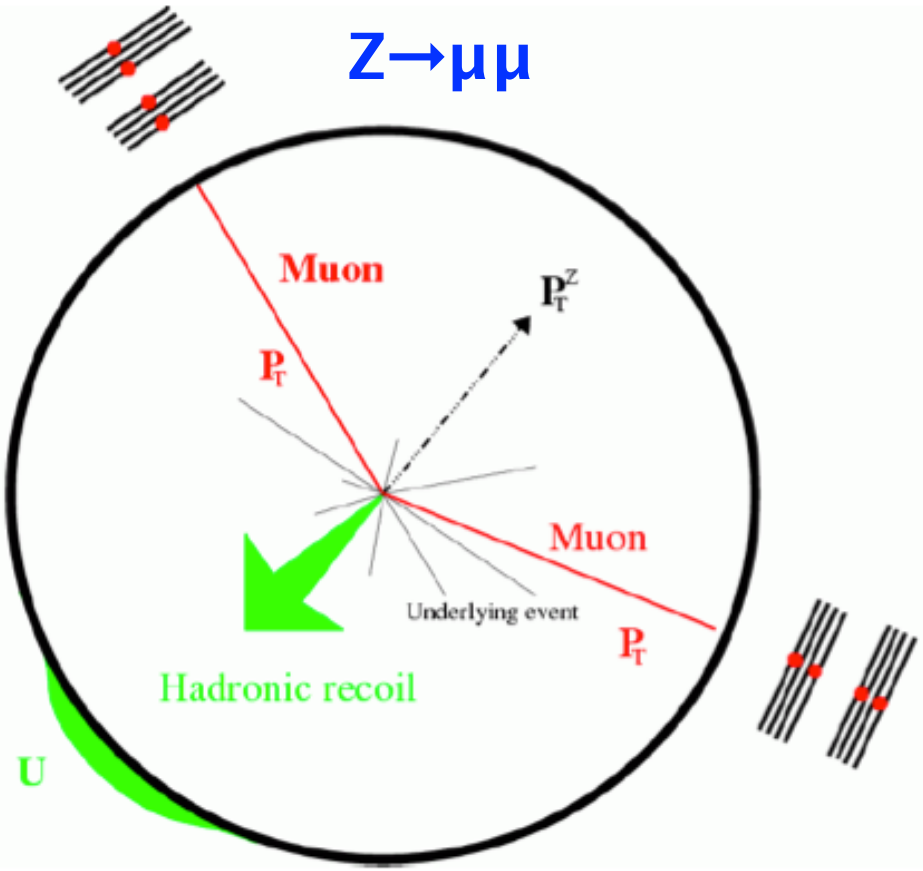


Data
Simulation

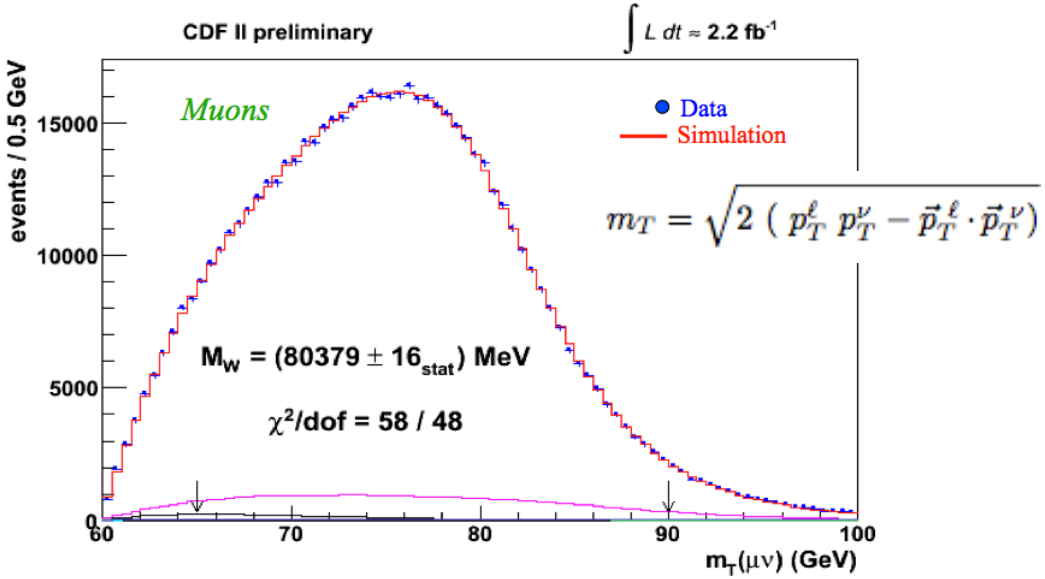
Tail of E/p spectrum used for tuning model of radiative material

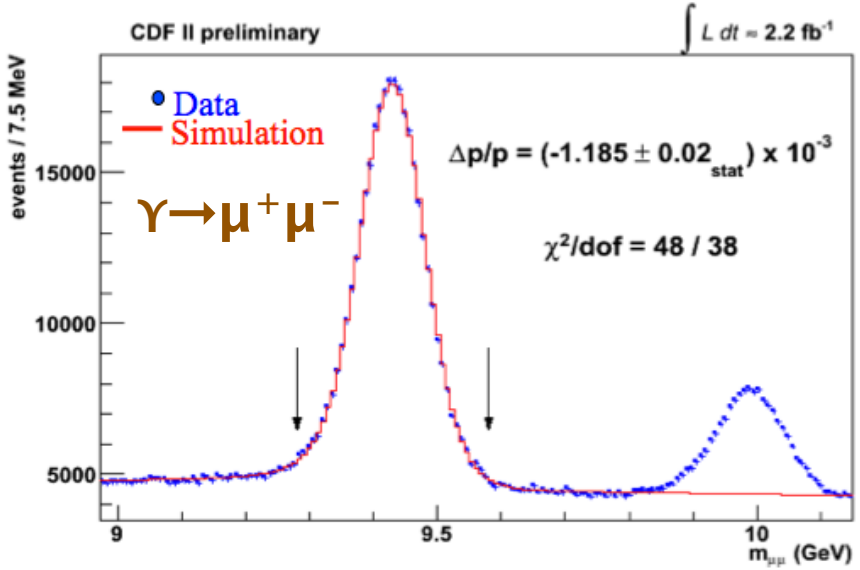
W mass measurement

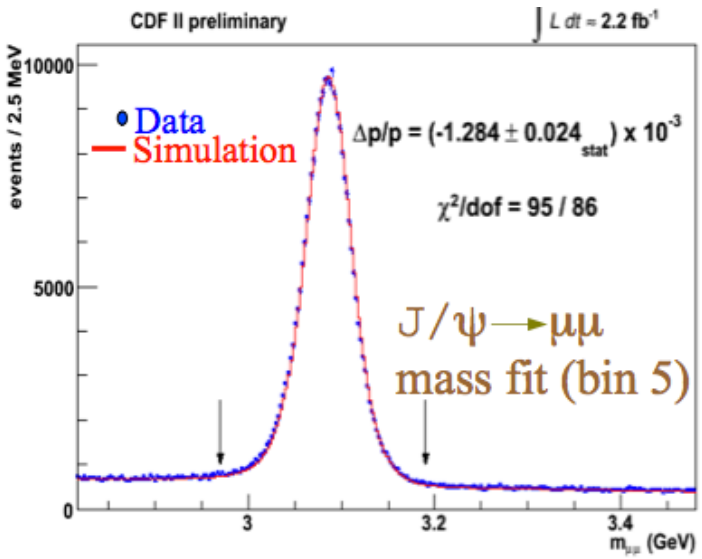


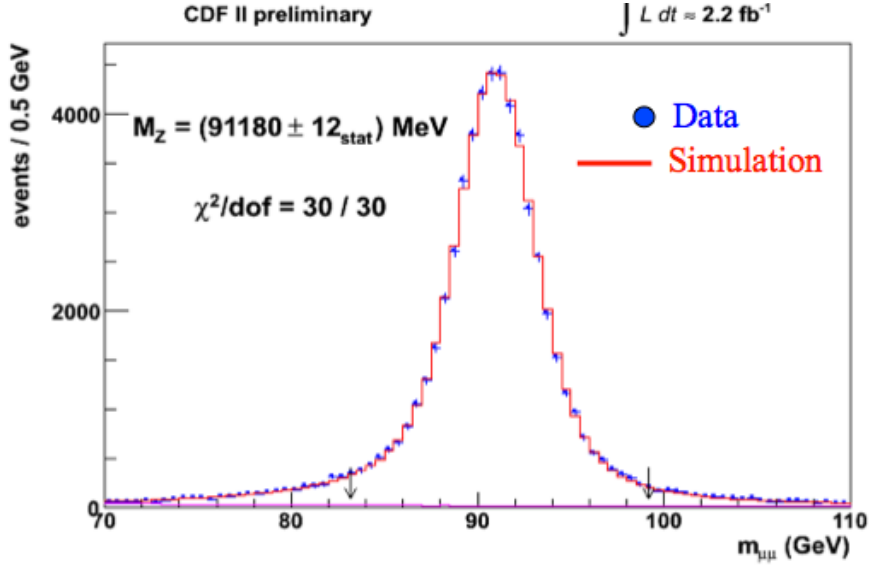


W mass measurement





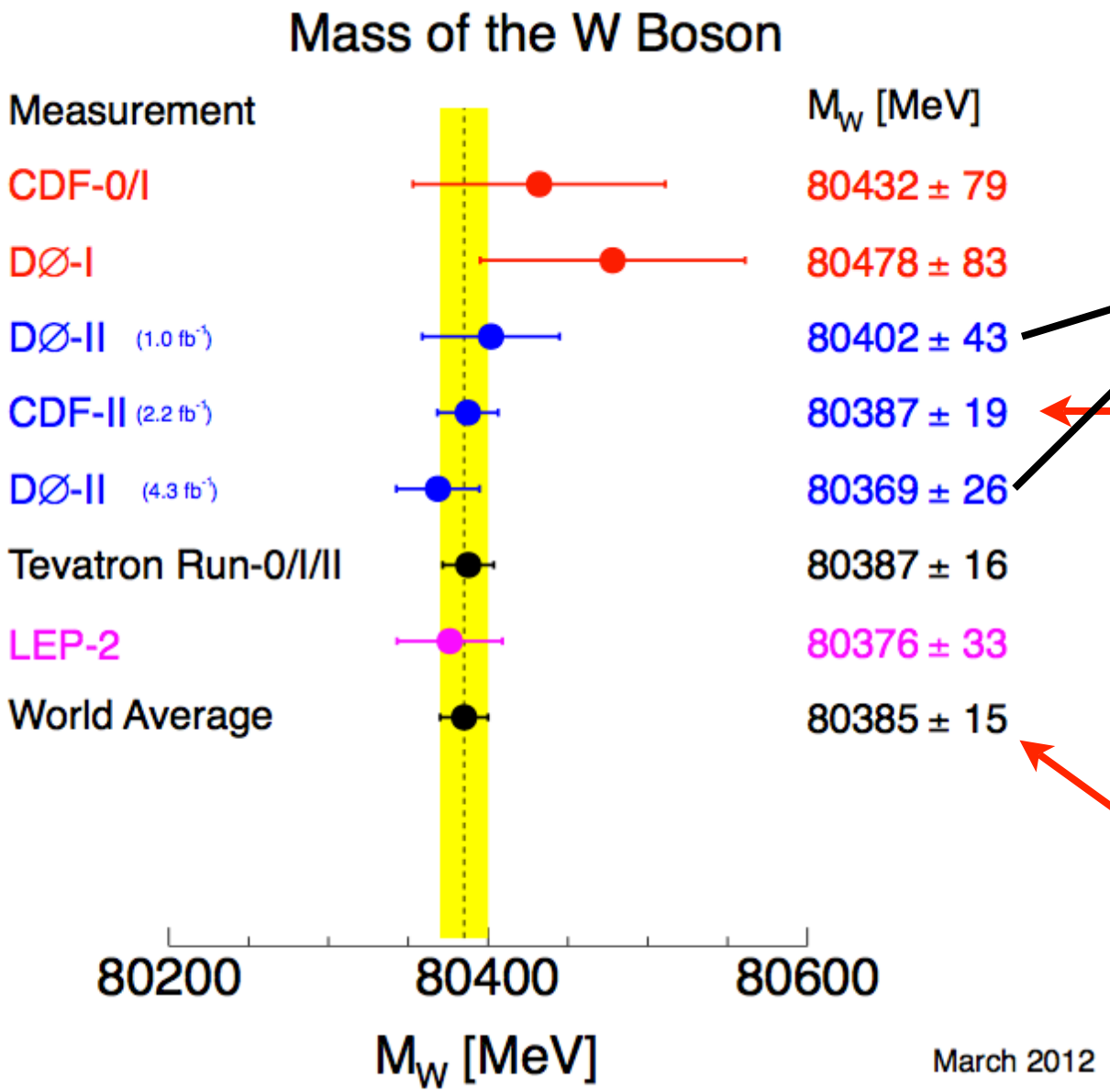




fit simultaneously m_T, lepton p_T, neutrino p_T for muons and electrons

$$M_W = 80.387 \pm 0.012_{stat} \pm 0.015_{syst}\ \mathrm{MeV}$$

W mass measurement

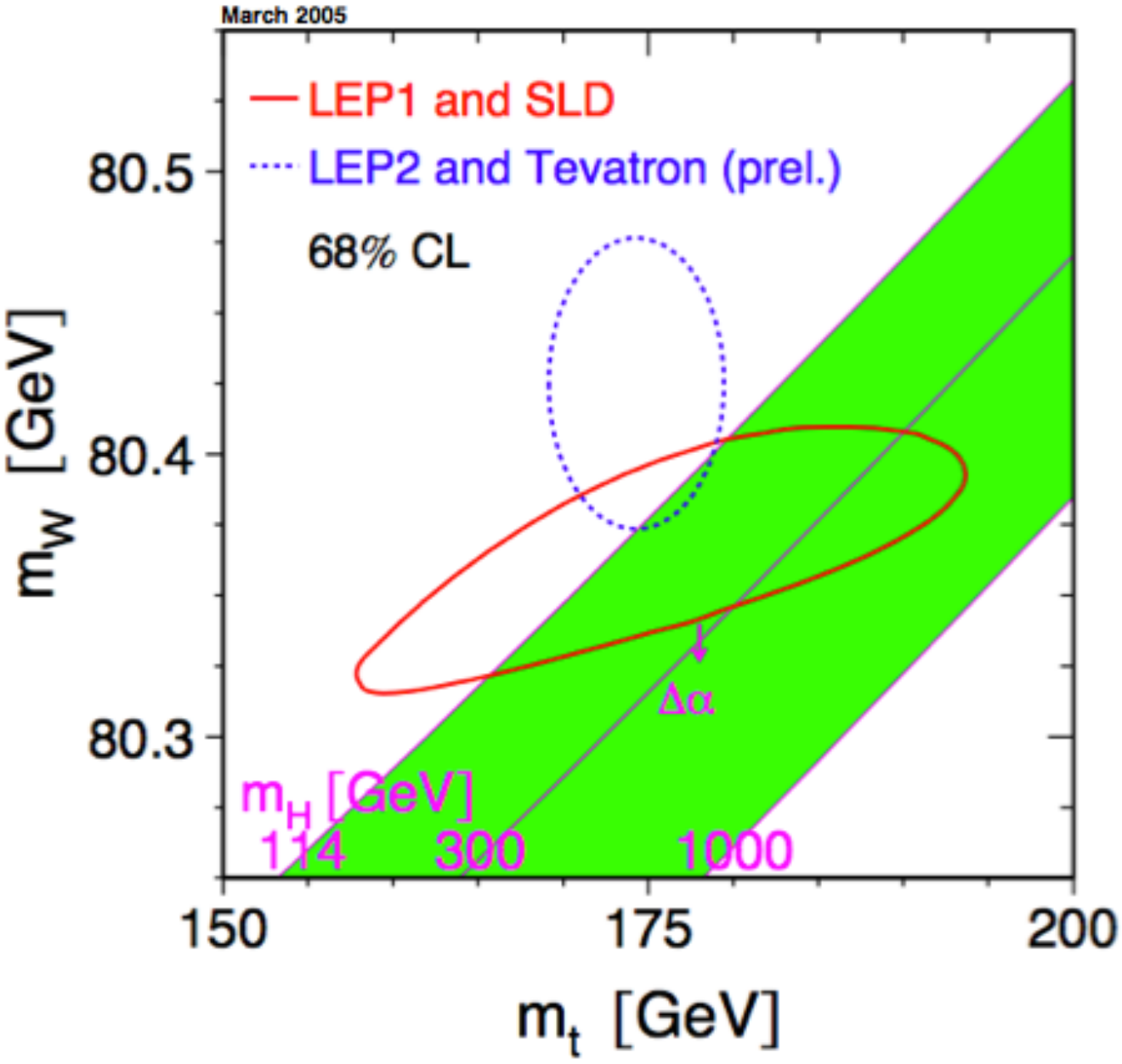


UCL
Oxford

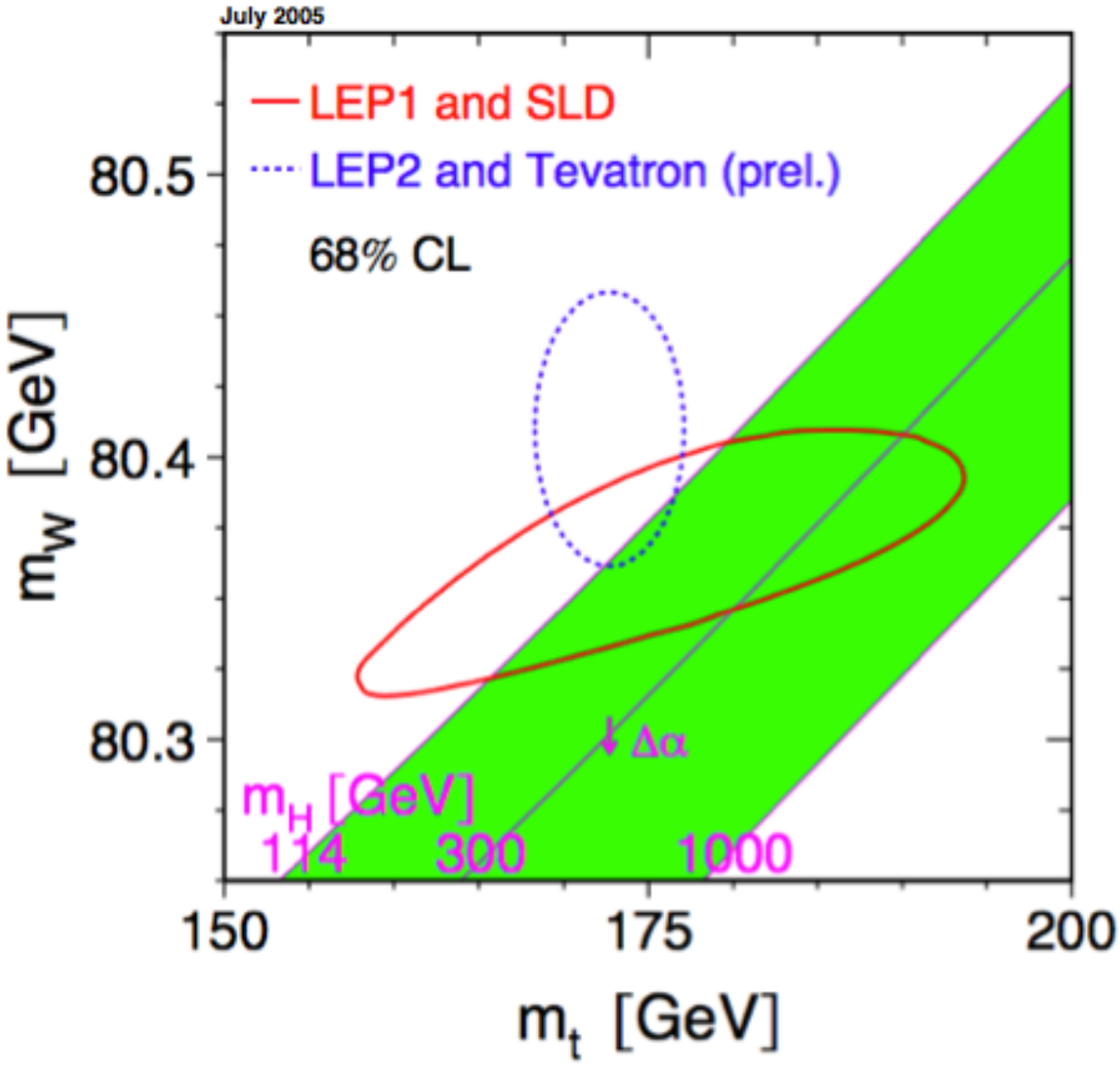
±23

NEW

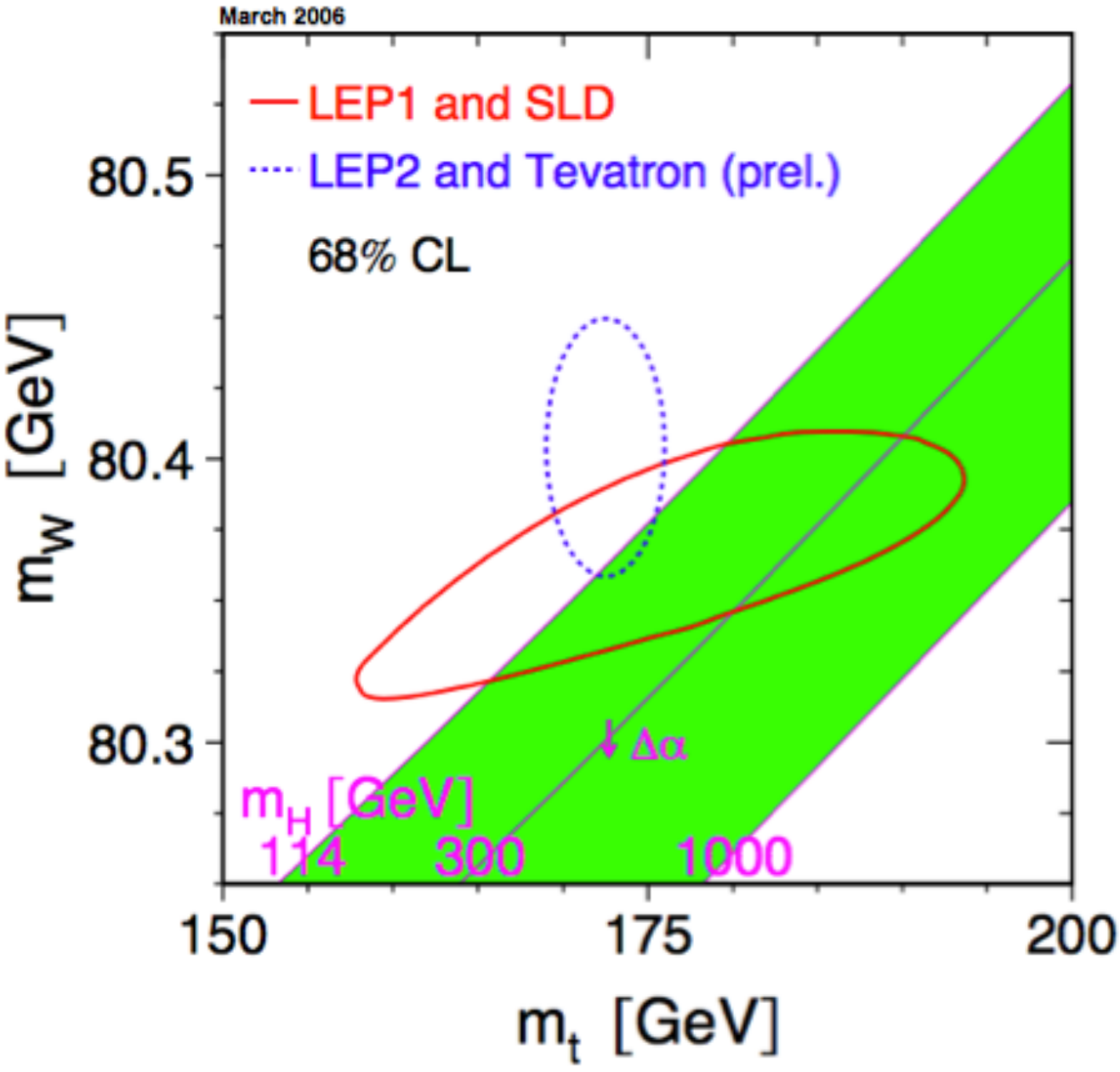
History m_{top} vs. M_W



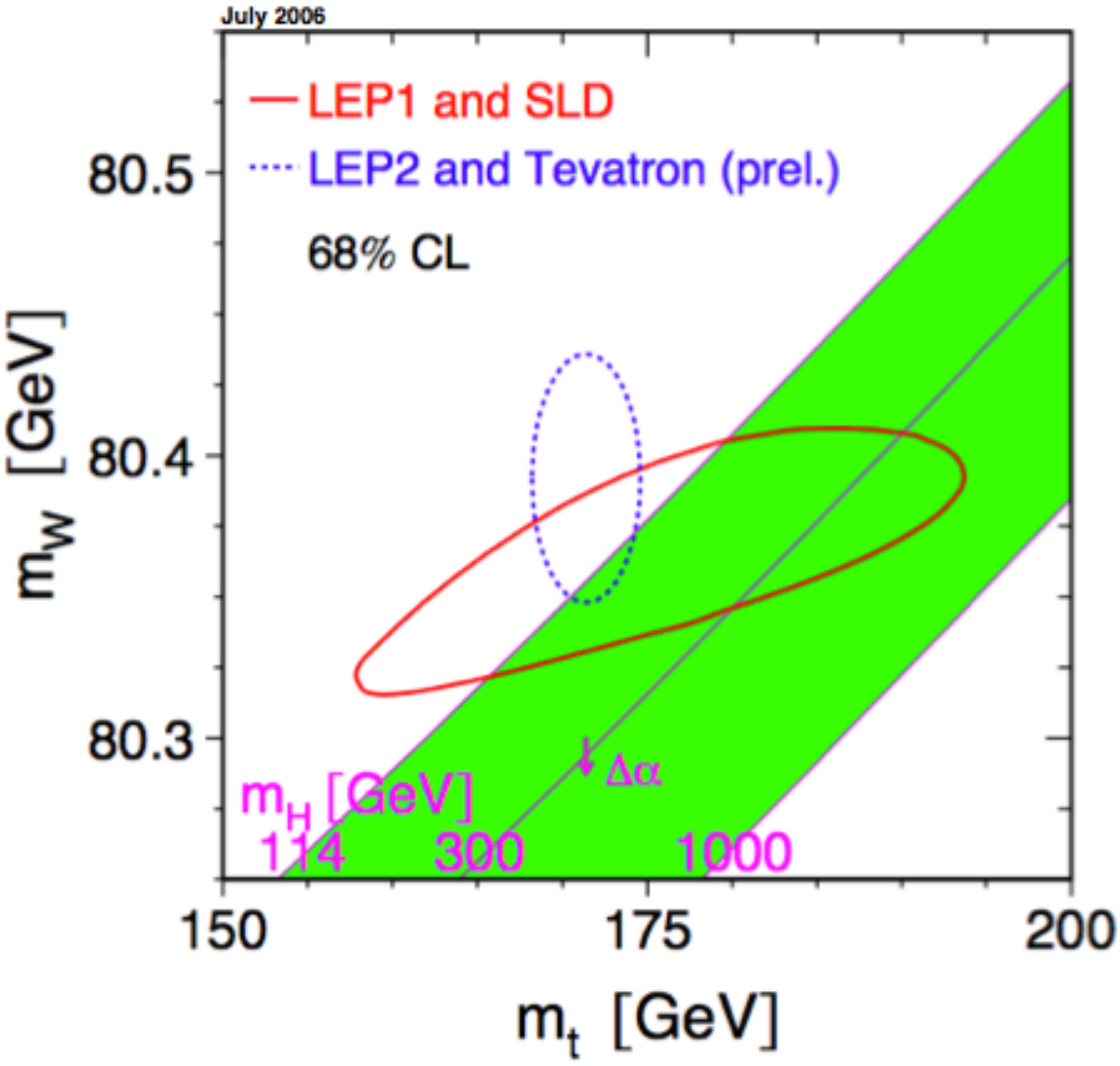
History m_{top} vs. M_W



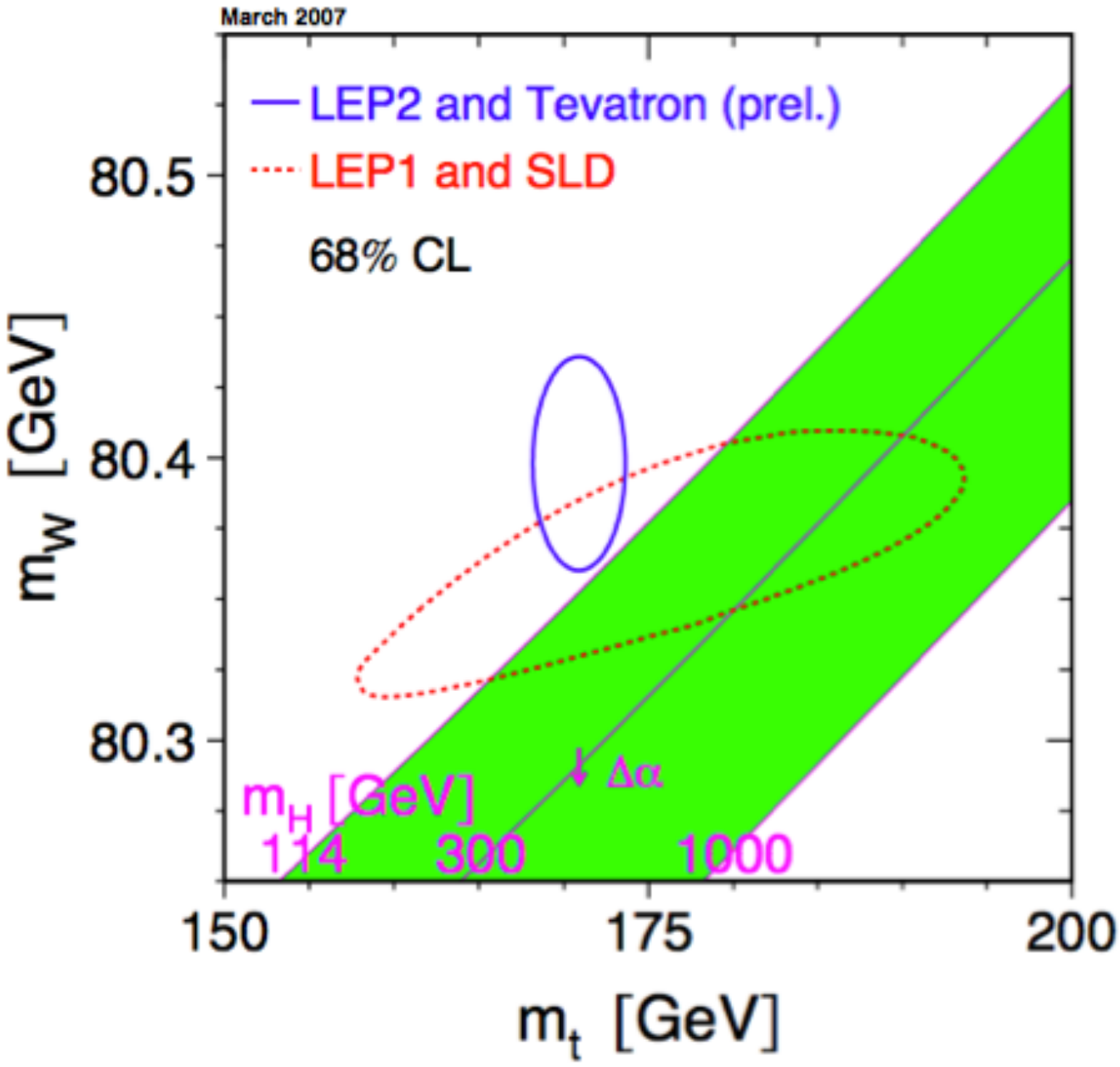
History m_{top} vs. M_W



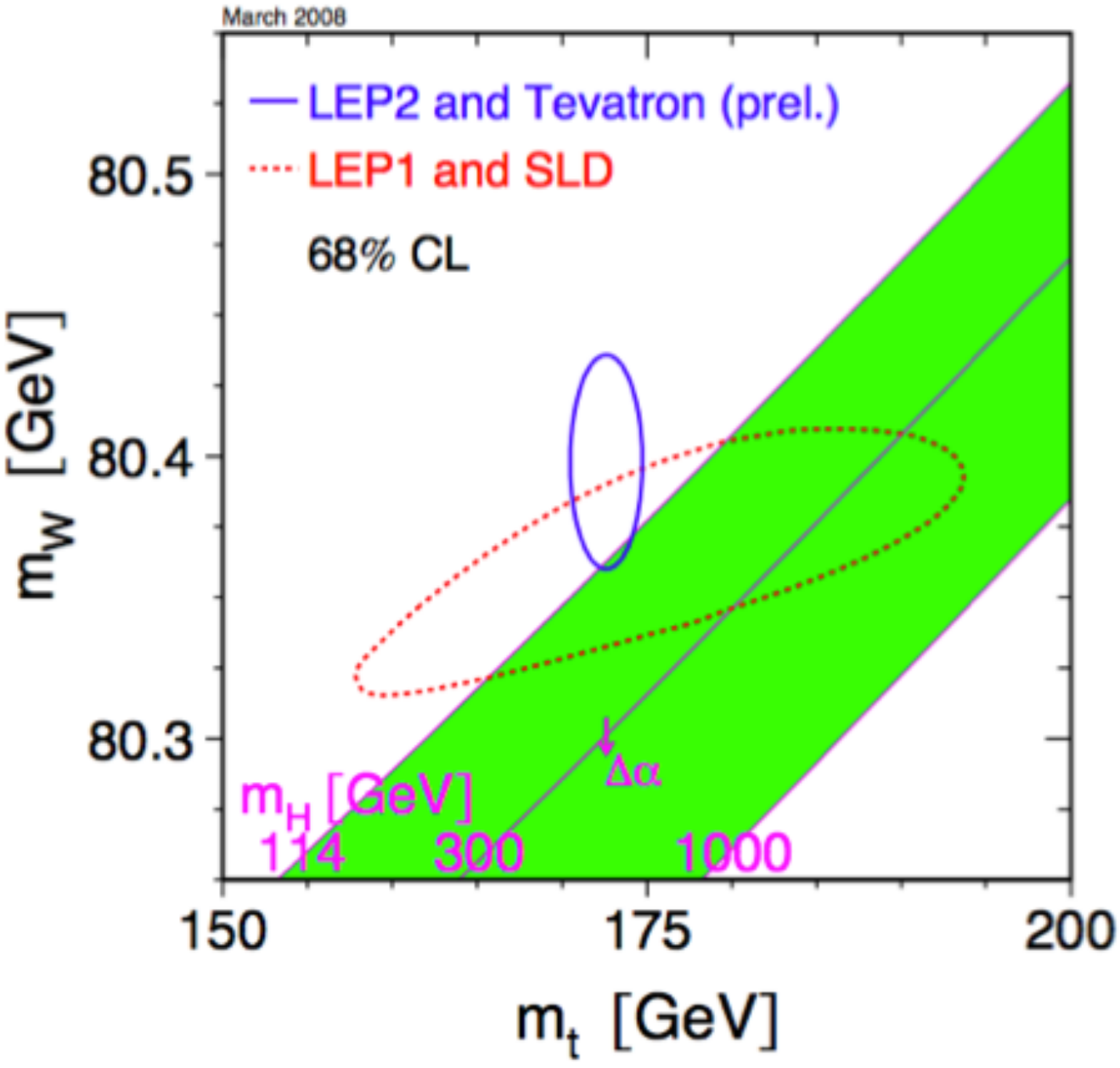
History m_{top} vs. M_W



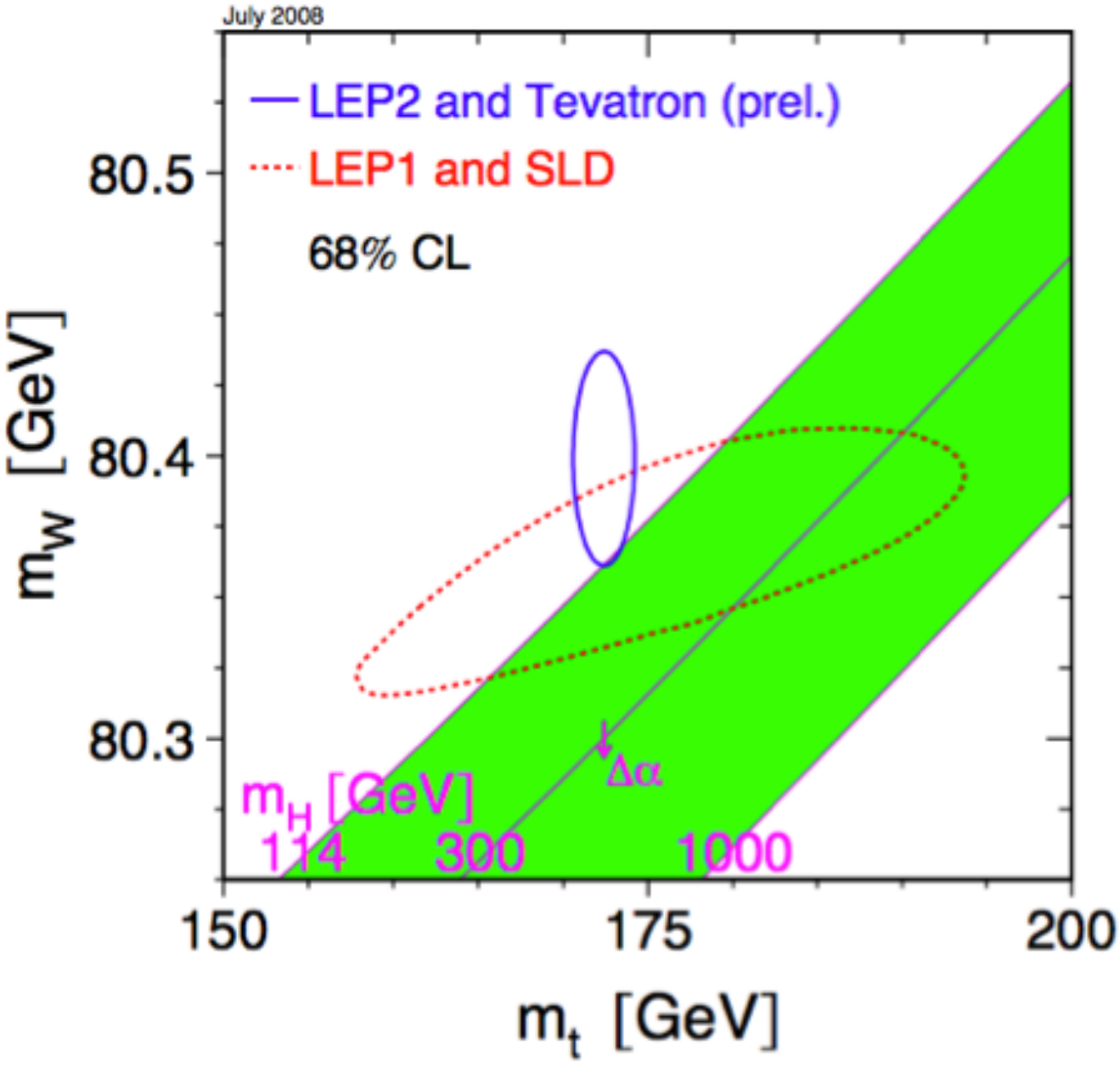
History m_{top} vs. M_W



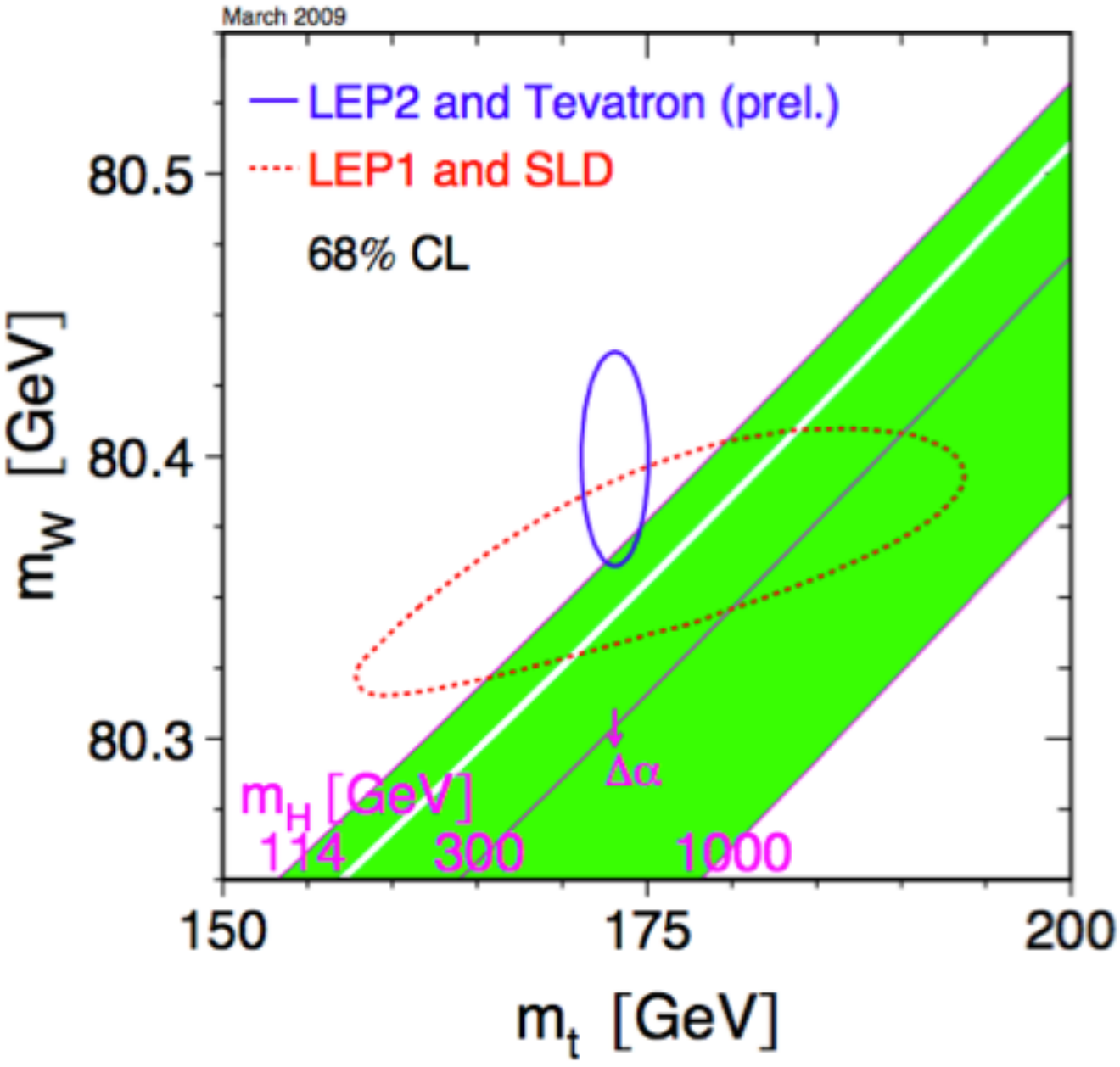
History m_{top} vs. M_W



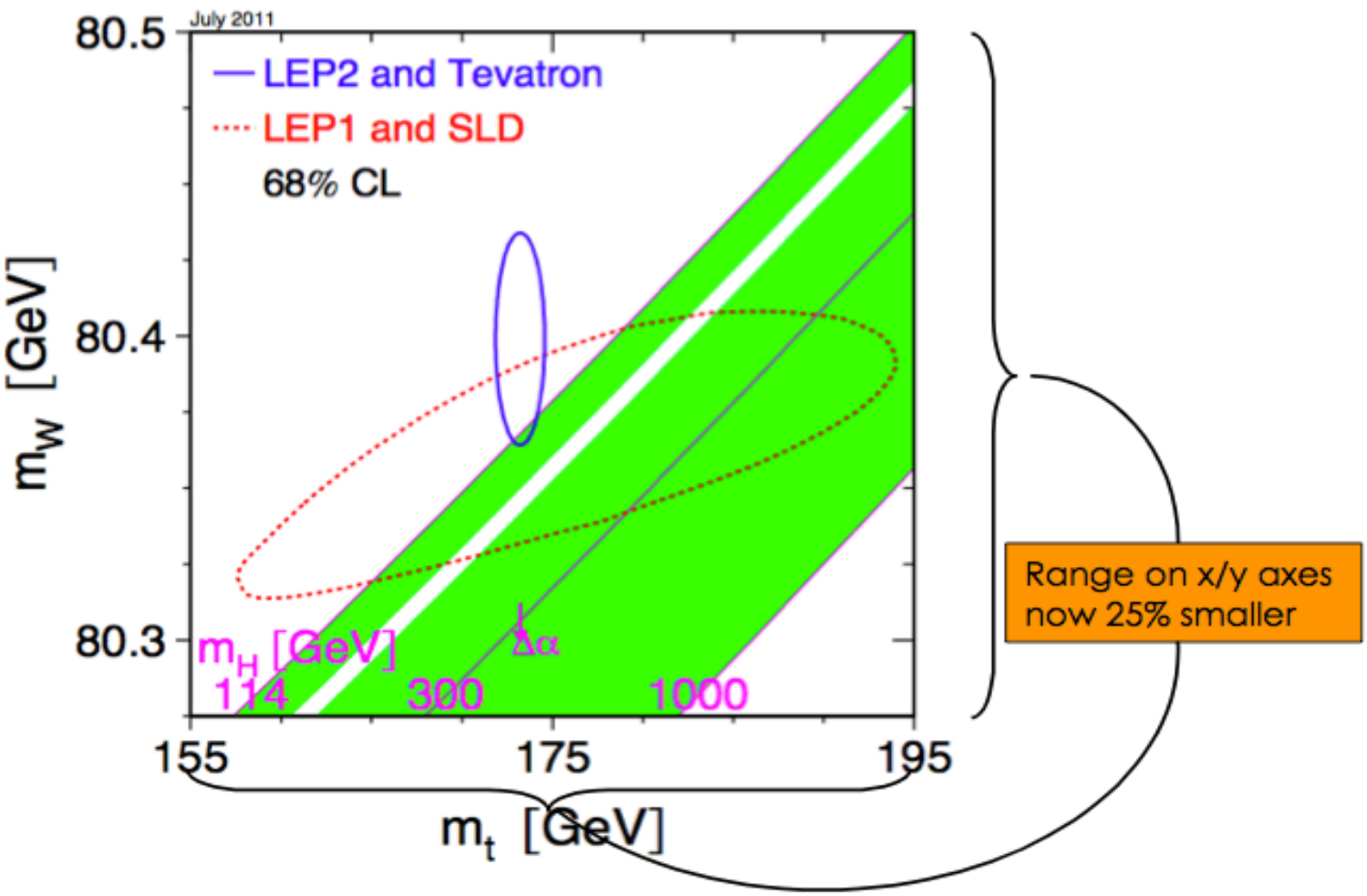
History m_{top} vs. M_W



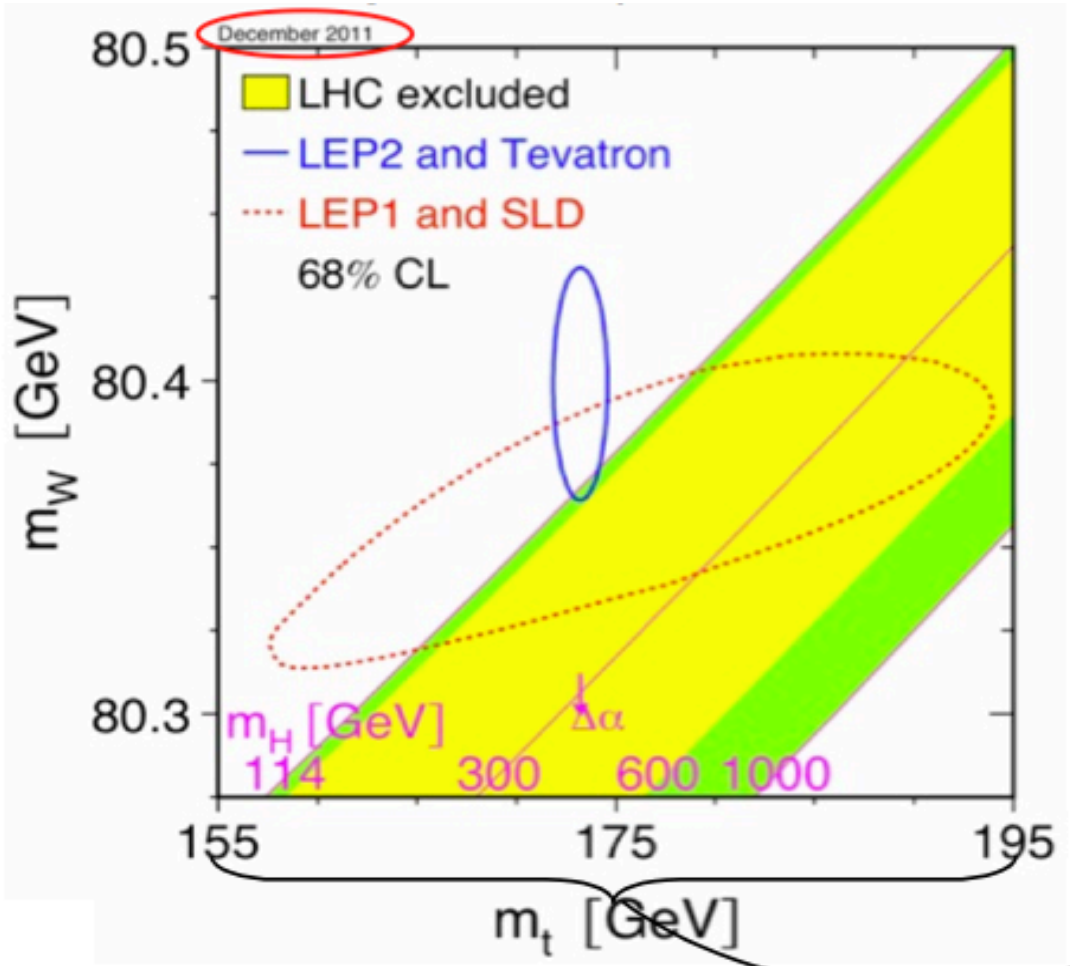
History m_{top} vs. M_W



History m_{top} vs. M_W

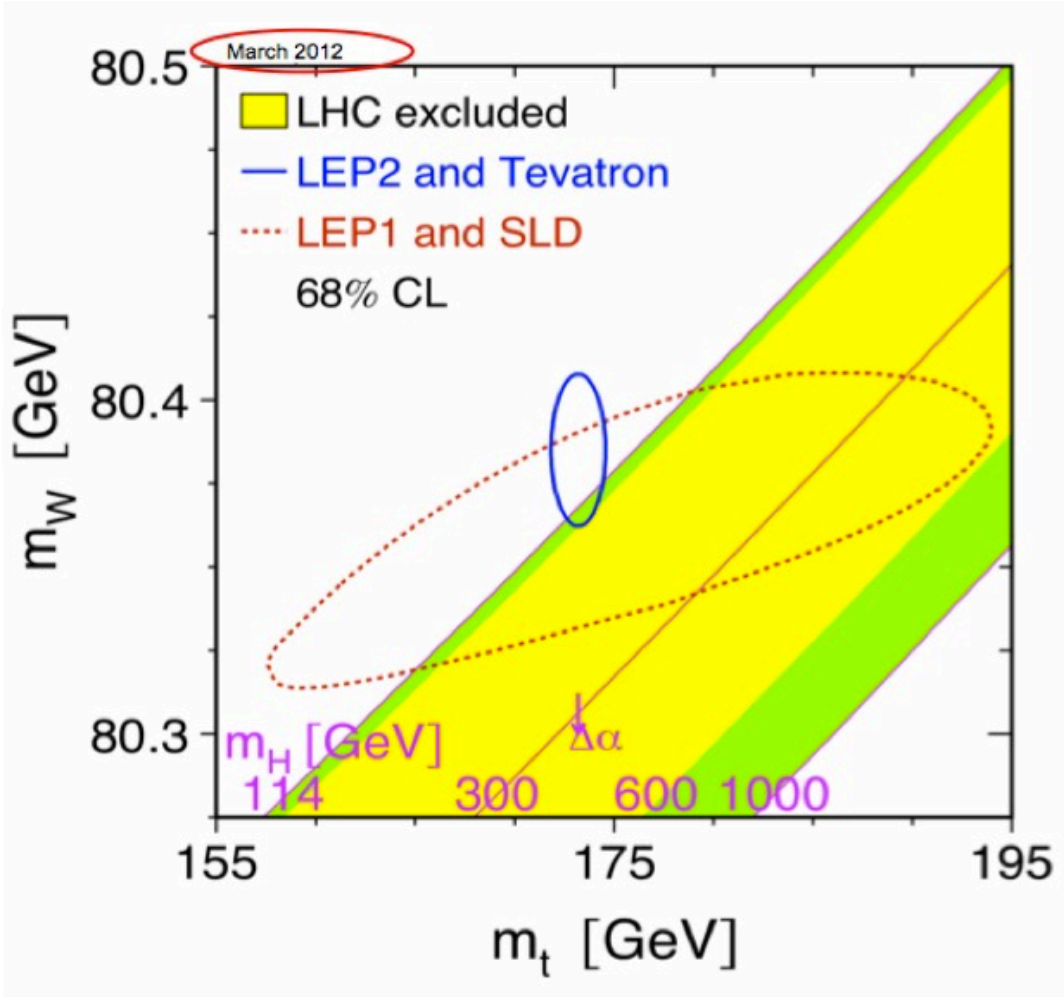


History m_{top} vs. M_W

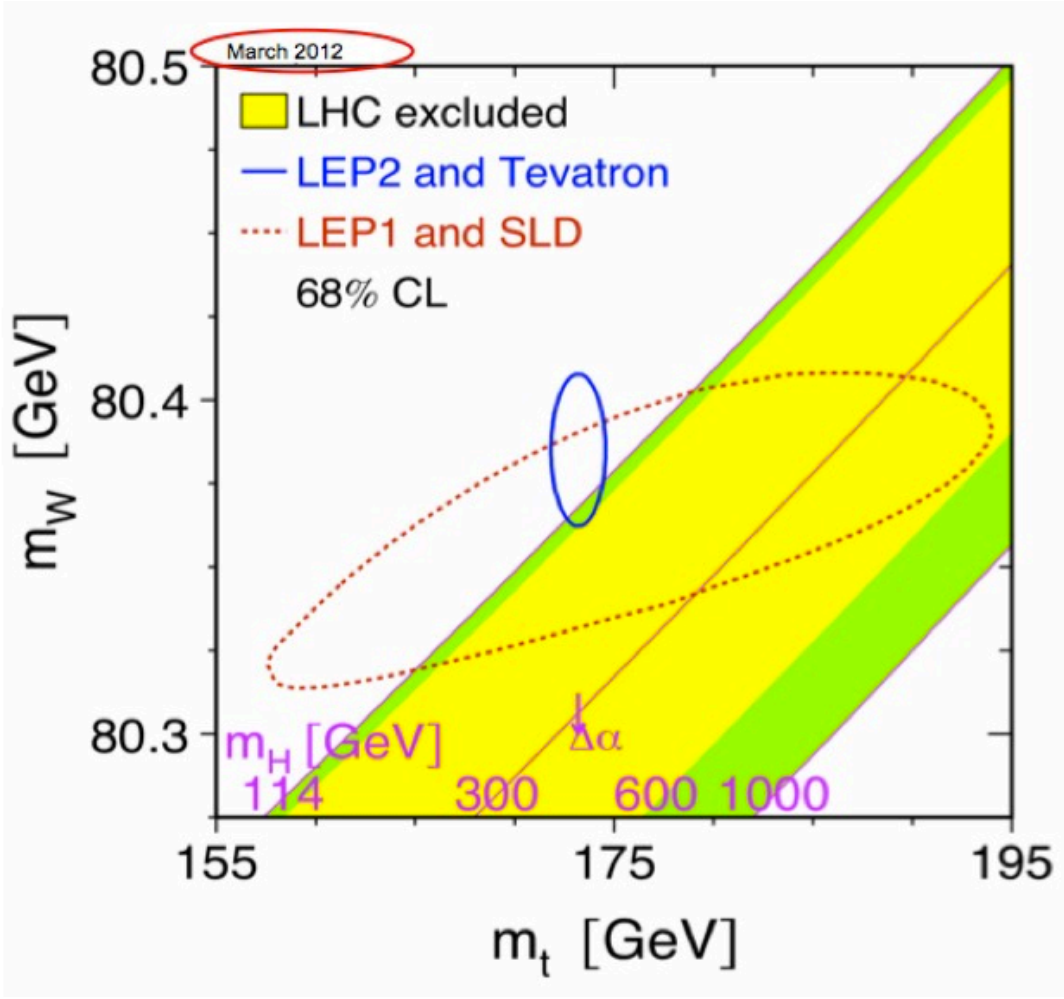


Range on x/y axes now 25% smaller

History m_{top} vs. M_W

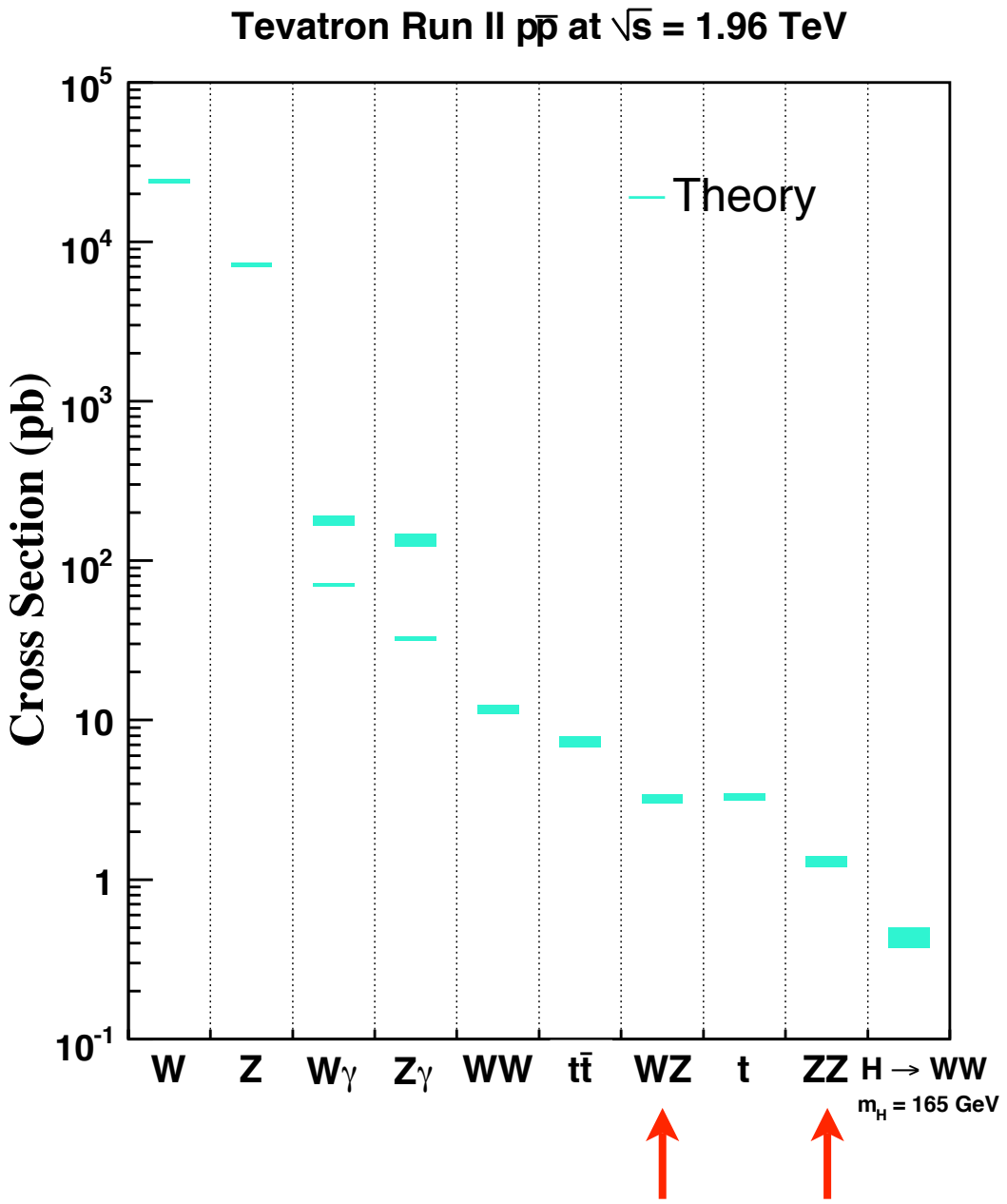


History m_{top} vs. M_W

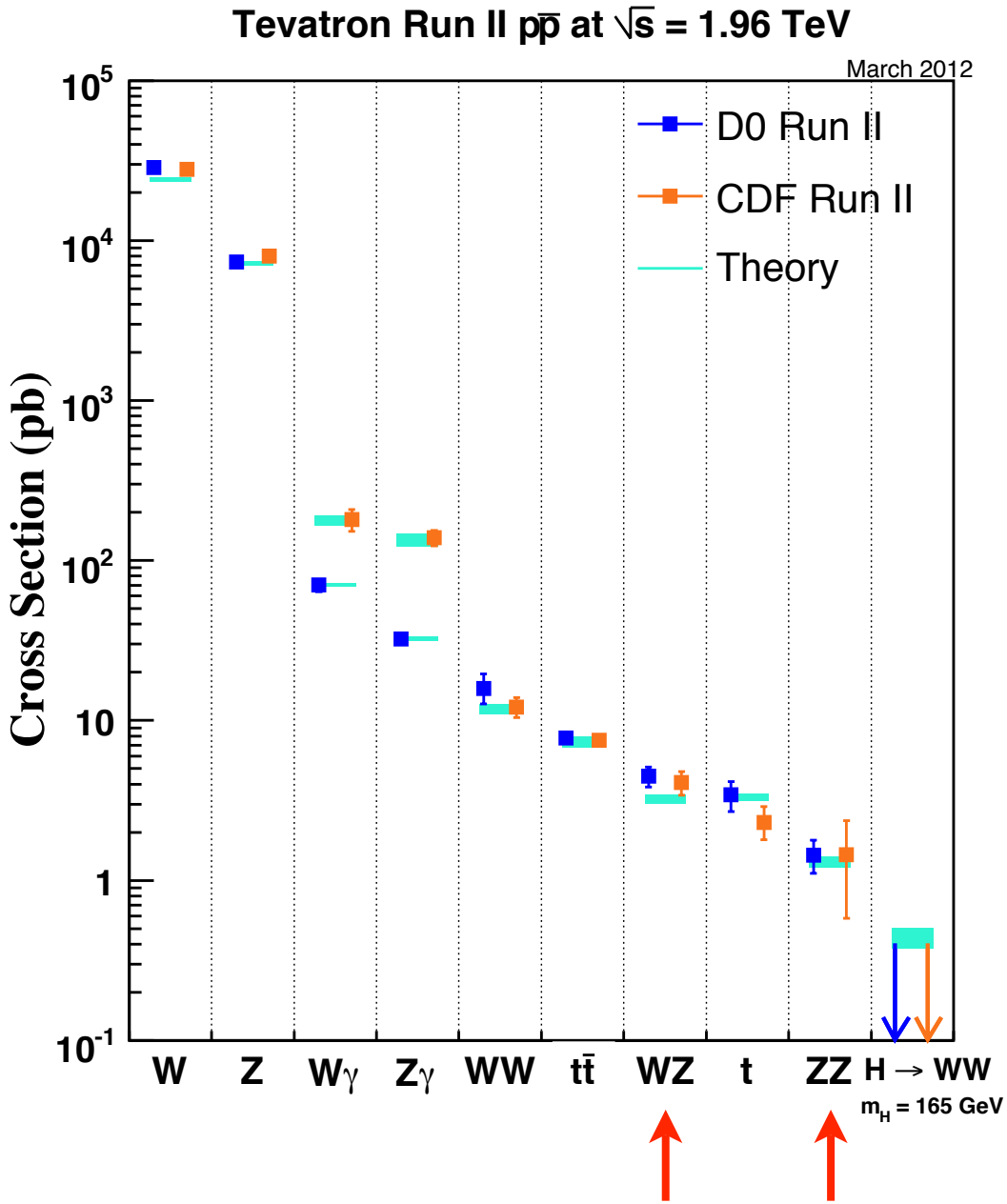


→ SM is self-consistent for low Higgs mass

Tevatron Cross Sections

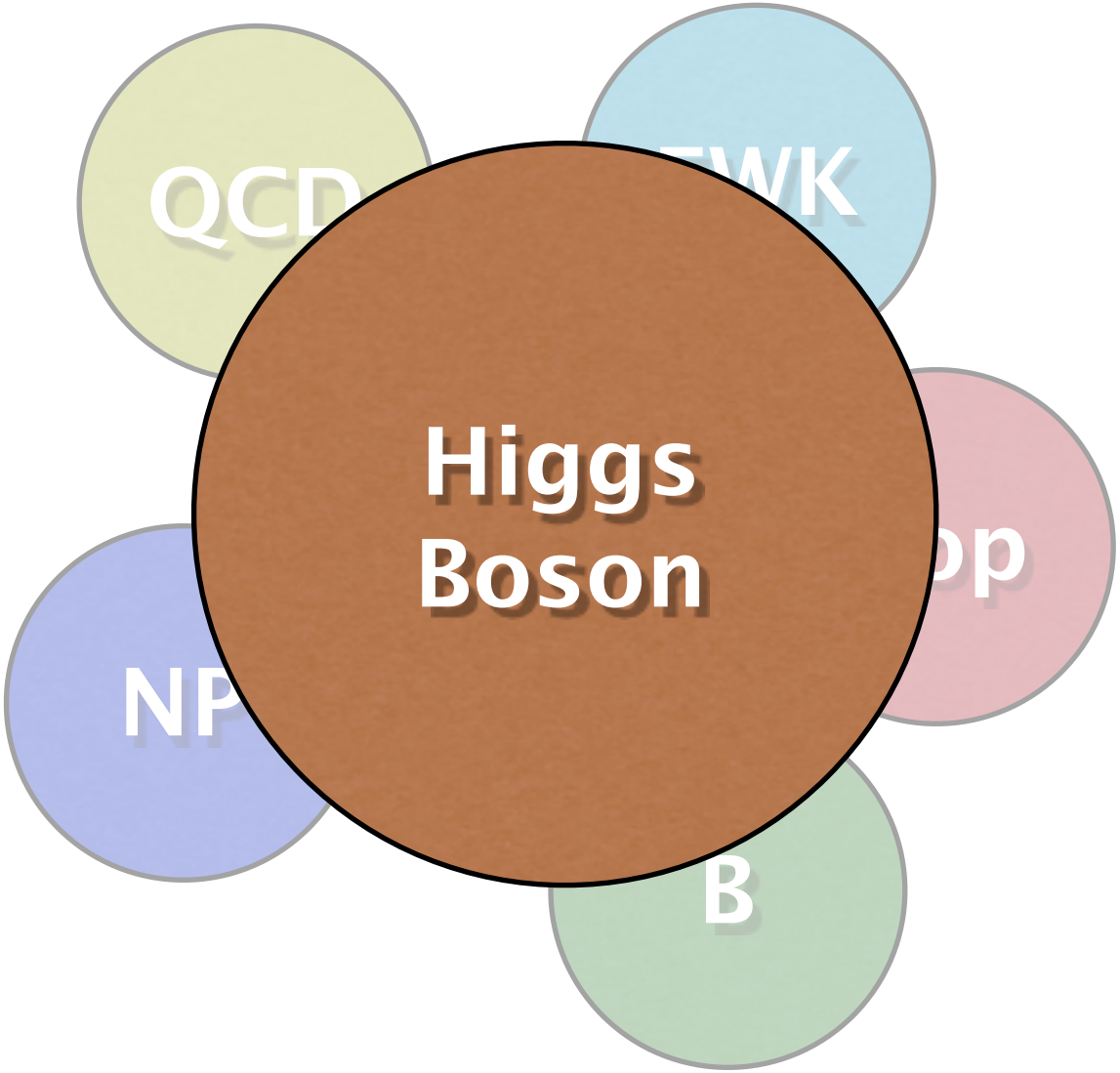


Tevatron Cross Sections



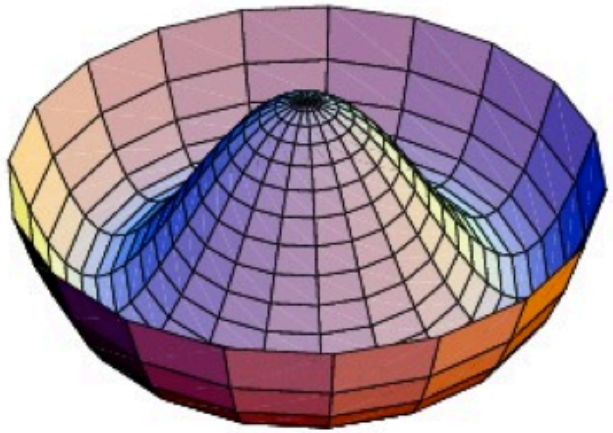
Manchester

Tevatron Results for Winter 2012

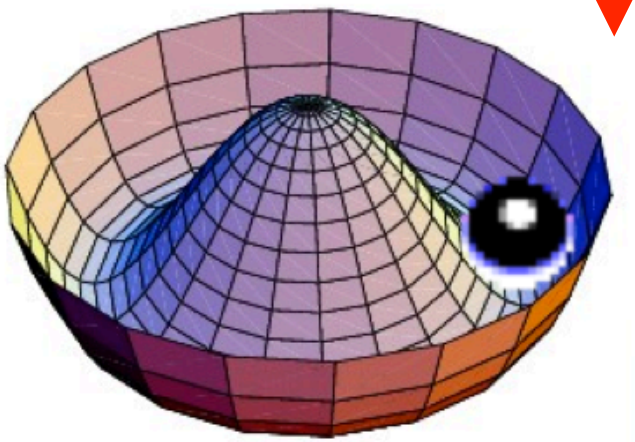


The Higgs Potential

Higgs potential:



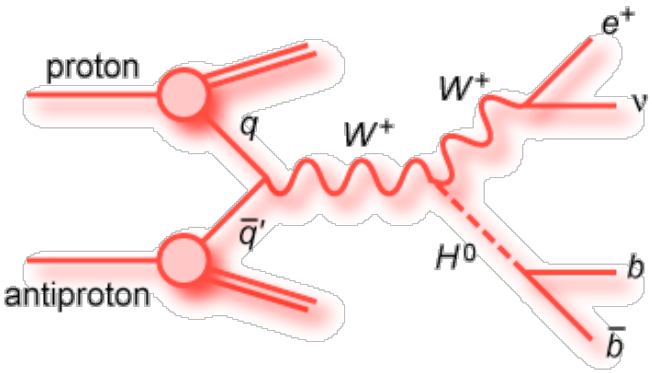
Higgs ground state:

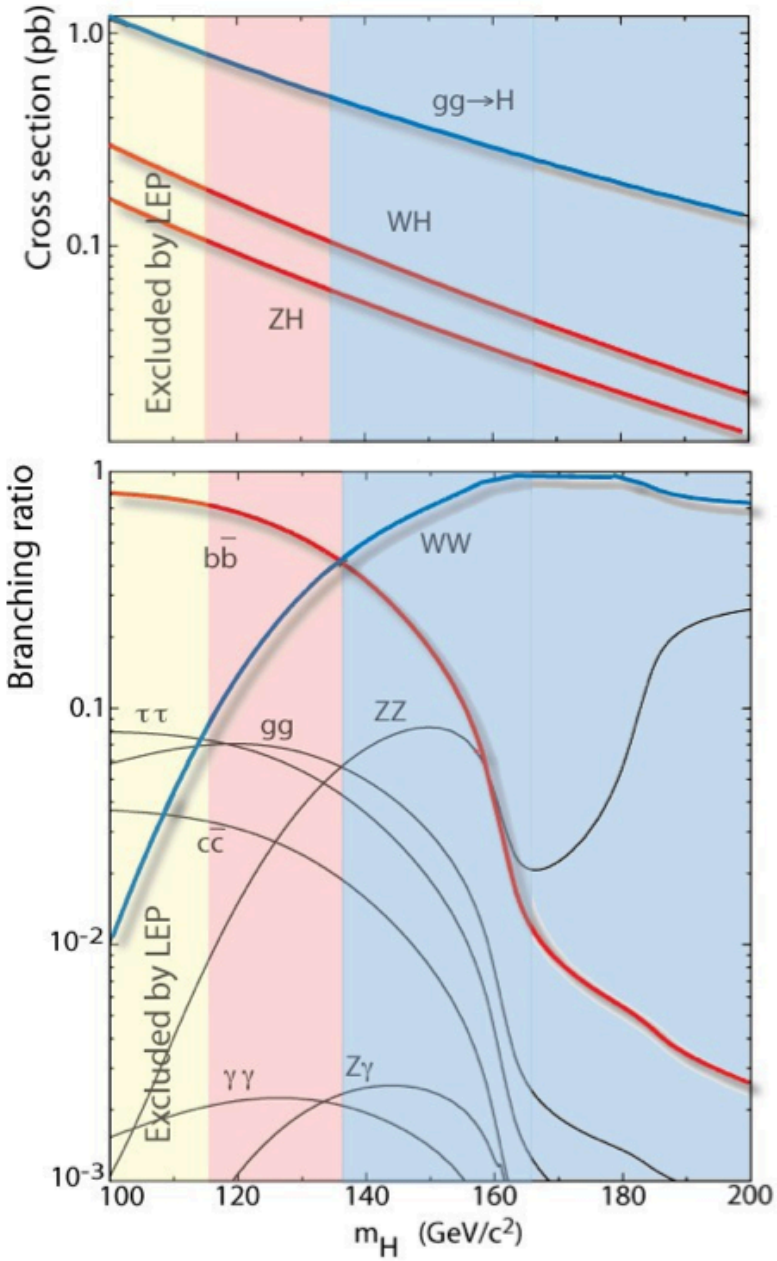


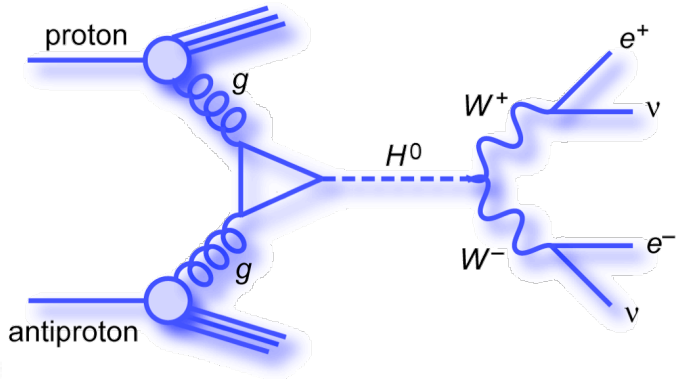
spontaneous symmetry breaking

$$\mathcal{L} = -\frac{1}{2} Tr(W_{\lambda\rho} W^{\lambda\rho}) - \frac{1}{4} B_{\lambda\rho} B^{\lambda\rho} + W_\lambda^+ W^{-\lambda} m_W^2 \left(1 + \frac{H}{v}\right)^2 + \frac{1}{2} Z_\lambda Z^\lambda m_Z^2 \left(1 + \frac{H}{v}\right)^2 + \left\{\bar{\psi} \frac{i}{2} \gamma^\lambda D_\lambda \psi + h.c.\right\} - \bar{\psi} M \psi \left(1 + \frac{H}{v}\right) + \frac{1}{2} \partial_\lambda H \partial^\lambda H - \frac{1}{2} m_H^2 H^2 \left[1 + \frac{H}{v} + \frac{1}{4}\left(\frac{H}{v}\right)^2\right]$$

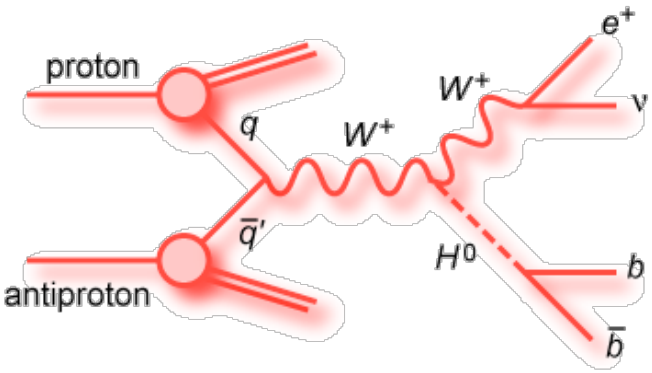
SM Higgs Decays

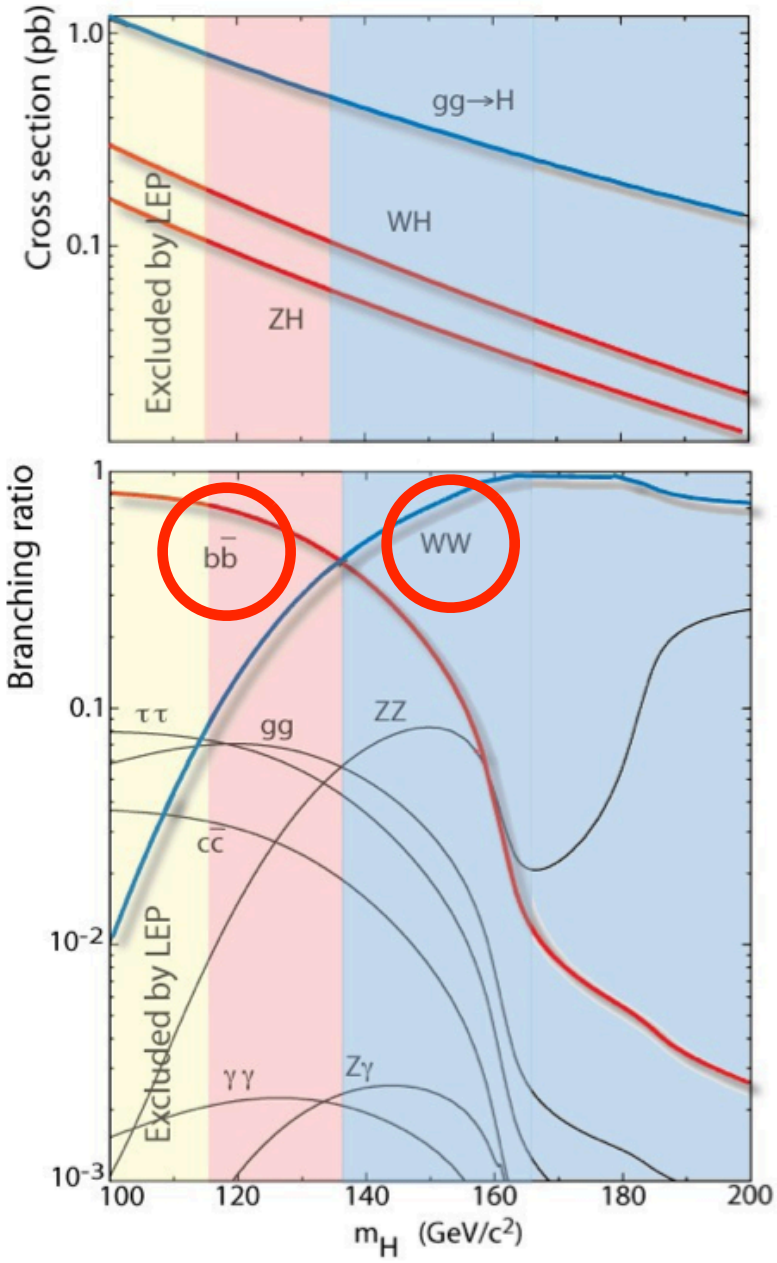


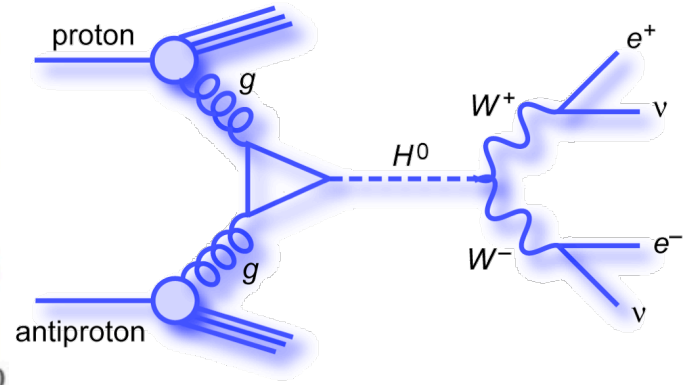




SM Higgs Decays

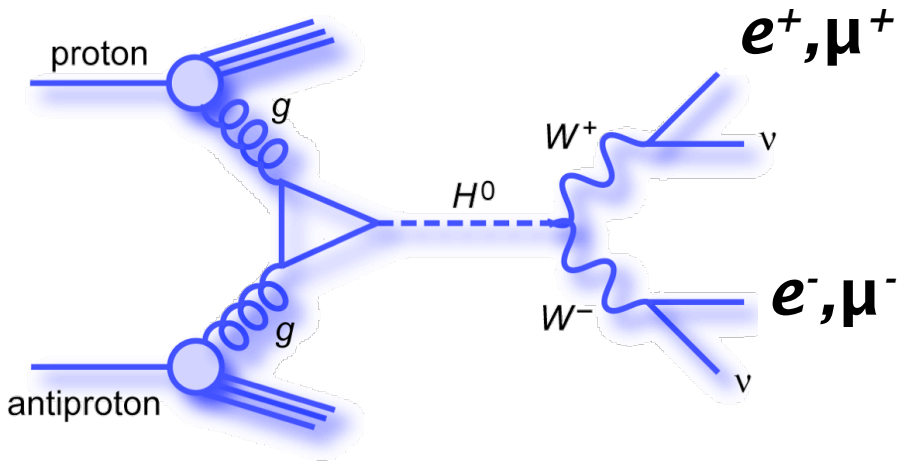




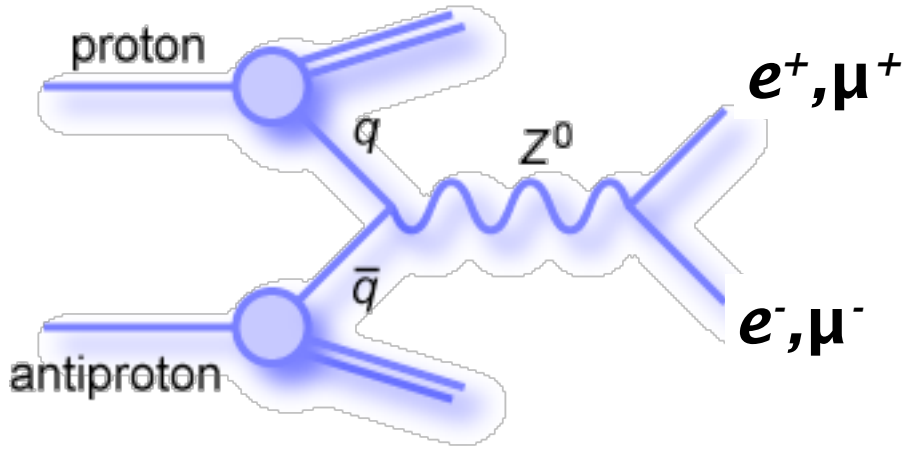


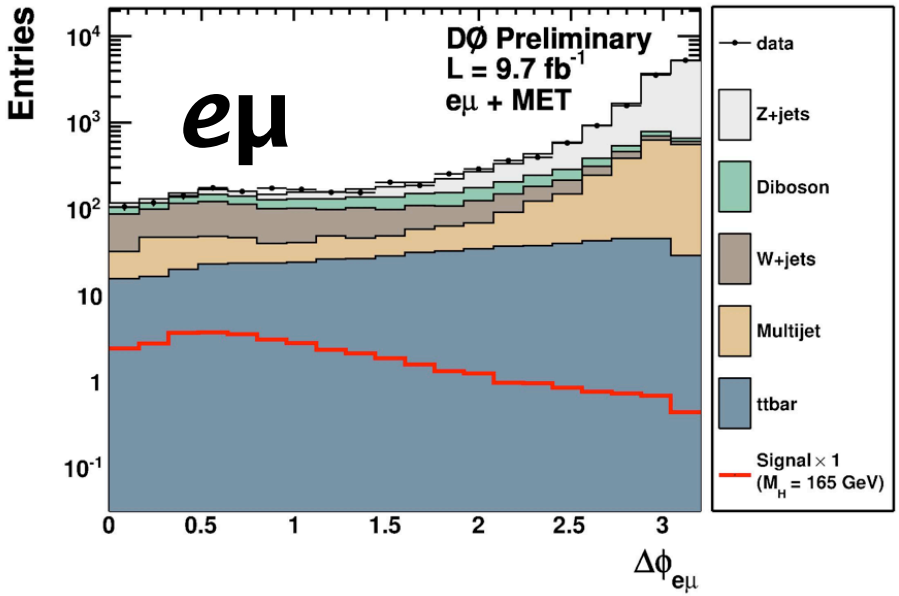
Search for H→WW→ee, eμ, μμ

signal



background

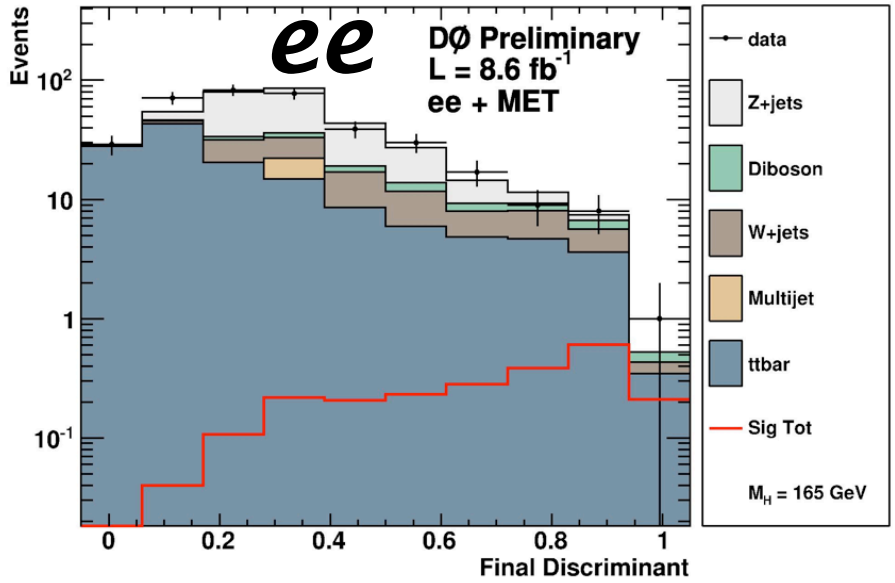


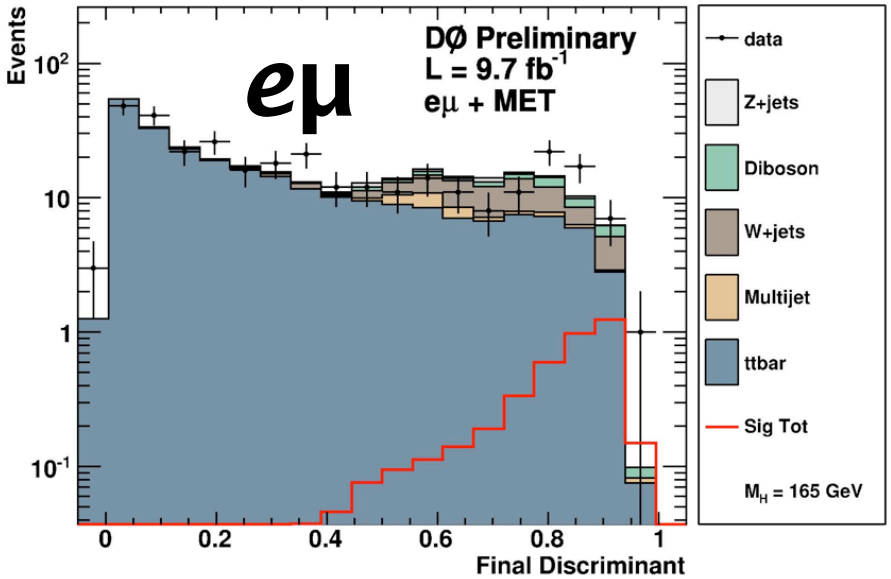


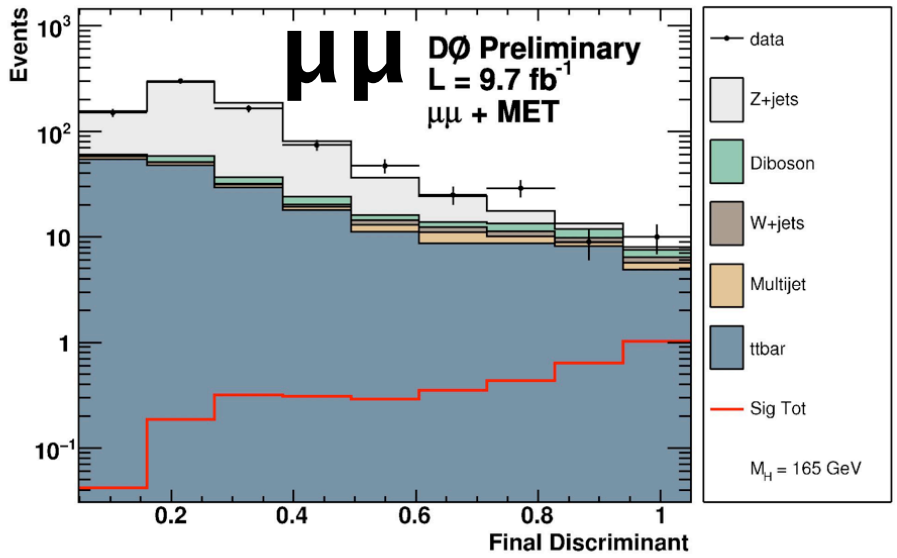
Search for H→WW→ee, eμ, μμ

- analyse 0, 1, and ≥ 2 jets
- final decision tree discriminant

- added data, improved background modeling, better background rejection and increased acceptance
- 14% improvement of expected limits at lower masses

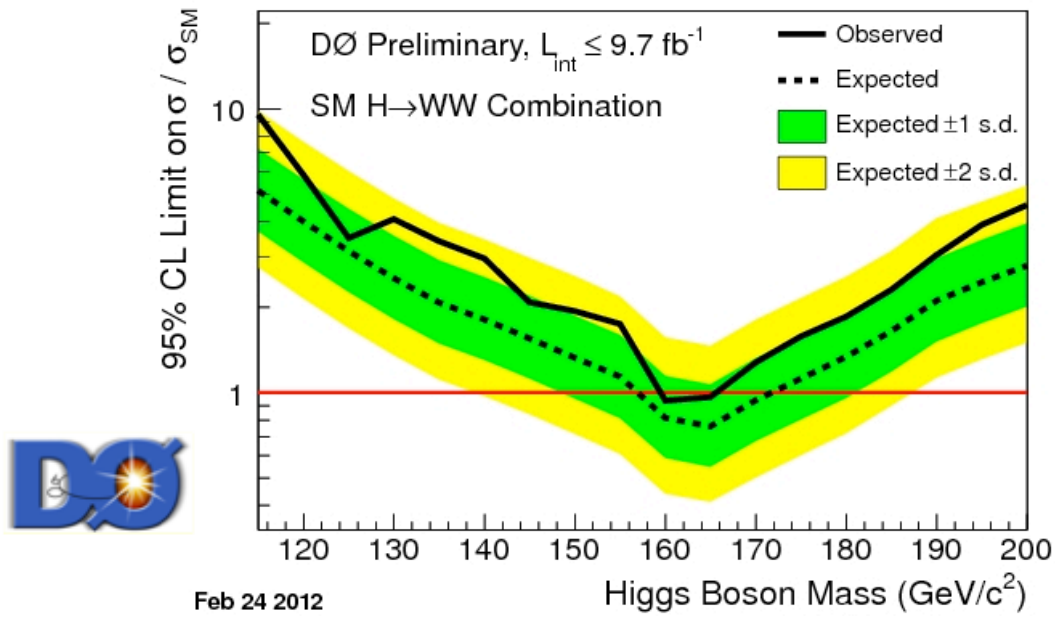






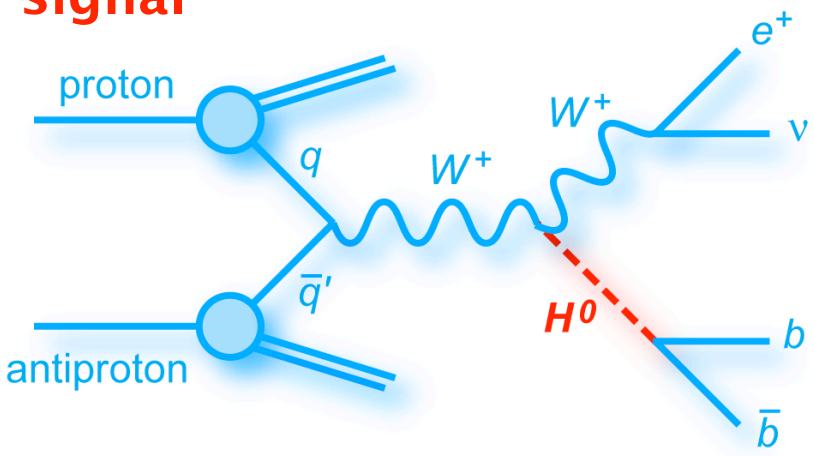
SM Higgs Search

10 fb^{-1}

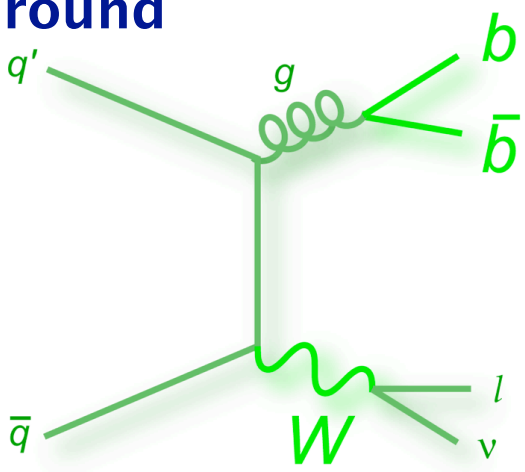


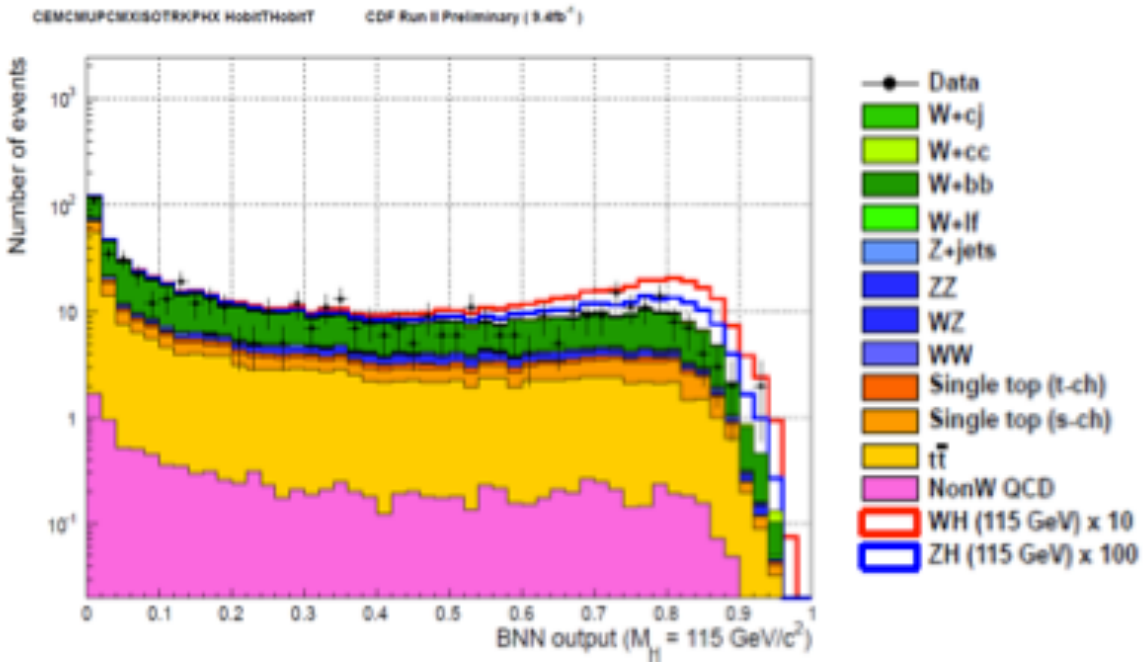
Associated WH Production

signal



background

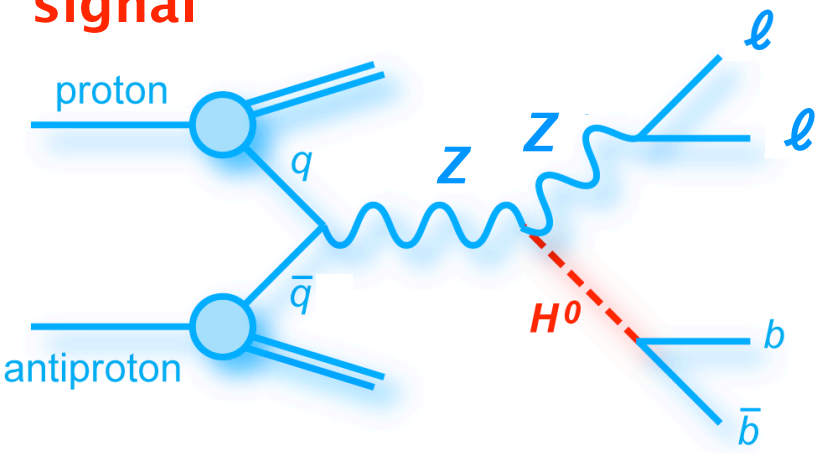




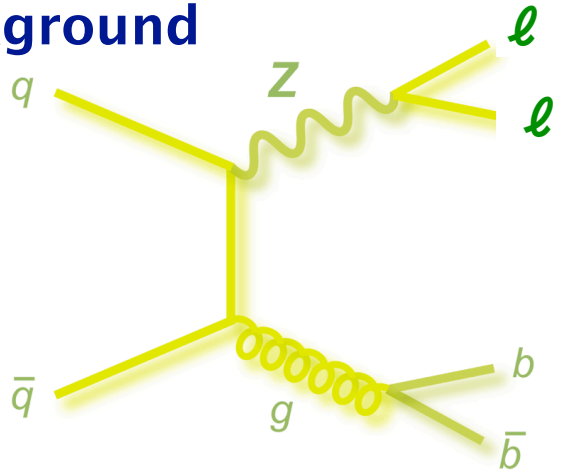
- **added data, improved b-tagging, new triggers, update of 3-jet bin**
- **30% improvement of expected limits**

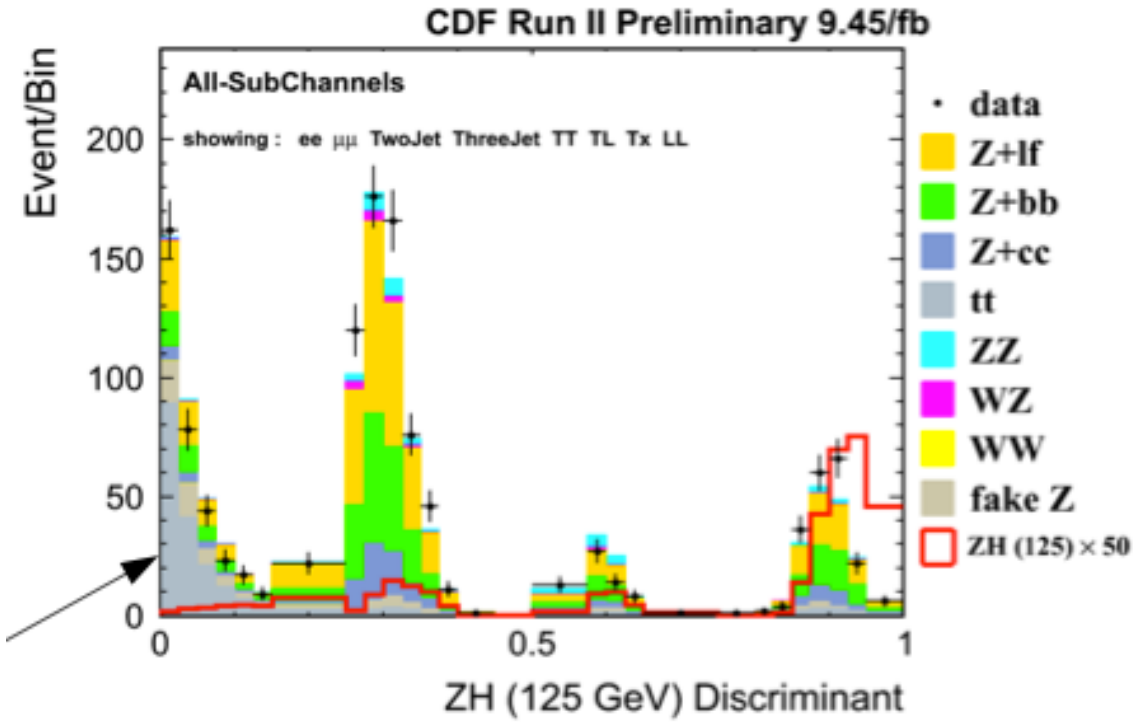
Associated ZH Production

signal



background

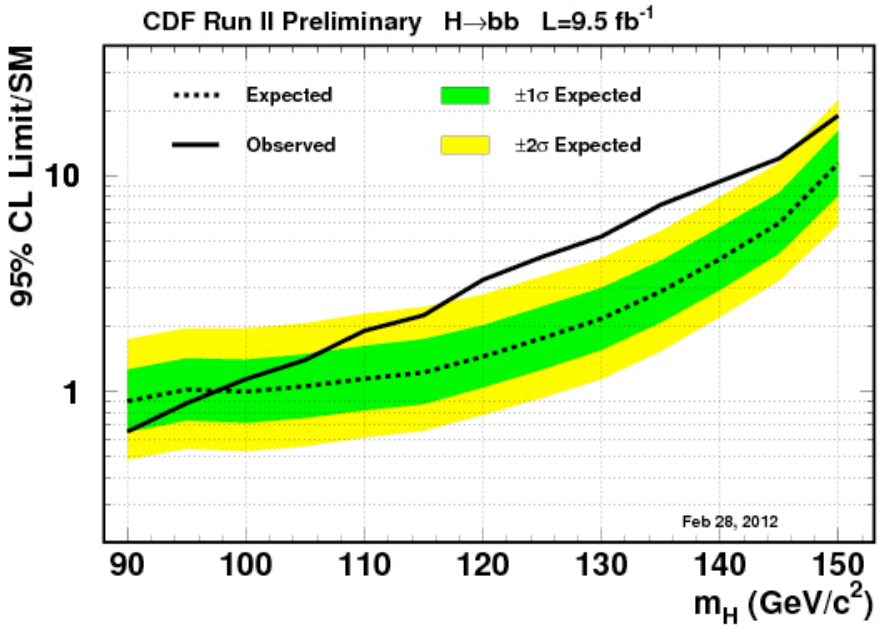


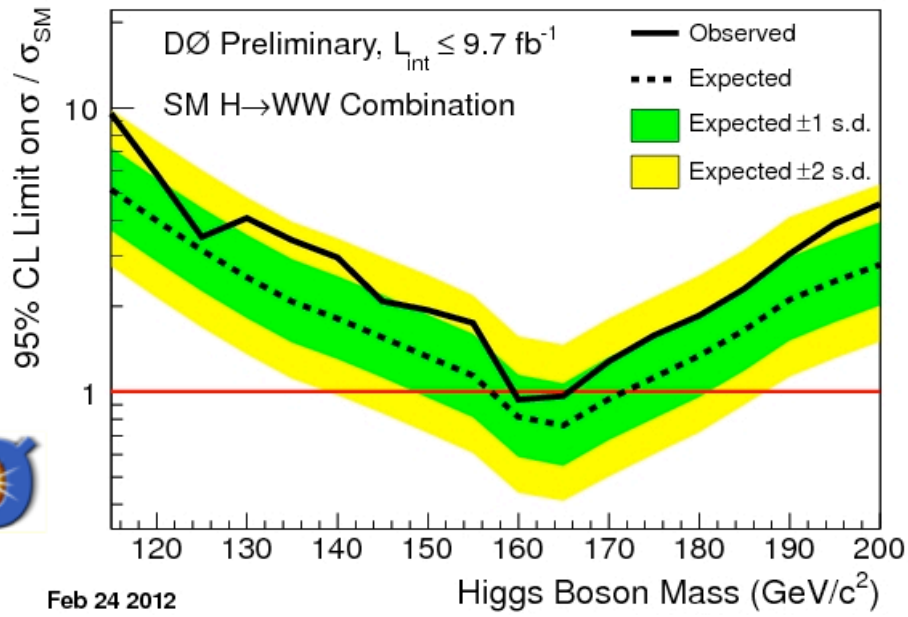


- added data, improved b-tagging, new triggers, better background rejection and lepton acceptance
- 34% improvement of expected limits

SM Higgs Search

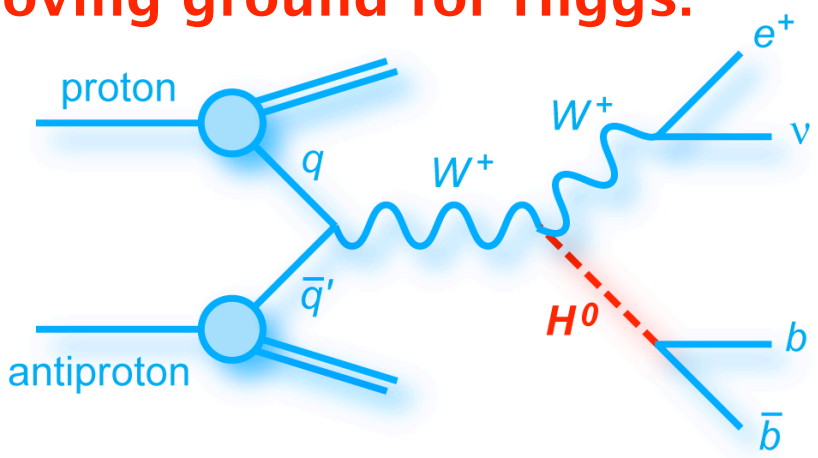
10 fb^{-1}

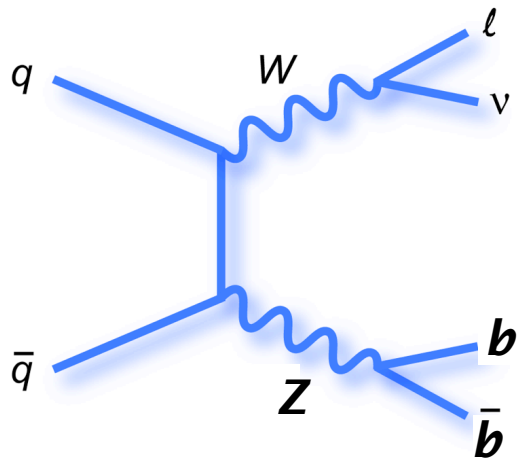


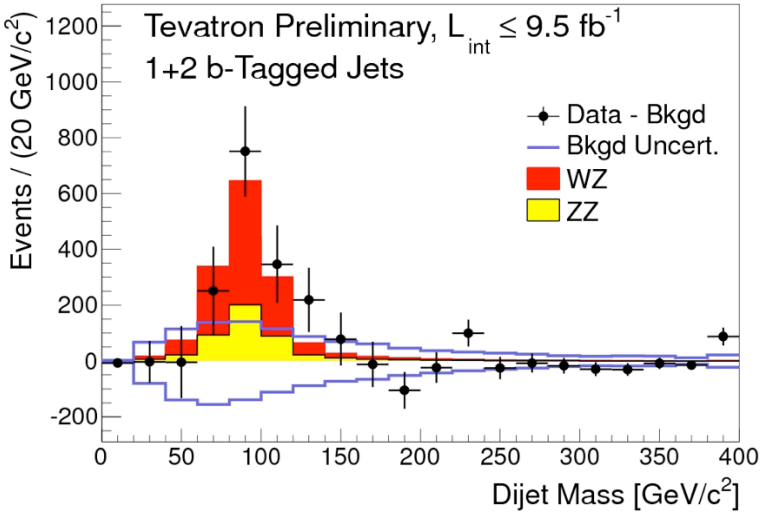


WZ+ZZ Cross Section

proving ground for Higgs:





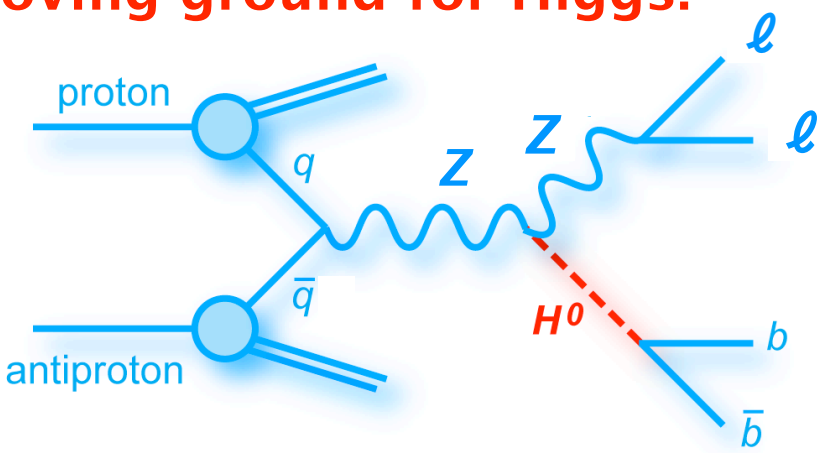


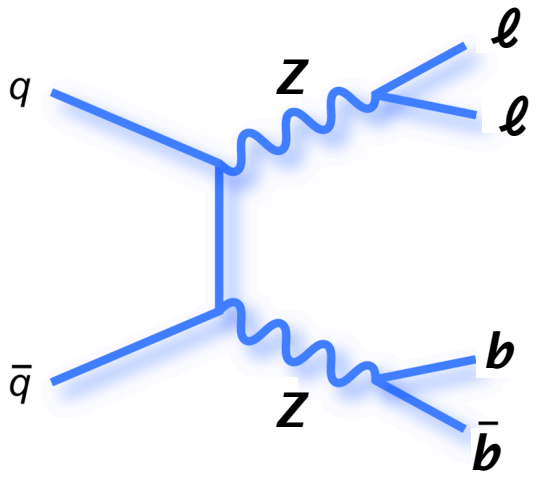
$$\sigma(\ WZ + ZZ\ ) = 4.47 \pm 0.64\ (\text{stat})\ ^{+0.73}_{-0.72}\ (\text{syst})\ \text{pb}$$

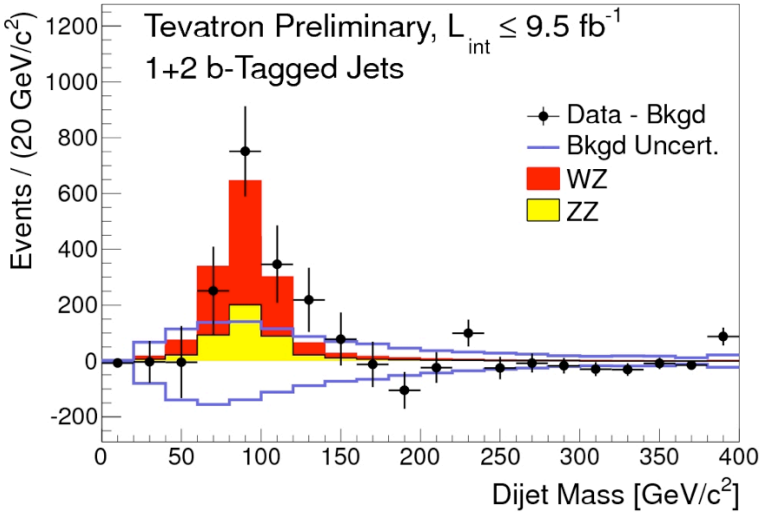
→ **good agreement with the SM** $\sigma(WZ + ZZ) = 4.4 \pm 0.3$ pb

WZ+ZZ Cross Section

proving ground for Higgs:







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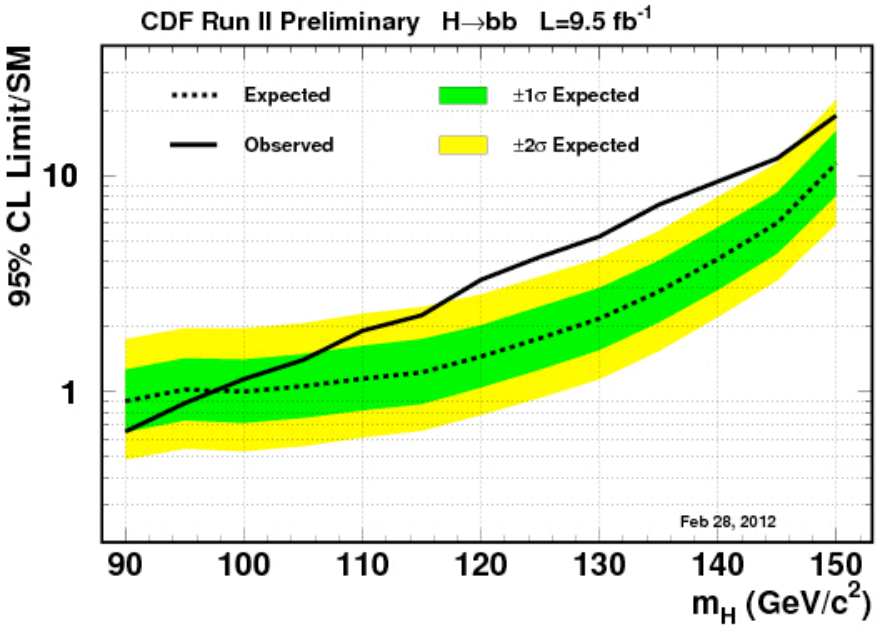
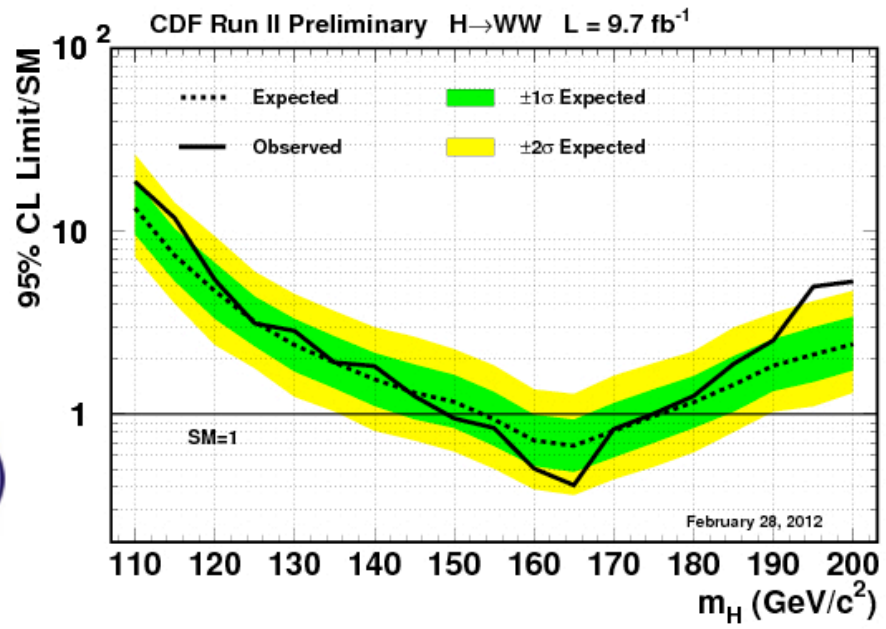
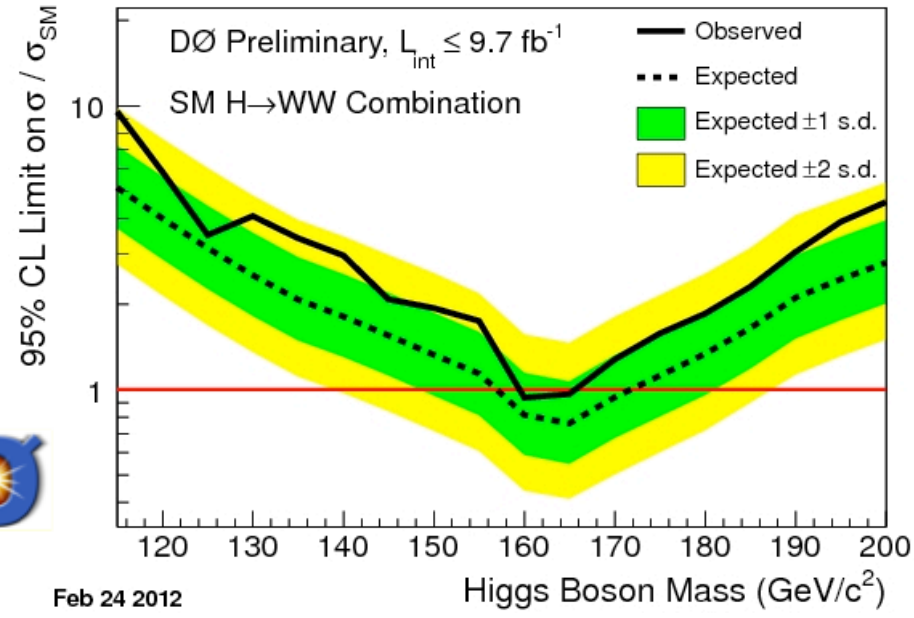
SM Higgs Search

10 fb^{-1}

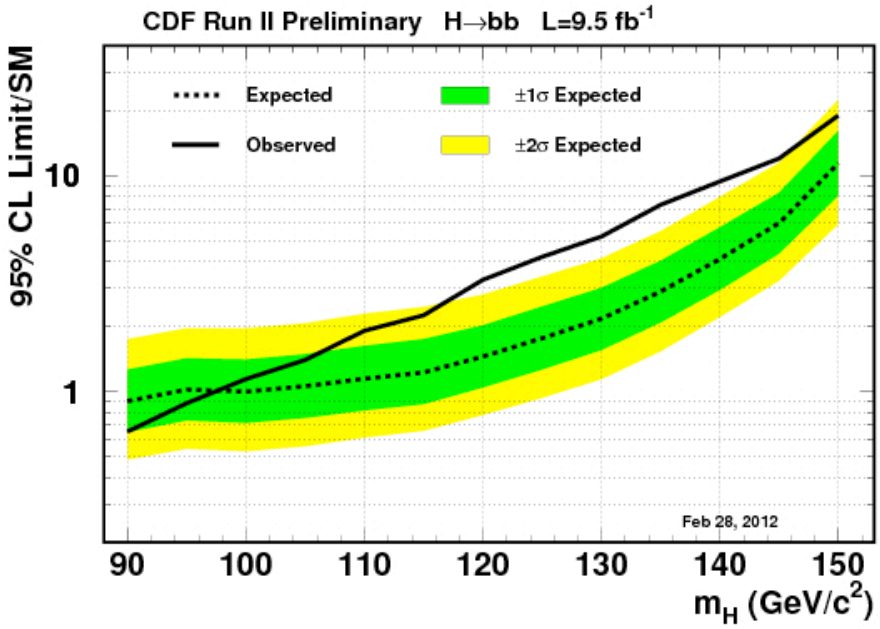


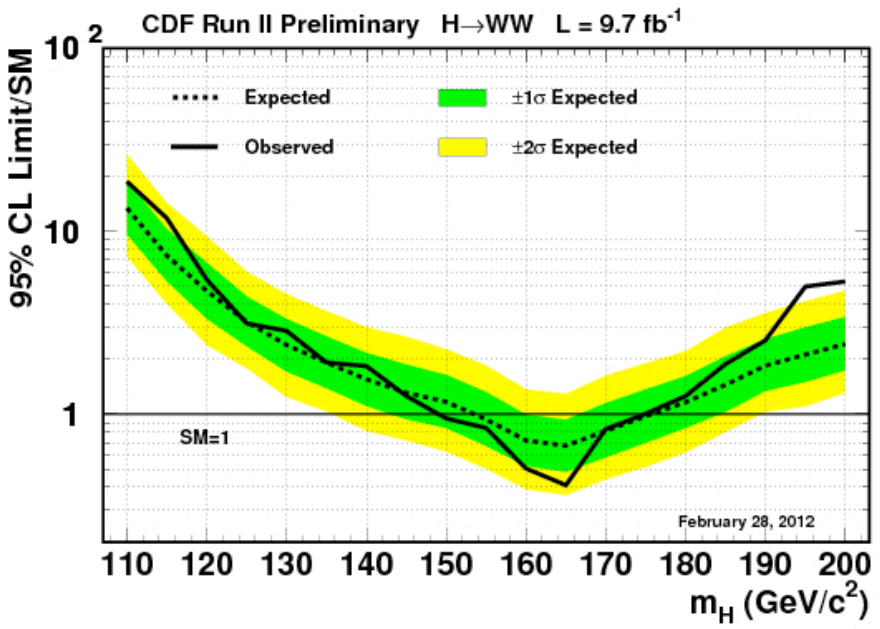


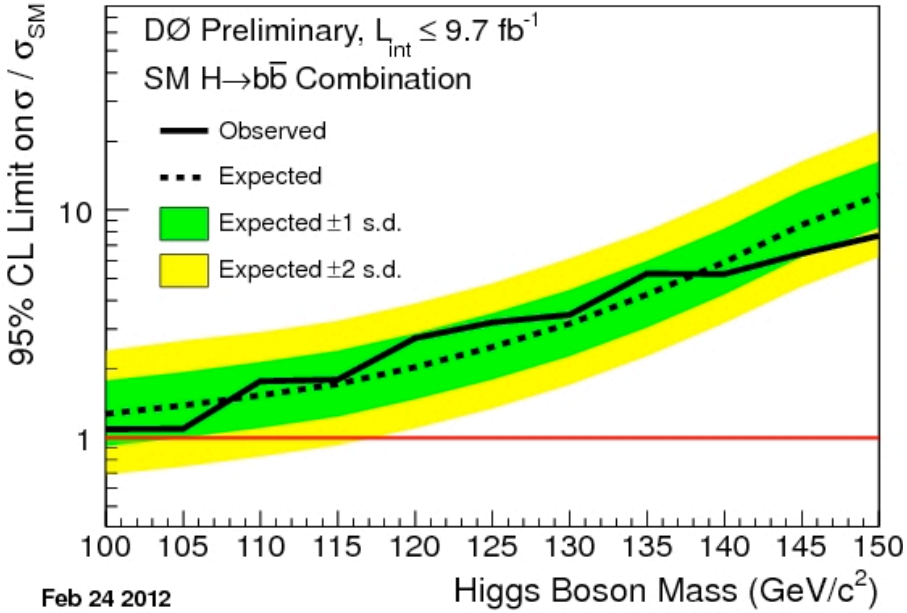


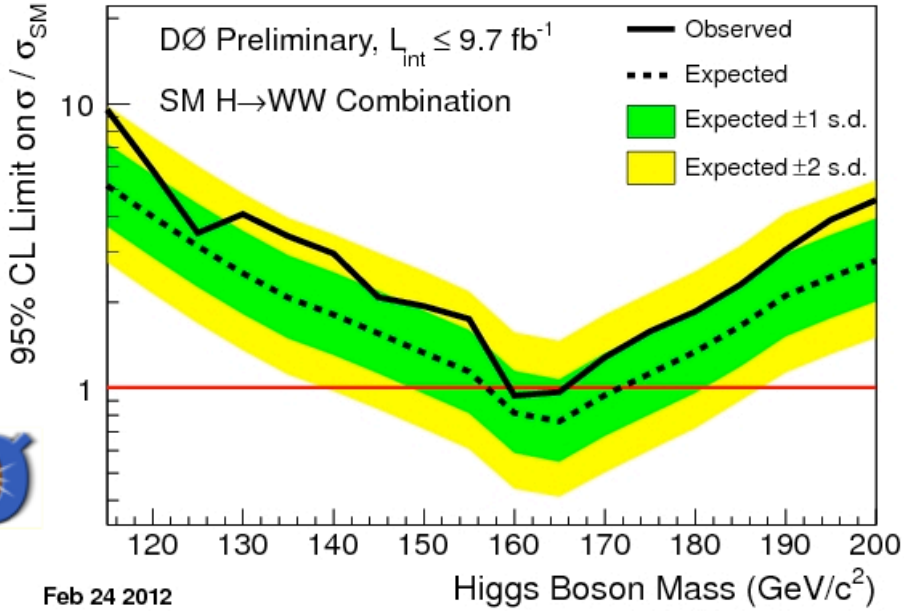
SM Higgs Search

10 fb^{-1}

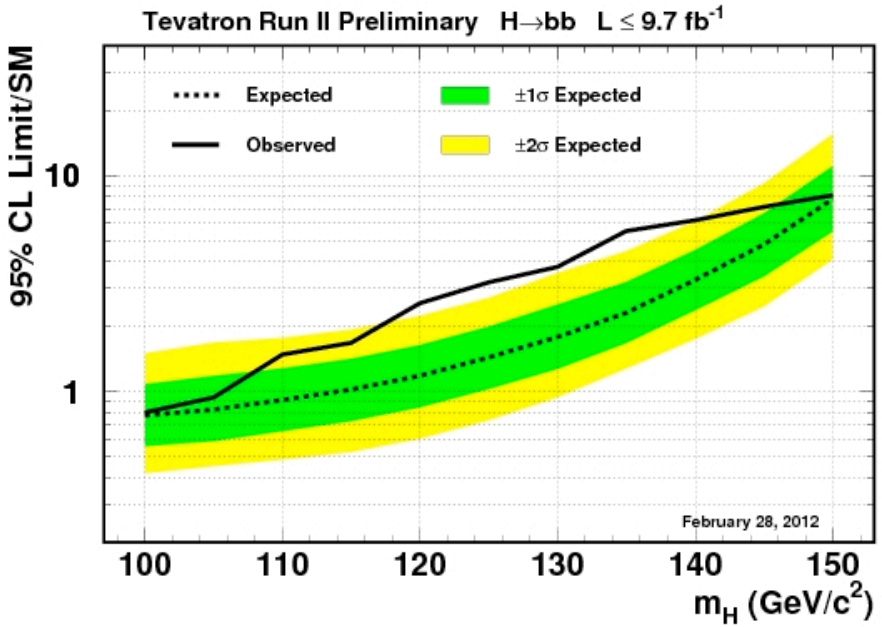


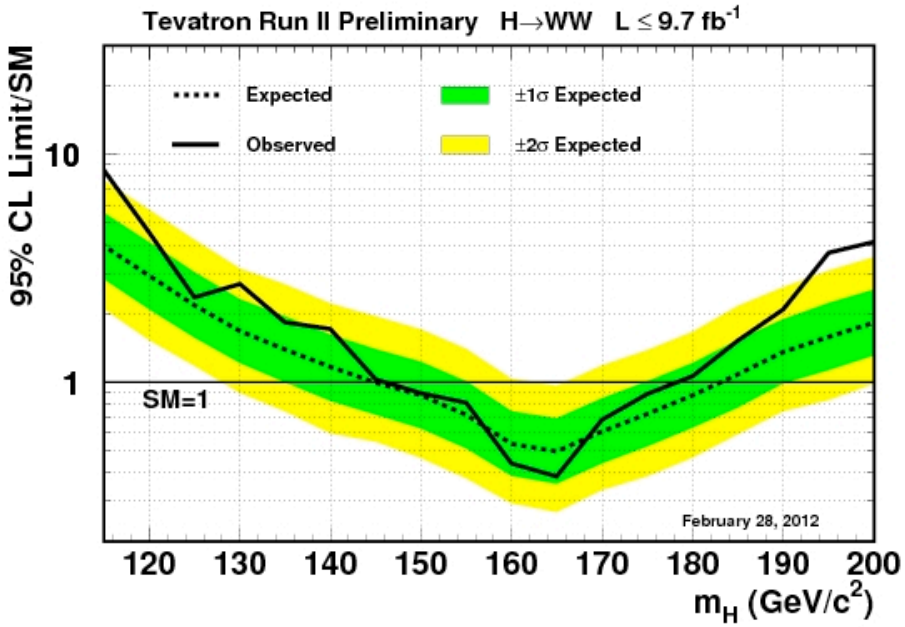


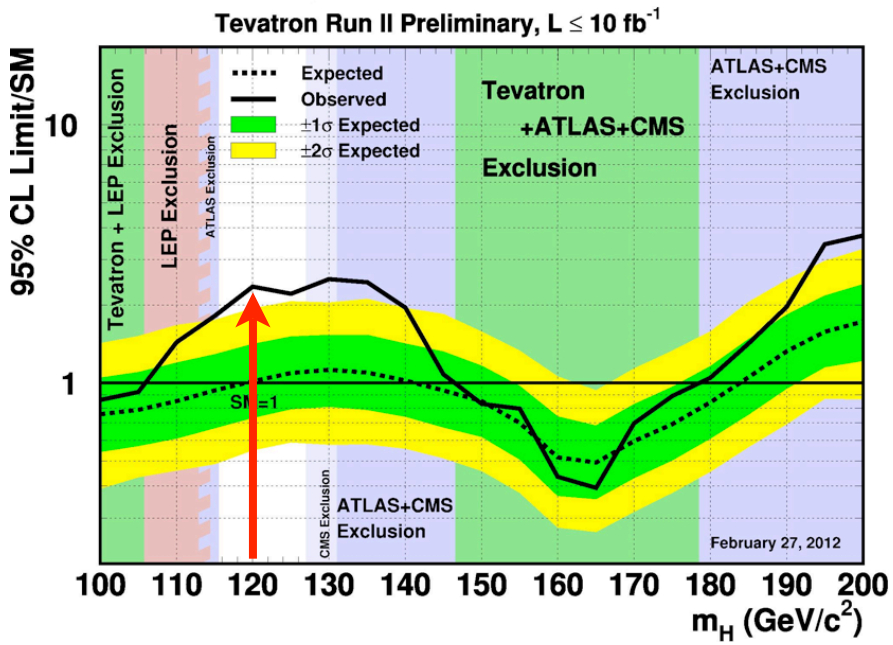




SM Higgs Search







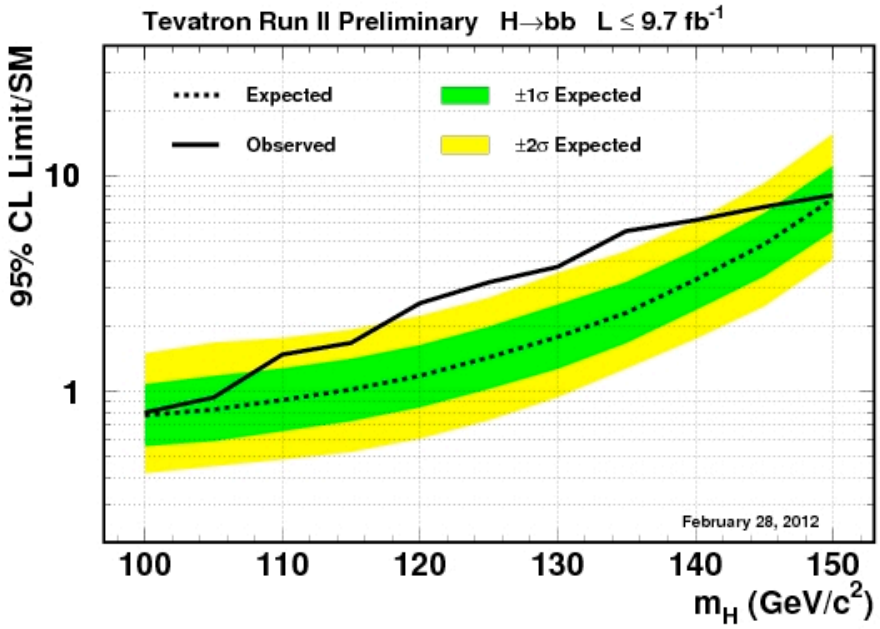
2.7σ (local)
2.2σ (global)

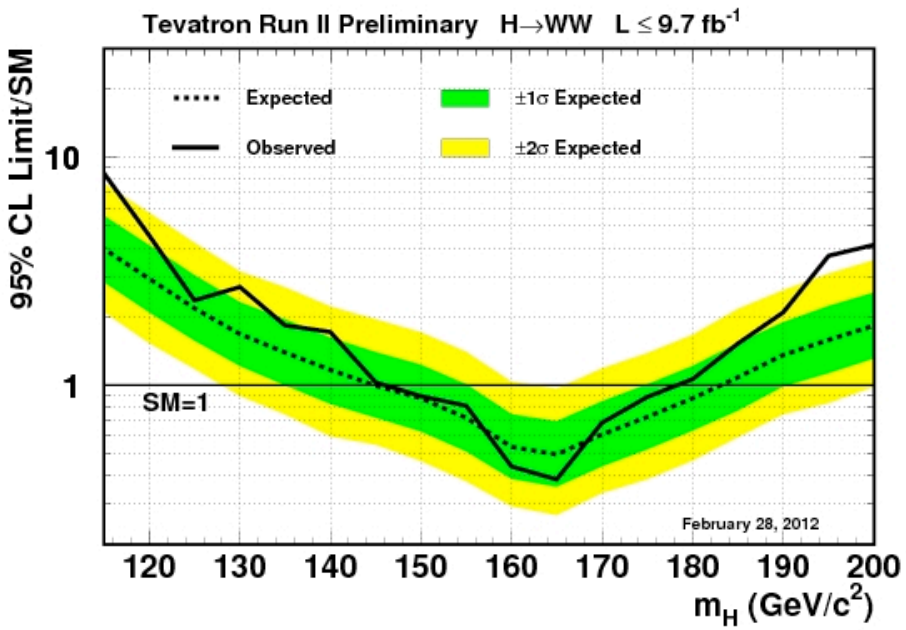
10 fb^{-1}

Imperial
Manchester

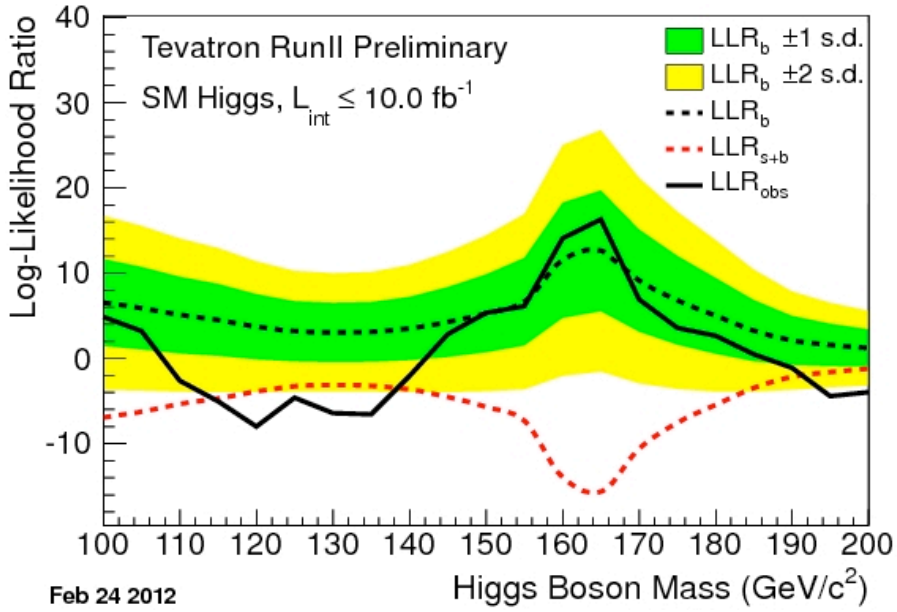
Glasgow

SM Higgs Search





2.7σ (local)
2.2σ (global)



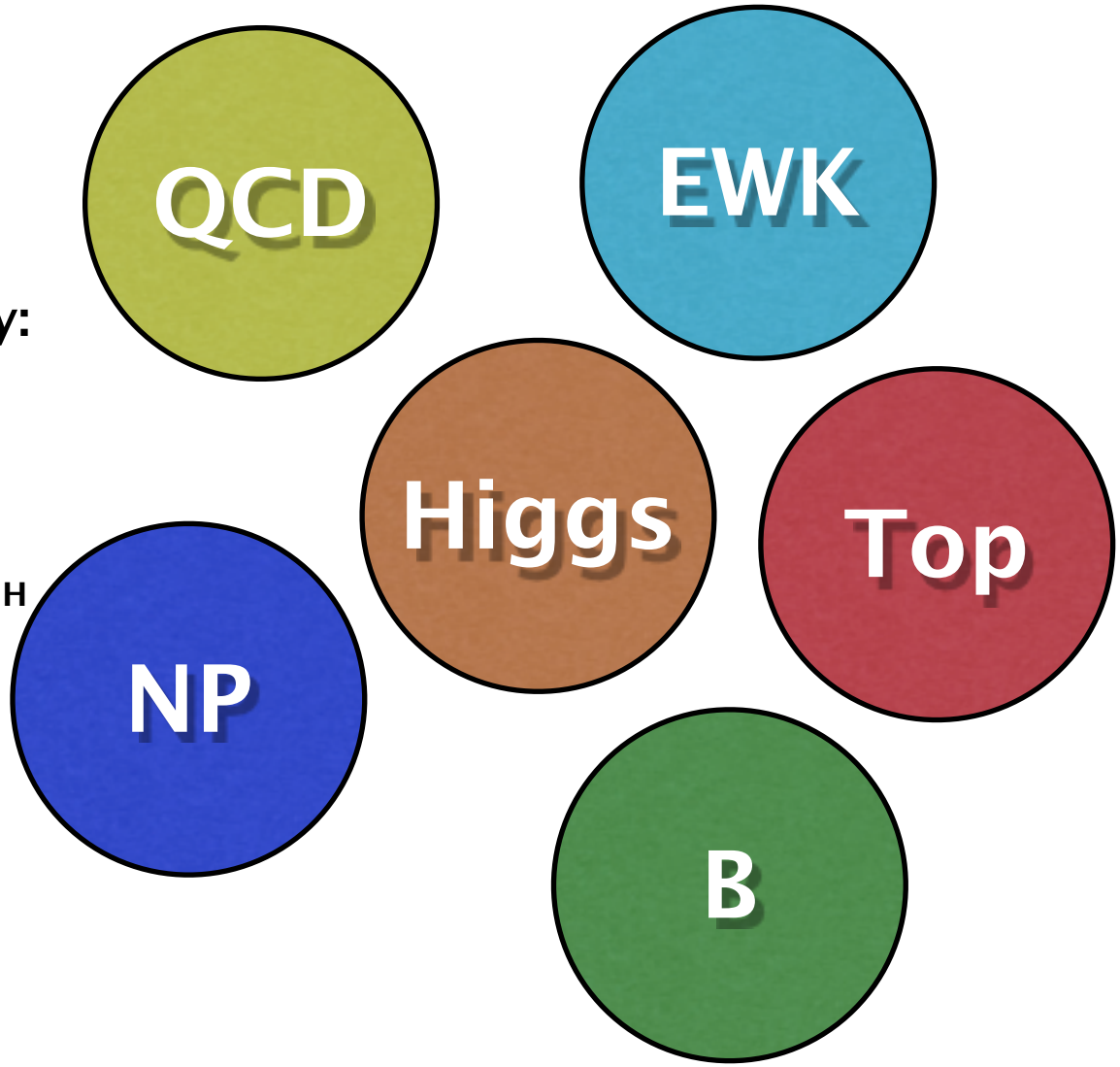
10 fb^{-1}

Imperial
Manchester

UCL
Oxford
Glasgow

Summary

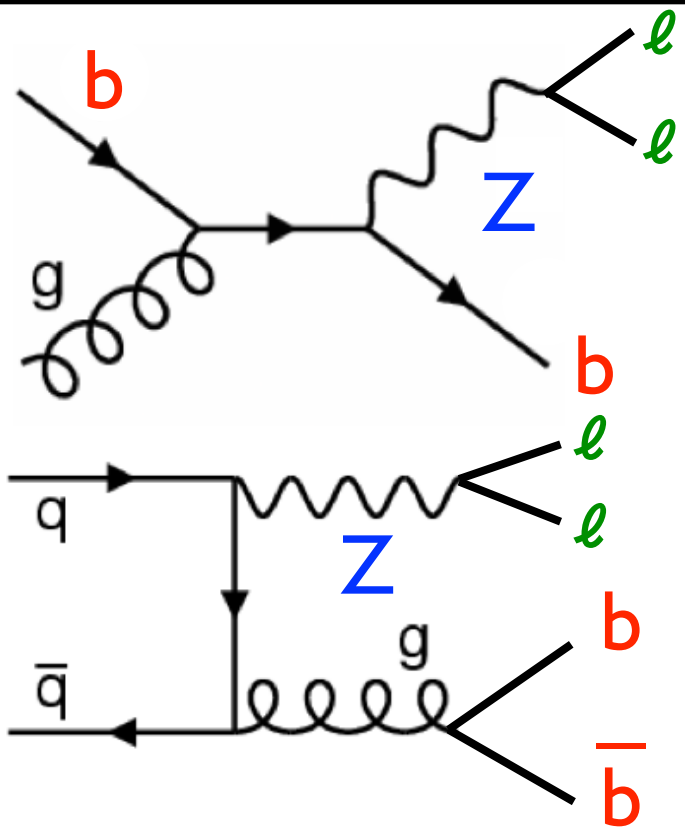
- many exciting new results for the winter conferences!
- many analyses are competitive with the LHC
- some analyses are complementary: evidence for $t\bar{t}$ spin correlation
- W mass uncertainty: 0.019%
  we can double the dataset
  ⇒ SM is self-consistent for low M_H
- Tevatron is unique due to sensitivity to $H \to b\bar{b}$ decay
  increase sensitivity further
  ⇒ excess in the range
  $115 < m_H < 135$ GeV

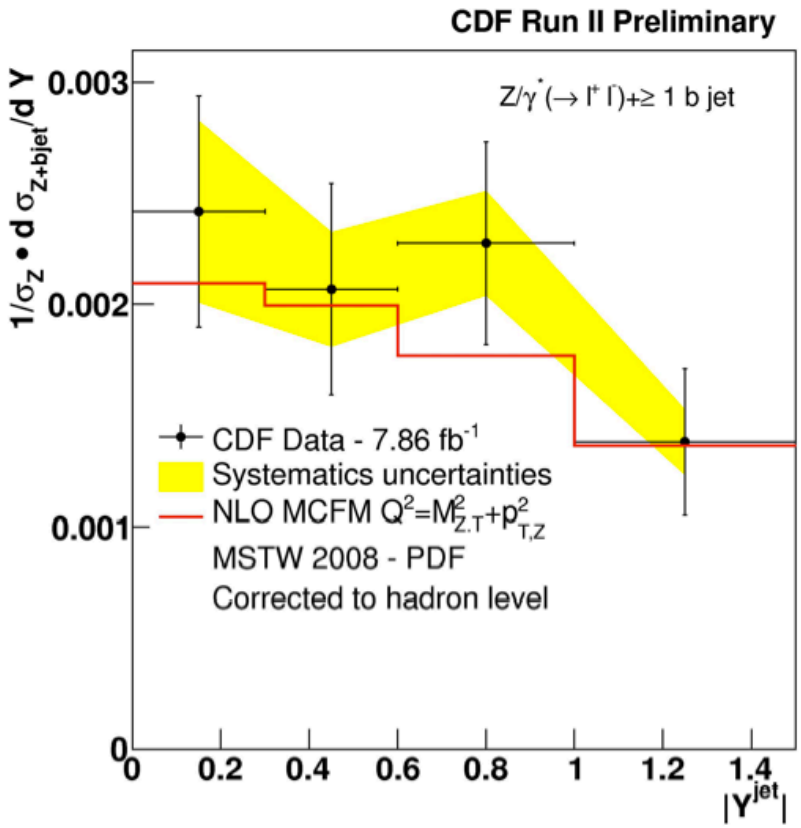


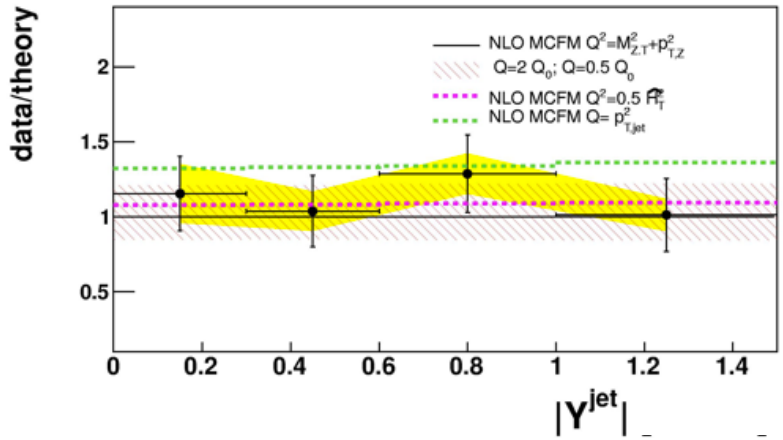
Thanks to all CDF and DØ colleagues who have contributed!

Backup

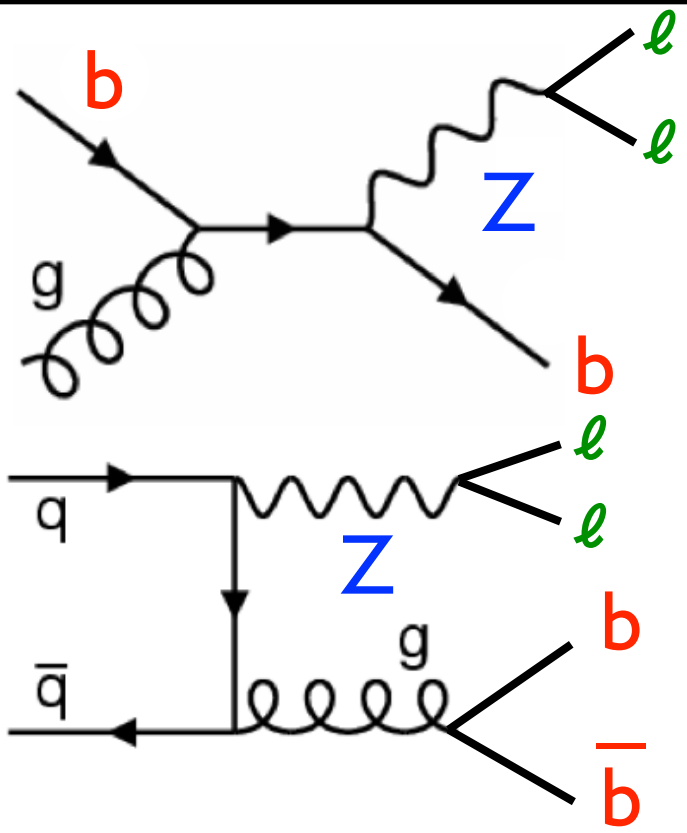
Z+b-jet Cross Section

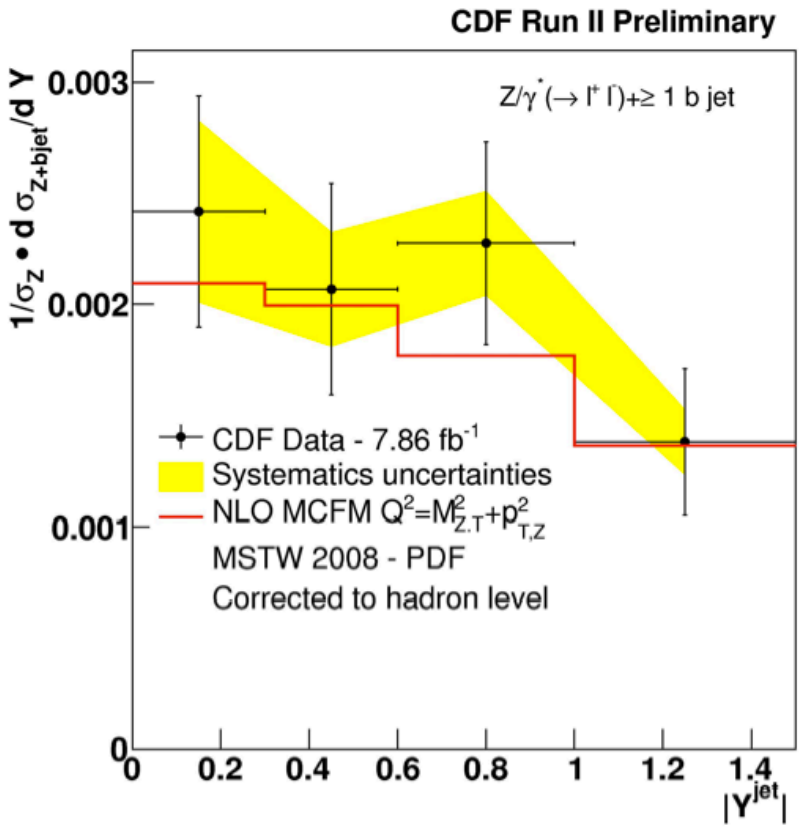






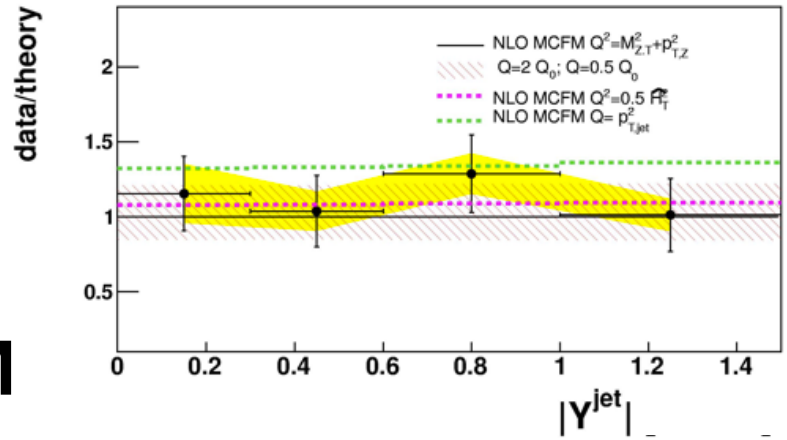
Z+b-jet Cross Section





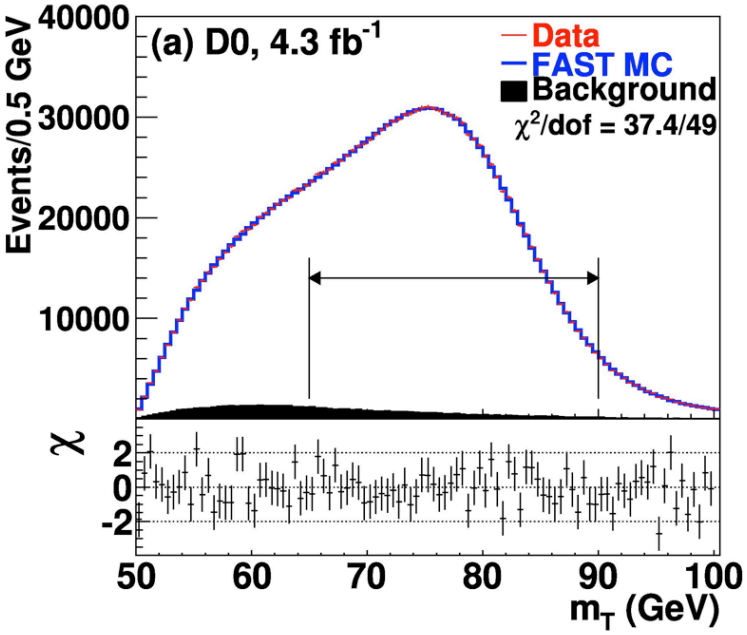
$$\frac{\sigma_{Z\_bjet}}{\sigma_Z} = 0.293 \pm 0.030^{stat} \pm 0.036^{syst}\,\%$$

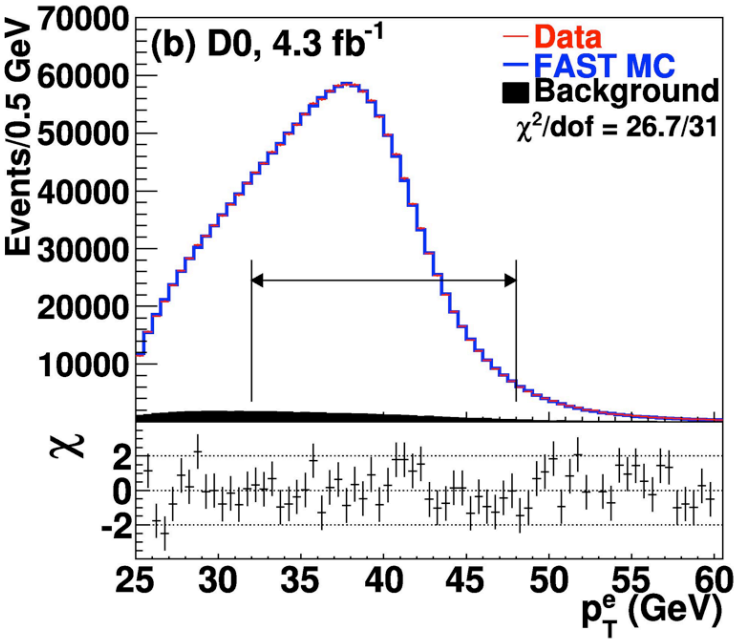
MCFM NLO: 0.27%



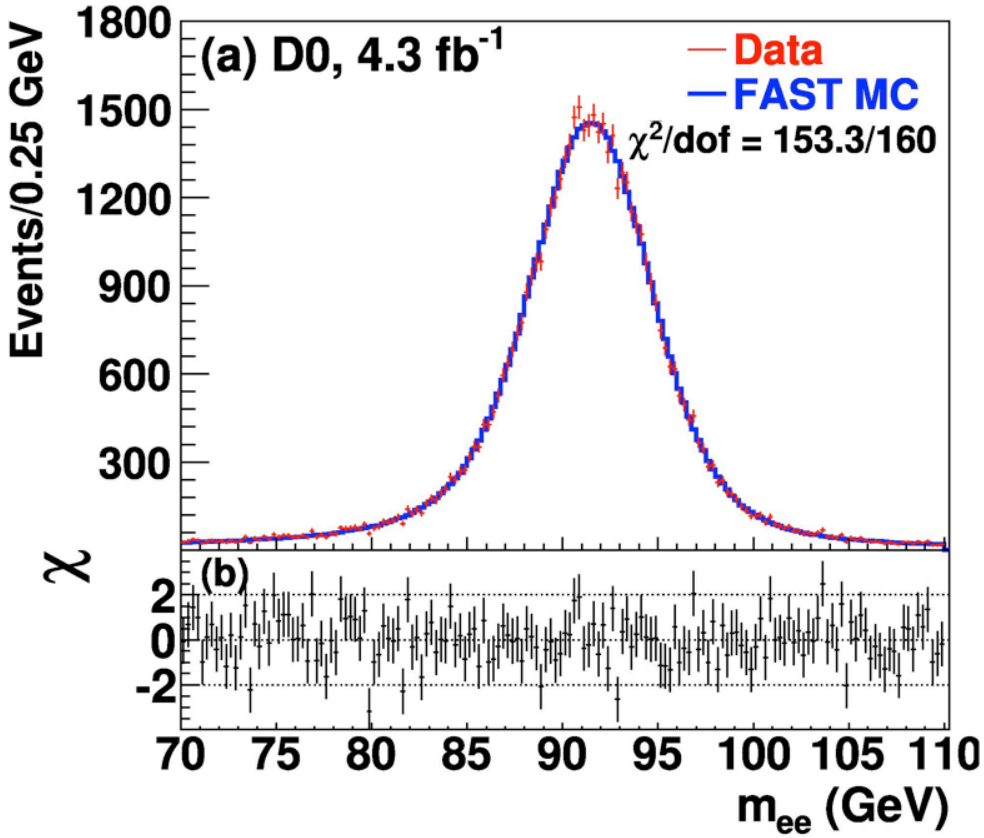
→ good agreement with the SM

W mass measurement





$$m_T = \sqrt{2\,(\,p_T^{\ell}\,p_T^{\nu} - \vec{p}_T^{\,\ell}\cdot\vec{p}_T^{\,\nu}\,)}$$



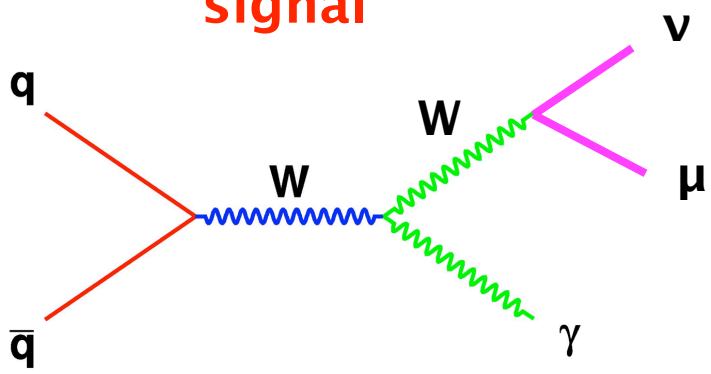
combined fit:

$$M_W = 80.375 \pm 0.011\ (\text{stat}) \pm 0.020\ (\text{syst})\ \text{GeV}$$

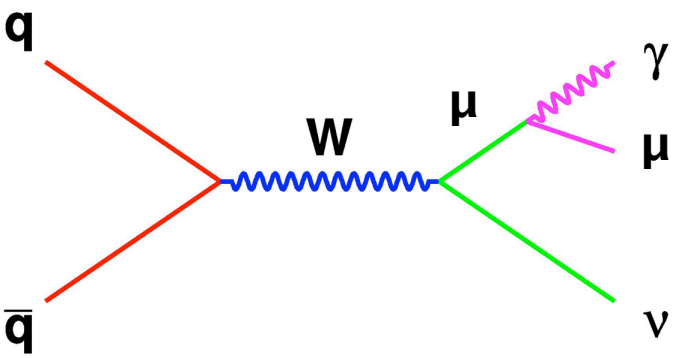
Wγ Cross Section and WWγ Couplings

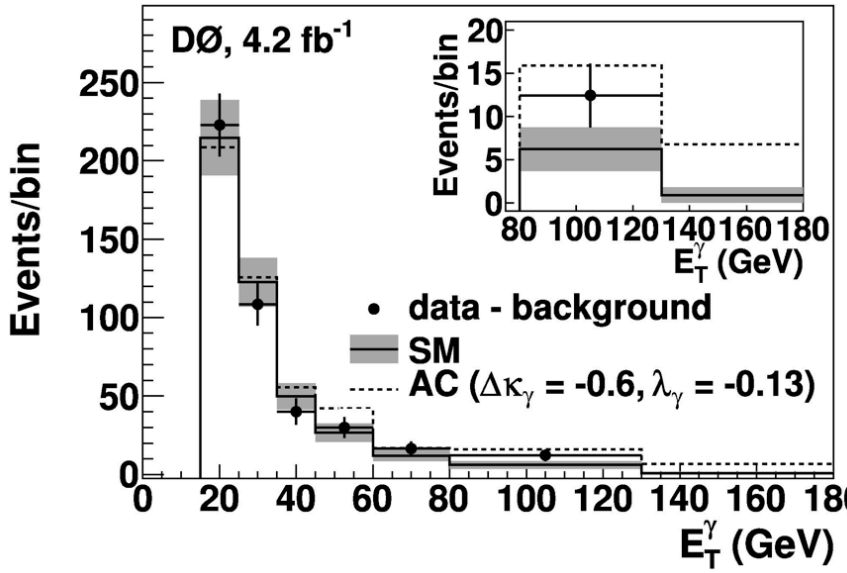
analyse non-abelian gauge structure

signal



background





Phys. Rev. Lett. 107, 241803 (2011)

cross section in agreement with SM

background rejection:
tight cut on transverse mass $M_T(\mu,\gamma,MET)$

Wγ Cross Section and WWγ Couplings

analyse non-abelian gauge structure

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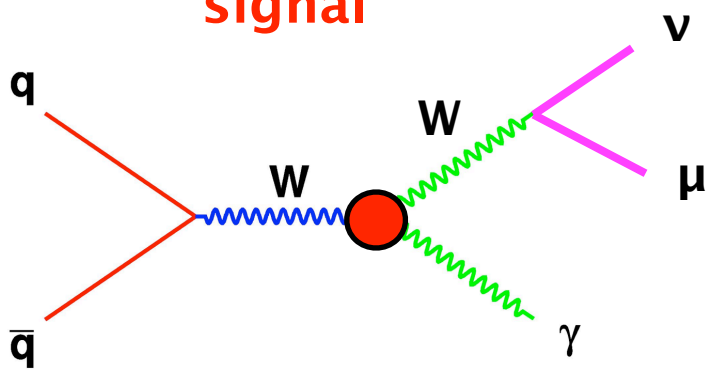
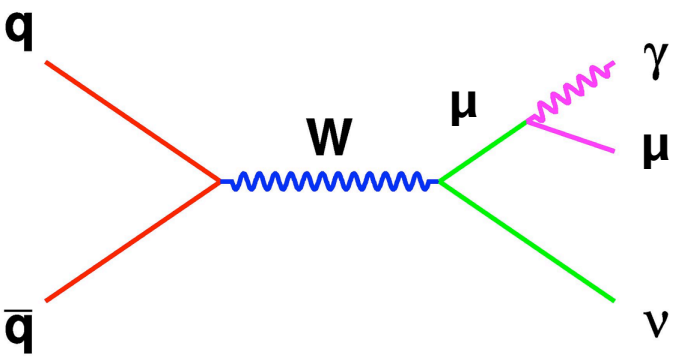
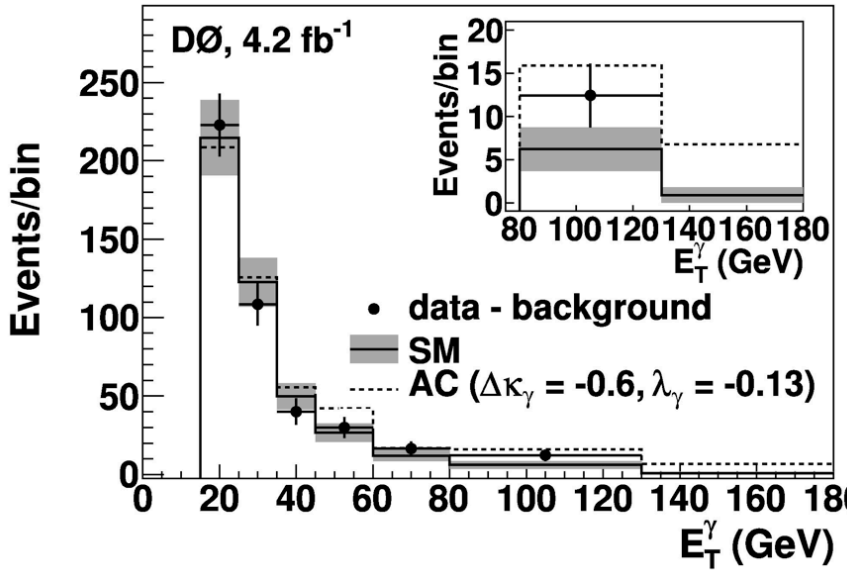


background

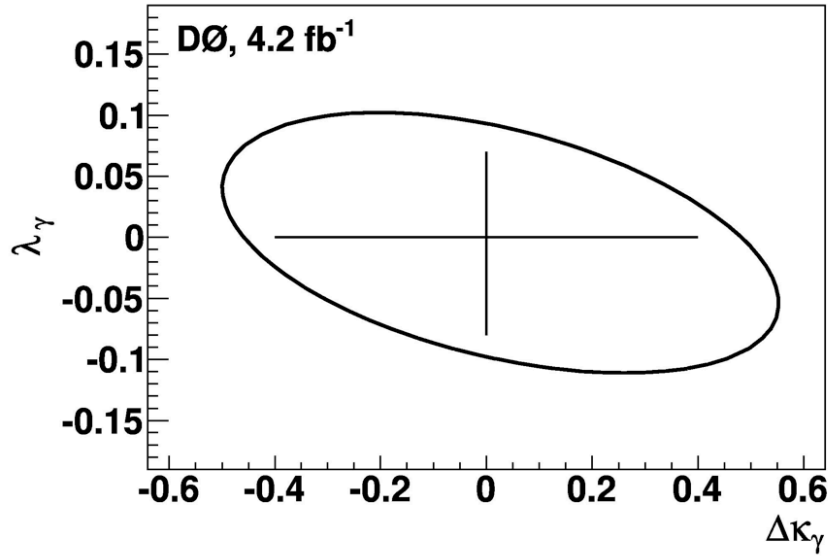




Phys. Rev. Lett. 107, 241803 (2011)

cross section in agreement with SM

strongest limits on anomalous couplings from Tevatron



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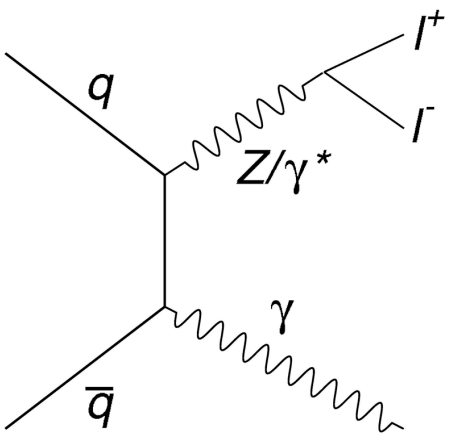
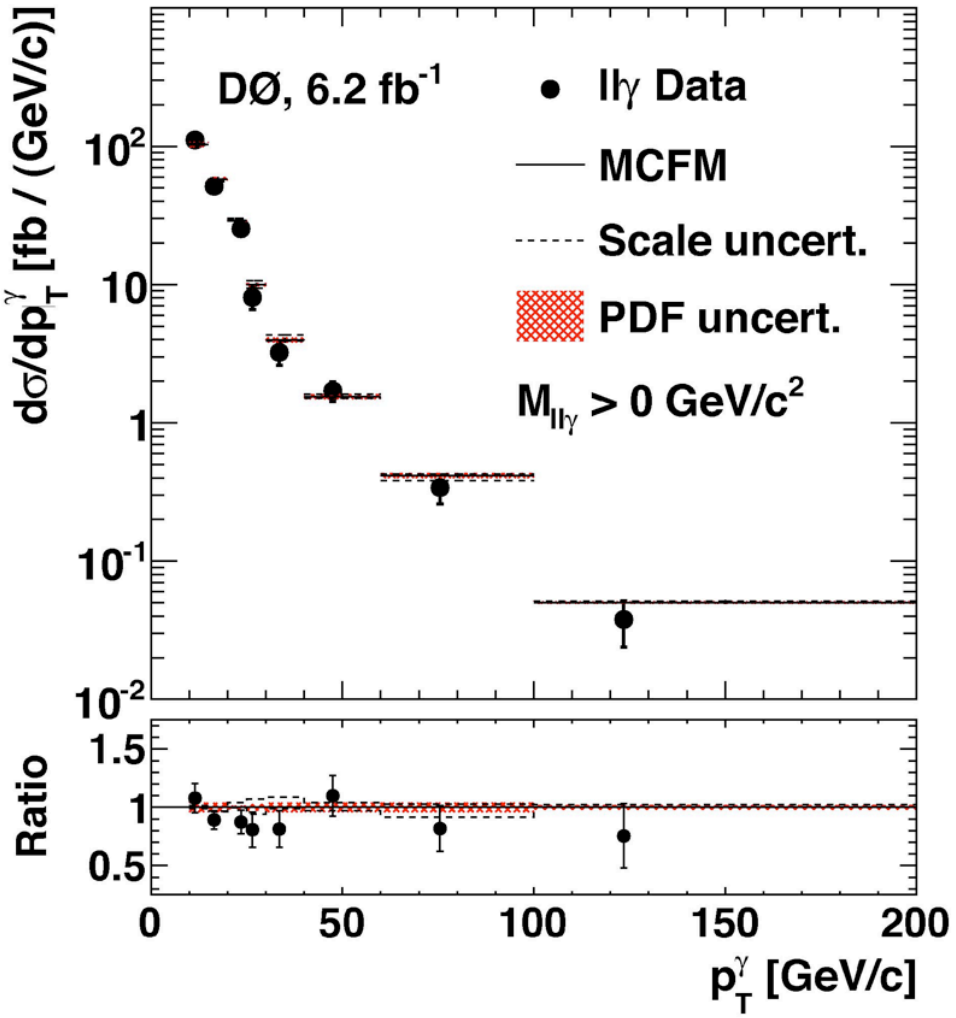
Zγ Cross Section and ZZγ, Zγγ Couplings





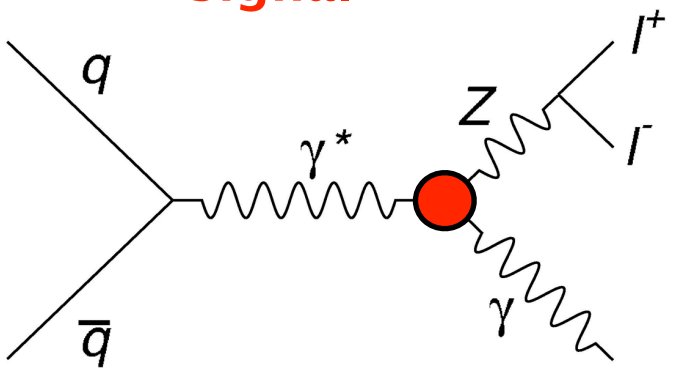
Phys. Rev. D 85, 052001 (2012)

cross section in agreement with SM

Zγ Cross Section and ZZγ, Zγγ Couplings

analyse non-abelian gauge structure

signal



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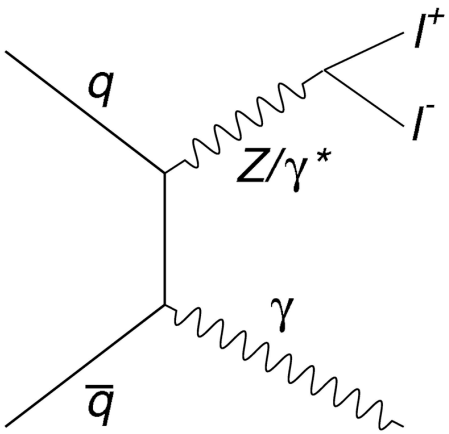
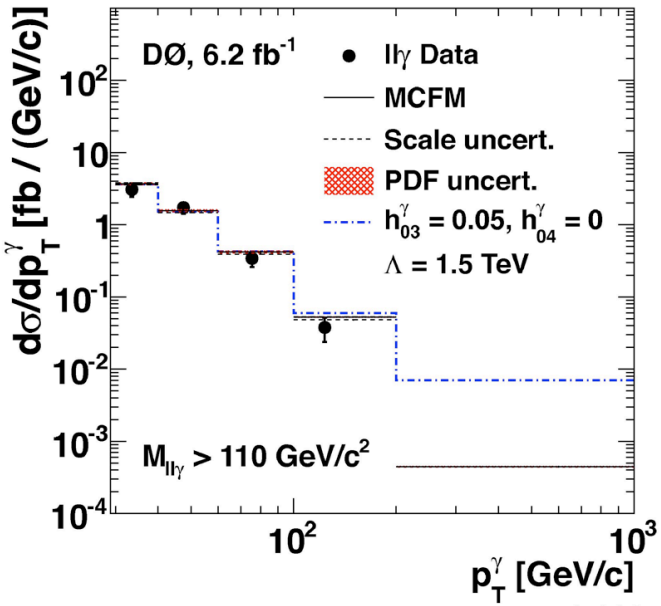
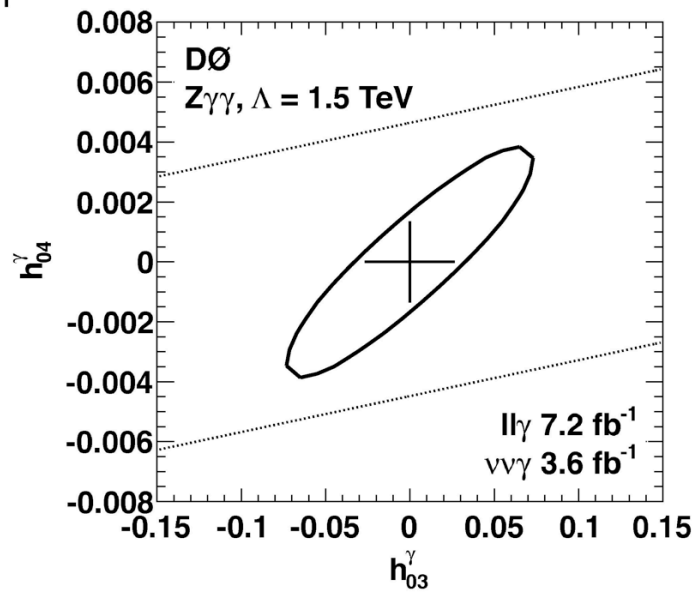




Phys. Rev. D 85, 052001 (2012)

cross section in agreement with SM

no hint for anomalous couplings

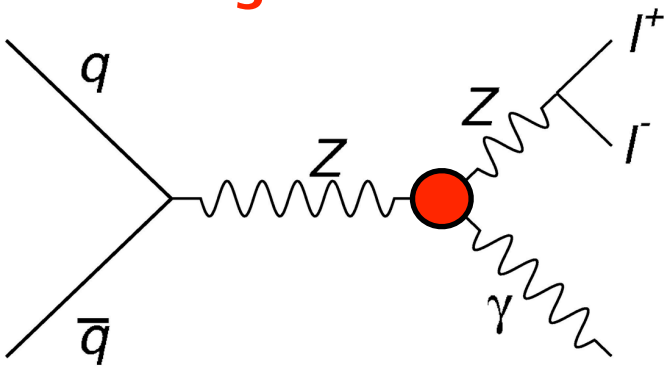


background rejection:
tight cut on invariant mass M(ℓ,ℓ,γ)

Zγ Cross Section and ZZγ, Zγγ Couplings

analyse non-abelian gauge structure

signal



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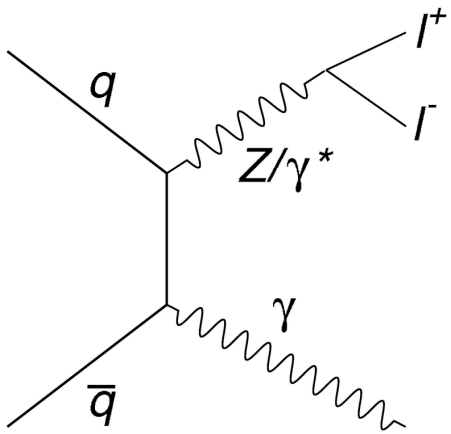

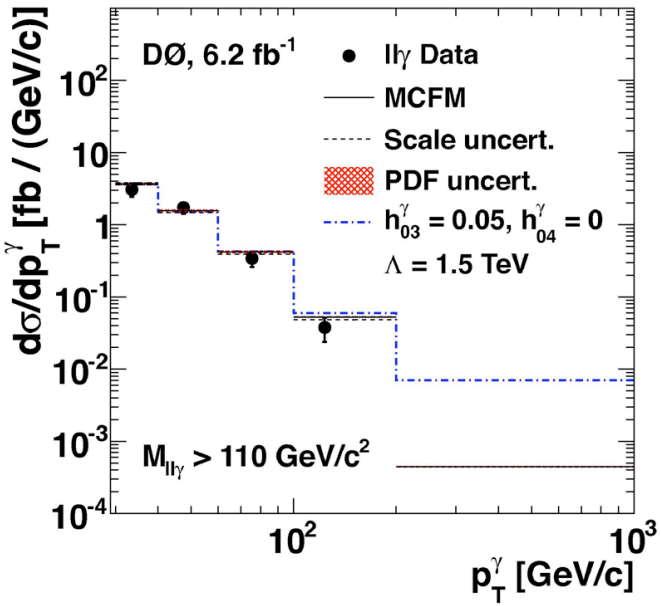

Phys. Rev. D 85, 052001 (2012)

cross section in agreement with SM

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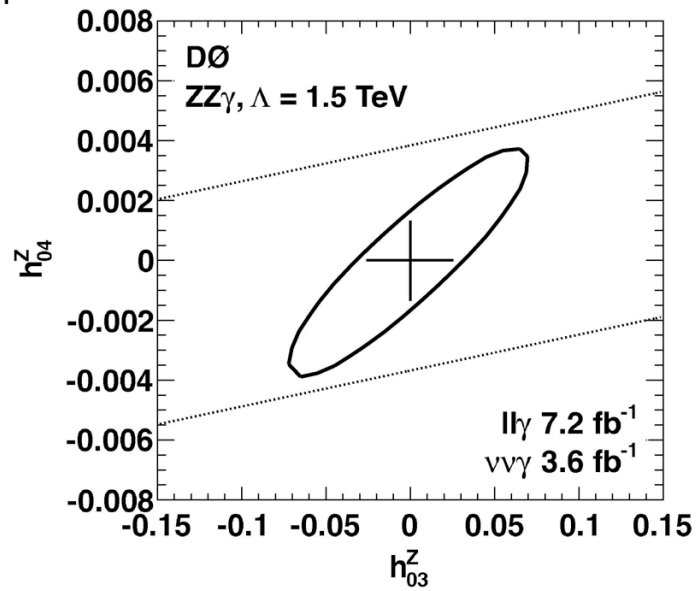
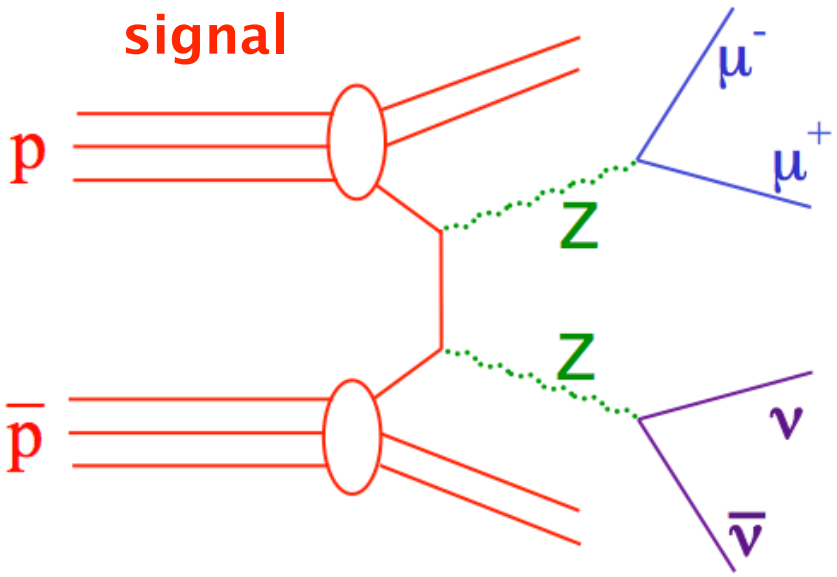
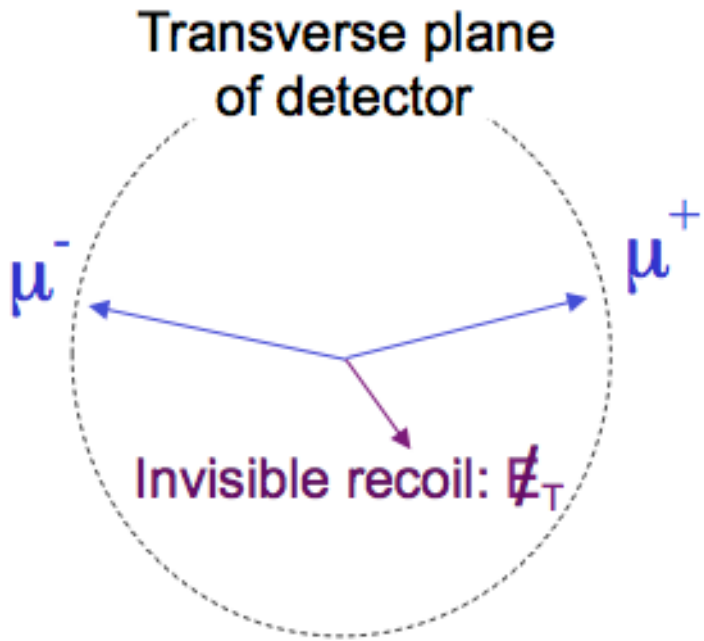


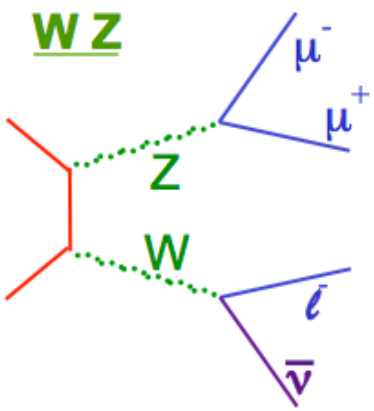
background rejection:
tight cut on invariant mass M(ℓ,ℓ,γ)

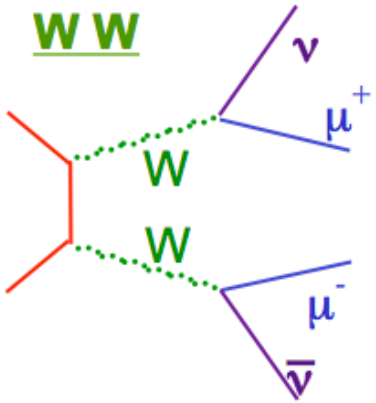
$ZZ \to \ell^+\ell^-\bar{\nu}\bar{\nu}$ Cross Section

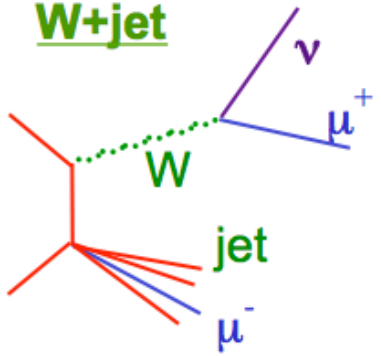


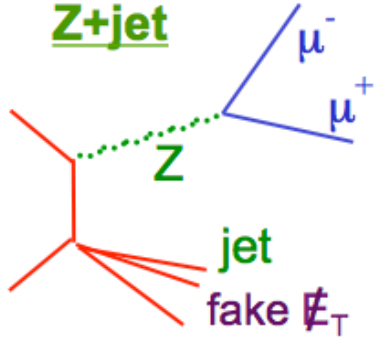


backgrounds

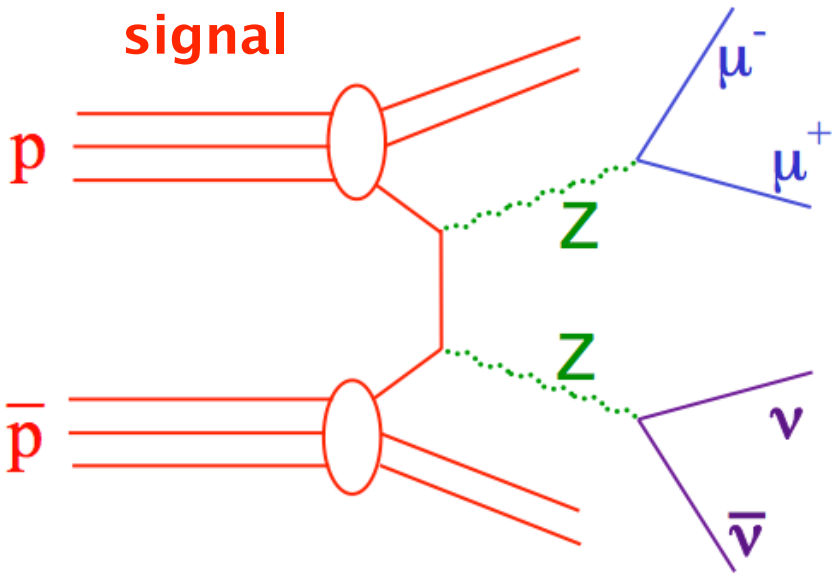


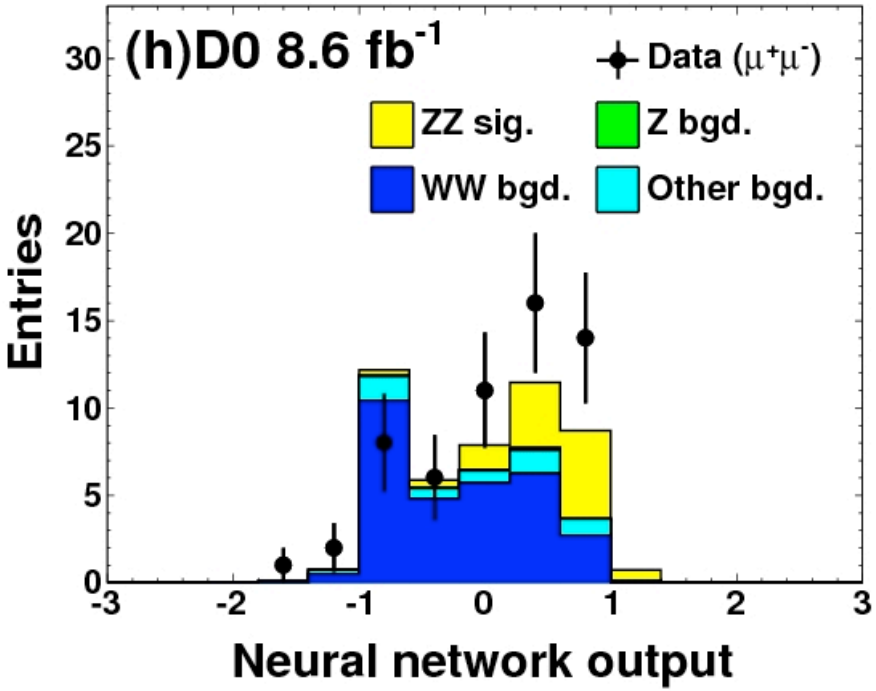




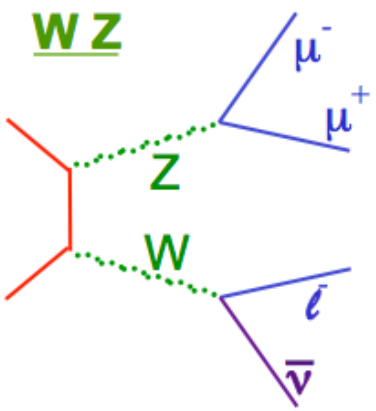


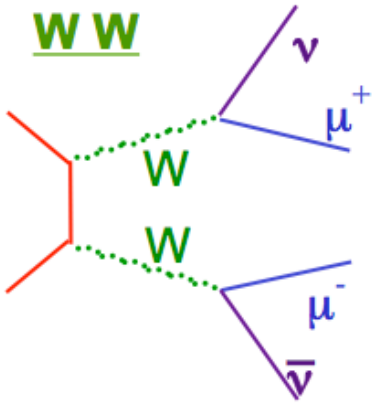
$ZZ \to \ell^+\ell^-\bar{\nu}\bar{\nu}$ Cross Section

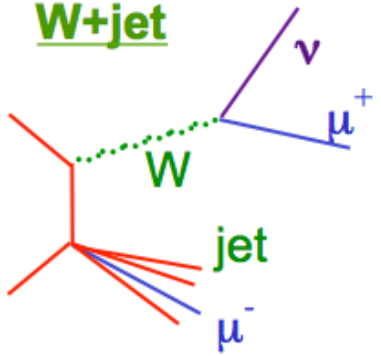


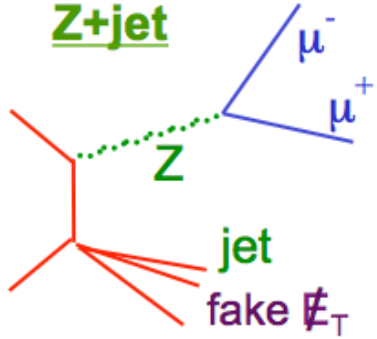


backgrounds



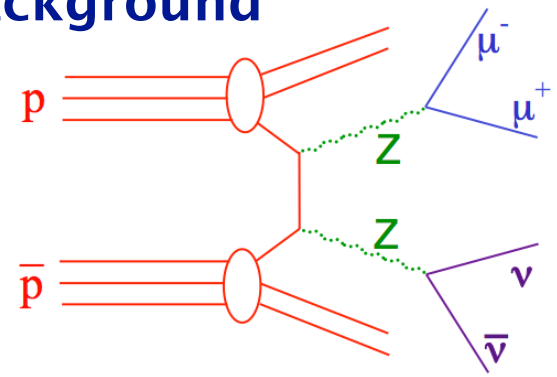




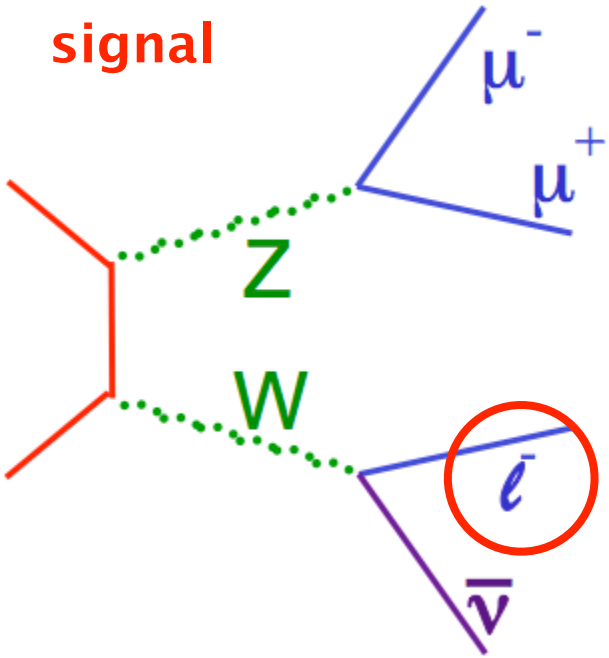


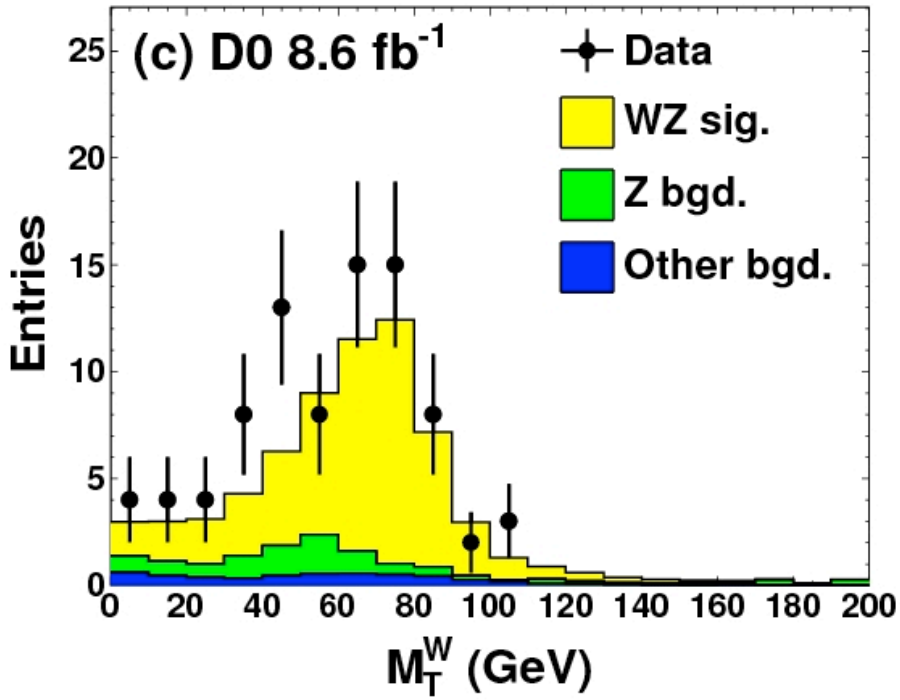
$WZ \to \ell^+\ell^-\ell^\pm\nu$ Cross Section

background

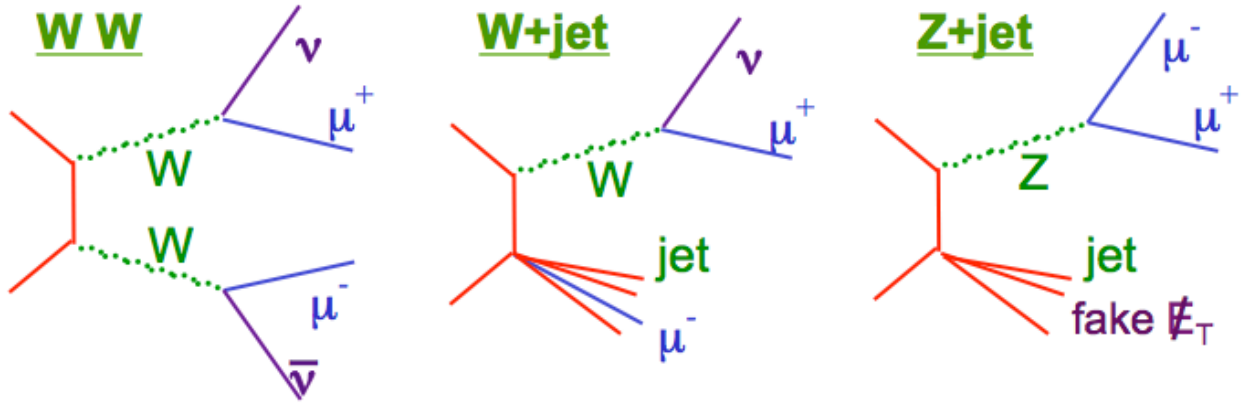


signal





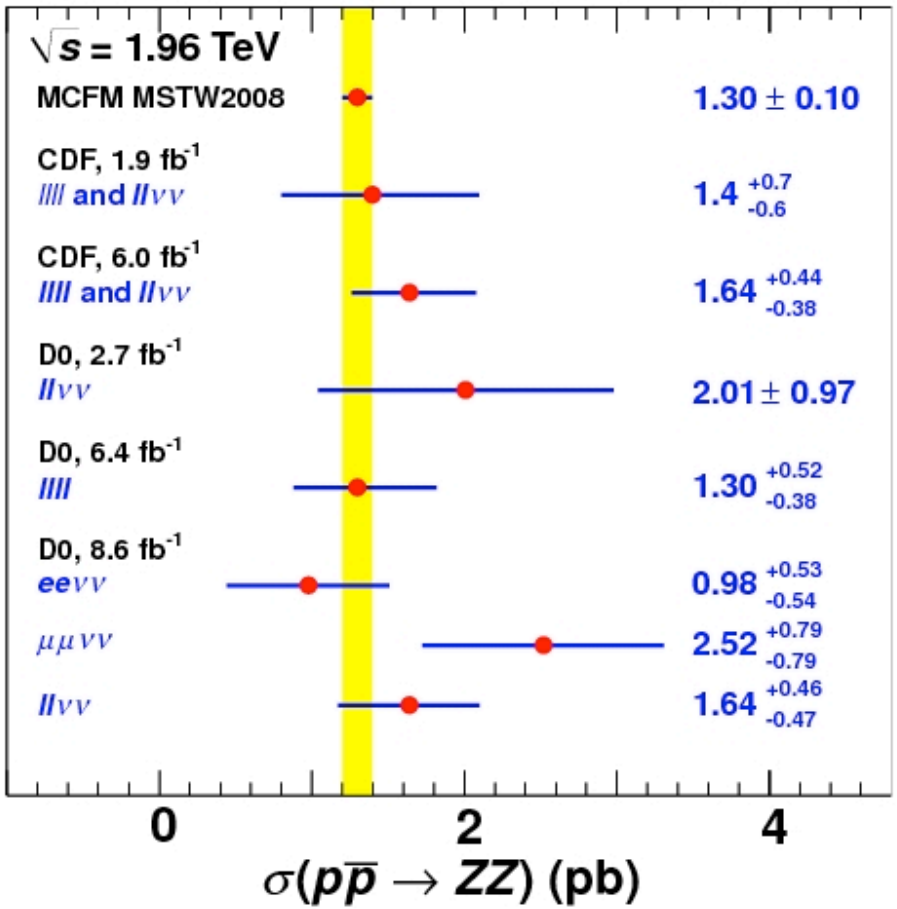
backgrounds

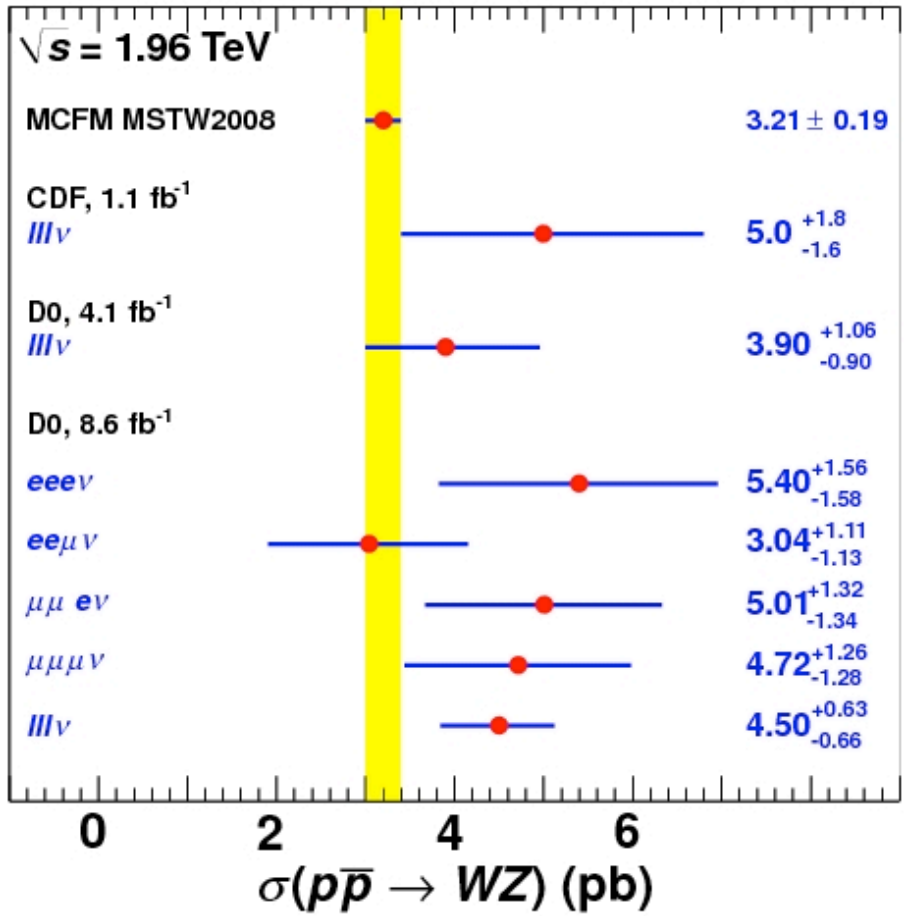


ZZ, WZ Cross Sections

measure ratio of ZZ, WZ over inclusive Z cross section:

arXiv:1201.5652 [hep-ex]



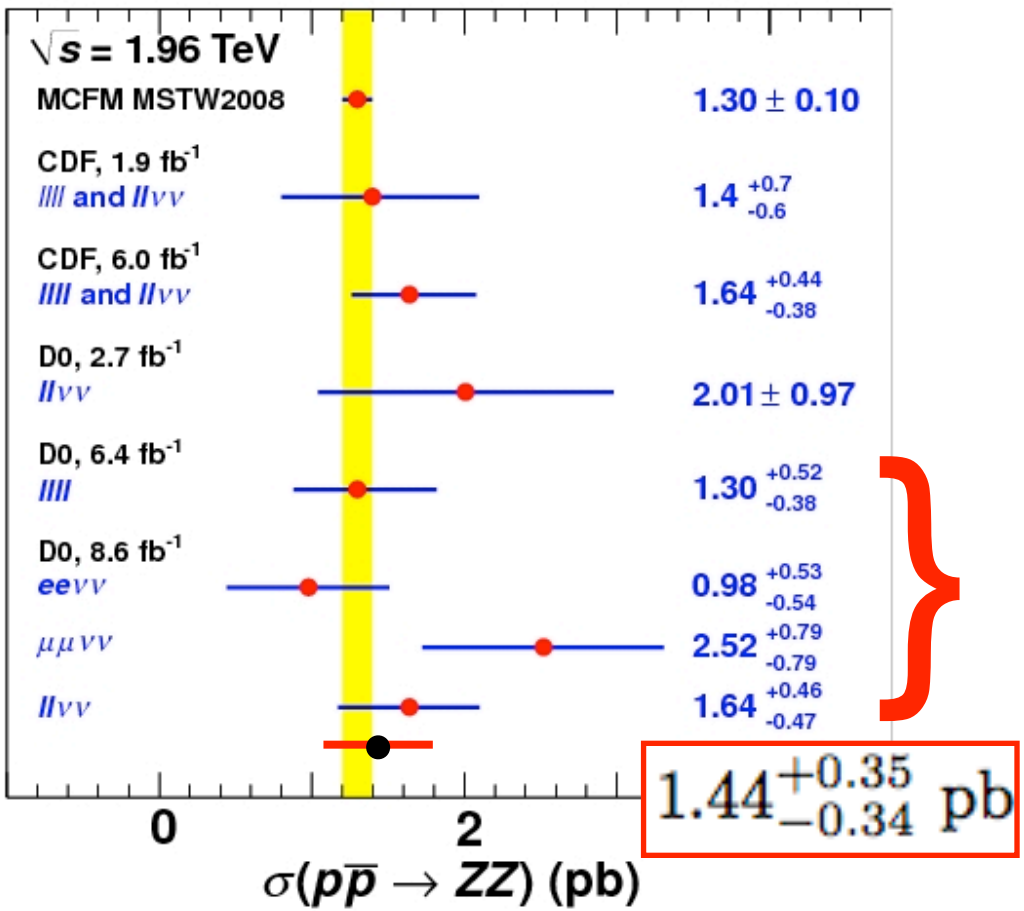


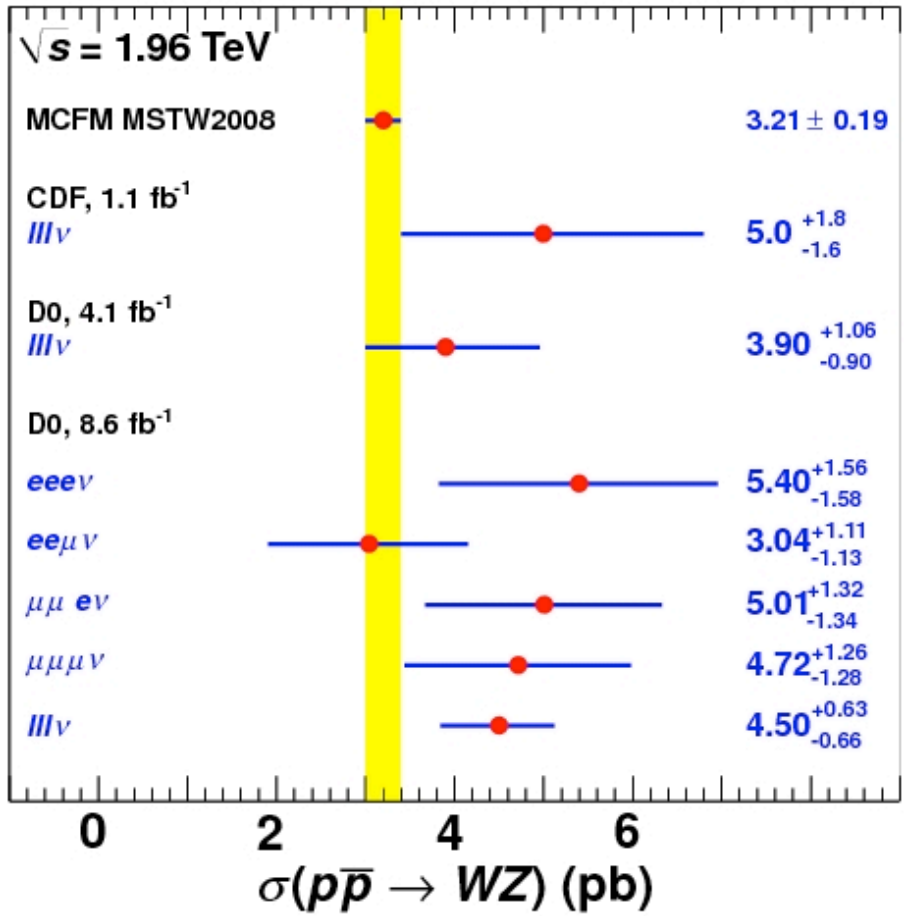
→ **good agreement with the SM**

ZZ, WZ Cross Sections

measure ratio of ZZ, WZ over inclusive Z cross section: Manchester

arXiv:1201.5652 [hep-ex]

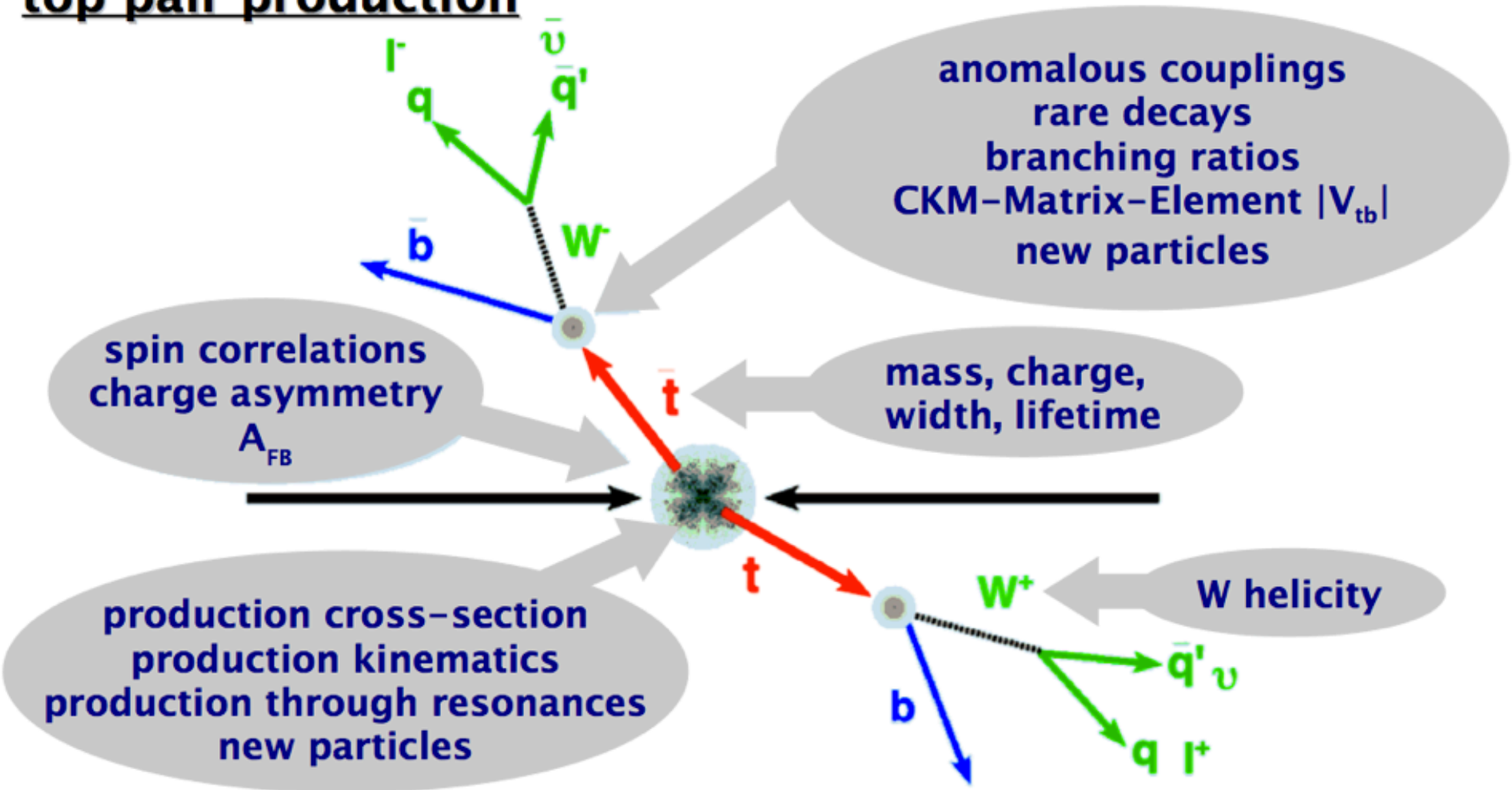




→ **good agreement with the SM**

Top Quark Analyses

top pair production

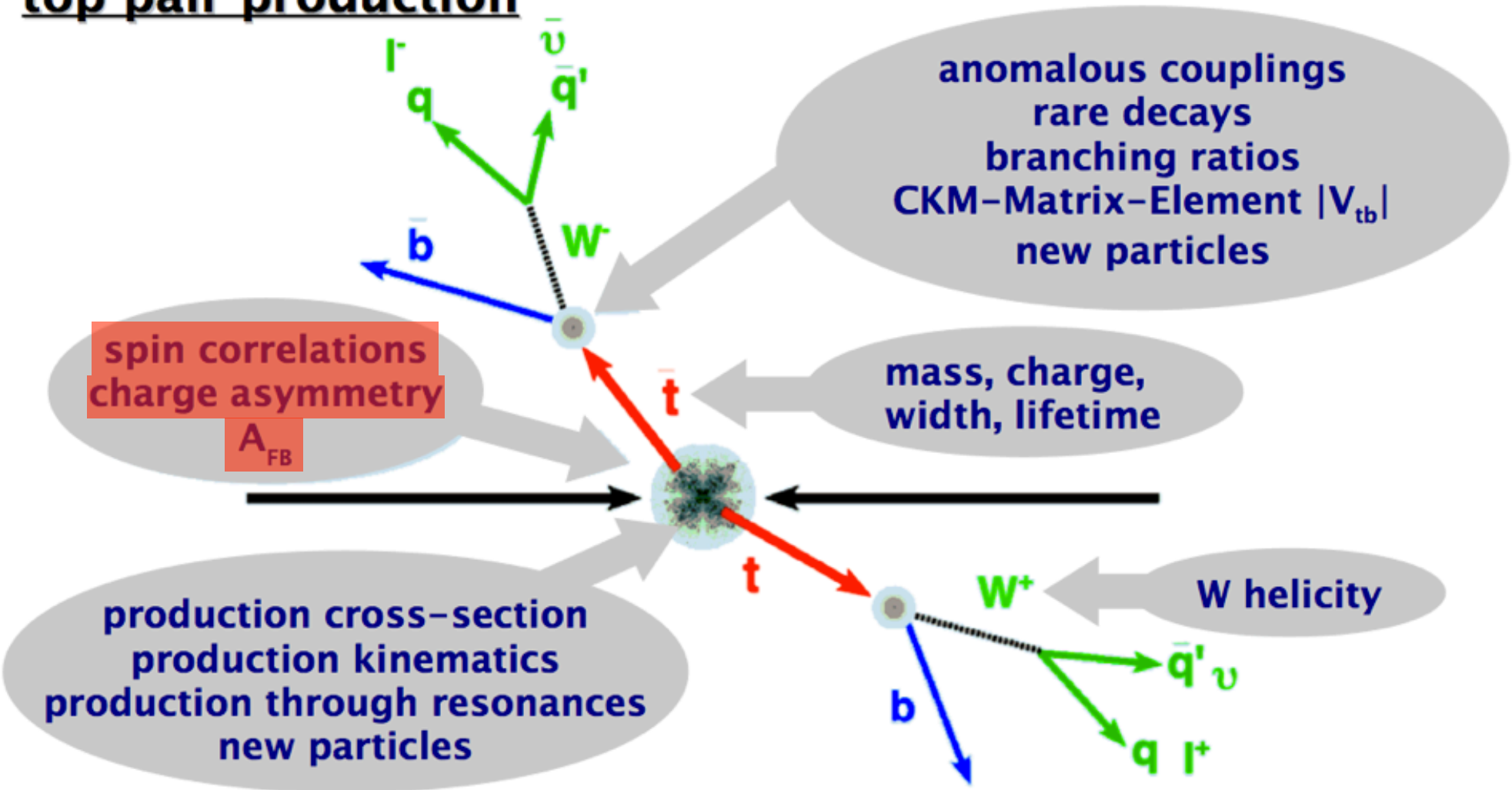


single top production

production cross section, CKM-Matrix-Element $|V_{tb}|$, anomalous couplings, searches for new particles

Top Quark Analyses

top pair production

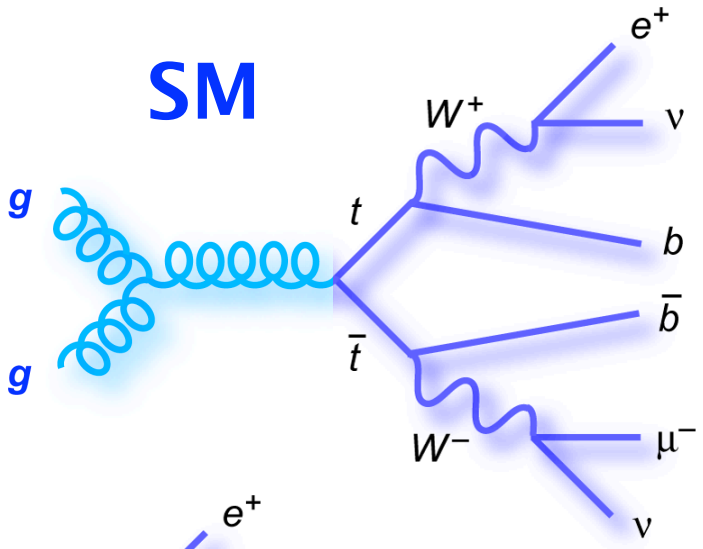


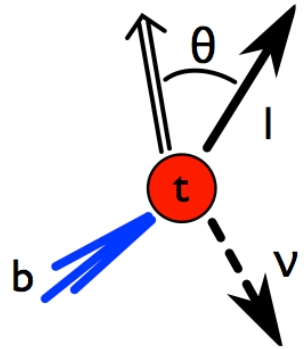
single top production

production cross section, CKM-Matrix-Element $|V_{tb}|$, anomalous couplings, searches for new particles

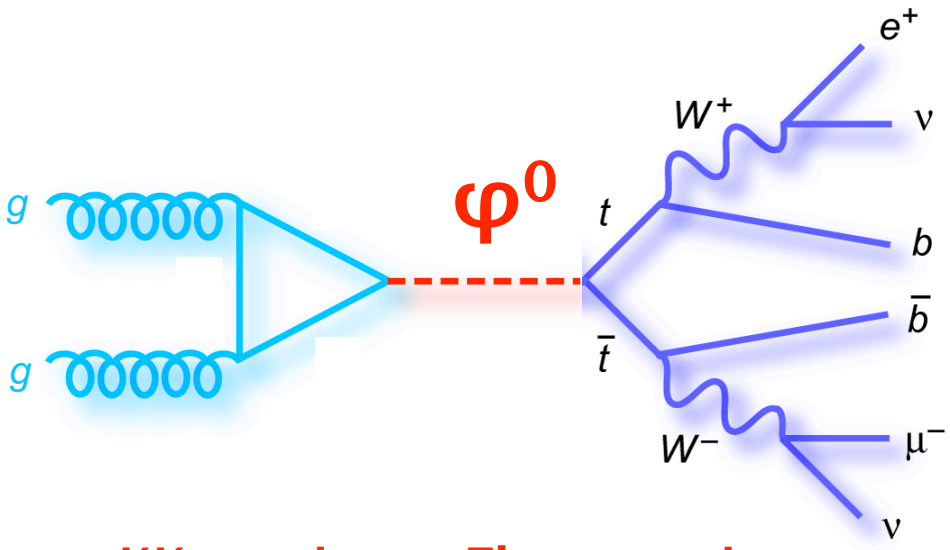
New physics impact on spin correlations

- important test of SM and sensitive search for physics beyond
- analyse the whole chain of top pair production and top decay

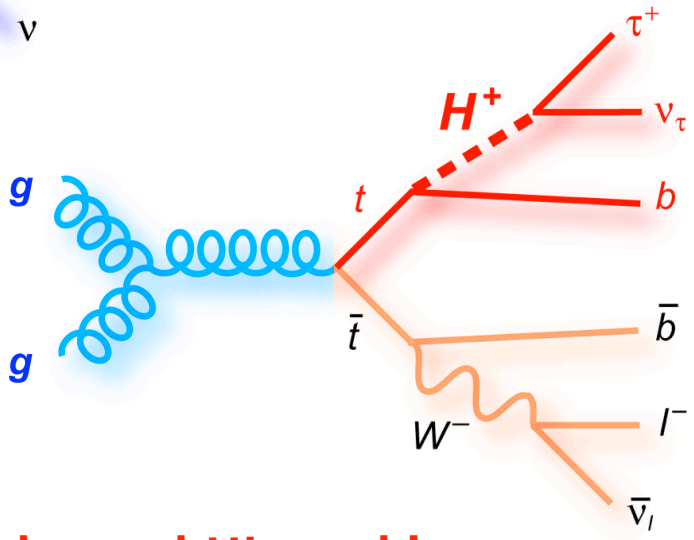




Phys. Lett. B 702, 16 (2011)



Higgs, KK gravitons, Z', stop pairs, ...



charged Higgs, b', ...

Matrix Element Method: spin correlation

G. Mahlon and S. J. Parke,
Phys. Rev. D 53, 4886 (1995)
Phys. Lett. B 411, 173(1997)

H=uncorrelated

$$\sum |\mathscr{M}|^2 = \frac{g_s^4}{9} F\overline{F} \left(2 - \beta^2 s_{qt}^2\right) /2$$

kinematics of top
and anti-top decay

β: velocity of top in $t\bar{t}$ rest frame
s_{qt}: sine between initial quark and top

Matrix Element Method: spin correlation

β: velocity of top in $t\bar{t}$ rest frame
s_{qt}: sine between initial quark and top
c_{qt}: cosine between initial quark and top

G. Mahlon and S. J. Parke,
Phys. Rev. D 53, 4886 (1995)
Phys. Lett. B 411, 173(1997)

$$\sum |\mathscr{M}|^2 = \frac{g_s^4}{9} F\overline{F}\left[(2-\beta^2 s_{qt}^2) - \Delta\right]$$

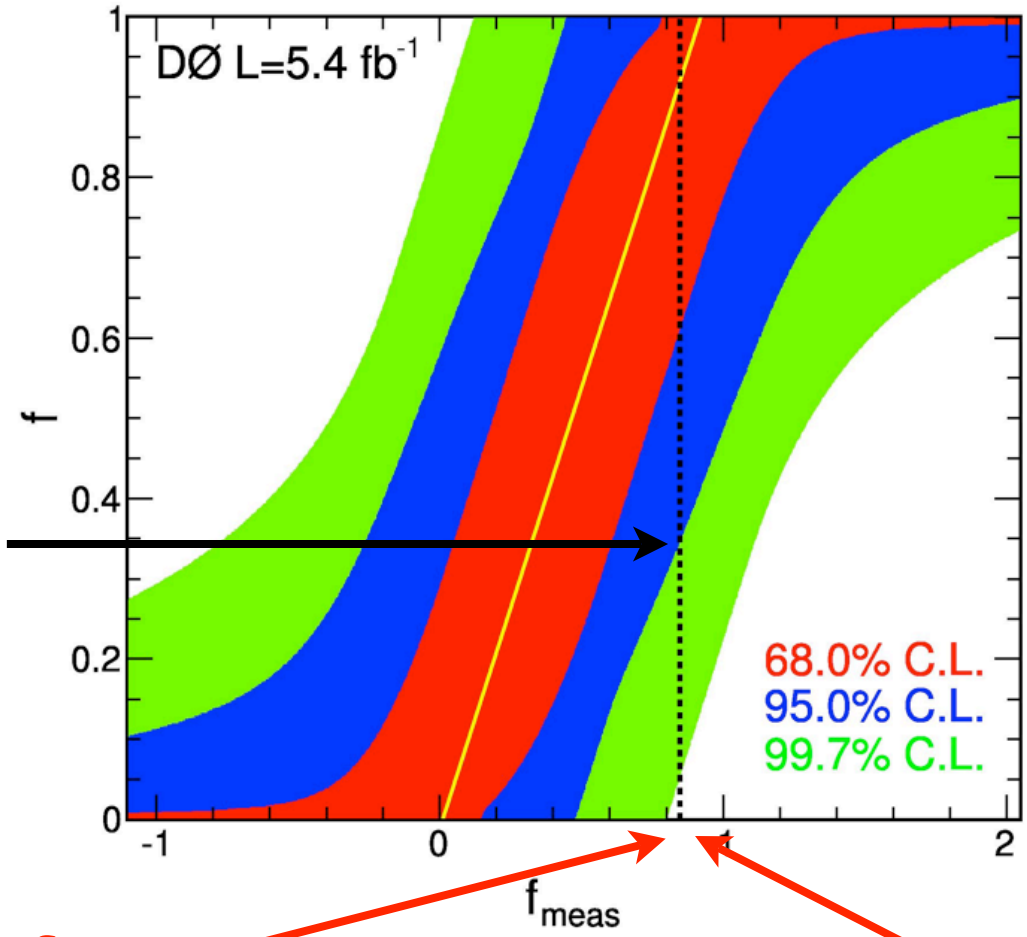
H=correlated

kinematics of top
and anti-top decay

$$\Delta = \frac{(1 - c_{\bar{\ell}q}c_{\ell\bar{q}}) - \beta(c_{\ell\bar{t}} + c_{\bar{\ell}t}) + \beta c_{qt}(c_{\bar{\ell}q} + c_{\ell\bar{q}}) + \frac{1}{2}\beta^2 s_{qt}^2(1 - c_{\bar{\ell}\ell})}{\gamma^2(1 - \beta c_{\bar{\ell}t})(1 - \beta c_{\ell\bar{t}})}$$

Exclusion Limits

$$C = 0.66 \pm 0.23\,(\text{stat+syst})$$



f > 0.344 at 95% CL

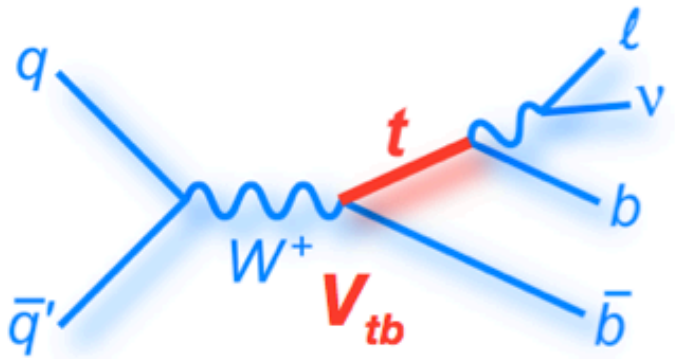
first exclusion of hypothesis H=uncorrelated (f=0) with more than 3σ

$$f_{\text{meas}} = 0.85 \pm 0.29(\text{stat} + \text{syst})$$

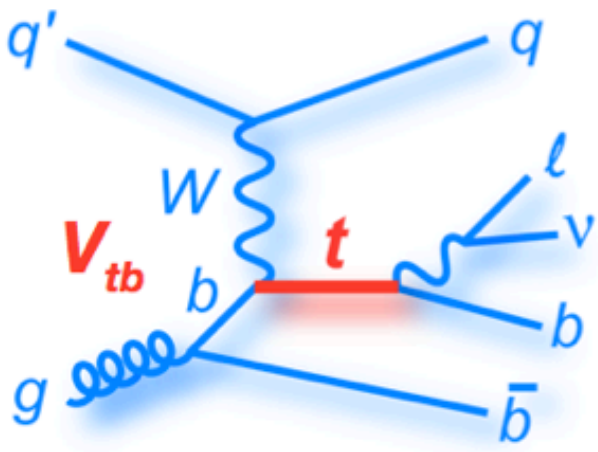
Single Top Quark Production

direct measurement of $|V_{tb}|$

s-channel:



t-channel:



- jets
- lepton
- missing E_T
- b-jets

Phys. Rev. D 84, 112001 (2011)

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

Victor Bazterra, 10 February

$$\sigma(p\bar{p} \to tb + X) = 0.68^{+0.38}_{-0.35}\ \text{pb}$$

$$\sigma(p\bar{p} \to tqb + X) = 2.86^{+0.69}_{-0.63}\ \text{pb}$$

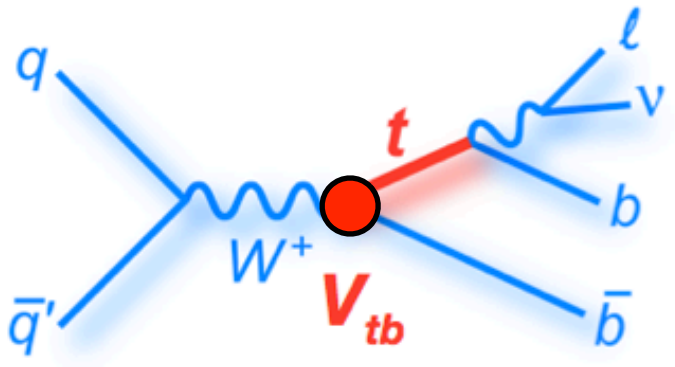
$$\sigma(p\bar{p} \to tb + tqb + X) = 3.43^{+0.73}_{-0.74}\ \text{pb}$$

$$|V_{tb}| = 1.02^{+0.10}_{-0.11}$$

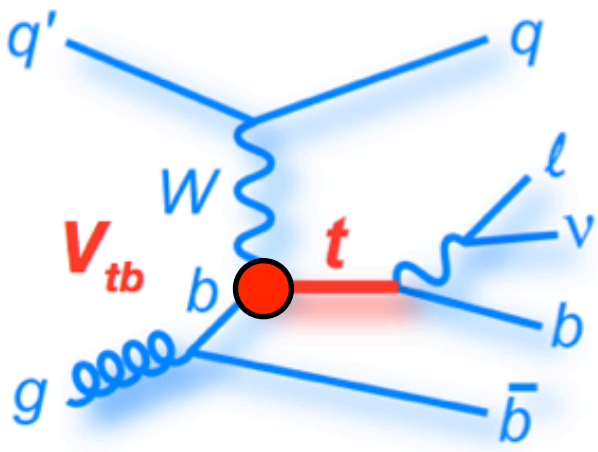
Single Top Quark Production

search for anomalous Wtb couplings

s-channel:



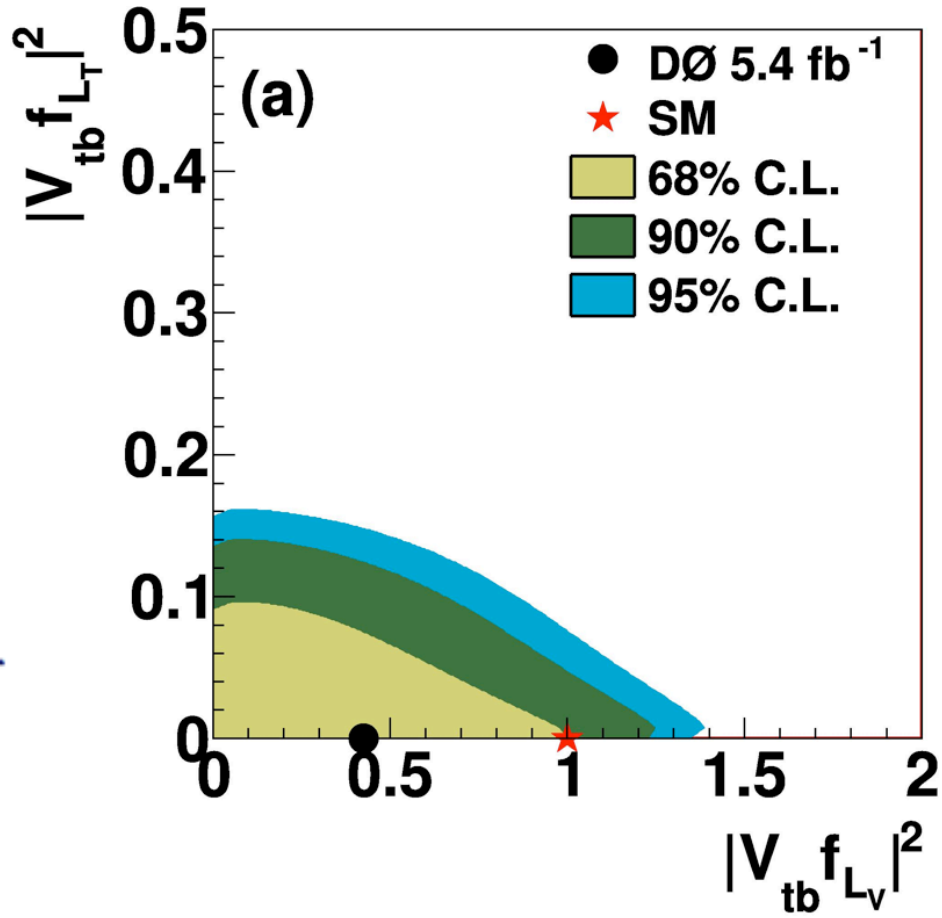
t-channel:



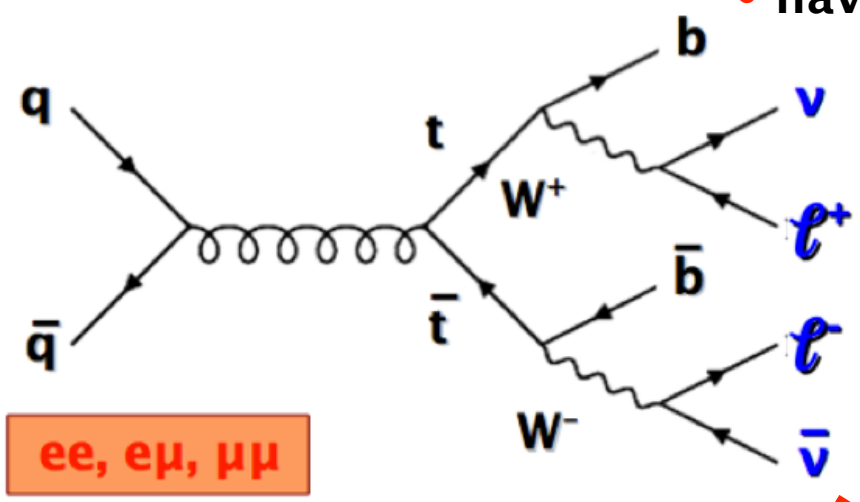
- jets
- lepton
- missing E_T
- b-jets

Phys. Lett. B 708, 21 (2012)

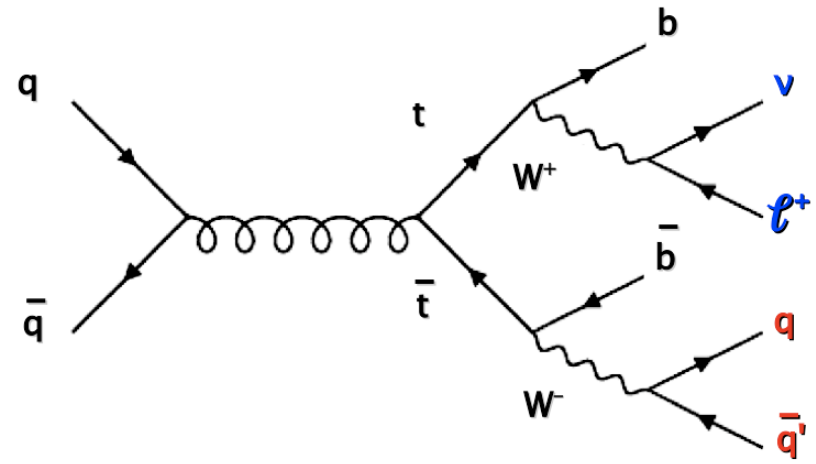
Victor Bazterra, 10 February



Top Quark Mass



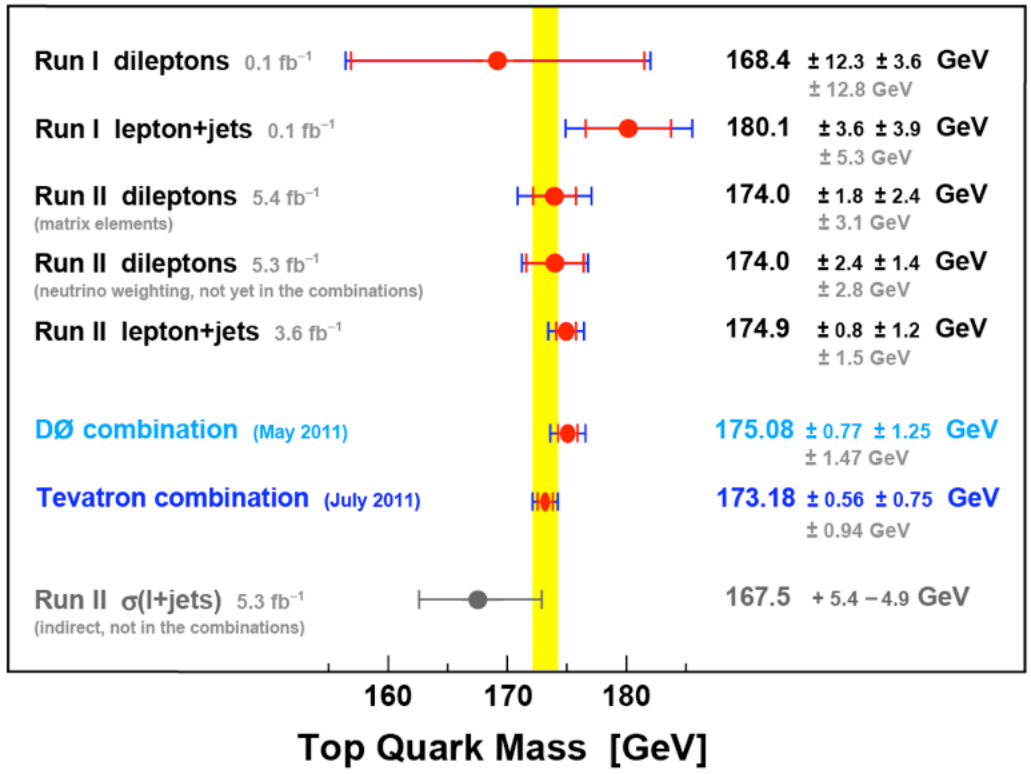
ee, eμ, μμ



- flavor dependence of jet energy scale

systematics smaller by ~O(1 GeV)

$$m_t = 174.0 \pm 2.4(\text{stat}) \pm 1.4(\text{syst}) \text{ GeV}$$

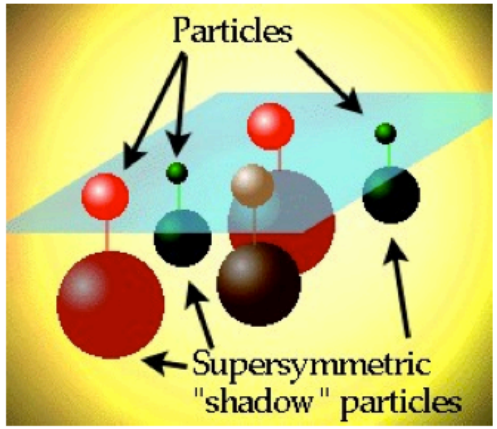


- calibration of jet energy scale

⇒ improve systematic uncertainties

Beyond the Standard Model

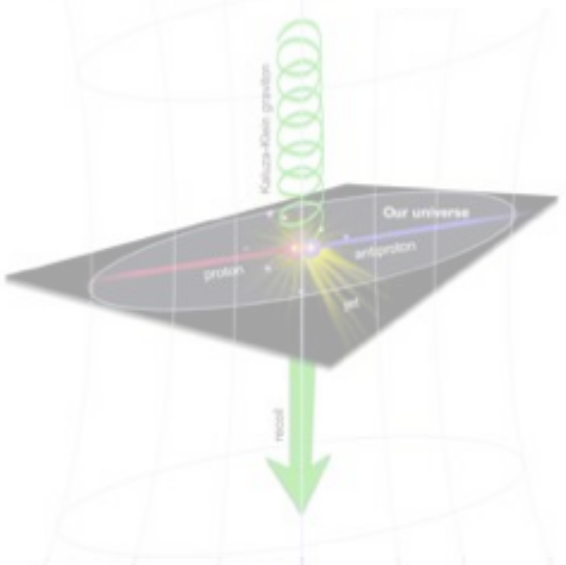
Supersymmetry



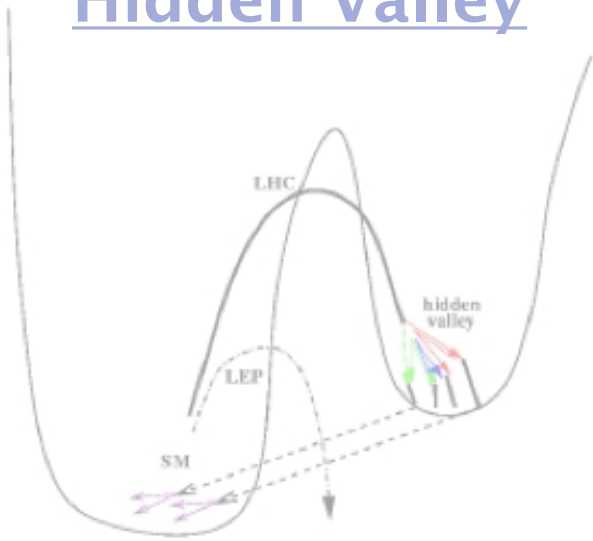
Name	Spin	Superpartner	Spin
Electron	1/2	Selectron	0
Muon	1/2	Smuon	0
Tau	1/2	Stau	0
Neutrino	1/2	Sneutrino	0
Quark	1/2	Squark	0

Name	Spin	Superpartner	Spin
Graviton	2	Gravitino	3/2
Photon	1	Photino	1/2
Gluon	1	Gluino	1/2
$W^{+,-}$	1	Wino$^{+,-}$	1/2
Z^0	1	Zino	1/2
Higgs	0	Higgsino	1/2

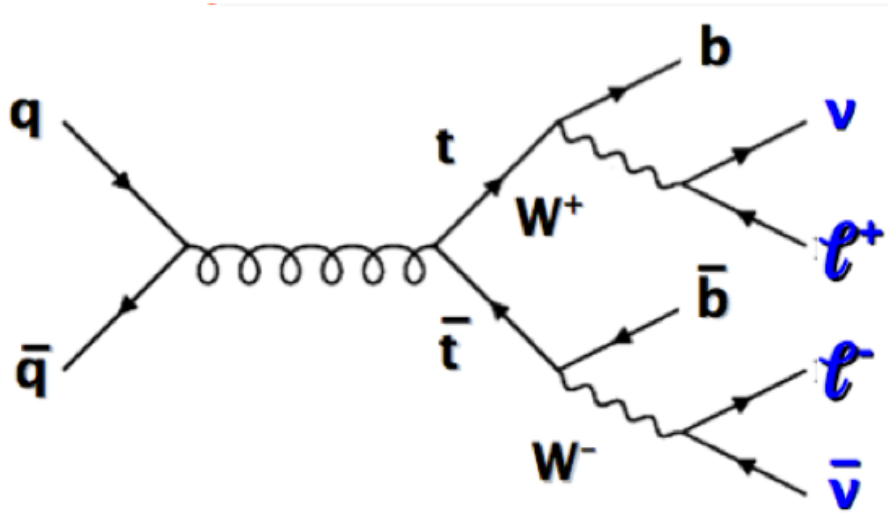
Extra dimensions



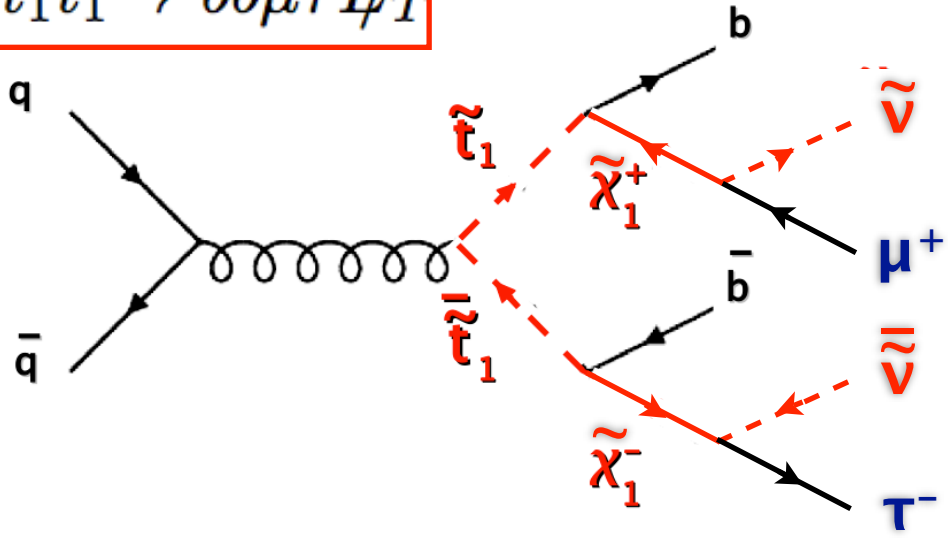
Hidden Valley



Search for Stop Pair Production

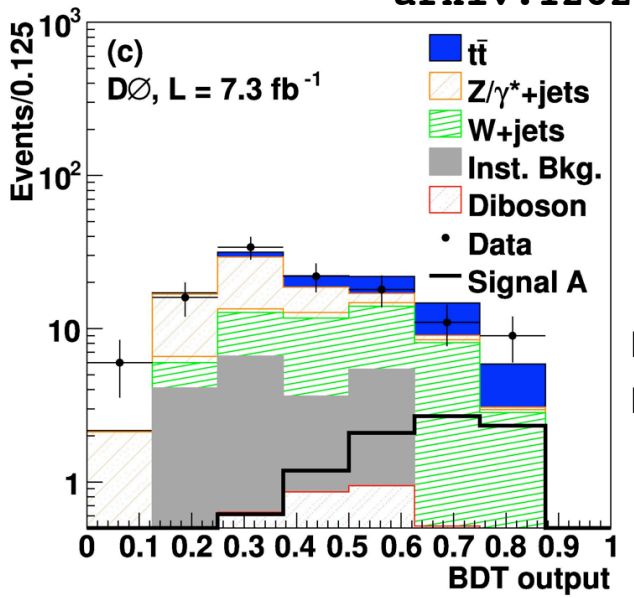


$\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow b\bar{b}\mu\tau\not{E}_T$

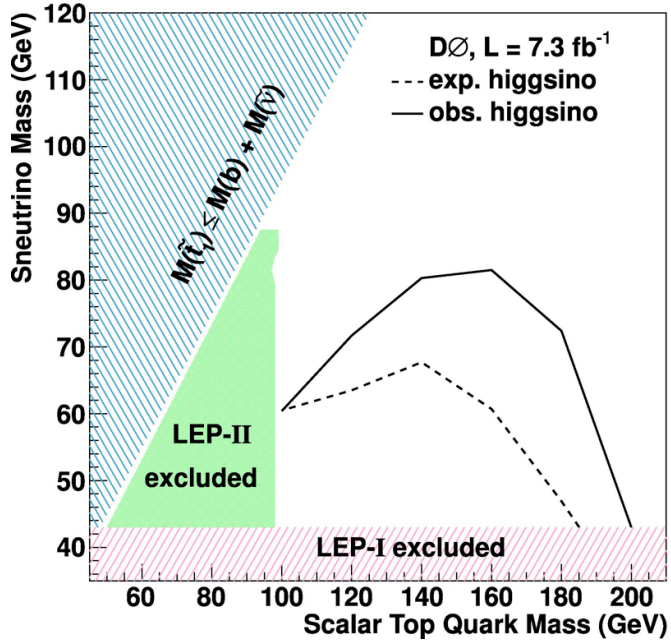


SUSY search in 3rd generation

arXiv:1202.1978 [hep-ex]

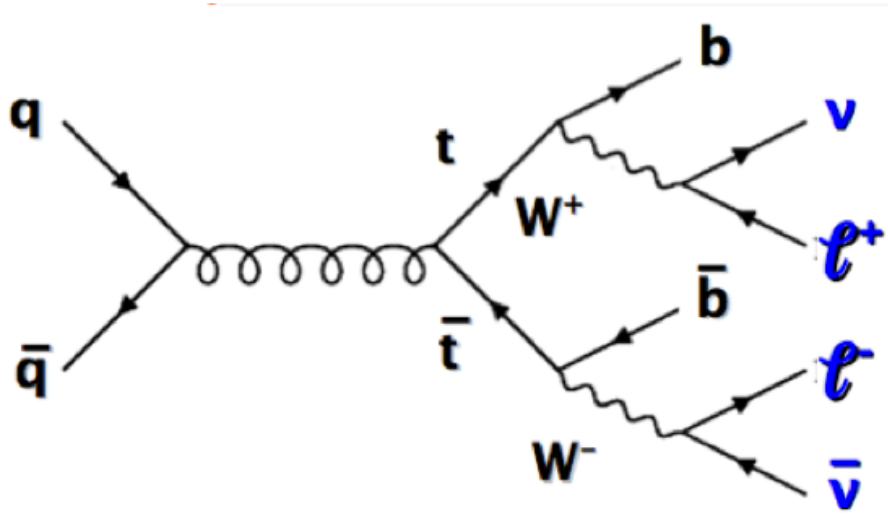


$m_{\tilde{t}} = 180$ GeV
$m_{\tilde{\nu}} = 60$ GeV



higgsino

Search for Stop Pair Production



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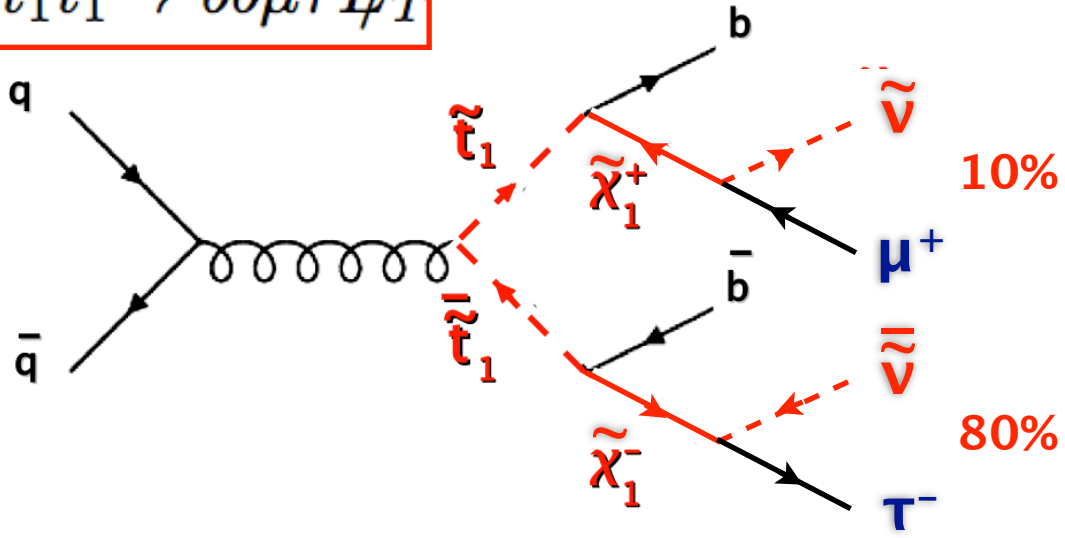
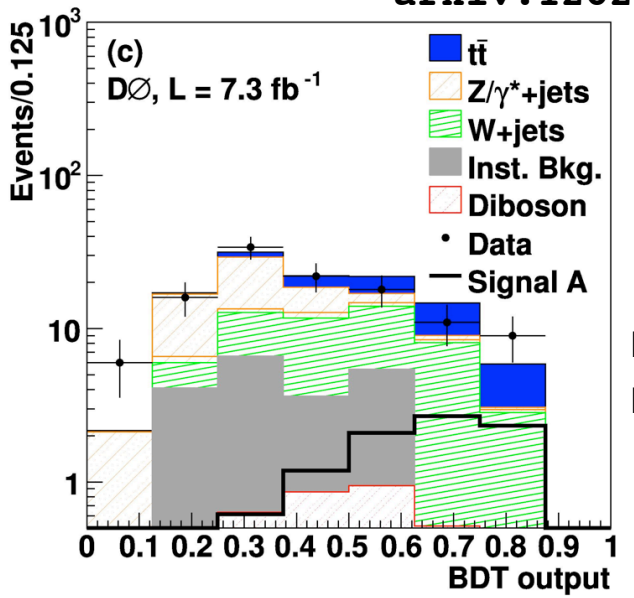


first Tevatron limits

arXiv:1202.1978 [hep-ex]



$m_{\tilde{t}} = 180$ GeV
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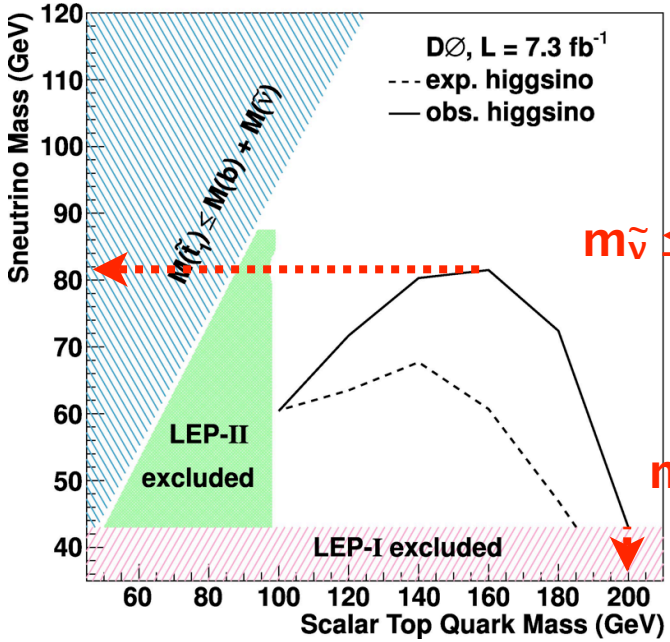


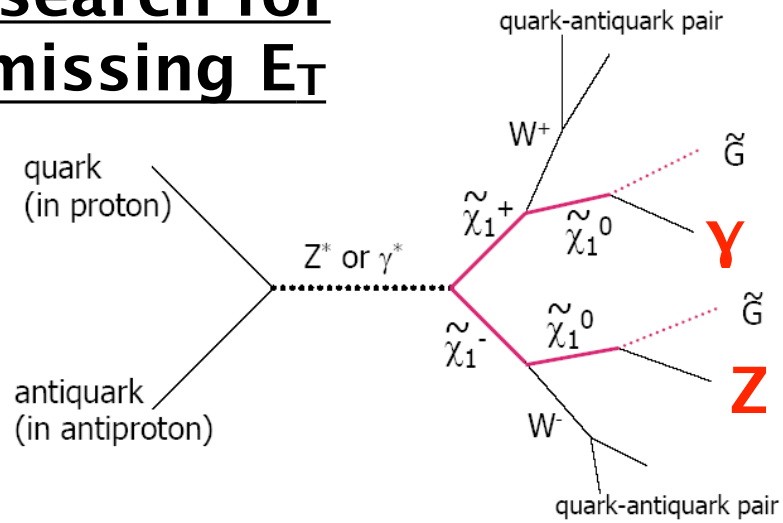
higgsino

$m_{\tilde{\nu}} \leq 81$ GeV

$m_{\tilde{t}} \leq 200$ GeV

Search for Gravitinos (GMSB SUSY)

first search for
Zγ+missing E_T



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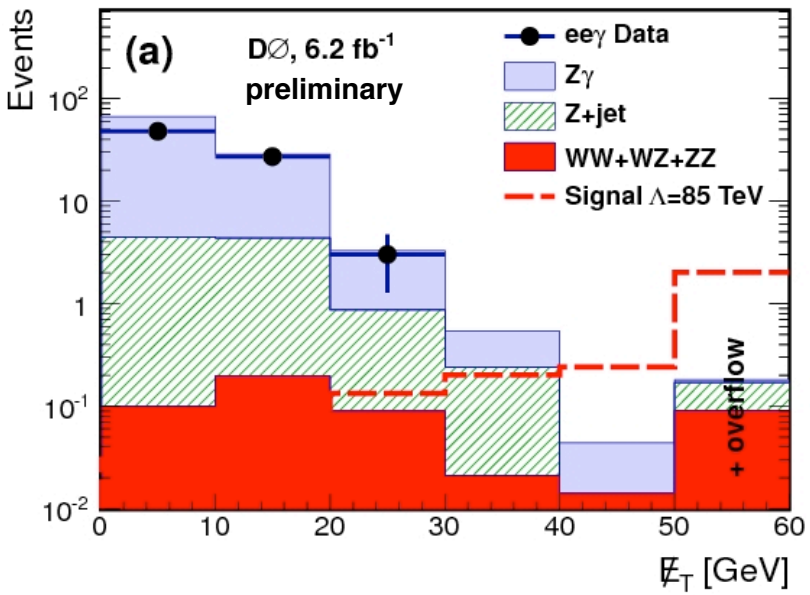
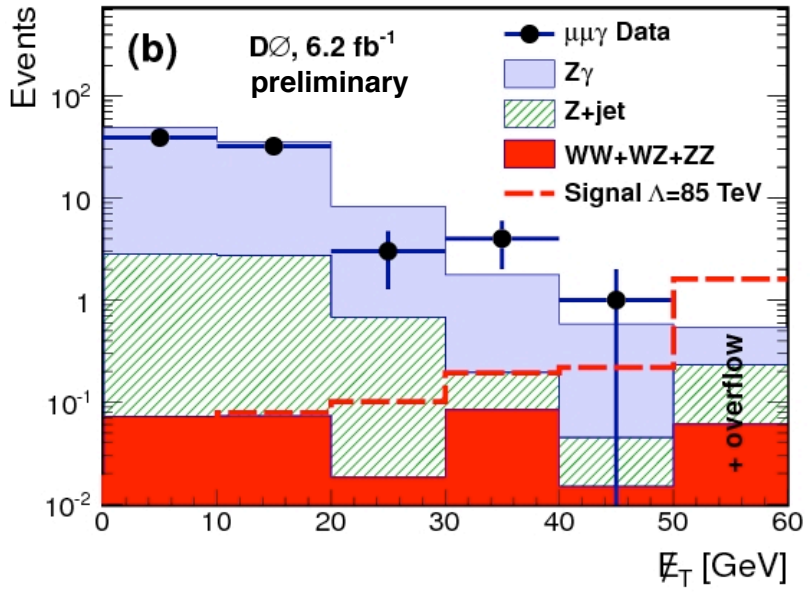
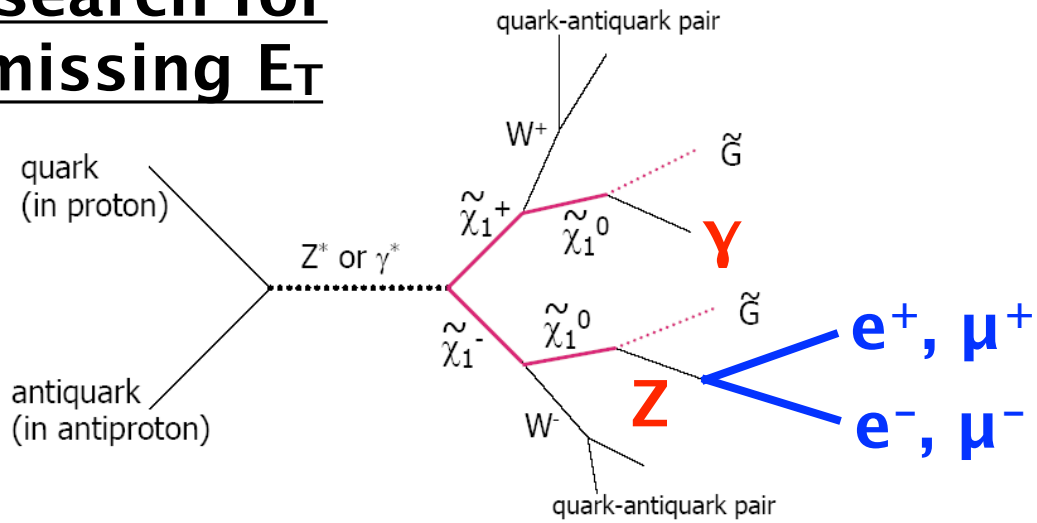
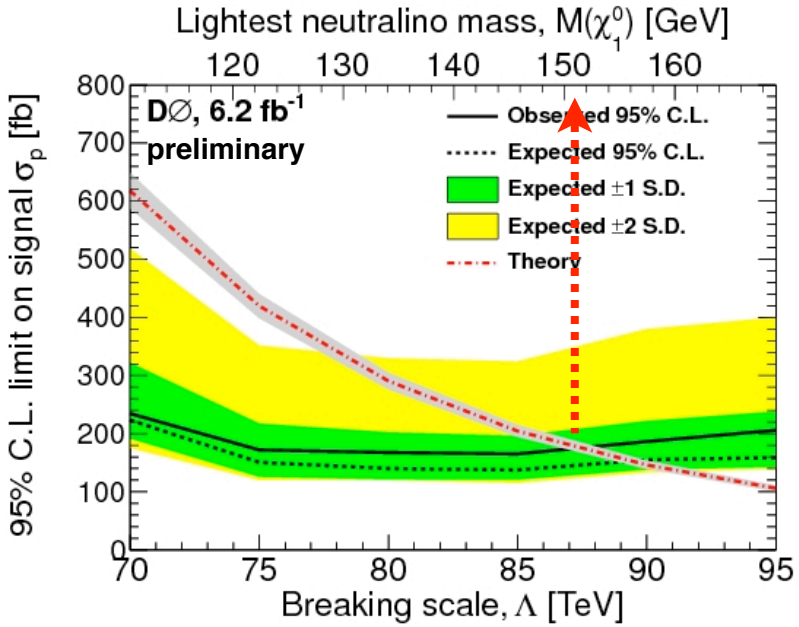




first search for Zγ+missing E_T

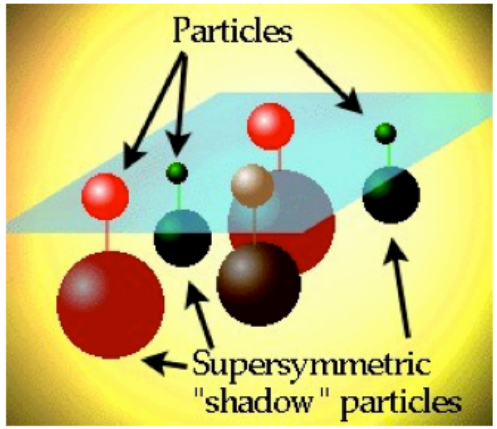




$m_{\tilde{\chi}_1^0} \leq 151$ GeV

Beyond the Standard Model

Supersymmetry



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Name	Spin	Superpartner	Spin
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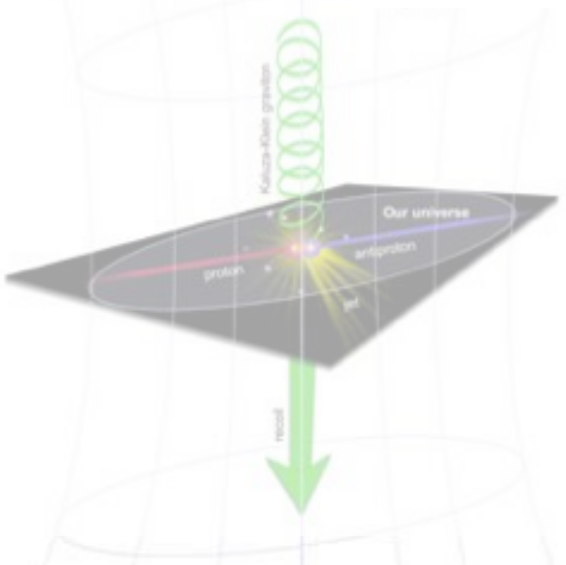
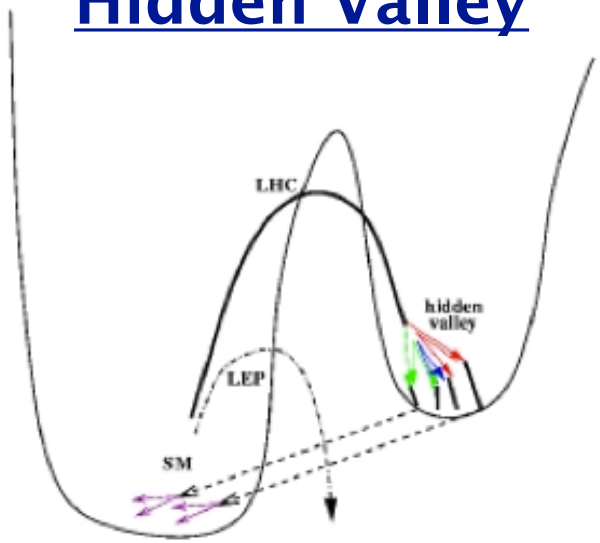
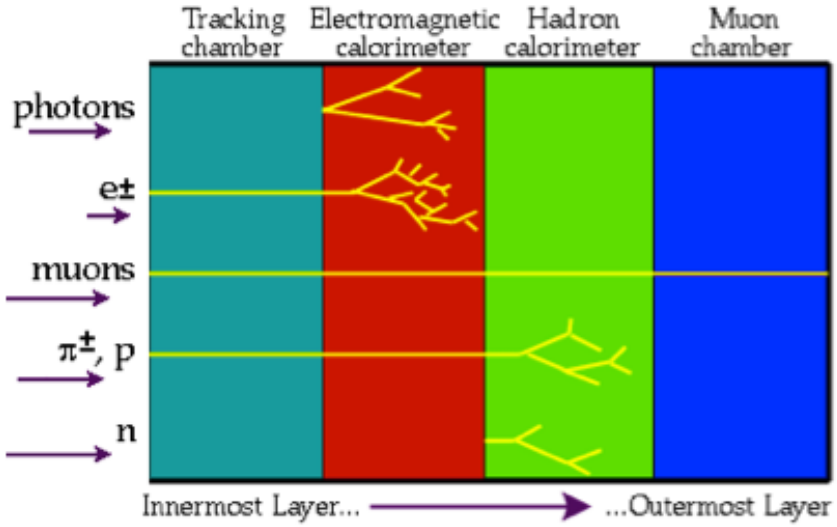
Extra dimensions



Hidden Valley

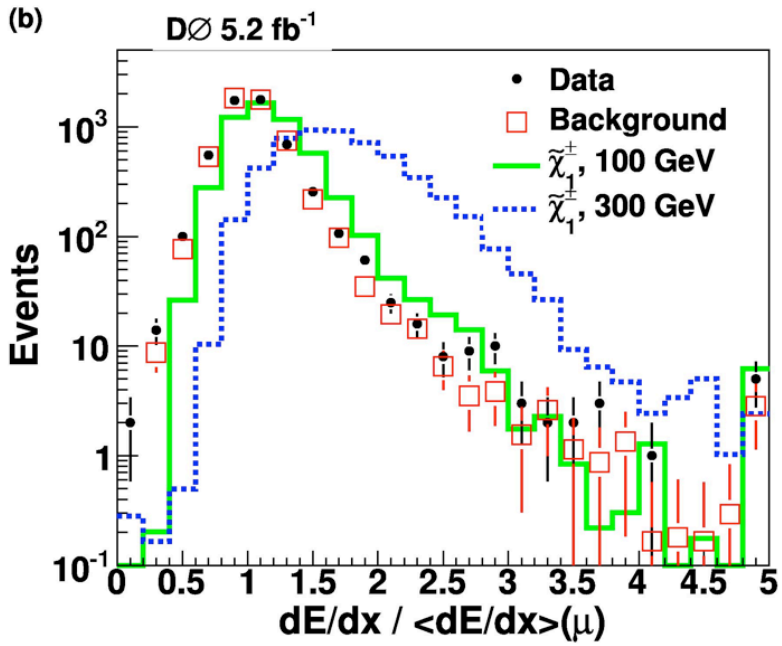


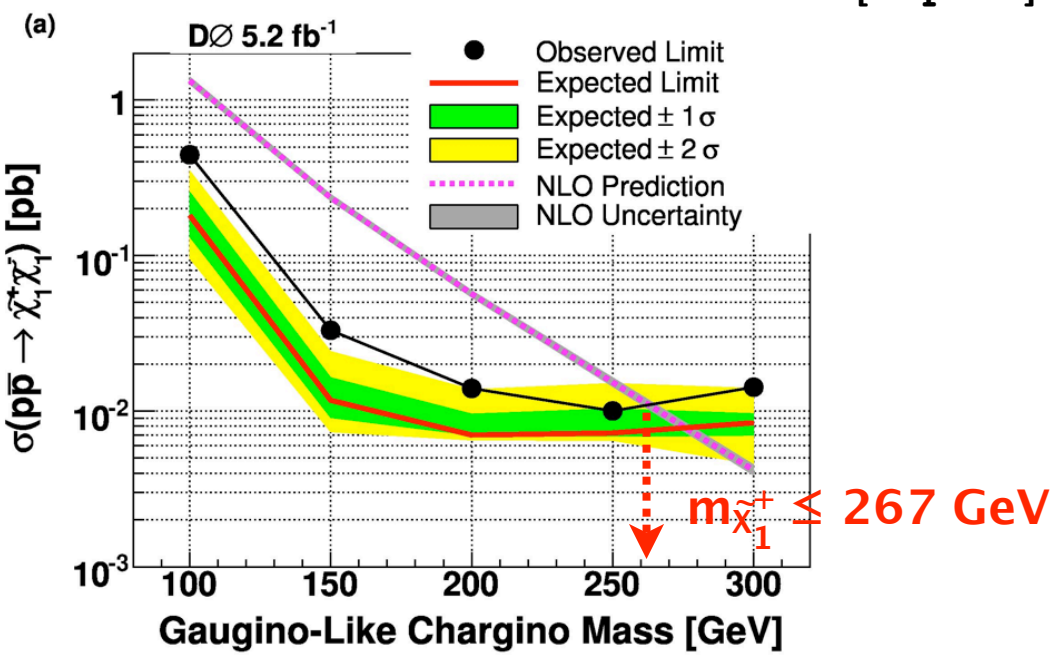
Charged Massive Long-Lived Particles



- could resolve problems in cosmology (observed lithium production which is difficult to to explain in the standard model of big bang nucleosynthesis)
- in SUSY models with AMSB, the NLSP can be a CMLLP, e.g. chargino
- look like slow, massive long-lived muons: measure speed and ionisation energy loss

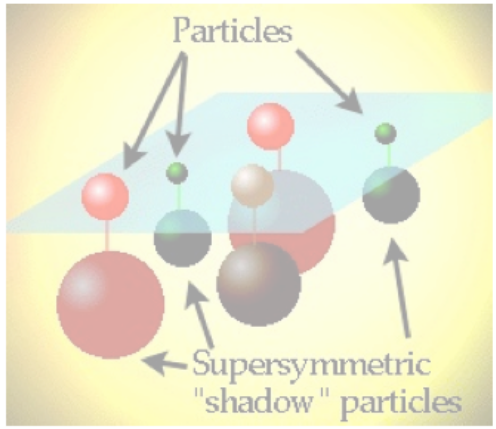
arXiv:1110.3302 [hep-ex]





Beyond the Standard Model

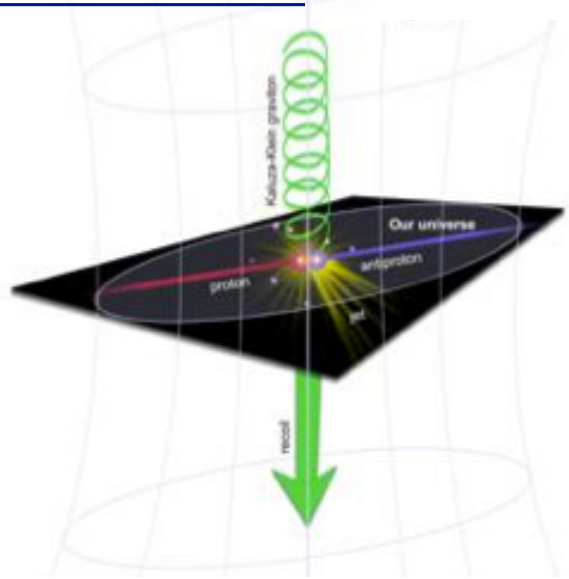
Supersymmetry



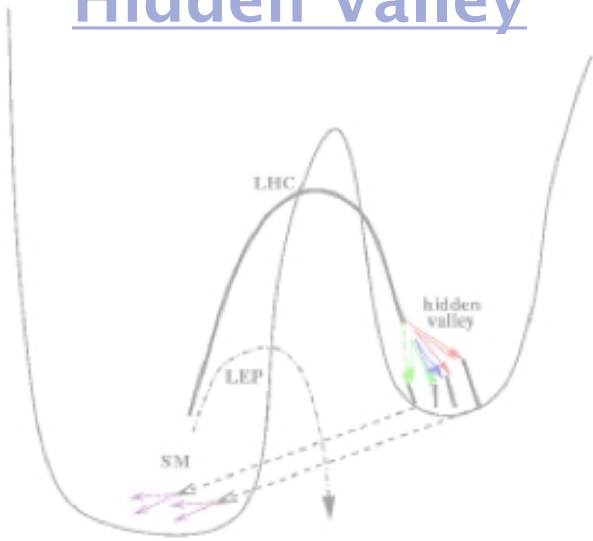
Name	Spin	Superpartner	Spin
Electron	1/2	Selectron	0
Muon	1/2	Smuon	0
Tau	1/2	Stau	0
Neutrino	1/2	Sneutrino	0
Quark	1/2	Squark	0

Name	Spin	Superpartner	Spin
Graviton	2	Gravitino	3/2
Photon	1	Photino	1/2
Gluon	1	Gluino	1/2
$W^{+,-}$	1	Wino$^{+,-}$	1/2
Z^0	1	Zino	1/2
Higgs	0	Higgsino	1/2

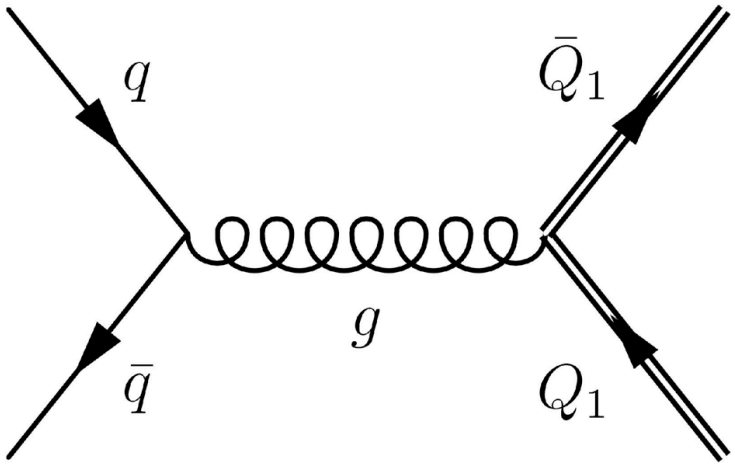
Extra dimensions

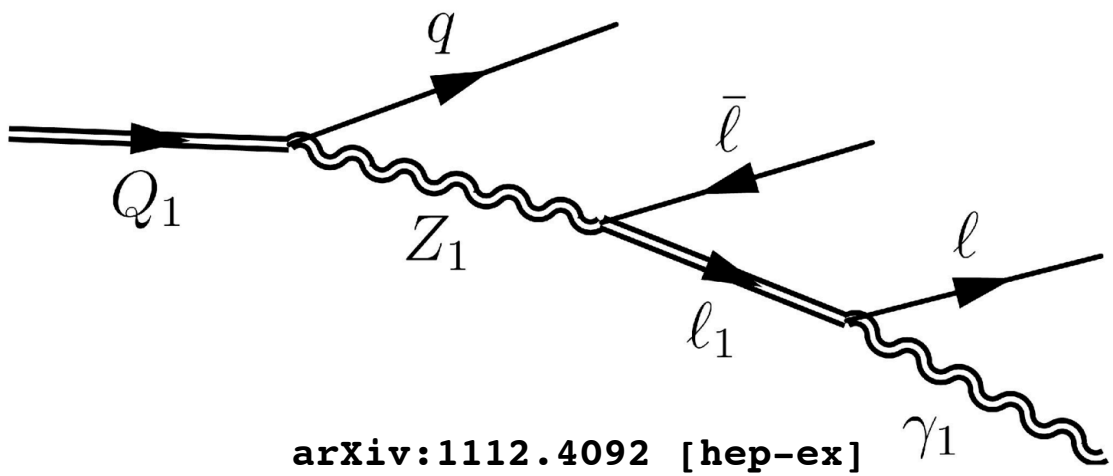


Hidden Valley



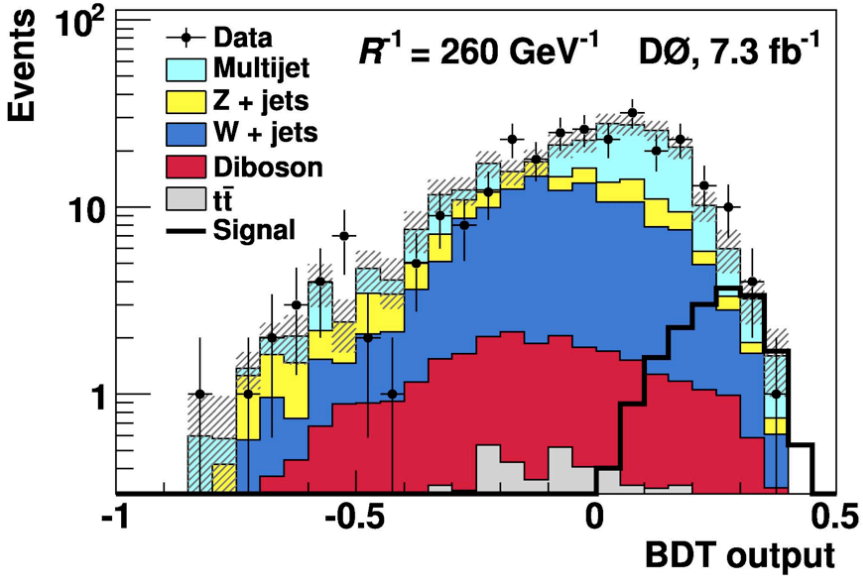
Minimal Universal Extra Dimensions

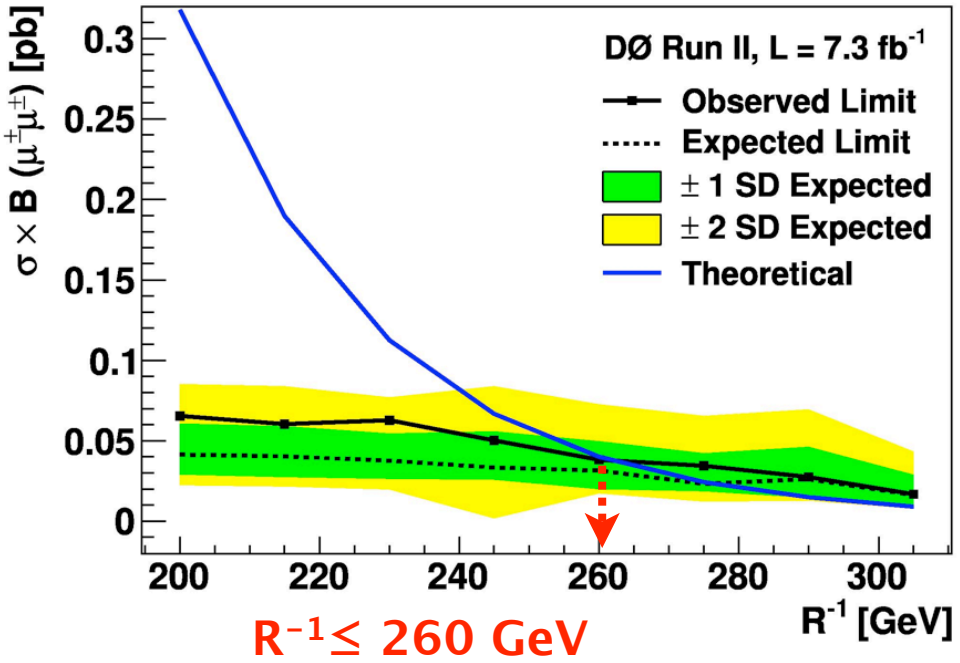




arXiv:1112.4092 [hep-ex]

- pair production of Kaluza-Klein quarks
- search for 2 muons with the same charge



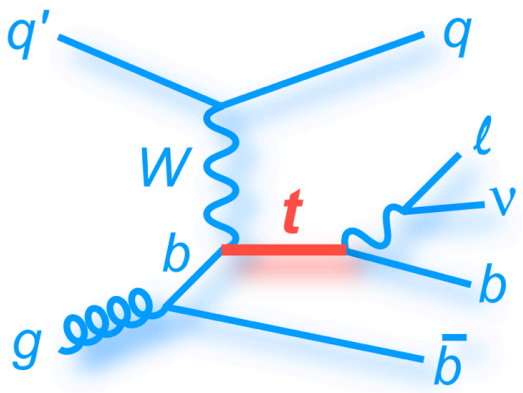


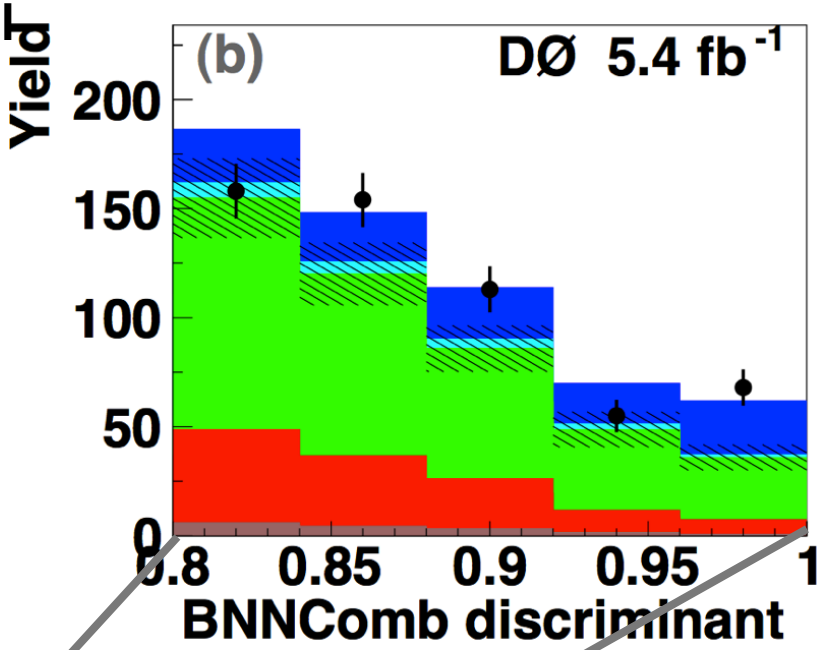
$R^{-1} \leq 260$ GeV

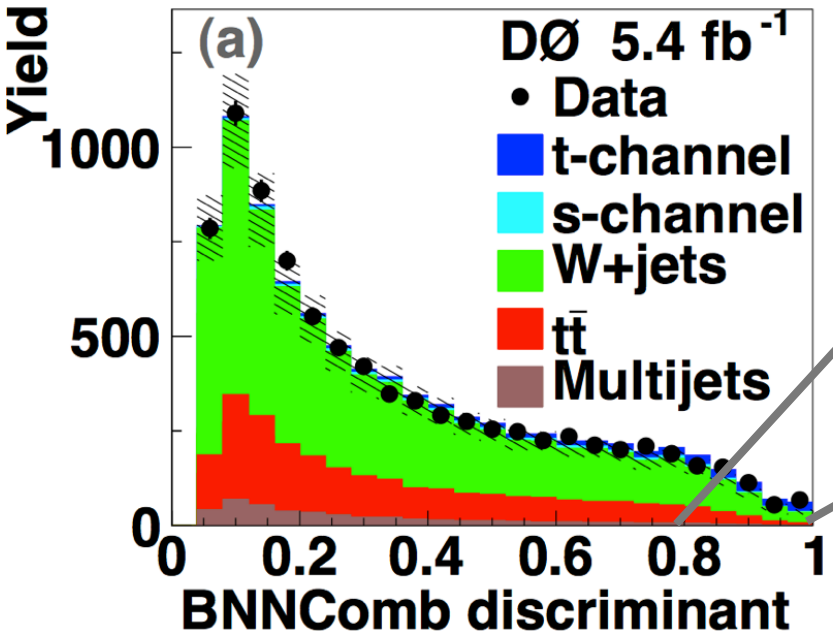
→ first direct lower limit on compactification scale in this channel

Single Top t-channel

- 2, 3, 4 jets with 1, 2 b tags
- train multivariate analysis for t-channel
- double data set





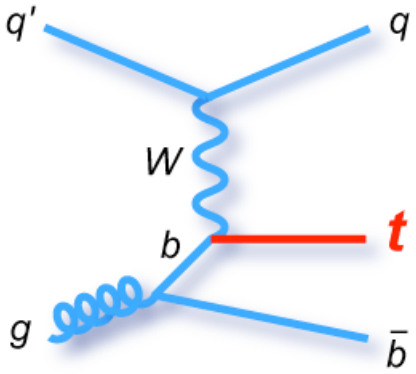


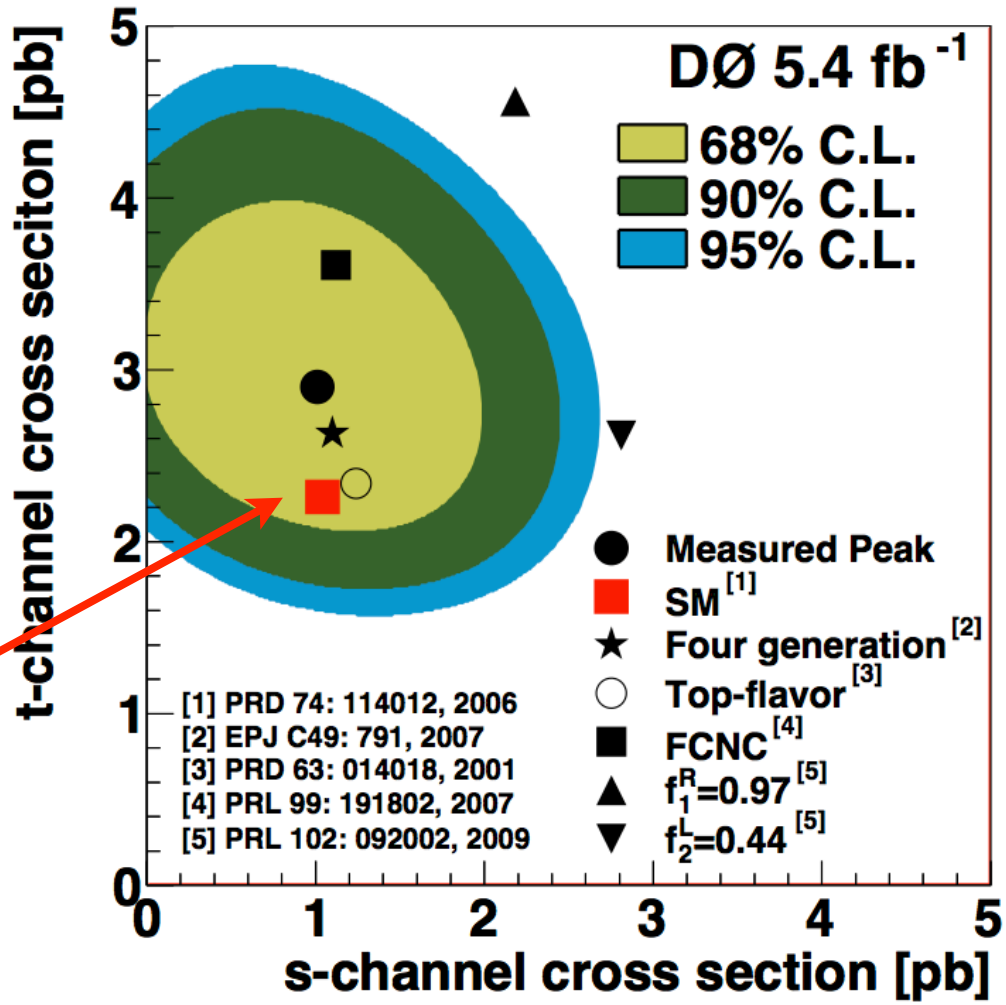
σ_{tb} = 2.26 ± 0.12 pb

$NNLO_{approx}$, m_{top} = 172.5 GeV

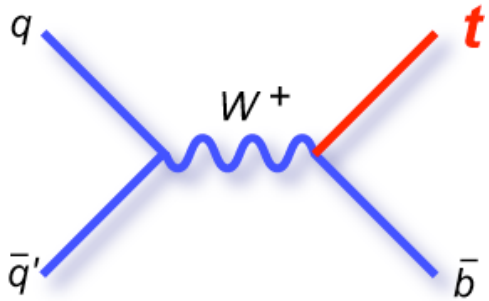
σ(t-channel)=2.90±0.59 pb

Single Top s- vs. t-channel





SM



good agreement with Standard Model

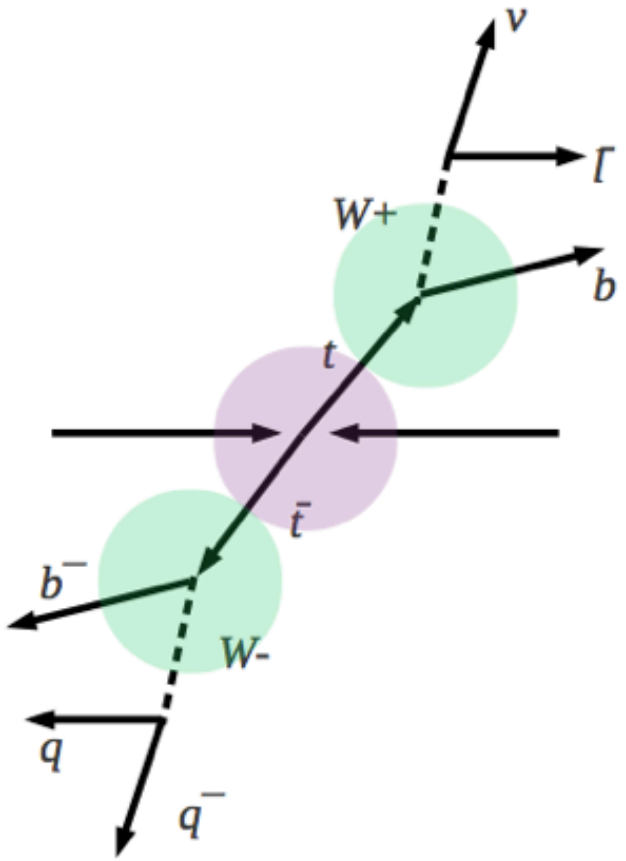
Search for Lorentz Invariance Violation

- General Lorentz-violating terms added to SM Lagrangian
  - Effective field theory treatment for LV
  - Not constrained to be the same for all particle species

$$|\mathbf{M}|^2 = \overbrace{P\,F\,\bar{F}}^{\text{Standard Model}} + \overbrace{(c_R + c_L)_{\mu\nu}\,(\delta P_p + \delta P_\nu)^{\mu\nu}\,F\,\bar{F}}^{\text{Production Corrections}} + \overbrace{(c_L)_{\mu\nu}\,(P(\delta F)^{\mu\nu}\,\bar{F} + P\,F(\delta \bar{F})^{\mu\nu})}^{\text{Decay Corrections}}$$

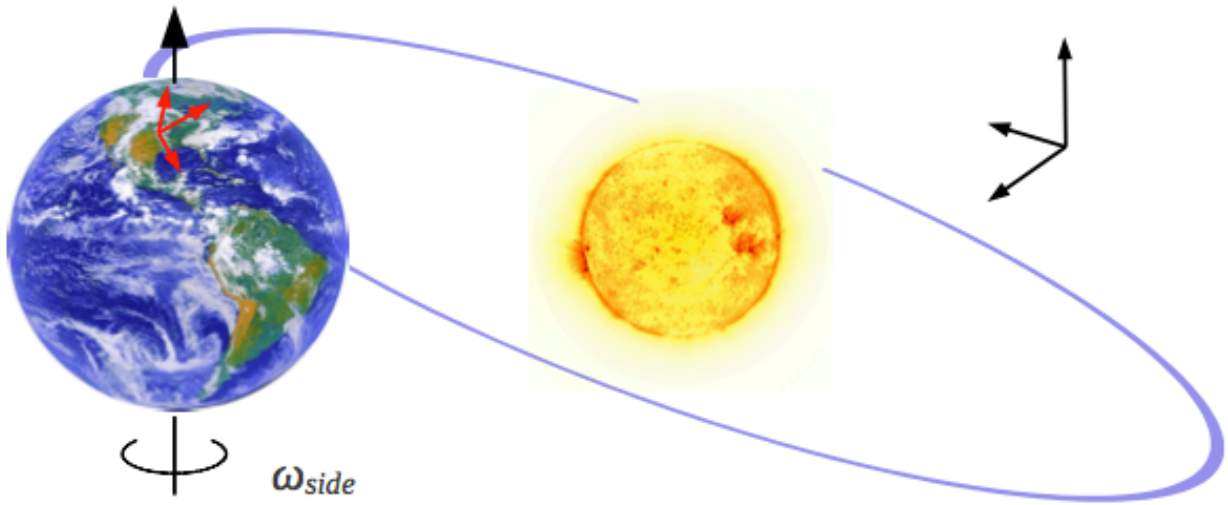
  - c_R and c_L are symmetric, traceless matrices containing coefficients which parametrize the strength of Lorentz violation in the top quark sector
  - Set limits on elements of c_R and c_L, as well as linear combinations $c = c_L + c_R$ and $d = c_L - c_R$.

  - Top sector only accessible to high-energy particle colliders
    - Tight limits already set on LV other particle sectors



Search for Lorentz Invariance Violation

- GOAL: Estimate components of c_R and c_L matrices



$$c_{L(R)}^{\text{Apparatus}} = \hat{R}\left(\omega_{side} t\right)_{(\text{Sun} \rightarrow \text{Apparatus})} c_{L(R)}^{\text{Sun}}$$

SM extension

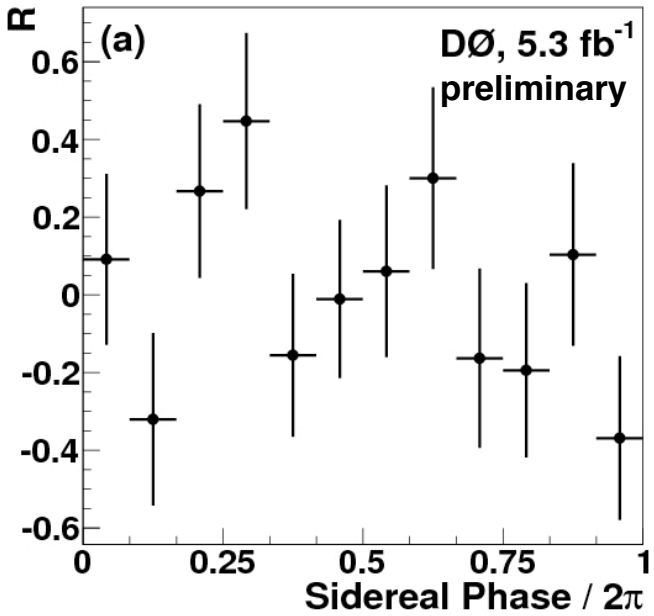
- D-Zero events projected onto different components of SME matrices c_R and c_L
  - Varies with sidereal frequency as detector rotates with Earth
  - Unique signature!
  - Time-dependent event rate.

Search for Lorentz Invariance Violation

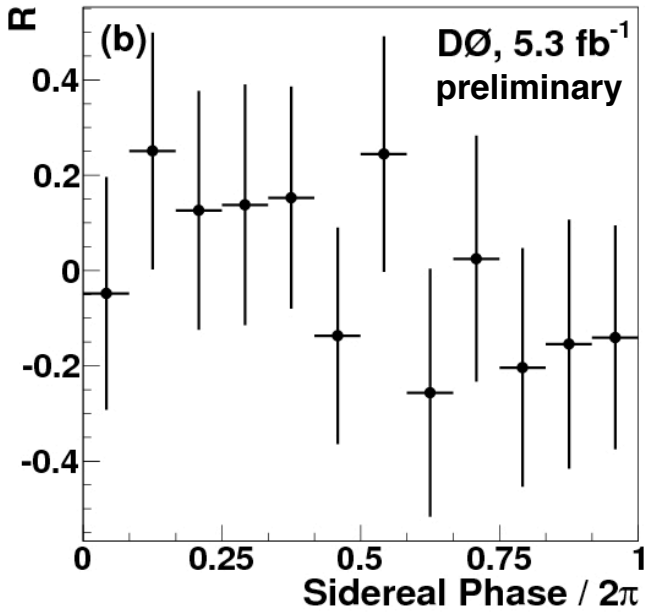
$$N_i \approx N_{\rm tot} \frac{\mathcal{L}_i}{\mathcal{L}_{\rm int}} \left[1 + f_{\rm S} f_{SME}(\phi_i)\right]$$

- $\mathcal{L}_i$ is the integrated luminosity over appropriate bin of sidereal phase ϕ_i
- f_S is the fraction of signal ($t\bar{t}$) events

$$R_i \equiv \frac{1}{f_{\rm S}} \left(\frac{N_i / N_{\rm S+B}}{\mathcal{L}_i / \mathcal{L}_{\rm int}} - 1 \right)$$



(a) e+>3-jets $t\bar{t}$ candidates

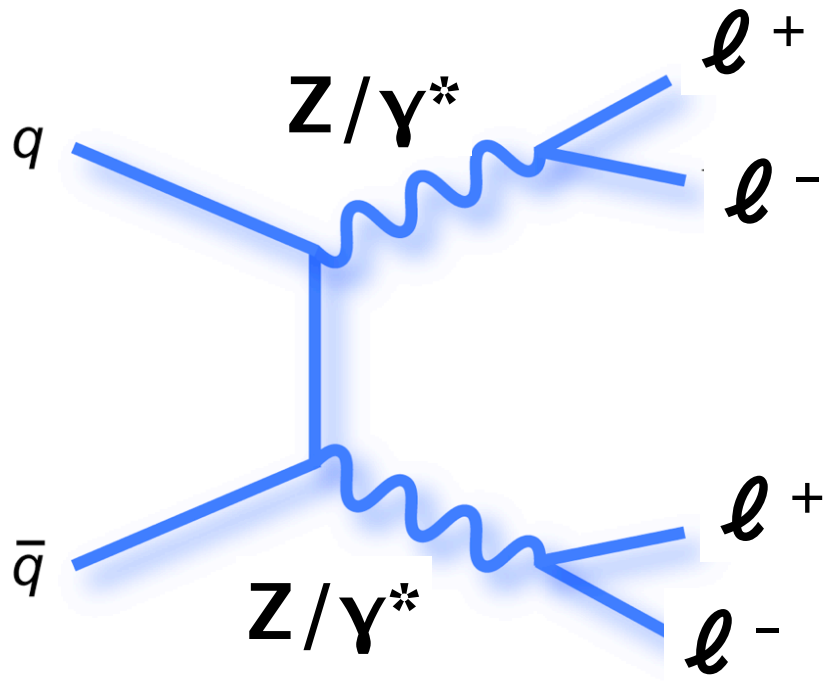


(b) μ+>3-jets $t\bar{t}$ candidates

→ **no indication of time dependence of $t\bar{t}$ cross section**

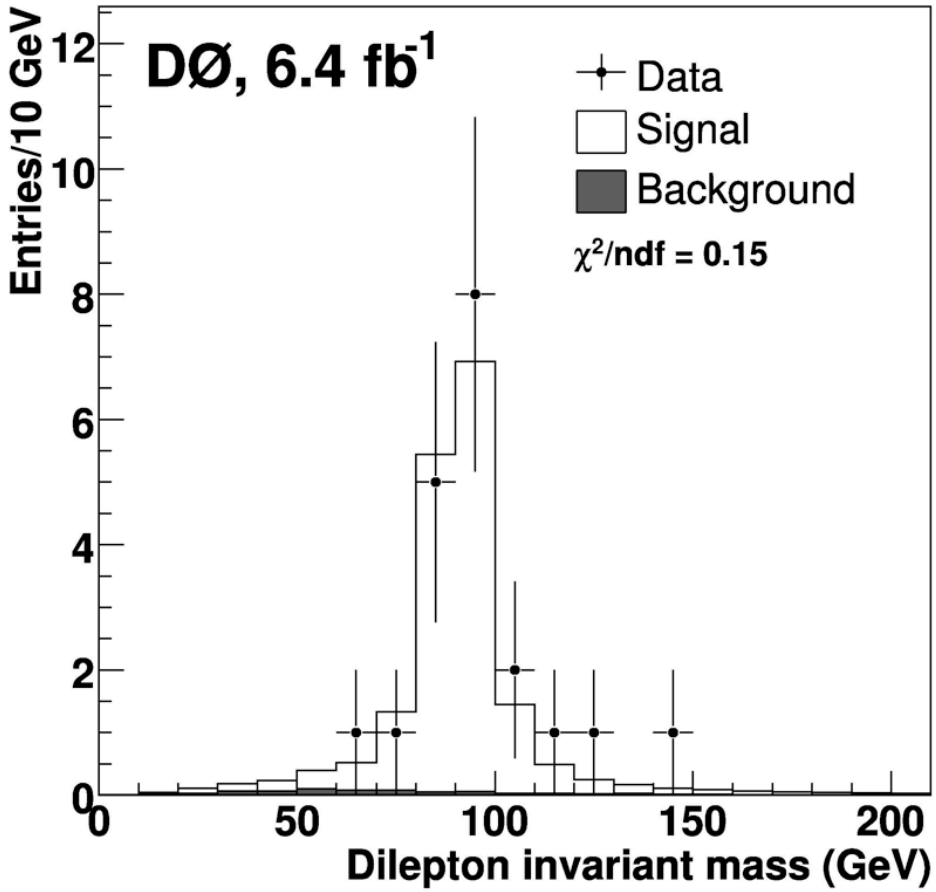
→ **first constraints on LIV in free quark sector $(c_L)_{XX}$, $(c_L)_{XY}$, … , $(c_R)_{XX}$, …**

ZZ→ℓ ℓ ℓ ℓ Production

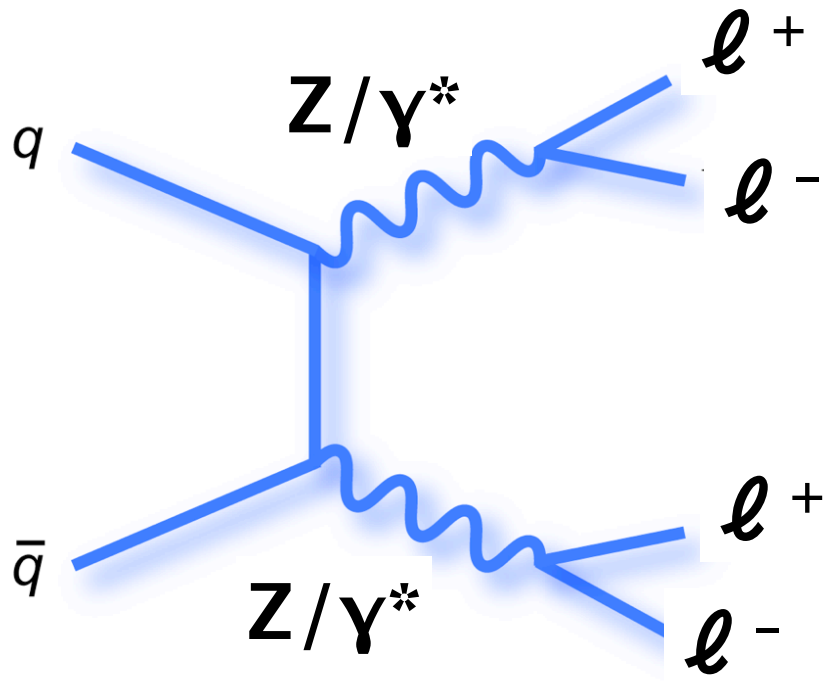


important background
to H→ZZ searches

eeee, eeμμ, μμμμ



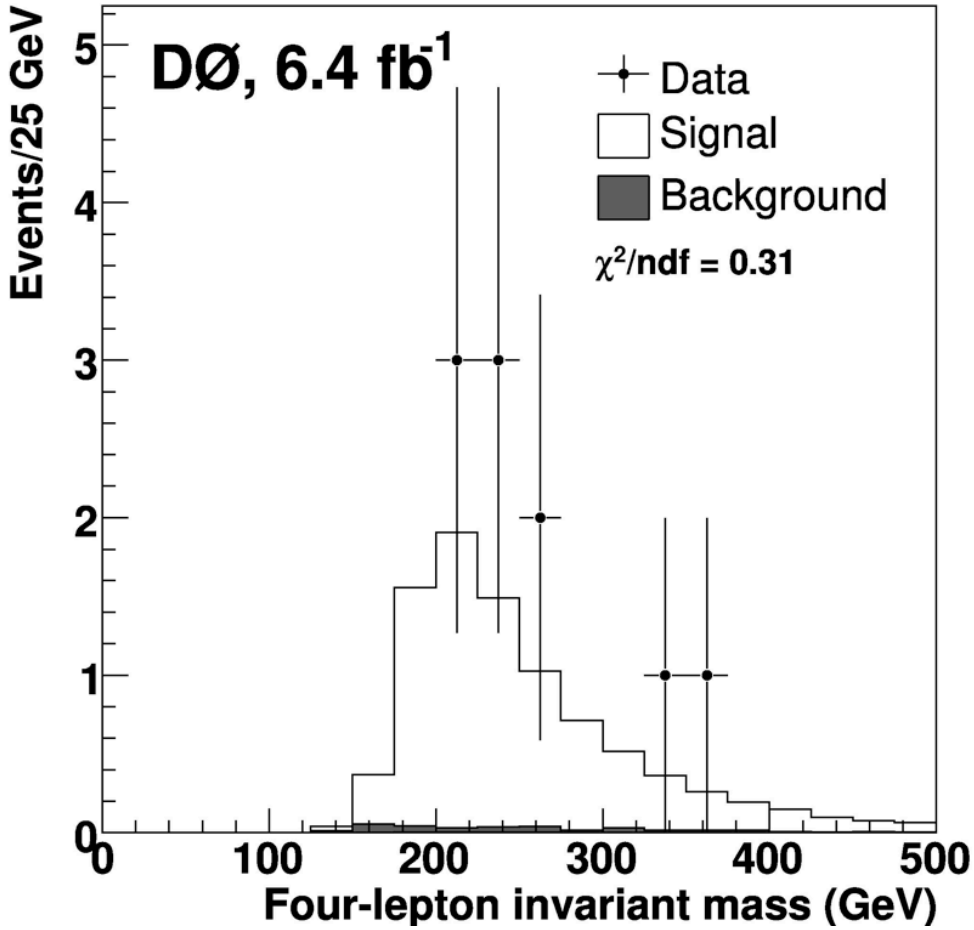
ZZ→ℓ ℓ ℓ ℓ Production



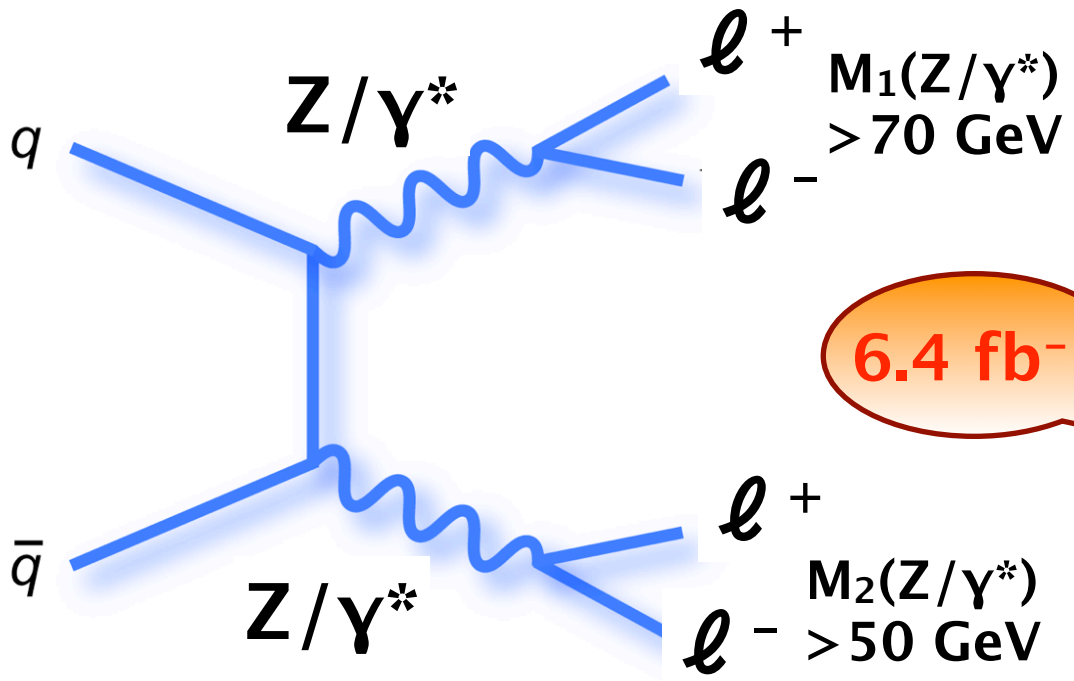
important background to H→ZZ searches...

- data: 10 events
- signal: 8.73±0.45
- background: 0.35±0.04 (jets faking electrons, muons in jets, top pair production)

eeee, eeμμ, μμμμ

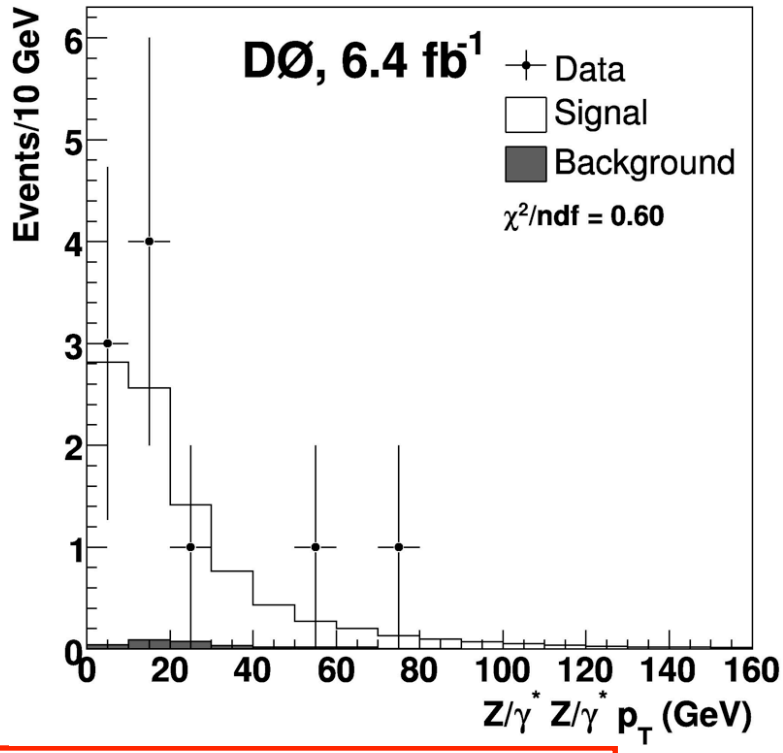


$ZZ \to \ell\ell\ell\ell$ Production



6.4 fb^{-1}

eeee, eeμμ, μμμμ

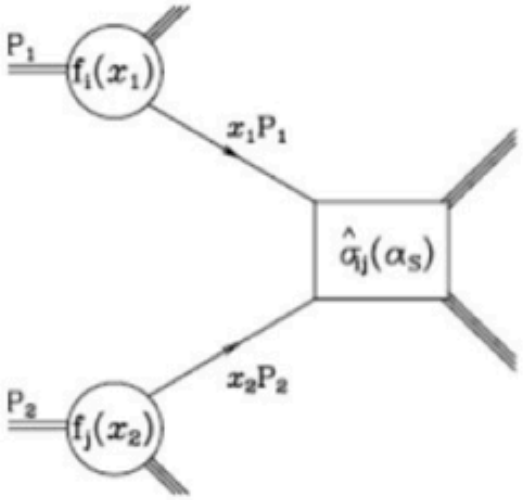


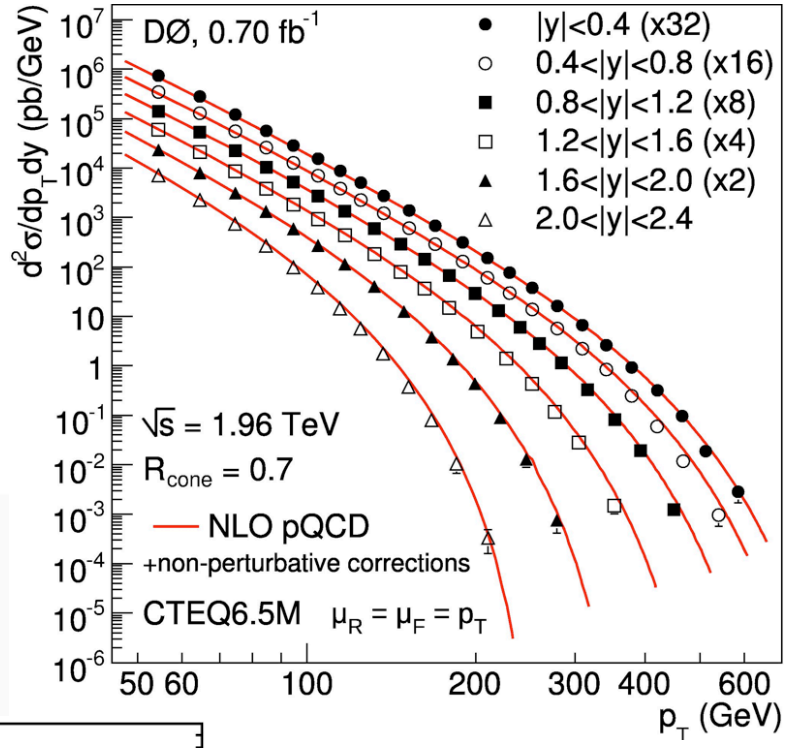
SM: $\sigma(Z/\gamma^* Z/\gamma^*) = 1.4 \pm 0.1$ pb

$$\sigma(p\bar{p} \to Z/\gamma^* Z/\gamma^*) = 1.35^{+0.50}_{-0.40}\,(\text{stat}) \pm 0.15\,(\text{syst})\ \text{pb}$$

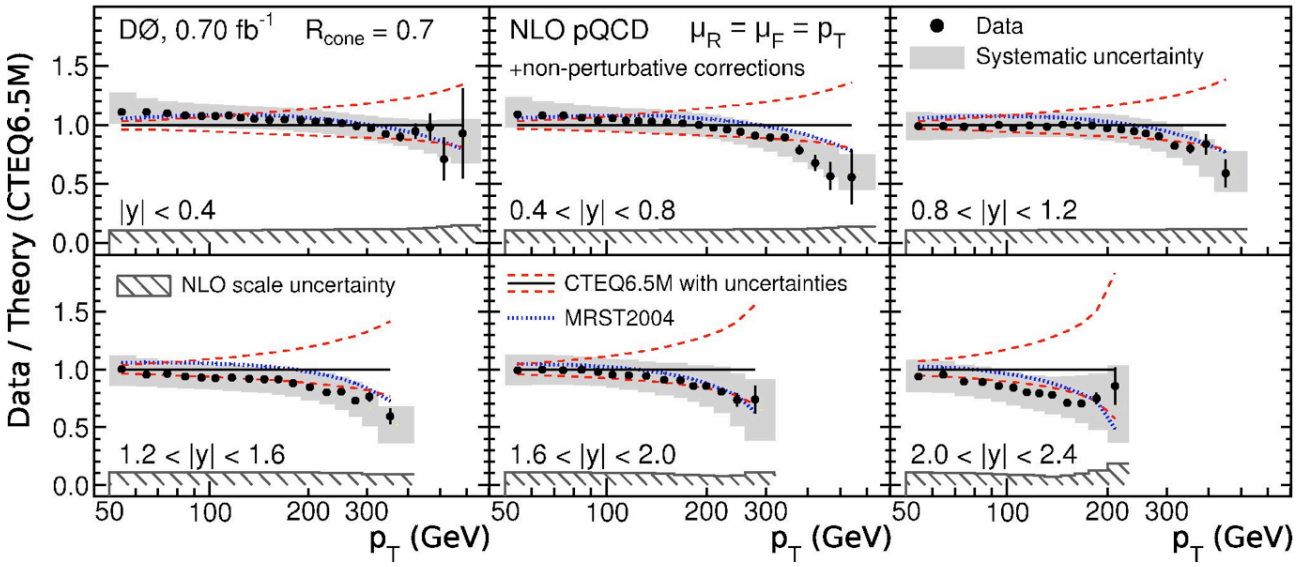
- smallest cross section measured at hadron collider
- most precise measurement
- examine kinematic distributions

Inclusive Jet Cross Section





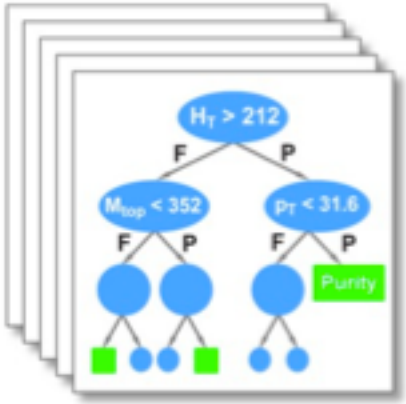
- **constrain pdfs (here: CTEQ6.5M)**



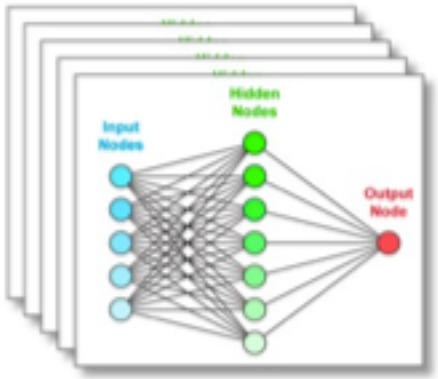
- **excellent agreement with QCD prediction over 9 orders of magnitude**
- **no excess at high E_T:**
  → no hint for quark substructure

Mulitvariate Analyses

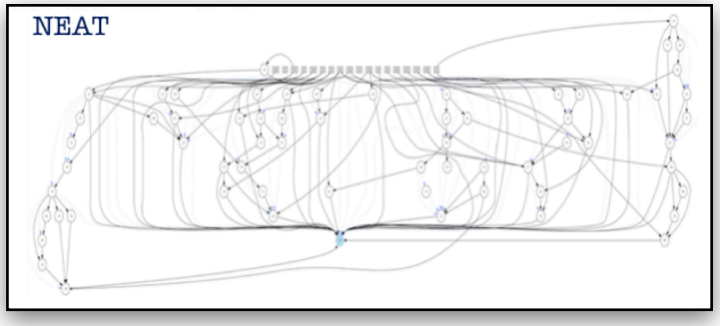
Boosted Decision Trees



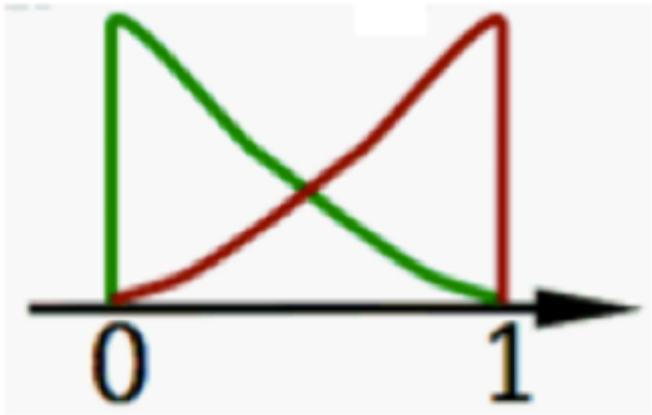
Boosted Neural Networks



Neuroevolution of Augmenting Topologies

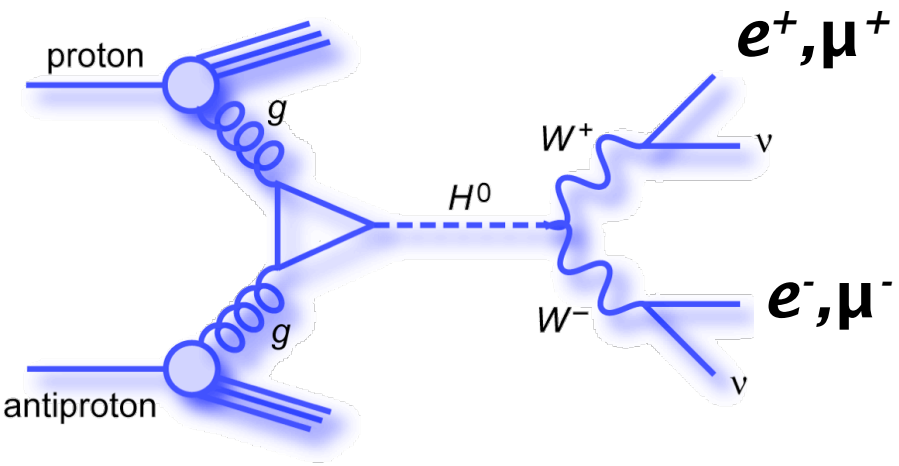


background **signal**

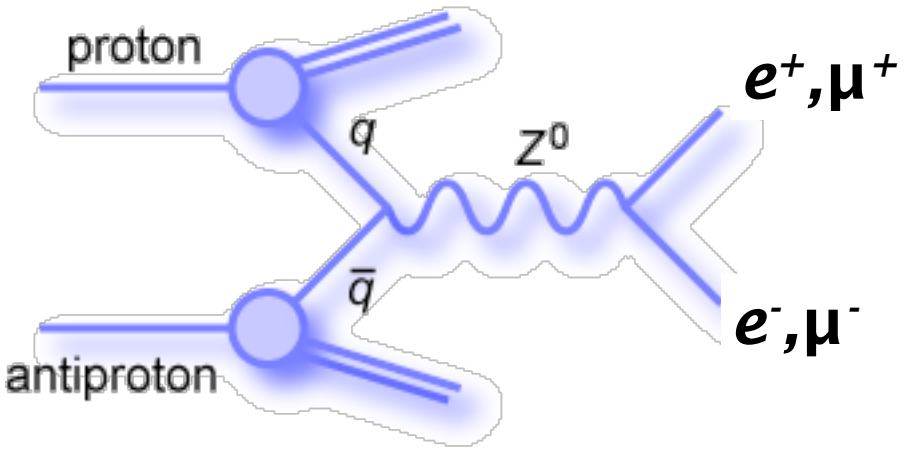


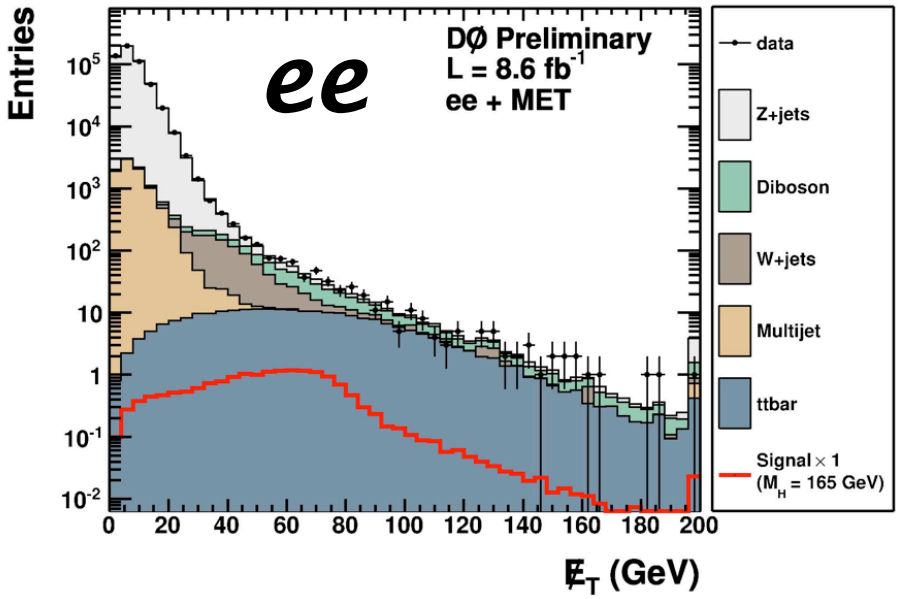
Search for H→WW→ee, eμ, μμ

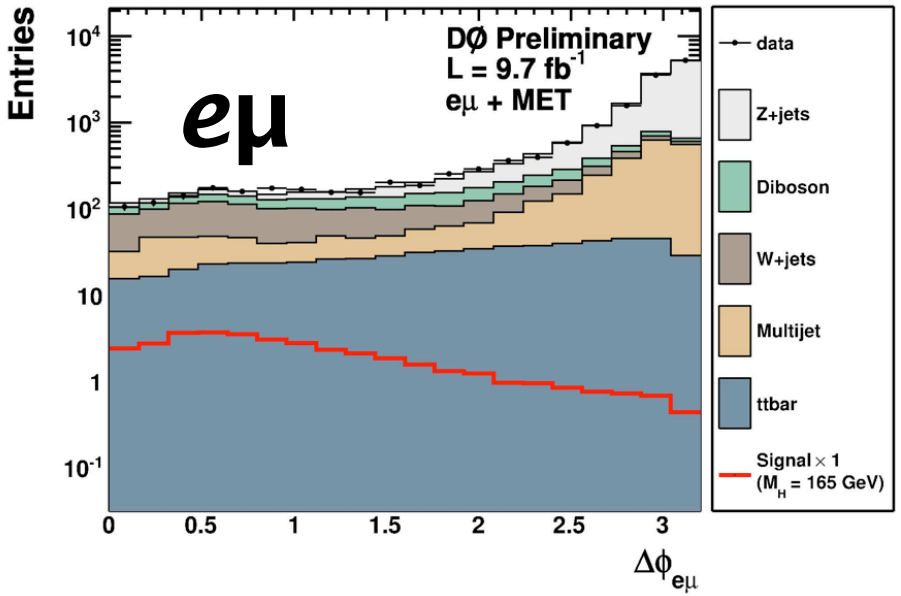
signal



background



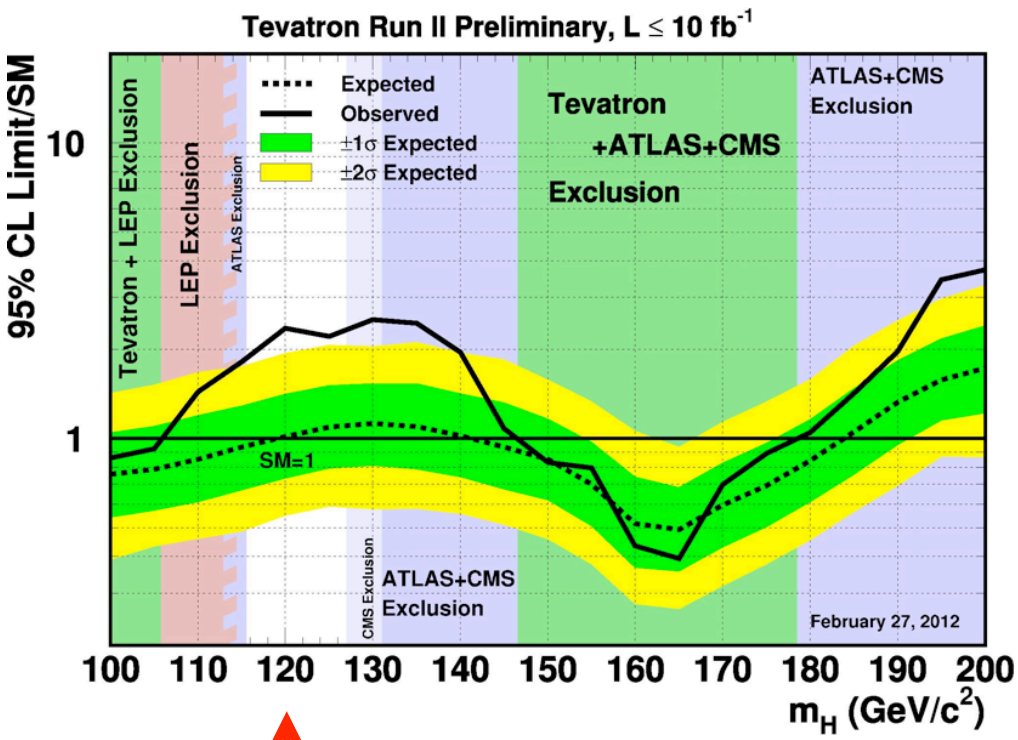




background rejection

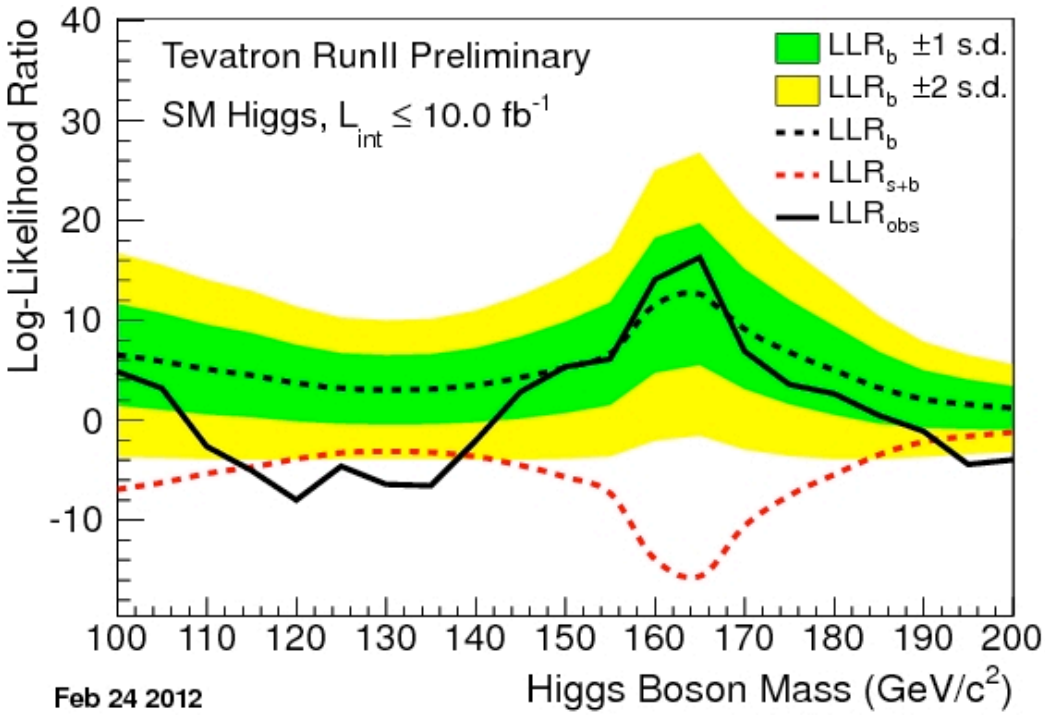
- eμ: cut on minimal transverse mass
- ee, μμ: decision tree discriminant

SM Higgs Search

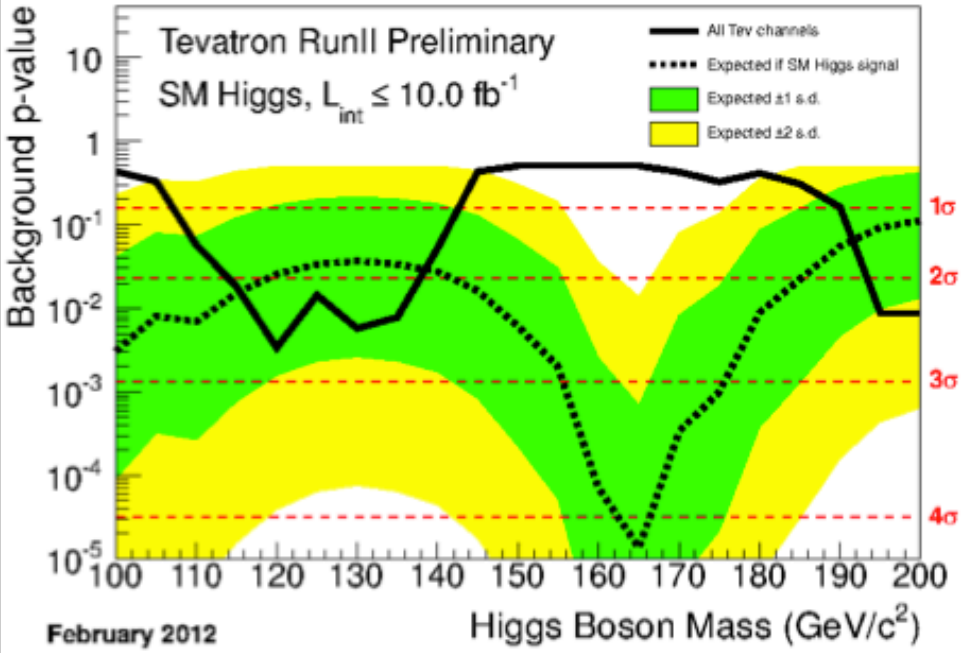


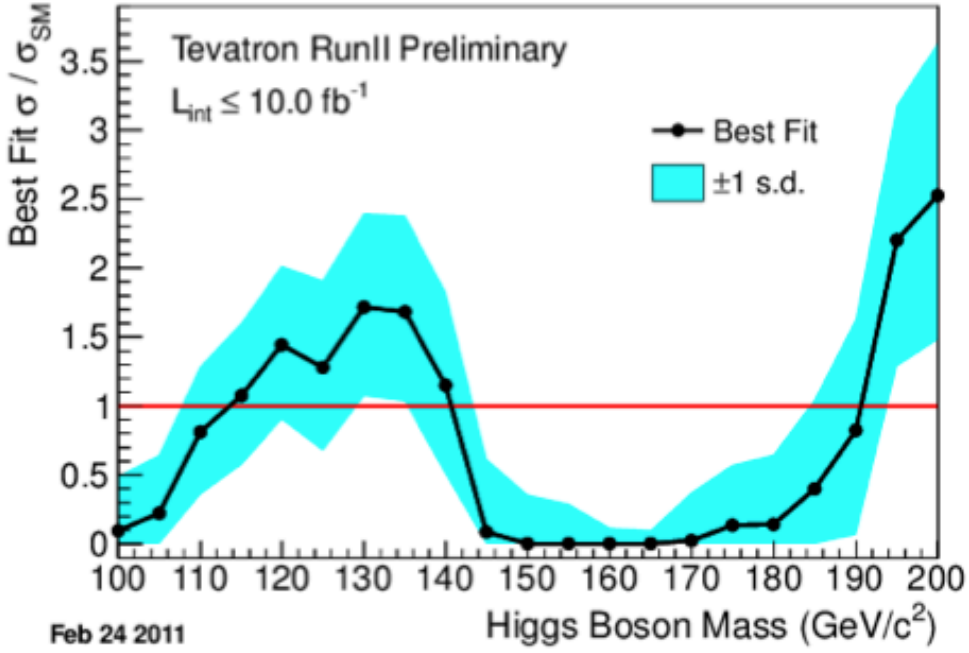
10 fb^{-1}

2.7σ (local)
2.2σ (global)



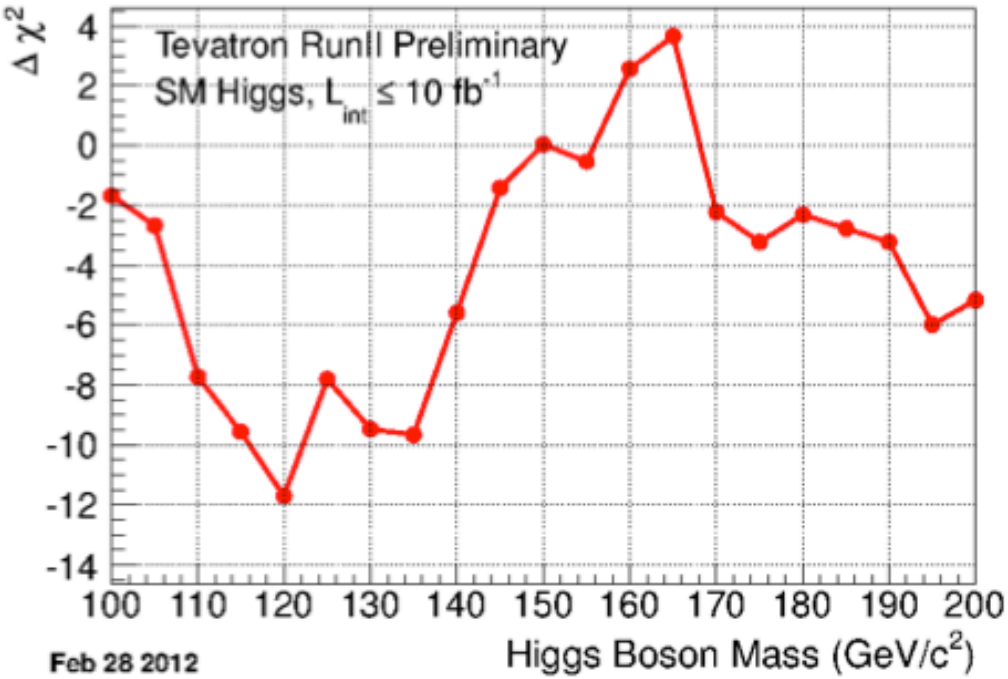
SM Higgs Search

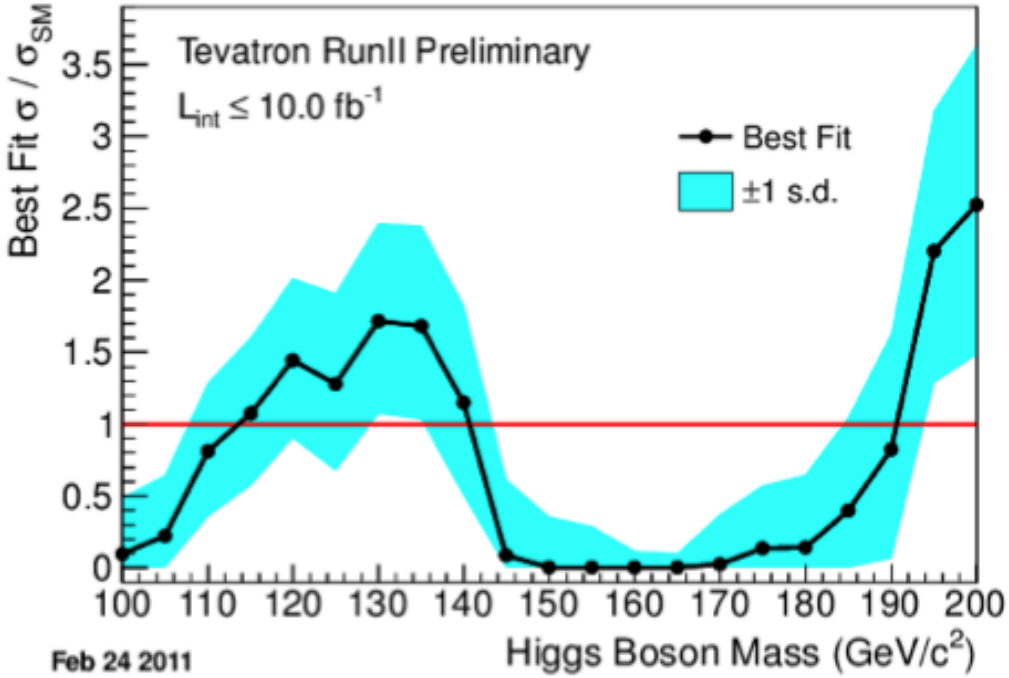




- **Two different tests of the data, comparing to S+B and B-only predictions**
  - **Left:** Local p-value distribution for background-only expectation.
    - Minimum local p-value: 2.7 standard deviations
    - Global p-value with LEE factor of 4: **2.2 standard deviations**
  - **Right:** Maximum likelihood fit to data with signal as free parameter.

SM Higgs Search



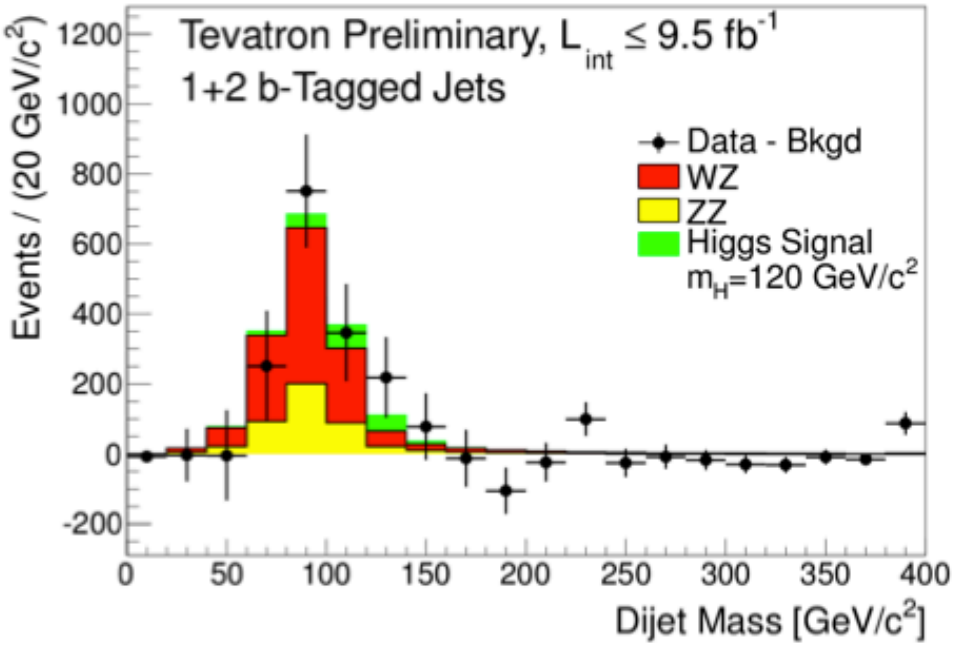


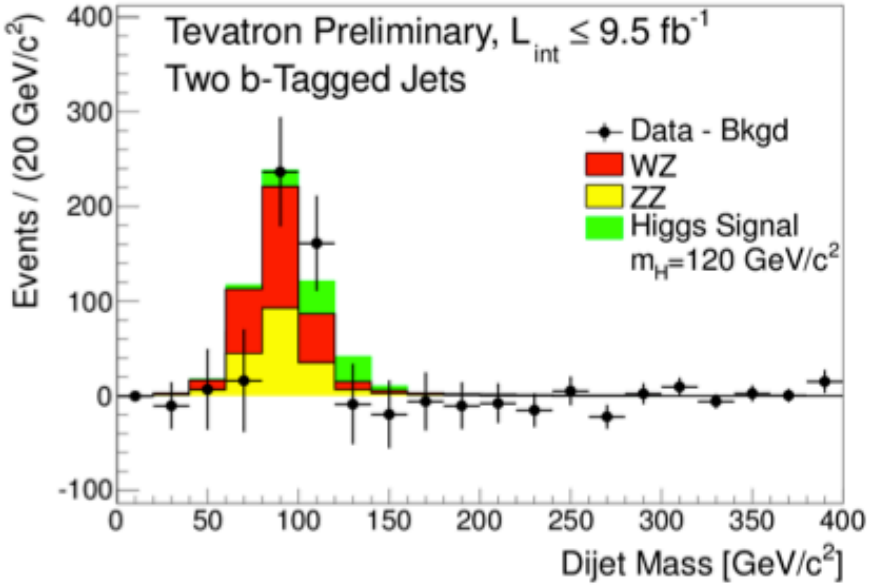
$\Delta\chi^2$ test with fixed signal prediction from SM theory agrees well with freely floating signal rate estimation

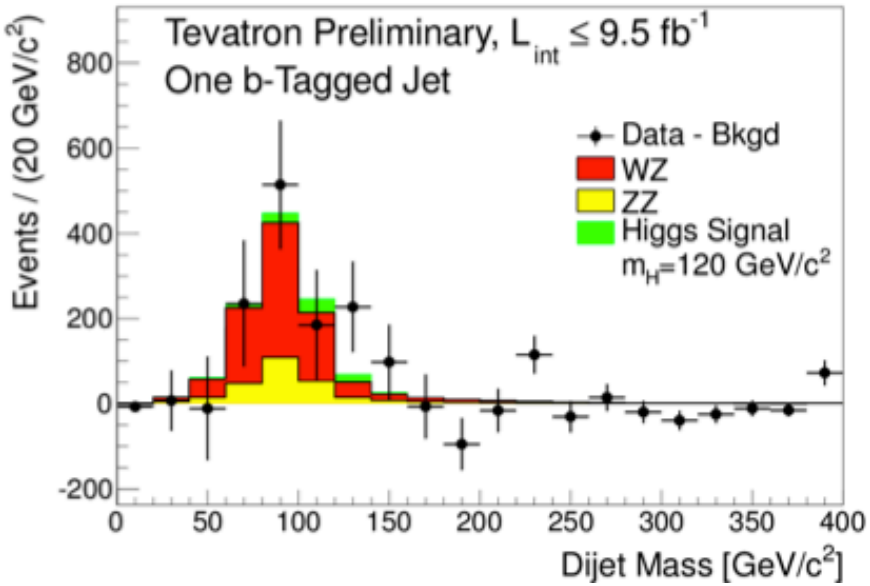
- $\Delta\chi^2$ minimum in the region $115 < M_H < 135$ GeV
- Region above M_H=150 never falls below $\Delta\chi^2 = -6$

SM Higgs Search

- Simple overlay of H→bb signal prediction for the dijet invariant mass (M_H = 120 GeV)
  - Data and diboson prediction come from Tevatron low mass WZ/ZZ measurement
  - Additional signal is not incompatible

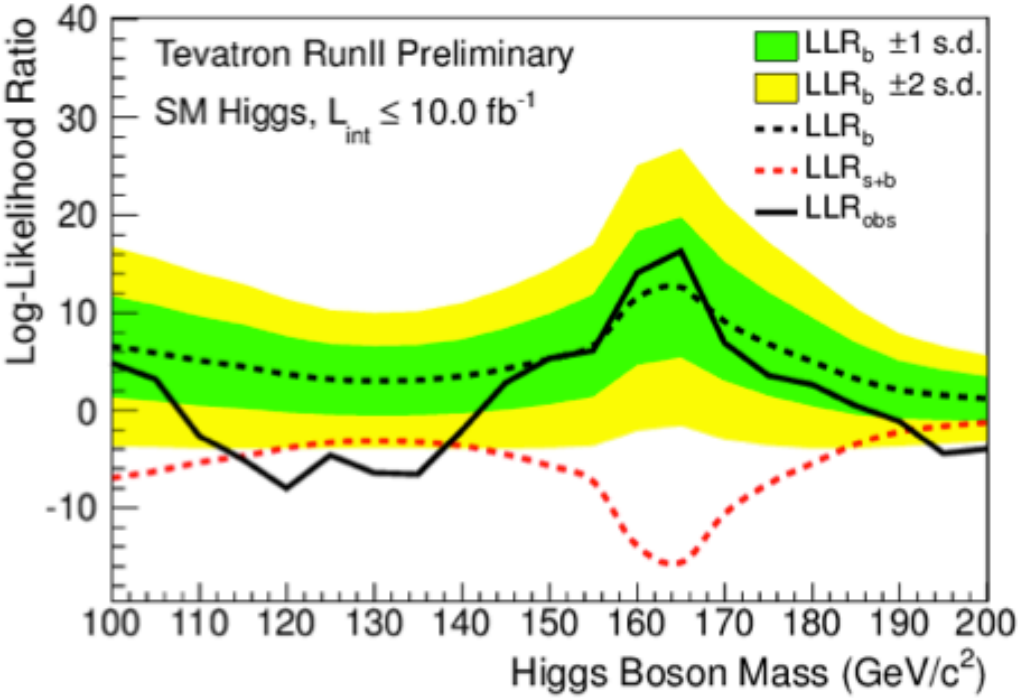




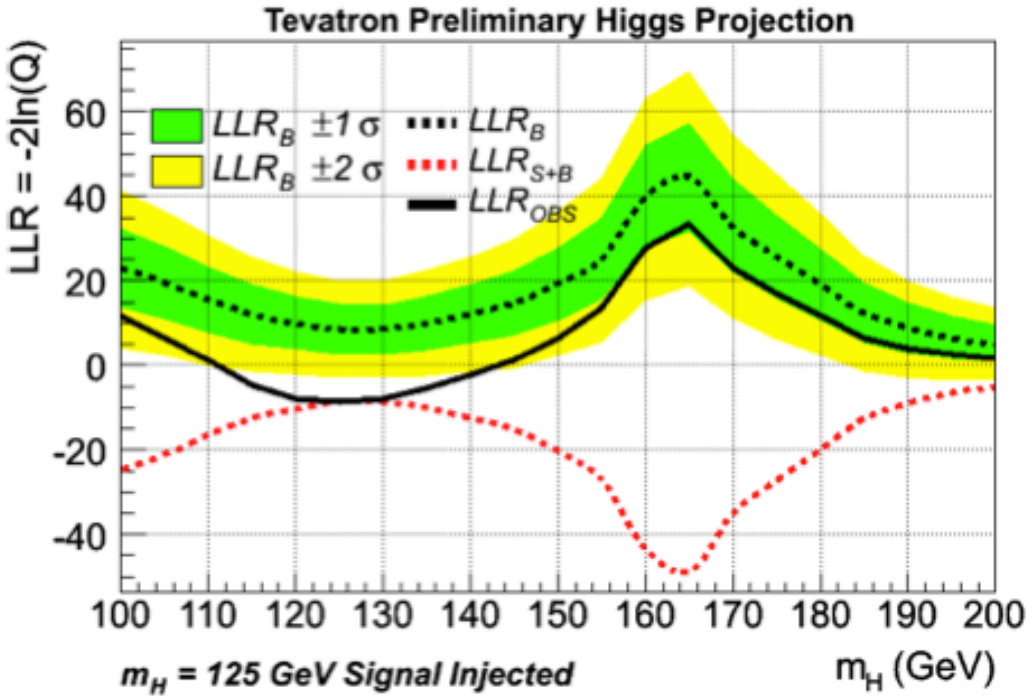


SM Higgs Search

Real Data Analysis

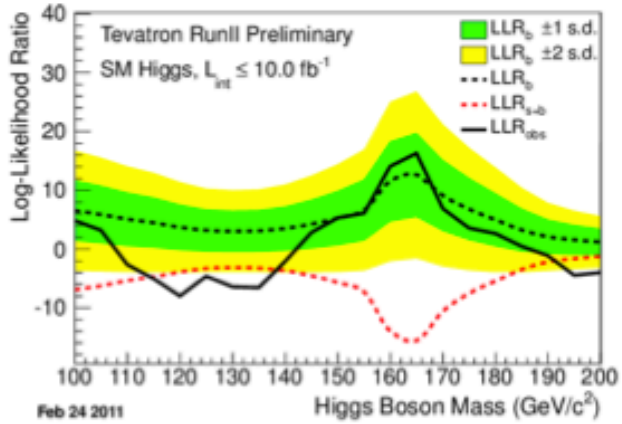


3σ Signal Injection Study

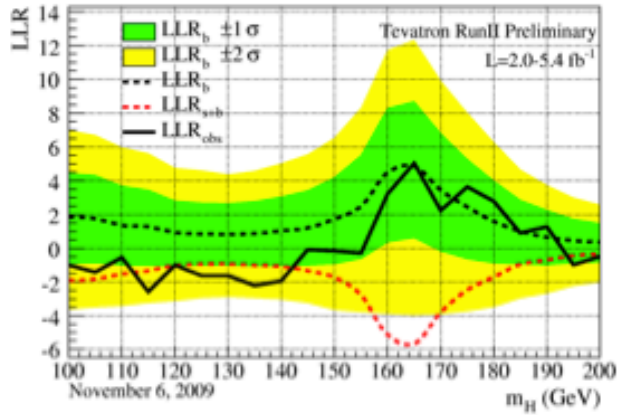


- **An obvious question:** does the global signature you observe make sense for a SM Higgs signal?
  - Consider a study performed by injecting M_H=125 GeV Higgs signal to our search, luminosity scaled so the excess is 3 s.d. above the background prediction.
  - Expect broad excess over entire mass range. +1 standard deviation at M_H=200 GeV

SM Higgs Search



2012



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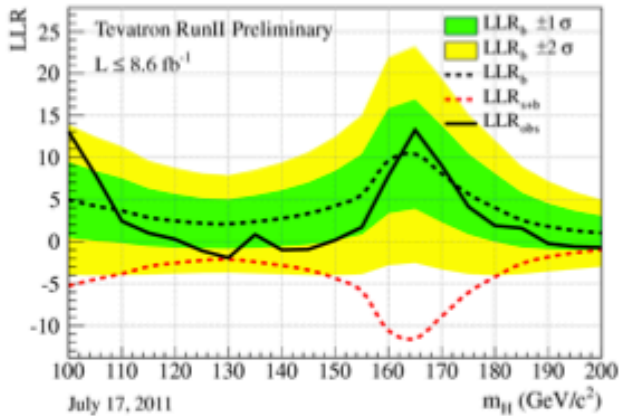

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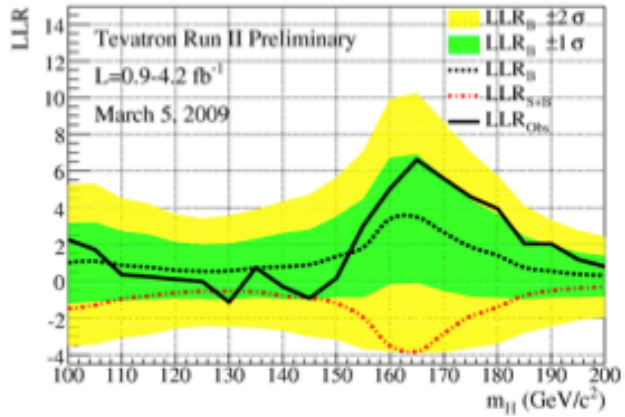

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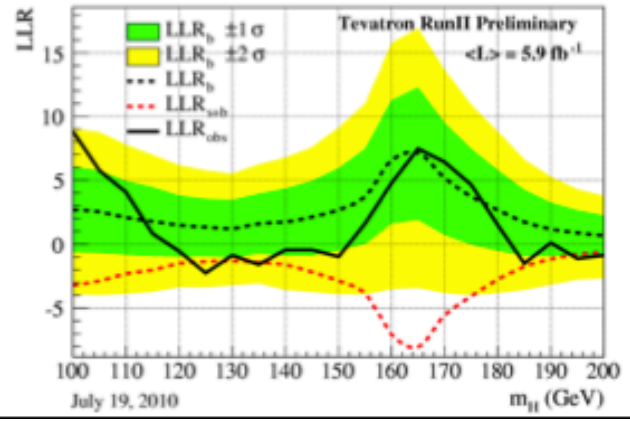

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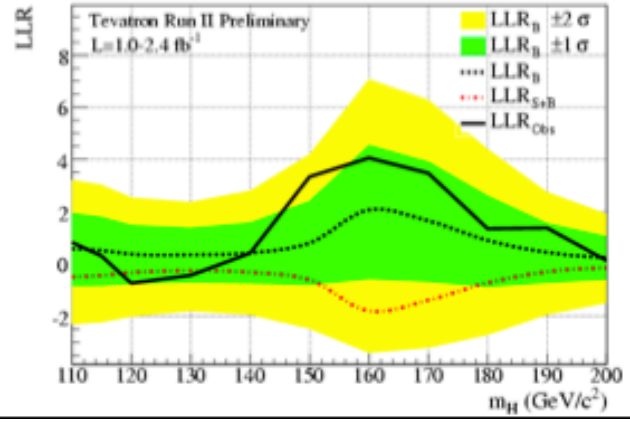

2007