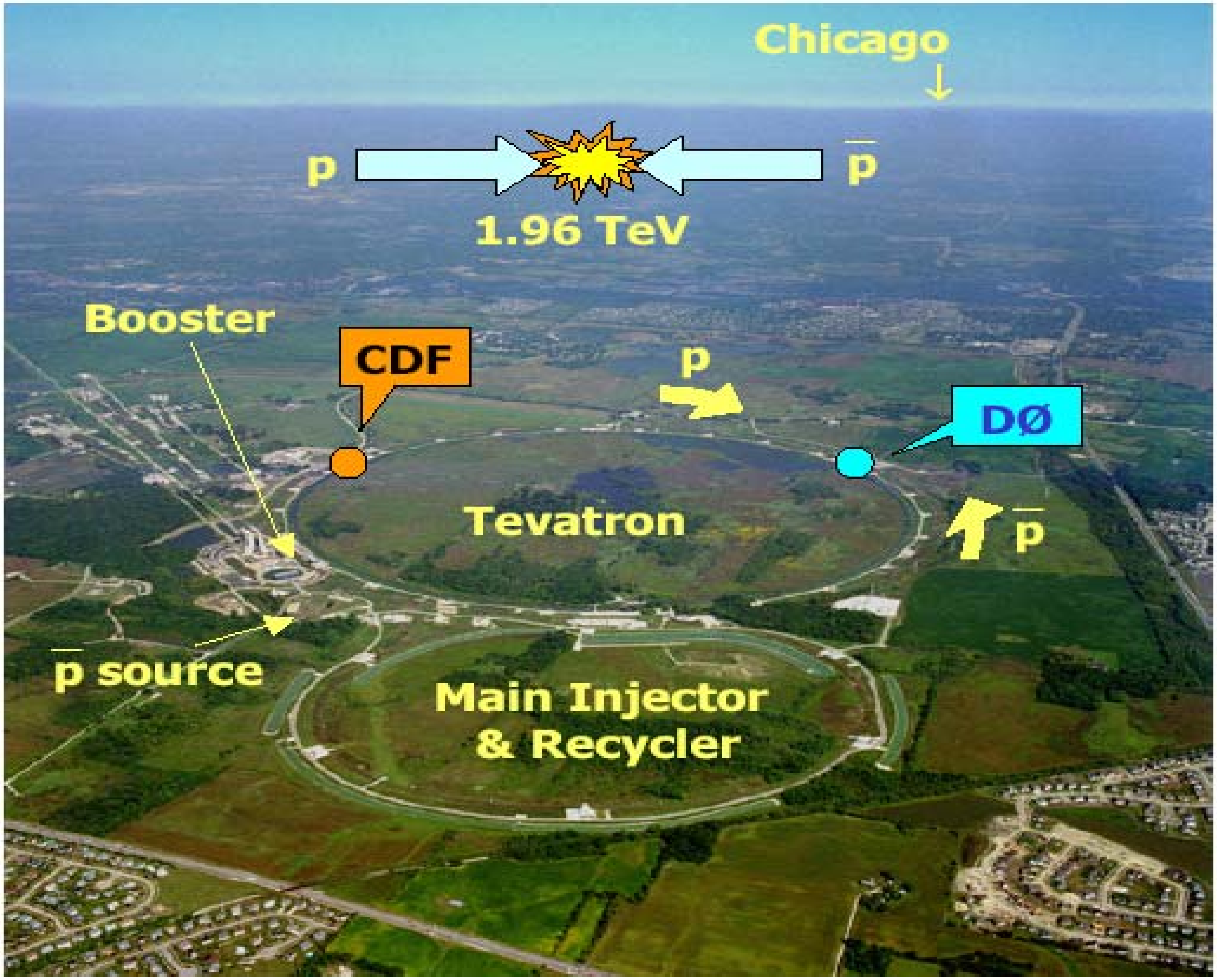
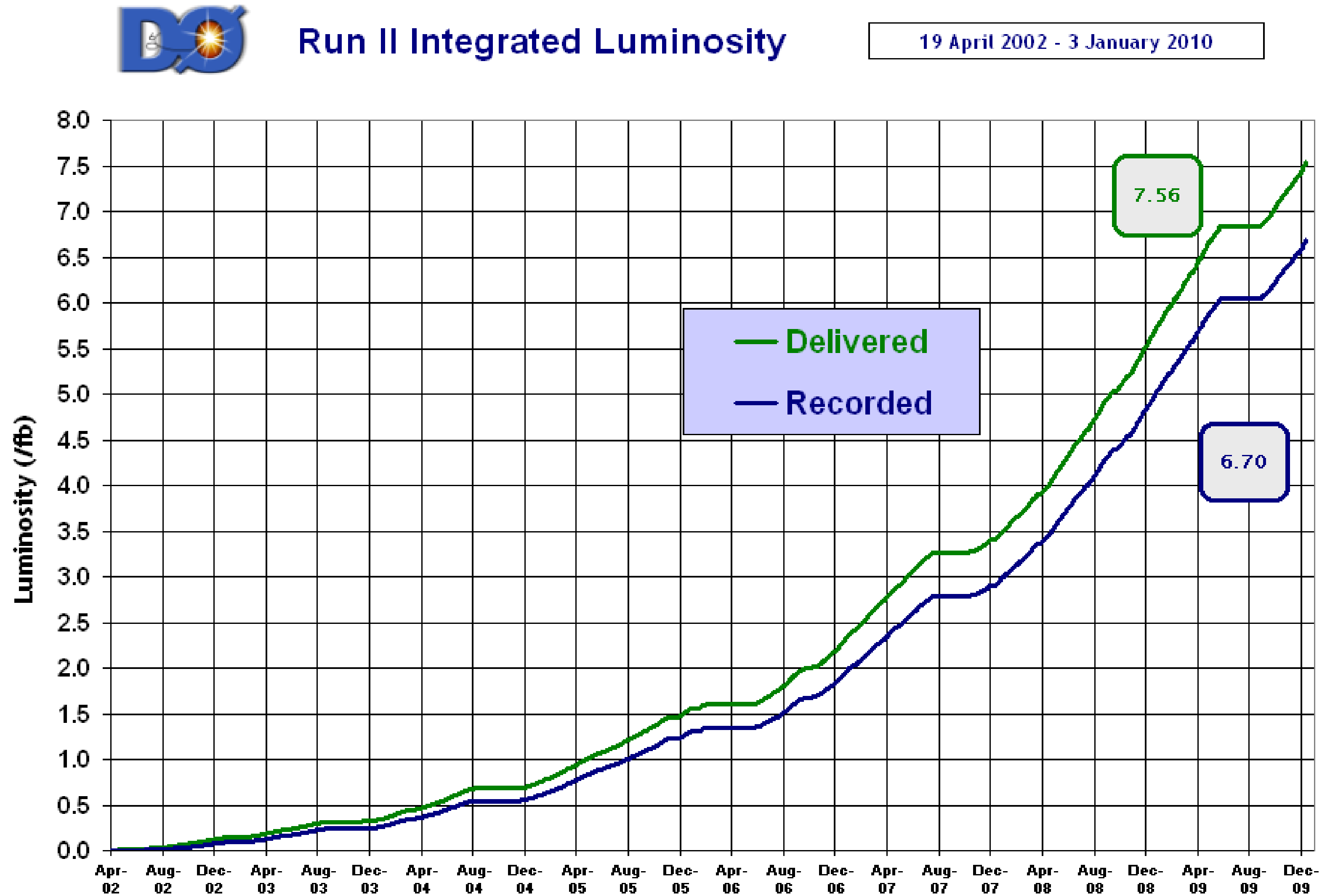
Direct and Indirect Probes for New Heavy Fermions at D0

Elemér Nagy

CPPM and Fermilab

The Tevatron



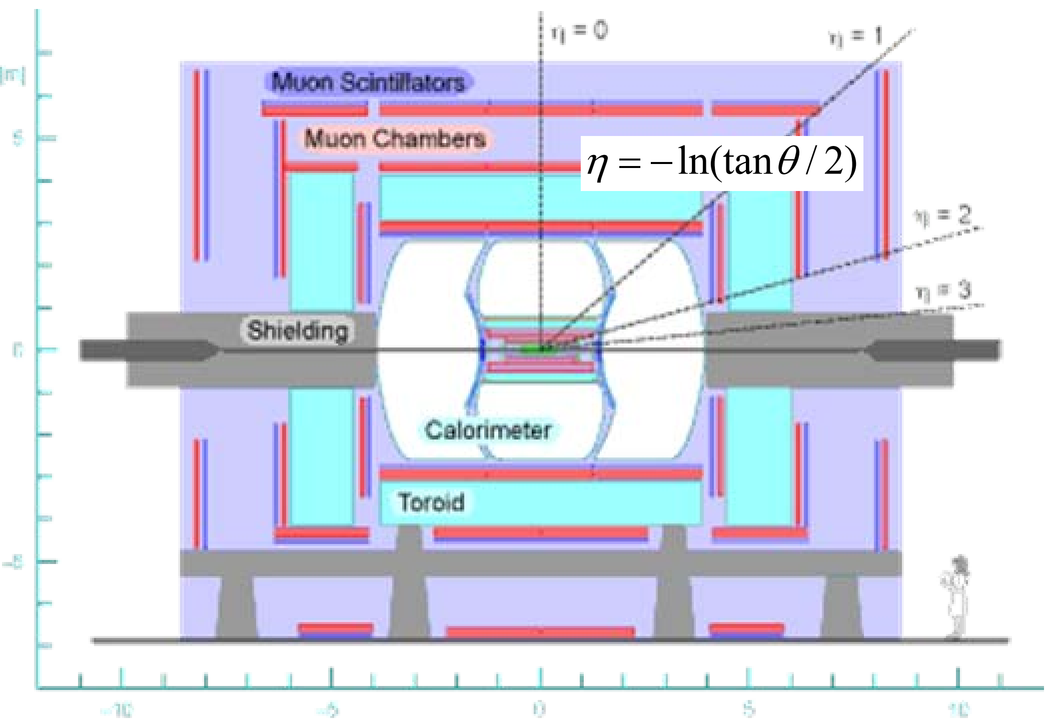


Present talk includes analyses with 1 – 5.4 fb^{-1} data

The D0 Experiment

510 physicists from 89 institutes of 18 countries

The D0 Detector



Charged track reconstruction in central tracker system: SMT + CFT in 2T solenoid field

Central Preshower (CPS) helps photon and electron pointing disentangle em and hadronic jets

Reconstruction of em and hadronic jets in a liquid argon calorimeter

Muon identification using scintillators and drift tubes in a 1.2 T toroidal field. Provides also timing information

Direct searches for new heavy fermions

In this talk we consider searches for long-lived new particles

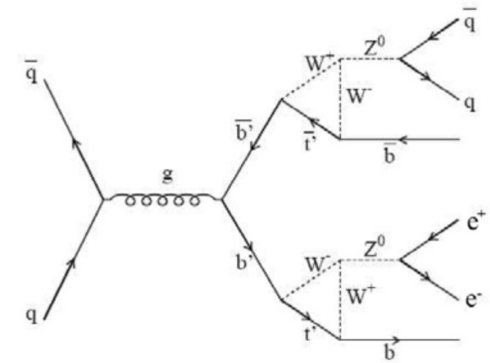
Long-lived parents decaying into electron or photon pairs

Limit of a quasi MI search interpreted as limit on $M_{b'}$

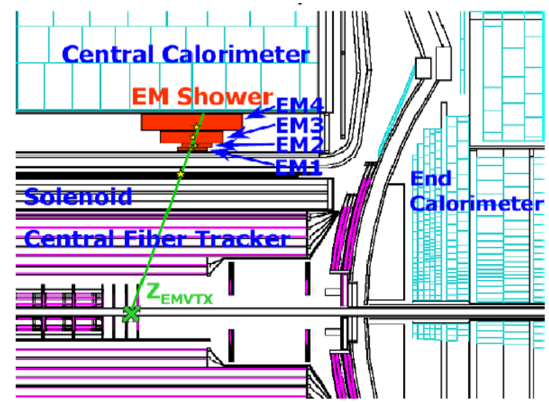
Long-lived charged massive particles

Limits set in the SUSY (GMSB, AMSB,…) framework,

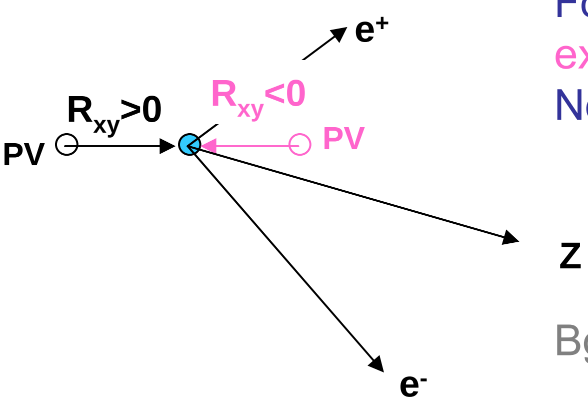
Search for long-lived b' b'→Z+b



If $m_{b'} < m_t$ → b' can travel even several meters
The displaced vertex is reconstructed
by the tracker (CDF)
or using the calorimeter and CPS (D0)

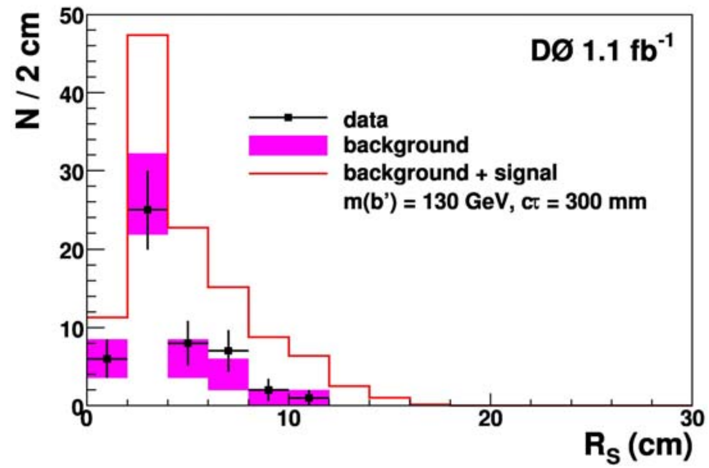


Two p_T>20 GeV em cluster selected in the calorimeter
The central preshower (CPS) provides
photon (or high pT electron) pointing
The distance R between their intersection and the PV
in the r-Φ plane determined

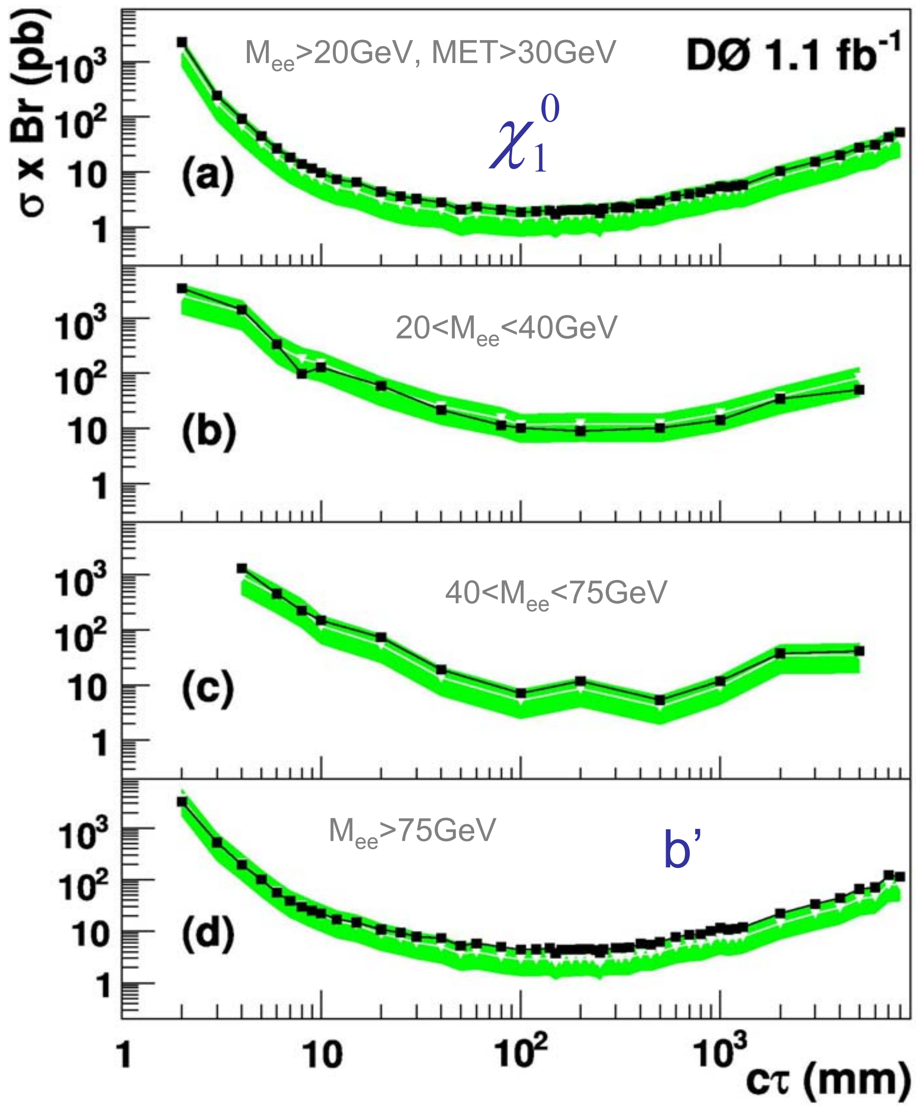


For long-lived particles
excess of R_{xy} >0 expected
Not observed in data

Bg estimated from R_{xy}<0



Cross section x BR limits

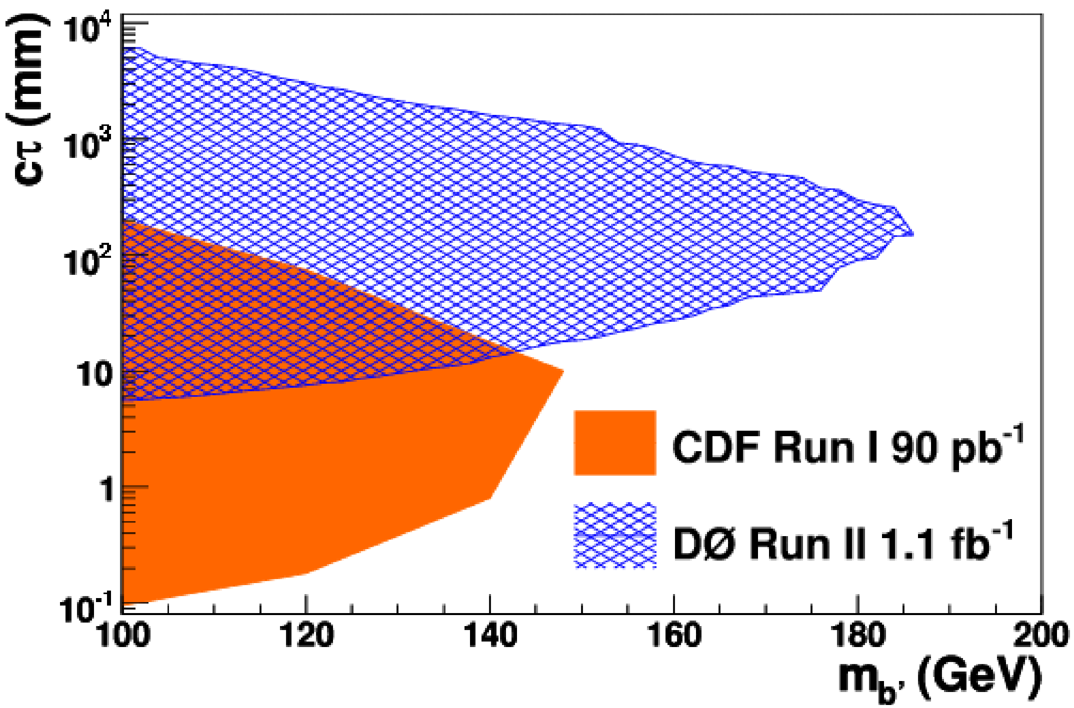


$$\text{GMSB}: \ \chi_1^0 \rightarrow Z + \tilde{G}$$

The acceptance doesn't depend significantly on the original fermion's (b',χ,…) mass

$$p\bar{p} \rightarrow b'b' \rightarrow Zb + Zb \rightarrow e^+e^- + X$$

Several meters of lifetime have been excluded for b'→Z+b ($m_{b'} < m_t$)



CDF's published result is complementary.
Displaced Z→μμ decays have been studied using tracker information

If t' is vectorlike t'→Z+t may exist
t' can be also long-lived
if mass mixing with the top quark is negligible ($\sin\theta_L < 10^{-8}$)

(B.Dobrescu et al, arXiv:0902.0792v2)

$$L = 3\left(\frac{10^{-8}}{\sin\theta_L}\right)^2 \left(\frac{450\ \mathrm{GeV}}{m_{t'}}\right)^3 \beta_{t'}[\mathrm{cm}]$$

Production can be enhanced by a G' massive color octet field (see later)

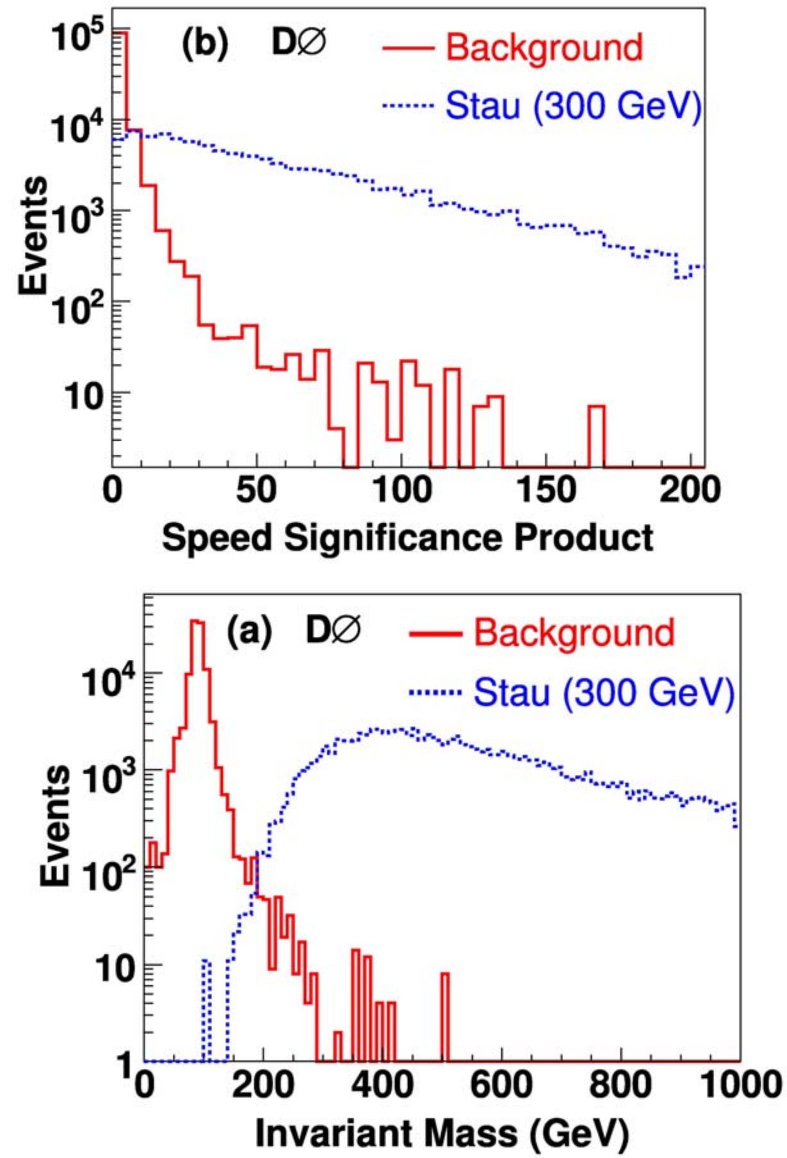
Search for Charged Massive long-lived (Stable) Particles

These CMSP's
appear as muons in the detector,
but they are slower: $v \sim p/E$
Speed significance (sps): $(1-v)/\sigma_v$
$\sigma_t \sim 2\text{-}3$ ns in D0 muon detector

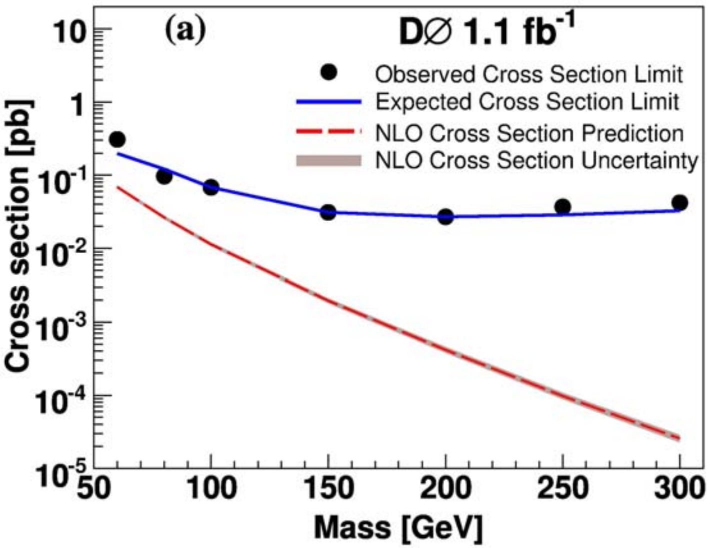
Select: 2 muons $p_T > 20$ GeV
- at least 1 muon isolated
- cosmic ray veto
- sps > 0 for both muon
- cut optimized in the $M_{\mu\mu}$ vs $sps_1 * sps_2$ plane depending on the CMSP mass

Background are muons of mismeasured time: estimated from data $Z \rightarrow \mu\mu$ (sps<0)

Data is compatible with expectation of the SM
Observed 1-2 events (depending on M_{CMSP})
Typical background ~2 events for M_{CMSP} > 80 GeV



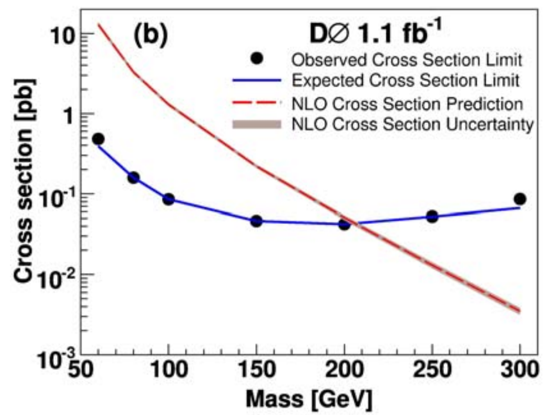
95% upper limits on GMSB stau pair production



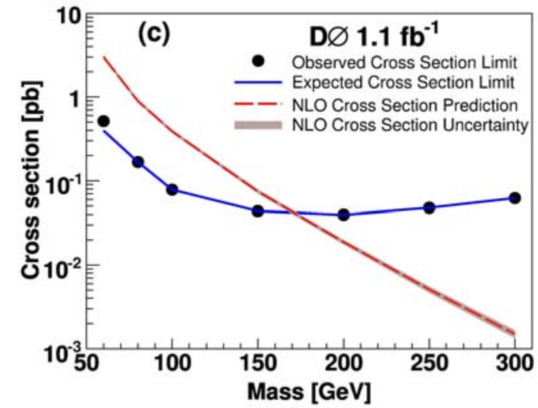
For long-lived chargino pair production in AMSB

if $M_{\chi_1^\pm} - M_{\chi_1^0} \leq 150$ MeV

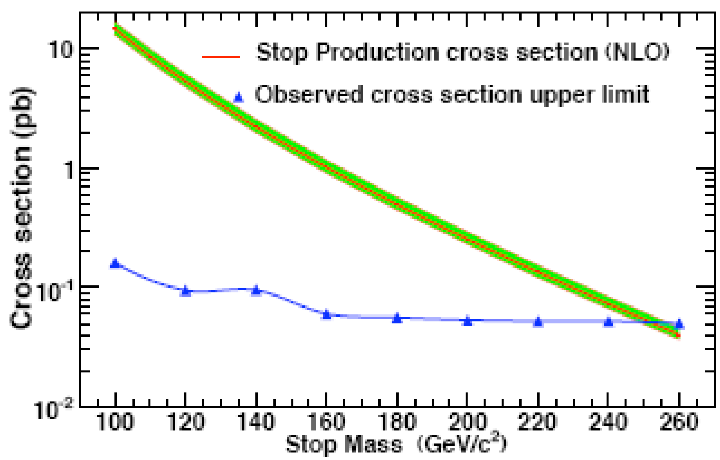
Gaugino-like



Higgsino-like



Similar (~10^{-1} pb) cross section limit is obtained by CDF interpreted as a stop particle



All the above cross section limits can be reinterpreted as new (e.g. 4th gen.) fermions if produced with similar kinematics

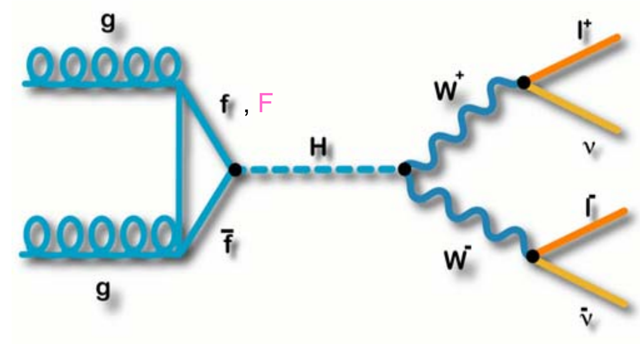
Indirect searches for new heavy fermions

in SM Higgs production

Search for $H \to WW^*$

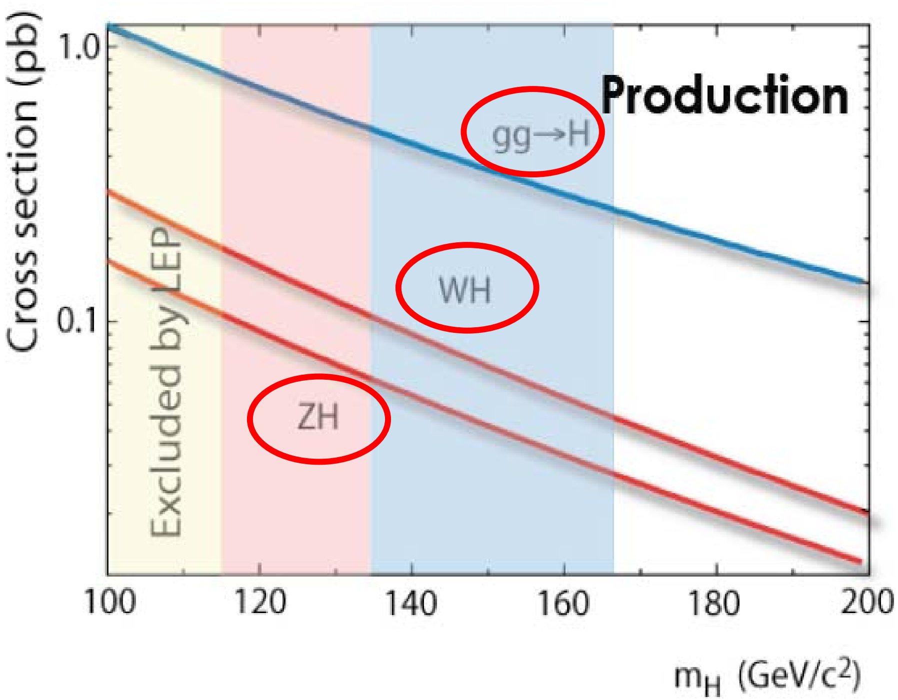
Search for $G' \to tt' \to ttH \to ttbb$

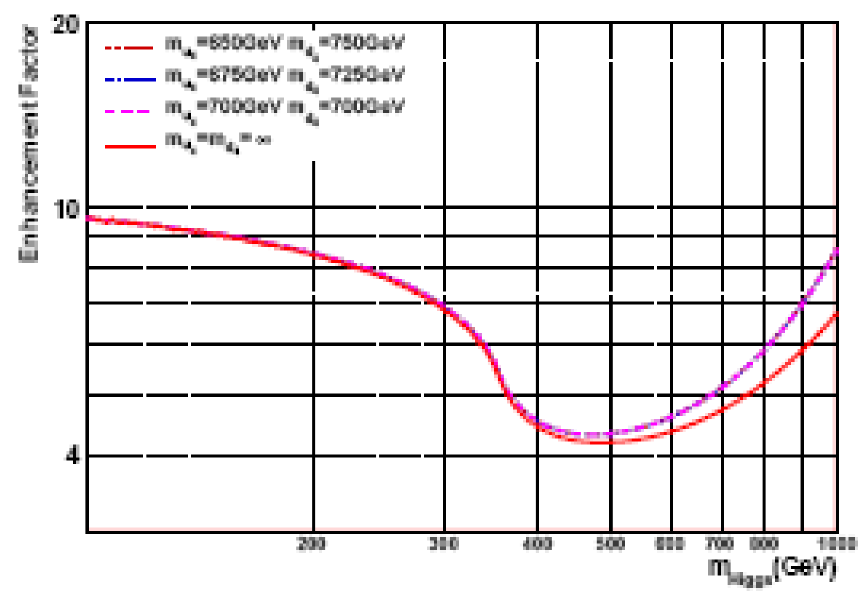
Search for H→WW*



Sensitive to > 3 SM generation since

- additional heavy fermion (F) loops in the dominant gg-fusion process enhances
  ~9 times the Higgs production cross section
- the WW* decay is the best to study the gg-fusion production
  the bb and gg final states are swamped by the QCD background





N.Becerici Schmidt et al, arXiv:0908.2653v3

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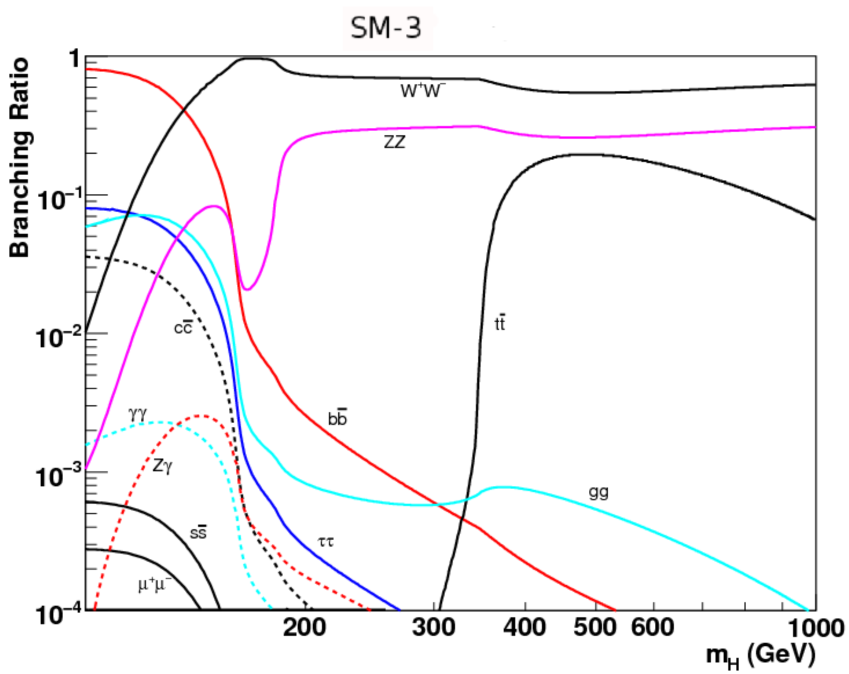
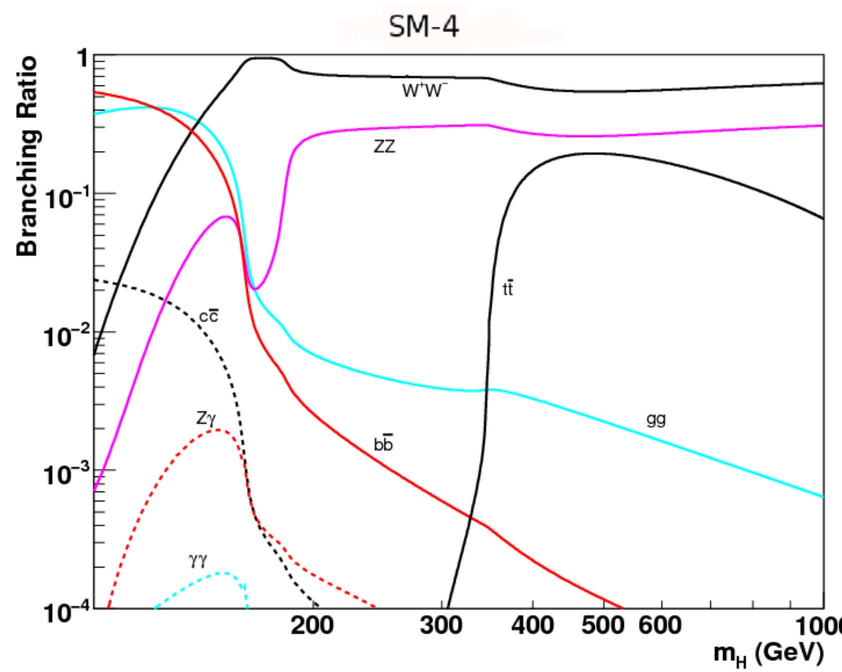
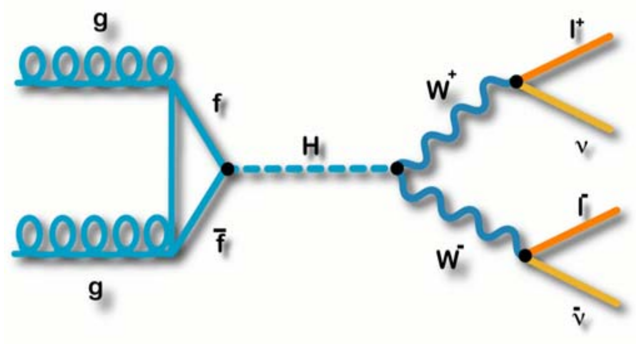




The WW* decay is dominant at high Higgs masses:
$M_H > 135$ GeV

Most recent D0 result used 5.4 fb^{-1}

(all data before the last summer shutdown)



Opposite sign (OS) charged leptons
and MET

ee, eμ and μμ combinations (also from τ decays)

Will be considered later also:
charged lepton + MET + jet-pair

Other final states (production and decay mechanisms) also considered but they are smaller:

W/Z associate production (Higgs Strahlung) ~ 10 smaller

Vector Boson (W/Z) Fusion (VBF)
$q_1q_2 \rightarrow (V^*V'^*)q_3q_4 \rightarrow Hq_3q_4$
~ 2 x smaller than Higgs Strahlung

Event selection

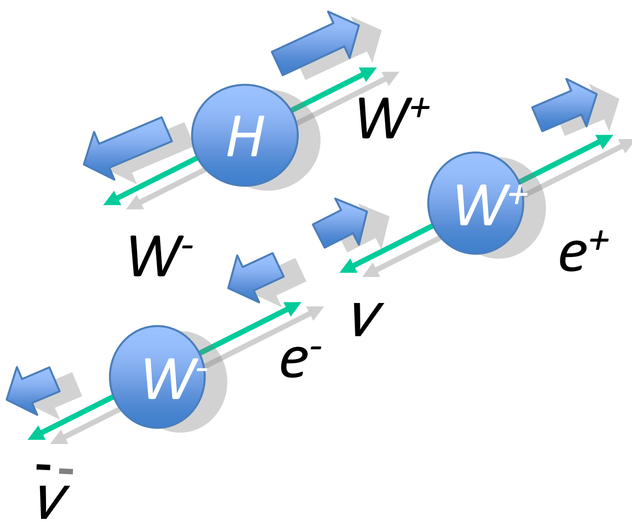
Final state		$e\mu$	ee	$\mu\mu$
Cut 0	Pre-selection	lepton ID, leptons with opposite charge and $p_T^\mu > 10$ GeV and $p_T^e > 15$ GeV invariant mass $M_{\ell\ell} > 15$ GeV $\mu\mu$: $\Delta\mathcal{R}(\mu, \text{jet}) > 0.1$ and $p_T^\mu > 20$ GeV for the leading μ		
Cut 1	$\Delta\phi(\ell, \ell)$ (rad)	< 2.0	< 2.0	< 2.0
Cut 2	Missing Transverse Energy $\not{E}_T$ (GeV)	> 20	> 20	> 25
Cut 3	$\not{E}_T^{\text{Scaled}}$	> 6	> 6	
Cut 4	$M_T^{min}(\ell, \not{E}_T)$ (GeV)	> 20	> 30	> 20

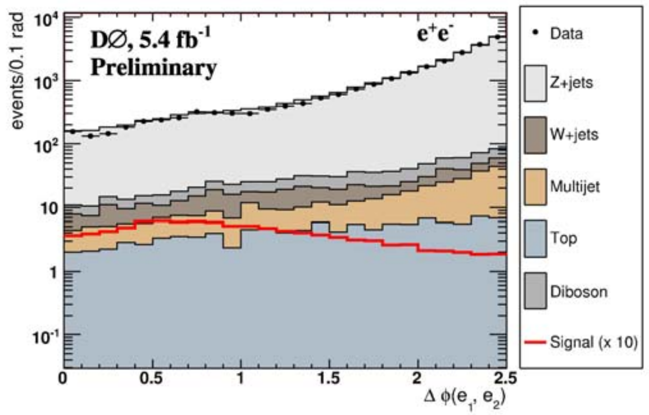
$$\not{E}_T^{\text{Scaled}} = \frac{\not{E}_T}{\sqrt{\sum_{\text{jets}} \left(\Delta E^{\text{jet}} \cdot \sin\theta^{\text{jet}} \cdot \cos\Delta\phi(\text{jet}, \not{E}_T)\right)^2}}$$

$$M_T(l, \not{E}_T) = \sqrt{2 p_T^l \not{E}_T \left(1 - \cos\Delta\phi(l, \not{E}_T)\right)}$$

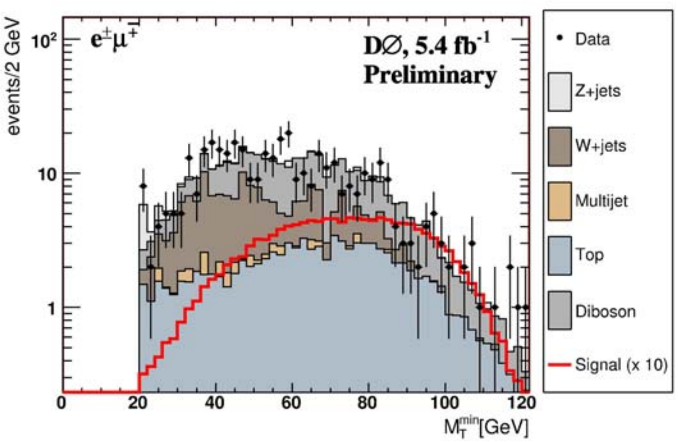
Best discriminating variable: $\Delta\varphi(l^+,l^-)$

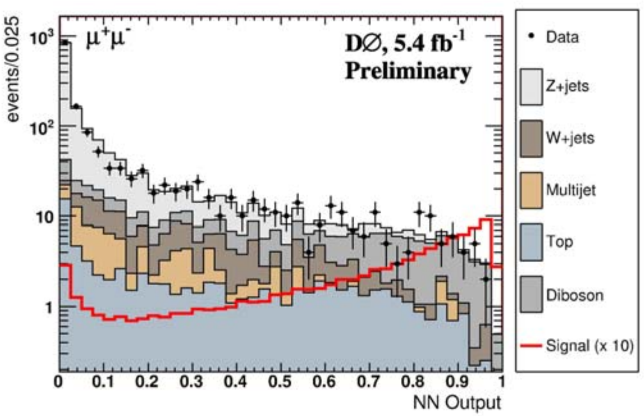
$S_H = 0 \rightarrow$ the leptons prefer the same direction





Good agreement after pre-selection

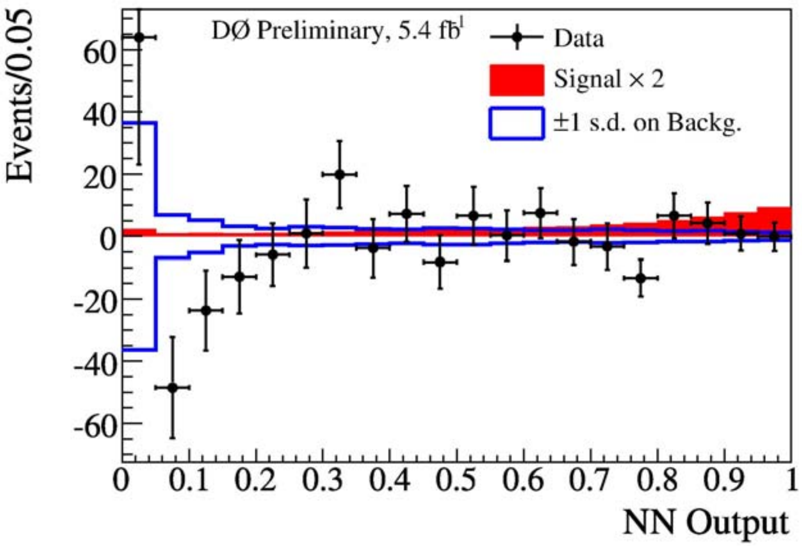


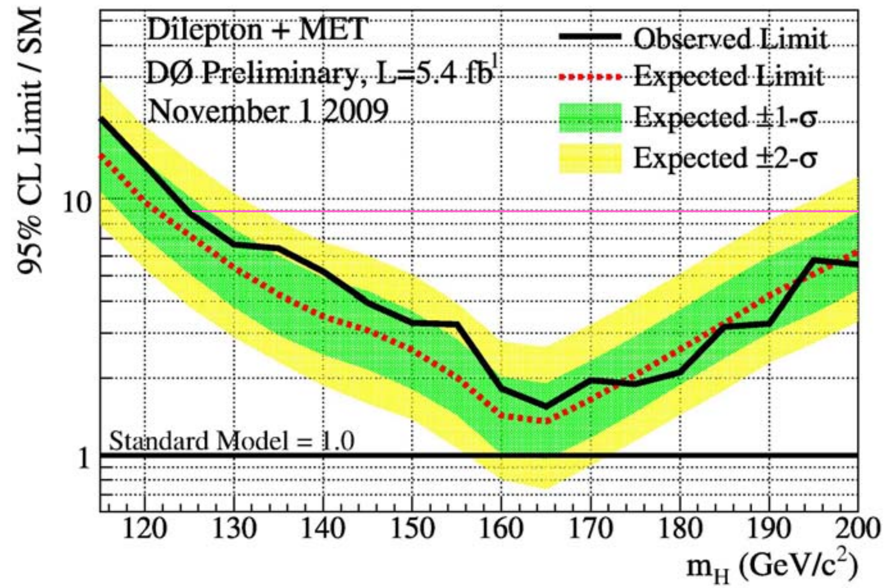


Good agreement after final selection

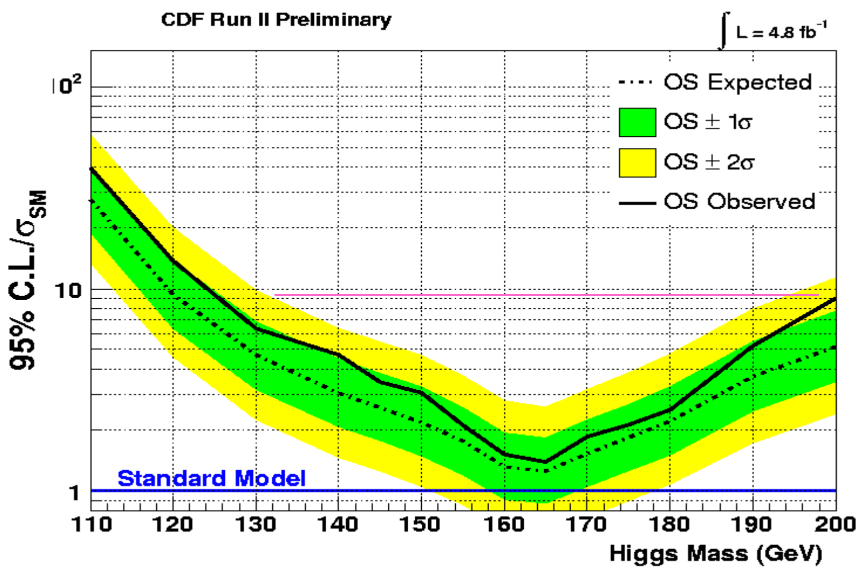
NN for final discrimination between s/b

D0 all channels combined





CDF has obtained comparable limit on SM Higgs cross section (4.8 fb^{-1})



Approximate sensitivity for a 4^{th} generation fermion can be obtained by a line at ~9 x SM

Determination of a precise limit on 4^{th} generation fermions in a combined CDF-D0 analysis is underway

Search for t’ in Higgs production

Proposed by B.Dobrescu, K.Kong, R.Mahbubani (JHEP 0906:001,2009, arXiv:0902.0792v2)

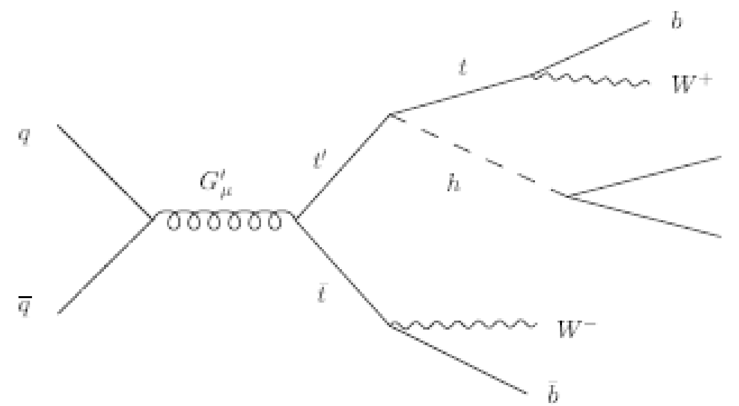
Assuming:

extended $SU(3)_1 x SU(3)_2$ gauge sector of G_1 and G_2 color octet spin=1 fields,
with coupling strength of h_1 and h_2 ($r = h_1/h_2$ relative strength)
spontaneously broken to massless G (gluon) and massive G’ fields

t’ vector like singlet of mass-mixing $s_L = \sin \theta_L$ with top quark

Increases t’t’ pair production wrt gluon s-channel process (may explain CDF excess)

tt’ pair can be created copiously
this can increase Higgs production
qq→G’→tt’→ttH→ttbb
compared to the corresponding SM process
qq→G→tt→ttH→ttbb



Search was carried out using 1 fb^{-1} dataset

Assuming W→lν (l = e,μ) and W→qq decays giving rise to lνqqbbbb final states

one selects events with

e/μ (p_T > 20 GeV)

MET > 20 GeV (e+jets) or > 25 GeV (μ+jets)

>=3 jets (p_T > 20 GeV)

applying b-tag

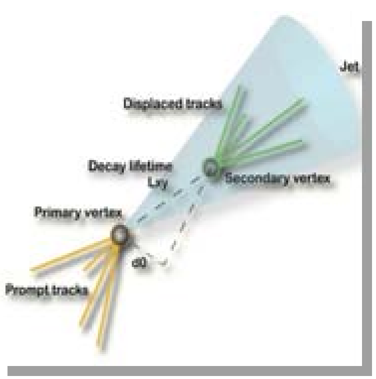
b-tagging

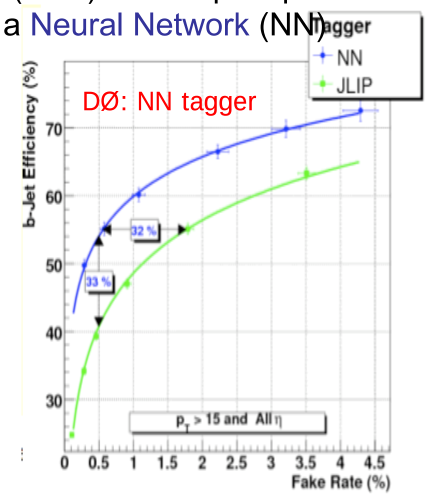
Uses the fact that b-quarks has non-negligible finite life time

Search for secondary vertex

Calculate jet lifetime probability (JLIP) from impact parameters

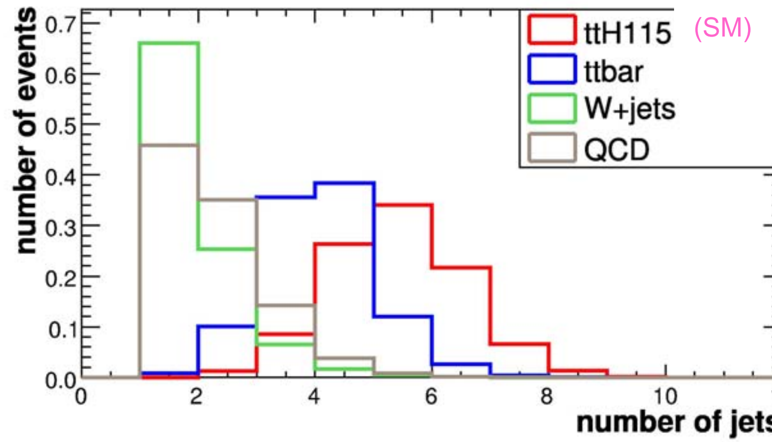
Combine these informations in a Neural Network (NN)

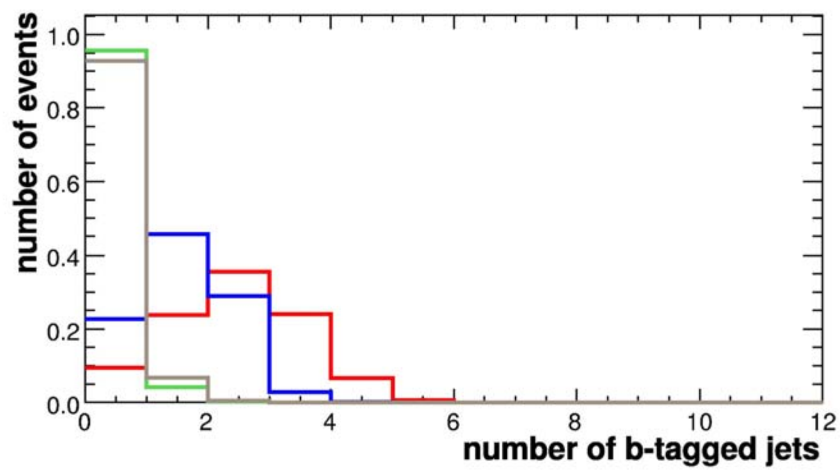




Background: tt, W+jets and multijet

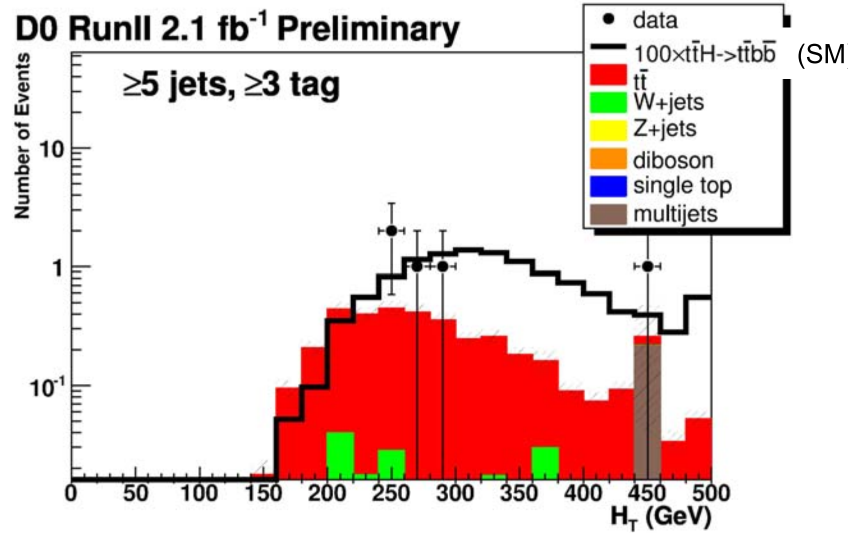
Separated from signal using (b-tagged) jet multiplicity





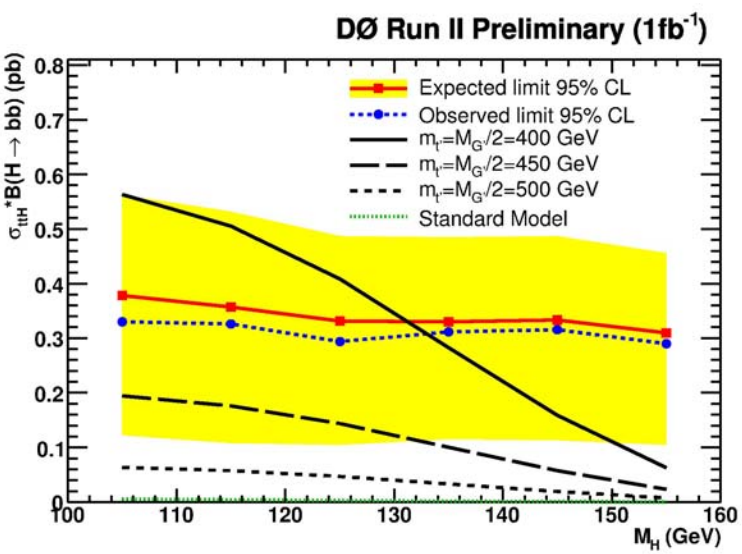
Select 24 sub-samples
Electrons or muons
3,4,>4 jets
0,1,2,>3 b-tag

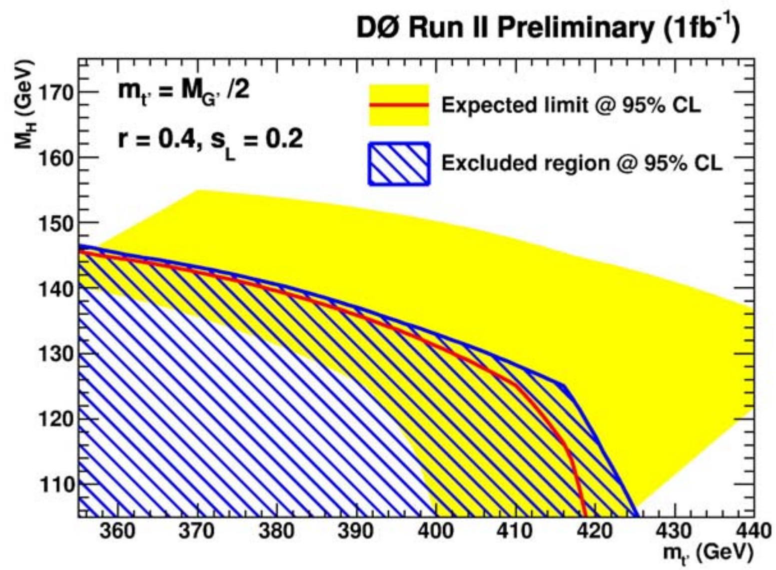
σ_{tt}, $\sigma_{ttH,}$ and σ_{W+j} fitted to the number of observed events



Data agrees with SM background:
σ_{tt} agrees with SM value
σ_{ttH} is compatible with 0

Limit obtained assuming that the event kinematics of G→ttH and G'→tt'→ttH are the same





Summary

- Direct and indirect searches were presented for new heavy fermions at D0
- No such fermions have been yet discovered
- Limits on production cross sections, masses and lifetimes have been shown together with the corresponding CDF results
- Some of the limits were directly given in terms of possible 4^{th} generation fermions
- More results on searches for heavy fermions will be coming soon

More details can be obtained from the D0 and CDF public web pages:

http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

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

Thanks

Help from the Physics Group Conveners at D0

Gustaaf Brooijmans, Arnaud Duperrin (New Phenomena)
Wade Fisher, Aurelio Juste, Krisztian Peters (Higgs Physics)
Frederic Deliot, Aran Garcia-Bellido, Christian Schwanenberger (top Physics)

and from the analysers

is greatly appreciated!

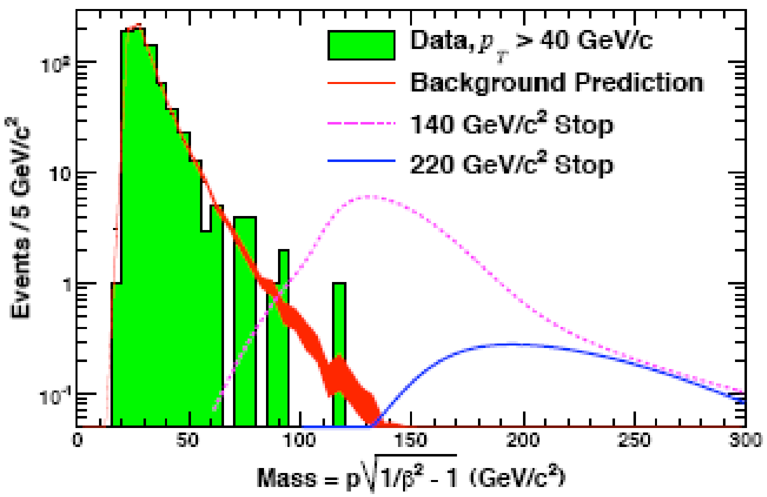
Backup material

CHAMP

Search for charged, massive stable particles (stop)

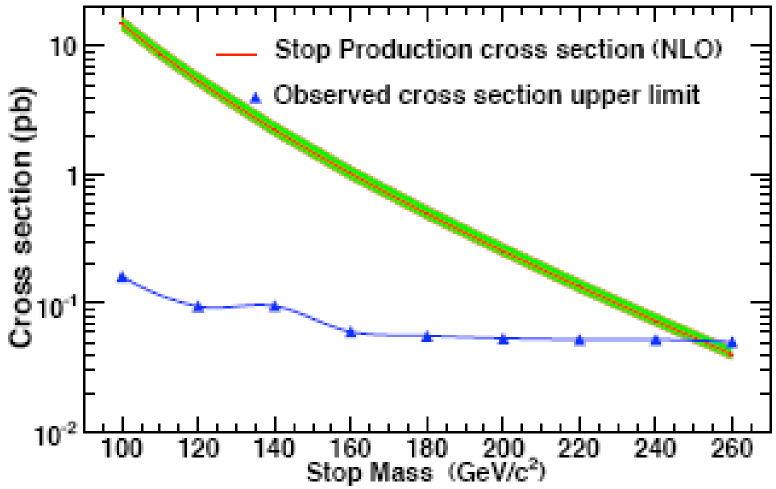
Select: 2 high p_T (p_T>40 GeV)
slow (v < 0.9)
penetrating (muon-like) tracks
Reject cosmics
Calculate mass: $M^2=p^2(1/v^2-1)$

1 event remains beyond M > 100 GeV
Distribution agrees with bg prediction



Determine: $v = d_{TOF}/(t_{TOF}-t_0)$
t_0 from p_T<20 GeV particles
in TOF and in COT track residuals

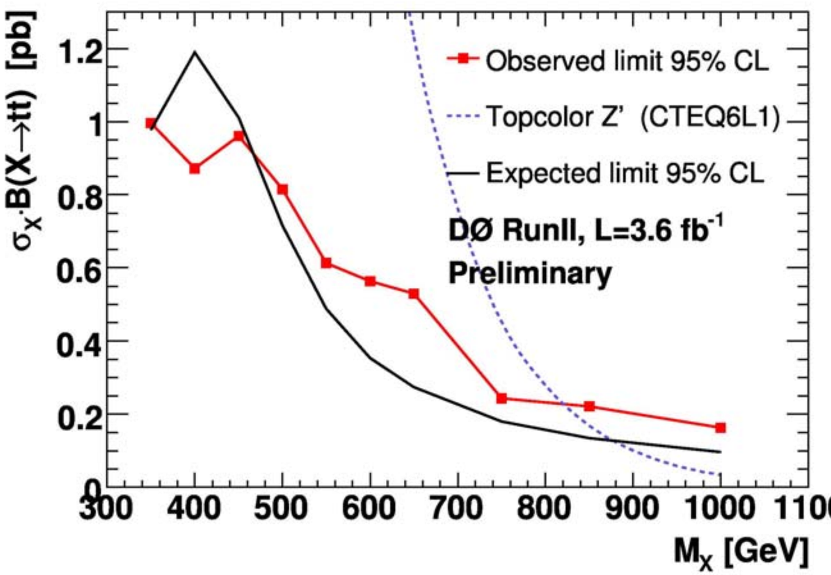
Estimate background by convoluting
p^2 and $1/v^2-1$ distributions of particles
with 20 < pT < 40 GeV (mainly $W\rightarrow l\nu$)

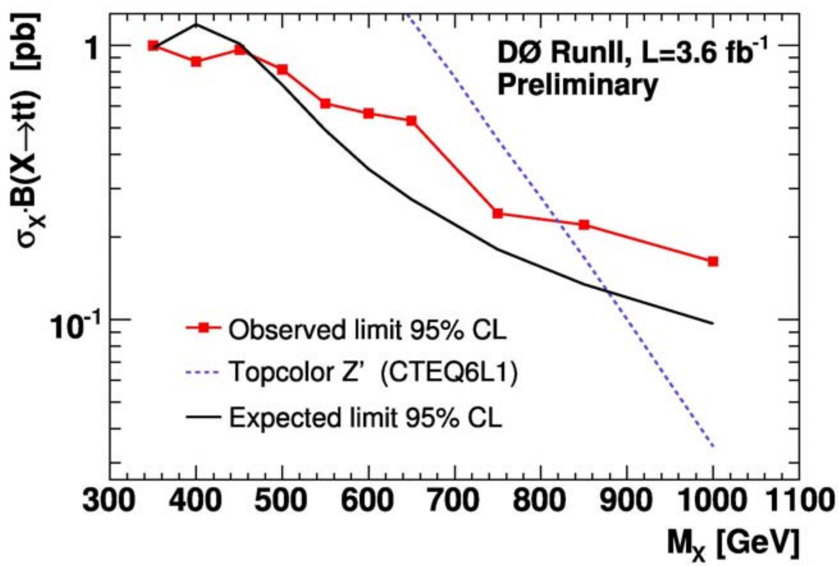


$M_{\tilde{t}}$ < 250 GeV excluded

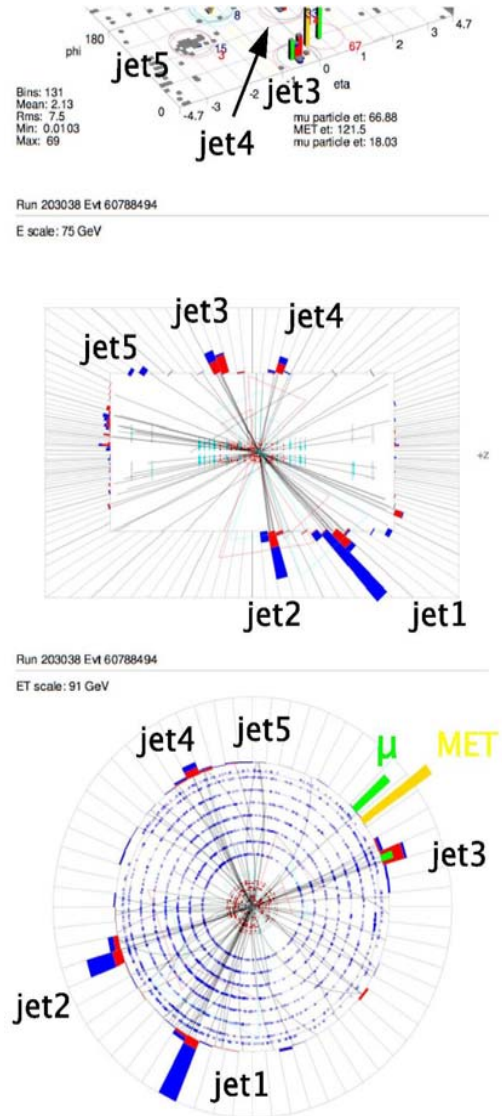
PRL 103, 021802 (2009)

Limit on tt_{bar} Resonances

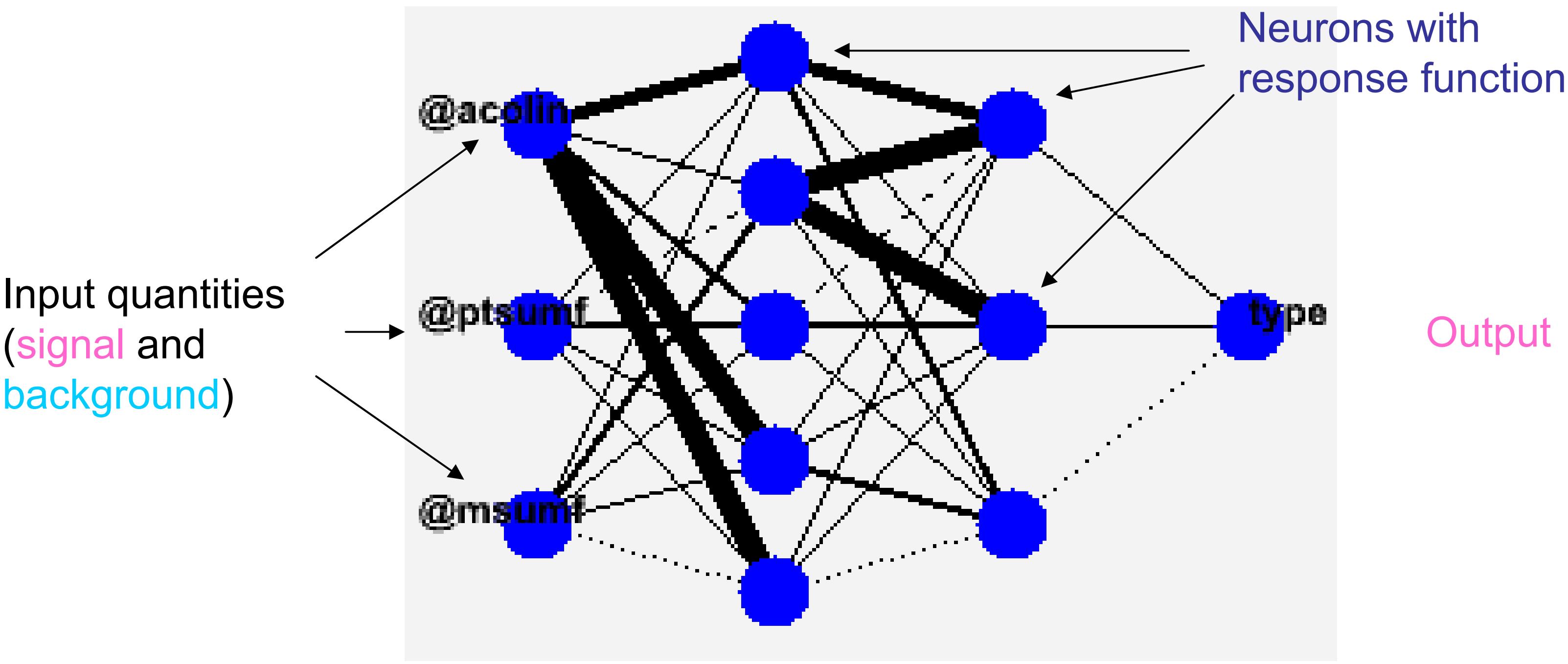




Event with 5 jets
out of which 3 b-tagged



Artificial Neural Network



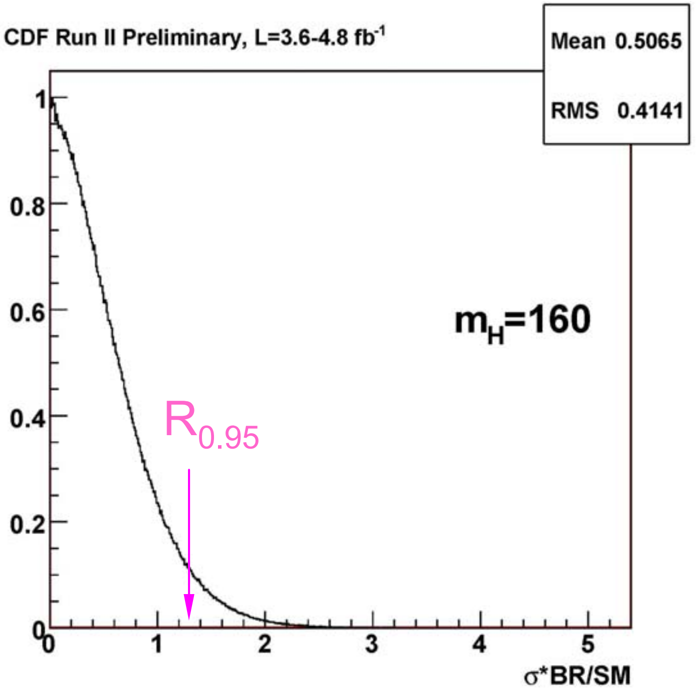
The neuron response function parameters are optimized
by minimizing an error function which requires that the output value
of signal events is close to 1 and
that of the background events is close to 0

The Bayesian limit setting method

Calculates Bayesian posterior probability of R, p(R|N) with a flat prior π(R)=const where $R=(\sigma \times BR)/(\sigma \times BR)_{SM}$ and N is the ensemble of the observed number of events in all bins of the final variable distributions in all analysis channels

Determine $R_{0.95}$ defined as $\int_0^{R_{0.95}} p(R|N)dR = 0.95$

Integrate over the uncertainties of
all nuisance parameters:
Luminosity
Energy scales
Object id efficiencies
Fake rates
Other model parameters, etc.



Calculation of the Bayesian posterior probability p(R|N)

Combined likelihood with flat prior π(R) and Gaussian $\pi(\theta_k)$ of the nuisance parameters θ_k:

$$\mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}, \vec{\theta}) \times \pi(\vec{\theta}) = \prod_{i=1}^{N_C} \prod_{j=1}^{Nbins} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}} / n_{ij}! \times \prod_{k=1}^{n_{np}} e^{-\theta_k^2/2}$$

$\mu_{ij} = R\, s_{ij} + b_{ij}$

s_{ij} and b_{ij} are the expected SM signal and background in channel i and bin j

p(R|N) is the integral of the likelihood $\mathcal{L}$ over all variables except R

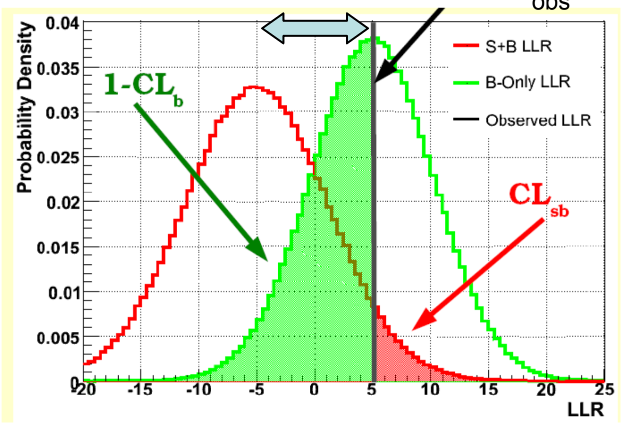
The semi-frequentist or CLs limit setting method

Log-Likelihood-Ratio (LLR) as test statistics: $LLR = -2\ln\frac{P(N|H_1)}{P(N|H_0)}$

H_0 and H_1 - test hypotheses of background w/o and w/ signal
N - ensemble of number of events
P - Poissonian pdf of N: $P = e^{-\mu}\mu^N/N!$
includes pdf of nuisance parameters θ: $\exp[-\frac{(\theta-\theta_0)^2}{2\sigma_\theta^2}]$

Profiling:
LLR is minimized wrt the nuisance parameters

LLR_{obs} = LLR(N=Data)
LLR_b = LLR(N=Background)
LLR_{sb} = LLR(N=Signal+Background)

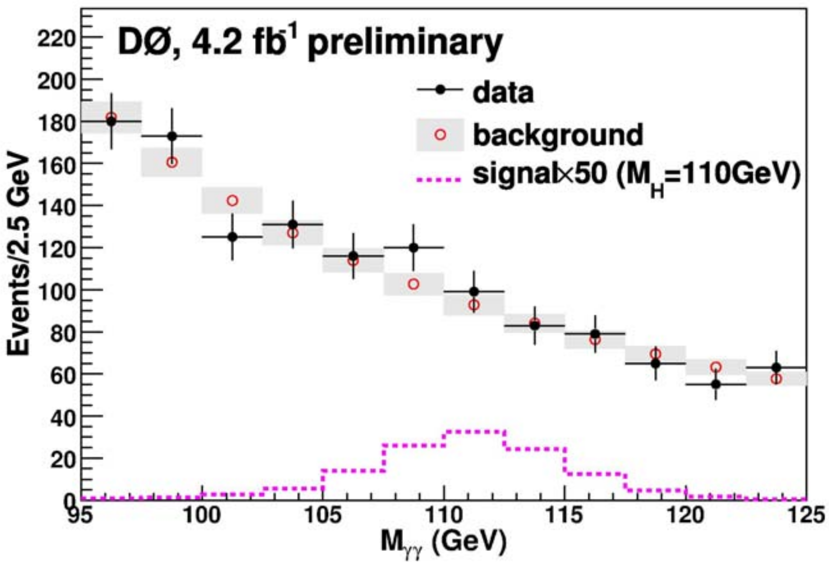


Confidence levels:
$1-CL_b = p(LLR_b < LLR_{obs}|H_0)$
$CL_{sb} = p(LLR_{sb} > LLR_{obs}|H_1)$
$CL_s = CL_{sb}/CL_b$

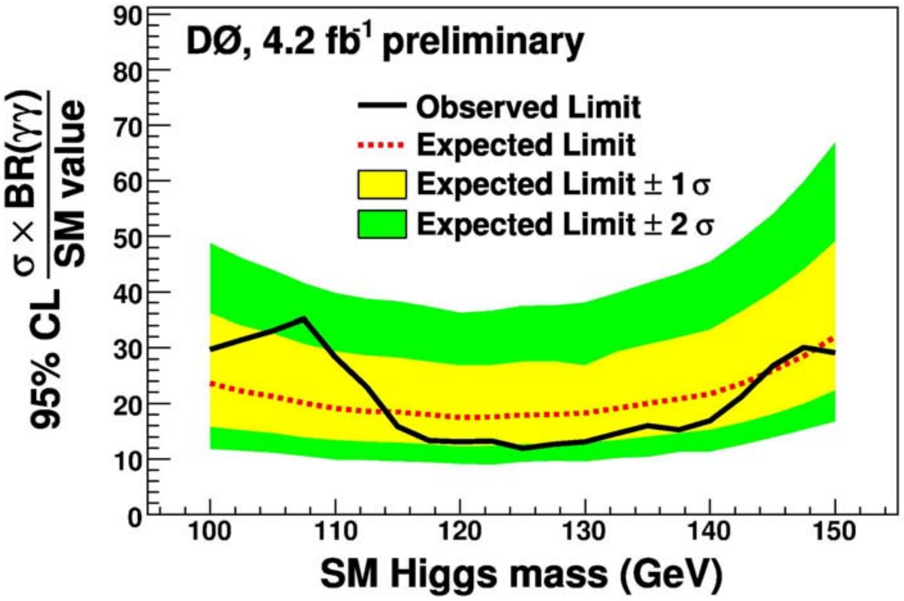
A signal $R=(\sigma xBR)/(\sigma xBR)_{SM}$ is excluded @ 95% CL if $CL_s(R)= 0.05$ i.e. $1-CL_s(R)= 0.95$

It has been checked that the Bayesian and CLs methods give comparable results (~10%)

H→γγ search



DØ, 4.2 fb-1 preliminary
data
background
signal×50 (MH=110GeV)
Events/2.5 GeV
Mγγ (GeV)



DØ, 4.2 fb-1 preliminary
Observed Limit
Expected Limit
Expected Limit ± 1 σ
Expected Limit ± 2 σ
95% CL σ × BR(γγ) / SM value
SM Higgs mass (GeV)

Perspectives of the SM Higgs searches at the Tevatron